Beyond the LHCb Phase-1 Upgrade
28-31 May **La Biodola, Isola d'Elba (Italy)**

SiPMs for the aerogel RICH at Belle II ?

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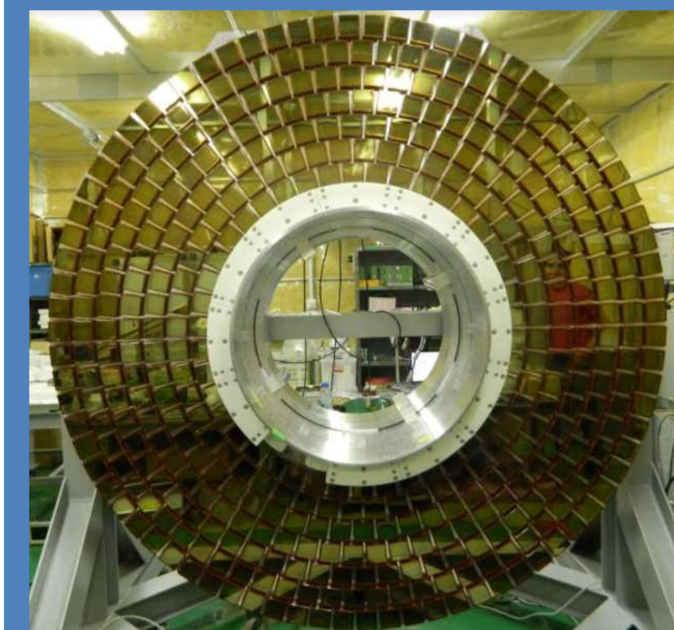
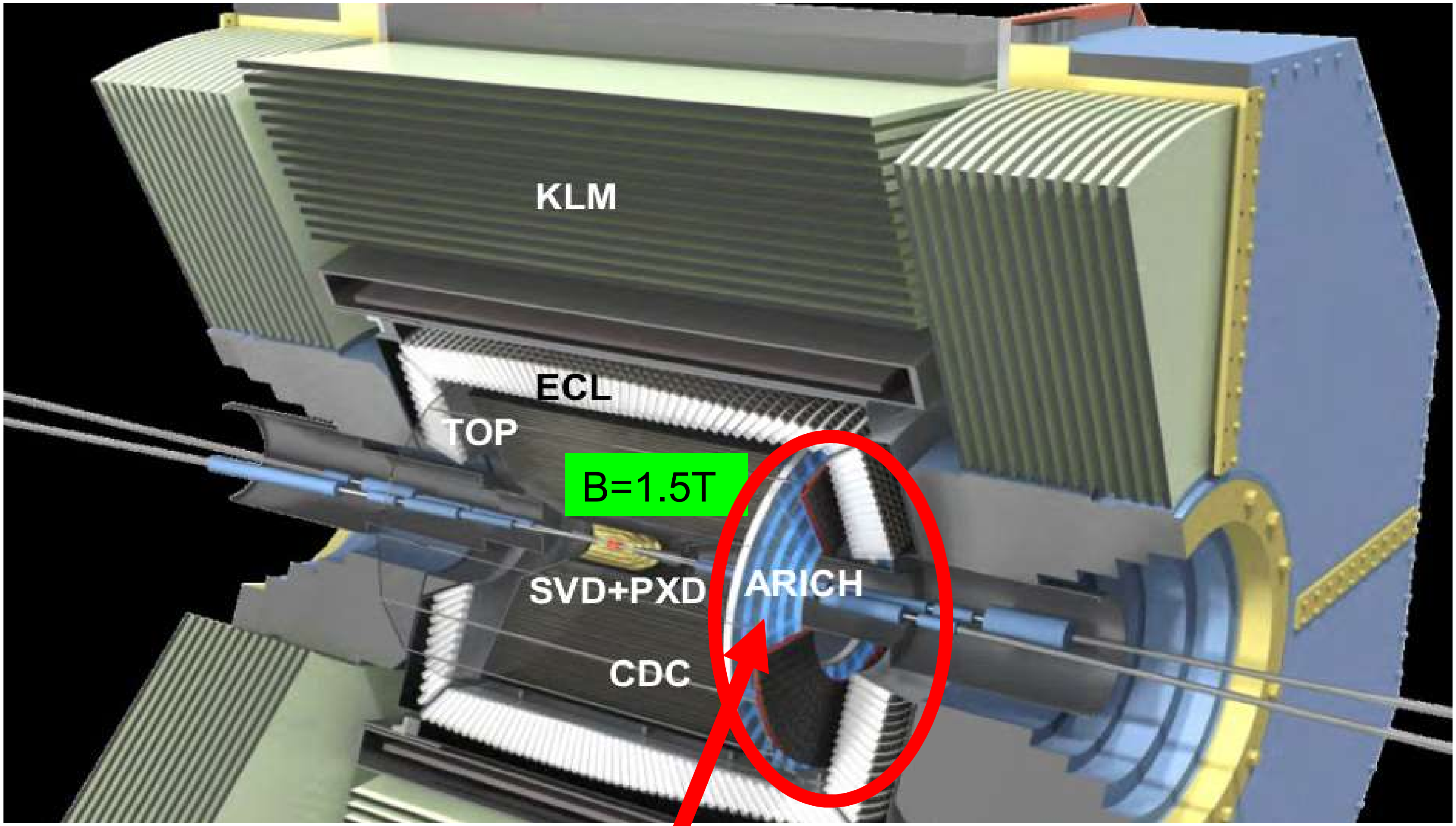
Jožef Stefan Institute, Ljubljana, Slovenia

Contents:
- Belle II ARICH
- Sensor candidates
- RICH with SiPMs
- Results
- Summary



SiPMs ?

Particle identification in Belle II

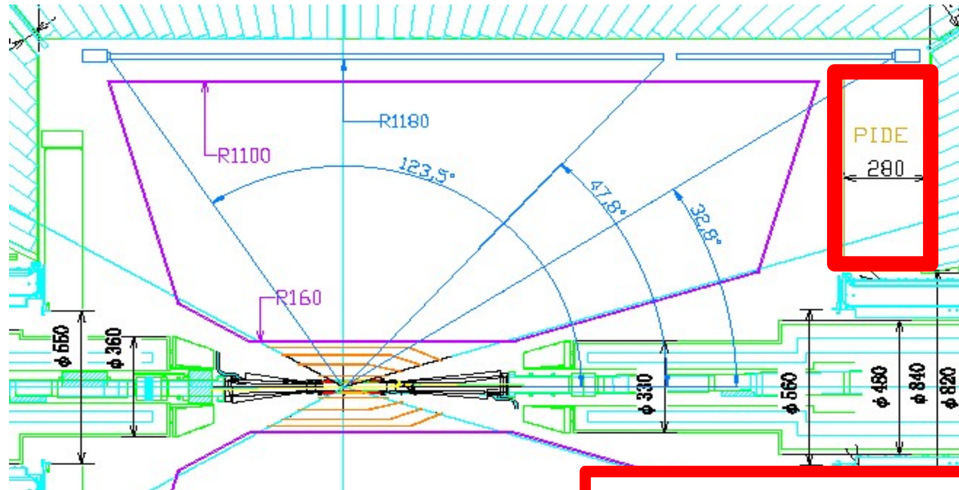


Two dedicated particle ID devices - both RICHes – designed to fit into available space:

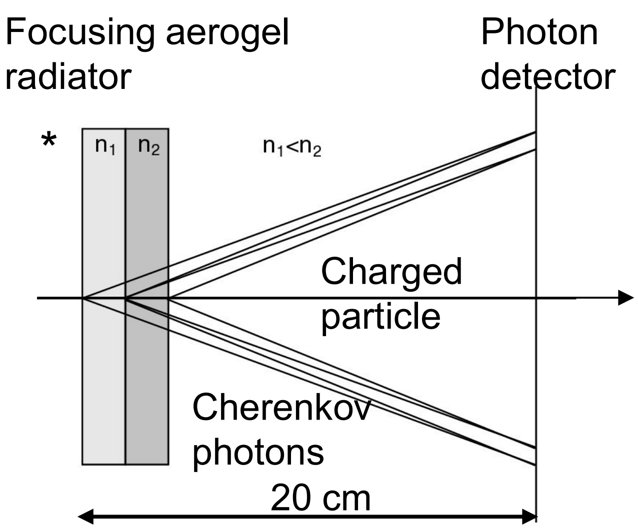
- Barrel: imaging Time-Of-Propagation (TOP)
- End-cap: **Proximity focusing Aerogel RICH (ARICH)**

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



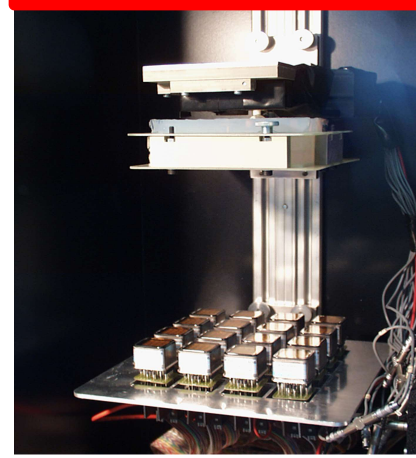
Selected type:
proximity focusing aerogel RICH



- $\langle n \rangle \sim 1.05$
- θ(π) ≈ 307 mrad @ 3.5 GeV/c
- θ(π) - θ(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

* to increase the number of photons without degrading the resolution

Proof of the principle with MA PMTs 2001

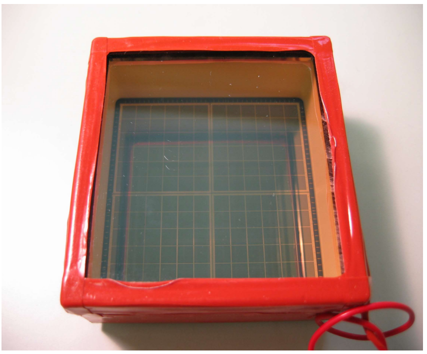


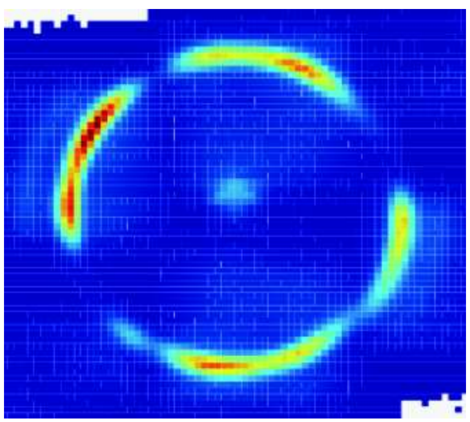
T.Iijima, S.Korpar et al. NIMA548 (2005) 383

