LAPPD beam test results

CERN testbeam Oct. 2022

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remote

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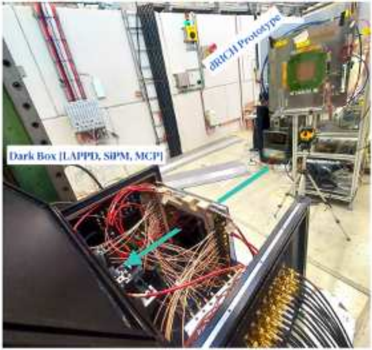
Why measuring timing of LAPPDs

- Large Area Picosecond Photodetectors were expected to have ps timing,
- smaller MCPs from other brands show about 10 ps TTS,
- for RICH and PET applications 10 ps timing would allow better reconstruction of photon origin,
- LAPPDs feature high gain 10^6, while noise is small: for LAPPD N.89 estimated 14 ps SPE electronics resolution $= \frac{t_{rise}}{S/N}$ (TTS not included),
- planar geometry excludes complex electron trajectories,
- preliminary tests performed with lasers indicated 30÷50 ps,
- we decided to verify it on the beam at CERN,
- optimized setup to have timing uncertainties $\sigma <$10 ps.

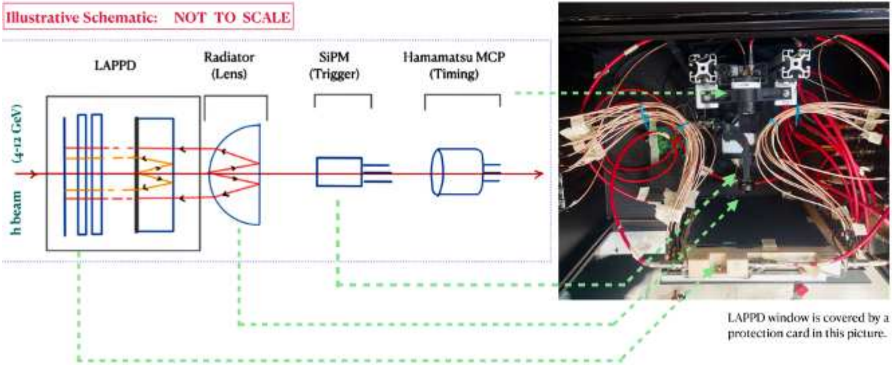
Experimental hall at T10 beamline

CERN PS, Hall T10

LAPPD installed downstream of dRICH prototype



Measurement setup

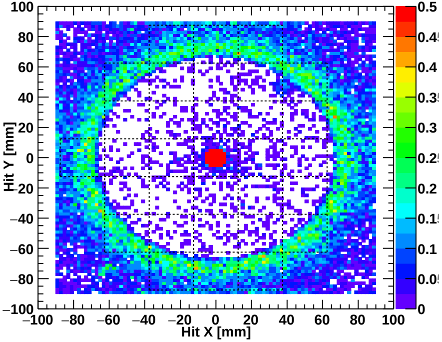


LAPPD window is covered by a protection card in this picture.

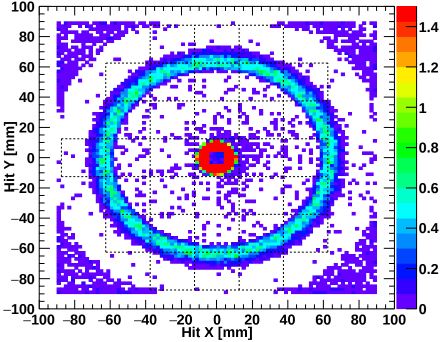
60 mm Direct vs. backward reflection - ring

- direct configuration gives broad ring (11 p.e./pad),
- backward reflection gives narrow ring (12 p.e./pad),
- beam spot is larger for backward reflection.

direct



backward reflection



Trigger SiPM and reference MCP

Hamamatsu MPPC SiPM (S13360-6025CS)

Scintillating fibers
Kuraray 3HF(1500)MJ
diameter = 500 μm
array = 10×10

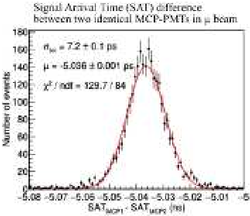
SiPM = 6×6 mm²
gain = 10 mV/p.e
risetime = 20 ns
falltime = 100 ns

The SiPM and the Lens mount

SiPM onboard amplifier

Hamamatsu MCP-PMT (R3809U-50)

Tube diameter = 45 mm

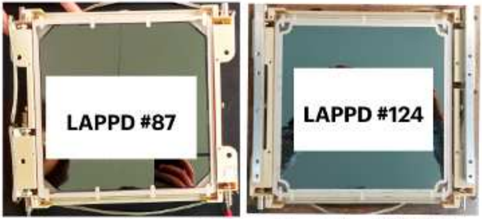


NIM A 960 (2020) 163592

Photocathode
Window = quartz, diameter = 11 mm 3.2 mm thick
Spectral response : 160 to 850 nm; peaks at 430 nm

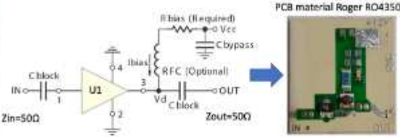
Typical Characteristics
Gain = 2 × 10⁵ ; Dark current = 10 nA
Rise time = 150 ps
Transit time = 550 ps
Transit time spread = 25 ps (RMS=10 ps)

LAPPD readout



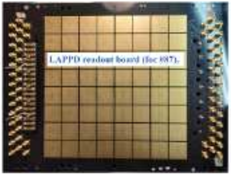
Can you spot an important difference between the two LAPPD tiles?

