# The CBM-RICH project

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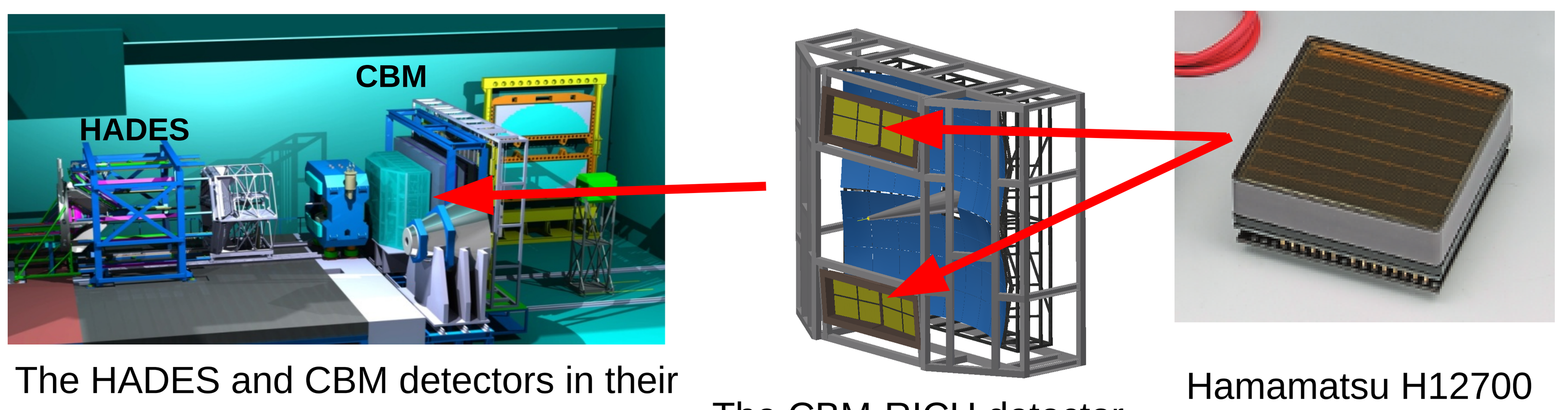
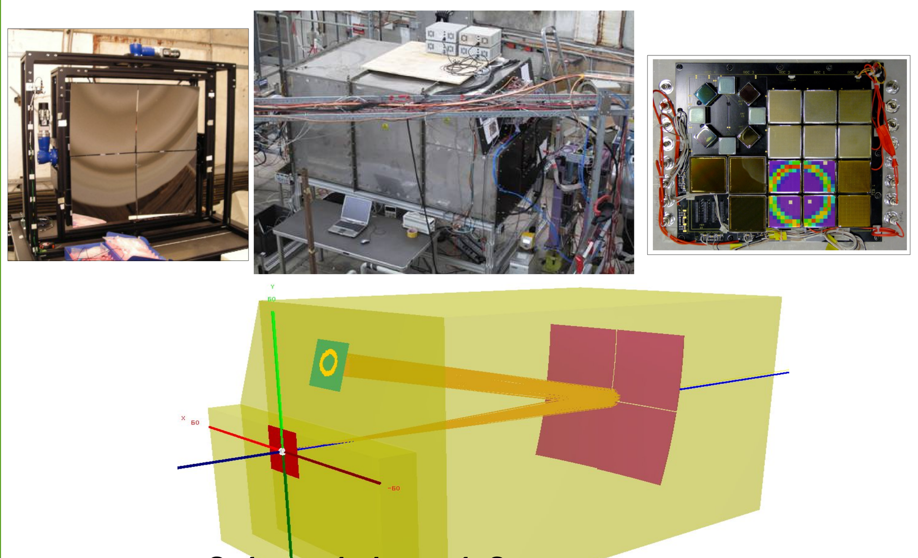
## Overview

The CBM experiment is part of the **F**acility for **A**nti-Proton and **I**on **R**esearch **FAIR** in Darmstadt. It will study the phase diagram of **C**ompressed **B**aryonic **M**atter, in particular in the region of high net-baryon density and moderate temperature, using heavy ion collisions up to 11 AGeV at SIS100, allowing for unprecedented interaction rates up to 10 MHz Au+Au. Start of operation is planed for 2022.
Important part of the CBM setup is a **R**ing **I**maging **CH**erenkov detector (RICH), aiming for good electron/ pion separation, necessary for measurements of rare dilepton decays of vector mesons like ρ → e+ e-.
The design of this RICH detector is close to final [1], and has been verified by building a large prototype, tested in beam at CERN PS. Recently, 1100 Hamamatsu H12700 Multianode PMTs have been ordered to equip the photon detector. Delivery and series testing of sensors has already started.



