Institut "Jožef Stefan", Ljubljana, Slovenija

Photodetectors and sensors for particle identification and new physics searches
22 November 2023 @ CERN

Characterization of LAPPD for RICH applications

Rok Pestotnik

On belhaf of Ljubljana Photon detector group:

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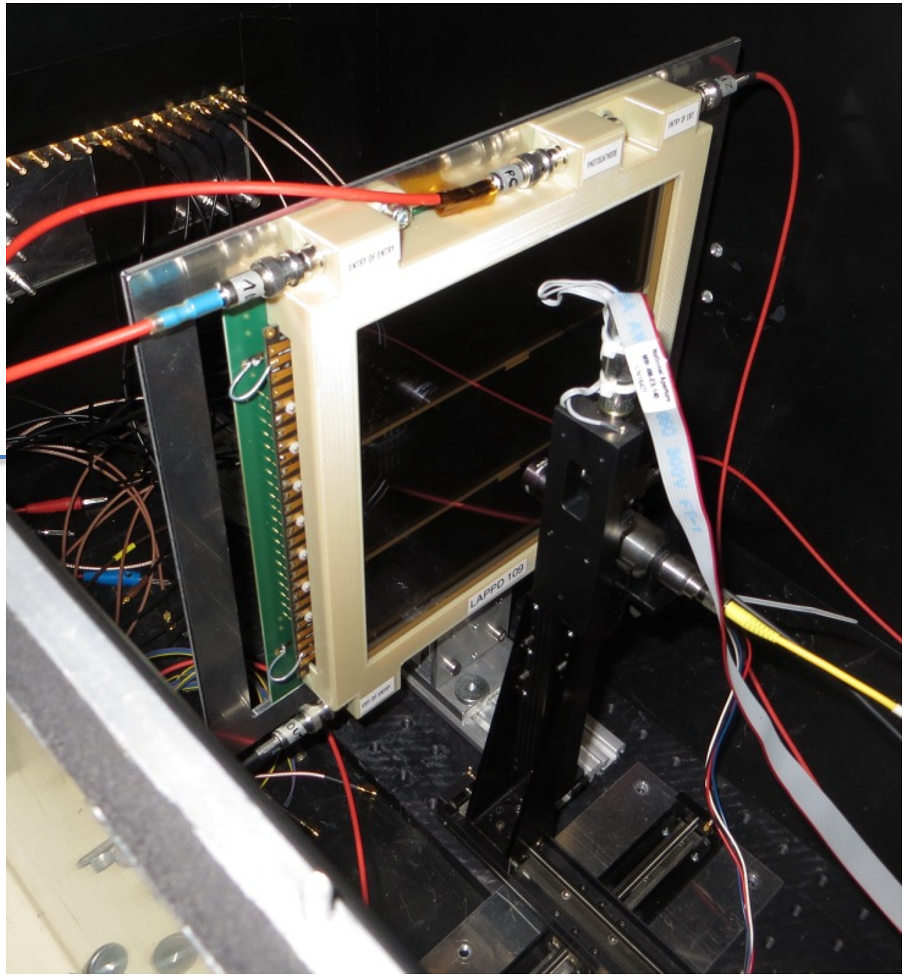
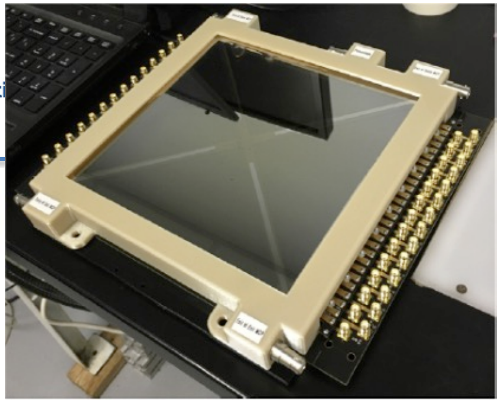


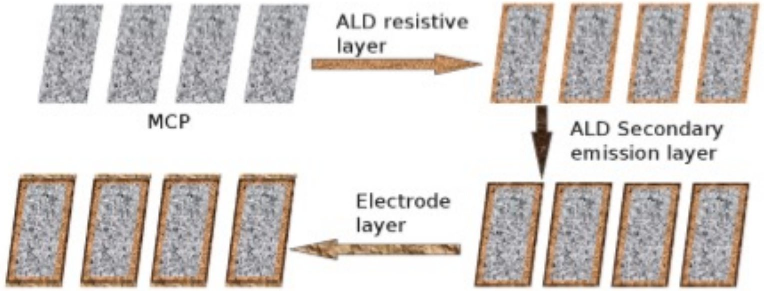
Outline

- Motivation
- Tests of the LAPDDs
- Timing distributions
- Charge distributions
- Charge sharing
- Test with multichannel ASICs: FastIC, PETSys

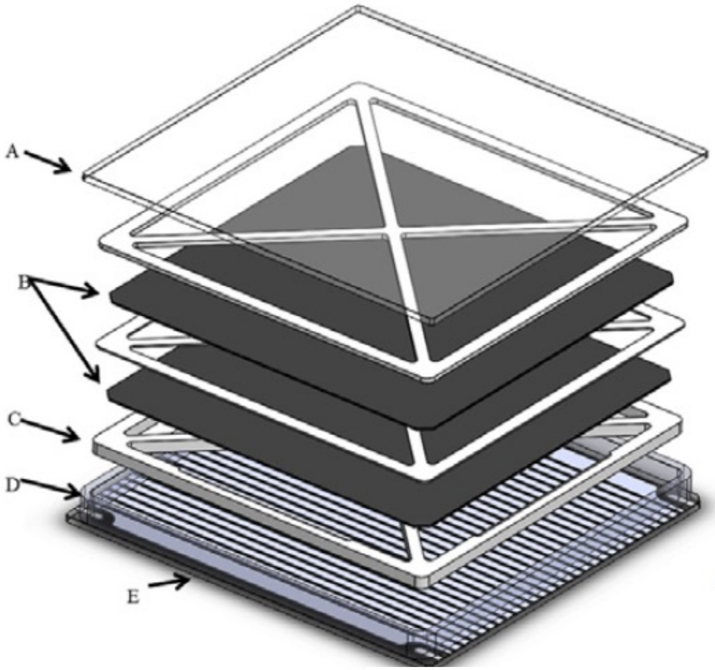
Large Area Picosecond Photodetector

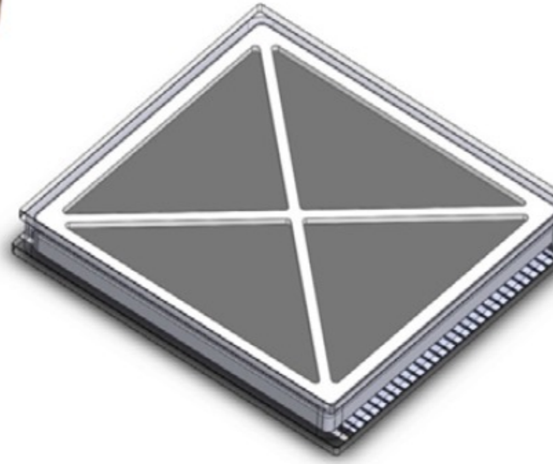


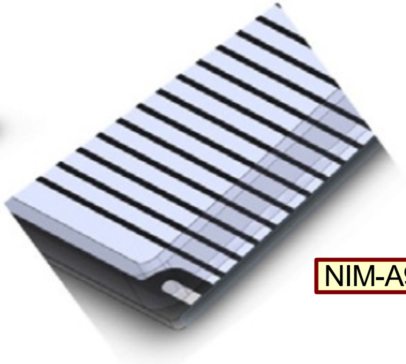
R&D started in 2009 led by a collaboration of universities
In **2014 Incom** Inc. founded to commercialize the device.
Main characteristics:
- chevron pair of ALD-GCA-MCPs
- large area 203 mm x 203 mm
- ~ 195 mm x 195 mm active area
- > 90 % active fraction (spacers)
- lower cost per area (50 k$ ▸ ~20 k$ for large orders?)



Consists of several layers separated by spacers (C):
- fused silica glass window with Multi-Alkali (K2NaSb) photocathode (A)
- two MCP layers in chevron configuration (B)
- back plate with anode (D):
    - Gen-I: direct coupled - segmented into 5.2 mm strips with 1.7 mm gap (50 Ohm impedance)
    - Gen-II: resistive anode plain with capacitive coupled readout electrode - custom







NIM-A936(2019)148

Aerogel RICH @ Belle II

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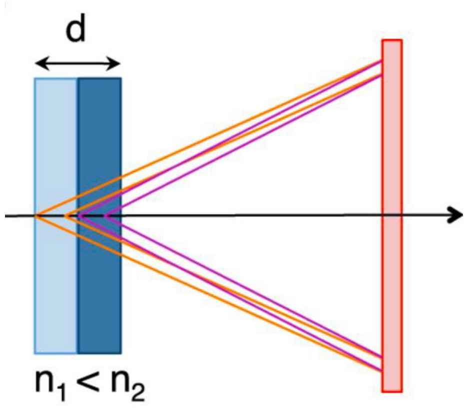
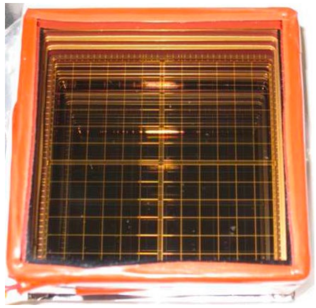
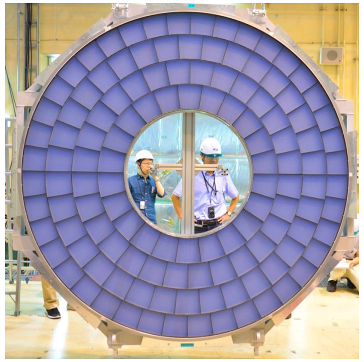
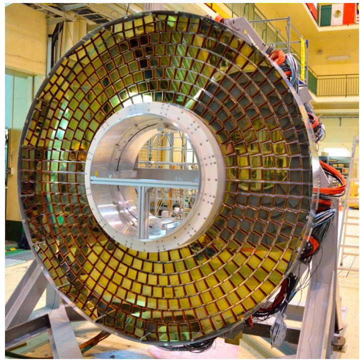


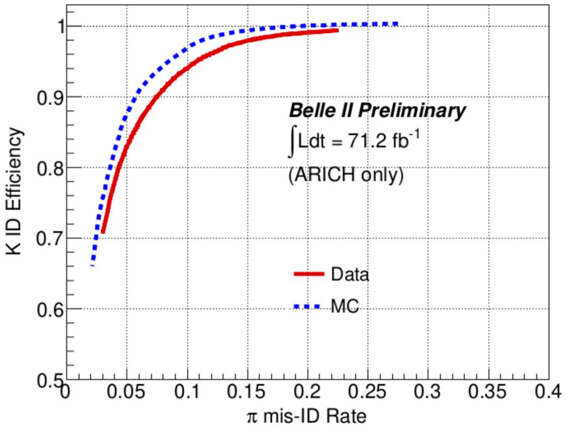
- double layer focusing aerogel radiator (20+20 mm)
- 160 mm expansion gap
- photon detector : 420 HAPDs - Hybrid Avalanche Photo Detectors







ARICH K efficiency vs. π misidentification probability



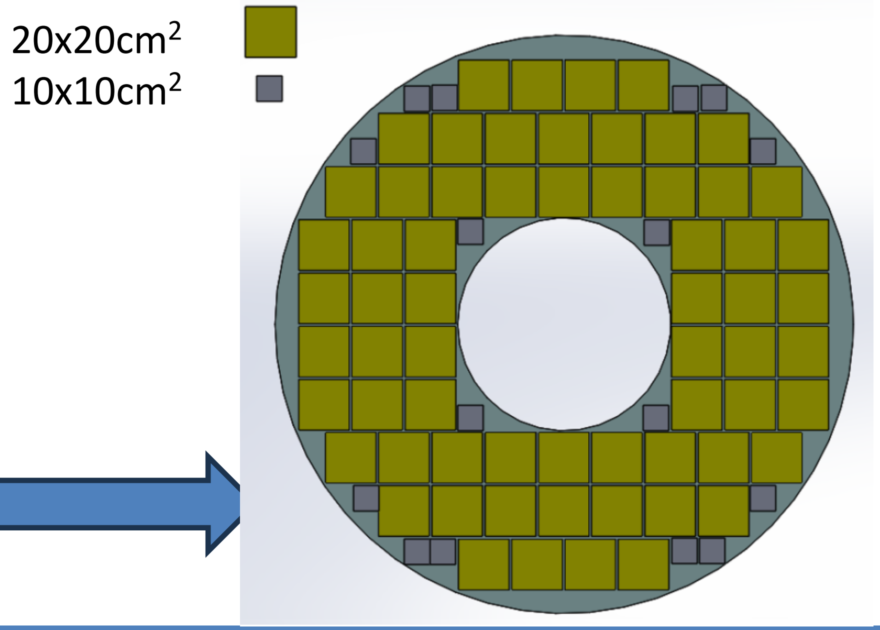
Belle III ~2033

Proposal: increase the luminosity 5x

- Higher backgrounds
- HAPD – accumulated dose too high - will not be able to operate
- Search for new technologies:
  Candidates: SiPM, MCP-PMT

LAPPDs?

Possible LAPPD tiling scheme



LHCb RICH (1 and 2) Upgrade II

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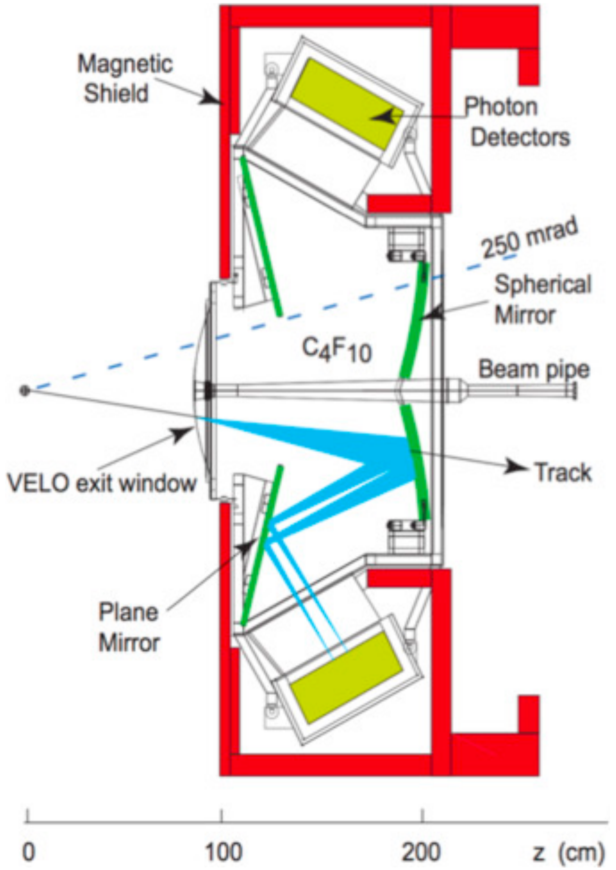
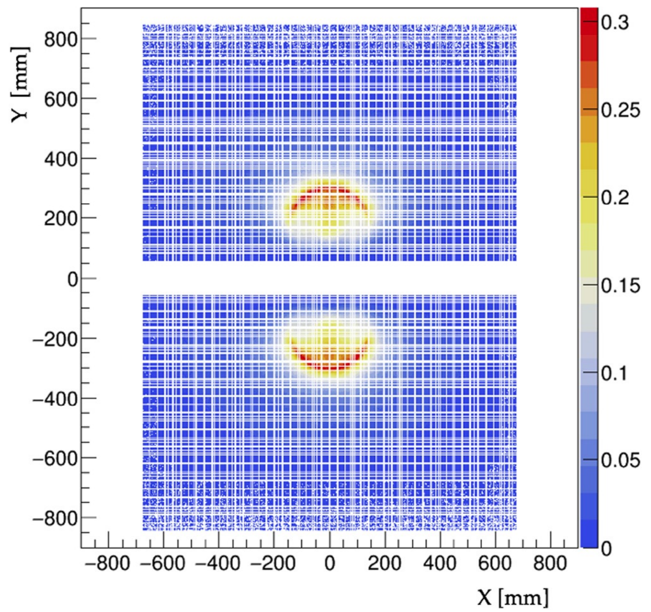
Standard RICH design

- Gas radiator
- Focusing optics
- Single photon detectors



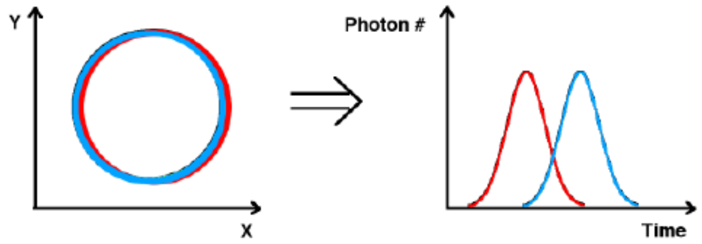
- Keep peak Occupancies
  - (time and space) < 30%
- Improve Single Photon Ch. Angle resolution < 0.5 mrad



