The Belle II Experiment

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Belle II Collaboration

- B factories
- SuperKEKB
- Belle II

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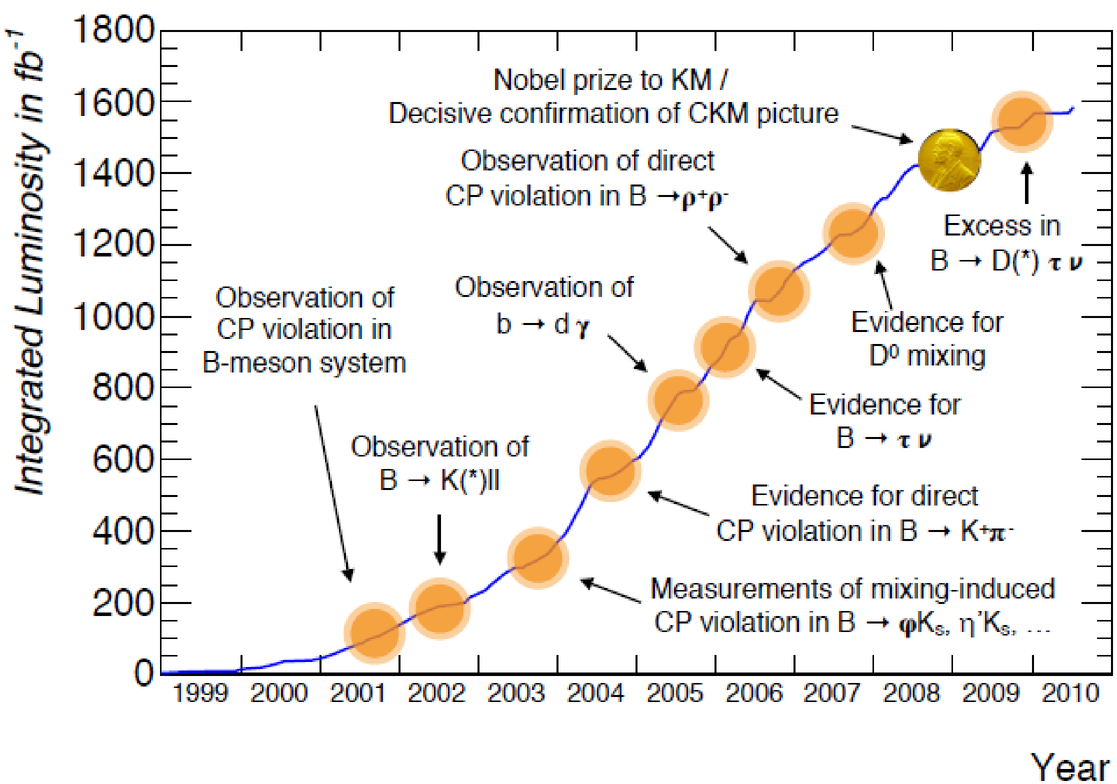
The B Factories: A Success Story

- 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).
- And provided the experimental confirmation that led to the 2008 Nobel prize 'for the discovery of the origin of the broken symmetry which predicts the existence of at least three families of quarks in nature'



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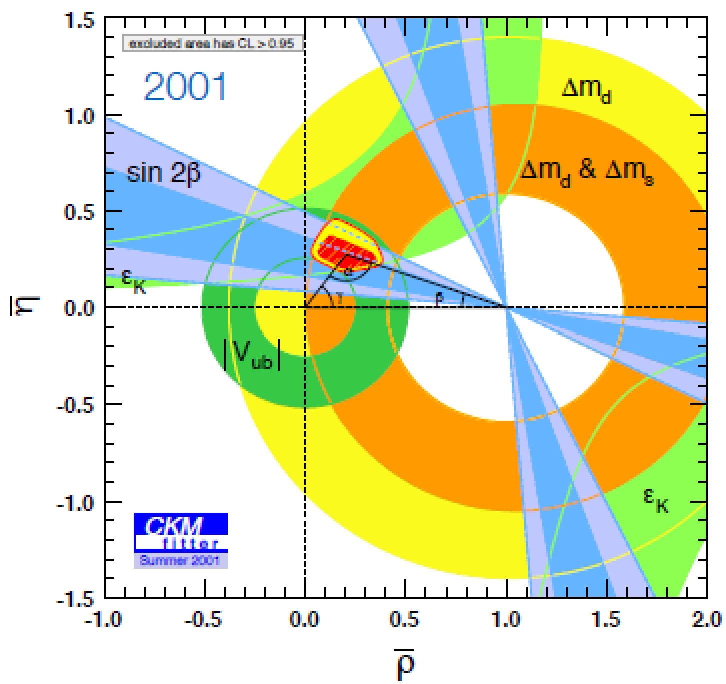
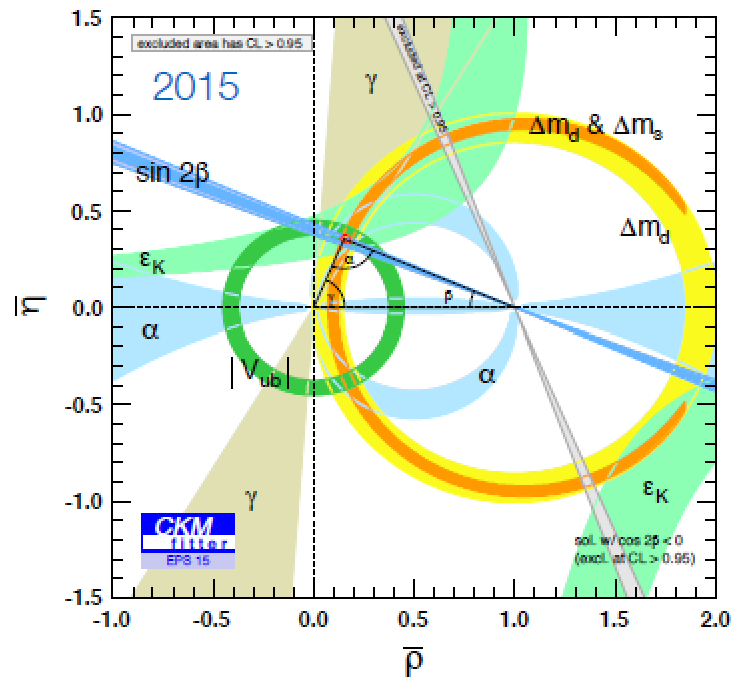




Is this the end of B-physics?

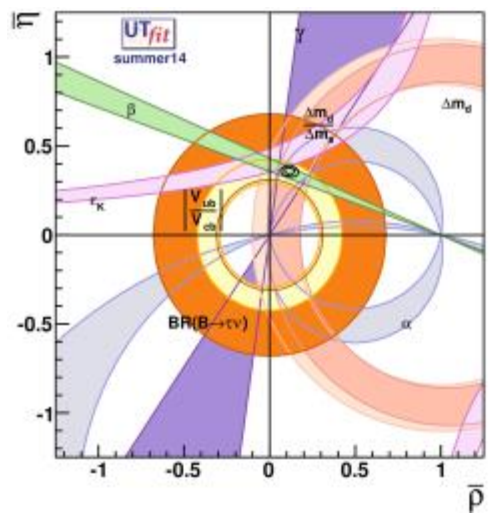
Super Flavor Factory

- There is still room for new physics contributions. Many potential sources:
  - Flavor changing neutral currents
  - Lepton flavor violating decays
  - B → τ tree level new physics
  - Precision CKM measurements/new sources of CPV

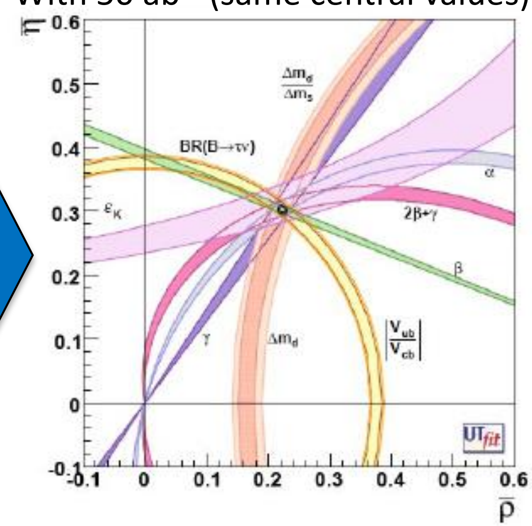
Observable	SM theory	Current measurement (early 2013)	Belle II * ($50\,\mathrm{ab}^{-1}$)
$S(B \to \phi K^0)$	0.68	0.56 ± 0.17	± 0.018
$S(B \to \eta' K^0)$	0.68	0.59 ± 0.07	± 0.011
α from $B \to \pi\pi, \rho\rho$		$\pm 5.4°$	$\pm 1°$
γ from $B \to DK$		$\pm 11°$	$\pm 1.5°$
$S(B \to K_S \pi^0 \gamma)$	< 0.05	-0.15 ± 0.20	± 0.035
$S(B \to \rho\gamma)$	< 0.05	-0.83 ± 0.65	± 0.07
$A_{CP}(B \to X_{s+d}\gamma)$	< 0.005	0.06 ± 0.06	± 0.005
A^d_{SL}	-5×10^{-4}	-0.0049 ± 0.0038	± 0.001
$\mathcal{B}(B \to \tau\nu)$	1.1×10^{-4}	$(1.64 \pm 0.34) \times 10^{-4}$	$\pm 3\%$
$\mathcal{B}(B \to \mu\nu)$	4.7×10^{-7}	$< 1.0 \times 10^{-6}$	$\gg 5\sigma$
$\mathcal{B}(B \to X_s\gamma)$	3.15×10^{-4}	$(3.55 \pm 0.26) \times 10^{-4}$	$\pm 6\%$
$\mathcal{B}(B \to K^{(*)}\nu\bar{\nu})$	3.6×10^{-6}	$< 1.3 \times 10^{-5}$	$\pm 15\%$
$\mathcal{B}(B \to X_s\ell^+\ell^-)$ $(1 < q^2 < 6\,\mathrm{GeV}^2)$	1.6×10^{-6}	$(4.5 \pm 1.0) \times 10^{-6}$	$\pm 0.10 \times 10^{-6}$
$A_{FB}(B^0 \to K^{*0}\ell^+\ell^-)$ zero crossing	7%	18%	5%
$\lvert V_{ub}\rvert$ from $B \to \pi\ell^+\nu$ $(q^2 > 16\,\mathrm{GeV}^2)$	9% → 2%	11%	2.1%