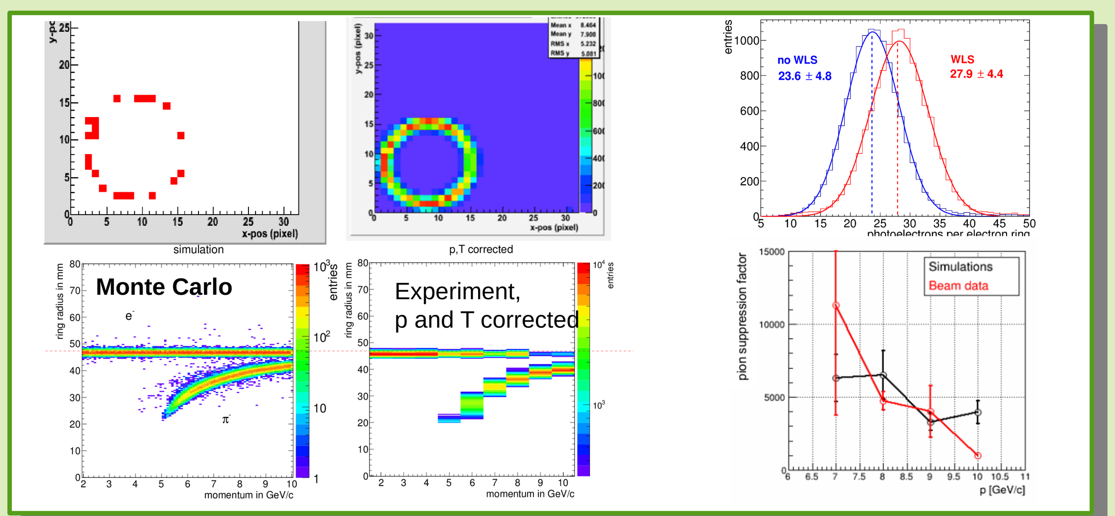

The HADES and CBM detectors in their common experiment cave at SIS 100 — The CBM-RICH detector — Hamamatsu H12700 photon sensor