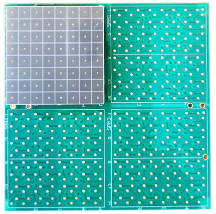
Replace currently installed MAPMTs with SiPMs with good timing resolution

Requirements

- **A lot of pixels -> Photodetectors and assoc. electronics**
  - Pixel size ~ $1mm^2$
- 40 MHz interaction rate
- An excellent lens -> Optical and gas systems
- A fast and precise shutter -> Gating and time resolution ~ 150ps
- High PDE in green to reduce dispersion



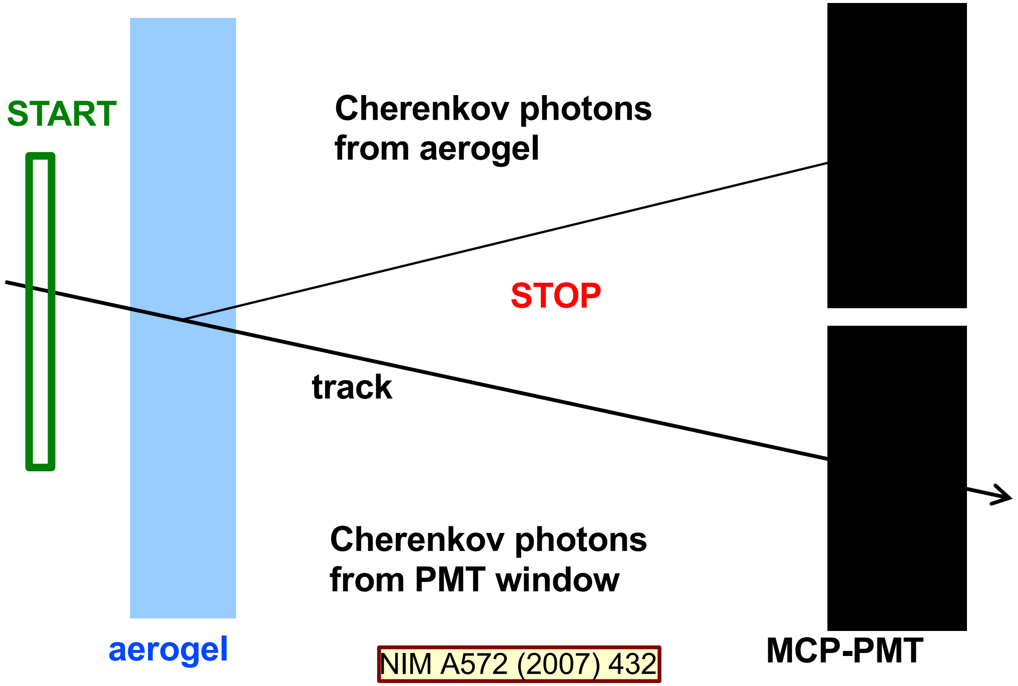
Separate space overlapping events



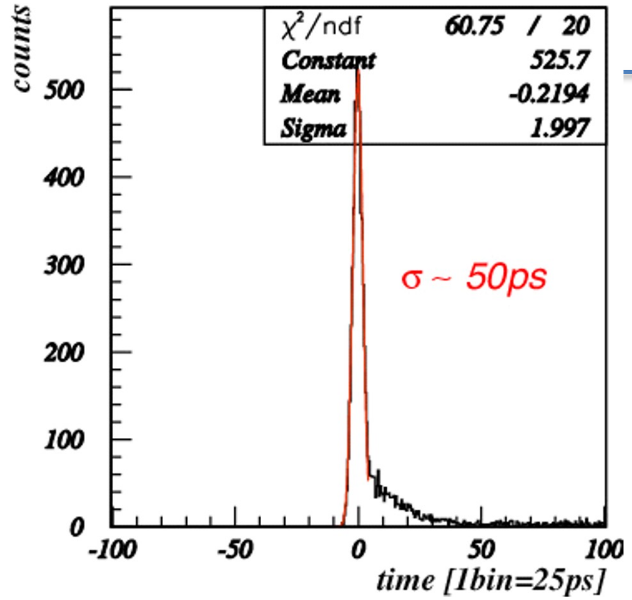
Baseline Upgrade 2 design:
SiPM + FastRICH RO chip (FastIC family)
Can LAPPDs serve as a suitable candidate?

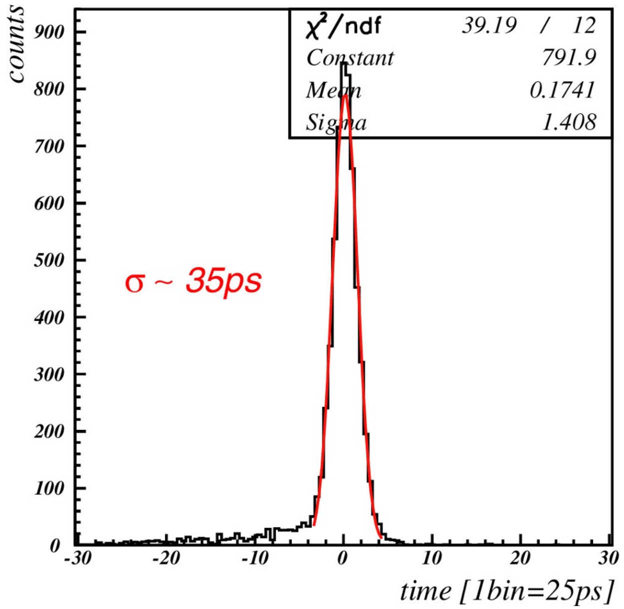
Belle II ARICH R&D: Photonis MCP-PMT

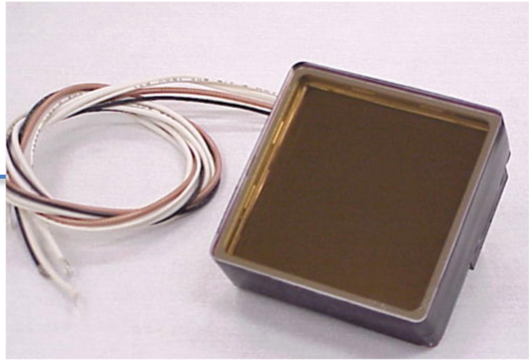
Model 85015/A1:
- two MCP steps - chevron configuration
- 8x8 anode pads @6.5 mm pitch, gap ~ 0.5mm
- bialkali photocathode
- gain ~ 0.6 x 10^6 (@2400V)
- 10μm pores → operates up to 1.5 T
- size ~ 59mm
- effective area fraction ~ 80%
- excellent timing < 40ps - single photon
- window thickness 1.5mm

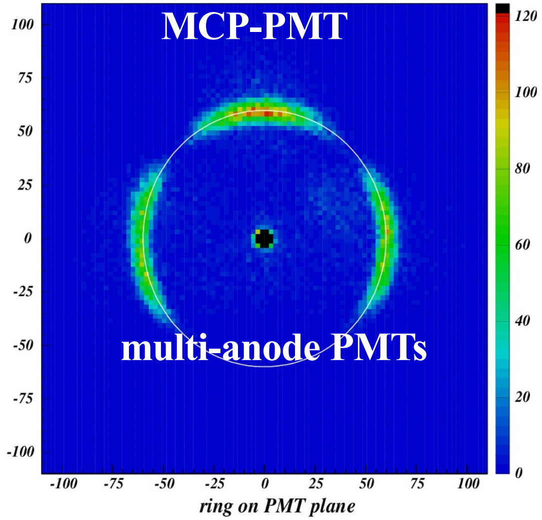


NIM A572 (2007) 432







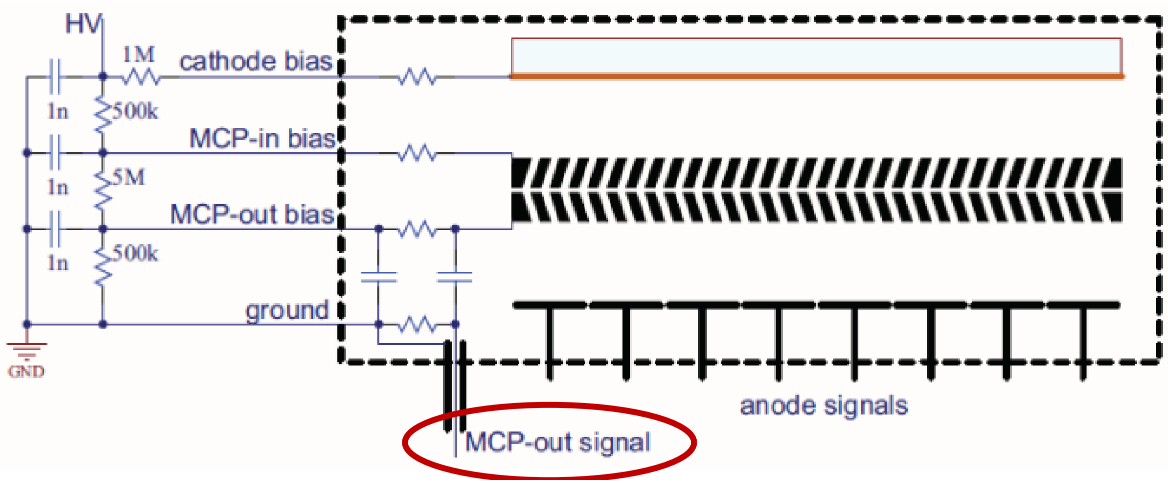


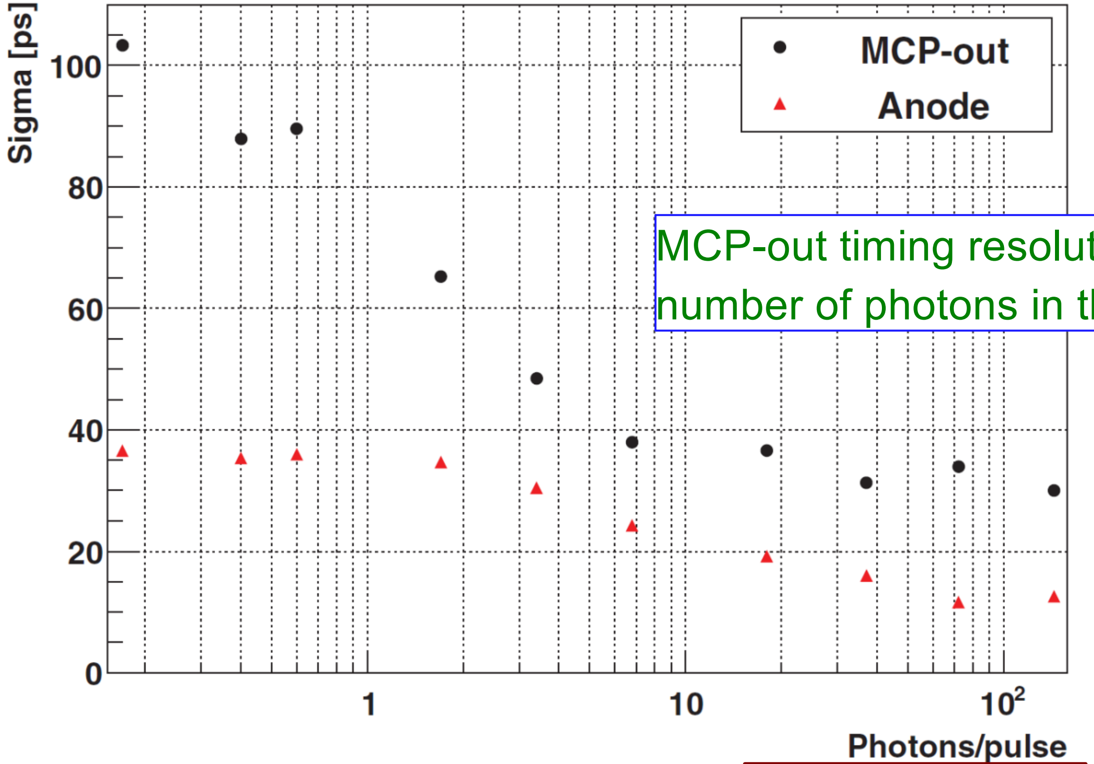
Beam test result of 25μm sample:
- σ_ϑ~13 mrad (single cluster)
- number of clusters per track N ~ 4.5
- σ_ϑ~ 6 mrad (per track)
- **→ ~ 4 σ π/K separation at 4 GeV/c**

NIM A567 (2006) 124

Single timing channel per module

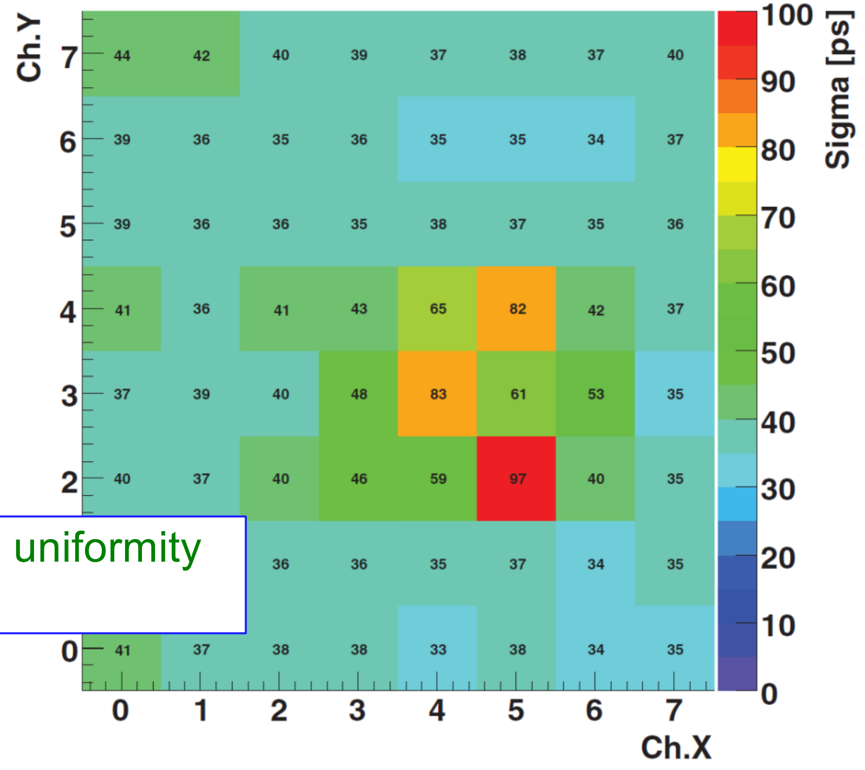
- electronics for Belle II ARICH + TOF could be simplified if a common electrode signal could be used for timing and signals from anode pads for position
- MCP-out signal was tested for common timing





IEEE NSS(2009) N25-136

MCP-out timing resolution vs. average number of photons in the laser pulse

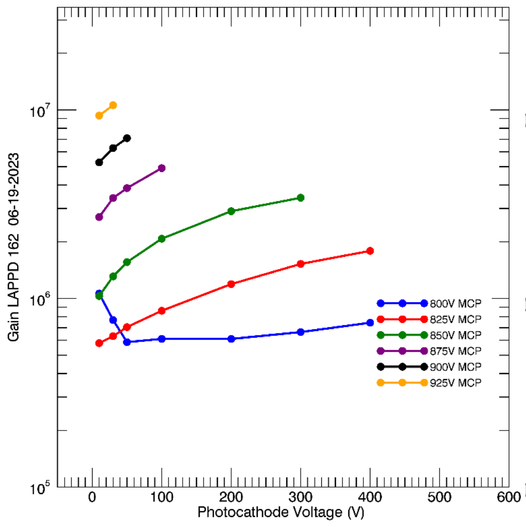


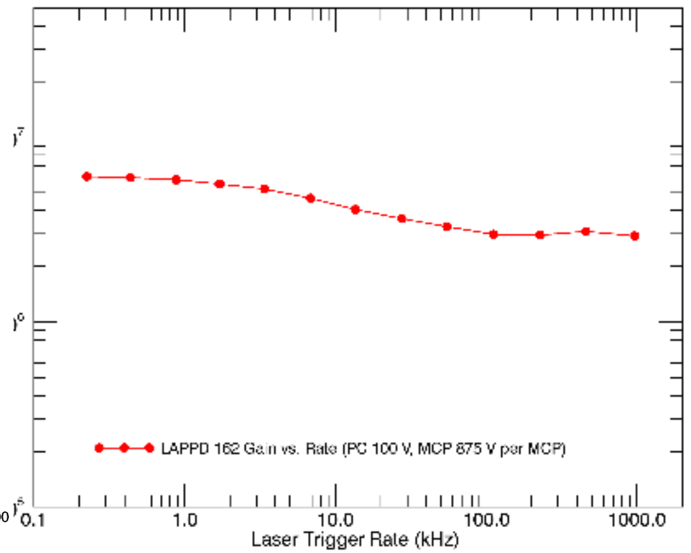
MCP-out timing resolution uniformity ≈ 10 photons