Choice of the photo sensor: 3 candidates

HAPD

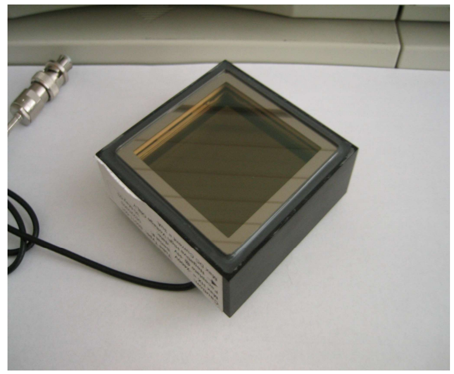
Baseline

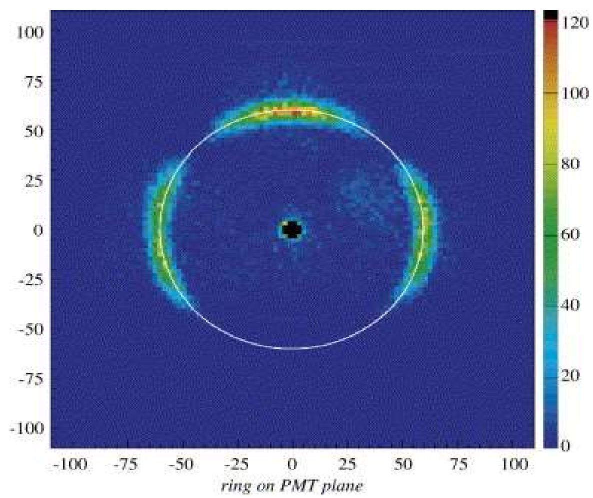




S.Nishida et al,
NIMA610(2009)65

64 ch. 10 μm MCP PMT

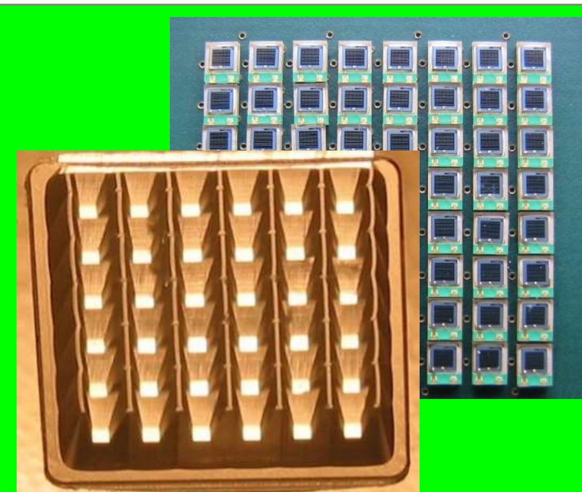


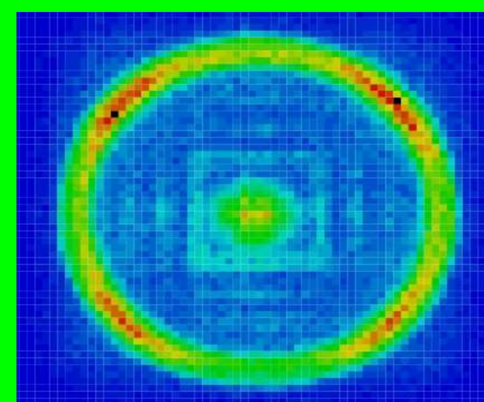


P. Križan et al, NIMA567 (2006) 124

S.Korpar et al, NIMA639 (2011) 162

SiPM + light guide





S.Korpar et al, NIMA613 (2010) 195

SiPM characteristics

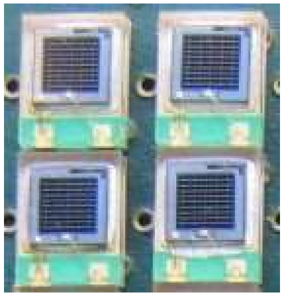
- **works in magnetic field**
- low operation voltage ~ (10-100)V
- peak PDE (= QE x ε_{geiger} x ε_{geo}) up to 65% (@400nm - Hamamatsu data sheet *)
- gain ~ 10^6
- time resolution ~ 100-200 ps
- dark counts ~ few 100kHz/mm^2
- radiation damage (p,n)

Can such a device be used in a RICH?

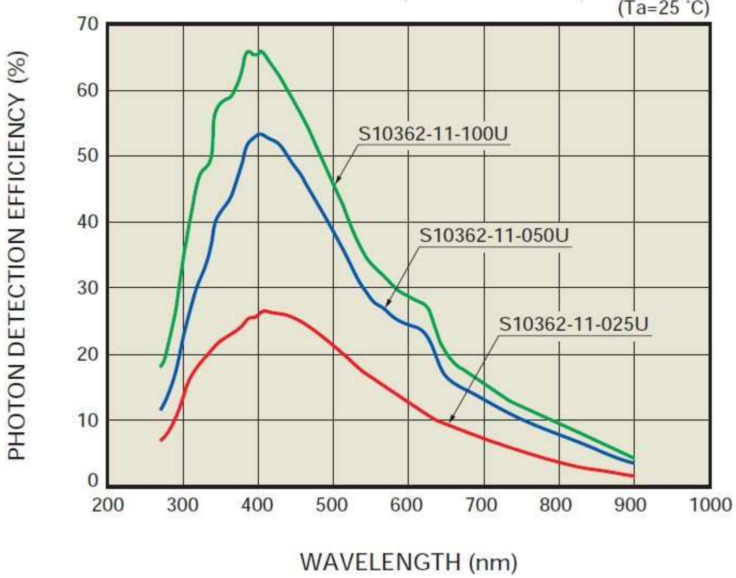
For detection of single photons:

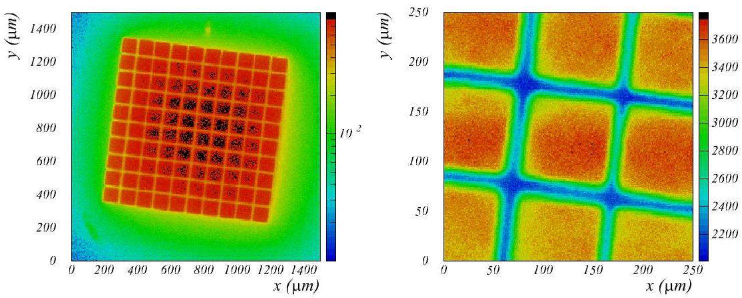
- linearity is not needed
- larger pixels preferred due to a higher efficiency

*includes afterpulses and cross talk



Hamamatsu: HC100, HC050, HC025

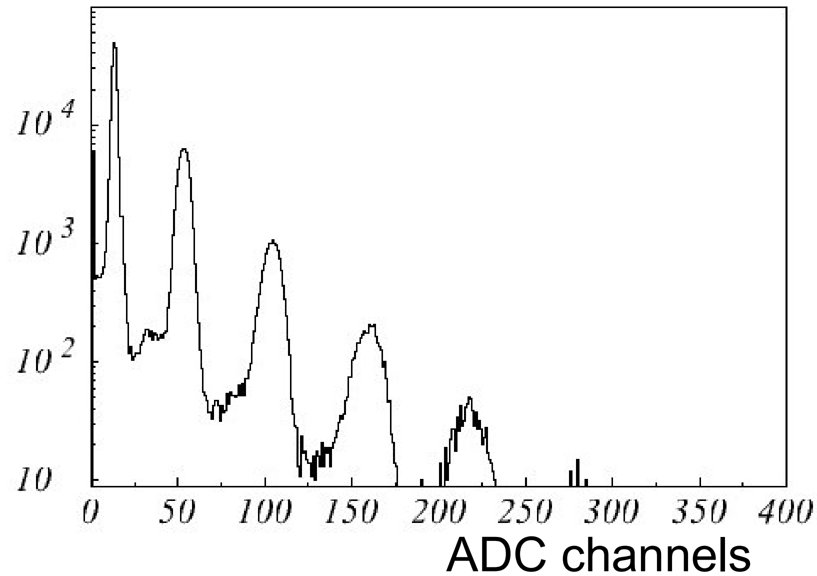




SiPM characteristics 2

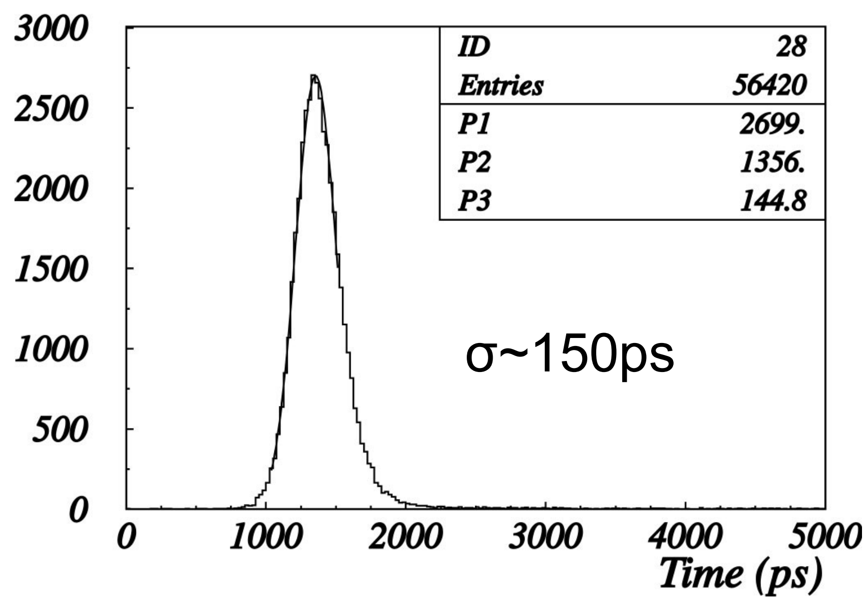
Typical pulse height distribution:

- signal is well separated from pedestal level
- single photon pulses are the same as dark current pulses



Typical timing distribution:

- narrow time window can be used to reduce the contribution of dark current pulses to the Cherenkov image

