Tests and comparison of various photon detection devices for the CBM-RICH

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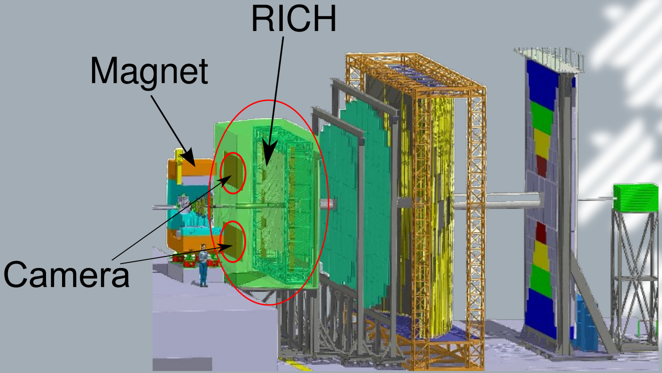
Overview

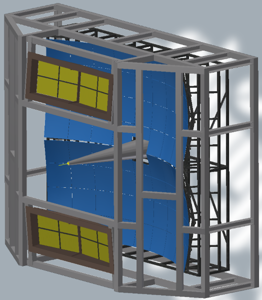
The CBM detector

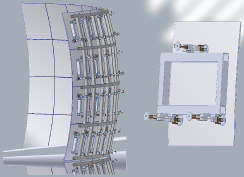


RICH detector directly behind magnet → high magnetic stray field, especially in region of camera

The CBM-RICH detector

- Gaseous RICH detector with CO_2 as radiator
- Curvature radius of mirror 3 m → ring radius for electrons ≈ 4.6 cm
- Operating wavelength range 200 – 800 nm → CO_2 transmission cut-off at 190 nm
- → MAPMTs/MCPs as photon detection devices (approx. 800 pieces @ 55k channels)
- The main goal: separation of electrons and pions (→ pion suppression)





Tested MAPMTs and MCPs

MAPMT: Hamamatsu H8500 (8-stage SBA version: H10966)

- Size: 52 mm × 52 mm, 8 × 8 pixel
- UV-extended borosilicate glass, Bialkali cathode, 12 dynode stages
- also tested version with Superbialkali cathode and 8 dynode stages
- for comparison we also got "bad" marked (by Hamamatsu) pieces

MAPMT: Hamamatsu R11265

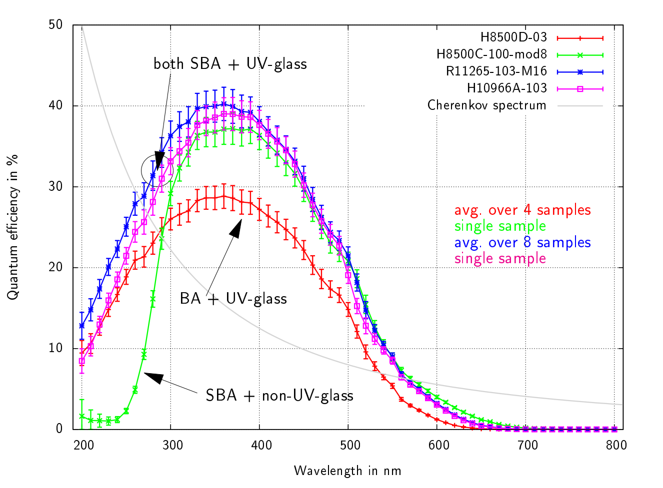
- Size: 26 mm × 26 mm, 4 × 4 pixel
- UV-extended borosilicate glass, Superbialkali cathode, 12 dynode stages
- Hamamatsu recommended MAPMT for single-photon measurements

MCP: Photonis XP85012

- Size: 59 mm × 59 mm, 8 × 8 pixel
- quartz glass, Bialkali cathode
- advantage over PMTs: magnet-field resistance ($\sim 1 - 2$ T); better timing

Quantum efficiency (I)

