Beam test, first hints about the data

CERN PS T10 beamline

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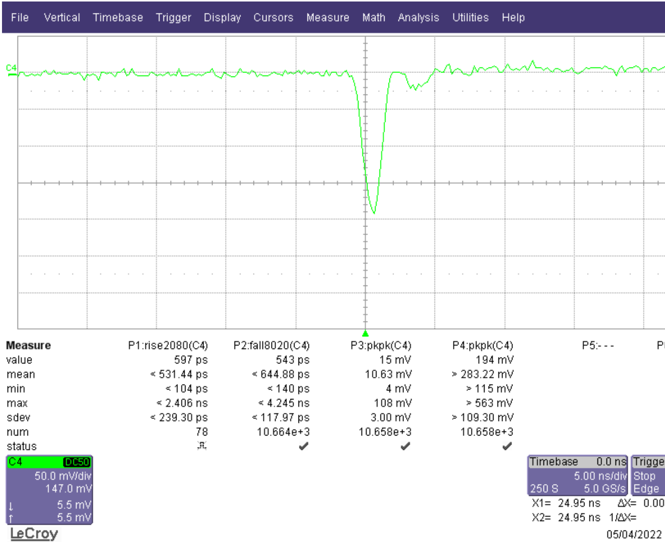
remote

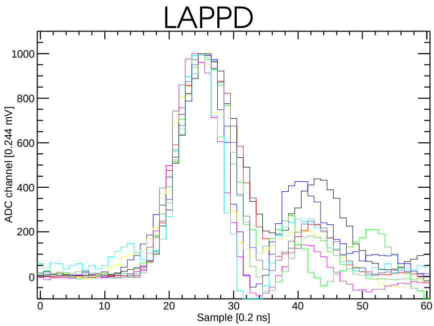
Expected results

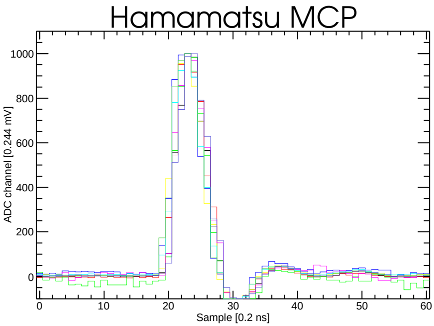
- previously (lab studies, tile 87) estimated 14 ps SPE resolution (TTS not included),
- based on signal risetime and S/N,
- optimized setup to have all other timing uncertainties <20%, which corresponds to 9.3 ps.



Measured LAPPD signals w.r.t. Hamamatsu MCP

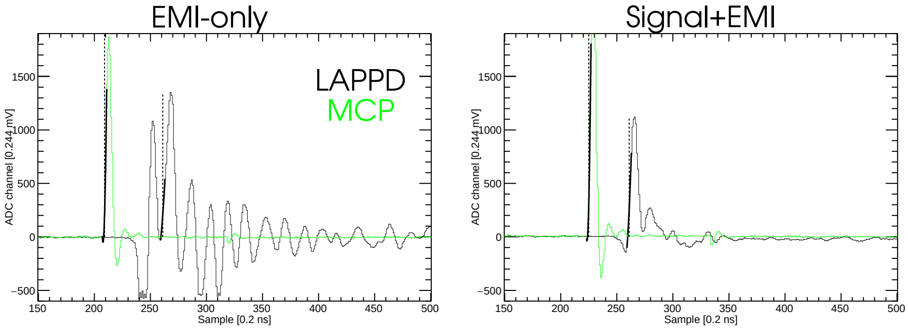
- LAPPD risetime (20-80%) was about 0.75 ns,
- Hamamatsu MCP had 0.4 ns (intrinsic 0.16 ns),
- V1742 digitizer has BW=0.5 GHz →0.45 ns is its intrinsic limit on risetime (20-80%).
- LAPPD 1 inch pad has large capacitance 5.2 pF, assuming 50Ω load we expected 0.26 ns.





