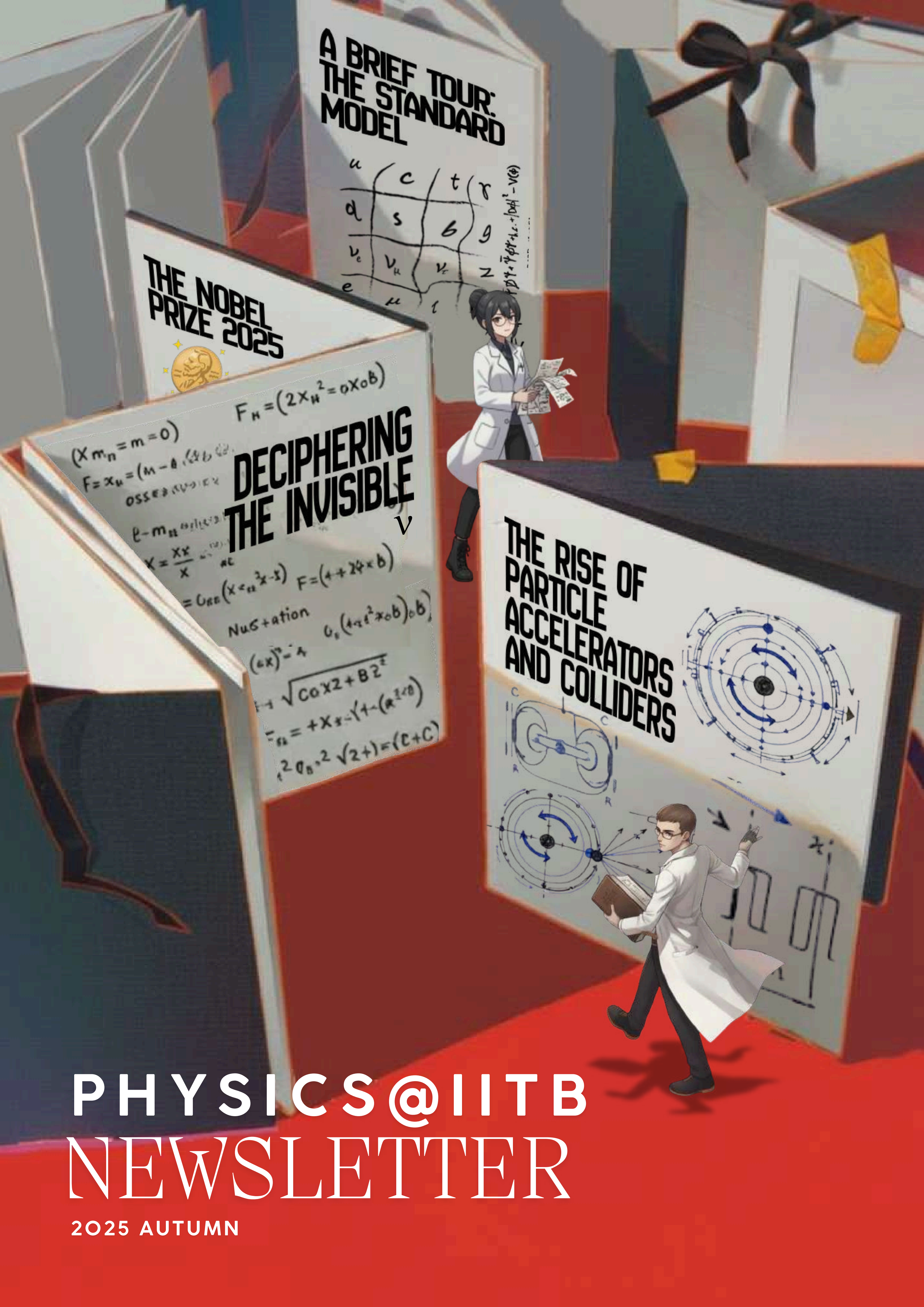


PHYSICS@IITB NEWSLETTER

2025 AUTUMN

"Mathematics is a game where mathematicians invent the rules.

Physics is a game where the rules are given to us by nature.

What is interesting is that the rules of nature appear to be in the same mathematical rules as the mathematicians have concocted."

P. A. M. Dirac

CONTENTS

EDITOR'S LETTER

Hello everyone!

As the 2025-26 Autumn Semester here comes to an end, I am filled with joy to bring to you the first issue of the Physics Department Newsletter for this academic year. This time around, our newsletter revolves majorly around themes of High Energy Physics.

We begin with discussing particle accelerators and colliders (pg. 4), accompanied by a brief description of the Standard Model (pg. 15), and a deeper dive into the fascinating physics and history of the "ghost particles" - neutrinos (pg. 22). We also spoke to two of our very own Engineering Physics graduates, who are working in the field. Find the complete interviews in pages 33 and 36.

The Nobel Prize in Physics for this year was announced just recently, and for people curious to know more, we cover, in pg. 29, the works of John Clarke, Michel H. Devoret and John M. Martinis on the demonstration of quantum tunneling in large scales.

For those looking for something more fun in here, we have a section on some physics related media recommendations (pg. 39), by a couple of our own faculty, for all the book lovers, cinema enthusiasts and any other curious being. This newsletter also includes a crossword (pg. 43), followed by a gallery of all events held by the Students' Association of Physics Department this semester (pg. 40). For this issue, instead of the usual transcribed version for a professor interview, we hosted a podcast with Prof. Uma Sankar, who recently retired as a professor from the Department of Physics and is now working with CLE, IIT Bombay. Go to pg. 44 to know more!

I cannot thank enough all the members of the Editorial Team who helped bring this newsletter together. Thanks to Pushti (our dearest DGSec), Ananya and Prem from the Department Council. If the design catches your eye, send your appreciation to Jahnavi from the Editorial Team. A hearty thanks across the globe to our student interviewees, Kabir and Rehmat, some of the coolest people I have known. Lastly, I am very grateful to all the faculty contributors to this issue: Prof. Uma Sankar, Prof. Pradeep Sarin and Prof. Amitabha Nandi.

I really hope you enjoy reading this newsletter, and I encourage you all to reach out to the Editorial Team for all kinds of feedback; it helps us improve and provide you with quality newsletters. Happy reading!

Vansha Hansda,
Editor-in-Chief,
Department of Physics,
IIT Bombay.

THE RISE OF PARTICLE ACCELERATORS AND COLLIDERS

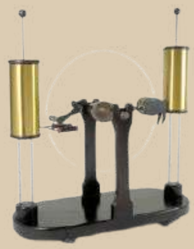
GURU JAHNAVI M
PHYSICS UNDERGRAD | CLASS' 28

It all started with a simple question: what lies within the very heart of things? And, as usual, physicists refused to stop at "we don't know." Instead, they built gigantic machines to hurl particles at ridiculous speeds and watch what happens when they crash, because why not turn curiosity into controlled destruction? From early tabletop accelerators to the mighty colliders stretching beneath countries, each generation of these machines has peeled back another layer of reality. They've uncovered quarks, bosons, and more existential crises than we care to admit. This is the story of how humanity's biggest questions, and biggest toys, came together to reveal the tiniest building blocks of the universe.

It all started with the generation of potential difference. Scientists experimented with static electricity to create high voltages.

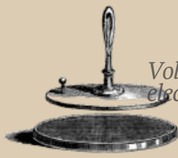
In the 18th century, devices like the Winter plate electrical machine, Volta's electrophorus (1775), and Le Roy's electrostatic machine were among the first tools to produce controlled electric potentials. By the late 19th century, the Wimshurst machine (circa 1880) could reach hundreds of kilovolts, powering early experiments in electrical discharges. These voltage generators kicked off a cascade of discoveries:

Winter Plate Electrical Machine

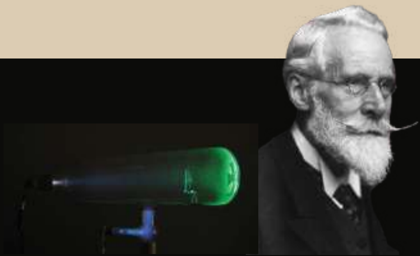


Le Roy's electrostatic machine

Wimshurst machine (circa)



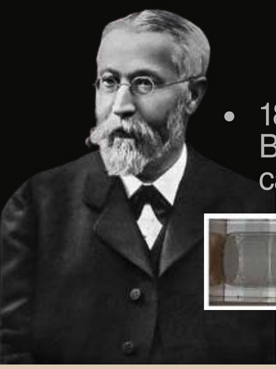
Volta's electrophorus



- 1879 – William Crookes observes gas discharges in evacuated tubes.

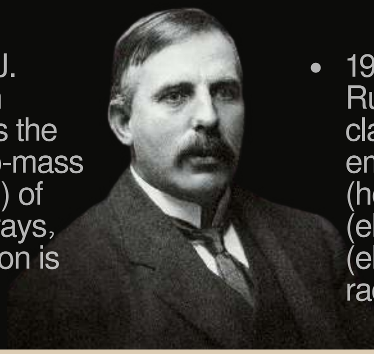
- 1895 – W.C. Röntgen discovers X-rays.

- 1896 – Henri Becquerel discovers radioactivity; later explored by Pierre and Marie Curie.



- 1897 – Ferdinand Braun builds the first cathode ray tube.

- 1897 – J.J. Thomson measures the charge-to-mass ratio (q/m) of cathode rays, the electron is born.



- 1900 – Ernest Rutherford had classified radioactive emissions into **α** (helium nuclei), **β** (electrons), and **γ** (electromagnetic radiation)

PHYSICS MOTIVATIONS FOR MAN-MADE PARTICLE ACCELERATORS

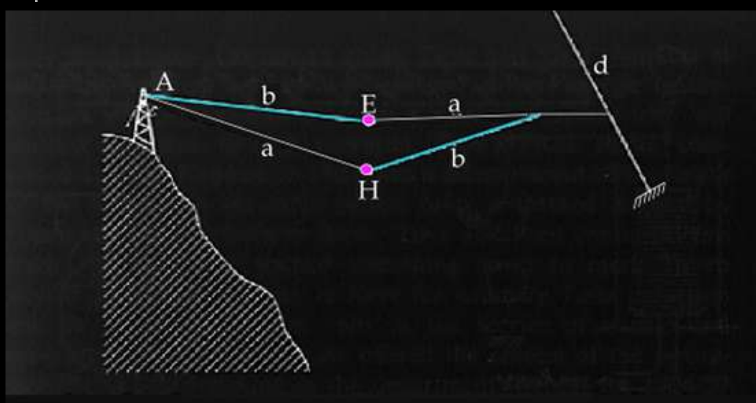
In 1913, when Hans Geiger and Ernest Marsden, under the guidance of Ernest Rutherford, bombarded atoms with alpha particles of 5 to 10 MeV. Their experiments revealed that atoms have a tiny, massive nucleus much smaller than the atom itself overturning the earlier "plum pudding" model. Rutherford, addressing the Royal Society in 1927, famously said:

> *"... if it were possible in the laboratory to have a supply of electrons and atoms of matter in general, of which the individual energy of motion is greater even than that of the alpha particle, ... this would open up an extraordinary new field of investigation...."*

Early radioactive sources and primitive devices could only emit particles with energies of a few hundred kilovolts, far too low to probe nuclear structure. According to the uncertainty principle, resolving the nucleus (size r) requires energies around E~hc/r~70 keV, while classical estimates show that α particles need about 3 MeV to overcome the Coulomb barrier of nuclei like lithium-7. In 1929, George Gamow's tunneling theory revealed that particles below 1 MeV could still penetrate this barrier, an insight that inspired John Cockcroft and Ernest Walton to build the first accelerator in 1932, achieving ~400 kV and producing the first artificial nuclear reactions.

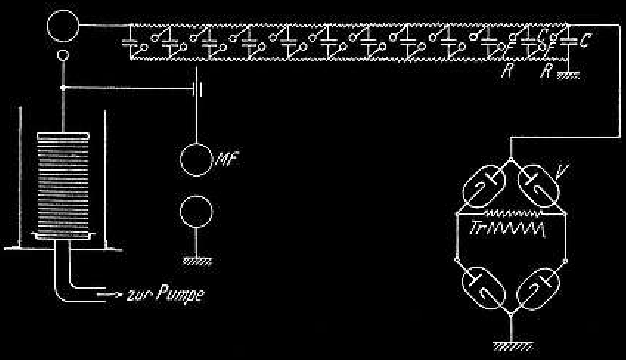
FIRST, IMPULSIVE, AND CURIOUS HIGH VOLTAGES

Between 1928–1930, C. Urban, A. Brasch, and F. Lange tried a daring idea in the Italian Alps, using the potential difference between storm clouds and the ground to create massive voltage drops between two suspended spheres.



Brash and Lange's lightning catcher. E and H are the spheres between which the discharge occurs; AE, the antenna; a,a, insulators; b,b, conductors; d, a grounded wire. A.Brash and F.Lange, *Zs. F. Phys.,70 (1931), 17*

The experiments were, unsurprisingly, dangerous, during one attempt, C. Urban was killed by lightning.
The two who survived the experiment went on to design an accelerator tube capable of withstanding that voltage. They designed an impulsive spark-gap accelerator, where voltage from a transformer was multiplied by a chain of capacitors and discharged across an evacuated laminated tube, creating short bursts of high-energy particles.



Brasch and Lange's discharge tube and impulse generator. Voltage from the transformer Tr multiplied by the string of capacitors discharges across the constantly pumped laminated tube.

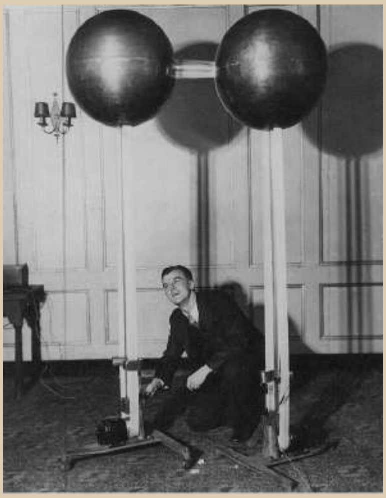
THE COCKCROFT-WALTON ACCELERATOR

By 1932, John Cockcroft and Ernest Walton, working under Ernest Rutherford at the Cavendish Laboratory, built what became the first practical high-energy particle accelerator.
Their design used a voltage-multiplier circuit, a chain of capacitors and diodes, to reach about 400 kilovolts, enough to accelerate protons produced from hydrogen gas discharges. When these protons hit a lithium target, the reaction $_3Li^7 + {}_1H^1\ (p) = 2\ {}_2He^4\ (2\,\alpha)$ was observed, the first artificial nuclear transmutation ever achieved.

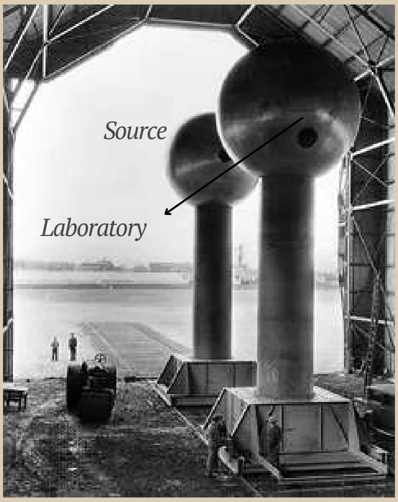
John Cockcroft *Ernest Walton*

It earned them the 1951 Nobel Prize in Physics, and showed that man-made accelerators could now do what natural radioactivity once did: probe and change the nucleus itself. Further progress in electrostatic accelerators was driven mainly by advances in charging systems and insulation technology, leading to the development of the Van de Graaff accelerator.

A NEW IDEA: THE FIRST VAN-DE-GRAAFF ACCELERATORS

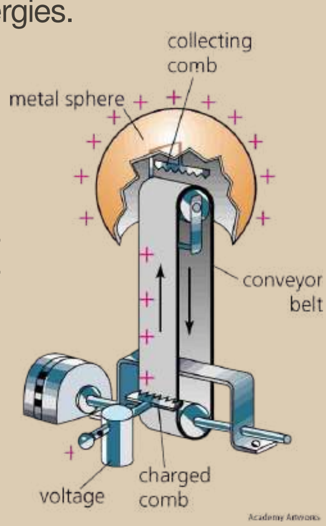


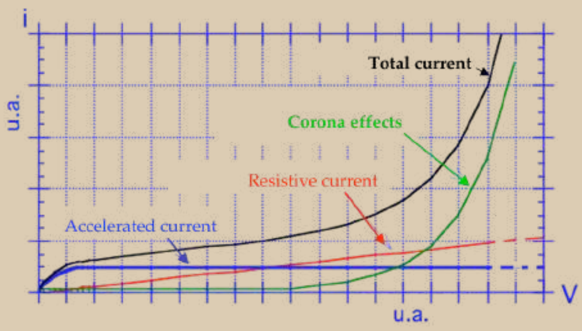
Robert Jemison Van de Graaff



In 1931 at MIT, Robert J. Van de Graaff introduced a revolutionary design: an electrostatic accelerator capable of reaching millions of volts. His earliest machines, using air-insulated metal spheres and a moving belt to transfer charge, could generate potentials up to 5 million volts. These iconic "Van de Graaff generators," with their spectacular sparks and huge globes soon became the workhorses of nuclear physics laboratories for accelerating beams to unprecedented energies.

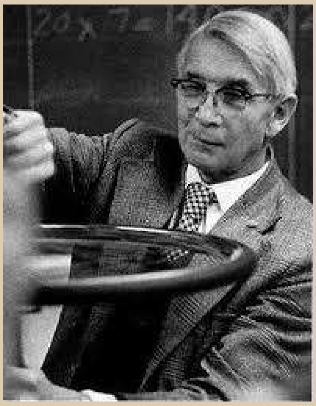
Its charging system used a non-conducting conveyor belt that picked up charge via corona discharge from a sharp "comb" connected to a DC source. The belt carried this charge inside a hollow metal sphere, where it was transferred through another comb to the inner surface, steadily raising the sphere's potential. The belt motor supplied the mechanical work needed to move enough charge per unit time, compensating for the extracted beam current and inevitable losses.





In practice, the maximum voltage achievable depended on factors like corona discharge, leakage currents, mechanical strength of the belt and the terminal radius.
Even under ideal conditions, voltages rarely exceeded ~25 MV, but that was enough to make the Van de Graaff a workhorse for nuclear physics for decades.

THE PRINCIPLE OF ELECTRO-DYNAMIC (MULTIPLE) ACCELERATION



Gustav Ising

In 1924, Professor Gustav Ising published a groundbreaking idea: using rapidly switched, non-conservative electric fields to accelerate particles in multiple steps, not just one big push. This principle of "multiple acceleration" laid the foundation for all modern linear accelerators (linacs). As Nobel laureate E.O. Lawrence later recognized, Ising's method was the real start of a new era:

> *"...he surely is the father of the developments of the methods of multiple acceleration."*

Ising's approach used a series of alternating voltages and gaps, allowing particles to steadily gain energy as they "surf" through the machine, an idea that would revolutionize how we reach higher energies.

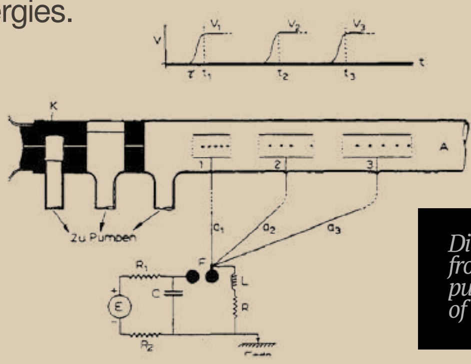
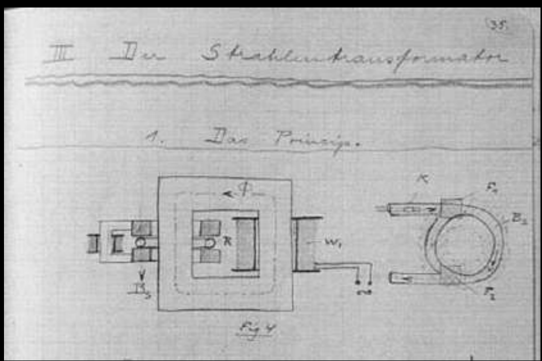


Diagram of Linear accelerator from prof G Ising's pioneer publication (1924) of the principle of multiple acceleration of ions

Around the same time as linac ideas were developing, 1923 saw a breakthrough of a different kind, Rolf Widerøe's "ray transformer" concept, which introduced the principle behind the betatron. Instead of pushing particles in a straight line, the betatron used magnetic fields to drive electrons in a circular orbit, accelerating them by the ever-changing magnetic flux (like a transformer, but for rays!).



