# Silicon Photomultiplier as a Photon Sensor for RICH Counter

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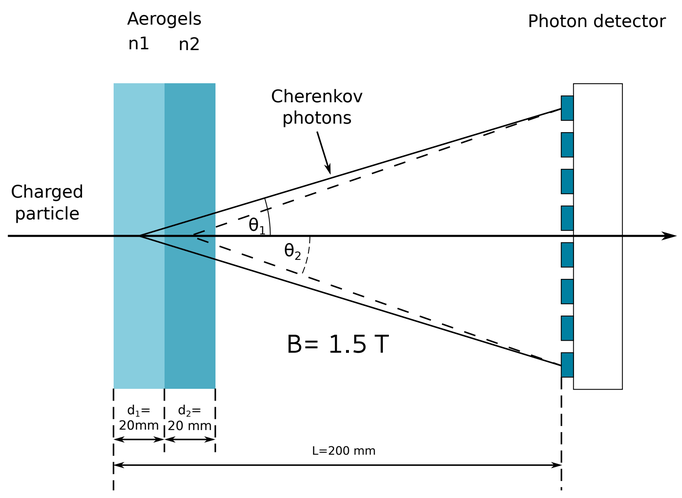
## Motivation



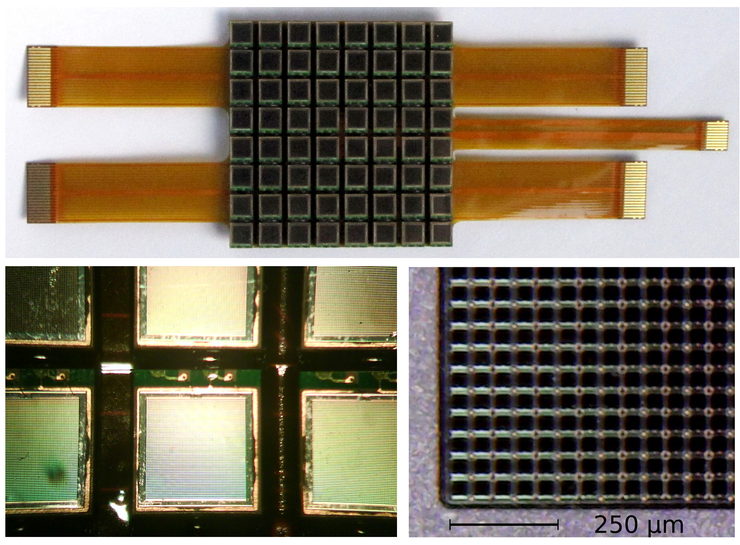

- Ring Imaging Cherenkov (RICH) counter with aerogel
- Separation of pions and kaons $p$ = [1,4] GeV/c
- Proximity focusing configuration
- Number of detected photons:

$$N \propto d \sin^2 \theta$$

- Thicker radiator: larger $N$, but also larger error $\sigma_\theta$
- Non-homogeneous radiator produces overlapping rings on the photon sensor plane
- Resulting in: more photons, without loss of resolution

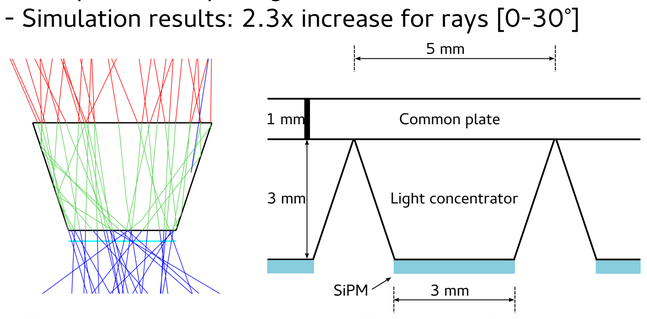
## SiPM Characteristics

- Array of SiPMs: Hamamatsu MPPC S11834-3388DF
- Multi-Pixel Photon Counter (MPPC) is a novel 8x8 SiPM array, each SiPM representing one 5x5 mm$^2$ channel
- Large active area: 3x3 mm$^2$
- Pixel pitch: 50 µm
- Fill factor: 61.5%
- Dark counts rate is rather low ~$10^5$ Hz/mm$^2$
- Operating voltage (70±10) V
- Operation in a high magnetic field

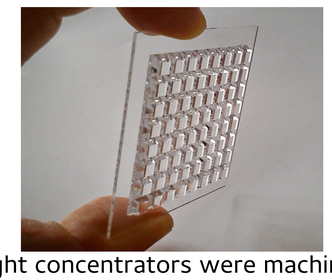



## How to Increase the Acceptance of MPPC?

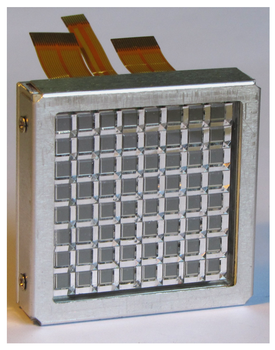
- Inital acceptance 3x3 mm$^2$/5x5 mm$^2$ = 36%
- Study of an array of light concentrators
- Simulation results: 2.3x increase for rays [0-30°]




