VCI 2013, 11.-15.2.2013, Vienna

Aerogel RICH for the Belle II spectrometer

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Outline

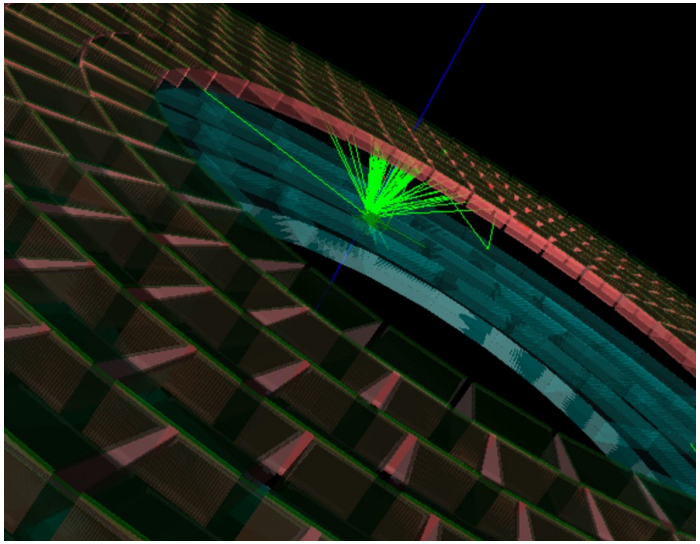
Introduction

Requirements

Design

Expectations and beam test results

Summary



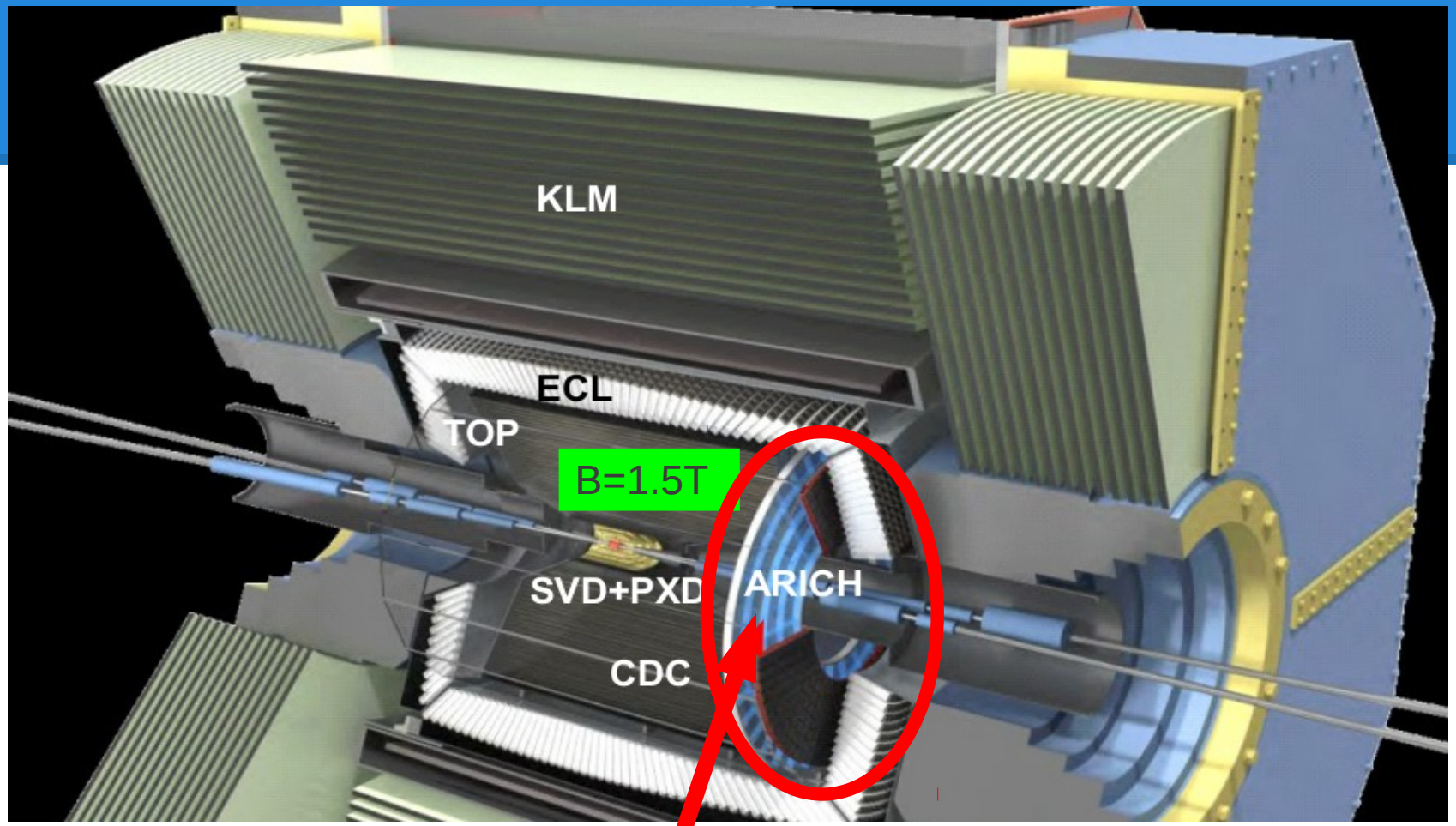
Belle II at SuperKEKB B factory

- Precision measurements of rare B , D and τ decays

- SuperKEKB will deliver 40 times higher event rates.
- Belle II will collect 50ab^{-1} by 2022 → 50 times larger data set compared to Belle experiment.
  - Higher rates
  - Much higher backgrounds

→ Significant upgrade of the detector needed.

Particle identification in Belle II



Two dedicated particle ID devices - both RICHes – designed to fit into available space:

- Barrel: Time-Of-Propagation (TOP)

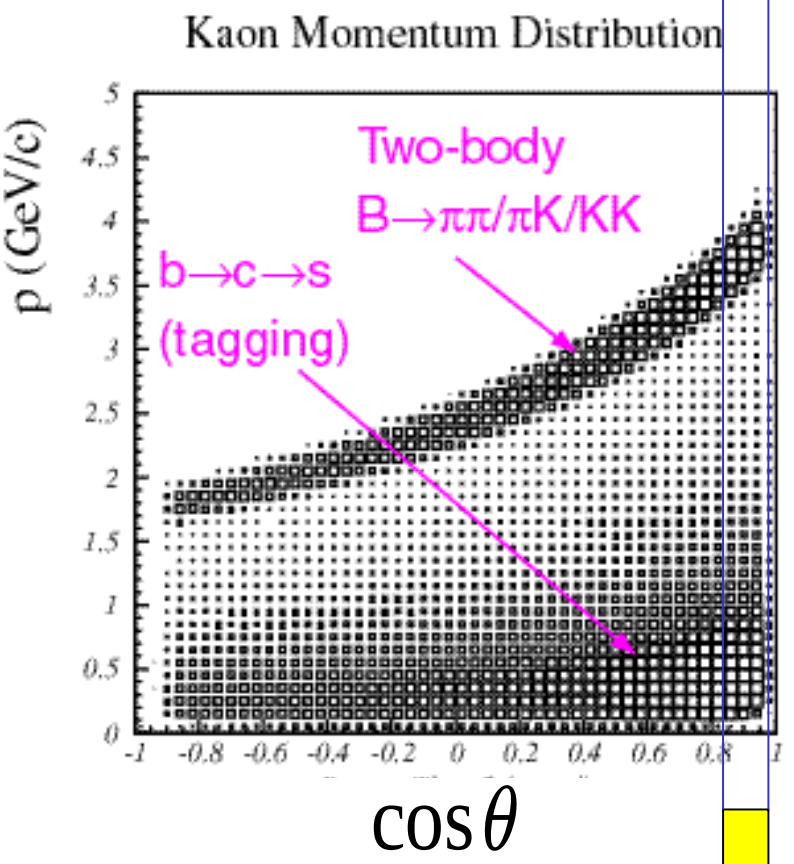
talk K. Matsuoka: Design and performance study of the TOP counter, Wednesday

- End-cap: **Proximity focusing Aerogel RICH (ARICH)**

Particle identification requirements

- improve π/K separation in the forward (high momentum) region for few-body B decays
- good π/K separation for

  b → d γ , b → s γ
- improve purity in fully reconstructed B decays
- low momentum (<1GeV/c) e/μ/π separation (e.g. for B → Kll)
- keep high the efficiency for tagging kaons

