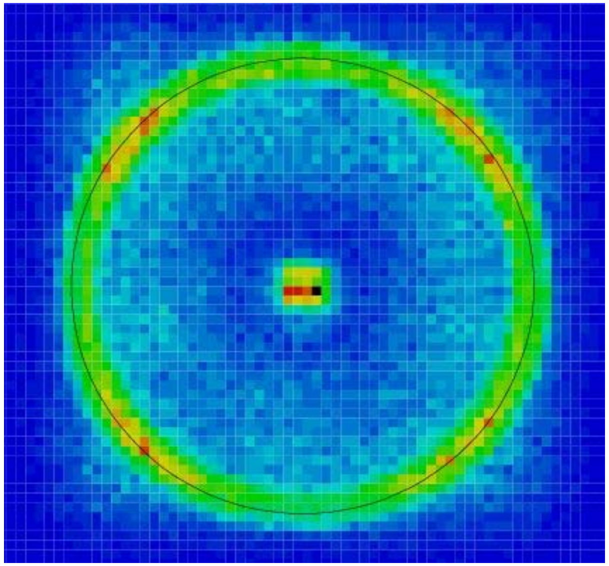
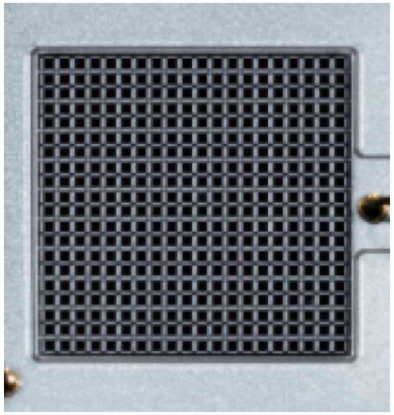




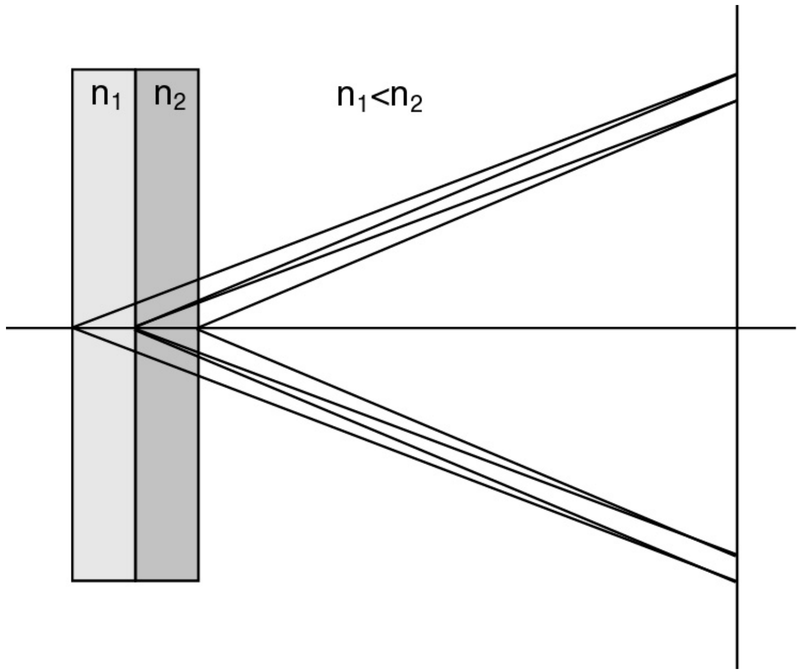
Photon detector R+D for the forward PID device

Peter Križan

University of Ljubljana and J. Stefan Institute

SuperB meeting Orsay, Februar 16, 2009

Forward PID device candidate: proximity focusing RICH



"focusing" configuration: stack two or more tiles with different refractive indices → NIM A548 (2005) 383

K/π separation at 4 GeV/c

$\theta_c(\pi)$ ~ 308 mrad (n = 1.05)

$\theta_c(\pi) - \theta_c(K)$ ~ 23 mrad

$\delta\theta_c$(meas.) = σ_0 ~ 14 mrad,

typical value for a 20mm thick radiator and 6mm PMT pad size

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

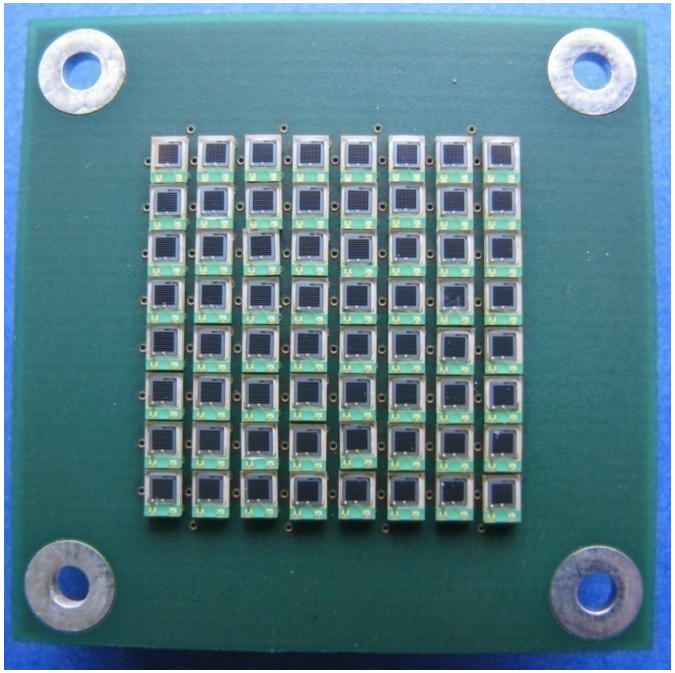
Separation: $[\theta_c(\pi) - \theta_c(K)]/\sigma_{track}$

→ 5σ separation with N_{pe}~10

→need a highly efficient photon detector for 1.5 T

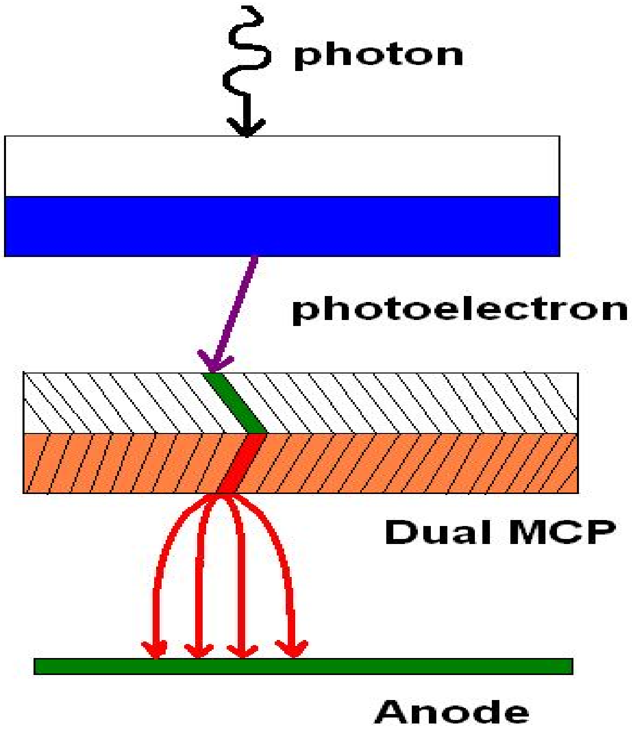
Contents

- Update on SiPM as single photon counter
- Update of Photonis/Burle MCP PMT



Photon detector candidate: MCP-PMT

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



→excellent performance in beam and bench tests

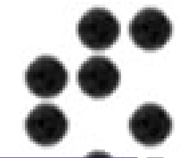
→ very fast (σ~40ps for single photons)

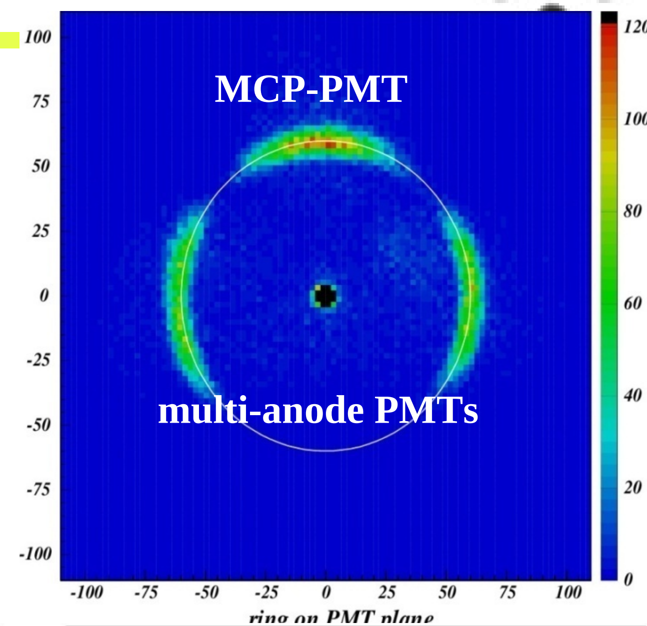
Measured properties of BURLE MCP-PMTs

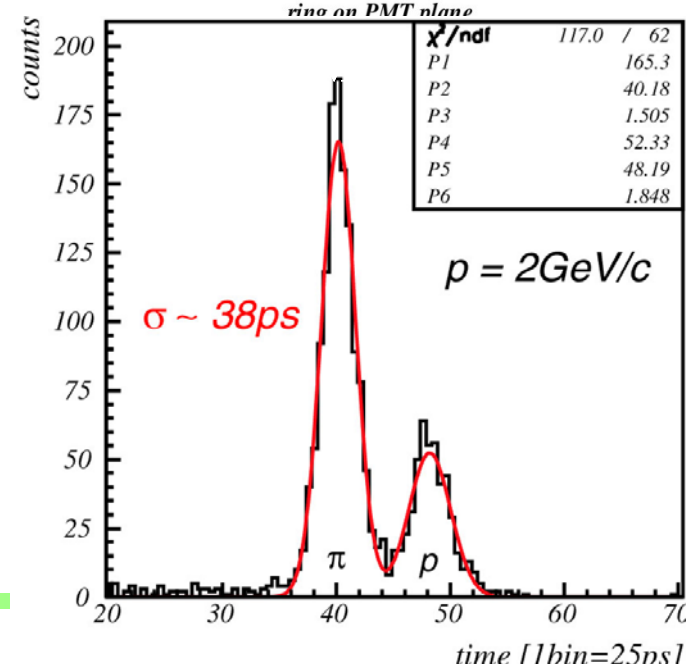
Performance in **beam** tests:

- very stable
- σ_ϑ~15 mrad (single hit)
- number of hits per track N~ 11 for a closely packed tubes
- → σ_ϑ~ 4 mrad (per track) → > 5 σ π/K separation at 4 GeV/c
- fast (40ps single photon resolution)

→ Can be used as a TOF counter



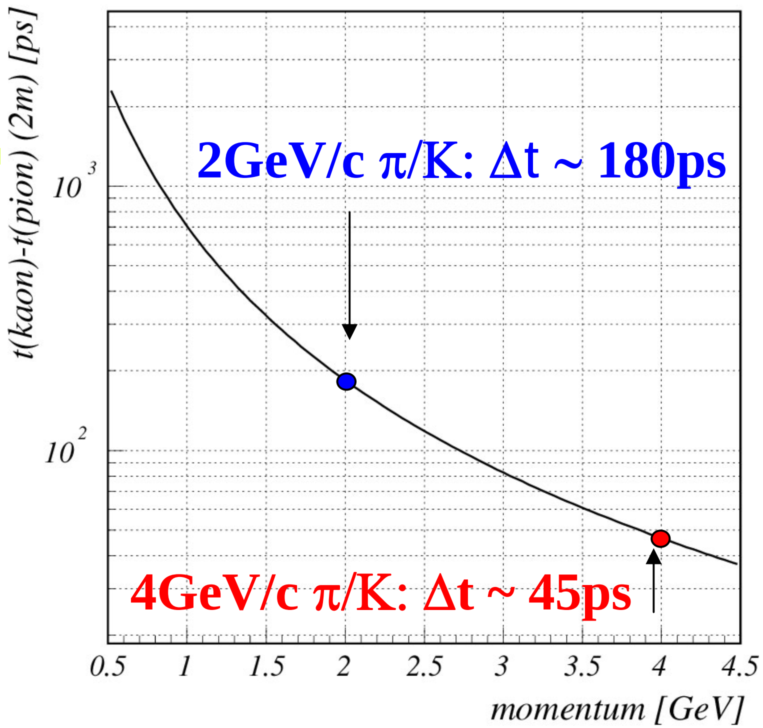


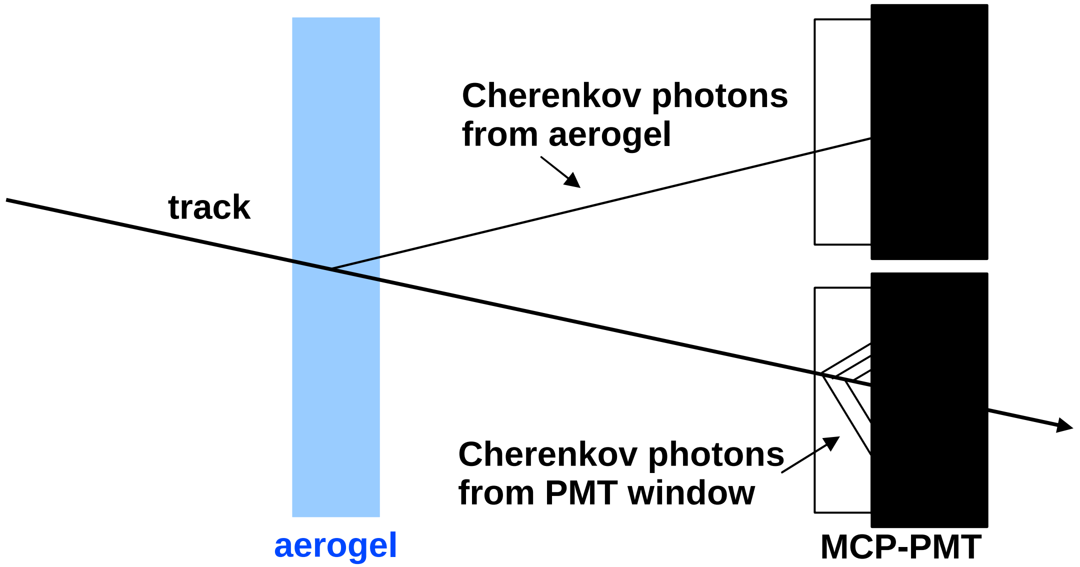


TOF capability

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

Time difference between π and K →



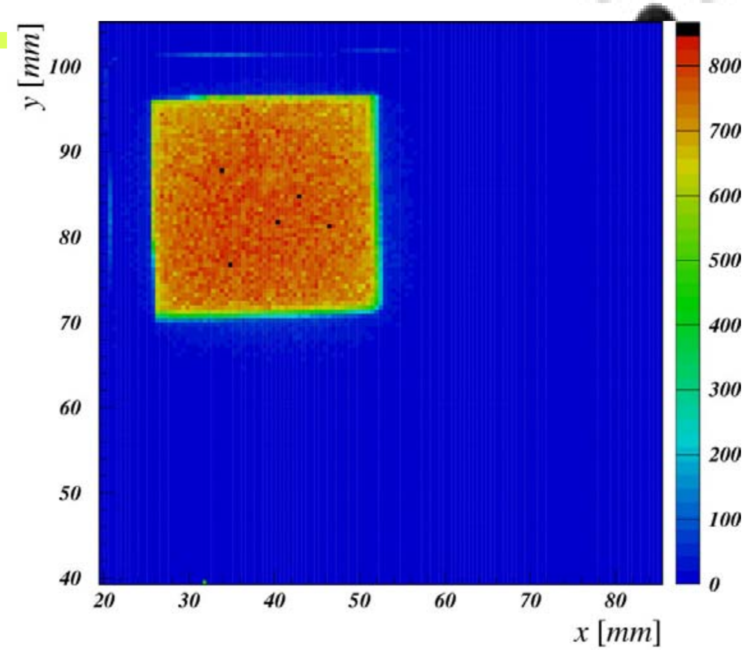


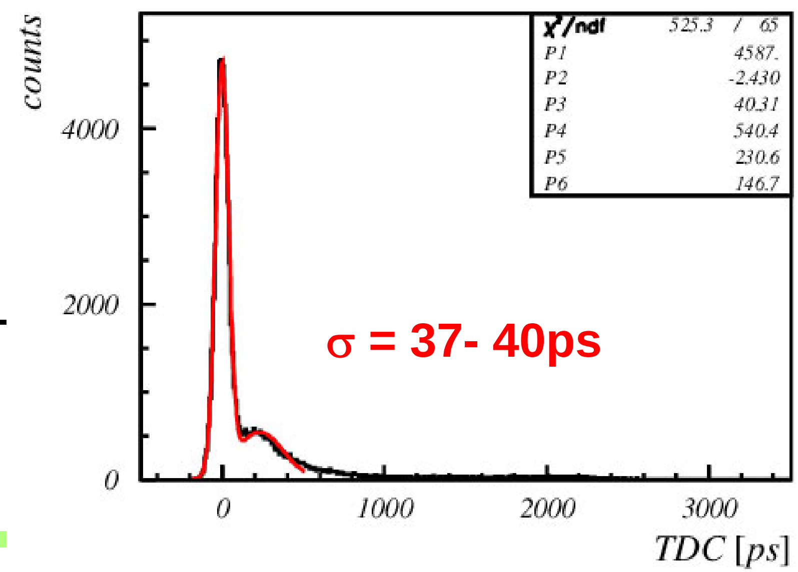
Cherenkov photons from the window can be used for the TOF measurement

Measured properties of BURLE MCP-PMTs - 2

Performance in **bench** tests:

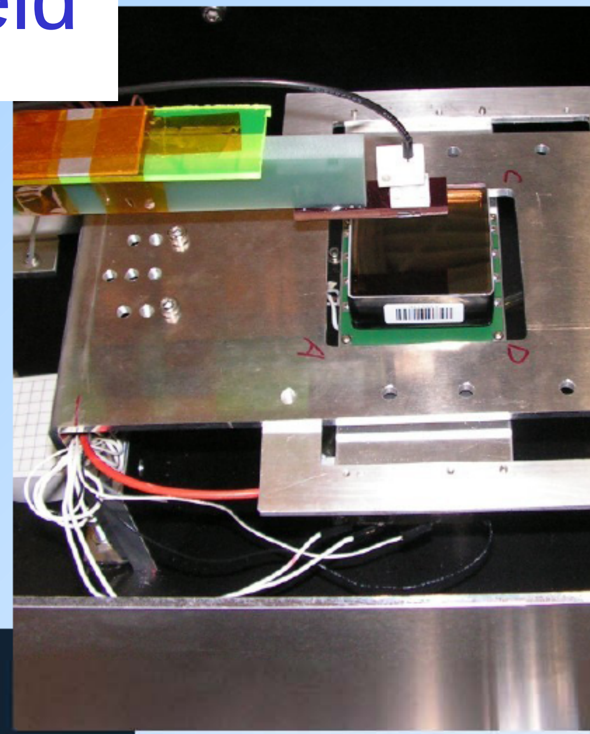
- good uniformity
- fast (<40ps single photon resolution)
- cross talk properties understood – most will disapear in magnetic field
- charge sharing could be used to improve the spatial resolution
- tails in time distribution understood – will be reduced with a higher voltage difference to the first MCP

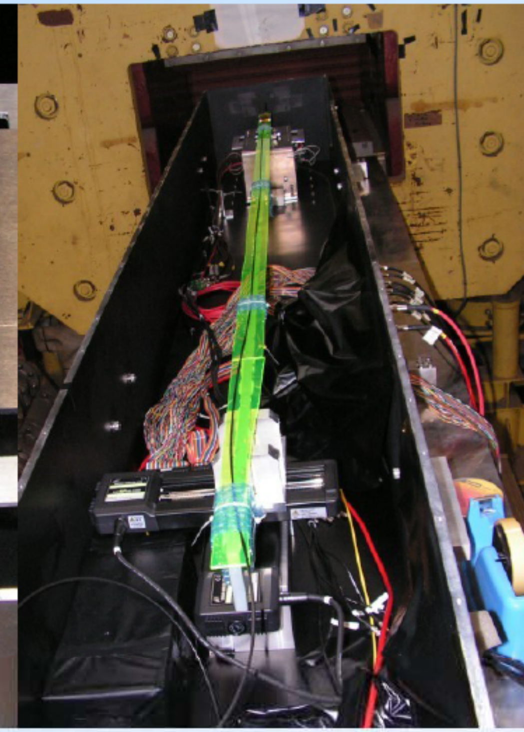




Tests in magnetic field

- B up to 1.5 T
- light source - laser:
  - vawelength 439 nm
  - spot size < 0.5 mm
  - pulse timing 90 ps (FWHM)





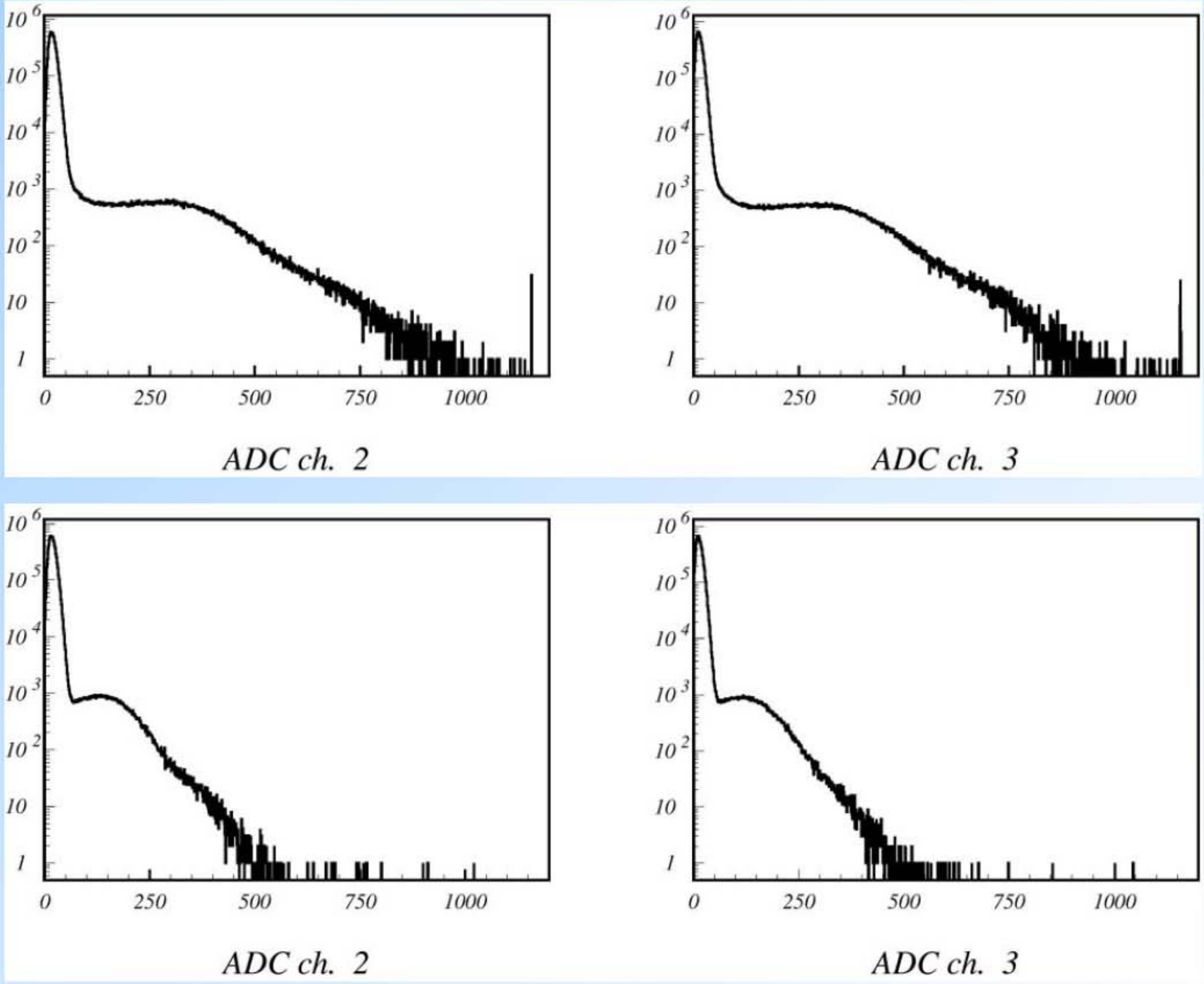
Signal detection:

- amplification x5 (PMT amp) x200 (ORTEC FTA820A) → passive splitter:
  - → LE discriminator (PHILIPS 708) → TDC (Kaizu works KC3781A)
  - → ADC (LeCroy 2249A)

