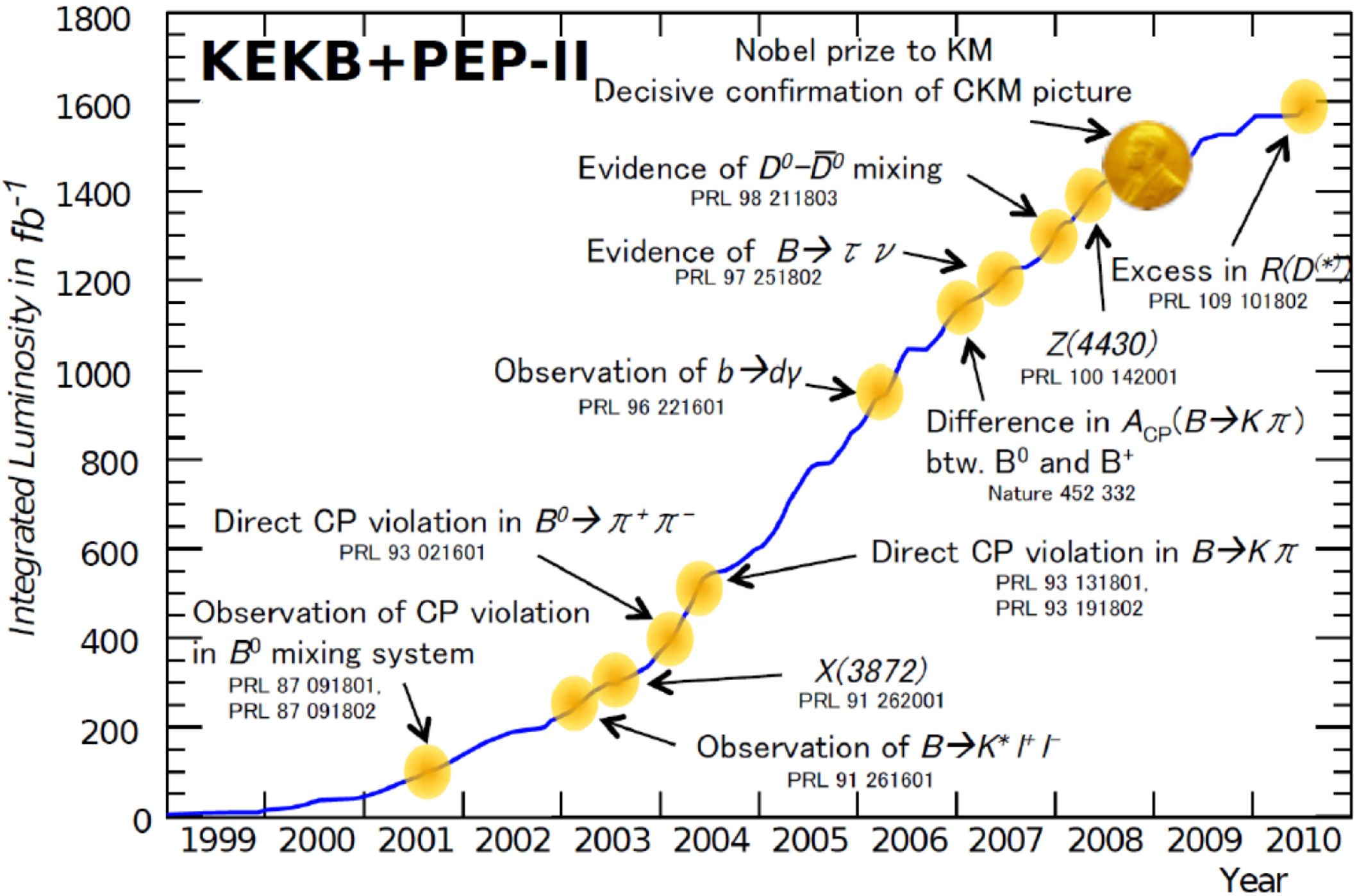
Status and perspective of Belle II at SuperKEKB

Pavel Krokovny
Budker Institute of Nuclear Physics
and
Novosibirsk State University

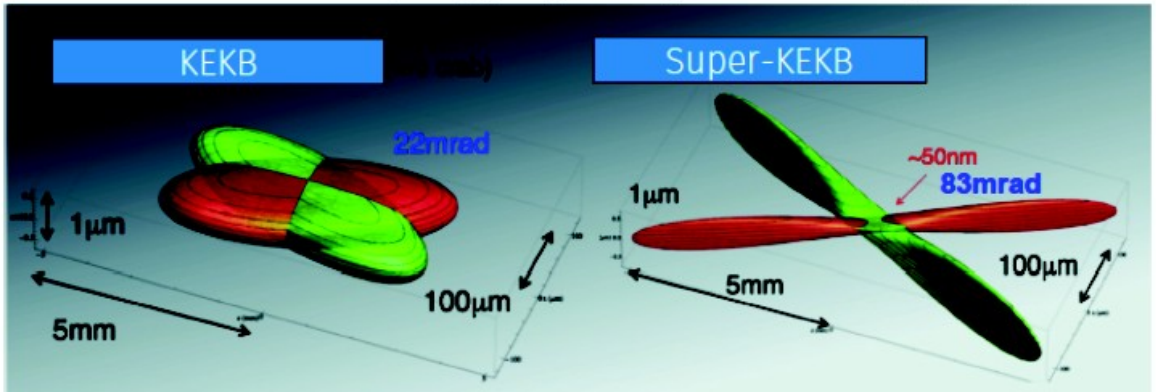
The B factory legacy



KEK Inter-University Research Institute Corporation
High Energy Accelerator Research Organization

SuperKEKB collider

Nano-beam scheme firstly proposed by P. Raimondi for SuperB



	E (GeV) LER/HER	β^*_y (mm) LER/HER	β^*_x (cm) LER/HER	φ (mrad)	I (A) LER/HER	L ($cm^{-2}s^{-1}$)
KEKB	3.5/8.0	5.9/5.9	120/120	11	1.6/1.2	2.1×10^{34}
SuperKEKB	4.0/7.0	0.27/0.30	3.2/2.5	41.5	3.6/2.6	80×10^{34}

factor 20

factor 2-3

reduced boost

factor~ 40-50

Lorentz factor

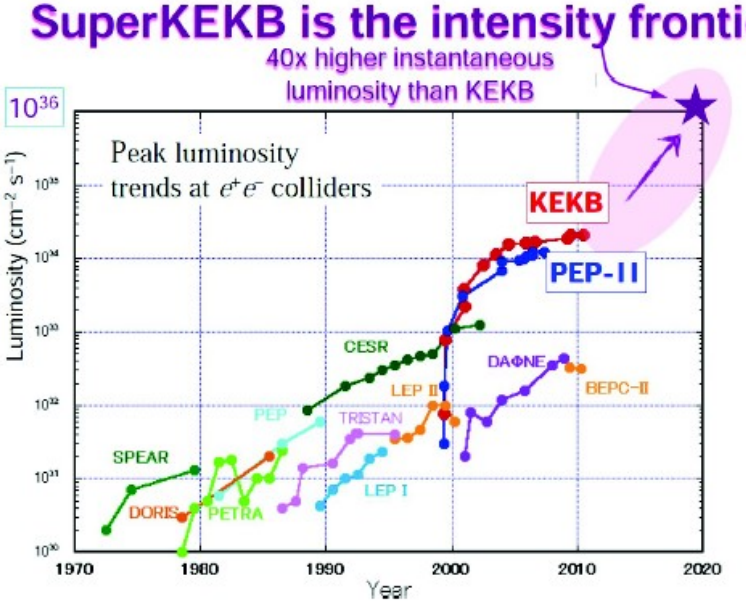
beam current

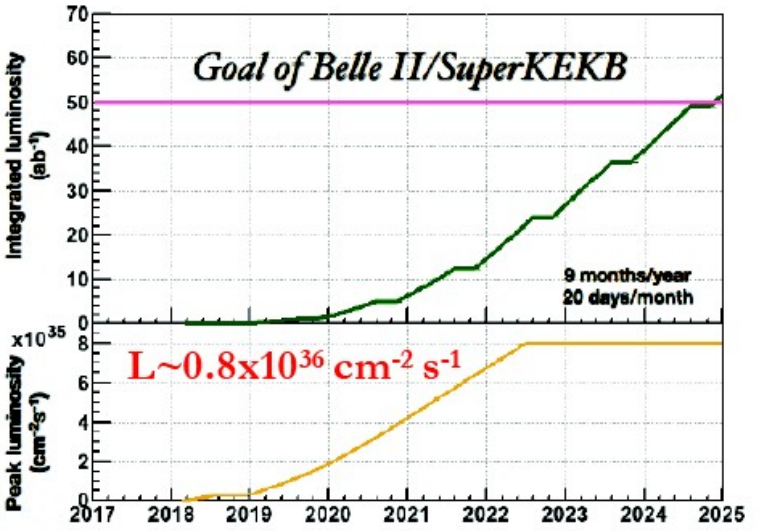
$$\text{Luminosity } L = \frac{\gamma_\pm}{2 e r_e}\left(1+\frac{\sigma^*_y}{\sigma^*_x}\right)\frac{I_\pm \xi_{y\pm}}{\beta_{y\pm}}\frac{R_L}{R_{\xi_y}}$$

vertical beta function at IP

Beam size ratio at IP

Geometrical reduction factors

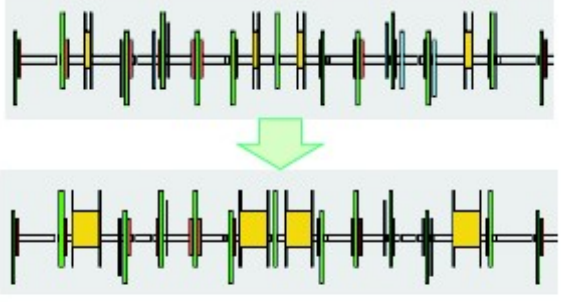




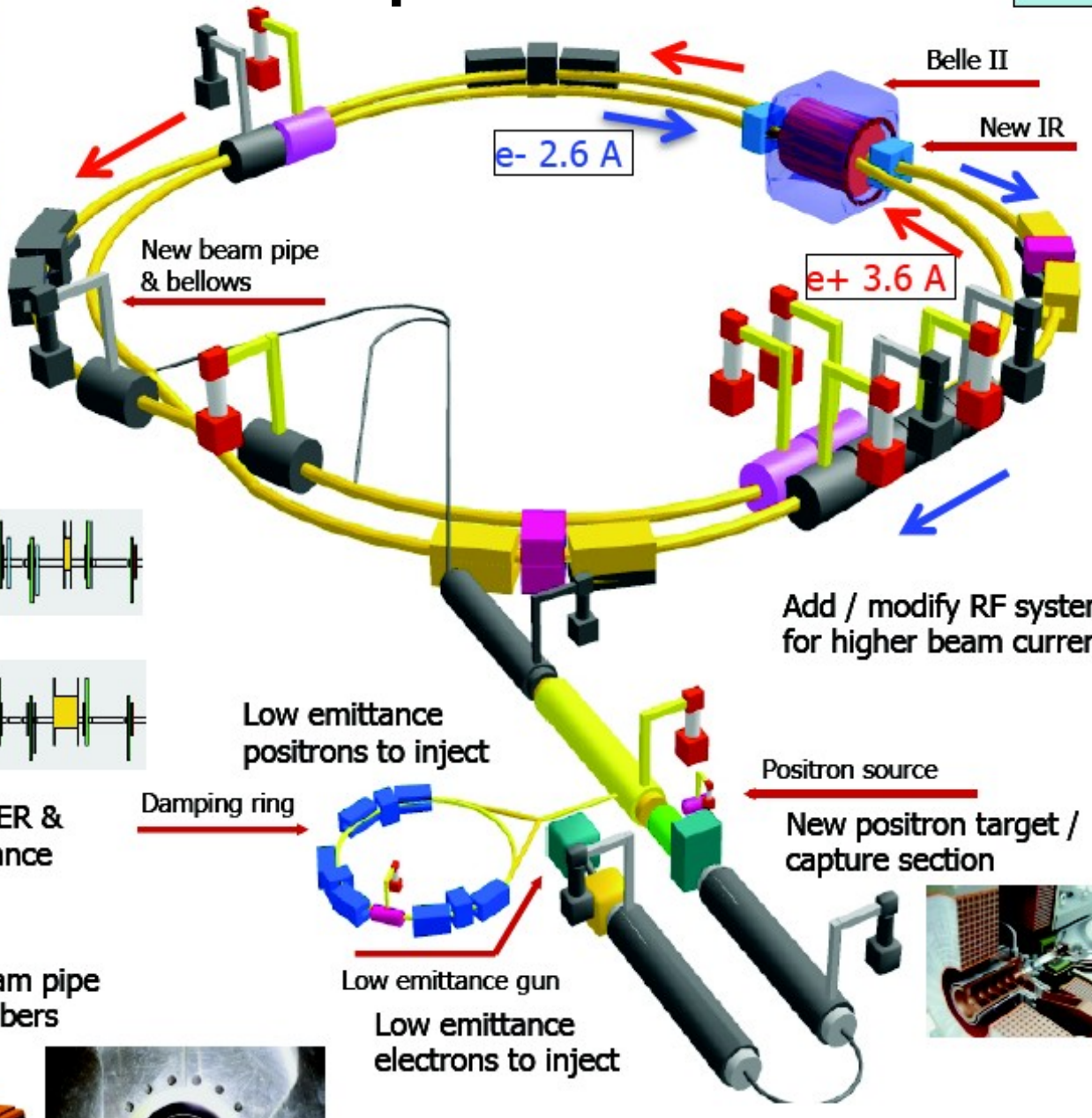
Super KEKB

Grey is recycled, coloured is new

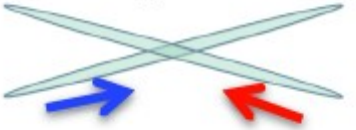
Replace short dipoles with longer ones (LER)



Redesign the lattices of HER & LER to squeeze the emittance



Colliding bunches

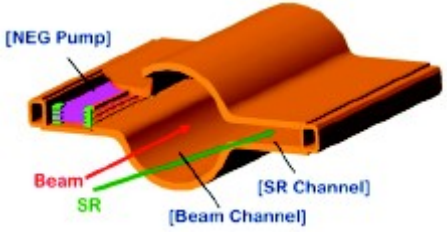


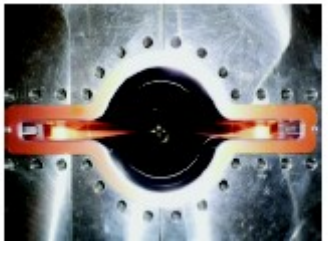
New superconducting / permanent final focusing quads near the IP

