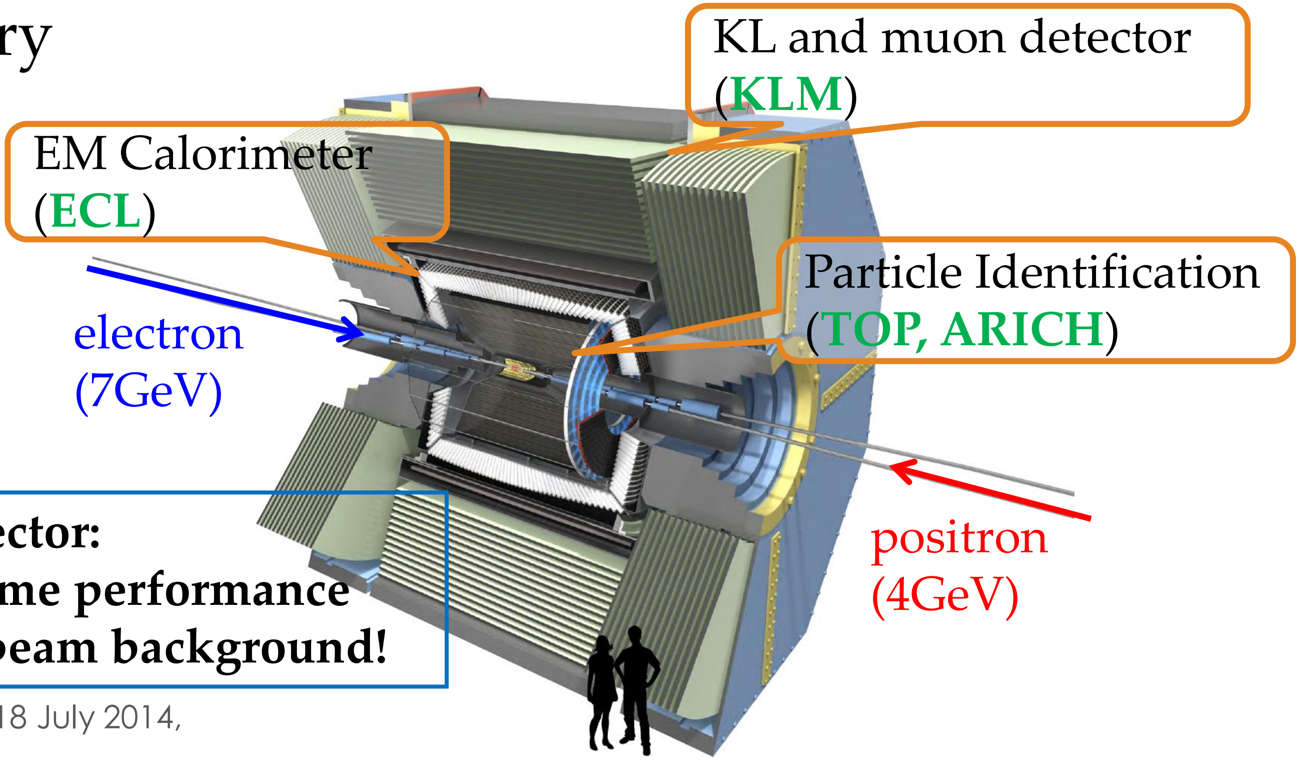
Particle identification for Belle II

Tomokatsu Hayakawa
(KMI, Nagoya University)
on behalf of the Belle II collaboration

Kobayashi-Maskawa Institute
for the Origin of Particles and the Universe

Outline

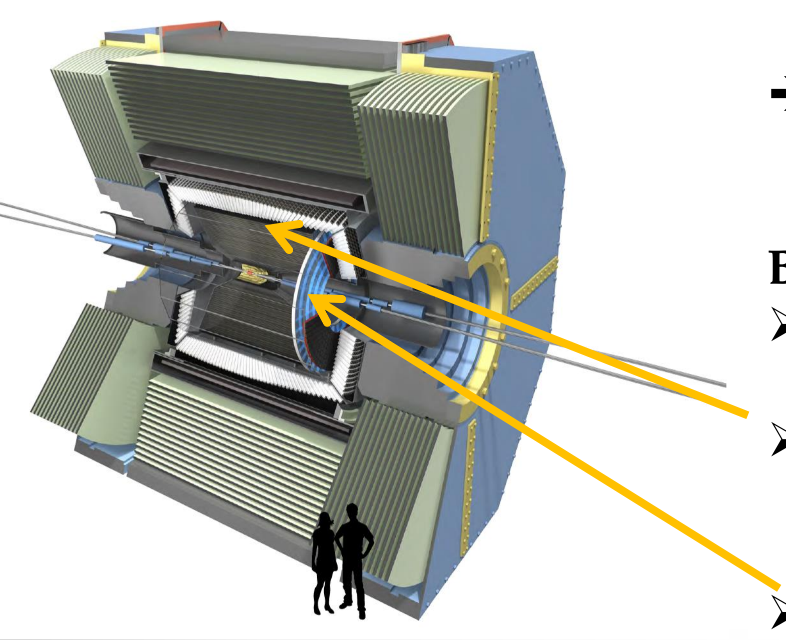
- PID system for Belle II
  - **T**ime **O**f **P**ropagation (**TOP**) counter
  - **A**erogel **R**ing **I**maging **CH**erenkov detector (**ARICH**)
- EM Calorimeter (**ECL**)
- $K_L\mu$ detector (**KLM**)
- Summary



Belle II detector:
better or same performance under x20 beam background!

PID system for Belle II

- Upgrade for SuperKEKB and Belle II (to achieve **40 times** peak luminosity).
- Particle identification (PID) system will be replaced with new detectors.



Belle PID

- Combination of
  - Time of Flight (**TOF**)
  - Central Drift Chamber (**CDC**): dE/dx
  - Threshold type Aerogel Cherenkov Counter (**ACC**)

➔ Effective momentum range is not wide enough for all particles from various decays.

Belle II PID

- Two **RICH** type systems cover the whole momentum range.
- Barrel:
  Time Of Propagation (TOP) counter (16 modules)
- Forward endcap:
  Aerogel Ring Imaging CHerenkov detector (ARICH).

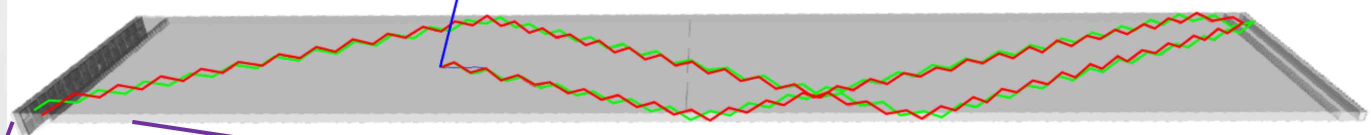
Barrel PID: TOP counter

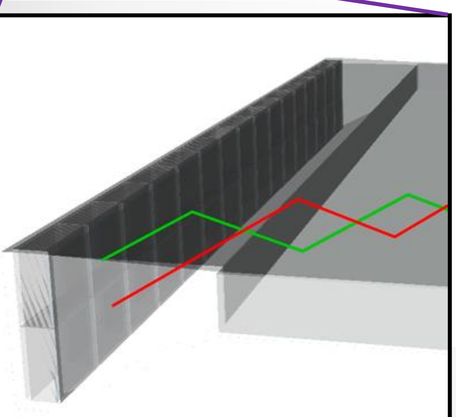
- **Time Of Propagation (TOP)** counter is a compact **RICH** detector.
- Cherenkov ring imaging with **precise time measurement** (σ~50ps)
  - ✓ **Internally reflected Cherenkov light pattern** measured.
  - ✓ **Focusing mirror system** to minimize chromatic dispersion.
- Reconstruction of Cherenkov angle (θ_c)
  from <u>two hit coordinates (X,Y)</u> and <u>Time Of Propagation (TOP) of photon</u>.
  - ✓ Difference of θ_c ➔ Difference of path length ➔ Difference of TOP

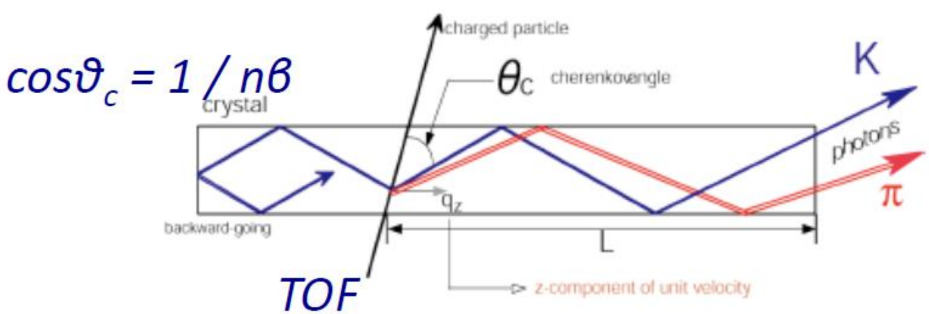
Read-out:
High time resolution position sensitive photo-detector

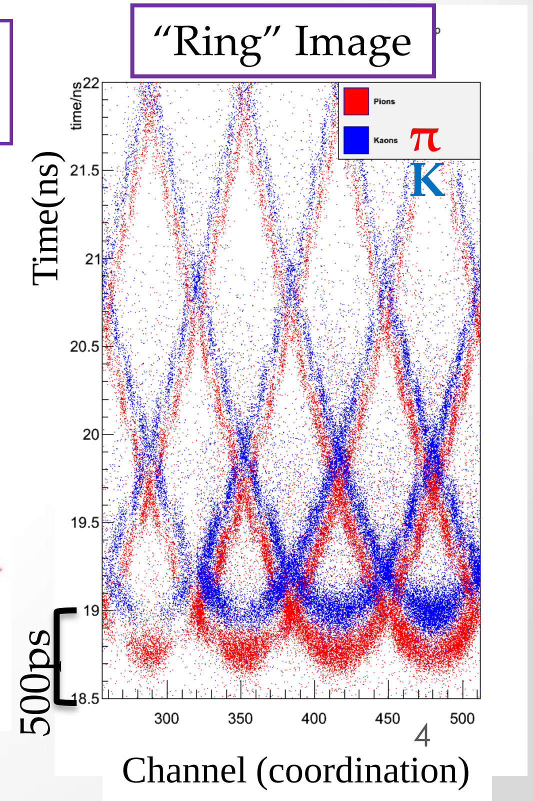
High quality **quartz radiator**
(Cherenkov photons bounce off > **100 times** at the quartz faces)

