Univerza v Ljubljani

Ljubljana contribution

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University of Ljubljana and J. Stefan Institute

FP7 PET meeting, Rome, October 14, 2008

Contents

Our experience relevant for this project:

•Photon detectors for high magnetic fields

•Low noise electronics

•Data aquisition systems

•Image reconstruction

Main activities of the group:

•Cherenkov counters: photon detector and electronics R+D, construction, commissioning and data analysis in HEP experiments (Belle, HERA-B)

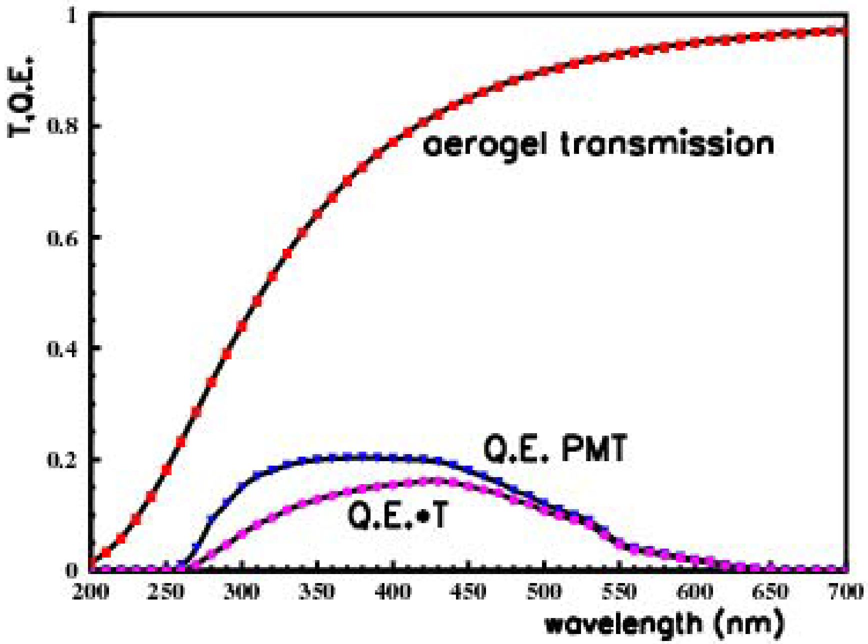
•Silicon detector for Belle: tests of electronics, alignment

•PET: R+D of a PET module with SiPMs as photon detectors

Photon detectors for a RICH counter

Needs:

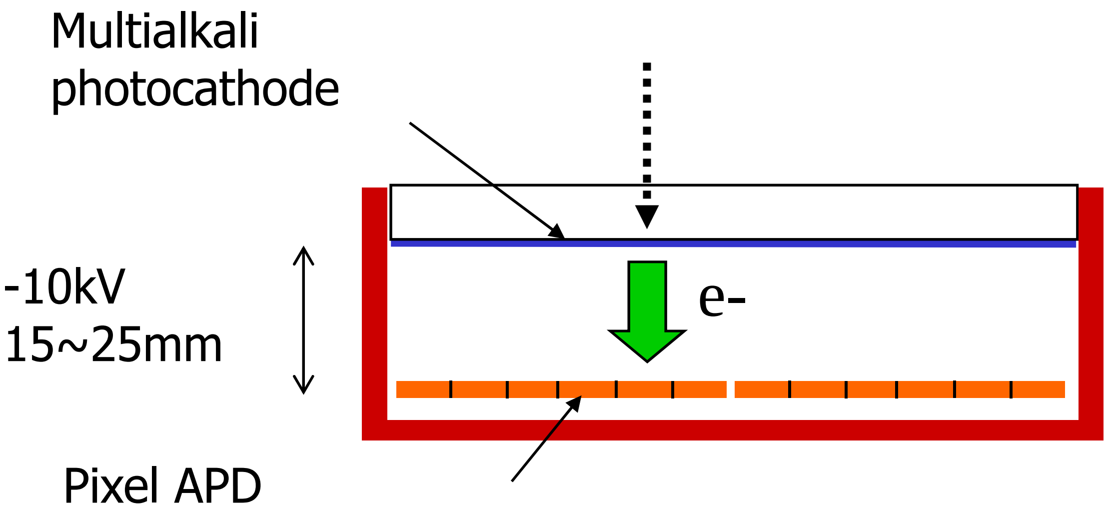
- Operation in high magnetic field (1.5T)
- High efficiency at λ>350nm
- Pad size ~5-6mm

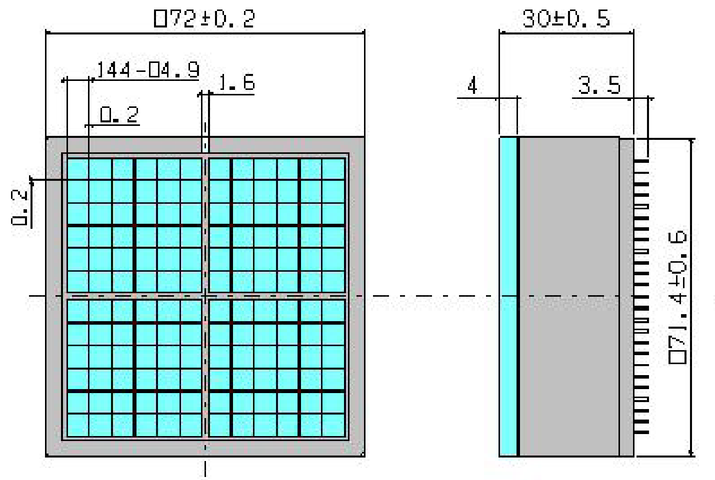


Candidates:

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

Photon detector candidate: Large active area HAPD

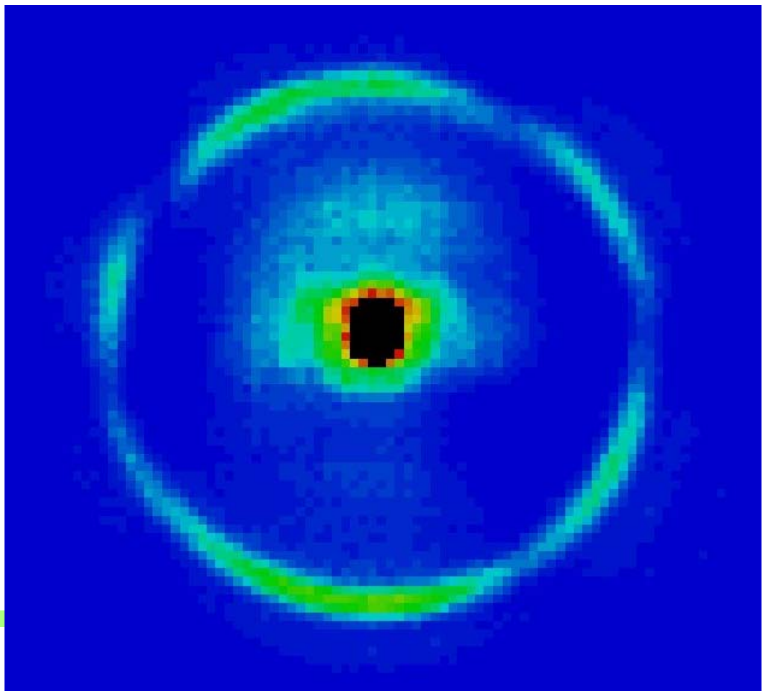




R&D project in collaboration with Hamamatsu.

Works better in high B field than without it...

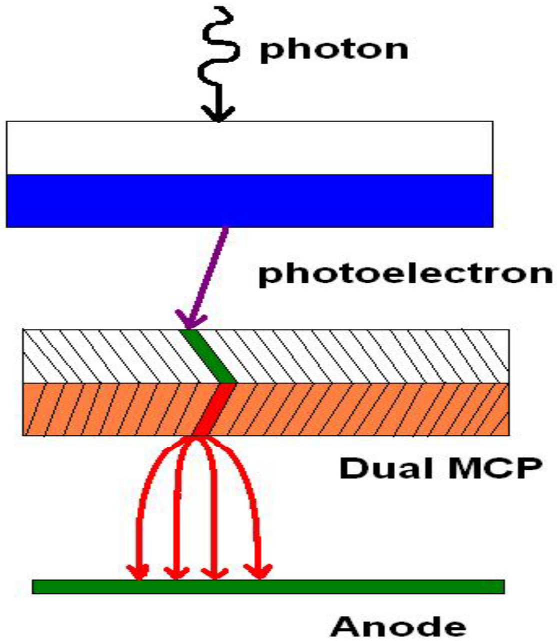
First beam test results →



→NIM A595 (2008) 150

Photon detector candidate: BURLE/Photonis MCP-PMT

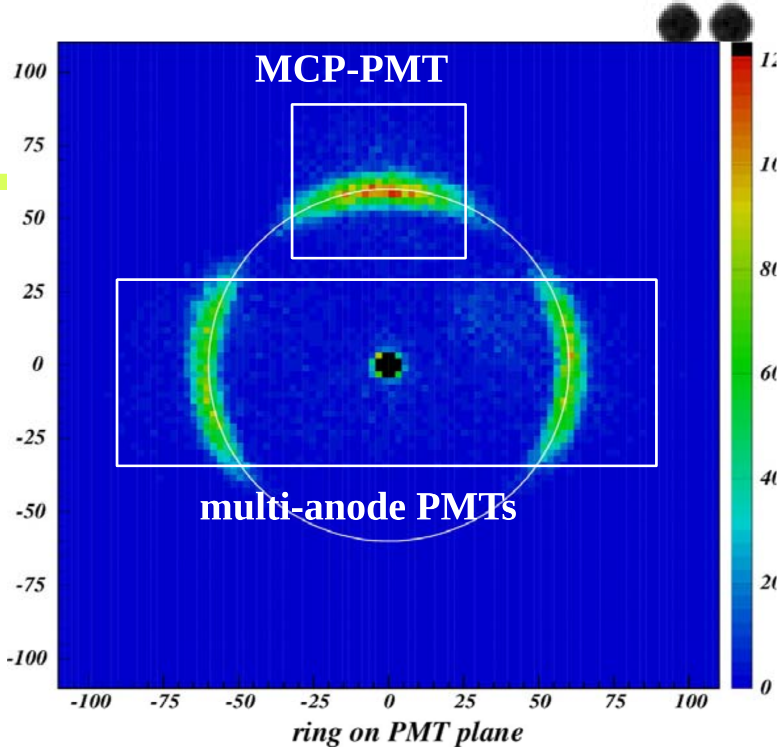
BURLE 85011 microchannel plate (MCP) PMT: multi-anode PMT with two MCP steps

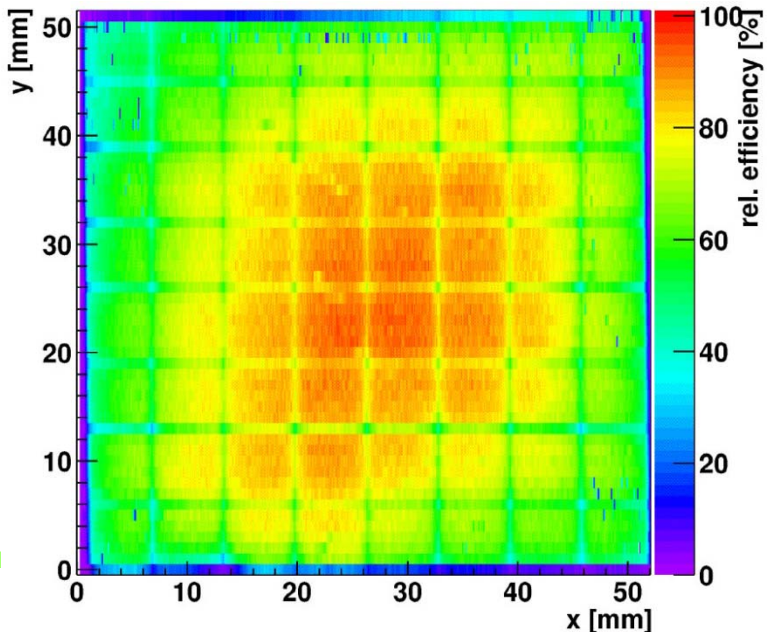


→good performance in beam and bench tests, NIMA567 (2006) 124

→ very fast →

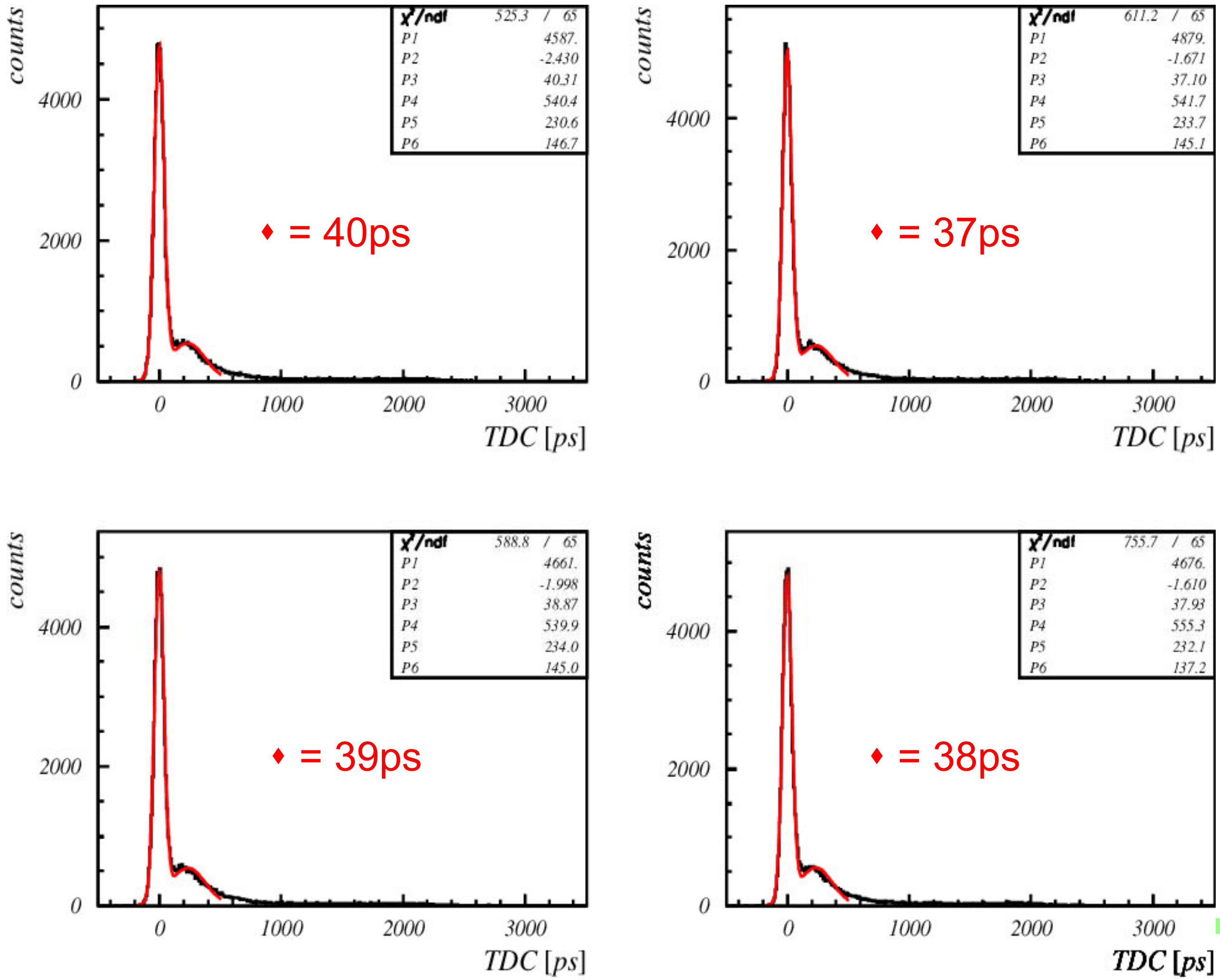
→ ageing?