Multiple hit cross talk on LAPPD

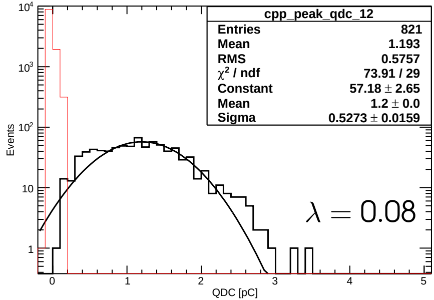
- in single hit measurements (laser) signals are clean,
- in multiple hit events (Cherenkov ring + beam spot) strong cross talk was observed,
- 30-90% of events have at least one EMI distortion,
- EMI distortion on signal affects rising edge (timing),
- in affected events 17/31 channels are distorted.



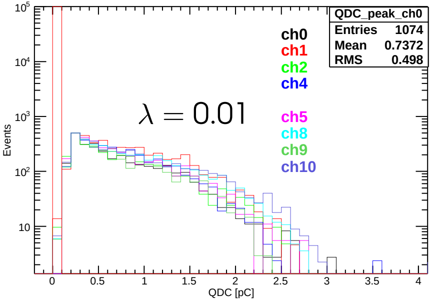
LAPPD SPE charge calibrations

- 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 $\times$2),
- At CERN observed SPE=0.7 pC, but some backgound could be still present.

LAPPD N.87 875/875 V



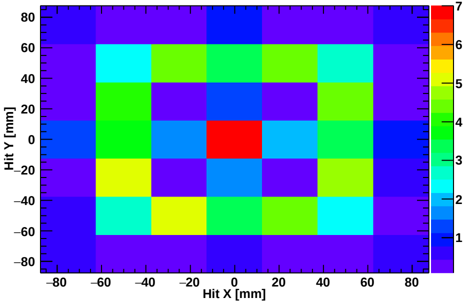
LAPPD N.124 800/900 V



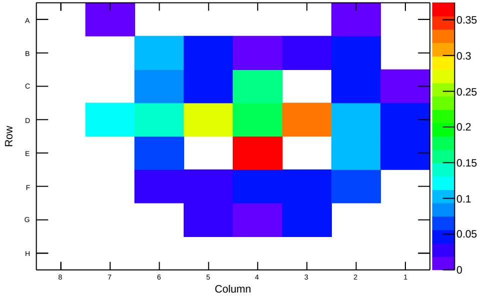
Cherenkov ring

- 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).

Geant4 (p.e.)



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

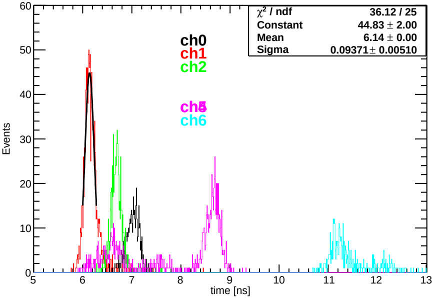


beam spot 316 p.e.

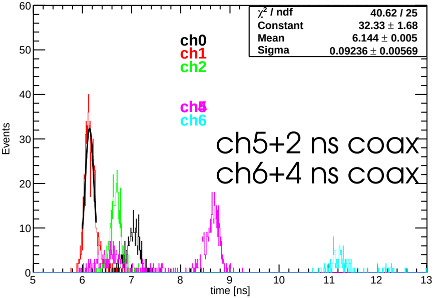
SPE timing resolution

- 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



Summary

- measured timing is 10 times larger than the naive (TTS=0) expectations, but agrees with TTS(PC=50 V) measured by Vincenzo,
- why TTS is so large? Hamamatsu MCP <10 ps!
- Cherenkov rings were observed, although 32-channels limited coverage,
- beam spot signal was suppressed,
- LAPPD showed 3 times slower risetime w.r.t. naive estimates,
- LAPPD gain is in agreement with expectations within factor of 2,
- cross-talk on the standard Incom readout PCB does not allow to measure multi-hit events cleanly.

