Tests of a Silicon Photomultiplier Module for Detection of Cherenkov Photons

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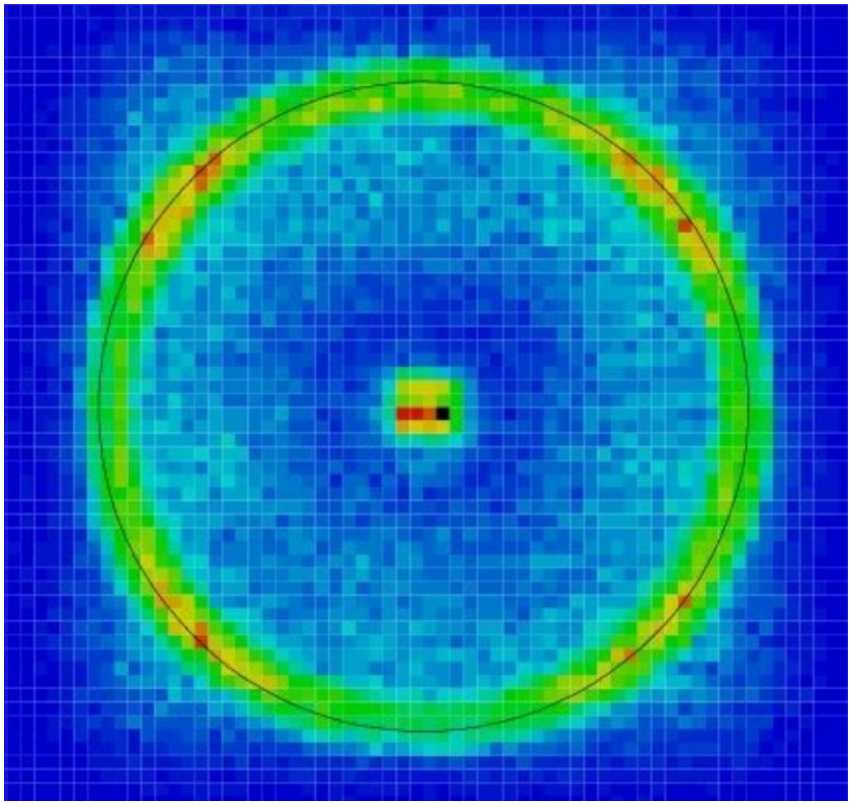

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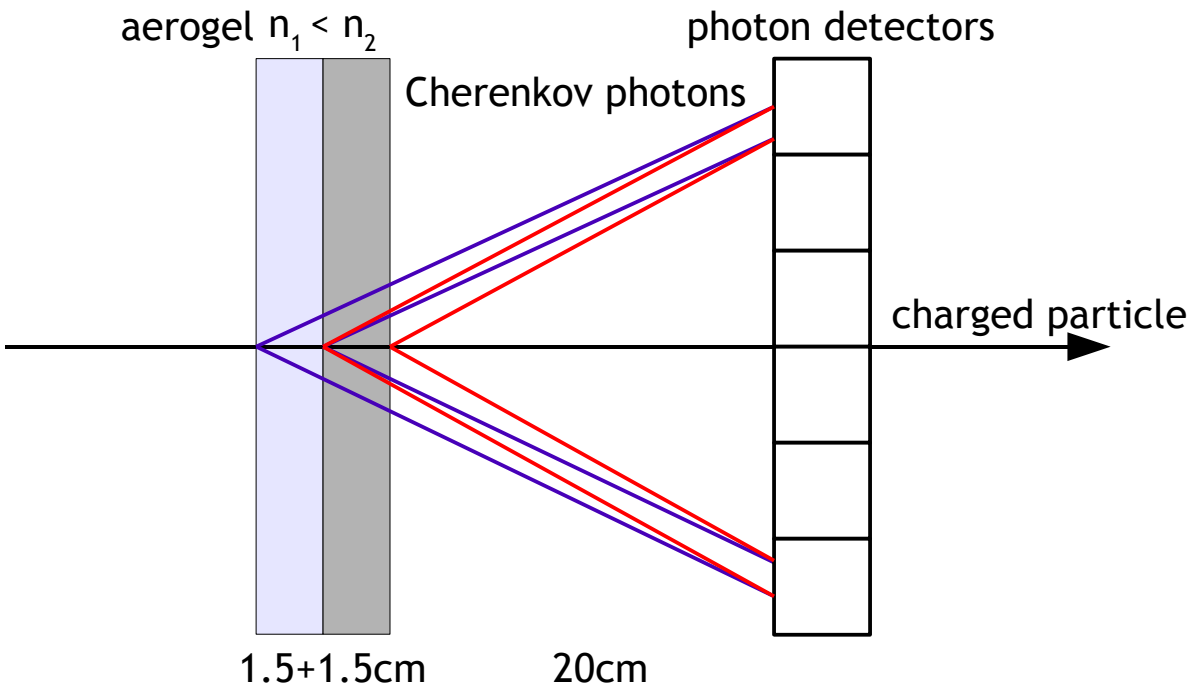
Outline

- Motivation – BELLE II PID upgrade
- Silicon Photomultiplier (SiPM)
- Array of 8×8 SiPMs
- Beam tests in CERN
- Light guides
- Results with light guides
- Summary

BELLE II PID upgrade

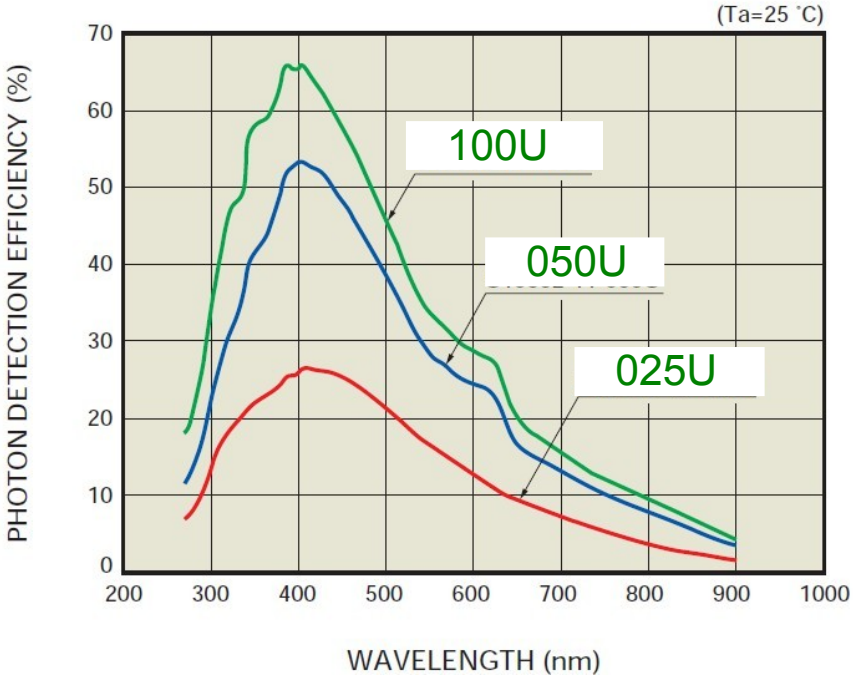
- 4σ K/π separation at 4GeV/c
- proximity focusing RICH with aerogels in focusing configuration
- photon detector requirements:
  - single photons
  - high efficiency at λ > 350nm
  - operation in high magnetic field (1.5T)
  - pad size ~ 5-6mm



Silicon PhotoMultiplier

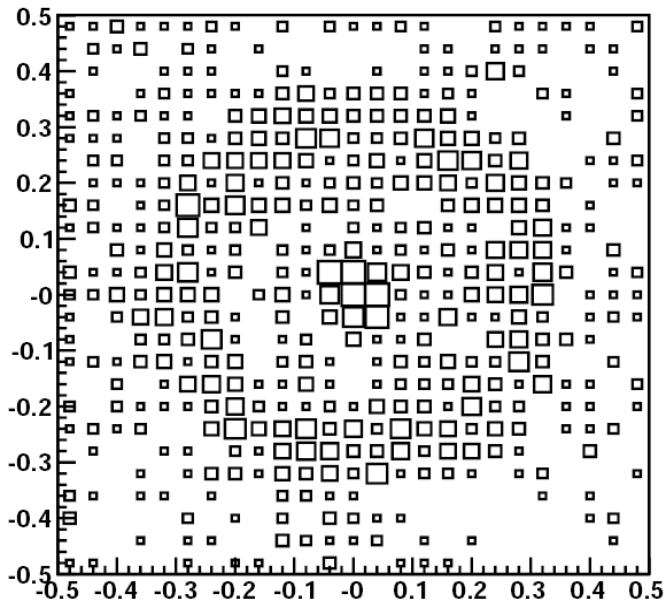
- SiPM
  - an array of APDs operating in Geiger mode
  - low operation voltage (10-100V)
  - gain ~ 10^6
  - peak PDE ~ 65% @400nm [Hamamatsu] (incl. geom. efficiency)
  - time resolution ~ 100ps
  - works perfectly in high magnetic field
  - dark counts ~ few 100kHz/mm^2

Hamamatsu MPPC S10362-11-



SiPM: Problems in Cherenkov photon detection

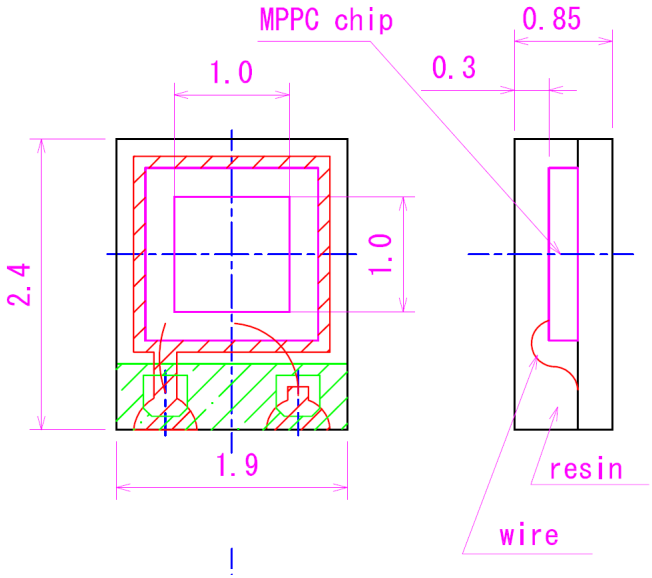
- dark noise signals have same height as single photon signals
- signal to noise ratio can be improved:
  - select only signals inside small time window
  - collect more photons per SiPM with light guides



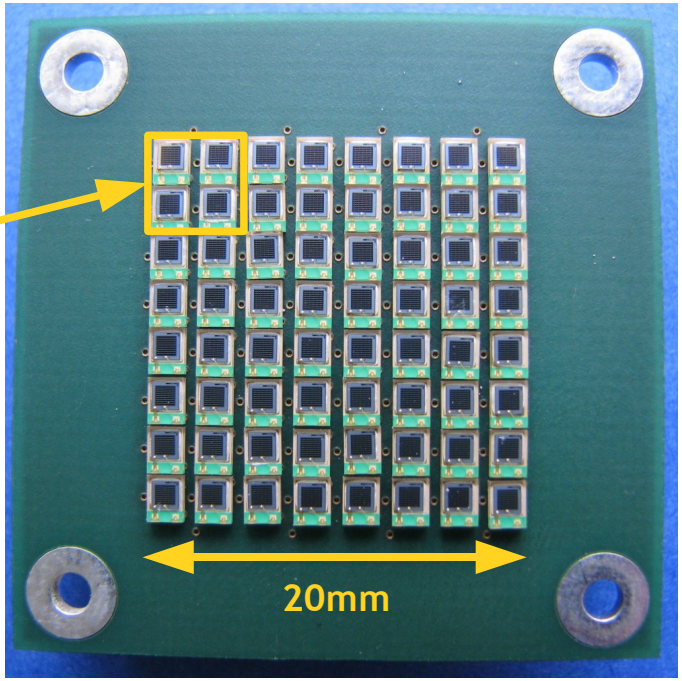
Proof of principle: cosmic ray test, published in NIM A594 (2008) 13.

