Univerza v Ljubljani

Impact of timing and cross-talk properties of Burle MCP PMTs on counter performace – status report

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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.

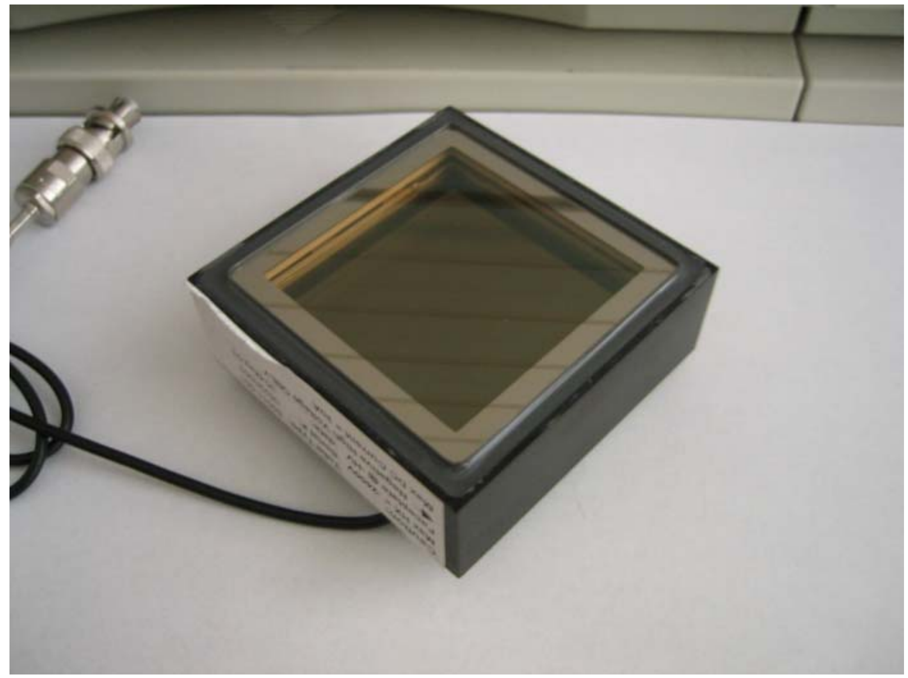
Additional bench tests needed: study detailed timing properties and cross-talk.

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

Basic parameters of BURLE MCP-PMTs

Both tubes with 6mm photocathode to MCP distance

- 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



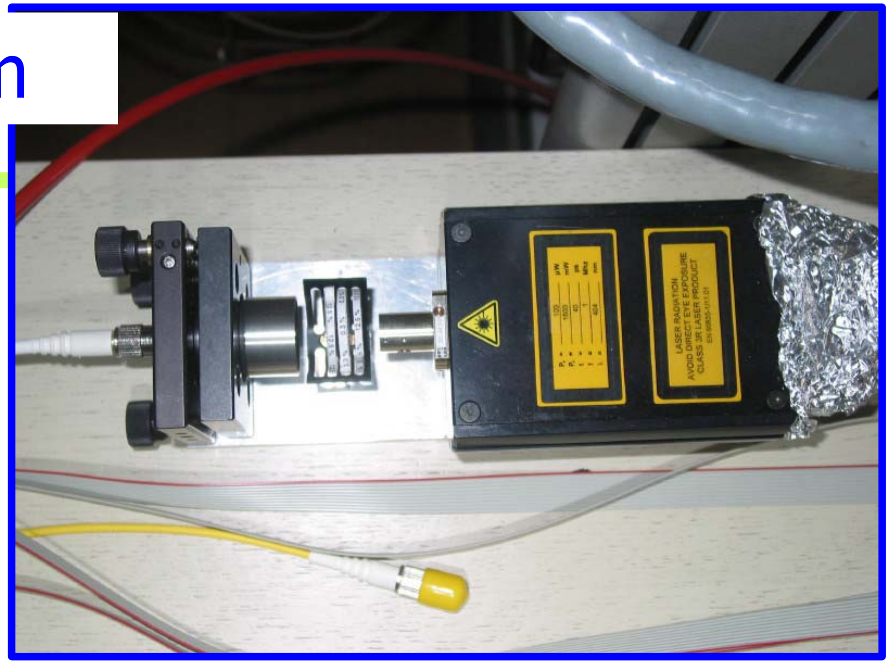
BURLE 85011 MCP-PMT

- 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

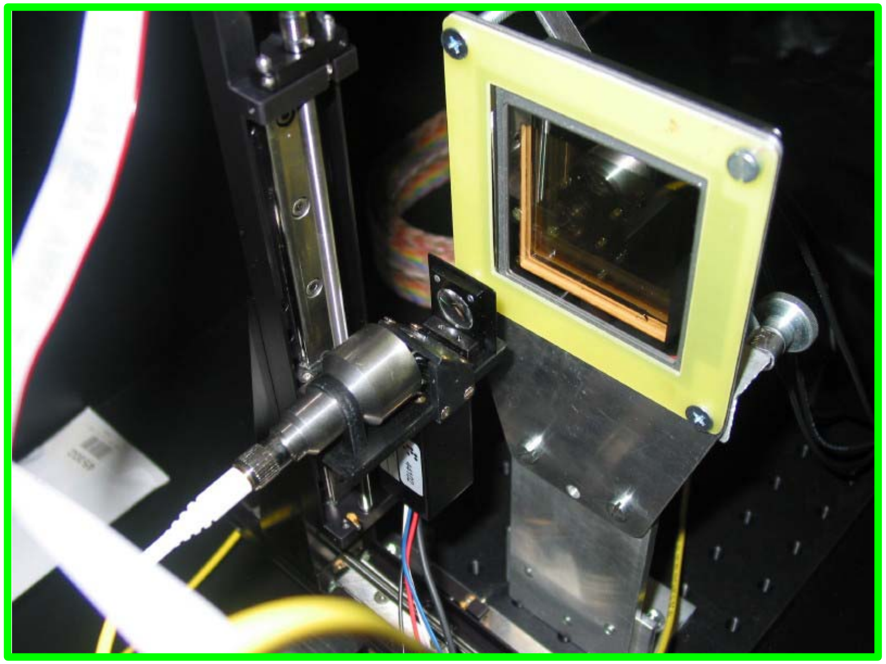
Scanning setup: optical system



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:

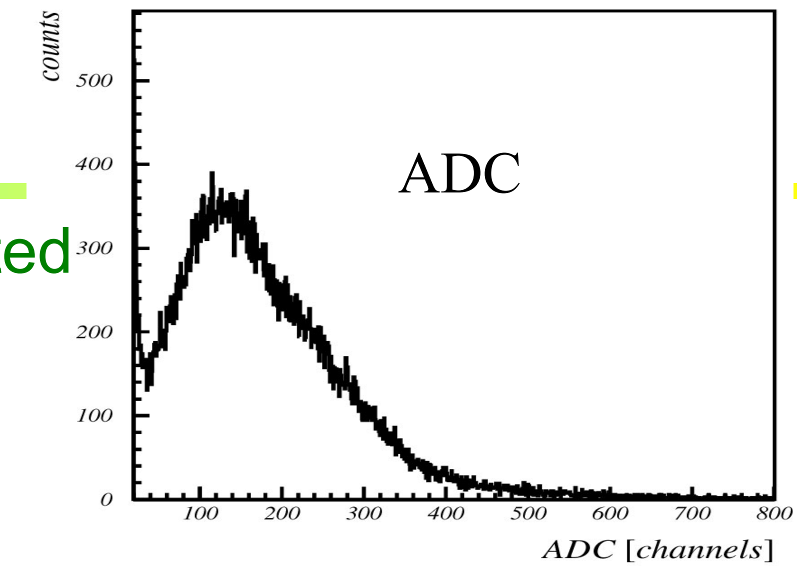
- optical fiber coupler (expanding)
- semitransparent plate
- reference PMT (Hamamatsu H5783P)
- focusing lens (spot size σ ~ 10μm)

