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

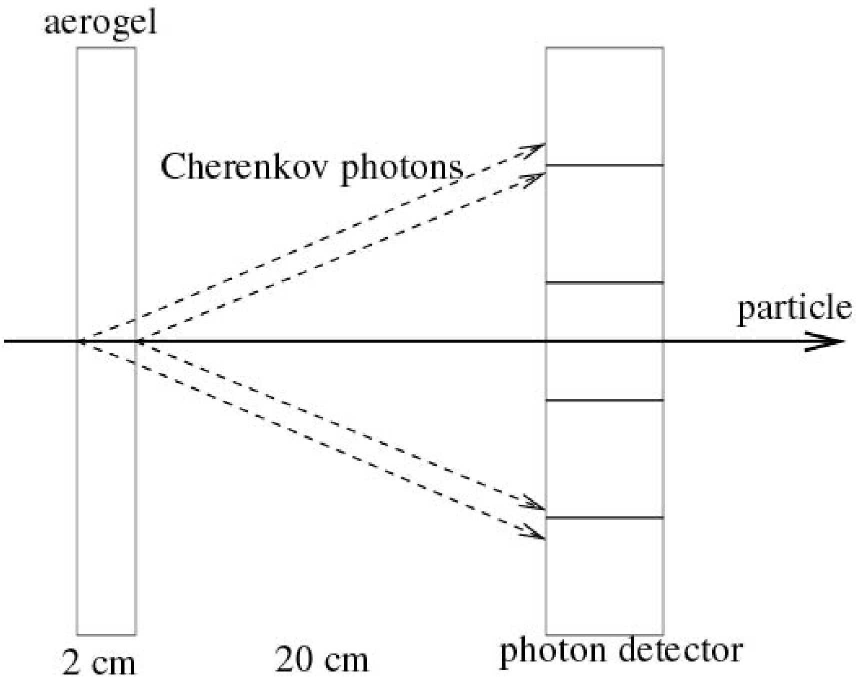
SiPMs for PET

Summary

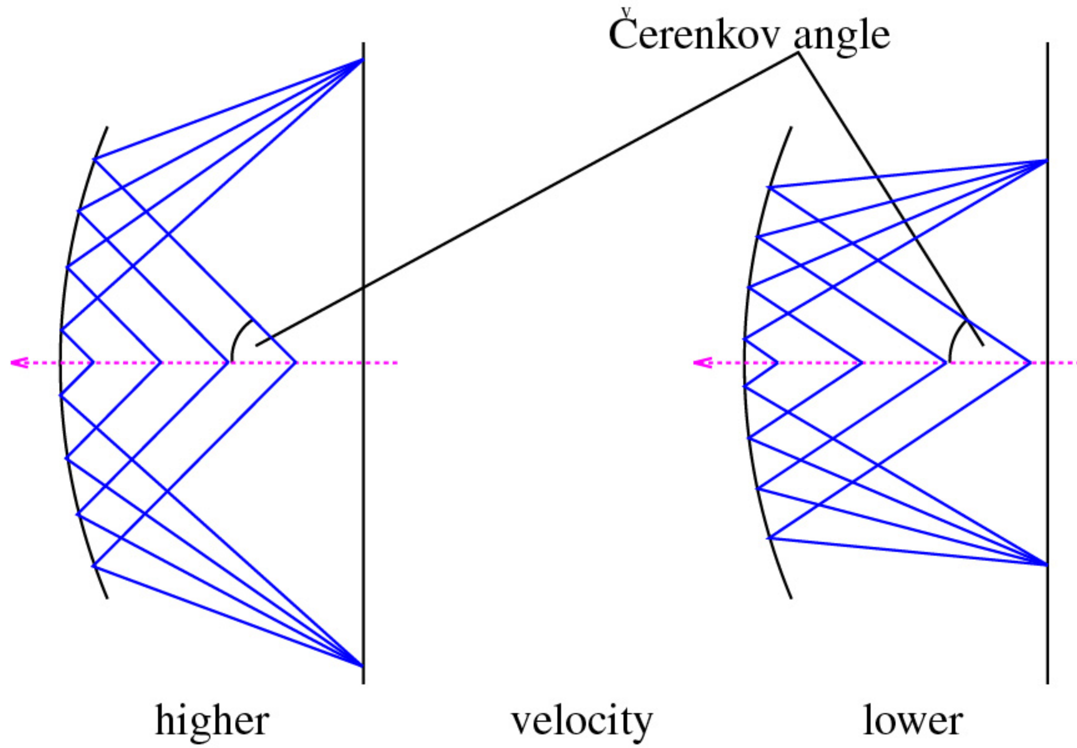
Measuring Cherenkov angle

Idea: transform the direction into a coordinate → ring on the detection plane

→ Ring Imaging CHerenkov



Proximity focusing RICH



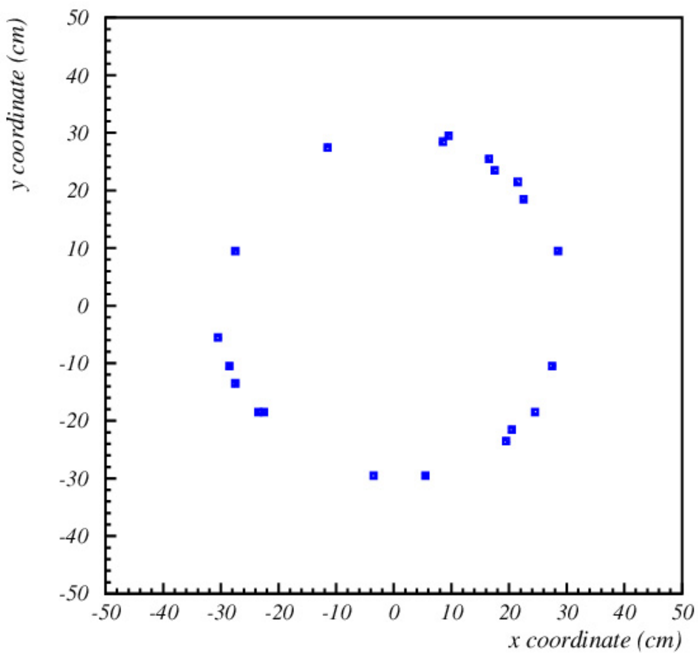
RICH with a focusing mirror

Photon detection in RICH counters

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

→ detection of single photons with

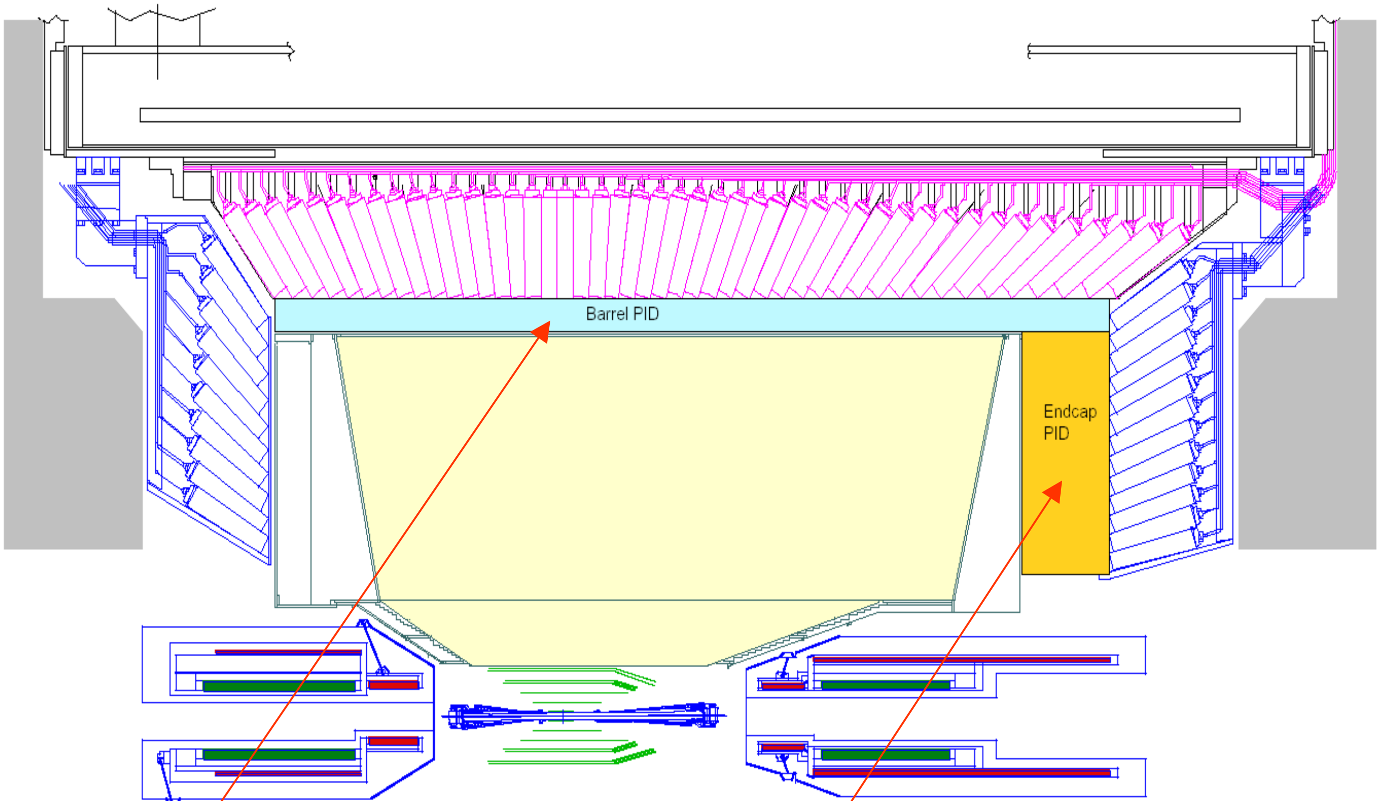
- sufficient spatial resolution
- high efficiency and good signal-to-noise ratio
- over a large area (square meters)



Special requirements:

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

Belle upgrade – side view

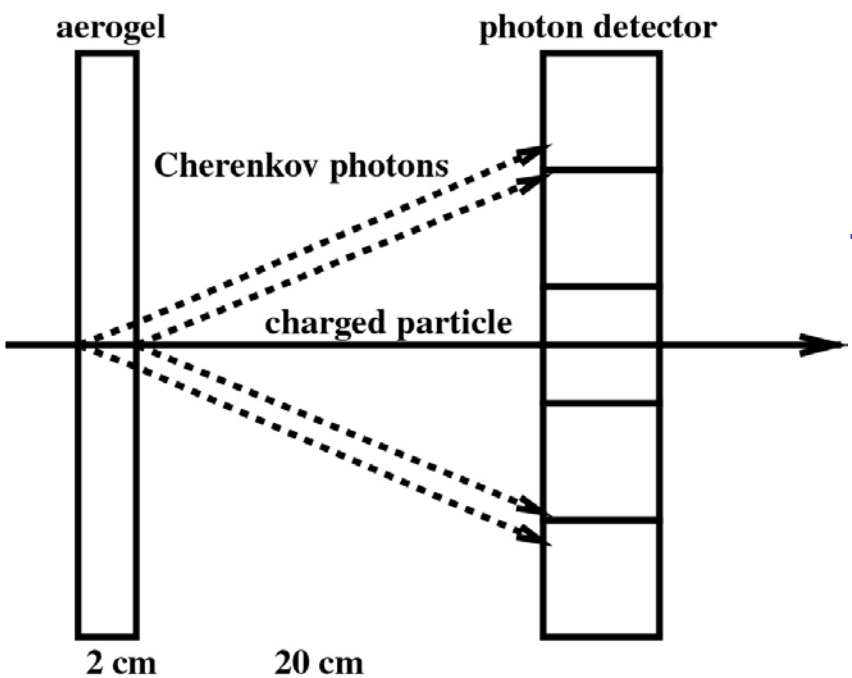


Two new particle ID devices, both RICHes:

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

Endcap: proximity focusing RICH

Endcap: Proximity focusing RICH



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

For single photons: $\delta\theta_c$(meas.)=σ_0 ~ 14 mrad,
typical value for a 20mm thick radiator and 6mm PMT pad size

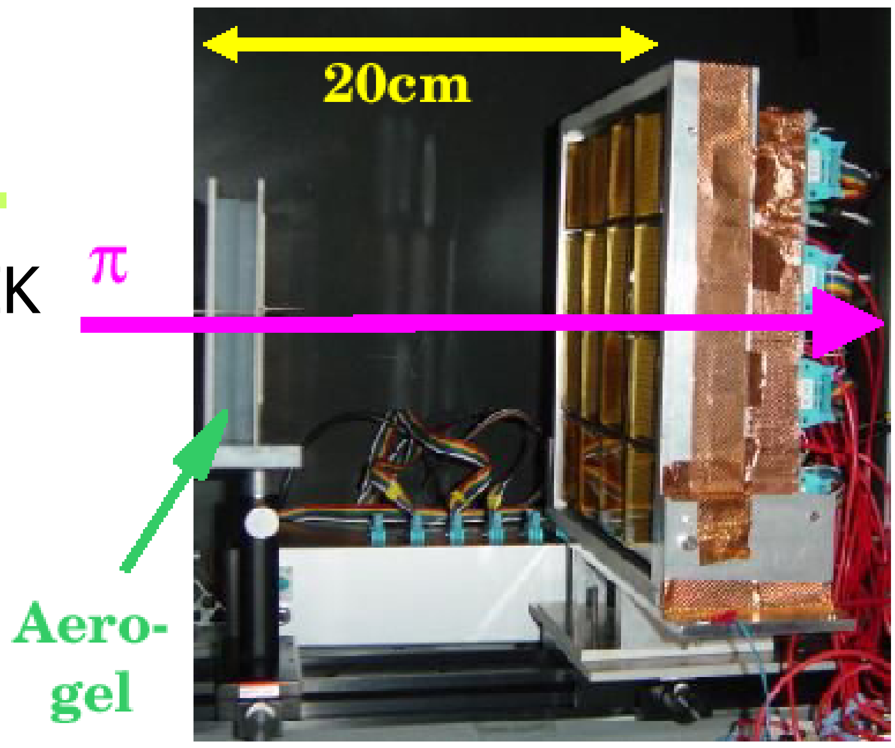
Per track: $$\sigma_{track} = \frac{\sigma_0}{\sqrt{N_{pe}}}$$

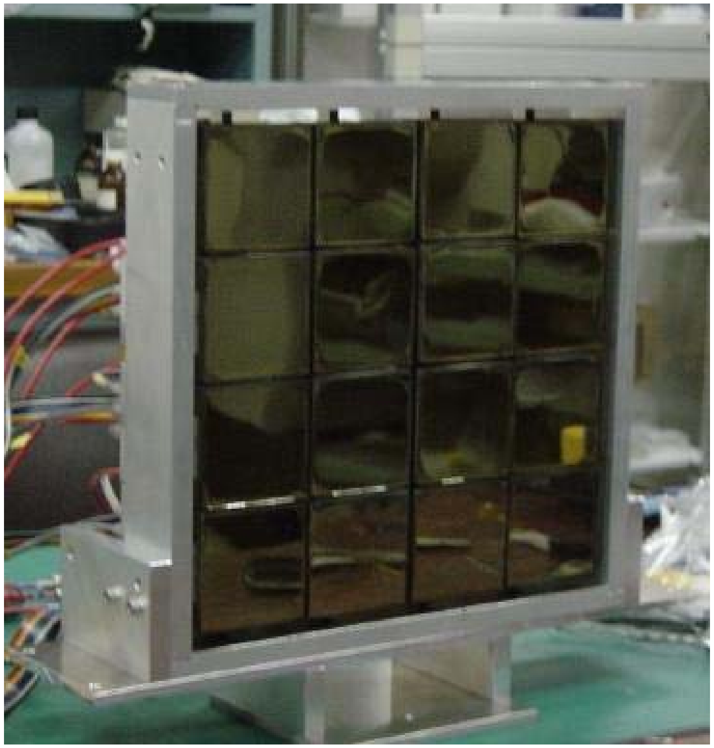
Separation: $[\theta_c(\pi)-\theta_c(K)]/\sigma_{track}$

→ 5σ separation with N_{pe}~10

Beam tests

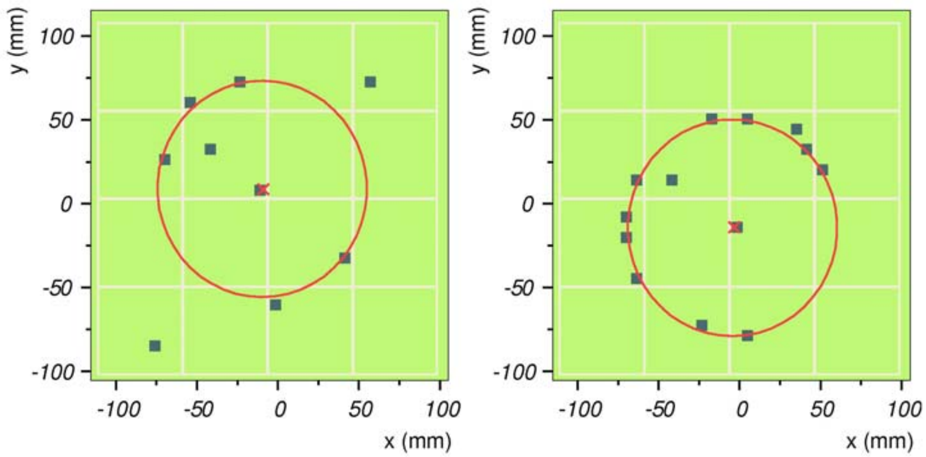
pion beam (π2) at KEK





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

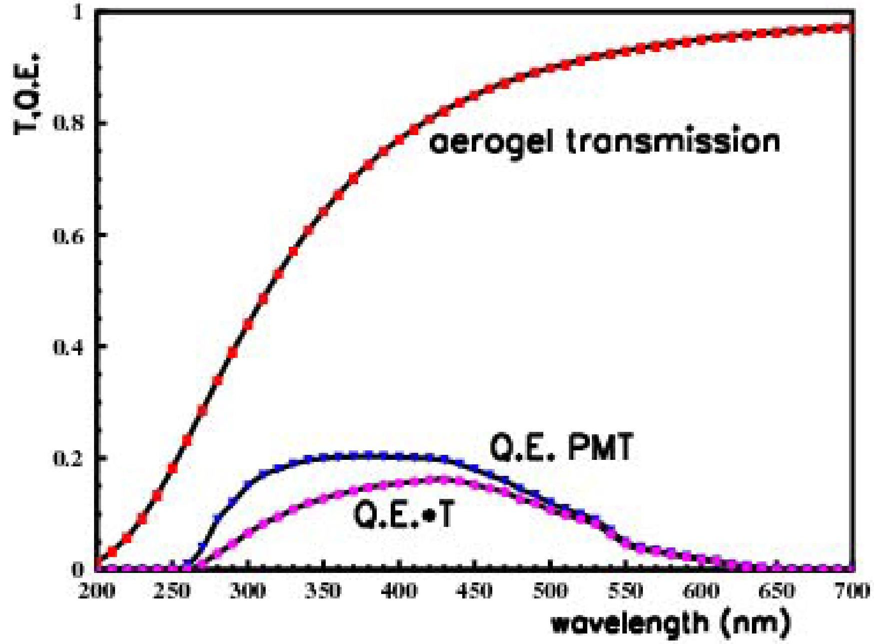
Clear rings, little background



Photon detectors for the aerogel RICH

Needs:

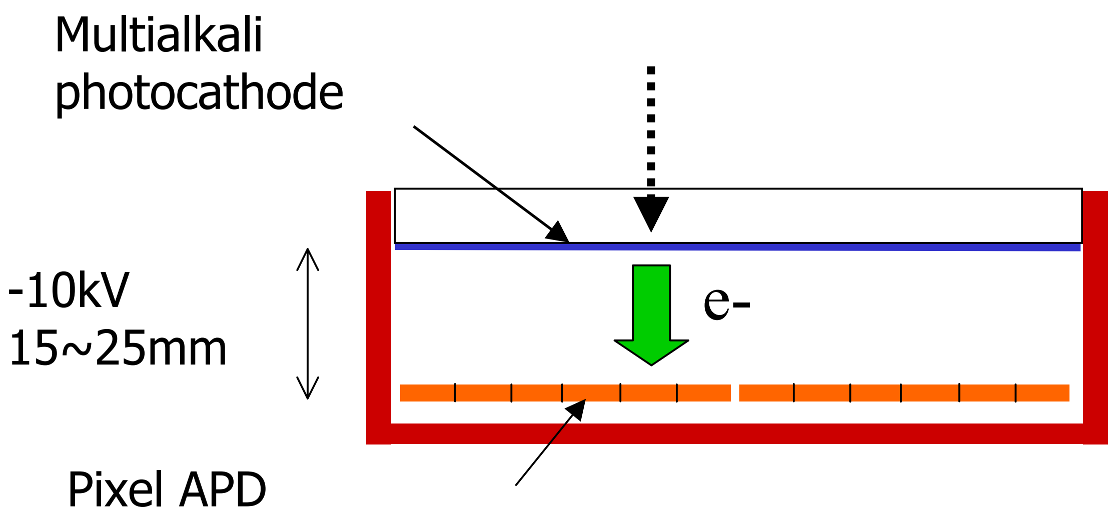
- Operation in high magnetic field (1.5T)
- High efficiency at λ>350nm
- Pad size ~5-6mm

