Univerza *v Ljubljani*

PID for super Belle: R&D status

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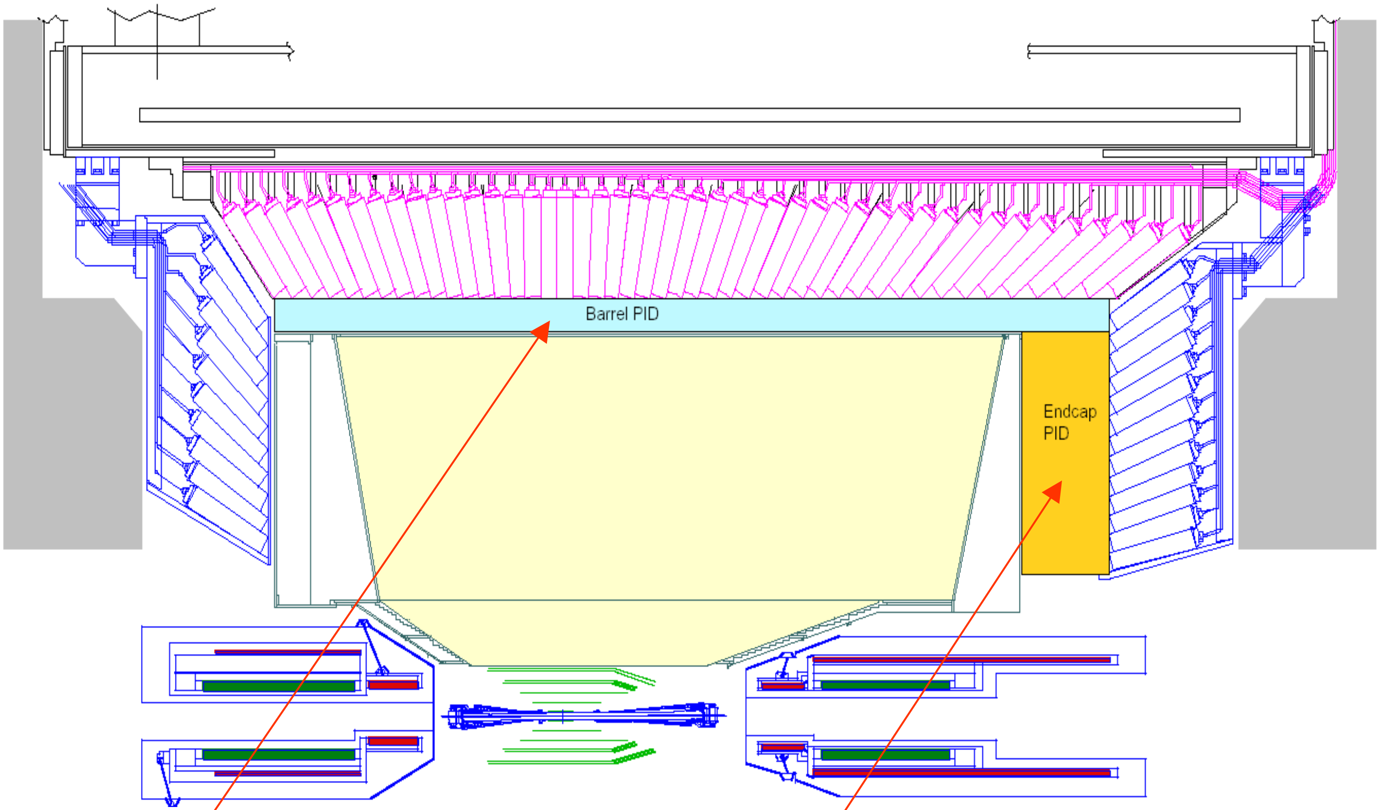
Belle upgrade – side view



Two new particle ID devices, both RICHes:

Barrel: Time-Of-Propagation (TOP) (baseline), focusing DIRC

Endcap: proximity focusing RICH

Contents

Aerogel RICH:

- Photon detector studies (MCP PMT, HAPD, SiPM)
- Read-out R+D
- Open issues

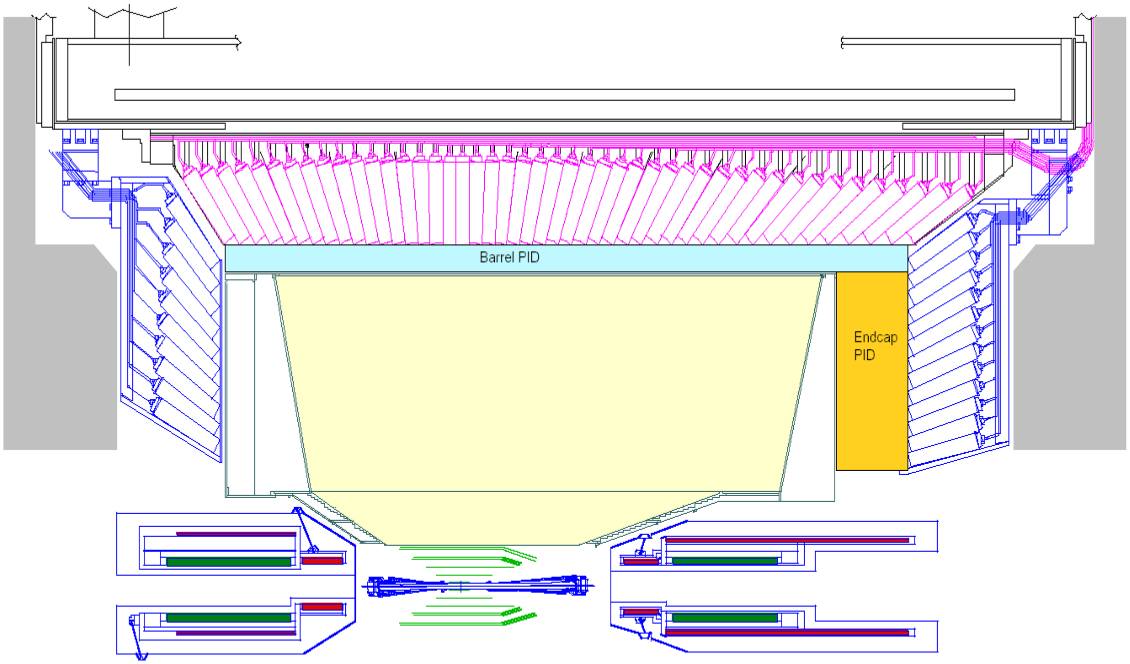
TOP: → next talk

- Photon detector studies (MCP PMT)

Focusing DIRC:

- Beam test, read out electronics

PID upgrade in the endcap



improve K/π separation in the forward (high p) region for few-body decays of B mesons

good K/π separation for b → dγ , b → sγ

improve purity in fully reconstructed B decays

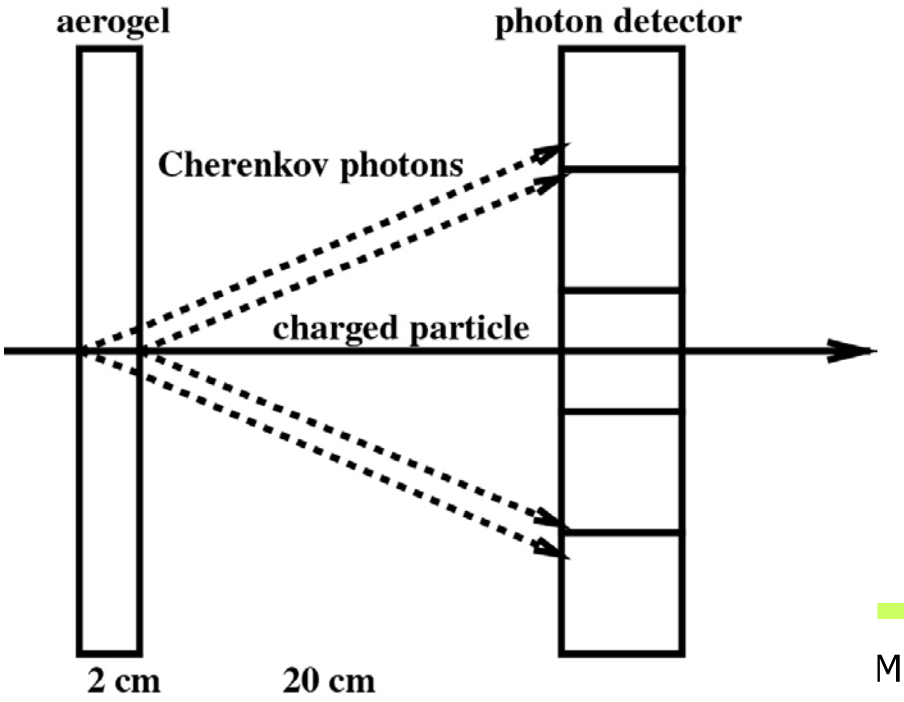
low momentum (<1GeV/c) e/μ/π separation (B → Kll)

keep high the efficiency for tagging kaons

Proximity focusing RICH in the forward region

Requirements and constraints:

- ~ 5 σ K/π separation @ 1-4 GeV/c
- operation in magnetic field 1.5T
- limited available space ~250 mm



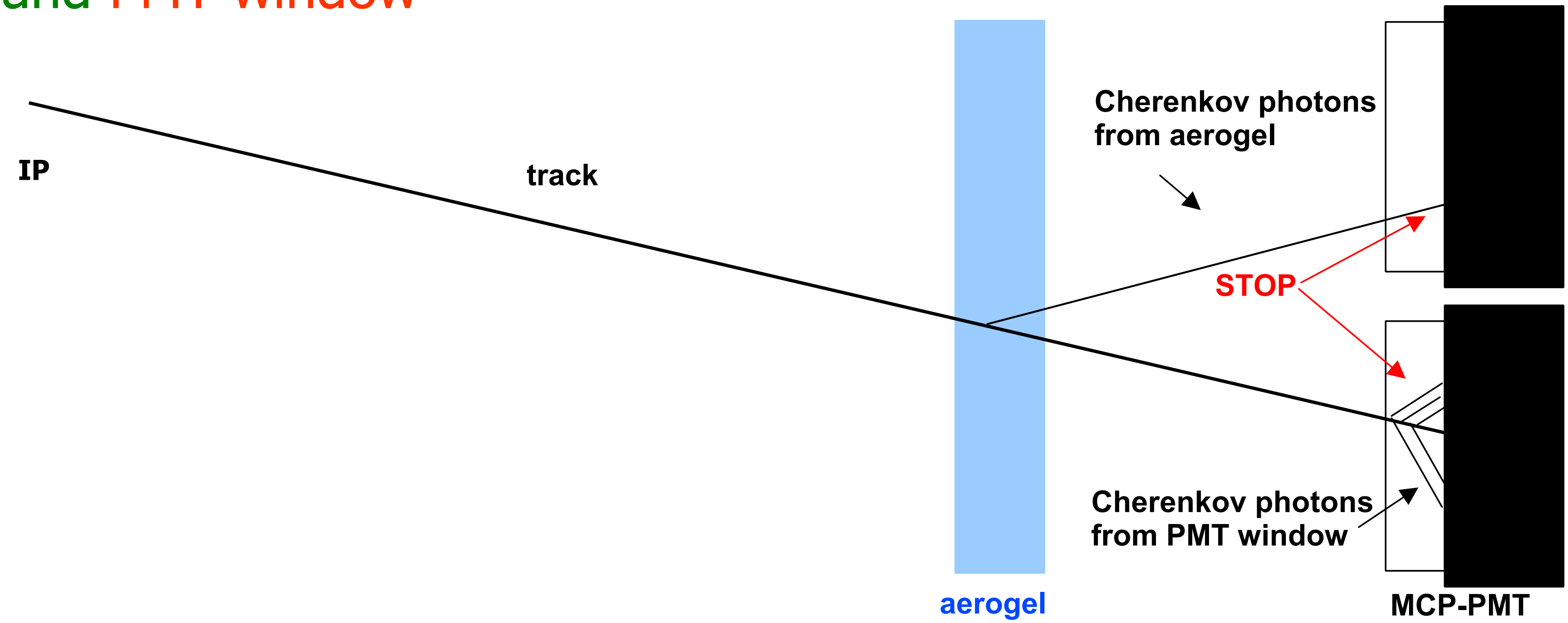
M2

- n = 1.05
- $\theta_c(\pi)$ ~ 308 mrad @ 4 GeV/c
- $\theta_c(\pi) - \theta_c(K)$ ~ 23 mrad
- pion threshold 0.44 GeV/c,
- kaon threshold 1.54 GeV/c

- time-of-flight difference (2m):
  t(K) - t(π) = 180 ps @ 2 GeV/c
  45 ps @ 4 GeV/c

Time-of-flight measurement

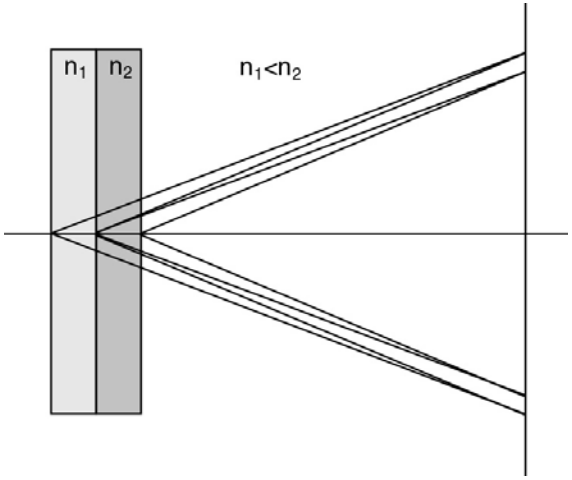
Time-of-flight with Cherenkov photons from aerogel radiator and PMT window



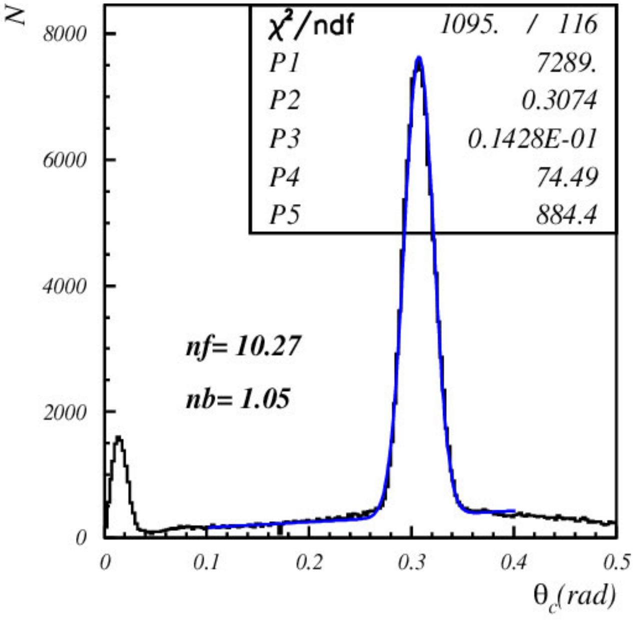
→can positively identify kaons bellow Cherenkov threshold in aerogel (1.5 GeV)

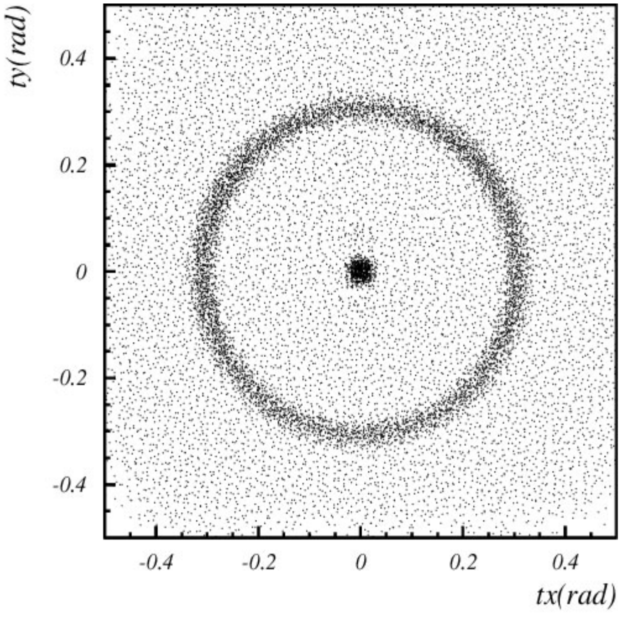
→a fast photon detector is an advantage

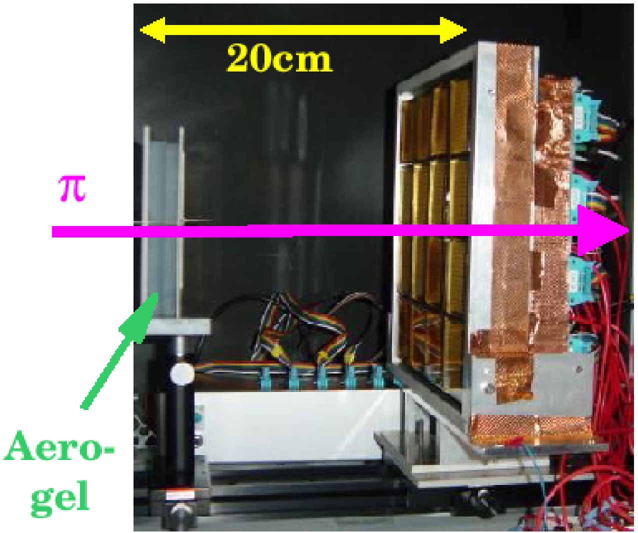
Beam tests: very good performace



2cm+2cm focusing aerogel radiator







→ This photon detector does not work in magnetic field...

