Study of 144-channel Hybrid Avalanche Photo-Detector for Belle II RICH Counter

VCI2010

Susumu Shiizuka

Nagoya University

for

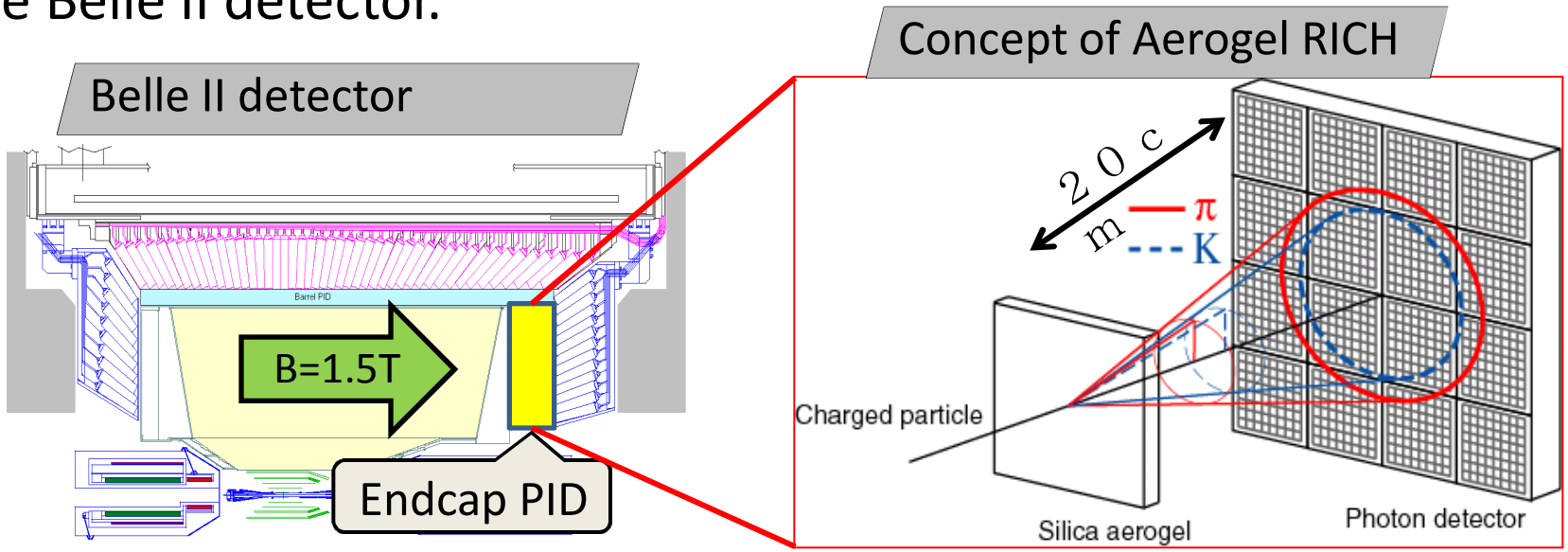
Belle II Aerogel RICH group

Contents

- Introduction
- Development of new 144ch HAPD + ASIC
- Performance in magnetic field
- Neutron irradiation test
- Beam test of Aerogel RICH with HAPD
- Summary

Belle II Aerogel RICH

We are developing a proximity focusing Ring Imaging Cherenkov (RICH) counter with aerogel radiator for the upgrade of the forward endcap PID in the Belle II detector.



To achieve 4 σ K/π separation, we need a brand new photodetector with,

(1)Large effective area (2) High sensitivity to single photon

(3)Position resolution($5\times5mm^2$) (4)Immunity to magnetic field(1.5Tesla)

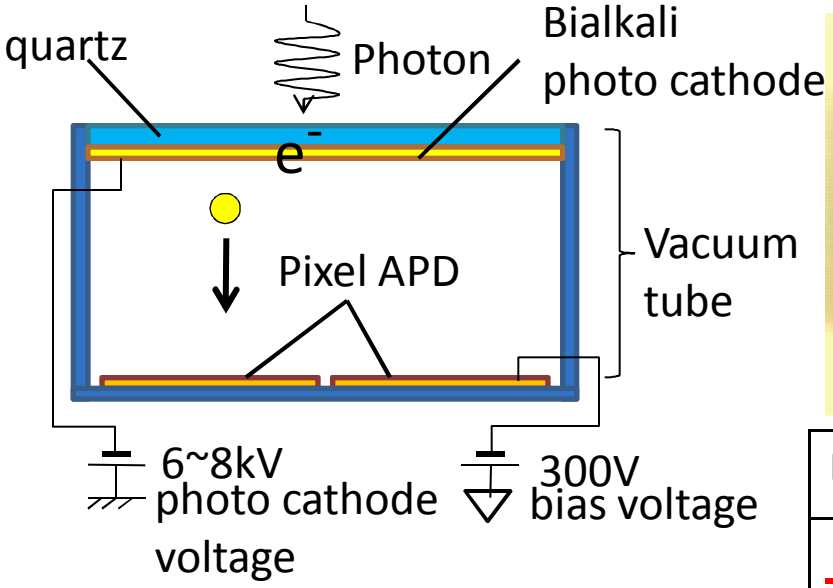
(5) Immunity to radiation

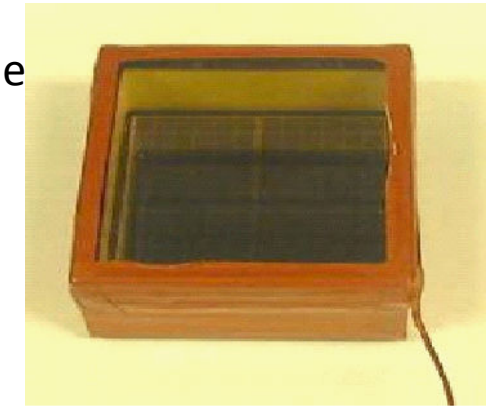
New 144ch multi-pixel HAPD

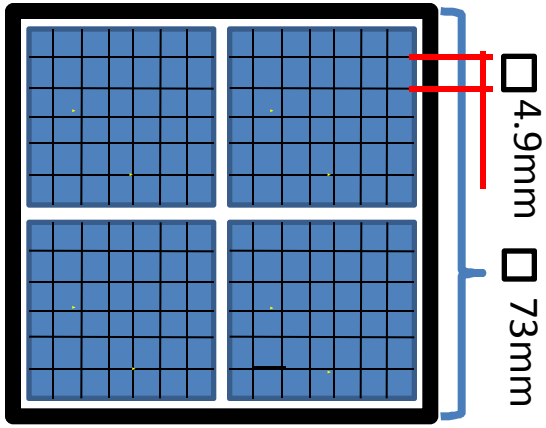
We have been developing

a new 144ch Hybrid Avalanche Photo Detector (HAPD)

with Hamamatsu Photonics since 2002.



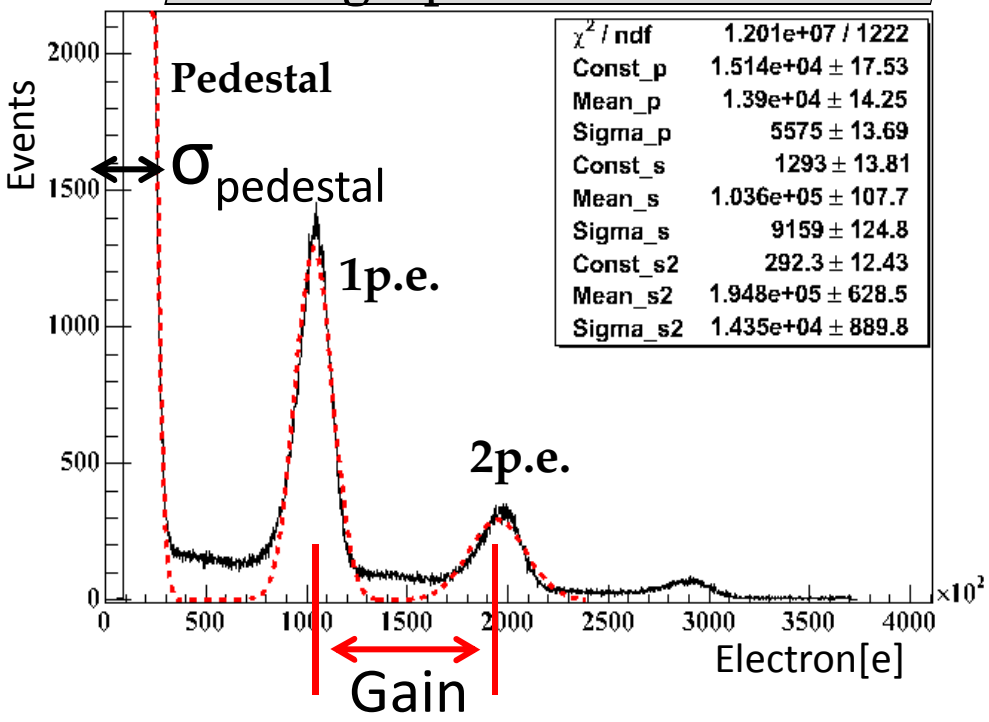




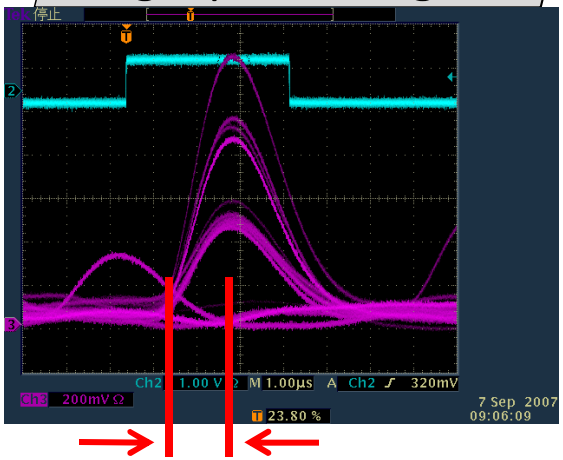
Peak quantum efficiency	25% ➡32%
Effective area ratio	**64%**
Capacitance	80pF
Bombarding gain	1300 ~ 1800
Avalanche gain	~50
Total gain	**10^4 ~ 10^5**
Required numbers	540 HAPDs

