Study of 144 Channel Multi-Anode Hybrid Avalanche Photo-Detector for the Belle II RICH Counter

Ichiro Adachi

KEK

2010.05.05

Outline of this talk

- Introduction
  - Belle II RICH Counters
  - Aerogel RICH
  - Hybrid Avalanche Photo-Detector
- Bench Test
  - Single Photon Response
  - Operation under a Magnetic Field
- Neutron Radiation Damage
- Beam Test Results
- Conclusions

Belle II Aerogel RICH R&D Group

I.Adachi, R.Dolenec, K.Hara, T.Iijima, M.Imamura, S.Iwata,

H.Kawai, S.Korpar, P.Krizan, T.Kumita, E.Kuroda, S.Nishida, S.Ogawa,

R.Pestotnik, S.Shiizuka, T.Sumiyoshi, M.Tabata, S.Tagai, R.Verheyden

IPNS, KEK, Tsukuba, Japan
J.Stefan Institute, Ljubljana, Slovenia
Dept. of Physics, Nagoya Univ., Nagoya, Japan
Dept. of Physics, Chiba Univ., Chiba, Japan
Dept. of Physics, Toho Univ., Funabashi, Japan
Faculty of Chemistry and Chemical Engineering, Univ. of Maribor, Maribor, Slovenia
Faculty of Mathematics and Physics, Univ. of Ljubljana, Ljubljana, Slovenia
Dept. of Physics, Tokyo Metropolitan Univ., Hachioji, Japan

Belle II RICH Counters

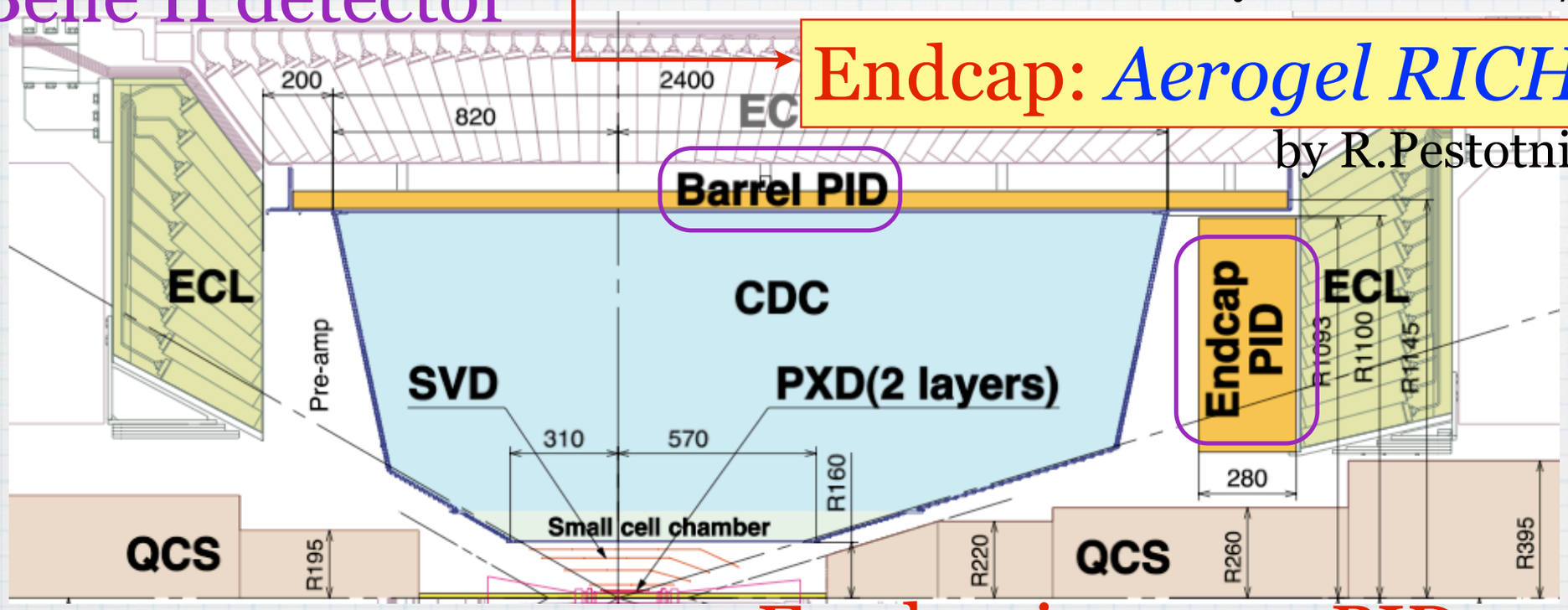
* Upgrade plan of Barrel and Endcap PID devices for the Belle II experiment at KEK

  threshold-type aerogel Cherenkov counter

Barrel: *Time-of-Propagation counter*
by K.Nishimura/M.Staric/K.Inami

Endcap: *Aerogel RICH counter*
by R.Pestotnik/P.Krizan

Belle II detector



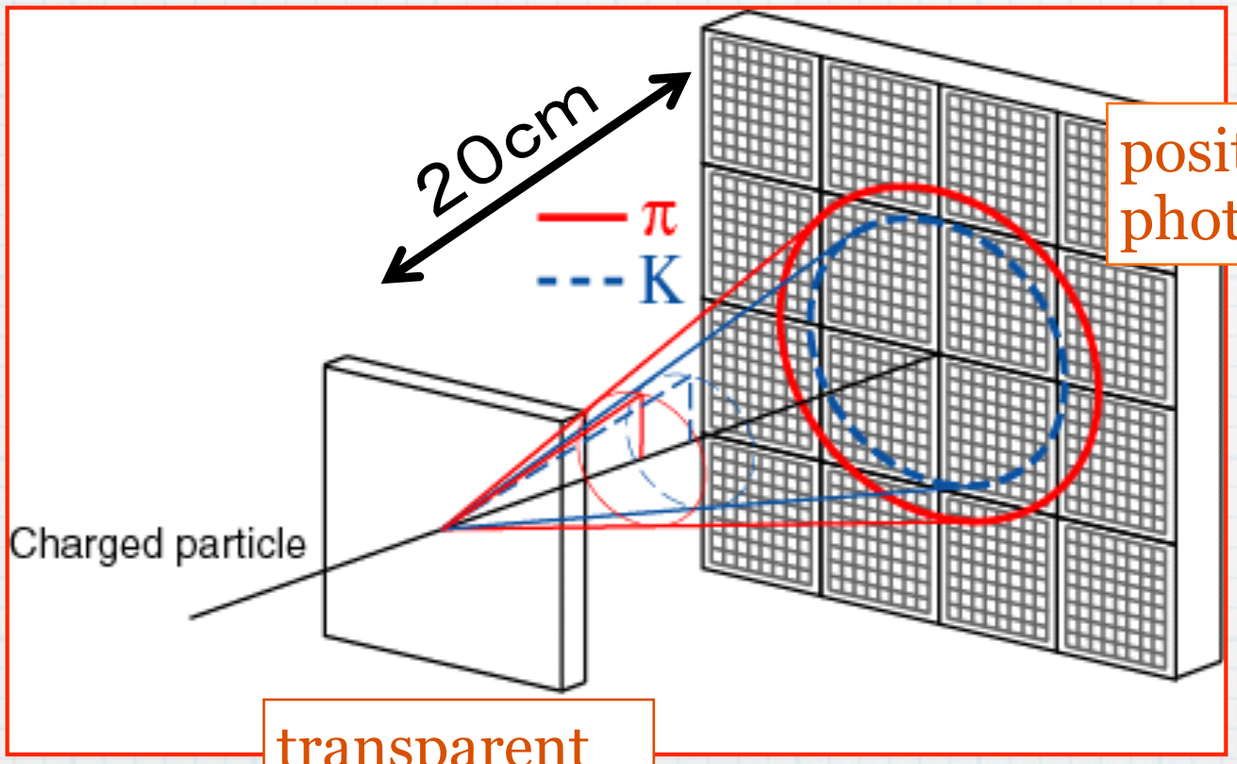
Further improve PID performance
Cope with higher background

Aerogel RICH Counter

* Proximity focusing RICH based on silica aerogel radiator

target: more than 4σ π/K separation at 4 GeV/c

(up to 1.5 GeV/c at present Belle)



See poster session on Thursday

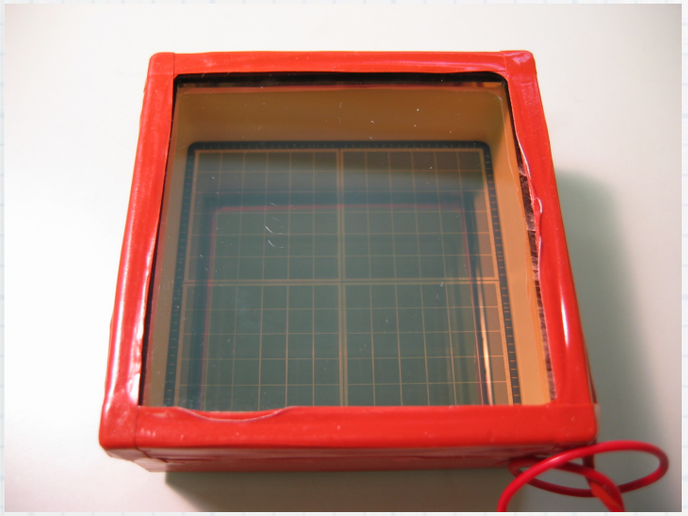
Requirements

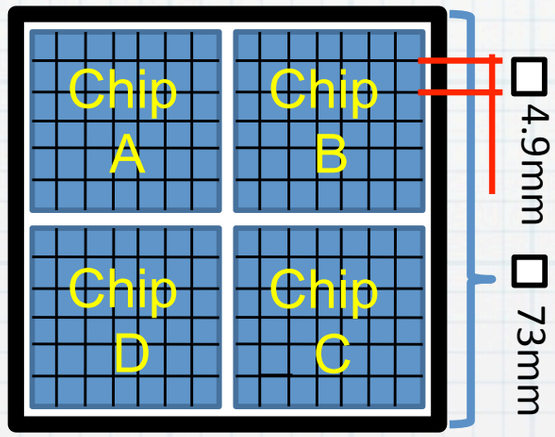
- High sensitivity to single photon
- Position resolution of 5×5 mm²
- Large sensitive area
- Immunity to high magnetic field

