Univerza *v Ljubljani*

SiPMs for Čerenkov imaging

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Photon detectors for Ring Imaging CHerenkov counters

Example: proximity focusing RICH for the Belle upgrade

SiPMs as single photon counters (uniformity, timing)

Detection of Cherenkov photons with SiPMs

SiPMs for PET

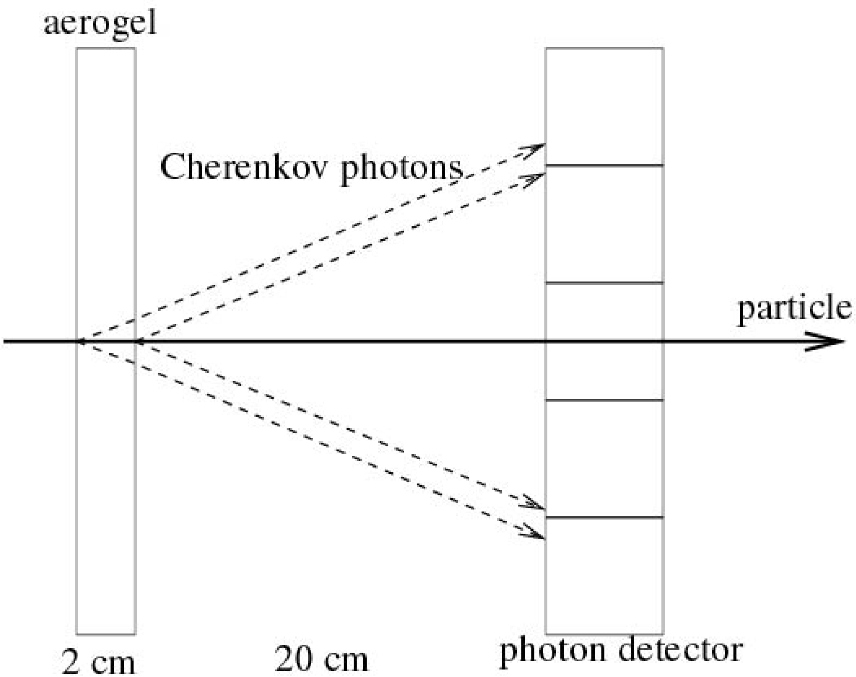
Summary

Measuring Cherenkov angle

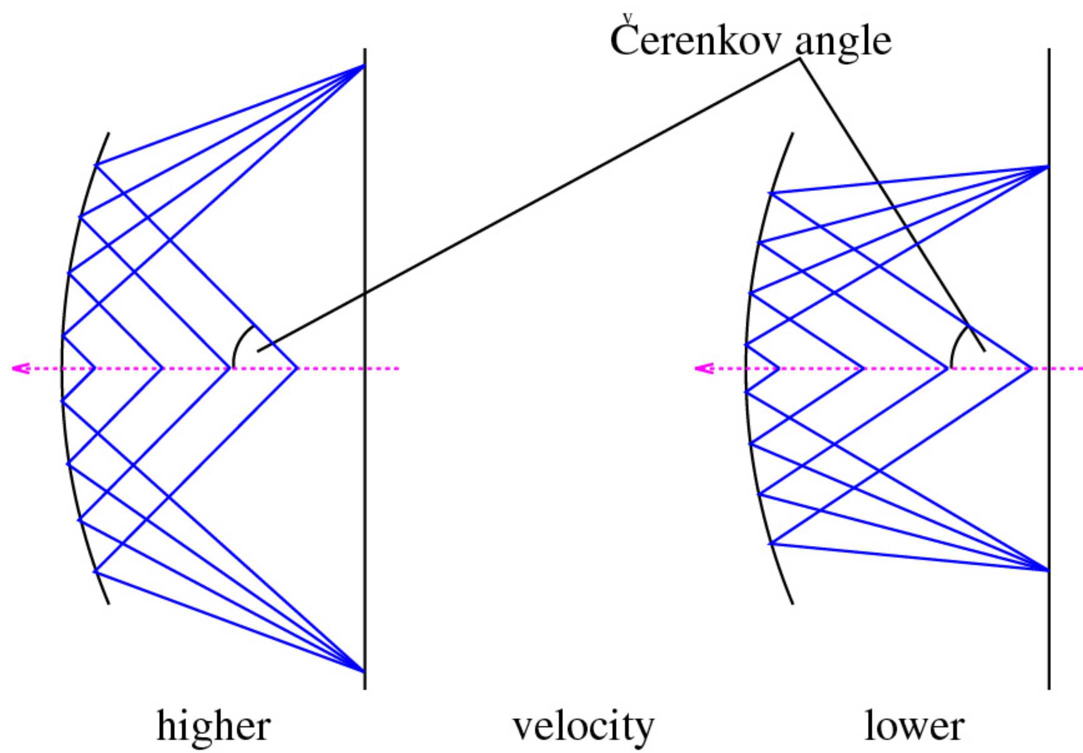
Idea: transform the direction into a coordinate →

ring on the detection plane

→ Ring Imaging CHerenkov



Proximity focusing RICH



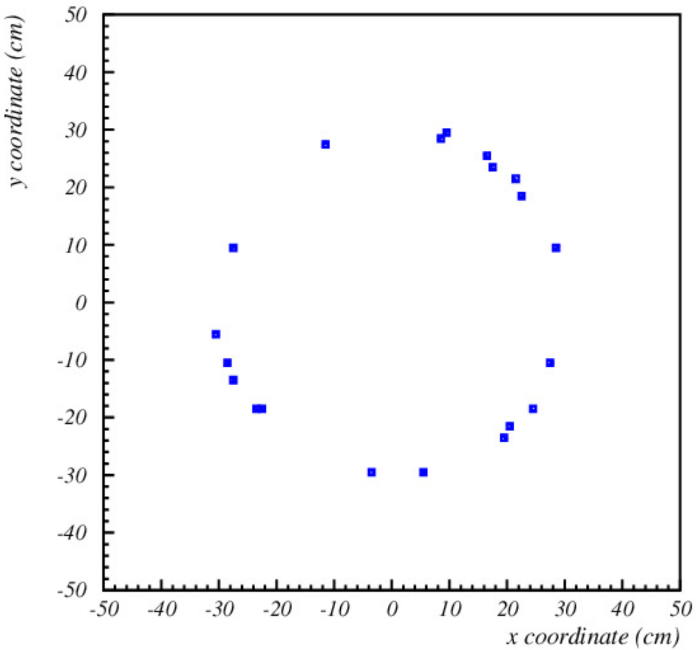
RICH with a focusing mirror

Photon detection in RICH counters

RICH counter: measure photon impact point on the photon detector surface

→ detection of single photons with

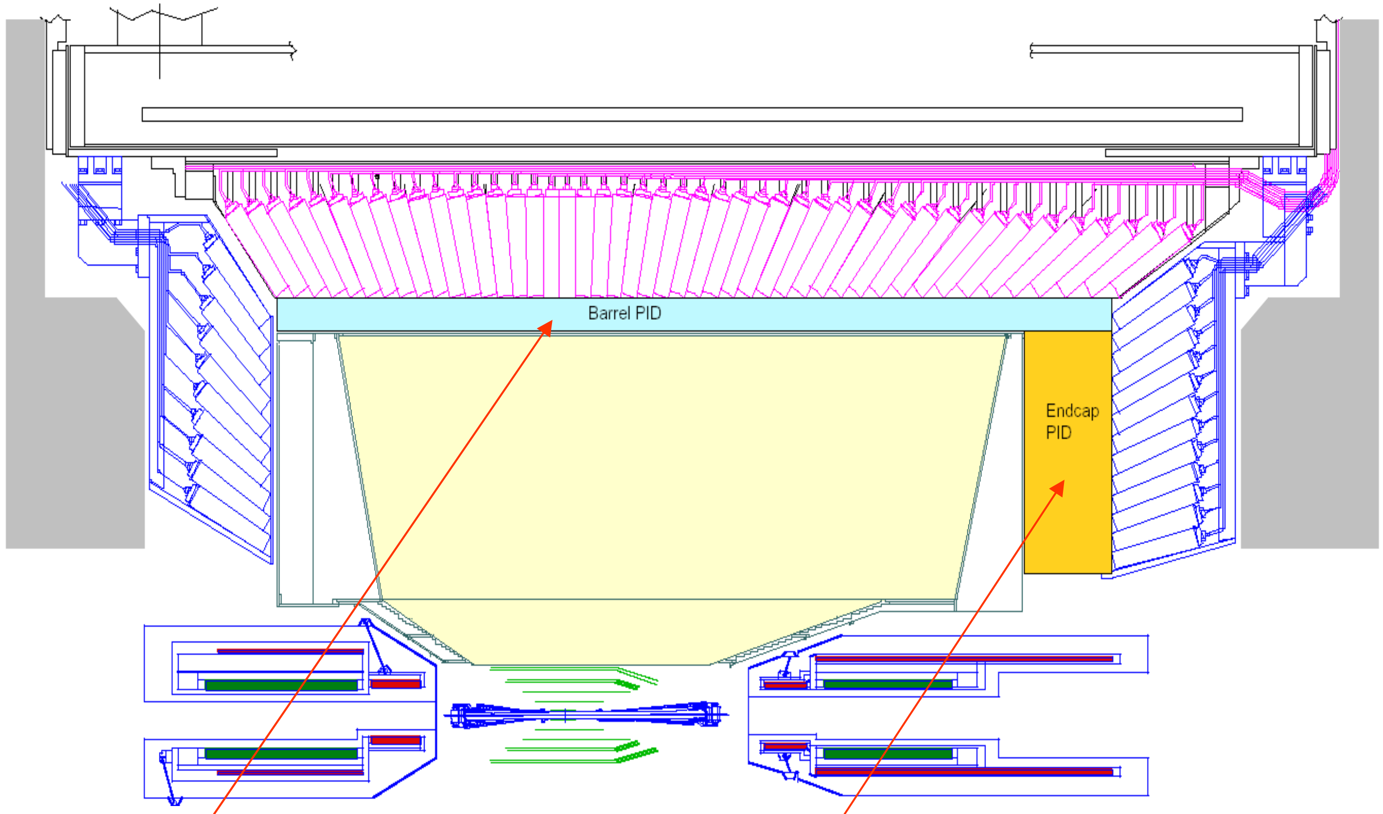
- sufficient spatial resolution
- high efficiency and good signal-to-noise ratio
- over a large area (square meters)



Special requirements:

- Operation in magnetic field
- High rate capability
- Very high spatial resolution
- Excellent timing (time-of-arrival information)

Belle upgrade – side view

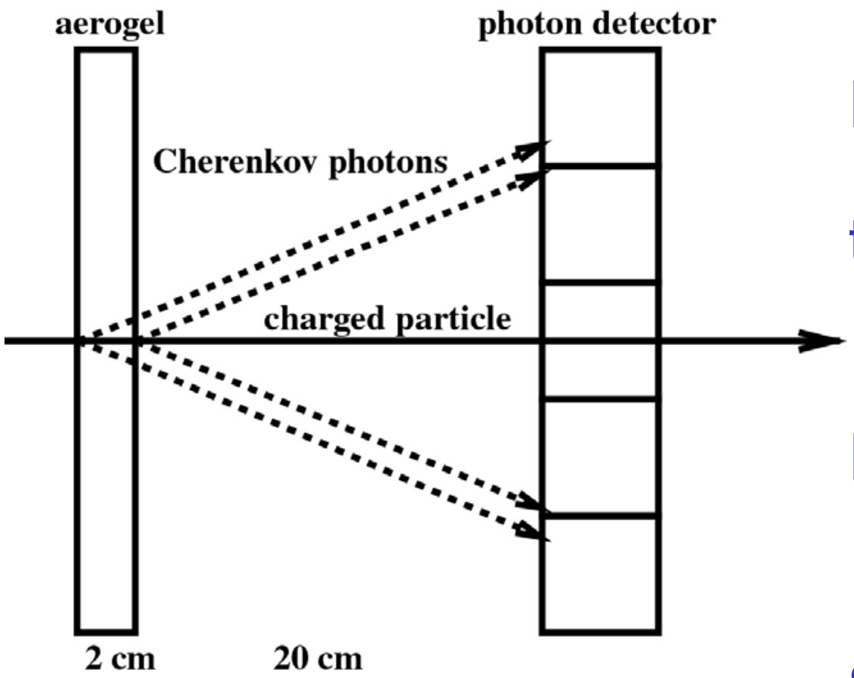


Two new particle ID devices, both RICHes:

Barrel: Time Of Propagation (TOP) counter or focusing DIRC

Endcap: proximity focusing RICH

Endcap: Proximity focusing RICH



K/π separation at 4 GeV/c:
$\theta_c(\pi) \sim 308$ mrad ($n = 1.05$)
$\theta_c(\pi) - \theta_c(K) \sim 23$ mrad

For single photons: $\delta\theta_c$(meas.)$=\sigma_0 \sim 14$ mrad,
typical value for a 20mm thick radiator and 6mm PMT pad size

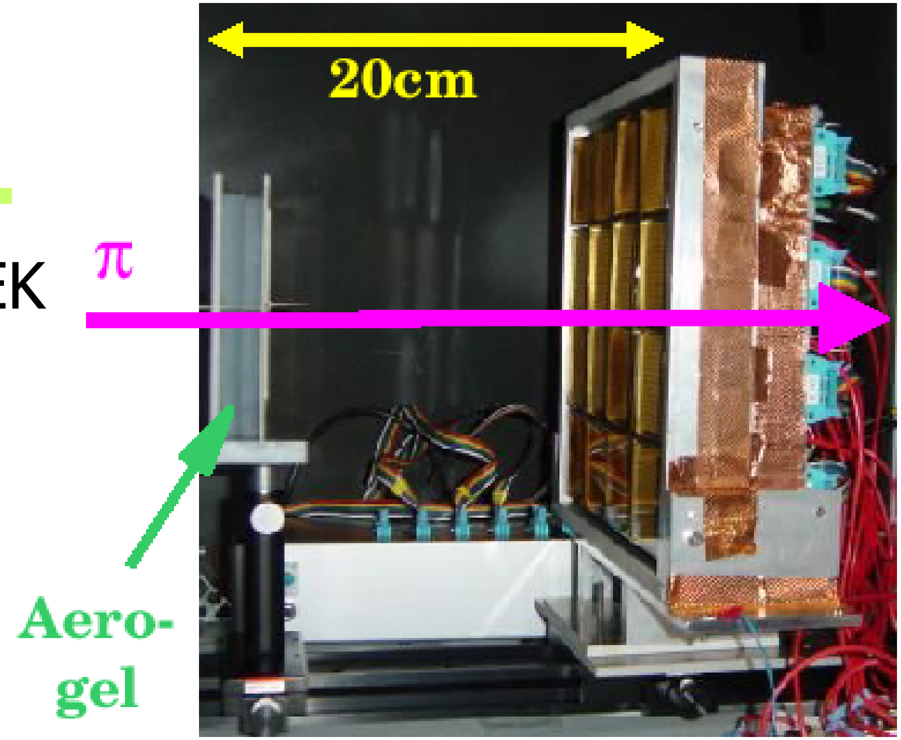
Per track: $$\sigma_{track} = \frac{\sigma_0}{\sqrt{N_{pe}}}$$

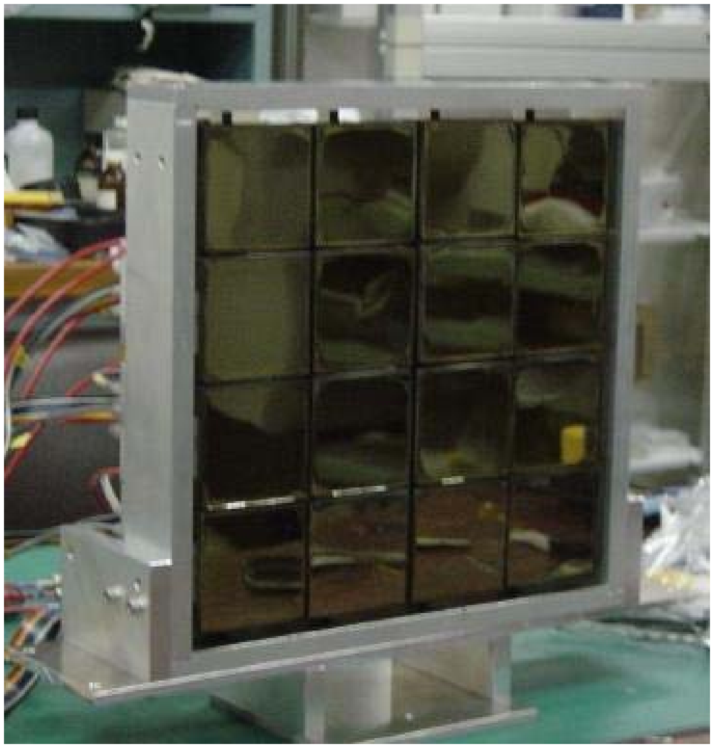
Separation: $[\theta_c(\pi)-\theta_c(K)]/\sigma_{track}$

→ 5σ separation with $N_{pe}\sim 10$

Beam tests

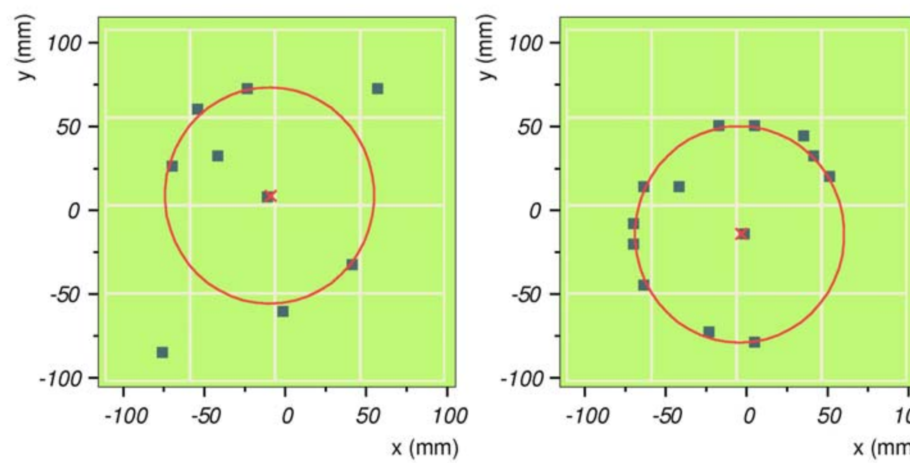
pion beam (π2) at KEK





Photon detector: array of 16 H8500 (‘flat pannel’) PMTs

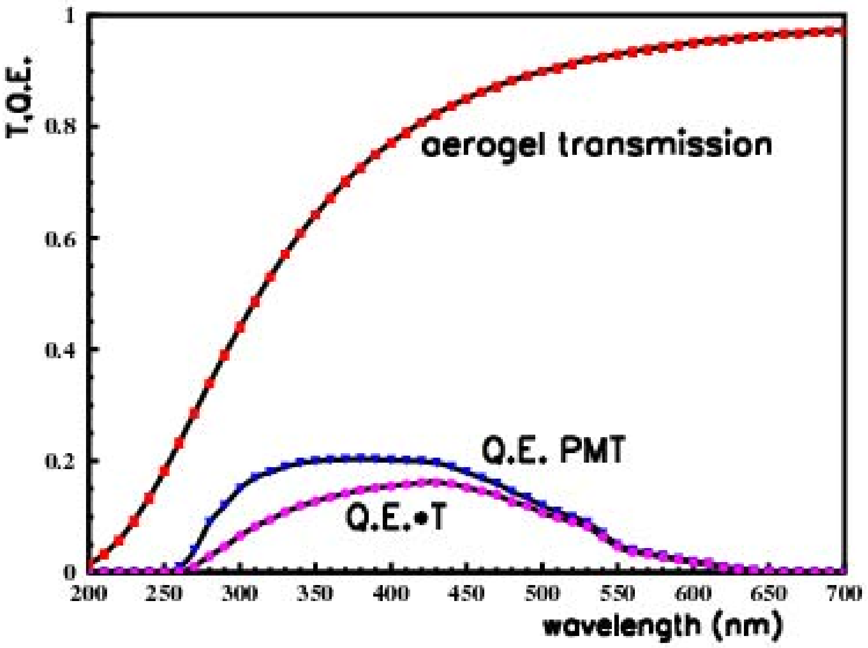
Clear rings, little background



Photon detectors for the aerogel RICH

Needs:

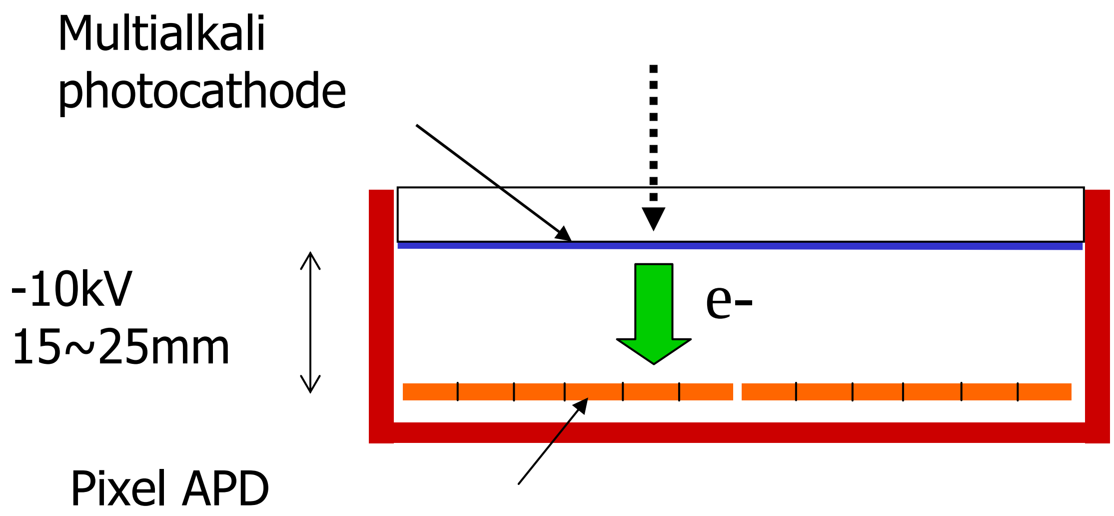
- Operation in high magnetic field (1.5T)
- High efficiency at λ>350nm
- Pad size ~5-6mm

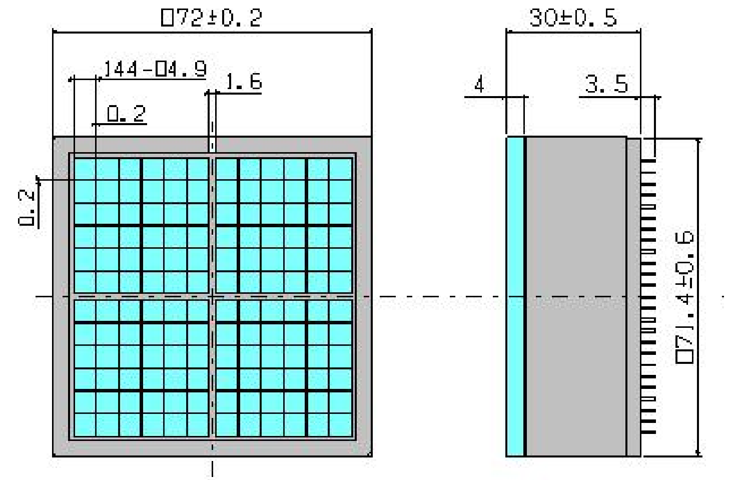


Candidates:

- MCP PMT (Burle 85011)
- large area HAPD of the proximity focusing type (R+D)
- SiPM?

