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

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KEK

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Belle II

Belle II Aerogel RICH Counter

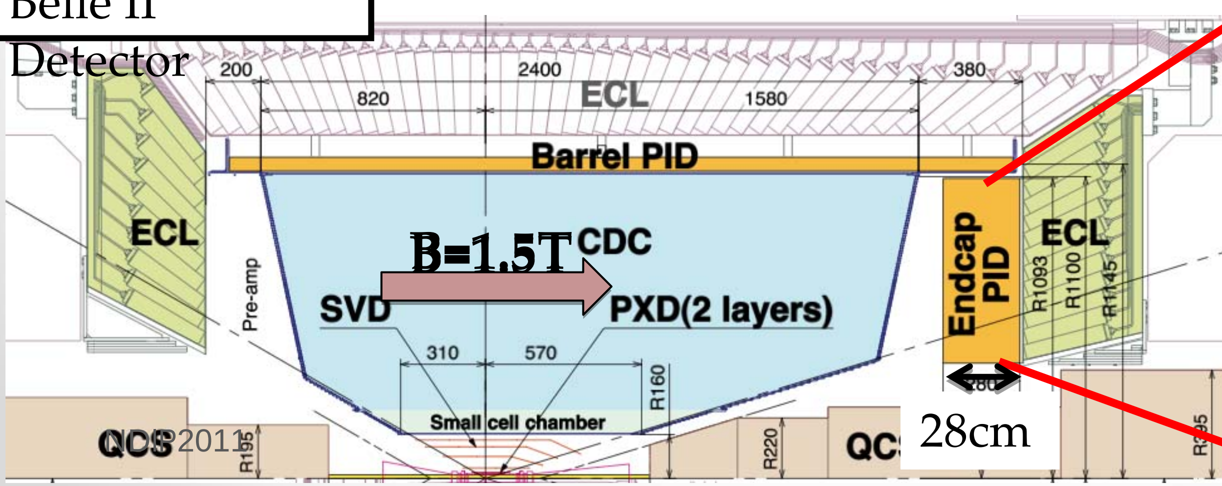
- Particle ID plays an essential role in B factory experiments.
  - o Especially K/π ID tells us flavor transition of b quark.
- **Belle II** → attack New Physics in flavor structure

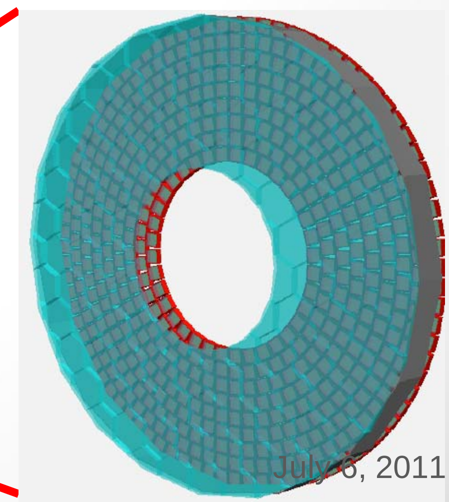
  Distinguish B→ππ from Kπ, B→ργ from $K^*\gamma$, etc. → PID up to 4GeV/c
- Upgrade of Belle endcap PID

  <2GeV/c by threshold-type aerogel Cherenkov counter

→ **Aerogel RICH counter**

Belle II Detector

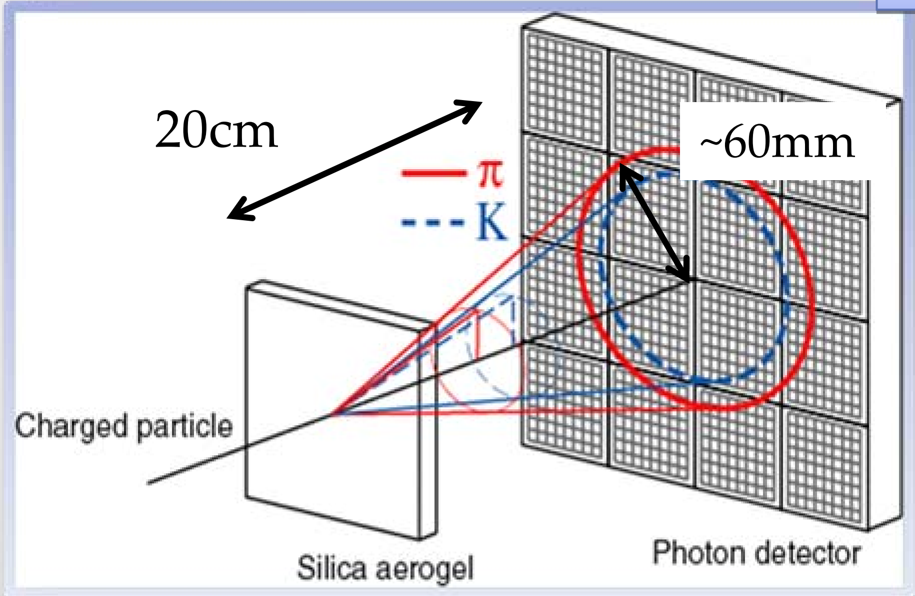




Concept of Belle II Aerogel RICH

- Proximity focusing RICH based on silica aerogel radiator

Target: <u>more than 4σ K/π separation at 4 GeV/c</u>



$\theta_c^{\pi} - \theta_c^{K} \sim 23$mrad (n=1.05)@4GeV/c
→ angle resolution: $\sigma_\theta/\sqrt{N_{p.e.}} < 6$mrad

Essential components

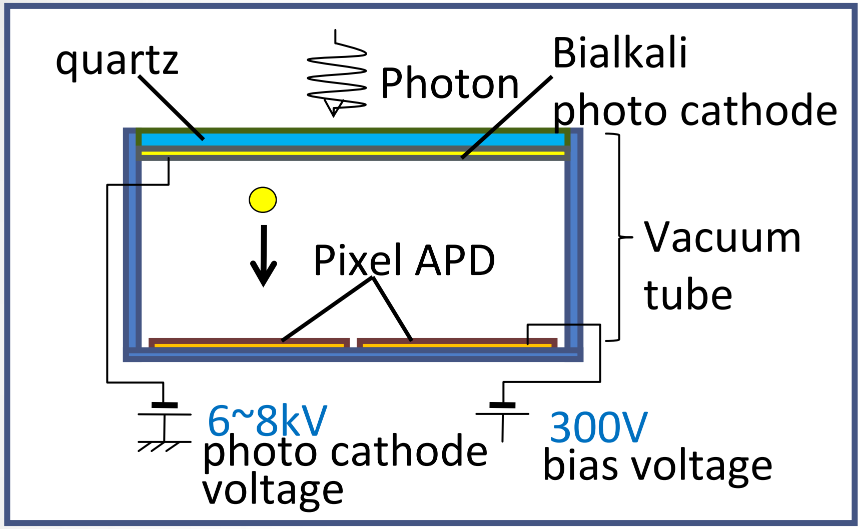
Silica Aerogel
Refractive index ~1.05
Highly Transparent

Photodetector : 144ch HAPD
Large sensitive area
High sensitivity to single photon
Position resolution of 5x5 mm^2
Immunity to high magnetic field (1.5T)

Readout electronics
Readout 10^5 channels at once
→ **Development of dedicated ASIC**

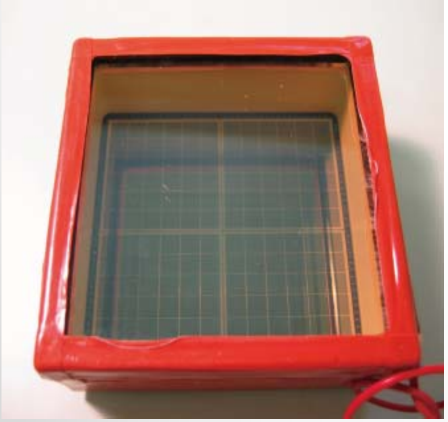
144ch Hybrid Avalanche Photo Detector

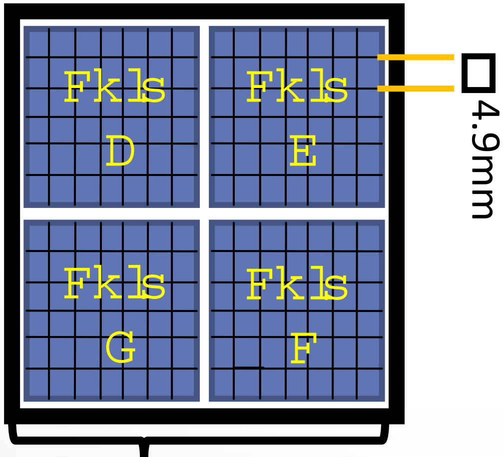
- We have been developing a new 144ch Hybrid Avalanche Photo Detector (HAPD) with Hamamatsu Photonics since 2002.