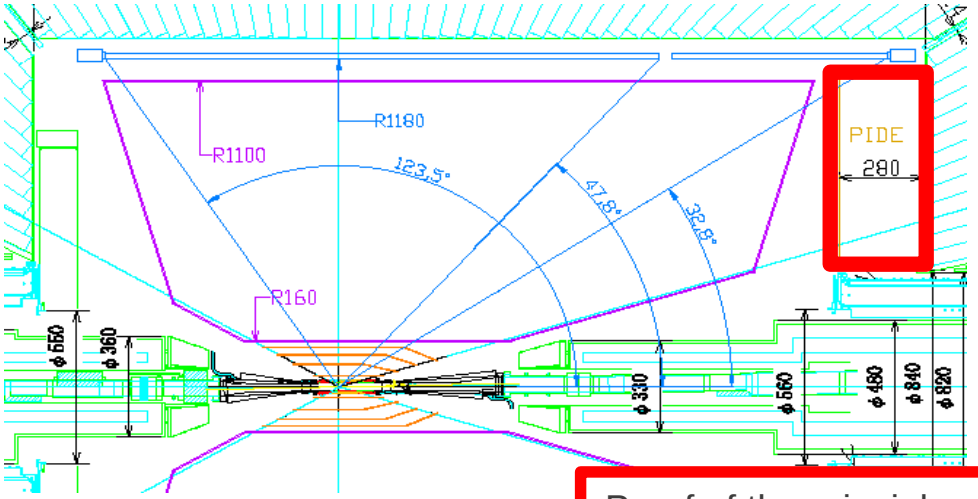


Forward endcap

Proximity focusing Aerogel RICH design

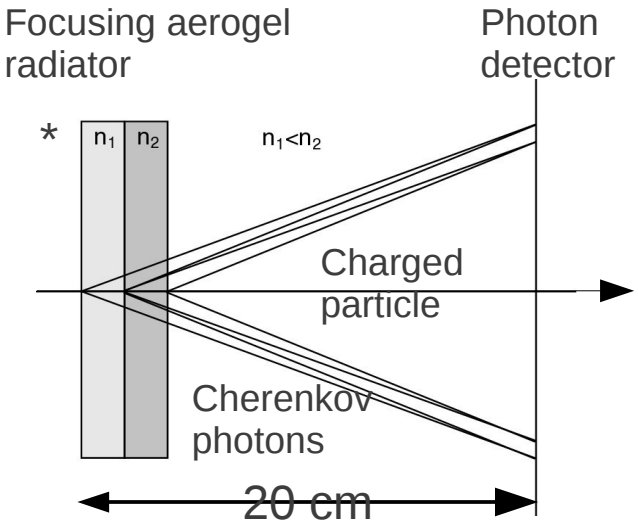
Goals and constraints:

- > 4 σ K/π separation @ 1-3.5 GeV/c
- operation in magnetic field 1.5T
- limited available space ~280 mm
- radiation tolerance (n,γ)



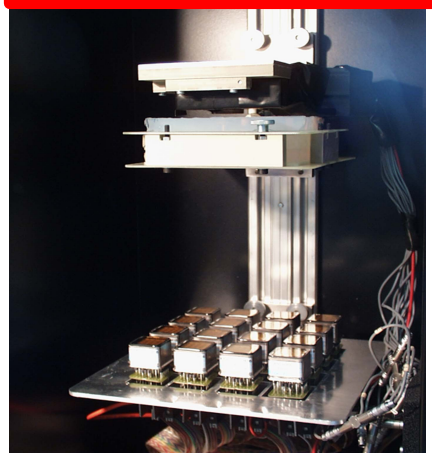
Selected type:

proximity focusing aerogel RICH



- <n> ~ 1.05
- $\theta_C(\pi) \approx 307$ mrad @ 3.5 GeV/c
- $\theta_C(\pi) - \theta_C(K) = 30$ mrad @ 3.5 GeV/c
  - pion threshold 0.44 GeV/c,
  - kaon threshold 1.54 GeV/c
- neutron fluence: up to ~10^{12} n/cm2
- radiation dose: up to ~1000 Gy

Proof of the principle with MA PMTs 2001



T.Iijima, S.Korpar et al. NIMA548 (2005) 383

* to increase the number of photons without degrading the resolution

Aerogel radiator

Highly transparent hydrophobic silica aerogel as a radiator

- Two 2cm thick layers $n_1 = 1.055$ $n_2 = 1.065$
- large tiles $18 \times 18 \times 2 cm^3$ to minimize photon losses at the edges

Two production methods:

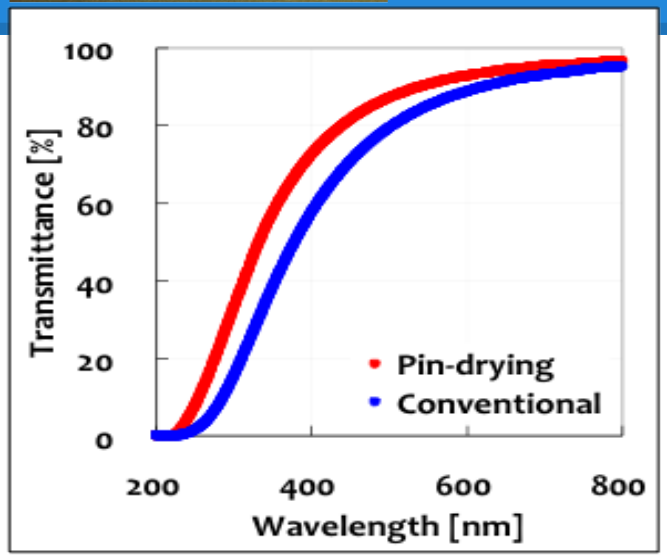
Conventional method:

- chemical synthesis process directly coupled to control of transparency and n
- Difficult to produce transparent aerogel with n>1.05
- ready for mass-production of 1.055 samples

New "pin-drying (PD)" method:

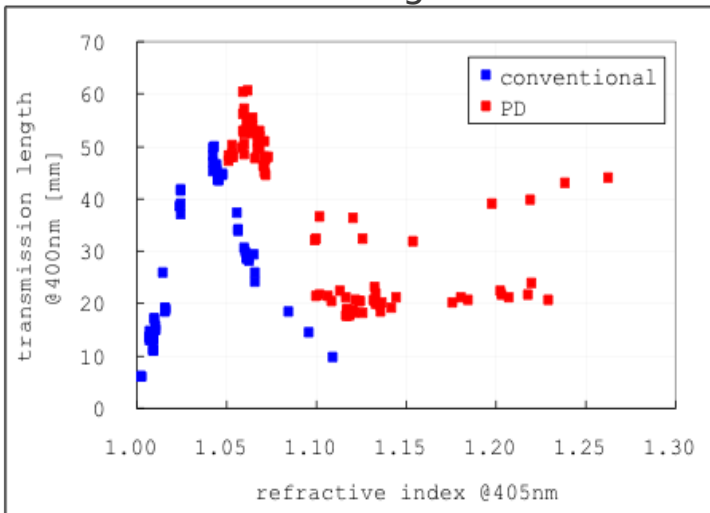
- transparency and index control (almost) decoupled
  - chemical synthesis → highly porous structure
    - excellent optical transparency
  - pin-drying → squeeze alcogel to adjust n
- we are optimizing the process to produce crack free samples of n=1.065 in a controlled way

see also poster: I.Adachi et al. Study of Highly Transparent Silica Aerogel for the Belle II RICH Counter



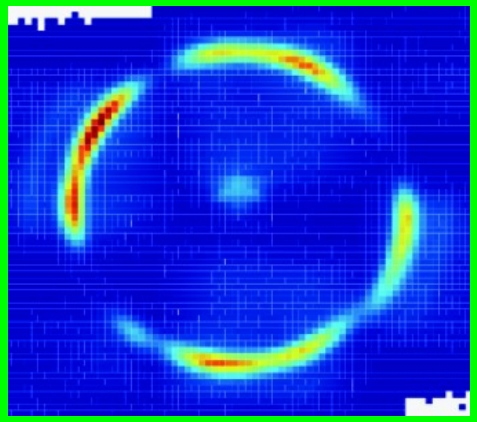
$I(\lambda) = I_0(\lambda) \exp[-d/\Lambda_T(\lambda)]$

Λ_T:transmission length d:thickness



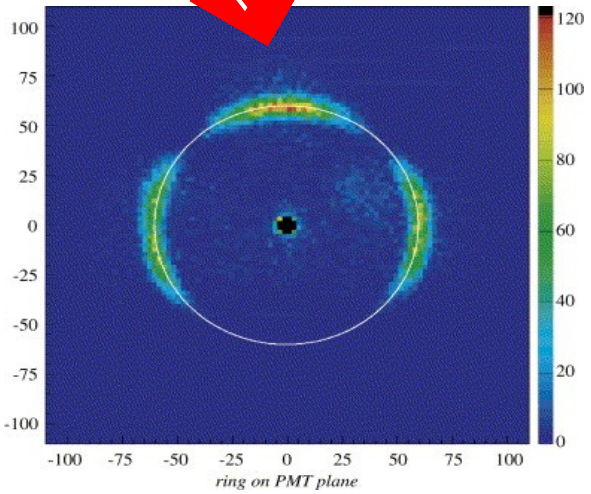
Choice of the photo sensor : 3 candidates

HAPD	64 ch. 10 μm MCP PMT	SiPM 1x1mm^2 + light guide



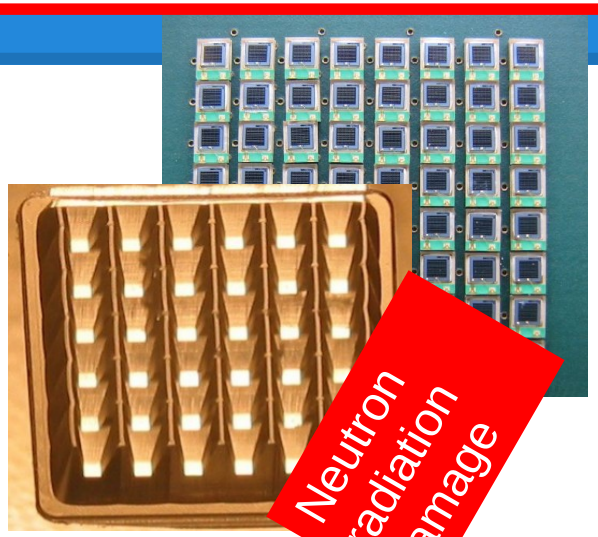
S.Nishida et al, NIMA610(2009)65

Aging

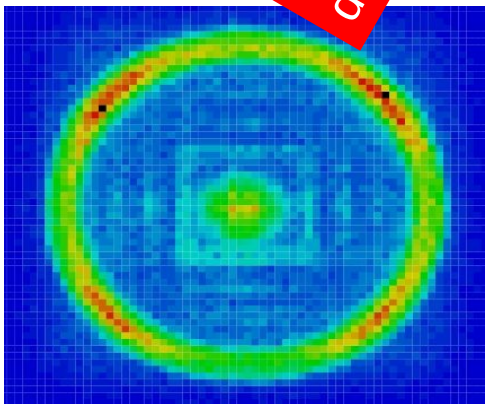


P. Križan et al, NIMA567 (2006) 124

S.Korpar et al, NIMA639 (2011) 162



Neutron radiation damage

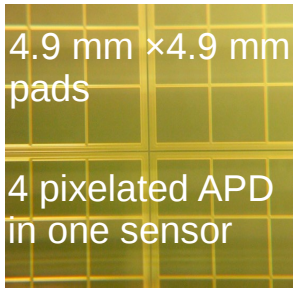


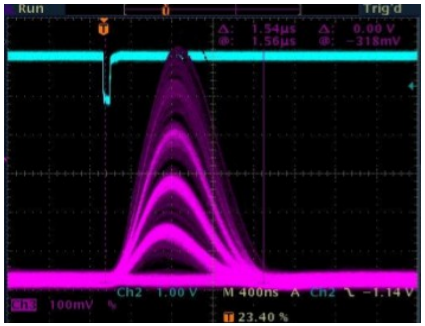
Extrapolated numbers: 4cm aerogel n=1.05, light guides → N_{det}=34