Hybrid Avalanche Photo-Detector

144-ch Hybrid Avalanche Photo-Detector

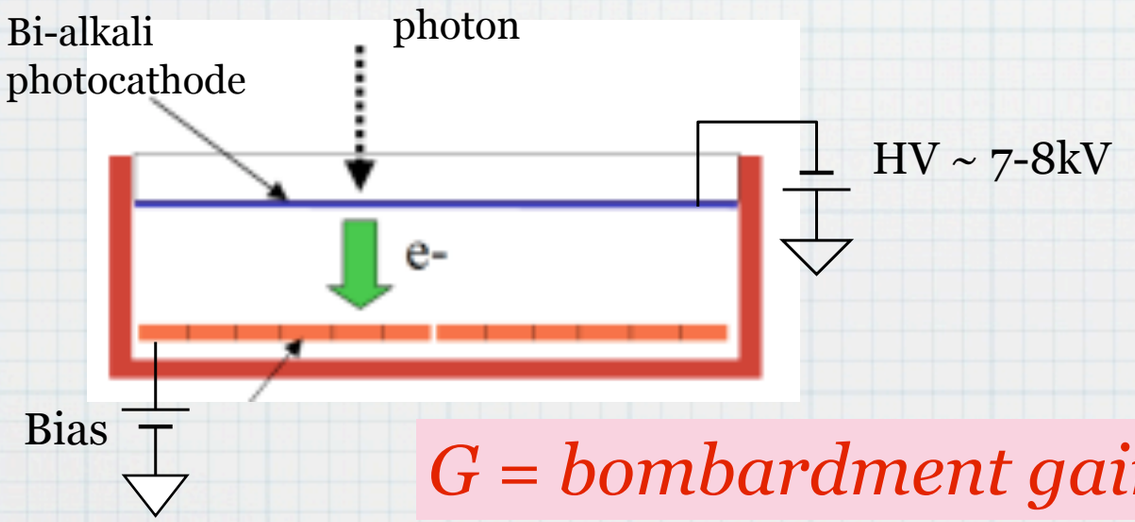
* Hybrid avalanche photo-detector (HAPD)
* developed with Hamamatsu Photonics





4 avalanche diode (AD) chips (refer as A-D) are enclosed in one HAPD
Each AD is pixelated to 6×6 pads

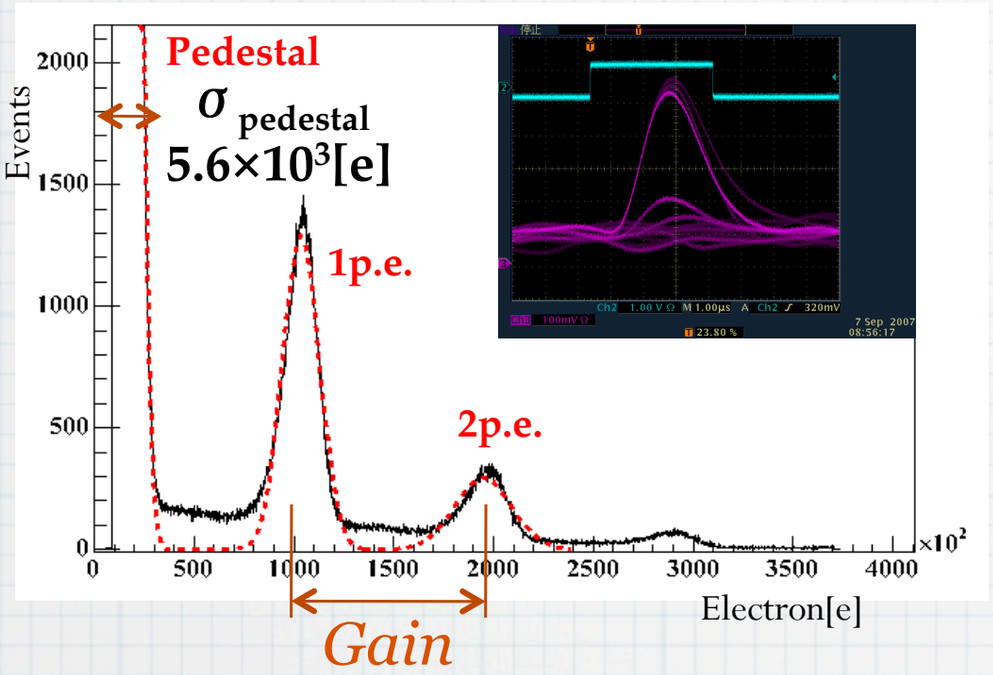
package	73×73mm²
sensitive area	64%
# of pixels	144(36×4chips)
capacitance	80pF
weight	220g



G = bombardment gain(~1200)×avalanche gain(~40)

Single Photon Response

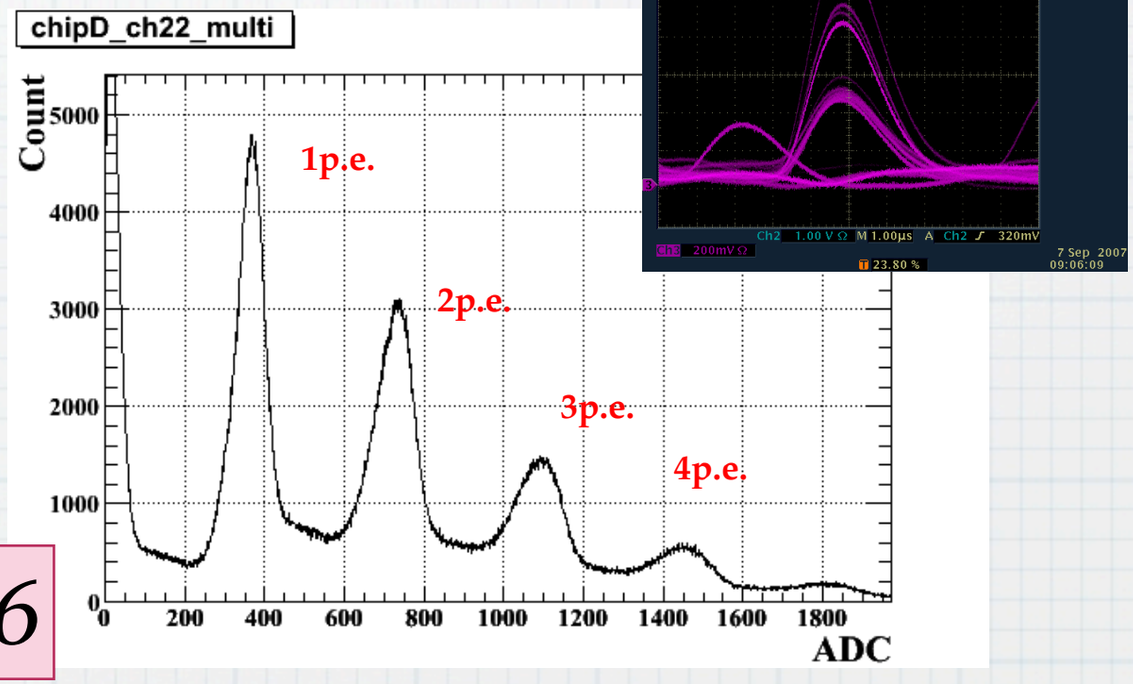
single photon response



pulse height spectrum
(HV:-8.5kV , bias:343V)

blue LED illuminated

multiple photons response



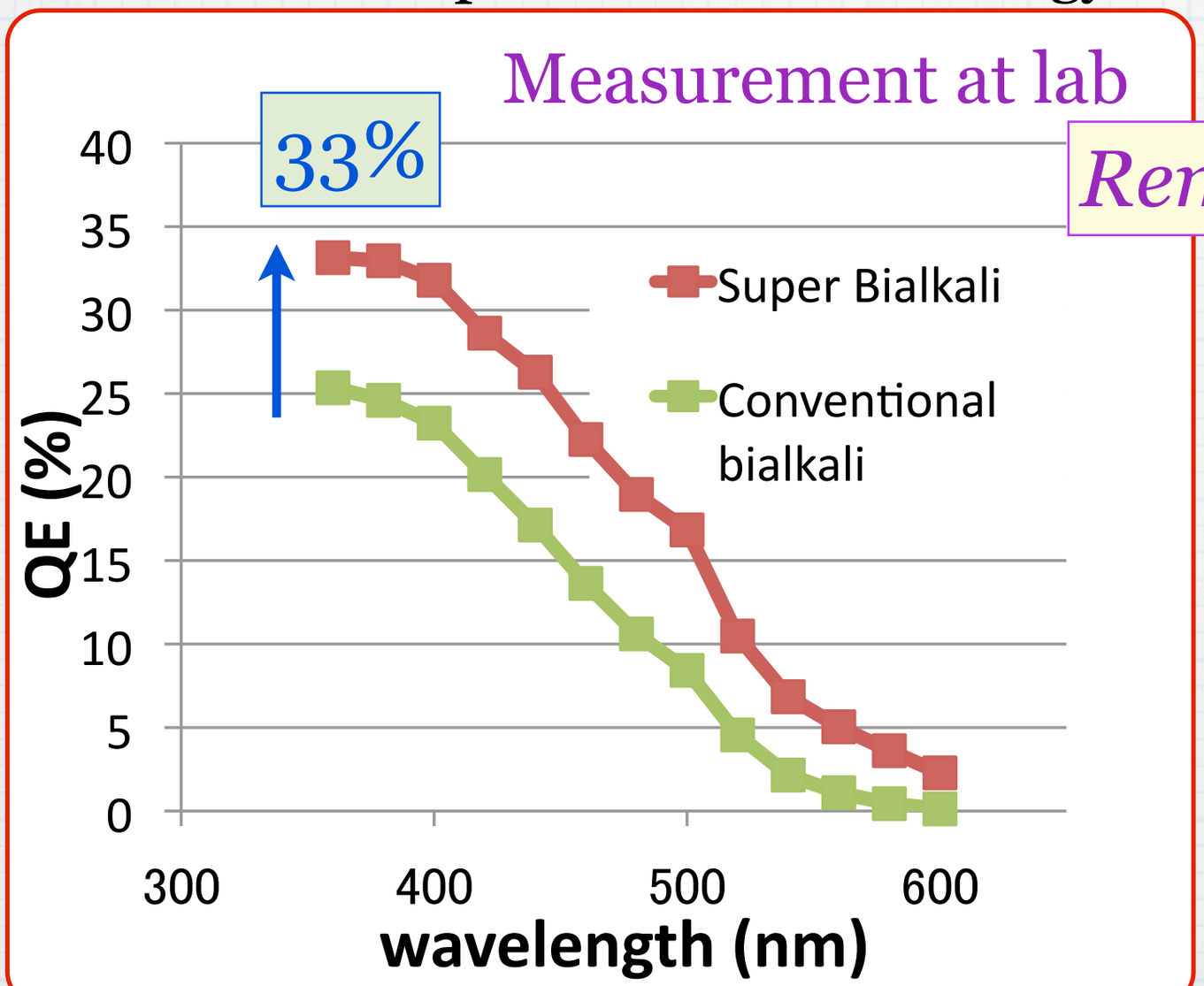
$G = 9.1 \times 10^4$

$S/N = G/\sigma_{pedestal} \sim 16$

Clear single photon signal observed

HAPD QE Improvement

- New fabrication facility for HAPD installed early 2009 at Hamamatsu and production process examined in detail
- High QE (>30%) sample successfully fabricated recently
  - "Super Bialkali" technology

