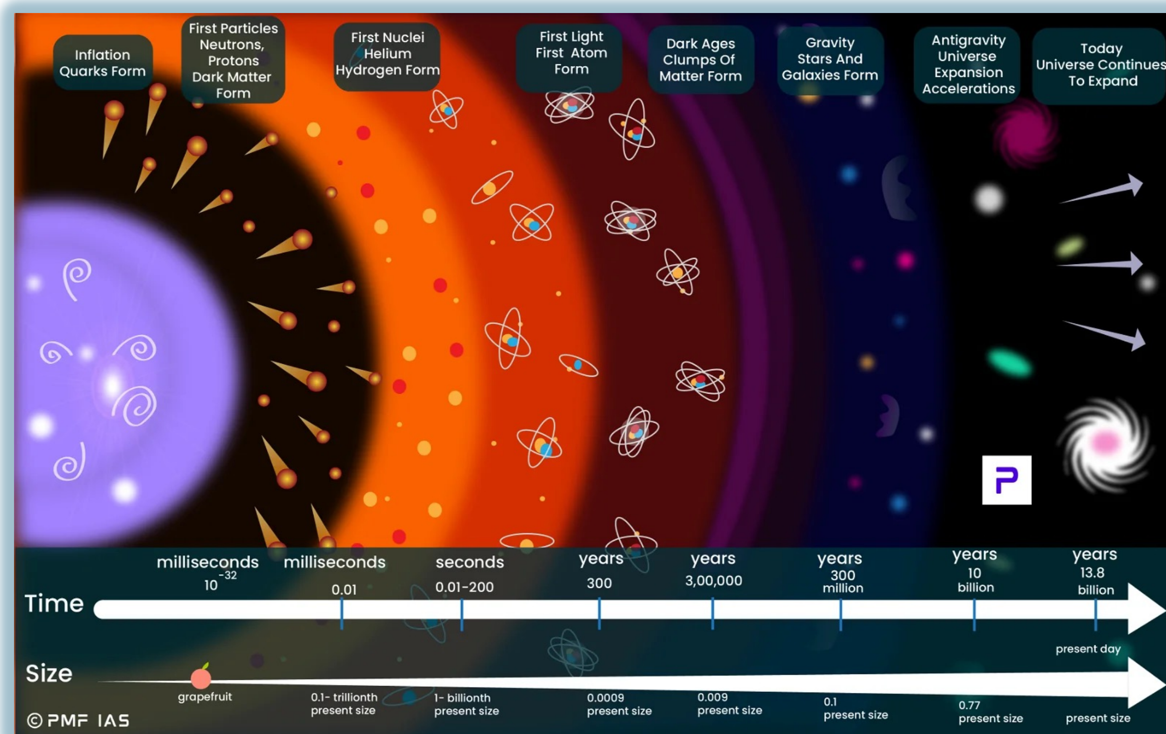
The Belle II Experiment

Dr. Seema Choudhury

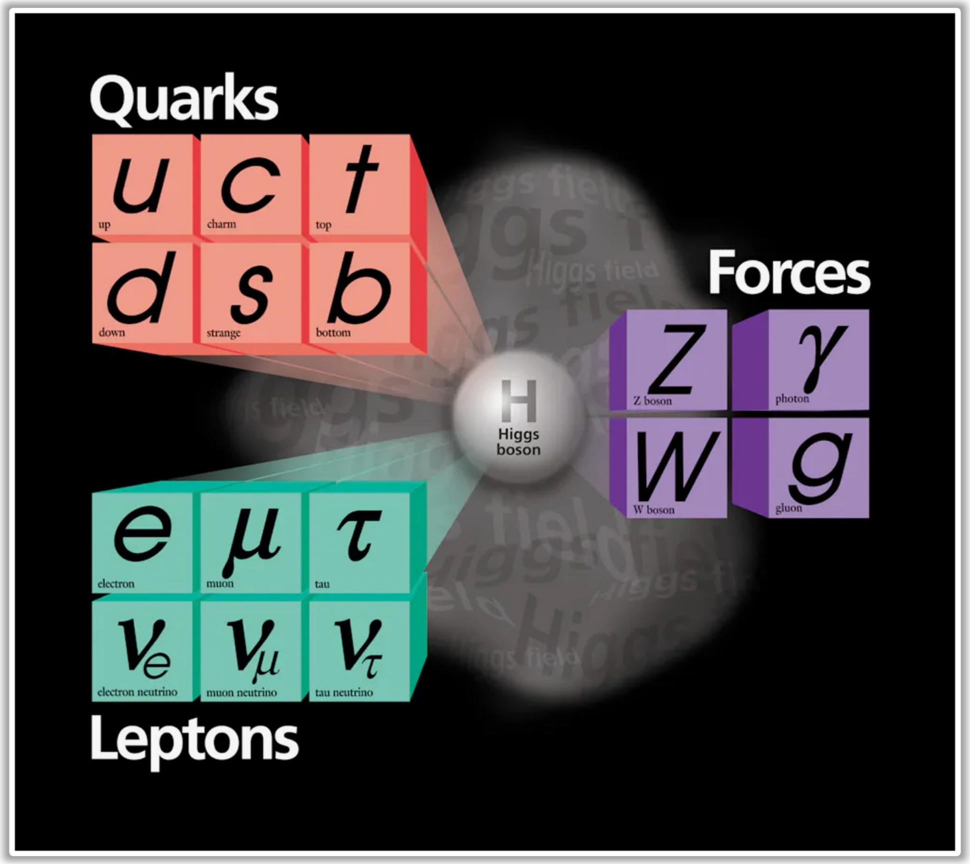
Iowa State University

Birth of the Universe

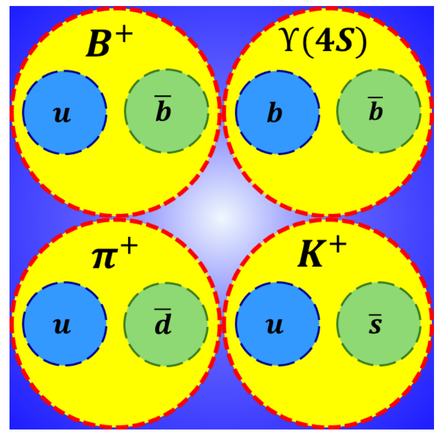
- ✓ The early universe was hot and filled with high-energy particles
- ✓ After the Big Bang exploded with enormous energy, the universe began to cool down
- ✓ But what made Big Bang happen in the first place? We don't know…
- ✓ To understand what the Universe was like during those initial moments, scientists use particle accelerators
- ✓ To detect and record particles resulting from accelerator collisions, we use detectors, ex: Belle II
- ✓ Unravel the mysteries of the subatomic world



Standard Model (SM) of Particle Physics



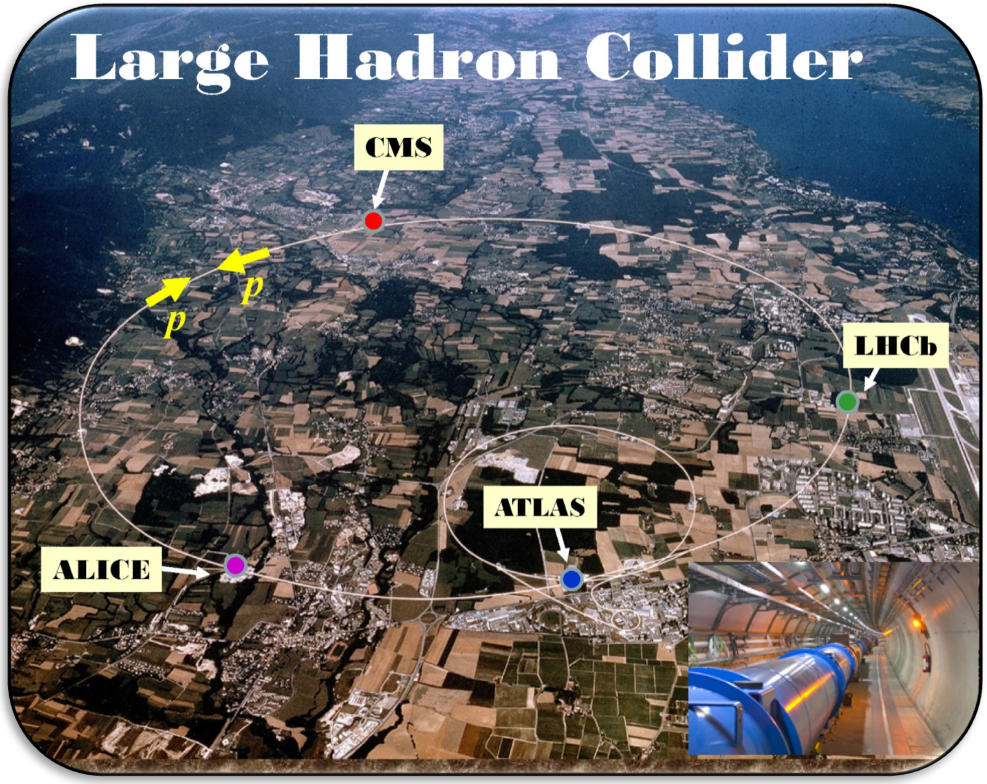
- ✓ Includes matter particles (quarks and leptons), force carriers (gauge bosons), and Higgs boson
- ✓ Describes the fundamental particles and their interactions

