Timing and cross-talk properties of Burle multi-channel MCP PMTs

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Motivation for fast single photon detection in high B fields

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Summary

Hot topics in photon detection for RICHes

For improved PID in super B factories:

- Belle PID upgrade in the barrel and forward regions
- DIRC upgrade for Super B in Frascati

Single photon detection with:

Operation in high magnetic field (1.5T)

Excellent timing (time-of-arrival information)

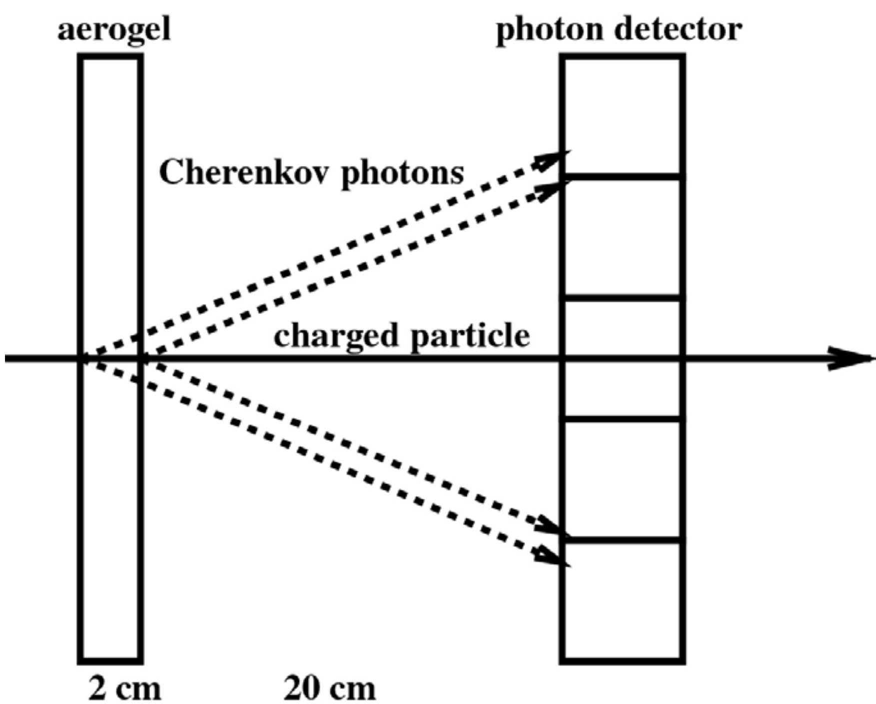
Proximity focusing RICH in the forward region

Requirements and constraints:

→talk by Toru Iijima

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

→ Proximity focusing aerogel RICH

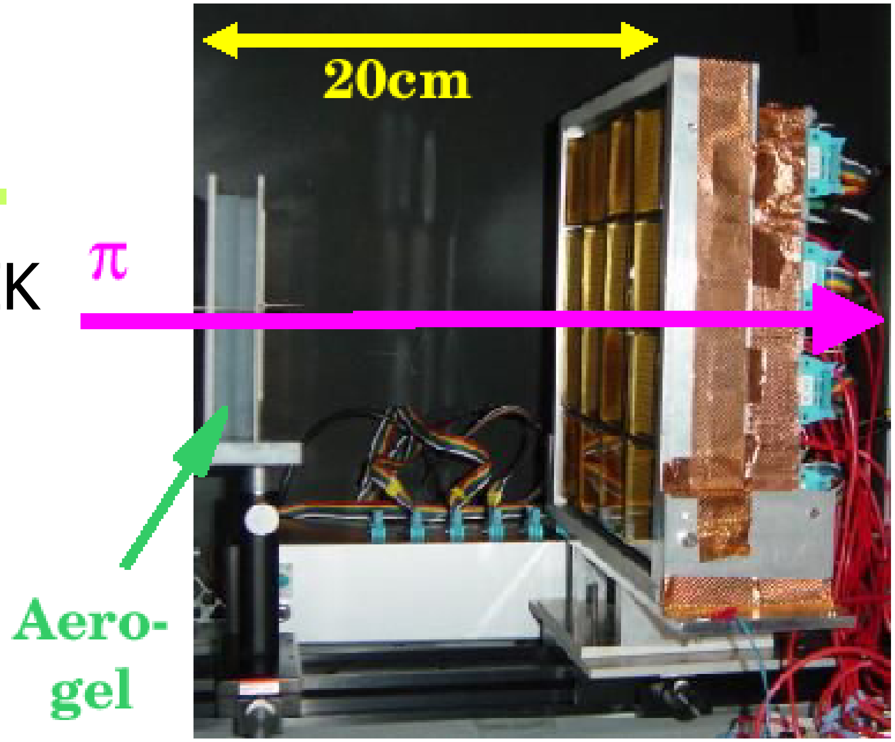


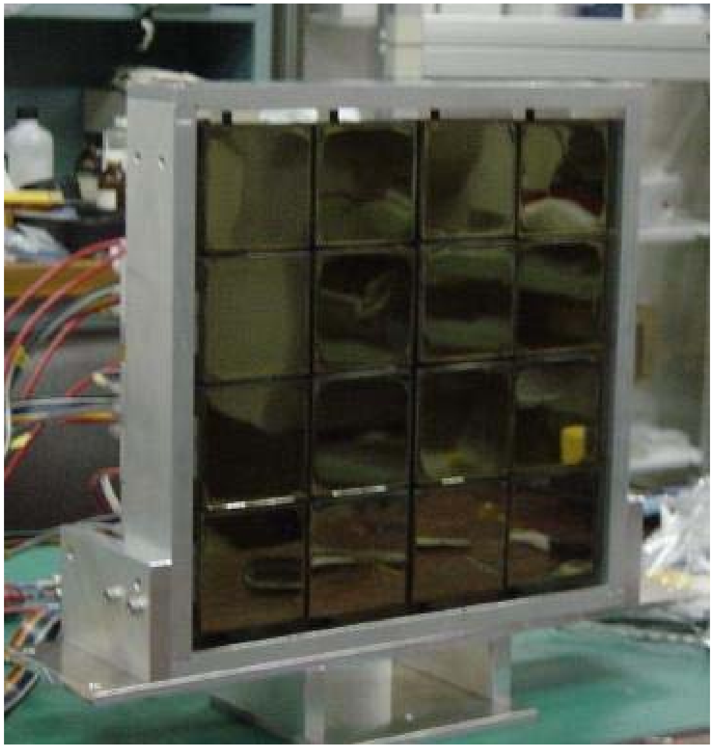
- n = 1.05
- $\theta_c(\pi)$ ~ 308 mrad @ 4 GeV/c
- $\theta_c(\pi) - \theta_c(K)$ ~ 23 mrad
- pion threshold 0.44 GeV/c,
- kaon threshold 1.54 GeV/c

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

Beam tests

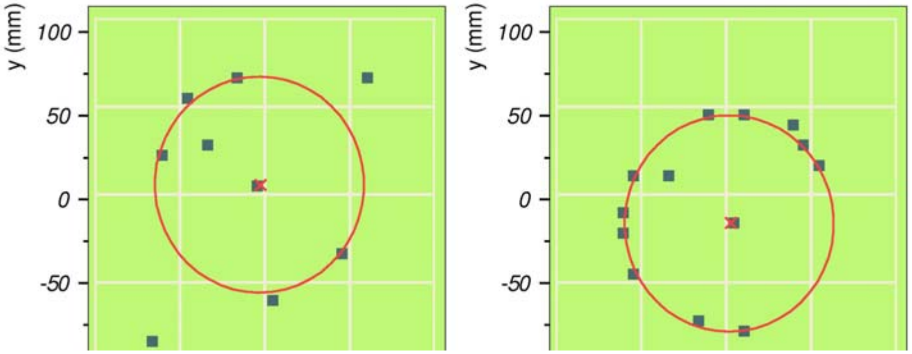
pion beam (π2) at KEK





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

Clear rings, little background



- → This photon detector does not work in magnetic field

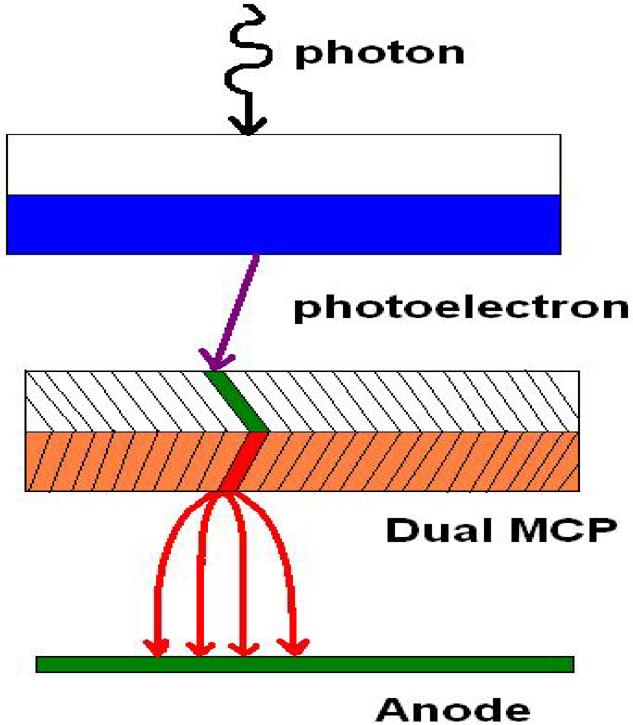
Photon detectors for the aerogel RICH

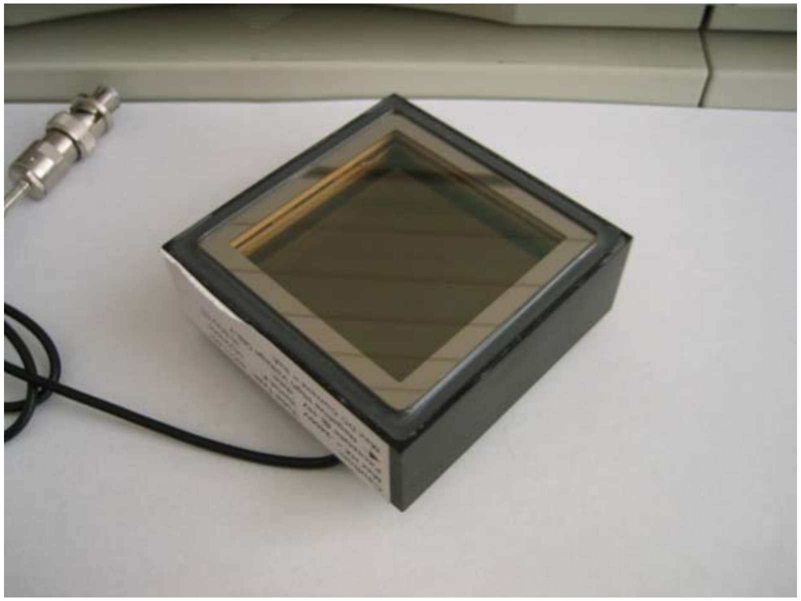
Photon detector candidates for 1.5T:

- BURLE 85011 microchannel plate (MPC) PMT
- Multichannel H(A)PD – R+D with Hamamatsu
  → talk by Shohei Nishida
- SiPM (G-APD) → talk by Samo Korpar

Photon detector candidate for 1.5 T: MCP-PMT

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

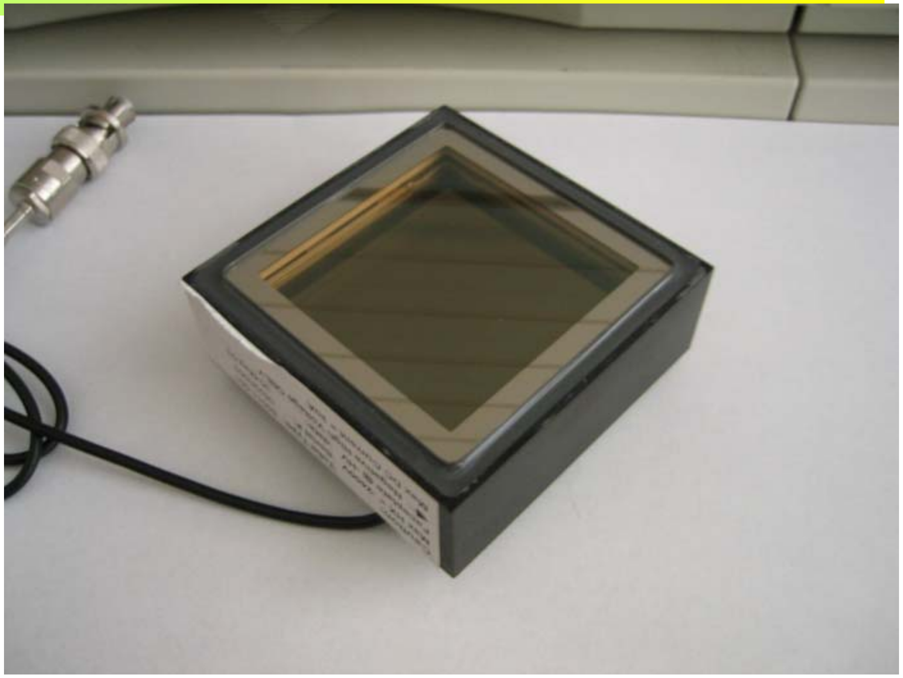




→excellent performance in beam and bench tests
→ very fast (σ=50ps for single photons)

