RICH Collaboration

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Supported by:

THE CBM RICH DETECTOR

Tariq Mahmoud
HIC for FAIR Workshop,
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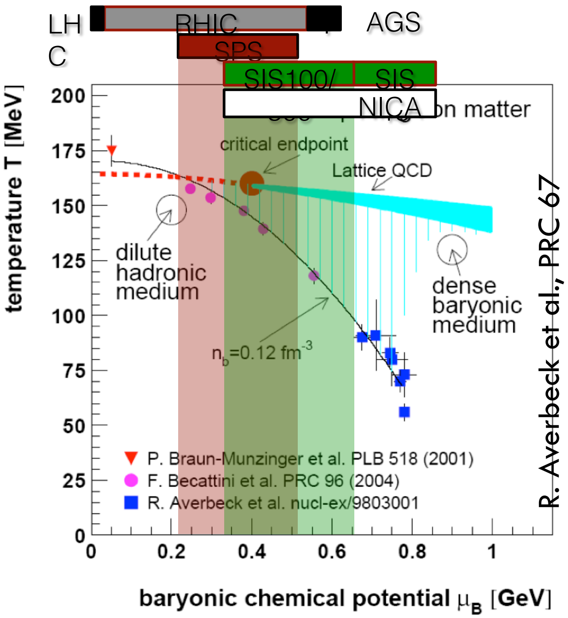
„Wer nicht generalisieren kann, hat keinen Sinn für Details“

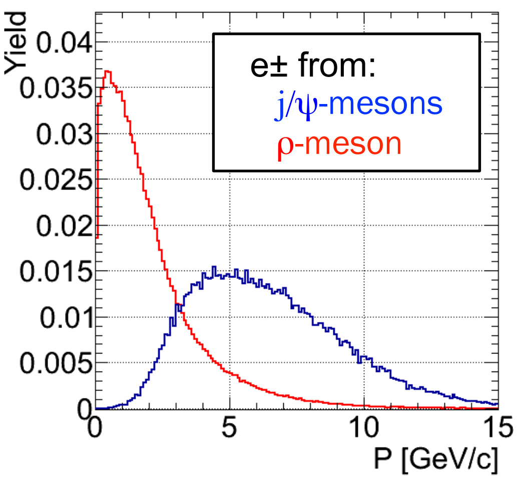
Outline

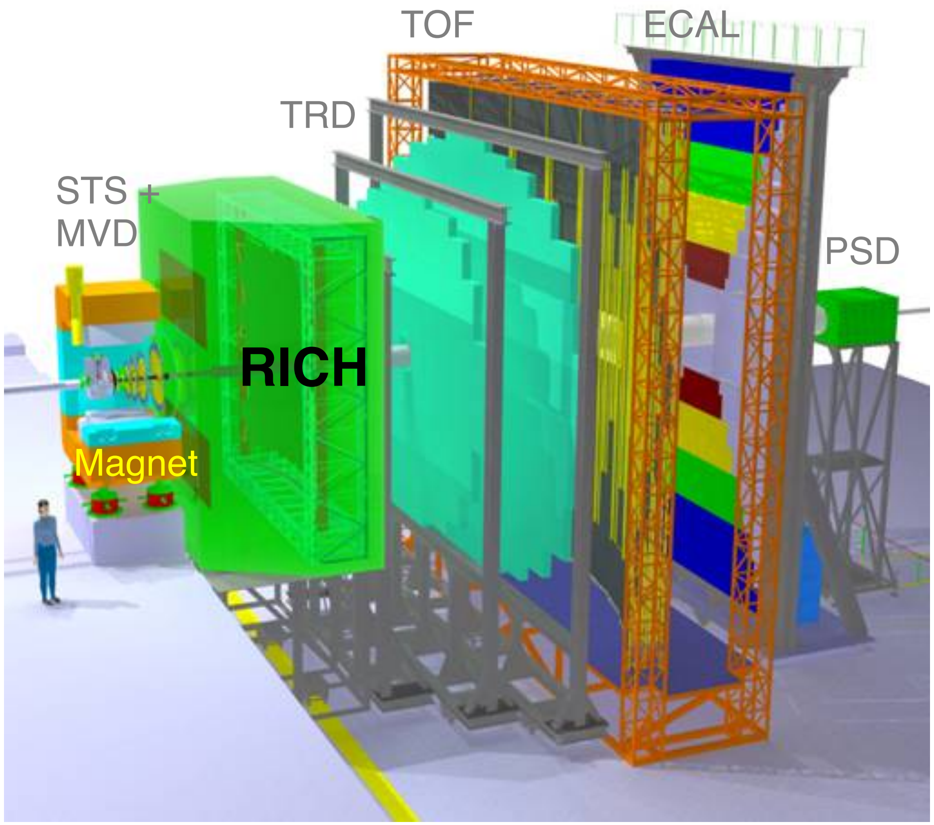
- Introduction & motivation
- The RICH concept
- The RICH prototype
- PMT radiation hardness
- Mirror alignment system
- Geometry optimization
- Conclusion

Introduction: The CBM Experiment



R. Averbeck et al., PRC 67 (2003) 024903

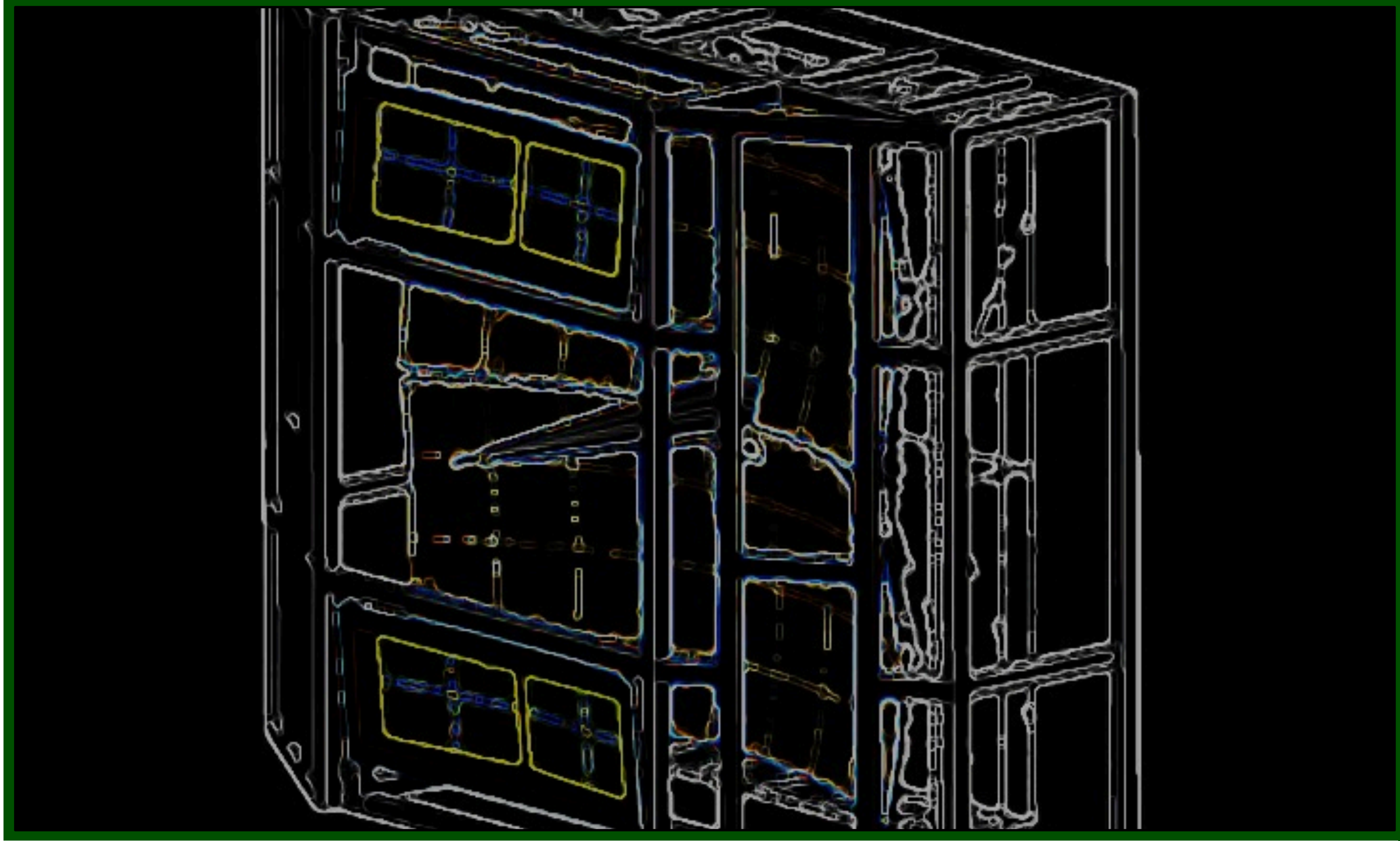




Rare probes: (ρ,ω,ϕ → e±) & (j/ψ, ψ' → e±)

TRD: <u>tracking</u>, electron identification
RICH: electron identification

pion rejection factor of $\geq 10^4$



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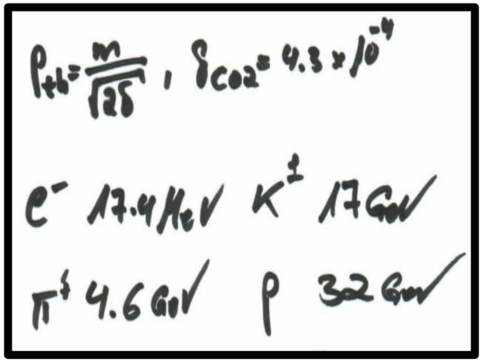
The RICH Concept

The RICH Concept

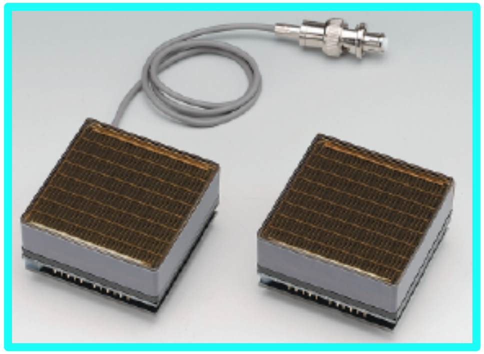


Radiator

- CO_2; γ_{th} = 33
- $p_{\pi,th}$ = 4.65 GeV/c
- Length=1.7 m. V ≈30 m^3

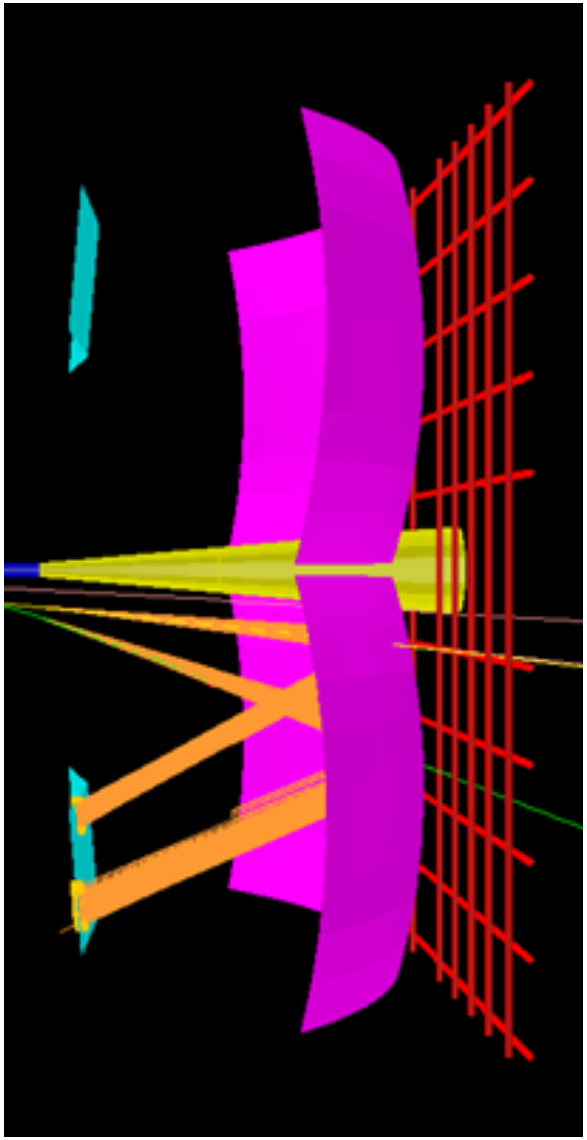
Mirror

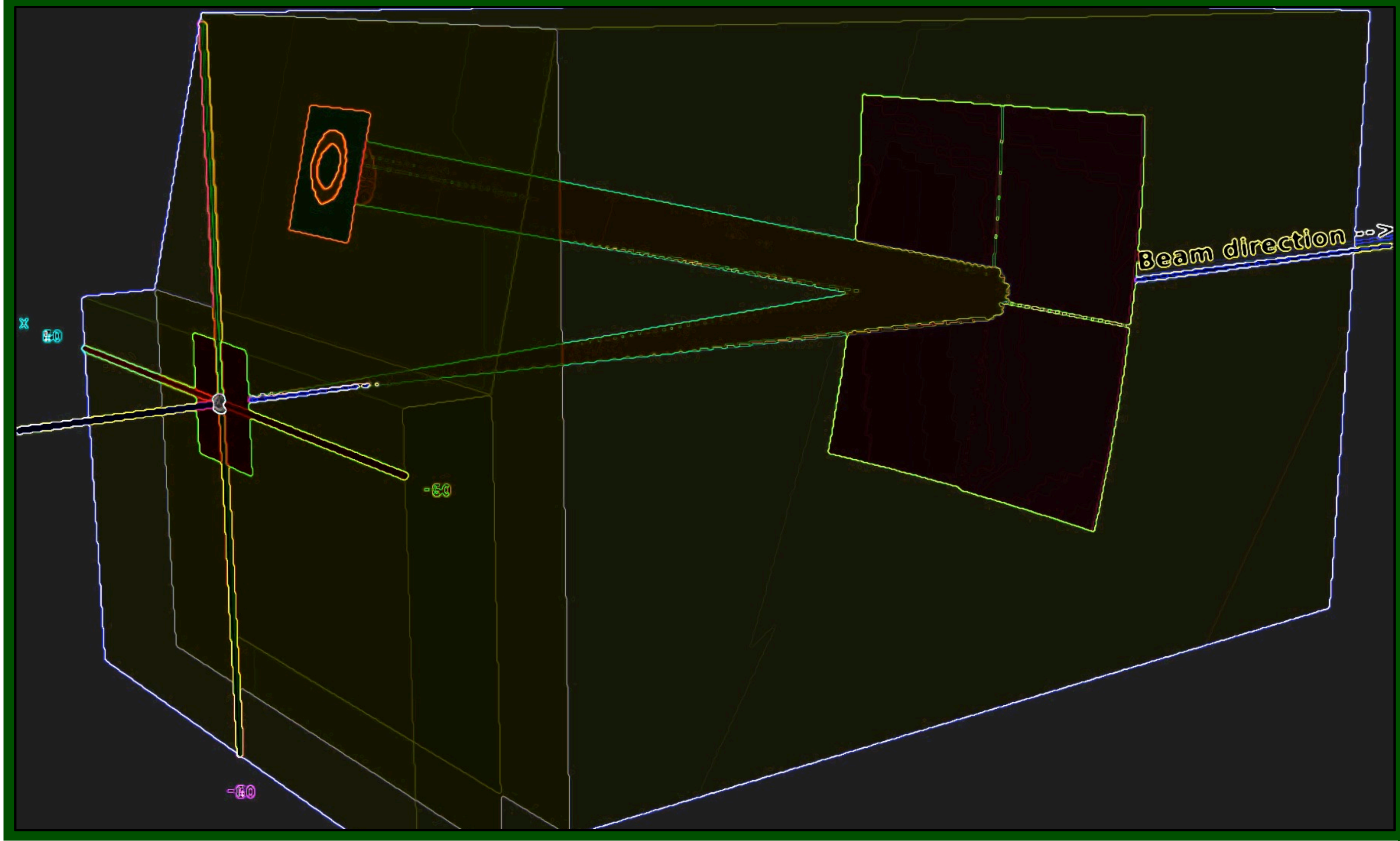
- SIMAX-glass, Al+MgF_2
- R = 3m, d ≤ 6mm
- 11.8 m^2 (Tiles of 40×40 cm^2)
- JLO OLOMOUC