Array of 8×8 SiPMs

- 64 Hamamatsu S10362-11-100P SMD MPPCs
  - 100μm cell size
  - 1×1mm^2 active surface
  - 0.3mm epoxy layer above active area
  - dark noise ~ 600kHz/SiPM
  - blocks of 2×2 MPPCs added into single channel
    → 16 readout channels
  - pad active area: 4mm^2/pad size: 5.08×5.08mm^2
    → pad geometric acceptance: **15.5%**

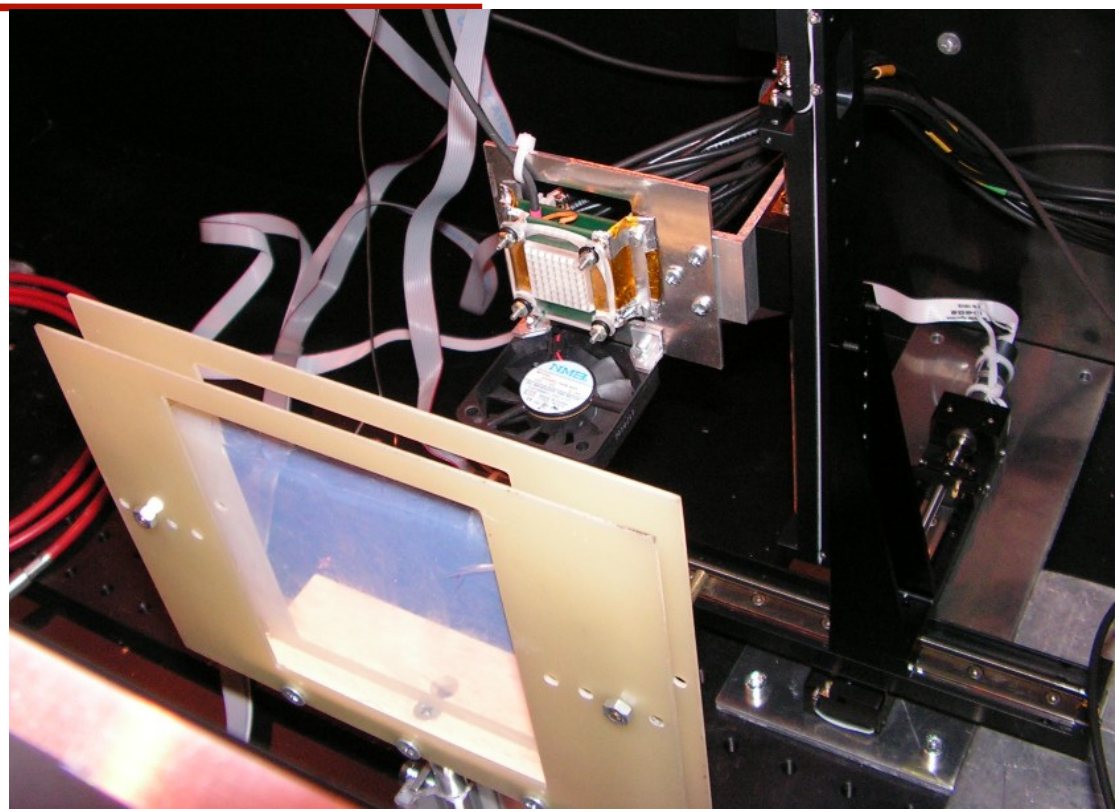


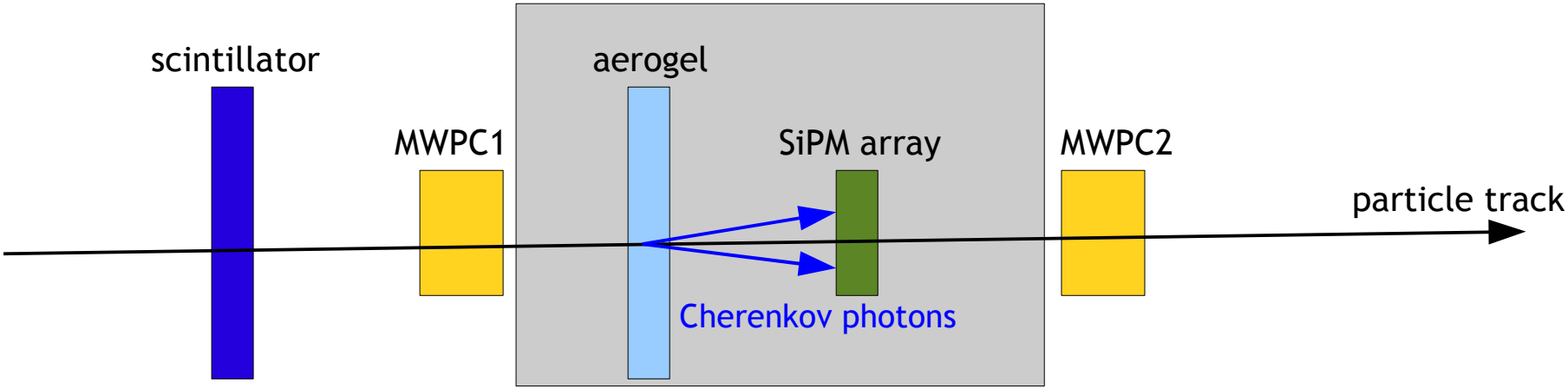
1 pad consisting of 2×2 SiPMs



Beam test at CERN

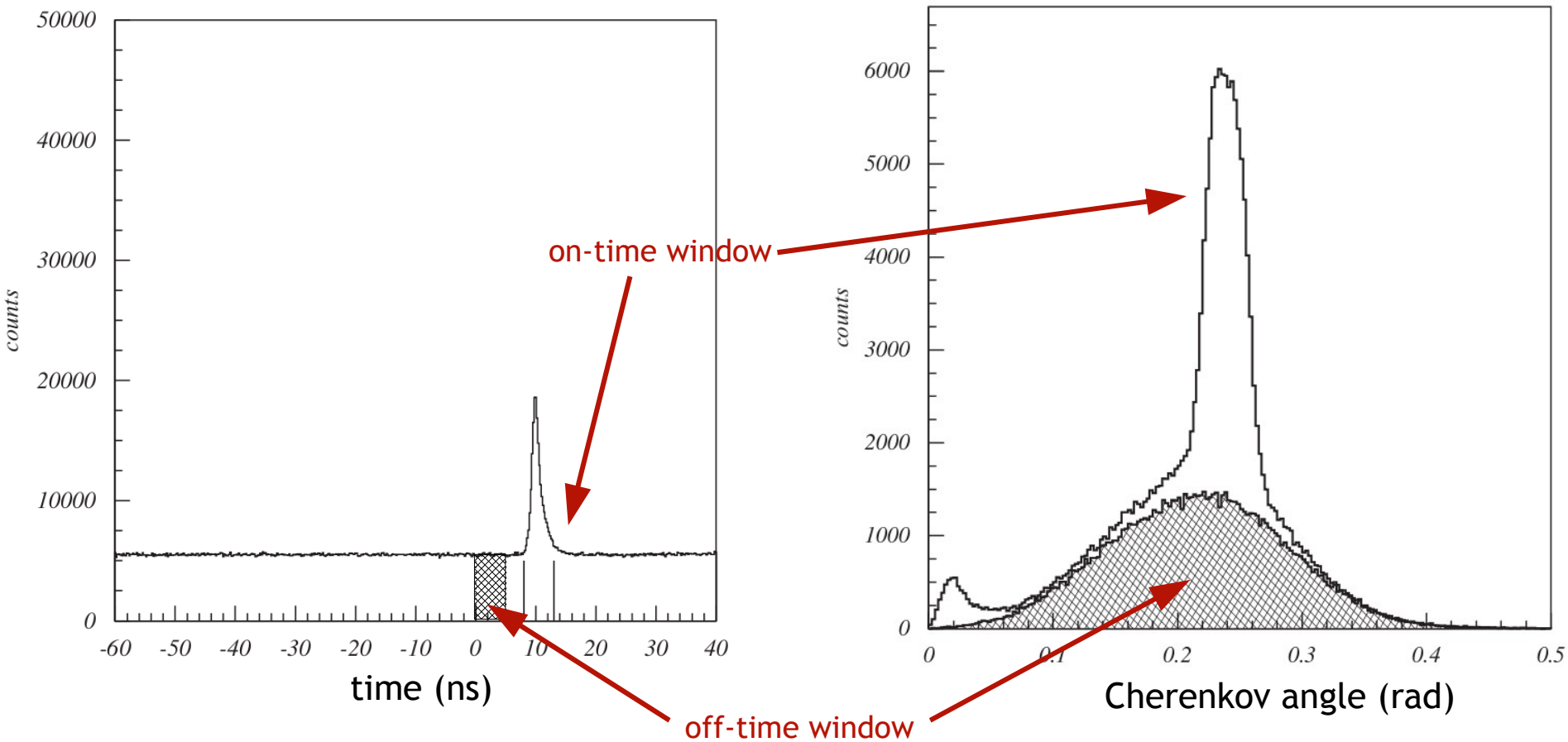
- +120GeV/c pions
- scintillator for timing
- 2 MWPC with delay line readout for tracking
- multi hit TDC
- aerogel n=1.03, d=10mm, attenuation length=14mm, distance to photon detector 115mm





