Aerogel RICH Counter for the Belle II Forward PID

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KEK

RICH2013 @ Shonan

Dec. 2, 2013

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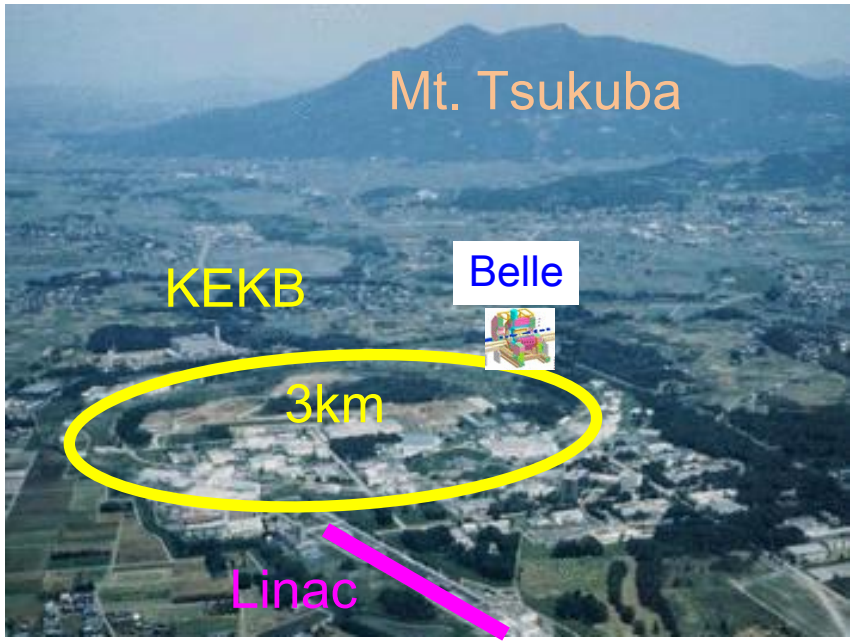
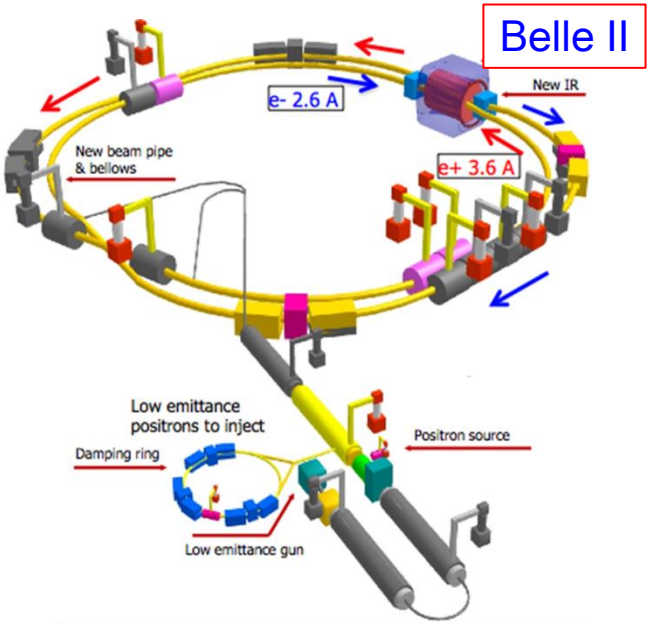
(Belle II Aerogel RICH Group)

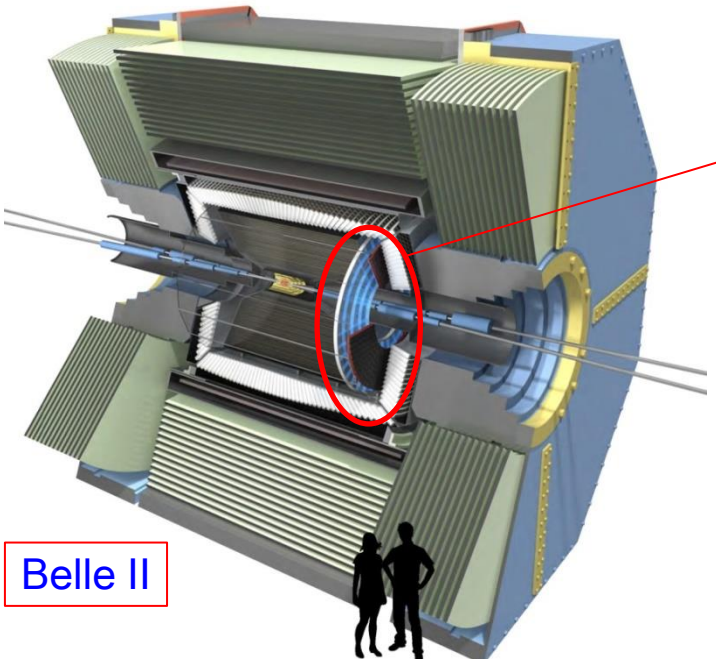
SuperKEKB and Belle II

- KEKB / Belle : B factory experiment @ KEK (1999-2010)
  - ✓ World highest luminosity ($2.11 \times 10^{34}\ cm^{-2}\ s^{-1}$). Accumulated 1 ab^{-1}.
  - ✓ Discovery of CP Violation in B system and verification of KM mechanism.
- Upgrade to SuperKEKB and Belle II.
  - ✓ 40 times higher luminosity, aiming at 50 ab^{-1}.
  - ✓ Search and study of New Physics.
- Particle identification (K/π separation) is a key issue.



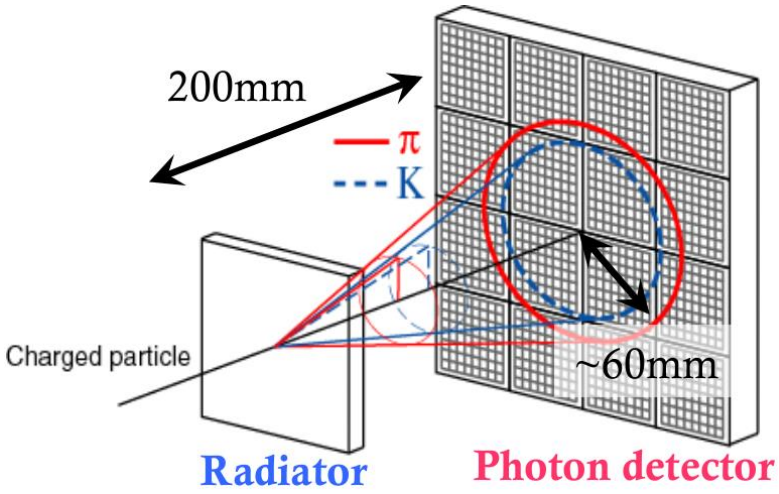


Aerogel RICH



Endcap PID:
Replace threshold-type Aerogel Cherenkov Counter to Aerogel RICH

Concept of Aerogel RICH

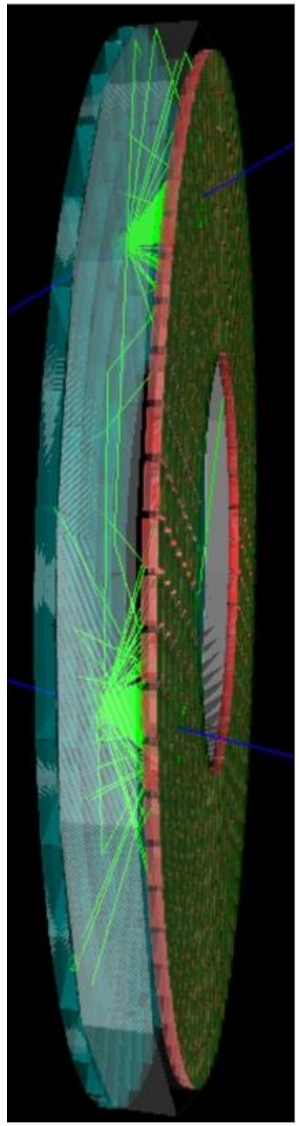


$$\theta_C(\pi) - \theta_C(K) \simeq 23 \text{ mrad}$$

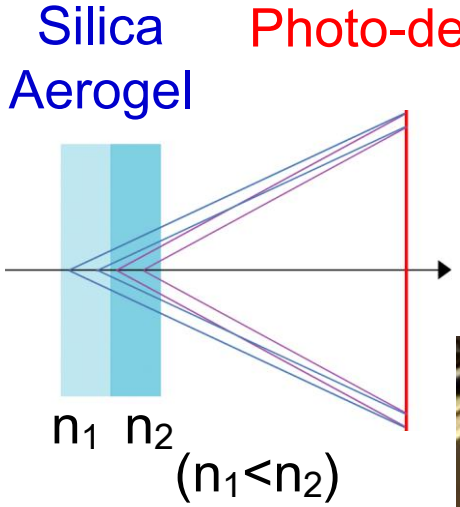
(@ 4 GeV; n = 1.05)

Target:
K/π Separation up to 4 GeV.

