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

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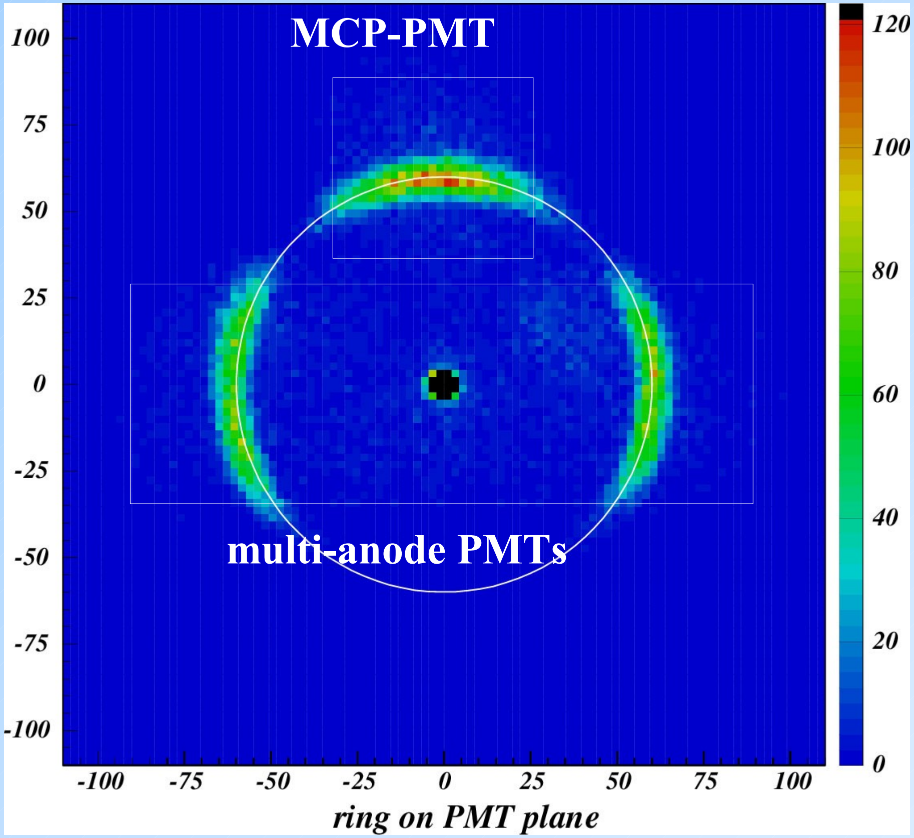
Outline of the talk:
- Motivation: RICH, TOF
- Basic parameters of BURLE MCP-PMTs
- Experimental setup
- Test results
- Summary and plan

Motivation: possible applications (Belle aerogel RICH group)

RICH detector

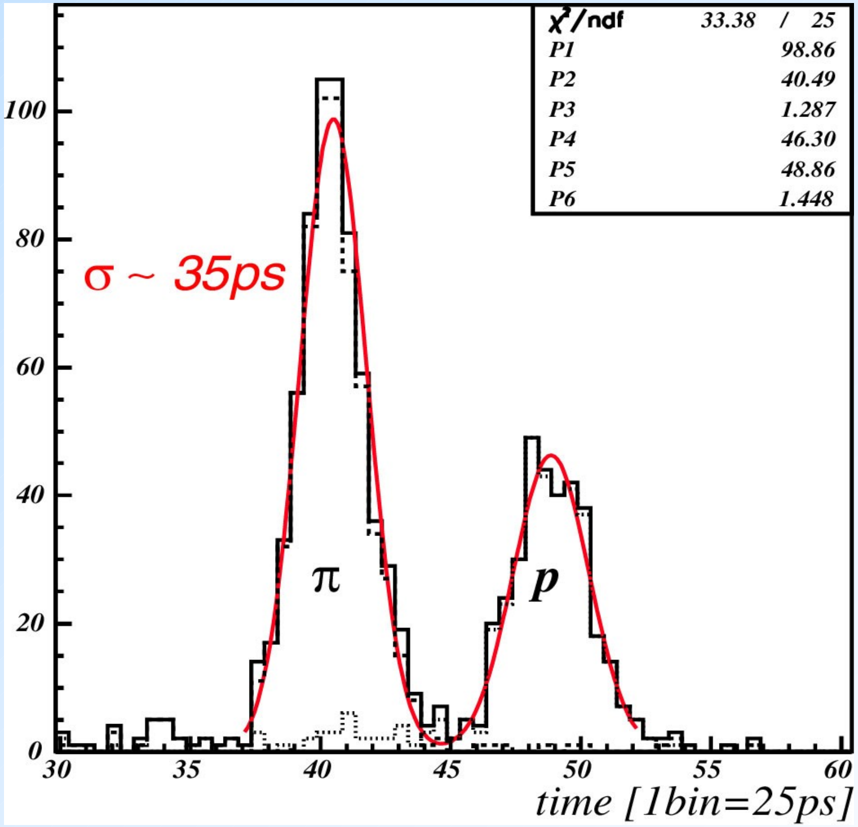
- $\sigma_\vartheta \sim$ 6 mrad (per track)



NIM A567 (2006) 124

TOF counter

- test with pions and protons at 2 GeV/c (65 cm)



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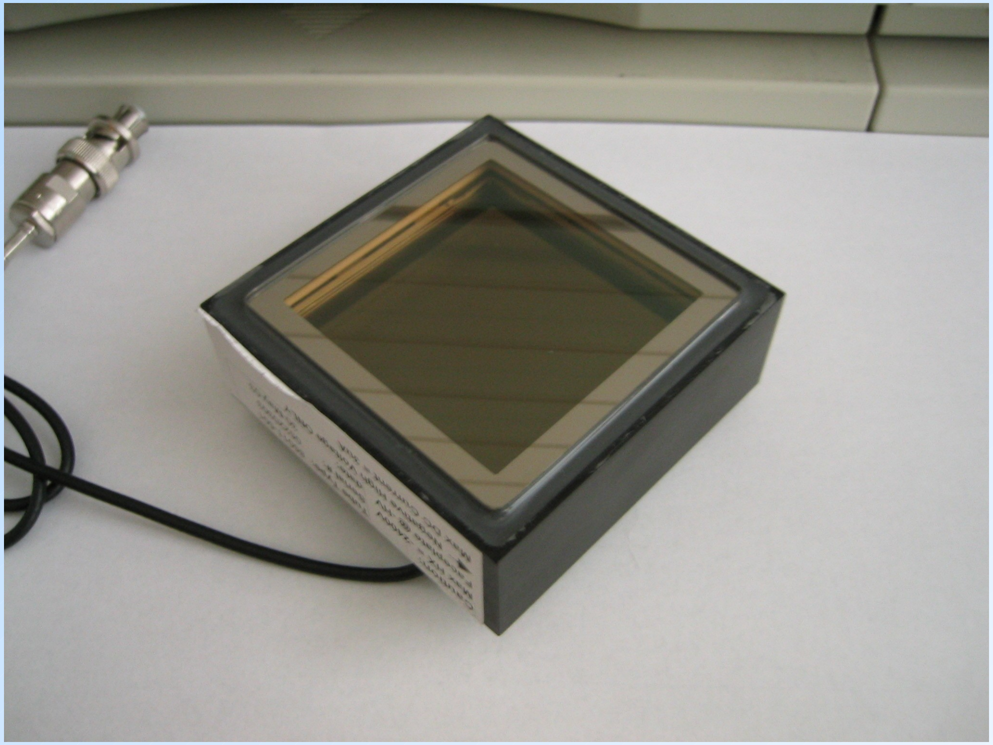
Basic parameters of BURLE MCP-PMTs

- multi-anode PMT with two MCP steps
- bialkali photocathode
- gain ~ 0.6×10^6
- collection efficiency ~ 60%
- box dimensions ~ 71mm square
- 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

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Scanning setup: optical system

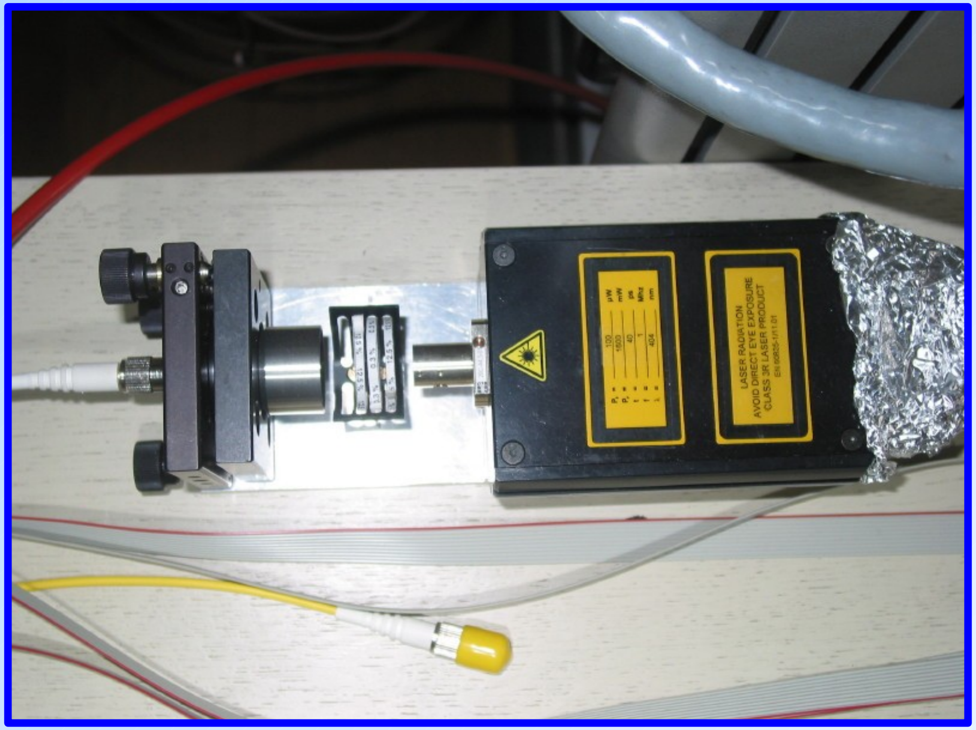
Outside dark box:

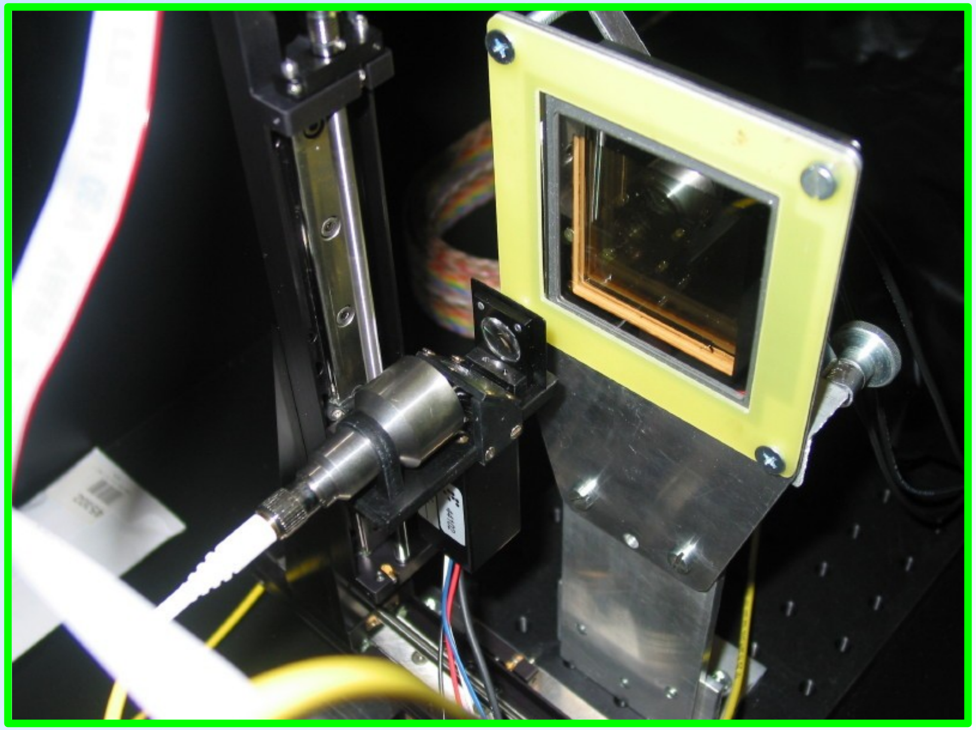
- PiLas diode laser system EIG1000D (ALS)
- 404nm laser head (ALS)
- filters (0.3%, 12.5%, 25%)
- optical fiber coupler (focusing)

