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Federal Ministry of Education and Research

Belle II

The Phase 2 Run of Belle II

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Belle II Collaboration

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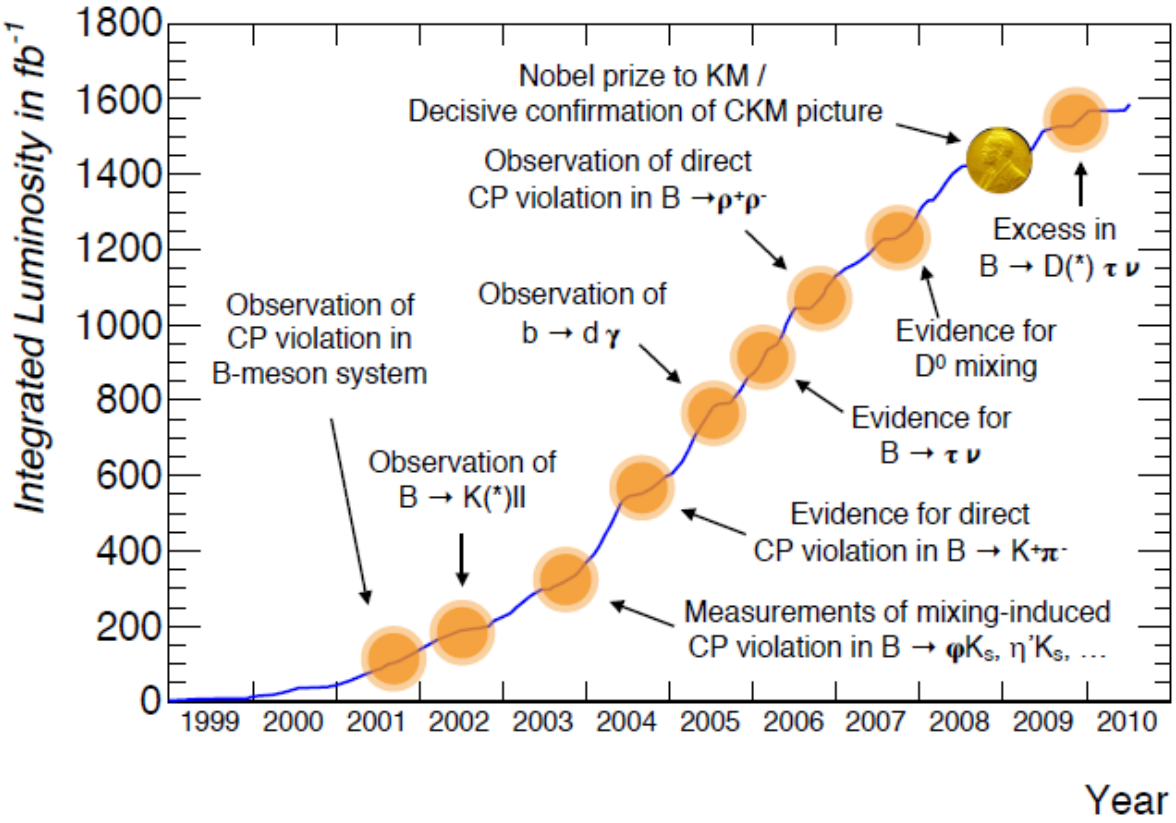
The B Factories: A Success Story

- The B factories Belle and BaBar ran from 1999 to 2010.
- They recorded over 1.5 ab^{-1} of data ($1.25 \cdot 10^9$ BB).
- Both experiments provided the experimental confirmation that led to the 2008 Nobel prize



Super Flavor Factory

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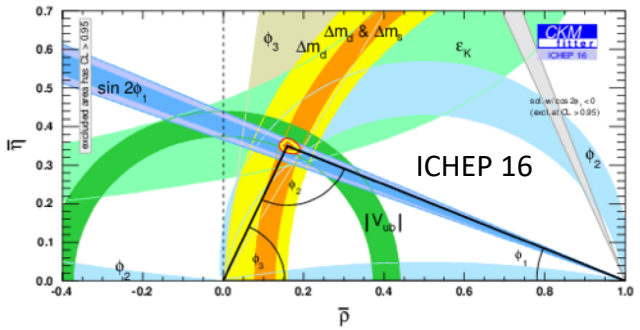
- Search for physics phenomena beyond SM in B, D and τ decays through precision measurements of the CKM sector and studies of rare or forbidden processes
- Many potential NP sources:
  - Flavor changing neutral currents
  - Lepton flavor violating decays
  - B → τ tree level new physics
  - New sources of CPV

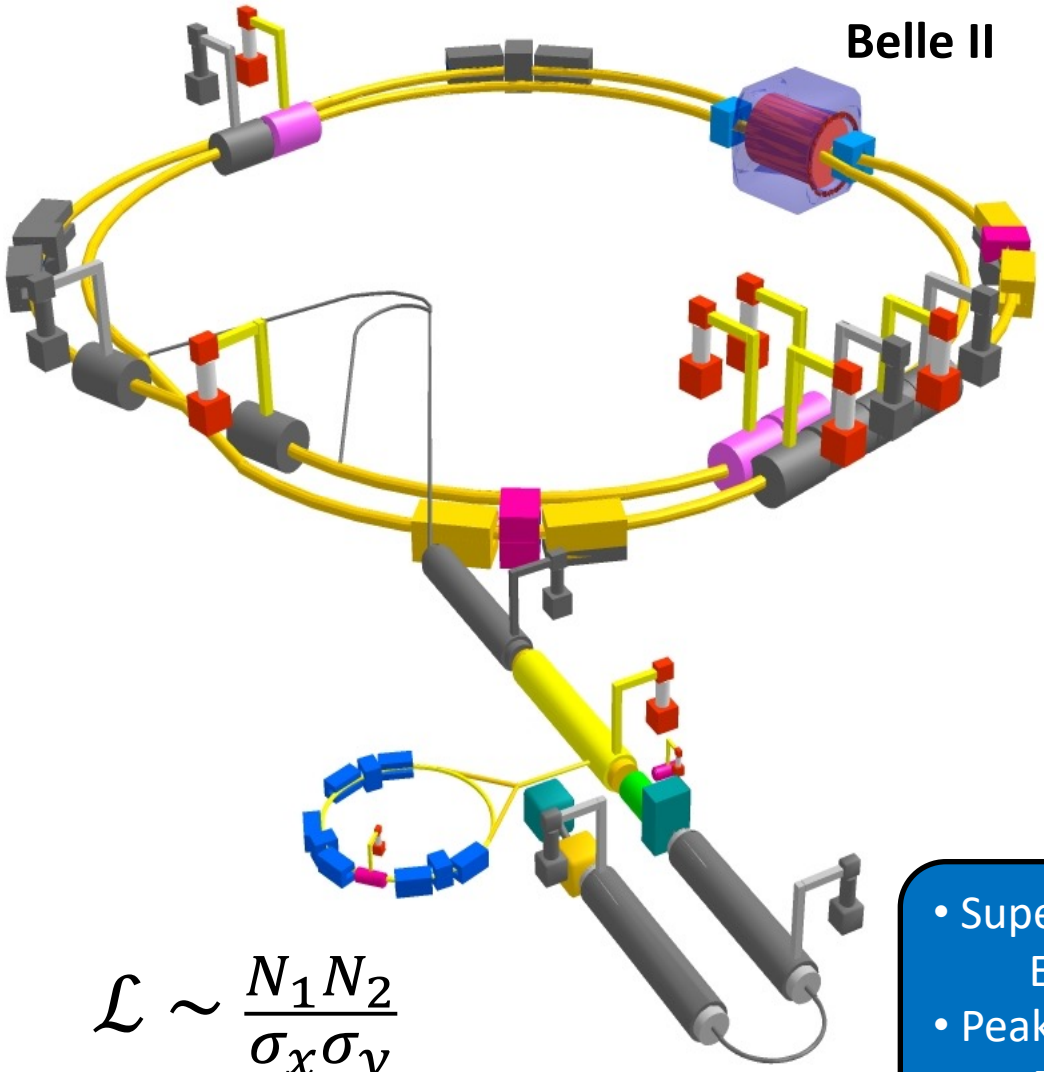
1. High luminosity accelerator
   SuperKEKB
2. High-resolution and large-coverage detector
   Belle II

For details, check the following contributions:

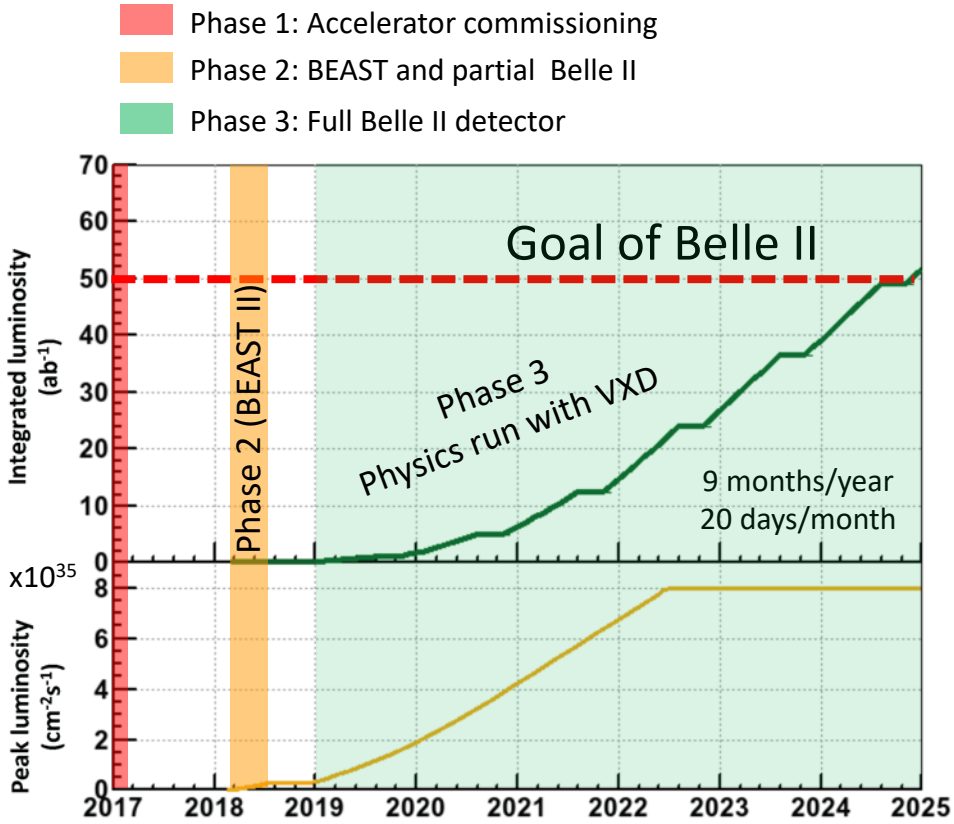
- G. Del Pietro: 'First data at Belle II – dark sector physics'
- A. Morda: 'CP violation sensitivity at Belle II'
- M. Merola: 'Studies of missing energy in B decays at Belle II'



The SuperKEKB Accelerator

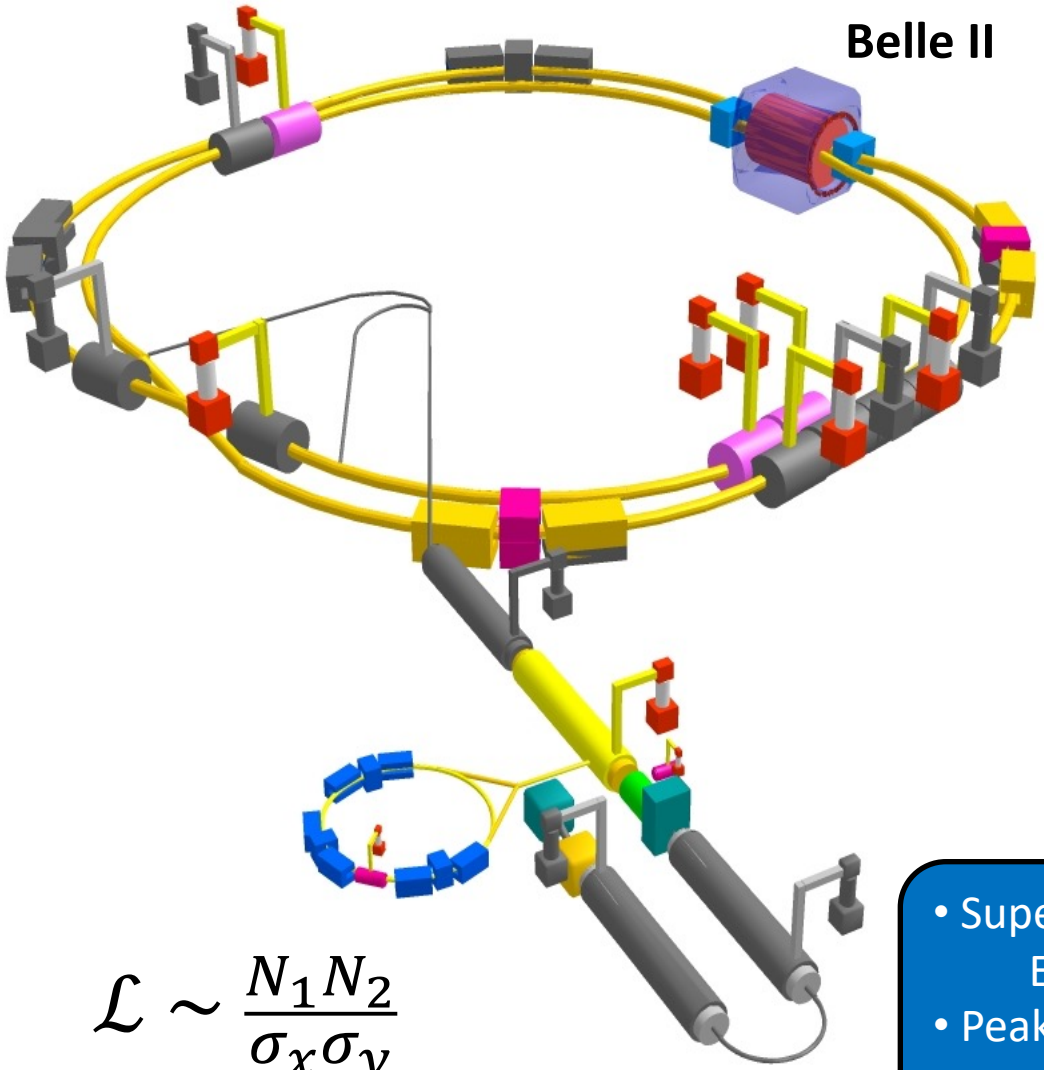


$$\mathcal{L} \sim \frac{N_1 N_2}{\sigma_x \sigma_y}$$



- SuperKEKB: Asymmetric energy e^+e^- collider
  E_{cm} = m(ϒ(4S)) = 10.58 GeV
- Peak luminosity: $\mathcal{L}$ = $8 \cdot 10^{35}$ cm^{-2} s^{-1} (x40 than KEKB)
  Beam size reduction. Higher current (x2 higher).

The SuperKEKB Accelerator



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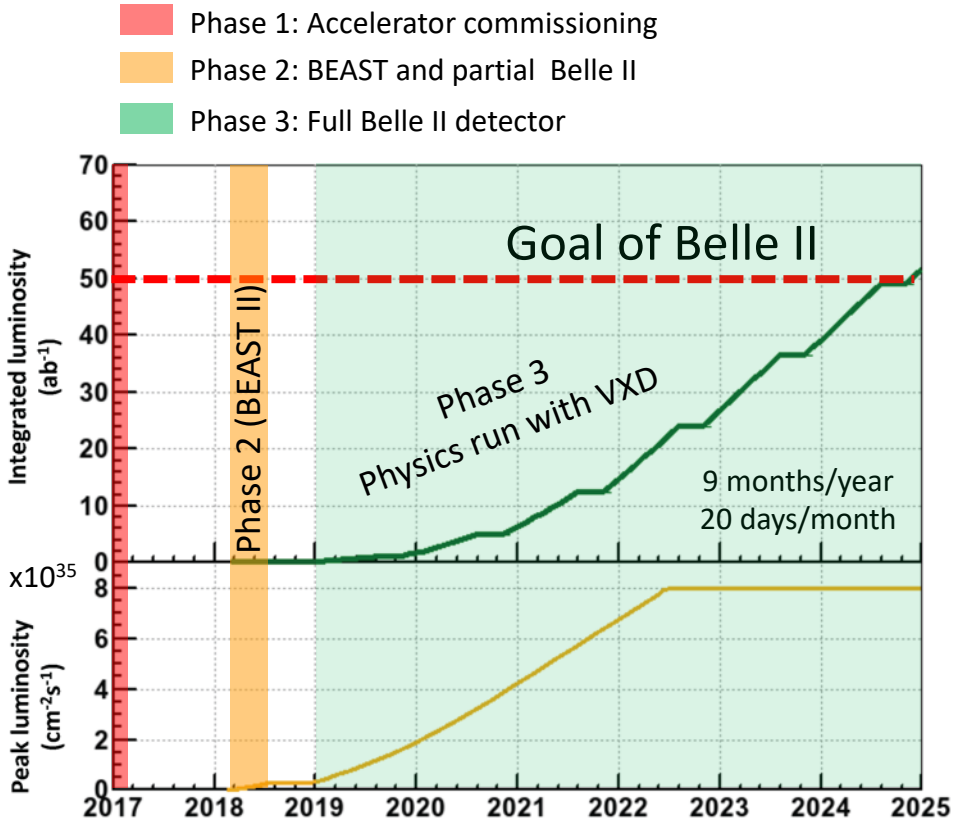