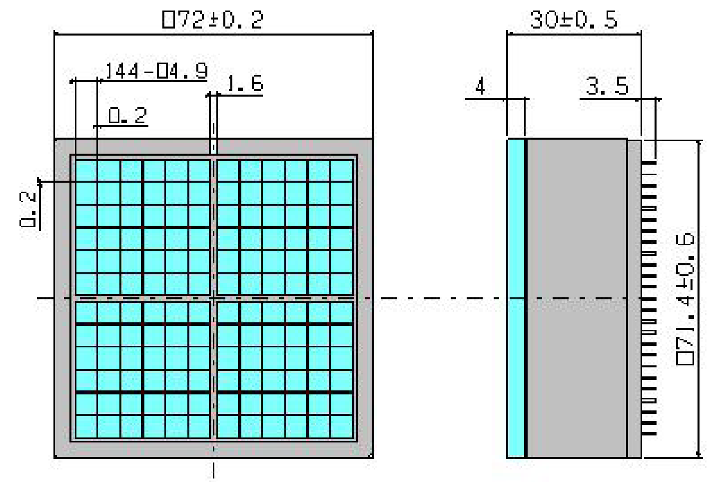


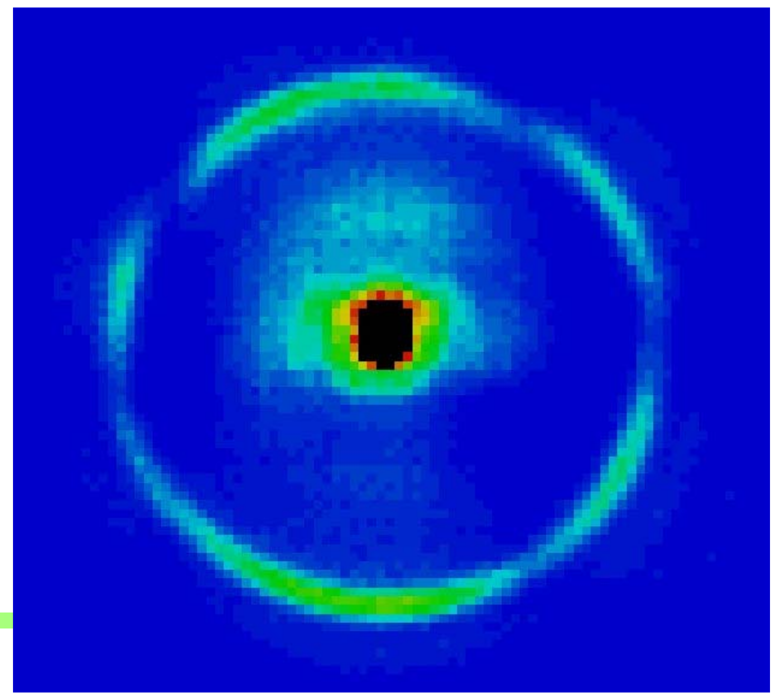
Candidates:

- 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.

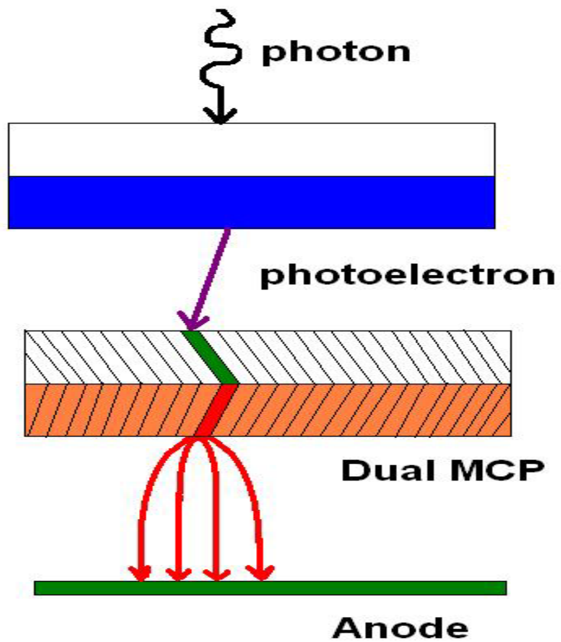
Long development time, now working test samples.

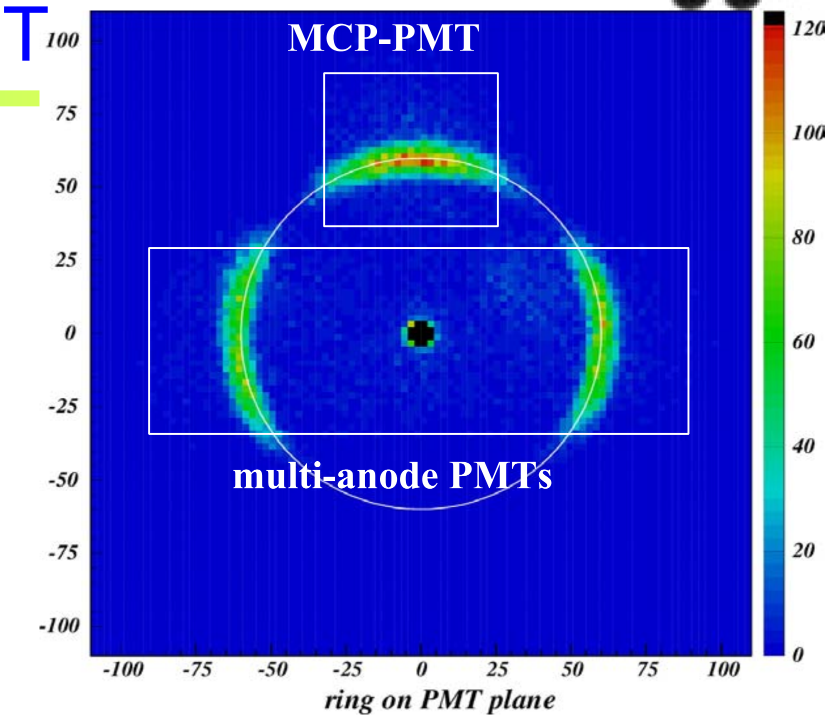
First beam test results →

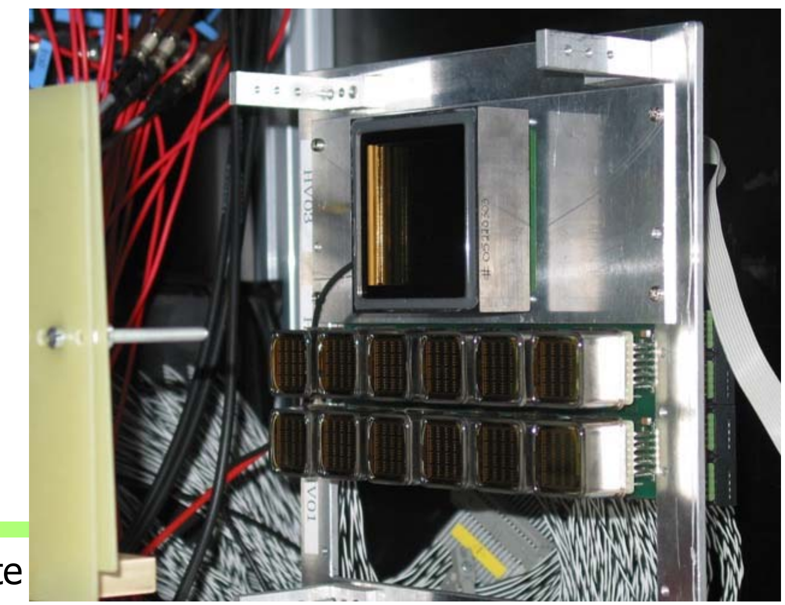
→NIMA, RICH07 proc.

Photon detector candidate: BURLE/Photonis MCP-PMT

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







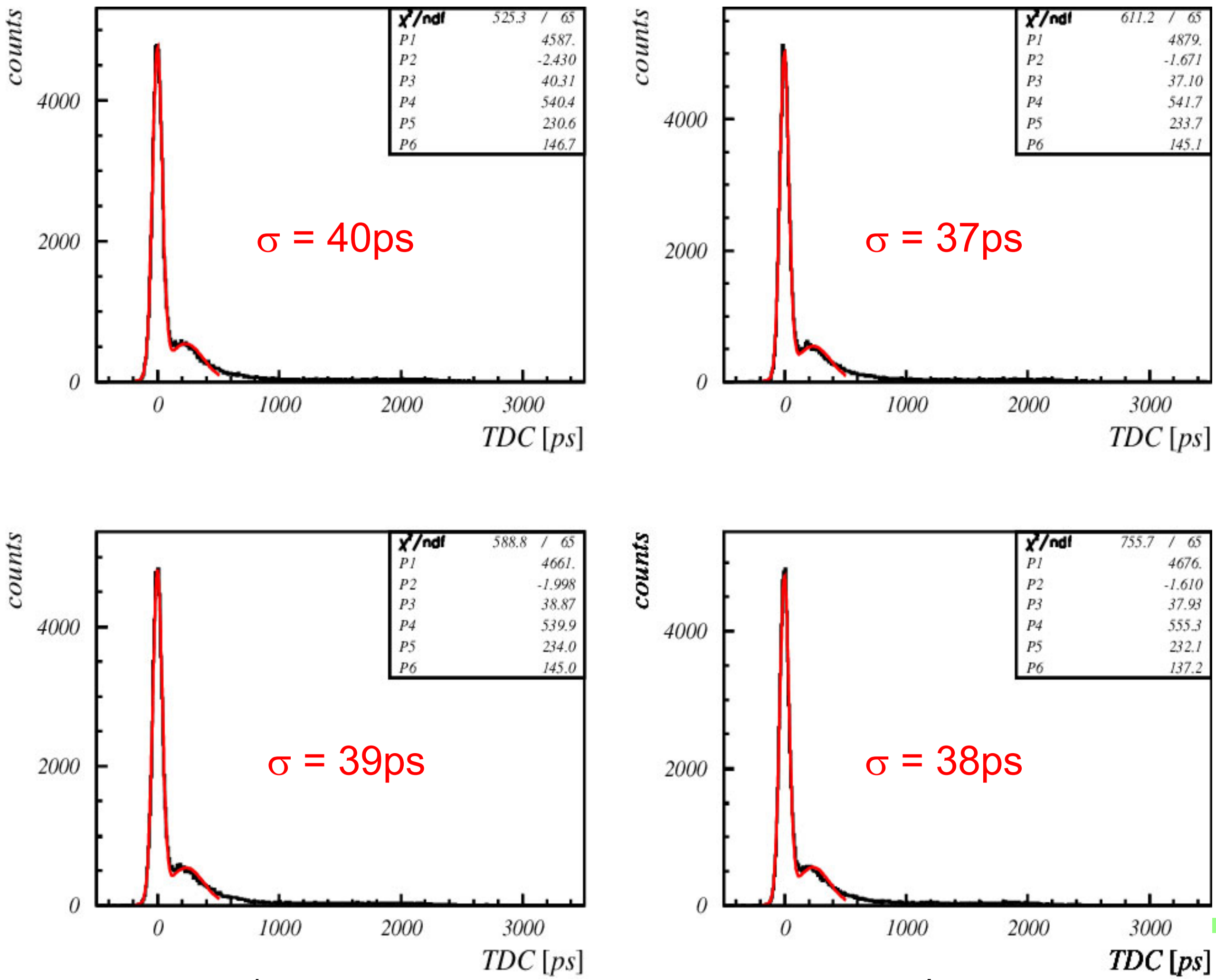
→good performance in beam and bench tests, NIMA567 (2006) 124

→ 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 <u>single photon pulse height</u>

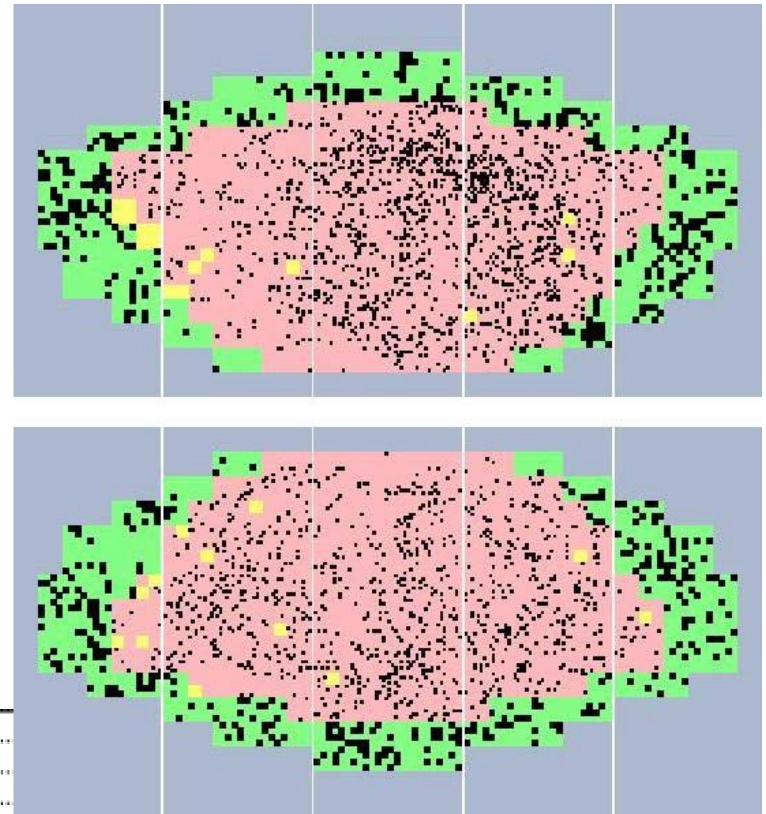
-radiation hardness

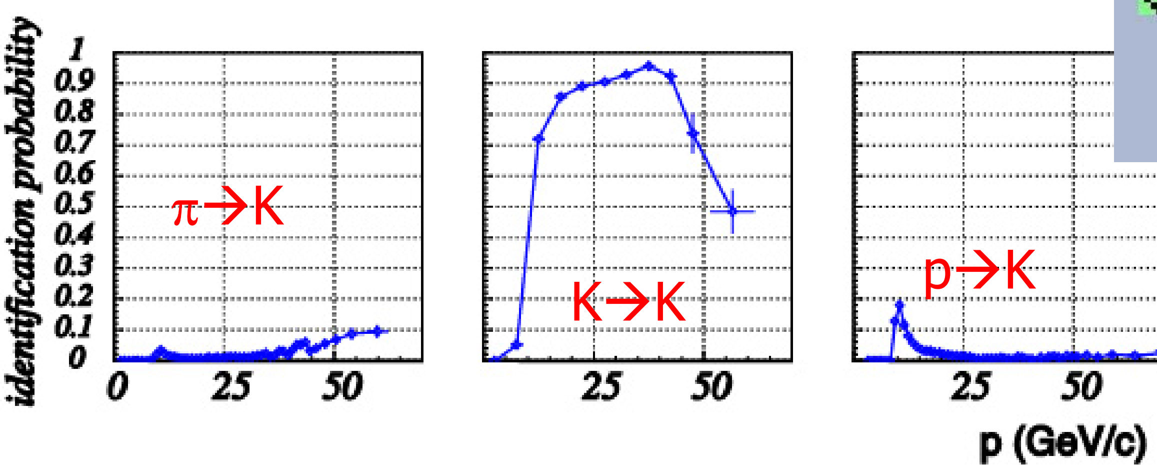
Can such a detector work?

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

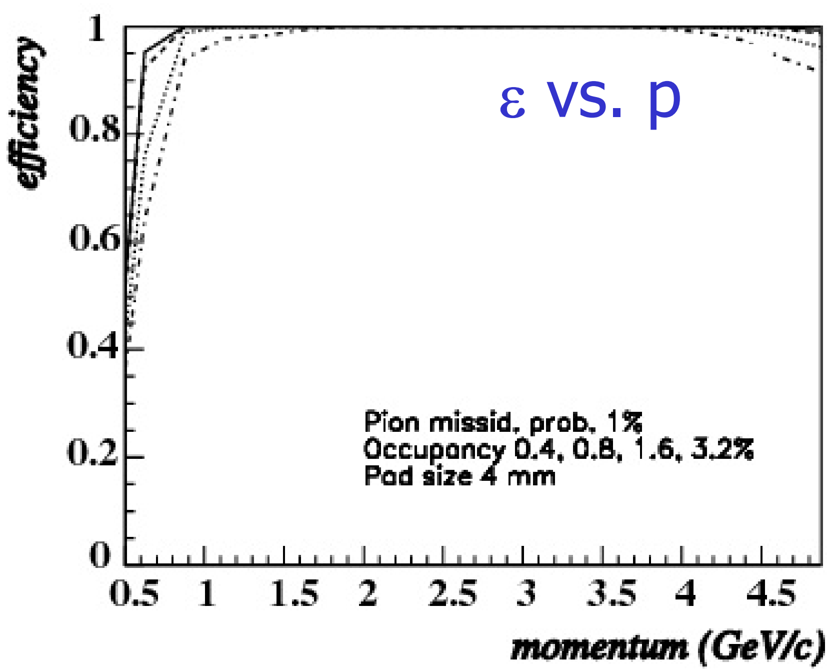


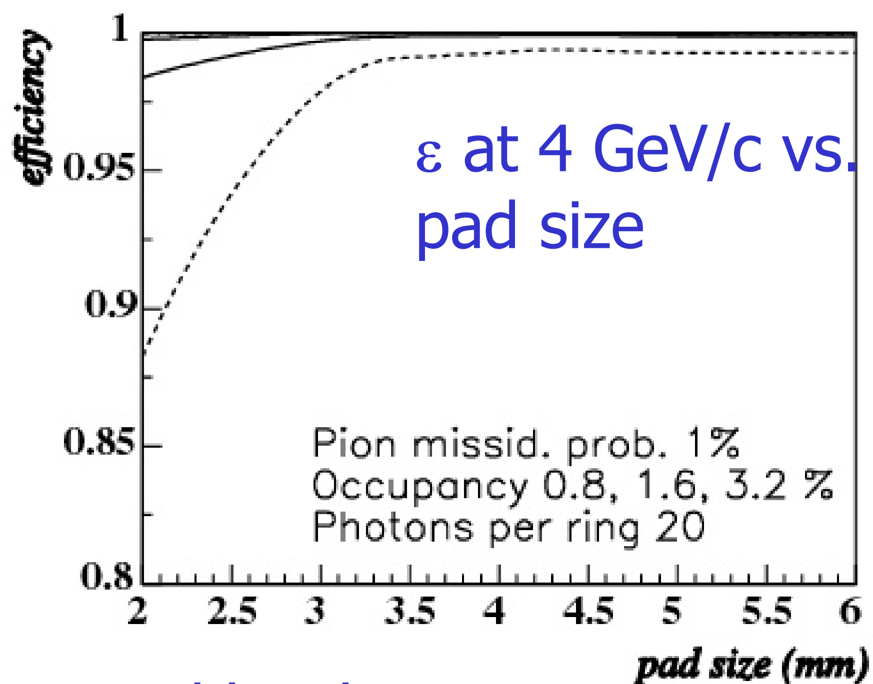


Can such a detector work?