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

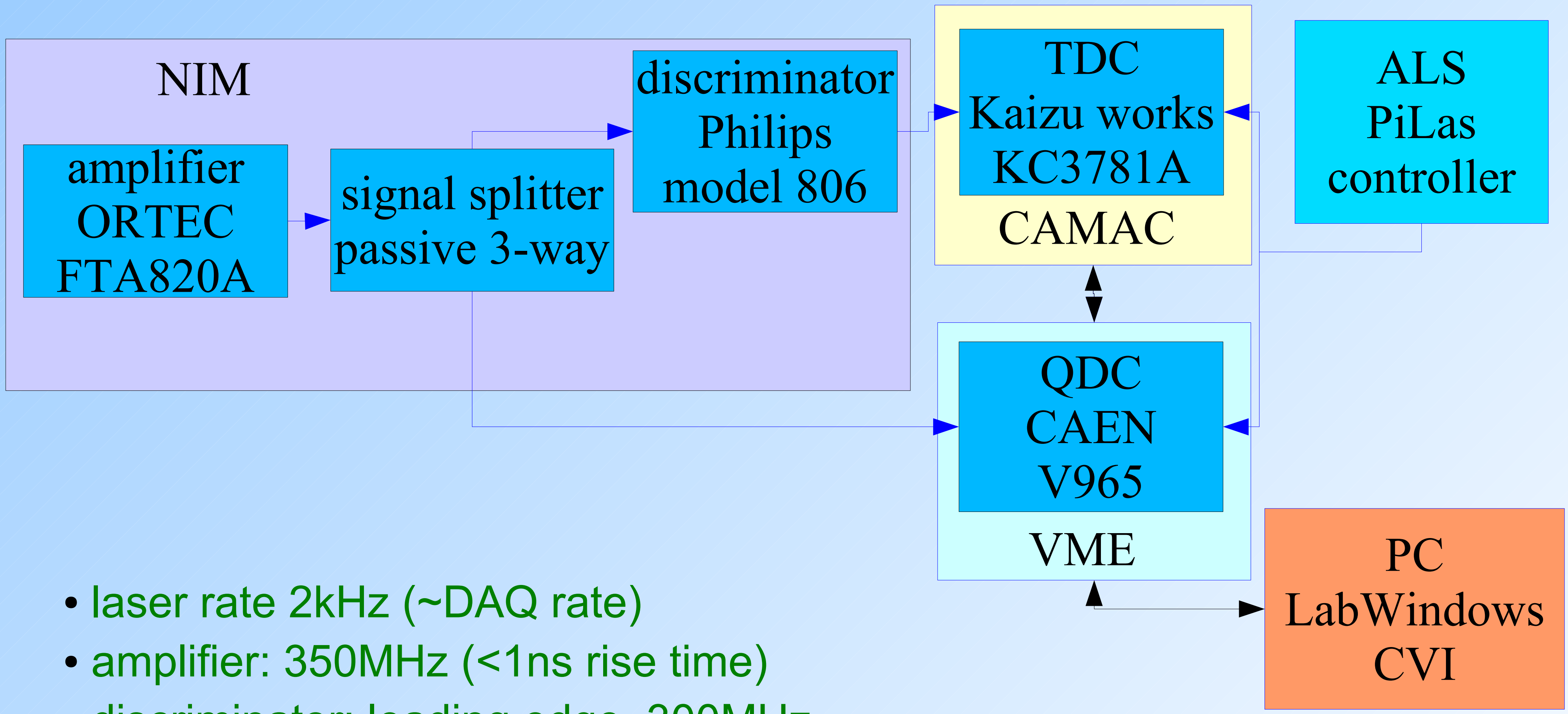
Inside dark box mounted on 3D stage:

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





Scanning setup: readout



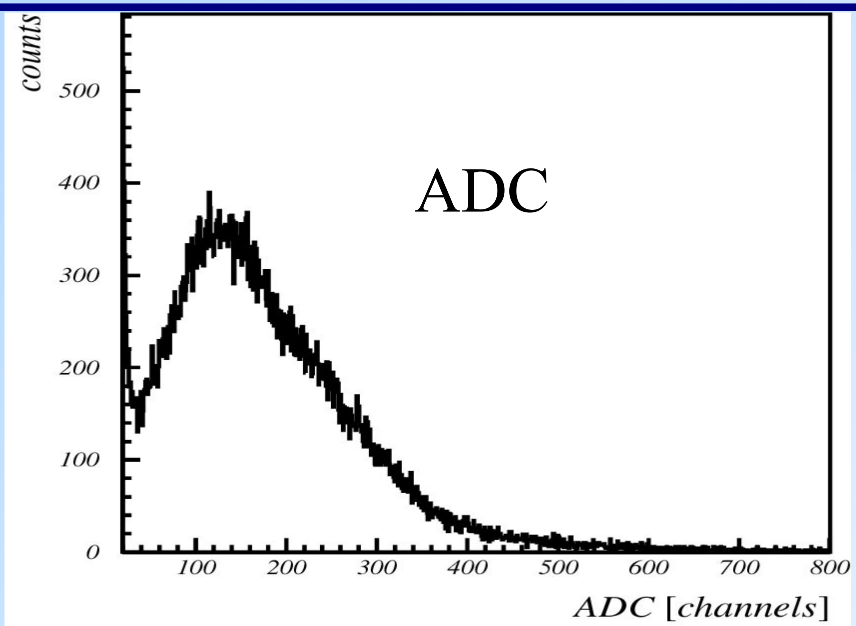
- laser rate 2kHz (~DAQ rate)
- amplifier: 350MHz (<1ns rise time)
- discriminator: leading edge, 300MHz
- TDC: 25ps LSB(σ~11ps)
- QDC: dual range 800pC, 200pC
- HV 2400V

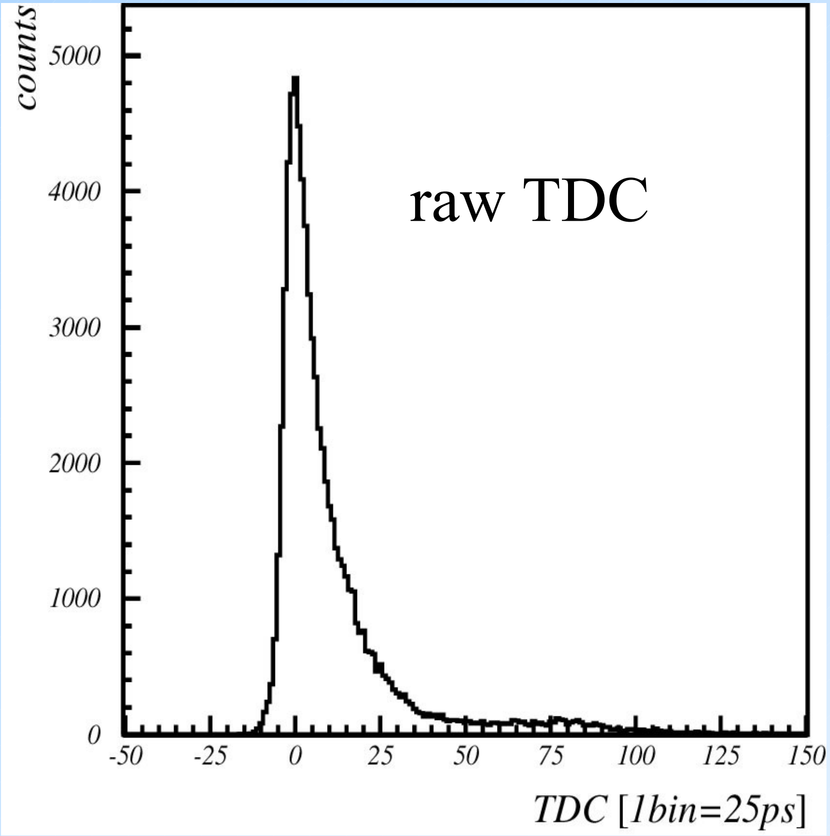
Time walk correction

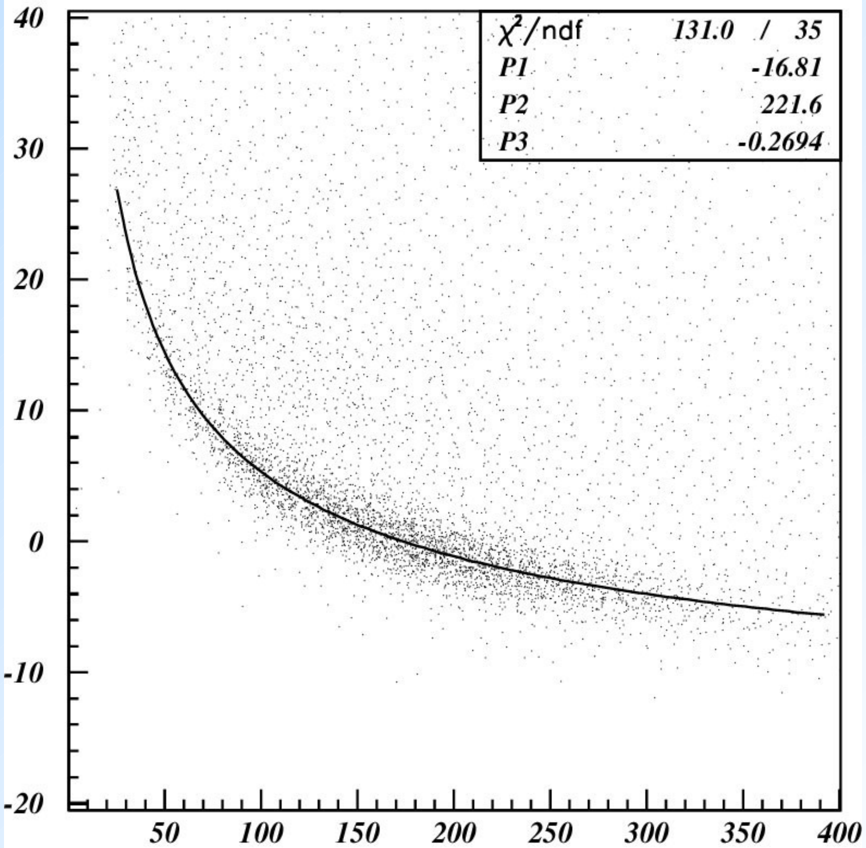
- TDC vs. ADC correlation is fitted with