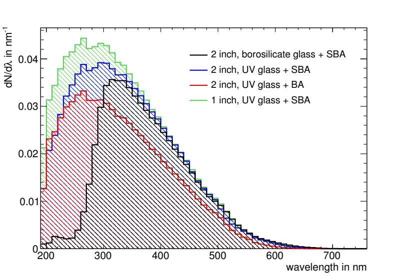
QE of several Hamamatsu PMTs (R11265, H8500C/D, H10966)



→ SBA cathode with nearly 30 % higher QE than BA at ∼ 350 nm, in deep-UV no difference (considered same PMT type)

Quantum efficiency (II)

Cherenkov spectrum folded with QE, mirror reflectivity and CO_2 absorption
→ results specifically for our RICH



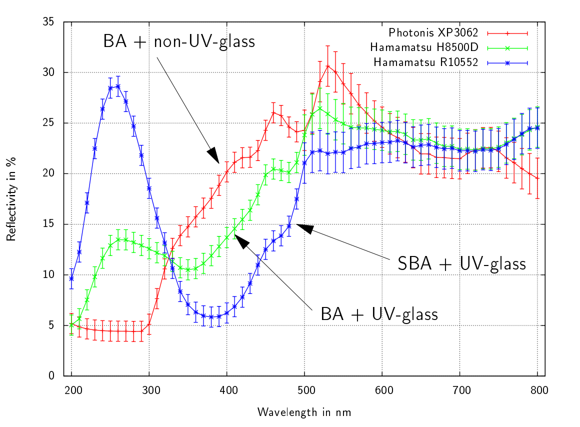
→ area as measure for number of detected hits (neglecting dynode system)

MAPMT type	thickness of front glass	window	photo-cathode	no. of dynodes	relative no. of detected Cherenkov photons (%)
R11265-103-M16	0.8 mm	UV-window	SBA	12	100
H10966A-103	1.5 mm	UV-window	SBA	8	89.7
H8500D-03	1.5 mm	UV-window	BA	12	71.6
H8500C-100-mod8	1.5 mm	borosilicate glass	SBA	8	62.6

→ Why no gain of SBA cathode below $\sim 250\,\mathrm{nm}$ (at 2-inch)?

Reflectivity of PMT cathodes

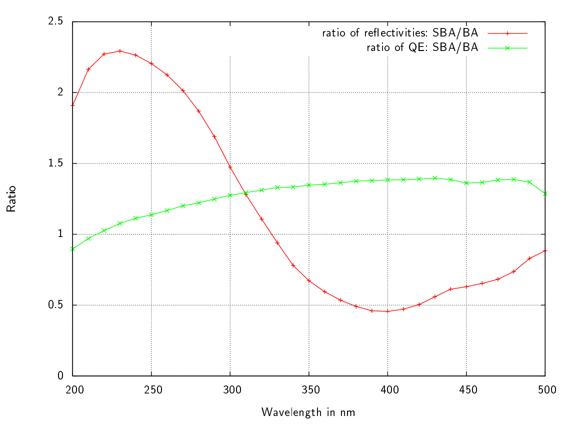
Specular reflectivity measured under $\sim 7^\circ$ (diffuse reflectivity not measured, necessary for quantitative evaluation)
$\rightarrow$ possible explanation for behaviour below 250 nm



$\rightarrow$ SBA cathode with highly increased reflectivity below 300 nm

Ratio SBA/BA - QE and reflectivity

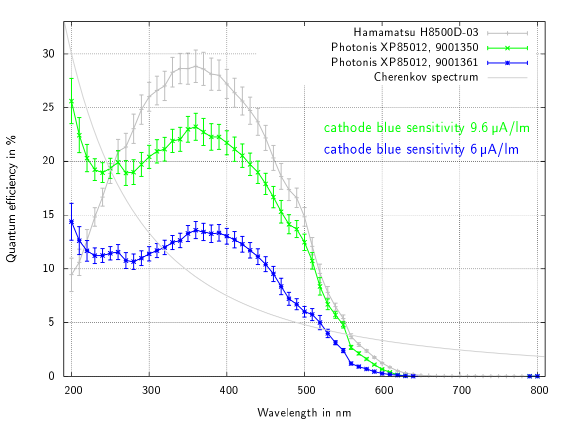
Ratio of SBA/BA for quantum efficiency and reflectivity