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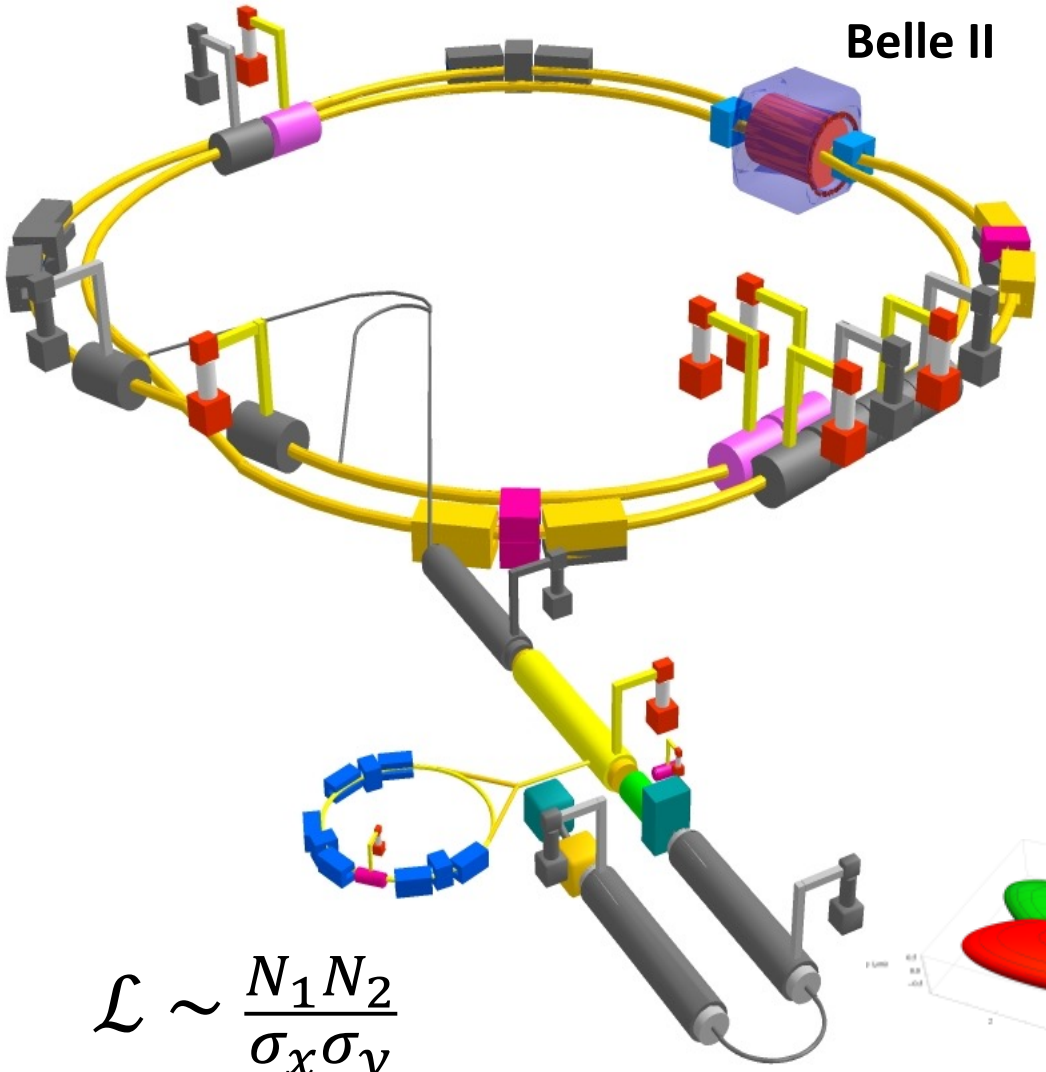

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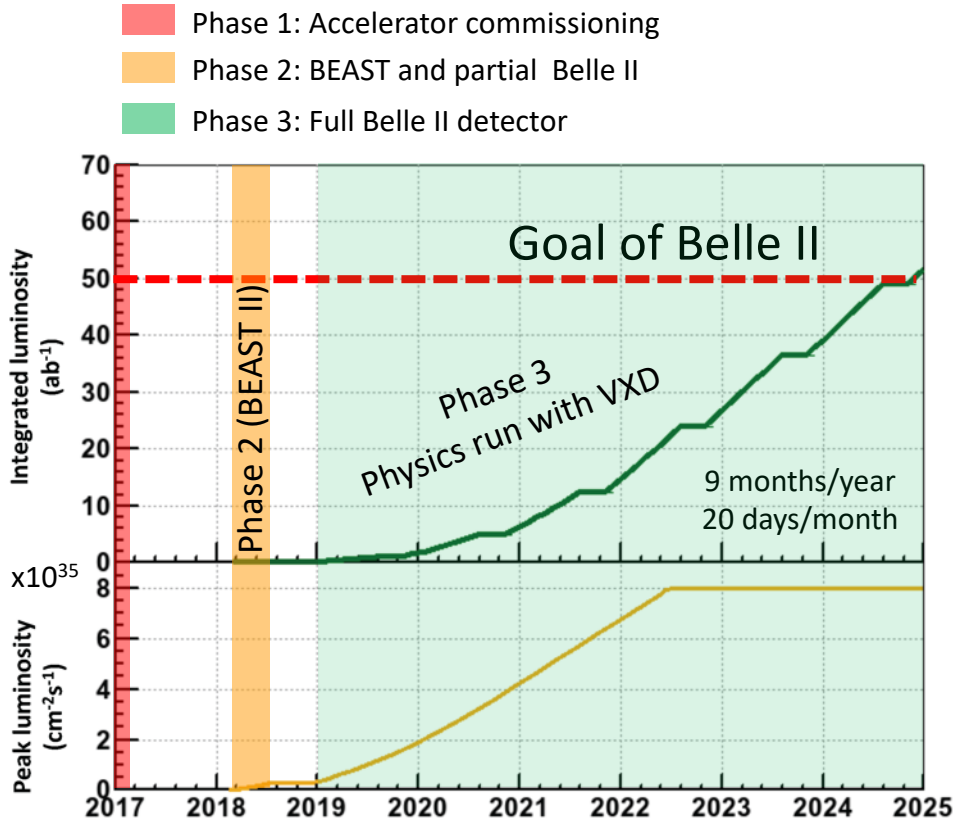
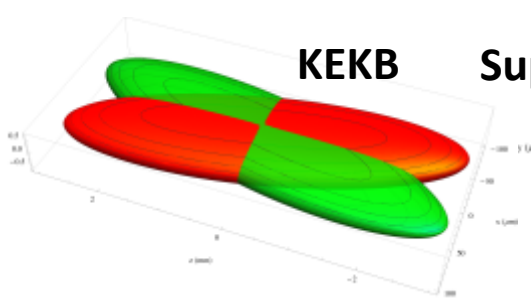
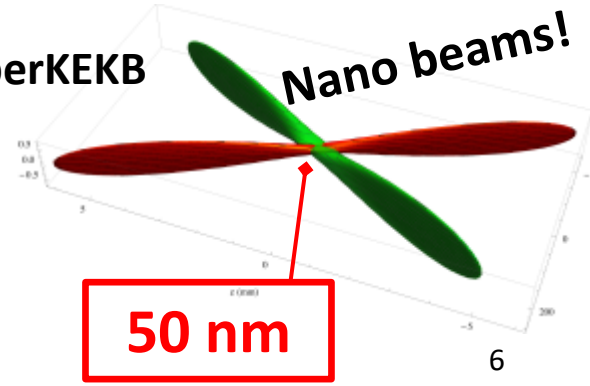
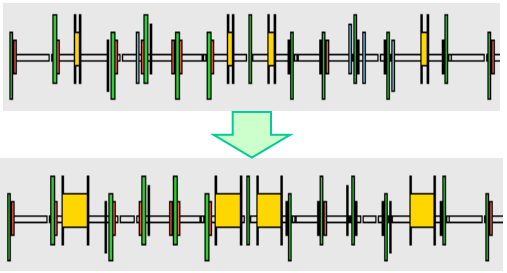






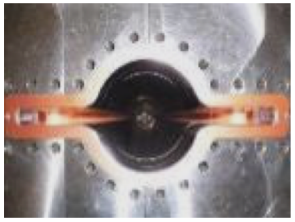
Going For a Super B-Factory: SuperKEKB

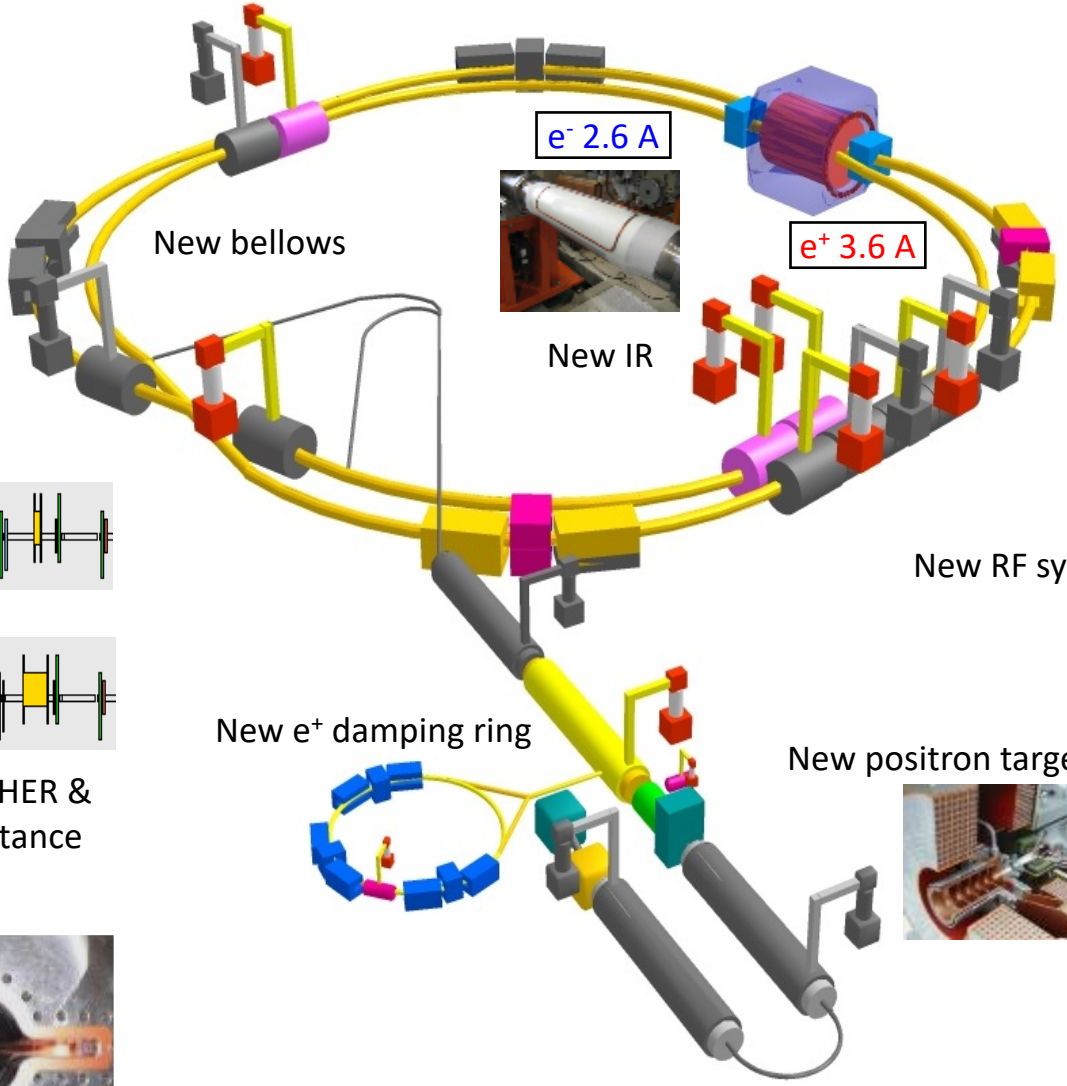
Replace short dipoles with longer ones (LER)



Redesign the lattices of HER & LER to squeeze the emittance

TiN-coated beam pipe





New final focusing quads near the IP

New RF systems

Complete refurbishment to achieve x40 higher luminosity compared to KEKB

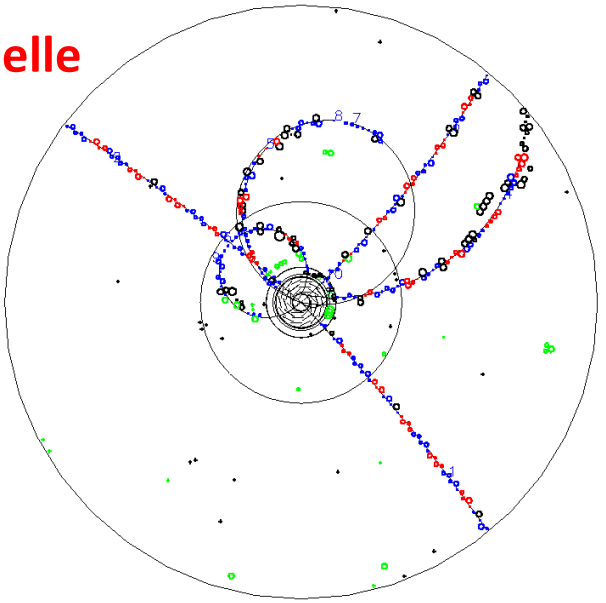
The Belle II Detector

40 times higher luminosity implies

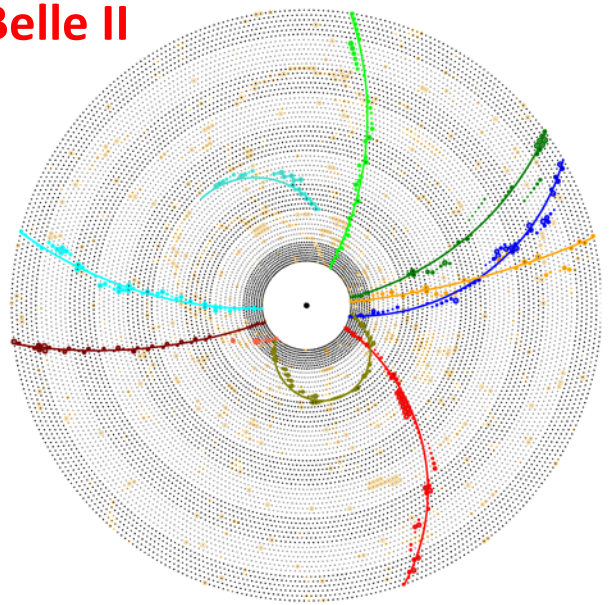
- **Higher event rate**
  - Higher trigger rate
  - Increased DAQ and computing requirements
- **Higher background**
  - Radiation damage
  - Occupancy
  - Fake hits and pile-up
- Changes in detector
  - $\beta\gamma$ reduced by factor 1.5
  - Improved vertexing needed
- Results in significant upgrade

→ Belle II

Belle



Belle II



The Belle II Detector

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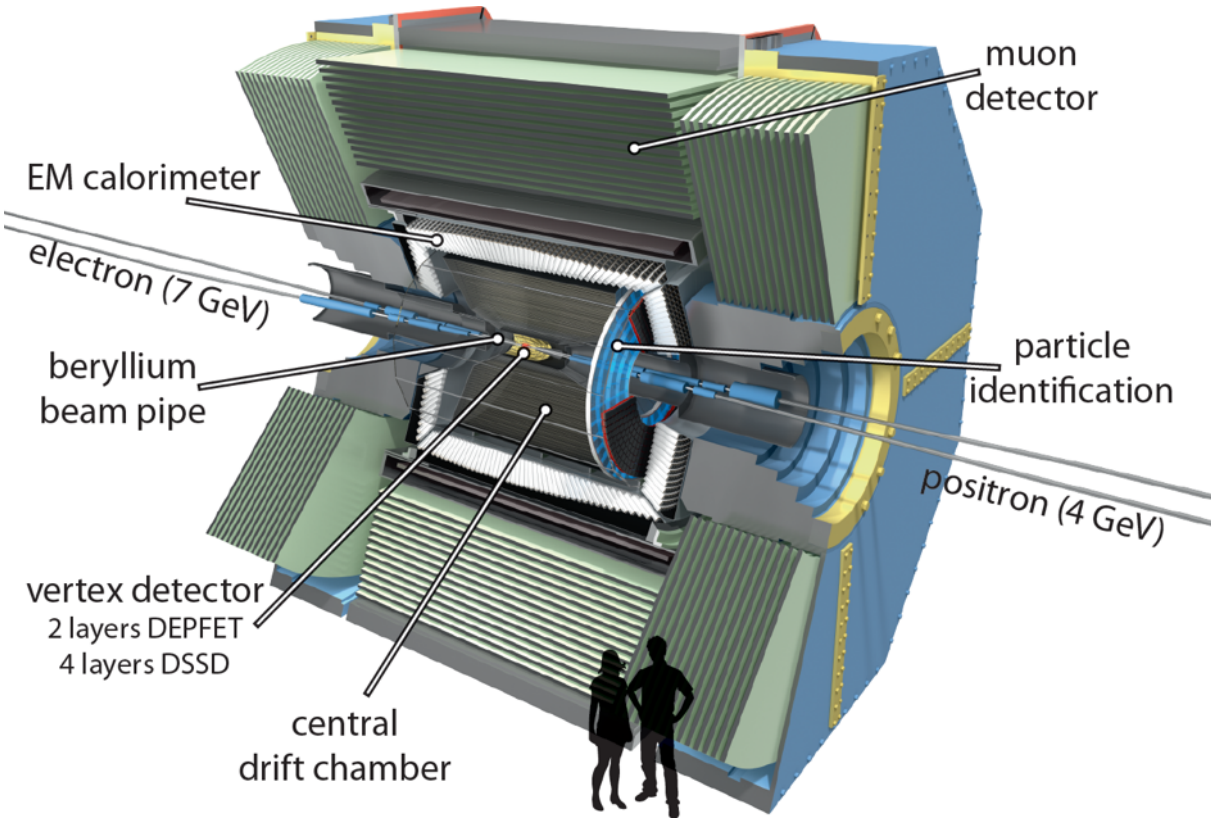
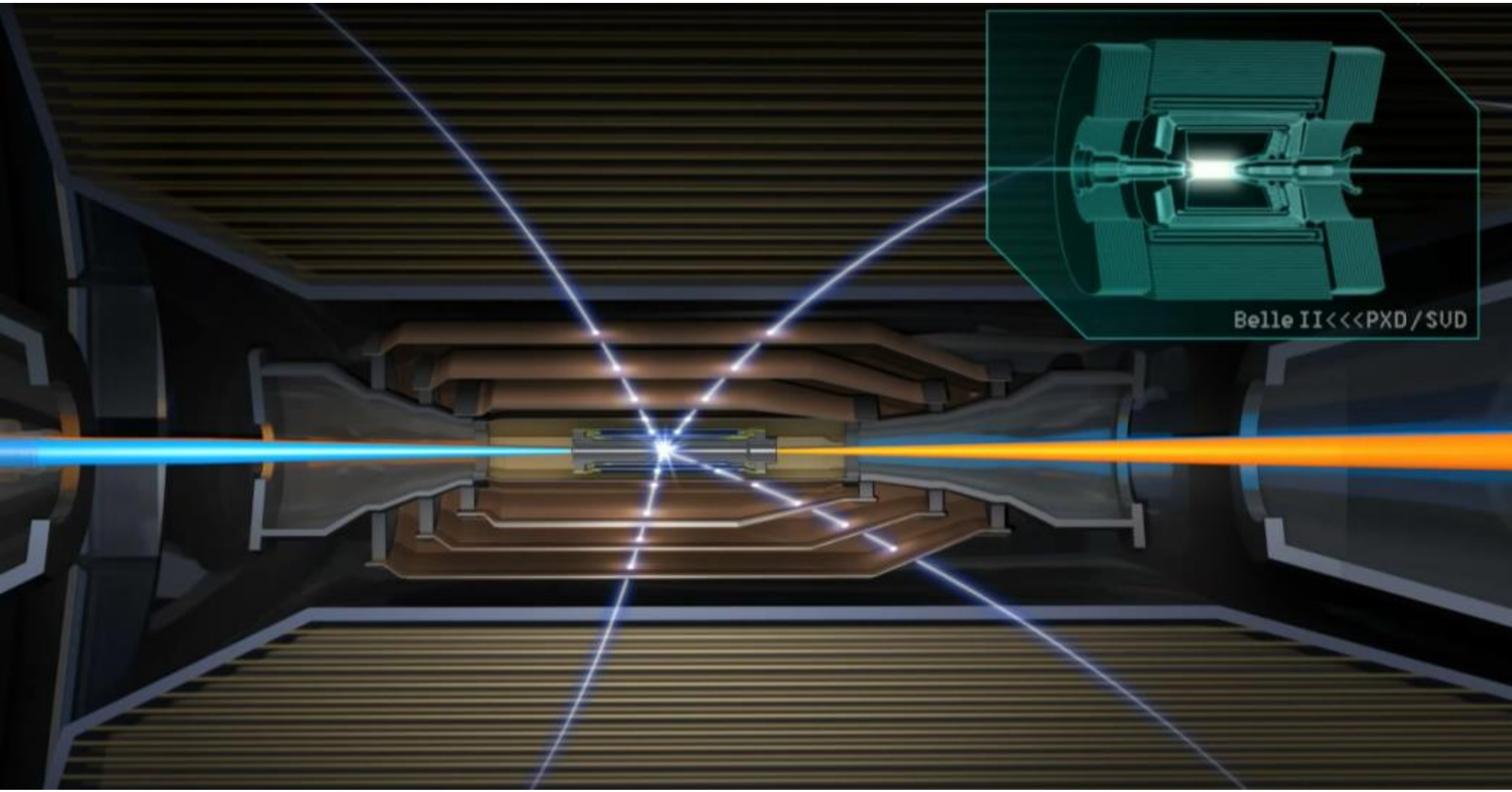
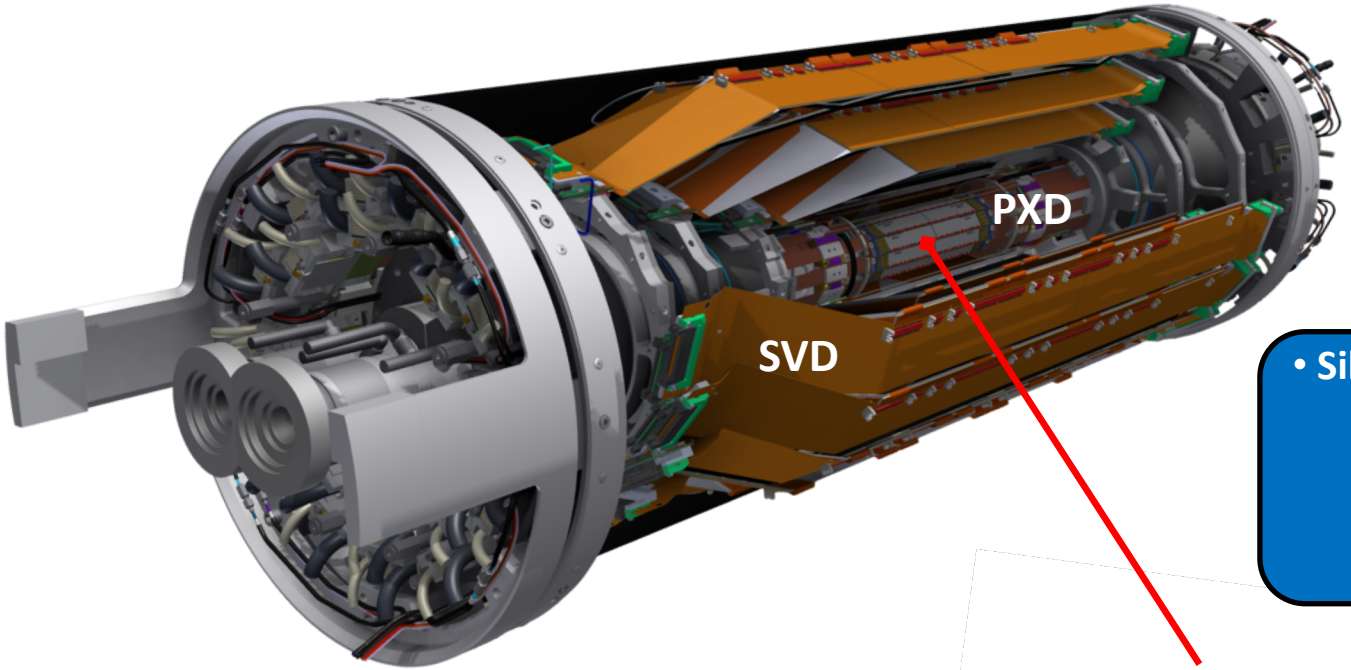
- Areas of improvement:
  - Light inner detector
  - Precise vertexing/tracking
  - Particle identification
  - E.M. calorimetry
  - K^0_L and muon ID
  - Data handling capabilities