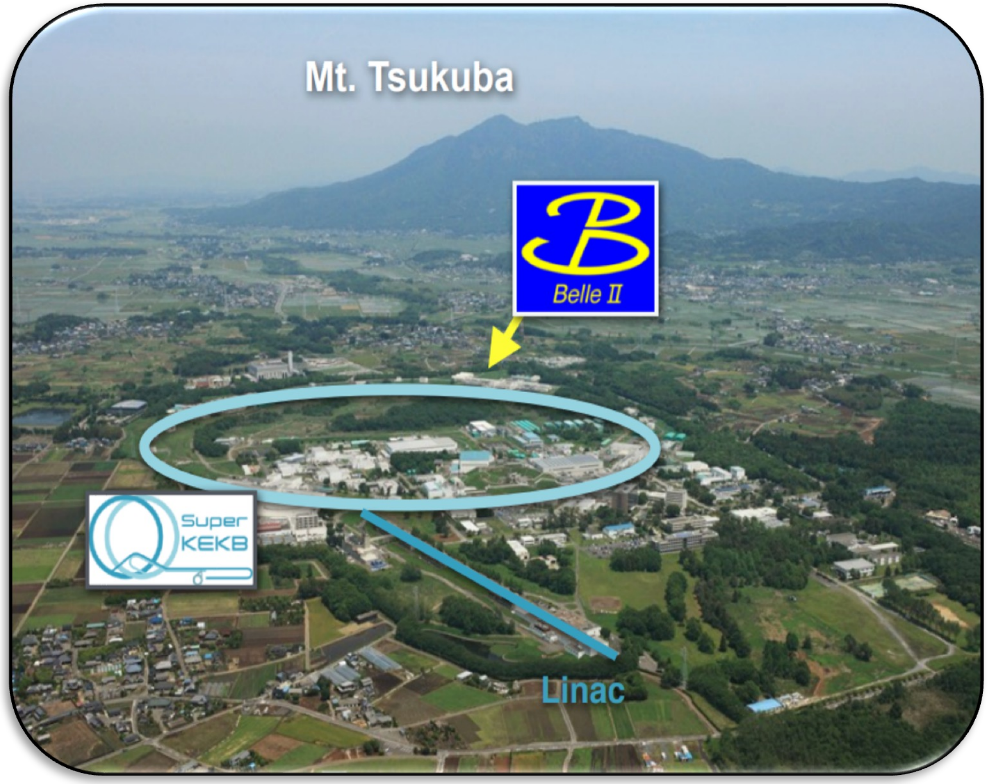


- ✓ Remain Unexplained:
  - ✓ Matter-antimatter asymmetry
  - ✓ Neutrino mass
  - ✓ Dark matter, Dark energy
  - ✓ Unknown origin of generations/flavors

- ✓ **New Physics beyond the SM?**

Particle Physics Experiments



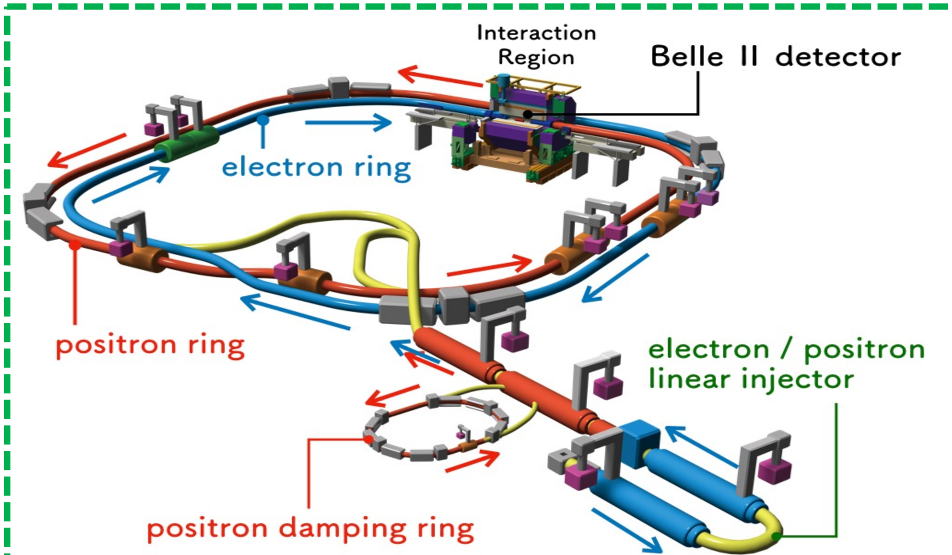


Belle II Experiment:
SuperKEKB Accelerator and Belle II detector

SuperKEKB Accelerator

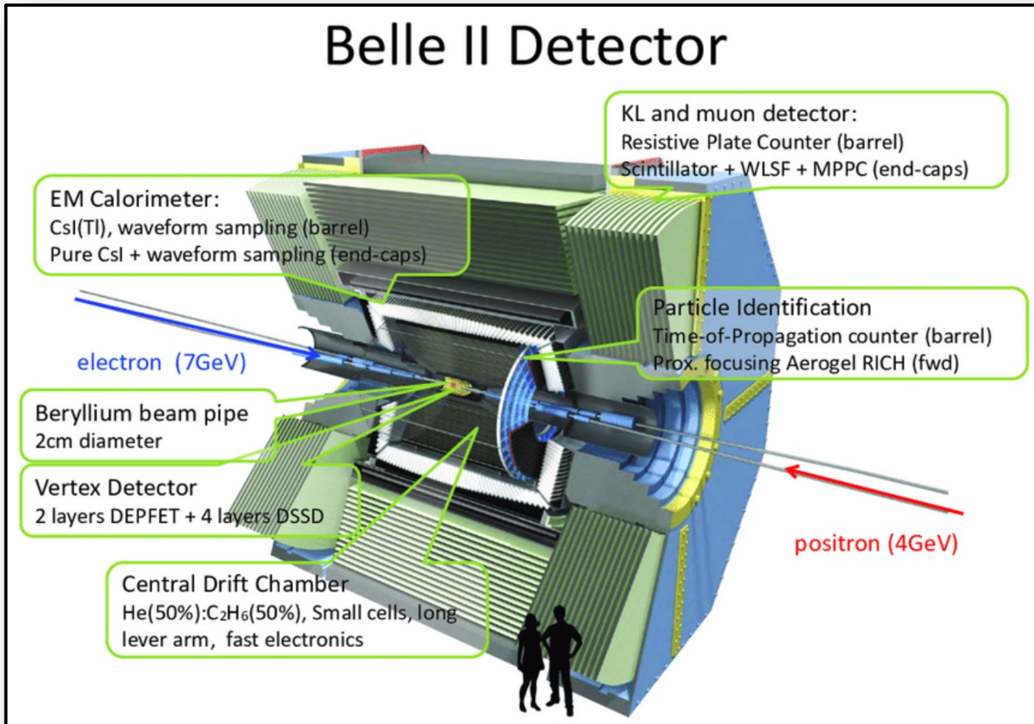
- ✓ Situated at High Energy Accelerator Research Organization (KEK), Japan
- ✓ SuperKEKB is a circular collider with a circumference of ~3 km
- ✓ Asymmetric energy electron (7 GeV) - positron (4 GeV) collider at CM energy close to Υ(4S) resonance