MC simulation of the counter response: assume 1mm² active area SiPMs with 0.8 MHz (1.6 MHz, 3.2 MHz) dark count rate, 10ns time window

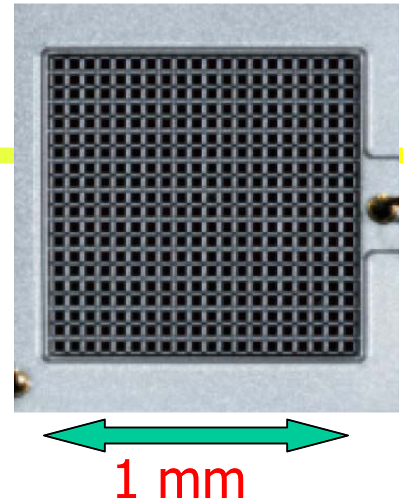
K identification efficiency at 1% π missid. probability





For different background levels

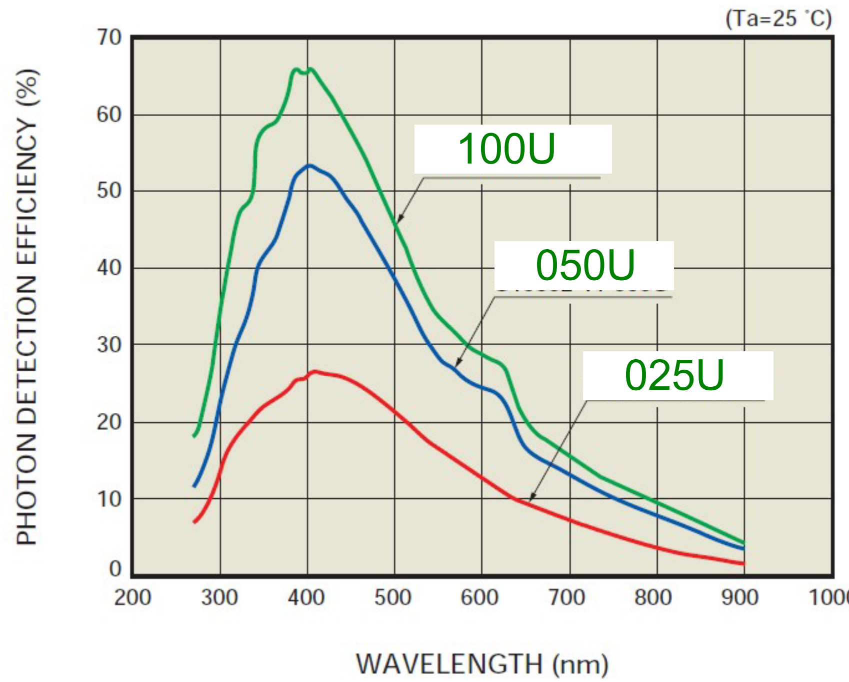
SiPMs as photon detectors?



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)

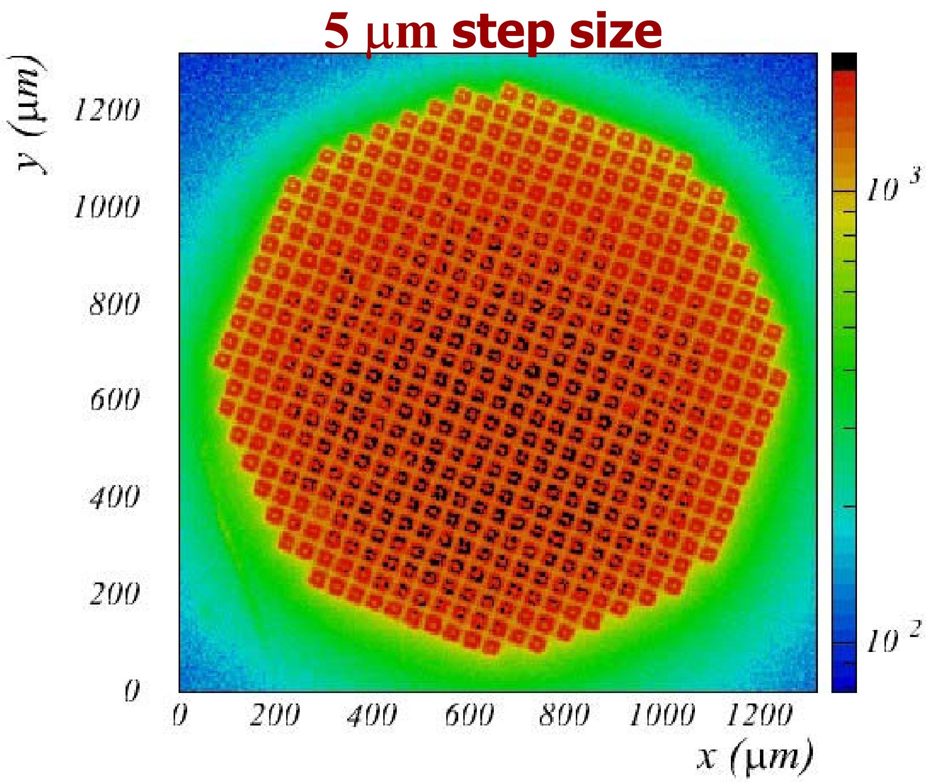


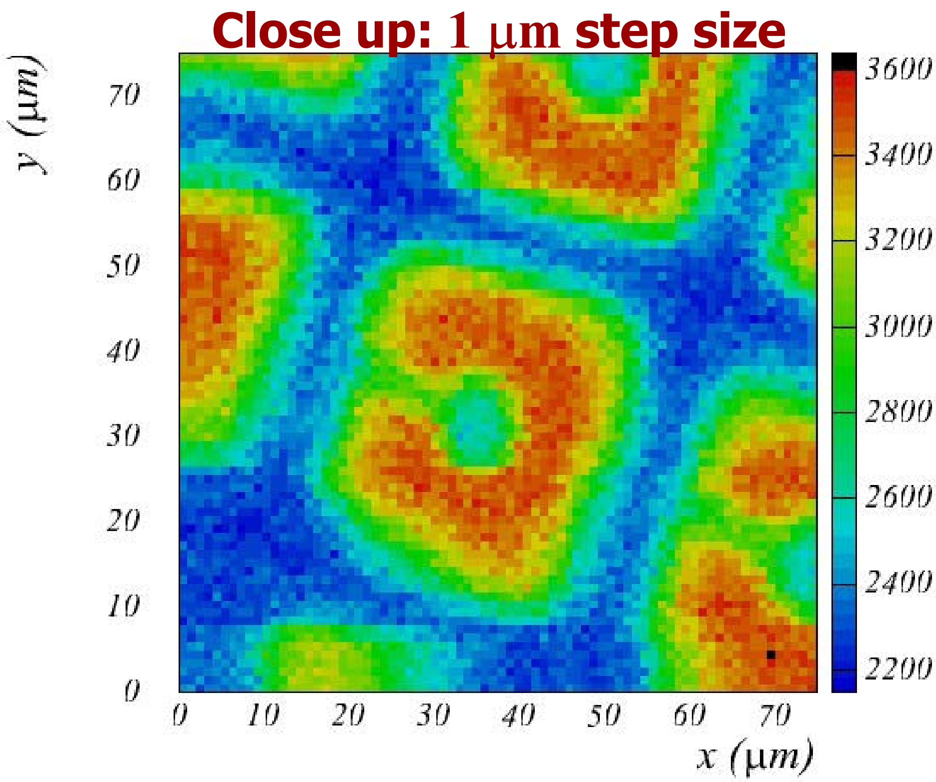
Hamamatsu MPPC: S10362-11

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

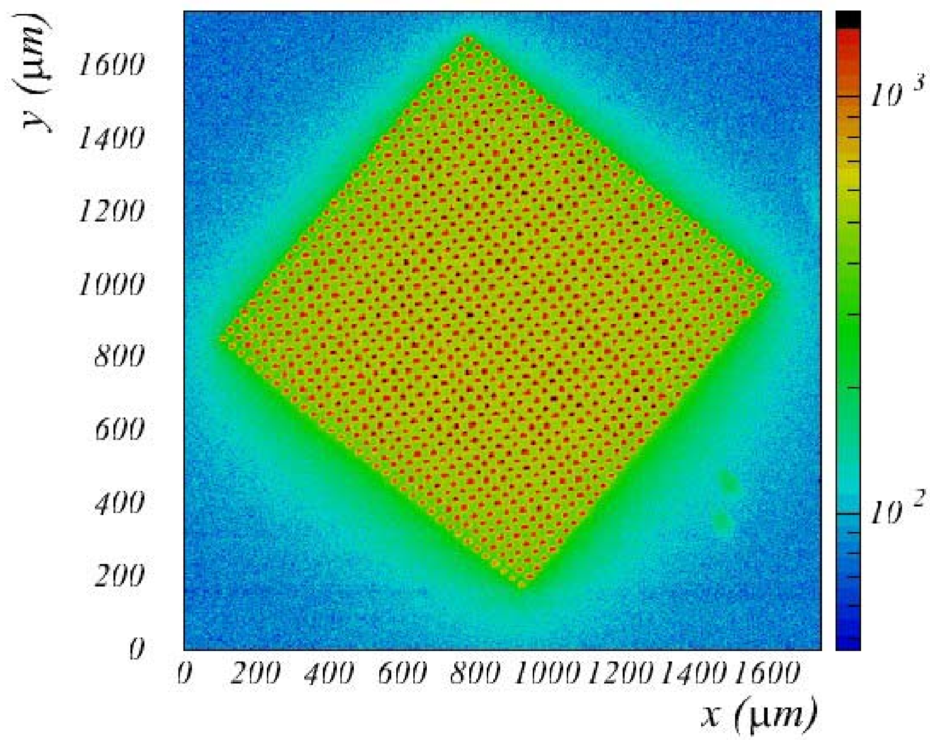
S137 (CPTA/Photonique)

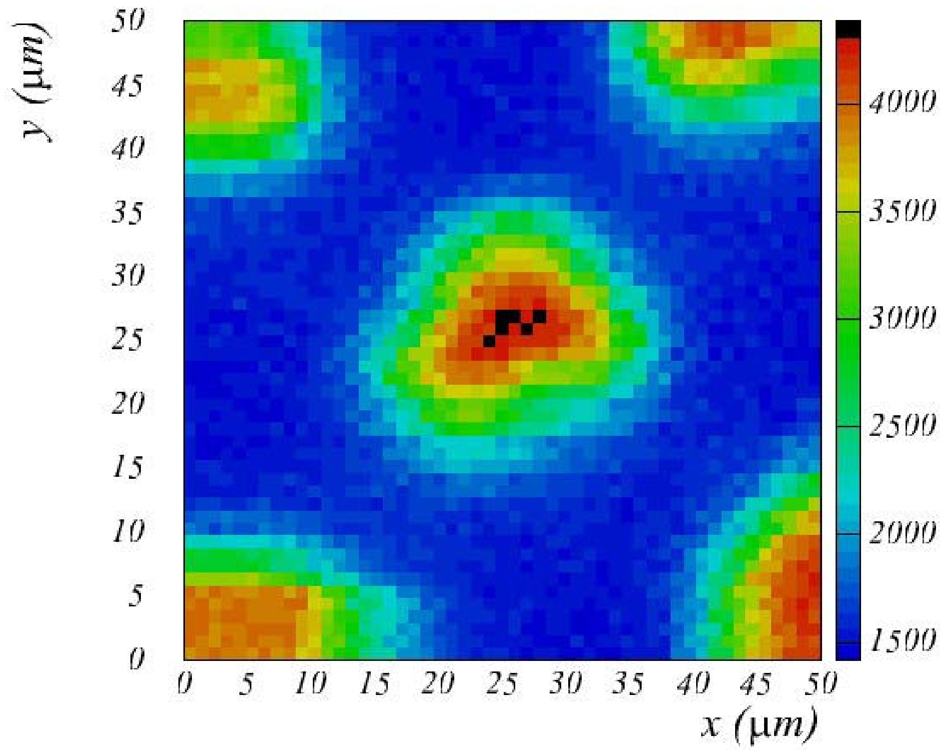




Surface sensitivity for single photons 2

E407 (Pulsar/MEPHI)

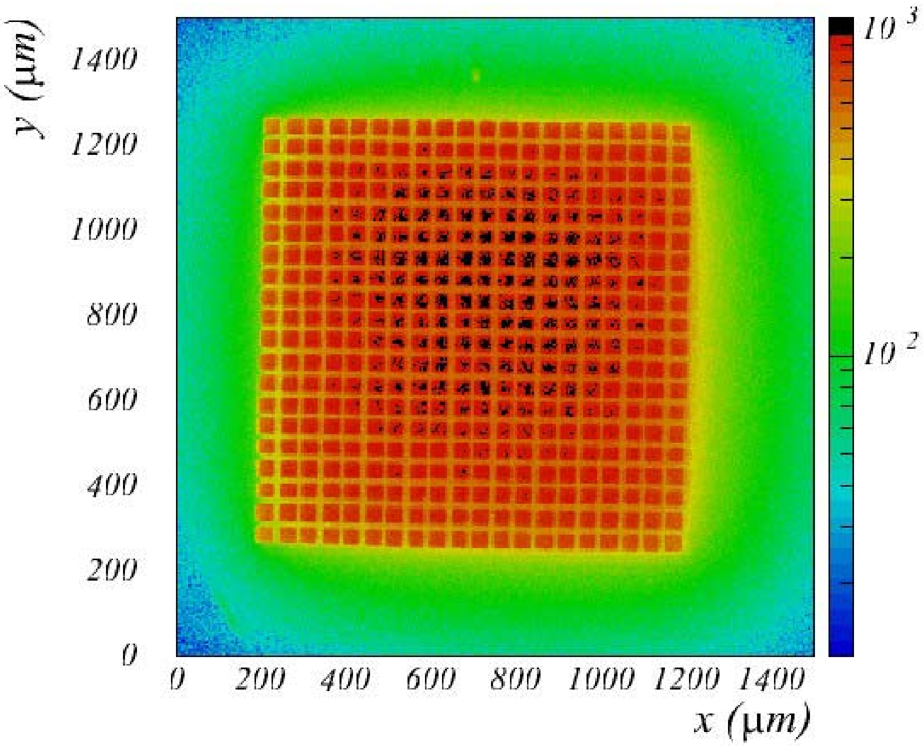




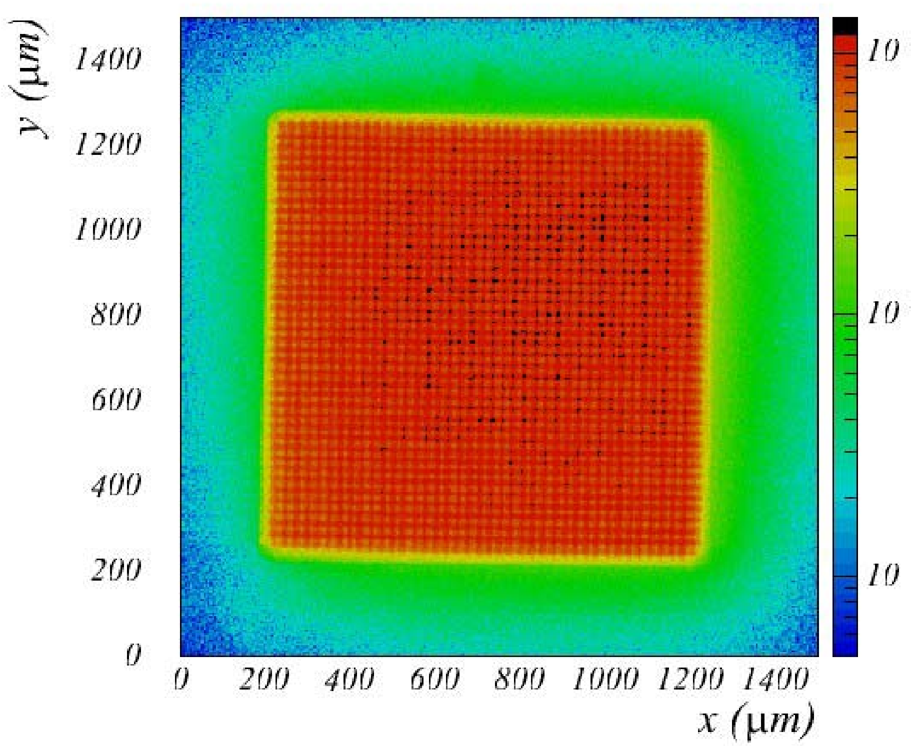
Surface sensitivity for single photons 3