Custom made preamplifiers by INFN, Genova



Gain = 10 (20 dB), BW = 2 GHz, output = inverting

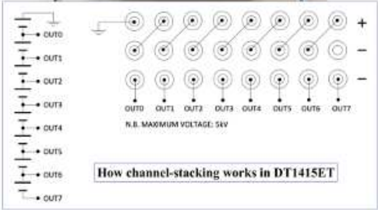
additional PCB for grounding anode



Present version comprises 8 input/output per unit

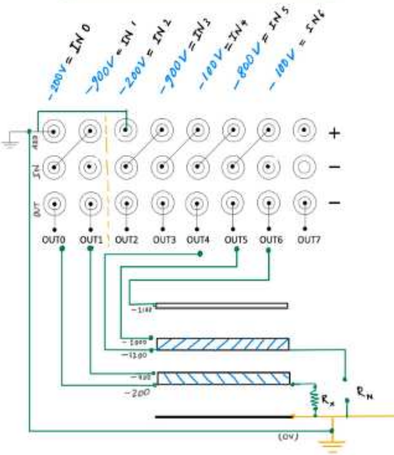
LAPPD bias voltages

CAEN DT1415ET Floating HV supply

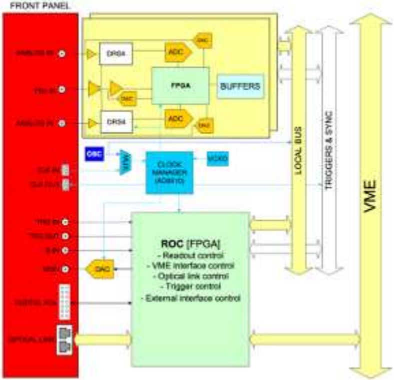


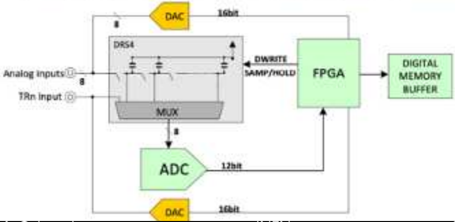
How channel-stacking works in DT1415ET

How we used it: An example set of voltages



DAQ system



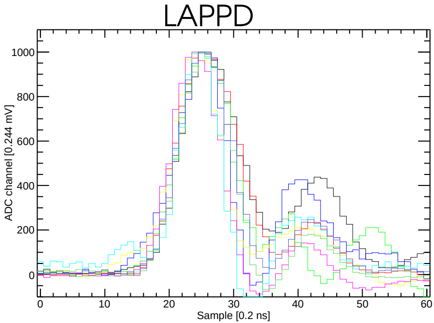


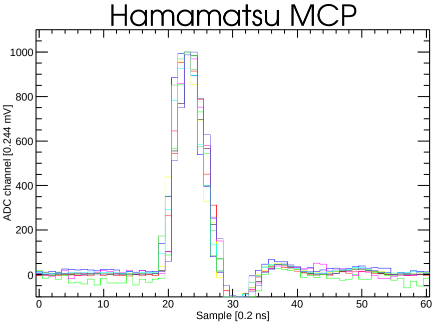
V1742 Board:

> 4 DRS chips
> 5 GS/s -> 200 ps
> 32 Analog channels
> 2 fast triggers (1 global trigger)
> each channel has 1024 SCA (Cells)
> one 12 bit ADC in each chip

Measured LAPPD signals w.r.t. Hamamatsu MCP

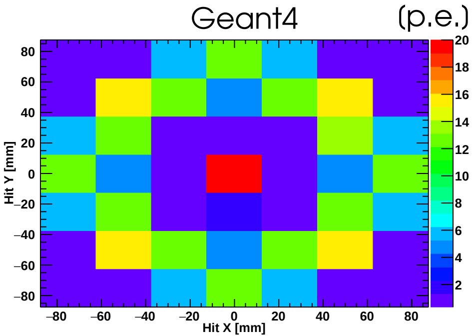
- LAPPD risetime (20-80%) was about 0.75 ns,
- Hamamatsu MCP had 0.4 ns (intrinsic 0.16 ns),
- V1742 digitizer has BW=0.5 GHz →0.45 ns is its intrinsic limit on risetime (20-80%),
- LAPPD 1 inch pad has large capacitance 5 pF, assuming 50Ω load we expected 0.26 ns.

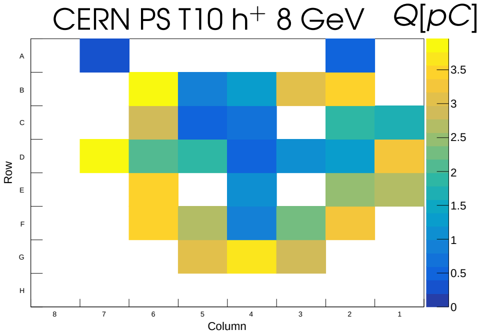




Lens Cherenkov ring in UV

- in UV lens Cherenkov ring was observed at expected radius (60 mm), with expected shape,
- 3 p.e./pad were measured, expected 12 p.e./pad,
- beam spot was suppressed by a factor of $>$100 (grease+black tape on the window),
- 32 channels were barely sufficient to cover entire ring.





beam spot 180 p.e.

Number of Cherenkov photons

- assume proton beam with P=12 GeV/c, β_p=0.9969589 and $\theta_C = 48.4^\circ$ in fused silica (n=1.51 at 250 nm),
- the number of Cherenkov photons (in range of LAPPD photocathode sensitivity) produced in 1 mm of quartz:

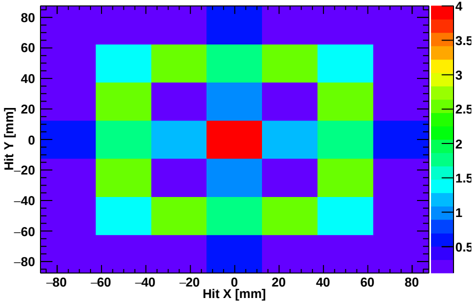
$$N_\gamma = 0.0256 * \left\{ \frac{1}{160nm} - \frac{1}{560nm} \right\} = 114 \frac{photons}{mm},$$

- thus in 5 mm thick LAPPD window we produce 570 photons,
- in 14 mm thick aspheric lens we produce 1600 photons,
- assuming 30% mean QE of Na_2KSb photocathode we estimate: 170 p.e. from LAPPD window and 480 p.e. from aspheric lens,
- Geant4 simulation gives 180 p.e. from LAPPD window and 300 p.e. from aspheric lens.

Lens Cherenkov ring in Visible

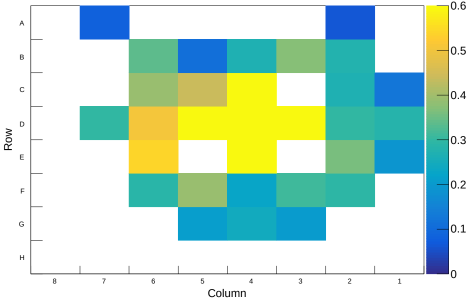
- in visible narrower lens Cherenkov ring was observed,
- 0.5 p.e./pad were measured, expected 2 p.e./pad,
- beam spot suppression degraded by a factor of 10 (next day, after few opening of the box).

Geant4 (p.e.)



beam spot 180 p.e.

CERN PS T10 h^+ 8 GeV $Q[pC]$

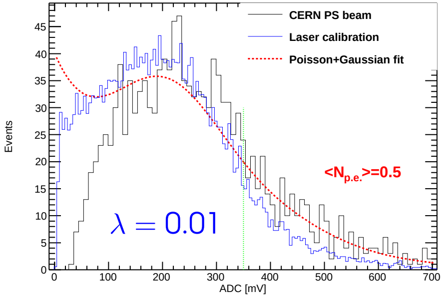


beam spot 6 p.e.

LAPPD SPE charge calibrations

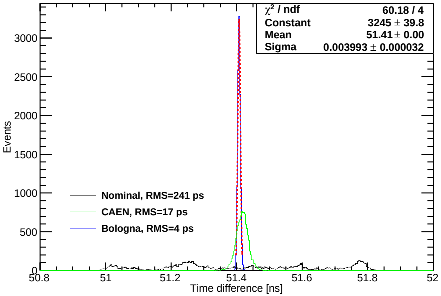
- LED SPE calibrations performed at CERN and Laser SPE calibrations performed at Trieste agree with beam-on spectra in Cherenkov ring pads,
- LAPPD N.124 at 800/900 V should have gain of 4×10^6, expected SPE at 1.28 pC,
- the observed SPE peak at 1.15 pC, in agreement,
- using laser calibration data estimated CERN $N_{p.e.}$=0.5 (80% at 1 p.e., 2 p.e. timing RMS broadening of 1.5%).