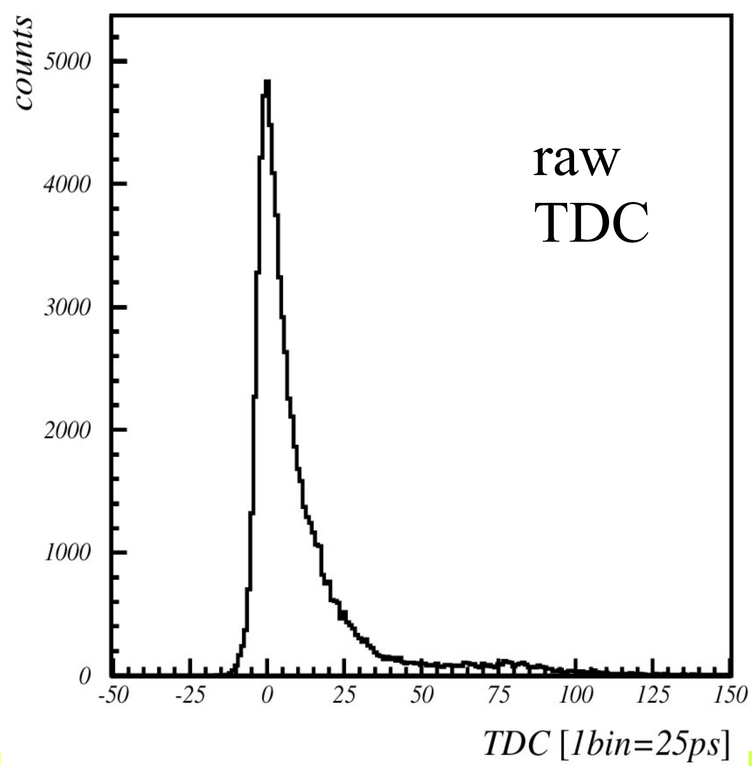
Time walk correction

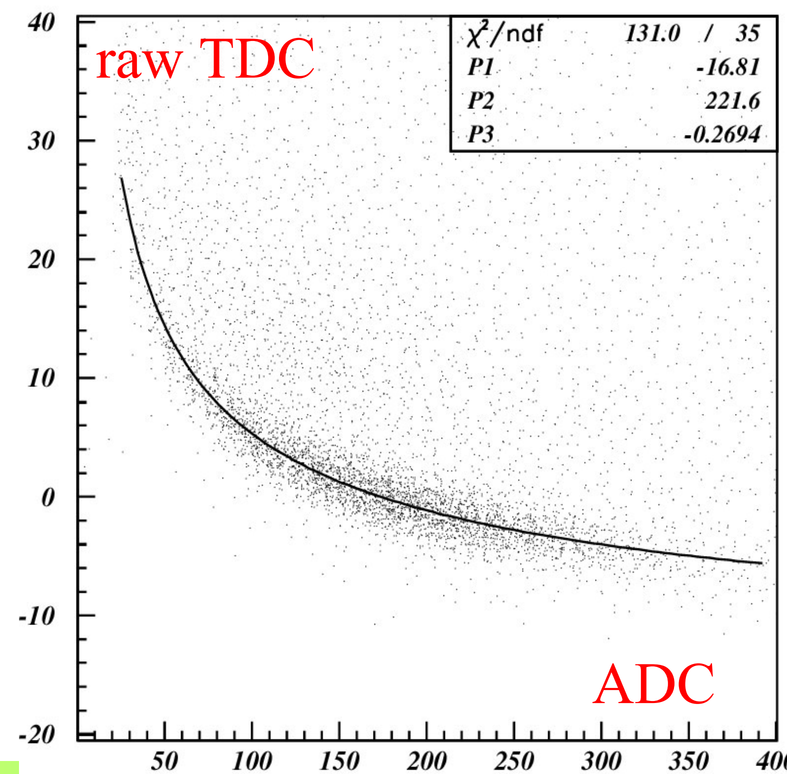
TDC vs. ADC correlation is fitted with

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

and used for TDC correction

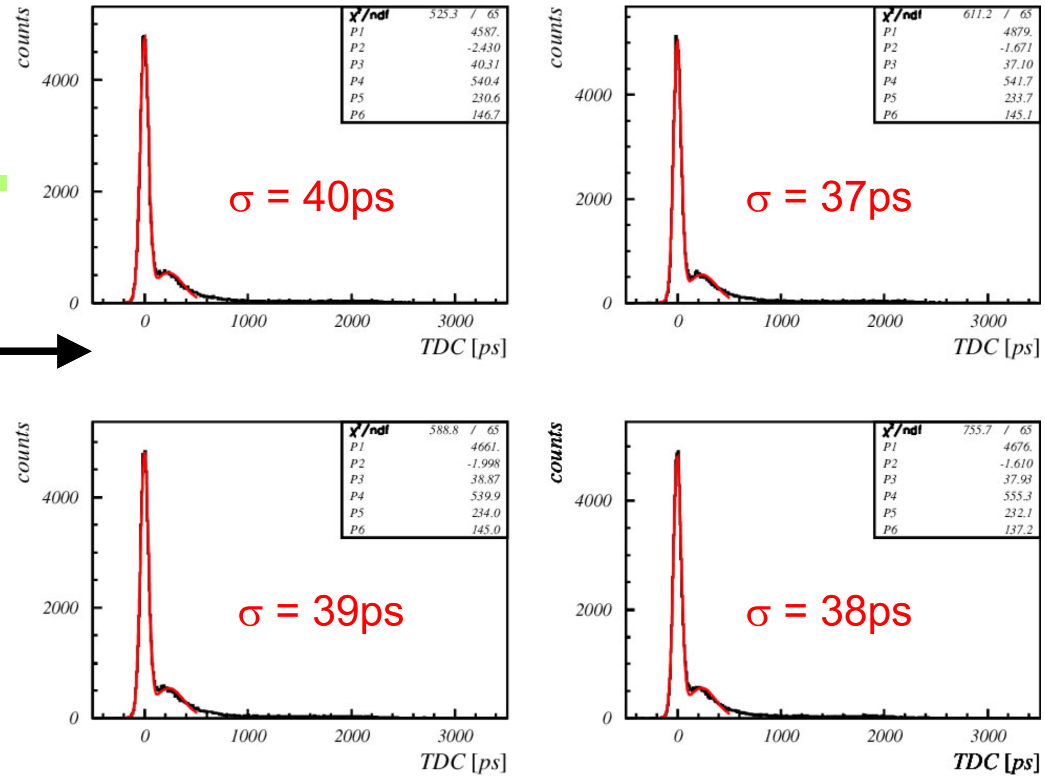


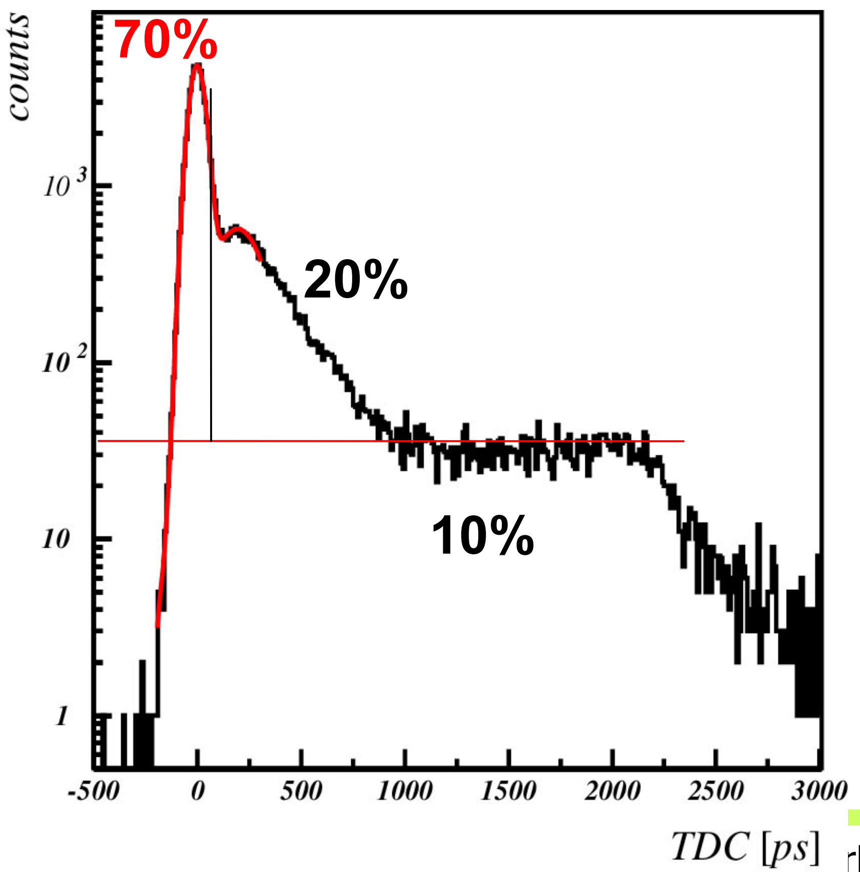




Corrected TDC

Corrected TDC distributions for all pads





Response:

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

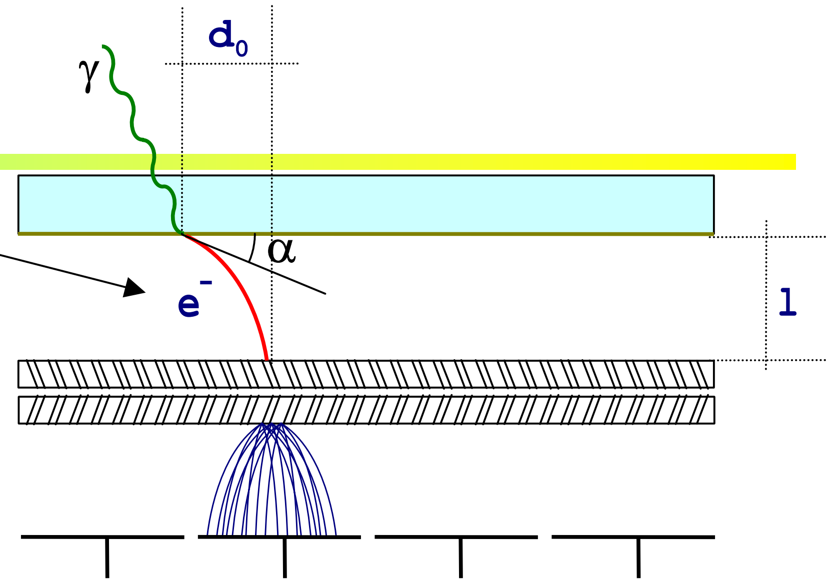
Photon electron detection: modeling

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:

- $d_{0,max}$ ~ 0.8 mm
- t_0 ~ 1.4 ns
- Δt_0 ~ 100 ps



Backscattering:

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

Charge sharing

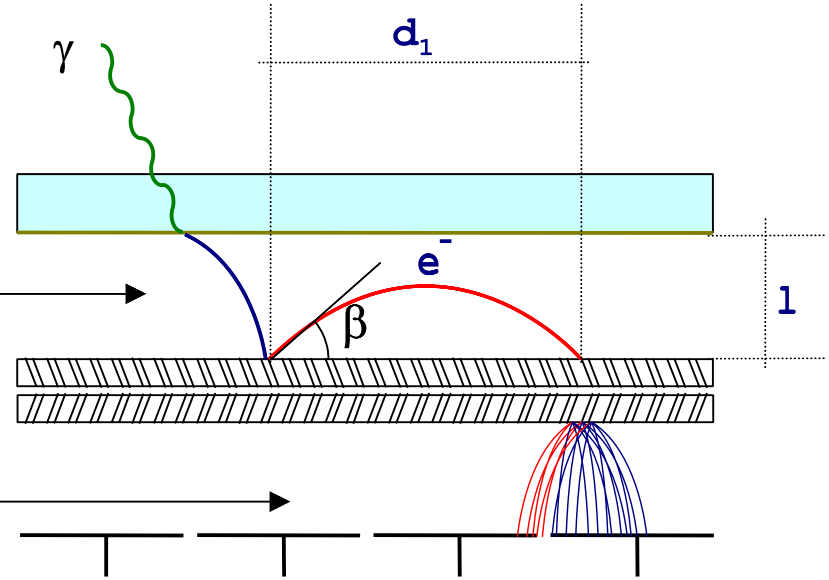
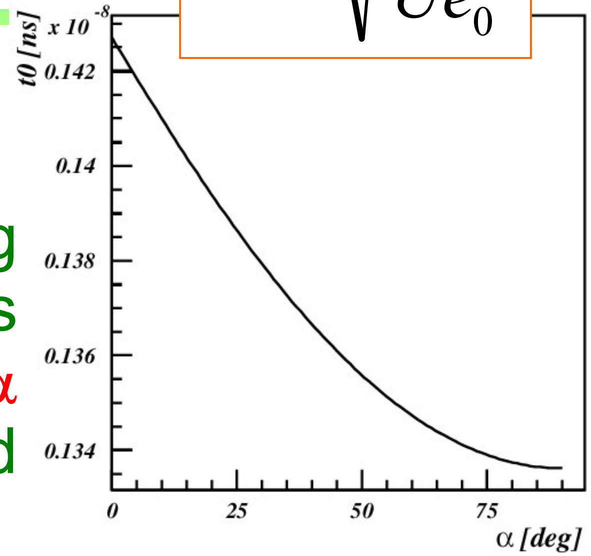
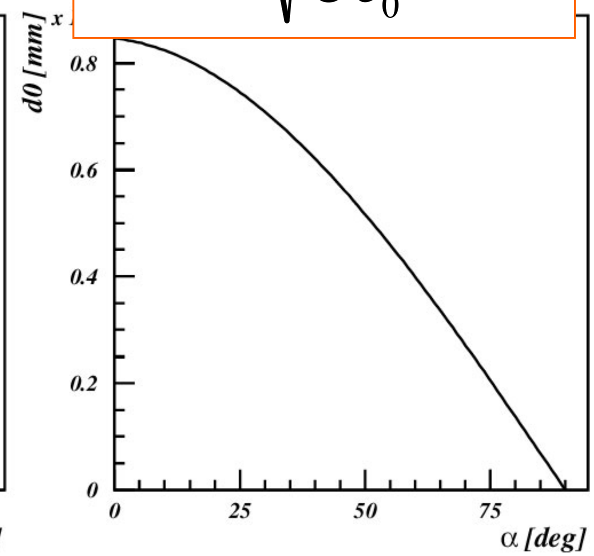


Photo-electron: simple estimates

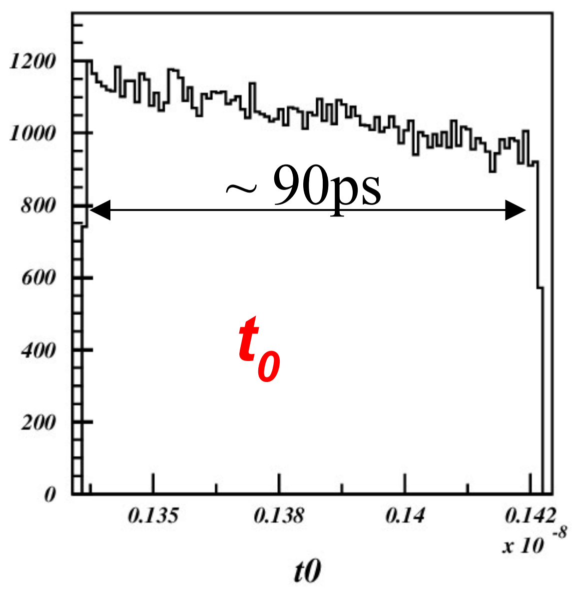
$$t_0 \approx l\sqrt{\frac{2m_e}{Ue_0}}$$

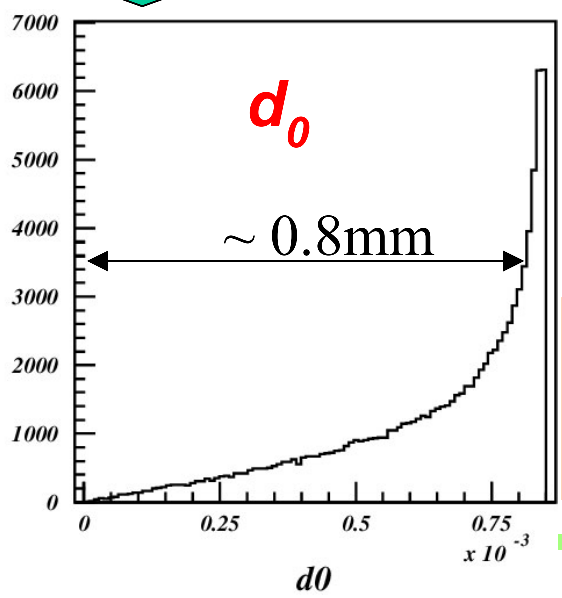
$$d_0 \approx 2l\sqrt{\frac{E_0}{Ue_0}}\cos\alpha$$