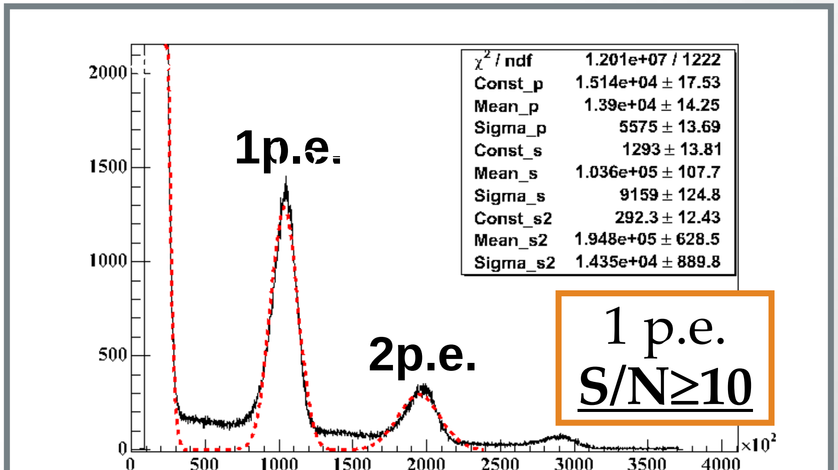


Specification

Peak QE	**32%**
Effective area ratio	**64%**
Capacitance	80pF
Bombarding gain	1300 ~ 1800
Avalanche gain	~50
Total gain	**10^4 ~ 10^5**



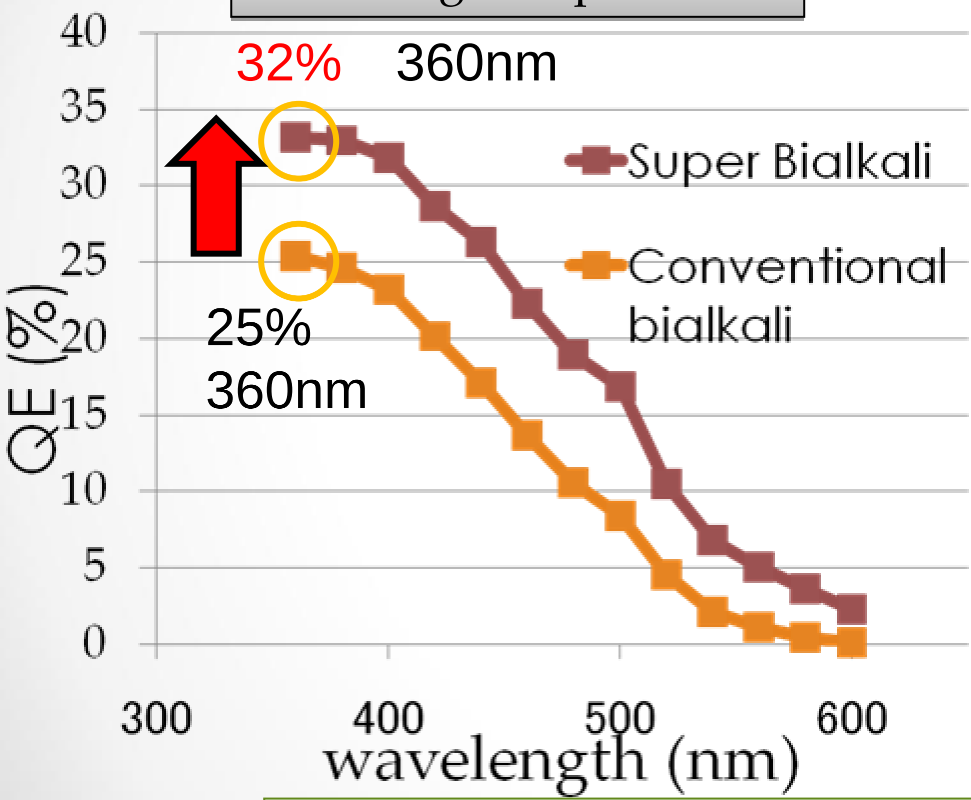




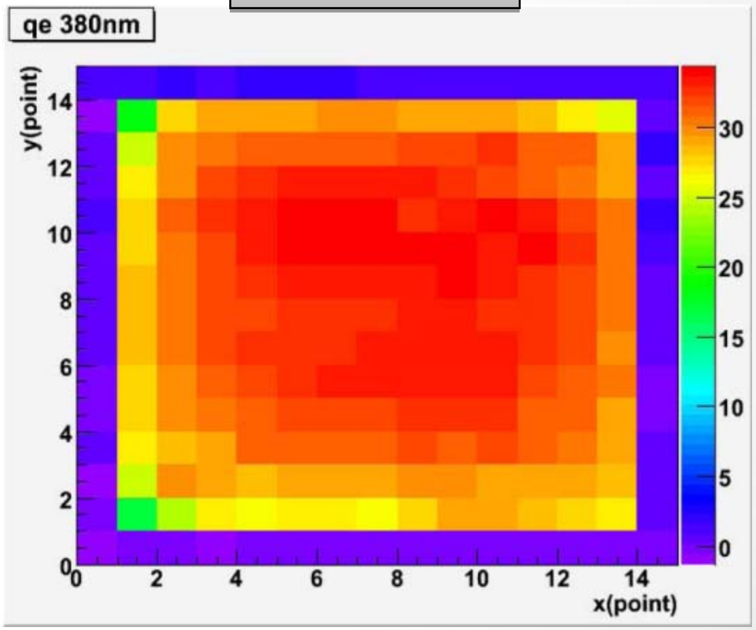
Quantum Efficiency

HAPD QE has been greatly improved with "super bialkali" technology by Hamamatsu.

Wavelength dependence



Uniformity



Good uniformity

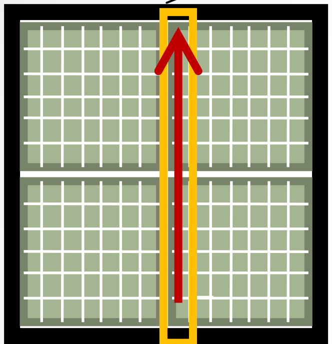
Peak QE ~32% has been achieved

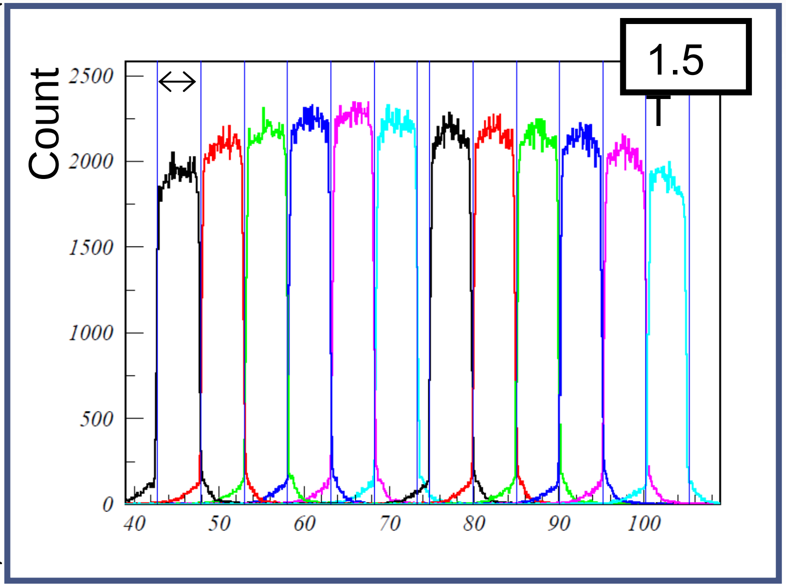
(bialkali average : 25%)