## CBM-RICH prototype studies



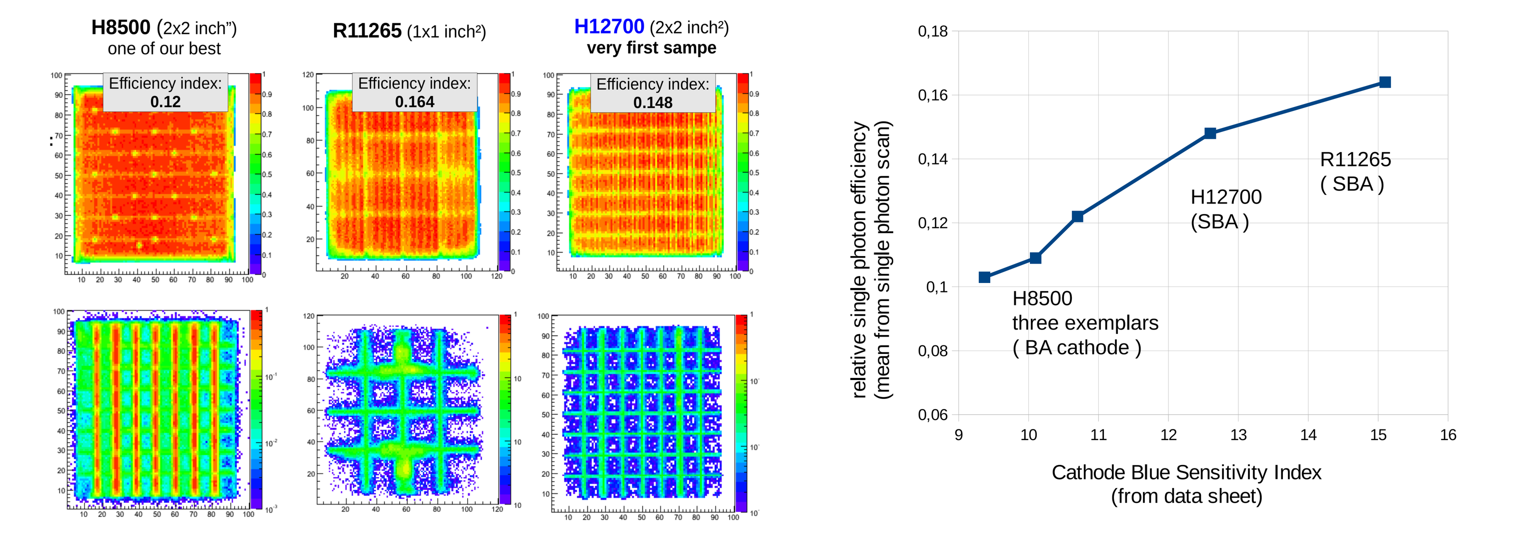

**Full size prototype:**
- Resembles RICH design in all important dimensions
- $CO_2$ gas radiator, 2 mbar, gas purification system
- Remote-tiltable, segmented mirror system, 1.5 m focal length
- Different MAPMT photon sensors on common detection plane
- Tested at CERN PS-T9, mixed e / μ / π beam up to 10 GeV/c

**Results and achievements:**
- More than 20 photons / ring, agreement with MC simulations
- ~18% photon gain with WLS coating on PMTs possible [3]
- Good electron / pion separation up to 10 GeV/c
- Mirror misalignment up to 1mrad tolerable
- Exceptional low dark rates (10 Hz/pixel) with MAPMT readout
- First tests of FPGA-TDC based readout scheme in beam

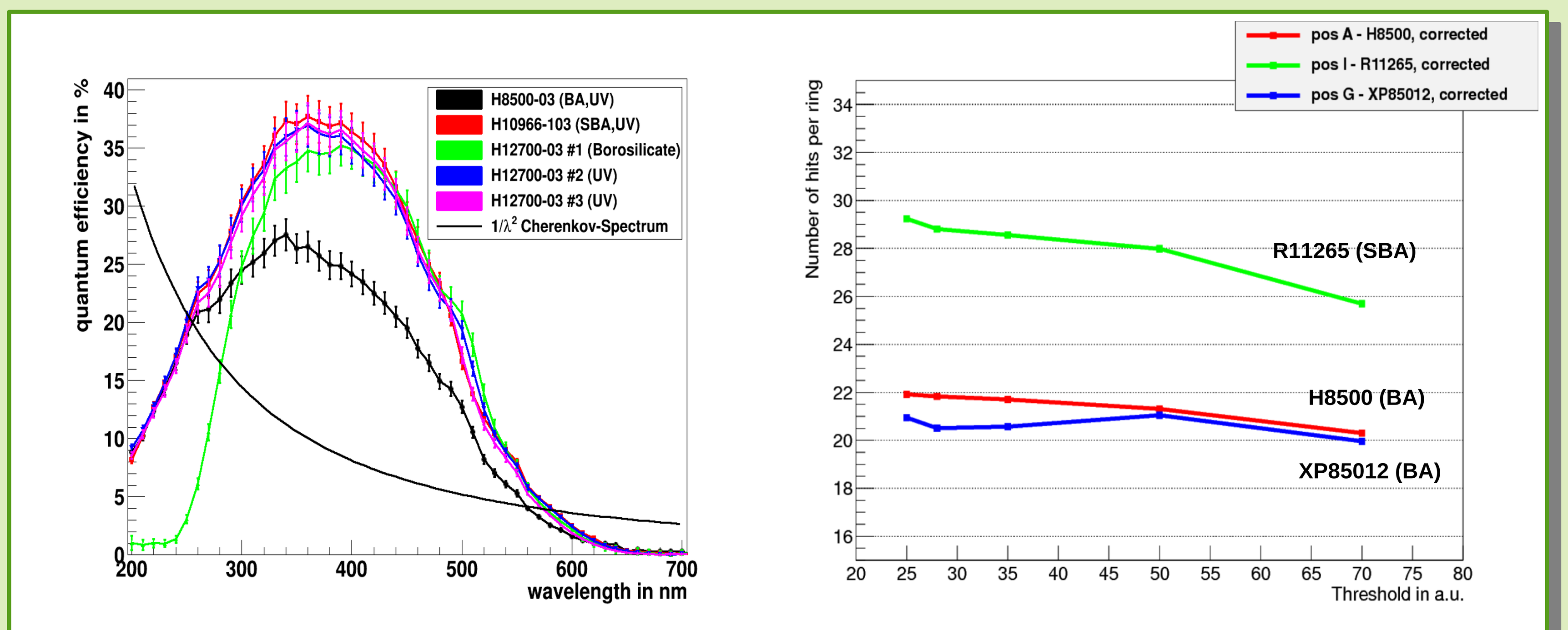



Integrated and single-event Cherenkov rings, ring hit multiplicity with- and without additional WLS coating (top).
Ring radius as function of momentum in data and MC simulation, achieved pion suppression factor (bottom).