Camera

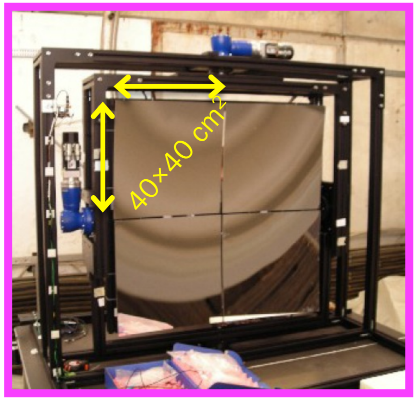
- 2.4 m^2, 55k Ch.
- MAPMT: H12700B series (Hamamatsu)

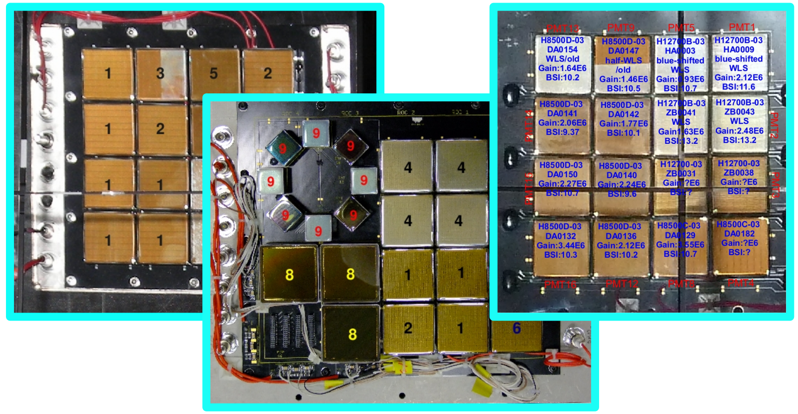




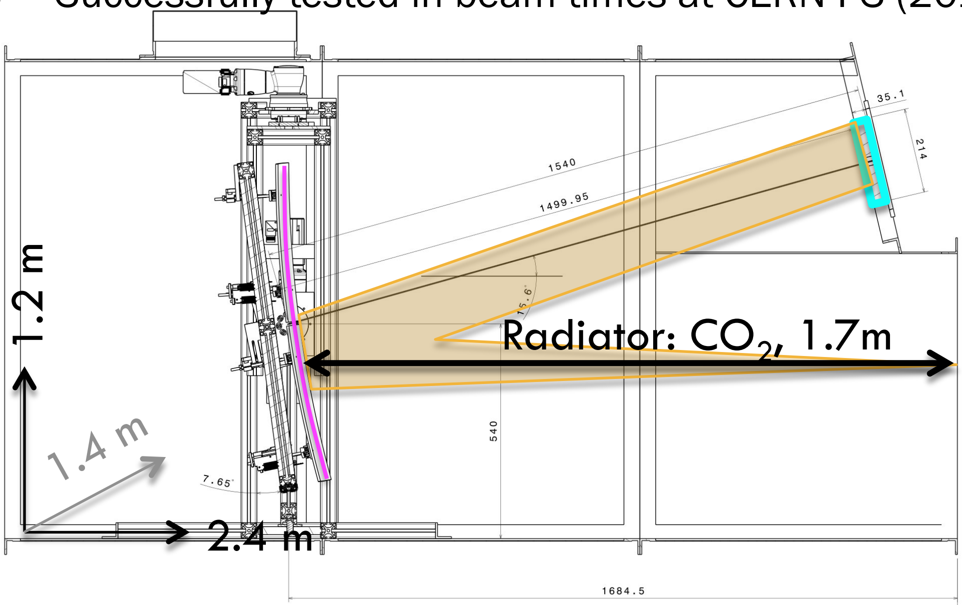
Real Size Prototype

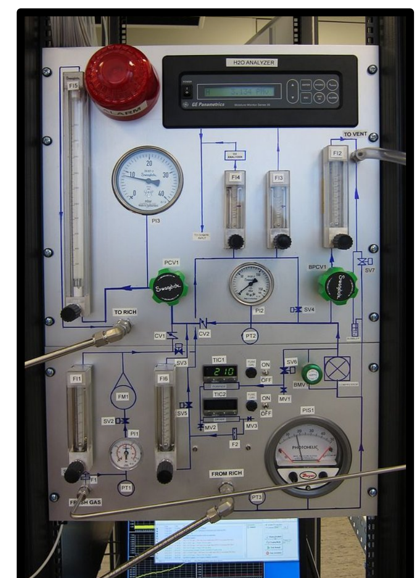
The RICH Prototype





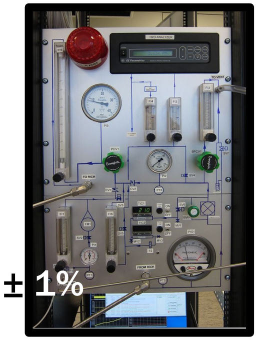
- Laterally scaled: Modules of the main components have the <u>same dimensions and properties</u> as foreseen in the RICH concept
- Successfully tested in beam times at CERN PS (2011, 2012, 2014)

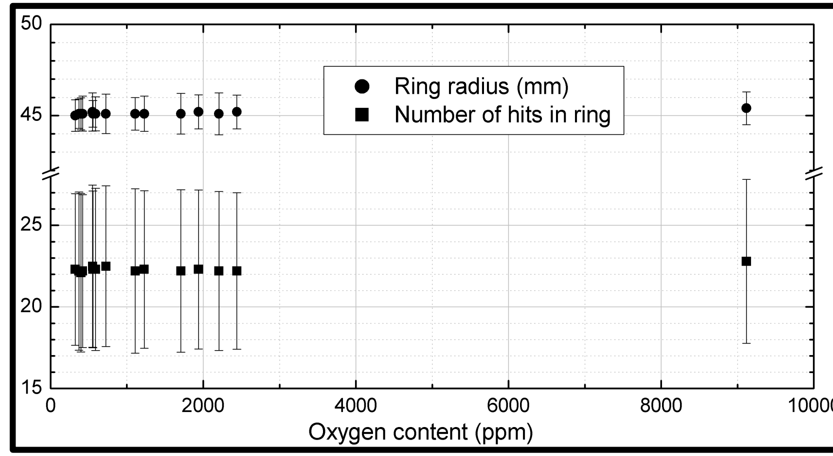




Research topics with the Prototype

RADIATOR (CO_2; length=1.7 m.)



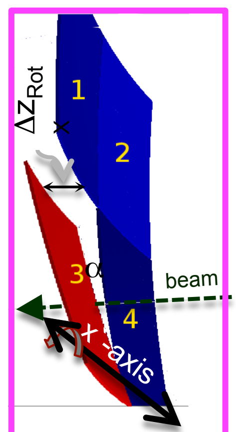


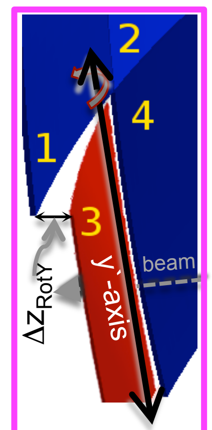
Normal operation:

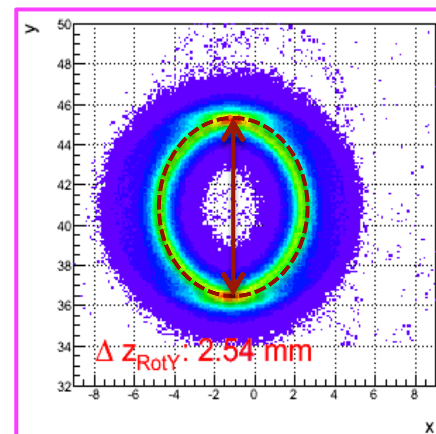
- Constant differential pressure of 2 mbar ± 1%
- O_2 (H_2O) impurity about 80 (250) ppm
- Tested up to impurity of 10000 (1100) ppm for O_2 (H_2O).

MIRROR
(SIMAX-glass, JLO OLOMOUC, Al +MgF_2, R = 3m, d ≤ 6mm, Tiles of 40×40 cm²)

$\Delta Z_{RotX\ (Y)} \leq 0.35$ mm ($\alpha_{X(Y)} \leq 1$ mrad) is tolerable

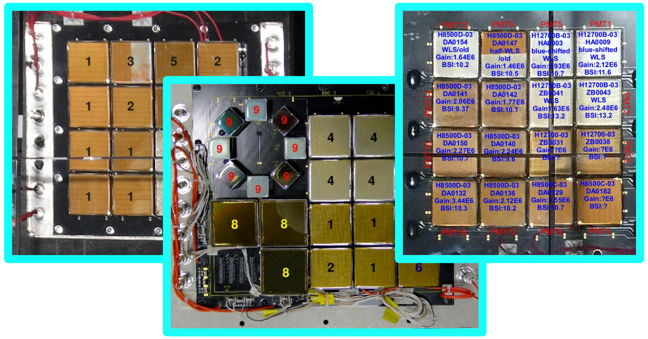






CAMERA (several types of PMTs)

Research topics with the Prototype



CAMERA (several types of PMTs)

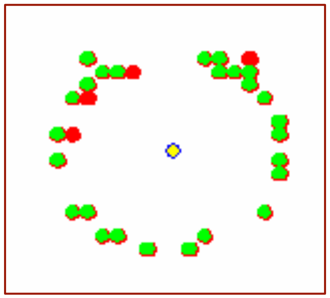
- **PHOTONIS**: Micro Channel Plate (MCP) → XP85012
- **HAMAMATSU**: Multi-anode Photomultiplier Tubes (MAPMT)
  - H8500 : 12-dynodes and Bialkali photo cathode (Baseline)
  - H10966: H8500 with 8-dynodes and Super-Bialkali photo cathode.
  - R11265: 12-dynodes and Super-Bialkali photo cathode.
  - H12700: 10-dynodes (dynode system as in R11265) and *advanced* Bialkali photo cathode
- **WAVELENGTH SHIFTING FILMS**: increases the PMT quantum efficiency (QE)

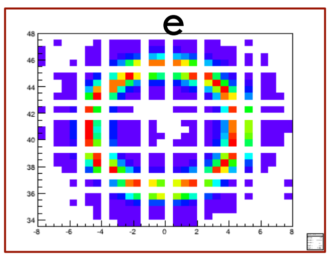
- **Ring properties:**
  - number of hits per ring,
  - ring radius,
  - elliptic major and minor axes (A&B) , B/A-ratio,
  - dR (ring resolution)

Ring properties (qualitative)

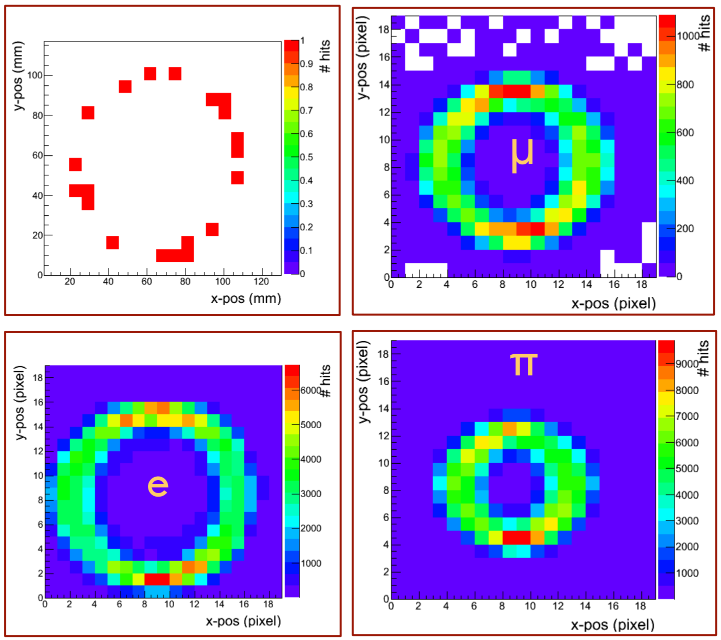
- **HAMAMATSU**: H8500, H10966, R11265, H12700 (also with WLS)
- **PHOTONIS**: XP85012