Tests in magnetic field: pulse height

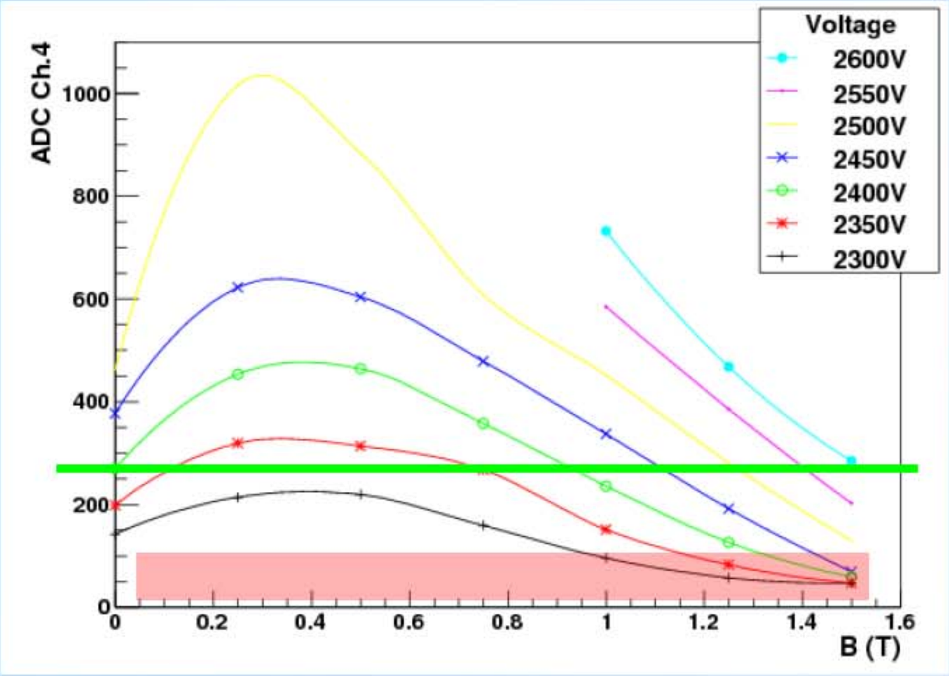
- HV = 2400 V
- B = 0 T

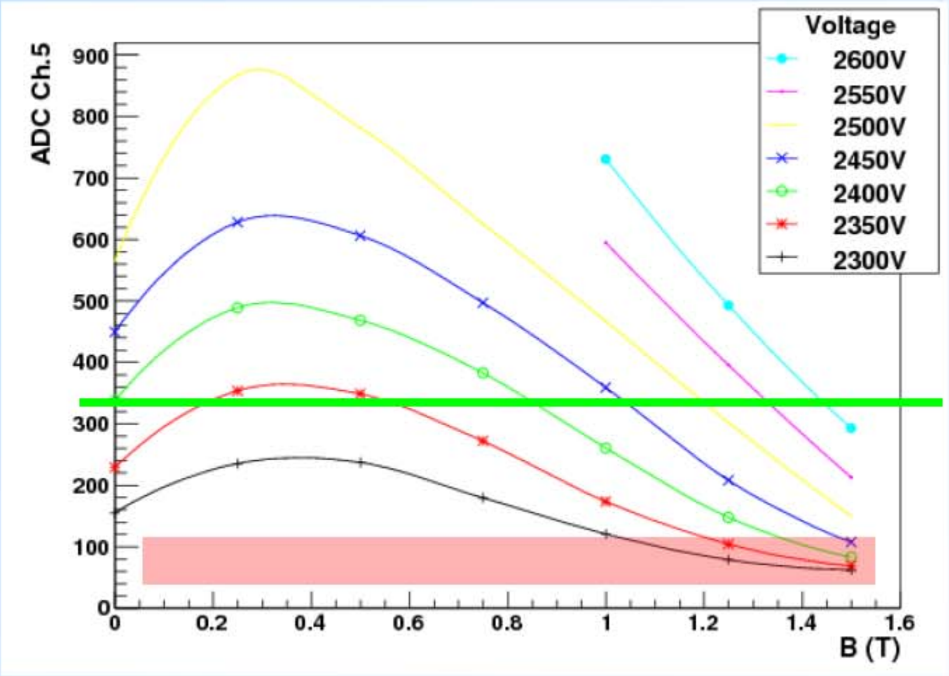
- HV = 2500 V
- B = 1.5 T



Tests in magnetic field 3

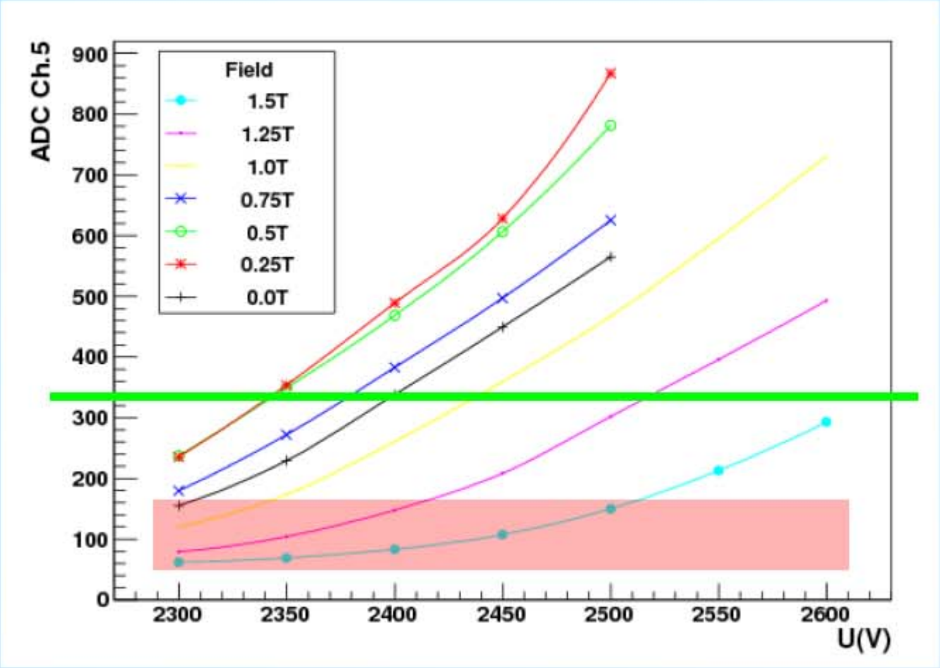
Gain as a function of magnetic field for different operation voltages.

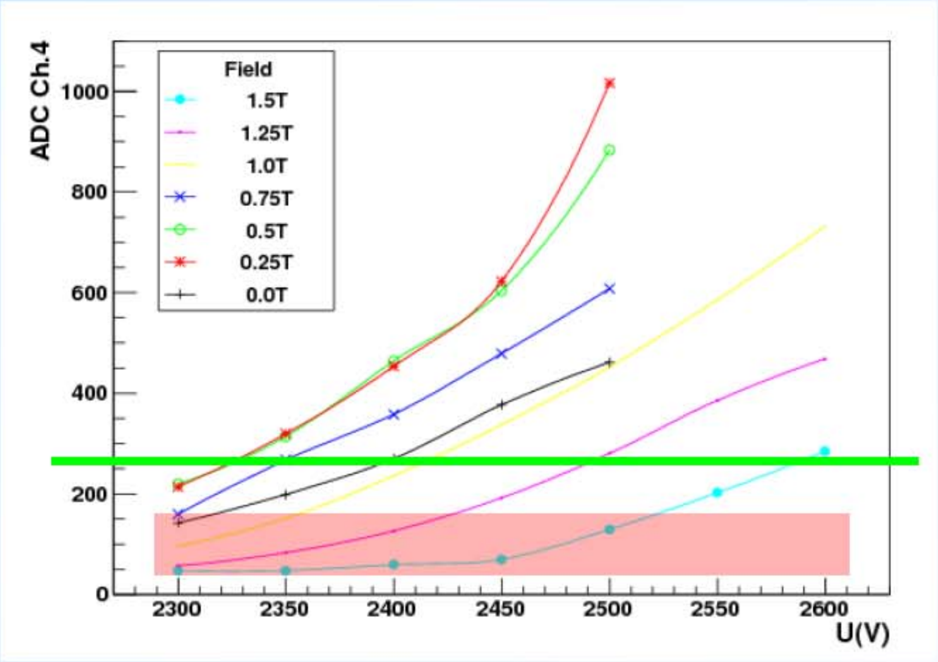




Tests in magnetic field 4

Gain as a function of aplied voltage for different magnetic fields.

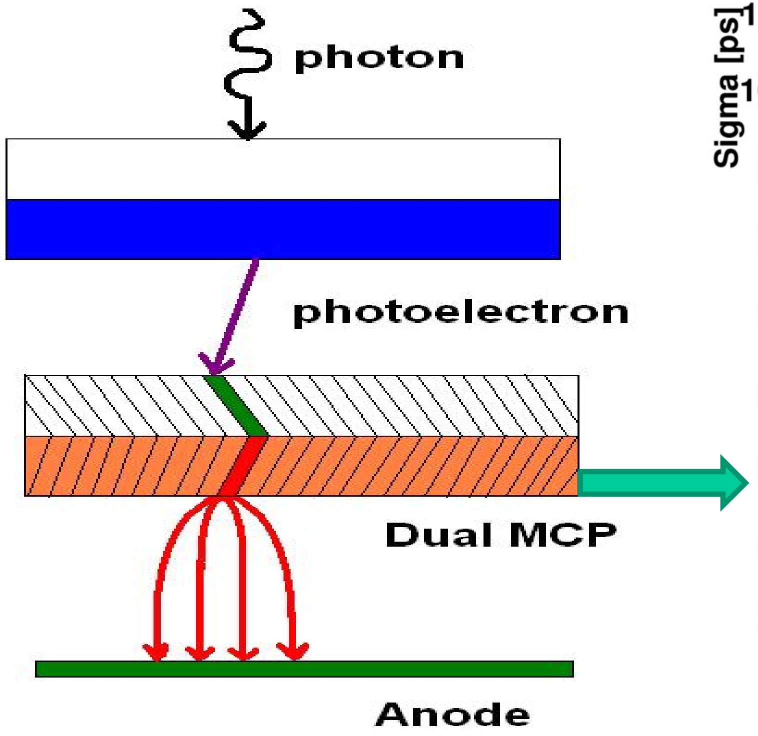


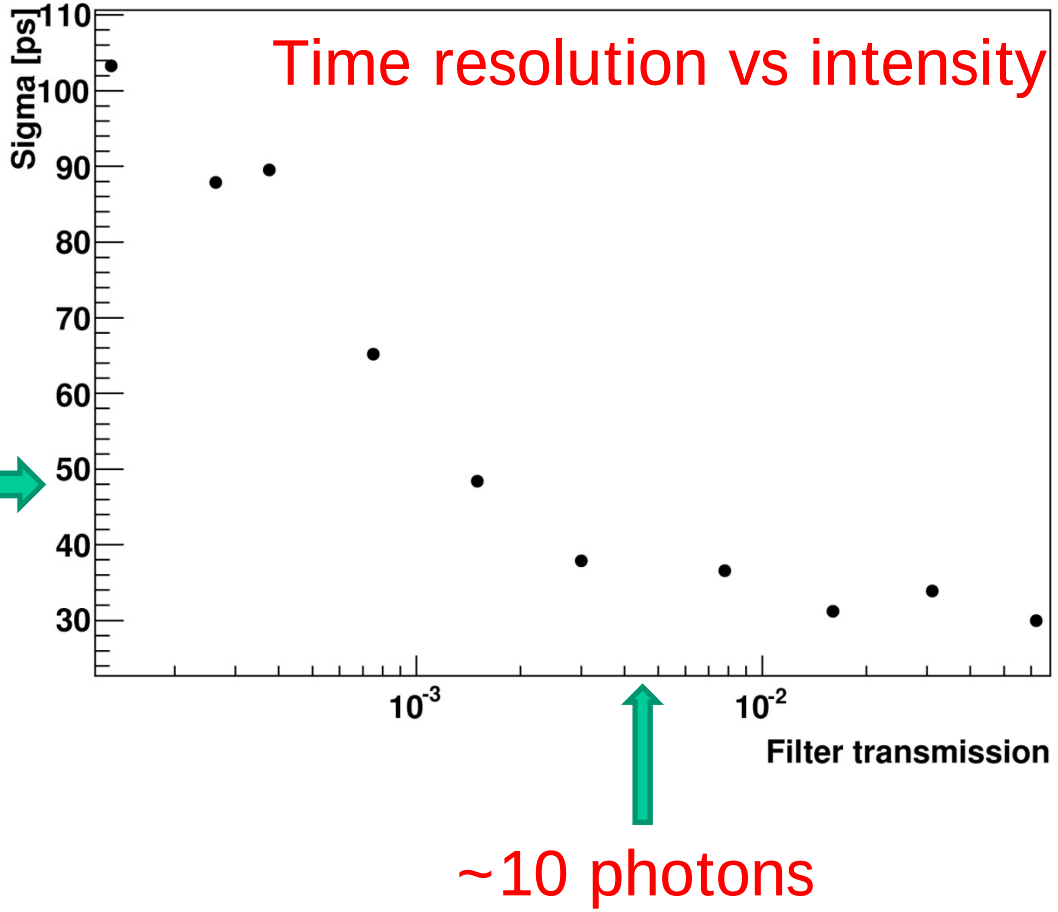


Still to be done in spring: time resolution vs B field and HV

TOF capability: to save on electronics, need one signal per tube (not 64)

Can we measure the time of arrival by using a single channel from the second MCP stage?





Very preliminary!

Ageing – data from Burle/Photonis

Several discussions with Emile Schyns, Group Product Manager, Micro Channel Plates

Current performance (no Al protection layer): → 50% drop of efficiency after 10-15C/tube = 350-540mC/cm^2

Expect ~10mC/cm^2/year on ARICH (extrapoled from the Belle TOF rates, to be checked wth BaBar estimates)

Photonis: expect to improve the ageing by a factor >5 (use a different scrubbbing technique, deep UV → electrons)

→ Ageing most probably not a problem any more (homework for us to check our rate estimates)

Summary

Burle multianode MCP PMTs have been tested in beam and bench tests → stable operation, very good performance

They have excellent timing properties → a promising photon detector also for very precise time measurements.

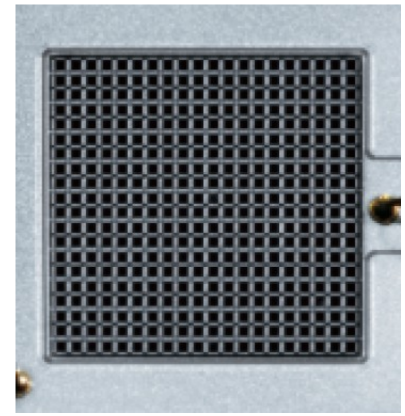
Additional bench tests were carried out: study detailed timing properties and cross-talk, performance in magnetic field

Still some work to do…

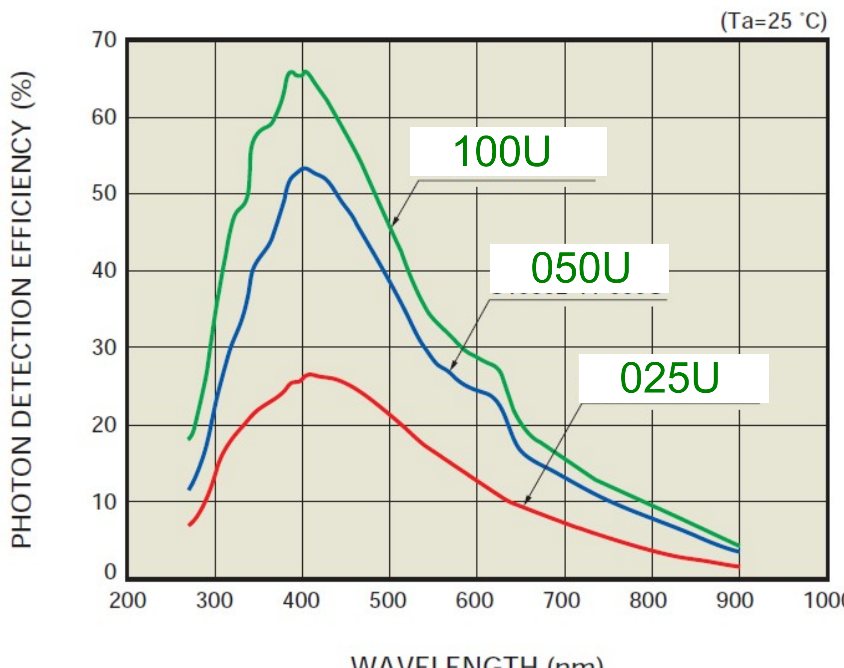
- Bench studies of timing in magnetic field impact
- Read-out electronics (wave-form sampling, G. Varner?)
- Ageing studies – to verify producer data
- Cost estimate

Candidate: SiPM (G-APD)

- SiPMs as single photon counters (uniformity, timing)
- Detection of Cherenkov photons with SiPMs
- Light collectors
- Radiation hardness, enutron flux
- Summary



1 mm



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

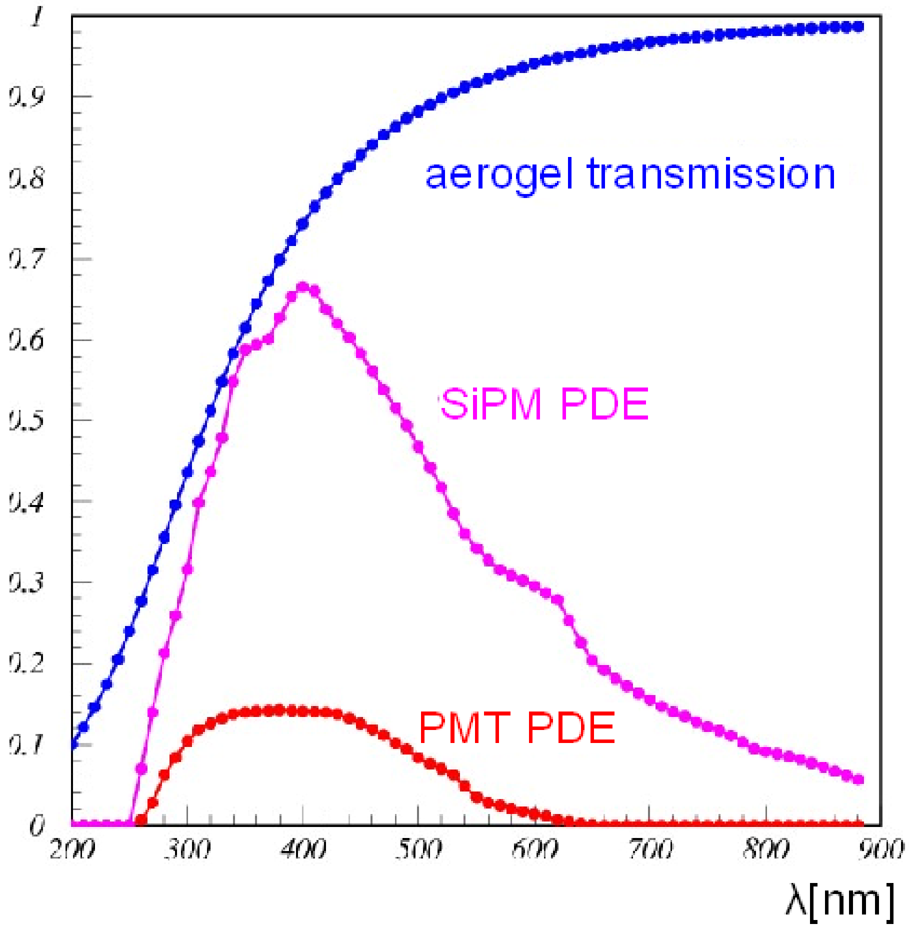
-high dark count rate (100kHz – 1MHz) with single photon pulse height

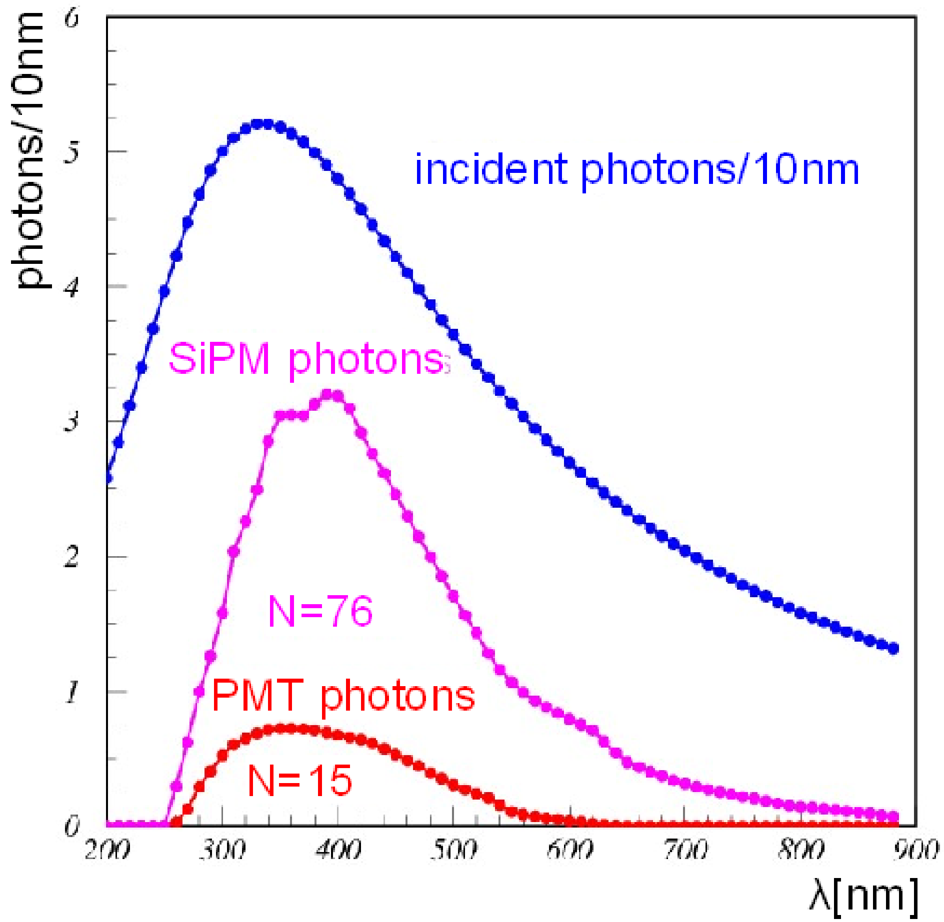
-radiation hardness

SiPMs: expected number of photons

Expected number of photons for aerogel RICH with multianode PMTs or SiPMs(HC100), and aerogel radiator: thickness 2.5 cm, n = 1.45 and transmission length (@400nm) 4cm.