Basic parameters of BURLE MCP-PMTs

- multi-anode PMT with two MCP steps
- bialkali photocathode
- gain ~ 0.6 x 10^6
- collection efficiency ~ 60%
- box dimensions 71x71mm^2
- active area fraction ~ 52%
- 2mm quartz window



BURLE 85011 MCP-PMT

- 64 (8x8) anode pads
- pitch ~ 6.5mm, gap ~ 0.5mm
- 25 μm pores

BURLE 85001 MCP-PMT

- 4 (2x2) anode pads
- pitch ~ 25mm, gap ~ 1mm
- 10 μm pores

Beam tests of Burle MCP PMT

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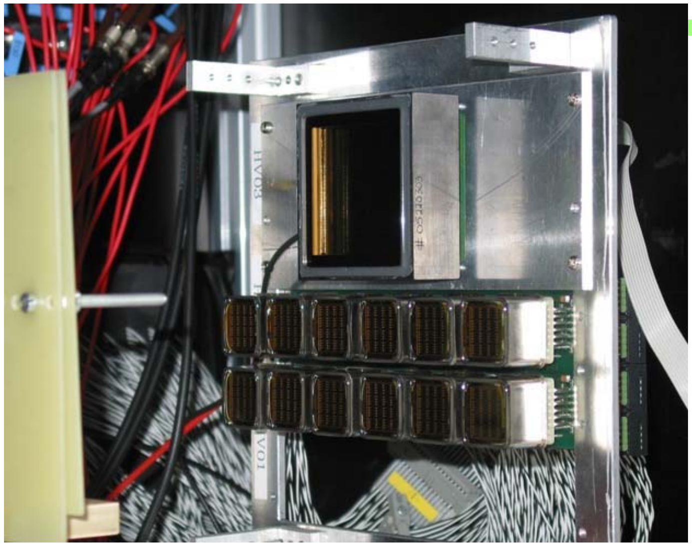
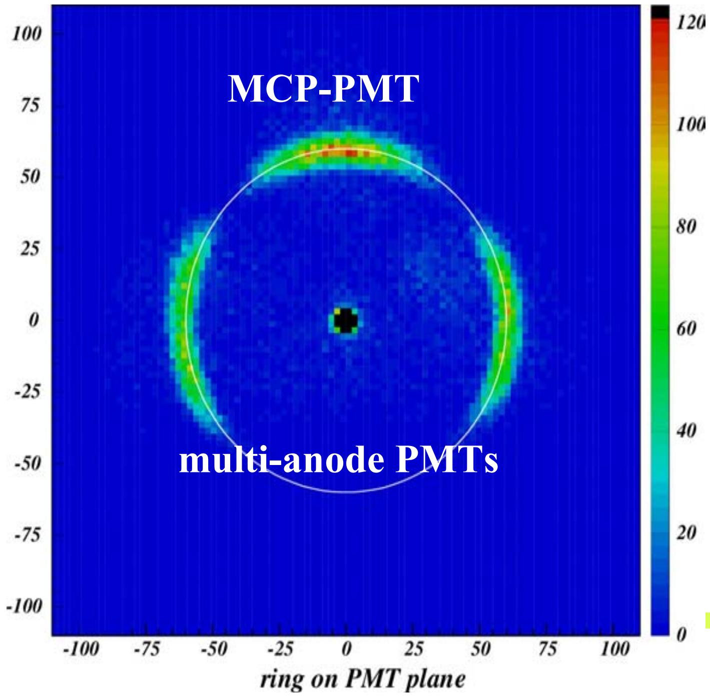




Tested in pion beam combination with multi-anode PMTs.
→Stable operation, very good performance

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**

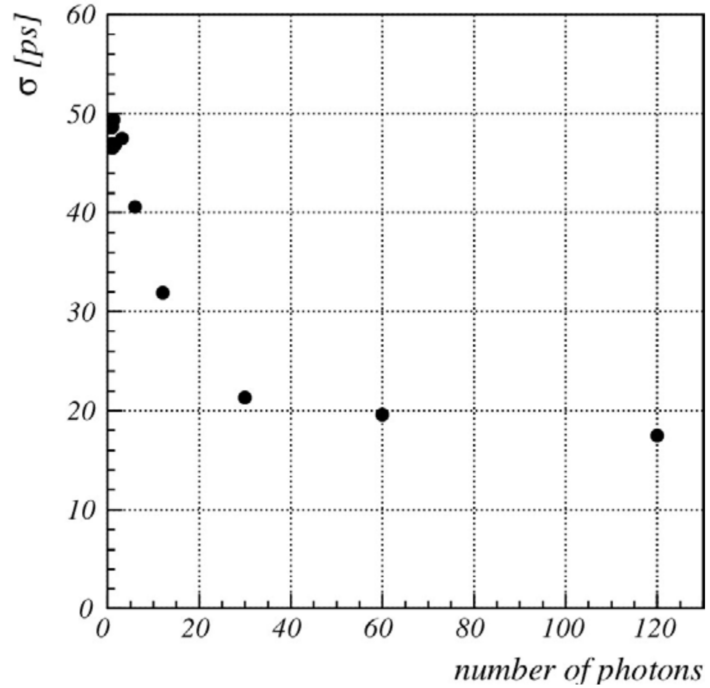
To do list:

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

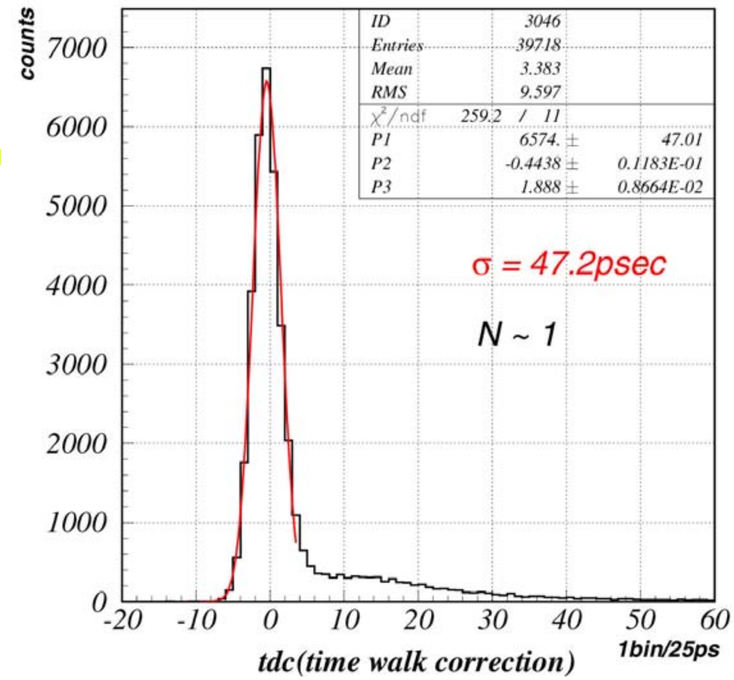
MCP-PMT timing properties

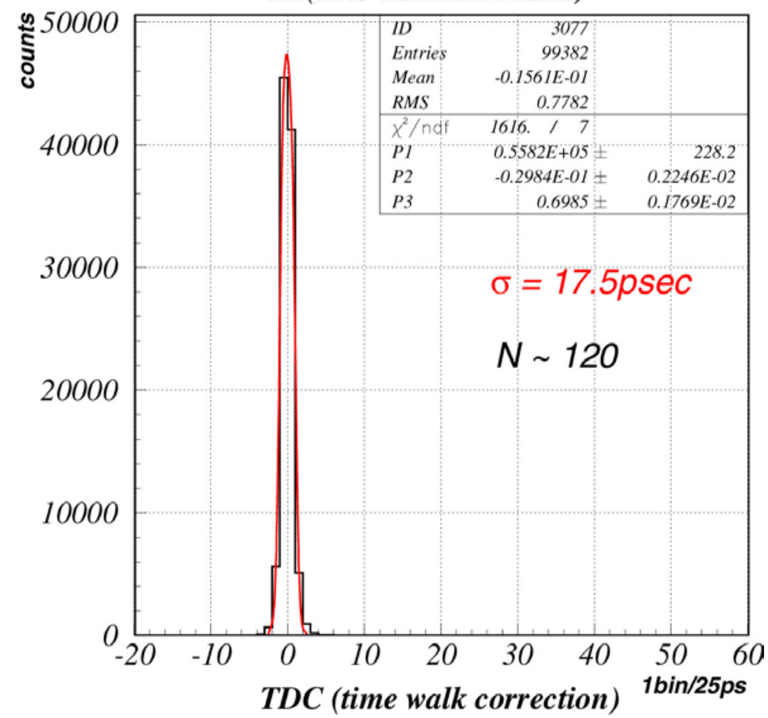
Bench tests with pico-second laser:

- amplifier ORTEC FTA820A
- discriminator PHILIPS 308
- CAMAC TDC Kaizu works KC3781A, 25ps LSB
- CAMAC charge sensitive ADC



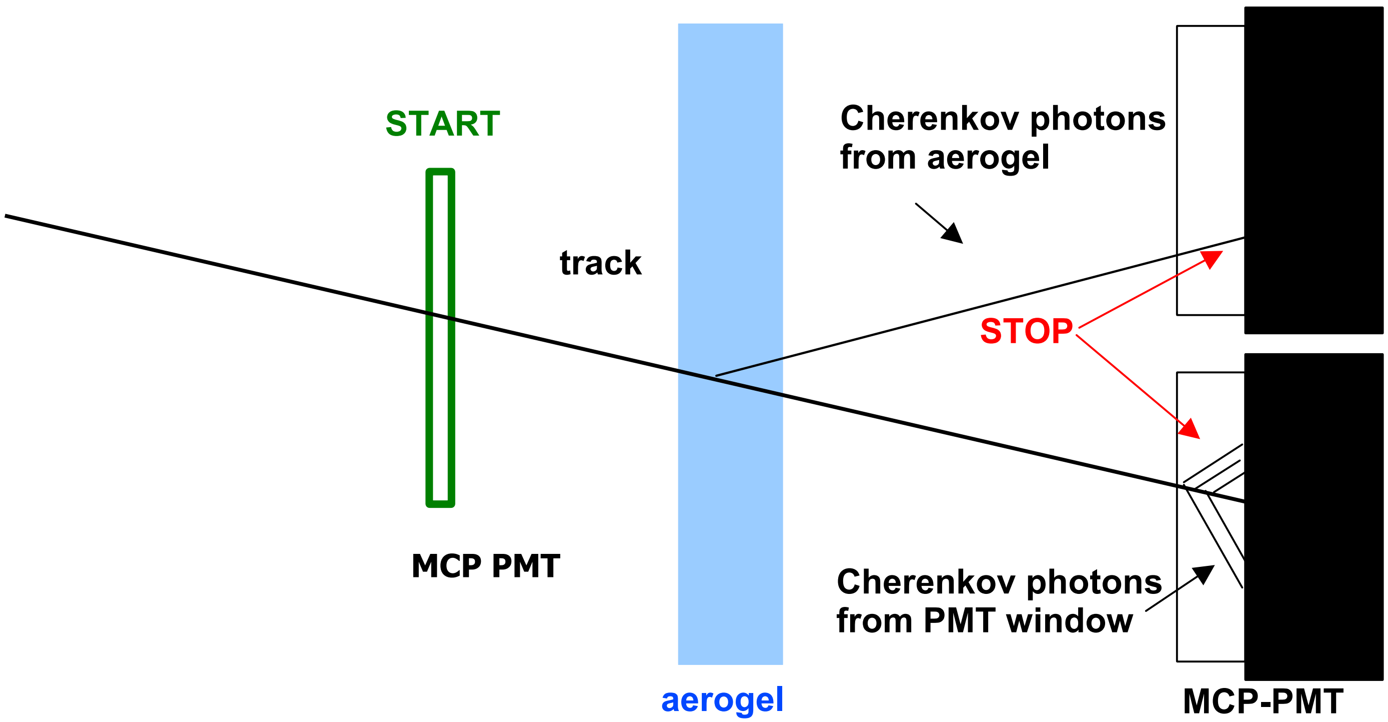
Time resolution as a function of the number of detected photons.





Beam test: time-of-flight measurement

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



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→talk by Toru Iijima

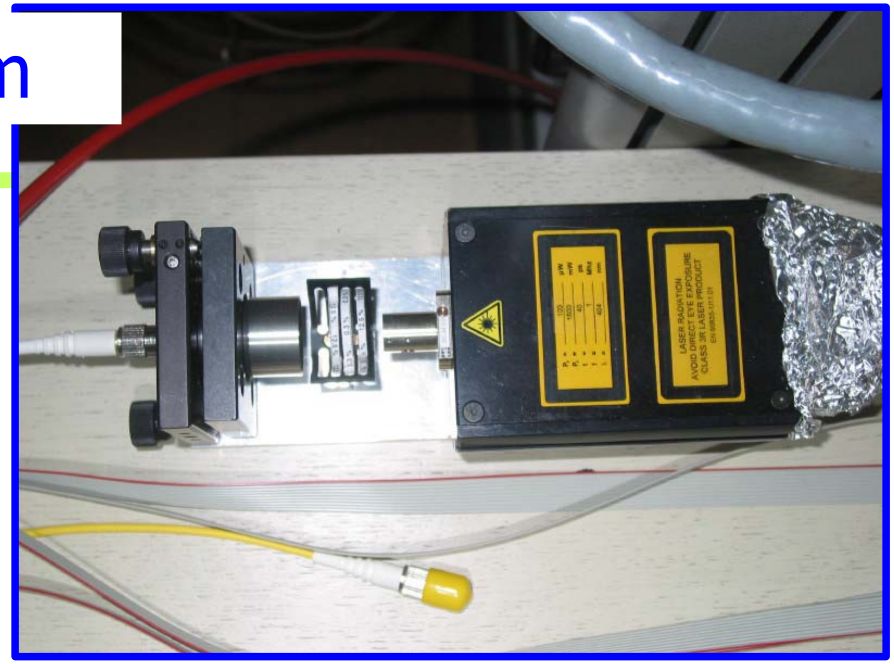
New bench tests: cross-talk and timing properties

Burle MCP PMT has excellent timing properties, a promising photon detector also for very precise time measurements.