e.g.) $B \to \rho\gamma$ v.s. $K^*\gamma$



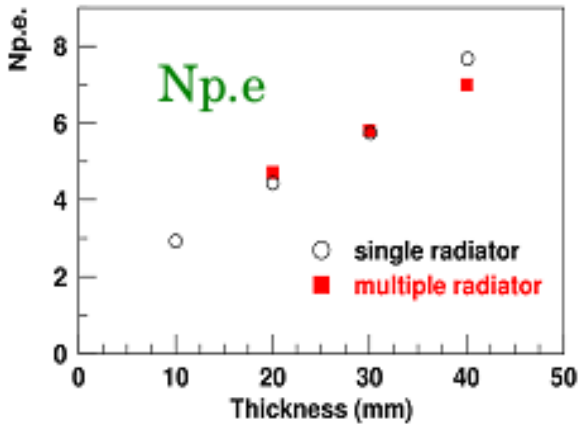
Silica Aerogel

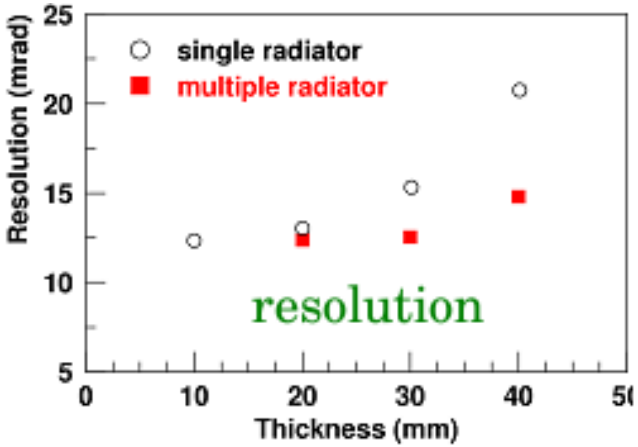


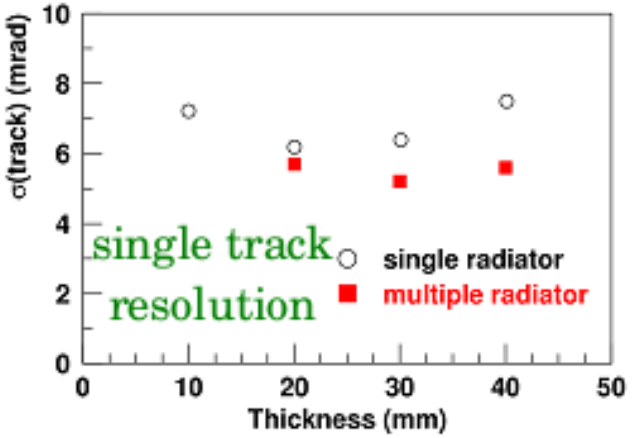
- 2-layer (2cm+2cm) aerogel tiles.
- n_1<n_2: focusing (n_1=1.045, n_2=1.055).
- High transmission length (40-60mm) required.
- Mass production started.

Talk by M.Tabata on Dec. 4 (Wed)

(old result)





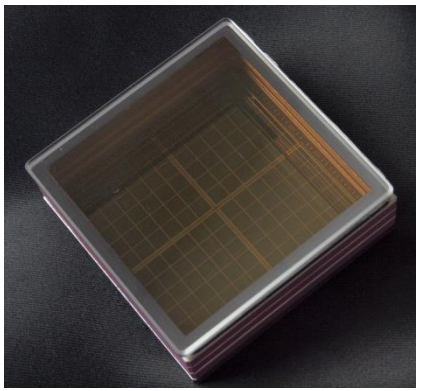


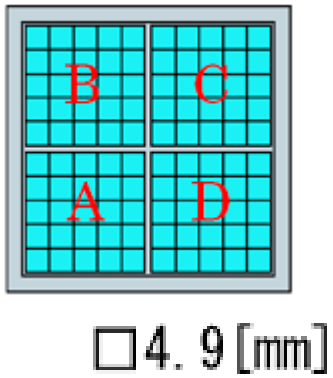
HAPD

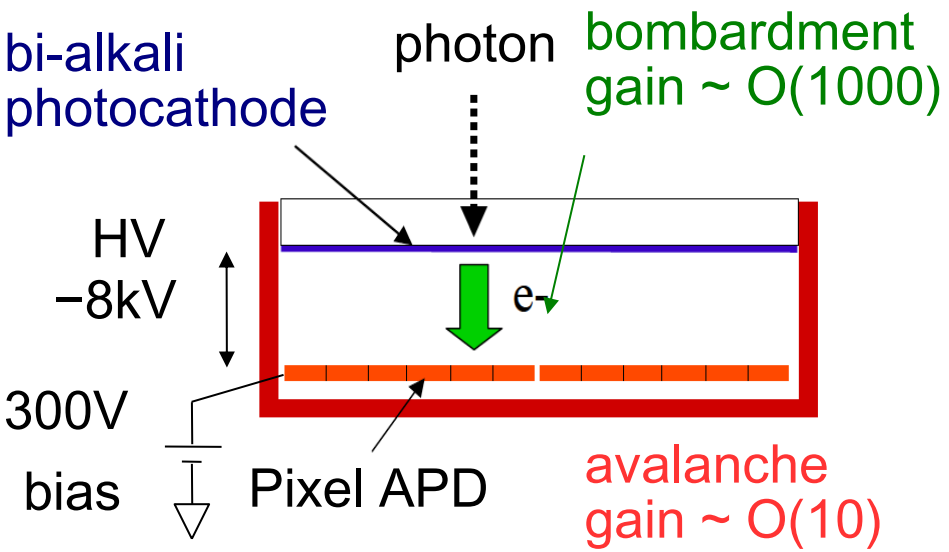
Photo-detector

- ~5mm pixel size. Large coverage.
- Immune to 1.5T magnetic field.
- Radiation tolerance (neutron, gamma).

⇨ HAPD (Hybrid Avalanche Photo-Detector)







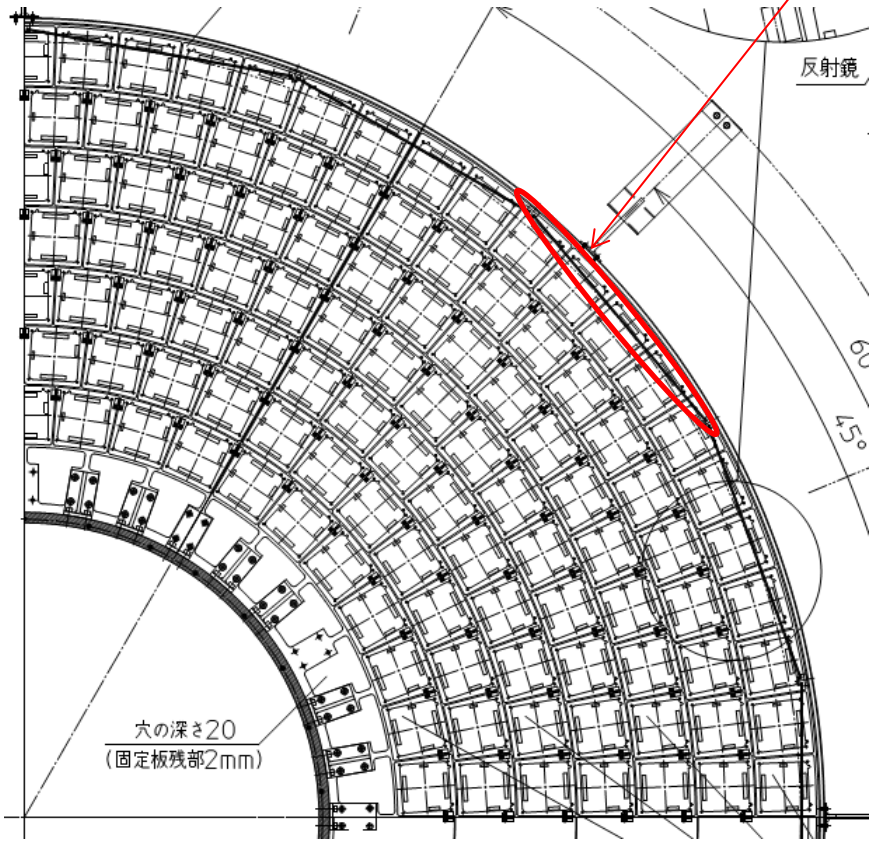
- Developed with Hamamatsu Photonics.
- 144 channels (36-ch APD chip × 4).
- Gain ≥45000.
- Peak QE ~28%
- Size 73mm × 73mm.
- Effective area 63mm × 63mm (65%).

Talk by S.Korpar on Dec. 3 (Tue)

