The ARICH detector at Belle II experiment

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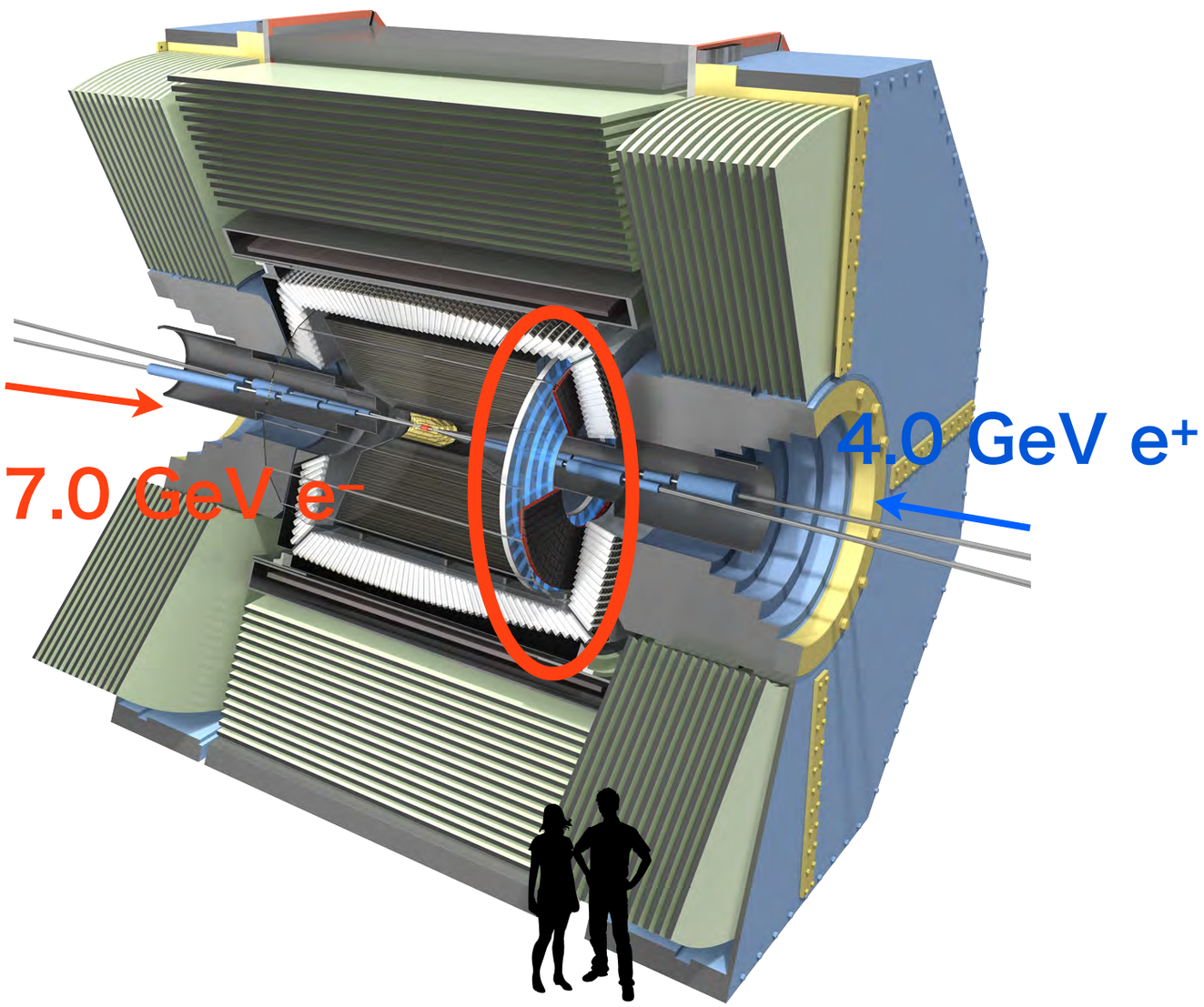
on behalf of Belle II ARICH group

Introduction

Belle is a luminosity frontier B-factory experiment run until 2010.

Upgrade for Belle II is ongoing (for 40 times larger luminosity).

Particle identification (PID) system will be replaced with new detectors.



Belle PID

Aerogel Cherenkov Counter (ACC).

Threshold type PID detector.

→ Effective momentum range is not wide enough for all particles from various B meson decays.

Belle II PID

Two detector systems cover the whole momentum range.

- Barrel part:
  Time Of Propagation counter (TOP).
- **Forward endcap part:**
  Aerogel Ring Imaging CHerenkov detector (ARICH).

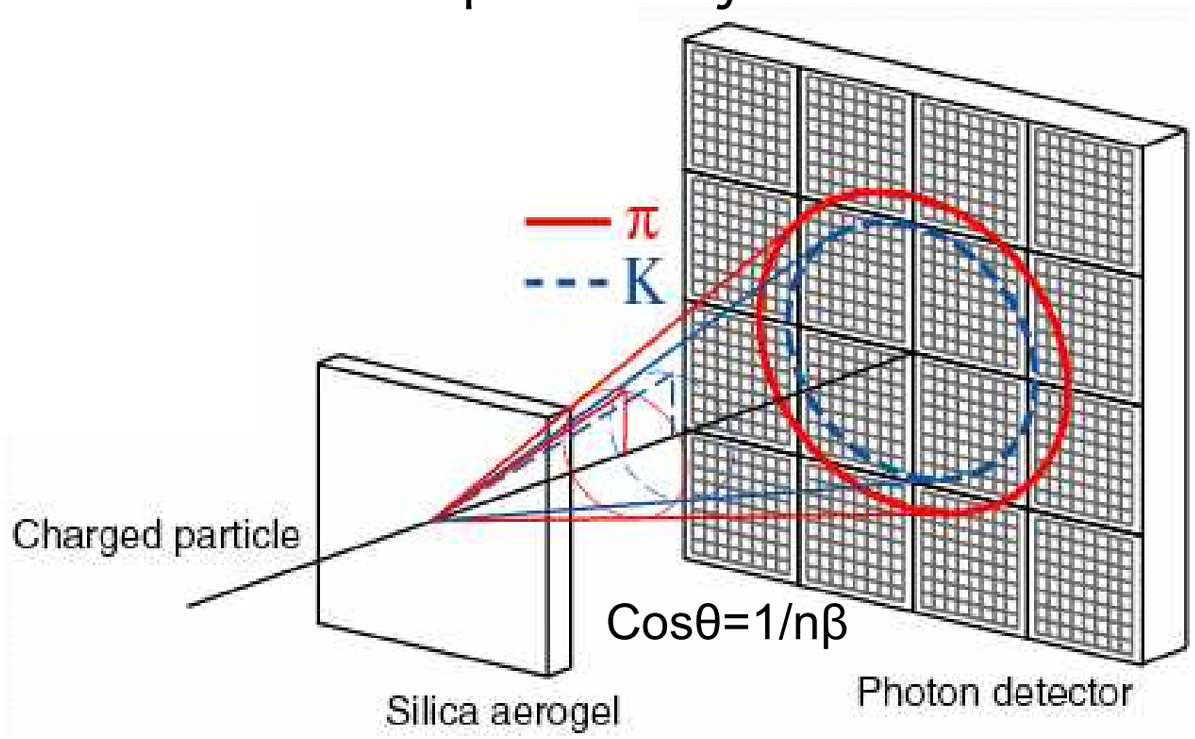
Overview of ARICH detector

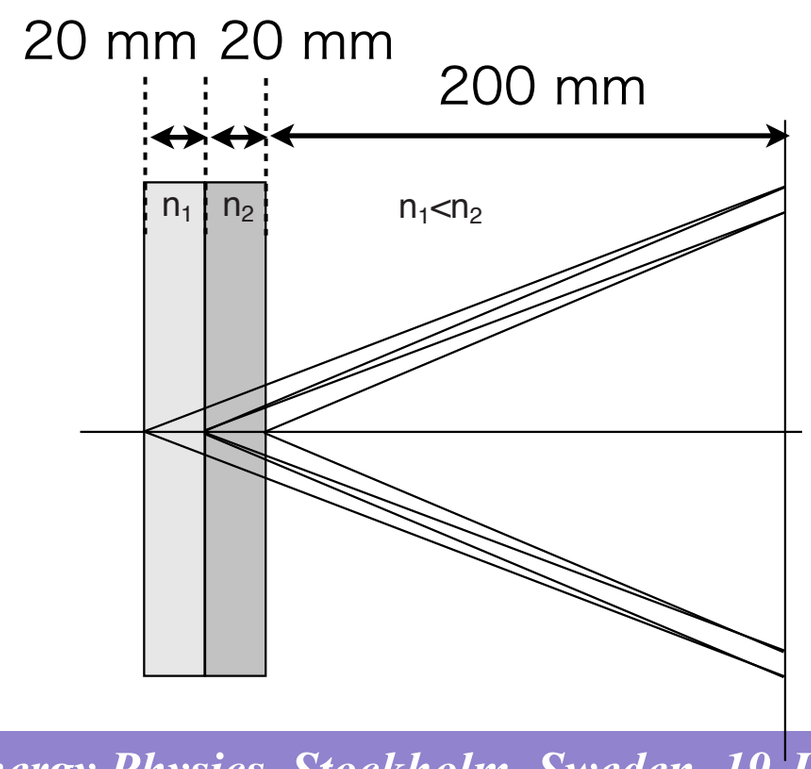
- Identify particle by difference of Cherenkov angle emitted in aerogel radiator.

  Cherenkov angle $\cos\theta_C = 1/n\beta$

  (n: aerogel refractive index, β: particle velocity)
- Proximity focusing due to limited space between drift chamber and electromagnetic calorimeter.
- Aerogel radiator in the focusing configuration (2 layers of aerogel with different refractive indices).

  → Increase photon yield without degrading the single photon resolution.





Requirement for system

- Requirement from physics analysis:

  K/π separation is essential for many B decay modes sensitive to new physics: $B^0 \to K^{*0}(\to K^+\pi^-)\gamma$/ $B^0 \to \rho^0(\to \pi^+\pi^-)\gamma$, $B^0 \to K^+\pi^-/\pi^+\pi^-$ ...

  Target: K/π separation at >5σ confidence level @ p =4 GeV/c.

  Separation = $\Delta\theta_C\sqrt{N_{p.e.}}/\sigma_C$

  $\Delta\theta_C$: Difference of Cherenkov angle between K and π (~23 mrad)

  σ_C: Observed Cherenkov angle resolution.

  $N_{p.e}$: Detected number of photo electron.

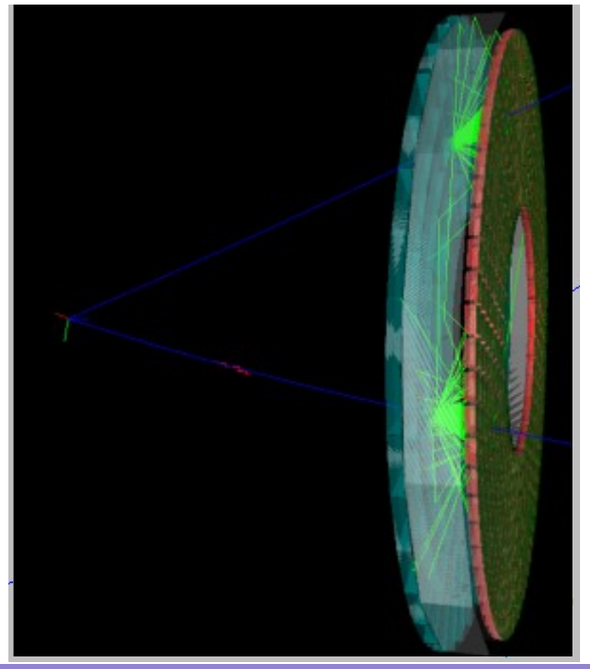
  } ⇒ Highly depends on detector performance.

- Survives in Belle II environment for 10 years.

  Radiation hardness both for γ/neutron.

- Works in high background environment.
- Covers acceptance of other sub-detectors in endcap region.

  → Round shape detector.

