LAPPD beam test results

CERN testbeam Oct. 2022

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remote

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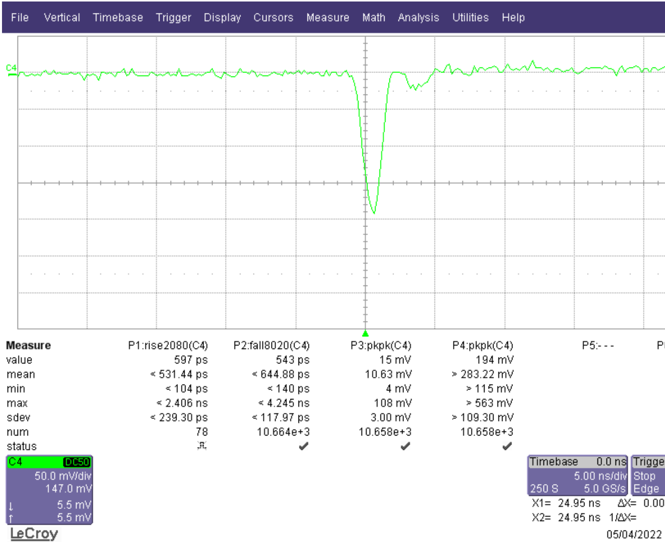
Expected results

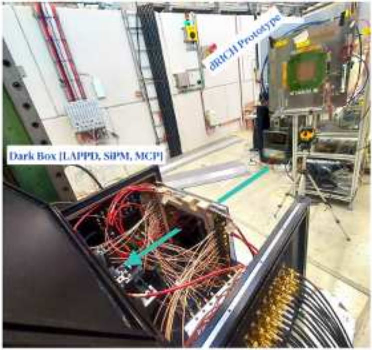
- estimated 14 ps SPE resolution (TTS not included),
- based on signal risetime and S/N-ratio,
- optimized setup to have all other timing uncertainties $<20\%$, which corresponds to 9.3 ps.



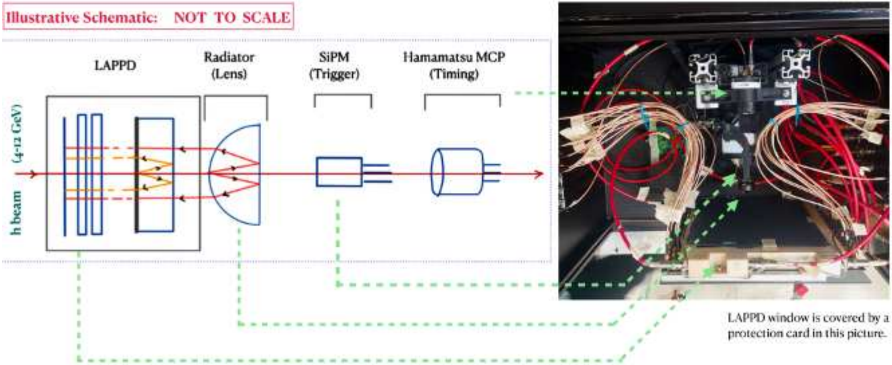
Experimental hall at T10 beamline

CERN PS, Hall T10

LAPPD installed downstream of dRICH prototype



Measurement setup



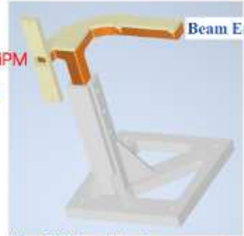
LAPPD window is covered by a protection card in this picture.

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

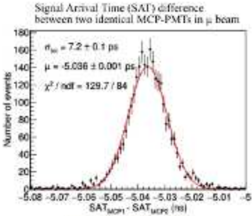


The SiPM and the Lens mount

SiPM onboard amplifier

Hamamatsu MCP-PMT (R3809U-50)

Tube diameter = 45 mm

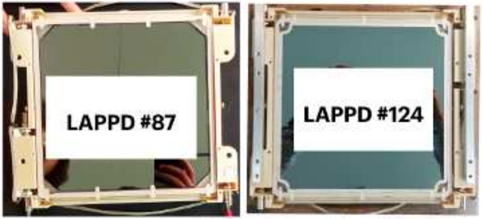


NIM A 960 (2020) 163592

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

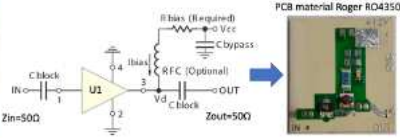
Typical Characteristics
Gain = 2 × 10⁵ ; Dark current = 10 nA
Rise time = 150 ps
Transit time = 550 ps
Transit time spread = 25 ps (RMS=10 ps)

LAPPD readout



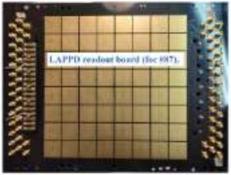
Can you spot an important difference between the two LAPPD tiles?