Hamamatsu MPPCs

H050C



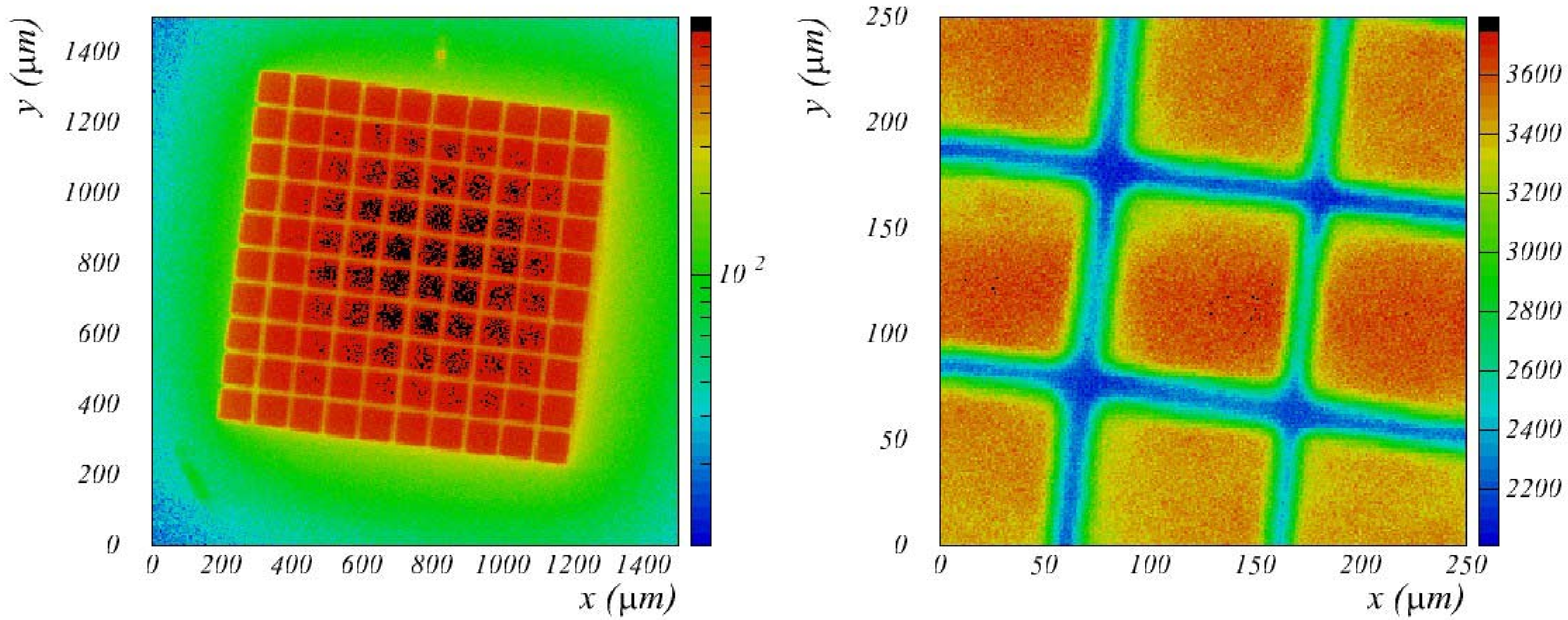
H025C



Surface sensitivity for single photons 4

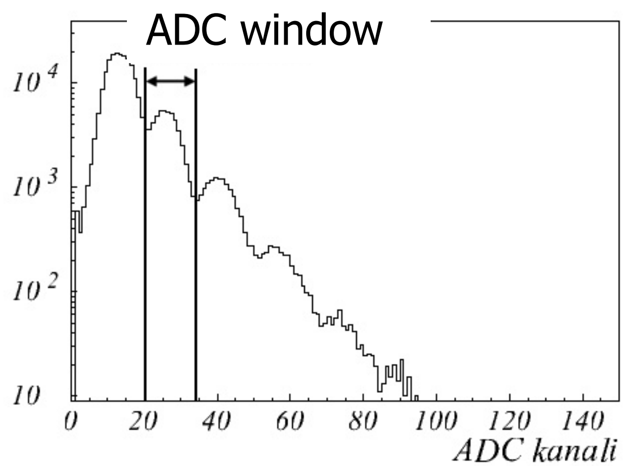
Hamamatsu MPPCs

H100C

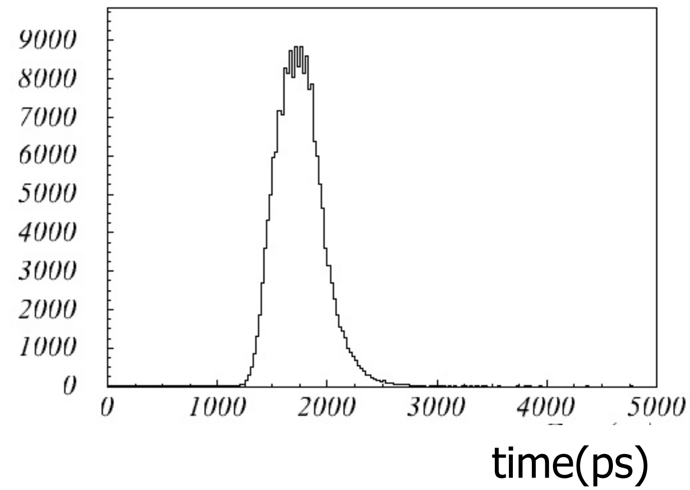


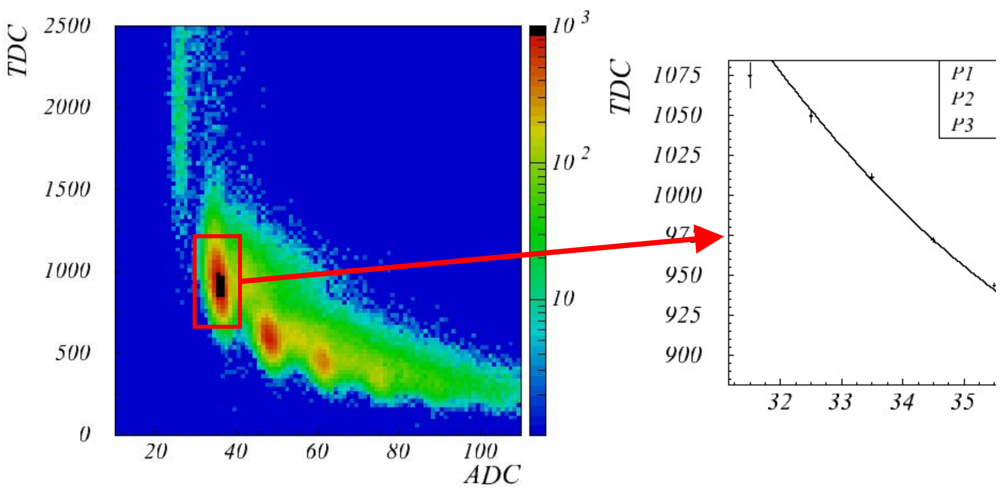
Time resolution: time walk correction

<< 1 photon

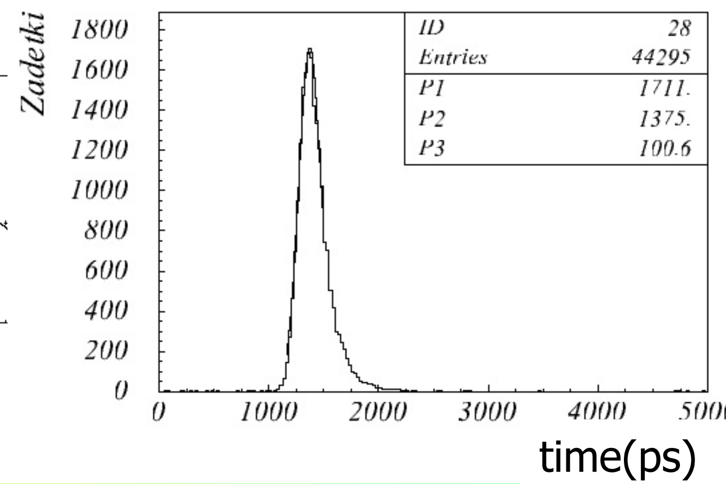


uncorrected TDC

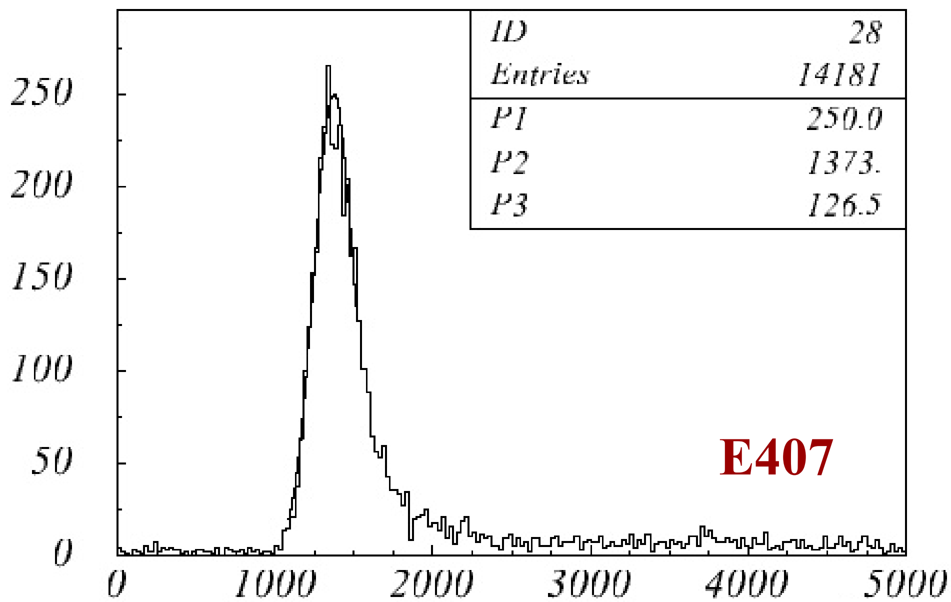


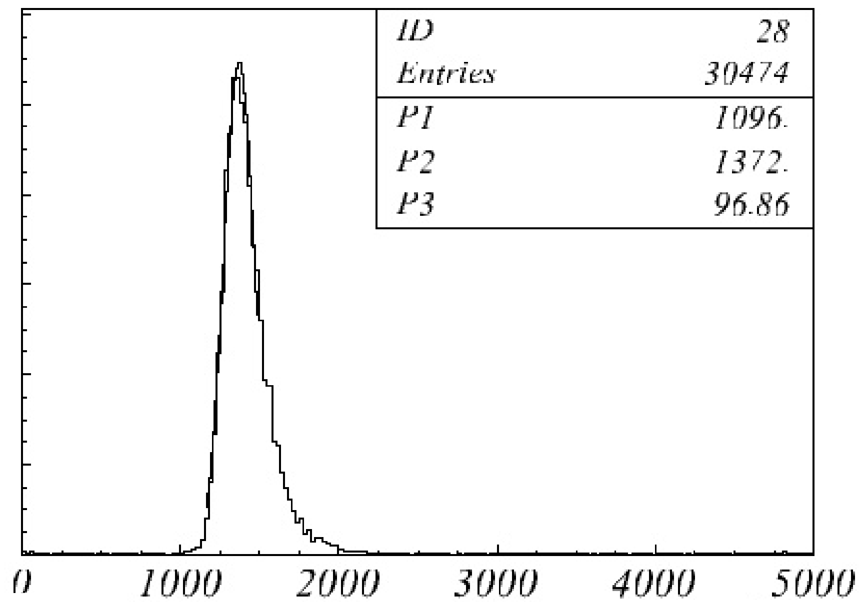


corrected TDC



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

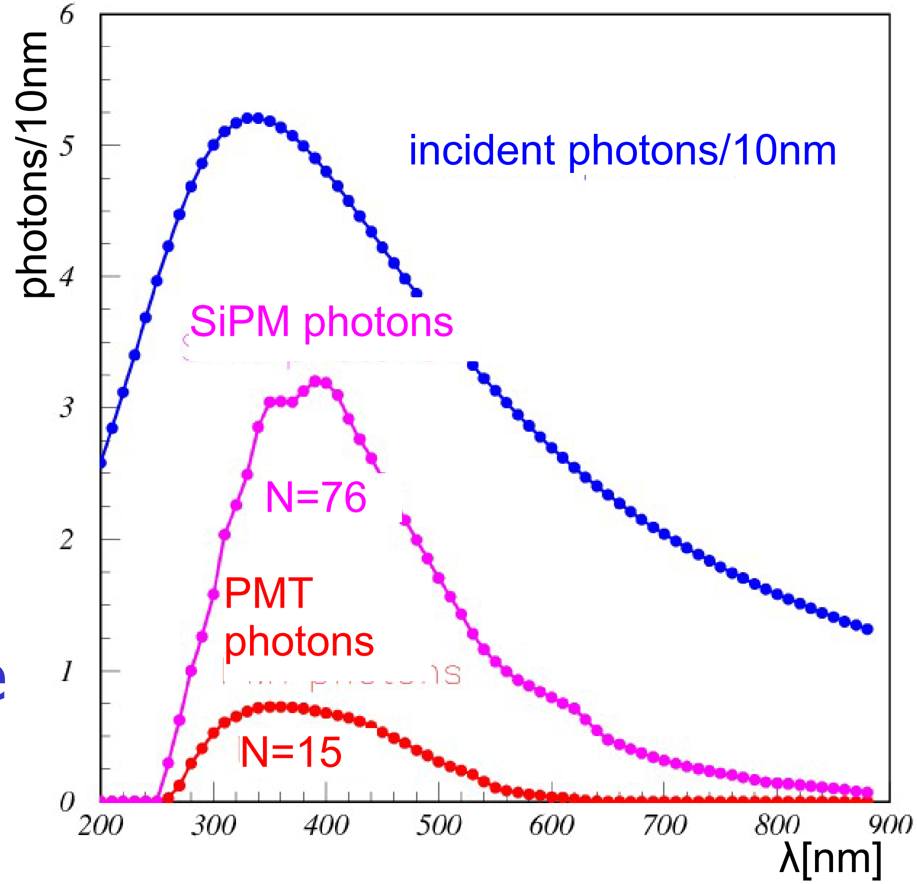
Expected number of photons for aerogel RICH

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

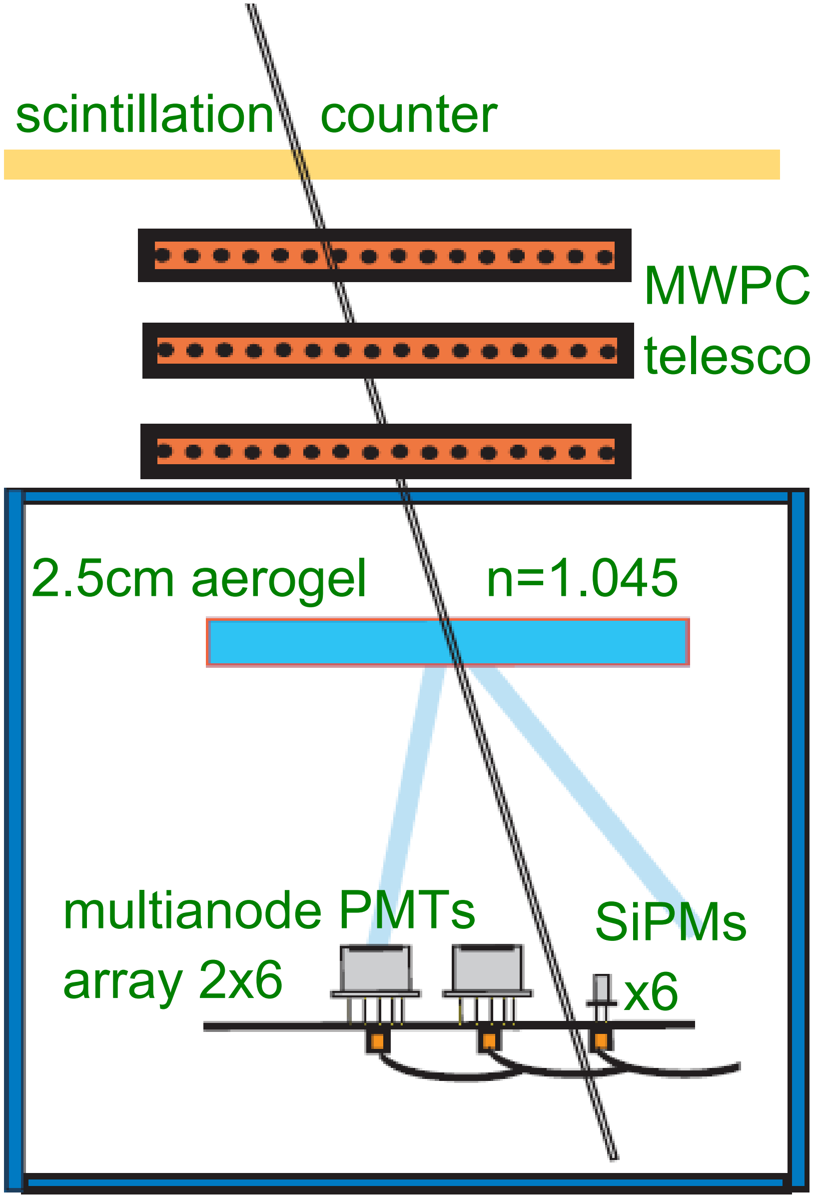
N_{SiPM}/N_{PMT}~5

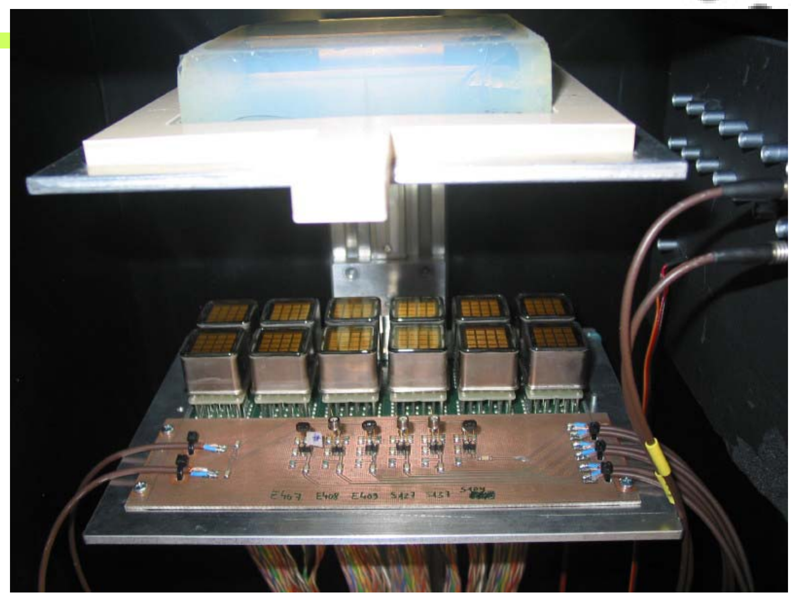
Assuming 100% detector active area

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



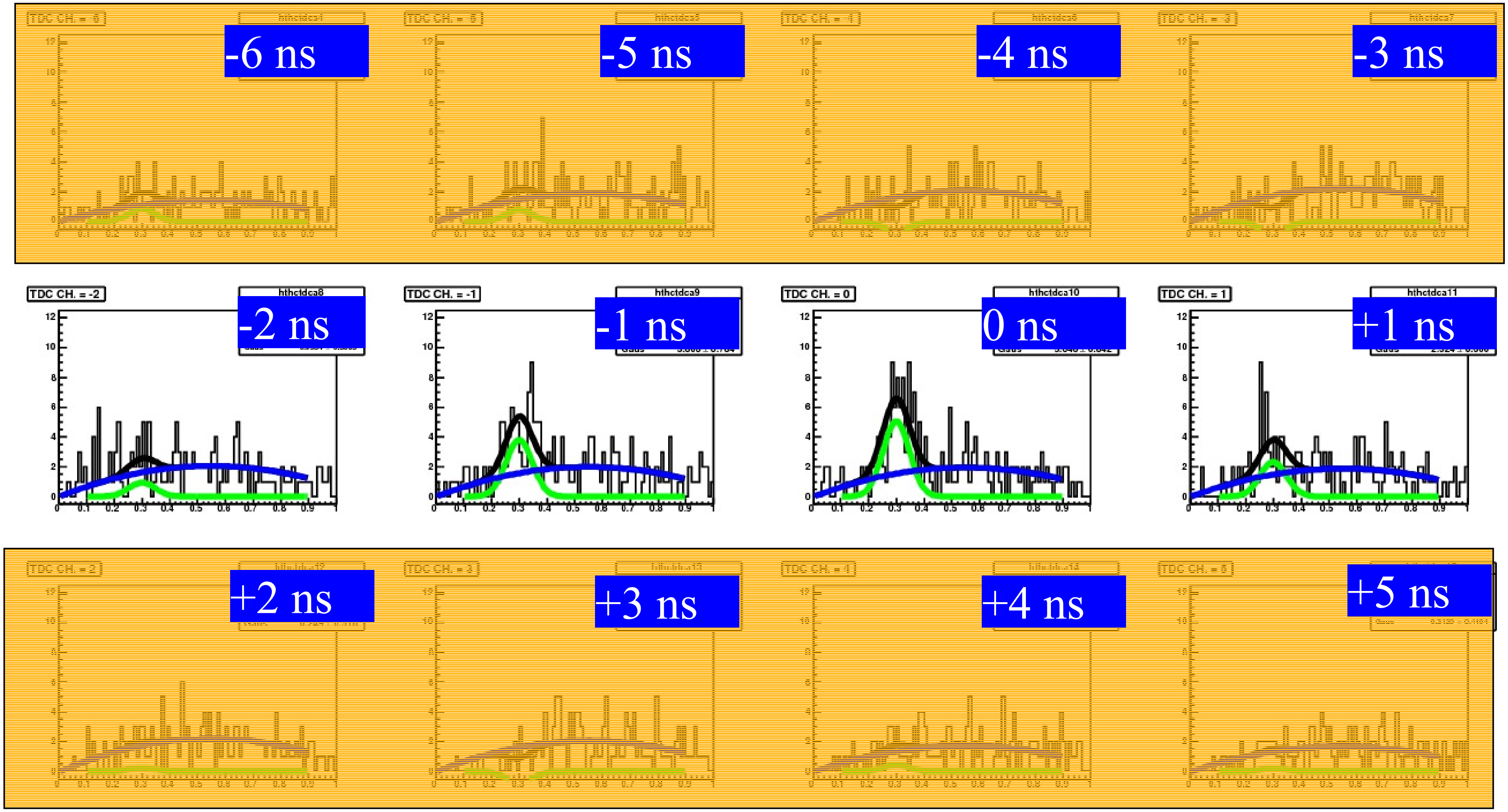


- 6 Hamamatsu SiPMs (=MPPC) of type 100U (10x10 pixels with 100μm pitch), background ~400kHz

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

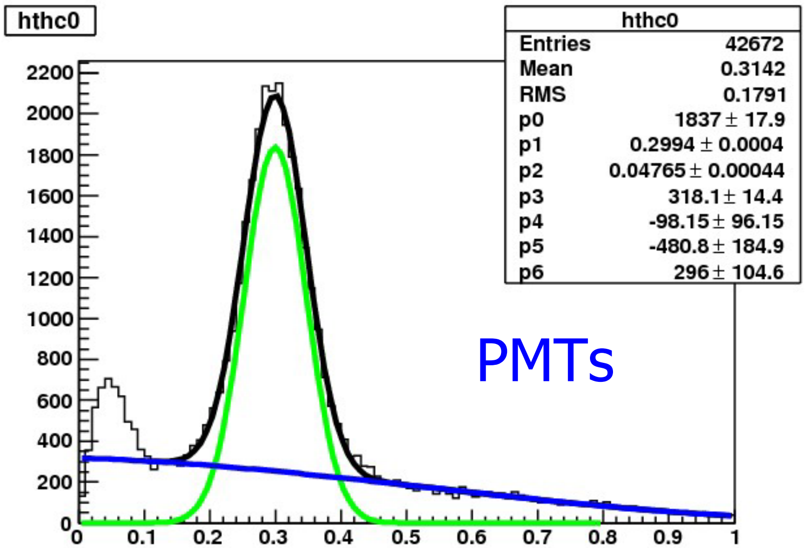
To be published in NIM A in ~3 weeks

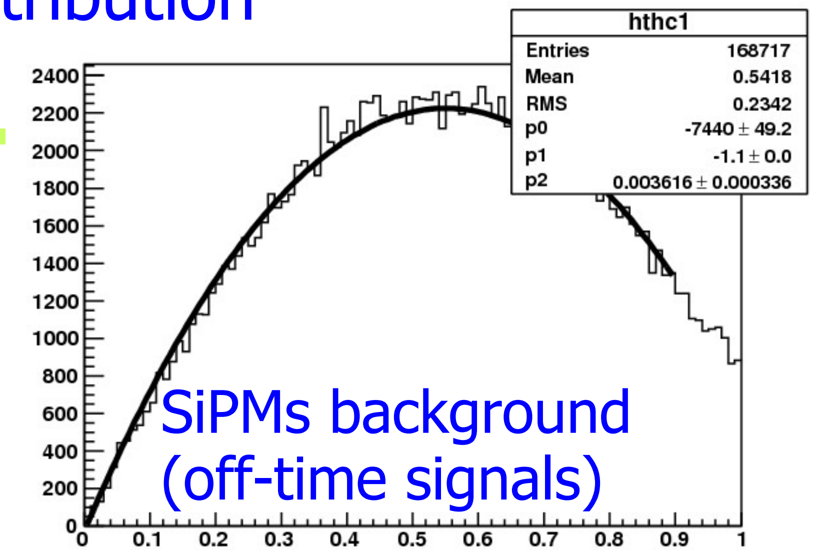
SiPM: Cherenkov angle distributions for 1ns time windows

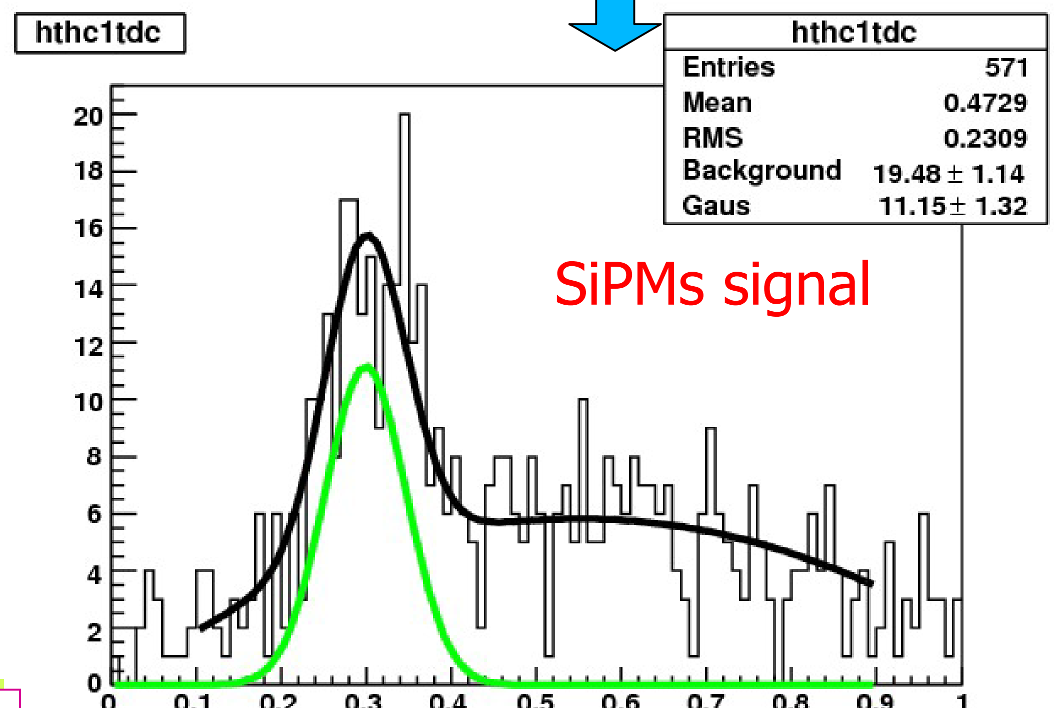


Cherenkov photons appear in the expected time windows →
First Cherenkov photons observed with SiPMs!