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





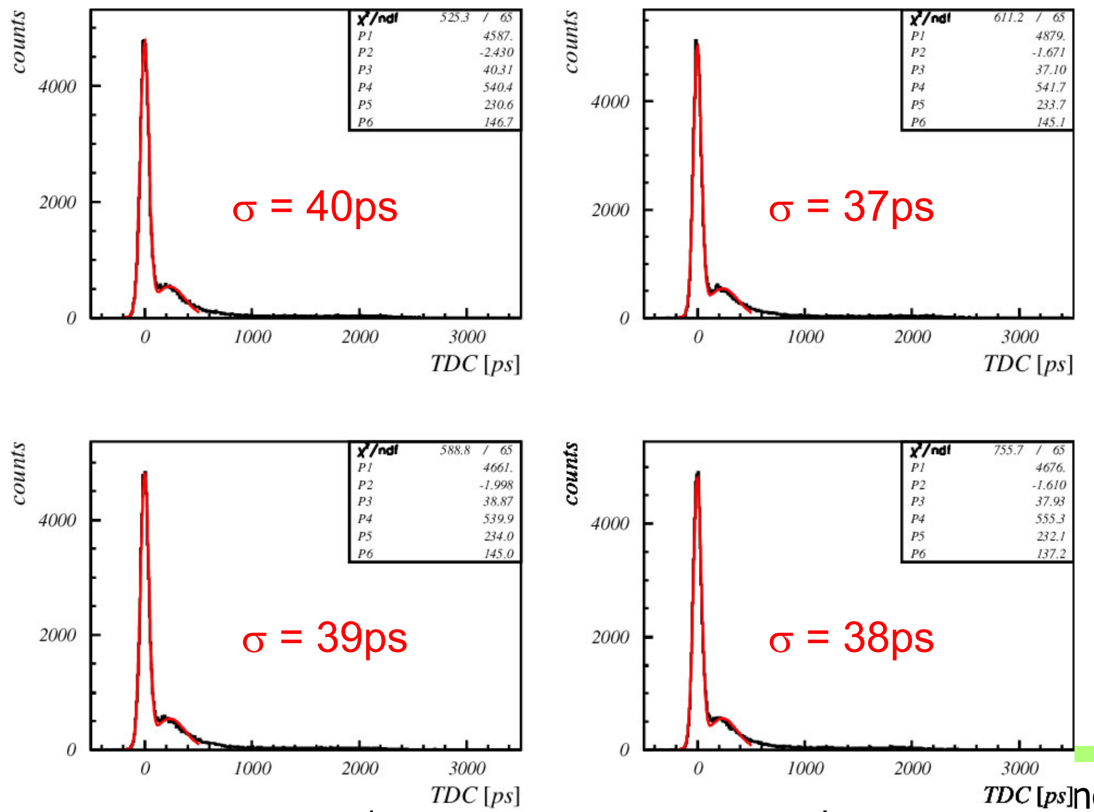
Maximum variation of photo-electron travel time.

$$\Delta t_0 \approx t_0\sqrt{\frac{E_0}{Ue_0}} \approx \frac{l}{Ue_0}\sqrt{2m_eE_0}$$

Timing resolution, contributions

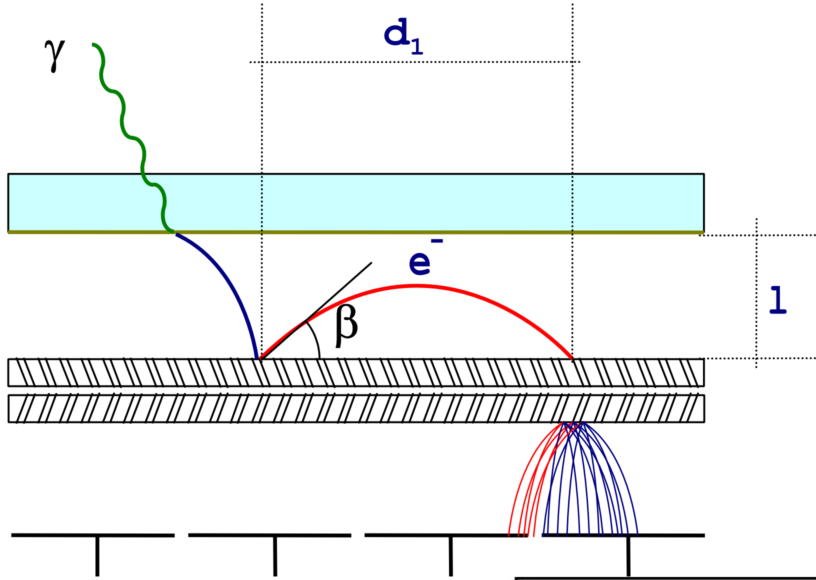
- Laser: 15ps (rms)
- Electronics: 12ps (rms)
- TTS of photo-electron (blue): 90ps/sqrt(12) = 26ps (rms)

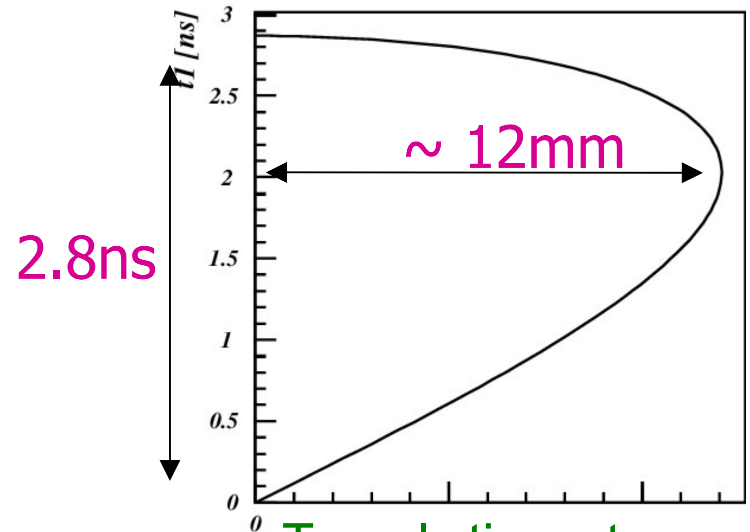
Sum in squares: 32ps → very close to 37-40ps



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

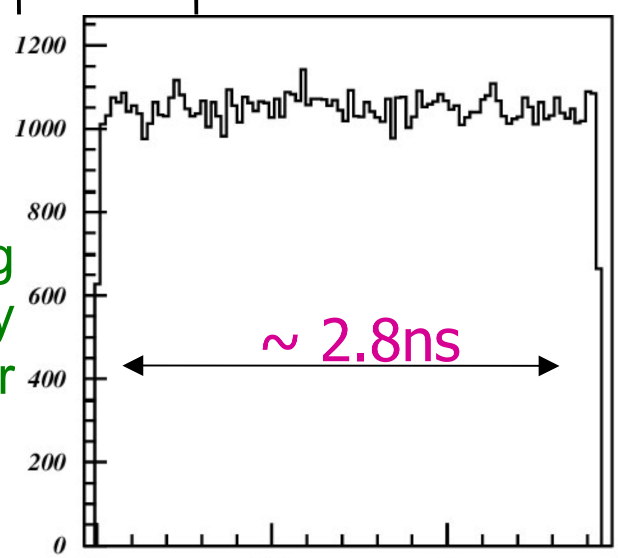
Elastic back-scattering



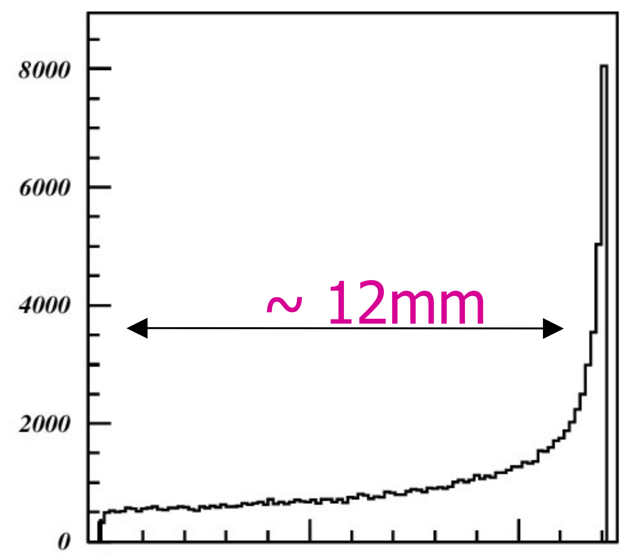


Travel time t_1 vs. travel distance d_1

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



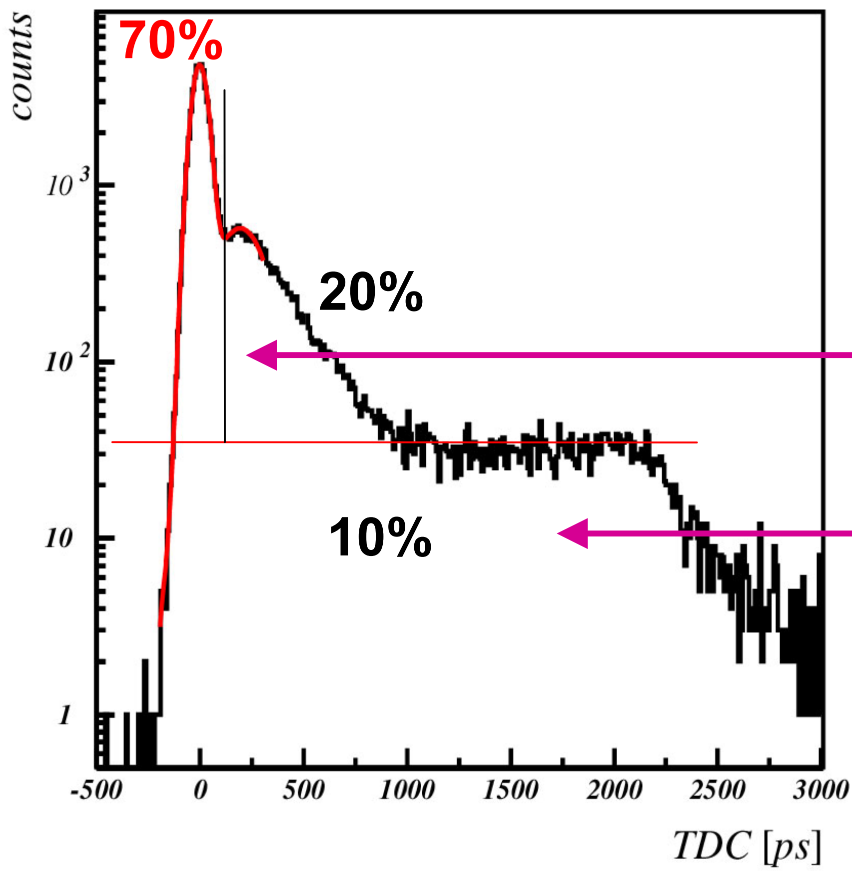
$$t_1 \approx 2 t_0 \sin \beta$$



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

Understanding time-of-arrival distribution

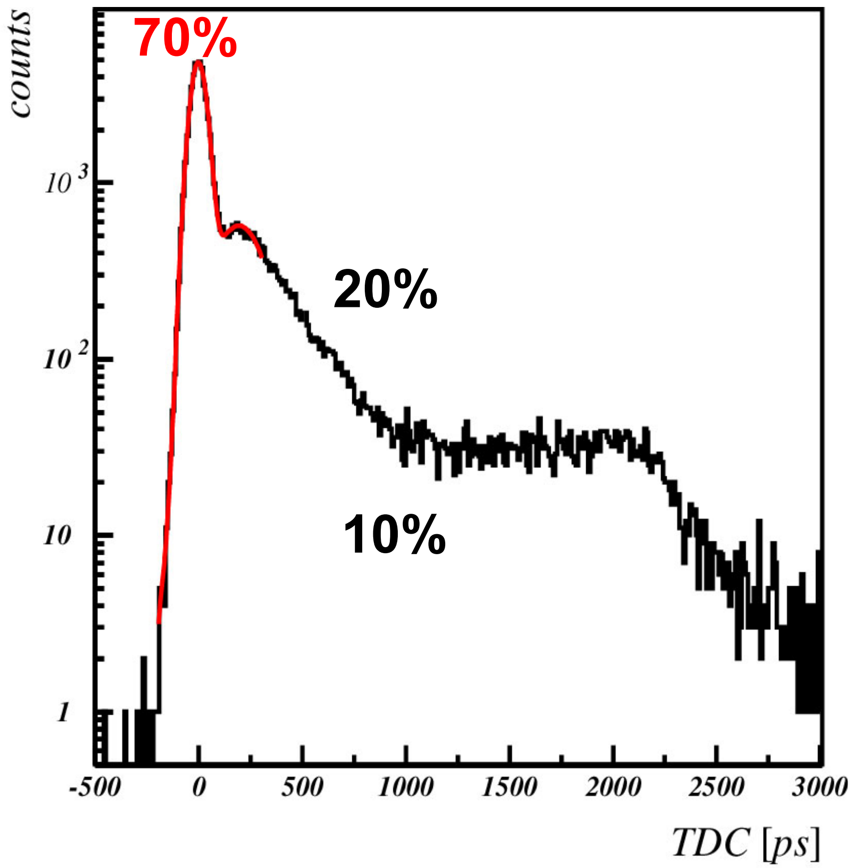
Normal photo-electrons



Inelastically scattered photo-electrons?