Custom made preamplifiers by INFN, Genova



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

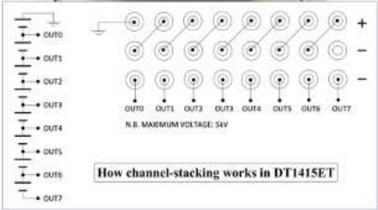
additional PCB for grounding anode



Present version comprises 8 input/output per unit

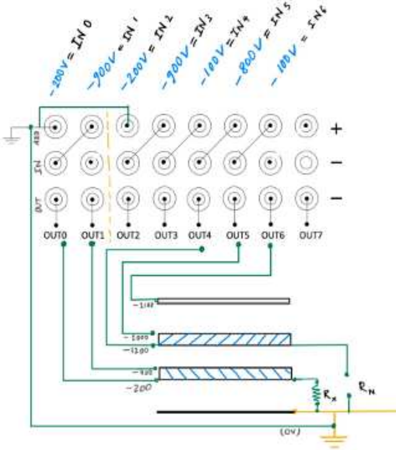
LAPPD bias voltages

CAEN DT1415ET Floating HV supply



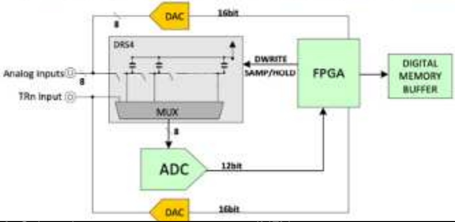
How channel-stacking works in DT1415ET

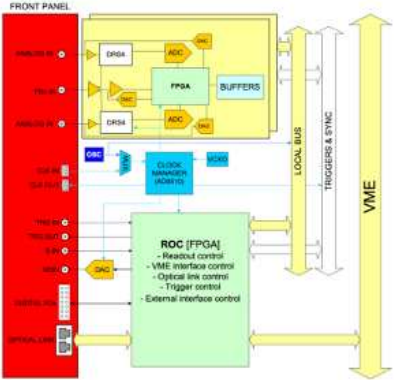
How we used it: An example set of voltages



DAQ system

WEINER VME crate:
CAEN V1718 controller board
CAEN V1742 Digitizer board with 32 readout channels



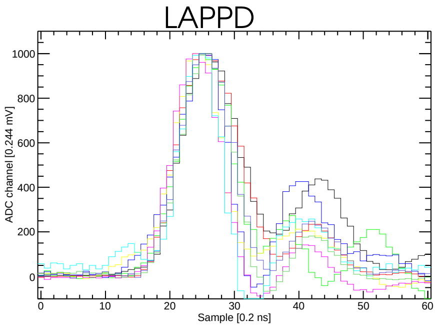


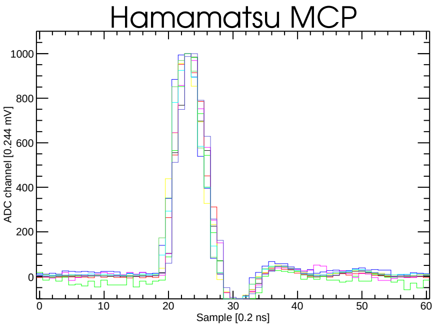
V1742 Board:

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

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.

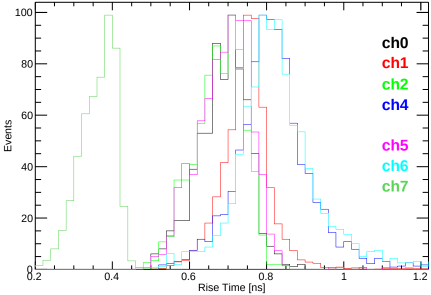




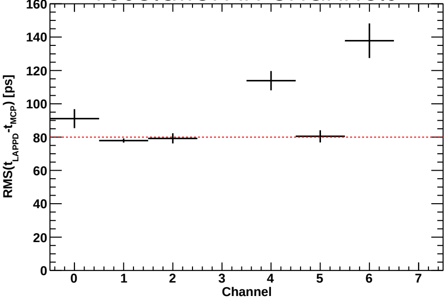
LAPPD signal risetime

- 15% variations of risetime channel-to-channel,
- some correlation with timing resolution observed,
- components on PCB are two TCM4-452X+ transformers BW=4.5 GHz,
- large risetime in nearby pads: B6+C6 and F3+G3,
- parasitic capacitance in some pads?
- SPE elect. resolution: 750ps/(250mV/1.2mV)≃4 ps.

risetime in channels



resolution in channels

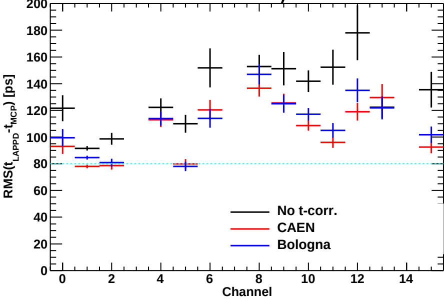


DRS4 timing calibrations

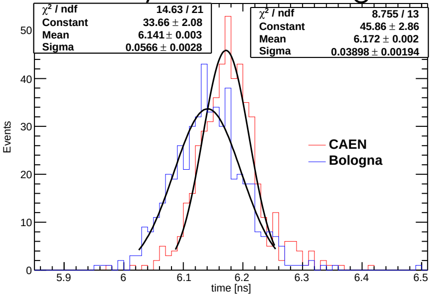
- timing corrections are significant: 52 ps broadening,
- CAEN corrections give best resolution of 39 ps,
- Bologna corrections lead to broadening of 41 ps,
- Bologna corrections give 31 ps shorter delay,

$$T_j^{ch1}-T_k^{ch7} = (j-k)\times 200ps+\sum_{i=1}^{i\leq j}(\Delta t_i^{ch1}-200ps)-\sum_{i=1}^{i\leq k}(\Delta t_i^{ch7}-200ps)$$

SPE run with acrylic filter

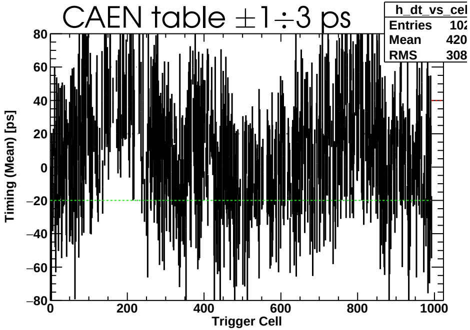


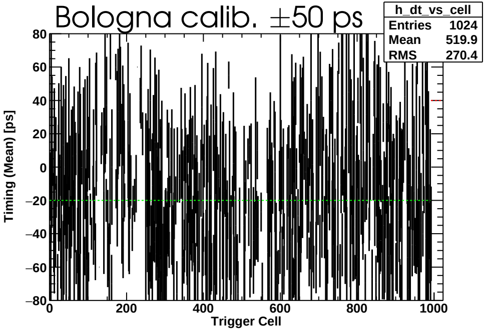
no acrylic filter, lower gain



CAEN vs. Bologna calibrations

- CAEN provides small corrections $\pm 1 \div 3$ ps per cell,
- Bologna method gives fixed pattern correction: -50 ps per even and $+50$ ps per odd cells,
- selected events with delay of exactly 31 cells (odd),
- studied the timing as a function of MCP channel cell,
- CAEN correction has less cell-to-cell oscillations, but has broad offsets of about 40 ps.