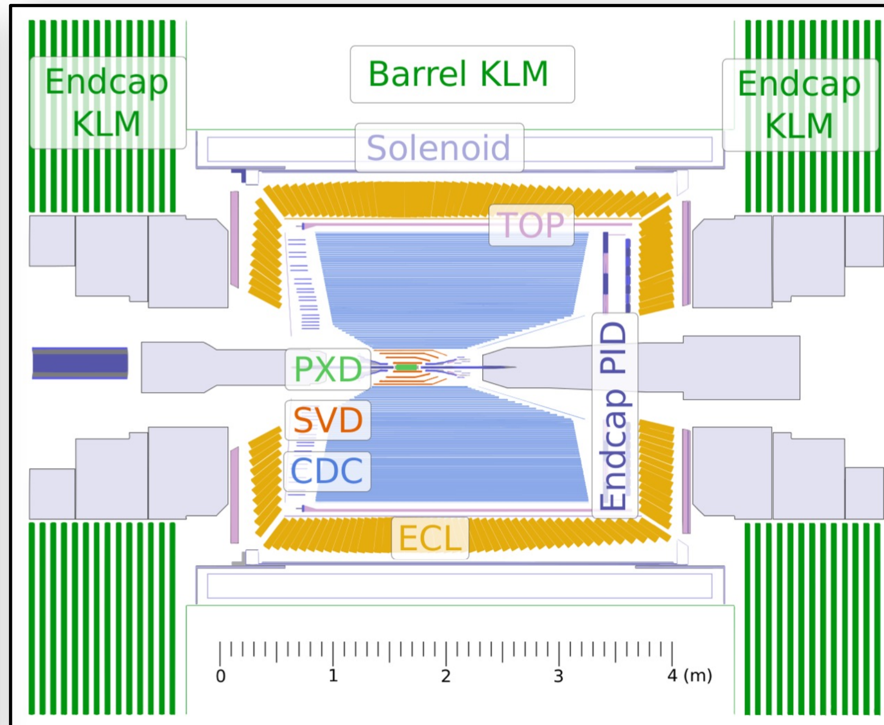
- ✓ Create conditions similar to those right after the Big Bang by slamming electron-positron together at nearly the speed of light, releasing high energy particles
- ✓ These extreme conditions allow scientists to study the fundamental particles and forces that shaped the Universe



SuperKEKB Accelerator

Belle II Detector





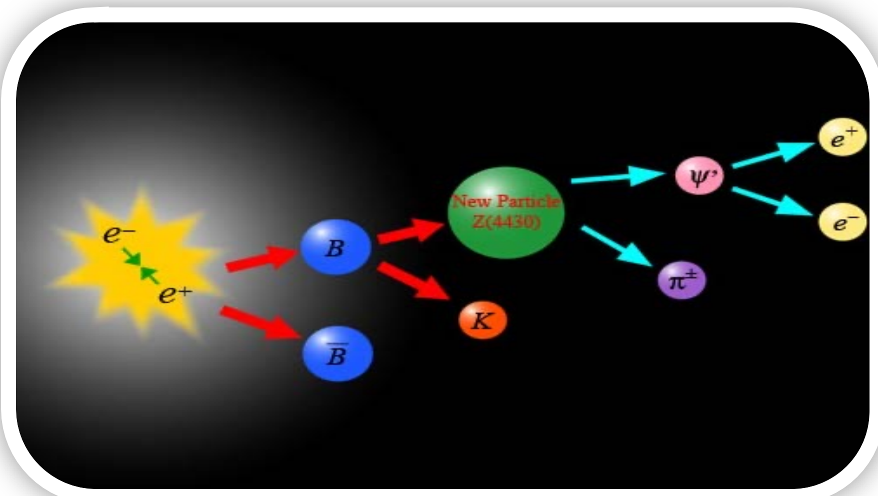
- ✓ Surrounds the collision point of the SuperKEKB accelerator
- ✓ Goal is to measure the trajectories, energies, and momenta of particles produced from electron-positron collisions

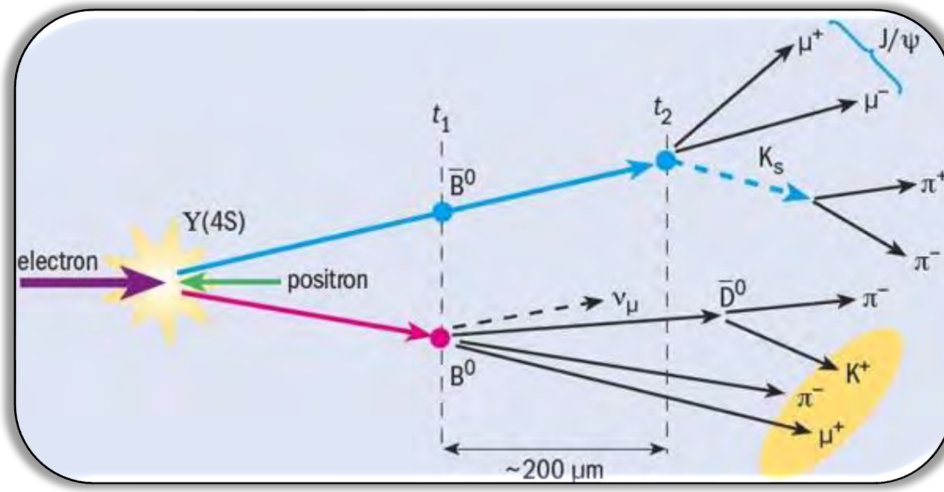
How the Belle II Detector works …

Electron-Positron Collision

Motivation for Belle II experiment

- ✓ To study the properties of *B* mesons and other particles
- ✓ Understand matter-antimatter asymmetry of the universe with precise measurement of *CP*-violation parameters
- ✓ Discover new fundamental particles that complete the SM at high energy or set stringent constraints on their dynamics





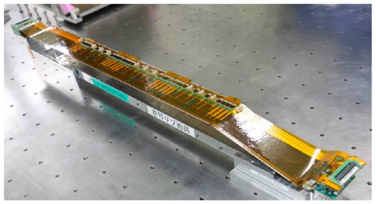
- ✓ Final state mesons like π^+, K^+, p^+ composed of quarks, in addition to *e*- and $\mu-$ can be identified in the Belle II detector
- ✓ Energy deposit by γ and K_L