Photon detector candidate: Large active area HAPD

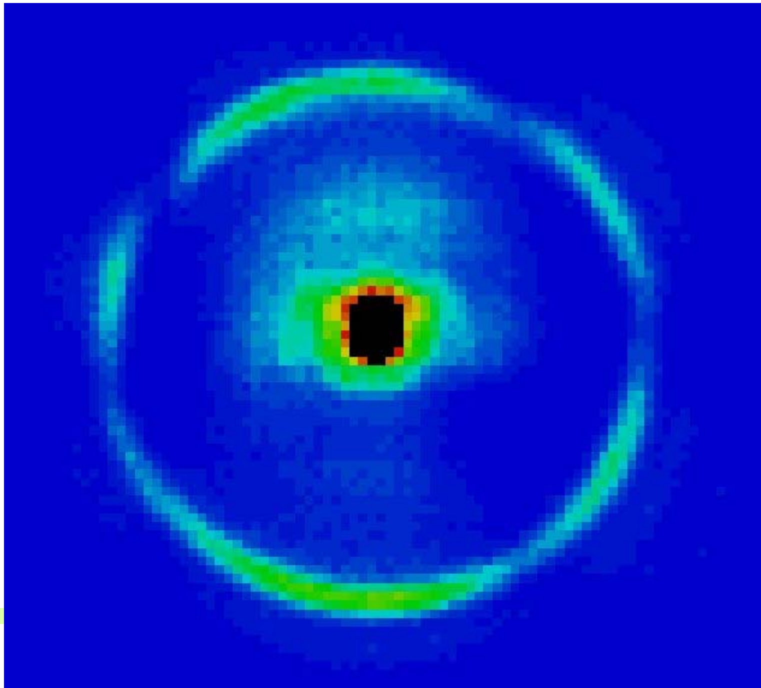




R&D project in collaboration with Hamamatsu.

Long development time, now working test samples.

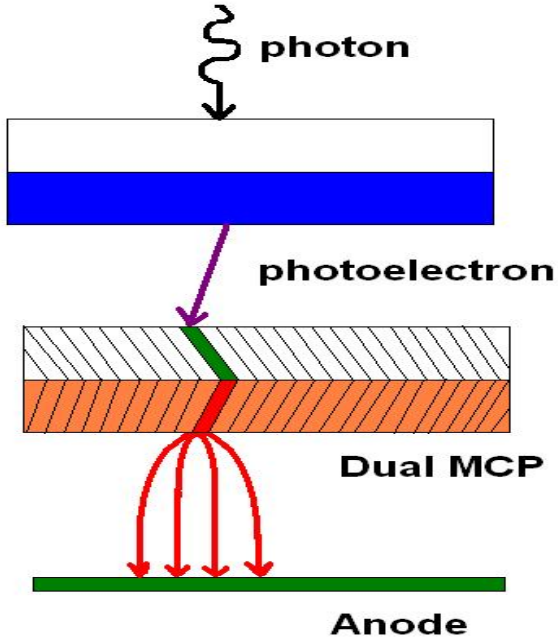
First beam test results →

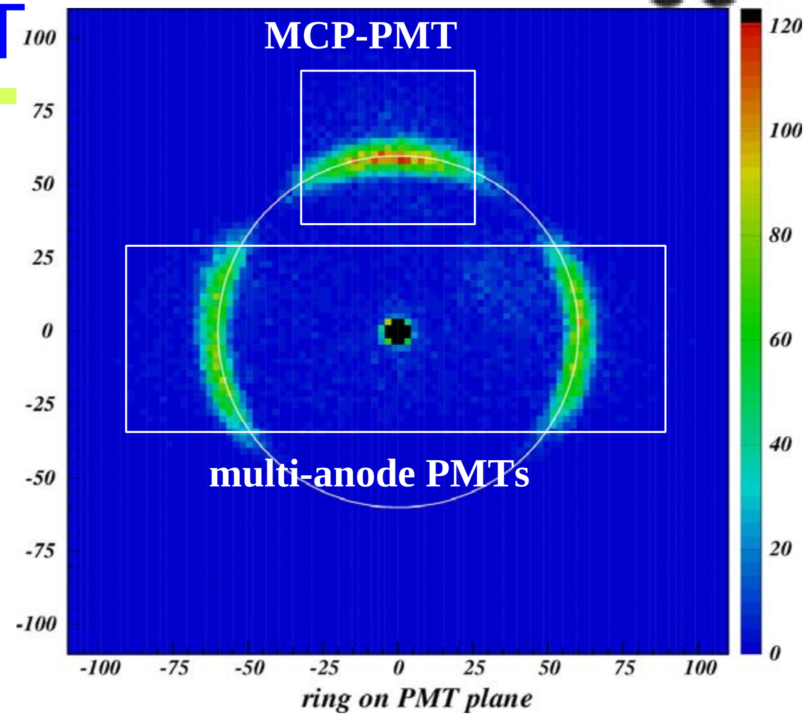


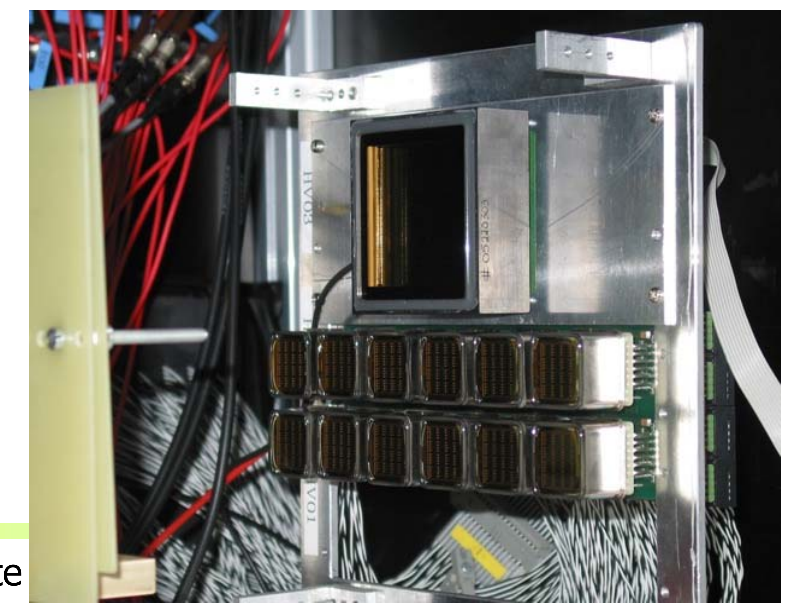
→NIMA, RICH07 proc.

Photon detector candidate: BURLE/Photonis MCP-PMT

BURLE 85011 microchannel plate (MCP) PMT: multi-anode PMT with two MCP steps



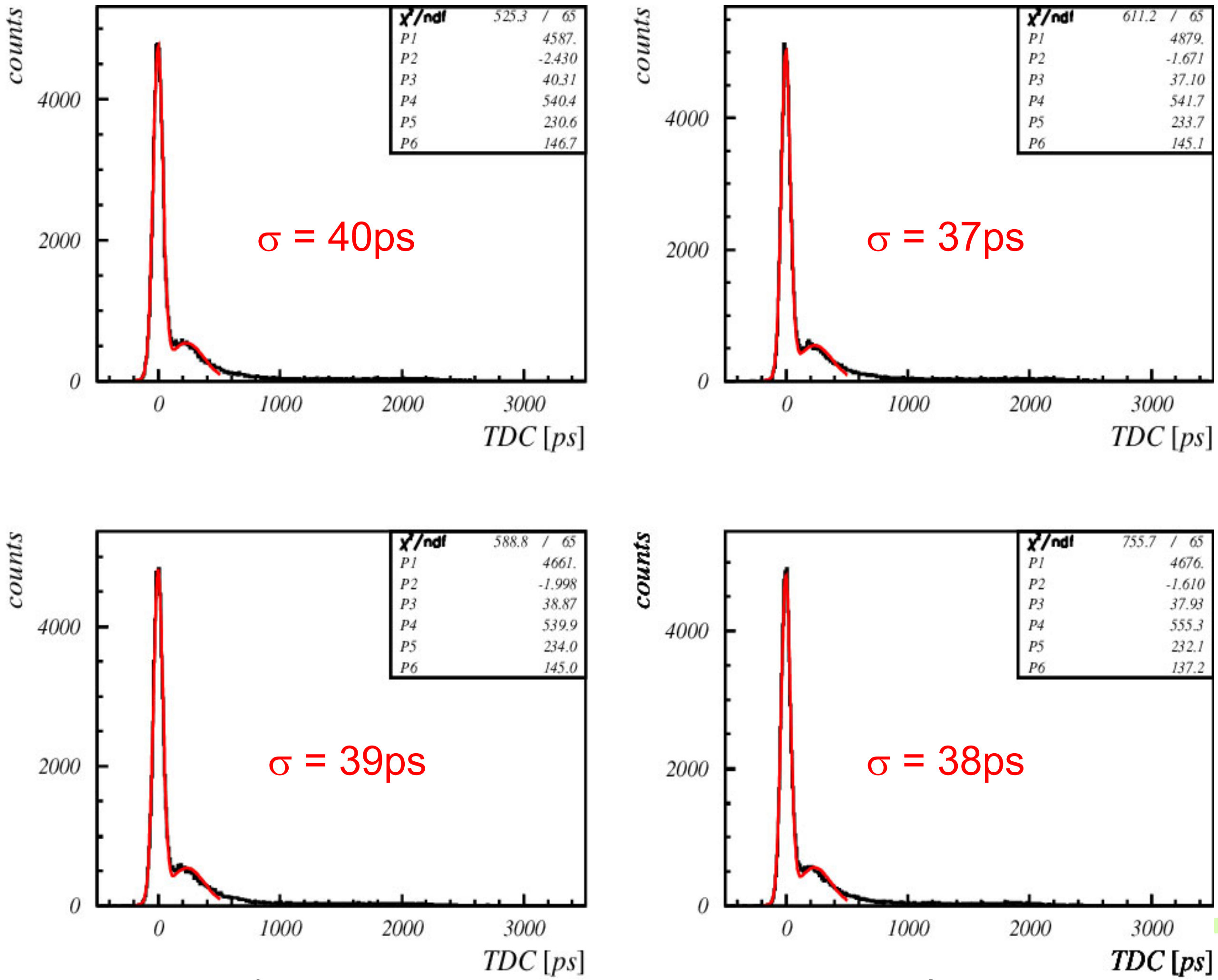




→good performance in beam and bench tests, NIMA567 (2006) 124
→ very fast →
→ R+D: ageing

Photon detector candidate: BURLE/Photonis MCP-PMT

BURLE 85011 microchannel plate (MCP) PMT: time resolution after time walk correction



Tails can be significantly reduced by:

- decreased photocathode-MCP distance and
- increased voltage difference

→NIMA, RICH07 proc.

SiPM as photon detector?

Can we use SiPM (Geiger mode APD) as the photon detector in a RICH counter?

+immune to magnetic field

+high photon detection efficiency, single photon sensitivity

+easy to handle (thin, can be mounted on a PCB)

+potentially cheap (not yet...) silicon technology

+no high voltage

-very high dark count rate (100kHz – 1MHz) with single photon pulse height

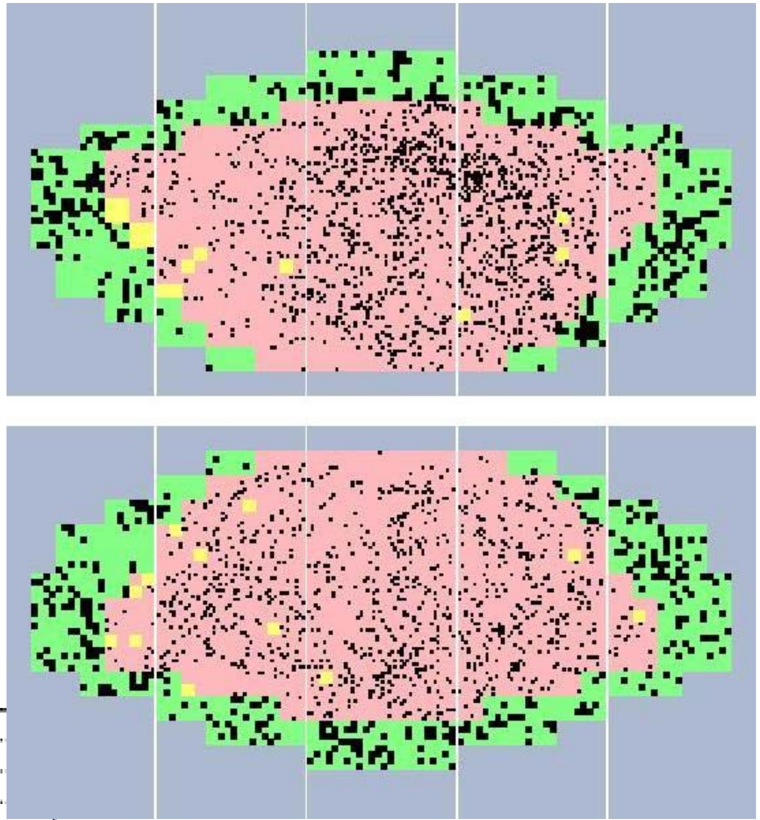
-radiation hardness

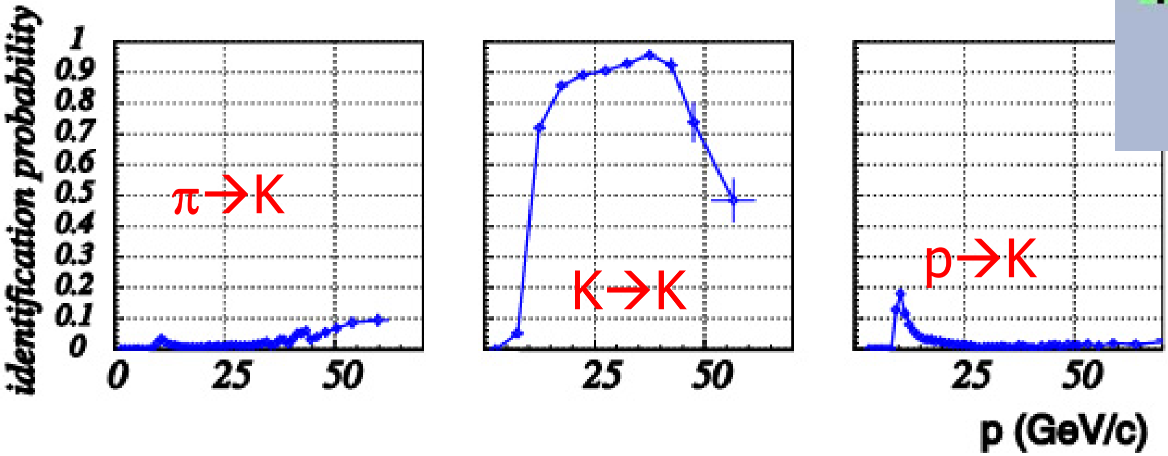
Can such a detector work?

Experience from HERA-B RICH: successfully operated in a high occupancy environment (up to 10%).

Need >20 photons per ring (had ~30) for a reliable PID.

HERA-B RICH event



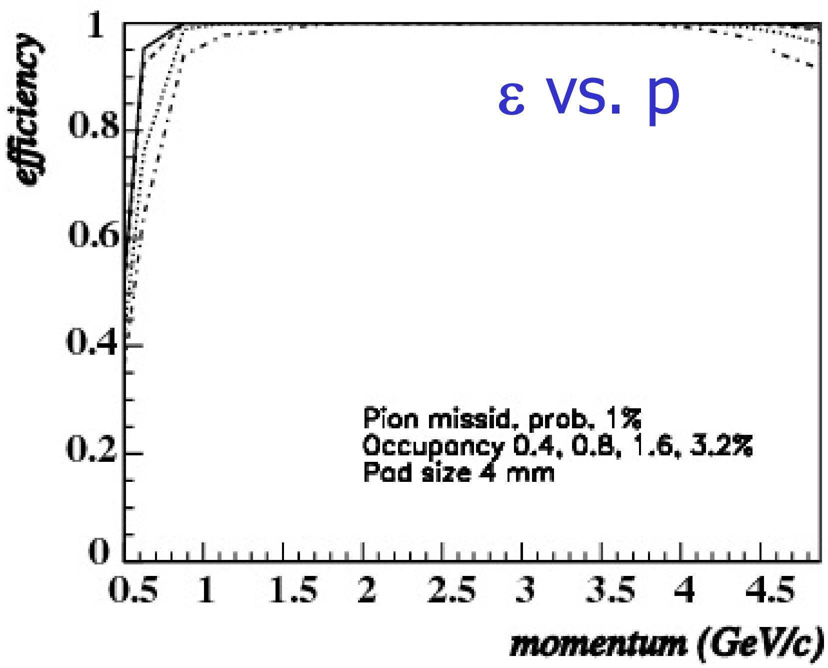


Can such a detector work?

