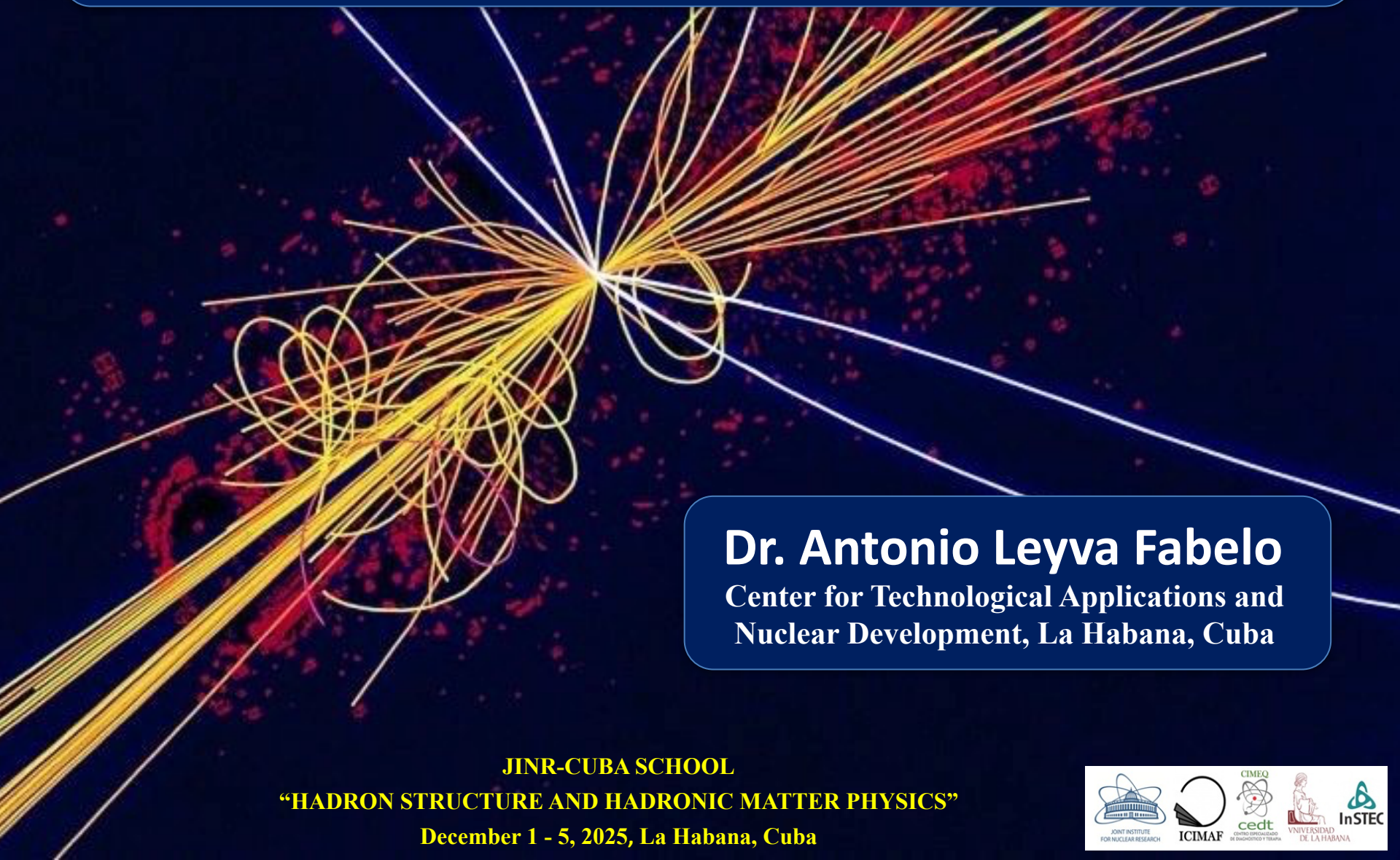
Particle Detectors



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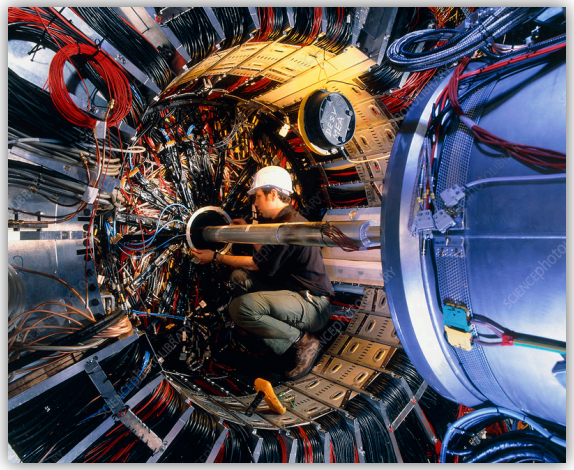
JINR-CUBA SCHOOL

"HADRON STRUCTURE AND HADRONIC MATTER PHYSICS"

December 1 - 5, 2025, La Habana, Cuba

What We'll Cover Today

- Concept of particle detector
- The physical principles behind radiation detection
- Main types of detectors
- How detectors are integrated into large-scale experiments
- Current challenges and prospects







Definition of Particle Detectors

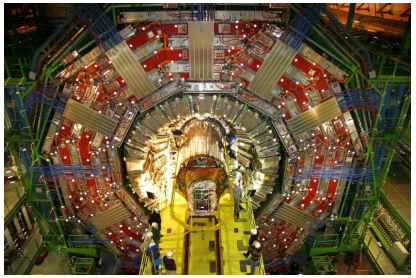
A particle detector is a scientific instrument that allows us to observe, identify, and measure elementary particles by detecting the physical effects they produce when interacting with matter. These effects are transformed into measurable signals for analysis of particle properties.

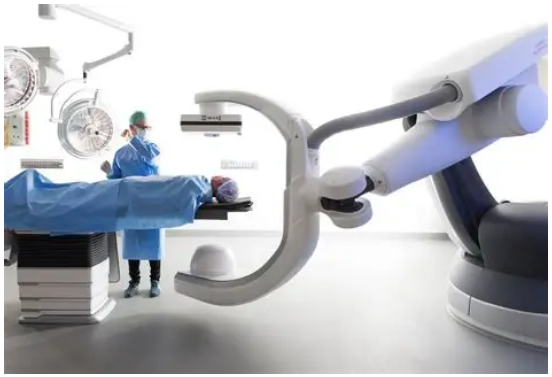
"Radiation detectors are our eyes in the subatomic world"

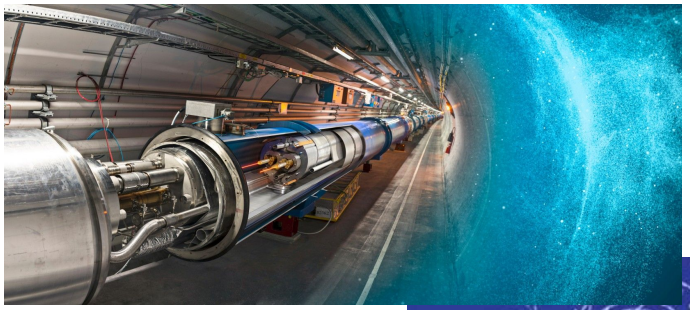
- From discovering the electron to confirming the Higgs boson, every major advance in particle physics has depended on radiation detectors.

Particle Detectors Uses

- Nuclear and particle physics
- Medical imaging and nuclear medicine
- Radiation protection and dosimetry
- High-energy astrophysics
- Applied physics and engineering

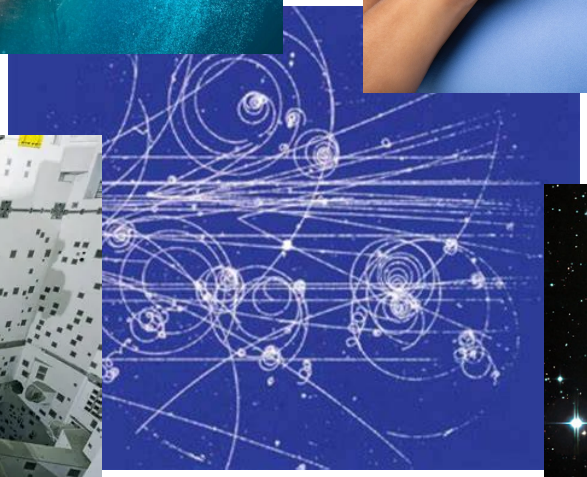


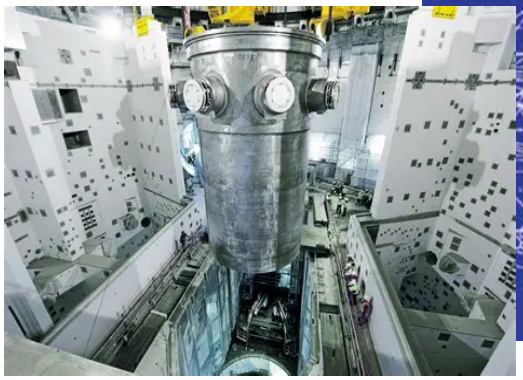






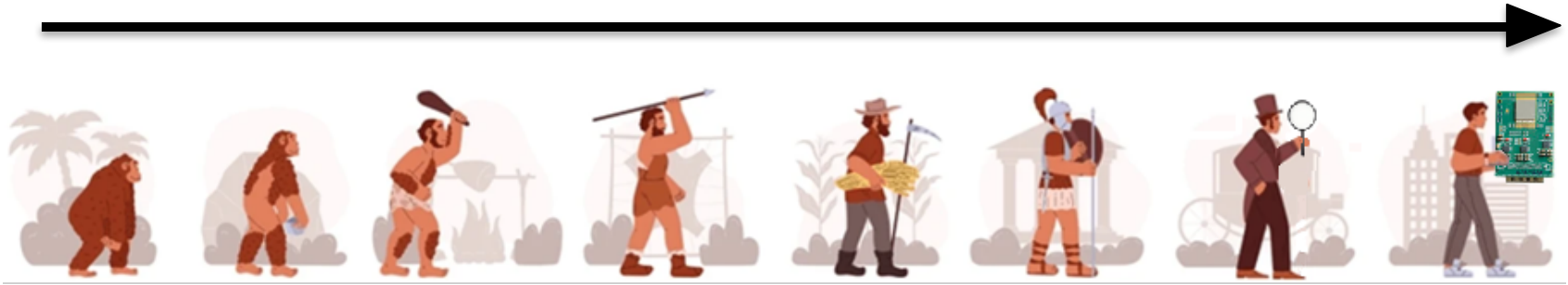








Timeline of Particle Detectors



Exploring the world of detectors

“QUICK CHRONOLOGICAL TOUR”

Timeline of Particle Detectors

1903

«First single-particle detector»

Spinthariscope

William Crookes (UK)



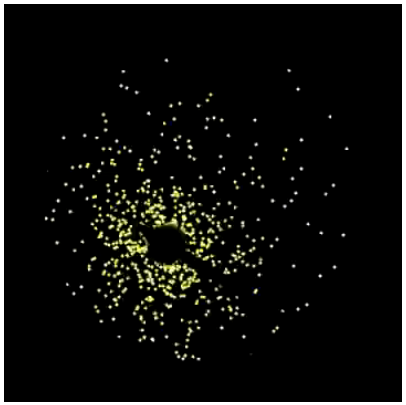
Radioactive source



radium salts

Fluorescent screen

Magnifying lens



OP: Visible scintillations in zinc sulfide observed through a lens.



AP: It was the first device to detect individual particles. It allowed direct visual observation and counting of alpha particles, providing irrefutable evidence for the corpuscular nature of radioactivity

Note:
OP = Operating Principle
AP = Advance for Physics

Timeline of Particle Detectors

1911

«First device to visually record the path of ionizing particles»

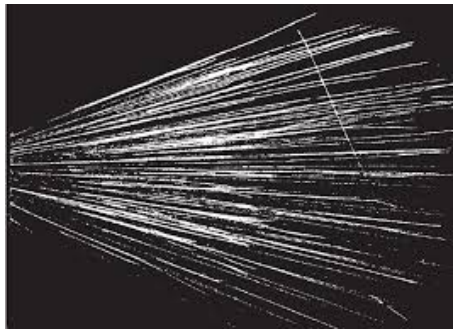
Cloud Chamber

Charles Wilson (UK)





OP: It used supersaturated vapor that condensed into tiny droplets along the ionization trails left by charged particles, producing visible tracks.





AP: Direct visualization of particle tracks; basis for particle discoveries.

Timeline of Particle Detectors

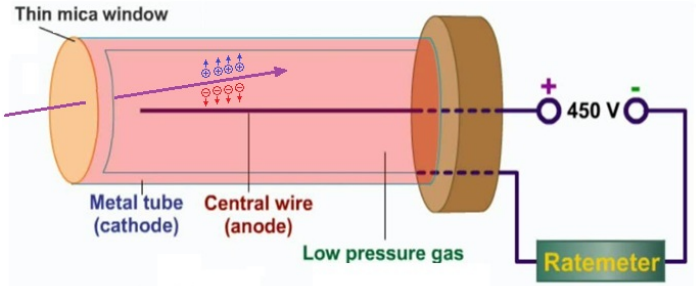
1928

Geiger-Müller Tube

Hans Geiger and Walther Müller (Germany)







OP: It operates by applying a high voltage across a cylindrical cathode and a central anode wire; when radiation enters the tube, it ionizes the gas, initiating a cascade of electrons that produces a sharp electrical pulse.

GMT cannot distinguish particle energy levels, since each event produces the same output signal.



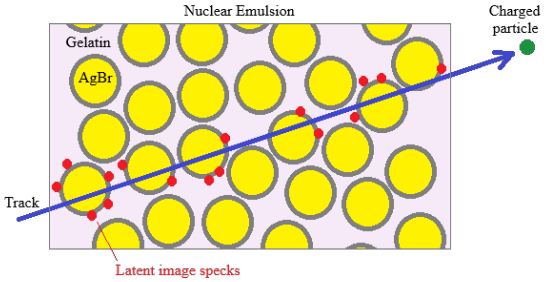
AP: Its simplicity, robustness, and audible response made it essential in radiation monitoring, nuclear safety, and educational demonstrations.

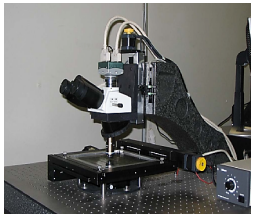
Timeline of Particle Detectors

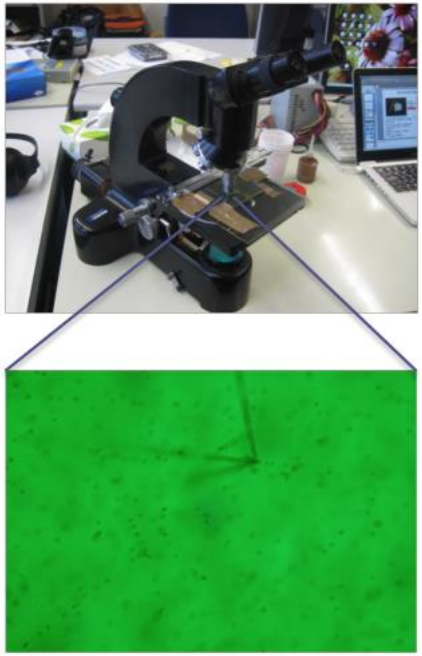
1930-1950

Photographic Nuclear Emulsions

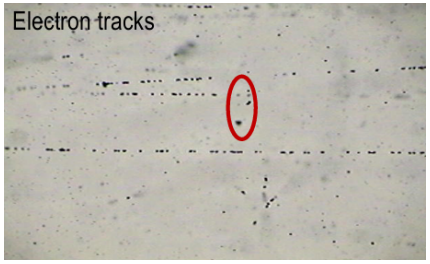
Several authors, with Marietta Blau (Austria) standing out.

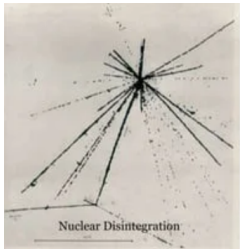






OP: **Specialized photographic plates with a dense layer of silver halide crystals suspended in gelatin, which undergo chemical changes when traversed by charged particles.**





AP: **Widely used in cosmic ray studies and early particle physics experiments. High resolution for studying interactions and decays.**

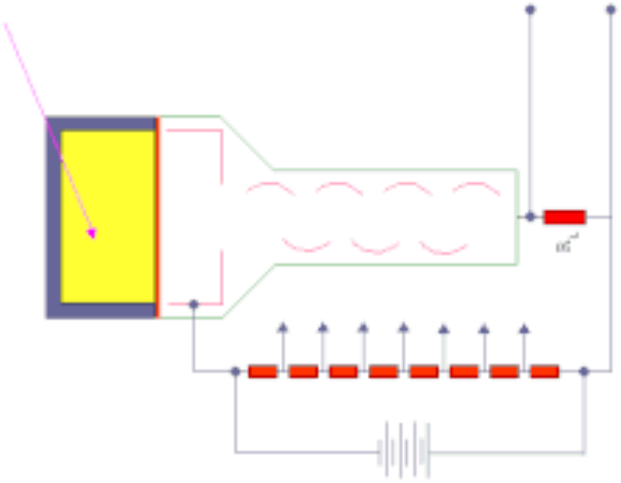
Timeline of Particle Detectors

1944-1948

Scintillation detectors and photomultiplier tubes

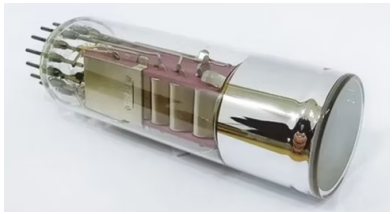
Various collaborations (USA, Europe)

«Combines light-emitting materials with highly sensitive light detector»





OP: Ionizing radiation excites scintillator material; produced photons hit the photocathode, creating electrons multiplied by a PMT via dynodes to produce electrical signals.





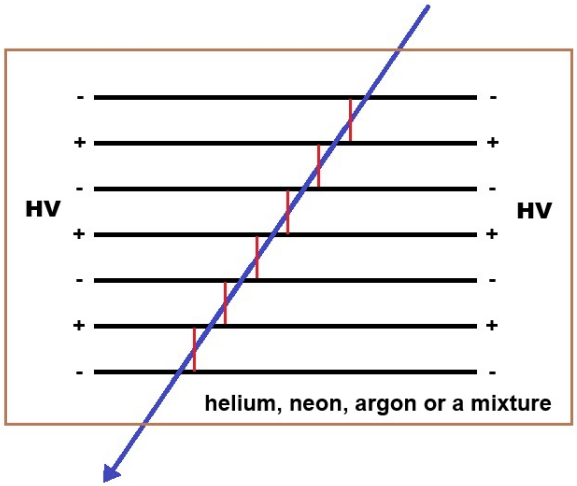
AP: Very high speed (nanosecond response) and the ability to perform energy spectroscopy. It allowed for the measurement of not just the presence, but also the energy of a particle, quickly and efficiently.

Timeline of Particle Detectors

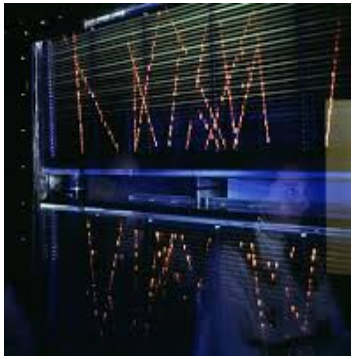
1950s

Spark Chamber | Various groups

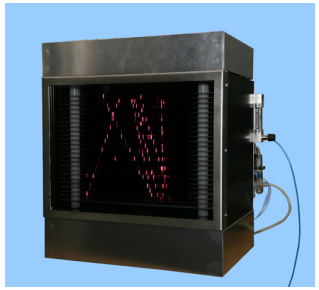




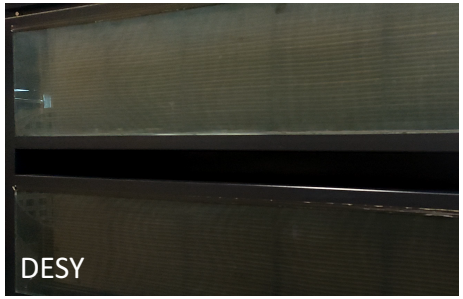
OP: When a charged particle passes through a series of metal plates in a gas-filled chamber, it ionizes the gas along its trajectory. A HV pulse applied across the plates causes sparks forming at the ionization sites, effectively tracing the particle's path.