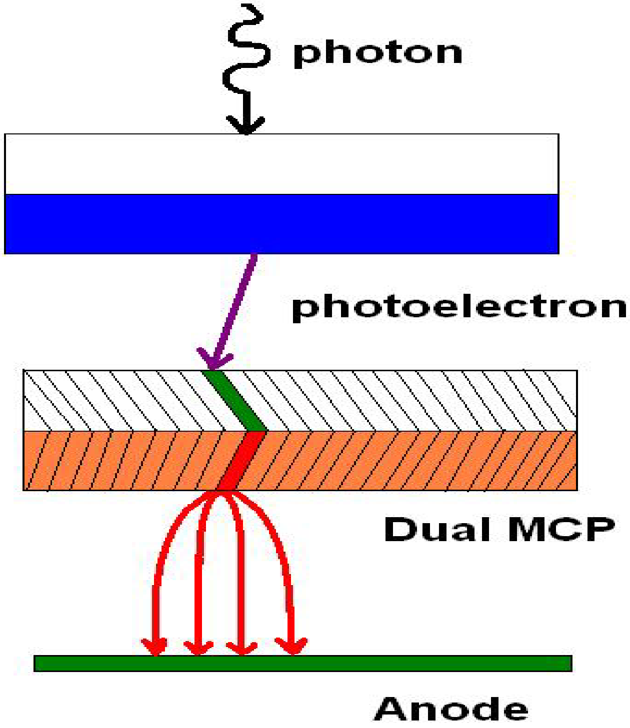
Photon detectors for the aerogel RICH

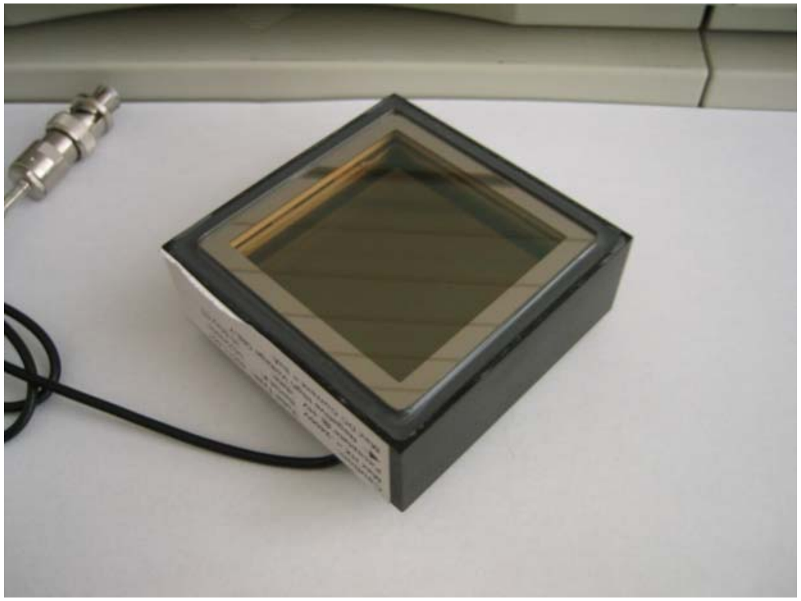
Photon detector candidates for 1.5T:

- BURLE 85011 microchannel plate (MPC) PMT
- Multichannel H(A)PD – R+D with Hamamatsu
- SiPM (Geiger mode APD)

Photon detector candidate for 1.5 T: MCP-PMT

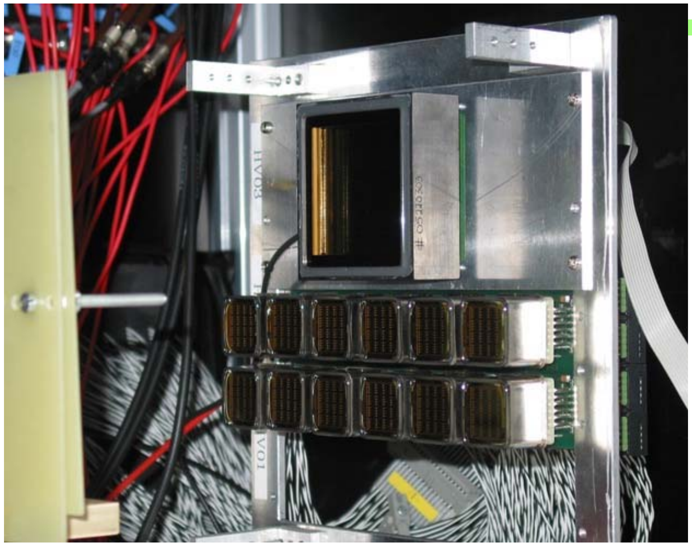
BURLE 85011 microchannel plate (MCP) PMT: multi-anode PMT with two MCP stages, 8x8 anode pads, pitch ~ 6.5mm



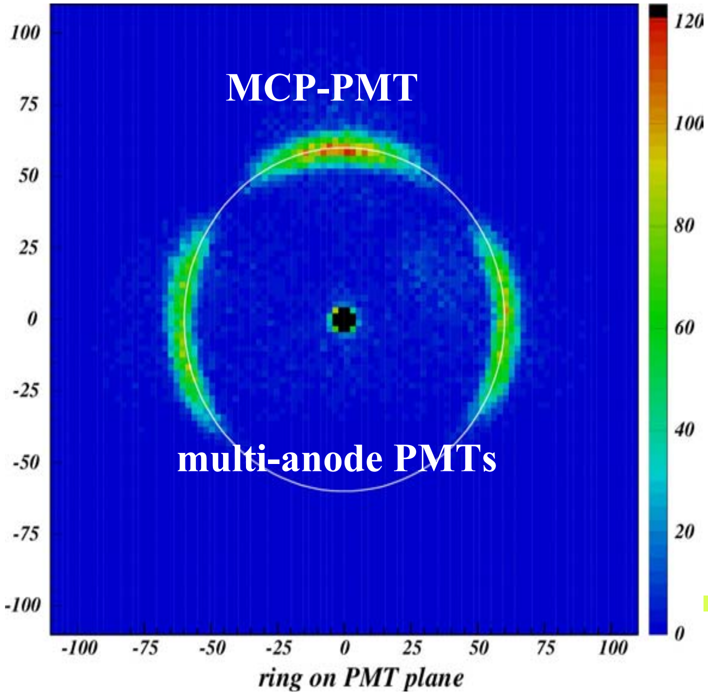


→excellent performance in beam and bench tests
→ very fast (σ~40ps for single photons)

Beam tests of Burle MCP PMT



Tested in pion beam combination with multi-anode PMTs.
→Stable operation, very good performance



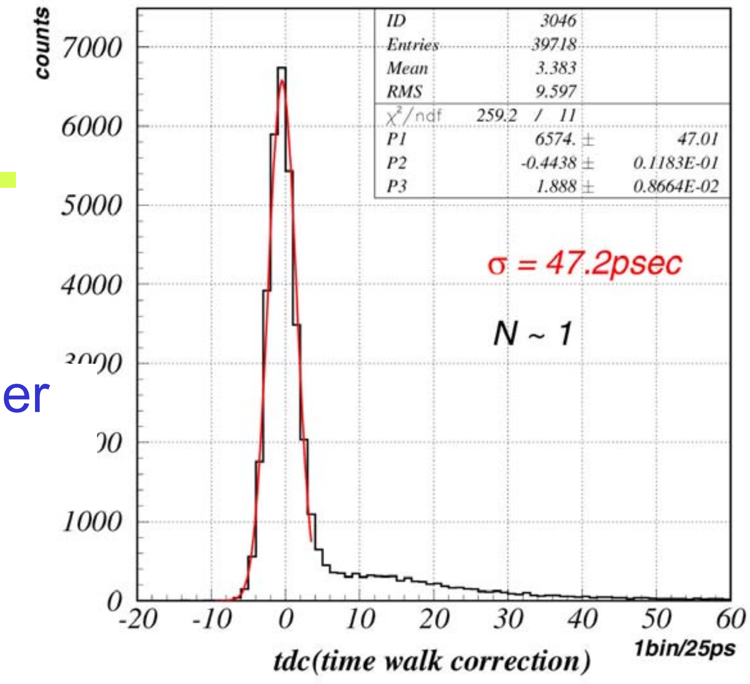
Results:
- σ_ϑ~13 mrad (single cluster)
- number of clusters per track N~ 4.5
- σ_ϑ~ 6 mrad (per track)
- → **~ 4 σ π/K separation at 4 GeV/c**

To do list:
- improve collection efficiency and active area fraction →higher number of det. photons → done
- aging study

MCP-PMT timing properties

Bench tests with pico-second laser

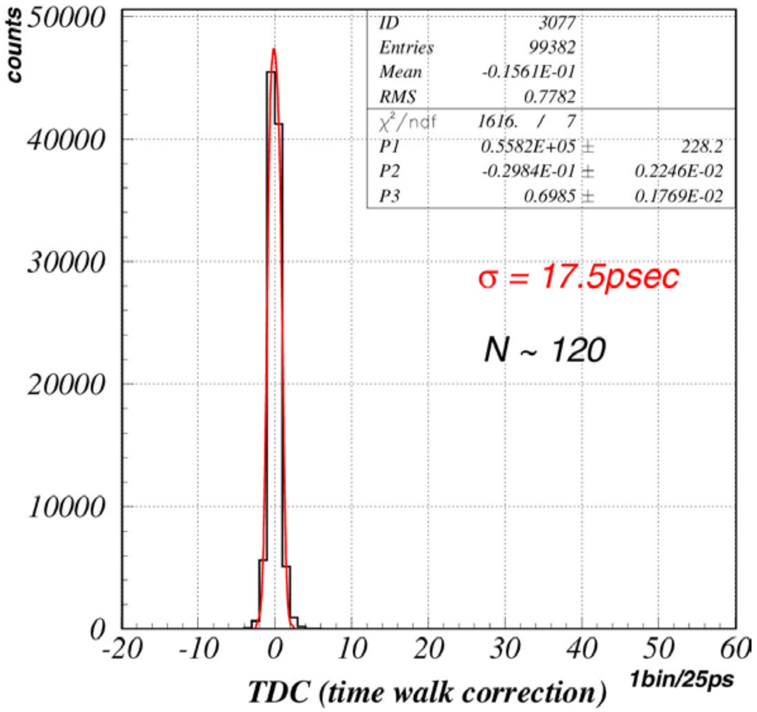
Time resolution as a function of the number of detected photons →



Additional bench tests needed: study detailed timing properties and cross-talk.

Determine their influence on the

- position resolution and
- time resolution



Scanning setup: optical system

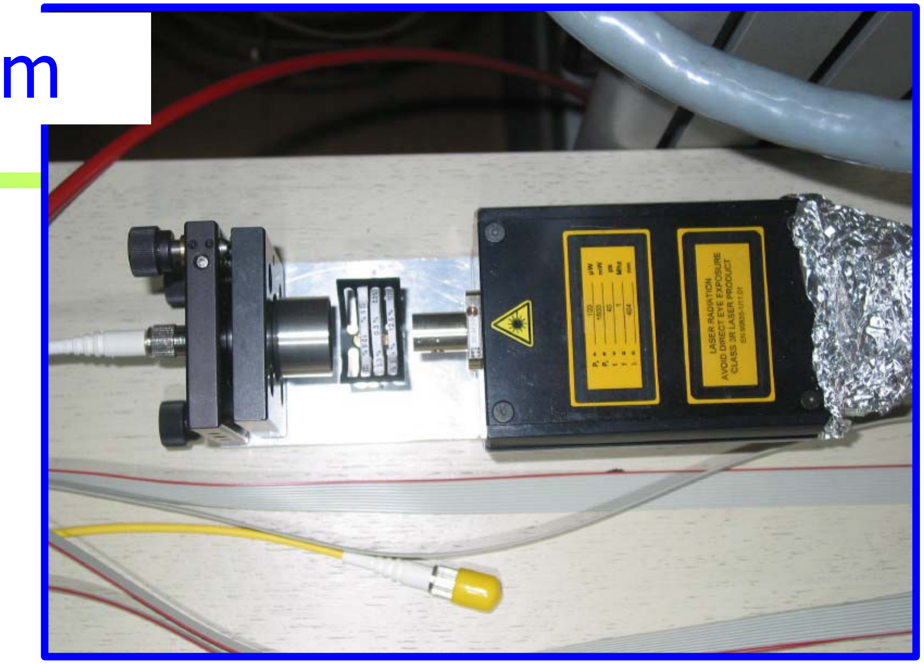
Outside dark box:

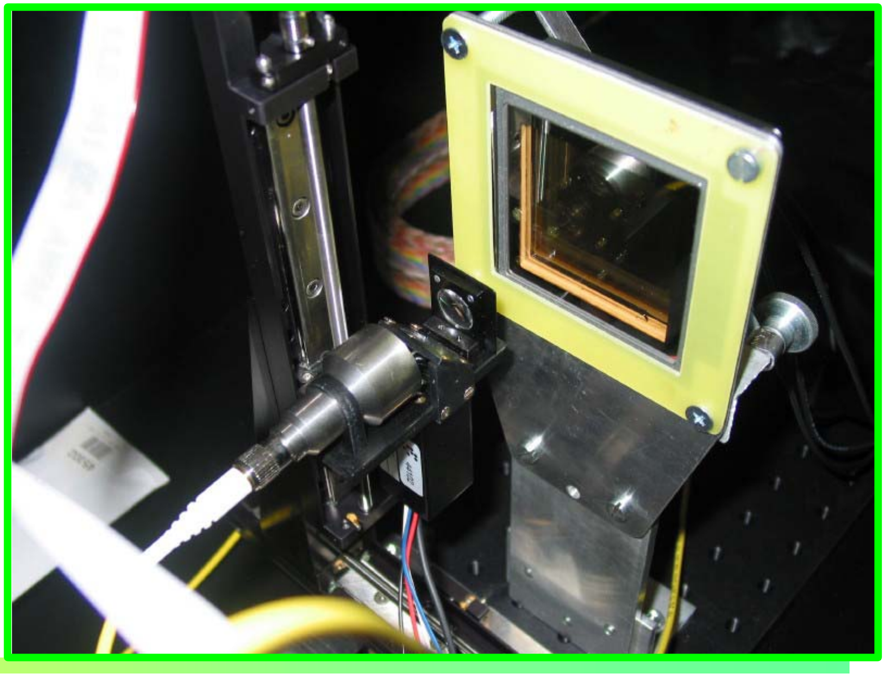
- PiLas diode laser system EIG1000D (ALS)
- 404nm laser head (ALS)
- filters (0.3%, 12.5%, 25%)
- optical fiber coupler (focusing)

- optical fiber (single mode,~4μm core)

Inside dark box mounted on 3D stage:

- optical fiber coupler (expanding)
- semitransparent plate
- reference PMT (Hamamatsu H5783P)
- focusing lens (spot size σ ~ 10μm)