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

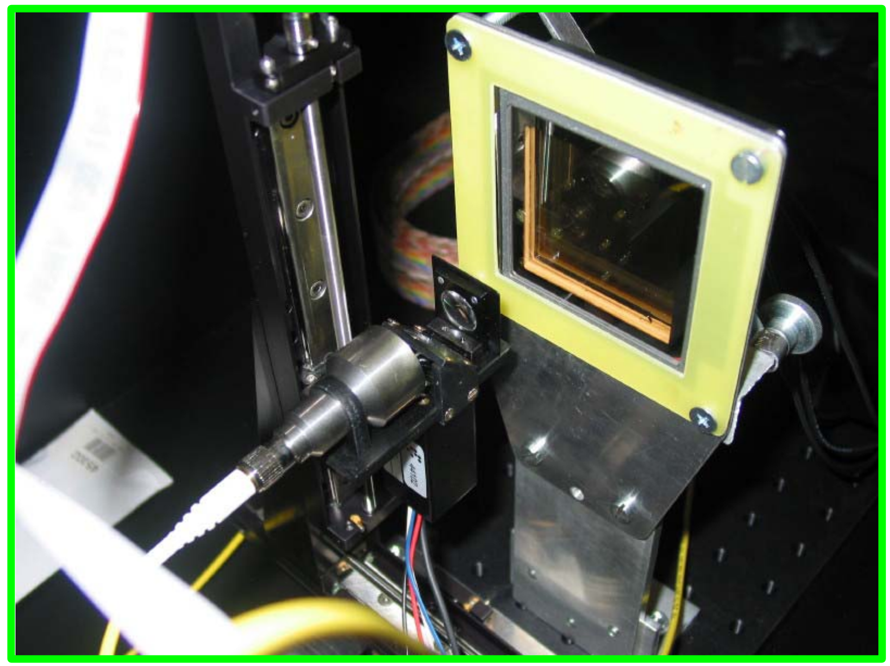
Determine their influence on the
- position resolution and
- time resolution

Scanning setup: optical system



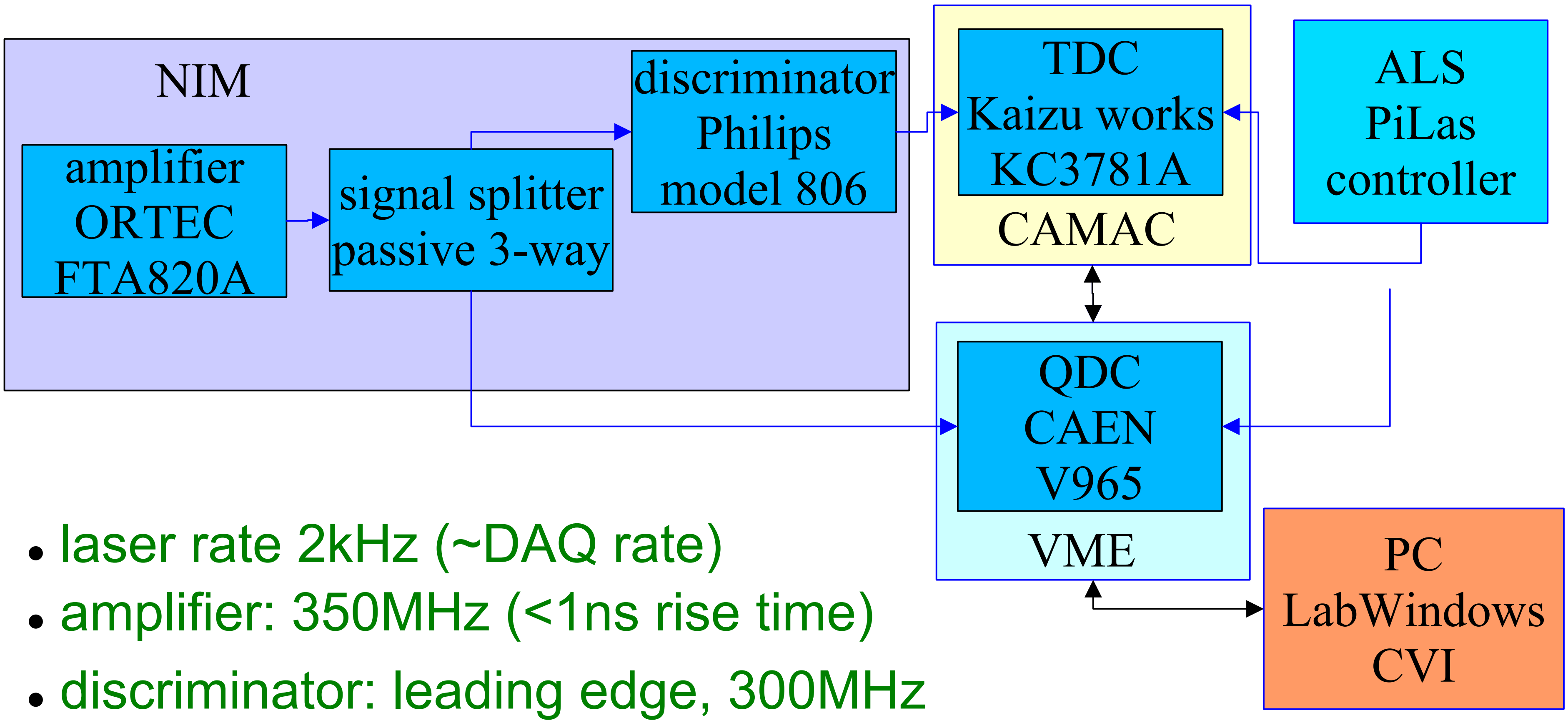
Outside dark box:
- PiLas diode laser system EIG1000D (ALS)
- 404nm laser head (ALS)
- filters (0.3%, 12.5%, 25%)
- optical fiber coupler (focusing)

- 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)

Scanning setup: read-out



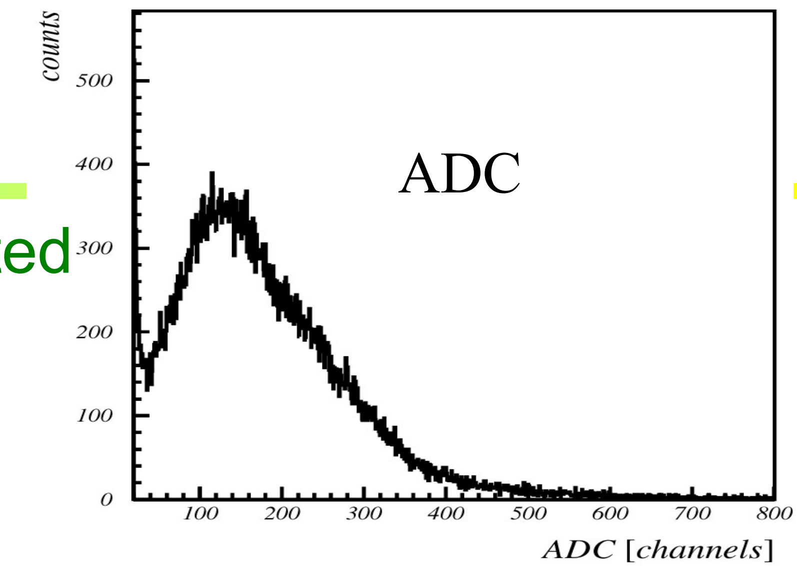
- laser rate 2kHz (~DAQ rate)
- amplifier: 350MHz (<1ns rise time)
- discriminator: leading edge, 300MHz
- TDC: 25ps LSB(σ~11ps)
- QDC: dual range 800pC, 200pC
- HV 2400V