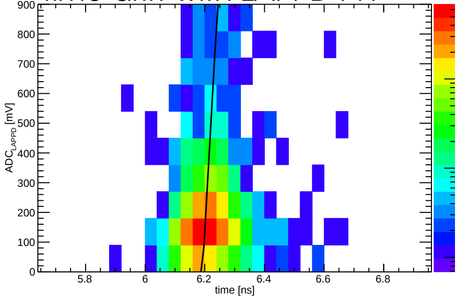




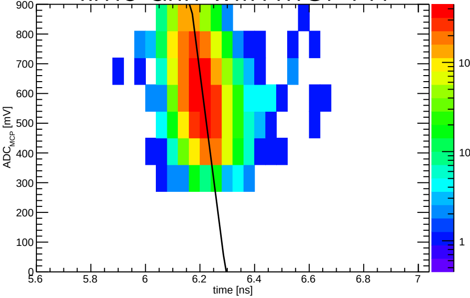
LAPPD and MCP PH-corrections on time

- time difference depends on signal Pulse Height,
- in LAPPD drift is +0.05 ps/mV,
- in Hamamatsu MCP drift is -0.1 ps/mV,
- after correction the residual PH-dependence is <5 ps.

time drift with LAPPD PH



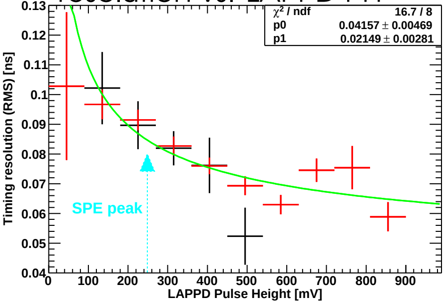
time drift with MCP PH



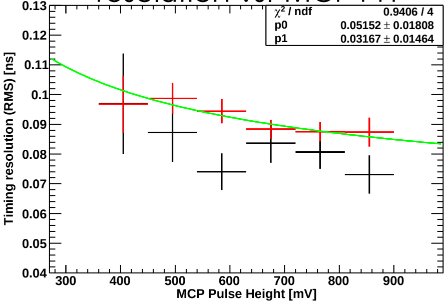
Final SPE LAPPD timing resolution

- SPE timing resolution of 80 ps (RMS) was observed,
- the resolution is $a + b/\sqrt{V}$ function of LAPPD PH,
- constant term of 40 ps agrees with no filter σ,
- $N_{p.e.}$ term is approximately $= 40\ ps/\sqrt{N_{p.e.}}$,
- no significant dependence on Hamamatsu MCP PH.

resolution vs. LAPPD PH



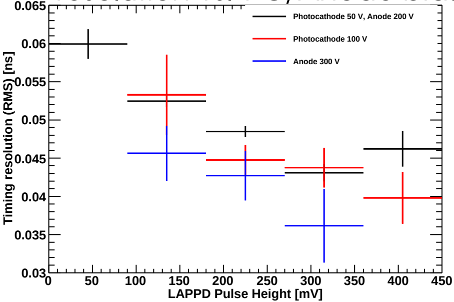
resolution vs. MCP PH



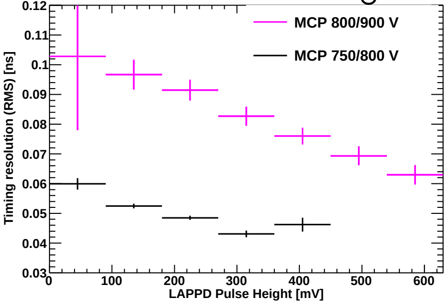
Bias voltage dependence

- increasing Photocatode voltage from 50 V to 100 V leads to 11% improvement,
- increasing Anode voltage from 200 V to 300 V leads to 16% improvement,
- dependence on LAPPD gain is under study.

resolution vs. PC/Anode bias



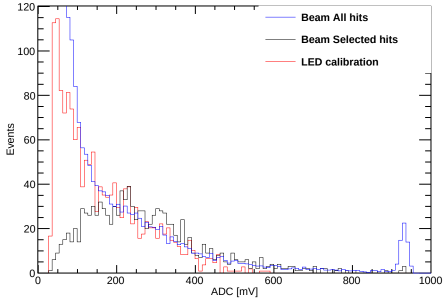
resolution vs. LAPPD gain



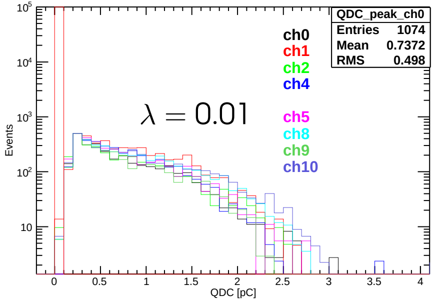
LAPPD SPE charge calibrations

- LED SPE calibrations performed at CERN 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=1.28 pC (includes $\times2$),
- At CERN observed SPE=0.9 pC (1.5 pC for selected hits), but some background could be still present.

LED SPE calibrations vs. beam



Collected SPE charge



Summary

- tested 20 μm pore LAPPD N.124 capacitively coupled to the Incom readout board with 1 inch pads,
- observed SPE timing RMS of about 80 ps,
- it can be described as: $40\ ps + 40\ ps/\sqrt{N_{p.e.}}$,
- increasing PhotoCathode and Anode bias voltage improves resolution by 11% and 16%,
- LAPPD showed risetime of 750 ps (expected 260 ps),
- large cross-talk between pads was observed.