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

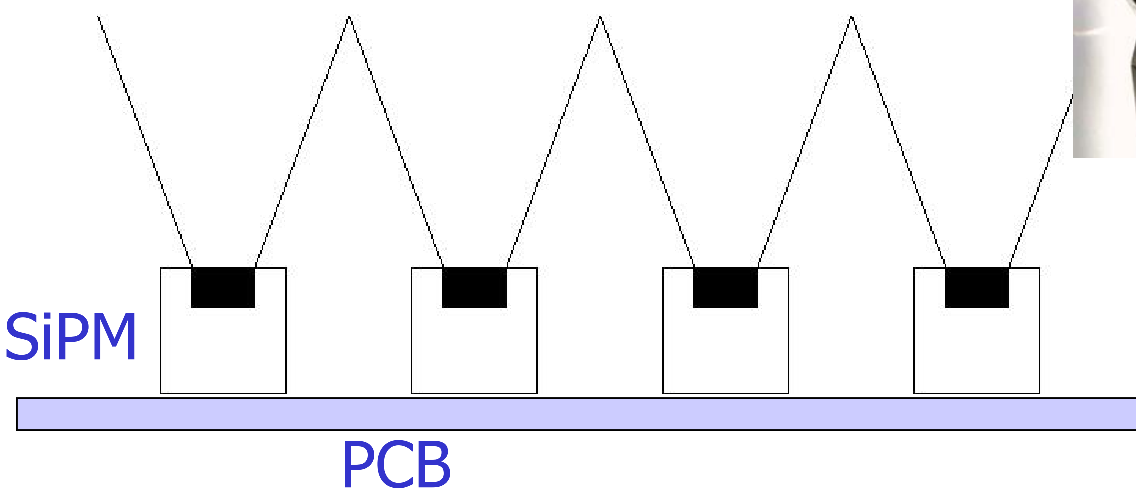
To be published in NIM A in ~3 weeks

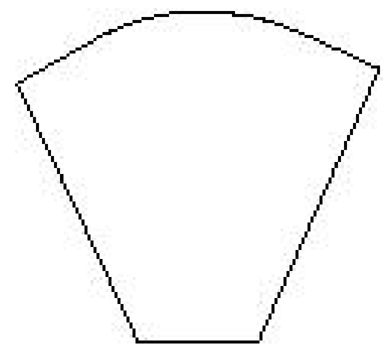
SIPMs: improving signal/noise

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

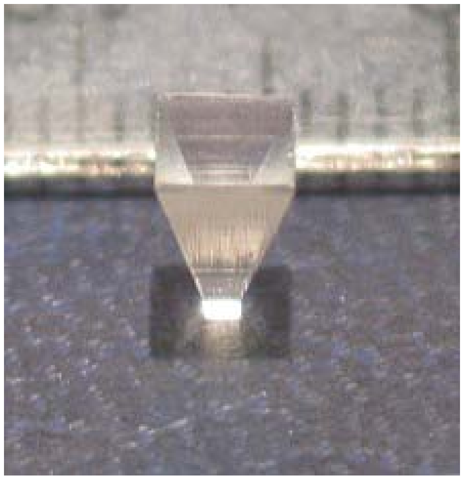


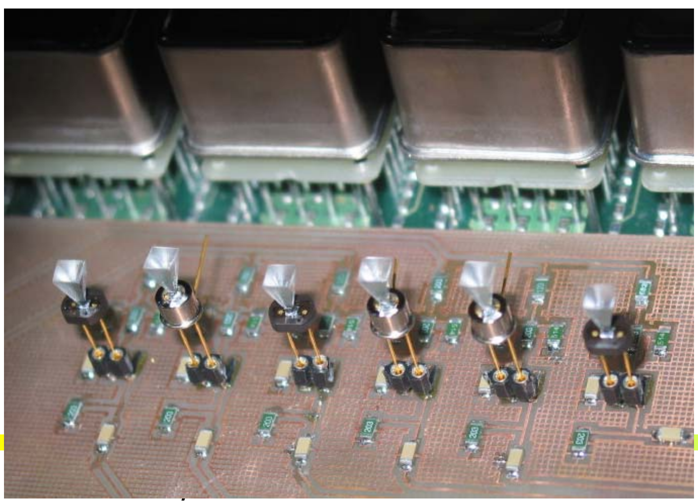


or combine a lens and mirror walls

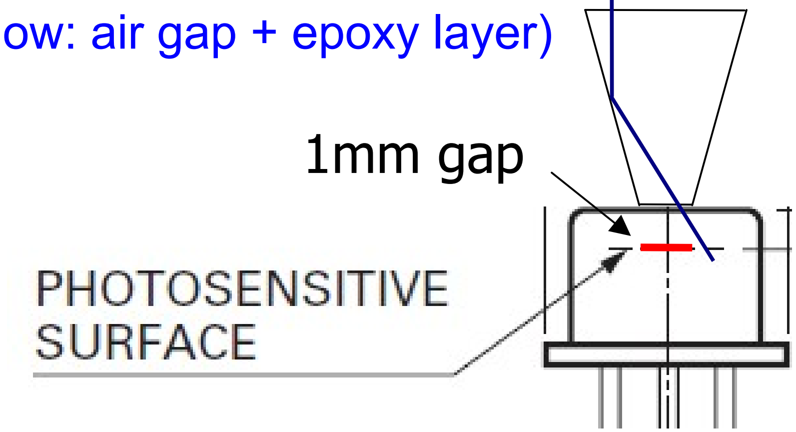
Light collection: improve signal to noise ratio

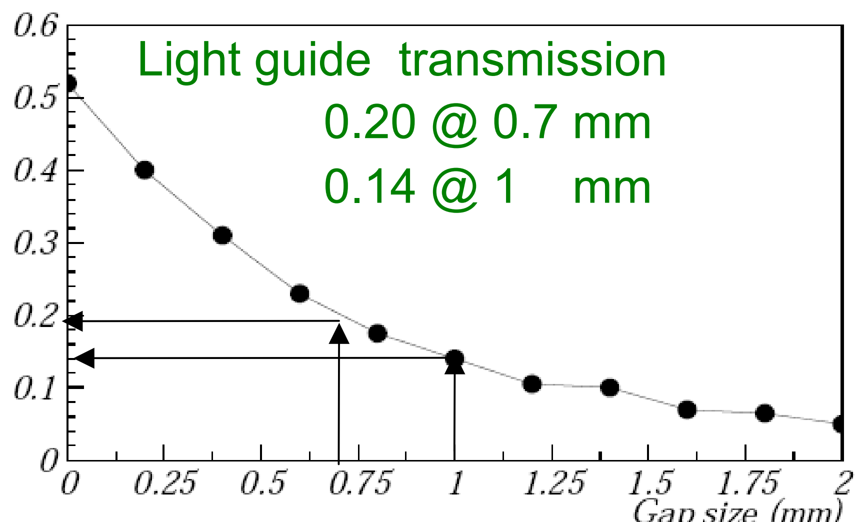
Machined from a plastic plate (HERA-B RICH lens material).





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

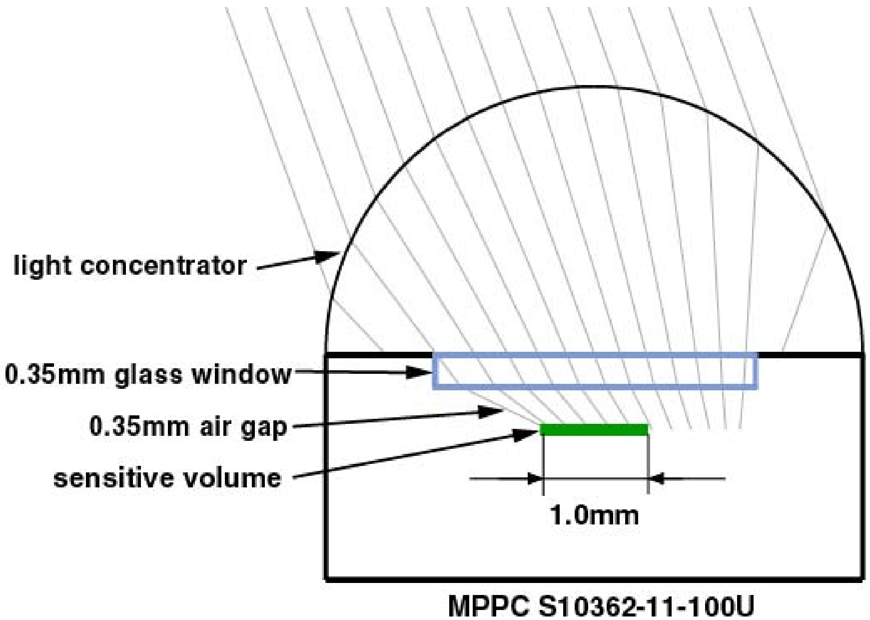


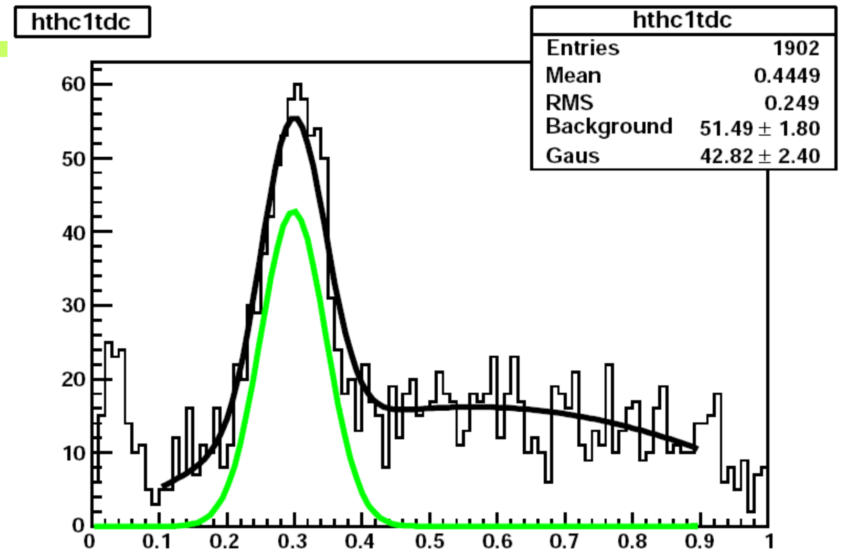


Gap size (mm)

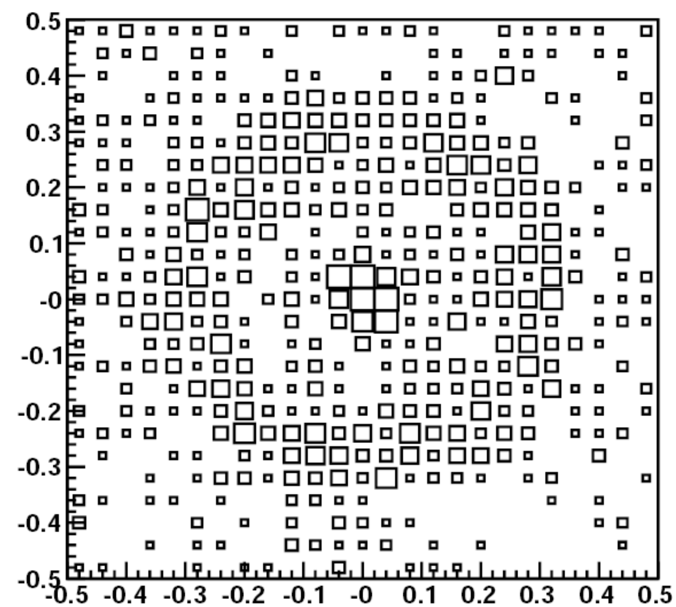
Cherenkov photons with light collectors

First attempt: use the top of a blue LED



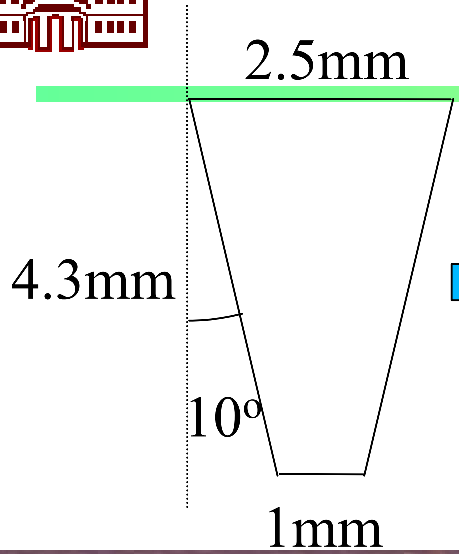


- Yield increase in agreement with the expectations
- Further improvements possible by
  - Using SiPMs with a reduced epoxy protective layer
  - using a better light collector