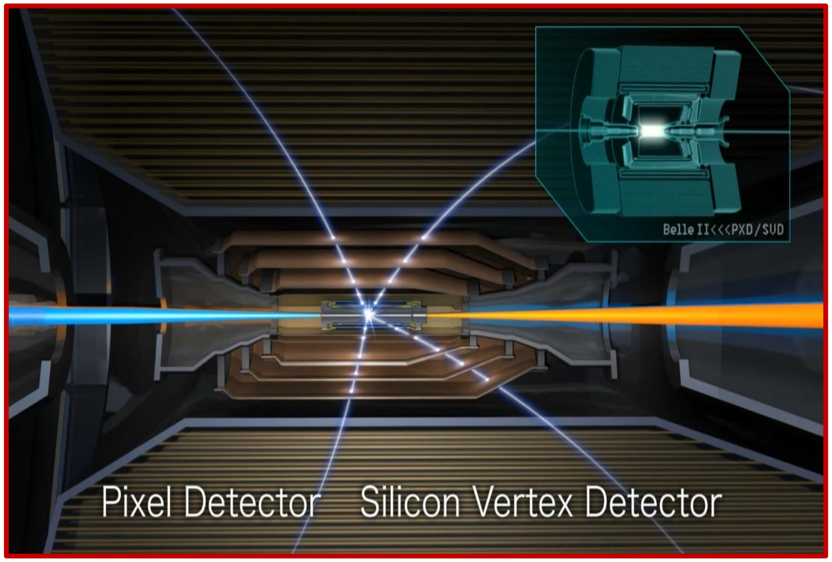
Vertex Detectors: PXD & SVD

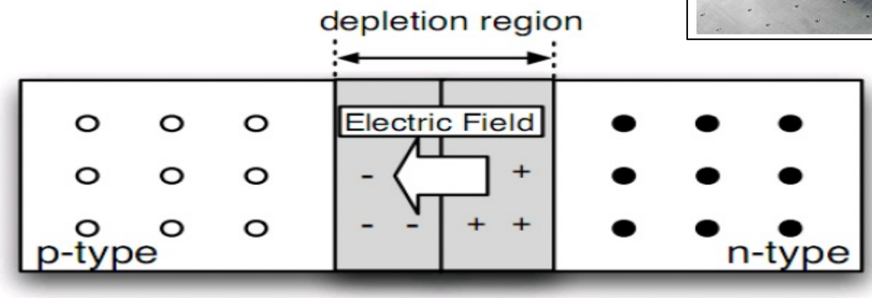
- ✓ Essential for precise decay vertex measurements
- ✓ Vertex detector (VXD) consists of
  - ✓ Pixel detector (PXD): 2 layers
  - ✓ Strip detector (SVD): 4 layers
- ✓ PXD and SVD have silicon sensors

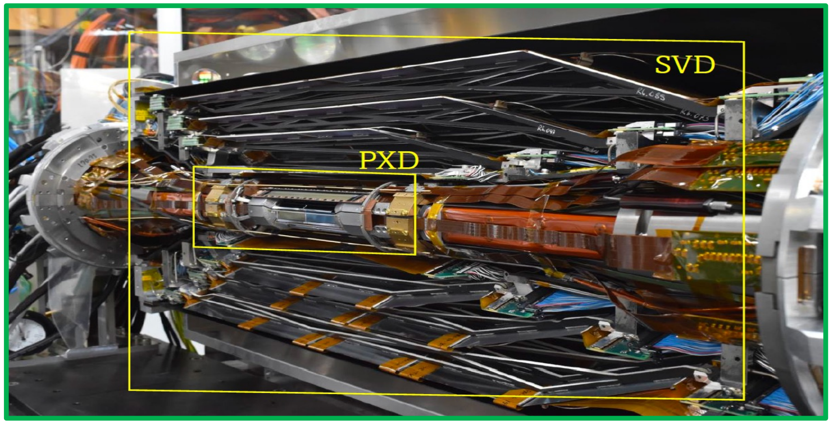
PXD sensor

SVD sensor



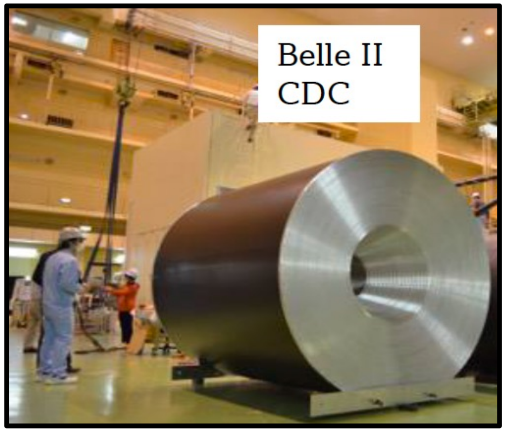


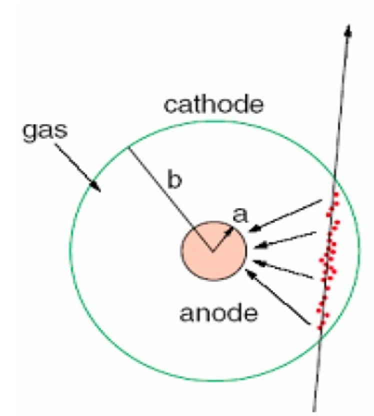


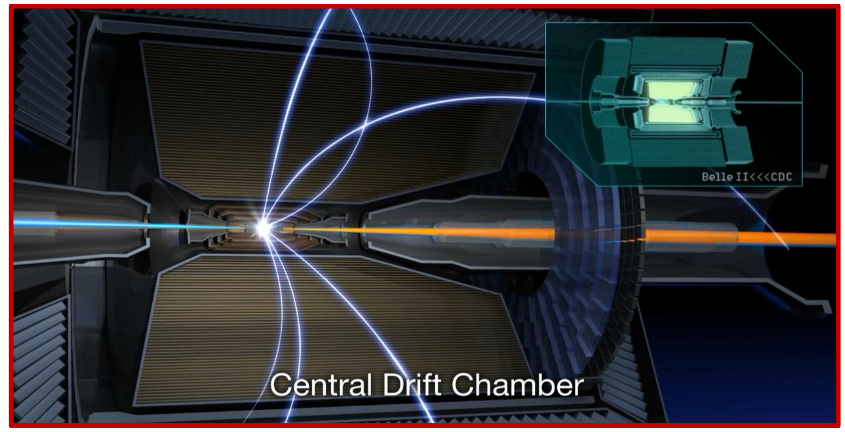


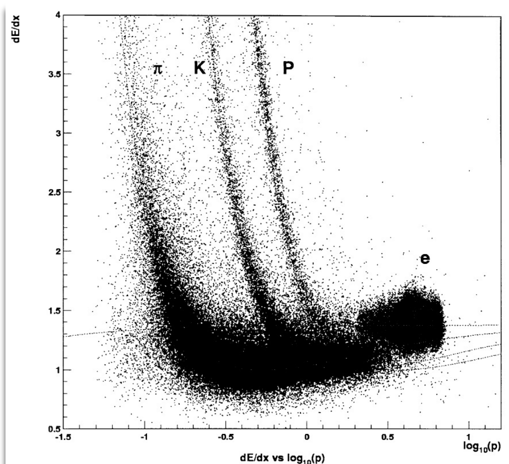
- ✓ Depleted region around p-n junction when bias voltage is applied
- ✓ When charged particles pass through the depleted region, electron-hole pairs are generated