References

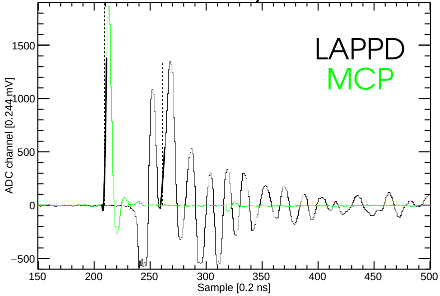
1. M. Amarian *et al.*, "The CLAS forward electromagnetic calorimeter", *Nucl. Instr. and Meth.* **A460**, 239 (2001).
2. M. Guillo, "EC Time Calibration Procedure for photon runs in CLAS", CLAS-Note-2001-014, 2001.
3. M. Osipenko, "Geometrical alignment of CLAS DCs using tracks with constrained vertex",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

Backup slides

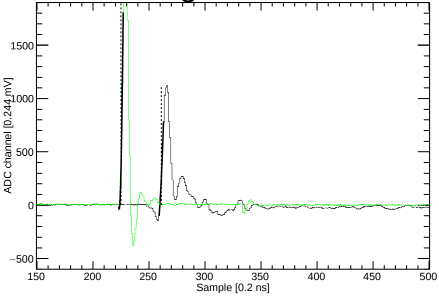
Multiple hit cross talk on LAPPD

- in single hit measurements (laser) signals are clean,
- in multiple hit events (Cherenkov ring + beam spot) strong cross talk was observed,
- 30-90% of events have at least one EMI distortion,
- EMI distortion on signal affects rising edge (timing),
- in affected events 17/31 channels are distorted.

EMI-only



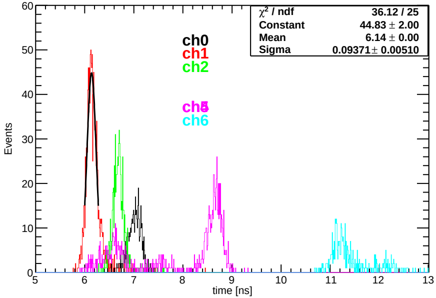
Signal+EMI



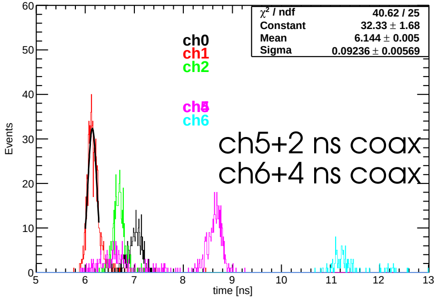
SPE timing resolution

- Geant4 gives ideal (light only) estimate: $\sigma \sim 8$ ps,
- signals in MCP allow (TTS=0) to obtain: 450 ps/(600 mV/1.5 mV)=1 ps,
- signals in LAPPD allow (TTS=0) to obtain: 750 ps/(200 mV/1.5 mV)=6 ps,
- measured resolution is 10 times larger, but agrees with TTS(PC=50 V)=90 ps measured by Vincenzo.

All hits

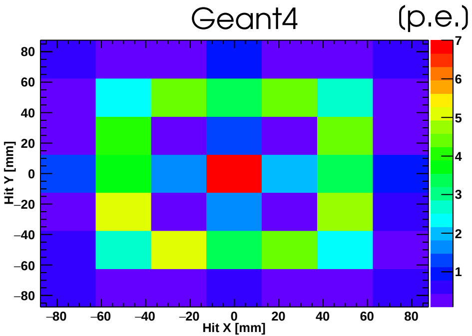


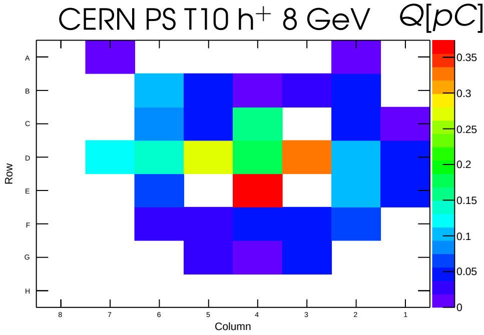
SPE hits



Cherenkov ring

- Cherenkov ring was observed,
- normalization of average is affected by cross-talk,
- beam spot was suppressed by a factor of 10 (grease+black tape on the window),
- 32 channels are barely sufficient to cover entire ring (25 mm pads, ring radius 60 mm).



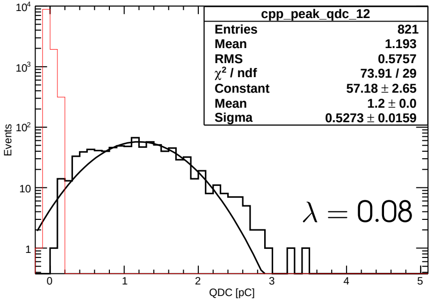


beam spot 316 p.e.

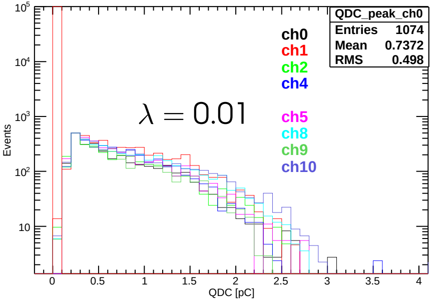
LAPPD SPE charge calibrations

- LAPPD N.87 at 875/875 V had gain of 3.3×10^6, SPE=0.53 pC in INCOM datasheet; missing a factor of 2 from V1742 input voltage divider, including it we measured 1.2 pC with laser pulser,
- LAPPD N.124 at 800/900 V should have gain of 4×10^6, expected SPE=1.28 pC (includes $\times2$),
- At CERN observed SPE=0.7 pC, but some background could be still present.