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

and used for TDC correction

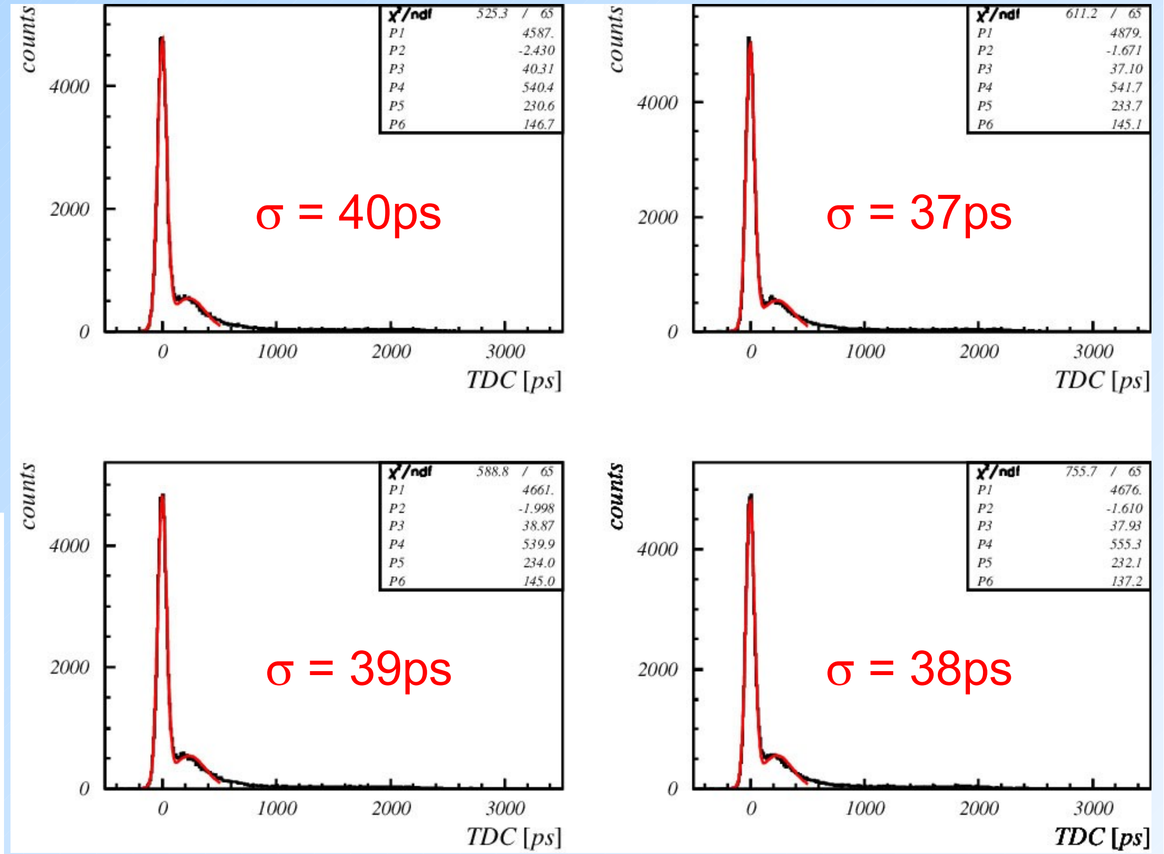


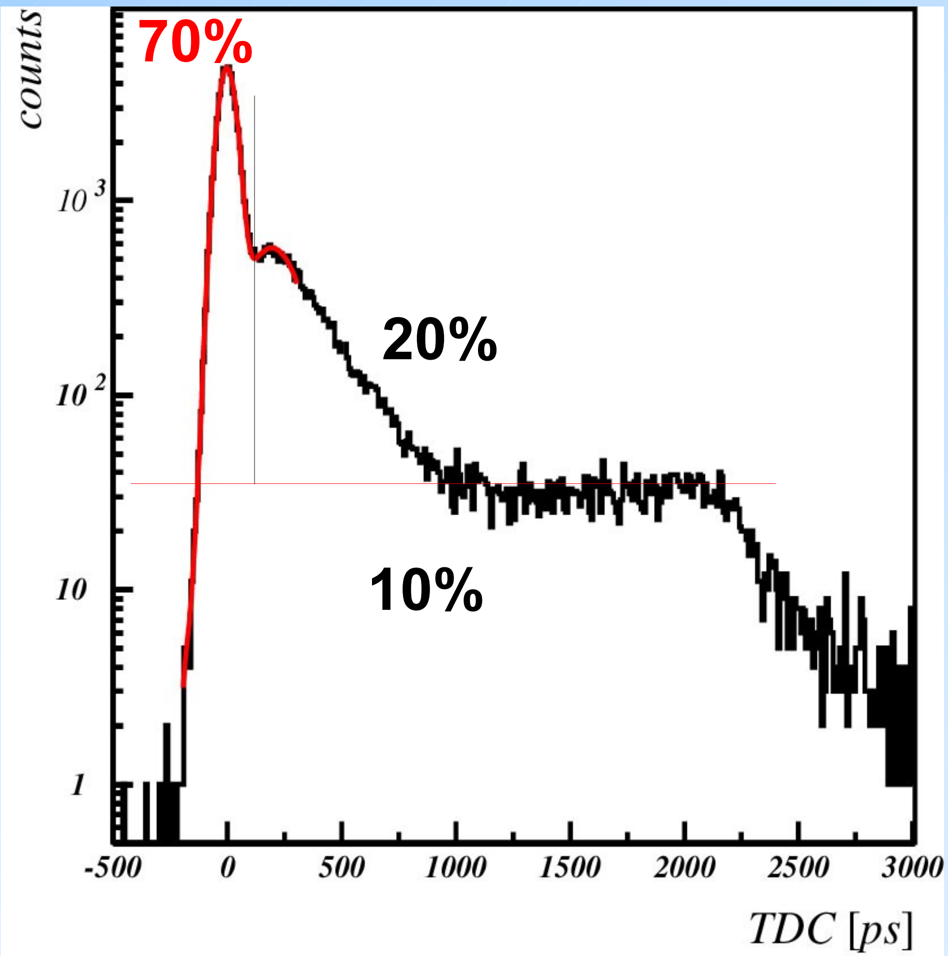




Corrected TDC

- corrected TDC distributions for all pads





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

Photon detection

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

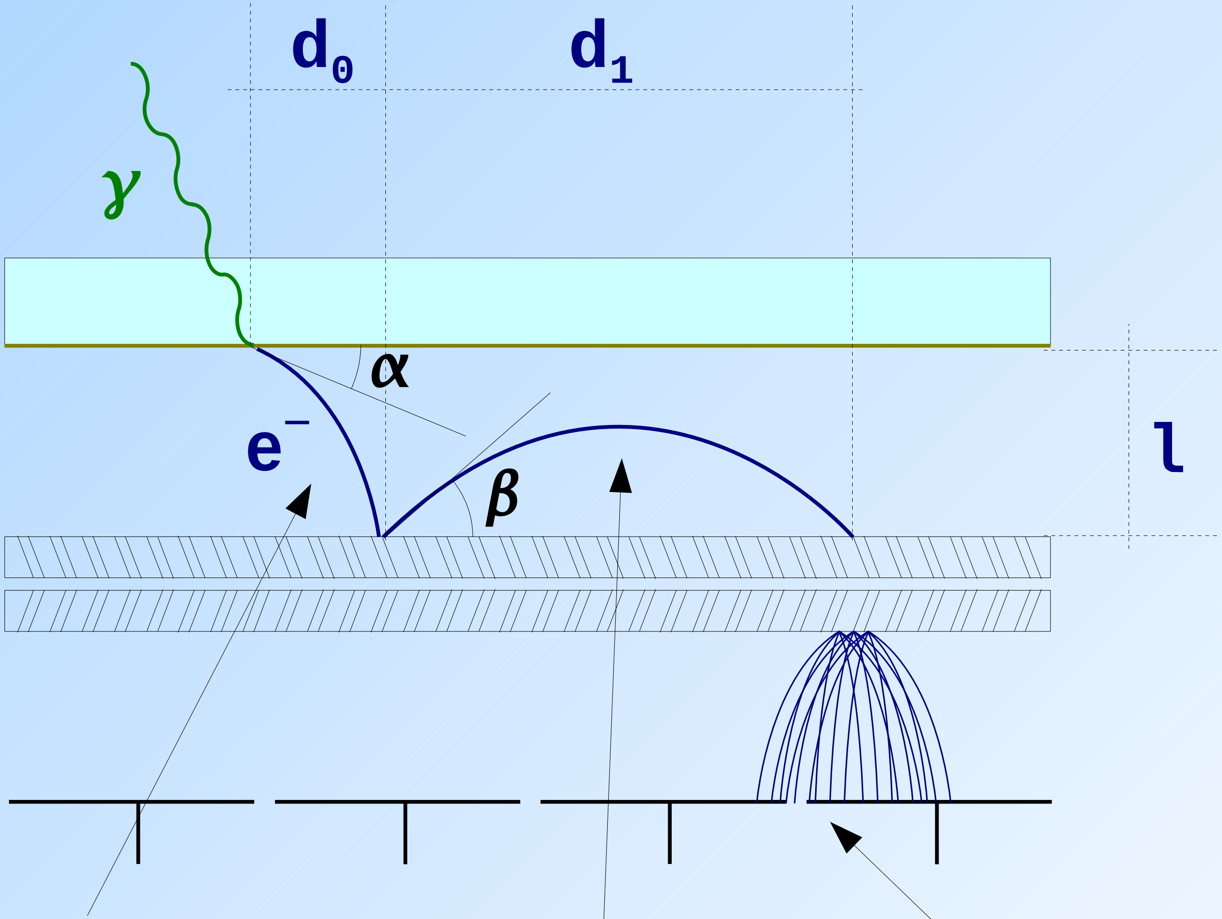


Photo-electron:

- $d_{0,max} \sim 0.8$ 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

Photon detection

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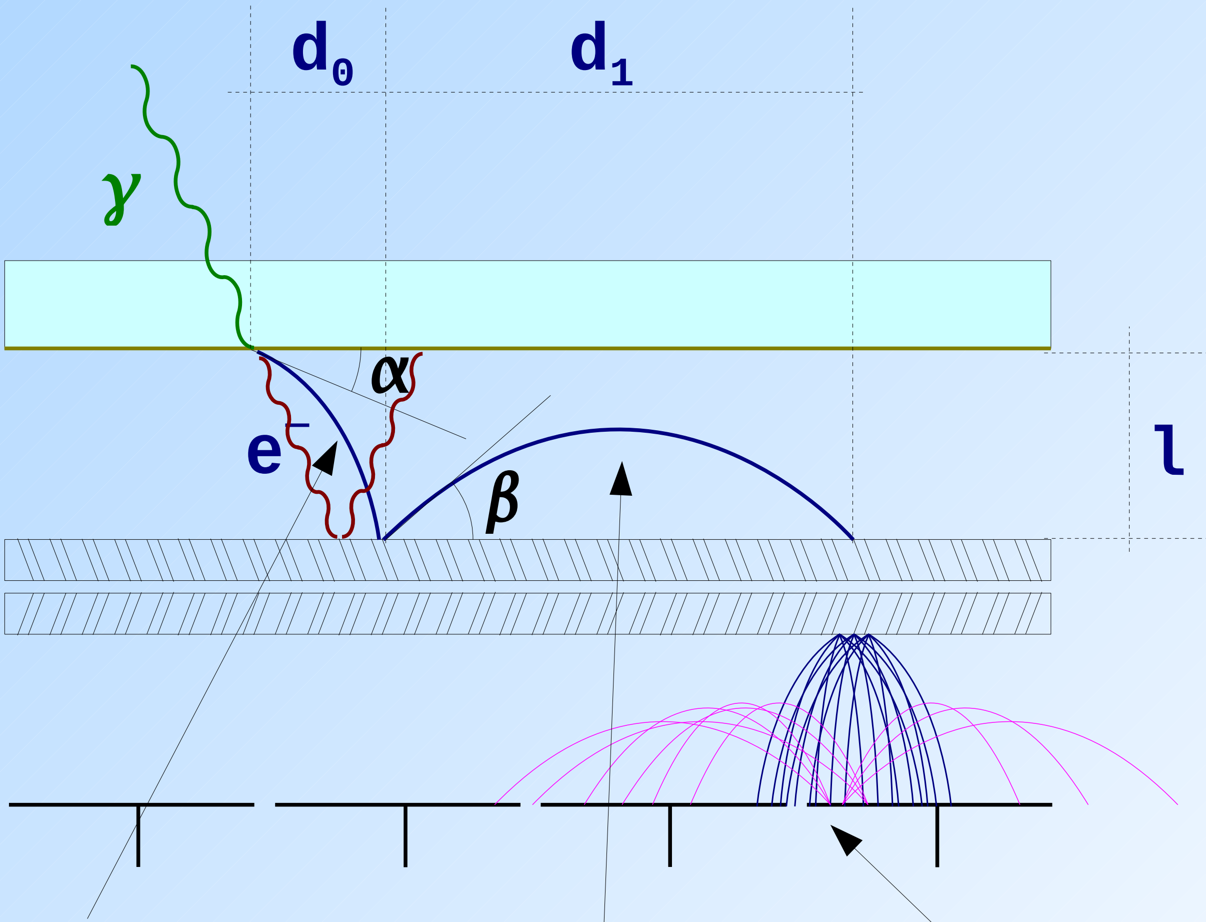

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Charge sharing

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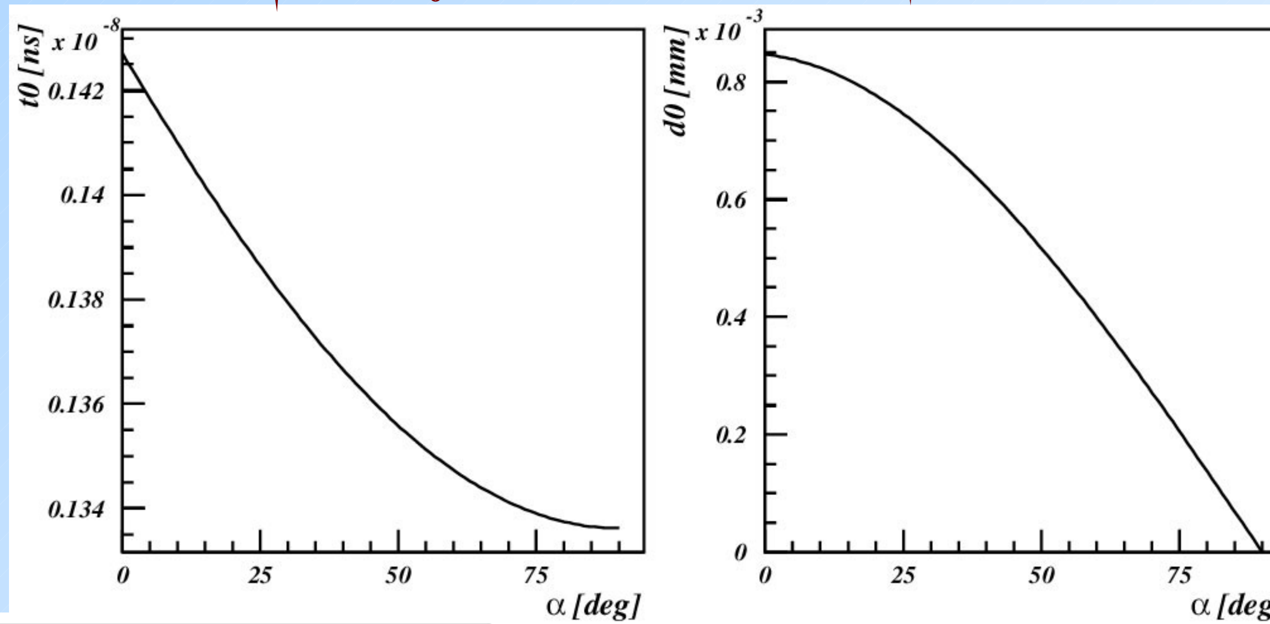
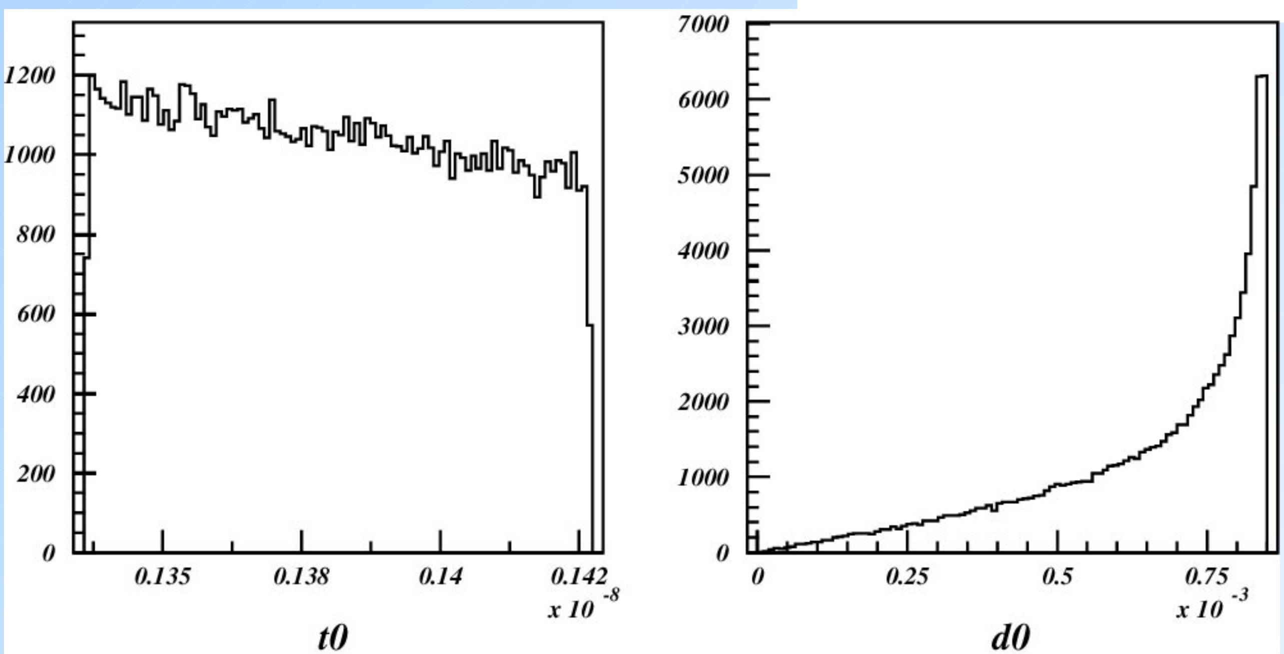
Photo-electron

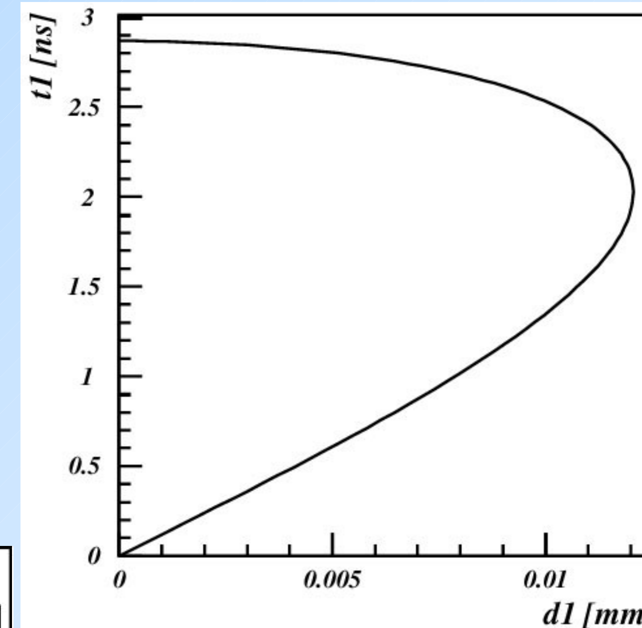
$$t_0 \approx \sqrt{\frac{2 m_e l^2}{U e_0}} \qquad d_0 \approx 2 l \sqrt{\frac{E_0}{U e_0}} \cos(2\alpha)$$