→ correlation between reflectivity and QE clearly visible

Quantum efficiency (III)

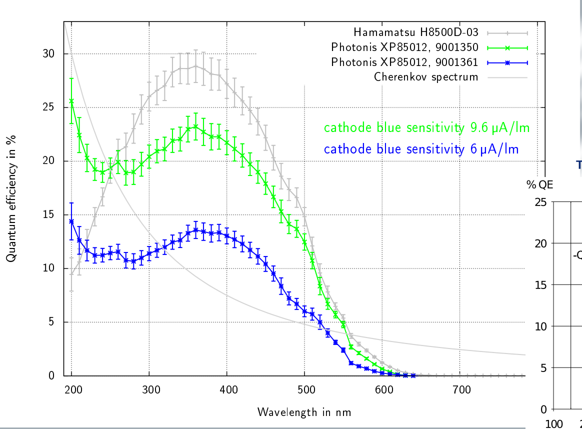
2 × Photonis XP85012 + Hamamatsu H8500 for comparison; all BA

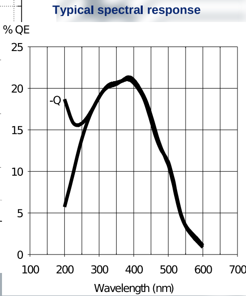


→ 1 MCP out of Photonis' specifications (min. c.b.s. 7 µA/lm, avg. 8.5 µA/lm)
→ both very good at smallest wavelengths (perfect for Cherenkov spectrum)
→ QE in UV underestimated, see e.g. also NIM A325 (1993) 367-369

Quantum efficiency (III)

2 × Photonis XP85012 + Hamamatsu H8500 for comparison; all BA





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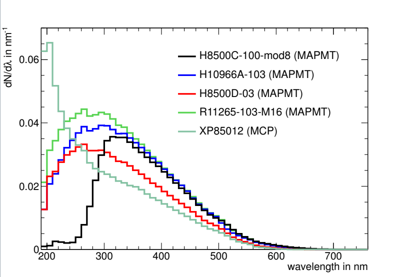
→ both very good at smallest wavelengths (perfect for Cherenkov spectrum)
→ QE in UV underestimated, see e.g. also NIM A325 (1993) 367-369

Quantum efficiency (IV)

Cherenkov spectrum folded with QE, mirror reflectivity and CO_2 absorption; with additional MCP (the good one)
→ results specifically for our RICH



→ area as measure for number of detected hits

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R11265-103-M16	0.8 mm	UV-window	SBA	12	100
H10966A-103	1.5 mm	UV-window	SBA	8	89.7
XP85012	?	UV-grade fused silica	BA	MCP	75.7
H8500D-03	1.5 mm	UV-window	BA	12	71.6
H8500C-100-mod8	1.5 mm	borosilicate glass	SBA	8	62.6

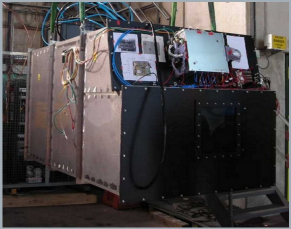
CBM-RICH prototype

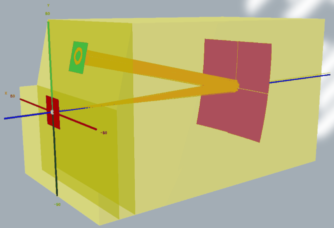
Up to now only differences and effects of cathodes investigated!

- For proving and evaluating our RICH-concept, ring finding and fittig algorithms, performance (especially number of photons per ring), etc. building of CBM-RICH prototype
- One main goal: in-beam performance comparison of different photon detection sensors
- All important properties of equal size as in full CBM-RICH later
- Tested during two beamtimes at CERN
- More details on prototype and various investigations later by Tariq Mahmoud

Beamtime overview

- Beamtime at PS accelerator at CERN, beamline T9 ($\rightarrow$ up to $\sim 10\,\mathrm{GeV/c}$)
- Data taken mostly with electrons at $3\,\mathrm{GeV/c}$ (ultra-relativistic)
- Two different kinds of data:
  1. Cherenkov data
  2. LED pulser data (simultaneously taken between beam spills; LED homogeneously illuminating whole camera)