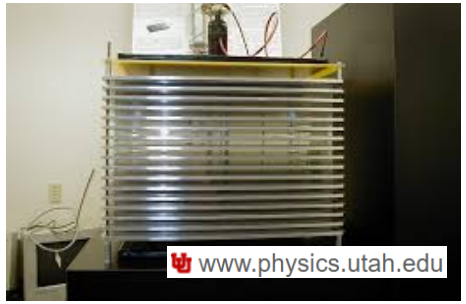


https://cds.cern.ch/record/39277



Mark III Spark Chamber
University of Cambridge





AP: Enabled fast, repeatable tracking of cosmic rays and accelerator-produced particles.

Timeline of Particle Detectors

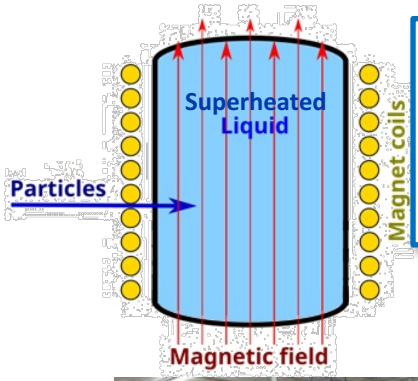
1952



Bubble Chamber

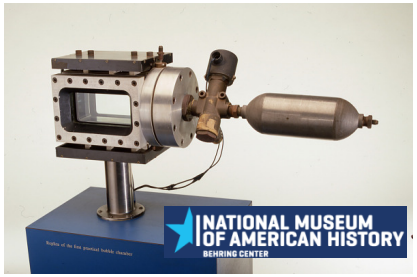
Donald Glaser (USA)





OP: When a particle passes through a superheated liquid, it ionizes the liquid along its trajectory, triggering localized boiling and forming a trail of tiny bubbles. These tracks are photographed for analysis.

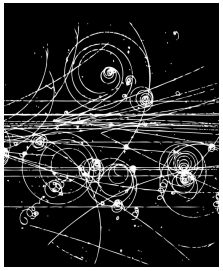












AP: High-density visual data; enabled discovery of many hadronic particles.

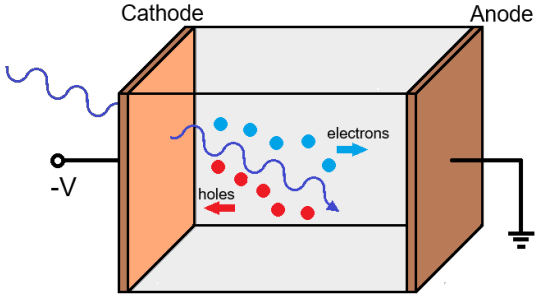
Timeline of Particle Detectors

1960s

«Semiconductor detectors revolutionized radiation detection in the mid-20th century»

Semiconductor Detector (Si, Ge)



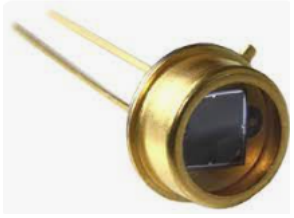


OP: **A charged particle creates electron-hole pairs in the depletion region. An electric field drifts these charge carriers, generating an electrical signal whose charge is proportional to the deposited energy.**



AP: **Compact design, excellent energy resolution, and electronic readout capabilities. They became the standard for gamma and X-ray spectroscopy.**







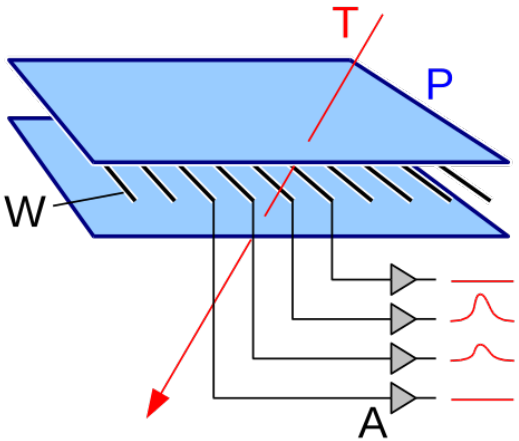
Timeline of Particle Detectors

1968

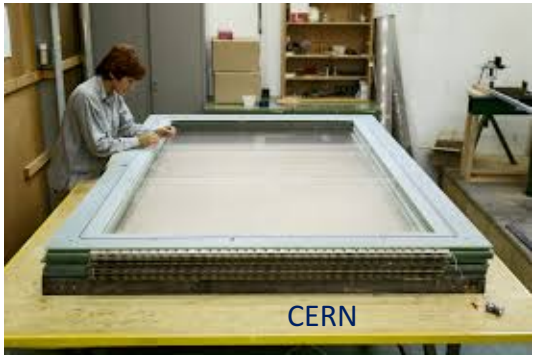
Multiwire Proportional Chamber

Georges Charpak (CERN)

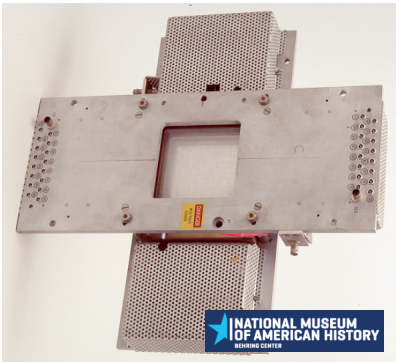




OP: **MWPC use a grid of fine anode wires held at high voltage within a gas-filled chamber; when a charged particle passes through, it ionizes the gas, and the resulting electrons drift toward the wires, triggering avalanches that produce detectable signals.**







AP: **Precise 2D reconstruction of particle trajectories. High event rate and precision. Direct electronic readout.**

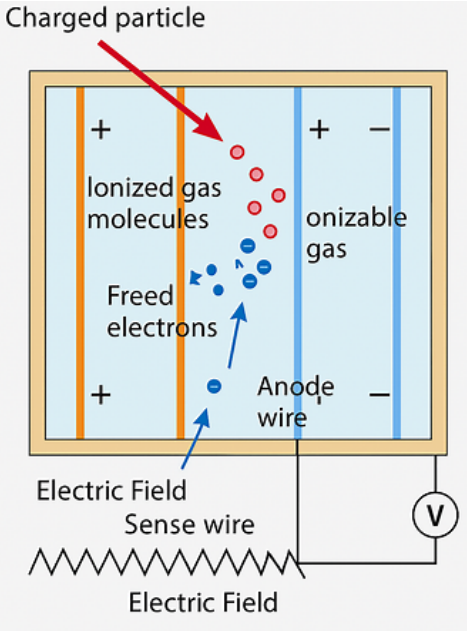
Timeline of Particle Detectors

1970s

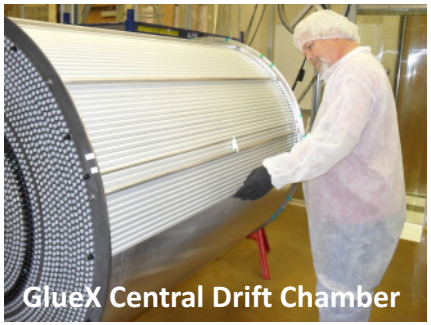
«An evolution of wire-based detectors»

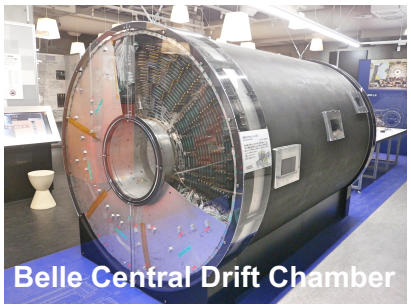
Drift Chamber

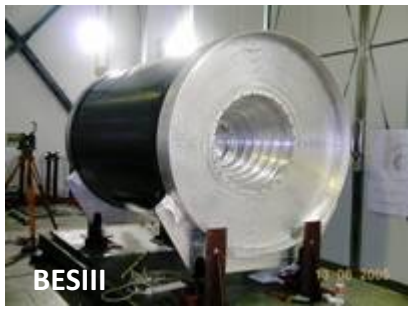
Various groups



OP: **Operates by detecting the ionization trail left by a particle as it passes through a gas-filled chamber; the liberated electrons drift toward sense wires under the influence of an electric field. By measuring the time taken by the electrons to reach the wires (known as drift time), the position of the particle's trajectory can be reconstructed with high resolution.**







AP: **Better spatial resolution and fewer electronic channels for a given surface area**

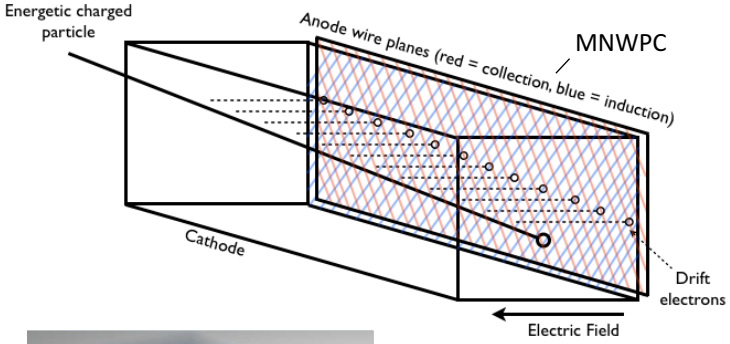
Timeline of Particle Detectors

1970s

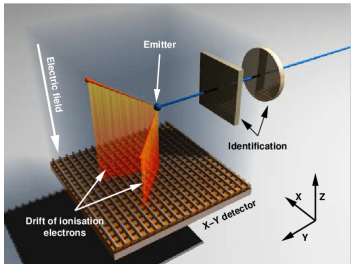
Time Projection Chamber

David Nygren (USA)

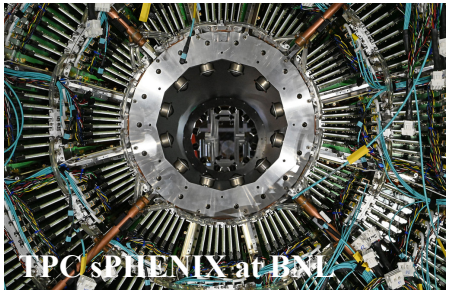


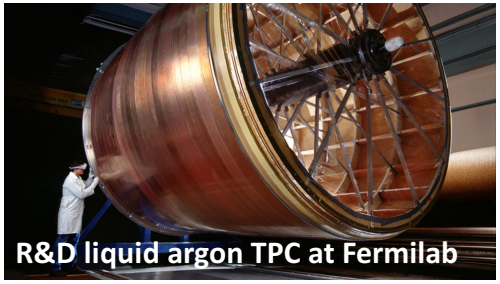


OP: **It consists of a large gas-filled volume with a uniform electric field. When a particle traverses the chamber, it ionizes the gas, and the liberated electrons drift toward a readout plane over a known time interval. By combining the drift time with the position of the electron arrival, the full 3D trajectory of the particle can be reconstructed.**





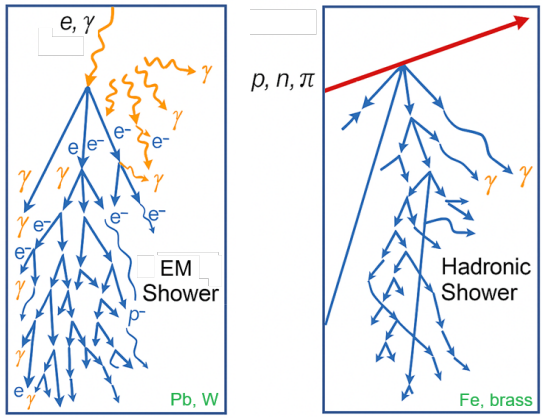




AP: **The definitive 3D track detector. Precise volumetric tracking and energy loss measurement.**

Timeline of Particle Detectors

1970 – 1980



Electromagnetic and Hadronic Calorimeters

Collective contribution from the scientific community

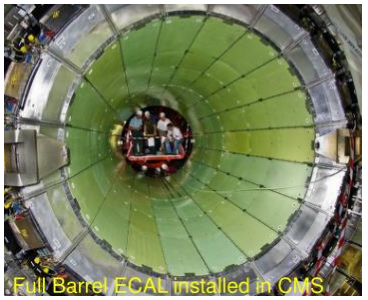
OP: They are "total absorption" detectors. Their goal is to completely stop a particle and measure its total deposited energy. ECALs capture electromagnetic showers from electrons/photons, while HCALs absorb hadronic showers from strongly interacting particles, both converting deposited energy into detectable signals proportional to the particle's energy.

ECAL is closer to the collision point because electrons and photons produce electromagnetic showers that develop quickly and within a relatively small volume.

HCAL is placed outside the ECAL, surrounding the detector, because hadrons generate hadronic showers that are deeper, more irregular, and involve nuclear interactions plus secondary electromagnetic components. Containing these showers requires much more material and thickness than for electromagnetic showers.



AP: Precise measurement of particle energy and identification, with fast and robust signals for trigger systems. They became absolutely essential components of all general-purpose detectors.



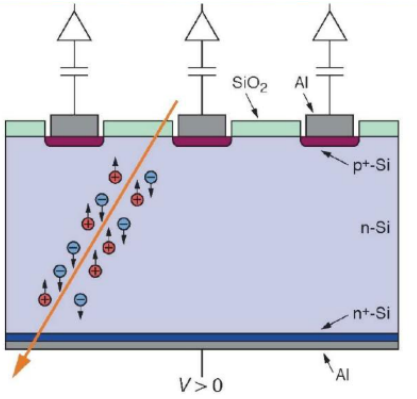
Timeline of Particle Detectors

1980s

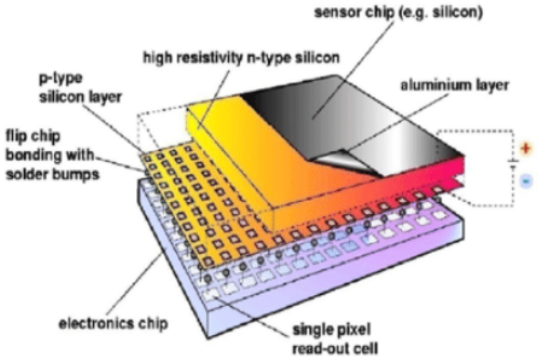
Micro-pattern Semiconductor Detector

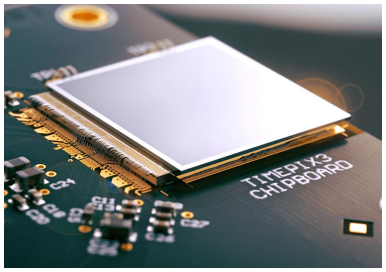
Collaborations in high-energy physics

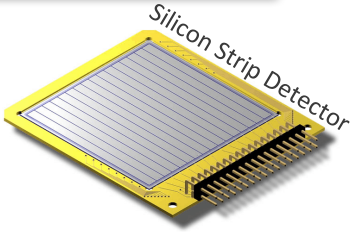
«The advanced solid-state devices»

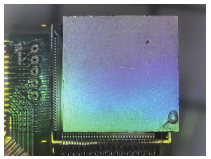


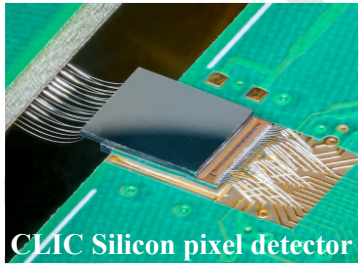
OP: **It works by converting the ionization energy of a passing particle into electron–hole pairs, collecting them under an electric field, and using finely segmented electrode patterns to achieve high-precision spatial and energy measurements.**













AP: **Spatial resolution of tens of microns. They are fundamental for vertex reconstruction and identifying short-lived particles.**

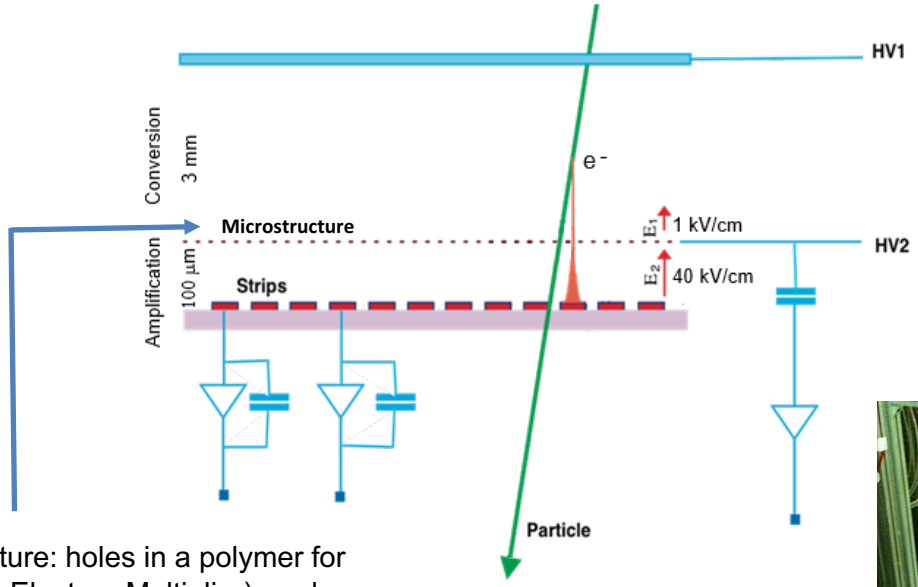
Timeline of Particle Detectors

1990 – present

«The microfabricated evolution of gas detectors»

Micro-pattern Gaseous Detectors

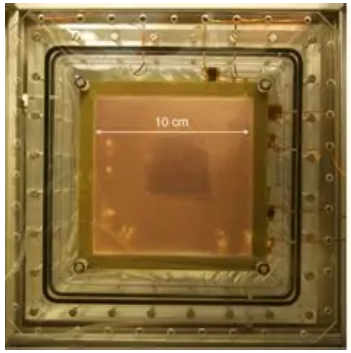
CERN and international teams

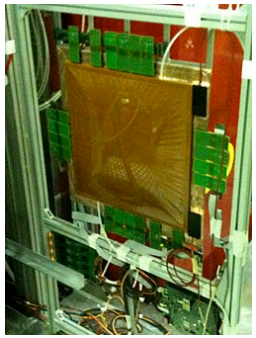


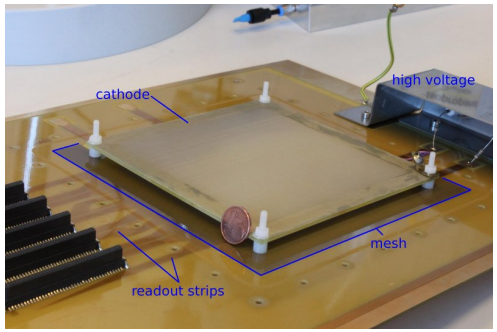
OP: **It transforms the ionization trail of a charged particle in gas into a measurable electrical signal by guiding electrons into micro-structured amplification regions, where avalanches occur and are read out with fine segmentation.**

Microstructure: holes in a polymer for GEM (Gas Electron Multiplier), and microperforated mesh for Micromegas (MICRO-MEsh GAseous Structure)

Used to generate intense local electric field that amplify the electronic signal







AP: **High-rate capability and spatial resolution in tracking systems. High radiation tolerance. Simple and more scalable than silicon detectors for covering large areas.**

Timeline of Particle Detectors

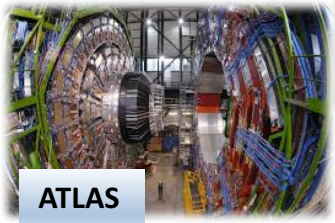
1998 – present → Future

Modern Hybrid Colossal Detector Systems

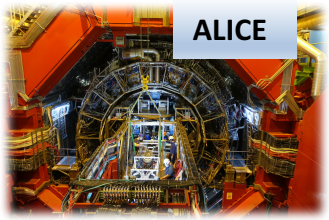
International collaborations of thousands of scientists and engineers

OP: They are cylindrical concentric systems that combine all the previous detector types into one gigantic system.

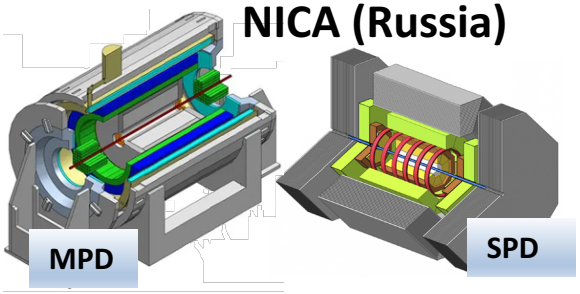
LHC (CERN)



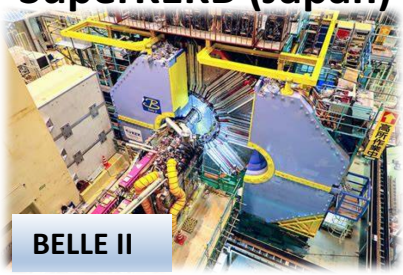




NICA (Russia)



SuperKEKB (Japan)



RHIC (USA)



AP: Represent the pinnacle of detection technology. Higher sensitivity, speed, and compactness.