References

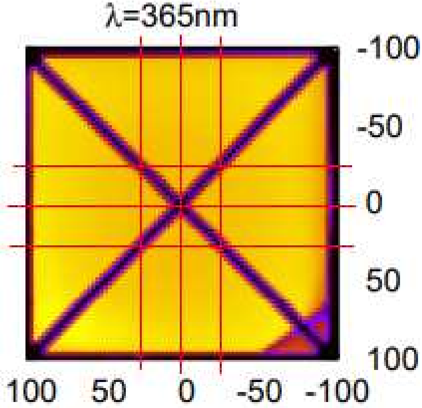
1. M. Amarian *et al.*, "The CLAS forward electromagnetic calorimeter", *Nucl. Instr. and Meth.* **A460**, 239 (2001).
2. M. Guillo, "EC Time Calibration Procedure for photon runs in CLAS", CLAS-Note-2001-014, 2001.
3. M. Osipenko, "Geometrical alignment of CLAS DCs using tracks with constrained vertex",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

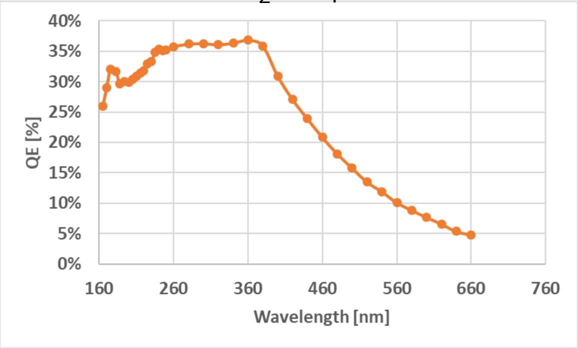
LAPPD.87 with Na_2KSb photocathode



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

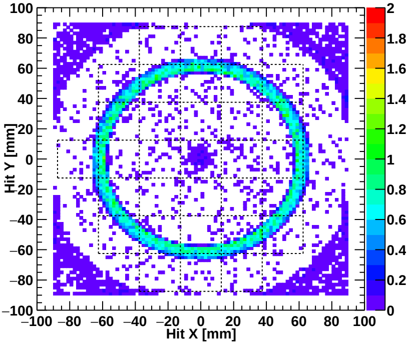


$$N_\gamma = 0.0256 * \left\{ \frac{1}{160nm} - \frac{1}{560nm} \right\} * 0.30 = 34 \frac{p.e.}{mm},$$

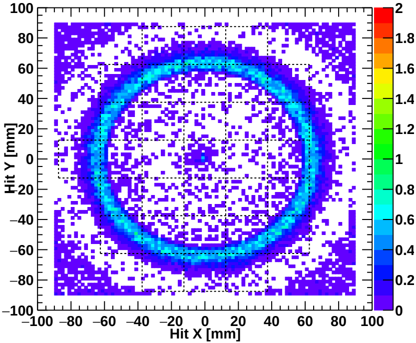
60 mm backward, chromatic dispersion - ring

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

no dispersion



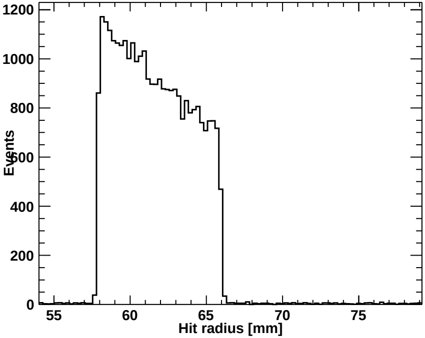
physical



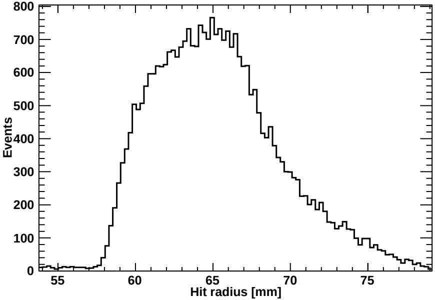
60 mm backward, chromatic dispersion - radius

