Behaviour of Multi-anode Photomultipliers in Magnetic Fields for the LHCb RICH Upgrade

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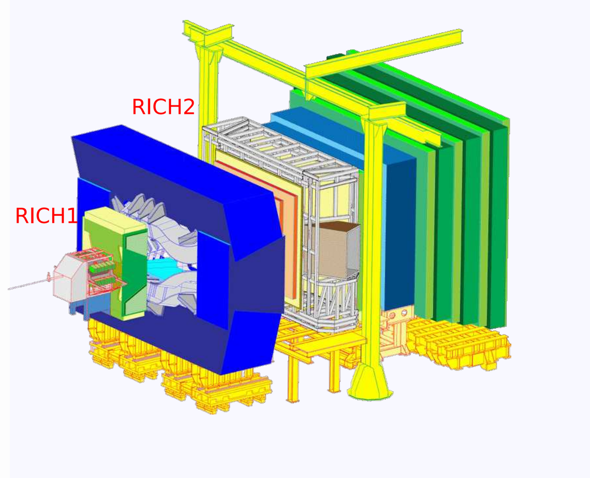
The Upgrade of LHCb RICH Detectors

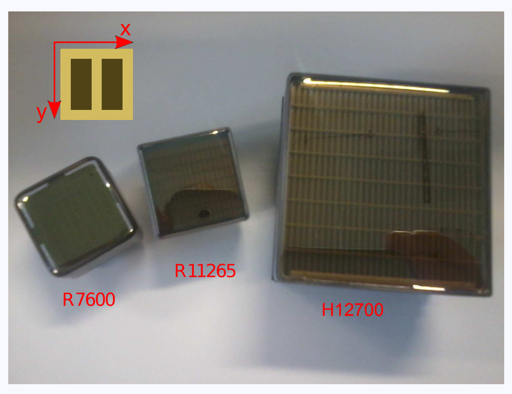
The LHCb upgrade will take place in 2018: higher luminosity $2 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$



Challenges of RICH upgrade:

- new readout electronics (dead time $< 25\,\mathrm{ns}$, low power consumption, radiation tolerance)
- new photon detectors (sensitive to single photon between 200 and 600 nm, good spatial resolution, high Quantum Efficiency)
- significant modifications to RICH1 to reduce peak occupancy (optics to be optimized, mechanics to be redesigned)

Multi-anode Photomultipliers



Two candidates tested: R7600 and R11265, 1" Hamamatsu 64-channel (8×8 pixels) Multi-anode Photomultiplier. R11265 preferred: bigger active area (77% vs 50%) and better separation of the single photo-electron signal from noise.

Candidate for peripheral areas of RICH2: H12700, 2" Hamamatsu 64-channel (8×8 pixels) Flatpanel PMT $\Rightarrow$ PID performance only slightly degraded and costs significantly reduced.

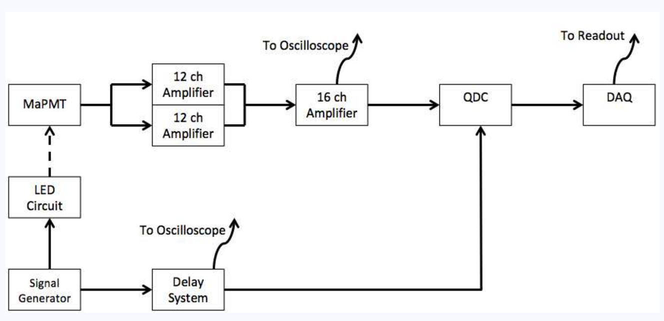
General requirements for RICH:

- high active area $\rightarrow$ 77%
- high collection efficiency
- high QE $\rightarrow \sim 30-35\%$
- good uniformity $\rightarrow$ factor 2-3 of channel-to-channel gain variation
- low dark counts $\rightarrow$ < 0.4 nA per pixel
- low cross talk $\rightarrow$ < 2% to direct neighbours
- low sensitivity to magnetic fields

Residual magnetic fields from the LHCb dipole magnet: about 30 G in RICH1 and 15 G in RICH2. Magnetic fields cause loss of gain and photo-detection efficiency.