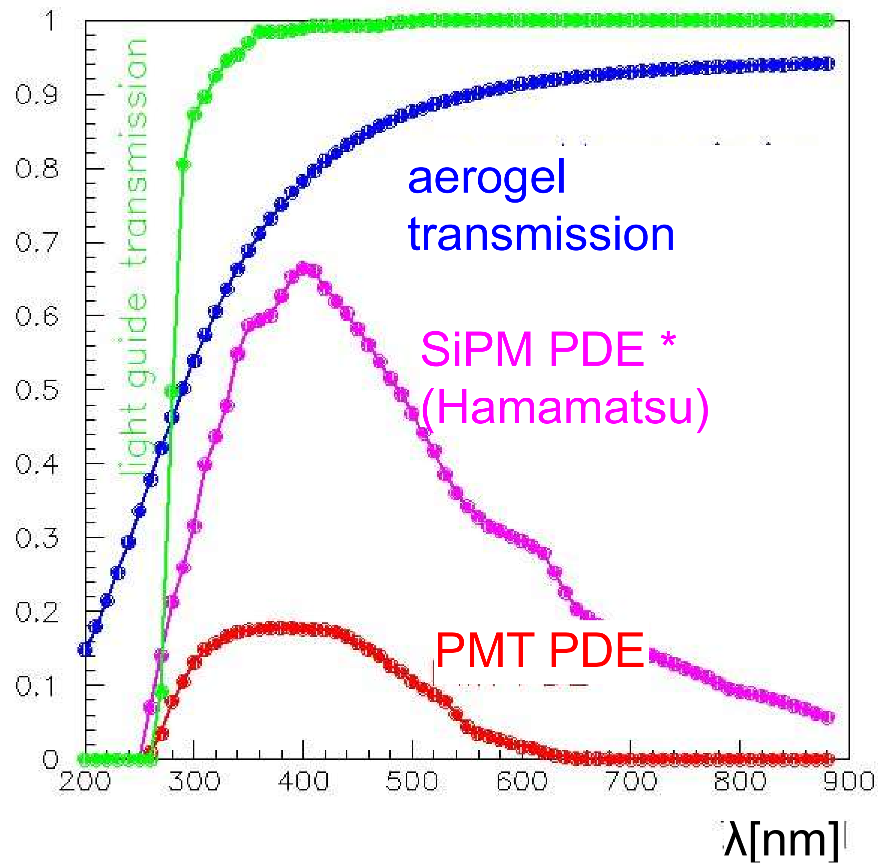


R. Pestotnik @ VCI 2007

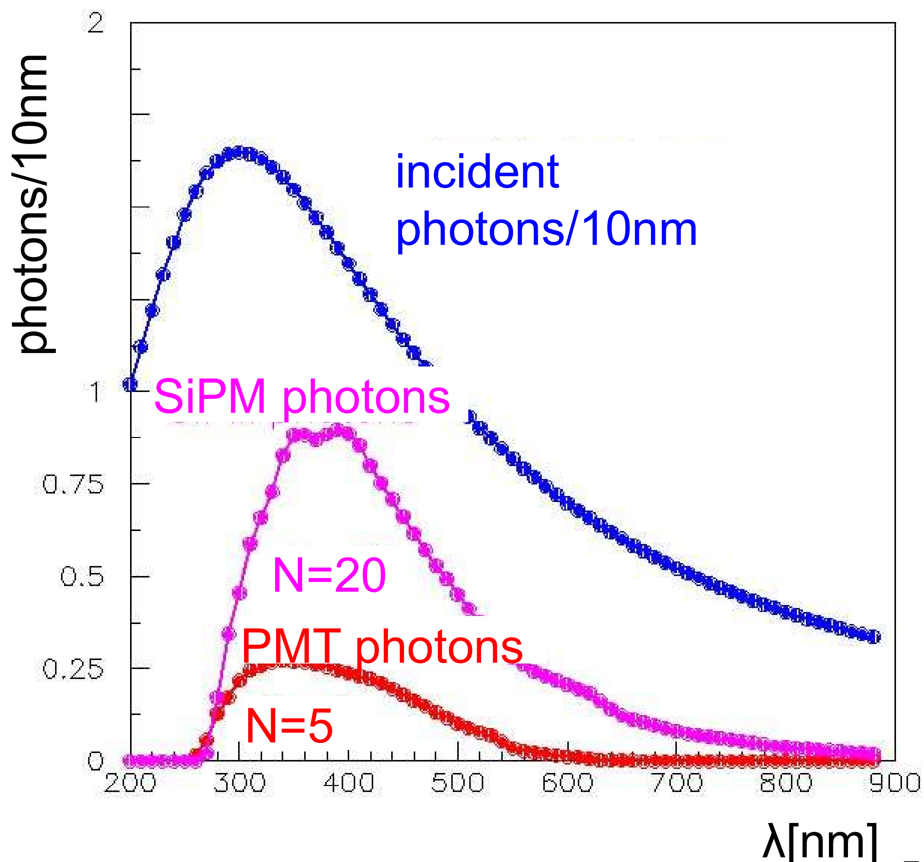
Expected number of photons

Expected number of photons for aerogel RICH (beam test prototype):
multianode PMTs (peak QE ~ 25%, collection eff. ~ 70%) or
MPPCs (HC100)
aerogel radiator: thickness 1cm, n=1.03 and transmission length 2.5 cm (@400nm)

N_{SiPM}/N_{PMT}~4



*including optical cross talk and afterpulses

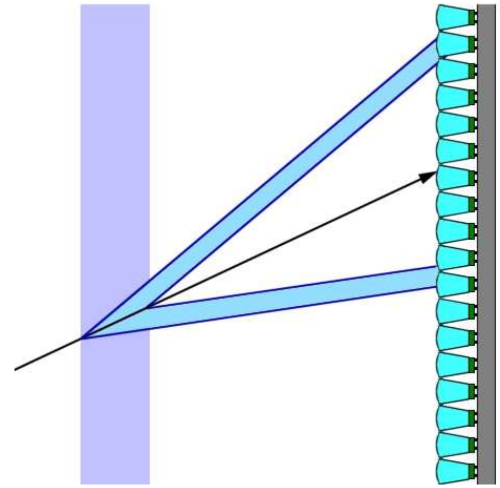


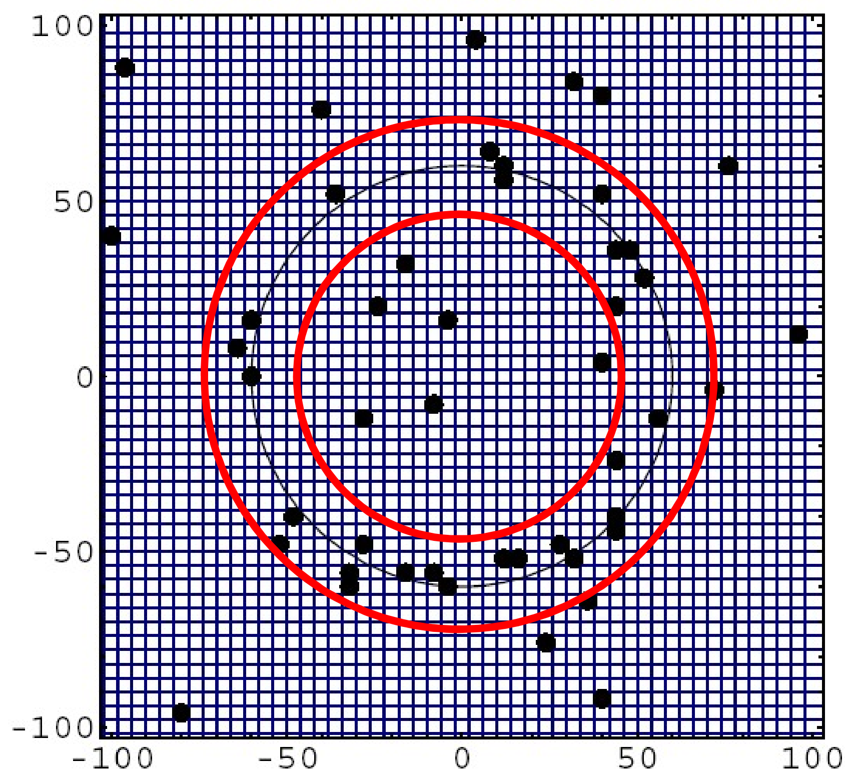
Signal to noise

Expected number of background hits depends on:

- ring area ~ 2000 mm^2
- dark count rate ~ 600kHz/mm^2
- coincidence window ~ 5ns

$$N_{dark} \sim 6 \quad \rightarrow \quad N_{ph}/N_{dark} \sim 3.3$$

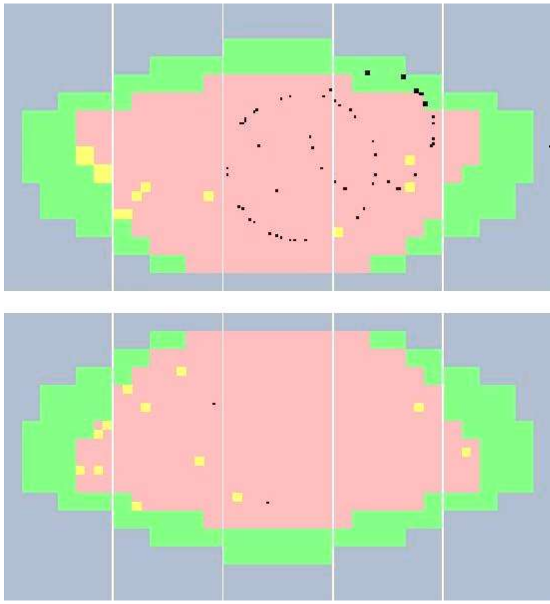




Ratio can be increased by:

- **smaller ring image area**
- **narrower time window**
- **use of light collection system (light guides) to increase effective area of the sensor**

Can such a detector work?

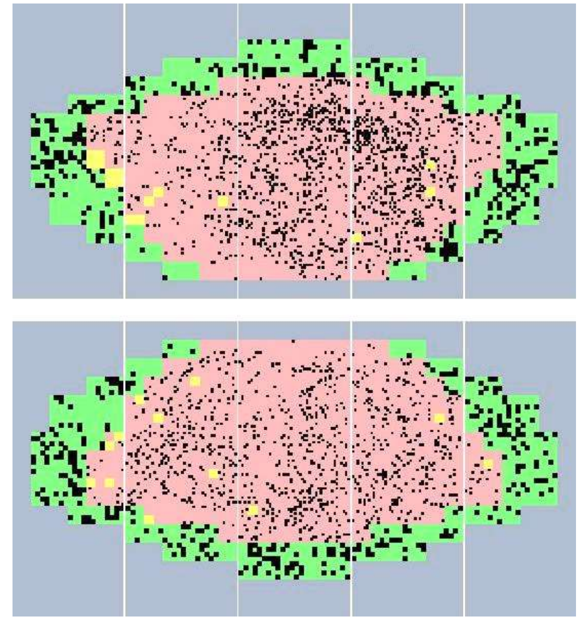


HERA-B RICH experience:

Little noise,

~30 photons per ring

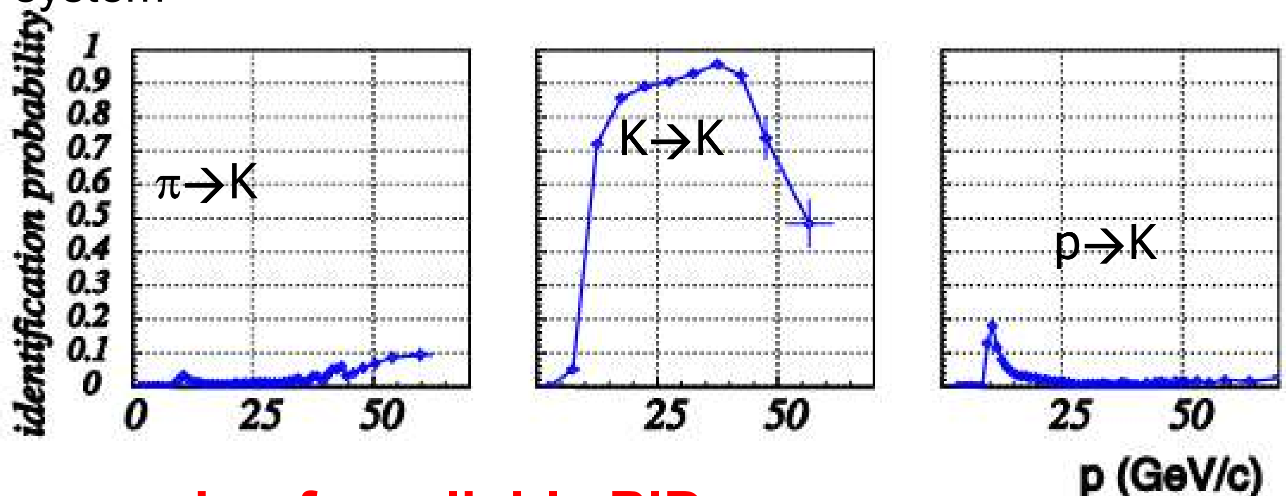
Typical event



Worked very well!