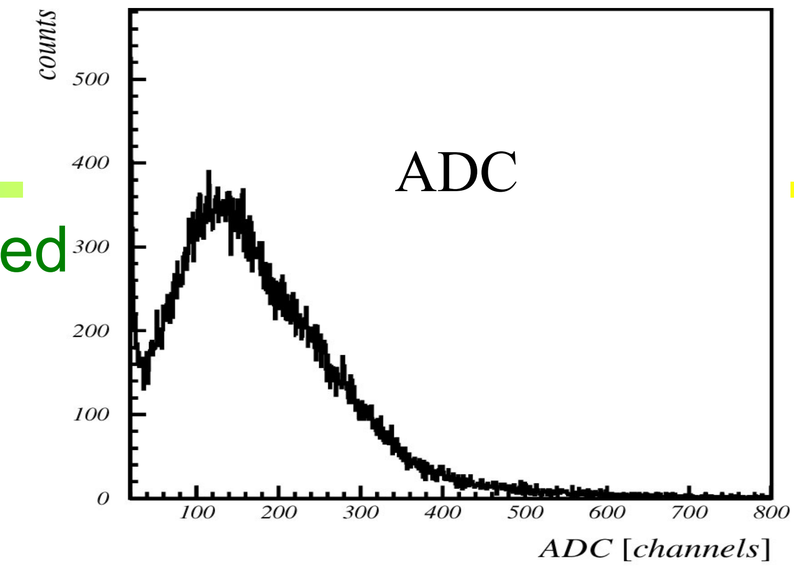


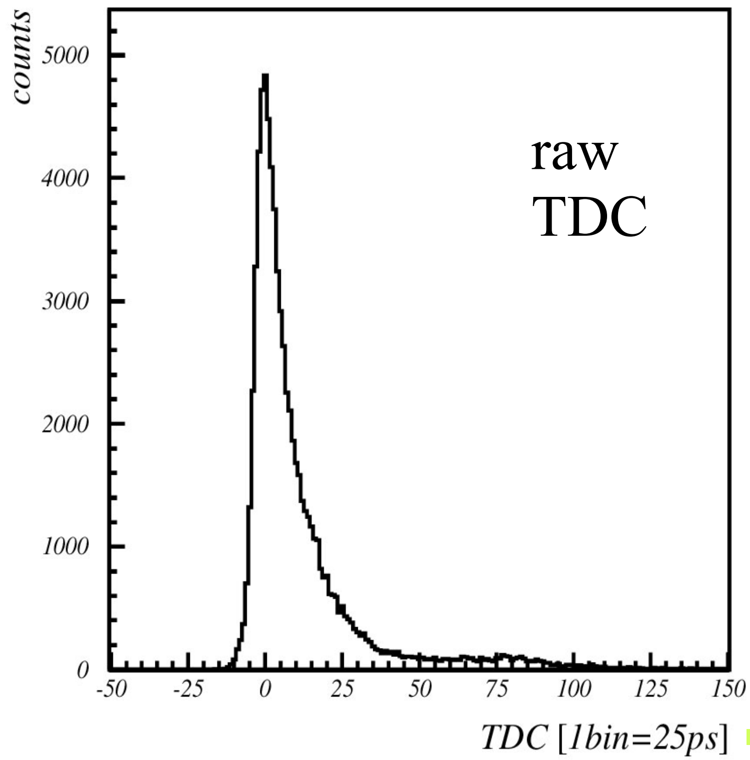
Time walk correction

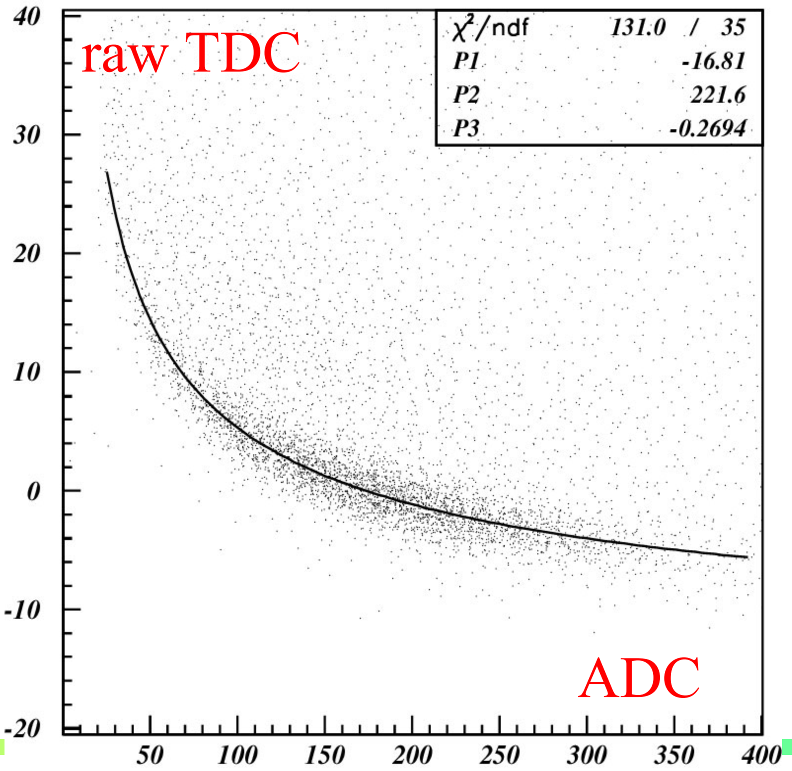
TDC vs. ADC correlation is fitted with

$$TDC = P1 + \sqrt{\frac{P2}{ADC - P3}}$$

and used for TDC correction

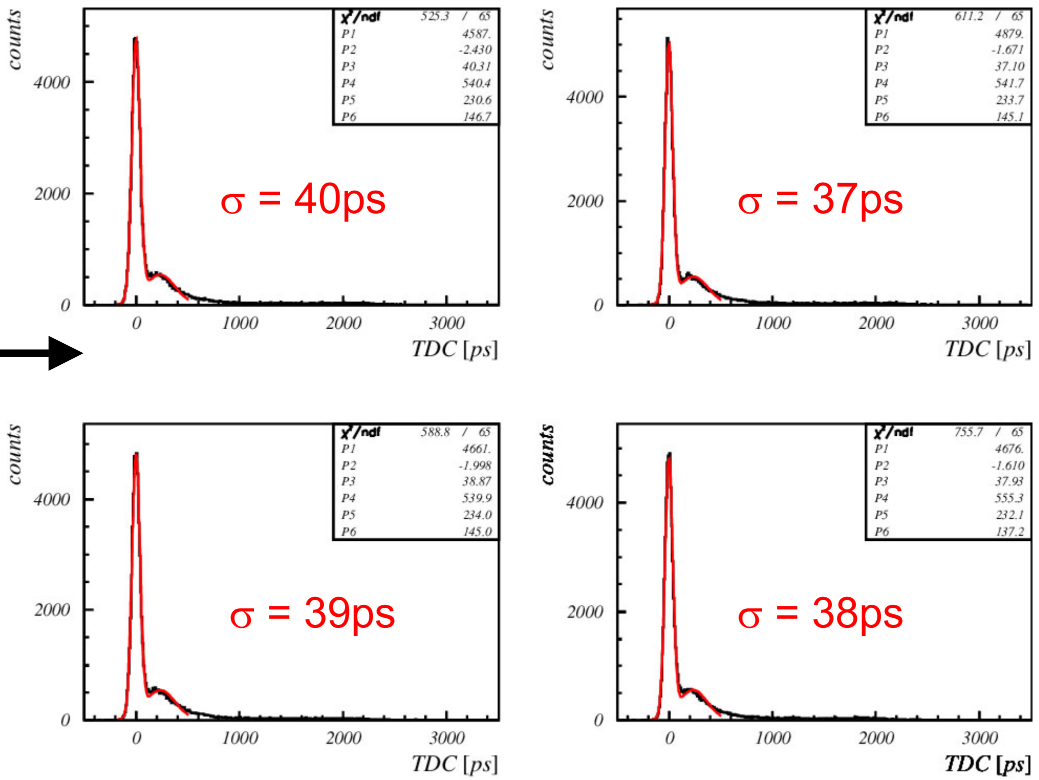


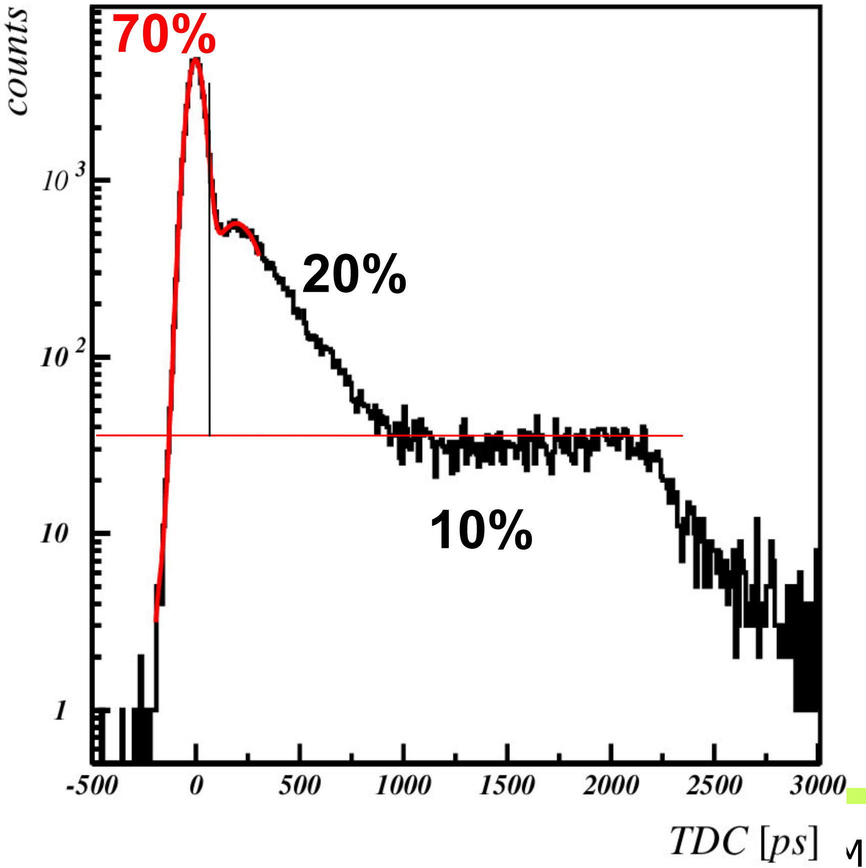




Corrected TDC

Corrected TDC distributions for all pads





Response:

- prompt signal ~ 70%
- short delay ~ 20%
- ~ 10% uniform distribution

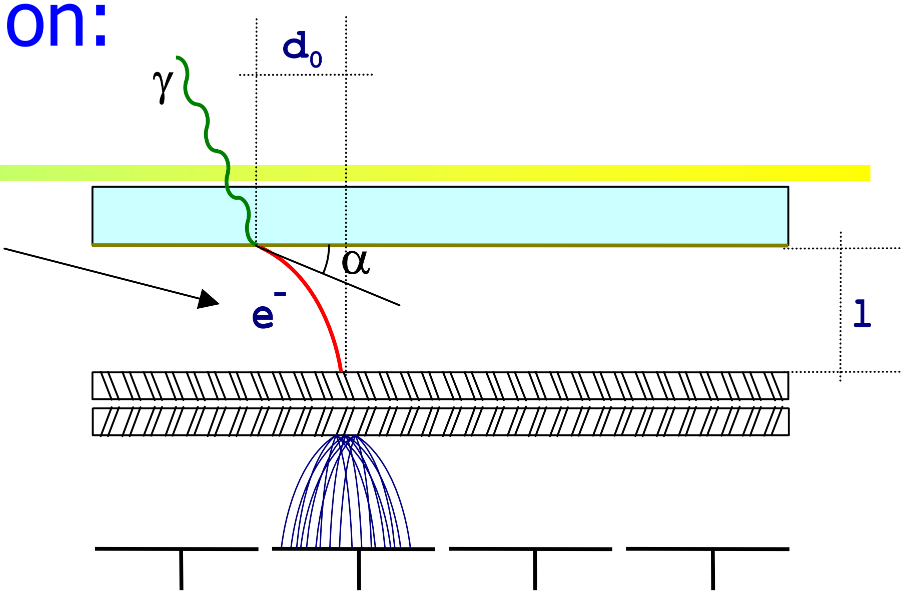
Photon electron detection: modeling

Parameters used:

- $U = 200$ V
- $l = 6$ mm
- $E_0 = 1$ eV
- $m_e = 511$ keV/c^2
- $e_0 = 1.6\ 10^{-19}$ As

Photo-electron:

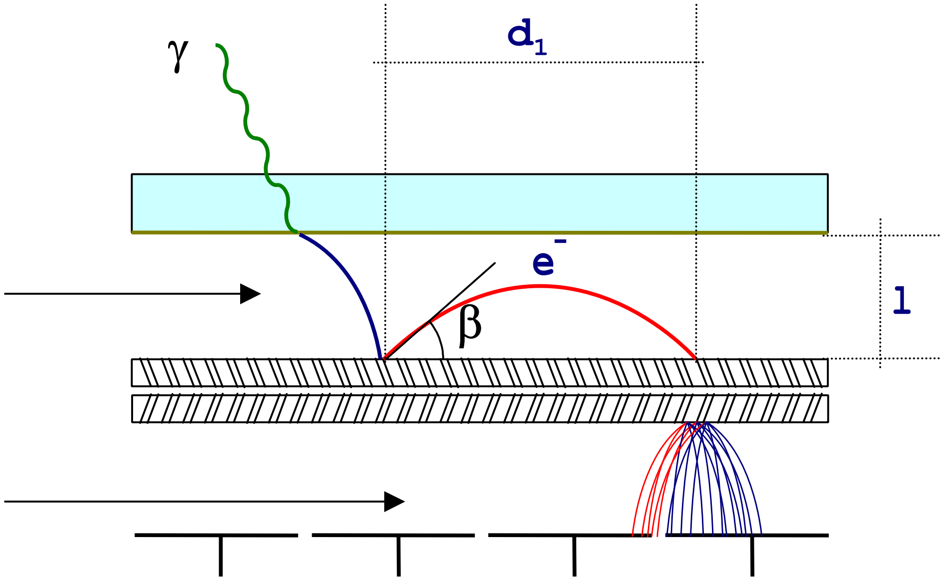
- $d_{0,max} \sim 0.8$ mm
- $t_0 \sim 1.4$ ns
- $\Delta t_0 \sim 100$ ps



Backscattering:

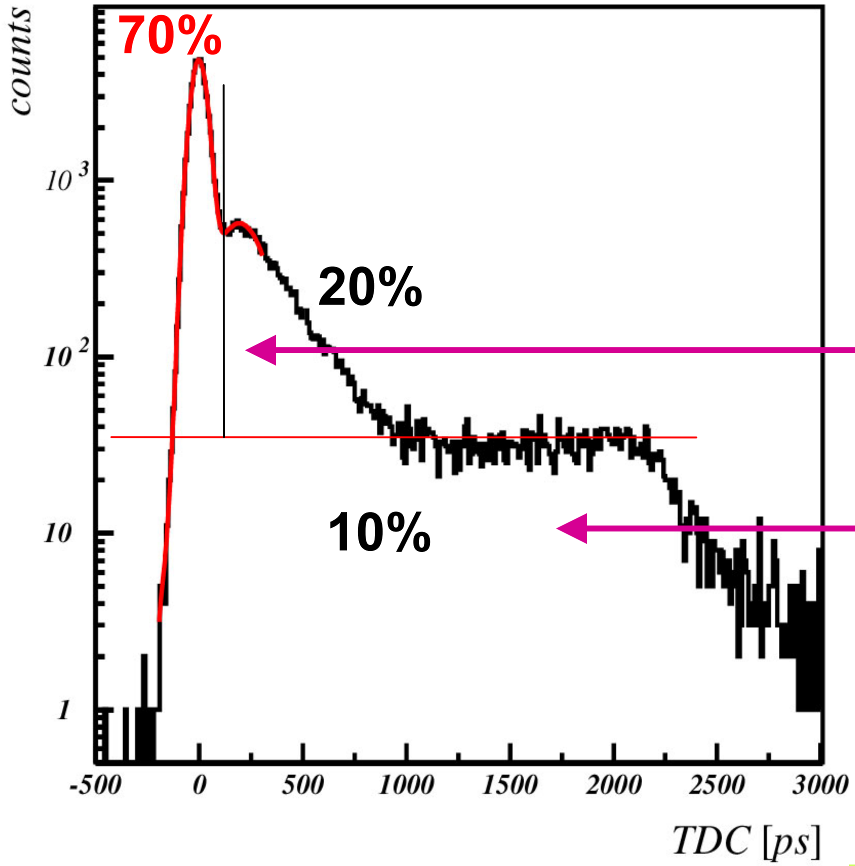
- $d_{1,max} \sim 12$ mm
- $t_{1,max} \sim 2.8$ ns

Charge sharing



Understanding time-of-arrival distribution

Normal photo-electrons

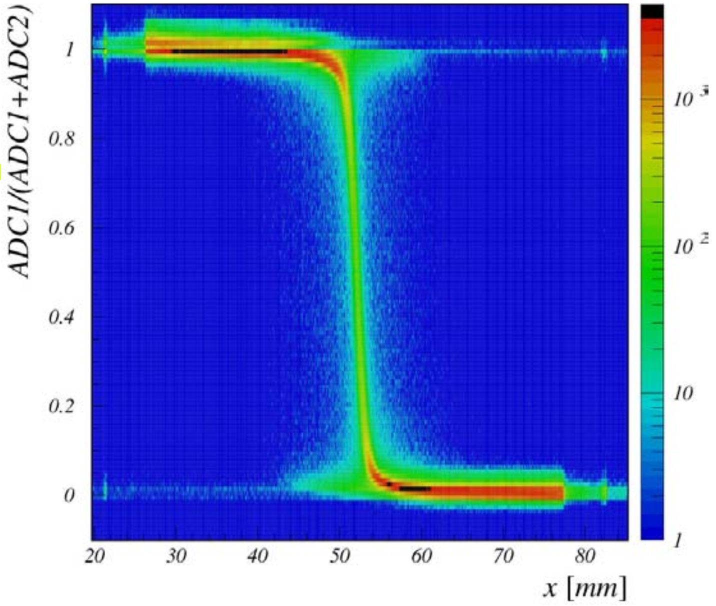


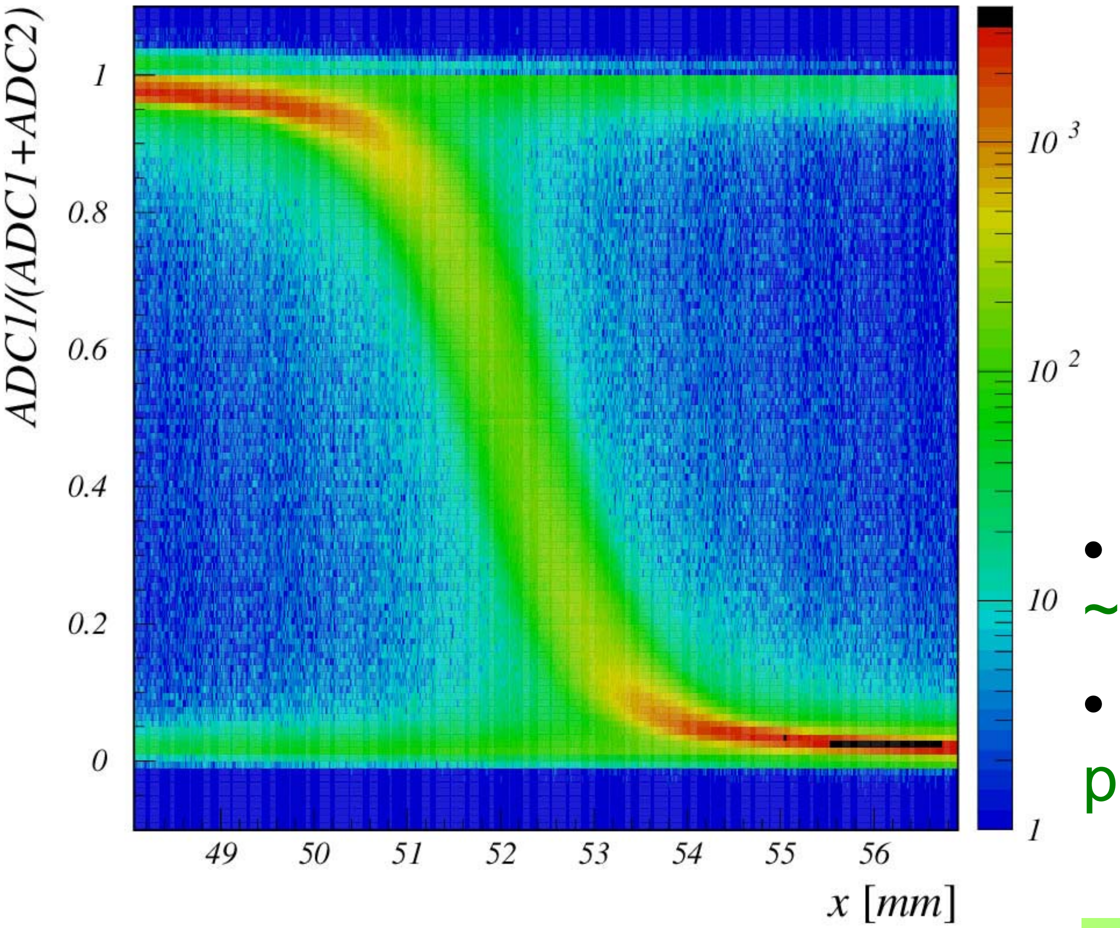
Inelastically scattered photo-electrons?