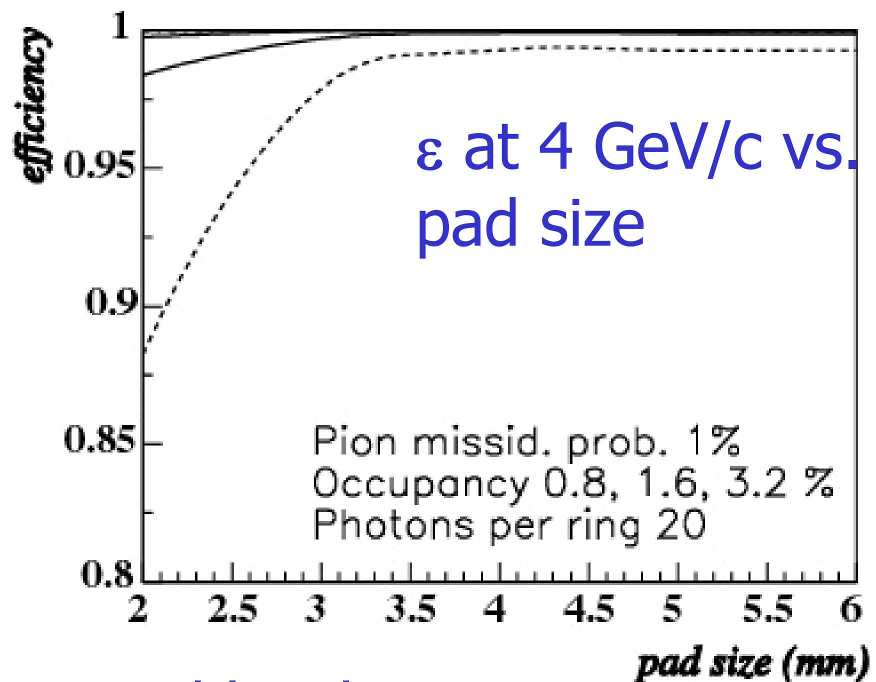
MC simulation of the counter response: assume 1mm^2 active area SiPMs with 0.8 MHz (1.6 MHz, 3.2 MHz) dark count rate, 10ns time window

K identification efficiency at 1% π missid. probability

ε vs. p

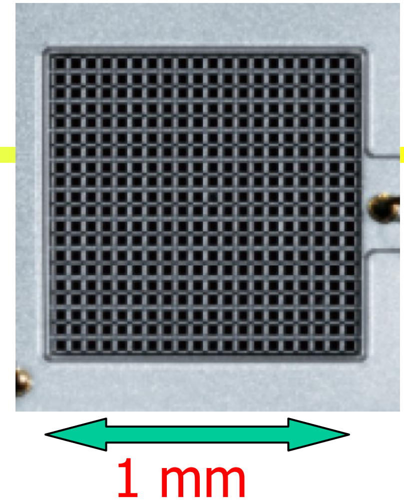


ε at 4 GeV/c vs. pad size



For different background levels

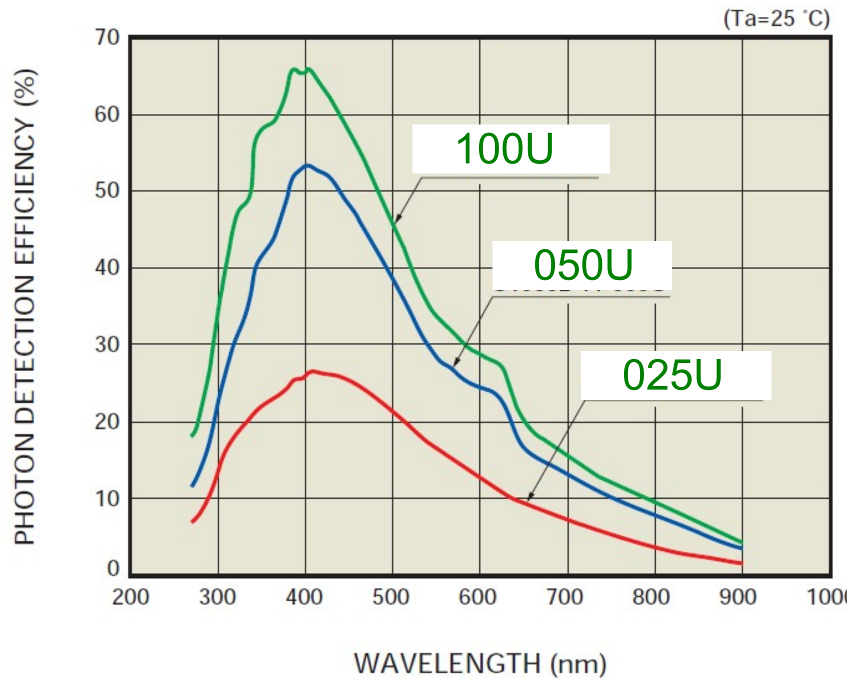
SiPMs as photon detectors?



SiPM is an array of APDs operating in Geiger mode. Characteristics:

- low operation voltage ~ 10-100 V
- gain ~ 10^6
- peak PDE up to 65%(@400nm)

  $PDE = QE \times \varepsilon_{geiger} \times \varepsilon_{geo}$
- ε_{geo} – dead space between the cells
- time resolution ~ 100 ps
- works in high magnetic field
- dark counts ~ few 100 kHz/mm^2
- radiation damage (p,n)

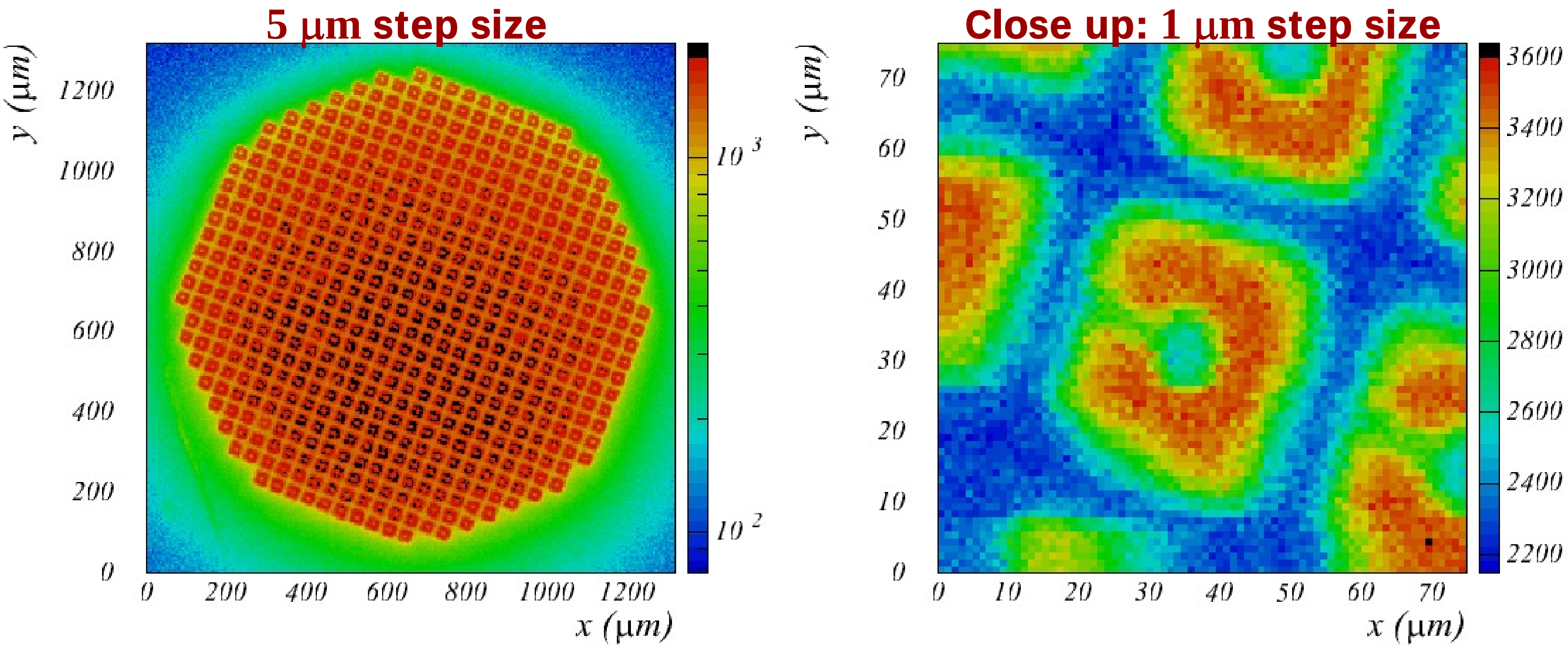


Hamamatsu MPPC: S10362-11

Surface sensitivity for single photons

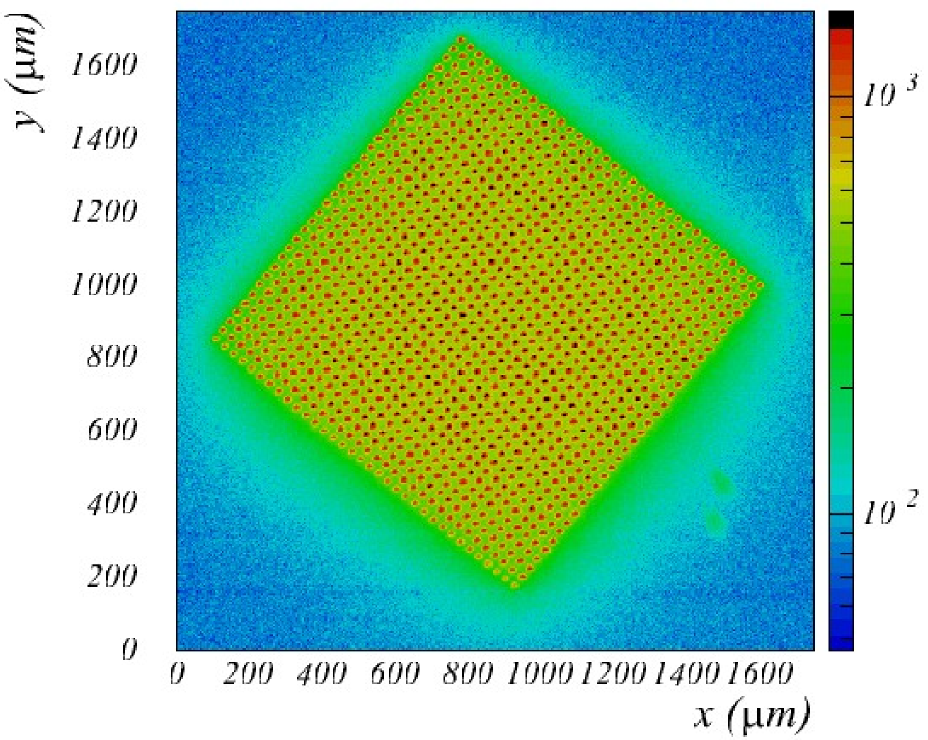
- 2d scan in the focal plane of the laser beam ($\sigma \approx 5$ μm)
- intensity: on average << 1 photon → single photons
- Selection: single pixel pulse height, in 10 ns TDC window

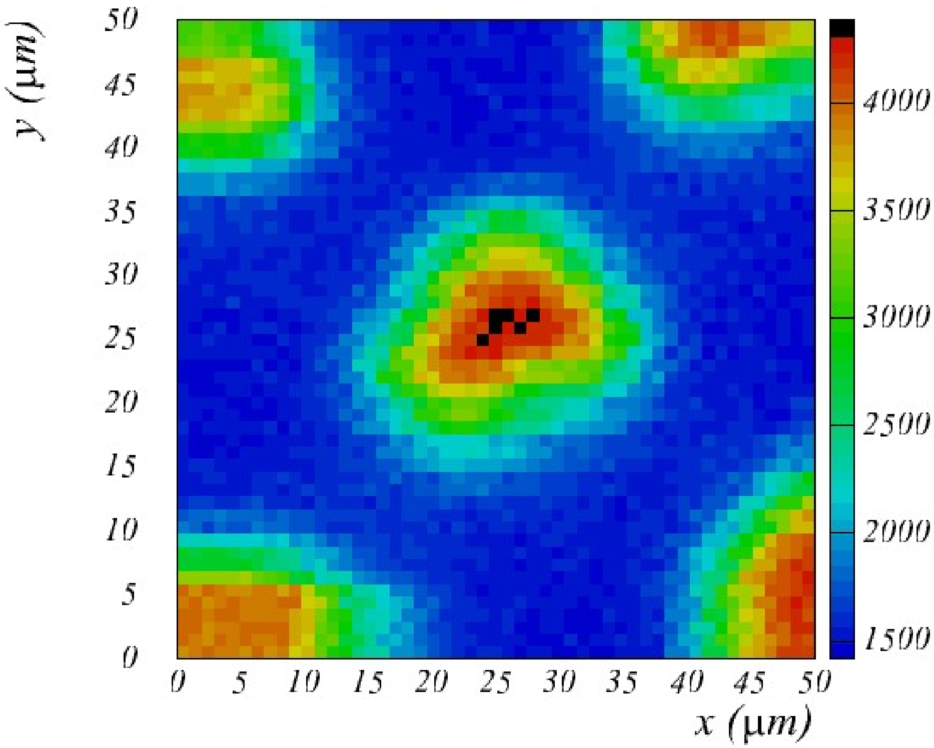
S137 (Photonique)



Surface sensitivity for single photons 2

E407 (Pulsar/MEPHI)