Timeline of Particle Detectors

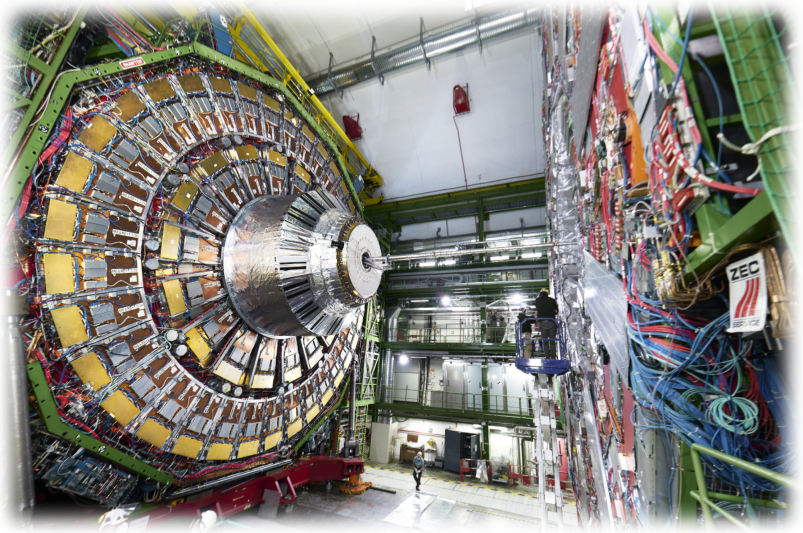
Future

The historical progression moves from **passive imaging techniques** to **fast electronic sensors** and finally to **integrated hybrid systems.**



Spintariscope

120 years



CMS - CERN

A paradigm shift has taken place !!!

Modern designs prioritize fine spatial resolution, high-rate performance, precise timing, radiation tolerance, and integrated real-time readout for full-event reconstruction.

Detector Key Properties

Property	Description
DETECTION EFFICIENCY	Probability that an incoming particle is successfully detected.
ENERGY RESOLUTION	Precision in measuring the energy deposited by radiation.
TIME RESOLUTION	Accuracy in determining the time at which an event occurs.
SPATIAL RESOLUTION	Precision in locating the point of interaction.
DEAD TIME	Period after an event during which the detector cannot record another.
DYNAMIC RANGE	Range of intensities or energies the detector can measure without saturation.
LINEARITY	Proportional response between deposited energy and output signal.

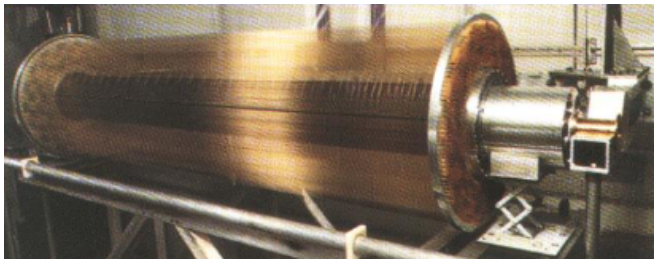
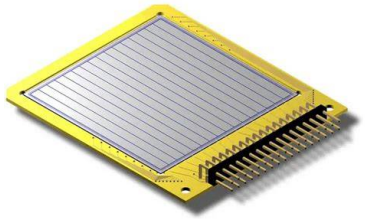
Detector Key Properties

Property	Description
SENSITIVITY	Ability to detect low levels of radiation.
STABILITY AND ROBUSTNESS	Resistance to environmental changes, radiation damage, temperature fluctuations, etc.
BACKGROUND REJECTION	Ability to discriminate between useful signal and unwanted noise.
SELECTIVITY / DISCRIMINATION	Ability to distinguish between different types of radiation (e.g., α vs β).
…AND OTHERS…	

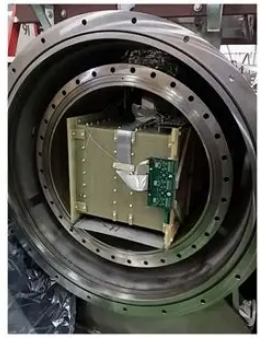
Classification of Particle Detectors

Key classification criteria:

- **Physical detection medium** (material where particle interactions produce measurable signals)
  - Gaseous detectors
  - Solid-state detectors
  - Scintillators
  - Cherenkov media
  - Cryogenic media



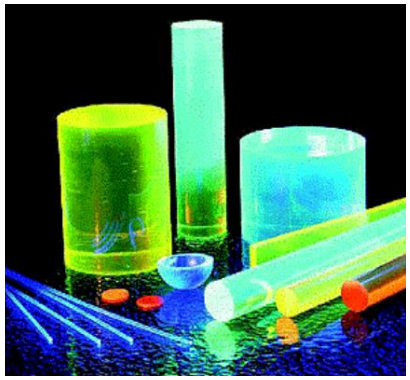

Classification of Particle Detectors

Key classification criteria:

- **Detection principle** (physical effect producing the detector signal)
  - Ionization
  - Scintillation
  - Cherenkov radiation
  - Transition radiation
  - Calorimetric absorption
  - Phonon/heat signals

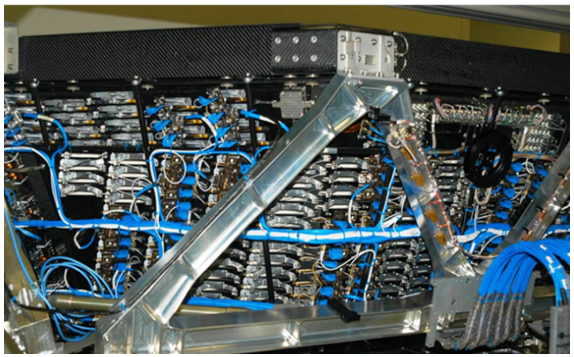








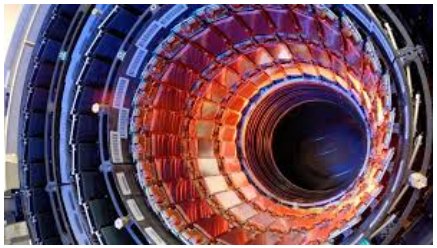




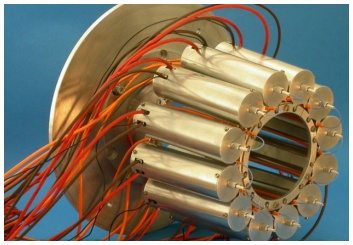
Classification of Particle Detectors

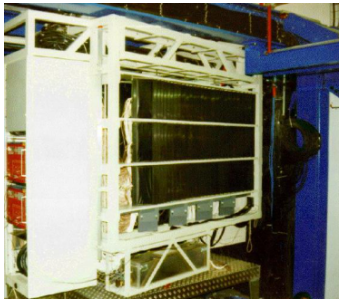
Key classification criteria:

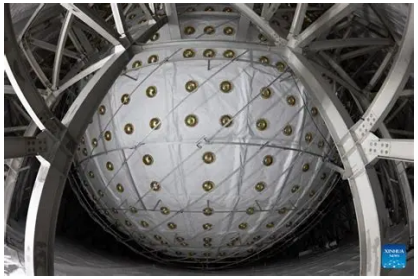
- **Experimental function** (roles detectors perform)
  - Tracking detectors
  - Calorimeters
  - Particle identification
  - Muon systems
  - Neutrino detectors
  - Veto and trigger layers

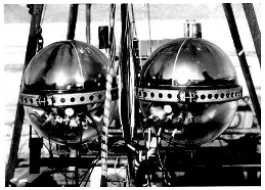












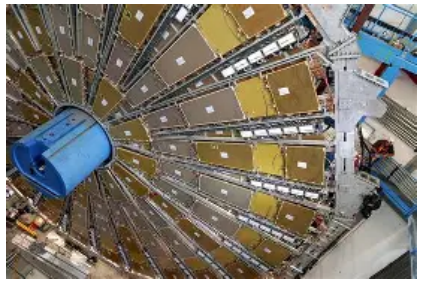
Classification of Particle Detectors

Key classification criteria:

- **Particle type sensitivity**
  - Charged particles
  - Photons and neutral hadrons
  - Muons
  - Neutrinos
  - Neutrons

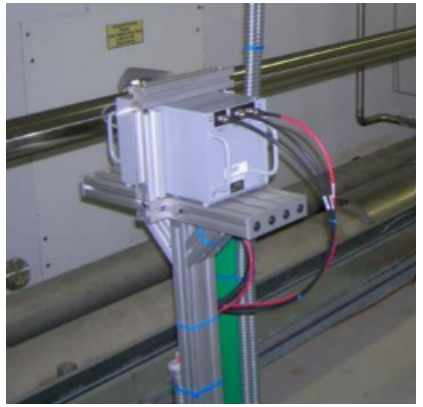










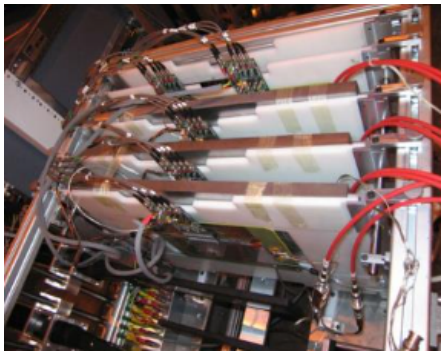




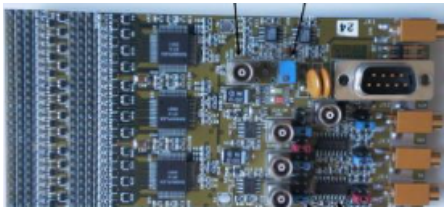
Classification of Particle Detectors

Key classification criteria:

- **Readout mechanism** (how signals become data)
  - **Analog readout**
  - **Digital readout**
  - **Time-based readout**
  - **Trigger and DAQ**





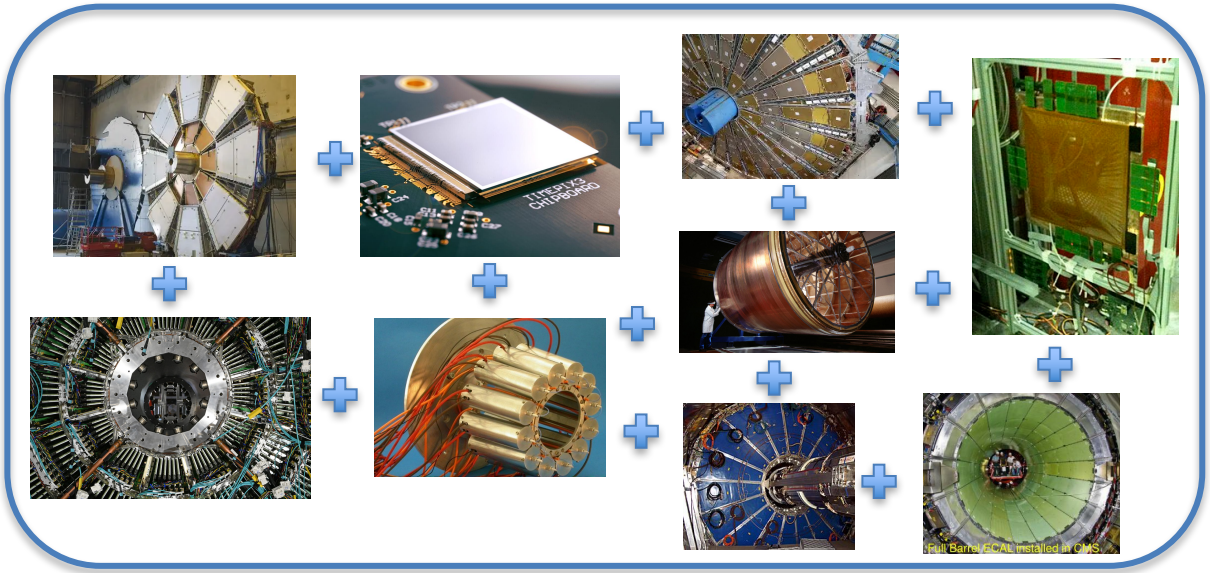


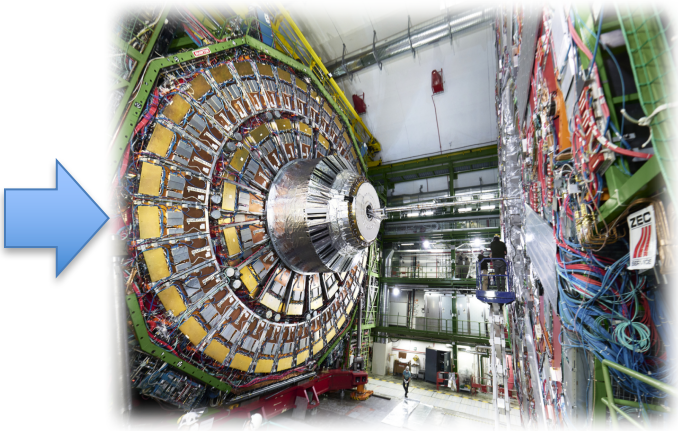


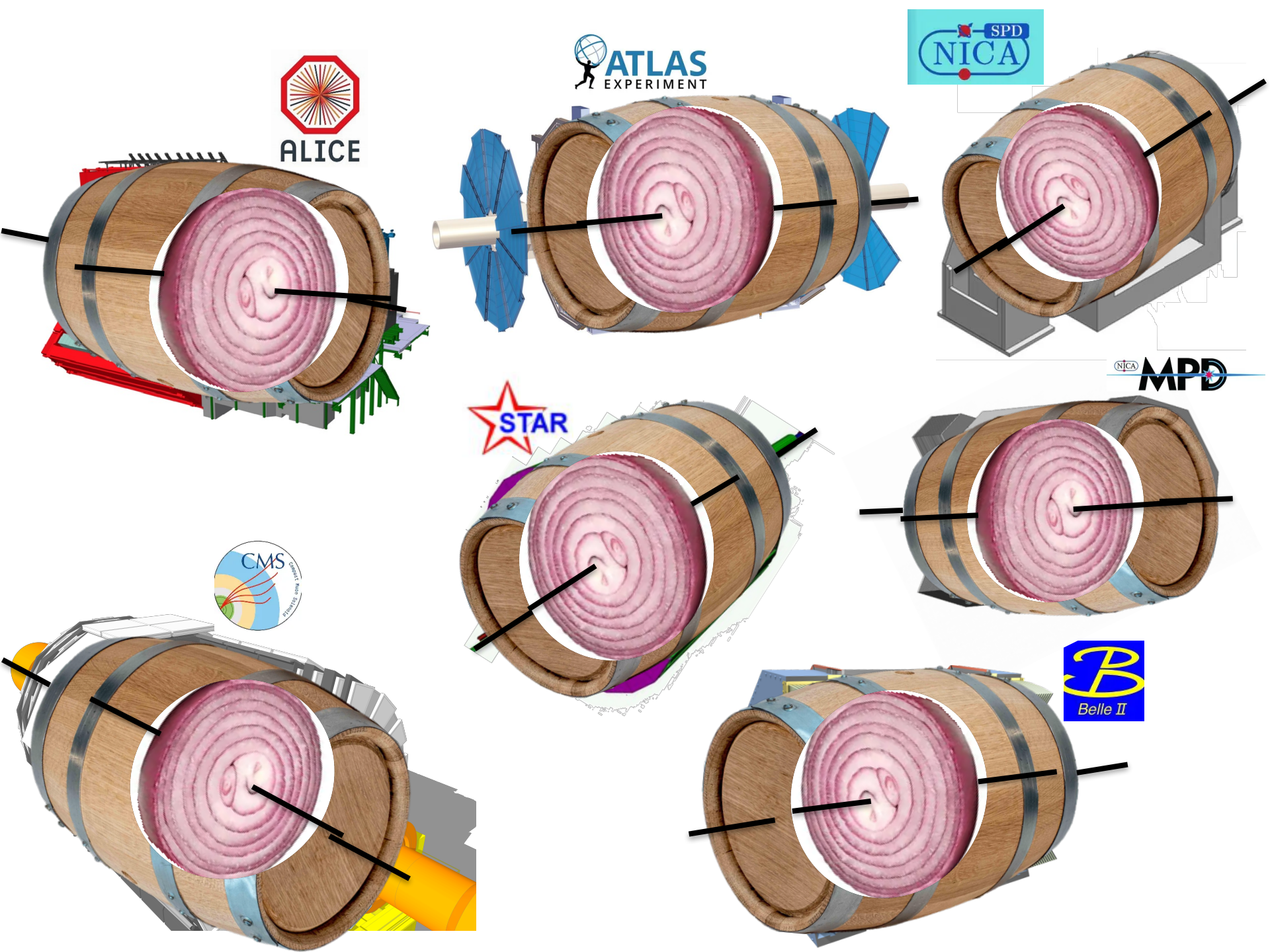
- **Geometrical coverage and acceptance.**
- **Time resolution and event-rate capability.**
- **ETC.**

From Individual Detectors to Full Experiments

- Each detector we've seen so far plays a unique role in identifying, tracking, or measuring particles.
- In large-scale experiments like ATLAS, CMS, ALICE, SPD or MPD, these technologies are combined into sophisticated systems designed to capture every aspect of a particle interaction—from origin to decay.

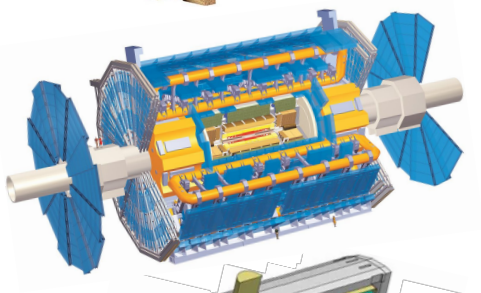


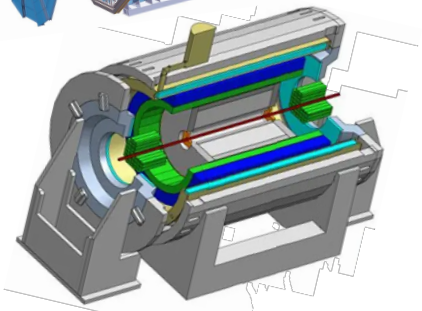


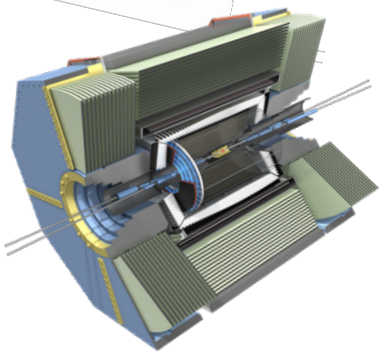

ALICE
ATLAS
EXPERIMENT
SPD
NICA
NICA
MPD
STAR
CMS
Belle II

Why Giant Barrel-Shaped Detectors?







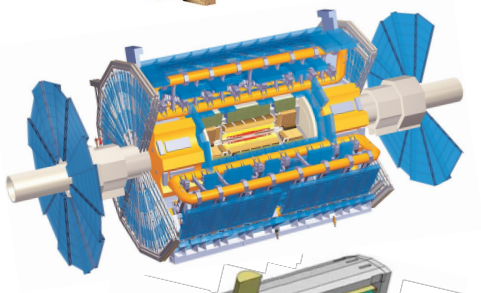


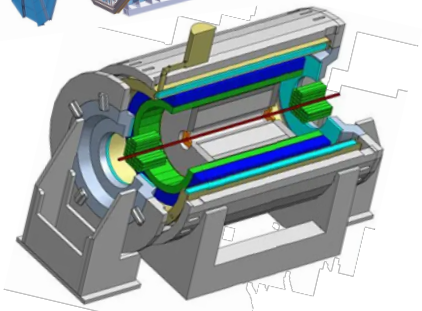
Advantages of the barrel geometry

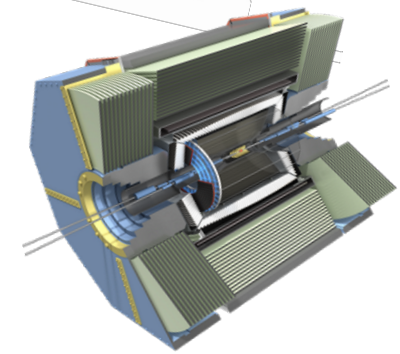
- This geometry guarantees nearly complete coverage around the interaction point, essential for reconstructing complex events.
- Cylindrical geometry allows construction in layered shells. Each layer can be accessed and upgraded independently.
- Most experiments use solenoidal or toroidal magnets to bend the trajectories of charged particles. Cylindrical geometry is ideal for generating a uniform magnetic field in the central region.