Elastically scattered photo-electrons

Charge sharing

Fraction of the signal detected on channel 1 vs. x position of light spot



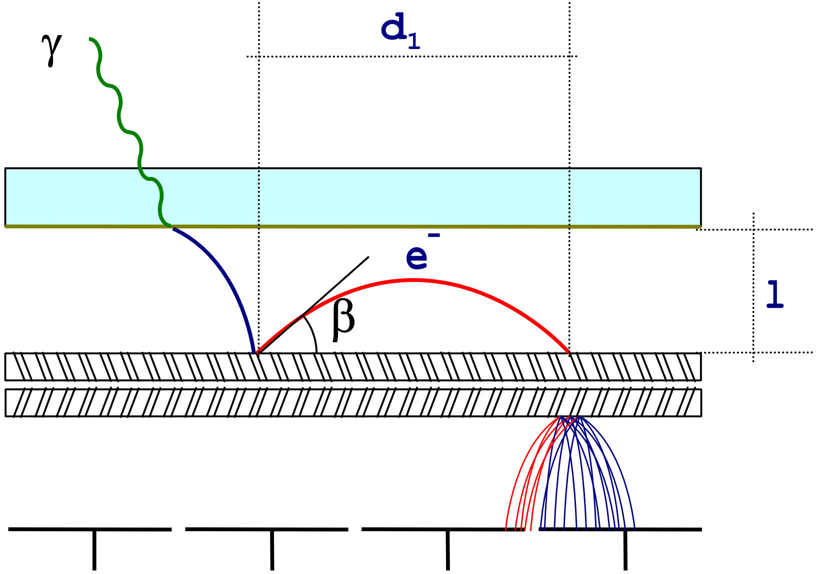


- sizable charge sharing in ~2mm wide boundary area
- can be used to improve position resolution

Conclusions

Back-scattering range and spread in timing depend on the

- photocathode-MCP plate distance
- photocathode-MCP plate voltage

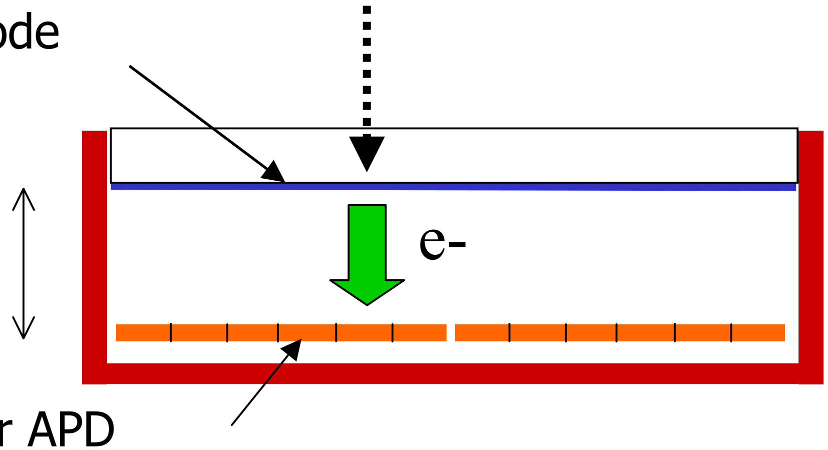


→The distance should be as small as possible, ~0.5mm-1mm (in the tested tube 6mm) → such a tube already exsists

→The voltage should be as high as possible, 500V max. allowed (in the tested tube fixed to 200V) → modify bleeder

→ Some of the effects will be reduced (or disappear) in high B field, some will remain (timing)

Photon detector candidate: H(A)PD

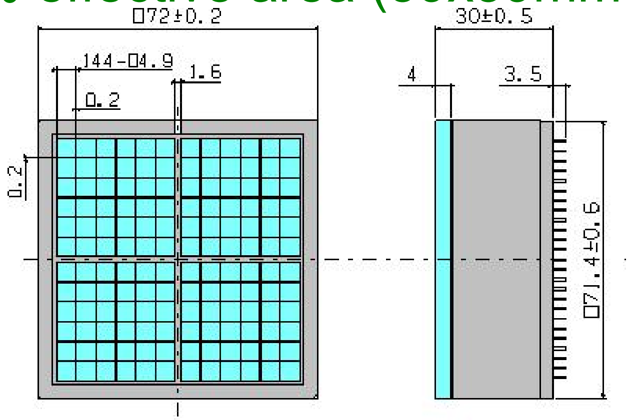


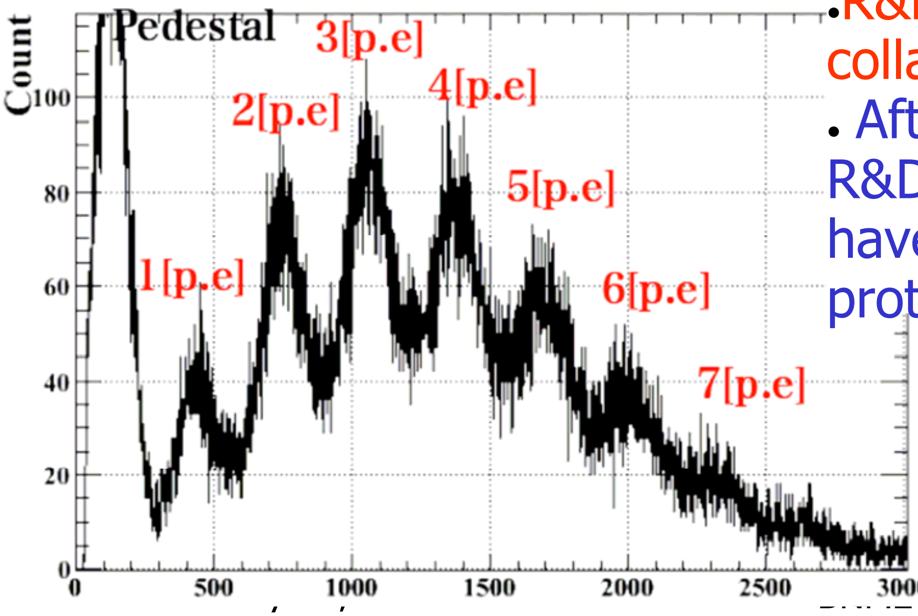
Multialkali
photocathode

-10kV
15~25mm

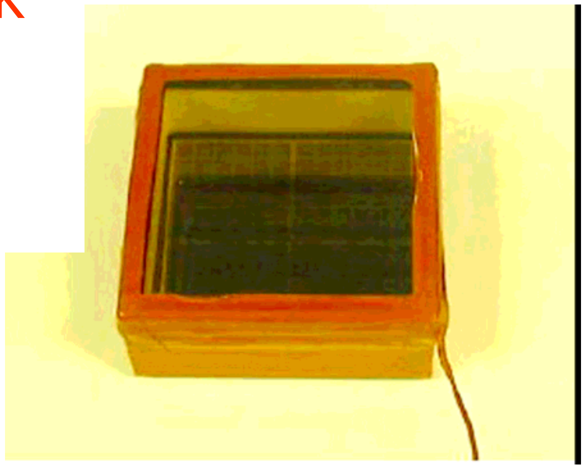
Pixel PD or APD

- 12 x 12 channels
- 65% effective area (59x59mm^2)





- R&D project in collaboration with HPK
- After a considerable R&D effort we finally have a full size prototype to study

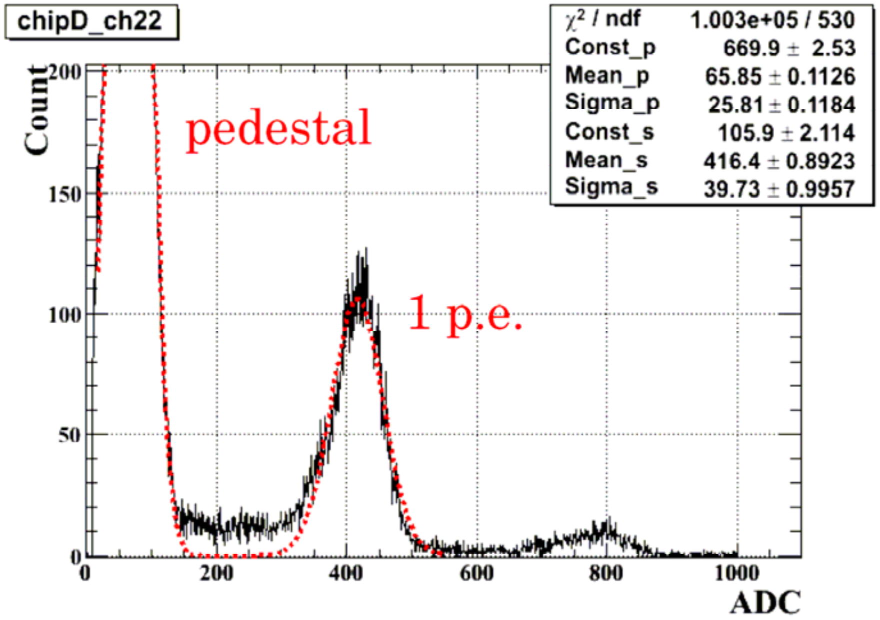


HAPD bench tests

ADC distribution of HAPD

- With Maximum bias voltage
- −8.5 kV high voltage
- 1 p.e. level light from LED

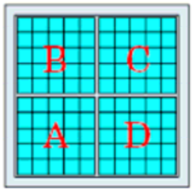
Clear separation between pedestal and 1 p.e. peak!!



channel	bias [V]	bombard-ment gain*	total gain	avalanche gain	S/N
chipA-22	331	1600	32000	20	8.8
chipB-29	331	1750	26000	15	8.4
chipC-22	337	1600	60000	37	15.1
chipD-22	343	1650	67000	42	13.4

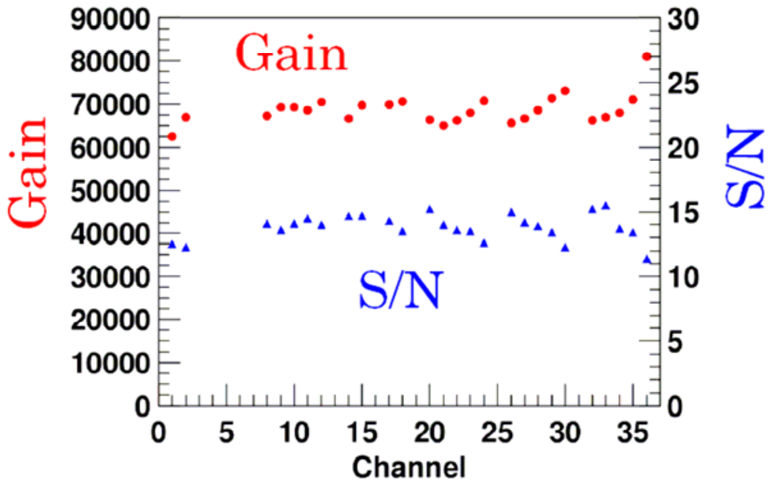
*=measured by Hamamatsu

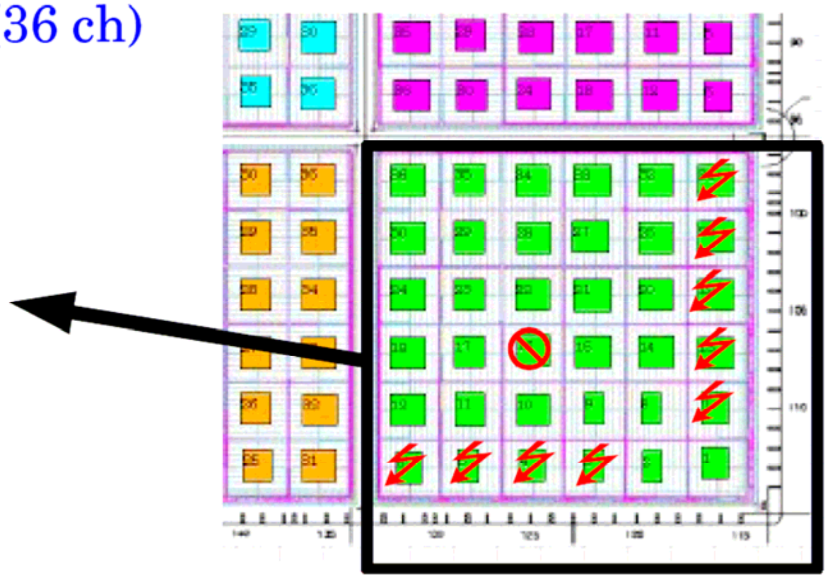
- All the four chips show good performance.
- avalanche gain depends on (max.) bias voltage.



HAPD bench tests

Measure uniformity for one APD chip (36 ch)



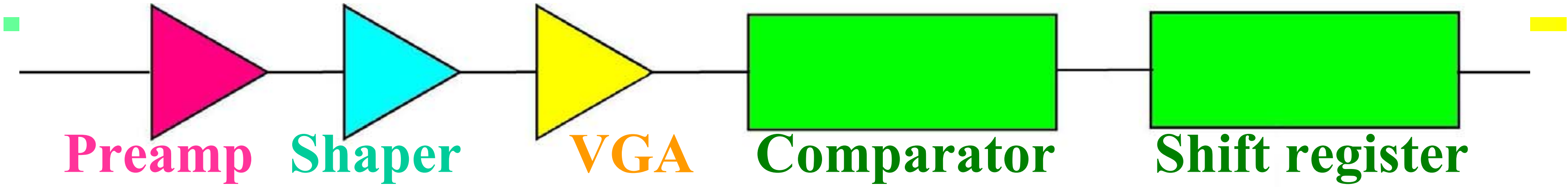


⊘ too noisy with bias voltage

↯ dominated by the crosstalk from neighboring channel

- No large channel dependence in gain, S/N.
- Problem in the channels at edge.
  - Similar effects seen in old samples.
  - Maybe distortion of the electric field inside the tube?

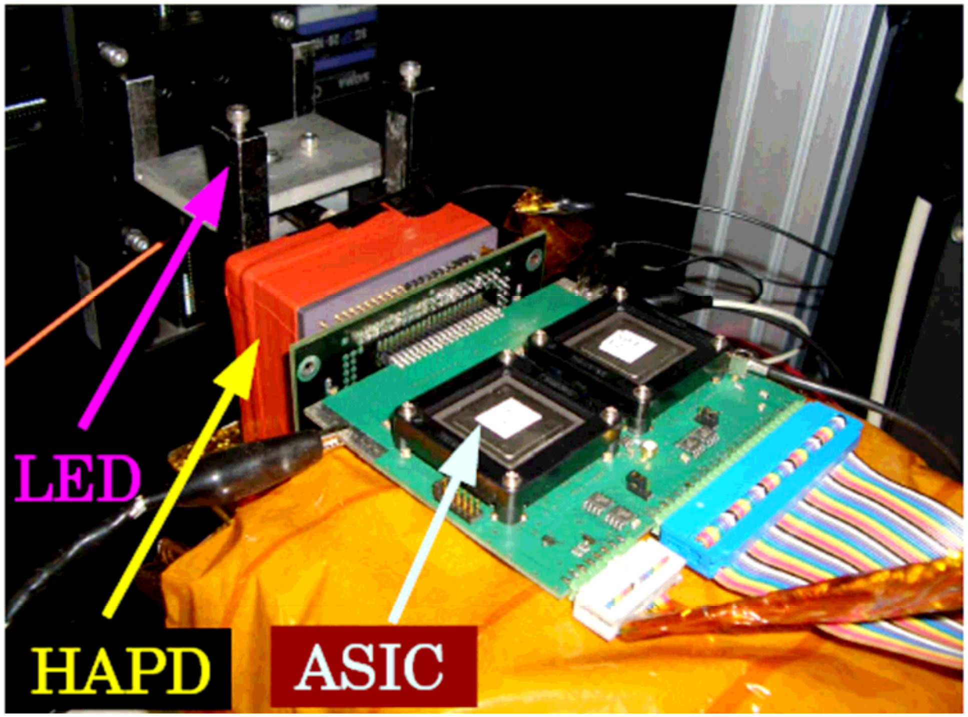
HAPD read-out R+D



Single photo-electron pulses recorded by the ASIC.

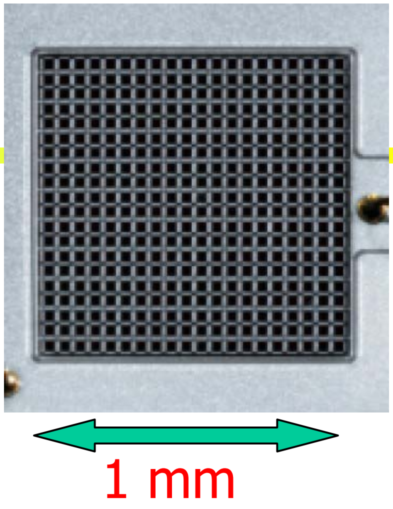
Noise: ~1900 e at 80pF (HAPD capacitance)

Now: studying cross-talk etc



Plan: next ASIC version: keep only the analog part (to reduce noise), digital moved to a FPGA.