Tracking System: CDC





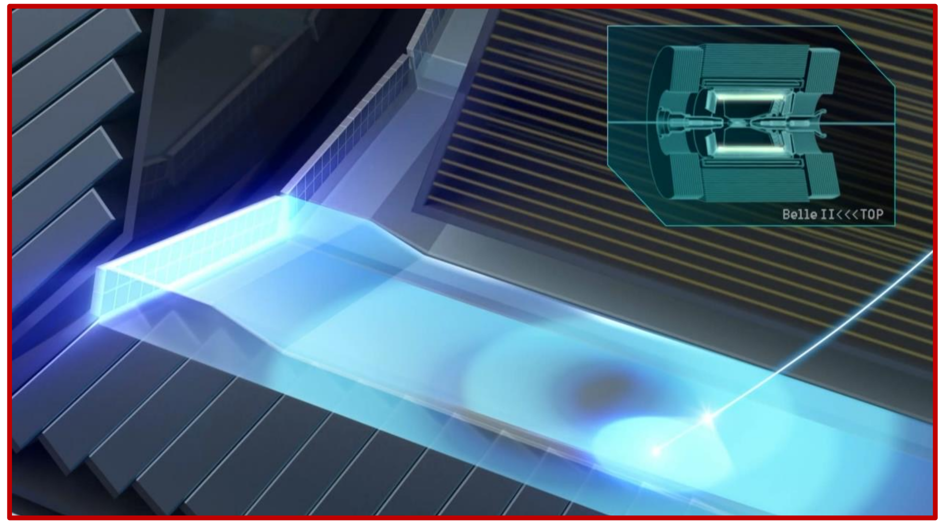


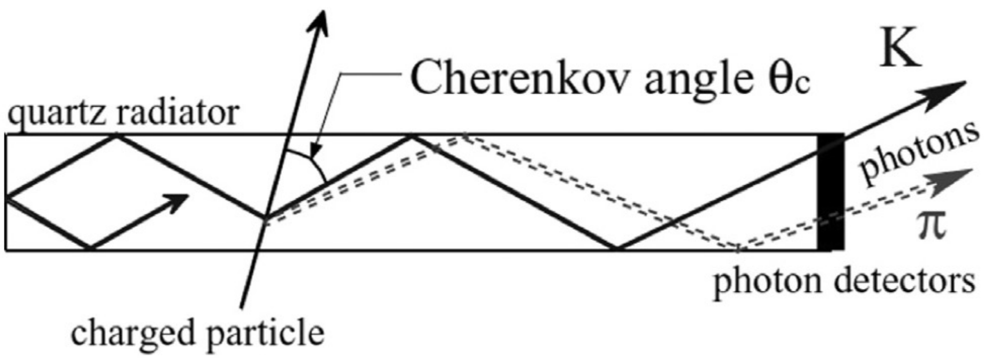


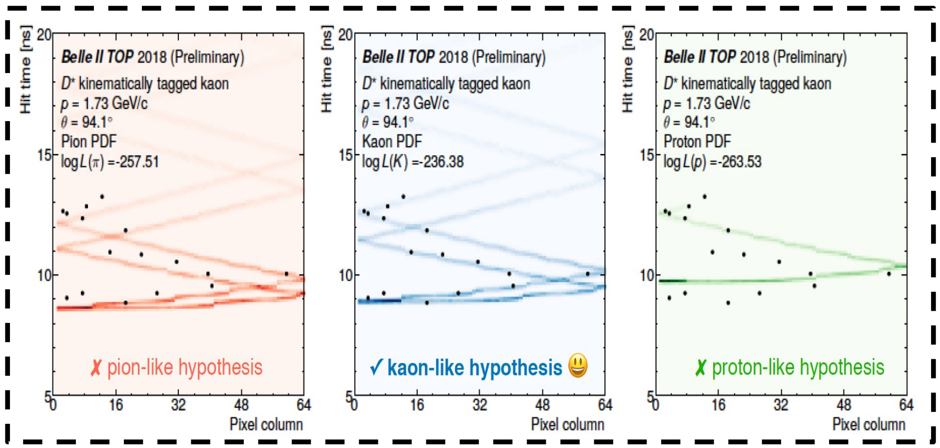
- ✓ Measure the charged particle's trajectory, momenta, and energy loss
- ✓ CDC chamber is filled with the gas mixture of He and ethane
- ✓ Charged particles passing the chamber ionize the gas molecules into ions and electrons
- ✓ Generated electrons are accelerated toward the vicinity of the anode wires, where gas amplification causes signal propagation
- ✓ Accurate position of the track can be obtained from the drift time of electrons
- ✓ Due to strong magnetic field, charged particles curve according to their momentum
- ✓ Particle identification using dE/dx

Particle Identification System: TOP

- ✓ Particle identification in the barrel, mainly kaon and pion
- ✓ TOP consists of quartz bars connected with PMTs
- ✓ When a charged particle passes through a transparent medium at a speed greater than the speed of light in that medium, it produces Cherenkov light
- ✓ Same momentum pion and kaon will have different velocities, and hence the angle of Cherenkov photons and propagation time
- ✓ Cherenkov lights emitted by kaon and pion go total internal reflection inside quartz bars before being detected by PMTs

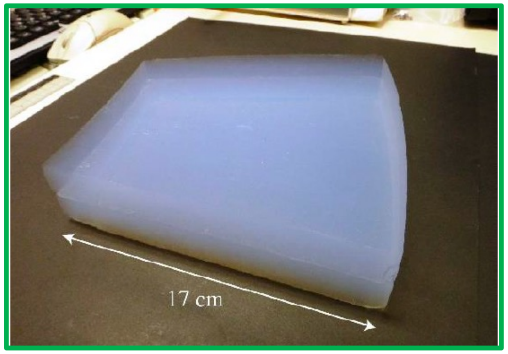


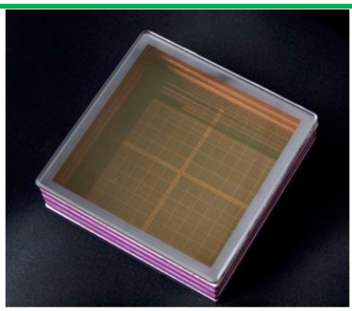




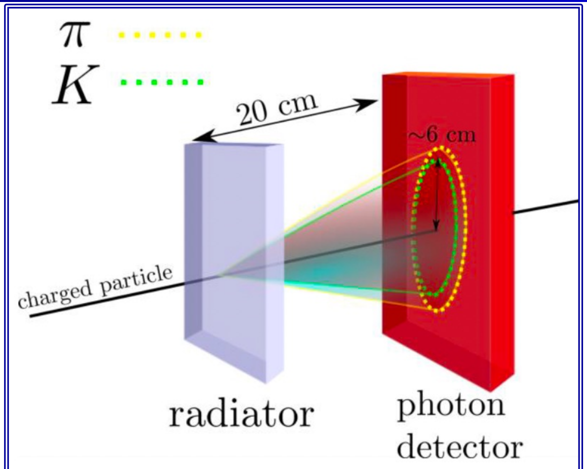
Particle Identification System: ARICH

- ✓ Particle Identification
- ✓ Provide kaon-pion separation
- ✓ On the forward side of the detector