HAPD Performance in B=1.5 T

one row scan

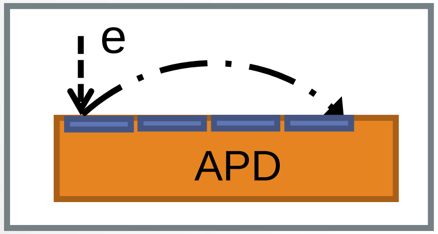
B=1.5T ⊗



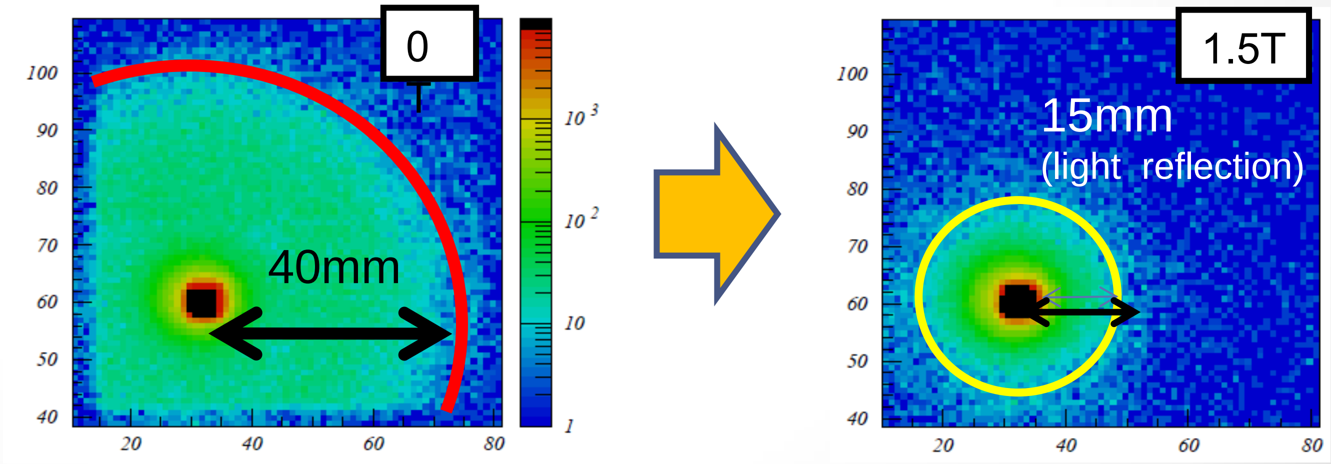


confirmed 5mm resolution

Measured with "Ushiwaka" magnet at KEK



Reduction of backscattering effect

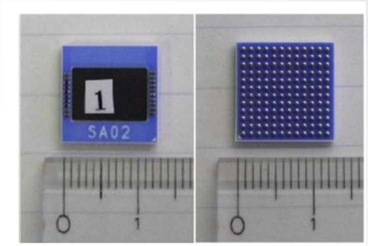


We have confirmed HAPD achieves 5mm position resolution and has improved performance in 1.5T.

ASIC for Readout of 144ch HAPD

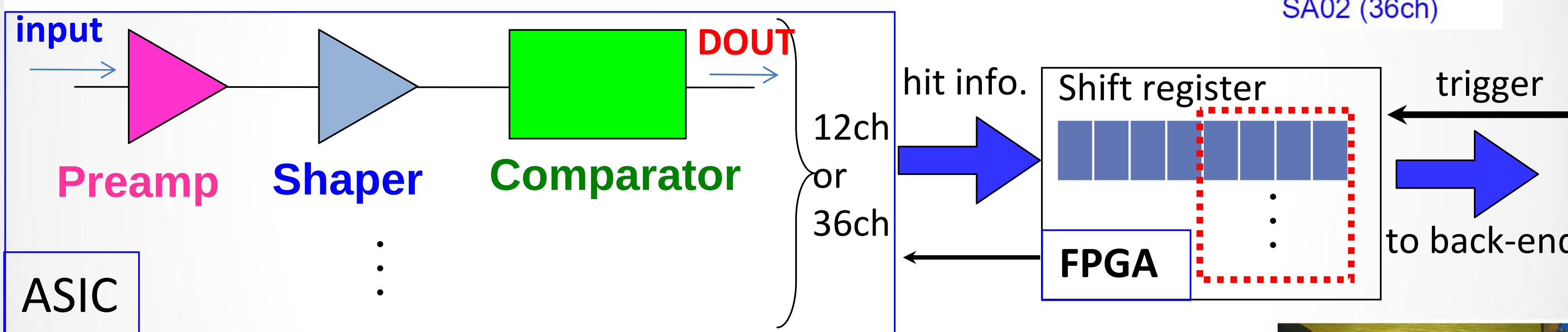
We need high density front-end electronics including high-gain and low-noise amplifier for A-RICH.

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

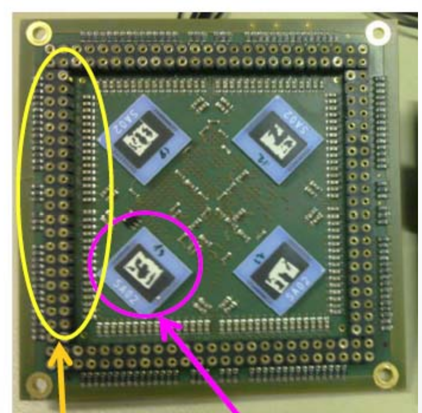


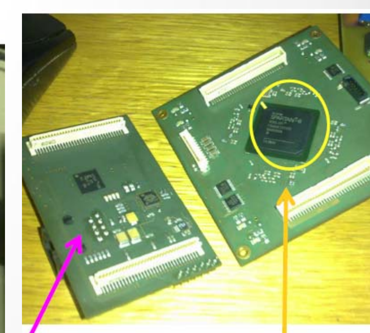
SA02 (36ch)

Circuit configuration (SA series)



- 4 step variable gain preamplifier.
- 4 step variable shaping time shaper. (250-1000ns)
- Comparator for the digitization of analog-signals.
  (We need **only on/off hit information**)
- We have developed new ASIC SA01(12ch)
  and SA02 (36ch).

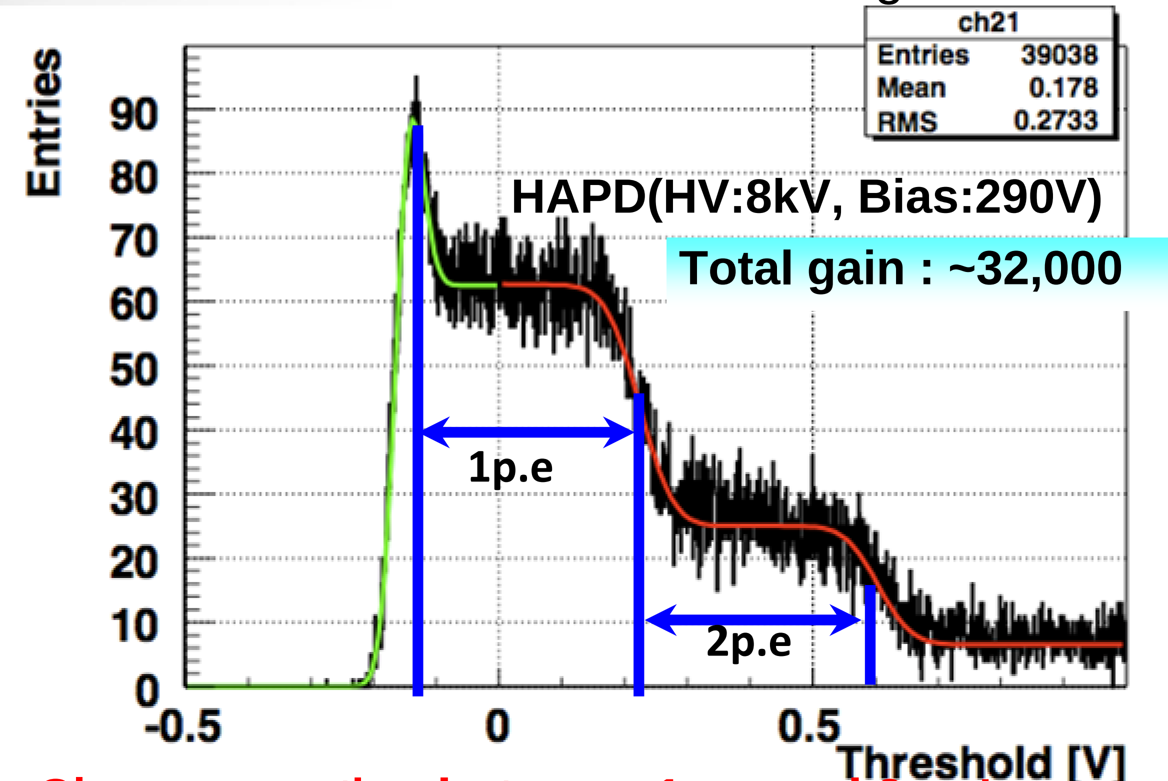


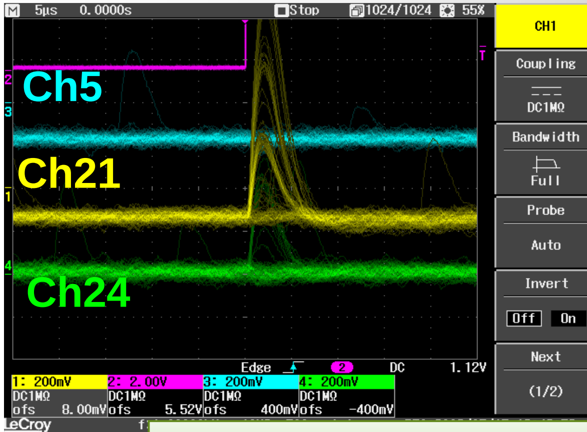


Readout test of HAPD with ASIC

Threshold scan result (SA01)