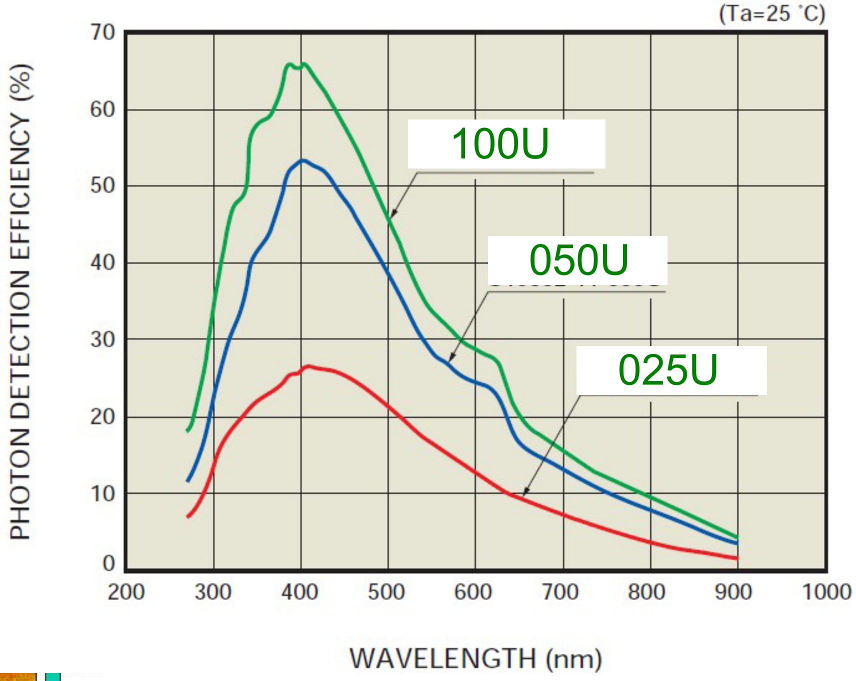
SiPMs as photon detectors?



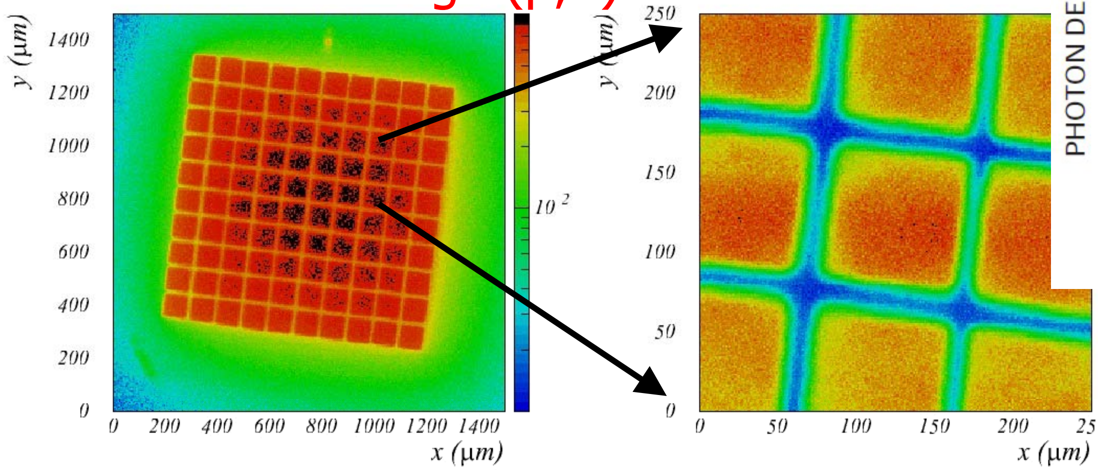
SiPM is an array of APDs operating in Geiger mode. Characteristics:

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

  PDE = QE x ε_{geiger} x ε_{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

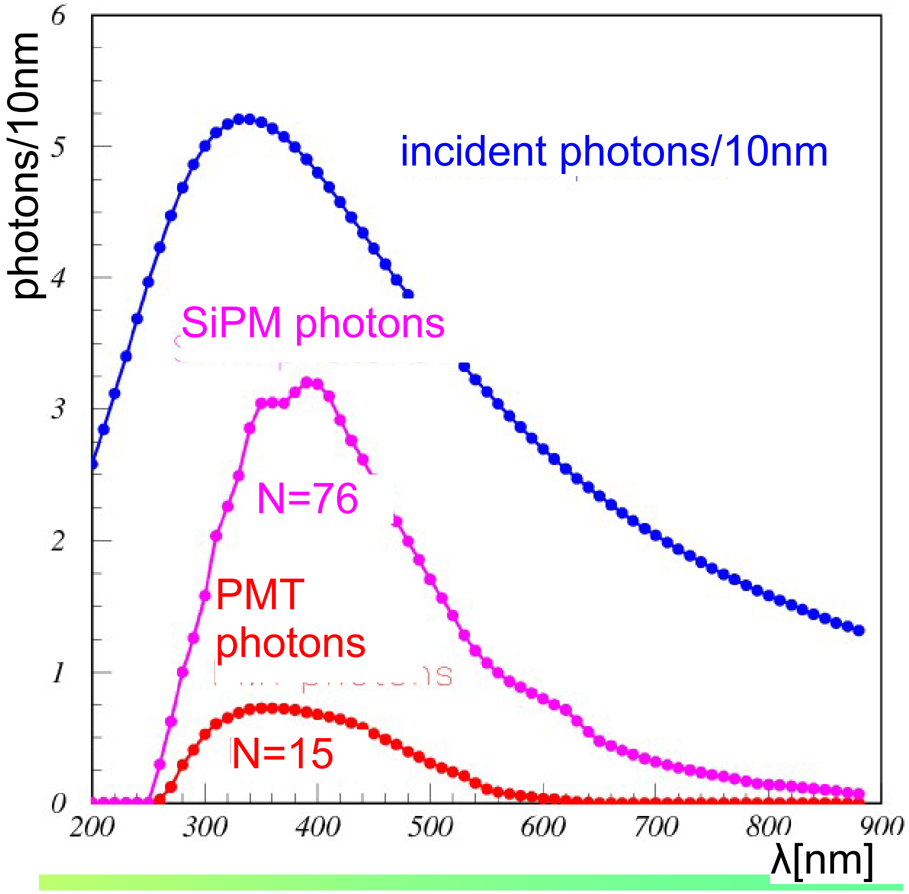


Expected number of photons for aerogel RICH

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

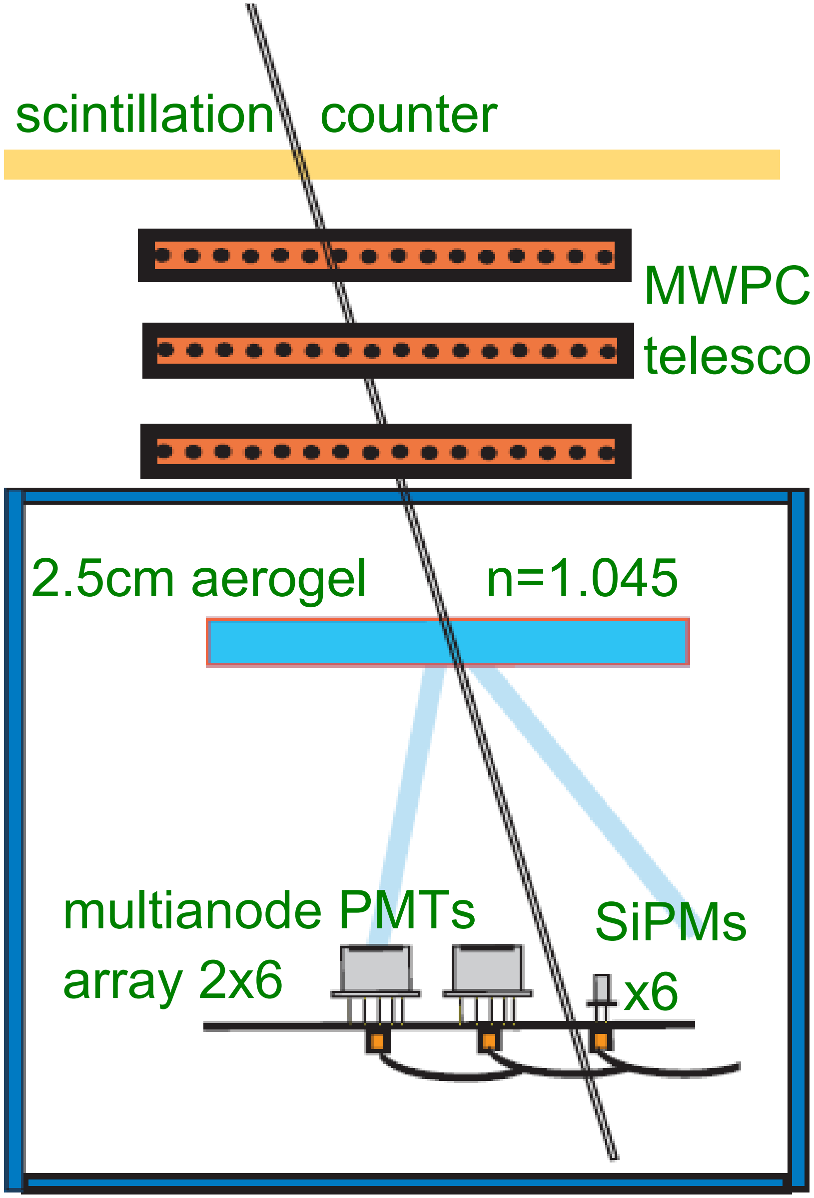
$N_{SiPM}/N_{PMT} \sim 5$

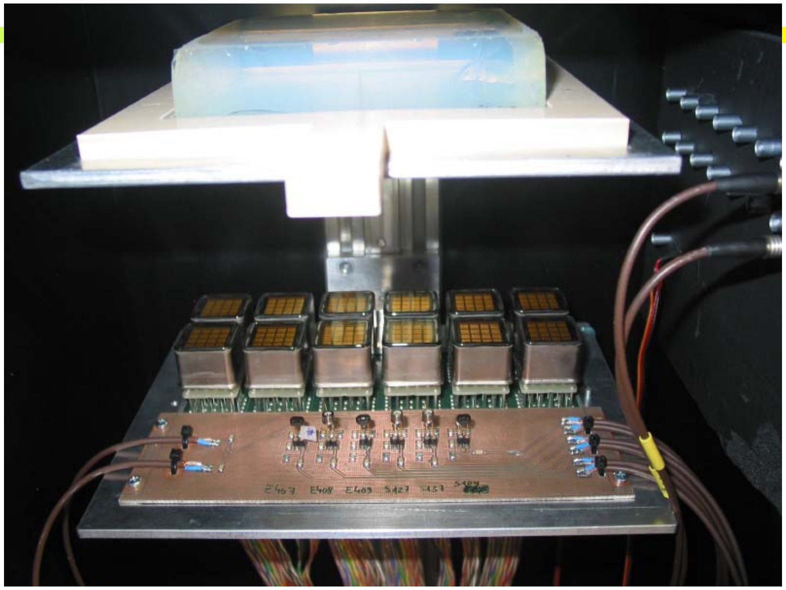
Assuming 100% detector active area



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

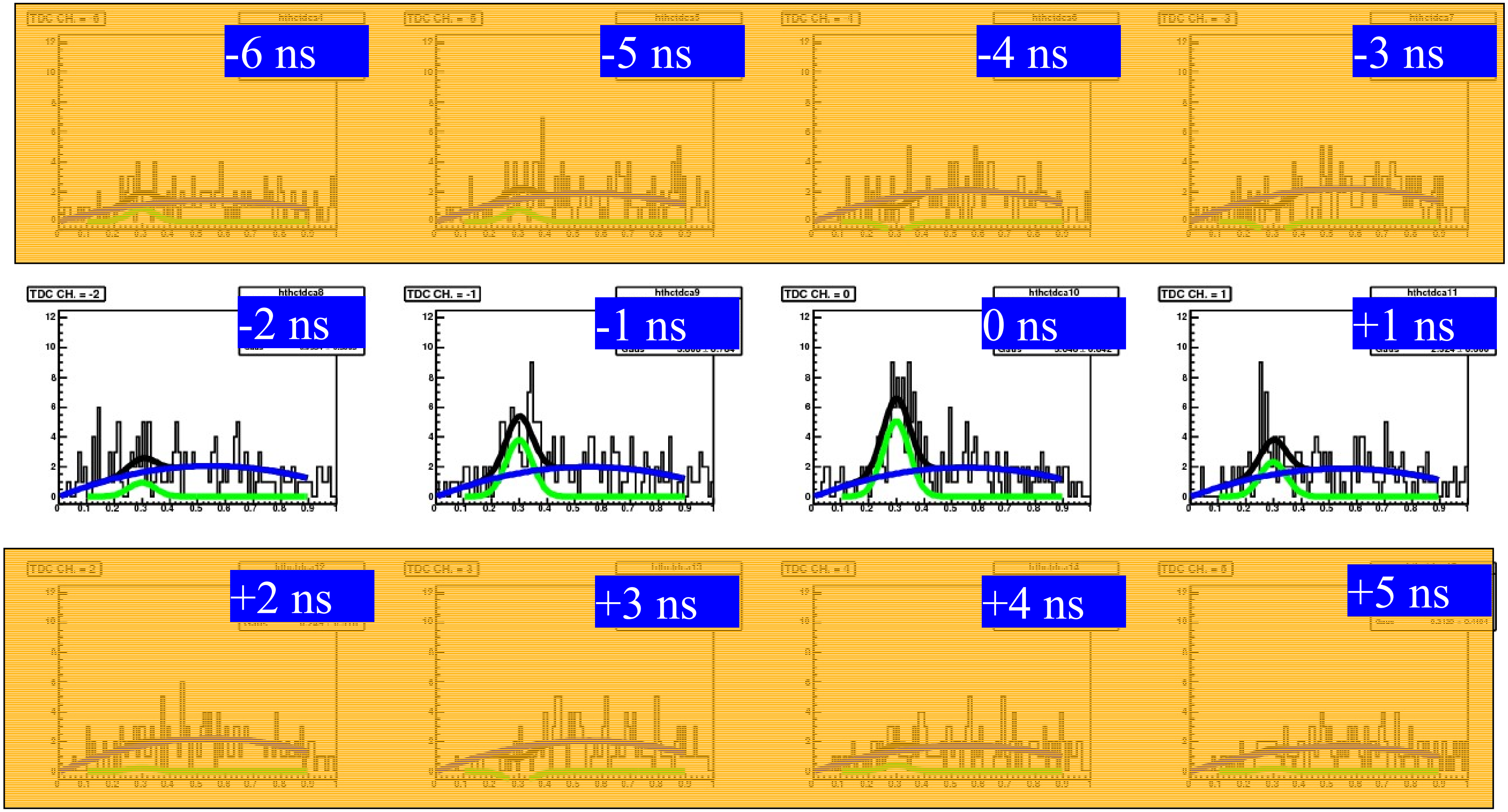
Cosmic test setup





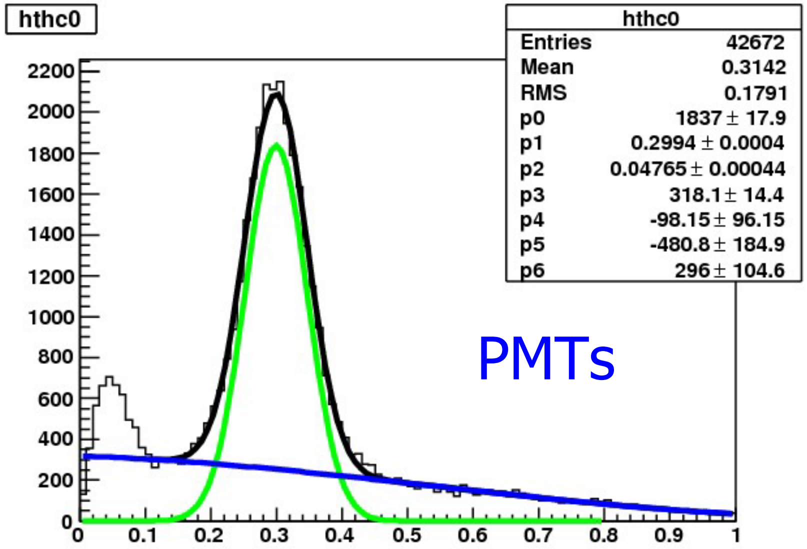
- 6 Hamamatsu SiPMs used:
  - 2x 100U; background ~400kHz
  - 2x 050U; background ~200kHz
  - 2x 025U; background ~100kHz
- signals amplified (ORTEC FTA820),
- discriminated (EG&G CF8000) and
- read by multihit TDC (CAEN V673A) with 1 ns / channel