Generated distributions assuming that photo-electron is emitted uniformly over the solid angle

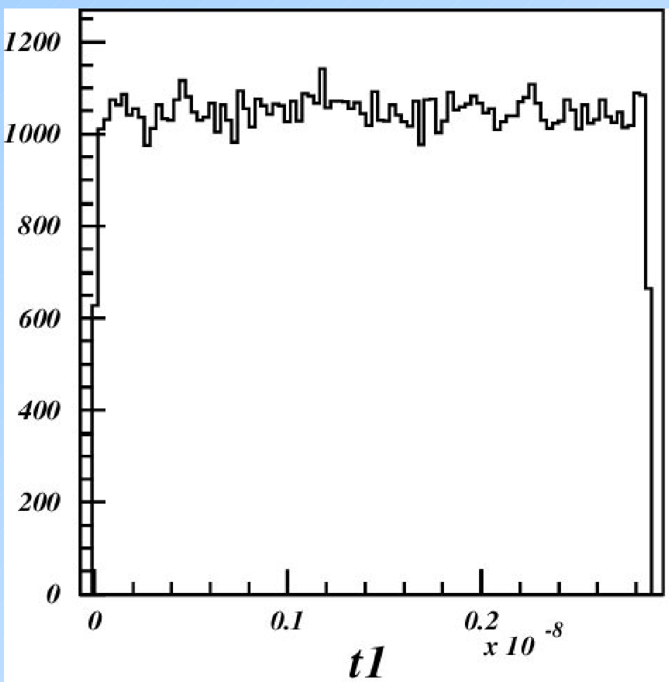


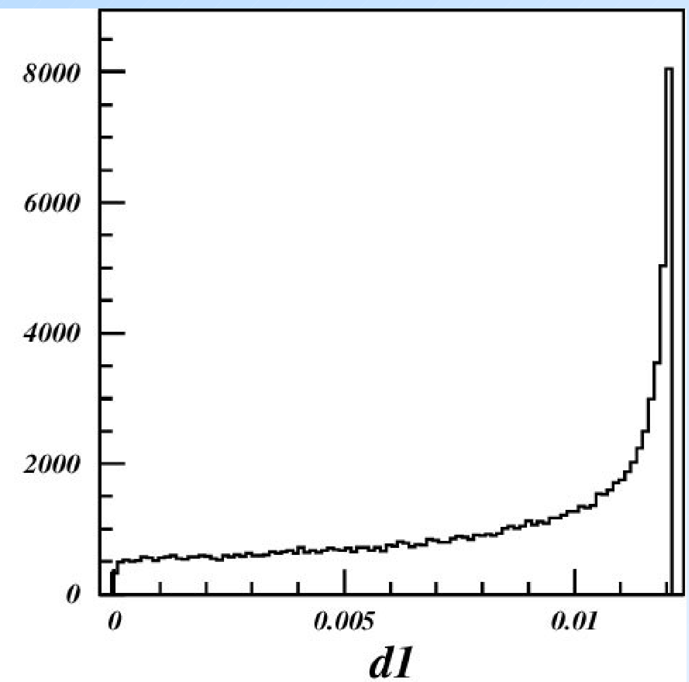
Elastic backscattering



Travel time vs. travel distance

Generated distributions assuming that backscattering is uniform over the solid angle



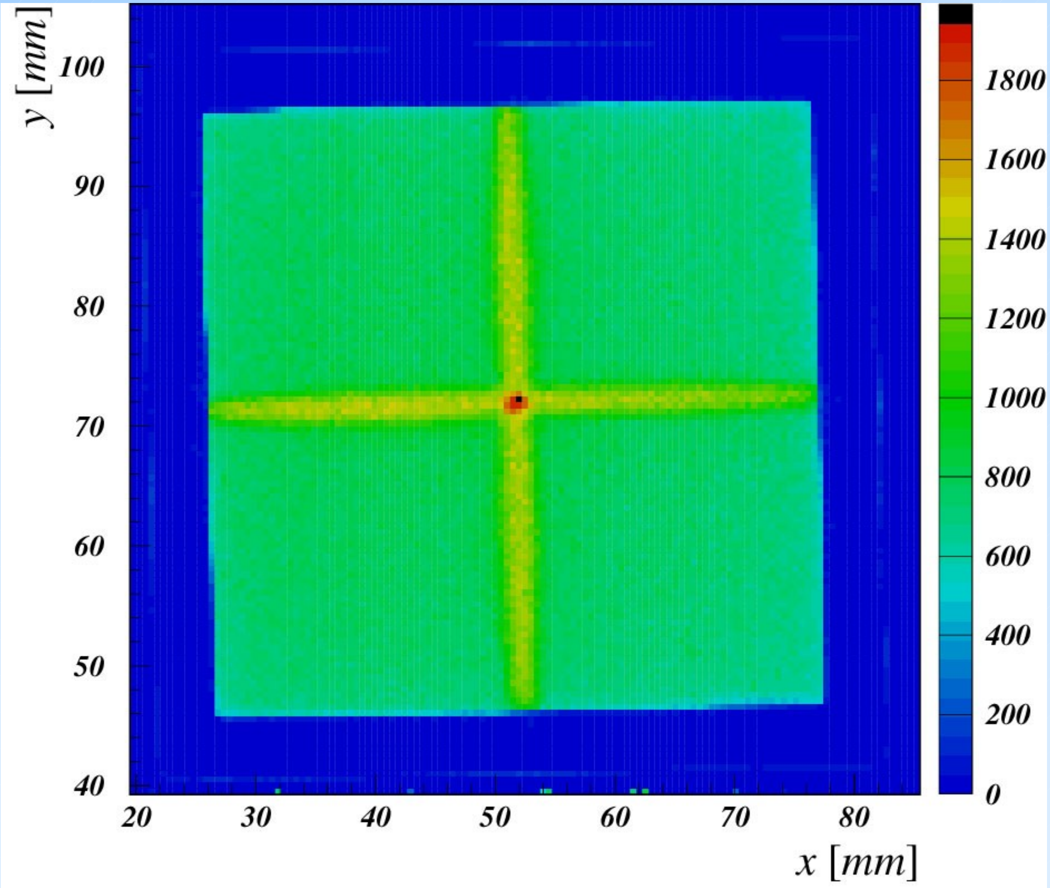


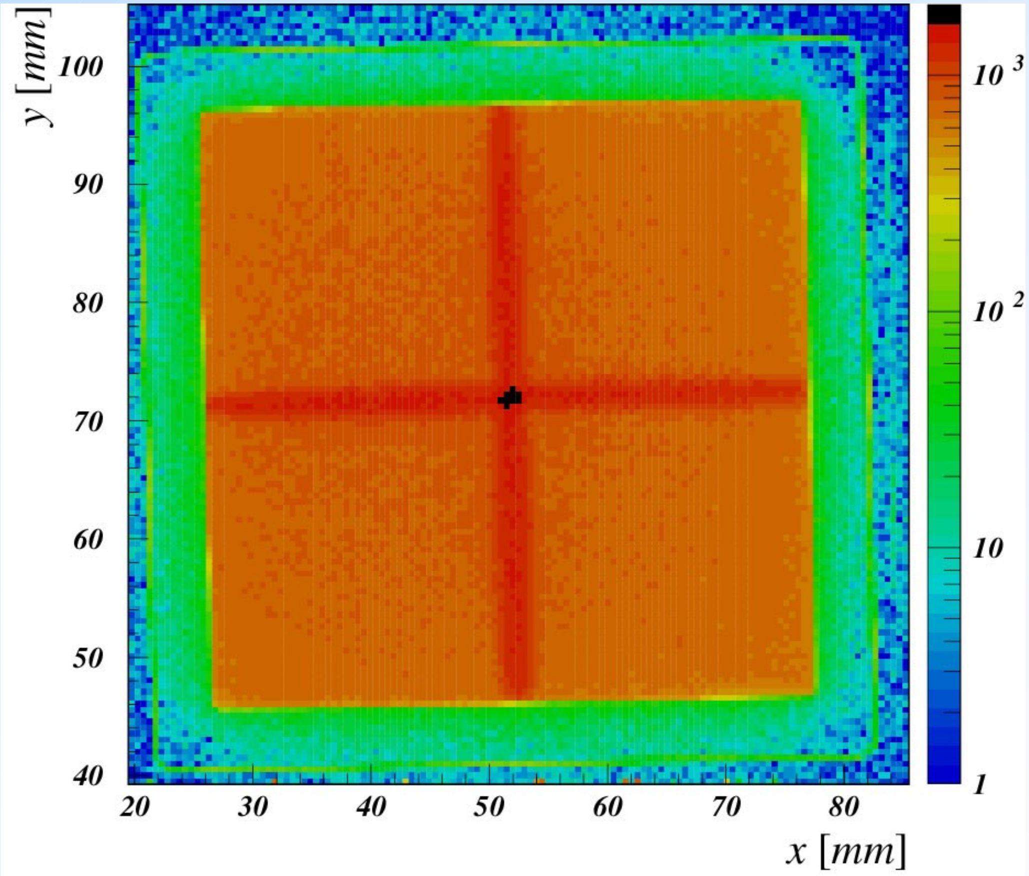
$$t_1 = 2\, t_0 \sin(\beta)$$

$$d_1 = 2\, l \sin(2\beta)$$

Photon detection uniformity

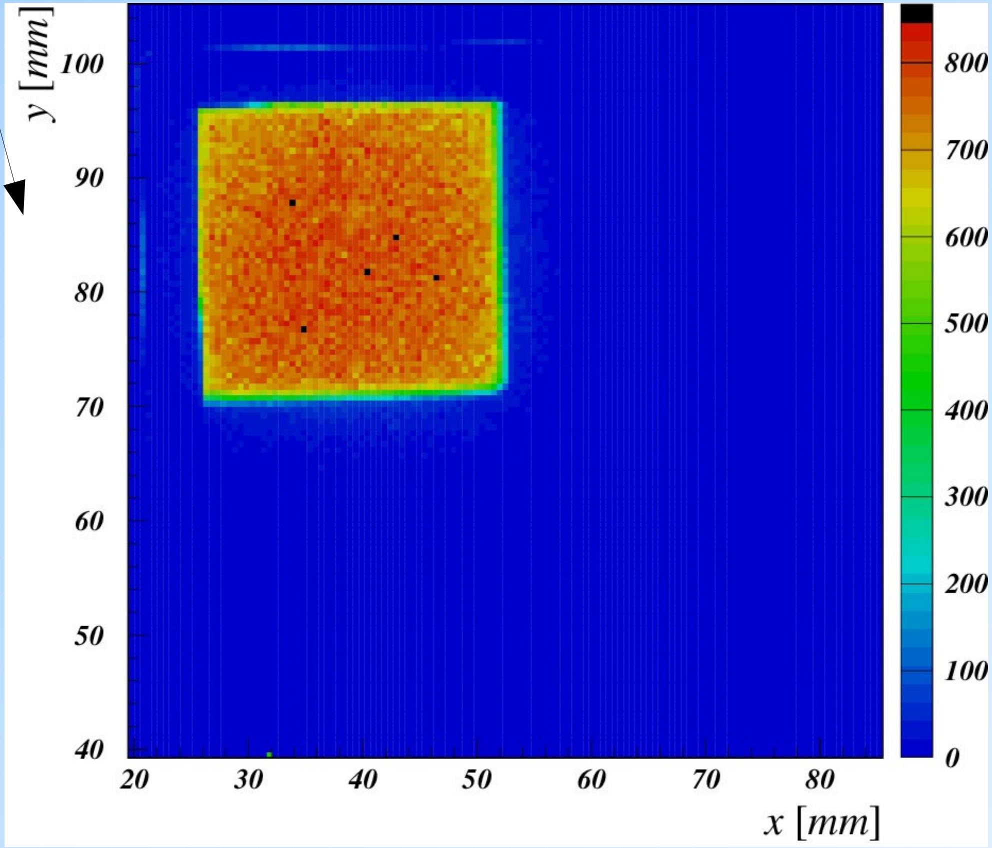
- Number of detected events at different positions of light spot – sum of all 4 channels
- double counting at pad boundaries due to charge sharing