- 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



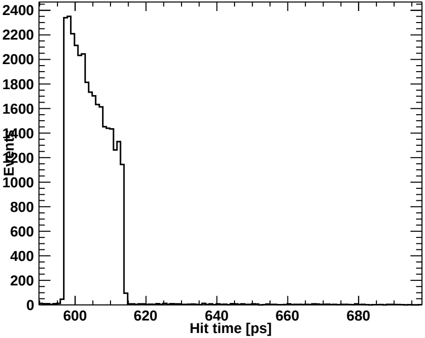
physical



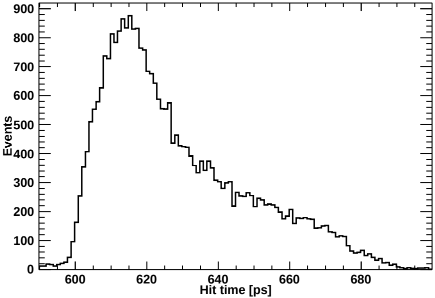
60 mm backward, chromatic dispersion - time

- 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

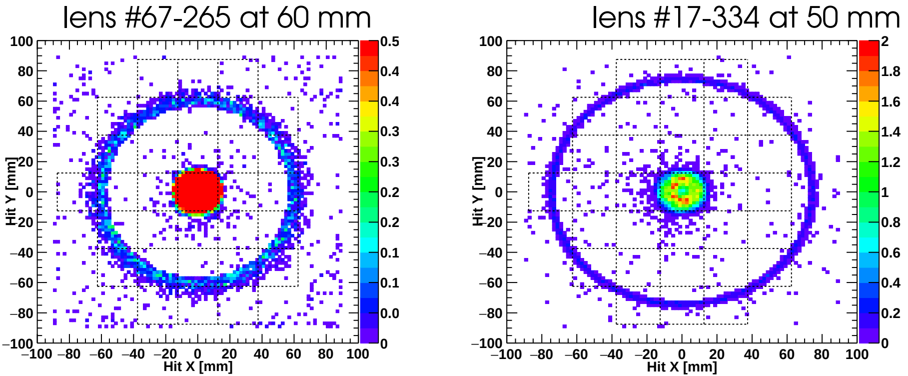


physical



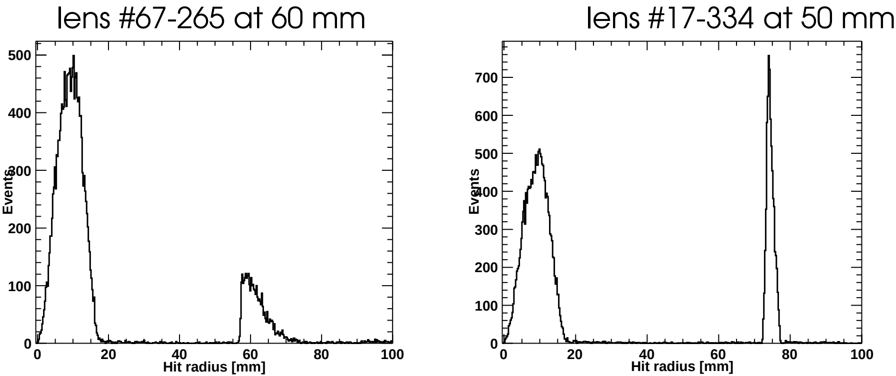
Lens.17-334 AF 50 mm backward BS 1 cm^2 - ring

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

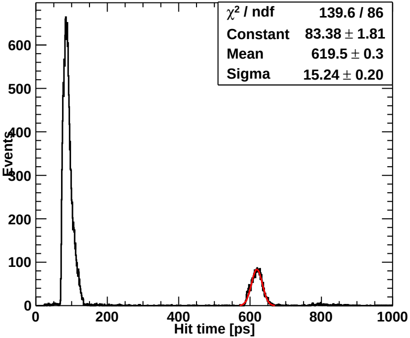
- lens #67-265: gives smoothed radius distribution,
- lens #17-334: gives Gaussian-like radius distribution,