* Large number of rings in the image comes from photon conversion – not seen by the tracking system

Kaon efficiency and pion, proton fake probability



Need > 20 photons per ring for reliable PID

Signal to noise

Expected number of background hits depends on:

- ring area ~ 2000 mm^2
- dark count rate ~ 600kHz/mm^2
- coincidence window ~ 5ns

$$N_{dark} \sim 6 \quad \rightarrow \quad N_{ph}/N_{dark} \sim 3.3$$

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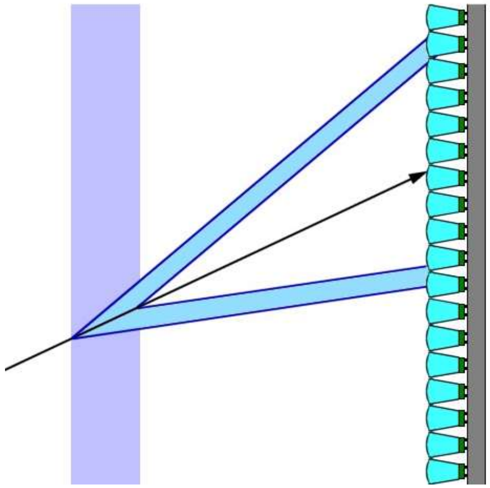
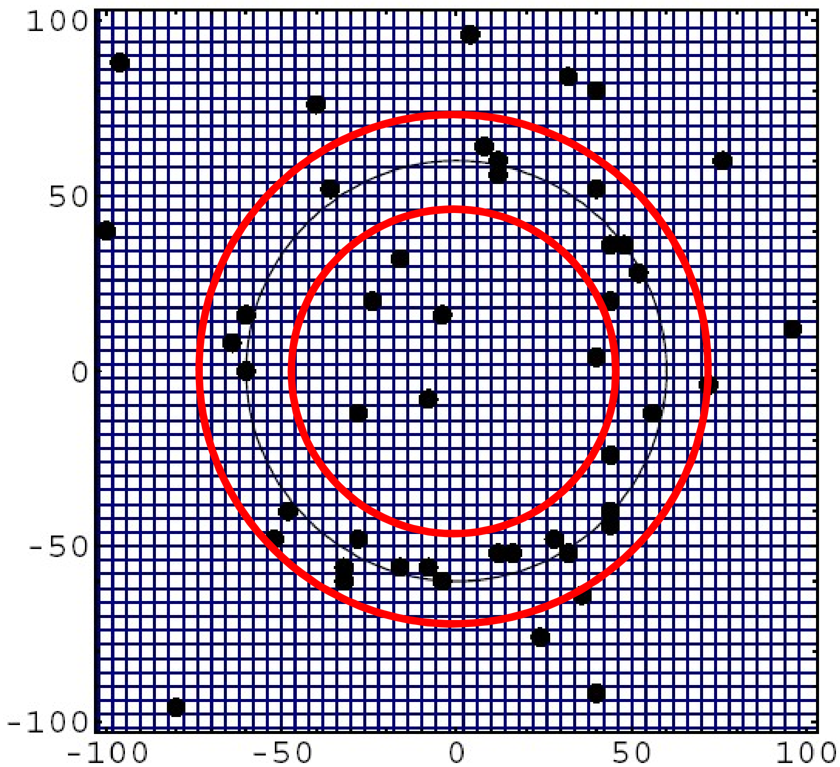




Test with cosmic rays

NIM A594 (2008) 13

First successful tests with cosmic rays:

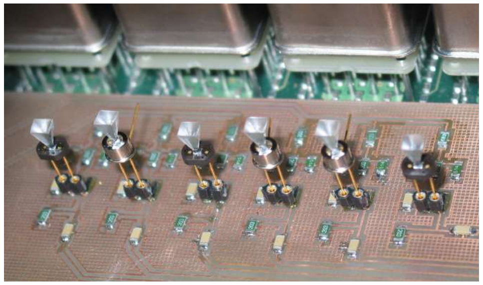
Scintillator trigger

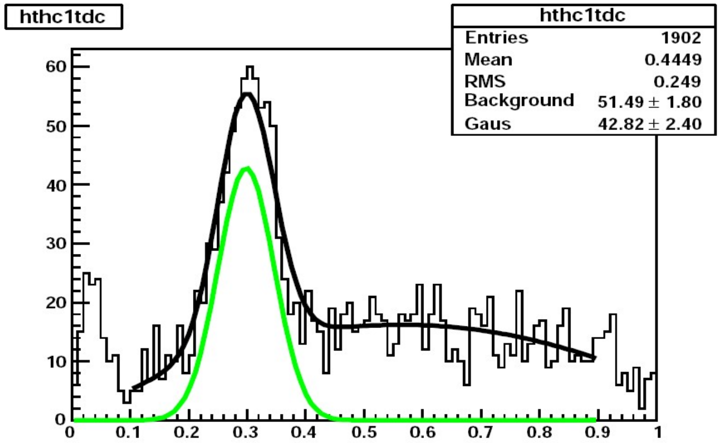
Aerogel radiator

thickness 1cm, n=1.03 and transmission length 2.5cm (@400nm)

6 SiPMs 1mm2

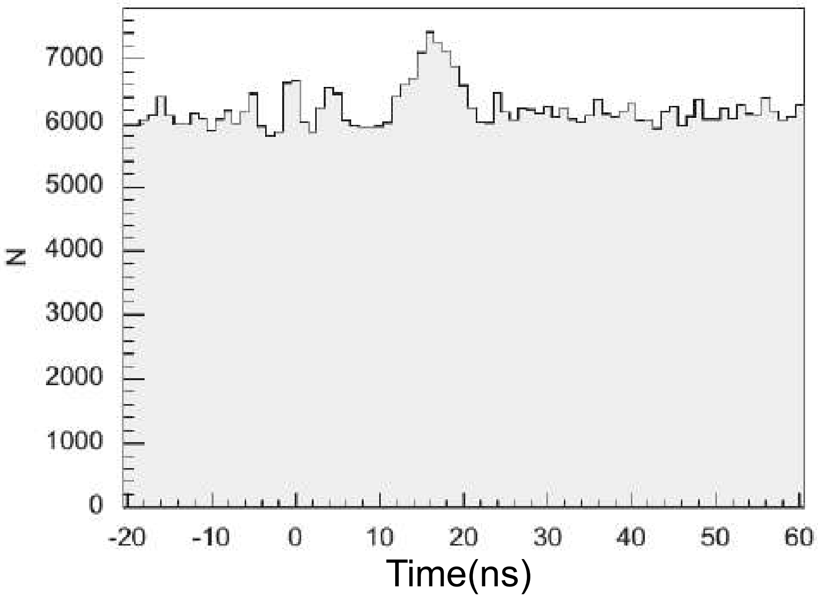
multi-hit TDC



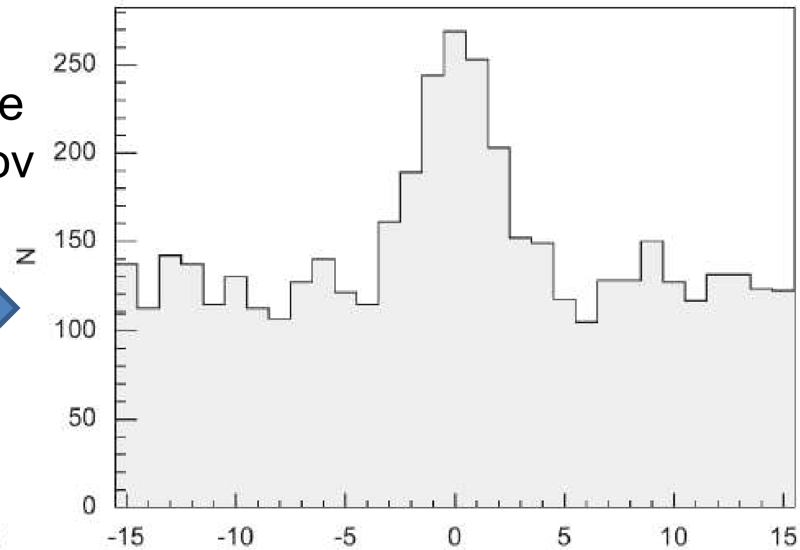


Cherenkov angle [rad]

Impact of timing



Cut on the Cherenkov angle



Signal to noise

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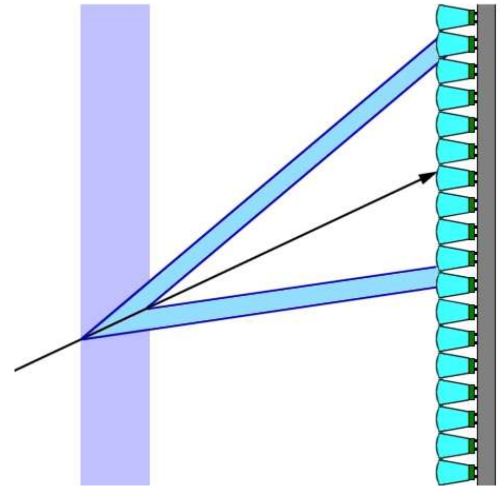

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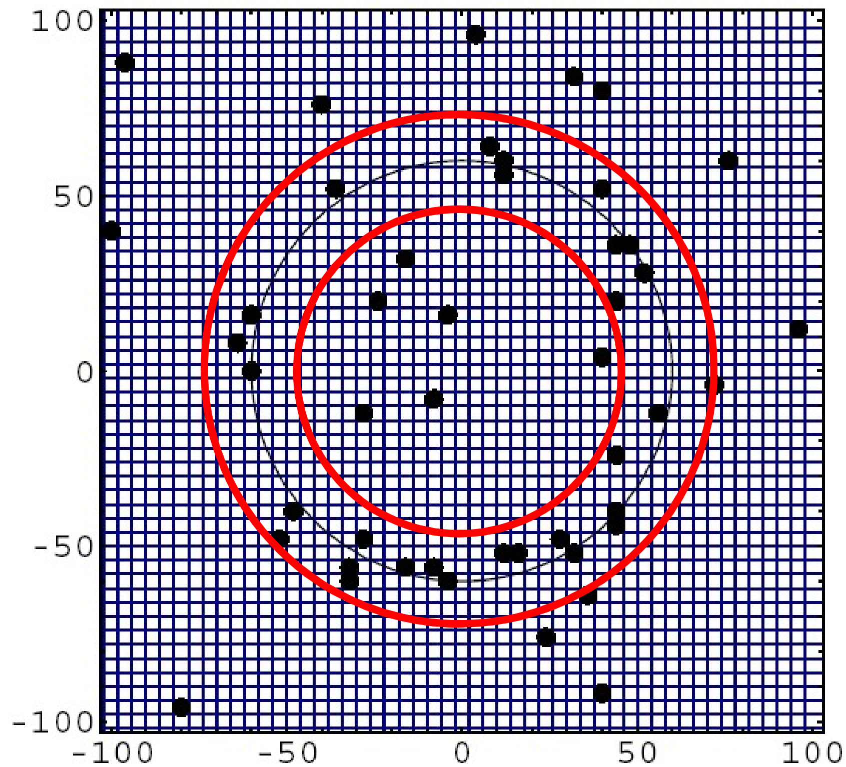
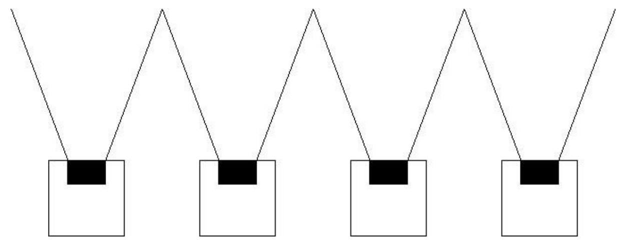