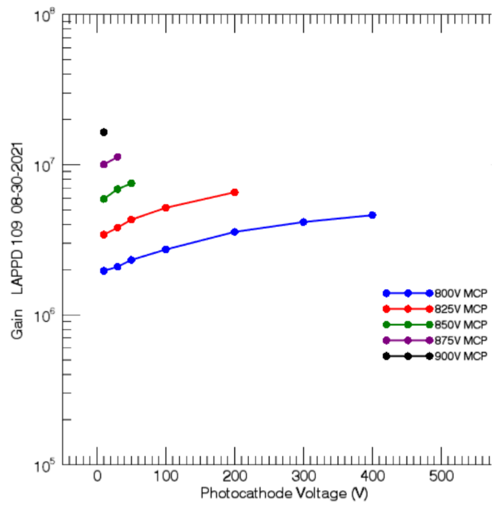
2 tested Samples
Gen II LAPPD #109 and #162

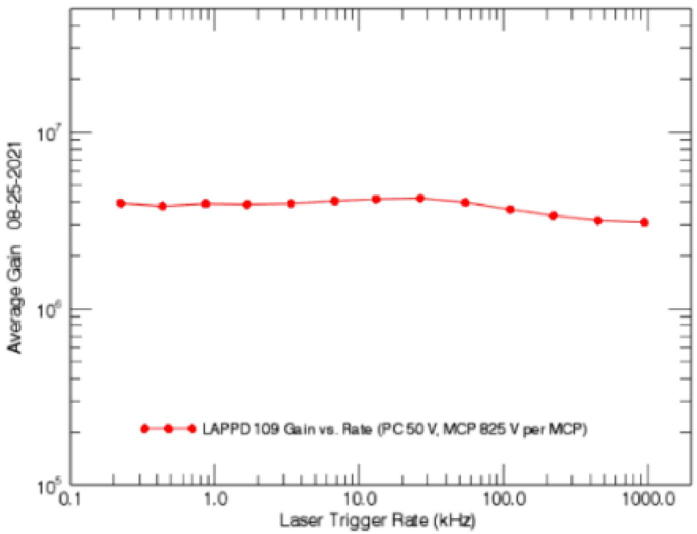
Characteristics (Incom):
- Size 230 mm x 220 mm x 22 mm
- fused silica glass window (5 mm), multi-alkali ph.cat. (Na_2KSb)
- peak QE (@365 nm)
  - #109 :≈ 27%
  - #162: ≈ 33%
- 2 MCPs: 13^o bias angle
  - #109: 20 μm pores at 25 μm pitch (>65% OAR)
  - #162: 10 μm pores at 13 μm pitch (>72% OAR),
- back plate with interior resistive ground plane anode –
  - #109 borosilicate – 5 mm thick
  - #162: ceramic - 2 mm thick
- capacitively coupled readout electrode
- two parallel spacers (active fraction ≈ 97 %)
- gain
  - #109: $\approx 5 \cdot 10^6$ @ ROP (825 V/MCP, 100 V/ ph.cathode)
  - #162: $\approx 4 \cdot 10^6$ @ ROP (875 V/MCP, 50 V/ ph.cathode)
- Dark Count rate at a threshold of 8x10^5 gain
  - #109: @ ROP: ~ 500 kHz/cm2
  - #162: @ ROP: ~ 400 Hz/cm2
- 5 HV levels: PC, MCP1in, MCP1out, MCP2in, MCP2out and resistive anode at ground potential

INCOM





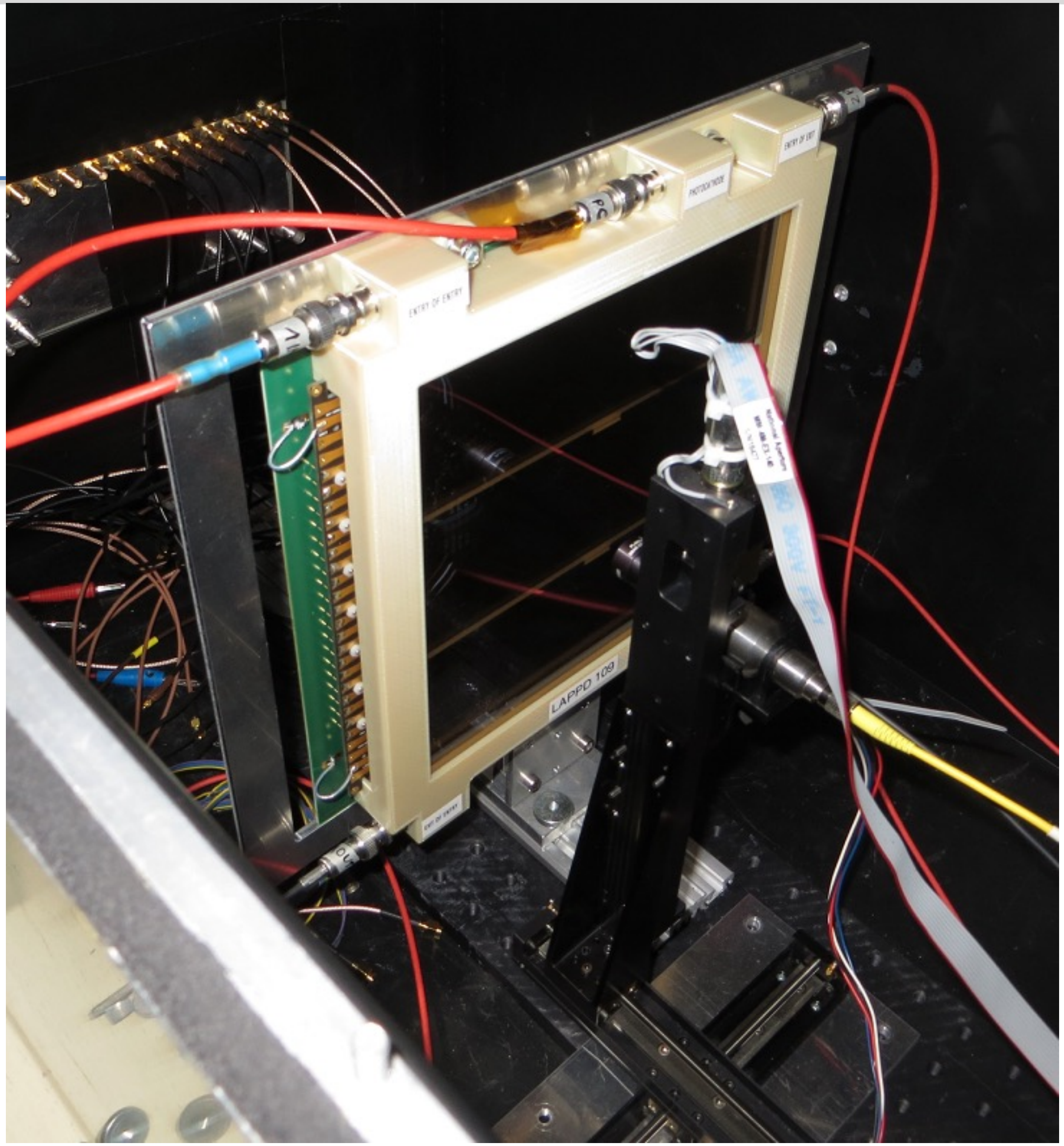




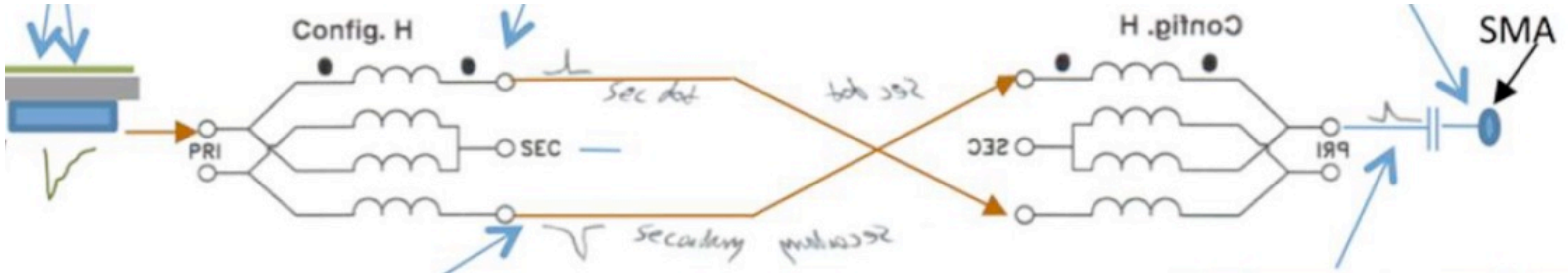
Experimental setup

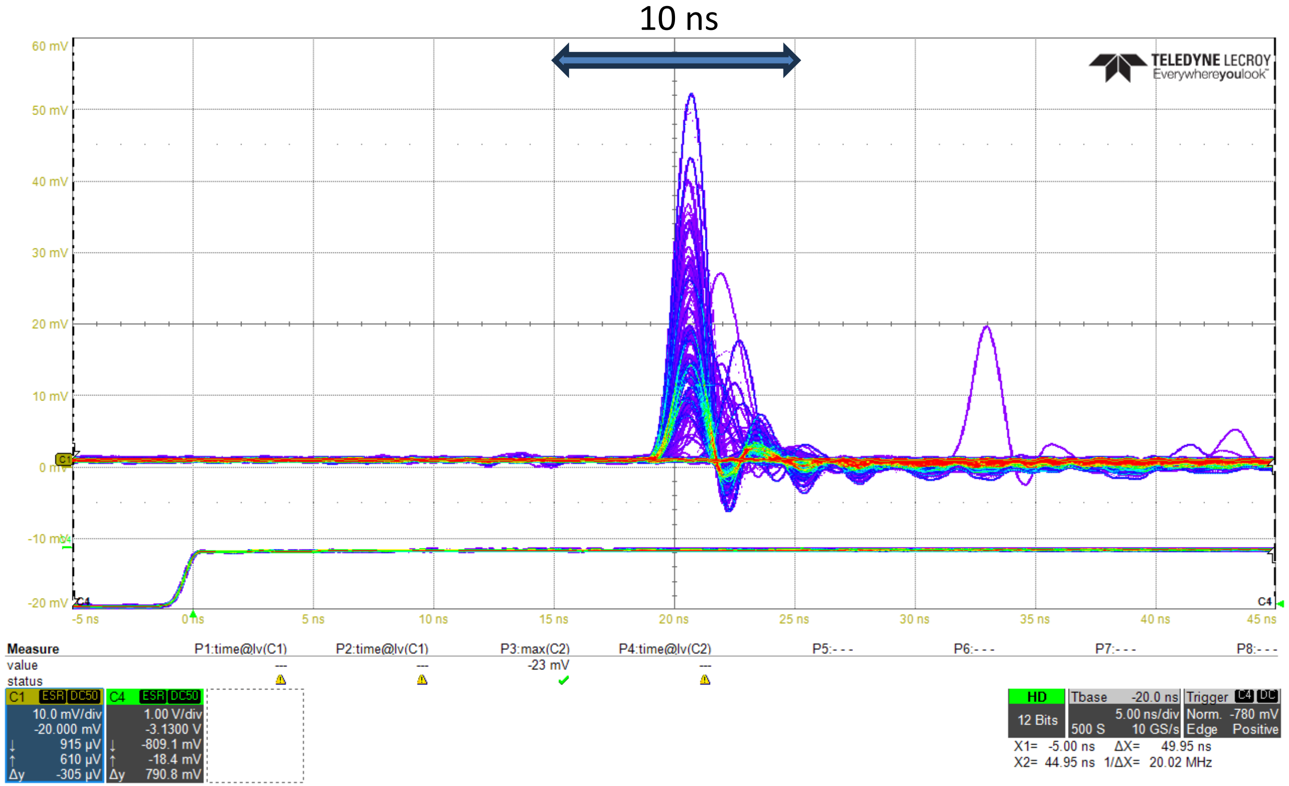
- Standard setup with QDC, TDC, 3D stage ...
- TDC value corrected for time-walk

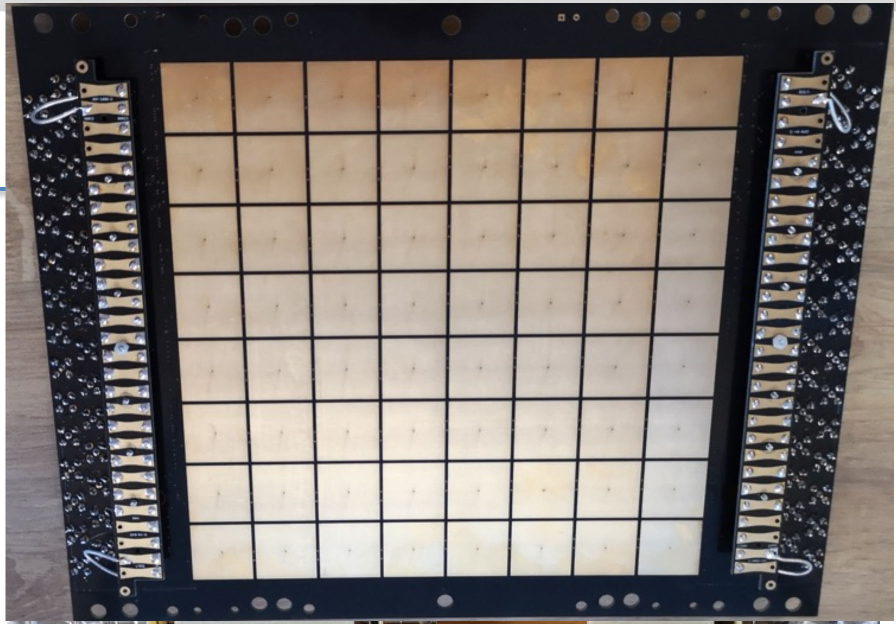
- ALPHALAS PICOPOWER™-LD Series of Picosecond Diode Lasers – 405 nm
- FWHM $\approx$ 20 ps
- light spot diameter on the order of $100\ \mu$m
- $\approx$ single photon light intensity