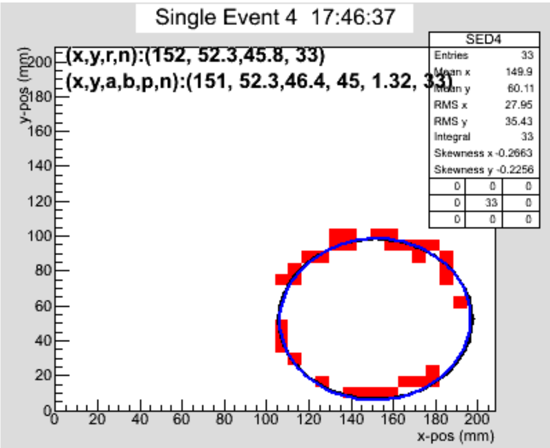
Simulation

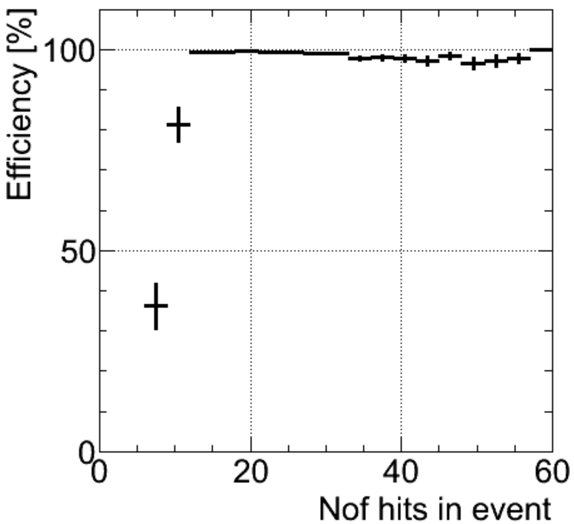




Data



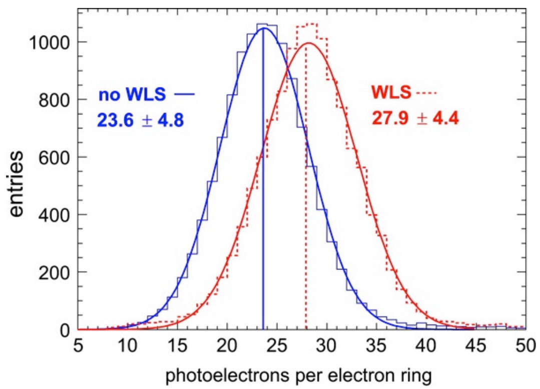




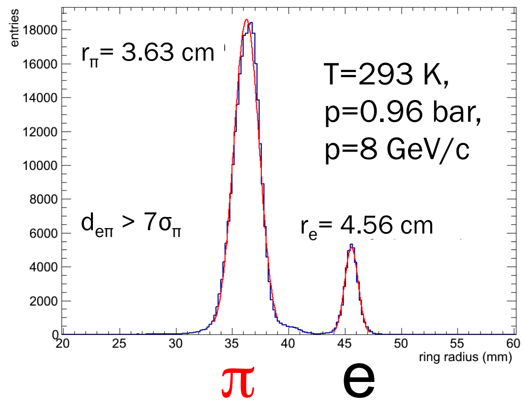
Ring properties (quantitative)

- **Hamamatsu**: H8500, H10966, R11265, H12700 (also with WLS)
- **Photonis**: XP85012

Number of hits per ring

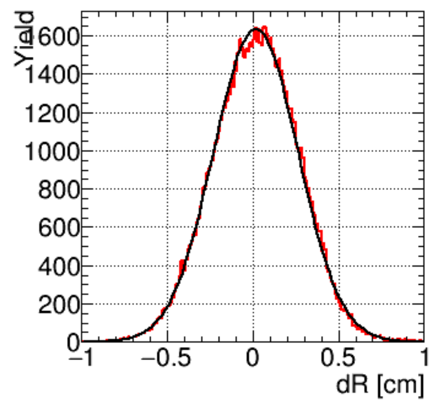


Ring radius



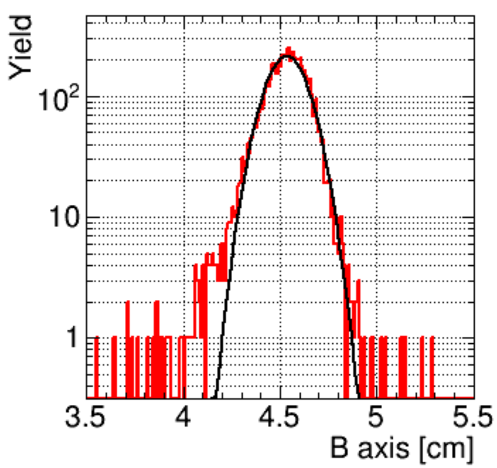
dR

m=0.02 σ=0.25

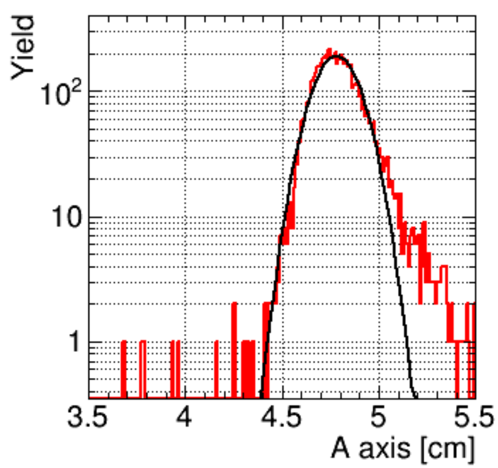


Elliptic major and minor axes (A&B) , B/A-ratio

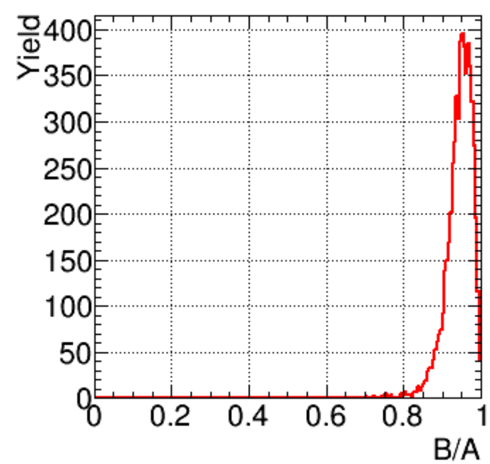
m=4.54 σ=0.10



m=4.79 σ=0.11



fhBoverAEllipse



Concept approved ...

Preparing building and operating the RICH detector:

- Gas system: with minor modification, the gas system can be used for the full RICH.
- Update the software with realistic parameters and geometry.

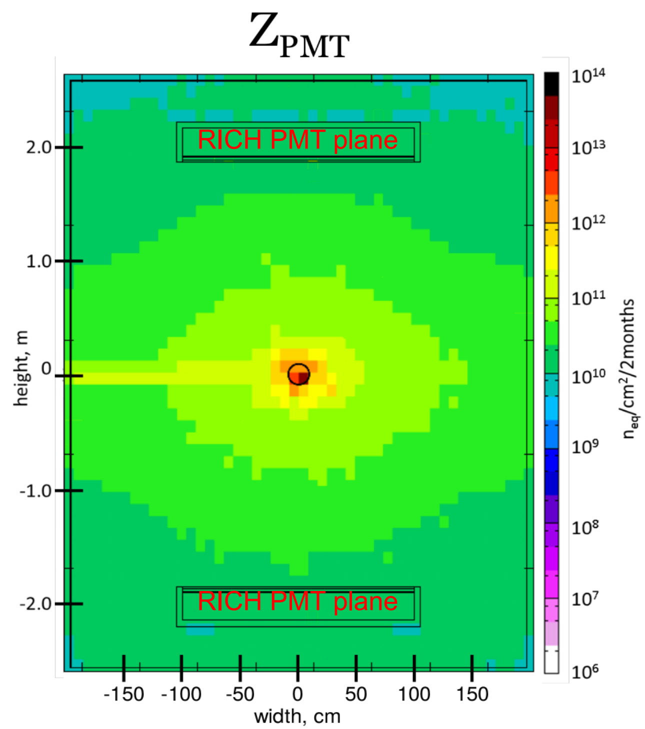
- Test radiation hardness and decide which photon detectors to choose.

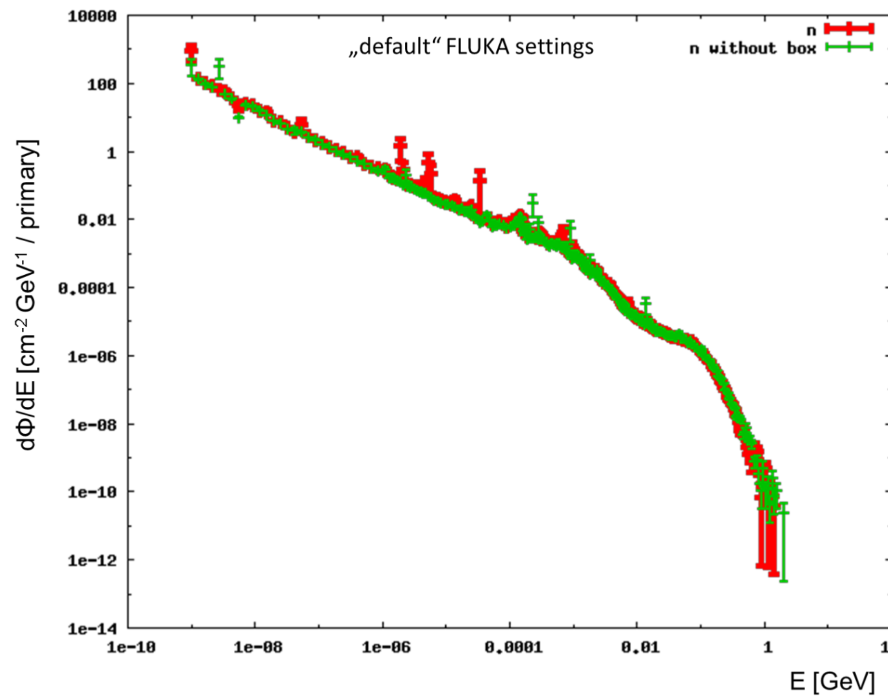
- (Re)optimize geometry.

- Towards operating the detector → Mirror alignment system.

Radiation Hardness

Radiation Hardness (RH)





Expected neutron dose rate at PMT sensor plane:
(Per 2 months operation at maximum intensity)

Expected neutron energy spectrum:
Mainly thermal neutrons

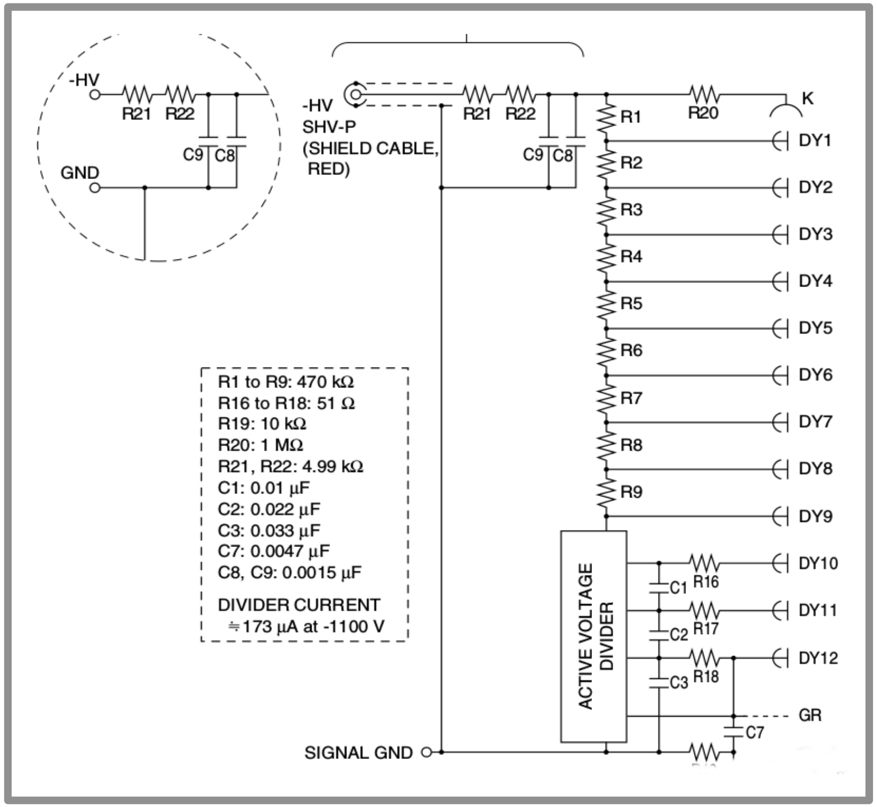
< ~5×10^{10} n_{eq}/ cm²/ 2 months
< 5 Gy / 2 months

→ CBM life time dose rate up to 20x higher: PMT sensors should survive 1×10^{12} n_{eq} / cm^2 and 100 Gy

RH: Potential Damage

- **PMT entrance window:**
  - transmission loss (Cherenkov photon absorption) → loss of hits.
- **PMT it self:** activation of materials therein (**consists of ca. 70% covar**) →
  - higher dark rate, lower QE, loss of gain and detection efficiency.
- **Dynode voltage divider** →
  - Loss of gain, PMT failure.