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





Analog monitor output

Result

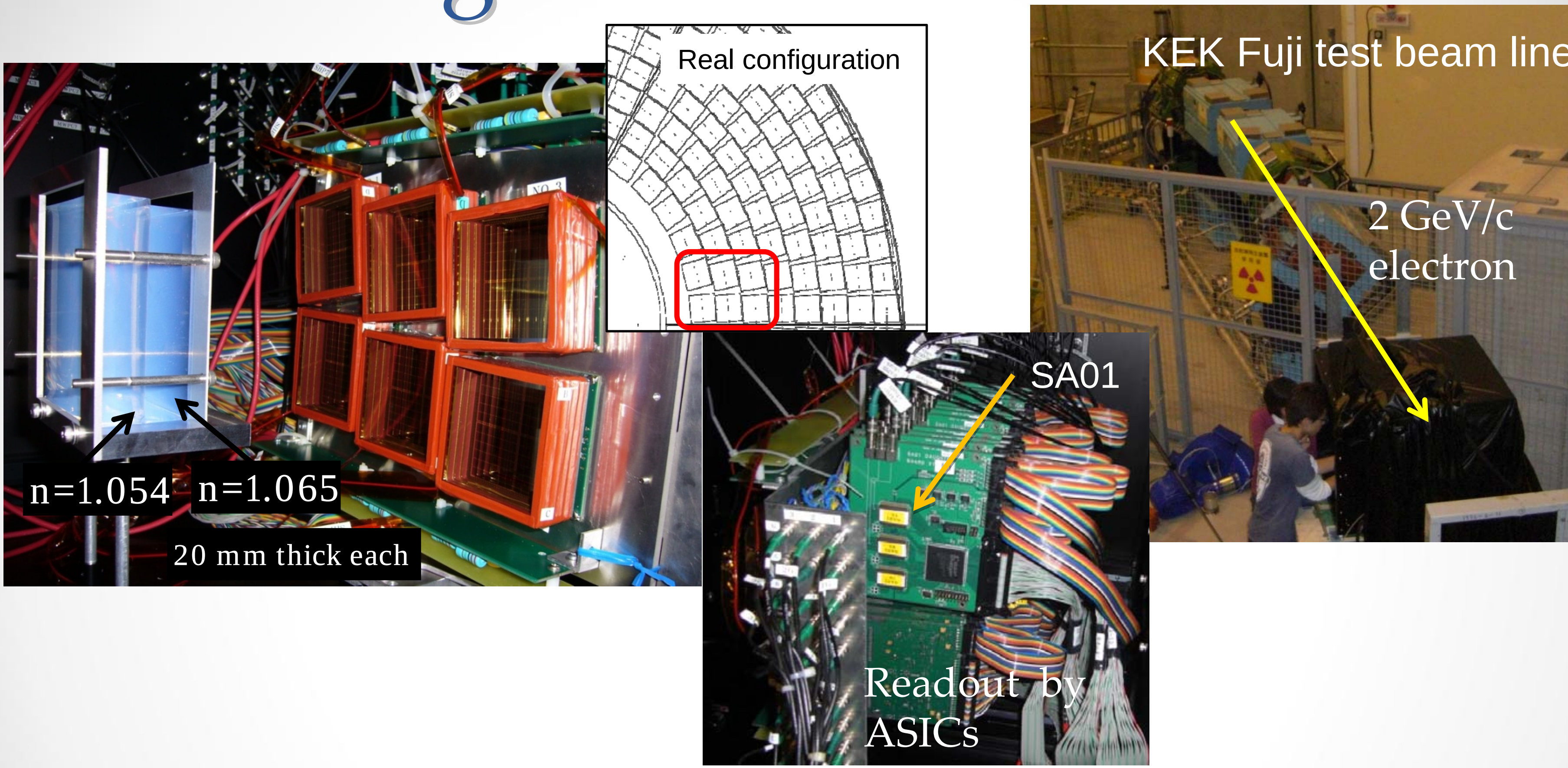
- Noise : ~2,000e$^-$
- Pulse height
  - 1p.e signal : 32,700e$^-$
  - 2p.e signal : 66,200e$^-$

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 has been confirmed.

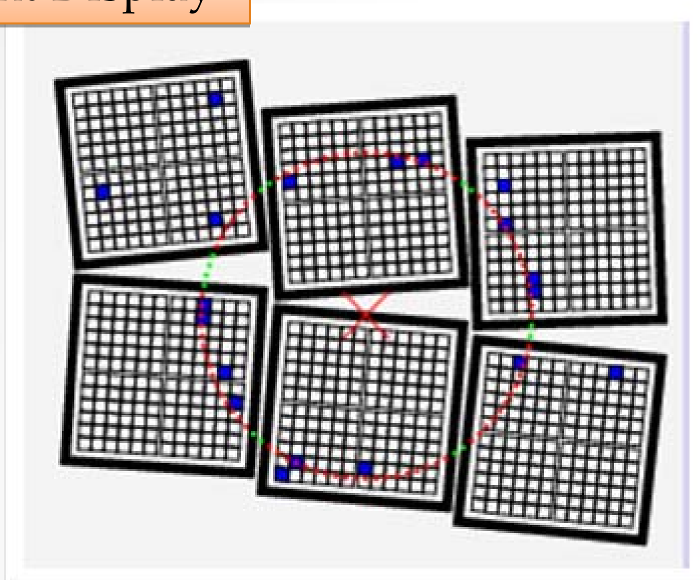
Aerogel RICH Beam Test



- Performed at Fuji test beam line in KEK November 2009.
- 6 HAPDs from recent batches (max QE 30%, avg. QE 24% @400nm).
- Aerogel radiators with improved transparency are used.
  - Transmission length@400nm > 45mm
- Track parameters are measured by two MWPCs.

Beam Test Result

Event Display



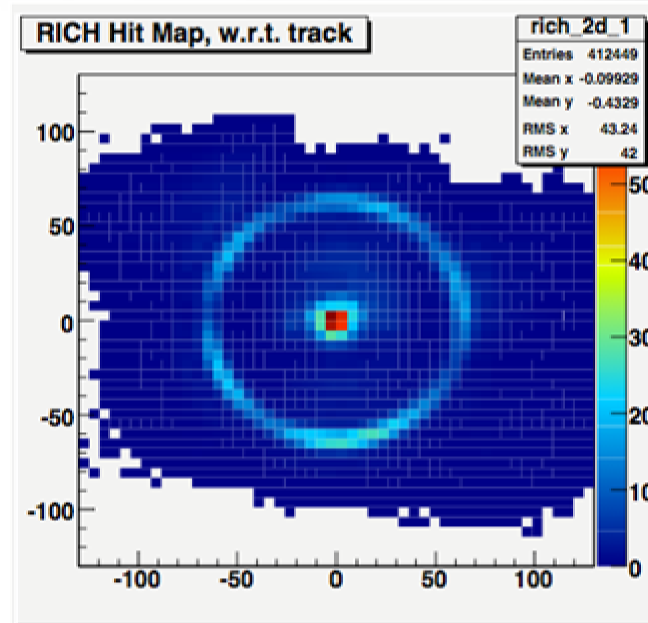
Clear ring image observed

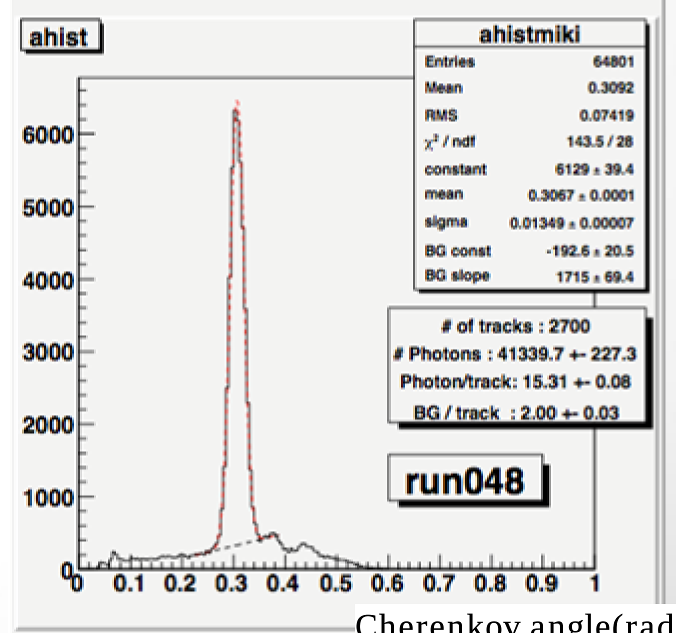
Cherenkov angle resolution: σ = 13.5 mrad

# of photoelectrons: 15.3

From naive calculation

6.6 σ K/π separation at 4 GeV/c achieved





Performance of RICH with HAPD

- **New 144ch HAPD**
  - Large effective area.
  - High sensitivity to single photon
  - Position resolution($5\times5mm^2$)
  - Immunity to 1.5 T magnetic field
- **Silica aerogel by new method**
  - Highly Transparent
- **Readout ASICs**

→ The prototype RICH using HAPD achieved enough performance for Belle II.