Elastically scattered photo-electrons

Time-of-arrival resolution



Resolution for single photons: rms of the TDC distribution = 450ps

→with N independent time measurements

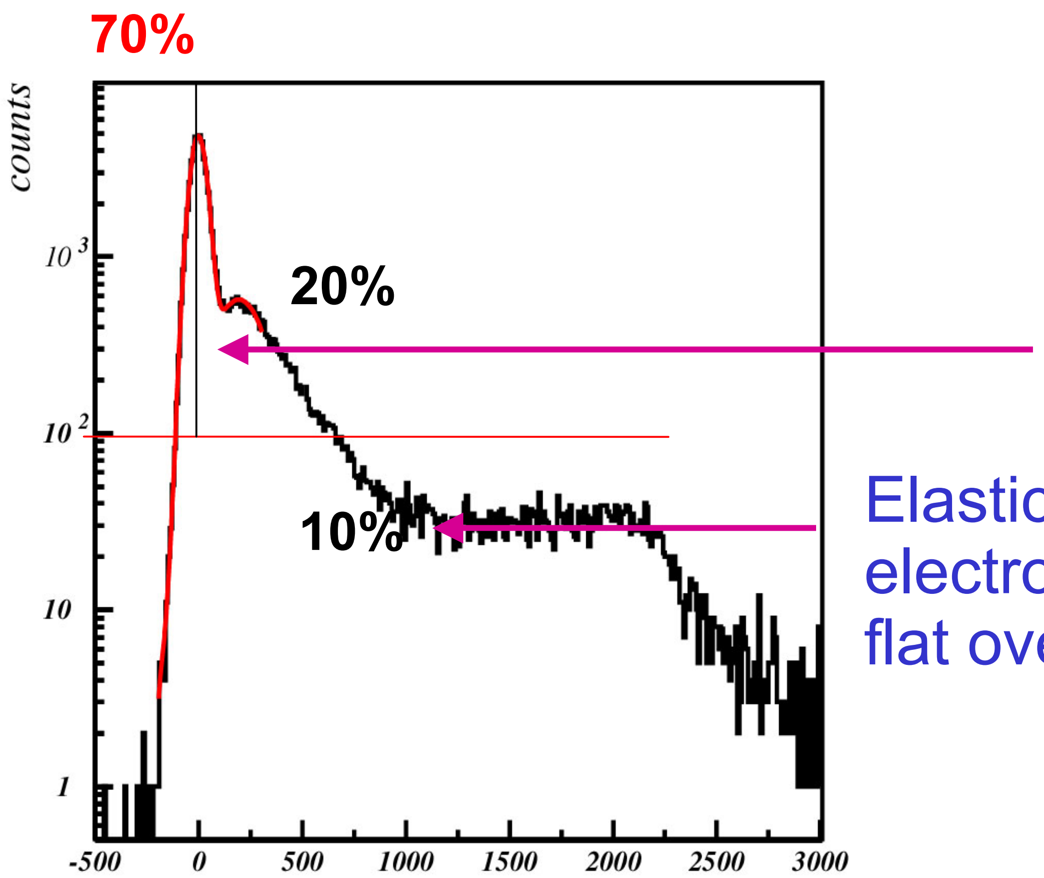
σ=450ps/sqrt(N)

=45ps for N=100!

Could be improved just like for dE/dx, e.g., by using only the 'first' ones

What happens if a tube with d=1mm is used in B field?

Main peak: Δt_0 flat over 90ps/6=15ps → rms=4.5ps → probably negligible contribution to timing



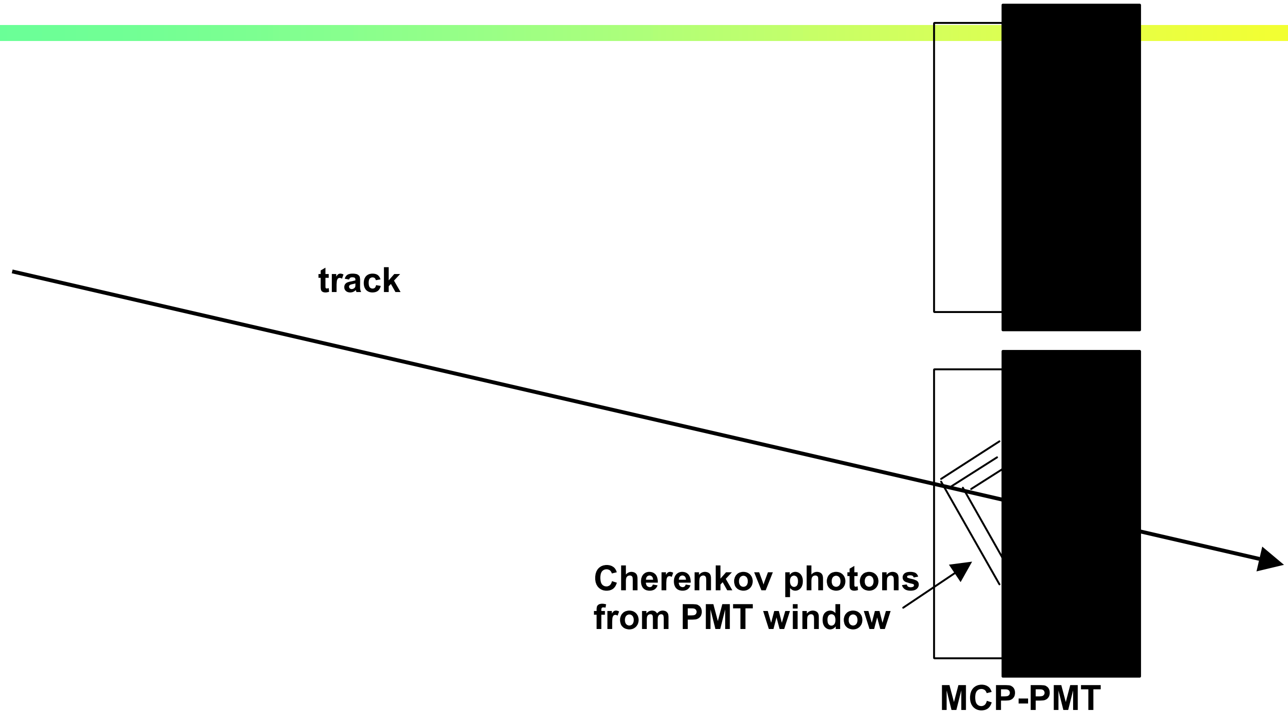
no effect of B field

Inelastically scattered photo-electrons?

Elastically scattered photo-electrons:
flat over 2.8ns/6~500s;

→rms of the TDC distribution 450ps → ~80ps, for N photons again use only the 'first' ones

Timing with hits in neighbouring channels

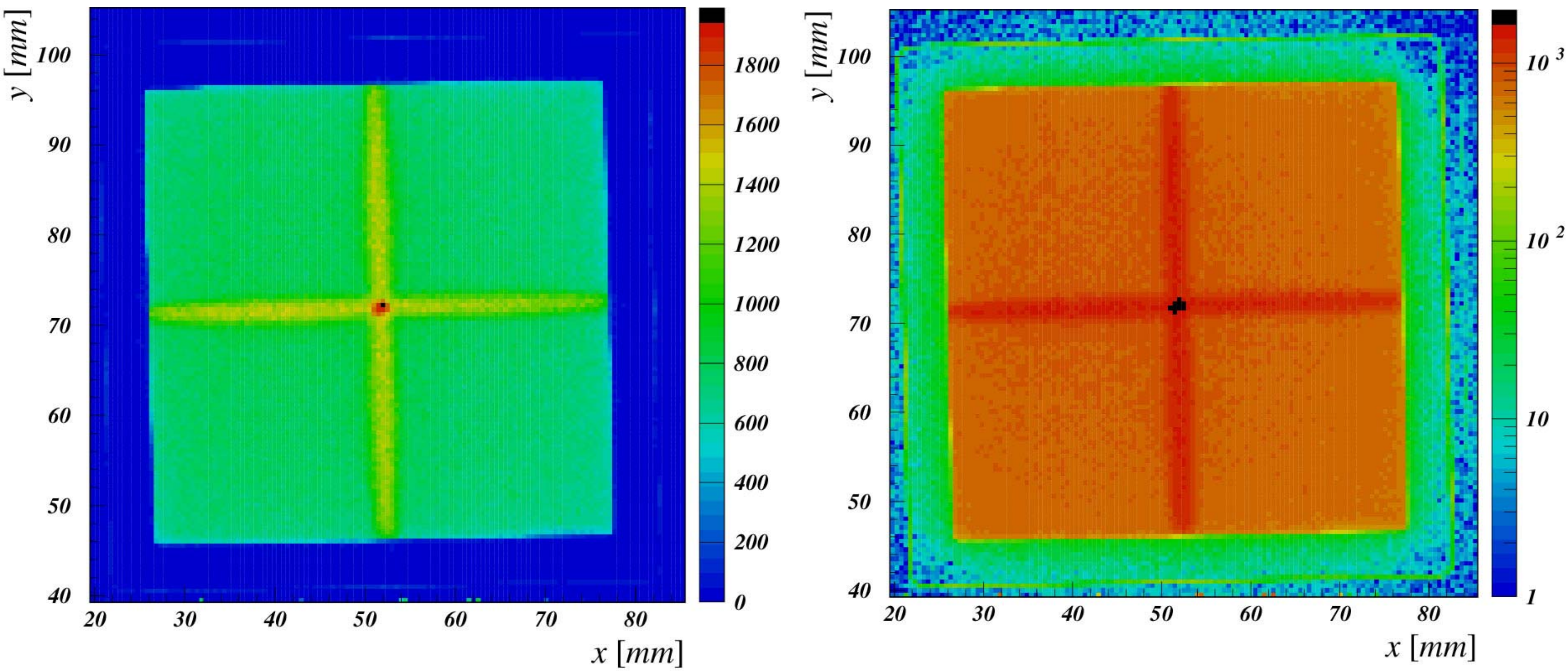


Typical situation in TOF measurements; not the same as multiphoton hits on a single pad.

A study is under way (measurements have already been done, but Samo did not manage to analyze the data yet), and we shall report about the results next time.