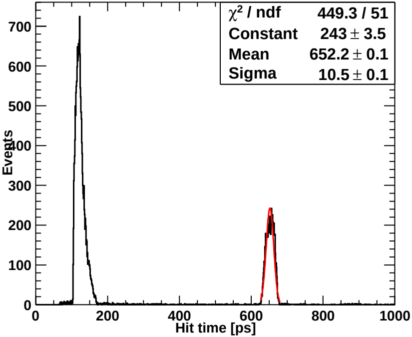
Lens.17-334 AF 50 mm backward BS 1 cm^2 - time

- 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

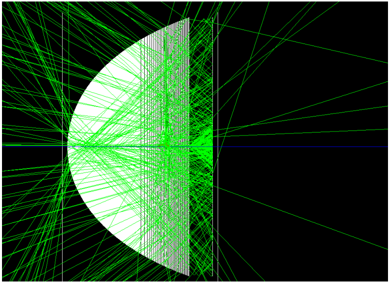


lens #17-334 at 50 mm

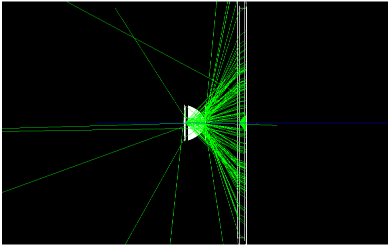


Setup for testbeam

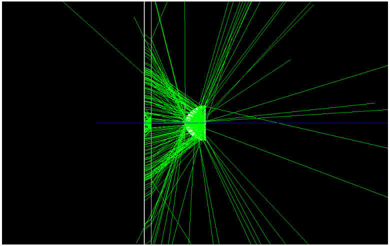
1. beam - protons 5-12 GeV/c,
2. aspheric lens radiator,
3. LAPPD with 32 ch readout by V1742 digitizer.



direct



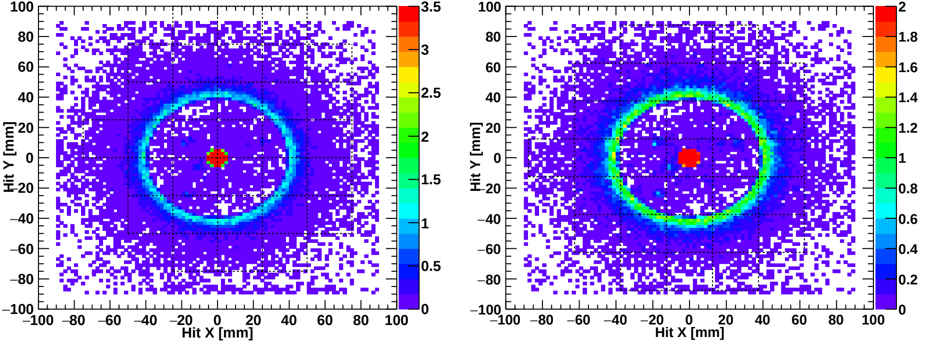
backward reflection



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,

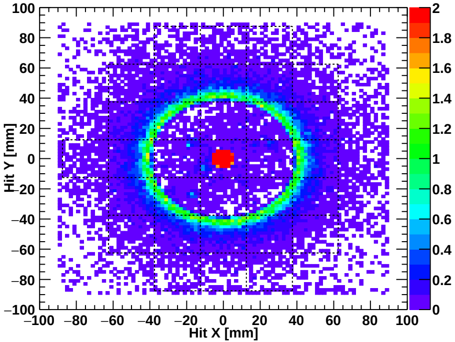
centered LAPPD LAPPD at (-12.5,-12.5) mm



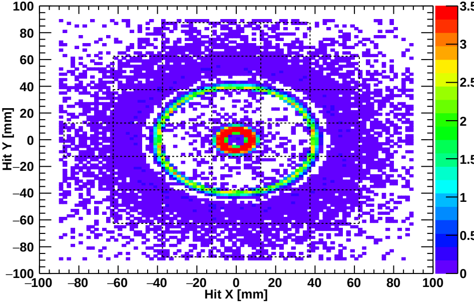
31 mm Direct vs. backward reflection - ring