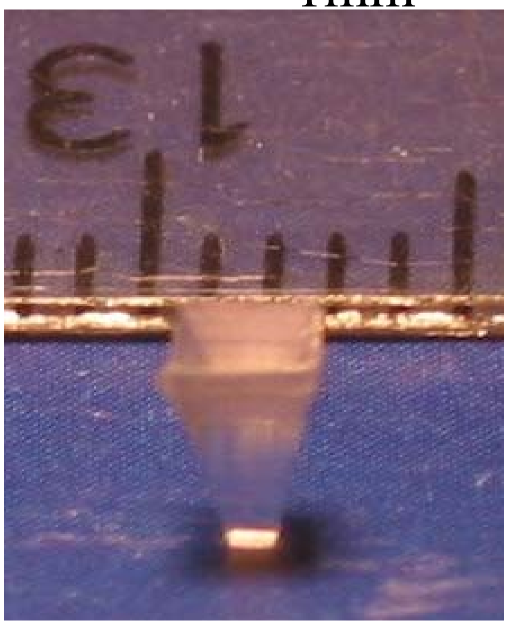


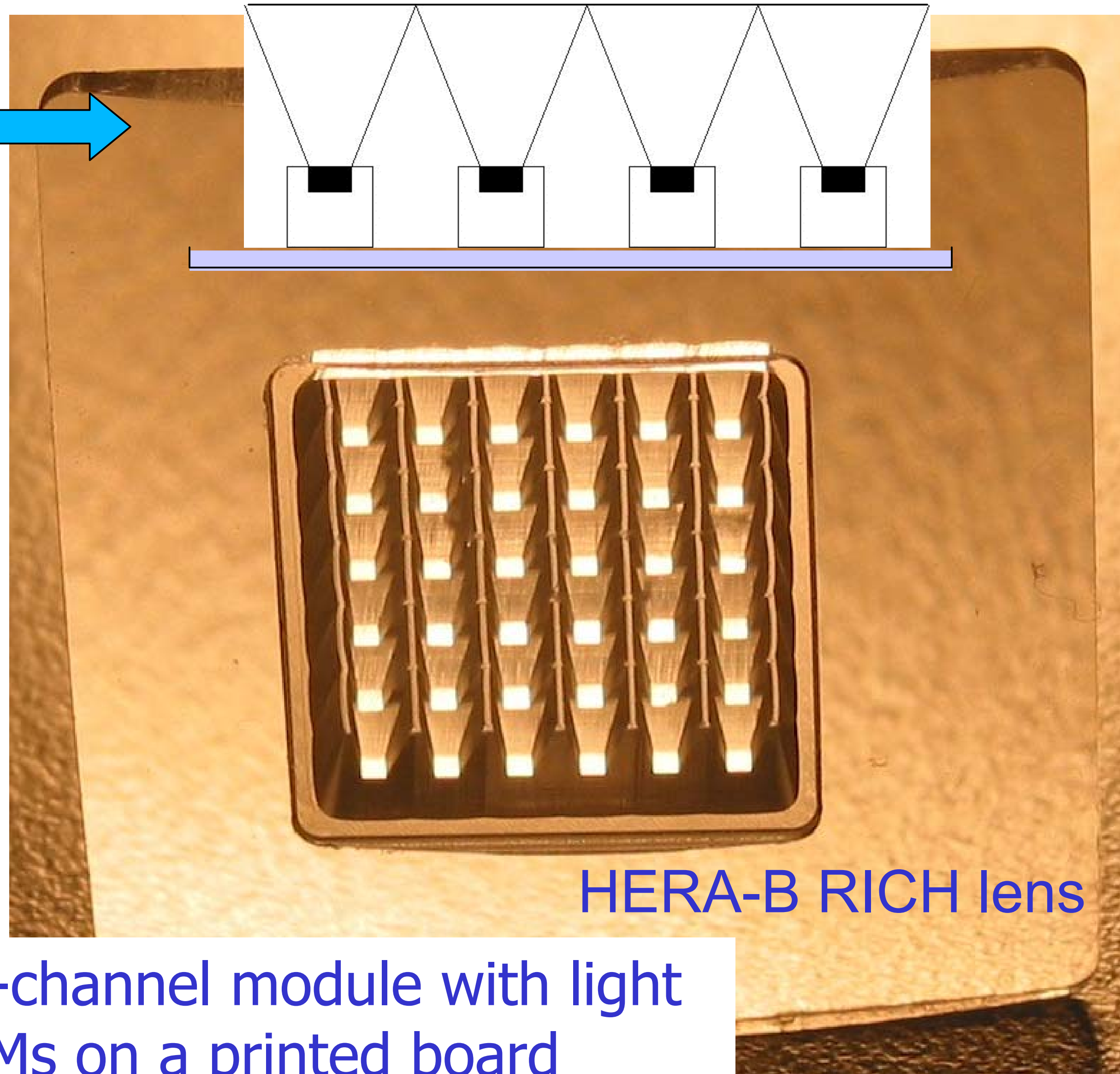
Hits in Cherenkov space

Detector module design



SiPM array with light guides

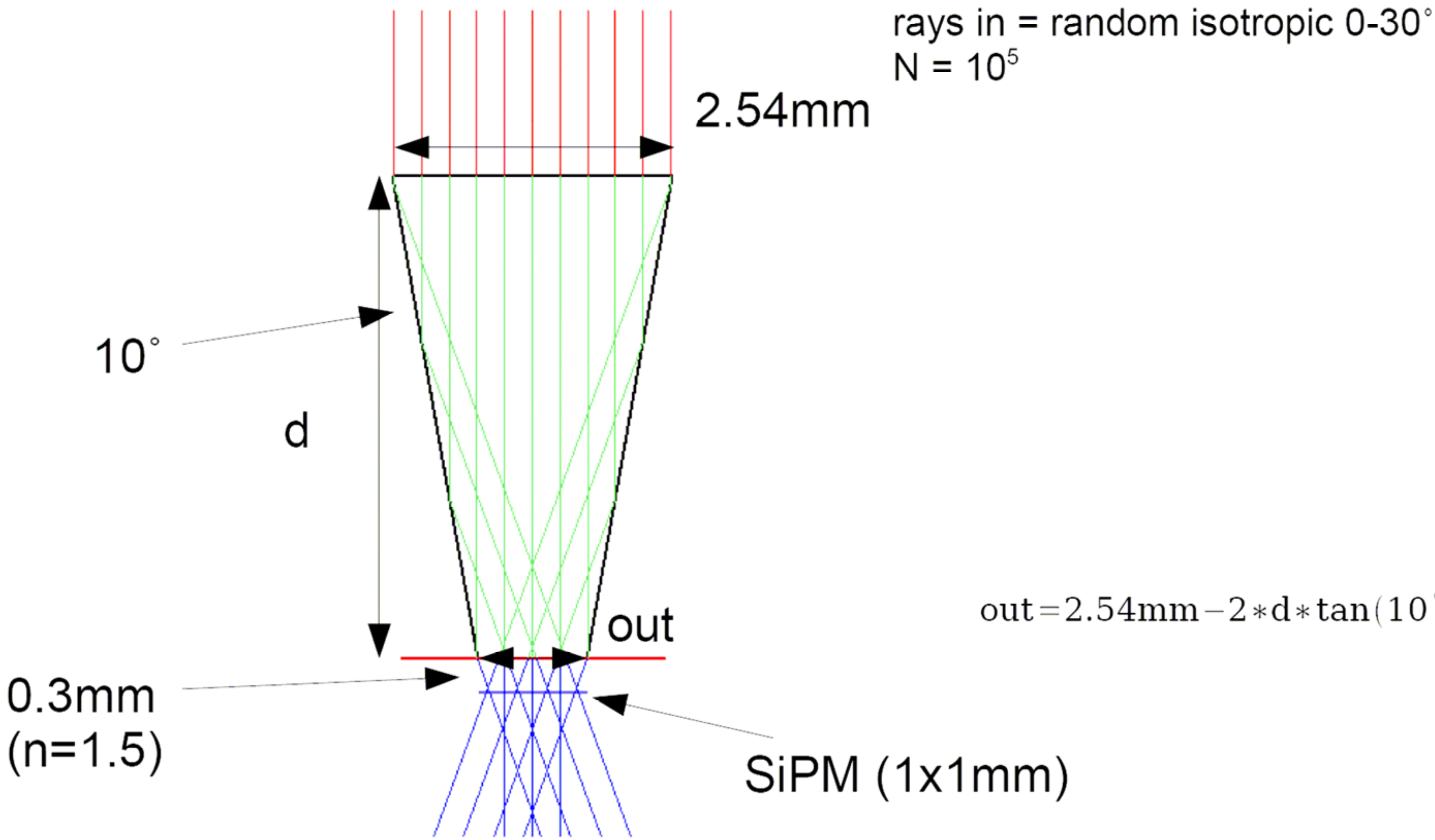




Aim: build a multi-channel module with light collectors and SiPMs on a printed board

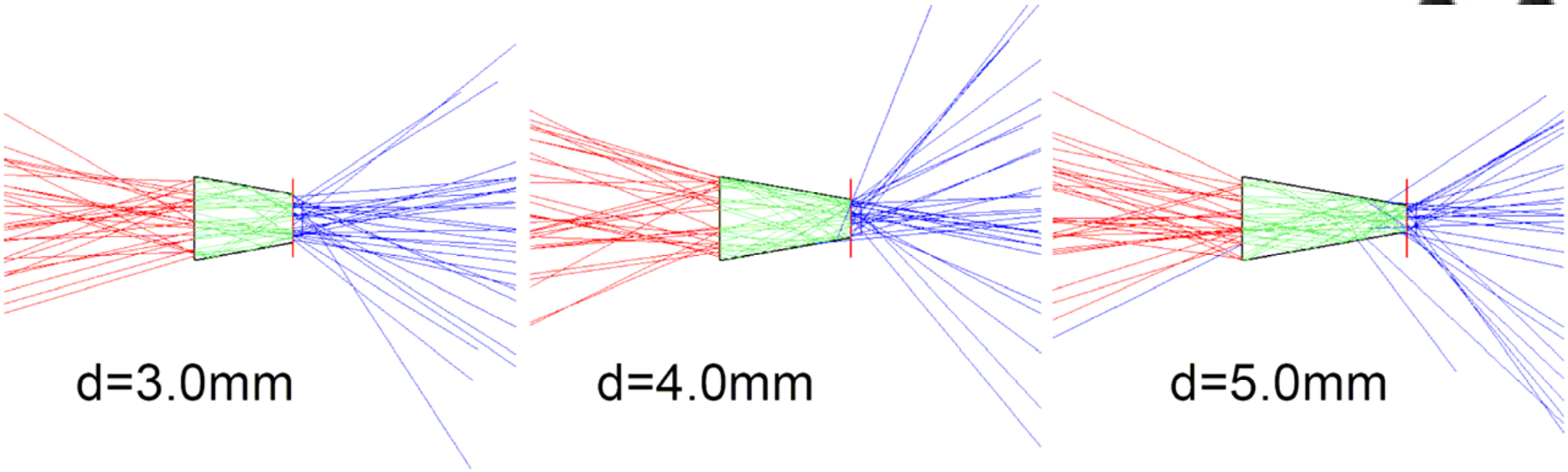
Light guide geometry optimisation

Light Guide Acceptance / (d and out)

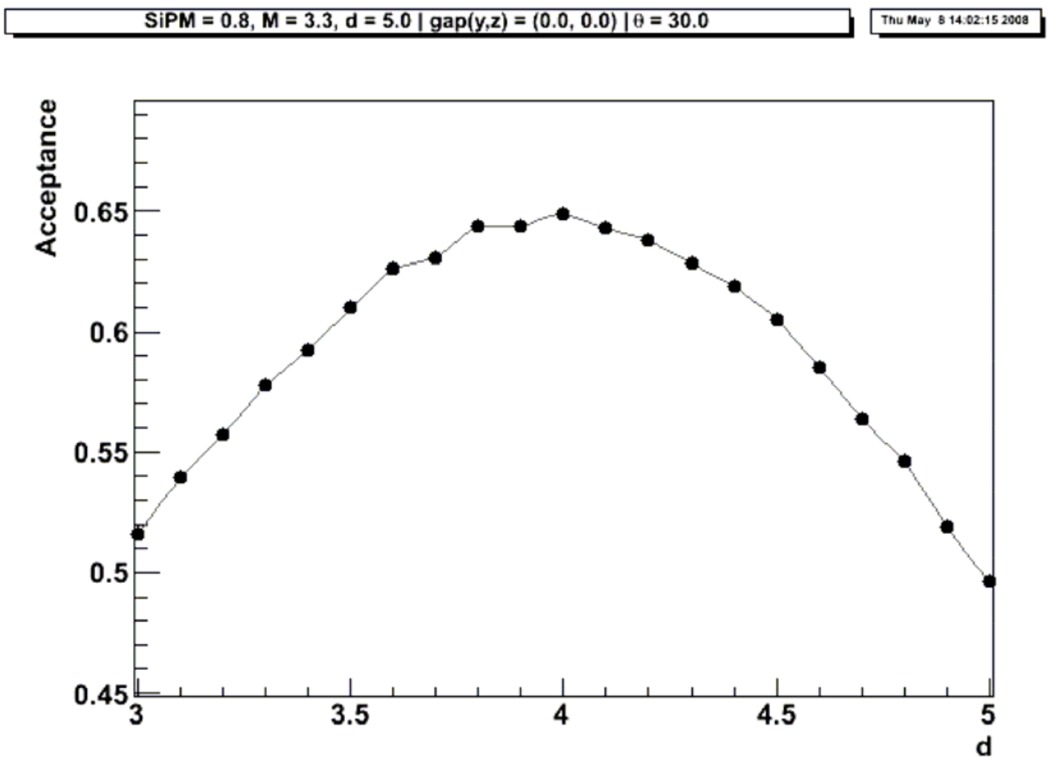


$$\mathrm{out} = 2.54\mathrm{mm} - 2 * d * \tan(10^\circ)$$

Light guide geometry optimisation

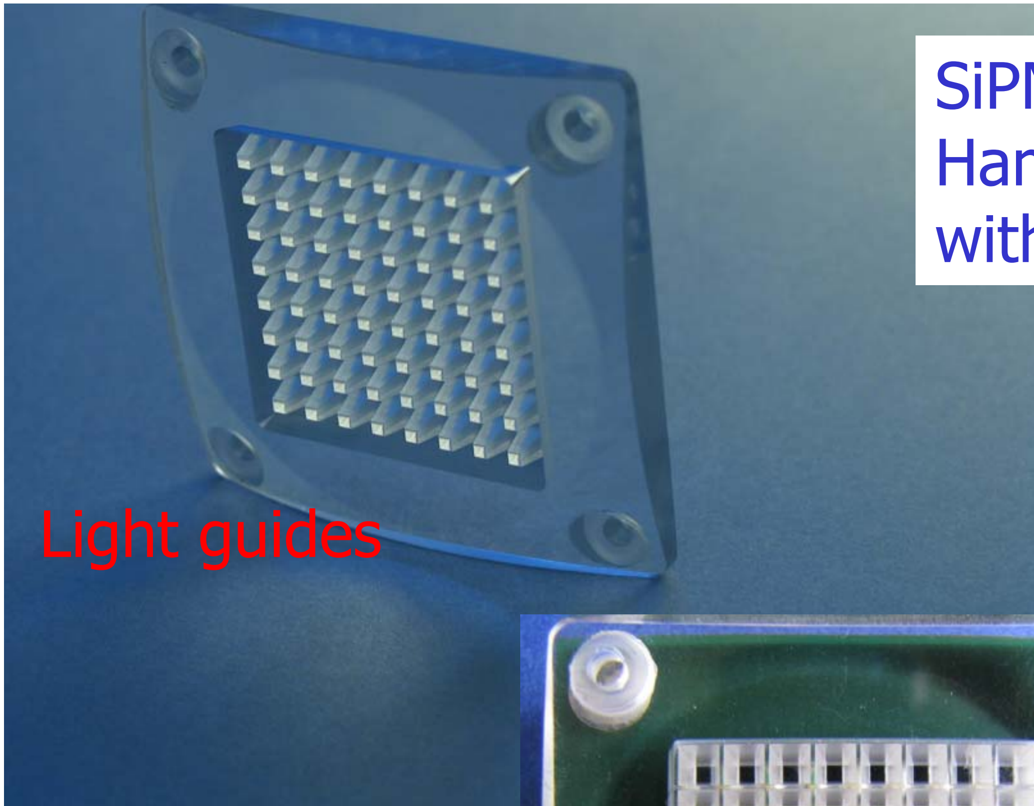


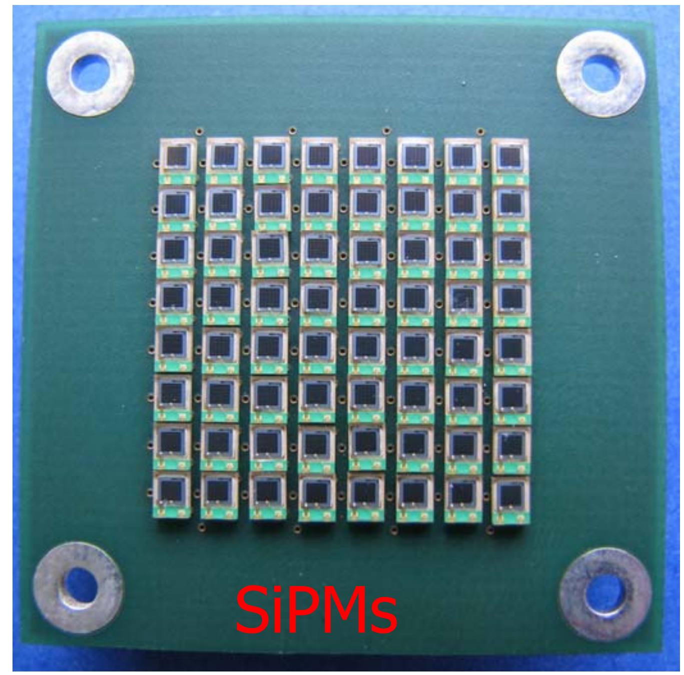
d (mm)	out (mm)	accept. (%)
3.0	1.48	51.6
3.1	1.45	54.0
3.2	1.41	55.7
3.3	1.38	57.8
3.4	1.34	59.2
3.5	1.31	61.0
3.6	1.27	62.6
3.7	1.24	63.1
3.8	1.20	64.4
3.9	1.16	64.4
4.0	**1.13**	**64.9**
4.1	1.09	64.3
4.2	1.06	63.8
4.3	1.02	62.8
4.4	0.99	61.8
4.5	0.95	60.5
4.6	0.92	58.5
4.7	0.88	56.4
4.8	0.85	54.6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



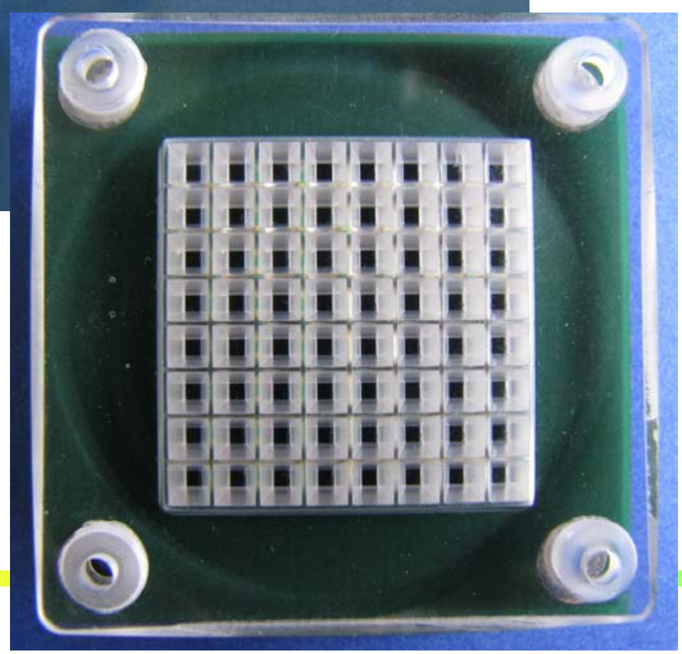
Detector module – final version for beam tests this week at KEK

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



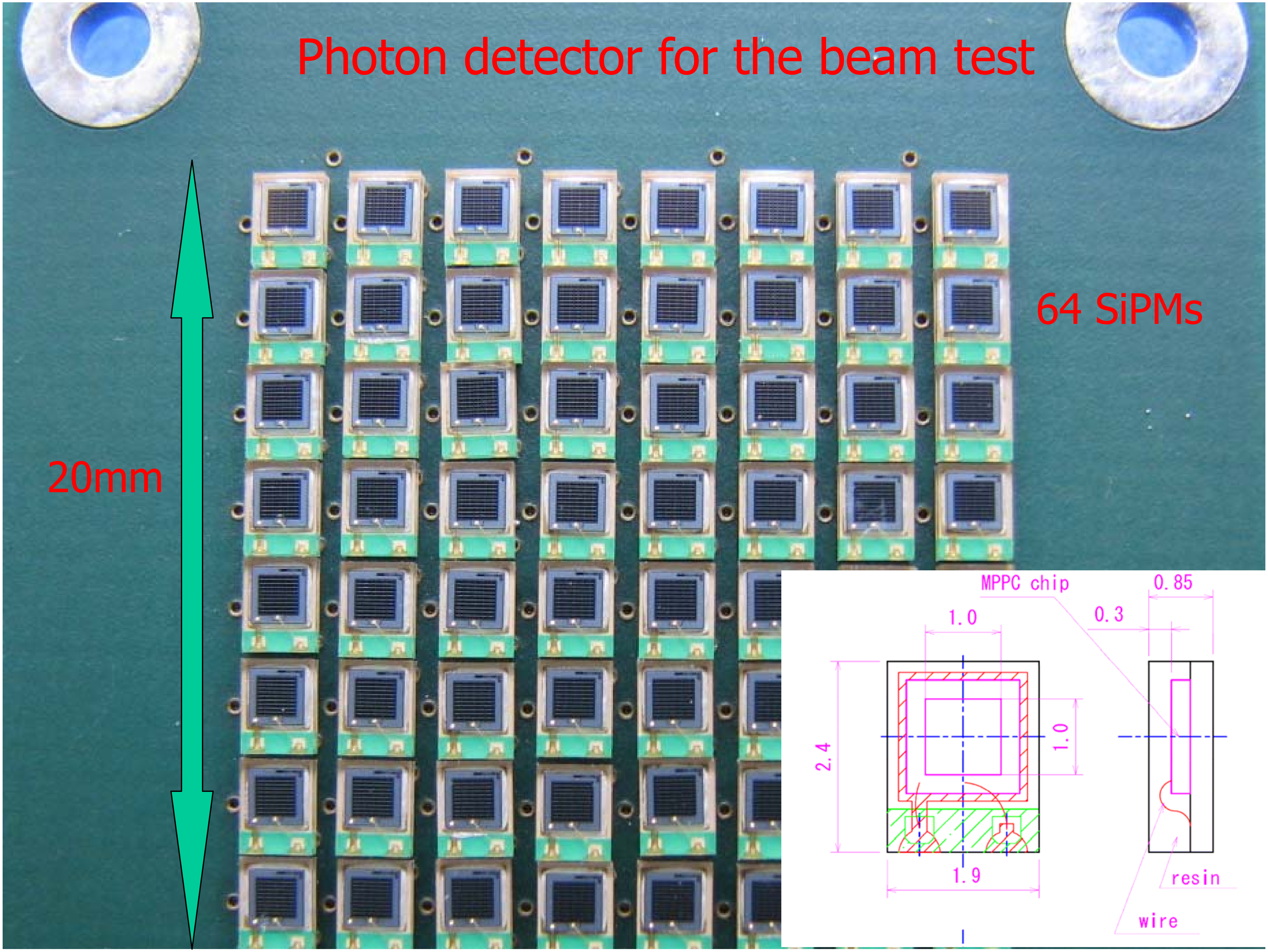


2cm



SiPMs + light guides

Photon detector for the beam test



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

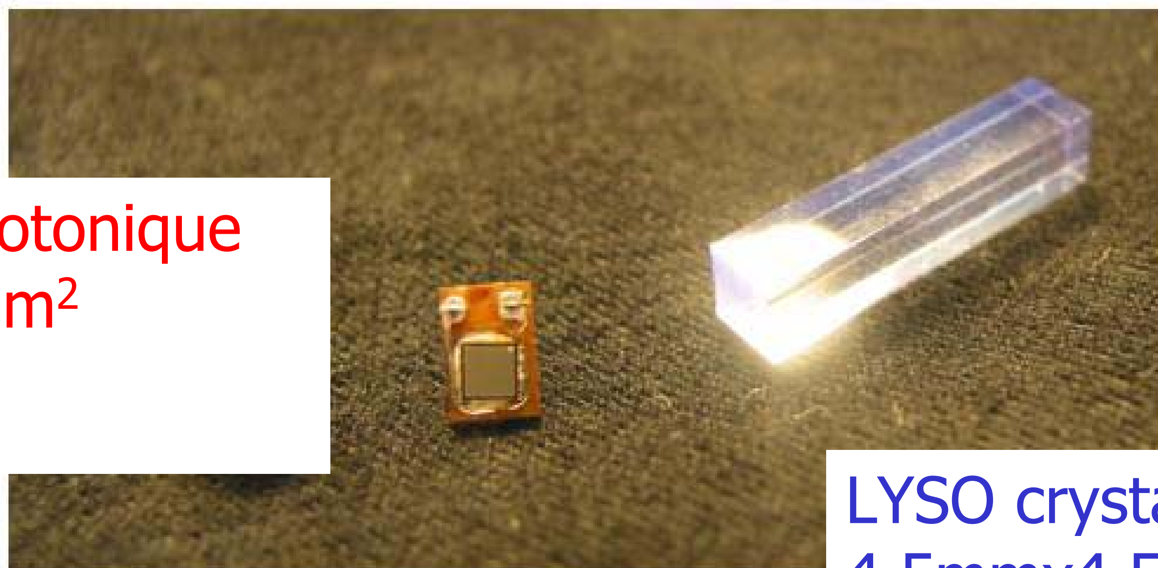
Explore other applications of the device → PET