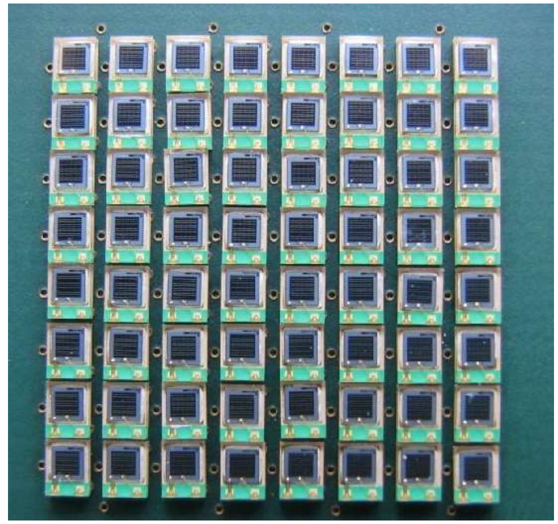
Ratio can be increased by:

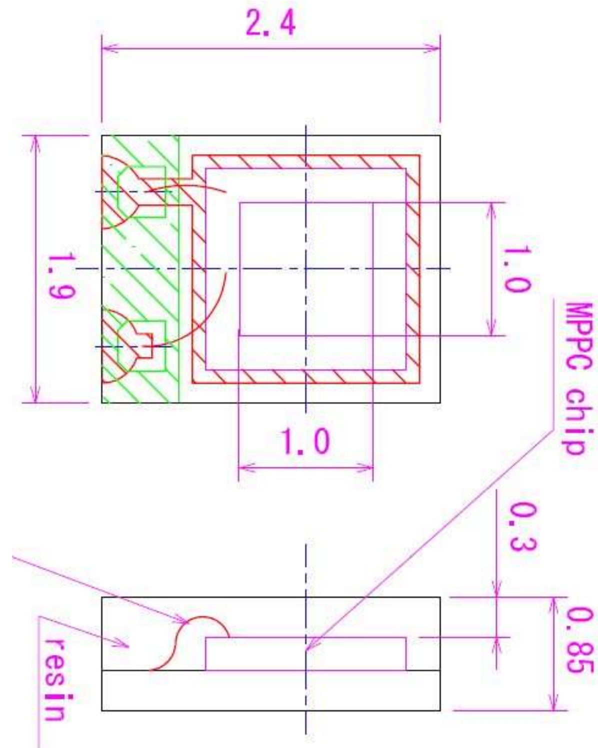
- **smaller ring image area**
- **narrower time window**
- **use of a light collection system to increase effective area of the sensor**

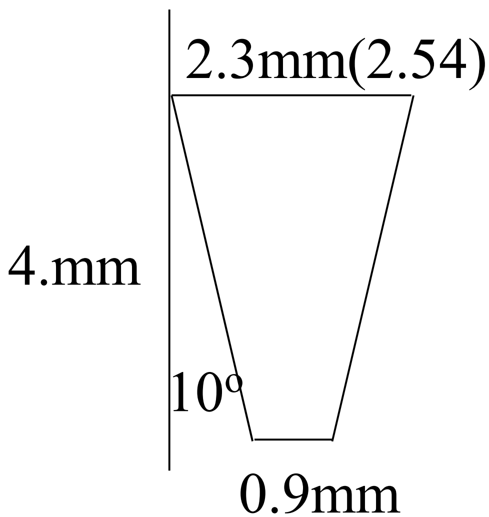
8x8 array of SMD-MPPCs

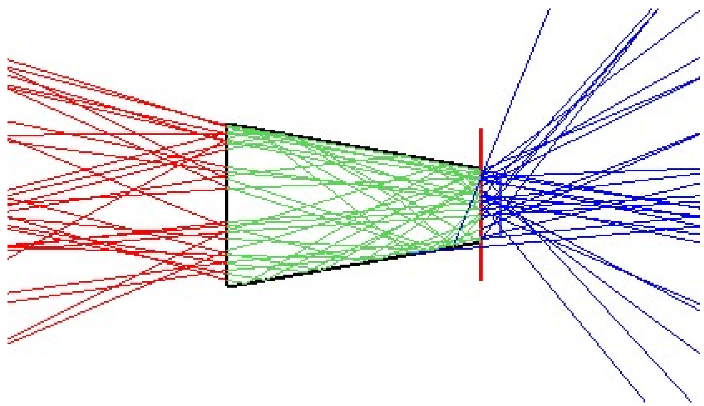
- Detector module with 8x8 array of SMD MPPCs at 2.54 mm pitch

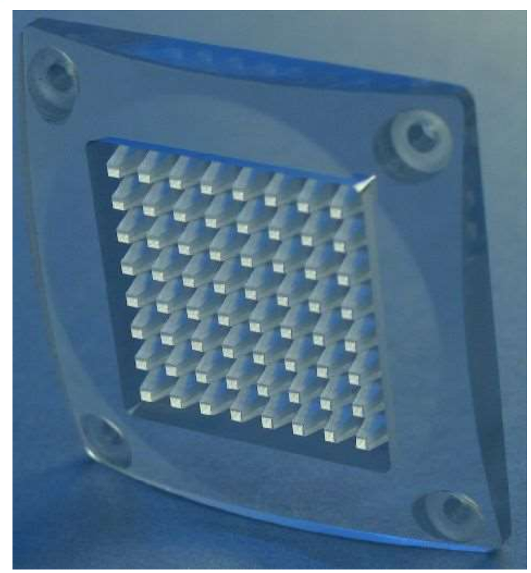








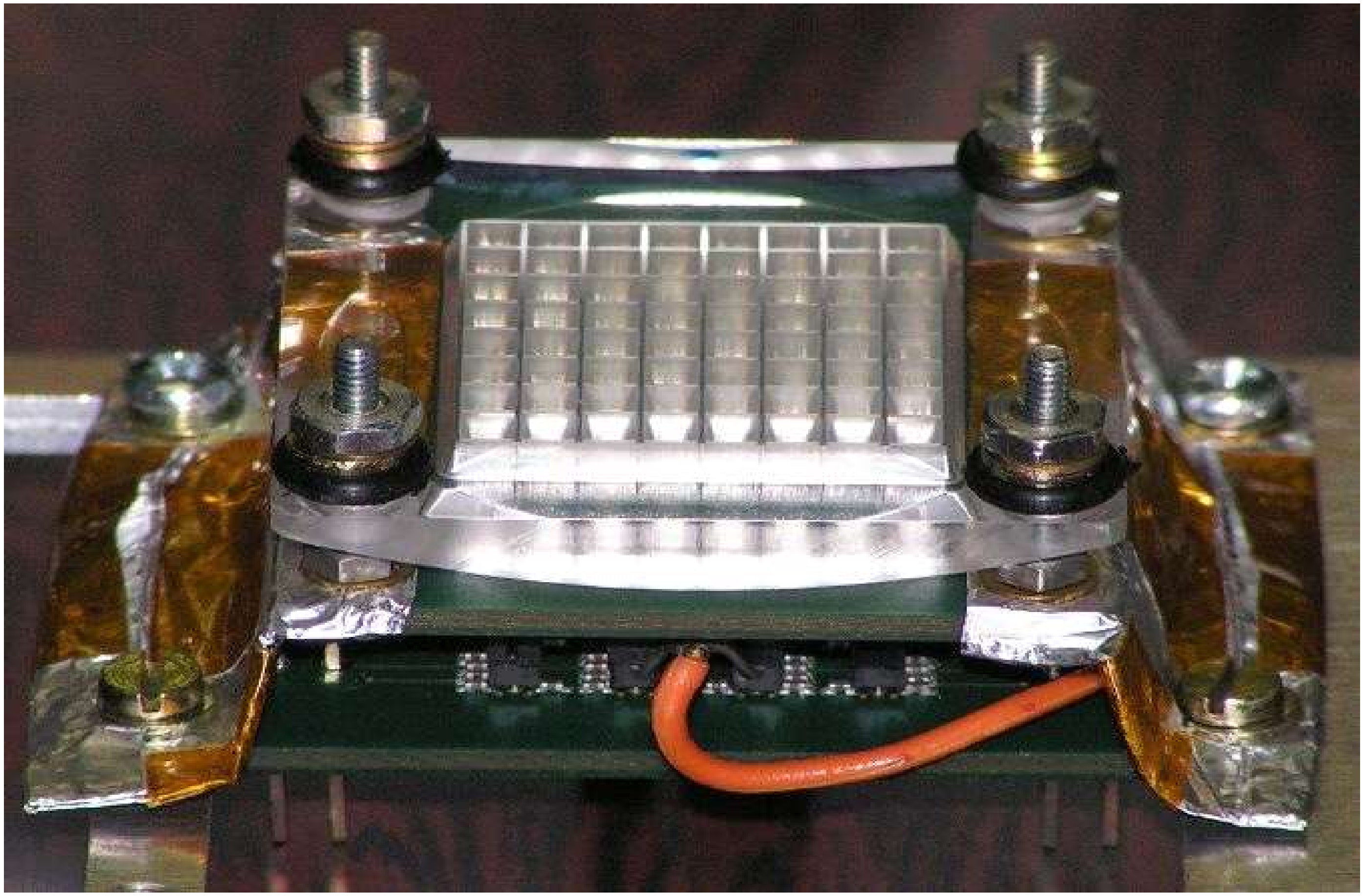




Light guides were machined from plastic (HERA-B lens material).