Focusing mirror end







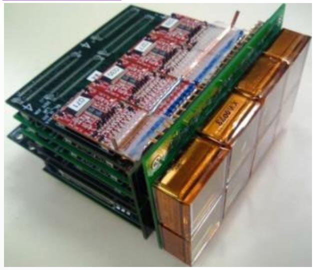


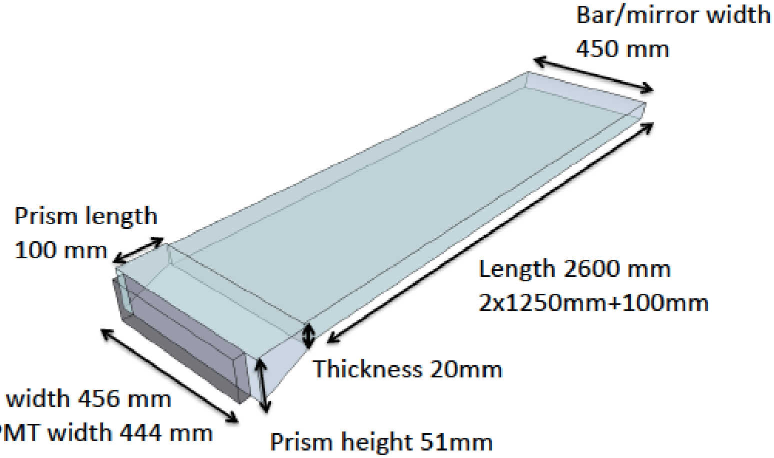
Detector components (TOP)

- **Photodetector**: Hamamatsu SL10 16ch **Micro Channel Plate (MCP)-PMTs**
  - Mass production completed. ➔ Inspections are in progress.
- **FEE**: **High-speed waveform sampling ASICs ("IRS")** developed by Hawaii group.
  - Final electronics production and validation starts late 2014.
- **Quartz Optics**: **high quality quartz** (Zygo, Okamoto, ITT)
  - Procedures for acceptance tests and assembly established well.
  - Mass production of precision optical components is now under way.
- **Quartz Bar Box**: Al honeycomb panels + PEEK material to support the quartz optics
- **Prototyping**: **1st full scale prototype has been assembled successfully in 2013.**

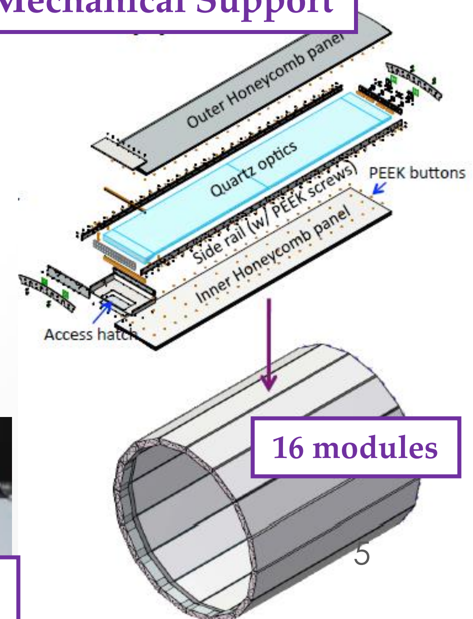
MCP-PMT

FEE





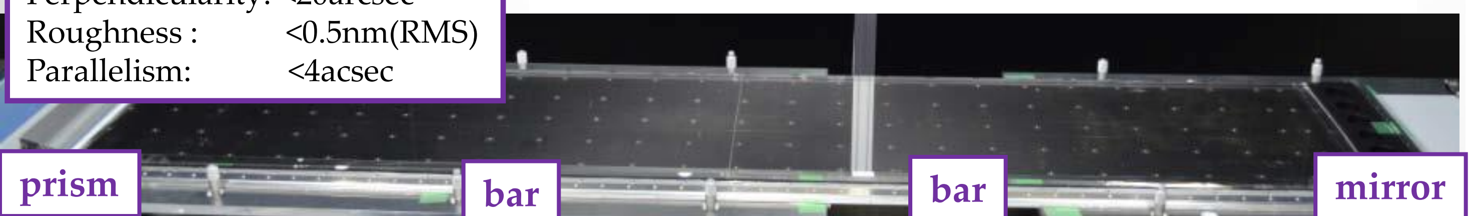
Mechanical Support



16 modules

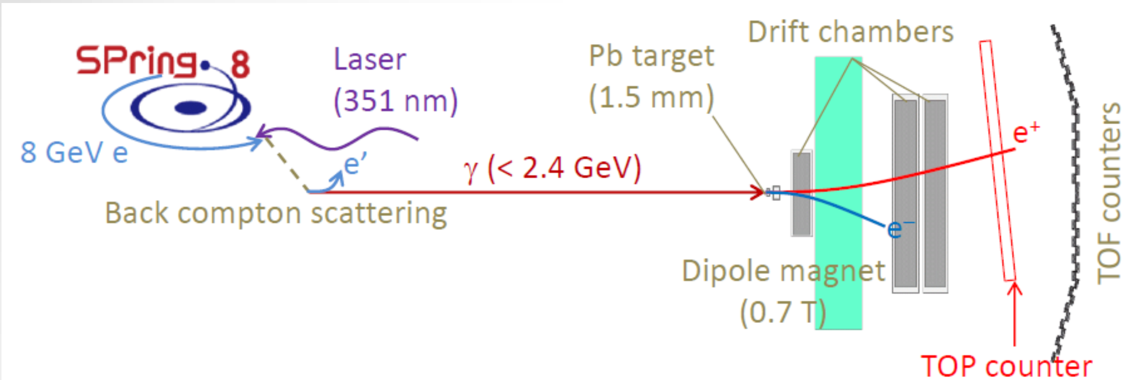
Quartz radiator

Perpendicularity: <20arcsec
Roughness : <0.5nm(RMS)
Parallelism: <4acsec

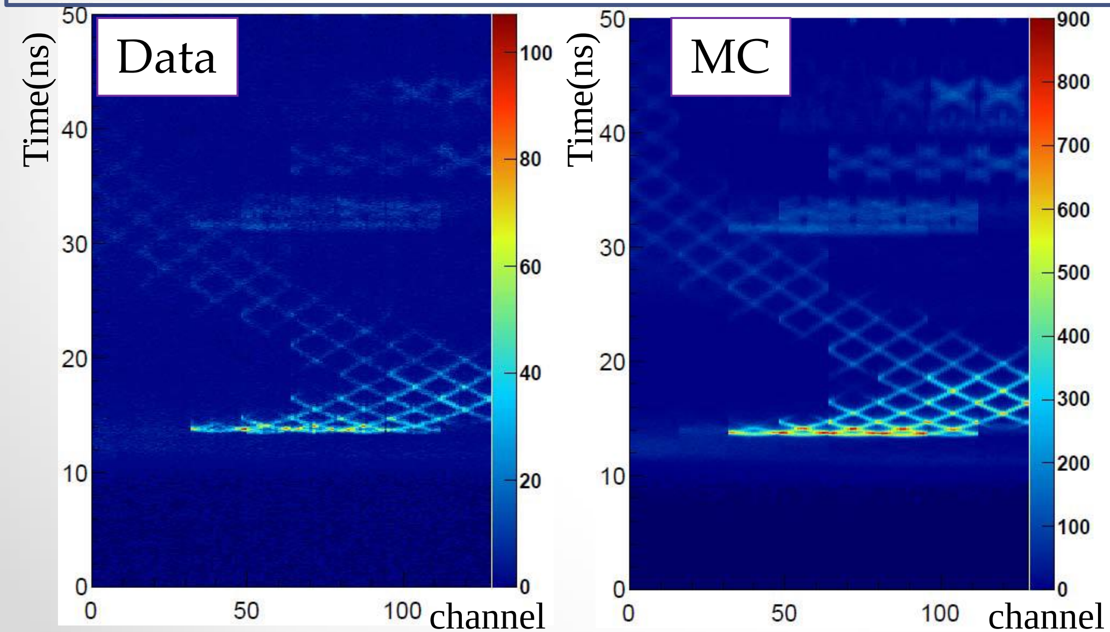


prism bar bar mirror

Beam Test (1) (TOP)



"Ring" image (Normal incidence, backup readout)

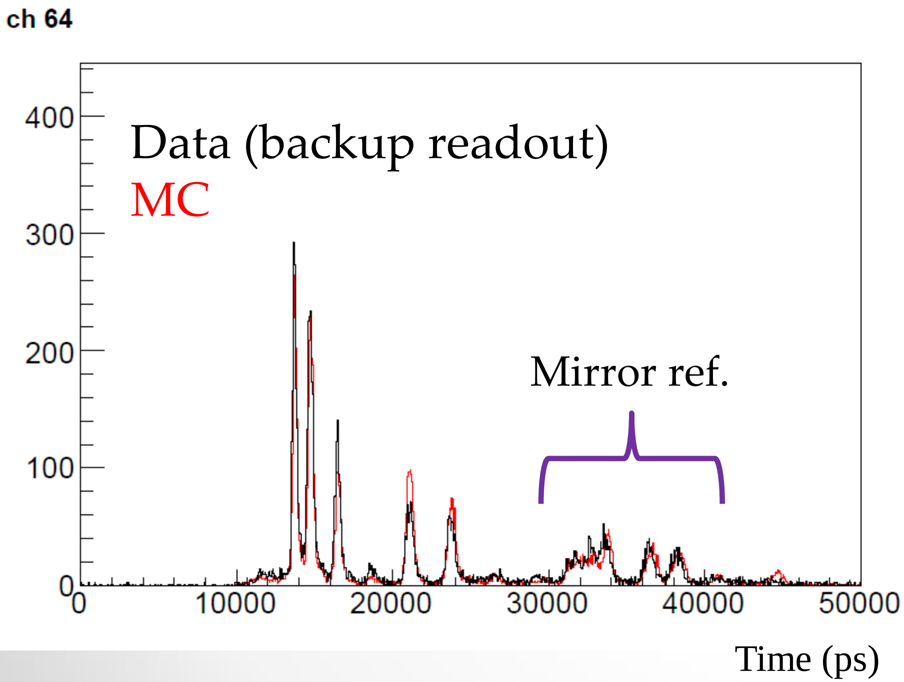


- Performance of the 1st full scale prototype Belle II TOP counter was evaluated at **SPring-8 LEPS**.
  - 2GeV/c positron beam
  - Precise beam timing: acc. RF
  - FEE: "IRS" and backup (CFD)
- **Beautiful "Ring" image obtained**.