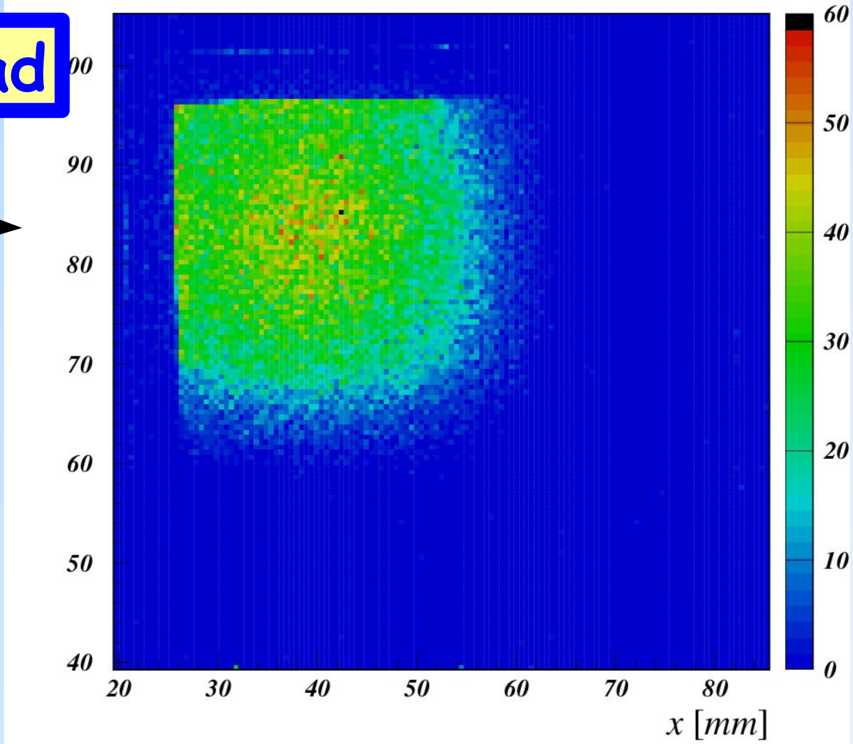


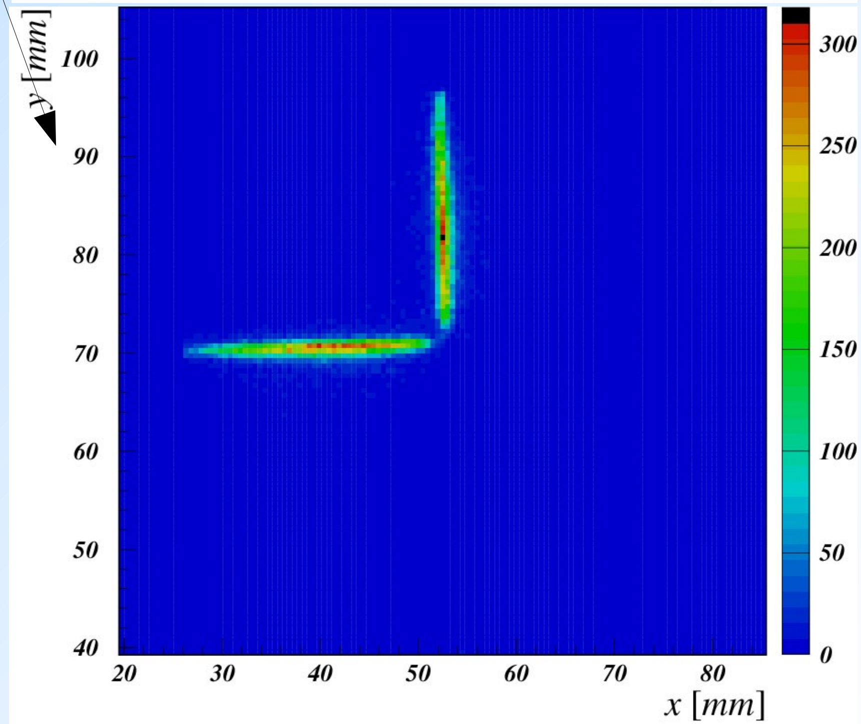


Photon detection uniformity – single pad

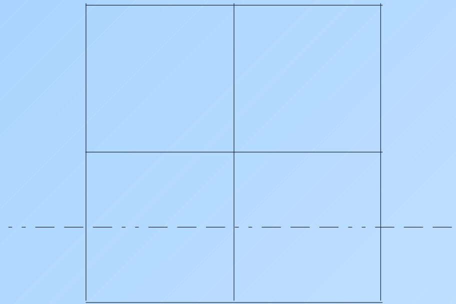
- number of delayed events with maximum signal detected by the pad
- number of events with maximum signal detected by other pads
- number of all detected events with maximum signal detected by the pad



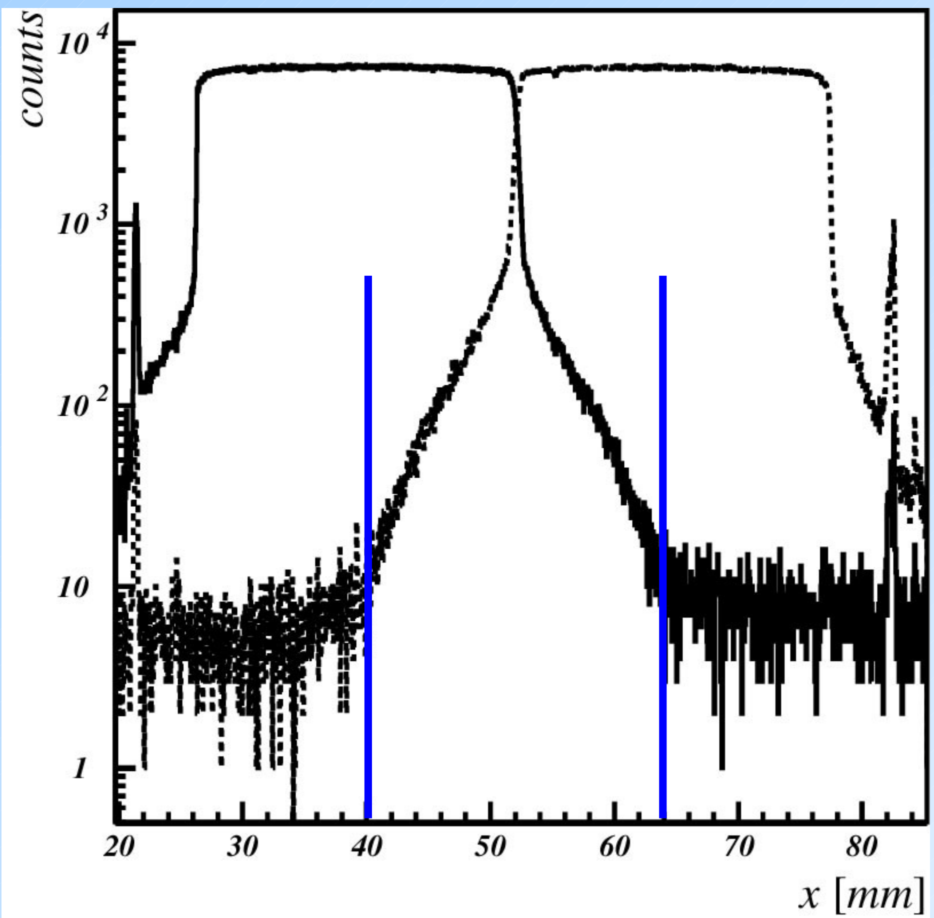




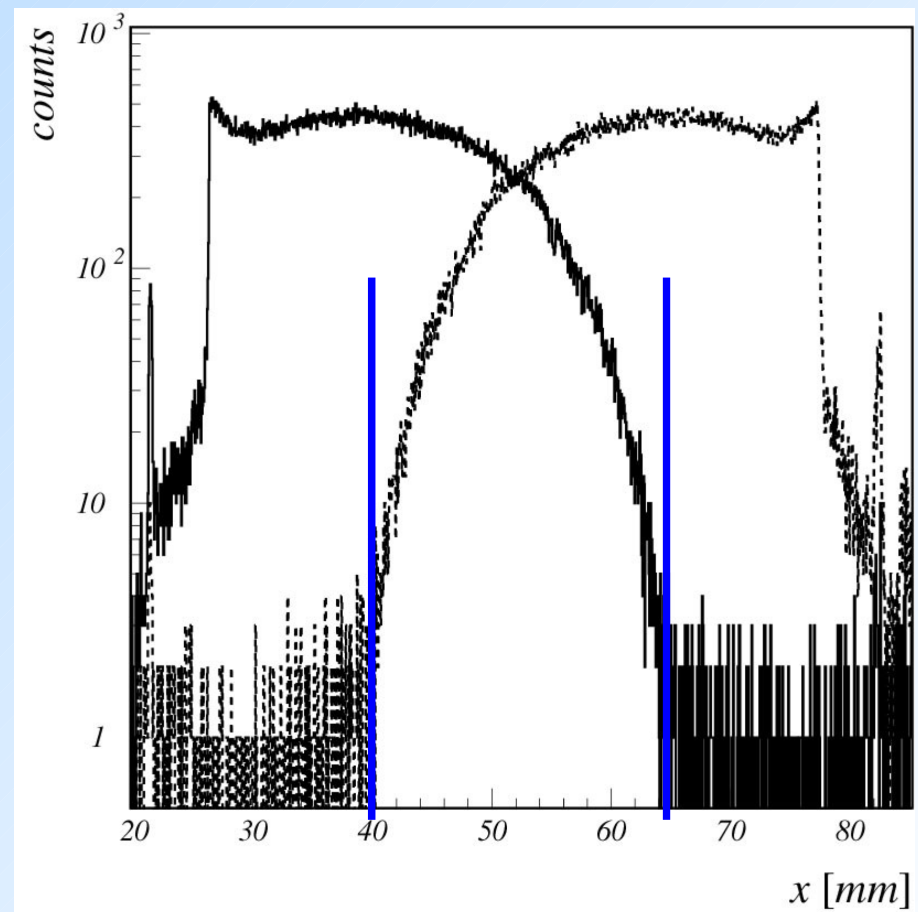
Detailed 1D scan



all events with maximum signal on channels 1 and 2

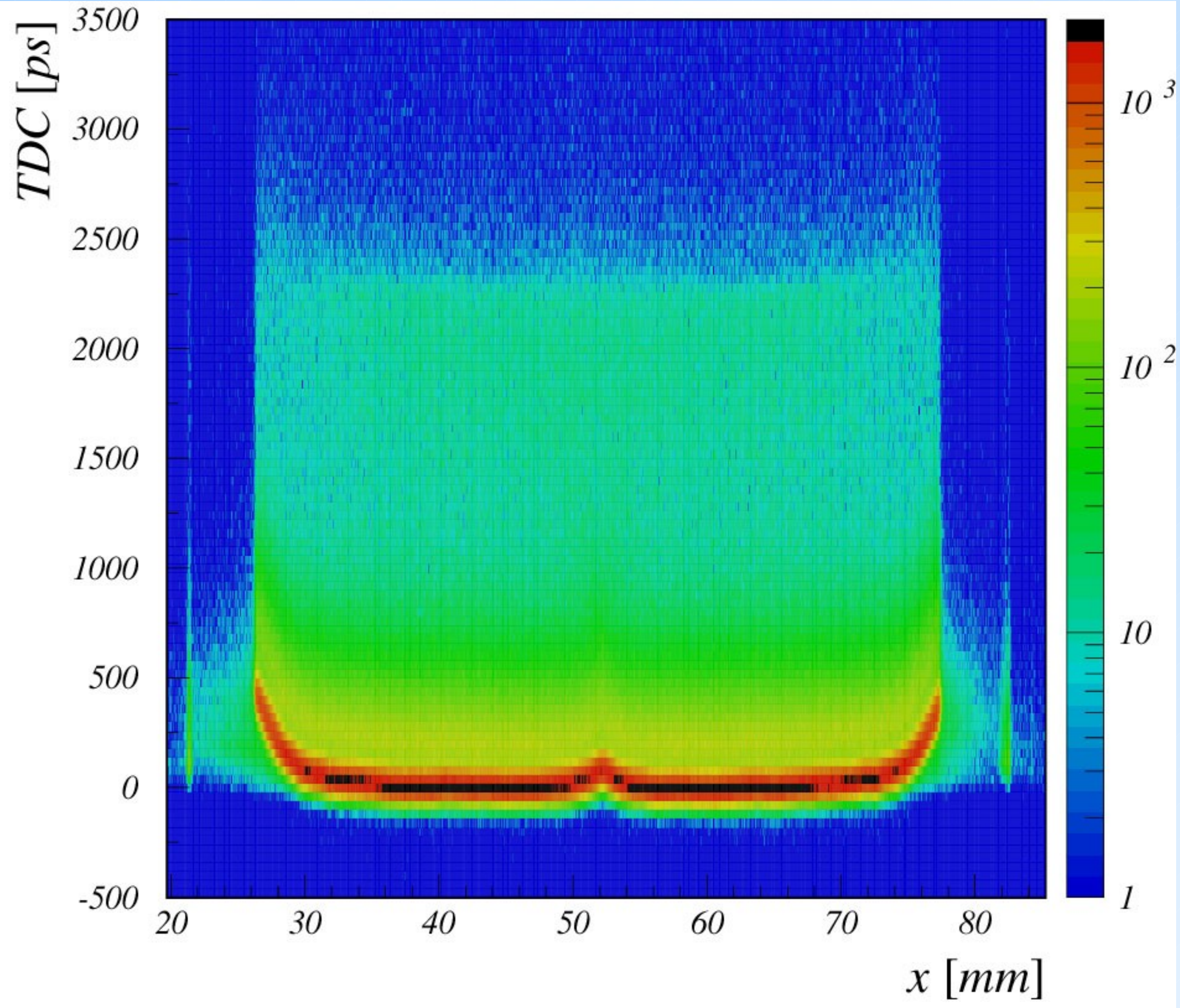


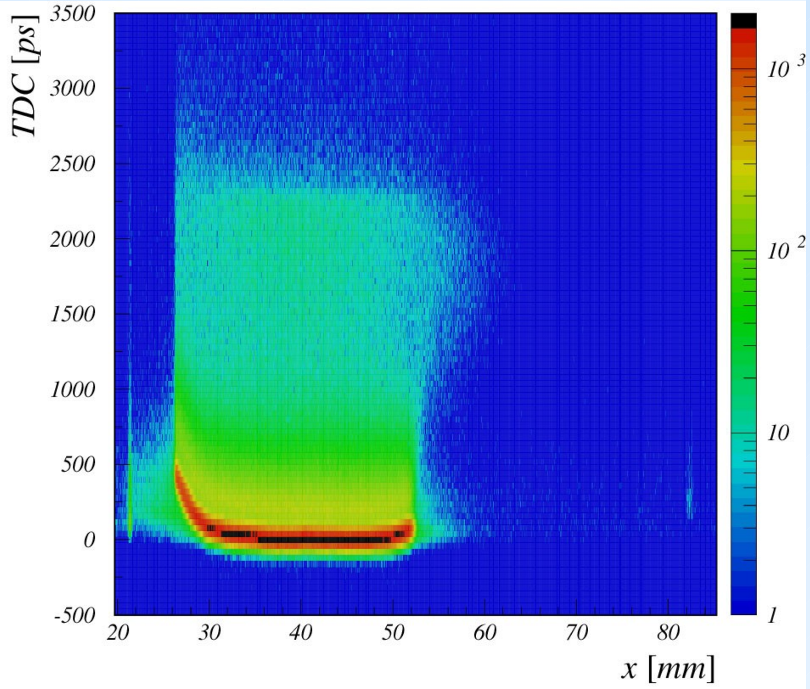
delayed (>1.1ns) events with maximum signal on channels 1 and 2