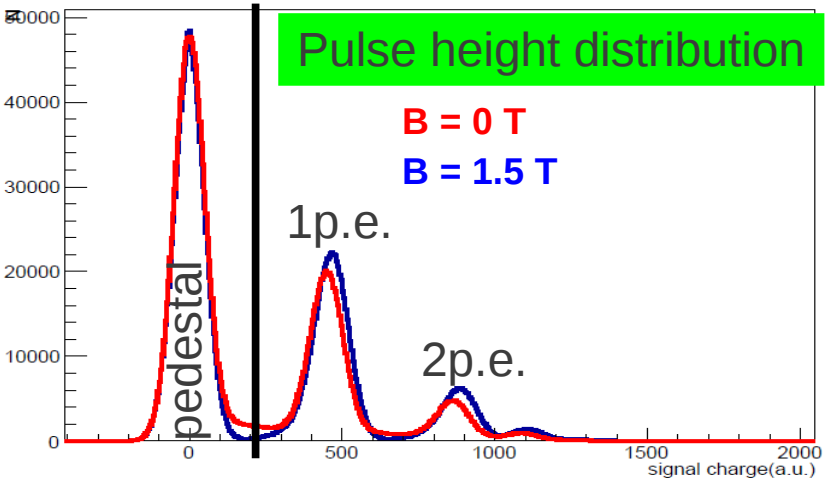
S.Korpar et al, NIMA613 (2010) 195

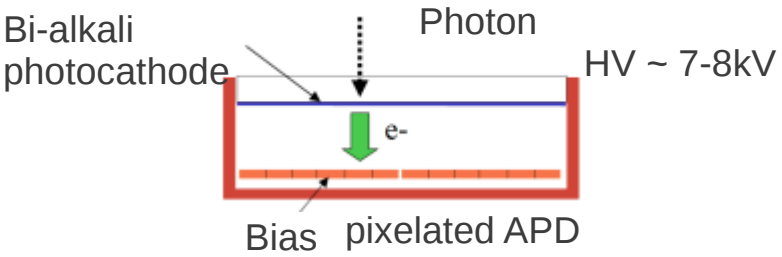
Hybrid Avalanche Photo-Detector

- 144 ch. HAPD developed with the Hamamatsu Photonics
- Excellent separation of single photoelectrons
- Works in a magnetic field of 1.5T





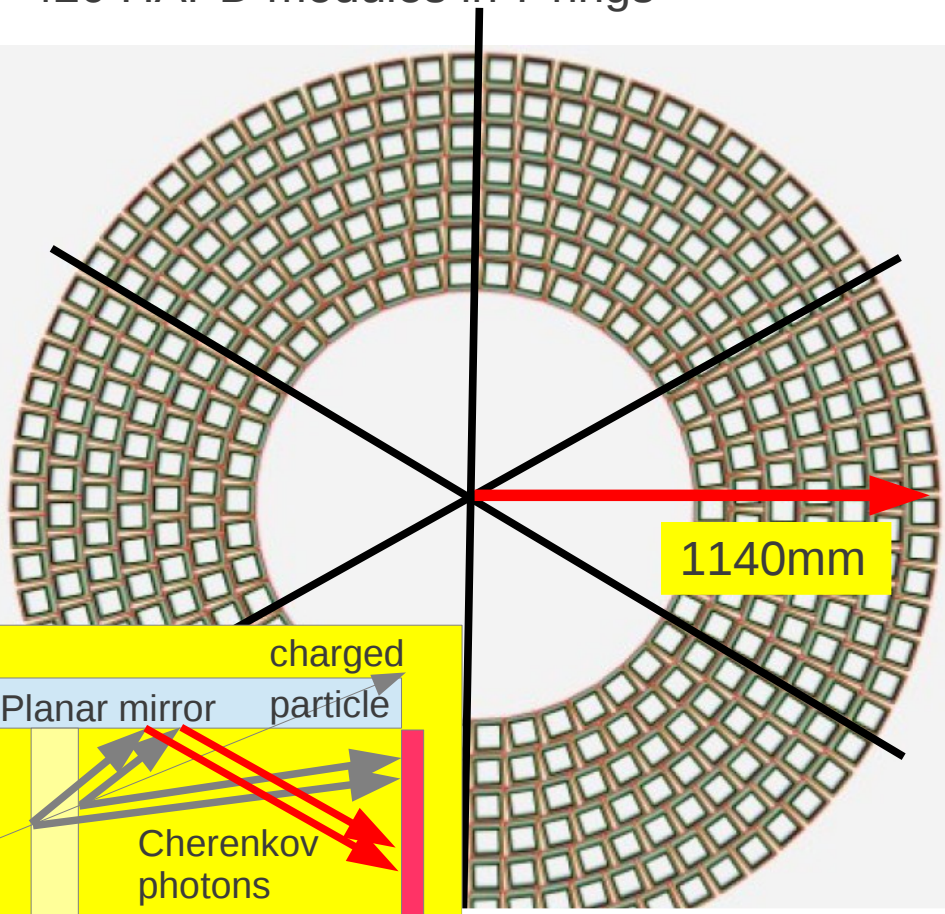


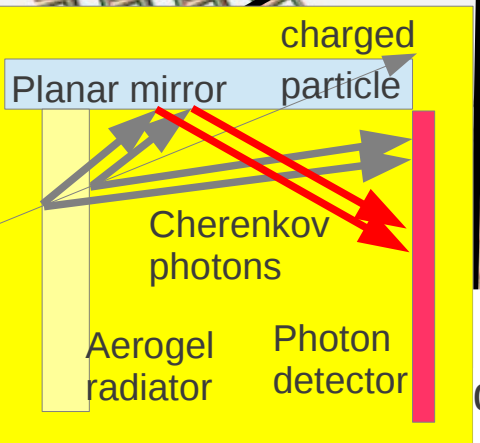


Specifications	
package	73×73mm2
sensitive area	64%
# of pixels	144(36×4chips)
capacitance	80pF
weight	220g
peak QE	28%
bombardment gain	1500
avalanche gain	~30
total gain	~45000