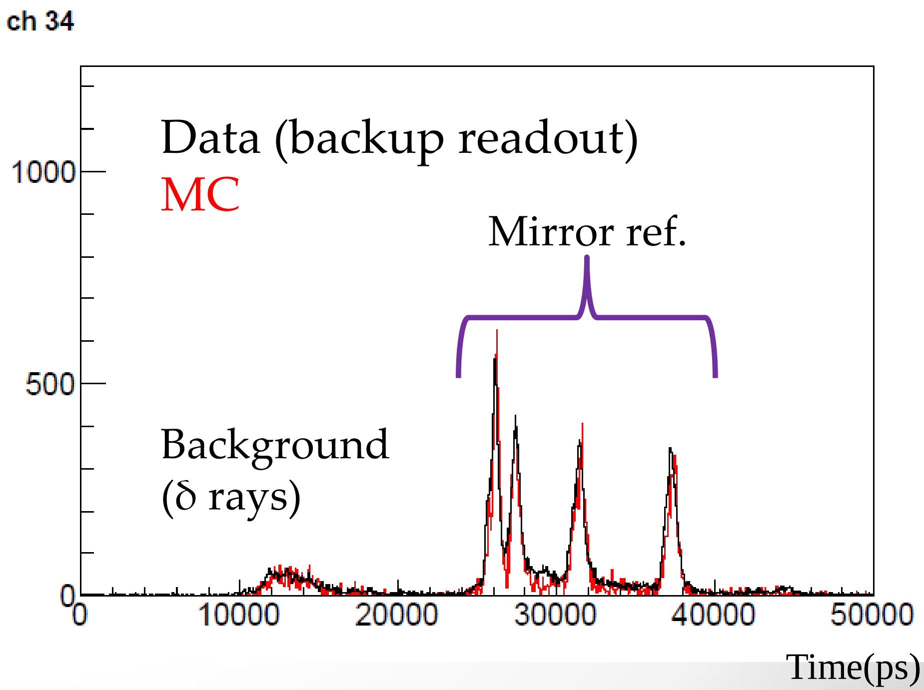
Beam Test (2) (TOP)

- **Time distribution** of each channel **in good agreement with MC expectation** based on the specification parameters for the optical components and the photon detector.
- **Number of detected Cherenkov photons** also obtained as expected
  ➔ Obtained results demonstrate that **the expected performance of the TOP counter has been well understood.**

Time distribution (**Normal incidence**)



Time distribution (**66-deg.** tilted track)



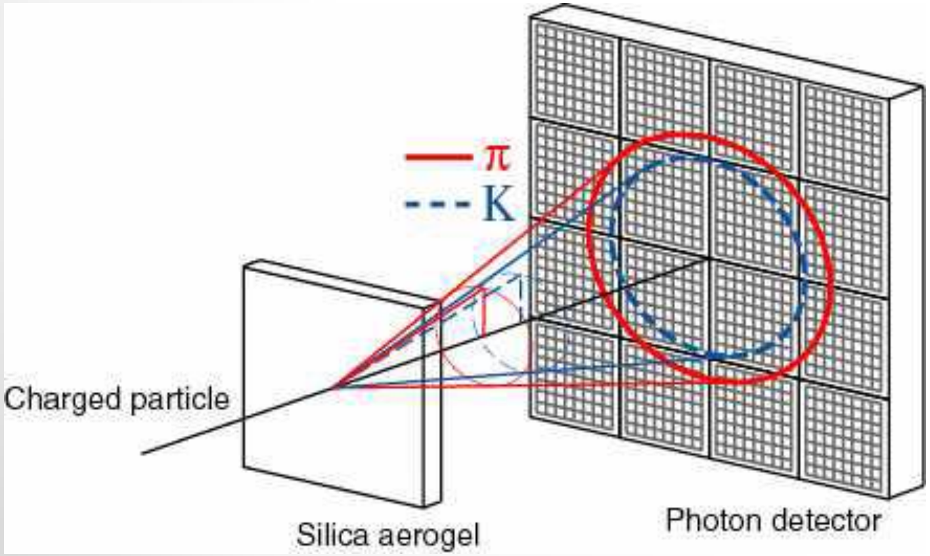
PID performance (TOP)

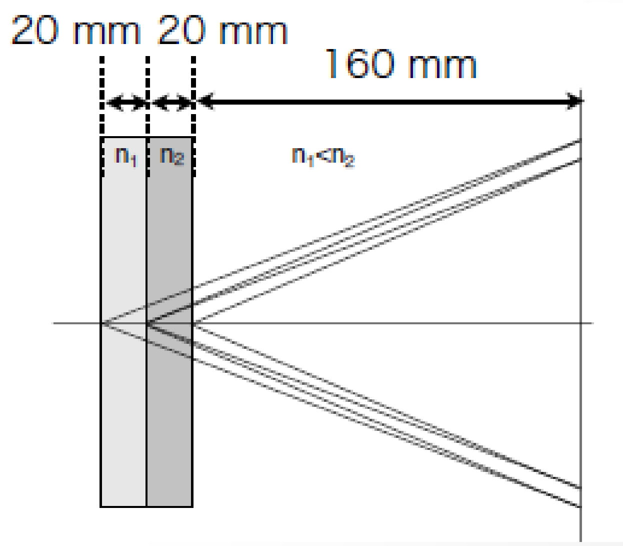
Decay mode	π efficiency with 2% K fakes π rate 100ps electronics jitter	π efficiency with 4% K fakes π rate 100ps electronics jitter	π efficiency with 4% K fakes π rate 50ps electronics jitter
$B \to \pi\eta\gamma$ vs $K\eta\gamma$	84.28 +/- 0.91	94.13 +/- 0.57	93.22 +/- 0.52
$B^+ \to \rho\gamma$ vs $K^*\gamma$	80.71+/-1.07	93.19+/-0.67	92.55 +/- 0.62
$B^0 \to \rho\gamma$ vs $K^*\gamma$	81.50+/- 0.78	92.63+/-0.49	92.13 +/- 0.46
$B^+ \to \pi\pi^0\gamma$ vs $K\pi^0\gamma$	83.55+/-0.76	94.03+/-0.46	93.47 +/- 0.43
$B^0 \to \pi\pi\gamma$ vs $K\pi\gamma$	79.50 +/- 0.67	91.48+/-0.45	92.56 +/- 0.38
$B^+ \to \pi\pi\pi^0\gamma$ vs $K\pi\pi^0\gamma$	75.00+/-0.72	90.50 +/-0.44	91.01 +/- 0.38
$B^0 \to \pi\pi\pi\gamma$ vs $K\pi\pi\gamma$	76.33+/-0.37	90.00+/-0.33	92.20 +/- 0.31

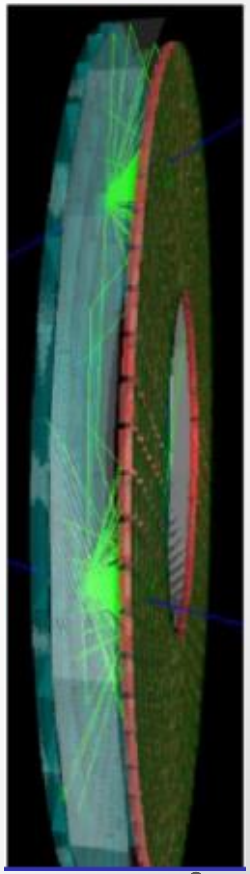
- Beam test performance adequate to do **1-2% measurement of $|V_{td}|/|V_{ts}|$.**
- Detector development is being finalized and construction will start soon.
  - System meets performance requirements, but still trying to push time resolution **< 50 ps**.
  - **1st Belle II TOP counter is scheduled to be assembled this fall.**

Endcap PID detector (ARICH)

- **Forward endcap PID**: **A**erogel **R**ing **I**maging **CH**erenkov detector (**ARICH**).
- Identify particle by difference of **Cherenkov angle** emitted in aerogel radiator.
  ➔ Cherenkov angle $\cos\theta_c = 1/n\beta$
- **Proximity focusing** due to limited space between central drift chamber (CDC) and electromagnetic calorimeter (ECL).
- **Aerogel radiator** in the focusing configuration
  (2 layers of aerogel with different refractive indices).
- 420 of 144-channel Hybrid Avalanche Photo Detector (**HAPD**).



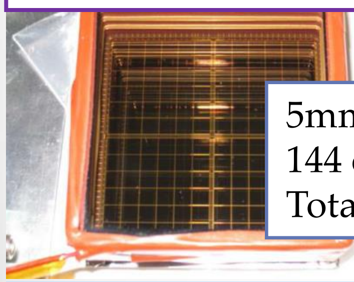




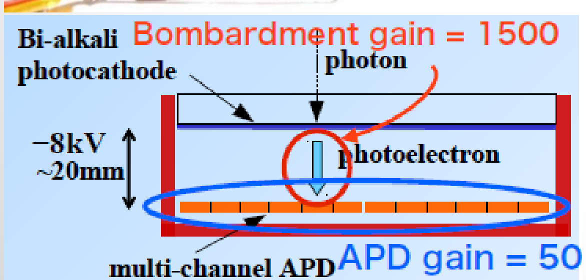
Detector Construction (ARICH)

- **Photodetector:** Mass production of HAPD has been started in last September.
  - ~250 (out of 450) HAPDs delivered from Hamamatsu / ~180 tested
- **Readout electronics:** in good shape
  - Mass production of ASIC completed.
  - Final version of Front-end board designed.
  - Successful read out the HAPD signal through FE + Merger.
- **Radiator:** **Successful completion of aerogel mass production!!**
  - Measurements/inspections are going on.