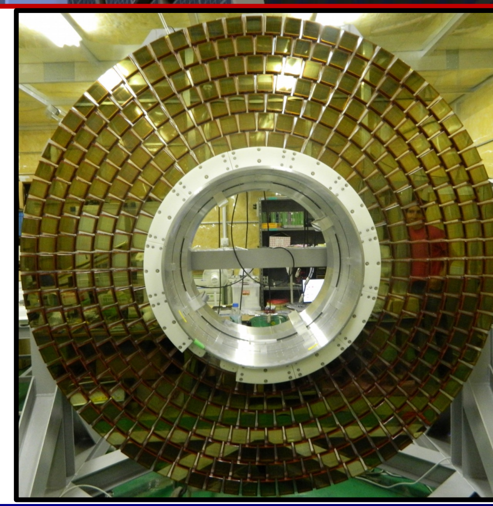


Hybrid Avalanche Photo-Detector



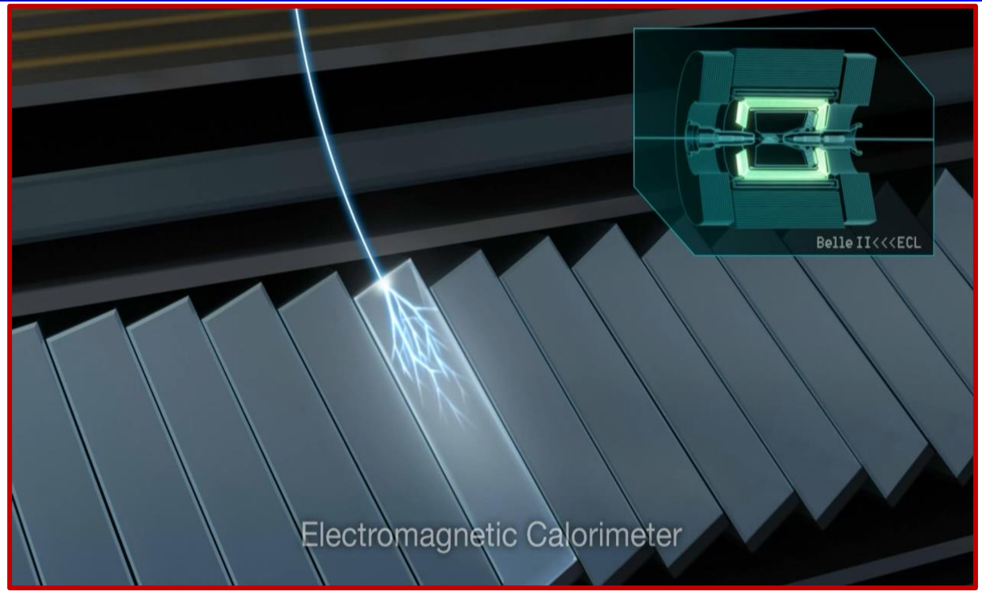
pions and kaons of equal momenta

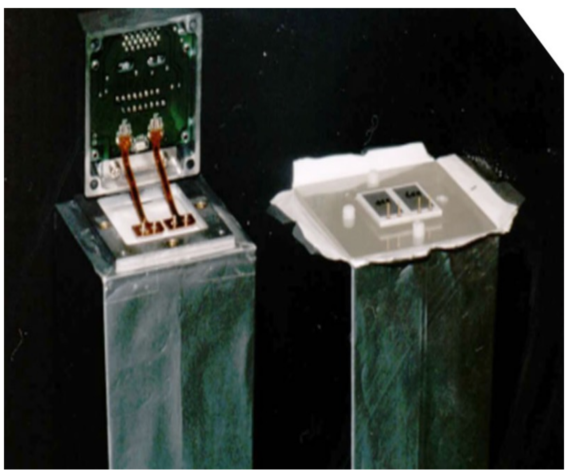
- ✓ Radiator consists of two layers of wedge-shaped aerogel tiles with different refractive indices: better focusing on the detector plane
- ✓ Cherenkov photons are emitted, forming a cone of Cherenkov light, when a charged particle of sufficient velocity passes through the aerogel
- ✓ Photos are detected using HAPD (Hybrid avalanche photon detector): very sensitive for photon detection

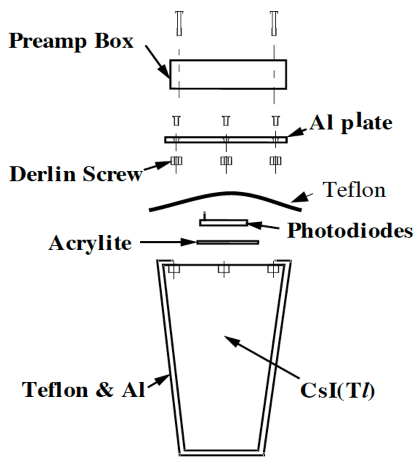


Electromagnetic Calorimeter: ECL

- ✓ ECL to measure the energy of electromagnetically interacting particles such as electrons and photons
- ✓ Distinguish electrons from muons: electron will stop in ECL, while muon will continue
- ✓ Electron identification relies on charge particle momentum and energy deposit in ECL
- ✓ In the barrel and endcap of the detector



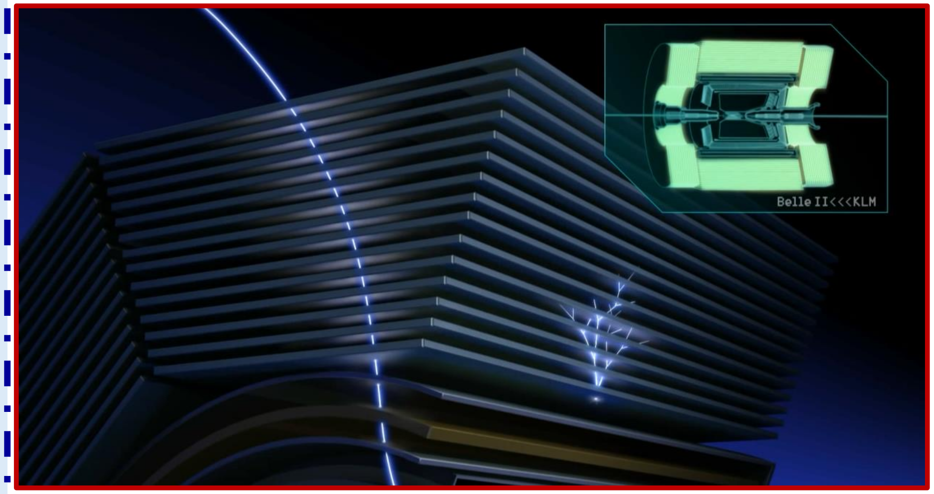


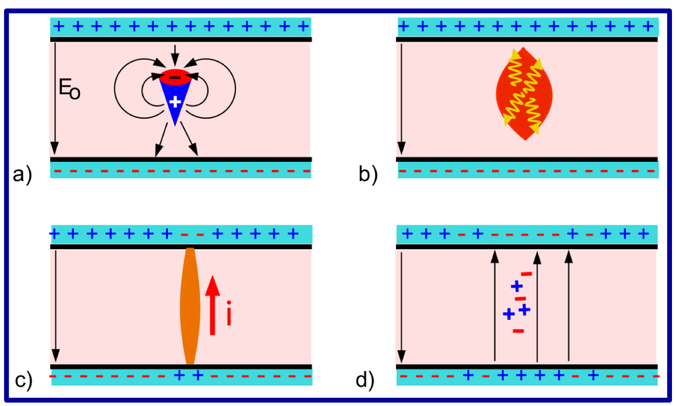


- ✓ ECL consists of thallium-doped CsI crystals with PIN-photodiode readout
- ✓ CsI(Tl) crystals create scintillation light when a particle flies into them
- ✓ Amount of light is proportional to the energy deposited in the crystal: can measure the energy of the the particle

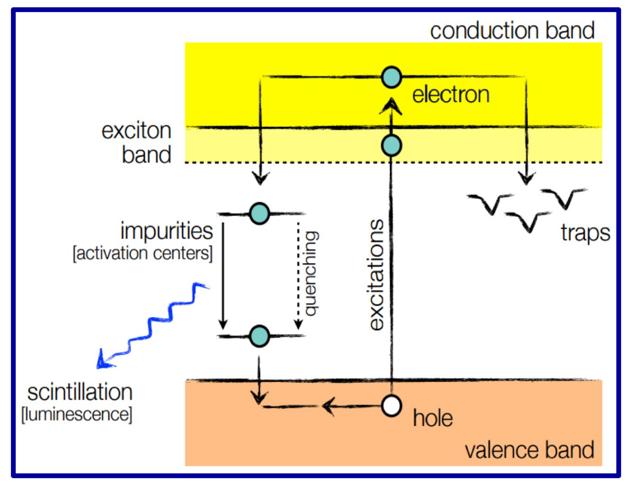
K_L and muon Identification System: KLM

- ✓ Identify particles that are undetected by inner detectors, i.e., muon and K_L (long-lived kaons)
- ✓ Covers barrel as well as endcap region of the detector
  - ➢ Barrel region: Scintillators (2 layers) + RPCs (13 layers)
  - ➢ Endcap region: Scintillators
- ✓ Multi-layer sandwich of Fe and active detector layers
- ✓ RPCs: Two parallel electrodes with a gas gap
- ✓ Scintillators: Plastic scintillator strips with silicon photomultiplier