Why Giant Barrel-Shaped Detectors?





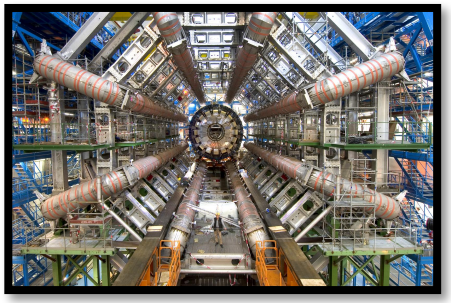




Advantages of the barrel geometry

- This shape allow for parallel construction, maintenance access, incremental upgrades, and absolutely facilitates the necessary hermeticity.
- The layered cylindrical design allows different subsystems to be placed concentrically.
- It is the most efficient geometry for studying high-energy collisions with thousands of particles emitted in all directions.

Why Giant Particle Detectores Have an Onion-Like Structure?

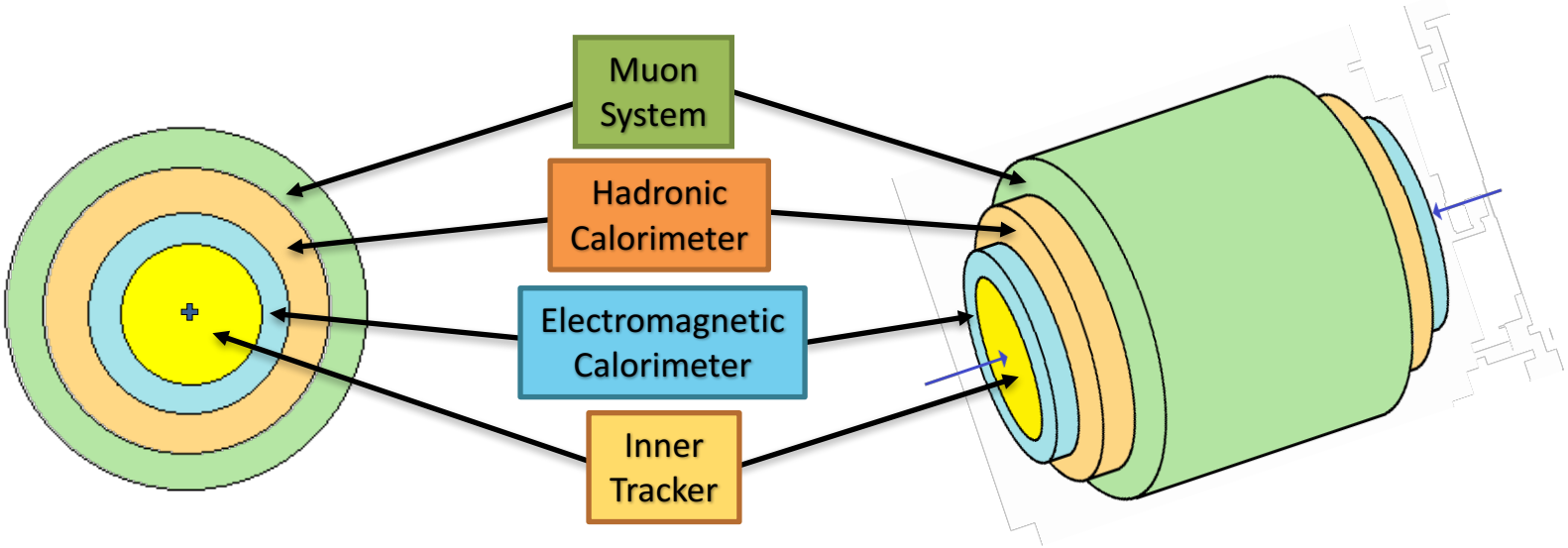






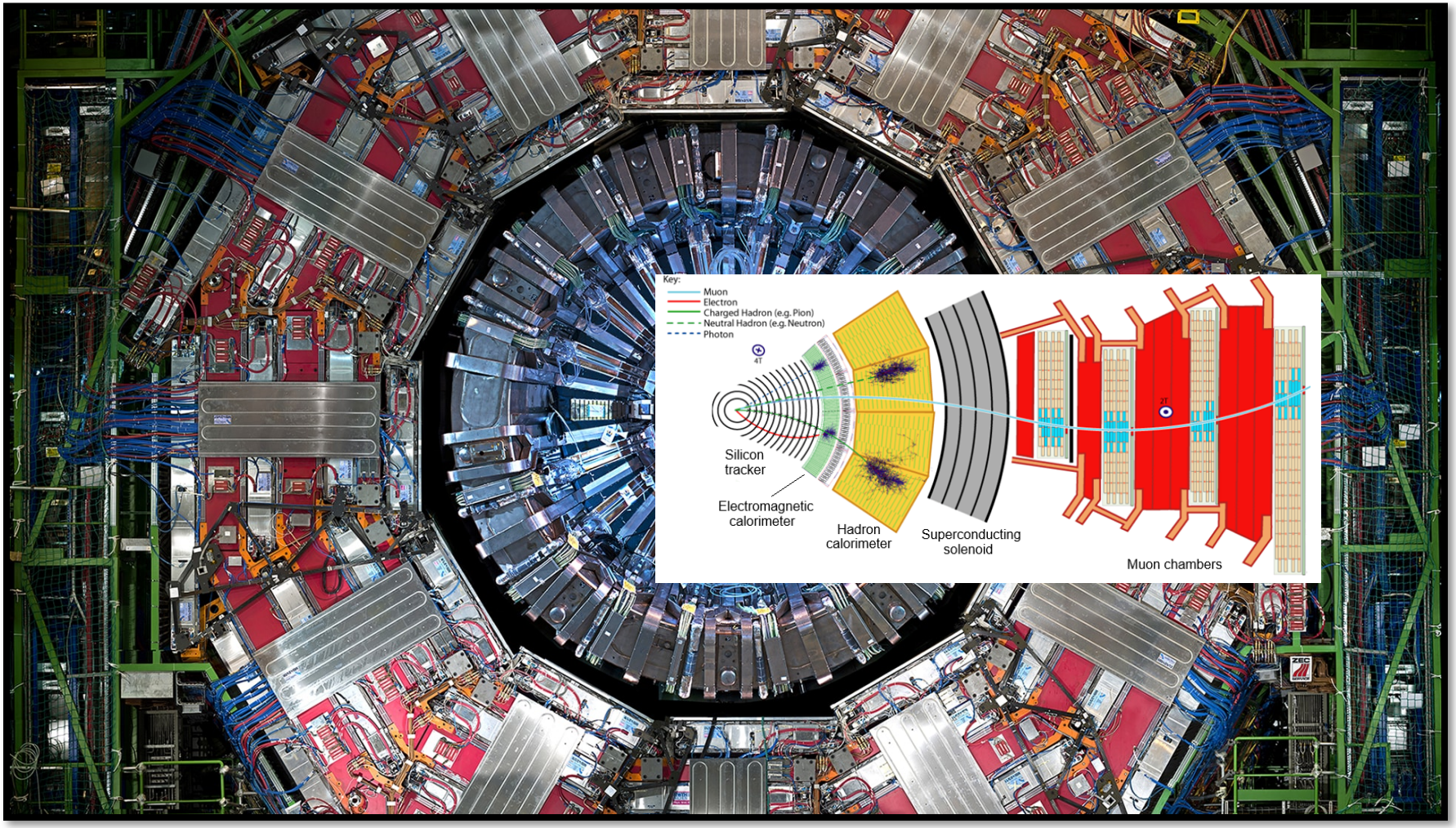
Concentric layered architecture

Maximize detection efficiency, spatial resolution, and particle identification capabilities.



Why Giant Particle Detectores Have an Onion-Like Structure?

Transverse slice througth CMS Detector



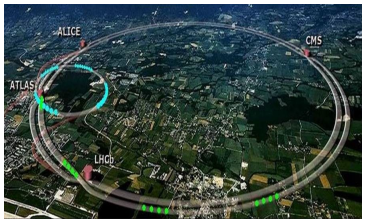
From Principles to Practice – Major HEP Experiments

Some of the most important high-energy physics experiments currently operating around the world



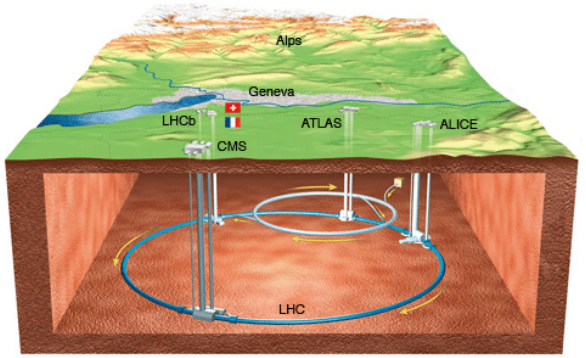
Experiments are not only detectors, but you also need possibilities to control the detectors, possibilities to take the data out and record it, possibilities to analyze the recorded data, etc.

LHC at CERN



The Large Hadron Collider (LHC) is the world's most powerful particle accelerator located at CERN, Switzerland. It collides protons or heavy ions at high energies to study fundamental particles and forces.







- Operational since 2009.
- It spans a 27-kilometer circular tunnel about 100 meters underground.
- LHC accelerates protons and heavy ions to energies up to 14 TeV.

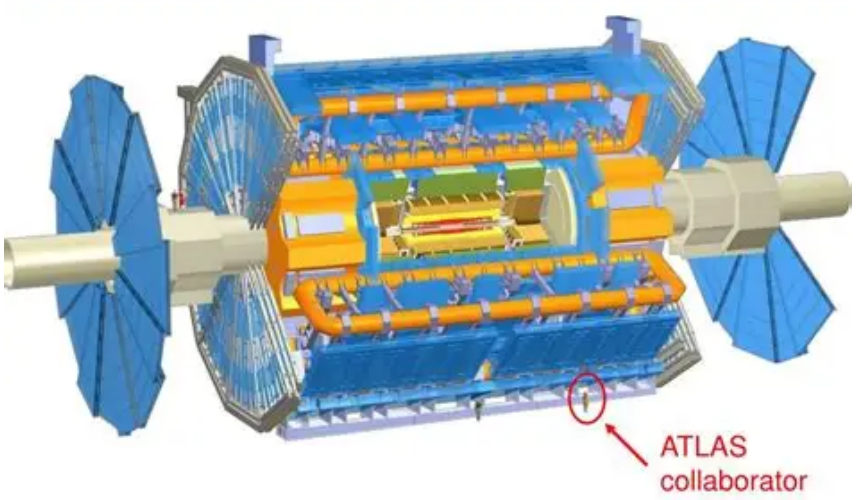
ATLAS at LHC, CERN

ATLAS (A Toroidal LHC ApparatuS)

ATLAS - The biggest-volume particle detector ever built for a collider. General-purpose detector for the studies of proton–proton and heavy-ion collisions.

Shape: cylindrical, multilayered detector around collision point
Detector dimensions: 46 meters long, 25 meters in diameter
Weight: ~7000 tonnes





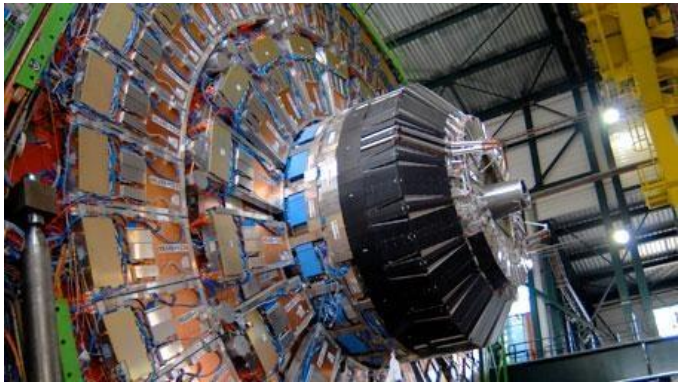
Installed and commissioned with LHC first beam operations in 2008.

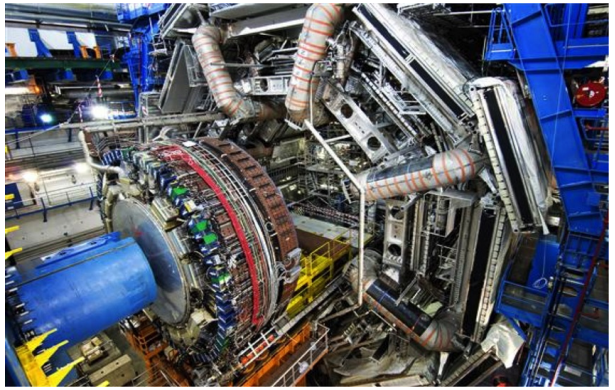
ATLAS at LHC, CERN

ATLAS (A Toroidal LHC ApparatuS)

Main Scientific Objectives

- Discovering and characterizing new particles and interactions
- Precision measurements of Standard Model processes
- Study of the Higgs boson properties and electroweak symmetry breaking
- Searches for dark matter candidates, supersymmetry, extra dimensions, and other beyond-Standard-Model phenomena
- Heavy-ion physics and quark–gluon plasma studies

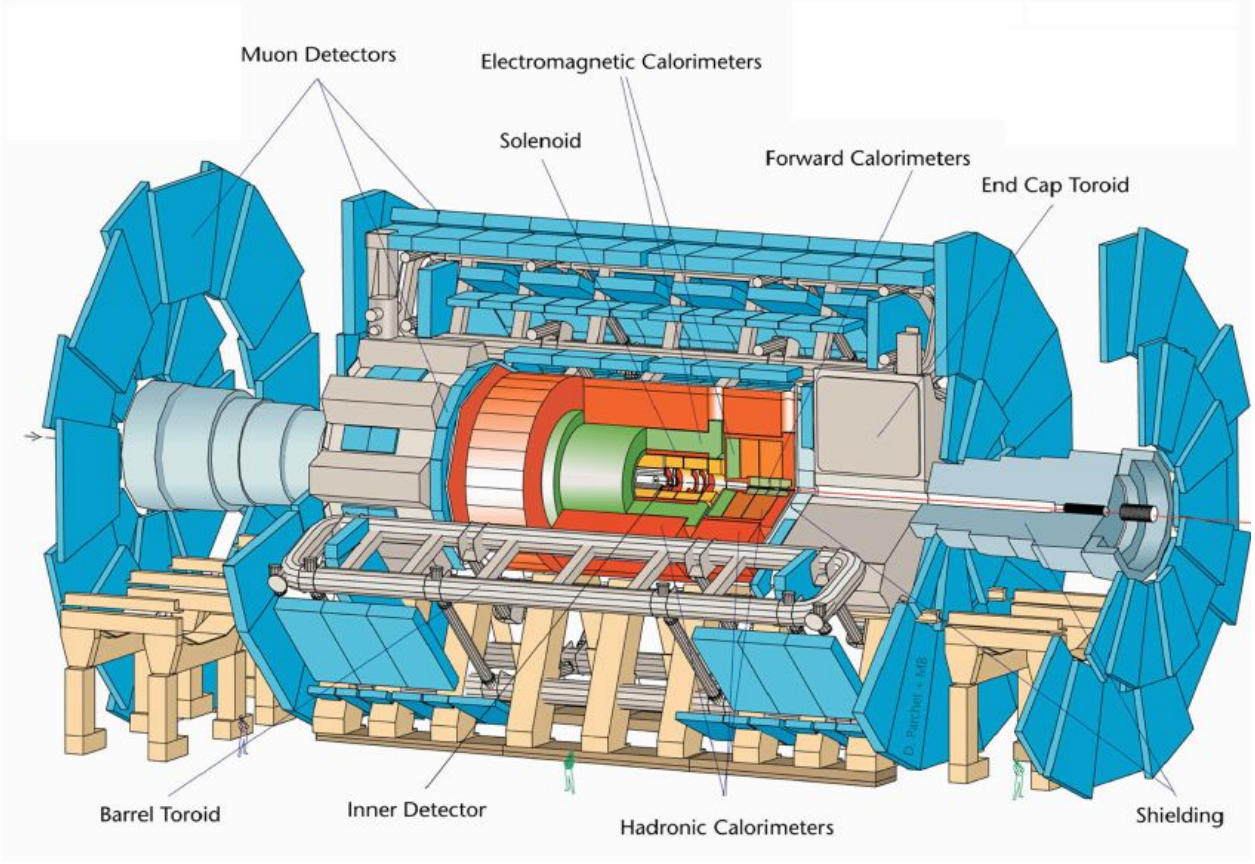


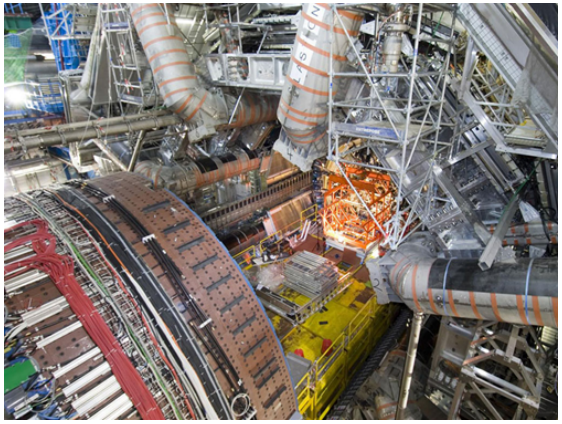


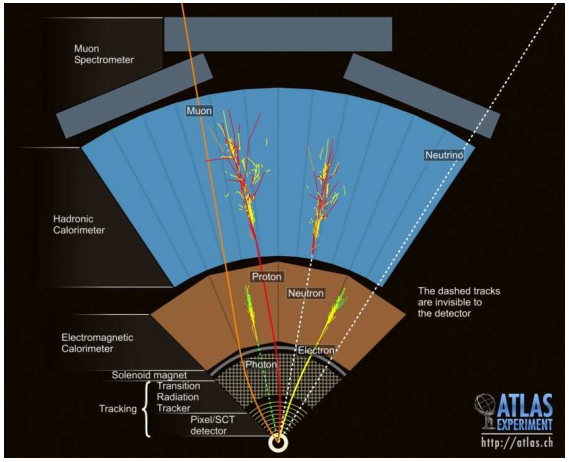
ATLAS

ATLAS (A Toroidal LHC ApparatuS)

at LHC, CERN





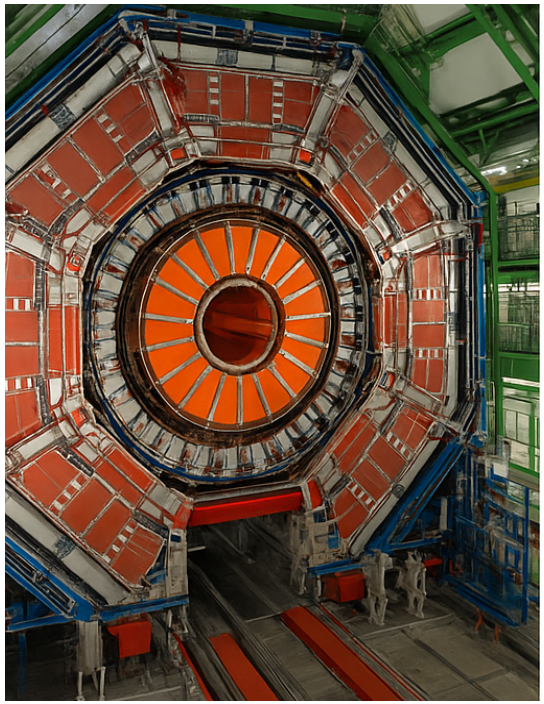


Schematic view of the layers of the ATLAS detector, showing a selection of particles and in which part they will be detected.

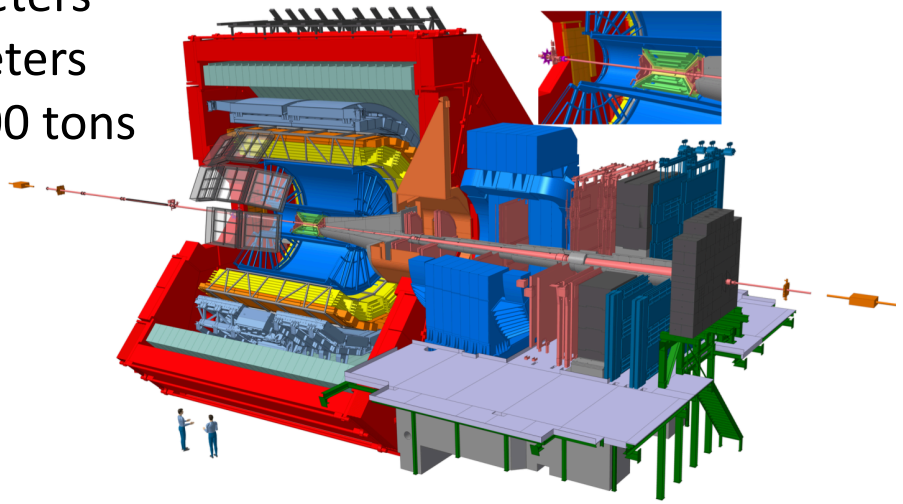
ALICE at LHC, CERN

ALICE (A Large Ion Collider Experiment)

ALICE - Specialized heavy-ion detector, one of the four major experiments at LHC. Optimized for very high track multiplicity and excellent particle identification.