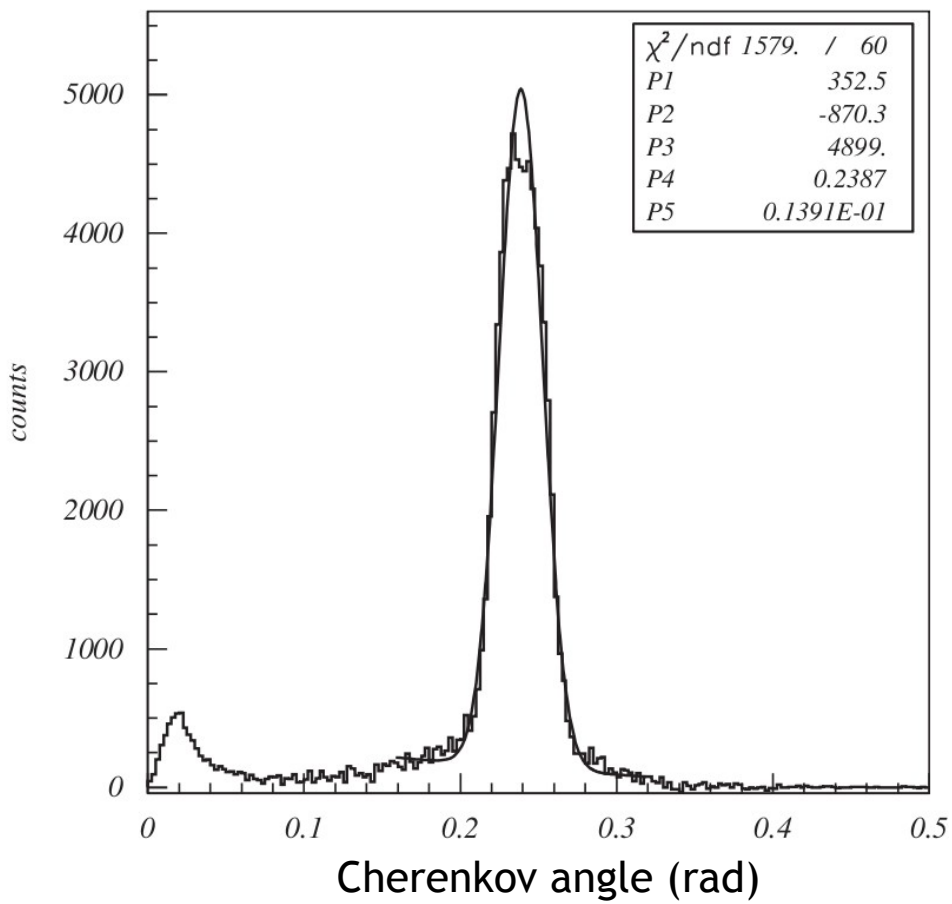
Results

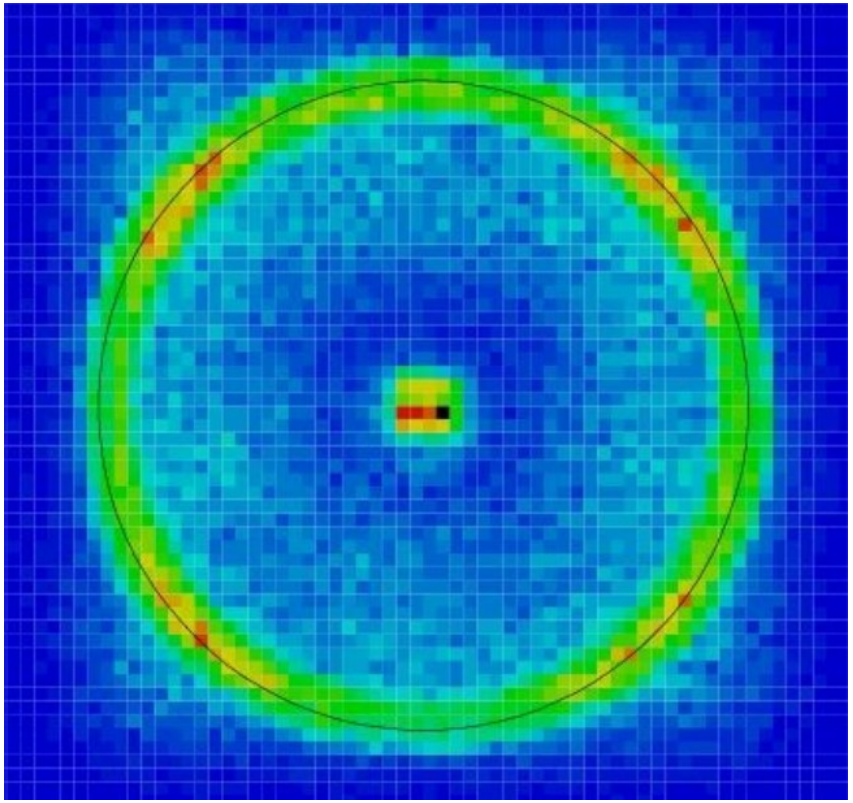
- total noise rate ~600kHz/MPPC = 35MHz
- hits in 5ns time window around the peak → Cherenkov angle analysis
  - SiPM noise background obtained from off-time window
  - background subtracted from on-time distribution



Results

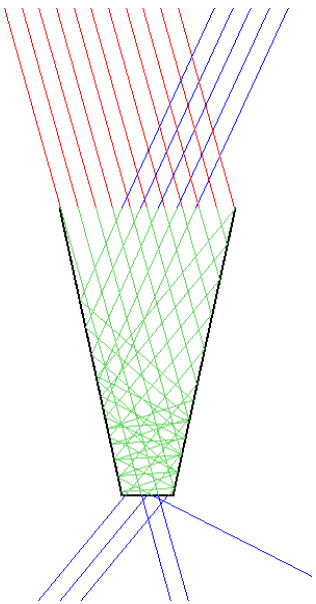
- background subtracted distributions in Cherenkov angle
  - resolution ~ 14mrad
  - photons/ring: 1.6



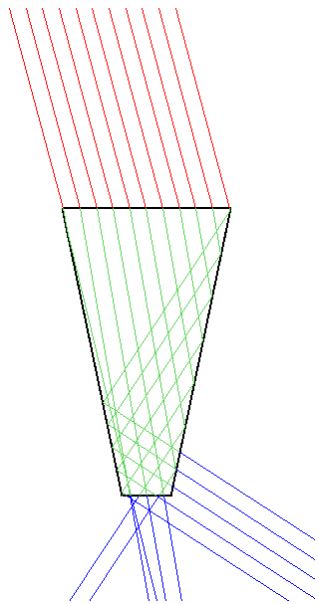


Light guides

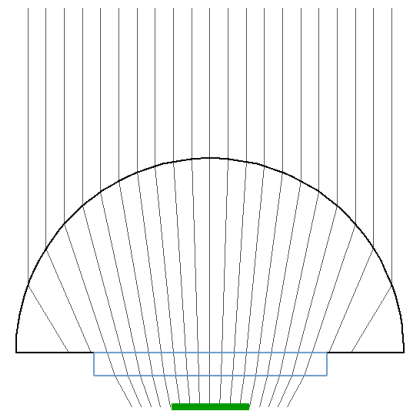
- concentrate light from larger surface
  - increase number of detected photons per single sensor
  - dark count remains the same
  - improve signal to noise ratio