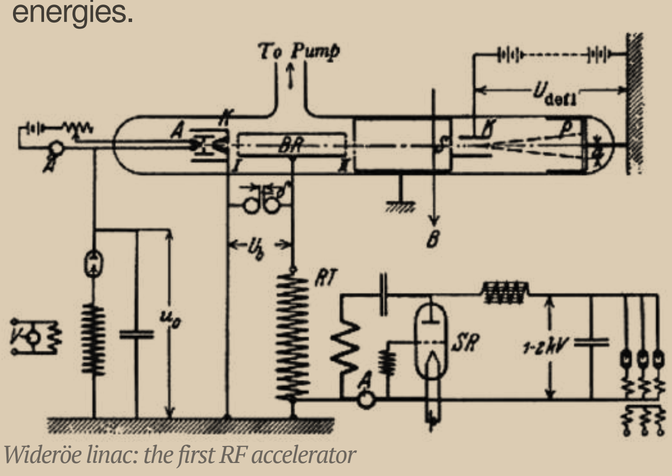
The First sketch in Rolf Wideroe's notebook of the Strahlentransformator (Betatron)

Although Widerøe's original device didn't yet work, because the mathematics of stabilizing the electrons' path hadn't been fully solved, his sketch laid the groundwork for the first practical circular accelerators. Widerøe's betatron idea, using changing magnetic fields to cycle particles in a ring, became the foundation for circular accelerators that could reach far higher energies.

In 1940, Donald W. Kerst built and operated the first functional betatron. Kerst did develop the theory of beam focusing, essential to have a stable circulating beam. Kerst's machine, soon industrialized as a powerful X-ray source and by 1944, similar machines were built for industry in Germany, with physicist Bruno Touschek contributing to their development.

The betatron, which uses magnetic induction to push electrons around in a ring, came with its own built-in limits. Because its maximum particle energy is inversely related to the particle mass, betatrons work exceptionally well for electrons, but not for heavier particles like protons. For example, a betatron with a 0.7-meter orbit and a 1 Tesla field can send electrons up to 210 MeV, but only manage 23.5 MeV for protons. Hence betatrons found their niche mainly in generating electron beams for research and practical X-ray sources, while heavier particles required different machines, like the cyclotron, to reach truly high energies.

Professor Kerst making an adjustment on the first betatron



Wideröe linac: the first RF accelerator

In 1927, Rolf Widerøe shifted from circular machines to build the first resonant linear accelerator: a two-section linac powered by alternating voltage, doubling ion energies from a modest 25 kV source to 50 kV. His "patented drawing" marks the true birth of all resonant (RF) accelerators, proving that multiple pushes at the right frequency could outpace any single high voltage shot.

Widerøe himself later wrote about the impact of his drift-tube accelerator:

> *"As I speak about my life… what always comes to my mind first is the Aachen drift-tube. Proving that it was possible to accelerate electrically charged particles with alternating potentials and without having to use the restricted possibilities of the (at that time usual) d.c. voltage, appears to me as my most fundamental piece of work. This was the major result which I presented in my dissertation in 1927 and it does appear to have had the most far reaching consequences."*

Rolf Wideroe

In Wideroe's linac, the length of each drift tube is matched to the particle's velocity and the RF frequency so that

$$L_i = \frac{v_i}{2f_{RF}}$$

This ensures the particle always passes each gap at the right accelerating phase. However, early RF systems used low frequency circuits (only tens of kHz), so the drift tubes had to be very long, making the setup impractical. The solution was to increase the RF frequency, but that became possible only after World War II with the development of radar technology and high-frequency resonant cavities.

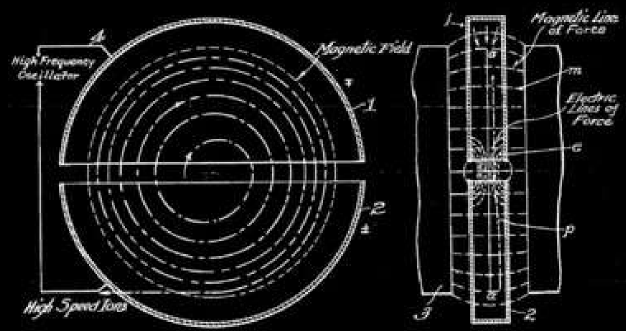
E.O. LAWRENCE: THE CYCLOTRON

E.O. Lawrence

Once the possibility of multiple acceleration was discovered, the idea of accelerating particles by passing them several times through a same accelerating "gap" rather than once through many different gaps came to the mind of several researchers in slightly different form. It was E.O. Lawrence, inspired by Wideroe's "ray transformer", that first presented, pursued and patented the scheme later named "cyclotron". (1929 -1932)

The a.c. voltage generator is connected across two hollow metal half-cylinders, called dees, which are separated by a small gap and placed inside a strong magnetic field along the axis. The charged particles are injected into this region and move inside the dees in half-circular paths due to the magnetic field. Each time they cross the central gap, they are accelerated by the electric field.

A key feature of the cyclotron is that the time taken for a half-circle does not depend on the particle's energy or orbit radius (as long as speeds are non-relativistic). This means that, once a particle starts in the right phase with the oscillating field, it remains in phase and continues to gain energy with every pass through the gap.



Lawrence's patent claim design.

In 1931, E.O. Lawrence and his graduate student M.S. Livingston built the first successfully operating cyclotron. It accelerated a few hydrogen molecule ions to an energy of about 80 keV. The results were first reported at the January 1931 APS meeting, marking a major step in accelerator physics. Following this success, several larger and more powerful cyclotrons were developed at the Lawrence Berkeley Laboratory (LBL) between 1935 and 1939, each achieving higher particle energies and improved performance.

In 1940, Lawrence began building the massive 184-inch cyclotron, featuring a 4.7-meter magnet pole. Although construction was delayed by the war and completed only in 1946, it became the first accelerator to exceed 100 MeV, achieving 200 MeV deuteron beams. By 1948, it enabled the production and study of mesons for the first time. Later upgrades pushed its performance further, to 350 MeV protons, 200 MeV deuterons, and 400 MeV alpha particles.

M.S. Livingston and Ernest Lawrence beside the 27-inch cyclotron, built in 1934

Lawrence's original 11 cm cyclotron

As scientists pushed for higher energies, classic cyclotrons faced two major challenges, loss of isochronicity (particles take the same amount of time to complete each orbit, regardless of their energy) at relativistic speeds and the rapid growth of magnet size and cost with increasing energy.
Modern cyclotrons overcome these limits using advanced designs:

- Superconducting (SC) cyclotrons, which achieve much higher magnetic fields for a given radius.
- Sector-focused cyclotrons (L.H. Thompson, 1938), which shape magnet poles to maintain isochronicity and focusing even at relativistic speeds.

E. McMillan and V.I. Veksler in the Bevatron control room

THE SYNCHROTRON

By 1943, scaling conventional cyclotrons to higher energies, especially for relativistic particles like electrons, became impractical. This challenge led British scientist M. Oliphant, deputy to E.O. Lawrence, to propose the "synchrotron."
He described it in a memo to the UK Directorate of Atomic Energy:

> *"Particles should be constrained to move in a circle of constant radius, allowing the use of an annular magnetic field that varies so the curvature remains constant as particles gain energy through successive accelerations by an alternating electric field between coaxial electrodes."*
>
> *M. Oliphant*

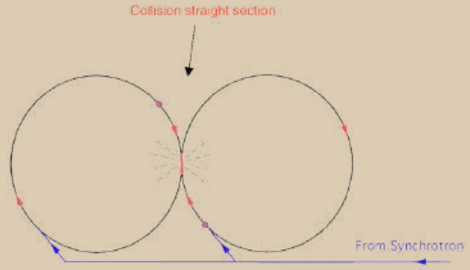
A major advancement came with the independent discovery of the "phase stability" principle by V.I. Veksler and E. McMillan, which solved the beam stability problem in synchrotrons and synchrocyclotrons. This principle ensured particles remained in phase with the accelerating field despite initial speed differences.

THE COLLIDERS

The story of particle accelerators takes a revolutionary turn with the idea of colliders. In 1943, Rolf Widerøe realized that to maximize the energy available in nuclear reactions, particles should collide head-on rather than strike stationary targets. He eloquently explained:

> *"...I had thus come upon a simple method for improving the exploitation of particle energies available... for nuclear reactions. As with cars (collisions), when a target particle (at rest) is bombarded, a considerable portion of the kinetic energy (of the incident particle) is used to hurl it (or the reaction products) away. Only a relatively small portion of the accelerated particle's energy is used to actually split or destroy the colliding particles. However, when the collision is frontal, most of the available kinetic energy can be exploited. For nuclear particles, relativistic mechanics must be applied, and... the effect... be even greater."*
>
> *...If it were possible to store the particles in rings for longer periods, and if these 'stored' particles were made to run in opposite directions, the result would be one opportunity for collision at each revolution. Because the accelerated particles would move very quickly they would make many thousand revolutions per second and one could expect to obtain a collision rate that would be sufficient for many interesting experiments."*

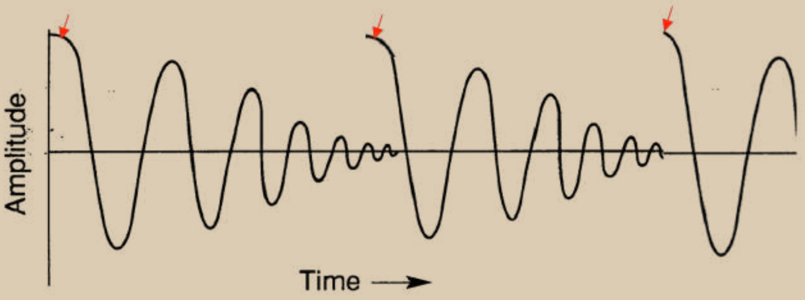
THE STORAGE RING–COLLIDER CONCEPT



The idea of colliding beams was first seriously considered in the mid-1950s. Around the same time, G. K. O'Neill, interested in proton–proton collisions, proposed the concept of storage rings, dedicated rings in which beams extracted from high-energy proton synchrotrons could be accumulated and stored for extended periods, often arranged in a figure-of-eight configuration so that the beams would collide in a common section.

O'Neill further recognized the advantages of storage rings for electrons. Electrons circulating in a curved path naturally radiate energy, causing oscillations of injected particles around the equilibrium orbit to dampen over time, eventually concentrating all particles near the orbit.

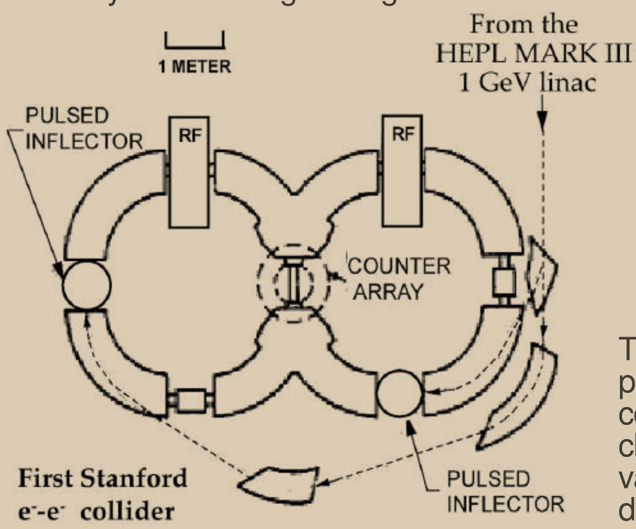
Gerard Kitchen O'Neill

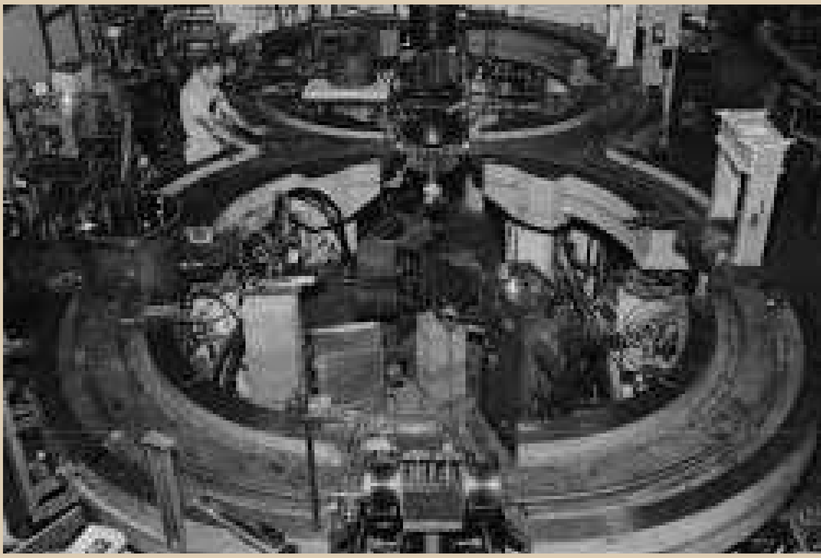


This damping allows frequent injections without disturbing the stored beam, gradually building higher intensities. As a result, electron storage rings could enable the study of electron-electron interactions at center-of-mass energies far beyond what was previously achievable, opening the door to high-energy collider experiments.

THE FIRST COLLIDER: PRINCETON–STANFORD EXPERIMENT

In 1957, G. K. O'Neill, B. Richter, W. C. Barber, and B. Gittelman began constructing the Princeton–Stanford electron–electron collider, designed to accelerate electrons to 500 MeV per beam using weak focusing. Richter and his colleagues were particularly motivated by the opportunity to study electron–electron scattering and to probe potential breakdowns of quantum electrodynamics at high energies.



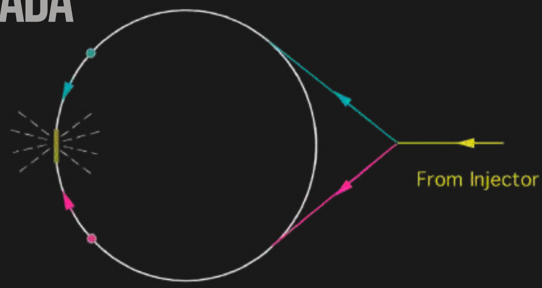


The first colliding-beam machine, a double-ring electron-electron collider, built by a small group of Princeton and Stanford physicists.

The first stored beam was achieved in 1962, drawing particles from the HEPL MARK III 1 GeV linac. Building the collider required overcoming significant technical challenges, including, creating the world's largest ultra-high vacuum system (two cubic meters at 10^{-9} torr) and designing injection kicker magnets with pulse widths as short as 80 ns. These innovations allowed the team to achieve stored beam currents in the hundreds of milliamps, marking a historic milestone in accelerator physics.

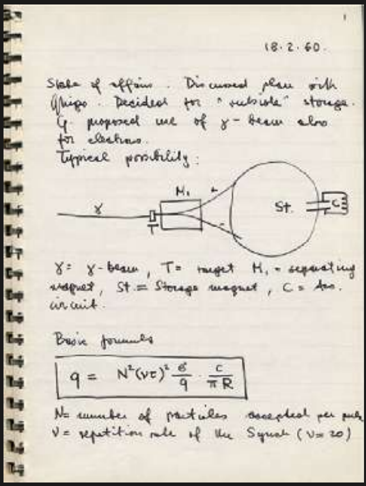
ELECTRON–POSITRON PHYSICS AND THE BIRTH OF ADA

In the early 1960s, Bruno Touschek, the lead theoretician at Frascati, proposed a new approach to high-energy physics. While skeptical of potential breakdowns in quantum electrodynamics, he realized that electron–positron annihilation offered a way to transfer energy "purely" to the vacuum, without introducing unwanted quantum numbers such as charge or large angular momentum.

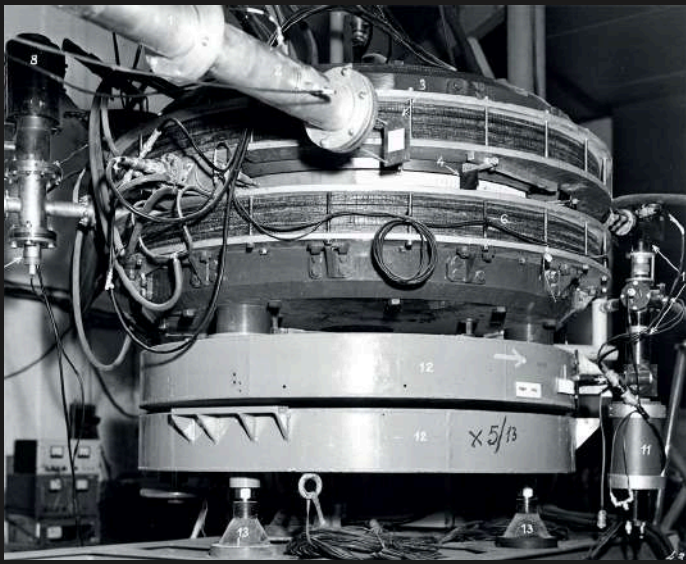


In 1960, Touschek presented a seminar at Frascati outlining the physics of e^+e^- annihilation and proposed a small, single storage ring: two bunches, one of electrons and one of positrons, would circulate in opposite directions within the same vacuum chamber, colliding once per turn. Within a week, preliminary studies showed no insurmountable barriers. The project was approved, funded, and construction began, with completion planned for just one year later. This machine was named the Anello di Accumulazione (AdA - also BT's beloved aunt), marking the birth of electron–positron collider physics.

Bruno Touschek



First page of Touschek's Storage Ring (SR) notebook, which he started in the day immediately following the Frascati meeting.



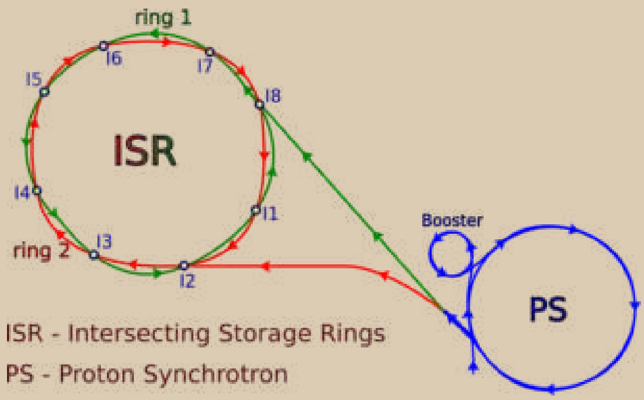
AdA on the rotating and translating platform at Orsay. On the left the injector beam channel.

It was never fully clear whether the beam first circulating in AdA was of electrons or positrons, infinite discussions would leave no definite answer (Bernardini 2006), and Touschek recorded them in the drawing

The limited intensity of the Frascati synchrotron beam meant AdA could not achieve enough stored particles for colliding beams experiments, which led the team to transfer AdA to Orsay, following Pierre Marin's suggestion, where the higher current from the Orsay linac made real electron-positron collisions possible.

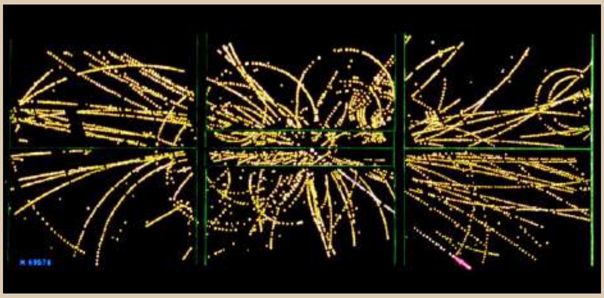
FROM ISR TO THE SP$\bar{\text{P}}$S: PIONEERING PROTON COLLIDERS

The Intersecting Storage Rings (ISR) at CERN, approved in 1965 and operational by 1971, were the world's first proton–proton colliders. The ISR featured two 31 GeV proton rings, each about 940 m in circumference, intersecting at eight points. Proton bunches from the PS (proton synchrotron) were injected at 25 GeV, stored side by side using a clever "stacking in momentum space" trick pioneered by Kerst's group, accelerated to full energy, and finally de-bunched for collisions.



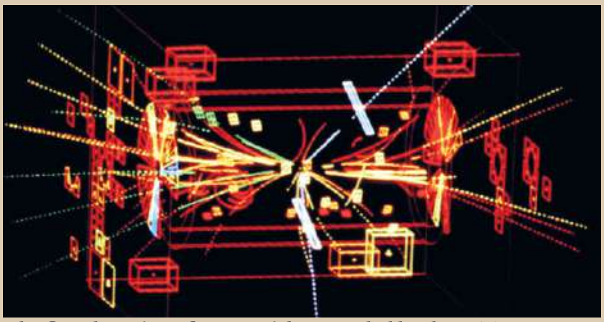
The main challenge was achieving high luminosity: beams needed to be intense while maintaining small dimensions. Despite the difficulties, the ISR set world records, storing beam currents up to 57 A per beam and achieving luminosities of $1.4 \times 10^{32} cm^{-2} s^{-1}$. The ultra-high vacuum system reached pressures as low as 10^{-11} torr to ensure long beam lifetimes.

The collider faced numerous unexpected problems, from resistive wall instabilities to sudden pressure bumps, whose solutions significantly advanced accelerator technology. A breakthrough came with Simon van der Meer's invention of stochastic cooling, which senses random density fluctuations in the beam and dampens them via active feedback, a technique crucial for the later realization of proton–antiproton colliders.