Photodetector: HAPD

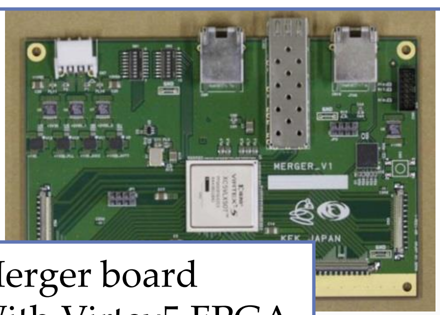


5mm pitch pixelated
144 channels cathode
Total gain ~7×10^5



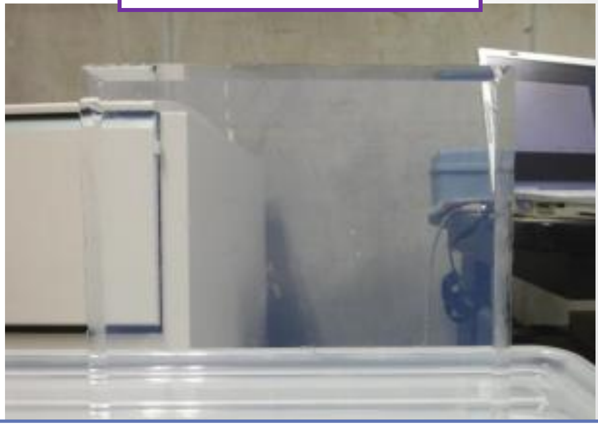
Readout electronics

Front-end board with 4 ASICs
And Spartan6 FPGA



Merger board
With Virtex5 FPGA

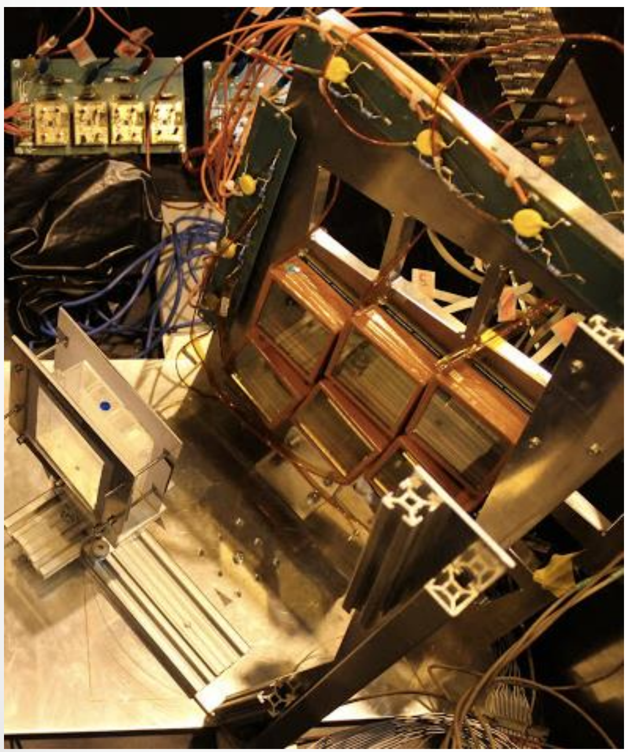
Aerogel radiator

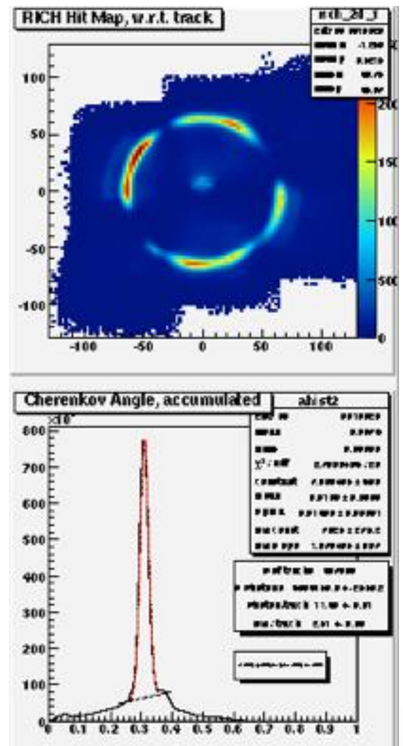


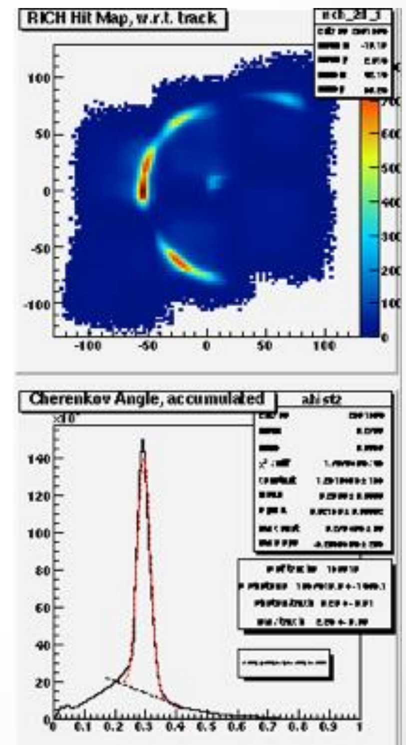
449 tiles delivered to KEK
n=1.045 (for upstream layer): 209
n=1.055 (for downstream layer): 240

Beam Test (ARICH)

- Beam tests performed to check performance of prototype ARICH.
  - Hadron beam @ SPS in CERN and electron beam @ DESY
- Simple performance estimation from cumulative Cherenkov angle distribution.
  - $\Delta\theta c = 14.1$ mrad, Npe = 11.4
  - ➔ K/π separation = 5.5σ **(SPS 120 GeV/c hadron beam, incident angle = 0deg case, similar for non-zero incidence.)**



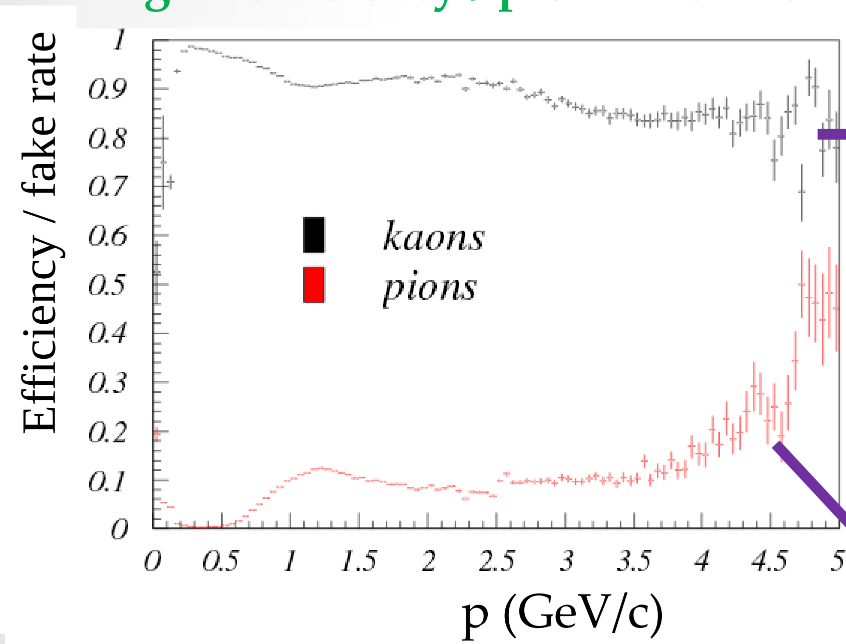


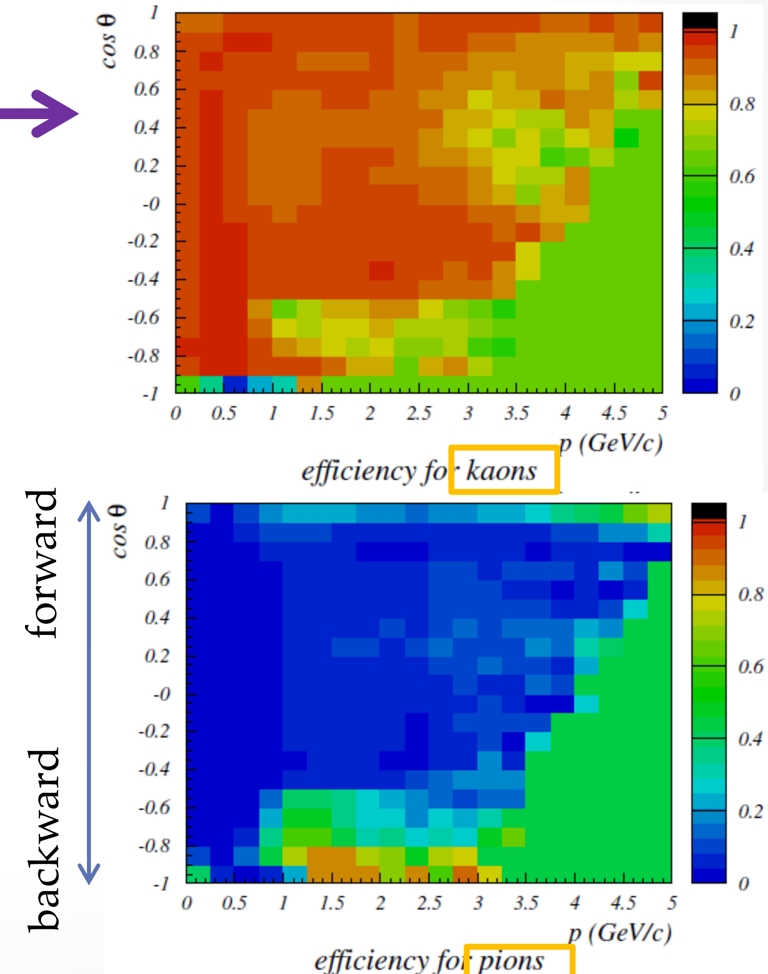


K/π separation: efficiency

- **Belle II PID (TOP+ARICH+dE/dx) performance**
- TOP / ARICH event reconstruction software already working well.
- + dE/dx (CDC) information to cover the backward region

→ **a.v.g. K efficiency / pion fake rate improved as expected. c.f. Belle PID (88%/9%)**

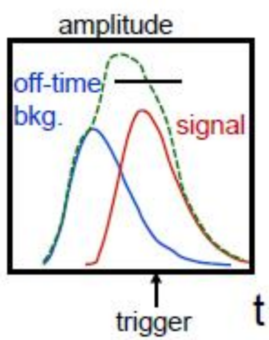


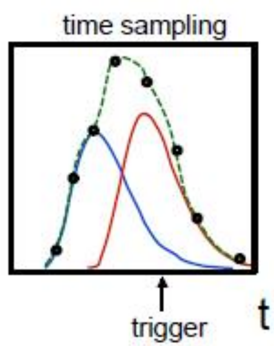


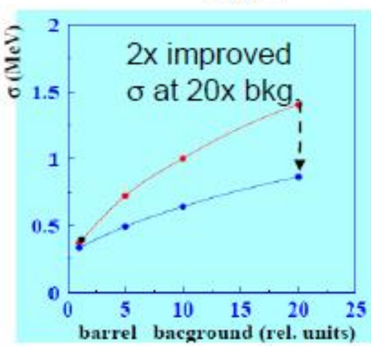
	Belle II PID
Averaged K efficiency	94%
Pion fake rate	4%

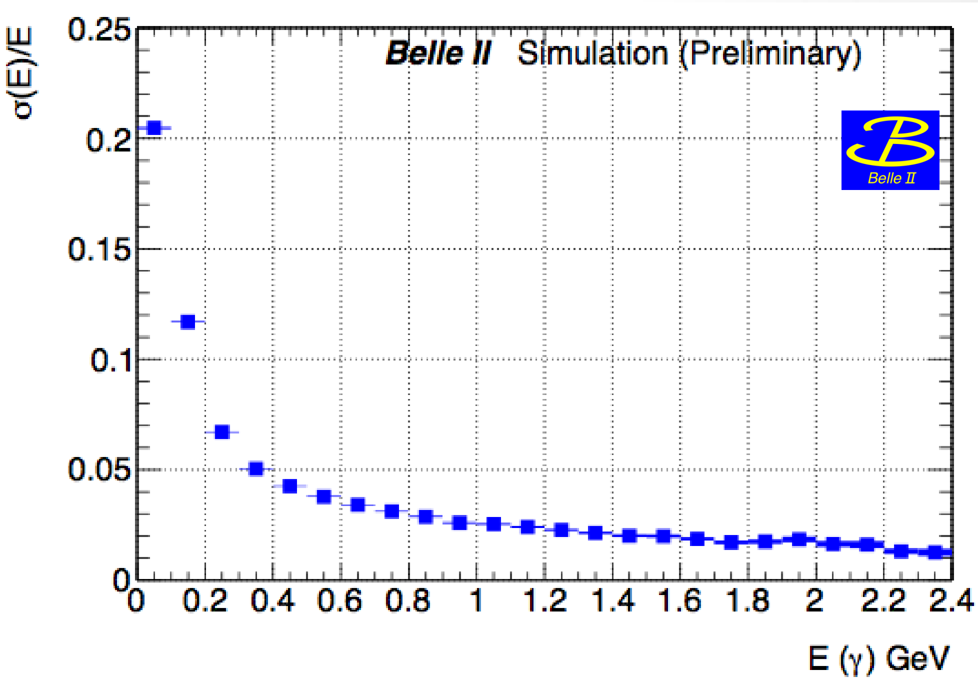
EM Calorimeter (Barrel ECL)