N_{SiPM}/N_{PMT}~5



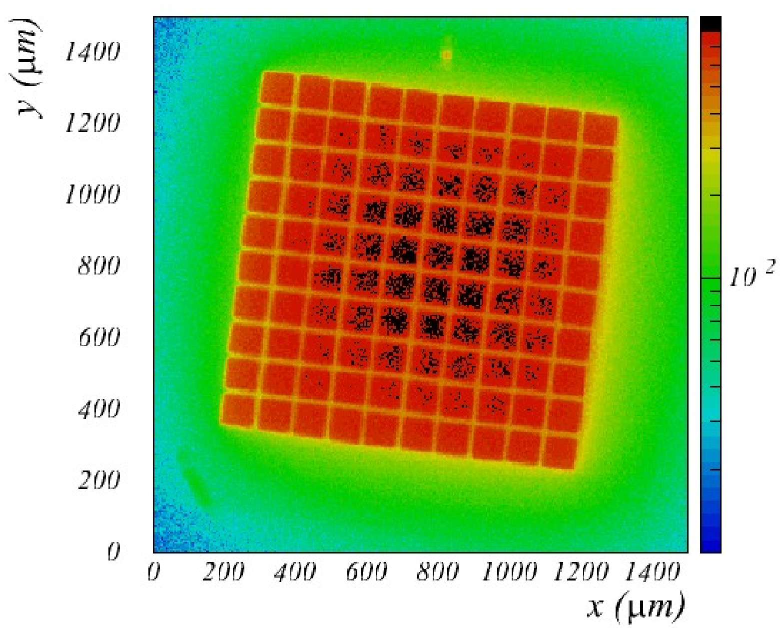


Surface sensitivity for single photons

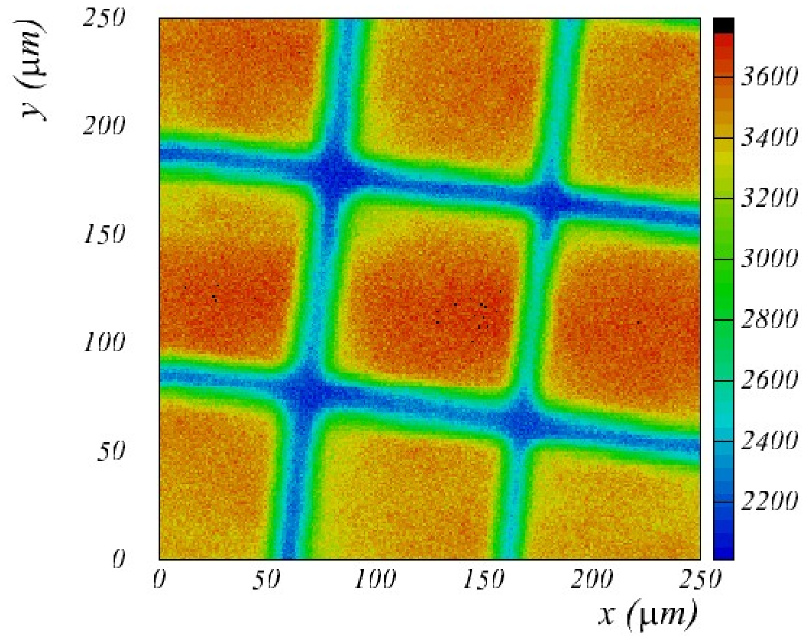
- 2d scan in the focal plane of the laser beam ($\sigma \approx 5\ \mu m$)
- intensity: on average << 1 photon → single photons
- Selection: single pixel pulse height, in 10 ns TDC window

Hamamatsu MPPC H100C

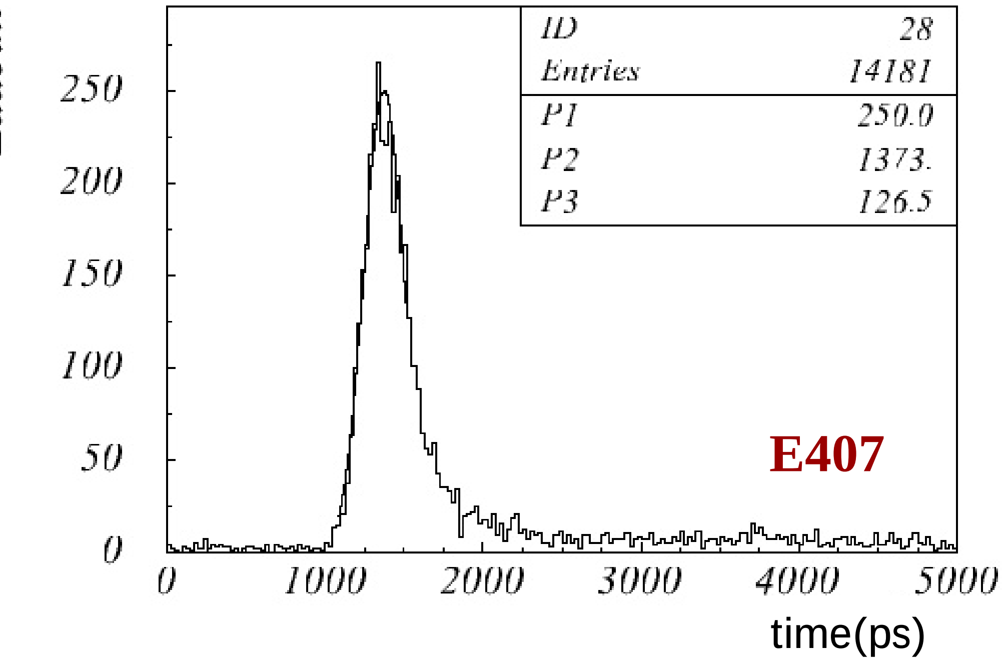
5 μm step size

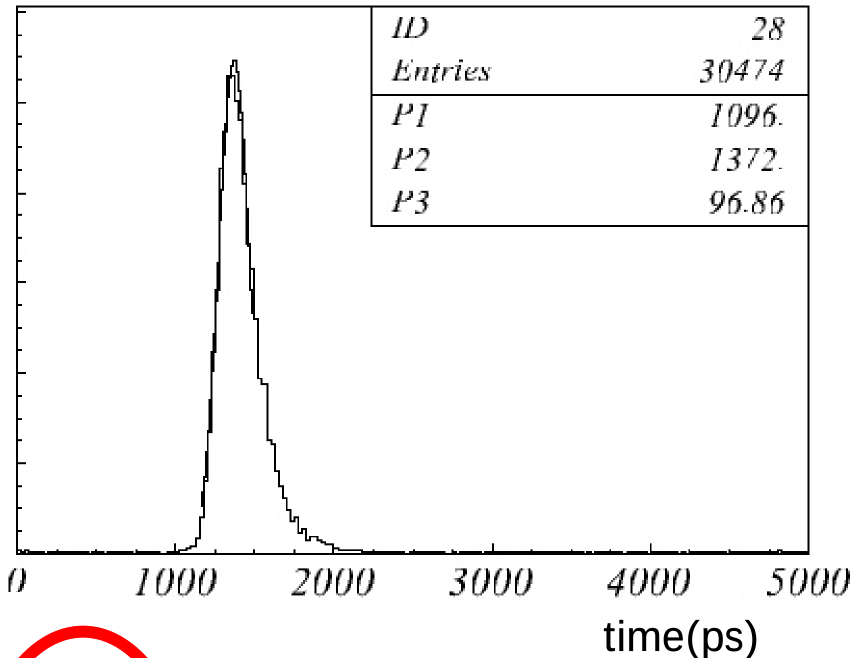


Close up: 1 μm step size



Time resolution: blue vs red

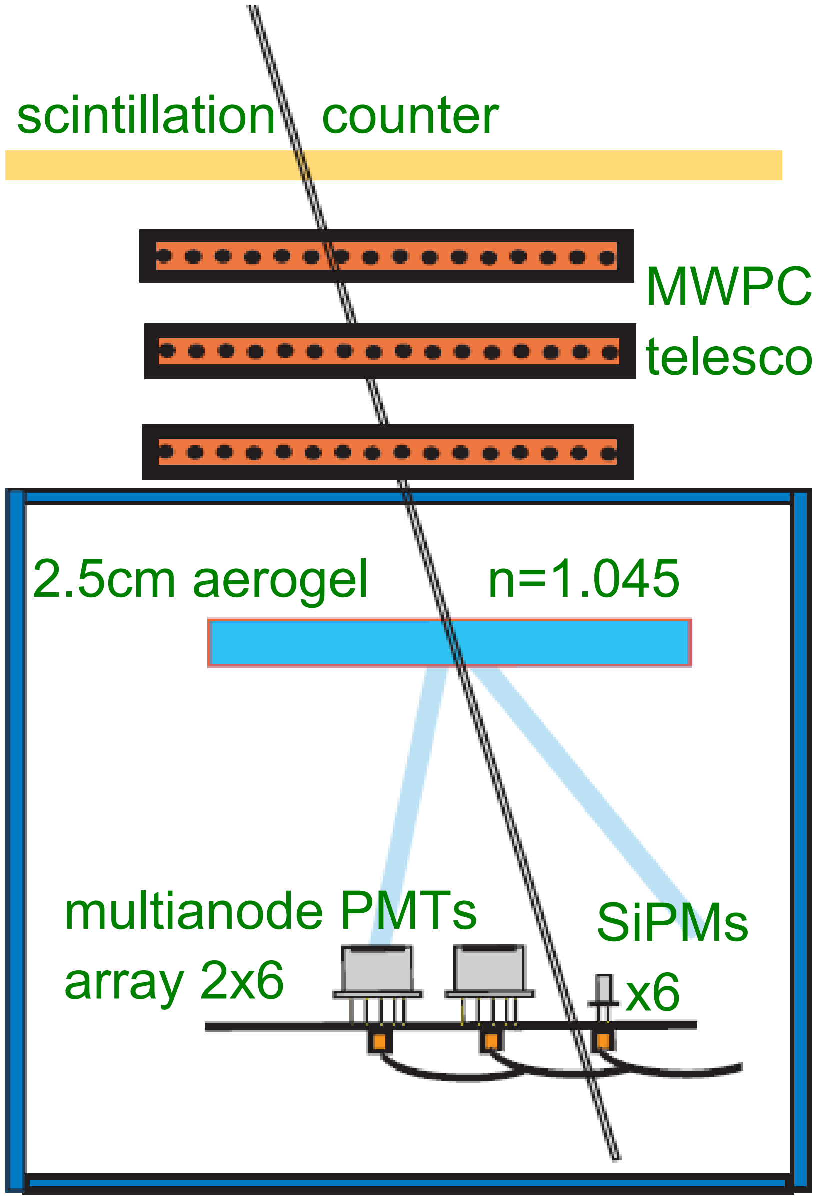


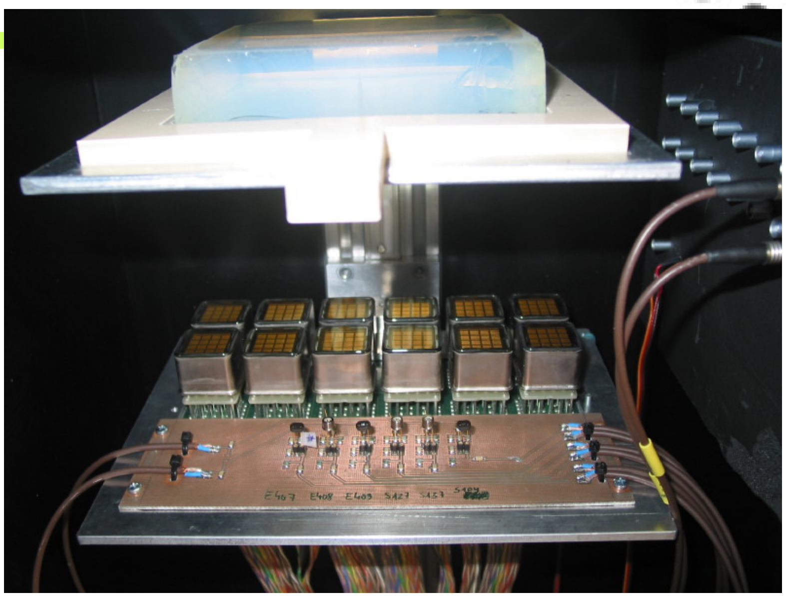


	E407	S137	H100C	H025C
σ_{red} (ps)	**127**	**182**	**145**	**154**
σ_{blue} (ps)	**97**	**151**	**136**	**135**

- $\sigma \approx 100$ ps
- $\sigma_{red} > \sigma_{blue}$

SIPMs: Cosmic test setup

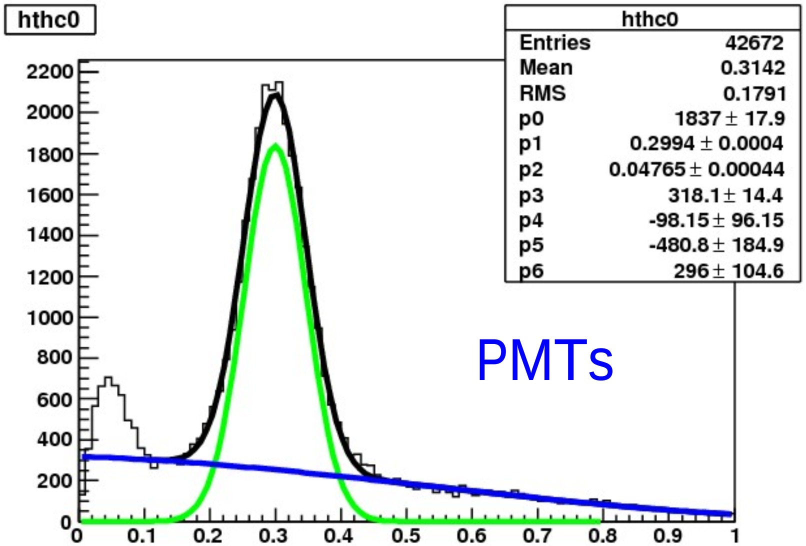


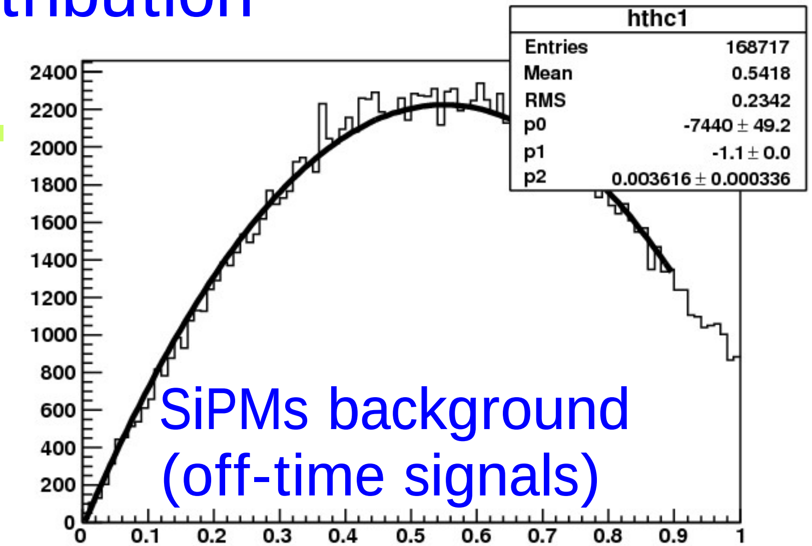


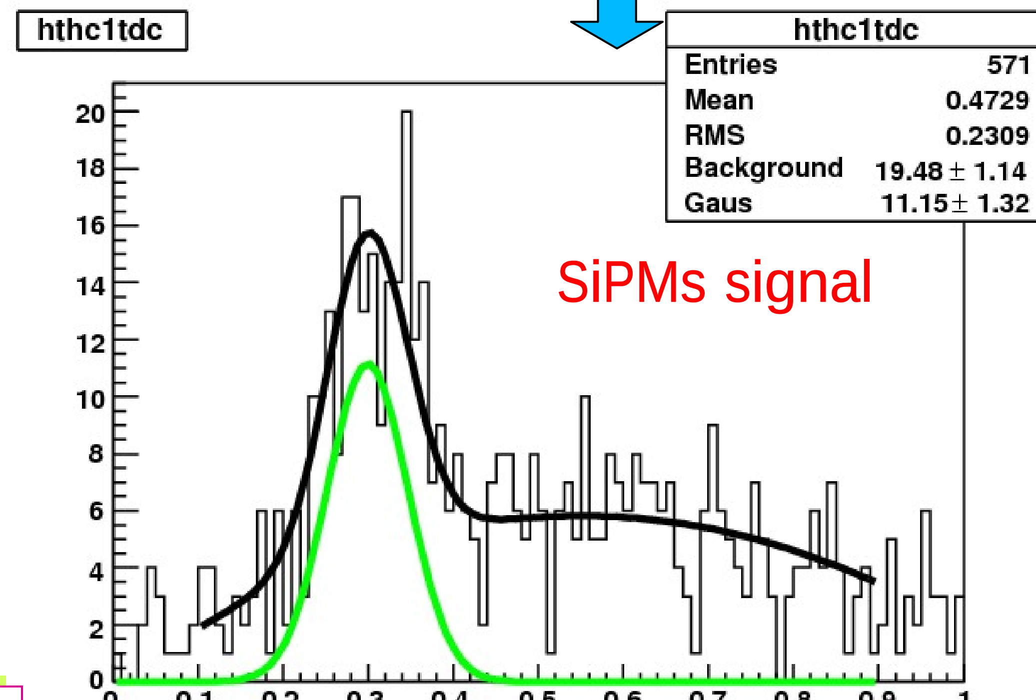
- 6 Hamamatsu SiPMs (=MPPC) of type 100U (10x10 pixels with 100μm pitch), background ~400kHz

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

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

Published in NIM A

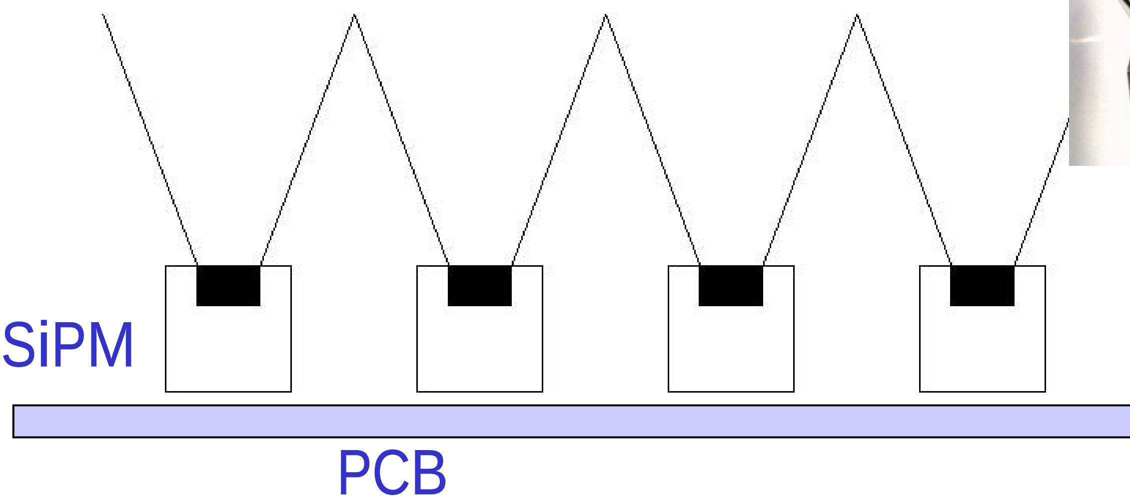
SIPMs: improving signal/noise

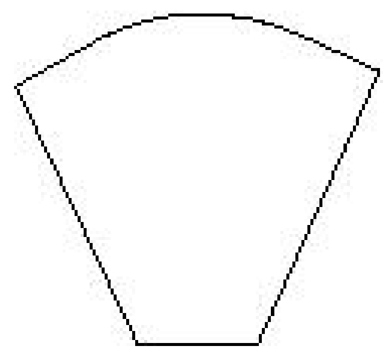
Improve the signal to noise ratio:

•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

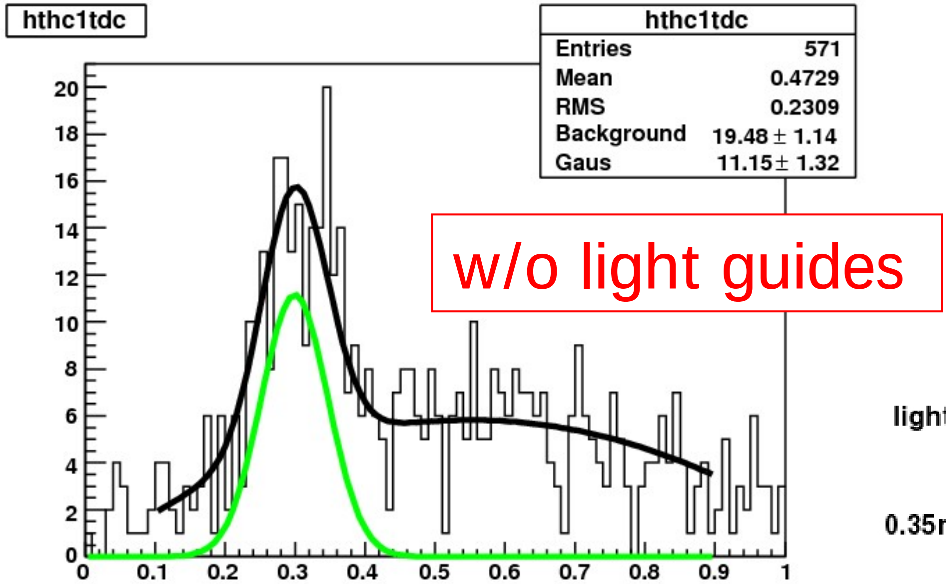
Light collector with reflective walls

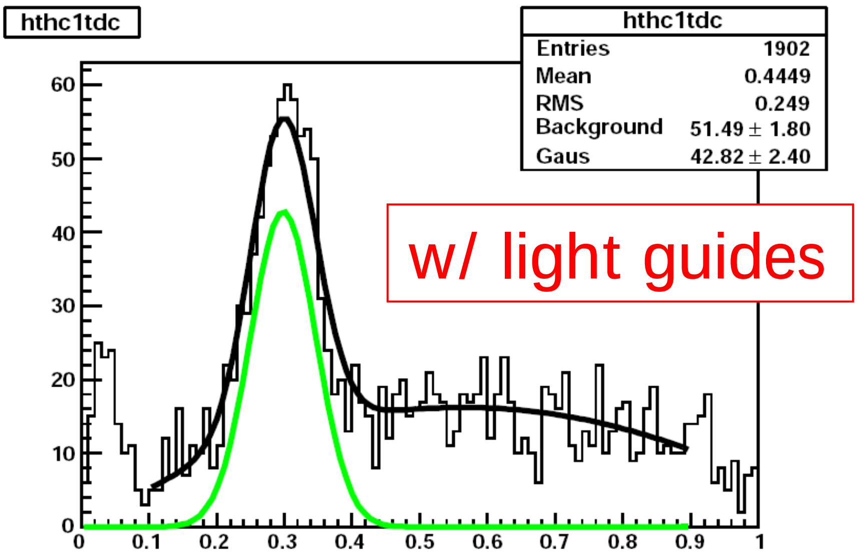




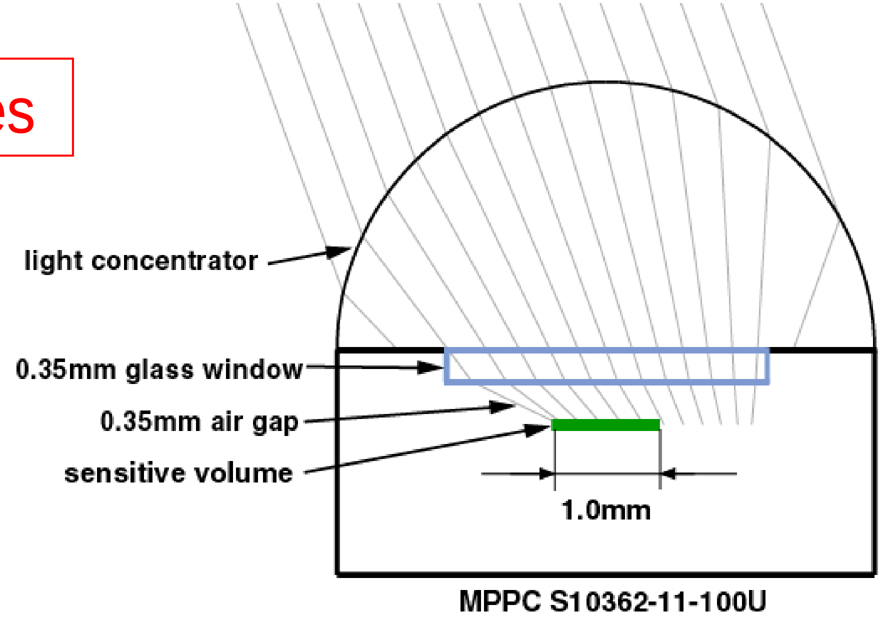
or combine a lens and mirror walls

Cherenkov photons with light collectors



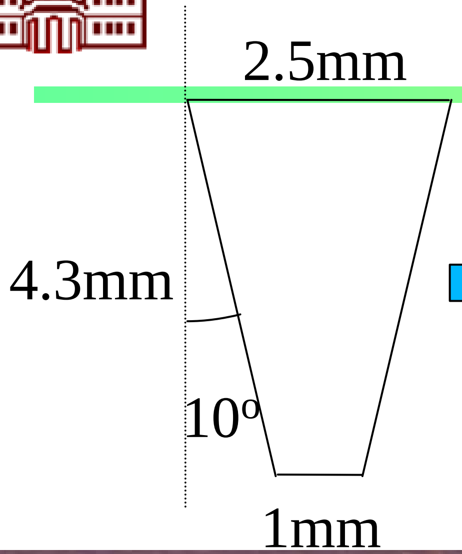


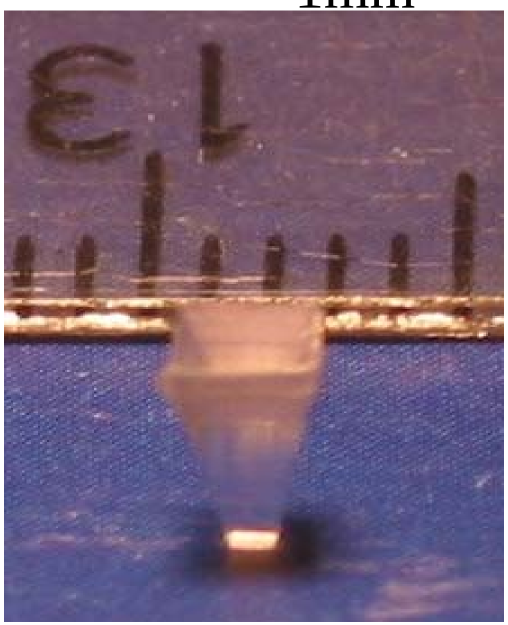
First attempt: use the top of a blue LED