Add / modify RF systems for higher beam current

New positron target / capture section

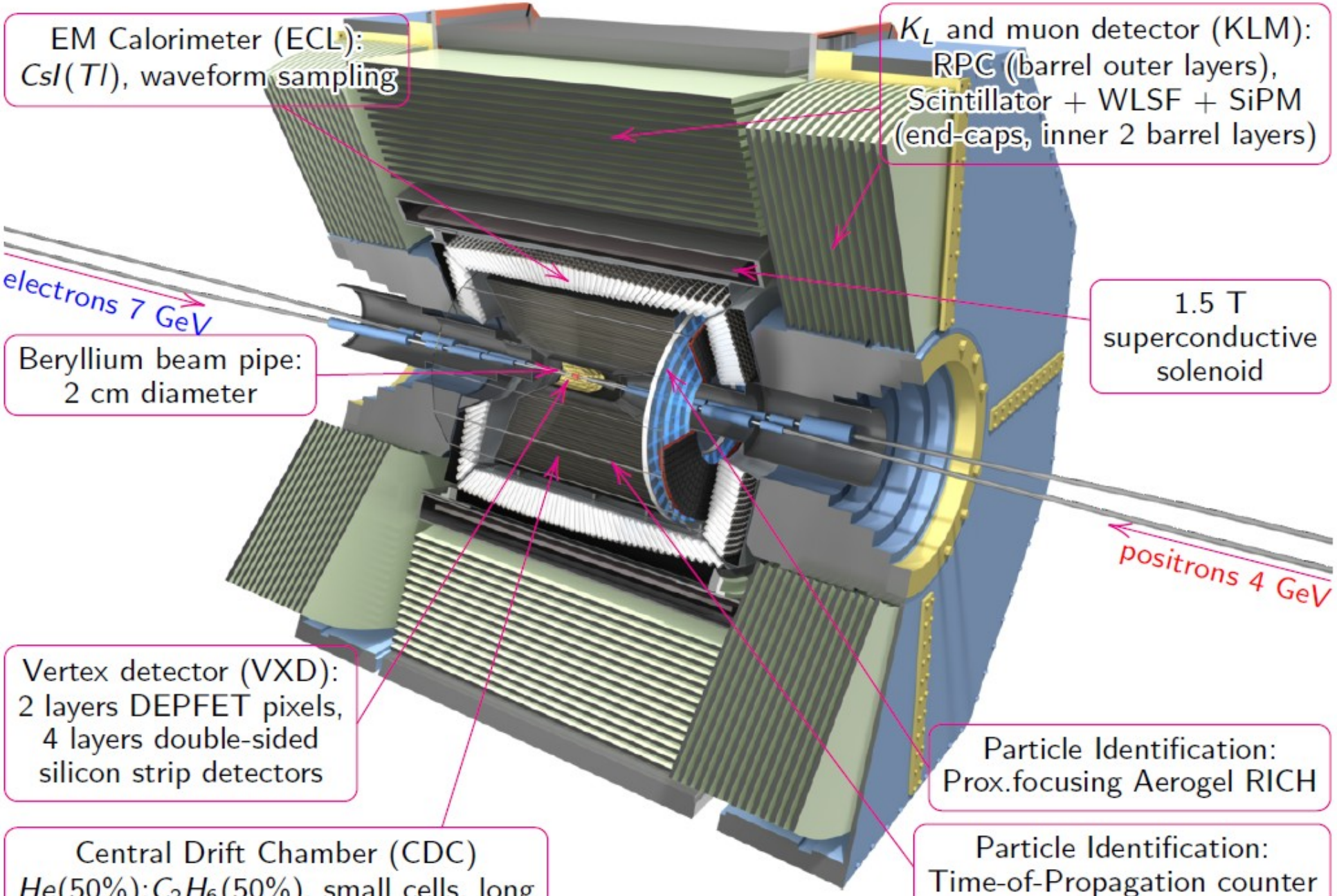
TiN-coated beam pipe with antechambers



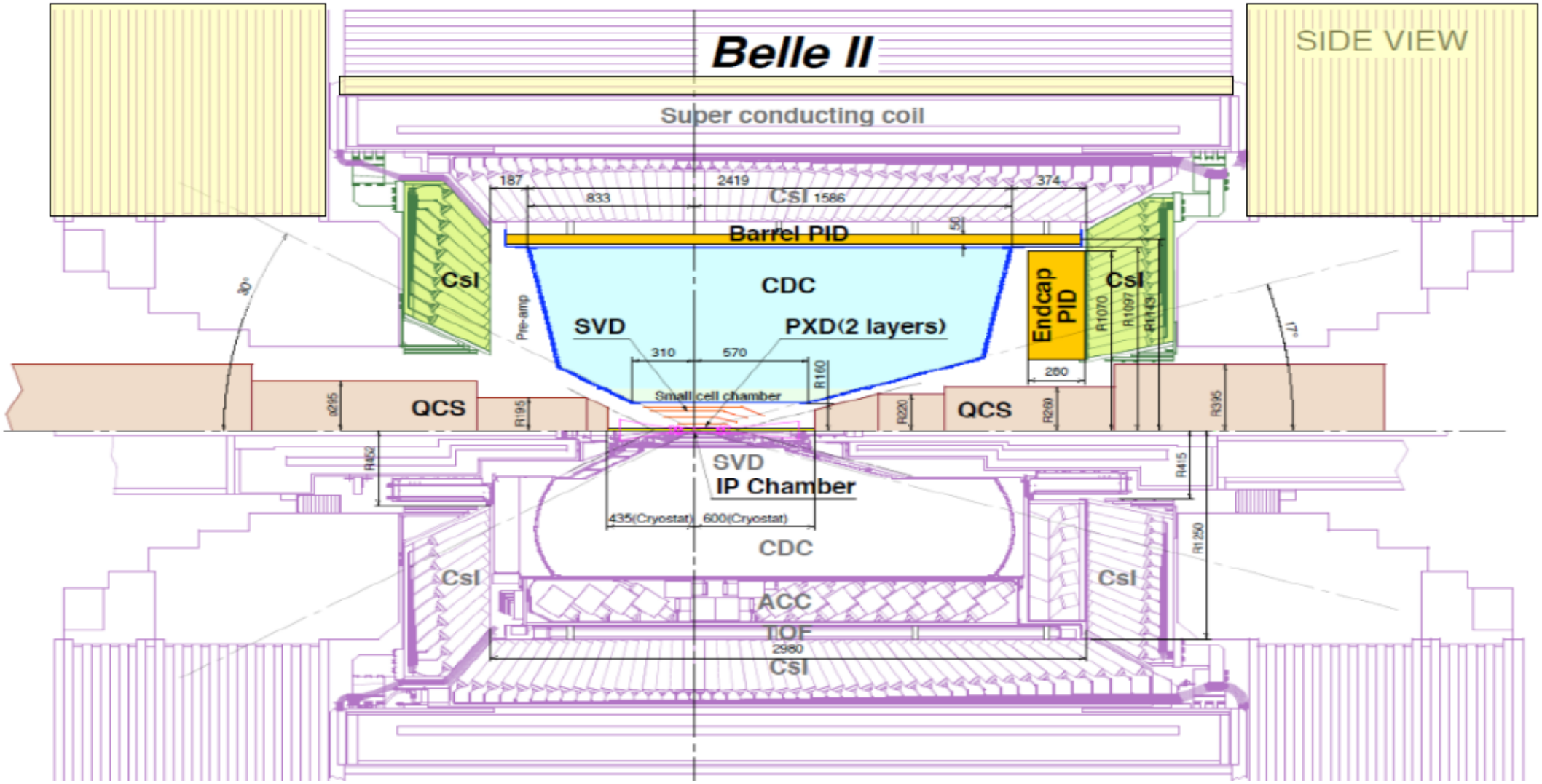


Almost entirely new machine!

Belle II detector



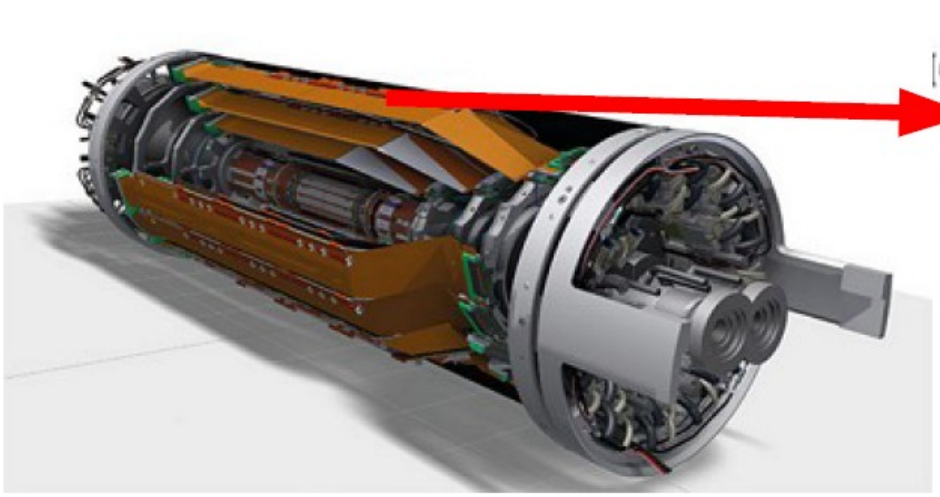
Belle II in comparison with Belle

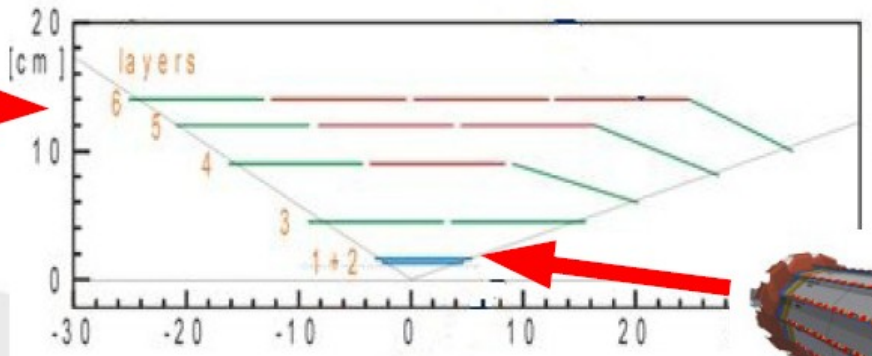


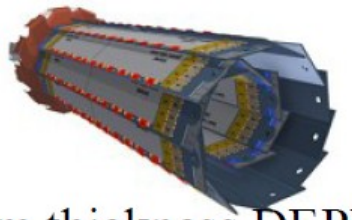
SVD 4 layers (DSSD)	→	2 DEPFET + 4 DSSD
CDC:		small cell, long lever arm
ACC+TOF	→	TOP+ARICH
ECL:		waveform sampling
KLM: RPC	→	Scintillator+SiPM

TDR
arXiv:1011.0352

Vertexing: SVD + PXD

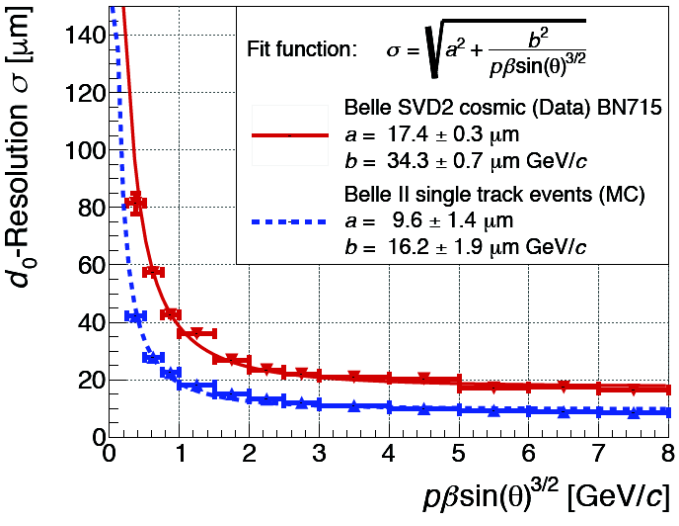


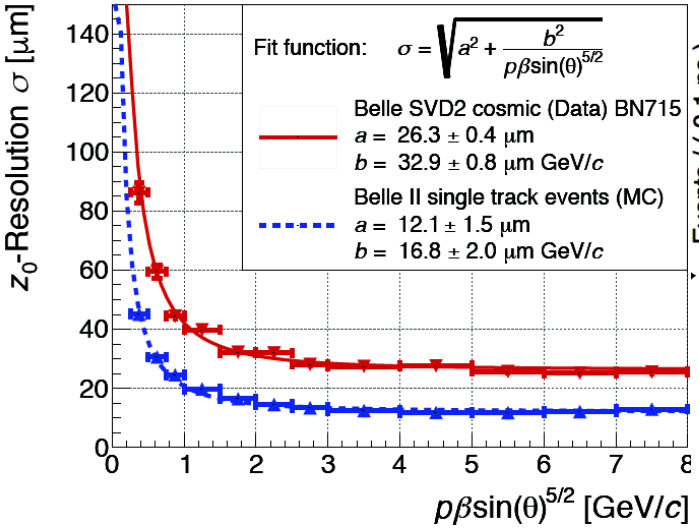


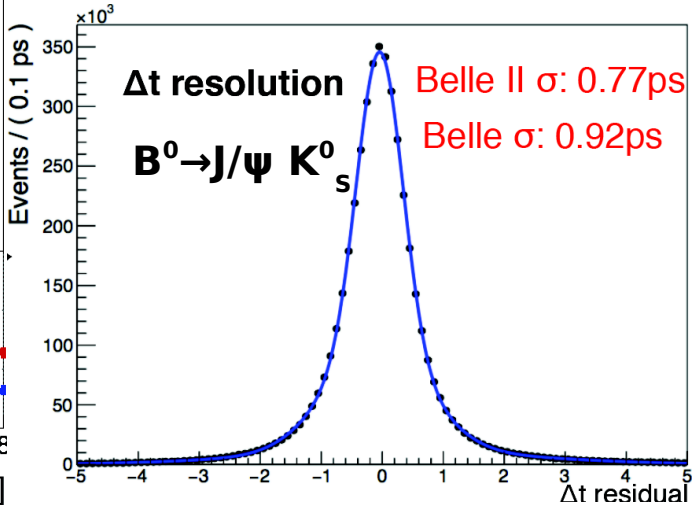


76 μm thickness DEPFET

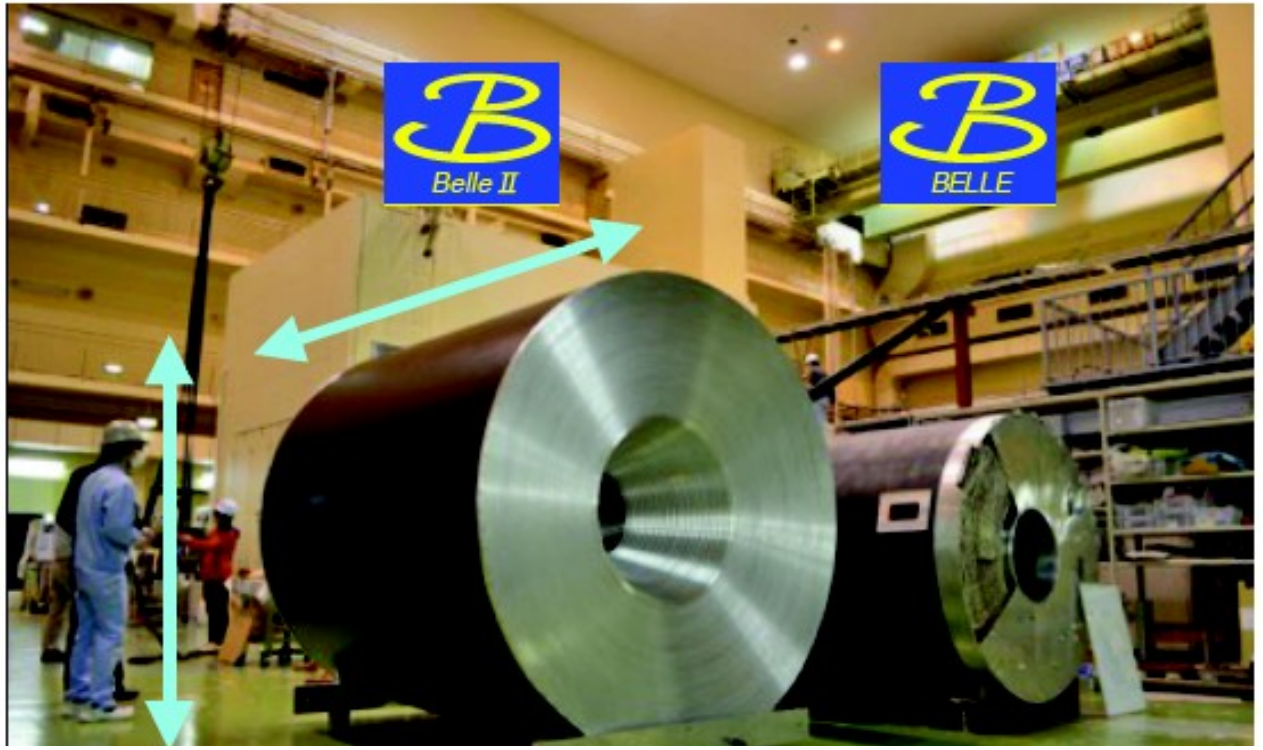
Belle II vertexing performance significantly improved in comparison with Belle