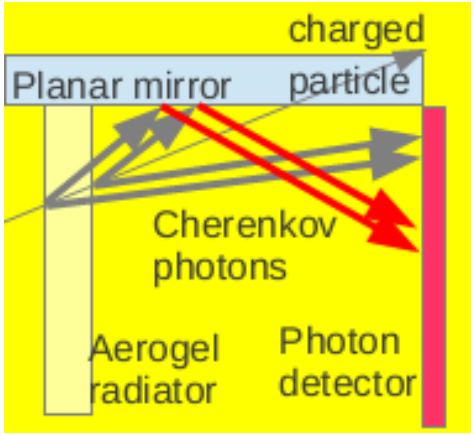
Aerogel RICH

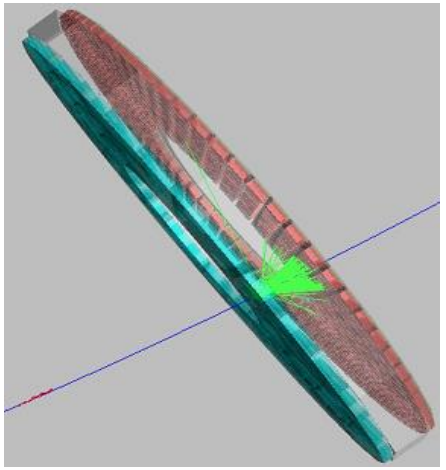
Aerogel RICH detector consists of

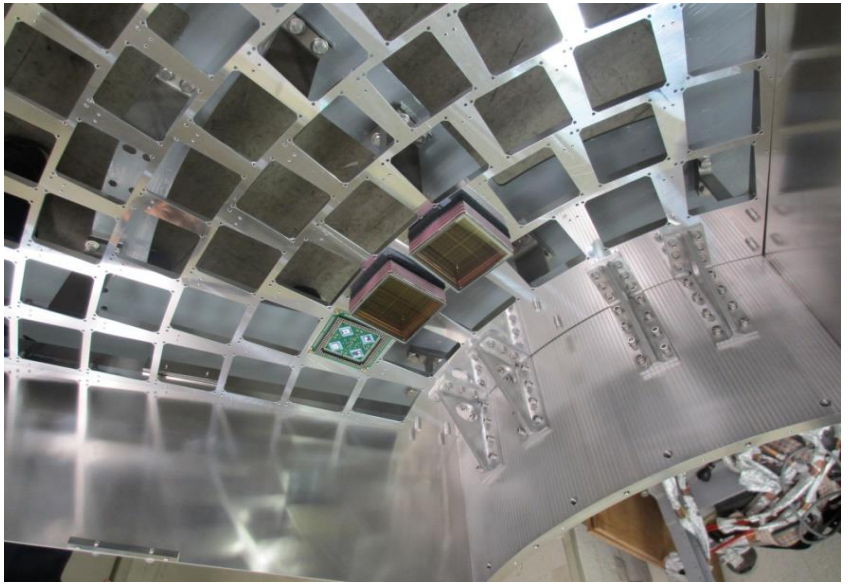
- 420 HAPD
- 248 Aerogel Tiles



HAPD: 8 rings → 7 rings

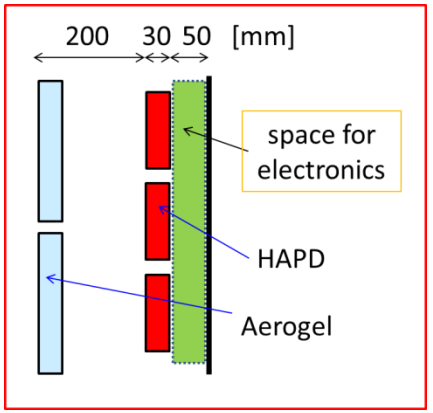




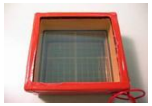


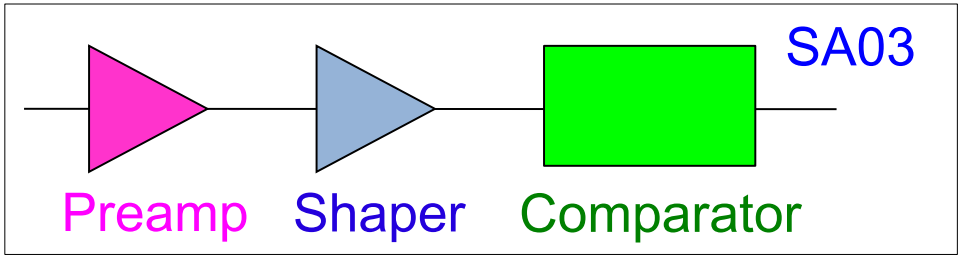
Electronics

- Total 60000 channels.
  - ✓ 1-bit ON/OFF information is enough.
- High-gain, low-noise.
- Only 5 cm available behind HAPD

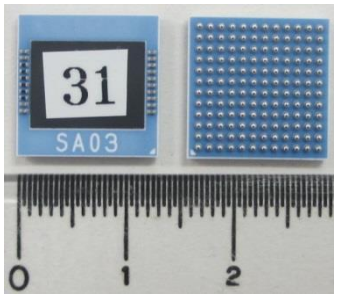


➡ ASIC (SA03)



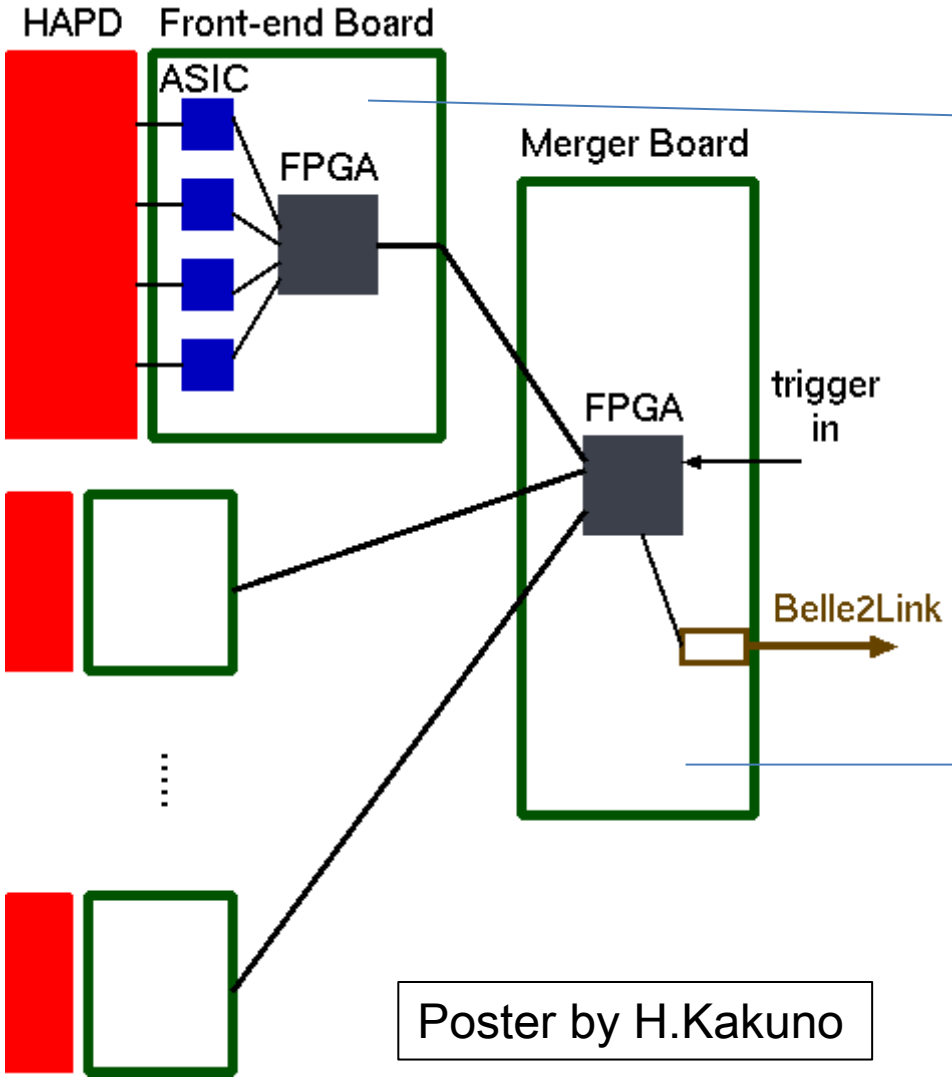


FPGA for readout



- CMOS 0.35 μm process @ TSMC and X-FAB.
- 36 ch / chip (i.e. 4 ASIC for one HAPD).
- Variable gain (3.1-12.5 V/pC) and shaping time (100-200ns).
- Common threshold but adjustable offset (16-bit; for each channel).
- DICE (Dual Interlocked CEll) register to be tolerant to SEU.
- Mass production started this year (@X-FAB).

Electronics



Boards are under final design.

Front-end Board

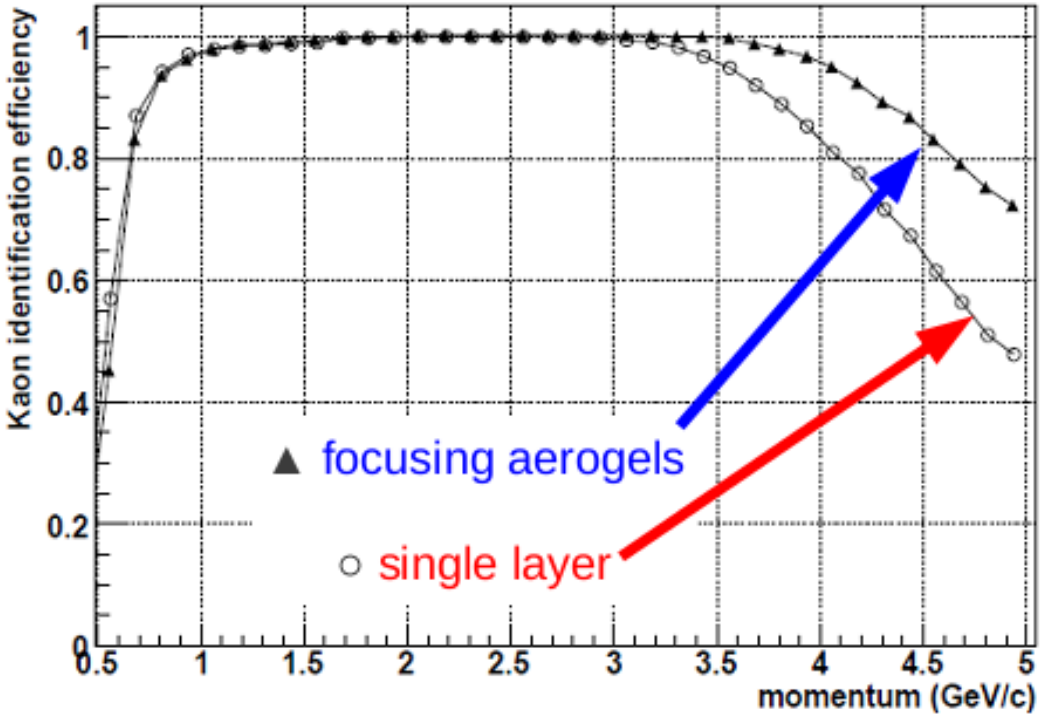
- 4 ASIC + Xilinx FPGA (Spartan6).
- Hit detection.
- ASIC parameter setting.