Design of Aerogel RICH

420 HAPD modules in 7 rings

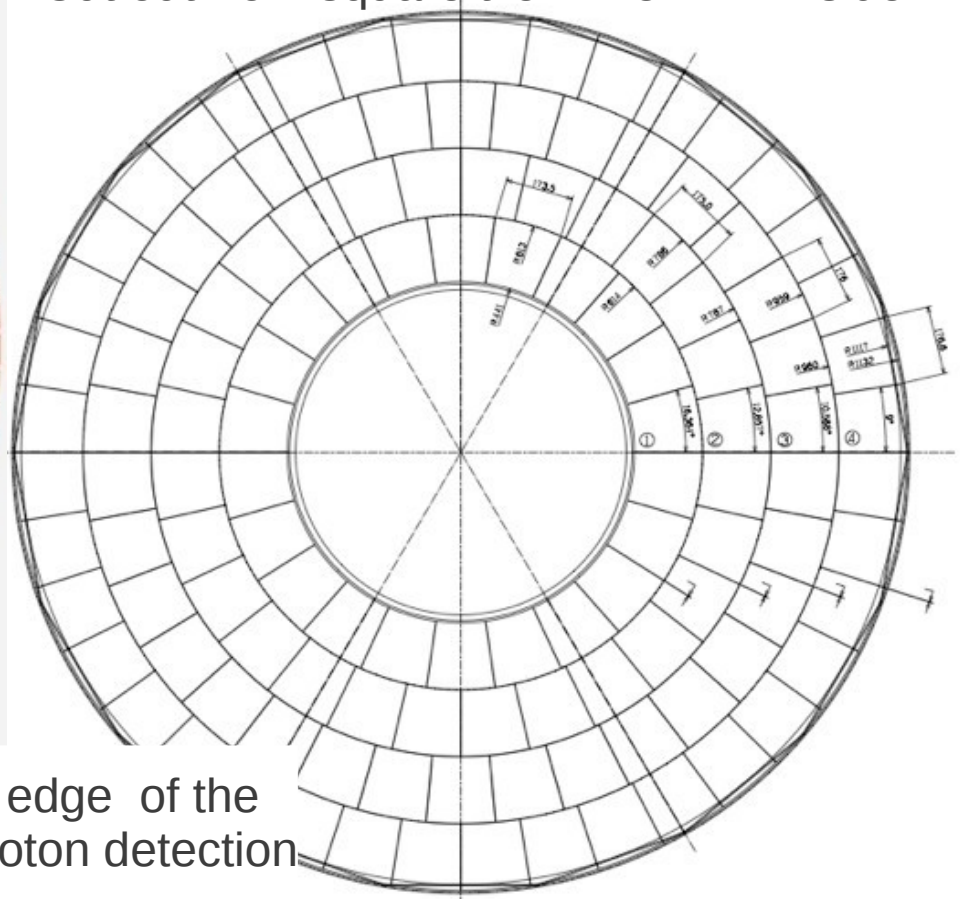




Aerogel : 124x2 pieces

-wedge shape, each layer 20mm thick

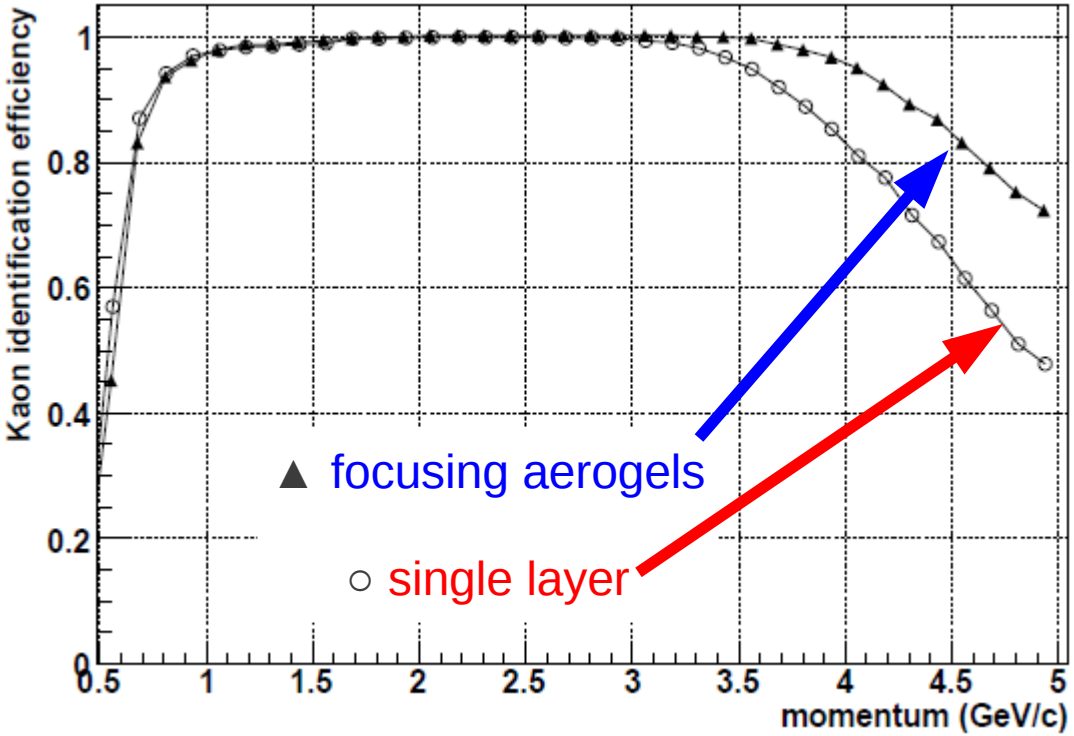
- 4 types depending on radius
- Cut out from square tile ~175 mm in side

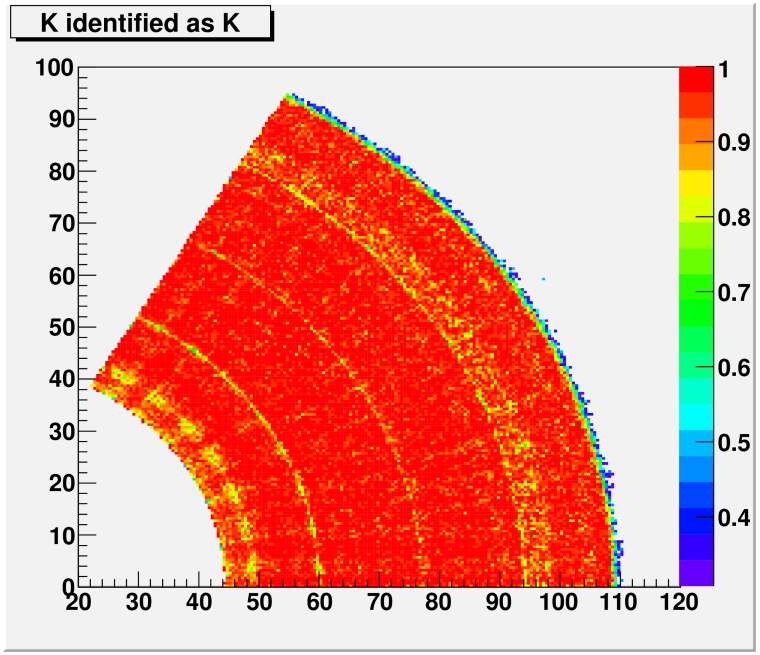


Planar mirrors on the edge of the detector to improve photon detection

Monte Carlo performance

Detailed simulation performed in the Belle2 software framework



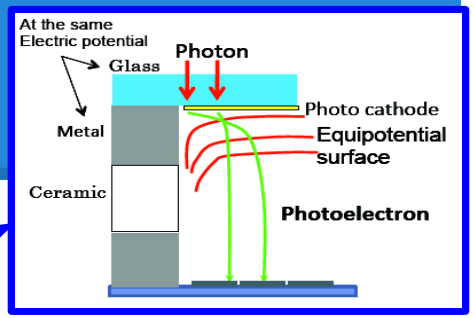


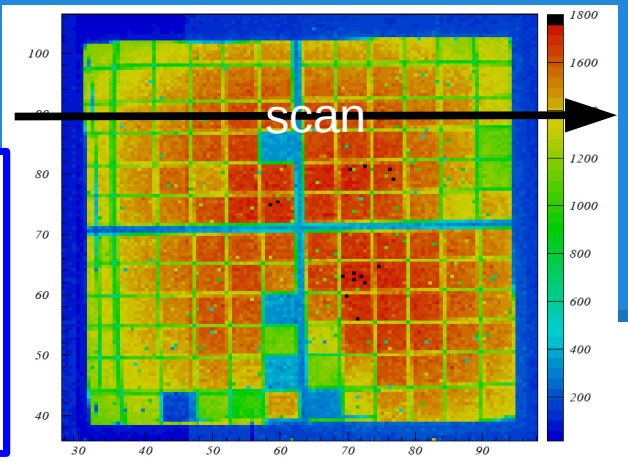
K id efficiency for p=3-4 GeV/c
- 1% pion misidentification

Excellent PID efficiency over wide momentum range.

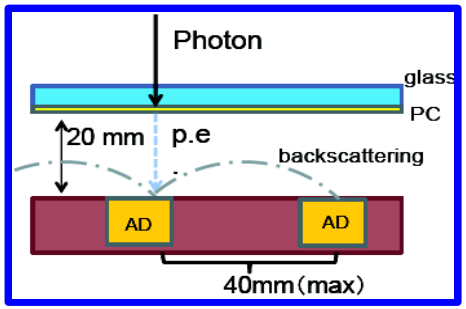
Homogeneous response over the sensitive area of the detector (1 sextant is shown)

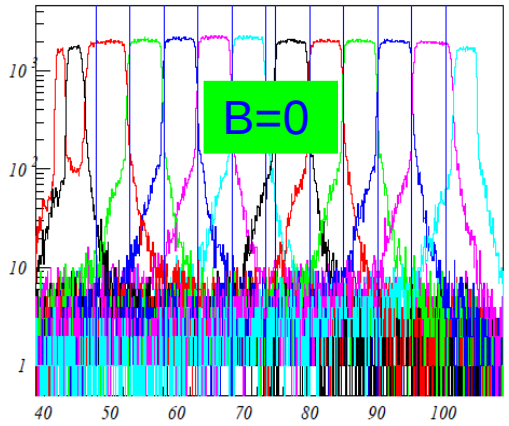
Performance in the magnetic field

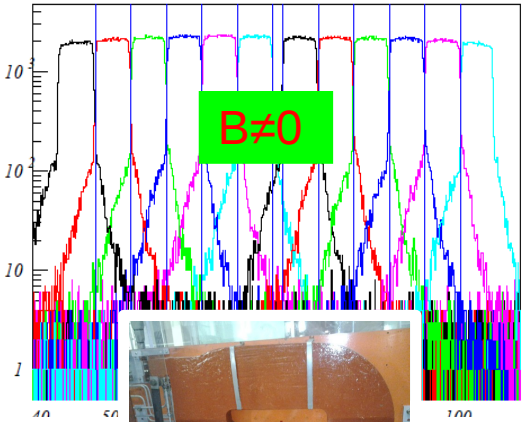


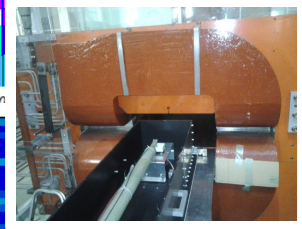


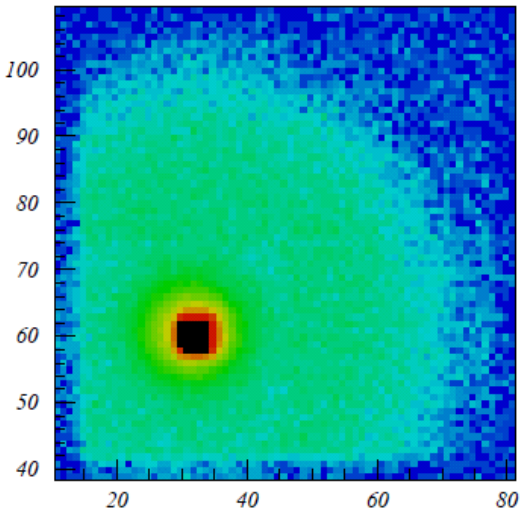
- distortion of electric field lines at HAPD edge produces irregular shapes of areas covered by each channel
- in magnetic field photoelectrons circulate along the magnetic field lines and distortion disappears