## Sensor evaluation




Spatially resolved single photon scans for different sensor types, showing the fraction of single photon events with >=1 detected hit pixel (upper line of plots) and >=2 hit pixels (lower line). The latter showing regions of increased cross talk.
R11265 and H12700 show much reduced cross talk compared to H8500. The "efficiency index" allows for relative comparison of detection efficiency between different PMTs. Efficiency is strongly correlated with the "Blue Sensitivity Index" from the PMT data sheet.



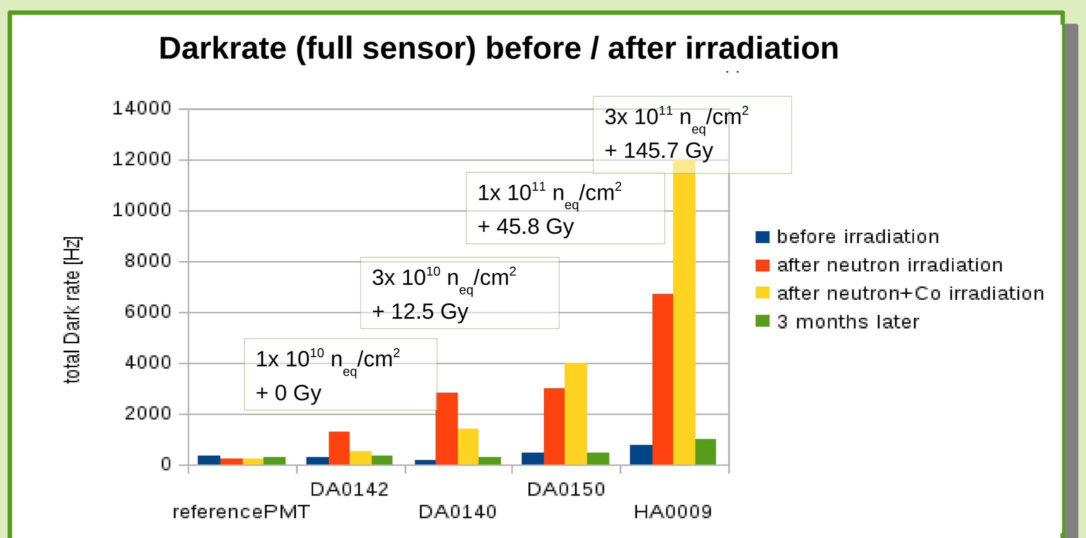

Quantum efficiency for standard H8500 MAPMT (BA cathode) and new H12700 MAPMT with "enhanced BA cathode".

Comparison of different photon sensors in terms of "detected photons per Cherenkov ring", measured with CBM-RICH prototype at CERN test beam.