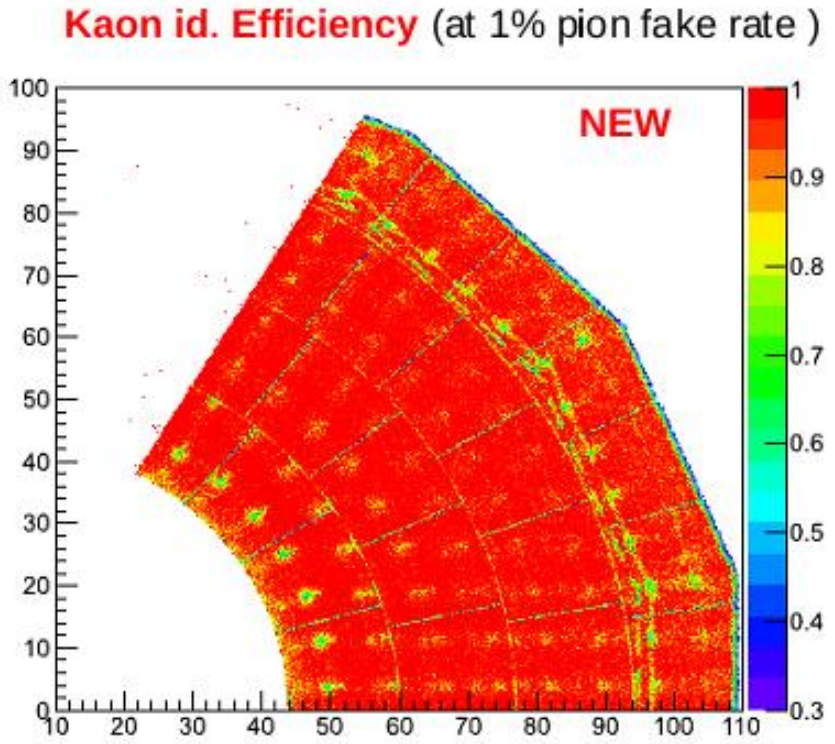
Merger

Poster by H.Kakuno

- Receive hitdata from 5-6 front-end boards, and send to DAQ.

Performance





- Monte Carlo simulation is performed under Belle2 software framework.
- Excellent PID performance over wide range of momentum.

Poster by S.Korpar

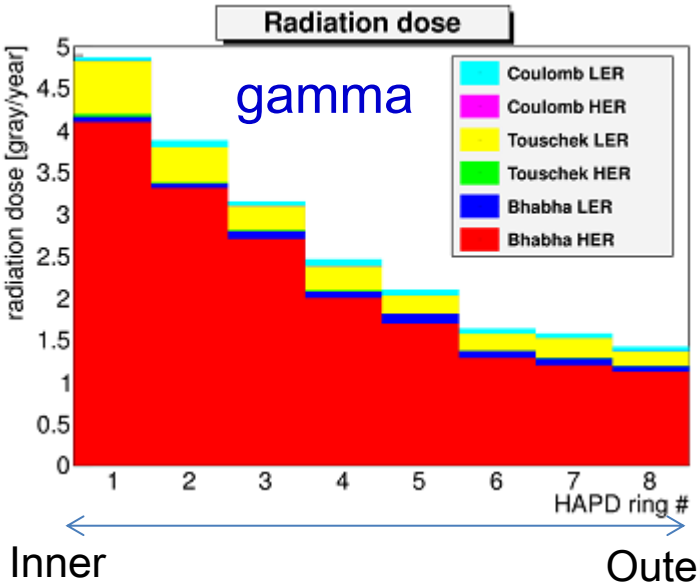
Radiation

Original estimation for 10 years operation.

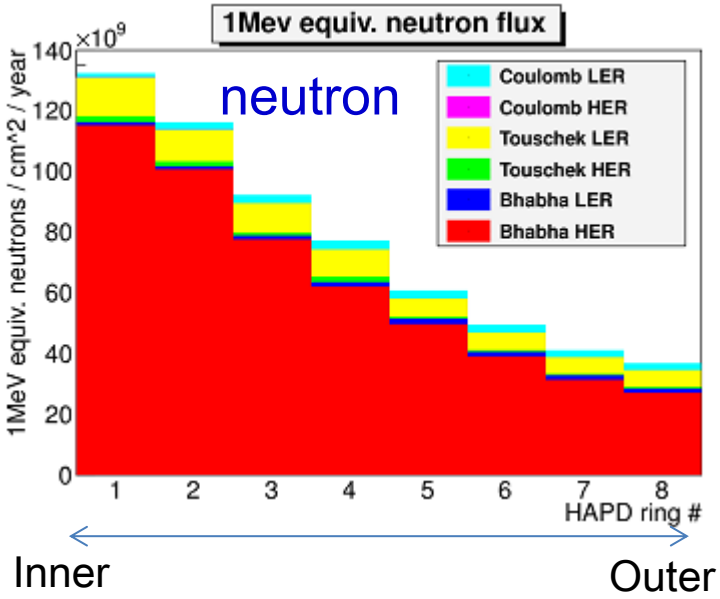
gamma: 1000 Gy

neutron: 10^{12} n/cm^2 (1MeV equiv.)

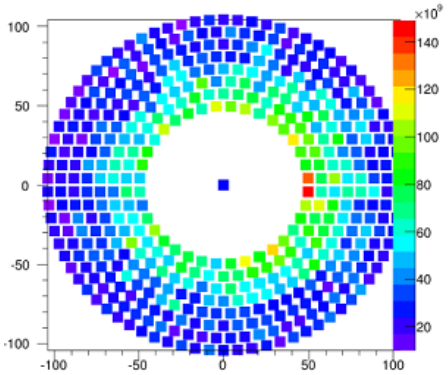
Recent simulation (with 8 HAPD rings)



< 50 Gy / 10years



< 1.3 × 10^{12} n/cm^2 / 10years

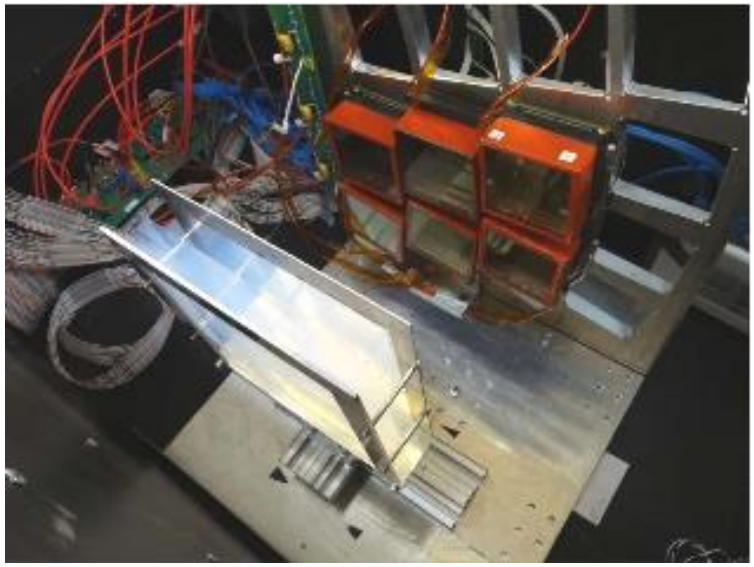


➡ Remove innermost HAPD layer and replace it with neutron shield.

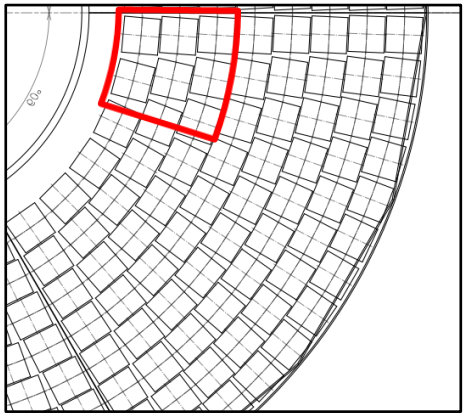
- No big impact on performance. Reduce number of HAPDs (and the cost).

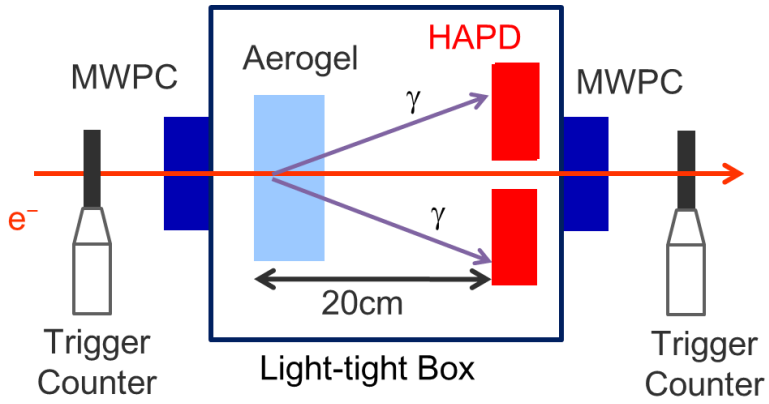
Study with Prototype Aerogel RICH

Beam test at DESY (2013) using prototype Aerogel RICH.