Laser SPE calibrations vs. testbeam data



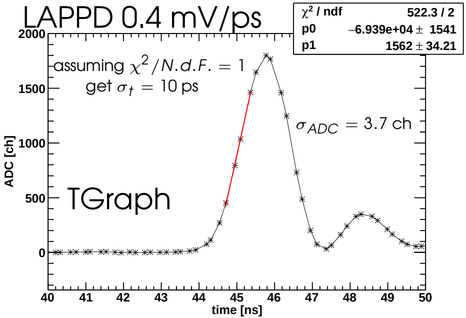
DRS4 timing calibrations

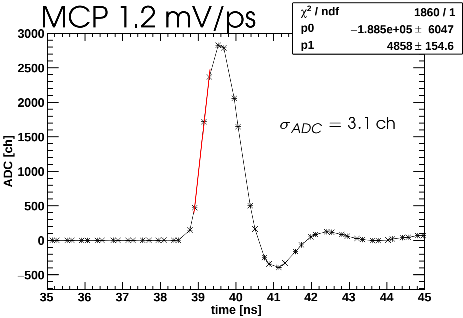
- we used timing calibration procedure developed by Vincenzo Vagnoni (INFN Bologna),
- validation of calibration gave 4 ps residual resolution,
- calibrated delays between cells are around 150/250 ps for even/odd cells,
- timing corrections are significant: 50 ps broadening.



LAPPD and MCP time measurements

- acquired raw waveforms (no CAEN on-line corrections) were converted in TGraphs with variable delays between samples (using Bologna calibrations),
- to measure time we fitted pulse rising edge in the region of 50% height with a linear function,
- time was determined as the crossing point of 50% height by the linear fit function.

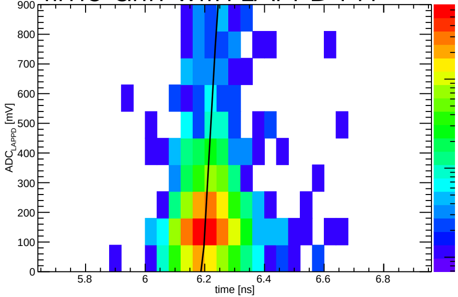




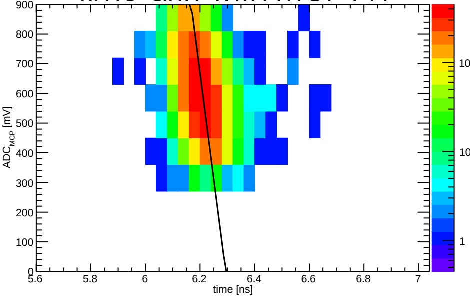
LAPPD and MCP PH-corrections on time

- linear function approximation in the fit leads to systematic effects on the time difference,
- time difference depends on signal Pulse Heights,
- in LAPPD time drift is about 0.1 ps/mV,
- in Hamamatsu MCP time drift is about 0.2 ps/mV,
- after correction the residual PH-dependence is <5 ps.

time drift with LAPPD PH



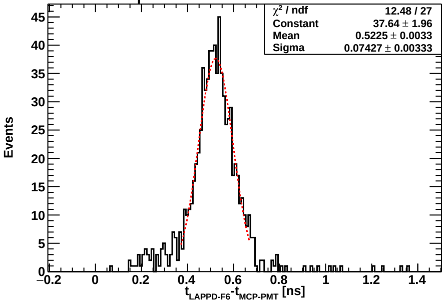
time drift with MCP PH



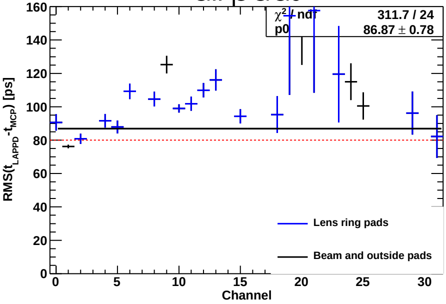
SPE timing results

- time difference distributions mostly appeared as a Gaussian-like peak,
- Gaussian fit was used to determine timing resolution,
- some pads showed significant background,
- pads on ch>7 received additional 33 ps jitter between different DRS4 chips,
- best SPE timing was 75 ps (pad F6, ch2), mean 87 ps.

pad F6, ch2

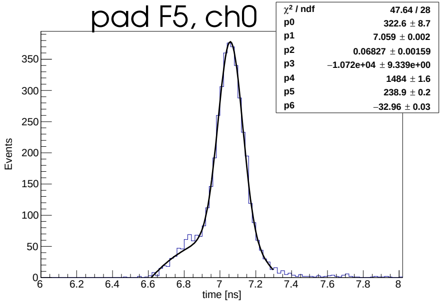


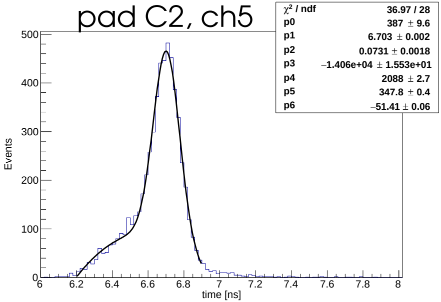
all pads



SPE timing background

- most common background - l.h.s. tail or a peak anticipated by about 0.3 ns,
- background is higher in pads near horizontal and vertical beam spot pads,
- perhaps due to Cherenkov in LAPPD window followed by multiple internal reflections,
- in affected pads 20% improvement fitting Gaus+pol,
- best SPE timing 68 ps (pad F5, ch0), mean 86 ps.

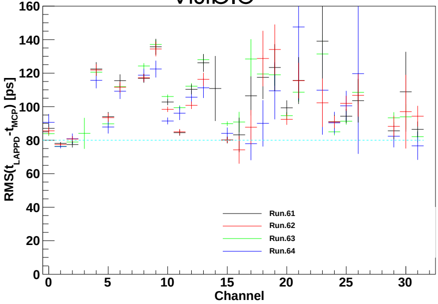




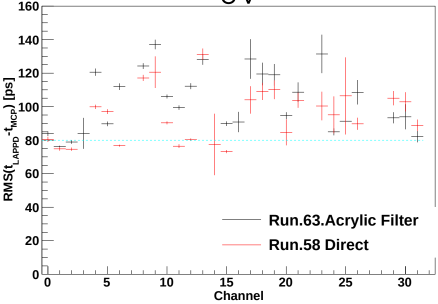
SPE timing consistency

- we took four different runs with acrylic filter,
- the results from these four runs agree within statistical uncertainties,
- run taken with UV photons gives better resolution because of 3 times larger mean number of p.e., but also limited to about 75 ps.