Single photon response

Pulse height distribution for Single photon irradiation



Single photon signal



Preamp:
CLEAR PULSE
580K

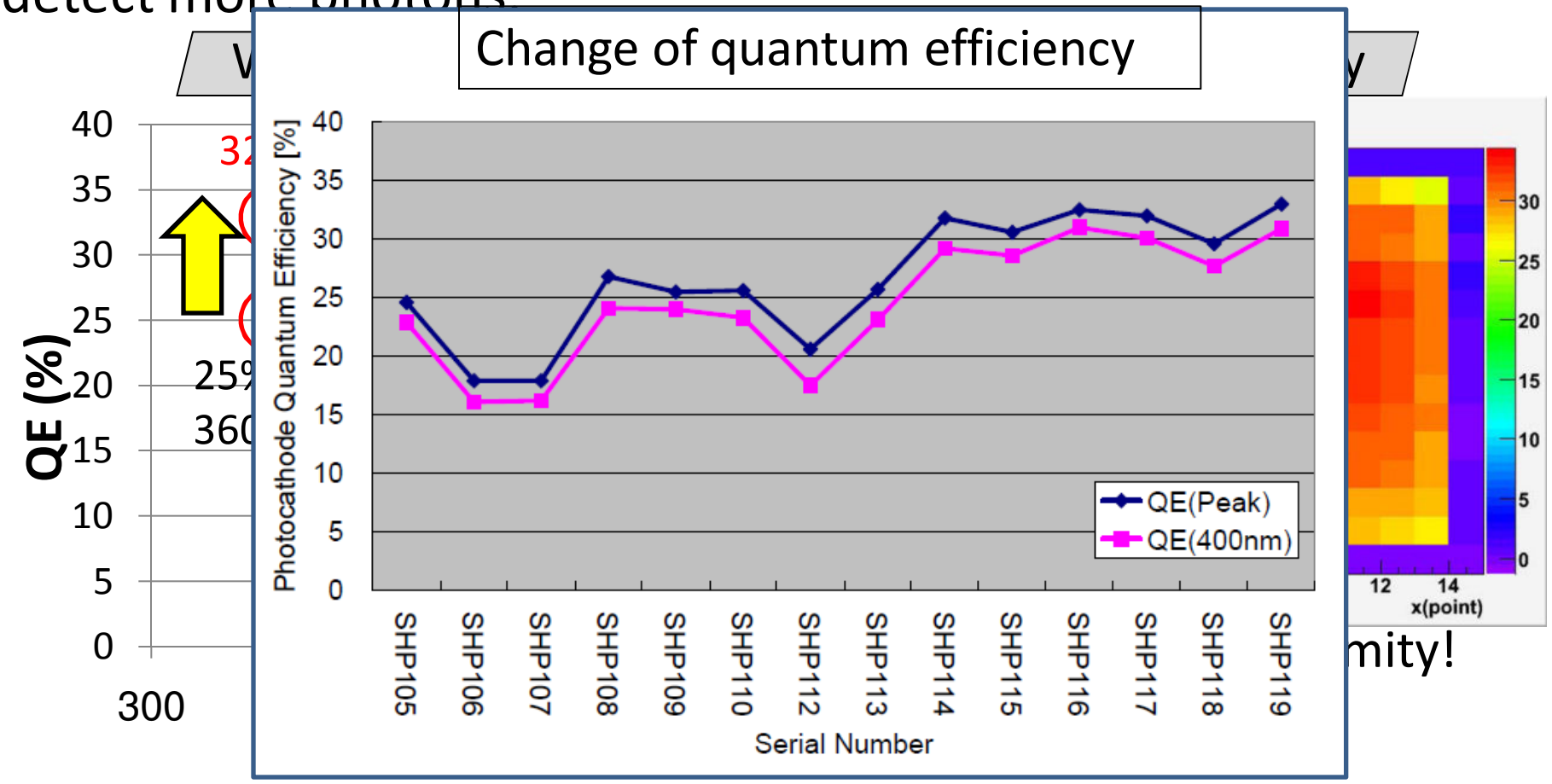
Shaper:
CLEAR PULSE
4417

$$S/N = \frac{Gain}{\sigma_{pedestal}} = 16$$

The 144ch HAPD has excellent single photon detection performance

Quantum efficiency

We are developing HAPD with super bialkali photo cathode to detect more photons.

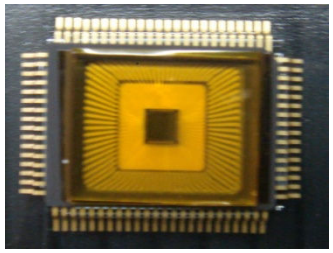


We achieved Peak QE ~32%. (bialkali average : 25%)

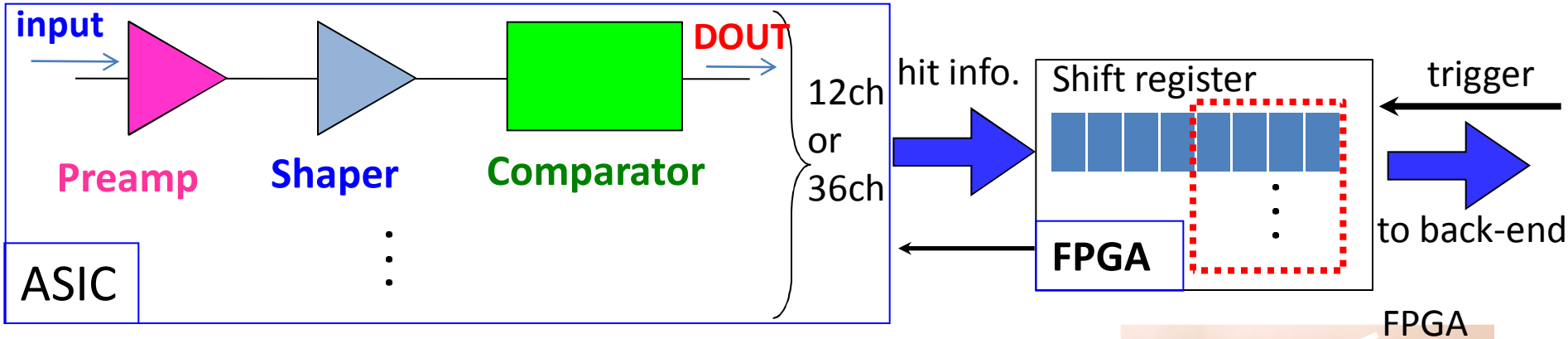
ASIC for readout of 144ch HAPD

We need high density front-end electronics including high-gain and low-noise amplifier for A-RICH.

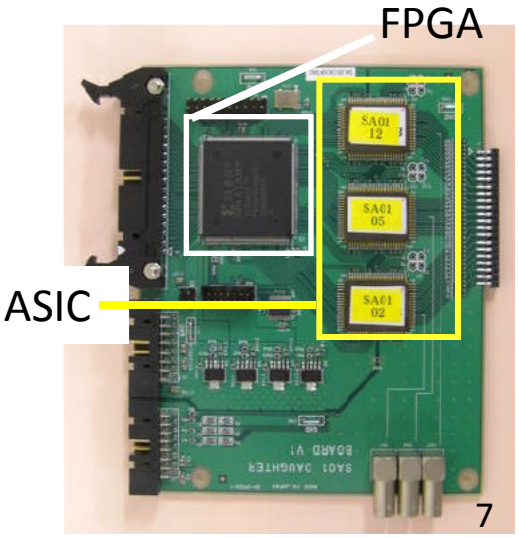
→ We have been developing ASICs for front-end electronics.
We planed to readout output of ASIC with FPGA.



Circuit configuration



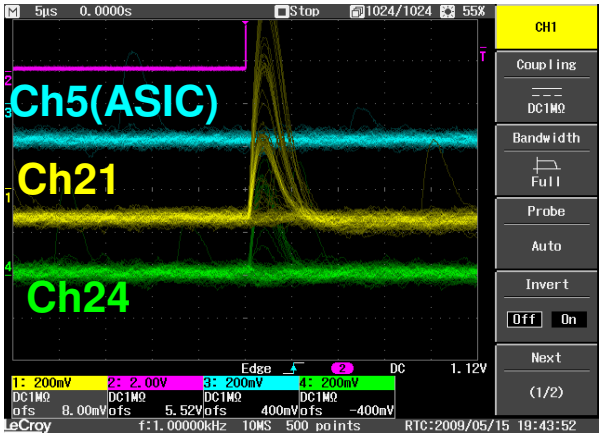
- 4 step variable gain preamplifier.
- 4 step variable shaping time shaper.
- Comparator for the digitization of analog-signals.
  (We need **only on/off hit information**)
- We have developed new ASIC SA01 and SA02.

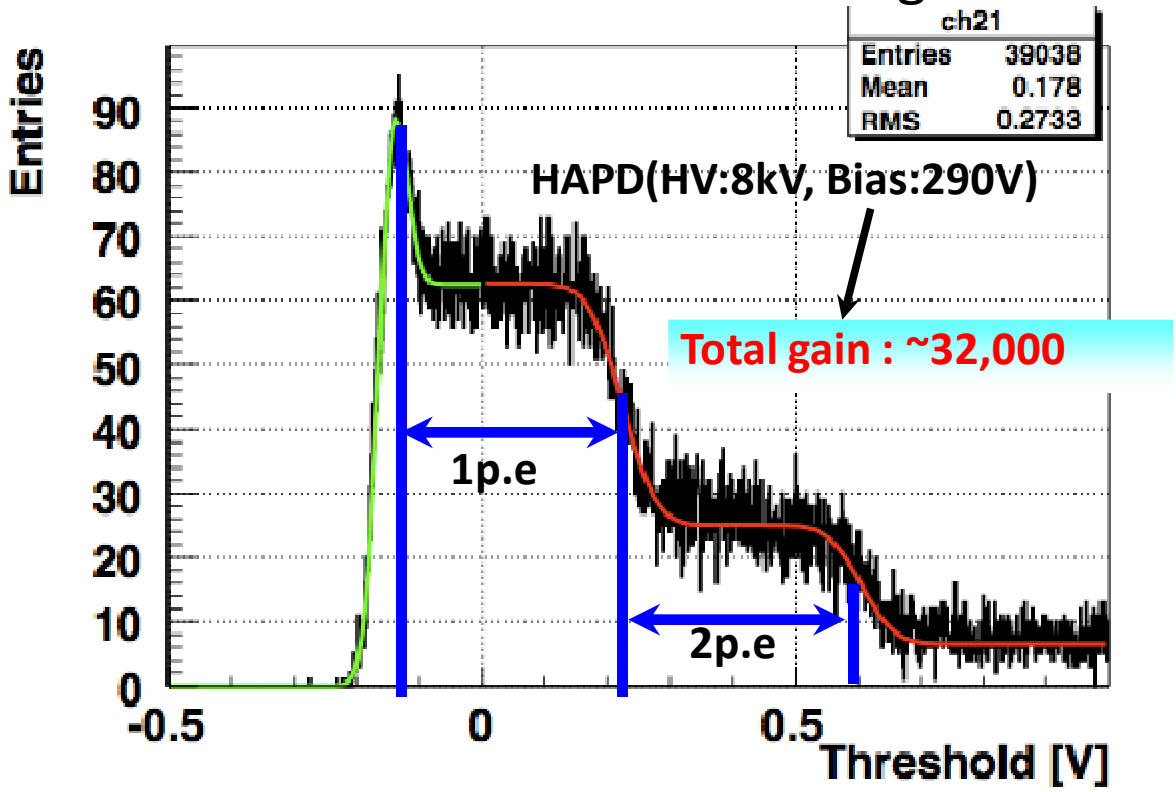


Readout test of HAPD with ASIC

Threshold scan

- Distribution of output ASIC for 100 LED light irradiations at each threshold voltage.