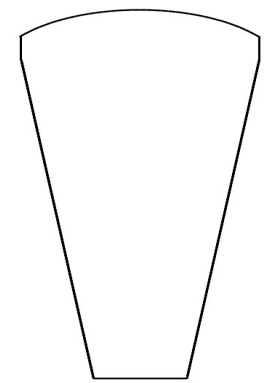
mirror walls



plastic truncated pyramid



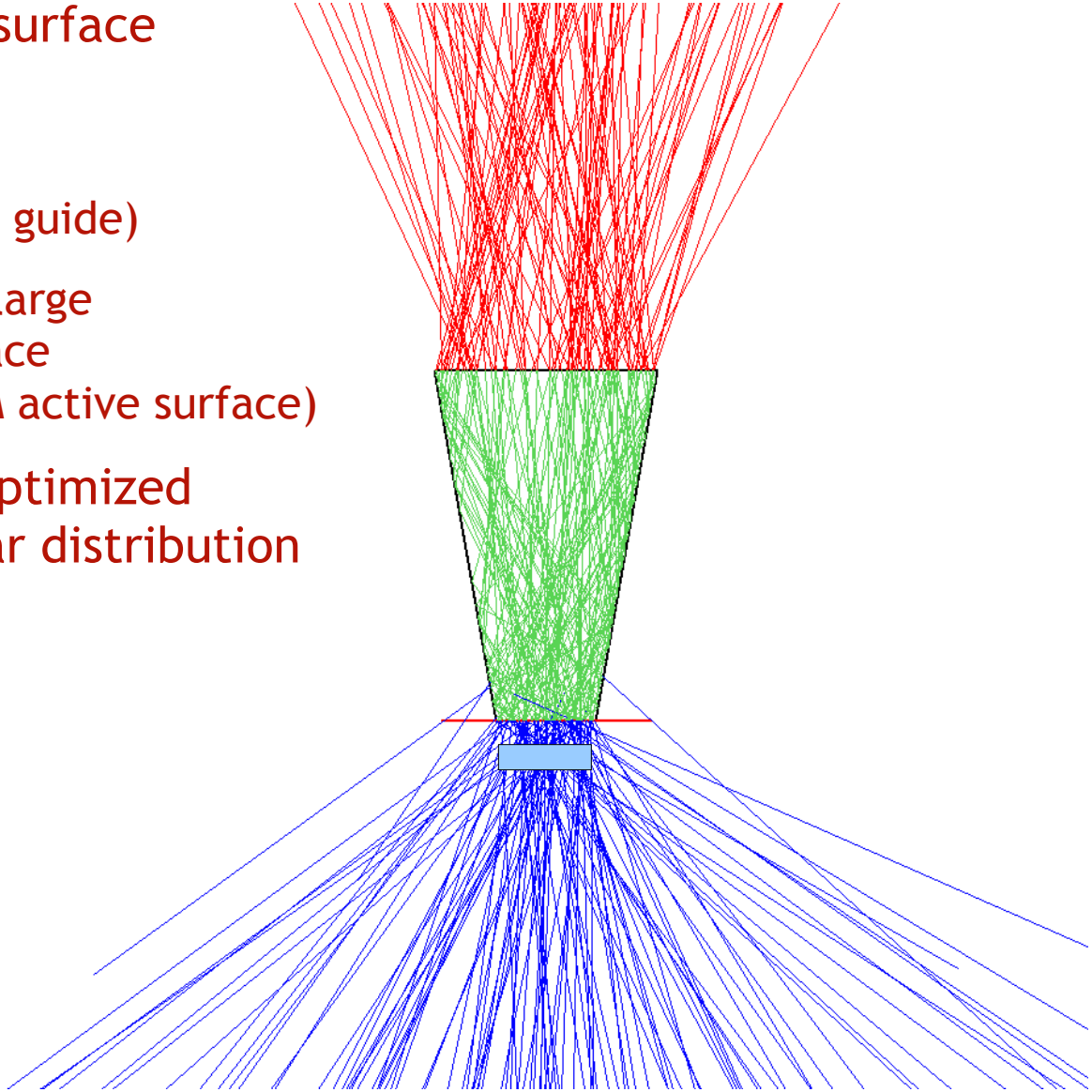
hemispherical light concentrator



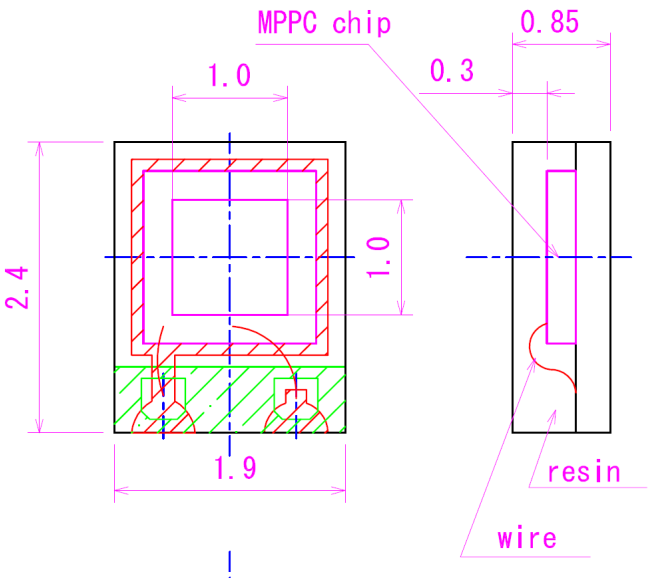
lens + truncated pyramid

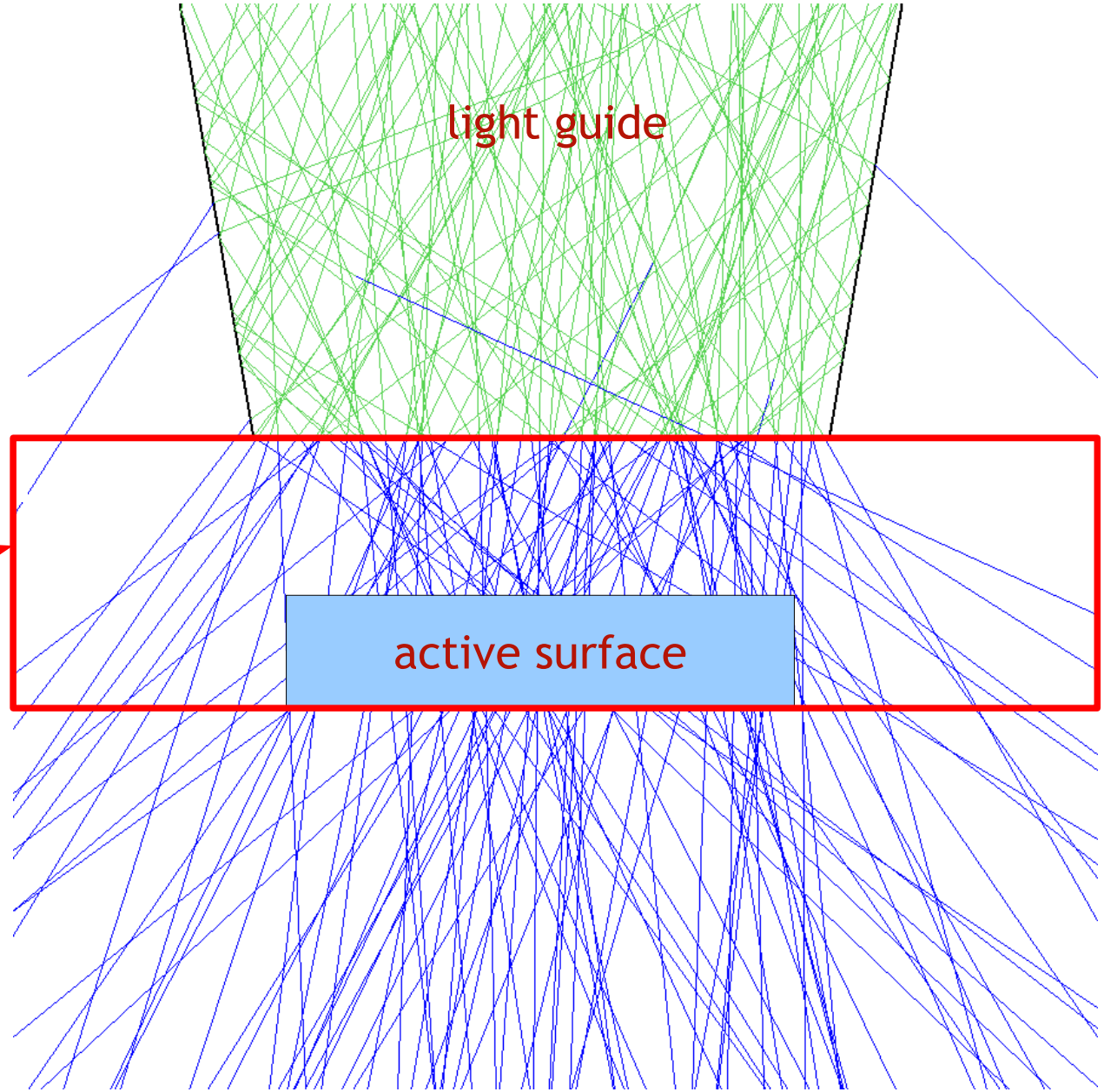
Light guides

- concentrate light onto smaller surface
  → increases angular spread
  - limits the angular acceptance
    (loss of total reflection in light guide)
  - light exiting light guide under large
    angles misses SiPM active surface
    (gap between LG exit and SiPM active surface)
- light guide geometry must be optimized
  for a given inbound light angular distribution
- RICH: $\theta_{Ch} \sim 18^\circ$ → should be OK



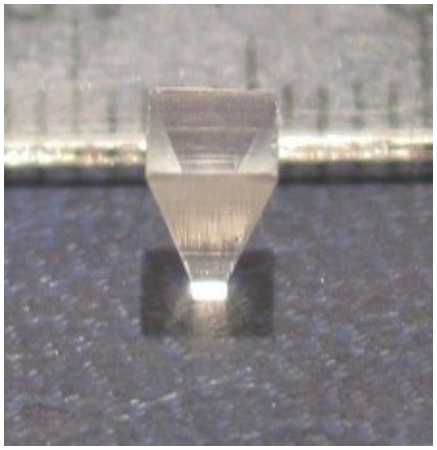
Light guides

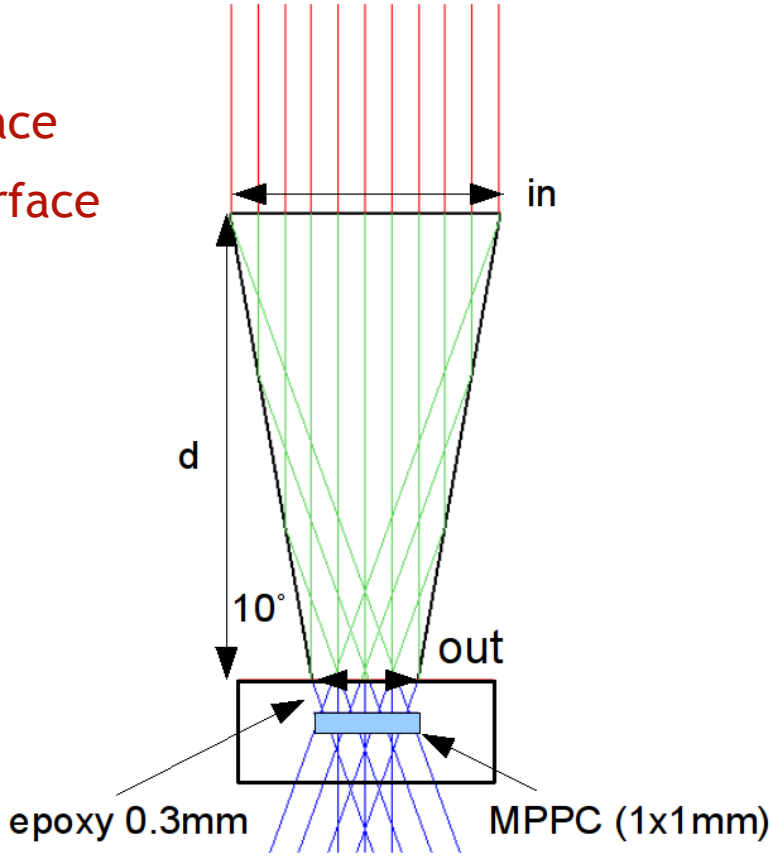




Light guides

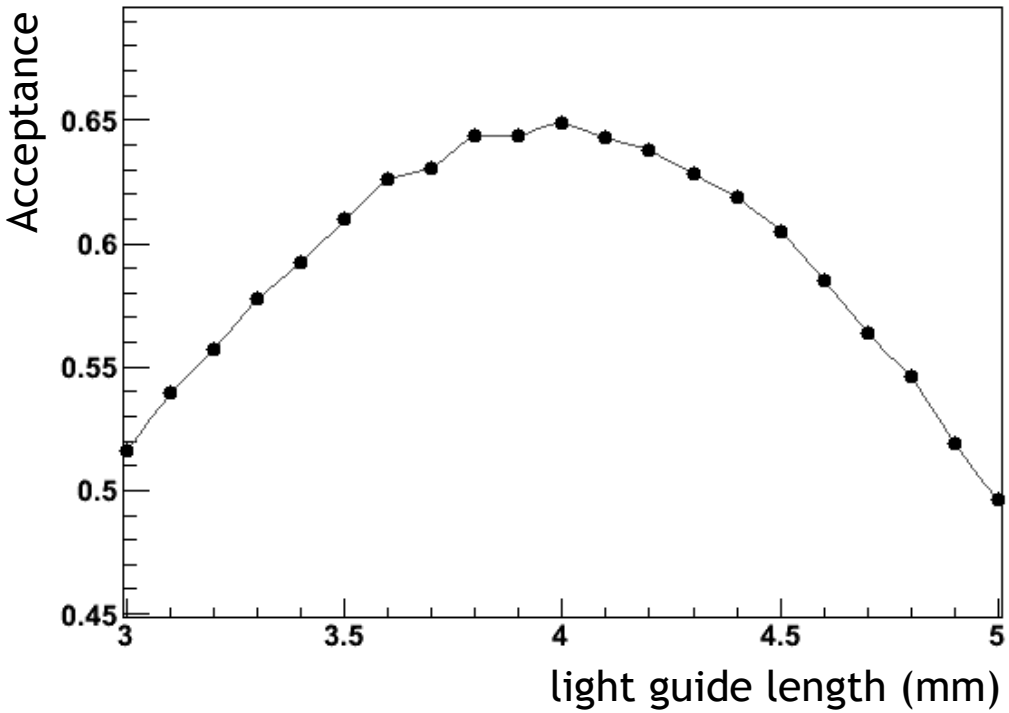
- most suitable/feasible to manufacture: truncated pyramid
  - machined out of HERA-B RICH lens (near UV transmission)
  - conical drills angled at 10° and 15°
- optical simulation:
  - refraction
  - total reflection
  - gap (epoxy layer) between LG exit and SiPM surface
  - inbound light uniformly distributed over entry surface and isotropically in angle (between 0° and 30°)
  - not included: absorption, imperfect surface