visible

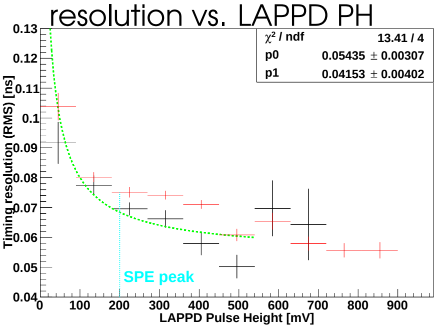


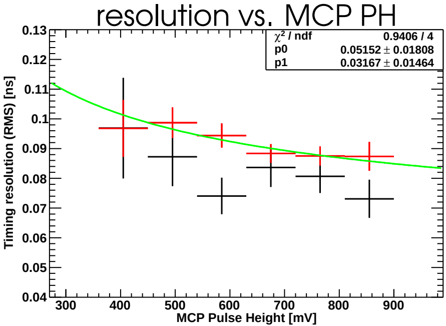
UV



PH-dependence of timing resolution

- the resolution is $\sqrt{p_0^2 + \frac{p_1^2}{V/V_{SPE}}}$ function of LAPPD PH,
- constant term was 50 ps, expected 18 ps,
- $N_{p.e.}$ term is approximately $= 40\ ps/\sqrt{N_{p.e.}}$,
- no significant dependence on Hamamatsu MCP PH.





Known timing uncertainties

Sources of timing uncertainties related to the experimental setup, which should appear as a contribution to the constant term p_0:

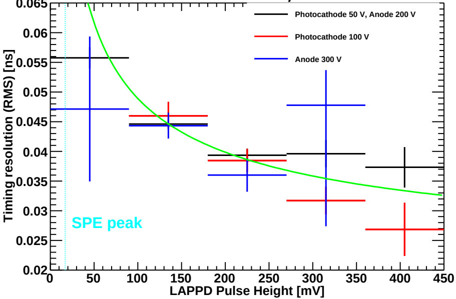
Source	Estimate
Hamamatsu MCP-PMT	10 ps
Geant4 detector geometry and chromatic dispersion	8.3 ps
Readout pad size	12 ps
Total	18 ps

Best resolution at very large $N_{p.e.} \simeq 23$ measured in this test was 27 ps, fairly close to expected.

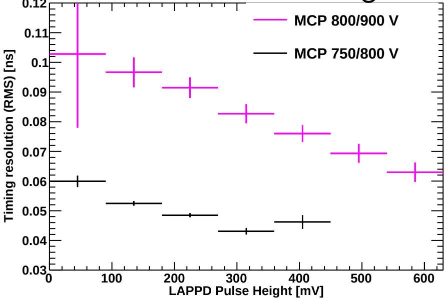
Bias voltage dependence

- timing resolution was insensitive to Anode voltage increase from 200 V to 300 V,
- increasing Photocatode voltage from 50 V to 100 V leads to improvement at high PH,
- there is no significant gain dependence of timing resolution (gain change by factor 10).

resolution vs. PC/Anode bias



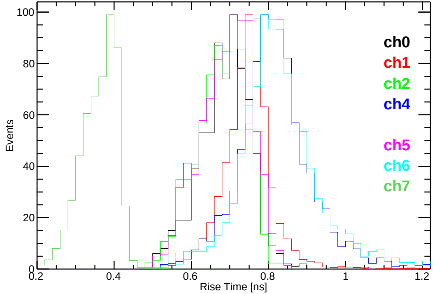
resolution vs. LAPPD gain



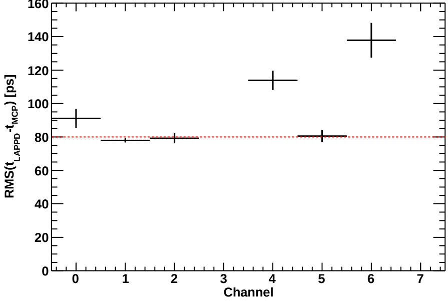
LAPPD signal risetime variations

- 15% variations of risetime channel-to-channel, not seen during the calibrations,
- some correlation with timing resolution observed,
- large risetime in nearby pads: B6+C6 and F3+G3,

risetime in channels

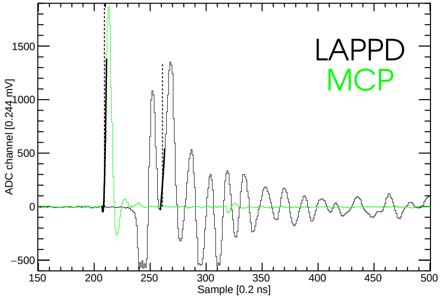


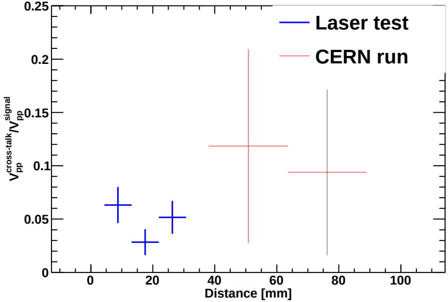
resolution in channels



Resistive anode cross-talk in LAPPD

- strong cross-talk between pads was observed at testbeam and in the lab,
- cross-talk appears as a dumped oscillator,
- the amplitude of oscillation is about 5÷10% of the primary signal,
- cross-talk amplitude seems to be independent from the pad location.





Summary

- tested 20 μm pore LAPPD N.124 capacitively coupled to the Incom readout board with 1 inch pads,
- test performed at CERN PS with 8 GeV positive hadrons,
- measured Cherenkov rings from quartz lens,
- observed SPE timing RMS of about 80 ps,
- it can be described as: 50 $ps + 40\ ps/\sqrt{N_{p.e.}}$,
- increasing PhotoCathode voltage improves resolution for large signals,
- large cross-talk between pads was observed.

References

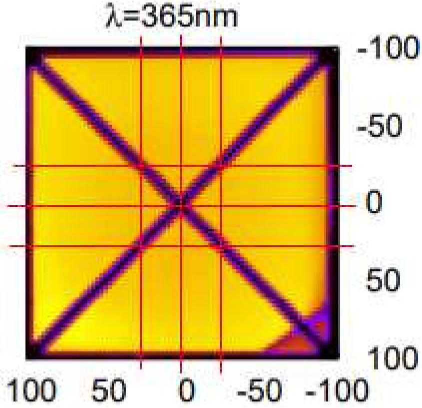
1. M. Amarian *et al.*, "The CLAS forward electromagnetic calorimeter", *Nucl. Instr. and Meth.* **A460**, 239 (2001).
2. M. Guillo, "EC Time Calibration Procedure for photon runs in CLAS", CLAS-Note-2001-014, 2001.
3. M. Osipenko, "Geometrical alignment of CLAS DCs using tracks with constrained vertex", CLAS-Note-2019-001, 2019.

Backup slides

LAPPD cross shadow

- LAPPD pads are large: 25×25 mm^2,
- MCP cross-shaped support shadow affects 4 central pads,
- but their geometrical efficiency remains $> 50\%$.