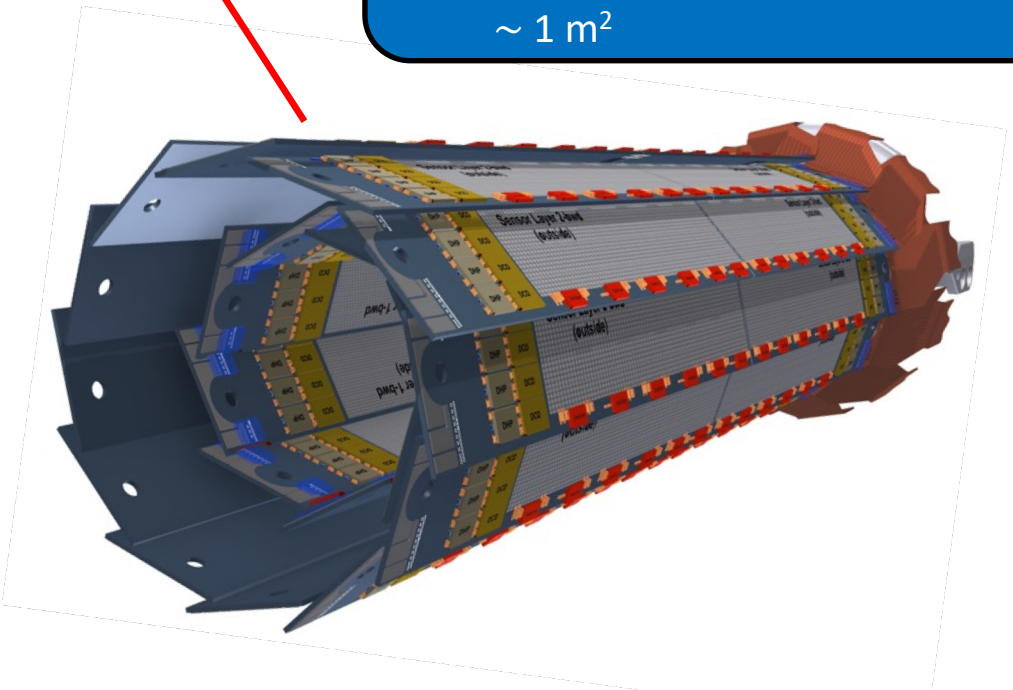
Vertex Detector (VXD)



6- Layers Vertex Detector: PXD and SVD



- **Silicon Vertex Detector (SVD)**
  - 4 layers of DSSD
  - r = 3.8 cm, 8.0 cm, 11.5 cm, 14 cm
  - L = 60 cm
  - ~ 1 m^2

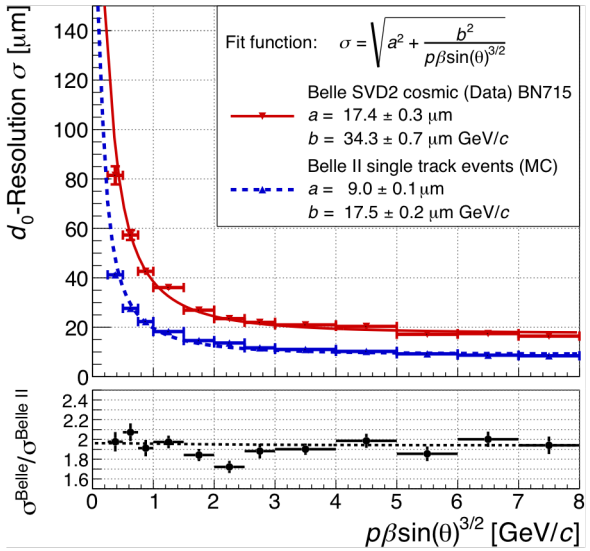


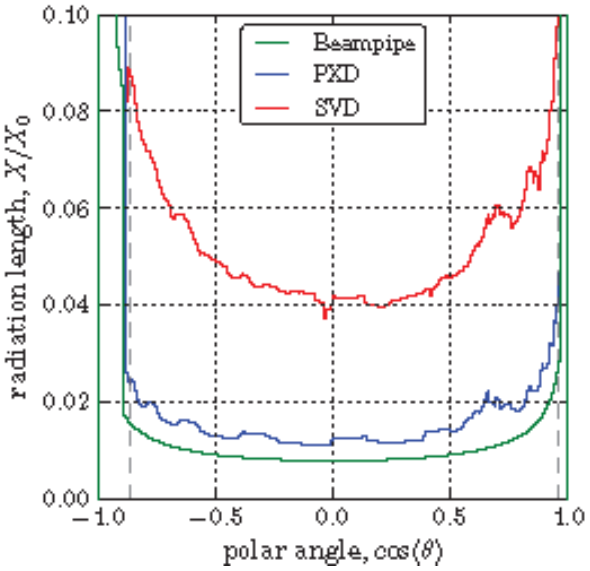
- **Pixel Detector (PXD)**
  - 2 layers of DEPFET pixels
  - r = 1.4 cm, 2.2 cm
  - L = 12 cm
  - ~ 0.027 m^2

Belle II VXD Requirements and Parameters

	Belle II PXD
Occupancy	0.4 hits/μm²/s (3% max)
Radiation	2 Mrad/year
	$2 \cdot 10^{12}$ 1 MeV n_{eq} per year
Integration time	20 μs
Momentum range	Low p (50 MeV - 3 GeV)
Acceptance	17°-155°
Material budget	0.21% X_0 per layer
Resolution	15 μm (50x75 μm²)

- Impact parameter resolution (15 μm), dominated by multiple scattering mainly in BP → Pixel size (50 x 75 μm²)
- Lowest possible material budget (0.21% X_0/layer)
  - Ultra-transparent detectors
  - Lightweight mechanics and minimal services in physics acceptance





The DEPFET Ladder

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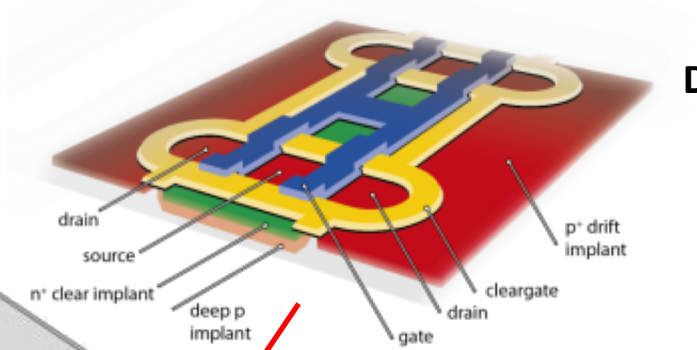
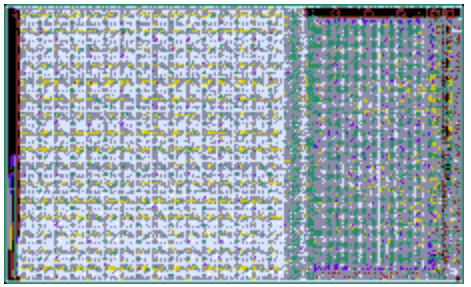
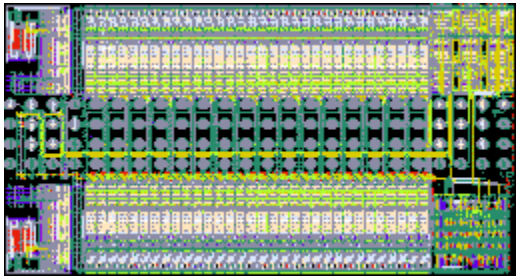


DCDB (Drain Current Digitizer)
Analog frontend



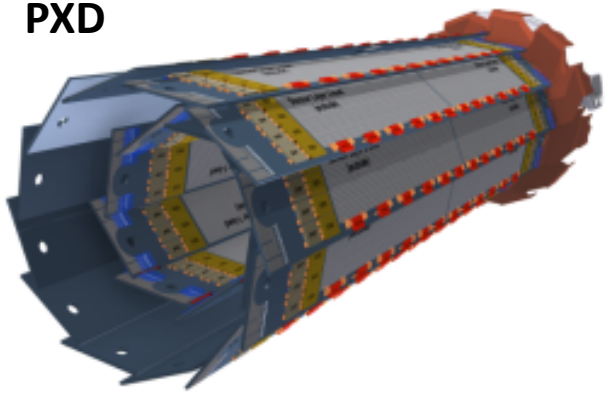
SwitcherB
Row control



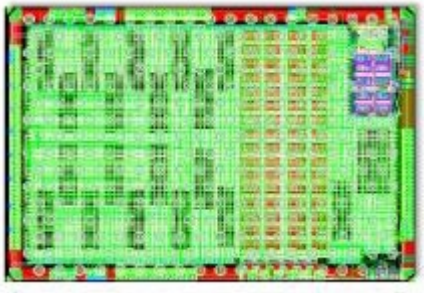
AMS/IBM HVCMOS 180 nm
Size 3.6 × 1.5 mm^2
Gate and Clear signal
Fast HV ramp for Clear

UMC 180 nm
Size 5.0 × 3.2 mm^2
TIA and 8-bit ADC
92 ns sampling time
Pedestal compensation

PXD

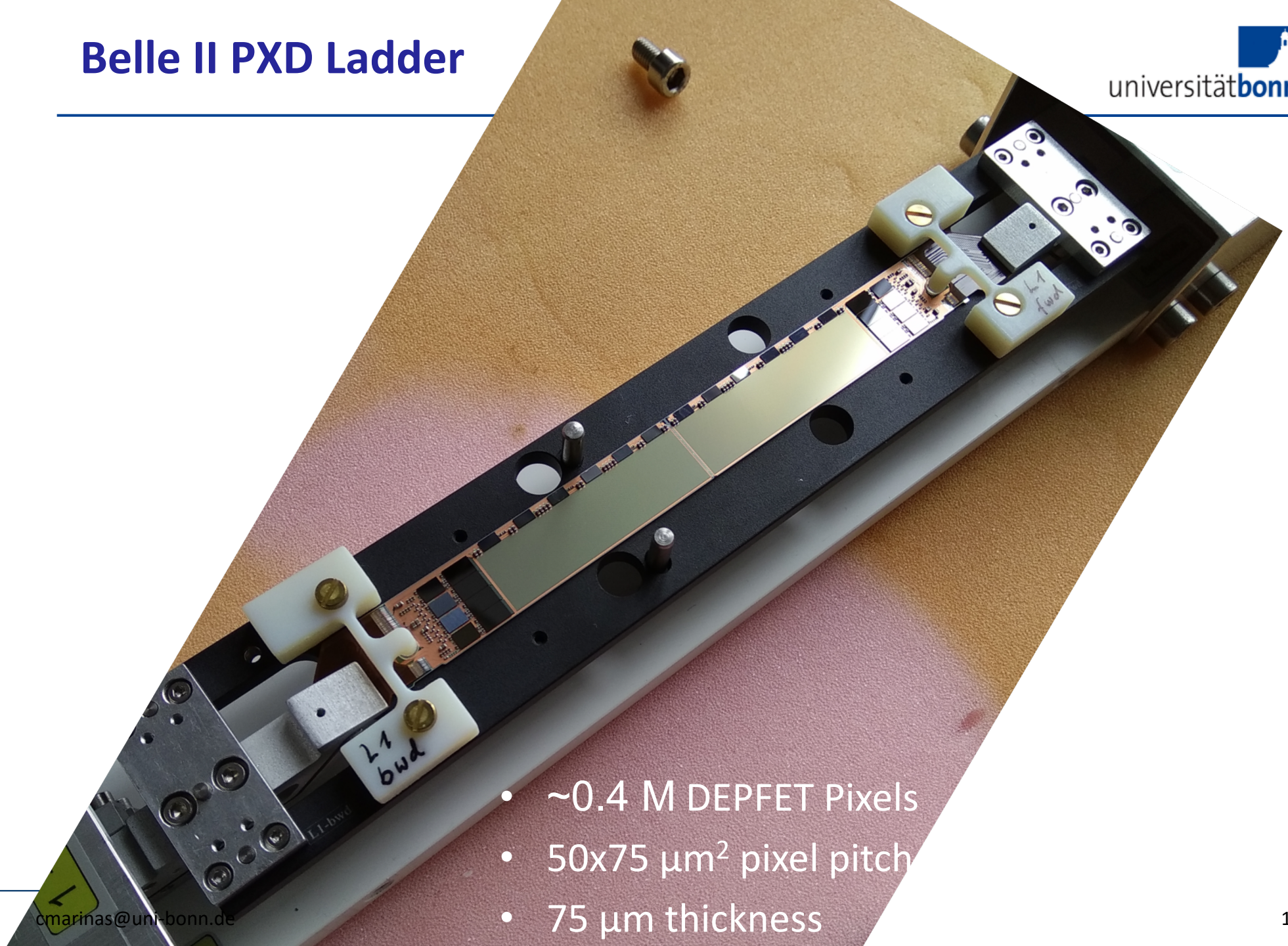


DHP (Data Handling Processor)
First data compression



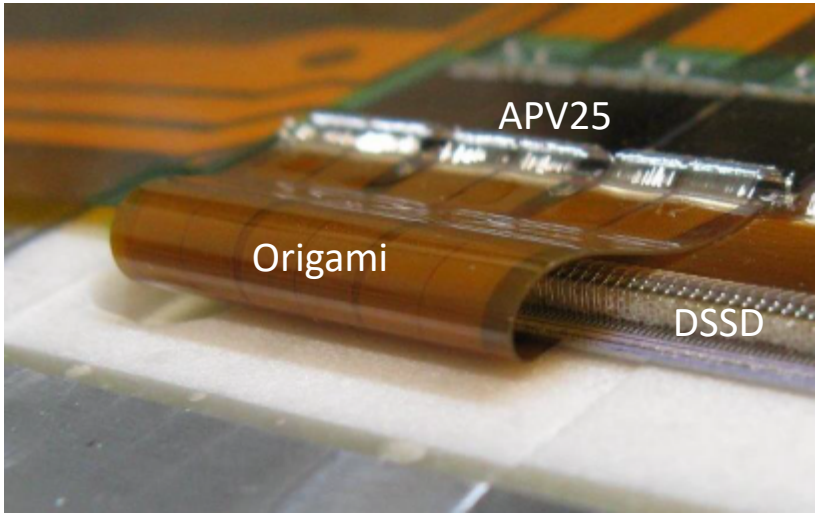
TSMC 65 nm
Size 4.0 × 3.2 mm^2
Stores raw data and pedestals
Common mode and pedestal correction
Data reduction (zero suppression)
Timing and trigger control