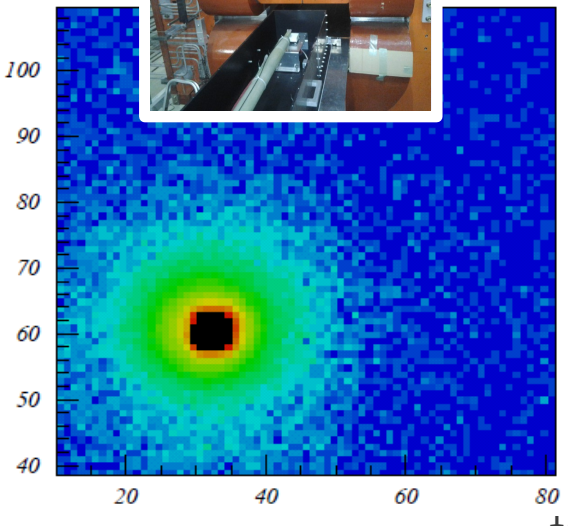












- photoelectrons are backscattered from APD and produce long range cross-talk
- in magnetic field photoelectrons follow magnetic field lines and fall back on the same place

(radius of 10 keV electron in 1.5 T is~100μm)

- scattered photons remain

Radiation hardness

- Severe beam-related background is expected in the Belle2 experimental environment.
- HAPD should be radiation-tolerant for those background sources.
- Several HAPD irradiation tests performed:
  - Tests in the nuclear reactor → neutrons
  - Irradiation with Co-60 → gamma-rays

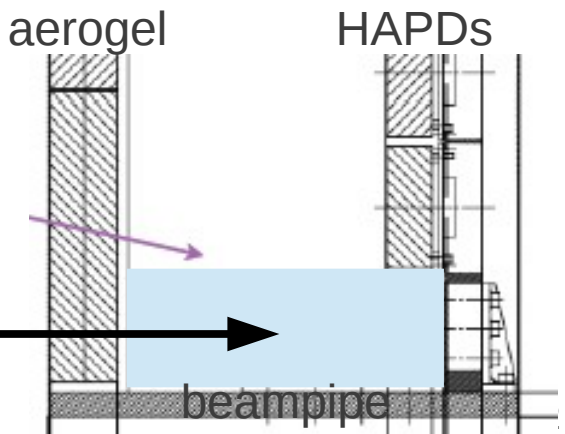
Original estimates for 10 years of Belle2 operation based on the Belle experience:

- neutrons: up to ~ 4×10^{11} n/cm^2 (1MeV eq.) → 4×10^{10} n/cm^2/year
- gammas: up to 1000 Gy (~ 100 Gy for most of HAPDs) → 100 Gy/year

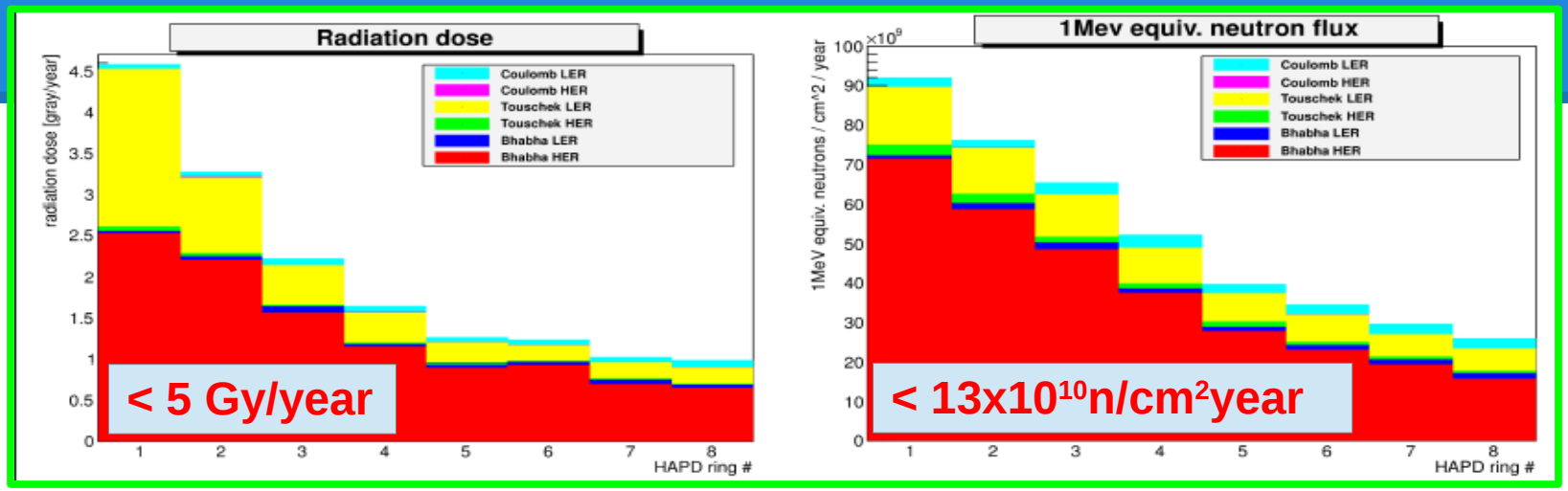
Software simulation of the background:

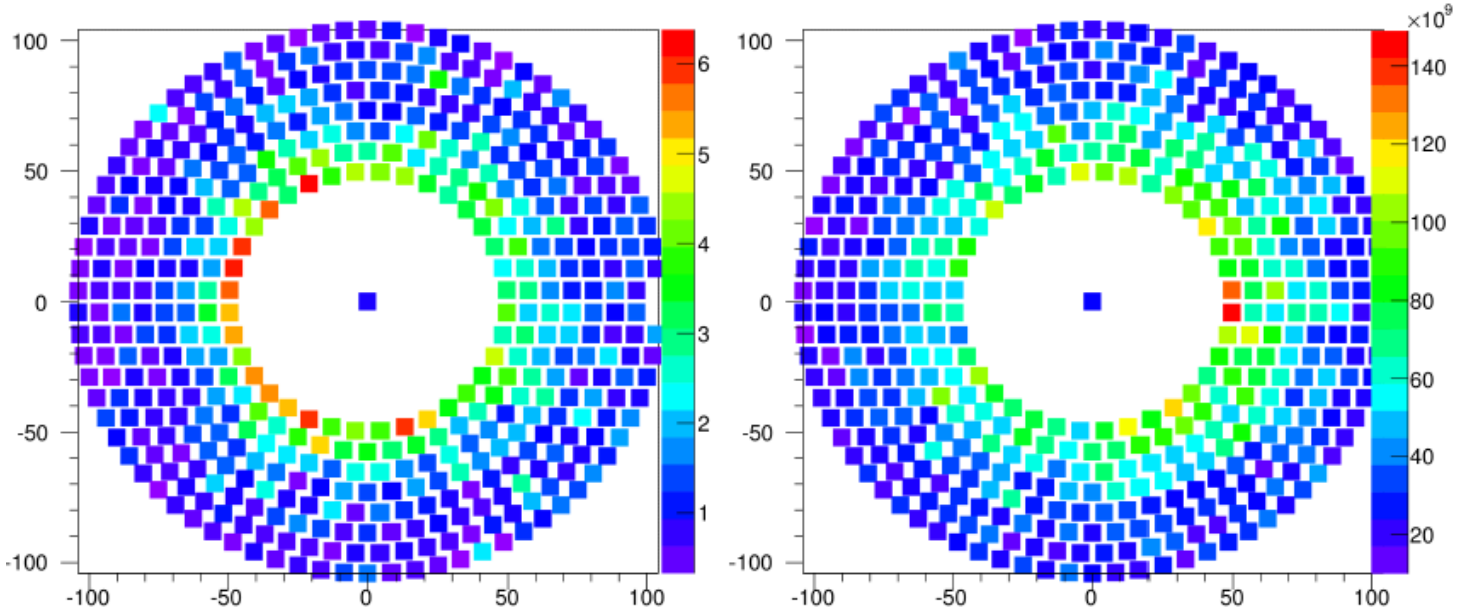
several iterations → shielding of the beam pipe with tungsten

- Results:
  - acceptable gamma radiation dose
  - neutron fluence is at the limit :
    - possible additional shielding inside RICH container
      - Polyethylene + 30% Boron



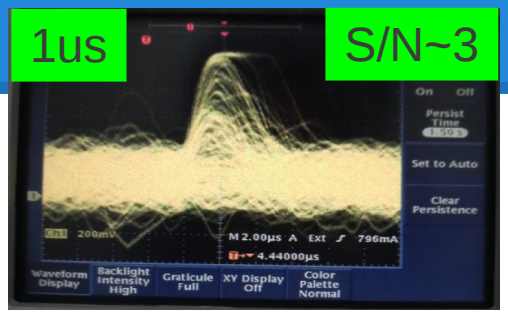
Simulation: expected radiation dose and neutron fluxes