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

2014 constraints

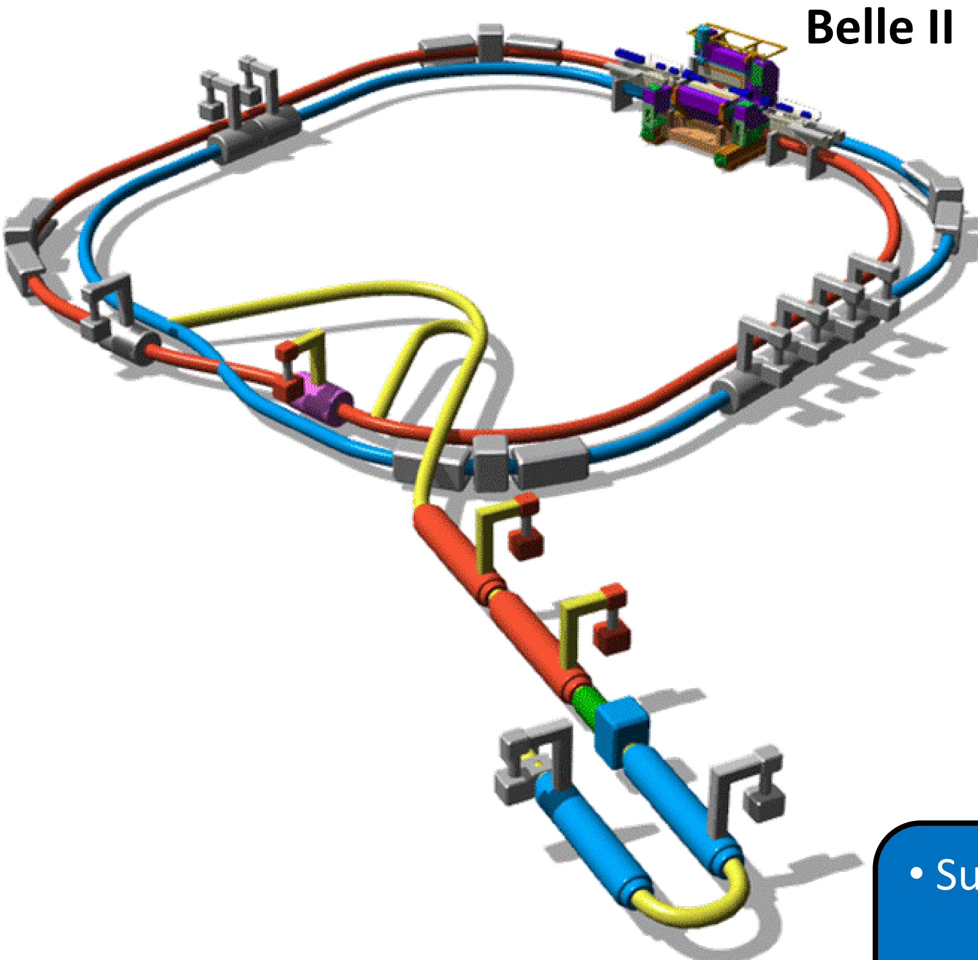


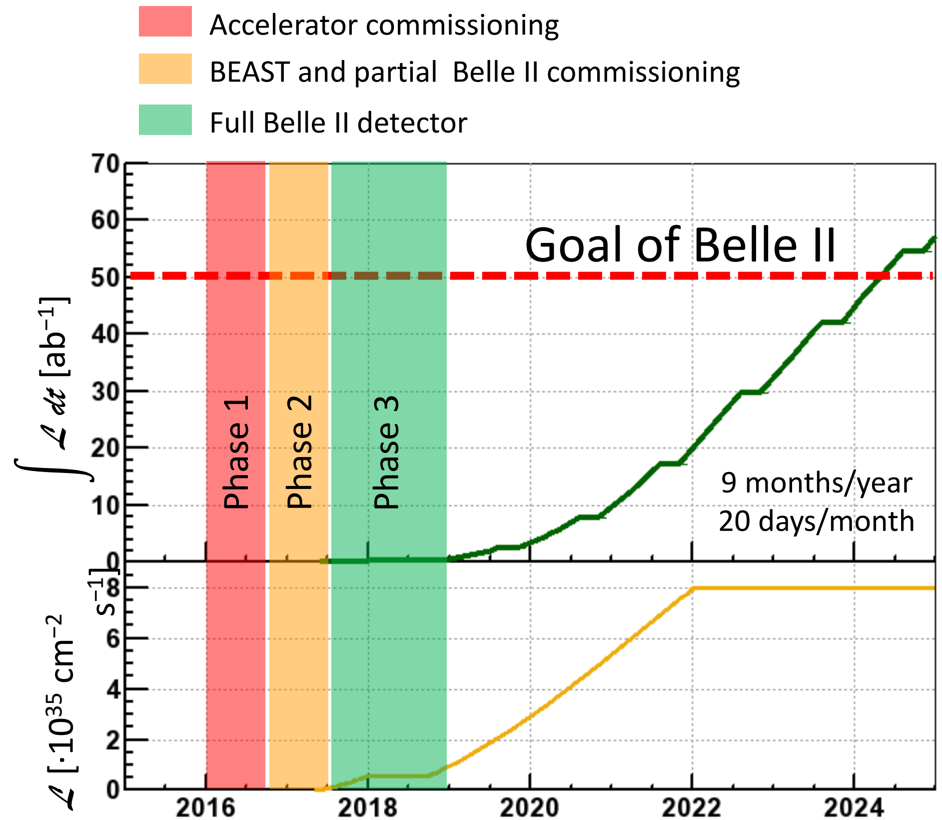
With 50 ab^{-1} (same central values)



→ Need 50 ab^{-1}

The SuperKEKB Accelerator



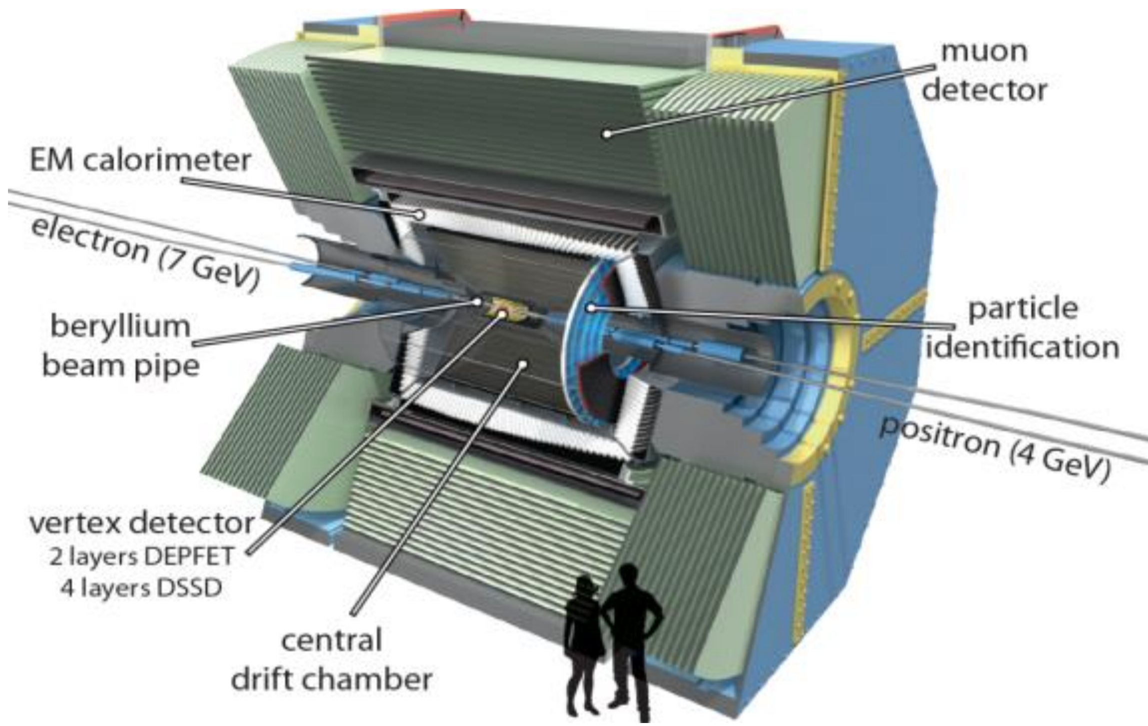


- SuperKEKB: Asymmetric energy e^+e^- collider
  $E_{cm} = m(\Upsilon(4S)) = 10.58$ GeV
- Peak luminosity: $\mathcal{L} = 8 \cdot 10^{35}$ cm^{-2} s^{-1} (x40 than KEKB)
  Beam size reduction (nm). Higher current (x2)

The Belle II Detector

Higher luminosity implies

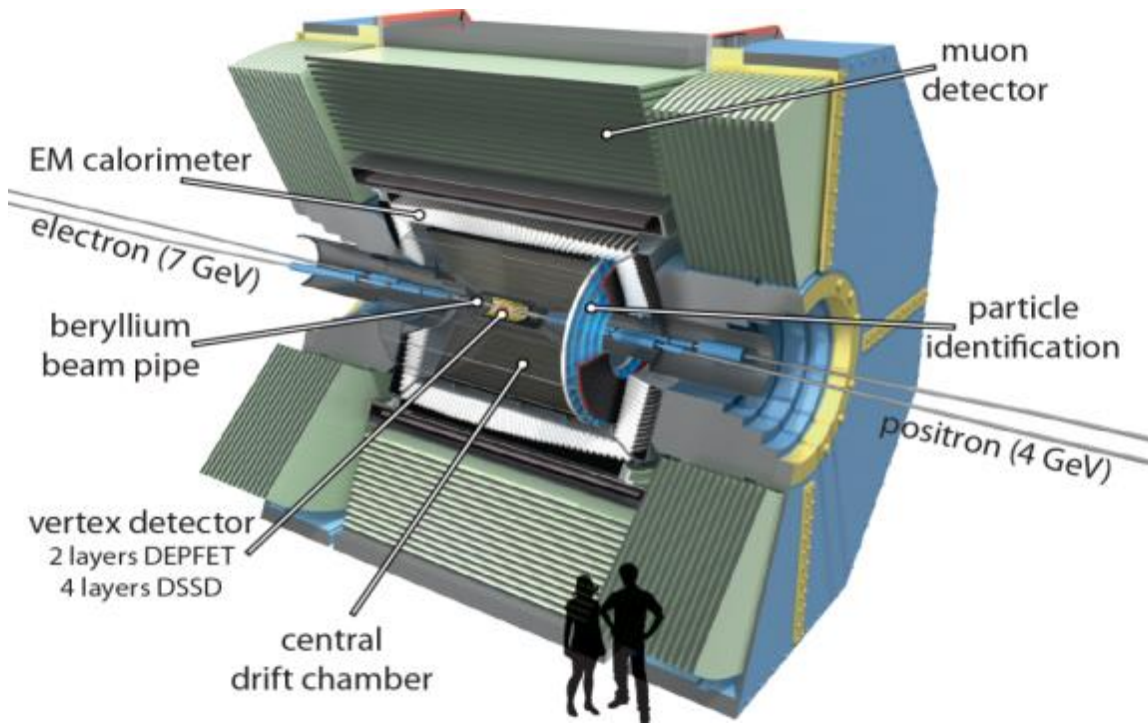
- Higher background
  - Radiation damage
  - Occupancy
  - Fake hits and pile-up
- Higher event rate
  - Higher trigger rate
  - Increased DAQ and computing requirements
- Changes in detector
  - $\beta\gamma$ reduced by factor 1.5
  - Improved vertexing needed



→ New detector: **Belle II**

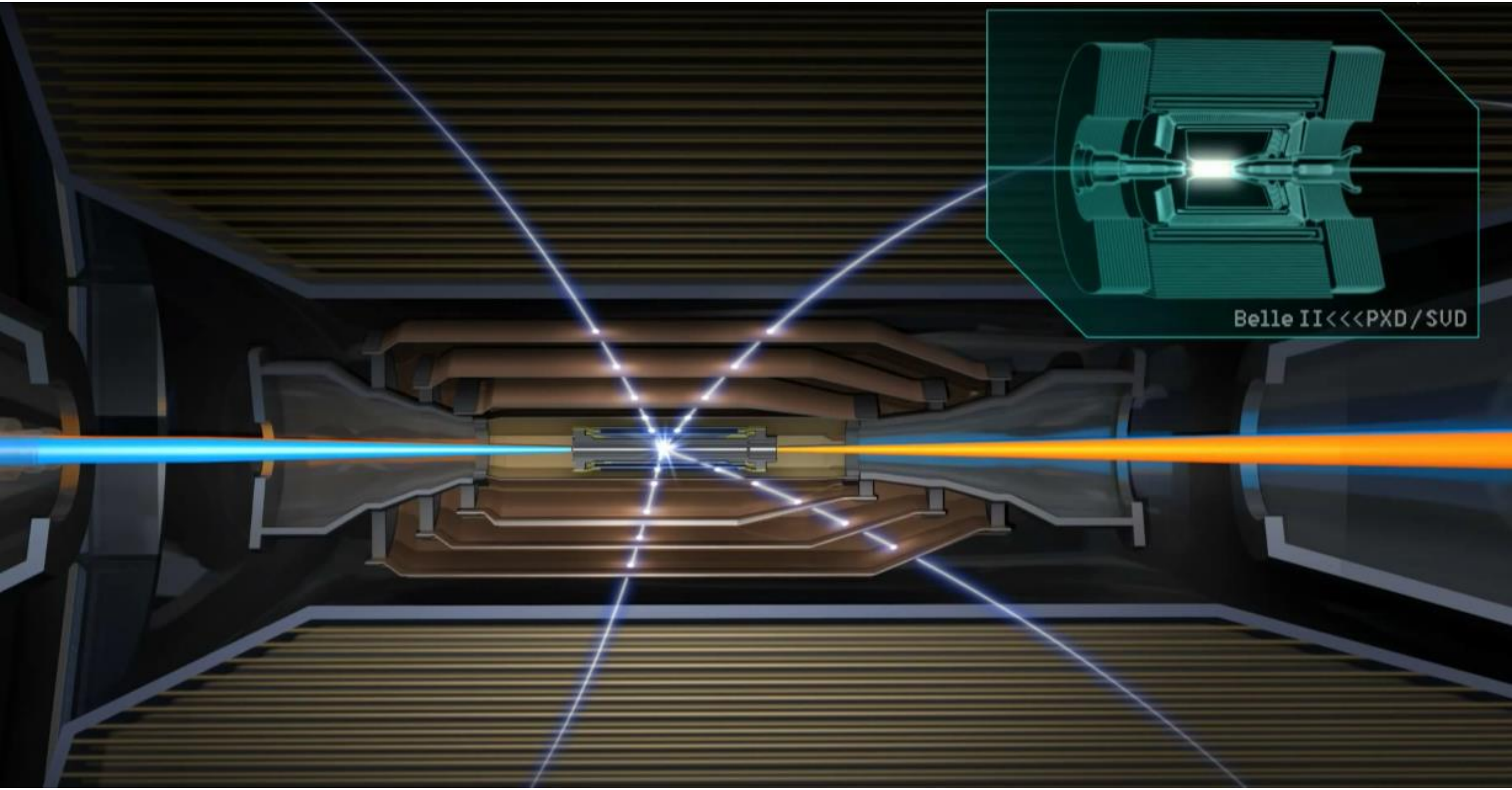
The Belle II Detector

- Detector requirements
  - Light material
  - Vertexing capability
  - Particle identification
  - E.M. calorimetry
  - K^0_L and muon ID
  - Data handling capabilities