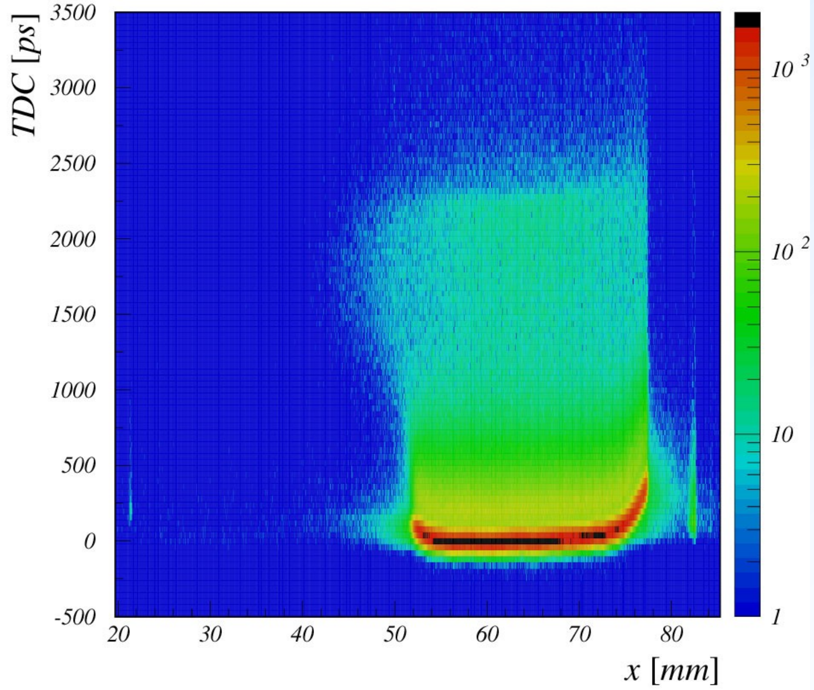


Timing uniformity

- TDC vs. x for channels 1 and 2
- large deviation at active area edge
- small deviation at pad boundaries

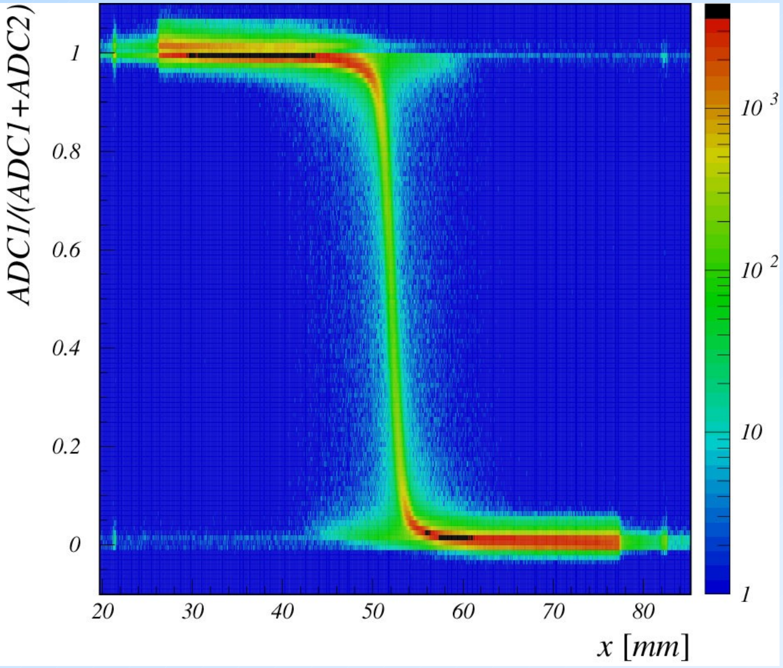


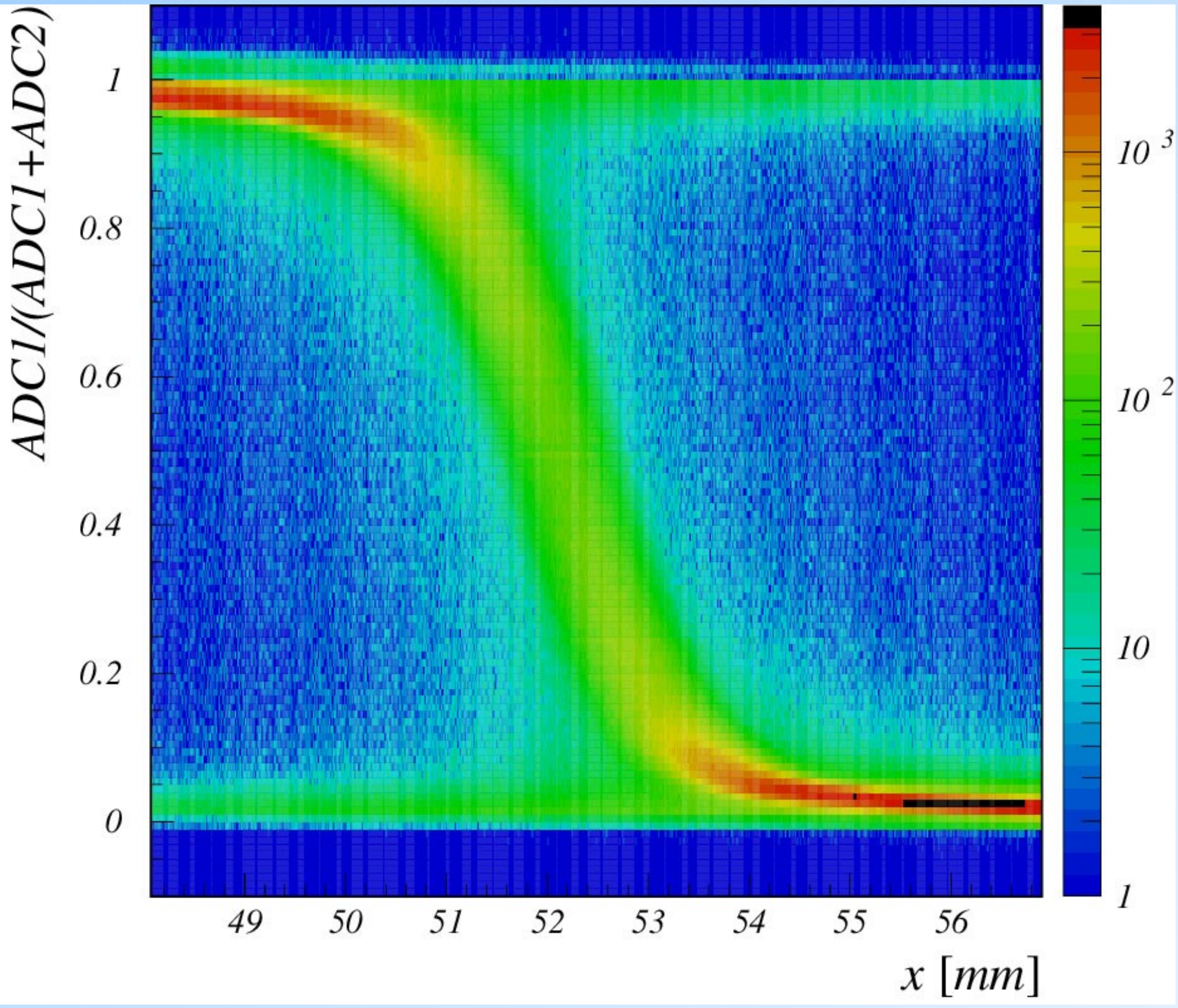




Charge sharing

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

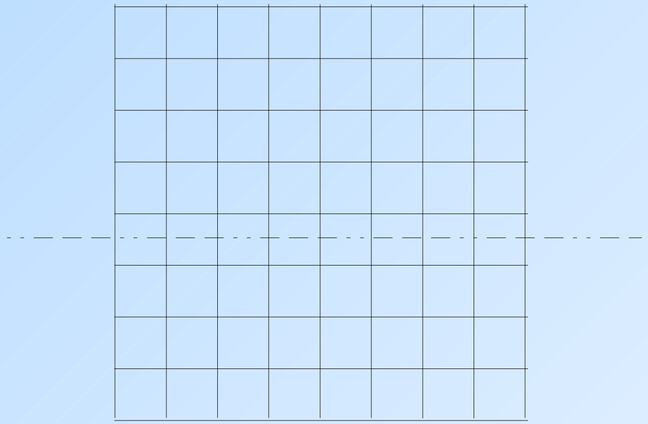


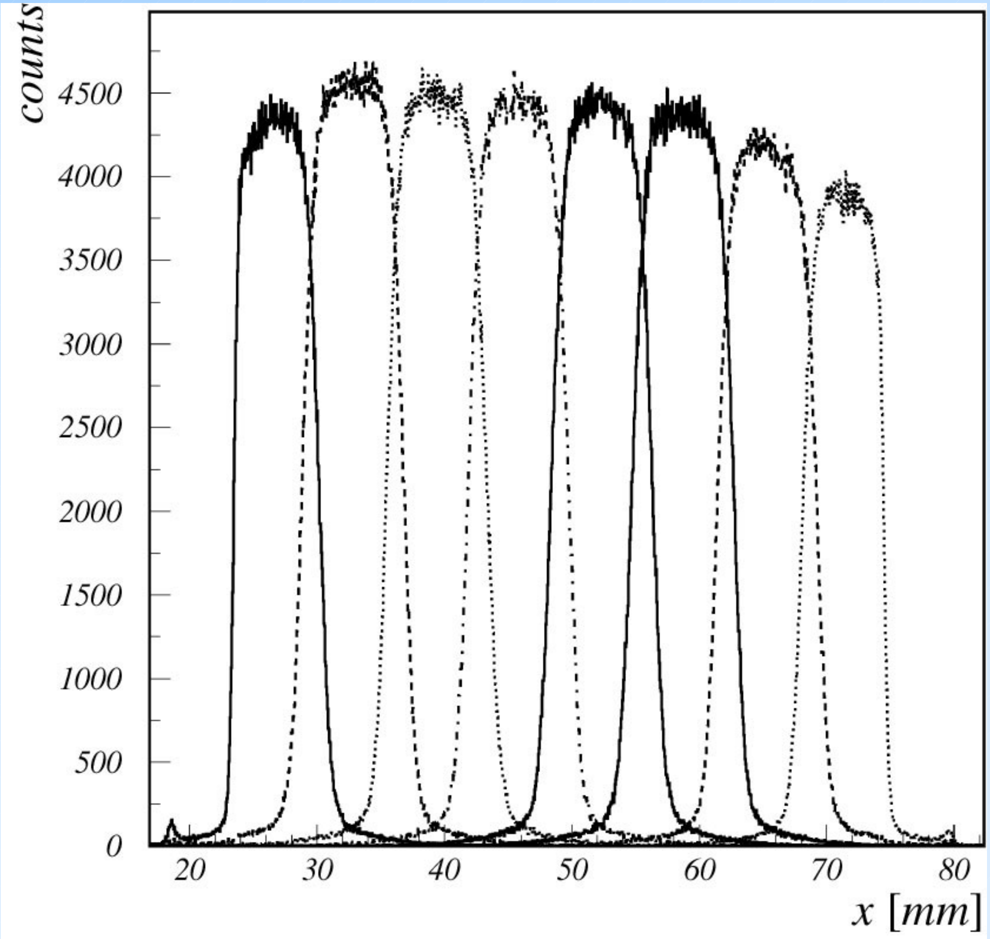


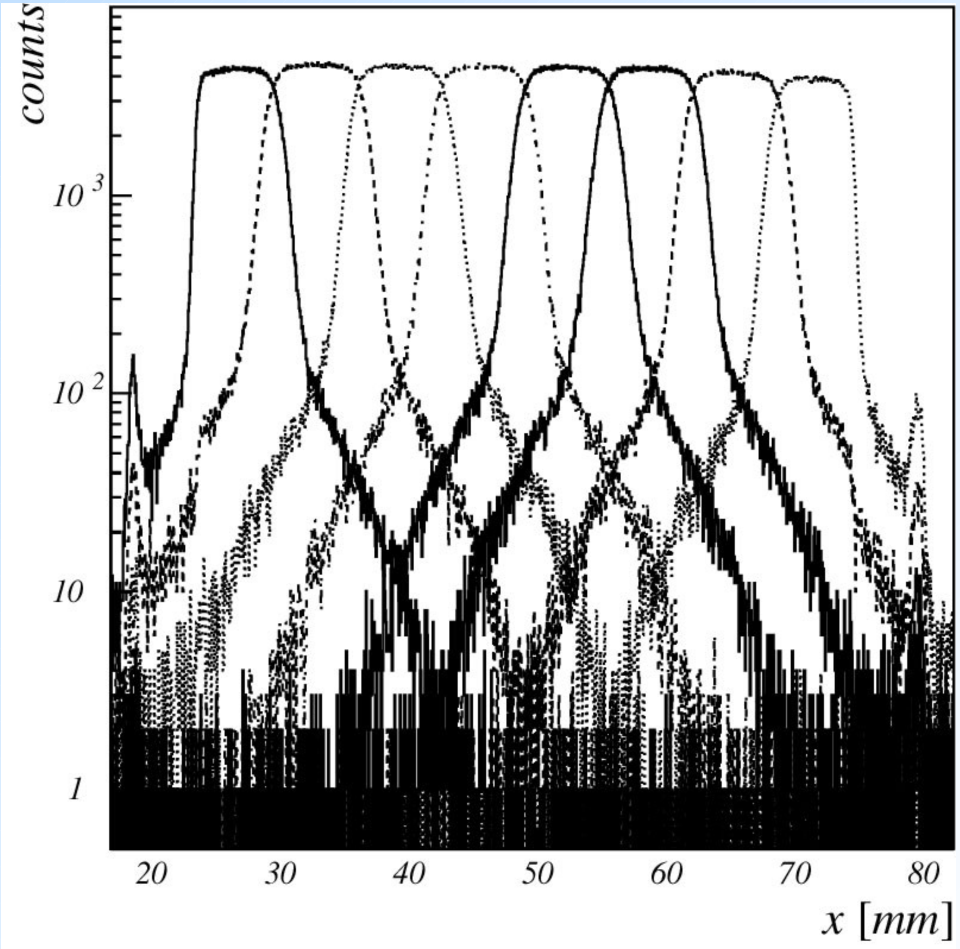
- sizable charge sharing in ~2mm wide boundary area
- can be used to improve position resolution