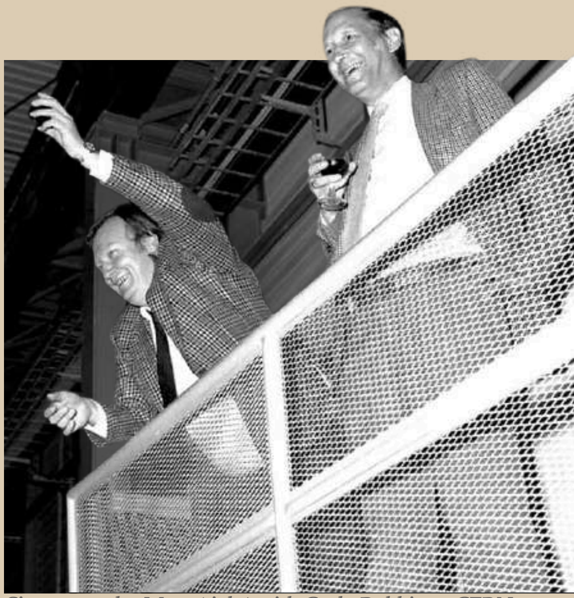
First direct production of the W boson in the UA1 experiment in late 1982.

Building on the ISR legacy, CERN developed the Sp$\bar{\text{p}}$S collider, operational from 1981 to 1984. This proton–antiproton collider had a 6.9 km circumference and a center-of-mass energy of 400 GeV, with two major experiments: UA1 and UA2. The Sp$\bar{\text{p}}$S achieved a historic milestone: the discovery of the W and Z bosons, confirming the electroweak unification of forces. The W boson was first observed by UA1 in January 1983, almost immediately followed by UA2, while the Z boson was detected by both groups later that year.



The first detection of a Z particle, recorded by the UA1 experiment on 30 April 1983. The two white tracks seen here reveal the electron–positron pair produced in the Z's decay.

These landmark achievements earned Carlo Rubbia (for leading the UA1 experiment) and Simon van der Meer the 1984 Nobel Prize in Physics, recognizing their crucial contributions to accelerator and particle physics. Today, the Sp$\bar{p}$S ring continues to serve CERN, accelerating protons for the LHC.



Simon van der Meer (right) with Carlo Rubbia at CERN, when 1984 Nobel Prize was announced

THE FIRST ELECTRON–PROTON COLLIDER: HERA AT DESY

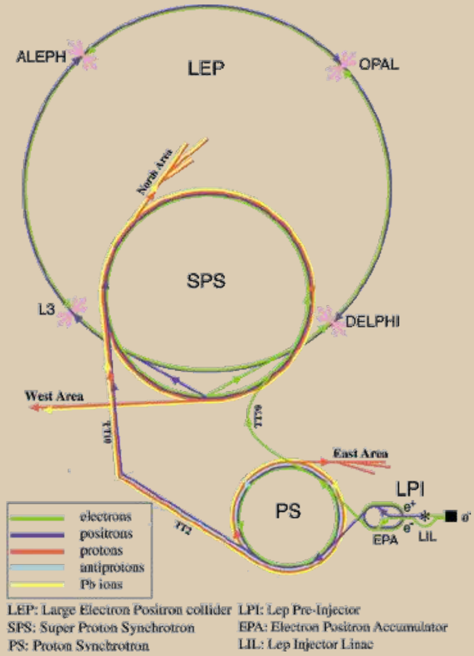
Breaking new ground in the 1990s, HERA (Hadron–Electron Ring Accelerator) at DESY (Deutsches Elektronen-Synchrotron) became the world's only electron–proton collider, offering physicists a unique microscope to probe the proton's inner structure. Approved in the late 1980s and operational from 1992 to 2007, HERA accelerated electrons to 30 GeV and protons to 820 GeV, circulating around a 6.3 km ring.

HERA hosted three major experiments: two general-purpose detectors, ZEUS and H1, and a specialized experiment, HERA-B, focused on bottom quark physics. Its crowning achievement was providing detailed measurements of the proton's structure, revealing the dynamic world of quarks and gluons within. For physicists, HERA was like a giant microscope smashing electrons into protons at almost light speed, shedding light on the very building blocks of matter and expanding our understanding of the strong force.

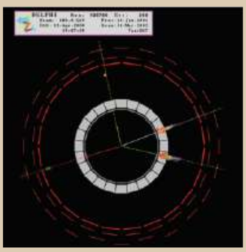
LEP: THE LARGE ELECTRON–POSITRON COLLIDER

Approved in 1981, LEP at CERN became the world's highest-energy electron–positron collider, with a 27 km circumference. Its first collisions, known as LEP 1, began in 1989 at 46 GeV per beam, precisely at the Z^0 resonance, allowing detailed studies of the electroweak interaction. In 1995, LEP 2 began after upgrading the accelerator. LEP ran until 2000, with decommissioning completed in 2001, and its tunnel now serves as the home of the LHC.

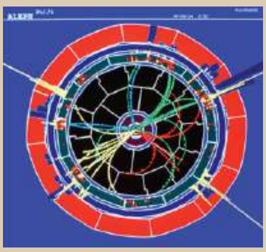
LEP hosted four major experiments, ALEPH, DELPHI, L3, and OPAL, each tackling different aspects of particle physics. Over its lifetime, LEP provided full validation of the Standard Model, measuring properties of the Z and W bosons with unprecedented precision and confirming the consistency of electroweak theory. Its success was built on innovative technical solutions, from ultra-precise beam control to cryogenic superconducting cavities, cementing LEP's legacy as one of the most influential colliders in the history of particle physics.



OPAL spots the decay of a Z boson into two jets originating from a quark–antiquark pair

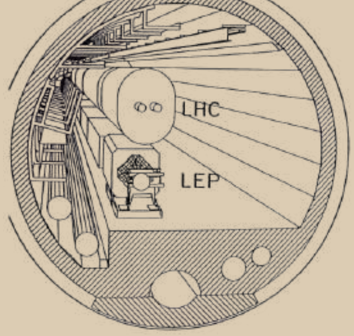


a pair of Z bosons decaying into two muons and two electrons in DELPHI



a four-jet event recorded in 2000 by ALEPH that was a candidate for the associated production and decay of a Z and a Higgs boson into quark-antiquark pairs.

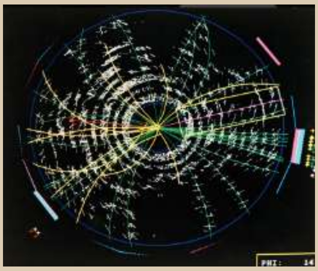
an L3 candidate for pair production of excited electrons decaying into an electron and a photon each



LHC in LEP tunnel

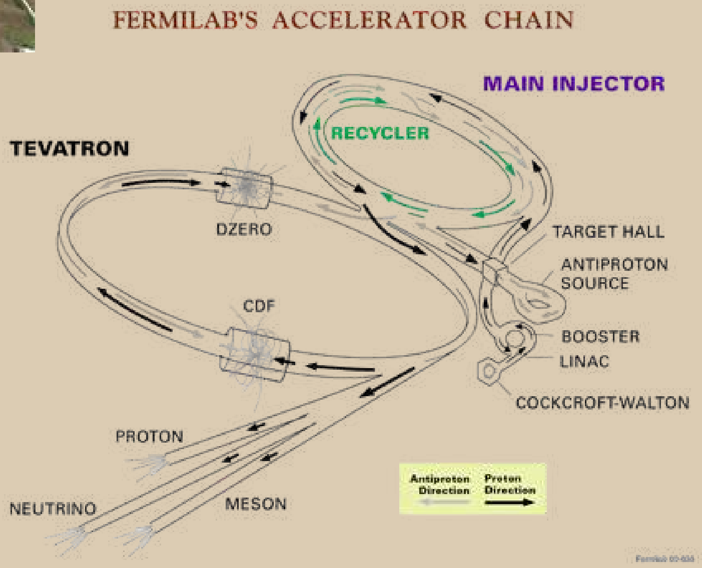
TEVATRON: FERMILAB'S PROTON–ANTIPROTON COLLIDER

The Tevatron at Fermilab was a proton–antiproton collider that pushed the energy frontier in the late 20th century. Its first run (Run 1, 1987–1995) reached a center-of-mass energy of 1.80 TeV, followed by Run 2 (2000–2008) at 1.96 TeV, which increased the cross sections for many interesting processes by roughly 40%.



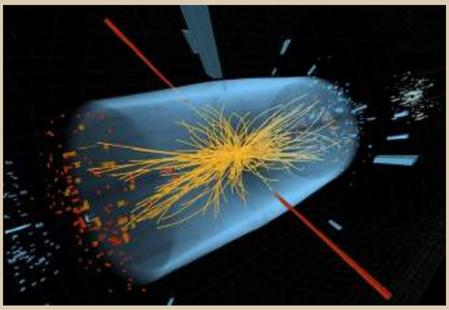
Discovery of the Elusive Top Quark, which for nearly two decades had been the last and crucial missing piece in the scientific picture of matter, was announced on March 2, 1995

The Tevatron's crowning achievement was the discovery of the top quark, the last missing piece of the Standard Model's quark family. This breakthrough confirmed a major prediction of particle physics and showcased the power of high-energy colliders



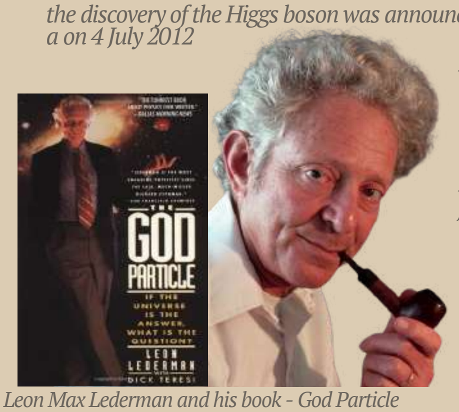
LHC: THE LARGE HADRON COLLIDER

The Large Hadron Collider (LHC) at CERN is currently the world's most powerful particle accelerator, designed to push the energy frontier far beyond its predecessors. Housed in the 27 km LEP tunnel, it accelerates protons up to 7 TeV per beam, achieving a center-of-mass energy of 14 TeV in collisions. The LHC began operation in 2008 and has since become the flagship facility for exploring fundamental physics.



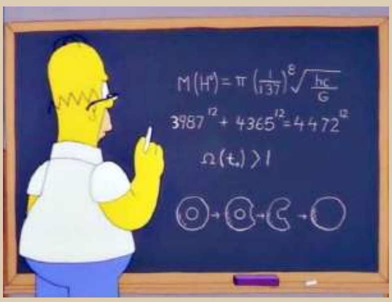
the discovery of the Higgs boson was announced a on 4 July 2012

The LHC hosts several major experiments, including ATLAS, CMS, LHCb, and ALICE, each with its unique focus, from general-purpose searches to heavy-ion collisions. Its crowning achievement came in 2012, when ATLAS and CMS announced the discovery of the Higgs boson, the particle responsible for giving mass to elementary particles and the final missing piece of the Standard Model. This milestone confirmed the Higgs mechanism proposed nearly five decades earlier and earned François Englert and Peter Higgs the 2013 Nobel Prize in Physics.



Leon Max Lederman and his book - God Particle

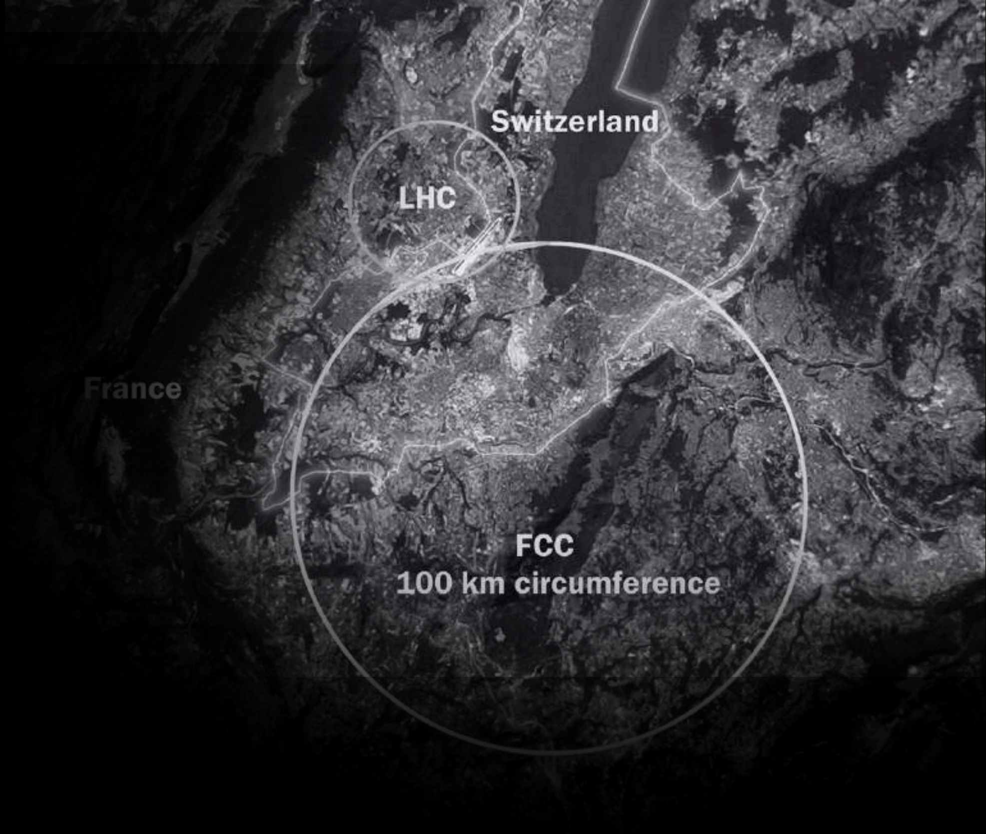
Physicist Leon Lederman unwittingly gave the Higgs boson what may be its most-disliked descriptor with the title of his book, The God Particle. Lederman likes to joke that he actually wanted to call the Higgs boson the "goddamn particle" because it's so darned difficult to find. The nickname makes for attention-grabbing headlines, but it also makes most particle physicists cringe.



In The Simpsons episode "The Wizard of Evergreen Terrace" (1998), Homer is seen writing an equation on a blackboard that astonishingly predicts the mass of the Higgs boson, fourteen years before CERN scientists confirmed the Higgs boson. The playful formula, combining

CERN scientists confirmed the Higgs boson. The playful formula, combining constants like the Planck constant, gravitational constant, and speed of light, gives a value of about 775 GeV, much higher than the actual 125 GeV found in 2012, yet remarkably close for a cartoon prediction.

THE FUTURE : FCC



As the LHC continues to push the limits of our understanding, CERN is already dreaming bigger, quite literally in circles. The proposed Future Circular Collider (FCC) would be a 100 km-long behemoth, dwarfing the LHC's 27 km ring, and could one day collide protons at energies up to 100 TeV.

The FCC aims to explore the frontiers beyond the Standard Model, probing dark matter, the Higgs field in unprecedented detail, and perhaps answering that age-old question every physicist secretly asks, "Is there more?" Still in the design phase, the FCC represents the next big thing in human curiosity and engineering.

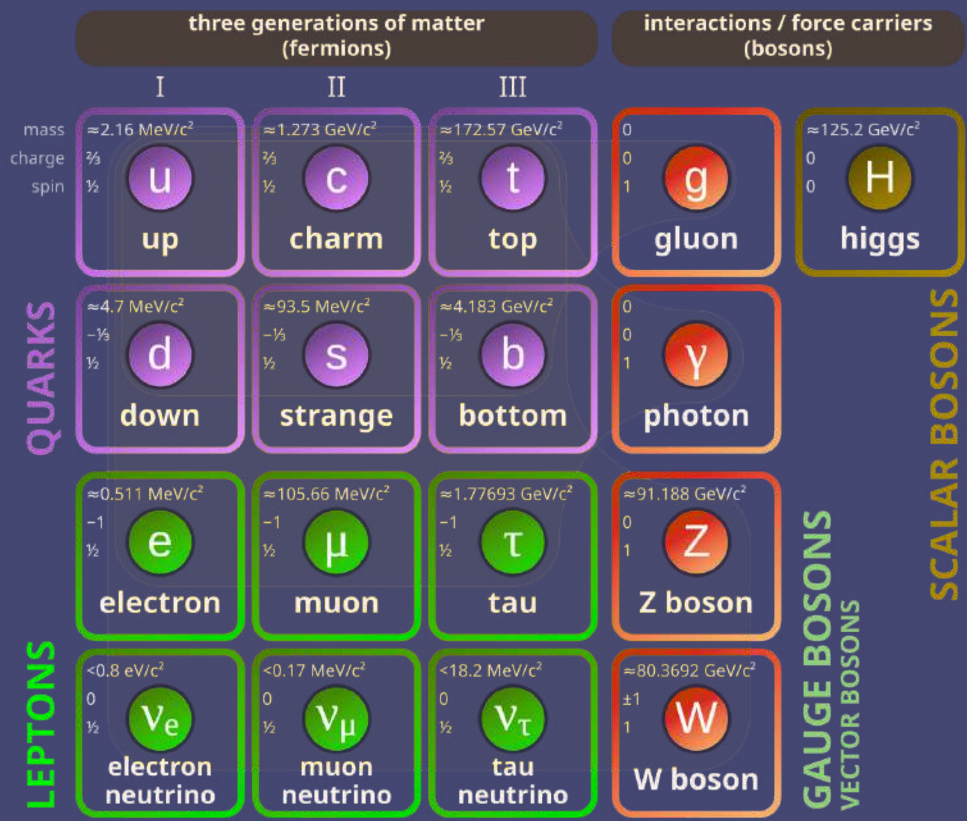
Particle colliders may not answer every cosmic question, but they prove one thing beyond doubt: physicists will go to absurd (and expensive) lengths just to make sense of their own existence.

And somewhere, between colliding particles and collapsing equations, we inch a little closer, not just to understanding the universe, but to understanding why we can't stop trying.

Scientists at Berkley with the 184" Synchrocyclotron after upgrade

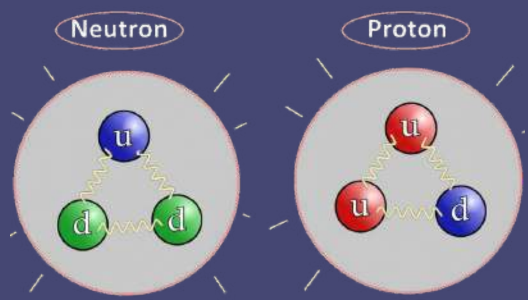
A BRIEF TOUR : THE STANDARD MODEL

What is the standard model of particle physics? To truly understand it, you would have to sit through a couple of years of advanced courses; however, to give context, it describes a framework or mechanism that helps us understand the fundamental particles and their interactions.



You may have seen this colorful table, perhaps in a textbook or a Veritasium video. In simple terms, it is like the periodic table of fundamental particles.
The left panel consists of 3 generations of fermions. Fermions are particles with half-spin that interact through fundamental forces mediated by bosons (right panel), and their interactions are determined by quantum numbers (like charge, color, and spin).

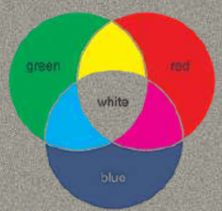
The basic difference between a quark and a lepton is that quarks experience the strong nuclear force, while leptons do not. Because of this, quarks are never found in isolation; they are always confined inside composite particles such as protons and neutrons. Leptons, such as electrons and neutrinos, can exist freely as individual particles. Additionally, quarks have fractional electric charges, whereas leptons have integer charges.

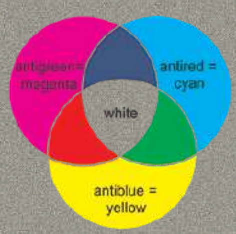


It is to be noted that each generation's particles are heavier than those of the previous one, but why do we have only three generations of them? This continues to be an open question (as of October 2025), something the Standard Model doesn't explain.

Now coming to the bosons, these are particles with integer values of spin quantum numbers - 0, 1. There are two types of bosons:
Gauge bosons, or vector bosons, behave like messengers of forces. For example, let's say when two electrons repel each other, they're exchanging virtual photons. Photons come under gauge bosons.