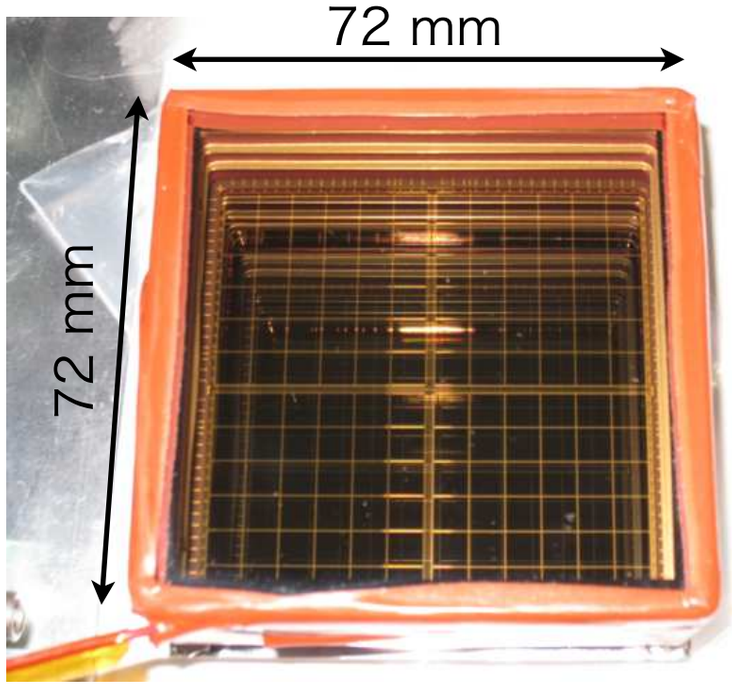


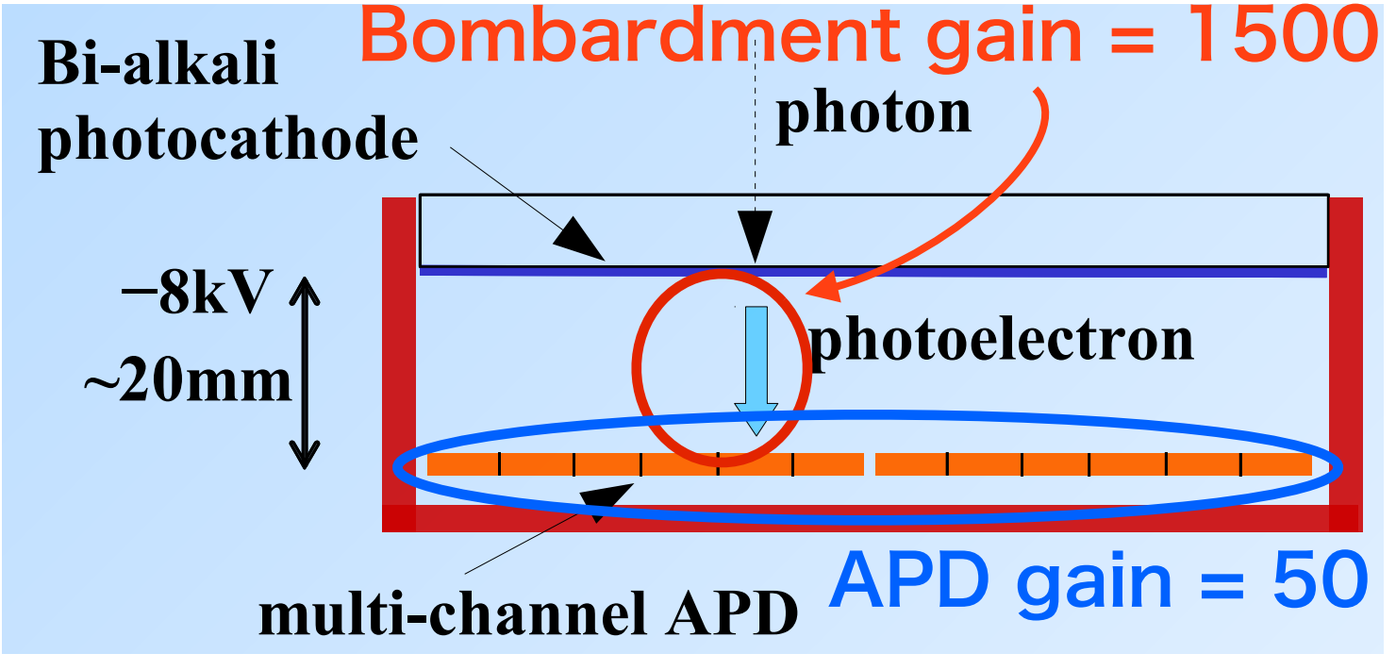
Photon detector

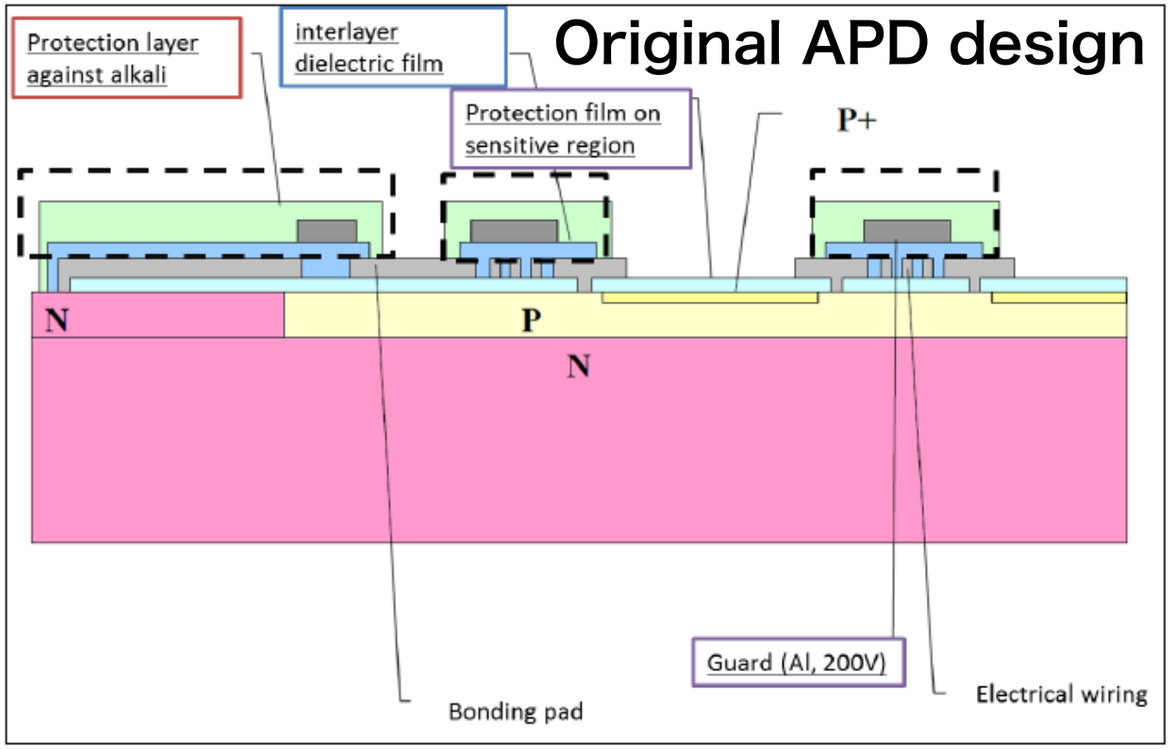
- Detect photon position with good resolution.
- Number of detected Cherenkov photon is not large. (~10 photons)

⇒ **Hybrid Avalanche Photo Detector (HAPD) is developed with Hamamatsu Photonics K. K.**

5 mm pitch pixelated 144 channels cathode APD.
High gain with hybrid amplification process.
420 sensors are used in total for ARICH.







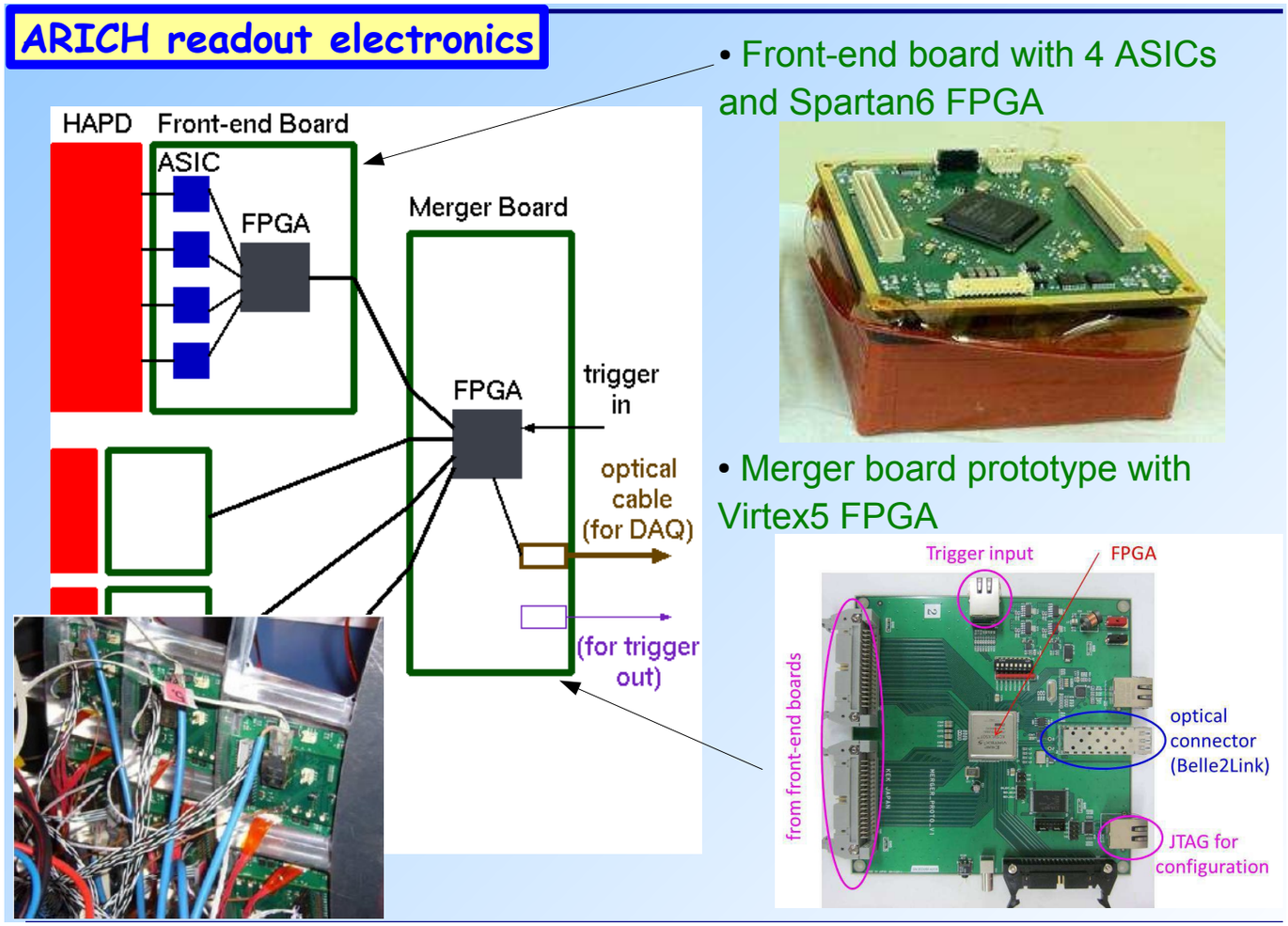
⇒ Total gain ~7×10^5.

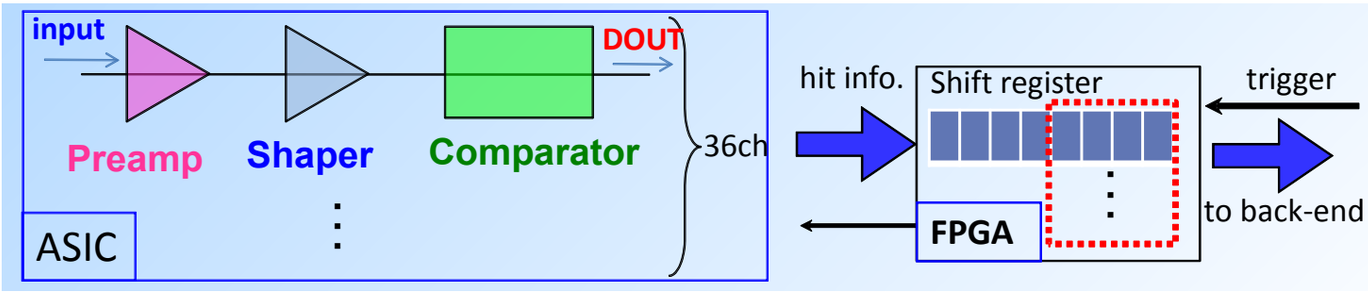
HAPD front-end readout

Signal from HAPD is converted to hit information by pre-amplifier, shaper and discriminator in front-end ASIC.
→ send to Belle II global DAQ readout through merger circuit.