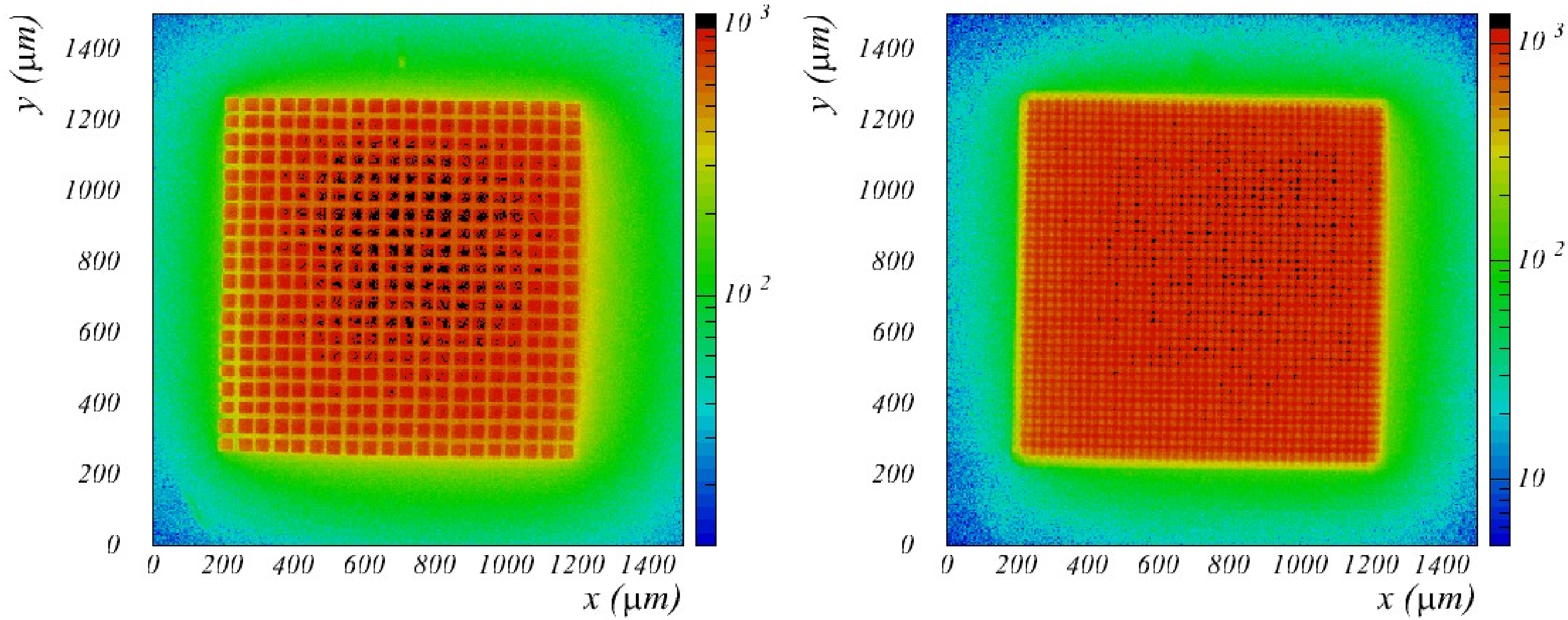




Surface sensitivity for single photons 3

Hamamatsu MPPCs

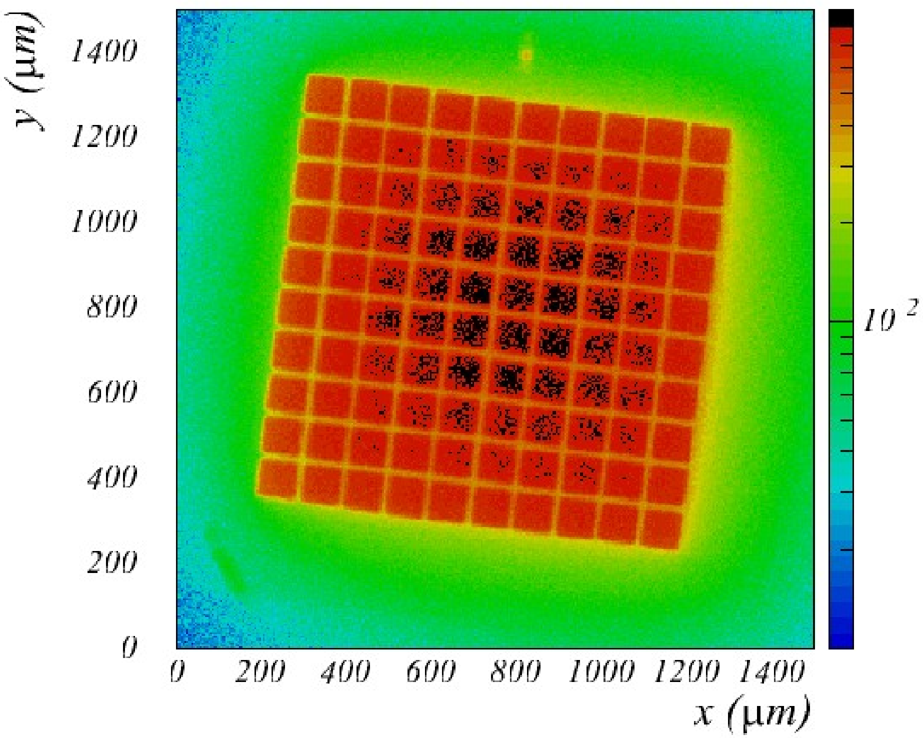
H050C H025C

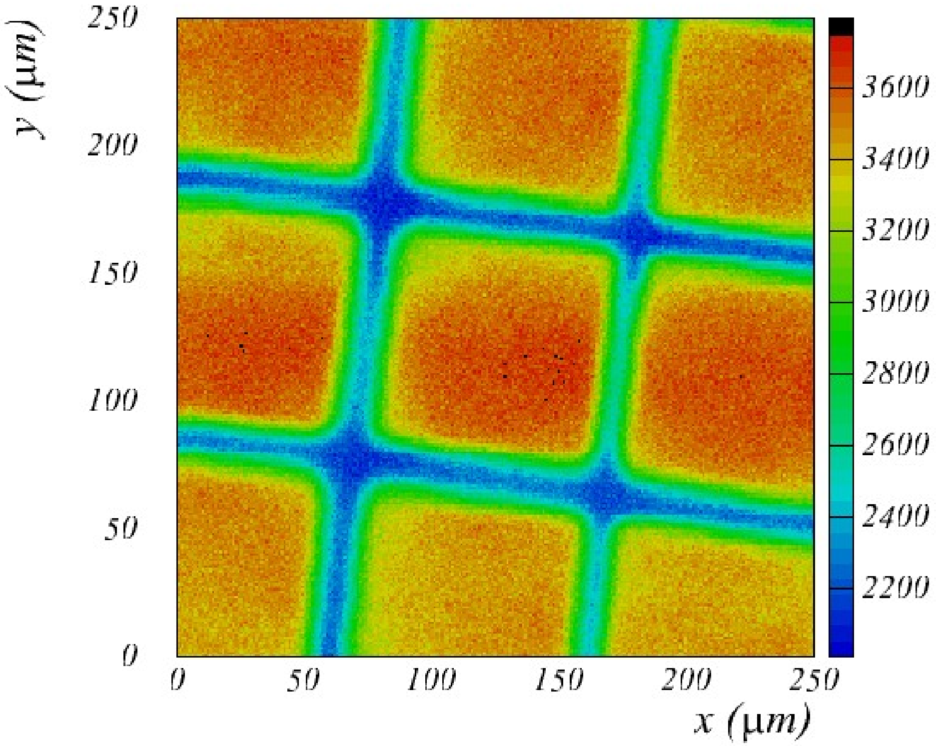


Surface sensitivity for single photons 4

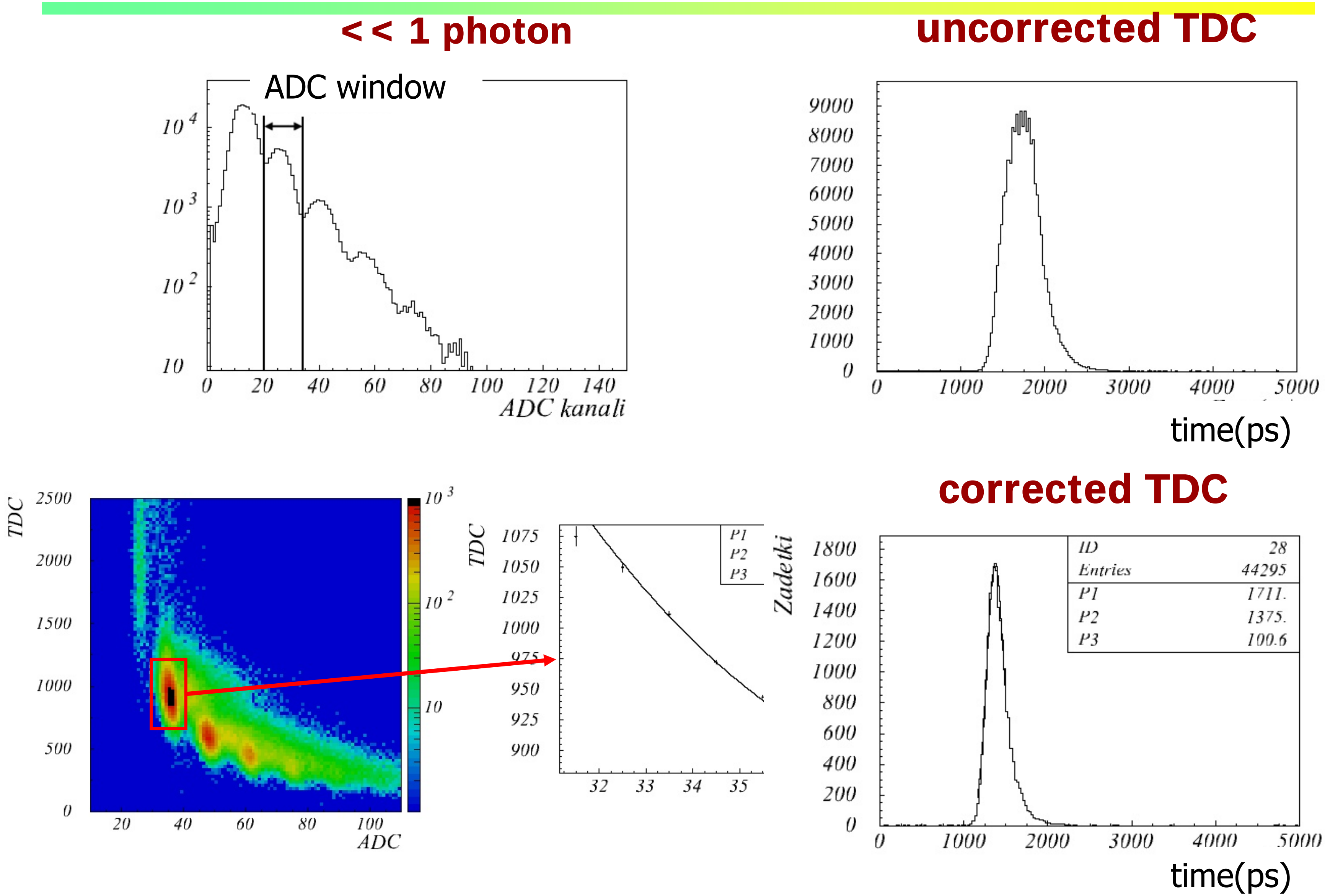
Hamamatsu MPPCs

H100C

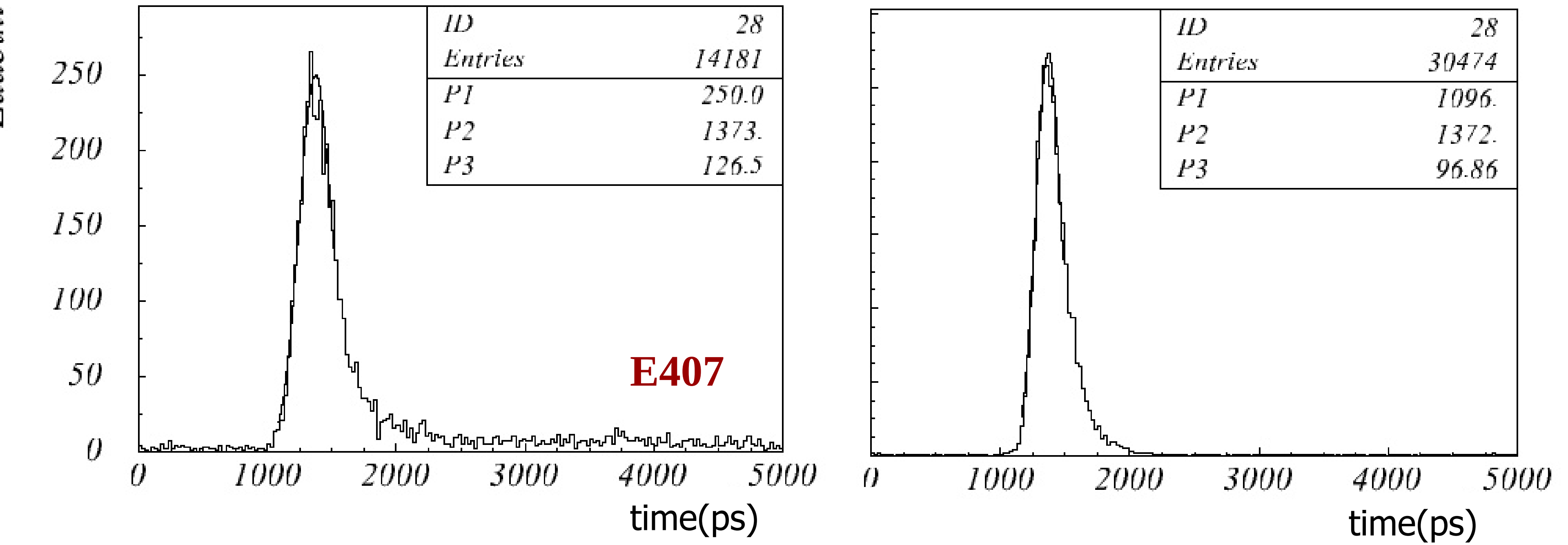




Time resolution: time walk correction



Time resolution: blue vs red



	E407	S137	H100C	H050C	H025C
σ_{red} (ps)	**127**	**182**	**145**	**212**	**154**
σ_{blue} (ps)	**97**	**151**	**136**	**358**	**135**

- $\sigma \approx 100$ ps

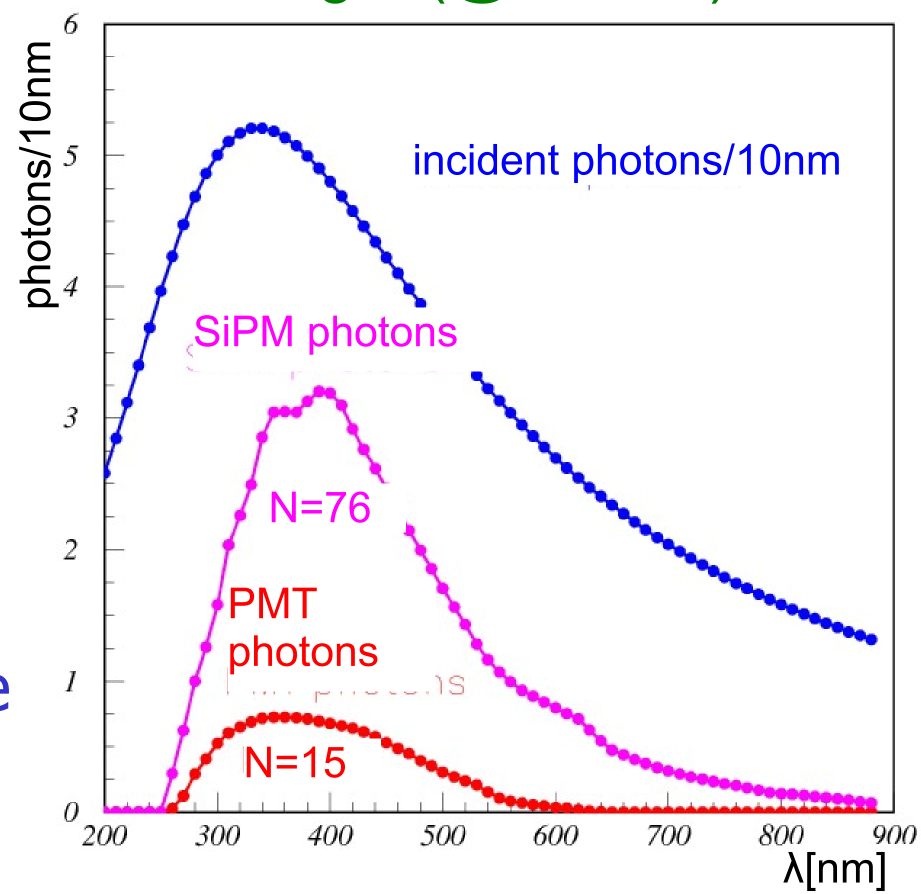
- $\sigma_{red} > \sigma_{blue}$

Expected number of photons for aerogel RICH

with multianode PMTs or SiPMs(100U), and
aerogel radiator: thickness 2.5 cm, n = 1.045
and transmission length (@400nm) 4 cm.

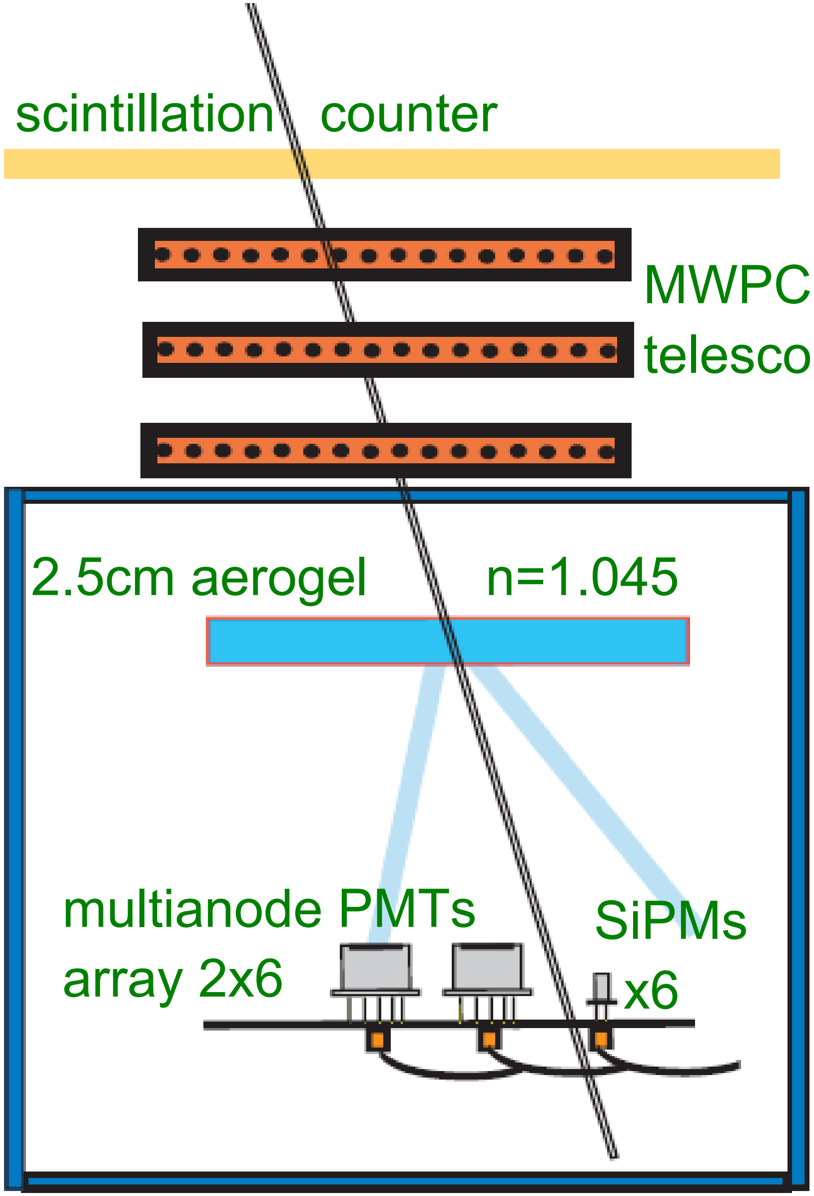
N_{SiPM}/N_{PMT}~5

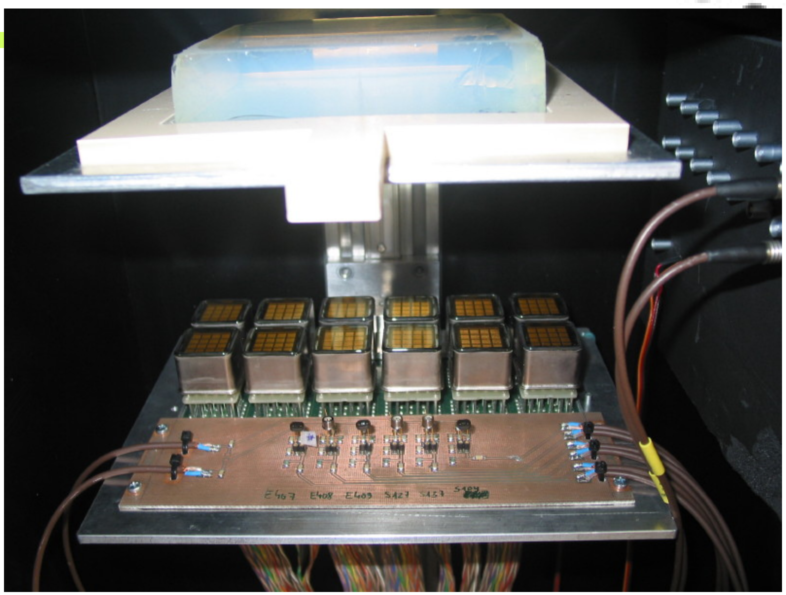
Assuming 100% detector active area



Never before tested in a RICH where we have to detect single photons. ← Dark counts have single photon pulse heights (rate 0.1-1 MHz)

SIPMs: Cosmic test setup



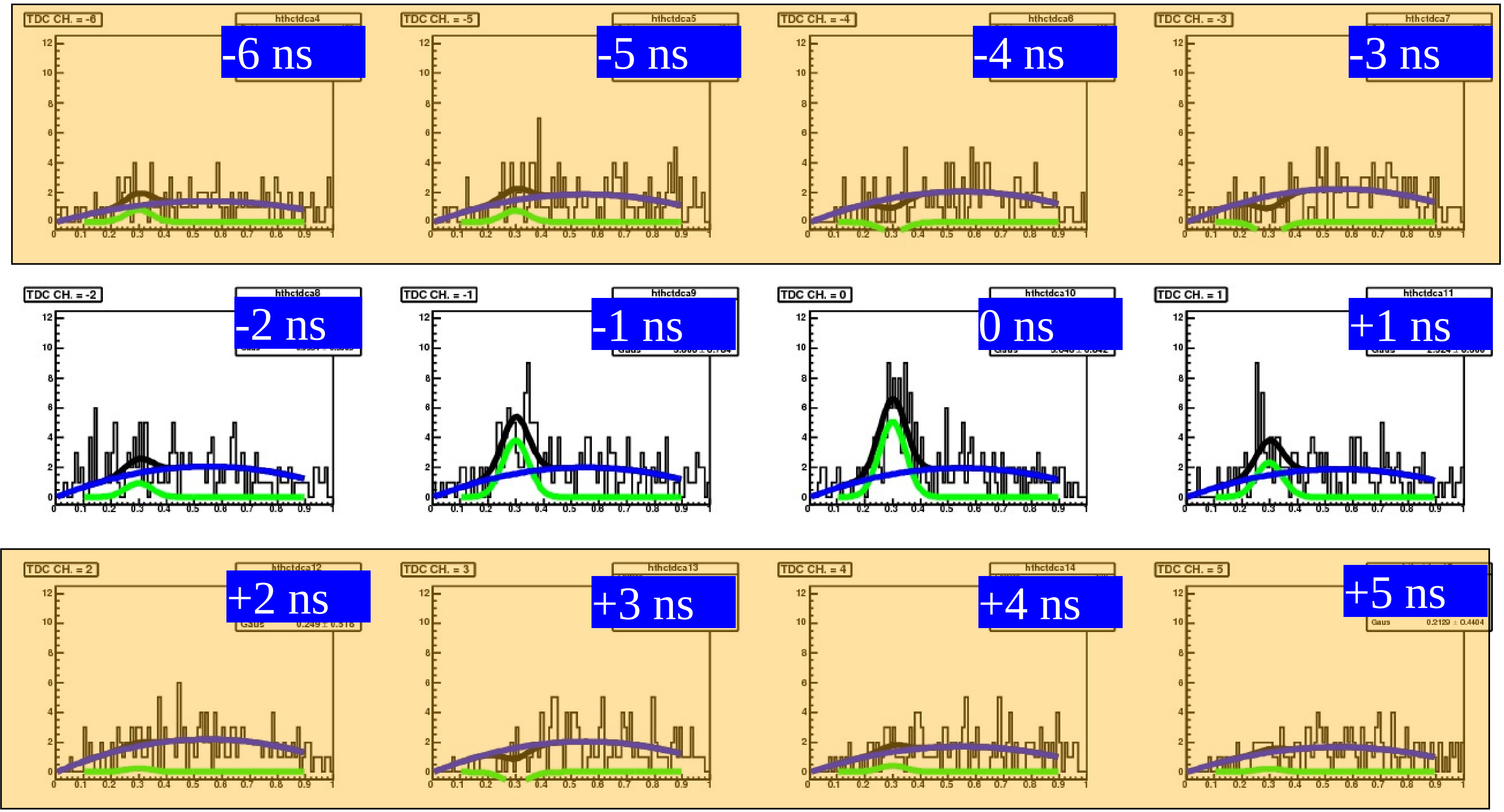


- 6 Hamamatsu SiPMs (=MPPC) of type 100U (10x10 pixels with 100μm pitch), background ~400kHz

- signals amplified (ORTEC FTA820),
- discriminated (EG&G CF8000) and
- read by multihit TDC (CAEN V673A) with 1 ns / channel

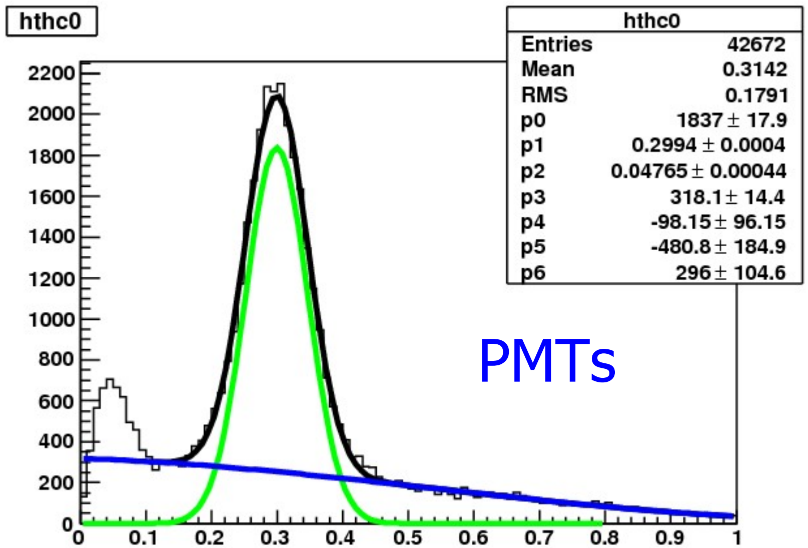
To be published in NIM A in ~3 weeks

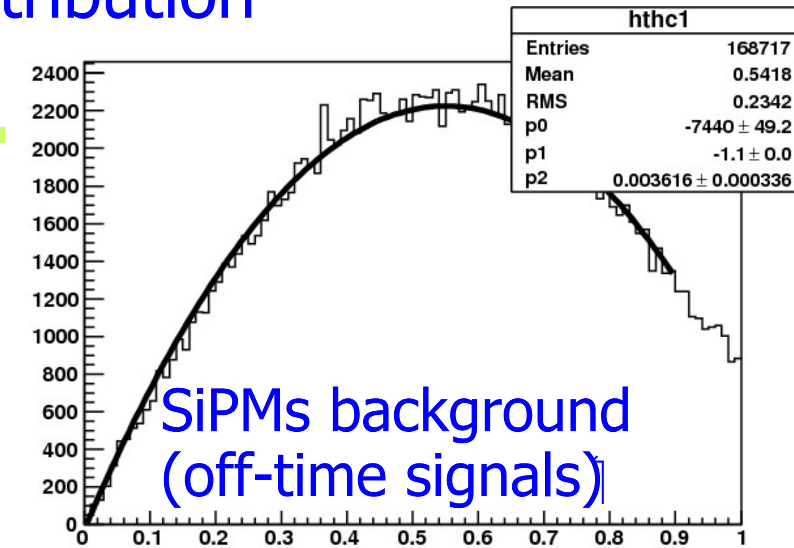
SiPM: Cherenkov angle distributions for 1ns time windows

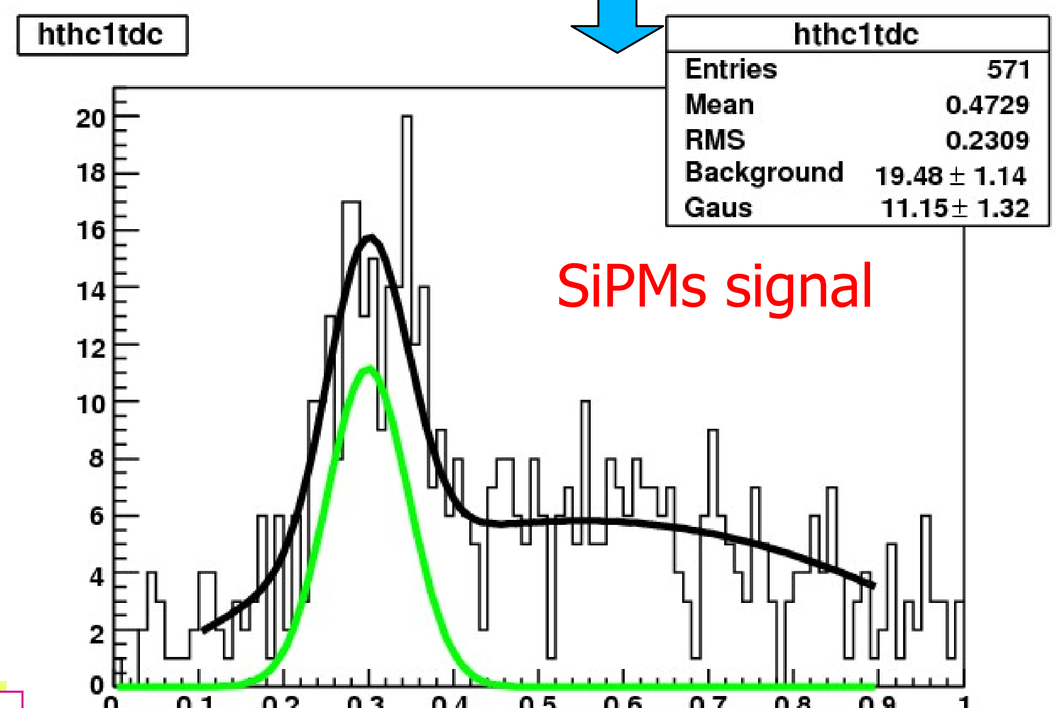


Cherenkov photons appear in the expected time windows →
First Cherenkov photons observed with SiPMs!