8x8: detection vs. x

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

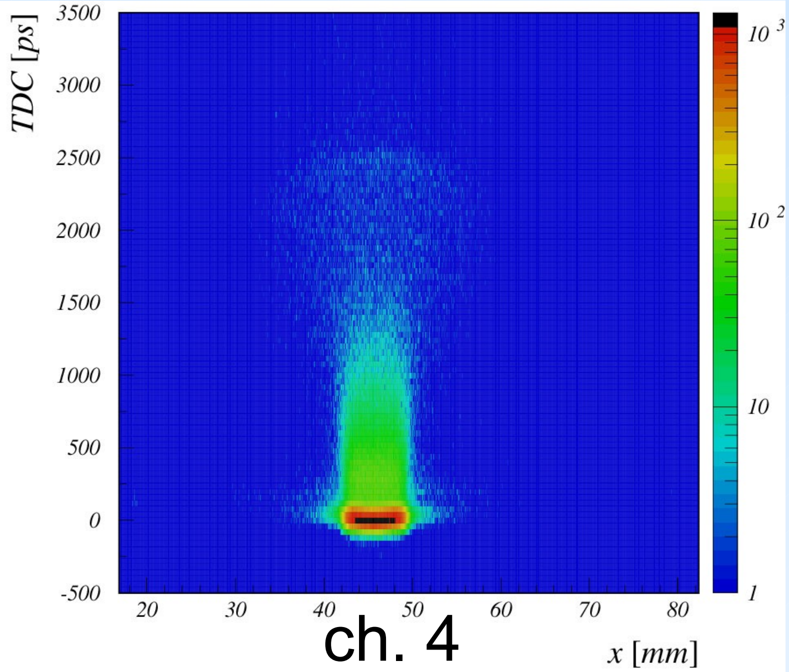


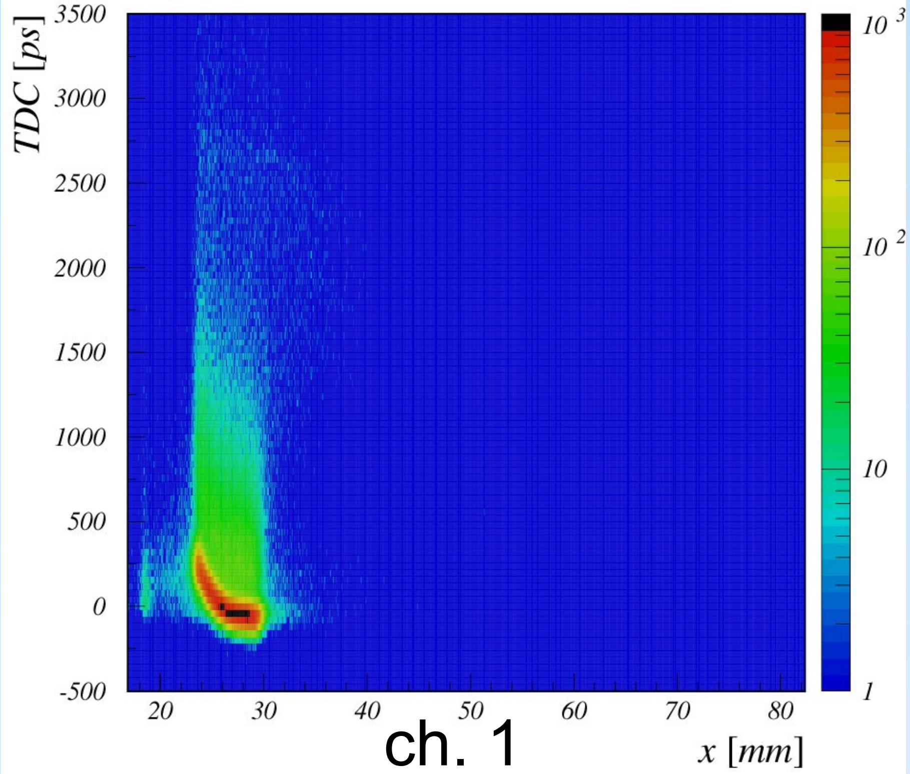


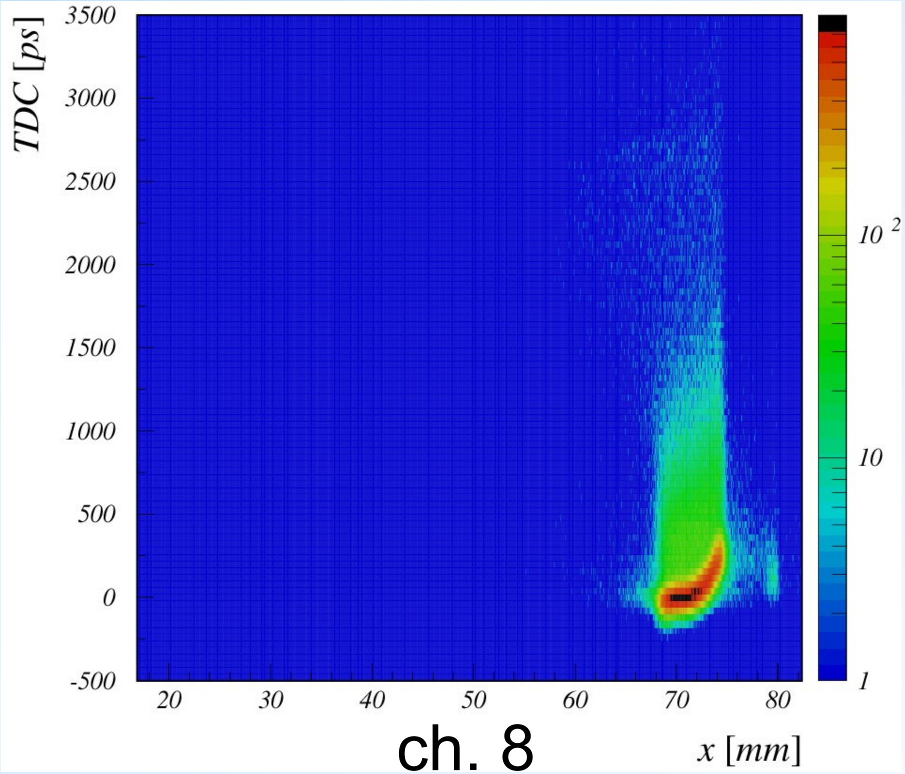


8x8: Timing uniformity for single pads

- TDC vs. x correlation of single pads
- uniform for central pads
- large variation for pads at the edge

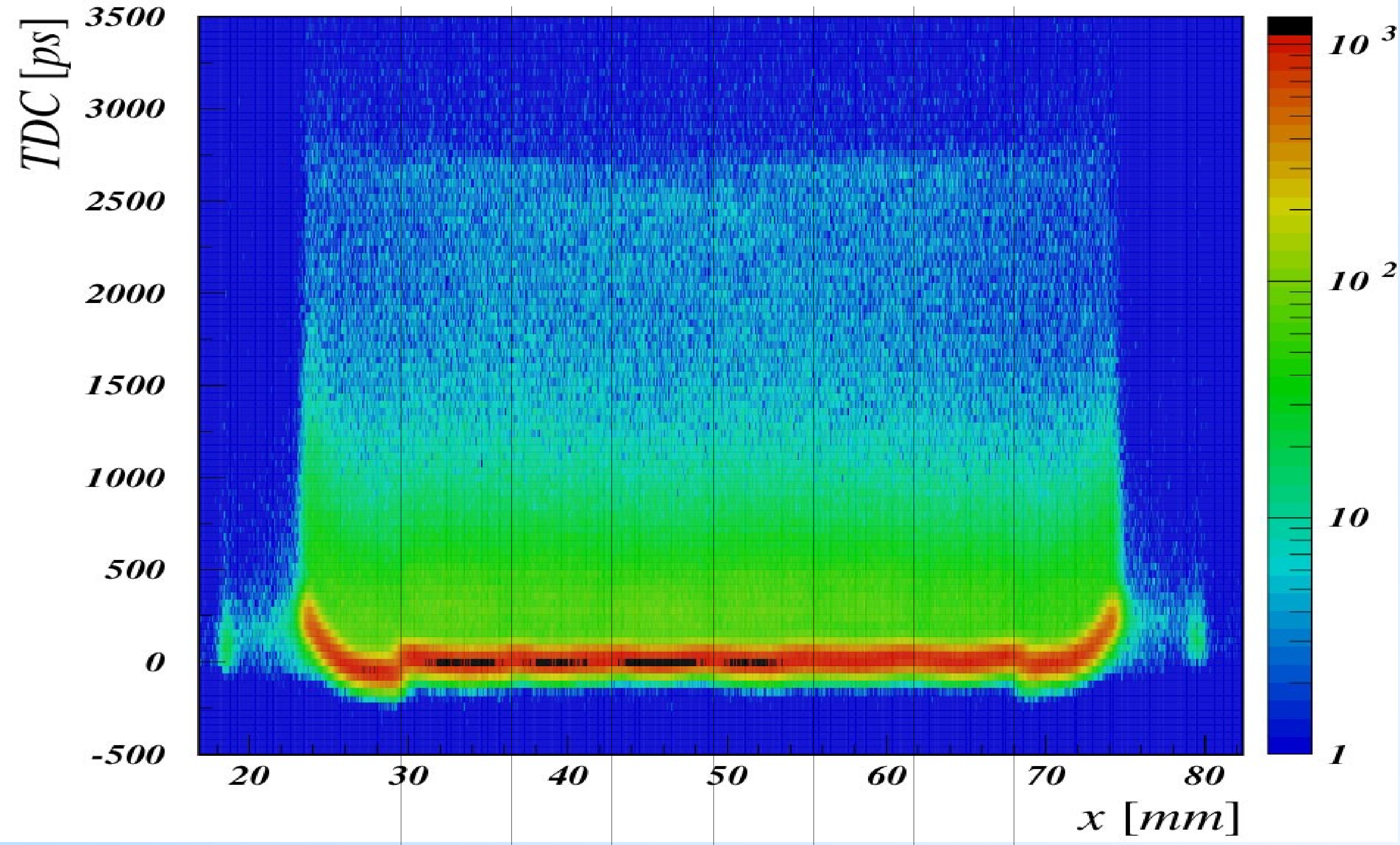






8x8: Timing uniformity

- TDC vs. x distribution for all channels



σ = 50.4 46.5 43.8 40.5 45.3 44.4 46.5 53.4 ps

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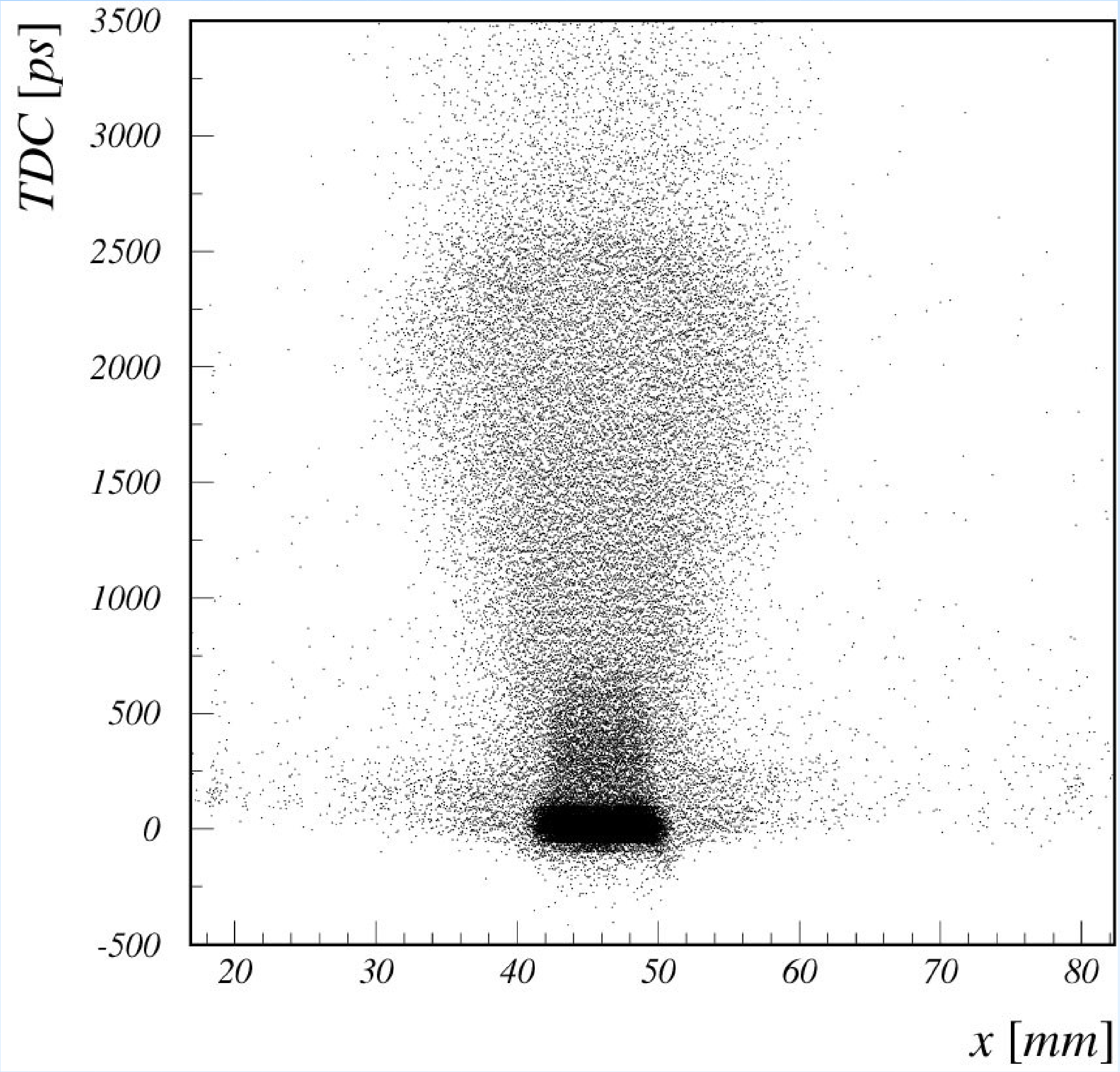
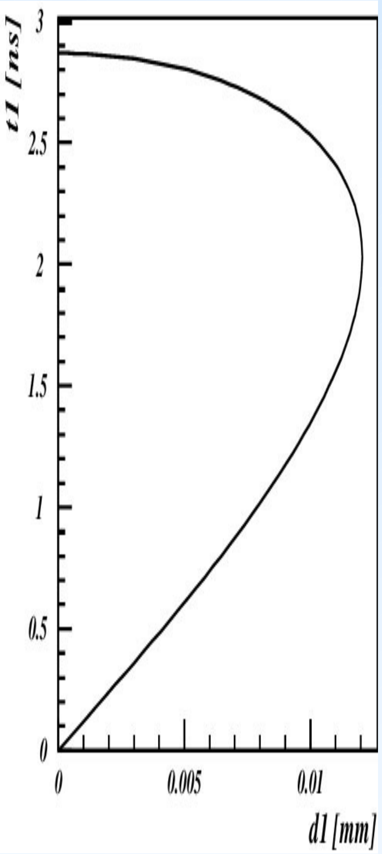
8x8: TDC vs. x

- TDC vs. x for pad in the middle





Summary and Plan

• A setup has been built to test position dependence of detection efficiency and time resolution with pico-second diode laser.
• 4 and 64 channel BURLE MCP-PMTs were tested with single photon pulses.
• Time resolution of prompt single photon signals is around 40 ps and deteriorates at the edge of active area and pad boundaries.