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

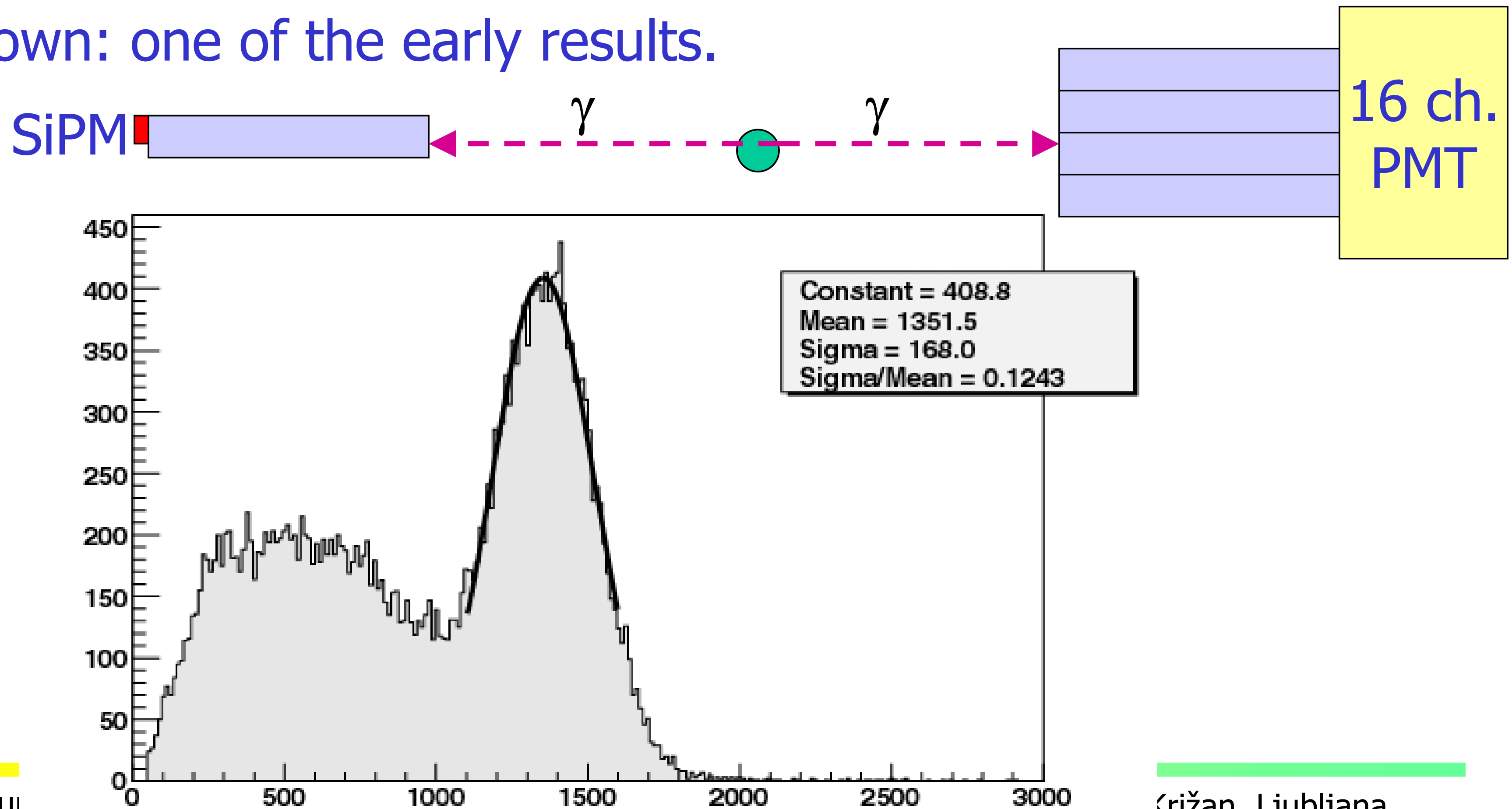
LYSO crystals 4.5mmx4.5mm

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.

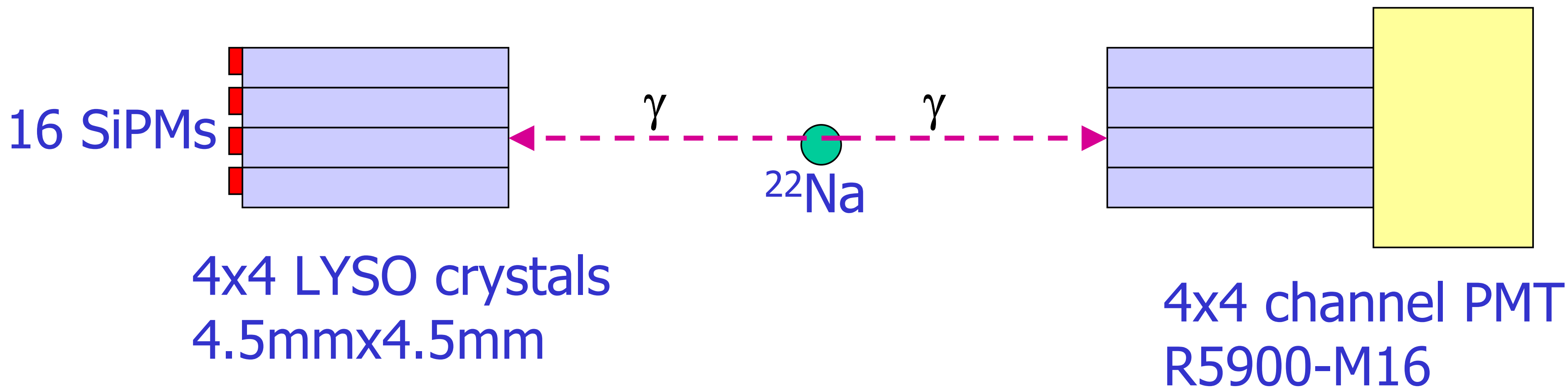


Next step…

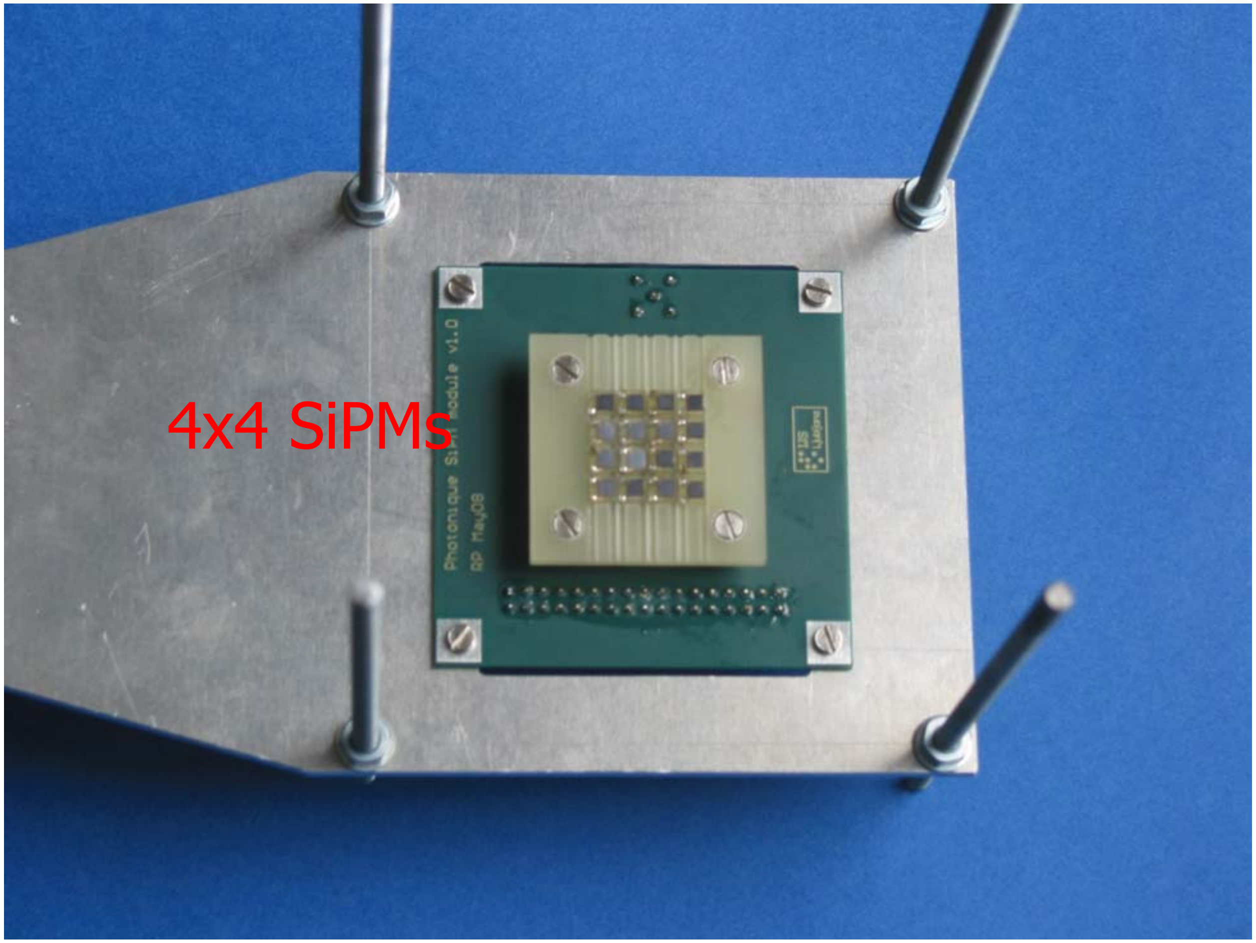
Test a PET module with:

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...

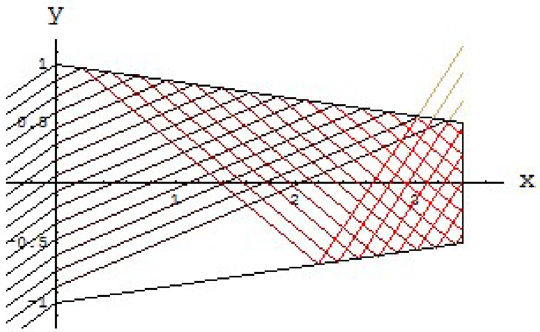


Reading out a 4x4 array of LYSO crystals

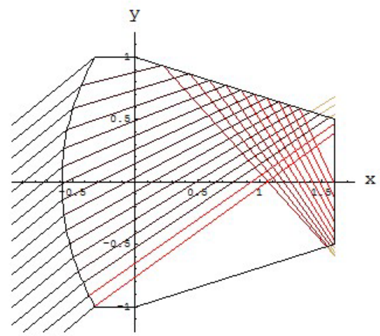
Module under test...

Back-up slides

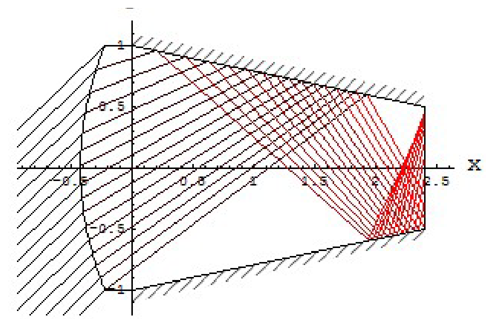
Planar entry window



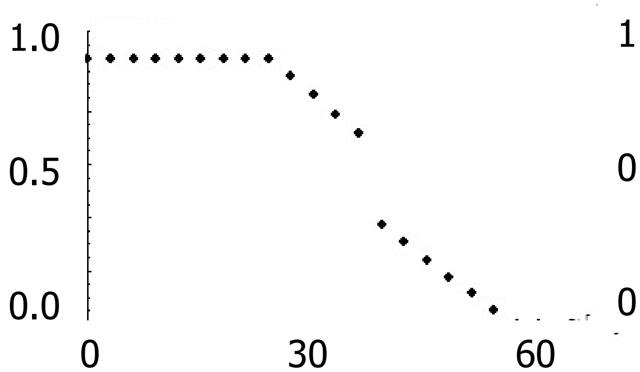
Spherical entry window

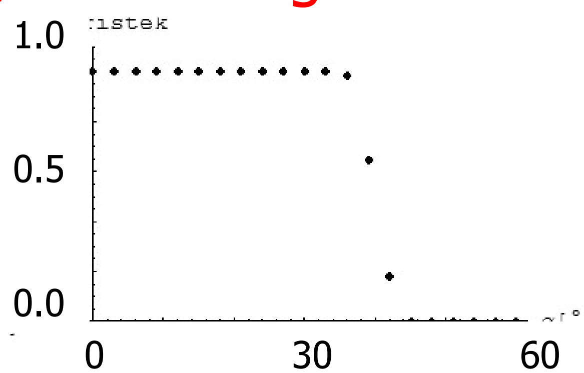


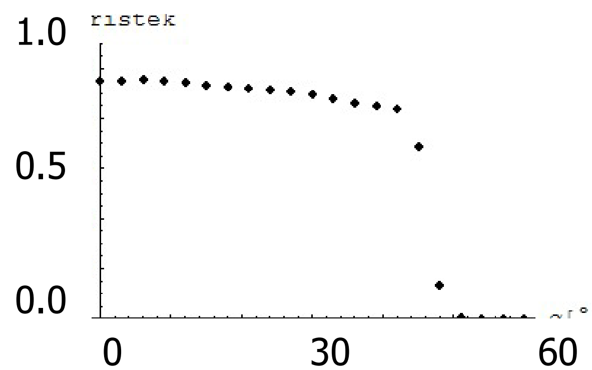
Spherical entry window, reflective sides



Efficieny vs. angle of incidence α



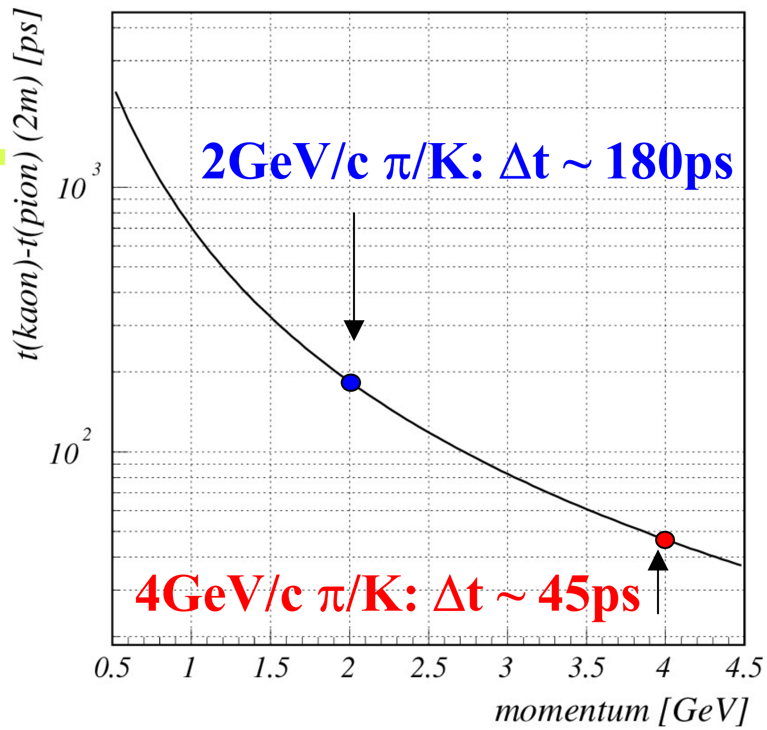




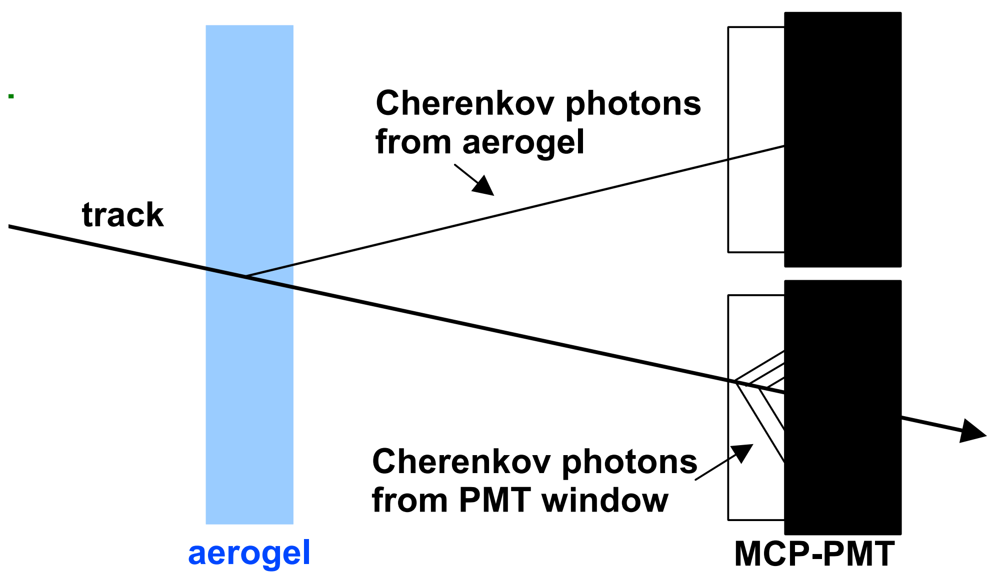
Light guide	d/a	R/a	α_{min} , α_{max}	I(-60°, 60°)
Planar entry	**3.4**	-	**–24°, 24°**	**64%**
Sph. entry	**1.6**	**2.0**	**–35°, 35°**	**66%**
Reflective sides	**2.4**	**2.6**	**–44°, 44°**	**69%**

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 →

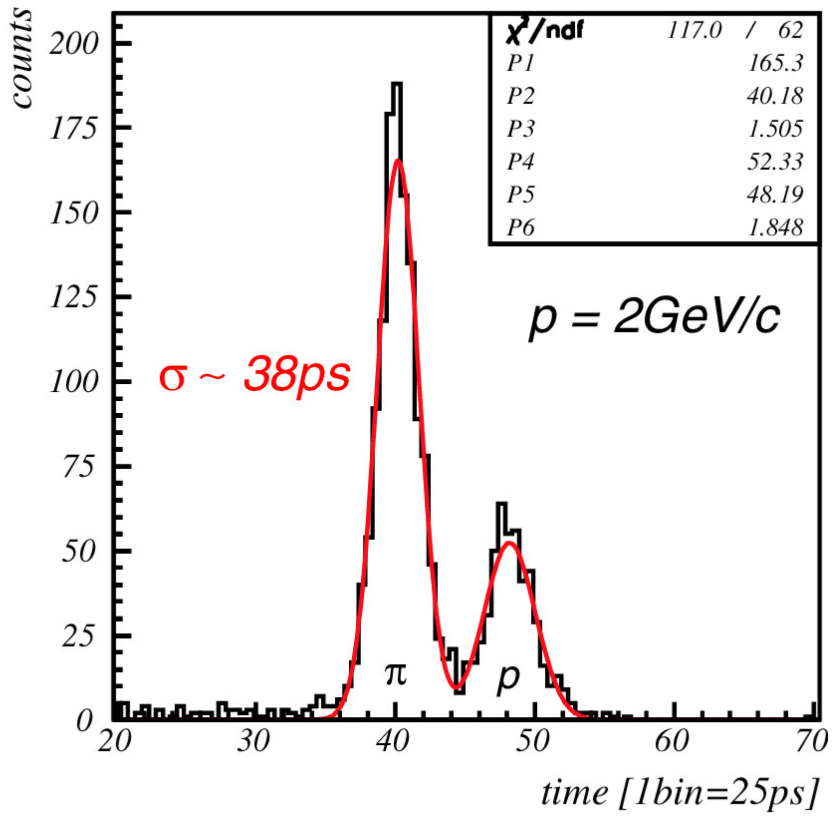


For time of flight: use Cherenkov photons photons emitted in the PMT window

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

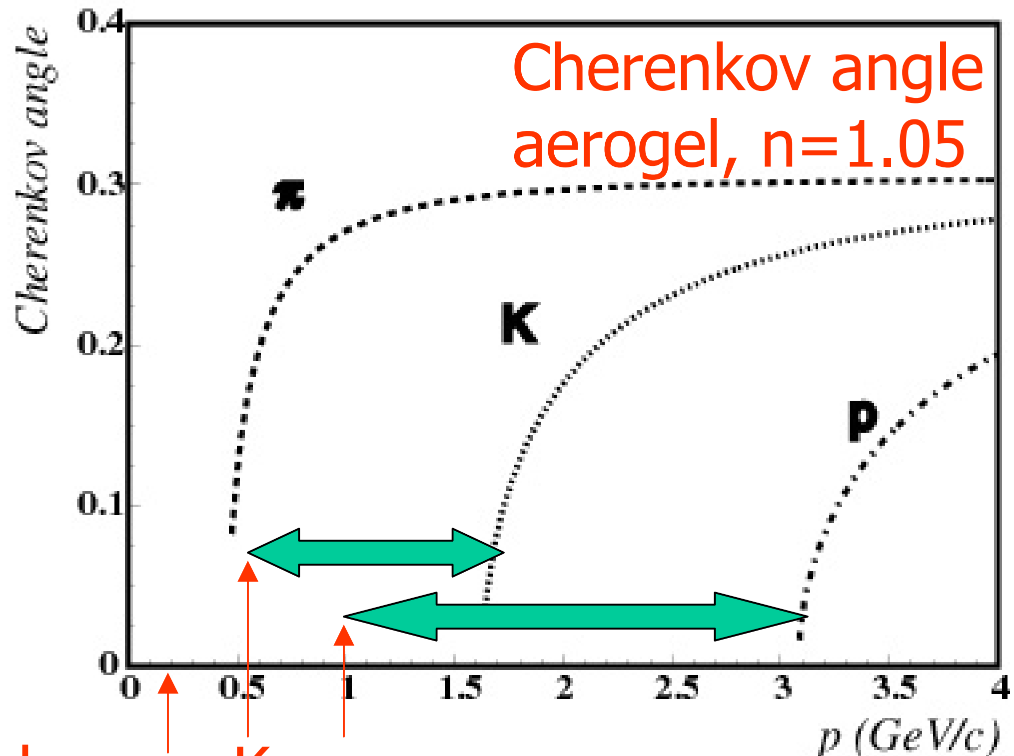
→ 3x better separation

NIM A572 (2007) 432

Time-of-flight with photons from the PMT window

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

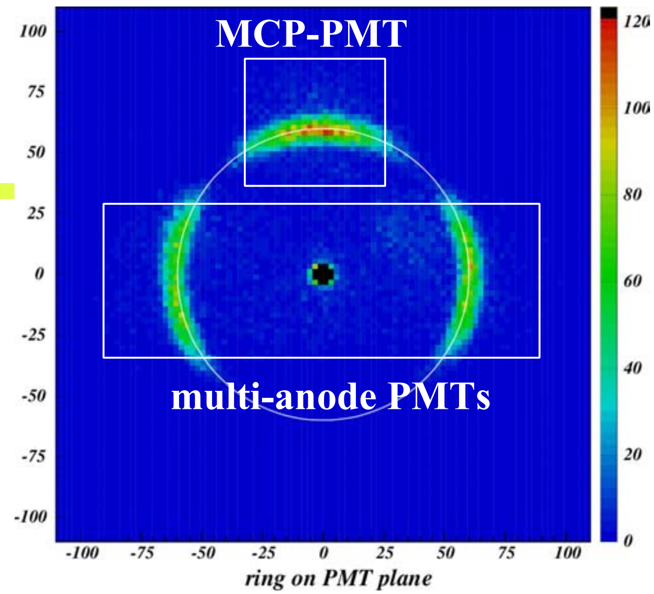
Aerogel: kaons (protons) have no signal below 1.6 GeV (3.1 GeV): identification in the veto mode.