Remaining concern：
Radiation tolerance of HAPD in Belle II

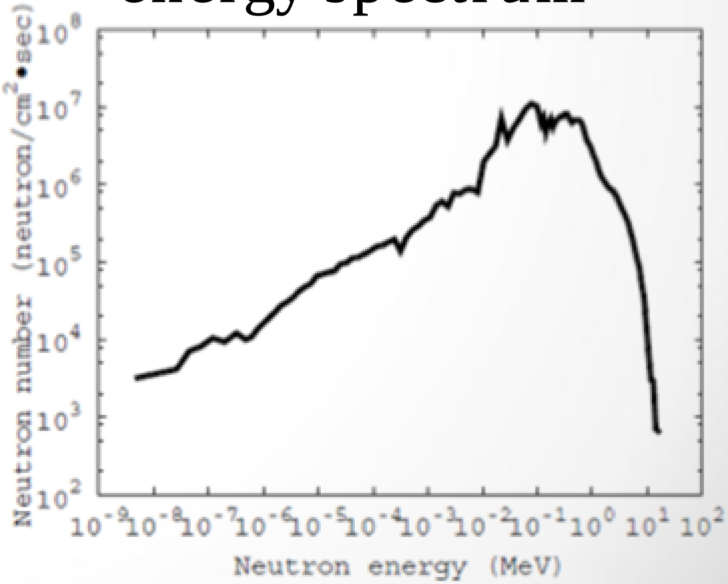
Neutron Irradiation Test of HAPDs

- Neutron damage of APDs is the most significant concern.
- In Belle II 1 year, 10^{11} n / cm^2 is expected
  → target: Belle II 10 years, 10^{12} n /cm^2
- Neutron irradiation tests are performed using reactor "Yayoi".

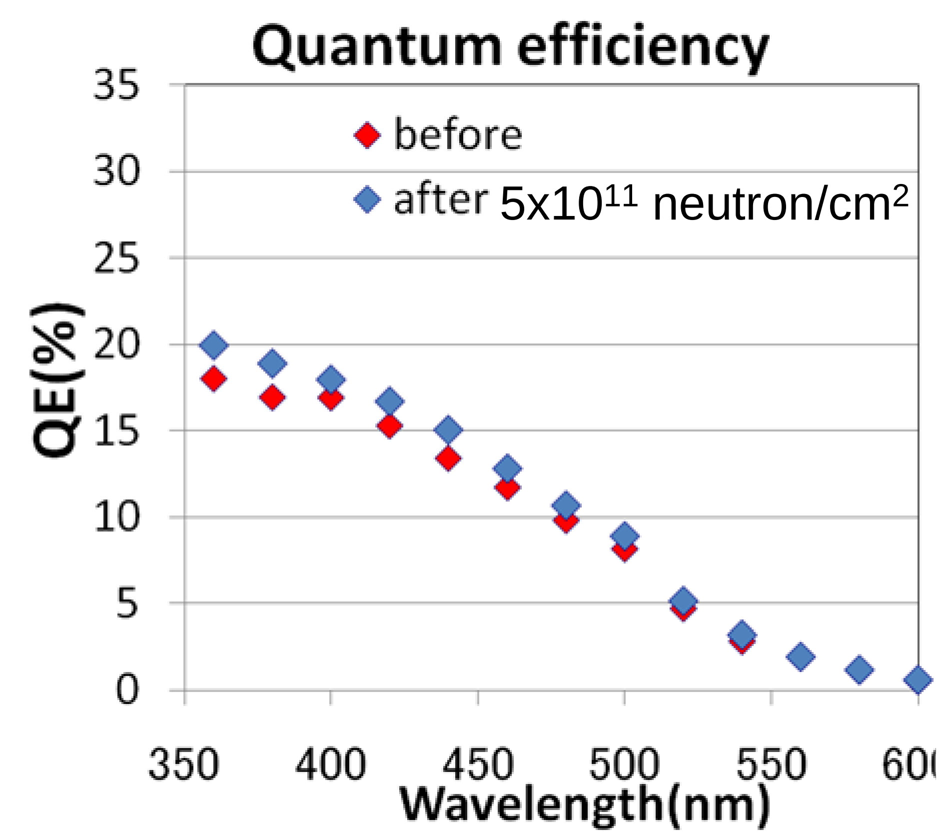
Reactor "Yayoi" of Tokyo Univ.

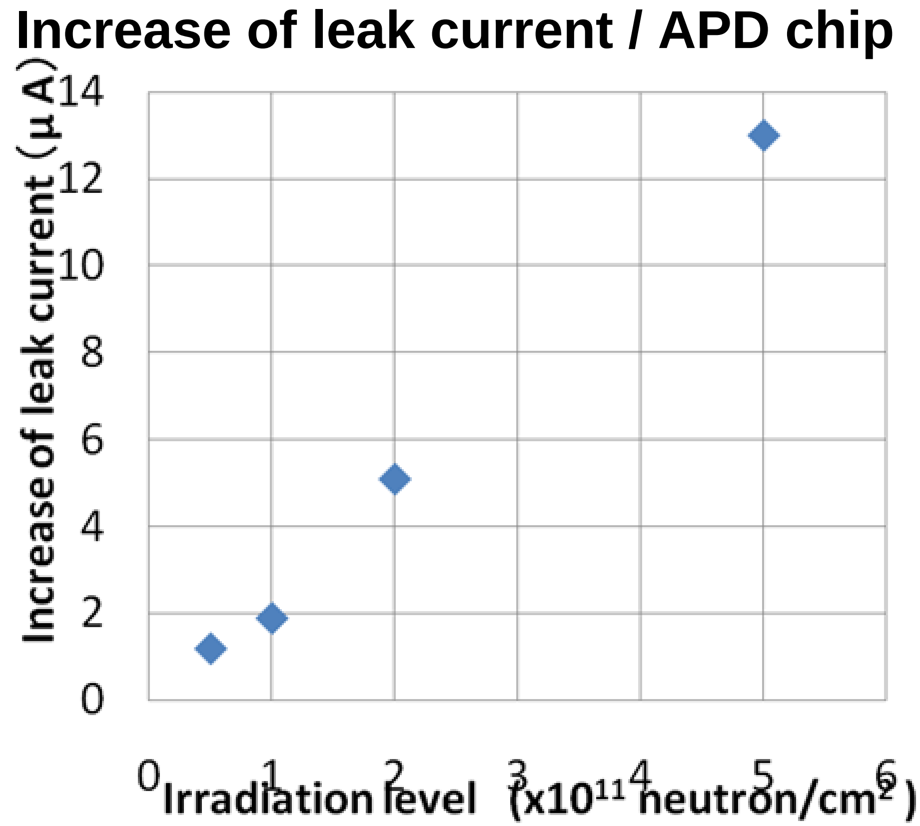
Flux: 2×10^8 neutrons/cm^2/sec at W=500W
Average energy: 370keV

energy spectrum



Influence of Neutron Irradiation

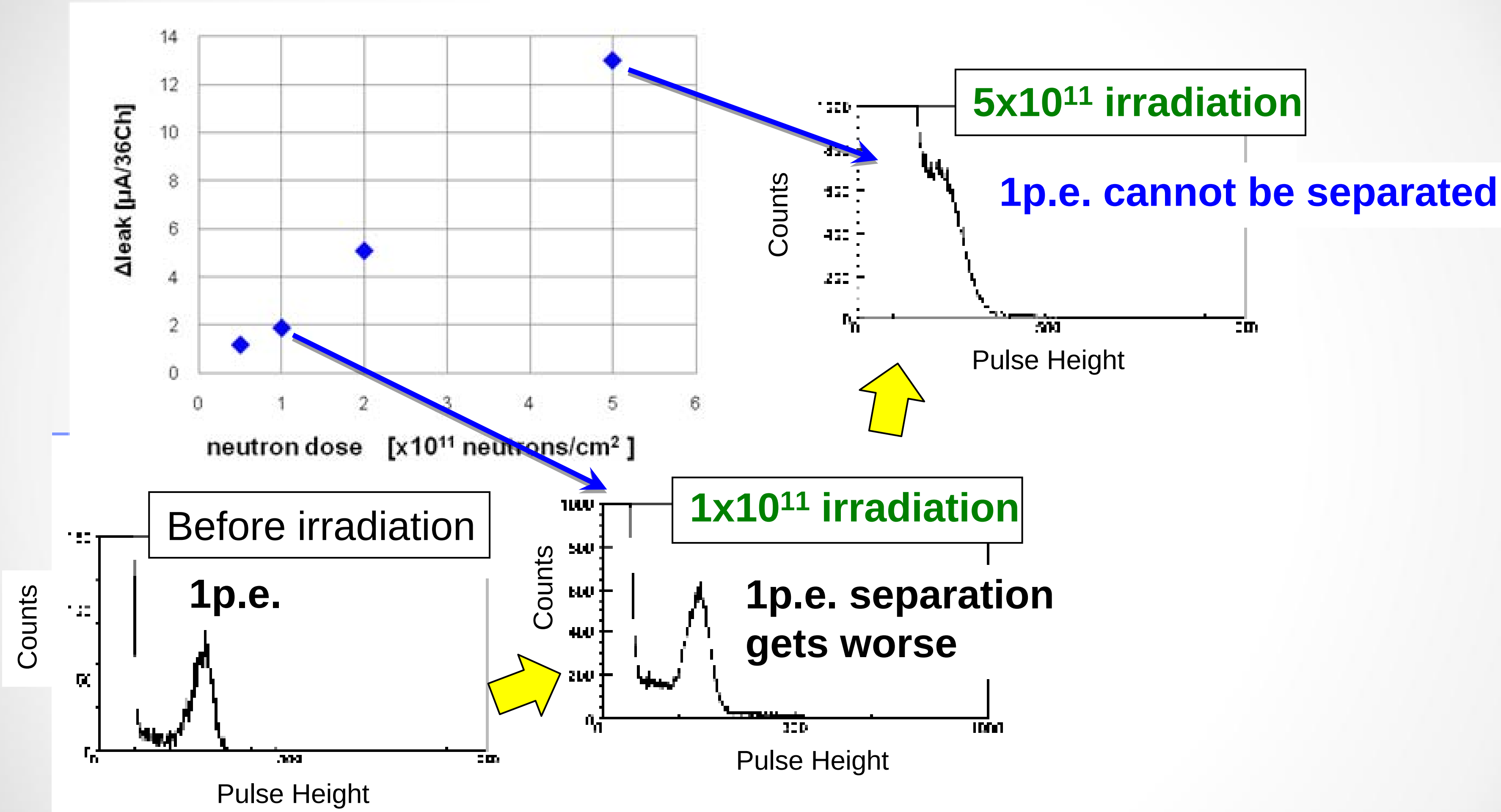




No degradation in QE

Increase of leakage current in APD

Increase of Noise by I_{leak}



Noise from increased I_{leak} must be reduced to keep 1 p.e. detection capability.