COLOR CHARGE INTERACTION

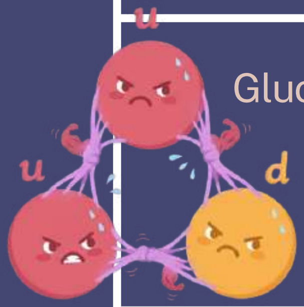


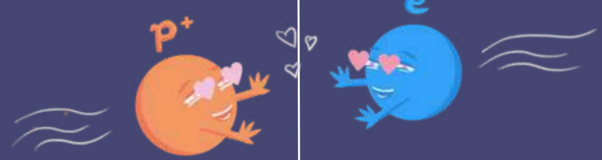


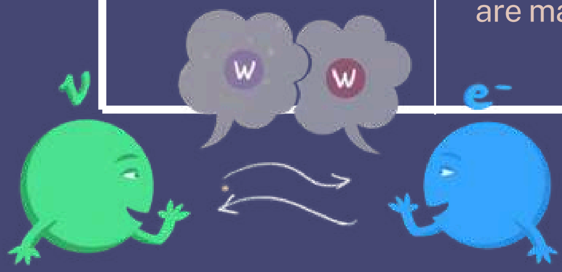
Quantum chromodynamics (QCD) is the study of strong interactions between quarks mediated by gluons. In the theory of QCD, color charges occupy a significant space. Like electric charges, color charges describe how these particles interact. A quark's color has 3 charges: red, green, and blue. An antiquark has anti-color charges: anti-red, anti-green, and anti-blue. Gluons are mixtures of two colors, such as red and anti-green, which constitutes their color charge. Keep in mind that it has nothing to do with the photons and their wavelengths. The colors here are purely notational. When these charges interact, they are mediated by gluons, with the interaction resulting in a strong attraction that intensifies as the particles move apart.

The types of gauge bosons are:

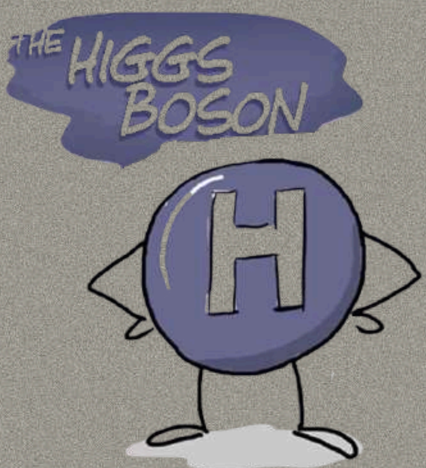
Gauge Boson	Type of interaction	Between?	More info
Gluons	Strong, short range (~10^{-15} m)	quarks, binding them into protons, neutrons, and nuclei	Quarks inside a proton constantly exchange gluons, which generate color charge interactions
Photons	Electromagnetic force, infinite range (since they are massless)	Electromagnetic interactions between charged particles	The virtual photon is the boson mediating the electromagnetic force between opposite charges, just as it mediates repulsion between like charges.
W & Z Bosons	Weak forces Very short (~10^{-18} m) because W/Z are massive	Weak nuclear interactions, responsible for radioactive decay	Neutrino interactions in the Sun or reactors involve W/Z bosons.







Scalar bosons are the background fields that modify particle properties but don't transmit forces. Here, we are looking at the famous particle, the Higgs boson. They have a 0 spin and aren't really forces but give mass to W/Z bosons and fermions.

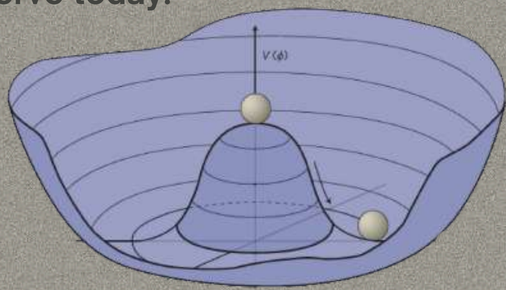


WHY THE HIGGS MATTERS

Quantum field theory elegantly formed the basis of quantum electromagnetic theory. However, the same could not be done for weak interactions, as the theory didn't allow for the weak force carriers, the W and Z bosons, to have any mass. If they did have any mass, a fundamental symmetry of the theory would be broken, and the theory would break down. This was an issue because these weak force carriers had to possess some non-negligible mass to be consistent with very short-range weak interactions.

Thus came the solution with the Brout-Englert-Higgs mechanism. This mechanism has two main components: an entirely new quantum field, the Higgs field, and a spontaneous symmetry breaking. A spontaneously broken symmetry is present in the equations of a theory, but broken in the physical system. The way this works for particle masses is as follows: when the universe was born, it was filled with the Higgs field in an unstable – but symmetrical – state. A fraction of a second after the Big Bang, the field found a stable configuration, but one that breaks the initial symmetry. In this configuration, the equations remain symmetrical, but the broken symmetry of the Higgs field gives rise to the masses of the W and Z bosons.

Think of symmetry breaking as if a ball were located at the top of a hill with no disturbance. Even a very minute nudge would break the symmetry, and the ball would take up a direction. Here, equations imply symmetry, but in the physical world, this symmetry breaks. As it later turned out, other elementary particles also acquire mass by interacting with the Higgs field, giving rise to the particle properties we observe today.



(From left to right) Robert Brout, Francois Englert and Peter Higgs

BEYOND THE TABLE

The Standard Model is often shown as a colorful table of particles, quarks, leptons, and bosons arranged in neat families. But the real theory does not begin as a table. At its core, the Standard Model is expressed as a single, compact mathematical object called the Lagrangian.

A Lagrangian describes how a physical system evolves. In this case, it encodes every known fundamental particle and the forces between them. Although the equation is famously dense, each part of it corresponds to a specific piece of physics:

PART 1

$$-\frac{1}{2}\partial_\nu g^a_\mu \partial_\nu g^a_\mu - g_s f^{abc}\partial_\mu g^a_\nu g^b_\mu g^c_\nu - \frac{1}{4} g_s^2 f^{abc} f^{ade} g^b_\mu g^c_\nu g^d_\mu g^e_\nu +$$

$$\frac{1}{2} i g_s^2 (\bar{q}_i^\sigma \gamma^\mu q_j^\sigma) g^a_\mu + \bar{G}^a \partial^2 G^a + g_s f^{abc} \partial_\mu \bar{G}^a G^b g^c_\mu - \partial_\nu W^+_\mu \partial_\nu W^-_\mu -$$

$$M^2 W^+_\mu W^-_\mu - \frac{1}{2}\partial_\nu Z^0_\mu \partial_\nu Z^0_\mu - \frac{1}{2c_w^2} M^2 Z^0_\mu Z^0_\mu - \frac{1}{2}\partial_\mu A_\nu \partial_\mu A_\nu - \frac{1}{2}\partial_\mu H \partial_\mu H -$$

This part of the Lagrangian describes gluons, the particles that carry the strong nuclear force. Unlike photons, gluons interact with each other because they carry color charge. This self-interaction is what leads to color confinement, the reason quarks are never found alone.

PART 2

A large portion of the Lagrangian is devoted to describing the behavior of bosons, particularly the W and Z bosons that mediate the weak force. Bosons act as force carriers: photons carry electromagnetism, gluons carry the strong force, and W/Z bosons carry the weak force. The Higgs boson plays a different role, its interactions, which give particles mass, appear in the next section.

$$- \partial_\nu W_\mu^+\partial_\nu W_\mu^- -$$
$$M^2W_\mu^+W_\mu^- - \frac{1}{2}\partial_\nu Z_\mu^0\partial_\nu Z_\mu^0 - \frac{1}{2c_w^2}M^2Z_\mu^0Z_\mu^0 - \frac{1}{2}\partial_\mu A_\nu\partial_\mu A_\nu - \frac{1}{2}\partial_\mu H\partial_\mu H -$$
$$\frac{1}{2}m_h^2H^2 - \partial_\mu\phi^+\partial_\mu\phi^- - M^2\phi^+\phi^- - \frac{1}{2}\partial_\mu\phi^0\partial_\mu\phi^0 - \frac{1}{2c_w^2}M\phi^0\phi^0 - \beta_h[\frac{2M^2}{g^2} +$$
$$\frac{2M}{g}H + \frac{1}{2}(H^2 + \phi^0\phi^0 + 2\phi^+\phi^-)] + \frac{2M^4}{g^2}\alpha_h - igc_w[\partial_\nu Z_\mu^0(W_\mu^+W_\nu^- -$$
$$W_\nu^+W_\mu^-) - Z_\nu^0(W_\mu^+\partial_\nu W_\mu^- - W_\mu^-\partial_\nu W_\mu^+) + Z_\mu^0(W_\nu^+\partial_\nu W_\mu^- -$$
$$W_\nu^-\partial_\nu W_\mu^+)] - igs_w[\partial_\nu A_\mu(W_\mu^+W_\nu^- - W_\nu^+W_\mu^-) - A_\nu(W_\mu^+\partial_\nu W_\mu^- -$$
$$W_\mu^-\partial_\nu W_\mu^+) + A_\mu(W_\nu^+\partial_\nu W_\mu^- - W_\nu^-\partial_\nu W_\mu^+)] - \frac{1}{2}g^2W_\mu^+W_\mu^-W_\nu^+W_\nu^- +$$
$$\frac{1}{2}g^2W_\mu^+W_\nu^-W_\mu^+W_\nu^- + g^2c_w^2(Z_\mu^0W_\mu^+Z_\nu^0W_\nu^- - Z_\mu^0Z_\mu^0W_\nu^+W_\nu^-) +$$
$$g^2s_w^2(A_\mu W_\mu^+A_\nu W_\nu^- - A_\mu A_\mu W_\nu^+W_\nu^-) + g^2s_wc_w[A_\mu Z_\nu^0(W_\mu^+W_\nu^- -$$
$$W_\nu^+W_\mu^-) - 2A_\mu Z_\mu^0W_\nu^+W_\nu^-] - g\alpha[H^3 + H\phi^0\phi^0 + 2H\phi^+\phi^-] -$$
$$\frac{1}{8}g^2\alpha_h[H^4 + (\phi^0)^4 + 4(\phi^+\phi^-)^2 + 4(\phi^0)^2\phi^+\phi^- + 4H^2\phi^+\phi^- + 2(\phi^0)^2H^2] -$$
$$gMW_\mu^+W_\mu^-H - \frac{1}{2}g\frac{M}{c_w^2}Z_\mu^0Z_\mu^0H - \frac{1}{2}ig[W_\mu^+(\phi^0\partial_\mu\phi^- - \phi^-\partial_\mu\phi^0) -$$
$$W_\mu^-(\phi^0\partial_\mu\phi^+ - \phi^+\partial_\mu\phi^0)] + \frac{1}{2}g[W_\mu^+(H\partial_\mu\phi^- - \phi^-\partial_\mu H) - W_\mu^-(H\partial_\mu\phi^+ -$$
$$\phi^+\partial_\mu H)] + \frac{1}{2}g\frac{1}{c_w}(Z_\mu^0(H\partial_\mu\phi^0 - \phi^0\partial_\mu H) - ig\frac{s_w^2}{c_w}MZ_\mu^0(W_\mu^+\phi^- - W_\mu^-\phi^+) +$$
$$igs_wMA_\mu(W_\mu^+\phi^- - W_\mu^-\phi^+) - ig\frac{1-2c_w^2}{2c_w}Z_\mu^0(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) +$$
$$igs_wA_\mu(\phi^+\partial_\mu\phi^- - \phi^-\partial_\mu\phi^+) - \frac{1}{4}g^2W_\mu^+W_\mu^-[H^2 + (\phi^0)^2 + 2\phi^+\phi^-] -$$
$$\frac{1}{4}g^2\frac{1}{c_w^2}Z_\mu^0Z_\mu^0[H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2\phi^+\phi^-] - \frac{1}{2}g^2\frac{s_w^2}{c_w}Z_\mu^0\phi^0(W_\mu^+\phi^- +$$
$$W_\mu^-\phi^+) - \frac{1}{2}ig^2\frac{s_w^2}{c_w}Z_\mu^0H(W_\mu^+\phi^- - W_\mu^-\phi^+) + \frac{1}{2}g^2s_wA_\mu\phi^0(W_\mu^+\phi^- +$$
$$W_\mu^-\phi^+) + \frac{1}{2}ig^2s_wA_\mu H(W_\mu^+\phi^- - W_\mu^-\phi^+) - g^2\frac{s_w}{c_w}(2c_w^2 - 1)Z_\mu^0A_\mu\phi^+\phi^- -$$
$$g^1s_w^2A_\mu A_\mu\phi^+\phi^-$$

PART 3

$$- \bar{e}^\lambda(\gamma\partial + m_e^\lambda)e^\lambda - \bar{\nu}^\lambda\gamma\partial\nu^\lambda - \bar{u}_j^\lambda(\gamma\partial + m_u^\lambda)u_j^\lambda -$$
$$\bar{d}_j^\lambda(\gamma\partial + m_d^\lambda)d_j^\lambda + igs_wA_\mu[-(\bar{e}^\lambda\gamma^\mu e^\lambda) + \frac{2}{3}(\bar{u}_j^\lambda\gamma^\mu u_j^\lambda) - \frac{1}{3}(\bar{d}_j^\lambda\gamma^\mu d_j^\lambda)] +$$
$$\frac{ig}{4c_w}Z_\mu^0[(\bar{\nu}^\lambda\gamma^\mu(1 + \gamma^5)\nu^\lambda) + (\bar{e}^\lambda\gamma^\mu(4s_w^2 - 1 - \gamma^5)e^\lambda) + (\bar{u}_j^\lambda\gamma^\mu(\frac{4}{3}s_w^2 -$$
$$1 - \gamma^5)u_j^\lambda) + (\bar{d}_j^\lambda\gamma^\mu(1 - \frac{8}{3}s_w^2 - \gamma^5)d_j^\lambda)] + \frac{ig}{2\sqrt{2}}W_\mu^+[(\bar{\nu}^\lambda\gamma^\mu(1 + \gamma^5)e^\lambda) +$$
$$(\bar{u}_j^\lambda\gamma^\mu(1 + \gamma^5)C_{\lambda\kappa}d_j^\kappa)] + \frac{ig}{2\sqrt{2}}W_\mu^-[(\bar{e}^\lambda\gamma^\mu(1 + \gamma^5)\nu^\lambda) + (\bar{d}_j^\kappa C_{\lambda\kappa}^\dagger\gamma^\mu(1 +$$
$$\gamma^5)u_j^\lambda)] +$$

This portion of the Lagrangian describes how matter particles, interact through the weak force. It also reflects the organization of matter into three generations, each with increasing mass. The weak force allows heavier particles to decay into lighter ones, and this section includes their basic interactions with the Higgs field, which gives many of them mass. Notably, this formulation assumes neutrinos are massless, an assumption now known to be incorrect.

PART 4

$$(\bar{u}_j^\lambda \gamma^\mu(1+\gamma^5)C_{\lambda\kappa}d_j^\kappa)] + \frac{ig}{2\sqrt{2}}W_\mu^-[(\bar{e}^\lambda\gamma^\mu(1+\gamma^5)\nu^\lambda) + (\bar{d}_j^\kappa C_{\lambda\kappa}^\dagger\gamma^\mu(1+\gamma^5)u_j^\lambda)] + \frac{ig}{2\sqrt{2}}\frac{m_e^\lambda}{M}[-\phi^+(\bar{\nu}^\lambda(1-\gamma^5)e^\lambda) + \phi^-(\bar{e}^\lambda(1+\gamma^5)\nu^\lambda)] - \frac{g}{2}\frac{m_e^\lambda}{M}[H(\bar{e}^\lambda e^\lambda) + i\phi^0(\bar{e}^\lambda\gamma^5 e^\lambda)] + \frac{ig}{2M\sqrt{2}}\phi^+[-m_d^\kappa(\bar{u}_j^\lambda C_{\lambda\kappa}(1-\gamma^5)d_j^\kappa) + m_u^\lambda(\bar{u}_j^\lambda C_{\lambda\kappa}(1+\gamma^5)d_j^\kappa] + \frac{ig}{2M\sqrt{2}}\phi^-[m_d^\lambda(\bar{d}_j^\lambda C_{\lambda\kappa}^\dagger(1+\gamma^5)u_j^\kappa) - m_u^\kappa(\bar{d}_j^\lambda C_{\lambda\kappa}^\dagger(1-\gamma^5)u_j^\kappa] - \frac{g}{2}\frac{m_u^\lambda}{M}H(\bar{u}_j^\lambda u_j^\lambda) - \frac{g}{2}\frac{m_d^\lambda}{M}H(\bar{d}_j^\lambda d_j^\lambda) + \frac{ig}{2}\frac{m_u^\lambda}{M}\phi^0(\bar{u}_j^\lambda\gamma^5 u_j^\lambda) - \frac{ig}{2}\frac{m_d^\lambda}{M}\phi^0(\bar{d}_j^\lambda\gamma^5 d_j^\lambda) + \bar{X}^+(\partial^2 - M^2)X^+ + \bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 -$$

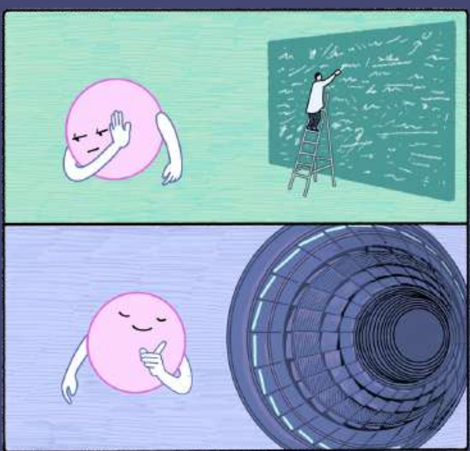
In quantum mechanics, there is no single definite path a particle takes, and this can introduce redundant terms into the mathematical description of the theory. To correct for these redundancies, physicists include ghosts, virtual entities that do not correspond to real particles. This section of the Lagrangian accounts for how matter particles interact with Higgs ghosts, virtual artifacts from the Higgs field.

PART 5

$$\frac{ig}{2}\frac{m_d^\lambda}{M}\phi^0(\bar{d}_j^\lambda\gamma^5 d_j^\lambda) + \bar{X}^+(\partial^2 - M^2)X^+ + \bar{X}^-(\partial^2 - M^2)X^- + \bar{X}^0(\partial^2 - \frac{M^2}{c_w^2})X^0 + \bar{Y}\partial^2 Y + igc_w W_\mu^+(\partial_\mu\bar{X}^0 X^- - \partial_\mu\bar{X}^+ X^0) + igs_w W_\mu^+(\partial_\mu\bar{Y}X^- - \partial_\mu\bar{X}^+ Y) + igc_w W_\mu^-(\partial_\mu\bar{X}^- X^0 - \partial_\mu\bar{X}^0 X^+) + igs_w W_\mu^-(\partial_\mu\bar{X}^- Y - \partial_\mu\bar{Y}X^+) + igc_w Z_\mu^0(\partial_\mu\bar{X}^+ X^+ - \partial_\mu\bar{X}^- X^-) + igs_w A_\mu(\partial_\mu\bar{X}^+ X^+ - \partial_\mu\bar{X}^- X^-) - \frac{1}{2}gM[\bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c_w^2}\bar{X}^0 X^0 H] + \frac{1-2c_w^2}{2c_w}igM[\bar{X}^+ X^0\phi^+ - \bar{X}^- X^0\phi^-] + \frac{1}{2c_w}igM[\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-] + igMs_w[\bar{X}^0 X^-\phi^+ - \bar{X}^0 X^+\phi^-] + \frac{1}{2}igM[\bar{X}^+ X^+\phi^0 - \bar{X}^- X^-\phi^0]$$

The final part of the Lagrangian introduces Faddeev–Popov ghosts, another type of mathematical correction. These ghosts are used to cancel redundancies that arise in calculations involving the weak force, ensuring the theory remains consistent.

From Pauli's "ghost" particles (neutrinos) to Higgs' "God" particles, and in spite of its limitations, like its inability to explain dark matter or the strange asymmetry between matter and antimatter, the Standard Model stands today as one of the famous theories that unites quarks, leptons, and bosons into a single, elegant picture of reality. The deeper we look, more questions arise.



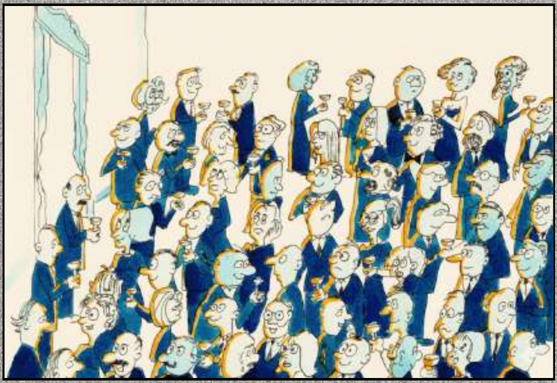
The Standard Model doesn't predict everything by itself, it needs experimental inputs like the masses of particles. Two numbers are especially important: the top quark and the Higgs boson. Our current best measurements of these suggest the universe might be in a metastable state, stable for now, but not forever.