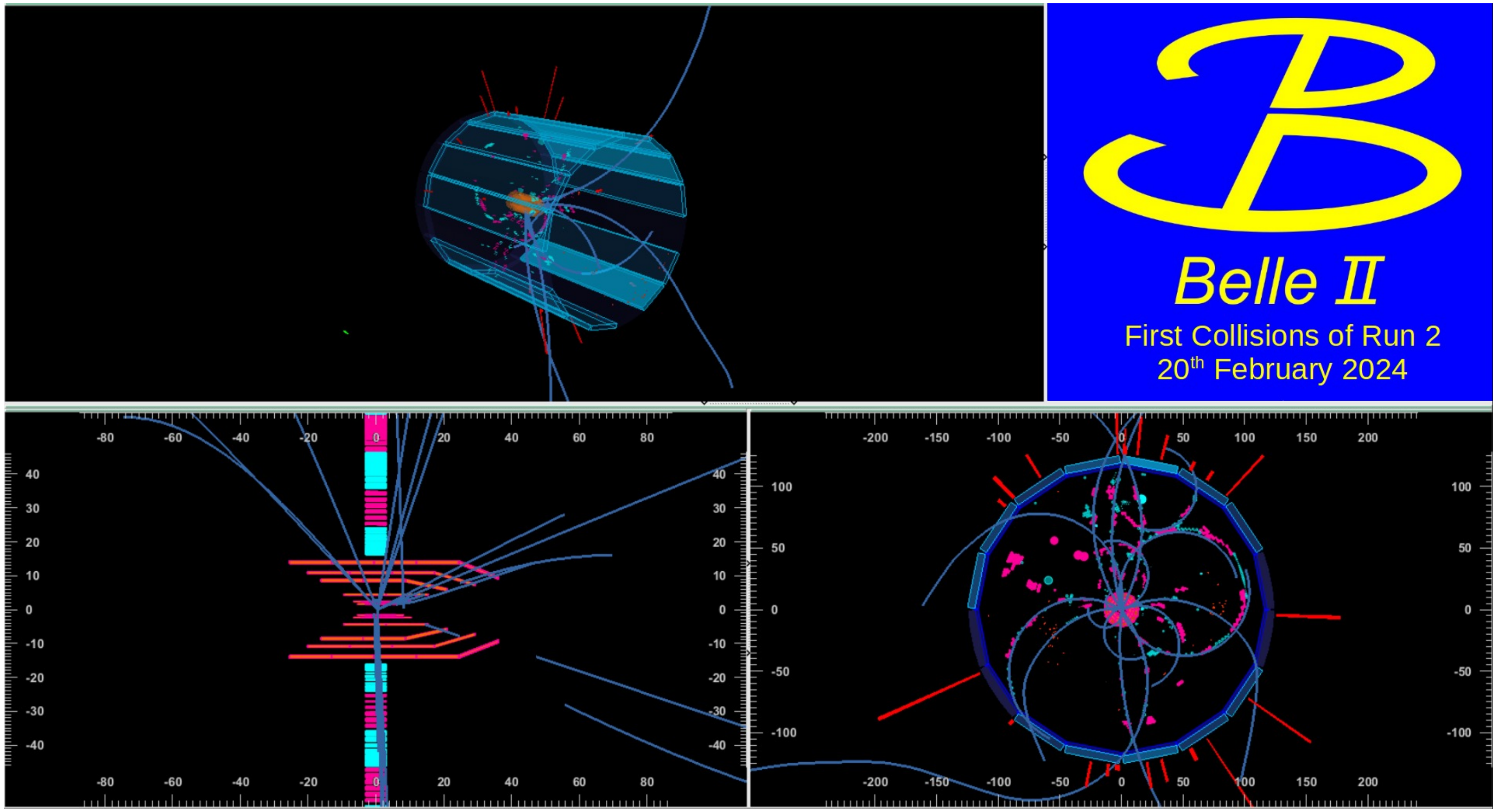




- ✓ In RPCs, charged particles ionize the gas, creating ions and electrons and hence avalanche charge carriers due to potential
- ✓ In scintillators, charged particles excite electrons into higher energy bands, and during quenching and de-excitation, generated photons

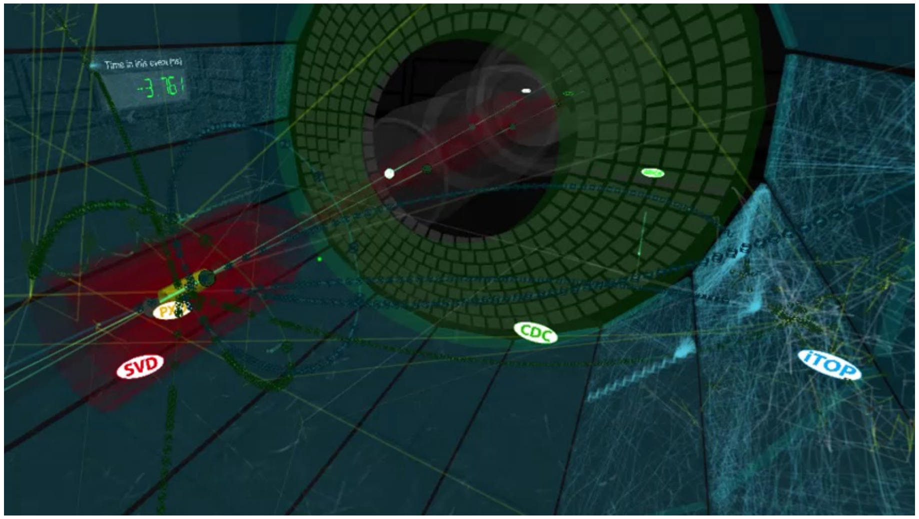


Belle II Event Display



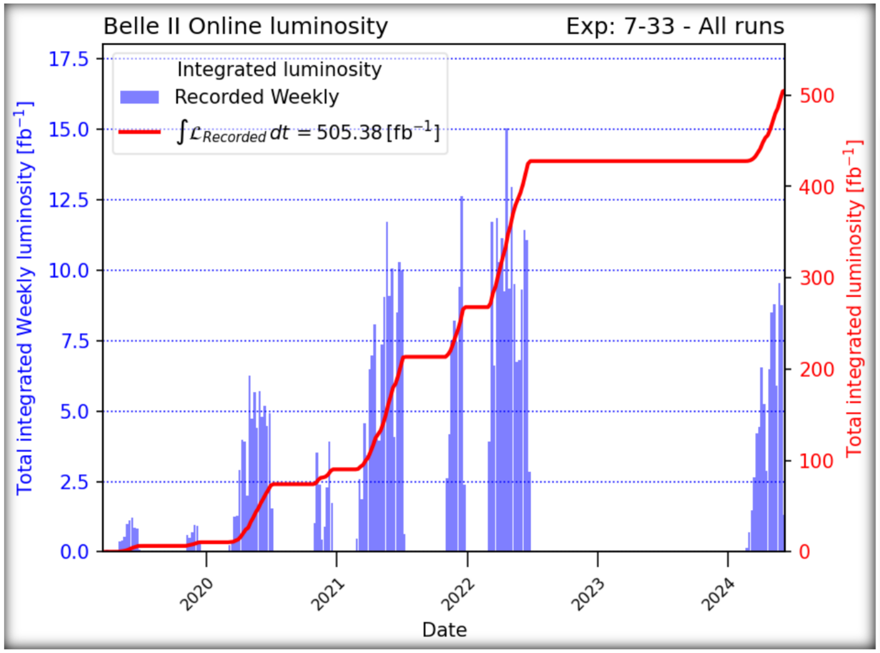
Belle II online event display: https://evdisp.belle2.org