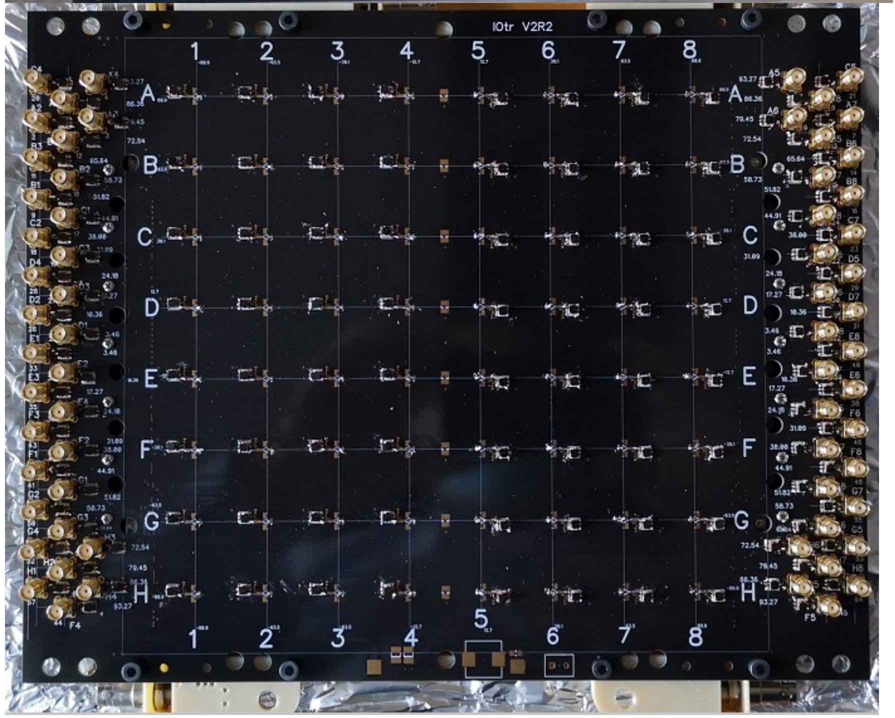


LAPPD – Incom sensing electrode



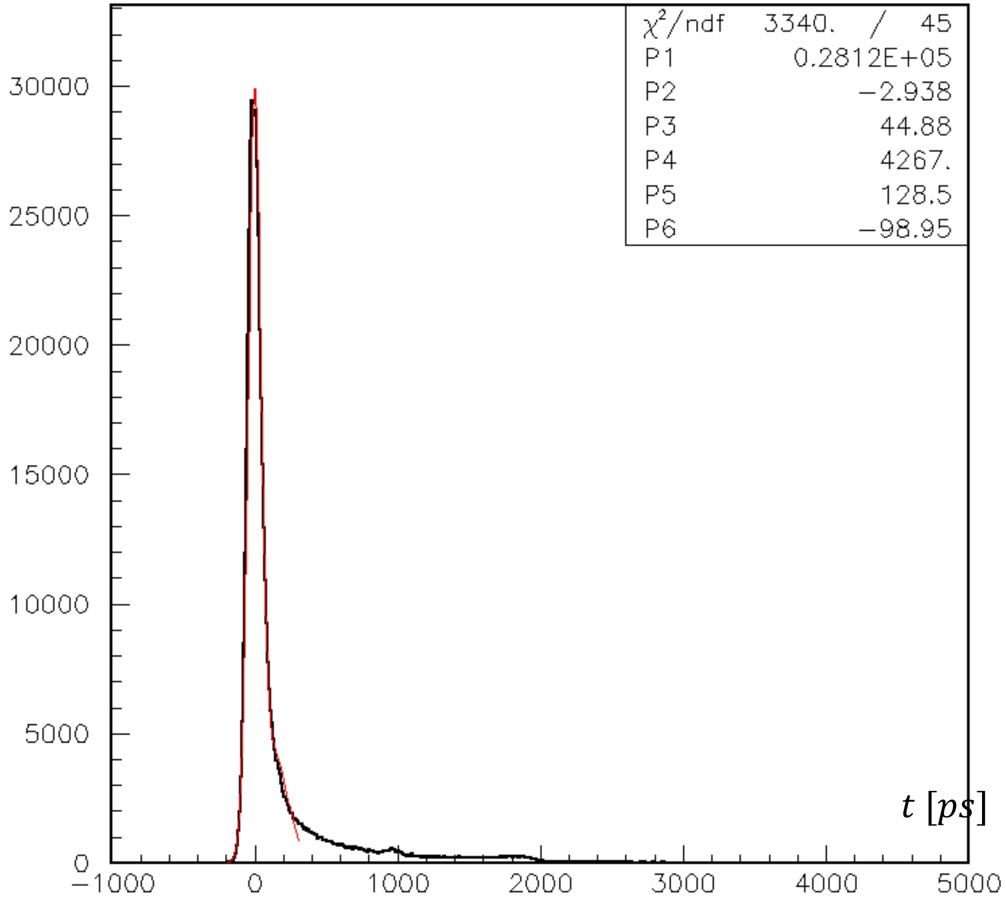


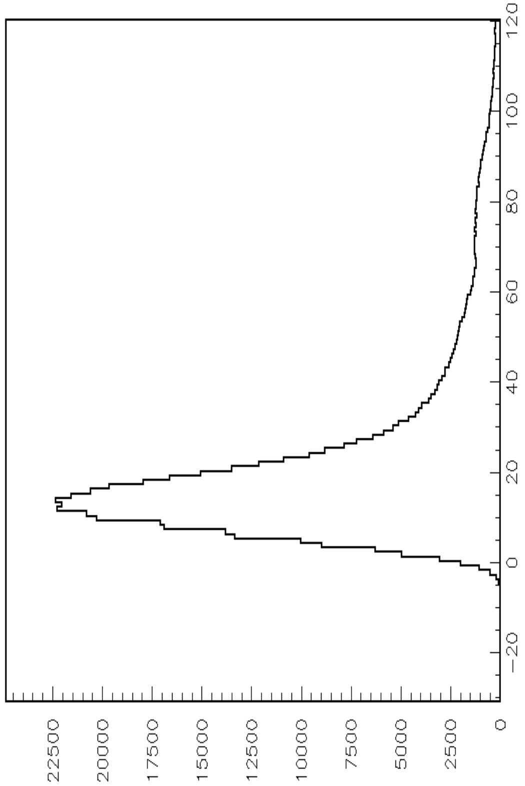


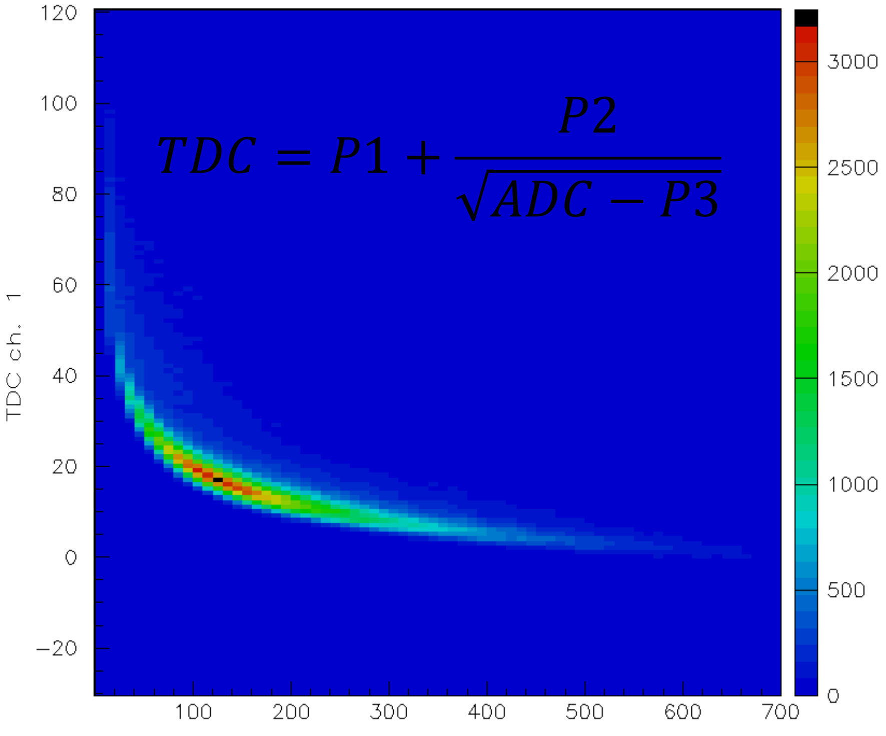


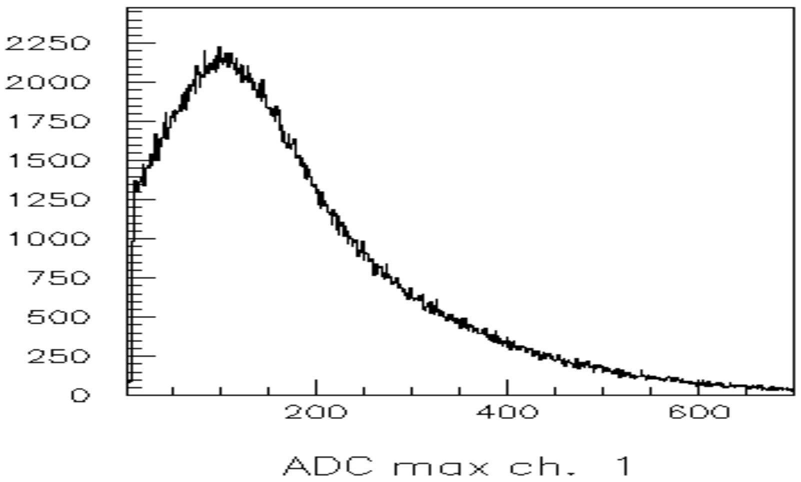
LAPPD – time-walk correction

- TDC corrected for time-walk
- timing resolution (prompt peak) $\sigma \approx 40$ ps after correction



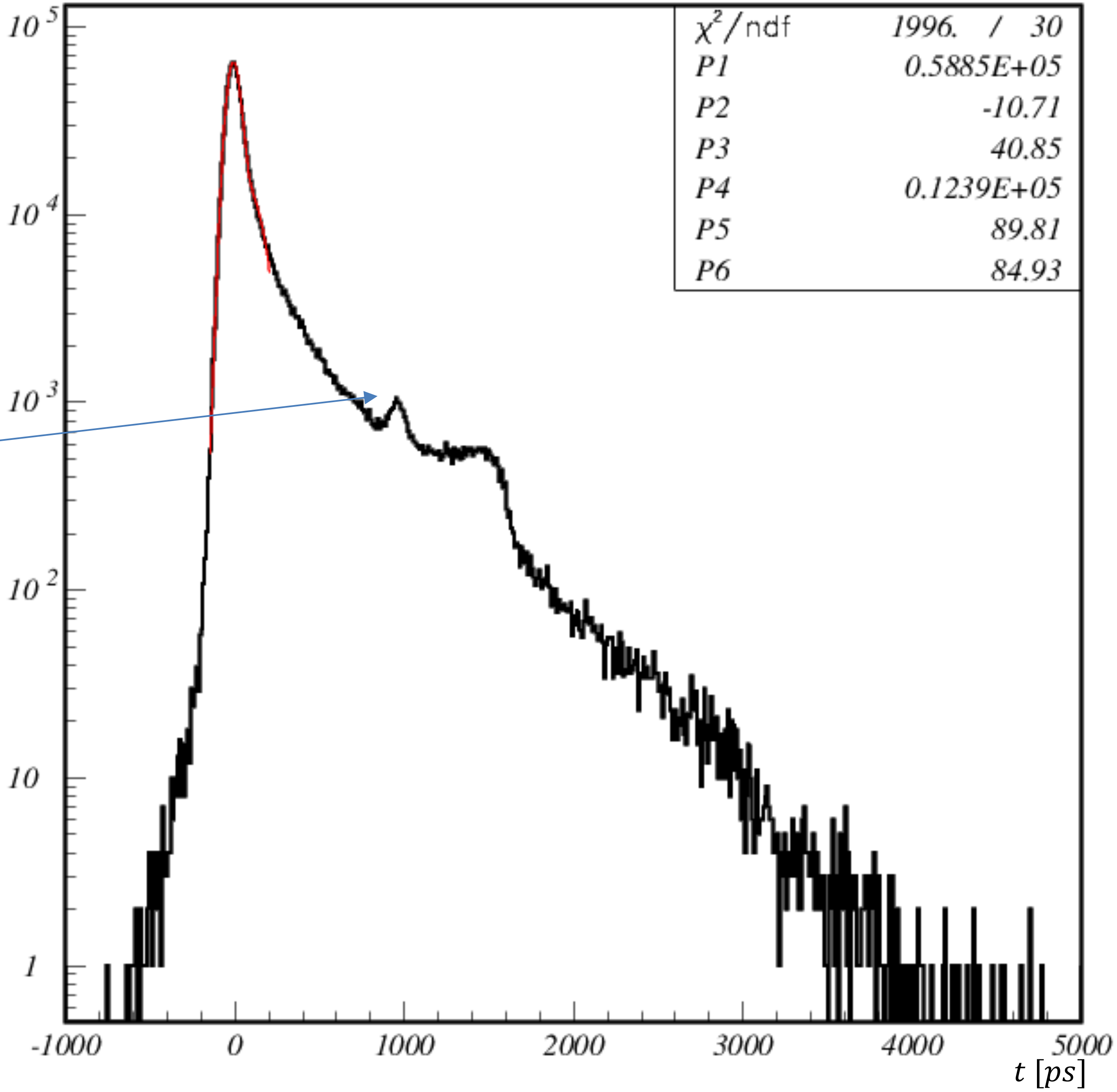






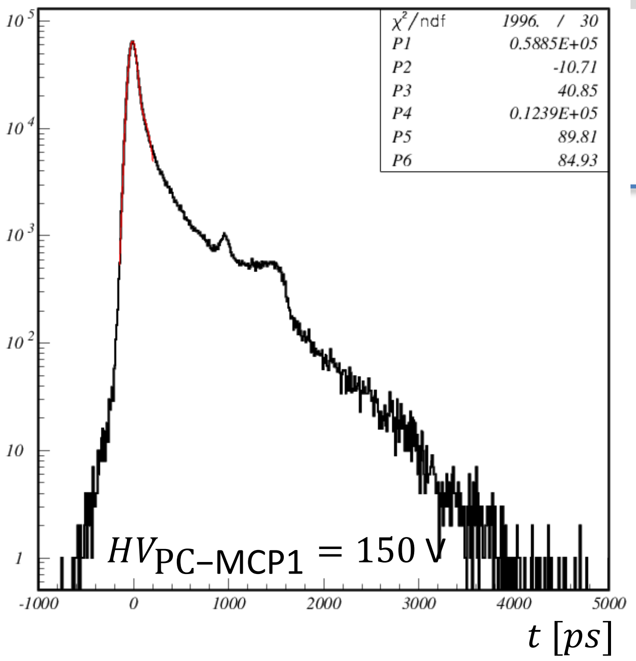
LAPPD – timing distribution

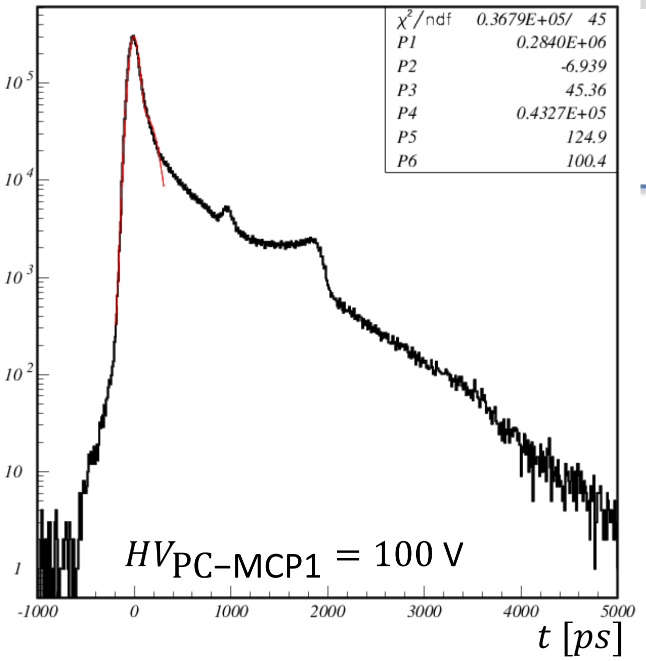
- measured timing distribution typical for MCP-PMT
- main prompt peak with some inelastic and elastic backscattering contribution
- additional small peak at about 1 ns delay probably due to some reflection (light?), delay not affected by PC-MCP1 voltage
- plot is for the PC-MCP1 voltage of 150 V and ROP for others

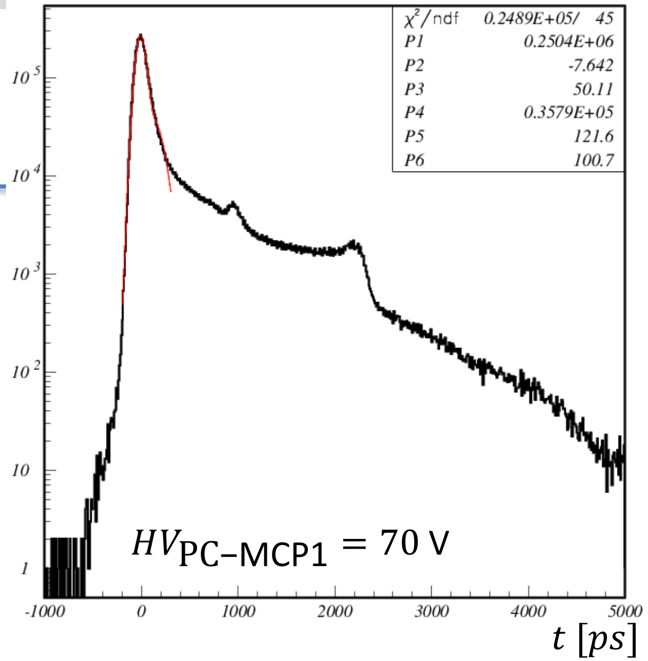


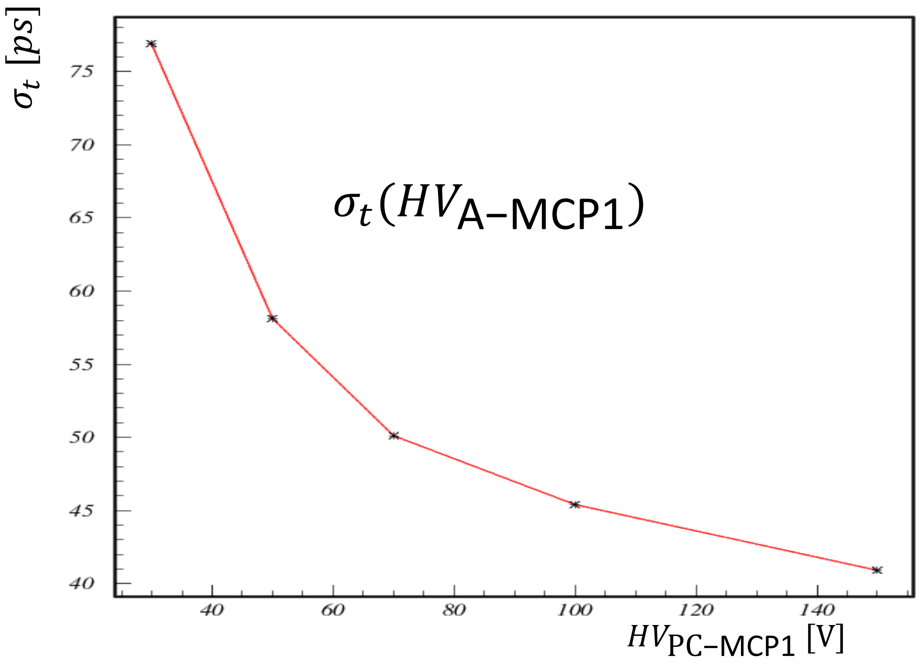
LAPPD – timing

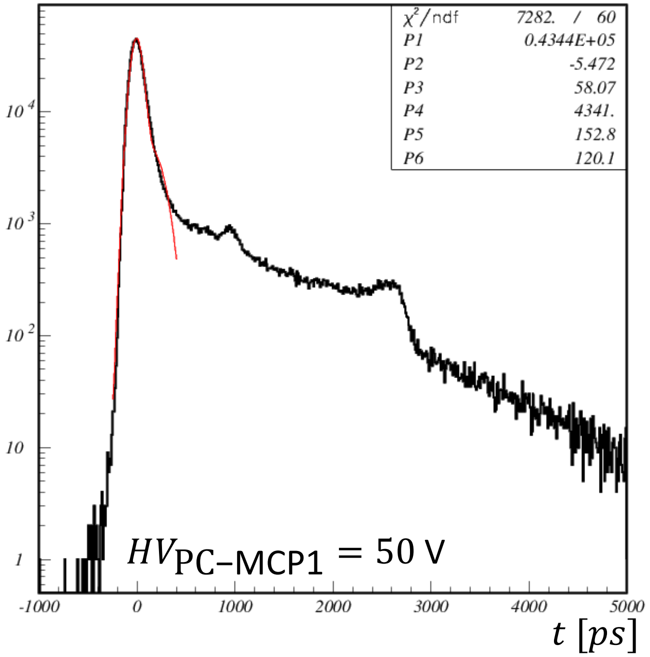
- corrected TDCs for several PC-MCP1 voltages
- time resolution vs PC-MCP1 voltage