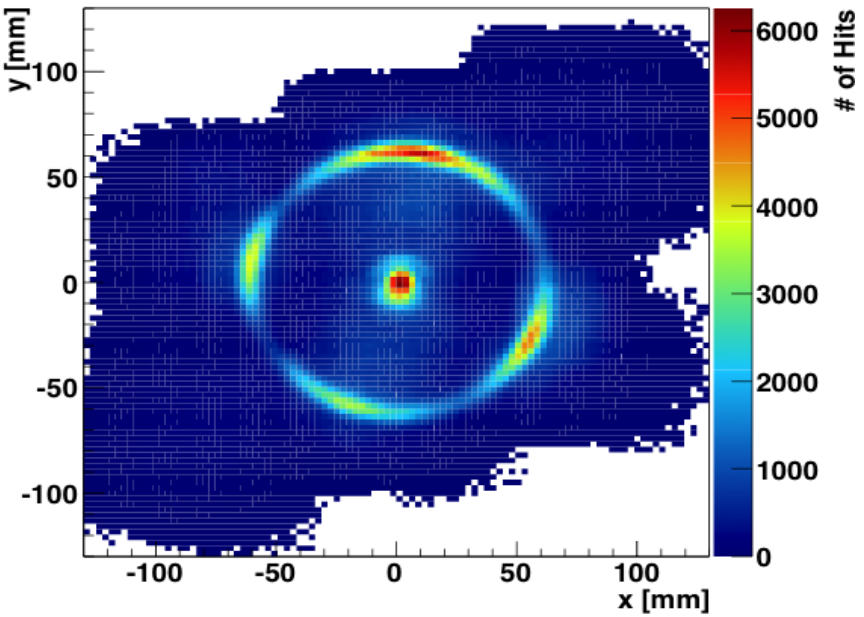
- 2 × 3 HAPD configurations (a part of the actual layout).
- 2-layer aerogel.
- Front-end board with ASIC (close to final).
- Study items:
  - ✓ System test with the latest electronics.
  - ✓ Aerogel Study.
  - ✓ Effect of radiation.

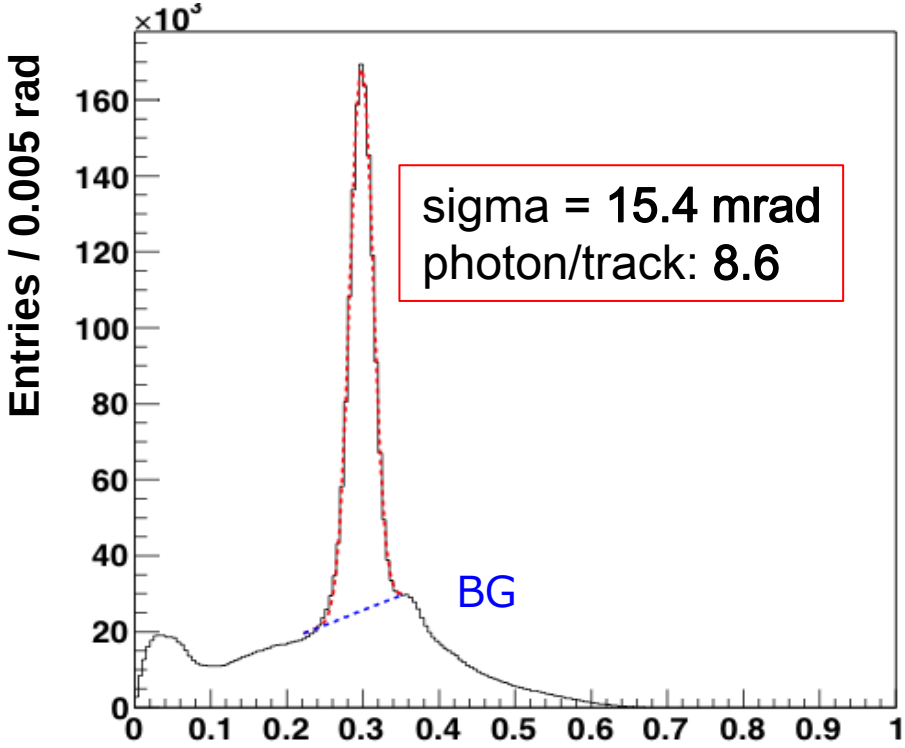




Study with Prototype Aerogel RICH

Accumulated hits





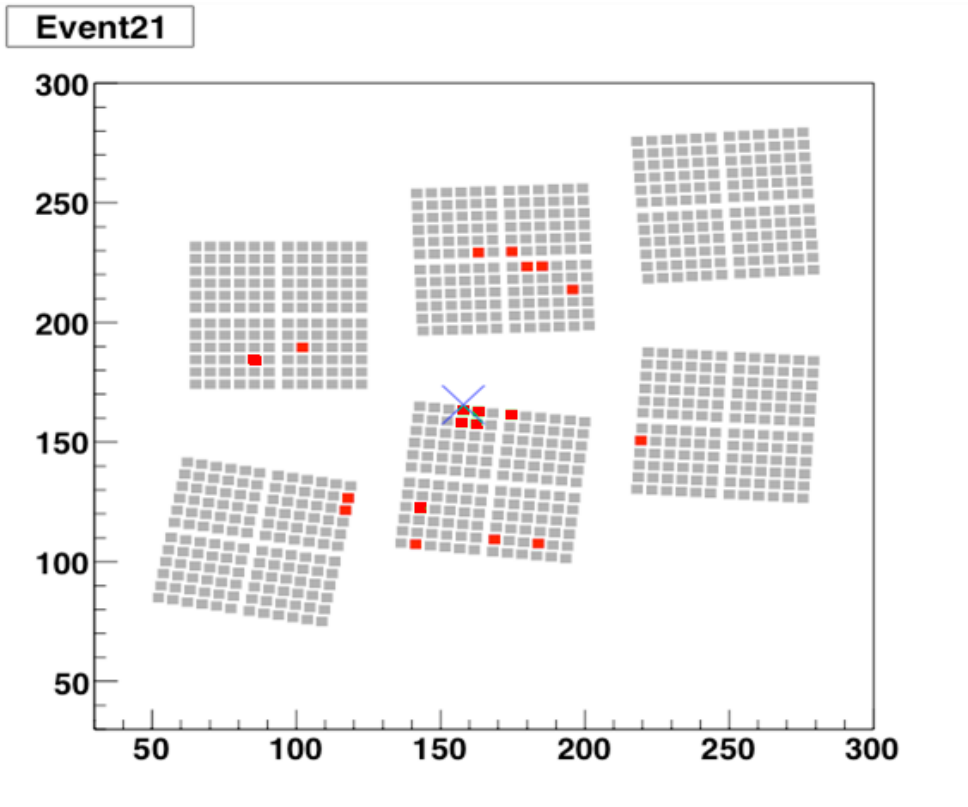
Naïve estimate from accumulate hits.

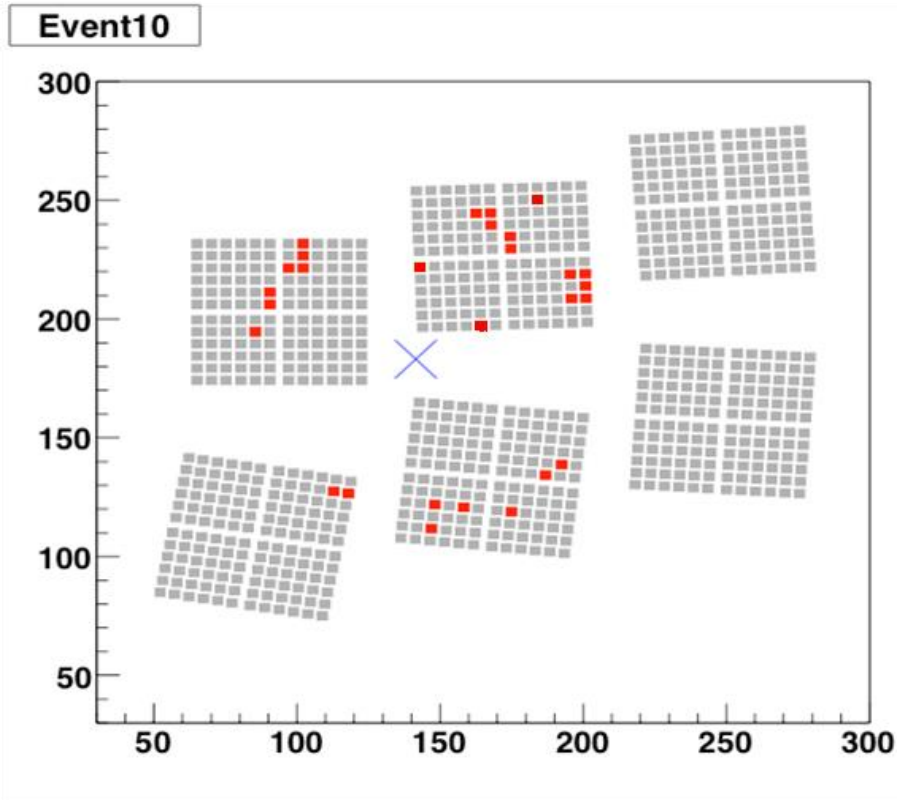
$$\frac{\Delta\theta_C}{\sigma_\theta}\sqrt{N_{p.e.}} \Rightarrow \mathbf{4.4\sigma}$$

Event-by-event performance is under study.