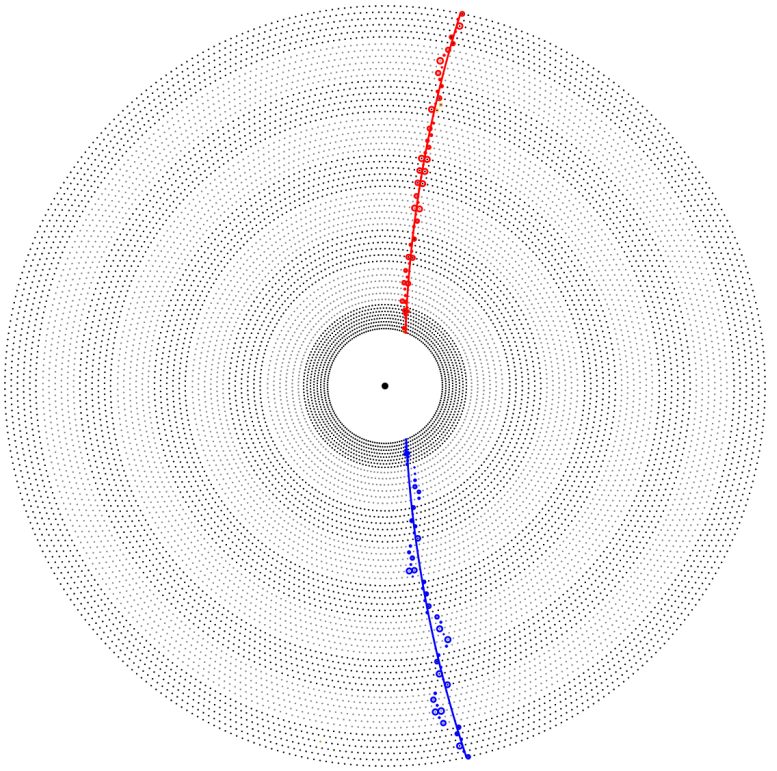


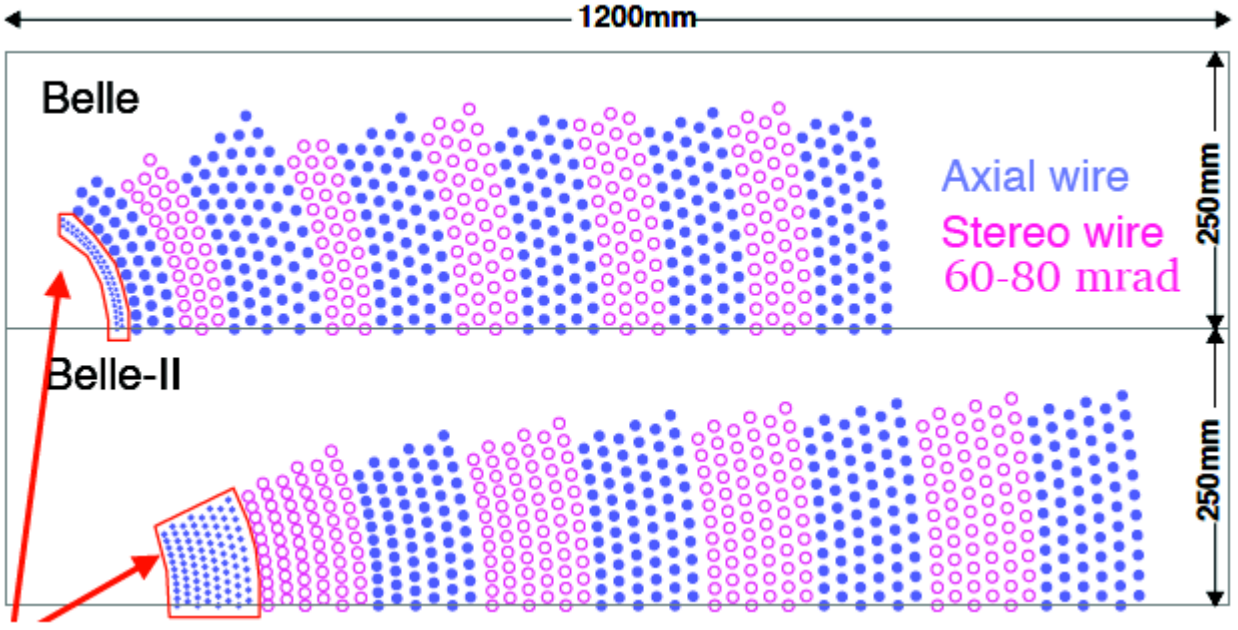


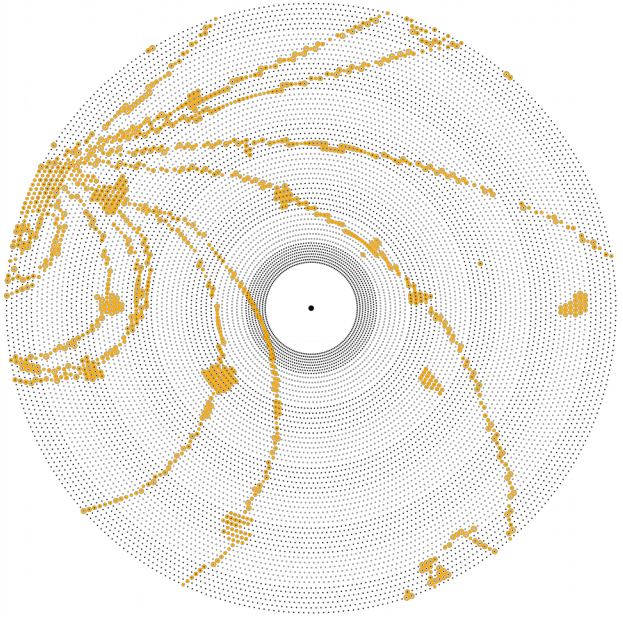


Central Drift Chamber



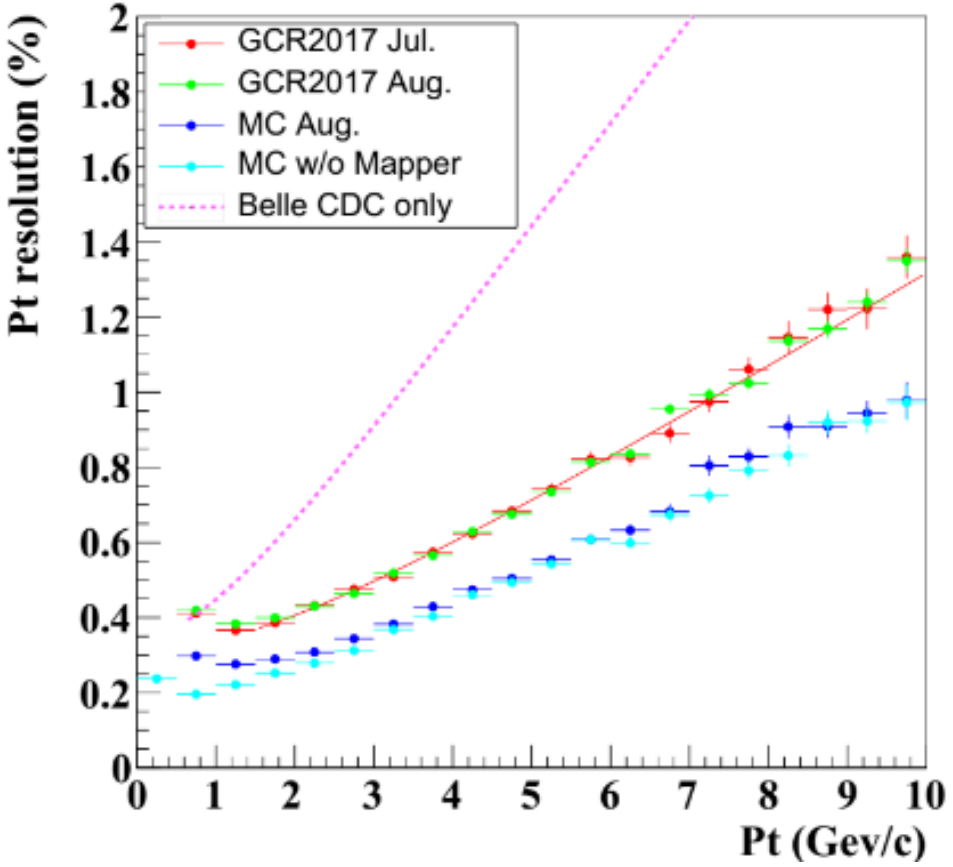






CDC performance

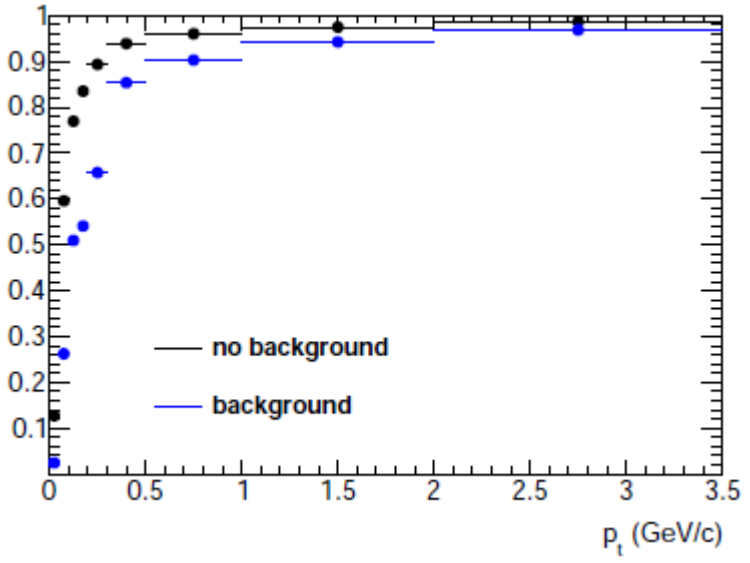
Transverse momentum resolution (CDC only)

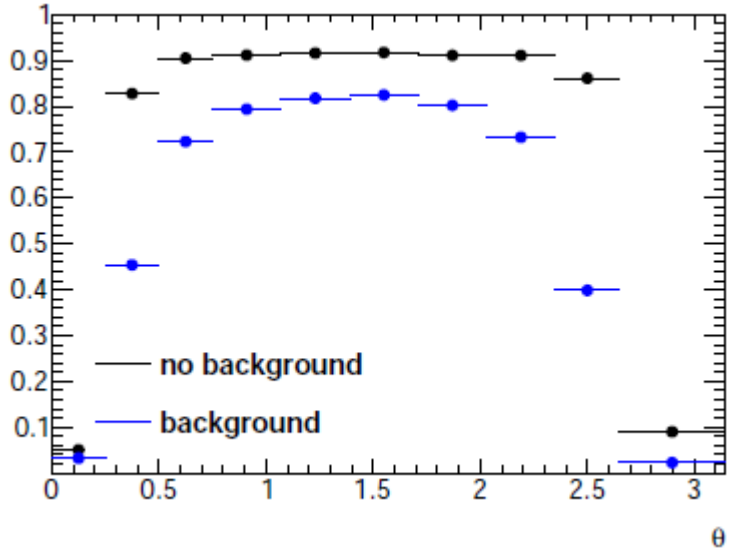


$$\frac{\sigma_{p_t}}{p_t} \sim 0.3\%/\beta \oplus 0.1\% \cdot p_t[GeV/c]$$

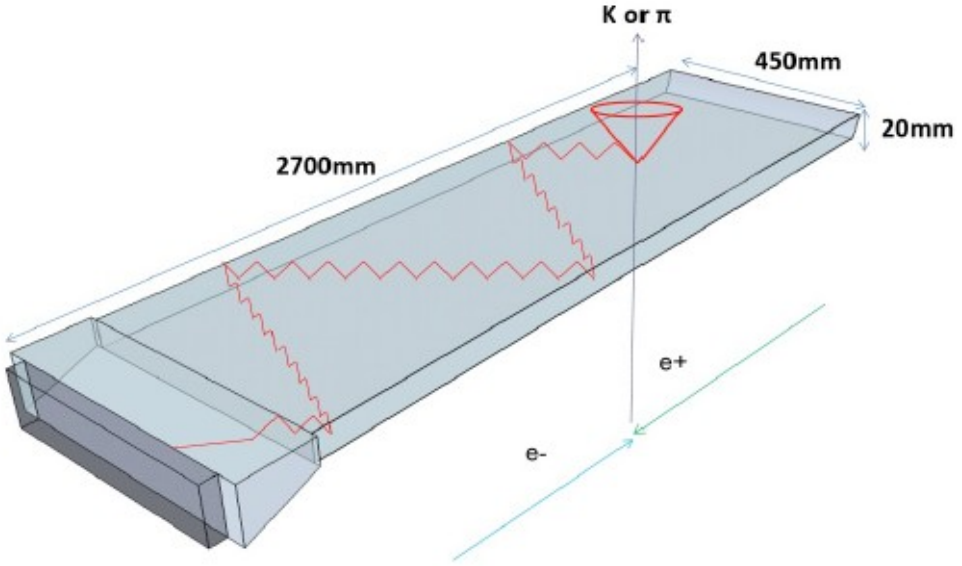
$$\sigma\left(\frac{dE}{dx}\right)\Big|_{\text{MIP}} \sim 5\%$$

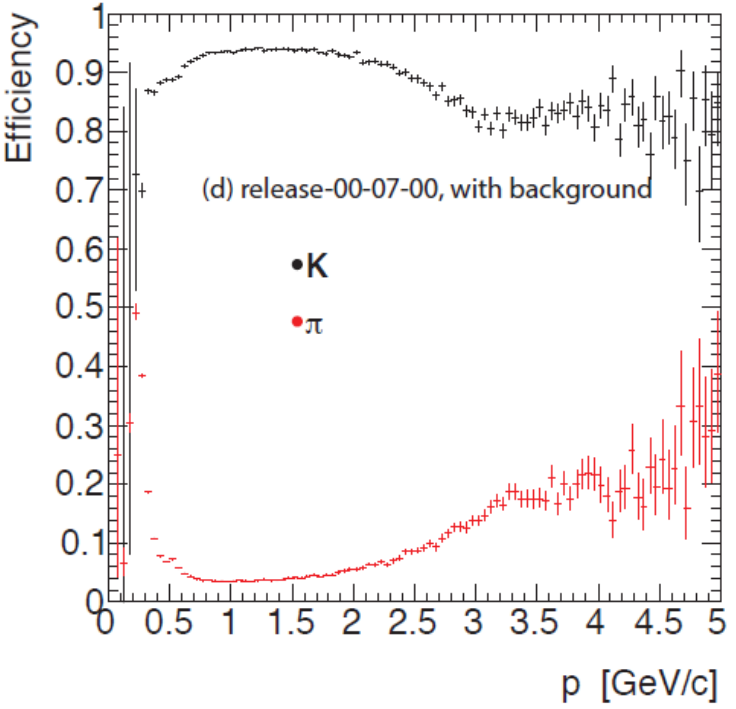
Track reconstruction efficiency (CDC only)

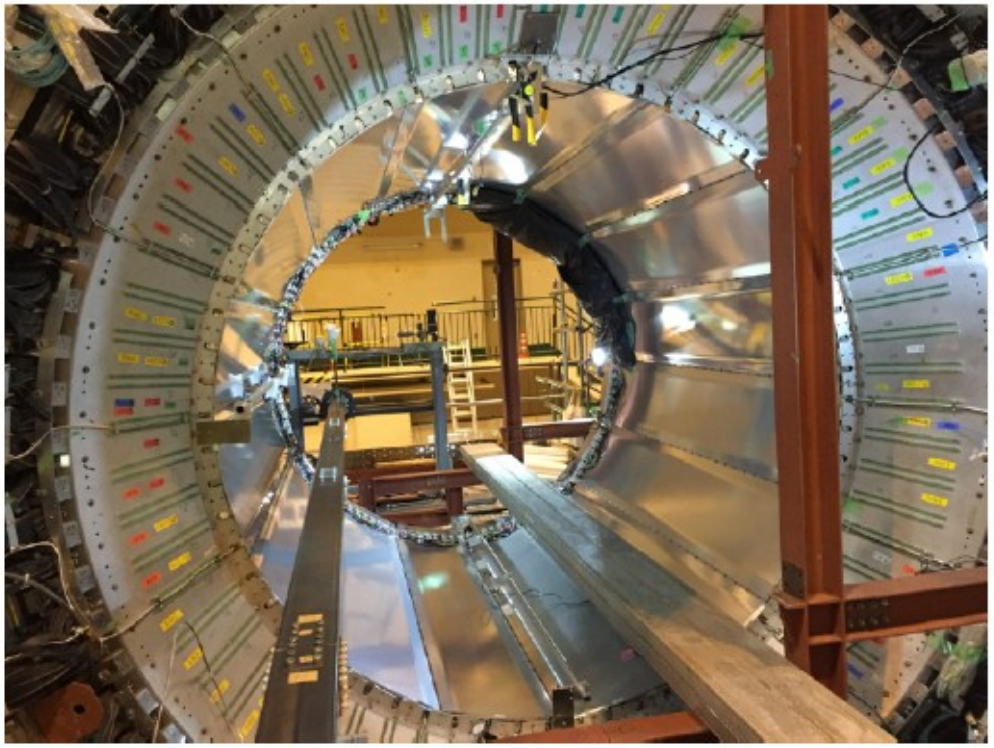




Barrel PID: Time of Propagation



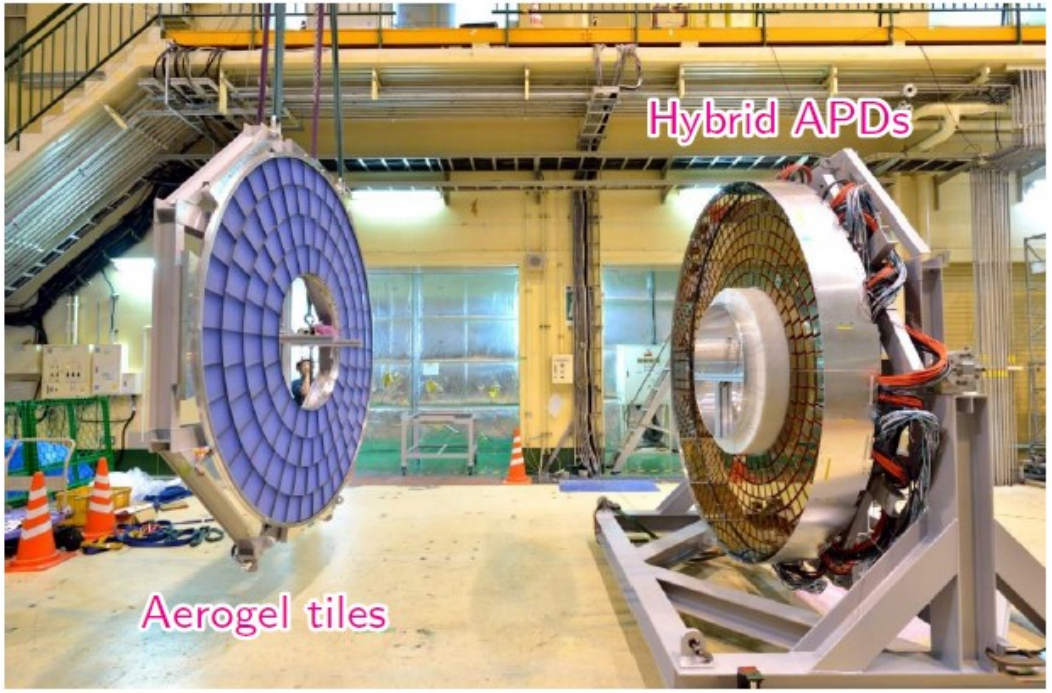


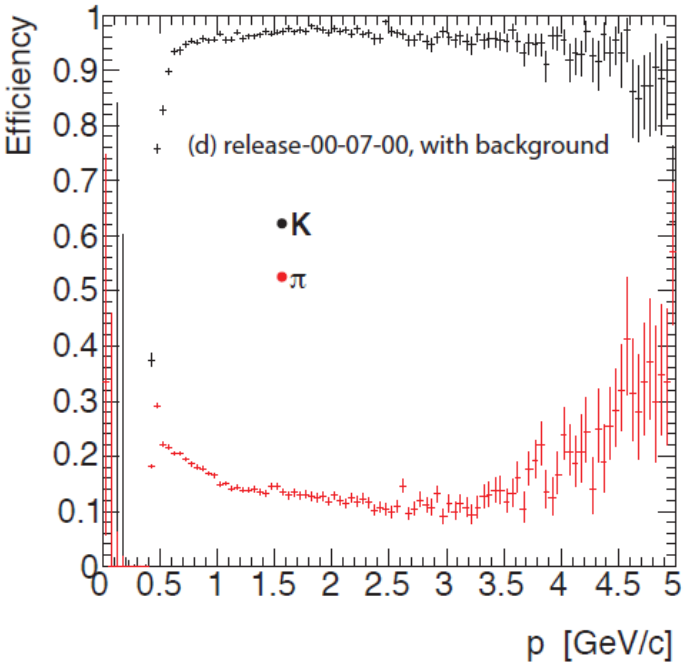


Cherenkov angle is reconstructed using hit position in the photo detector plane and time of propagation.