Settings of ASIC components (gain, peaking time, offset level) are controlled by FPGA.

Front-end electronics design is close to final version and production will start soon.



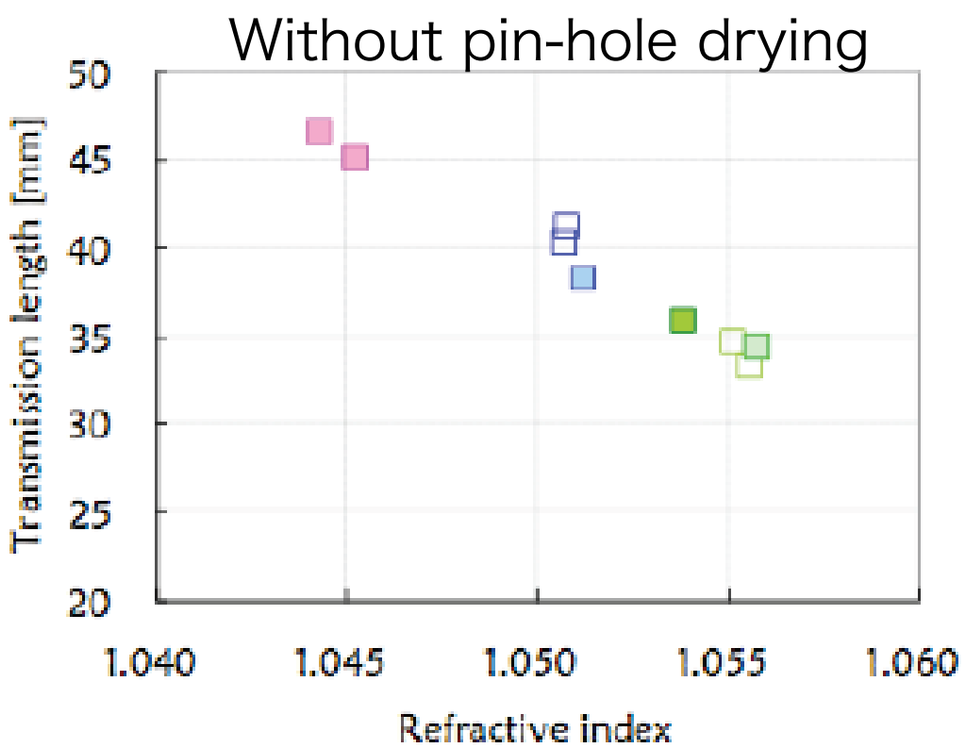


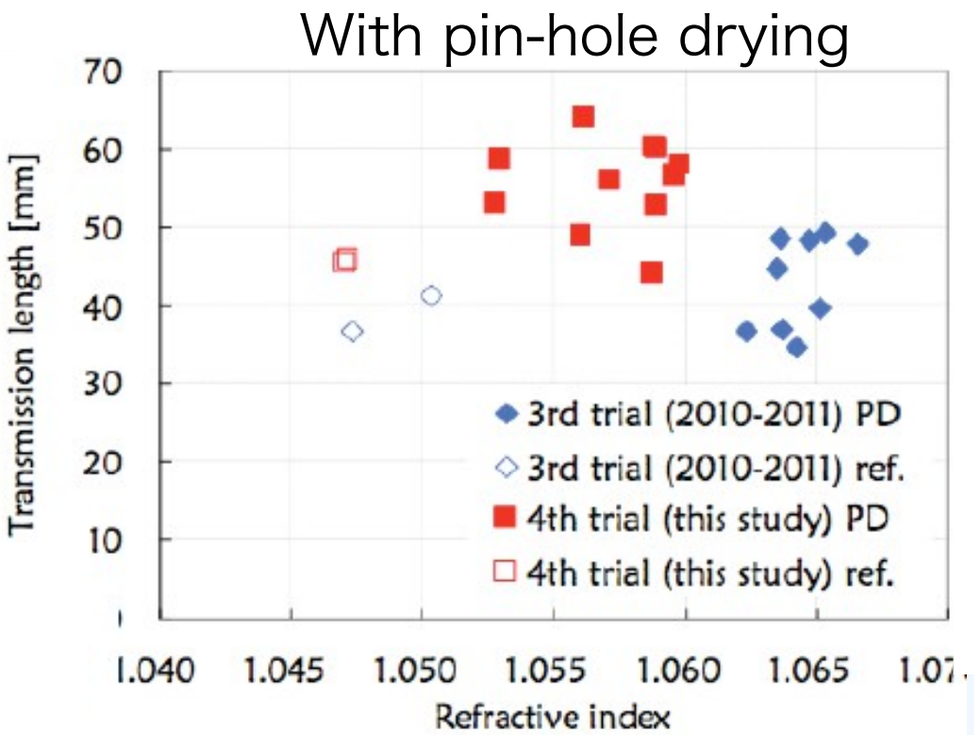
Aerogel radiator

- Distance between aerogel and HAPD window is 200 mm. ⇒ refractive index ~1.04-1.06
- Need to be transparent to suppress photon scattering.

  Target transmission length: >40 mm (@λ = 400 nm).

  → Introduce new technique to produce high transparency and refractive index aerogels. (pin-hole drying)



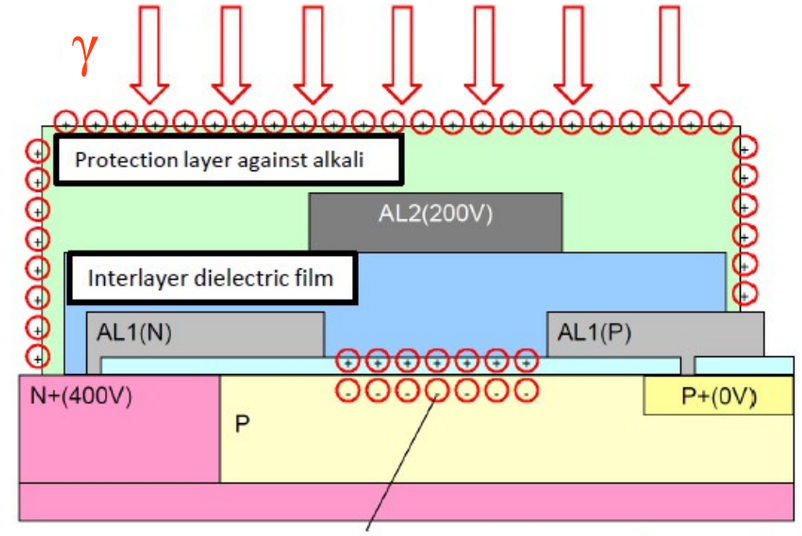


HAPD radiation hardness

Requirement for 10 years Belle II operation:

HAPD should keep performance for irradiation of

- 1000 Gy γ
- 1.0×10^{12} neutron / cm^2



1. Positive charges accumulate in the interlayer dielectric film **and/or** the protection layer against alkali
2. P layer under it changed to "N" layer
3. P-"N" junction around the APD sensitive region breaks down

APD degradation scenarios

- For γ:

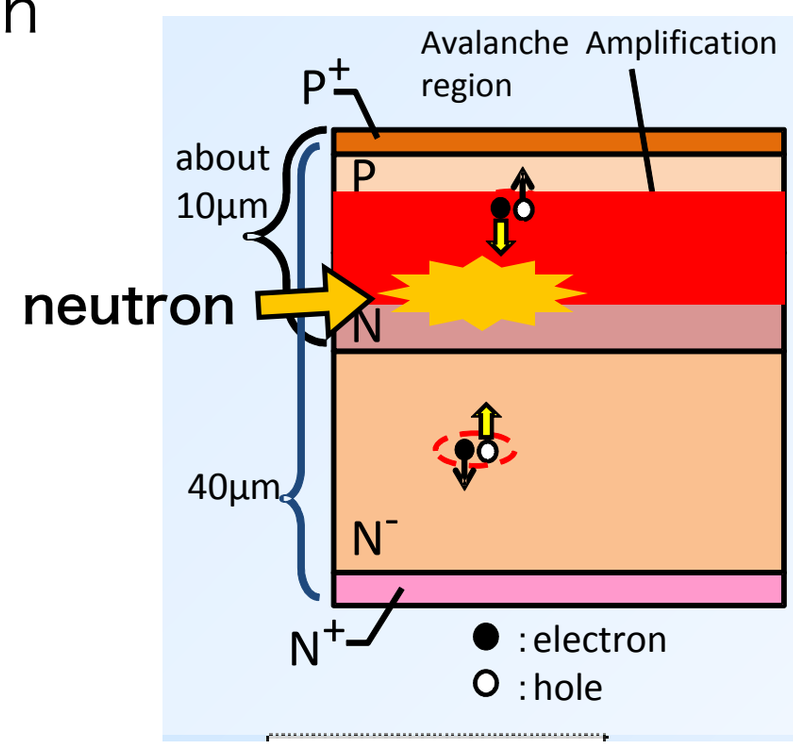
  Charge around structure on APD surface.

  → Degrade breakdown HV and can not reach enough APD gain.

- For neutron:

  Neutron induce lattice defects in bulk and leakage current increases.

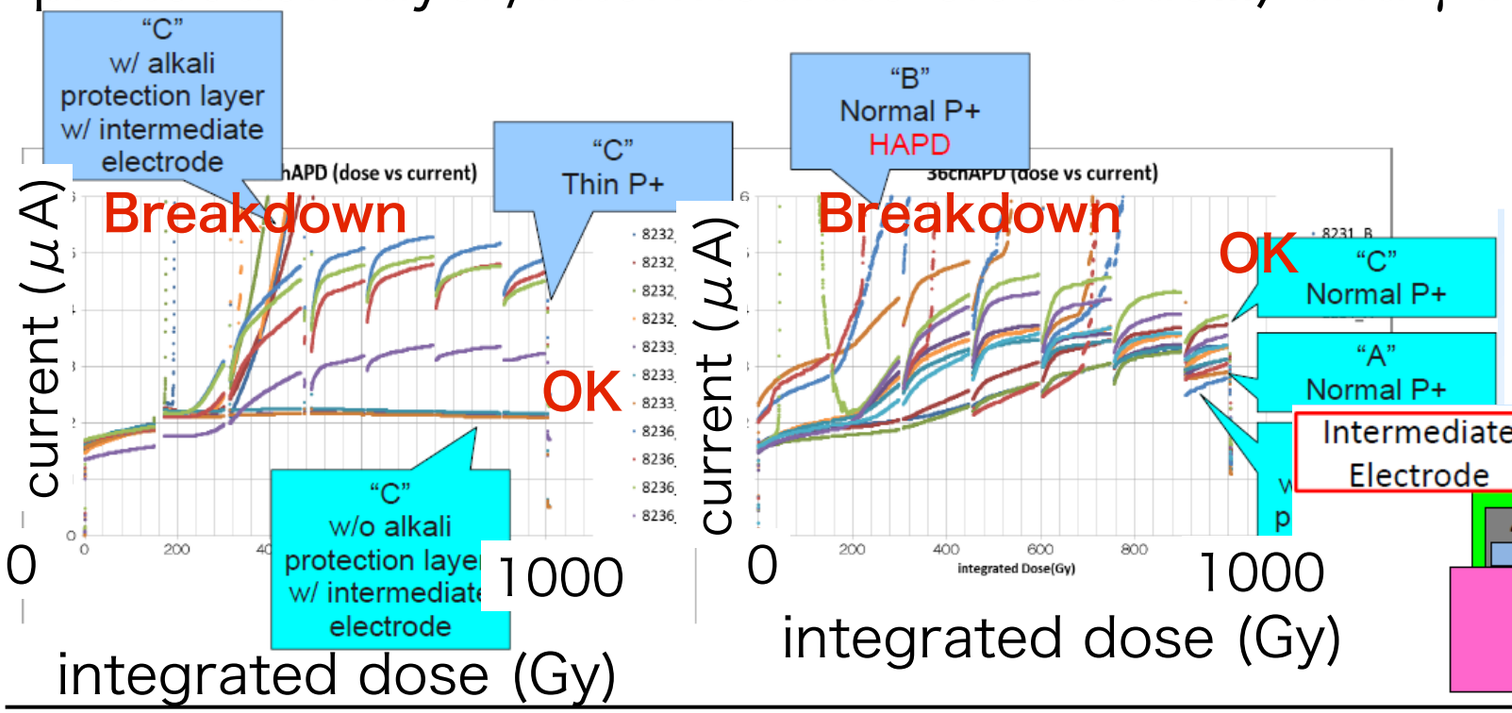
  → S/N becomes worse.