- 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



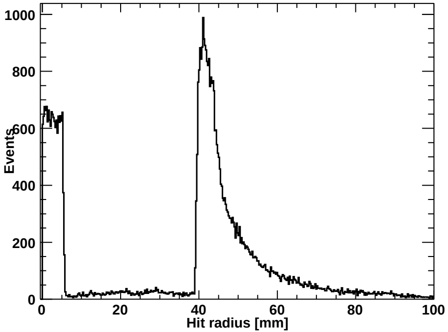
backward reflection



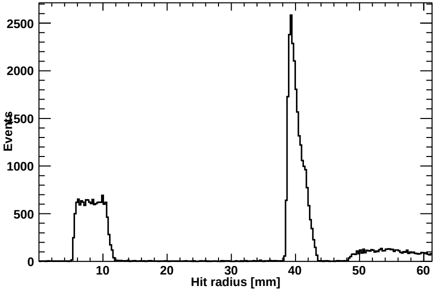
31 mm Direct vs. backward reflection - radius

- 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



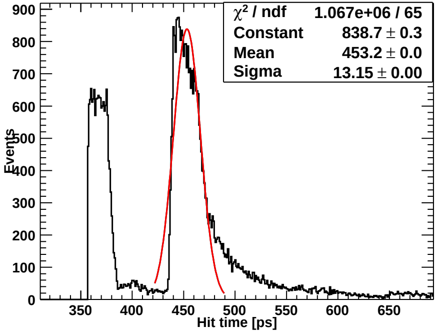
backward reflection



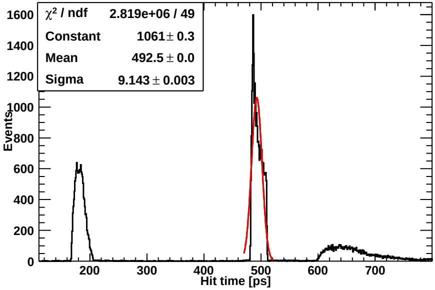
31 mm Direct vs. backward reflection - time

- 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



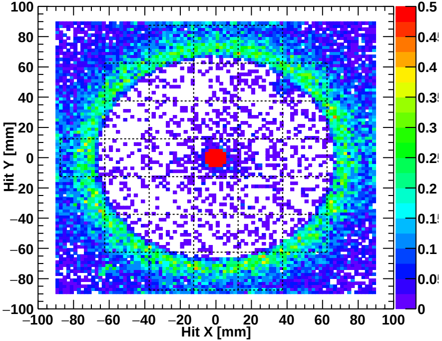
backward reflection



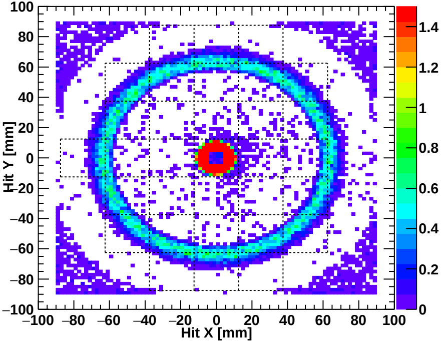
60 mm Direct vs. backward reflection - ring

- 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.

direct

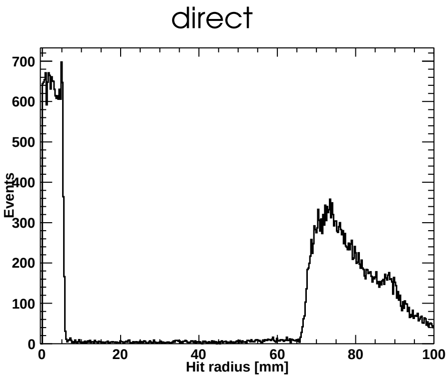


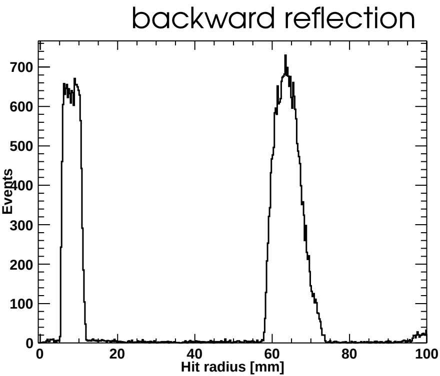
backward reflection



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.