Result

- Noise : ~2,000e⁻
- Pulse height
  - 1p.e signal : 32,700e⁻
  - 2p.e signal : 66,200e⁻

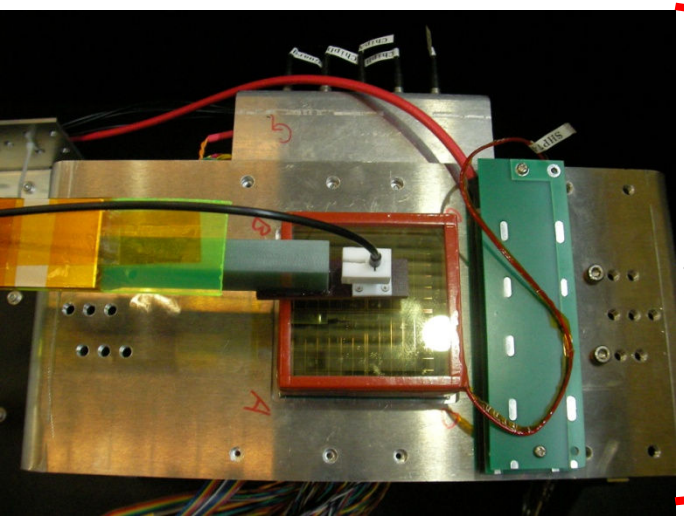
S/N : ~17

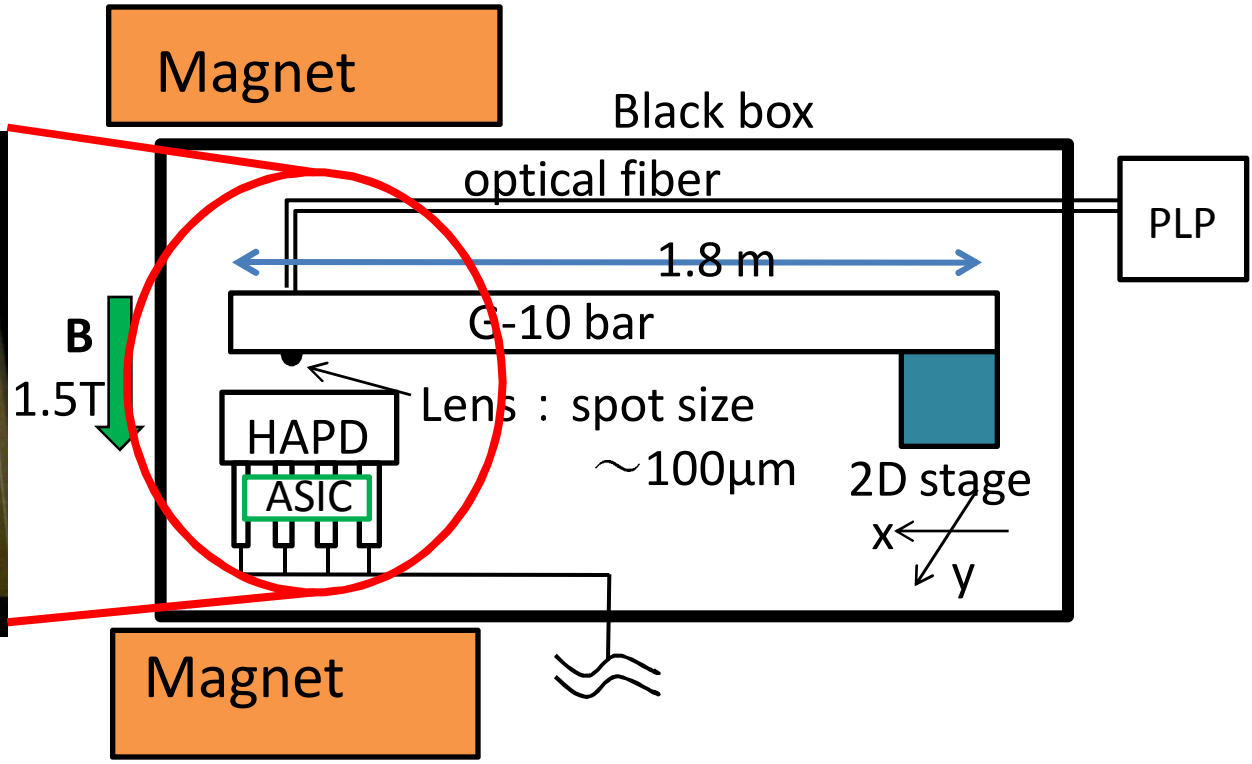
- **Clear separation between 1p.e and 2p.e!**
- **Very high S/N ratio (target > 7)!**

Good performance of readout system with ASIC + FPGA is confirmed!

Test in magnetic field

- We measured HAPD in the 1.5T magnetic field
- using a special equipment to scan the HAPD surface with pulse laser(controlled by a 2D stage outside the magnet).

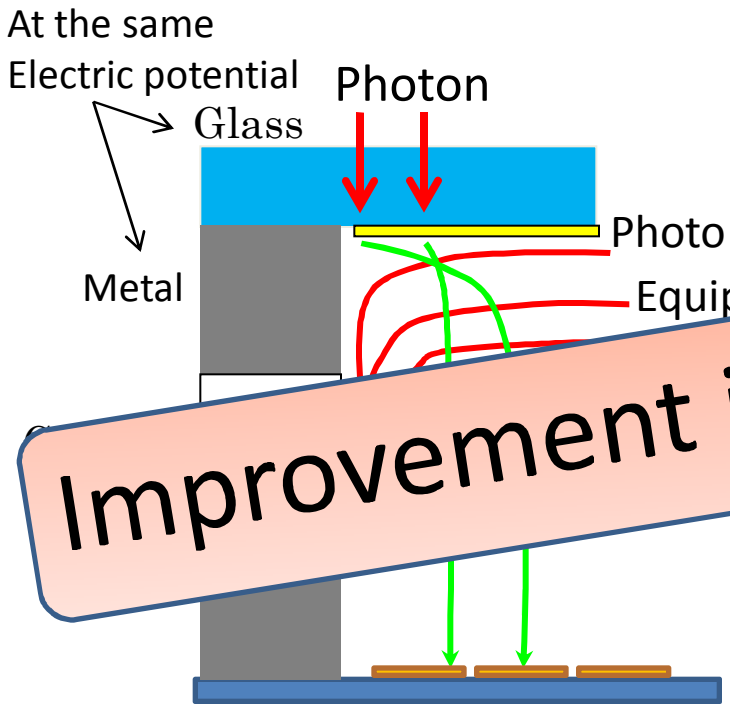




Effect of magnetic field

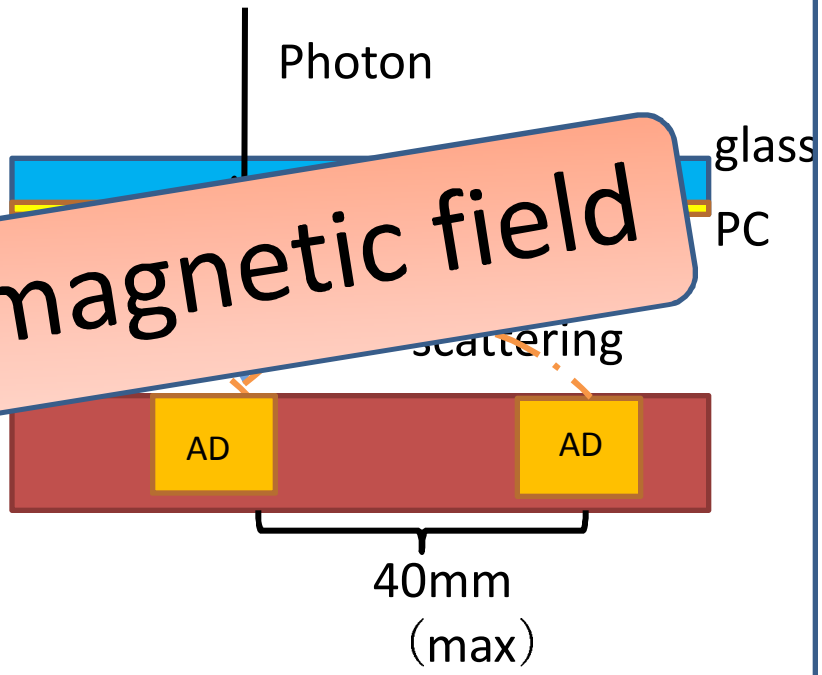
In magnetic field, we expect improved performance.

Image Distortion effect by side wall



•Distorted electric field near the side wall carries photoelectrons to the neighboring AD pixel.