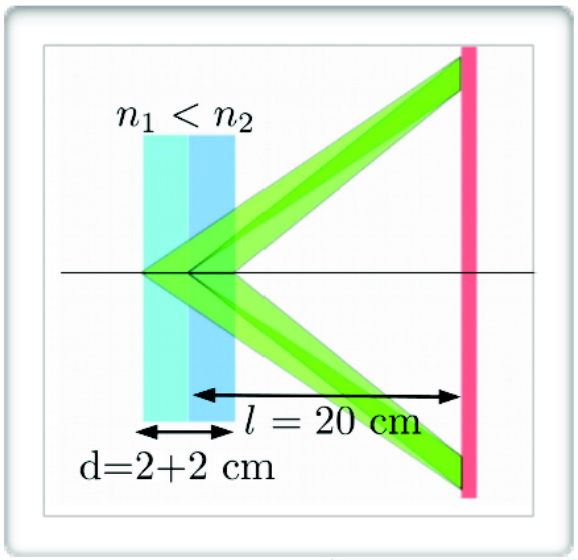
16 quartz bars: 125 x 45 x 2 cm
32 Micro-channel plate PMTs
Hamamatsu SL-10

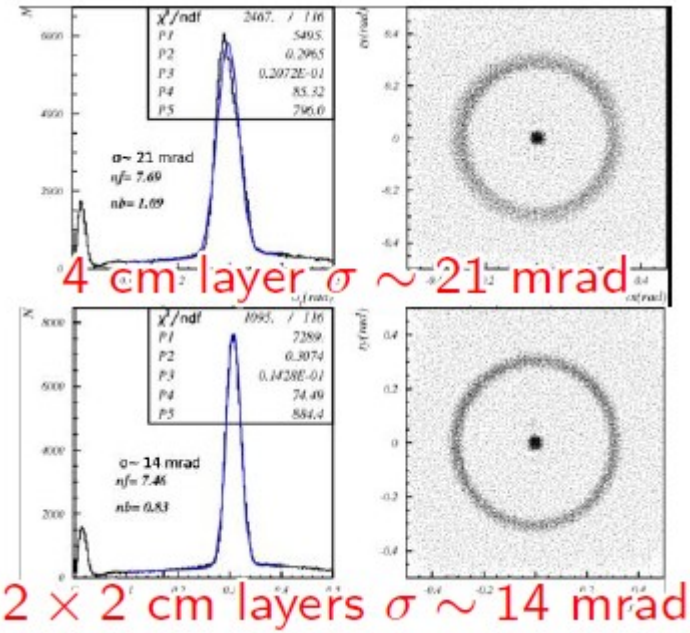
Forward PID: Aerogel RICH

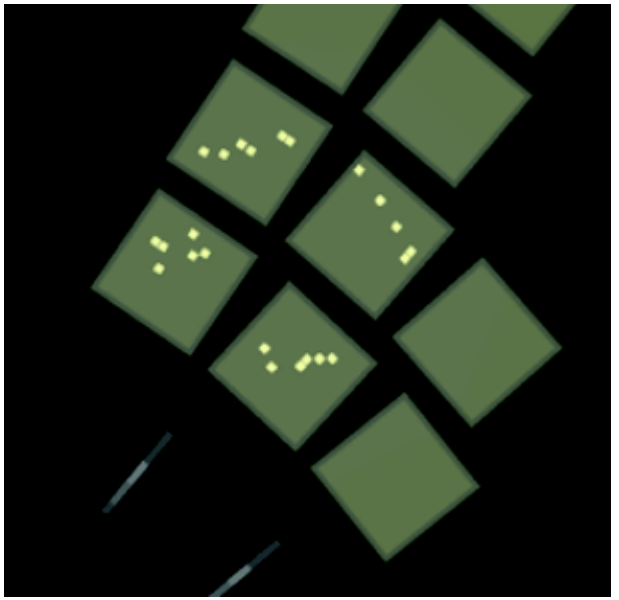




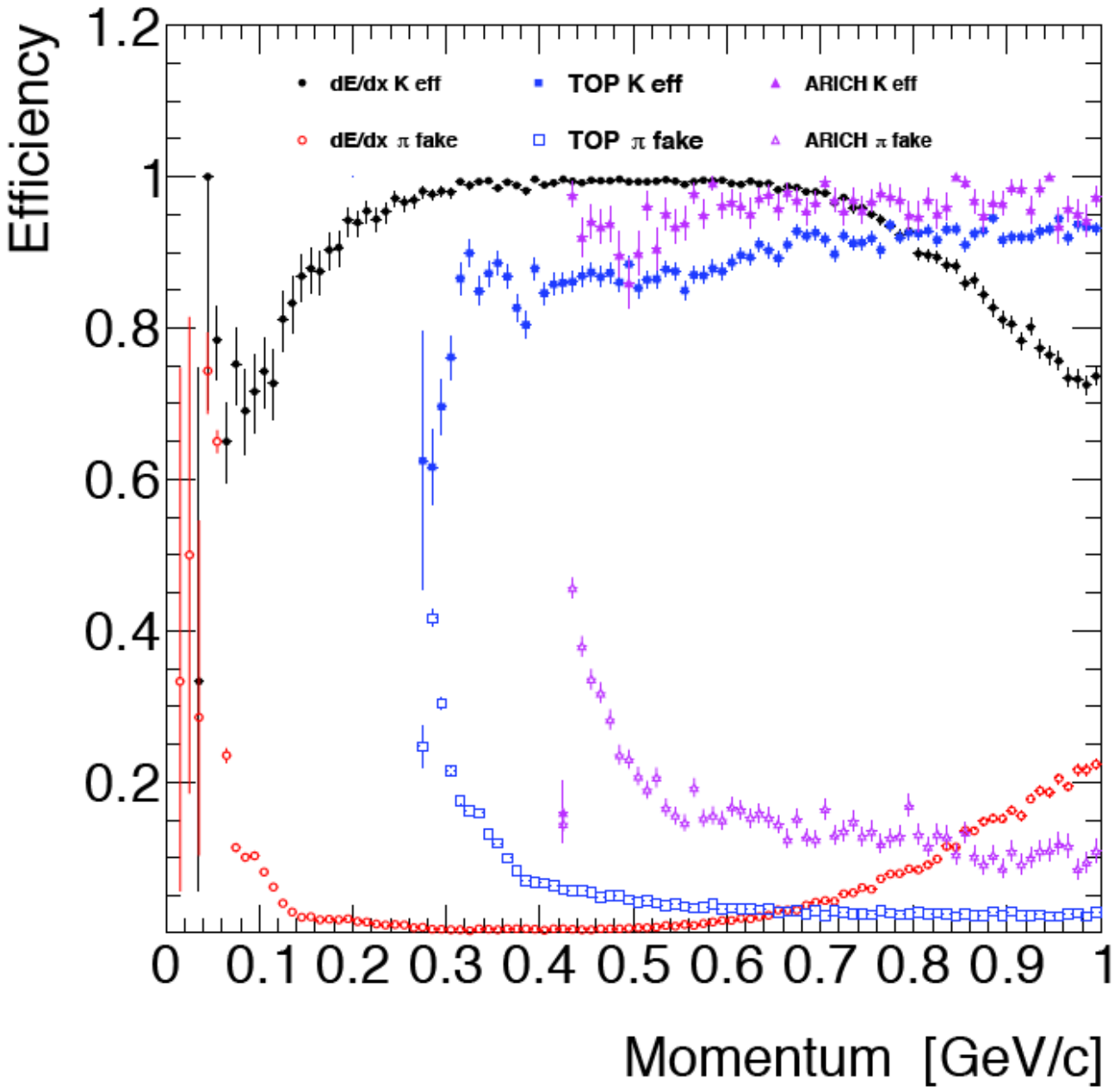
$n_1 = 1.045,\ n_2 = 1.055$



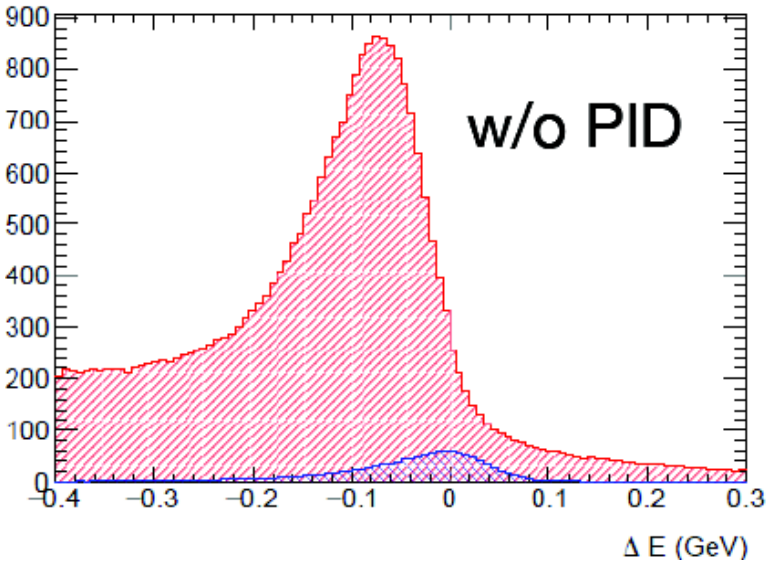


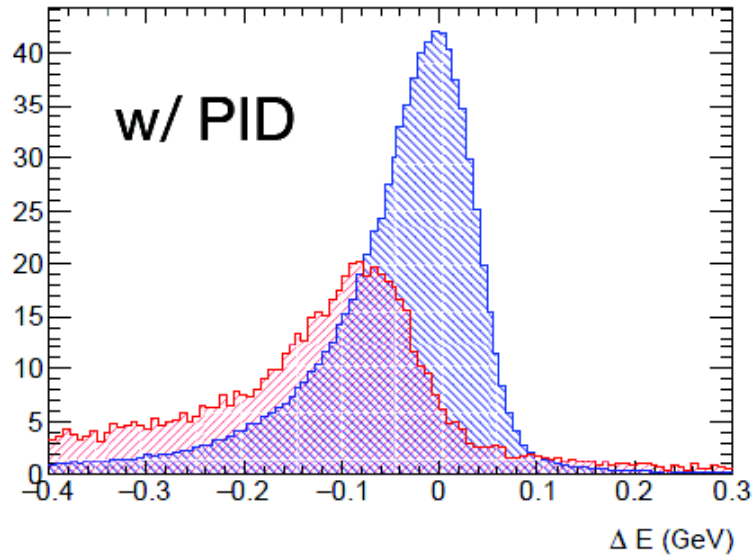


K/π separation

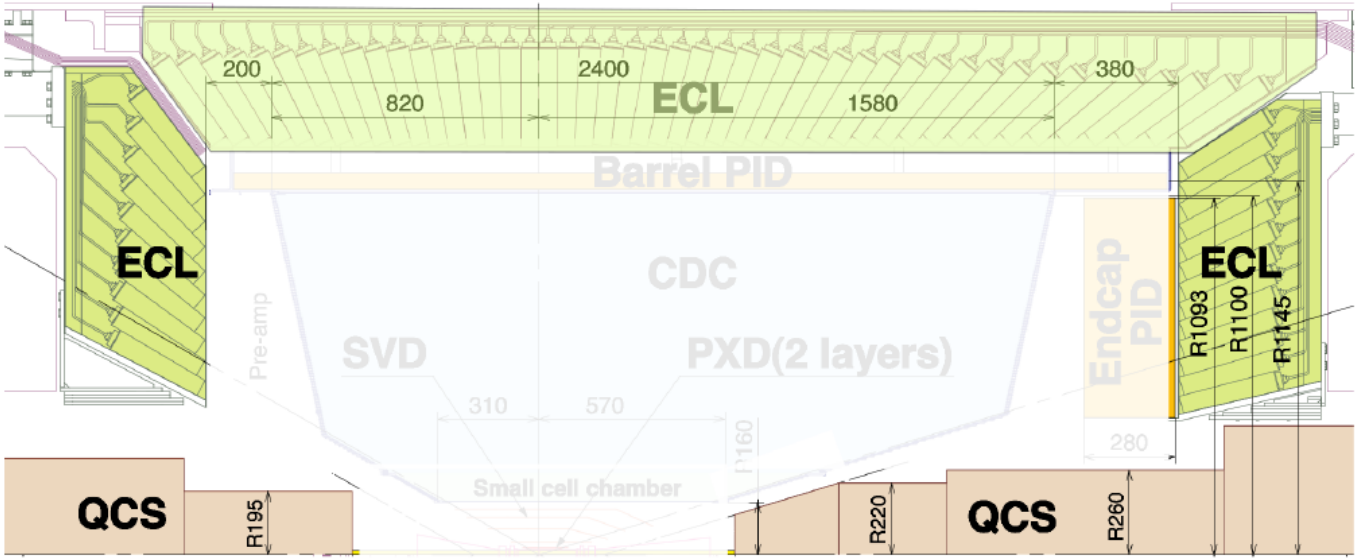


$B^0 \to \rho^0\gamma$ vs. $K^{*0}\gamma$





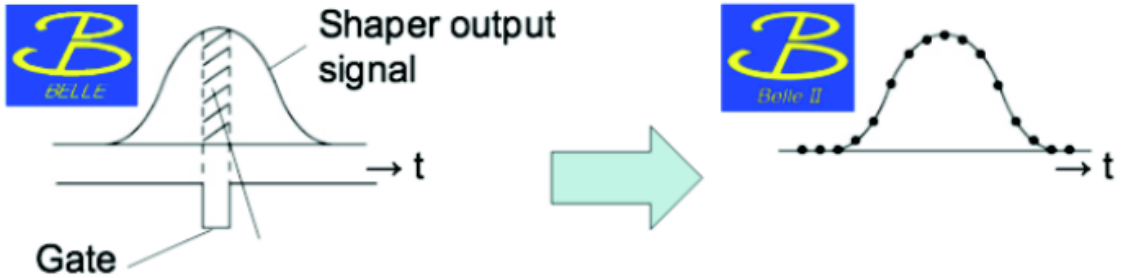
Electromagnetic Calorimeter

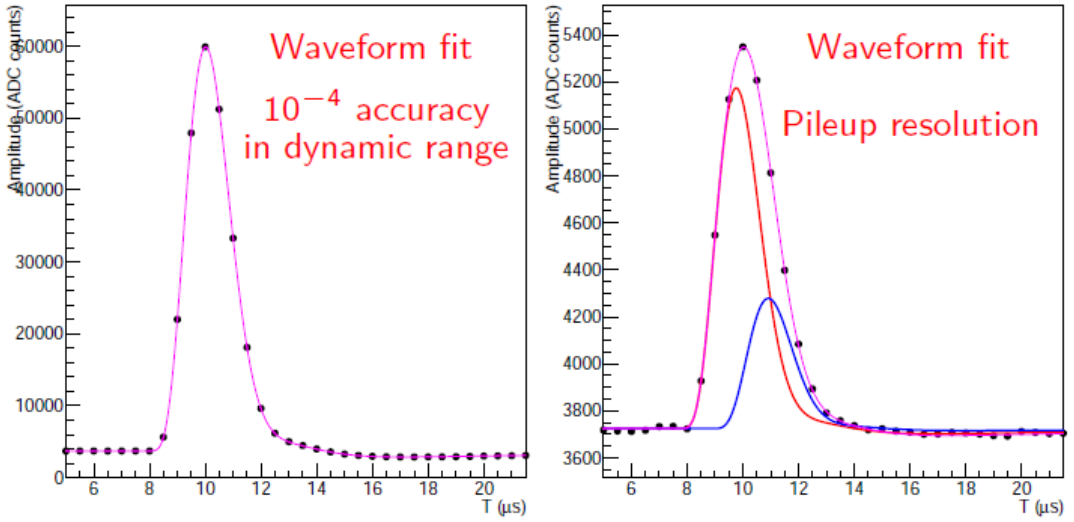


8736 CsI(Tl) crystals, 16 X_0

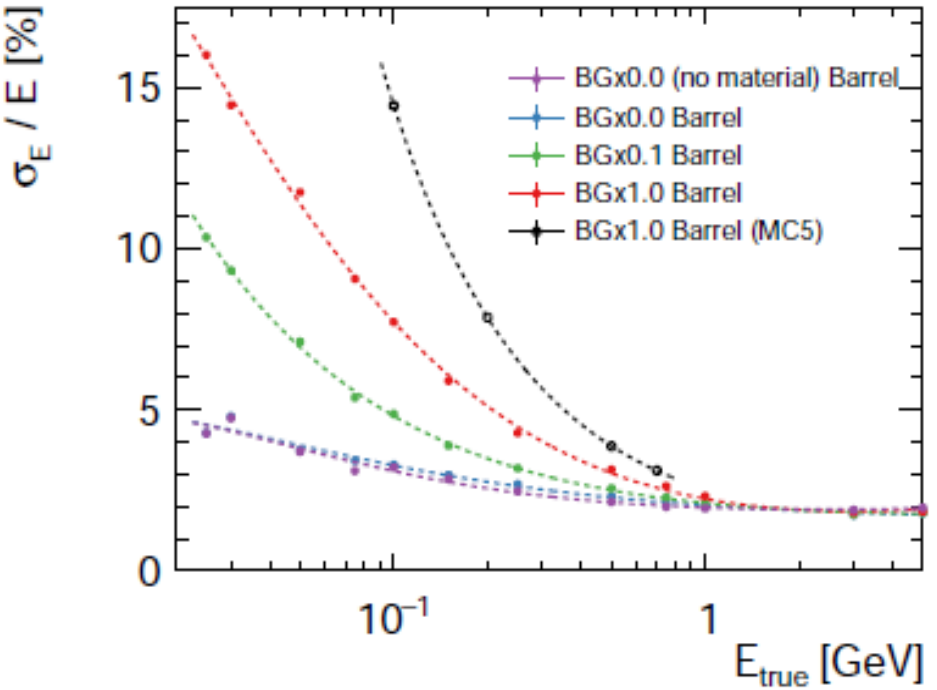
Upgrade of electronics

- Shorter signal sampling (1000 → 500ns)
- The waveform sampling (2 MHz)
- Fit form to extract amplitude and time