SiPM Cherenkov angle distribution







Fit function is a combination of

- a background (quadratic) and
- a signal (Gaussian).

Only scale parameters are free

→ SiPMs give 5 x more photons than PMTs per photon detector area – in agreement with expectations

To be published in NIM A in ~3 weeks

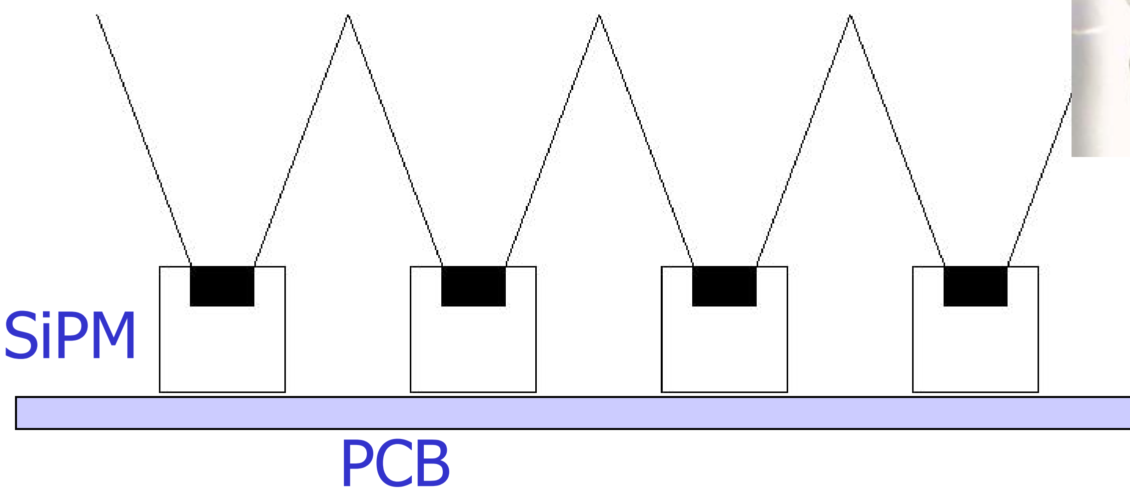
SIPMs: improving signal/noise

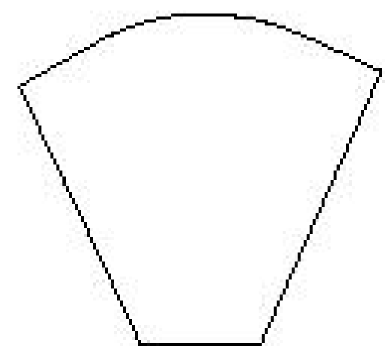
Improve the signal to noise ratio:

•Reduce the noise by a narrow (few ns) time window

•Increase the number of signal hits per single sensor by using light collectors and by adjusting the pad size to the ring thickness

Light collector with reflective walls

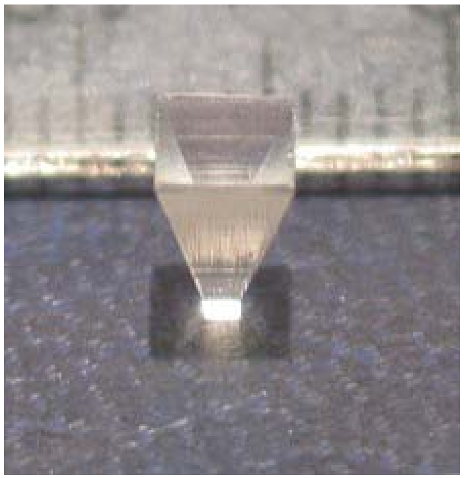


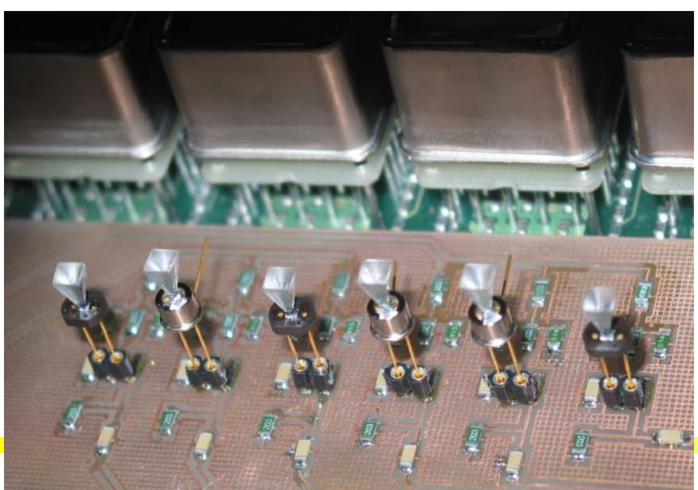


or combine a lens and mirror walls

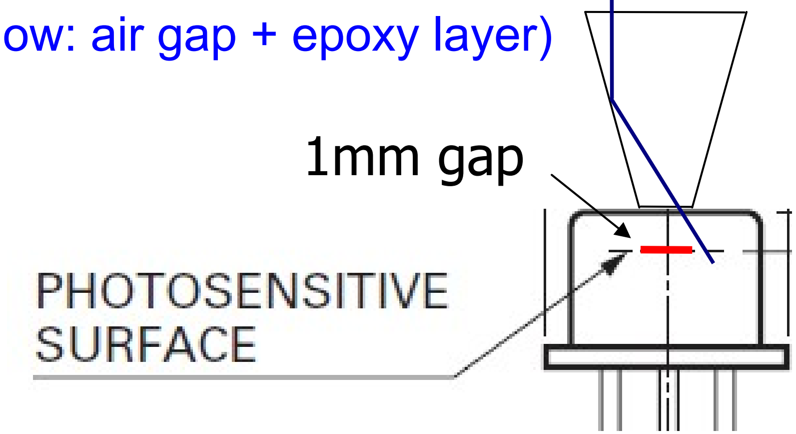
Light collection: improve signal to noise ratio

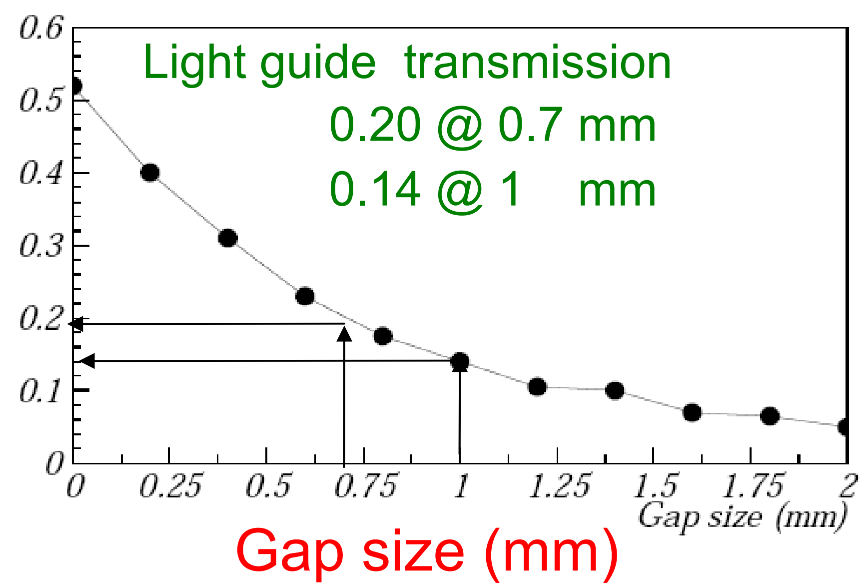
Machined from a plastic plate (HERA-B RICH lens material).





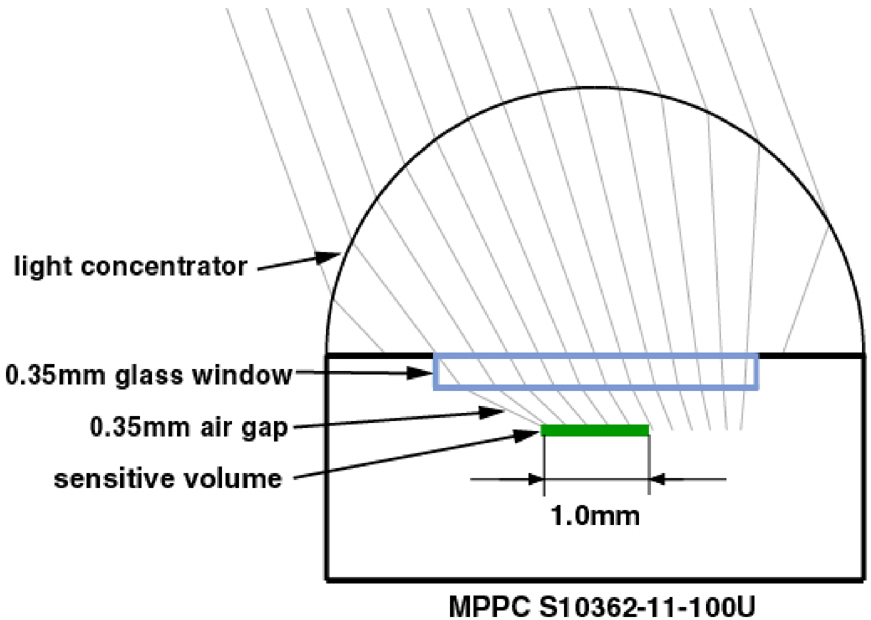
Light guide should be as close as possible to the SiPM surface (now: air gap + epoxy layer)

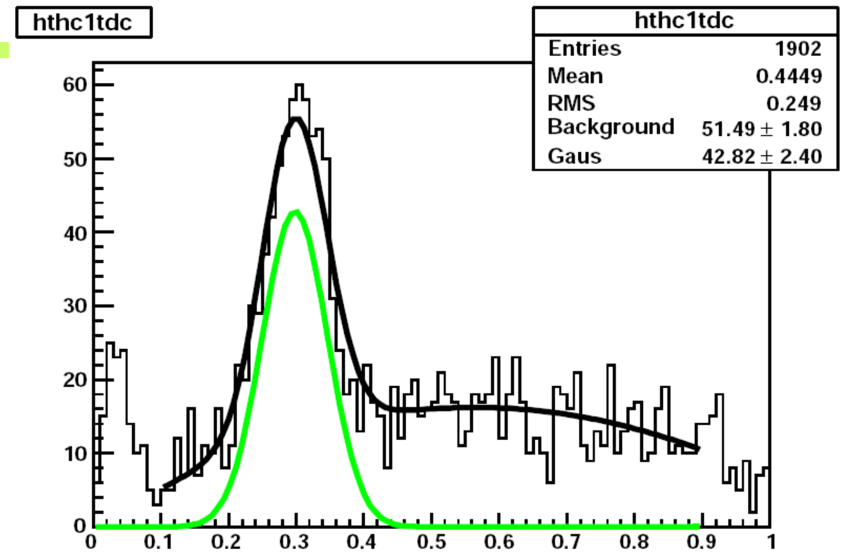




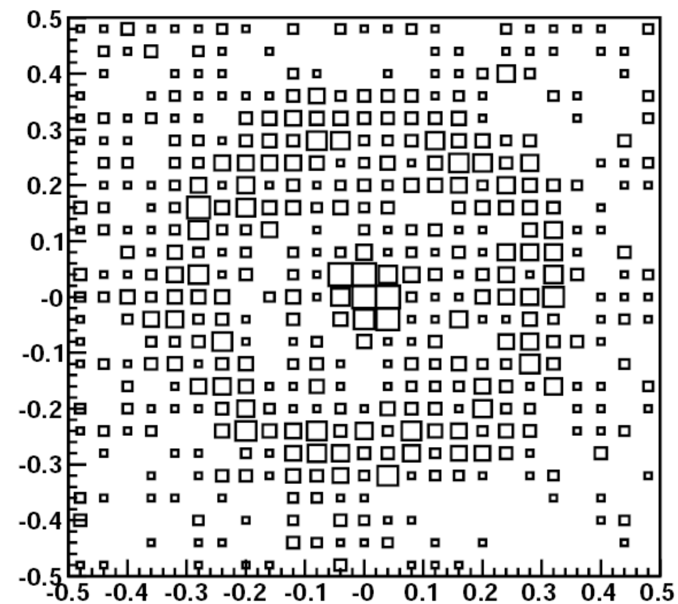
Cherenkov photons with light collectors

First attempt: use the top of a blue LED



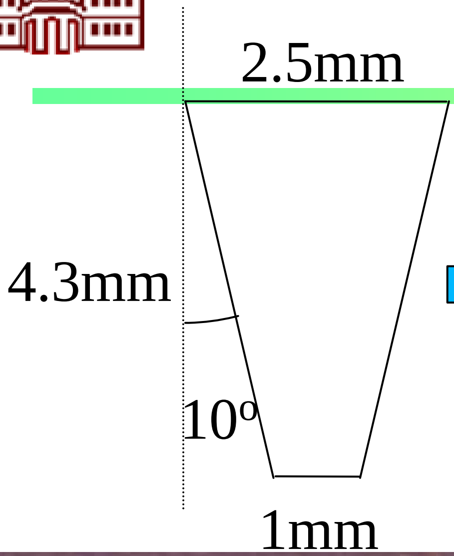


- Yield increase in agreement with the expectations
- Further improvements possible by
  - Using SiPMs with a reduced epoxy protective layer
  - using a better light collector

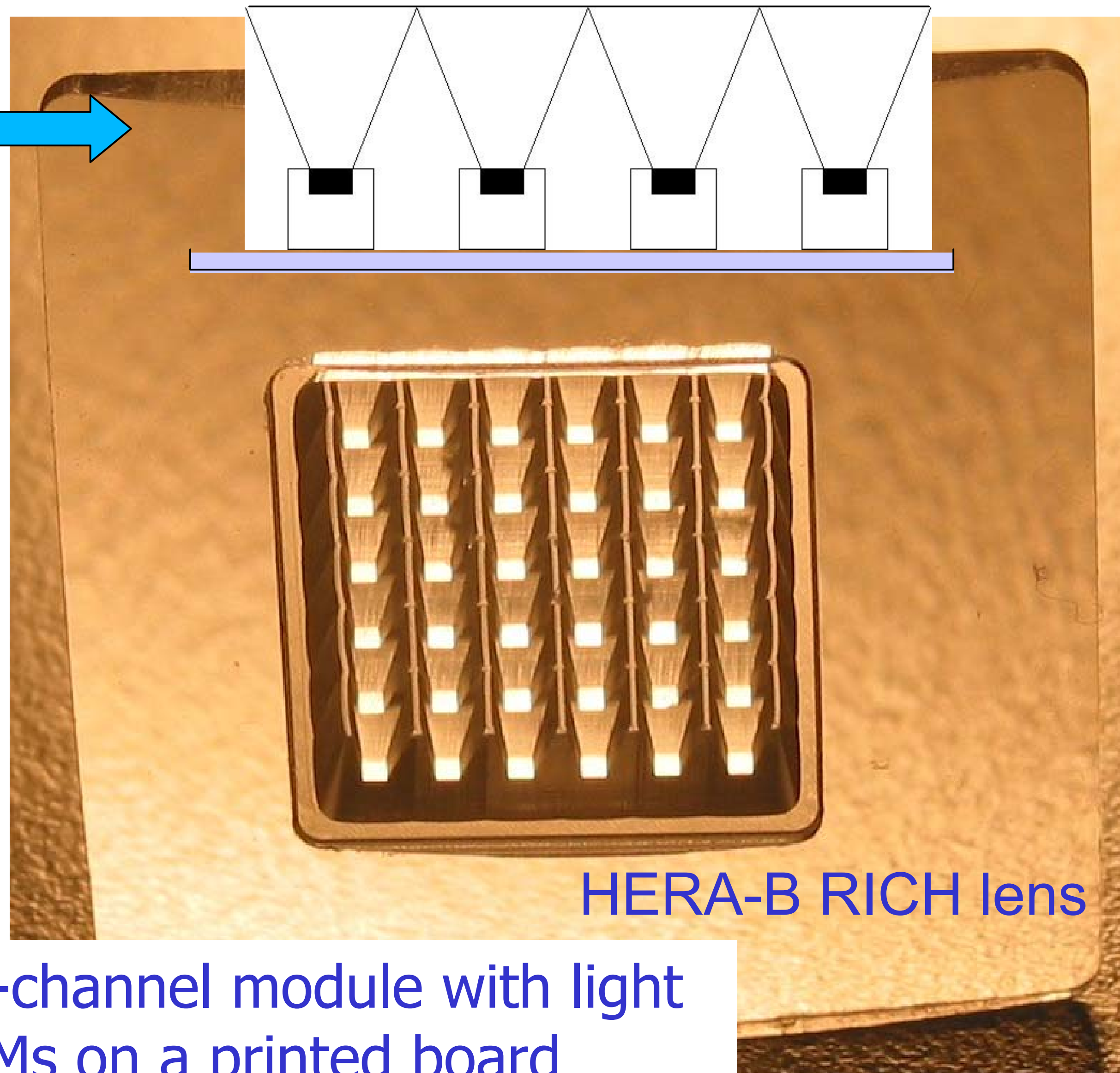


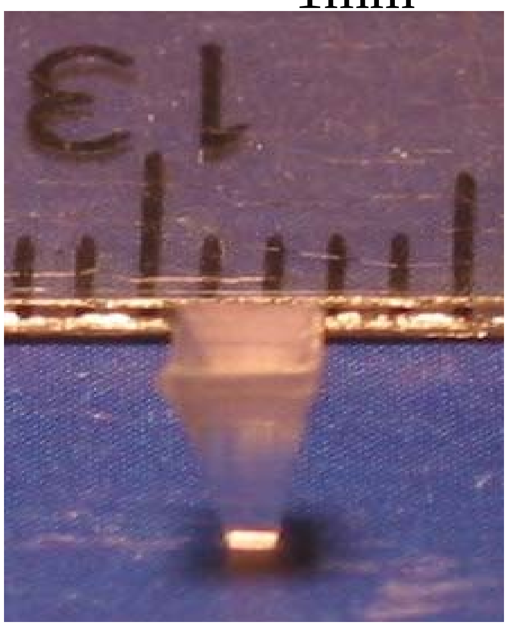
Hits in Cherenkov space

Detector module design



SiPM array with light guides



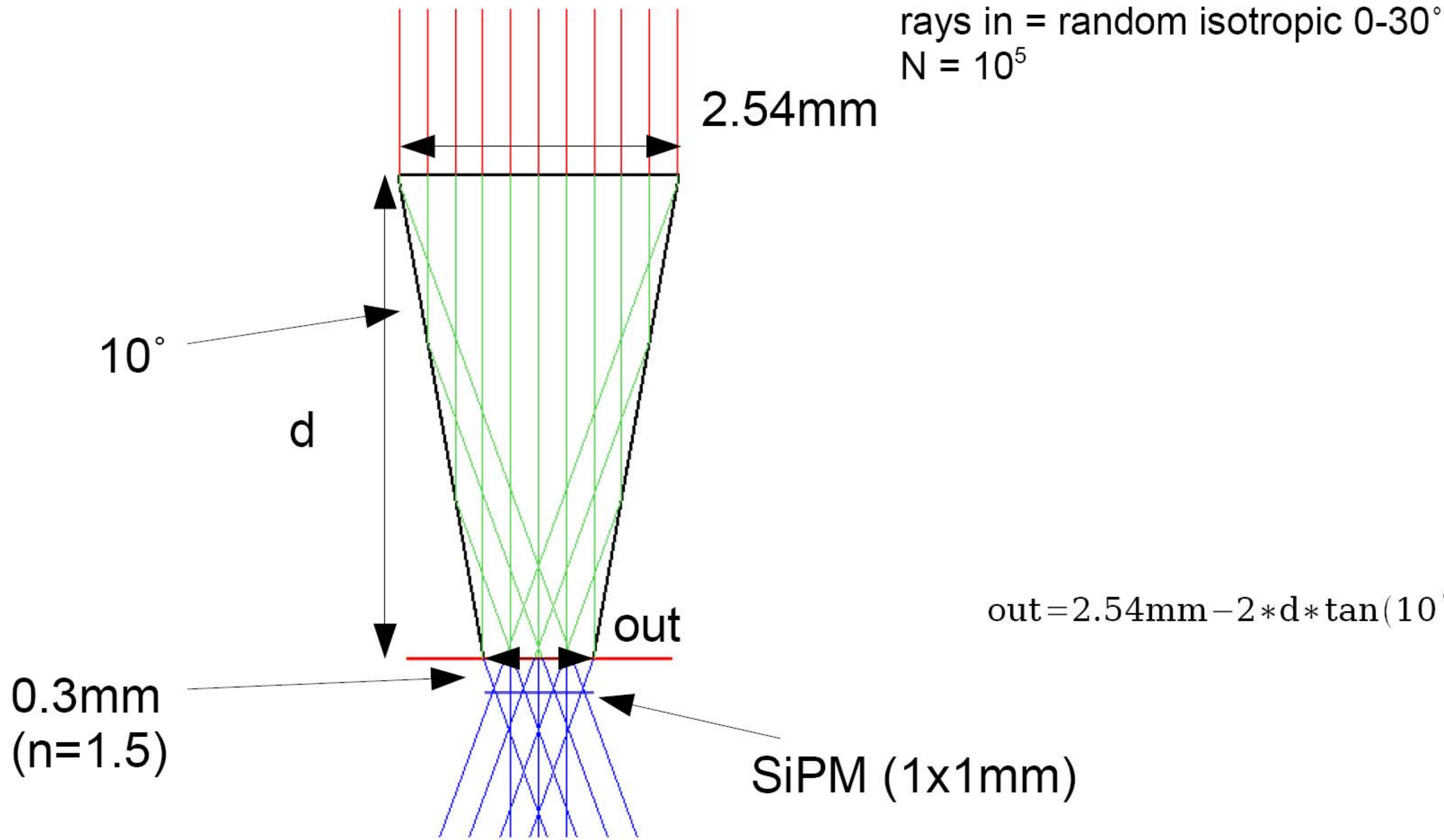


HERA-B RICH lens

Aim: build a multi-channel module with light collectors and SiPMs on a printed board