Photoelectron backscattering

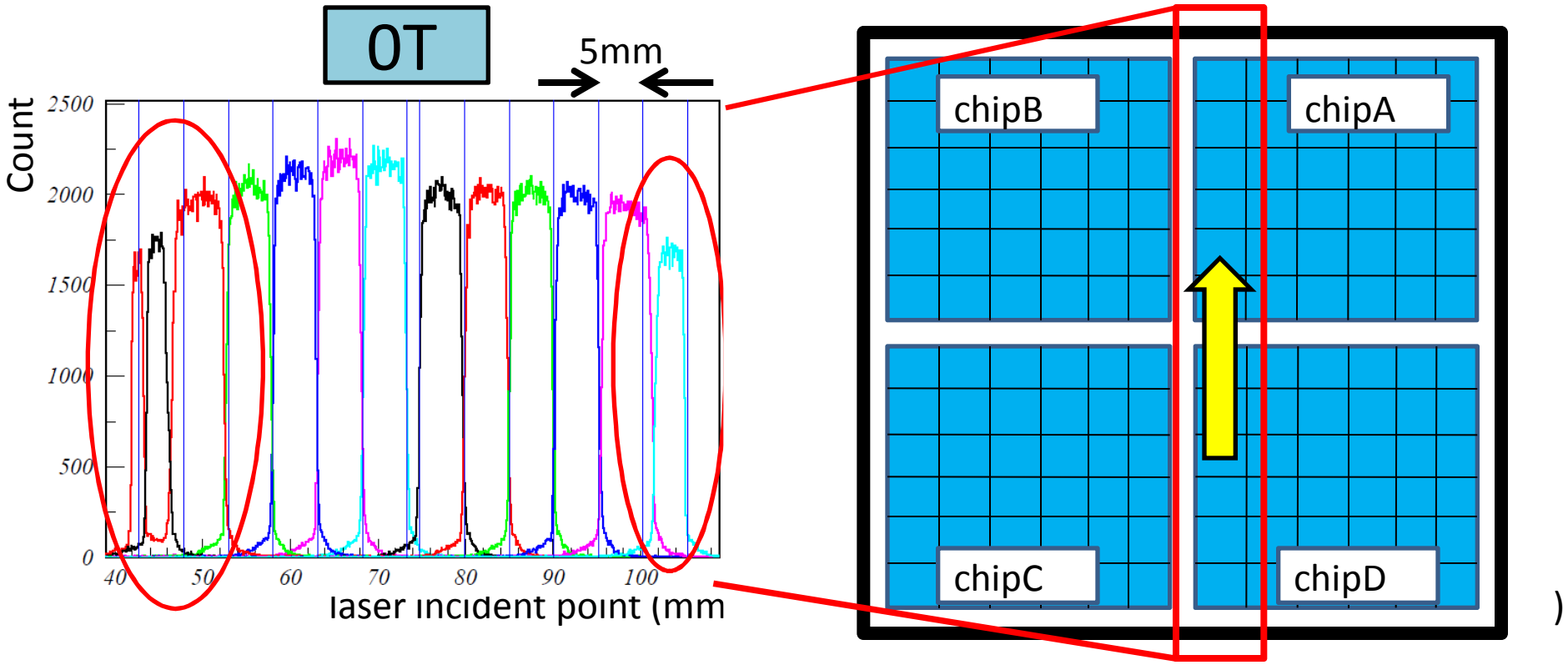


•The photoelectrons hitting the AD are backscattered and spread within 40mm.

Improvement in the magnetic field

We confirm these behaviors in the magnetic field of 1.5T

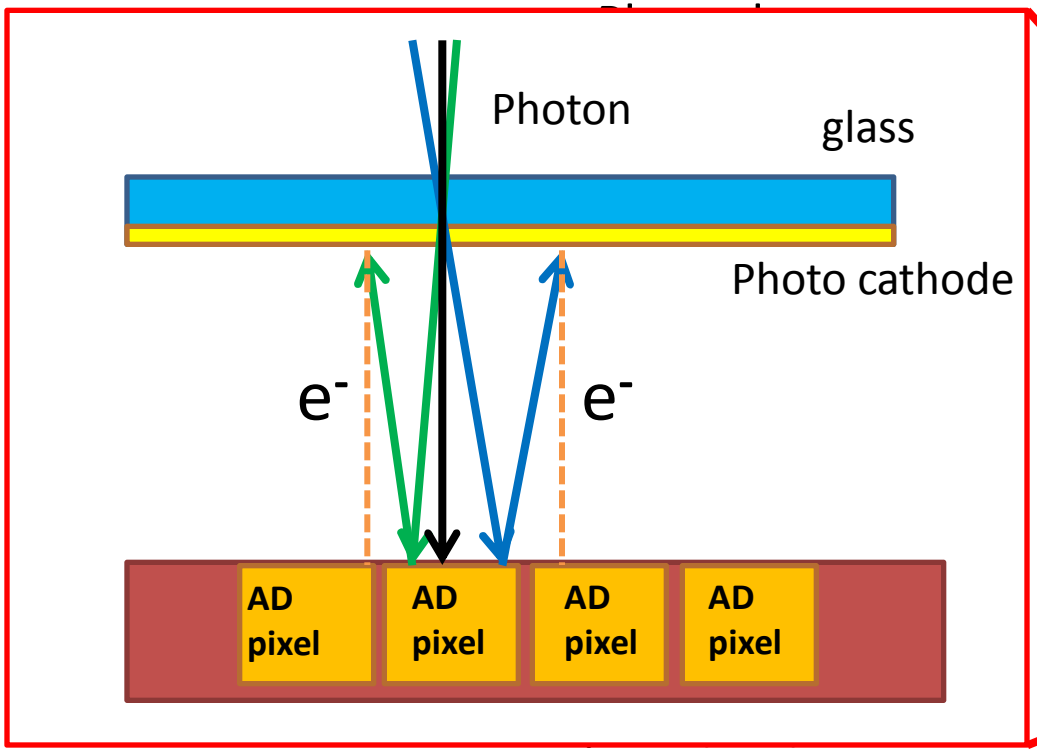
Image distortion effect



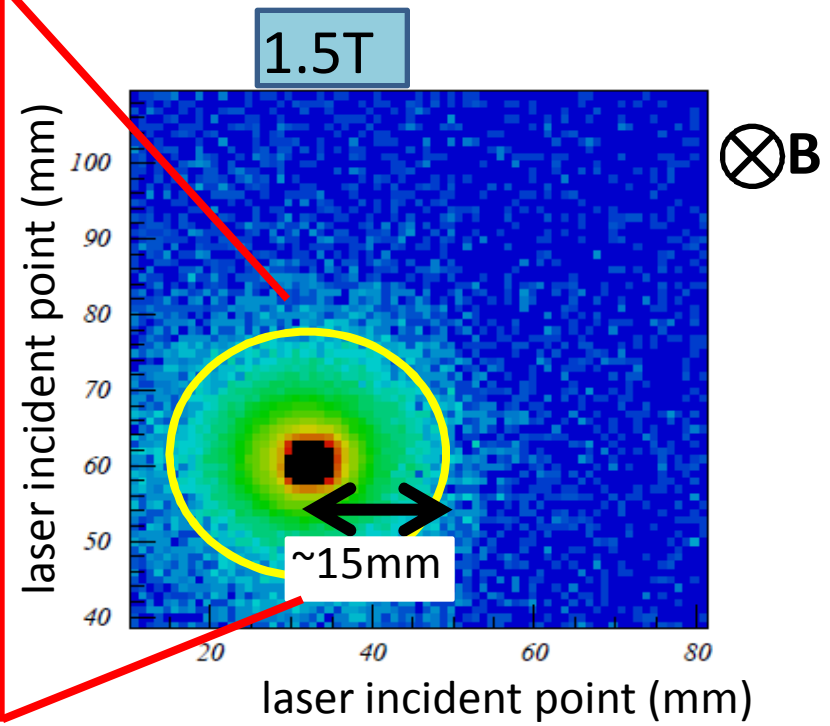
・As expected, the distortion near the side wall is removed in the magnetic field of 1.5T.

We have achieved 5mm position resolution all over the HAPD surface in 1.5T.

Photoelectron Backscattering Effect



Reflection of light on the AD surface

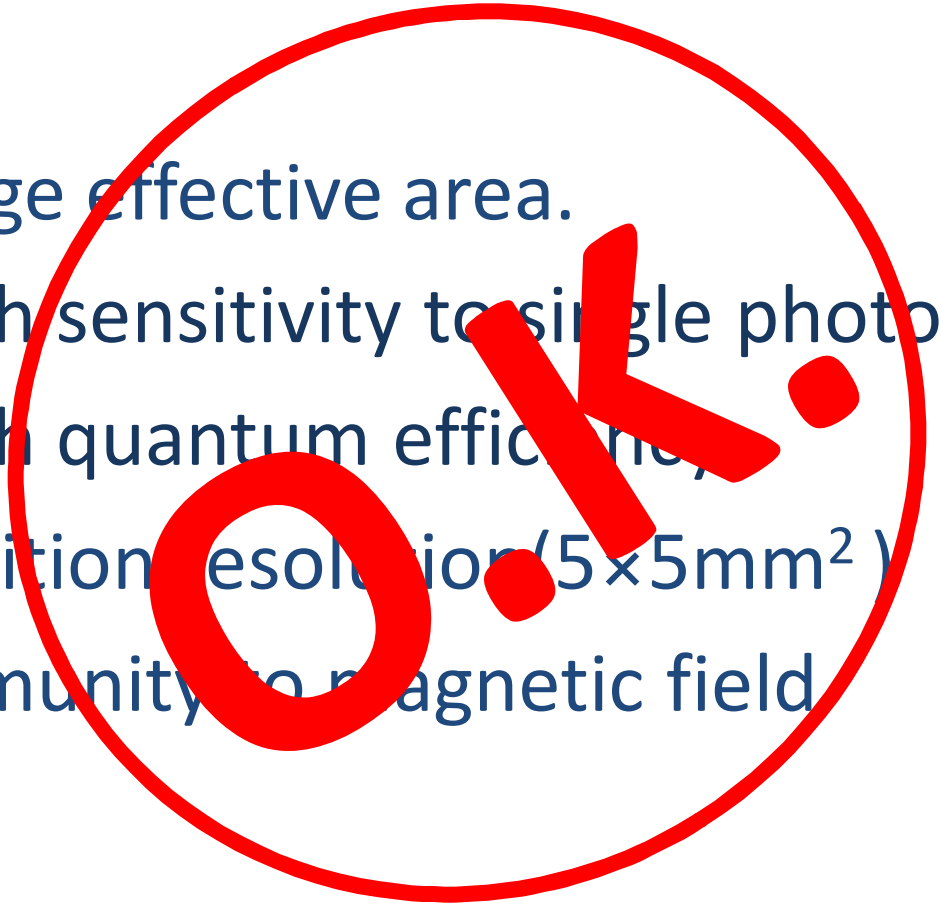


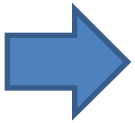
We confirm reduction of photoelectron backscattering effect.

Residual effect is due to reflection of light on the AD surface.