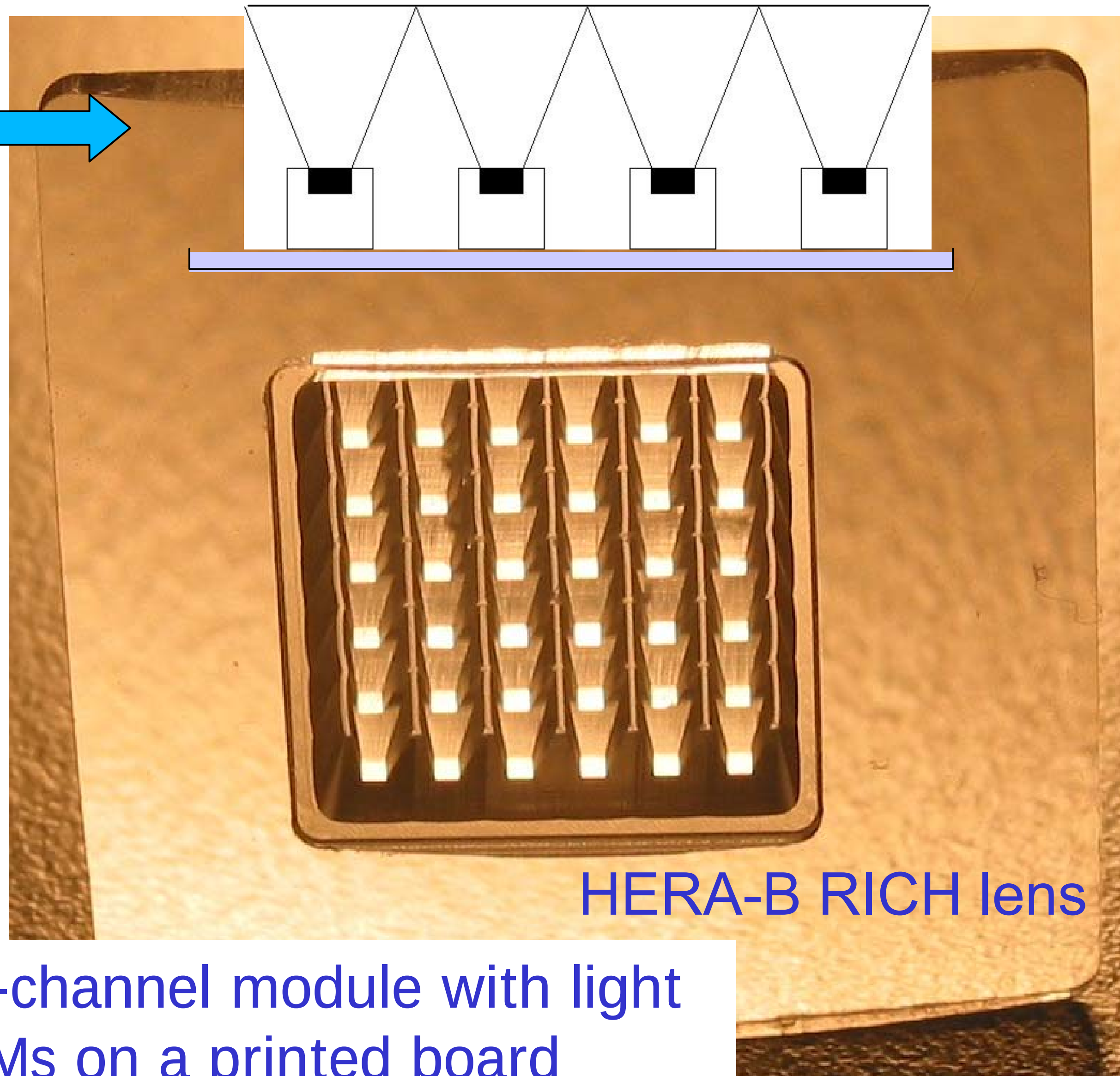
- Yield increase in agreement with the expectations
- Further improvements possible by
  - Using SiPMs with a reduced epoxy protective layer
  - using a better light collector

Detector module design





SiPM array with light guides

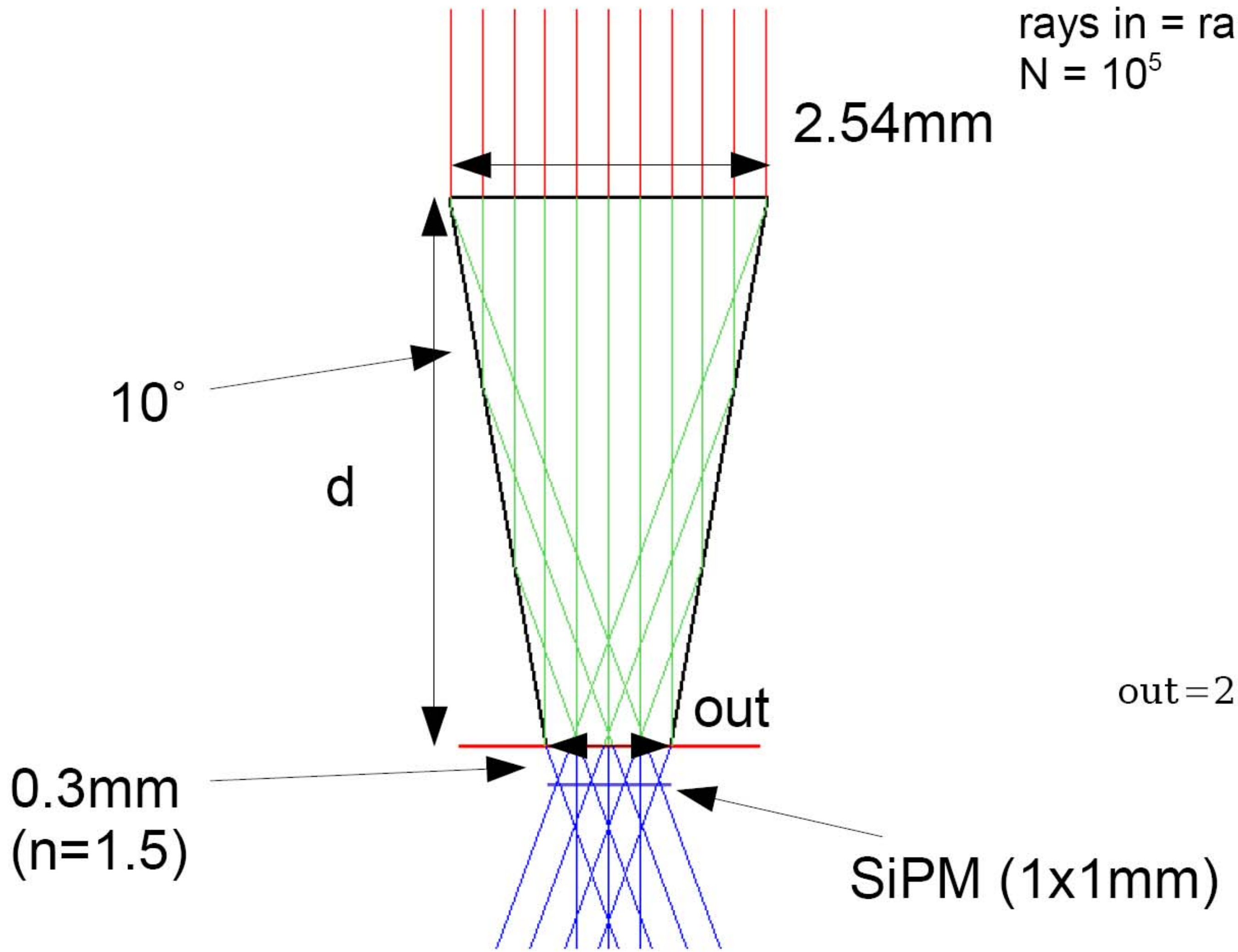


Aim: build a multi-channel module with light collectors and SiPMs on a printed board

Light guide geometry optimisation

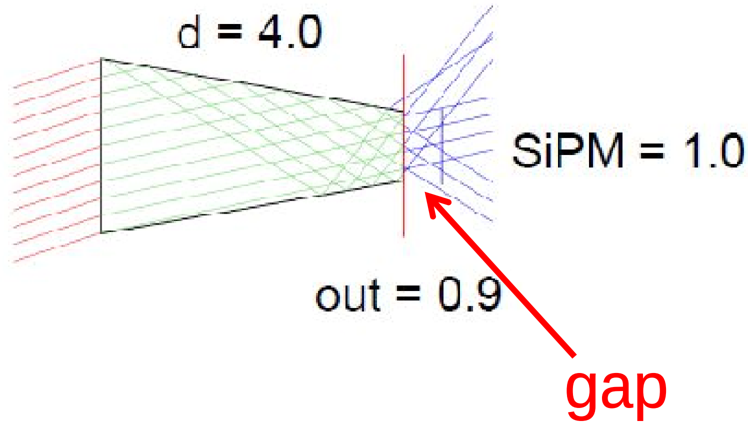
Light Guide Acceptance / (d and out)

rays in = random isotropic 0-30°
N = 10^5



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

Light guide simulation



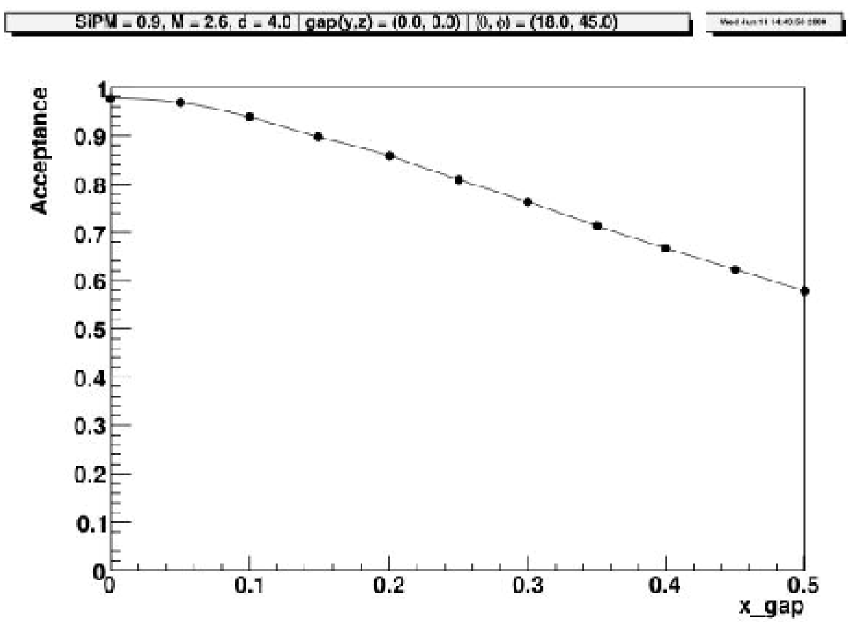
Simulation includes:

- refraction at LG entrance
- total reflection
- gap between LG exit and SiPM surface

Not included:

- absorption
- imperfect surface

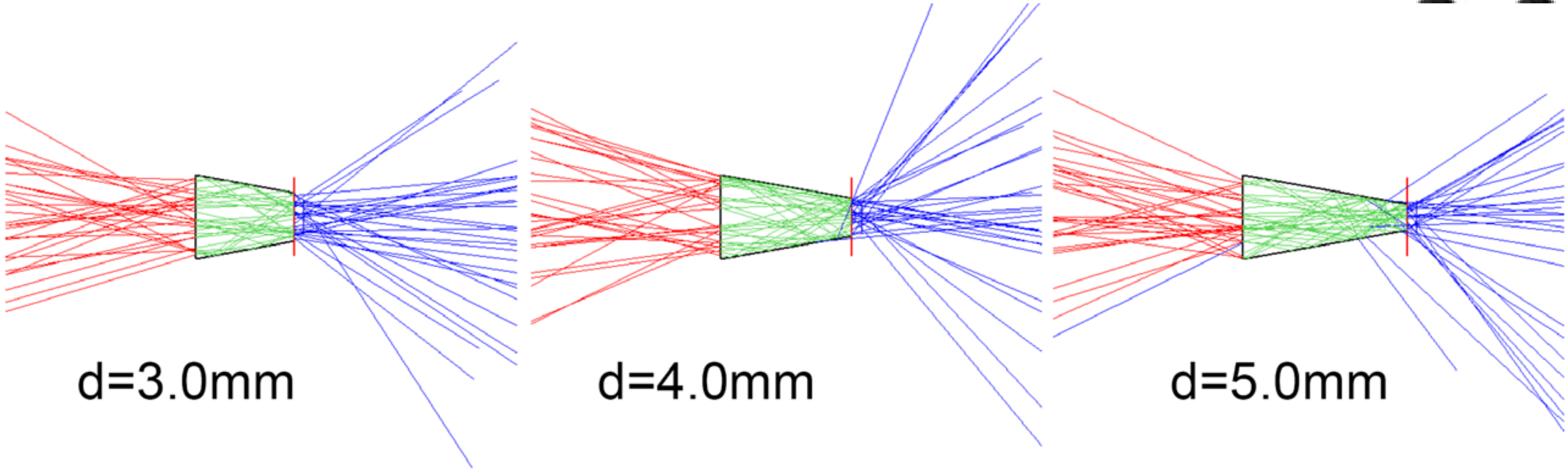
θ = 18°
φ = 45°



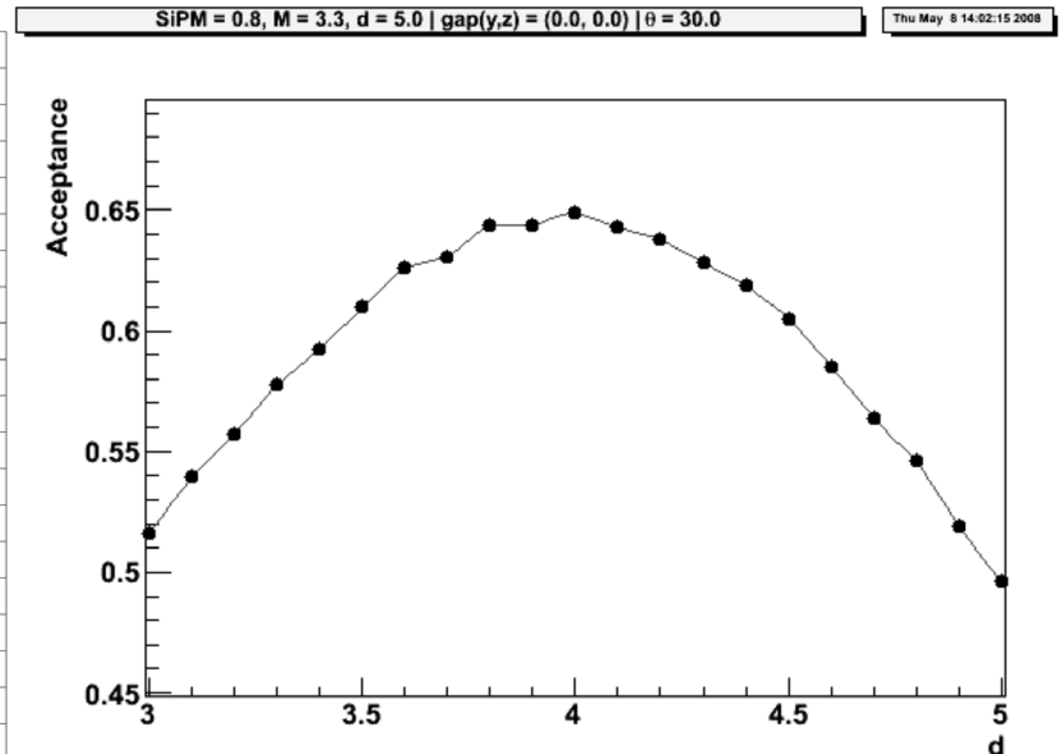
t=18,p=45			
gap	w	w/o	A
0.00	97.67	19.03	5.13
0.05	96.62	19.09	5.06
0.10	94.11	18.98	4.96
0.15	89.68	18.77	4.78
0.20	85.99	18.87	4.56
0.25	81.06	18.99	4.27
0.30	**76.12**	**19.1**	**3.99**
0.35	71.49	18.95	3.77
0.40	**66.85**	**19**	**3.52**
0.45	62.44	18.98	3.29
0.50	**58.39**	**19**	**3.07**

Acceptance vs gap size

Light guide geometry optimisation

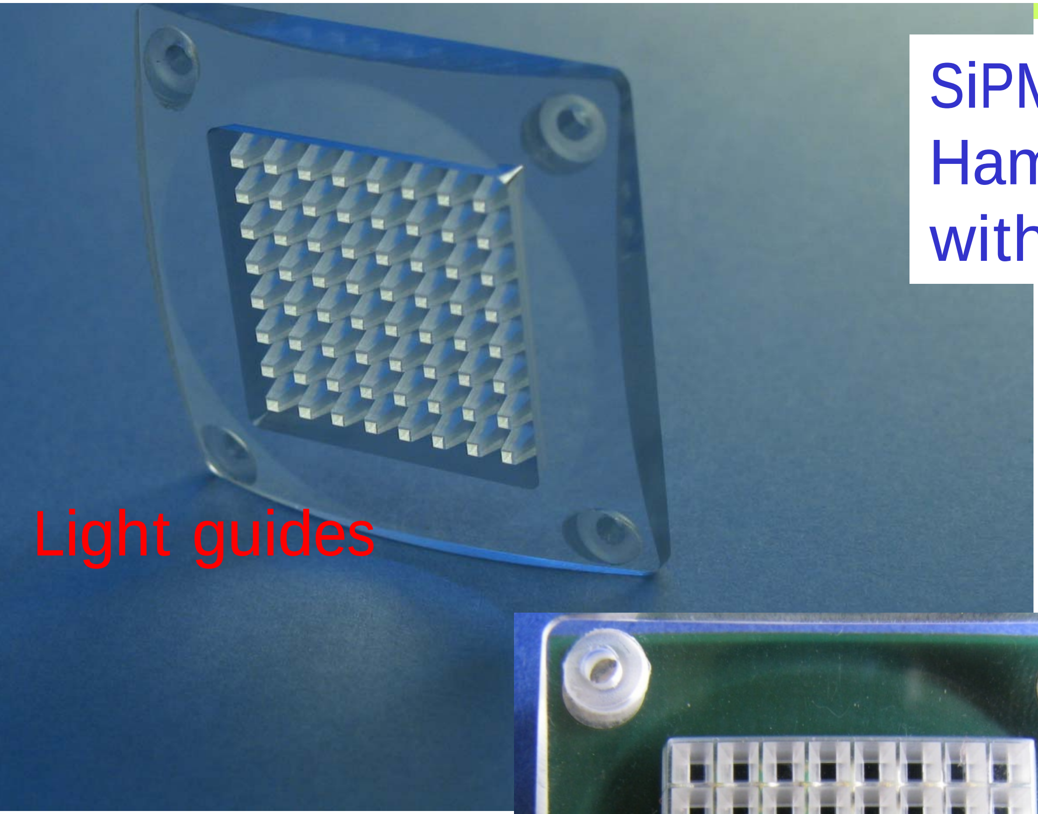


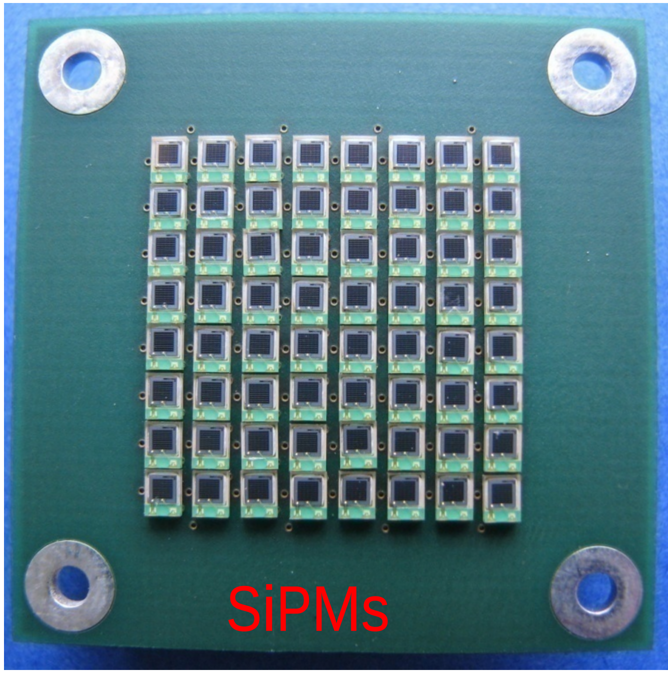
d (mm)	out (mm)	accept. (%)
3.0	1.48	51.6
3.1	1.45	54.0
3.2	1.41	55.7
3.3	1.38	57.8
3.4	1.34	59.2
3.5	1.31	61.0
3.6	1.27	62.6
3.7	1.24	63.1
3.8	1.20	64.4
3.9	1.16	64.4
4.0	**1.13**	**64.9**
4.1	1.09	64.3
4.2	1.06	63.8
4.3	1.02	62.8
4.4	0.99	61.8
4.5	0.95	60.5
4.6	0.92	58.5
4.7	0.88	56.4
4.8	0.85	54.6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