Study with Prototype Aerogel RICH

Typical event display





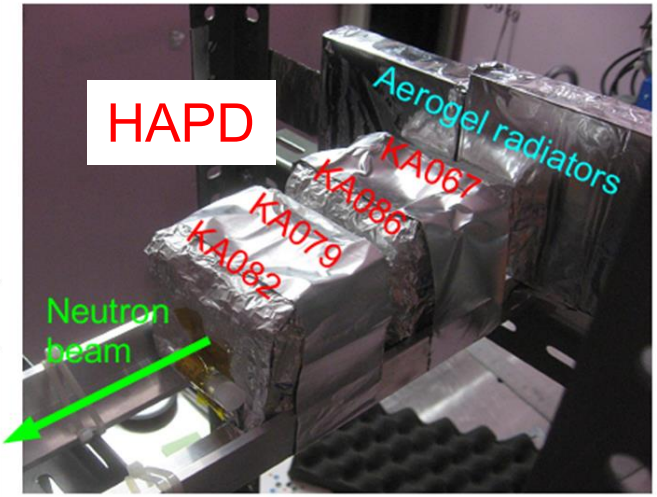
Performance with Irradiated HAPDs

One issue of the HAPDs has been the radiation tolerance.

➡ Check the performance using HAPDs after irradiations at the beam test.

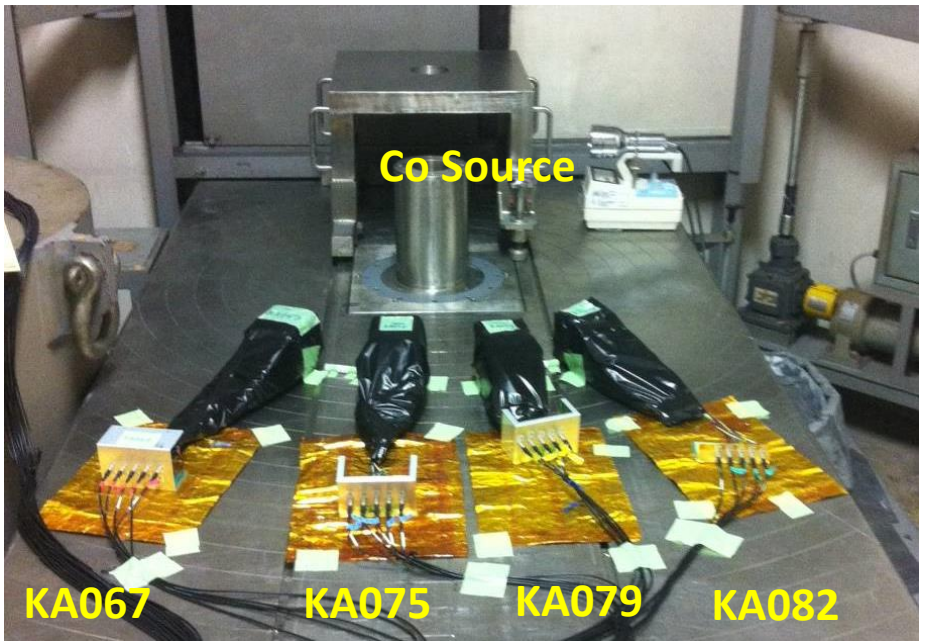
Neutron irradiation @ J-PARC MLF

- 1-2 $\times 10^{12}$ n/cm^2

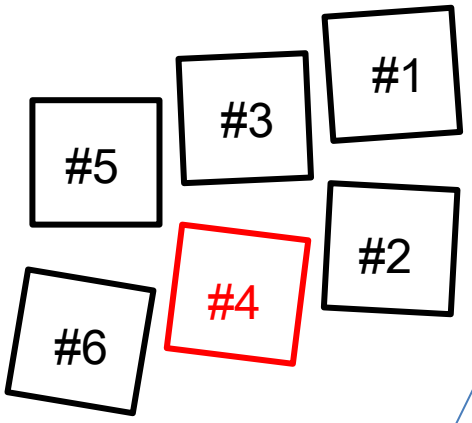


Gamma irradiation @ Nagoya Univ.

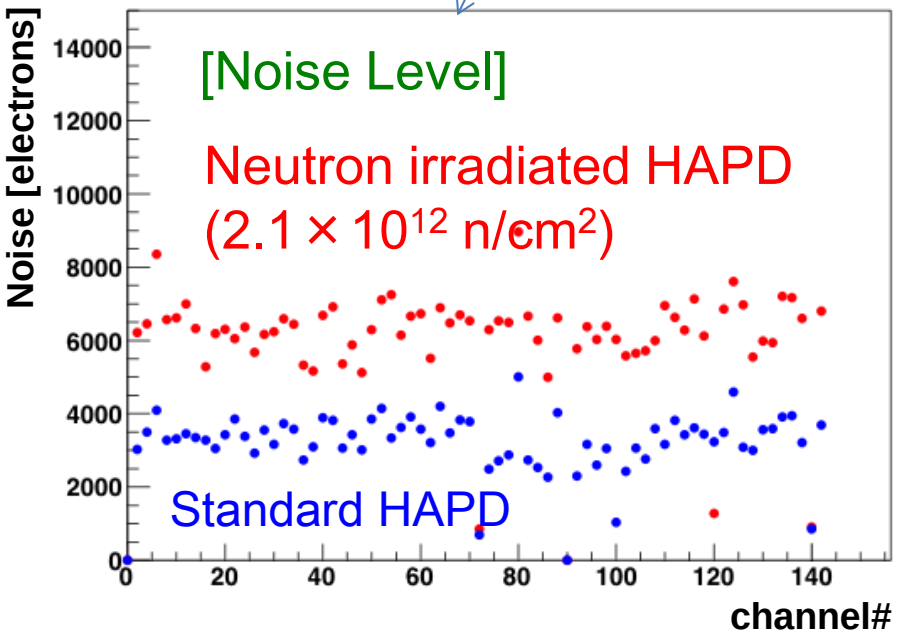
- ^{60}Co
- ~1000Gy (50Gy/hour)

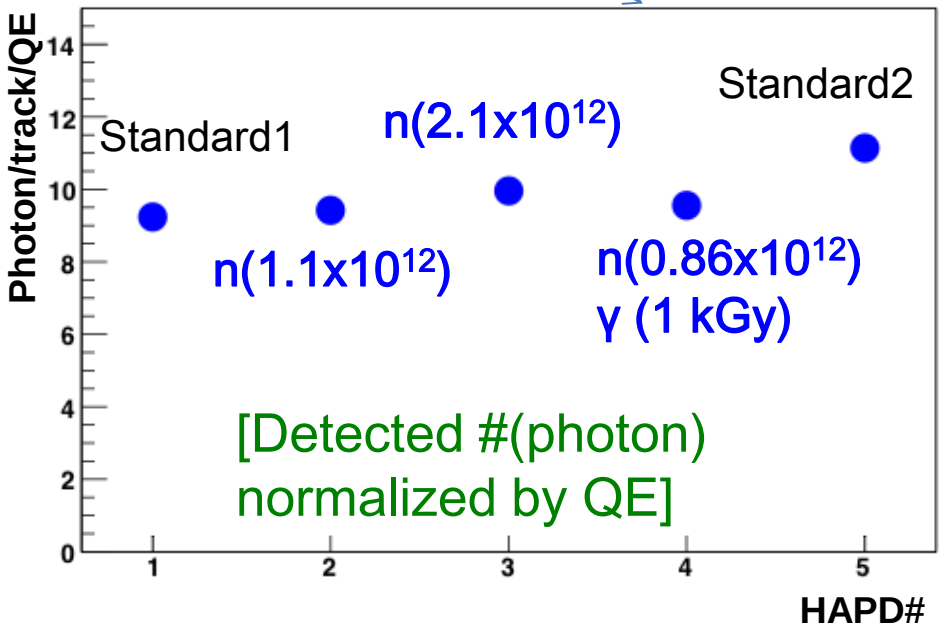


Performance with Irradiated HAPDs



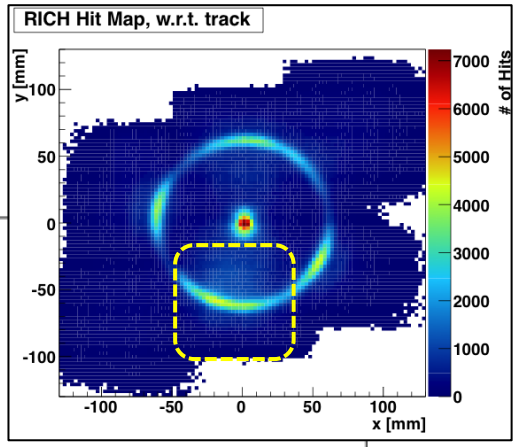
- Beam test performed using irradiated HAPDs.
- Replace one of the HAPDs (#4) to irradiated samples.
  - ✓ Neutron 2.1×10^{12} n/cm^2.
  - ✓ Neutron 0.9×10^{12} n/cm^2 and gamma 1000 Gy.
- Threshold level increased to the irradiated samples.
- No difference found in the detected number of photons/