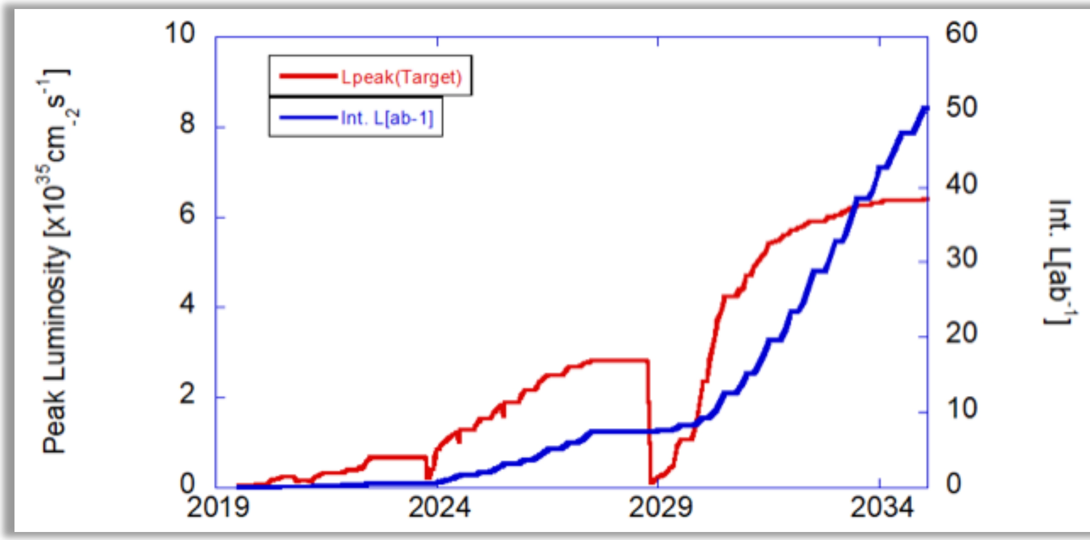
Belle II Virtual Reality



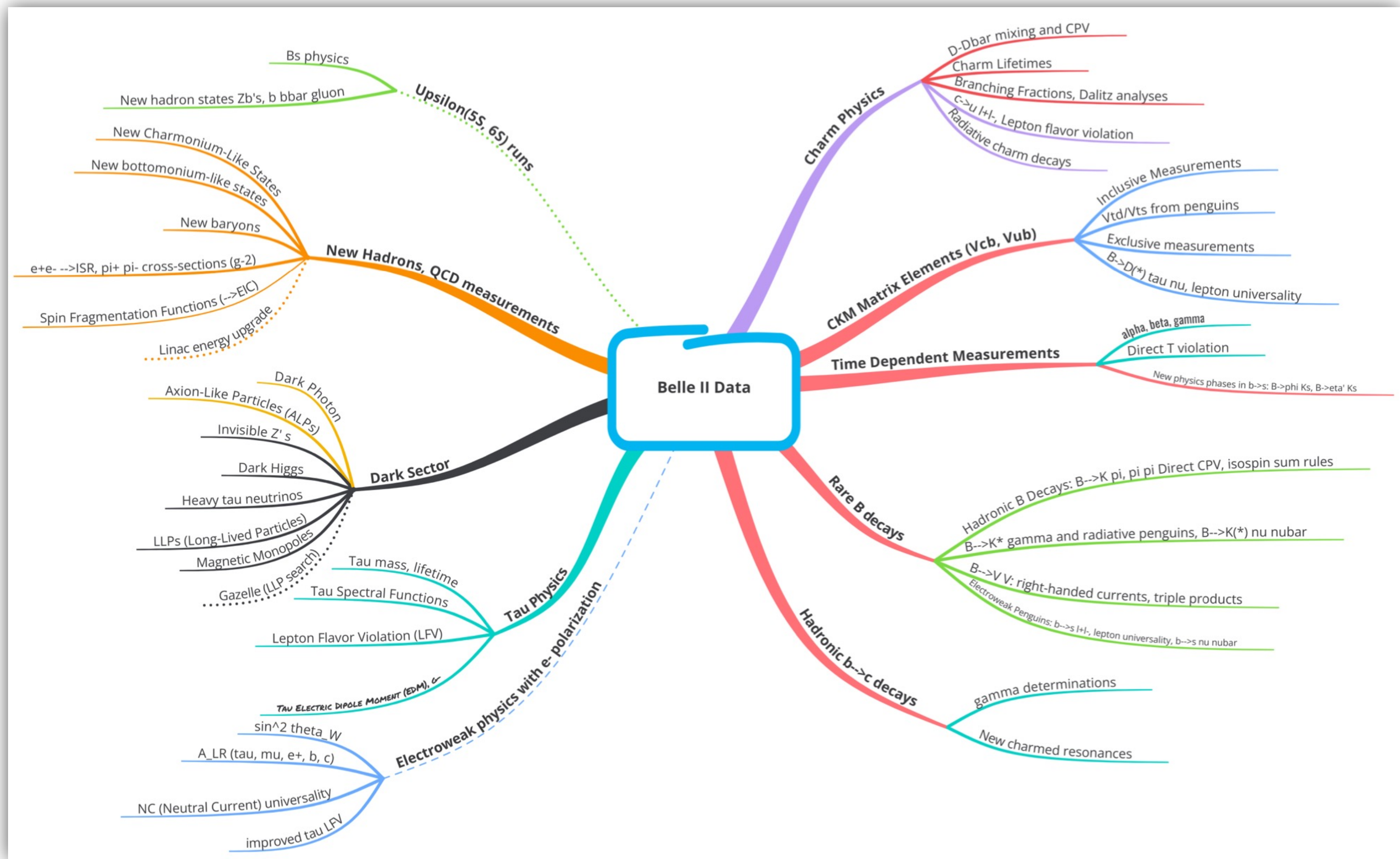
Belle II Luminosity

- ✓ Luminosity: Rate at which the particles collide, resulting in data that physicists can analyze
- ✓ More luminosity = more frequent collisions = more data for particle physicist to study

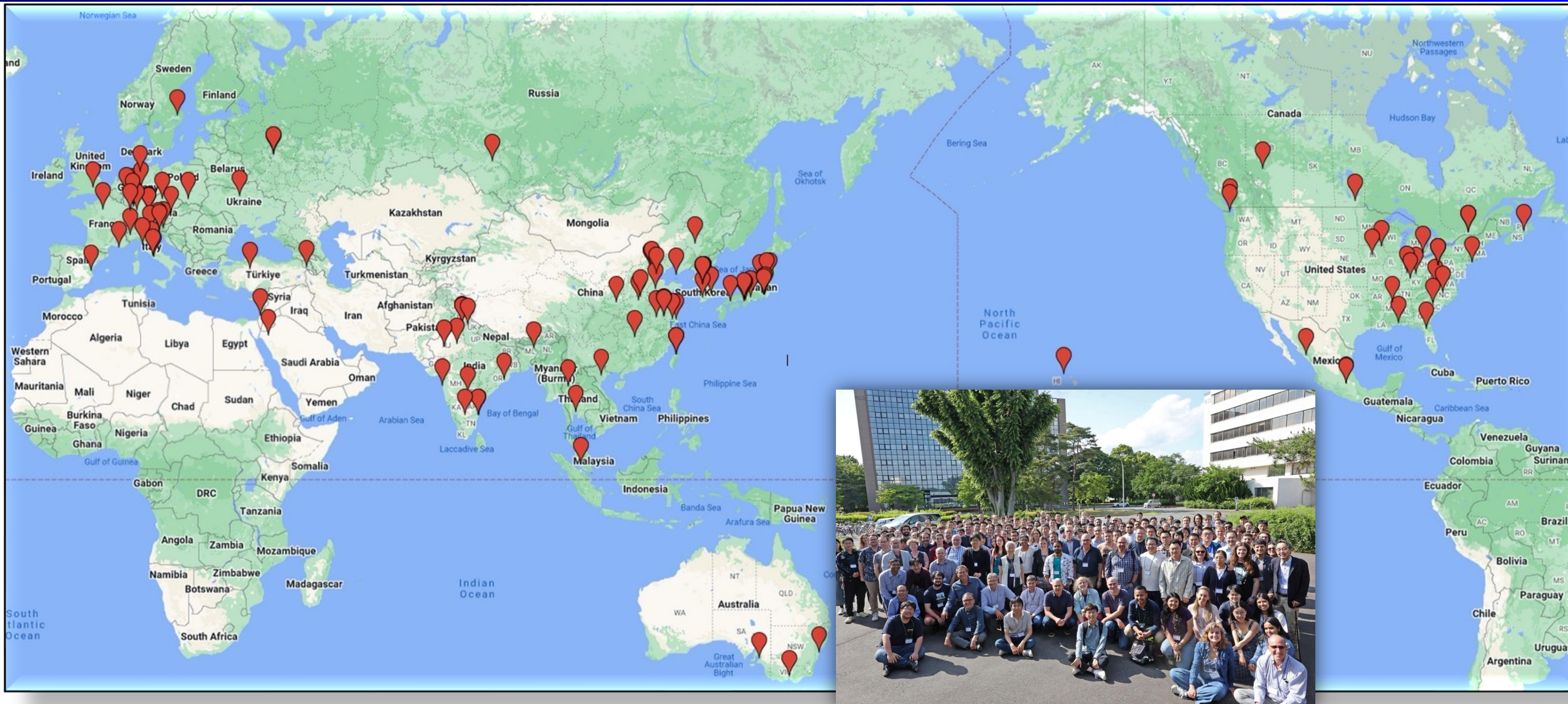




Belle II Physics Program



Belle II Collaboration



- ✓ Belle II is an international collaboration
- ✓ Over ~1160 collaborators from different institutions in 27 countries (124 institutes)

US institutes: BNL, CMU, Cincinnati, Duke, Florida, Hawaii, ISU, Indiana, Louisville, Luther, Mississippi, Pittsburgh, S-Alabama, S-Carolina, VPI, Wayne State