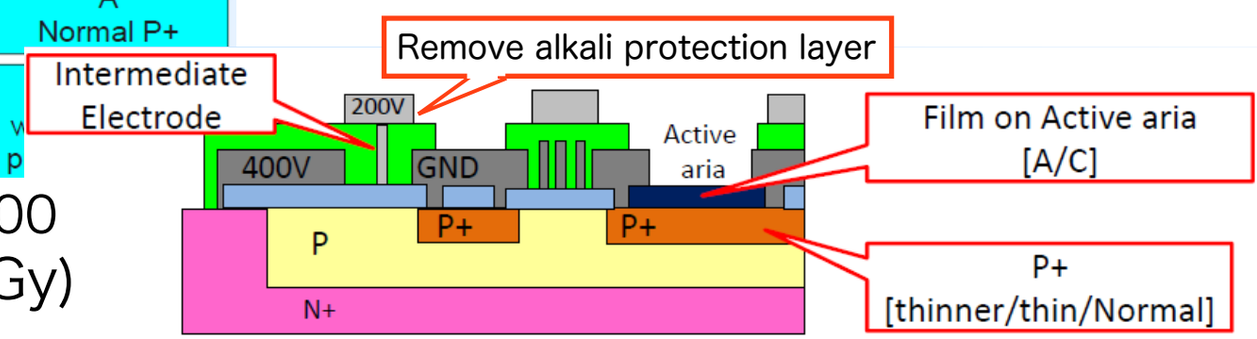
⇒ Perform irradiation tests and determine APD design and materials to minimize the effect.

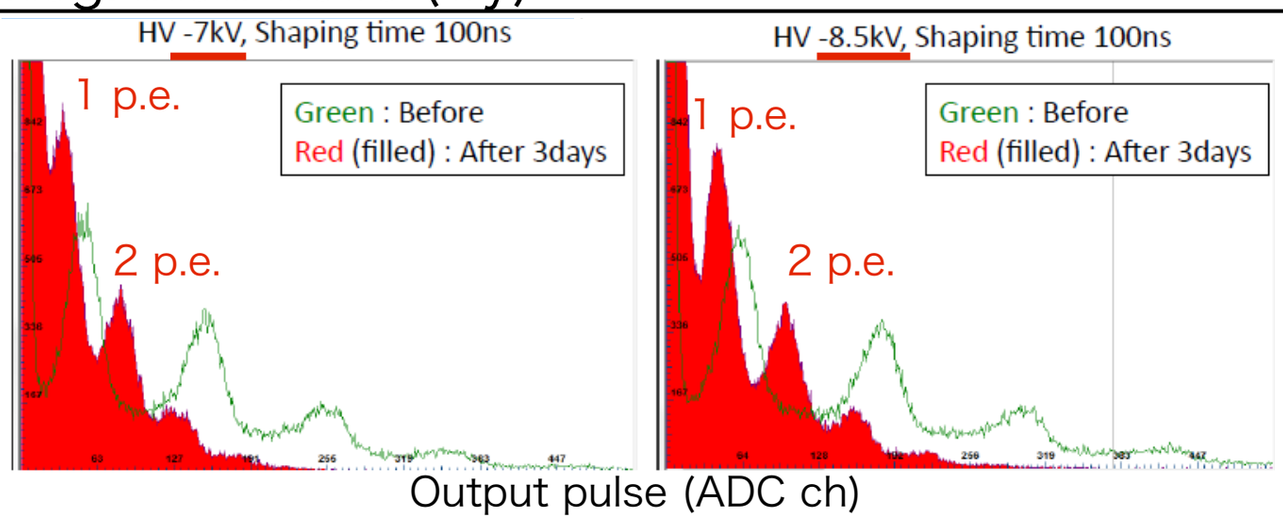
HAPD radiation hardness test

Changing APD structure (active area window film material, w/ or w/o alkali protection layer/intermediate electrode...) and γ irradiation tests have been done.

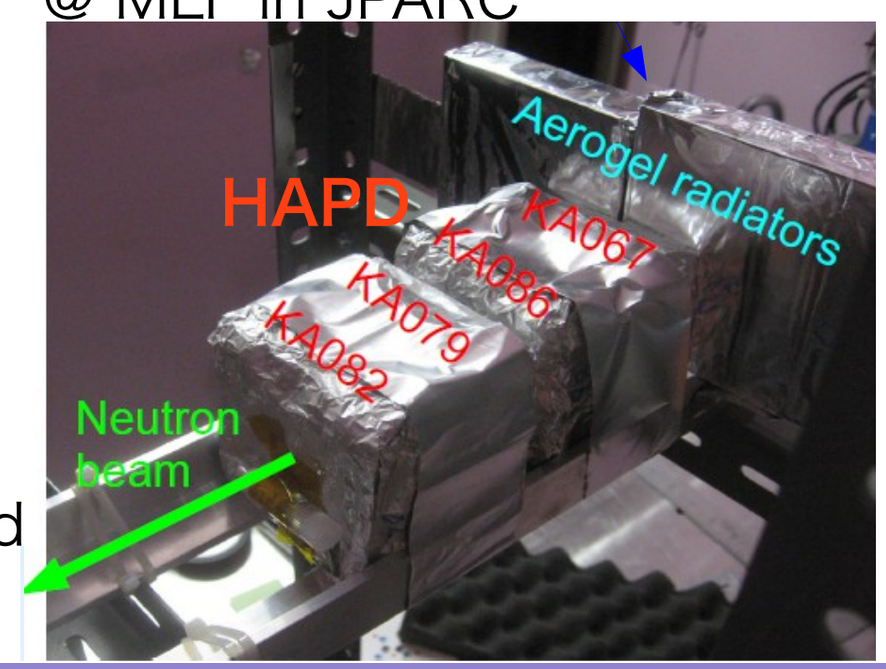


⇒ Changing the structure on APD surface prevents breakdowns.





Neutron irradiation setup @ MLF in JPARC

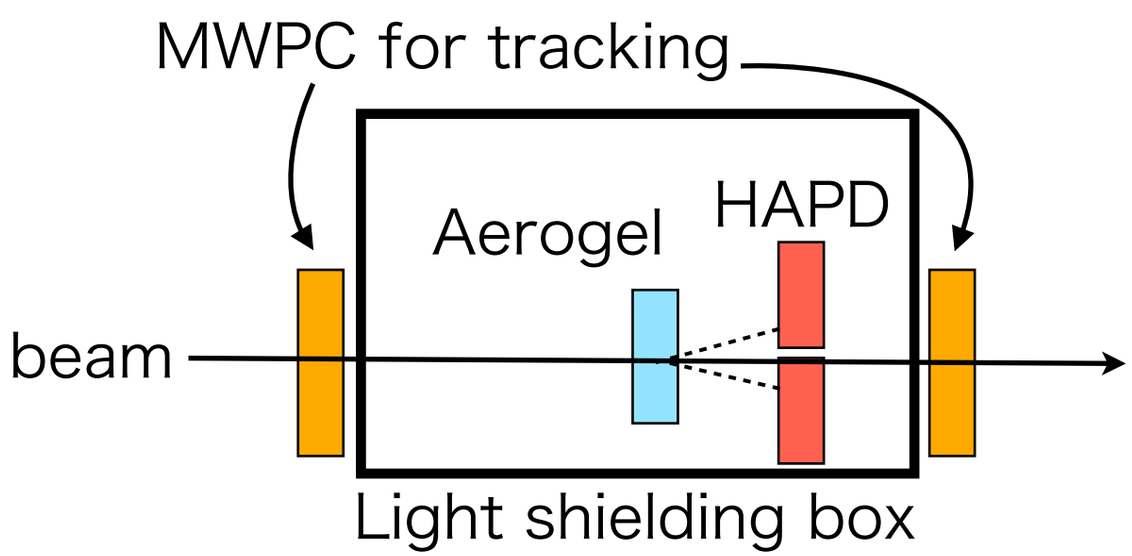


⇒ Thinner P/P+ layer structure improves S/N.
S/N can be further improved by increasing of HV and optimization of shaping time in front-end electronics.

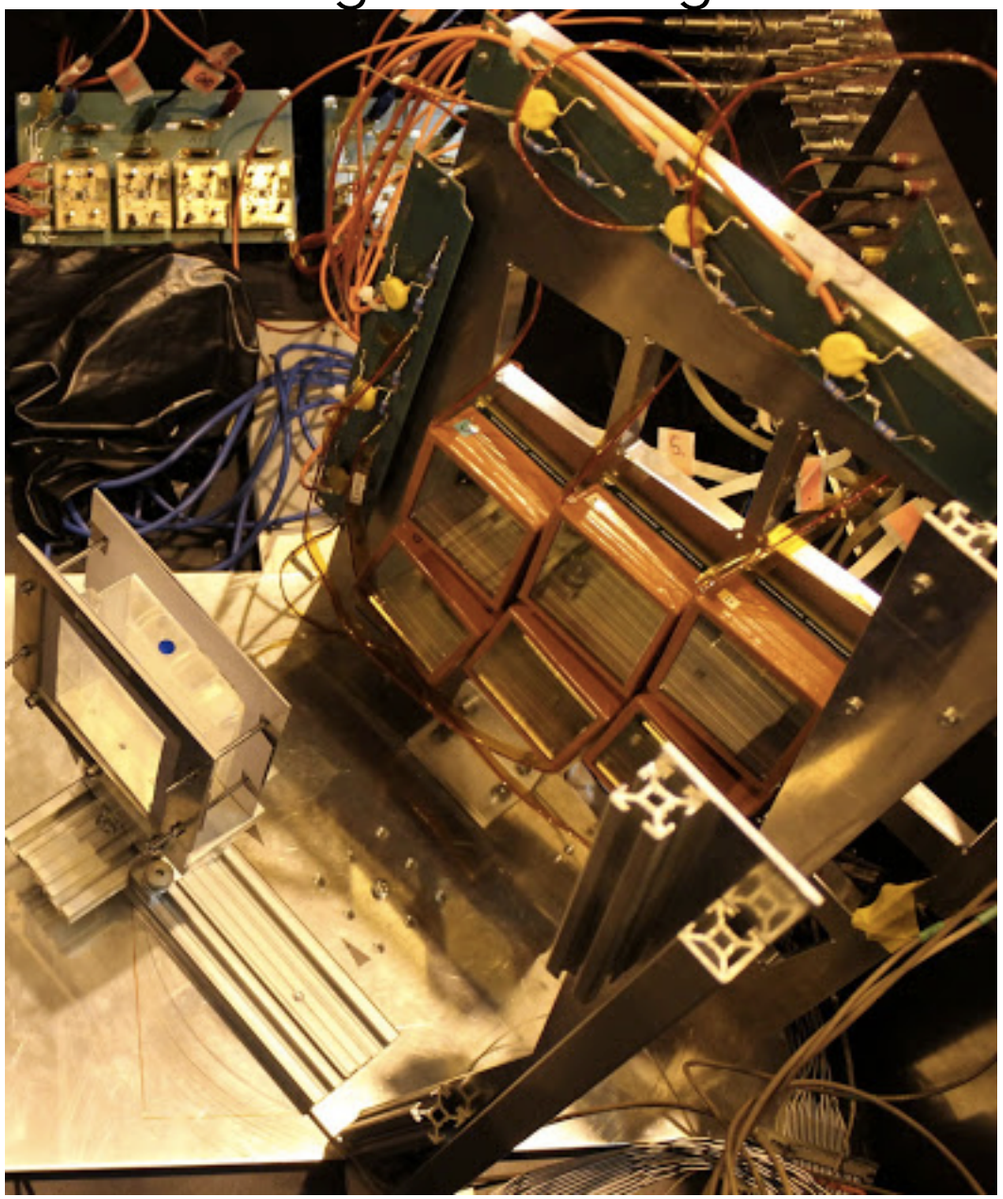
Beam test

Setup prototype ARICH with 6 HAPDs in real geometry and check performance for hadron beam @SPS in CERN and electron beam @DESY and Fuji exp. hall in KEK.