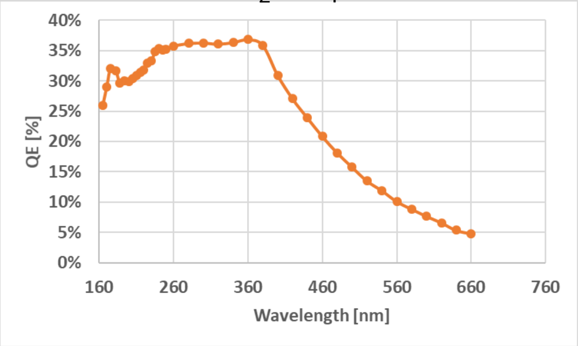
LAPPD.87 with Na_2KSb photocathode



LAPPD Quantum Efficiency

- in wavelength range 180-400 nm QE of LAPPD is $> 30\%$,
- numerical convolution $dN/d\lambda(\lambda)$ and $QE(\lambda)$: 33.6 p.e./mm.
- analytic estimate of Cherenkov p.e. yield assuming average QE=30%:

LAPPD.12 with Na_2KSb photocathode

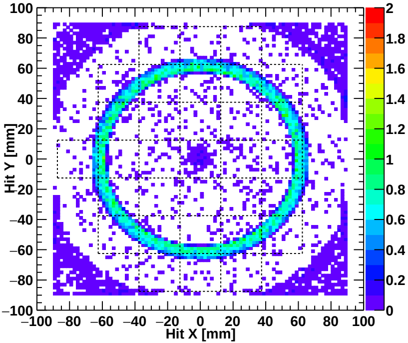


$$N_\gamma = 0.0256 * \left\{ \frac{1}{160nm} - \frac{1}{560nm} \right\} * 0.30 = 34 \frac{p.e.}{mm},$$

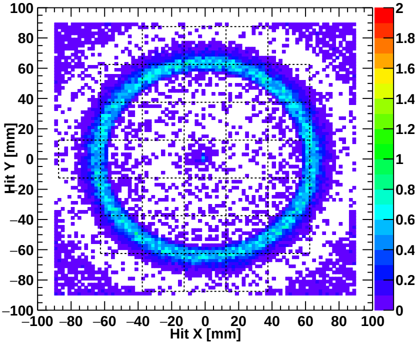
60 mm backward, chromatic dispersion - ring

- Cherenkov ring is wide even without chromatic dispersion,
- chromatic dispersion adds more width to the ring.

no dispersion



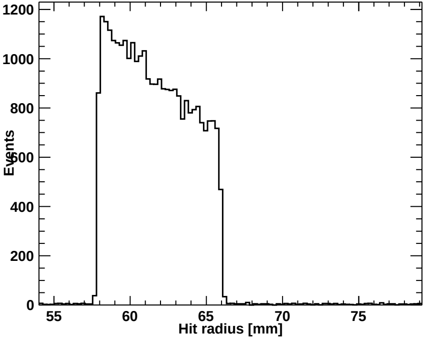
physical



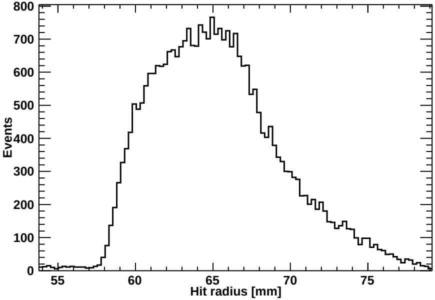
60 mm backward, chromatic dispersion - radius

- Cherenkov ring is 8 mm wide even without chromatic dispersion,
- the width is related to emission point uncertainty: it varies from 4.3 mm to 13.8 mm (from lens face - first 4.3 mm is blind).
- chromatic dispersion doubles the width of the ring.

no dispersion



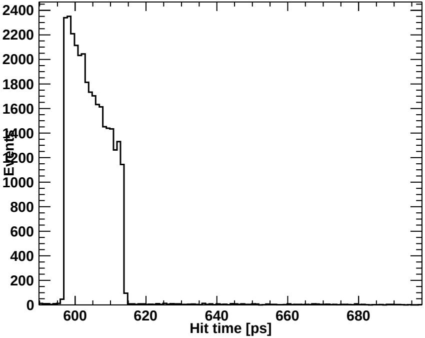
physical



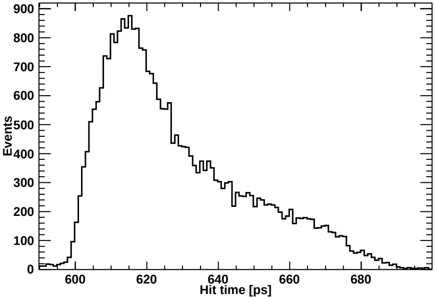
60 mm backward, chromatic dispersion - time

- without chromatic dispersion total width of Cherenkov photon timing distribution is 17 ps,
- chromatic dispersion delay fraction of photons increasing the width by 5 times.

no dispersion



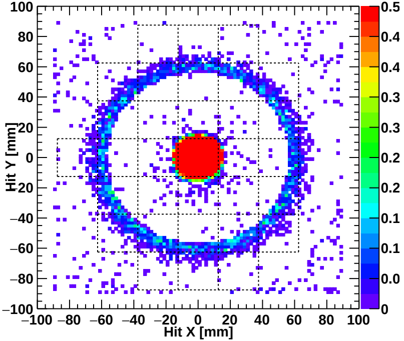
physical



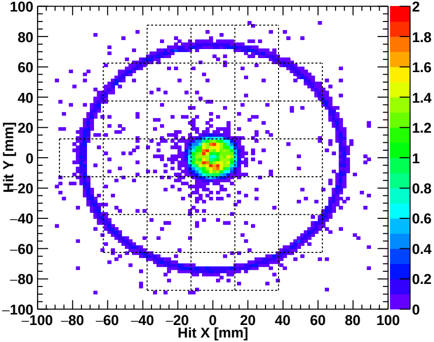
Lens.17-334 AF 50 mm backward BS 1 cm^2 - ring

- lens #67-265: (3 p.e./pad),
- lens #17-334: (4 p.e./pad),
- lens #17-334 gives better separation of Cherenkov photons from primary beam: +3 pads instead of +2 pads

lens #67-265 at 60 mm



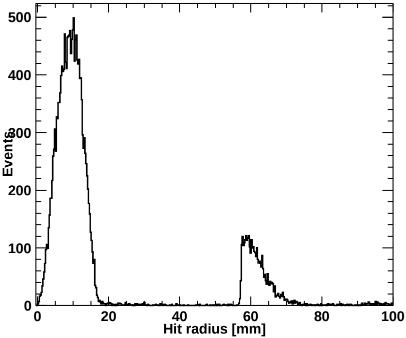
lens #17-334 at 50 mm



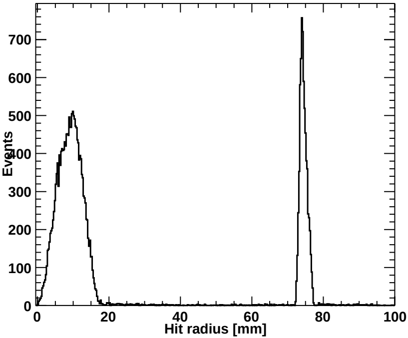
Lens.17-334 AF 50 mm backward BS 1 cm^2 - radius