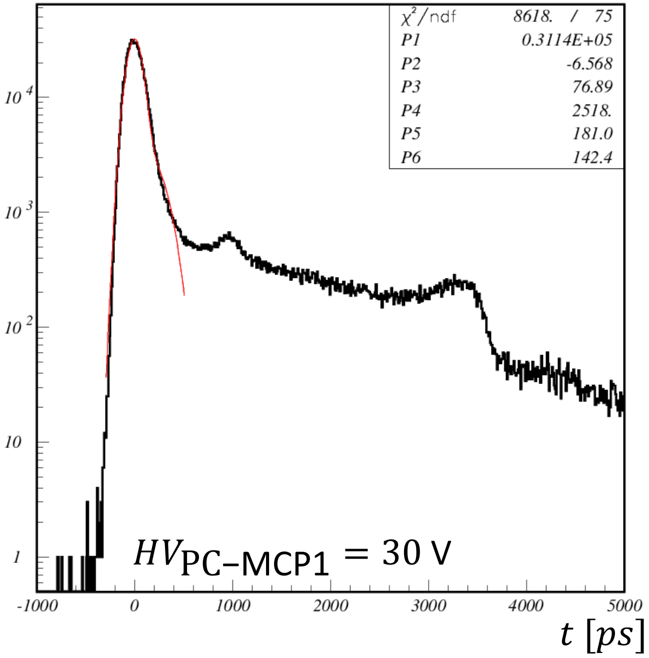






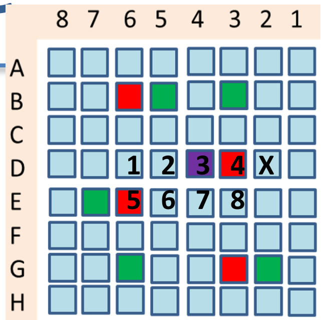


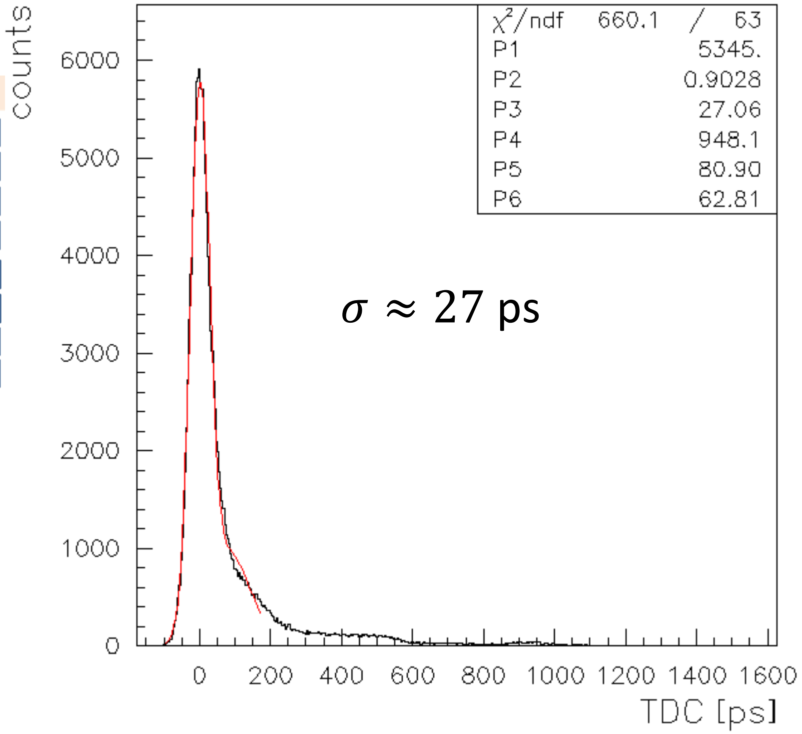


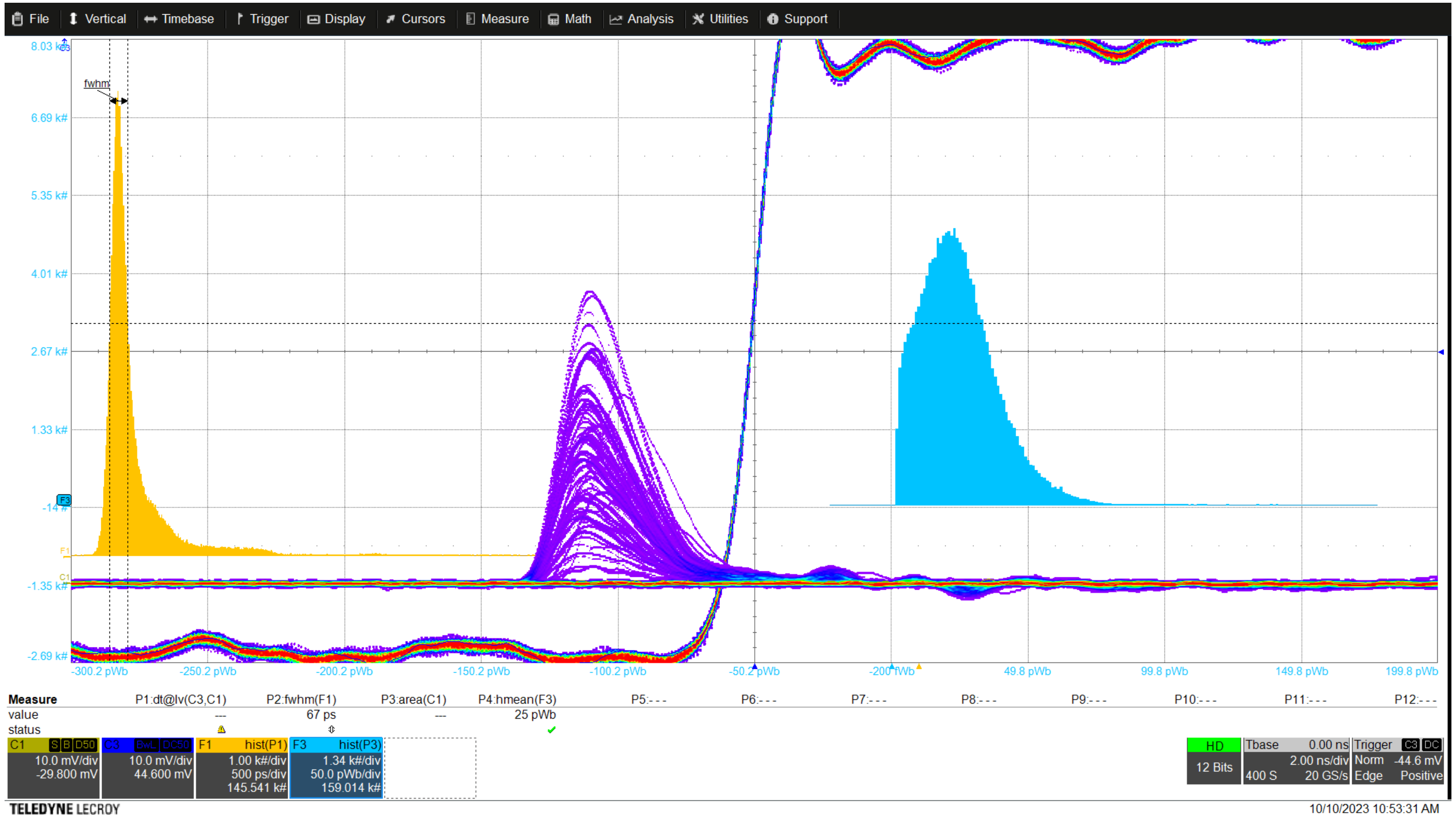


LAPPD #162 timing and signal charge

- oscilloscope screenshot with laser spot at the center of D2 pad
- TDC(yellow) and pulse integral(blue) histograms
- TDC main peak FWHM is 67 ps corresponding to sigma below 30 ps.
- Average pulse integral is 25 pVs -> ~ 3e6 electrons







- applied voltages and currents
- Anode-MCP2out, ... , MCP1in-PC (units V,uA)

VSet	VMon	IMon	ISet
200.00	200.18	0.3500	5.00
825.00	825.62	176.7500	200.00
200.00	200.22	0.0690	5.00
825.00	825.52	154.2340	200.00
200.00	199.98	0.0930	5.00

MCP-PMT: charge sharing

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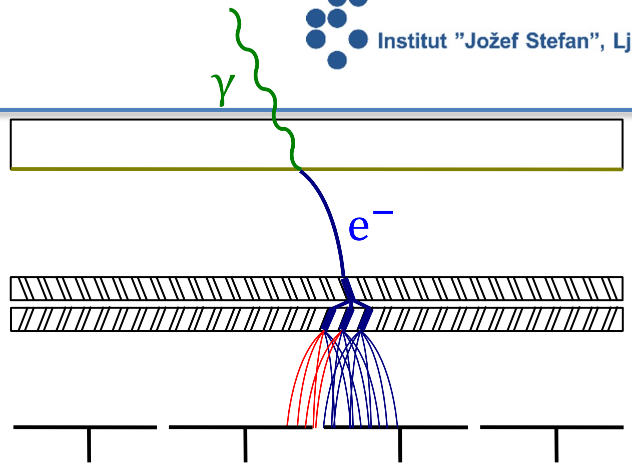
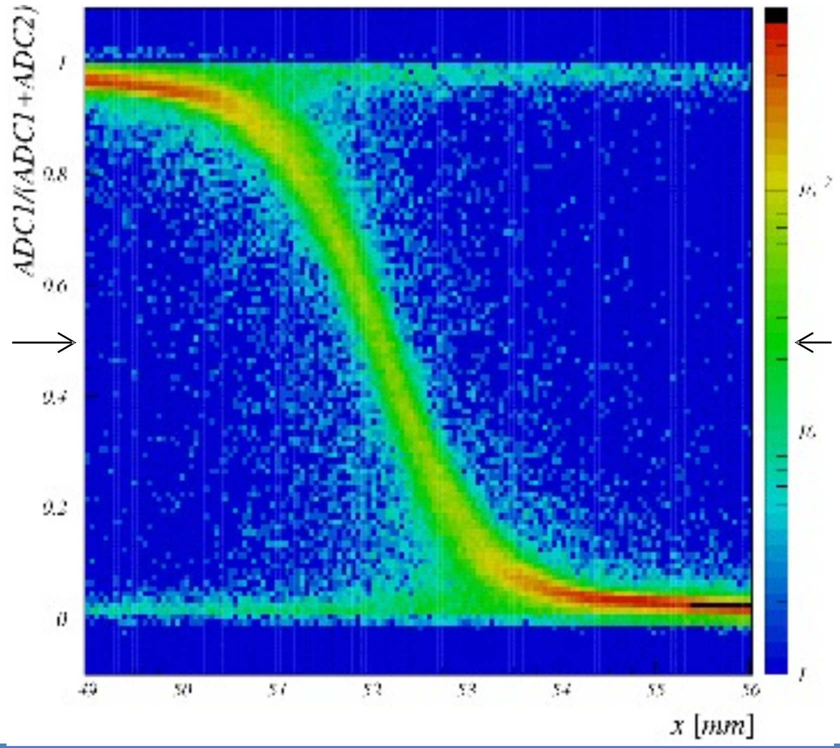
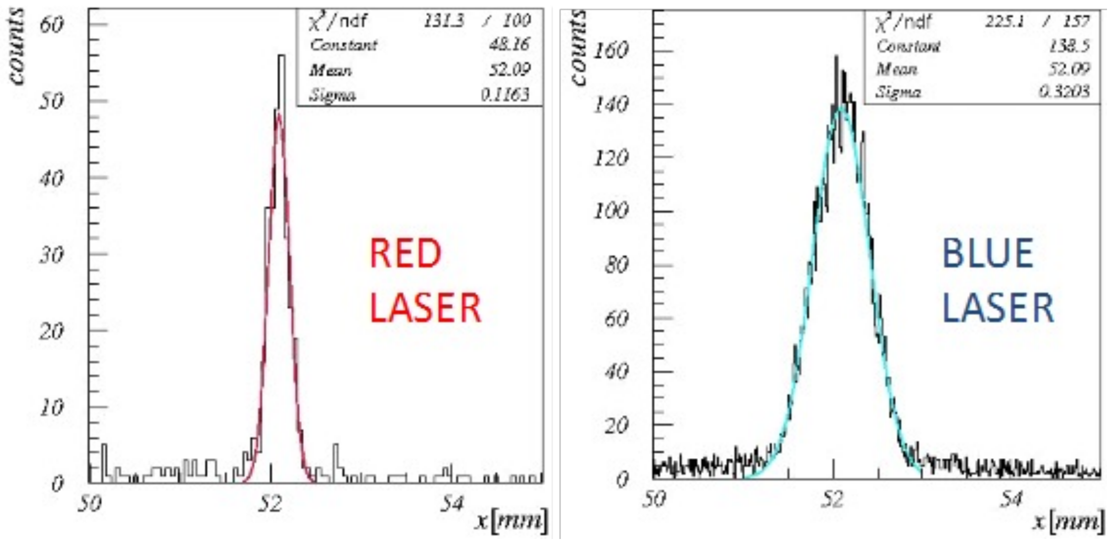
Secondary electrons spread when traveling from MCP out electrode to anode and can hit more than one anode → Charge sharing

Can be used to improve spatial resolution.



Fraction of the charge detected by left pad as a function of light spot position (red laser)





Slices at equal charge sharing for red and blue laser) – pad boundary. Resolution limited by photoelectron energy.

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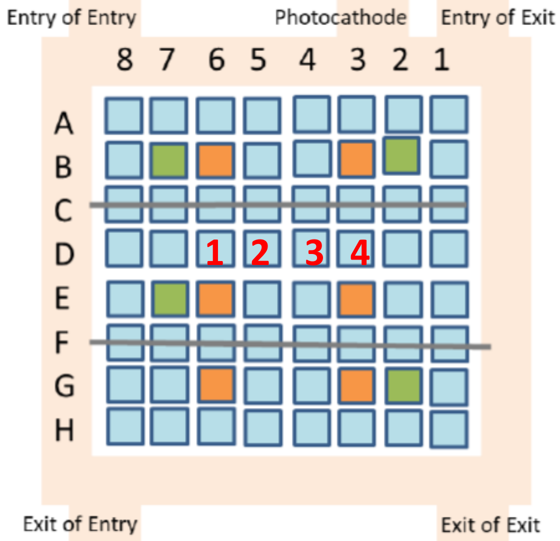
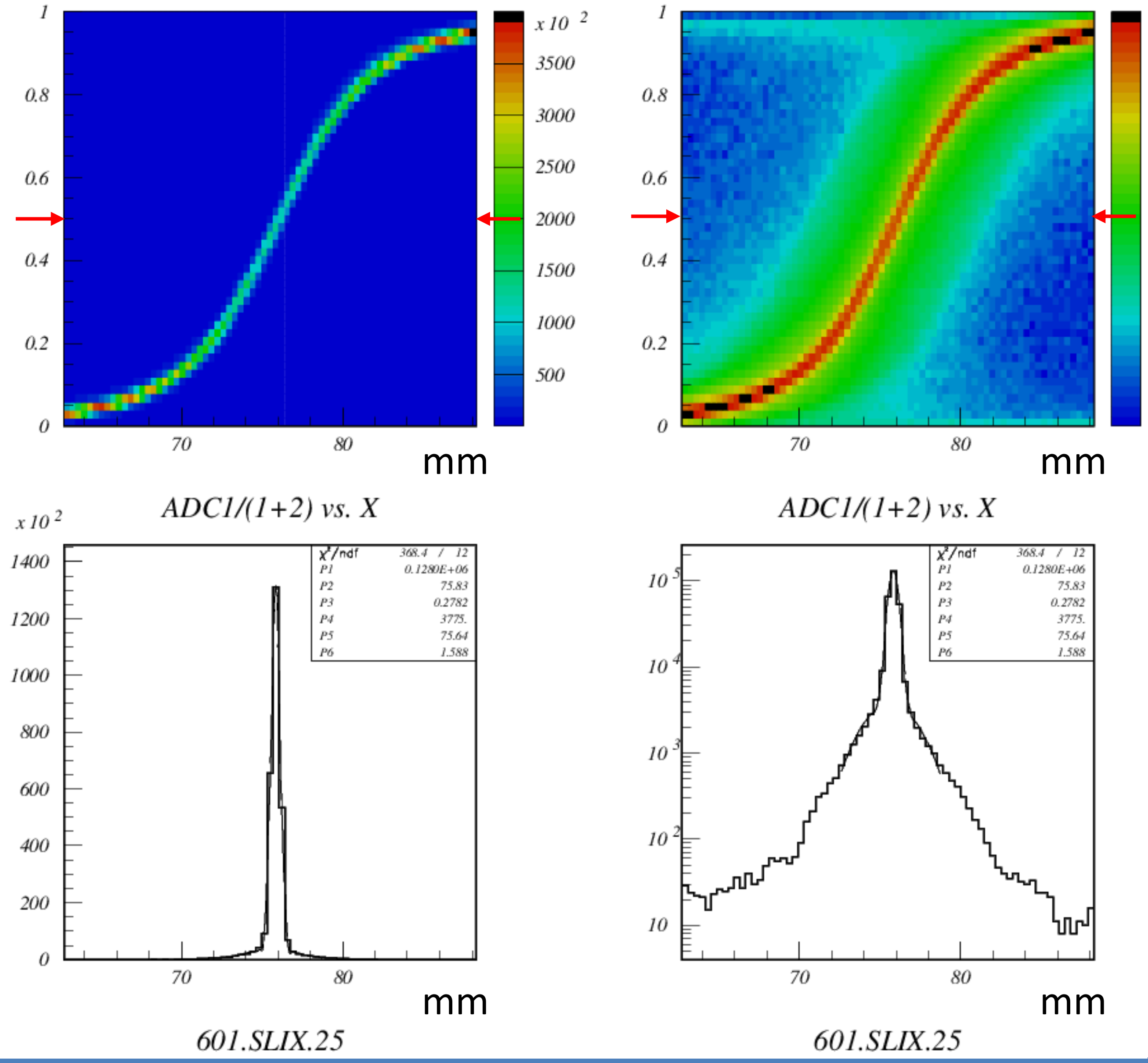
LAPPD – charge sharing