Photon detector candidate: BURLE/Photonis MCP-PMT

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



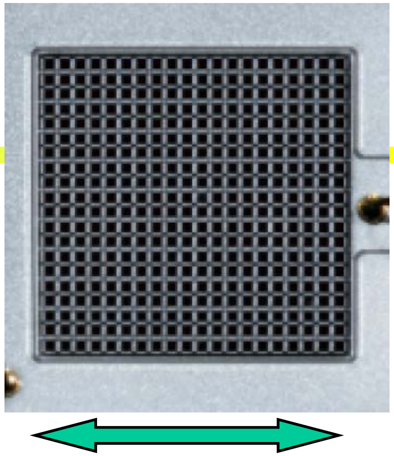
Tails can be significantly reduced by:

- decreased photocathode-MCP distance and
- increased voltage difference

→ NIM A595 (2008) 169

SiPMs as photon detectors

SiPM: array of APDs operating in Geiger mode.

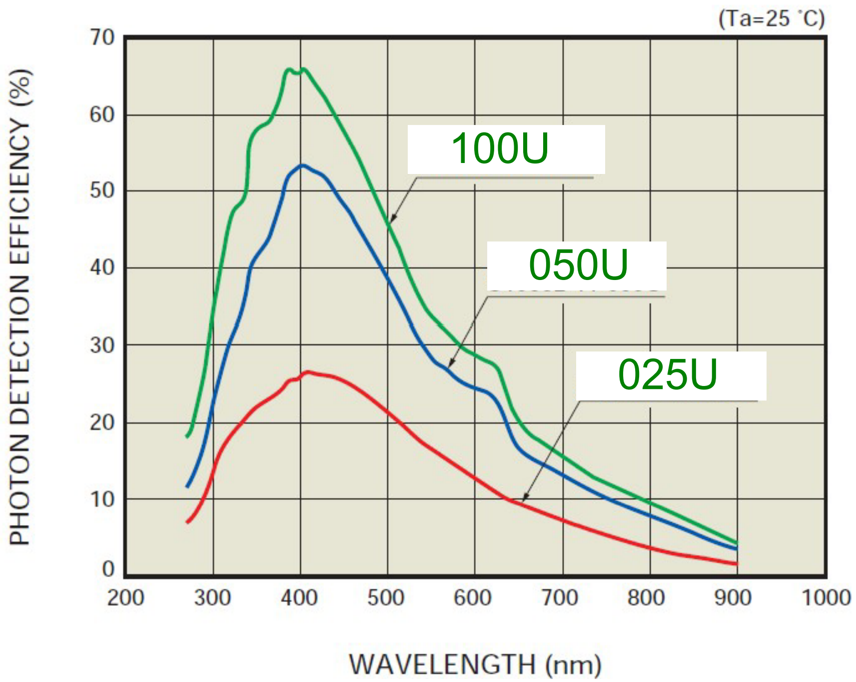


A lot of advantages:

- 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

But:

- dark counts ~ few 100 kHz/mm^2
- radiation damage (p,n)



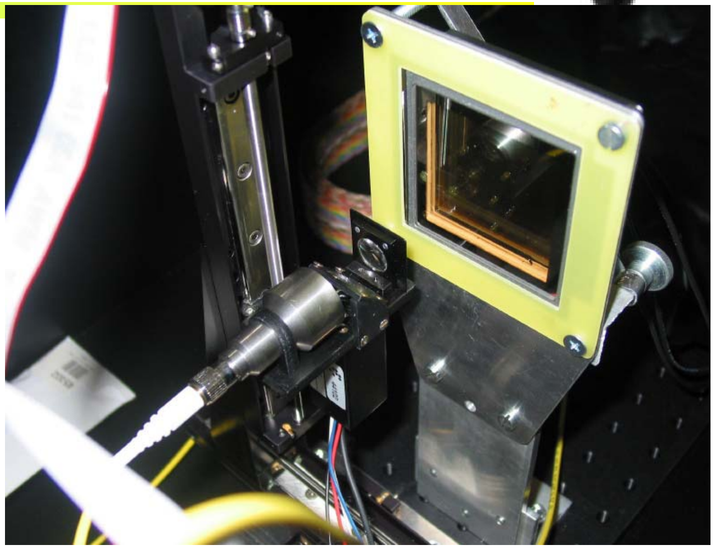
Hamamatsu MPPC: S10362-11

Surface sensitivity for single photons

2d scan in the focal plane of the laser beam ($\sigma \approx 5\ \mu m$)

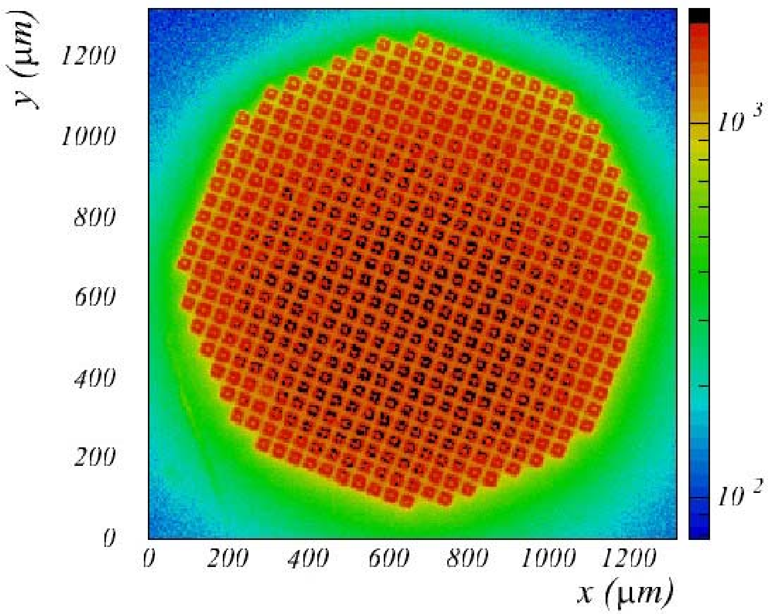
intensity: on average << 1 photon → single photons

selection: single pixel pulse height, in 10 ns TDC window

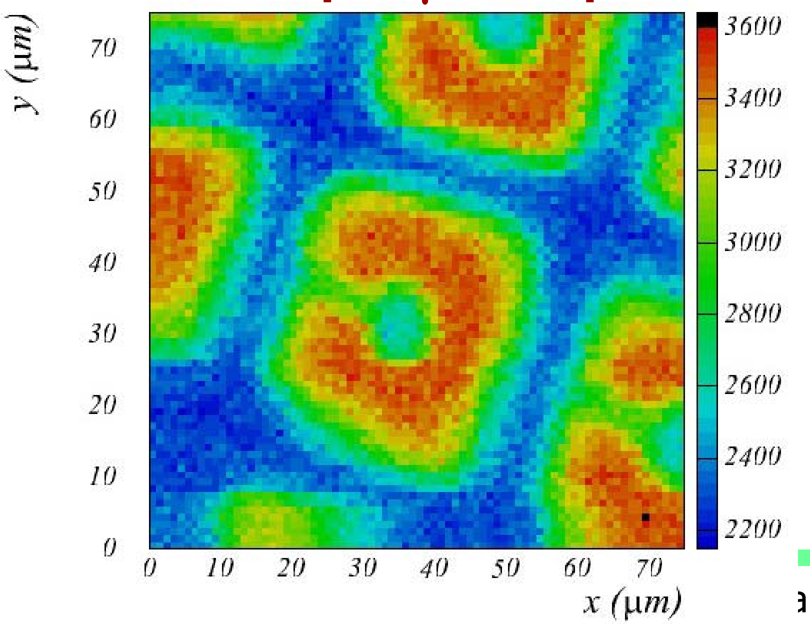


S137 (CPTA/Photonique)

5 μm step size

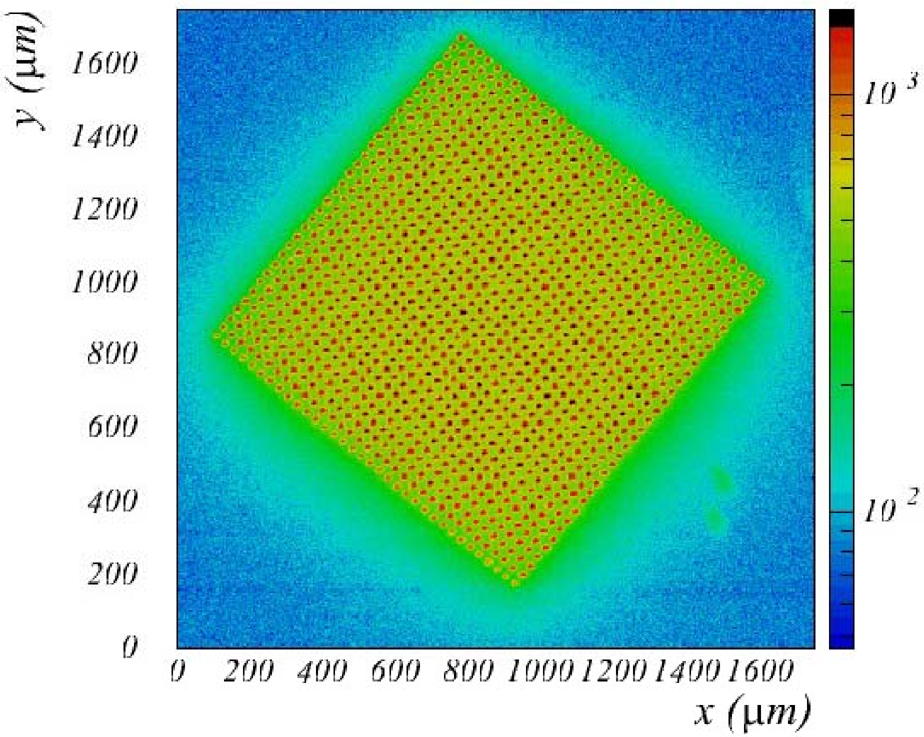


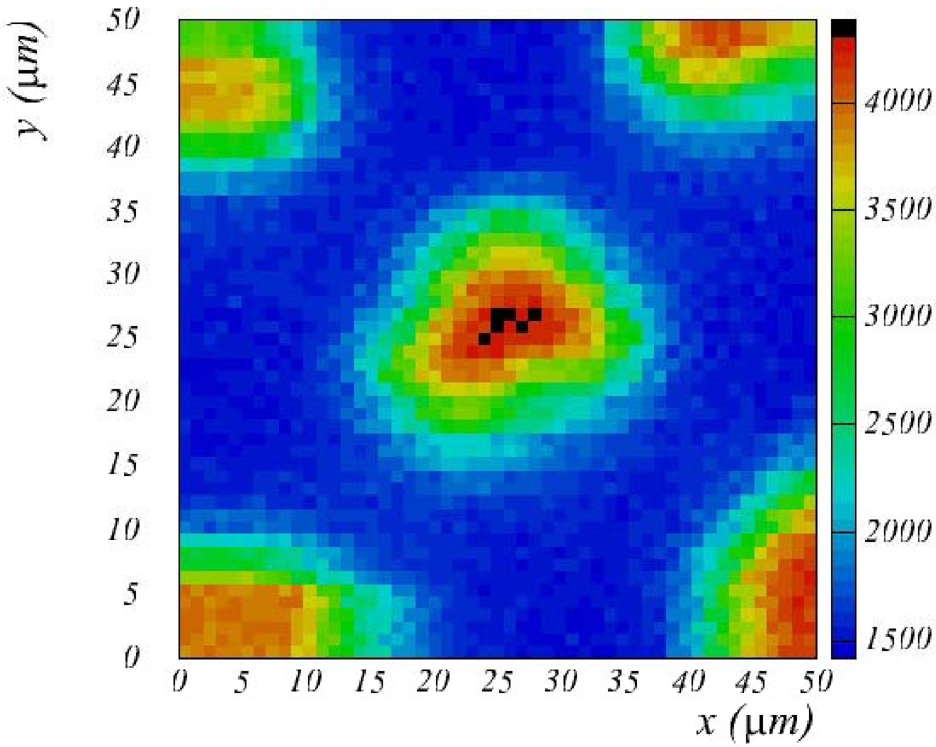
Close up: 1 μm step size



Surface sensitivity for single photons 2

E407 (Pulsar/MEPHI)

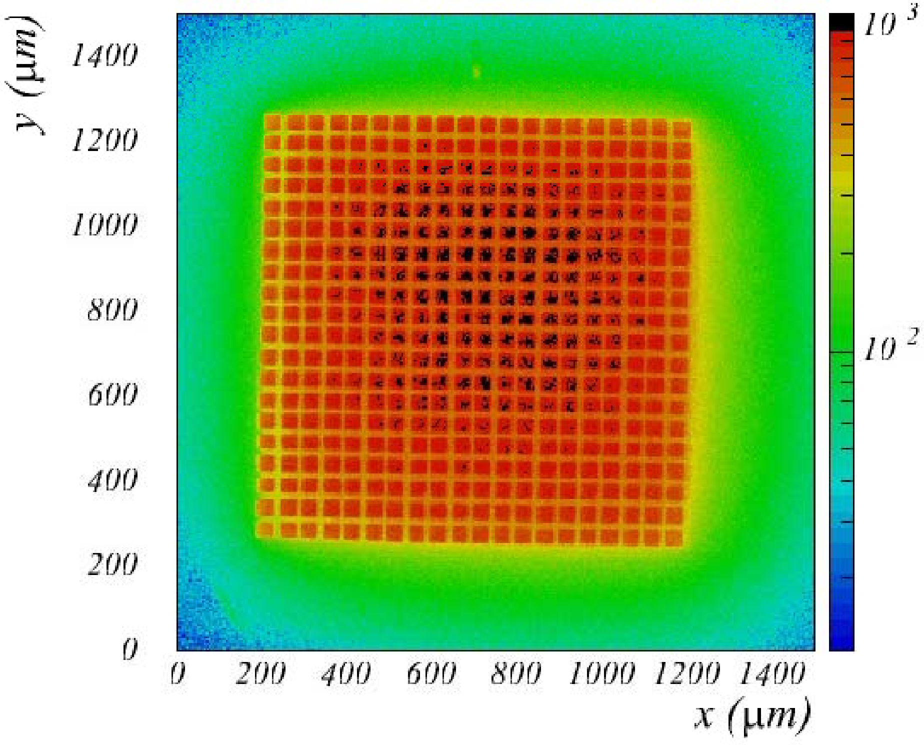




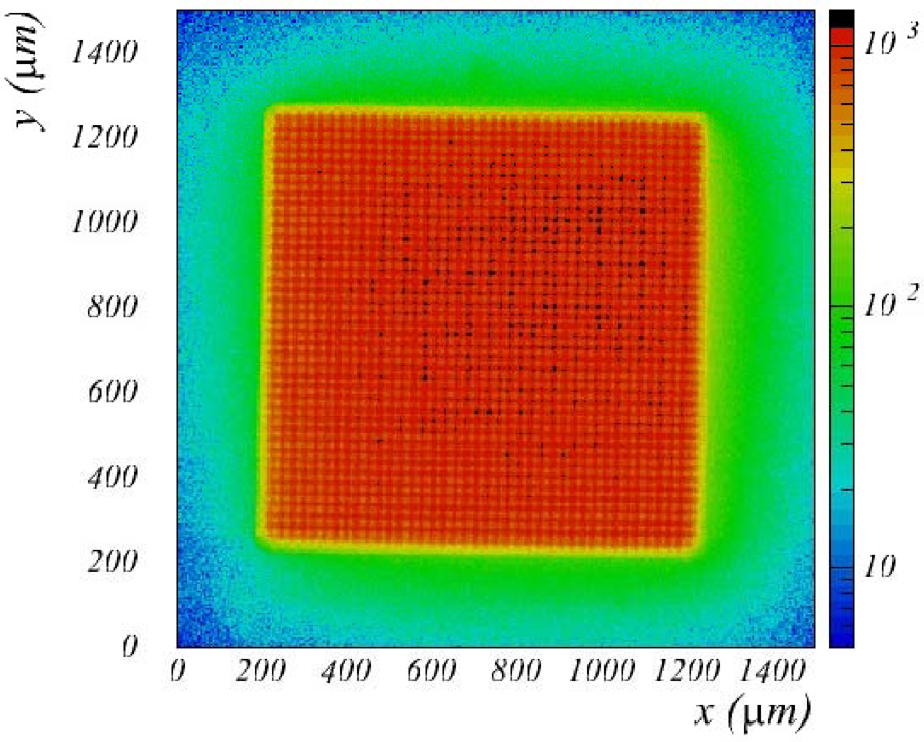
Surface sensitivity for single photons 3