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



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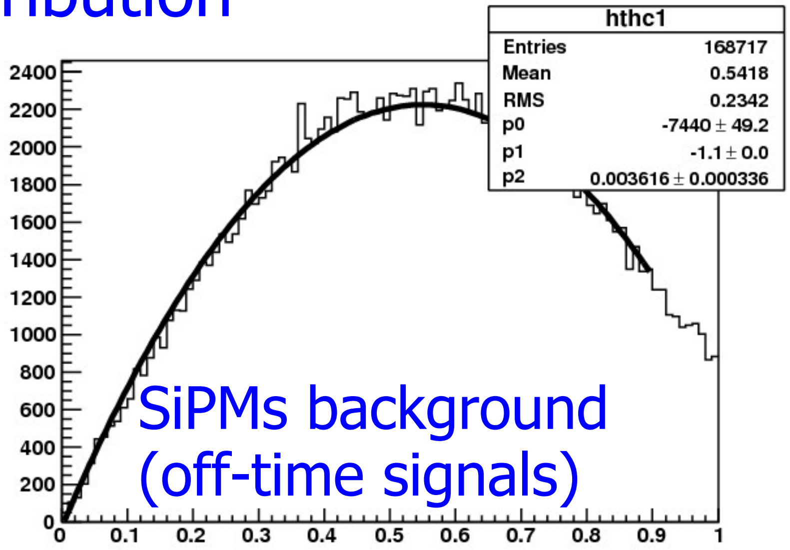
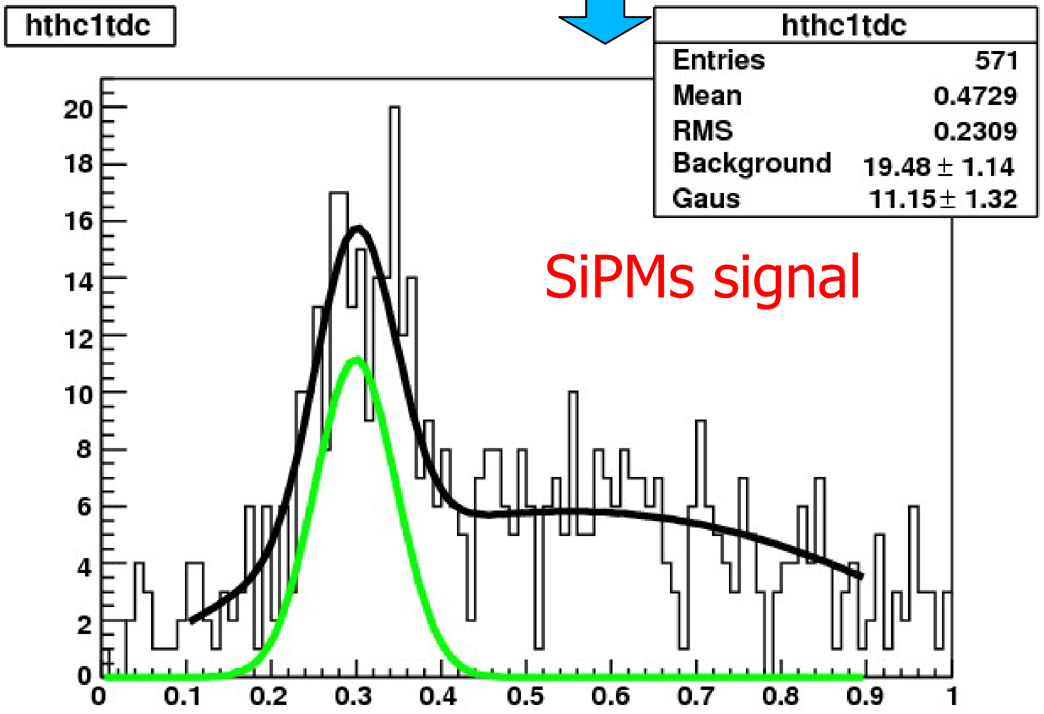


Fit function is a combination of

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

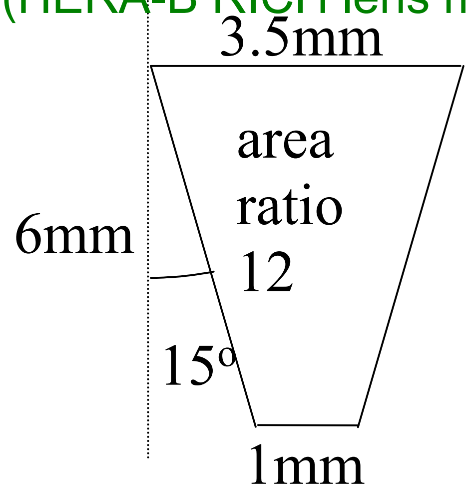
Only scale parameters are free – others fixed.

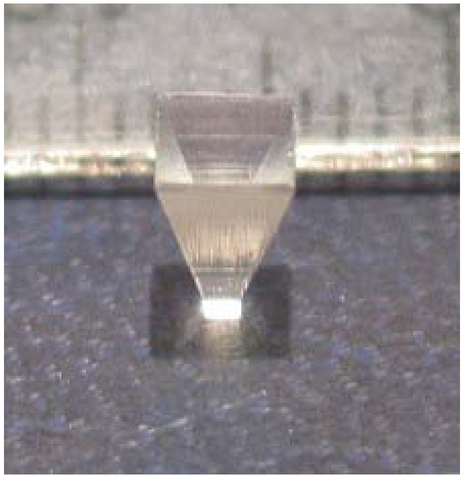


→ SiPMs give 4 x more photons than PMTs per photon detector area – in agreement with expectations

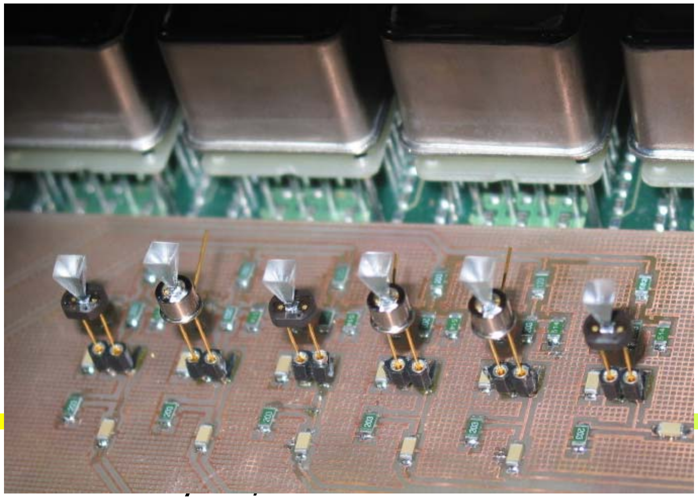
Light collection: improve signal to noise ratio

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

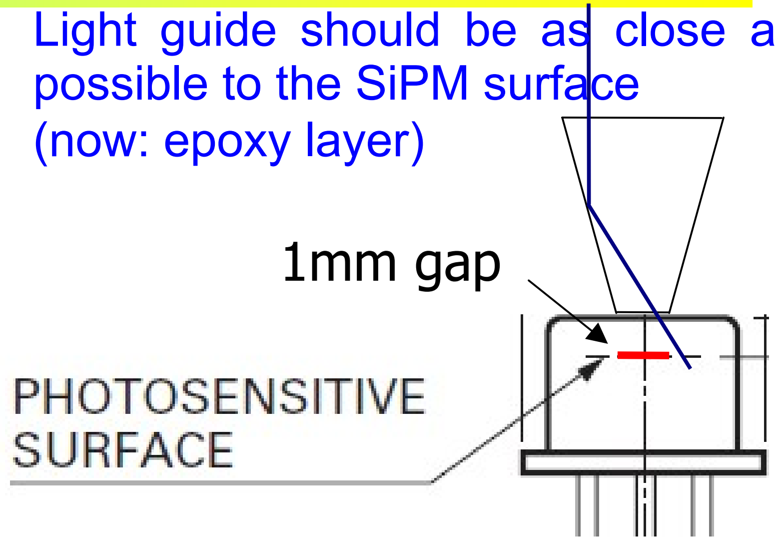


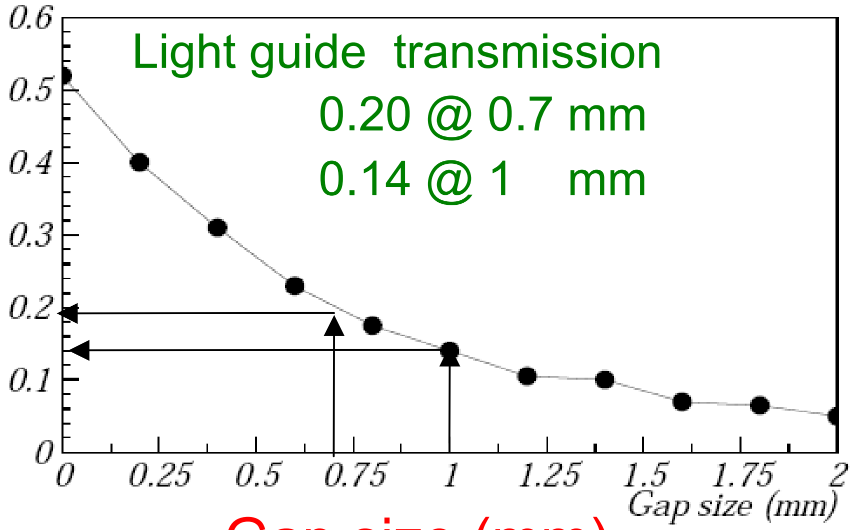


- average transmission 0.52



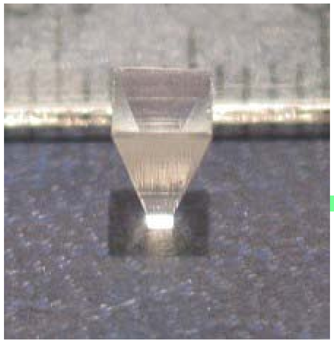
Light guide should be as close as possible to the SiPM surface (now: epoxy layer)





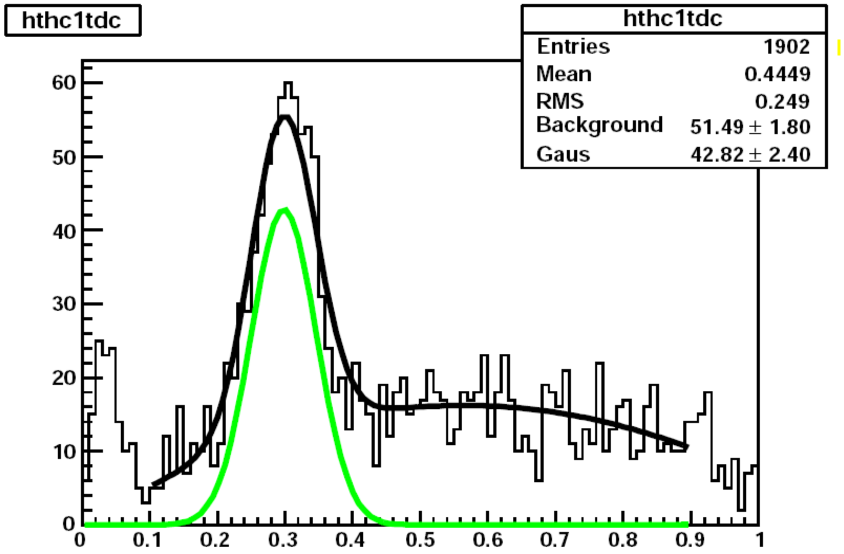
Light guide transmission
0.20 @ 0.7 mm
0.14 @ 1 mm

Gap size (mm)

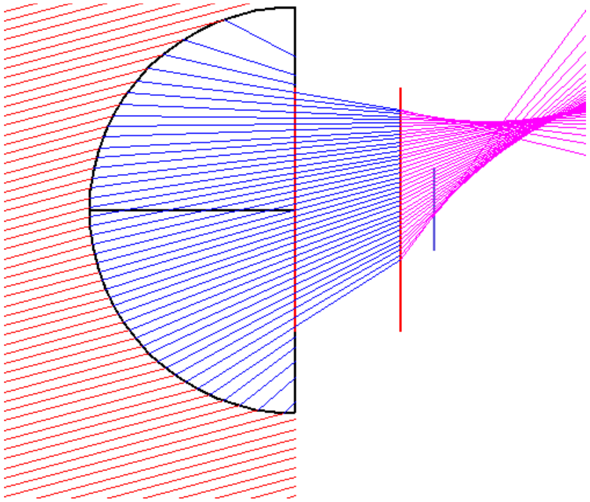


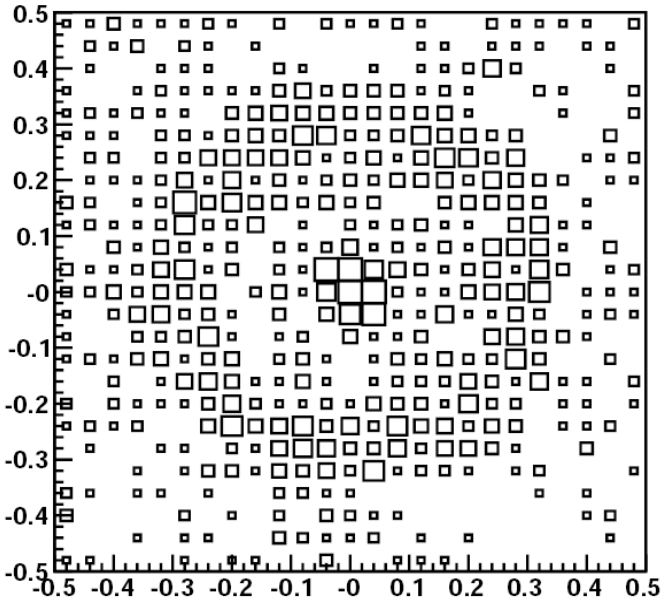
Cherenkov photons with light collectors

N_{with} / $N_{without}$ ~ 2.2



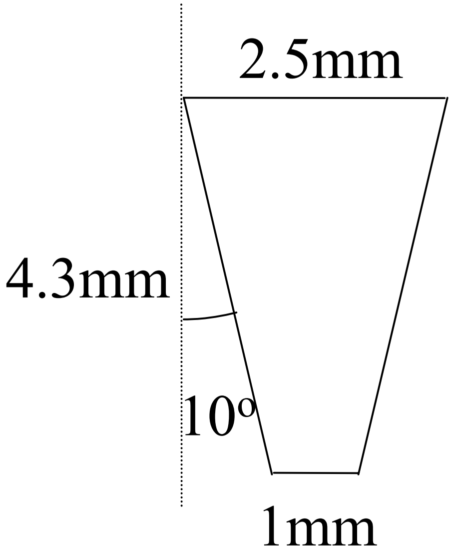
- in agreement with the expectations
- Further improvements possible by
  - reducing the epoxy protective layer
  - using better light collector

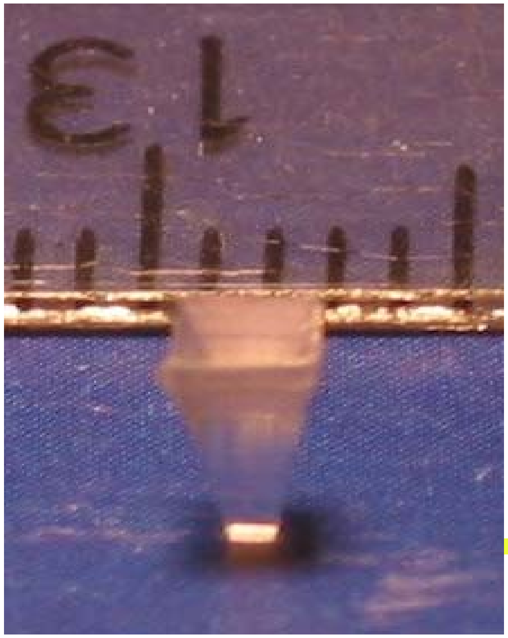


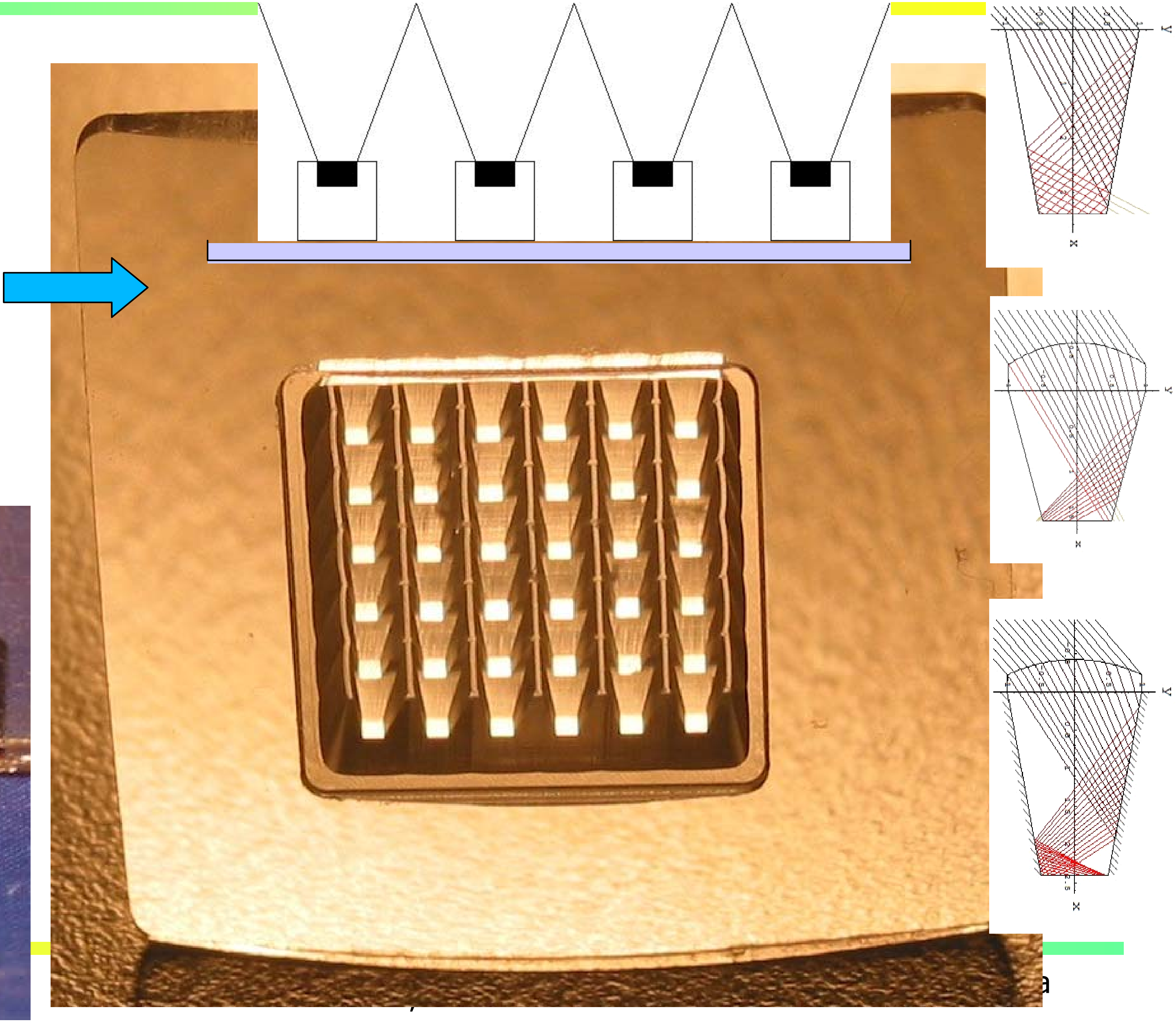


Detector module design

SiPM array with light guides







Photon detectors for the aerogel RICH, summary

BURLE 85011 MPC PMT

- Best understood, beam and bench tested, excellent timing
- Open issues: ageing, read-out for fast timing
- How well can we determine TOF start time at IP?