Covar: 54% Fe + 20 % Ni + 17% Co
(ρ = 8 g/cm3)



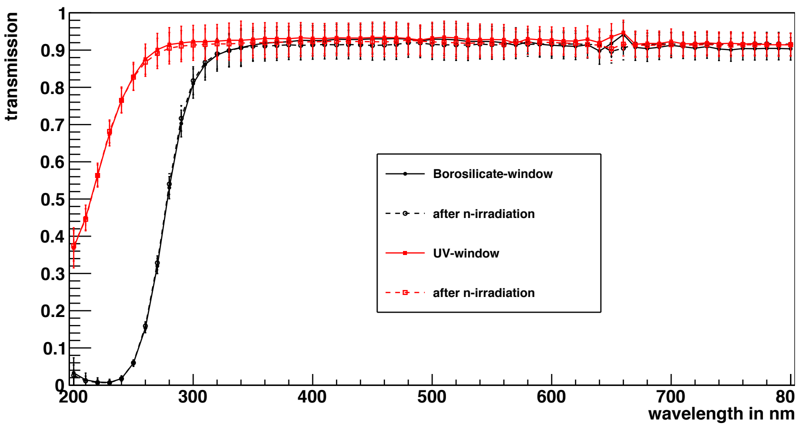
- Irradiate samples and compare results before and after irradiation
- Dynode voltage divider: Continuous voltage logging of last 5 dynodes

RH: irradiated samples

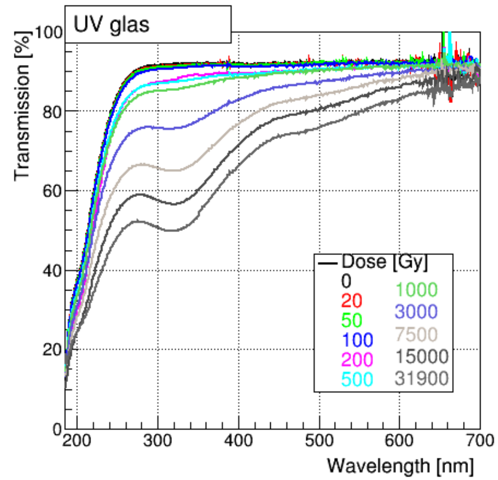
Serial-Nr	Type	Neutron dose	Gamma dose
BS-window 1		$1x\ 10^{12}\ n_{eq}/cm^2$	
UV-window 1		$1x\ 10^{12}\ n_{eq}/cm^2$	
BS-window 2		---	~ 32000 Gy
UV-window 2		---	~ 32000 Gy
HA0009	**H12700**	**$3x\ 10^{11}\ n_{eq}/cm^2$**	**145,7 Gy**
DA0150	H8500-D	$1x\ 10^{11}\ n_{eq}/cm^2$	45,8 Gy
DA0140	H8500-D	$3x\ 10^{10}\ n_{eq}/cm^2$	12,5 Gy
DA0142	H8500-D	$1x\ 10^{10}\ n_{eq}/cm^2$	
MCP		$1x\ 10^{11}\ n_{eq}/cm^2$	145,7 Gy
Voltage devider 1	H8500/H12700	$\sim 1x\ 10^{15}\ n_{eq}/cm^2$	---
Voltage devider 2	H8500/H12700	---	~ 1000 Gy
Quartz with WLS 1		$(1\text{-}3)\ x\ 10^{11}\ n_{eq}/cm^2$	---
Quartz with WLS 2		---	~ 50 & 100 Gy

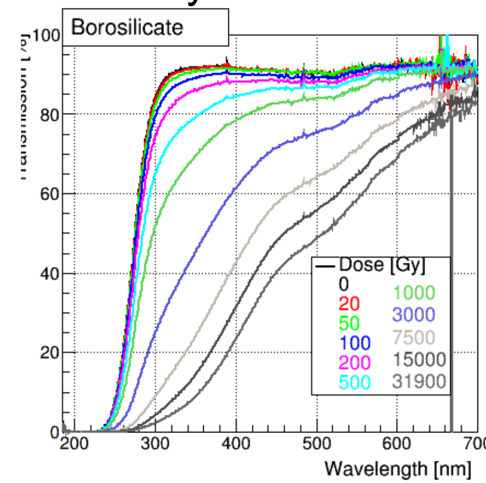
RH: BS &UV Windows

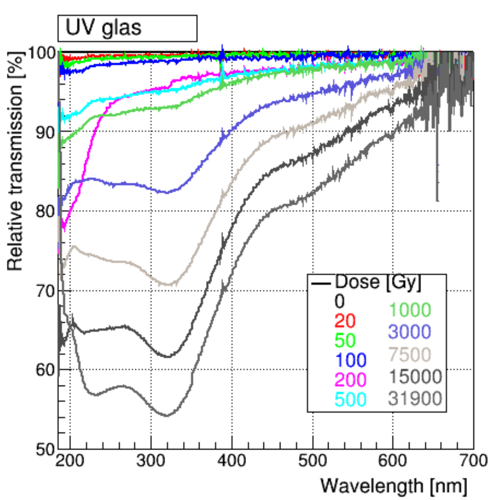
Neutron dose: 1x 10^{12} n_{eq}/cm^2

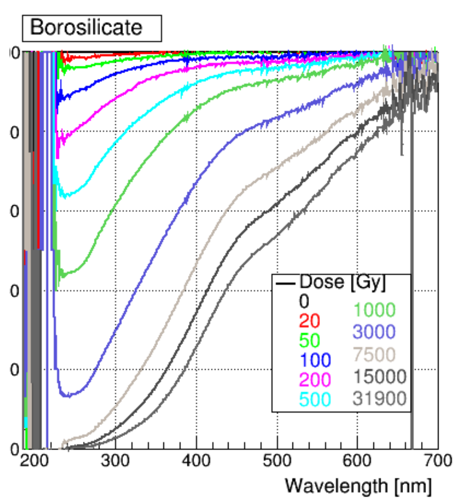


Gamma dose: 32000 Gy





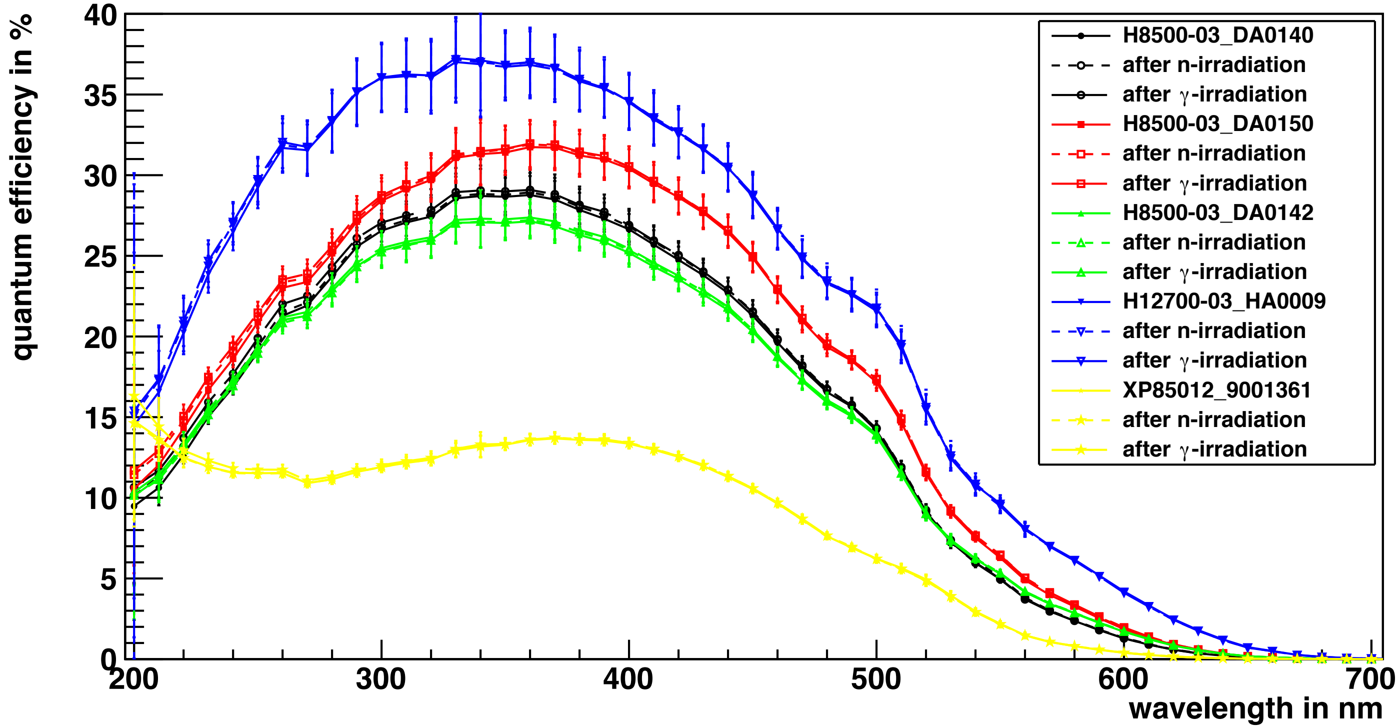




- ✧ No effect of neutron irradiation on both windows.
- ✧ Up to 3% (10%) of the photons are absorbed after gamma irradiation dose of 100 Gr in UV (BS) window.

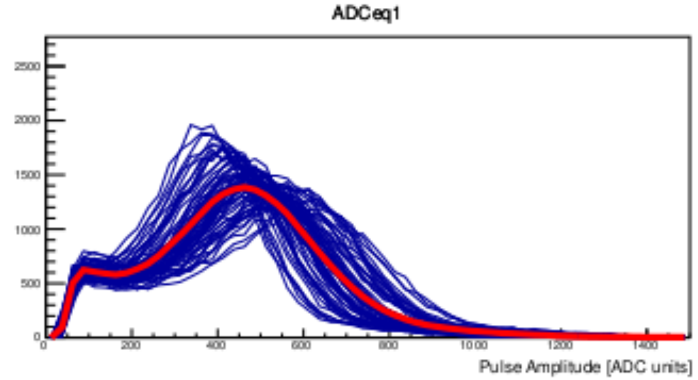
RH: PMTs QE

HA0009	**H12700**	**3x 10^{11} n_{eq}/cm^2**	**145,7 Gy**
DA0150	H8500-D	1x 10^{11} n_{eq}/cm^2	45,8 Gy
DA0140	H8500-D	3x 10^{10} n_{eq}/cm^2	12,5 Gy
DA0142	H8500-D	1x 10^{10} n_{eq}/cm^2	
MCP		1x 10^{11} n_{eq}/cm^2	145,7 Gy



- Neither the neutron nor the gamma irradiations affects the QE.

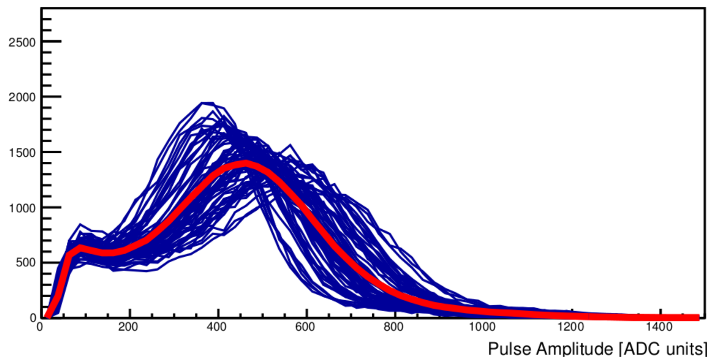
RH: PMTs, Single Photon Spectrum



Before irradiation

H12700

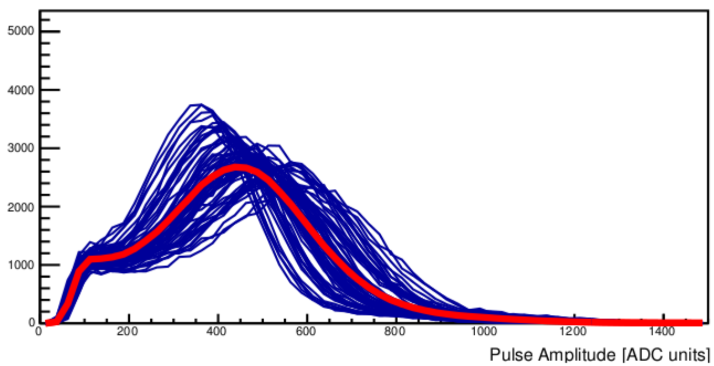
Mean gain: 2.2 x 10^6



After n-irradiation

3x 10^{11} n_{eq}/cm^2

Mean gain: 2.2 x 10^6



After n-and γ-irradiation

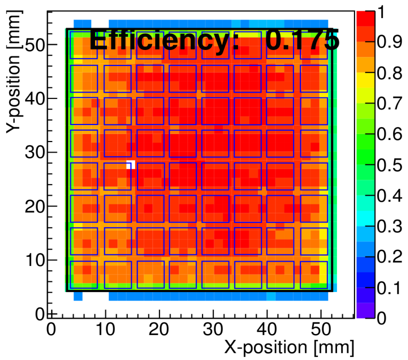
145,7 Gy

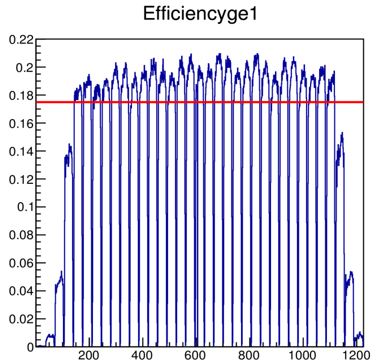
Mean gain: 2.1 x 10^6

- Neither the n- nor the γ-irradiations affects the single photon spectrum

RH: PMTs, Detection Efficiency

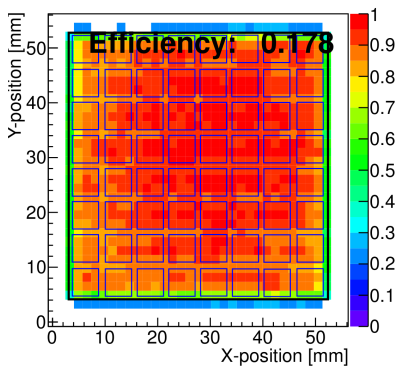
H12700

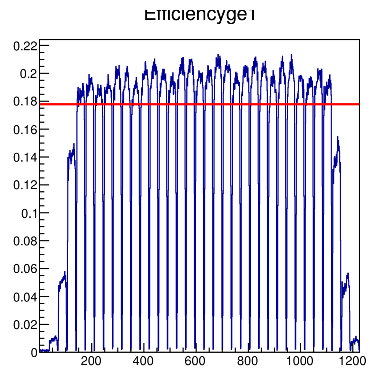




Before irradiation

Mean efficiency:
0.175 ± 0.01
(ref PMT: 0.139 / 0.136)

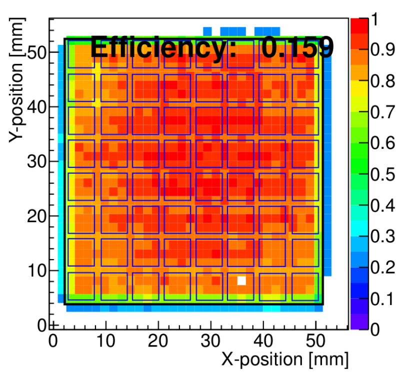


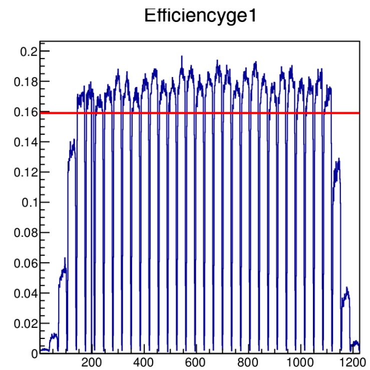


After n-irradiation

$3x\ 10^{11}\ n_{eq}/cm^2$

Mean efficiency:
0.178 ± 0.01
ref PMT: 0.141 / 0.144)
corrected mean: 0.172





After n-and γ-irradiation

145,7 Gy

Mean efficiency:
0.159 ±0.01
(ref PMT: 0.133 / ---)
corrected mean: 0.164

- Almost no effect from n-irradiation.
- About 6% loss of efficiency by γ-irradiation. Properly caused by the UV entrance window.