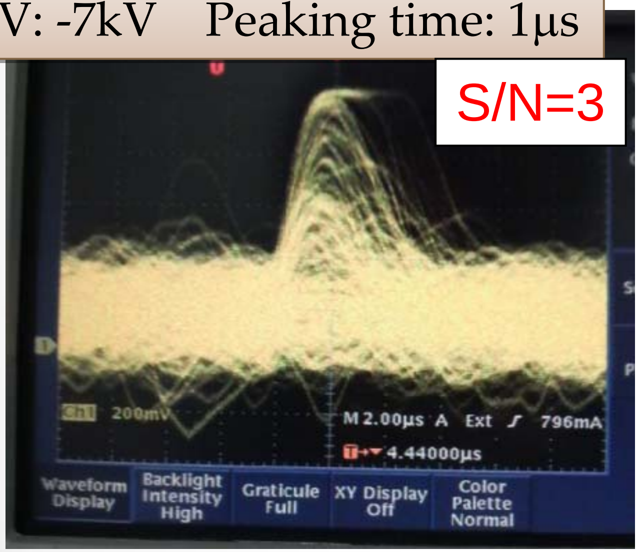
ASIC and HV Optimization

Shot noise by leakage current $\propto \sqrt{I_{leak}\,\tau_{peak}}$

Improvement

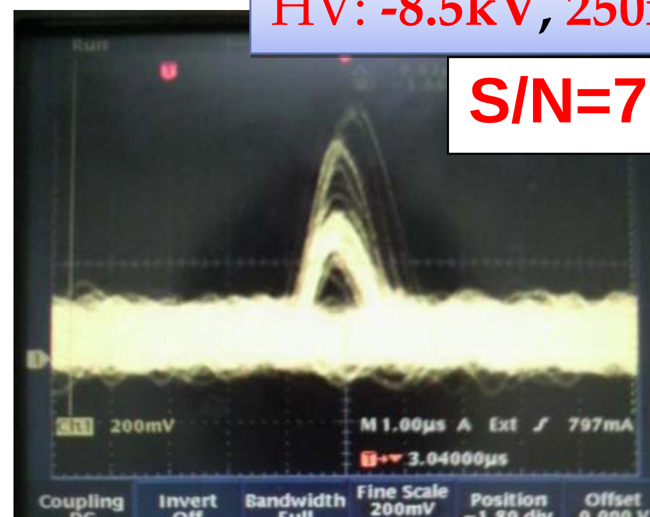
- **Shorter peaking time**
- **Increase HV (bombarding gain)**

5x10^{11} n/cm^2
HV: -7kV   Peaking time: 1μs



S/N=3

HV: -8.5kV, 250ns



S/N=7

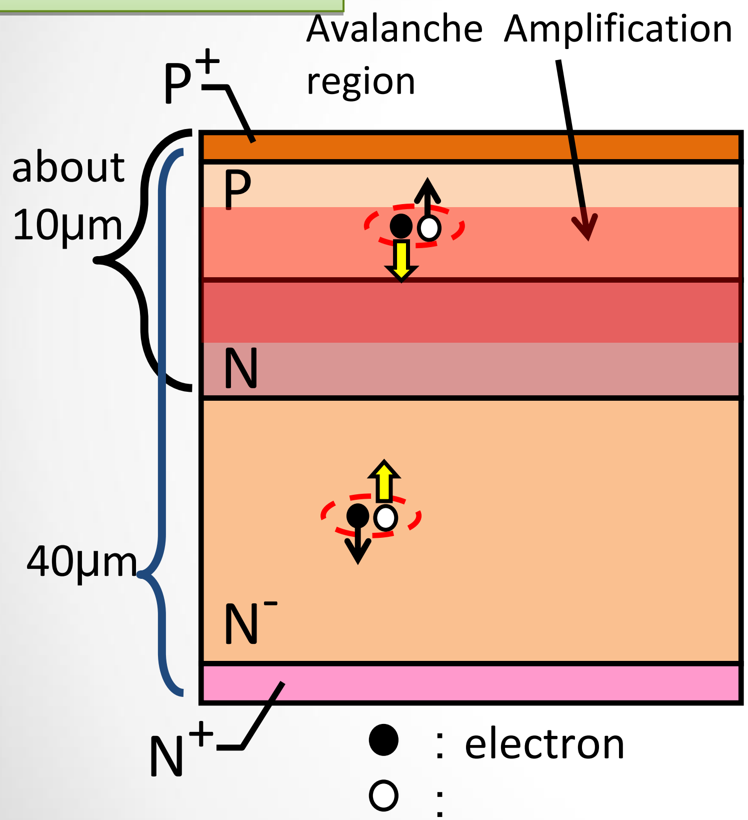
1/4 τ→ **0.5 x noise**
Bombarding gain 1300 → 1700,**1.3 x signal**

Achieved enough S/N=7 after 5x10^{11} n/cm^2(Belle II 5 years)

More Improvement for Belle II 10 years

5×10^{11} n/cm^2 S/N=7 has been achieved
1×10^{12} n/cm^2 expect S/N ~ 5 → **need more improvement**

APD structure



Shorter peaking time
→ new readout ASIC (SA03) with τ_{peak}=100ns (current:250ns)

More bombarding gain
→ APD with thinner P^+ layer

under development

Reduction of I_{leak}

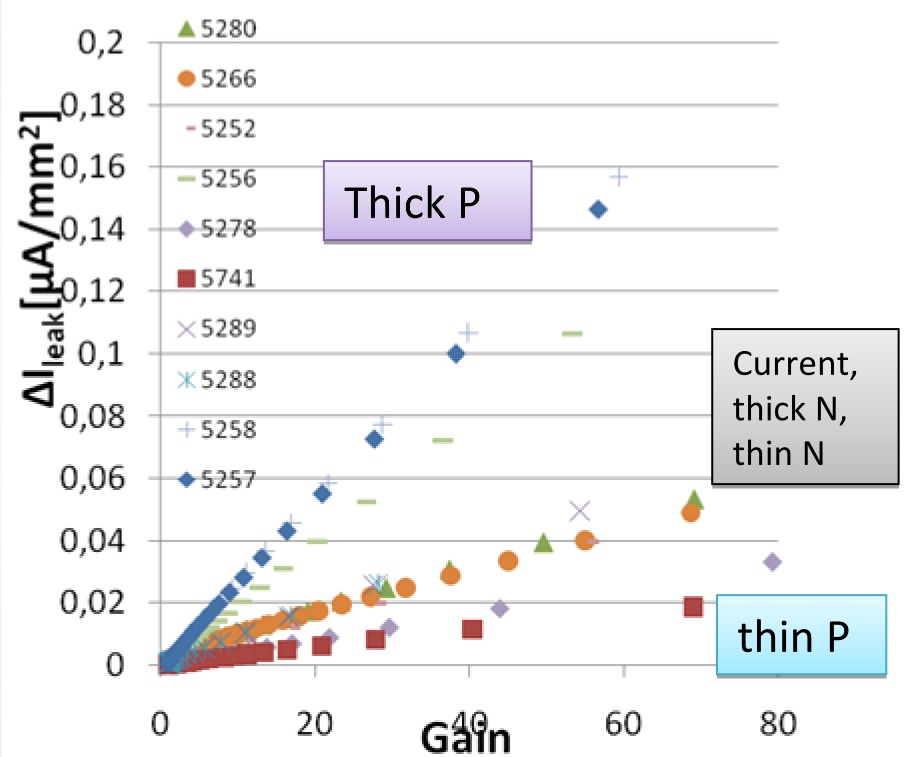
- Make thinner APD to reduce neutron induced lattice deficits
- Contribution of N-layer (hole) is about 1/100 of that of P-layer (e).