- Re-usage of the Belle's CsI(Tl) crystal calorimeter, but with **New electronics with 2MHz wave form sampling** to compensate for the larger beam-related backgrounds and the long decay time of CsI(Tl) signals
- **All 6624 ECL barrel channels tested with new electronics (all are alive.)**
- Belle II DAQ electronics tested in the ECL data transfer runs with the frequency up to 30 kHz.
- **This summer barrel electronics will be connected and cosmic test will be carried out**



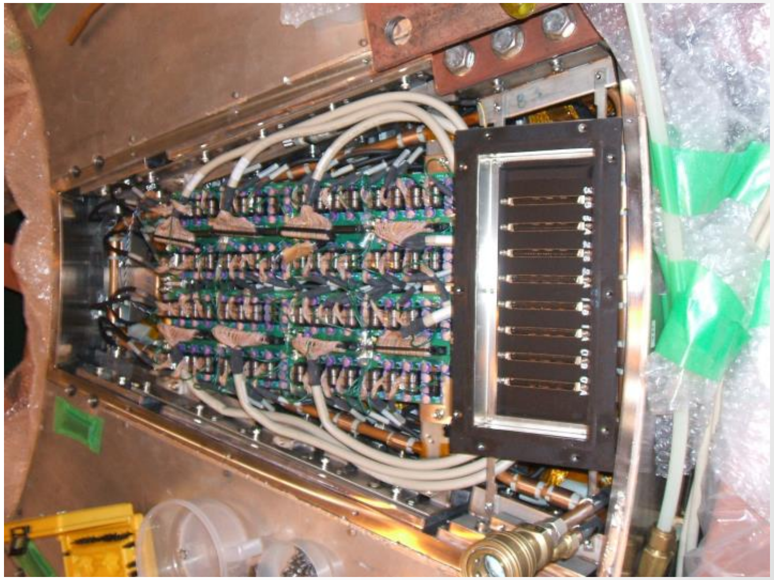






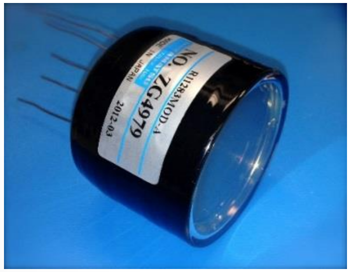
EM Calorimeter (Endcap ECL)

- At the first stage of the Belle II experiment, Belle endcap ECL (1152+ 960 channels) will be reused with new preamplifiers and readout electronics.
- The endcap bias filters modification has been performed. (15 people from Japan, Canada, Italy, Russia were involved.)
- Pedestal, test pulse position and cosmic peak position were tested.
  ➔ **All crystals alive and all PA shows expected response.**
- In 2015, endcap ECL will be installed in detector.

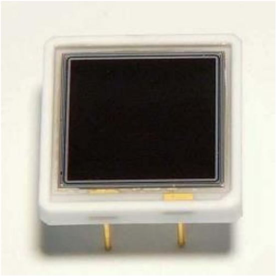


Endcap ECL upgrade

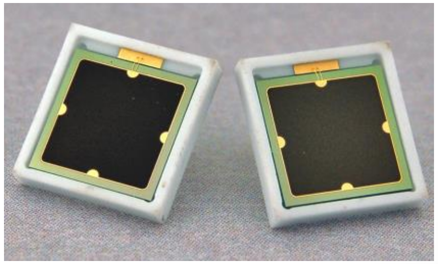
- Endcap ECL: CsI (Tl) ➔ **pure CsI** for faster performance and better radiation hardness (not day-1).
- **Main endcap ECL upgrade option**: **pure CsI + Hamamatsu photopentodes**
  - ☺ **Low pile-up noise and good energy resolution**
  - ☺ **Similar physical characteristics (as for CsI(Tl)), better radiation hardness**
  - ☹ No redundancy, notable dependency on magnetic field, new mechanical support
  - Second R&D option: **pure CsI + Si APD**
    - Hamamatsu/Excelitas/Advanced Photonix APDs are being tested.
    - One of the main points is to reach admissible level of electronic noise.



Hamamatsu Photopentodes



Hamamatsu APD S8664-1010 ($10x10mm^2$)

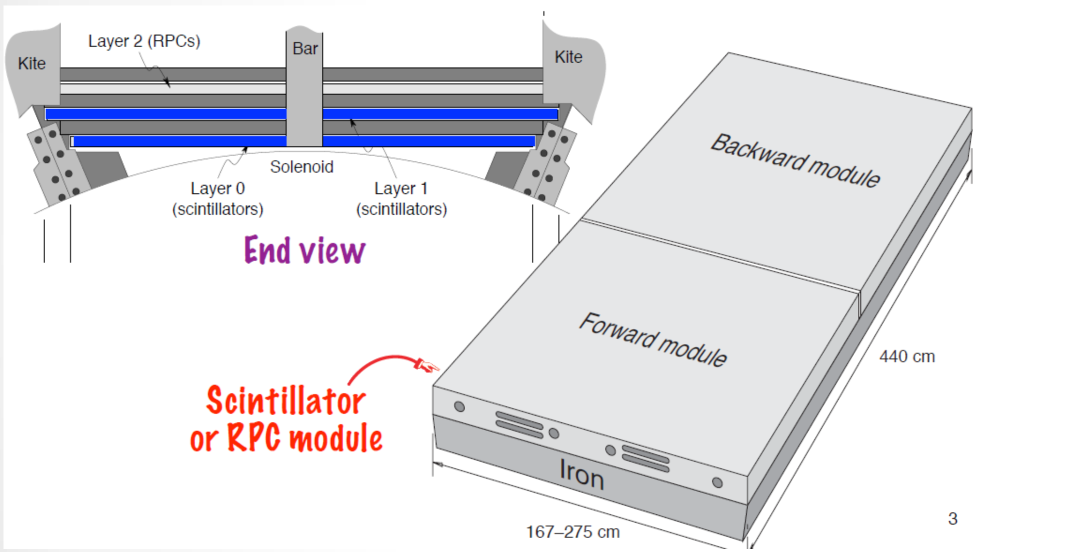


Excelitas C30739ECERH-2 ($5.6x5.6mm^2$)

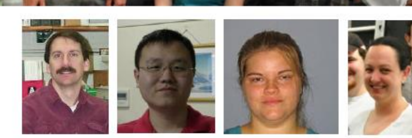
Advanced Photonix APD (16mm Active Dia.)

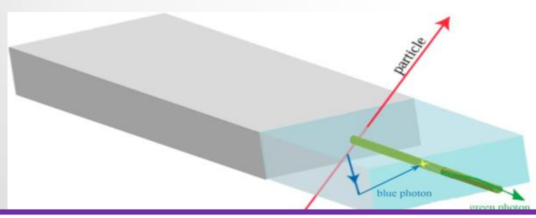
Barrel K_L-μ detector (BKLM)

- Belle Resistive Plate Counters (RPCs) will be reused, two inner layers has been replaced by **scintillator strips**.
- **Installation of new scintillator modules in innermost layers completed in 2013.**
- **Post-integration test will be done with new FEE in 2014.**

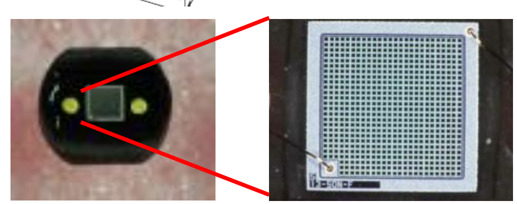


Virginia Tech crew





FNAL scintillator (40mm x 10.6mm) with co-extruded TiO_2 reflective coating delivers blue light to WLS fiber.



MPPC: Hamamatsu $1.3x1.3\ mm^2$ 667 pixels (used in T2K ND)

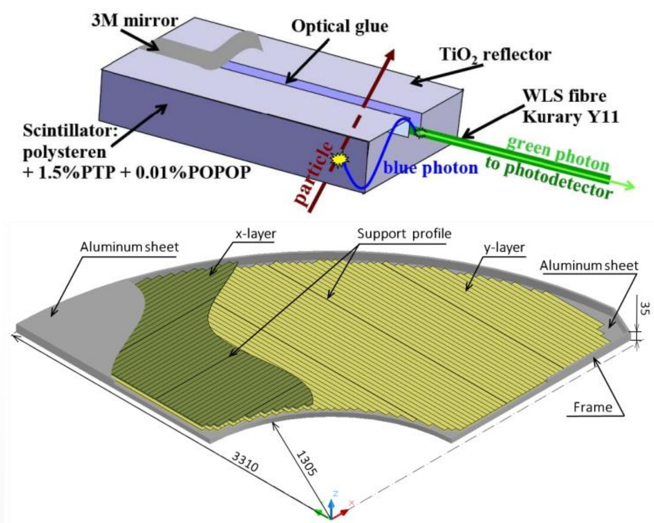
Edinburgh

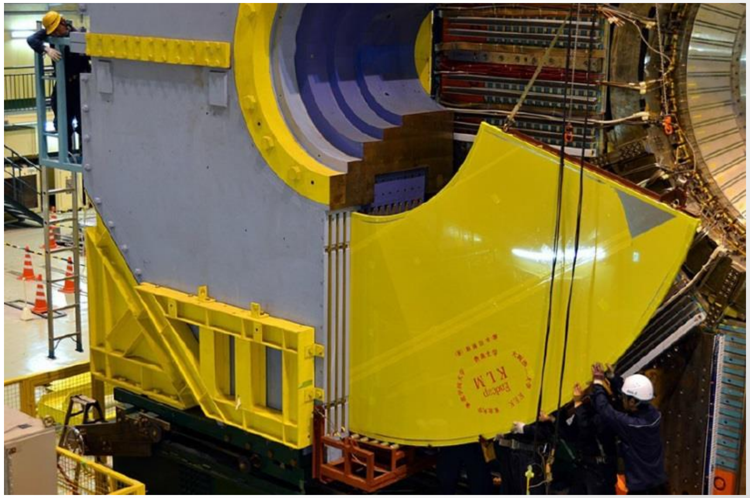
Endcap K_L-μ detector (EKLM)