NIMA 2009

MPPC Module

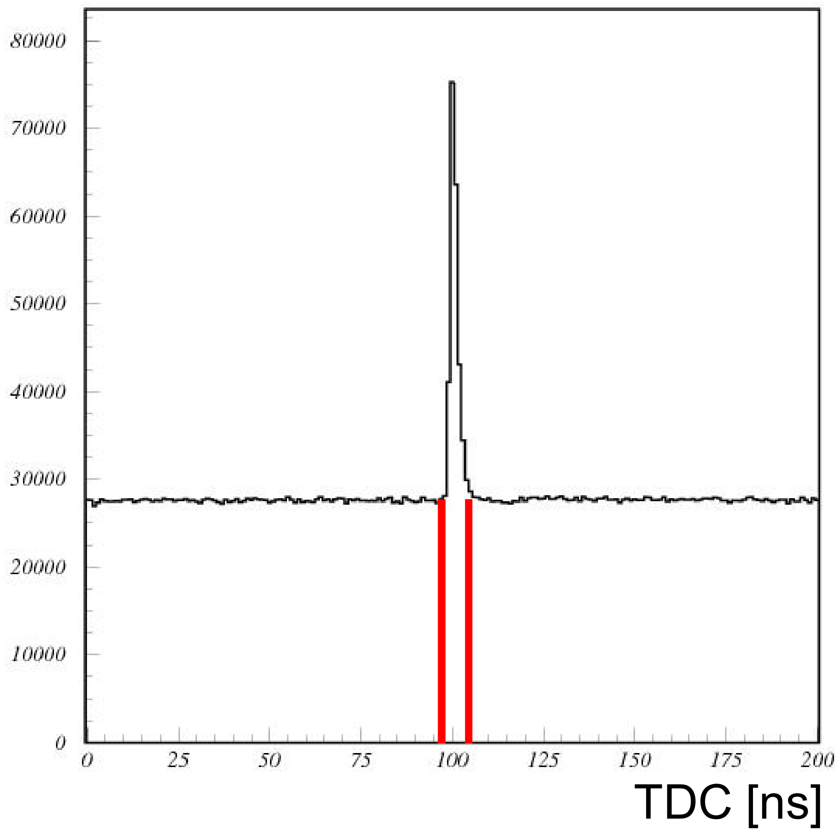


TDC distributions of MPPC hits for all events

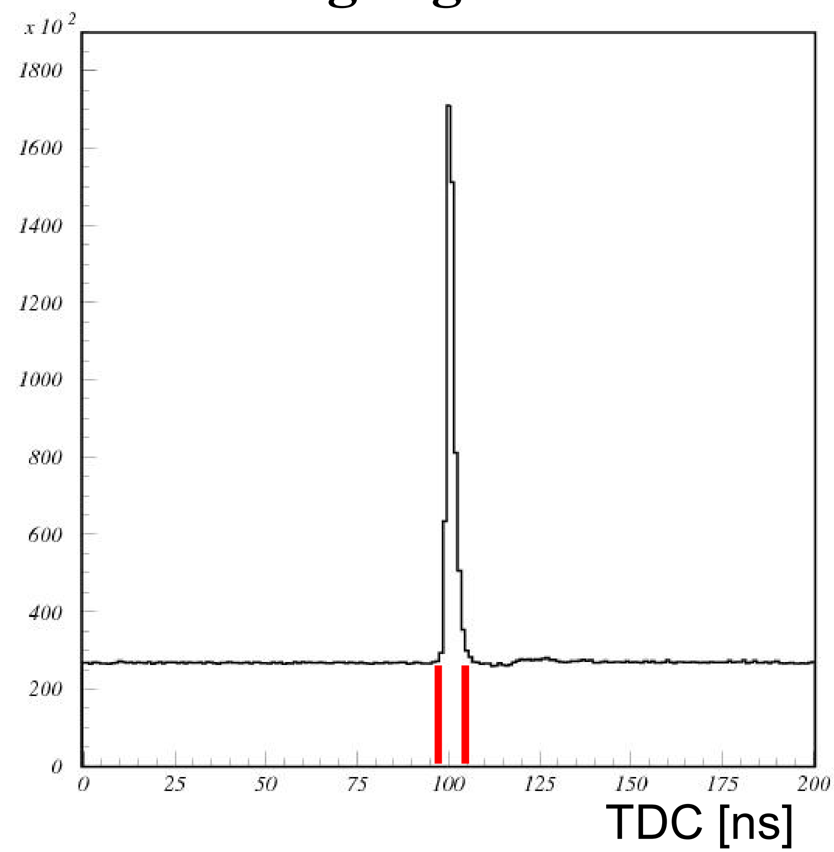
total noise rate ~ 35MHz (~600kHz/MPPC)

hits in the time window of 5ns around the peak are selected for Cherenkov angle analysis

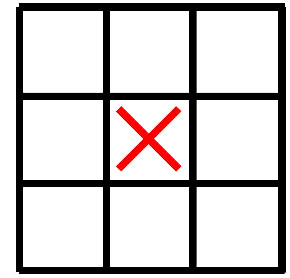
w/o light guides



w/ light guides

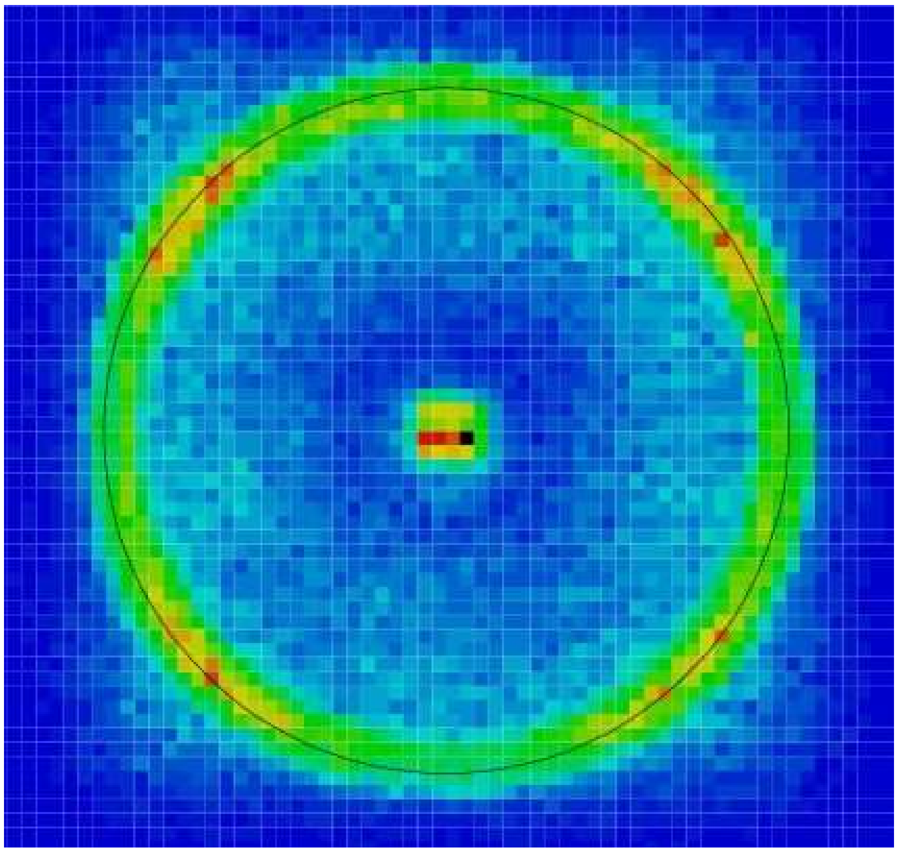


Ring images

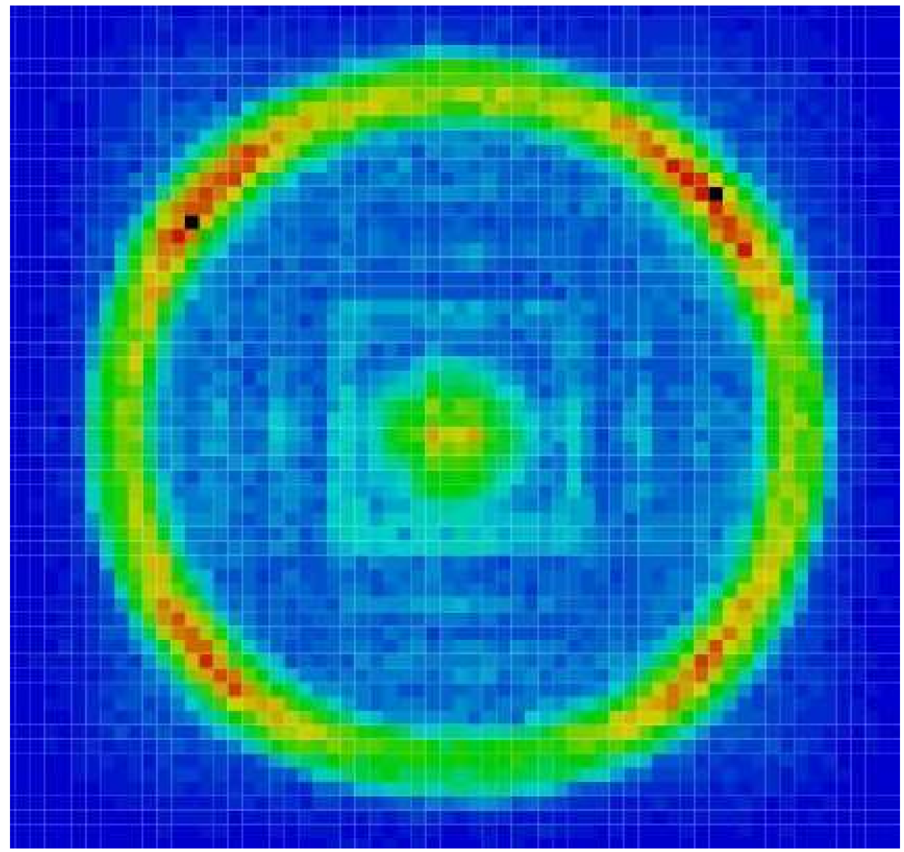


module was moved to 9 positions to cover the ring area
these plots show only superposition of 8 positions (central position is not included)

w/o light guides



w/ light guides



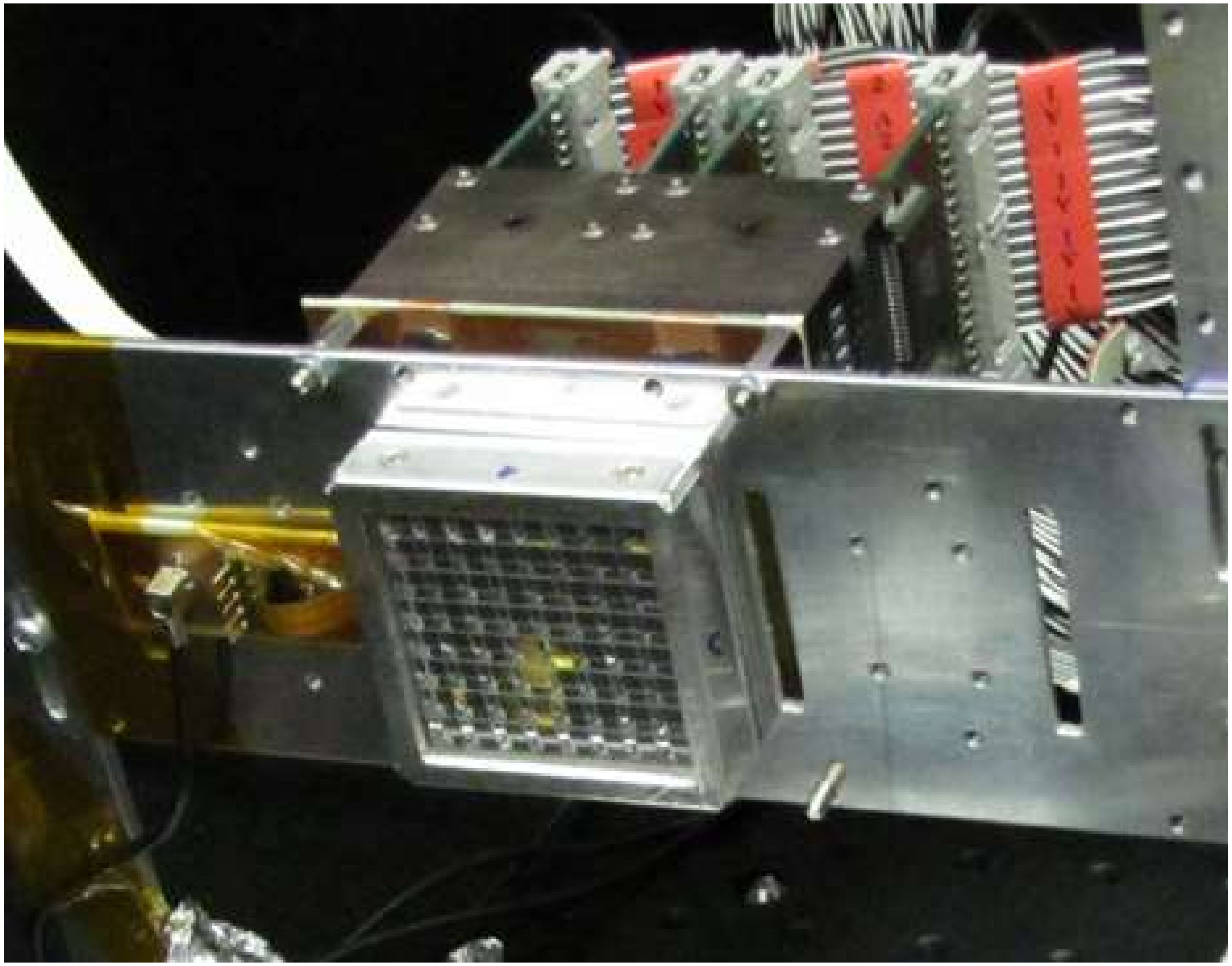
Number of photons

Expected number of photons is ~3/full ring, this includes:
Hamamatsu PDE
aerogel: 1cm thickness, n=1.03, 25mm attenuation length
dead time and double hit loss ~10%