Several setups and checks of performance.
- Different refractive index of aerogel.
- At different track incident angles.
- Readout front-end ASIC settings.
- Neutron/γ irradiated HAPD.



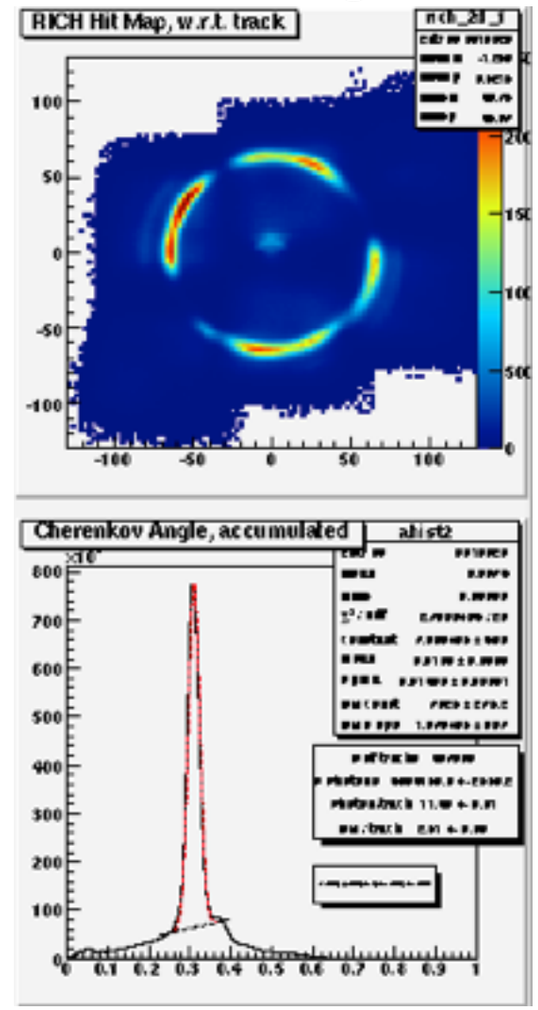
Picture in light shielding box



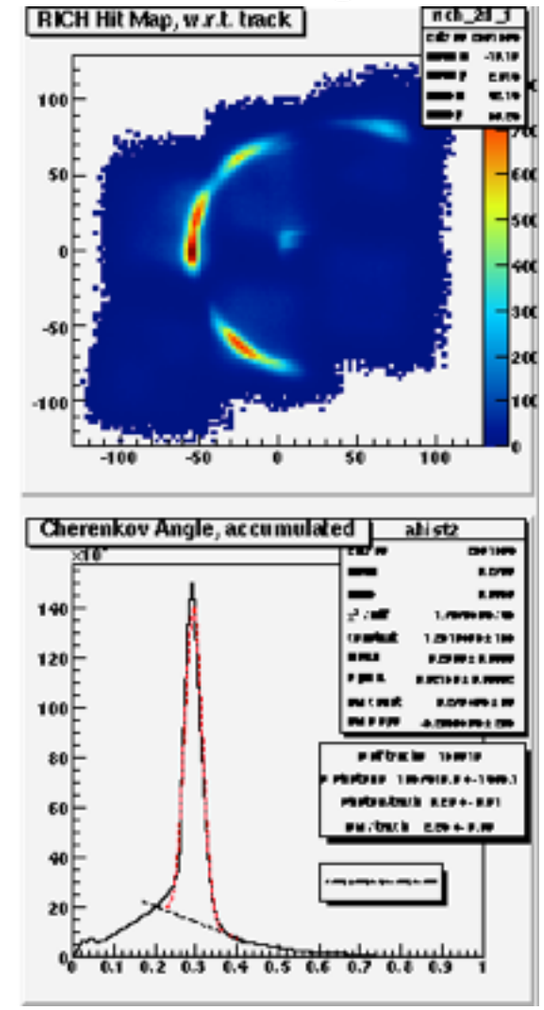
Beam test result

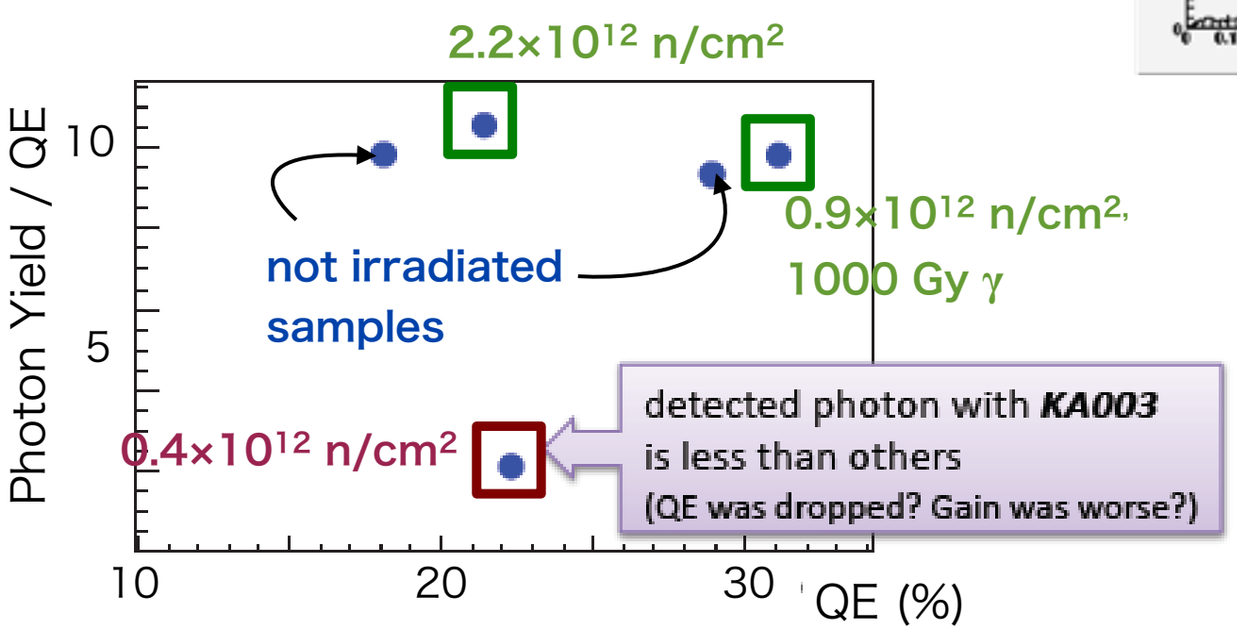
- Simple performance estimation from cumulative Cherenkov angle distribution:
  $\Delta\theta_C$ = 14.1 mrad, $N_{p.e}$ = 11.4.
  ⇒ K/π separation = 5.5σ
  (SPS 120 GeV/c hadron beam, incident angle = 0° case, similar for non-zero incidence)
- Neutron/γ irradiated HAPD works well after HV/readout parameter tuning. (preliminary)

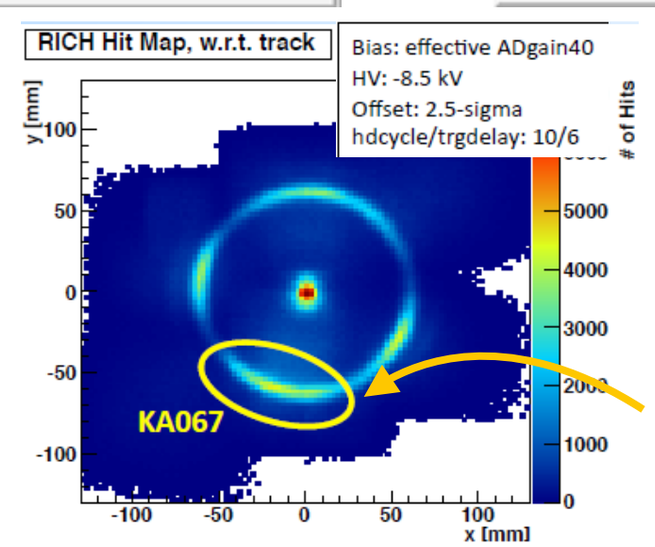
Incident angle = 0°



Incident angle = 30°







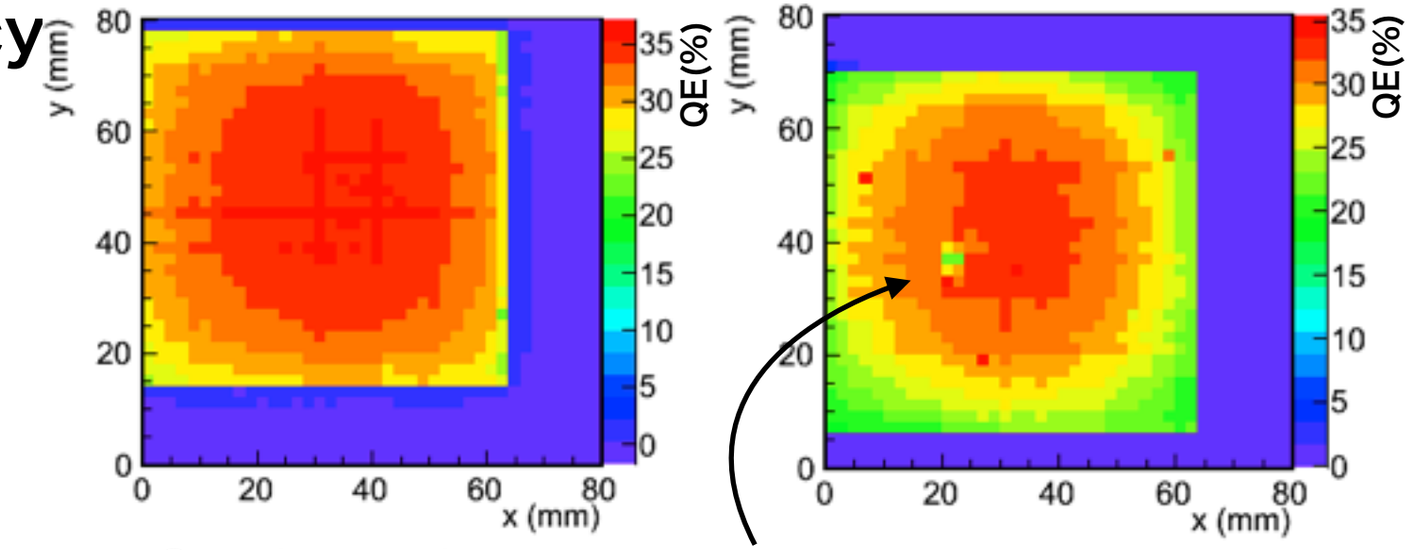
Ring image from irradiated HAPD

Validation system for HAPD

Photocathode Quantum efficiency (QE) measurement system

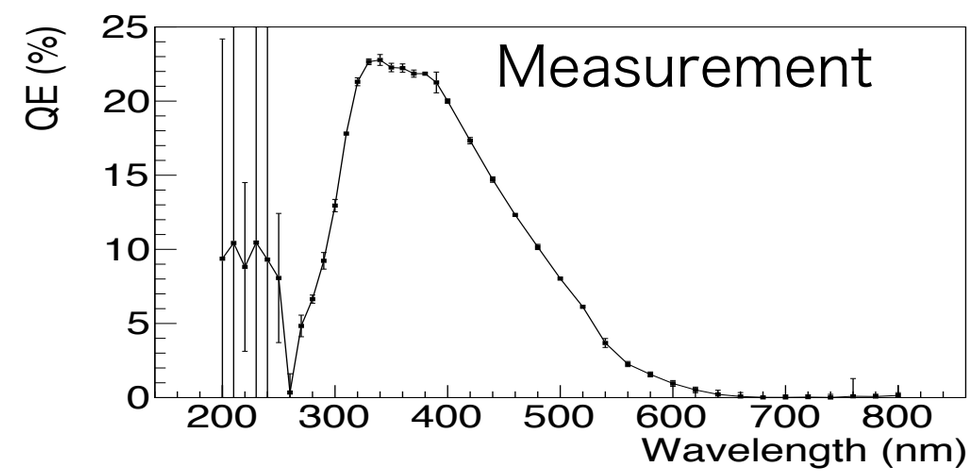
Illuminate monochromatic spot light and measure photoelectric current together with reference photo diode.