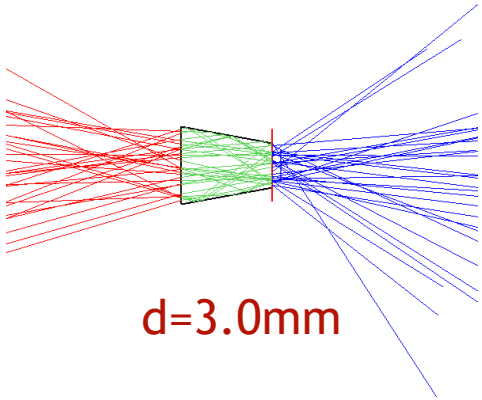


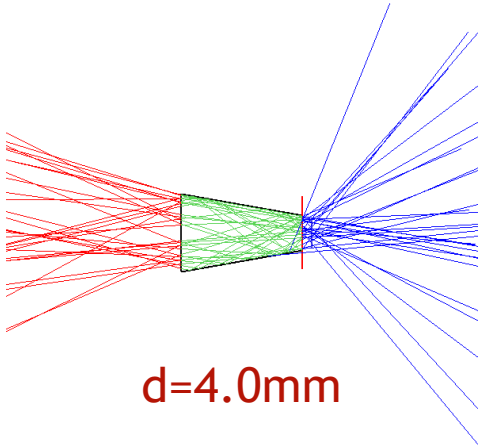


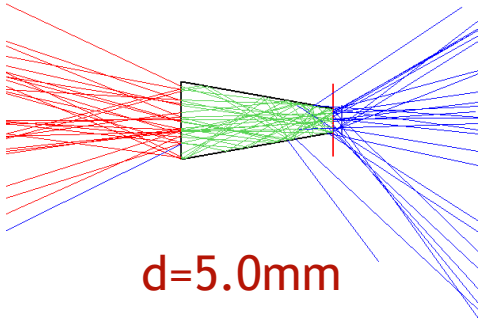
Light guides for 8×8 SiPM array

- geometry constraints:
  - fixed pitch → entry surface (2.54×2.54mm^2)
  - fixed side angle (10° drill)
  - gap fixed at 0.3mm
- only variable → length (d)
- optimization: d=4mm → acceptance=65%



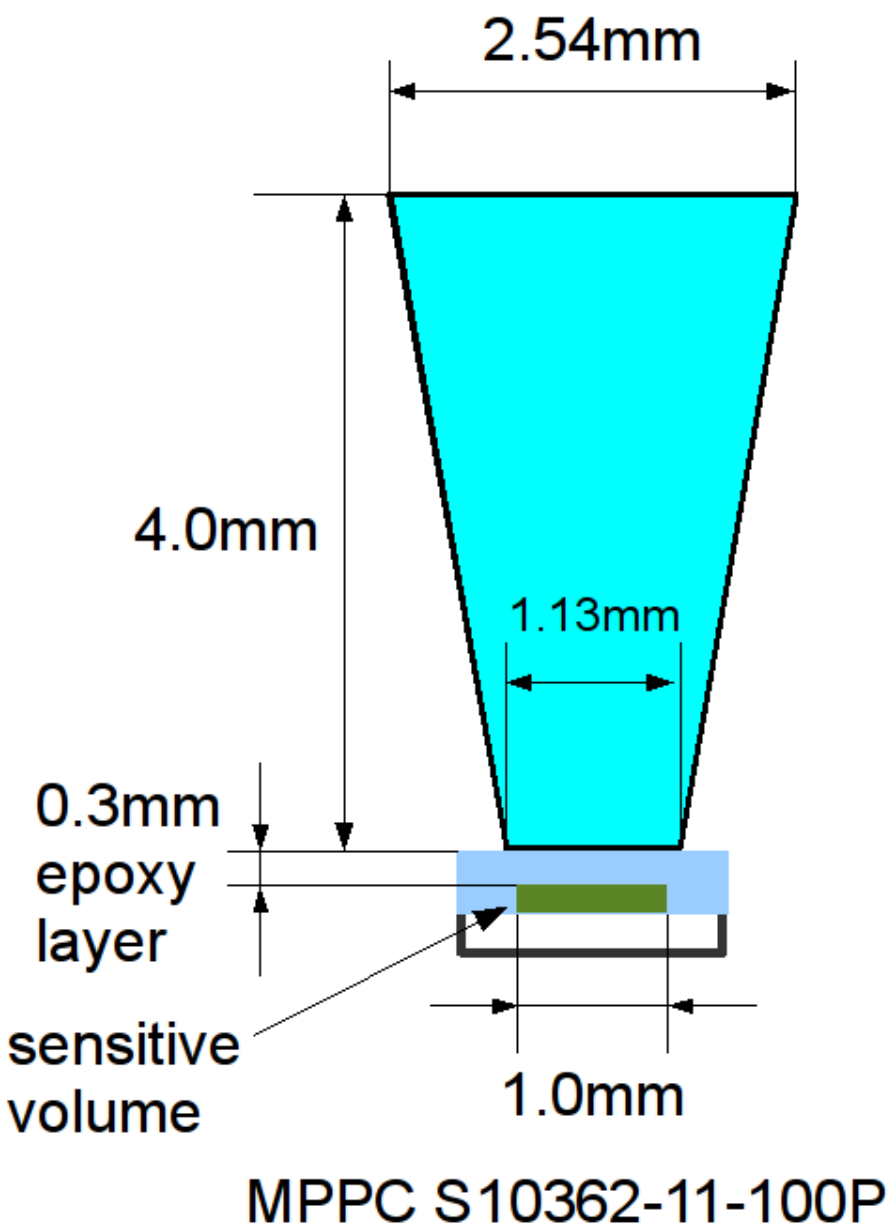






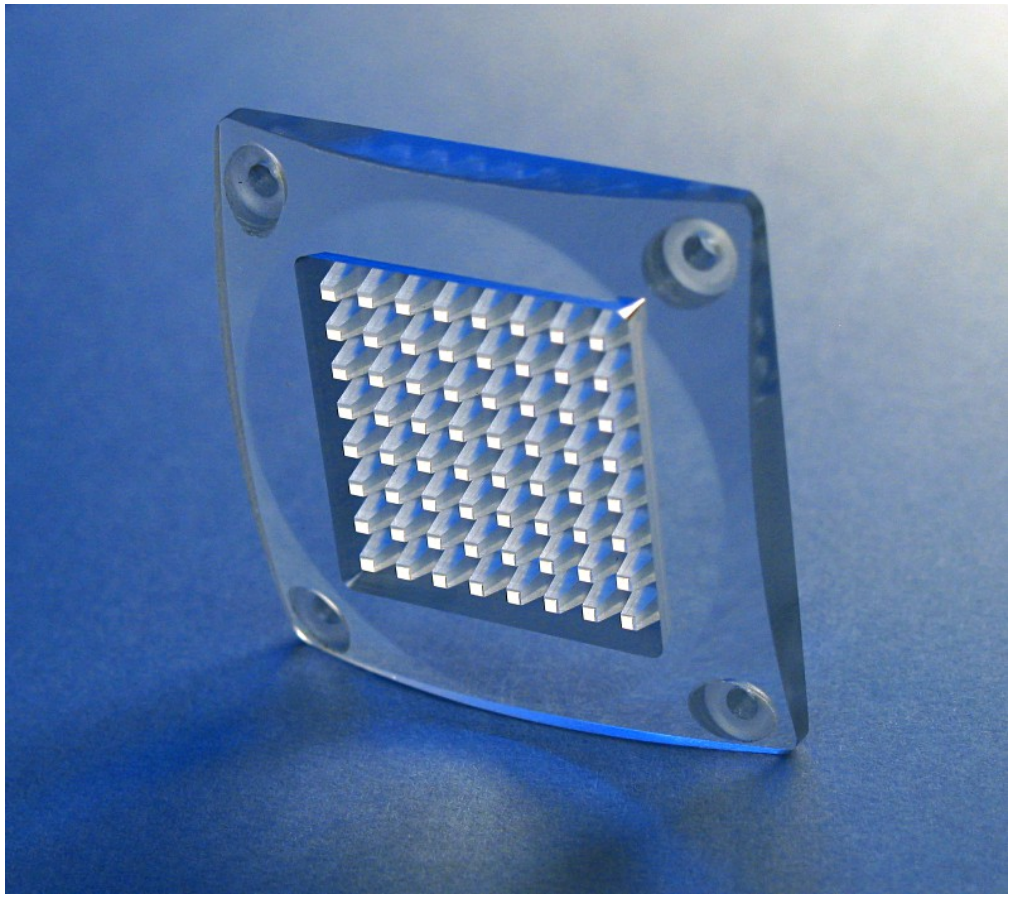
Light guides for 8×8 SiPM array

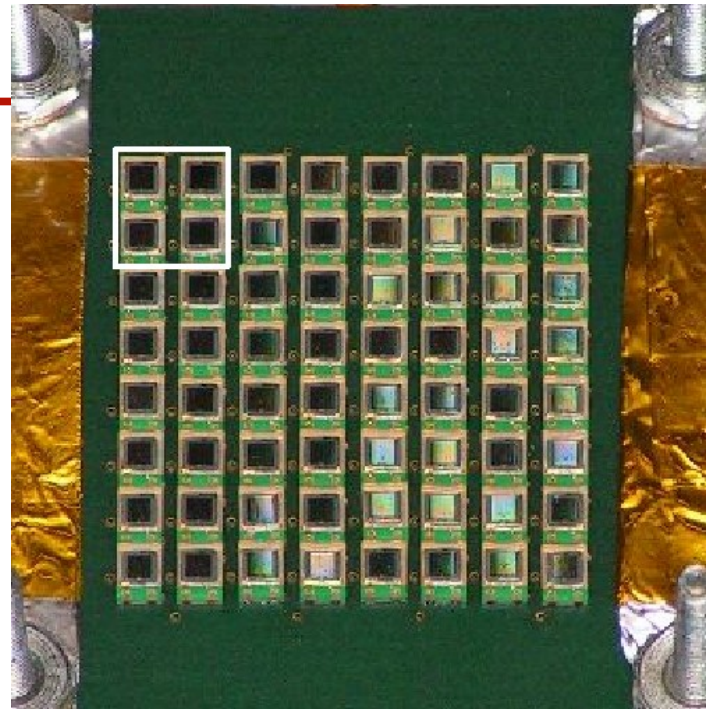
- goal: light guides with
  - length 4.0mm
  - entry $(2.54\text{mm})^2$
  - exit $(1.13\text{mm})^2$
- due to manufacturing limitations:
  - length 4.0mm
  - entry $(2.3\text{mm})^2$
  - exit $(0.9\text{mm})^2$
  - total pad acceptance: **54%** (15.5% w/o LG)