- Endcap RPCs replaced with **scintillators** to handle higher neutron backgrounds.
- 14 forward + 12 backward layers (2 backward outermost layers filled with shielding)
- Base element: **scintillator strip** produced by "Uniplast"
  - ✓ Block with two orthogonal layers of scintillator strips
  - ✓ Kurary Y11 WLS fiber
  - ✓ Hamamatsu MPPC S10362-11-050C
  - ✓ >99% geometrical acceptance, better efficiency for K_L and μ, $\sigma < 1$ ns
- **56 sectors installed in forward EKLM in April 2014.**
- **46 backward sectors to be installed this summer.**

TDR efficiencies for RPC

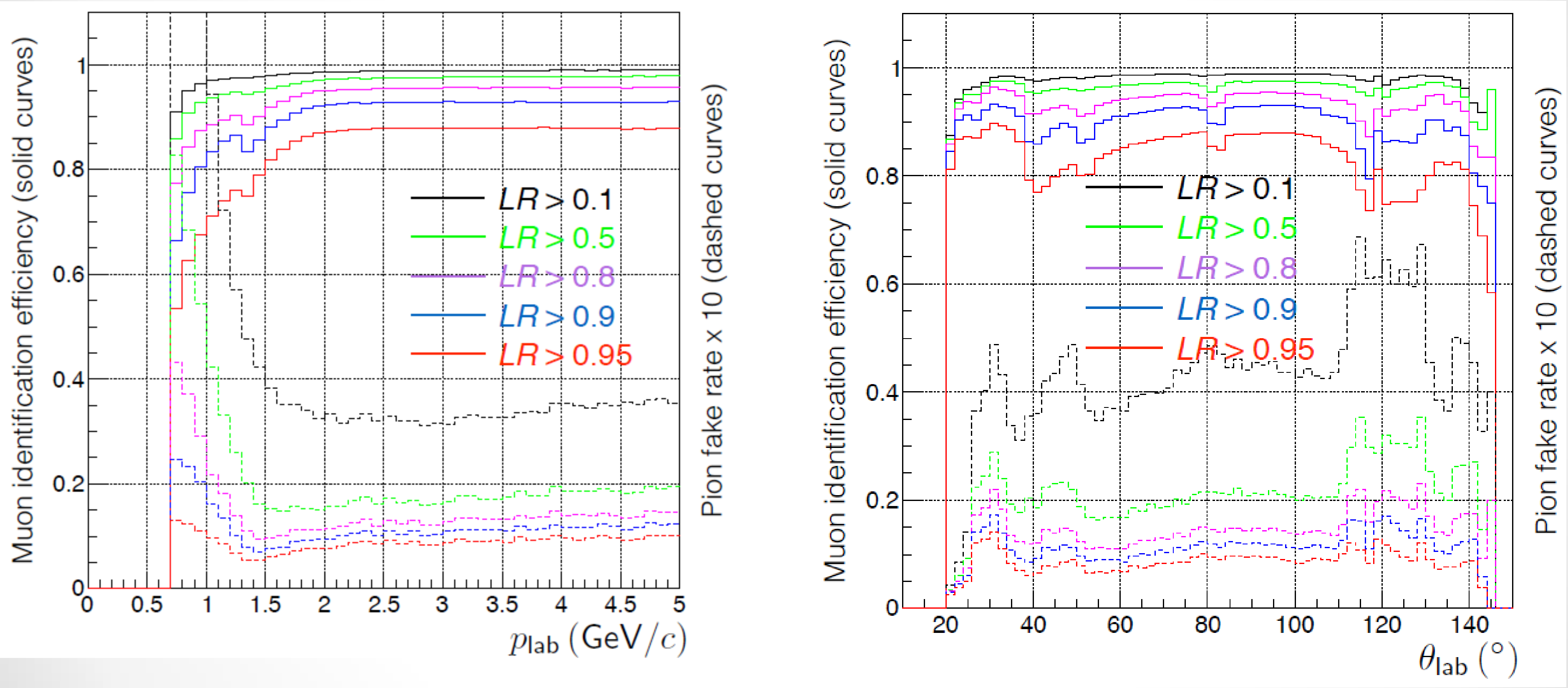
Layer	Endcap forward KEKB	Endcap forward SuperKEKB
0	0.91	0.0
1	0.93	0.0
2	0.94	0.0
3	0.94	0.0
4	0.94	0.0
5	0.92	0.0
6	0.93	0.0
7	0.92	0.0
8	0.92	0.0
9	0.90	0.0
10	0.87	0.0
11	0.82	0.0
12	0.78	0.0
13	0.77	0.0
14	N/A	N/A





Muon identification: efficiency

Belle II MuID: muon efficiency vs pion fake rate



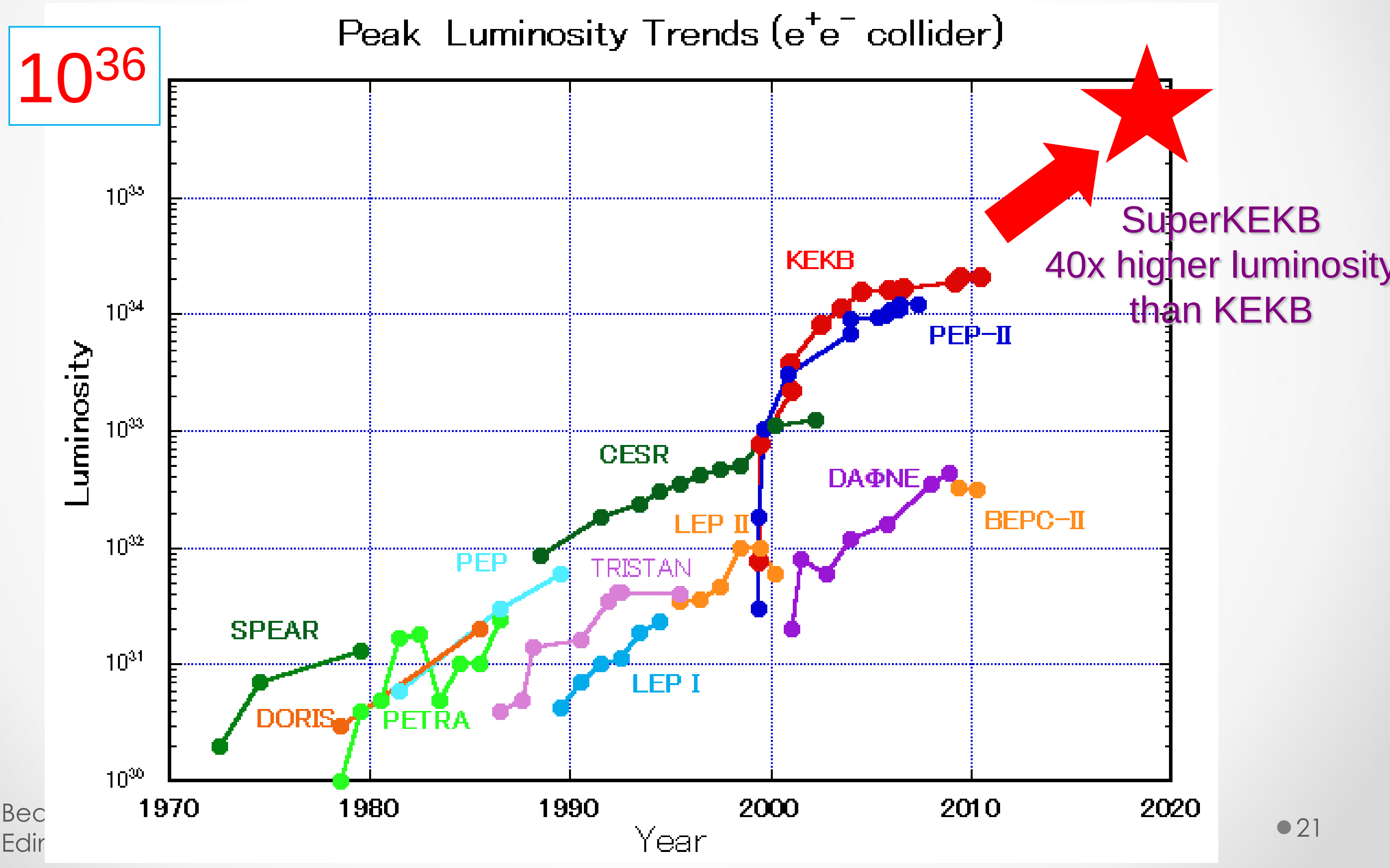
➢ **Muon identification software now works well.**

Summary

- Development of barrel PID system (**TOP**) is being finalized.
  - 1st full scale prototype has been successfully assembled in 2013.
  - Performance of the prototype was evaluated well at SPring-8/LEPS.
  - The 1st module assembly will start this fall.
- Construction of endcap PID detector (**ARICH**) in good shape.
  - Results of beam test with prototype ARICH satisfy requirement from physics motivation.
  - Detector installation will be done in 2015.
- K_L-μ detector (**KLM**) and EM Calorimeter (**ECL**) integration is proceeding according to schedule.
  - Post-integration test and software development are also going well.
- Belle II Detector construction will be completed in 2016.

backup

SuperKEKB
- Luminosity -



Belle II

SuperKEKB - Nano-Beam Scheme (1) -

- How to achieve L~10^{36}: "Nano-Beam" scheme
  - double the beam currents
  - squeeze vertical beta function (β^*_y) at IP (1/20)

$$L = \frac{\gamma_\pm}{2er_e}\left(\frac{I_\pm \xi_{y\pm}}{\beta^*_{y\pm}}\right)\left(\frac{R_L}{R_{\xi_y}}\right)$$