Detector Dimensions:
Length: ~26 meters
Height: ~16 meters
Weight: ~10,000 tons



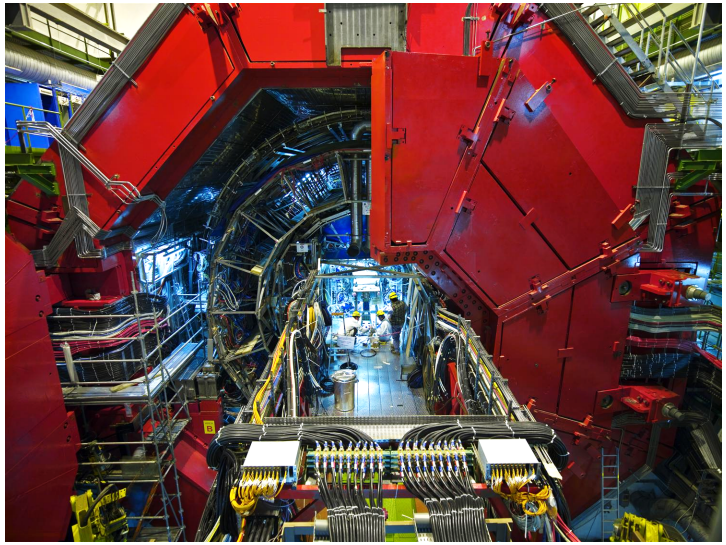
Installation and commissioning with LHC beams in the late 2000s

ALICE at LHC, CERN

ALICE (A Large Ion Collider Experiment)

Main Scientific Objectives

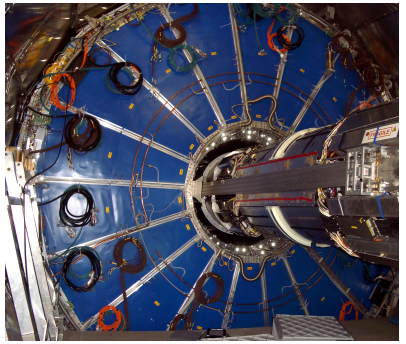
- Study formation and properties of quark–gluon plasma (QGP)
- Measure collective flow, temperature, and equation of state of QCD matter
- Investigate energy loss of hard probes (jet quenching) in the medium
- Study heavy-flavour production and quarkonia suppression/regeneration
- Measure electromagnetic probes (direct photons, dileptons) and initial-state effects

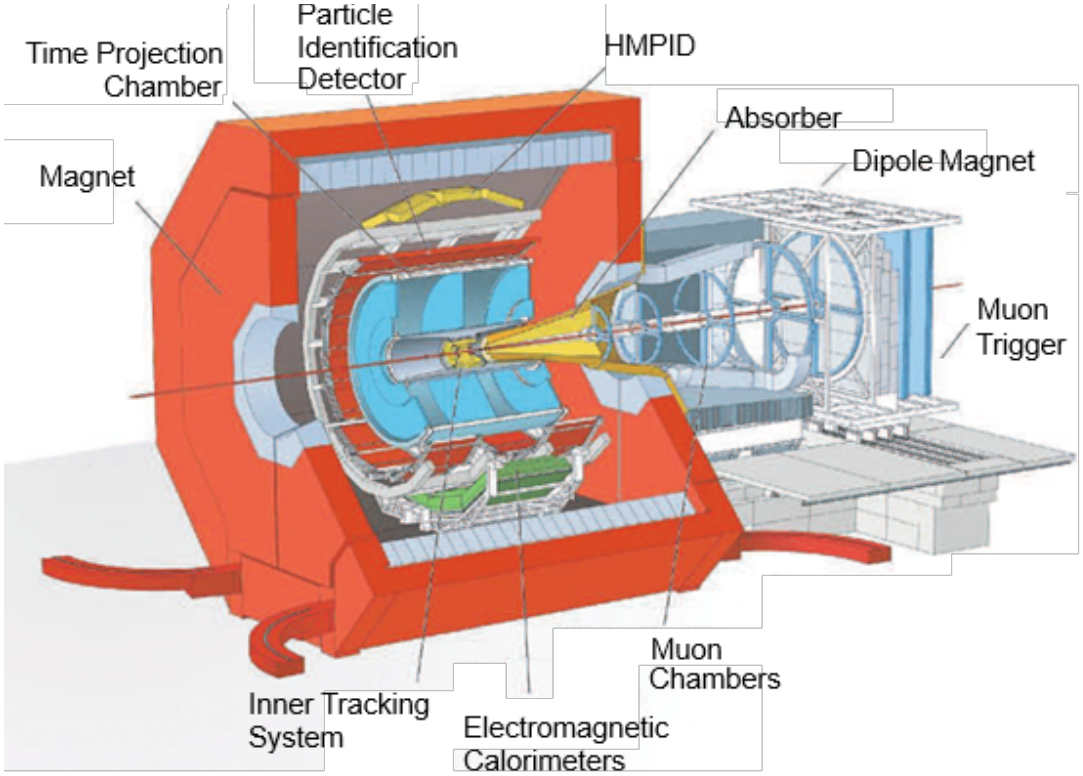


ALICE at LHC, CERN

ALICE (A Large Ion Collider Experiment)

«ALICE consists of central barrel detectors (for mid-rapidity) and forward detectors (for asymmetrical measurements)»





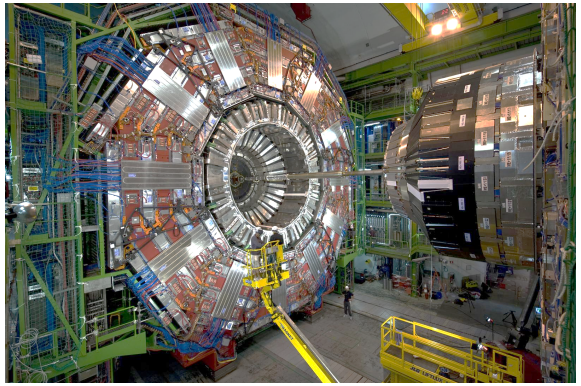
Inner Tracking System - close to the beam pipe for precision vertexing (silicon pixel and strip detectors)
Time Projection Chamber - main tracking volume for 3D particle trajectories and momentum measurement (gas-based chamber with drift field)
Electromagnetic Calorimeters - for energy measurement (scintillator and crystal-based detector)

Forward Muon Spectrometer - for detection of Forward Muon from heavy-flavor decays
HMPID - High-momentum particle identification via Cherenkov radiation
Time-of-Flight - Timing-based particle identification

CMS at LHC, CERN

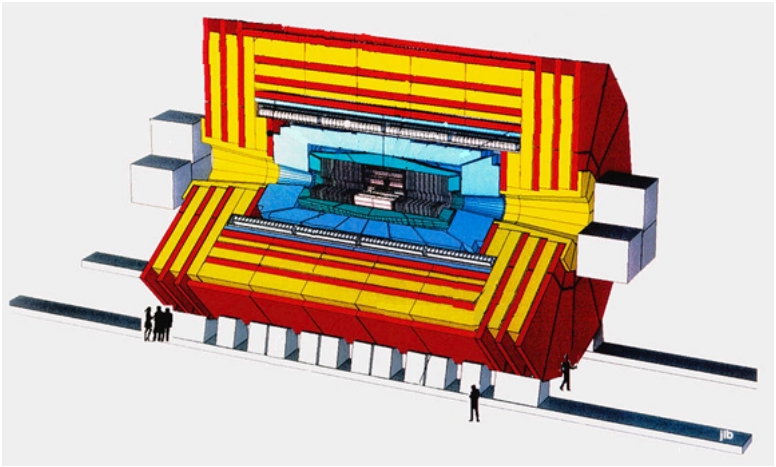
CMS (Compact Muon Solenoid)

CMS – a giant, onion-like general-purpose particle detector at the LHC designed to measure collisions with high precision, studying fundamental particles and forces.



Dimensions: 21 meters long,
15 meters wide, 15 meters high
Weight: ~14,000 tonnes
Start of Operation: 2009

Constructed around a powerful 4-tesla superconducting solenoid magnet. Unlike other LHC detectors, CMS was constructed in modules and lowered into its cavern.



CMS

CMS (Compact Muon Solenoid)

at LHC, CERN

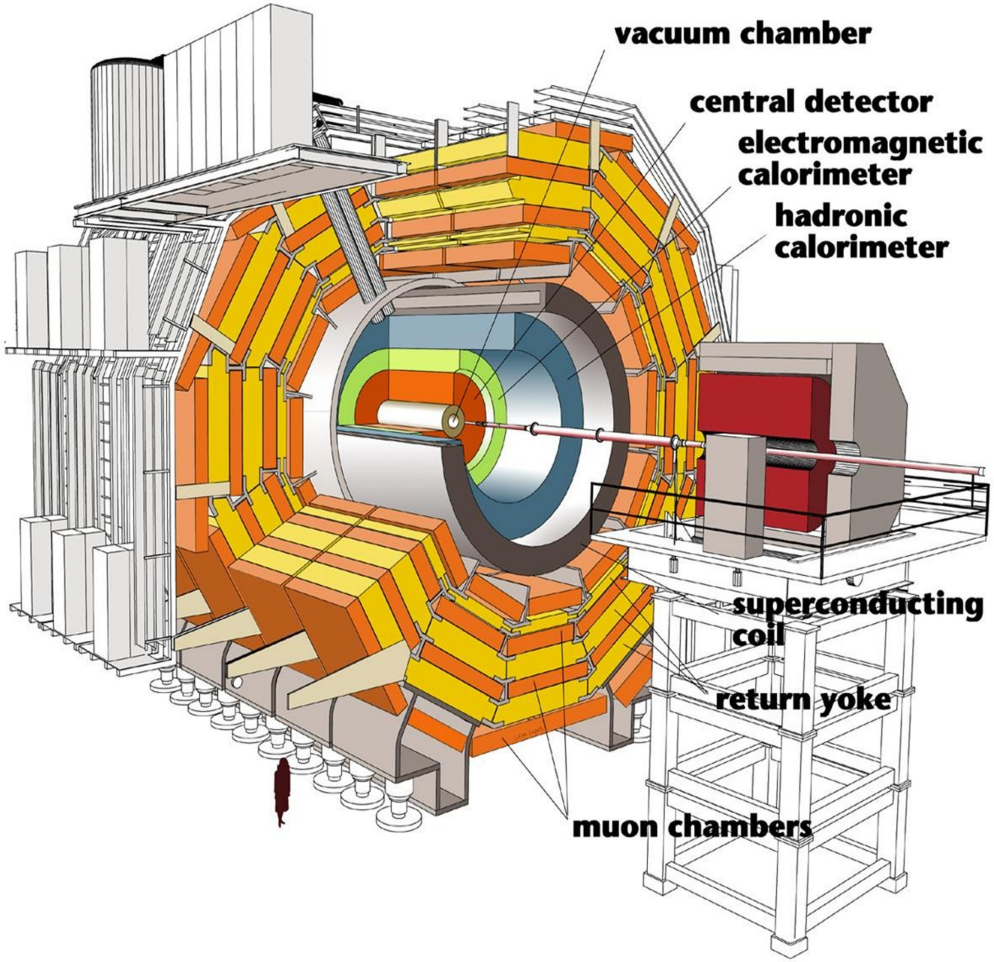
Main Scientific Objectives

- Discover new fundamental particles and interactions beyond the Standard Model
- Precision measurements of Higgs boson properties and electroweak processes
- Search for dark matter candidates and supersymmetric particles
- Study top quark physics, QCD, and heavy-ion collisions

CMS was one of the two detectors whose complementary measurements validated the existence of the Higgs boson, making the discovery robust and universally accepted.

CMS at LHC, CERN

CMS (Compact Muon Solenoid)



Silicon Tracker - Measures paths of charged particles with high precision (high-resolution silicon tracker inside solenoid).

ECAL - Detects and measures energy of electrons and photons.

HCAL - Measures energy of hadrons.

Solenoid Magnet - Generates a 4-tesla magnetic field to bend charged particles, enables a compact tracker with excellent momentum resolution.

Muon Detectors - Identifies and tracks muons, which penetrate all other layers.

Trigger and Data Acquisition System - integrated across layers. Selects interesting events from millions of collisions per second.

LHCb

LHCb (Large Hadron Collider beauty)

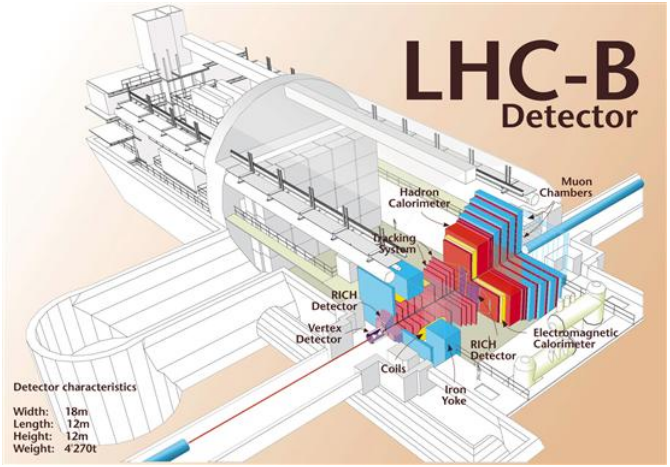
at LHC, CERN

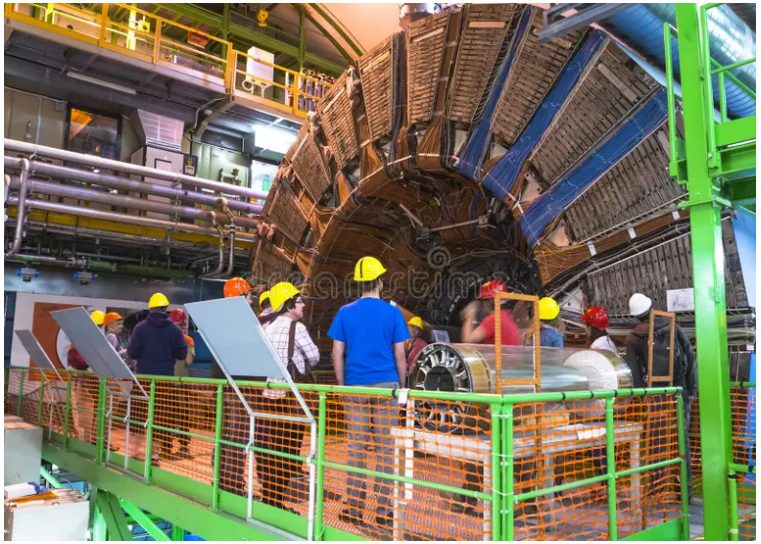
LHCb - Spectrometer optimized to detect particles emitted in the forward direction from proton-proton collisions

The LHCb experiment at CERN was constructed between 2001 and 2008 and began operation in 2009.

Dimensions: ~20 meters long,

5600 tonnes in weight





LHCb Detector
Weight: 5,600 tonnes
Height: 10 m
Length: 20 m

LHCb

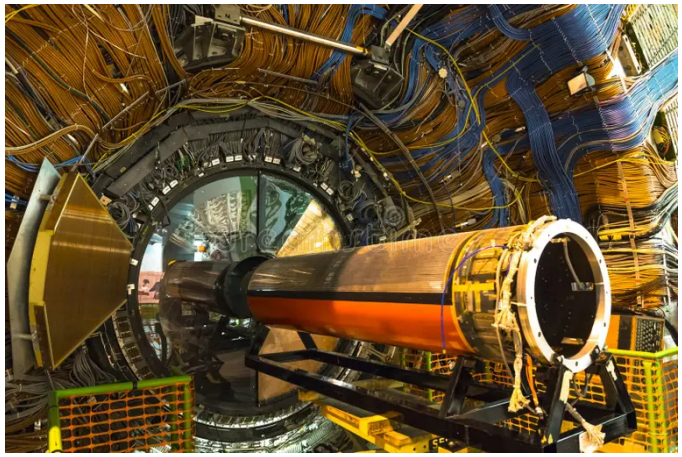
LHCb (Large Hadron Collider beauty)

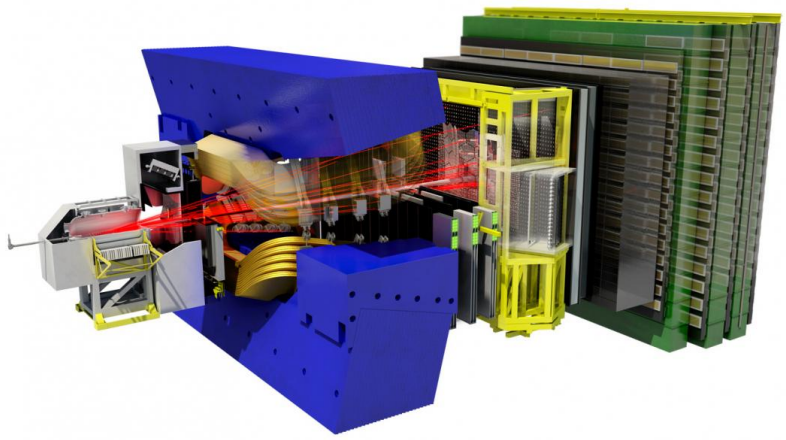
at LHC, CERN

Main Scientific Objectives

- CP Violation in Beauty and Charm Quarks
- Rare Decays and New Physics
- Heavy Flavor Physics
- Matter-Antimatter Asymmetry
- Charmonium and Exotic States
- Heavy Ion and Fixed-Target Physics





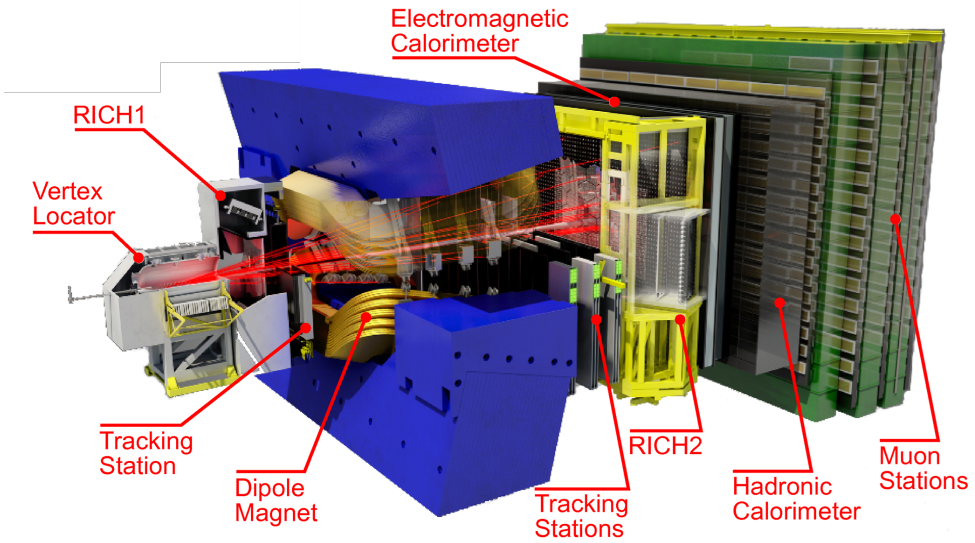


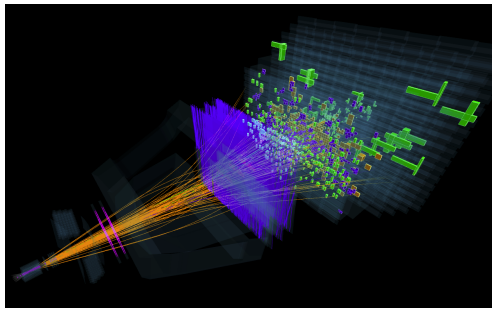
LHCb

at LHC, CERN

LHCb (Large Hadron Collider beauty)