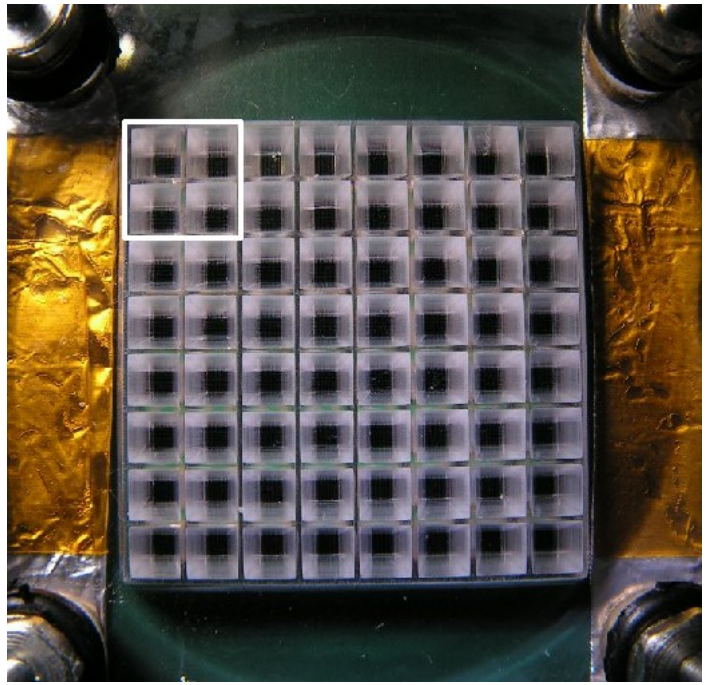


Light guides for 8×8 SiPM array

- array of light guides machined from HERA-B RICH lens material
  - 8×8 array with pitch 2.54mm
  - **3.5×** photons expected

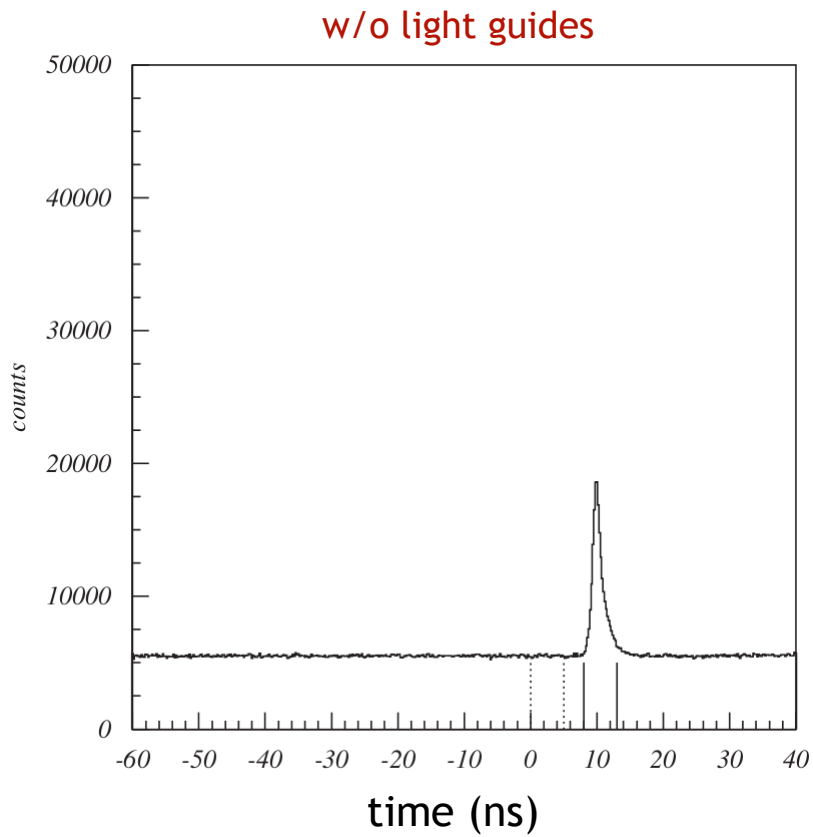


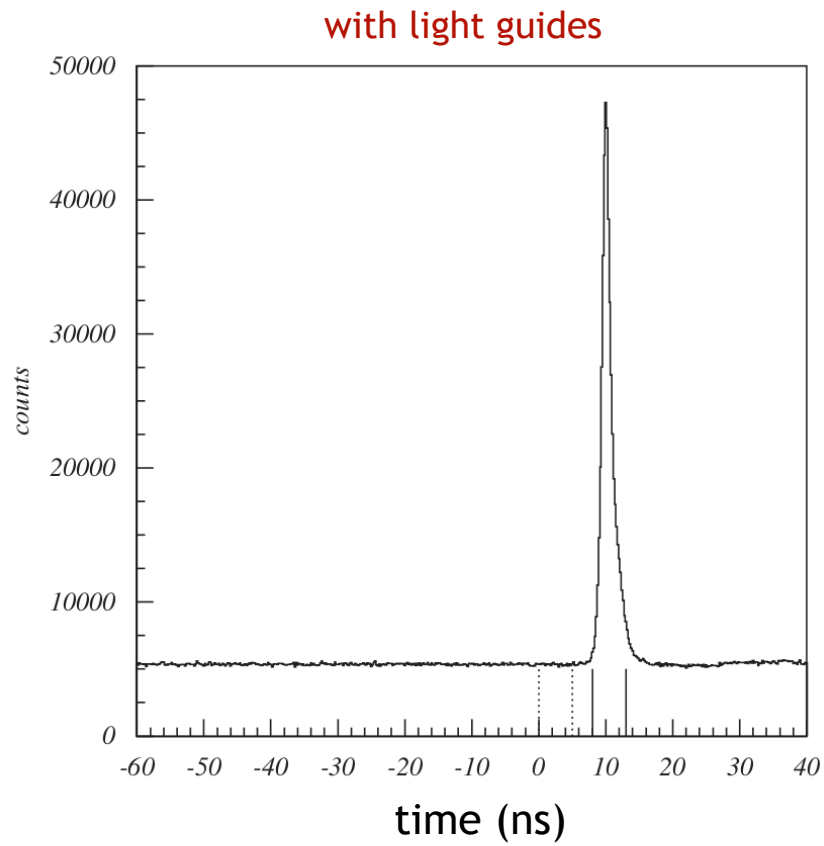




Beam test - Results

- time distribution of hits
- clear improvement of signal to noise ratio with light guides

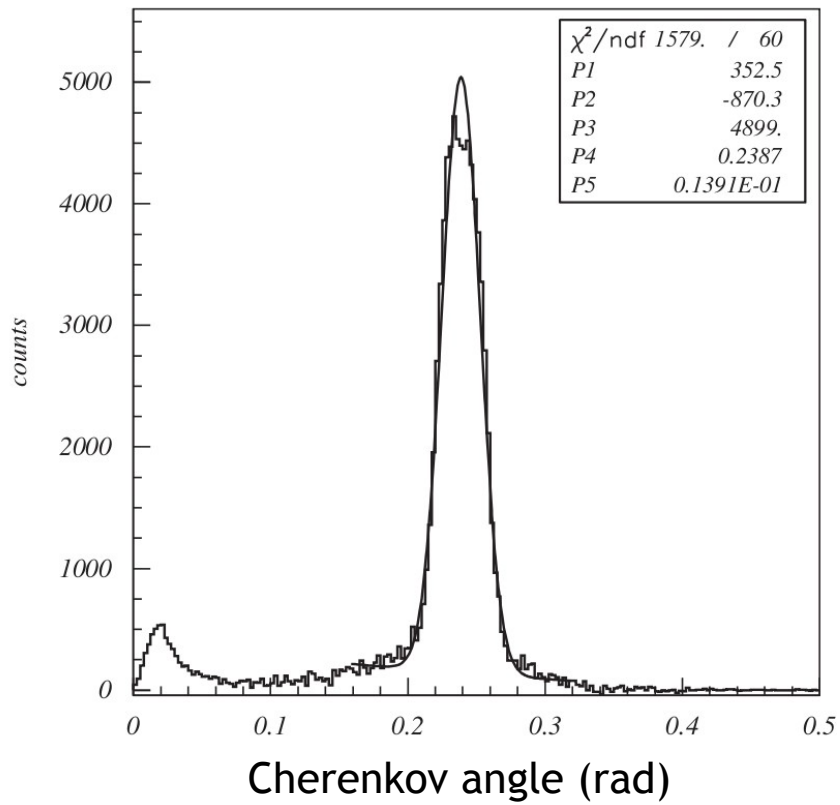




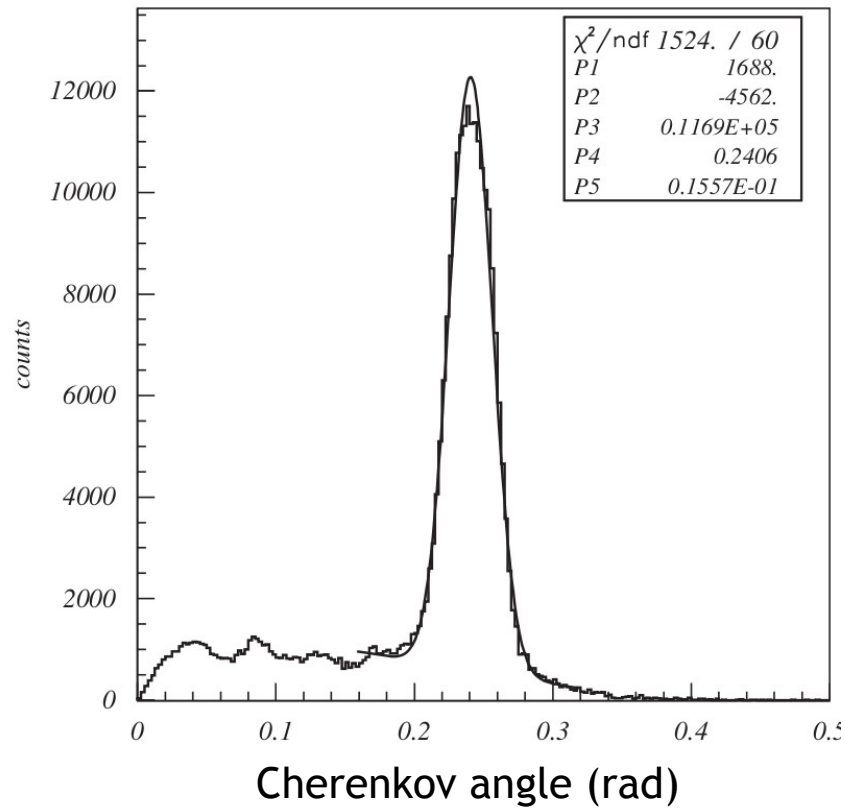
Results

- background subtracted distributions in Cherenkov angle
  - photons/ring w/o light guides: 1.6
  - photons/ring with light guides: 3.7
  - ratio of photons detected with and w/o light guides: **2.3**