Ready for physics run in **2018**

Vertex Detector (VXD)



Vertex Detector

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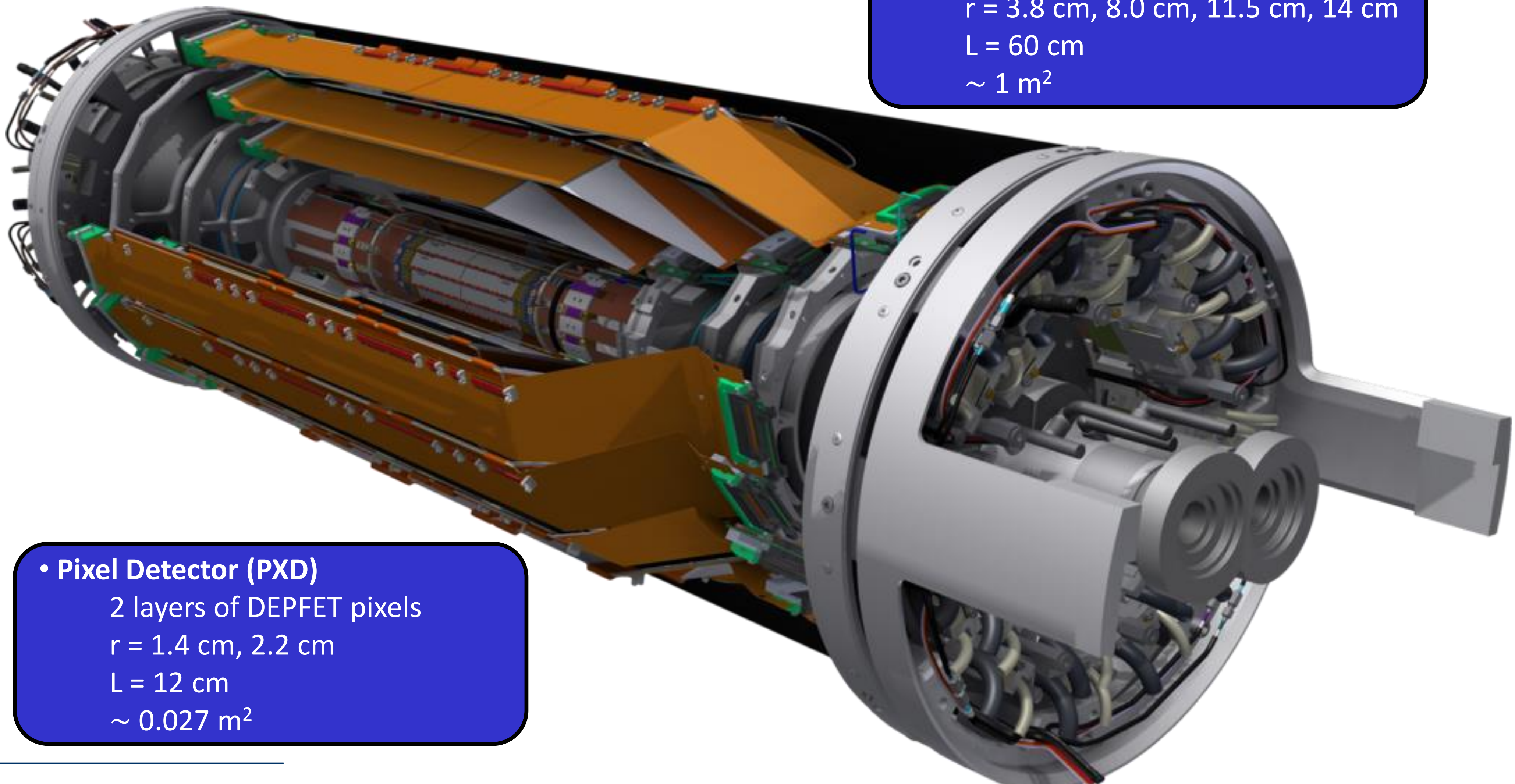
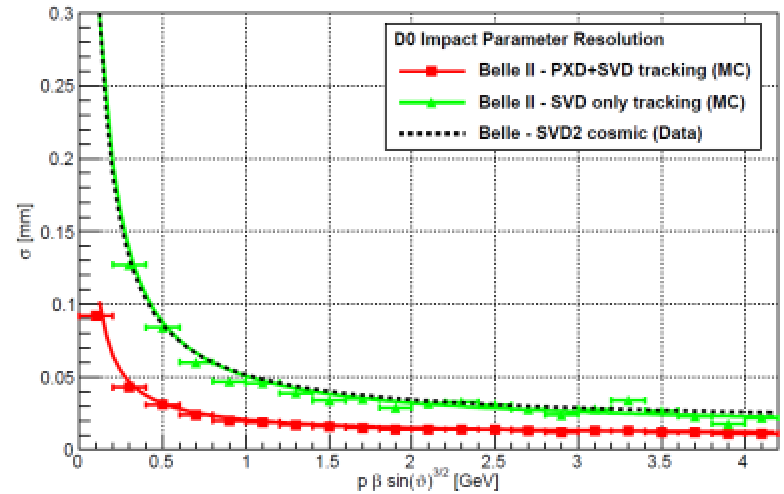


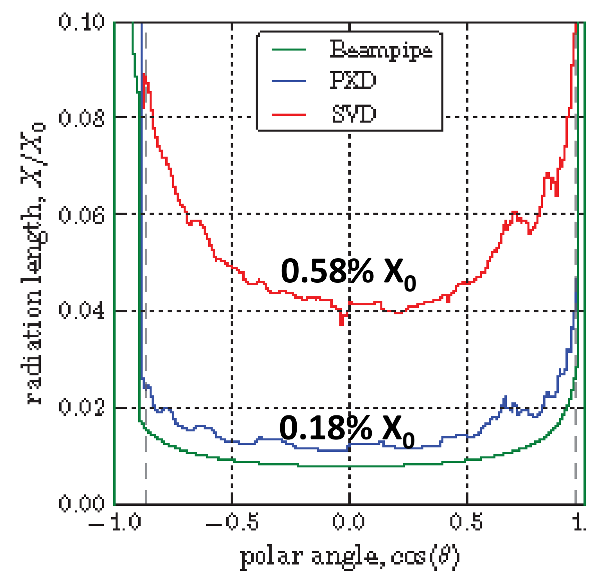
- **Silicon Vertex Detector (SVD)**
  4 layers of DSSD
  r = 3.8 cm, 8.0 cm, 11.5 cm, 14 cm
  L = 60 cm
  $\sim 1\ m^2$

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

Belle II Vertex Detector Requirements

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

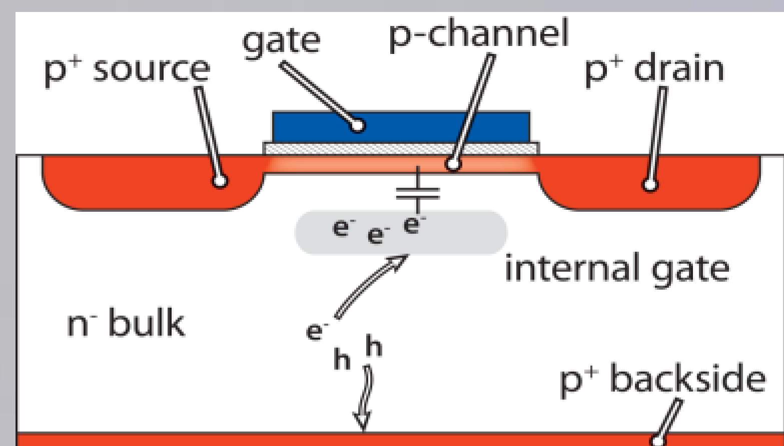




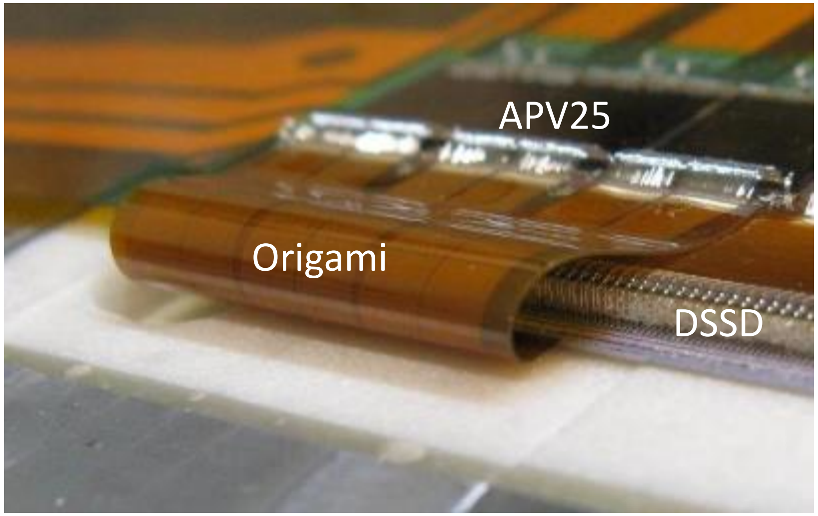
- Modest resolution (15 µm), dominated by multiple scattering → Pixel size (50 x 75 µm²)
- Lowest possible material budget (0.2% X_0/layer)
  - Ultra-transparent detectors
  - Lightweight mechanics and minimal services

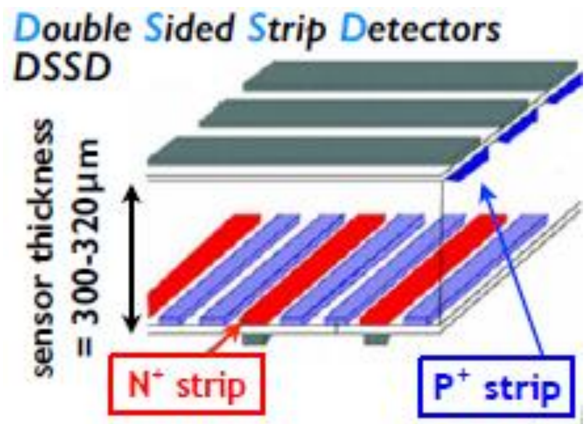
Belle II PXD Module

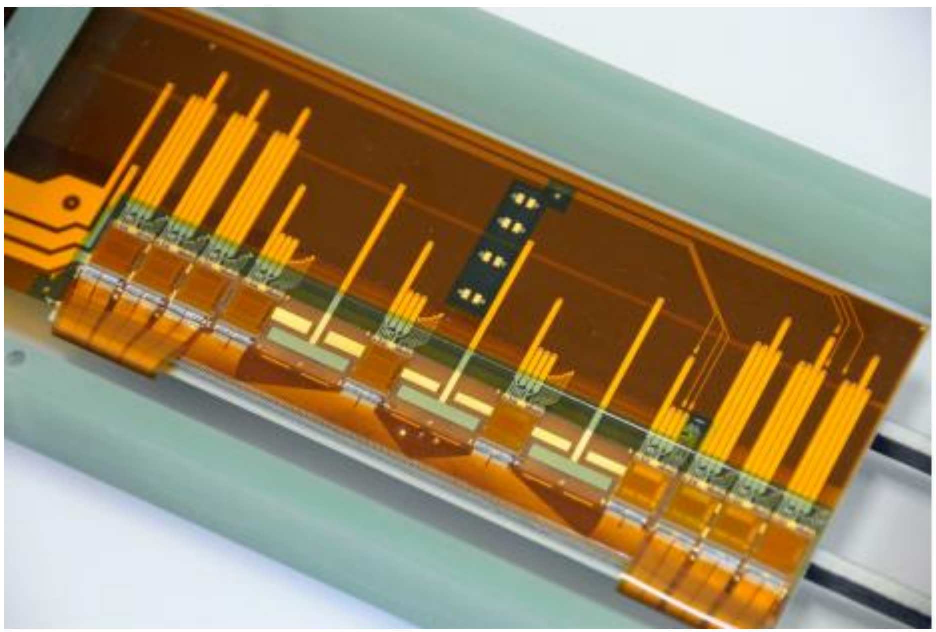
- 768x250 DEPFET Pixels
- 50x75 μm^2 pixel pitch
- 75 μm thickness