- lens #67-265: gives smoothed radius distribution,
- lens #17-334: gives Gaussian-like radius distribution,

lens #67-265 at 60 mm



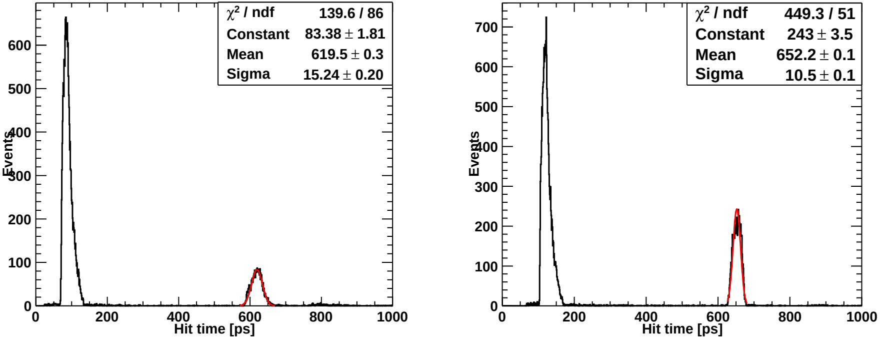
lens #17-334 at 50 mm



Lens.17-334 AF 50 mm backward BS 1 cm^2 - time

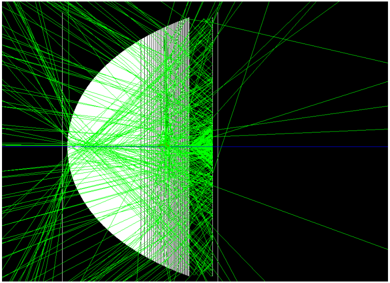
- lens #67-265, D 25 mm, EFL 20 mm; CT 14 mm:timing RMS of 15 ps,
- lens #17-334, D 50 mm, EFL 50 mm; CT 19.2 mm timing RMS of 10 ps,
- even with 1 cm^2 beam spot lens #17-334 satisfy requirements (< 22% broadening)

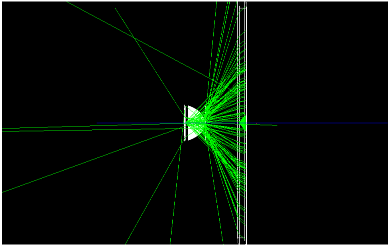
lens #67-265 at 60 mm　　　　lens #17-334 at 50 mm



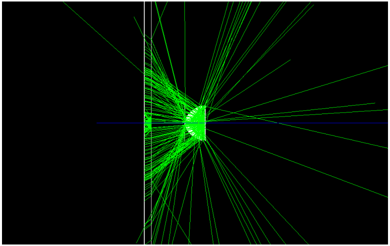
Setup for testbeam

1. beam - protons 5-12 GeV/c,
2. aspheric lens radiator,
3. LAPPD with 32 ch readout by V1742 digitizer.





direct

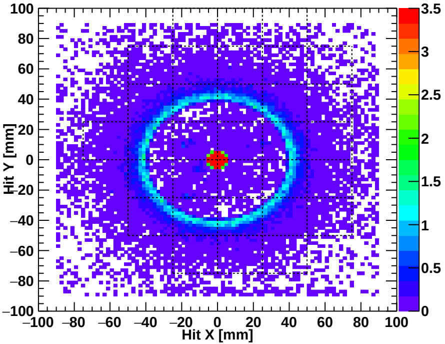


backward reflection

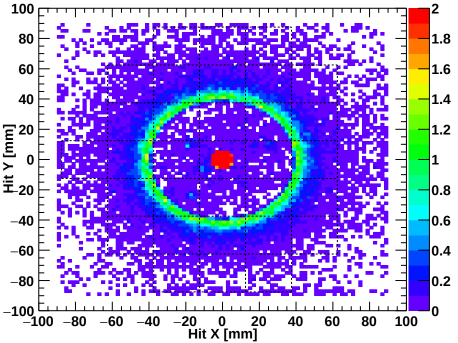
LAPPD mounting offset

- if beam impacts on LAPPD center it produces a signal in 4 pads reducing the spacial separation between beam and Cherenkov ring,
- offsetting LAPPD by 12.5 mm in X and Y the beam spot signal is focusing on just one pad,

centered LAPPD



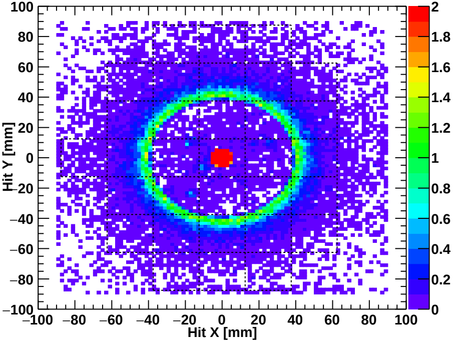
LAPPD at (-12.5,-12.5) mm



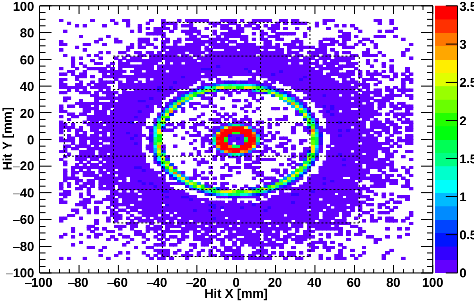
31 mm Direct vs. backward reflection - ring

- direct configuration gives broad ring(27 p.e./pad),
- backward reflection gives narrow and broad rings(33 p.e./pad),
- why?
- beam spot is larger for backward reflection.
- direct gives better spacial separations from beam hit.

direct



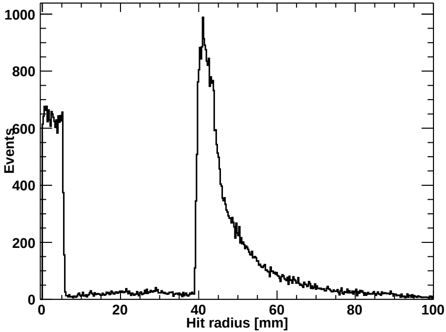
backward reflection



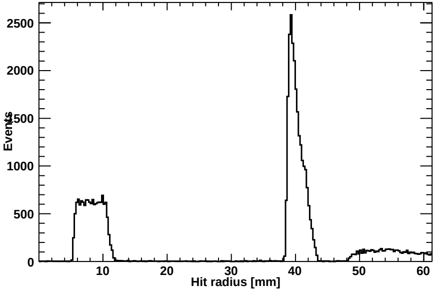
31 mm Direct vs. backward reflection - radius

- direct configuration gives broad ring,
- backward reflection gives narrow and broad rings,
- why?
- beam spot is larger for backward reflection.
- direct gives better spacial separations from beam hit.