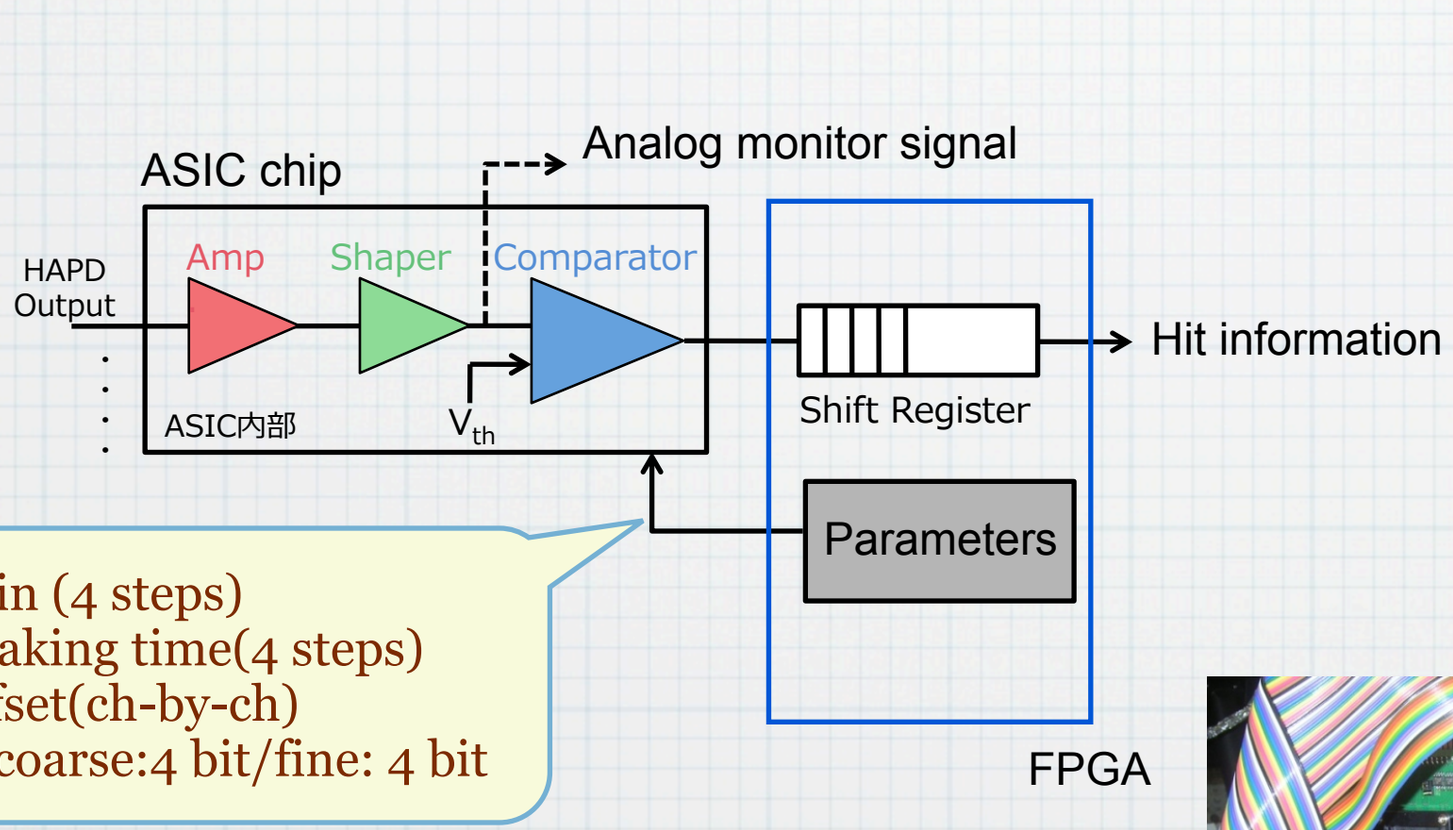


Remarkable progress !!

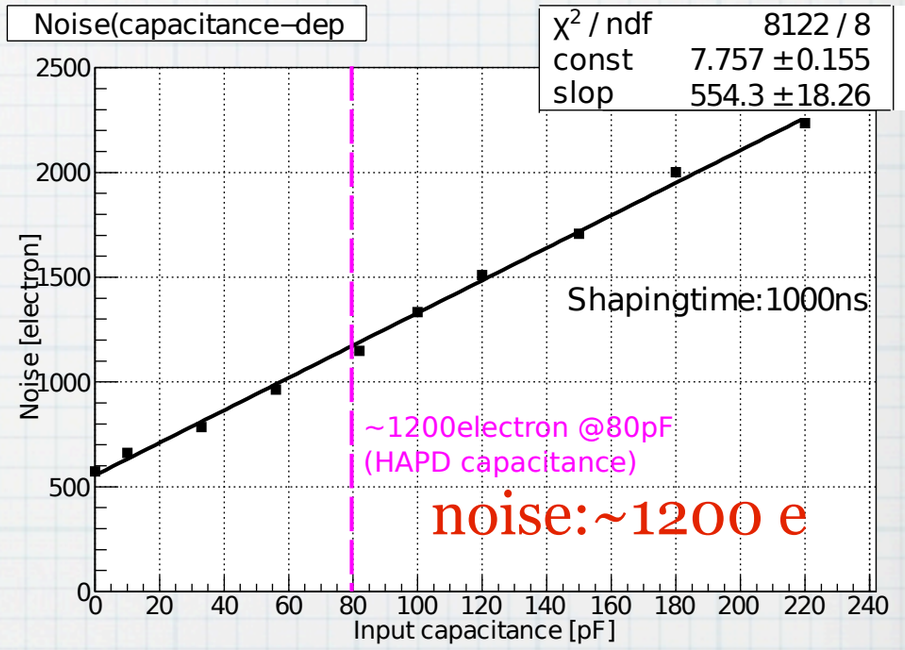
Further improvement expected as technology getting matured

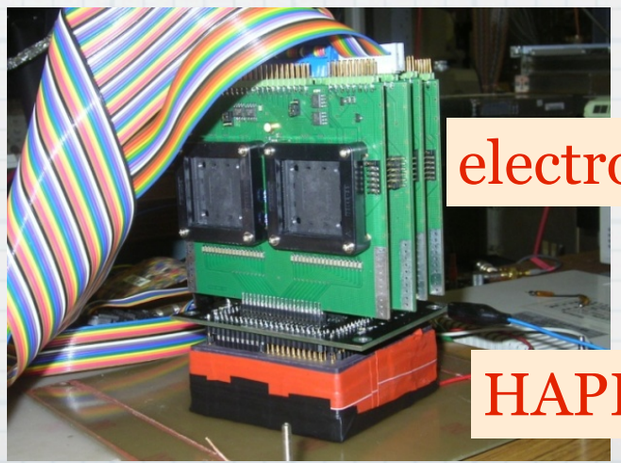
HAPD Front-end Electronics

- Custom-made ASIC chips have been developed as the dedicated readout for HAPD.
  - manage ~80K channels
  - prototyping almost completed after several iterations
  - effort to deal with more channels per chip



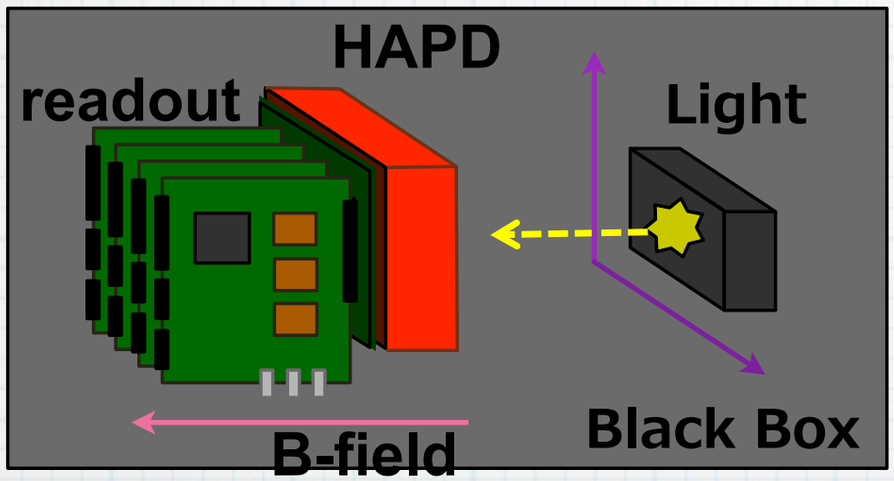
gain (4 steps)
peaking time(4 steps)
offset(ch-by-ch)
coarse:4 bit/fine: 4 bit



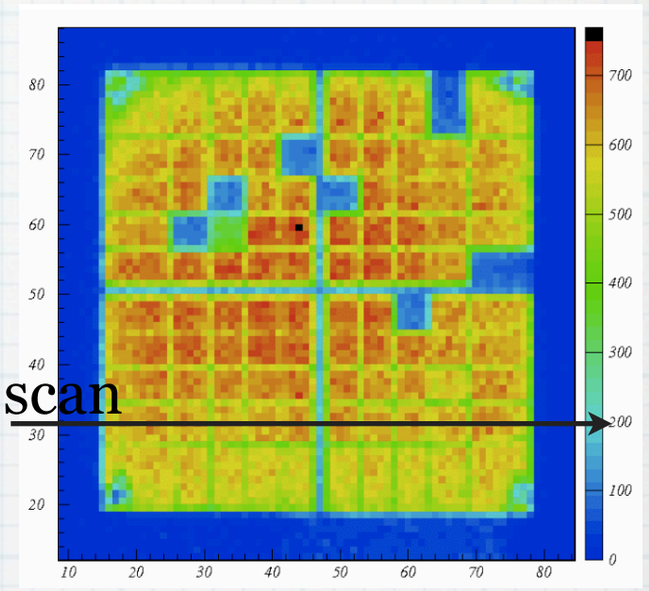


HAPD Response Scan & Operation in a Magnetic Field

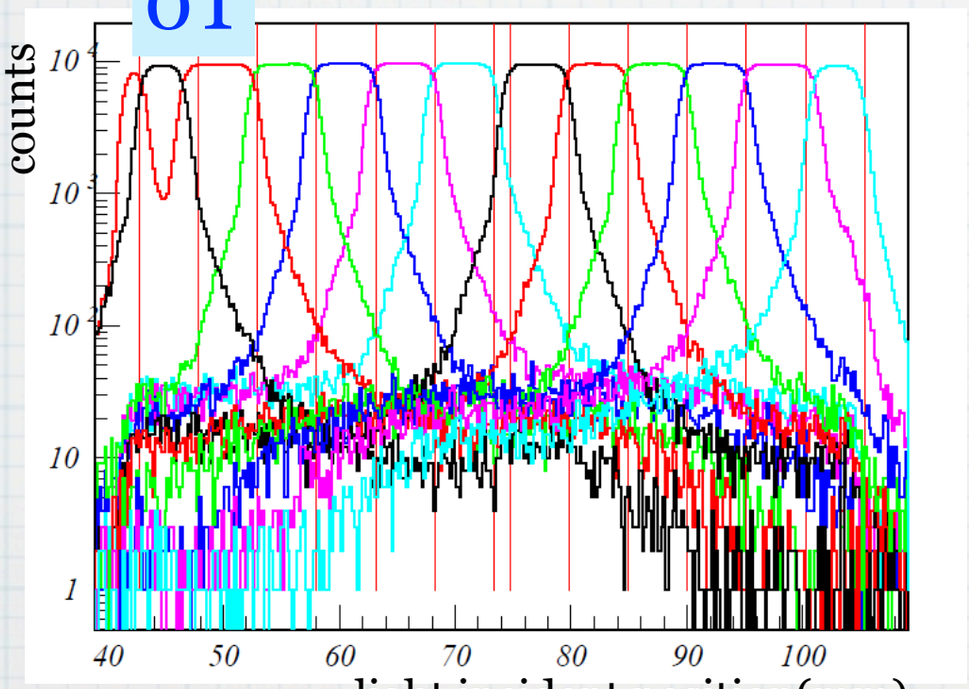
2D response scan carried out w/ & w/o an axial magnetic field of 1.5 Tesla