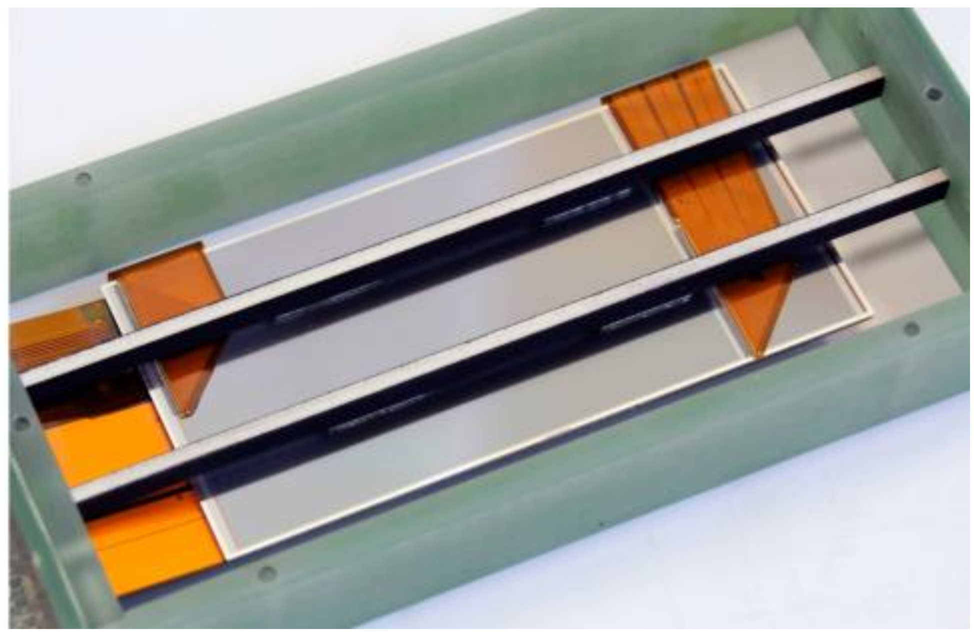


Belle II SVD Module

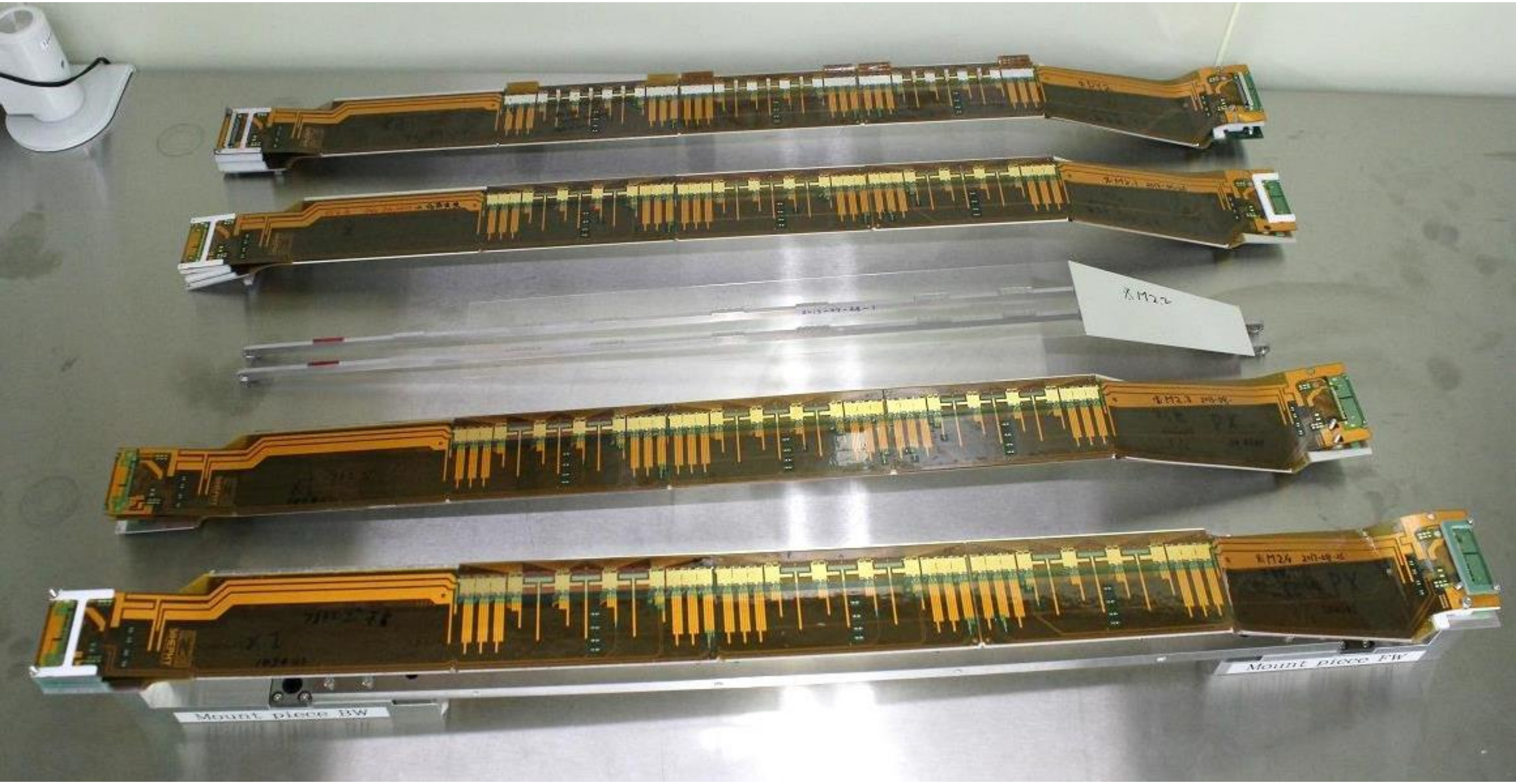








Layer 6 Ladders



Belle II Vertex Detector Beam Tests

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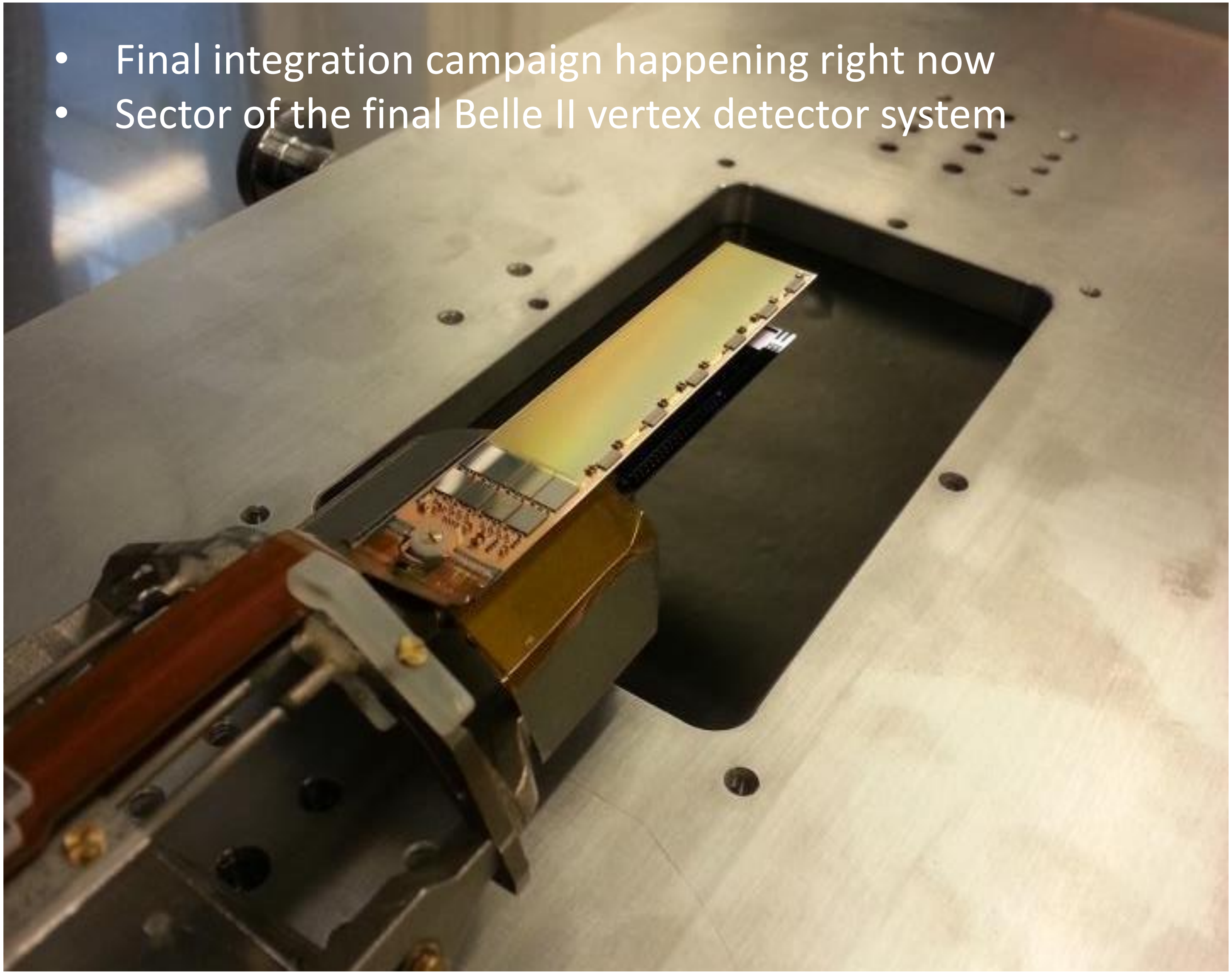
- Final integration campaign happening right now
- Sector of the final Belle II vertex detector system