Equipment & Setup

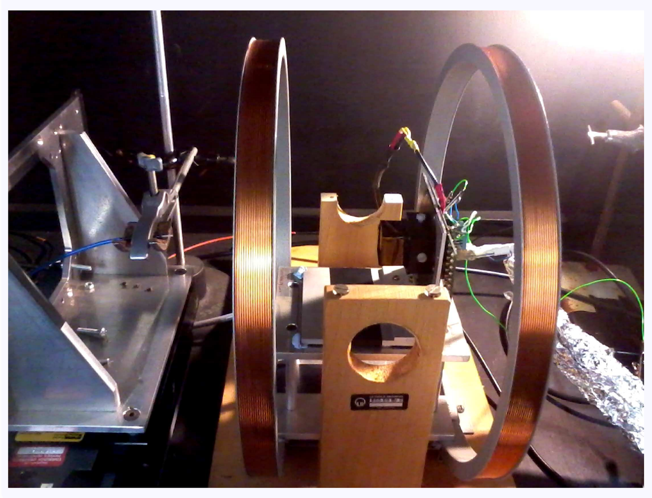
Acquisition chain



- light source: optical fibre feeding pulsed LED $\Rightarrow$ diffused light
- signal amplification: signal amplified by a factor 100 in two steps of 10
- digitizer: commercial QDC module

Magnetic field

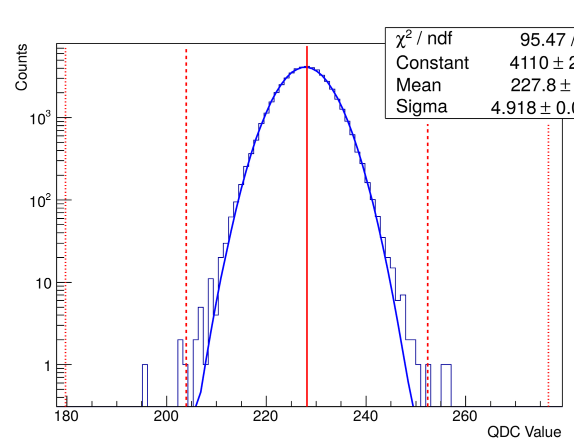
Helmholtz coils: field up to 30 G



Solenoid: field up to 9000 G

Testing Procedure

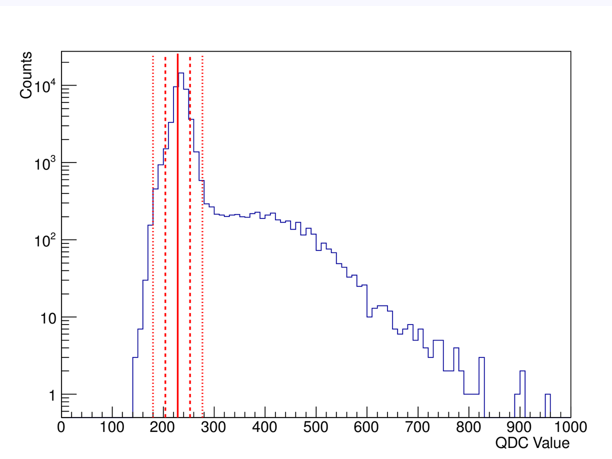
Data taking

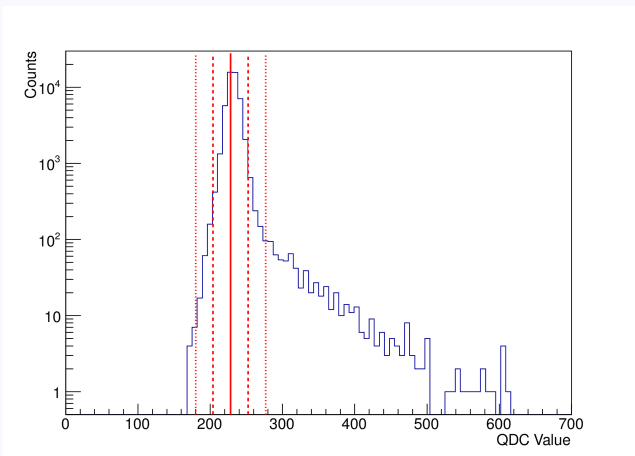


- pedestal run with LED off
- LED on $\Rightarrow$ light level adjusted to single photon mode (occupancy 10%)
- 10 kHz trigger rate - 250000 events each run
- reference run: $B = 0$ G
- runs with increasing magnetic field