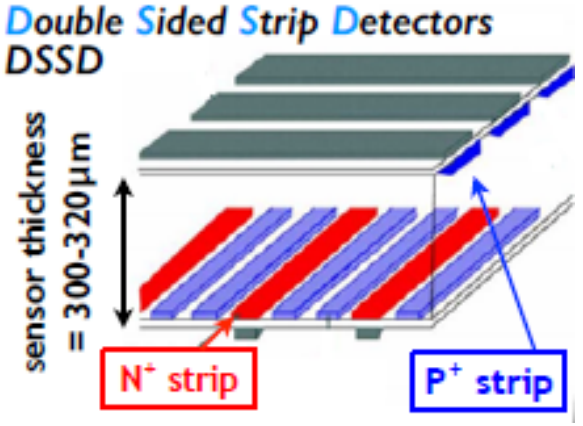
Belle II PXD Ladder

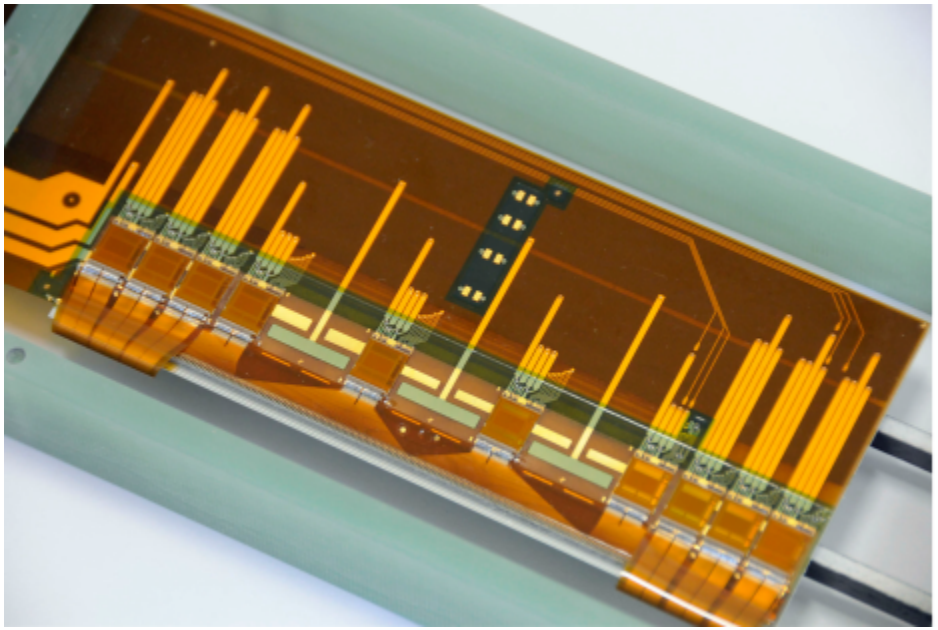


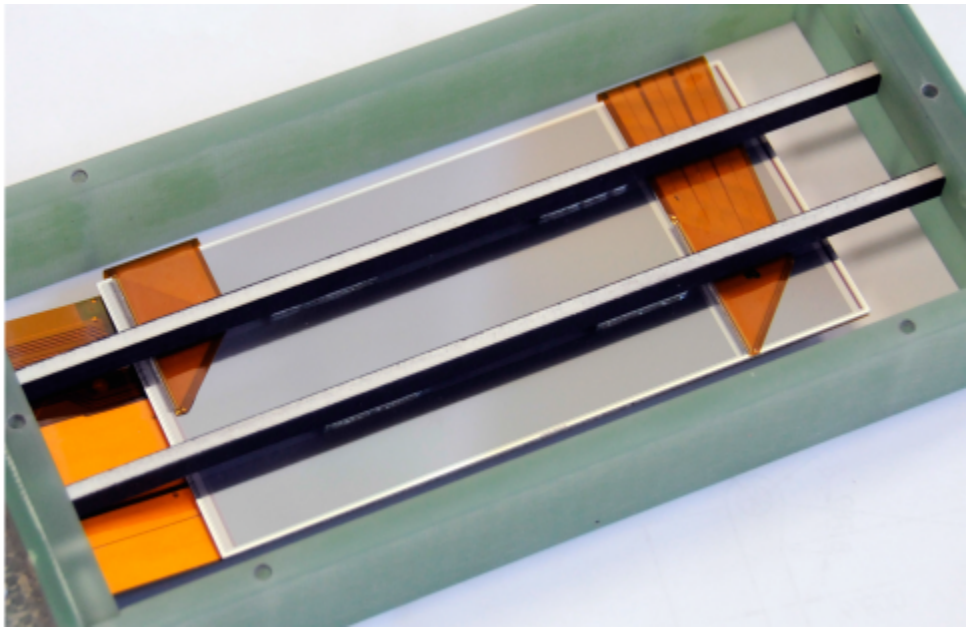
- ~0.4 M DEPFET Pixels
- 50x75 µm^2 pixel pitch
- 75 µm thickness

Belle II SVD Module

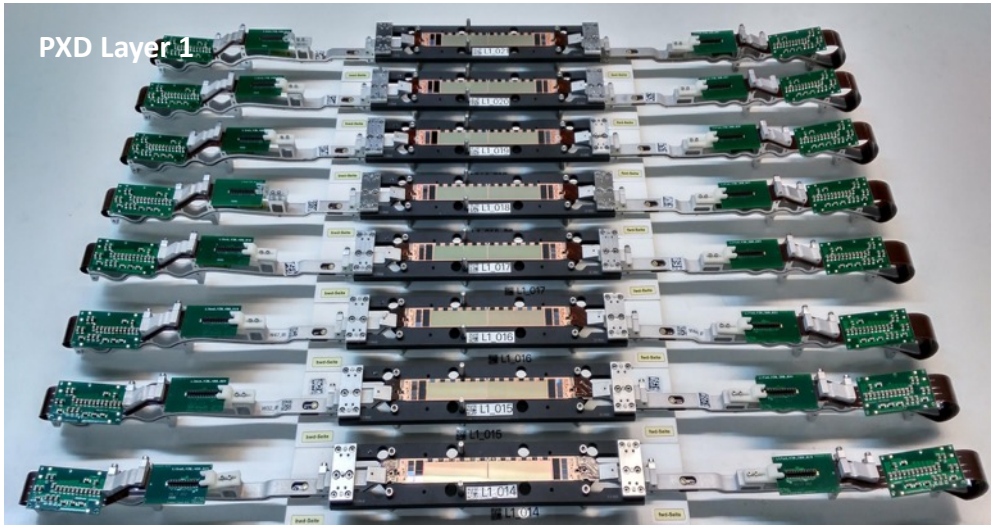






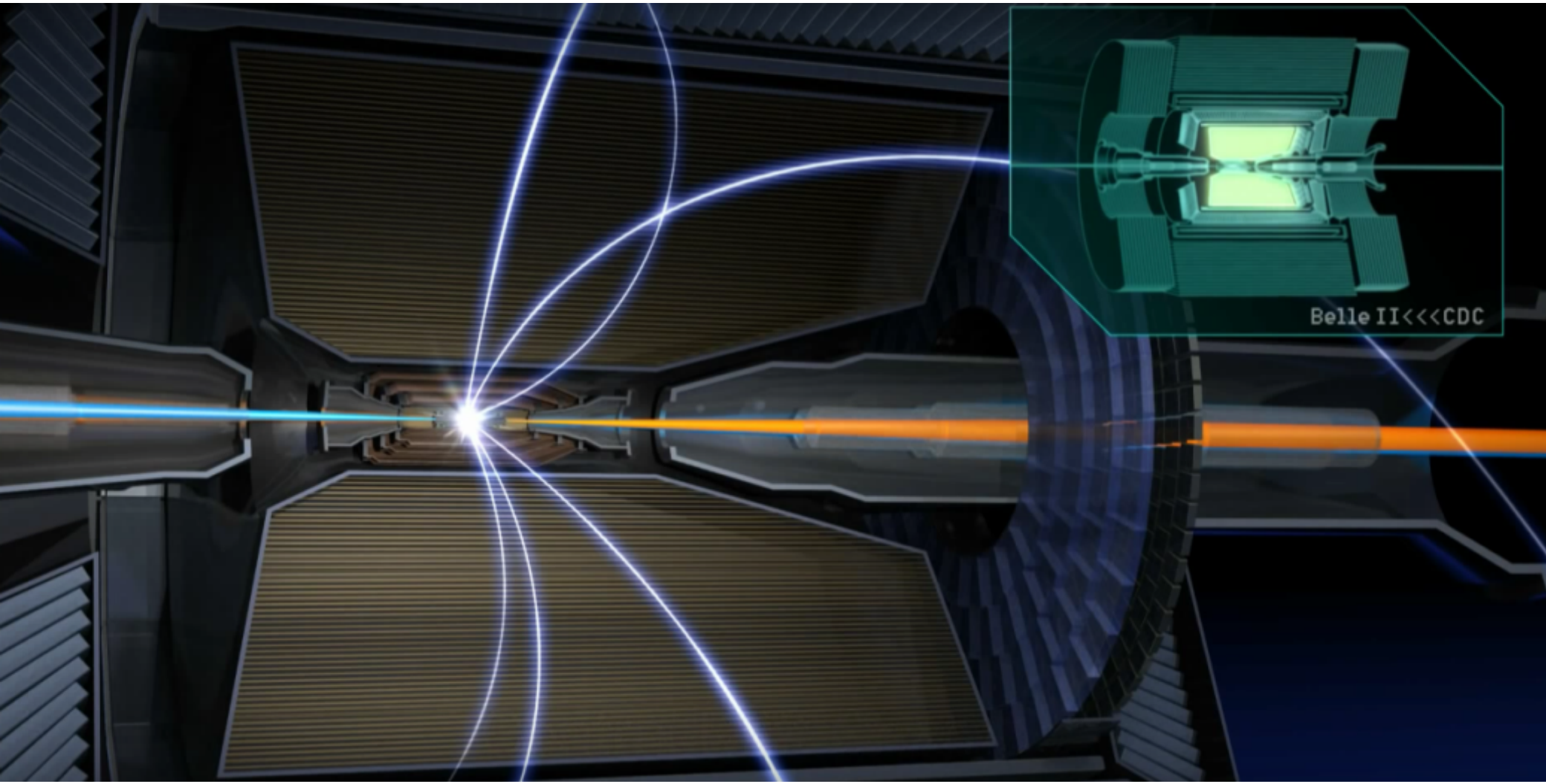


Readiness Phase 3 VXD



PXD and SVD are being finalized
Integration in August 2018

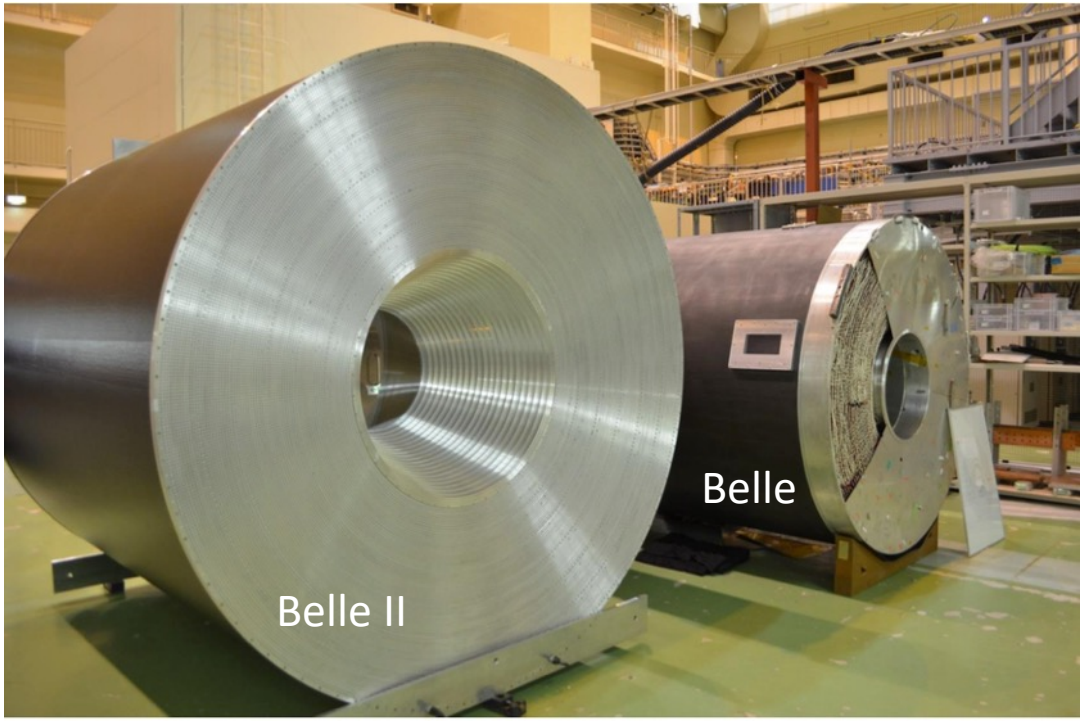
Central Drift Chamber (CDC)



Central Drift Chamber (CDC)

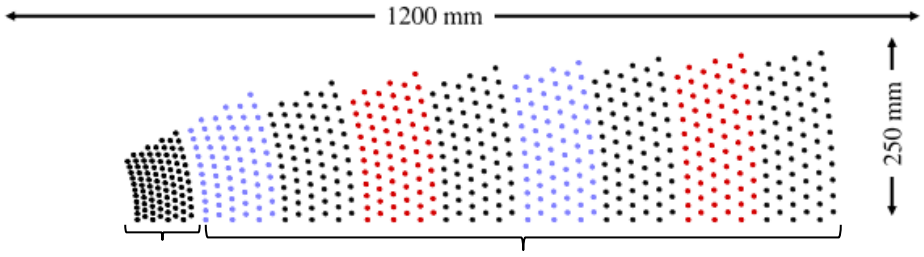
Three important roles:

- Track reconstruction and momentum determination
- Particle identification via dE/dx
- Trigger for background rejection



	Belle II CDC
Number of layers	56
Total sense wires	14336
Gas	He:C_2H_6 (1:1)
Sense wire	Au-W (ø30 µm)
Field wire	Al (ø126 µm)

Stereo and axial layers



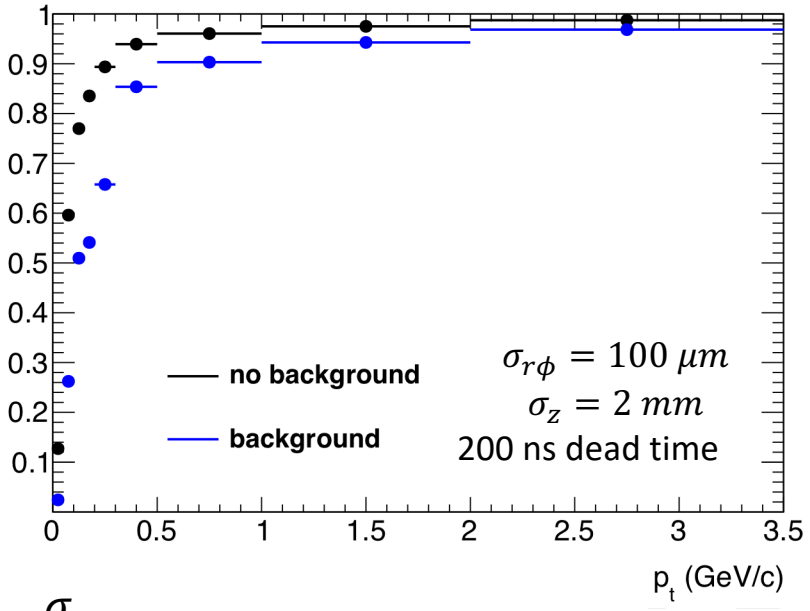
Small cell chamber

Large tracking volume

Central Drift Chamber (CDC)

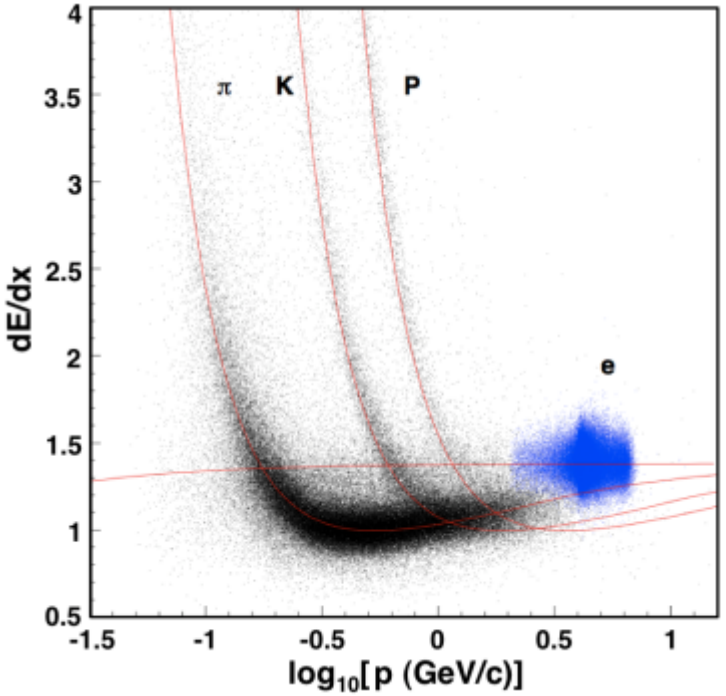
Three important roles:

- Track reconstruction and momentum determination
- Particle identification via dE/dx
- Trigger for background rejection



$$\frac{\sigma_{p_t}}{p_t} \sim 0.3\%/\beta \oplus 0.1\% \cdot p_t[GeV/c]$$

$$\sigma\left(\frac{dE}{dx}\right)\Big|_{\text{MIP}} \sim 5\%$$



Central Drift Chamber (CDC)