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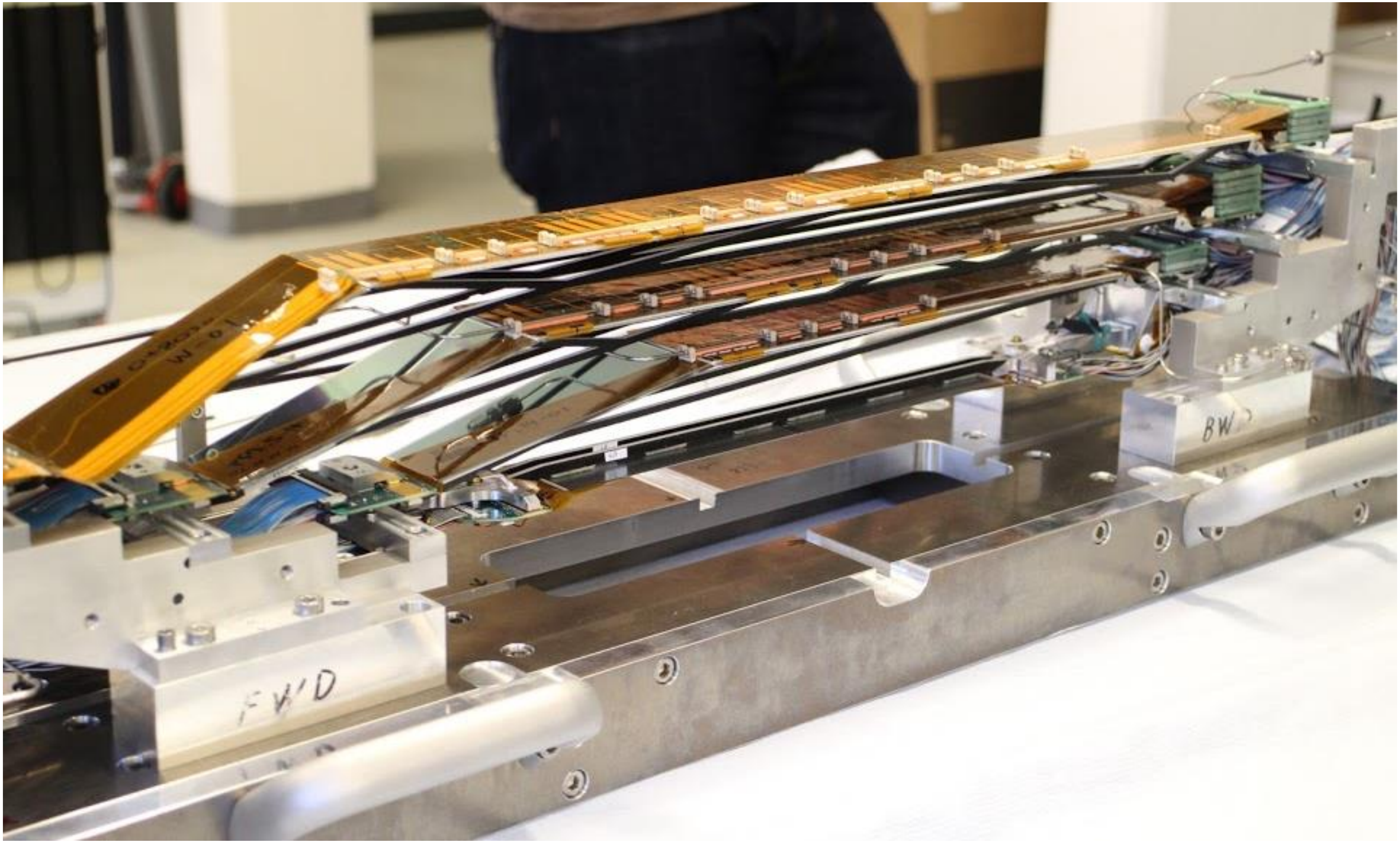
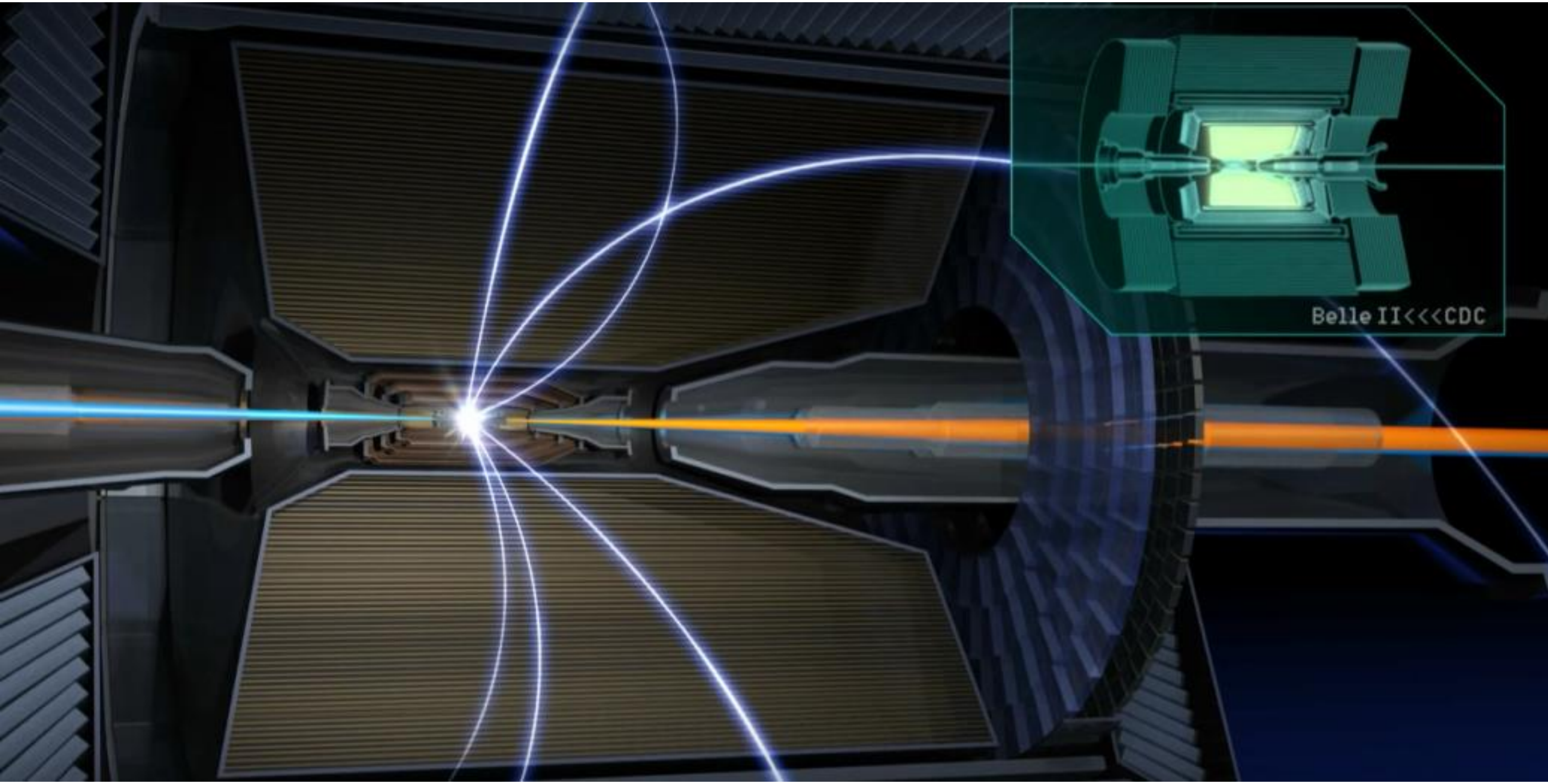


Central Drift Chamber (CDC)

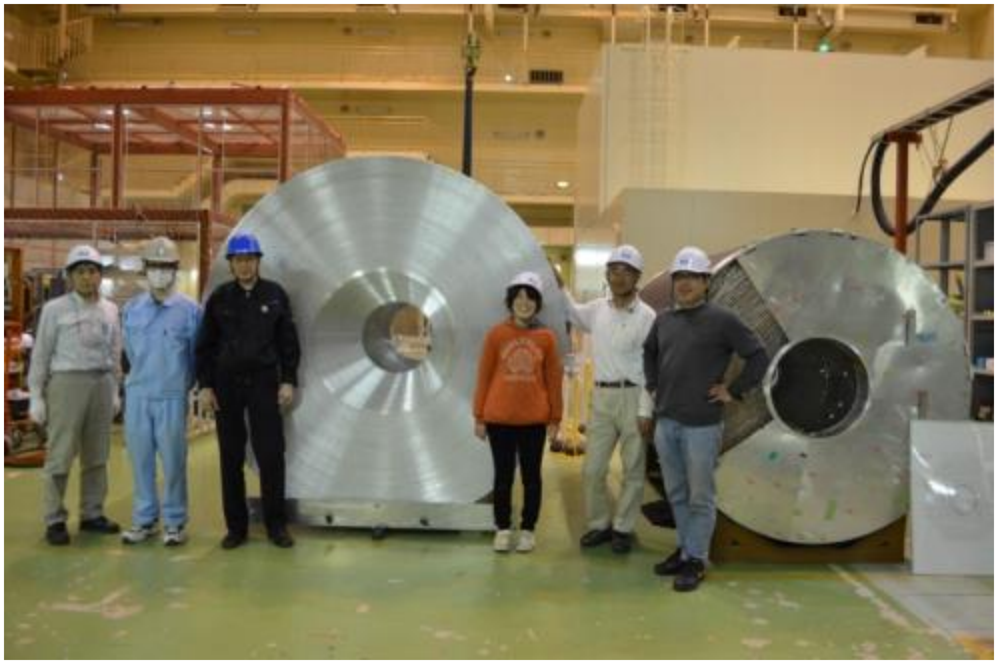


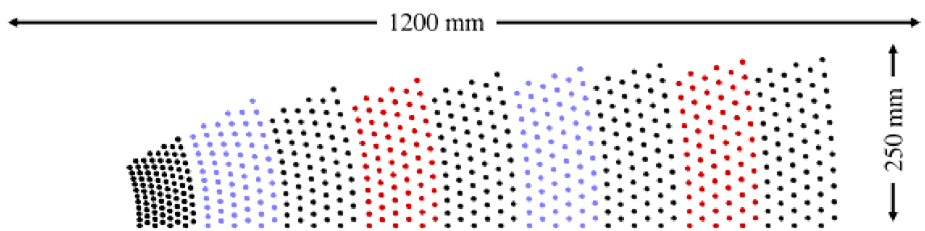
Central Drift Chamber (CDC)

Three important roles:

- Track reconstruction and momentum determination
- Particle identification via dE/dx
- Trigger for background reduction (3D z trigger)

	Belle II CDC
Number of layers	56
Total sense wires	14336
Gas	He:C_2H_6
Sense wire	W (ø30 µm)
Field wire	Al (ø120 µm)





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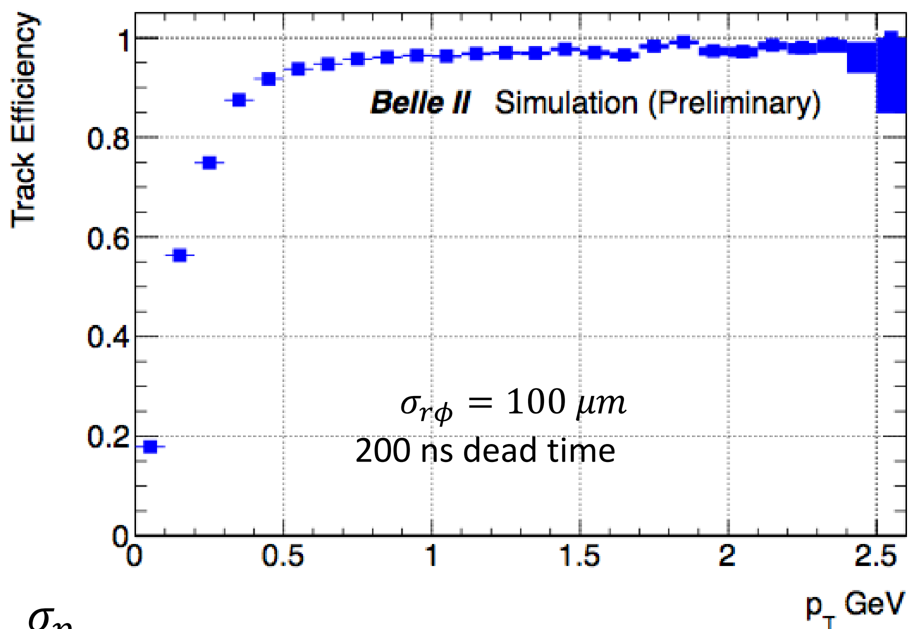
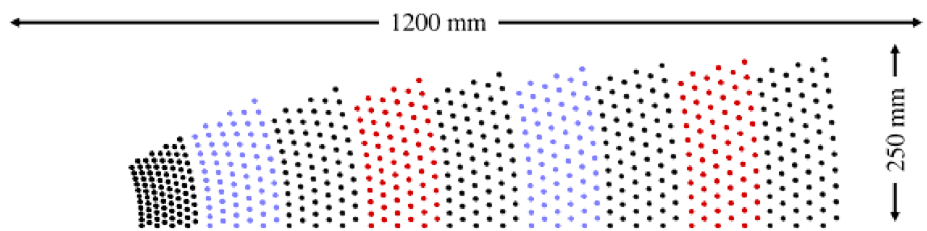
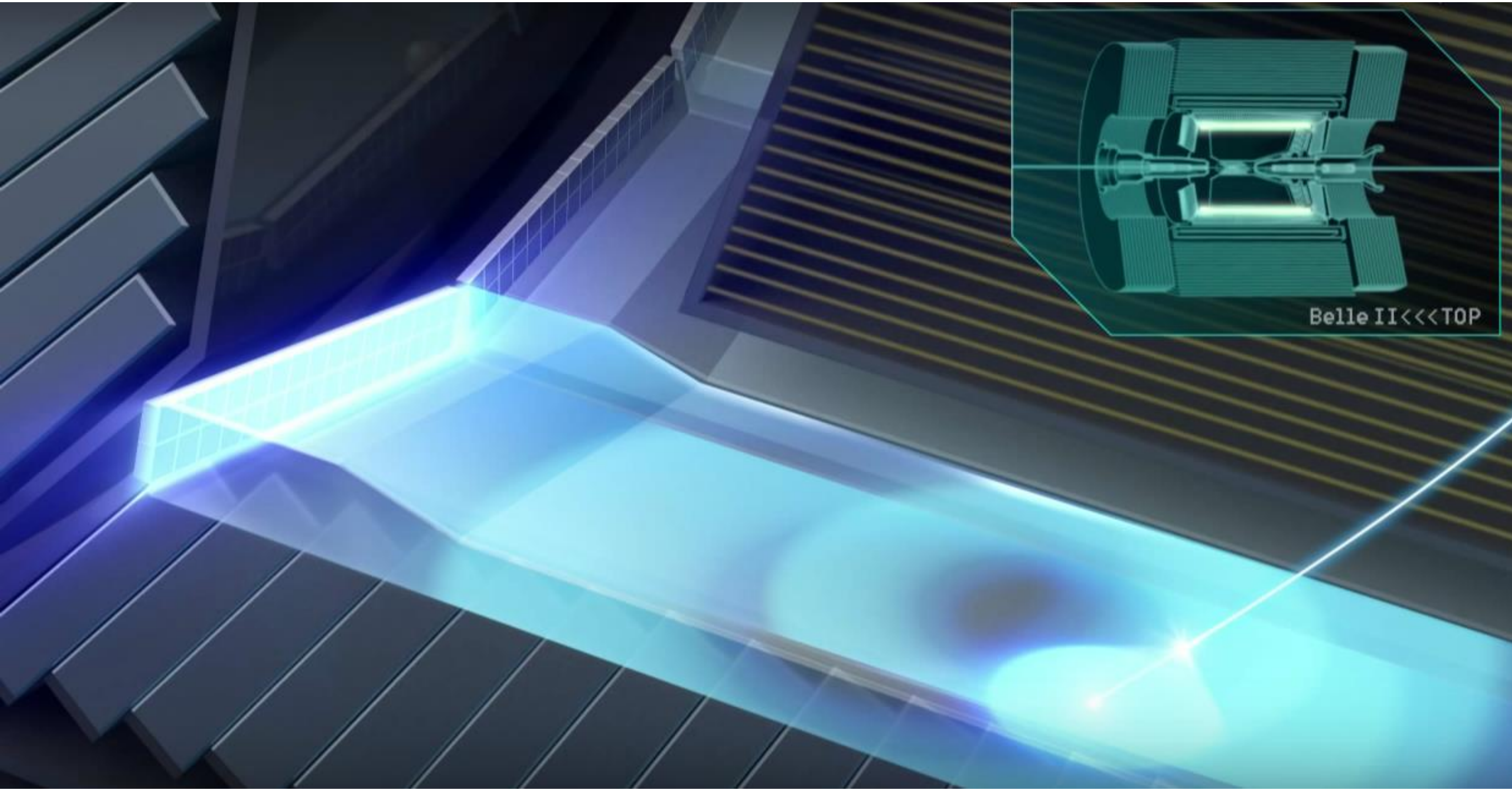




$$\frac{\sigma_{p_t}}{p_t} \sim 0.3\%/\beta \oplus 0.1\% \cdot p_t[GeV/c]$$

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

Time Of Propagation (TOP)