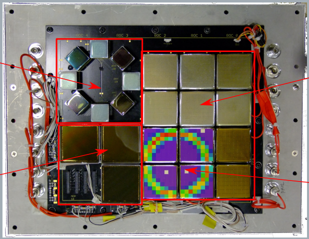




Beamtime

RICH prototype camera

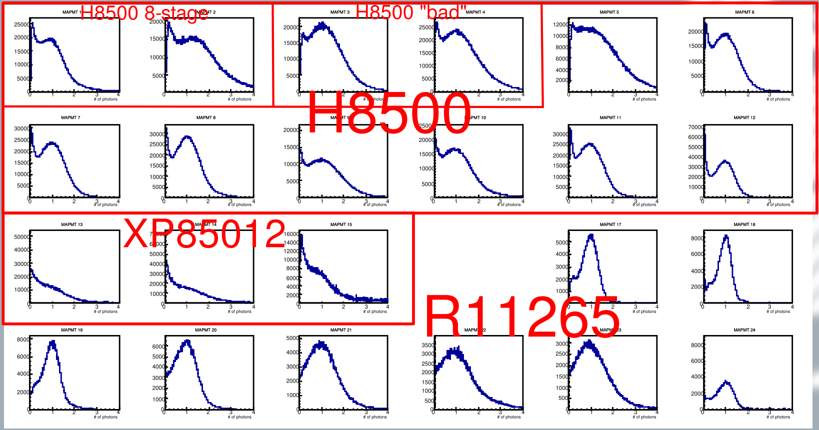
- Camera of RICH box with various MAPMTs/MCPs: 12x H8500, 8x R11265 (both MAPMTs), 3x XP85012 (MCPs), some of them covered with wavelength shifting film (WLS, → milky-looking surface)
- read out with self-triggered n-XYTER electronics → noise negligible; only time-cut of 100 ns applied (no ADC-cut except hardware threshold)



We would like to thank J. Schwiening for borrowing us 2 MCPs for this beamtime!

Single-photon sum-spectra - corrected

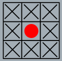
Corrected SP spectra; correction factor based on fit with exponential (crosstalk) + Gaussian (1 photon) + Gaussian (2 photons)