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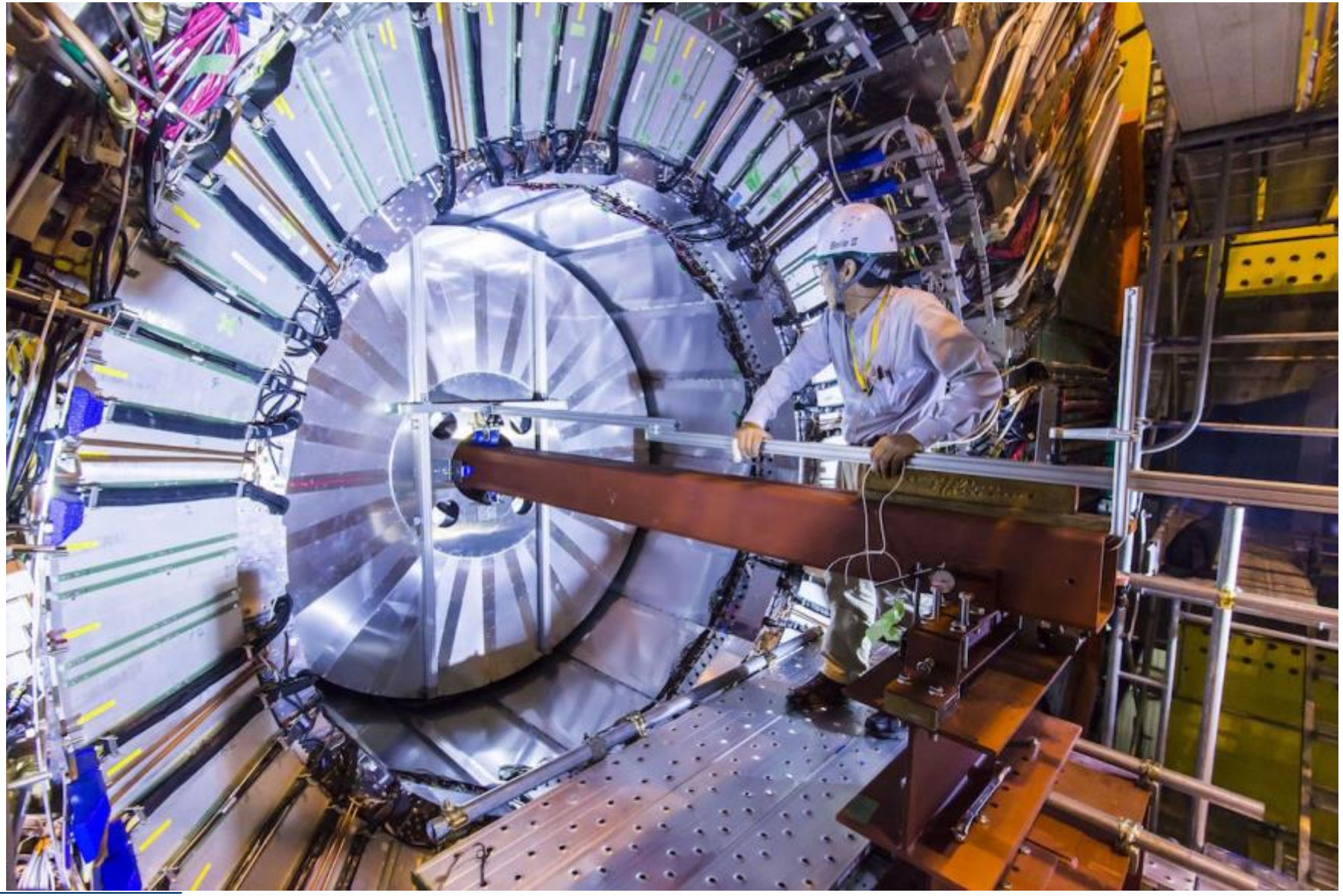

Time Of Propagation (TOP)

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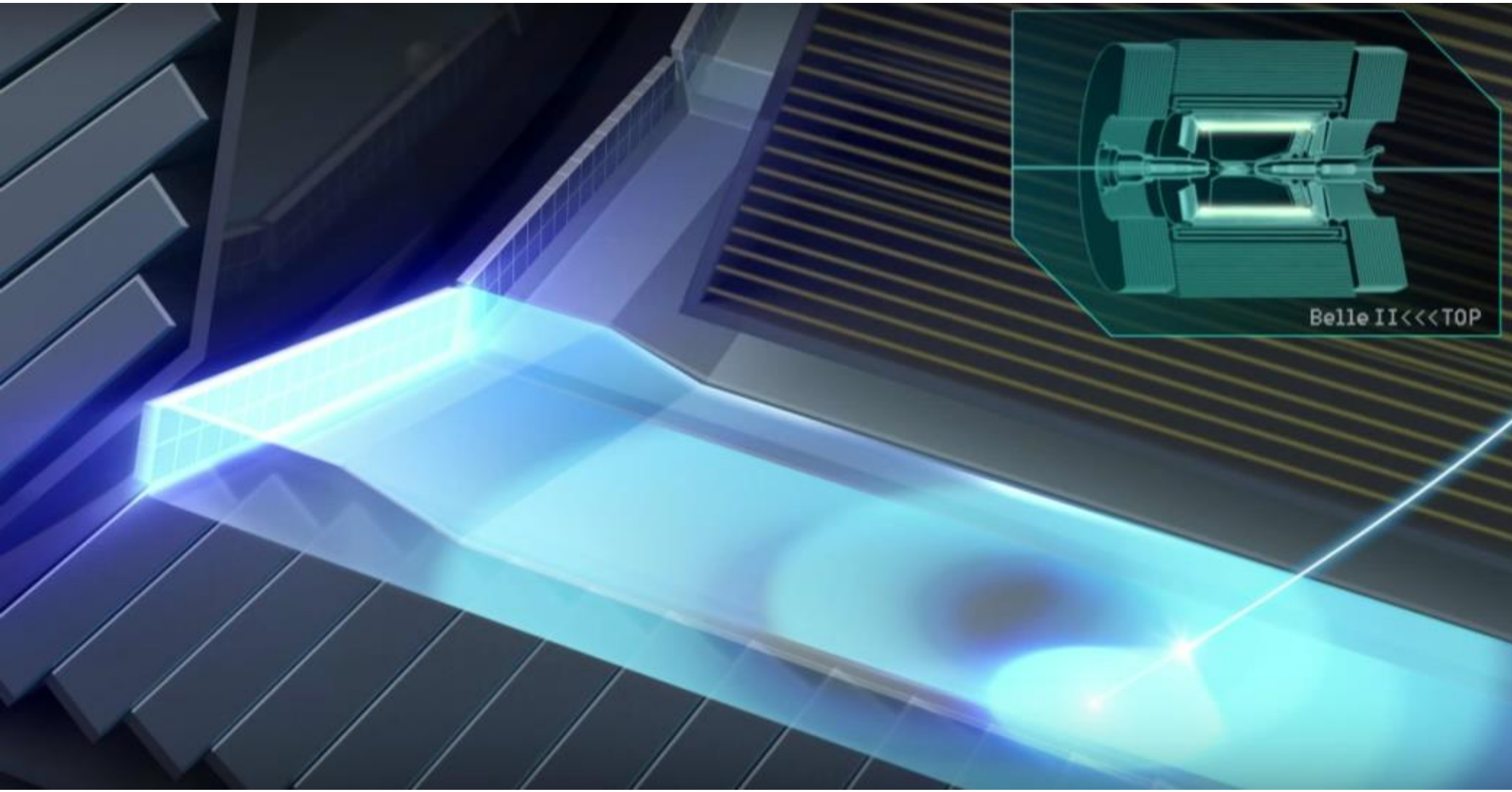
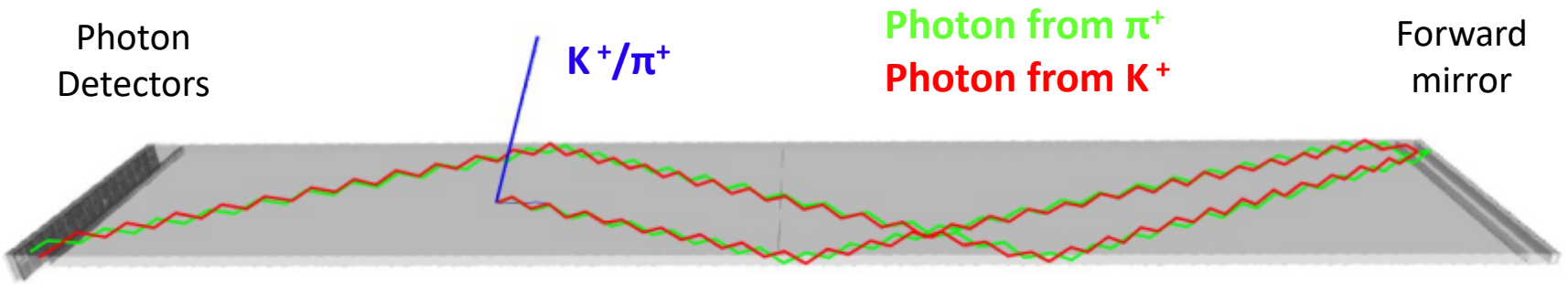
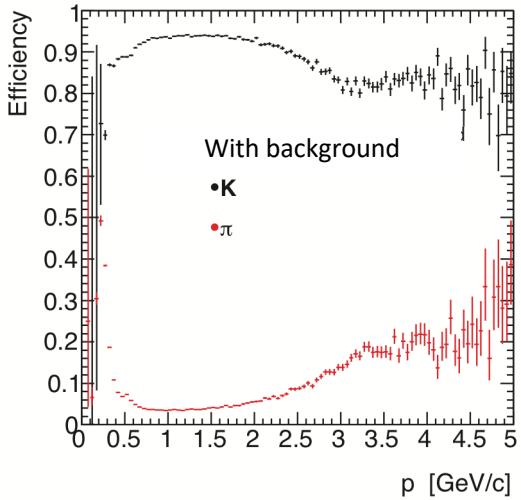


Time Of Propagation (TOP)

- TOP will be used for PID in the barrel region
- Each TOP module contains two quartz bars (2.5 m x 0.45 m x 2 cm), mirror, and array of PMT.



32 (segmented 4x4) Micro-channel plate PMT
Hamamatsu SL-10 MCP PMT
They can operate in a magnetic field
Gain = $5 \cdot 10^5$
Time resolution σ = 35 ps
QE > 24% at 380 nm



Quartz property	Belle II TOP
Flatness	< 6.3 μm
Roughness	< 0.5 nm (RMS)
Bulk transmittance	> 98% /m
Surface reflectance	> 99.9% /reflection

Time Of Propagation (TOP)

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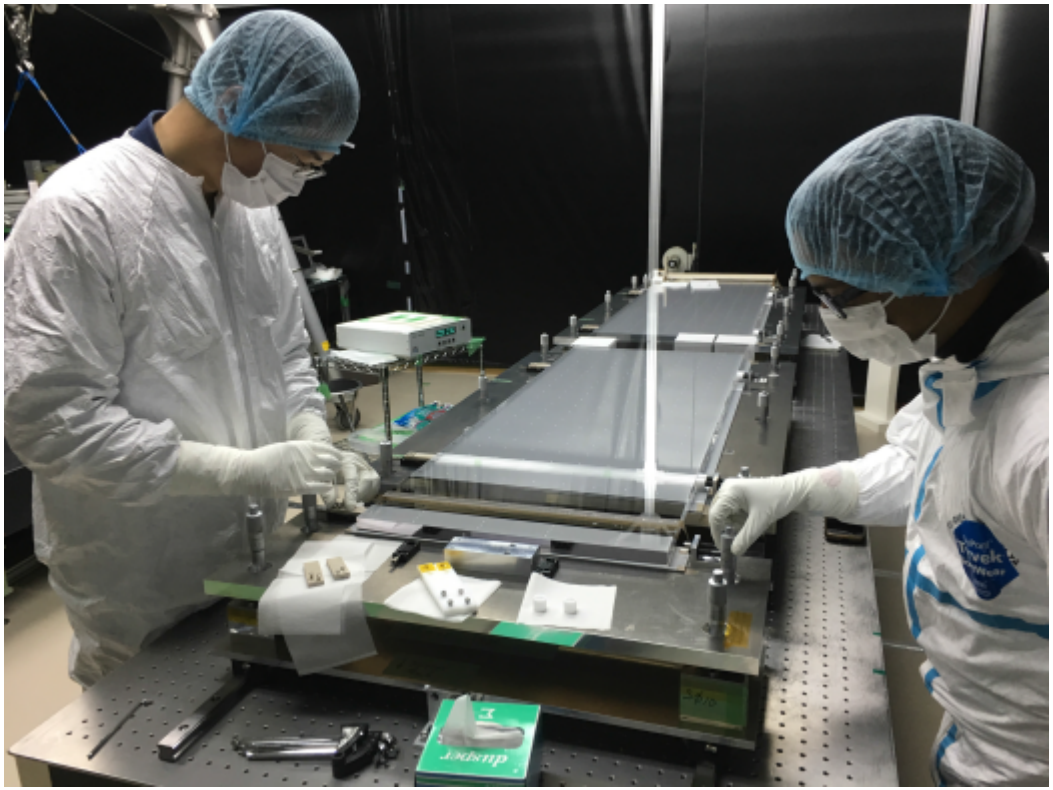

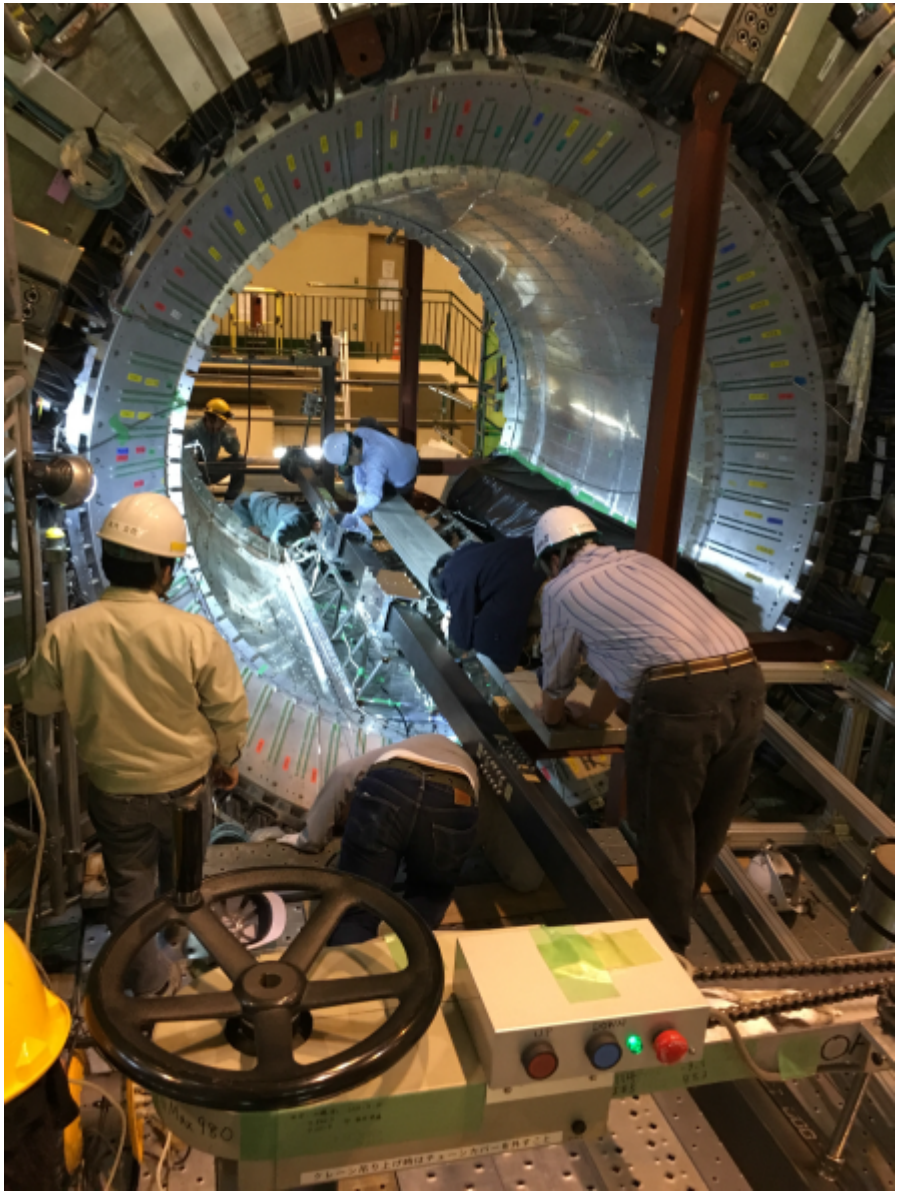

Aerogel Ring Imaging Cherenkov (ARICH)

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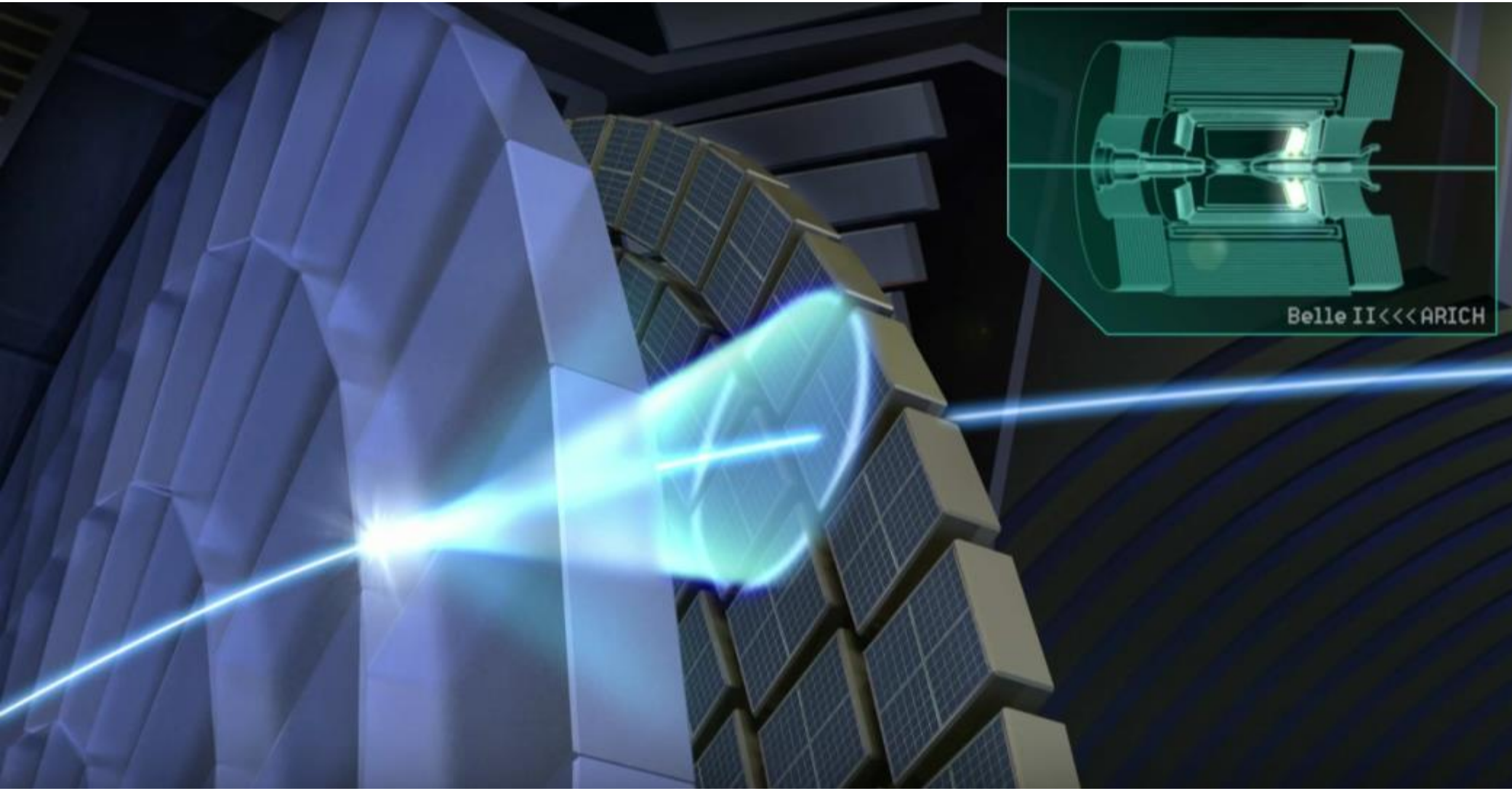