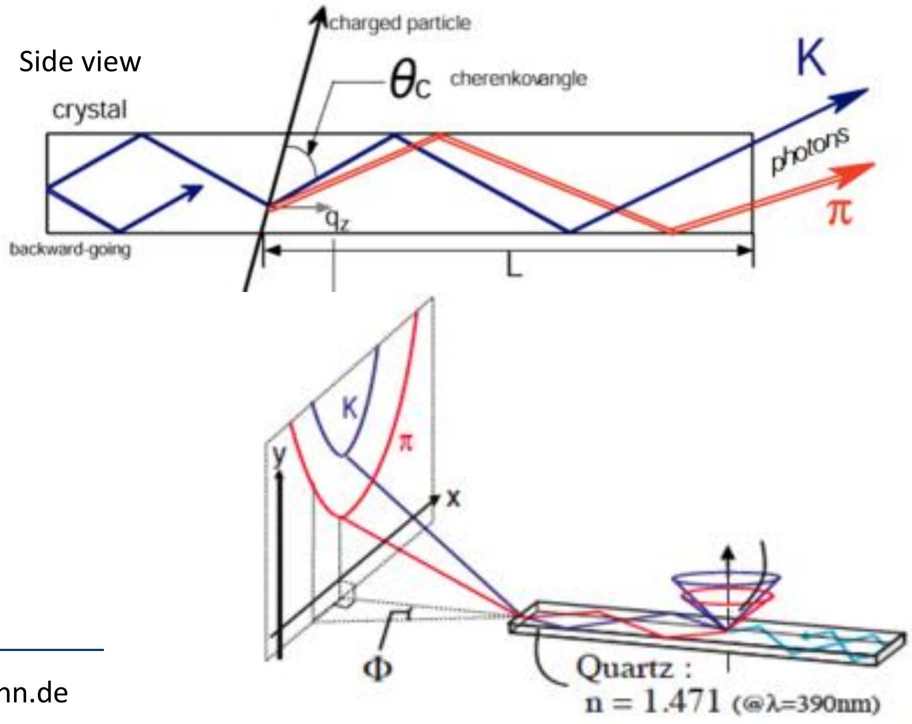


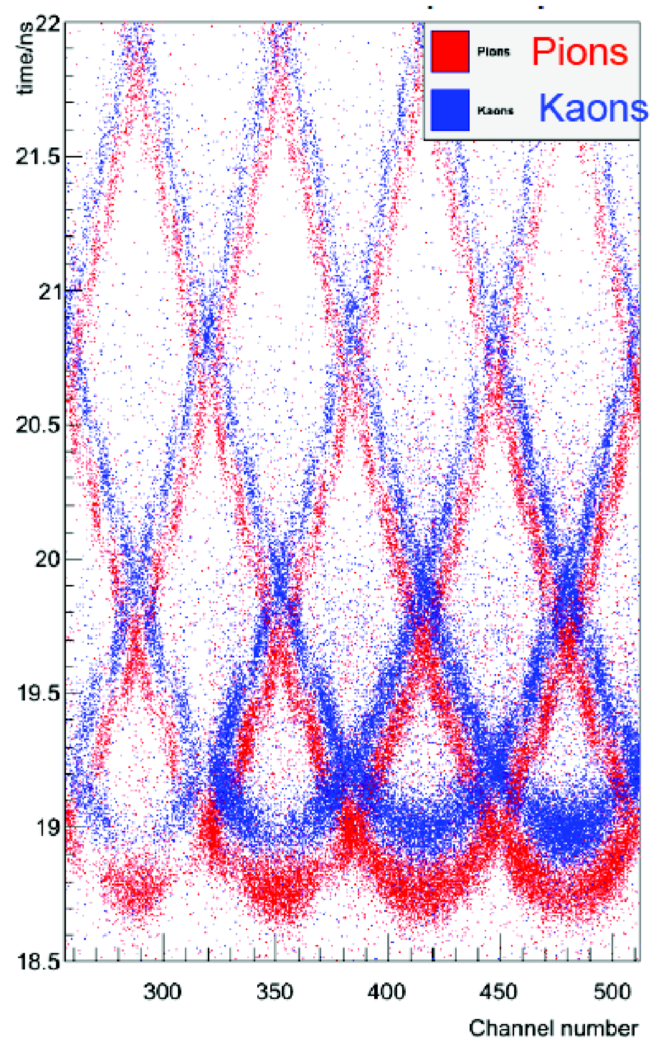
Time Of Propagation (TOP)

TOP will be used for PID in the barrel region

- When a charged particle passes through the quartz, it emits Cherenkov photons

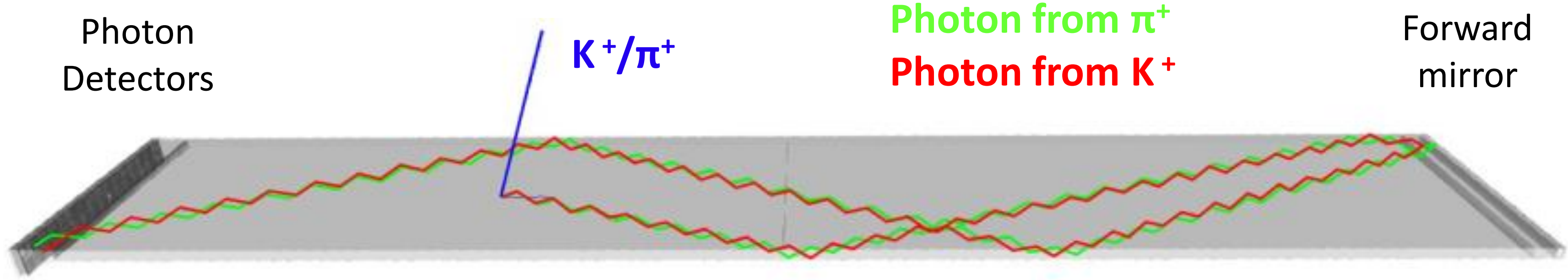
- The Cherenkov angle, and hence detection time/position depends on the mass of particle (for given track parameters).





Time Of Propagation (TOP)

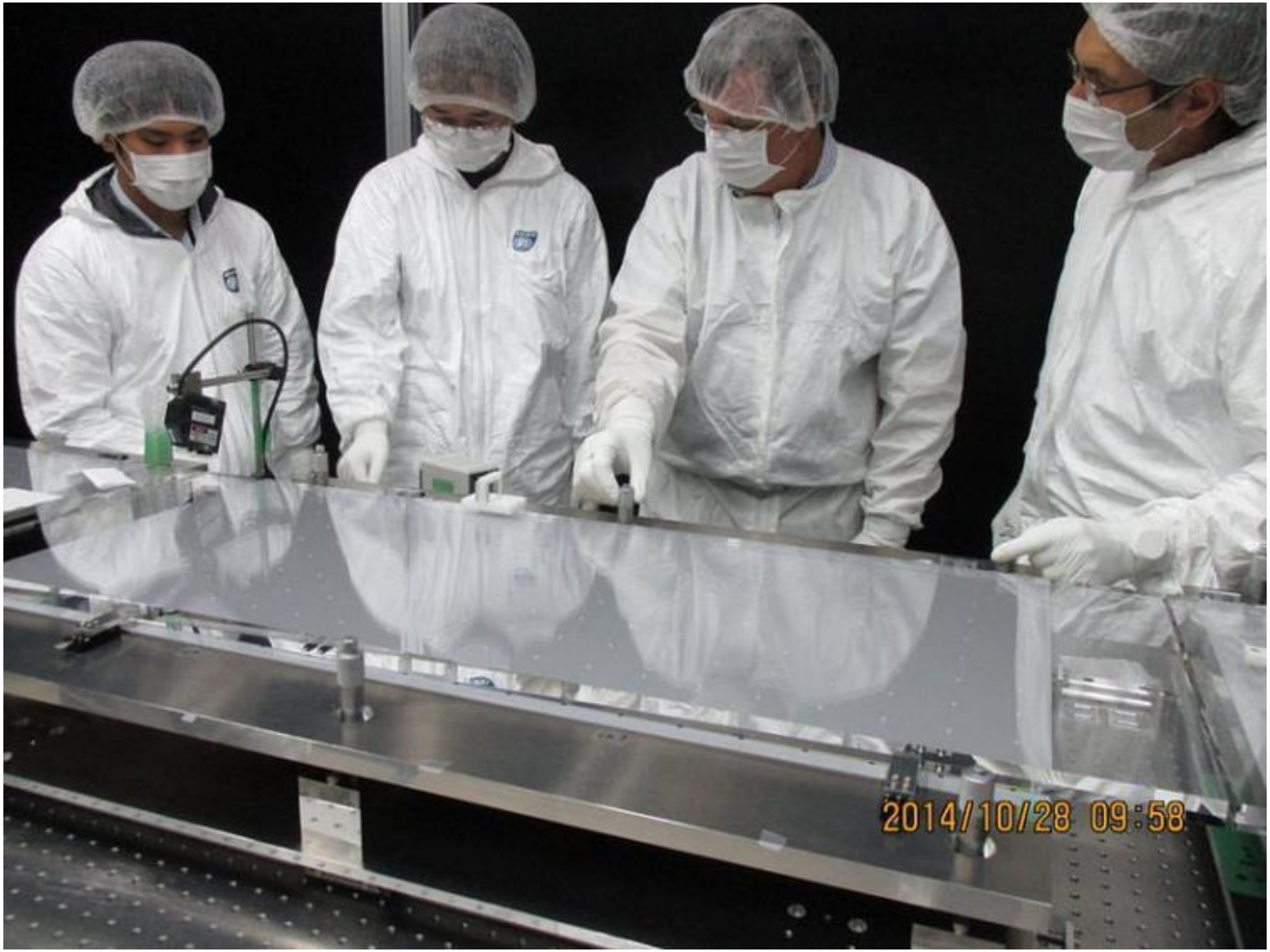
▪ Each TOP module contains two quartz bars (2.5 m x 0.45 m x 2 cm), mirror, and array of photodetectors.