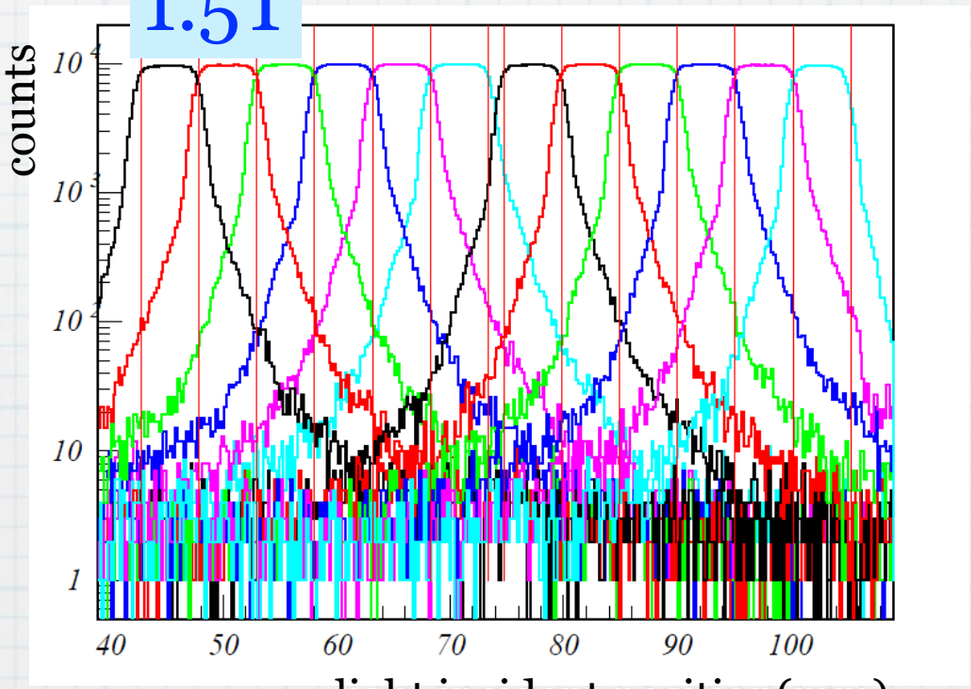
LED ~ 0.4 pe



0T

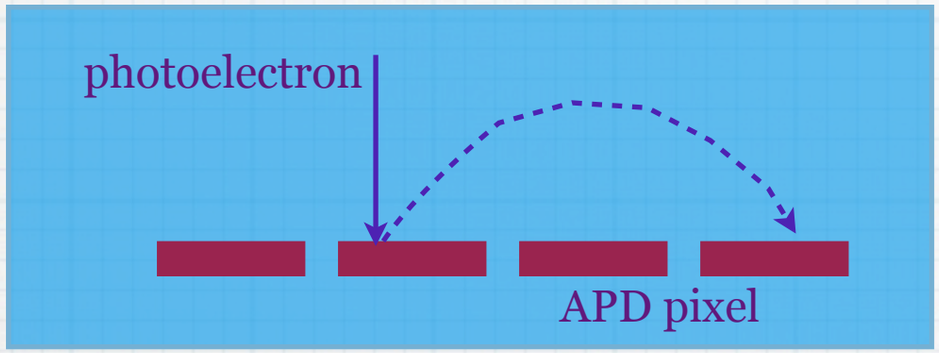


1.5T

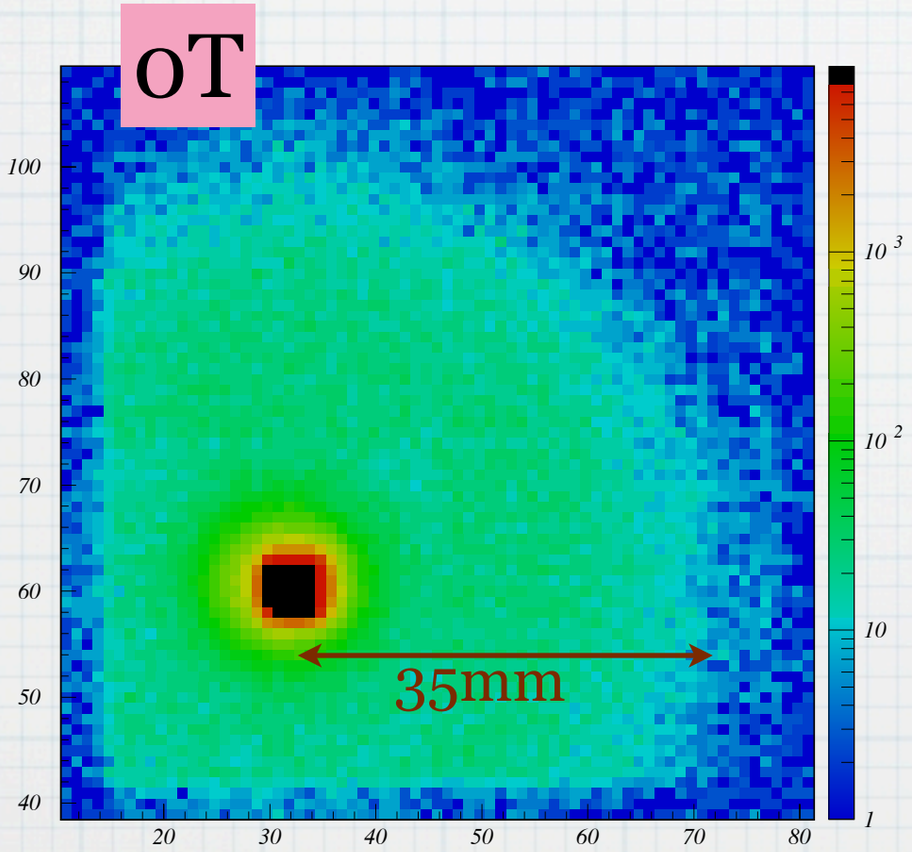


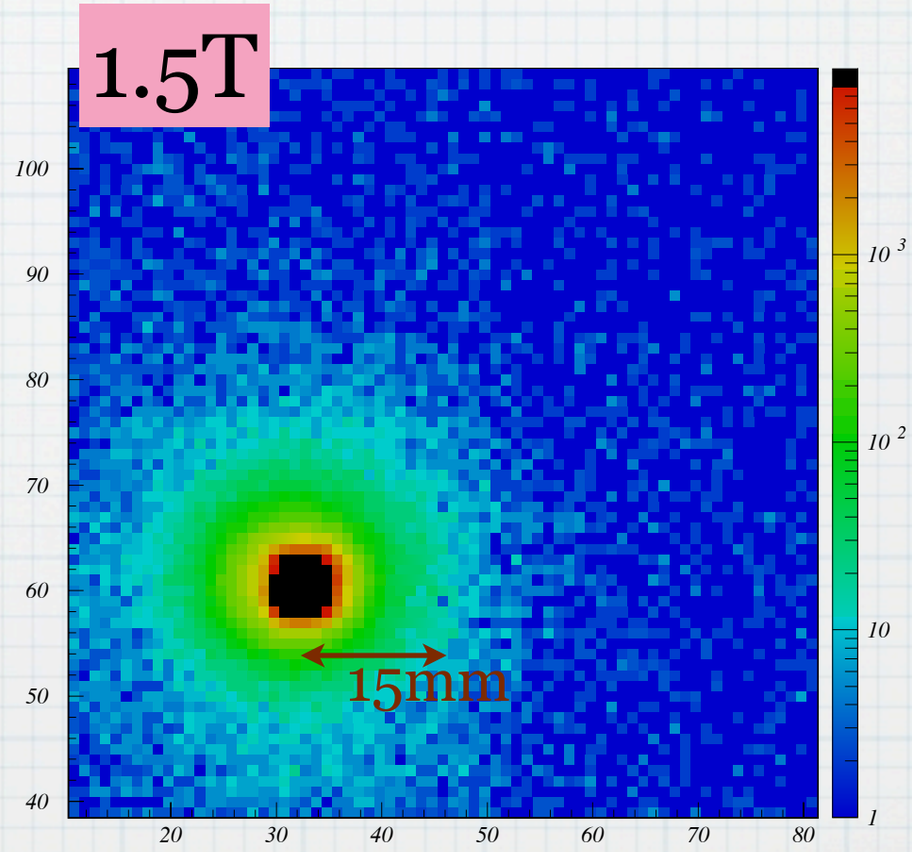
Back-scattering Effect

* photoelectrons back-scattered onto the APD surface : significantly reduced when B-field turned on



Residual spread can be considered as other effect such as light reflection





Neutron Radiation Damage

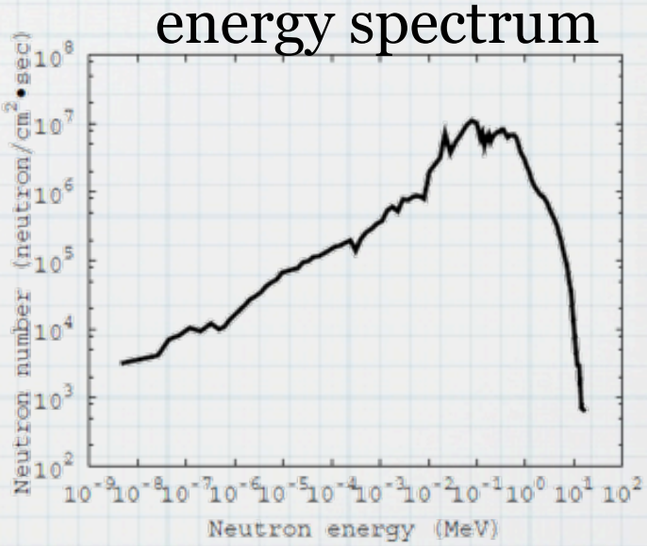
- HAPD bench test exhibits excellent performance on our requirements !
- High neutron dose is found in the present Belle experimental environment.
  - increase of photodiode leakage current observed at Belle
  - depends upon accelerator design

Belle II 1 year : $1\times10^{11}/cm^2$ expected

Neutron radiation test performed using nuclear reactor "Yayoi(弥生)" at Univ. Tokyo

- Flux: 2×10^8 neutrons/cm²/sec at W=500W
- Average energy: 370keV

energy spectrum



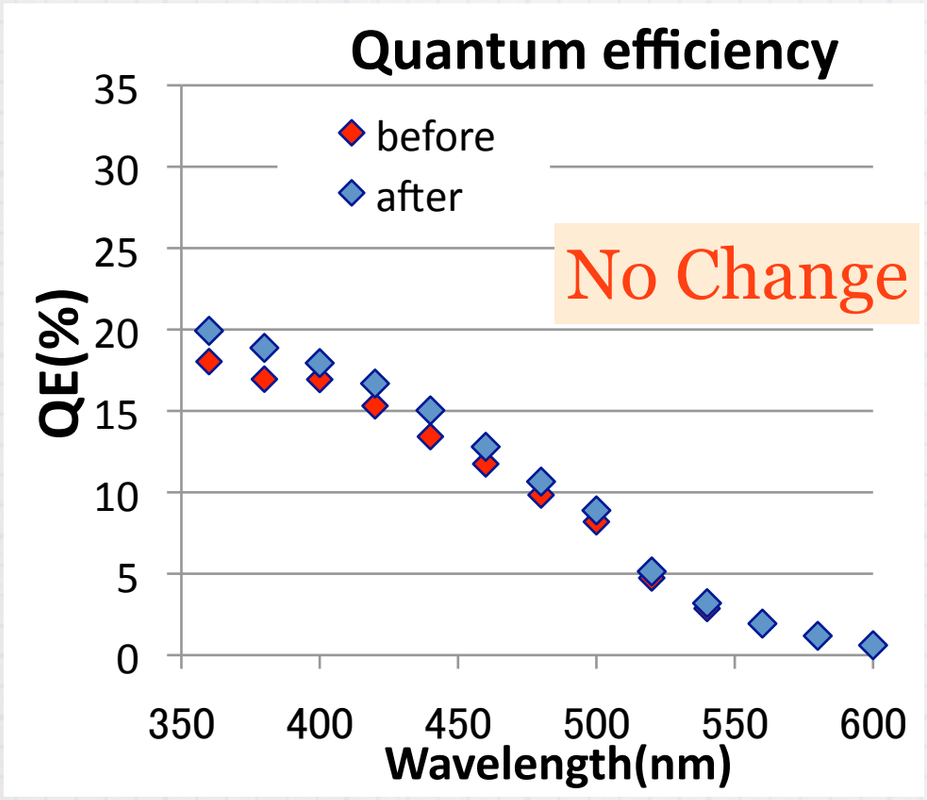
Neutron Radiation Damage(cont'd)