Aerogel Ring Imaging Cherenkov (ARICH)

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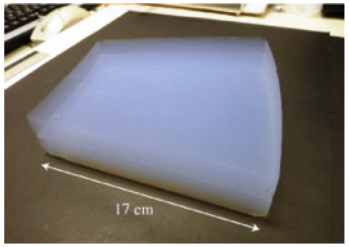
Particle identification in the forward endcap

- Radiator: Silica Aerogel

n = 1.045-1.055

Transmission length > 40 mm

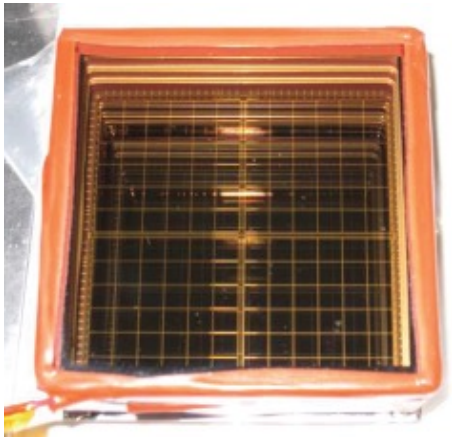


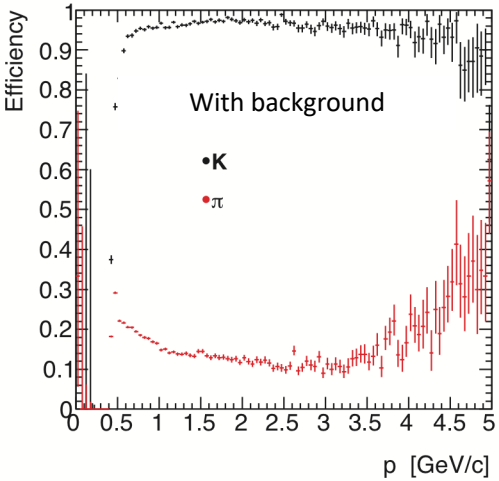
- Photon detection: Hybrid Avalanche Photo Detectors

420 units, 144 channels each, 5 mm pixelated

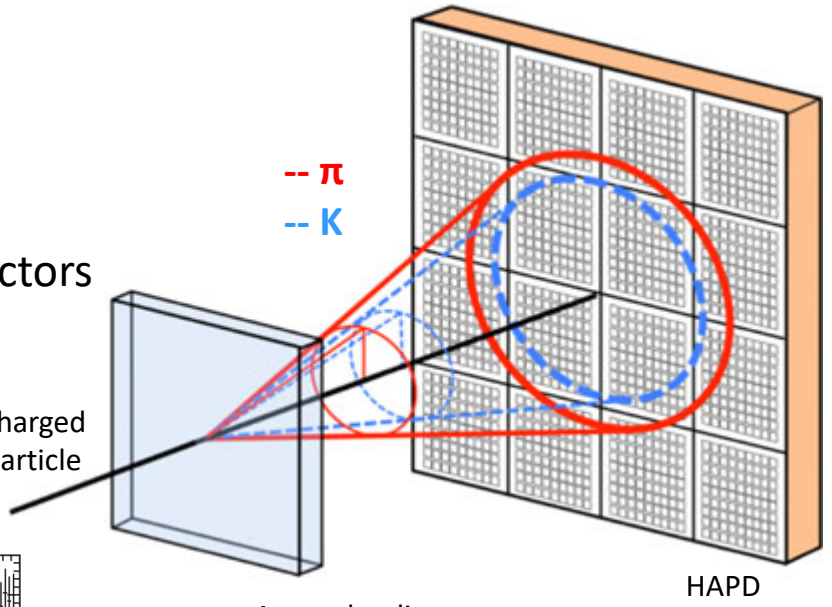
Gain = $7 \cdot 10^5$

QE > 28%





Proximity focusing aerogel



Aerogel Ring Imaging Cherenkov (ARICH)

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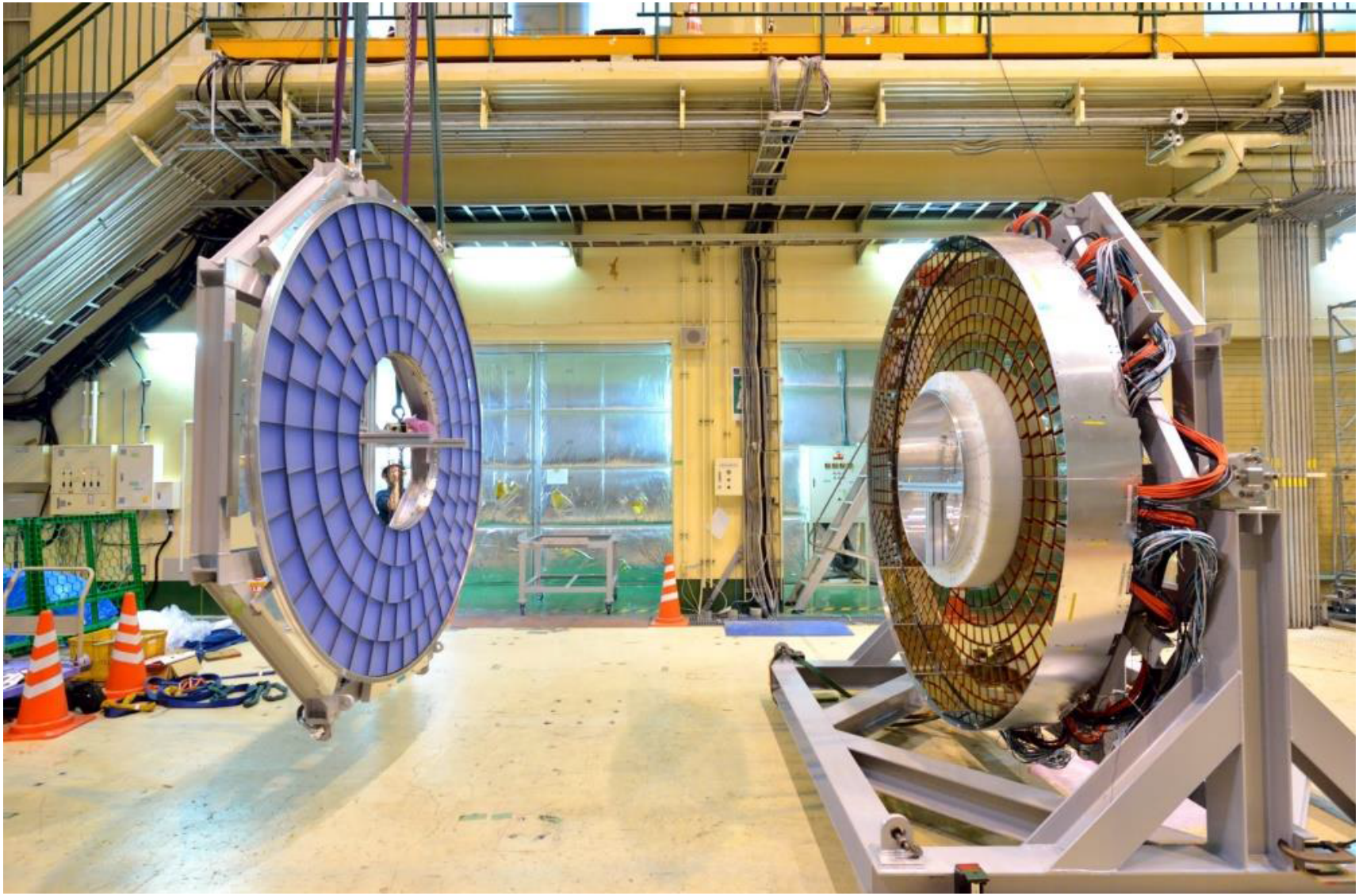
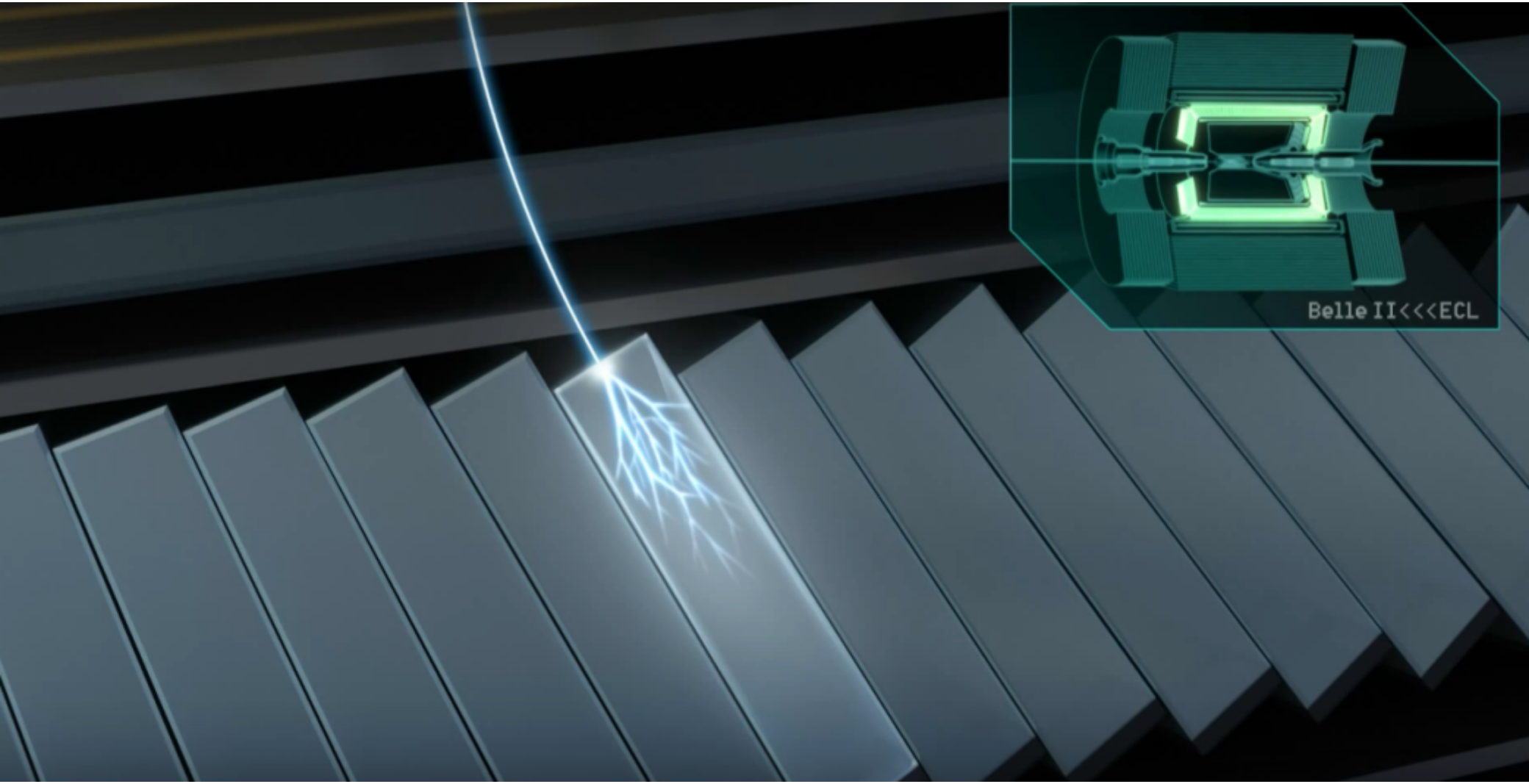


Electromagnetic Calorimeter (ECL)



Electromagnetic Calorimeter (ECL)

E.M. Calorimeter to measure:

Energy and angle of electrons/photons

Luminosity

Need upgrade due to high background:

- Barrel:

CsI(Tl) crystals reused

16.1 X_0 (30 cm)

New electronics 2 MHz waveform sampling

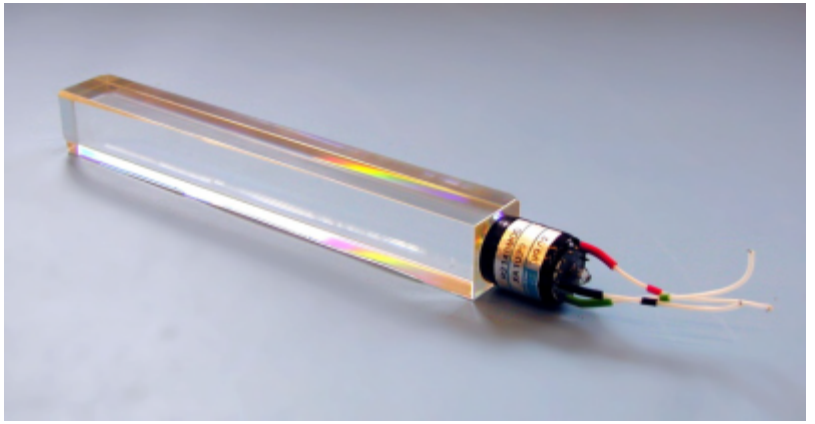
- Endcaps:

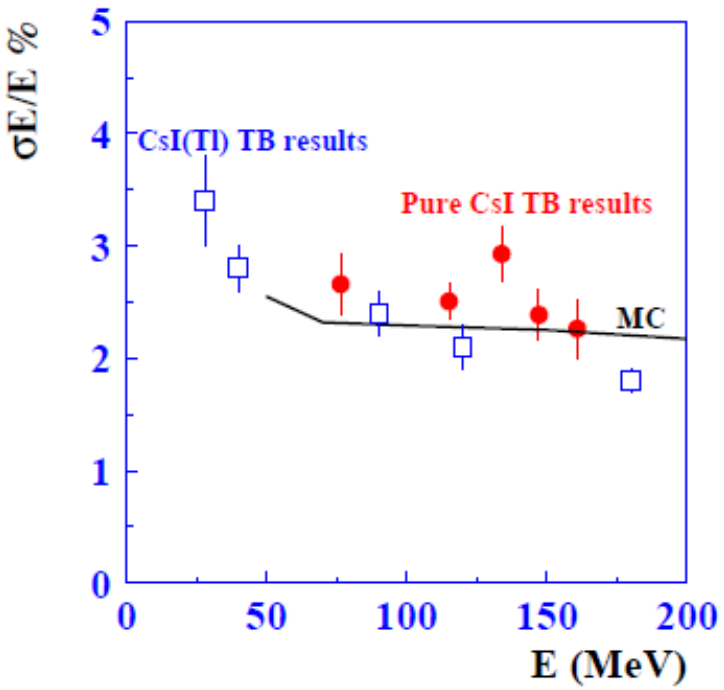
CsI(Tl), crystals reused

16.1 X_0 (30 cm)

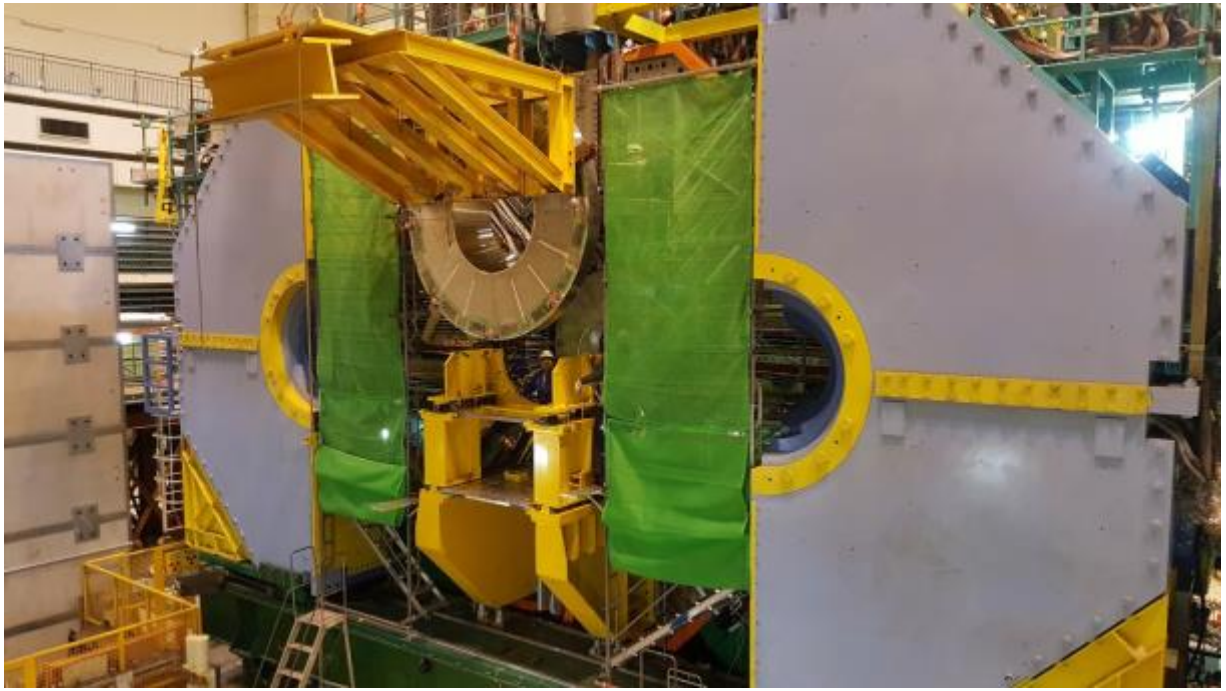
Replacement with pure CsI in future (under study)

Time constant (shaping) 30 ns





Electromagnetic Calorimeter (ECL)



K_L and Muon Systems (KLM)