LAPPD N.87 875/875 V



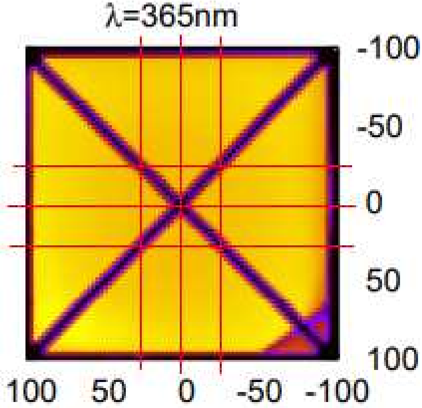
LAPPD N.124 800/900 V



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%.

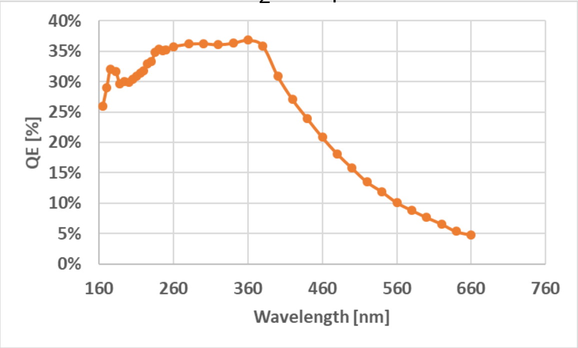
LAPPD.87 with Na_2KSb photocathode



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

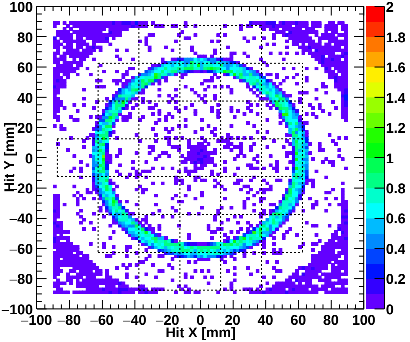


$$N_\gamma = 0.0256 * \left\{ \frac{1}{160nm} - \frac{1}{560nm} \right\} * 0.30 = 34 \frac{p.e.}{mm},$$

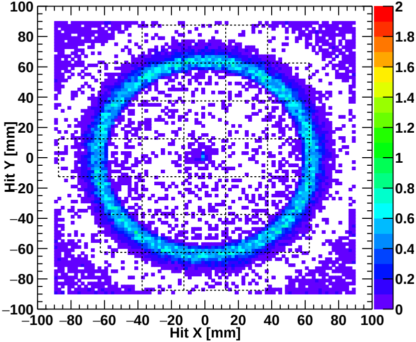
60 mm backward, chromatic dispersion - ring

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

no dispersion



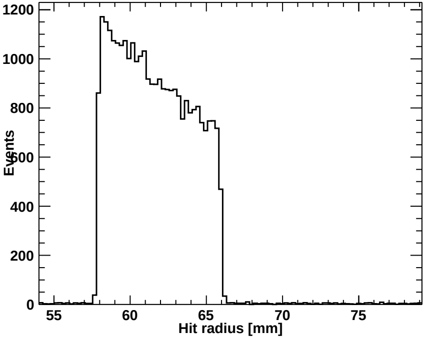
physical



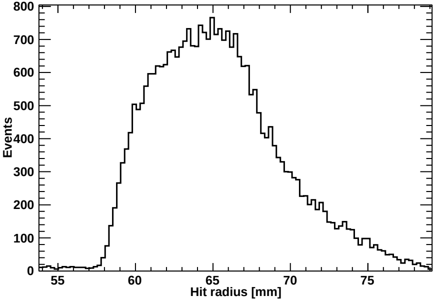
60 mm backward, chromatic dispersion - radius

- 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



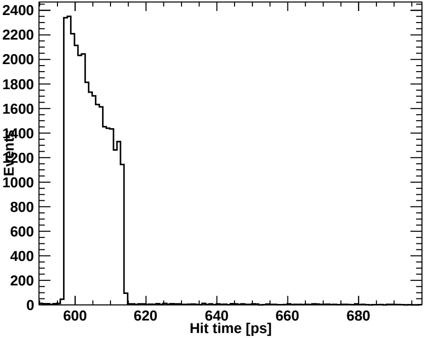
physical



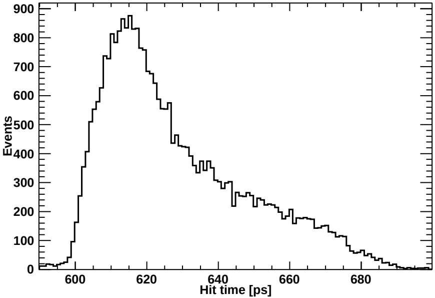
60 mm backward, chromatic dispersion - time

- 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



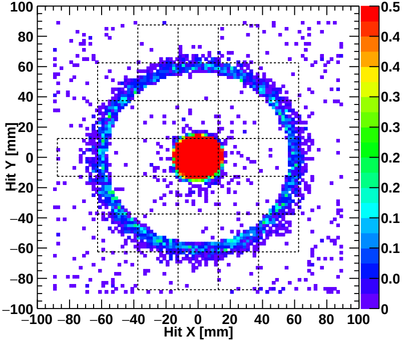
physical



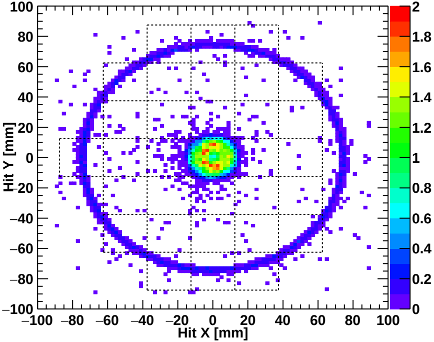
Lens.17-334 AF 50 mm backward BS 1 cm^2 - ring