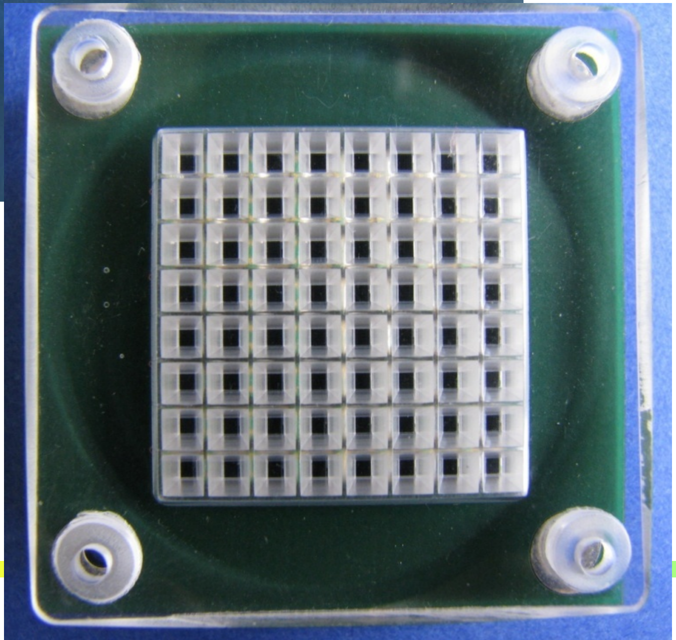
Detector module for beam tests at KEK

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



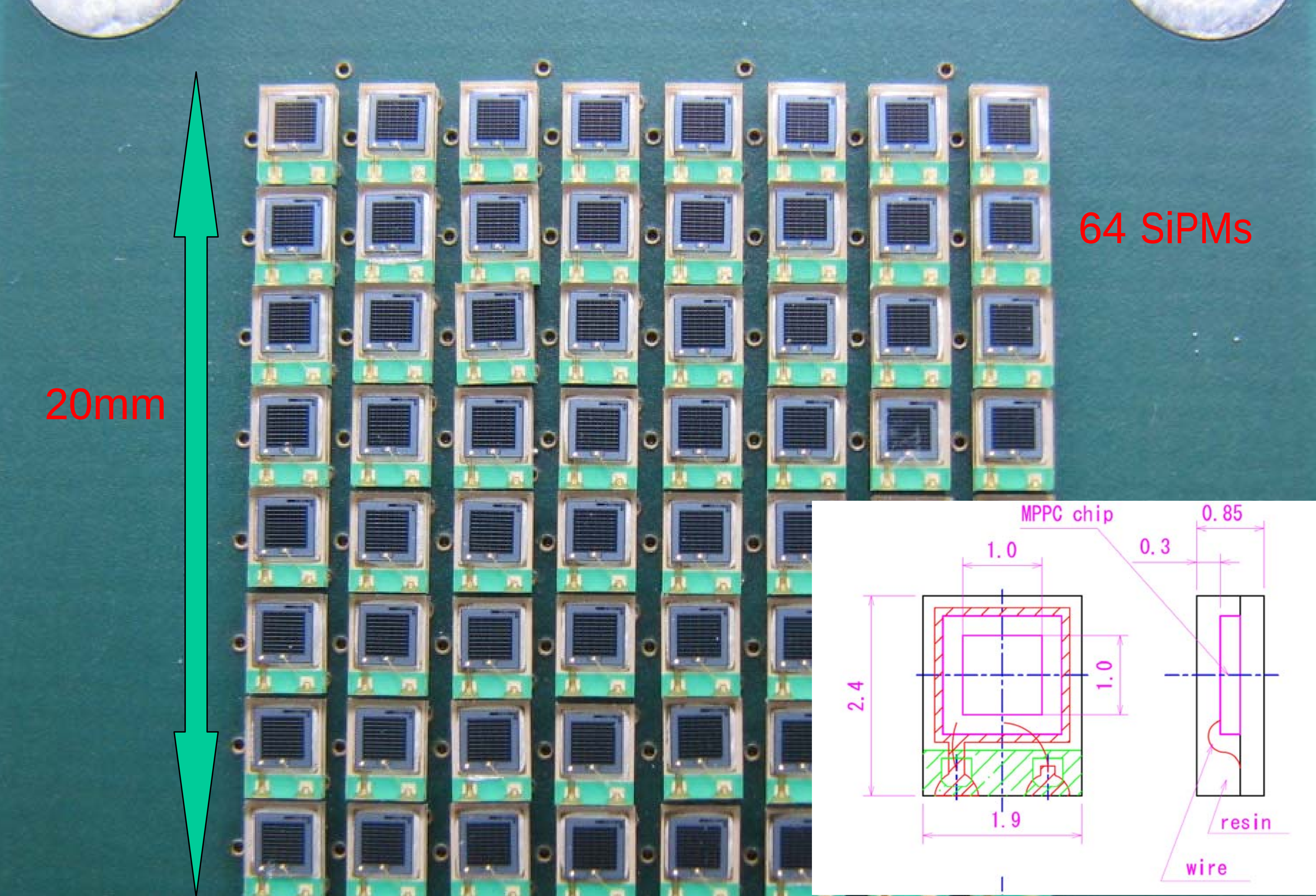


2cm

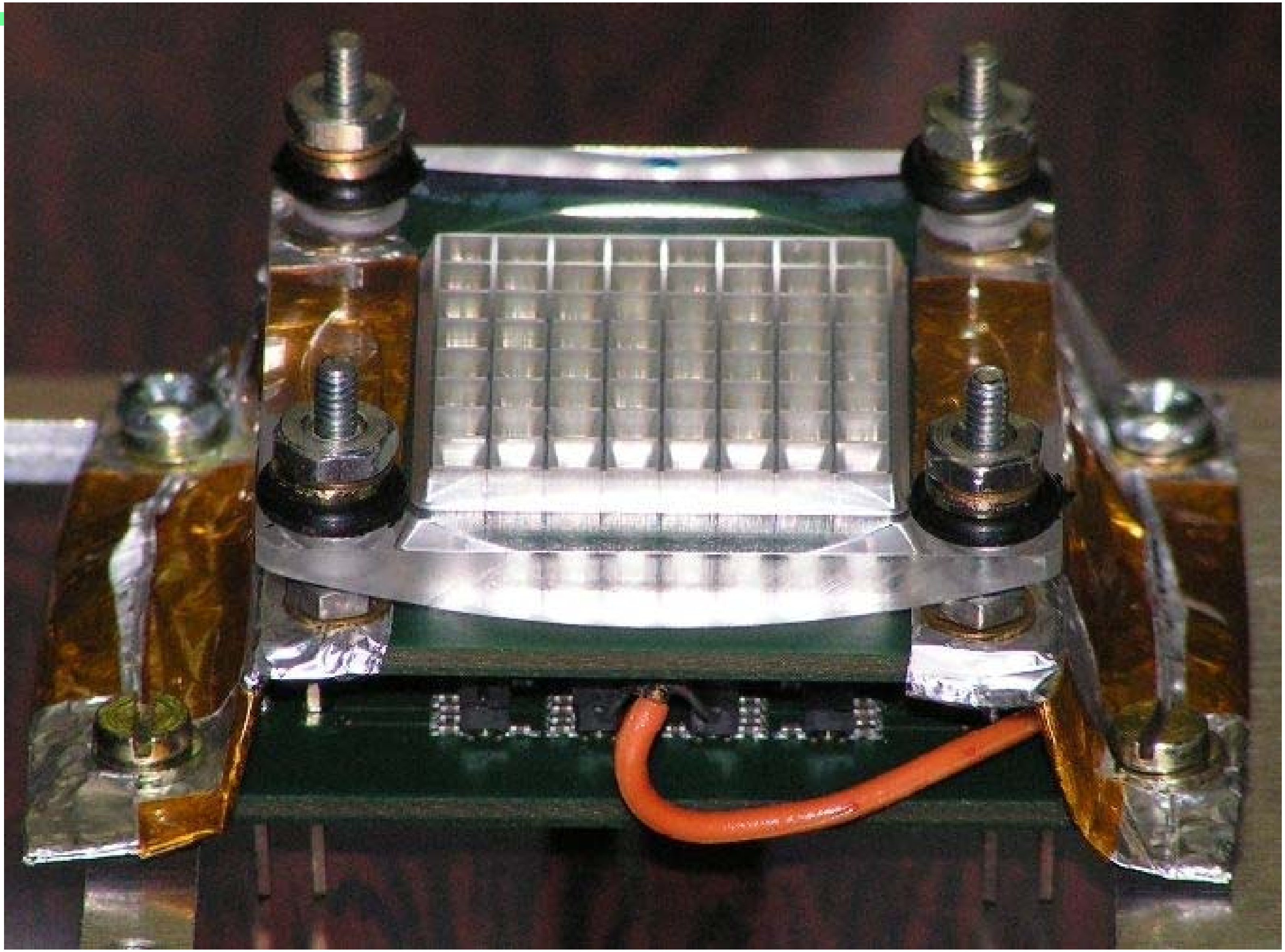


SiPMs + light guides

Photon detector for the beam test

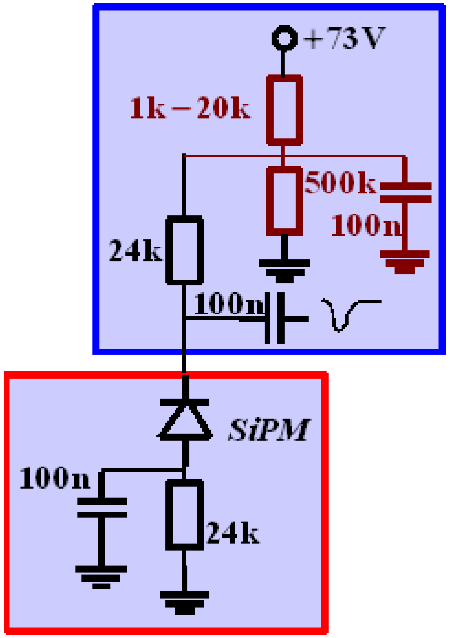


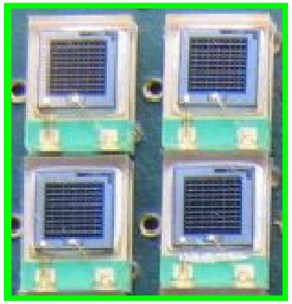
Fully assembled detector module

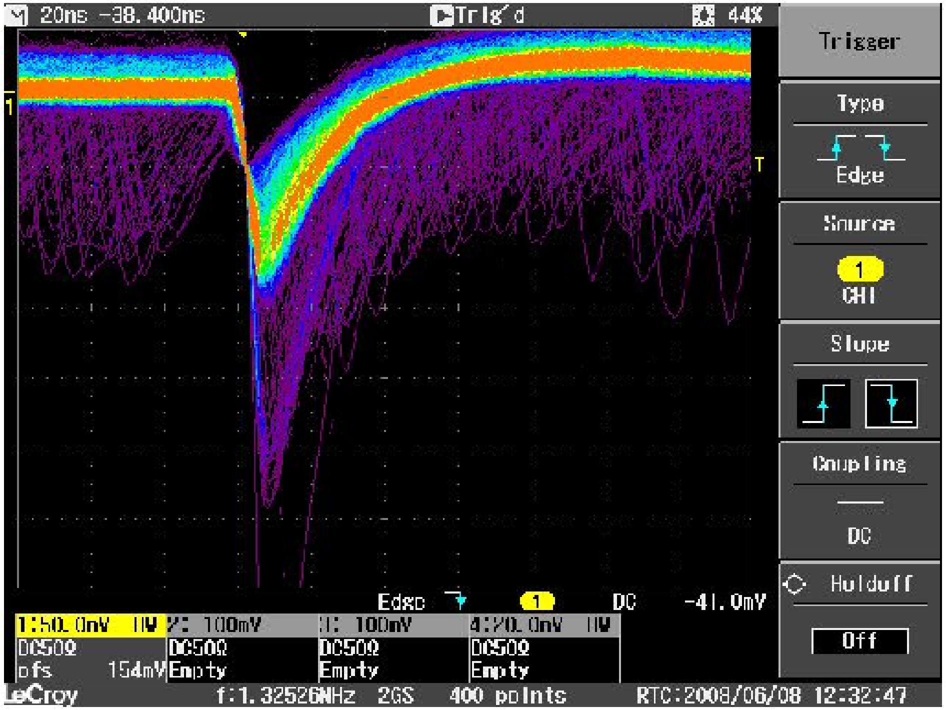


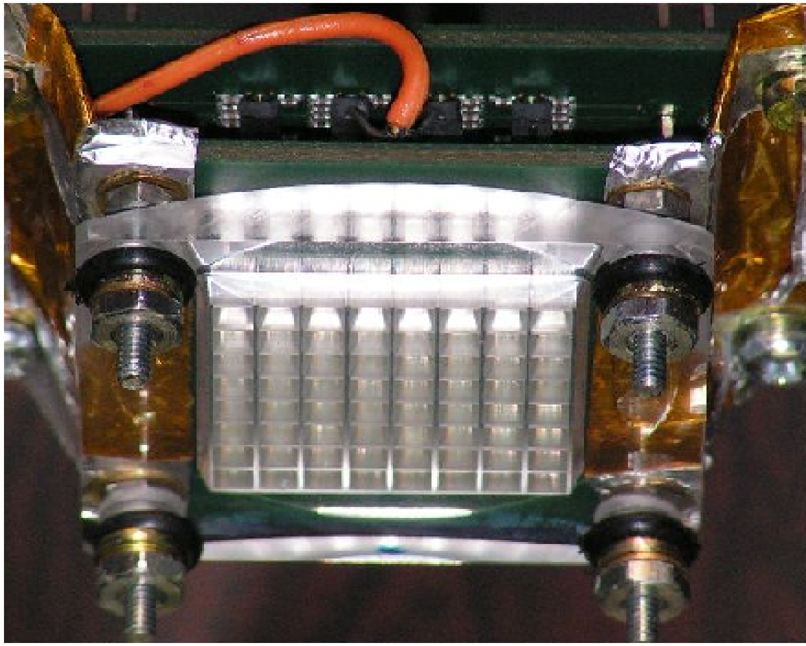
MPPC module

- main board with dividers, bias and signal connectors
- piggy back board with MPPCs (8x8 array of HC100 in SMD package; background ~ 400kHz/MPPC)
- light guides
- 16 electronics channels (4x4) - 4 MPPCs connected to single channel



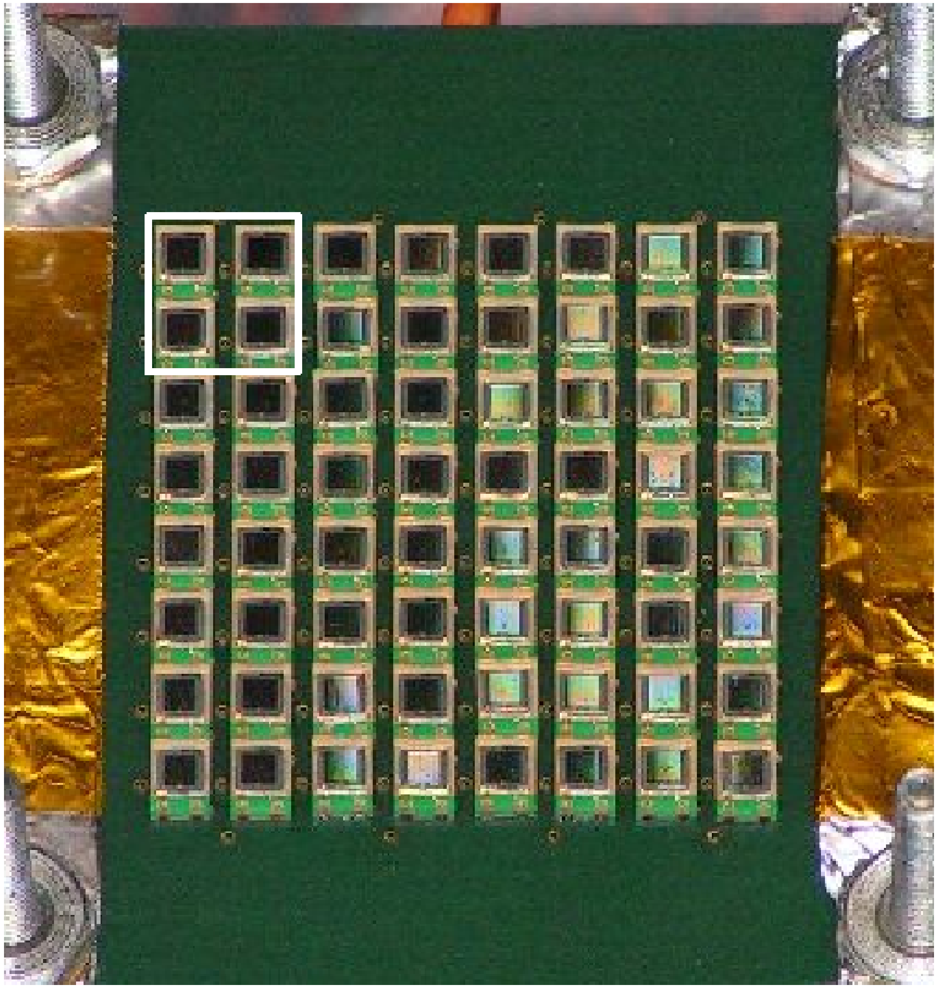


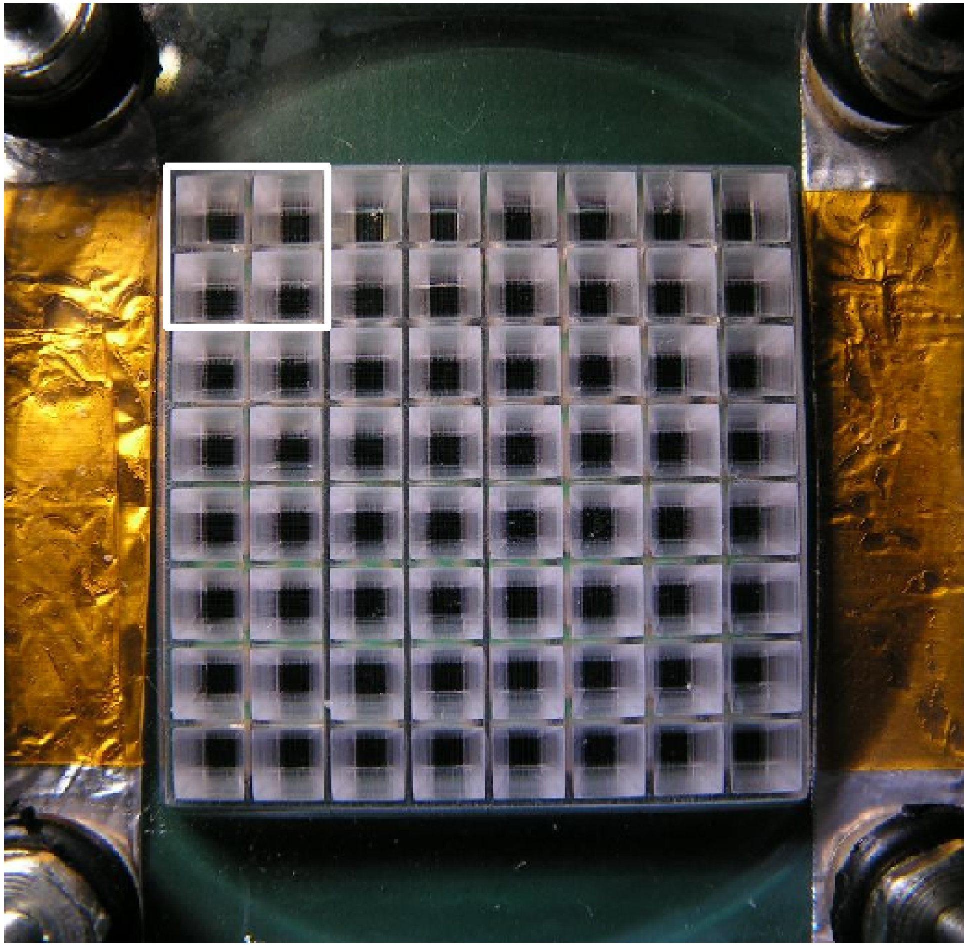




MPPC module 2

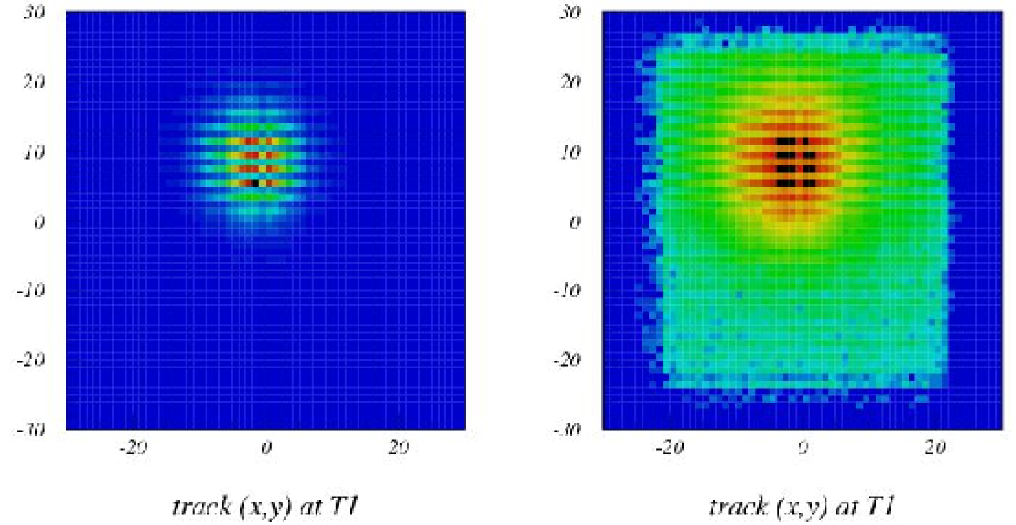
- pad size 5.08 mm, 4 mm2 active



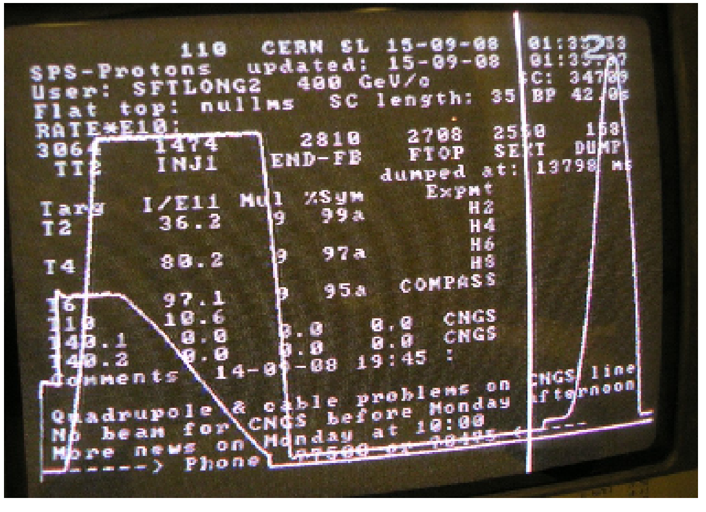


Beam area T4-H6-B @ CERN

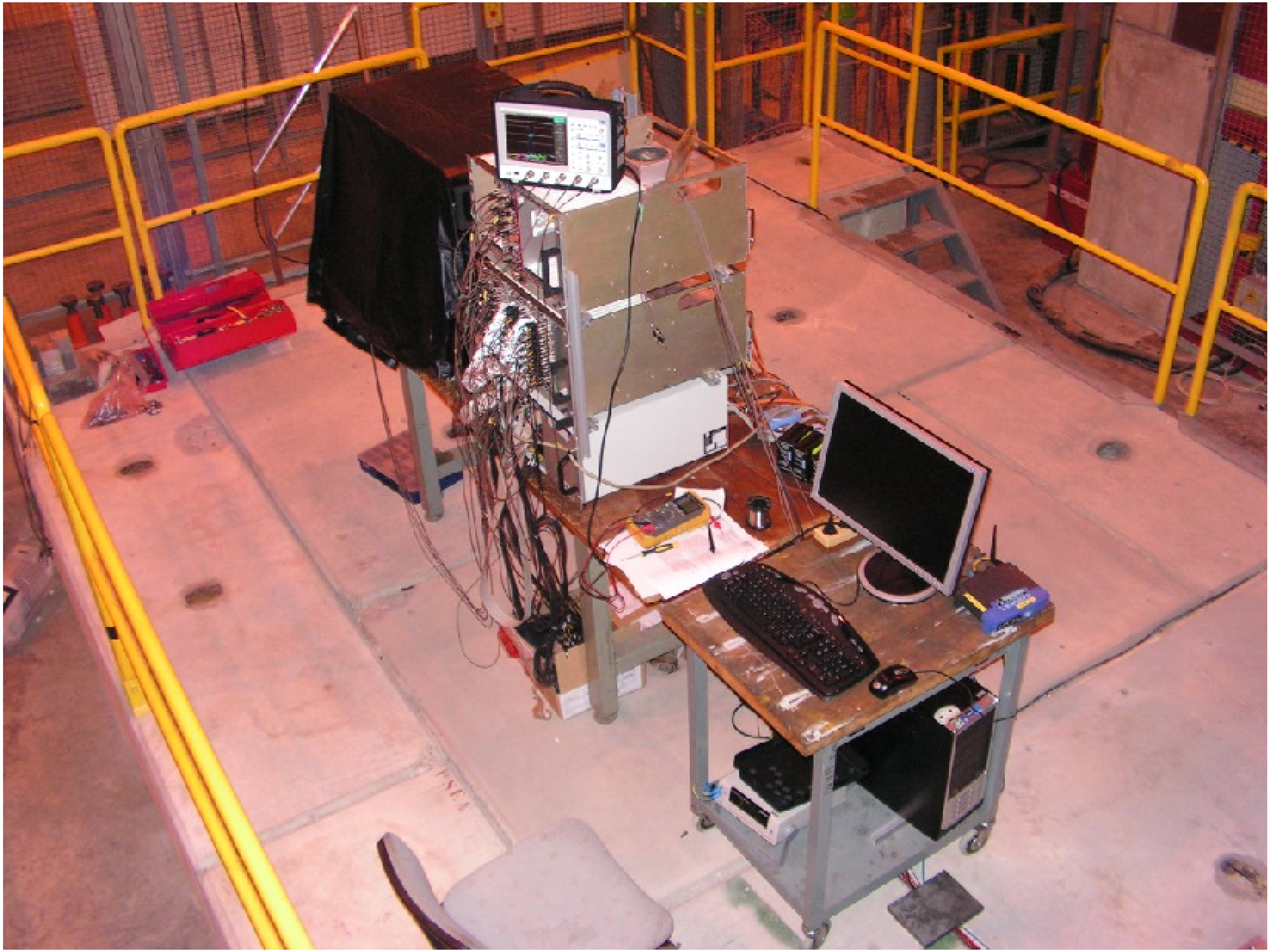
- +120 GeV/c pions
- spills every 42s for ~5s
- beam size ~1cm²



- beam profile (scale in mm)

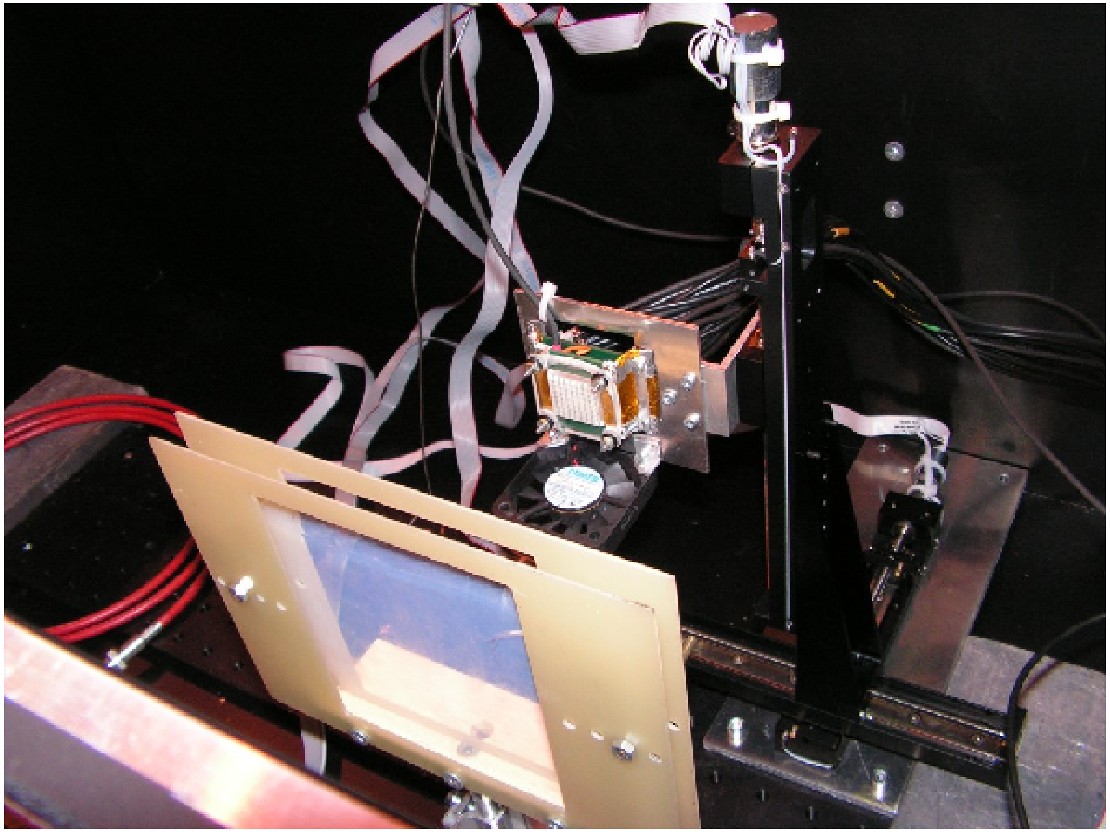


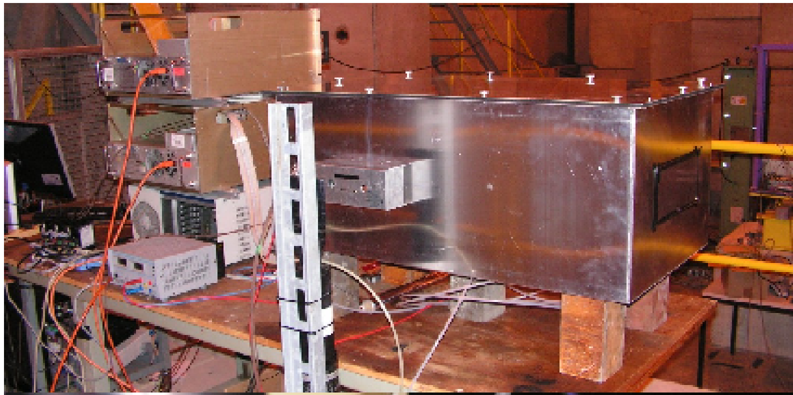
Beam area T4-H6-B

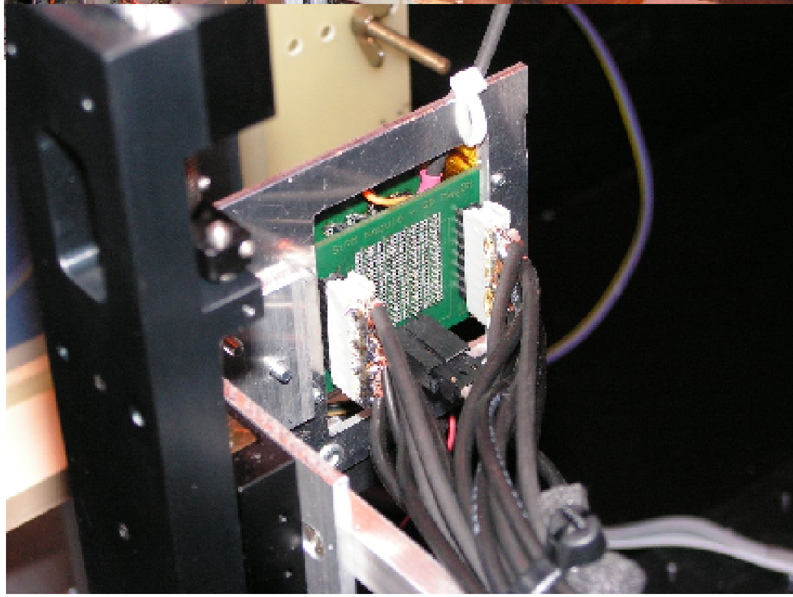


Beam test setup

- 2 MWPCs for tracking and scintillator for timing
- MPPC array w/o or w/ light guide mounted on 3D stage
- aerogel n=1.03, d=10mm (distance 130mm)
- hits detected by multi-hit TDC
- +120 GeV/c pions, beam size ~1cm^2