direct



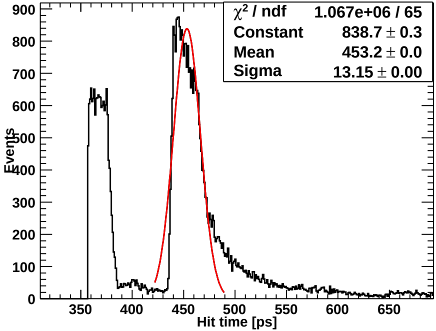
backward reflection



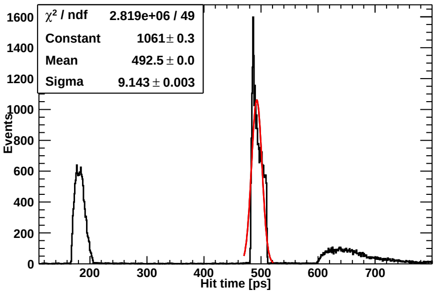
31 mm Direct vs. backward reflection - time

- direct configuration gives photon timing RMS of 13 ps, and 0.07 ns offset from proton impact,
- backward reflection gives photon timing RMS of 9 ps, and 0.31 ns offset from proton impact,
- backward reflection gives better time separations from beam hit.

direct

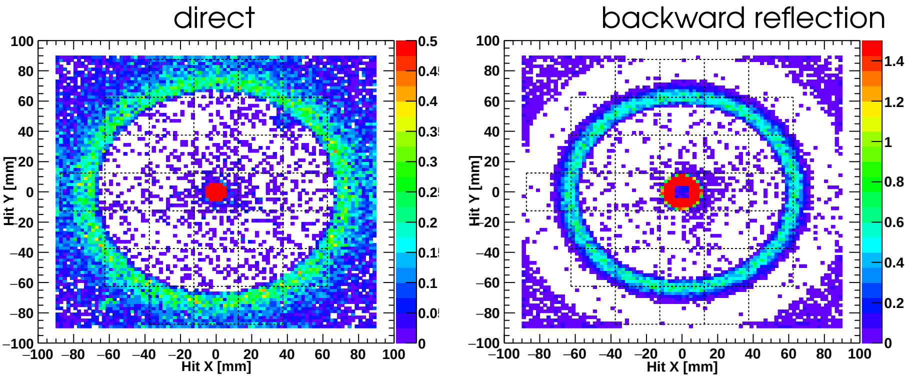


backward reflection



60 mm Direct vs. backward reflection - ring

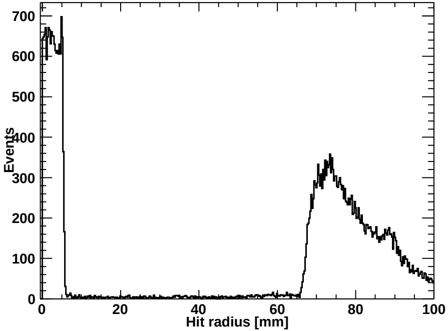
- direct configuration gives broad ring (11 p.e./pad),
- backward reflection gives narrow ring (13 p.e./pad),
- why?
- beam spot is larger for backward reflection.
- direct gives better spacial separations from beam hit.



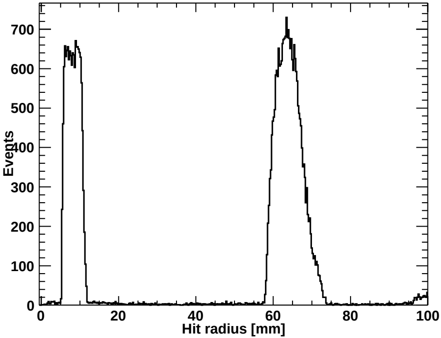
60 mm Direct vs. backward reflection - radius

- direct configuration gives broad ring,
- backward reflection gives narrow and broad rings,
- why?
- beam spot is larger for backward reflection.
- direct gives better spacial separations from beam hit.

direct



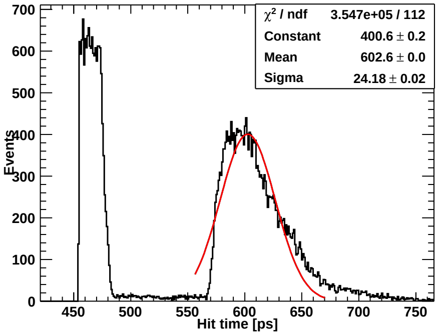
backward reflection



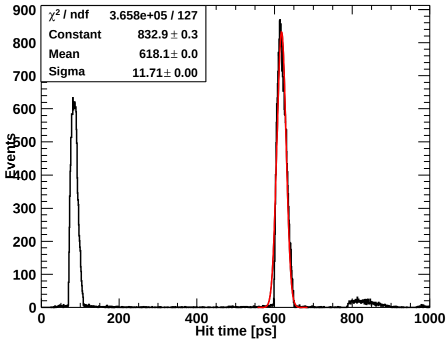
60 mm Direct vs. backward reflection - time

- direct configuration gives photon timing RMS of 24 ps, and 0.07 ns offset from proton impact,
- backward reflection gives photon timing RMS of 12 ps, and 0.31 ns offset from proton impact,
- backward reflection gives better time separations from beam hit.

direct



backward reflection



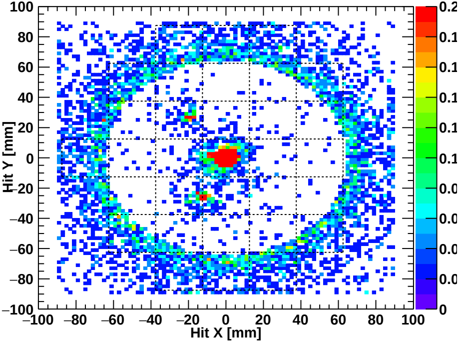
Step 1 conclusions

- too many photo-electron/pad: 27 for 31 mm and 13 for 60 mm (need SPE timing),
- spacial separation between beam spot (170 p.e.) and Cherenkov ring photons is just 1 pad (31 mm) or 2 pads (60 mm) - cross talk?,
- cross talk in the next (10%=17 p.e.?) and next-to-next (1%=2 p.e.?) pads? Perhaps larger than SPE?
- $>$ 60 mm distance is needed,
- timing distribution is too broad.

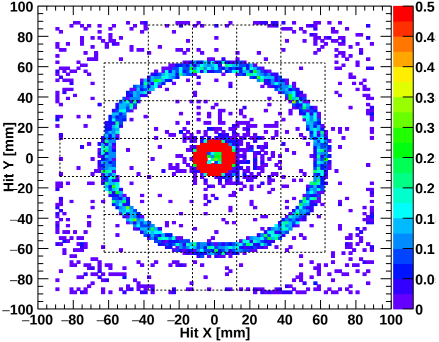
AF 60 mm Direct vs. backward reflection - ring

- direct configuration gives broad ring (2 p.e./pad),
- backward reflection gives narrow ring (3 p.e./pad),
- why?
- beam spot is larger for backward reflection.
- direct gives better spacial separations from beam hit.