LHCb is composed of several subdetectors arranged in sequence…

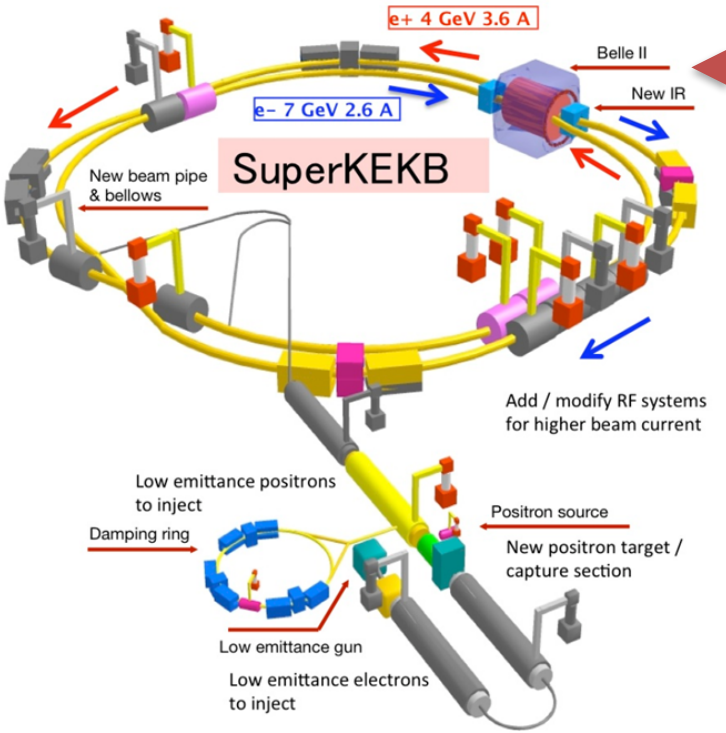


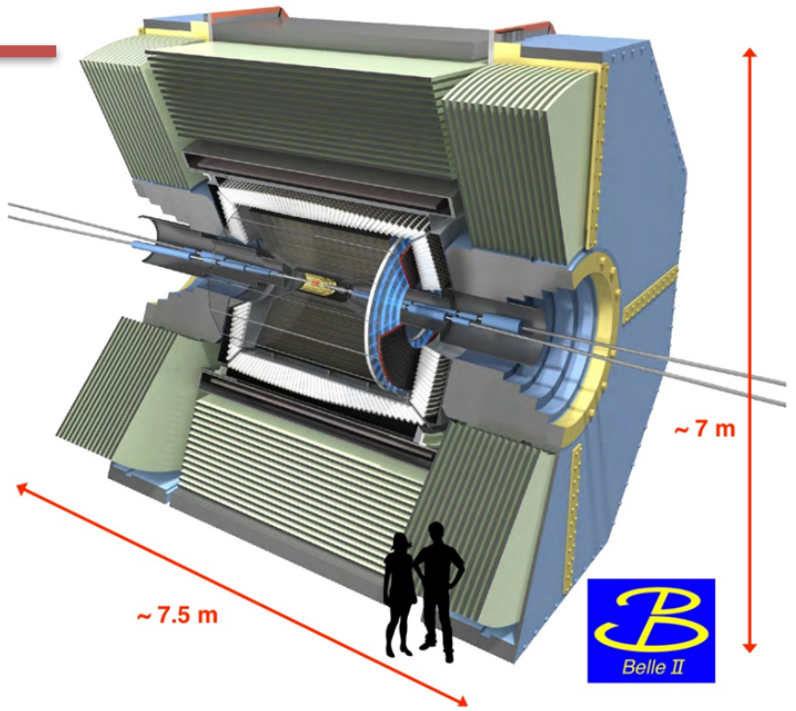


- **Vertex Locator -** Precisely tracks particles close to the collision point to identify decay vertices.
- **Ring Imaging Cherenkov (RICH) -** Identifies particle types by measuring Cherenkov radiation.
- **Tracking Stations -** Measure momentum of charged particles using silicon and straw detectors.
- **Calorimeters (ECAL & HCAL) -** Measure energy of electrons, photons, and hadrons.
- **Muon System -** Detects and identifies muons, crucial for many decay channels.

BELLE - II at SuperKEKB, Japan

BELLE II - A next-generation flavor-physics detector focused on B, D, τ physics and rare/forbidden processes.





SuperKEKB is a high-luminosity electron-positron collider located in Tsukuba, Japan, designed to produce large numbers of B mesons for precision studies in particle physics.

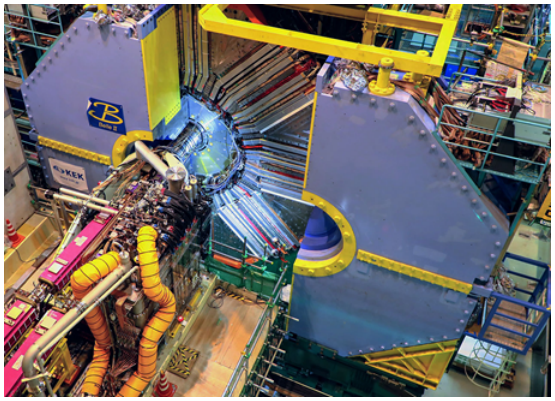
Detector length ~6–7 m; diameter ~3–4 m

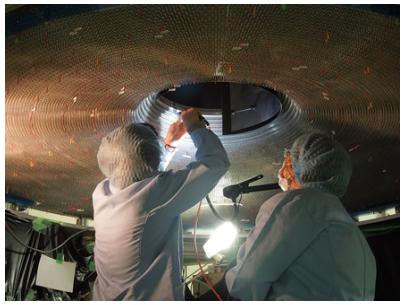
BELLE - II at SuperKEKB, Japan

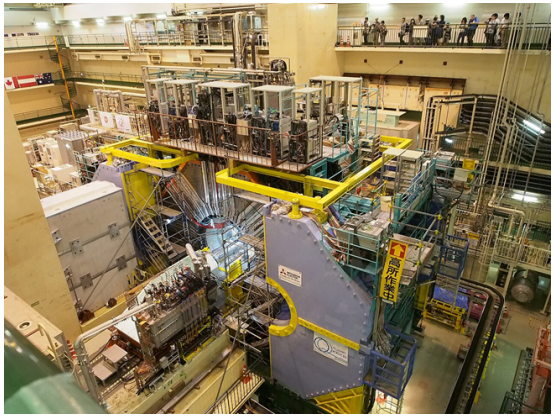
Main Scientific Objectives

- Precision measurement of CP violation
- Search for rare and forbidden decays
- Tests of lepton-flavor universality
- Precision measurements of hadronic form factors and fragmentation for flavor-model inputs
- New-physics searches using full-event reconstruction and missing-energy techniques

Belle II will be a central facility for flavor physics in the coming decade.

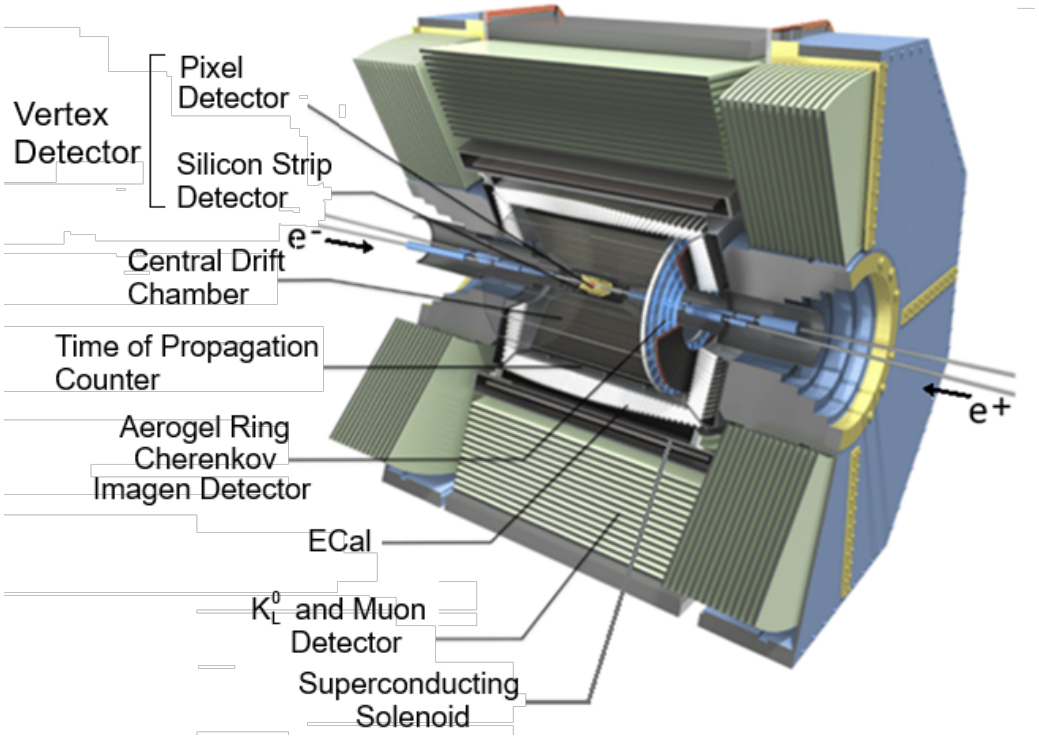






BELLE - II at SuperKEKB, Japan

- Belle II is built around a cylindrical geometry and consists of several concentric subdetectors, each optimized for specific tasks.



Vertex Detector - Composed of 2 layers of PD and 4 layers of SSD, provides high-resolution tracking close to the interaction point.
CDC - A large-volume gas detector that measures the momentum of charged particles.
TOP Counter - Cherenkov-based detector identifies charged particles by measuring the time and angle of Cherenkov light propagation.

ARICH Detector - Installed in the forward endcap, it uses aerogel radiators to identify particles by detecting Cherenkov rings.
ECAL - Measures the energy and position of photons and electrons with high precision.
K^0_L and Muon Detector - it identifies muons and neutral long-lived kaons using resistive plate chambers and scintillator strips.

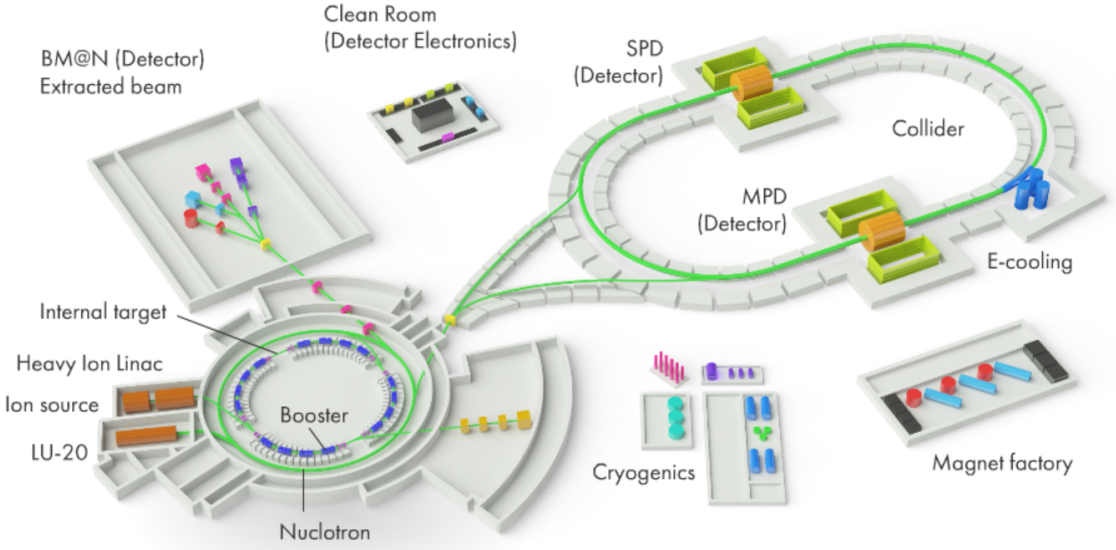
NICA



NICA collider (Nuclotron-based Ion Collider fAcility) is a Russian particle accelerator complex built at the Joint Institute for Nuclear Research (JINR) in Dubna, focuses on high-energy collisions similar to early universe conditions.


LU-20 - Light Ion Linear Accelerator


HILac - Heavy Ion Linear Accelerator



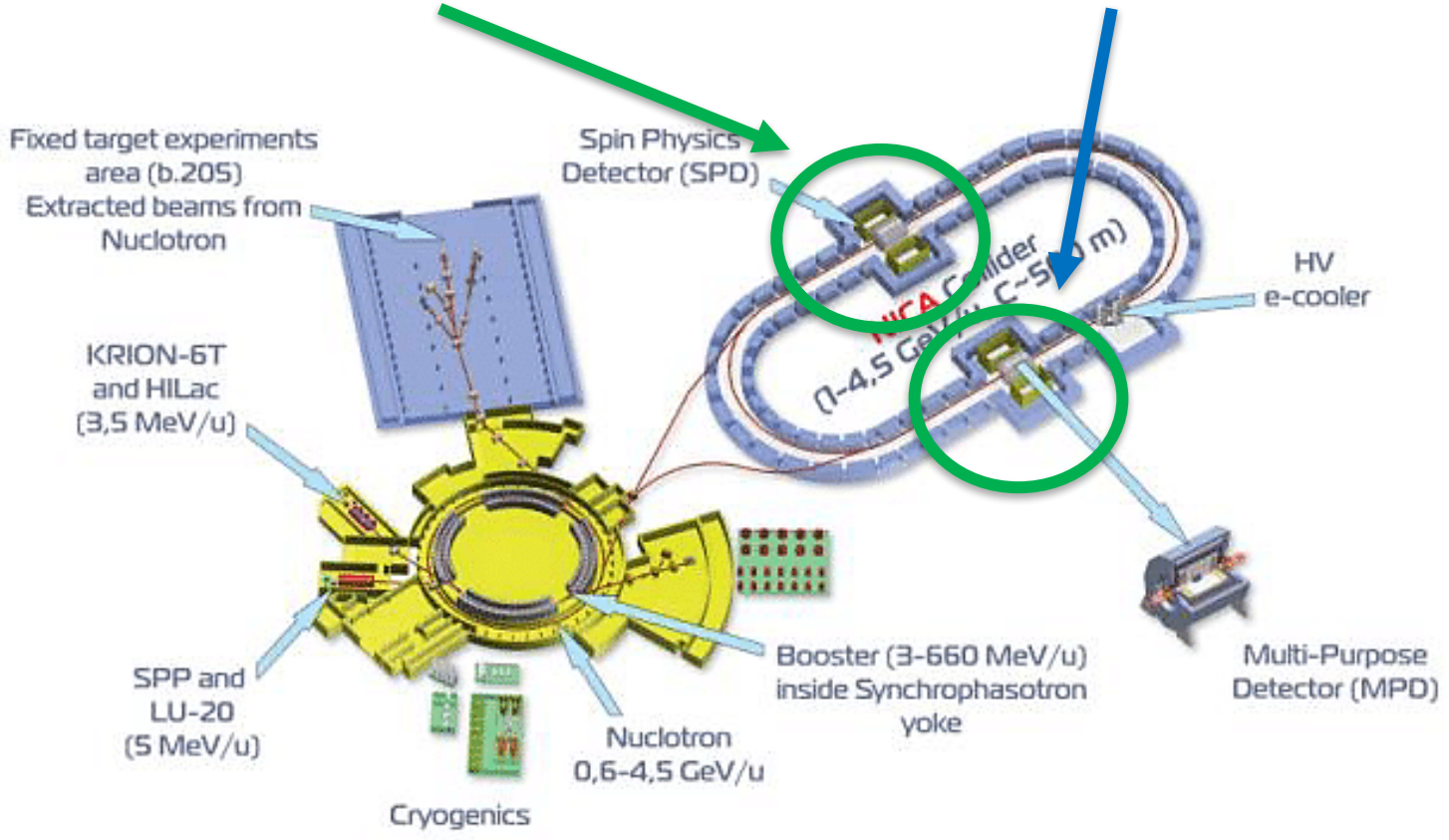
NICA - a cutting-edge accelerator complex designed to explore the properties of dense baryonic matter and the nature of strong interactions.

NICA



SPD (Spin Physics Detector)

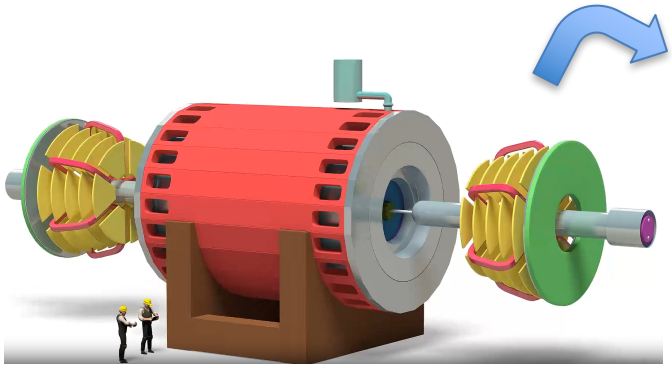
MPD (Multi-Purpose Detector)



MPD at NICA, Russia

MPD (Multi-Purpose Detector)

MPD - A universal detector designed to study heavy-ion collisions at high luminosity and moderate energies, aiming to explore the properties of dense baryonic matter and investigate phase transitions in strongly interacting systems.

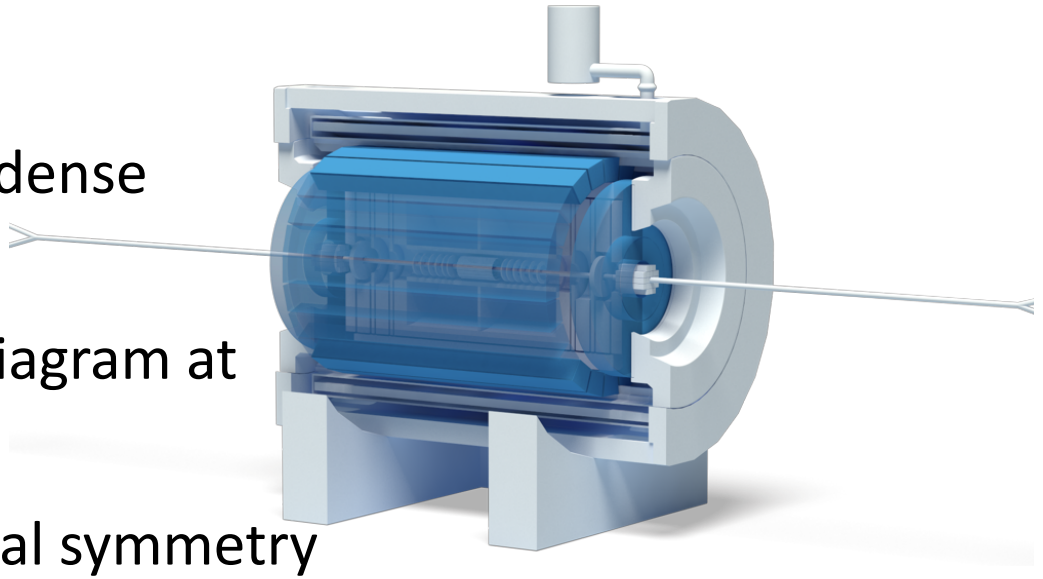




Collision energy range: √sNN = 4–11 GeV.
Supports collisions of heavy ions like gold and uranium.

MPD at NICA, Russia

MPD (Multi-Purpose Detector)



Main Scientific Objectives

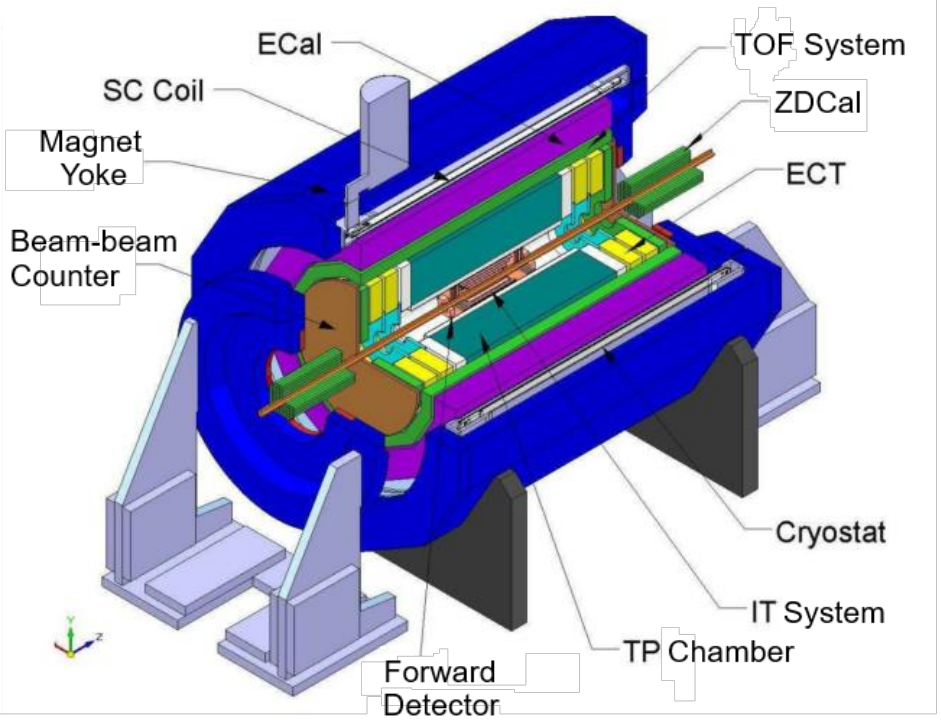
- Study properties of hot and dense baryonic matter.
- Investigate the QCD phase diagram at high baryon densities.
- Explore phenomena like chiral symmetry restoration, deconfinement, and critical point signals.