→ Thinner P layer

APD samples with various thickness of P and N layers are irradiated in 2010 Jan and June at

APD Neutron Irradiation Test Results

APD Δ leakage current ($10^{12}n/cm^2$)

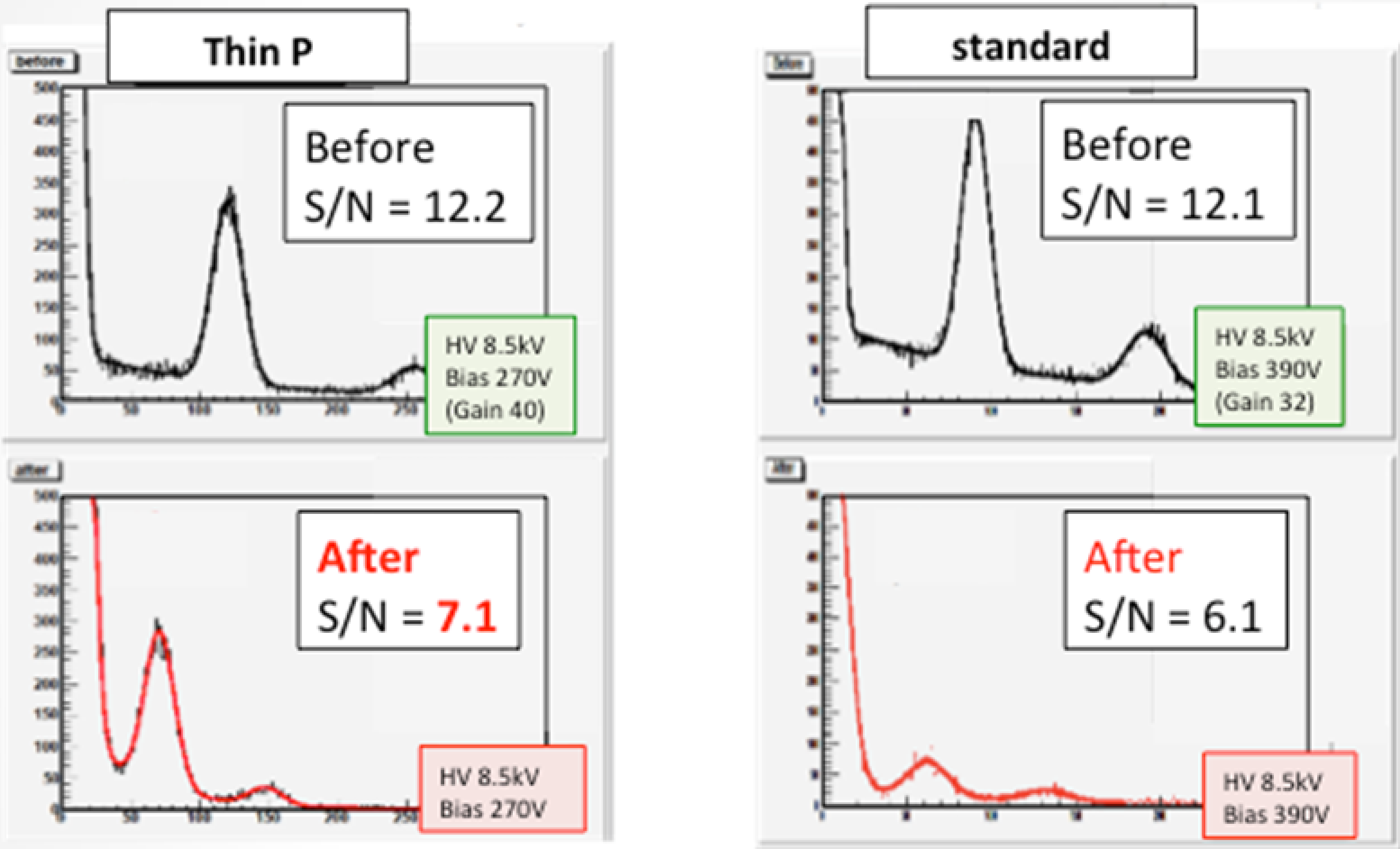


- Increase of I_{leak} depends on thickness of P layer
- No dependence on N layer thickness

Confirmed I_{leak} reduction by thinner P layer

→New HAPD sample with thinner-P APDs is produced and irradiated in 2010 Nov.

Thin-P HAPD Irradiation Test Result



Better S/N of HAPD with thin-P than the standard has been confirmed.

Conclusions

- New 144ch HAPD has been developed for Belle II Aerogel RICH counter.
  - Large sensitive area
  - High sensitivity to single photon
  - Position resolution of 5x5 mm^2
  - Immunity to high magnetic field (1.5T)

- Excellent PID performance of RICH with HAPD has been confirmed.

  → More than 5σ K/π separation demonstrated from test beam experiment.

- Remaining concern: Radiation tolerance of HAPD
  - Neutron damage manageable up to 5×10^{11} n/cm^2
  - It is confirmed that HAPD with thinner-P APD reduces neutron induced damage.

Future Plan

- Further studies of HAPDs for radiation hardness.
  - Gamma ray irradiation is under study.

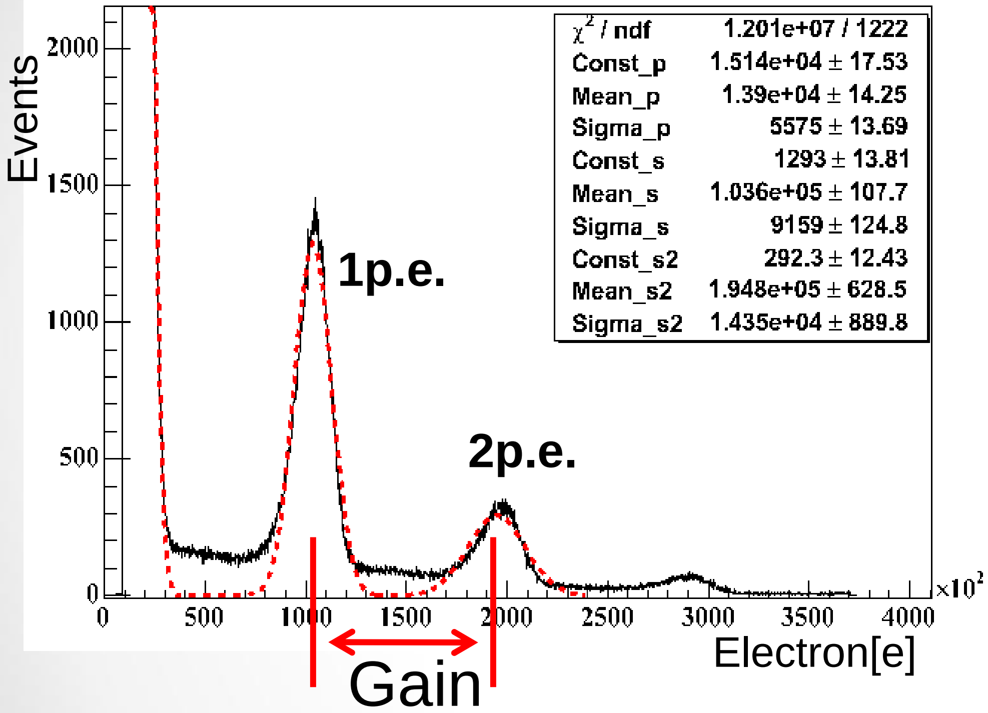
- Prototype Aerogel RICH test with hadron beam is scheduled in September, 2011 @CERN (SPS).

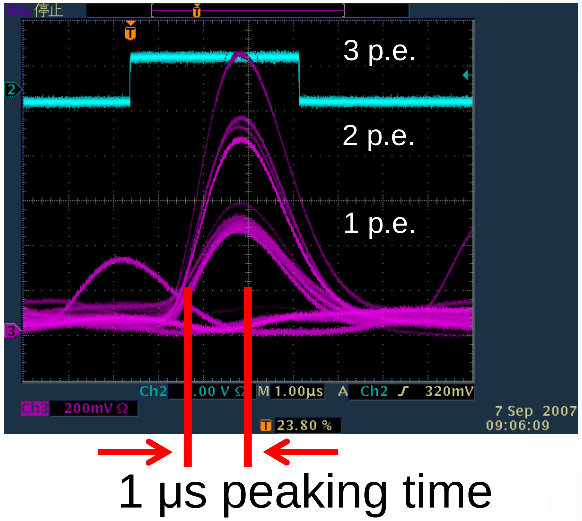
- Fix specification of HAPD and prepare for HAPD mass production.