- The truncated pyramids were fabricated from borosilicate glass (n=1.52 @ 404 nm) and glued on a common plate
- Keeping the same acitve area of the MPPC, but accepting more photons resulted also in improved S/N ratio

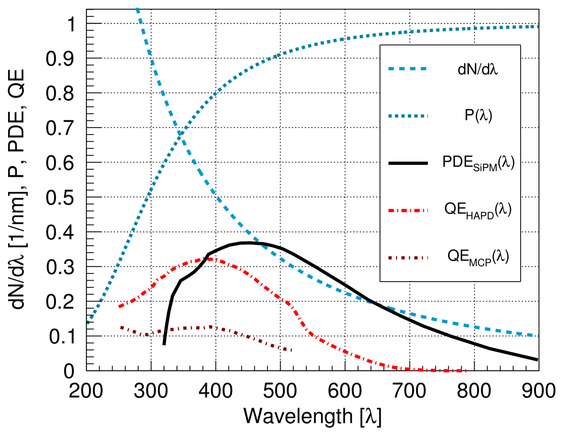


Light concentrators were machined from glass and assembled together with the MPPC into a module



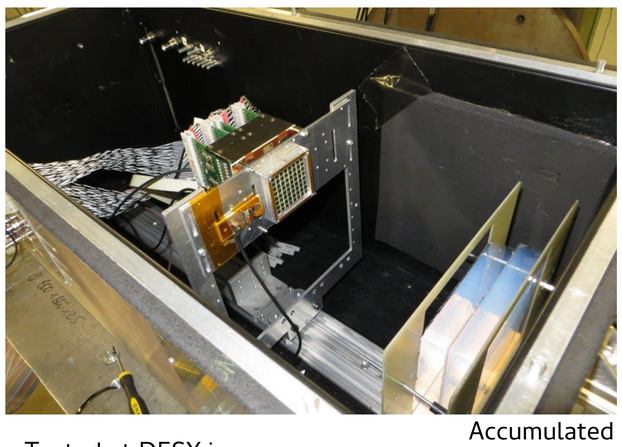
## SiPM as Photon Detector in ARICH

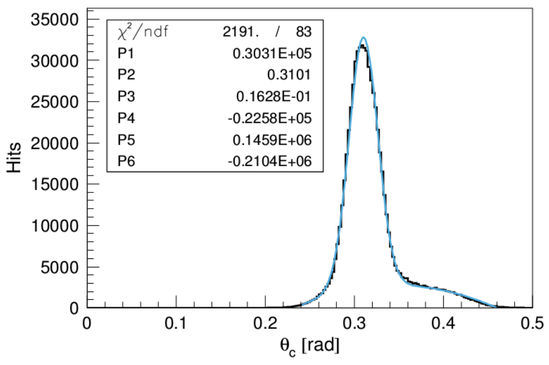
- An efficient sensor operating in magnetic field of $B$=1.5 T is needed for Belle II ARICH
- Three candidates were considered:
  1) Micro-channel plate PhotoMultiplier Tube (MCP-PMT)
  2) Hybrid Avalanche PhotoDiode (HAPD)
  3) Silicon PhotoMultiplier (SiPM)




- Emitted Cerenkov photons per wavelength interval: $dN/d\lambda$
- Probability that photon will not scatter in aerogel: P
- Photon detection efficiency (PDE) of SiPM has high peak: ~ 37%
- Compare with quantum efficiency of HAPD
- and quantum efficiency of MCP-PMT

## RICH Prototype in Test Beam

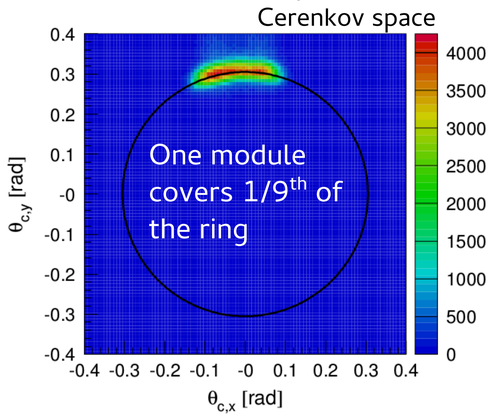


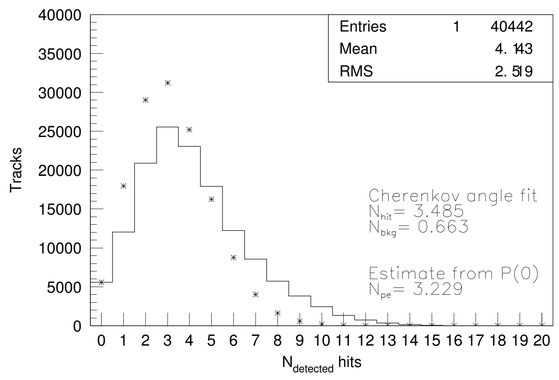



- Distribution of Cerenkov hits
- Number of detected photons with light concentrators: $N_{LC}$ = 3.5 hits/track → 32 hits/ring
- Without concentrators: $N_{wo}$ = 1.9 hit/track → 17 hits/ring