Multichannel H(A)PD – R+D with Hamamatsu

- Finally working samples, good progress in read-out electronics
- Open issues: more tests needed (beam+bench), ageing

SiPM (G-APD)

- Very good first results
- Open issues: radiation hardness, read-out with narrow time window

Aerogel RICH, status and plan

Photon detectors:

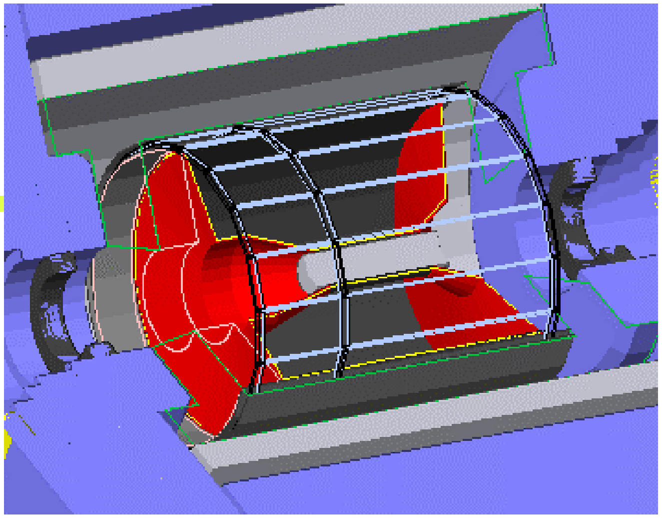
- Beam (March and June) and bench (ageing) tests in spring 2008, decision in autumn.
- Auxiliary checks: start time measurement

Aerogel production: well understood at small scale, prepare full production

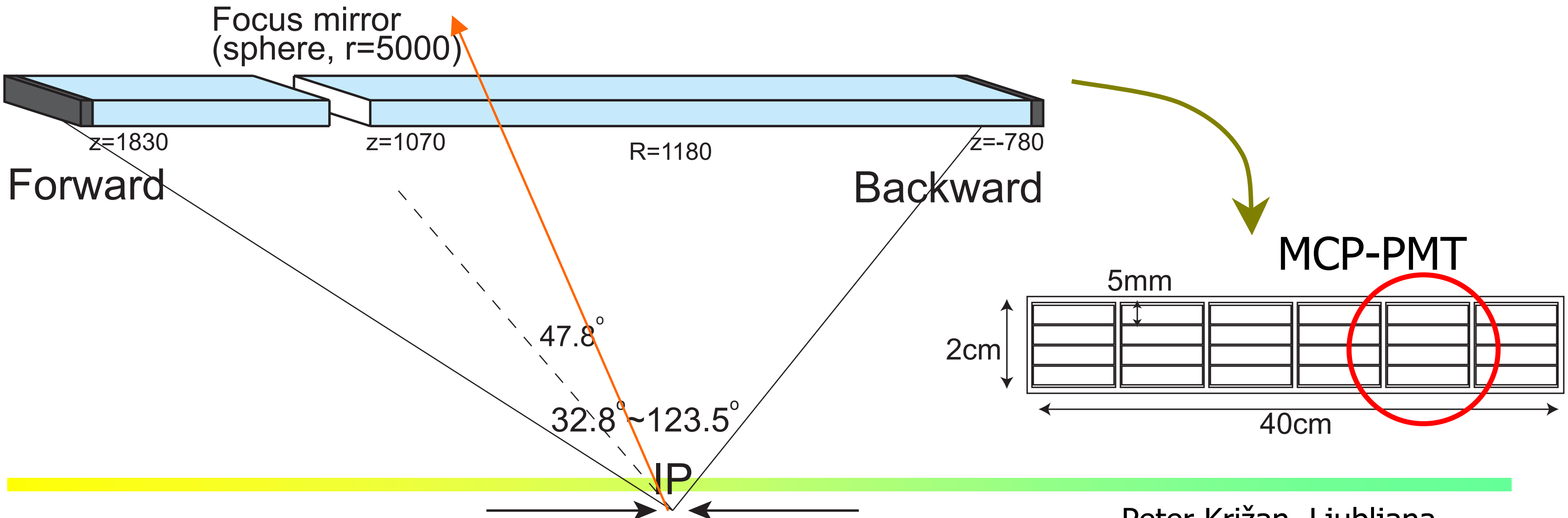
Read-out electronics: ongoing R+D

Mechanical structure: first designs

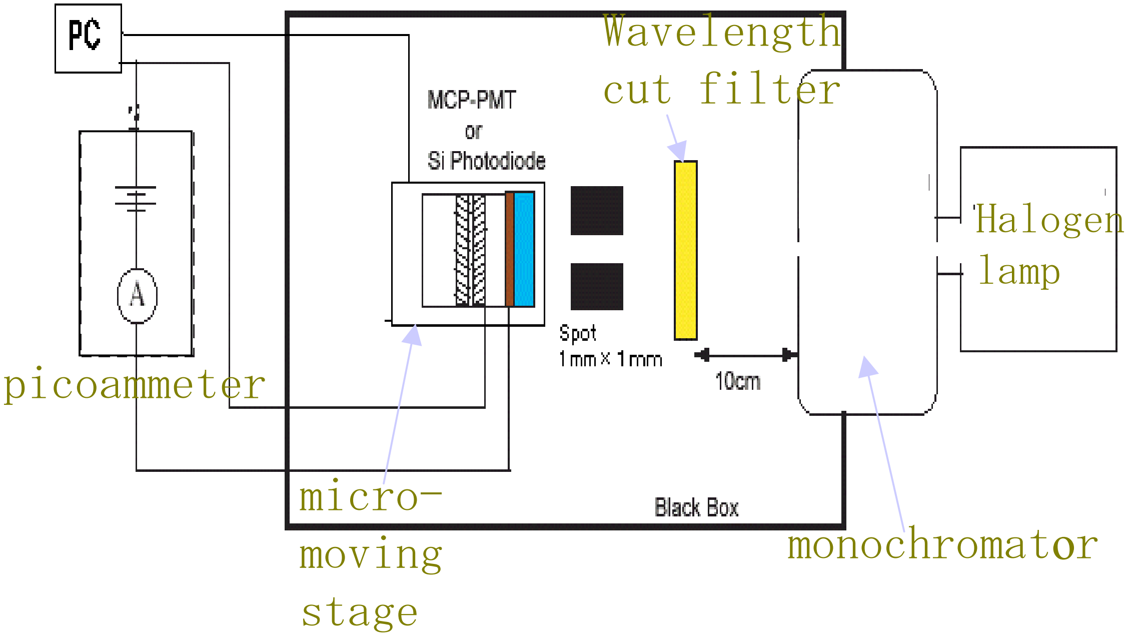
TOP counter

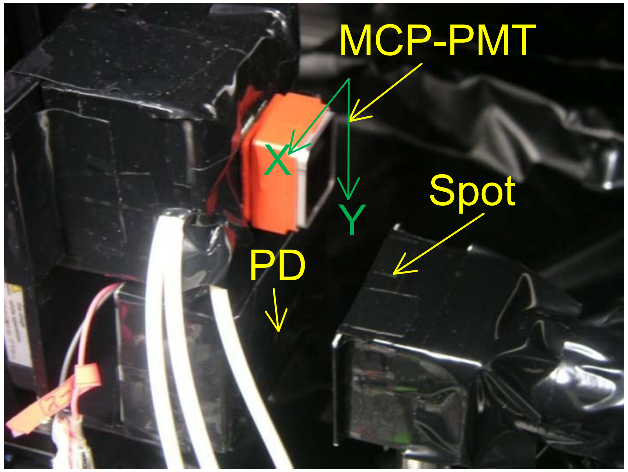


- Quartz: 255cm^L x 40cm^W x 2cm^T
  - Focus mirror at 47.8deg. to reduce chromatic dispersion
- Multi-anode (GaAsP) MCP-PMT
  - Linear array (5mm pitch), Good time resolution (<~40ps)
  - → Measure Cherenkov ring image with timing info.



MCP with GaAsP: Q.E. measurement

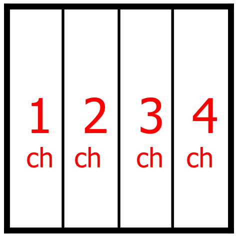




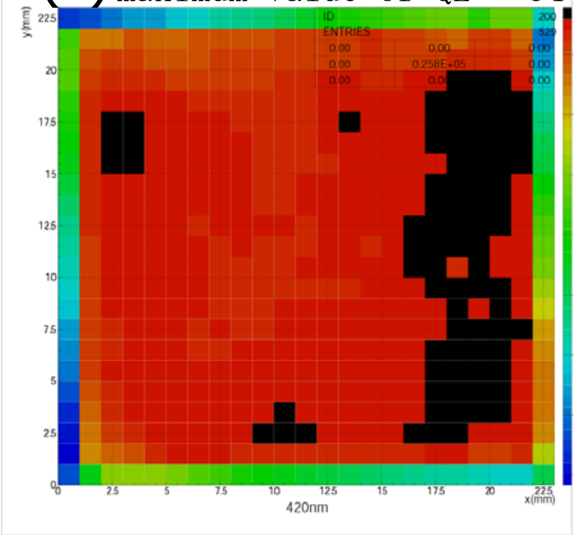
- light source (halogen lamp) + monochromator
- focus the light to 1mm×1mm
- MCP-PMT and photo diode are located on the micro-moving stage
- move the micro-moving stage with 1mm step
- measure the current with picoammeter

Position dependence of Q.E.

two-dimensional variation of Q.E. (wavelengths: 420, 580, 680nm)

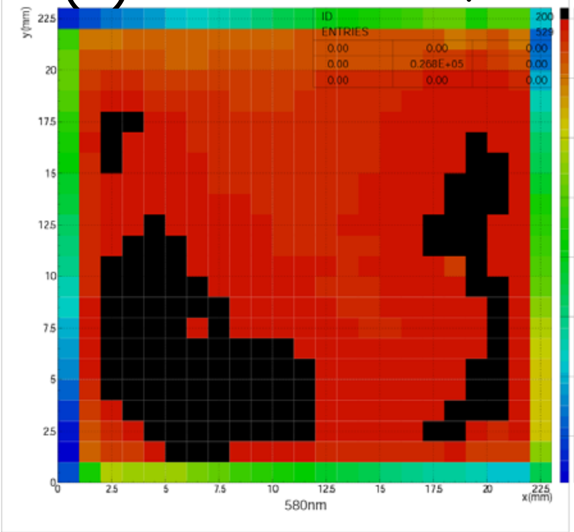


(1) maximum value of QE : 54%



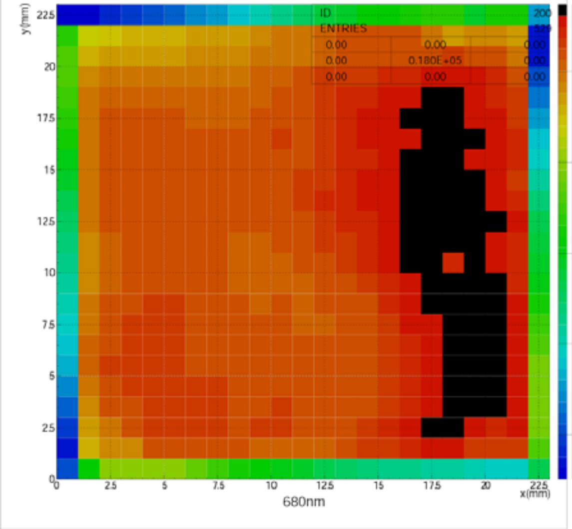
420nm

(2) maximum value of QE : 56%



580nm

(3) maximum value of QE : 40%

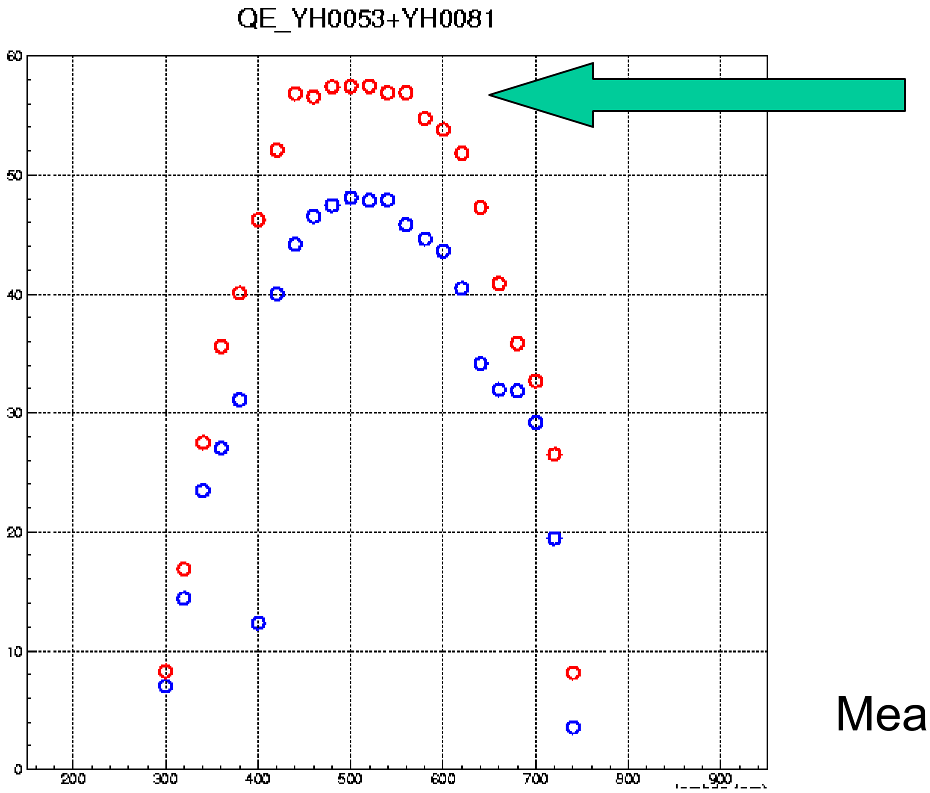


680nm

- No big differences at three wavelengths.
- Very good uniformity of Q.E.

Wavelength dependence of Q.E.

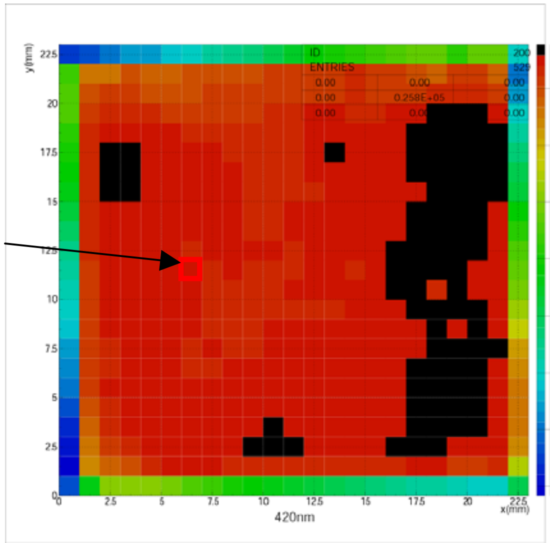
QE [%]



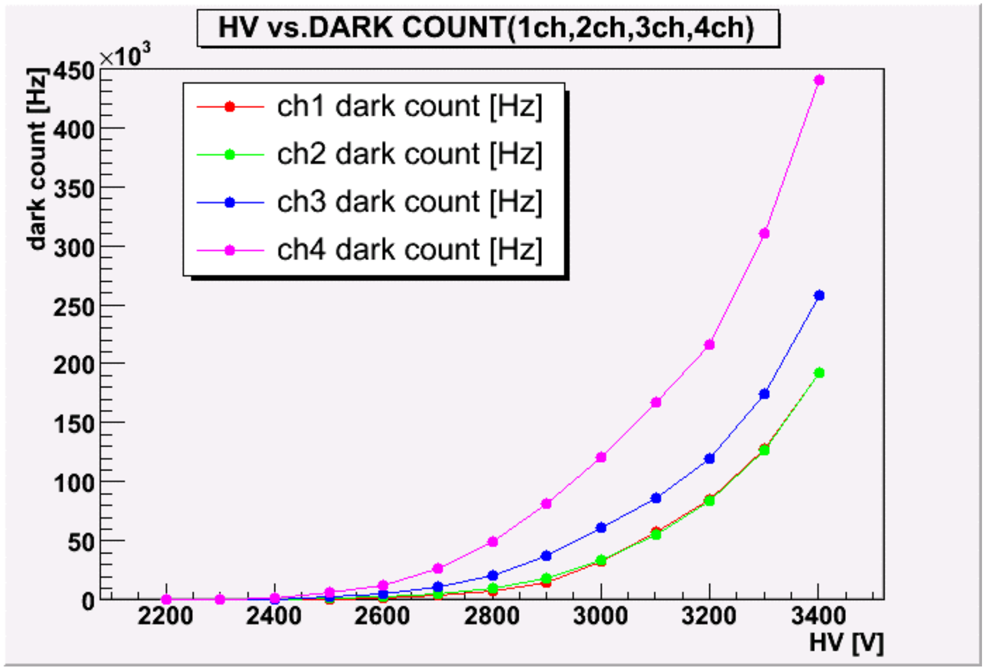
wavelength[nm]