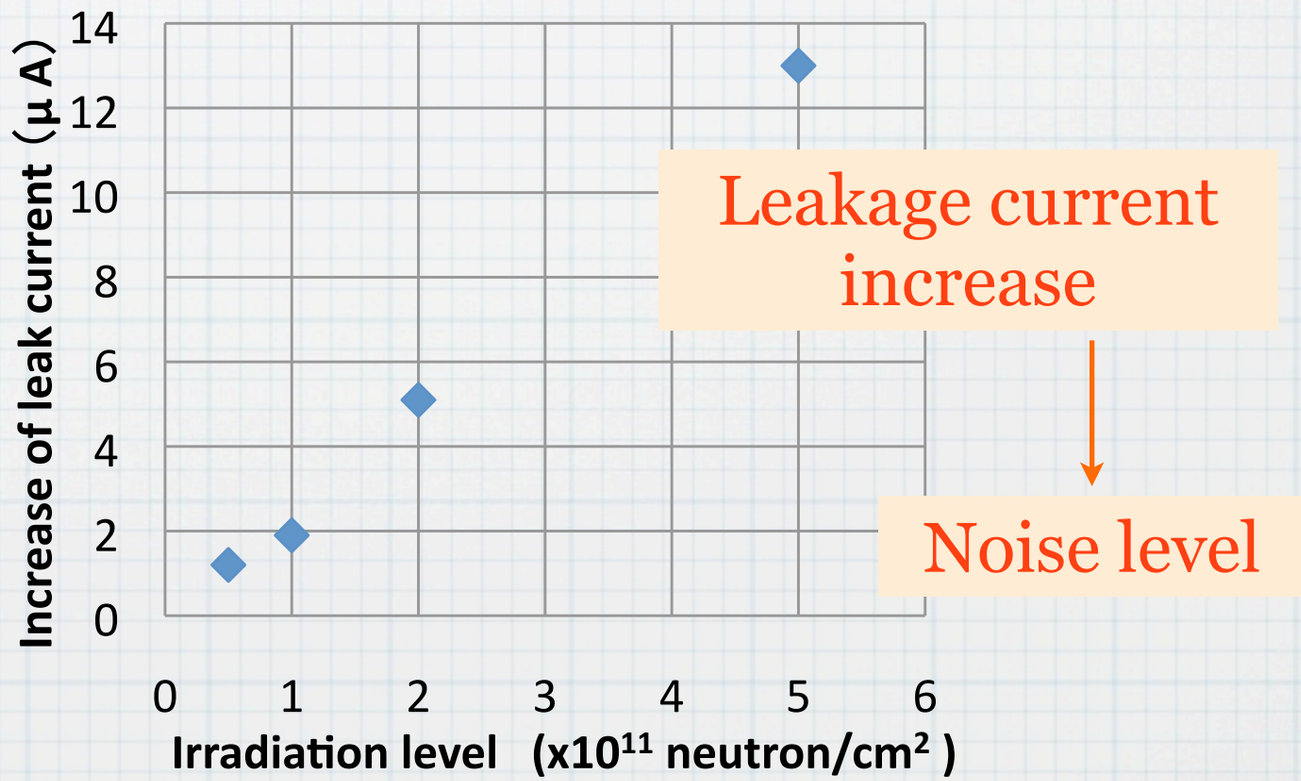
Several HAPDs irradiated

- 0.5×10^{11} neutrons/cm^2 : 0.5 year
- 1×10^{11} : 1 year
- 2×10^{11} : 2 years
- 5×10^{11} : 5 years

in unit of Belle II operation

Irradiation effect: QE & leakage current

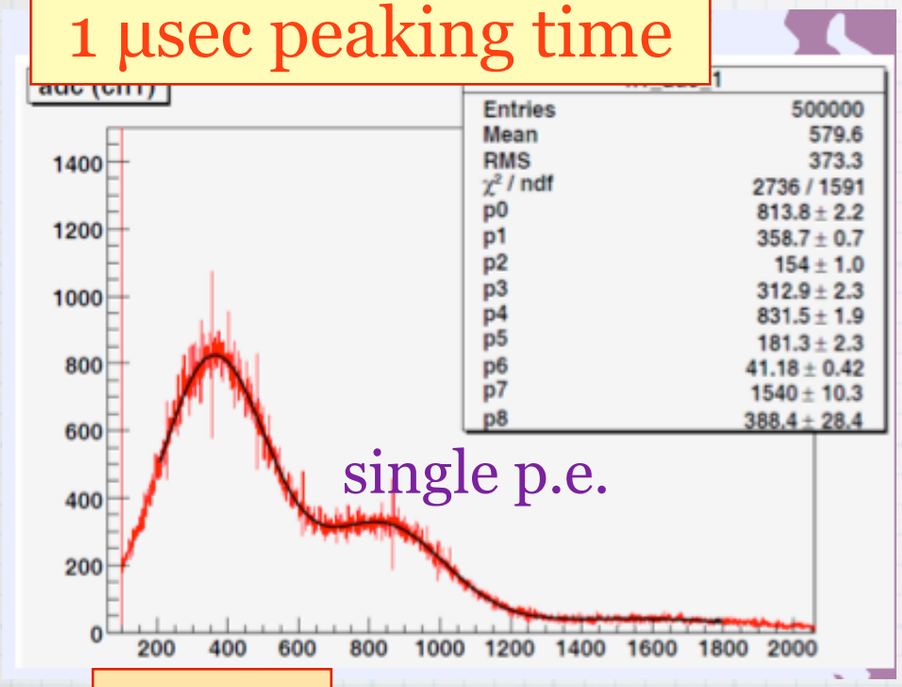




S/N after Neutron Irradiation

- Noise increase results in worse S/N
- S/N can be improved by optimizing electronics parameters & operating conditions
  - pulse height measurement done at bench for 5×10^{11} sample

1 µsec peaking time



HV = 7kV

S/N~3

S/N after Neutron Irradiation

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  - pulse height measurement done at bench for 5×10^{11} sample

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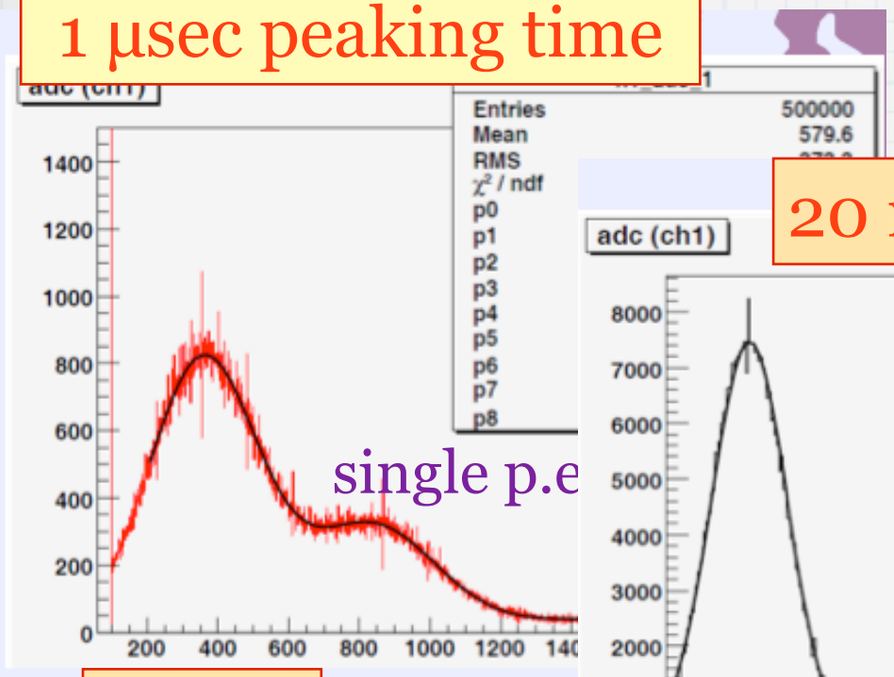
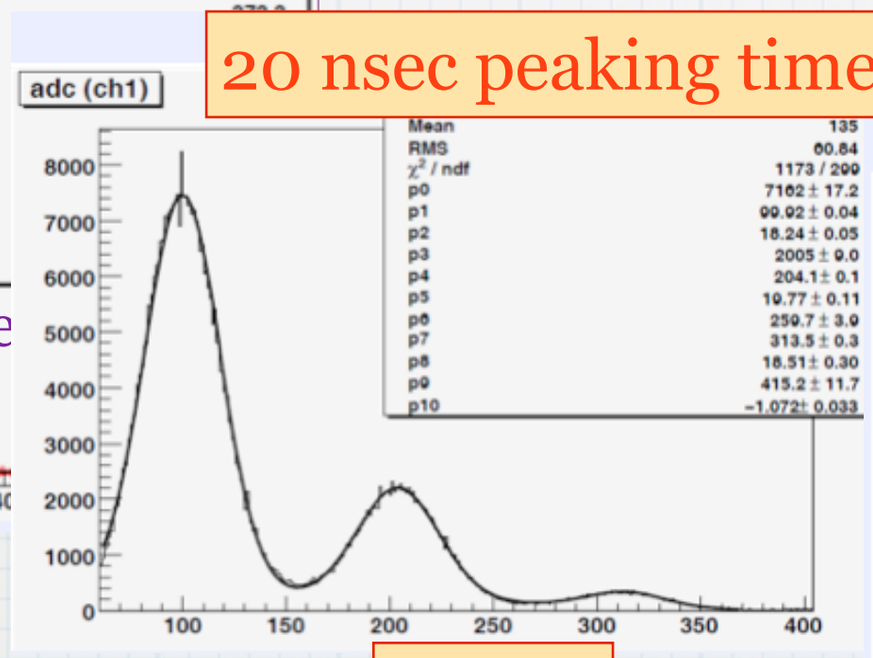
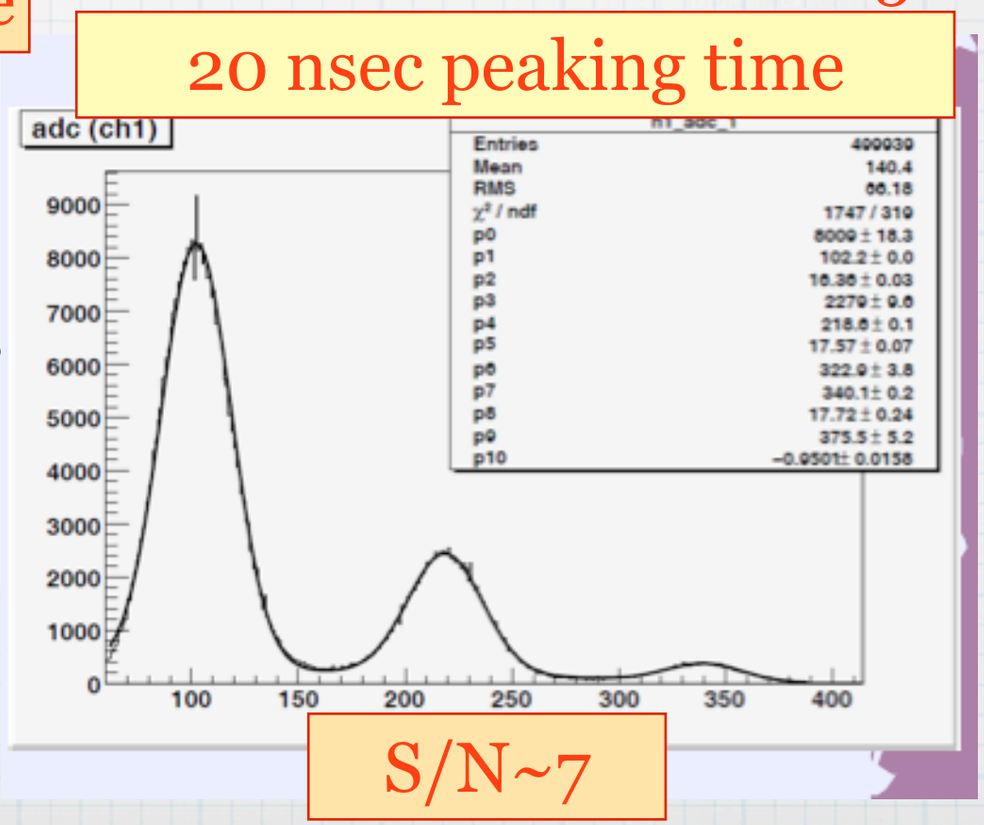