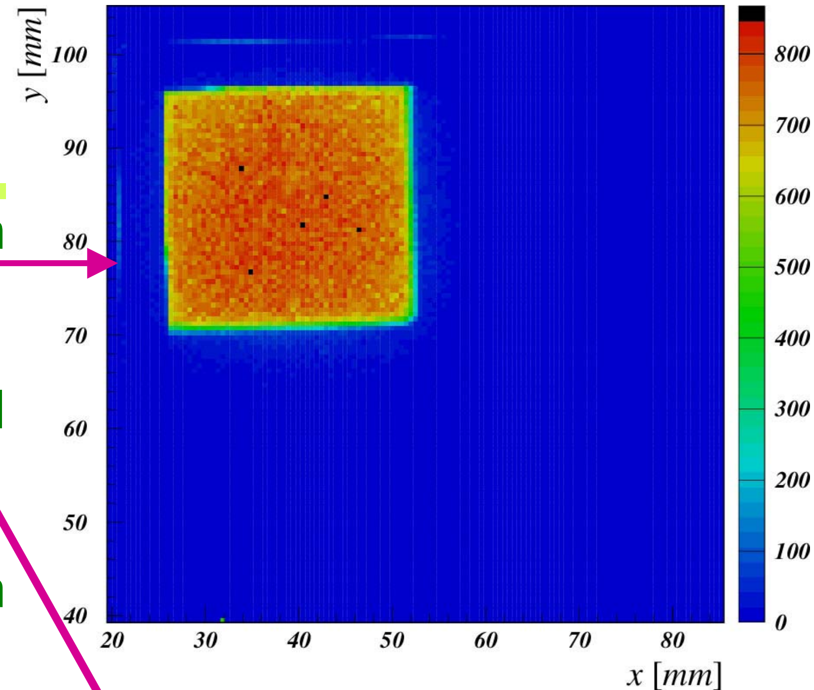
Photon detection uniformity

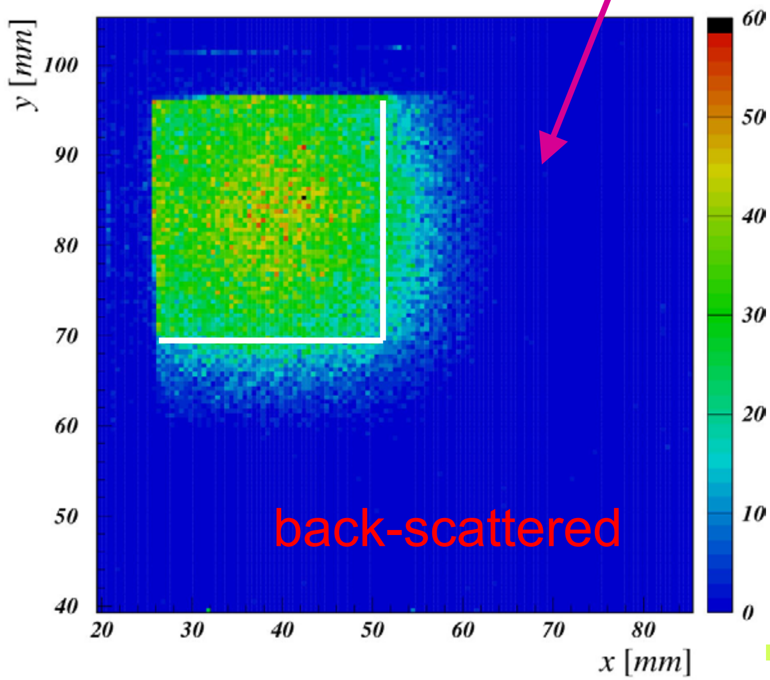
- Number of detected events at different positions of light spot – sum of all 4 channels
- double counting at pad boundaries due to charge sharing

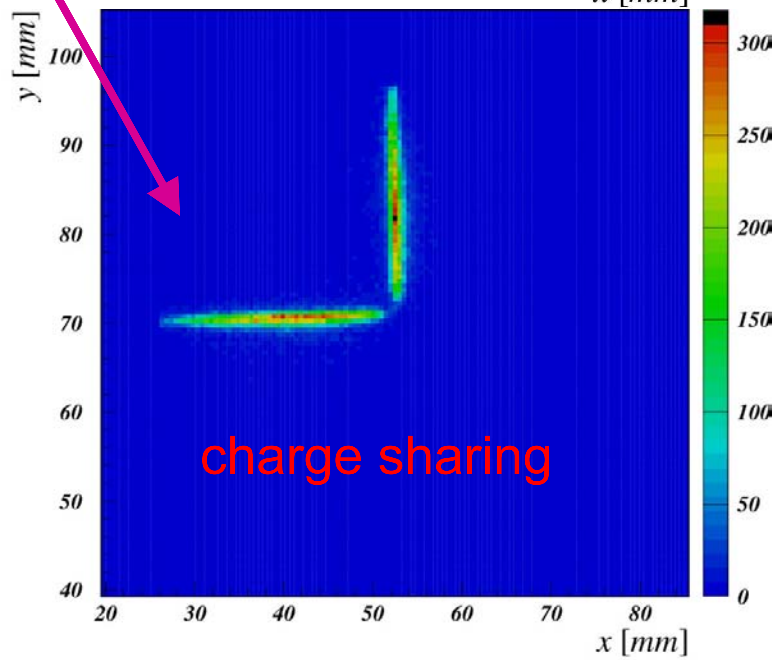


Photon detection response – single pad

- 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

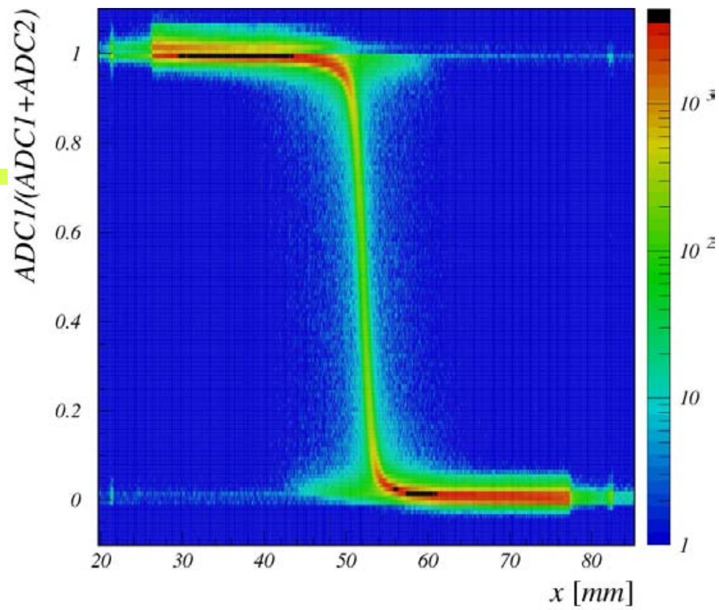


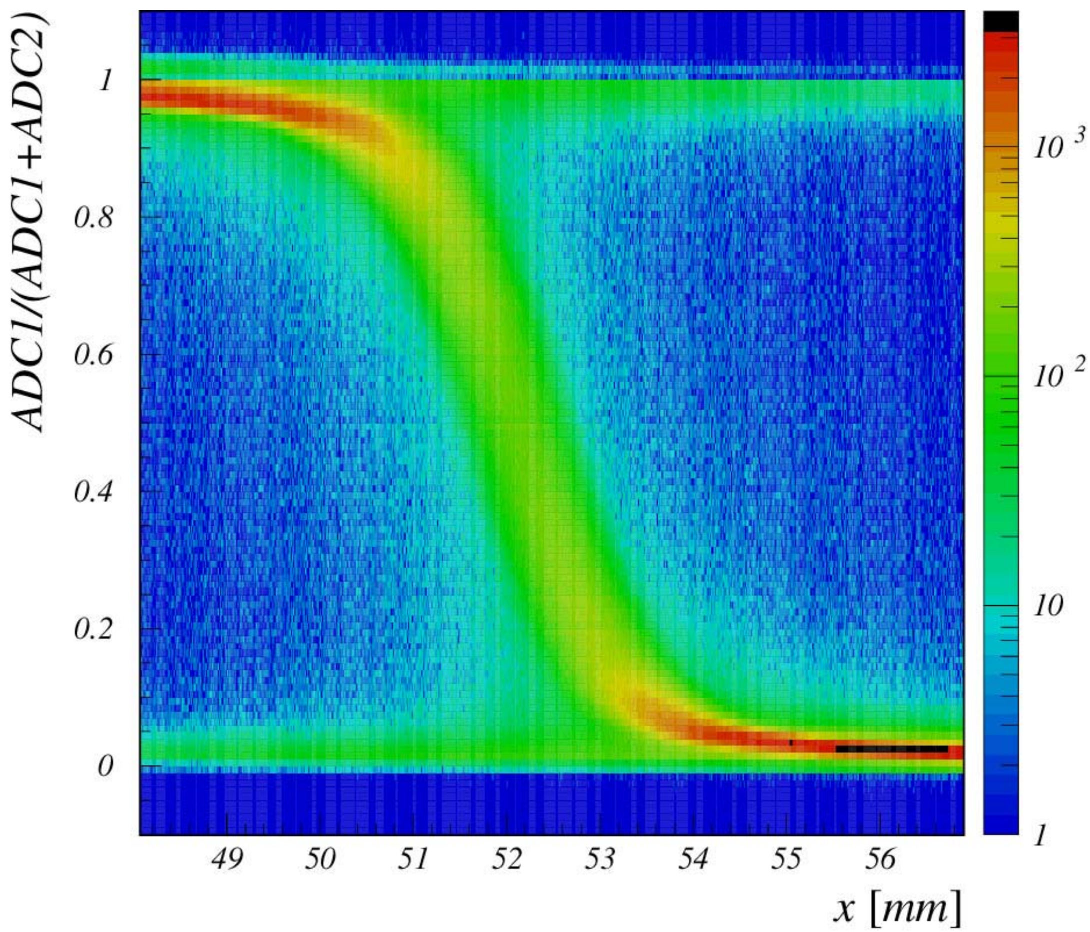




Charge sharing

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

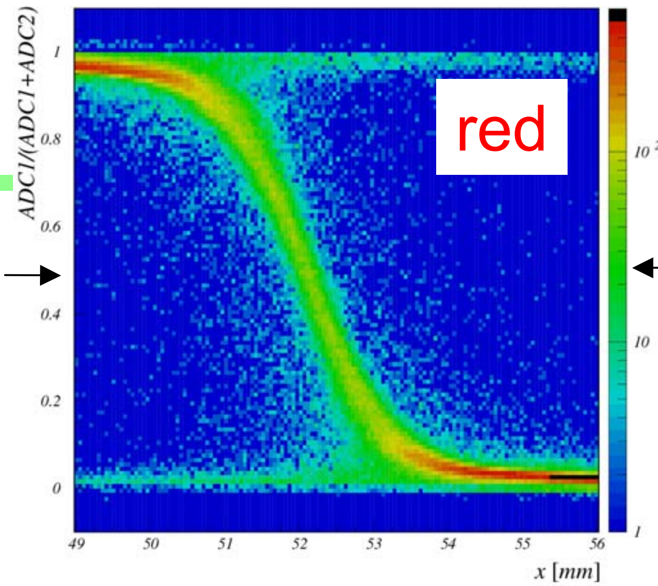


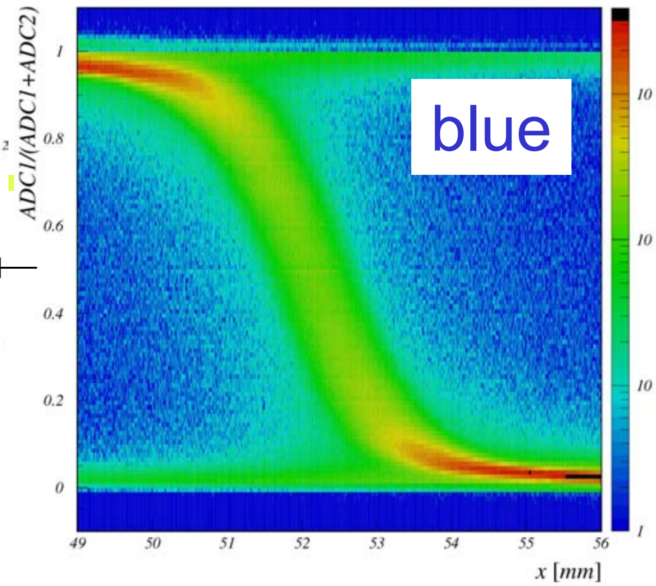


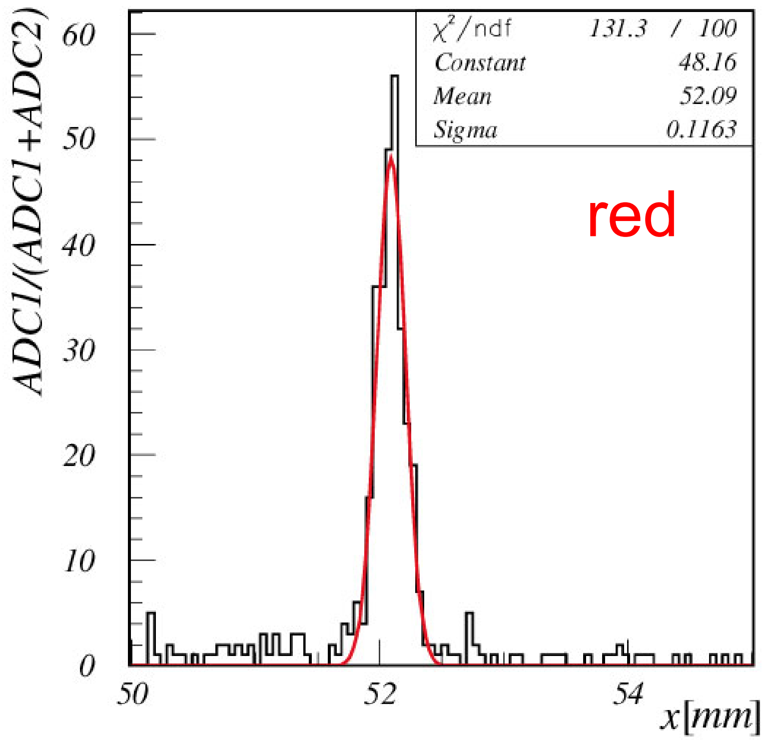
- sizable charge sharing in ~2mm wide boundary area
- can be used to improve position resolution