If you spot any errors or have suggestions, please let us know.
Article by, Gargi Joshi (Physics Undergrad, class'28)

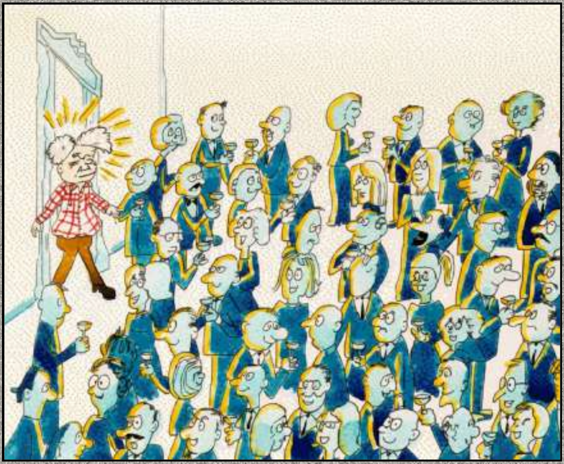
"IMAGINE A COCKTAIL PARTY.."

Back in the early 1990s, the UK's Science Minister, William Waldegrave, announced a challenge: explain the Higgs field and Higgs boson in plain language, and the best explanation would win a bottle of champagne. Physicist David Miller of University College London claimed the prize with a striking analogy. He compared the Higgs field to a crowded cocktail party full of people chatting. And it goes like:

Imagine a cocktail party where the room is full of physicists chattering quietly. This lively, ever-present crowd represents the Higgs field, filling all of space.

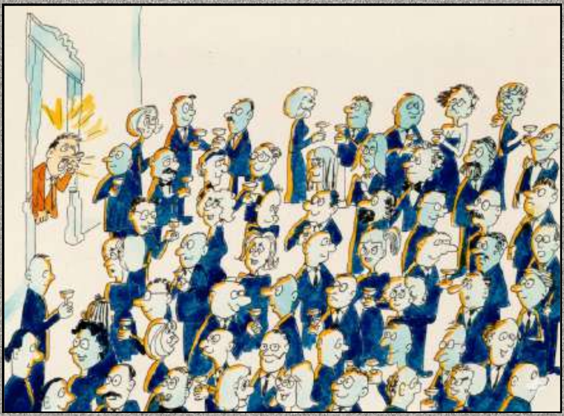


Now, suppose someone unknown walks in, say, an income tax officer. The room barely reacts, no one stops him, no one gathers around. He behaves like a particle that interacts very weakly with the Higgs field, therefore, he has little to no mass.



But then, a well-known scientist walks in, creating a disturbance as he moves across the room and attracting a cluster of admirers with each step..

this increases his resistance to movement, in other words, he acquires mass, just like a particle moving through the Higgs field...



... if a rumor crosses the room, ...it creates the same kind of clustering, but this time among the scientists themselves. In this analogy, these clusters are the Higgs particles.

source: CERN

DECIPHERING THE INVISIBLE

Can Ghost Particles Reveal New Physics?

Guru Jahnavi Madana
Physics undergrad | class ‘28

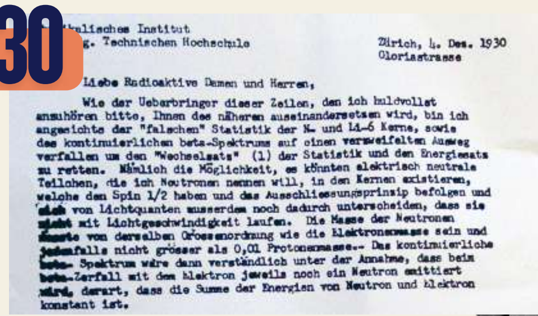
Physics is the quest to understand the most fundamental building blocks of reality and the laws governing them. From the vast cosmos to the tiniest particles, physicists seek patterns and principles that unify all phenomena. While some secrets come from grand cosmic events or high-energy experiments, others hide in the quietest, most elusive particles.

Enter the neutrino; ghost particles that pass through us by the trillions every second without so much as a “hello.” They’ve been playing hard to get since their discovery, forcing physicists to rethink the Standard Model, because who doesn’t love a good plot twist in fundamental physics?

This article reviews the history of neutrino research, explains what neutrinos actually are , and dives into the open questions that keep physicists chasing these elusive particles. Studying neutrinos is like detective work, searching for elusive clues. If you thought particle physics was all about flashy accelerators and smashing protons, think again.

THE ODYSSEY

1930


...alisches Institut
...g. Technischen Hochschule

Zürich, 4. Dez. 1930
Gloriastrasse

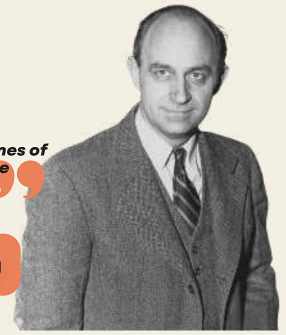
Liebe Radioaktive Damen und Herren,

Wie der Ueberbringer dieser Zeilen, den ich huldvollst anzuhören bitte, Ihnen des näheren auseinandersetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik und den Energiesatz zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den Spin 1/2 haben und das Ausschliessungsprinzip befolgen und sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen müsste von derselben Groessenordnung wie die Elektronenmasse sein und jedenfalls nicht grösser als 0,01 Protonenmasse.- Das kontinuierliche beta- Spektrum wäre dann verständlich unter der Annahme, dass beim beta-Zerfall mit dem Elektron jeweils noch ein Neutron emittiert wird, derart, dass die Summe der Energien von Neutron und Elektron konstant ist.

"I have hit upon a desperate remedy to save the 'exchange theorem'... and the law of conservation of energy."

Pauli proposed a "desperate remedy" to save energy conservation in beta decay: a particle which cannot be detected, in his playful letter to "radioactive ladies and gentlemen,". Thus, the neutrino was born on paper before it was ever seen.

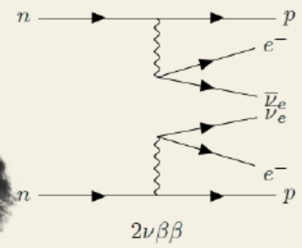
1934



"If I could remember the names of these particles, I would have been a botanist."

Enrico Fermi, father of world's first nuclear reactor, gave Pauli's ghost a name: neutrino, Italian for "little neutral one." With this, he built the first full theory of beta decay, weaving the neutrino into the fabric of a new fundamental interaction , the weak force.

1935



Maria Goeppert Mayer predicted a rare process: double beta decay. In it, two neutrons transform together into protons, releasing two electrons and two antineutrinos.

1937

Ettore Majorana proposed that neutrinos might be their own antiparticles, unlike most particles that have distinct opposites. Such self-conjugate entities, later called Majorana particles, opened the door to profound questions about the symmetry of matter and antimatter.

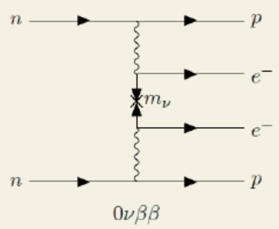
Fleeting Genius


Chi l'ha visto ?

Ettore Majorana ordinario di fisica teorica all'Università di Napoli, è misteriosamente scomparso dagli ultimi di marzo. Di anni 31, alto metri 1,70, snello, con capelli neri, occhi scuri, una lunga cicatrice sul dorso di una mano. Chi ne sapesse qualcosa è pregato di scrivere al R. P. E. Marinacci, Viale Regina Margherita 66 - Roma.

Ettore Majorana disappeared suddenly in 1938. Neither the man nor his particle was ever seen after that.

1939



Wendell Furry combined Goeppert Mayer's decay and Majorana's idea to propose neutrinoless double beta decay. If ever observed, this rare process would prove neutrinos are their own antiparticles, a discovery with sweeping consequences for the nature of matter itself.

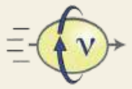
1956

Frederick Reines and Clyde Cowan finally caught the elusive neutrino using a 10-ton detector by a nuclear reactor. After five months of careful measurements, they telegraphed Pauli: "We are happy to inform you that we have definitively detected neutrinos." The ghostly particle had stepped out of theory into reality.

1957

Bruno Pontecorvo suggested that neutrinos might transform into their own antiparticles, much like neutral kaons mix with their antipartners. This radical idea planted the seeds for the broader concept of neutrino oscillations, which would emerge later as more neutrino flavors were discovered.

1958



Brookhaven experiments revealed that neutrinos are always left-handed, spinning opposite to their motion. Even today, only left-handed neutrinos and right-handed antineutrinos have been observed, hinting at a subtle asymmetry in nature.

1962

At Brookhaven's powerful Alternating Gradient Synchrotron, Leon Lederman, Mel Schwartz, and Jack Steinberger uncovered a second neutrino: the muon neutrino. Their discovery revealed that neutrinos come in multiple flavors, expanding the particle family.

1968

Ray Davis's underground experiment in the Homestake Mine caught neutrinos from the Sun, but only a third as many as predicted by John Bahcall. This puzzling shortfall, the solar neutrino problem, hinted at new physics in the neutrino itself.

1973

At CERN's Gargamelle bubble chamber, scientists observed neutral-current neutrino interactions, weak forces without charge exchange. This breakthrough pointed to a new mediator, the Z boson, later confirmed as a cornerstone of the Standard Model.

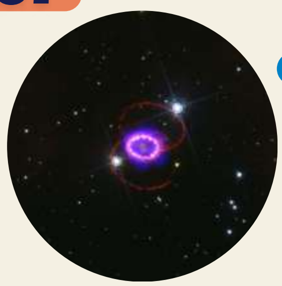
1975

After Martin Perl's discovery of the tau lepton at SLAC, physicists predicted a matching particle: the tau neutrino. Completing the parallel structure of leptons, its existence was clear in theory, though it would take 25 years, until 2000, for the DONUT experiment at Fermilab to confirm it.

1985

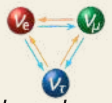
Japan's Kamiokande and the U.S. IMB experiments detected atmospheric neutrinos from cosmic-ray collisions. But the ratio of muon to electron neutrinos came out lower than expected, a puzzling shortfall soon dubbed the atmospheric neutrino anomaly.

1987



When a massive star dies, it often explodes as a supernova, releasing about 99% of its energy in the form of neutrinos. The neutrinos arrived before the light, inspiring the creation of SNEWS (Supernova Early Warning System), a global early-warning system for future supernovae.

1988



Super-Kamiokande found the first evidence that neutrinos oscillate between flavors, proving they have mass, confirming a decades-old idea from Bruno Pontecorvo.

2002

The Sudbury Neutrino Observatory confirmed solar neutrino oscillations, solving the long-standing solar neutrino problem first raised by Ray Davis.

2004

Japan's KamLAND experiment observed both the disappearance and reappearance of reactor electron antineutrinos, providing clear evidence of antineutrino oscillation.

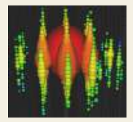
2005

KamLAND reported the first observation of geoneutrinos, neutrinos from radioactive decay inside Earth, offering a new way to study our planet's interior.

2010

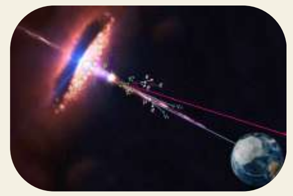
The OPERA experiment in Italy reported its first tau neutrino candidate from a CERN muon neutrino beam, marking direct evidence of muon-to-tau oscillation. By 2015, five events confirmed the discovery.

2012



On December 4, IceCube in Antarctica detected the most energetic neutrino ever, nicknamed Big Bird, with an energy of ~2 PeV – dwarfing typical neutrino energies.

2018



IceCube detected an ultra-high-energy neutrino pointing to a blazar 4 billion light-years away, marking the first identification of a neutrino's cosmic source and ushering in multimessenger astronomy.

2020

Borexino detected neutrinos from the Sun's carbon-nitrogen-oxygen (CNO) fusion cycle for the first time, confirming a long-predicted process fueling stellar energy production.

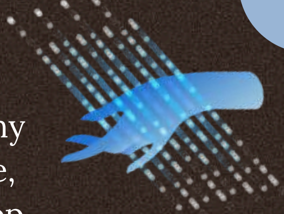
NEUTRINO..

Greek Symbol : Nu
Family : Lepton

Spin 1/2

Charge 0

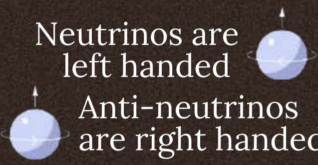
Right now, countless neutrinos are streaming through you. They're so shy that in your entire lifetime, just one might actually stop and interact.



Neutrinos are famously elusive, they interact only via 2 forces:

Neutrinos are left handed

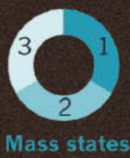
Anti-neutrinos are right handed



The 3 flavors :

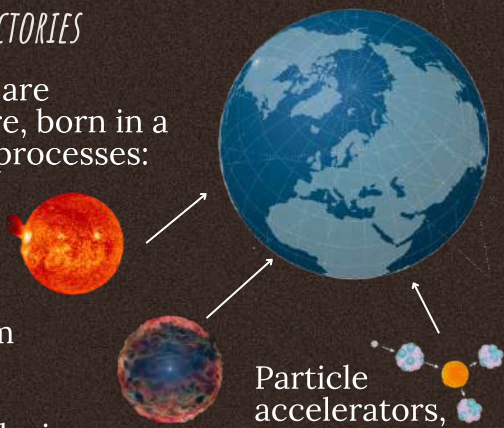
MASS Still uncertain, but known to be over a million times lighter than the electron.

Unlike electrons, muons, and taus, neutrinos don't have a definite mass. Each one is a quantum blend of three mass states, mixed in different ways to produce the various flavors.



NEUTRINO FACTORIES

Neutrinos are everywhere, born in a variety of processes:

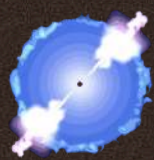


The Sun; fusion of hydrogen into helium

stellar explosions releasing a flood of neutrinos, Cosmic rays, colliding with air molecules in Earth's atmosphere

Particle accelerators, protons smashed into targets and Nuclear reactors, neutrinos from radioactive decay

Neutrinos might be their own antiparticles !



When a star explodes 99% of energy is carried away by the neutrinos

As a neutrino travels, the mix of its mass states shifts, causing it to change flavor. How quickly this happens depends on the mass differences, its energy, and the rules governing the mixing of states.

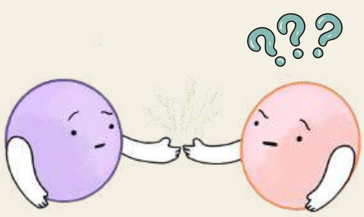
THE UNFINISHED CHAPTERS OF THE ODYSSEY

Even after decades of study, neutrinos continue to guard their secrets. Many questions remain unanswered, from the ordering of their masses to the possibility of hidden "sterile" types. These are the unfinished chapters of the odyssey, waiting for the next generation of explorers to uncover.

THE MYSTERY OF NEUTRINO MASS

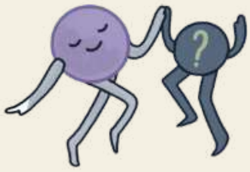
> ***"But our discovery proved that it is not perfect; neutrino has a small mass, and this cannot be explained by the Standard Model."***
>
> **Takaaki Kajita**

The story of the neutrino took a dramatic turn when experiments revealed that these ghostly particles can oscillate between flavors. That tiny shape shifting trick could only happen if they had mass, a revelation that cracked open the foundation of the Standard Model.



Other particles gain mass by interacting with the Higgs field. To use the Higgs mechanism, you need both a left-handed and a right-handed version of the particle. Neutrinos, as far as we can tell, only come in left-handed form. Without that right-handed partner, the Higgs has nothing to "grab onto." That's why their tiny mass can't be explained in the same way as other particles.

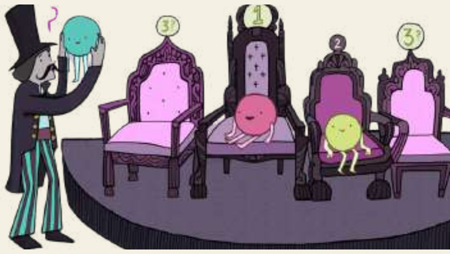
Perhaps neutrinos are their own antiparticles, Majorana particles. In that case, they could "marry themselves" to gain mass, through new interactions or a special Higgs-like field. Proof may come from the hunt for neutrinoless double beta decay.



Another elegant idea is the seesaw mechanism. Imagine pairing the known, light neutrino with a hypothetical ultra-heavy partner. On one side of the seesaw sits the heavy state, pressing down with enormous mass; on the other, the known neutrino is forced upward, becoming almost weightless.

Physicists know neutrinos exist in three mass states, but which is heaviest and which is lightest is still unknown. They've mapped the differences between the states and confirmed that the second is heavier than the first, but the full ordering remains unresolved. Cracking this "hierarchy puzzle" could illuminate how the forces of nature once unified in the early universe.

Understanding how neutrinos acquire mass and how their masses are arranged, remains one of the most important open questions in particle physics. The answers could point to physics beyond the Standard Model and reshape our picture of the universe at its most fundamental level.



STERILE NEUTRINO - SHADOW ON THE MAP

In the 1990s, the LSND experiment fired a beam of muon-antineutrinos but detected about 100 more electron-antineutrinos than expected. Later, MiniBooNE confirmed similar anomalies in both neutrino and antineutrino modes. These unexpected blips hinted at a mysterious "fourth" neutrino, a sterile type that doesn't interact like the familiar three. Physicists proposed sterile neutrinos as a simple fix to these puzzles, keeping the hunt for hidden particles alive.

Sterile neutrinos could exist across a wide range of mass scales, each with different consequences:

Light, eV-scale
probed by short-baseline experiments

KeV-scale
might contribute to dark matter.

10^{13} GeV scale
heavy seesaw neutrinos that help explain the small neutrino masses

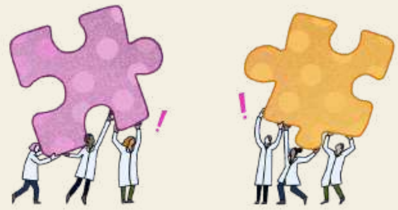
10^{15} GeV scale
physicists also start talking about grand unified theories and how different forces relate to one another.

Sterile neutrinos are even more elusive than active ones: they don't feel the weak force, only mix with the three known flavors (and gravity), making them invisible to detectors. In theory, a right-handed neutrino could be sterile, since it doesn't couple to the weak force. Experiments at LEP (Large electron - positron collider) showed that only three light neutrinos interact via the Z boson, so any extra neutrinos must truly be "sterile."

Hints appear elsewhere too. Gallium experiments and some reactor experiments see slight but persistent deficits, suggesting neutrinos may be oscillating into hidden sterile states. These results are intriguing but not definitive, experimental or nuclear effects could also be at play.

The case remains uncertain: IceCube has seen no disappearance signal expected from sterile neutrinos, and Planck satellite data shows the early universe acted as if only three light species existed. These don't rule them out entirely but make simple sterile models less likely.

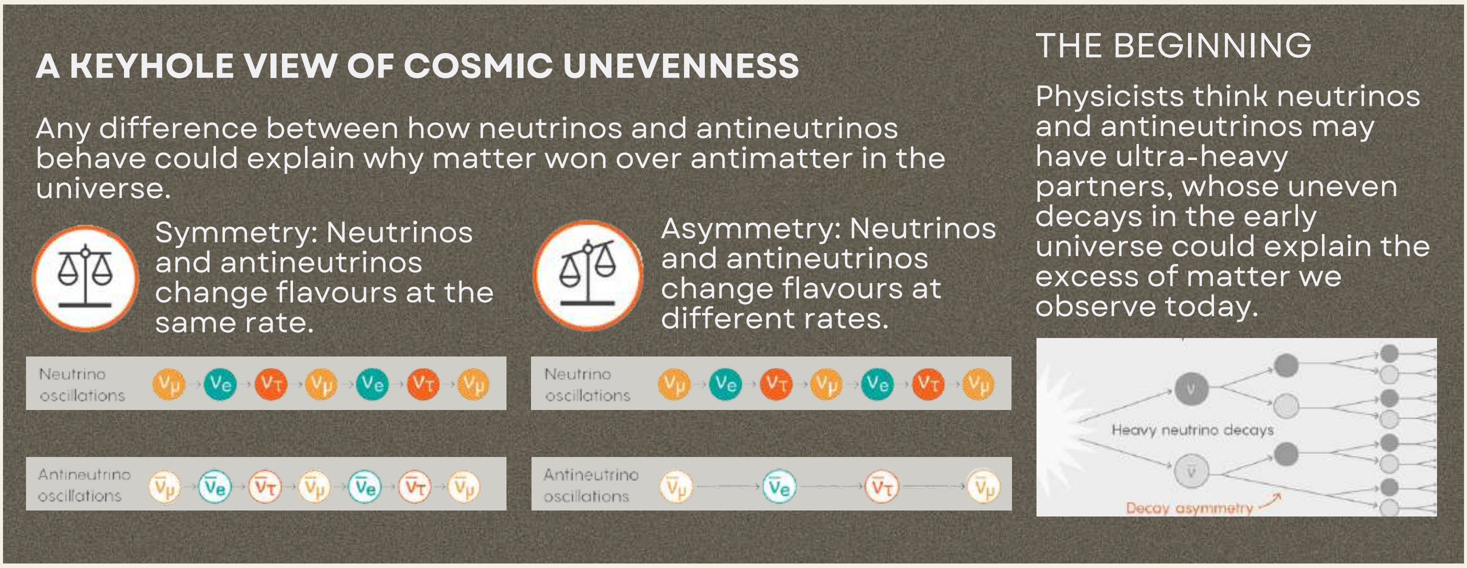
Whether phantom or profound, sterile neutrinos remain one of the boldest wild cards in modern physics, straddling the frontier between lab anomalies, cosmic puzzles, and the search for physics beyond the Standard Model.