Performance of HAPD

- Large effective area.
- High sensitivity to single photon
- High quantum efficiency
- Position resolution ($5\times5mm^2$)
- Immunity to magnetic field



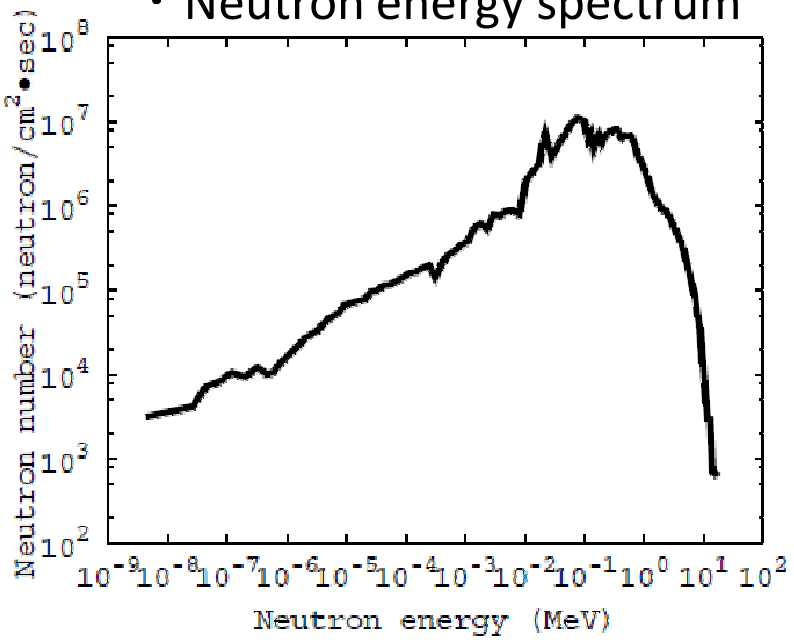

The remaining issue is neutron radiation tolerance.

Neutron irradiation test

- Concern influence on APD (lattice defects)
- Estimated neutron dose = 1×10^{12} neutron/cm^2 for 10 years in Belle II detector
- We carried out neutron irradiation test in October 2009.
  - Used nuclear reactor "Yayoi" , Tokyo university
    - Flux : 2×10^8 neutron/cm^2 ・ sec
    - Source size : ϕ=100mm

Reactor "Yayoi"

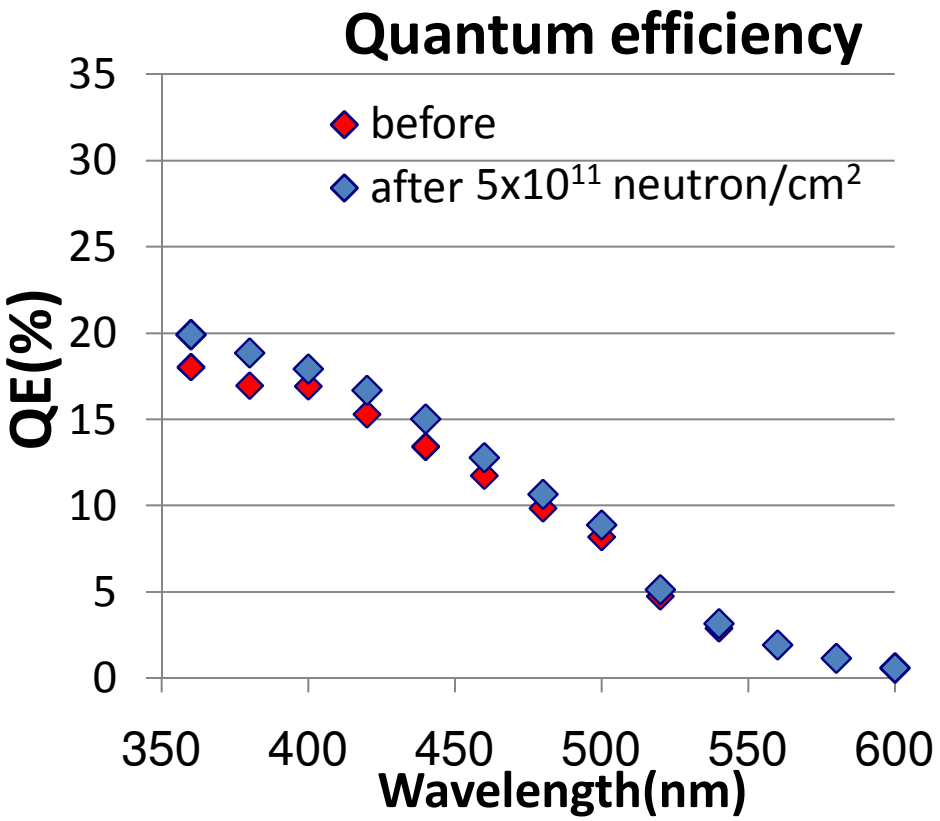
・ Neutron energy spectrum

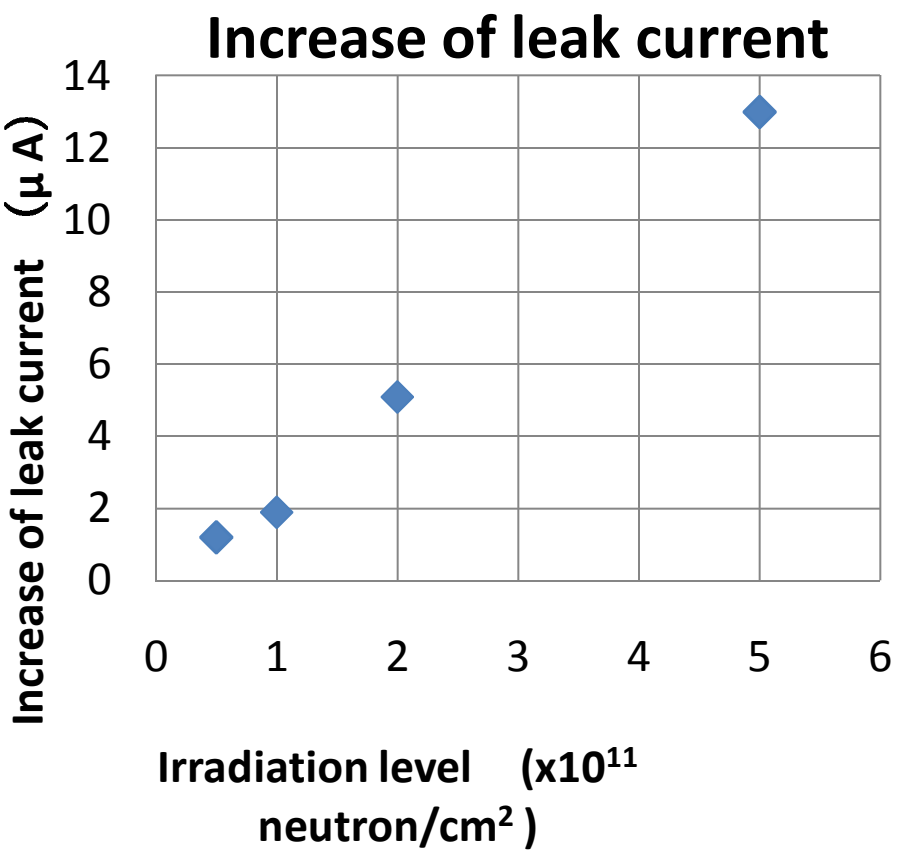


Irradiation level

- 0.5×10^{11} neutron/cm^2 (Belle II 0.5 years)
- 1×10^{11} neutron/cm^2 (1 years)
- 2×10^{11} neutron/cm^2 (2 years)
- 5×10^{11} neutron/cm^2 (5 years)

Influence of irradiation





Quantum efficiency is not affected.

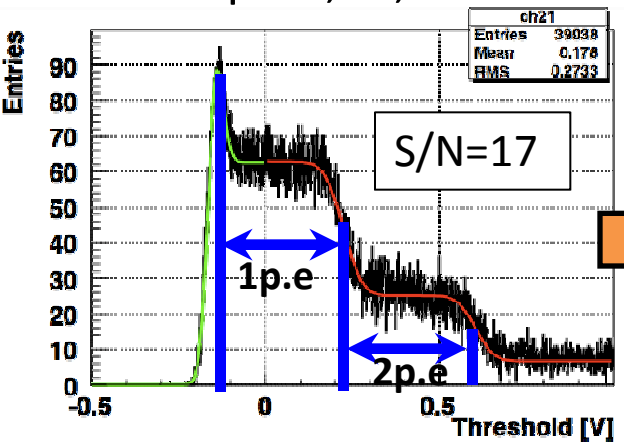
Neutron irradiation causes increase in leak currents.

Increase in noise

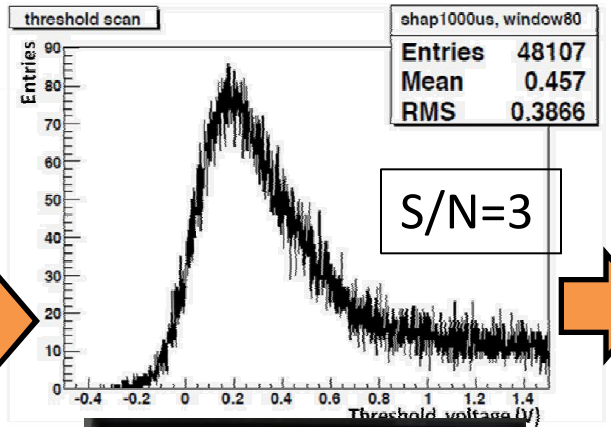
Single photon response after irradiation

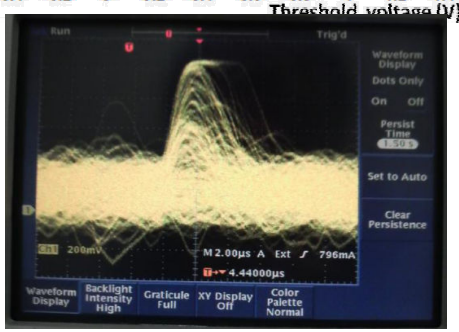
Measured S/N ratio by using the ASIC (S/N Target>7)