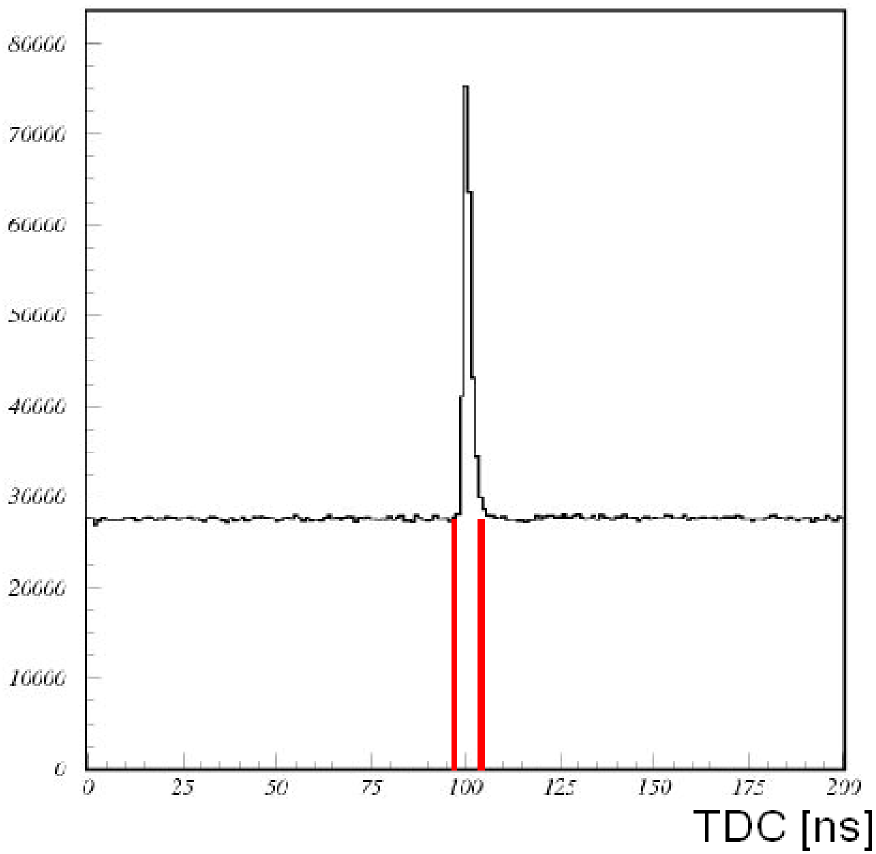




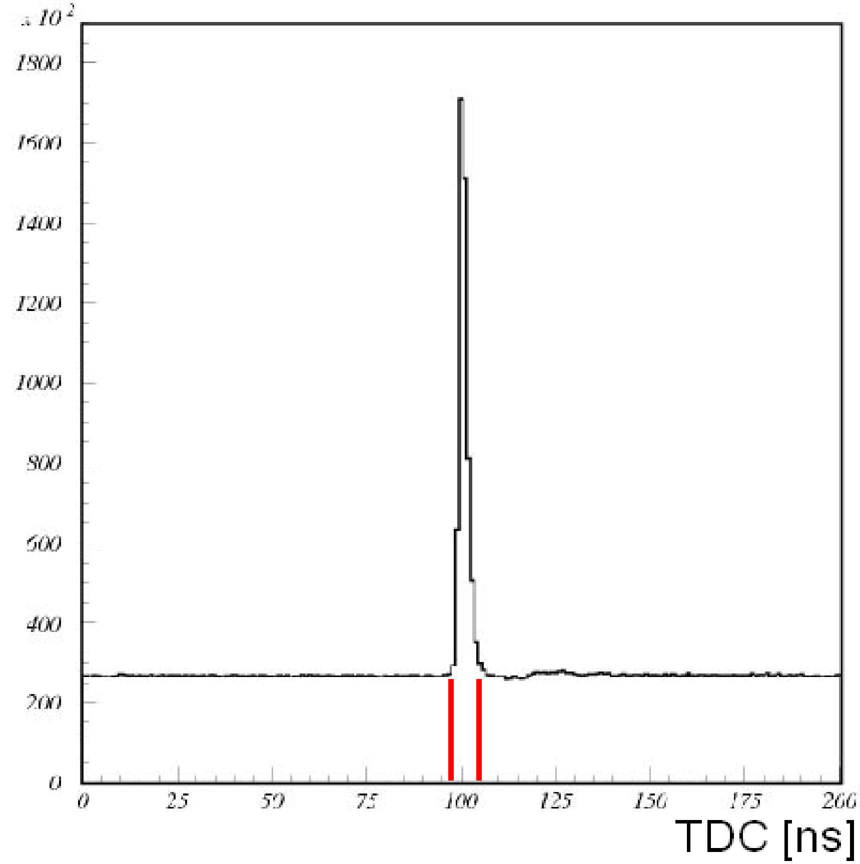
TDC distributions of MPPC hits for all events

- total noise rate ~ 35MHz (~600kHz/MPPC)
- hits in the time window of 5ns around the peak are selected for Cherenkov angle analysis

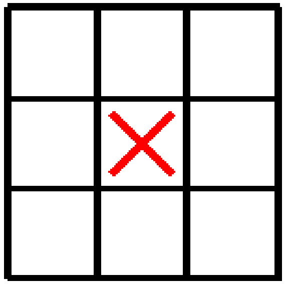
w/o light guides



w/ light guides

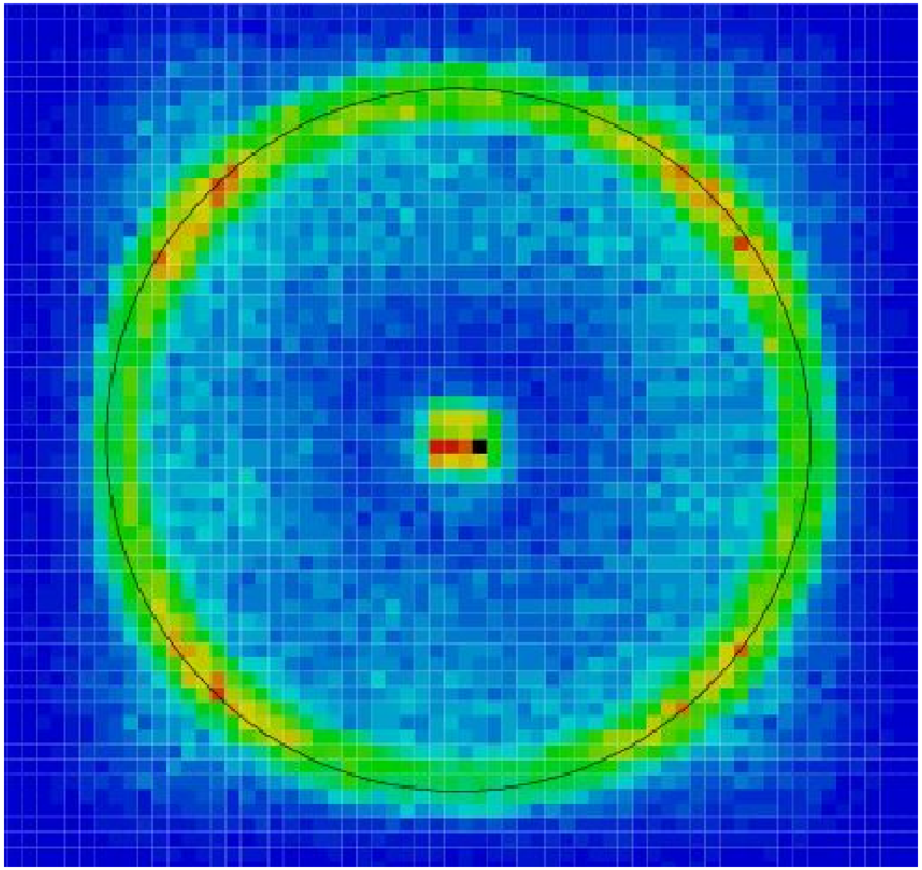


Ring images

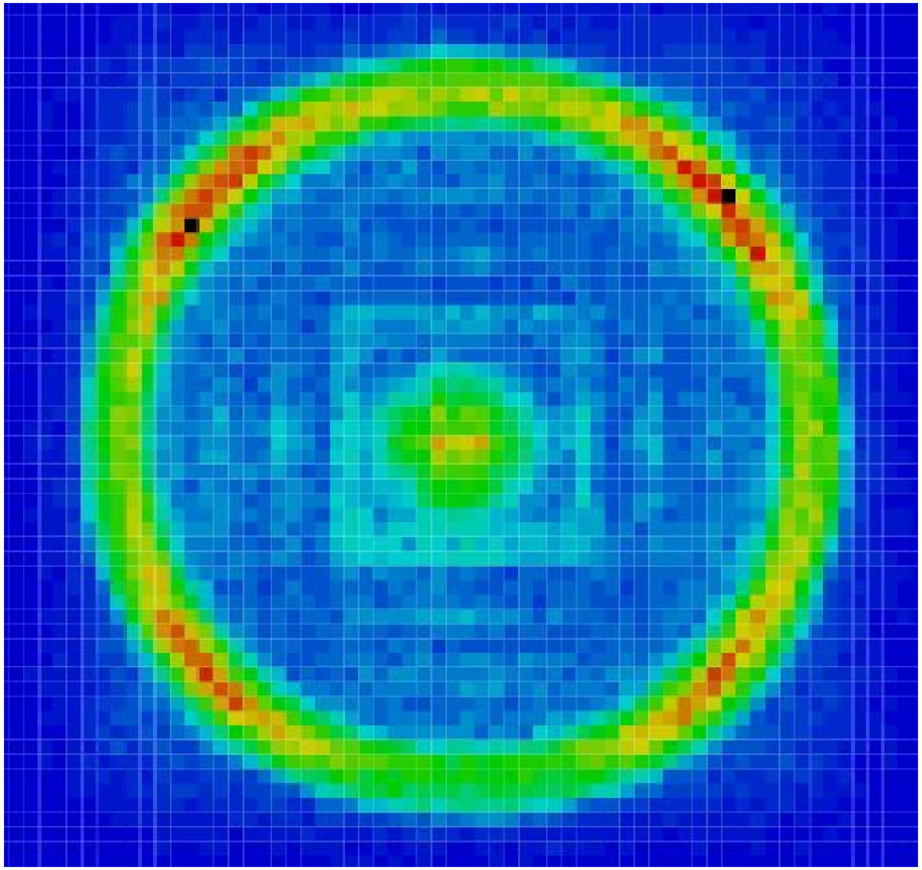


- module was moved to 9 positions to cover the ring area
- these plots show only superposition of 8 positions (central position is not included)

w/o light guides

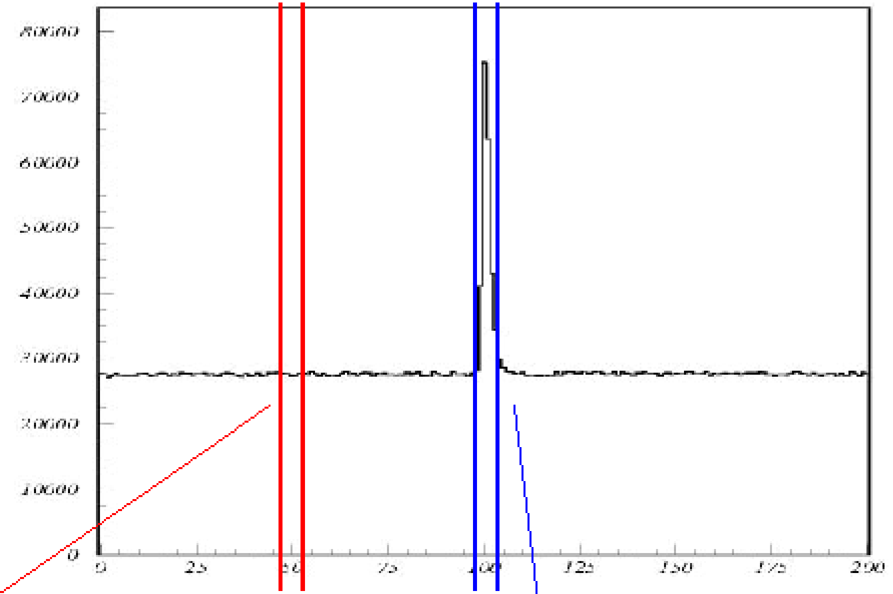


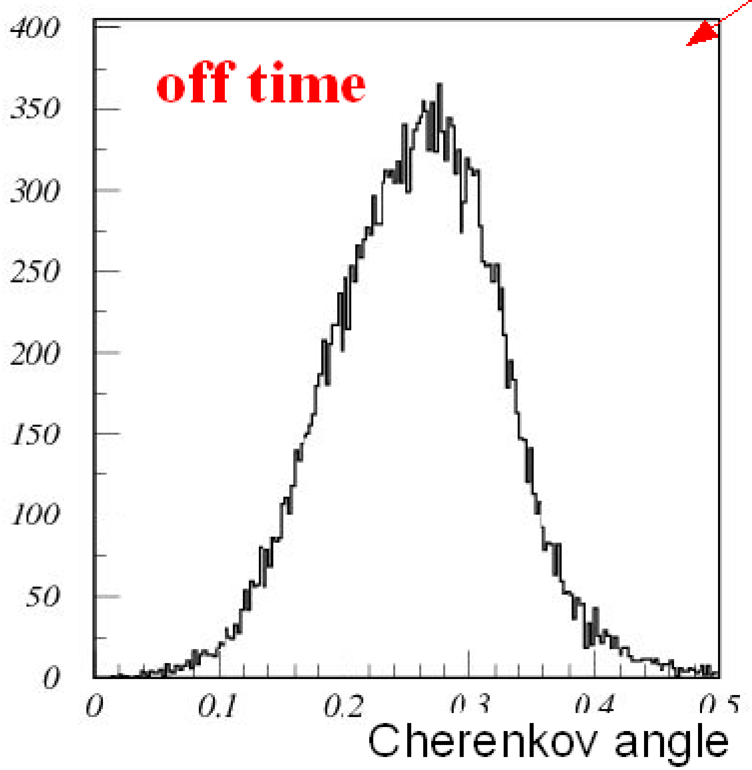
w/ light guides

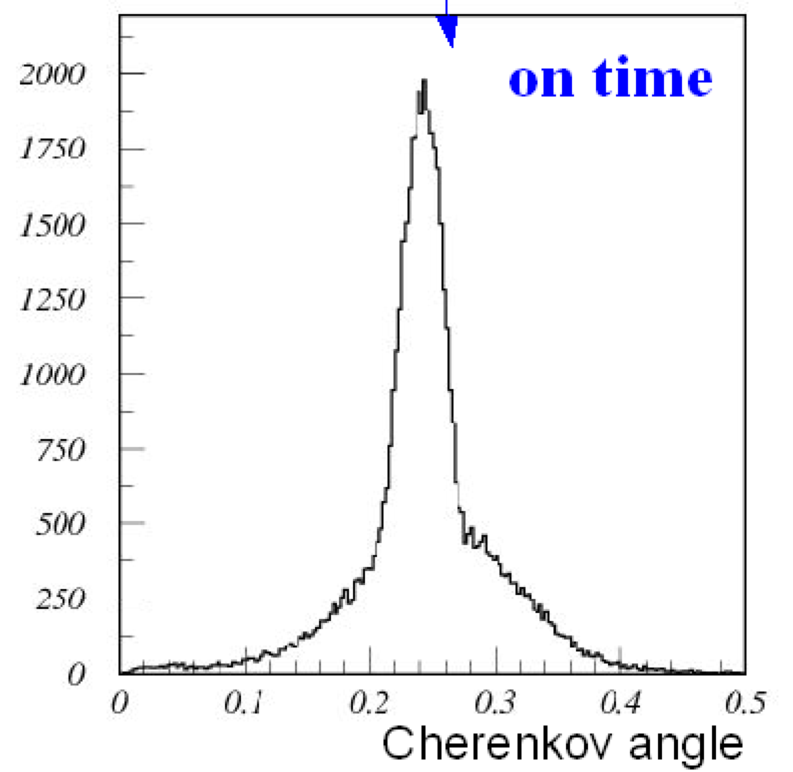


Cherenkov angle distributions

• background from SiPM noise hits is obtained from sideband in TDC distribution

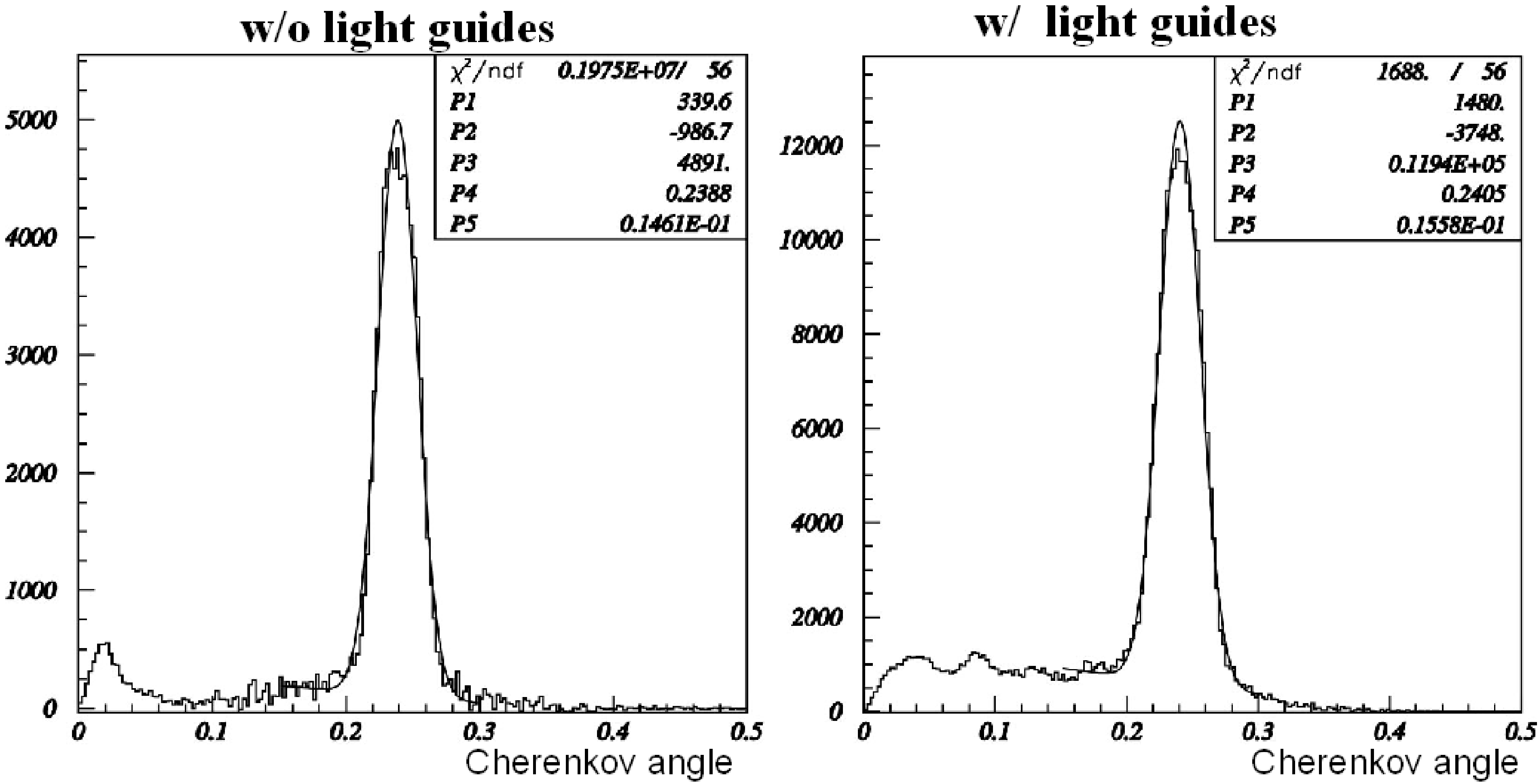






Cherenkov angle distributions

- background subtracted distributions
- ratio of detected photons w/ and w/o: ~ 2.3
- resolution within expectations (14.5mrad)



Number of photons

Expected number of photons is ~3/full ring, this includes:

- Hamamatsu PDE
- aerogel: 1cm thickness, n=1.03, 25mm attenuation length
- dead time and double hit loss ~10%

Measured (extrapolated to full ring - acceptance corrected):

- w/o LG ~ 1.6
- w/ LG ~ 3.7

Estimated numbers for aerogel with n=1.05 and thickness of 4cm (~5x) and better quality of light guides (surface polishing: ~2x) are

- w/o LG ~ 8
- **w/ LG ~ 37**

Summary of beam tests

Single Cherenkov photons were observed with SiPM RICH counter using cosmic rays and electron beam

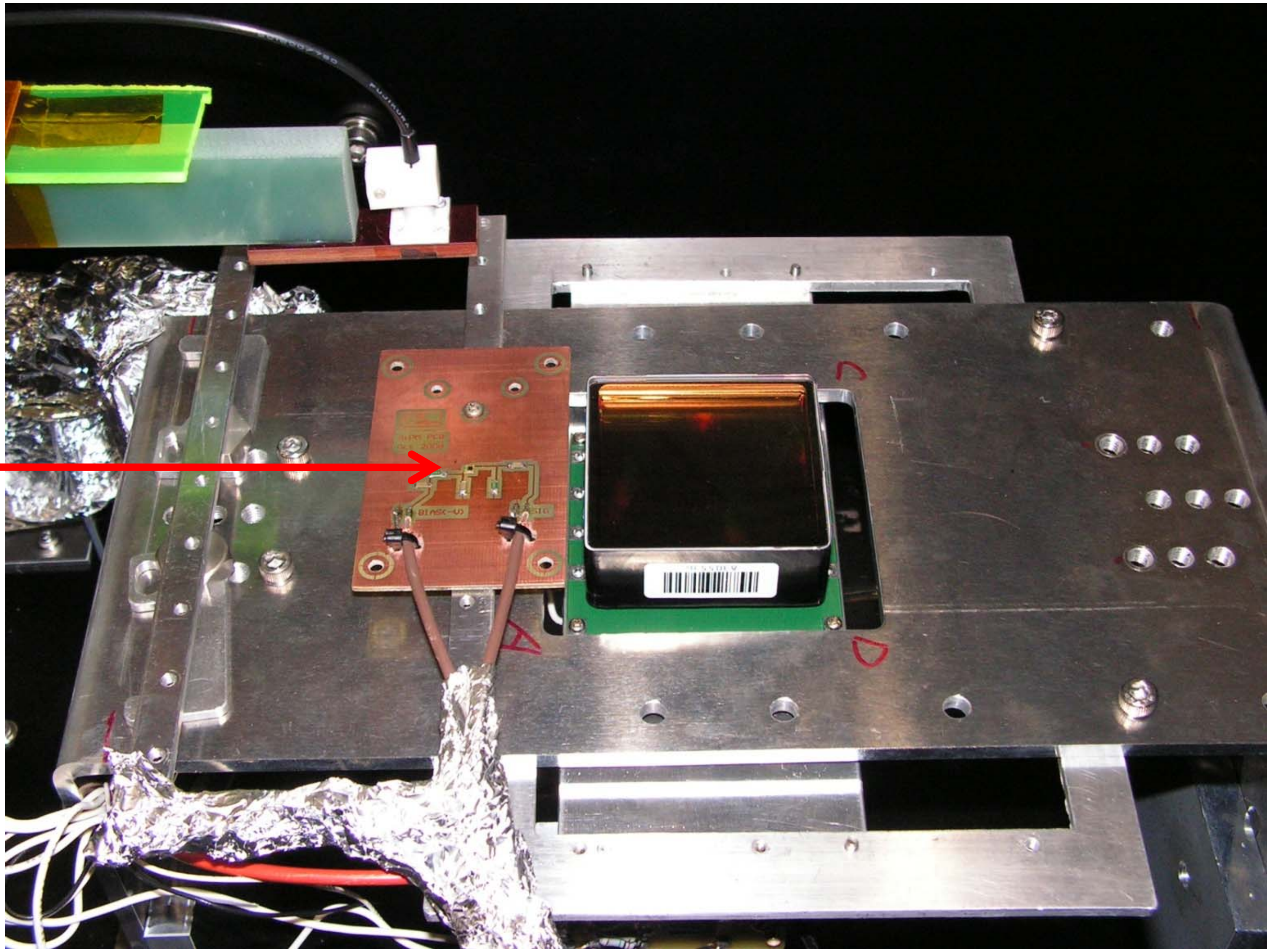
Different types of light guides were designed and studied