Data analysis

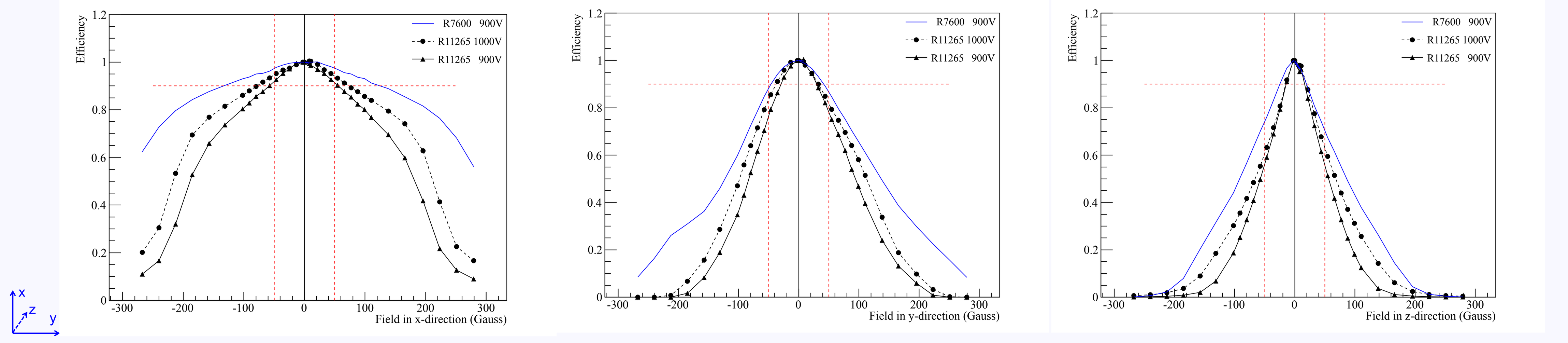
- gaussian fit of the pedestal $\Rightarrow$ mean (Q_0) and width (σ)
- QDC spectrum: number of events above threshold $Q_0 + n\sigma$ counted
- efficiency: number of events for a given field strength normalized to the number of events with zero field