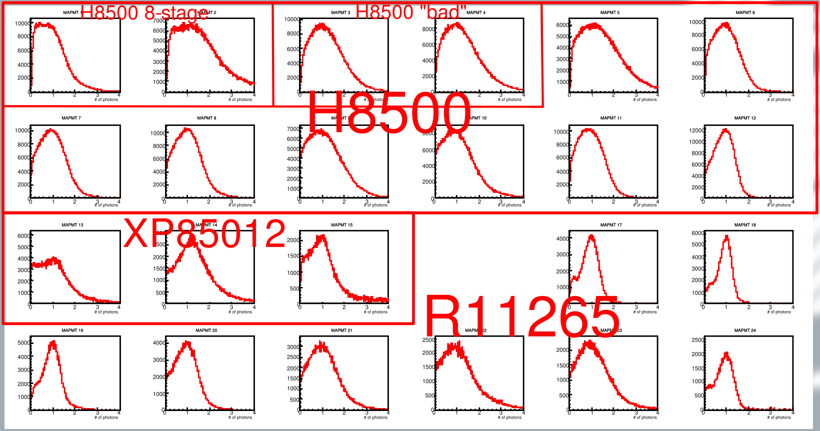


→ all types with different single-photon quality

Single-photon sum-spectra - corrected and crosstalk suppressed

Crosstalk suppression: only isolated hits →



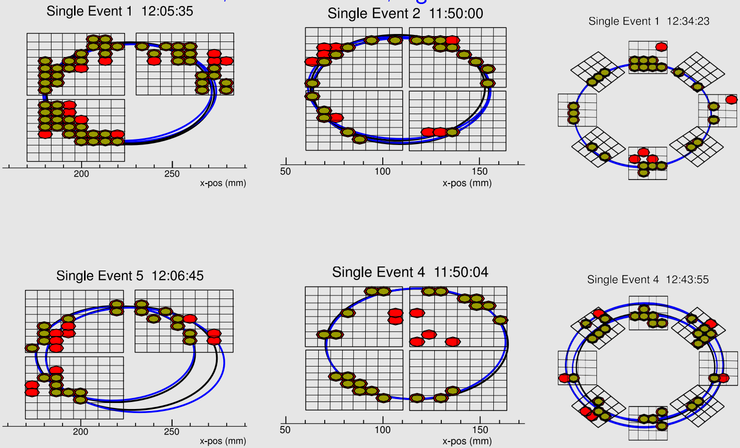


→ peak at 0 only due to crosstalk

Single-event displays

Some single-event displays

Left: XP85012 MCPs, middle: H8500, right: R11265

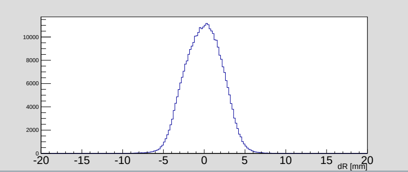


→ clear clustering visible on MCPs, nearly no single hits

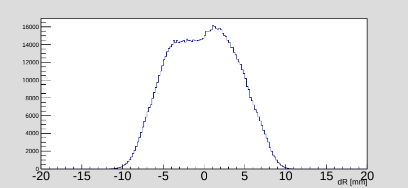
Ring width

dR = distance of each hit to fitted ring →  → RMS marks ring width

…for H8500 PMTs:



…for XP85012 MCPs (broader due to crosstalk):

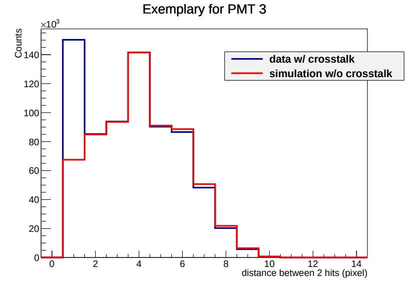


BUT: ring finder not optimized for crosstalk usage

Crosstalk estimation

Method for crosstalk estimation:

1. Select only events with 2 hits per PMT (for LED data)
2. Study distribution of distances between both hits → with crosstalk
3. Compare with simulation → without crosstalk
4. Excess in first bin (≡ neighbouring pixel) is measure for crosstalk amount

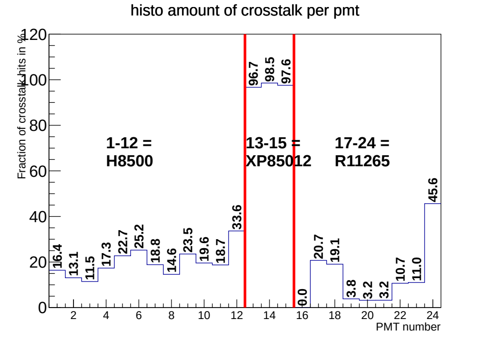


Problem: absolute crosstalk result depends on absolute illumination by LED

Crosstalk amount from dedicated LED run

1. indication for higher crosstalk of MCPs: ADC-spectra
2. indication: single-event display/ring width

here 3. indication: quantitative comparison for all tested sensors (not corrected for LED illumination)