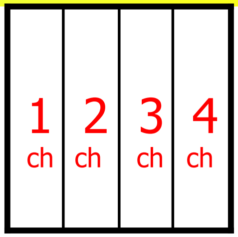
58%

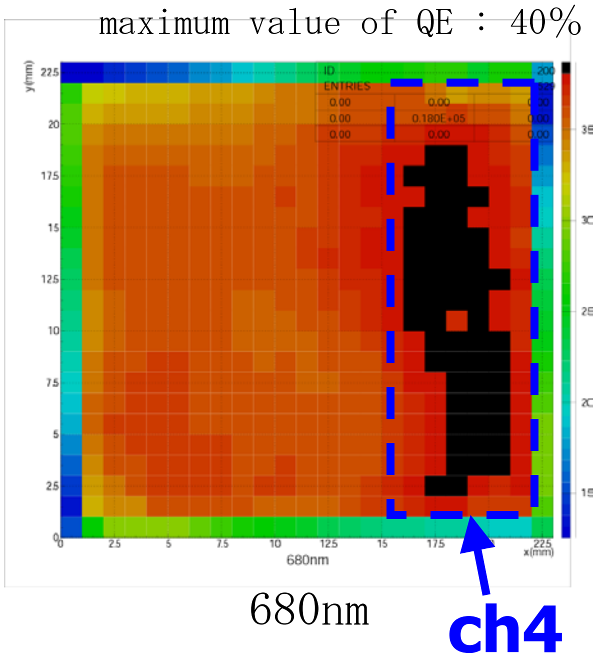
Measured here



Dark Count measurement



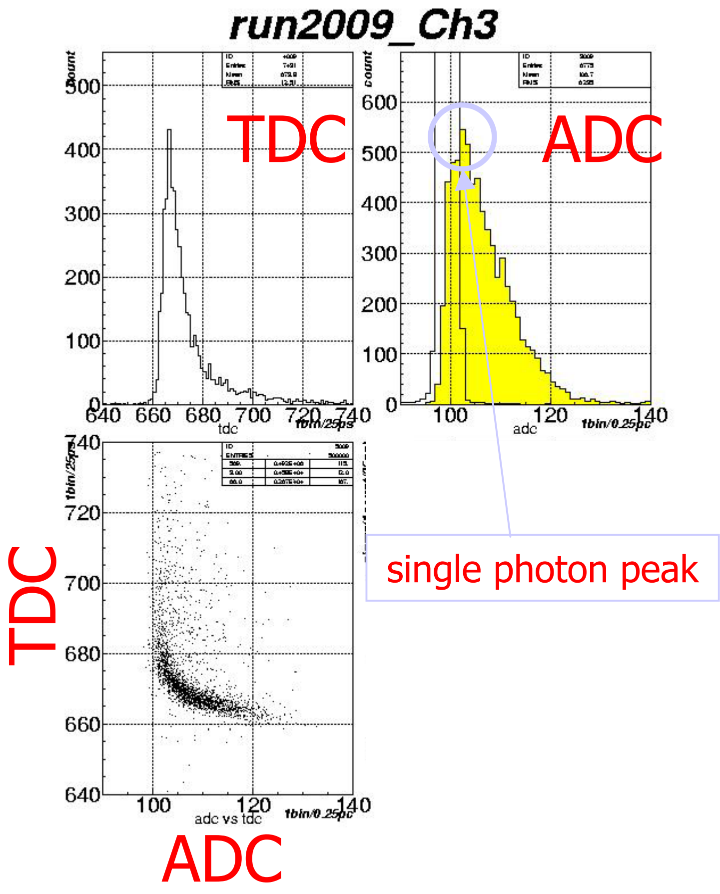




- Dark count rate: ch.4. 450 kHz at HV=3400V.
- It seems that the dark count rate is correlated with Q.E.

Time resolution measurement – single photons

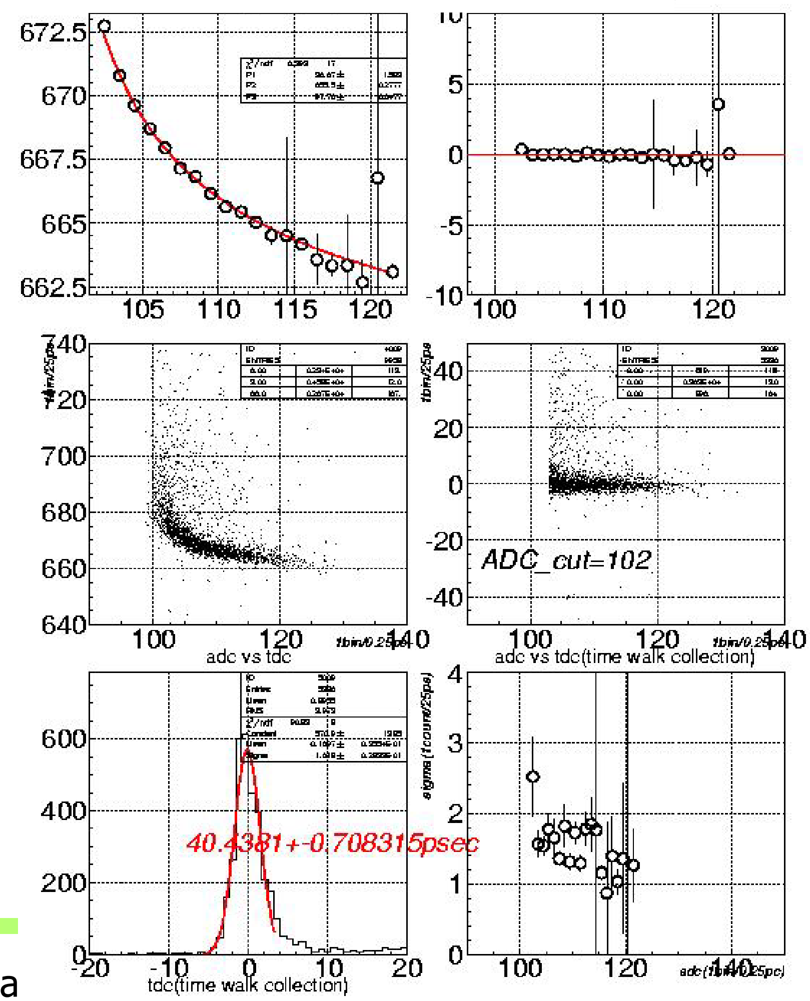
TTS : ~40ps



single photon peak

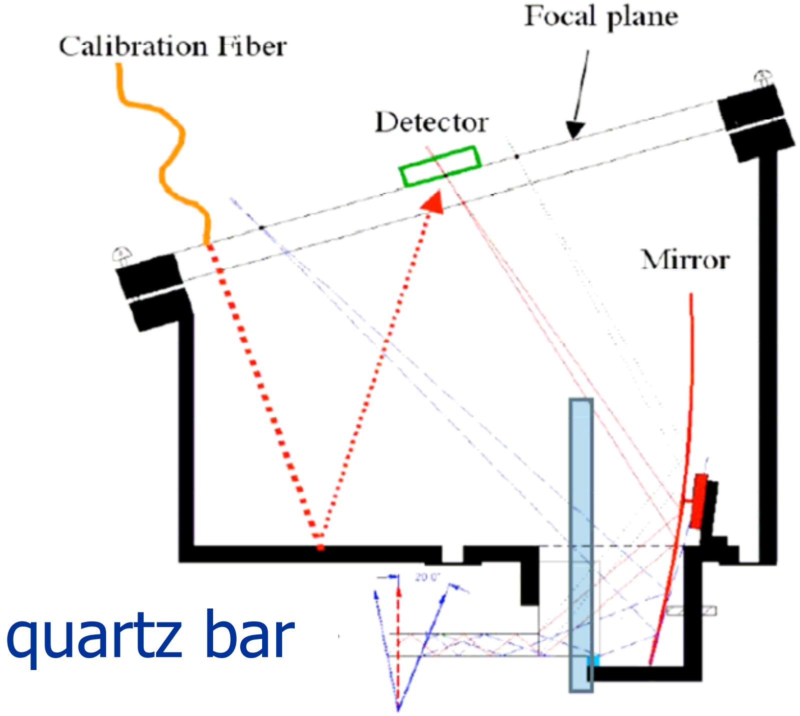
HV : 3000 V

Gain : ~1.5×10^5

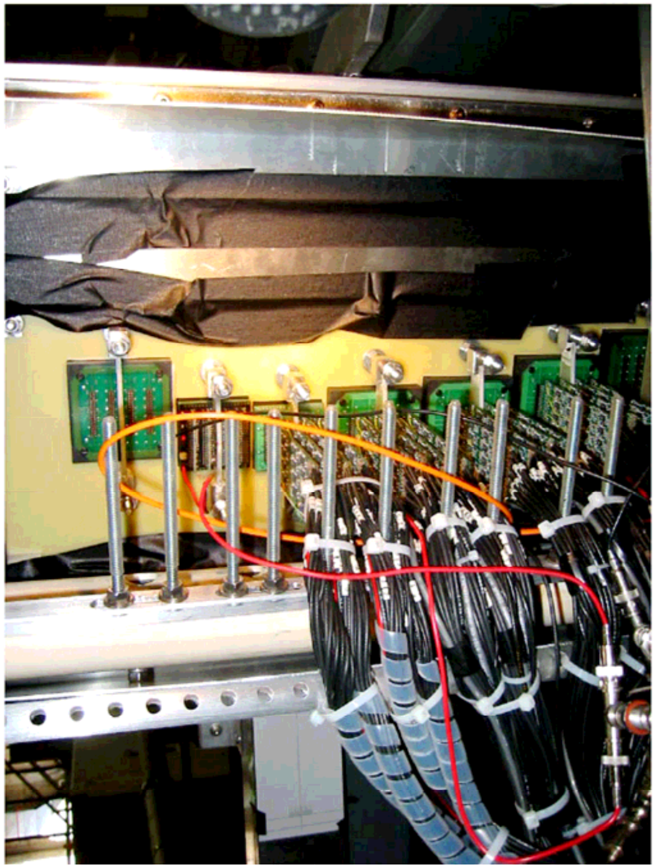


Focusing DIRC tests at SLAC

Gary Varner, Larry Ruckman (Hawaii)
with J. Va'vra, B. Ratcliff et al (SLAC)



quartz bar

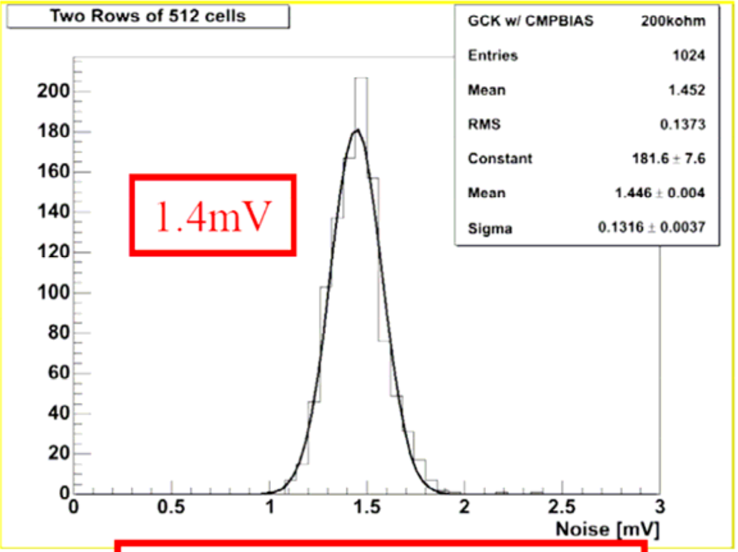


Photon detectors: flat pannel PMTs and Burle MCP PMTs, part of it read-out by Gary's wave sampling read-out

Buffered Large Analog Bandwidth (BLAB1)

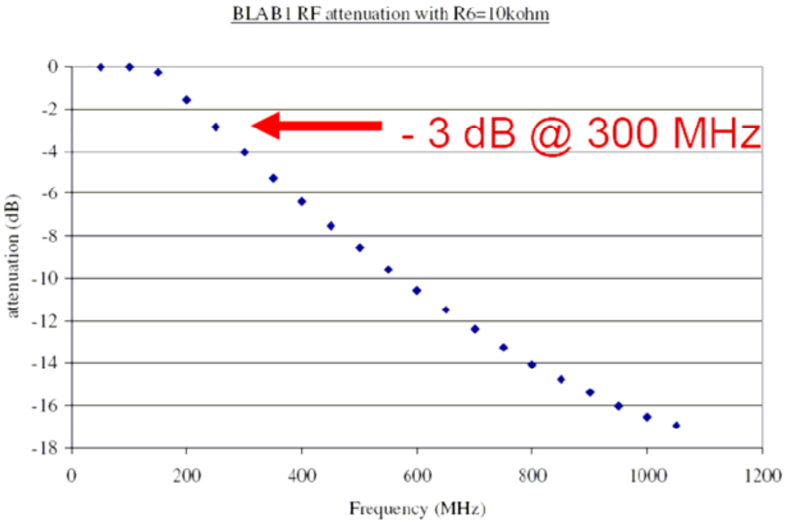
- Custom Analog-to-Digital (ADC)
- 65 k deep sampling
- High speed sampling
- Low power consumption
- 10 real bits of dynamic range

Measured Noise



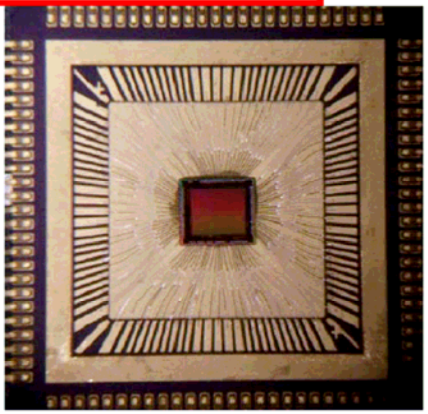
1.4mV

1.8V dynamic range

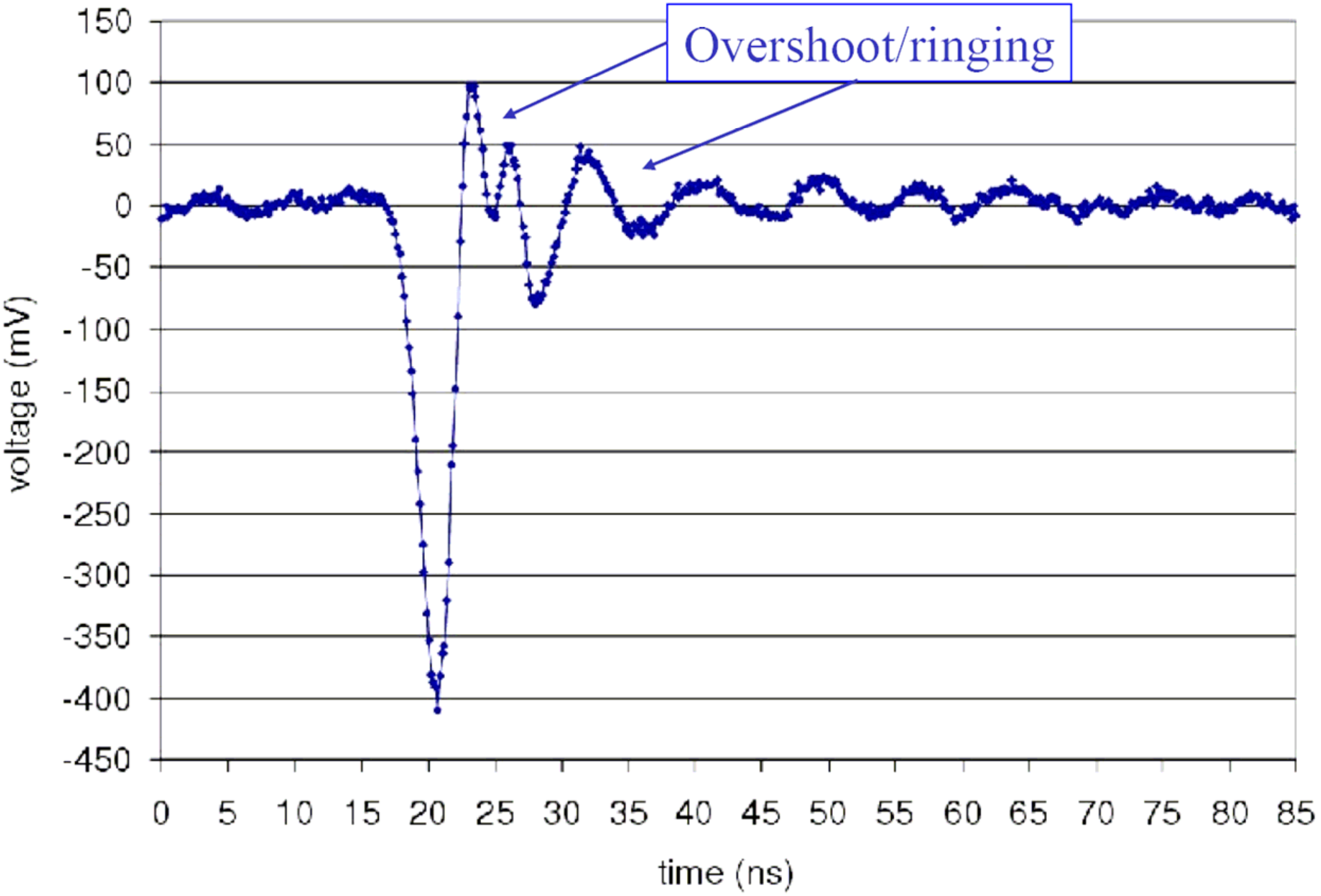


- 3 dB @ 300 MHz

BLAB1



Typical single p.e. signal [Burle]



Focusing DIRC tests at SLAC

Beam test data looks good, being analyzed

Plan for the next beam test: equip 7 MCP PMTs with BLAB read-out

Summary

Aerogel RICH:

- A lot of progress in understanding the photon detectors; more beam/bench tests in spring → decision in autumn
- Read-out: still a lot to be done, final choice depends on photon detector (timing or not)

TOP:

- Photon detector with GaAsP photocathode: excellent Q.E. and timing, dark count rate high.
- Plan: study ageing.

Focusing DIRC:

- Promissing beam tests at SLAC, progress in read-out electronics interesting for other devices as well.