- 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

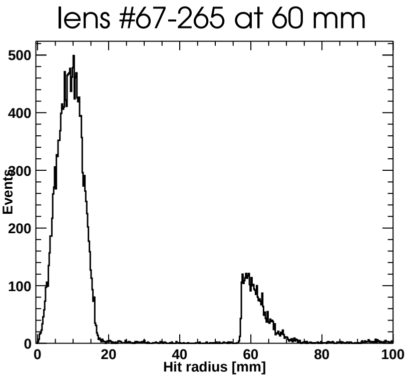


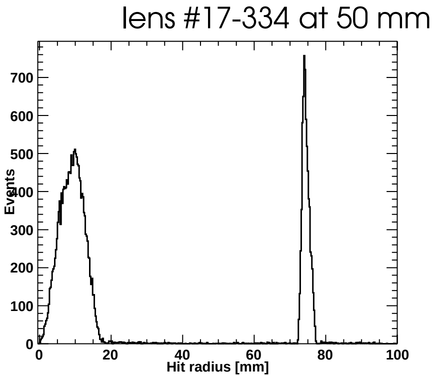
lens #17-334 at 50 mm



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,



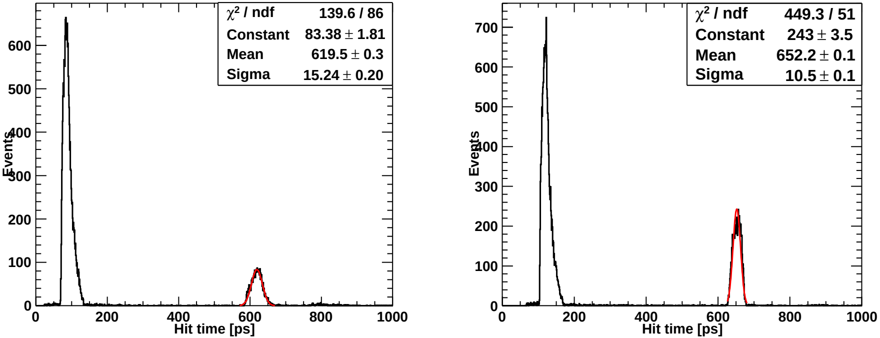


Lens.17-334 AF 50 mm backward BS 1 cm^2 - time

- 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)

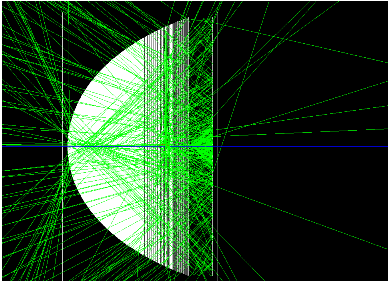
lens #67-265 at 60 mm

lens #17-334 at 50 mm

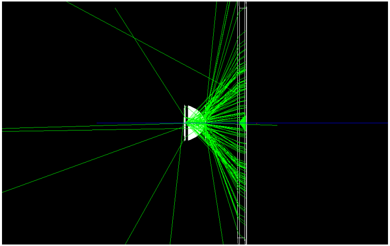


Setup for testbeam

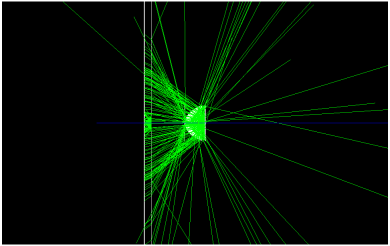
1. beam - protons 5-12 GeV/c,
2. aspheric lens radiator,
3. LAPPD with 32 ch readout by V1742 digitizer.



direct



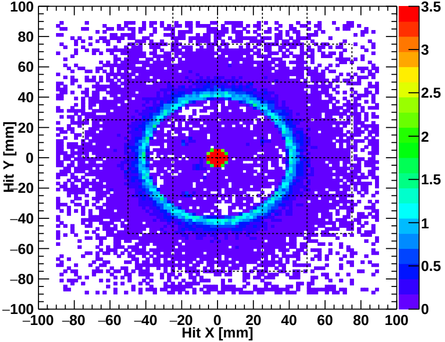
backward reflection



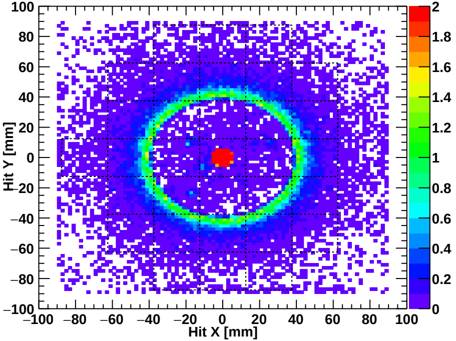
LAPPD mounting offset

- 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



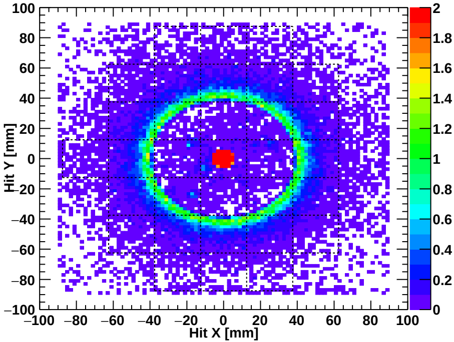
LAPPD at (-12.5,-12.5) mm



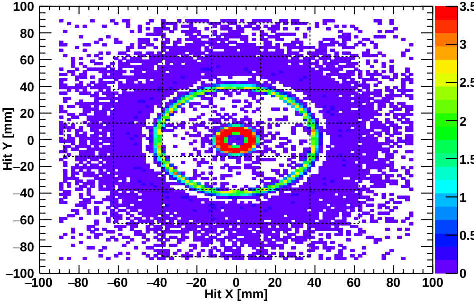
31 mm Direct vs. backward reflection - ring