A detector module was constructed using 8x8 array of MPPCs (SMD package) and a light guide array, and tested in the pion test beam

Preliminary results are roughly in agreement with expectations

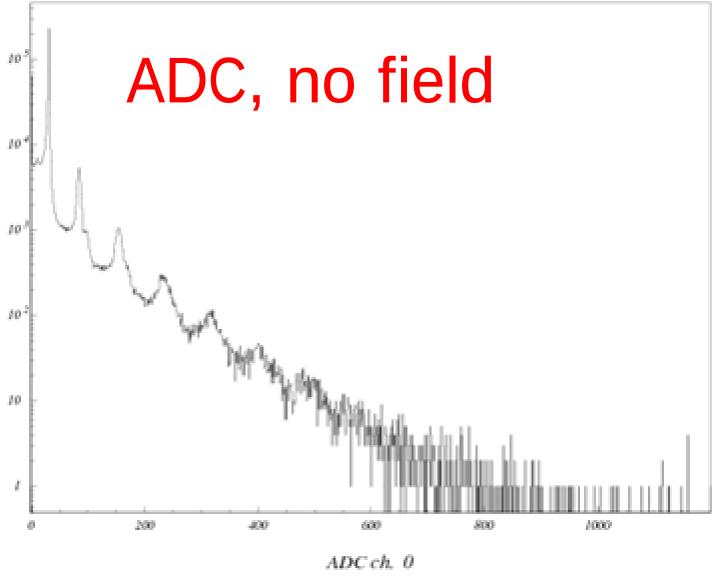
Tests of high B filed operation

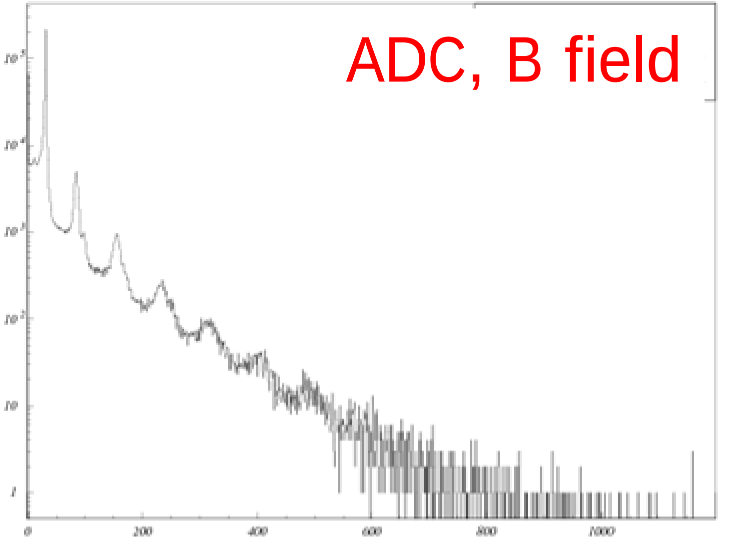
SiPM mounted in magnet (the same as HAPD and MCP PMT)



Tests of high B filed operation

As expected, no impact on sensor performance was observed.





Open question: sensitivity to neutrons

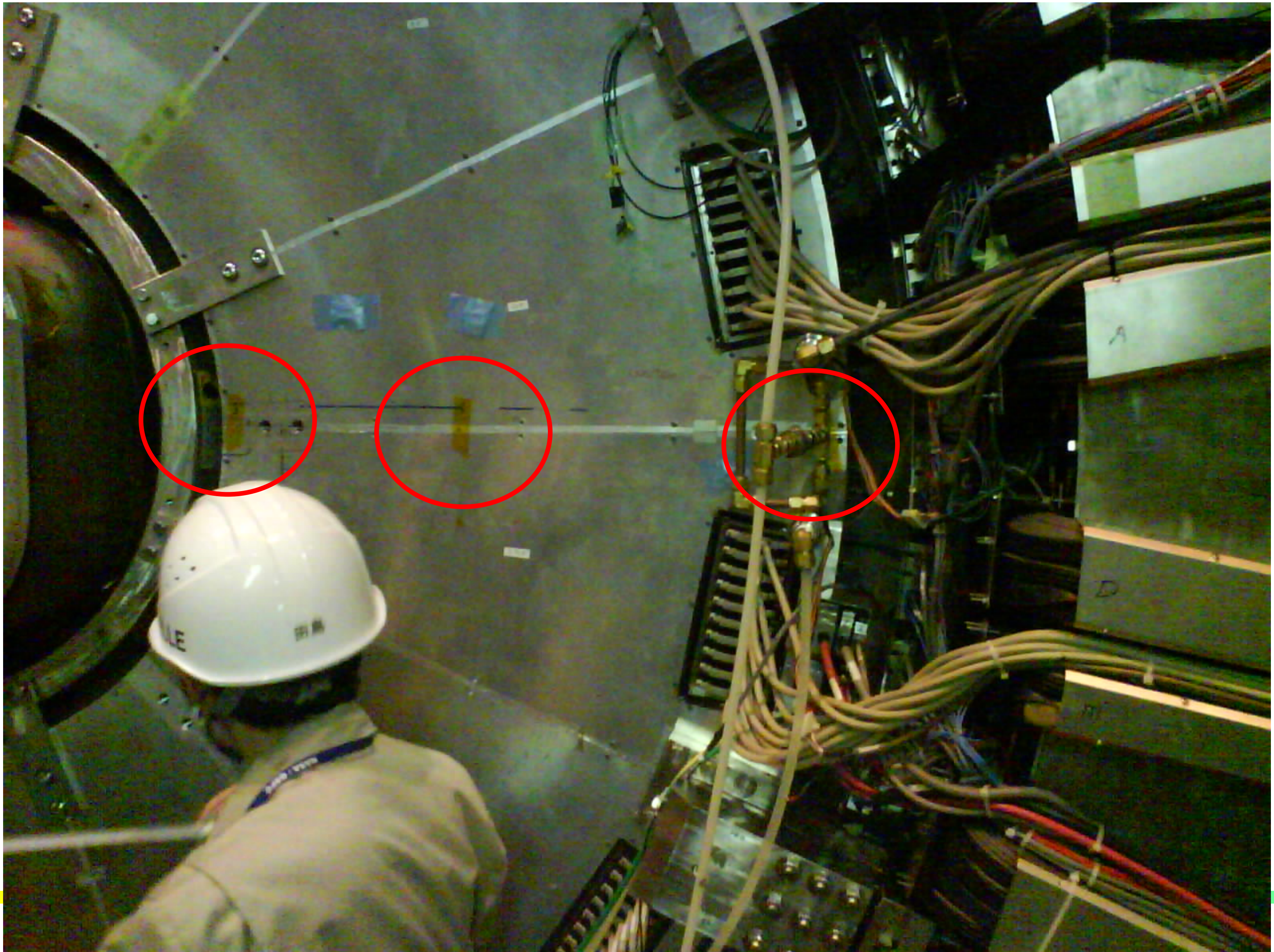
However: SiPMs are sensitive to neutron irradiation (dark count rate starts increasing drastically after ~10^{10} neutrons/cm^2)

→ We have to measure the neutron flux in the relevant detector region:

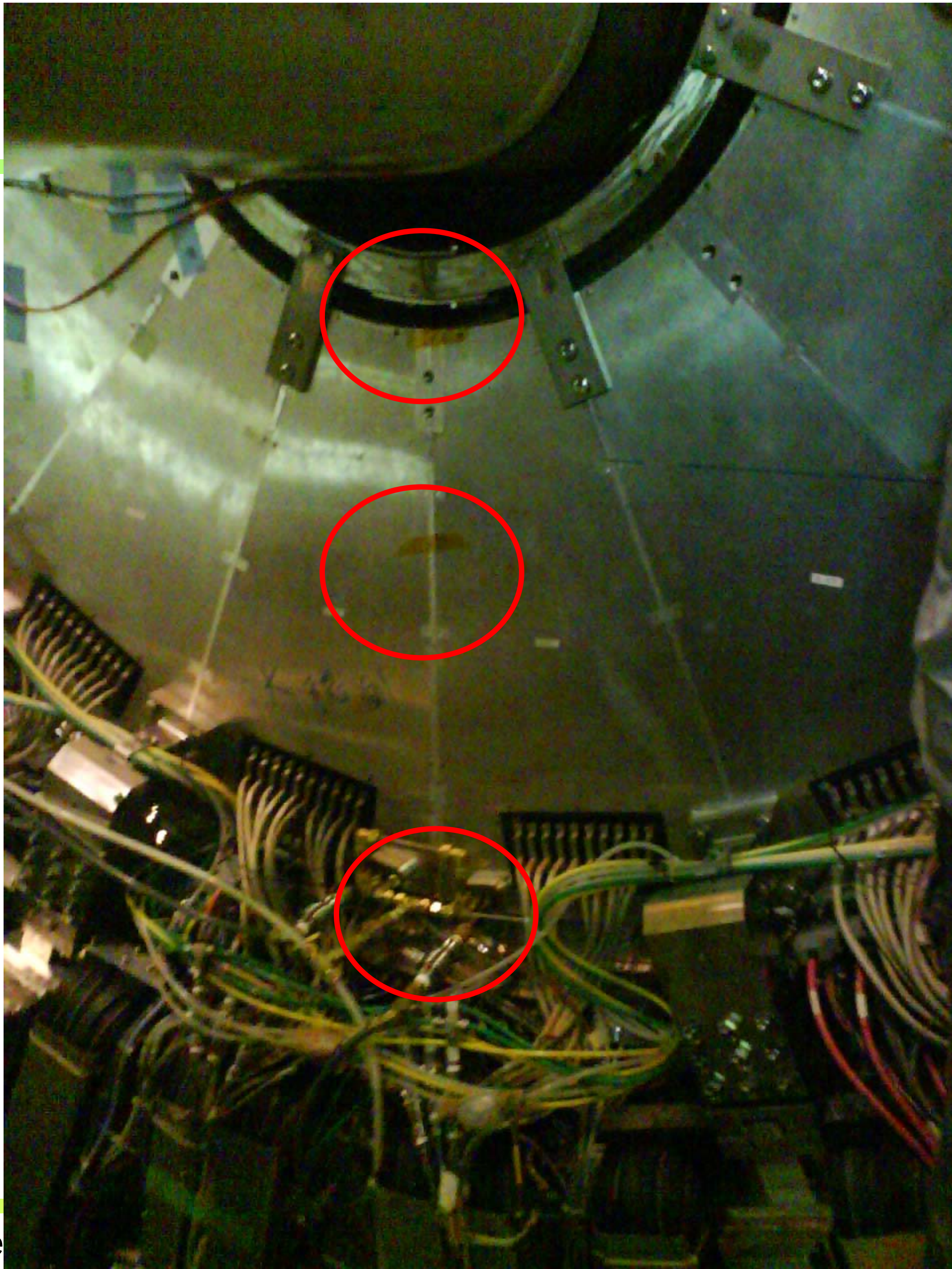
- calibrated Si diodes mounted in Belle, January-July 2008, extracted and determined the integrated flux (fluence)

- In July 2008 we have also mounted a few SiPMs in the proper place in the spectrometer, monitoring their performance during running.

Sensor positions 1, spring 2008 run



Sensor positions 2 spring 2008 run

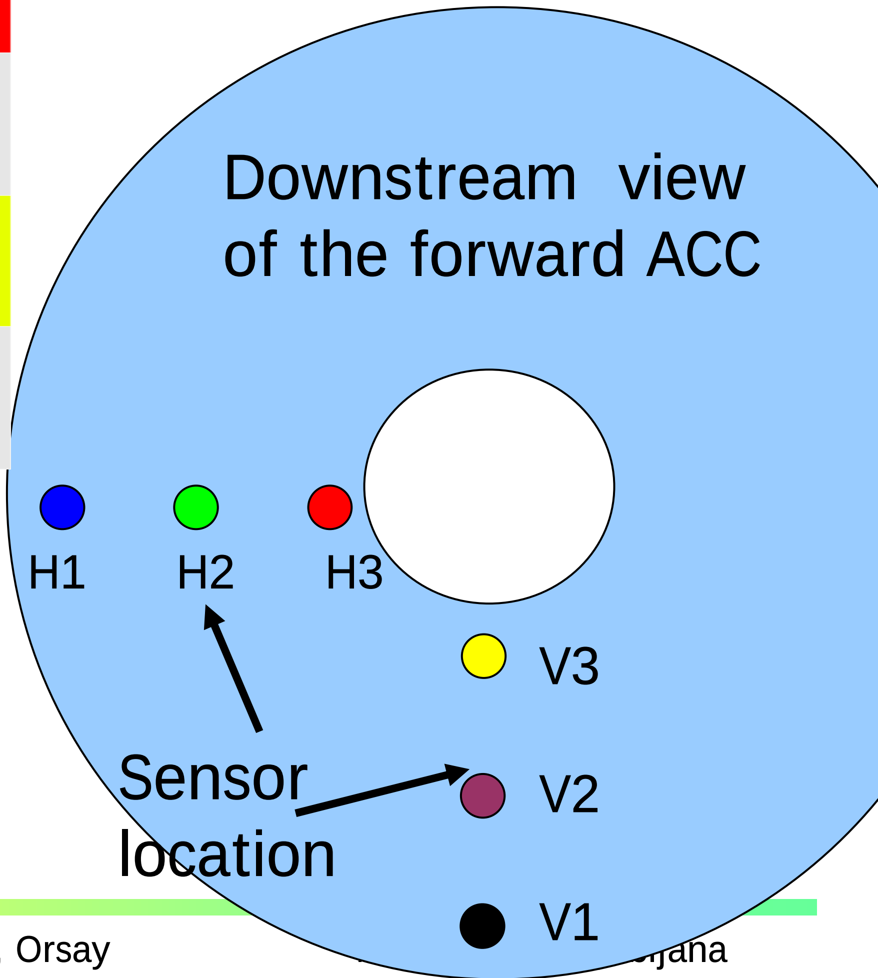


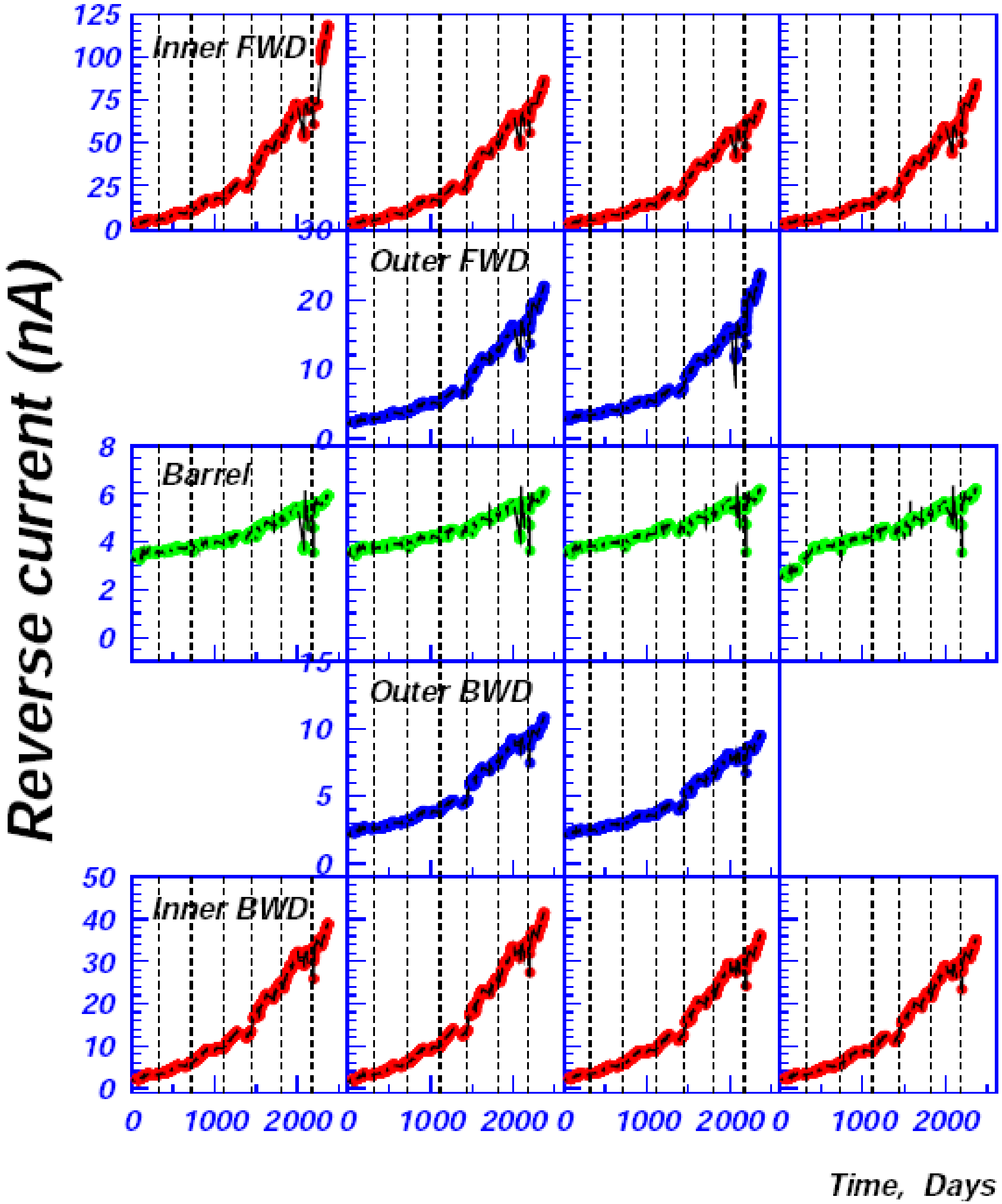
Results of measurements

6 ELMA diodes irradiated from Feb.-June 2008 (int.L=91 fb^{-1})

- The irradiation was determined from the I-V diode characteristics.

Horizontal diodes	H1	H2	H3
Dose ($10^9 n/cm^2$)	1.53	3.21	8.31
Vertical diodes	V1	V2	V3
Dose ($10^9 n/cm^2$)	9.18	2.52	7.35





ECL estimates

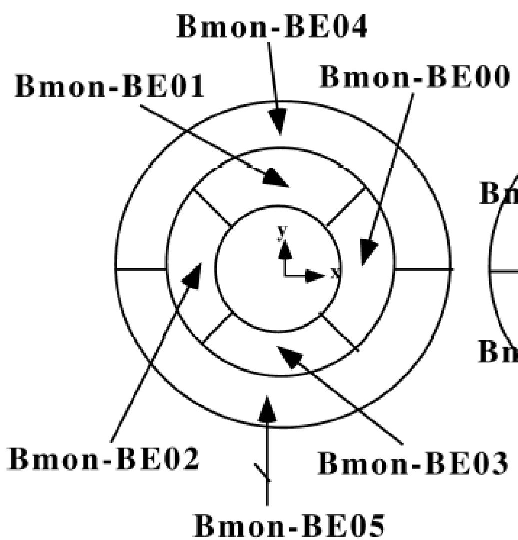
ECL photodiode bias current increases due to bulk damage → estimate the neutron fluence

Conversion factor:

1nA~ 7×10^{8}n/cm^{2}

Comparison with ECL data

Inner fwd (FE00): 9.5 10^9 n cm^{-2}
Inner fwd (FE01): 6.8
Inner fwd (FE02): 6.6
Inner fwd (FE03): 8.9
Outer fwd (FE04): 1.7
Outer fwd (FE05): 1.8



Horizontal diodes	H1	H2	H3
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Vertical diodes	V1	V2	V3
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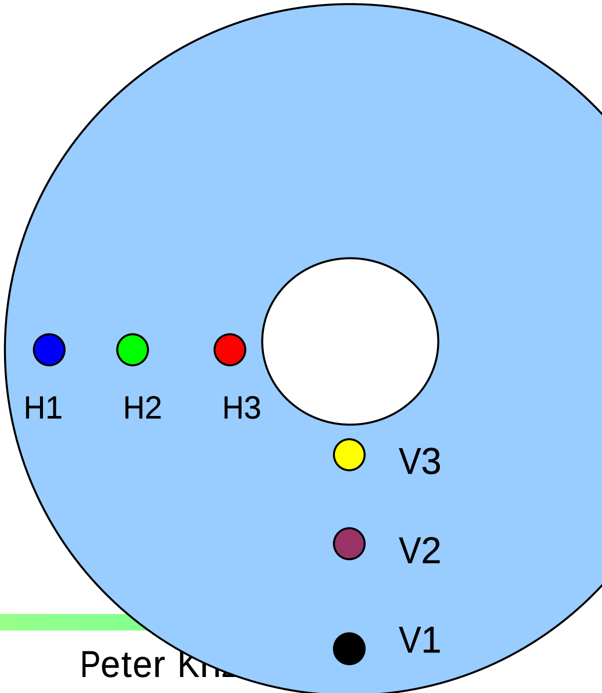
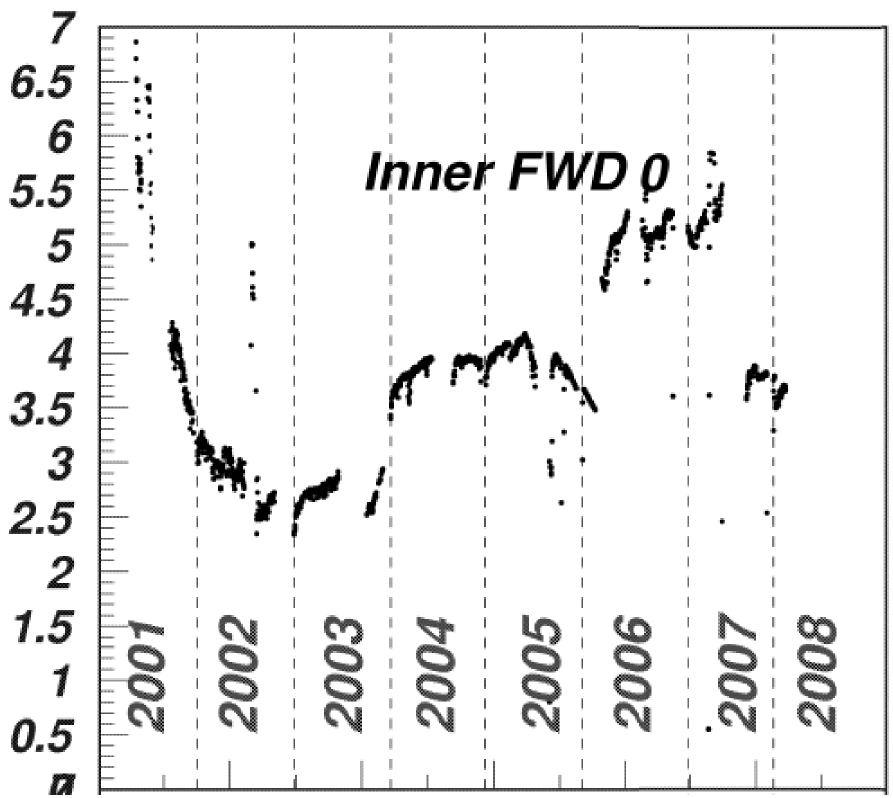