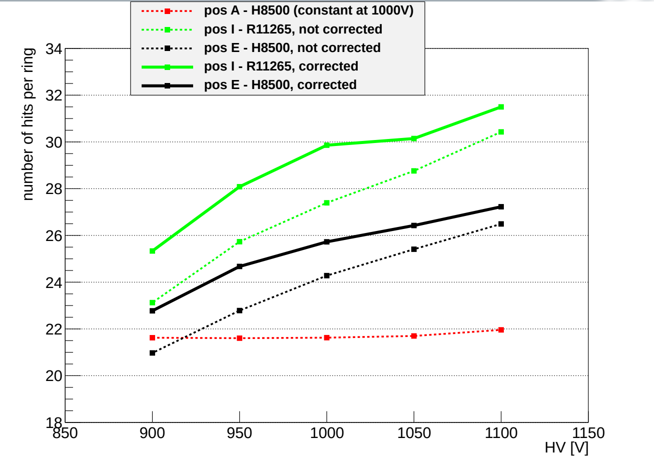


→ MCPs with much higher crosstalk amount, R11265 less than H8500

→ Conclusions for absolute numbers not yet possible

Performance for various HVs - number of hits per ring

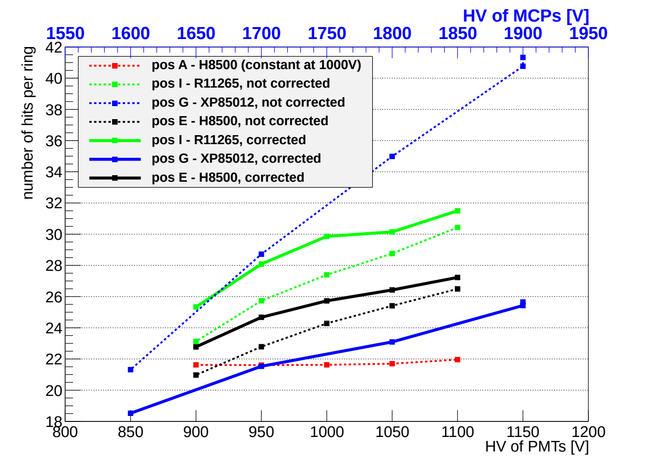
Solid lines allow for quantitative comparison of detection efficiency of different sensors (here for constant hardware threshold of 28)



(correction for temperature/pressure, geometrical coverage and crosstalk)

Performance for various HVs - number of hits per ring

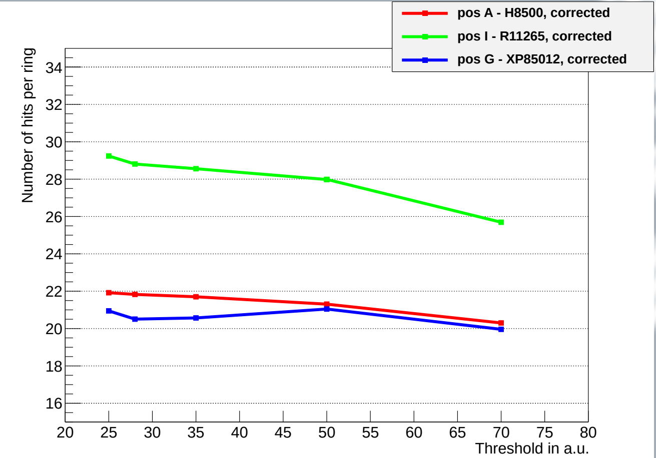
Solid lines allow for quantitative comparison of detection efficiency of different sensors (here for constant hardware threshold of 28)



(correction for temperature/pressure, geometrical coverage and crosstalk)

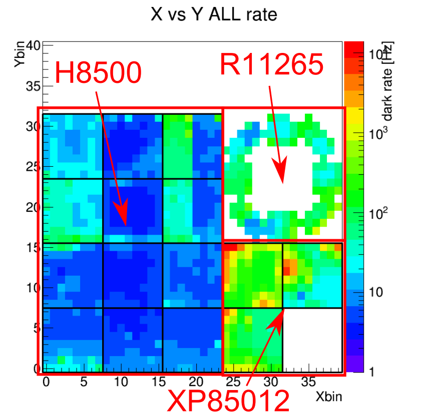
Performance for various hw thresholds - number of hits per ring

Solid lines allow for quantitative comparison of detection efficiency of different sensors (here for constant HV for each sensor)



(correction for temperature/pressure, geometrical coverage and crosstalk)

Noise measurements



- total dark hit rate per pixel in Hz, after several days in complete darkness
- measured with self-triggered n-XYTER readout system
- threshold: standard threshold as in previous plots, few % of single photon peak position
- roughly comparable threshold (relative to single photon peak) for all sensors

→ per-pixel rates for H8500 mostly < 10 Hz, R11265 up to a few 100 Hz (due SBA), XP85012 partially up to a few kHz

Summarized results up to now

Presented measurements

- Quantum efficiency measurements in lab
- Beamtime measurements with prototype, especially crosstalk and detection efficiency
- Crosstalk estimation at the moment only qualitatively possible

Main results

- **R11265 PMT with better performance than H8500 $\rightarrow$ less crosstalk, more hits per ring**
- **XP85012 MCP with comparable detection efficiency to H8500, though higher amount of crosstalk**

$\Rightarrow$ R11265 for our usecase the most promising solution (performance-wise)!
But 1.5$\times$ the price of H8500 for same covered area . . .