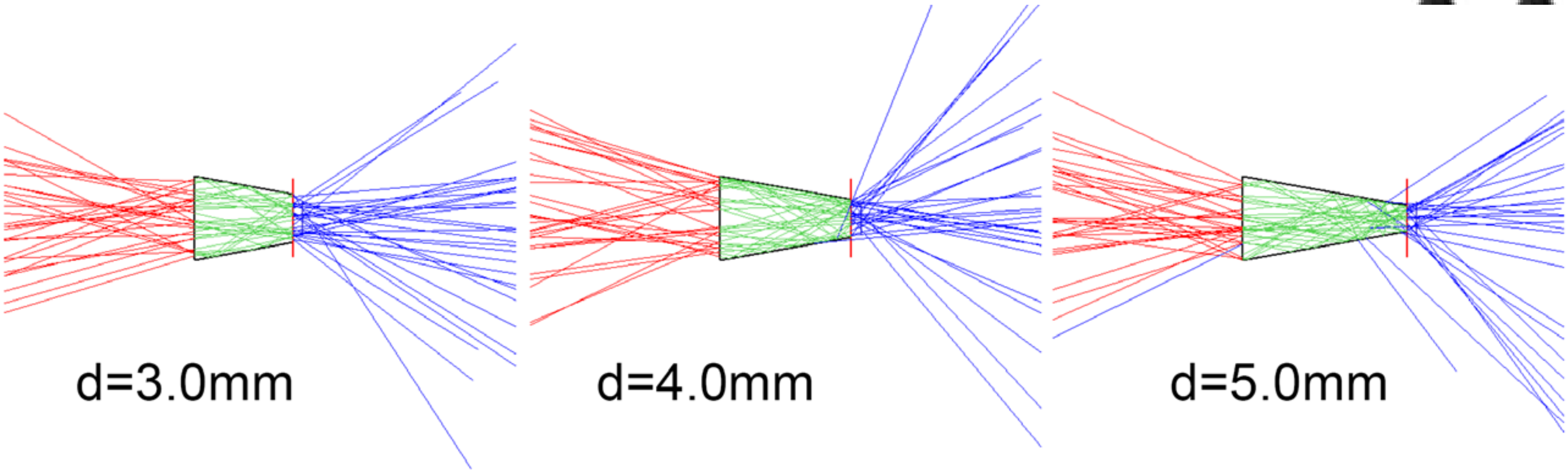
Light guide geometry optimisation

Light Guide Acceptance / (d and out)

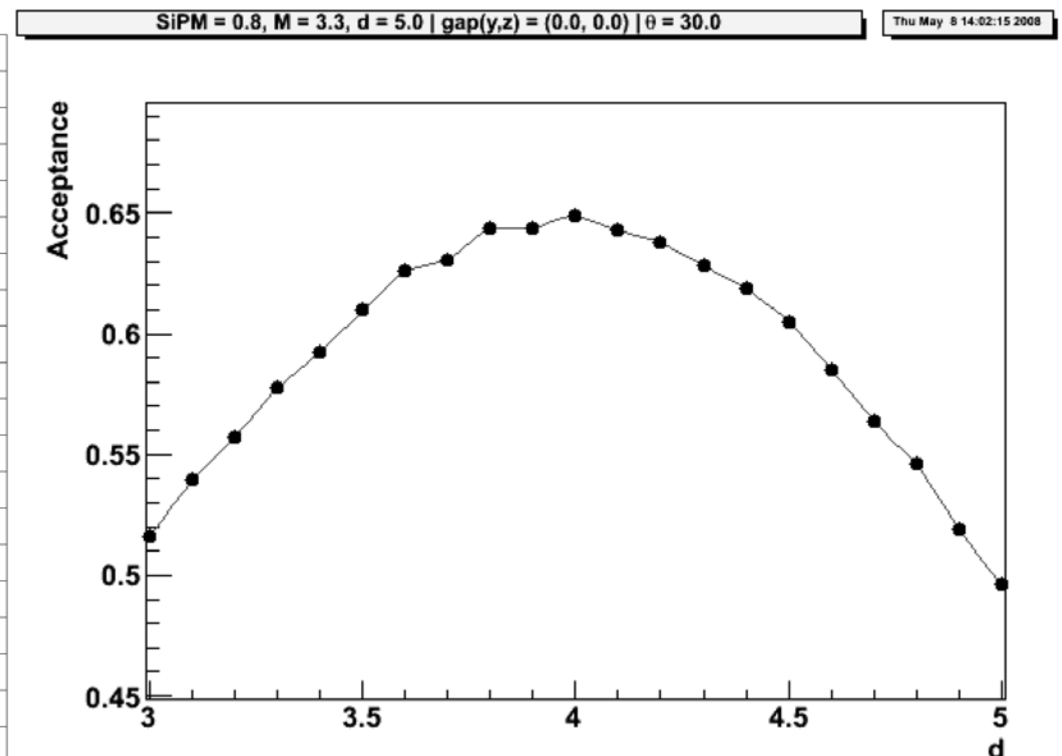


$$out = 2.54mm - 2*d*\tan(10^\circ)$$

Light guide geometry optimisation

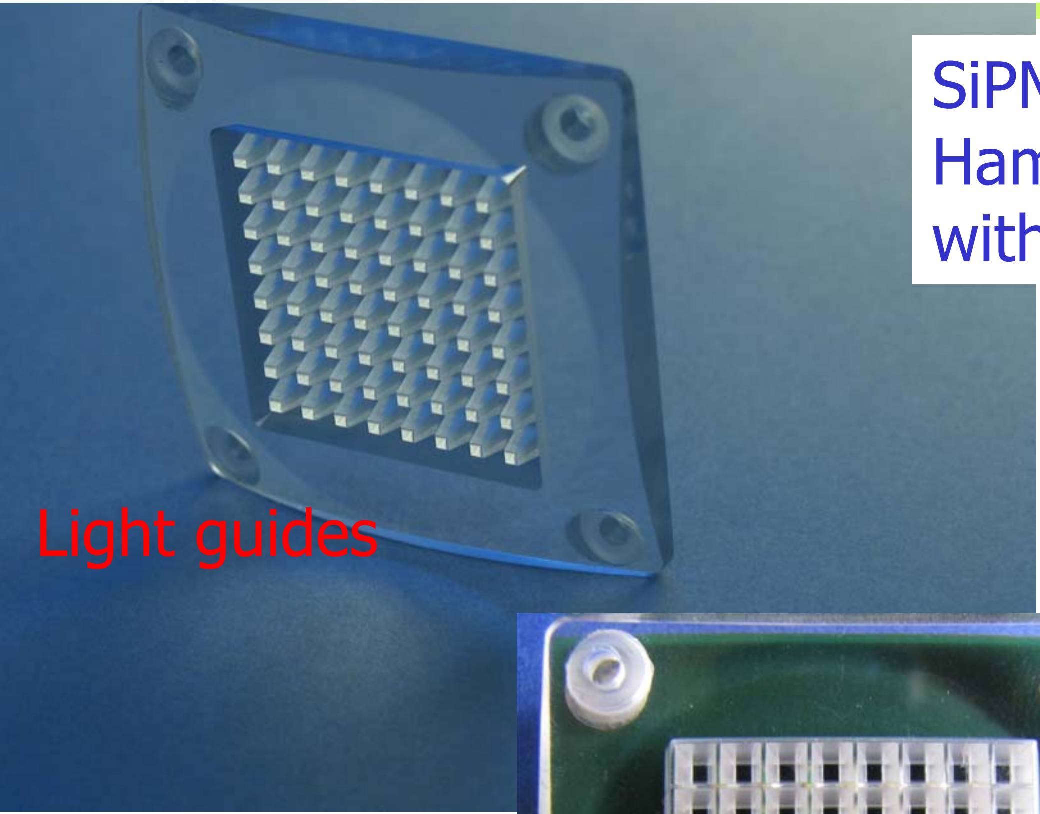


d (mm)	out (mm)	accept. (%)
3.0	1.48	51.6
3.1	1.45	54.0
3.2	1.41	55.7
3.3	1.38	57.8
3.4	1.34	59.2
3.5	1.31	61.0
3.6	1.27	62.6
3.7	1.24	63.1
3.8	1.20	64.4
3.9	1.16	64.4
4.0	**1.13**	**64.9**
4.1	1.09	64.3
4.2	1.06	63.8
4.3	1.02	62.8
4.4	0.99	61.8
4.5	0.95	60.5
4.6	0.92	58.5
4.7	0.88	56.4
4.8	0.85	54.6
4.9	0.81	51.9

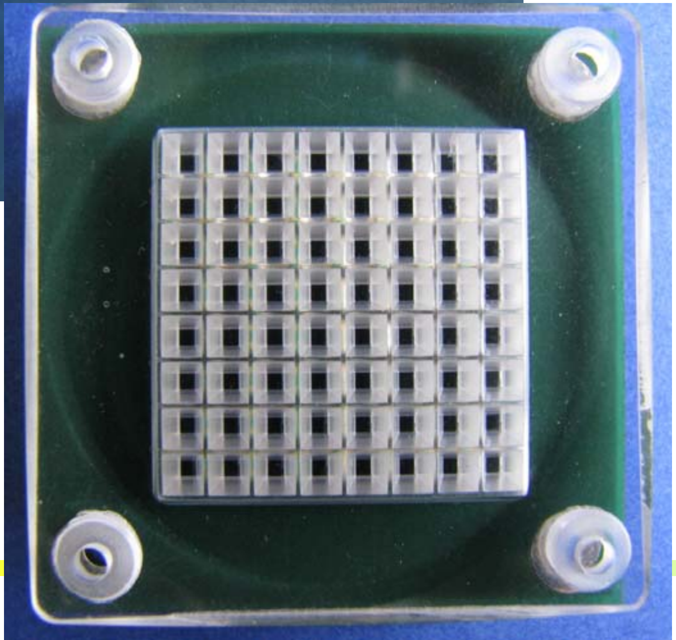


Detector module – final version for beam tests this week at KEK

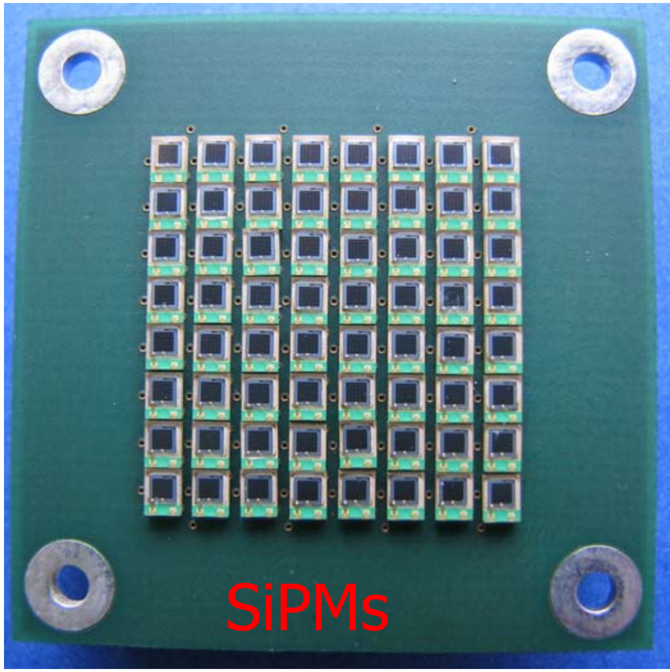
SiPMs: array of 8x8 SMD mount Hamamatsu S10362-11-100P with 0.3mm protective layer



Light guides



SiPMs + light guides

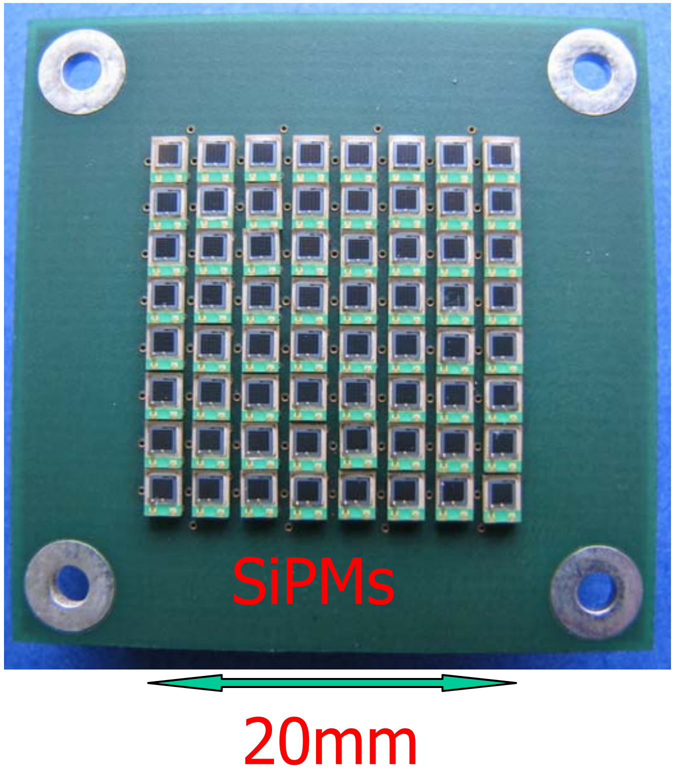


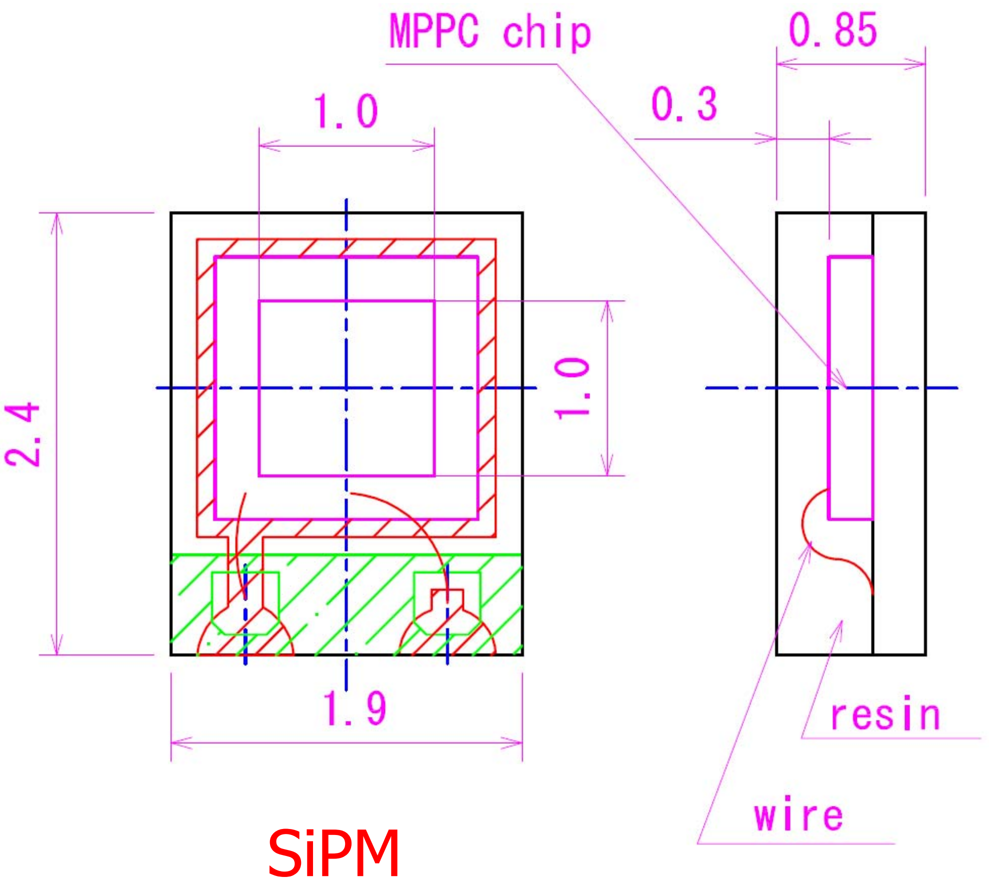
SiPMs

2cm

Photon detector for the beam test

SiPMs: array of 8x8 SMD mount Hamamatsu S10362-11-100P with 0.3mm protective layer





Open question: sensitivity to neutrons

However: SiPMs are sensitive to neutron irradiation (dark count rate starts increasing drastically after ~10^{10} neutrons/cm^2)

→ We have to measure the neutron flux in the relevant detector region: calibrated Si diodes mounted in the spectrometer since January, leave it there for ~1 year, extract and determine the integrated flux (fluence)

→We will also mount a few SiPMs in the proper place in the spectrometer, register their performance during running.

Summary

Single Cherenkov photons were observed for the first time with SiPM in a RICH counter using cosmic rays

Small size light guides were designed, machined and attached to the SiPMs.

SiPMs are a promising candidate for photon detection in future RICH counters

Plan:

Further study of different light collection systems

Test a larger array

Open issue: influence of neutrons on the counter performance

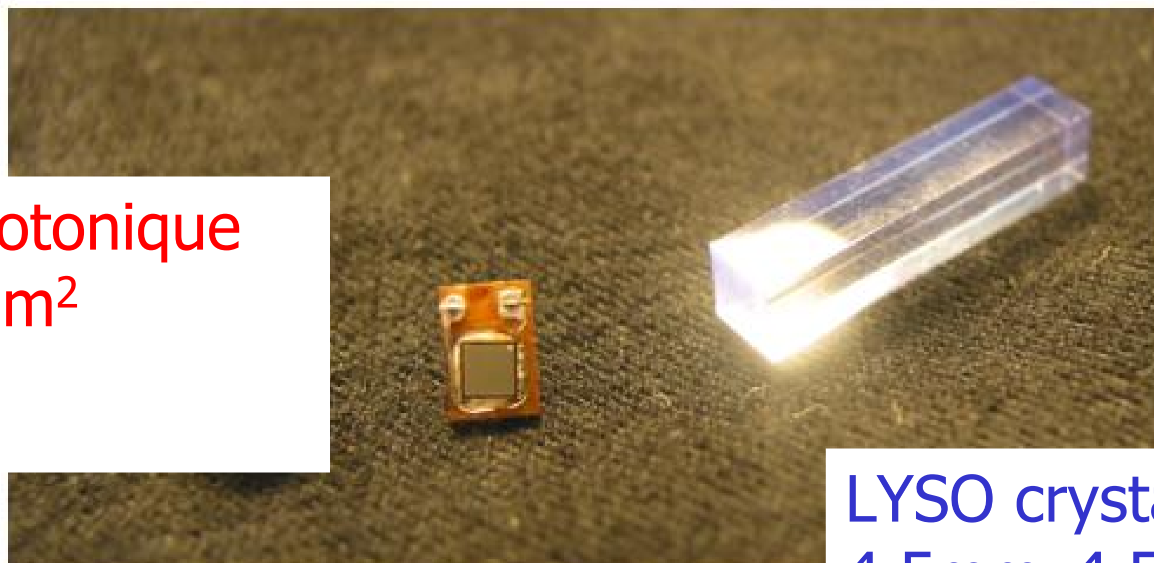
Explore other applications of the device → PET

We also work on a PET module...