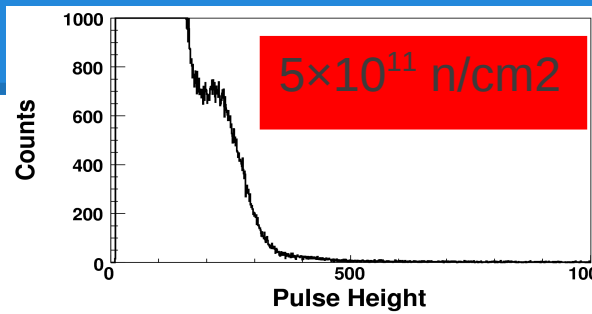


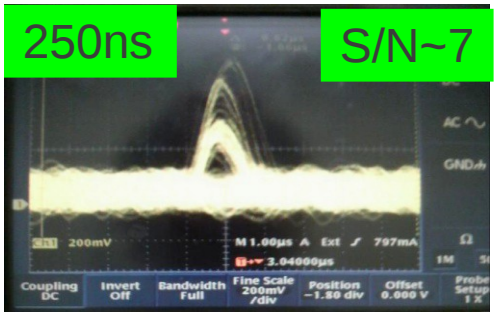


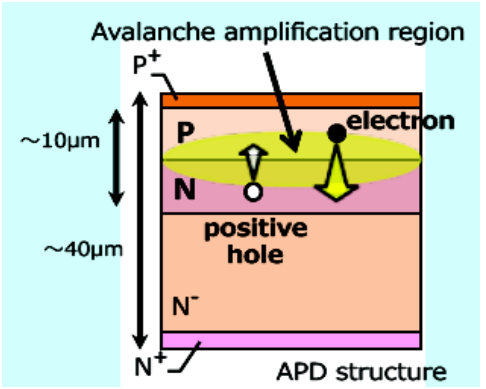
Neutron irradiation

- No change in QE
- Increase in leakeage current
- S/N deterioration









Solutions:

→ Shorter shaping time

Readout electronics with flexible functionality

→ Modification of APD structure

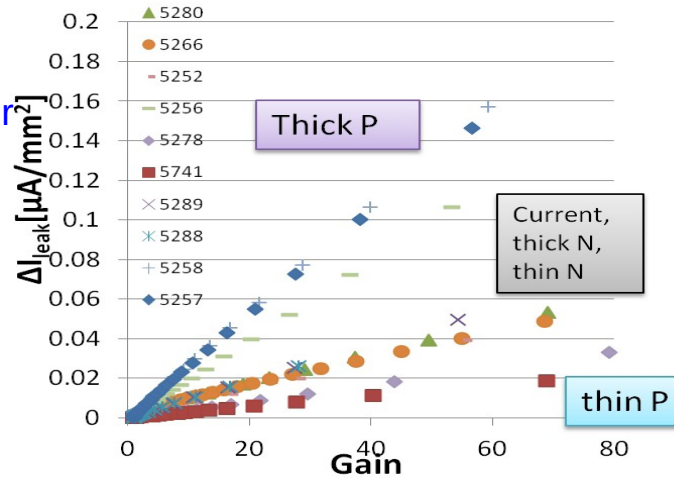
Thinner p⁺ layer to increase bombardment gain

Thinner p layer to reduce increase of the leakage current

Main source of leakage current: thermally generated electrons in p layer due to the lattice defects produced by neutrons.

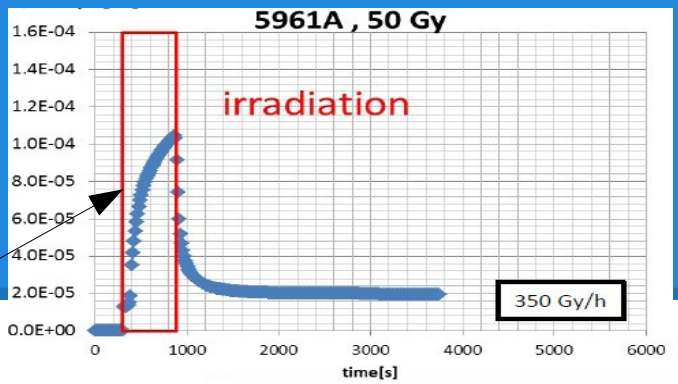
As expected:

the increase of the leakage current is smaller with thin p



Both methods are expected suppress degradation up to 10^{12} n/cm2

Gamma irradiation



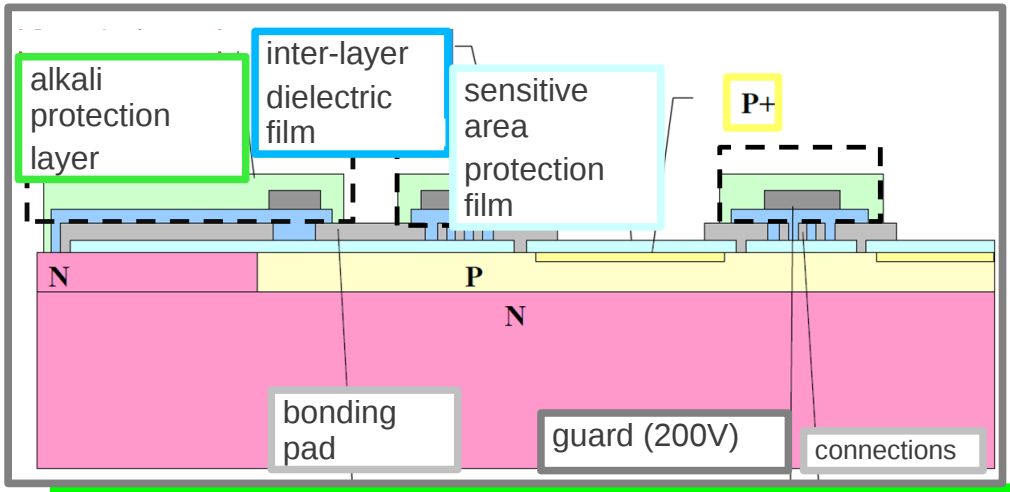
Initial tests (2010) of APDs with thin p and p+ layers indicated fast raise of leakage current during irradiation.

- not previously observed with similar APDs

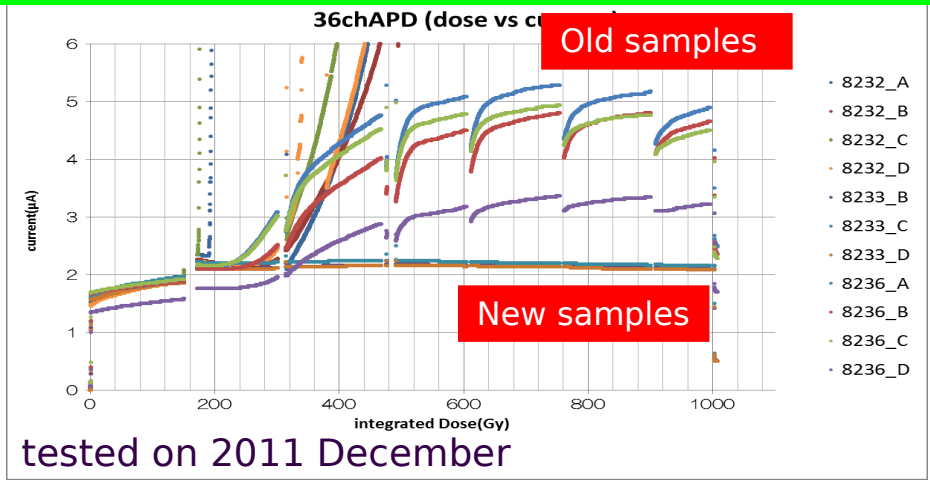
To identify the reason for the high sensitivity to ionizing radiation we have tested several single channel APDs with different structures:
standard type for photon detection, different HAPD type with thin/thick p/p+ layers.

Modifications:

- Increase of leakage current suppressed by improving a protection film covering sensitive area
- Alkali protection layer removed to avoid a drop of "breakdown" voltages