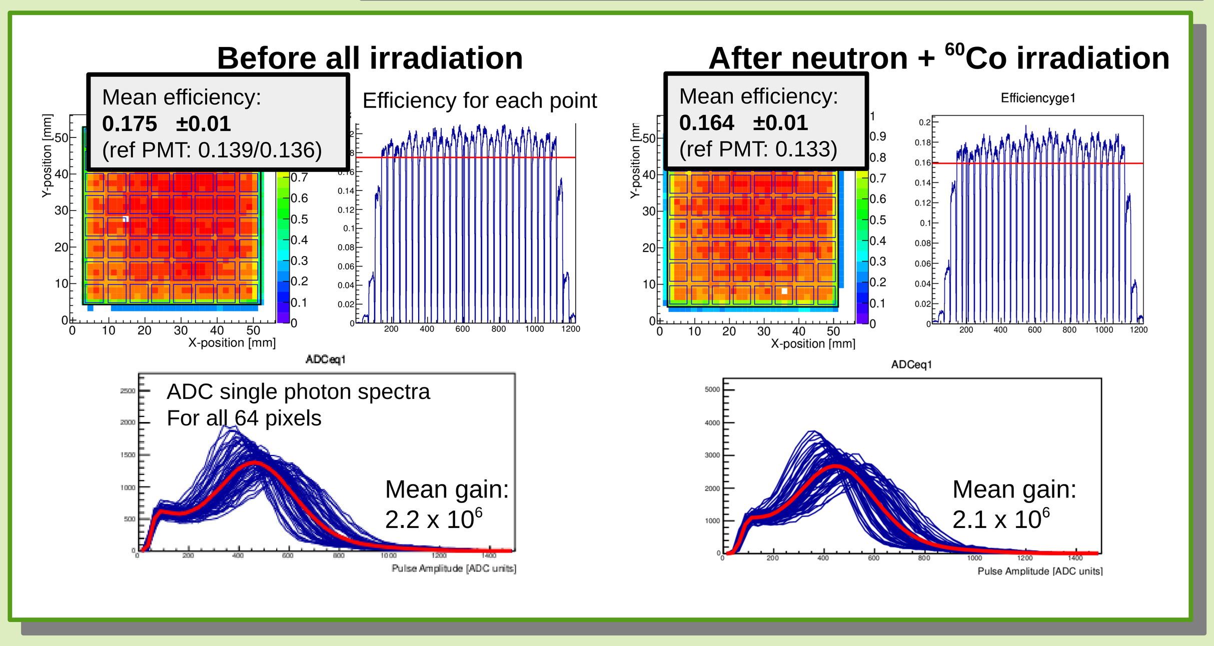
## Sensor radiation hardness

The CBM-RICH photon sensors will be exposed to a significant radiation dose up to 1012 neq/cm² non-ionizing neutrons, and up to 100 Gy ionizing dose. H12700 is a metal-package MAPMT with active voltage divider.

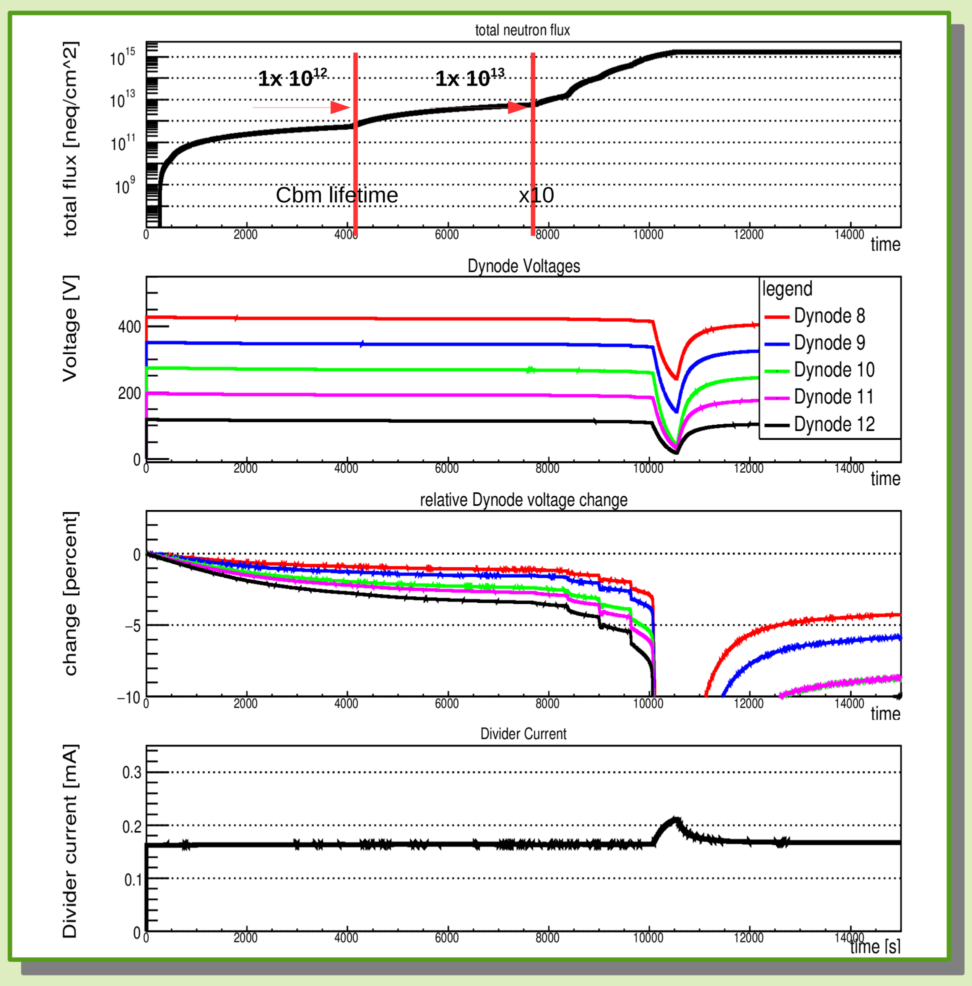
**Possible damage scenarios include:**
- Activation of Covar metal (containing $^{60}$Co), leading to dark rate increase
- Radiation damage to glass window, cathode, or dynodes
- Ionization damage to transistor in divider circuit