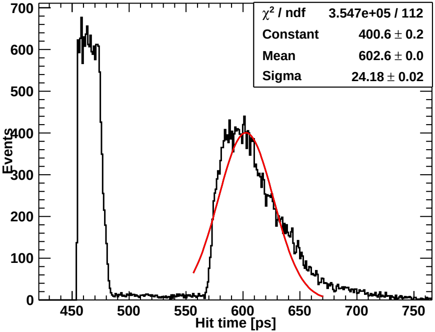




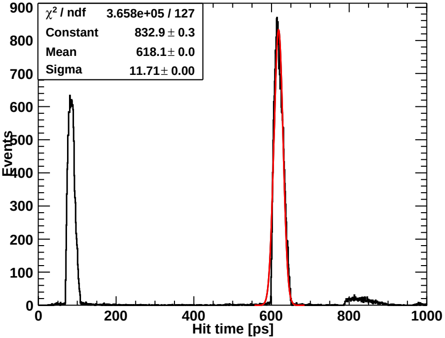
60 mm Direct vs. backward reflection - time

- 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



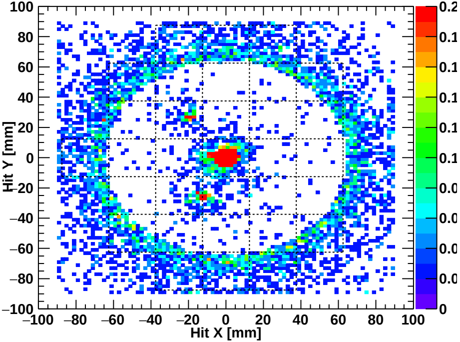
Step 1 conclusions

- 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.

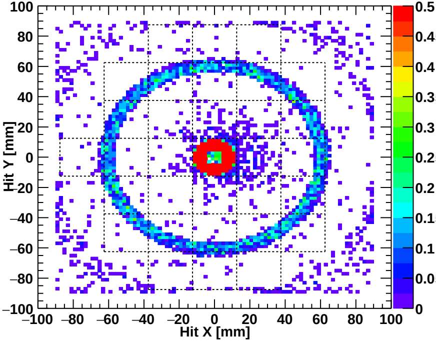
AF 60 mm Direct vs. backward reflection - ring

- 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



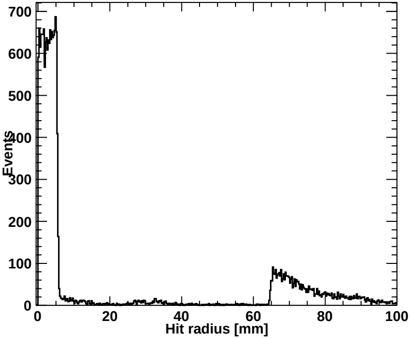
backward reflection



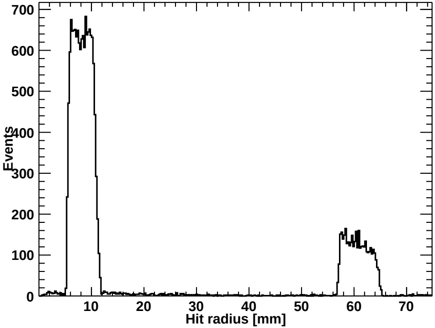
AF 60 mm Direct vs. backward reflection - radius