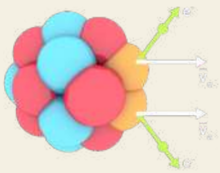
WHY IS THERE SOMETHING RATHER THAN NOTHING

One of the biggest cosmic riddles is simple to state: why is there something rather than nothing? In other words, why does matter dominate over antimatter in the universe? Neutrinos might hold the answer.

A fraction of a second after the Big Bang, primordial heavy neutrinos could have decayed in a process known as leptogenesis. Calculations suggest these decays were slightly asymmetric, producing fewer leptons (electrons muons, tau particles) than antileptons. Standard Model processes then converted this tiny imbalance into a one-part-per-billion excess of baryons (protons and neutrons) over antibaryons. The rest annihilated, leaving just the matter we see today.



inspired by: QuantaMagazine


Double beta decay


Neutrinoless Double beta decay

The mechanism becomes even more compelling if neutrinos are Majorana particles, their own antiparticles. In that case, neutrinos can violate lepton number in processes like neutrino-less double beta decay. Observing such decay would indicate that neutrinos and antineutrinos are fundamentally identical except for helicity (left vs. right-handedness), making leptogenesis a plausible route for the cosmic matter-antimatter asymmetry.

Complicating the picture, CP violation, differences in oscillation probabilities between neutrinos and antineutrinos, provides another source of asymmetry. Even if neutrinos are Majorana particles, their behavior can differ subtly depending on helicity. Experiments comparing muon-to-electron neutrino transitions with their antineutrino counterparts are probing this CP-violating phase.

Finally, the seesaw mechanism links the tiny masses of known neutrinos to hypothetical ultra-heavy partners. These heavy states,

Particle physicists require a lot of data to be confident that a physical effect is real rather than a statistical fluctuation.

Evidence (3σ)
when there's less than a 0.3% probability that a bump in the data could arise by sheer chance.

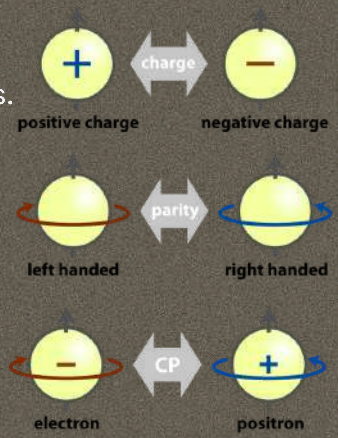
Discovery (5σ)
has less than a 0.00006% probability of arising by chance (gold standard)

present in the early universe, may have tipped the scales during leptogenesis, leaving the matter-antimatter imbalance we see today.

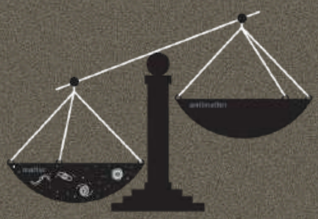
In short, neutrinos may carry the key to the universe's earliest moments. Their true nature: Majorana or Dirac, left-handed only or paired with heavy counterparts, could explain one of the deepest asymmetries of all: why we exist at all.

WHAT IS CP?

CP stands for Charge conjugation (C), swapping particles with antiparticles, and Parity (P), flipping spatial coordinates like a mirror reflection. Together, they represent a fundamental symmetry in physics.



CP violation means the laws of physics treat particles and their antiparticles differently.



Essentially, particles and antiparticles don't behave as perfect mirror images.

CP violation is crucial because it helps explain why our universe has far more matter than antimatter.

CPT THEOREM- NATURE'S ULTIMATE SYMMETRY

It is a fundamental symmetry principle stating that the laws of physics remain unchanged if particles are replaced by antiparticles (C), spatial coordinates are inverted (P), and the direction of time is reversed (T), all simultaneously.

The CPT theorem is the only symmetry of nature known to hold exactly, even though C, P, and CP symmetries can be violated individually. It guarantees that a mirror-image universe made of antimatter and running backward in time would behave identically to ours.

RELIC AND COSMIC NEUTRINOS

While relic neutrinos remain undetected, their gravity shaped galaxies, clusters, and the cosmic web. In supernovae, dense neutrino clouds influence explosions and create heavy elements through neutrino-neutrino interactions. Their subtle effects on the CMB, galaxy distributions, and large-scale structure let scientists probe neutrino masses, mixing, and even sterile species, offering a window into both particle physics and the early universe.

THE ODYSSEY CONTINUES.......

> ***Neutrinos are some of the only palpable evidences of physics beyond the standard model. Everything we learn about neutrinos in the coming years is new physics.***

Andre de Gouvea

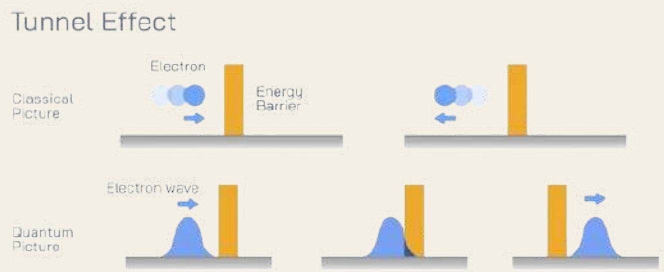
Neutrinos remain one of the universe's greatest mysteries, challenging our understanding of fundamental physics and cosmic origins. As experiments push boundaries and theories evolve, each discovery opens new questions. The journey to unravel the neutrino's true nature is far from over, promising profound insights into why our universe exists and why matter prevailed over antimatter. This unfinished odyssey continues to inspire curiosity and drive scientific exploration.

FROM ATOMS TO CIRCUITS

THE QUANTUM BREAKTHROUGH THAT WON THE 2025 NOBEL

The Nobel Prize in Physics 2025 was awarded jointly to John Clarke, Michel H. Devoret and John M. Martinis ”for the discovery of macroscopic quantum mechanical tunnelling and energy quantisation in an electric circuit”

The story of this year’s Nobel Prize begins nearly a century ago, when quantum mechanics first revealed that particles could sometimes slip through barriers that seemed insurmountable, a phenomenon now known as quantum tunnelling. In 1926, Erwin Schrödinger formulated his famous equation, showing that a particle’s wavefunction can extend into classically forbidden regions, allowing a nonzero chance of crossing a barrier. Soon after, Friedrich Hund applied this theory to molecules, demonstrating in 1927 that quantum tunnelling could explain how particles move between two potential wells. A year later, George Gamow used quantum mechanics to explain alpha decay in nuclei, showing that particles could escape by tunnelling through the nuclear barrier, a breakthrough that confirmed tunnelling as a real effect in nature. It is also what allows nuclear fusion to occur in the Sun’s core, enabling protons to overcome their mutual repulsion and fuse, even though the temperatures are not high enough for this to happen classically



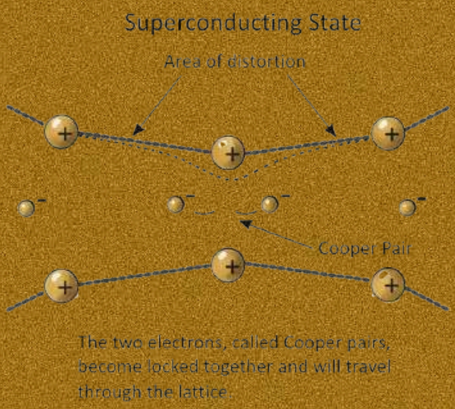
In the late 1950s, Leo Esaki’s experiments revealed that electrons could tunnel through barriers in semiconductors, leading to the invention of the tunnel diode and earning him the Nobel Prize in 1973. Around the same time, Ivar Giaever extended these ideas to superconductors, showing that electrons could tunnel through an insulating barrier between two superconductors. In 1960, Giaever’s experiments provided direct evidence for the existence of an energy gap in superconductors, a key prediction of the BCS theory, developed by John Bardeen, Leon Cooper, and Robert Schrieffer in 1957.

THE BCS THEORY

How electrons defy resistance by pairing up

BCS theory (named after John Bardeen, Leon Cooper, and Robert Schrieffer) explains how certain materials become superconductors, conducting electricity with zero resistance and expelling magnetic fields below a critical temperature.

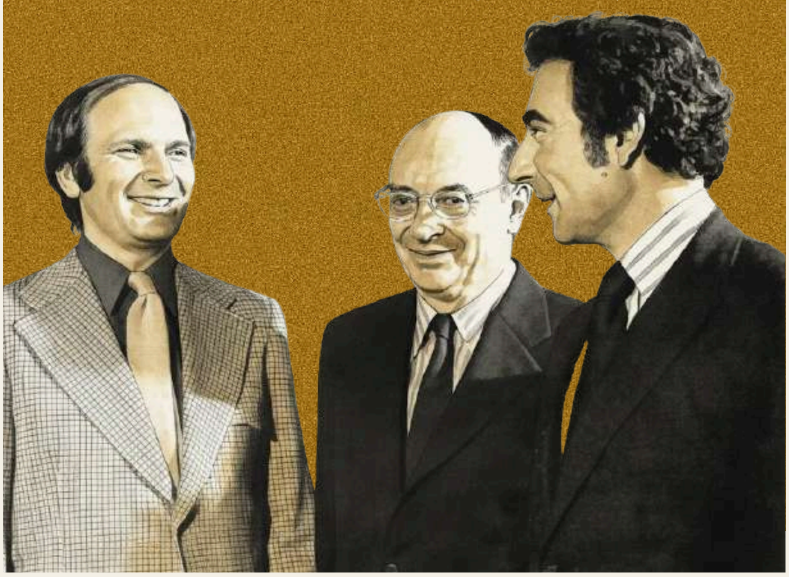
In normal metals, electrons (fermions[1]) move independently and scatter, causing resistance. In a superconductor, at low temperatures, electrons near the Fermi surface form Cooper pairs, bound states that act like bosons, allowing them to share a single quantum state. As an electron moves through the crystal lattice, it distorts nearby positive ions, attracting another electron. This indirect attraction, mediated by lattice vibrations (phonons), binds electrons into pairs.



The paired state has lower energy than unpaired electrons, creating an energy gap that protects Cooper pairs from being scattered by impurities or vibrations, hence, no electrical resistance.

All Cooper pairs join the same macroscopic wavefunction, a unified quantum state responsible for:

- Zero resistance (no energy loss)
- Meissner effect (expulsion of magnetic fields)



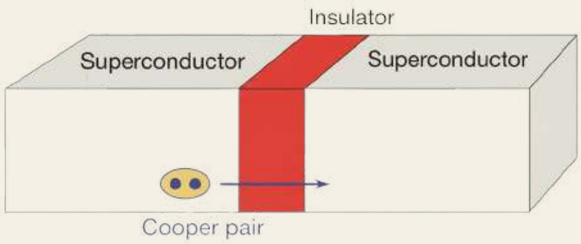
[1]Fermions are particles that obey the Pauli exclusion principles, no two can occupy the same quantum state (e.g., electrons, protons, neutrons).
Bosons are particles that can share the same state, allowing them to move collectively (e.g., photons, Cooper pairs).

In an ordinary conductor, electrons constantly collide with each other and with the atoms of the lattice.

In a superconductor, electrons unite as Cooper pairs, creating a resistance-free current. The gap in the figure marks the Josephson junction.

Cooper pairs act like a single quantum entity filling the entire circuit. This collective state is described by a shared wavefunction, the key element in the laureates' experiment.

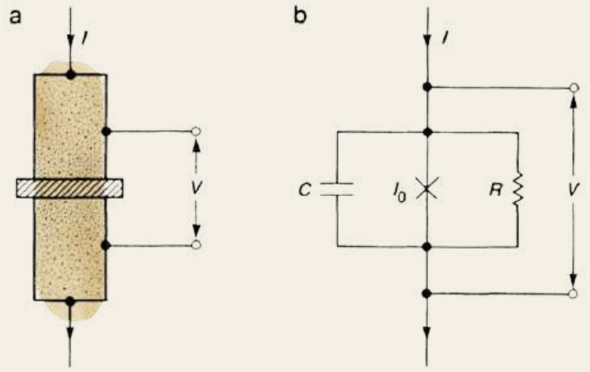
In 1962, Brian Josephson predicted that Cooper pairs could tunnel across a thin insulating barrier between two superconductors, creating a device now known as the Josephson junction. This quantum effect allows a supercurrent to flow with zero resistance and has led to practical applications such as SQUIDs (Superconducting Quantum Interference Devices), which are extremely sensitive magnetometers.



The next frontier was to test whether quantum phenomena like superposition and tunnelling could be observed in large, engineered systems. In quantum mechanics, "cat states" refer to superpositions of macroscopically distinct states, where a measurement on just one part can collapse the entire system's superposition. The below wavefunction describes a cat state with L (living) and D (dead) states.

$$\Psi(x_1, x_2, \ldots, x_N) \propto \Psi_L(x_1)\Psi_L(x_2) \ldots \Psi_L(x_N) + \Psi_D(x_1)\Psi_D(x_2) \ldots \Psi_D(x_N).$$

In 1973, Anthony Leggett posed the question: could smaller versions of Schrödinger's cat experiment be realized in superconducting systems? Superconductors, with their low resistance and weak coupling to environmental noise, offered a promising platform, especially at milli-Kelvin temperatures. This led to experiments with current-biased Josephson junctions, where researchers could probe macroscopic quantum tunnelling, demonstrating that even a collective variable describing billions of particles could tunnel through a barrier, just as predicted by quantum theory.



When a current I passes through the junction, scientists can measure the corresponding voltage V across it. The junction is characterized by its critical current Io (the maximum supercurrent that can flow without resistance) and its capacitance C, which determines how much charge can be stored. Real junctions also have a resistance R that accounts for tiny energy losses or damping.

At the heart of the Josephson junction lie two simple but powerful equations the Josephson relations:

$$I = I_0 \sin\delta \quad \& \quad \dot{\delta} = \frac{2e}{\hbar} V$$

Here, δ represents the phase difference between the quantum wavefunctions on either side of the junction. When voltage changes with time, an additional term arises due to the capacitance:

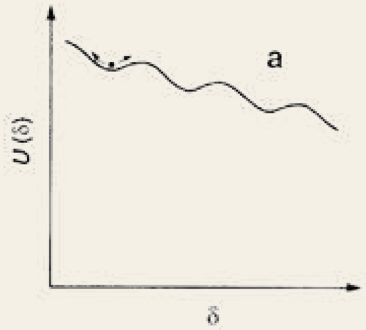
$$I = I_0 \sin\delta + \frac{\hbar}{2e} C \ddot{\delta}$$

Neglecting dissipation, this equation behaves just like Newton's law for a tiny, imaginary particle, a phase particle, moving in a potential landscape. The potential energy can be written as:

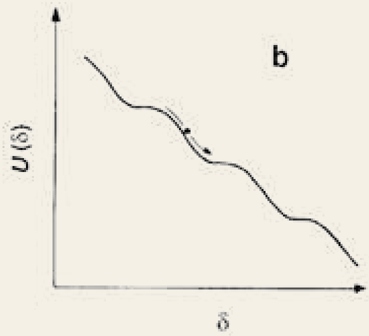
$$U(\delta) \propto -[\cos\delta + \left(\frac{I}{I_0}\right)\delta]$$

This landscape is known as the tilted washboard potential, picture a marble rolling in the grooves of a washboard that's slightly tilted. When the tilt is small, the marble (the phase particle) gets trapped in one of the valleys, corresponding to a zero-voltage state. When the tilt increases (the current exceeds Io), the marble escapes and rolls freely, the finite-voltage state.

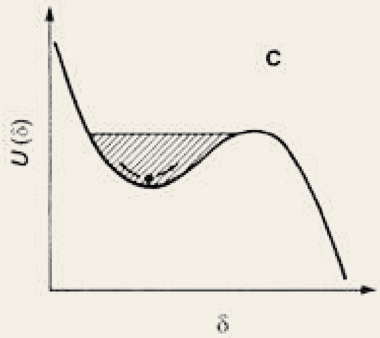
When the current is small (I<Io), the particle sits in a valley, trapped in a stable, zero-voltage state. No current escapes.



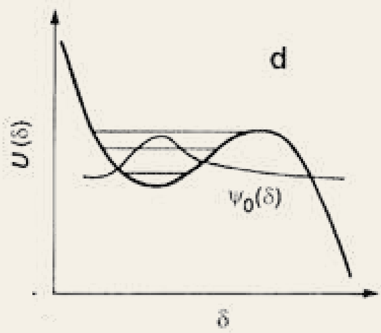
If the current exceeds the critical value Io, the slope becomes steep enough for the particle to roll freely, creating a finite voltage across the junction.

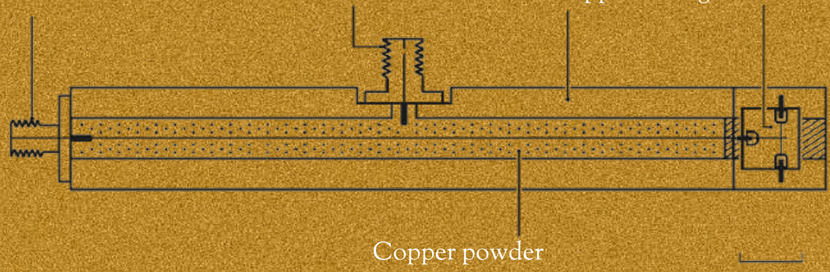


Classically, energy changes continuously, so the particle can take any value within the well.



In quantum mechanics, energy is quantized, only specific levels are allowed. At low temperatures, the particle can tunnel through the barrier into the next valley, escaping the trap even without enough classical energy.

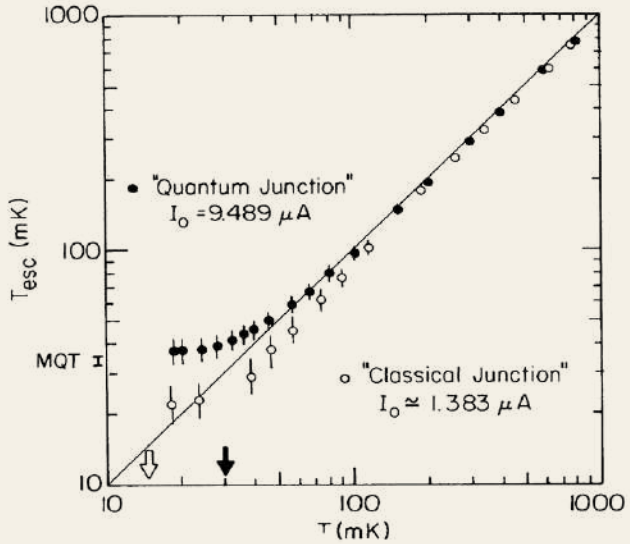




Previously, tunnelling and energy quantization had been observed only in systems involving a handful of particles. In this experiment, these same quantum effects appeared in a circuit containing billions of Cooper pairs, a macroscopic object behaving as a single quantum system

The researchers slowly increased the current through the junction while measuring the voltage across it thousands of times. At higher temperatures, the system behaved classically, the particle escaped only when thermal energy helped it over the barrier. But below a certain crossover temperature, the escape rate suddenly became independent of temperature. This meant that the system wasn't climbing over the barrier anymore, it was tunnelling through it. And crucially, this tunnelling wasn't from a single particle but from a collective macroscopic state made of billions of Cooper pairs acting as one. They confirmed this by comparing their measurements with precise theoretical predictions. Once they accounted for every parameter, the junction's capacitance, critical current, and damping resistance, the match between theory and experiment was almost perfect.

Having shown tunnelling, the Berkeley team went one step further. They exposed the system to microwave radiation of varying frequencies. If the phase particle inside the potential well truly behaved quantum mechanically, it should only absorb microwaves whose energy matched the difference between its discrete energy levels. And that's exactly what happened. At certain frequencies, the particle absorbed energy and tunneled out faster, a clear signature of quantized energy levels in a macroscopic system. This meant that their entire circuit, a tangible object you could hold, was behaving like a giant artificial atom, with distinct energy states separated by measurable gaps.



Graph. Escape temperature for a quantum junction saturates at low temperatures, illustrating macroscopic quantum tunnelling; classical junction remains temperature-dependent.

In summary, by demonstrating that entire electrical circuits can behave as macroscopic quantum systems—with quantized energy states and the ability to tunnel like a single "giant atom"—this year's Nobel-winning work has redefined what is possible in both fundamental physics and technology. Their discoveries now underpin quantum computers, powerful new sensors, and advanced experiments that probe the quantum-classical boundary, opening the way for a future where quantum phenomena shape both our understanding and our tools.