Single photon sensor darkrate (sum of 64ch) before and after short term irradiation with thermal neutrons and gammas from $^{60}$Co source. A clear increase in dark rate is observed, which quickly levels off after few weeks. No long-term activation of eg $^{60}$Co in Covar alloy (half-life : 5.3y).



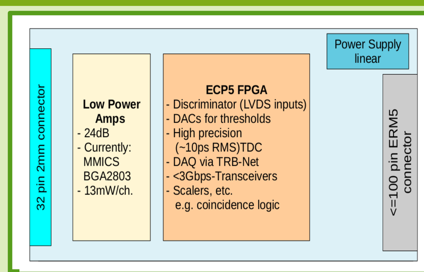

Spatially resolved, relative Single photon detection efficiency for H12700 MAPMT before and after irradiation with $3x10^{11}$ $n_{eq}$/cm² thermal neutrons and 145 Gy ionizing irradiation from $^{60}$Co source (top).
ADC single photon spectra for all 64 individual pixel with fitted peak position for gain determination (bottom).



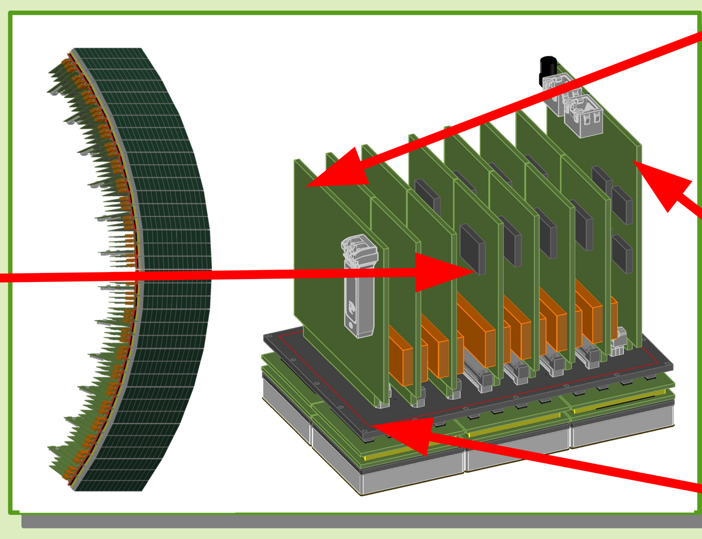

Voltage change of the last 5 transistor stabilized dynode voltages as function of integrated neutron dose during high intensity irradiation with thermal neutrons inside nuclear reactor core.

## Readout concept

- FPGA-TDC readout concept, based on HADES TRB3 TDC development [2]
- Excellent time resolution (<500ps, limited by sensor)
- Self-triggered, >> 100 kHz maximum hit rate per pixel
- Highly compact scheme, based on LATTICE ECP5 FPGA
- 3x2 MAPMTs (6x64 ch) carrier boards, serving as interconnect backplane between frontend modules
- Modules mounted to aluminum frame structure, allowing for curved focal plane



**12x DiRICH Frontend modules**
- 32 input channels per module
- Discrimination+TDC on single ECP5 FPGA
- Discrimination using LVDS line receivers
- All connections via PMT backplane
- 2Gb LVDS-link to Concentrator board



**Data Combiner module**
- Combine data from 12 DiRICH to single SFP output link (2Gb, later 5/10Gb)
- 2 Gb LVDS link to each DiRICH via backplane
- clock, power, via backplane

**Power module**
- Low-Voltage / High Voltage supply to backplane (6 PMTs share common HV channel)
- LDO / switching regulators, voltage measurement
- Clock / Trigger fan-out, distribution via backplane

**3x2 PMT carrier board / backplane**

[1] Technical design report for the CBM-RICH detector, GSI-2014-00528
[2] M. Traxler et al, JINST 6 12004 (2011)
[3] J. Kopfer, M. Dürr et al, NIMA 783 (2015), 43-50

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