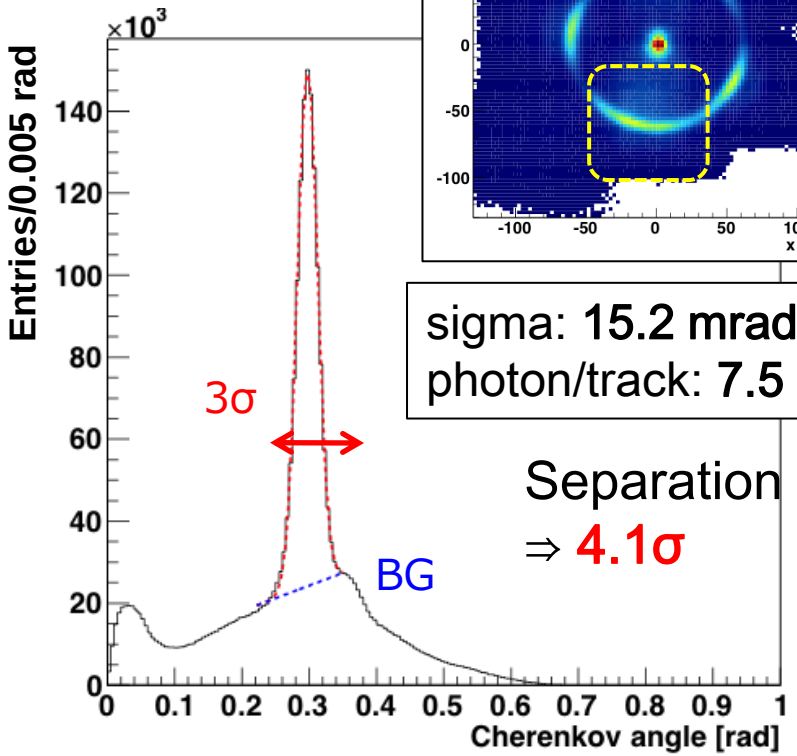




Performance with Irradiated HAPDs

n: 2.1x10^{12} n/cm^2
(QE 21.4%)

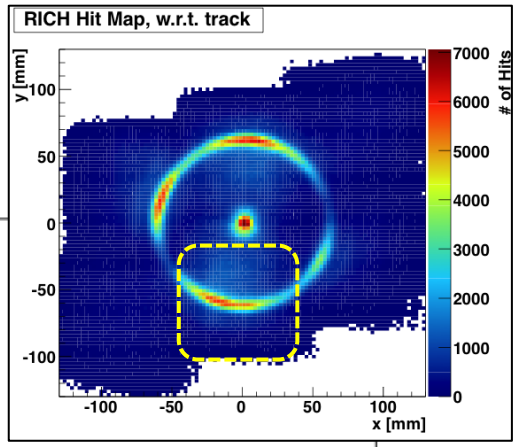


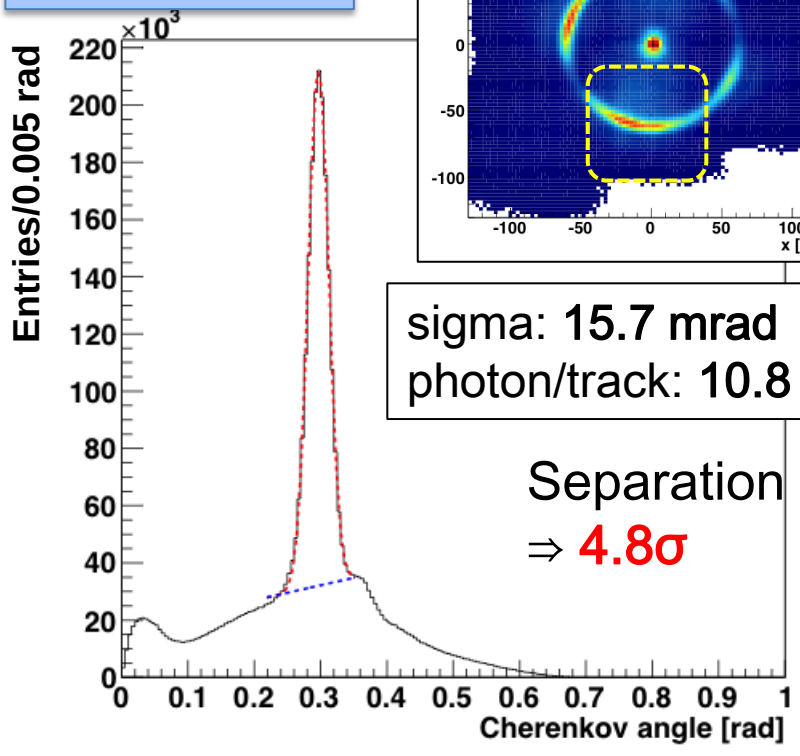


sigma: **15.2 mrad**
photon/track: **7.5**

Separation
⇒ **4.1σ**

n: 0.86x10^{12} n/cm^2
γ: 1 kGy
(QE 31.1%)





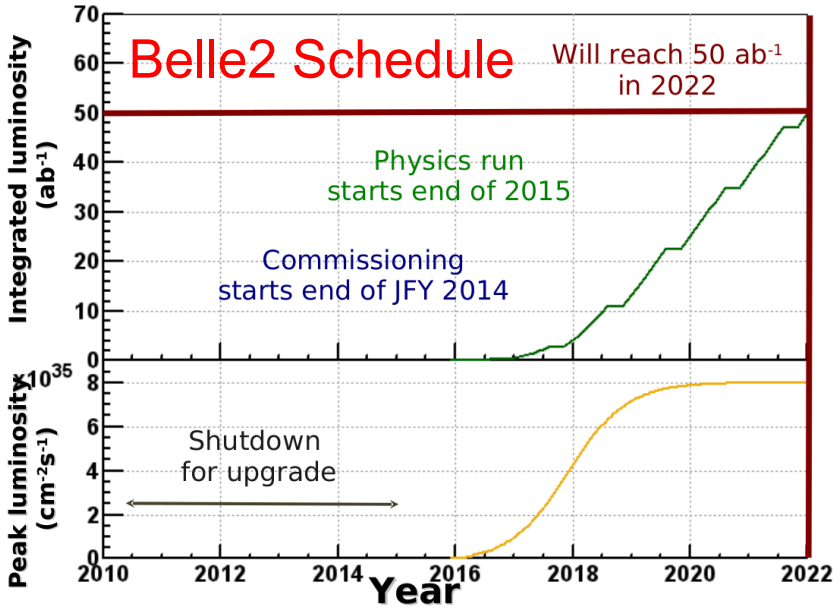
sigma: **15.7 mrad**
photon/track: **10.8**

Separation
⇒ **4.8σ**

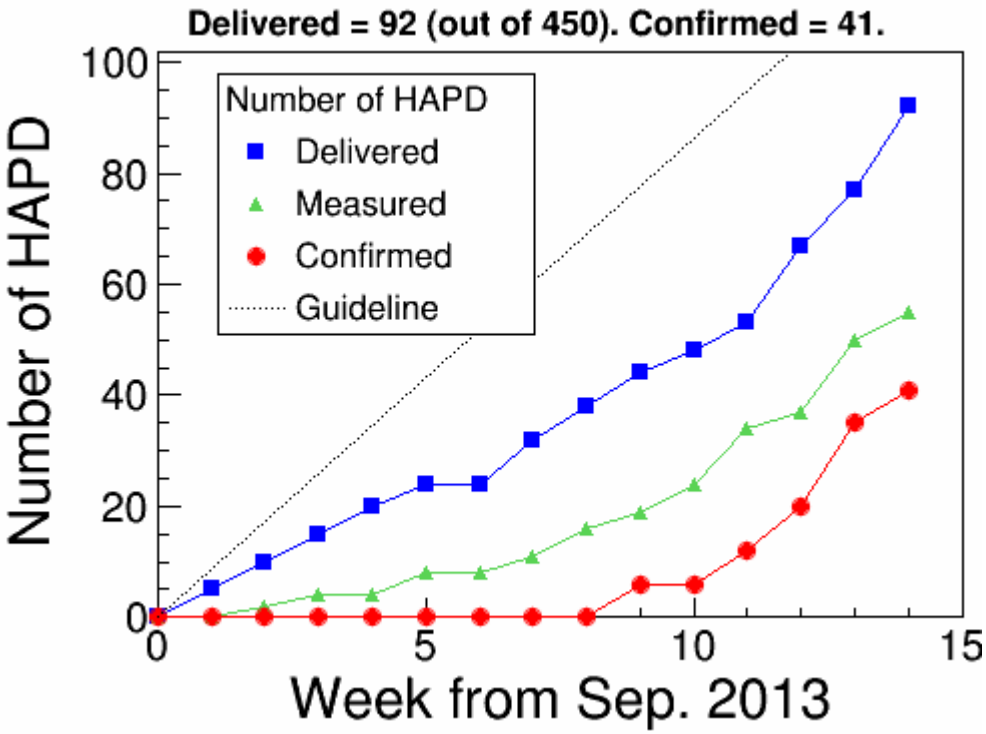
No significant performance degradation is expected for the predicted radiation.

Schedule

- Mass production of components already started.
  - ✓ HAPD (420 + spare): Sep. 2013- Sep. 2014.
  - ✓ Aerogel (248 + spare): Oct. 2013- Sep. 2014
  - ✓ ASIC: Jan. 2013- Jan. 2014.
- Electronics are (still) in test and under final design.
- Counter assembly is planned in 2014.
- Installation in 2015.