RH: PMTs, γ-Spectroscopy

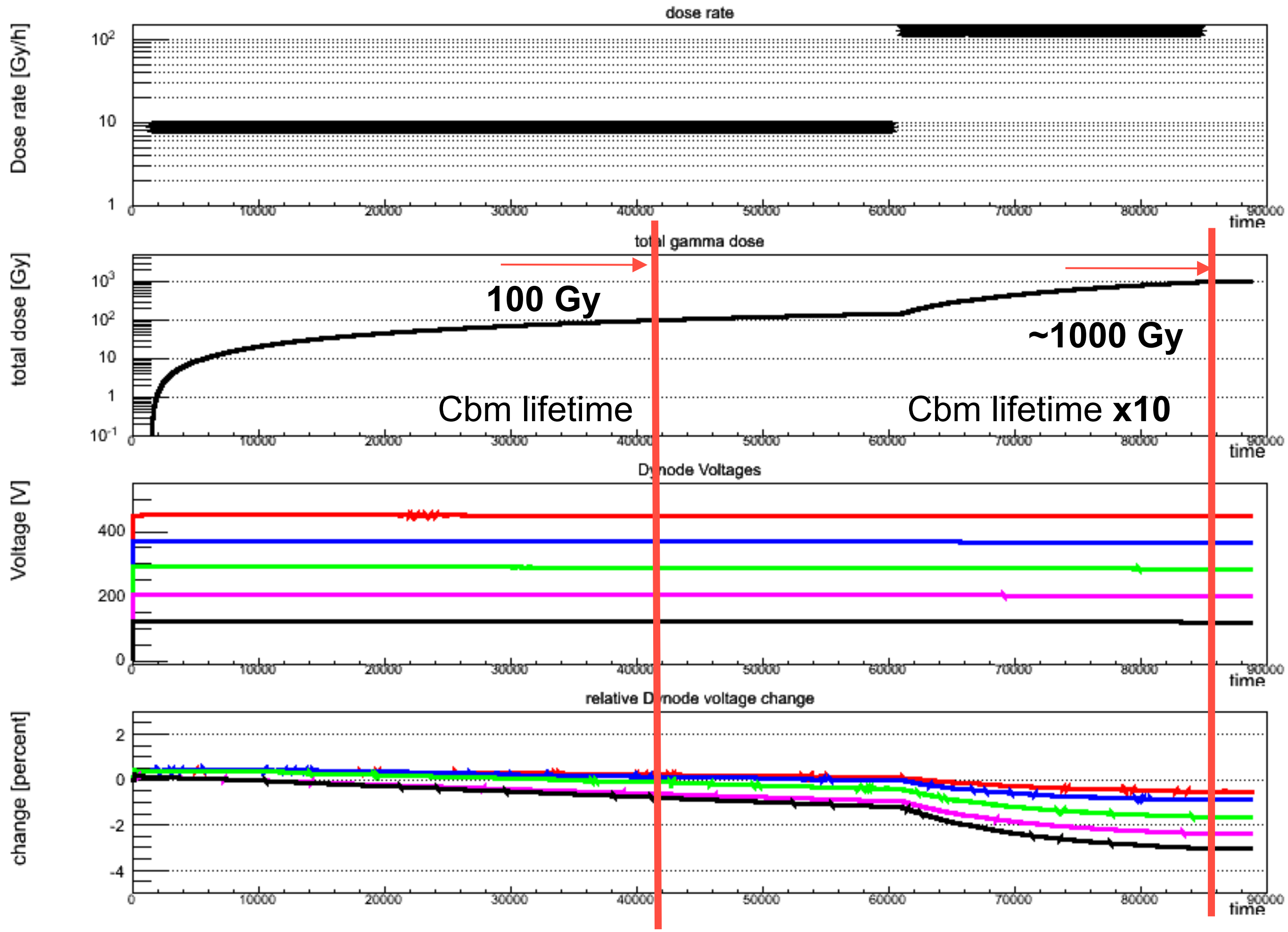
H8500 MAPMT (very similar to H12700 MAPMT)
irradiated with **1.3×10^{11} n_{eq} / cm^2 thermal neutrons** (~ 15% CBM lifetime dose)

Gamma spectroscopy results measured 24hr after irradiation:

Radionuclide	Activity [Bq]	Half-life	Used in
Br-82	1.70×10^3 ($\pm 3.4\times10^2$)	1.5 days	Voltage Divider PCB
Au-198	6.63×10^2 ($\pm 1.4\times10^2$)	2.7 days	Gold-plated contacts
Na-24	2.46×10^2 ($\pm 5.1\times10^1$)	15 hr	Glas window
Co-58	**3.03×10^1 ($\pm 7.3\times10^0$)**	**71.3 days**	**Covar metal case**
Co-60	**7.13×10^1 ($\pm 1.5\times10^1$)**	**5.3 years**	**Covar metal case**

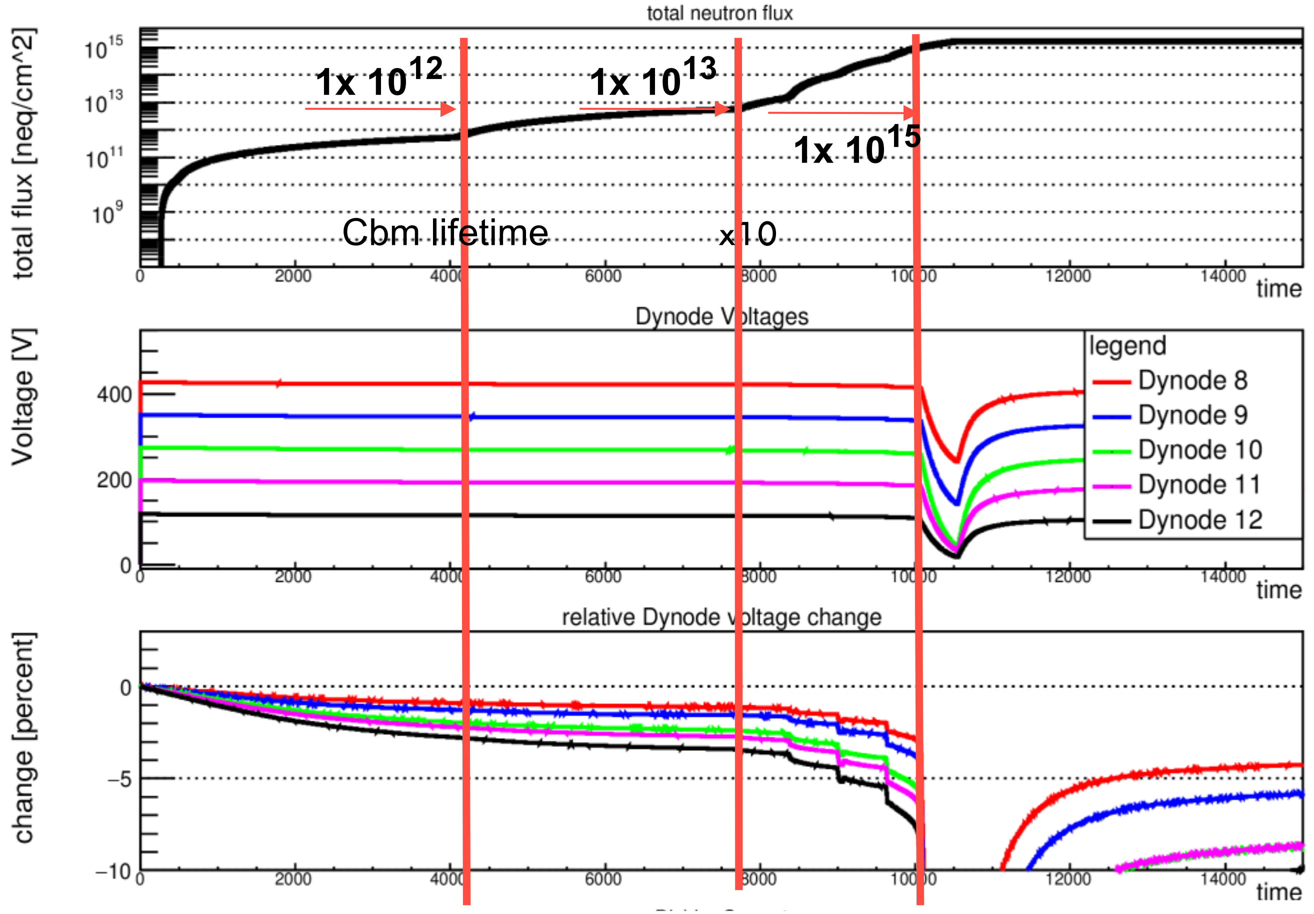
Co-60 contributes seriously to dark rates ... but only with 71Hz (homogeneously in space)
At high rates we have 1MHz Cherenkov photons per PMT → Co-60 dark rates are very low.

RH: PMT Voltage Divider (γ)



✧ No effect on voltage divider after 10x of the CBM life time from the γ-irradiation.

RH: PMT Voltage Divider (n)

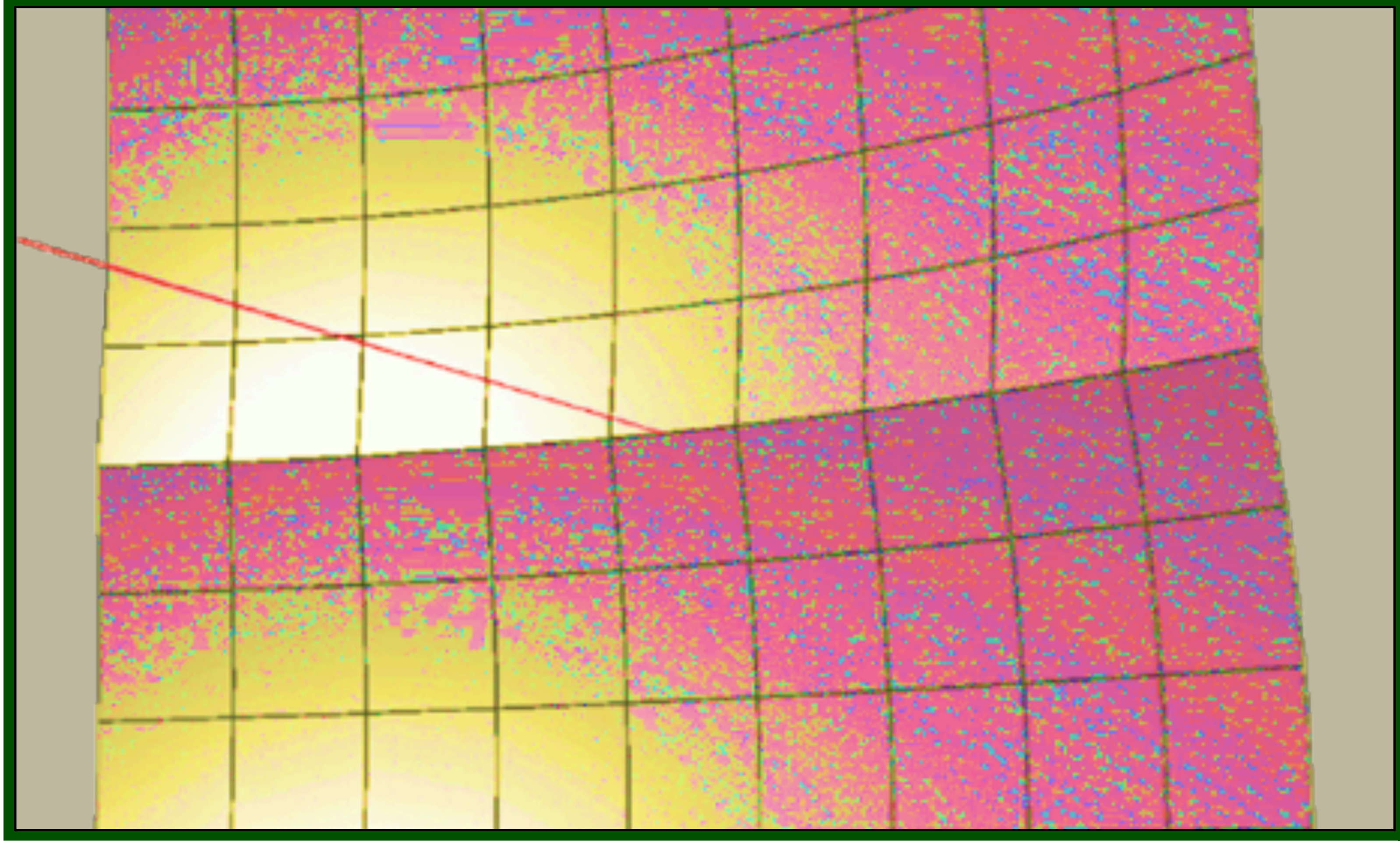


✧ Only after 1000x of the CBM thw n-irradiation damages the PMT voltage divider.

RH: WaveLength Shifting Films

Quartz with WLS 1	(1-3) x 10^{11} n_{eq}/cm^2	---
Quartz with WLS 2	---	~ 50 & 100 Gy

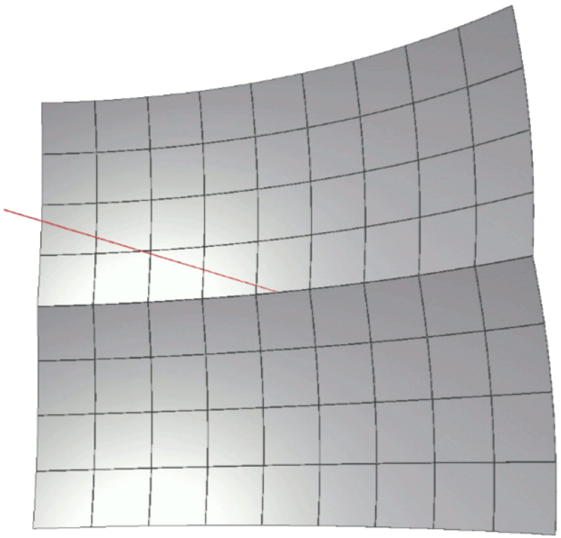
Analysis is on going.
First florescence results show no effect of n-irradiation on WLS within 10%.