New Hamamatsu H12700 PMT

Preliminary specs

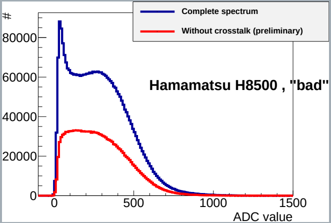
- Combines collection efficiency of R11265 with dimensions of H8500
- Same size and price as H8500
- But still only BA cathode
- Optimized dynode structure for better collection efficiency (according to simulations 60 % → 87 %)
- Therefore clearly better defined single-photon peak

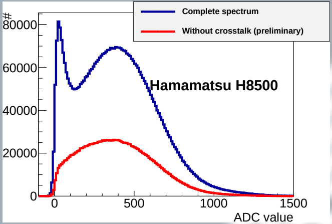
→ We are impatiently waiting for test samples!

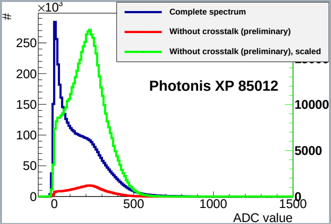
Thank you for your attention!

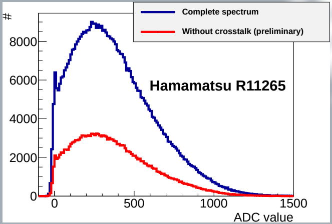
Backup slides

ADC spectra with and without crosstalk subtraction



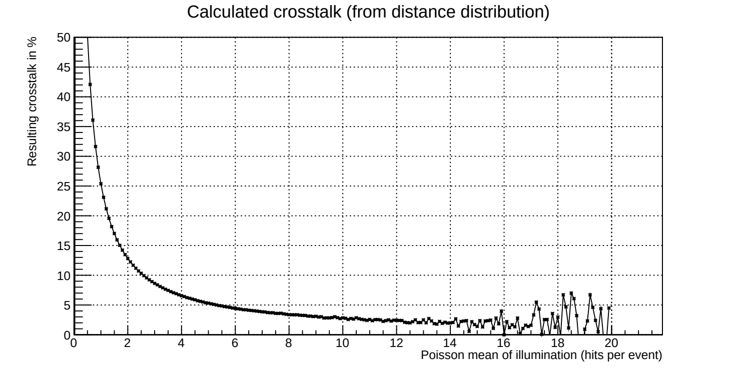






Illumination simulation

Simulation of calculated crosstalk amount for different illumination hit multiplicities (assumed crosstalk 10 %):