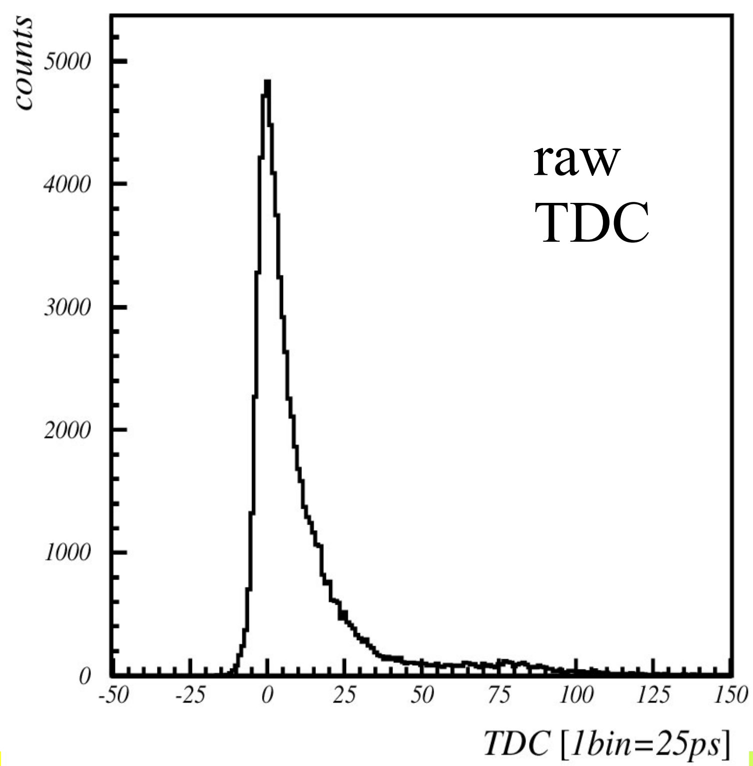
Time walk correction

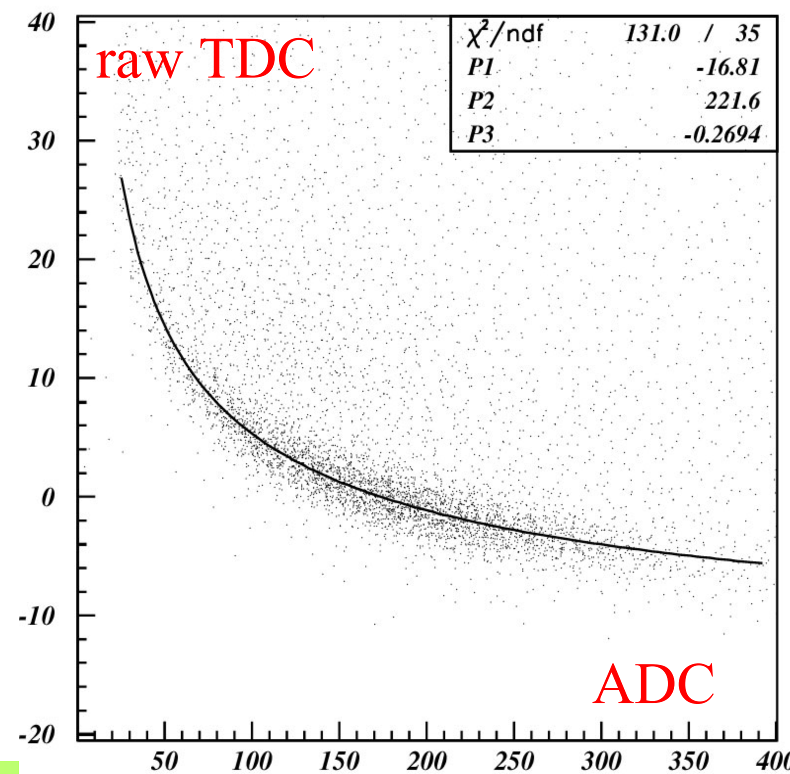
TDC vs. ADC correlation is fitted with

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

and used for TDC correction

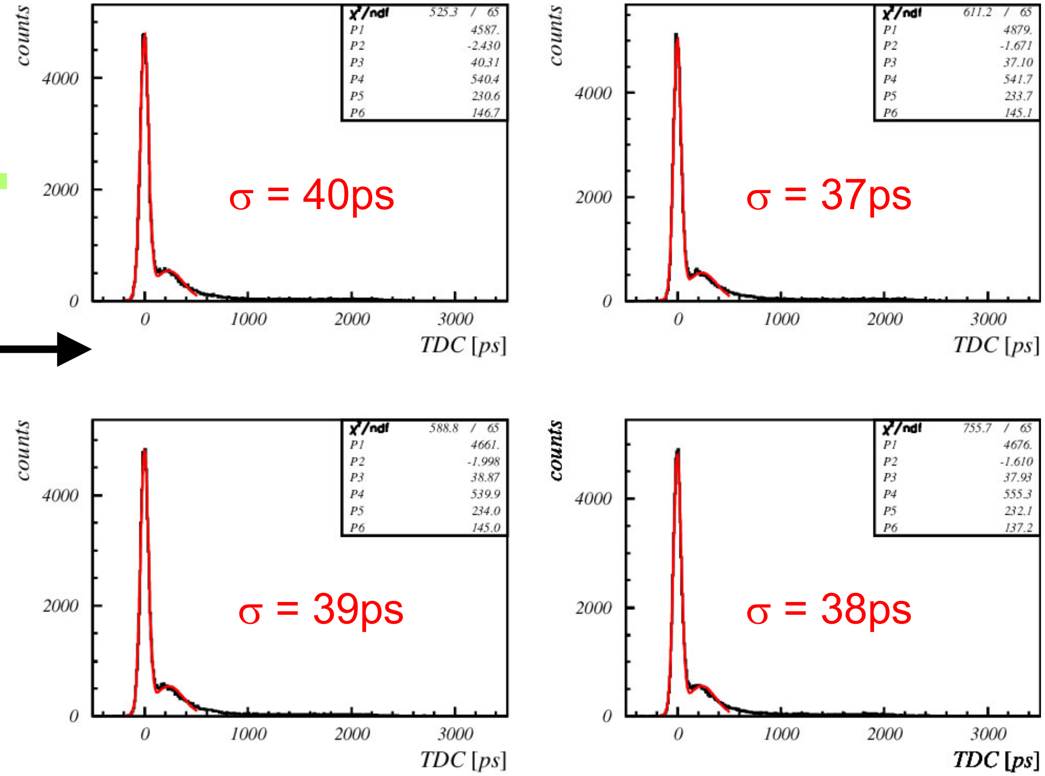


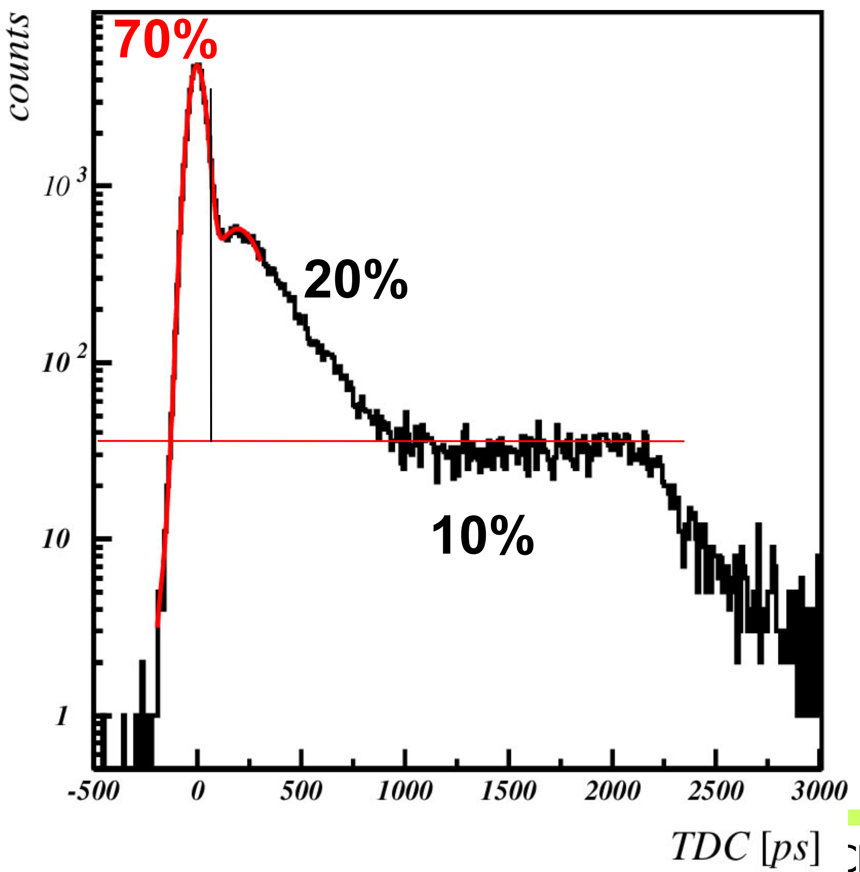




Corrected TDC

Corrected TDC distributions for all pads





Response:

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

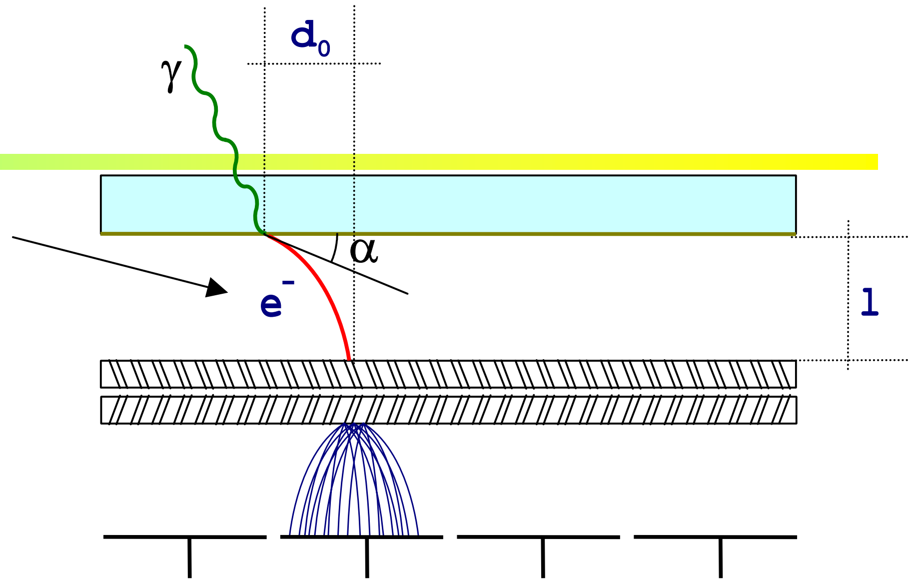
Photon electron detection: modeling

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

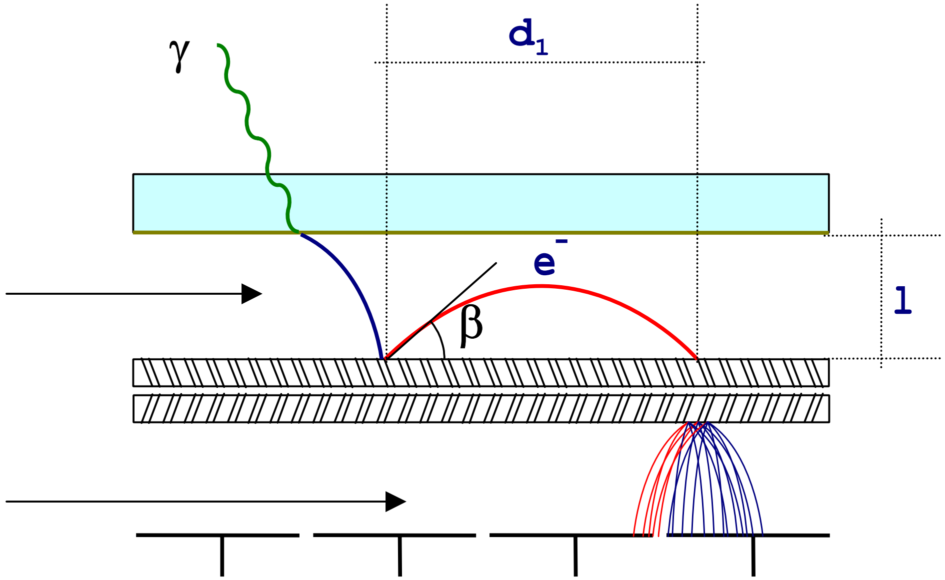
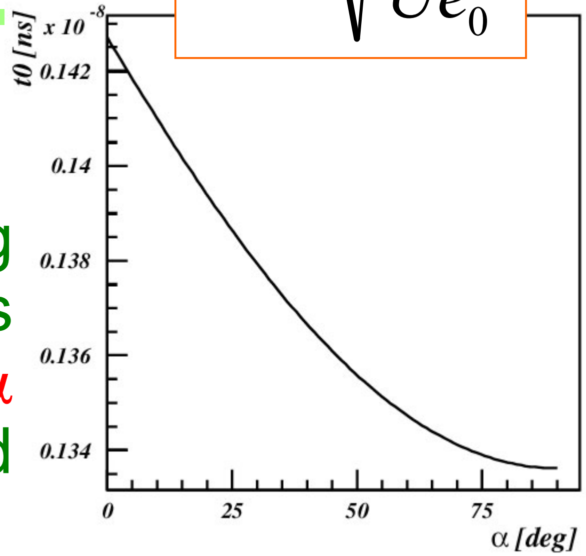
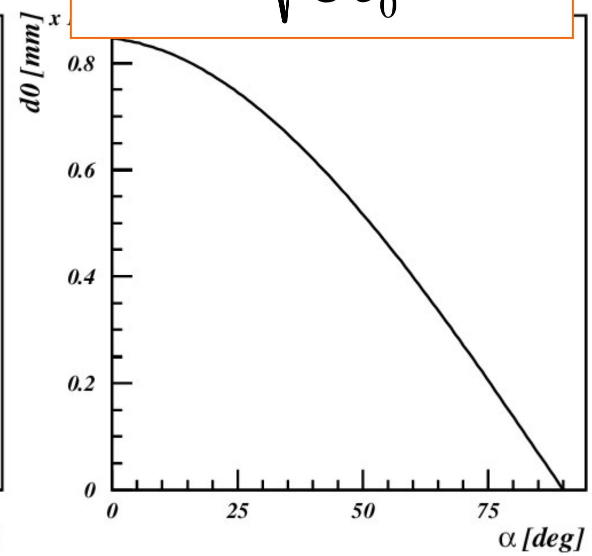


Photo-electron: simple estimates

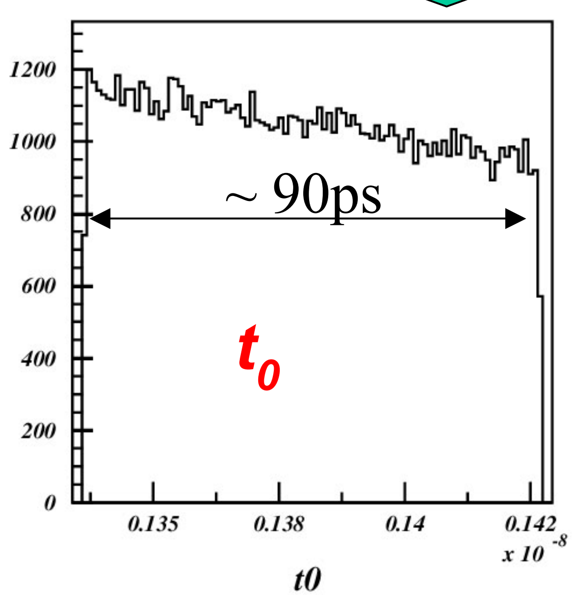
$$t_0 \approx l\sqrt{\frac{2m_e}{Ue_0}}$$

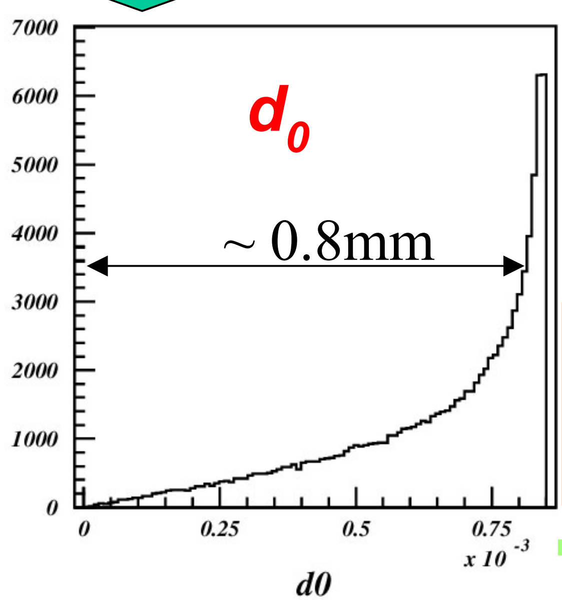
$$d_0 \approx 2l\sqrt{\frac{E_0}{Ue_0}}\cos\alpha$$





Distributions assuming that photo-electron is emitted at angle α uniformly over the solid angle