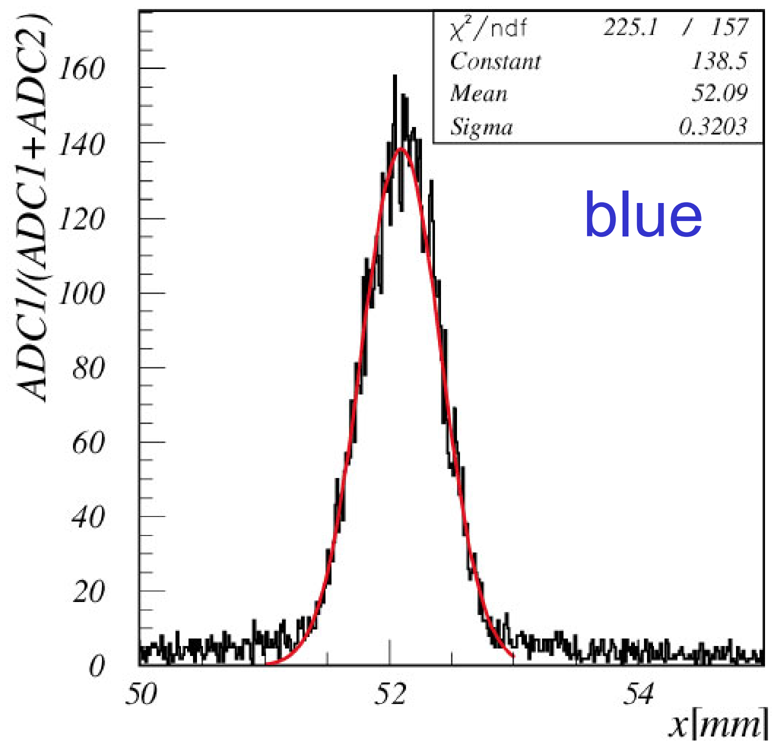
Charge sharing

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

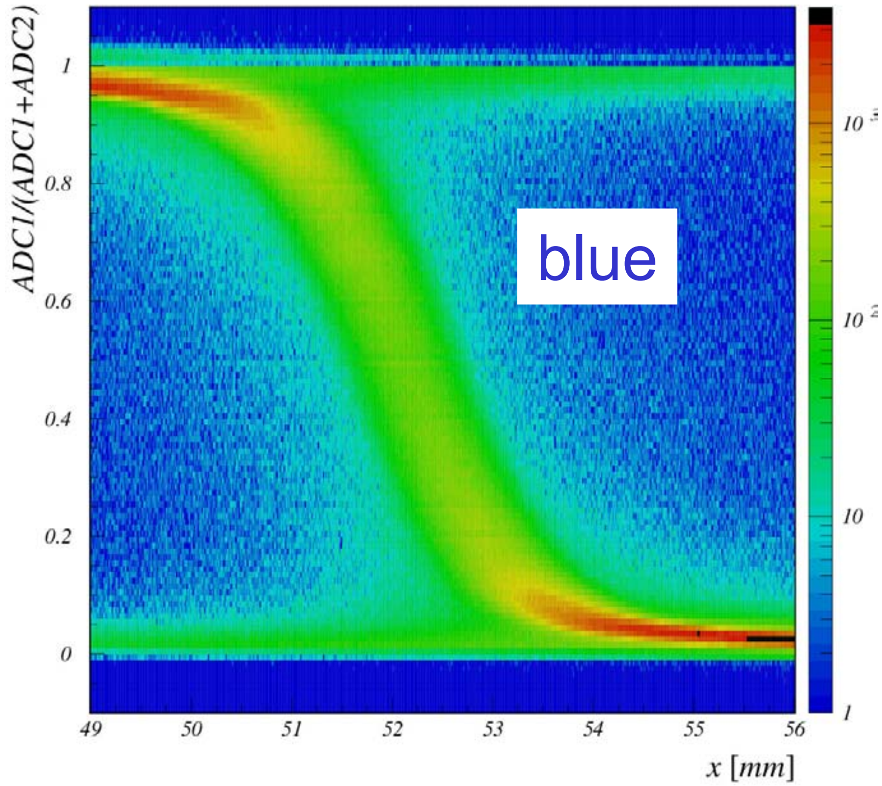
Charge sharing impact on photon impact point resolution

Charge sharing over +-2mm around teh boundary → can be used to improve the resolution for a sizeable fraction of the detector.

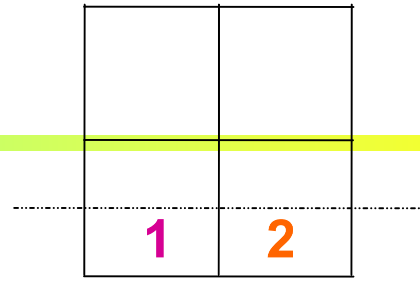
Ultimate resolution: depends on the color, 0.3mm for blue.

Smaller d: even better!

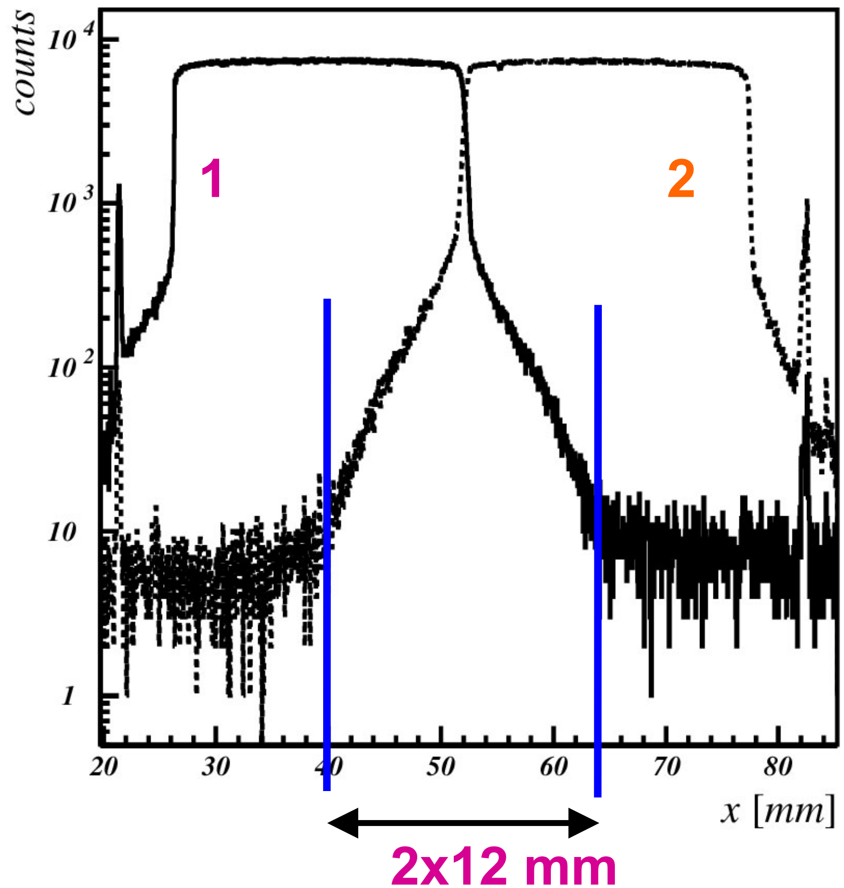
Magnetic field: even better! But: charge sharing area becomes smaller. This can be further tuned by the voltage at the last step.



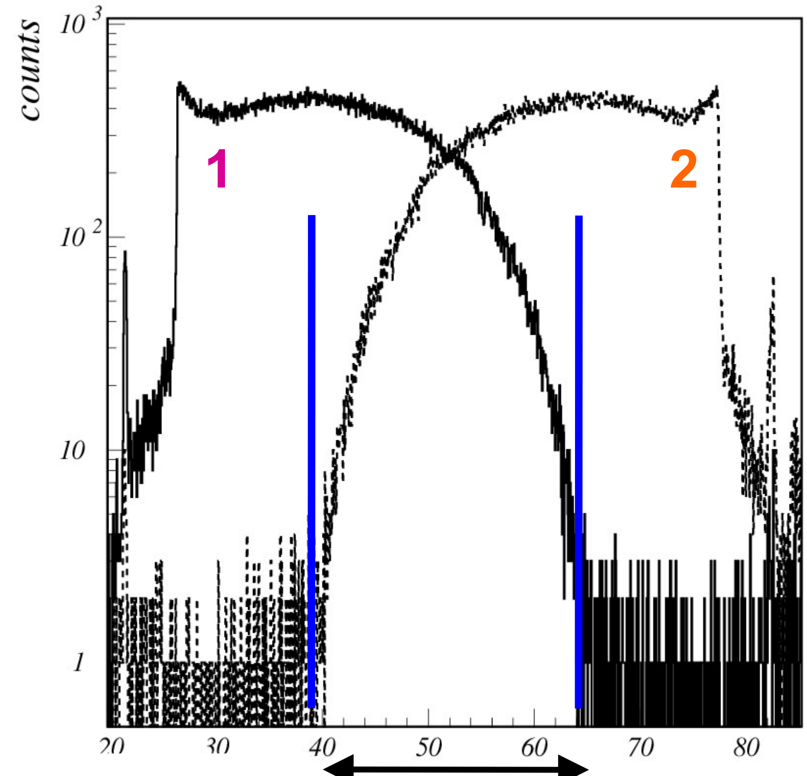
Detailed 1D scan



all events with maximum signal on channels 1 and 2



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



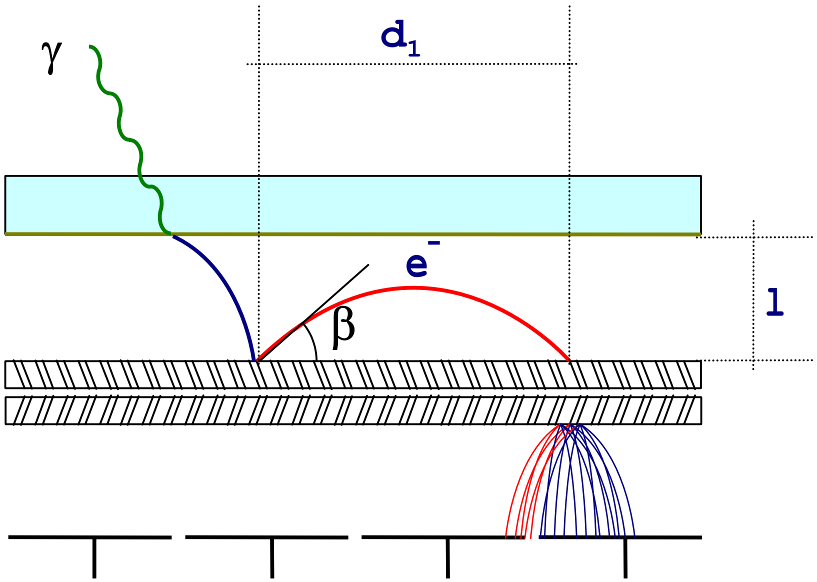
= range of back-scatterd photo-electrons

2x12 mm

What happens if a tube with d=1mm is used in B field?