w/o light guides



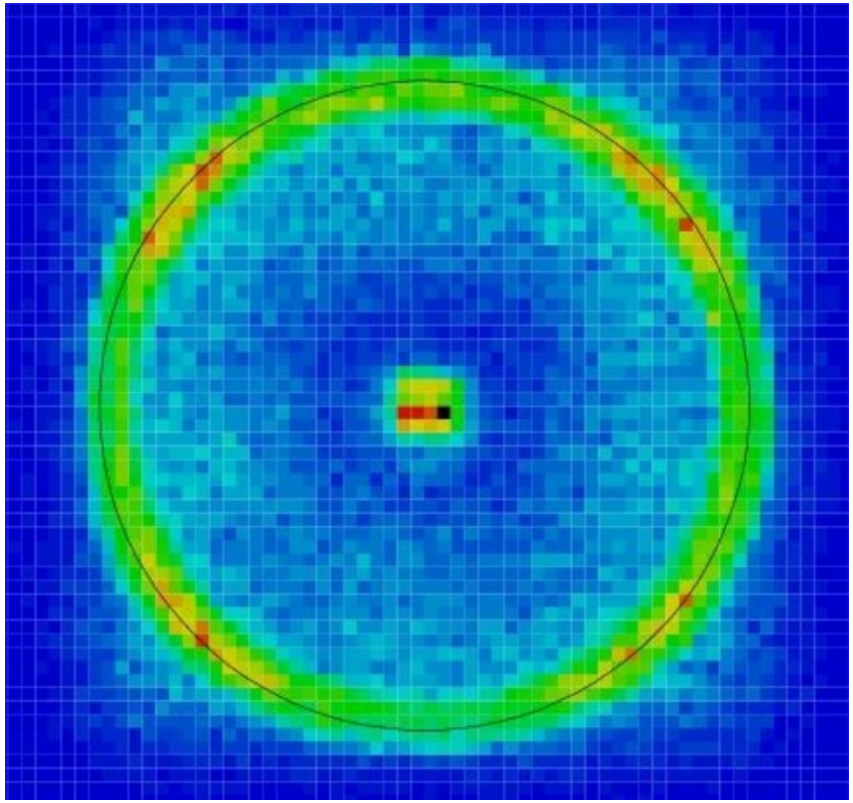
with light guides



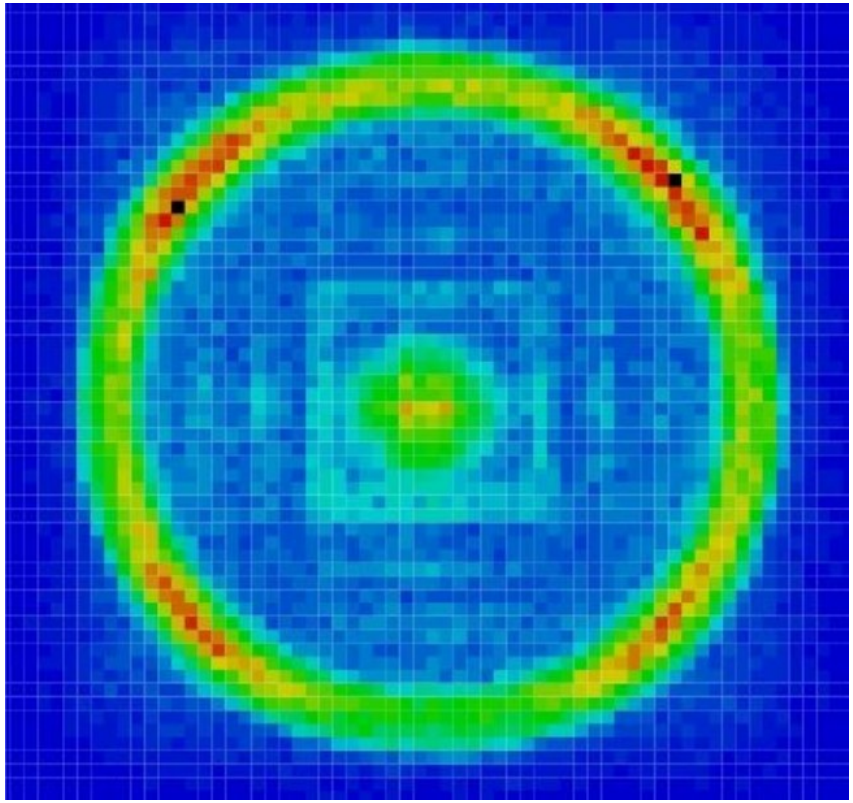
Results

- rings in Cherenkov angle space

w/o light guides



with light guides



Summary

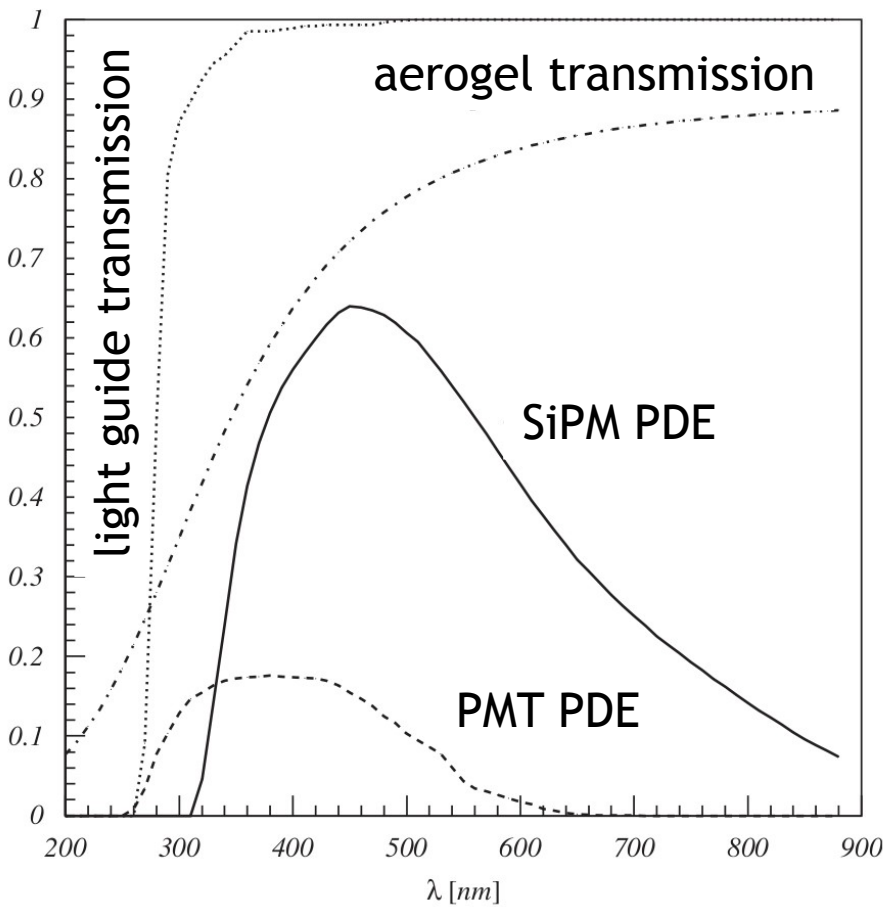
- a module of 64 SiPMs was tested in beam as a photon detector in RICH
  - dark noise suppressed by accepting only hits within 5ns window
  - detected **1.6** photons per ring
- light guides were used to improve signal to noise ratio
  - detected **3.7** photons per ring
  - improvement by **2.3×** is less than expected **3.5×** from simulations
    - light guide sides not polished
    - light guide exit surfaces not perfectly aligned with SiPM active surfaces
- this would be improved in the final detector:
  - use 30mm of aerogel with n=1.05 and better light attenuation length (**5×**)
  - improve light guide production and coupling to SiPMs (**2×**)
- expect ~ **30** photons per ring

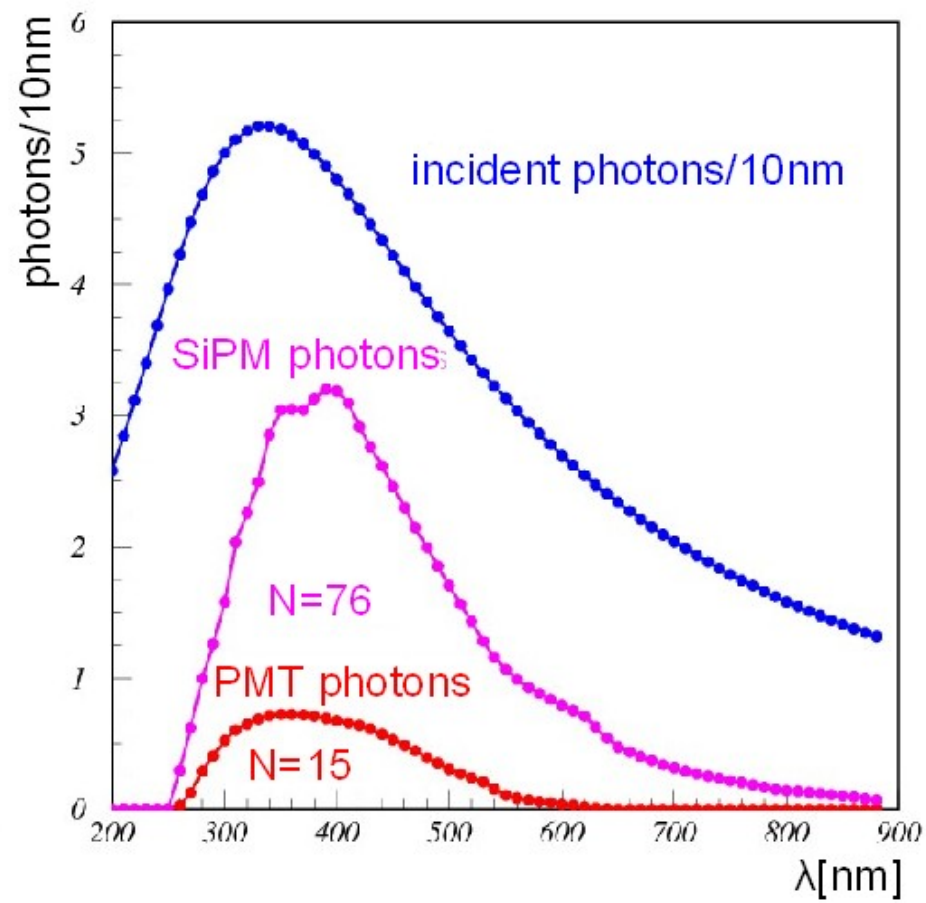
We have shown that SiPMs are excellent sensor for RICH counters