- fraction of the signal on channel 3 vs laser spot x position: $f(x) = \frac{q_3}{\sum_i q_i}$
- scan between the centres of pads 2 and 3 (top)

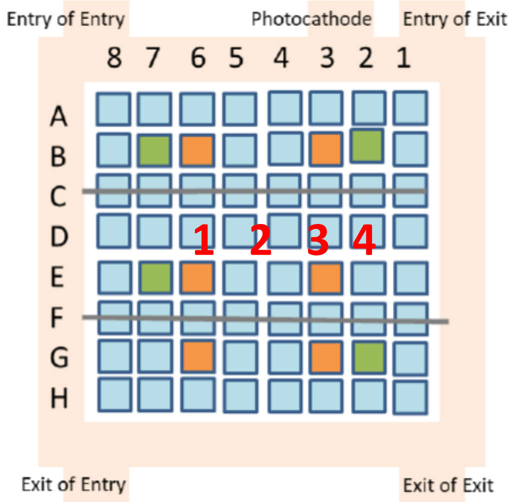


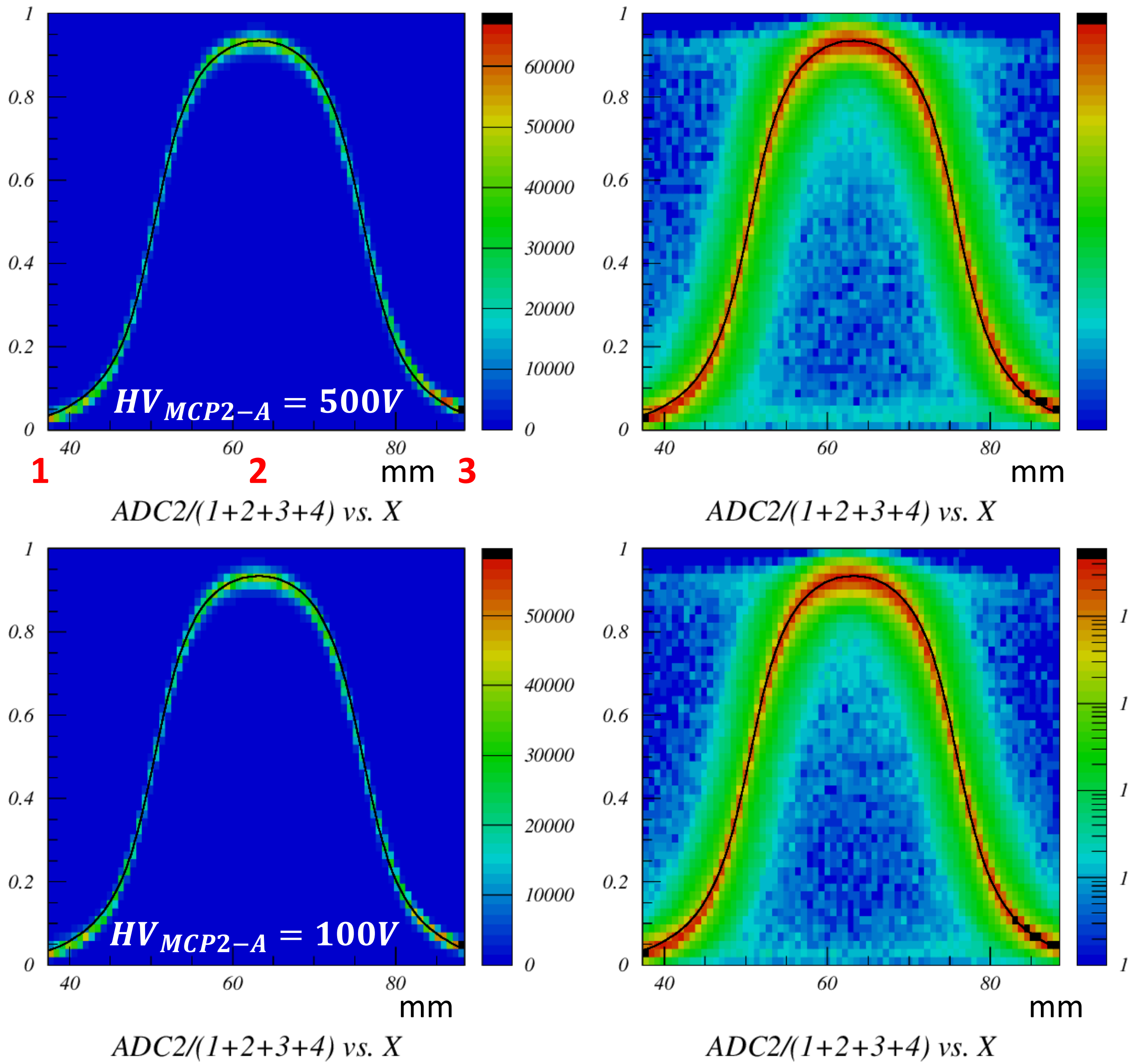
- central slice where signal is equally split between the pads (bottom)
- narrow peak is due to the light spot size and photoelectron spread
- longer tail from photoelectron backscattering - ≈ 6 mm on each side → ≈ 3 mm PC – MCP1 distance



LAPPD – induced charge fraction

- fraction of the signal on ch. 2 vs laser spot x position: $f(x) = \frac{q_2}{\sum_i q_i}$
- green band (log scale) indicates the range of a backscattered photoelectrons – twice the PC-MC1 distance (on each side)
- ROP for upper plots and 100 V between MCP2 and A for lower ones
- Signal spread not mainly from electron spread but induced charge spread on coupled electrode





LAPPD – PLANCON

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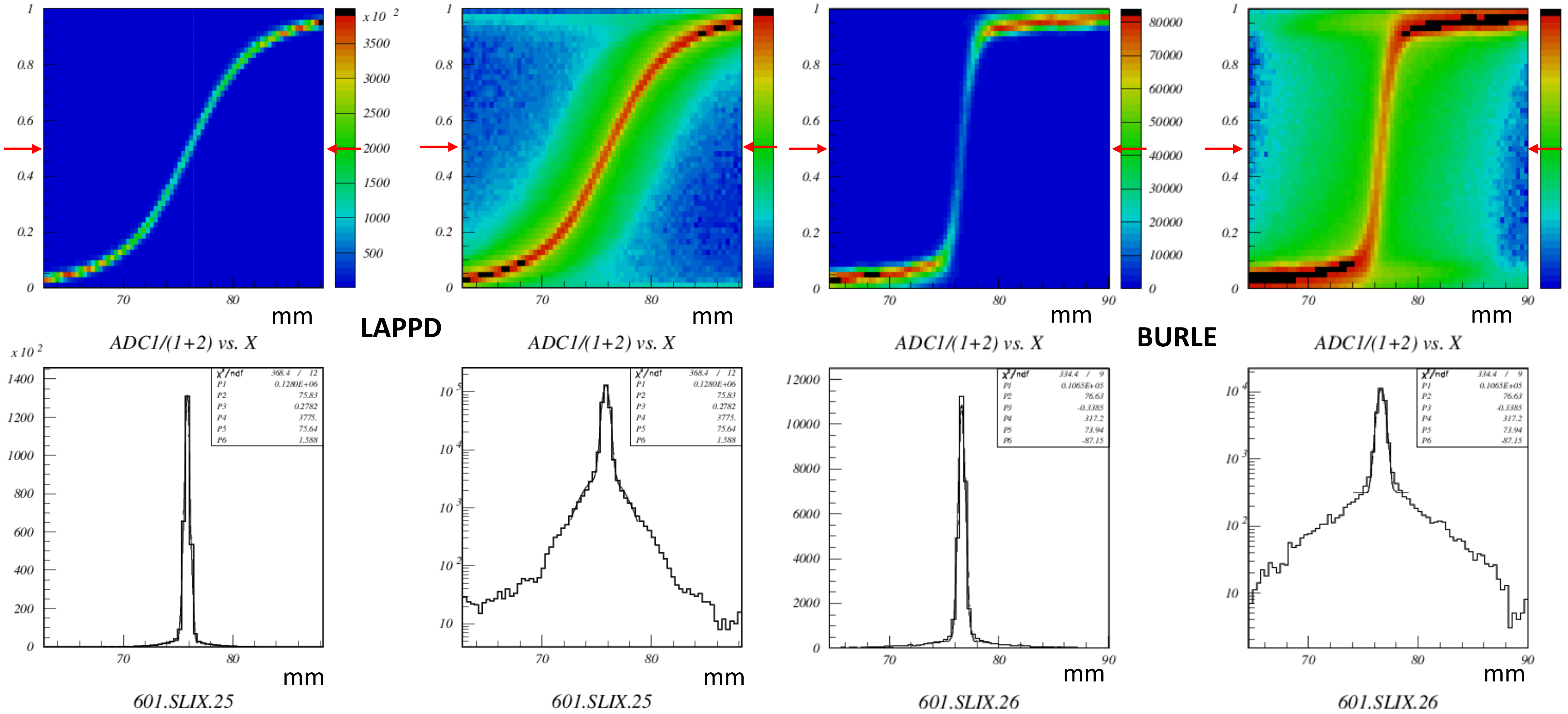
LAPPD (capacitive coupling) – BURLE PLANACON (internal anodes) signal spread comparison – same pad size, same range

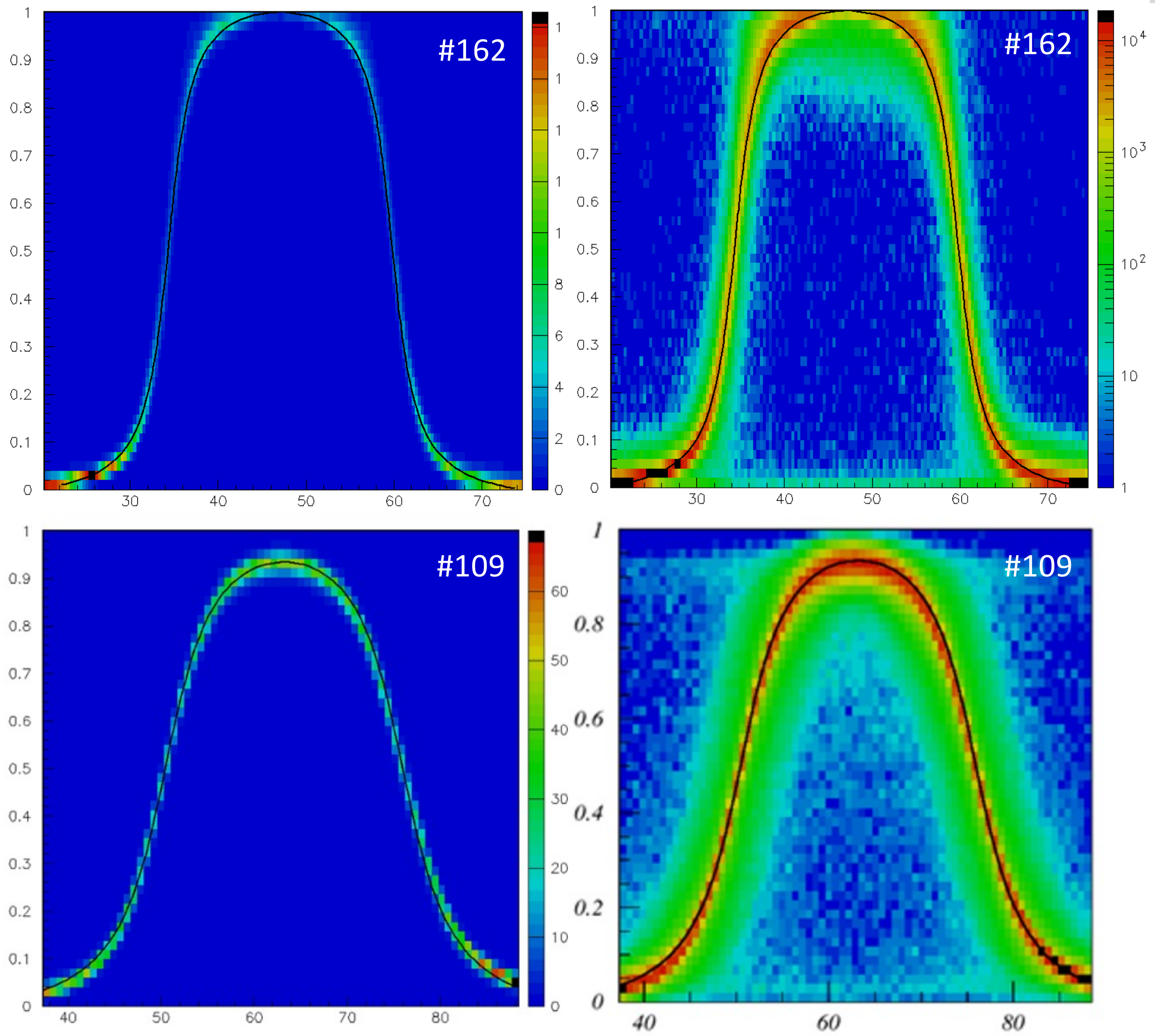


Charge sharing #162 vs. #109

- An example plot for charge sharing between pads D3-D5 for:
  - 162 (top) compared with similar plot for
  - 109 (bottom).

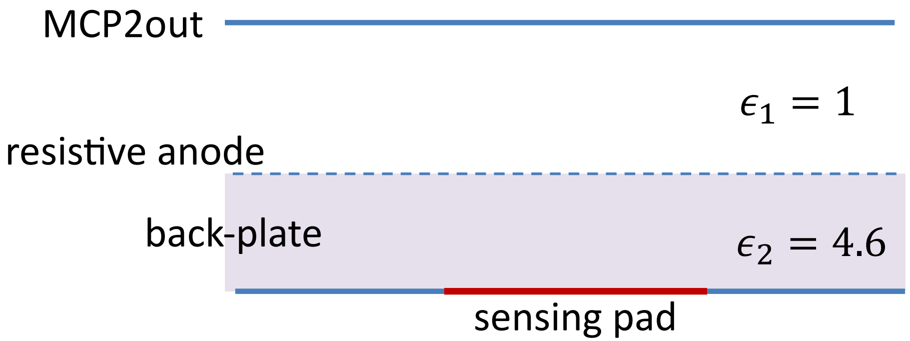
- One can see reduced signal spread as expected.

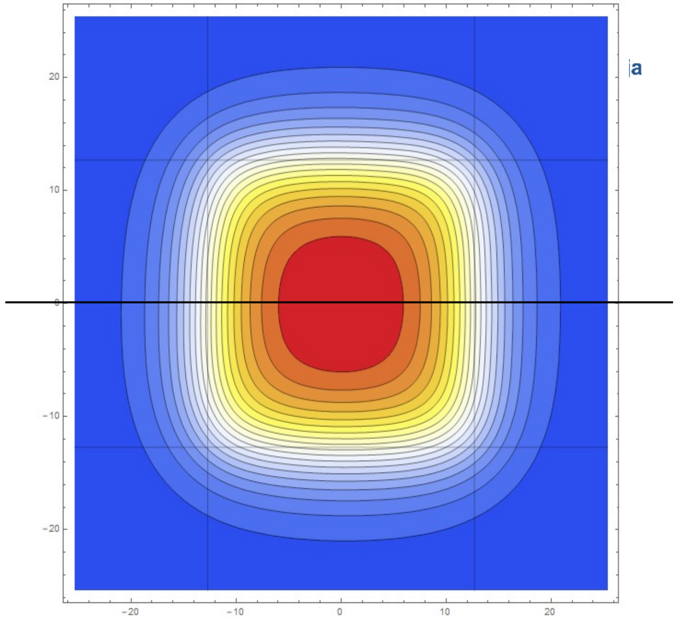
- From backscatter component range (~2mm) one can also see that PC-MCP1in distance was reduced:
  - from about 3mm (109)
  - to about 1mm (162).