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

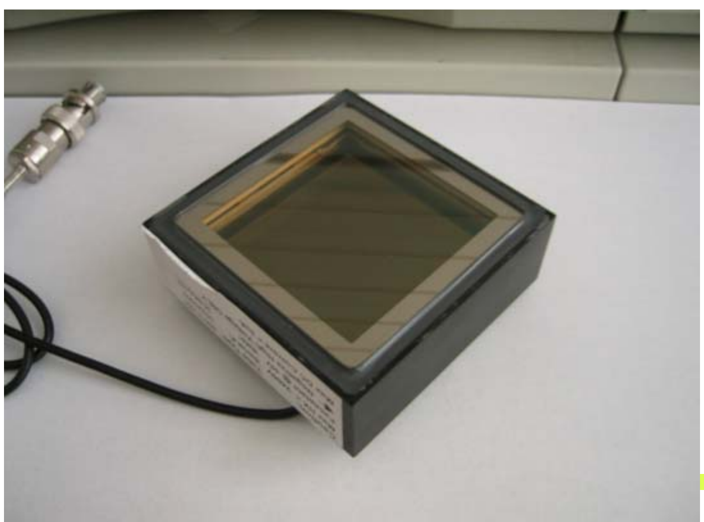


BURLE 85011 MCP-PMT:

- 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

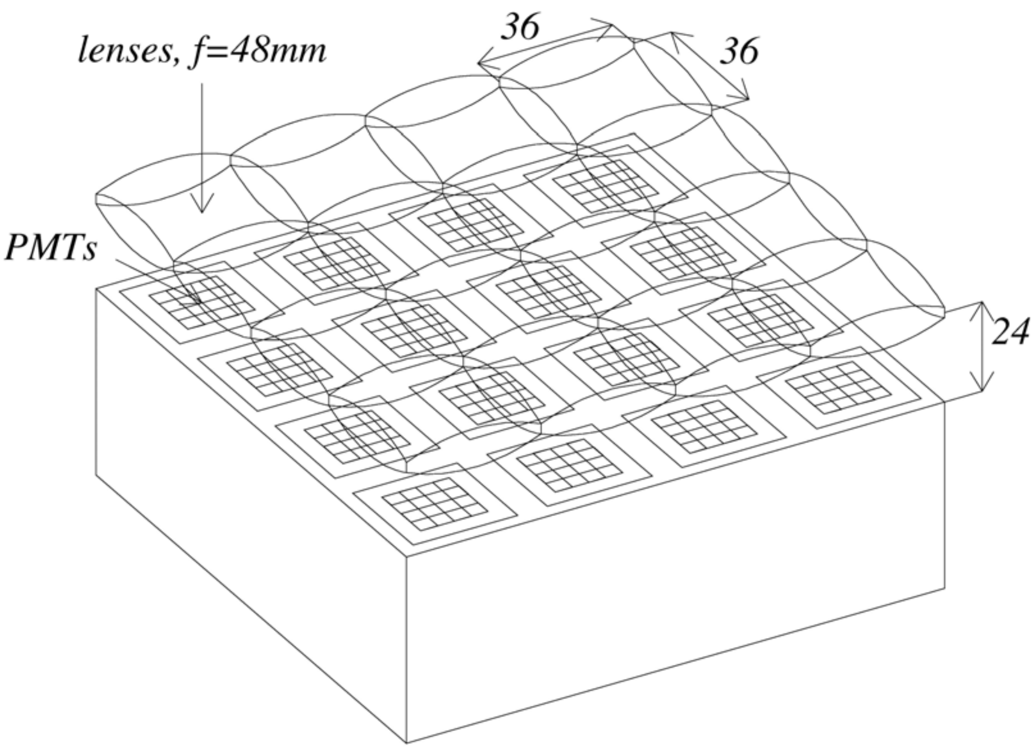
- σ_ϑ~13 mrad (single cluster)
- number of clusters per track N ~ 4.5
- σ_ϑ~ 6 mrad (per track)
- **-> ~ 4 σ π/K separation at 4 GeV/c**



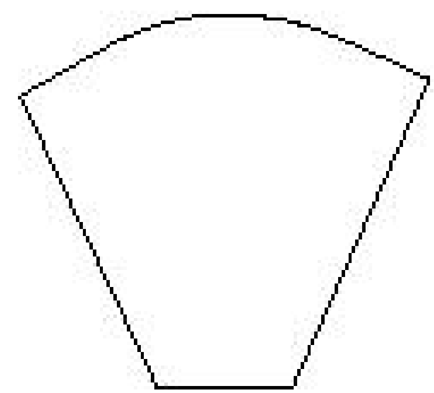
- 10 μm pores required for 1.5T
- collection eff. and active area fraction should be improved
- aging study should be carried out

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

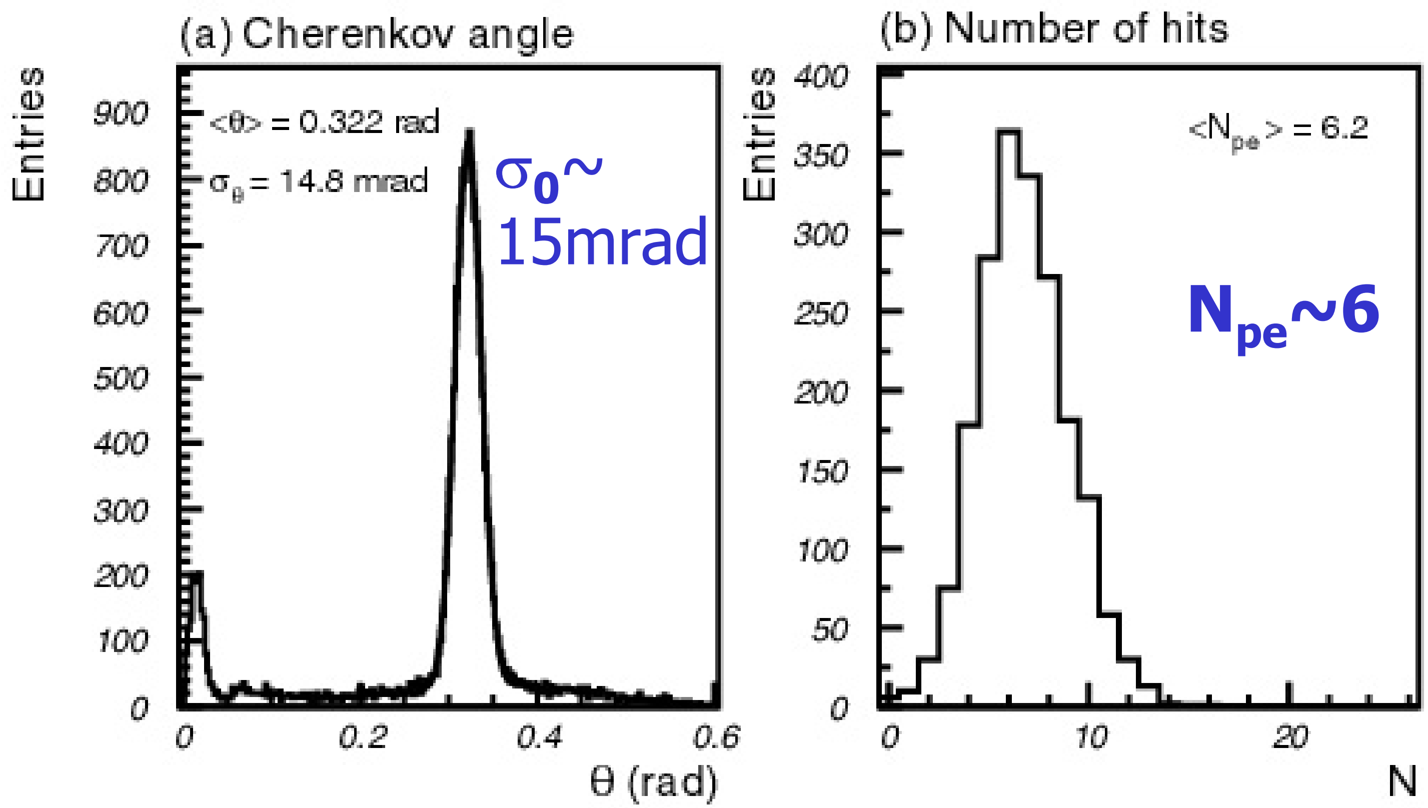


Beam test: Cherenkov angle resolution and number of photons

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

Beam test results with 2cm thick aerogel tiles:

>4σ K/π separation



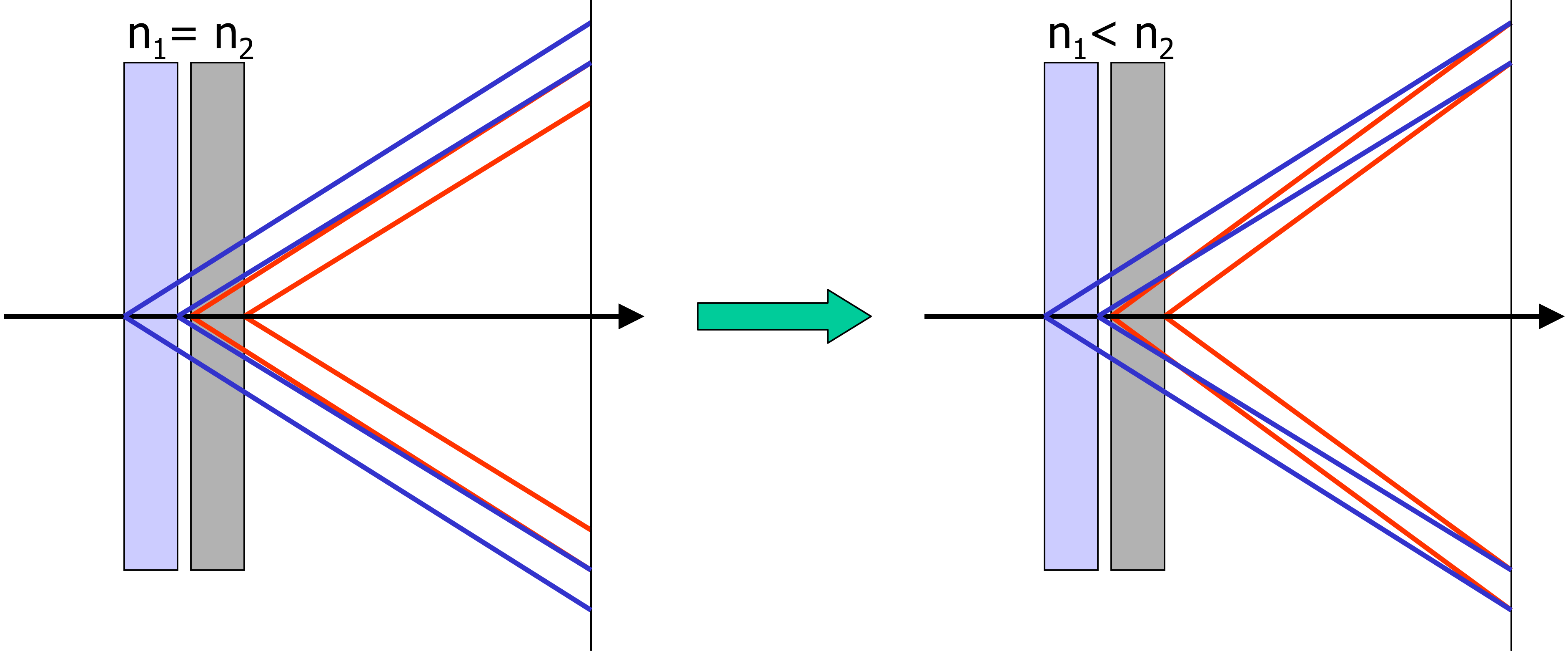
→ Number of photons has to be increased.

Radiator with multiple refractive indices

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

normal

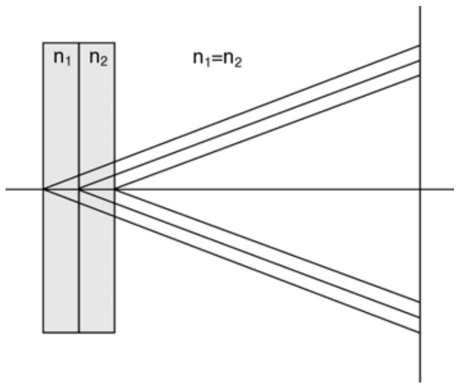
→ stack two tiles with different refractive indices: "focusing" configuration

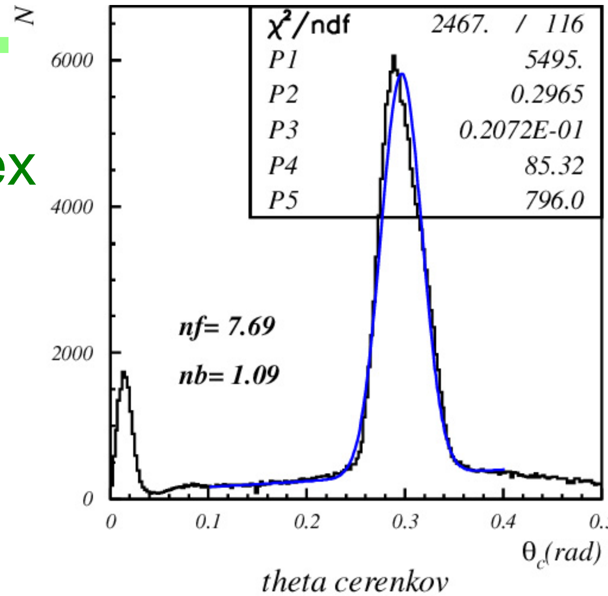


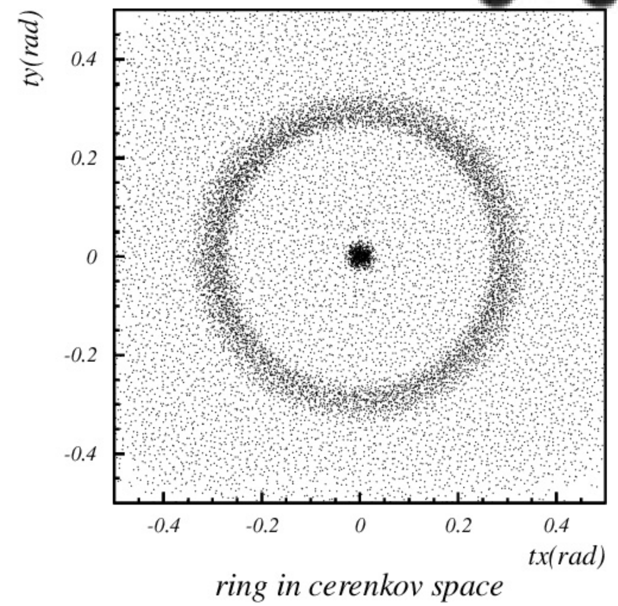
→ focusing radiator

Focusing configuration – data

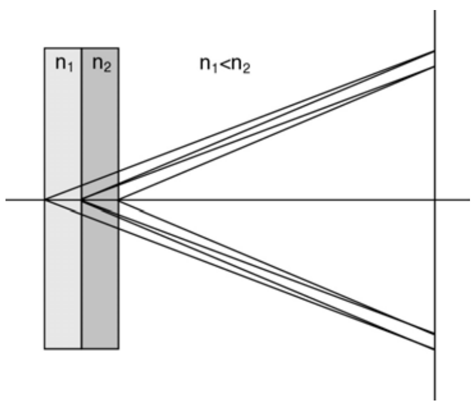
4cm aerogel single index

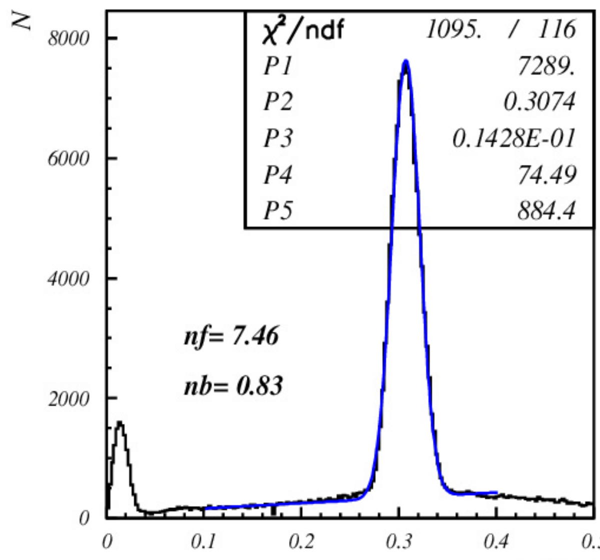


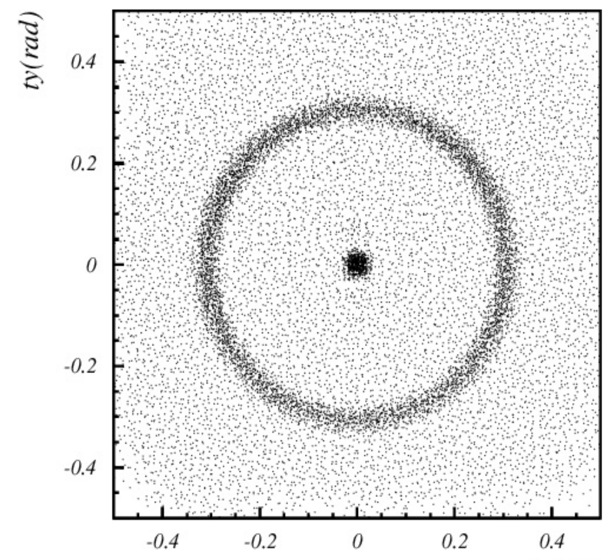




2+2cm aerogel







→NIM A548 (2005) 383