Test a PET module with:

4x4 array of LYSO crystals (4.5 x 4.5 x 20(30) mm^3)

SiPMs: Photonique 2.1x2.1 mm^2

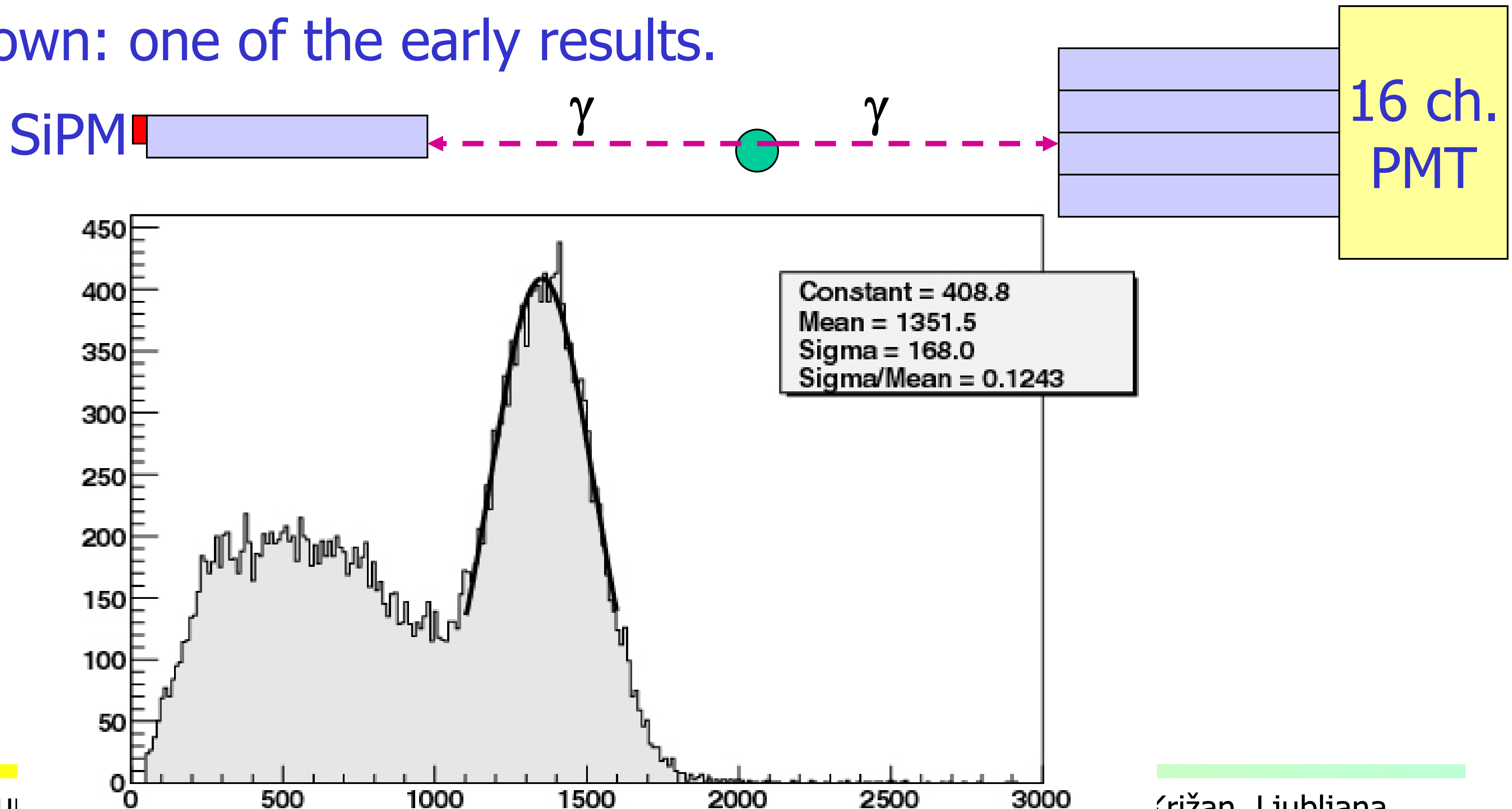


SiPMs: Photonique 2.1x2.1 mm^2

LYSO crystals 4.5mmx4.5mm

We also work on a PET module 2

- Some tests with Na22 in coincidence with a 4x4 LYSO+MAPMT module
- Best: ~9% (rms) energy resolution
- Shown: one of the early results.

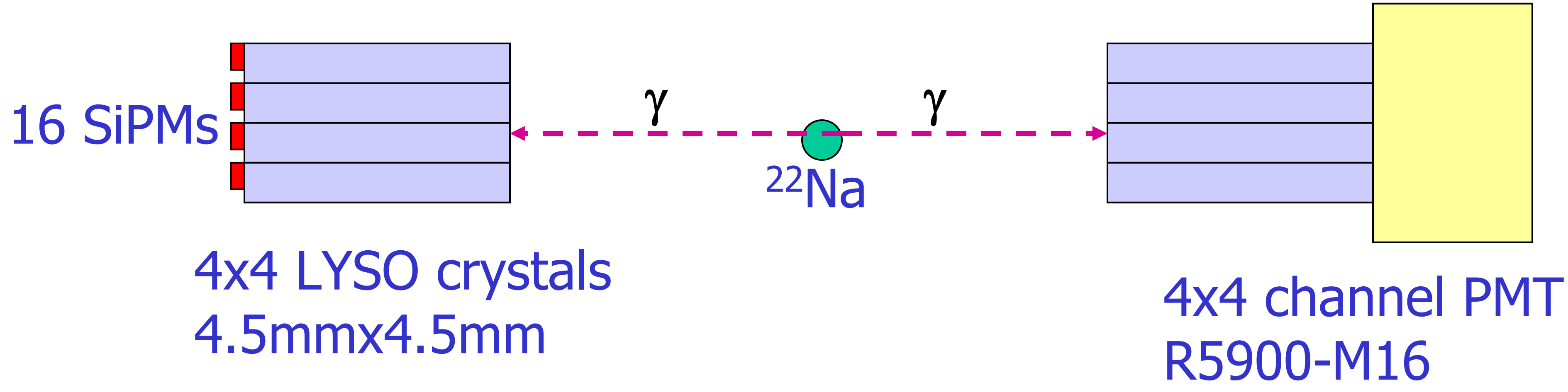


Next step…

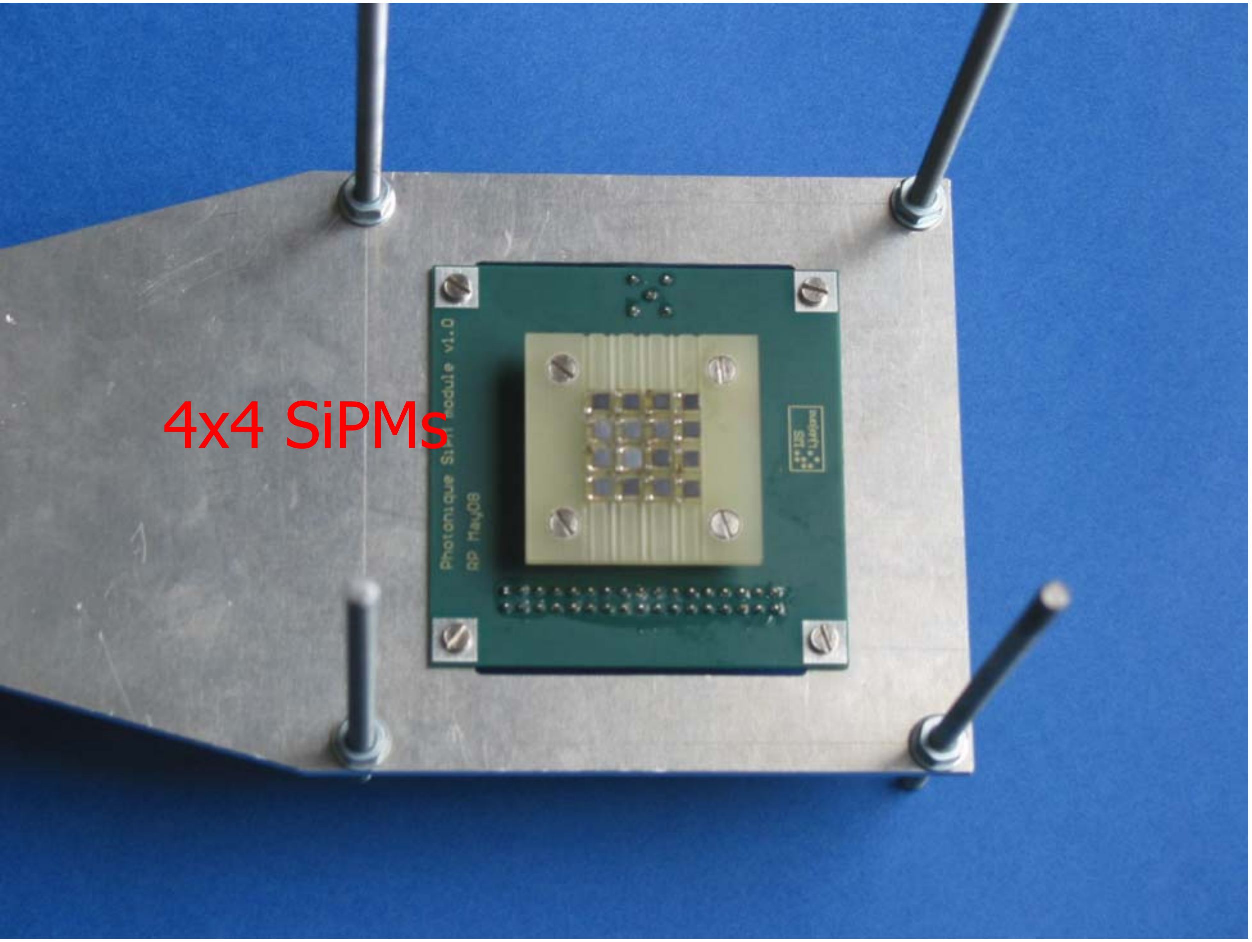
Test a PET module with:

4x4 array of LYSO crystals (4.5 x 4.5 x 20(30) mm^3)

16 SiPMs (Photonique 2.1x2.1 mm^2)



Next step...

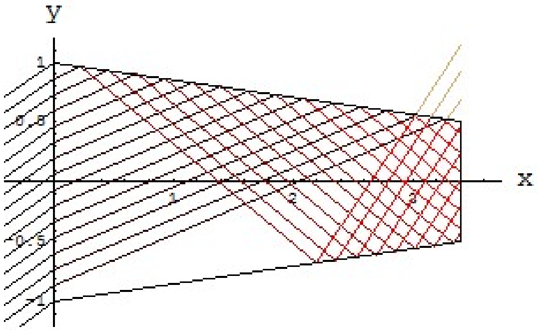


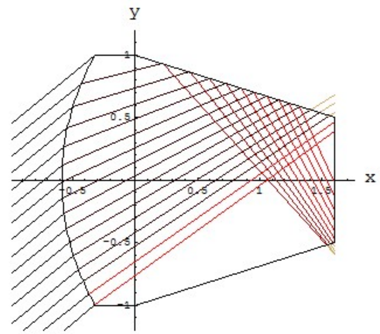
Reading out a 4x4 array of LYSO crystals

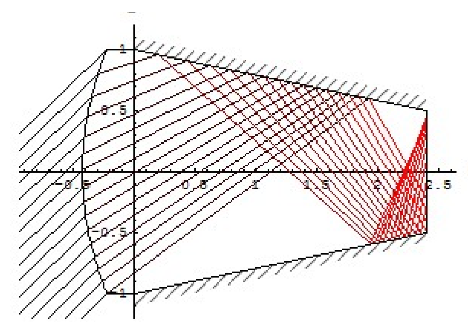
Module under test...

Back-up slides

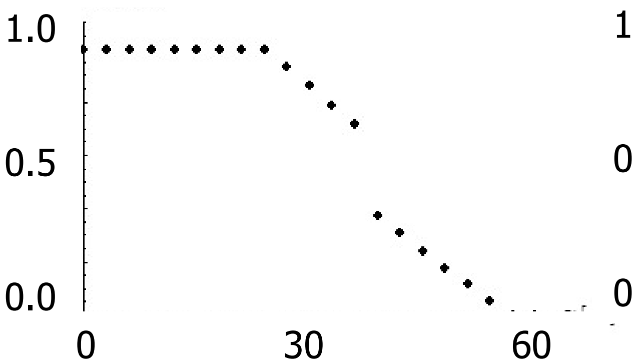
Planar entry window / Spherical entry window / Spherical entry window, reflective sides

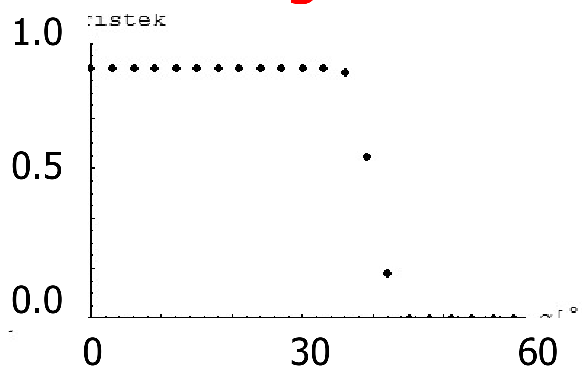


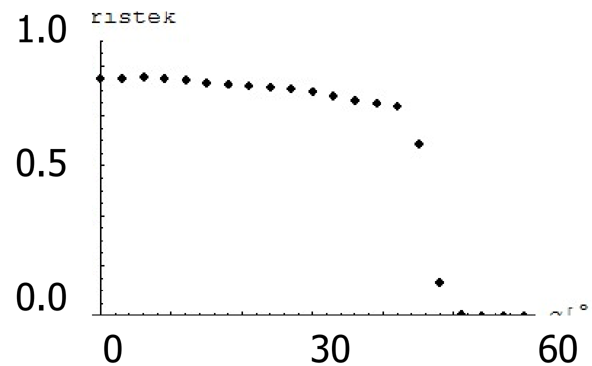




Efficieny vs. angle of incidence α





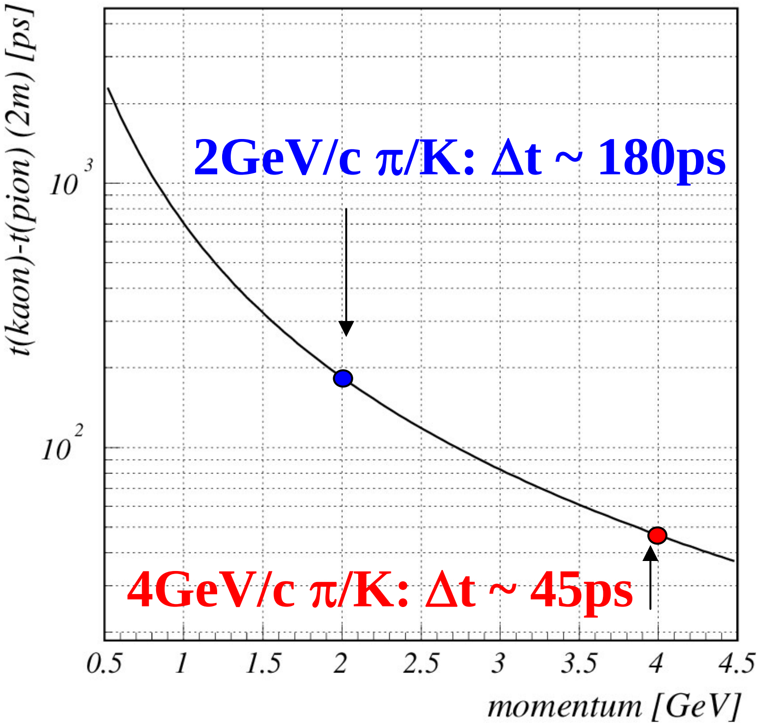


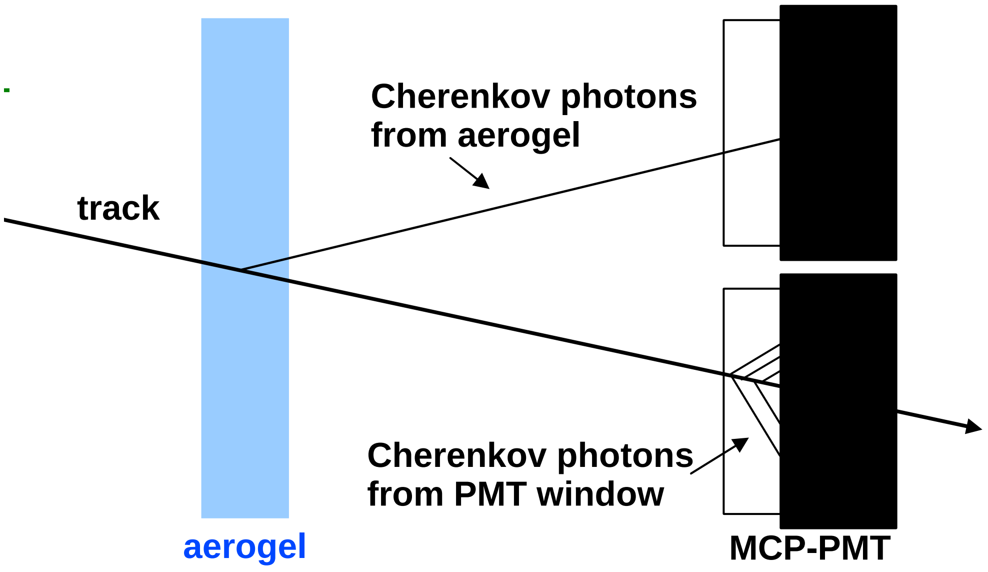
Light guide	d/a	R/a	α_{min}, α_{max}	I(-60°, 60°)
Planar entry	**3.4**	-	**-24°, 24°**	**64%**
Sph. entry	**1.6**	**2.0**	**-35°, 35°**	**66%**
Reflective sides	**2.4**	**2.6**	**-44°, 44°**	**69%**

TOF capability of a RICH

With a fast photon detector (MCP PMT), a proximity focusing RICH counter can be used also as a time-of-flight counter.

Time difference between π and K →



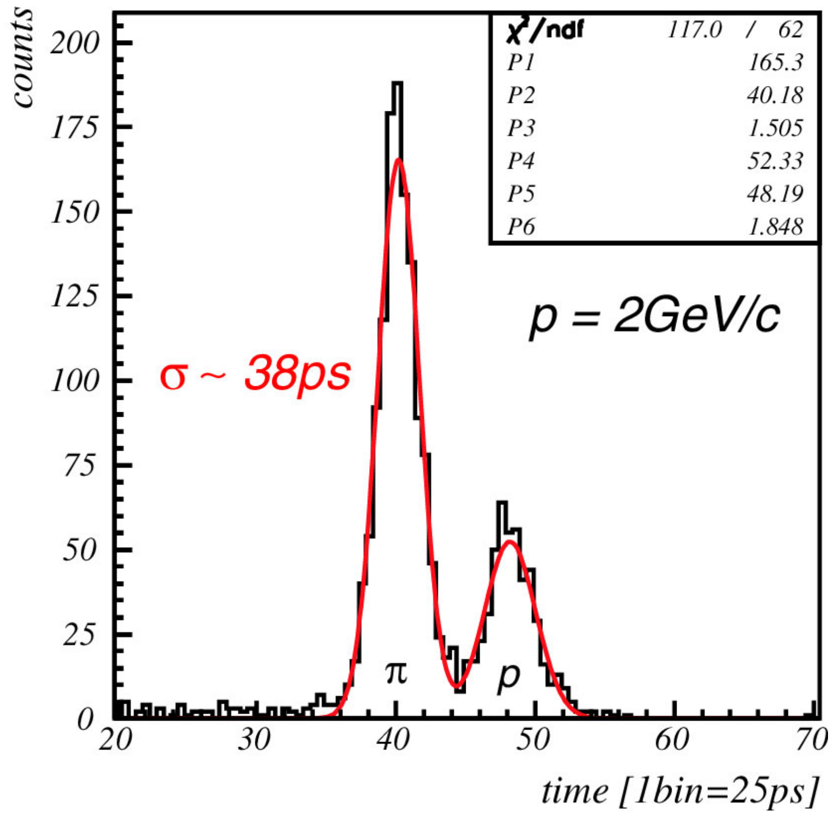


For time of flight: use Cherenkov photons photons emitted in the PMT window

TOF capability: window photons

Expected number of detected Cherenkov photons emitted in the PMT window (2mm) is ~15

→ Expected resolution ~35 ps



TOF test with pions and protons at 2 GeV/c.