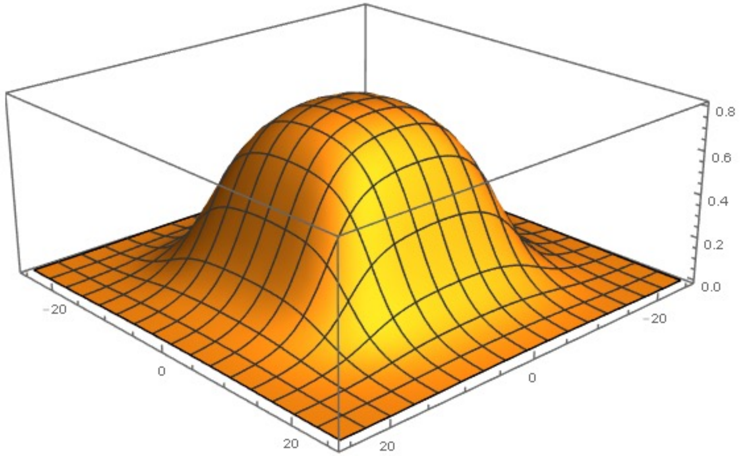


LAPPD charge sharing

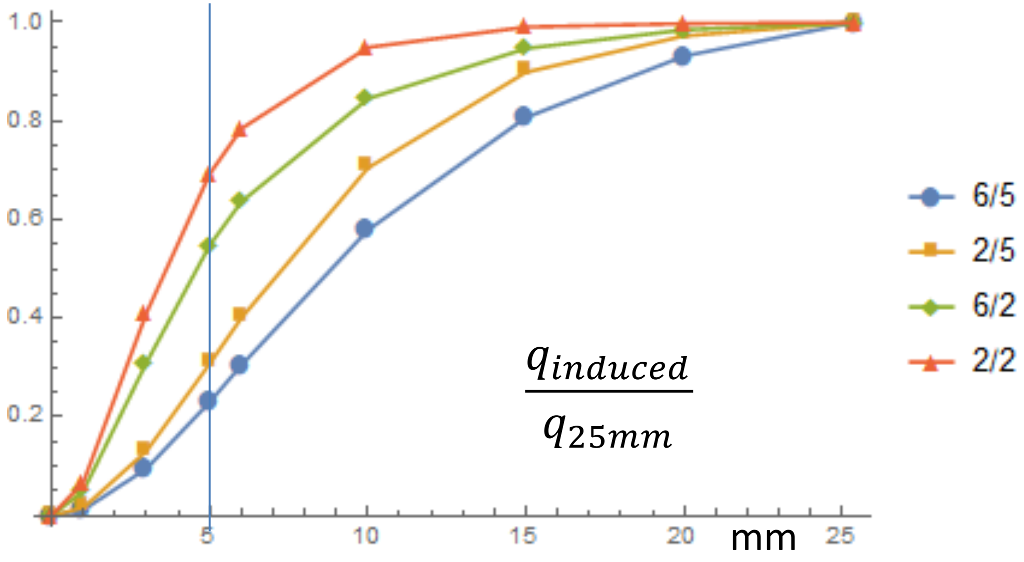
- calculation of charge sharing for different MCP2out-resistive anode/resistive anode-sensing electrode distances (6/5-measured, 2/5, 6/2, 2/2)

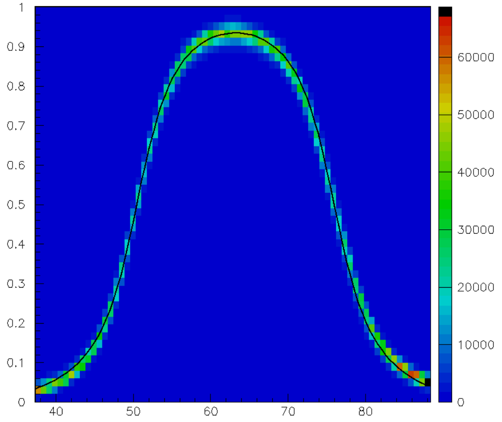


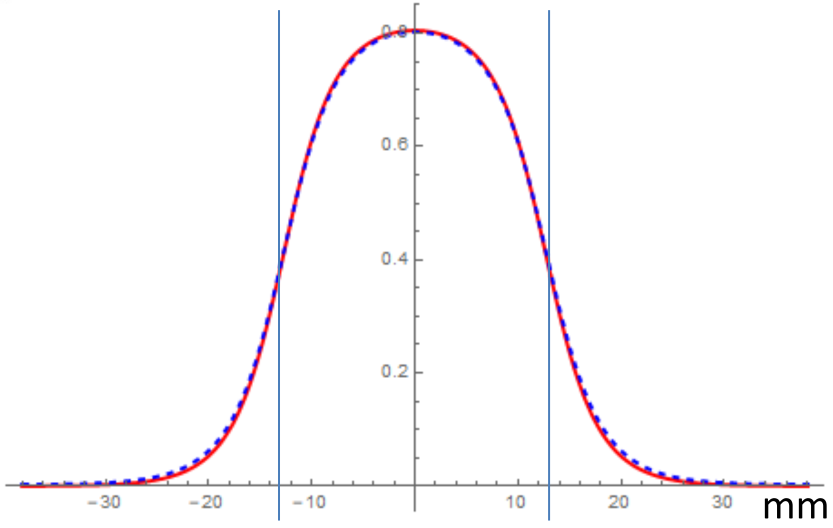




- fraction of the charge induced vs. square pad size when signal is produced in the centre of the pad

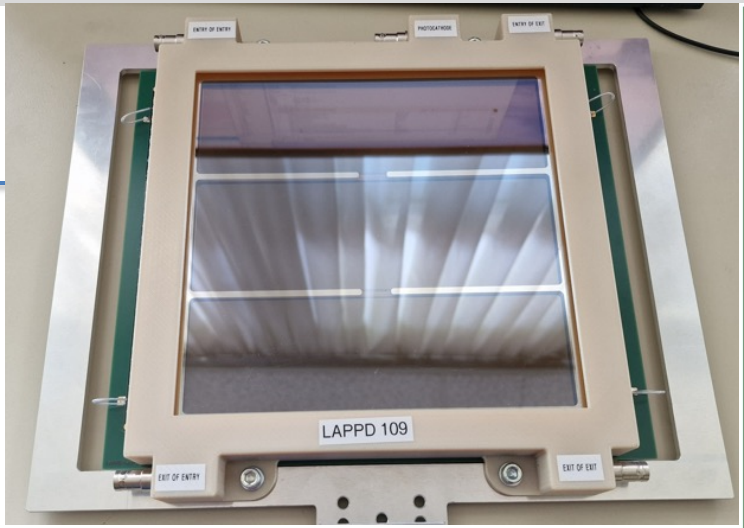


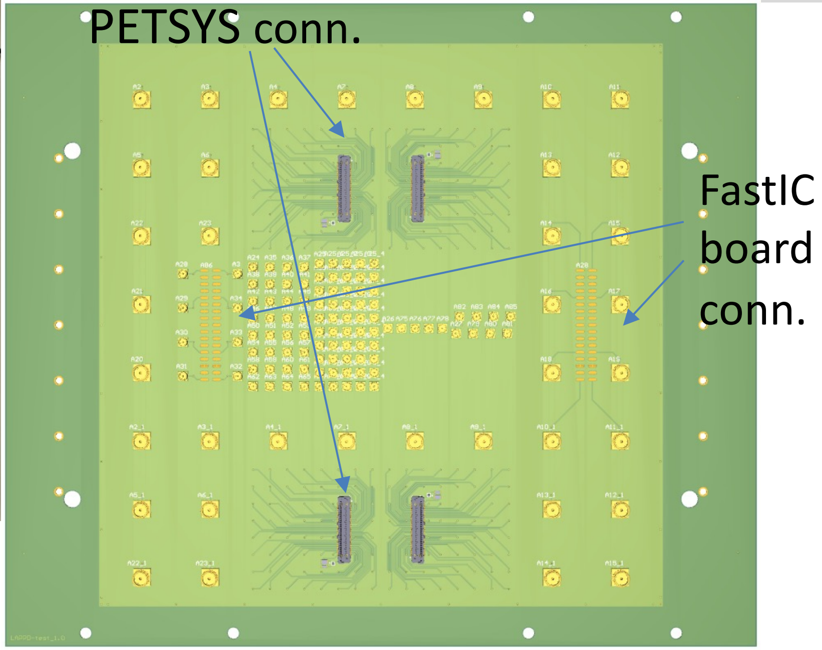


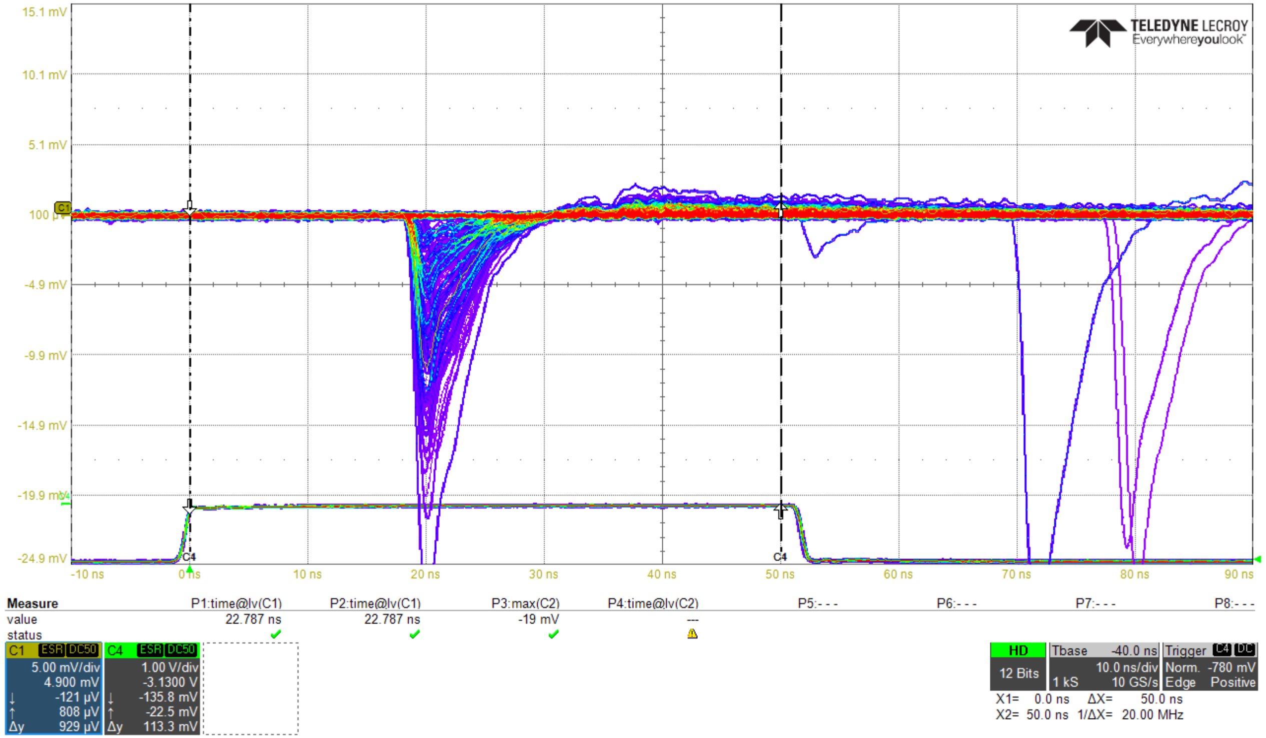


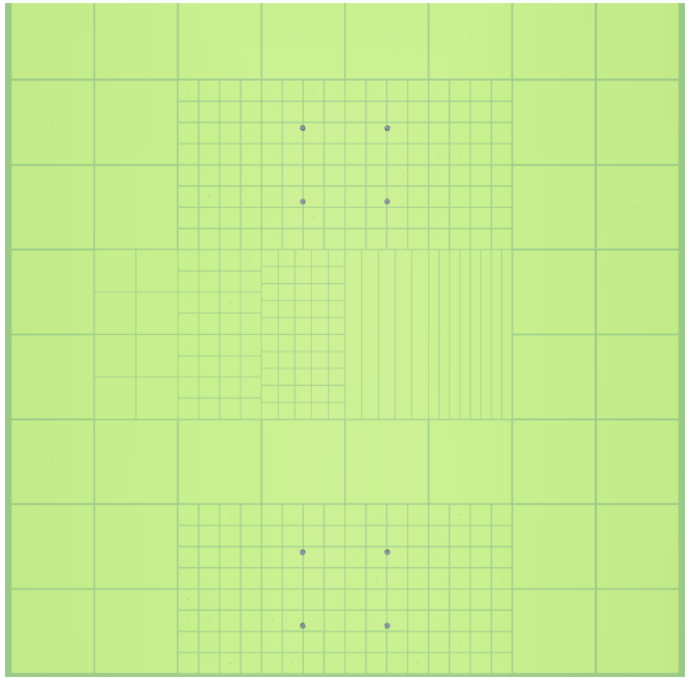
LAPPD – IJS sensing electrodes

- capacitively coupled electrode produced at IJS with several different patterns:
  - pads: 5 mm, 6 mm, 12.5 mm, 25 mm
  - 50 mm long strips: 5 mm, 3 mm
  - PETSYS connector (256 6mm pads)
  - FastIC connector (12.5 mm and 25 mm pads)