Hamamatsu MPPCs

H050C



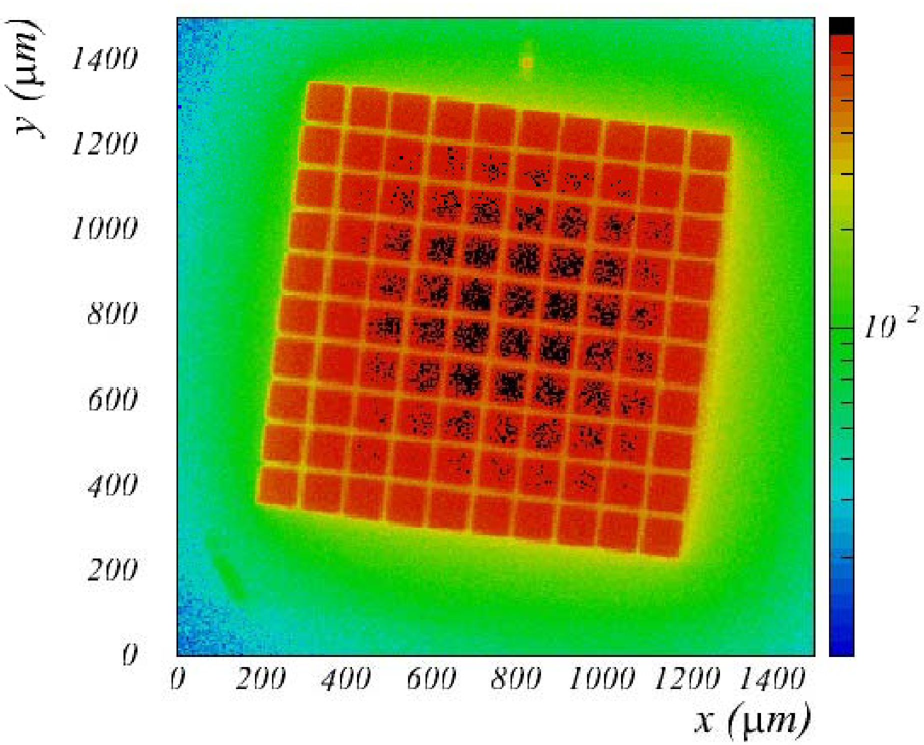
H025C

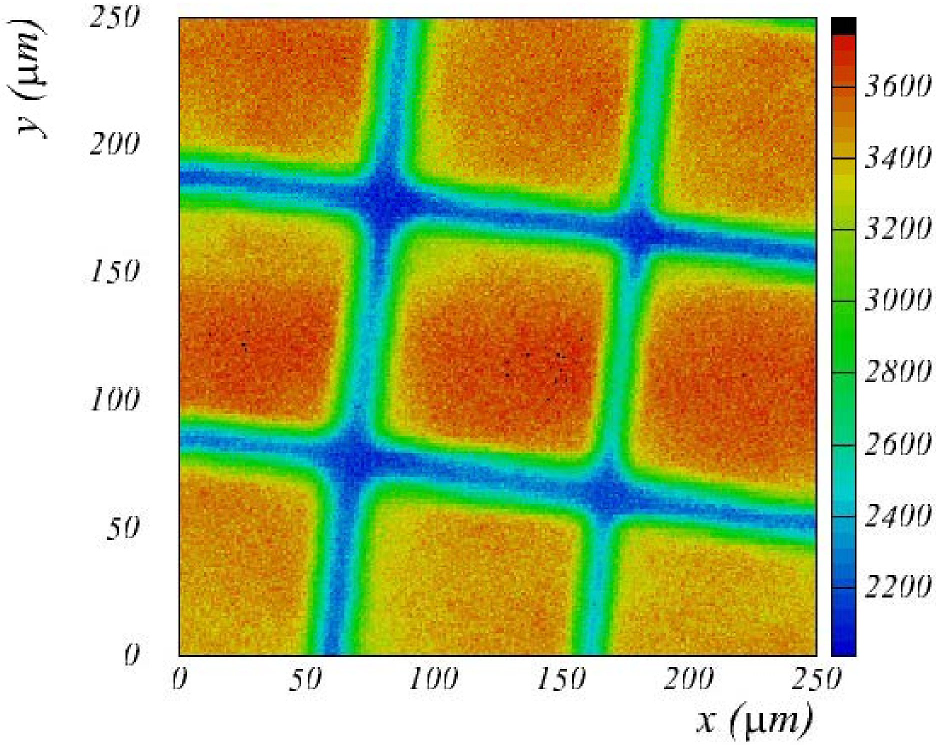


Surface sensitivity for single photons 4

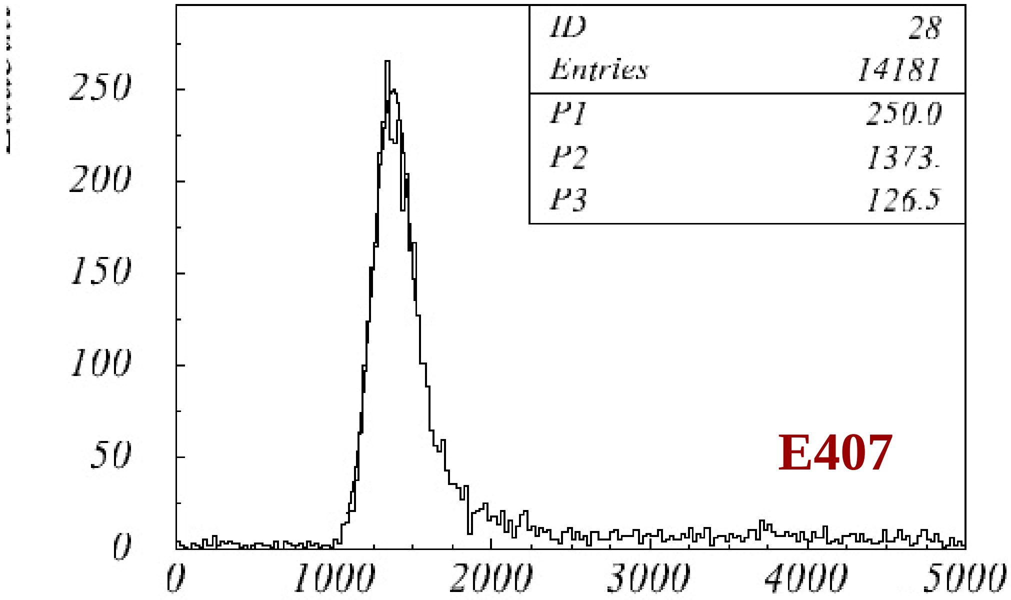
Hamamatsu MPPCs

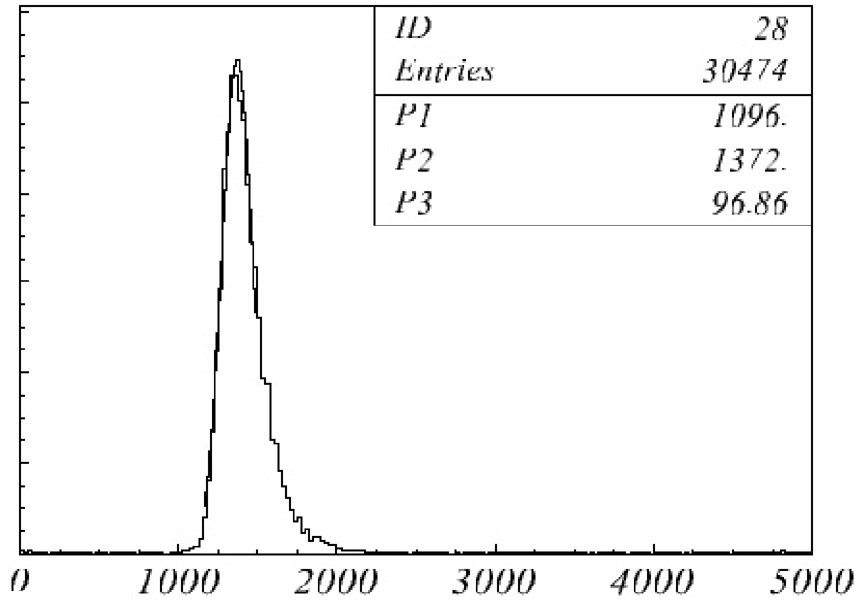
H100C





Time resolution after time walk correction: blue vs red



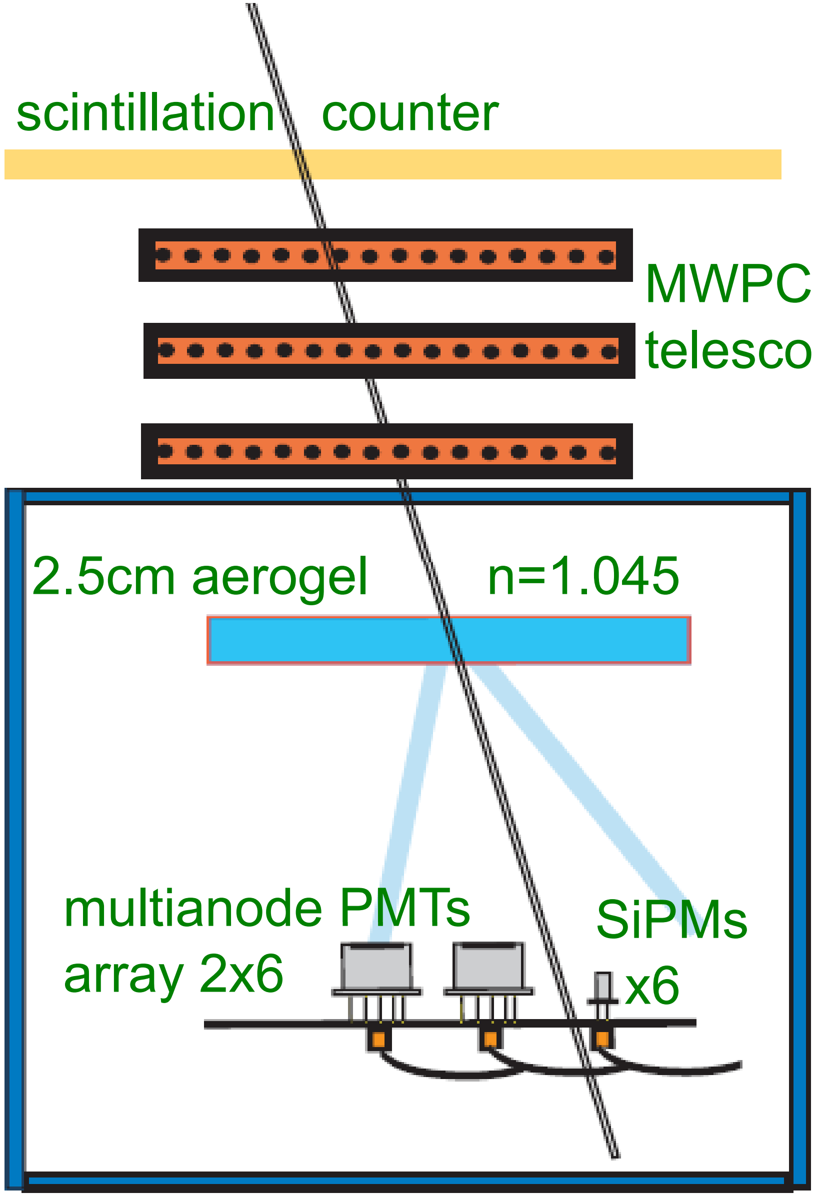


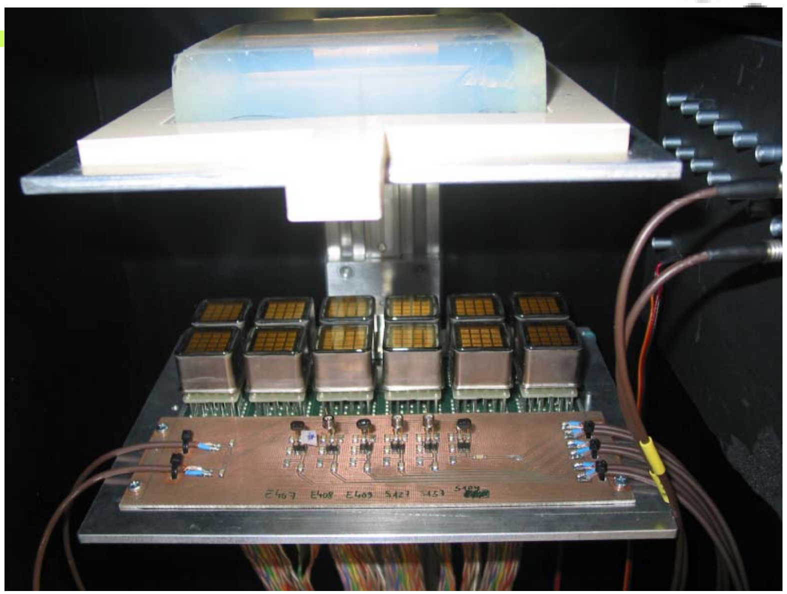
	E407	S137	H100C	H050C	H025C
σ_{red} (ps)	**127**	**182**	**145**	**212**	**154**
σ_{blue} (ps)	**97**	**151**	**136**	**358**	**135**

- $\sigma \approx 100$ ps

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

SIPMs: Cosmic test setup



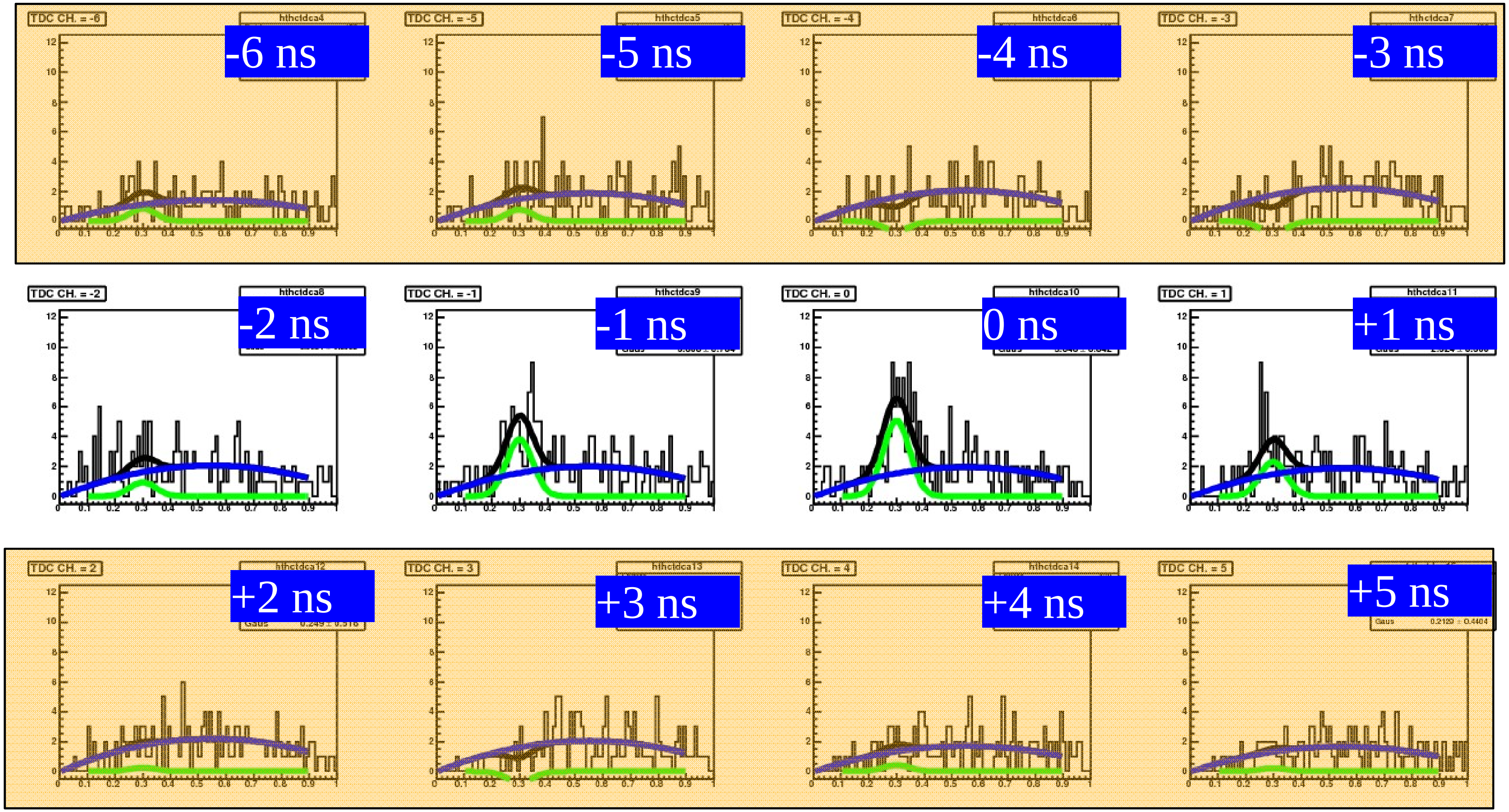


- 6 Hamamatsu SiPMs (=MPPC) of type 100U (10x10 pixels with 100µm pitch), background ~400kHz