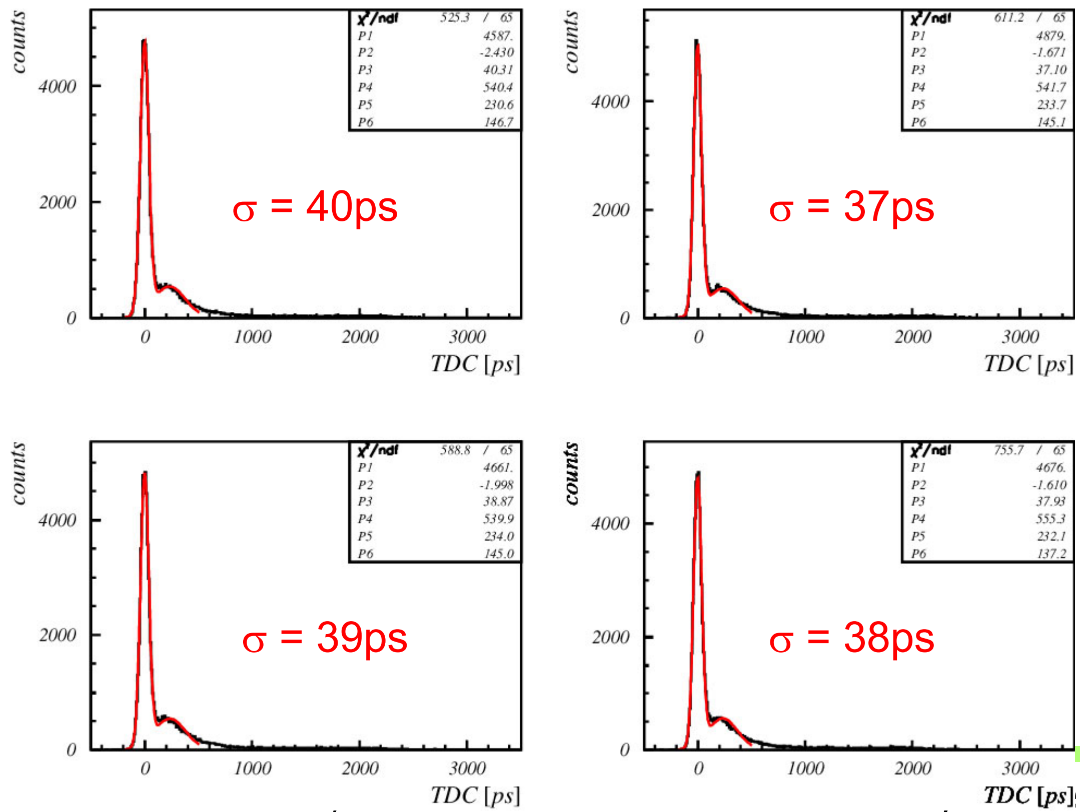
Maximum variation of photo-electron travel time.

$$\Delta t_0 \approx t_0\sqrt{\frac{E_0}{Ue_0}} \approx \frac{l}{Ue_0}\sqrt{2m_e E_0}$$

Timing resolution, contributions

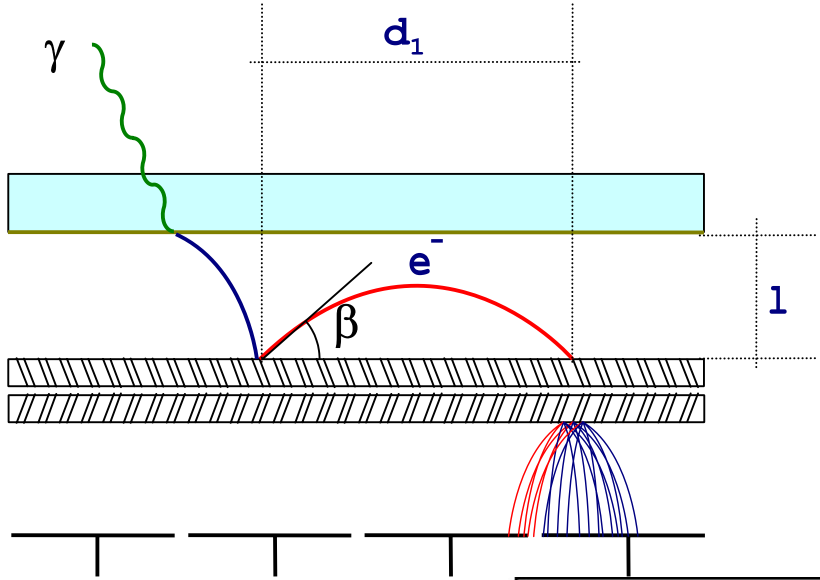
- Laser: 15ps (rms)
- Electronics: 12ps (rms)
- TTS of photo-electron (blue): 26ps (rms)

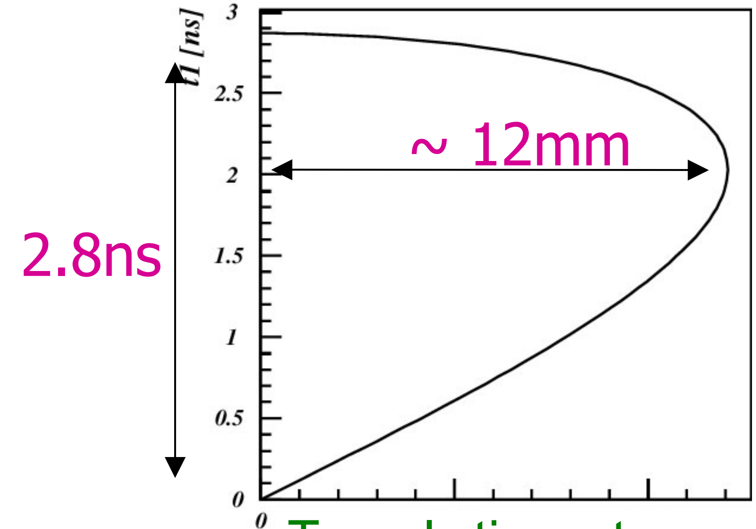
Sum in squares: 32ps → very close to 37-40ps



Time resolution of the main peak seems to be dominated by the photo-electron time spread

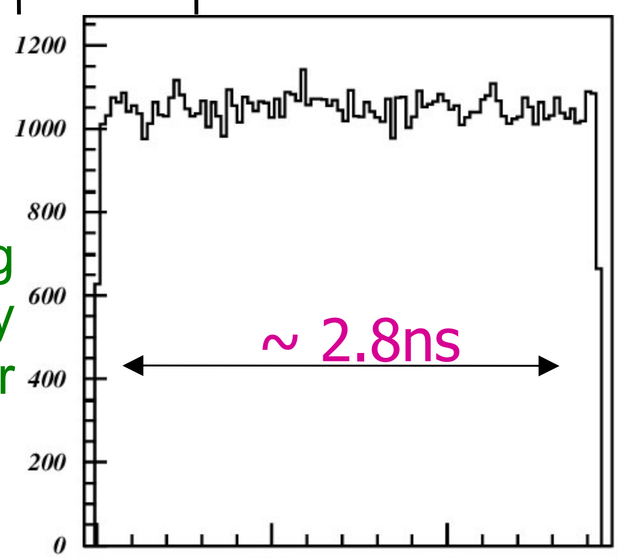
Elastic back-scattering



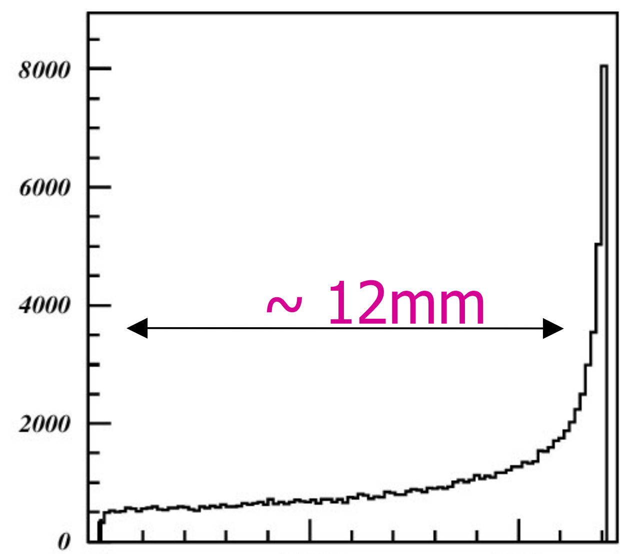


Travel time t_1 vs. travel distance d_1

Distributions assuming that back-scattering by angle β is uniform over the solid angle



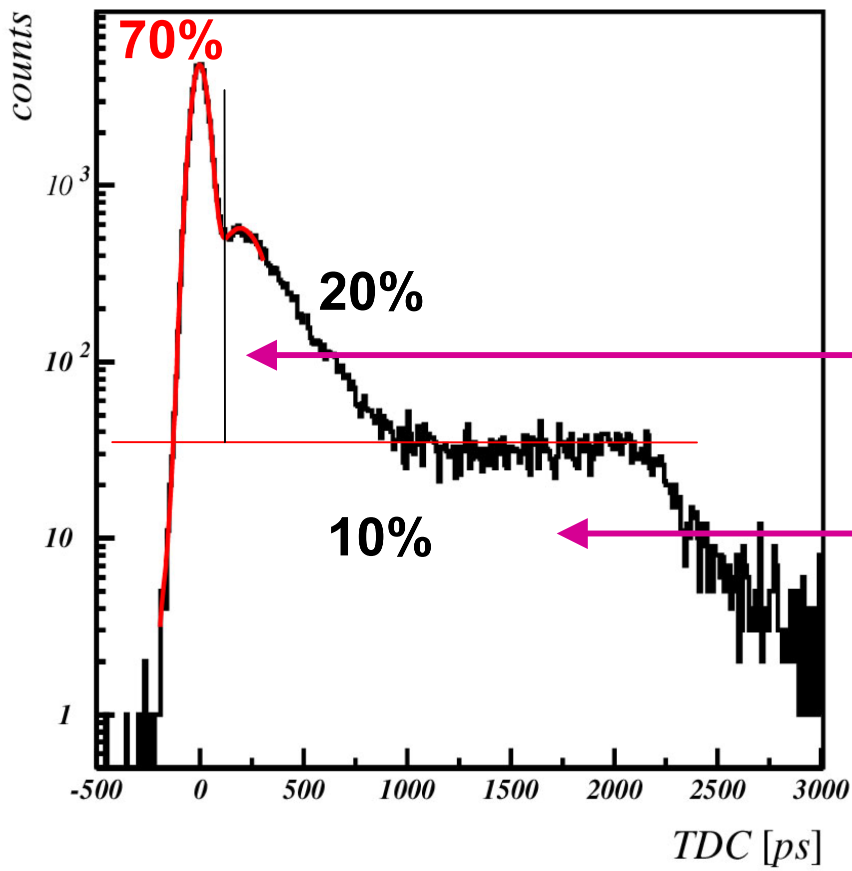
$$t_1 \approx 2 t_0 \sin \beta$$



$$d_1 \approx 2 l \sin 2\beta$$

Understanding time-of-arrival distribution

Normal photo-electrons

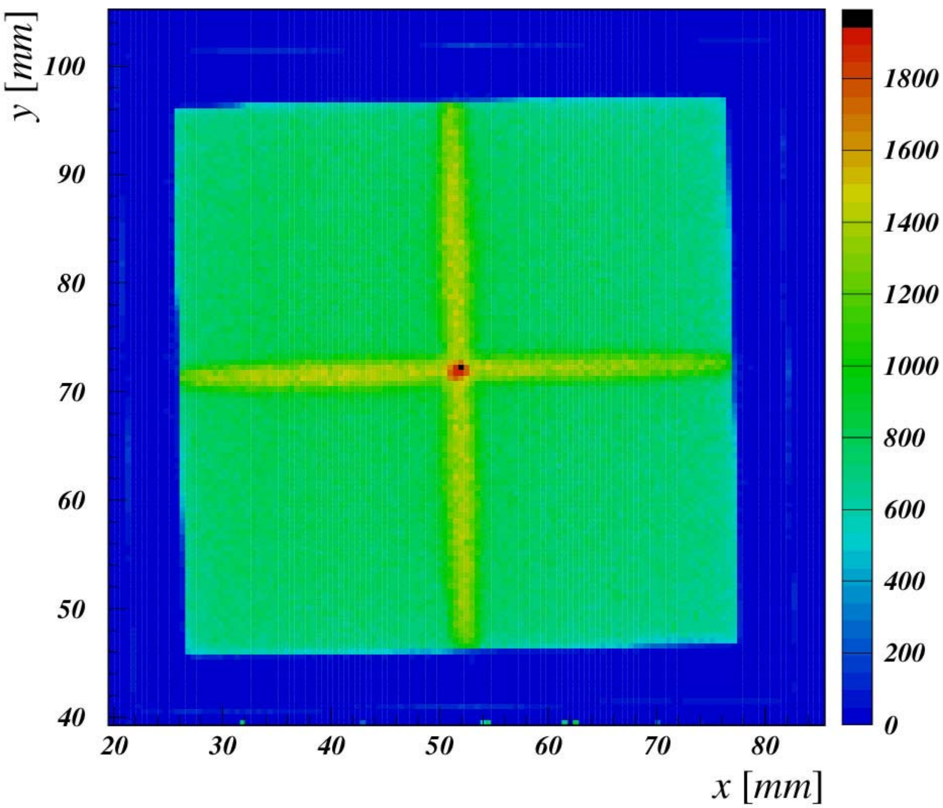


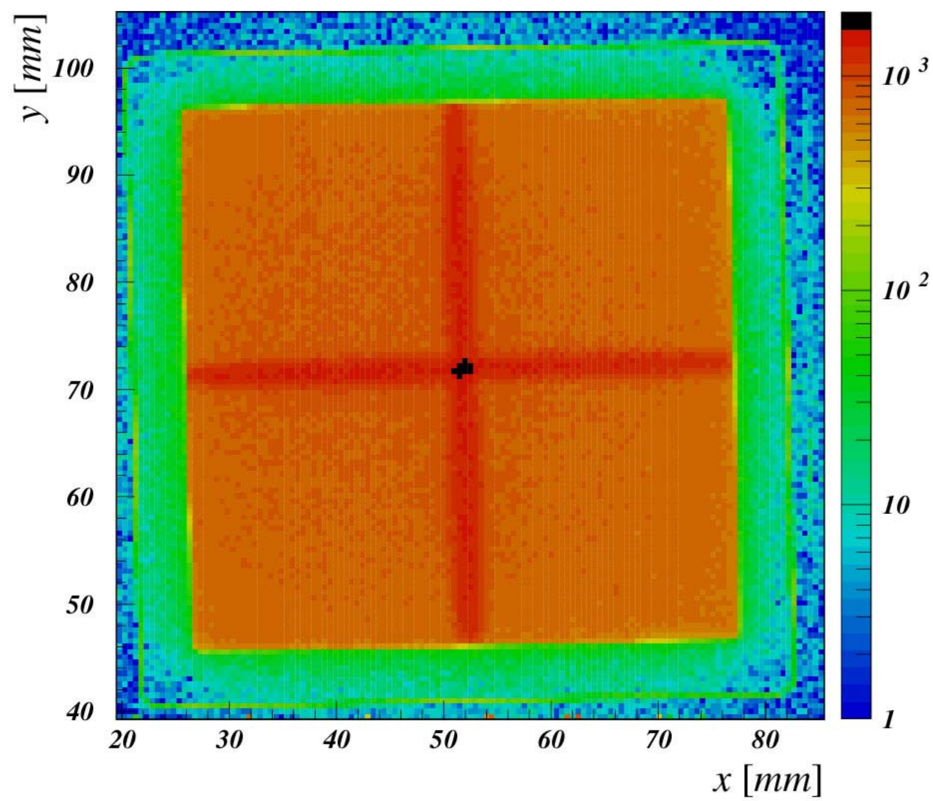
Inelastically scattered photo-electrons?