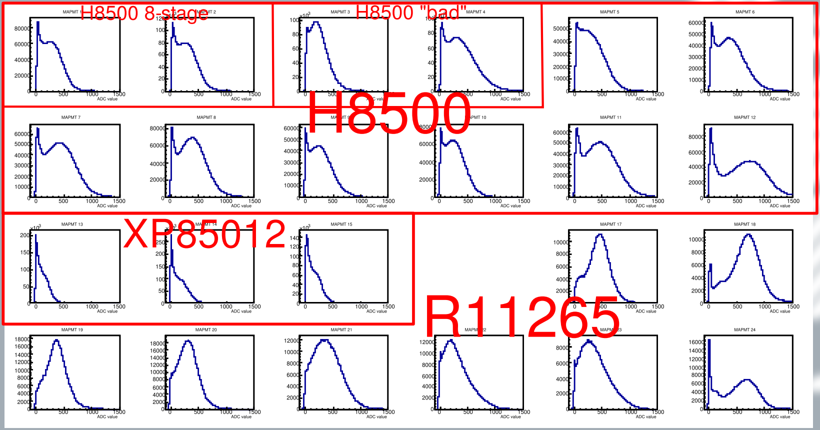


WLS

... to come

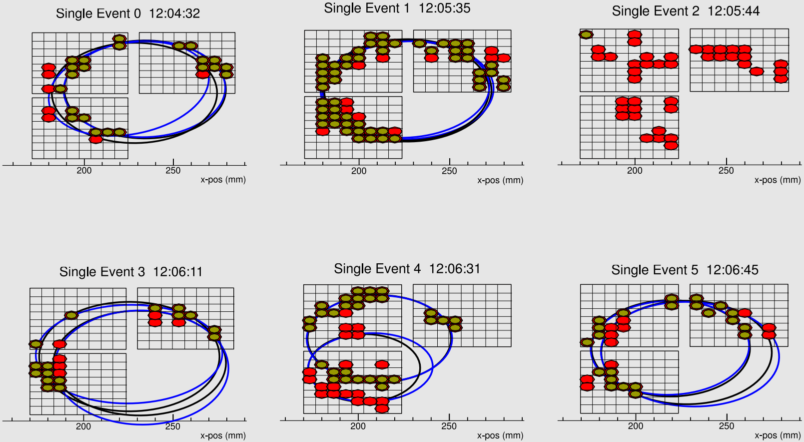
Single-photon sum-spectra (all 64/16 pixel)

Single-photon (SP) spectra of all 23 tested MAPMTs and MCPs



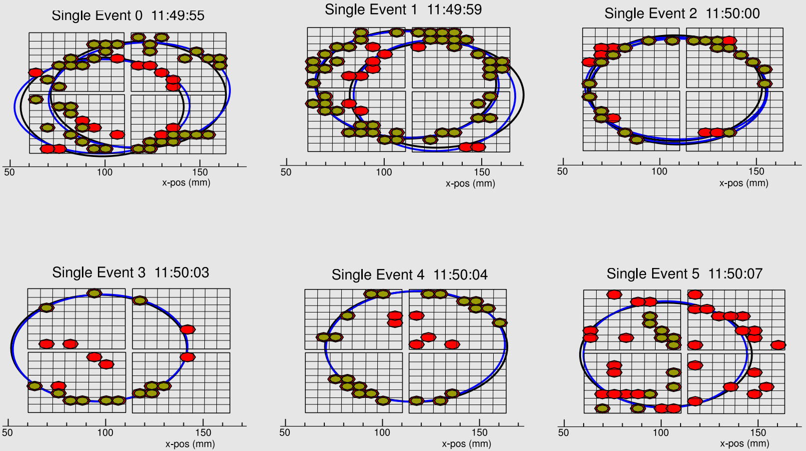
Single-event displays (I) - XP85012

Some single-event displays of the XP85012 MCPs



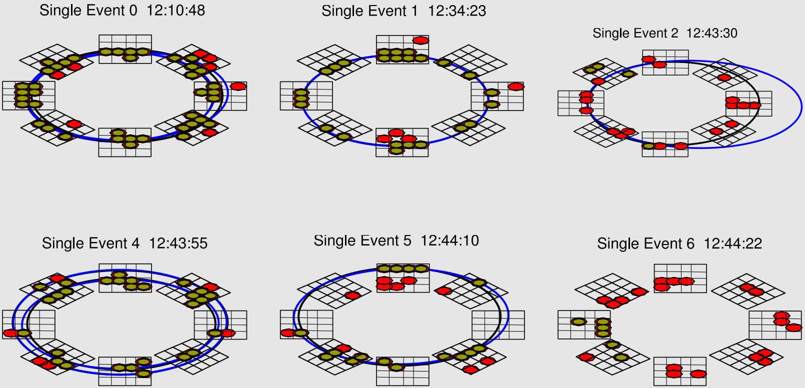
Single-event displays (II) - H8500

Some single-event displays of the H8500 MAPMTs



Single-event displays (III) - R11265

Some single-event displays of the R11265 MAPMTs



Setup for reflectivity measurements