20 nsec peaking time



HV = 8.5kV

20 nsec peaking time

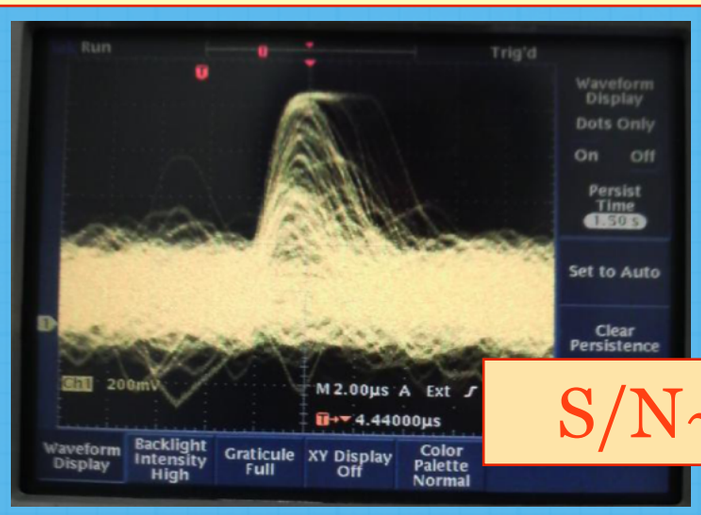


S/N Recovery with ASIC Front-end

* The same test done with the present ASIC readout

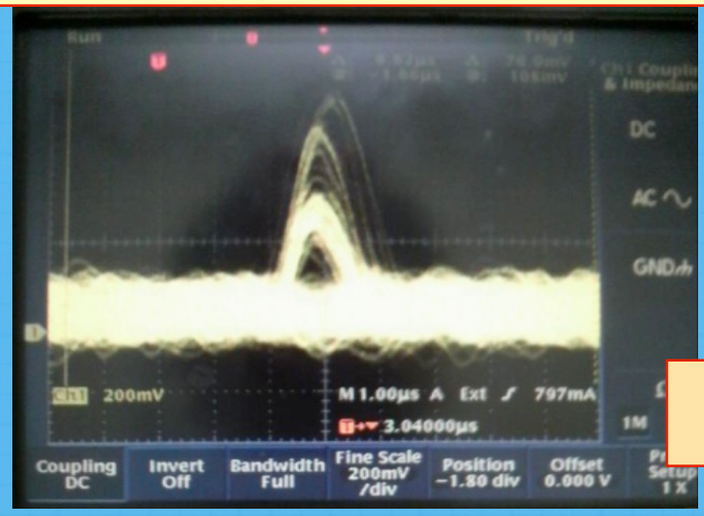
Analog monitor signal out from ASIC

1 µsec peaking time + HV 7kV



S/N~3

250 nsec peaking time + HV 8.5kV



S/N~7

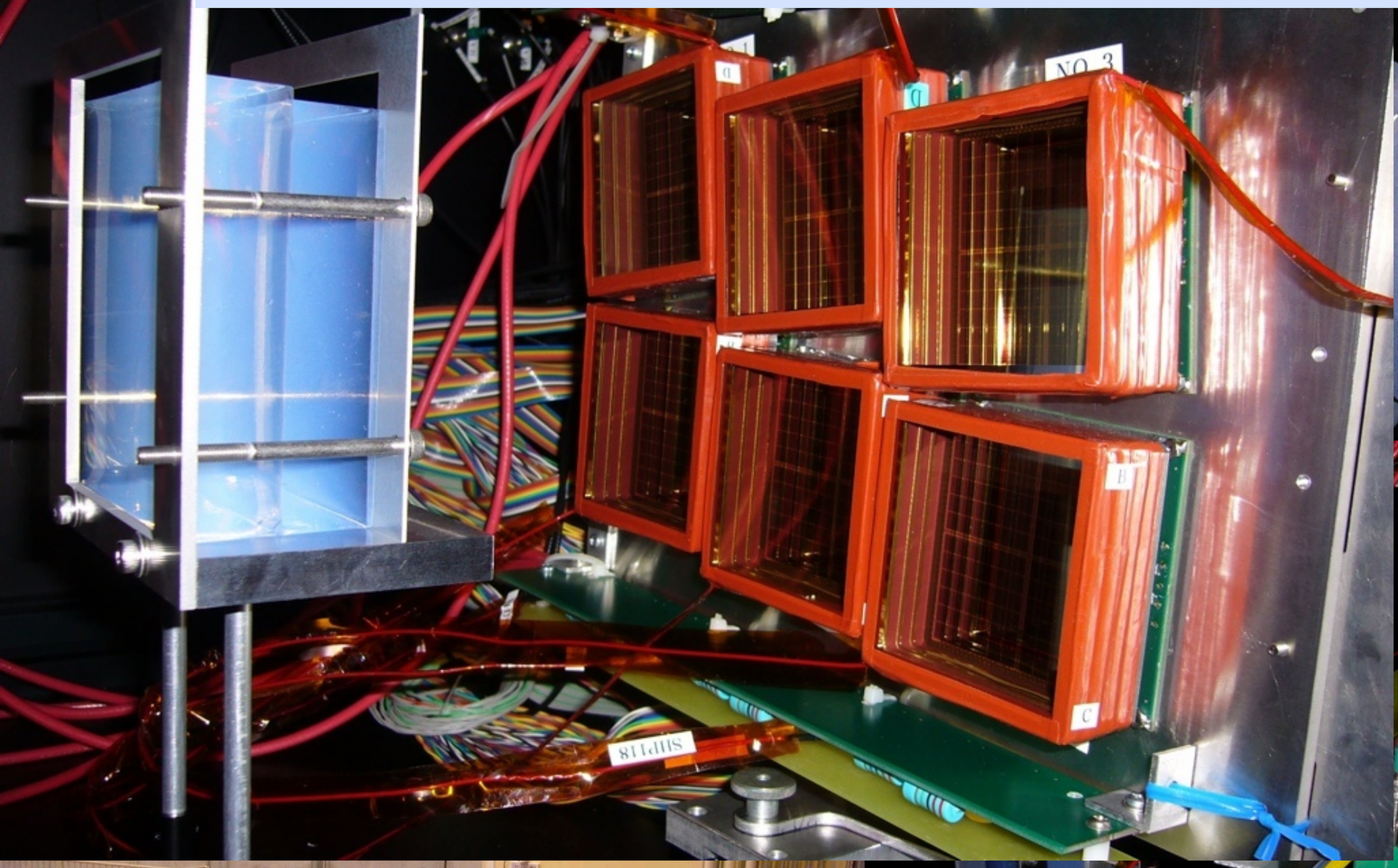
* The same results confirmed using digitized signal

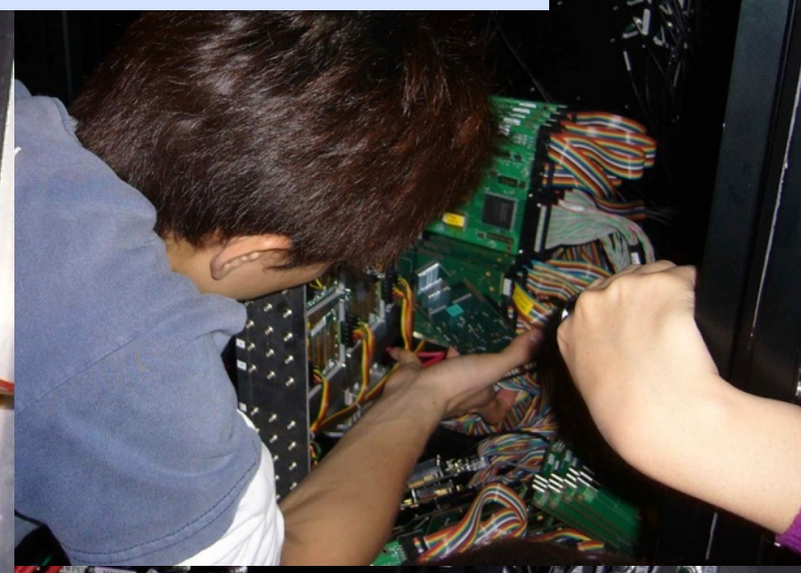
Single photon detection can be made up to 5×10^{11}
Further optimizations in electronics readout will be done