These objectives aim to deepen our understanding of nuclear matter under extreme conditions, like those in neutron stars or the early universe.



MPD at NICA, Russia

MPD (Multi-Purpose Detector)



Subsystems

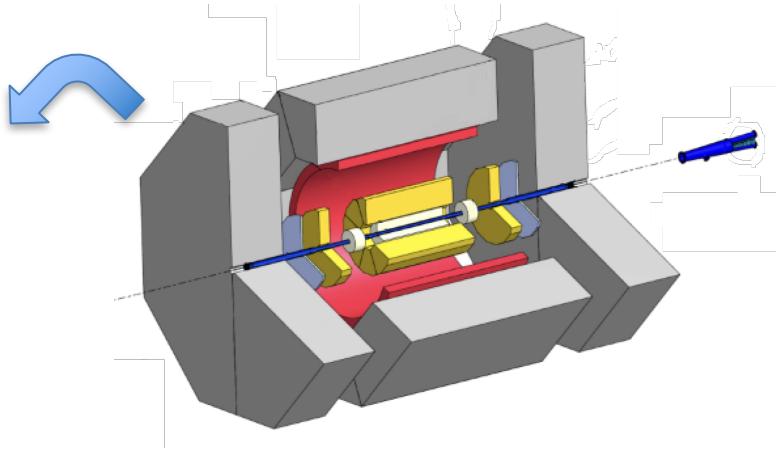
- **ITS -** Located close to the interaction point, it enhances vertex resolution and helps identify short-lived particles
- **TPC -** The main tracking device, providing 3D reconstruction of charged particle trajectories and momentum measurement inside a 0.5 T magnetic field
- **TOF Detector -** Measures particle flight times to distinguish between pions, kaons, and protons, essential for particle identification
- **ECAL -** Detects and measures the energy of photons and electrons, contributing to neutral particle reconstruction.
- **HCAL -** Measures the energy of hadrons and supports jet and event characterization.
- **Beam-beam Counters** and **Zero-degree Calorimeters** for triggering and centrality determination
- **Muon Detector (planned) -** Will be used to identify muons and study heavy flavor production and dilepton channels

SPD at NICA, Russia

SPD (Spin Physics Detector)

SPD - A versatile instrument developed to investigate collisions involving polarized protons and deuterons, focusing on the nucleon's spin structure and providing experimental tests of QCD in the spin domain.





Collision energy: up to $\sqrt{s}$ = 27 GeV

Expected very high luminosity: 10^{32} cm^{-2} s^{-1}

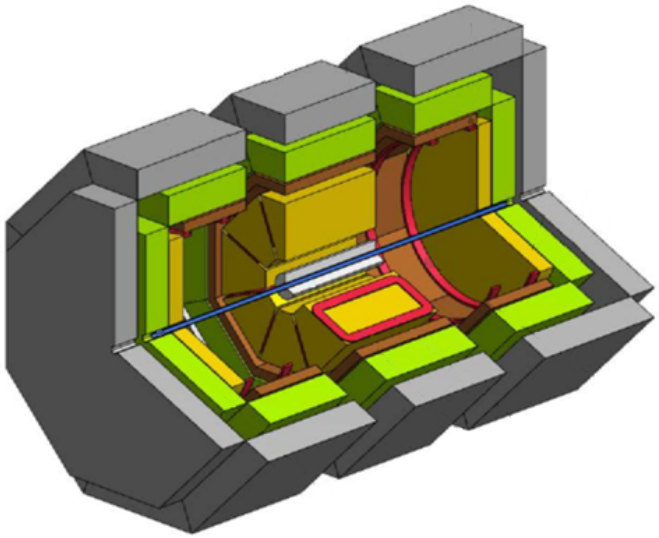
SPD at NICA, Russia

SPD (Spin Physics Detector)

Main Scientific Objectives

- Study the spin structure of the nucleon.
- Investigate polarization phenomena in proton and deuteron collisions.
- Measure asymmetries in processes such as Drell-Yan pair production, charmonium, and prompt photons.

These studies will provide access to transverse momentum-dependent parton distribution functions, essential for understanding nucleon dynamics.

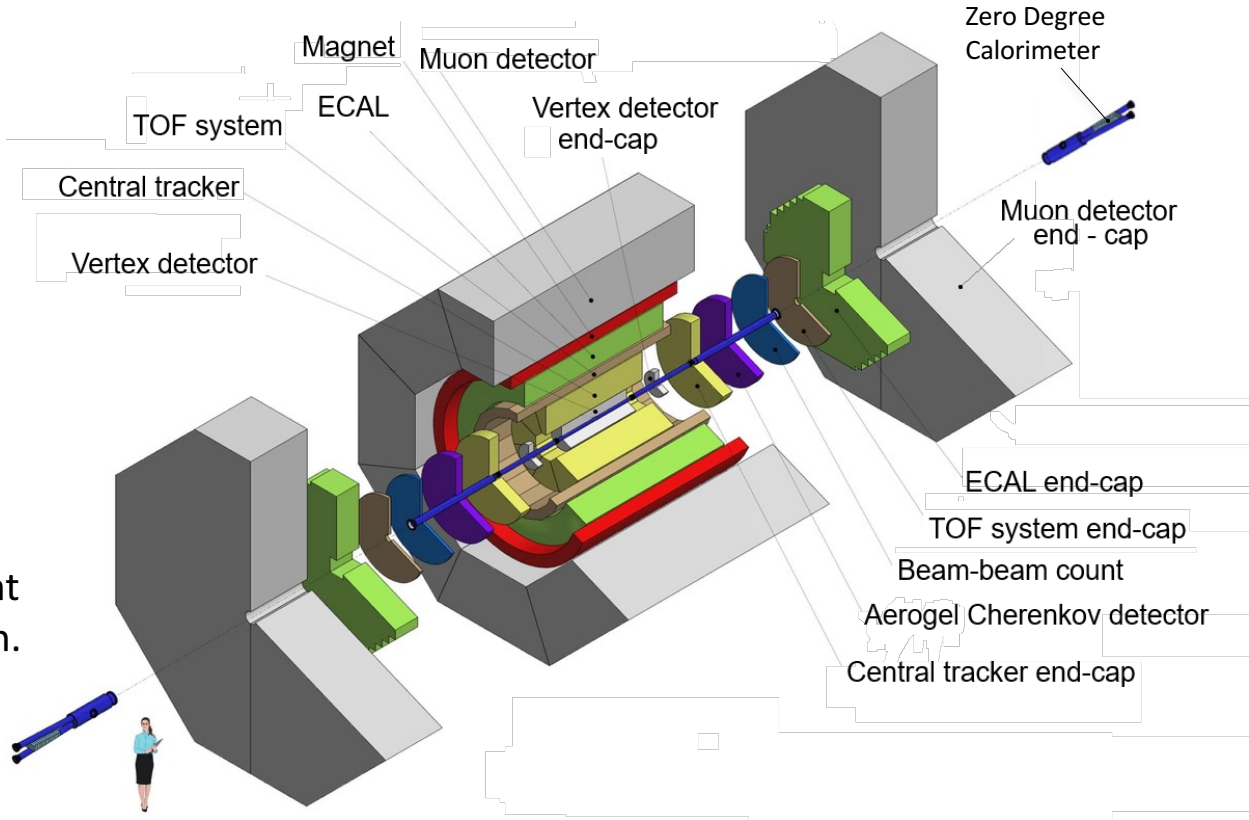


SPD at NICA, Russia

SPD (Spin Physics Detector)

Subsystems

- **Vertex Detector**: Located closest to the interaction point, it provides high-resolution tracking for identifying primary and secondary vertices.
- **Central Tracker**: A large-volume tracking system that reconstructs charged particle trajectories and momenta.
- **TOF System**: Measures particle flight times to aid in particle identification.
- **ECAL -** Detects and measures the energy of photons and electrons, essential for studying electromagnetic processes and neutral particles.



- **HCAL -** Measures the energy of hadrons and contributes to event characterization and jet reconstruction.
- **Muon Detector -** Positioned in the outer layers to identify muons, which are key probes in spin physics and heavy flavor studies.

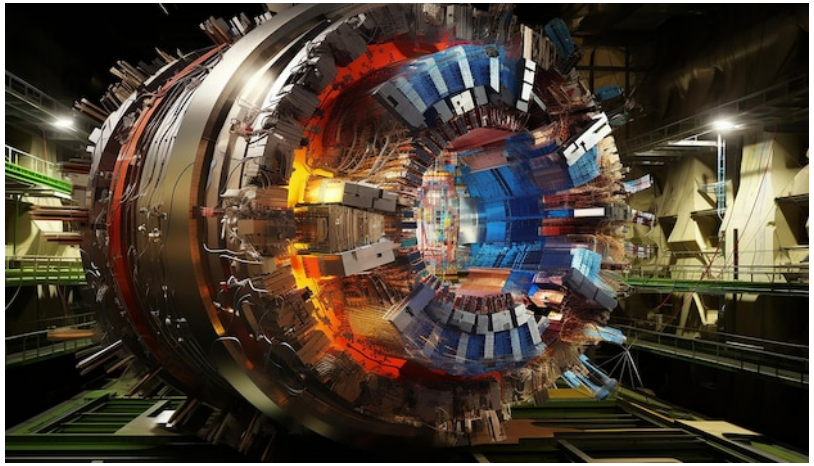
Upcoming & Future HEP Experiments

What does the future hold for us in this field of knowledge?

Powerful Accelerators + Ultra-sensitive Detectors

Future **supercolliders** are essential tools to push the boundaries of particle physics and answer unresolved questions about the universe.





Supercolliders are not just bigger machines, they are smarter, faster, and more precise, designed to unlock the next layer of nature's secrets.

Upcoming & Future HEP Experiments

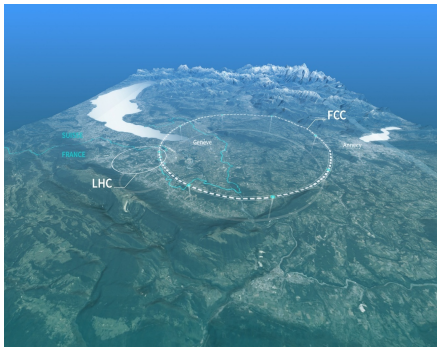
"A particle detector for a future supercollider must be thin, fast, radiation-proof, and intelligent—able to track particles with picosecond precision, measure energies finely, and process massive data streams in real time."

Required essential characteristics of these Detectors:

- High granularity and spatial resolution
- Fast timing (~20–50 ps) to resolve pile-up
- Radiation hardness for high-luminosity environments
- Low material budget to reduce scattering
- Modular design for upgrades and global collaboration
- AI-driven data acquisition

These DETECTORS will enable discoveries in Higgs physics, dark matter, QCD, and beyond.

Future Circular Collider (FCC)



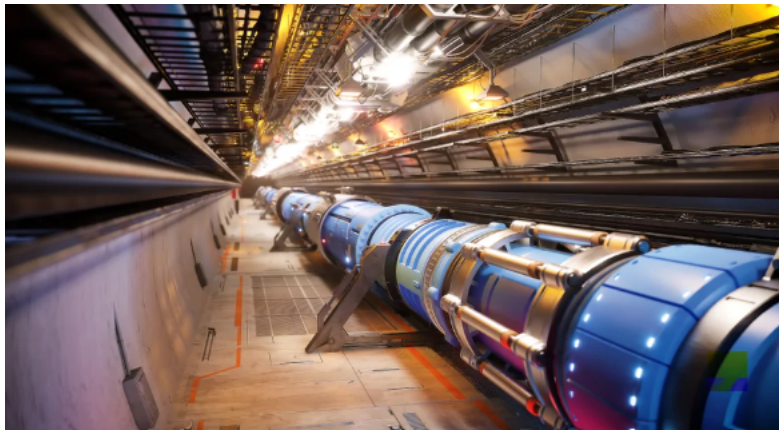
Location: CERN (Geneva, Switzerland). A new underground tunnel with a circumference of **90-100 km** (compared to the LHC's 27 km).

It will consist of two phases:

Phase 1. FCC-ee (electron-positron collider).

Planned Operational Date: ~ 2045-2060

Main Goal: To serve as a ***"Higgs and Electroweak Factory"***. It will produce millions of Higgs bosons and billions of Z and W bosons in an extremely clean environment to measure their properties with unparalleled precision.





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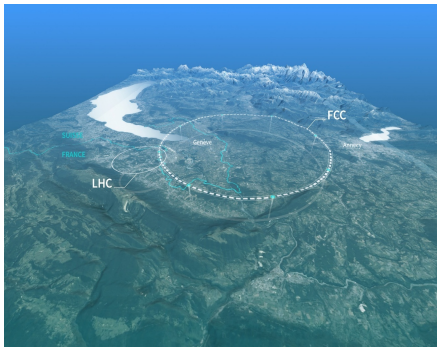

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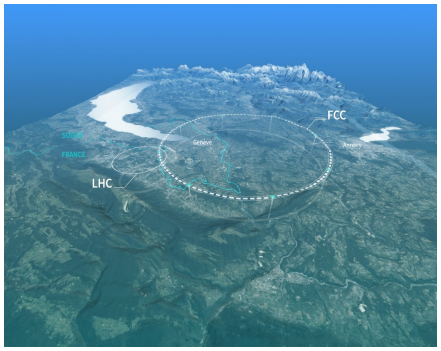
Detector: At least two new, advanced general-purpose detectors are planned. Ultra light tracking system (silicon vertex + large drift chamber) to minimize material and maximize resolution. High granularity calorimeters, including dual readout concepts, for accurate energy measurement of photons, electrons, and jets. Advanced systems to distinguish particle types efficiently. Compact muon detectors integrated into the magnet return yoke.

Future Circular Collider (FCC)



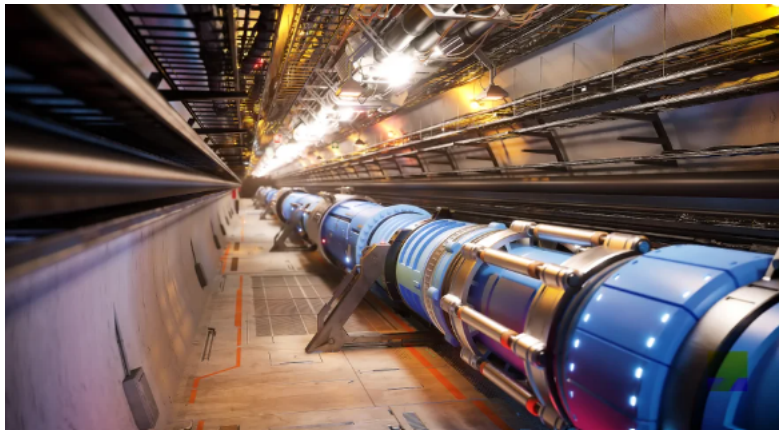
Location: CERN (Geneva, Switzerland). A new underground tunnel with a circumference of **90-100 km** (compared to the LHC's 27 km).

It will consist of two phases:

Phase 2. FCC-hh (proton-proton collider).

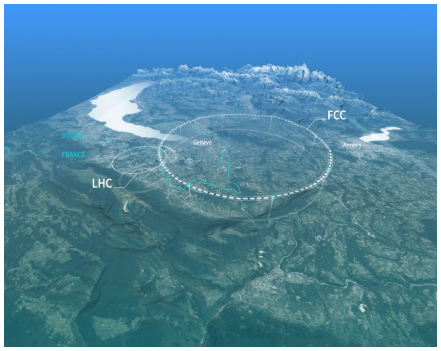
Planned Operational Date: ~ 2065 (following the FCC-ee).

Main Goal: To be the ***"Successor to the LHC"***. It will collide protons at a center-of-mass energy of 100 TeV (compared to the LHC's 14 TeV). Its primary objective is the direct discovery of new, massive particles and the detailed exploration of electroweak symmetry breaking.





Future Circular Collider (FCC)



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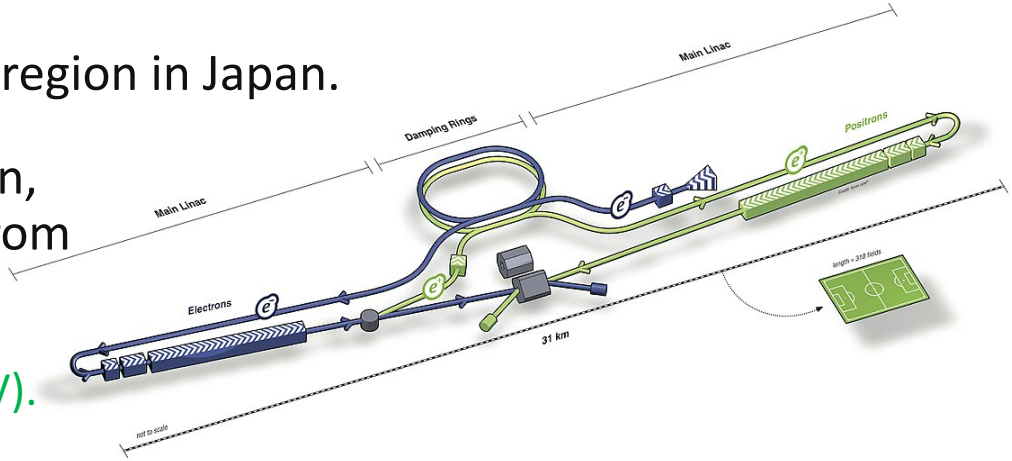
Detector: New, much more robust detectors will be required to handle the extreme conditions. Ultra radiation hard silicon trackers with very fine granularity. High granularity calorimeters capable of resolving complex jets and measuring energies with high precision. Large, robust muon chambers integrated into the magnet return yoke. AI driven, ultra fast electronics to handle enormous event rates. Real time selection of rare processes.

International Linear Collider

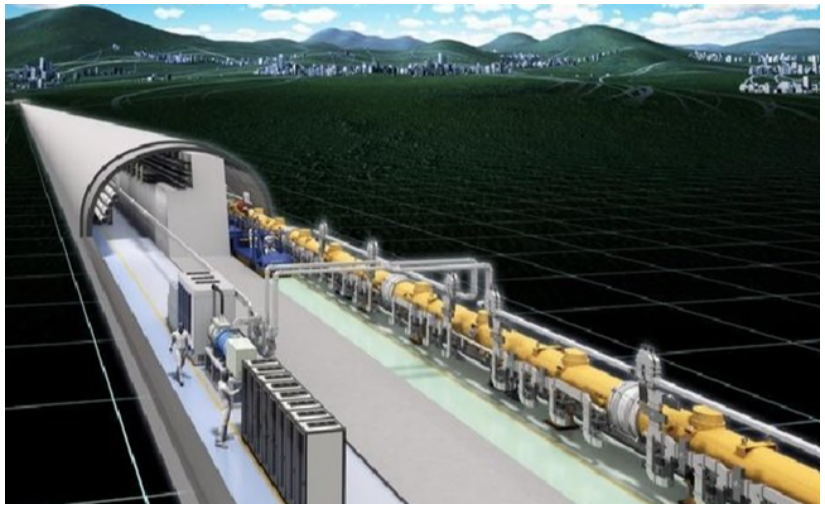
Location: Proposed for the Kitakami region in Japan.