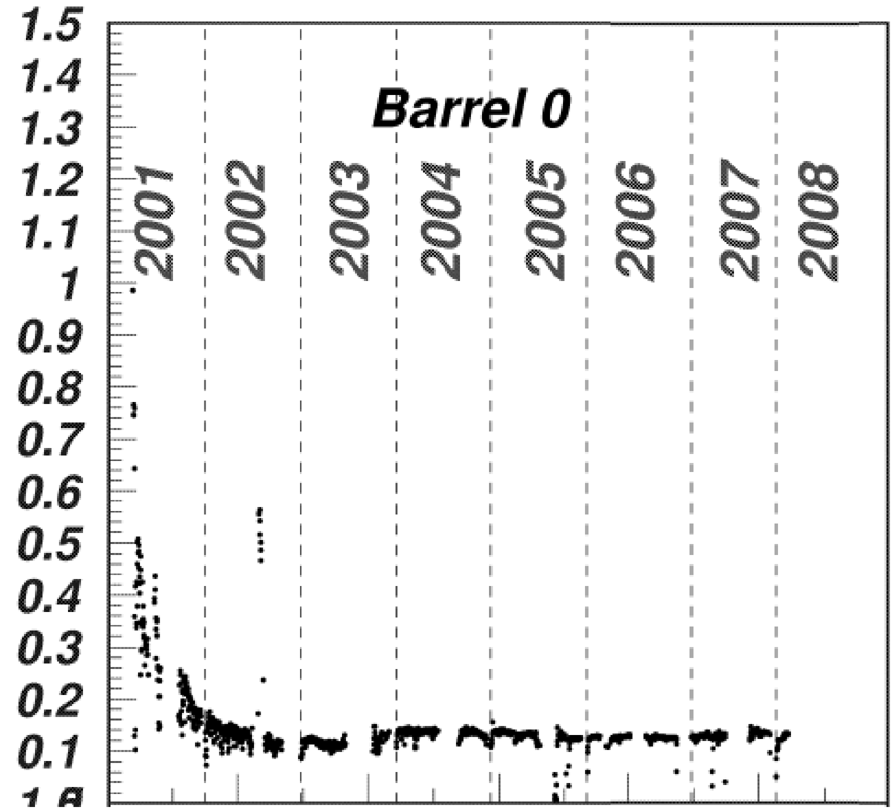
→Good agreement (appart from V1)

Bias current increase

ΔI_{bias} / (Integrated beam current)



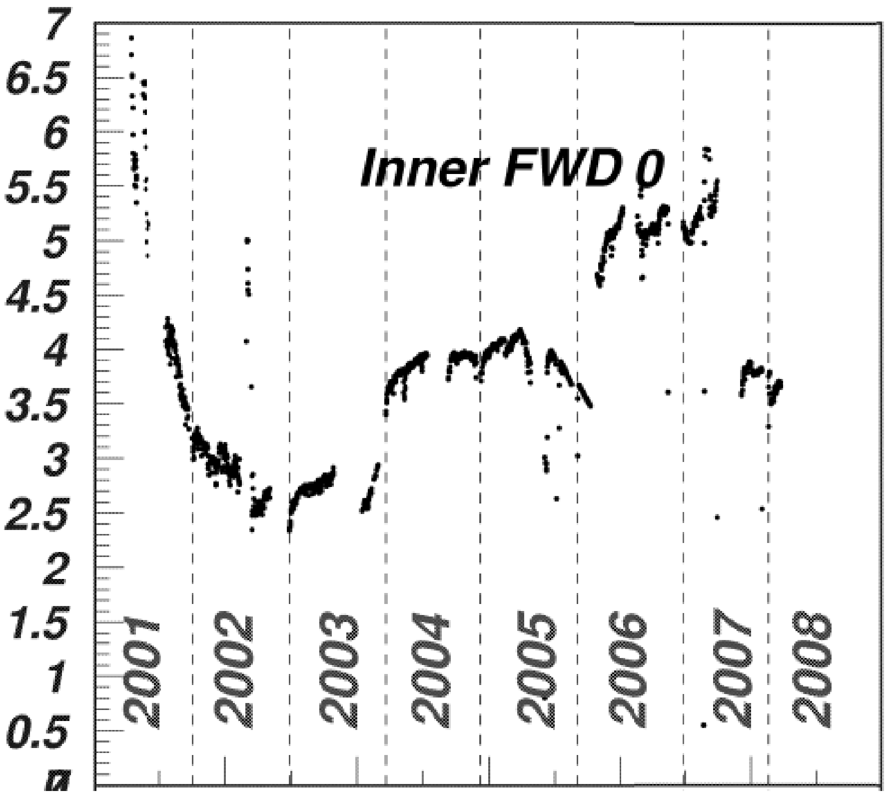
Inner forward region

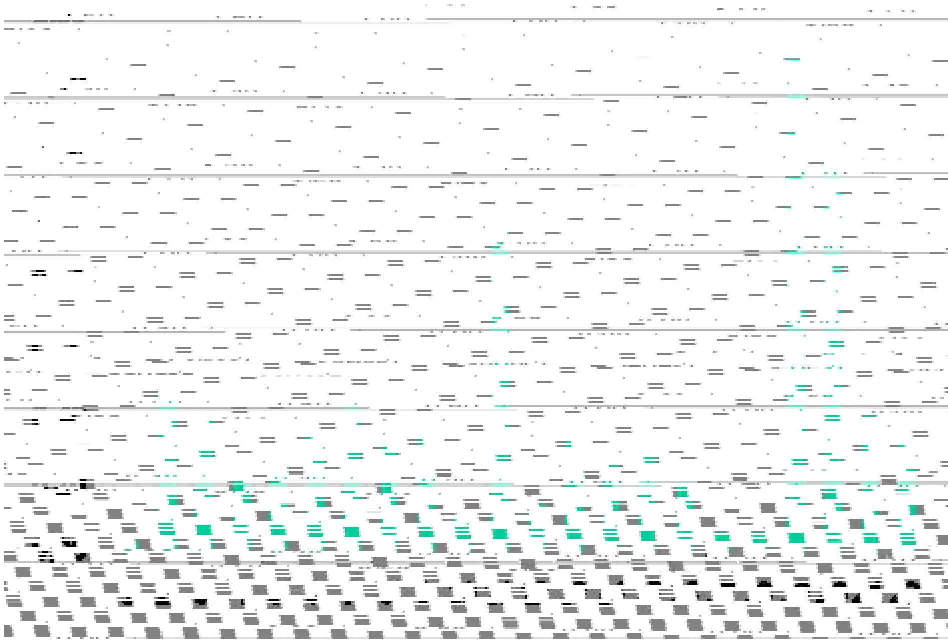


Typical barrel region

Bias current increase

Inner forward region





ΔI_{bias} normalized to integrated beam current

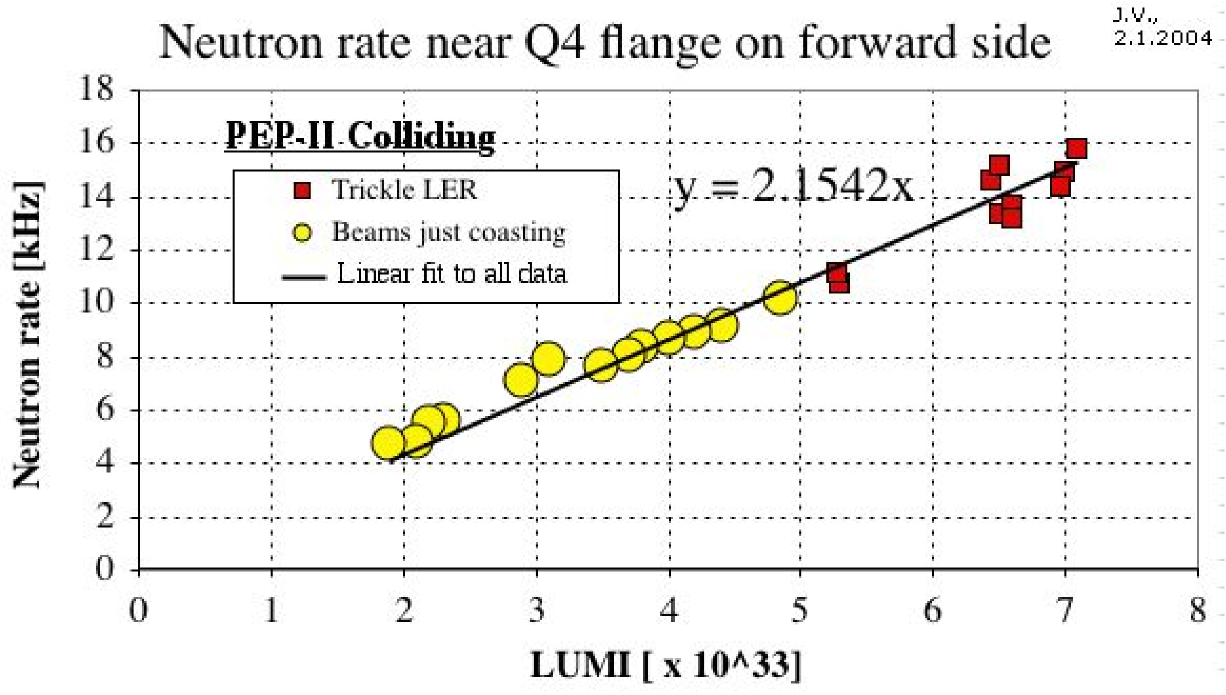
ΔI_{bias} normalized to integrated luminosity for differnt run periods

Neutron fluence – how to extrapolate?

Belle: looks more like with currents

BaBar: with lumi

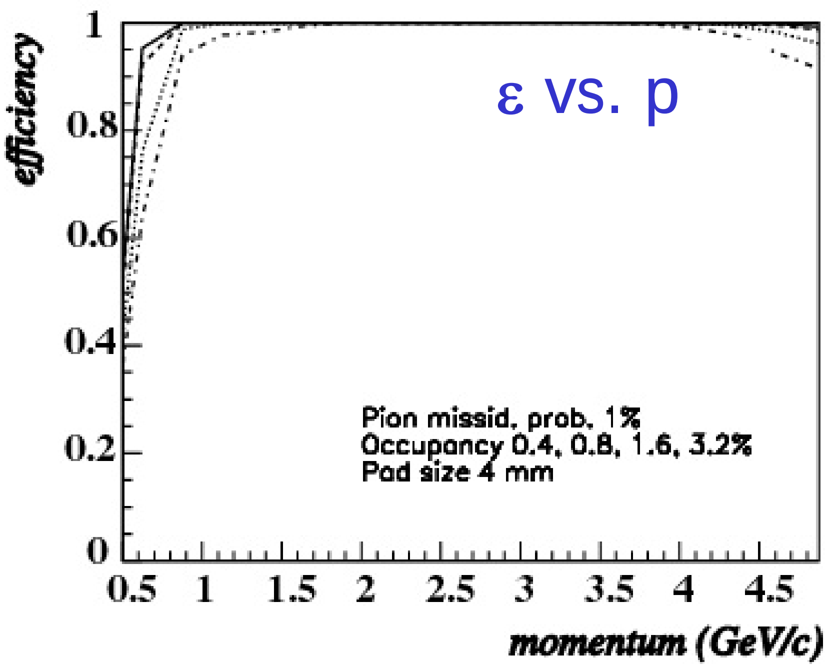
Super B factory: somewhere in between? Where? What are the coeffcients?

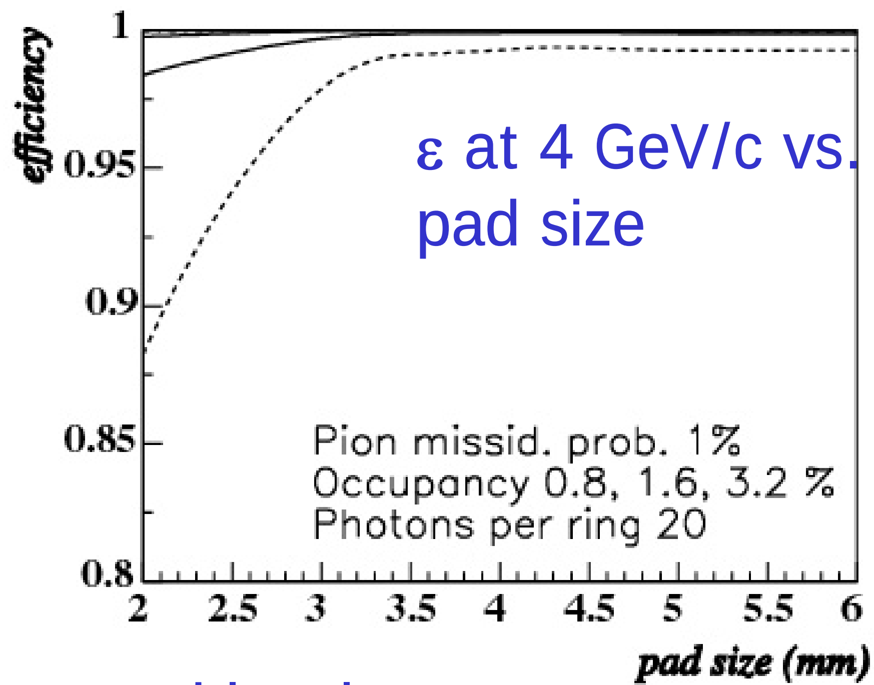


PID efficiency vs occupancy

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

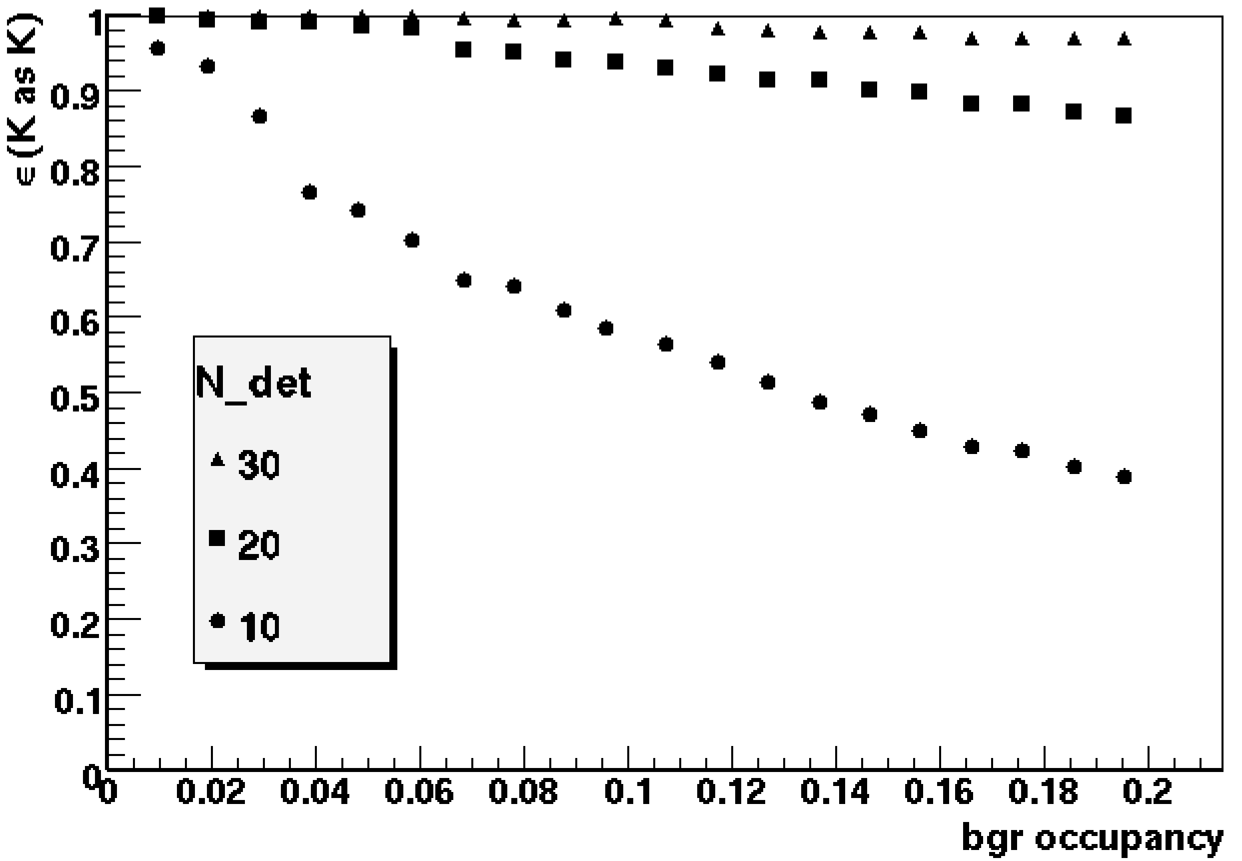
K identification efficiency at 1% π missid. probability





For different background levels

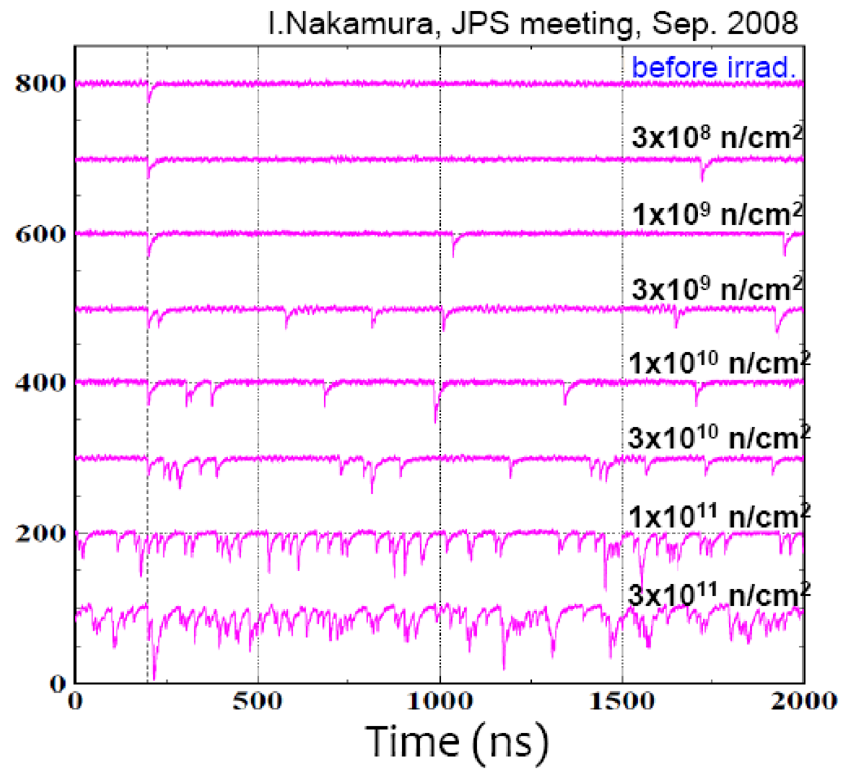
PID efficiency vs occupancy



~40MHz

For different number of photons per ring vs background level

Radiation damage



Measured fluence:

90/fb → 1-10 10^9 n cm^{-2}

Expected fluence at 50/ab

→ if bckg x20: 2-20 10^{11} n cm^{-2}

→ Worst than the lowest line

The monitoring diodes were not at the right place (mounted behind ECL instead of in front of it). However, n flux is probably quite similar – check with new data.

→Not trivial to use present SiPMs as single photon detectors in a Super B factory because of radiation damage by neutrons

Cost

Need: about 500k pieces.

→cost/piece would have to be <10 USD to be competitive with the other two detectors

Single piece ~70EUR / piece
T2K bought a large quantity for ~20 USD / piece

Summary

A module with small size light guides was designed, machined and attached to the SiPMs, and tested in the beam

Cherenkov rings were measured in the test beam

A large number of photons per ring (>20, possibly even >30) is expected → excellent performance

Radiation field in the present detector extrapolated to the 50/ab looks prohibitively high.

Cost would have to be considerably reduced for this option to become competitive.

Plan:

→Keep monitoring SiPM performance and radiation in Belle

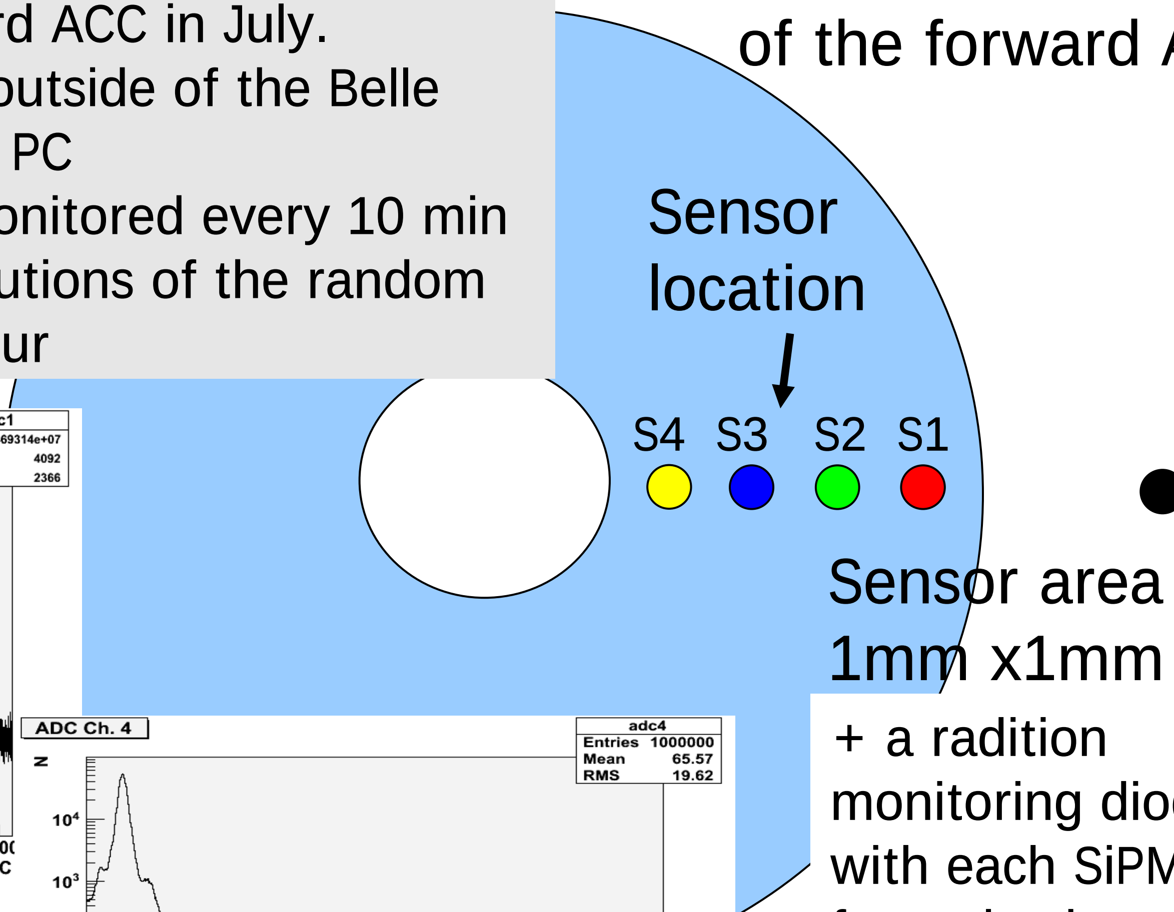
→By using MC of the new IR make reliable extrapolation estimates

→Wait for breakthrough in radiation hardness and cost

Monitoring of SiPMs behind forward ACC

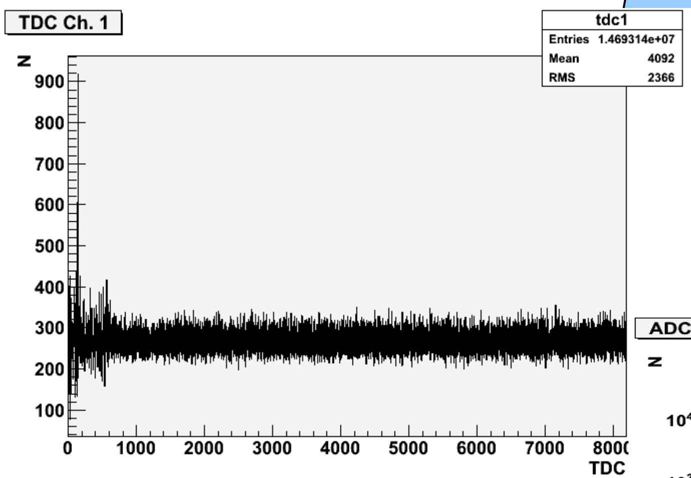
- 4 Hamamatsu MPPC sensors were mounted at the backside of the forward ACC in July.
- 1 reference MPPC is run outside of the Belle detector close to the DAQ PC
- The leakage current is monitored every 10 min
- The TDC and ADC distributions of the random hits are acquired every hour

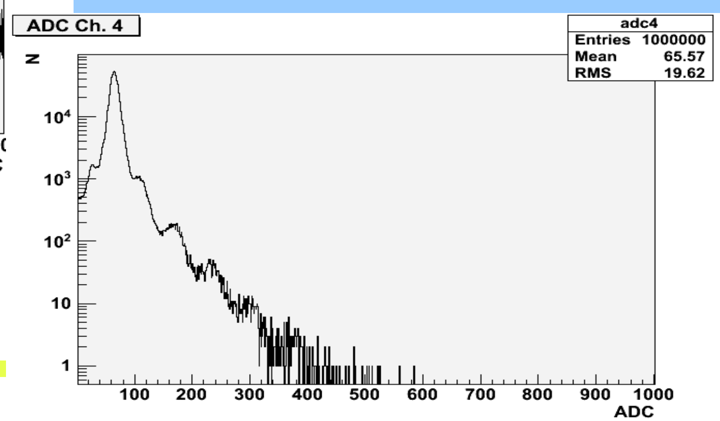
Downstream view of the forward ACC



Sensor area 1mm x1mm

+ a radition monitoring diode with each SiPM for x-check





Back-up slides

High occupancy environment: RICH can 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