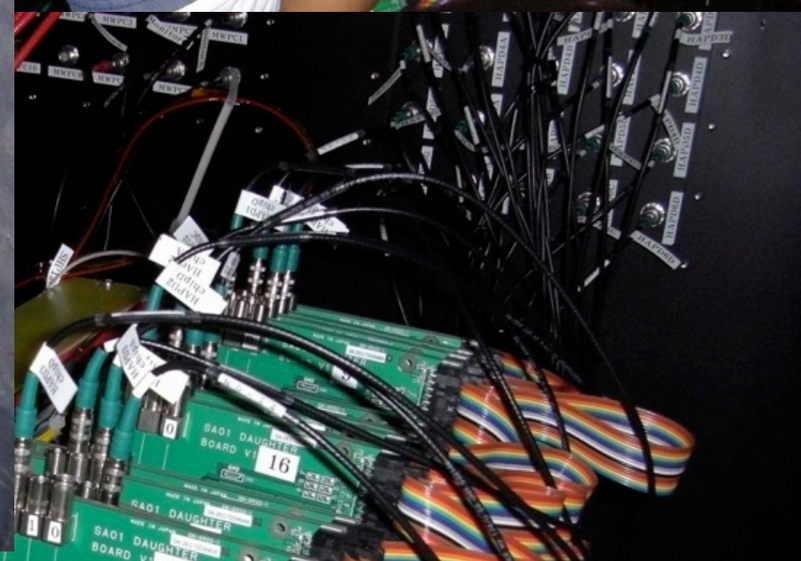
Further Improvements

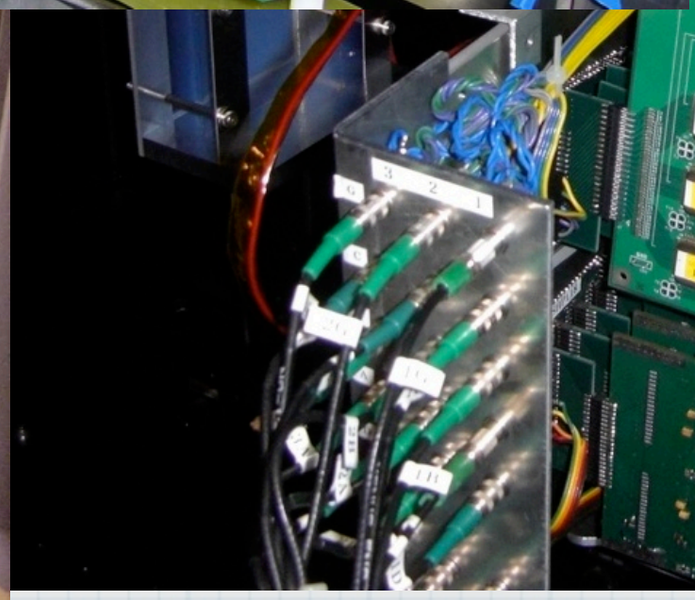
- Possibility of new APD structure
  - reduction of leakage current increase: $I_{leak} \propto V_{APD}$
  - thinner silicon layer in APD is being developed at Hamamatsu
    - various type of APDs irradiated
    - test in progress

Beam Test in November 2009









Beam Test in November 2009

6 HAPDs arranged as 2×3 configuration
(1 high QE HAPD:ε~33%)

2 layers of 20-mm thick aerogel radiators

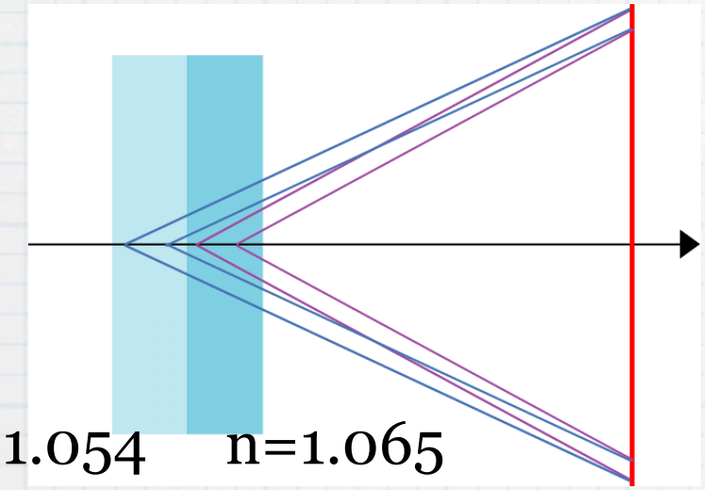
Track parameters by two MWPCs

Front-end electronics attached at HAPDs

2 GeV/c electrons at Fuji Test Beam Line

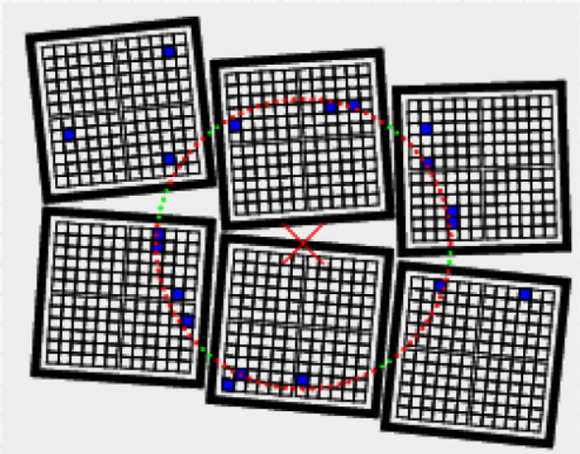
Beam Test Results (1)

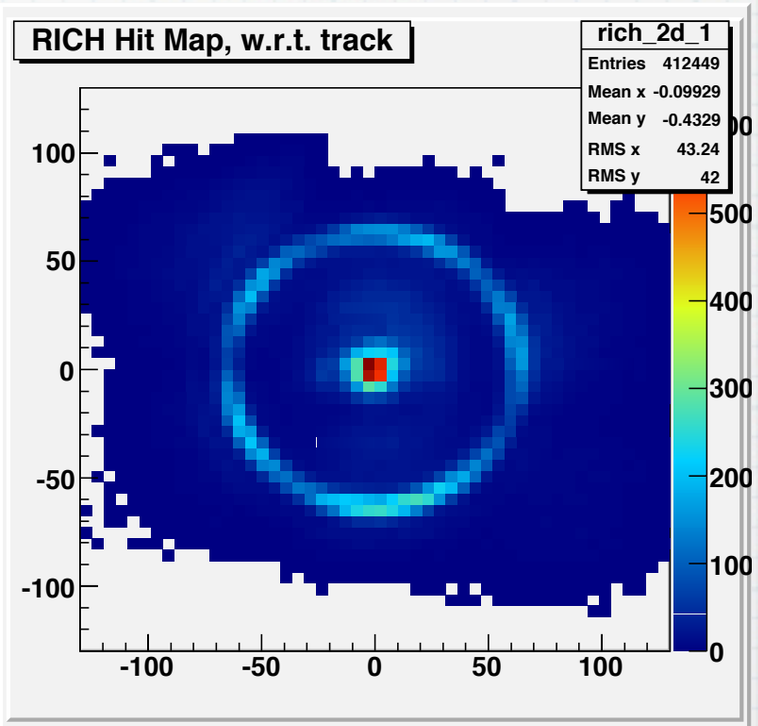
"focusing" configuration of 2 aerogel layers

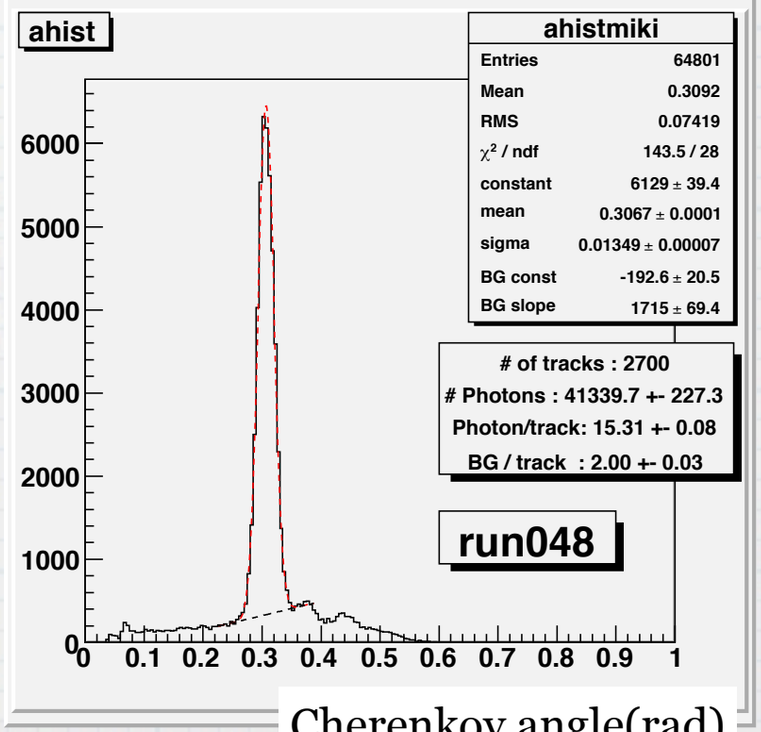


20 mm thick each

event display







Clear ring image observed

Cherenkov angle resolution: σ = 13.5 mrad

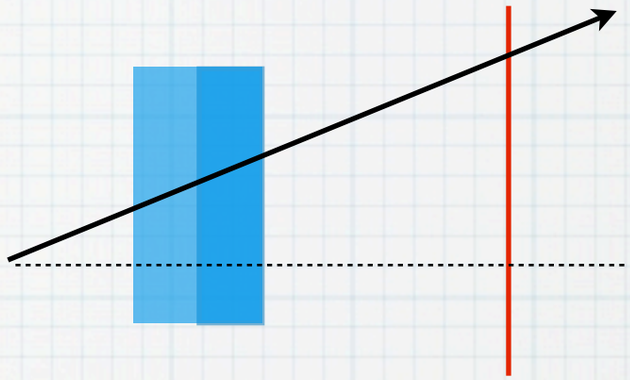
# of photoelectrons: 15.3

From naive calculation

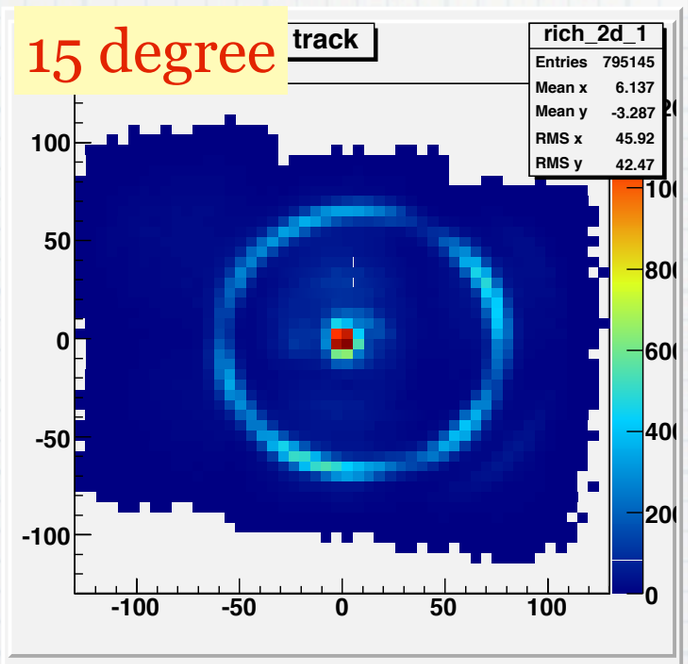
→ 6.6 σ K/π separation at 4 GeV/c achieved