Distance between start counter and MCP-PMT is 65cm

→ In the real detector ~2m

→ 3x better separation

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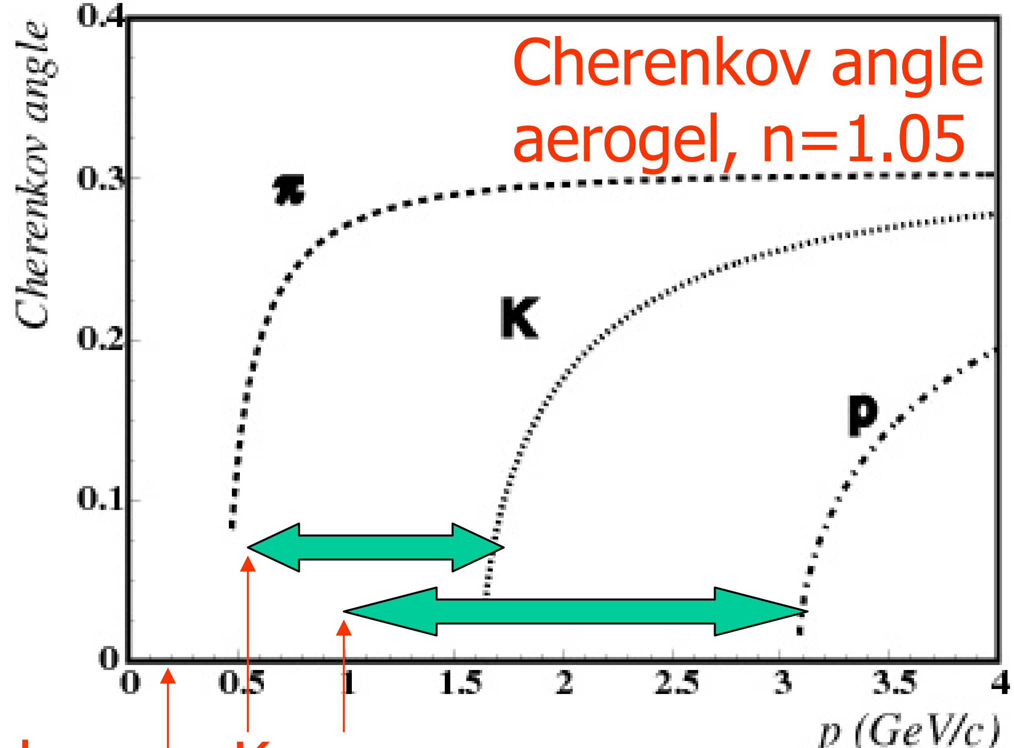
Time-of-flight with photons from the PMT window

Benefits: Čerenkov threshold in glass (or quartz) is much lower than in aerogel.

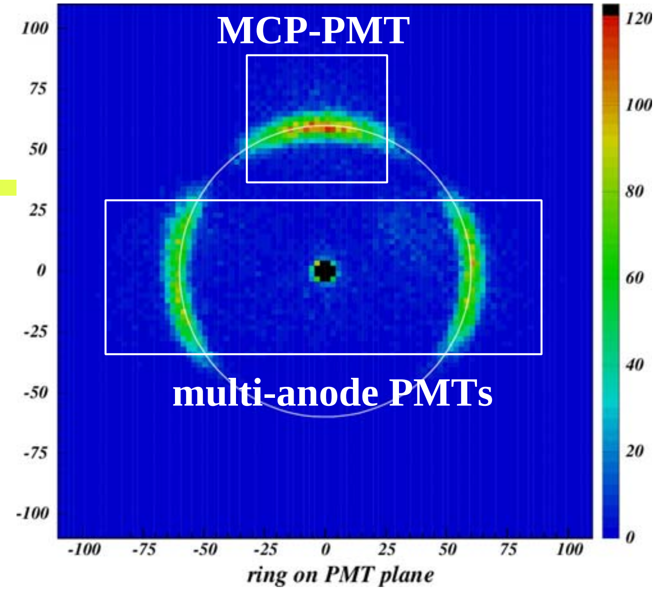
Aerogel: kaons (protons) have no signal below 1.6 GeV (3.1 GeV): identification in the veto mode.



Threshold in the window: π K p

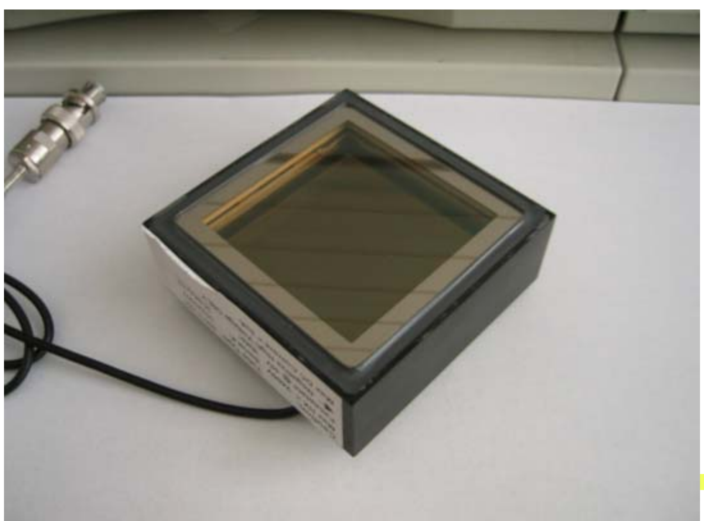
Window: threshold for kaons (protons) is at ~0.5 GeV (~0.9 GeV): → positive identification possible.

Photon detector candidate: MCP-PMT



BURLE 85011 MCP-PMT:

- multi-anode PMT with two MCP steps
- 25 μm pores
- bialkali photocathode
- gain ~ 0.6 x 10^6
- collection efficiency ~ 60%
- box dimensions ~ 71mm square
- 64(8x8) anode pads
- pitch ~ 6.45mm, gap ~ 0.5mm
- active area fraction ~ 52%



- Tested in combination with multi-anode PMTs

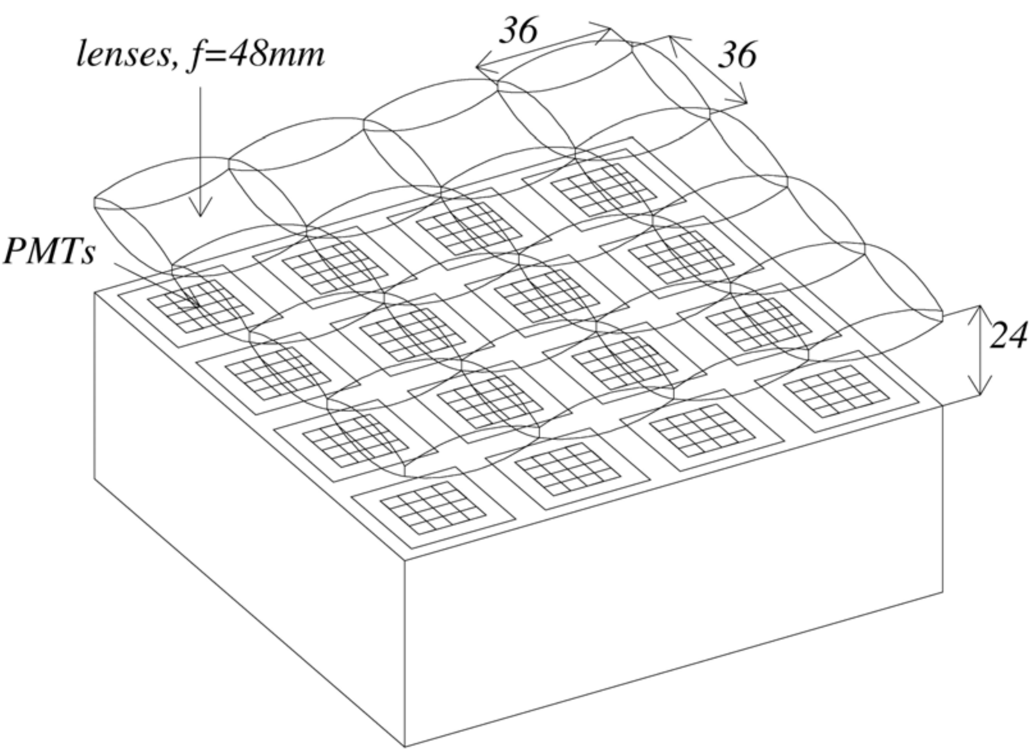
- σ_ϑ~13 mrad (single cluster)
- number of clusters per track N ~ 4.5
- σ_ϑ~ 6 mrad (per track)
- **-> ~ 4 σ π/K separation at 4 GeV/c**

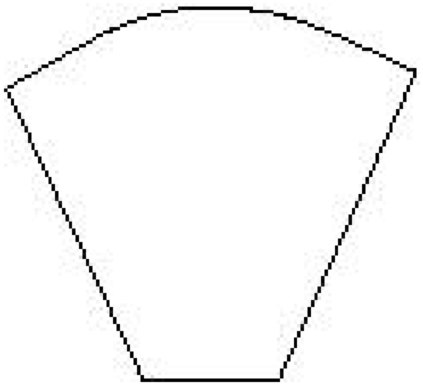
- 10 μm pores required for 1.5T
- collection eff. and active area fraction should be improved
- aging study should be carried out

Light collection: single vs multi channel

Multichannel device+imaging light collection system: Has a very limited angular acceptance

Single channel: combine a lens and mirror walls



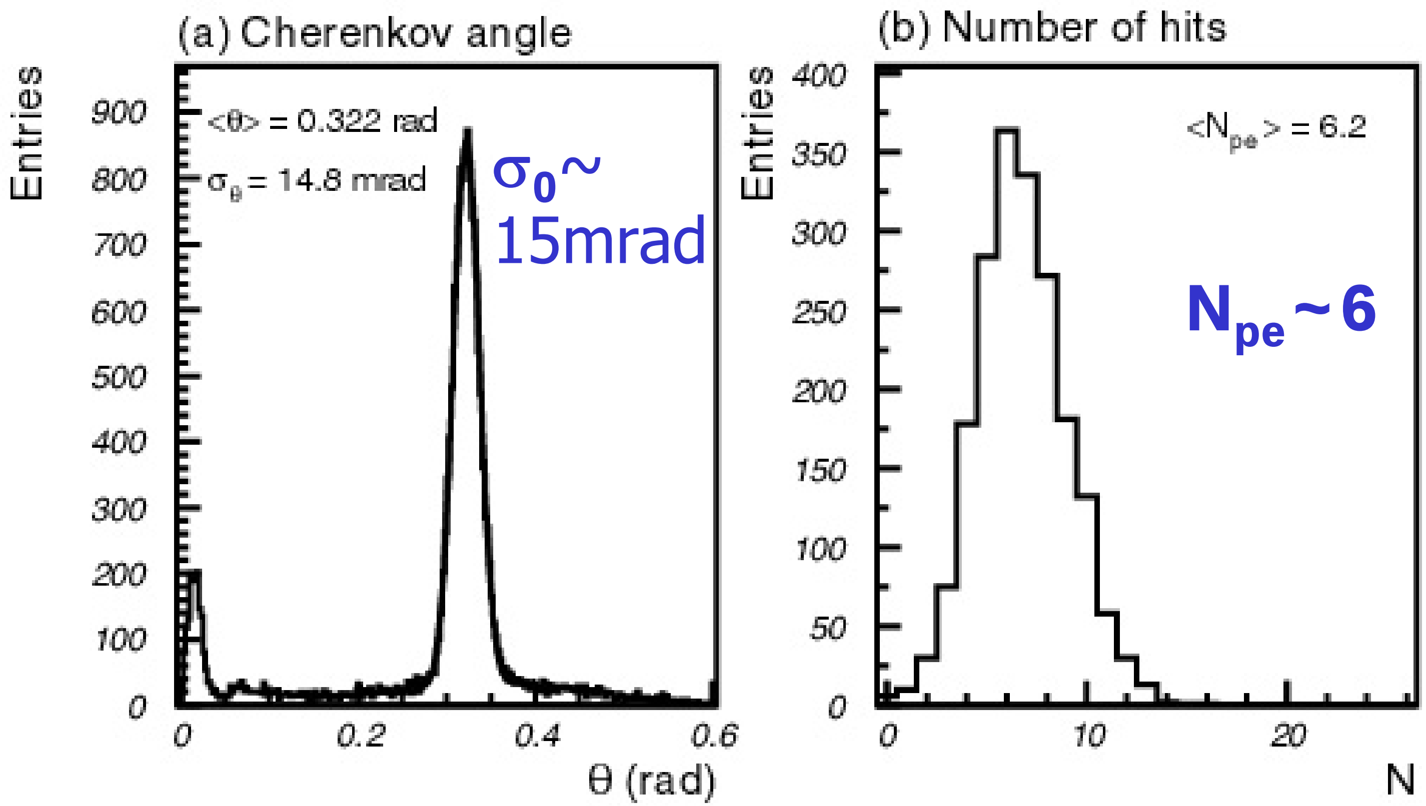


Beam test: Cherenkov angle resolution and number of photons

NIM A521(2004)367; NIM A553(2005)58

Beam test results with 2cm thick aerogel tiles:

>4σ K/π separation



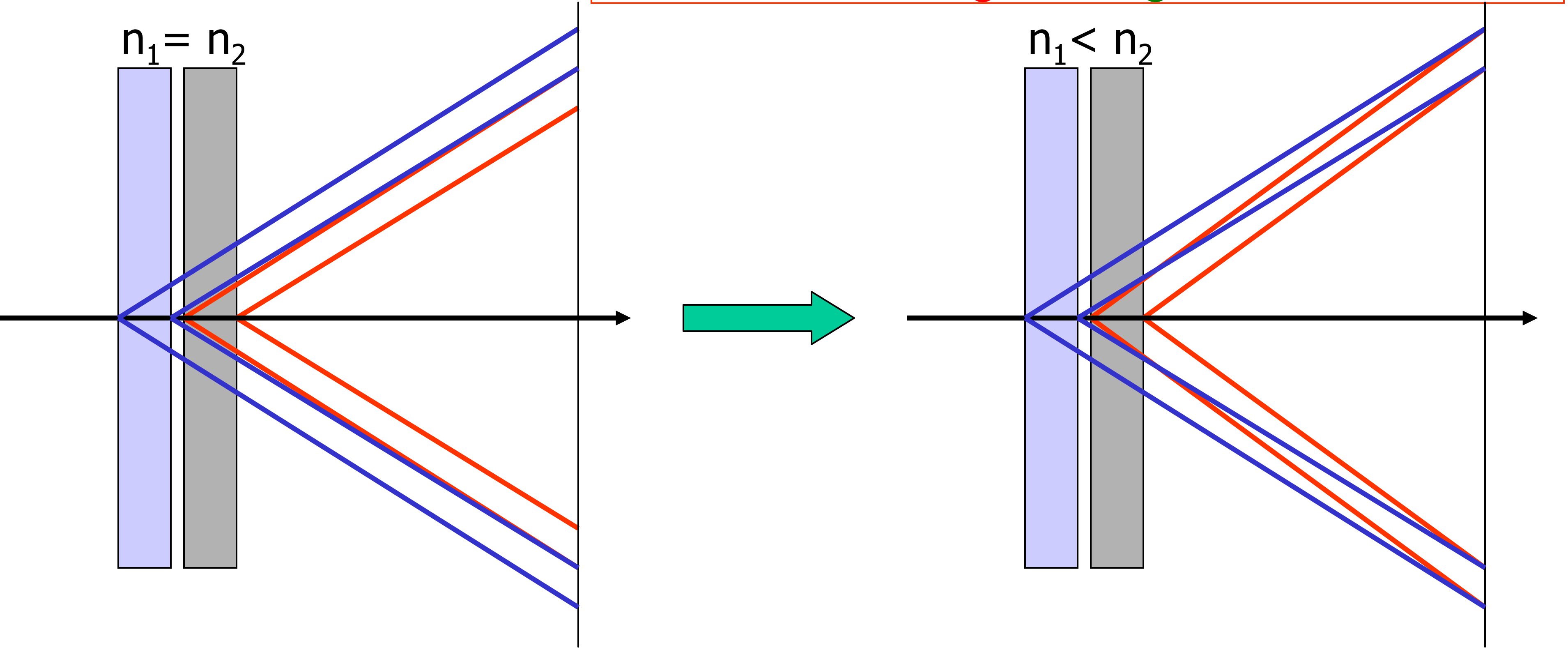
→ Number of photons has to be increased.

Radiator with multiple refractive indices

How to increase the number of photons without degrading the resolution?

normal

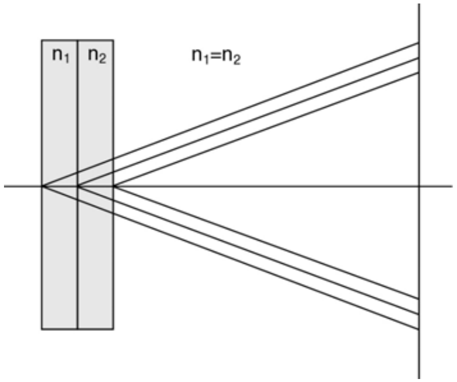
→ stack two tiles with different refractive indices: "focusing" configuration

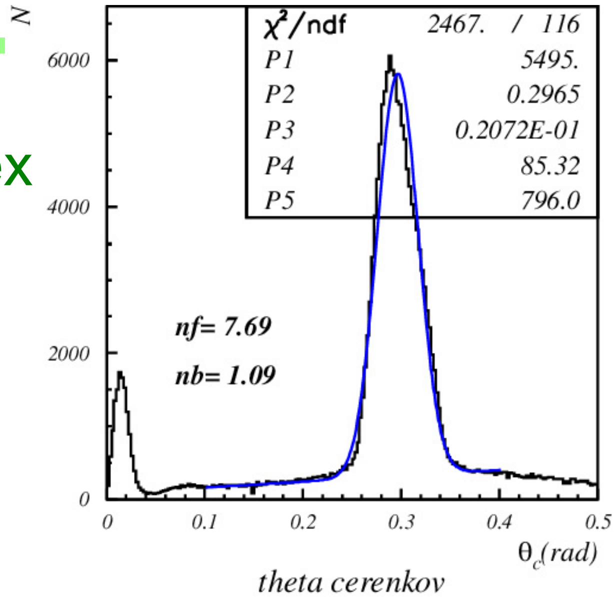


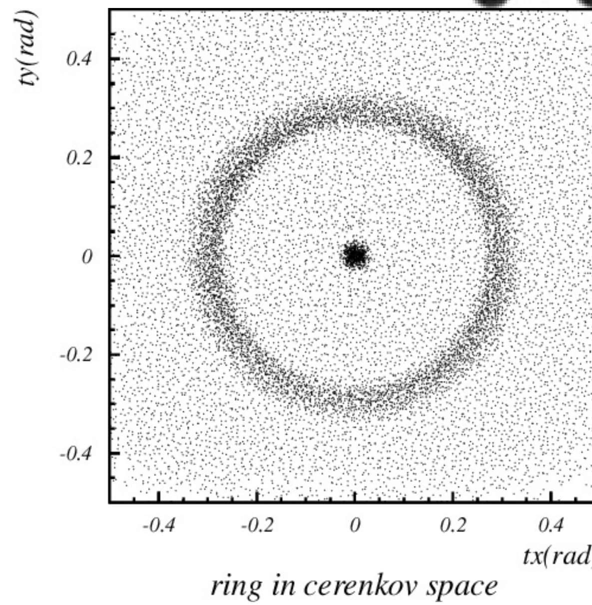
→ focusing radiator

Focusing configuration – data

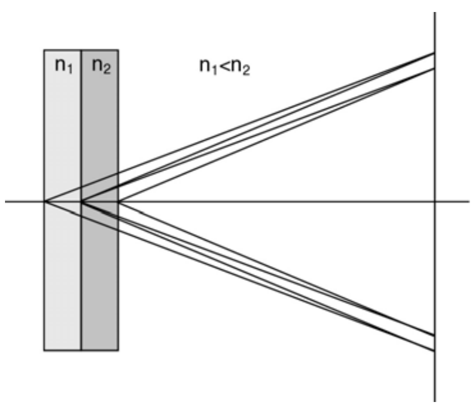
4cm aerogel single index

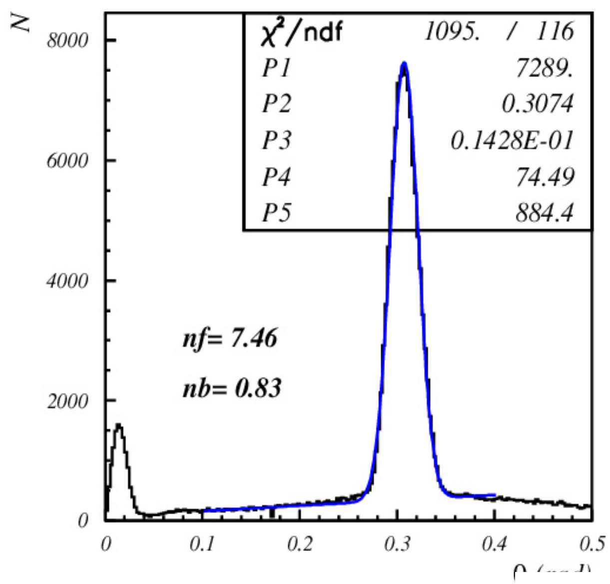


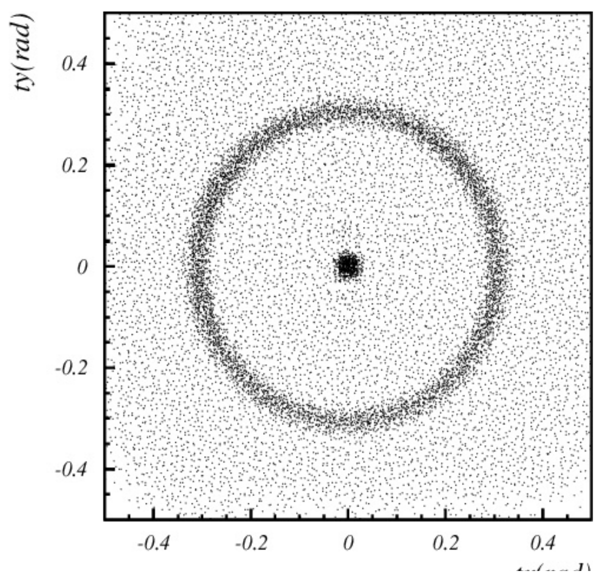




2+2cm aerogel







→NIM A548 (2005) 383