Measured (extrapolated to full ring - acceptance corrected):
w/o LG ~ 1.6
w/ LG ~ 3.7

Estimated numbers for BelleII ARICH: aerogel with n=1.05 and thickness of 4cm (~5x) and better quality of light guides (surface polishing: ~2x) are
w/o LG ~ 8
w/ LG ~ 37

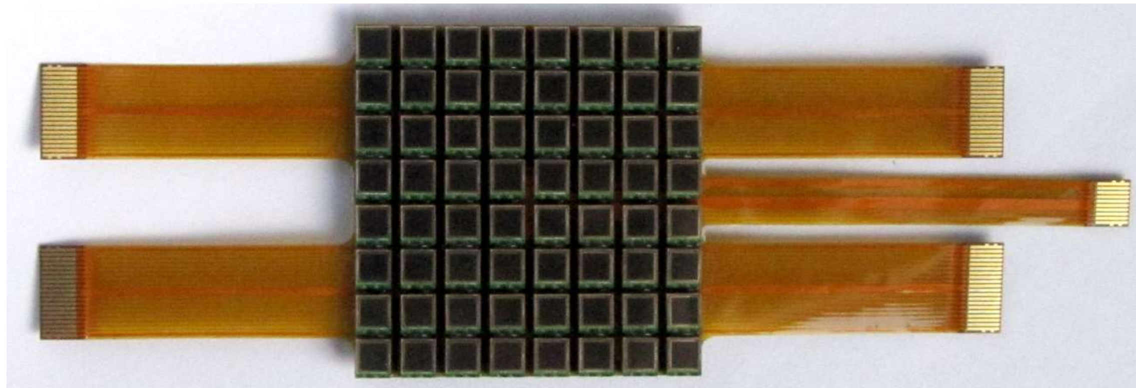
Next step – full module of SiPMs



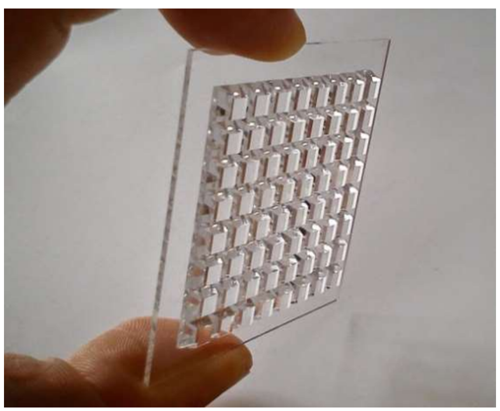
Module components

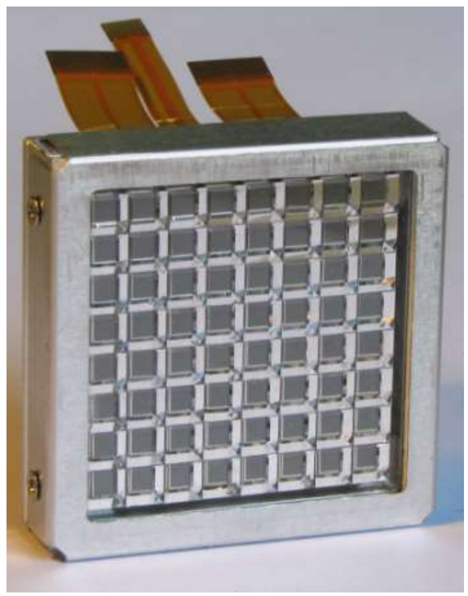
Hamamatsu MPPC array
S11834-3388DF

Single SiPM: 3600 cells
8 x 8 SiPMs 3x3mm2
pitch size 5 mm



Light concentrators
Borosilicate glass

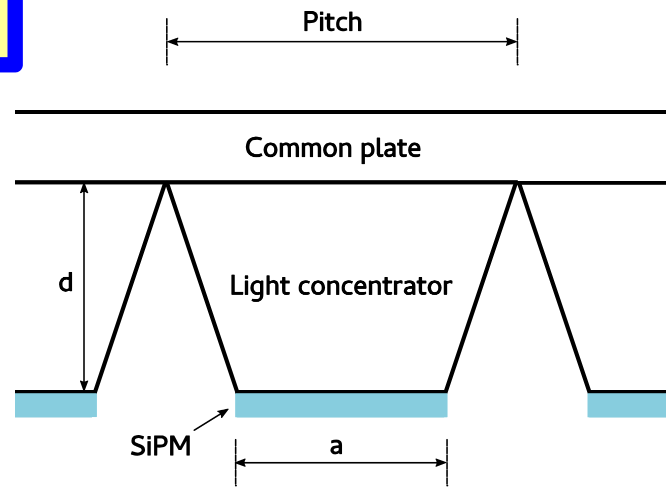




Module:
SiPM array
Light concentrators
Optical grease
Al frame

Readout:
ASD8 front-end boards (HERA-B RICH)
Amplifier/Shaper/Discriminator

Light concentrators

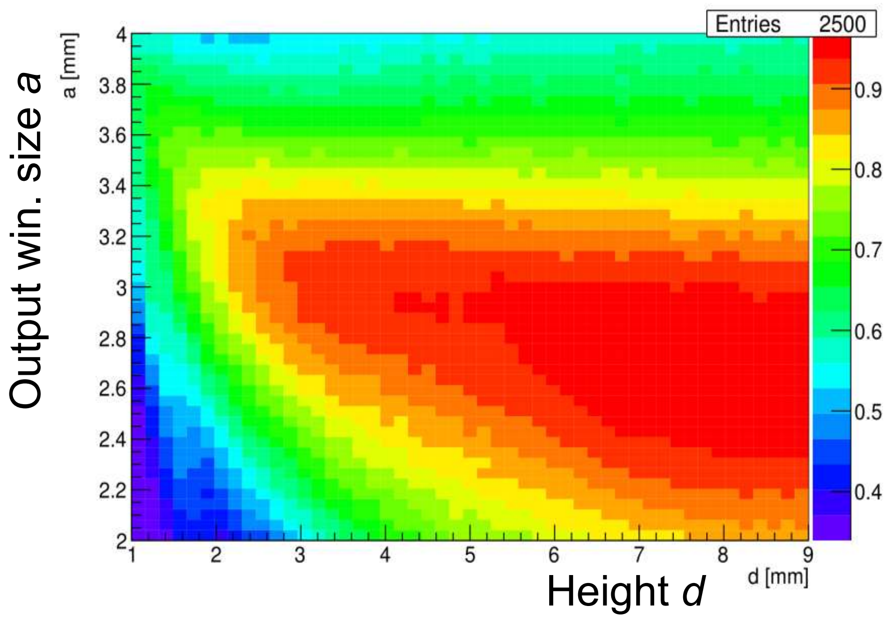


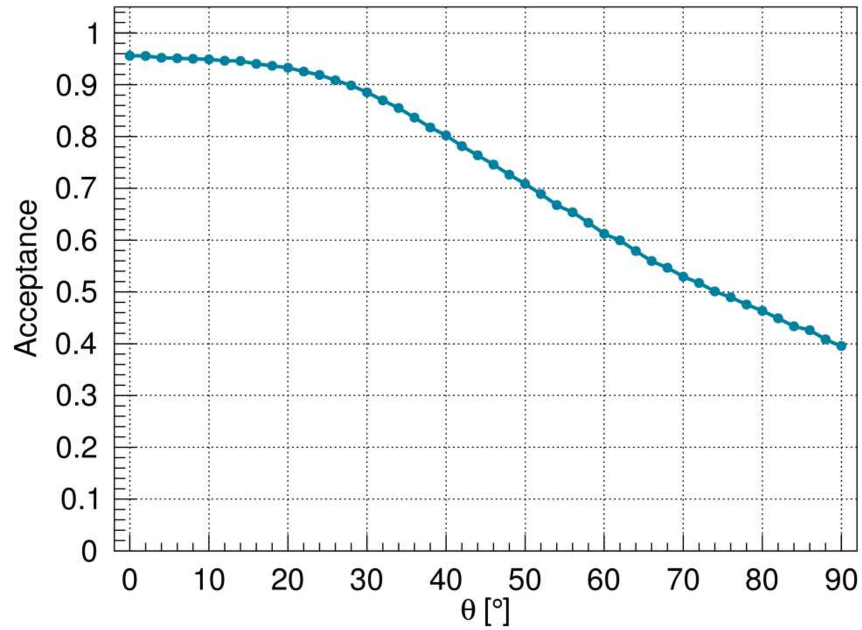
Acceptance of the MPPC module

$$\left(\frac{SiPM\ size}{Pitch}\right)^2 = \left(\frac{3}{5}\right)^2 = 0.36$$

Improve acceptance

- Ray tracing Monte Carlo study
- Acceptance as function of *d* and *a*





Acceptance as function of maximal angle of incidence

Korpar et al. NIM A 766 (2014) 107

Performance of the concentrators

Surface scan with a triggered low intensity point like source

- Average number of detected photons/ event

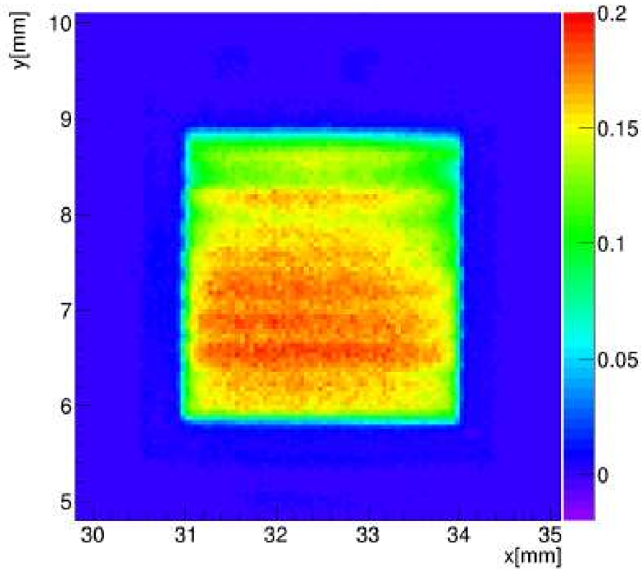
Clear improvement

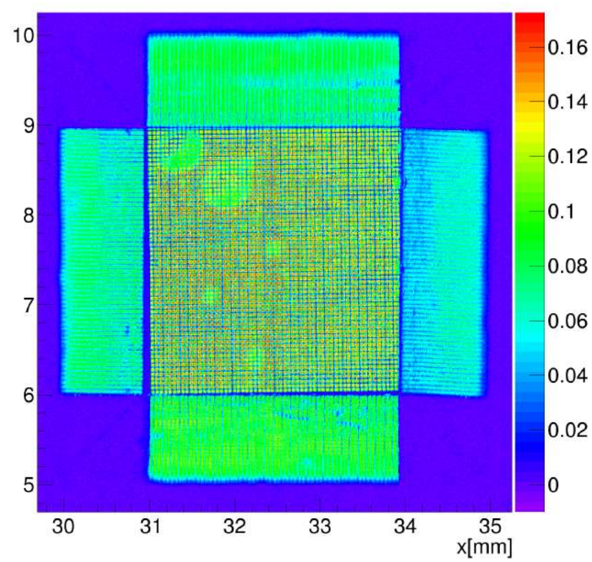
w/o concentrator

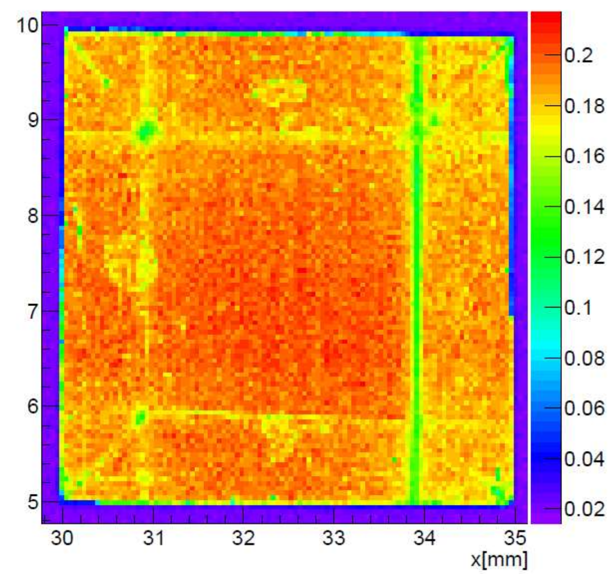
with concentrators

w/o optical grease

with optical grease





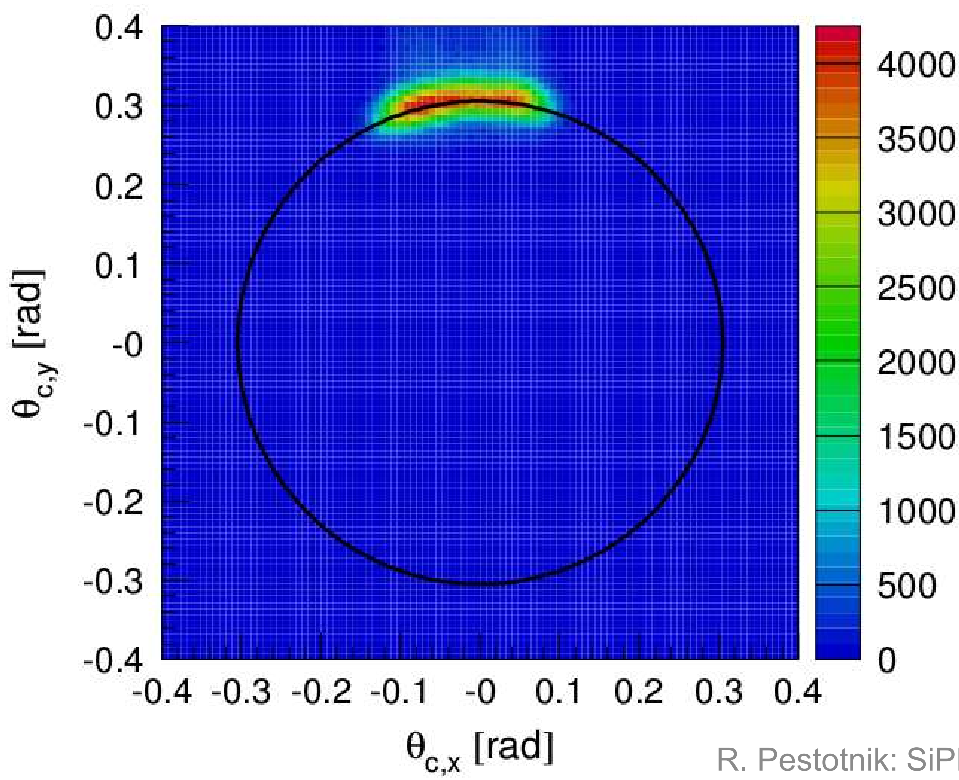