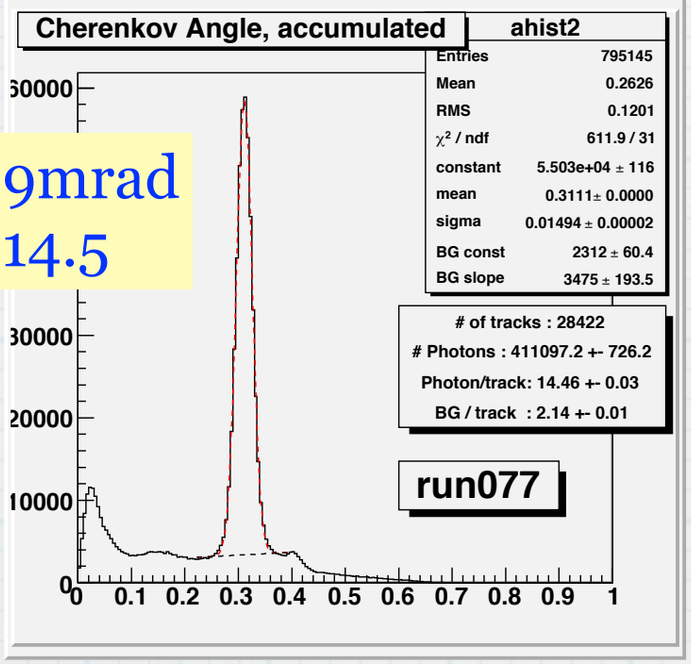
Beam Test Results (2)

* Performance for inclined tracks



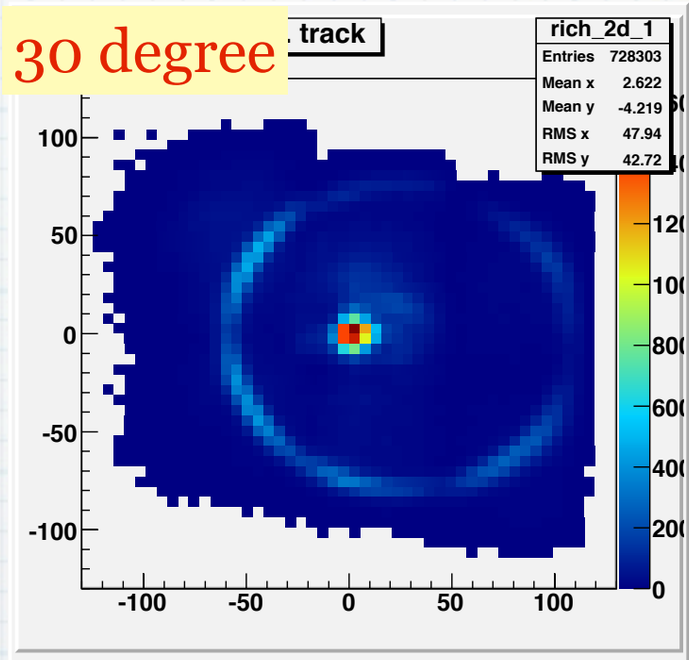
15 degree

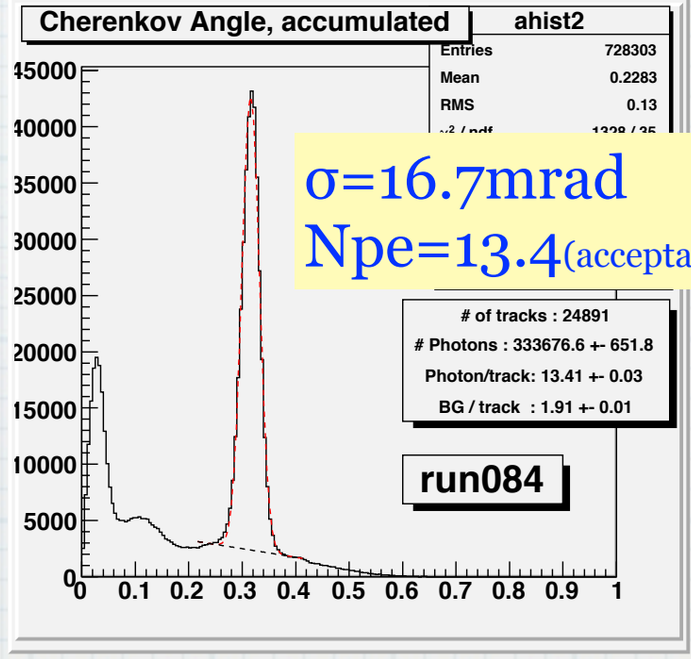




σ=14.9mrad
Npe=14.5

30 degree





σ=16.7mrad
Npe=13.4(acceptance limited)

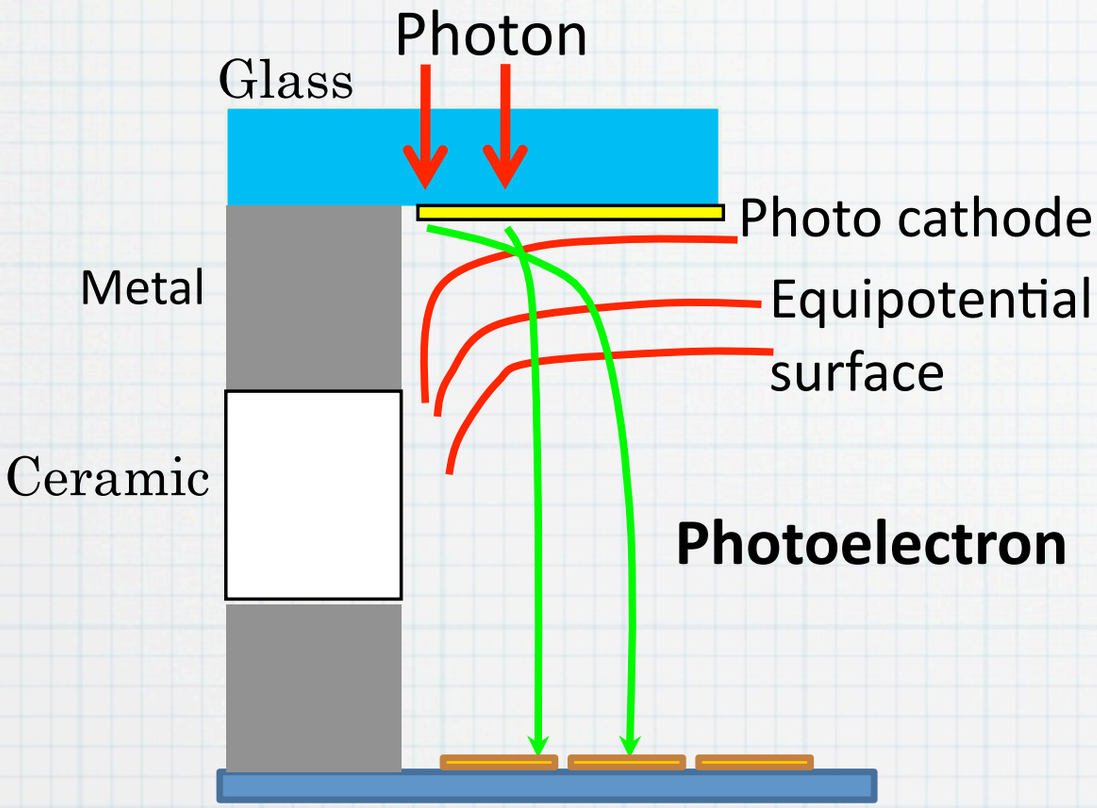
More than 5σ separation kept

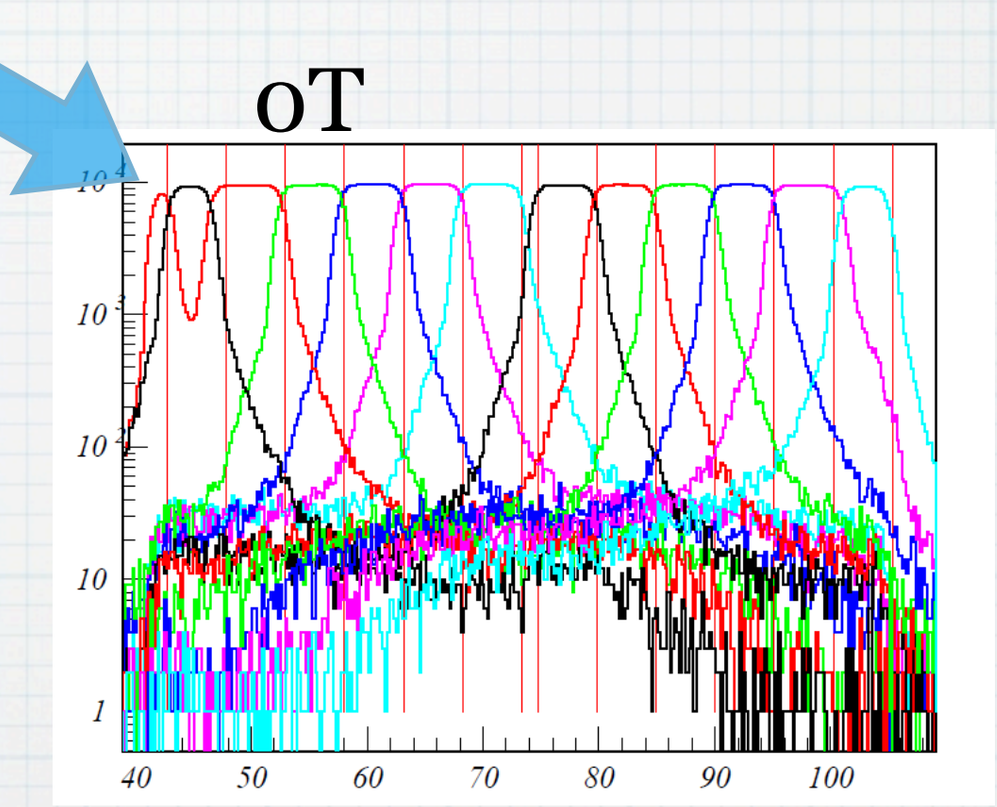
Still works fine!

Conclusions

- 144 channel multi-anode HAPD has been developed with Hamamatsu Photonics
- Excellent performance was shown from bench test results
  - single photon response
  - operation under a magnetic field
  - high QE sample available
- Further work on neutron radiation in progress
  - manageable up to 5×10^{11} neutrons/cm^2
- More than 5σ π/K separation demonstrated from test beam experiment using a prototype
- This HAPD is the baseline photon detector for Belle II Aerogel RICH counter

HAPD Field Distortion

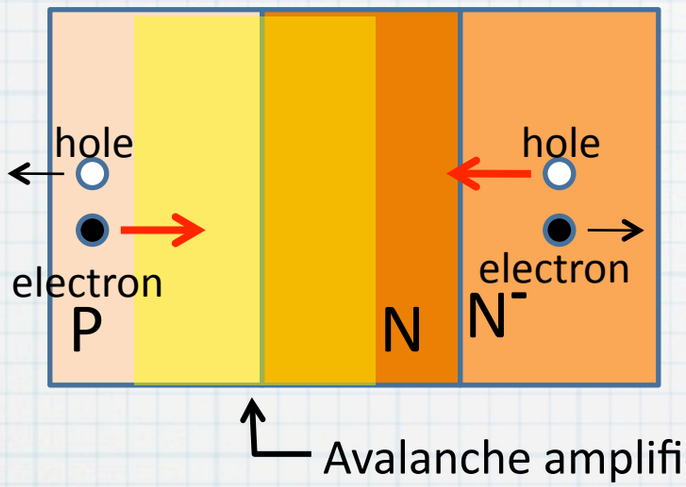




Thin APD Structure

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.