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

→ NIM A594 (2008) 13

SiPM: Cherenkov angle distributions for 1ns time windows



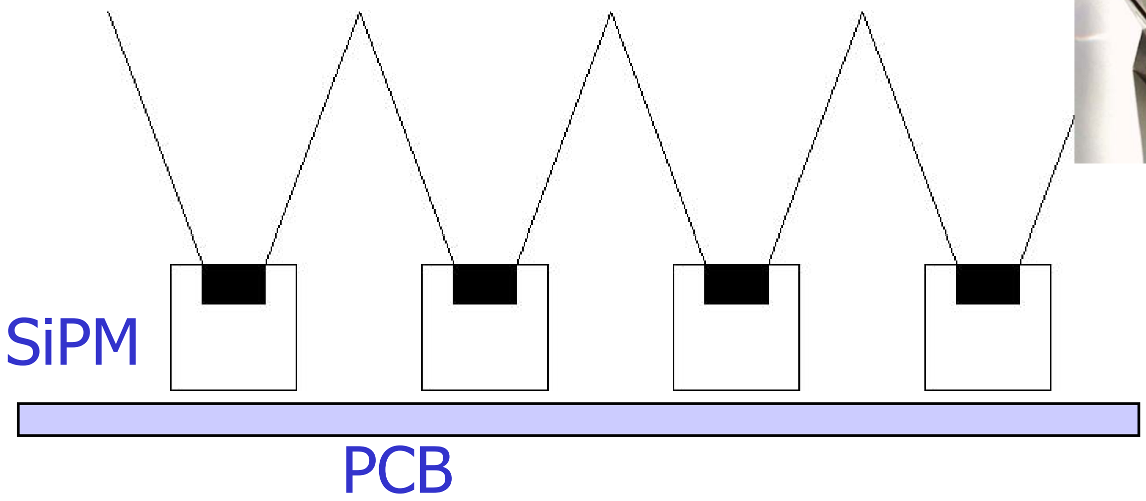
Cherenkov photons appear in the expected time windows →
First Cherenkov photons observed with SiPMs!

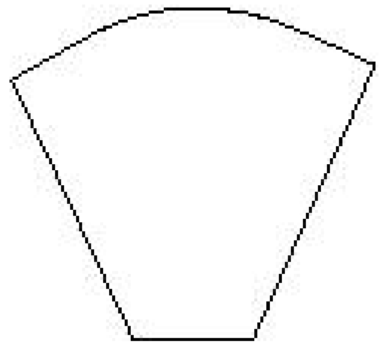
SIPMs: improving signal/noise

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

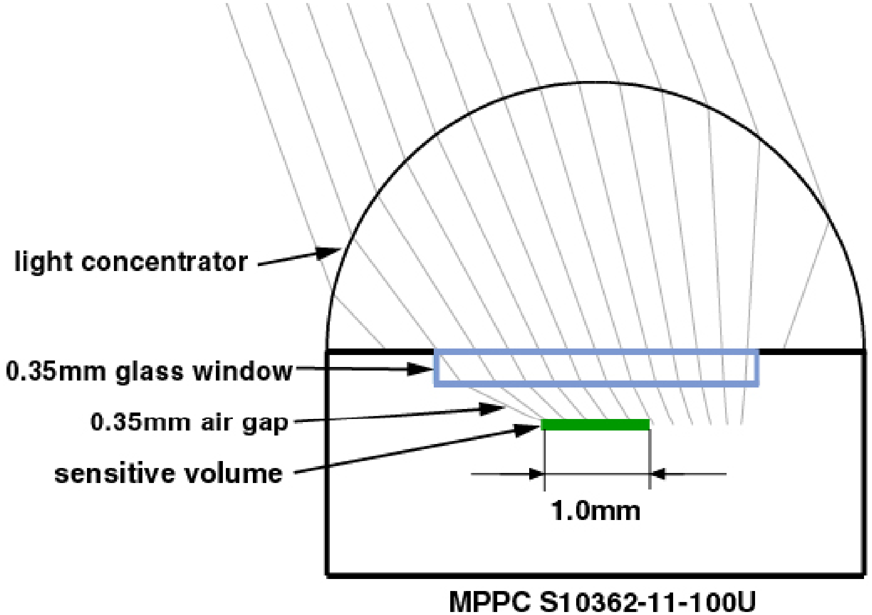


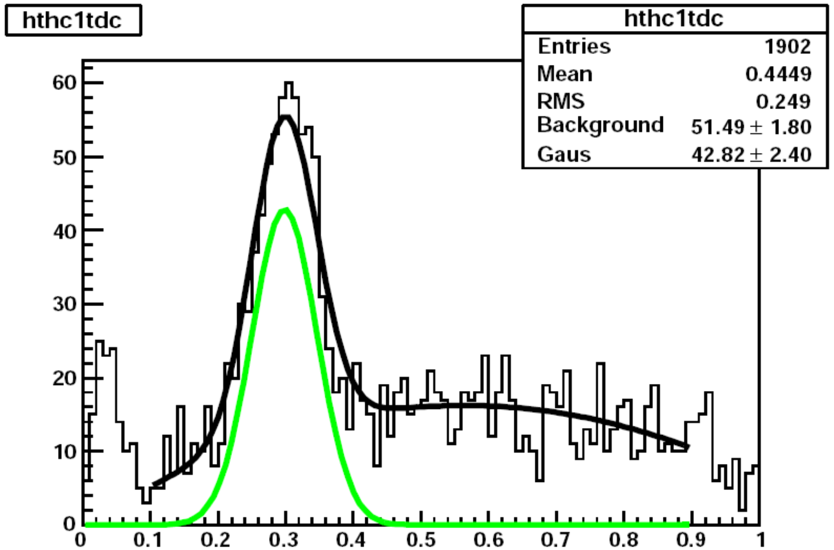


or combine a lens and mirror walls

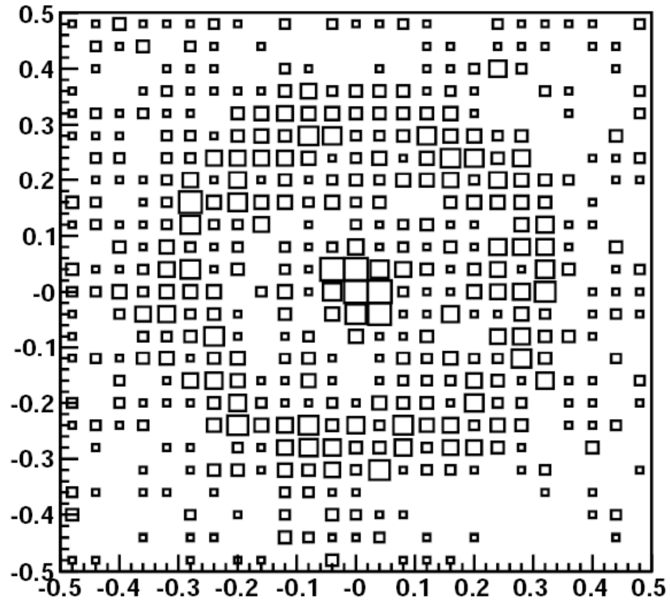
Cherenkov photons with light collectors

First attempt: use the top of a blue LED



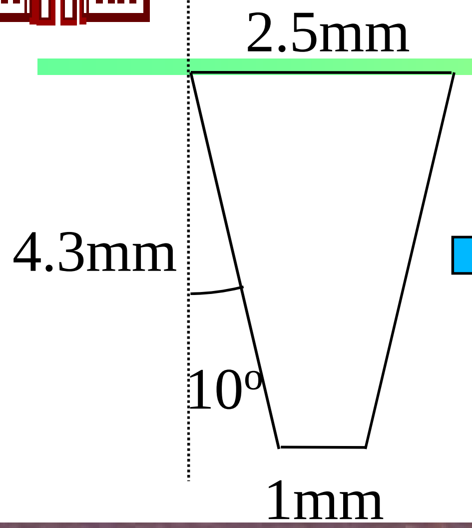


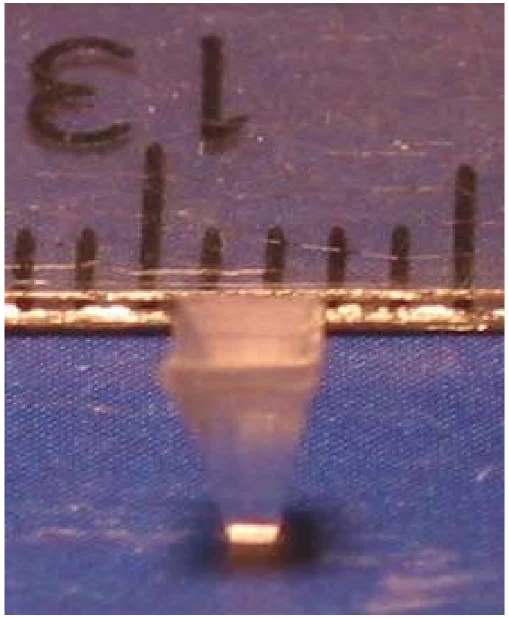
- Yield increase in agreement with the expectations
- Further improvements possible by
  - Using SiPMs with a reduced epoxy protective layer
  - using a better light collector

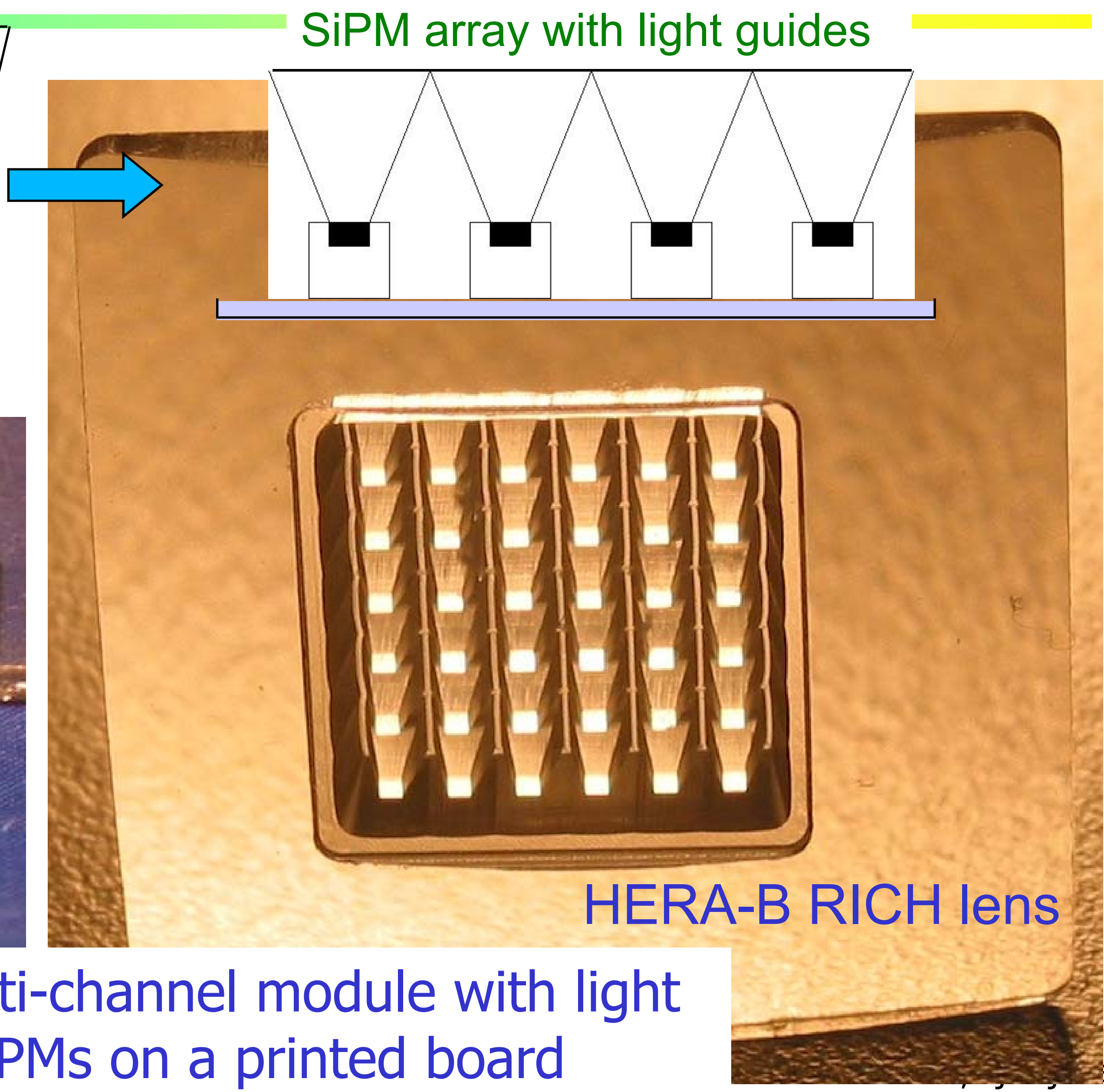


Hits in Cherenkov space

Detector module design



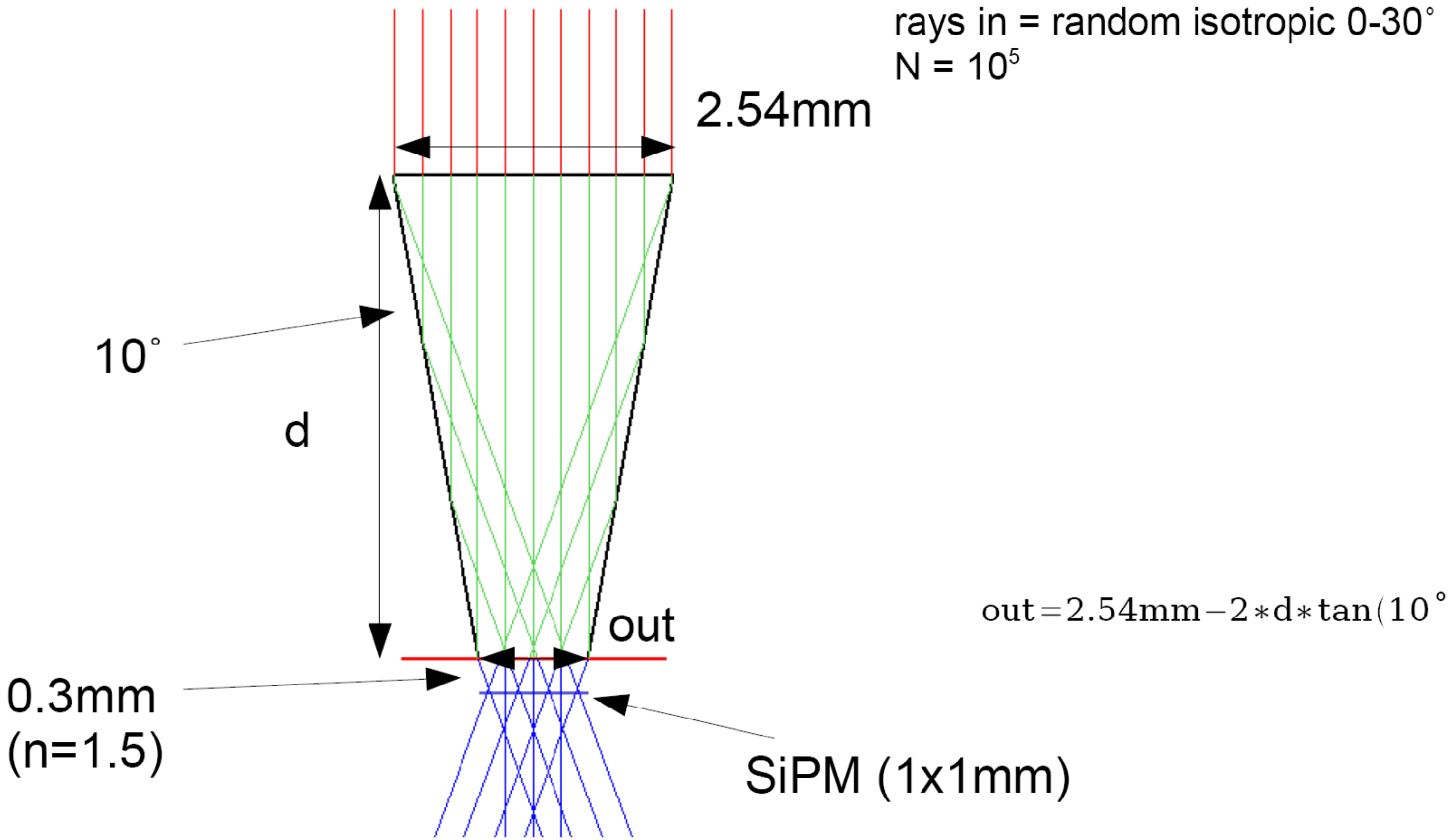




Aim: build a multi-channel module with light collectors and SiPMs on a printed board