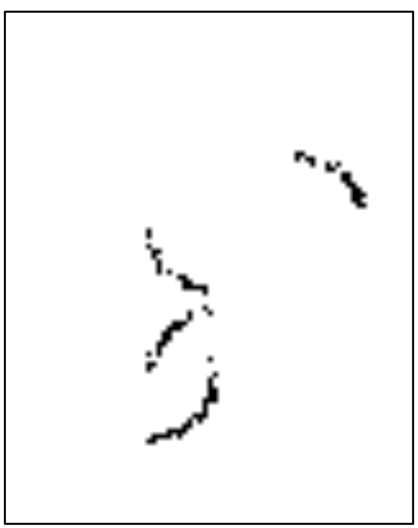


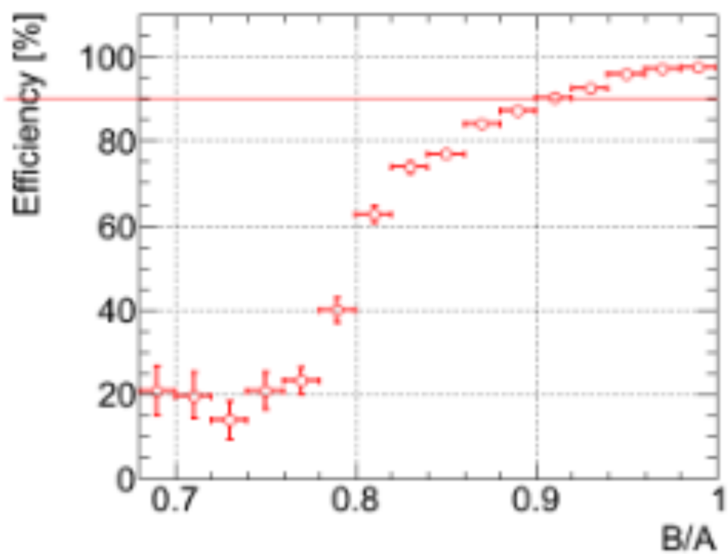
Mirror Alignment System

Mirror Alignment System

- Perfectly aligned and stable mirror system is prerequisite for accurate and high ring reconstruction efficiency.
- RICH will be moved → potential misalignment :
  - Ring splitting and distortion →
  - Double ring and ring-track mismatching →
  - Los of ring reconstruction efficiency →
  - Electron misidentification

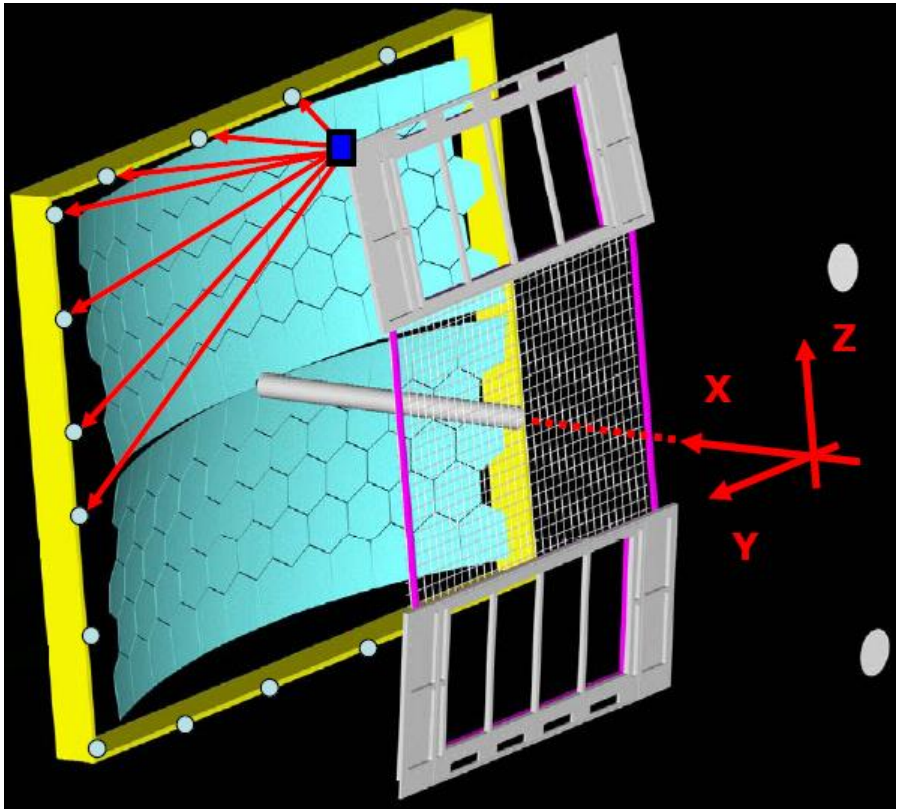






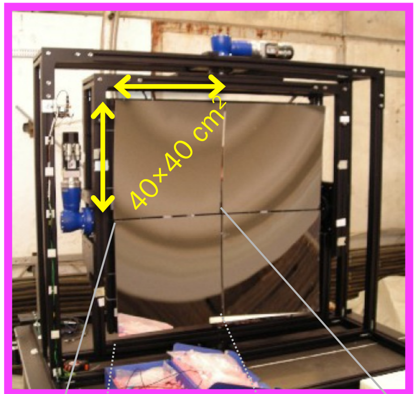
CLAM Principle

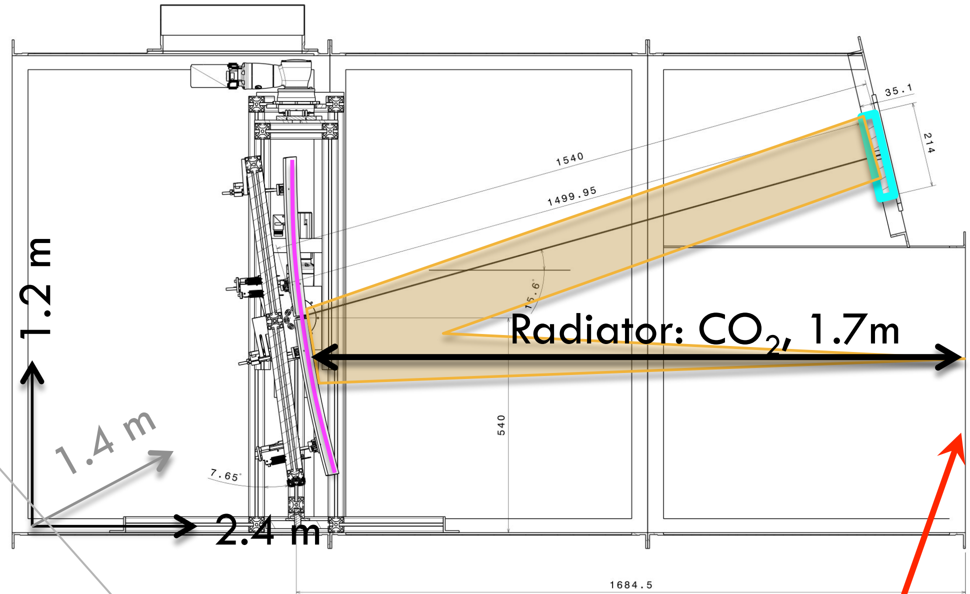
- Qualitative control measurement
  - Grid of retro-reflective stripes
  - Illuminate grid with LEDs
  - Record grid reflection through the mirrors
    - Perfect grid → alignment
    - Broken lines → misalignment
- Quantitative position measurement
  - Target dots on grid crossings
  - Target dots on external frame

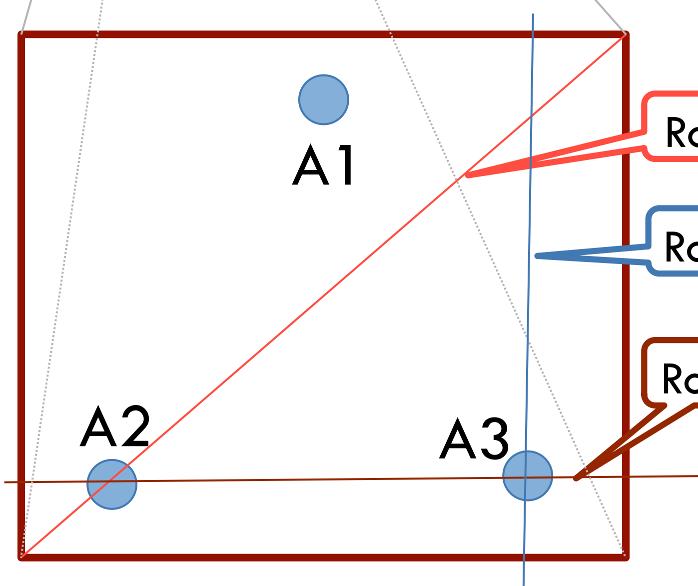


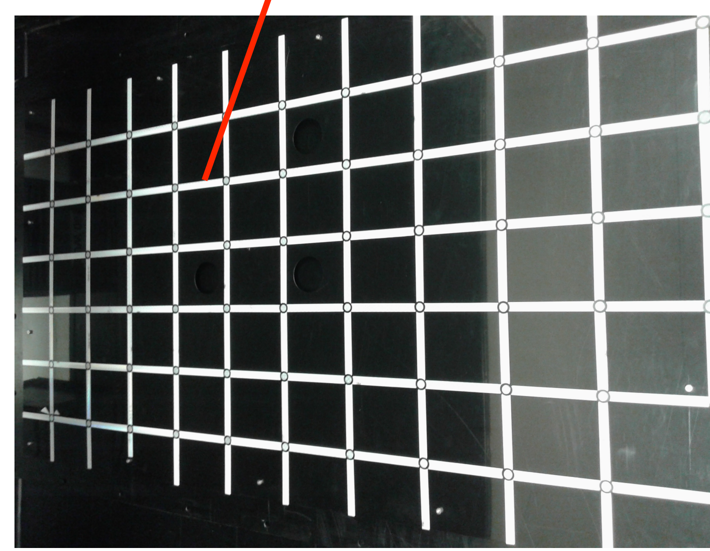
* Developed by the COMPASS experiment – Nucl. Instr. Meth. Phys. Res. A 553 (2005) 135

Prototype Setup



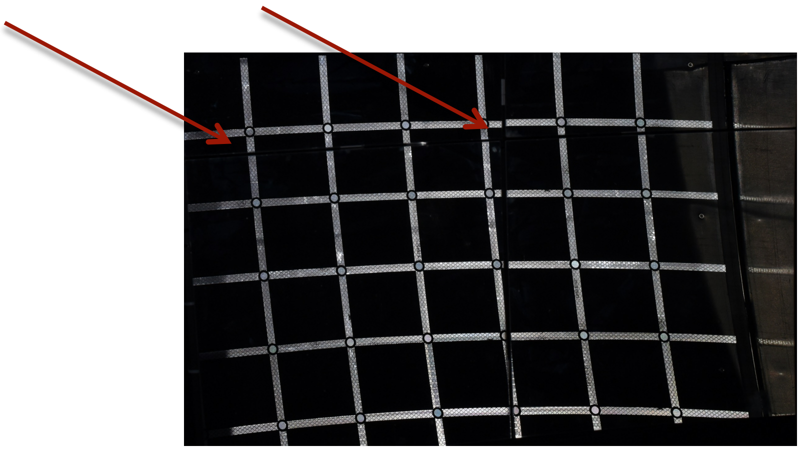


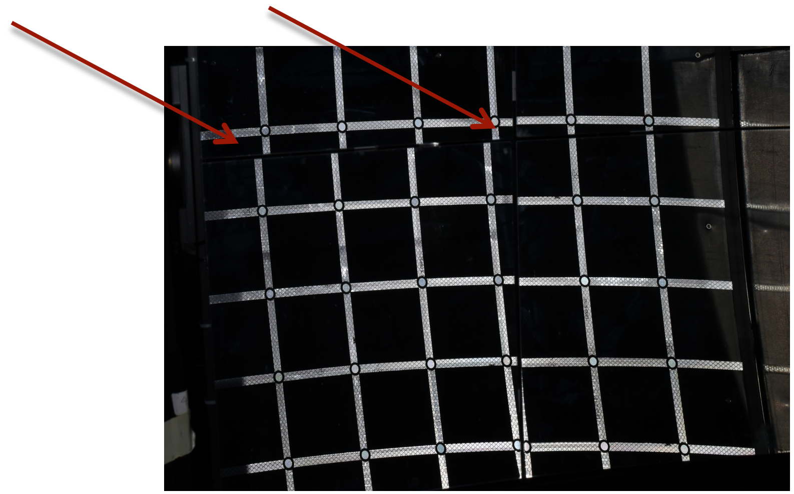


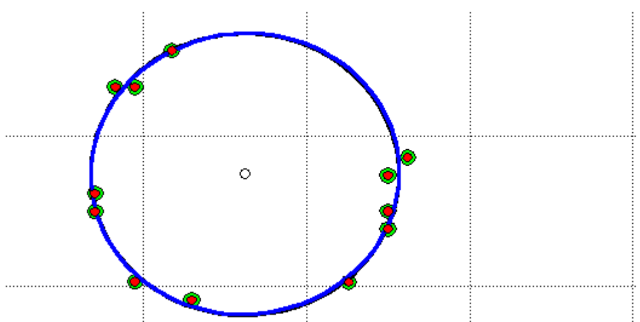


Qualitative Statements

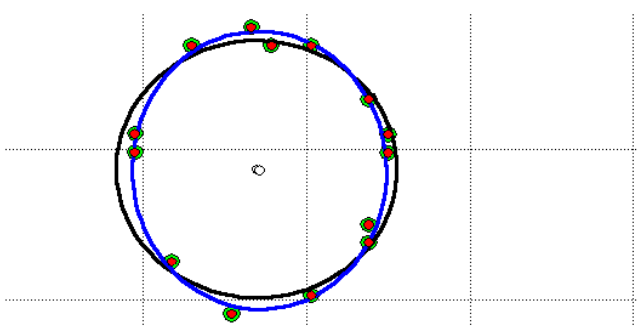
- Mirror system viewed by the CLAM camera and reconstructed rings
  - Left: right after the reference alignment
  - Right: lower left mirror rotated by 4 mrad Backwards around Y axis