- 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



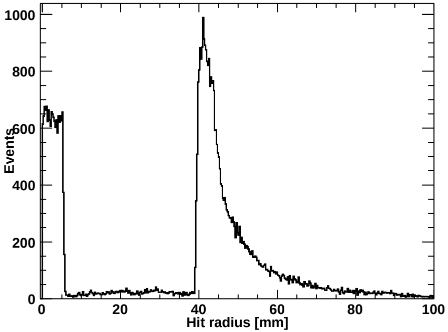
backward reflection



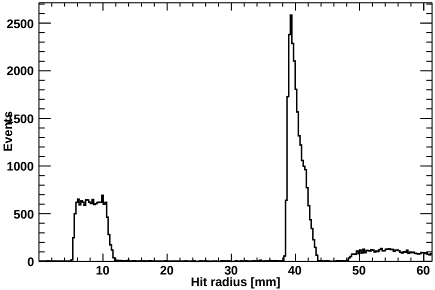
31 mm Direct vs. backward reflection - radius

- 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



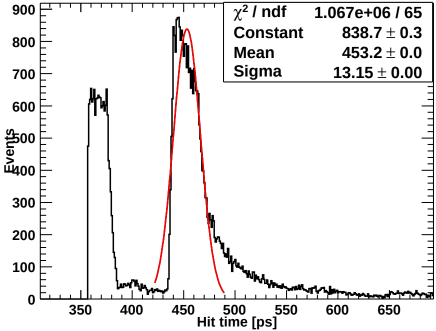
backward reflection



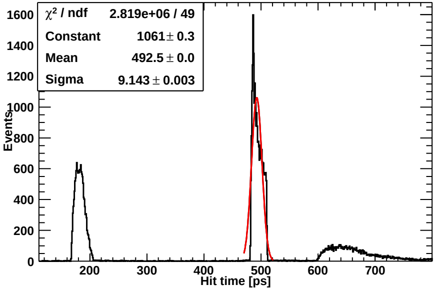
31 mm Direct vs. backward reflection - time

- 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

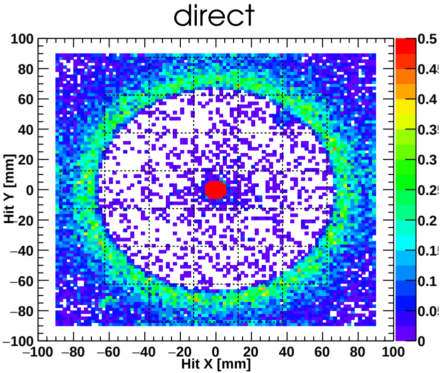


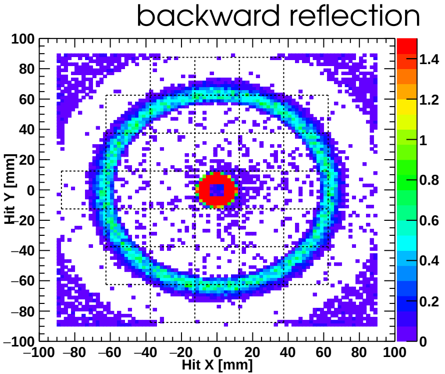
backward reflection



60 mm Direct vs. backward reflection - ring

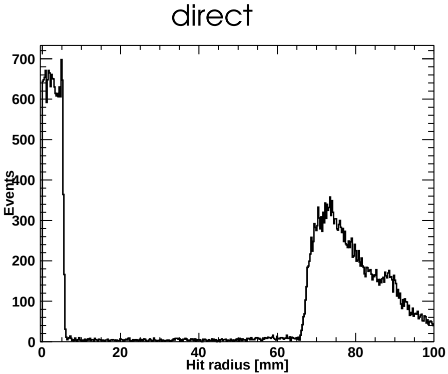
- direct configuration gives broad ring (11 p.e./pad),
- backward reflection gives narrow ring (13 p.e./pad),
- why?
- beam spot is larger for backward reflection.
- direct gives better spacial separations from beam hit.





60 mm Direct vs. backward reflection - radius

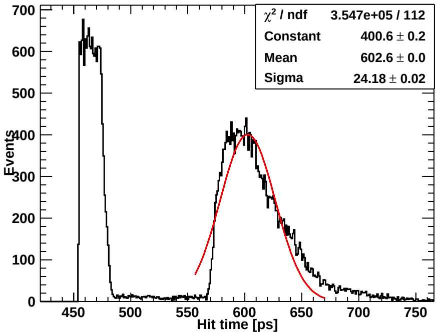
- direct configuration gives broad ring,
- backward reflection gives narrow and broad rings,
- why?
- beam spot is larger for backward reflection.
- direct gives better spacial separations from beam hit.



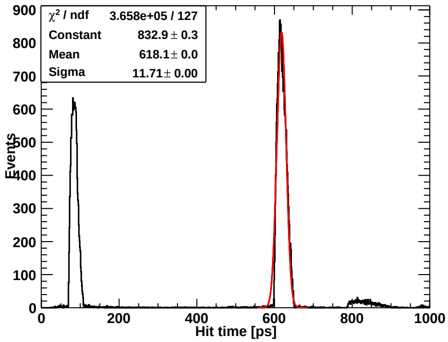
60 mm Direct vs. backward reflection - time

- 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



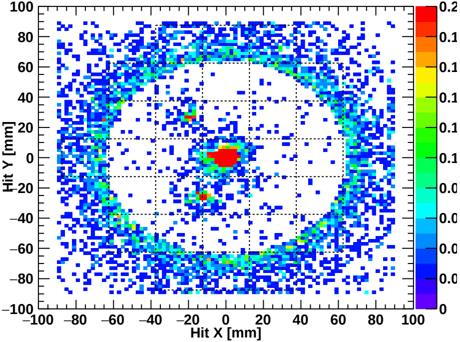
Step 1 conclusions

- 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.