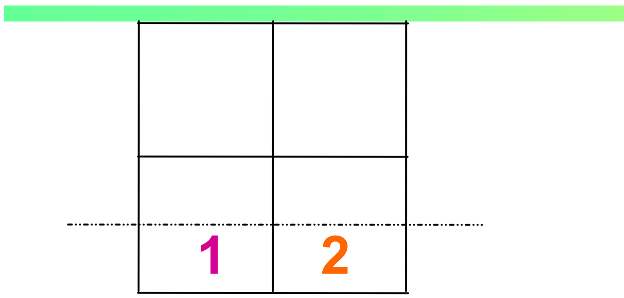
Back-scattering range depends on the

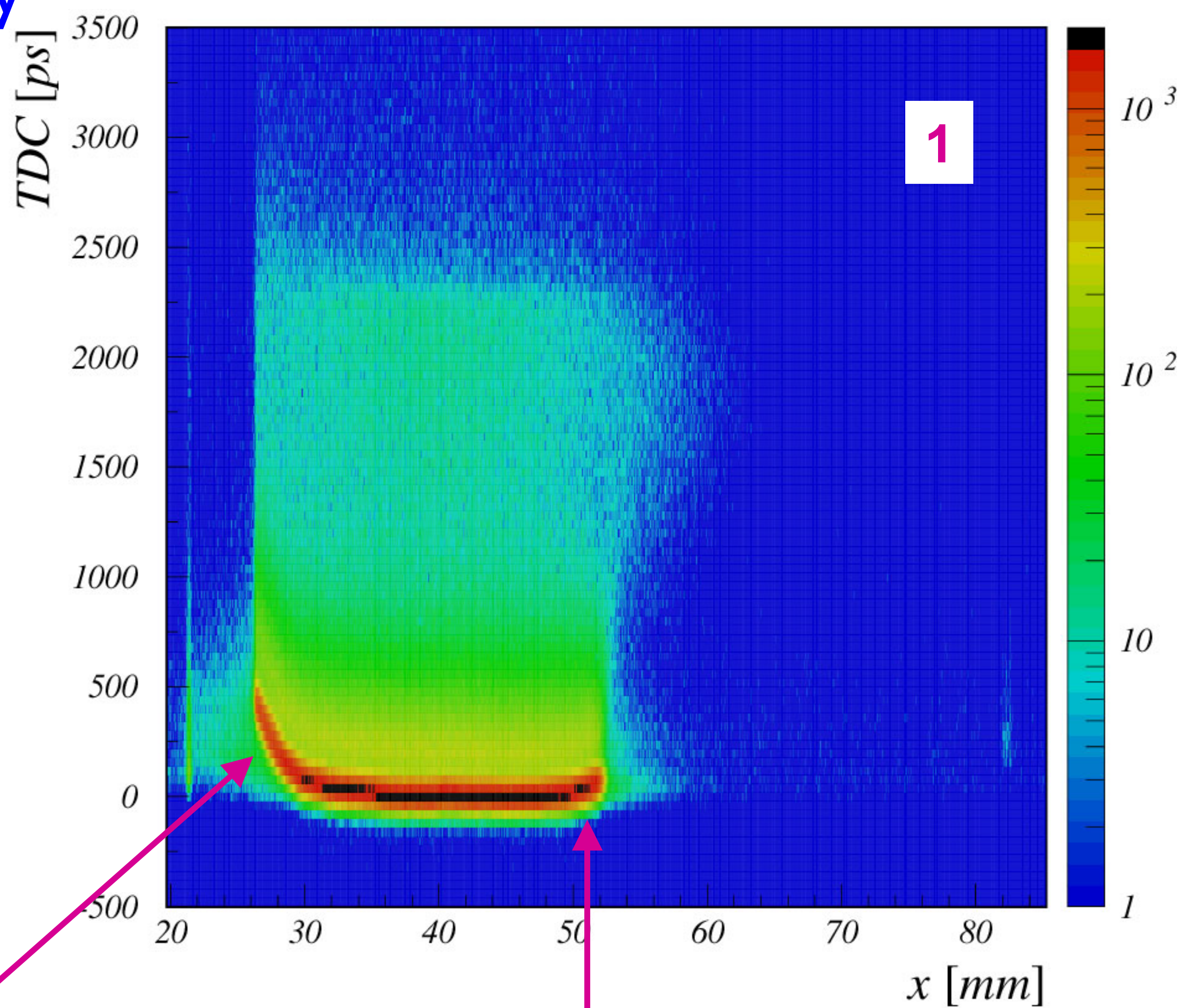
- photocathode-MCP plate distance
- photocathode-MCP plate voltage
- magnetic field