Before irradiation
1μsec, -7,000V

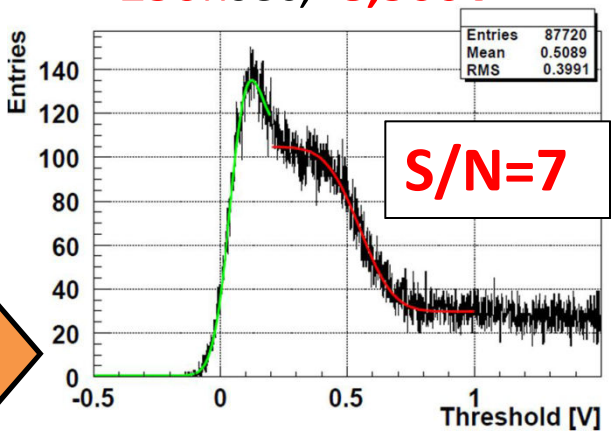


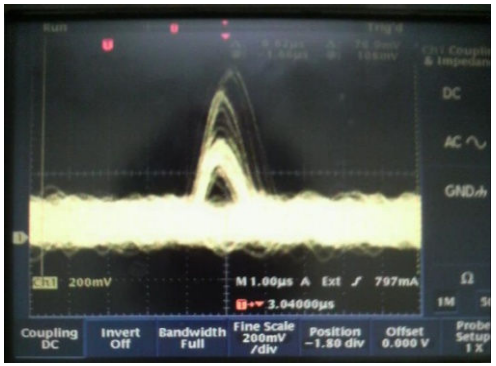
$5x10^{11}$ neutron/cm^2
1μsec, -7,000V





250nsec, **-8,500V**





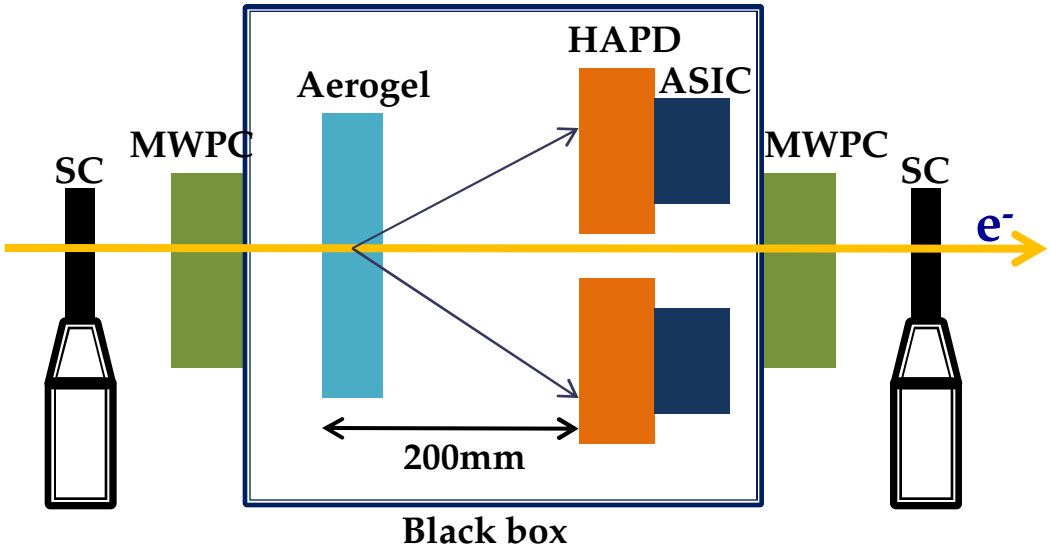
We can achieve S/N = 7 by optimizing the shaping time and HV

We can use the HAPD for 5 years in Belle II detector.

(Irradiation test up to $1x10^{12}$ neutron/cm^2 is underway.)

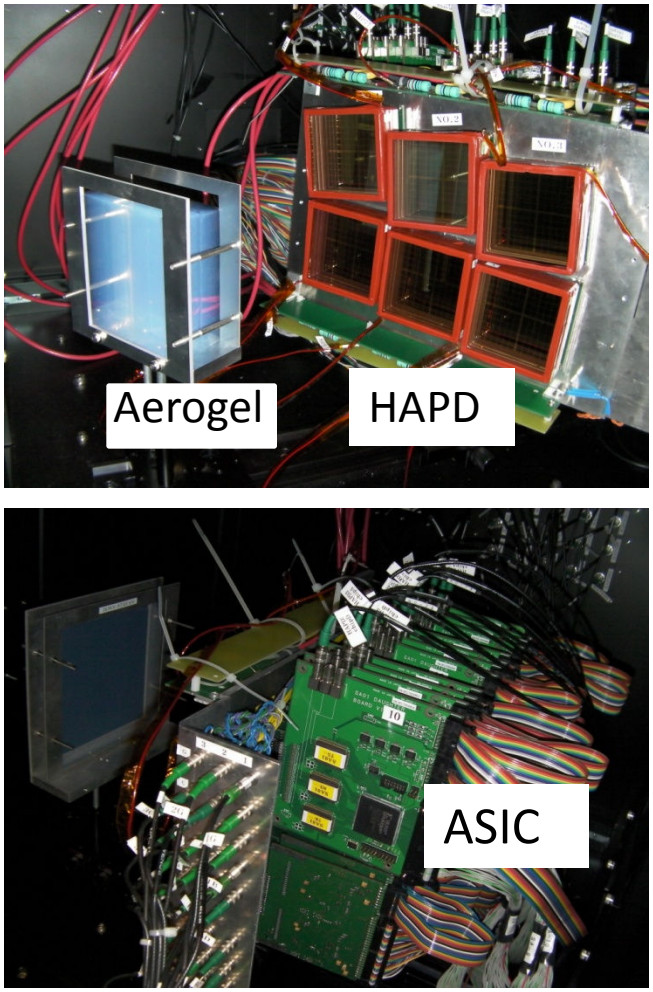
Beam test of Aerogel RICH with HAPD

- At Fuji test beam line in KEK November 2009.
- Electron beam with 2 GeV/c
- 6 HAPDs from recent batches
- Aerogel with improved transmission



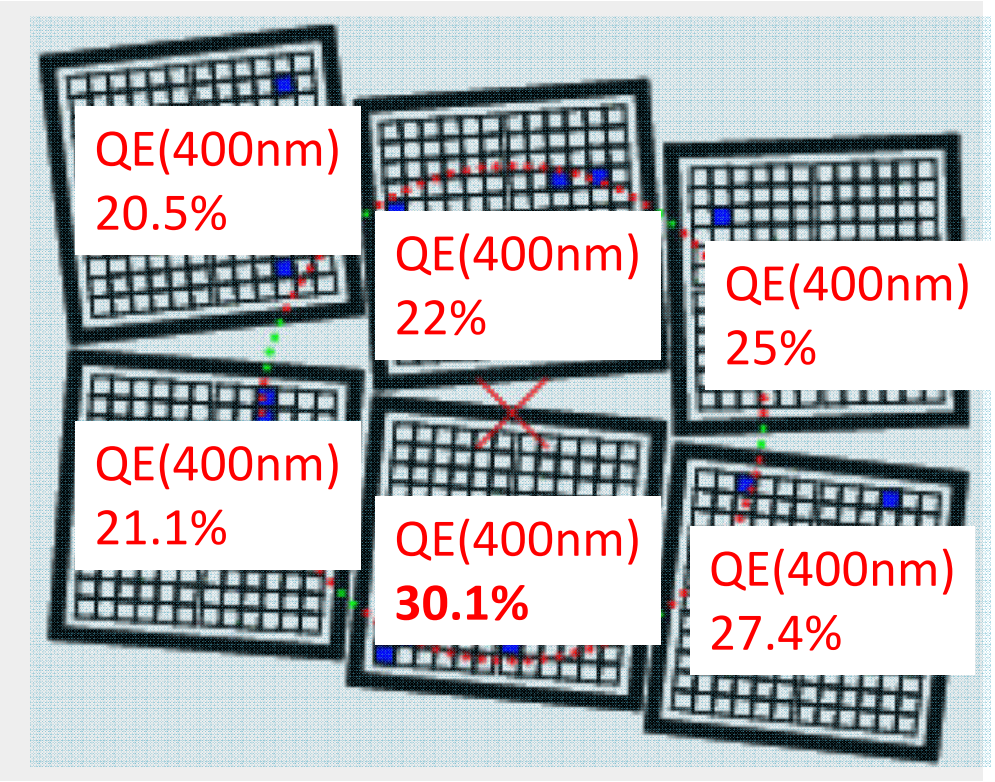
- **Track parameters determined by two MWPCs**