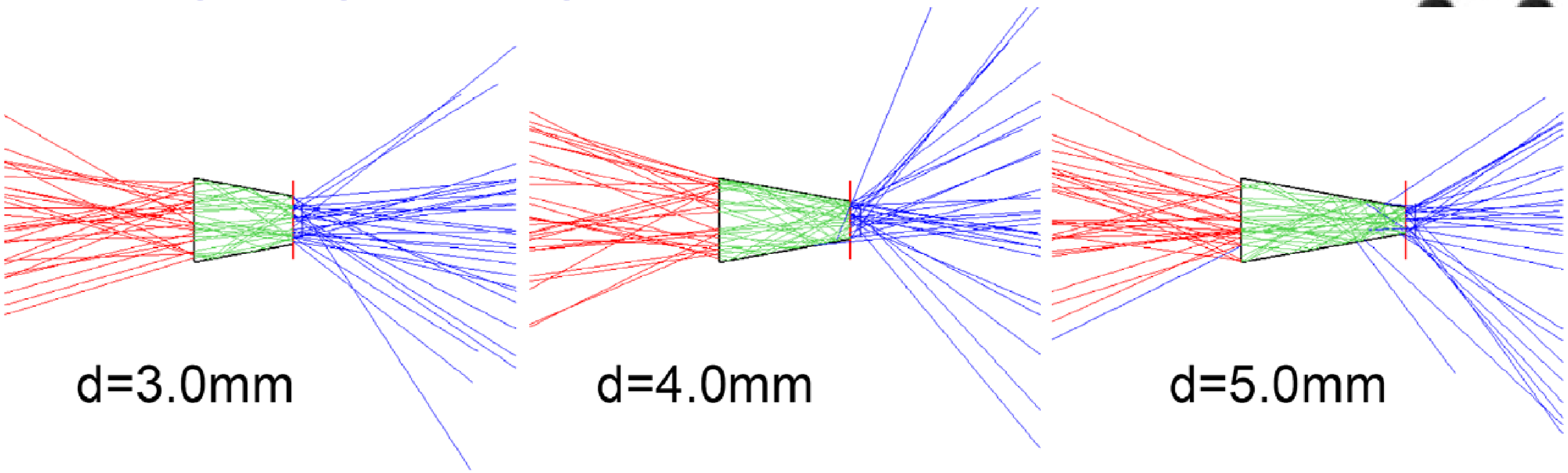
Light guide geometry optimisation

Light Guide Acceptance / (d and out)

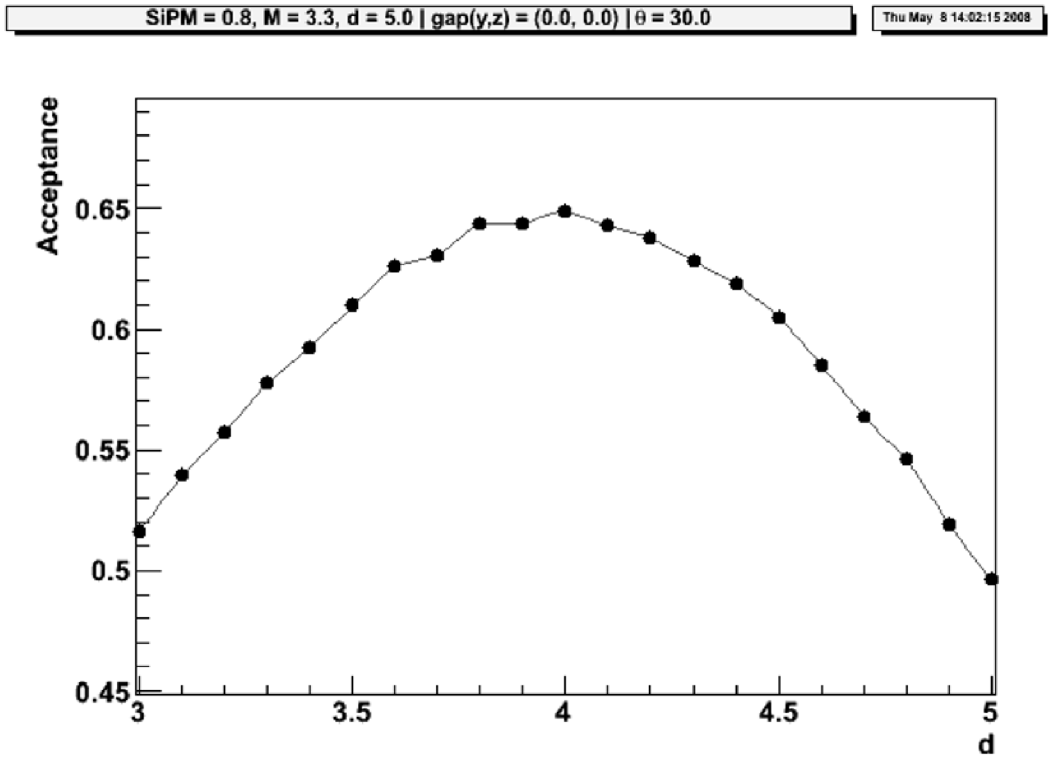


$$out = 2.54mm - 2 * d * \tan(10^\circ)$$

Light guide geometry optimisation

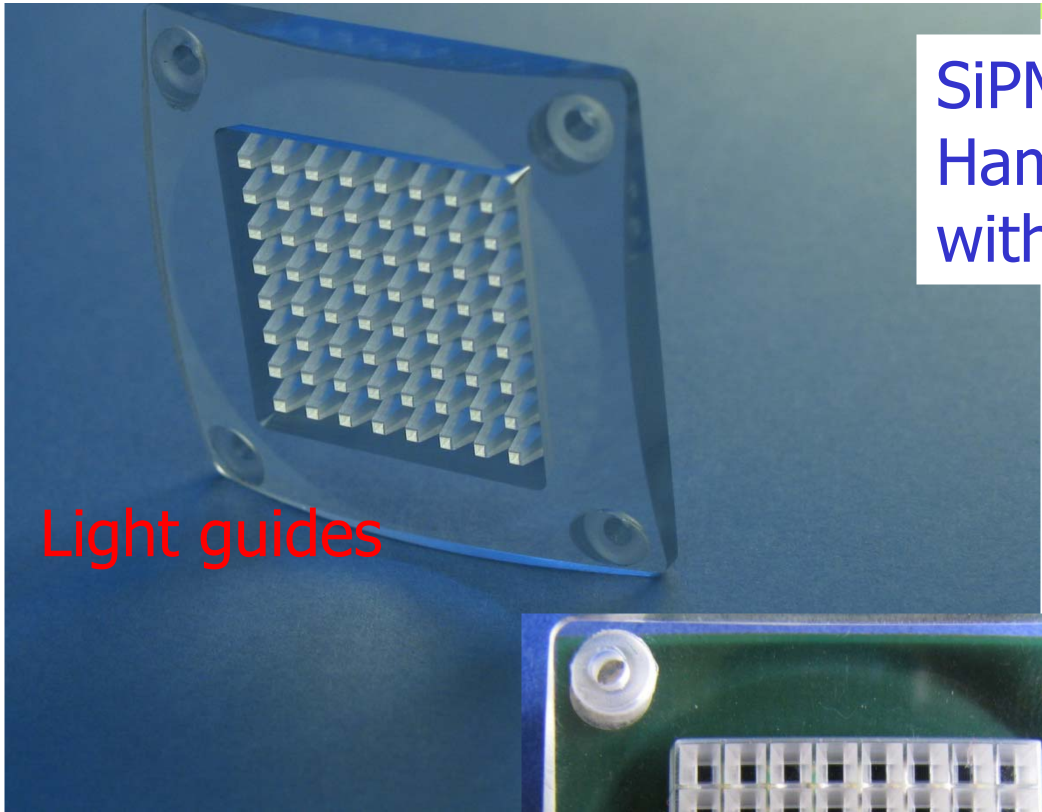


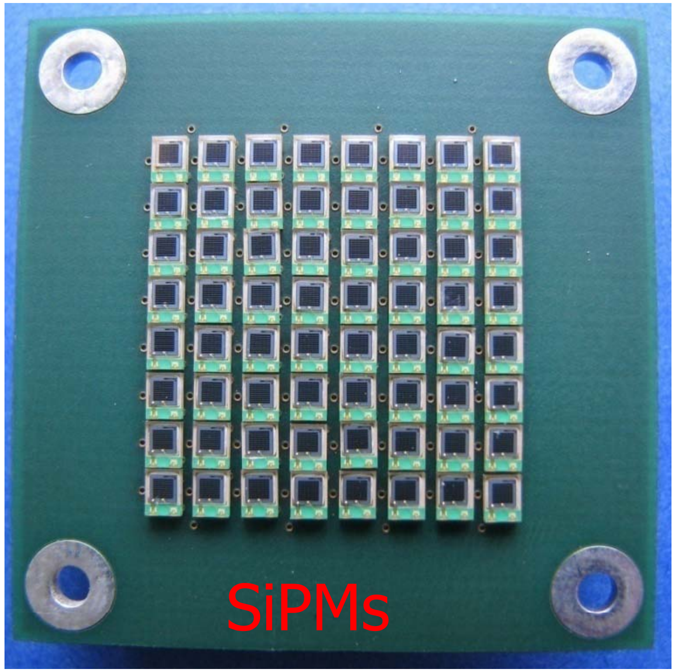
d (mm)	out (mm)	accept. (%)
3.0	1.48	51.6
3.1	1.45	54.0
3.2	1.41	55.7
3.3	1.38	57.8
3.4	1.34	59.2
3.5	1.31	61.0
3.6	1.27	62.6
3.7	1.24	63.1
3.8	1.20	64.4
3.9	1.16	64.4
4.0	**1.13**	**64.9**
4.1	1.09	64.3
4.2	1.06	63.8
4.3	1.02	62.8
4.4	0.99	61.8
4.5	0.95	60.5
4.6	0.92	58.5
4.7	0.88	56.4
4.8	0.85	54.6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



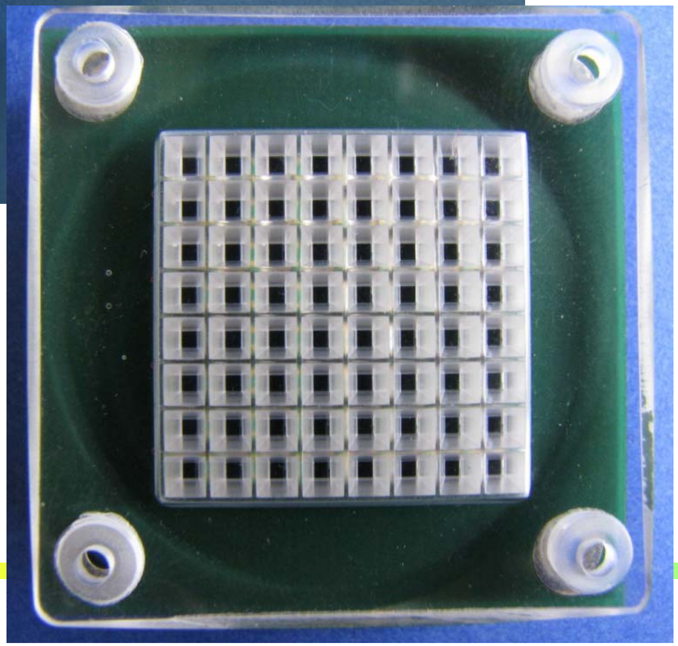
Detector module for beam tests at KEK and CERN