→ Back-scattering range will be drasticaly reduced in high B field

Timing uniformity





Time of arrival vs. x

good uniformity over
most of the surface

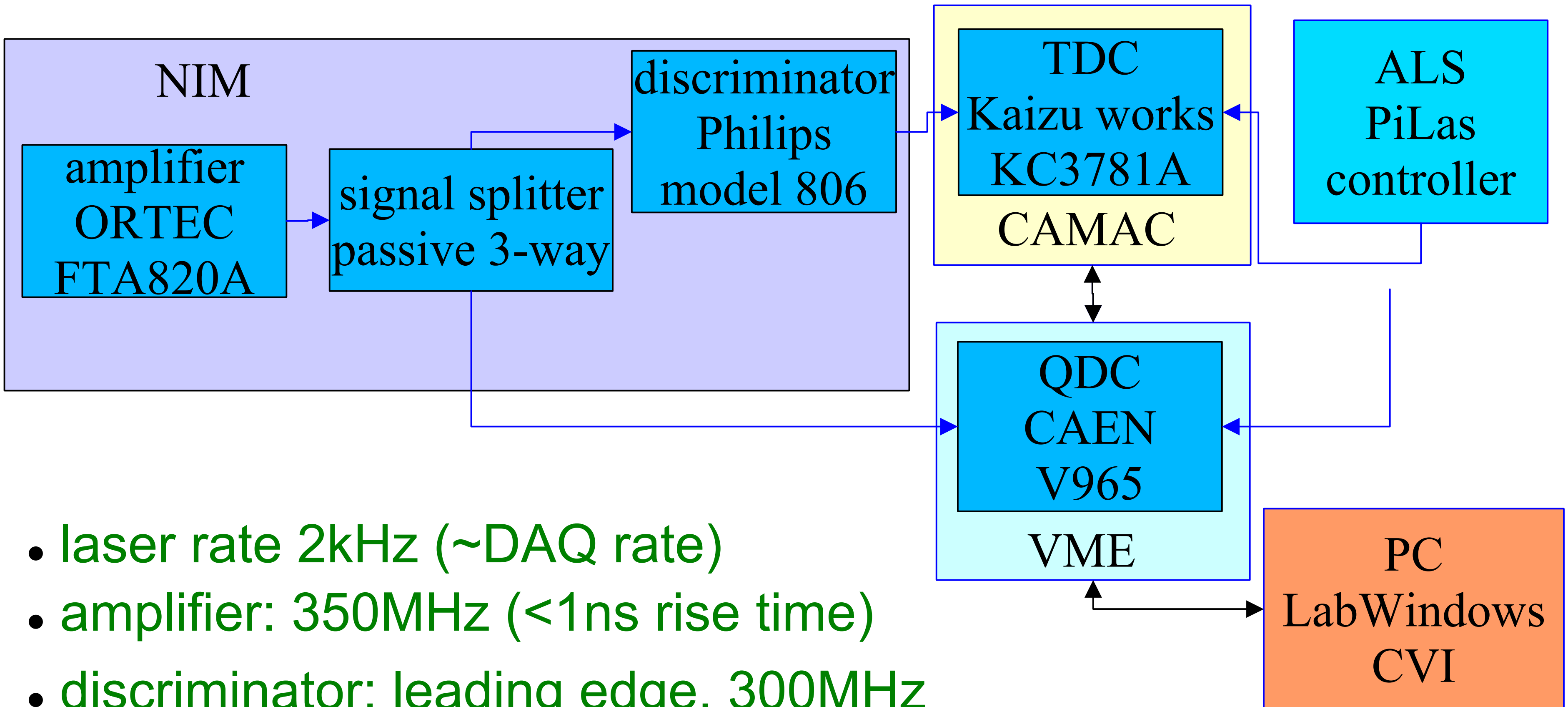
large deviation at active area edge

small deviation at pad boundaries

- → Not understood, need more tests, in particular in B field

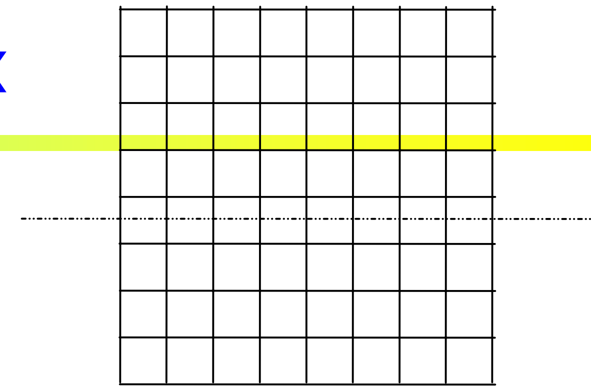
Back-up slides

Scanning setup: read-out

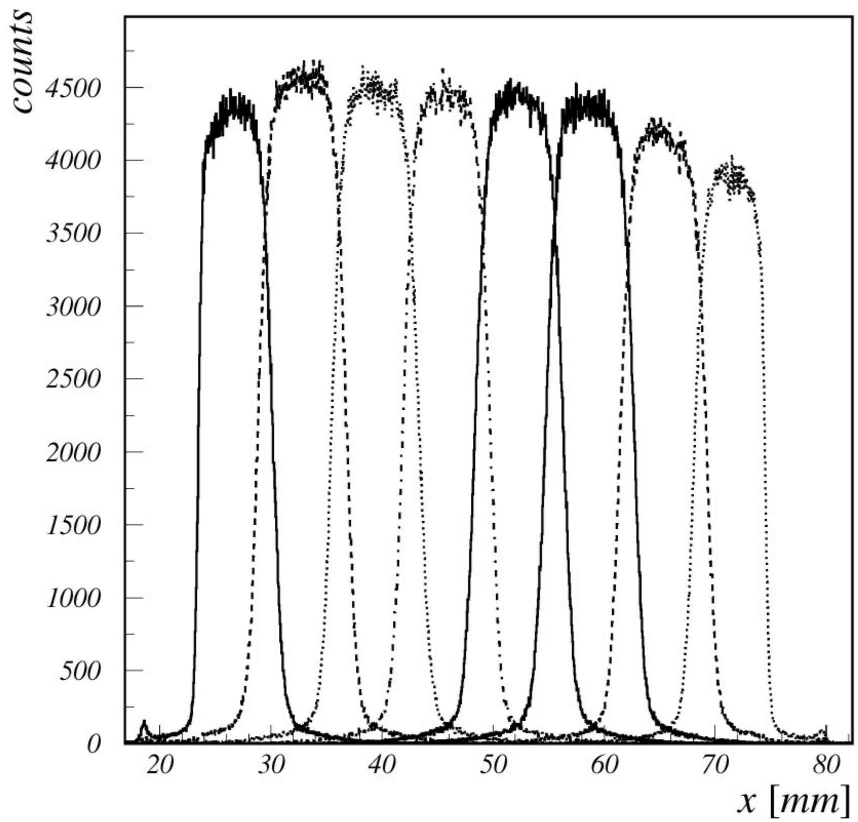


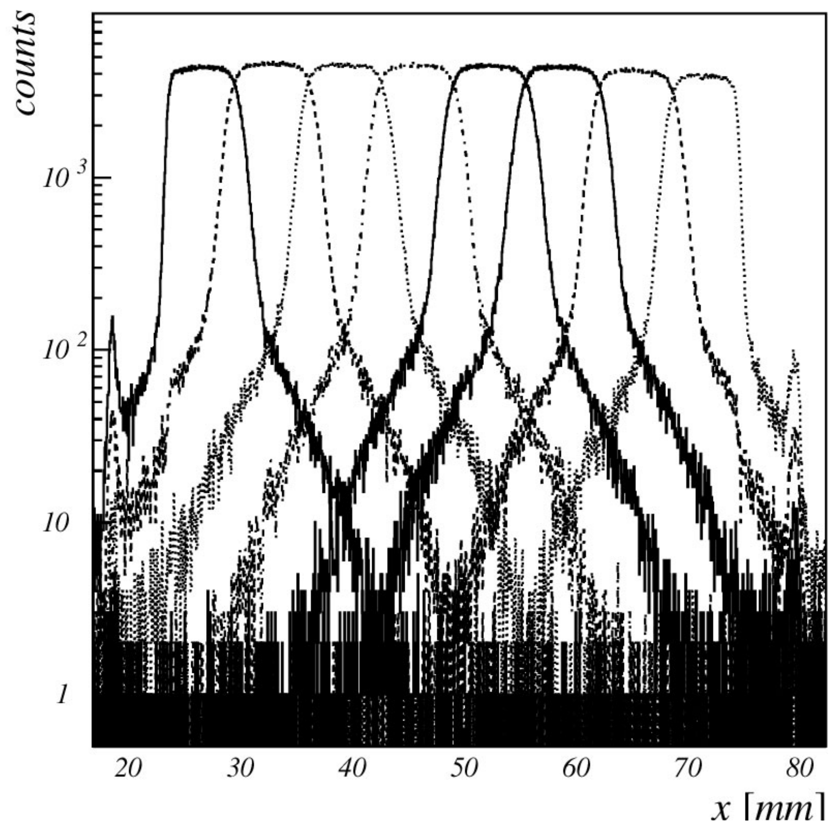
- laser rate 2kHz (~DAQ rate)
- amplifier: 350MHz (<1ns rise time)
- discriminator: leading edge, 300MHz
- TDC: 25ps LSB(σ~11ps)
- QDC: dual range 800pC, 200pC
- HV 2400V

MCP with 8x8 pads: detection vs. x



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



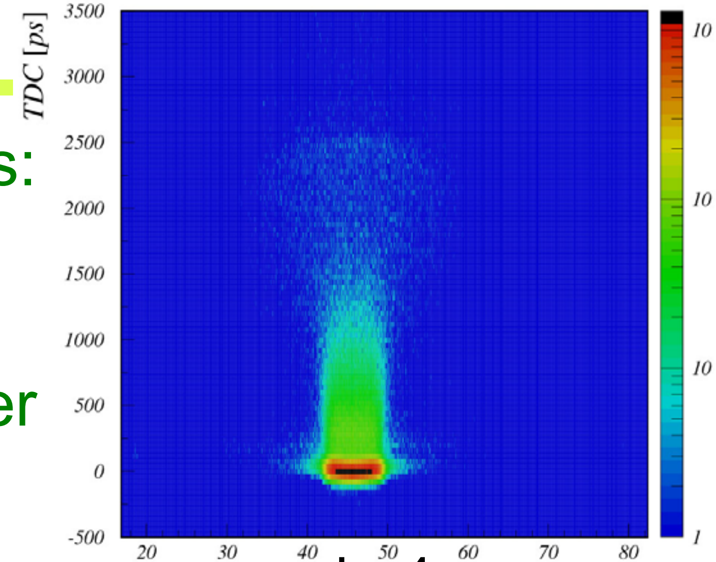


Response similar to 2x2 MCP PMT: charge sharing and long tails due to photo-electron back-scattering.

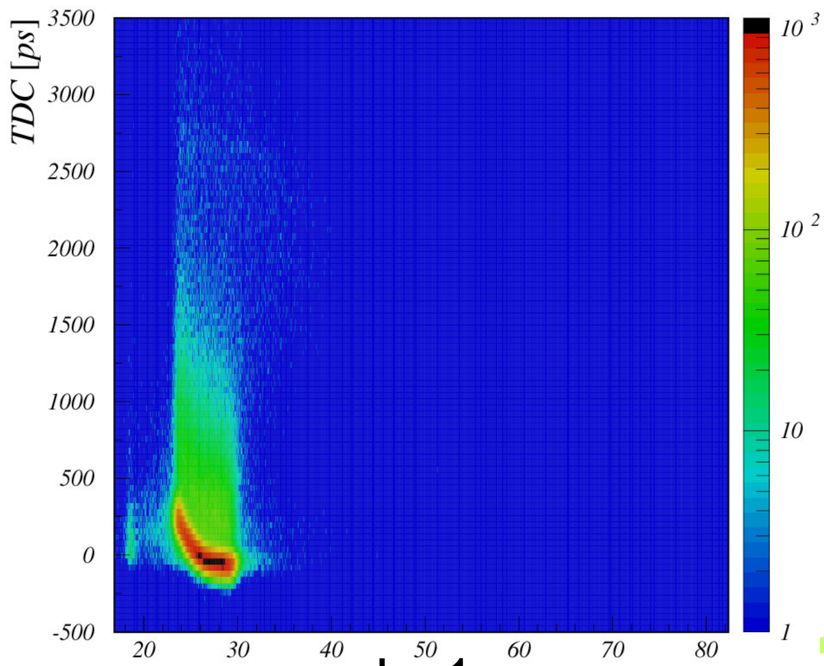
8x8: Timing uniformity for single pads

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

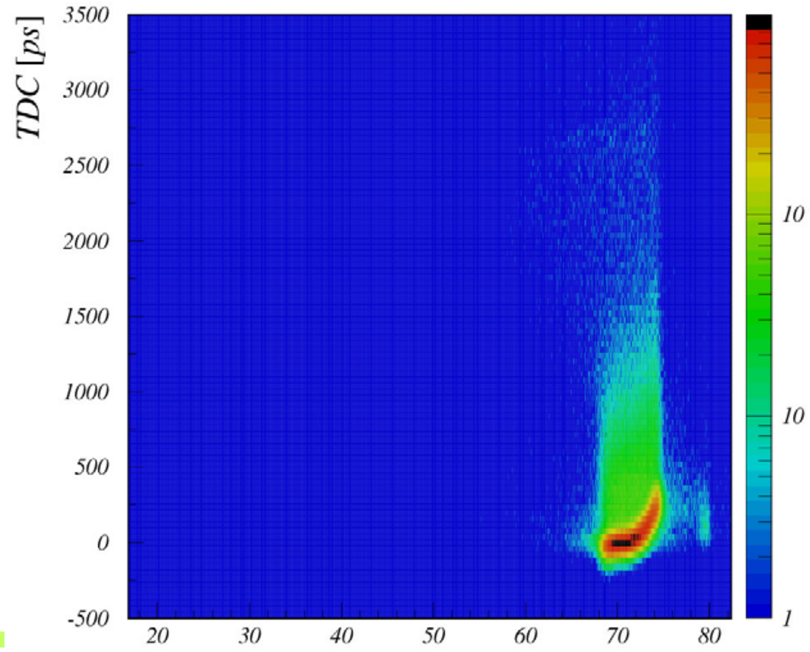
- uniform for central pads
- large variation for pads at the outer edges of the tube



ch. 4



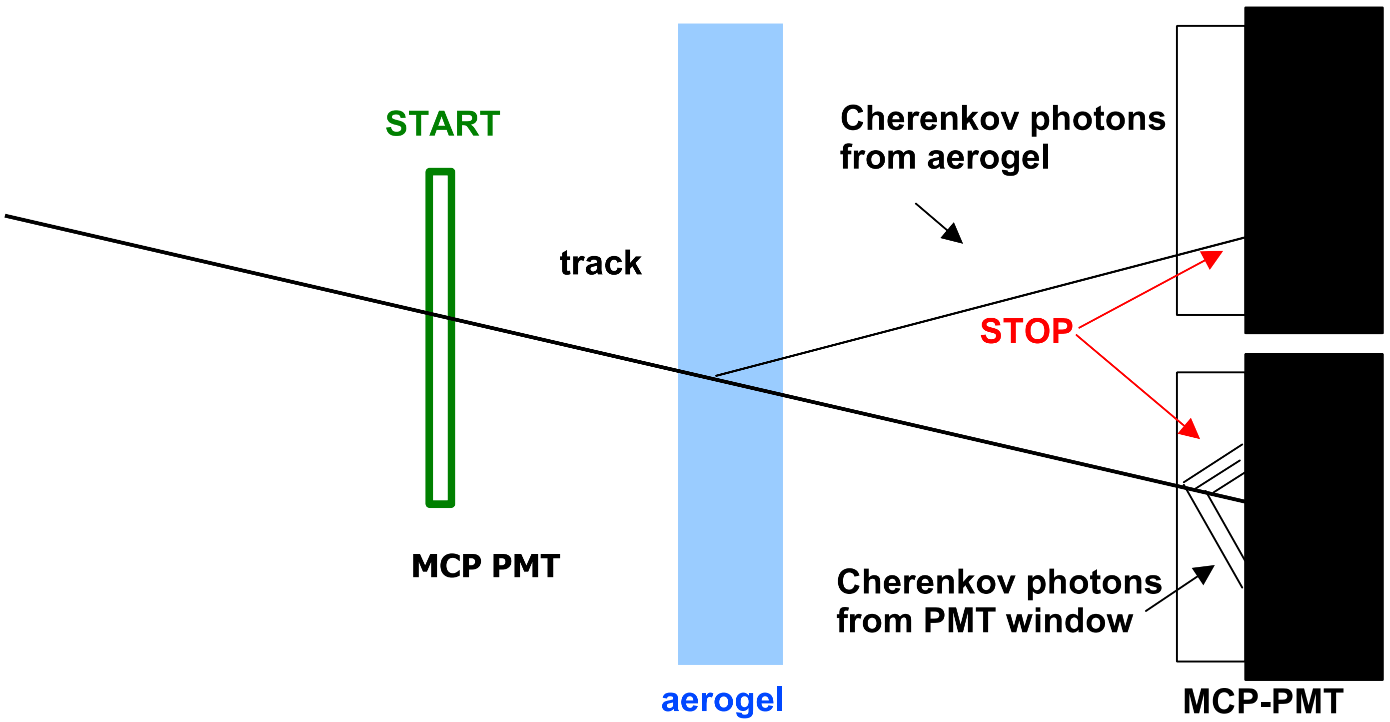
ch. 1



ch. 8

Beam test: time-of-flight measurement

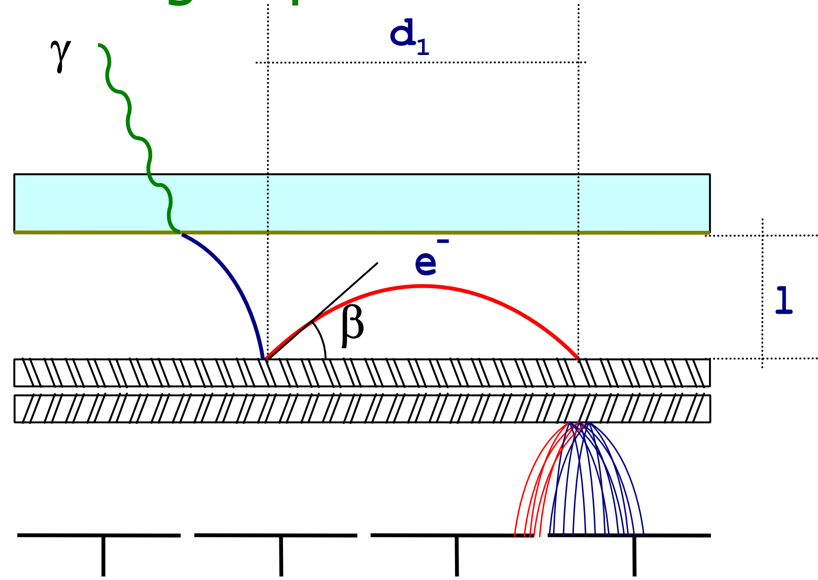
Time-of-flight with Cherenkov photons from aerogel radiator and PMT window



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)