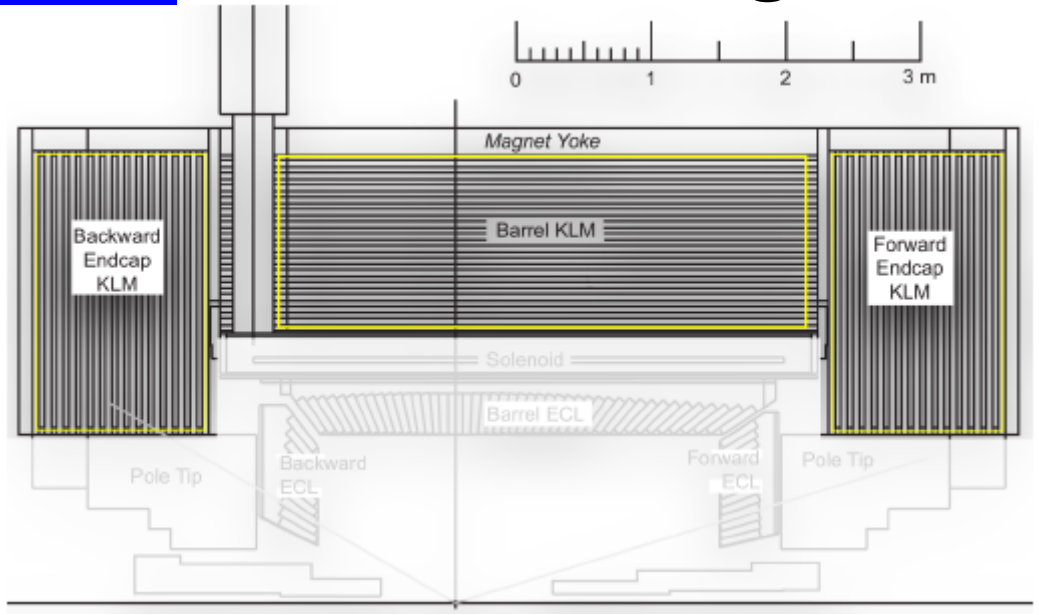


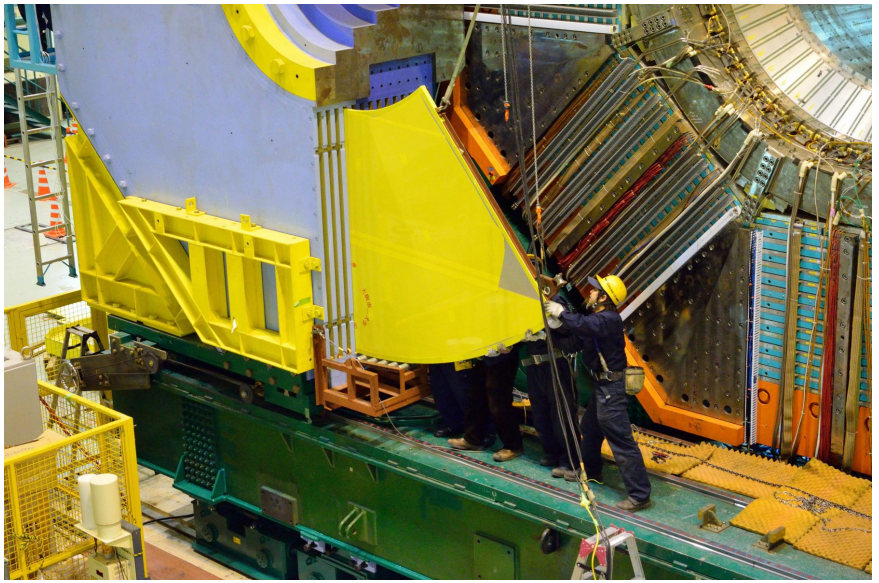


Energy resolution vs background

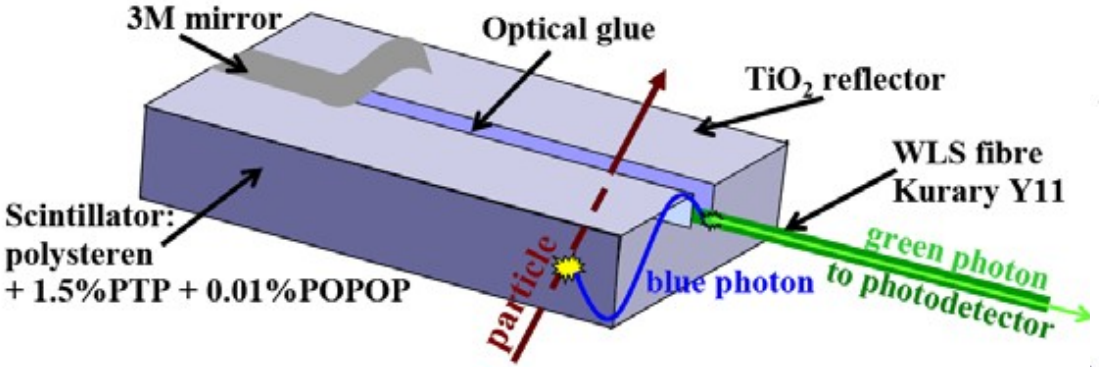


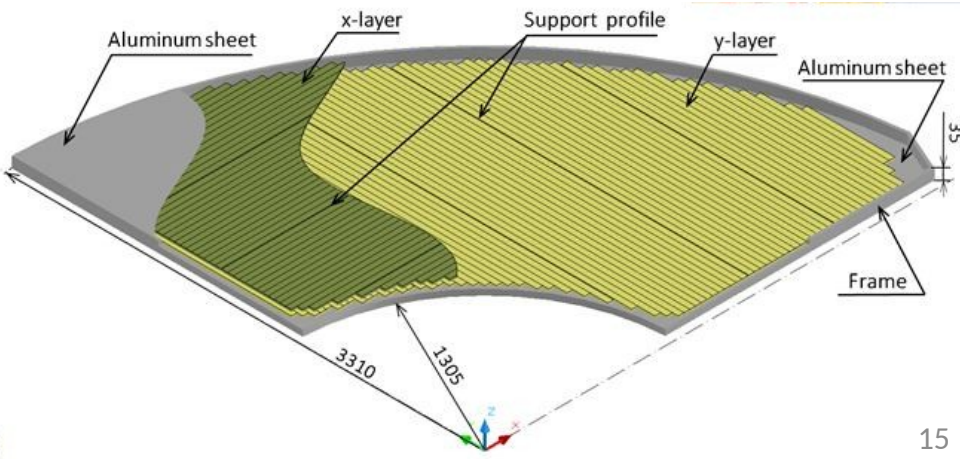
The KLong and Muon detector





RPCs in the endcaps and two inner barrel layers have been replaced with scintillator strips with WLS fibers and MPPC detectors in order to keep reasonable efficiency at high signal anf background rates.





Flavour Tagger

Two steps:

- Build 13 multivariate discriminators for topologies strongly correlated with the B flavour
- Use the output to another multivariate algorithm to provide q * r

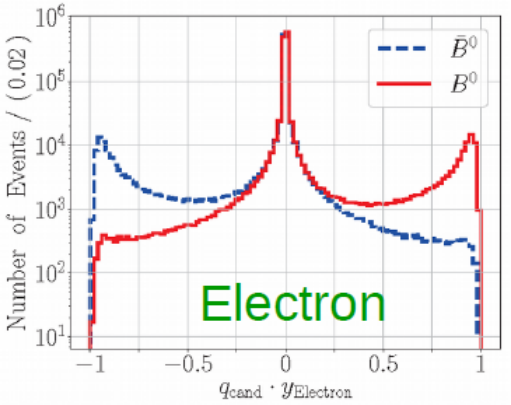
Categories	Targets for $\overline{B}^0$
Electron	e^-
Intermediate Electron	e^+
Muon	μ^-
Intermediate Muon	μ^+
Kinetic Lepton	l^-
Intermediate Kinetic Lepton	l^+
Kaon	K^-
Kaon-Pion	K^-, π^+
Slow Pion	π^+
Maximum P*	l^-, π^-
Fast-Slow-Correlated (FSC)	l^-, π^+
Fast Hadron	π^-, K^-
Lambda	Λ

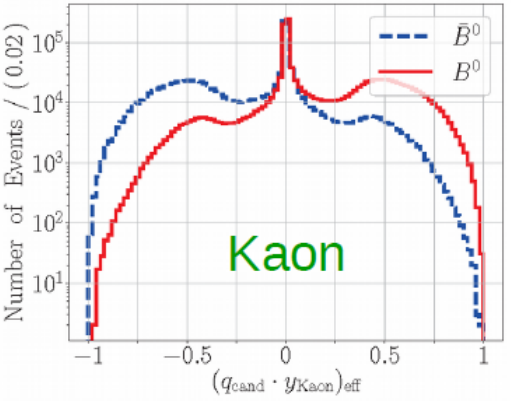
Underlying decay modes

$\overline{B}^0 \to D^{*+}\ \overline{\nu}_\ell\ \ell^-$
$\quad\hookrightarrow D^0\ \pi^+$
$\quad\quad\hookrightarrow X\ K^-$

$\overline{B}^0 \to D^+\ \pi^-\ (K^-)$
$\quad\hookrightarrow K^0\ \nu_\ell\ \ell^+$

$\overline{B}^0 \to \Lambda_c^+\ X^-$
$\quad\hookrightarrow \Lambda\ \pi^+$
$\quad\quad\hookrightarrow p\ \pi^-$

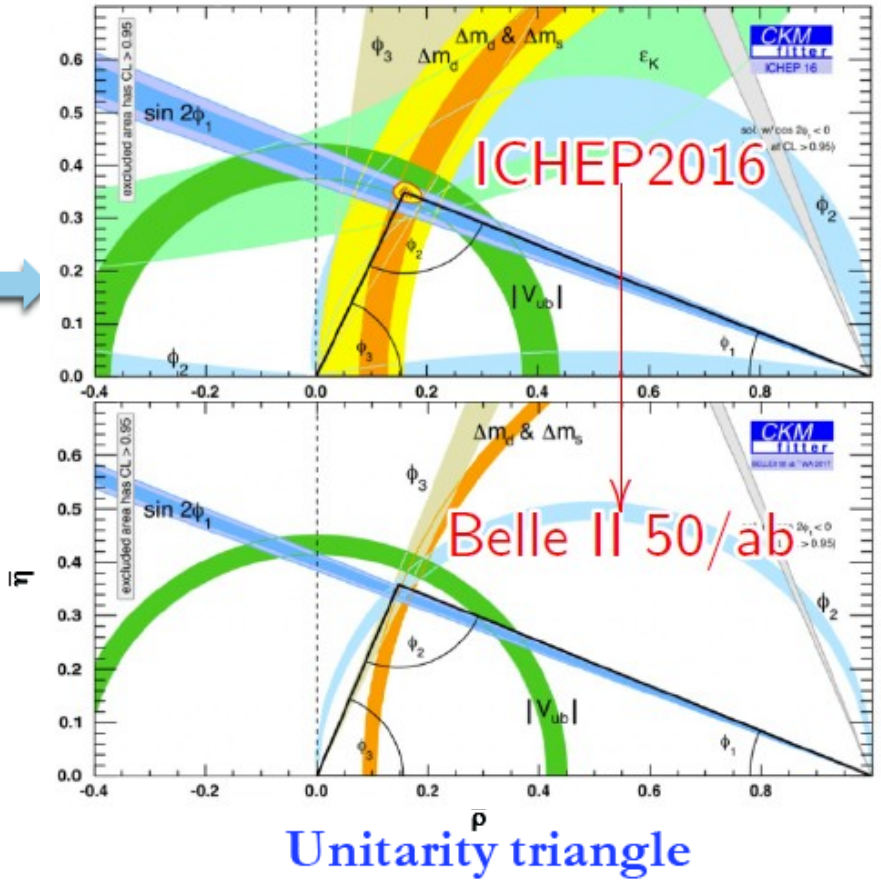




High tagging efficiency: $\varepsilon_{\text{BELLEII}} = 37\%$ $\varepsilon_{\text{BELLE}} = 30\%$

Physics program

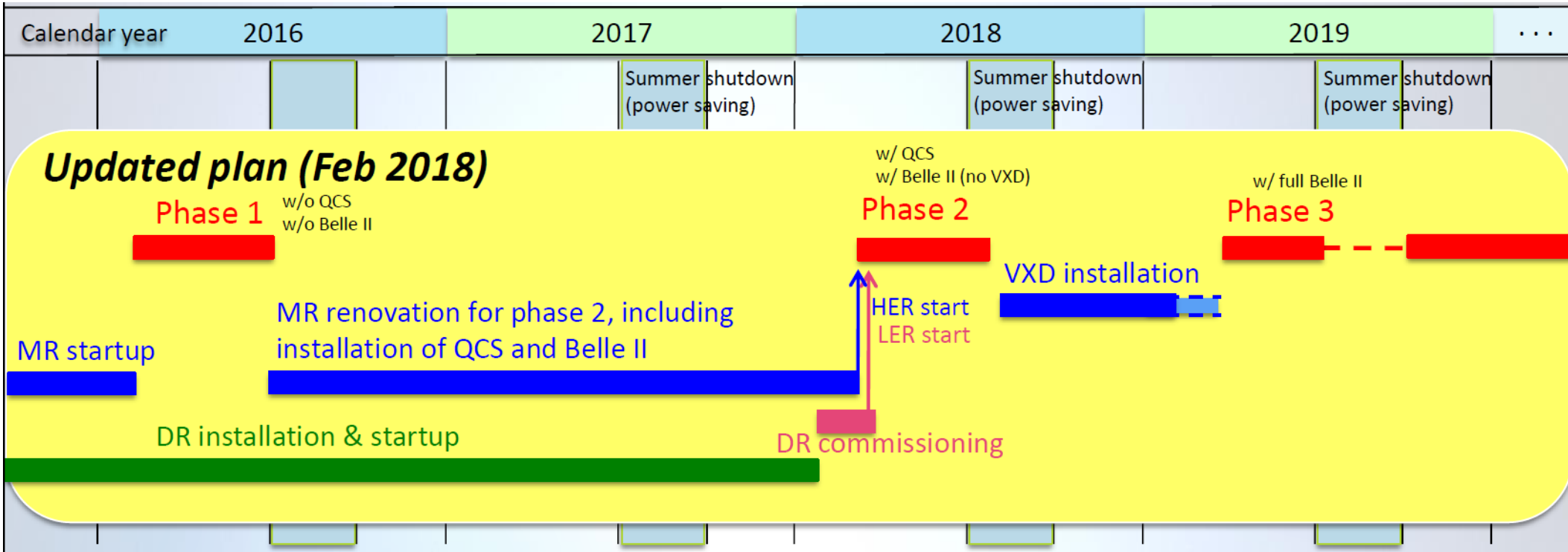
- **CPV in B decays** ($B \to J/\psi K^0, K^0\pi^0\gamma, K\pi$)
- **(Semi)leptonic B decays** ($B \to D^{(*)}l\nu, \pi l\nu, \tau\nu, \mu\nu$)
- **Rare B decays** ($B \to K\nu\nu, X_s\gamma, X_s ll, \gamma\gamma$)
- **Charm physics** ($D \to l\nu$, mixing, CPV)
- **LFV** tau decays ($\tau \to 3l, l\gamma$)
- **Dark Sector, Spectroscopy** (early physics)



Unitarity triangle

Observables	Expected th. accuracy	Expected exp. uncertainty	Facility (2025)
UT angles & sides			
ϕ_1 [°]	***	0.4	Belle II
ϕ_2 [°]	**	0.6	Belle II
ϕ_3 [°]	***	1.0	Belle II/LHCb
$\|V_{cb}\|$ incl.	***	1%	Belle II
$\|V_{cb}\|$ excl.	***	1.5%	Belle II
$\|V_{ub}\|$ incl.	**	3%	Belle II
$\|V_{ub}\|$ excl.	**	2%	Belle II/LHCb