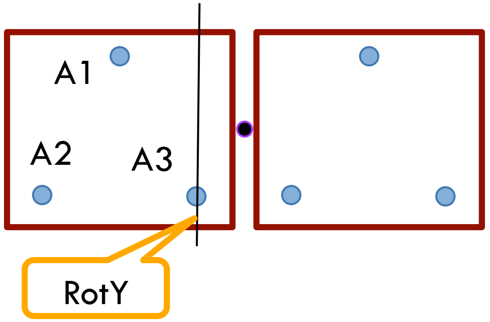


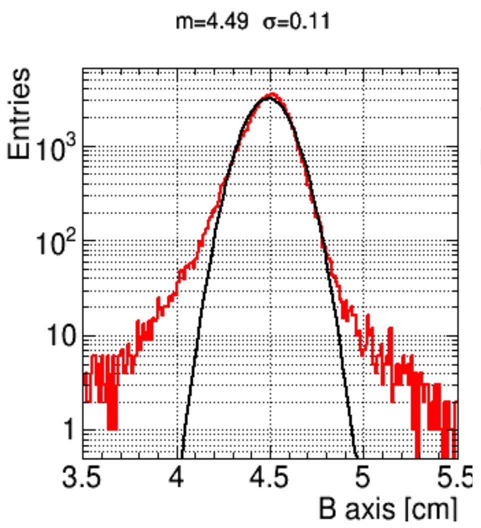
(x, y, R, n)=(8.1, 13.7, 4.72, 12)
(x, y, A, B, ϕ, n, B/A)=(8.1, 13.8, 4.75, 4.69, 0.69, 12, 0.99)

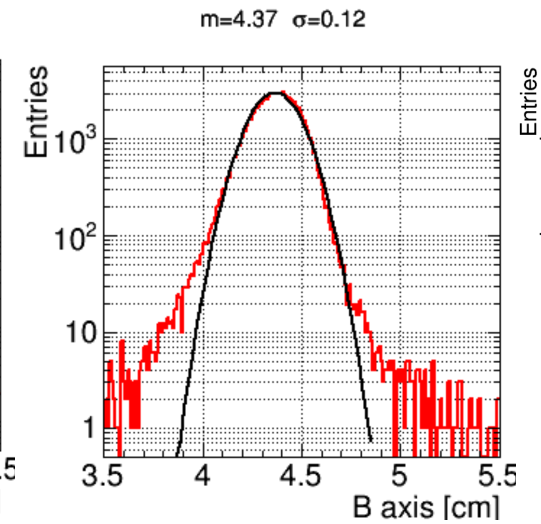


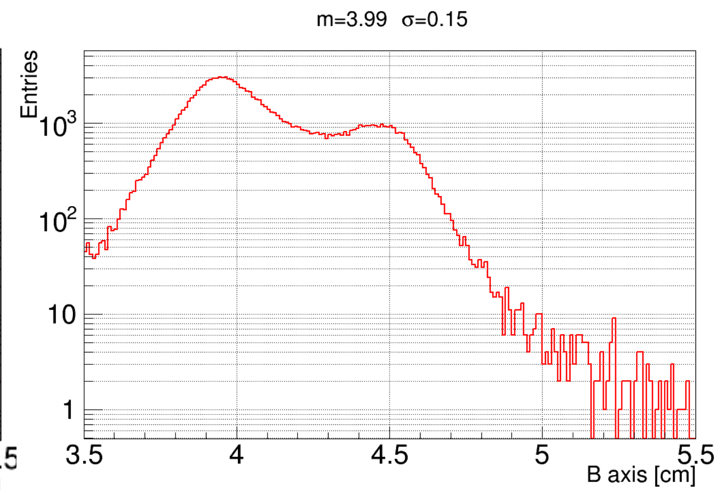
(x, y, R, n)=(8.5, 14.4, 4.30, 14)
(x, y, A, B, ϕ, n, B/A)=(8.6, 14.3, 4.65, 3.89, -1.55, 14, 0.84)