Lorentz factor

Beam current

Beam-Beam parameter

Vertical beta function

Geometrical reduction factors: 0.8-1.0

	KEKB Achieved	SuperKEKB
Energy (GeV) (LER/HER)	3.5/8.0	4.0/7.0
ξ_y	0.129/0.090	0.090/0.088
β^*_y (mm)	5.9/5.9	0.27/0.41
I (A)	1.64/1.19	3.60/2.62
Luminosity ($10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	2.11	80

x ~20

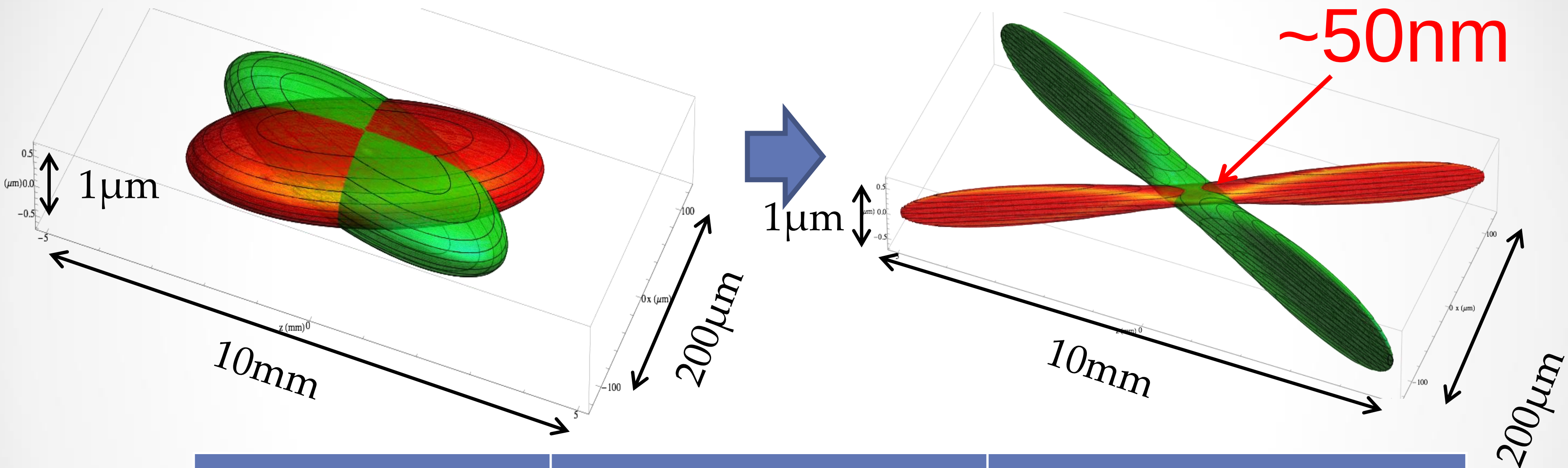
x ~2

x ~40

arXiv:1011.0352

SuperKEKB - Nano-Beam Scheme (2) -

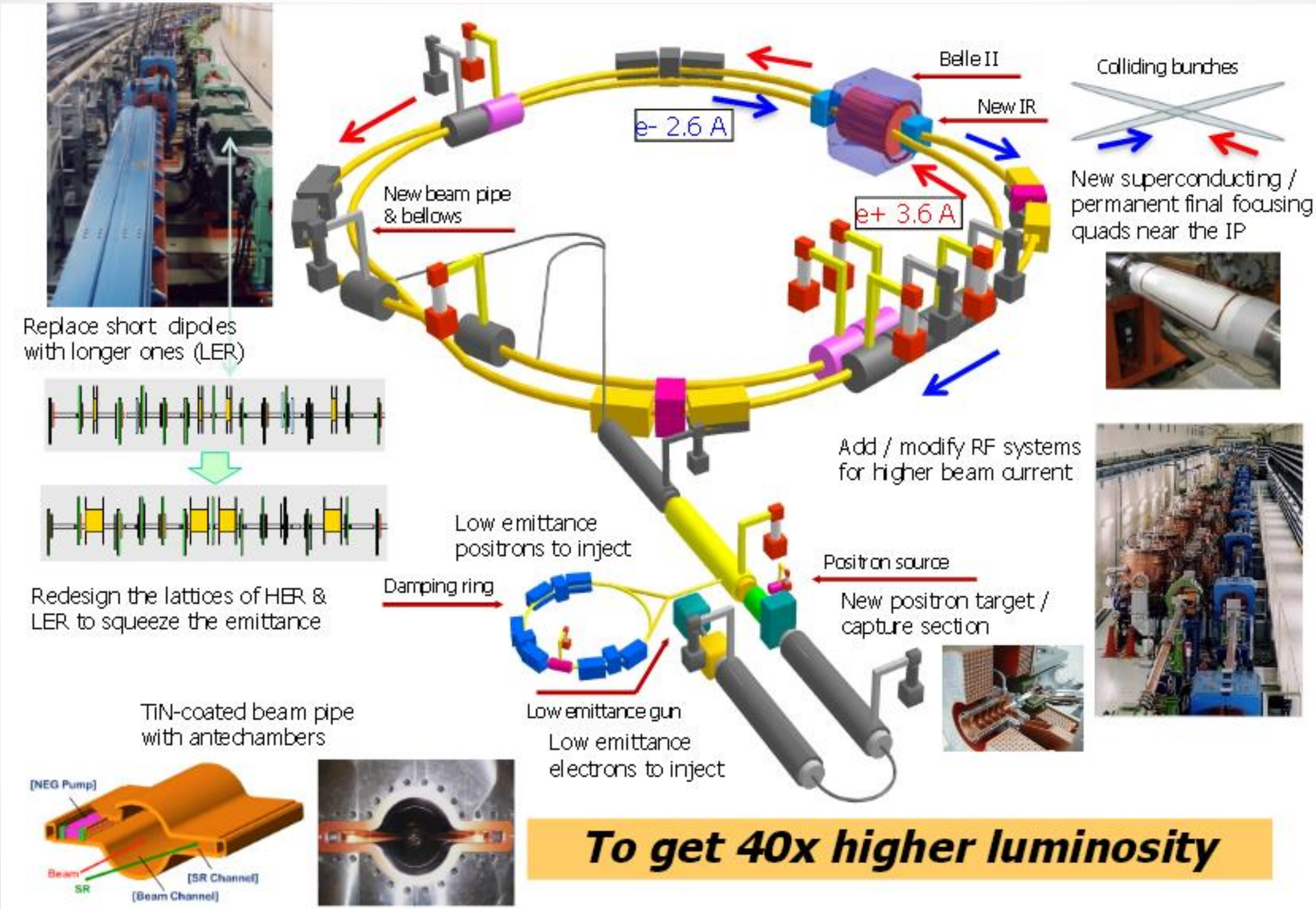
KEKB (without crab) **SuperKEKB**



	KEKB	SuperKEKB
Beam Size @ IP	100μm(H) x 2μm (V)	10μm (H) x 59nm (V)
Crossing angle	22mrad	83mrad

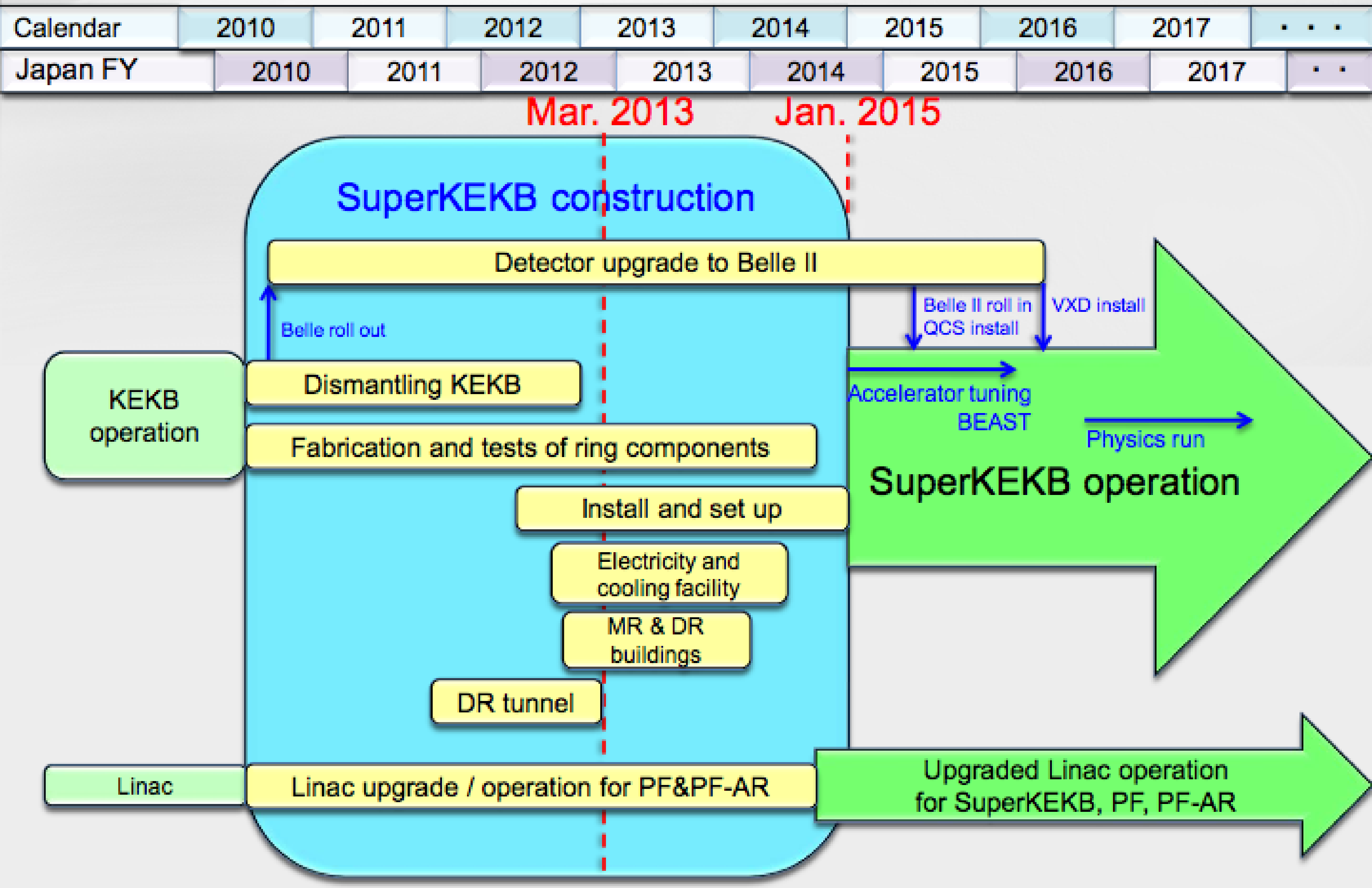
- Nano-Beam Scheme + a factor of 2 more beam current to increase luminosity
- Large crossing angle
- Change Beam energies to solve the problem of short lift-time for the LER