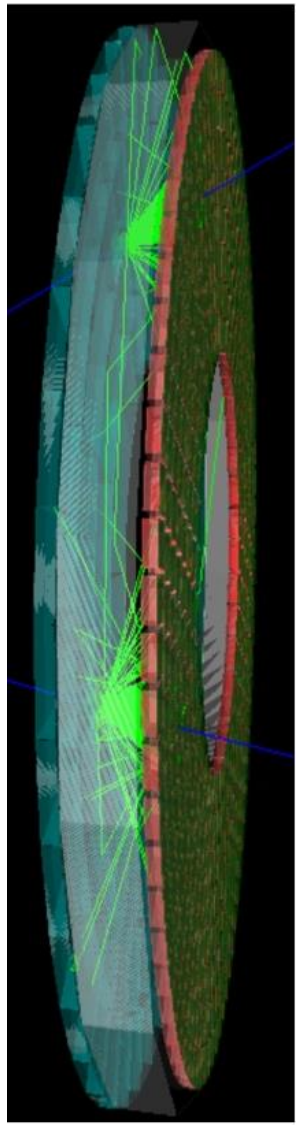


HAPD Mass Production



Summary

- We are developing Aerogel RICH Counter for the Belle II forward PID.
  - ✓ 2-layer aerogel (n=1.045 & 1.055).
  - ✓ 144 channel Hybrid Avalanche Photo-Detector.
  - ✓ Readout electronics based on the ASIC.
- Mechanical design is fixed. MC study is on-going.
- Beam test with prototype Aerogel RICH.
  - ✓ Performance was confirmed.
  - ✓ Radiation damage of HAPD was a concern; test with irradiated HAPDs were done.
- Mass production of detector components (HAPD, Aerogel …) started.



Backup

Dec. 3 (Tue) S.Korpar (Univ. Maribor and JSI)
"144-channel HAPD for Aerogel RICH at Belle II"

Dec. 4 (Wed) M.Tabata (JAXA)
"Silica Aerogel Radiator for Use in the A-RICH System Utilized in the Belle II Experiment"

Poster: S.Korpar (Univ. Maribor and JSI)
"Monte Carlo study of a Belle II proximity focusing RICH with aerogel as a radiator"

Poster: H.Kakuno (Tokyo Metropolitan Univ.)
"Readout ASIC and Electronics for the 144ch HAPD for Aerogel RICH at Belle II"

HAPD Specification

Specification of the HAPD(cont'd)

HAPD performance:

	Nominal	Min.	Max.
QE(%):	28	24	
V_{bias} (V):	250-500		
V_{guard} (V):	125-250		
$I_{leak(AD)}$ (μA):			1 (per channel)
Gain(AD,ch22):		30	
# of bad channel*:			10
$I_{leak(HV)}$ (pA):			300
Gain(Bomb.,ch22):	1800	1500	
Gain(Total, ch22):		45000	

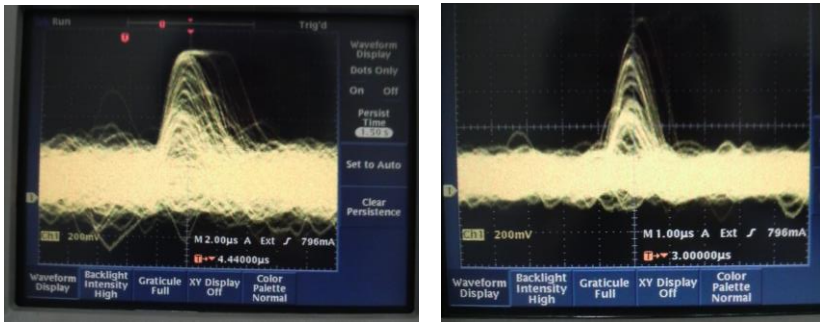
* bad channel: $I_{leak(AD)}$ >1μA or Gain(AD) < 30

Above Items are measured at HPK before they send.

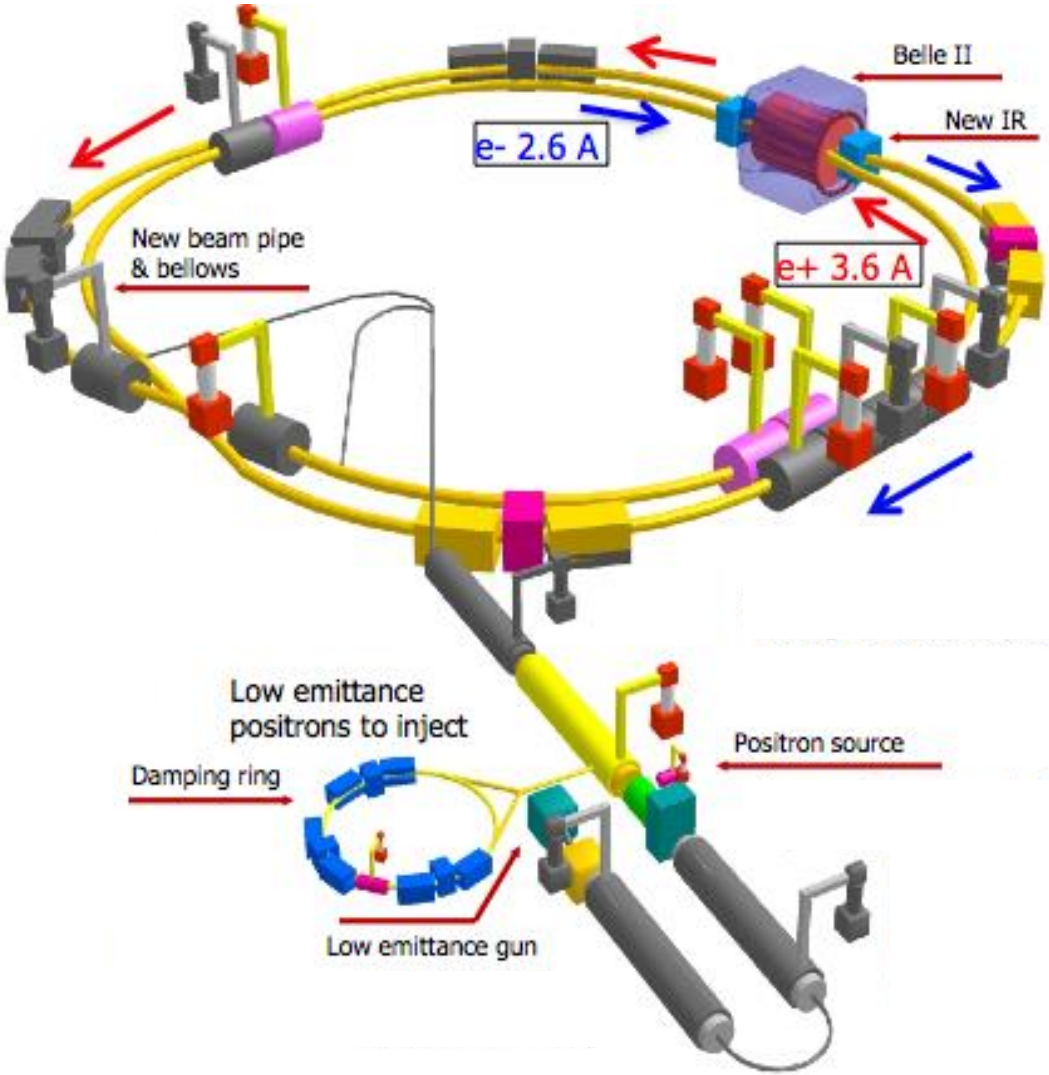
5

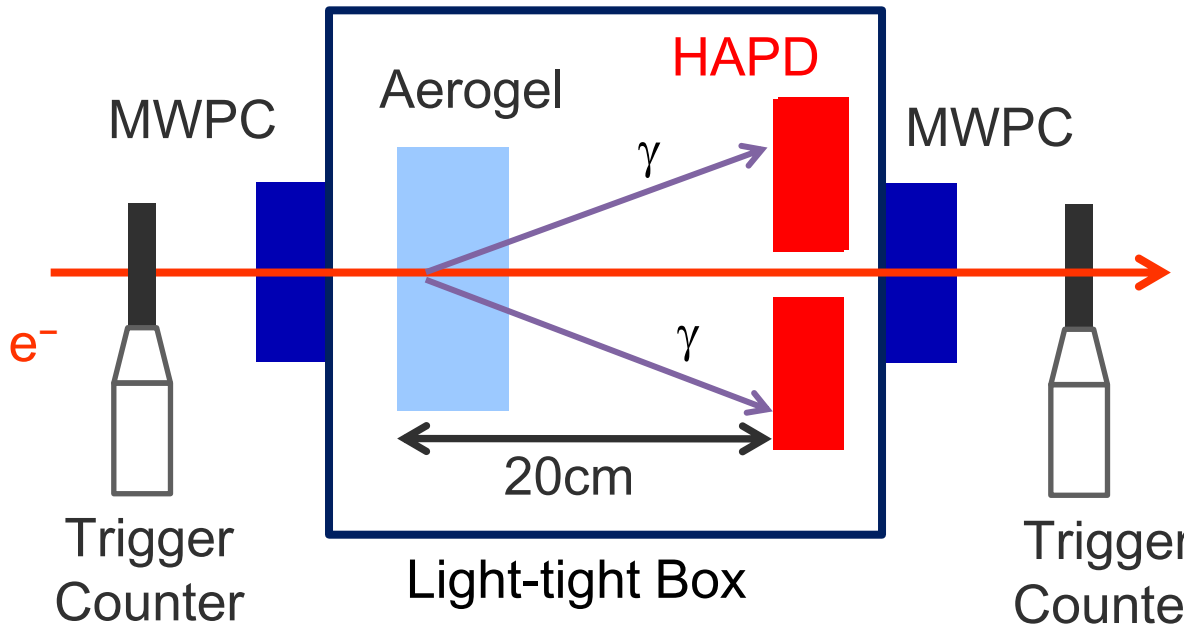
Electronics

SA01 monitor signal for
neutron-irradiated HAPD
(~ 5y operation at Belle2)



shaping time: 1000ns 250ns


Belle II
New IR
e- 2.6 A
New beam pipe
& bellows
e+ 3.6 A
Low emittance
positrons to inject
Positron source
Damping ring
Low emittance gun


HAPD
Aerogel
MWPC
MWPC
γ
γ
e⁻
20cm
Trigger
Counter
Light-tight Box
Trigger
Counter