Quantitative Statements







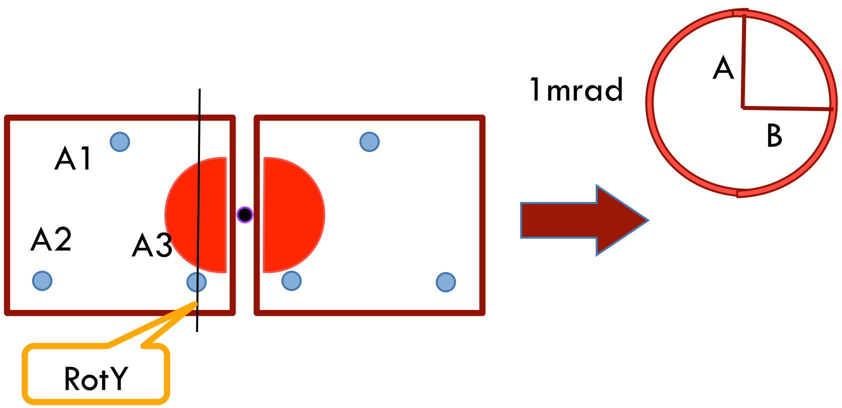


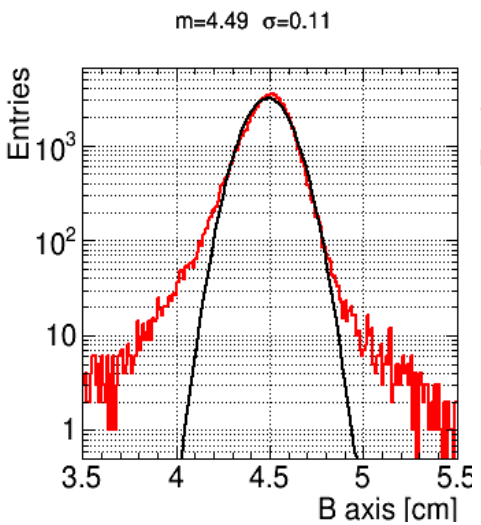
Reference: no displacement

1 mrad displacement

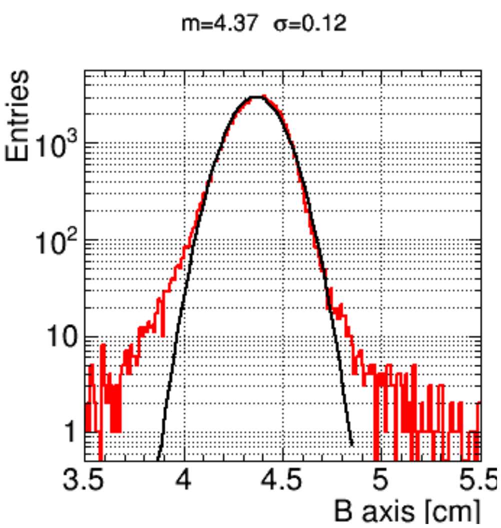
4 mrad displacement

Quantitative Statements



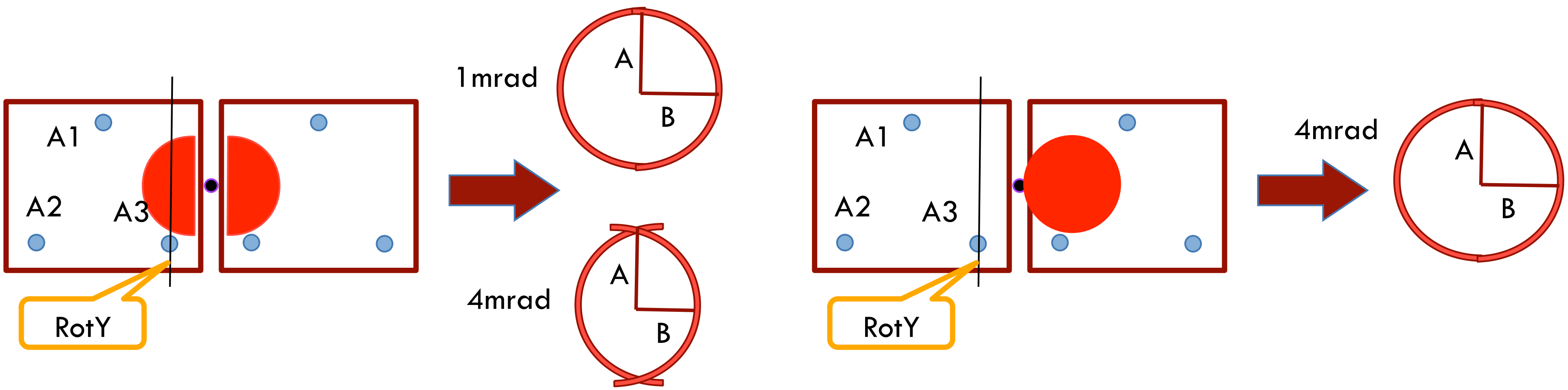


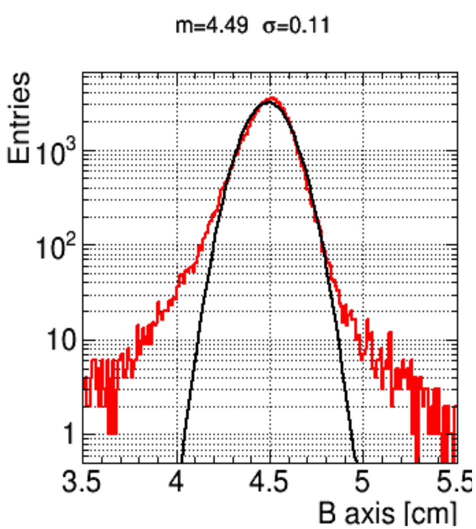
Reference: no displacement

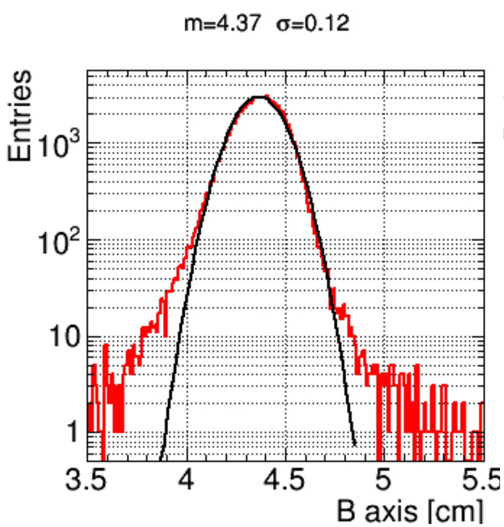


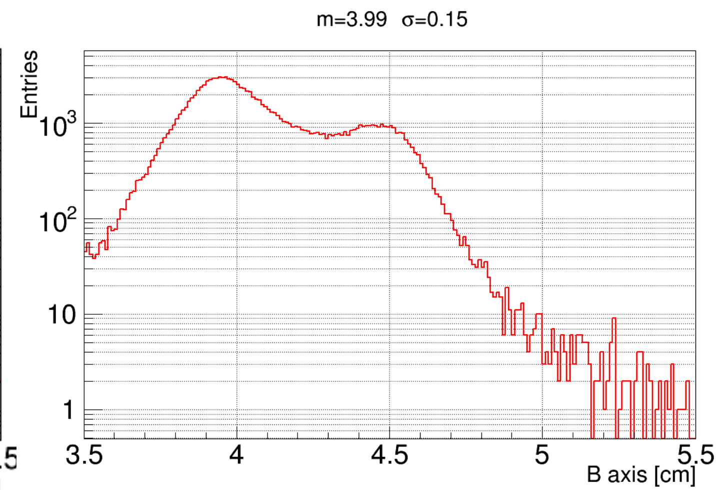
1 mrad displacement

Quantitative Statements





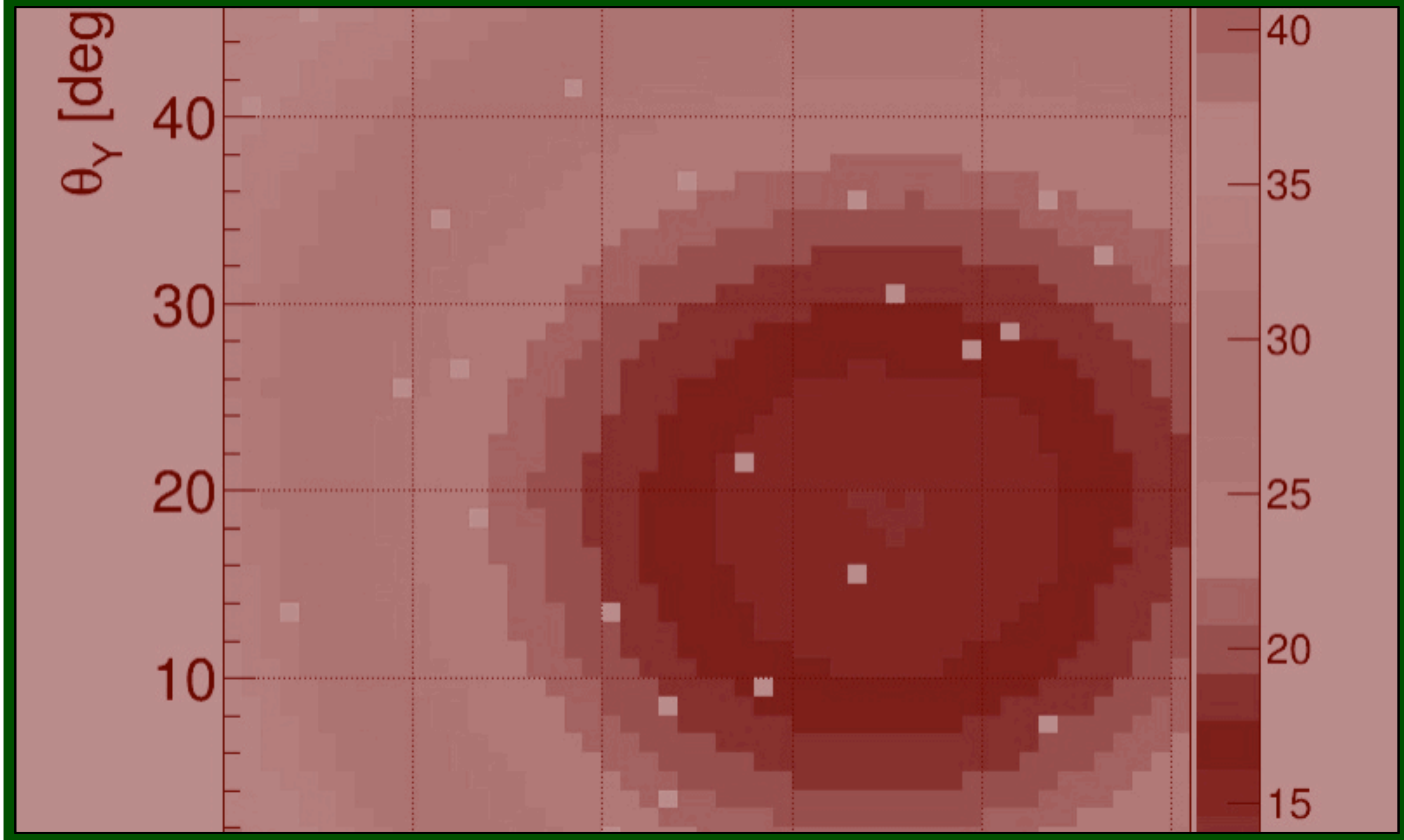




Reference: no displacement

1 mrad displacement

4 mrad displacement

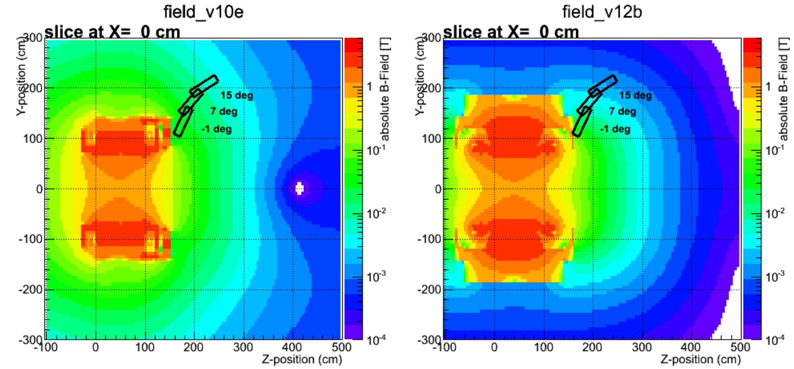


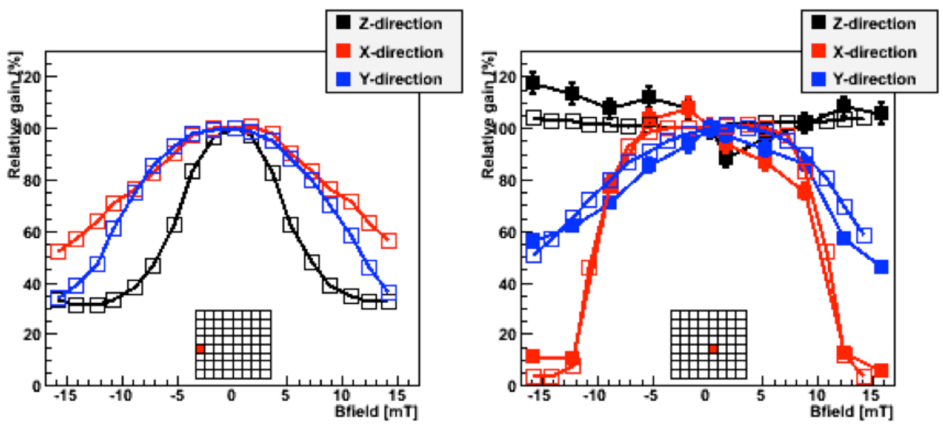
Geometry Optimization

CBM RICH
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

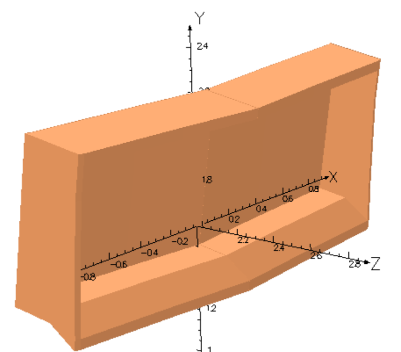
Geometry Optimization

- ✧ Current RICH geometry optimized in 2009:
  - ✧ mirror rotated by -1 deg
  - ✧ RICH starts at 1.6 m from IP
- ✧ RICH shifted by 20 cm upwards (start at 1.6m)
- ✧ High magnetic field at the PMT position (100mT).
- ✧ Only 2 mT can be tolerated!

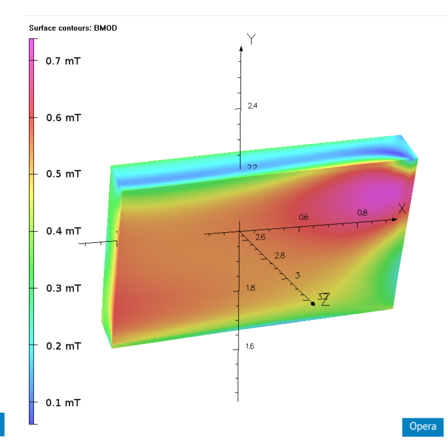




- ✧ Tilt the mirror-PMT system by 10 degrees
- ✧ Shield the PMTs with a box of steal



2 x 0.6 x0.1-0.15 m^3

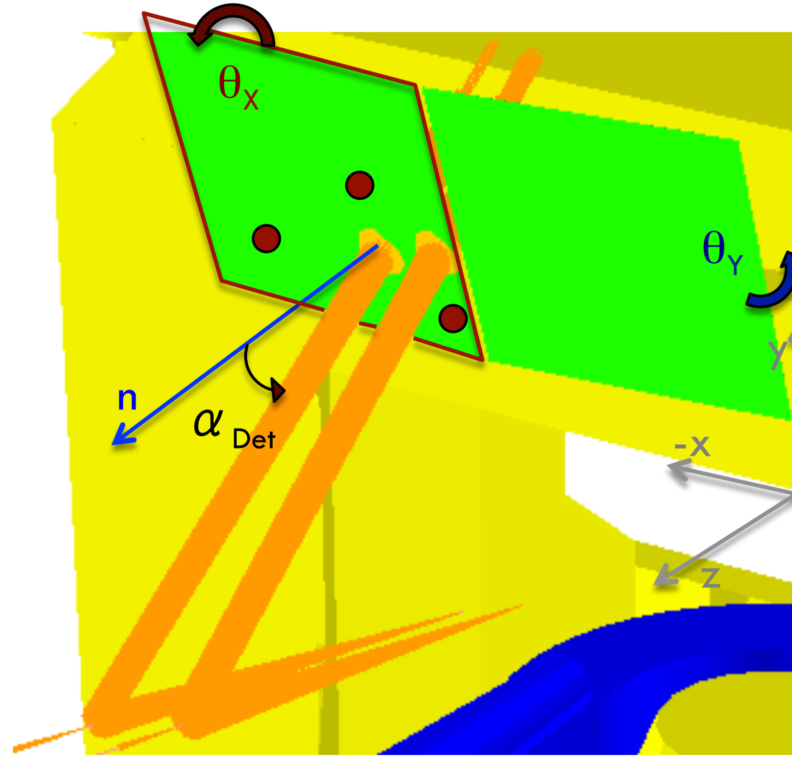


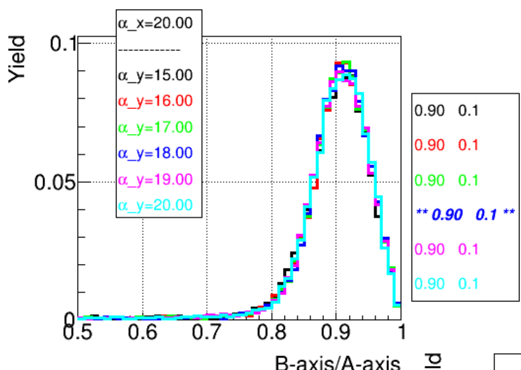
Maximum stray field is 1mT

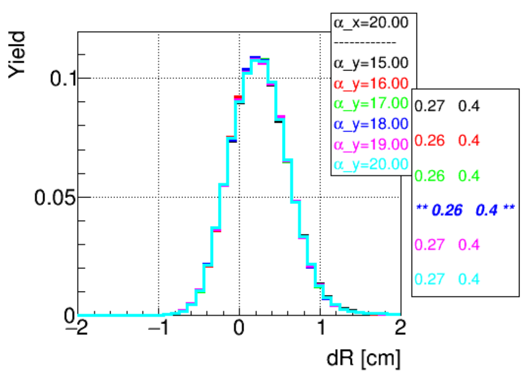
Geometry Optimization

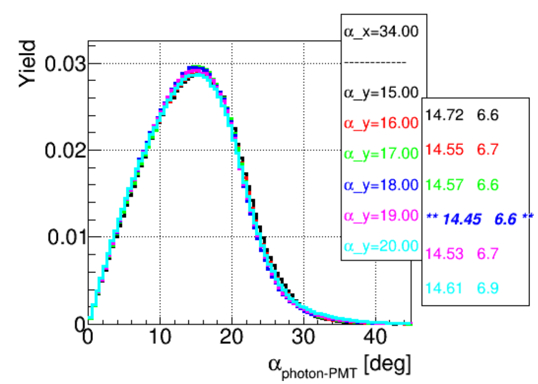
- Rotate PMT plane around x- and y-axis:
  - $0 < \theta_x < 50$ deg. & $0 < \theta_y < 50$ deg.

- Look at: B/A, dR and α (photons incident angle on the PMT plane)

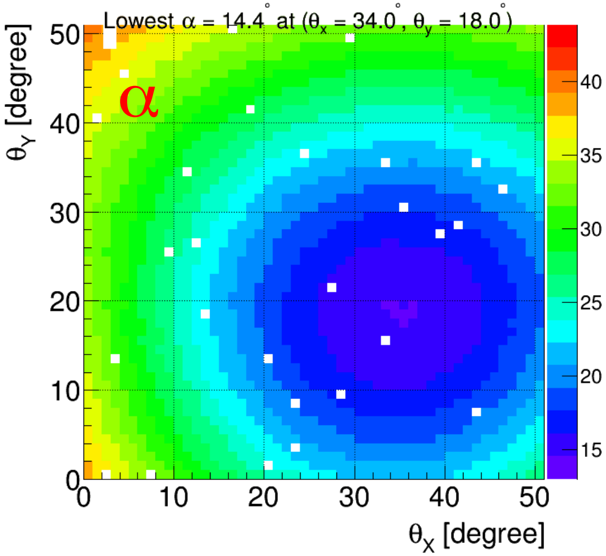


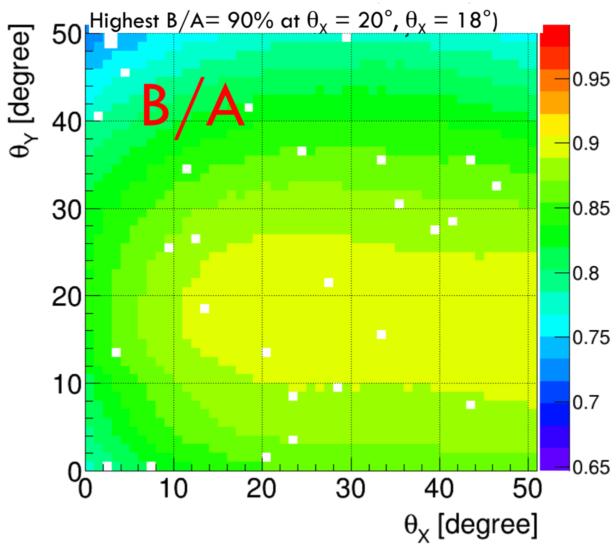


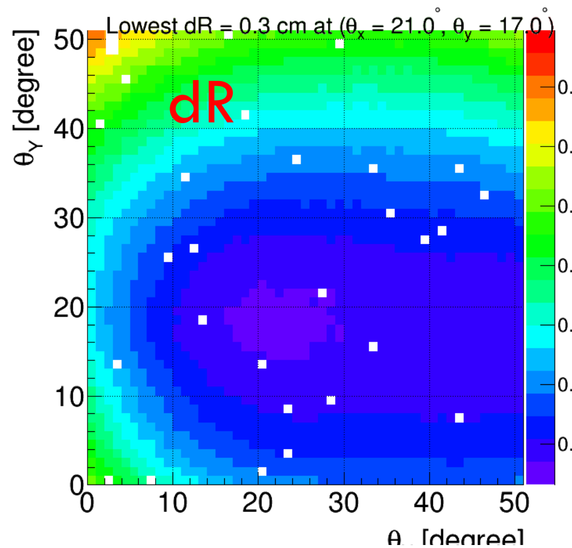




Geometry Optimization

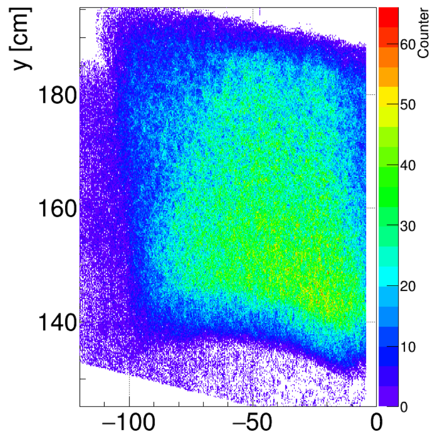






B/A = 0.89, dR = 0.27cm   α = 18.4°, dR = 0.26cm   α = 17.9°, B/A = 0.9

- At the three θ_x-θ_y combinations B/A, α, and dR are almost equal →
- Criteria are the number of PMTs needed and construction efforts →
- We consider $\theta_x = 20°$, $\theta_x = 18°$



Conclusion

- RICH concept was formed and verified.
- Real dimension RICH prototype build and tested.
- TDR approved in 2014.
- Geometry optimization is almost completed.
- Mirror alignment system being developed.
- MAPMTs von Hamamatsu are our candidates as photon detectors. (ordering these days).
- PMTs and WLS will survive the expected radiation during the CBM life time.