SuperKEKB

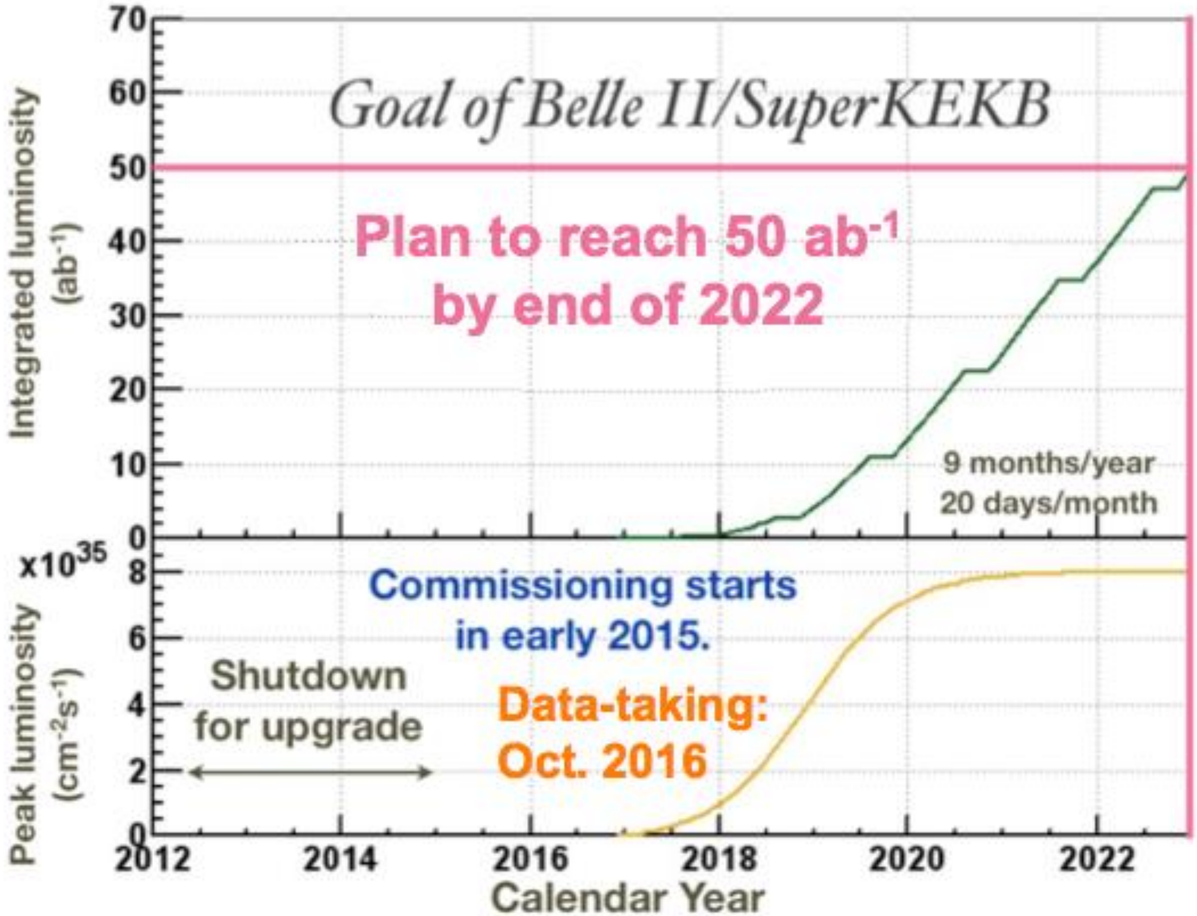


Belle II
Colliding bunches
New IR
e- 2.6 A
e+ 3.6 A
New superconducting / permanent final focusing quads near the IP
New beam pipe & bellows
Replace short dipoles with longer ones (LER)
Add / modify RF systems for higher beam current
Low emittance positrons to inject
Positron source
Damping ring
New positron target / capture section
Redesign the lattices of HER & LER to squeeze the emittance
Low emittance gun
Low emittance electrons to inject
TiN-coated beam pipe with antechambers
[NEG Pump]
Beam
SR
[SR Channel]
[Beam Channel]
To get 40x higher luminosity

SuperKEKB/Belle II schedule

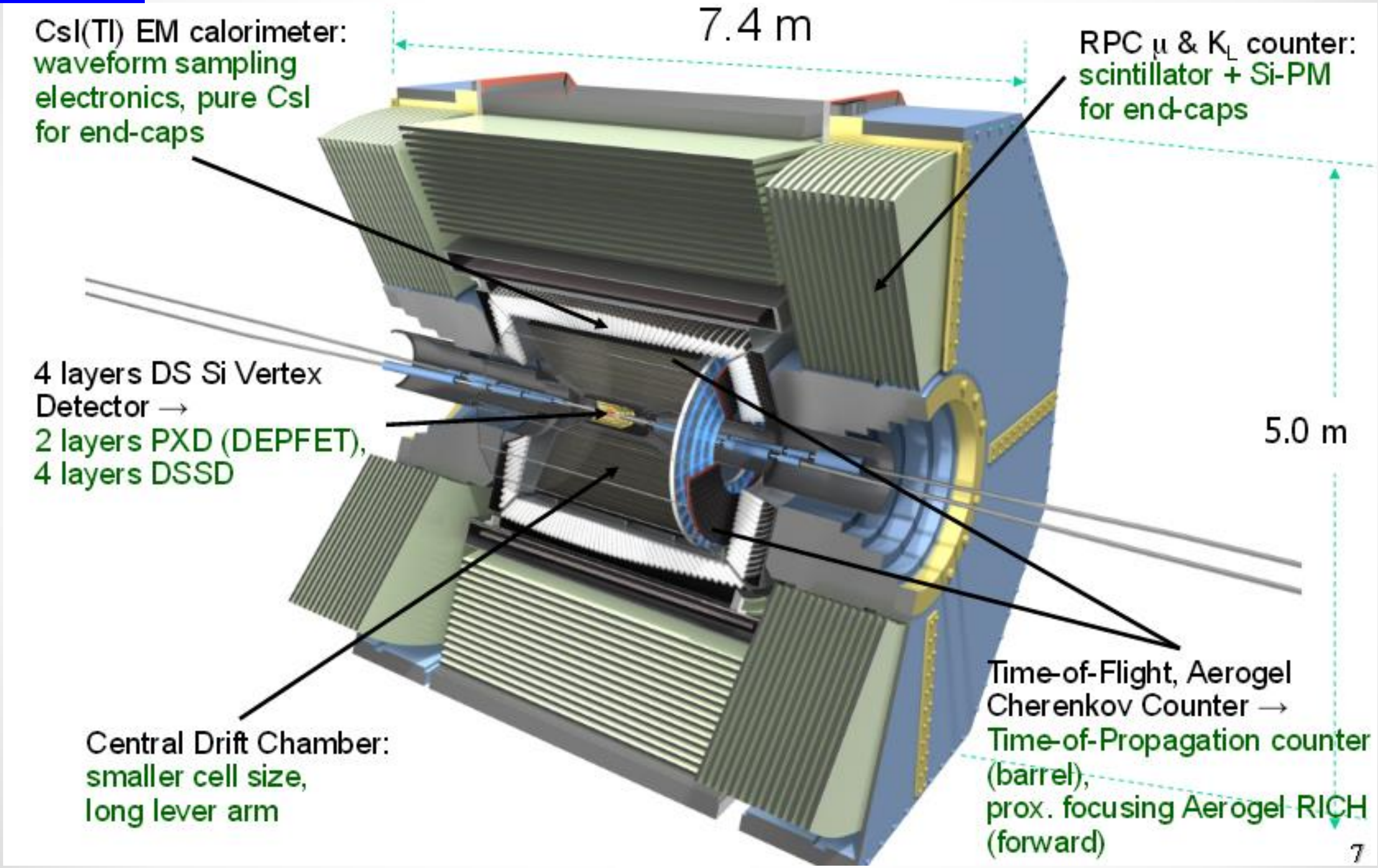


Timeline & goal



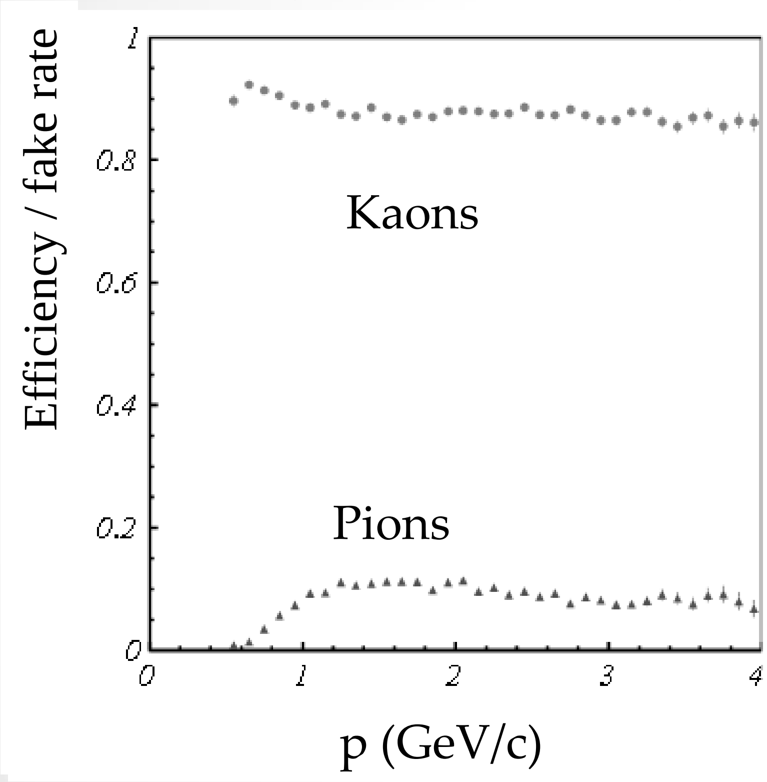
14

Belle II Detector



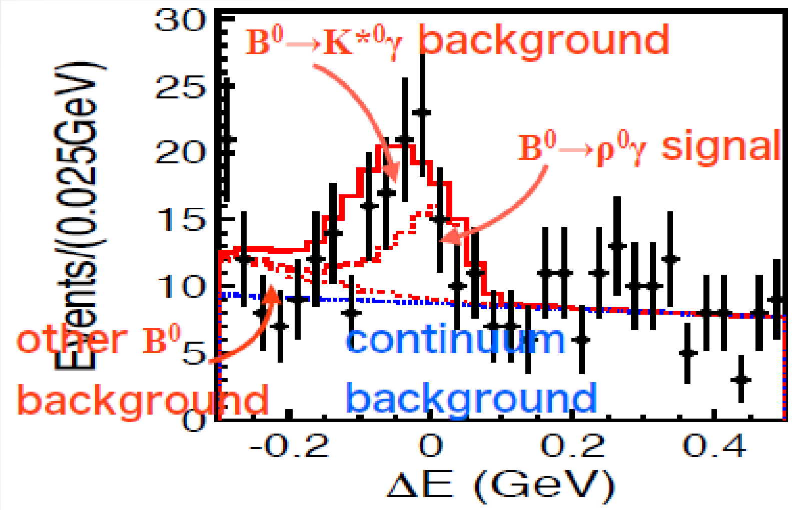
K/π separation: efficiency

Belle PID (ACC+TOF+dE/dx)



	Belle PID
Averaged K efficiency	88%
Pion fake rate	9%

PID impact on physics analysis

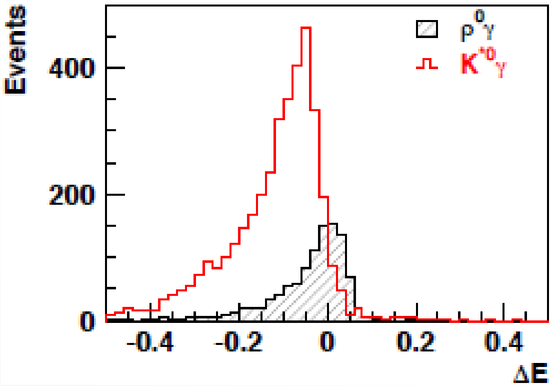


Belle experimental data
(657 million BBbar sample)

ΔE: energy difference between reconstructed B^0 and beam

Belle II 7.5 ab-1 expectation from MC

with Belle PID



with Belle II PID (TOP+ARICH)