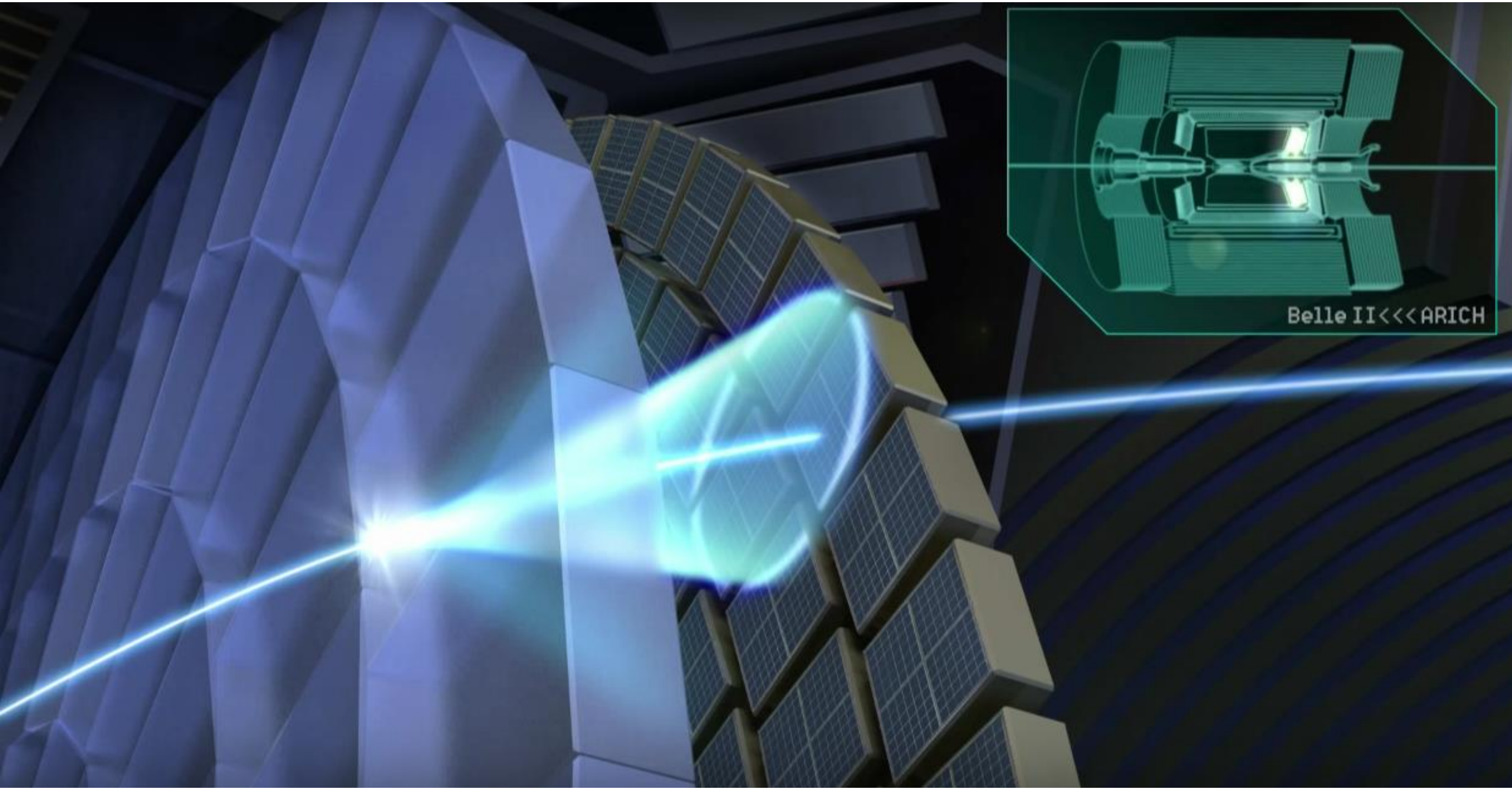
32 (segmented 4x4) Micro-channel plate PMT
Hamamatsu SL-10 MCP PMT
They can operate in a magnetic field
Gain = $2 \cdot 10^6$
Time resolution σ = 35 ps
QE > 24%

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

TOP Quartz



Aerogel Ring Imaging Cerenkov (ARICH)



Aerogel Ring Imaging Cerenkov (ARICH)

Particle identification in the forward endcap

K/π separation at >5σ confidence level at 4 GeV/c

- Radiator: Aerogel

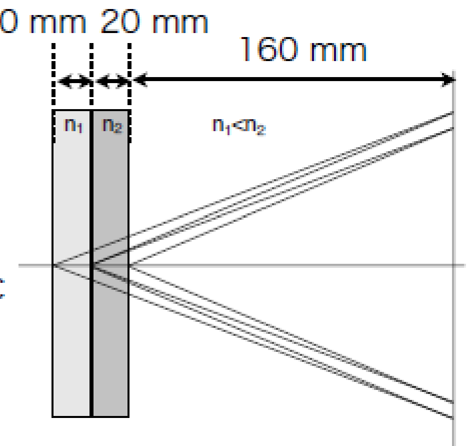
n = 1.045-1.055

Transmission length > 40 mm

$\theta_c(\pi) \approx 307$ mrad @ 3.5 GeV/c

$\theta_c(\pi) - \theta_c(K) = 30$ mrad @ 3.5 GeV/c

- pion threshold 0.44 GeV/c,
- kaon threshold 1.54 GeV/c

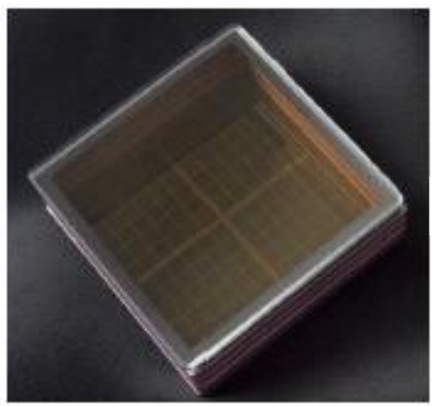


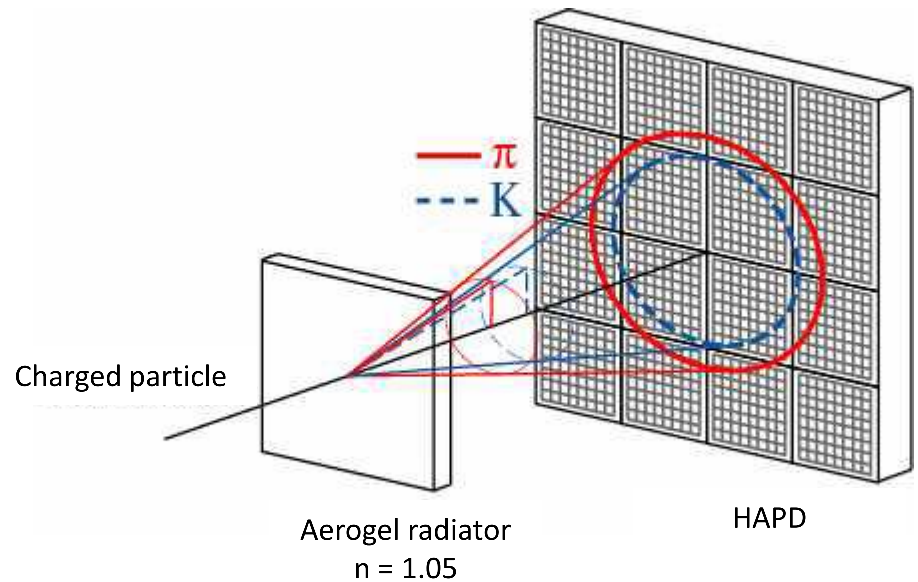
- Photon detection: Hybrid Avalanche Photo Detectors (HAPD)

420 units, 144 channels each, 5 mm pixelated

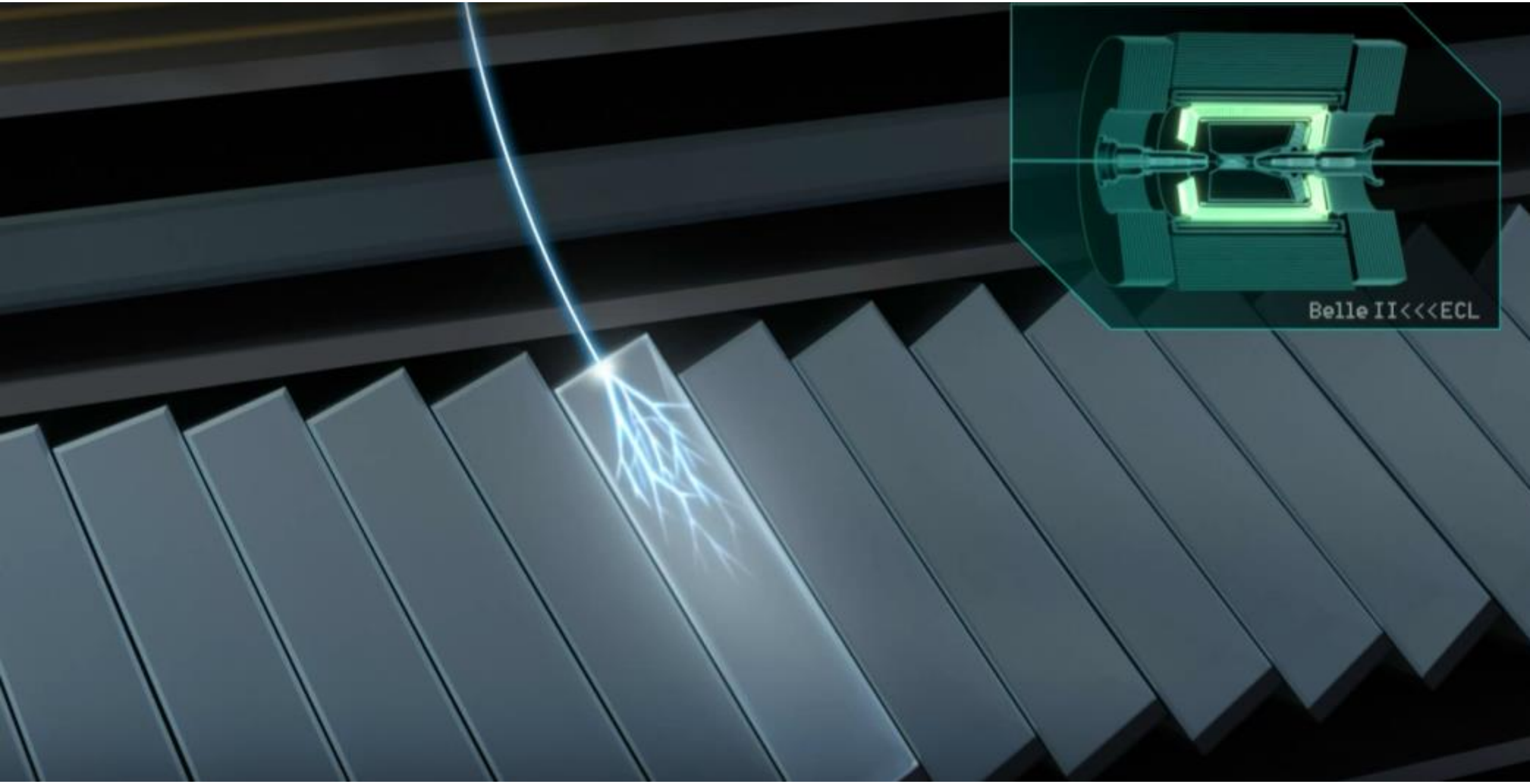
Gain = $7 \cdot 10^5$

QE > 28%





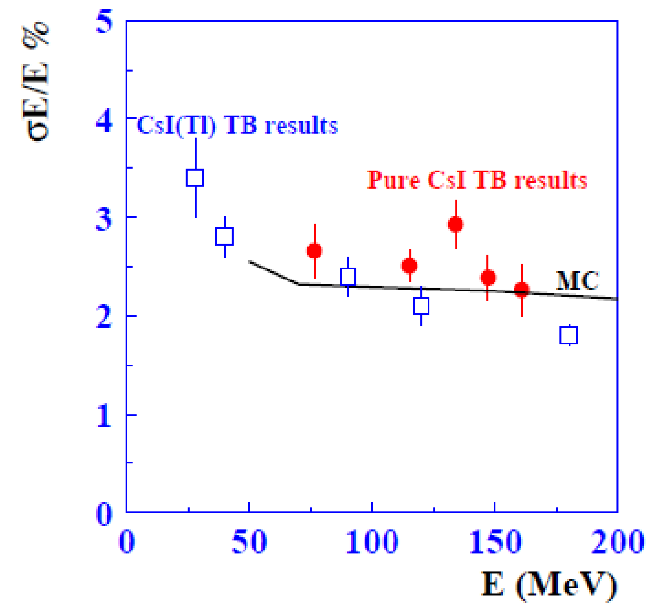
Electromagnetic Calorimeter (ECL)



Electromagnetic Calorimeter (ECL)

E.M. Calorimeter to measure:

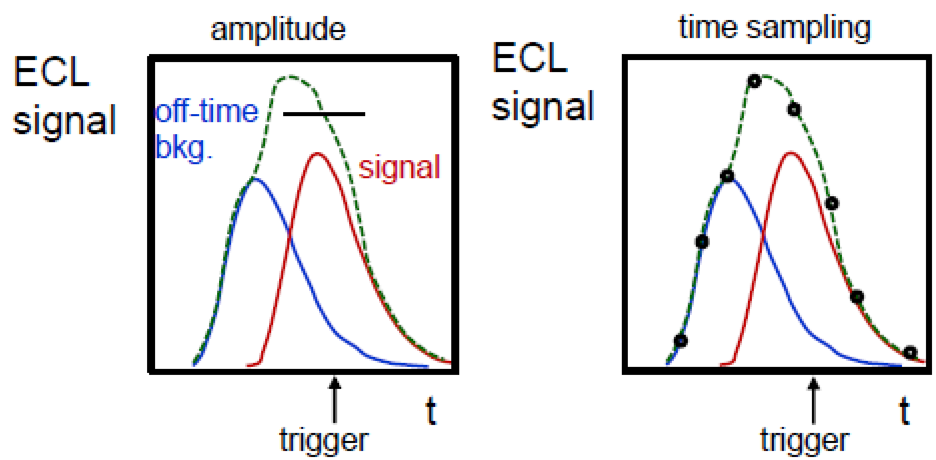
- Energy/angle of photon (20 MeV – 4 GeV)
- Electron identification
- K_L detection together with KLM
- Luminosity