Elastically scattered photo-electrons

Photon detection uniformity

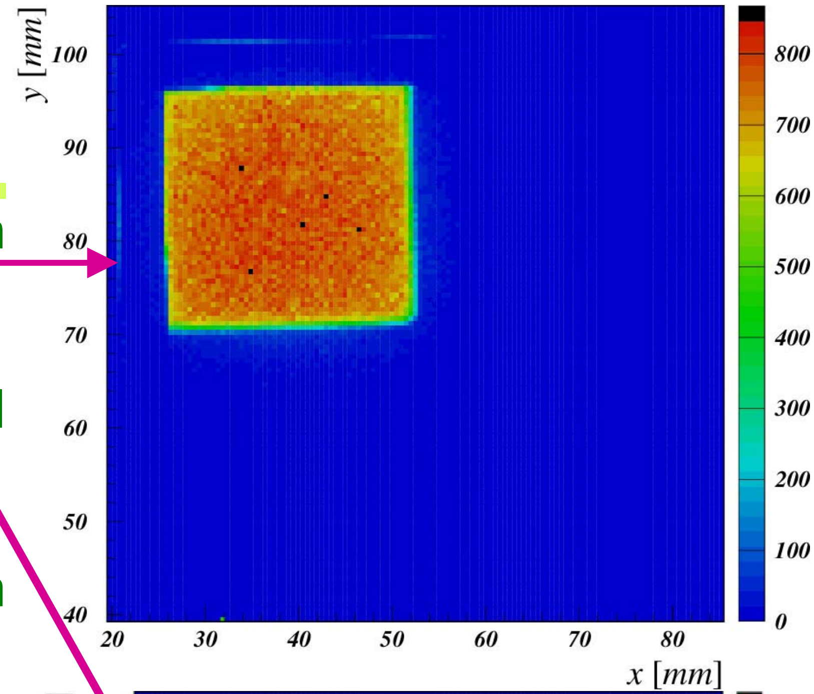
- Number of detected events at different positions of light spot – sum of all 4 channels
- double counting at pad boundaries due to charge sharing



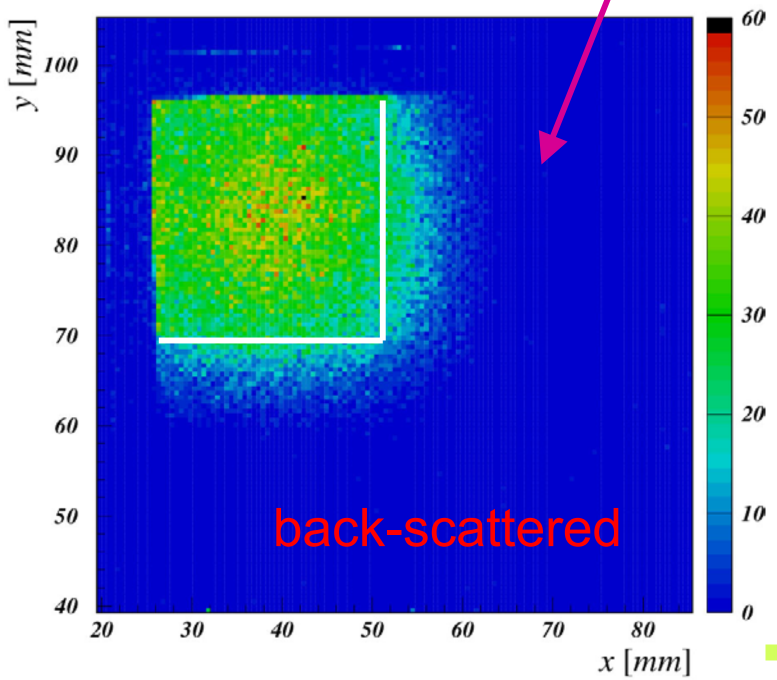


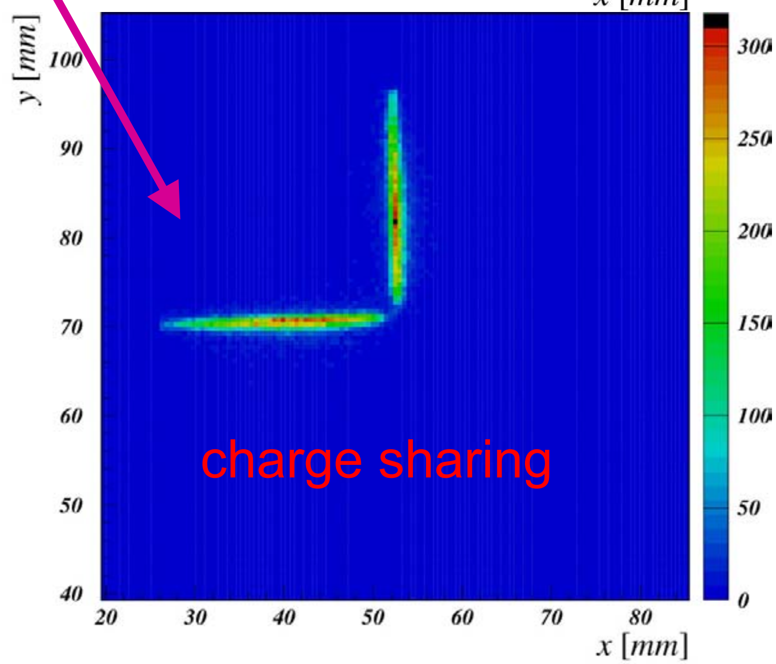
Photon detection response – single pad

- number of all detected events with maximum signal detected by the pad



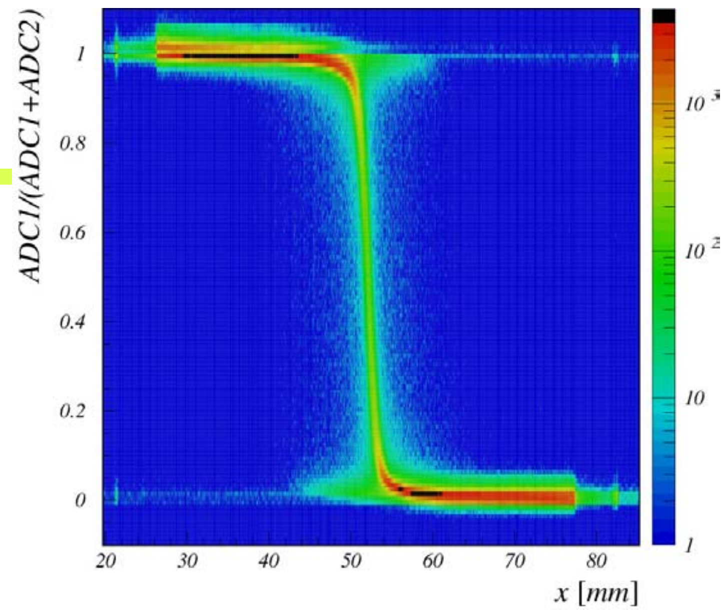
- number of events with maximum signal detected by other pads
- number of delayed events with maximum signal detected by the pad