Schedule



Phase 1
without QCS or Belle II

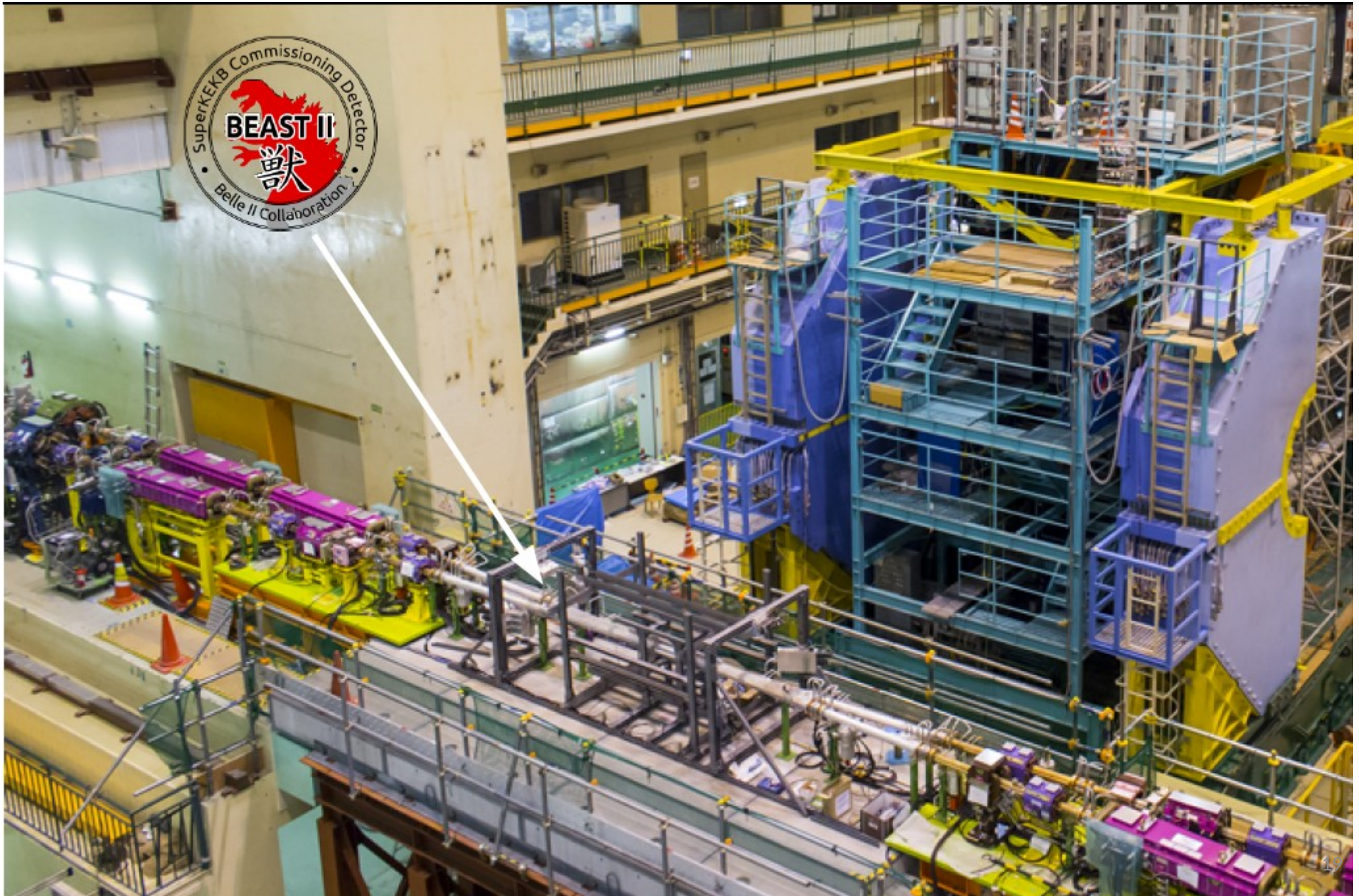
Vacuum scrubbing
Basic machine tuning
… Finished in success

Phase 2
with QCS and Belle II without VXD
Background study
Luminosity tuning
(target: 1 x 10^{34} /cm^2/s)

Phase 3
Physics run

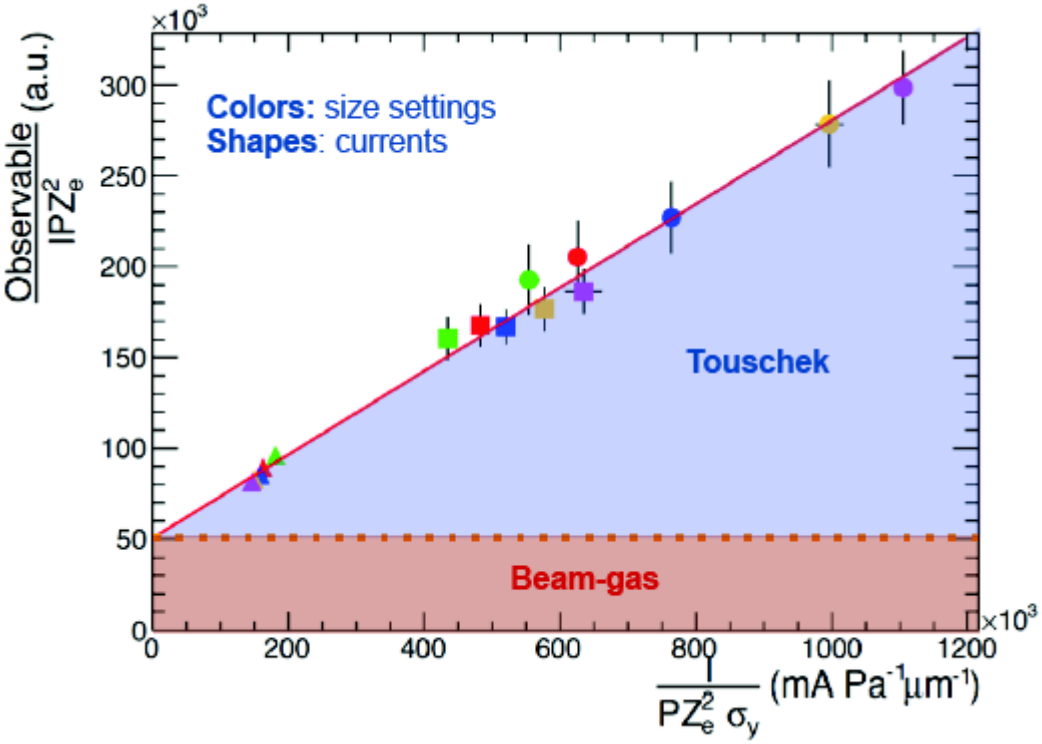
Luminosity tuning
(target: 8 x 10^{35} /cm^2/s)

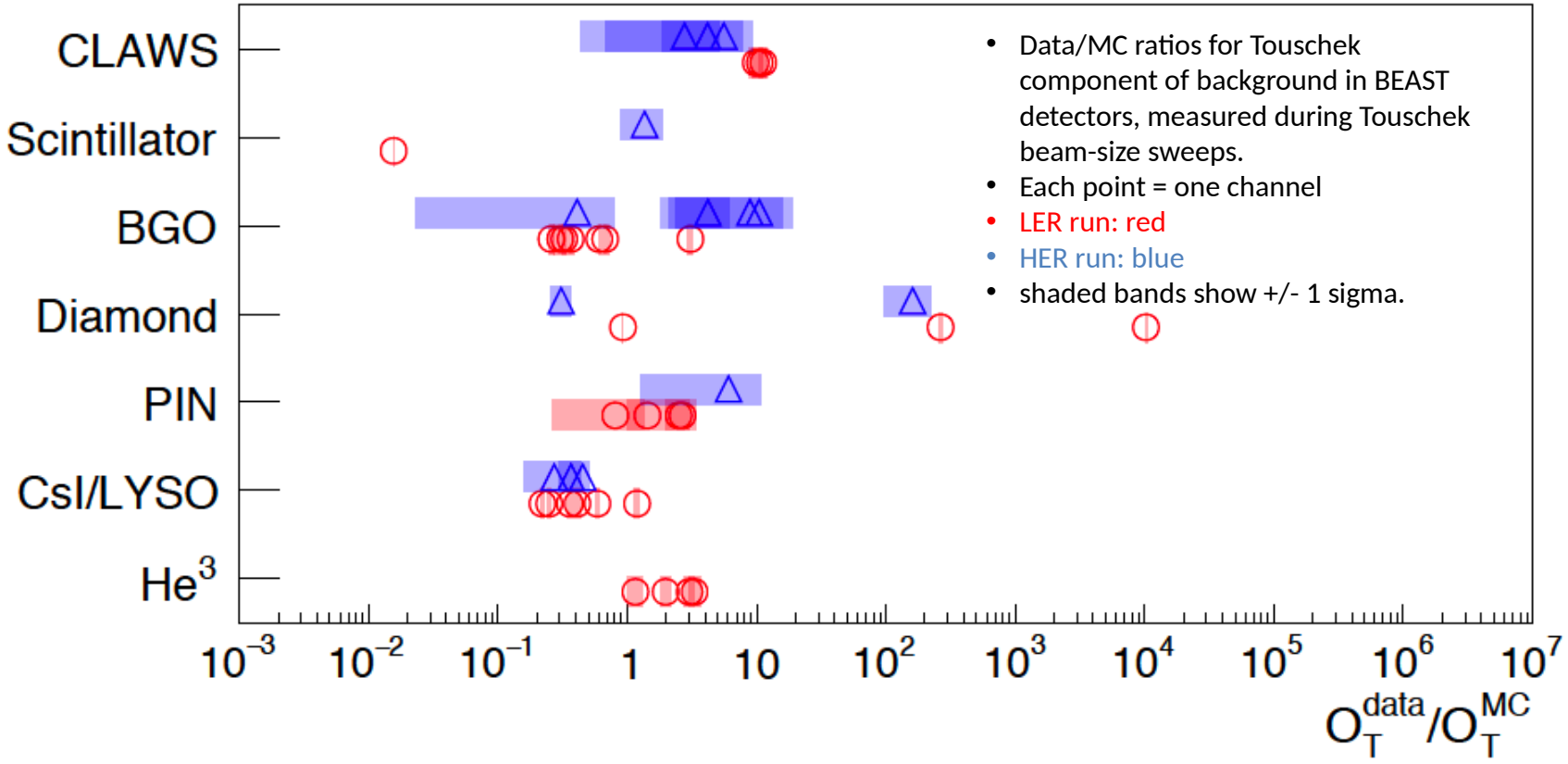
Belle II Exorcism for A STable beam



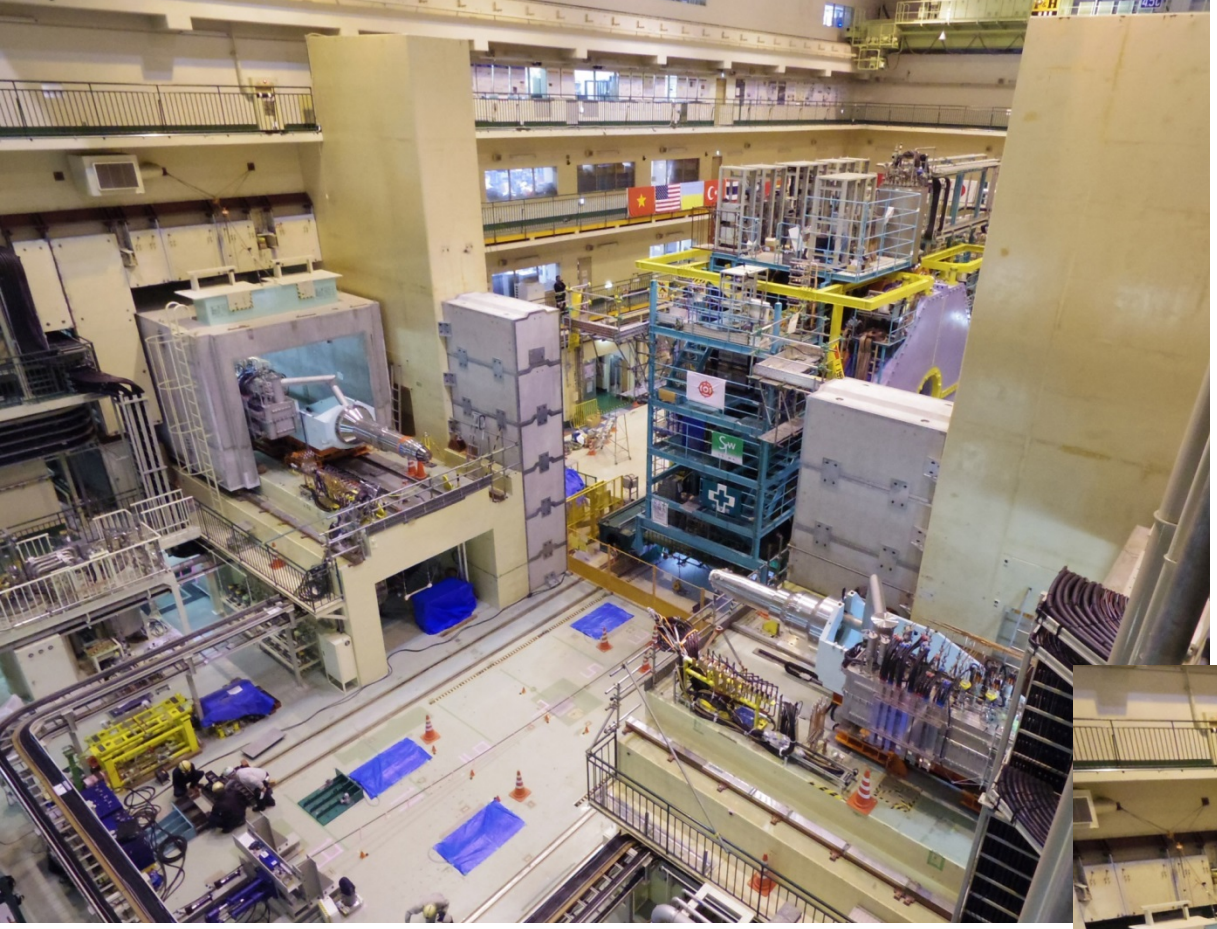
BEAST II Result
Touschek Scattering

arXiv:1802.01366

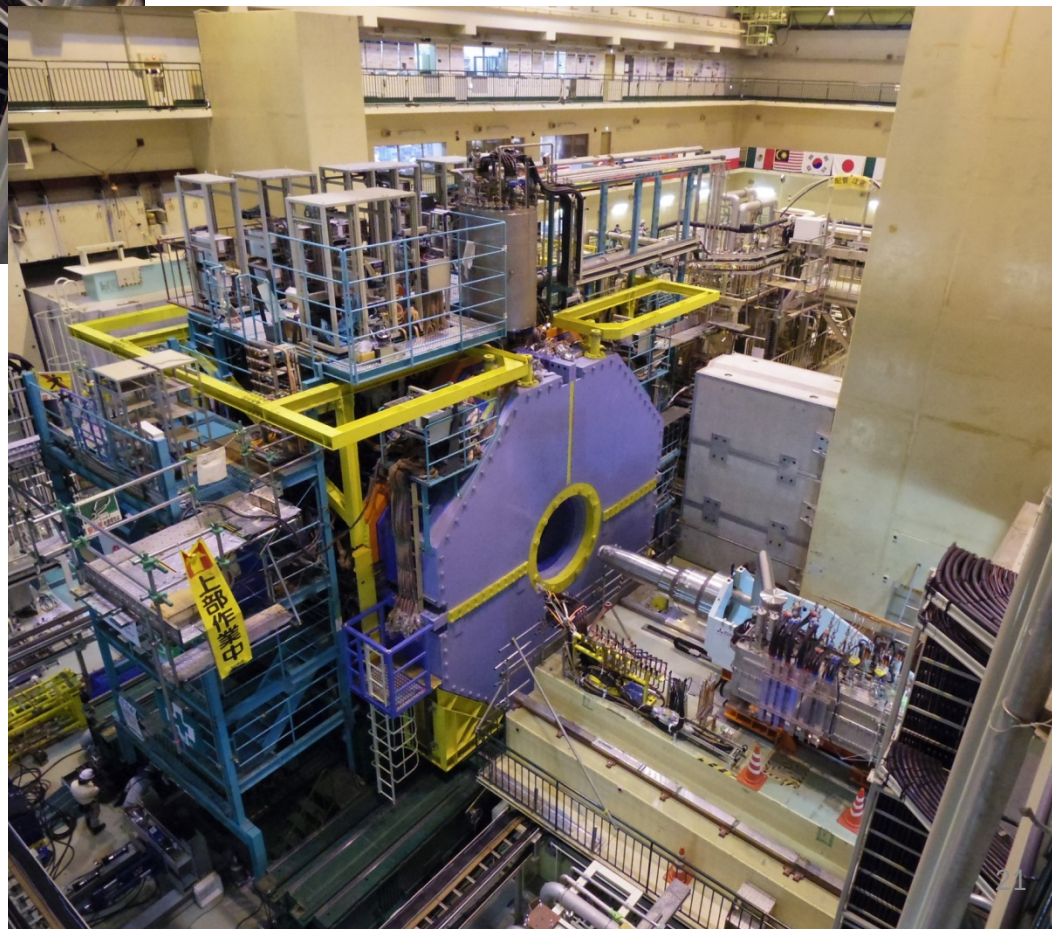




- Data/MC ratios for Touschek component of background in BEAST detectors, measured during Touschek beam-size sweeps.
- Each point = one channel
- LER run: red
- HER run: blue
- shaded bands show +/- 1 sigma.