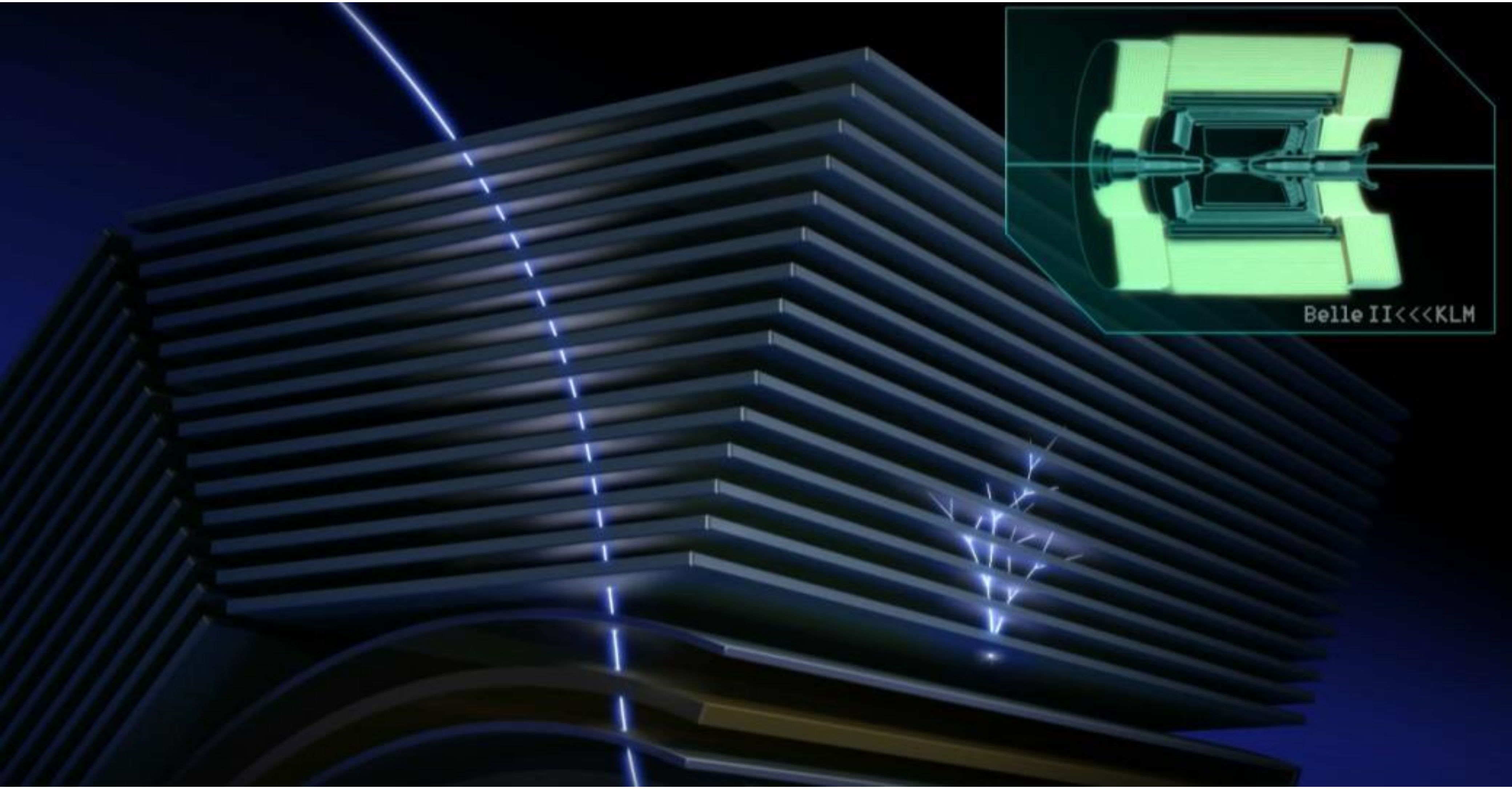
Need upgrade due to high backgrounds:

- Barrel: CsI(Tl), crystals reused.
  New electronics waveform sampling
  Time constant 1 μs
  16.1 X_0 (30 cm)

- Endcaps: CsI(Tl), crystals reused.
  Replace with pure CsI in future
  New electronics waveform sampling
  Time constant 30 ns
  PMT Gain = 255
  QE > 25 %



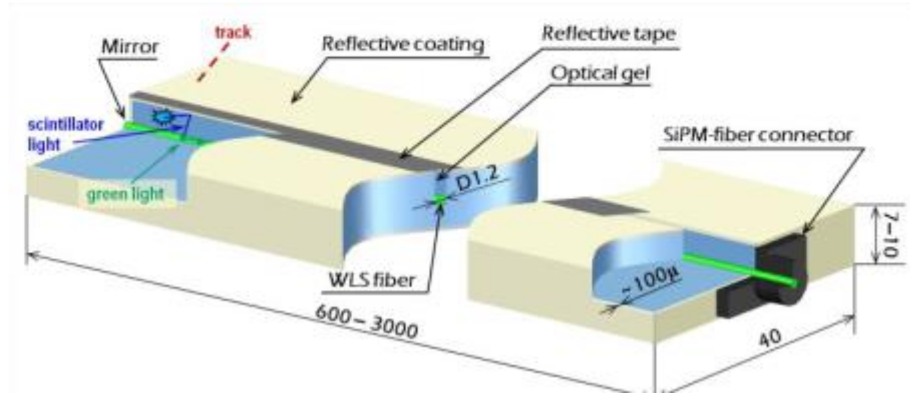
K_L and Muon Systems (KLM)



K_L and Muon Systems (KLM)

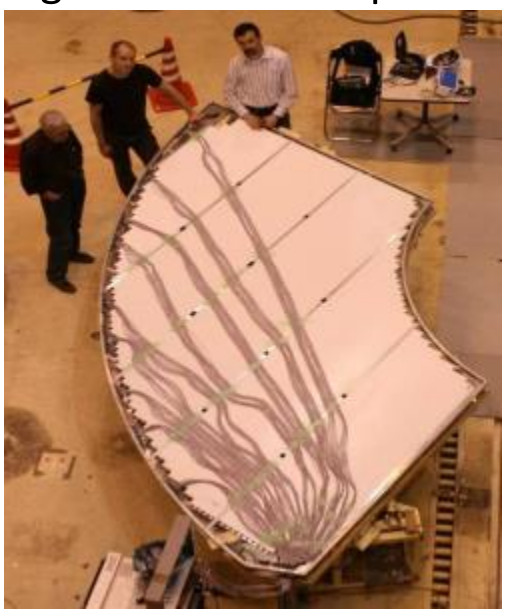
- Barrel:

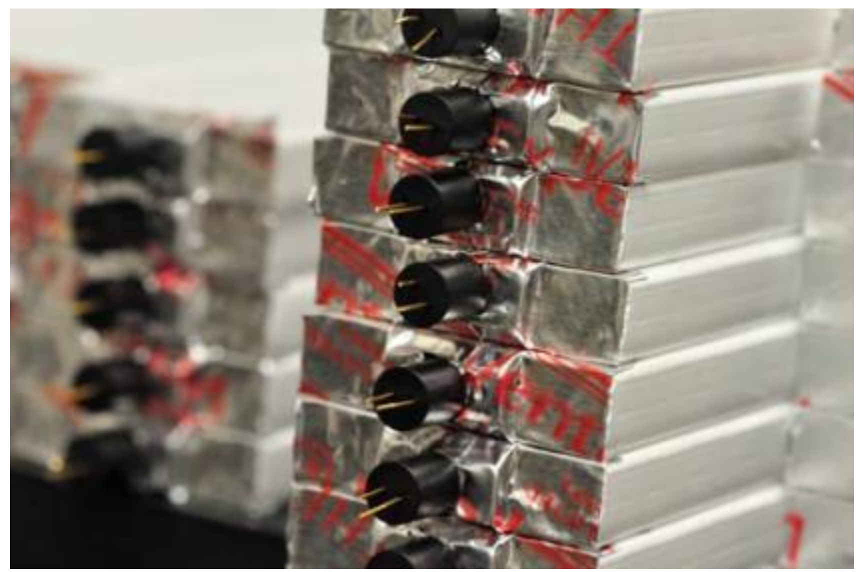
Belle RPCs reused
Two inner layers replaced by scintillator strips due to increased backgrounds
Scintillator strips with WLS fibers
Multi-pixel photon counter detectors (MPPC)



- Endcap:

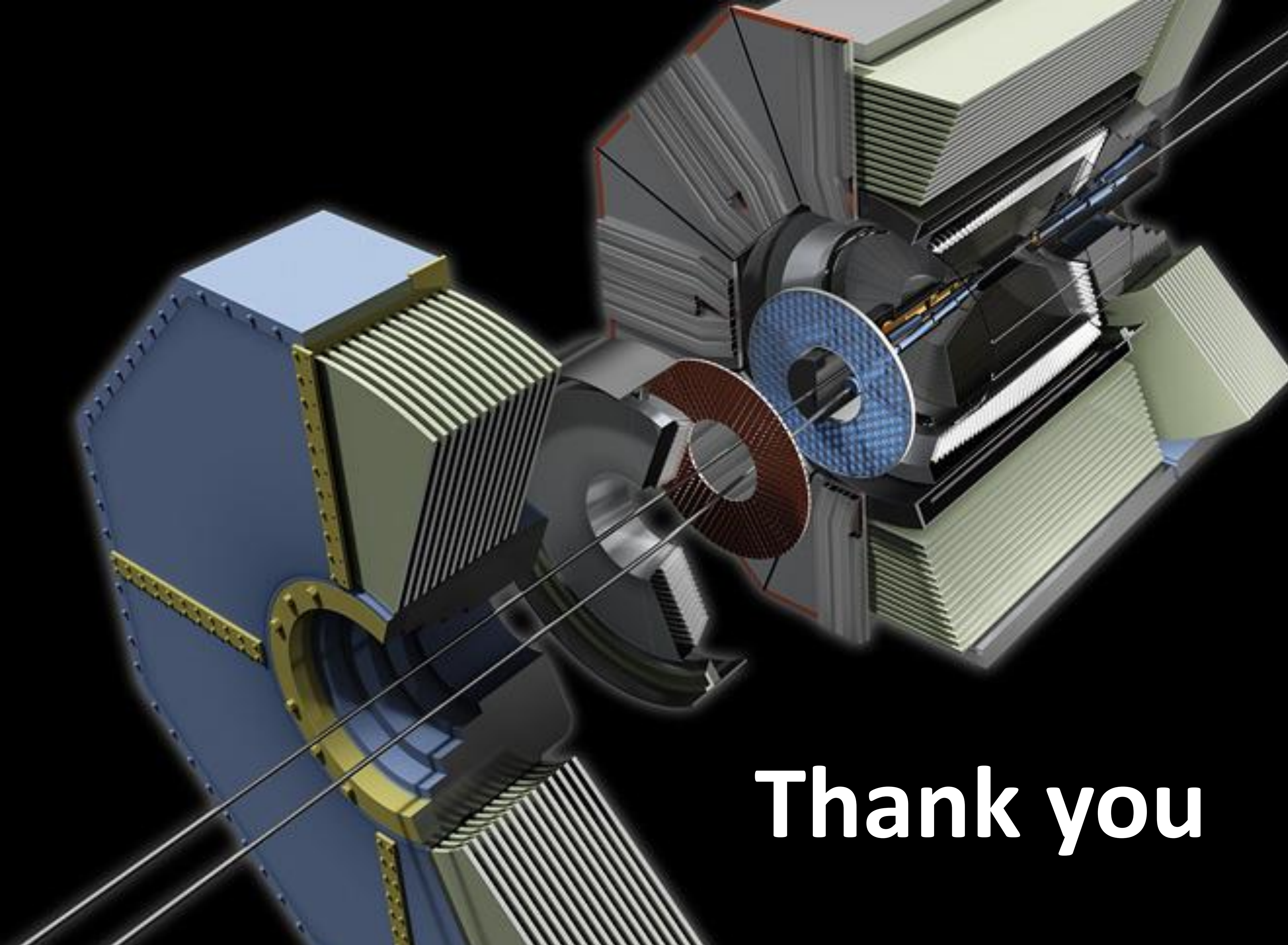
RPCs replaced with scintillators
99% geometrical acceptance. σ ~ 1ns





Summary

- B-factories had many successful physics results and hints of new physics.
- Belle II will further explore these opportunities with a target integrated luminosity of 50 ab^{-1}
- Detector to start operation in 2016 and start taking physics data in 2018.



Thank you