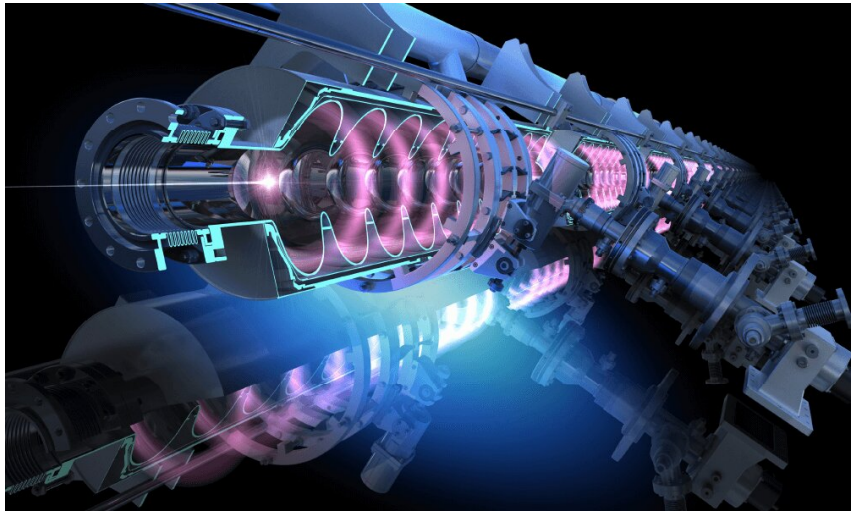
Planned Operational Date: Uncertain, pending a formal political decision from Japan. Could begin in the 2030s.



Energy: 250 GeV (upgradable to 500 GeV).

Main Goal: A precision "Higgs Factory." It would study the Higgs boson's properties with far greater precision than the LHC.





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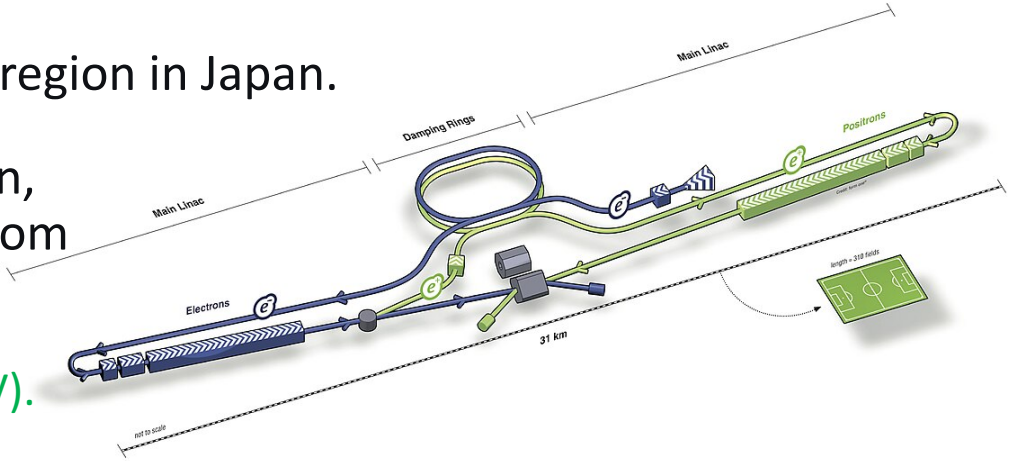


Main Goal: A precision "Higgs Factory." It would study the Higgs boson's properties with far greater precision than the LHC.

Detectors: Two detector concepts are proposed: the ILD (International Large Detector) and the SiD (Silicon Detector), both optimized for "particle flow" reconstruction in a clean electron – positron environment. Both concepts aim to maximize precision in Higgs and electroweak measurements.

Electron-Ion Collider (EIC)

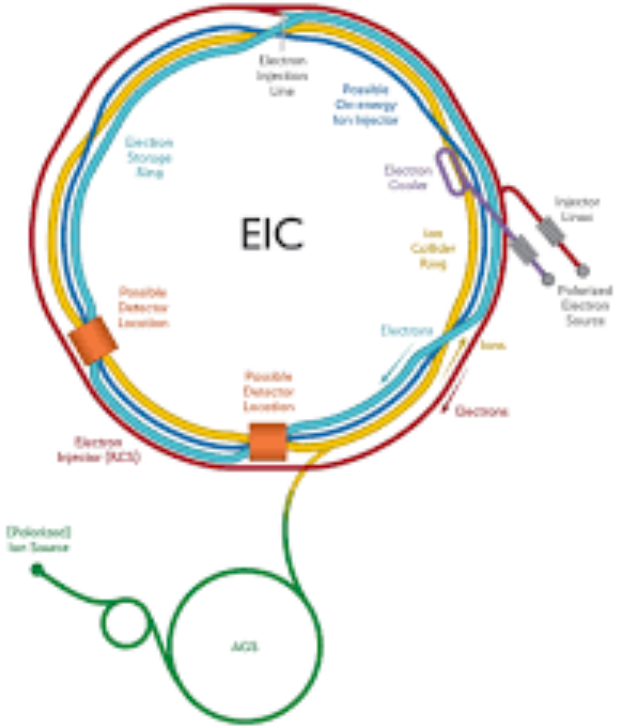
Location: Brookhaven National Laboratory (BNL), USA.

Type: Collider of electrons with protons or heavier ions.

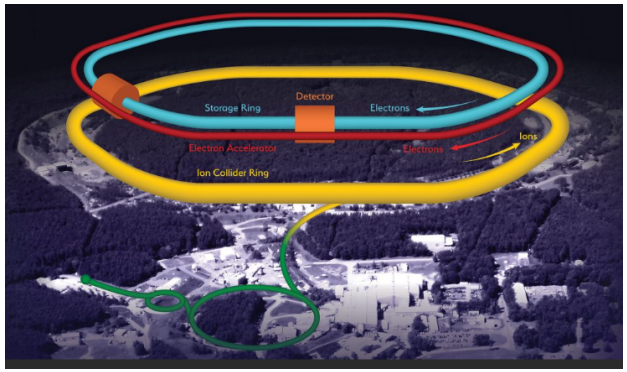
Planned Operational Date: Expected in the 2030s.

Main Goal: To precisely map the internal 3D structure of the proton and nuclei.

It is considered the "Hubble Telescope" for the study of the strong nuclear force.









Electron-Ion Collider (EIC)

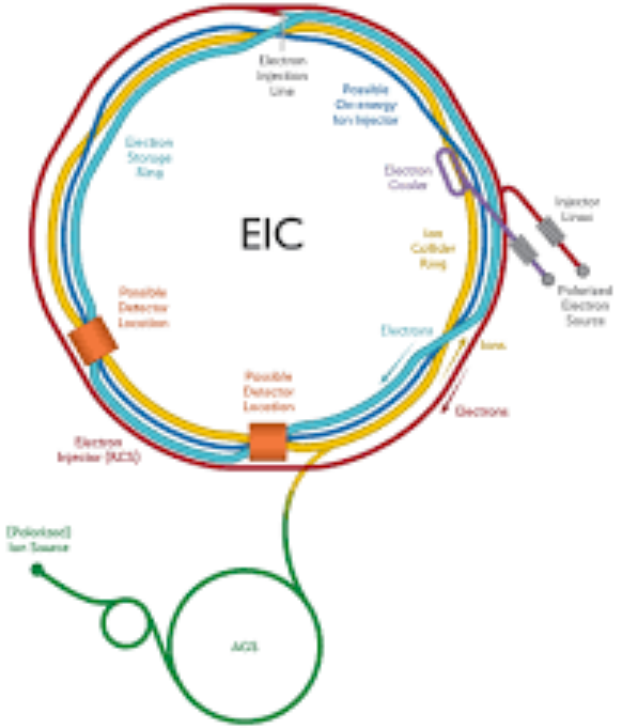
Location: Brookhaven National Laboratory (BNL), USA.

Type: Collider of electrons with protons or heavier ions.

Planned Operational Date: Expected in the **2030s**.

Main Goal: To precisely map the internal 3D structure of the proton and nuclei.

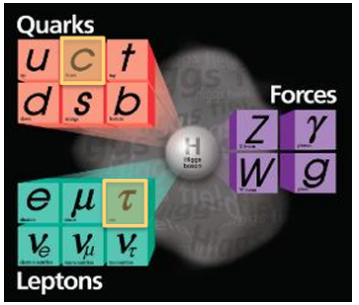
It is considered the "Hubble Telescope" for the study of the strong nuclear force.



Detectors: **State-of-the-art detector called ePIC, possessing a general-purpose 4π detector system, with advanced particle identification and tracking systems, designed to study the internal structure of protons and nuclei with high precision.**



Super Tau-Charm Facility (STCF)

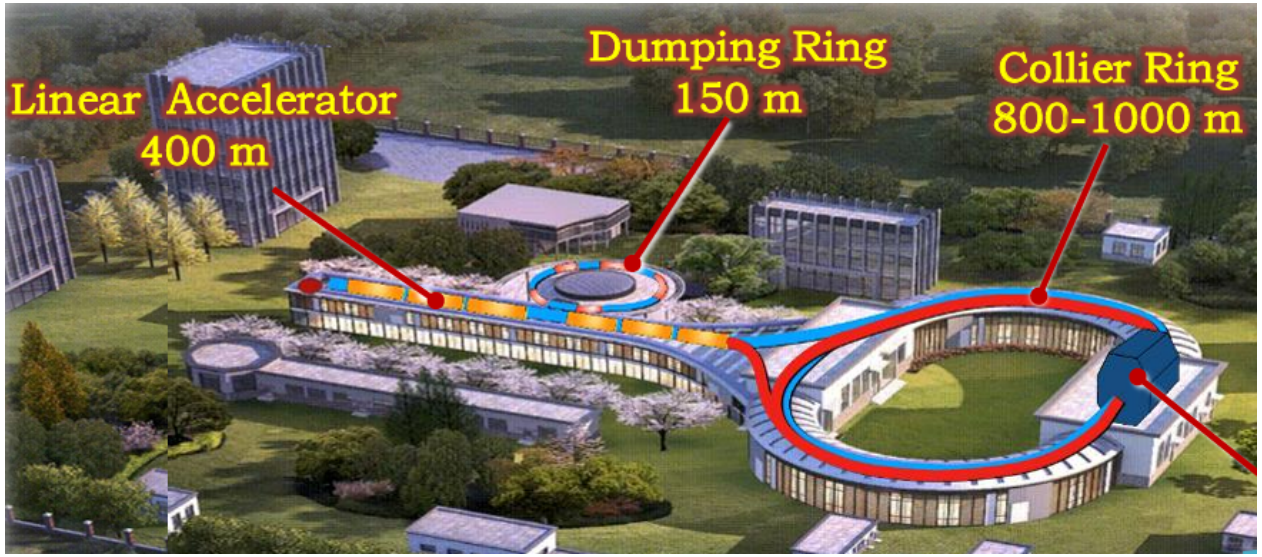


Location: Proposed in China.

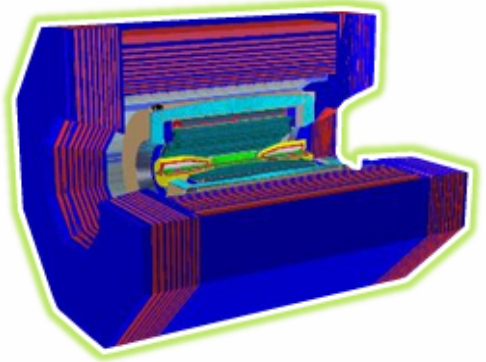
Type: Electron-positron collider.

Planned Operational Date: To be defined, possibly in the **2030s**.

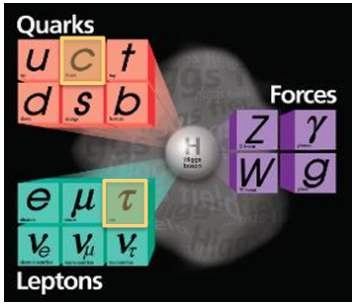
Main Goal: To produce enormous quantities of tau leptons and charm quarks to perform high-precision studies of CP violation and search for new physics in the lepton and charm sectors.







Super Tau-Charm Facility (STCF)



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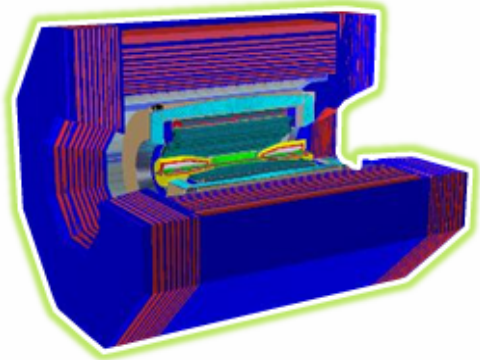
Type: Electron-positron collider.

Planned Operational Date: To be defined, possibly in the **2030s**.

Main Goal: To produce enormous quantities of tau leptons and charm quarks to perform high-precision studies of CP violation and search for new physics in the lepton and charm sectors.



Detectors: **a 4π general-purpose spectrometer optimized for precision studies in charm and tau physics. The planned subsystems include a silicon vertex detector, a central tracking system, electromagnetic calorimeters, time-of-flight detectors, and a muon detection system.**



Upgrades the LHC (CERN)

High-Luminosity LHC (HL-LHC) Project

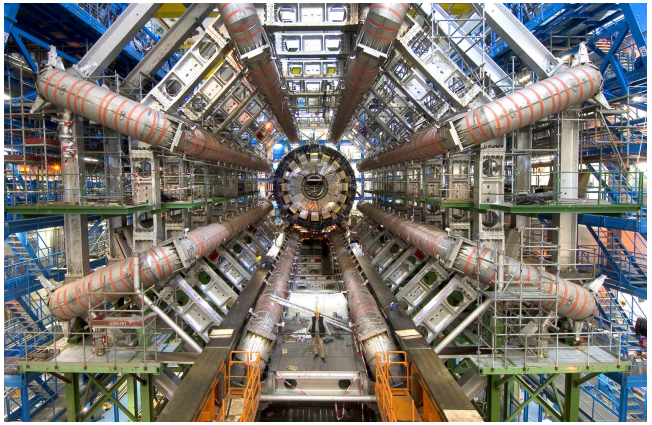


Location: CERN.

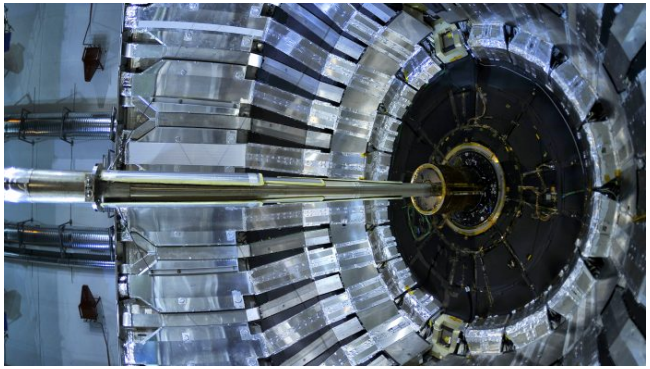
Planned Operational Date: ~2029 until ~2040.

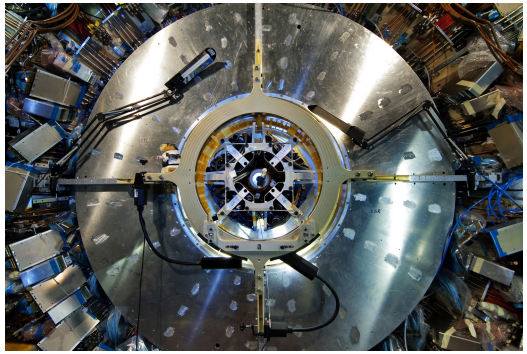
Main Goal: A major upgrade of the LHC accelerator and its experiments to increase the integrated luminosity by a factor of 10.

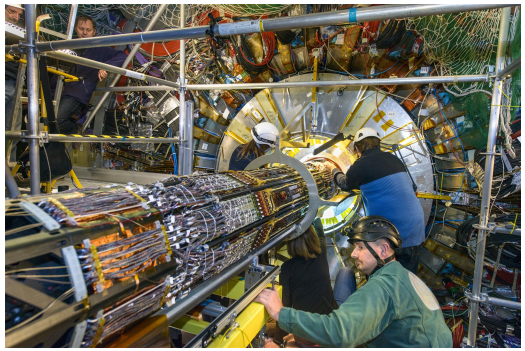
Detector upgrades:



ATLAS and CMS: Major upgrades including new all-silicon inner trackers, improved calorimeters, and new timing detectors to handle the challenging high-pileup environment.







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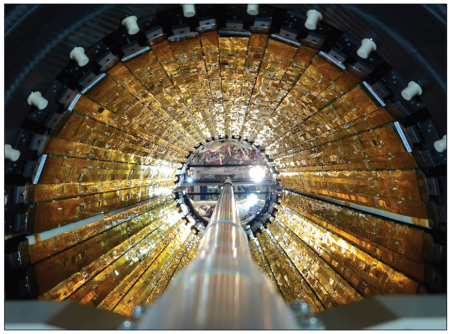
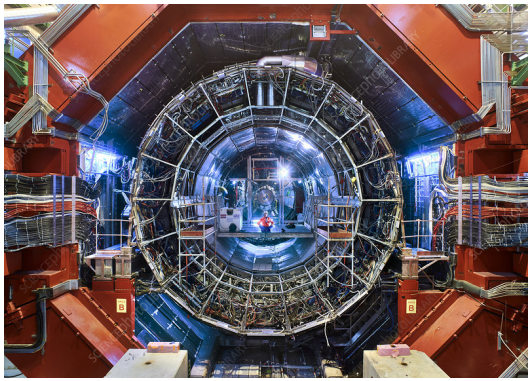
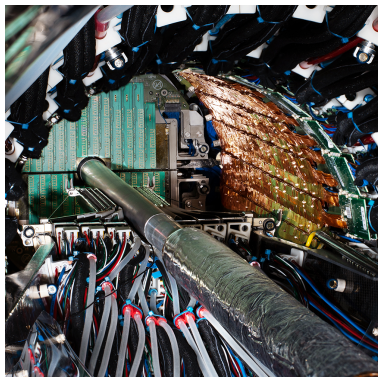


ALICE: Upgrades its innermost silicon tracker for ultra-precise vertexing and adding a new forward calorimeter to detect photons at small angles—together opening new windows into the quark–gluon plasma and the structure of matter at extreme densities.





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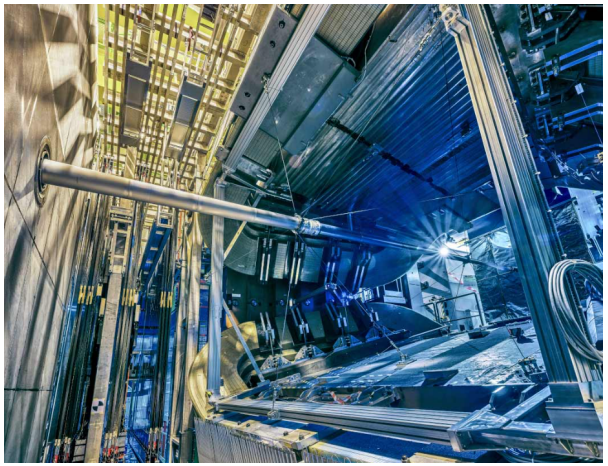
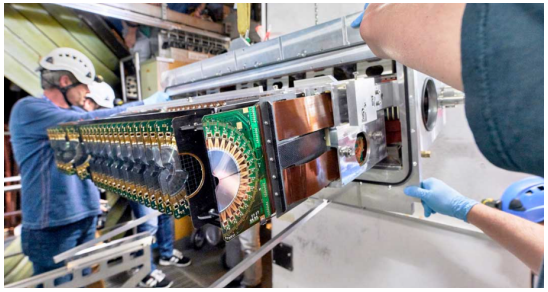
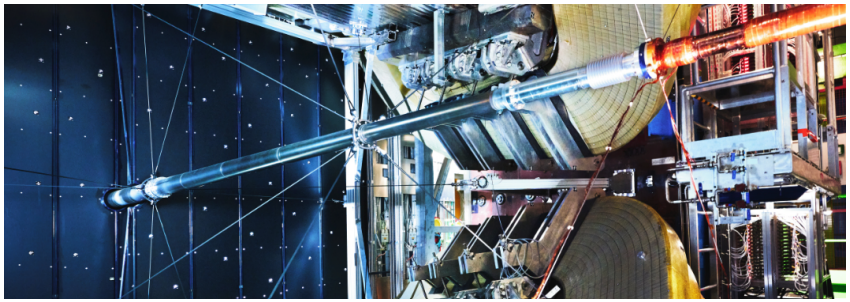
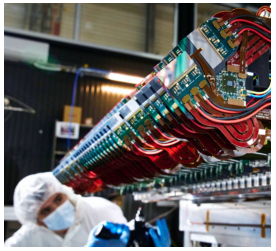


LHCb: A complete transformation into a triggerless, real-time analysis system, increasing its recorded collision rate by a factor of 50. LHCb is upgrading its vertex, calorimeter, and Cherenkov systems, along with faster electronics, so it can continue to lead in flavor physics during the High-Luminosity LHC era.







THANK YOU!!!

Disclaimer: The images presented herein are primarily taken from publicly accessible online reports, especially from the official websites of the respective experiments. Only a limited number are original photographs or video recordings captured by the author.