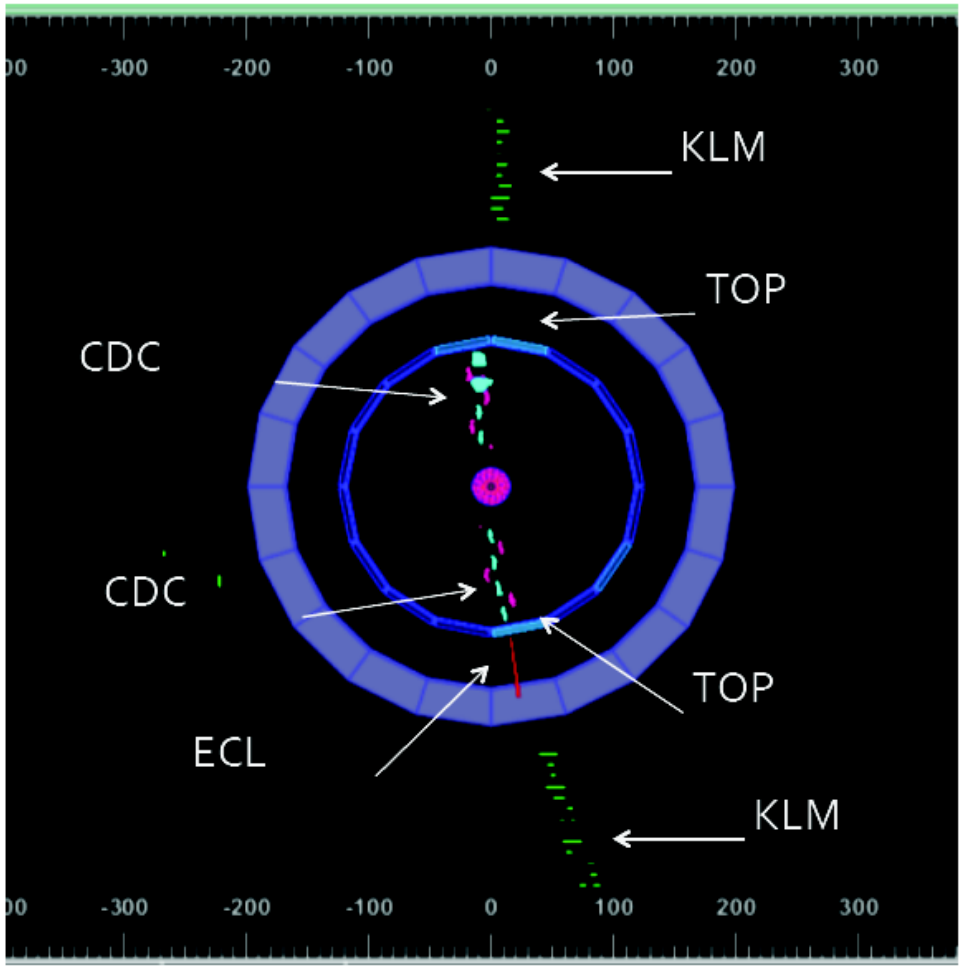


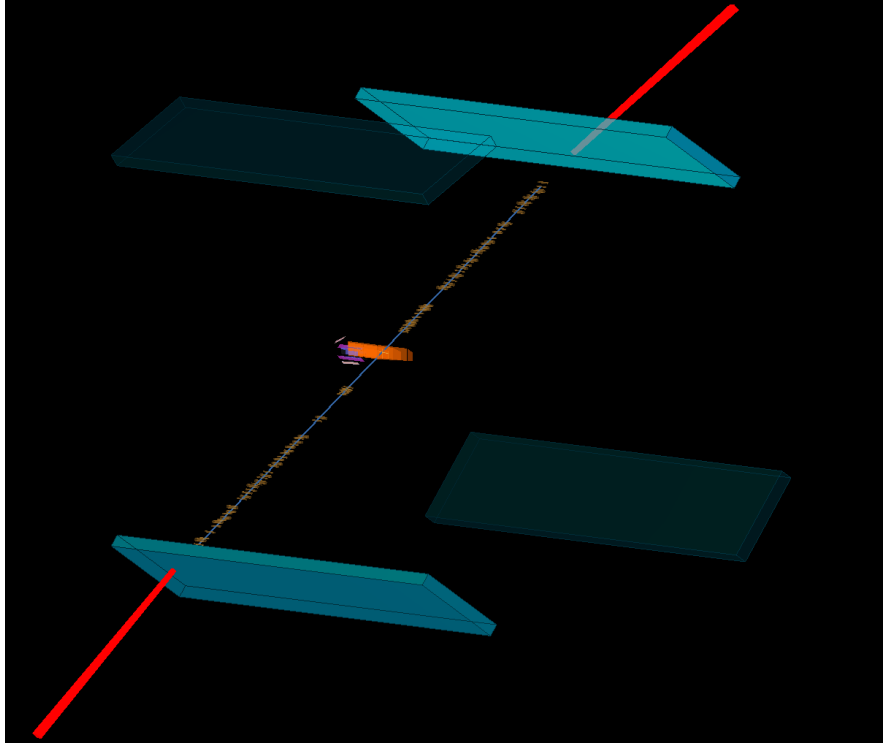
SuperKEKB & Belle II are getting ready

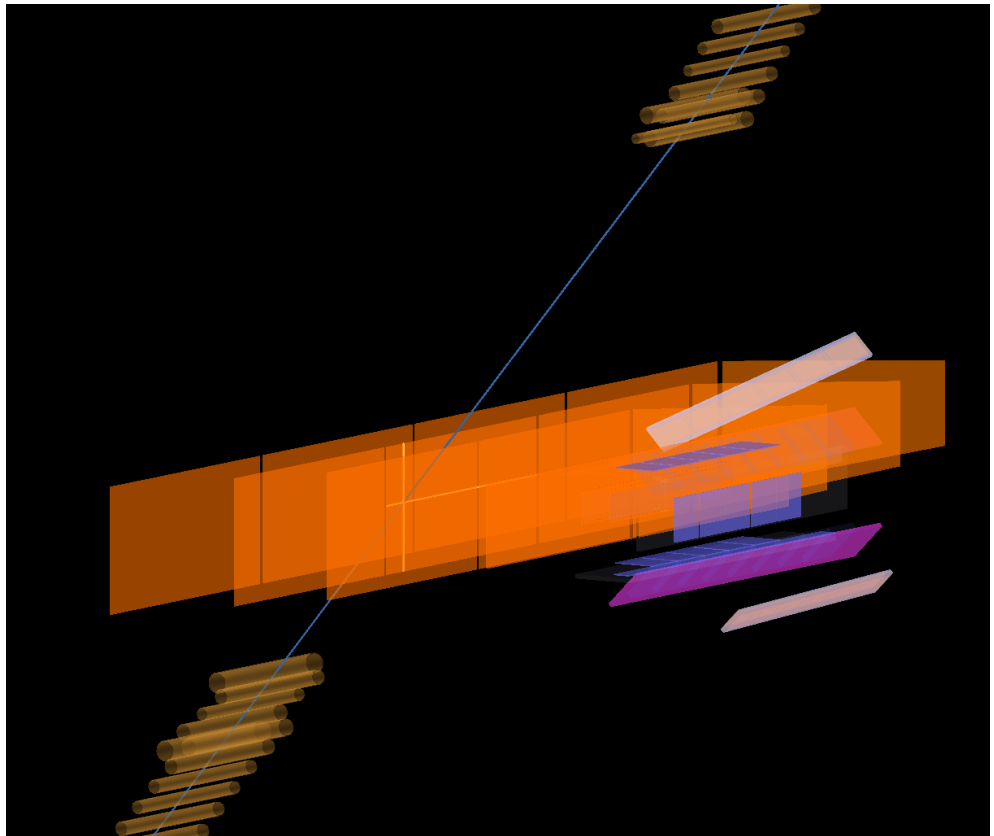


for first collision in April

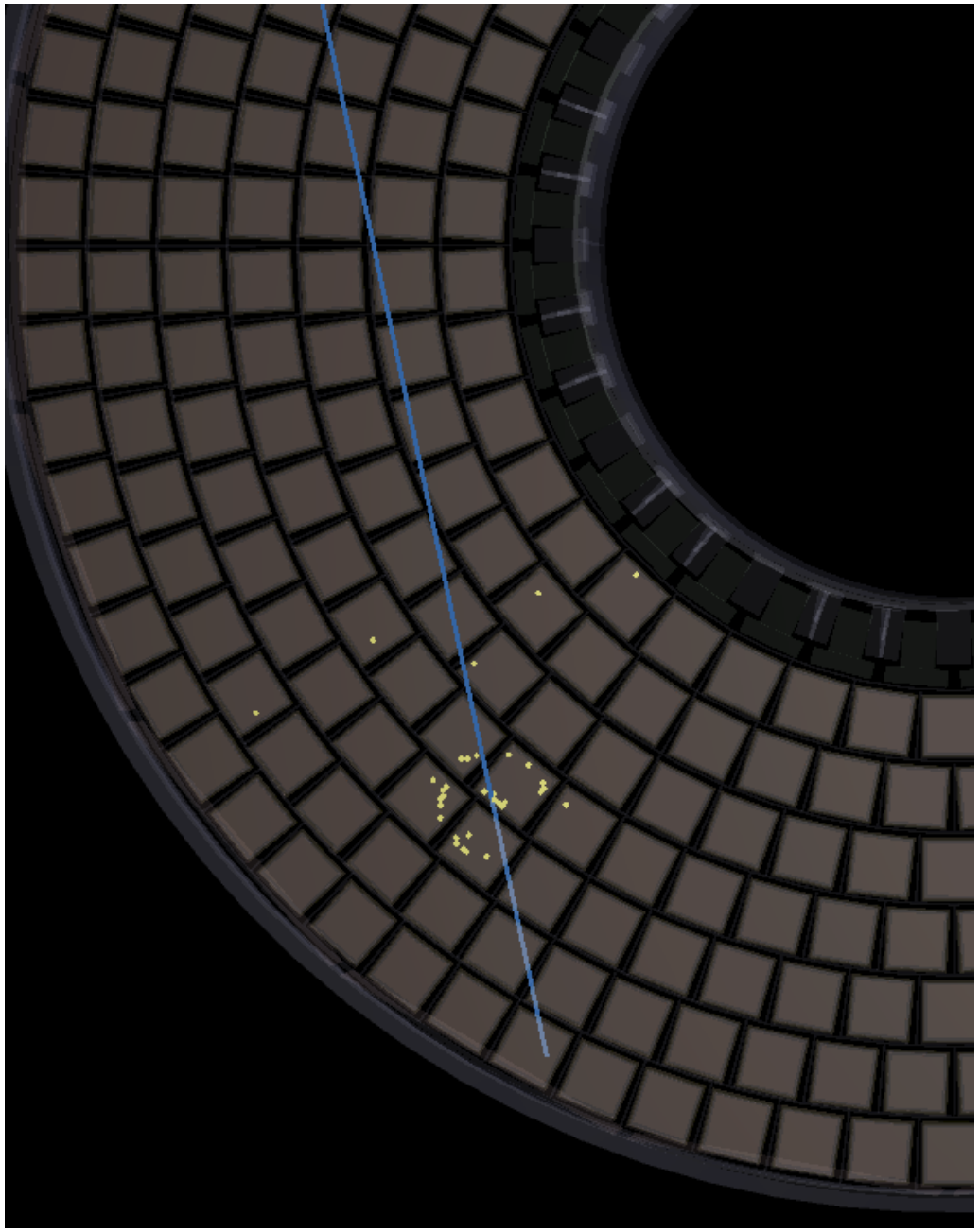
Tracks in SVD

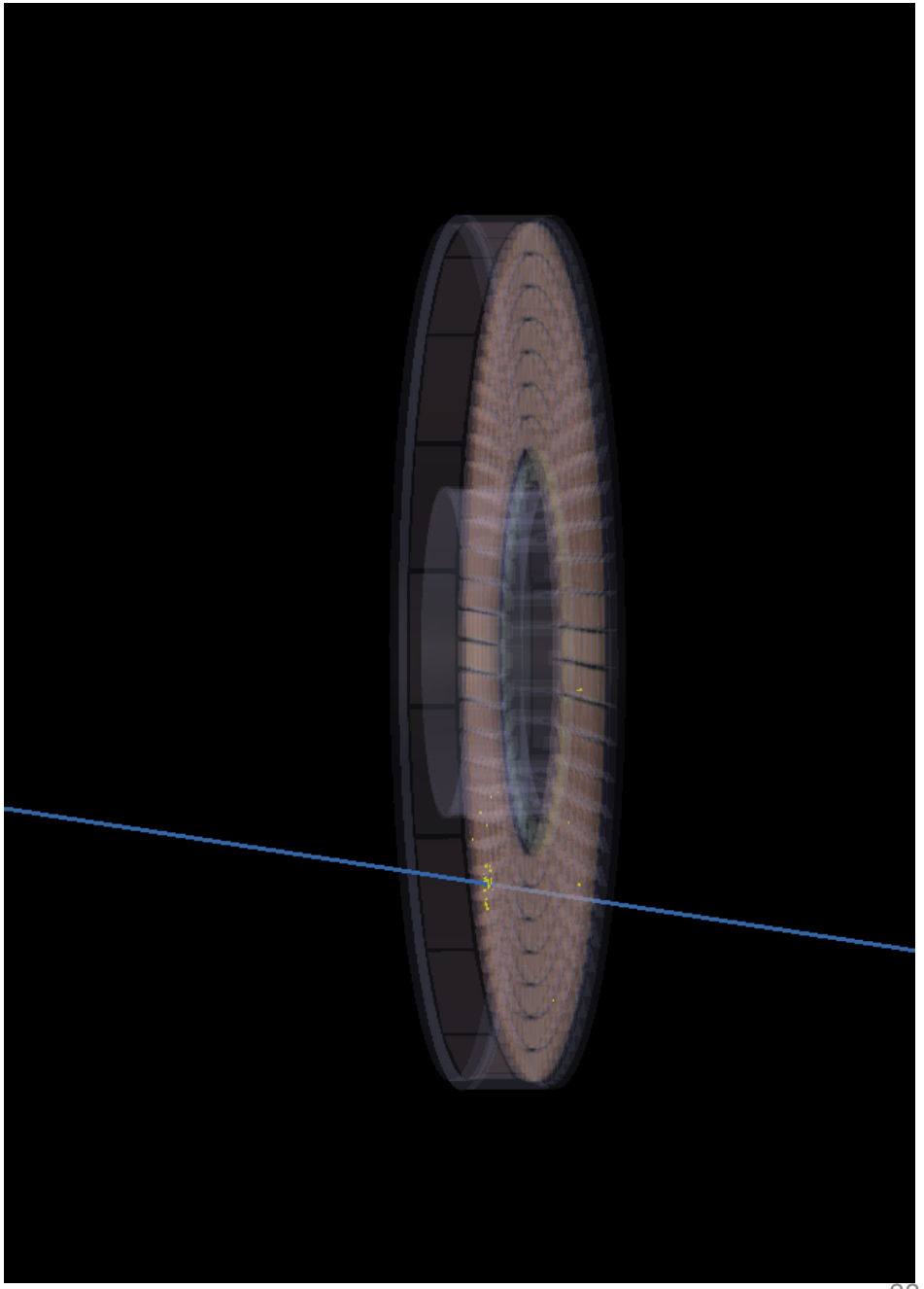




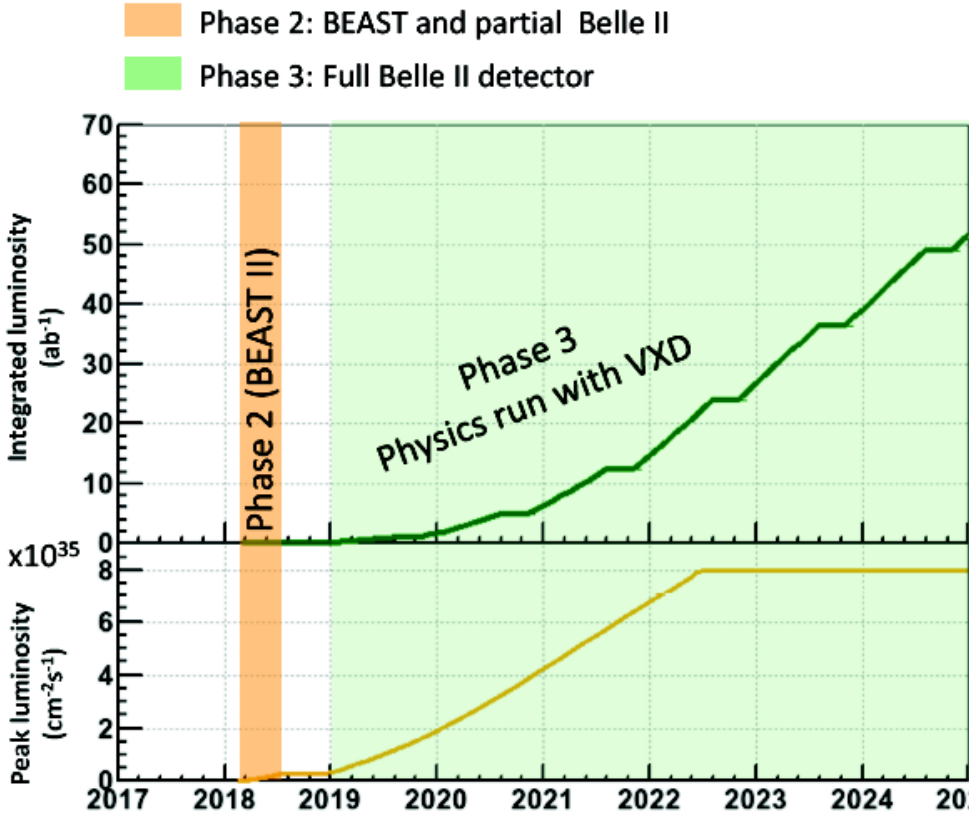


RICH signal in cosmic run





Phase II



Commissioning of accelerator and detectors

- Start sring 2018, duration ~5 months
- Beam collisions with focusing magnets (QCS)
- Target luminosity is 10^{34} cm^{-2}s^{-1}
- Up to 40 fb^{-1} for physics analyses
- W/o vertex detector → no time dependent measurements

What can be done with early physics data?