PERFECT PASTA SAUCE

Ig Nobel

Each year, the Ig Nobel Prizes celebrate research that makes people laugh first, and think later, honoring studies that are both quirky and clever. The 2025 Ig Nobel Prize in Physics went to scientists from ISTA and UC Berkeley for exploring something deliciously unexpected: the physics of perfect pasta sauce. Their study of the Roman classic cacio e pepe revealed that the secret to a creamy, lump-free sauce lies in phase transitions, the same kind of physics that governs magnets and superconductors.

By mapping a phase diagram for the sauce, the researchers showed how cheese proteins and starch interact at different temperatures. Too little starch, and the sauce enters a "mozzarella phase", stringy and clumpy. Add just enough (around 2–3%), and the sauce becomes smooth and stable. It's a delightful reminder that physics isn't confined to labs or blackboards, sometimes, it simmers right on your stovetop.

Picture. The winners of the Ig Nobel Physics Prize presented their research during the awards ceremony at Boston University. The team's comedic sketch ended with some compulsory pasta eating.

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https://phys.org/news/2025-09-ig-physics-nobel-prize-pasta.html
If you notice any errors or inaccuracies, please feel free to reach out to us for corrections.
Guru Jahnavi Madana, Physics Undergrad, Class '28.

THEORIST WITH A POET'S PULSE

We sit down with **Rehmat Singh Chawla**, an alumnus of IIT Bombay's Engineering Physics program, now pursuing his MSc in Physics with Extended Research at Imperial College London...as he traces how mathematical elegance shapes his understanding of the universe.

Could you start by telling us about your journey to IIT Bombay and into the world of physics?

My name is Rehmat Singh Chawla, and I grew up in Mohali, Punjab. Like many students, I reached a crossroads in 10th grade and chose the non-medical path. My initial goal was simple: I wanted to be a scientist. It was the only job that seemed truly attractive.

I prepared for the KVPY, and while I didn't get into IISC, I did well enough in JEE to find Engineering Physics at IIT Bombay as an option. By then, physics had become my favorite of the sciences. It felt like a perfect fit, hand-in-glove. I graduated with Honors in Physics and a Minor in Mathematics, as I always enjoyed the more mathematical problems. It took me a couple of years to figure out which field of physics I wanted to pursue, but I eventually landed on the intersection that felt most like home: mathematical and theoretical physics.

What in the World is High Energy Physics (HEP)? For our readers, how would you explain High Energy Physics in simple terms?

I'd distinguish between three related fields.

First, there's Experimental High Energy Physics. This is exactly what it sounds like: physics at energies far higher than anything we experience in daily life. The goal is to probe what's happening at a sub-nuclear level. What's going on inside protons and neutrons? What forces and particles come into play at these tiny scales? If anything, it's closer to archaeology: painstakingly sifting through subtle clues in detector data to reconstruct worlds and processes we can never access directly.

Then you have Theoretical High Energy Physics. It started as a complement to the experiments, building theories to explain the observations. This really took off with Paul Dirac in the early 1930s, right after the laws of quantum mechanics were laid down. He started working on quantum field theory, quantizing light just as they had quantized electrons.

A huge turning point was the development of the Standard Model of Particle Physics. It's our "periodic table" for fundamental particles and has been incredibly successful. But it's also a bit like a brilliant, half-finished movie. It describes the known characters and plot perfectly but completely leaves out major players like gravity and dark matter.

So today, theoretical HEP tries to fix these flaws and explain the great unknowns. The ultimate goal, the holy grail, is a theory of quantum gravity that unites everything.
Finally, there's Mathematical Physics, which is sometimes seen as a subset of theoretical physics. Here, physicists take very abstract mathematical subjects and find surprising links back to physics. It's not always about chasing quantum gravity; sometimes it's more math than physics, exploring the fundamental structures that underpin reality.

What first sparked your curiosity in physics, and was there a specific moment you knew HEP was your calling?

I've loved the logical structure of science from a young age. But in 11th grade, you encounter real physics. I had an excellent teacher who understood every problem so completely and could explain it with incredible precision. He never said a wrong word. He's at least half the reason I got into Physics. I was captivated by how you could start with a few principles and completely deconstruct a complex system.
The cutting-edge fields of quantum mechanics and gravity always interested me. The more mathematical it got, the more excited I became. However, my journey had many detours. I joined IITB during the lockdown, my grades started to slip.I also got deeply involved in club activities and the hundred other opportunities IITB offered.
By the end of my third year, I was working on projects in medical physics and optical materials; I interned at Jagiellonian University in Poland with an experimental group. I was heading back to campus when it hit me like a lightning bolt. I was doing a math minor, but none of the physics I was exploring used the kind of math I loved!
It was a true "Archimedes in the bath" kind of moment. I asked myself, "What field of physics actually uses this math?" The answer was theoretical high energy physics. I realized that the courses I had taken just for curiosity,, like particle physics and general relativity, had been leading me here all along. I just didn't know the field had a name. That's when I decided to switch.

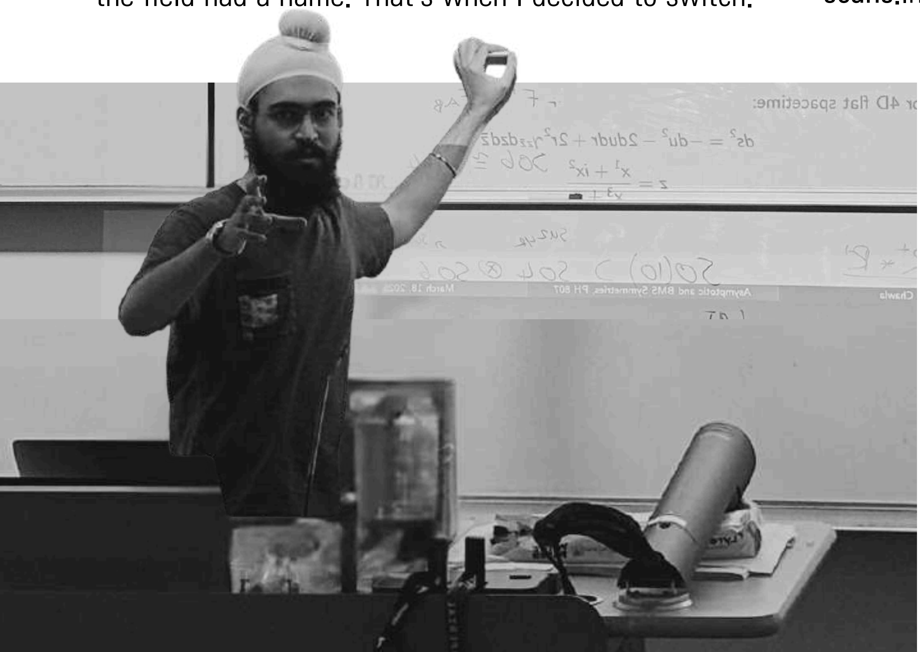
"Does Theoretical Physics Want Me?" -Rehmat Singh

That's a powerful realization. But HEP can seem intimidating. What advice do you have for students who are curious but hesitant?

For me, the path became obvious once I looked. But for many, the big question is: "I want theoretical physics, but does theoretical physics want me?" It's a very competitive field with few positions, and success is never guaranteed.
I grappled with this. "Am I good enough for this? Will I enjoy such abstract work with no experiment to bounce off of?" Back then, I didn't have a clear answer. What got me through was realizing that careers aren't set in stone. I decided that if I was going to bet on being a physicist, a career that's already a bit of a gamble, I might as well go all-in on what I truly love instead of settling halfway. If I failed, that would be a problem for future me. If I'm going all-in, I'm going all-in.

Could you walk us through some of the research you were involved in at IITB?

I worked on several projects, but two major themes were medical imaging and mathematical physics.
One project was on **Positron Emission Tomography scans.**In a PET scan, a radioactive isotope emits a positron (the antimatter version of an electron). When this positron meets an electron, they annihilate, creating two high-energy photons that fly off in opposite directions. The challenge is correctly pairing these photons. My project, "Coincidence Discrimination using Polarisation," explored a fascinating quantum solution. The two created photons have **entangled polarisations.** My simulations showed that by using this property, we could significantly improve the accuracy of PET scans, especially for high-activity sources.



My bachelor's thesis, guided by Professor Pichai Ramadevi, dove headfirst into Knot Theory. Yes, the mathematical study of knots! These aren't your shoelaces; they are closed loops in 3D space with deep connections to physics. In certain topological quantum field theories, like Perturbative Chern-Simons theory or N=4 Super-Yang-Mills theory, calculations correspond directly to "knot invariants", mathematical objects that distinguish different knots. It's a beautiful and deep connection between abstract math and fundamental physics, and I was thrilled when my work on a related topic was awarded Best Poster in THEP at Symphy 2024, our department's annual symposium.

HEP is famous for its massive collaborations, but theoretical work can be solitary. What's your take on community and skills?

That's true. My internship in Poland was part of a group working on the J-PET detector, which was a great learning environment. But my advisor there cautioned that in very large collaborations, it can be hard to make a unique name for yourself. In my field of theoretical physics, large collaborations don't really exist, so it's a different world.
Regarding skills, it's actually been the other way around for me: skills I picked up outside of physics have been invaluable within it. I taught myself to code for fun, and now it helps me write really good, efficient code. My advice to any aspiring researcher is this: learn how to write good code, not just code that works. It will save you countless hours.

What role did mentorship and peers play in your journey?

Peers, for the most part. Sitting in the computer lab all day, talking to people, helped me figure out what I wanted and how to get there. As someone who has also been a Department Academic Mentor and a mentor for reading projects, I know how crucial that peer support is.Organizing sessions, interviewing alumni, and even volunteering at conferences like the Indian Strings Meeting shaped my perspective and helped me plan for the future.

Finally, what's next for you, both professionally and personally?

Professionally, I'm here at Imperial College London working on my Master's. The immediate goal is my thesis and then applying for PhD programs, which is always a stressful season!
Personally, I want to spend more time writing. I write a lot of poetry; it's a creative outlet and a way to process things. I've been involved in literary arts for a while, from publishing a story in an anthology to judging slam poetry at IITB's cultural fest, Mood Indigo. I find that whether it's physics, poetry, or even competitive quizzing, it's all about finding patterns and elegance in the world. It's another way of making sense of this wonderfully complex universe we're in.

Call out to me once more

O rows of desks and lecture halls,
Call out to me once more
O empty roads and rambling walks,
Call out to me once more
O noisy score from room next door,
Call out to me once more
O tree-rimmed lake-edged home off home,
Call out to me once more.

O hours spent slogging, arduous days,
Interspersed with coffee breaks
Rants erupted, tea was spilled
A camaraderie most singular built
O baubled ceilings, nights of vice
Company till crack of light
Through sanguine love and pardoned hate
We forged these friendships 'spite of fate

O petrichor and sunset-smote
O rooftop scenes and days of birth
O frenzied clicks and lectures slow
O laughs familiar and smiles adored
O haunted rooms and vaunted halls
Give me reason to come home
O memory-laden mud and walls
Call out to me once more.

~Rehmat Singh Chawla

Between Blackboards & Black Holes

We had the pleasure of sitting down with IIT Bombay alumnus **Kabir Bajaj**, who recently embarked on his PhD journey at Princeton, to talk about his path from the classrooms of Noida to the frontiers of High Energy Physics.

Could you start by telling us a little about yourself-where you grew up and how you found your way to IIT Bombay?

I was born in Chandigarh but grew up in Delhi, with my schooling at Delhi Public School, Noida. My interest in physics sparked around 8th or 9th grade. I was sure it was what I wanted to pursue, and since biology was definitely not my thing, the path through JEE became clear.
After JEE, my main options were BSc Physics at IIT Kanpur and Engineering Physics at IIT Bombay. I chatted with some seniors who advised that IIT Bombay offered more flexibility in case I ever changed my mind. That wisdom, along with the same logic for choosing it over IISc, led me to Powai. It's advice I still pass on to juniors today: always leave room for a phase transition in your plans!

For readers who might think physics is just about apples falling on heads, how would you explain High Energy Physics in simple terms?

HEP is essentially the physics of all the cool stuff you see in comics or hear about in pop science! In high energy theory, we deal with black holes, the expansion of our universe, colliding subatomic particles to see what comes out sometimes even trying to make tiny black holes from those collisions.
It's about asking the most fundamental questions. But here's the catch: while it sounds simple and exciting in a comic book, the reality is, as Galileo said, "Mathematics is the language in which God has written the universe." And that language can be insanely difficult. It involves a tremendous amount of math and countless hours just thinking. So, if you love abstract math and prefer thought experiments to lab work, HEP theory could be your universe.

What advice would you give to first or second-year students who are curious about HEP but feel intimidated by its scale?

It's a marathon, not a sprint. If you're in your first year, start by exploring online resources there are tons out there. Try to get a broad overview of your interests and approach professors in the department working in those areas. In my case I was interested in high energy theory, so I approached Prof Ramadevi. They'll typically give you something to read, which is the first and longest step. You have to be patient and build your foundation.
Once you have a knowledge base, you can look for a project. Don't be afraid to apply outside IITB. HEP is a vast field with many subfields, and you might not find an expert in your specific niche within the department. I mailed Professor Sachin Jain at IISER Pune in my second year, and that's how I got my first real research problem. If you start in your second year, by the time you're applying for grad school in your fourth year, you'll be well-prepared.

What first sparked your curiosity in Physics, and was there a specific “transition moment” that drew you to HEP?

I vividly remember a National Geographic series back in 8th or 9th grade, I think it was voiced by Morgan Freeman. Each episode tackled a fascinating cosmic question supernovae, cosmic inflation, and so on. At the time, I thought this was all astrophysics.

When I came to IIT Bombay, I realized these fundamental questions were actually being explored in high energy theory. The real ”aha!” moment came thanks to a senior, Shoaib, who was my TA. He was working in string theory and would randomly tell us about his work. Hearing him talk about it was captivating, and he became a crucial guide for me throughout my four years.

Could you walk us through some of the research projects you were involved in at IITB?

My journey started with reading projects under Professor Ramadevi, learning Quantum Field Theory (QFT) and gravity, and Professor Vikram Rentala, exploring the black hole information paradox.

My first hands-on problem was with Professor Sachin Jain at IISER Pune. We were working on something called the ”conformal bootstrap.” The idea is to determine all the properties of a quantum system from just the bare minimum knowledge of symmetries and some physical principles. We were trying to apply a technique called the spinor-helicity formalism, usually used for scattering amplitudes, to these conformal field theories.

During my second-year summer at IISc with Professor Aninda Sinha, I worked on the S-matrix bootstrap. The S-matrix is like a grand catalogue of all possible particle interactions in a theory. If you know the matrix, you know the theory. A key lesson from that summer was not to juggle too many complex projects at once!

My most significant project, which led to my first paper, was with Professor Shiraz Minwalla at TIFR. The title was “Gray Galaxies in AdS_5”

We were studying a phenomenon called super radiance, where rotating black holes can fling particles out with more energy than they came in with. It’s an instability, and we were trying to figure out its endpoint in a specific type of spacetime known as Anti-de Sitter space. That project took about ten months and was an incredible learning experience.

Around the same time at TIFR, I worked with Professor Onkar Parrikar on Krylov complexity, a concept that beautifully merges quantum information theory with gravity. These two projects eventually became my Bachelor’s Thesis Projects (BTPs).

Could you share a memorable challenge and what you learned from it?

Definitely. During the project with Shiraz, a postdoc and I were stuck on an analytical calculation for nearly three months. We just couldn’t get it to work. Finally, we decided to try solving it numerically.

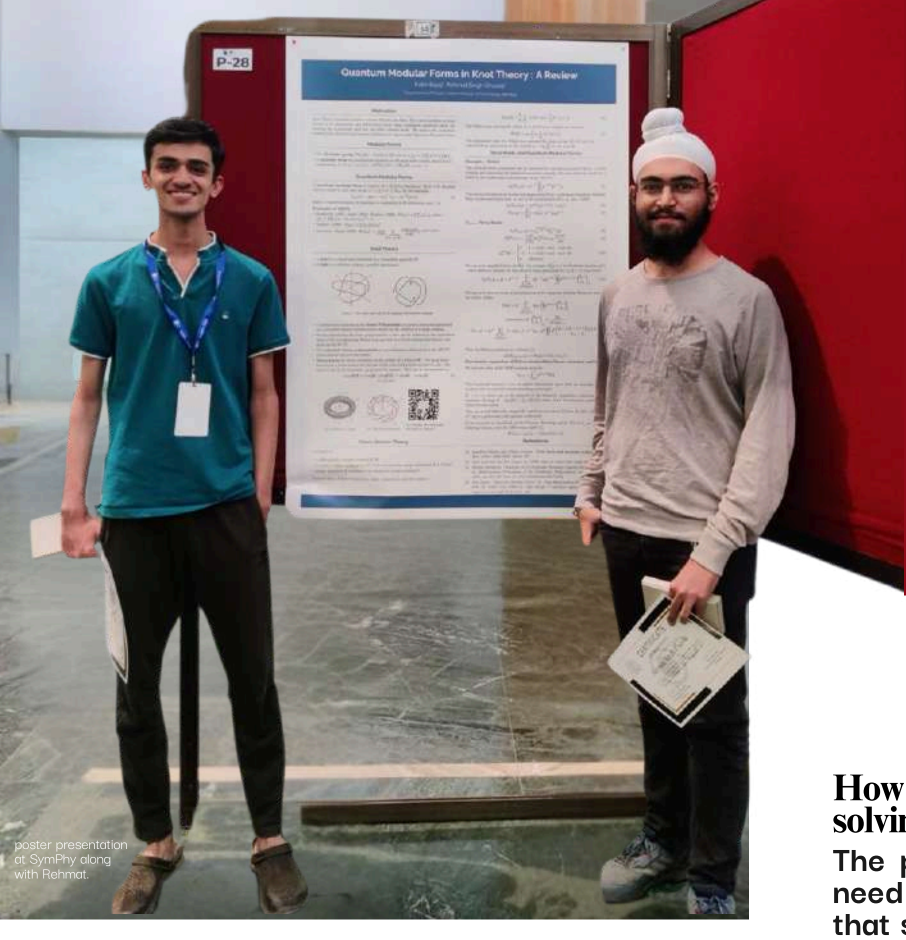
In theoretical physics, turning to numerics can sometimes feel like a last resort an admission that you couldn’t find the elegant, pen-and-paper solution. But we did it, and we got the answer in about an hour. It was a huge lesson: don’t look down on any tool that can get you to the truth.

The punchline?

Where do you see the most promising directions in HEP?

I’m personally interested in understanding inflation, the mechanism behind our expanding universe, and re-examining some older models through the ideas of holography. Holography essentially means that we can relate objects of quantum gravity (like black holes) to quantum field theories, which we study in particle accelerators I am also interested in exploring the ideas of bootstrap more as I did during my undergrad.

Indian Strings Meeting held at IIT Bombay



poster presentation at SymPhy along with Rehmat.

Looking back at your time at IIT Bombay, how do you feel about the journey?

It was a fantastic journey. IITB gave me incredible opportunities to attend conferences and meet brilliant people. Being so close to TIFR was a massive advantage for someone in my field. I don't think I would have been better off anywhere else. And of course, the late nights in the computer lab were definitely fun.

Looking back, what role did mentorship play in your journey? And what was your experience with collaboration?

Mentorship was everything. My senior, Shoaib, was my first guide. Professor Ramadevi was a constant source of support for three years, always there to help, and Professor Shiraz Minwalla was probably the best research advisor I've ever had; he taught me so much. Even my juniors helped; explaining concepts to them forced me to understand things better myself.