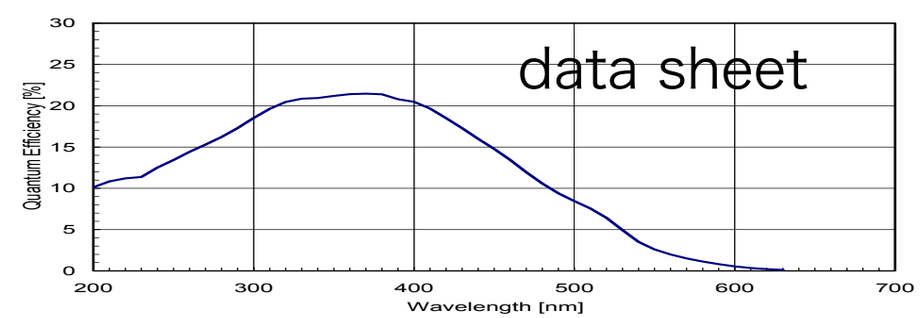
- 2D scan on whole effective area.
- Wavelength dependence.

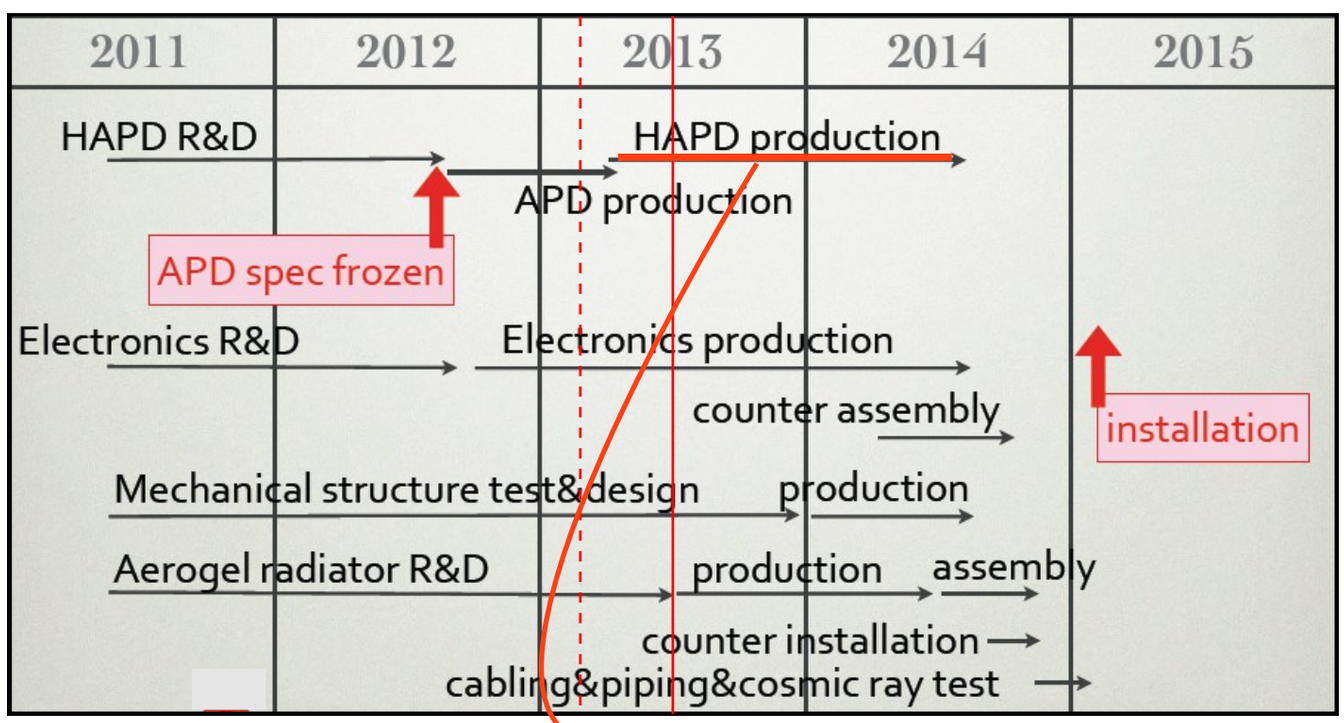


Good sample

Damage on photocathode







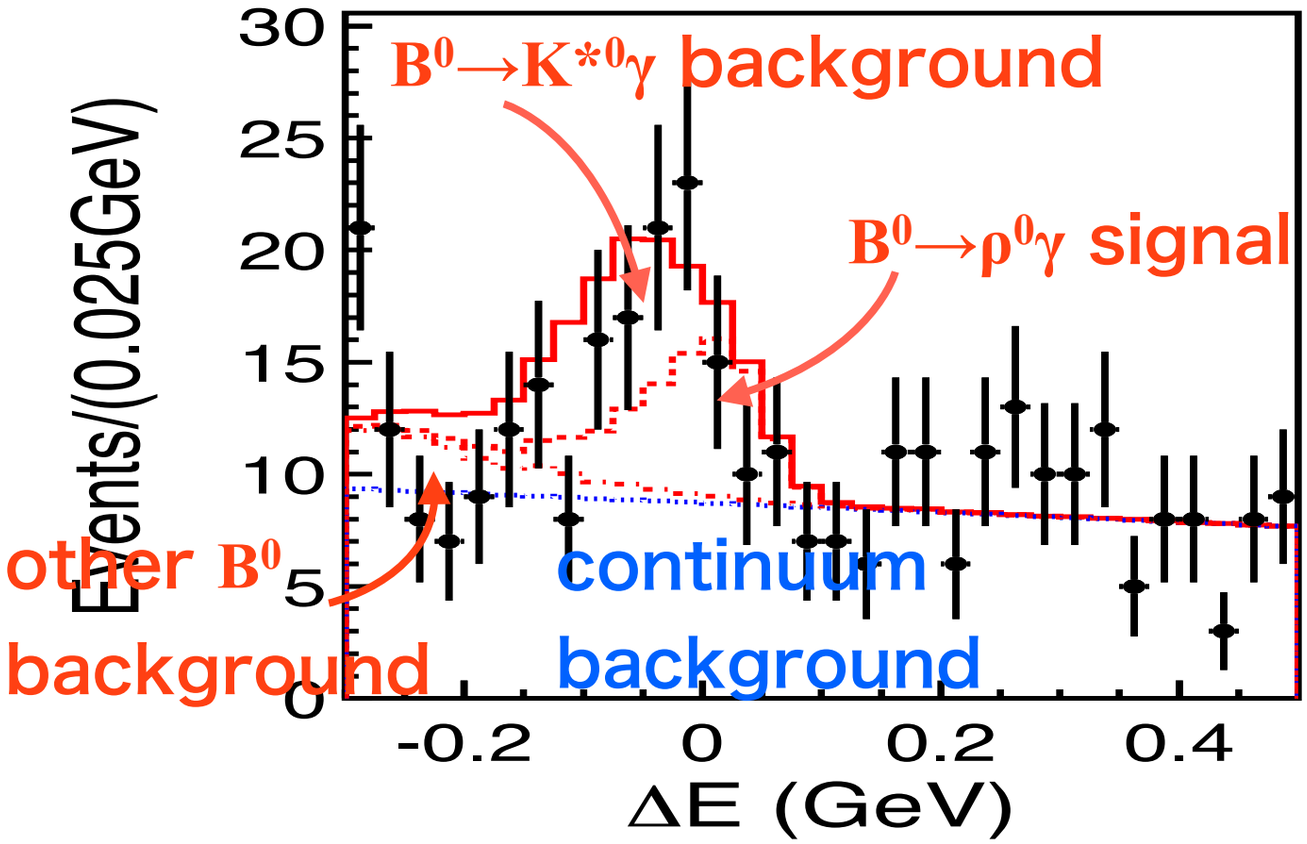
All produced 450 HAPDs are checked before installation.

Summary

- **For endcap PID in Belle II, ARICH detector will be installed.**
  Identify charged particles using information of Cherenkov ring image.
- **To detect Cherenkov photon position with high efficiency, a new device (HAPD) has been developed.**
  Hybrid amplification with electric field between photocathode and sensor part and 5 mm pixelated 144 channels APD (total gain ~7×10^5).
- **HAPD design is determined by results of radiation hardness tests.**
  HAPD samples after neutron/γ irradiation corresponding to 10 years Belle II operation perform well in beam test.
- **New technique was introduced for aerogel production process for high transparency/refractive index sample.**
- **Beam test result with prototype ARICH satisfies requirement from physics motivation.**
  Achieve >5σ separation power for K and π. (Simple estimation from single photon Cherenkov angle resolution and number of detected photon hits)
- **Production of final version electronics and HAPD will start soon and ARICH will be installed at beginning of 2015.**

backup

PID impact on physics analysis

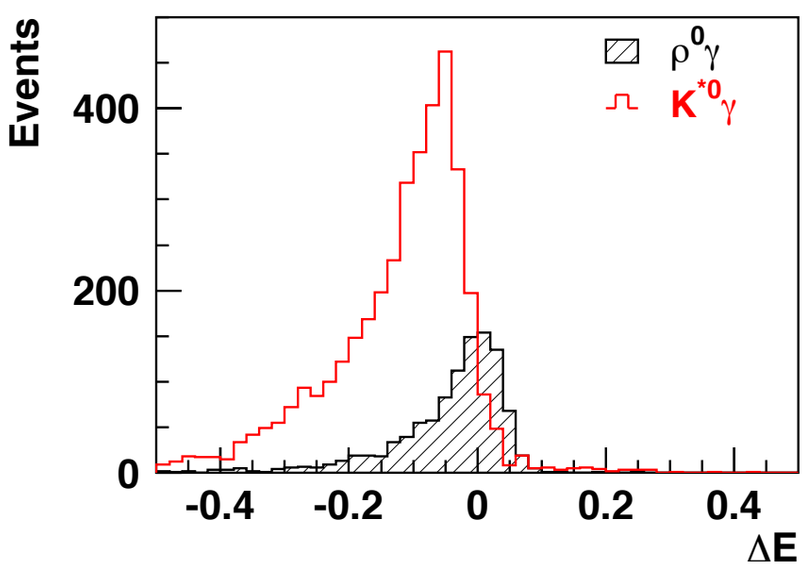


Belle experimental data (657 million $B\bar{B}$ sample)

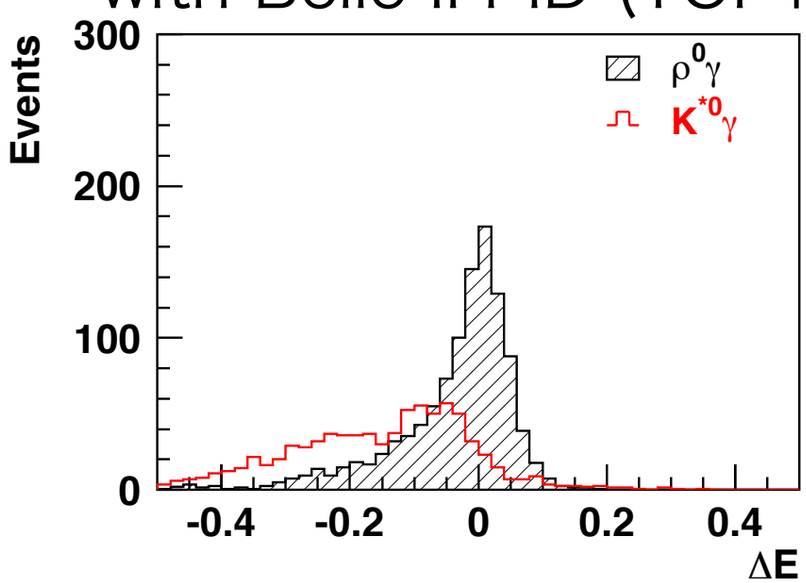
ΔE: energy difference between reconstructed B^0 and beam