- Tested at DESY in September 2013
Electrons with $p$=5GeV/c
- $\theta_C$=304 mrad (upstream), 343 mrad (downstream)
- Detector operated in binary mode
- Hits detected using time information only
- Narrow detection time window of 6 ns

Accumulated hits represented in Cerenkov space

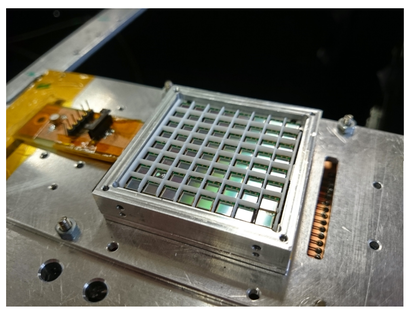


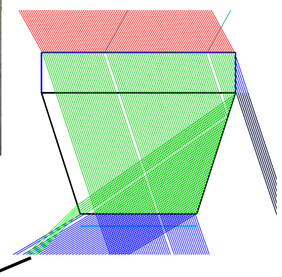




- Distribution of number of hits
- Full line: reconstructed data
- Stars: Poisson distribution from $N_{pe}$=-ln $P(0)$

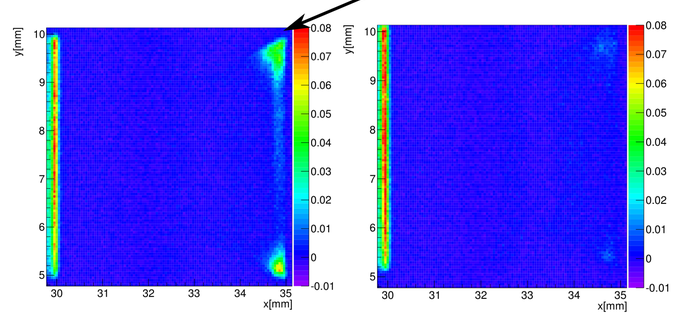
## Optical Crosstalk

Teflon filling between the pyramids

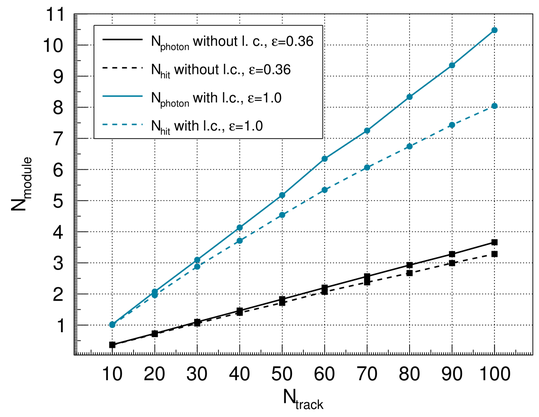




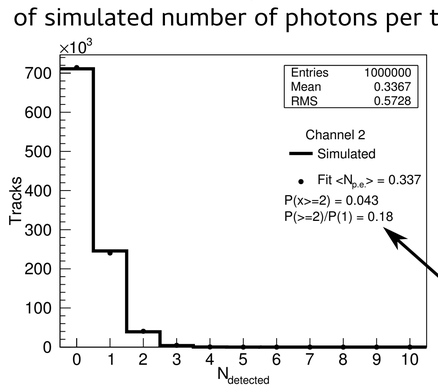
Registered hits in the neighbour channel without (left) and with (right) filling




## Multiple Hits




Number of detected photons and hits per module as a function of simulated number of photons per track




Binary mode ⇨ justified by a small number of hits per channel and a high granularity of detector

Estimate of lost hits: 18% (6% without concentrators)

## Conclusion

- SiPM is a compact, robust and thin photon sensor with high photon detection efficiency
- Operation in strong magnetic field
- An excellent photon sensor for RICH
- In a prototype RICH with aerogel as radiator and light concentrators there were $N$=32 detected hits per ring
- Kaon/pion separation at $p$=4 GeV/c:
8σ with light concentrators
6σ sigma without light concentrators
- Main weakness: SiPMs are sensitive to neutron irradiation
- The signal is degraded after neutron fluence of $10^{11}$ $n_{eq}$ per cm$^2$

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