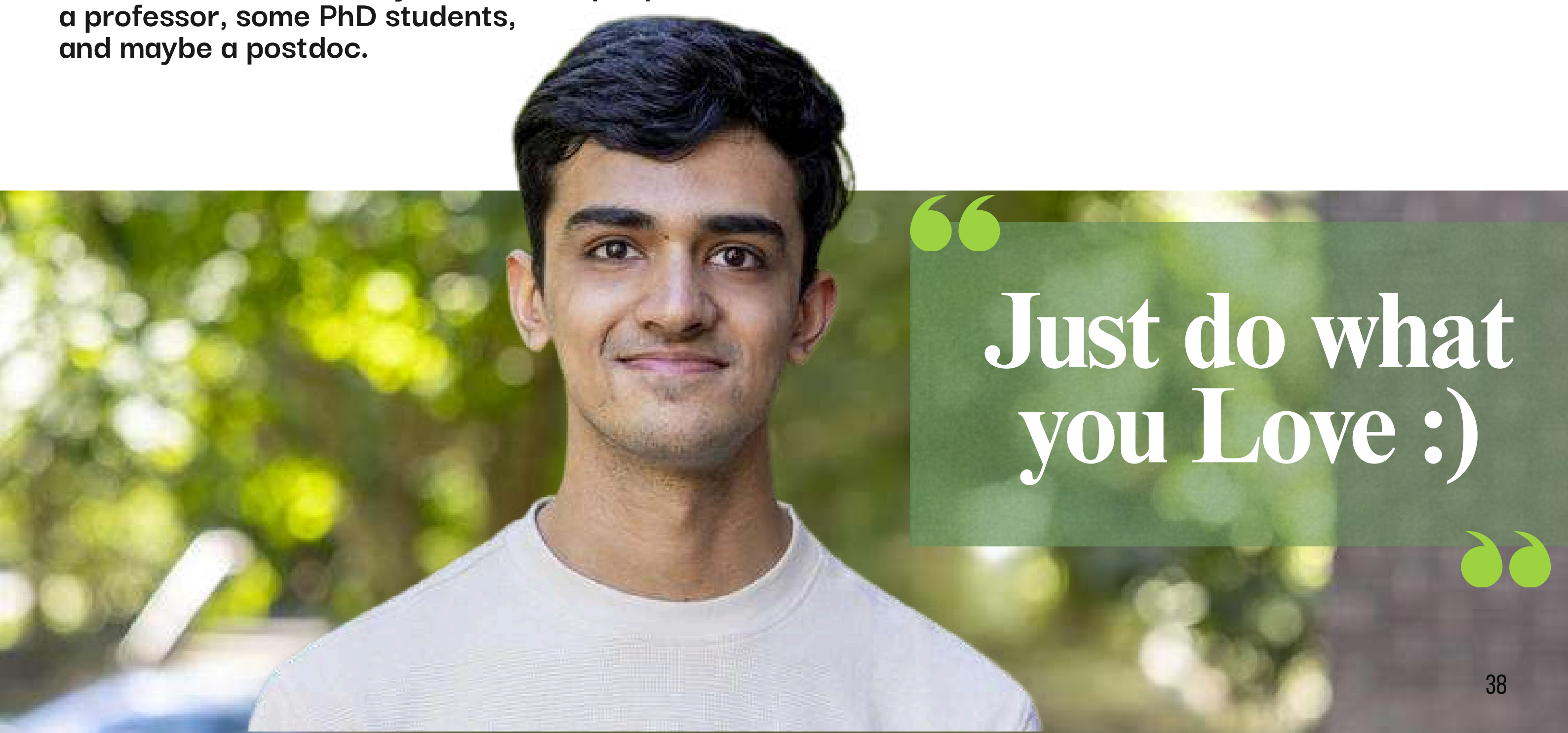
As for collaboration, it's a common misconception that all of HEP involves massive teams like CERN. That's true for experimental physics. In theoretical physics, collaborations are much smaller usually two to four people, like a professor, some PhD students, and maybe a postdoc.

How have the skills you learned, problem-solving, coding been useful?

The problem-solving is crucial. In my field, you need the stamina to work through calculations that span several pages. As for coding, I admit I always tried to stay away from it! But some basic Python for plotting with Matplotlib or running Monte Carlo simulations is useful. The real powerhouse in my field is Mathematica. It's an incredible tool for symbolic computations if you can't solve it on paper, Mathematica can probably handle it.

What is your closing message for students?

Just do what you love. Don't be intimidated by people saying a field is too tough or that opportunities are scarce. Reach out to seniors and professors everyone is willing to help. Don't get pressured by what others are doing. If you follow what genuinely excites you, you'll be fine.

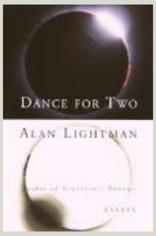


"Just do what you Love :)"

PROFESSOR'S PICKS

Books and films have a quiet way of shaping us, often long after exams are forgotten. In this section, our professors share a few of their personal recommendations, works that inspired them, or simply stayed with them, and might just do the same for you.

Prof. Pradeep Sarin

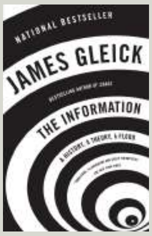


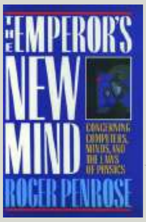
BOOK: DANCE FOR TWO
AUTHOR- ALAN LIGHTMAN

This is a book for anyone who has ever stared at the night sky and felt both infinitely small and profoundly connected. Lightman doesn't offer answers; he offers stillness, reflection, and the rare gift of seeing science as an art form.

"The art of reading is like meditation. You don't rush through it, you sit with it, breathe with it. A good book doesn't just inform, it quiets the noise around you and teaches you how to listen."

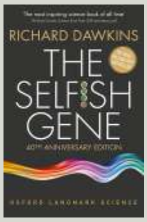
BOOKS:



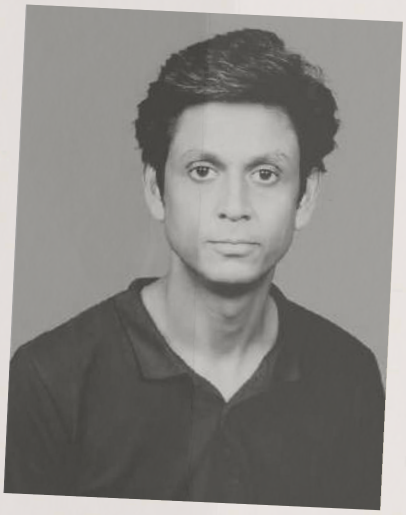


THE EMPEROR'S NEW MIND
AUTHOR- ROGER PENROSE

THE SELFISH GENE
AUTHOR- RICHARD DAWKINS



CHAOS, THE INFORMATION
AUTHOR- JAMES GLEICK



Prof. Amitabha Nandi

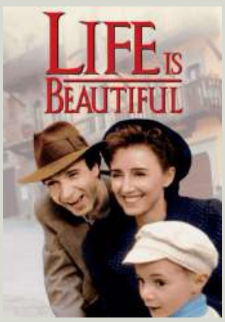
"If you want to enjoy reading beyond academics, try Asimov, Dawkins, or Wodehouse. Asimov will make you dream, Dawkins will make you think, and Wodehouse will make you laugh."

COMIC SERIES:

Asterix AND OBELIX
BY GOSCINNY AND UDERZO.

MOVIES:

Directed by Majid Majidi



Directed by Roberto Benigni

Directed by Andrei Tarkovsky

Directed by Andrei Tarkovsky

"I love watching films from different countries, it's a beautiful way to understand their culture, their diversity, their way of life. After all, I work on complex systems… and diversity is at the heart of them"

Additional Recommendations:

- Stanley Kubrick: 2001 Space Odyssey, Dr. Strangelove,
- Akira Kurosawa: Seven Samurai,
- Ron Fricke: Samsara, Baraka.

DEPARTMENT BUZZ...

A roundup of the latest events, highlights, and happenings across the Physics Department.

EVENTS & ACTIVITIES

- **INTRA-DEPARTMENT BADMINTON TOURNAMENT**

A spirited sports showdown bringing physics students together on the court.

NOT SO भौतिक': THE INAUGURAL PHYSICS DEPARTMENT FEST

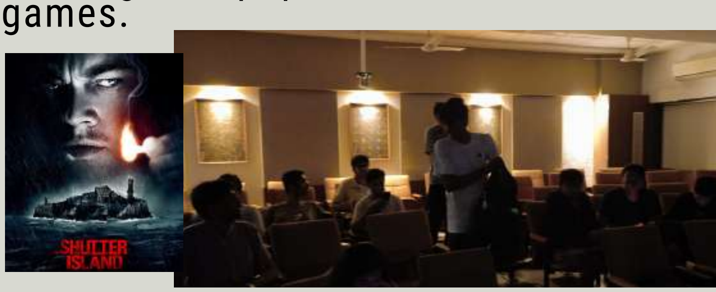
The department's first full-scale fest celebrating science, fun, and community. It included the following activities:

- **PHYSBUZZ INAUGURAL TALK : PROF. AMITABHA NANDI**

PhysBuzz, an initiative led by the DRC, Abhinav Bijlani, kicked off with an inaugural talk by Prof. Amitabha Nandi on Active and Soft Matter Systems.

- **MOVIE NIGHT: SHUTTER ISLAND**

A thrilling departmental movie evening with popcorn and mind games.



- **MASQUERADE FORMALS**

An elegant evening of masti, music, and masked charm.

- **LUKKHA NIGHT FOR EP STUDENTS**

A relaxed, laughter-filled hangout designed for the EP community.

- ## AMA SESSION WITH THE FACULTY

An open, engaging session featuring Prof. Soumya Bera, Prof. Hirdis Pal, and Prof. Uditendu Mukhopadhyay, where students explored research paths, academics, and life in physics.

JOURNAL CLUB HIGHLIGHTS

- ## HIGGS-TERICAL TALES FROM STANDARD MODEL PHYSICS

Aditya Choudhury &
Soham Sahasrabuddhe

A journey through the search for fundamental particles, the forces that bind the universe, and the century-long story that shaped the Standard Model and modern particle physics.

- ## LIFE, BUT MAKE IT PHYSICS

Ananya Priyaroop

An exploration of motion in living and non-living systems, from simple diffusion to active matter, revealing why cells refuse to sit still and why equilibrium is so overrated.

- ## WHEN LIGHT TWISTS: HOW POLARIZATION REVEALS SECRETS OF ACCRETION DISKS

Mehul Goyal

A deep dive into how polarized light from black hole accretion disks uncovers their geometry and relativistic effects, featuring fast analytical models to decode these cosmic signatures.

DEPARTMENT MERCHANDISE LAUNCH: WORLD OF CHAOS

Unveiled the official physics merch line inspired by dynamical systems. conceptualized and designed by the amazing duo of design convenors, Anamika and Nitansh.

- **SCREENING OF *BENDING LIGHT***

In collaboration with Krittika, the Astronomy club of IITB and Silver Screen, the film club of IITB

A documentary journey through the 1922 expedition that validated Einstein’s predictions.

TALKS, LECTURES & WORKSHOPS

- **UNIVERSITY OF CAMBRIDGE × IIT BOMBAY WORKSHOP**

A collaborative academic exchange exploring contemporary research directions in Semiconductors and Quatum technologies.

UNIVERSITY OF CAMBRIDGE X

- **SCPP WORKSHOP ON NEUTRINO AND DARK MATTER SYNERGIES**

A multi-day workshop bridging neutrino physics and dark matter studies.

- **INSTITUTE LECTURE – THE ν FRONTIER: CURRENT CHALLENGES AND OPPORTUNITIES IN NEUTRINO PHYSICS**

Prof. Dr. Joachim Kopp delivered an insightful lecture on the rapidly evolving landscape of neutrino research

POCKET RAZORS OF REASON

OCCAM’S RAZOR
The simplest explanation is usually the correct one.

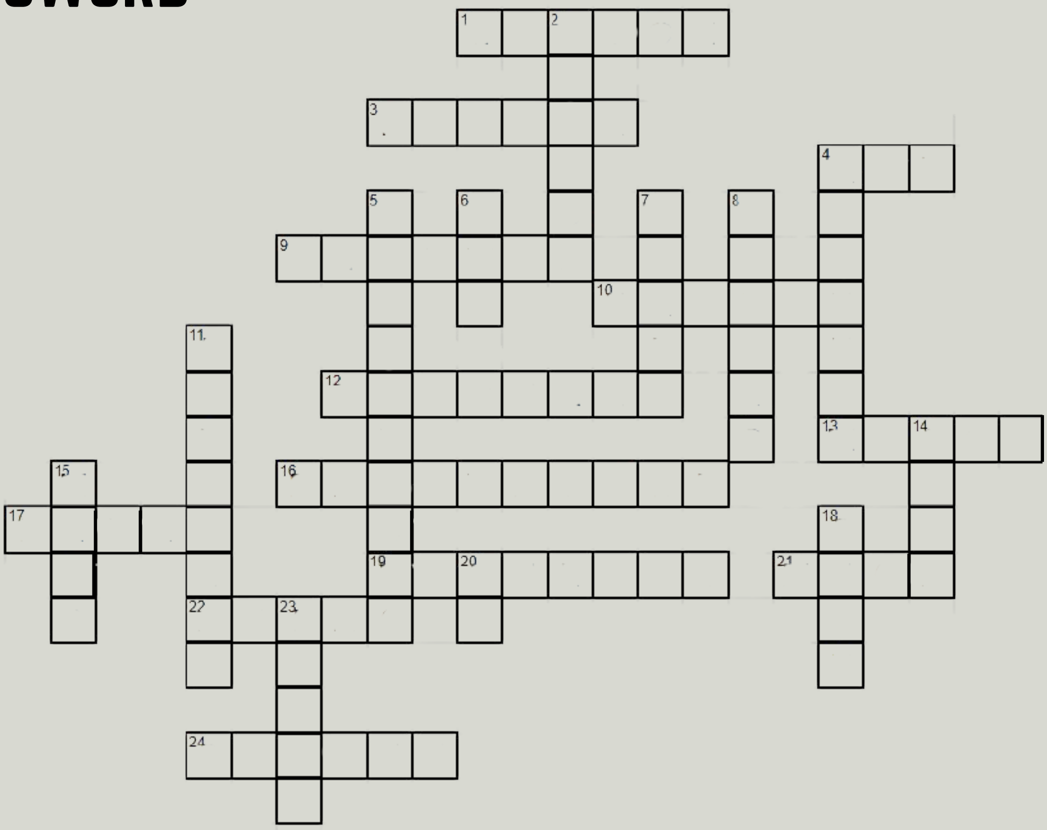
HITCHENS’ RAZOR
What can be asserted without evidence can be dismissed without evidence.

ALDER’S RAZOR (NEWTON’S FLAMING LASER SWORD)
Anything that cannot be settled by experiment or observation is not worth debating

SAGAN STANDARD
Extraordinary claims require extraordinary evidence.

GEEKOUT ZONE...

CROSSWORD



Across

1) The family of fundamental particles that includes the electron and its heavier siblings

3) The particle of light, a quantum of the electromagnetic field

4) The quantum field theory of the strong interaction

9) Physicist known for his diagrams illustrating particle interactions

10) A family of composite particles made of quarks

12) The heaviest known fundamental particle

13) A type of hadron made of a quark and an antiquark

16) The search for this elusive substance is a major goal of modern physics

17) Physicist famous for his exclusion principle

19) The ghostly lightweight lepton that rarely interacts

21) The second-lightest lepton

22) A toroid-shaped detector at the LHC, A _____ Experiment

24) The 'b' in LHCb stands for this

Down

2) Subatomic particle with a positive charge found in the nucleus

4) A fundamental, indivisible unit of a quantity

5) A type of particle accelerator where beams travel in a circle

6) A compact, general-purpose detector at the LHC

7) A fundamental fermion that comes in six "flavors"

8) This fundamental force is mediated by gluons

11) The lab near Chicago that housed the Tevatron

14) A particle's intrinsic angular momentum

15) Property of particles responsible for their interaction with the Higgs field

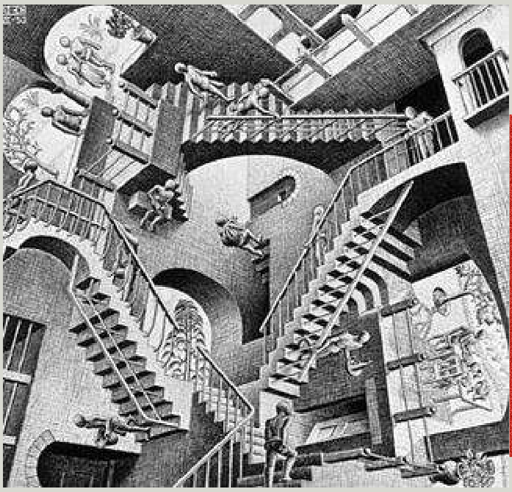
18) The type of symmetry that relates bosons and fermions in some theories

20) The lightest type of quark

23) A particle accelerator that boosts particles in a straight line

POP-SCI-PHY

1. The "lightsaber" sound in Star Wars is iconic. But very few know that its base audio came from a real physics phenomenon produced by electronics. Which physical effect contributed to the original sound?



2. M.C. Escher's Relativity (1953) shows multiple staircases and figures existing simultaneously under three conflicting gravitational orientations. This creates a paradoxical space where each "down" direction is valid for different inhabitants, challenging our usual sense of gravity and geometry. What mathematical or geometric concept underlies Escher's ability to depict these multiple, contradictory perspectives consistently within a single scene?

UNSCRAMBLE THE SCIENTIST!

Rearrange the letters in each scrambled phrase to reveal the name of a famous scientist.

Example:
Scrambled: Narwhales cried
Answer: Charles Darwin

These are also known as Anagrams. An anagram is a word or phrase formed by rearranging the letters of another. They're not only a fun puzzle but have been used historically for secret codes, literary play, and even by some scientists to encode messages.
Unscramble the following…

1. He robs nil
2. Char many friend
3. Kin also late
4. Aw, so ancient
5. Fresh router trend

Answers

Crossword

Across: 1. lepton, 3. Photon, 4. QCD, 9. Feynman, 10. Hadron, 12. TopQuark, 13. Meson, 16. Darkmatter, 17. Pauli, 19. Neutrino, 21. Muon, 22. ATLAS, 24. Beauty
Down: 2. proton, 4. Quantum, 5. cyclotrons, 6. CMS, 7. Quark, 8. strong, 11. Fermilab, 14. Spin, 15. Mass, 18. SUSY, 20. up, 23. Linac

Pop-Sci-Phy

1. Electromagnetic interference (EM coupling); the audio buzz caused when a TV's scanning beam induced signals in nearby audio equipment.
2. The concept of multiple vanishing points arranged symmetrically, allowing different orientations to coexist on the same plane through carefully constructed perspective, similar to how curved spaces can have different local geometries in physics

Unscramble the scientist

1) Niels Bohr, 2) Richard Feynman, 3) Nikola Tesla, 4) Isaac Newton, 5) Ernest Rutherford

TUNE IN: A CONVERSATION WITH PROF. UMA SANKAR

Curious about the journey of a physicist who shaped minds and inspired generations? Scan the QR code to listen to Prof. Uma Sankar share stories from his illustrious career, insights into the world of physics, and reflections on life as a professor.

Inspiring, enlightening, and full of surprises!

click the below link

https://youtu.be/EA568kWNKP4?si=r7JNdzGR5UjOswcp

REFERENCES & CREDITS...

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A brief tour: The Standard Model
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https://www.symmetrymagazine.org/article/how-do-neutrinos-get-their-mass
Credits to Soham for crafting the lines under each neutrino on the cover of this article.

Theorist with a Poet's Pulse: Interview by Ritika, Image credits; Rehmat Singh Chawla
Between Black Boards and blackholes: Interview by Ritika, Image credits; Kabir Bajaj
Department Buzz Pics: Credits to Ananya, Prem Lodhi, Youtube
Geekout zone:
Crossword- Ritika and Jahnavi
Pop-Sci-Phy: lightsaber; https://krotos.studio/blog/lightsaber-sound-effect-deep-dive
mc Escher's : http://www.scottmcd.net/artanalysis/?p=548
Unscramble the scientist;
https://shaastramag.iitm.ac.in/sites/default/files/print_issues/pdf/SHAASTRA%20May-June%202021.pdf
Podcast; by Samridh and Sidhdant, video edited by Prem Lodhi

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All content in this magazine has been lovingly collected, curated, and arranged by our dedicated team, with selective AI enhancements for polish and clarity. If you spot any mistakes or errors, please share them with us (we learn best from feedback!). The entire design and conceptualization is our original creation, brought to life with invaluable advice from our professors that made this journey even more exciting. We hope this issue sparks joy, curiosity, and endless discussions, cherish the time spent flipping through these pages!

Designed with love and hope to make physics more interactive, by GJ.

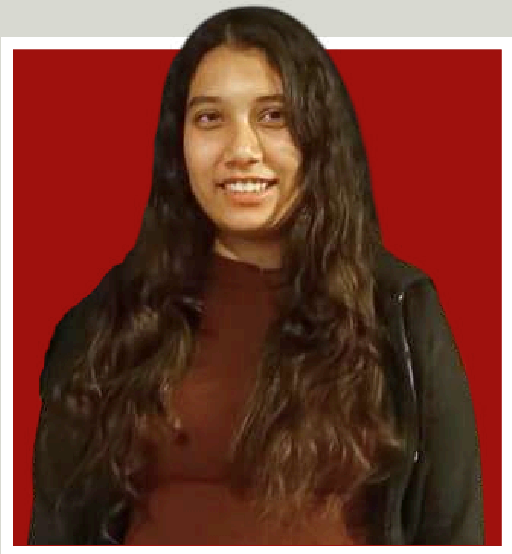
Got brain-bending puzzles, research bites, pop-sci gems, hot takes, or physics-art crossovers? You can contact us anytime. Let's make the next issue legendary together!

THE TEAM..

VANSHA

SAMRIDH

RITIKA



SIDHDANT

GARGI

JAHNAVI

DEPARTMENT OF PHYSICS

Indian Institute of Technology, Bombay
Students' Association of Physics Department