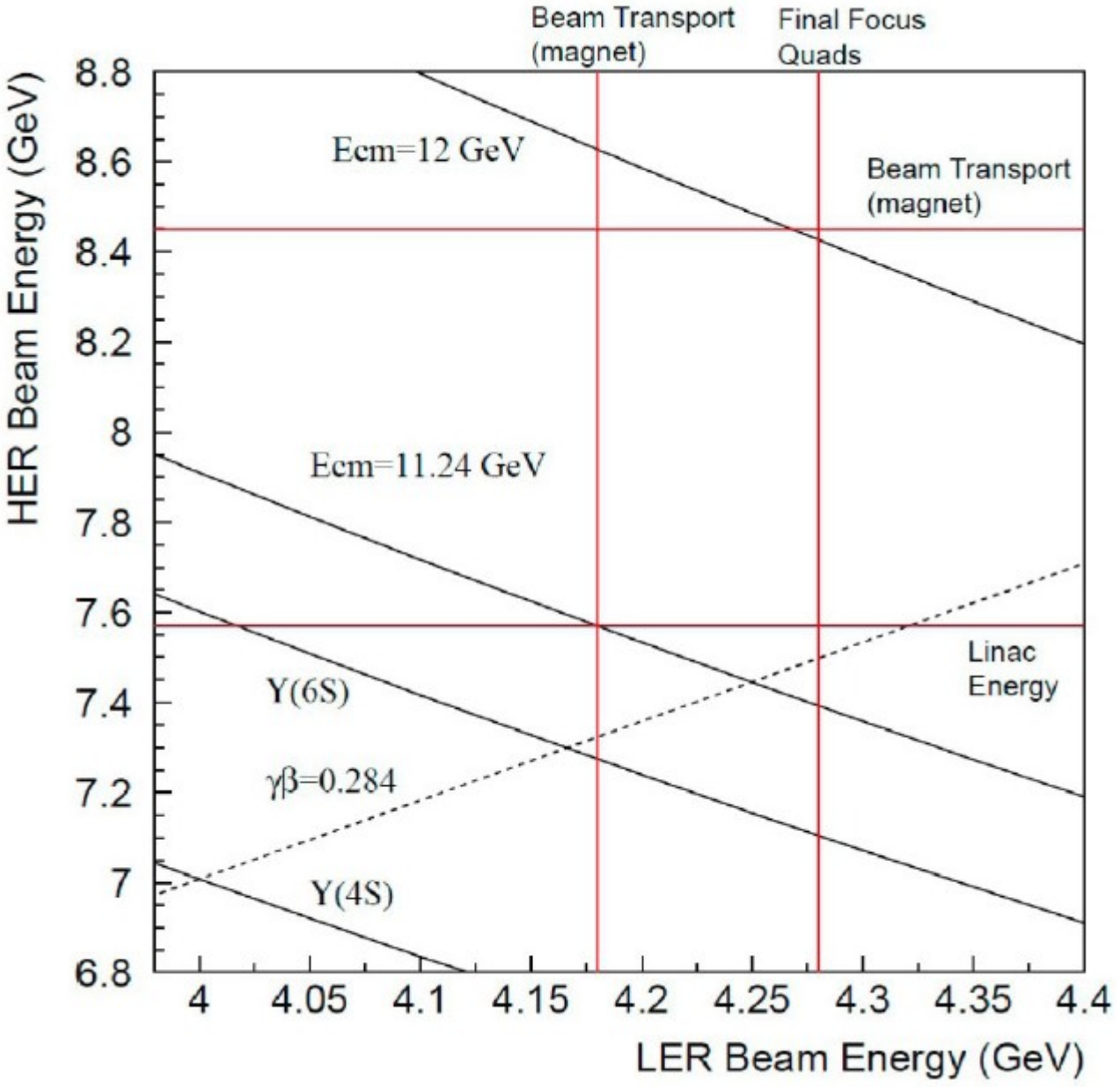
➔ Background studies
➔ Detector and trigger performance studies
➔ Simulation validation
➔ Exercising of calibration and alignment procedures
➔ Reconstruction algorithm tuning
➔ Physics measurements

Energy scan

Existing datasets [fb^{-1}]:

	CLEO	BaBar	Belle
Y(1S)	1.2		6
Y(2S)	1.2	14	25
Y(3S)	1.2	30	3
Y(4S)	16	433	711
Y(5S)	0.1	3.3	36
Y(6S)			5.5
Off res.	17	54	100

High energy is most promising



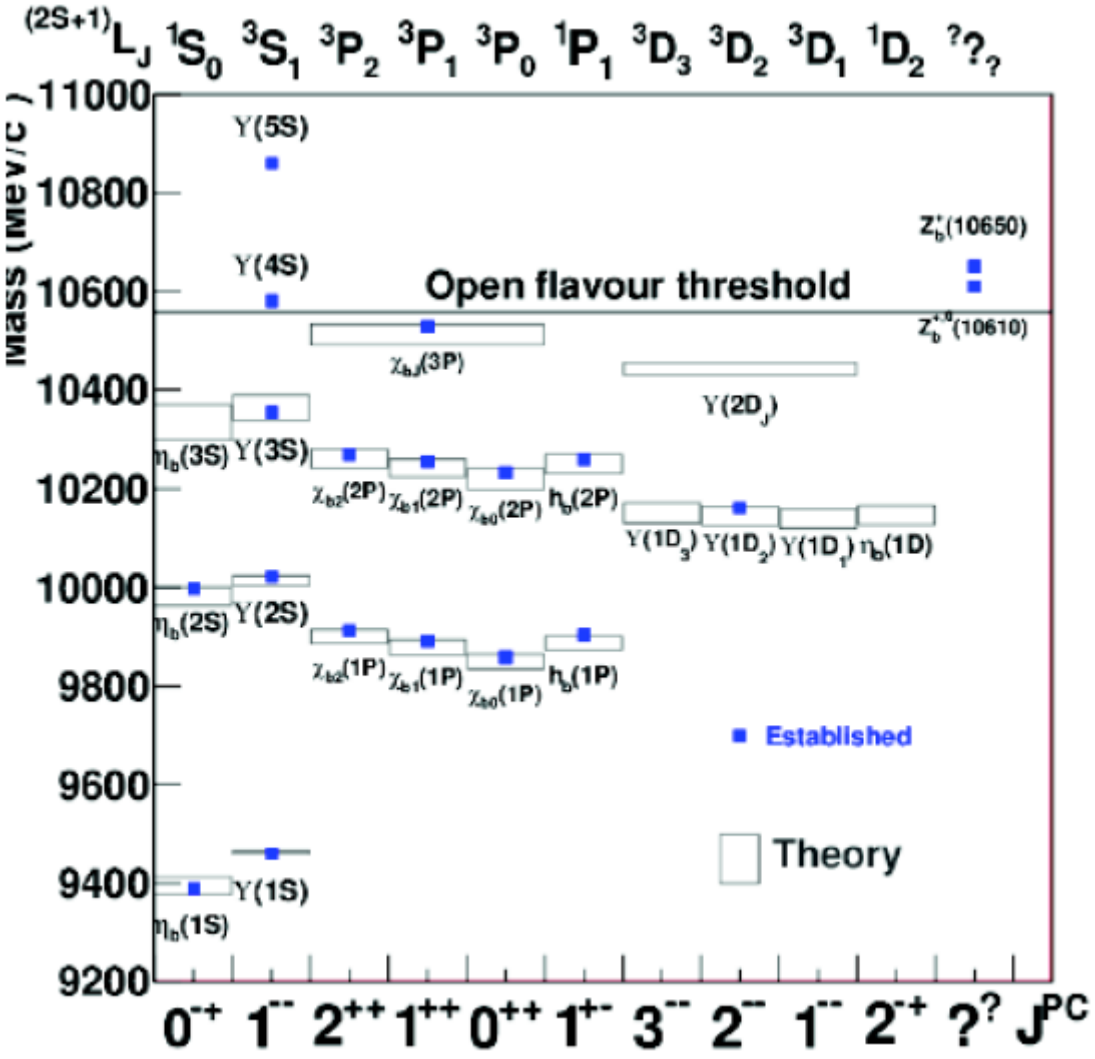
Study of Y(6S) decays

Known states:

- Y(nS) ππ and Y(mD) ππ
- Y(nS) η and Y(mD) η
- Y(nS) K^+K^-
- χ_b(mP) ω

Search for new states

- $Z_b^{\pm}\pi^{\mp} \rightarrow$ Y(nS) $\pi^+\pi^-$, h_b(mP) $\pi^+\pi$
- $W_b^{0}\pi^+\pi^-$ with $W_b^{0} \rightarrow \eta_b\pi$, $\chi_b\pi$, Y(nS)ρ
- $X_b^{0}\gamma$ with $X_b^{0} \rightarrow$ Y(1S)ω
- B(*) $\overline{B}$**, Bs(*) $\overline{Bs}$**, Λb $\overline{\Lambda b}$



Search for new conventional bottomonium states: hb(3P) and Y(2D)

Low multiplicity events

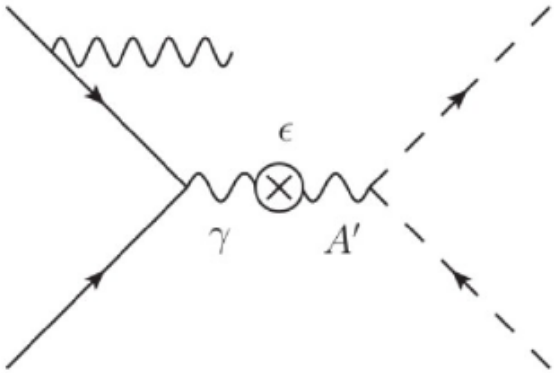
Trigger:

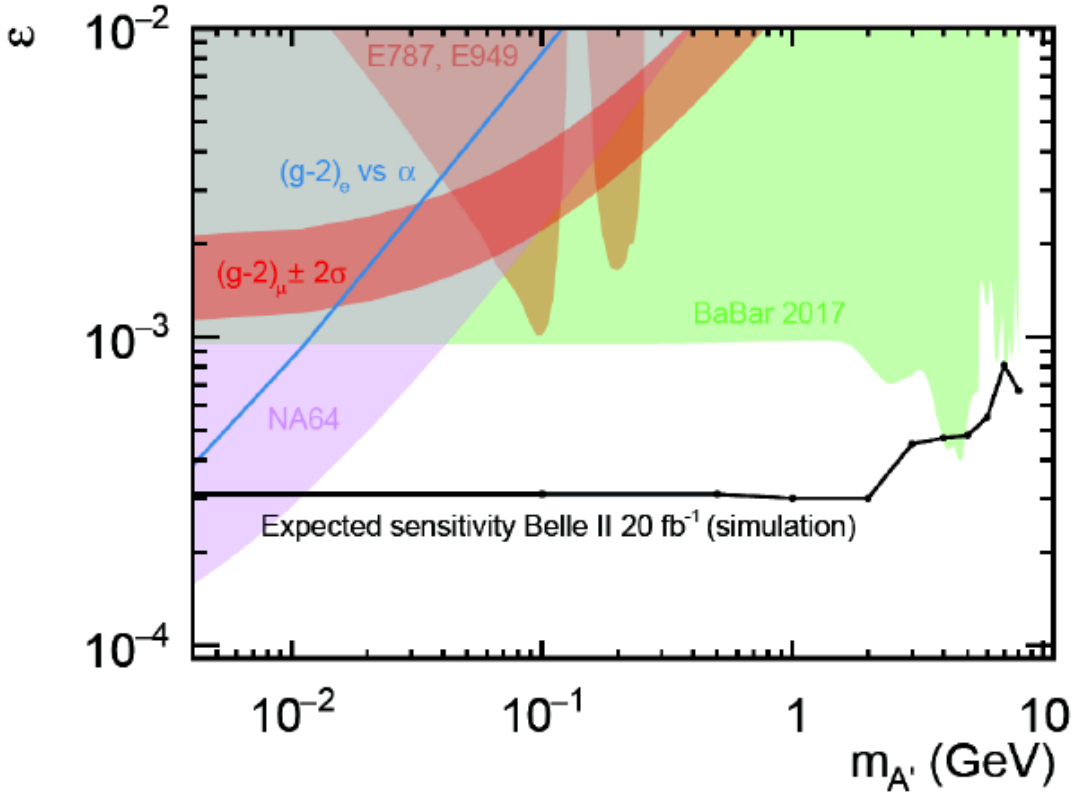
- ~100% efficient for B and charm decays
  - Low multiplicity events challenging because of large QED background
- Belle trigger was not optimized for low multiplicity
- Improvements of level 1 (L1) hardware trigger at Belle II:
  - Data rate increased from 16 to 190 Mbps
  - Logic implemented in FPGAs instead of hard coded
- Software based high level trigger (HLT) runs full reconstruction

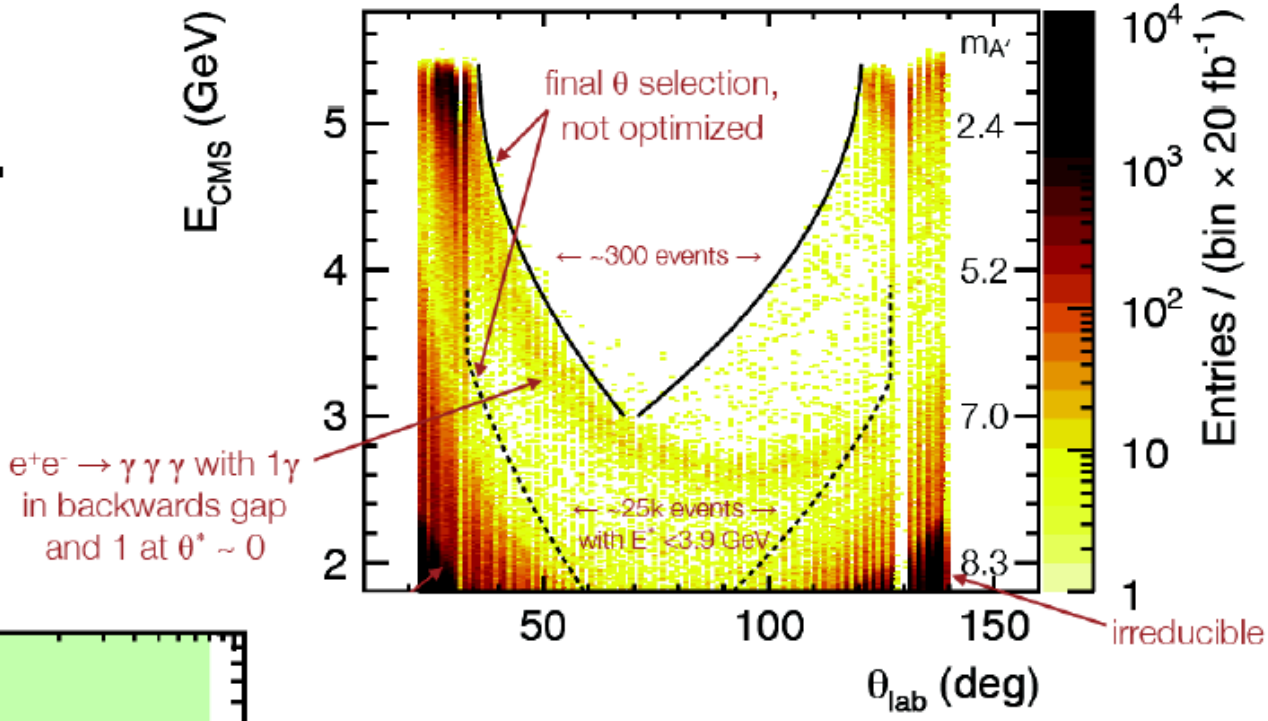
Development of triggers for low multiplicity:

- Search for new physics in low multiplicity events with phase 2 data

Dark Photon A’







- Kinetic mixing with SM photon

$$\sigma \propto \varepsilon^2 \alpha^2 \left(1 - m_{A'}^2 / E_{CM}^2\right) / E_{CM}^2$$

- Relevant for phase 2:
  Decay A’ → invisible
- Requires single photon trigger
  → Challenge: background

Summary

- Belle II phase 2 will start in April 2018. Accelerator and detector are commissioning. Expecting up to 40 fb^{-1} of data w/o vertex detector.

- First physics opportunities:
  - Exotic states and bottomonium studies @ Y(6S)
  - Dark photon search with single photon trigger

- The complete Belle II will be ready at fall 2018 to take data on Y(4S).
- We are looking forward to the next decade of exiting new results in search for New Physics beyond the Standard Model.

- Stay tuned for news from Belle II

  https://twitter.com/belle2collab
  https://www.facebook.com/belle2collab