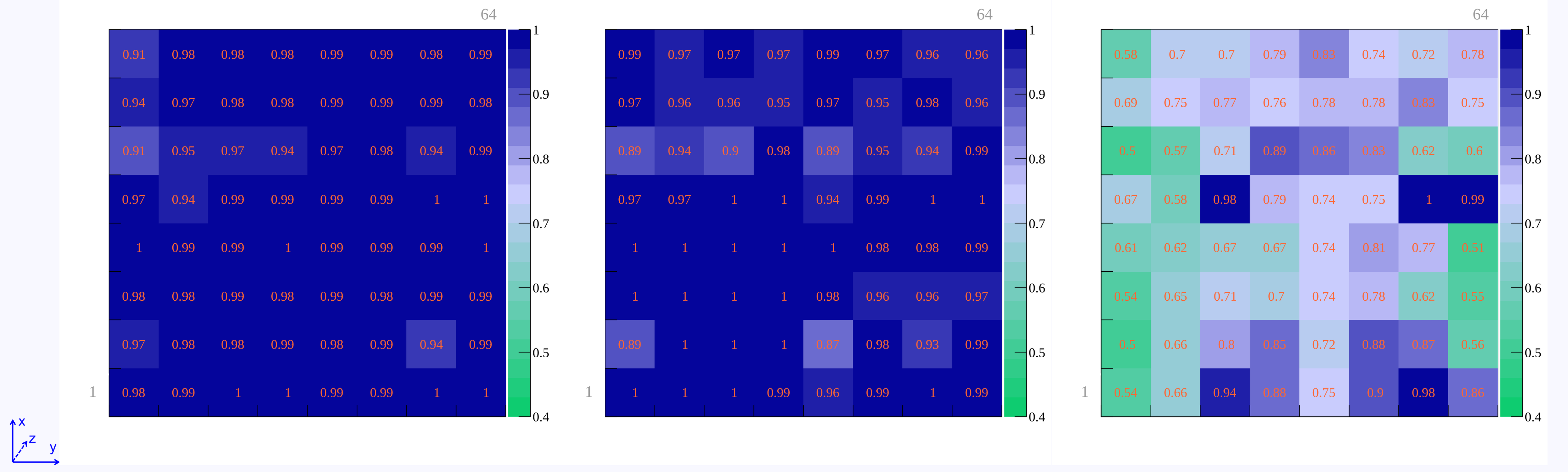


Spectrum of QDC values in small magnetic field (left) and high magnetic field (right), for the MaPMT R11265 operated at 1 kV. The red solid line indicates the pedestal mean, the dotted lines show $Q_0 \pm 5\sigma$ and $Q_0 \pm 10\sigma$.

MaPMT Response to Magnetic Field



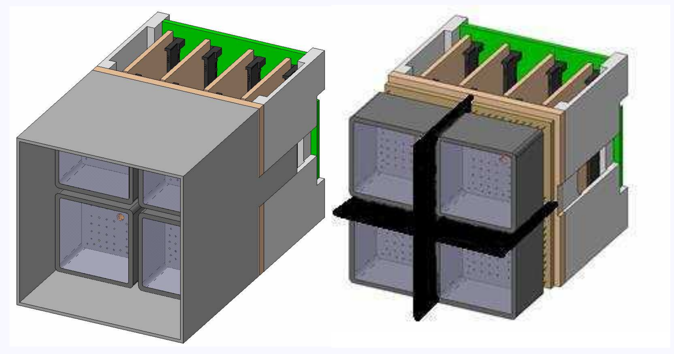
Efficiency curves averaged over all pixels of the R11265 and the R7600 as a function of the magnetic field applied in both transverse directions (x and y) and in the longitudinal direction (z). The horizontal red dotted line marks 90% efficiency, the vertical red dotted lines mark ± 50 G. The R7600 is more resilient to magnetic field than the R11265 and the performance is improved increasing the HV. Both MaPMTs are more sensitive to a magnetic field along the longitudinal direction and have different response to the two transverse orientations.



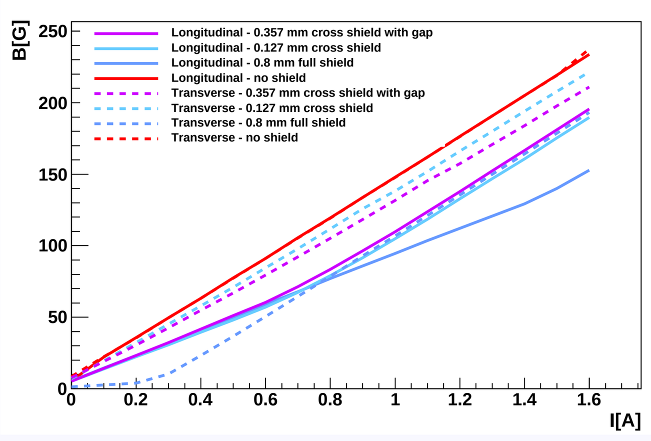
Maps of efficiencies for each pixel of the R11265 operated at 1kV at 30 G for the three magnetic field directions (x, y and z respectively). This is the maximum field expected in RICH1. For transverse orientations the efficiency stays close to 100%, 90% in the worst cases. For longitudinal orientation the efficiency can drop to 50%, with the edge columns (pixels 1-8 and 57-64) affected the worst. This causes the need for local shielding.