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

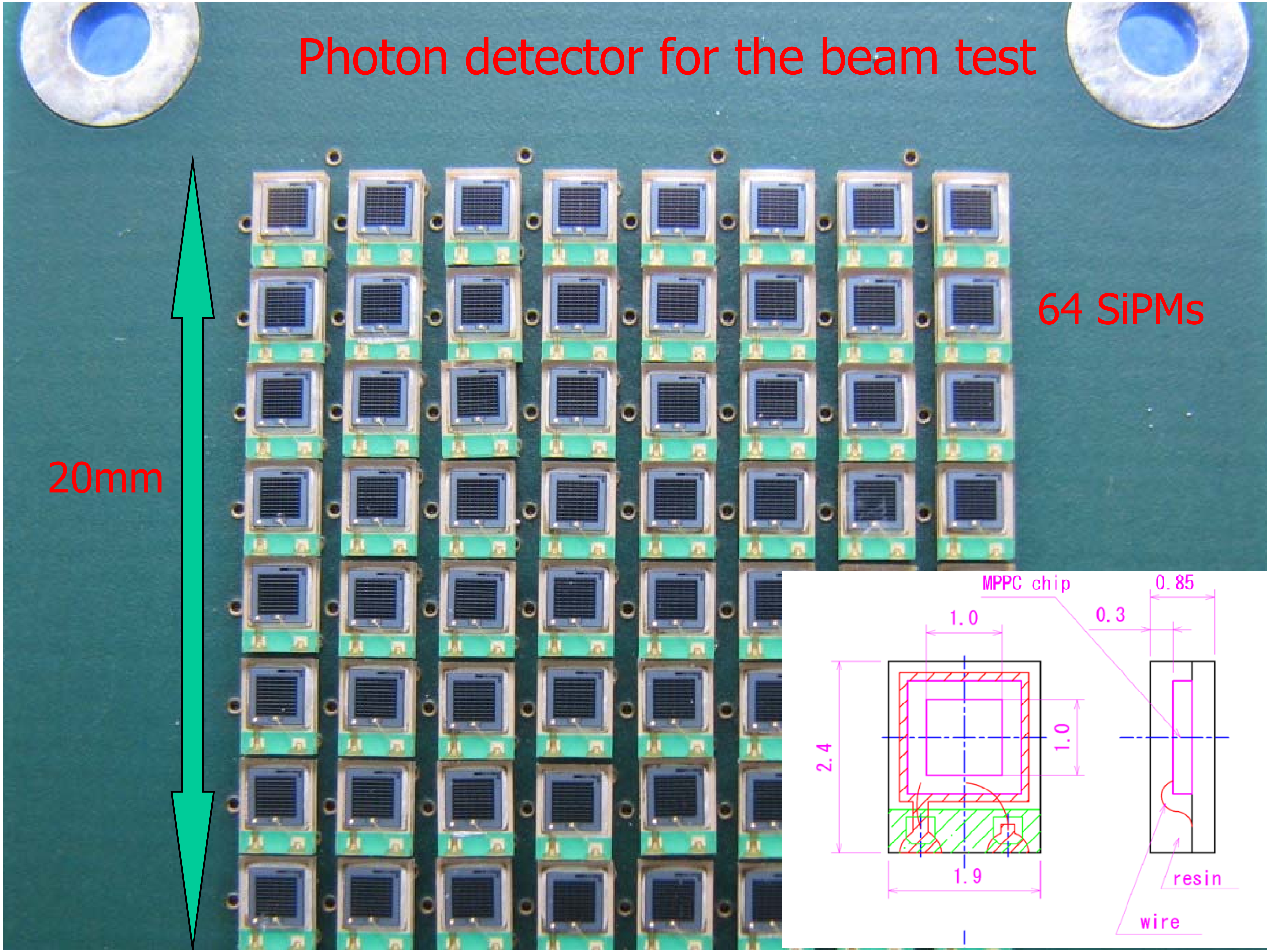




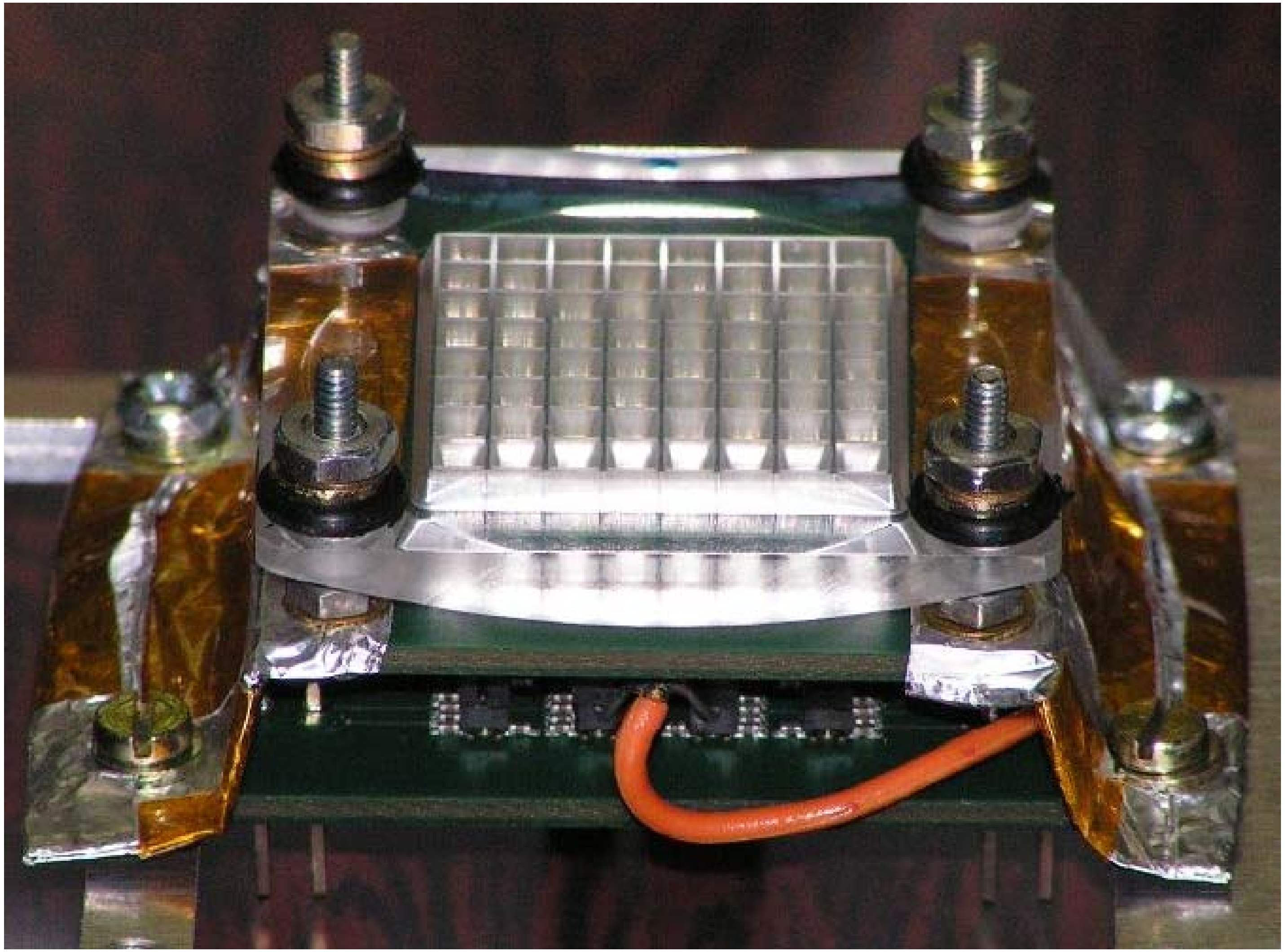
2cm



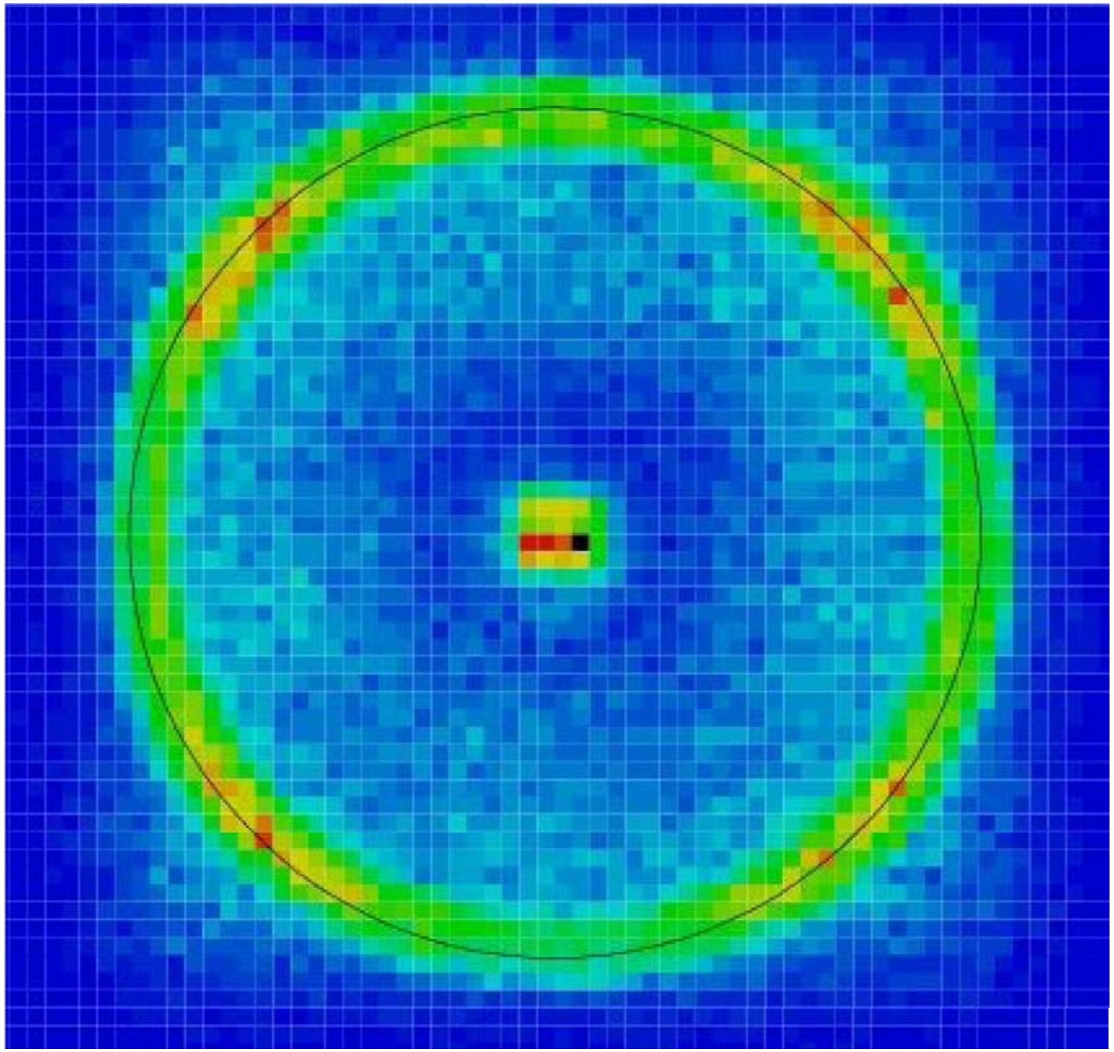
SiPMs + light guides


Photon detector for the beam test
64 SiPMs
20mm
MPPC chip
0.85
1.0
0.3
2.4
1.0
1.9
resin
wire

SiPM module with light guides, bais supply and signal routing board



Cherenkov ring with SiPMs

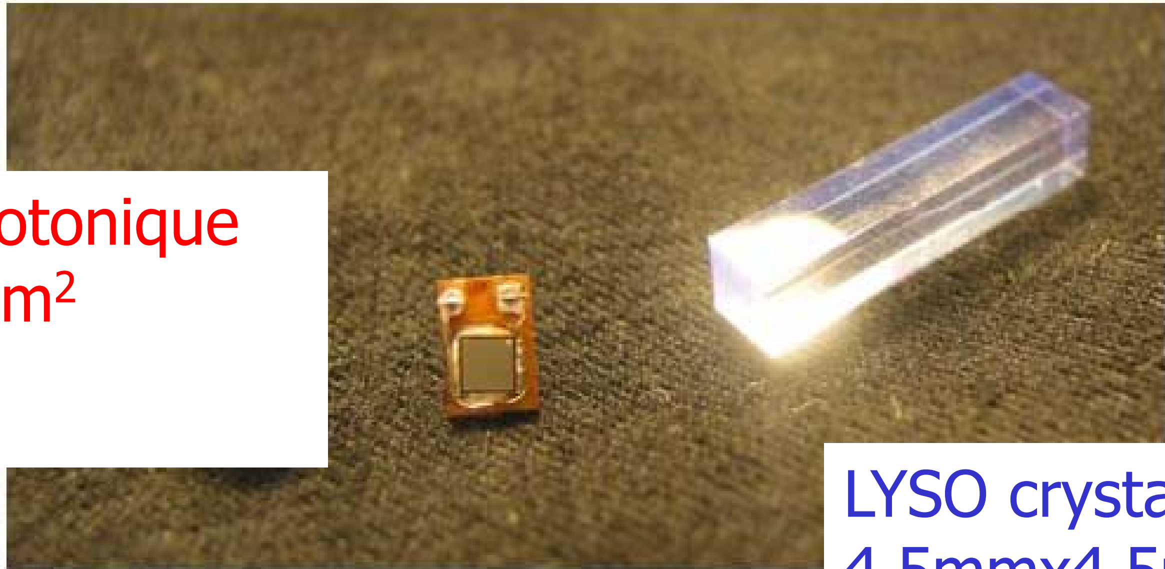


Studies of a PET module

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

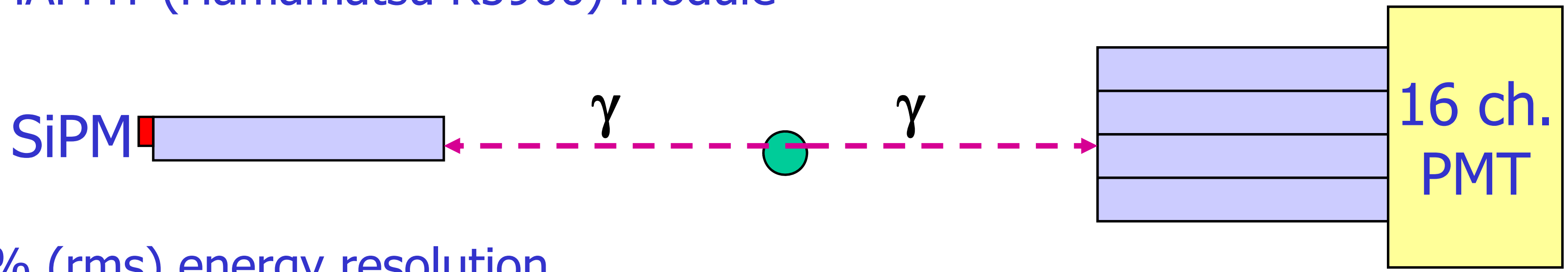


SiPMs: Photonique 2.1x2.1 mm^2

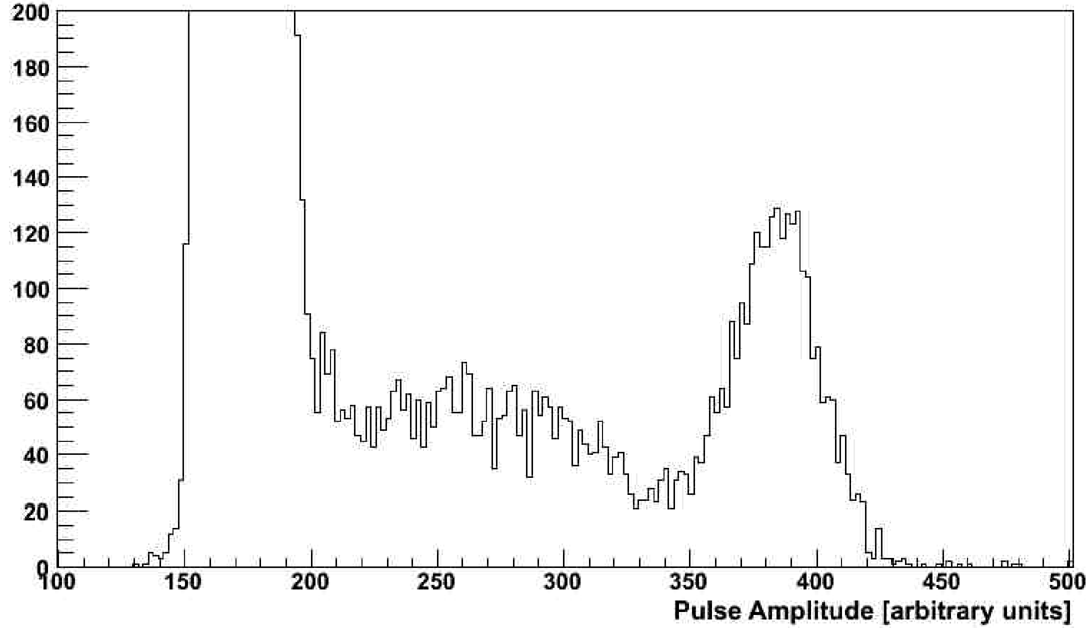
LYSO crystals 4.5mmx4.5mm

Studies of a PET module 2

2007: LYSO+SiPM tests with ^{22}Na in coincidence with a 4x4 LYSO + MAPMT (Hamamatsu R5900) module



~8% (rms) energy resolution

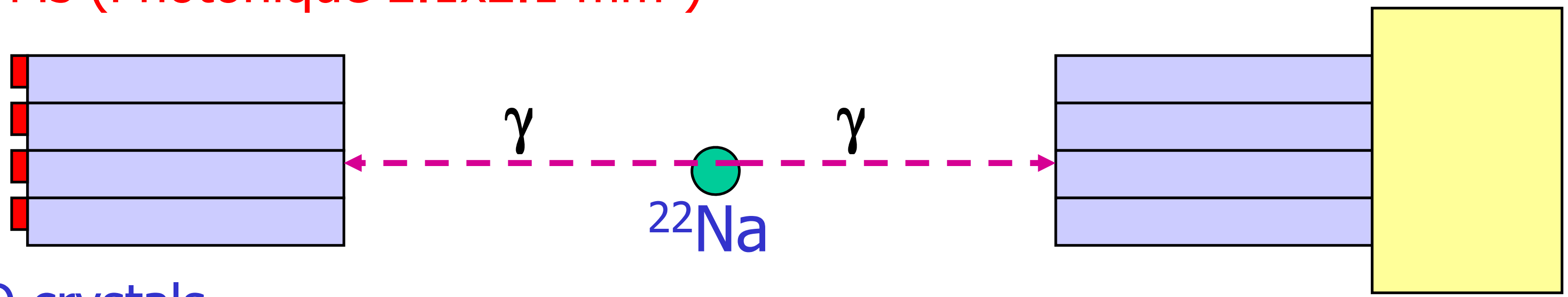


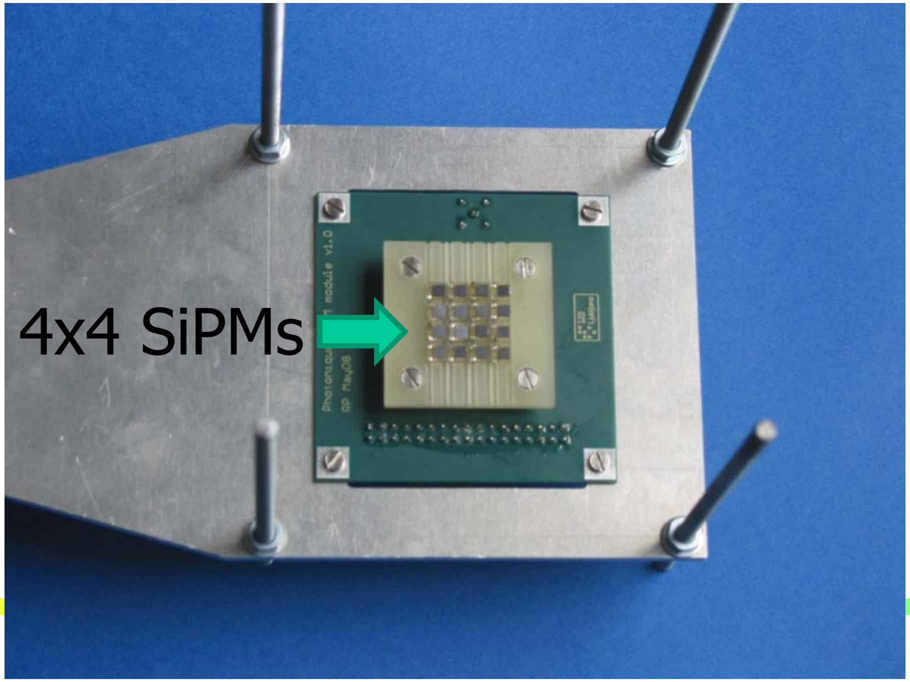
Studies of a PET module

Testing a PET module with:

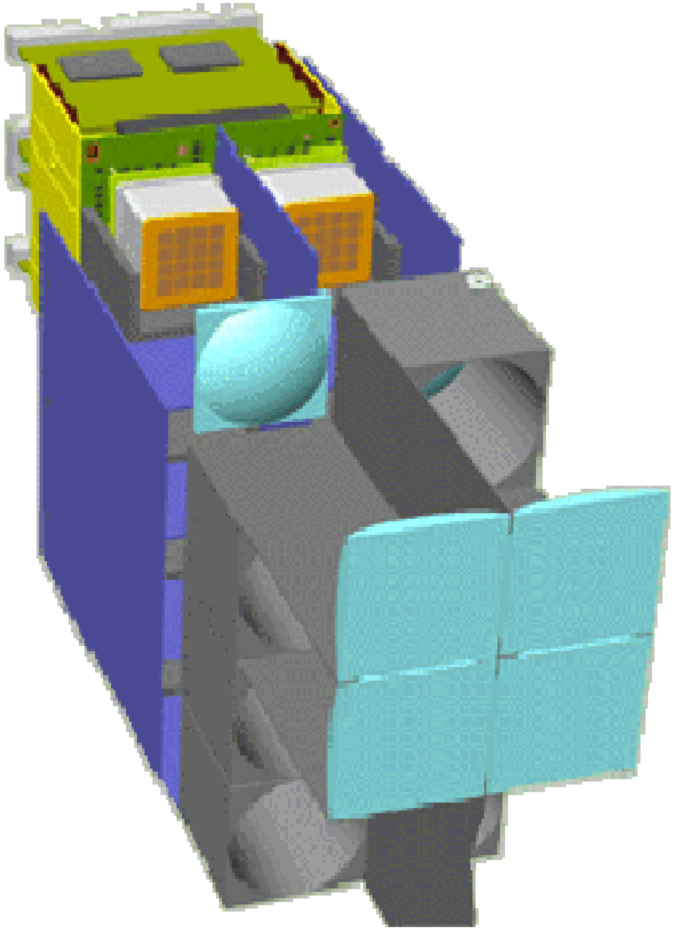
4x4 array of LYSO crystals (4.5 x 4.5 x 20(30) mm^3)

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





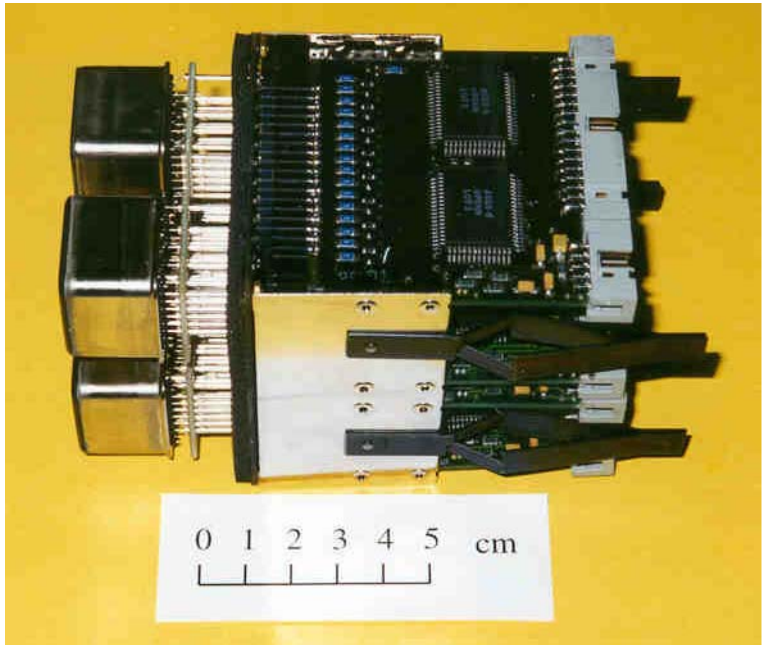
Read-out electronics



Experience with photon detector read-out system of the HERA-B RICH

•Front-end electronics board

•Voltage divider and signal routing board

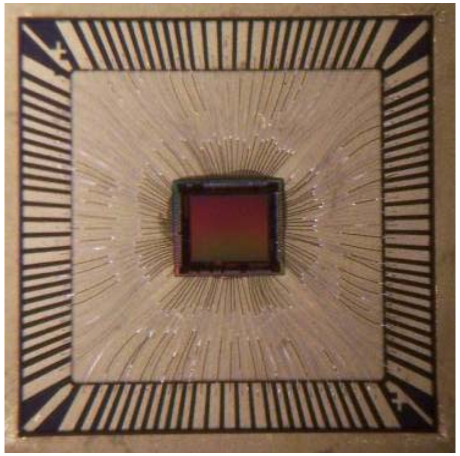


Read-out electronics 2

Read-out system for the Belle upgrade:

→Testing a waveform sampler based system as developed by G. Varner et al. at University of Hawaii.

→Very interesting also in combination with TOF PET

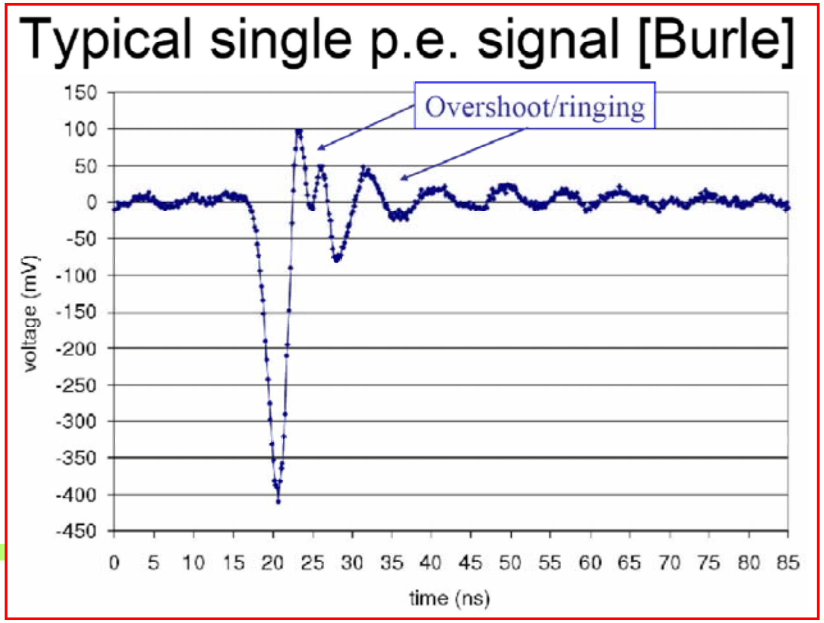


3mm x 2.8mm, TSMC 0.25um

- 64k samples deep
- Multi-MSa/s to Multi-GSa/s

Variant of the LABRADOR 3

Successfully flew on ANITA in Dec 06/Jan 07 (<= 50ps timing)



DAQ systems

We have considerable experience in DAQ in

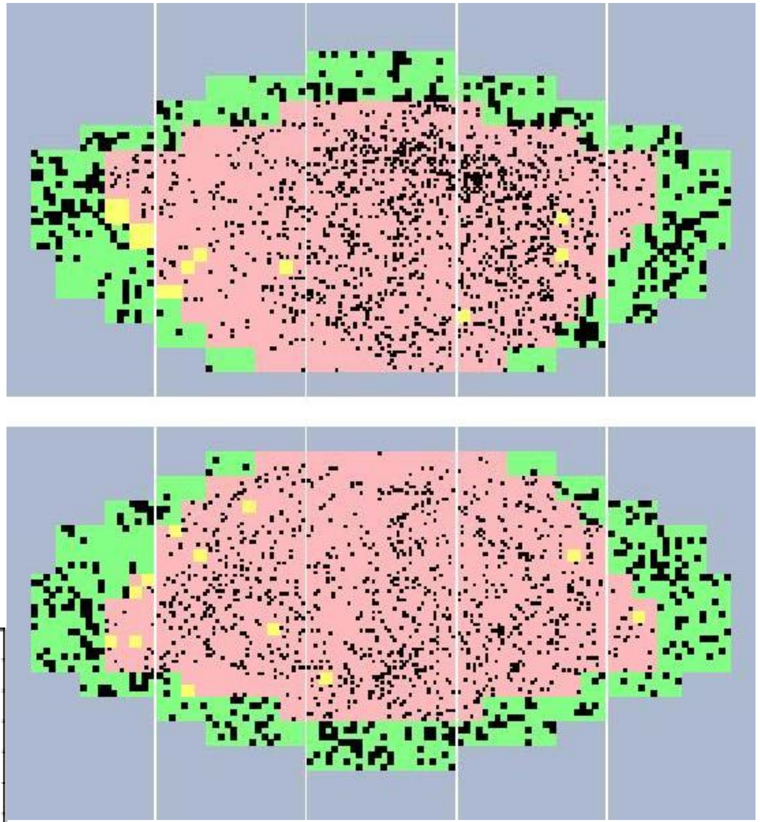
- large systems of spectrometers (HERA-B, Belle)
- stand-alone systems (test beams)

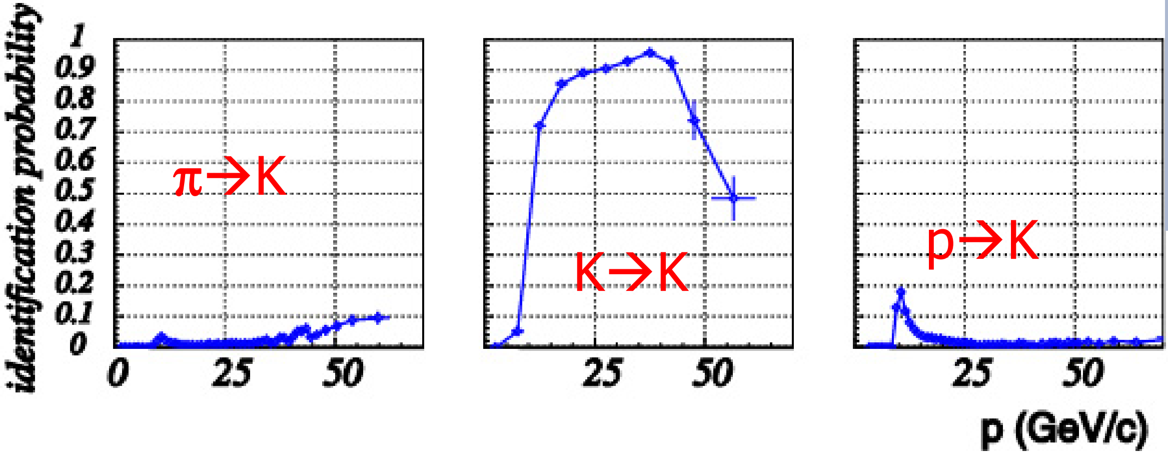
Data analysis

Experience from HERA-B RICH: successful analysis of complicated data patterns → employed a derivative of the expectation maximisation algorithm as used in PET image reconstruction

→Excellent particle identification performance in spite of a very hostile environment!

HERA-B RICH event: rings are well hidden...





Summary

Ljubljana has considerable experience relevant for this project:

•Photon detectors for high magnetic fields

•Low noise electronics

•DAQ

•Image reconstruction

•Geant4 MC

PET expertise:

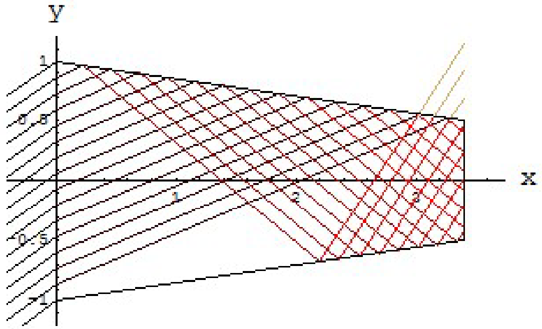
•wire chamber based PET system in nineties (including simulation and reconstruction)

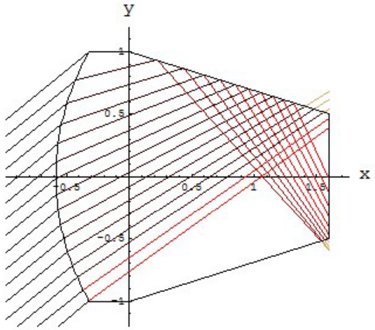
•small SiPM PET module

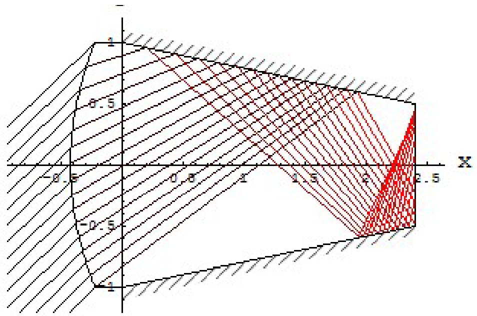
We hope to use this meeting to see how we fit in...