leakage current as a function of integrated dose

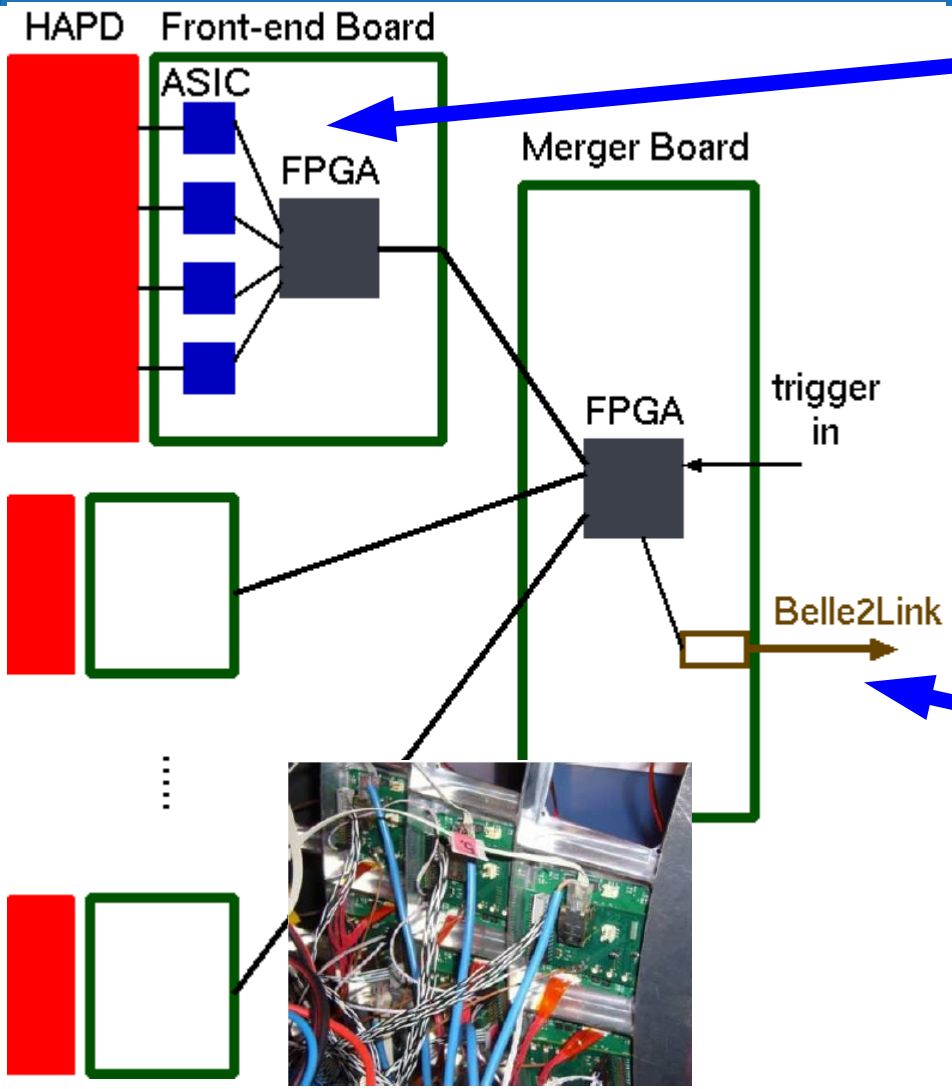


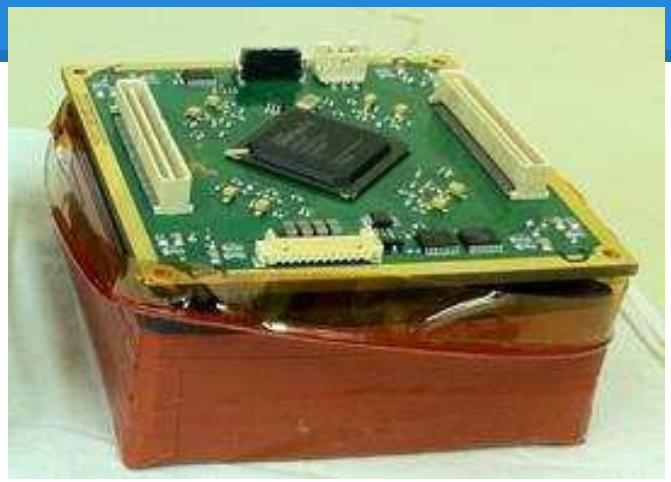
tested on 2011 December

Readout electronics

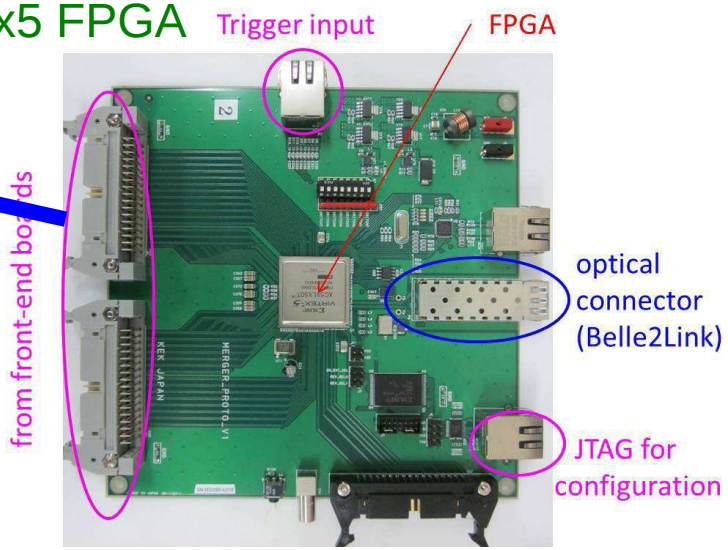
Front-end board with 4 ASICs and Spartan6 FPGA

limited space (~5cm) behind the HAPD

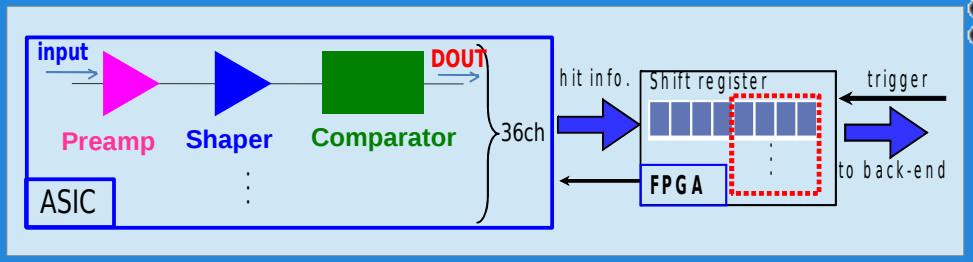




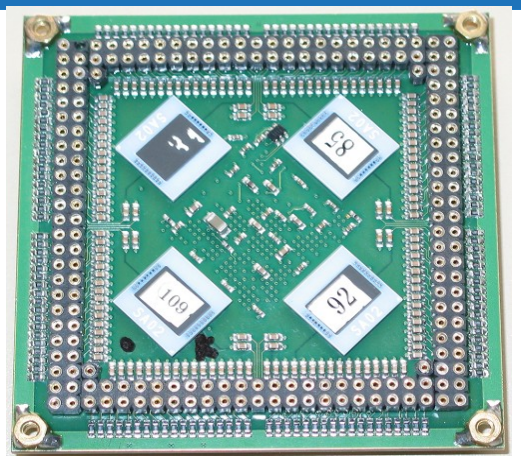
Merger board prototype with Virtex5 FPGA

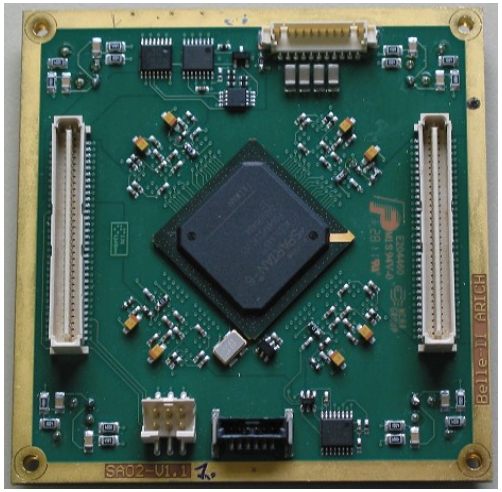


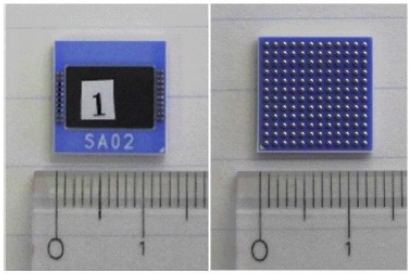
Front end board



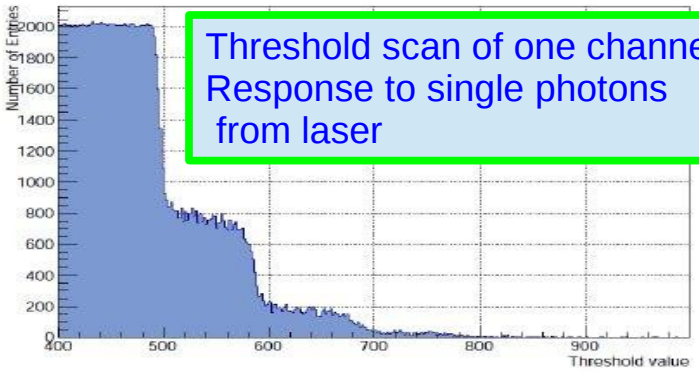
- 36 channel ASIC (preamp., shaper and comparator) provides hit information.
  - settings: 4 step gain, 4 step peaking time, offset level
  - peaking time >100 ns
- FPGA (Xilinx Spartan6):
  - hit detection,
  - coarse time-over-threshold measurement to discriminate between single Cherenkov photons from aerogel and the Cherenkov photons produced in the HAPD window
  - DAQ
  - monitoring of supply voltages and temperature





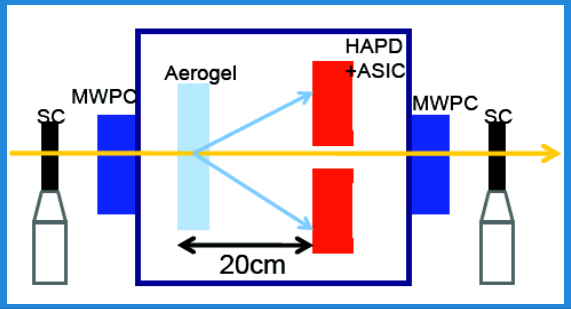


SA02 (36ch)

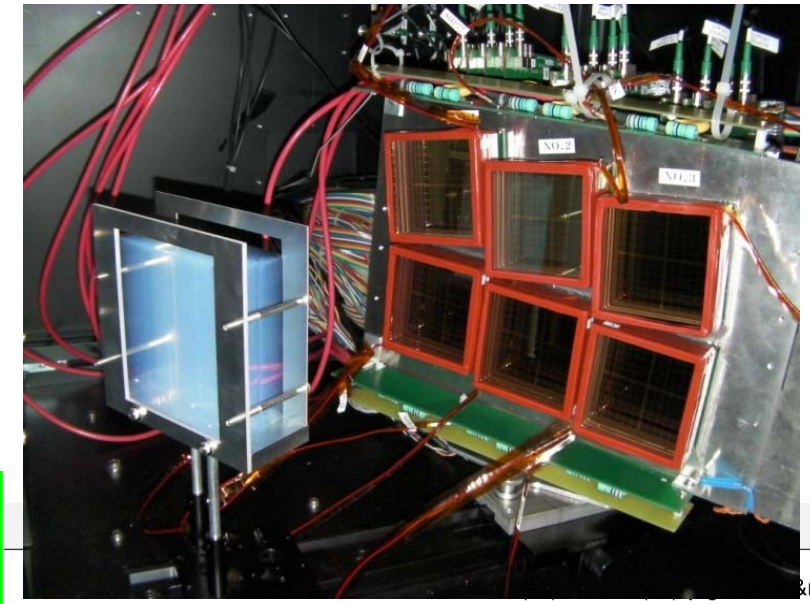


Threshold scan of one channel:
Response to single photons
from laser

Beamtest @ T4-H6 CERN SPS 2011



- 6 HAPDs arranged as in the final design
- new batch of HAPDs
- new aerogel radiator
- front-end electronics ~ close to final
- mirrors