Magnetic Shield

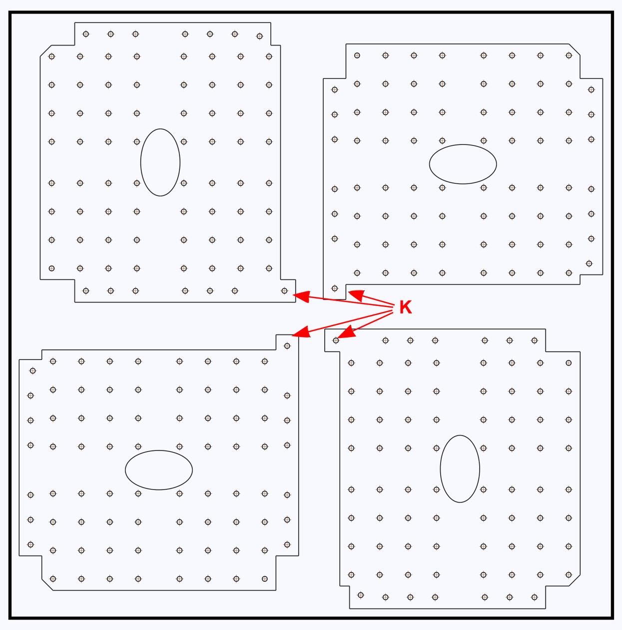
Two designs of μ-metal shields have been tested:



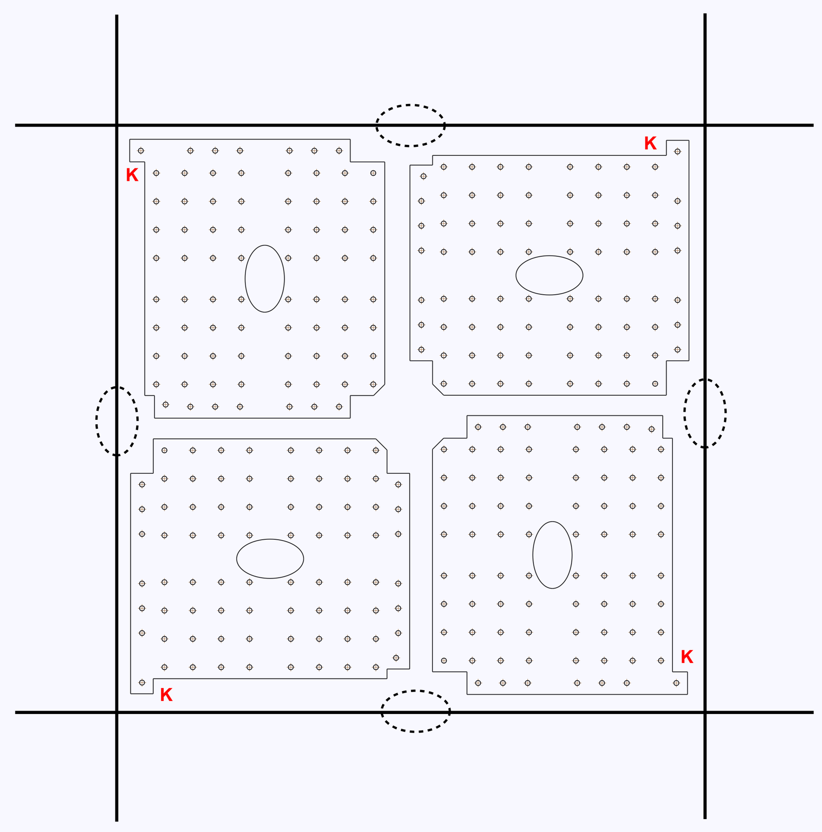
Shielding power measured with Hall probe for various shielding designs, thickness and field orientation:

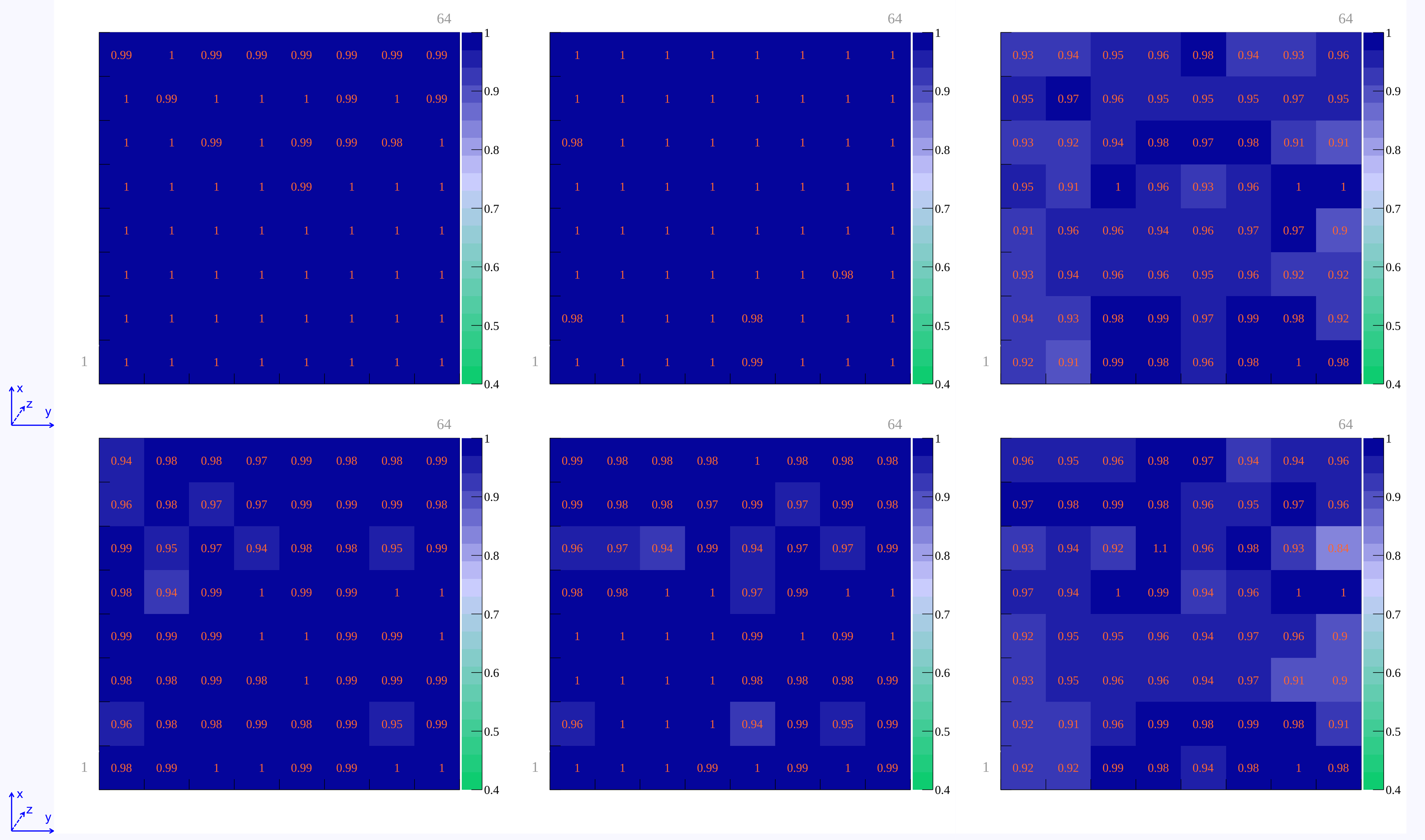


full shield around one Elementary Cell (4 MaPMT)



cross shield: 4 EC provide full shield for 4 MaPMT





Maps of efficiencies for each pixel of the R11265 operated at 1kV at 30 G for the three magnetic field directions (x, y and z respectively) with a full μ-metal shield (top line) of thickness 0.8 mm and with a cross μ-metal shield (bottom line) of thickness 0.357 mm. Both the shields have a protrusion of 1.2 cm with respect to the MaPMT window. Similar performance in the worst case (longitudinal field): efficiency$\geq$ 90%. Better performance of full shield in transverse magnetic field.

Conclusions

The behaviour of MaPMT R11265 and R7600 in magnetic fields has been studied and understood. Excellent efficiency recovery by means of a μ-metal shield surrounding 4 MaPMTs at a time. New magnetic shield design: easy to mount and cheap to manufacture. Preliminary results are very encouraging and indicate a performance similar to the full shield at the field intensity expected in RICH1 and RICH2.