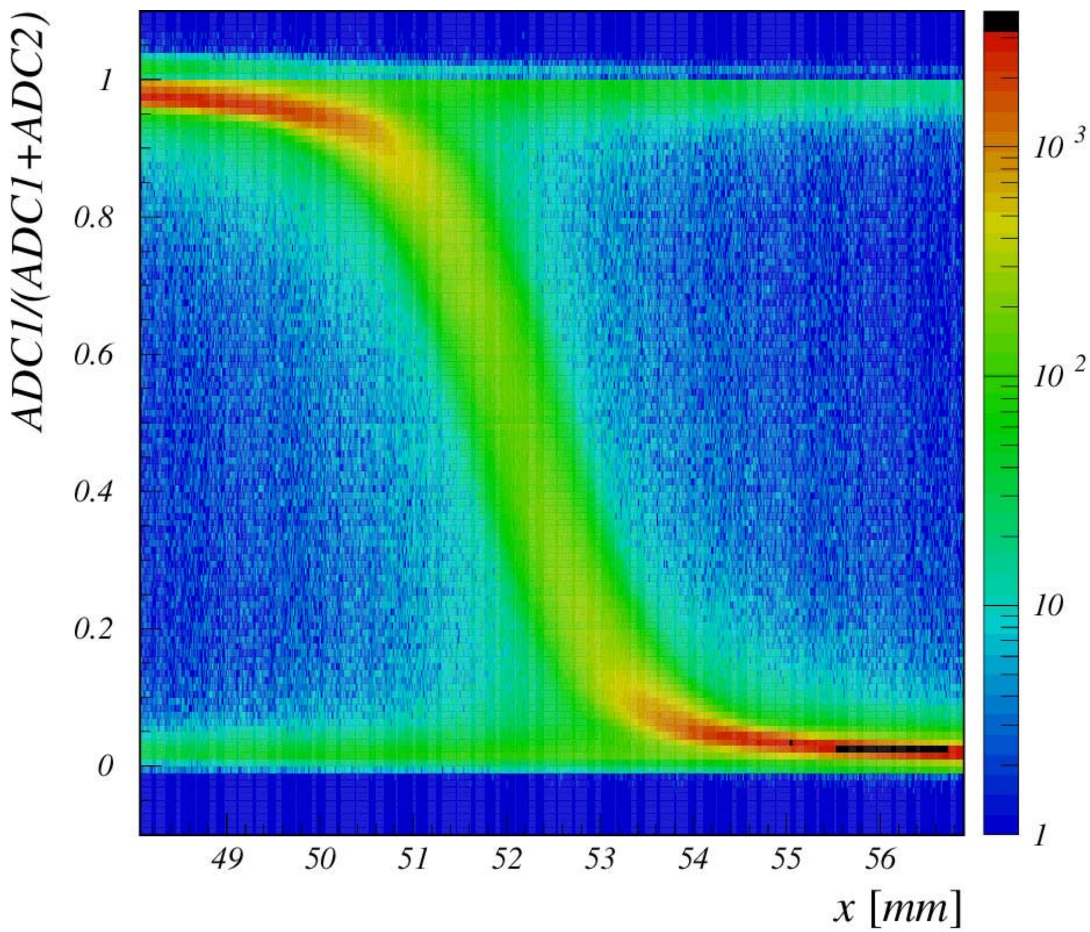




Charge sharing

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

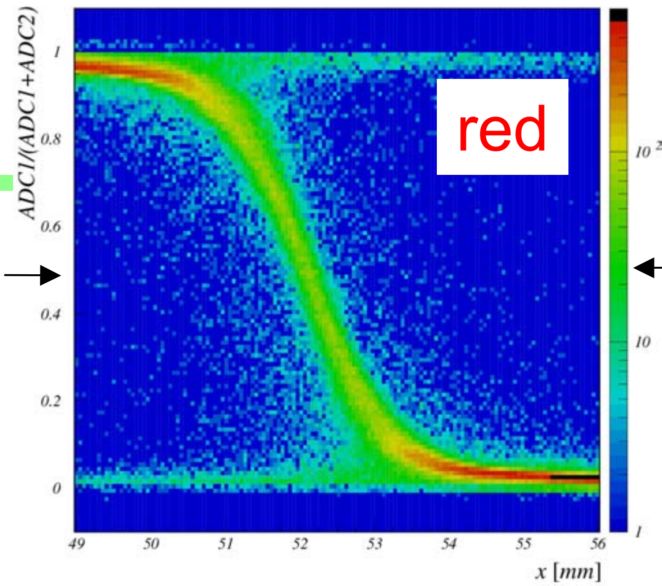


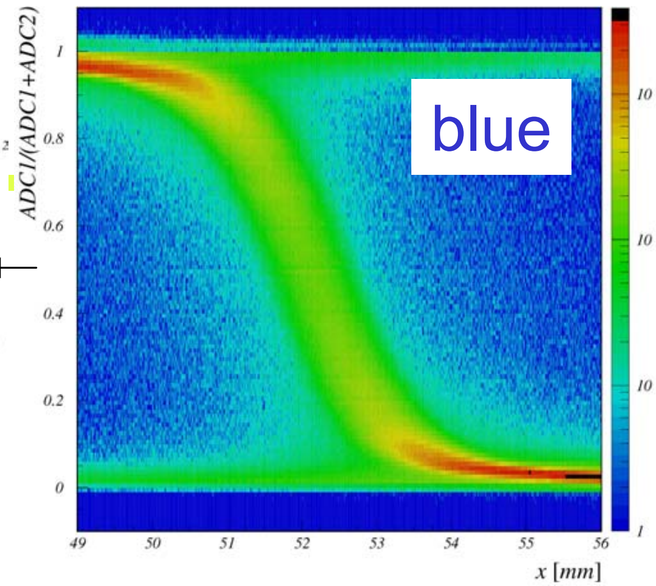


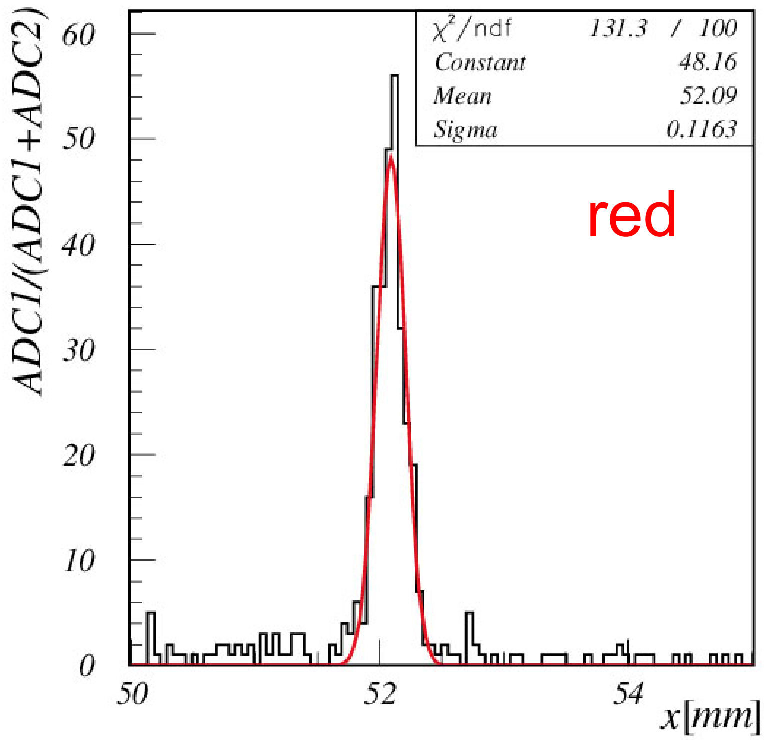
- sizable charge sharing in ~2mm wide boundary area
- can be used to improve position resolution

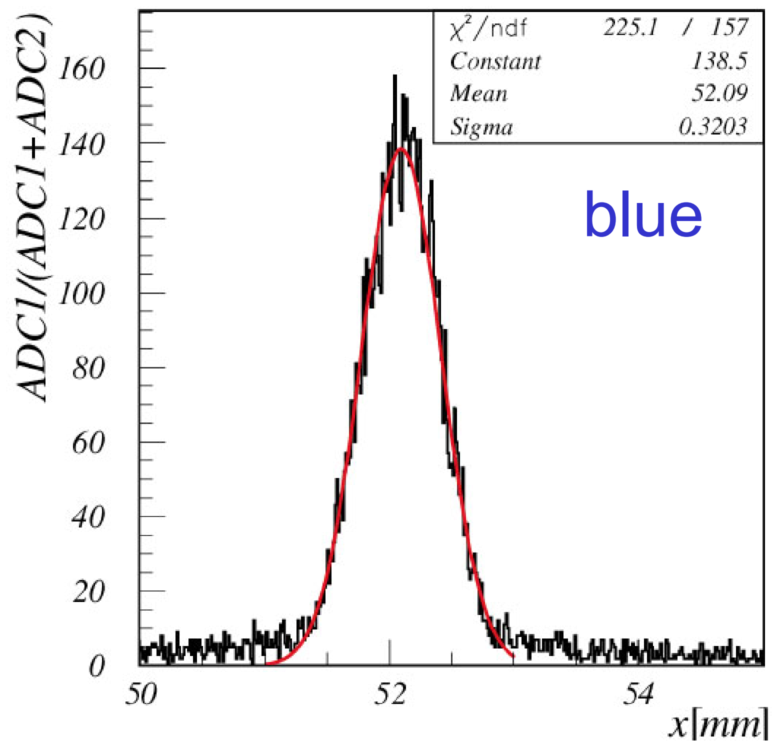
Charge sharing

Comparison of the charge sharing effect for red (635 nm) and blue (405 nm) laser



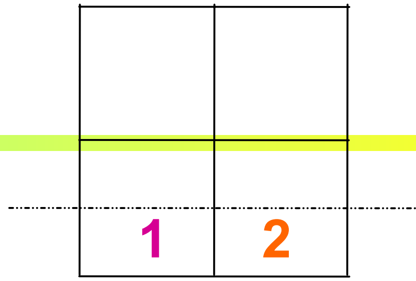




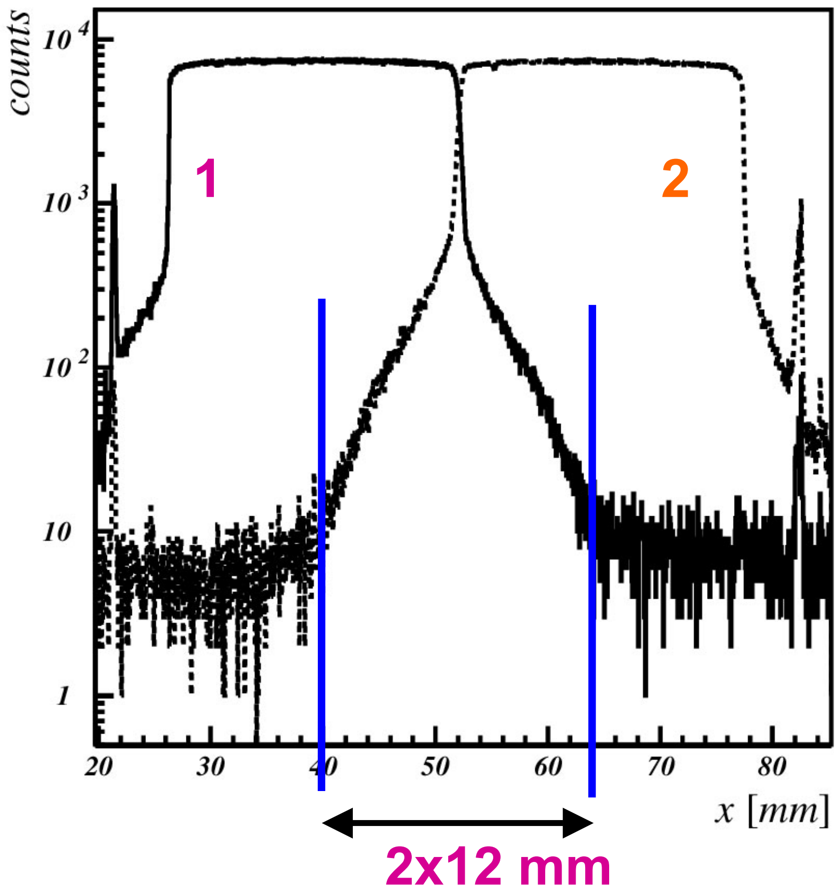


As expected: more photo-electron initial energy for blue photons

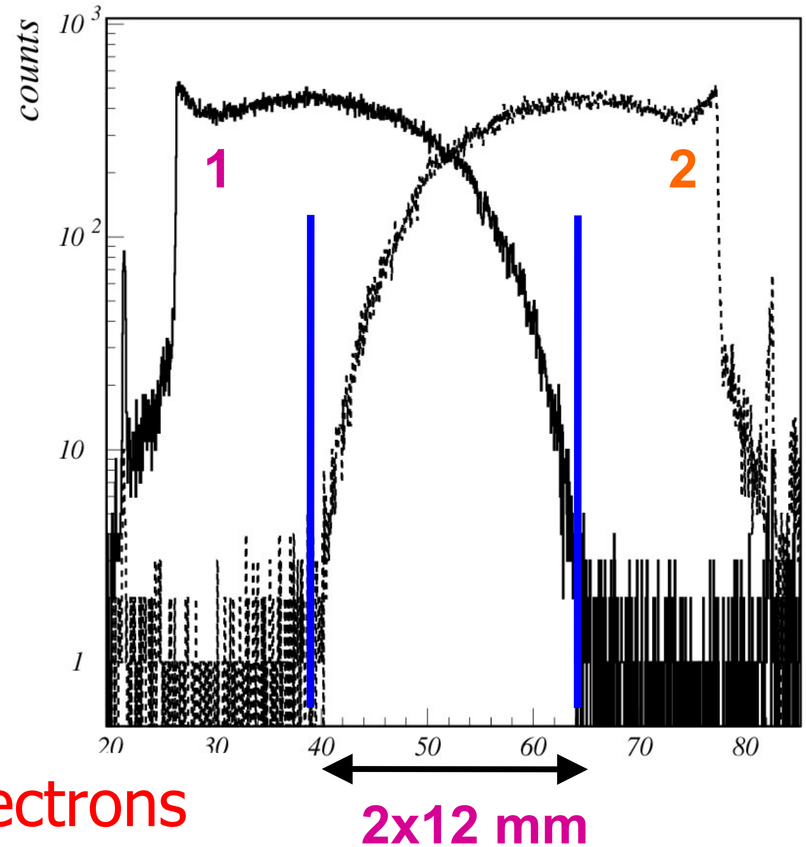
Detailed 1D scan



all events with maximum signal on channels 1 and 2

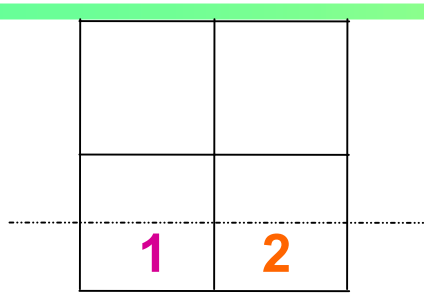


delayed (>1.1ns) events with maximum signal on channels 1 and 2



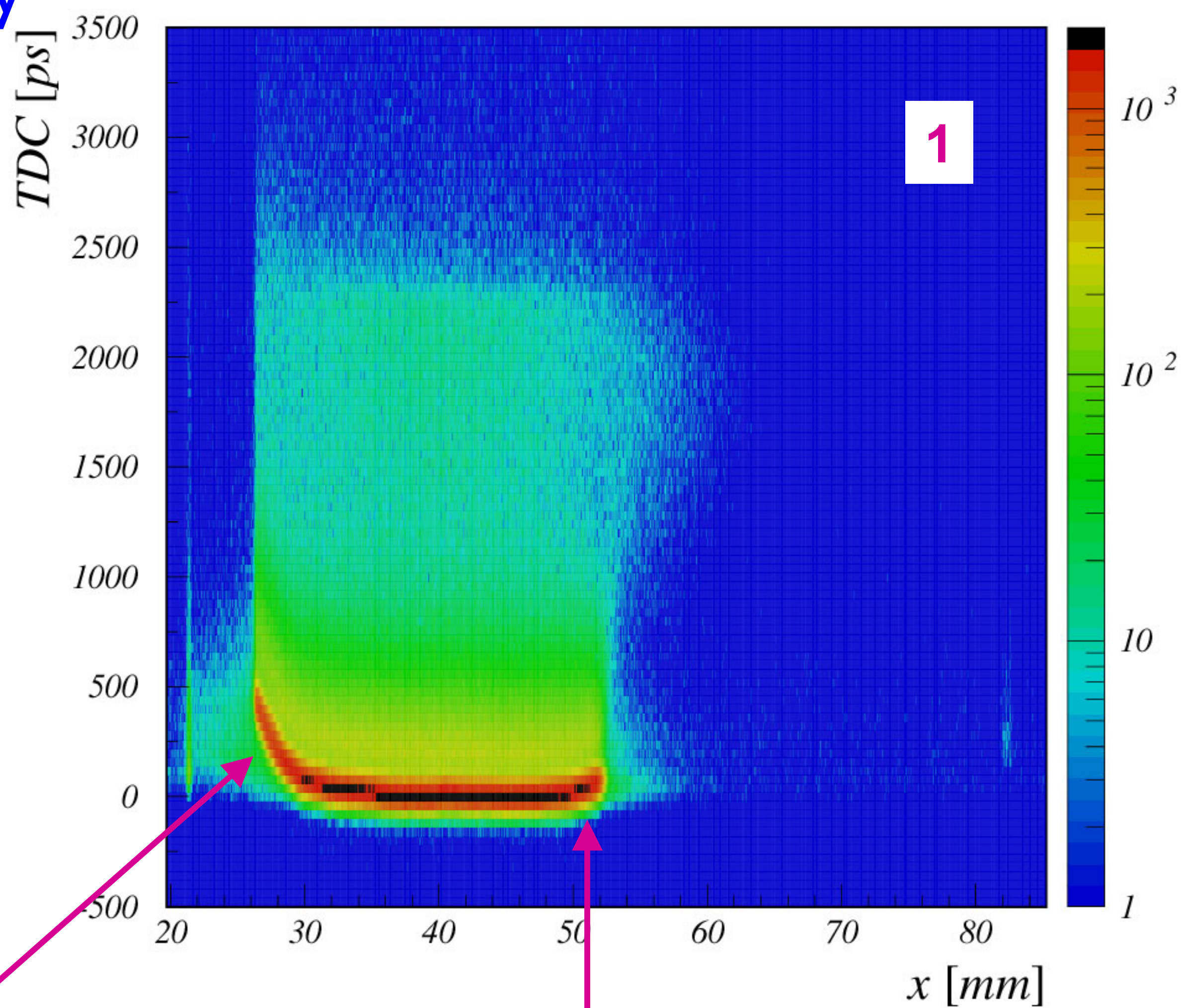
= range of back-scatterd photo-electrons