direct



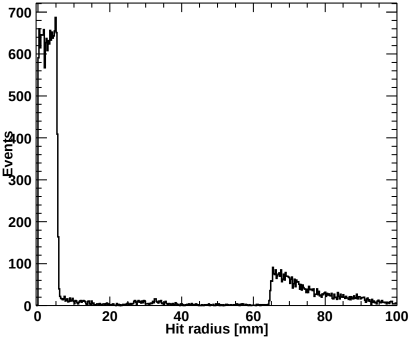
backward reflection



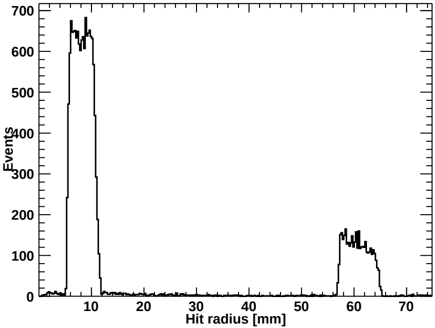
AF 60 mm Direct vs. backward reflection - radius

- direct configuration gives broad ring,
- backward reflection gives narrow and broad rings,
- why?
- beam spot is larger for backward reflection.
- direct gives better spacial separations from beam hit.

direct



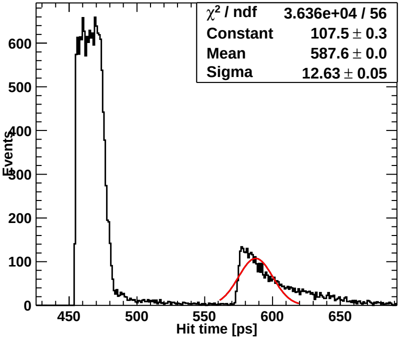
backward reflection



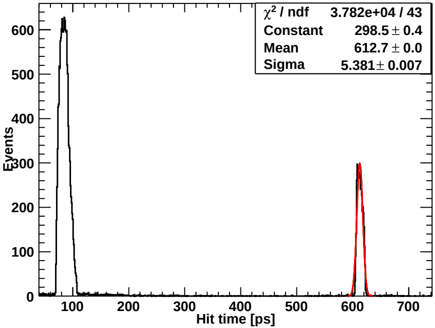
AF 60 mm Direct vs. backward reflection - time

- direct configuration gives photon timing RMS of 10-13 ps, and 0.07 ns offset from proton impact,
- backward reflection gives photon timing RMS of 3.5-5 ps, and 0.31 ns offset from proton impact,
- backward reflection gives better time separations from beam hit.

direct



backward reflection



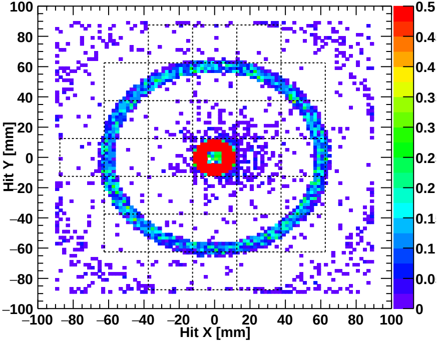
Step 2 conclusions

- number photo-electrons/pad is reduced: 3 for 60 mm (but need SPE timing),
- spacial separation between beam spot (170 p.e.) and Cherenkov ring photons is just 1 pad (31 mm) or 2 pads (60 mm) - cross talk?,
- cross talk in the next (10%=17 p.e.?) and next-to-next (1%=2 p.e.?) pads? Perhaps larger than SPE?
- $>$ 60 mm distance is needed,
- timing distribution for backward reflection configuration is OK.

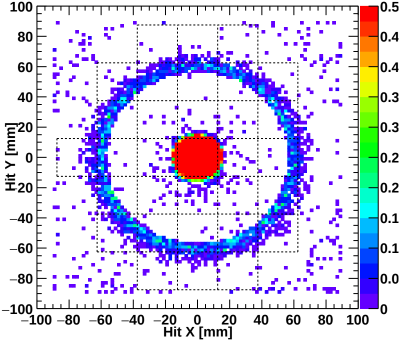
AF 60 mm backward reflection BS 1 cm^2 - ring

- beam spot 0 (3 p.e./pad),
- beam spot 1 cm^2 (3 p.e./pad),
- LAPPD beam spot is larger for BS 1 cm^2, entering in nearby pads (5 p.e./pad).

beam spot 0



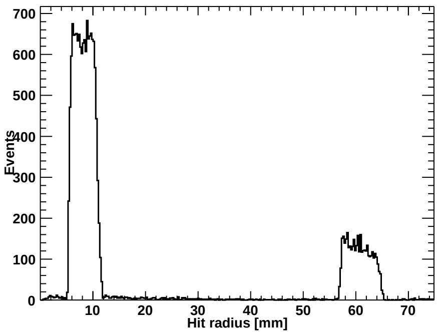
beam spot 1 cm^2



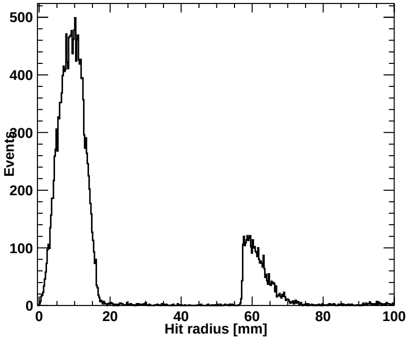
AF 60 mm backward reflection BS 1 cm^2 - radius

- beam spot 0 gives rectangular radius distribution,
- beam spot 1 cm^2 gives smoothed radius distribution,

beam spot 0



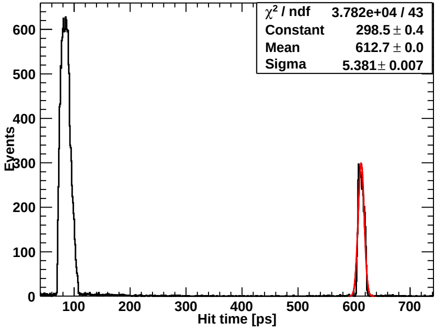
beam spot 1 cm^2



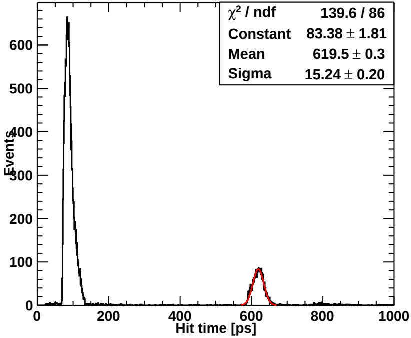
AF 60 mm backward reflection BS 1 cm^2 - time

- beam spot 0 timing RMS of 3.5-5 ps,
- beam spot 1 cm^2 timing RMS of 14-15 ps,
- beam spot 1 cm^2 is too large.

beam spot 0



beam spot 1 cm^2



Step 3 conclusions

- T10 beam spot is 15x10 mm^2,
- but the trigger MCP we plan to rent has active area 10x10 mm^2,
- simulated timing resolution increases from 5 to 15 ps, too large for our purpose,
- reducing active beam spot to 5x5 mm^2 allows to reach 8 ps (efficiency 17%),
- we must put beam profile monitor 5x5 mm^2 in front of trigger MCP,
- in backward reflection configuration attaching black adhesive tape on the central pad window section allows to suppress beam induced signal (reducing cross-talk issue).