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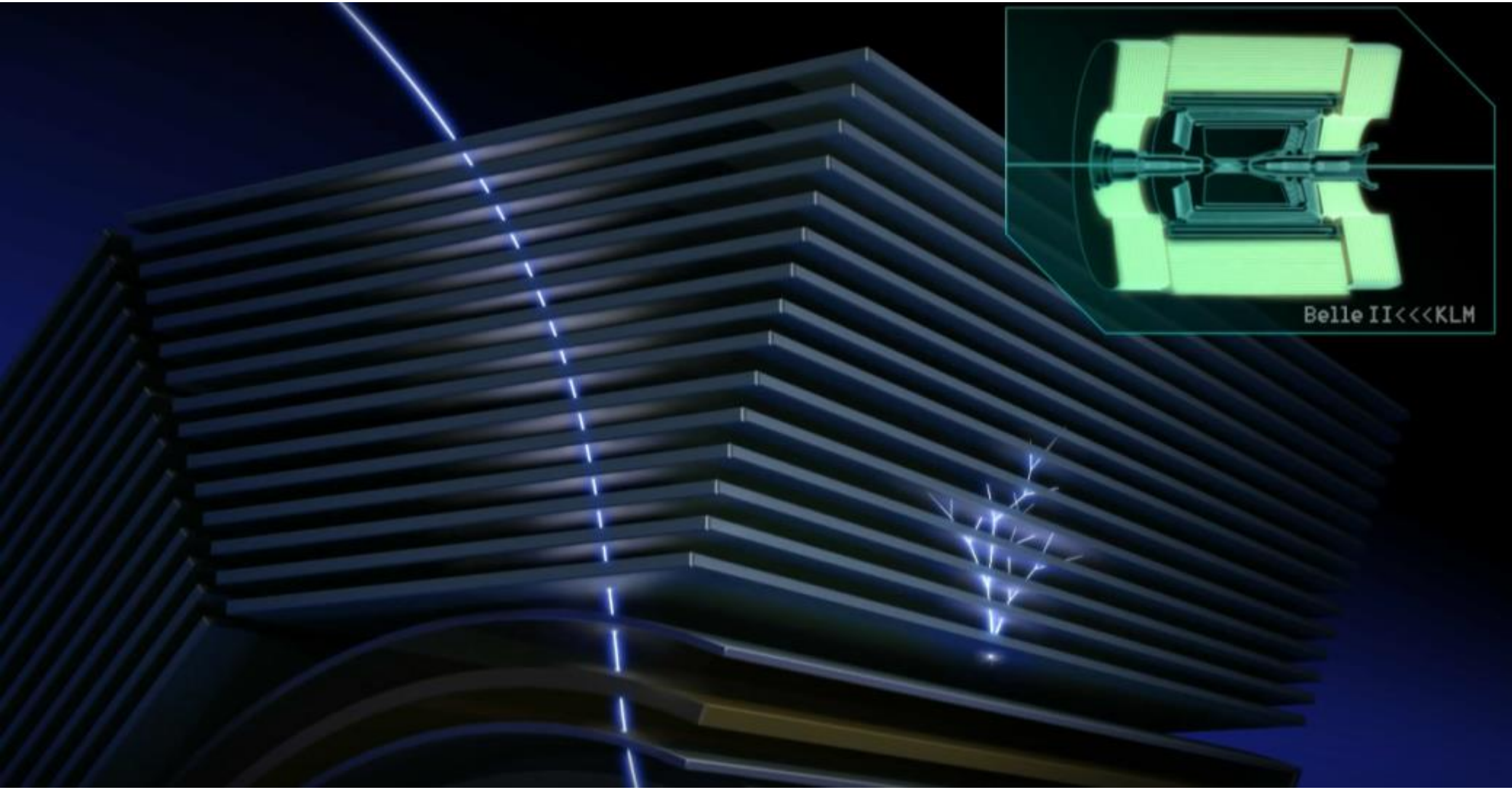
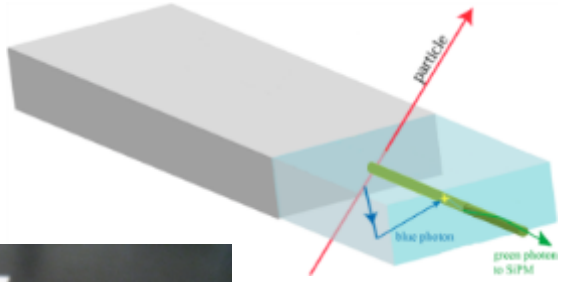


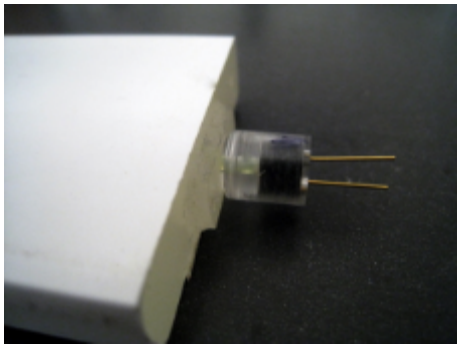
K_L and Muon Systems (KLM)

Large area thin planar detectors interleaved with the iron plates of the flux return yoke.

- Barrel:

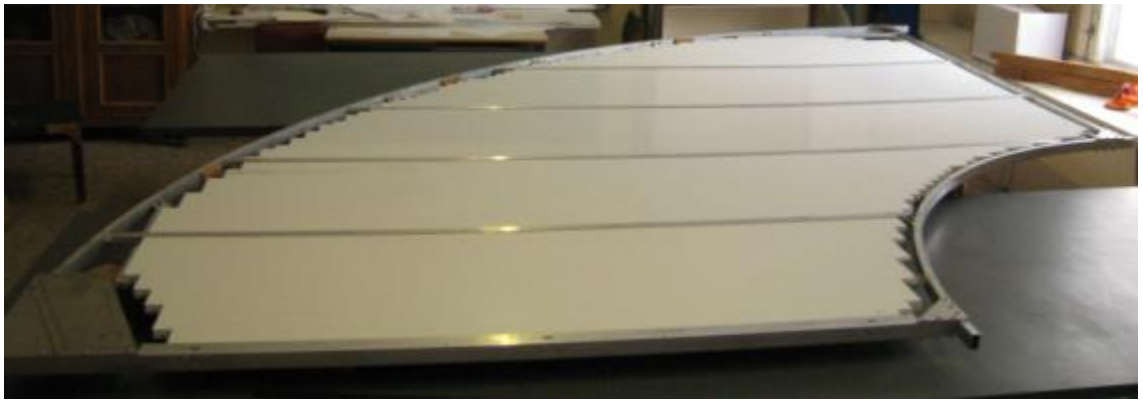
Belle RPCs reused
Two inner layers replaced by scintillator strips (BKG)
Scintillator strips with WLS fibers
Hamamatsu SiPM S10362





- Endcap:

RPCs replaced with polystyrene scintillators
99% geometrical acceptance. σ ~ 1ns



K_L and Muon Systems (KLM)

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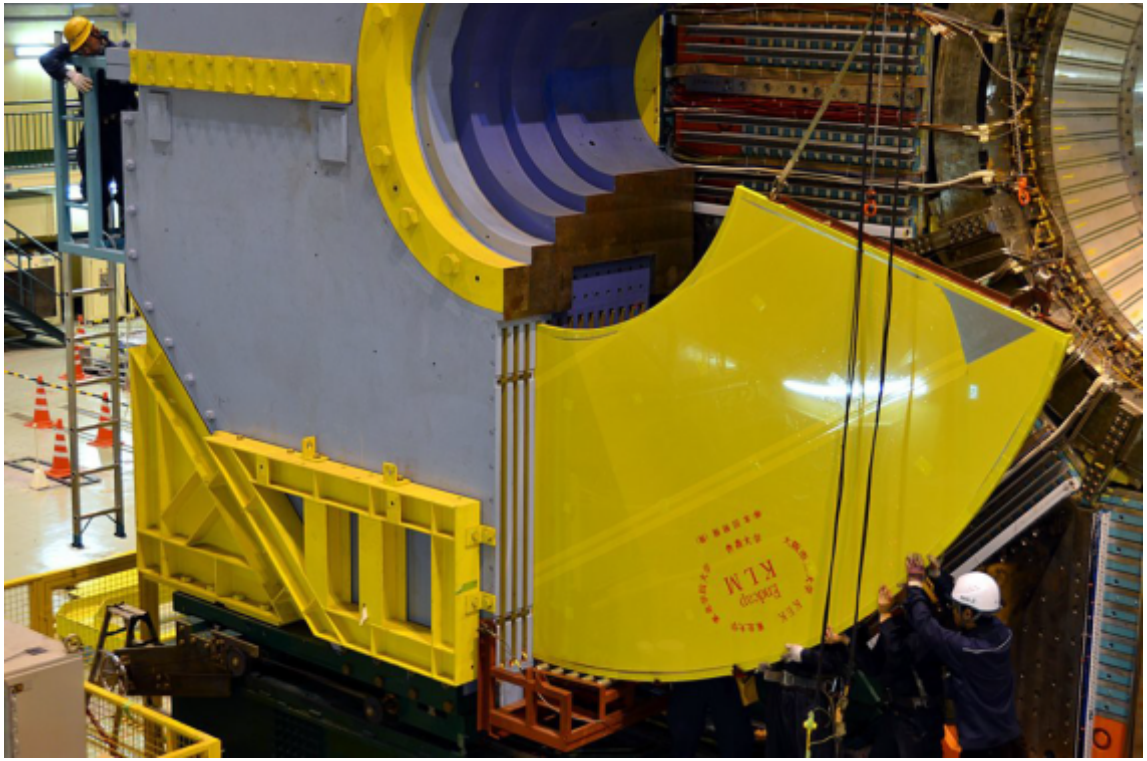
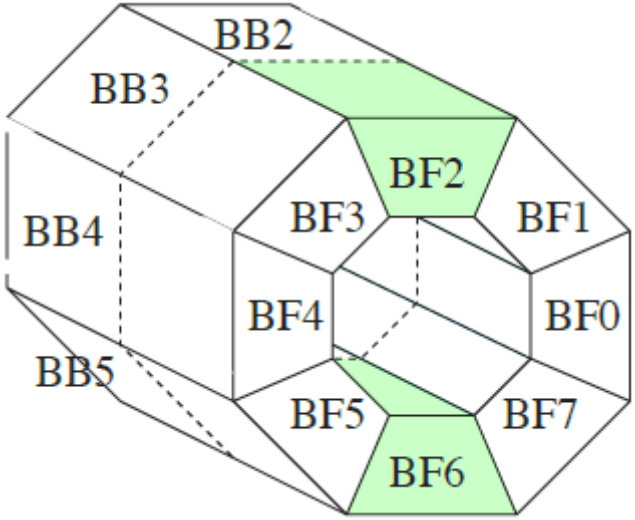
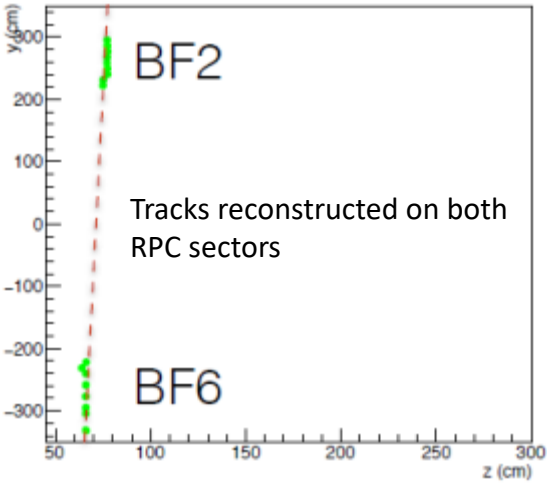
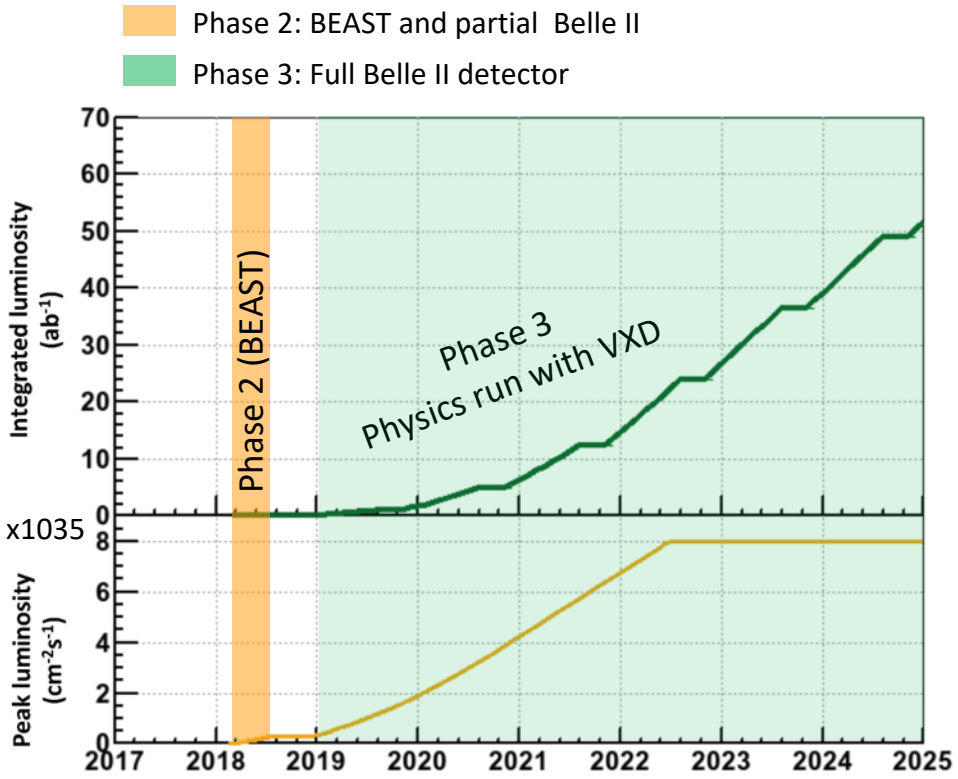






Phase 2



- The SuperKEKB accelerator is operating, for the first time, with QCS magnets
  - First operation with focused beams
  - First beam collisions
- The Belle II detector, minus the vertex detector (VXD), rolled into the beam line

Phase 3 VXD Volume

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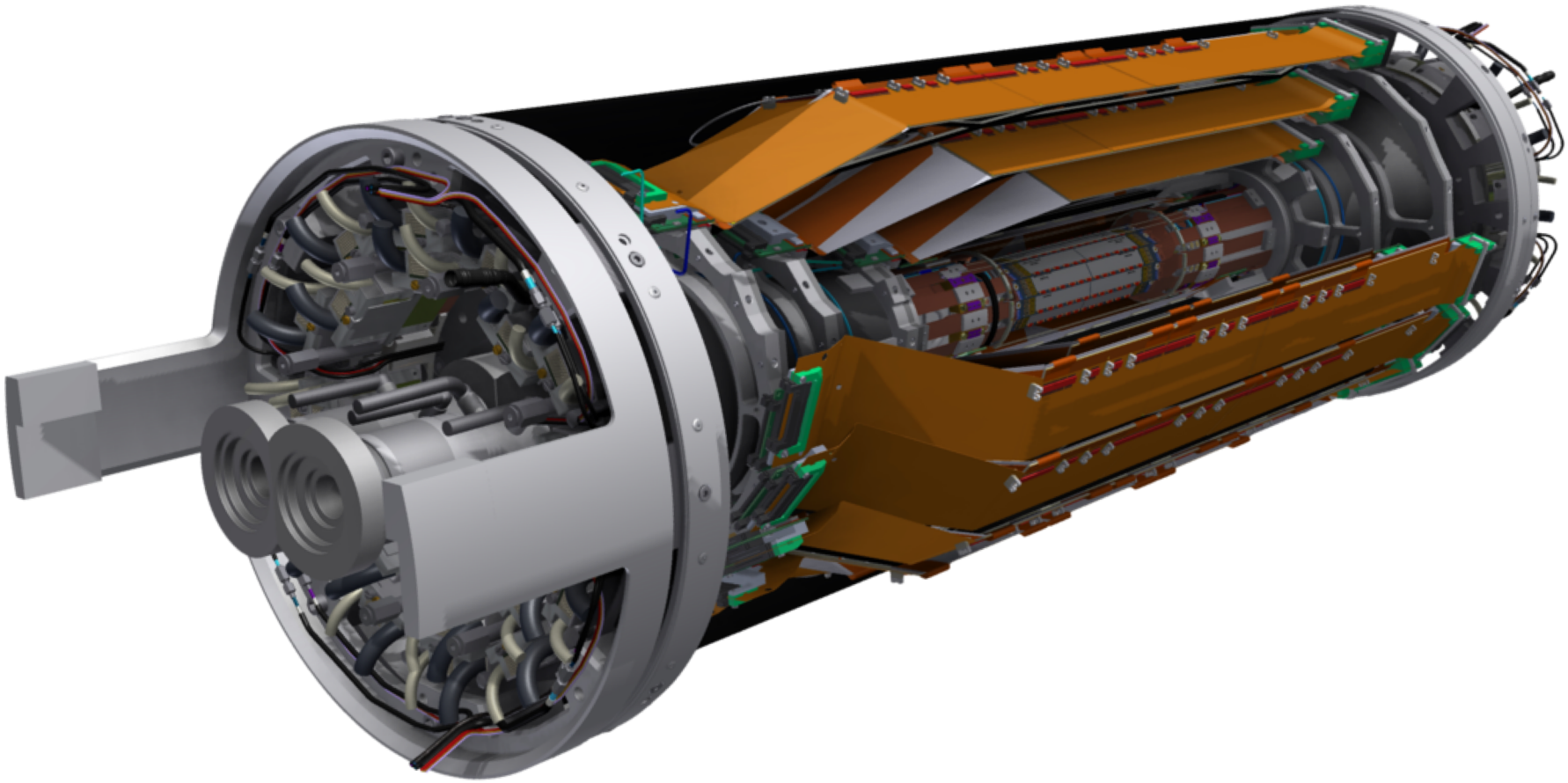
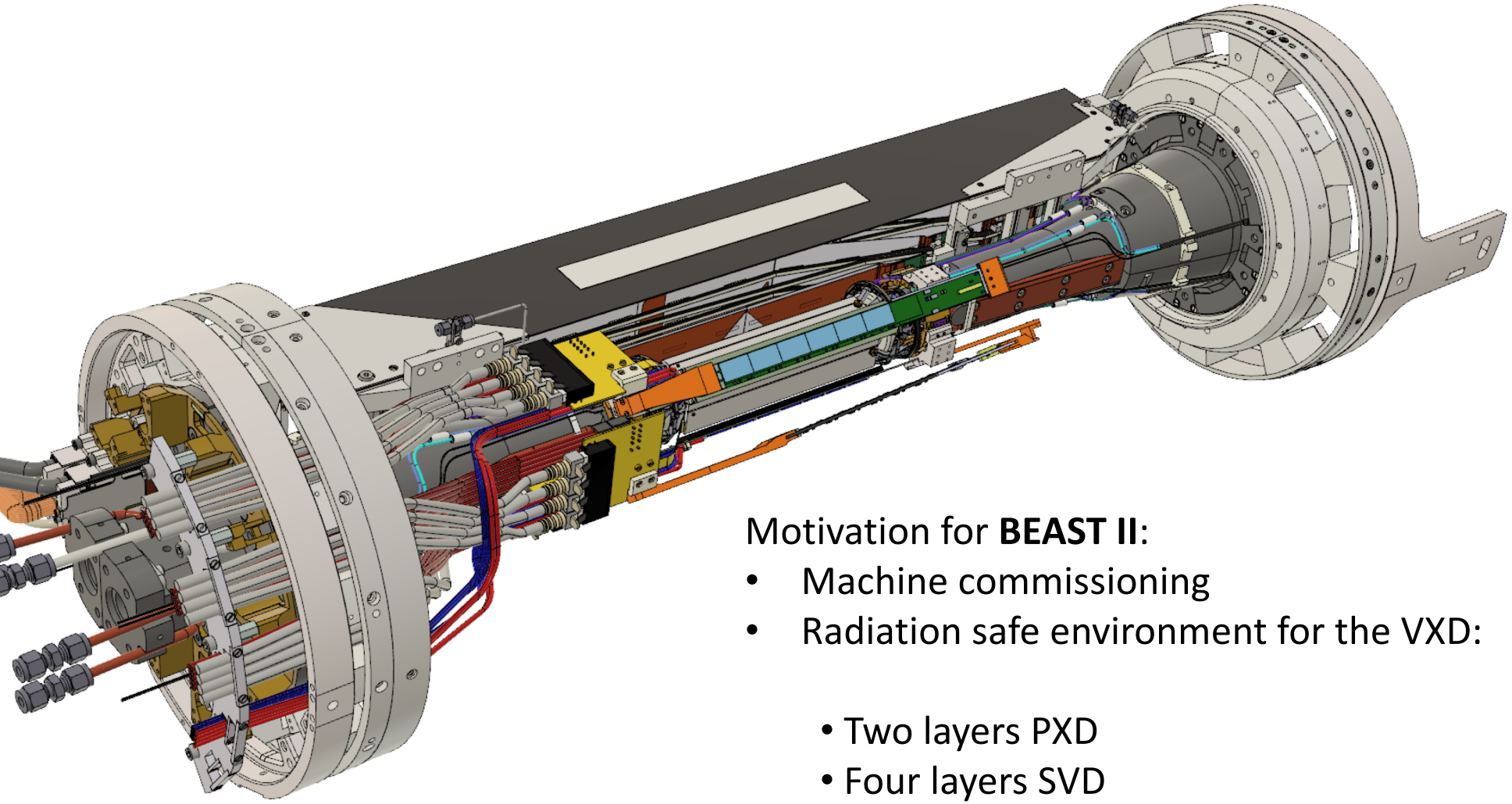