Backup slides

SiPMs: expected number of photons

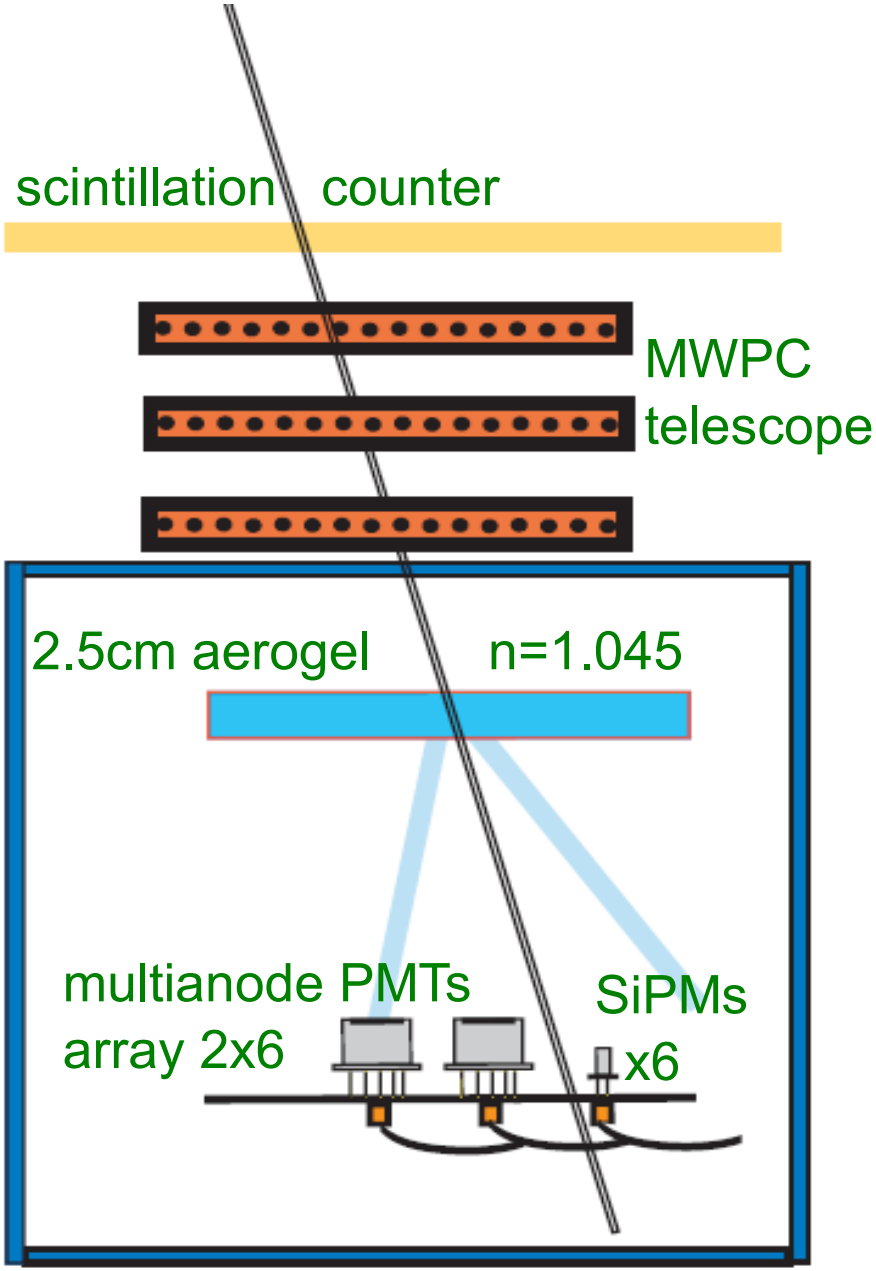
- Expected number of photons for aerogel RICH with multianode PMTs or SiPMS(HC100) and aerogel radiator: thickness 2.5cm, n=1.45, transmission length (@400nm) 4cm: N_{siPM}/N_{PMT}~ **5**

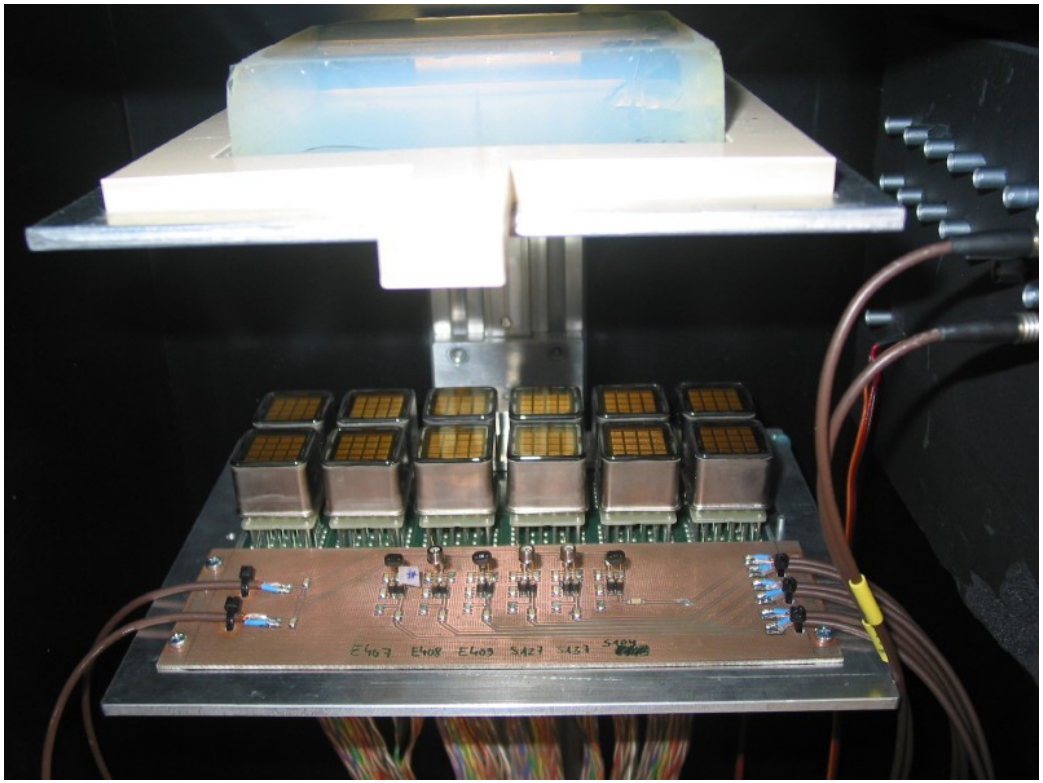




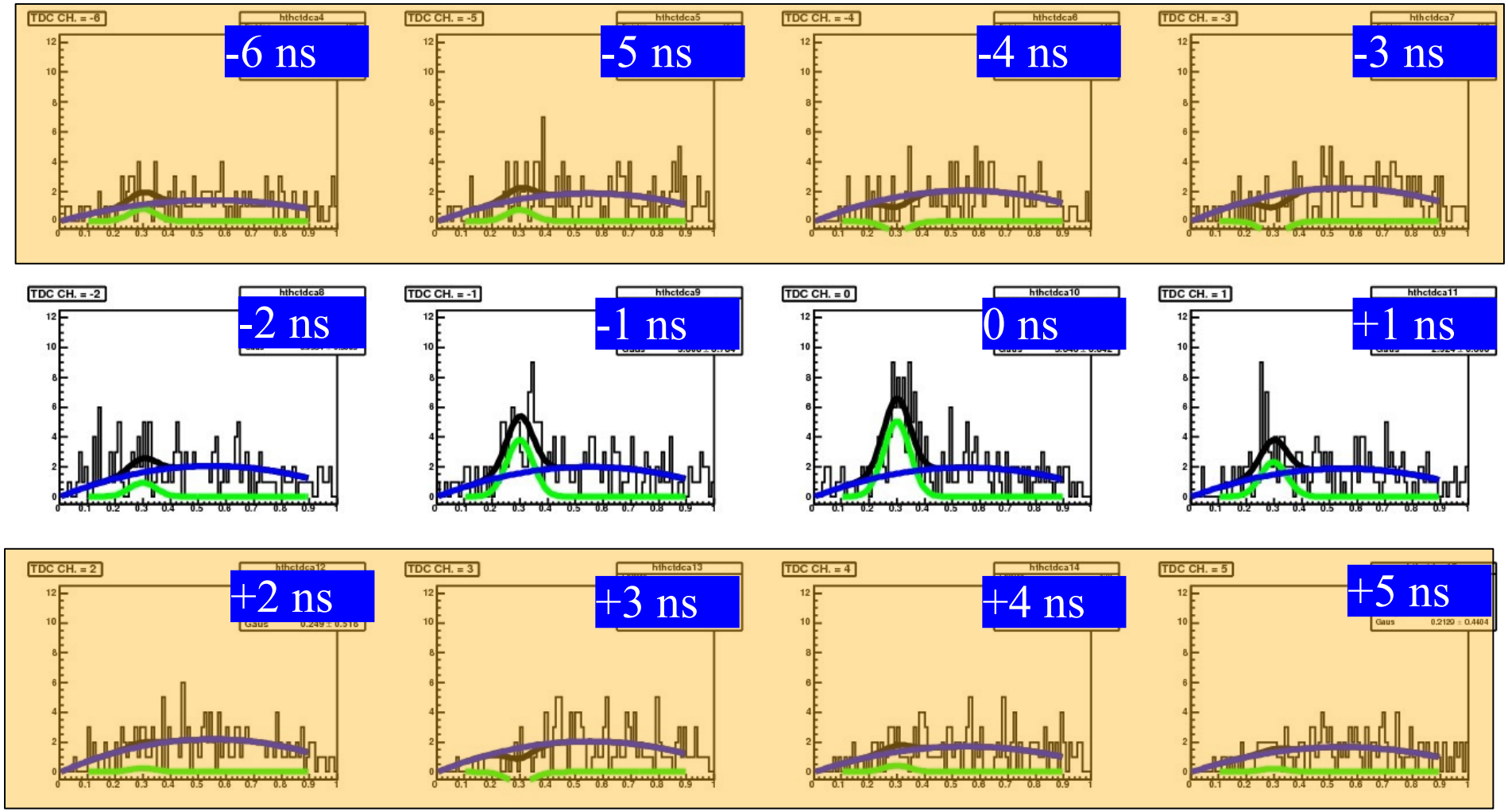
- Expected number of photons per ring for CERN beam test: **2.3** (w/o LG)

Cosmic tests





Cosmic tests



Cherenkov photons appear within expected time window

→ First Cherenkov photons observed with SiPMs