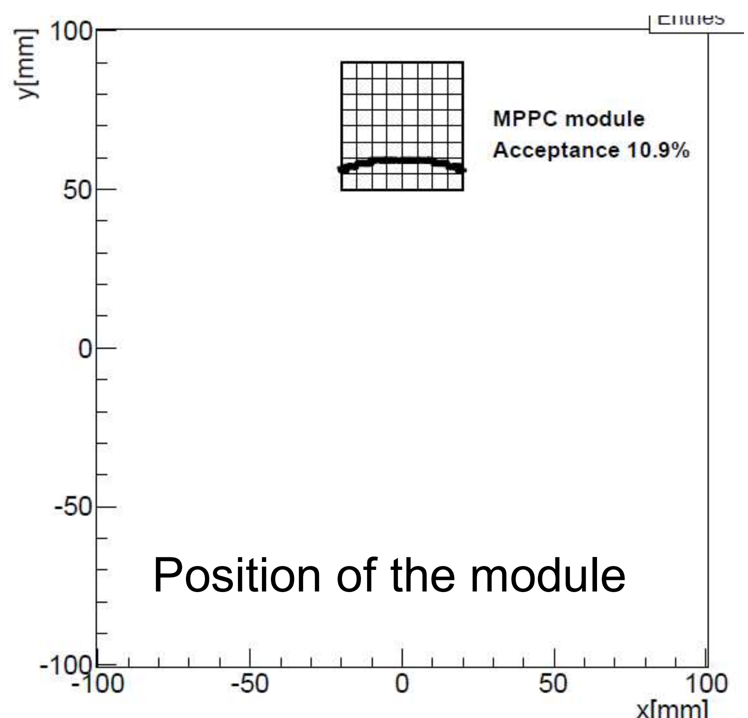
Beamtest results

Aerogel	Ref. index	Width [mm]	Λ [mm]	Expected θ
1 (upstream)	1.0485	19.4	44.0	305.34
2 (downstream)	1.0619	20.2	54.8	343.1

Slightly less than expected due to imperfect coupling + missalignment

Number of detected hits:
- With concentrators: $N_{LC} = 3.5$ hits/track $\rightarrow$ 35 hits/ring
- Without concentrators: $N_{wo} = 1.8$ hits/track $\rightarrow$ 18 hits/ring





Beamtest summary

Results from the beam tests are encouraging.

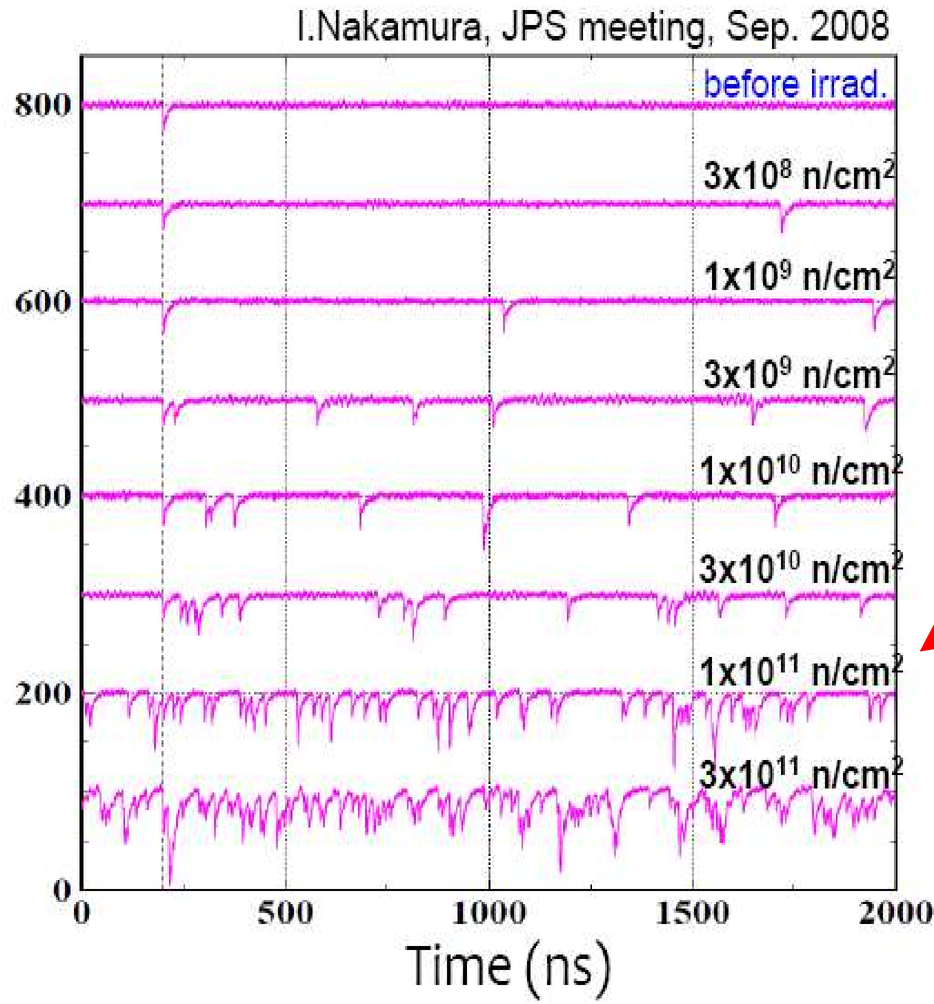
We can expect 35 hits per ring with an adequate resolution

The electronics for a RICH made of such SiPM modules can be made without big problems.

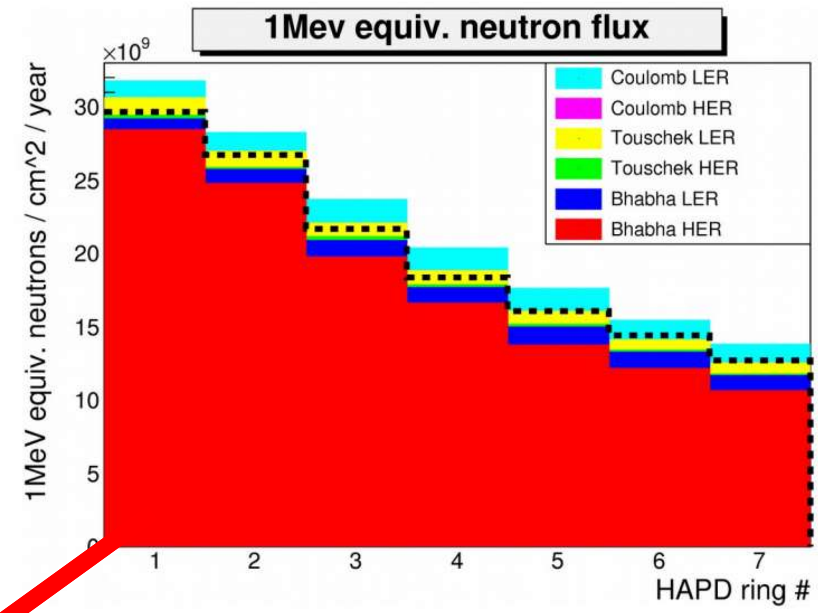
Can SiPMs survive radiation environment in Belle II?

Neutron damage

Time evolution of a SiPM signal



Expected neutron fluence per year as a function of the distance from the beam



~10^{11}n/cm^{2}year

Noise hits after one year

Unfortunately due to such a neutron load, the detector would not survive long enough.

Summary

A photon detector module was constructed using a MPPC array and a light concentrator.

A proximity focusing RICH with 4 cm aerogel radiator (n=1.05/1.06) and the detector module was successfully tested in an electron beam test in DESY.

For β =1 tracks 35 photons can be detected.

We achieved an efficiency increase with light guides of 1.9 (area ratio ~ 2.7)

SiPM can be used as a detector of single photons in RICH counters *

*** provided the neutron fluence is low enough**