- 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



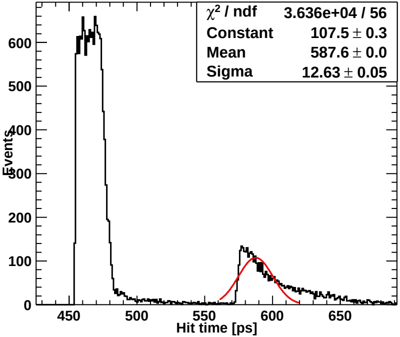
backward reflection



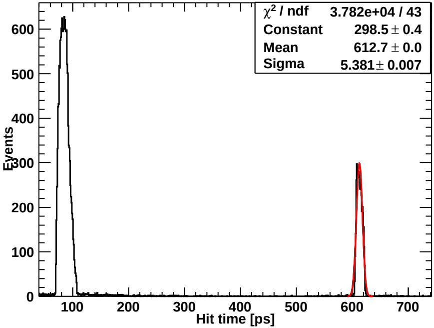
AF 60 mm Direct vs. backward reflection - time

- 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



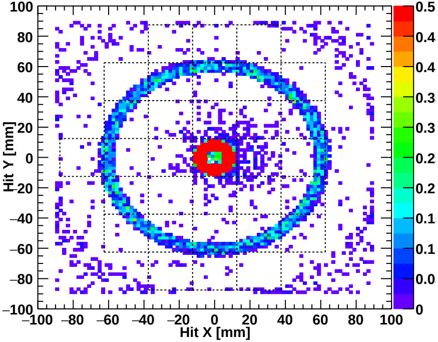
Step 2 conclusions

- 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.

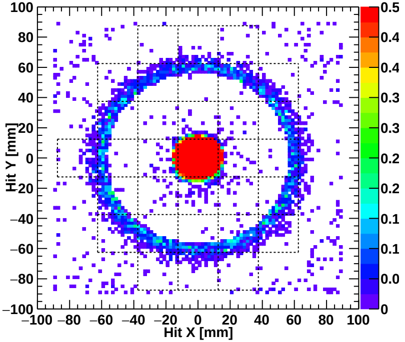
AF 60 mm backward reflection BS 1 cm^2 - ring

- 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

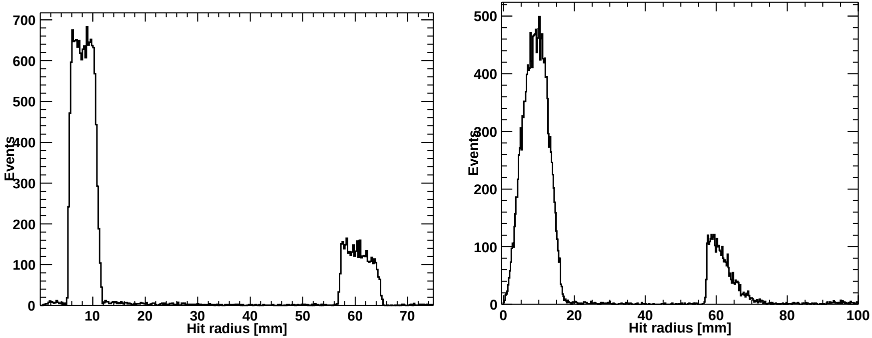


AF 60 mm backward reflection BS 1 cm^2 - radius

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

beam spot 0

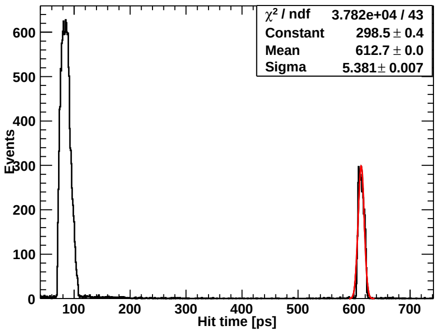
beam spot 1 cm^2



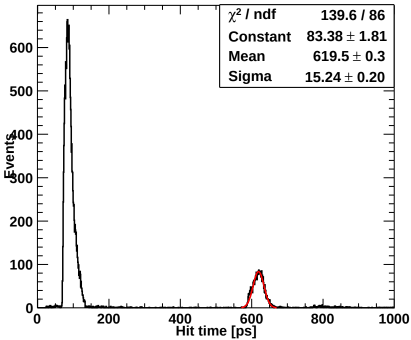
AF 60 mm backward reflection BS 1 cm^2 - time

- 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 $\theta_C = 48.4^\circ$ 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 174 p.e. from LAPPD window and 359 p.e. from aspheric lens.