backup

Single photon Response

Pulse height distribution for Single photon irradiation





Preamp.: Clear Pulse 580K

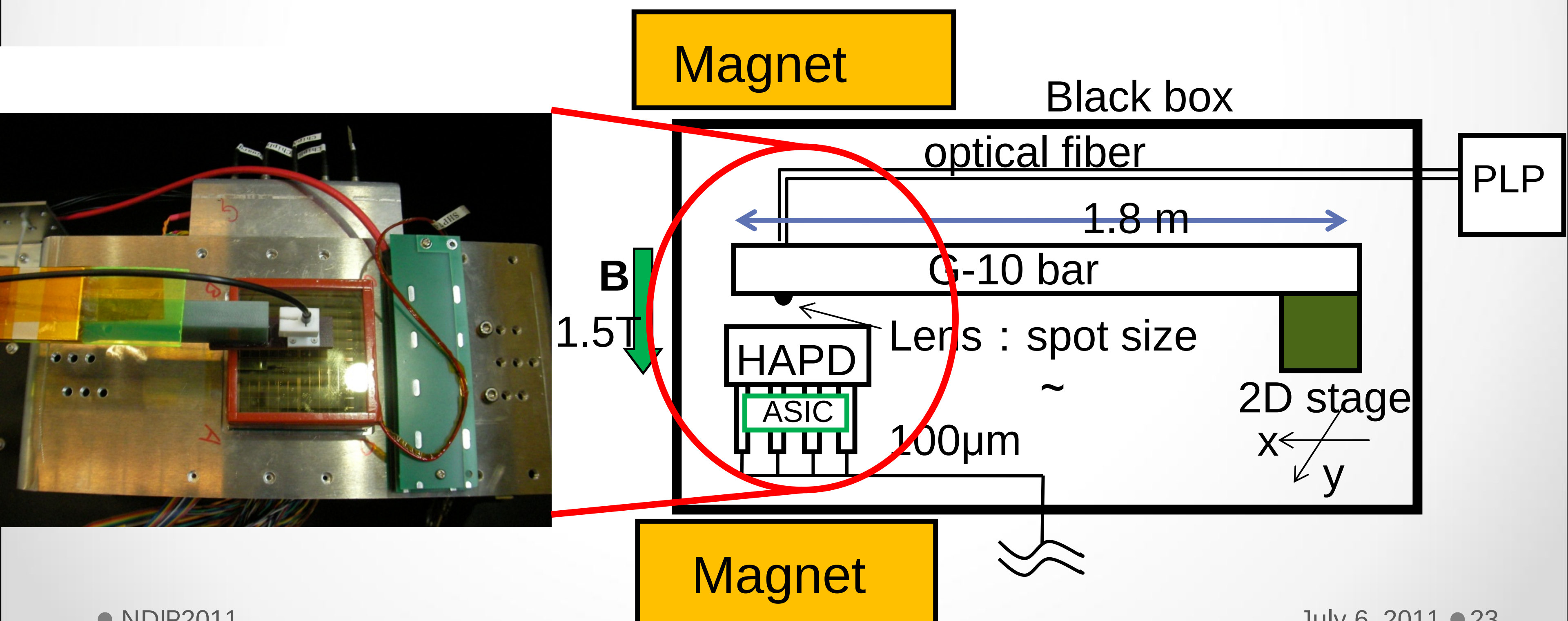
Shaping amp.: Clear Pulse 417

$$S / N = \frac{Gain}{\sigma_{1p.e.}} \geq 10$$

144ch HAPD has excellent single photon detection performance

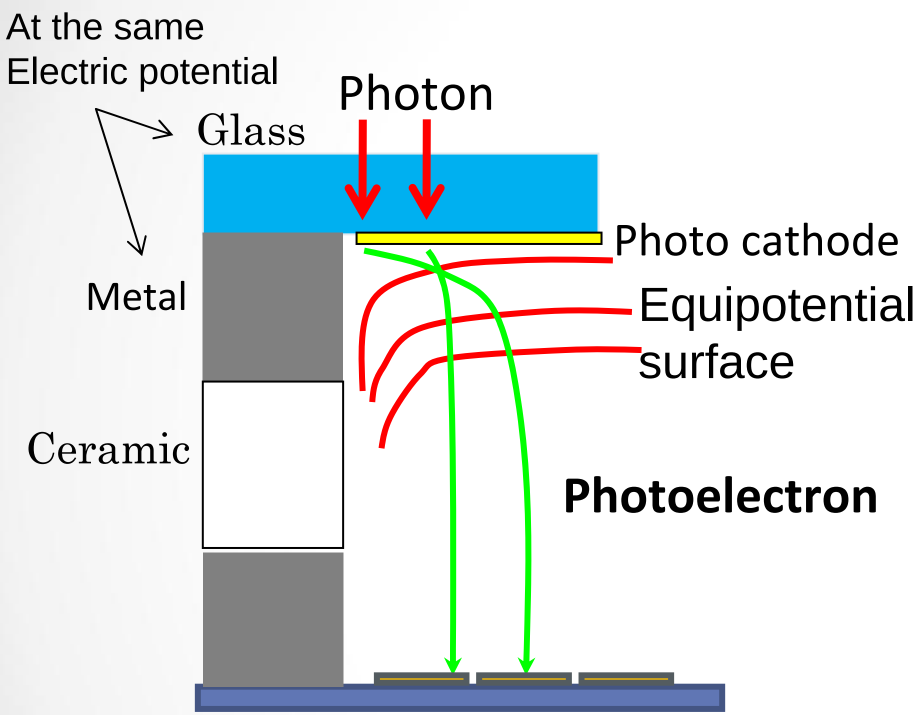
Test in magnetic field

Performance of HAPD in the 1.5T magnetic field is measured using a special equipment to scan the HAPD surface with pulse laser.



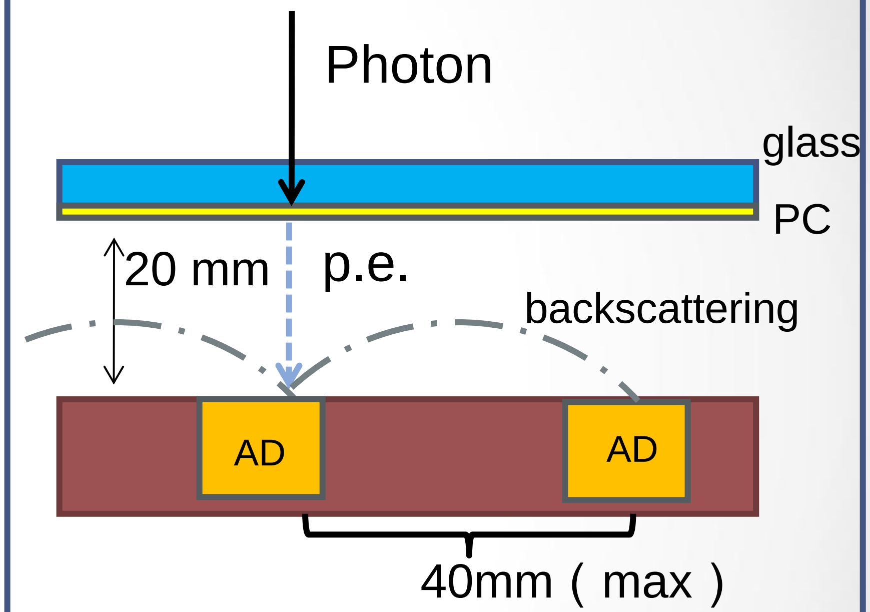
Effect of magnetic field

Image Distortion effect by side wall



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

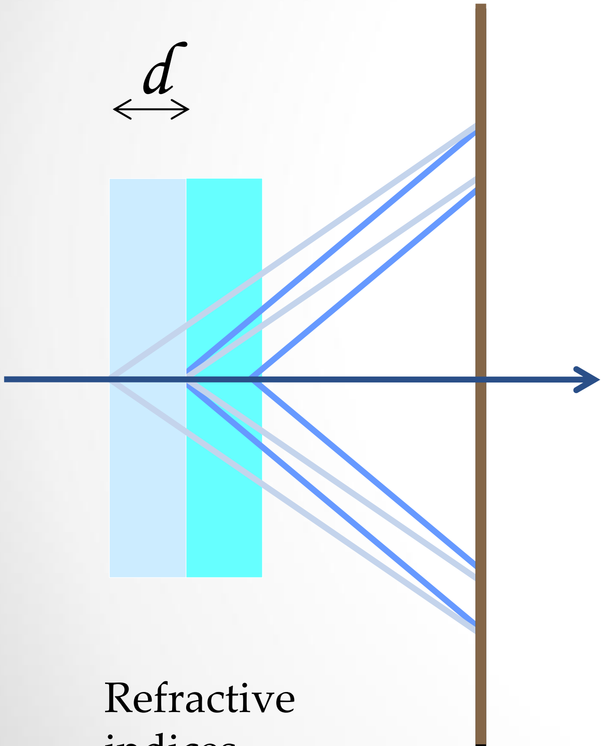
Photoelectron backscattering



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

HAPD performance is expected to be improved in a magnetic field.

Dual-layer Focusing Scheme



- Cherenkov angle resolution of proximity focusing RICH:

  $\sigma_{gel} / \sqrt{N_{p.e.}} \propto \sqrt{d}$

  → Limited by radiator thickness.

  - Increase effective thickness without degrading the angle resolution

    → **Focusing scheme**

    [T. Iijima, et al. NIMA 548,383 (2005)]

  - Transmittance of **larger n (>1.05)** is very important.

    → **Highly transparent aerogels** have been produced by new method.

    [M. Tabata et al. Conf. Rec. IEEE NSS 2005, 816; NIM A623, 339 (2010)]