Prototype Aerogel RICH

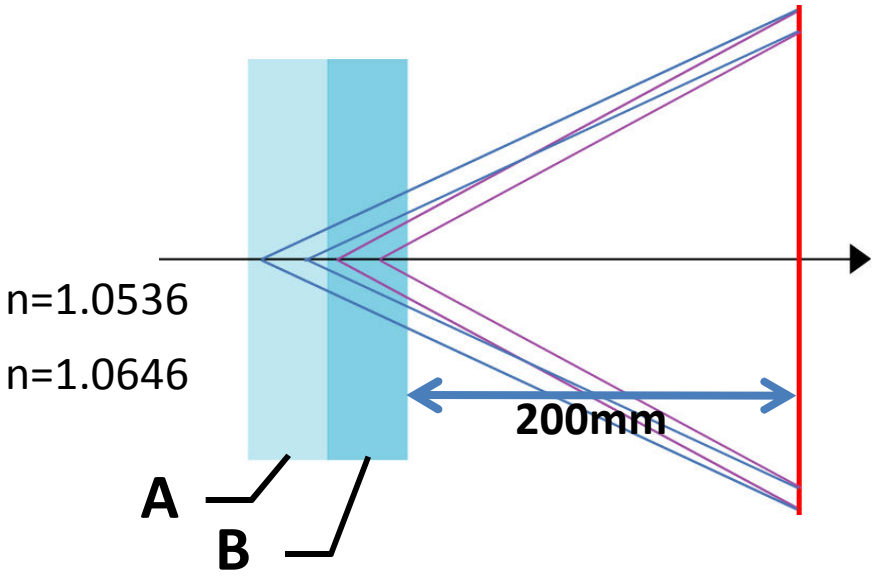


Ring image

Event display



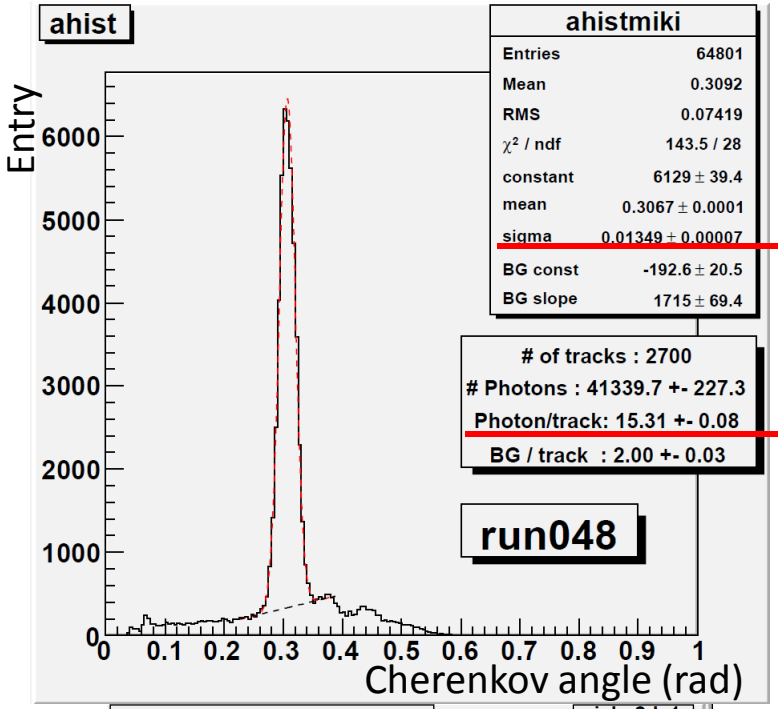
Focusing Type Aerogel

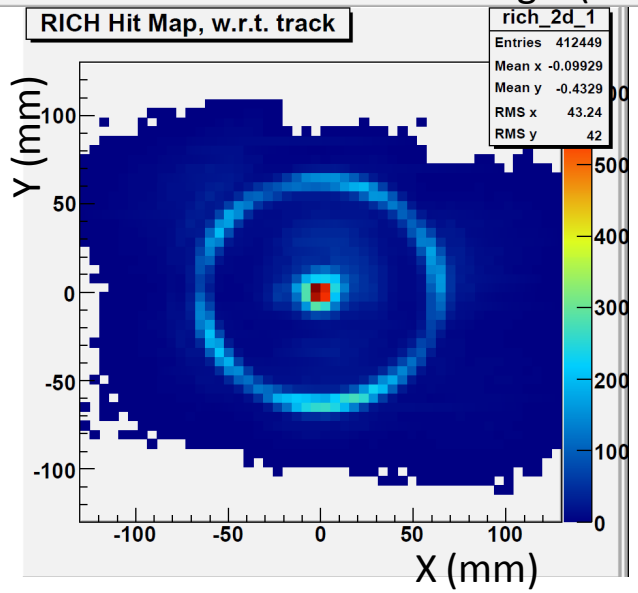


	Refractive index	thickness	Transmission length
A	1.0536	20mm	47.8mm
B	1.0646	20mm	55.4mm

See poster:M.Tabata "Status of Aerogel Radiator with High Refractive Indices" ID:263

Beam test result





Angler resolution=σ_0 13.5mrad

Number of photons/track=Npe 15.3p.e.

Angle resolution/track=σ_θ 3.5mrad

$$\sigma_\theta = \frac{\sigma_0}{\sqrt{Npe}}$$

K/π separation performance

6.6 σ at 4GeV/c

$$S = \frac{\theta_\pi - \theta_K}{\sigma\theta}$$

Aerogel RICH with HAPD has excellent K/π separation.

Summary

- We have developed a new 144ch multi-pixel HAPD
  + ASIC for the Belle II Aerogel-RICH
- The HAPD has
  - Good single photon sensitivity
  - High quantum efficiency(～30%)
  - Position resolution (5x5mm^2)
  - Immunity to magnetic field(1.5T)
- Neutron radiation damage is controllable(5x10^{11}).
- We have achieved Npe=15 σ_0 =13.5mrad with HAPD.

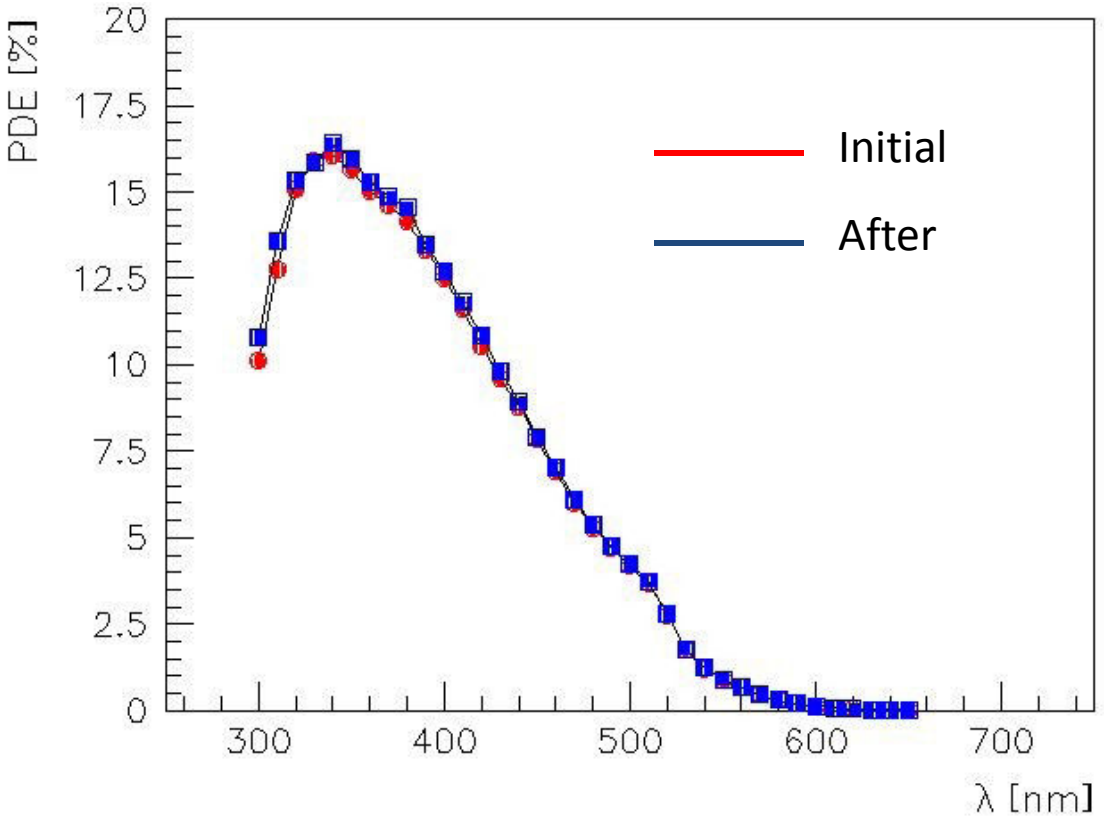
We have selected the new HAPD as the baseline photodetector for the Belle II Aerogel-RICH.

Thank You!

Back Up

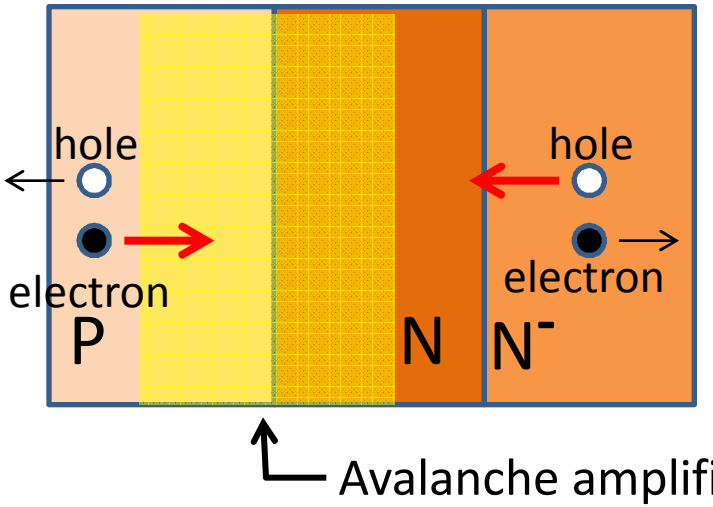
Aging tests

•comparison of initial Photon Detection Efficiency(PDE) and PDE after light irradiation(8years) show practically no change in performance



Improvement of leak current

Structure of APD

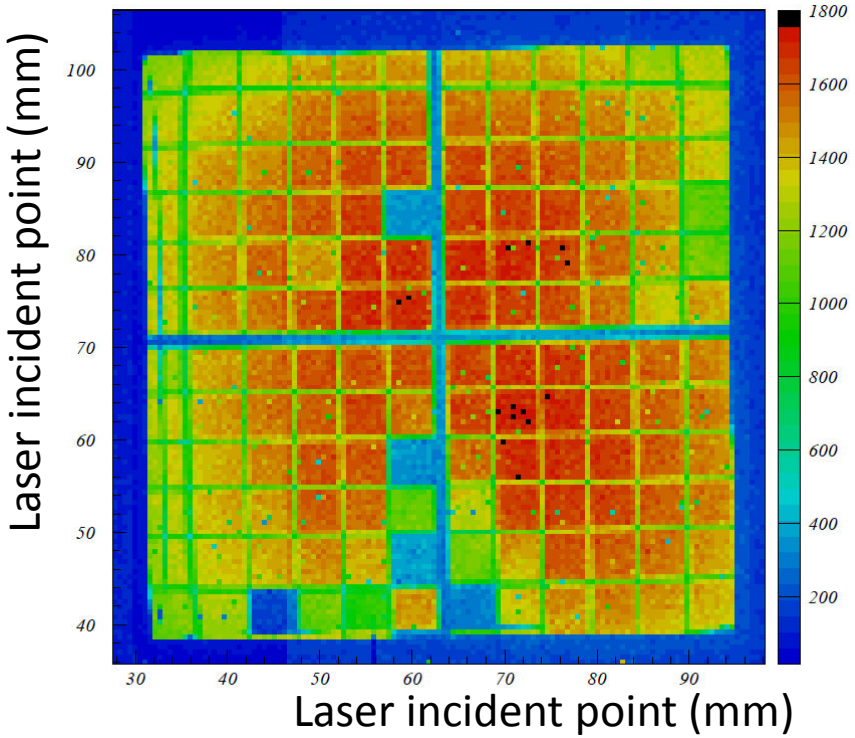


For n^- layer, Effect of holes making electron-hole pairs in the depletion layer is less than 1%, compare to electrons.

- Leak current from P layer contribute to increasing noise.
- We need reducing the thickness of P layer to decrease leak current.

Using thin APD reduce leak current.