BEAST Commissioning Phase

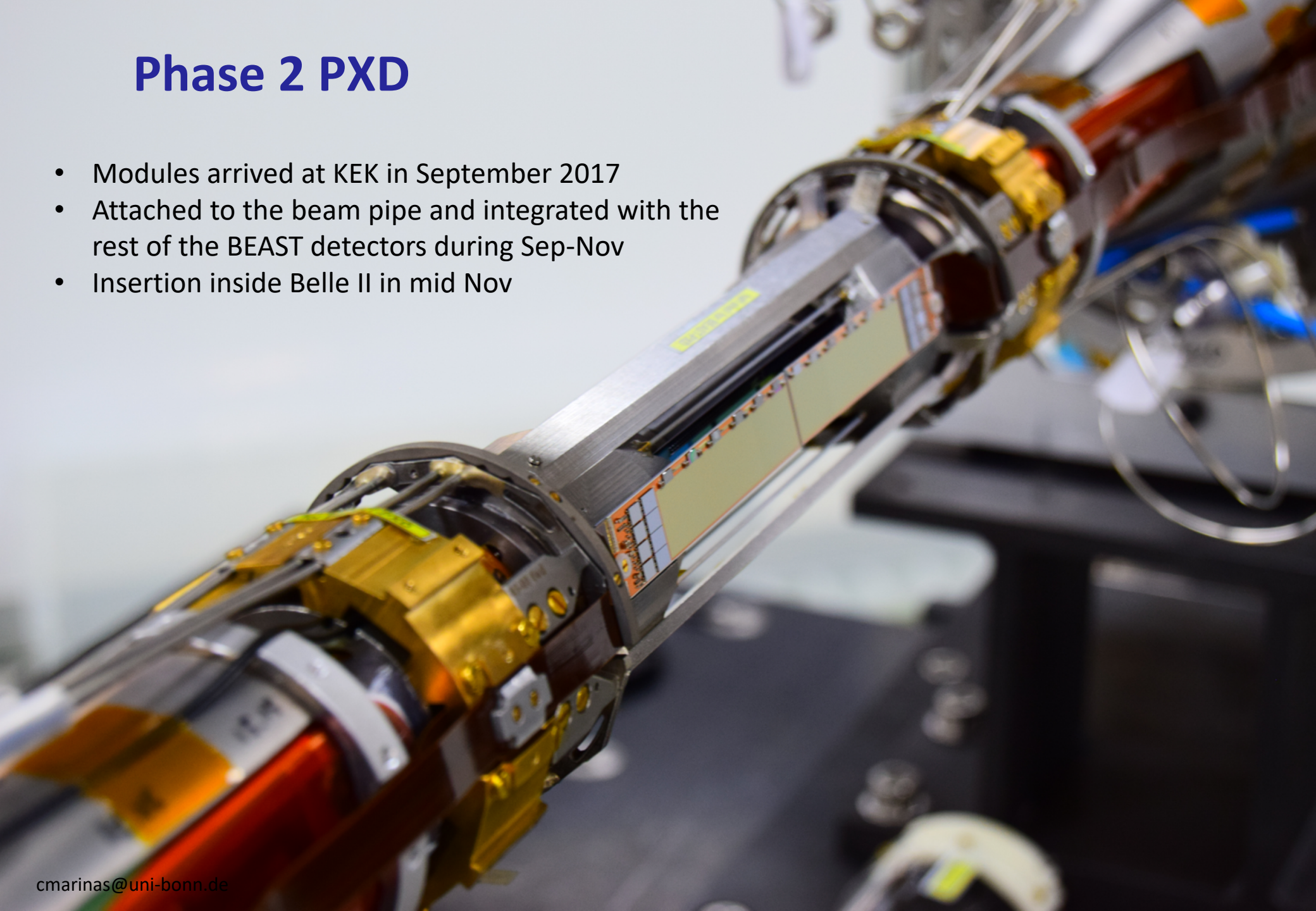


Motivation for **BEAST II**:

- Machine commissioning
- Radiation safe environment for the VXD:
  - Two layers PXD
  - Four layers SVD
  - Dedicated radiation monitors

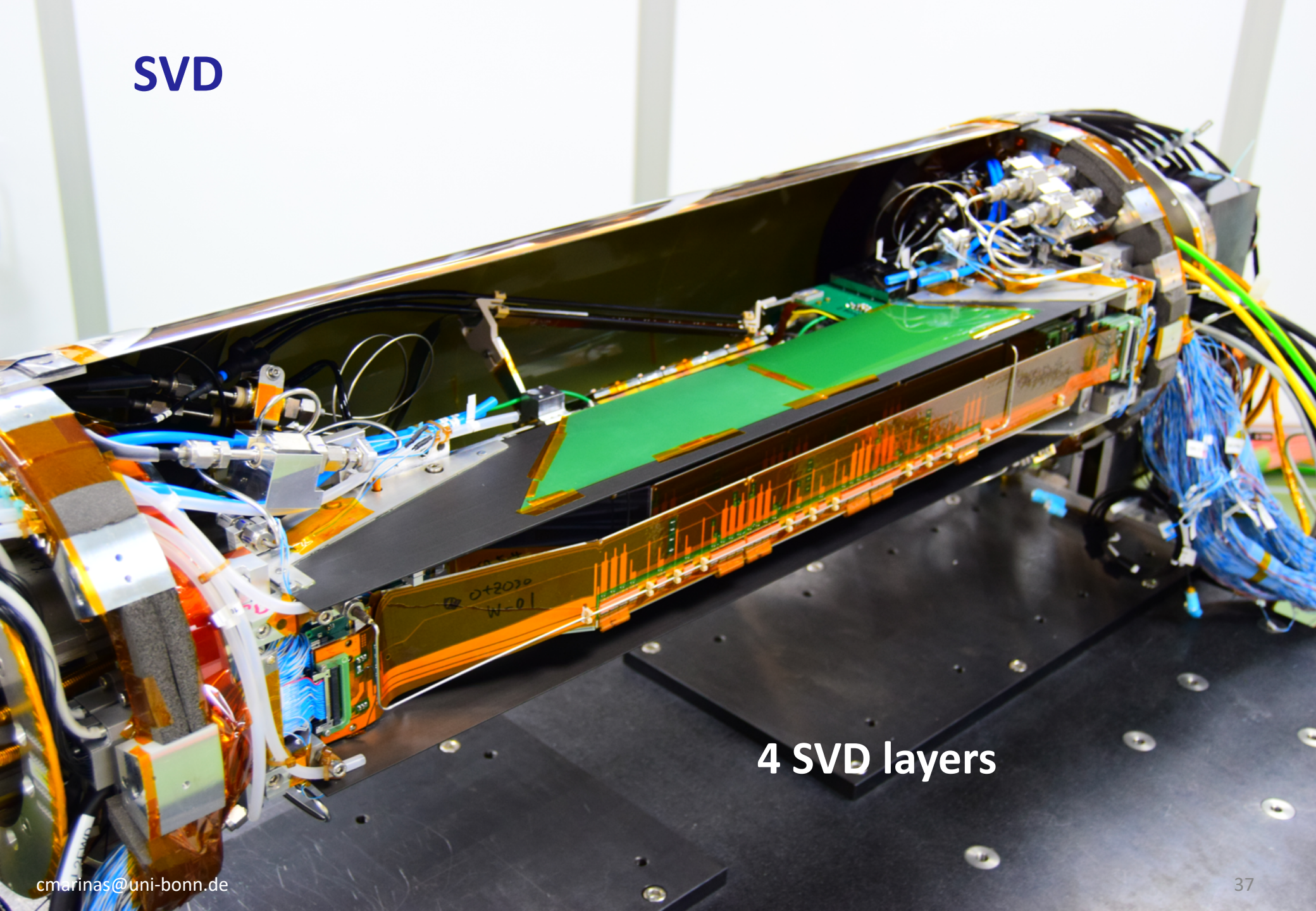
Phase 2 PXD

- Modules arrived at KEK in September 2017
- Attached to the beam pipe and integrated with the rest of the BEAST detectors during Sep-Nov
- Insertion inside Belle II in mid Nov

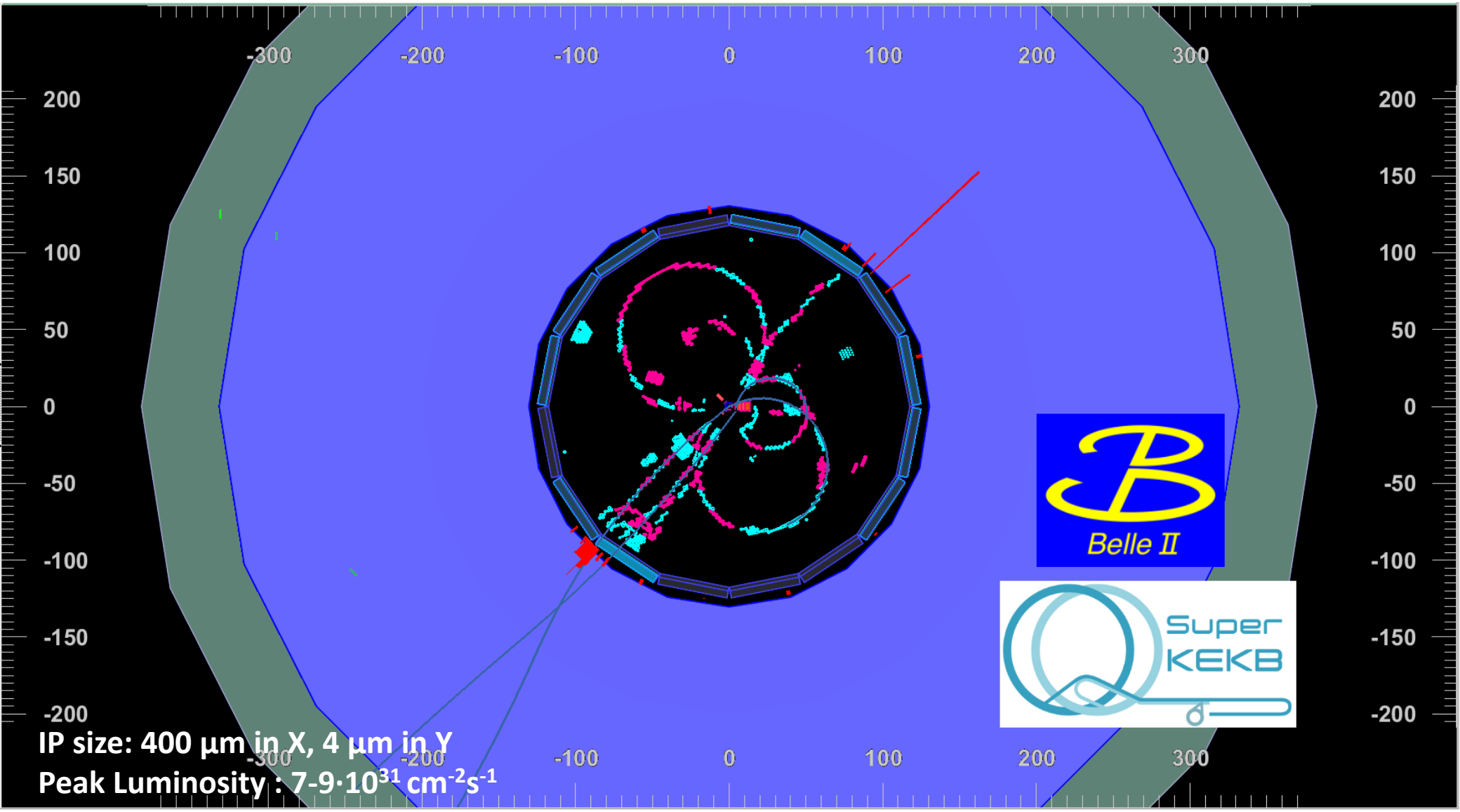


cmarinas@uni-bonn.de

SVD



Belle II First Collision (26 April 2018)



Outlook

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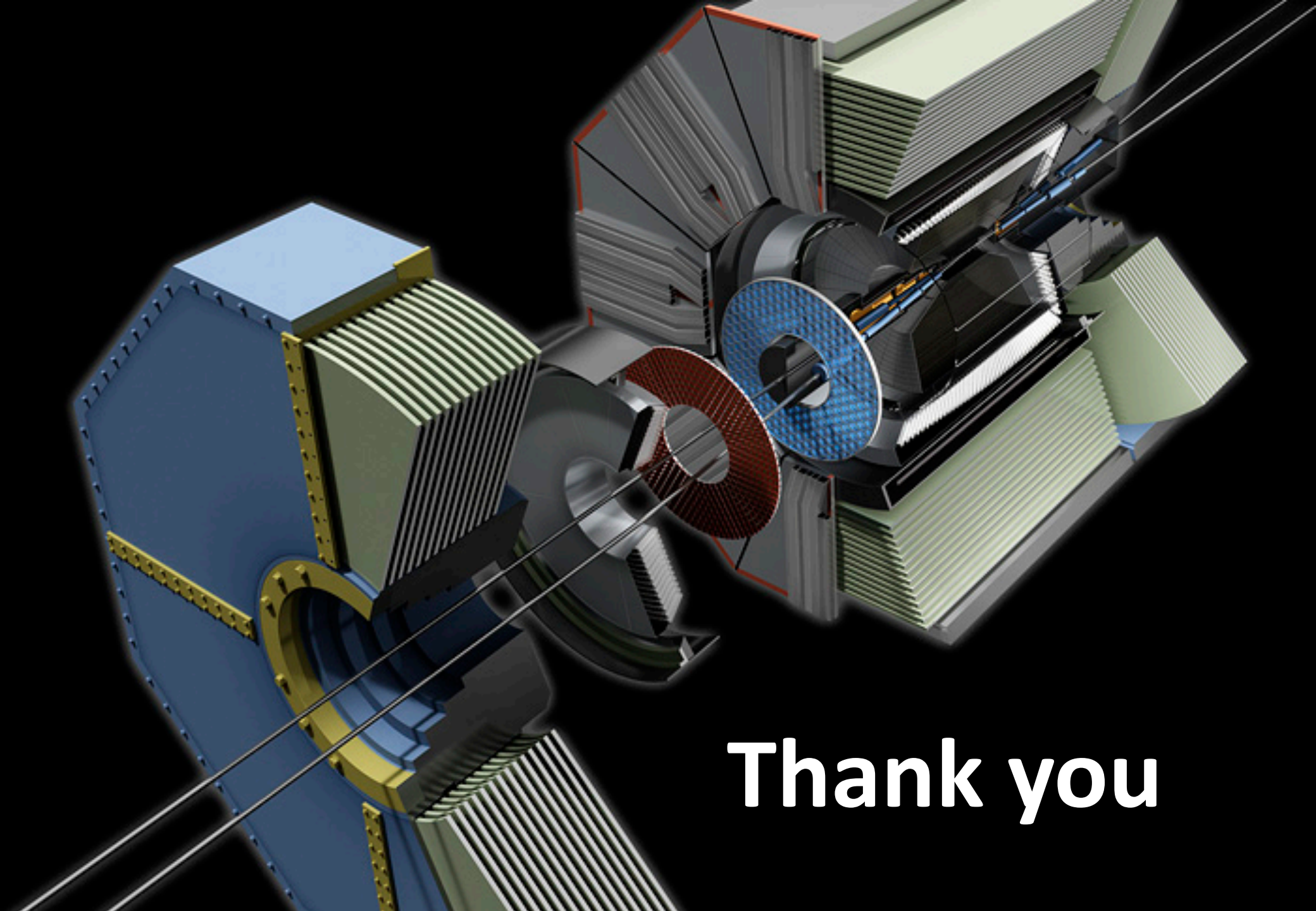
- Belle II will search for New Physics at the intensity frontier with a target integrated luminosity of 50 ab^{-1}
- Phase 2 started!
  - First collisions a week ago
- Phase 2 will run until July. **Physics data beginning 2019** (Phase 3)
- Stay tuned!


Thank you