The results consistent with previous beamtests

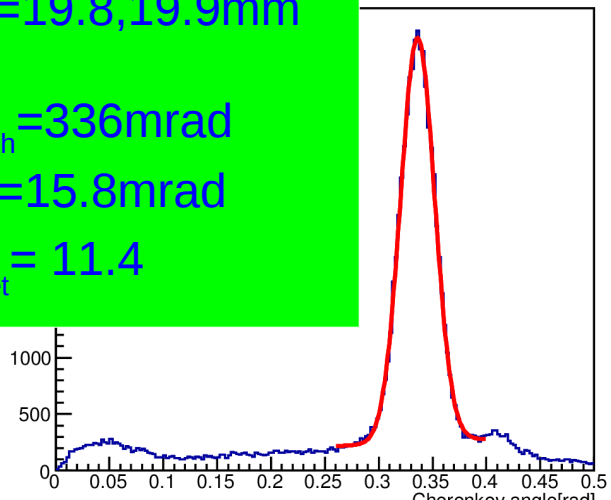
>5.5 σ K / π separation at 4 GeV/c

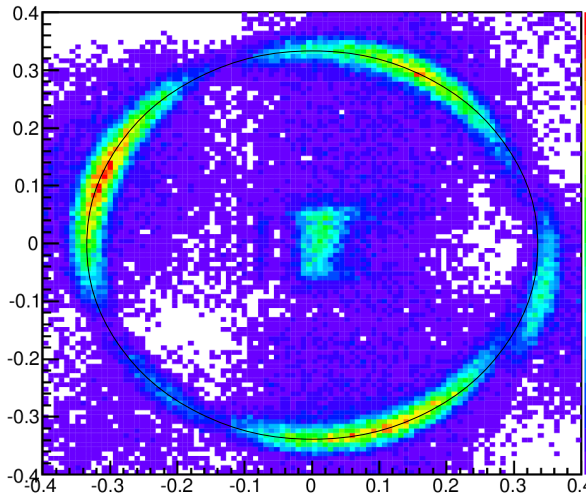
double aerogel
- n_0=1.050,1.065
- d =19.8,19.9mm

ϑ_{Ch}=336mrad

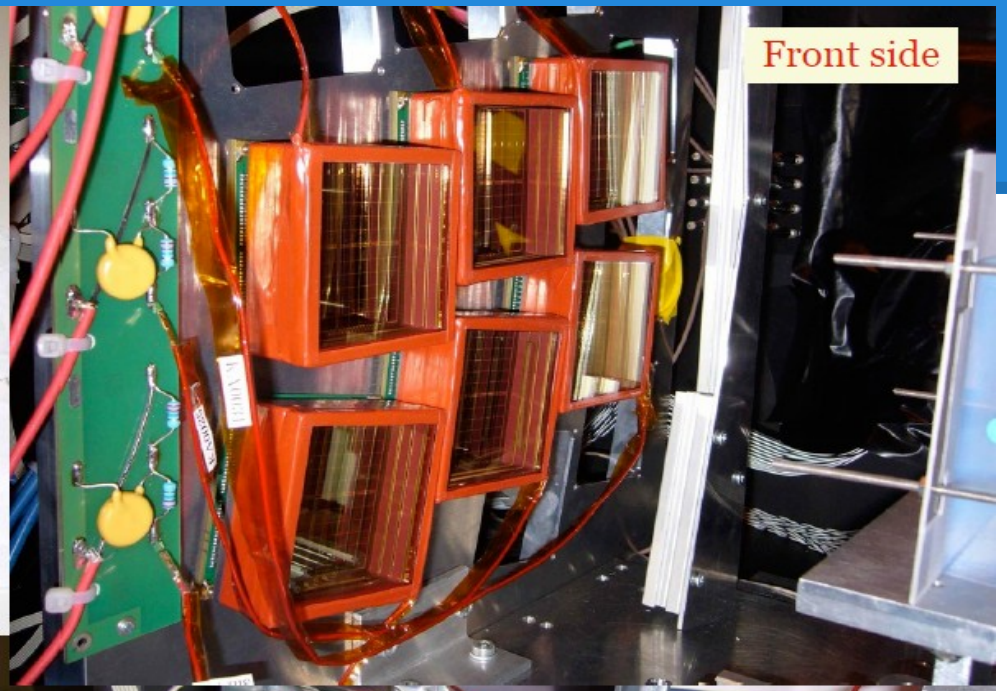
σ_{ϑ}=15.8mrad

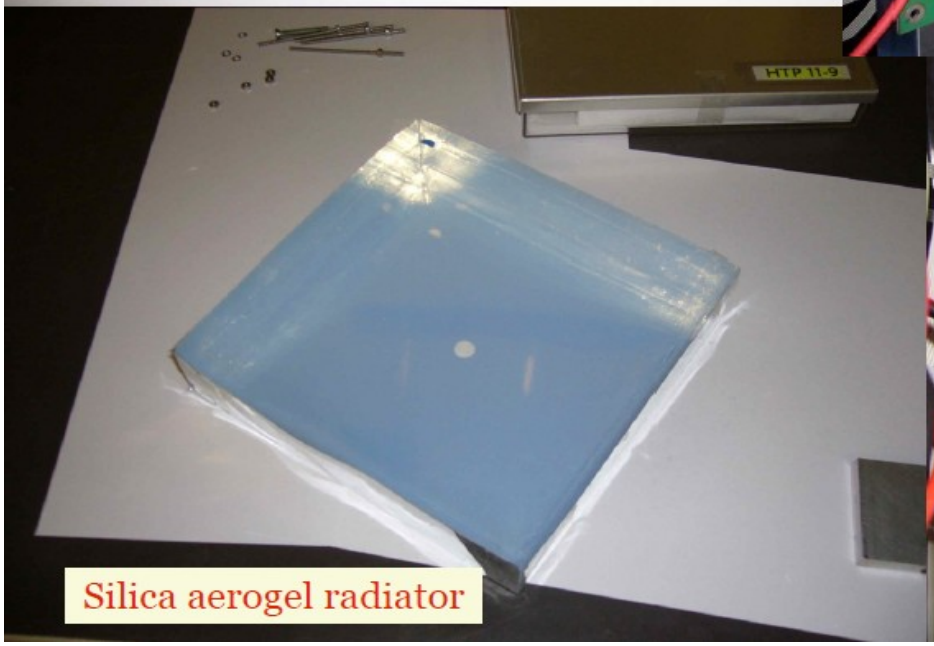
N_{det} = 11.4

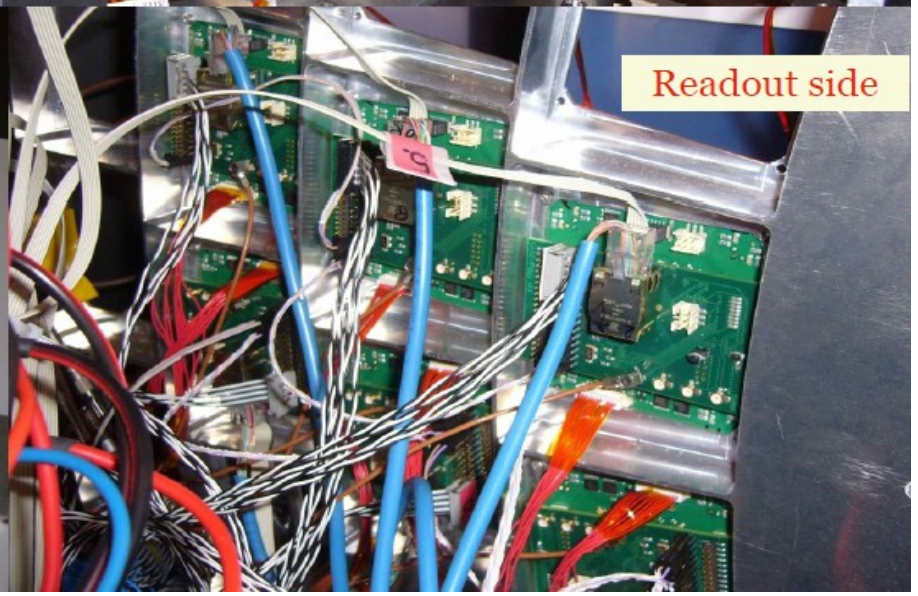




Beamtest @ T4-H6 CERN SPS 2011







Summary and plans

- Proximity focusing RICH with an aerogel as a radiator will be employed for efficient particle identification in the forward end-cap of the Belle2 spectrometer
  - Highly transparent hydrophobic aerogel with two layers in a focusing configuration (n=1.055,1.065) will be used as a radiator
  - Hybrid avalanche photo detector has been selected among three candidate sensors operating in a high magnetic field of 1.5 T
  - Front-end readout electronics of the photo sensors is based on the SA03 ASIC chip
- All the key components of the detector have been extensively tested on the bench and in the test particle beams.

The beamtest results and the detector simulations show that the designed detector will have an excellent kaon identification efficiency of more than 95% over wide range of momentum at a rather low pion misidentification probability of 1% .

- The mass production of the detector parts has started and will be ready for the integration tests in the second half of 2014
- The installation in the spectrometer will follow cosmic tests in January 2015