Belle II 7.5 ab^{-1} expectation from MC

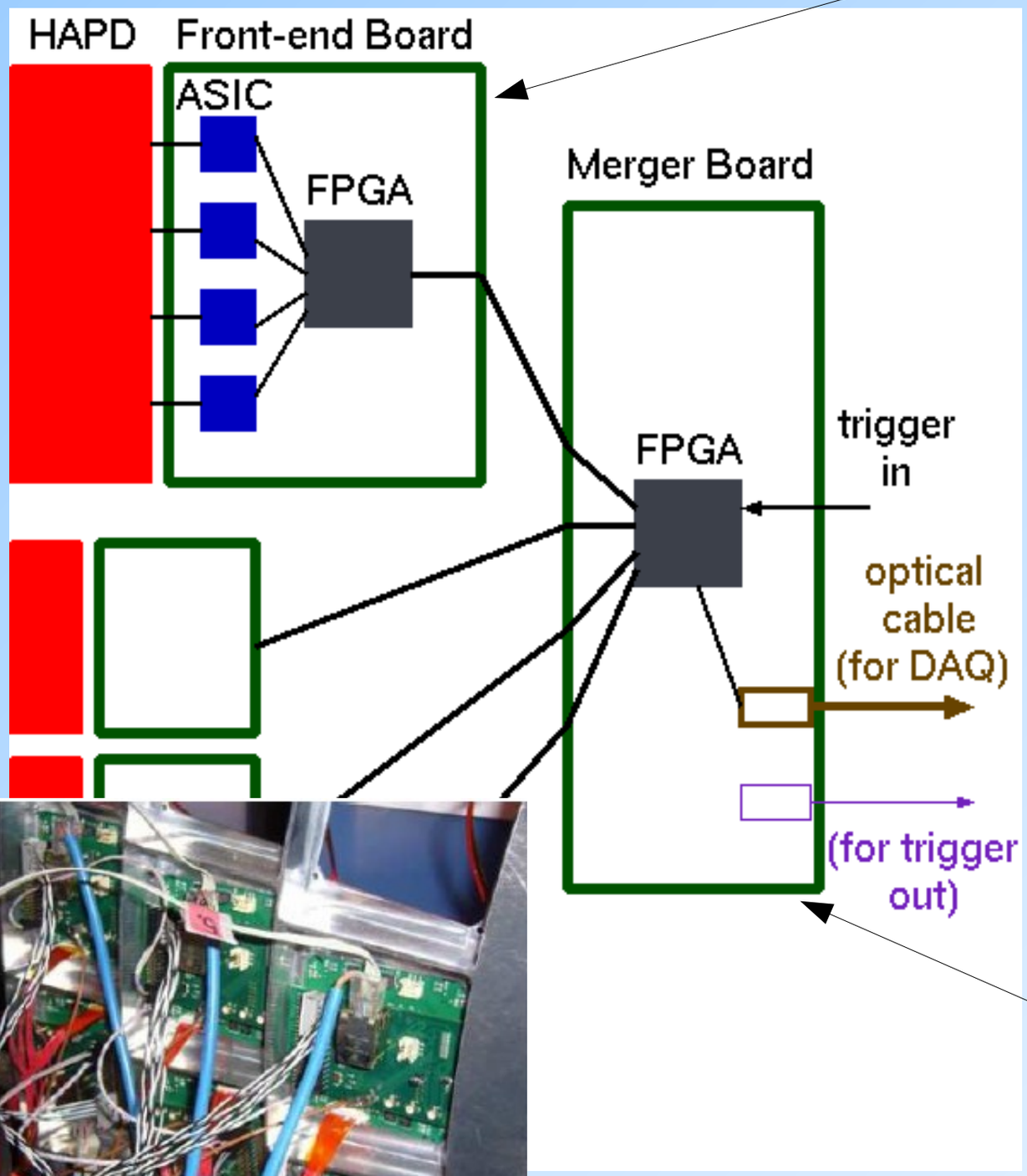
with Belle PID

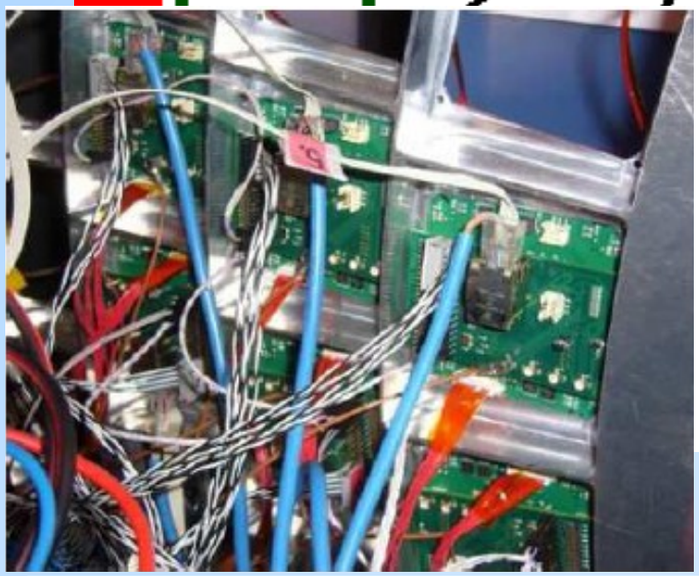


with Belle II PID (TOP+ARICH)