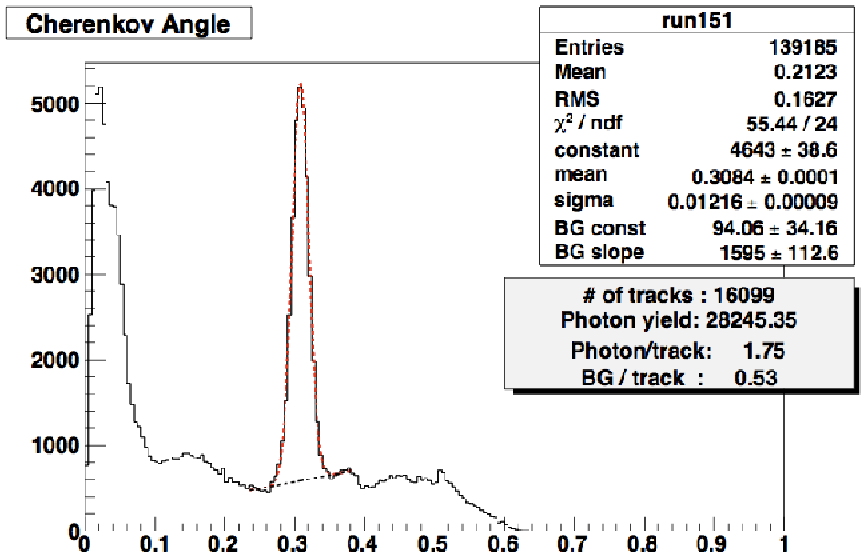
Surface scan



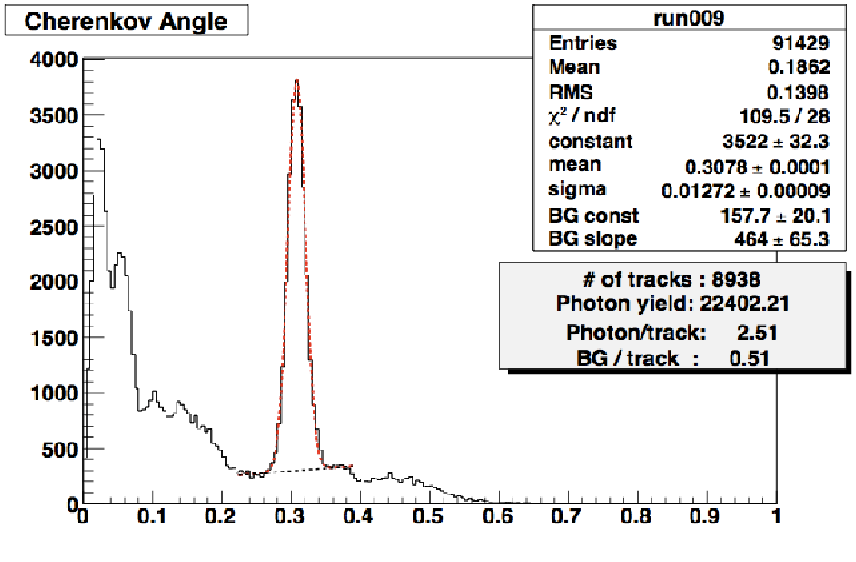
The HAPD response to surface scan shows the clear pixel shape and proves the good position detection performance.

Beam test with irradiated HAPDs

Irradiated HAPDs



Reference

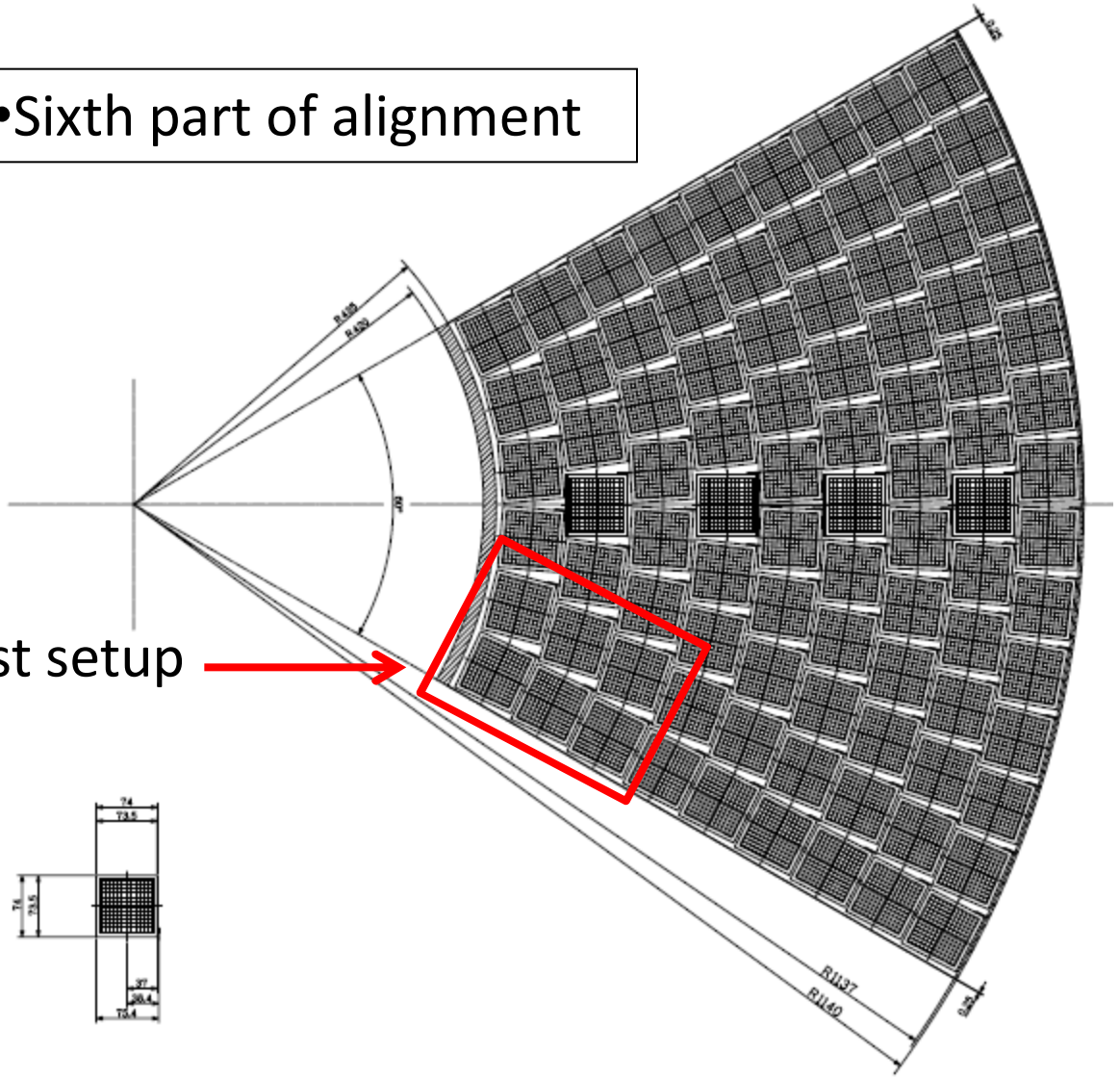


We could detect ring image with 2×10^{11} neutron/cm^2 irradiated HAPD.

Alignment of Aerogel RICH

- Sixth part of alignment

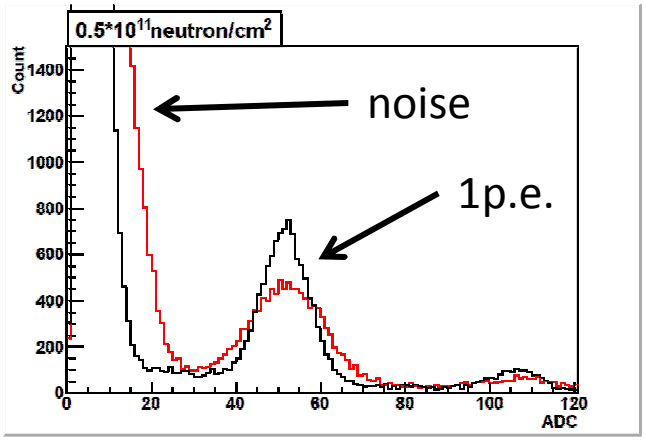
Use beam test setup

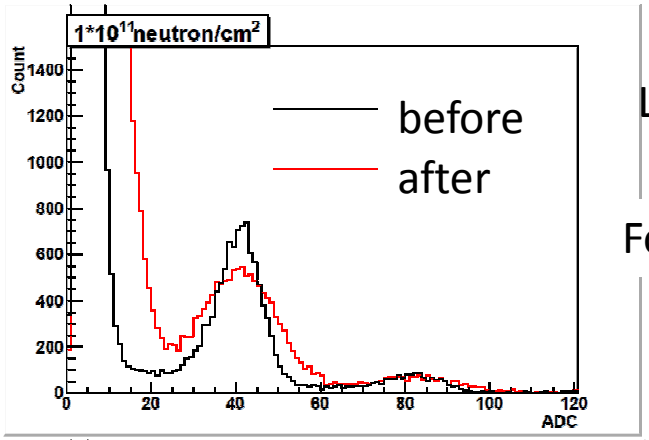


ADC distribution

Leak curret
1.2μA

For 0.5 years



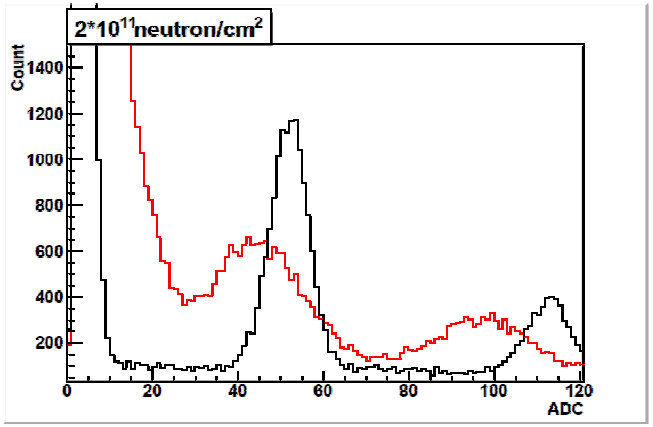


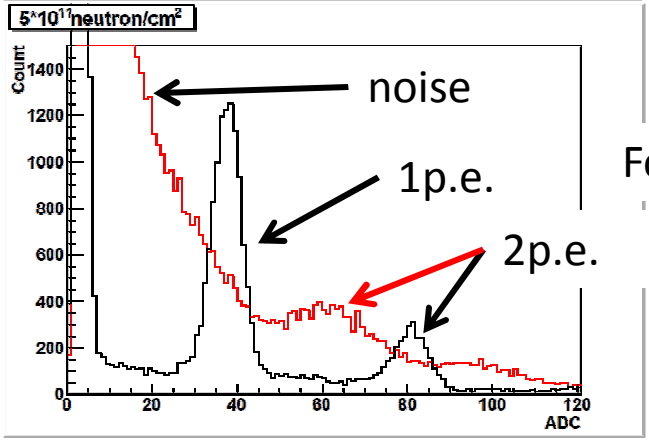
Leak current
2μA

For 1 year

Leak current
5μA

For 2 years





Leak current
13μA

For 5 years

Deterioration of sensitivity to single photon by irradiation damage