Plan:
• Use the red laser head (635nm) – smaller initial photo-electron energy.
• Test with multi photon pulses.
• Test with simultaneous hits on different channels.
• Measure optical cross-talk (photon scatering)
• Test in magnetic field ...

BACKUP SLIDES

Possible cross-talk sources:

- electron backscattering (max signal, delayed)
- charge sharing (not-max/max, prompt signal)
- electronics (position independent)
- induced charge (position dependant) ?
- photon scattering/reflections ?

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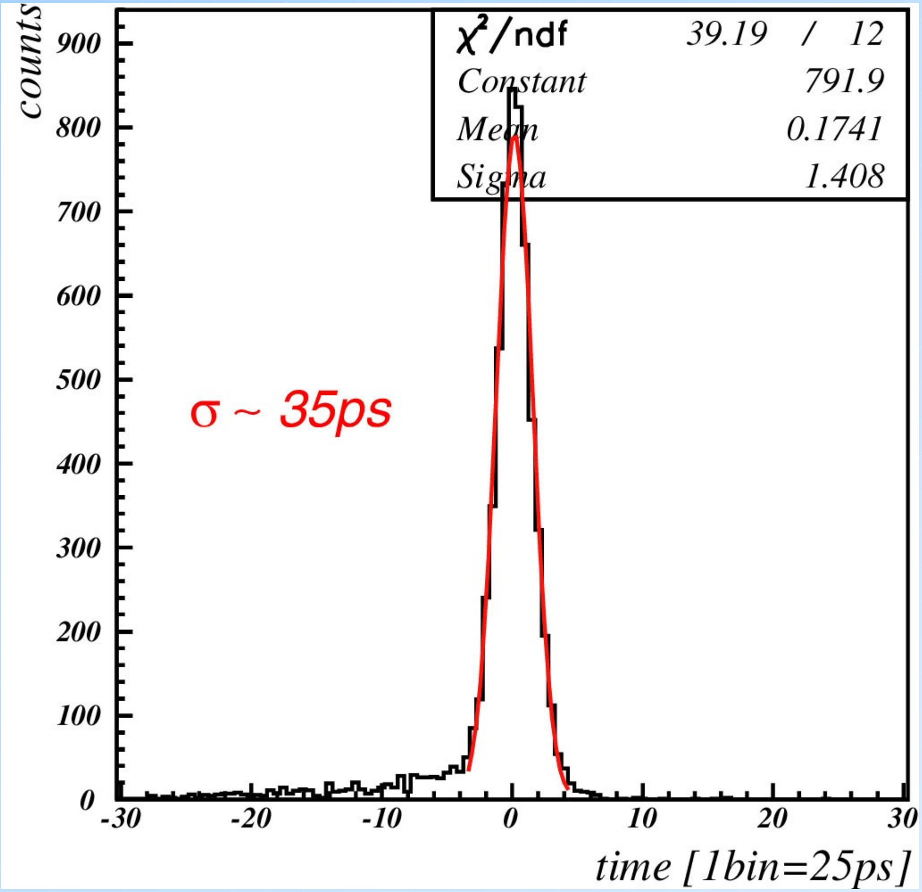
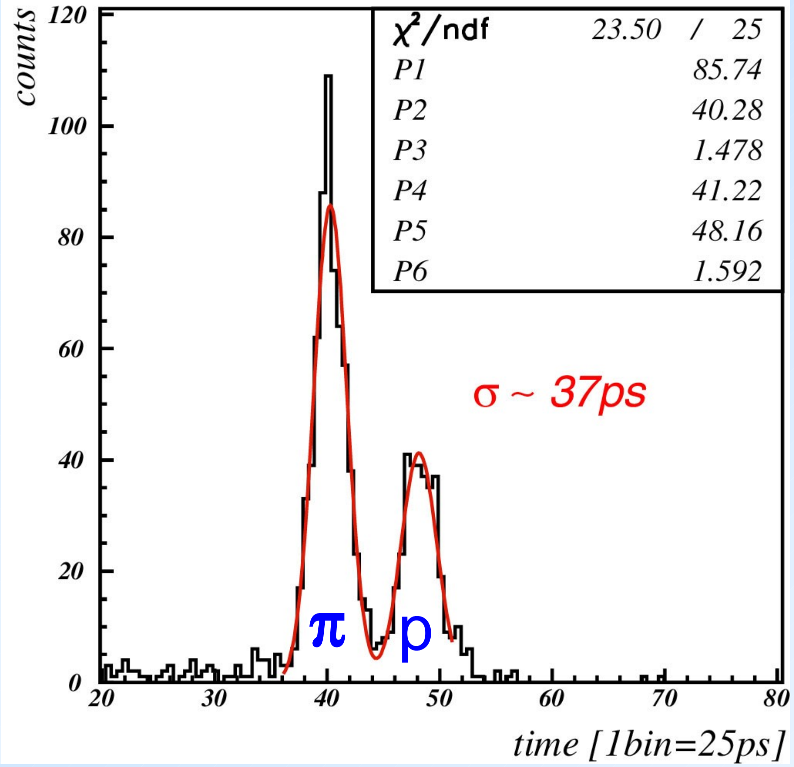
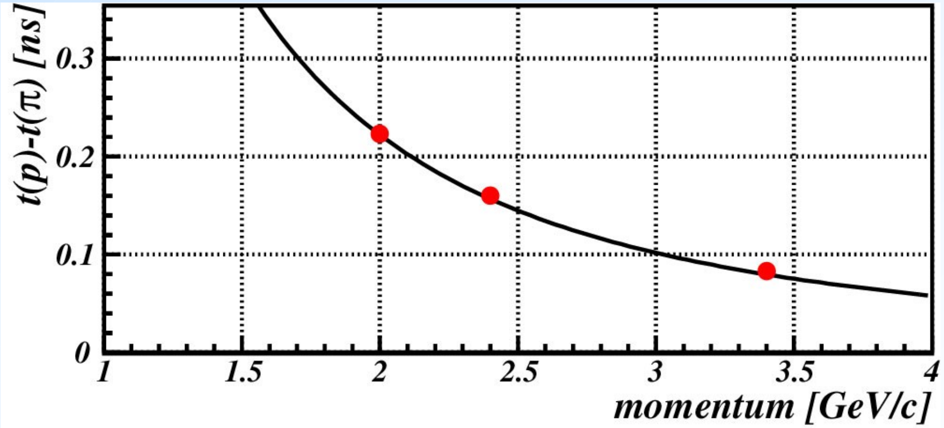
TOF: WINDOW PHOTONS

- expected number of detected Cherenkov photons emitted in the PMT window(2mm) is ~ 12 and expected resolution ~ 32 ps
- obtained resolution for window photons is ~ 35ps





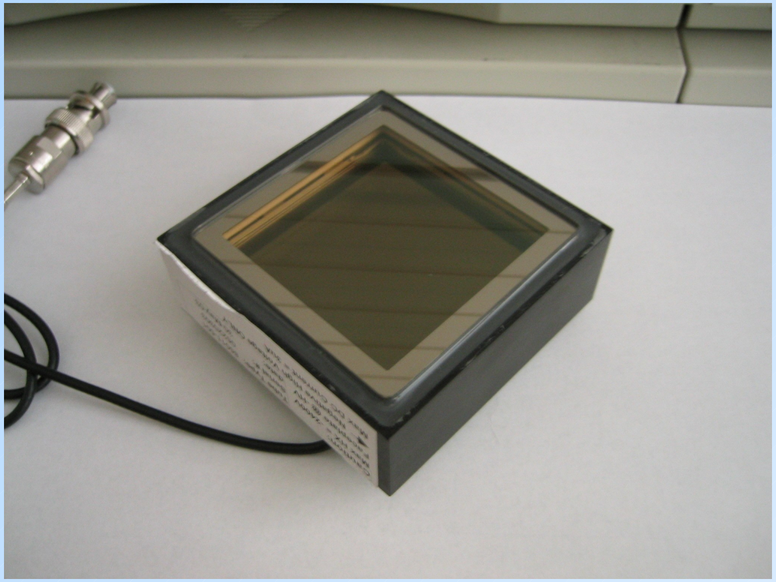
- TOF test with pions and protons at 2 GeV/c
- distance between start counter and MCP-PMT is 65cm

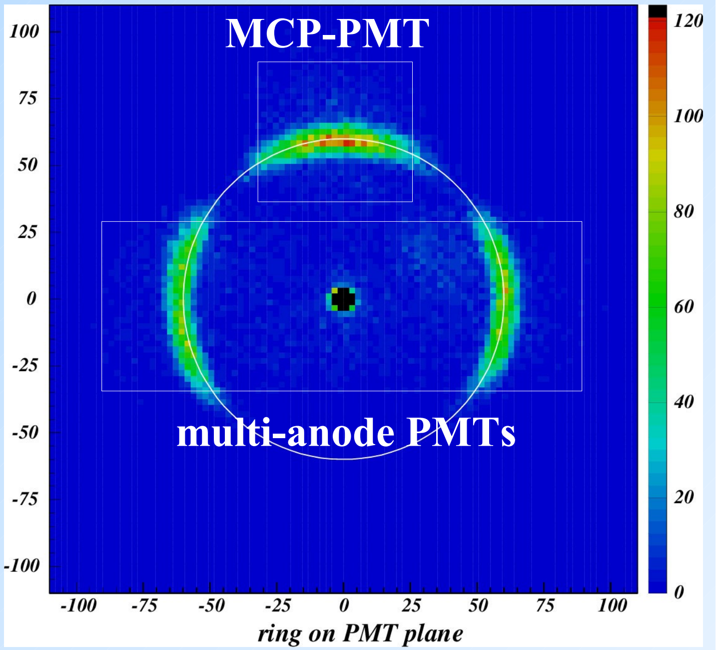


PHOTON DETECTION WITH MCP-PMT

BURLE 85011-501 MCP-PMT:

- multi-anode PMT with two MCP steps
- 25 μm pores
- bialkali photocathode
- gain ~ 0.6 x 10^6
- collection efficiency ~ 60%
- box dimensions ~ 71mm square
- 64(8x8) anode pads
- pitch ~ 6.45mm, gap ~ 0.5mm
- active area fraction ~ 52%





- Tested in combination with multi-anode PMTs

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

- 10 μm pores required for 1.5T
- collection efficiency and active area fraction should be improved
- aging study should be done

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MCPPMT: photo-electron

$$v'_{0x} = v'_0 \cos(\alpha) \qquad v'_0 = \sqrt{\frac{2E_0}{m_e}}$$

$$v'_{0y} = v'_0 \sin(\alpha)$$

$$a = \frac{Ue_0}{lm_e}$$

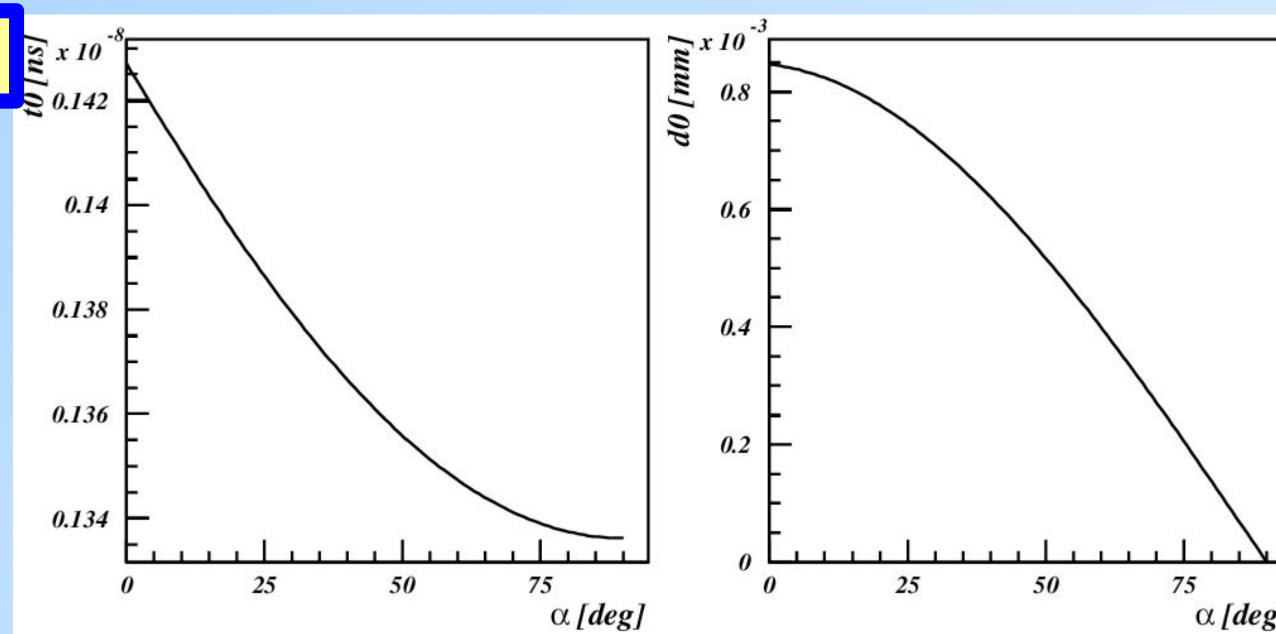
$$v_0 = \sqrt{\frac{2(E_0 + Ue_0)}{m_e}}$$

$$v_{0x} = \sqrt{\frac{2E_0 \cos^2(\alpha)}{m_e}}$$

$$v_{0y} = \sqrt{\frac{2(E_0 \sin^2(\alpha) + Ue_0)}{m_e}}$$

$$d_0 \approx 2l\sqrt{\frac{E_0}{U e_0}} \cos(2\alpha)$$

$$t_0 \approx \sqrt{\frac{2 m_e l^2}{U e_0}}$$



Generated distributions assuming that photo-electron is emitted uniformly over the solid angle