Timing uniformity



Time of arrival vs. x

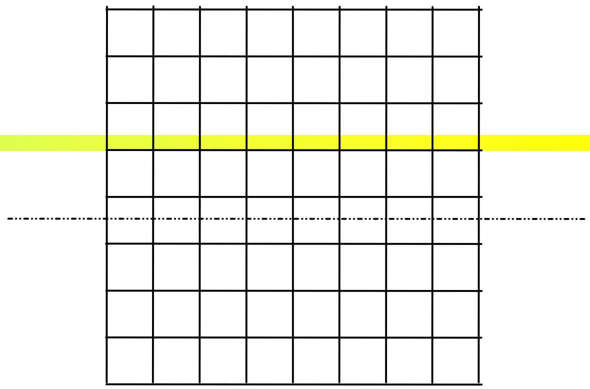
good uniformity over most of the surface



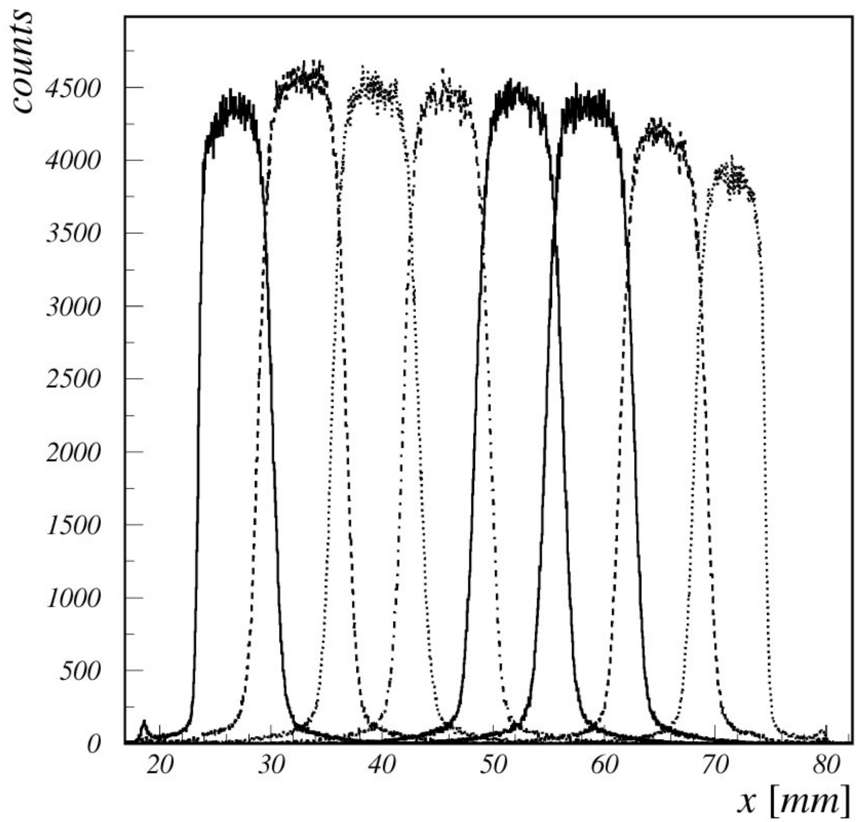
large deviation at active area edge

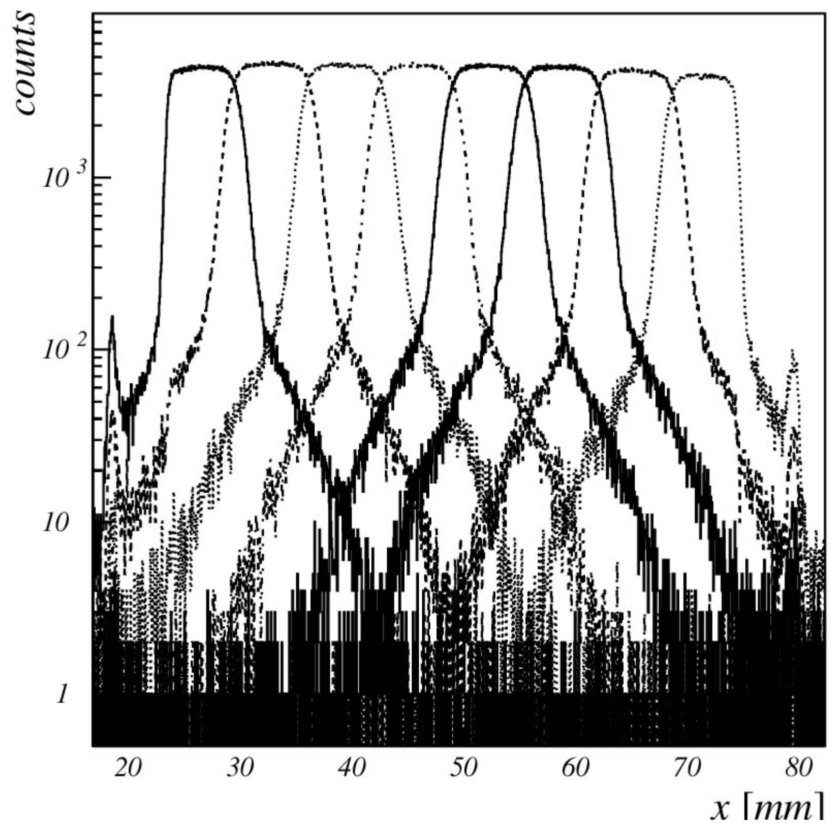
small deviation at pad boundaries

MCP with 8x8 pads: detection vs. x



- Number of detected signals vs. x
- Small variation over central part



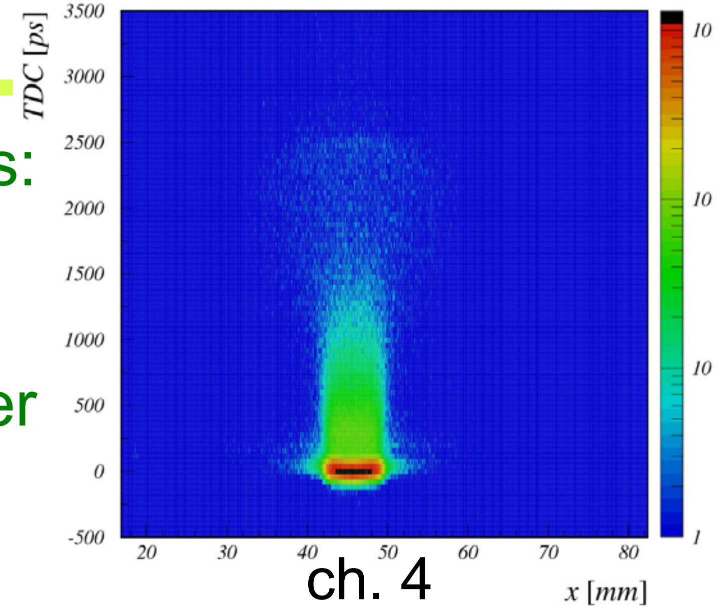


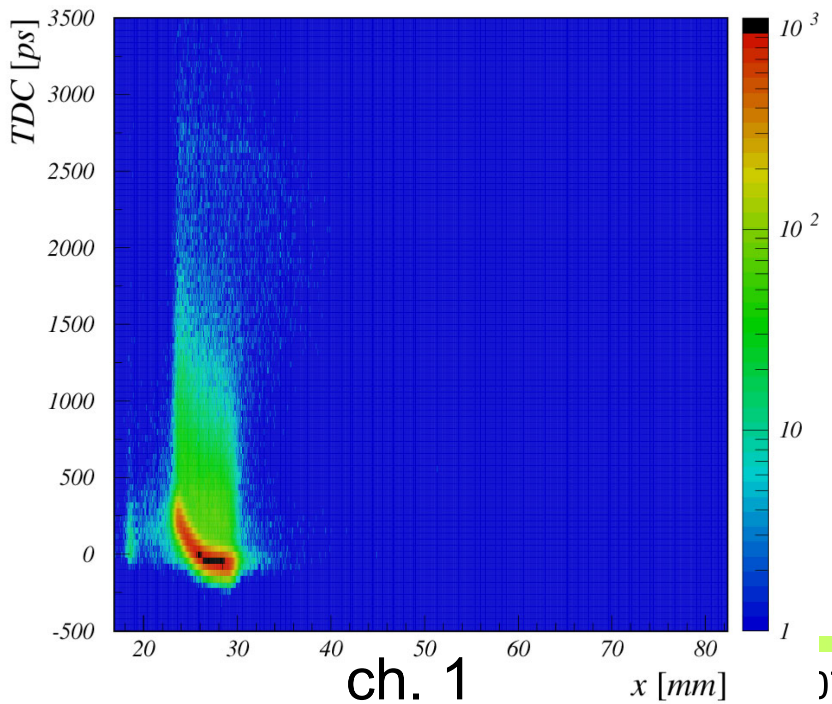
Response similar to 2x2 MCP PMT: charge sharing and long tails due to photo-electron back-scattering.

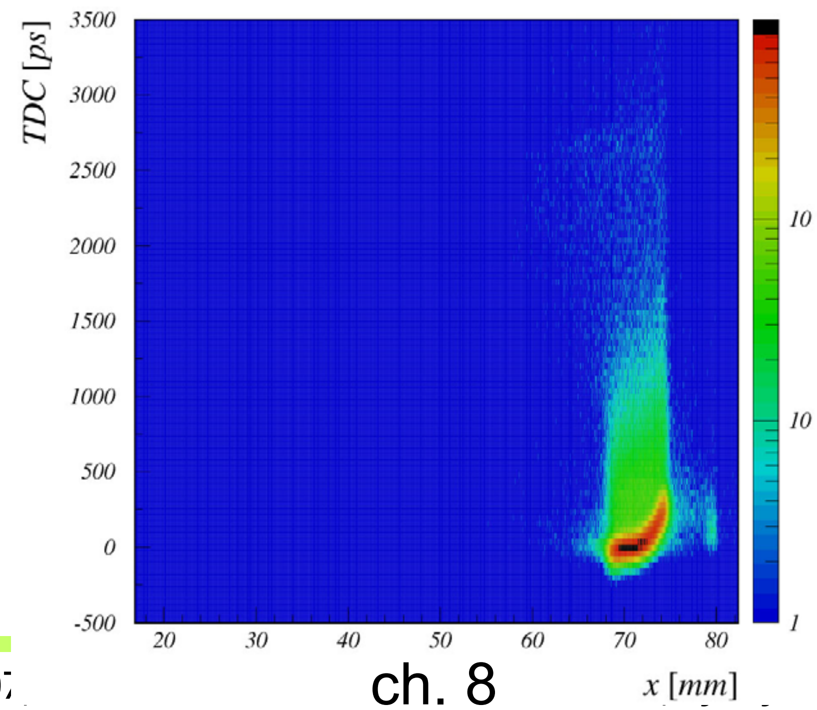
8x8: Timing uniformity for single pads

TDC vs. x correlation of single pads: same features as for the 2x2 tube

- uniform for central pads
- large variation for pads at the outer edges of the tube



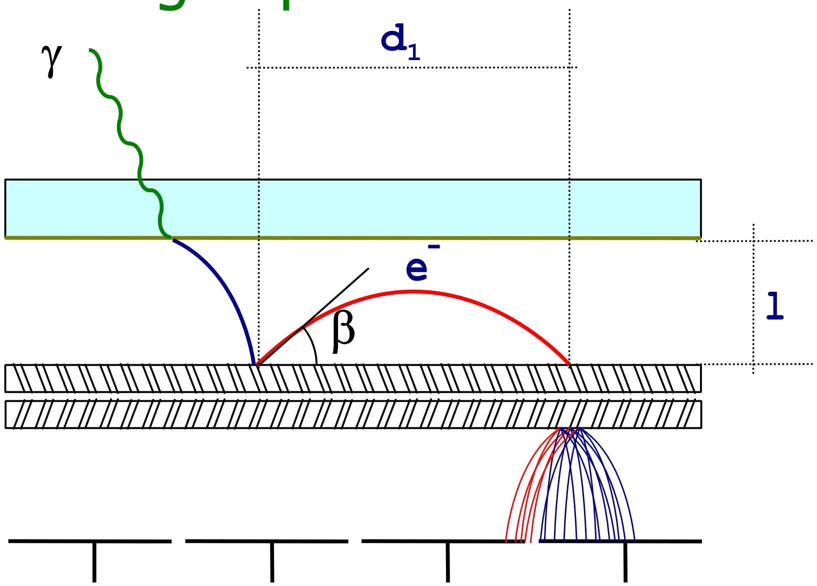




Conclusions

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)

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

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

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

Next: determine their influence on the position resolution and time resolution

Still some work to do...

- Read-out electronics (wave-form sampling, G. Varner?)
- Ageing studies
- Cost estimate...