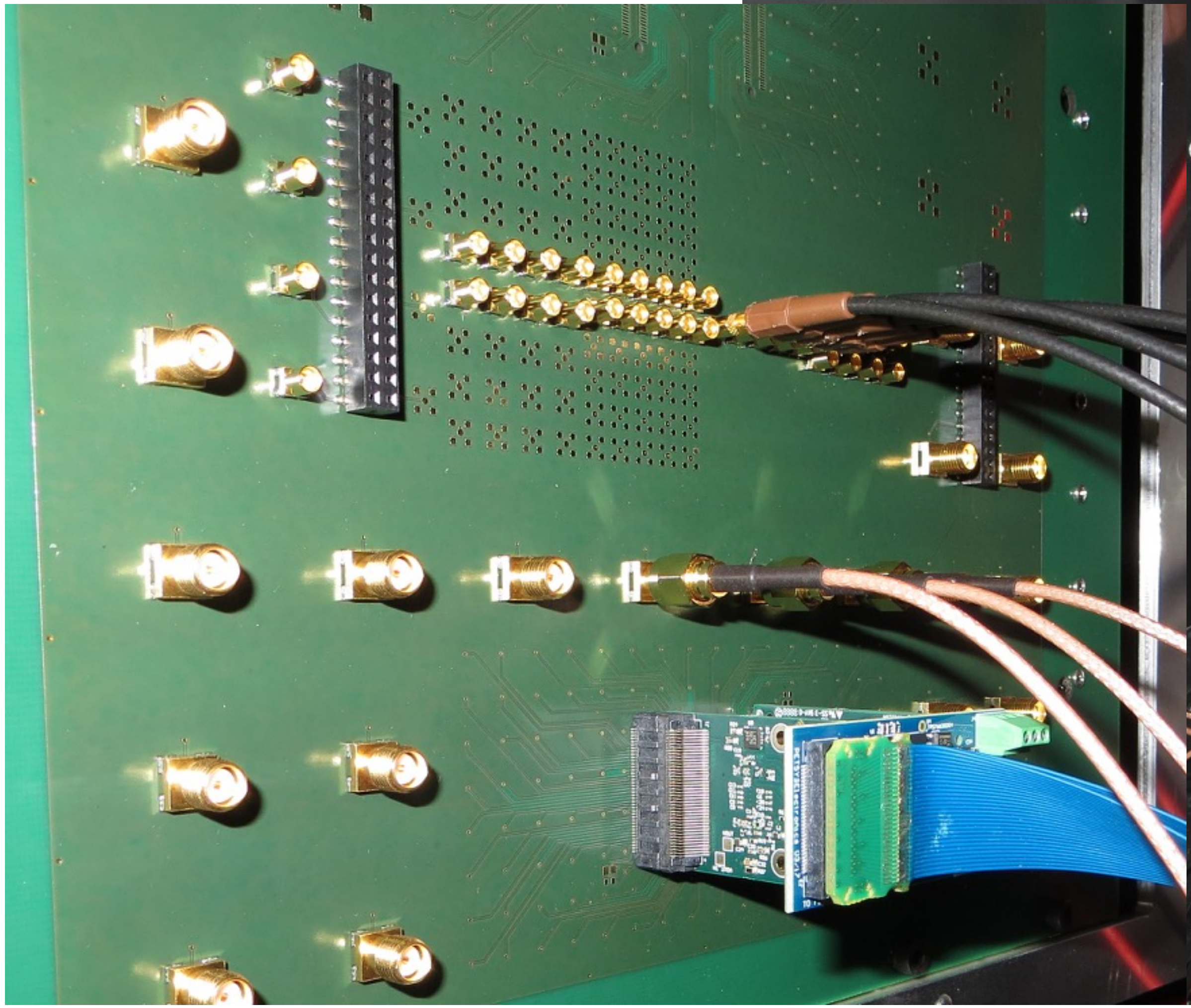


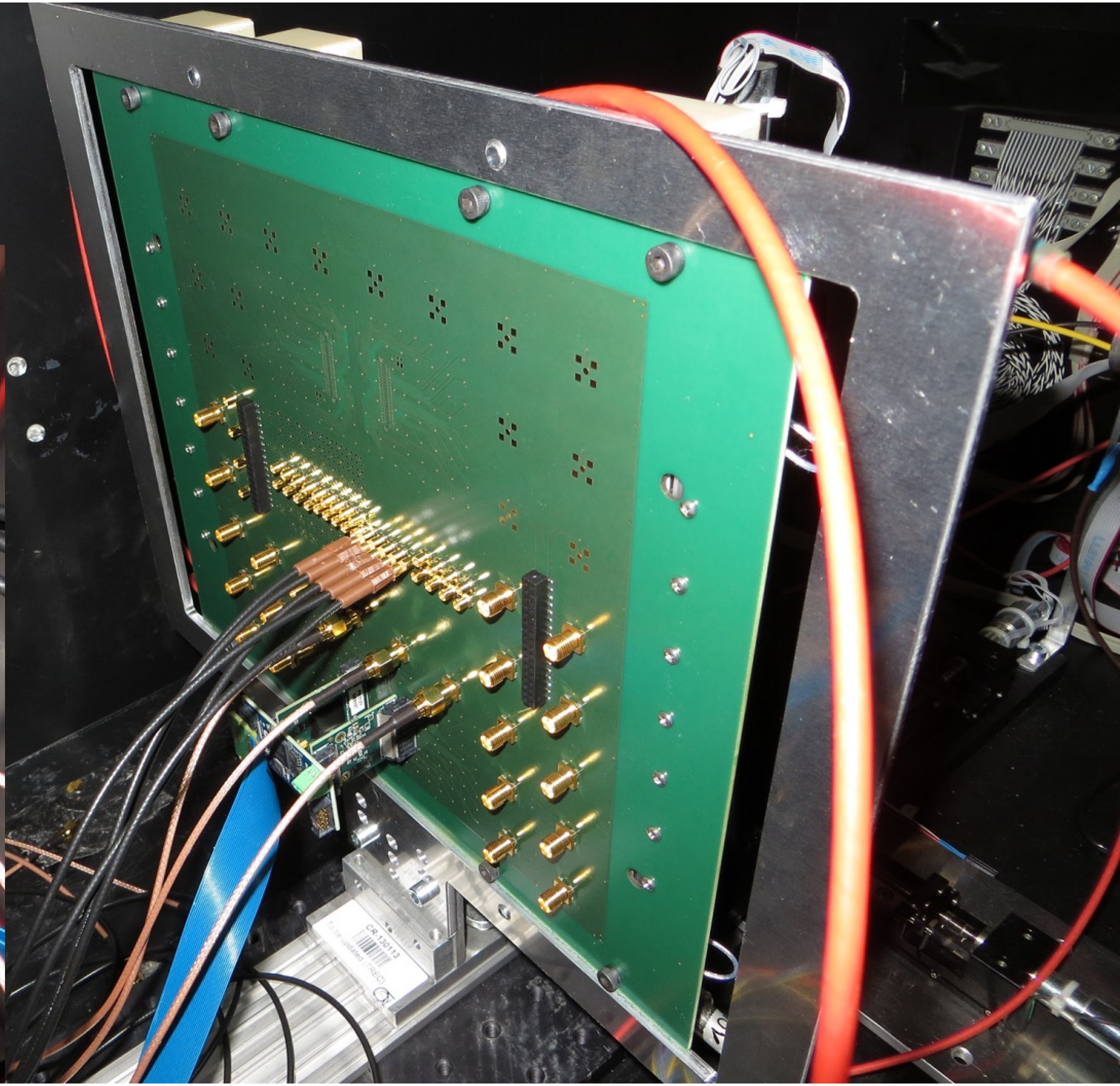




LAPPD + PETSYS

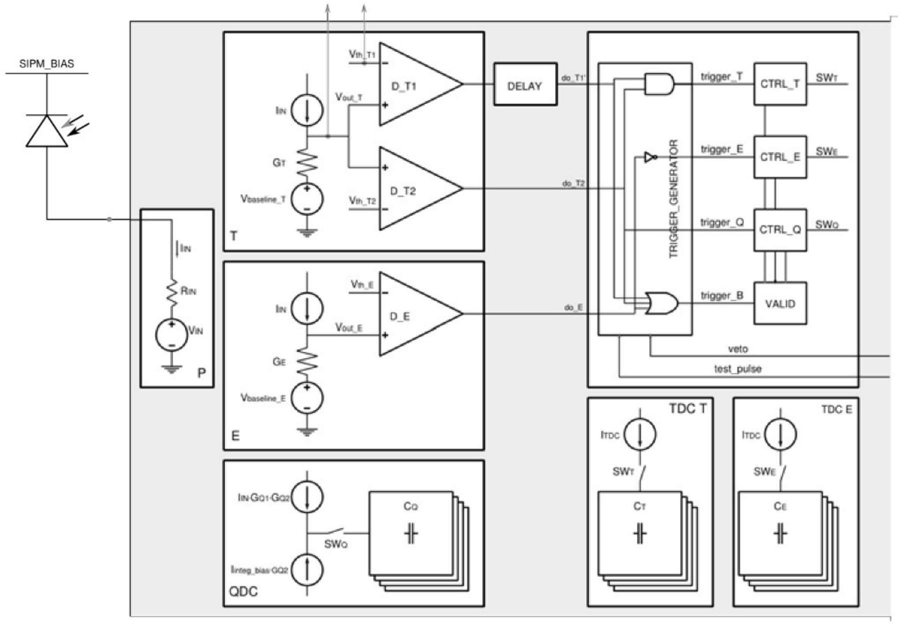
- $\frac{1}{4}$" pads
- 128 channels (16 x 8)

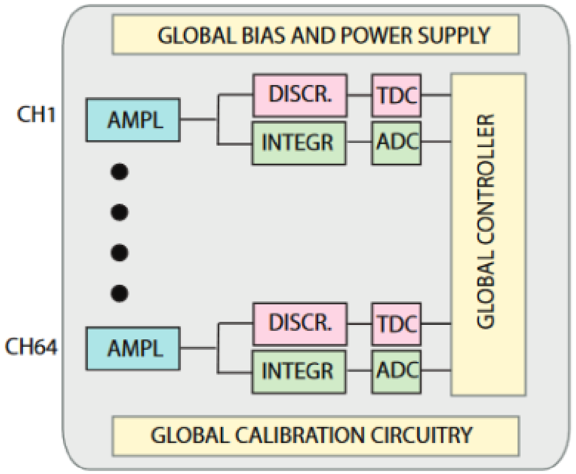


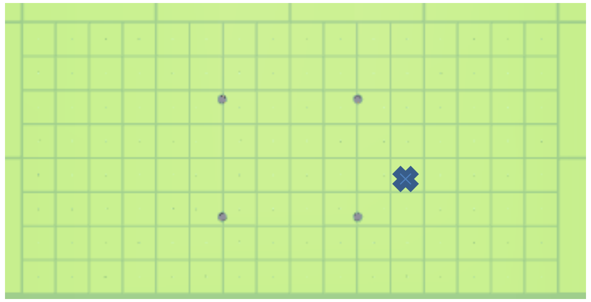


LAPPD + PETSYS

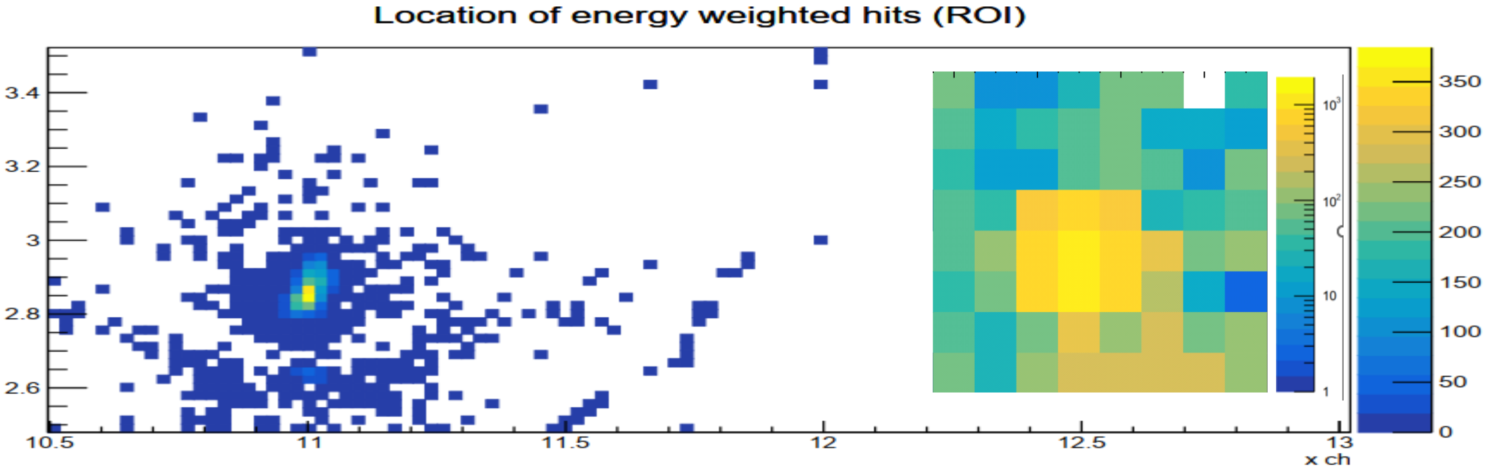
- Signal amplification and discrimination
- Gain adjustment per channel: 1, 1/2, 1/4, 1/8
- Dual branch quad-buffered analogue interpolation TDCs for each channel
- Quad-buffered charge integration for each channel
- Dynamic range: 1500 pC
- TDC time binning: 30 ps
- positive input signal polarity
- Max channel hit rate: 600 kHz
- Configurable timing, trigger and ToT thresholds
- Fully digital output



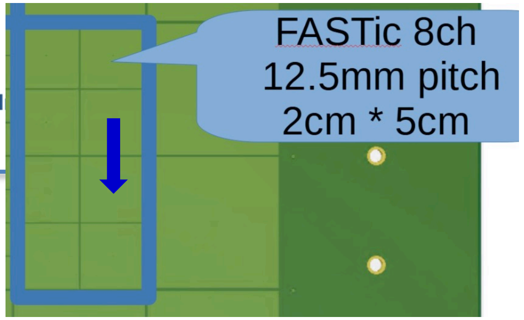




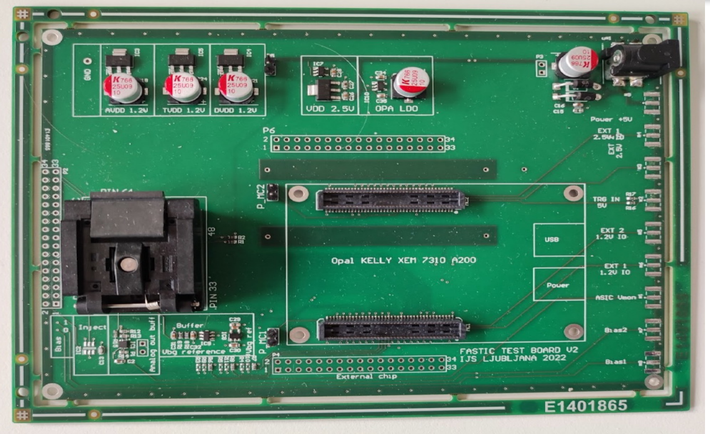
- Center of gravity with ToT



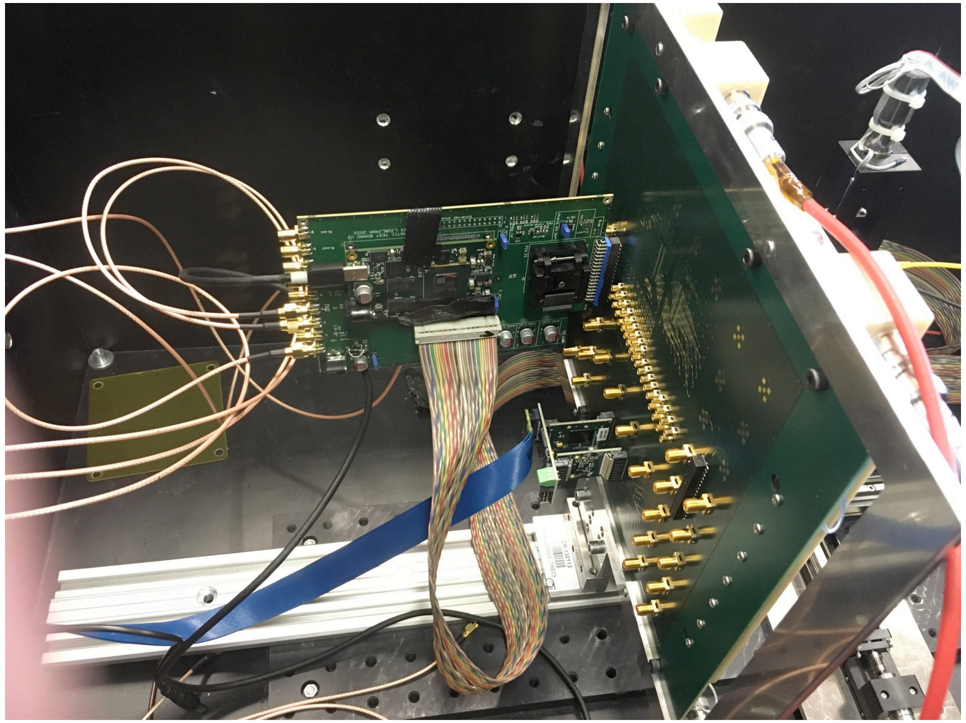
LAPPD + FastIC

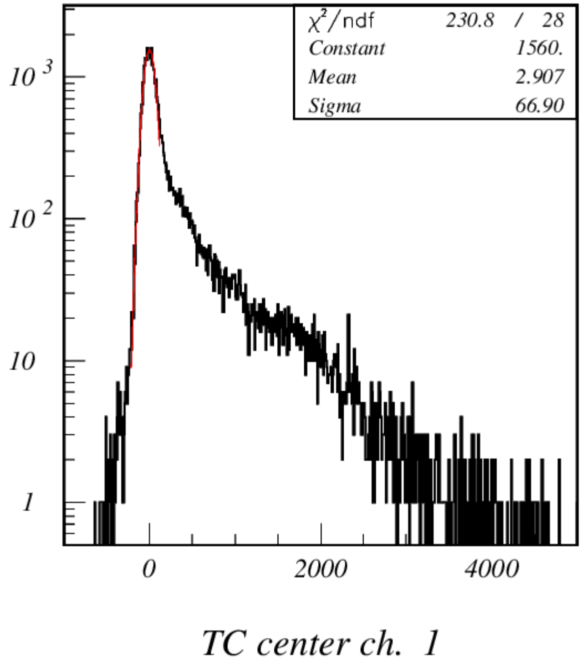


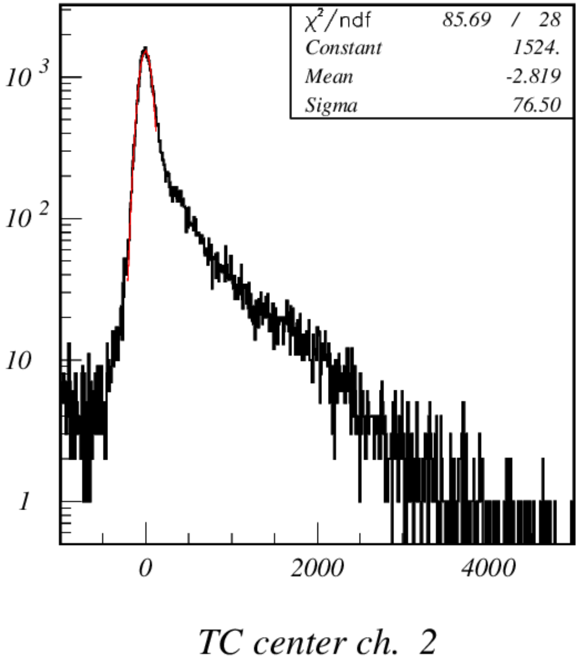
- 8 CH ASIC
- Technology 65 nm CMOS ~ 6 mW/ch
- Number of channels: 8 SE / 4 DIFF
- Connection Type Configurable SE (Pos/Neg polarity) DIFF, Sum of 4 (Pos/Neg polarity)
- Electronics Time Jitter ~ 25 ps rms
- Energy Resolution Linear (~ 2.5 % Linearity error



- Timing resolution $\approx 70\ ps$ with time-walk correction, ADC from shared signal on the neighbouring pad used







Conclusions

- Different photo detectors are being considered for the future PID projects
  - SiPMs (rad. hardness, cooling, annealing, light concentration …)
  - MCP-PMTs (INCOM(LAPPD, HRPPD), PHOTONIS, PHOTEK, HAMAMATSU …?)

- Both options need carefully designed low noise low power readout electronics to explore timing capabilities of both sensors (FastIC, FastRICH, …)

- Simulations and tests of hardware are in progress.