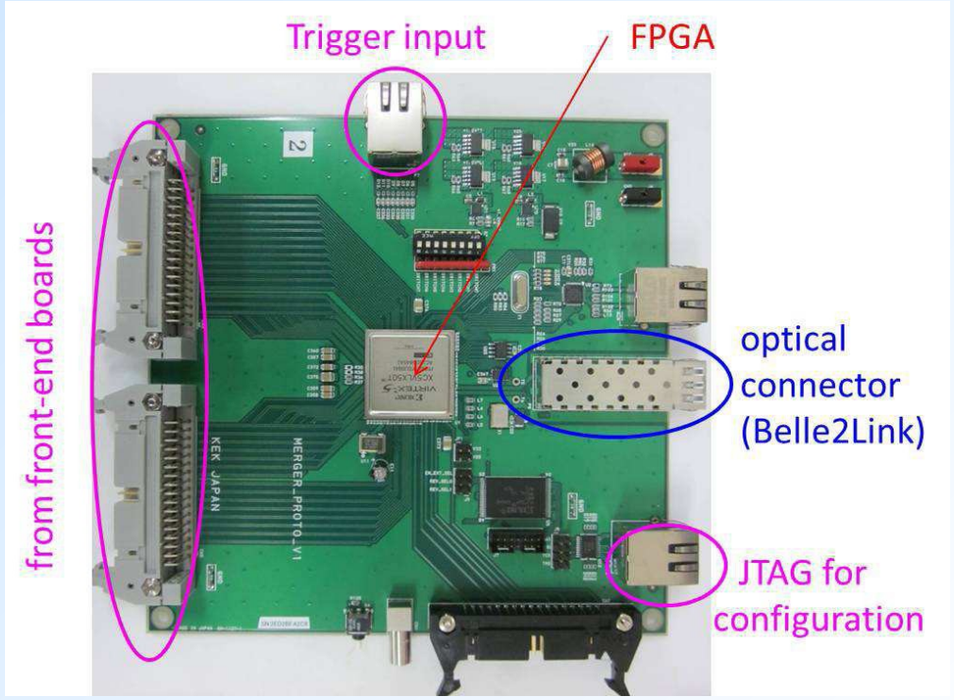
ARICH readout electronics

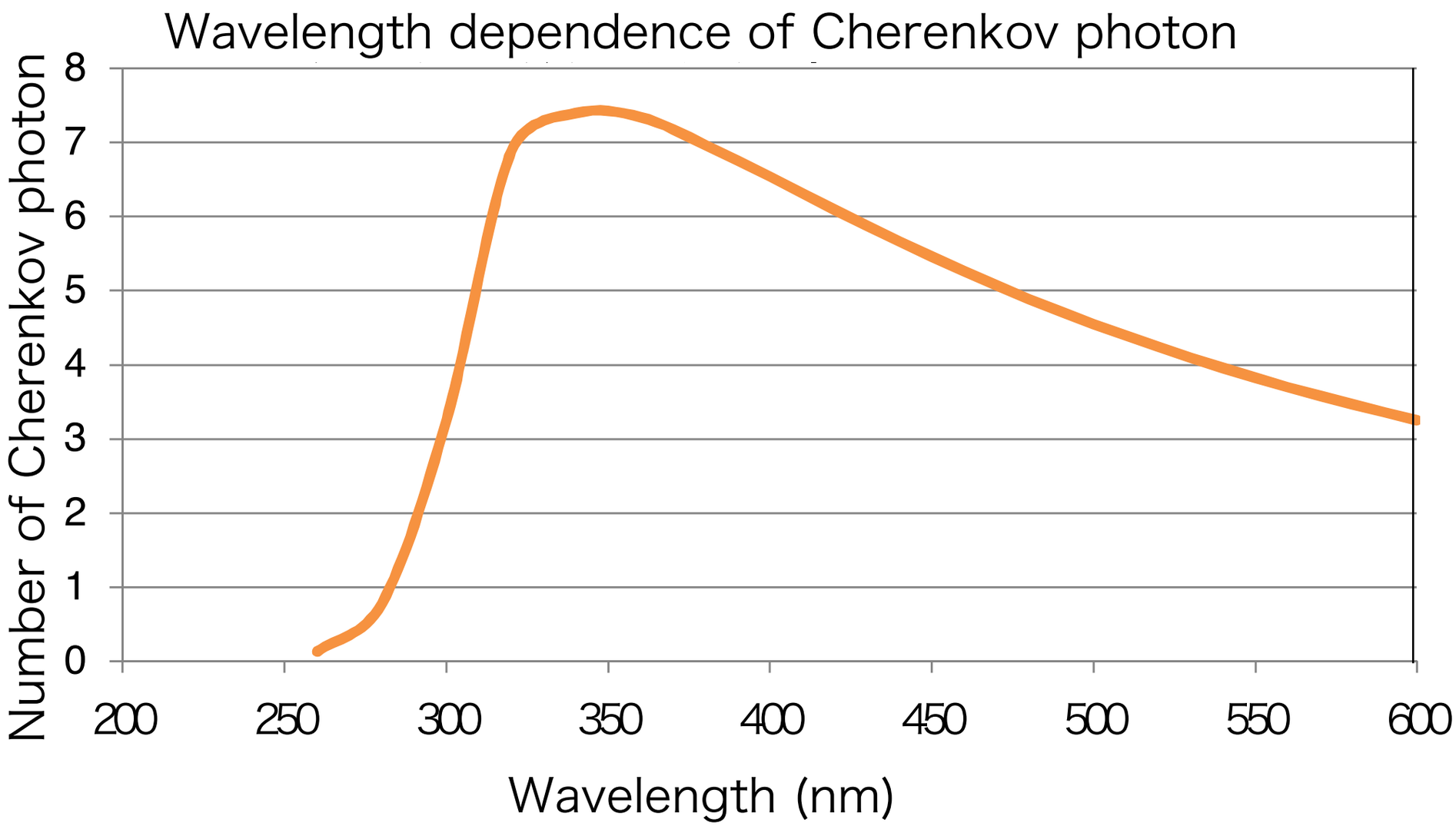




- Front-end board with 4 ASICs and Spartan6 FPGA

- Merger board prototype with Virtex5 FPGA

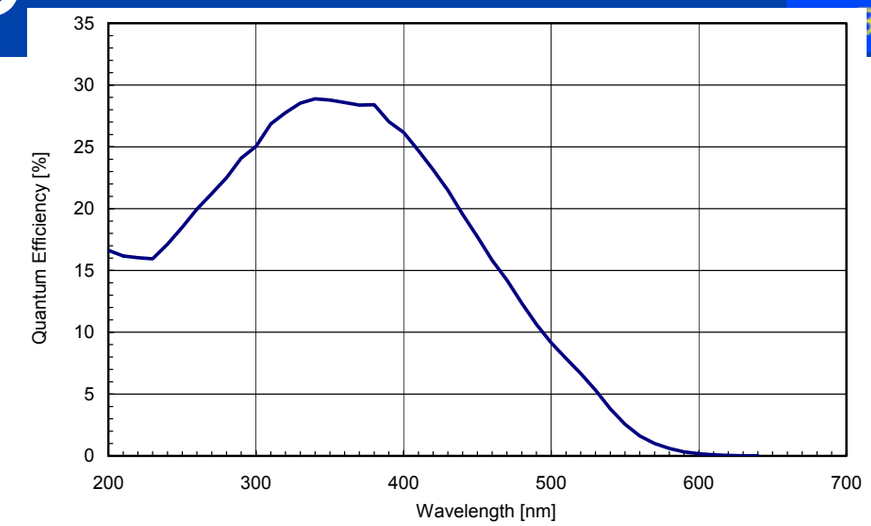


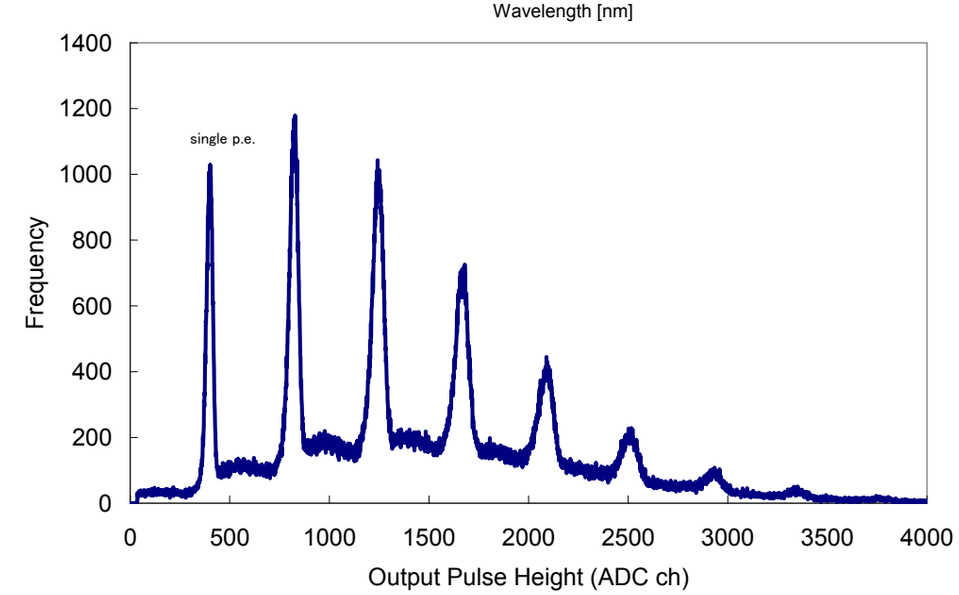

Wavelength dependence of Cherenkov photon
Number of Cherenkov photon
0
1
2
3
4
5
6
7
8
200
250
300
350
400
450
500
550
600
Wavelength (nm)

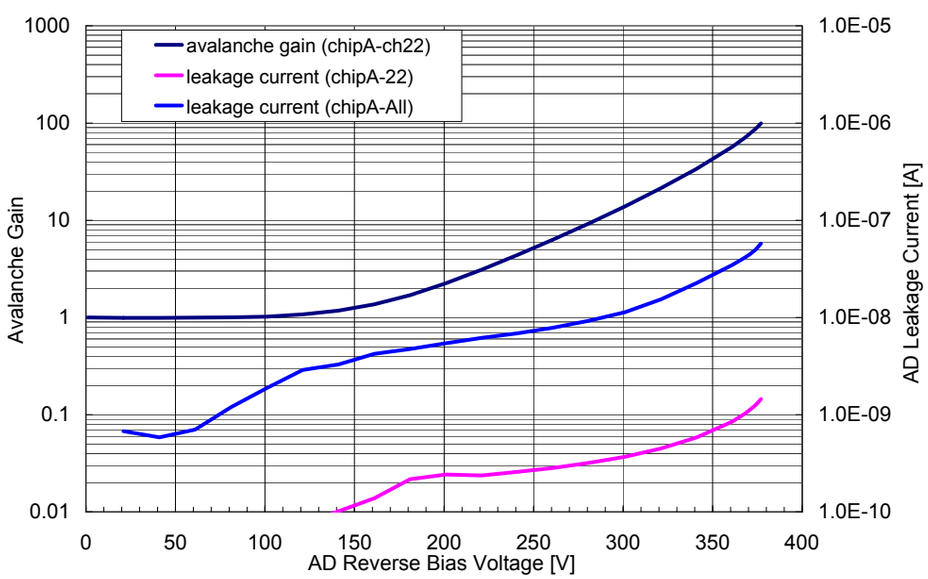
Typical HAPD performance

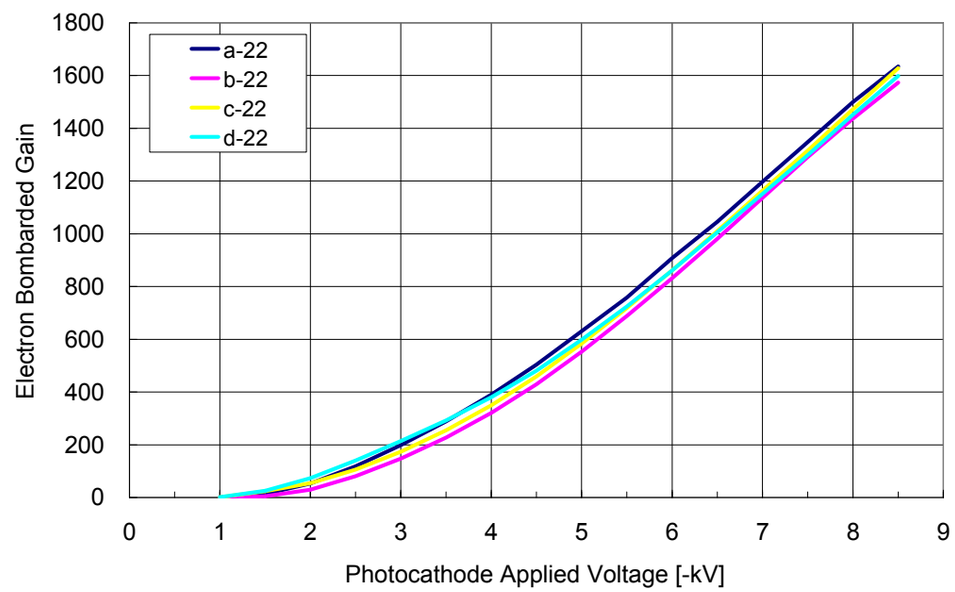
(data sheet)

	KA0041		
Quantum efficiency	400nm	26.2	%
	peak	28.9	%
Maximum high voltage	−8500		V
Bad channel	A	None	
	B	None	
	C	None	
	D	ch1	
Maximum high voltage for each APD chip	A	377	V
	B	368	
	C	364	
	D	377	
Maximum gain	A−ch22	161900 (8.5kV, 377V)	
	B−ch22	164600 (8.5kV, 368V)	
	C−ch22	104000 (8.5kV, 364V)	
	D−ch22	162500 (8.5kV, 377V)	









Photocathode Voltage: -8kV
AD Reverse Bias Voltage: 341V
Guard Voltage: +200V
Amplifier: Clear-Pulse 580K
Light Source: LED 470nm, 2kHz

HAPD performance

item		typical	requirement
QE	λ=400nm	28%	>=24%
bias voltage		250-500V	
leakage current	each ch at Vb-10V		<= 1μA
avalanche gain	each ch at Vb-10V		>=30
HV	-8.5kV		<= 300pA
bombardment gain	-8kV	1800	>=1500
Total gain	-8kV at gain=30		>=45000

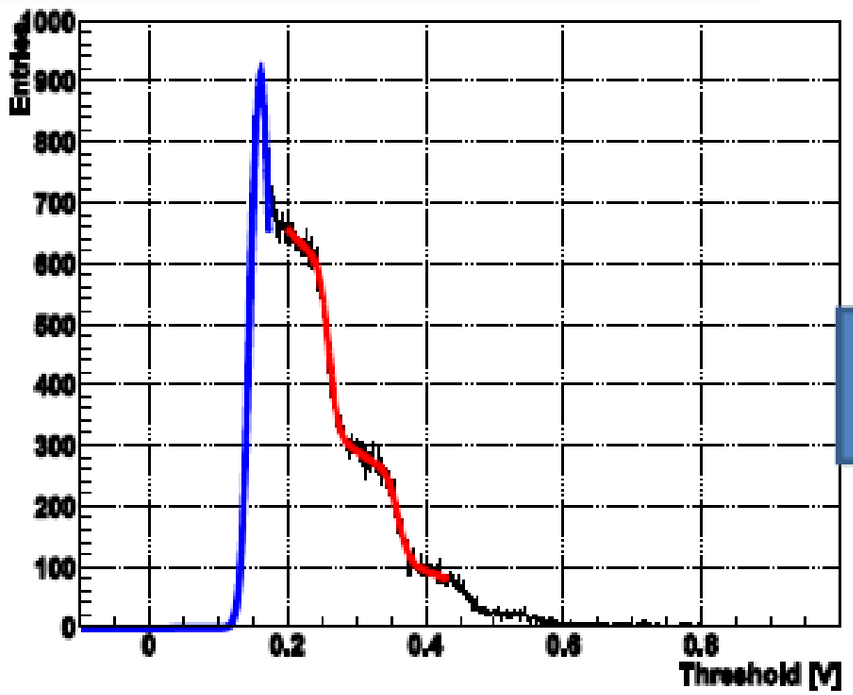
# of dead channels ≦ 10

(threshold scan@SA03)

KA058
Film A
Electrode ○
P+ thin
Neutron
8.5*10^11

*measured
by SA03(X-FAB,QFP)
(shaping time 100ns)

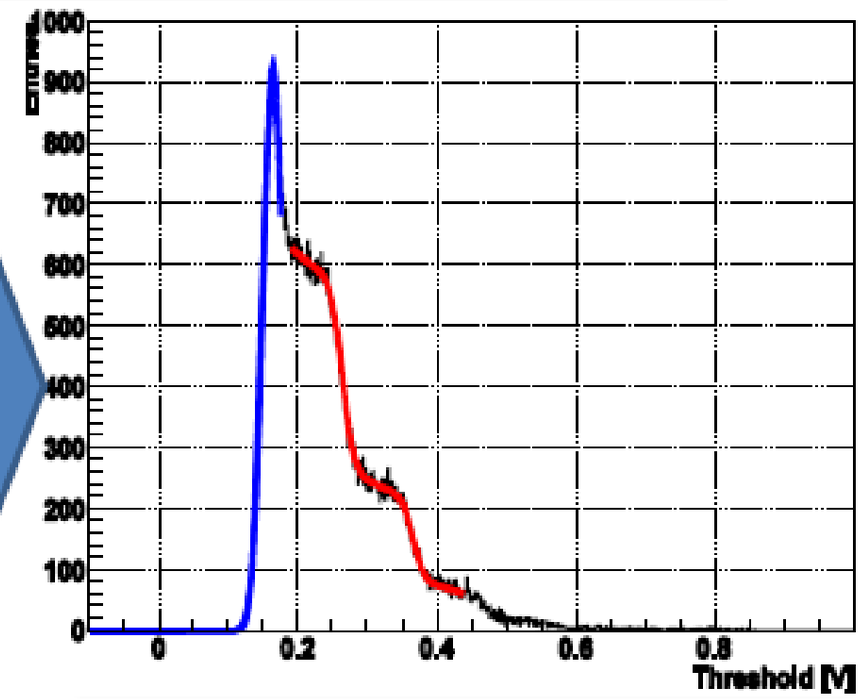
Before Gamma Irradiation



chip A-34ch:326.5V(17.26μA)
HV:-8.5kV

noise(gaus0) = 5464.03[e-]
2pe - 1pe = 39137.45[e-]
S/N(2pe-1pe/sigma0) = 7.16

After Gamma Irradiation



chip A-34ch: 326.5V(17.02μA)
HV:-8.5kV

noise(gaus0) = 5665.96[e-]
2pe - 1pe = 39763.47[e-]
S/N(2pe-1pe/sigma0) = 7.02

- **Noise Level & Total Gain dose not change before and after irradiation.**

Registration is now opening.

http://rich2013.kek.jp

Abstract deadline is 31 July.