Back-up slides

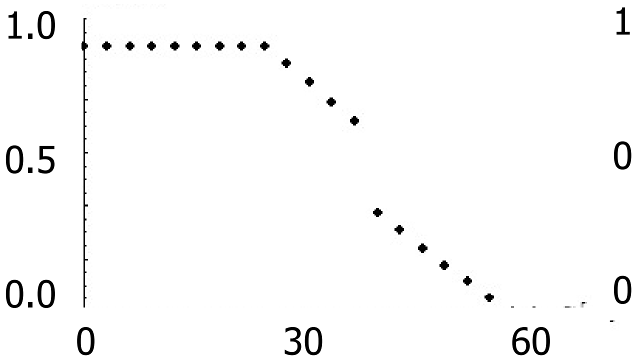
Planar entry window | **Spherical entry window** | **Spherical entry window, reflective sides**

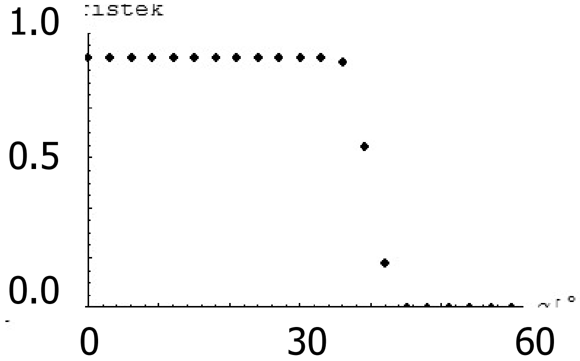


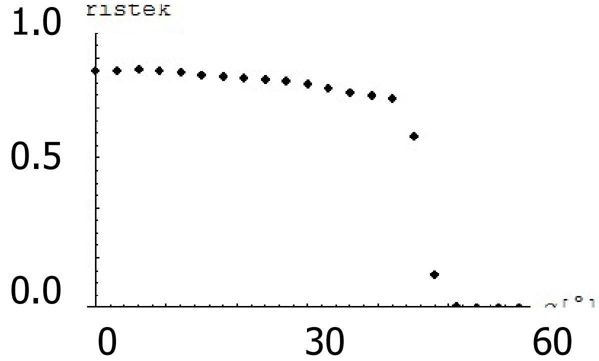




Efficieny vs. angle of incidence α



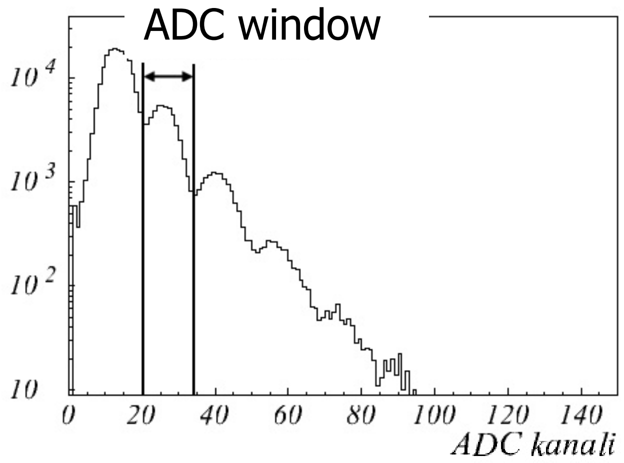




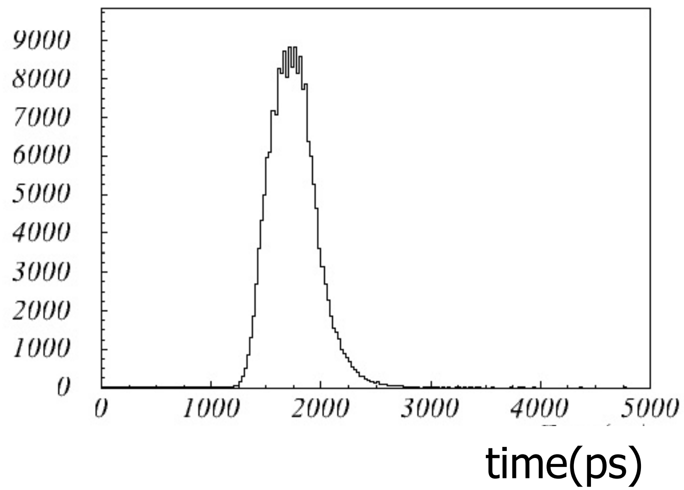
Light guide	d/a	R/a	α_{min} , α_{max}	I(-60°, 60°)
Planar entry	**3.4**	-	**-24°, 24°**	**64%**
Sph. entry	**1.6**	**2.0**	**-35°, 35°**	**66%**
Reflective sides	**2.4**	**2.6**	**-44°, 44°**	**69%**

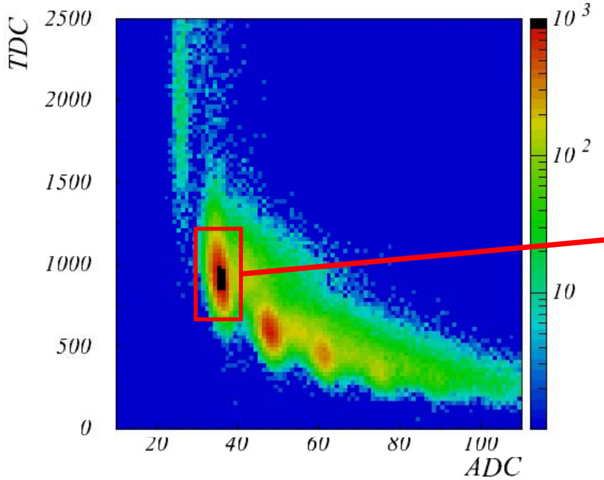
Time resolution: time walk correction

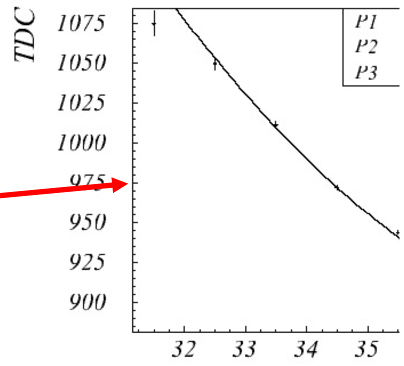
<< 1 photon



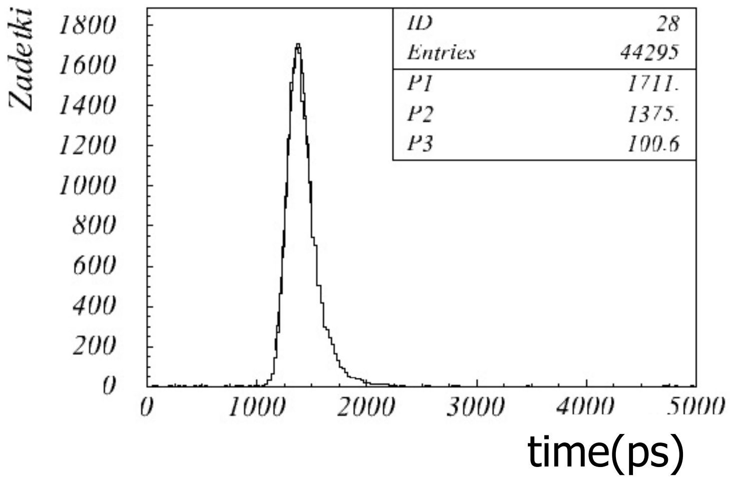
uncorrected TDC







corrected TDC



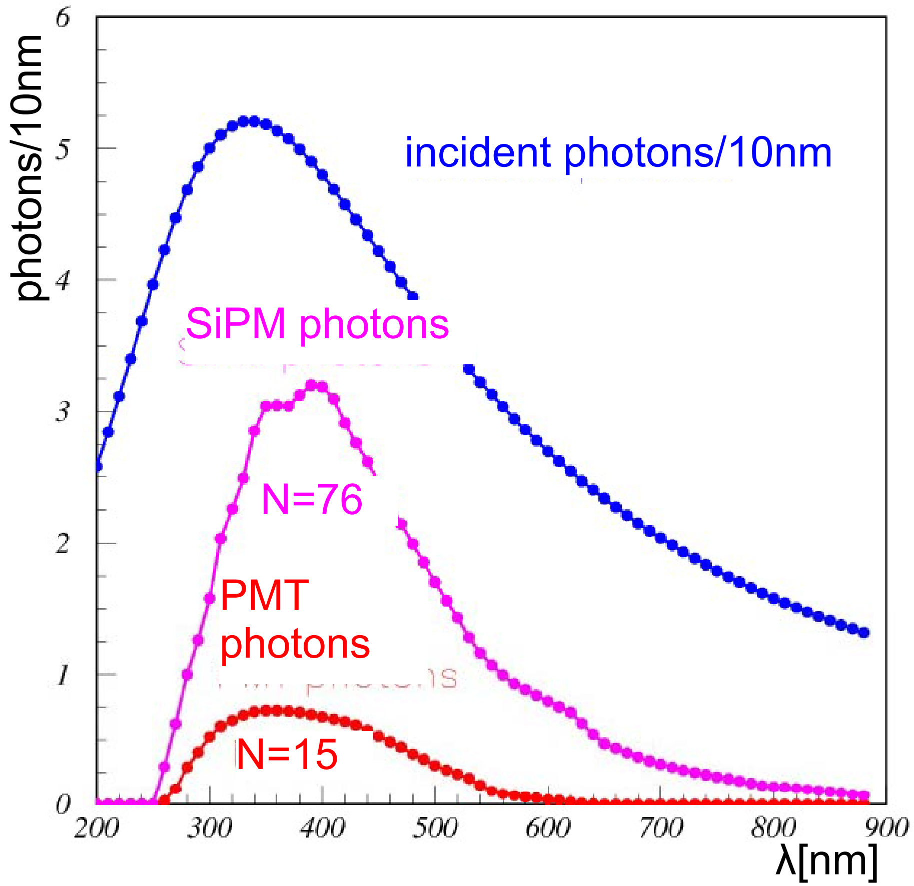
Expected number of photons for aerogel RICH

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

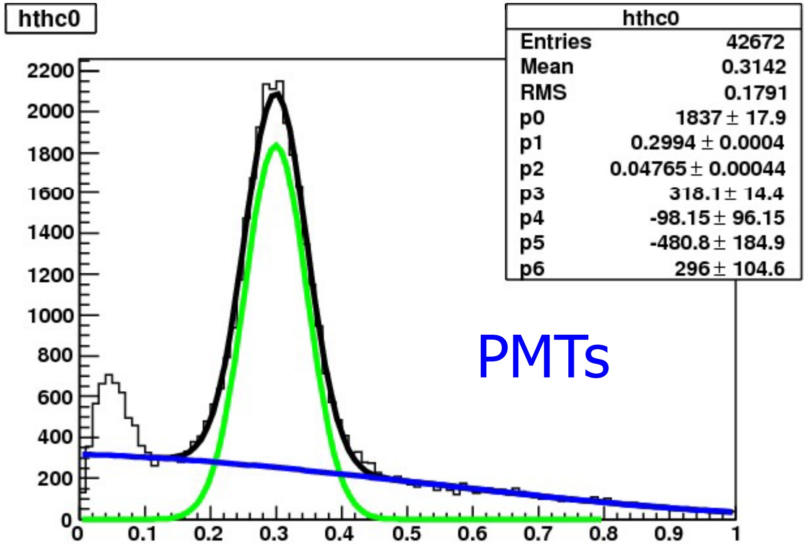
N_{SiPM}/N_{PMT}~5

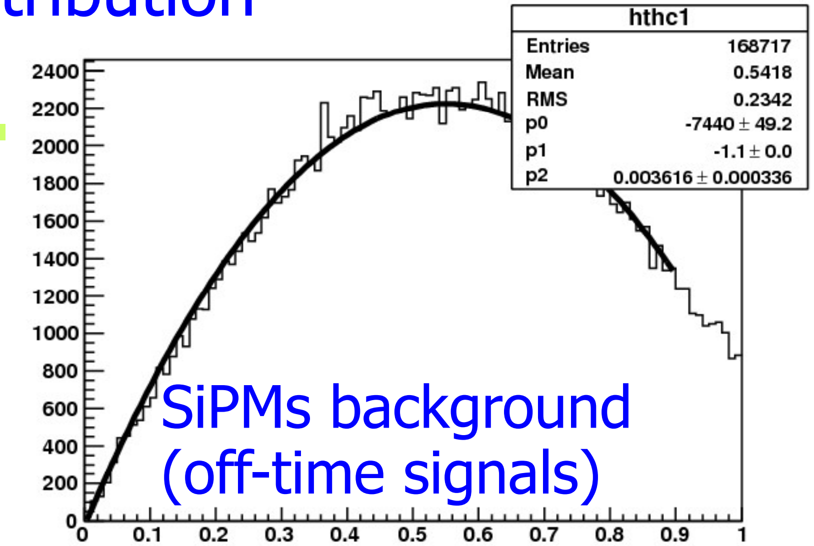
Assuming 100% detector active area

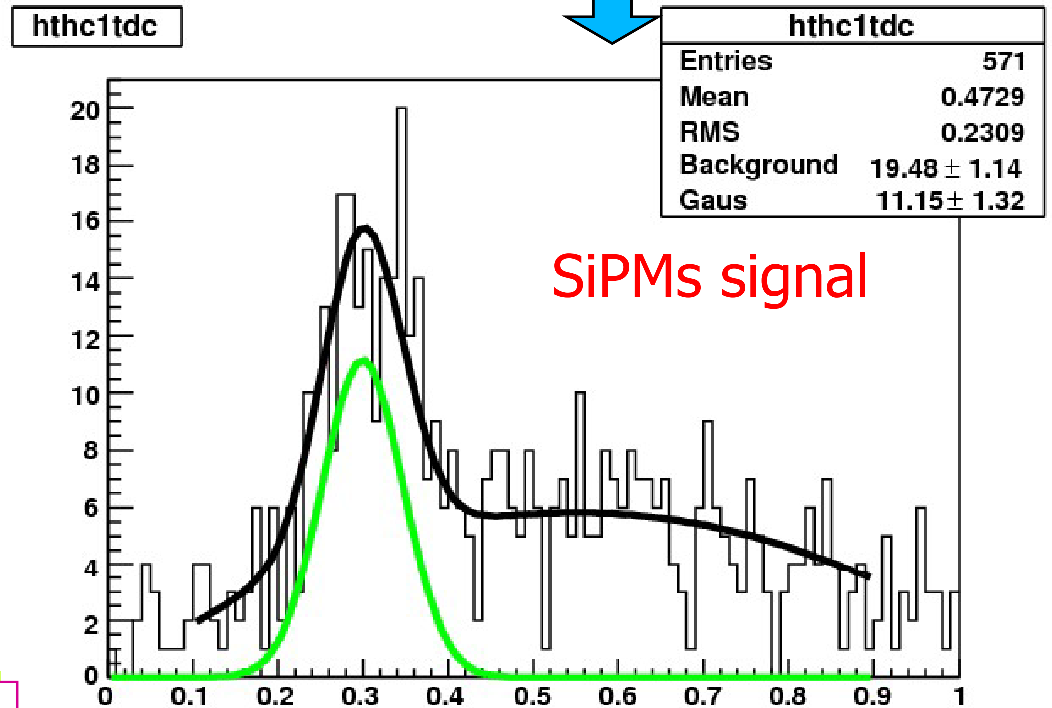
Never before tested in a RICH where we have to detect single photons. ← Dark counts have single photon pulse heights (rate 0.1-1 MHz)



SiPM Cherenkov angle distribution







Fit function is a combination of

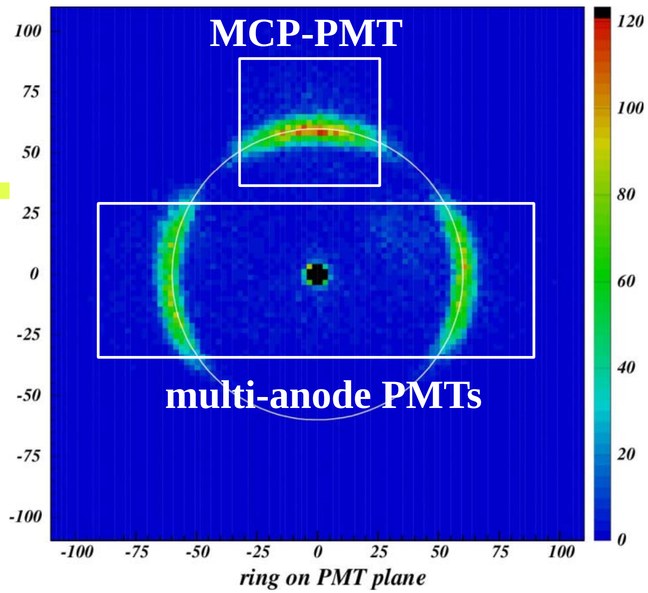
- a background (quadratic) and
- a signal (Gaussian).

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

Photon detector candidate: MCP-PMT

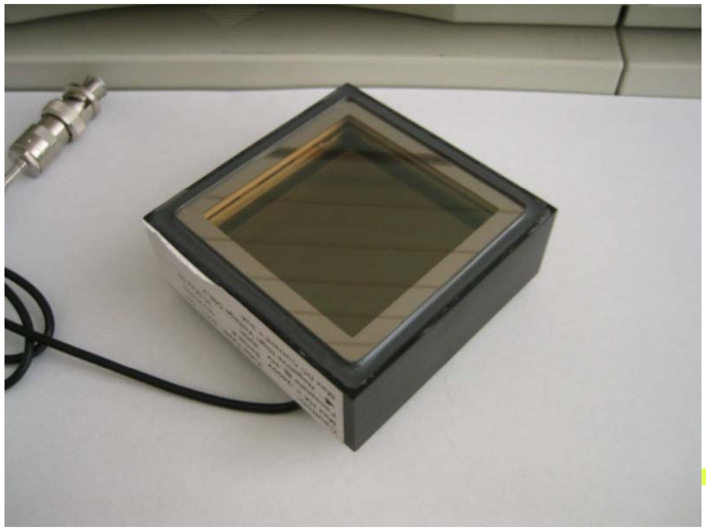


BURLE 85011 MCP-PMT:

- 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