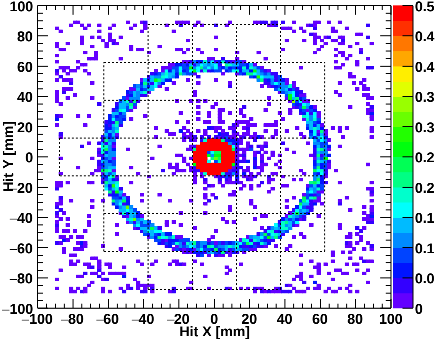
AF 60 mm Direct vs. backward reflection - ring

- 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



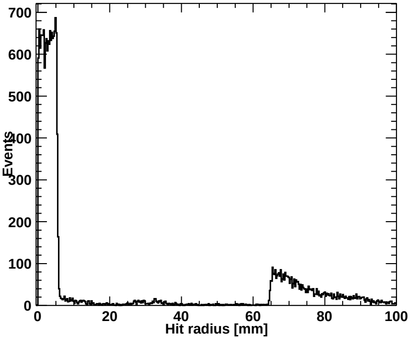
backward reflection



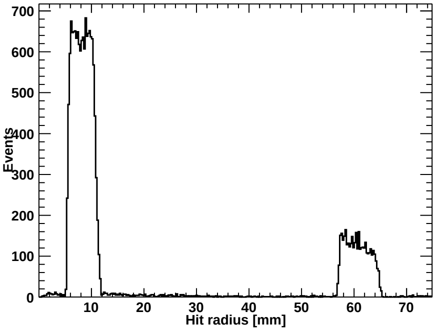
AF 60 mm Direct vs. backward reflection - radius

- 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



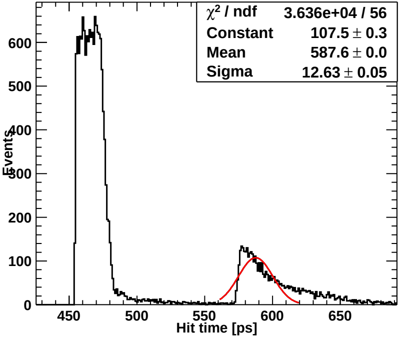
backward reflection



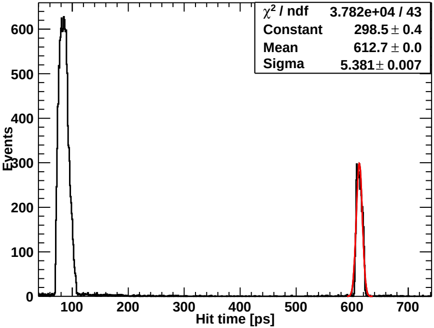
AF 60 mm Direct vs. backward reflection - time

- 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



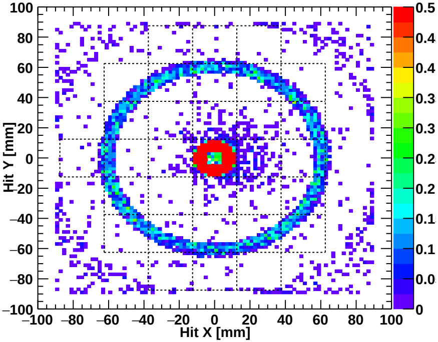
Step 2 conclusions

- 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.

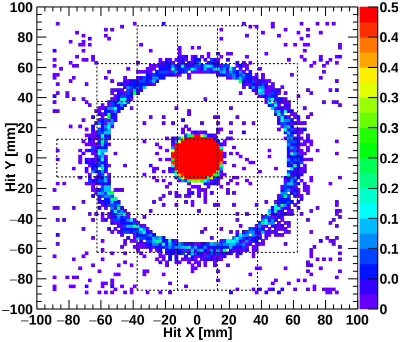
AF 60 mm backward reflection BS 1 cm^2 - ring

- 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



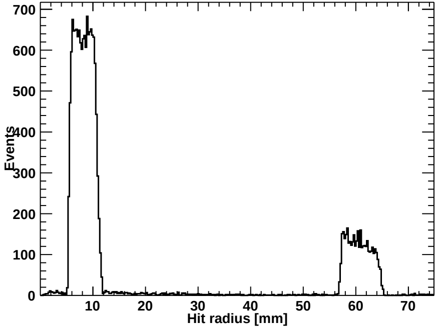
beam spot 1 cm^2



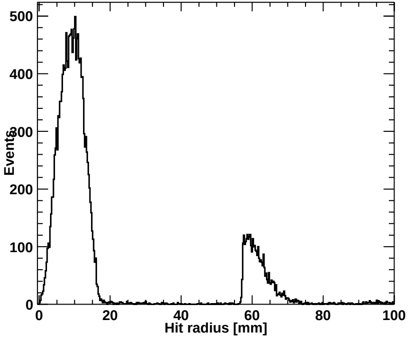
AF 60 mm backward reflection BS 1 cm^2 - radius

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

beam spot 0



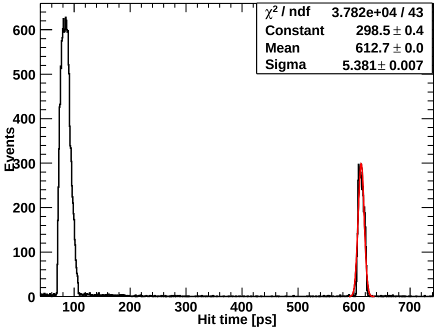
beam spot 1 cm^2



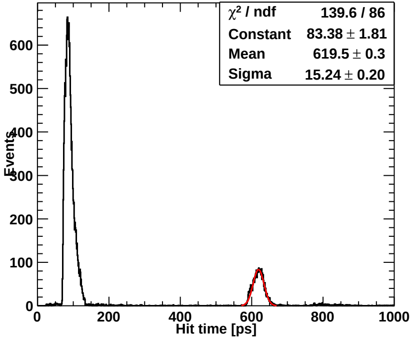
AF 60 mm backward reflection BS 1 cm^2 - time

- 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).

Number of Cherenkov photons

- assume proton beam with P=12 GeV/c, β_p=0.9969589 and $\theta_C = 48.4°$ 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 174 p.e. from LAPPD window and 359 p.e. from aspheric lens.