THE CBM RICH

RICH COLLABORATION

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OUTLINE

① Motivation & Introduction

i. The CBM Experiment

ii. The RICH Concept

iii. RICH Prototype & Electronics

② Radiation Hardness of the Photon Detector

③ Geometry Optimisation & PMT Shielding Box

④ Mirror & PMT Holding Structure

⑤ Summary

MOTIVATION

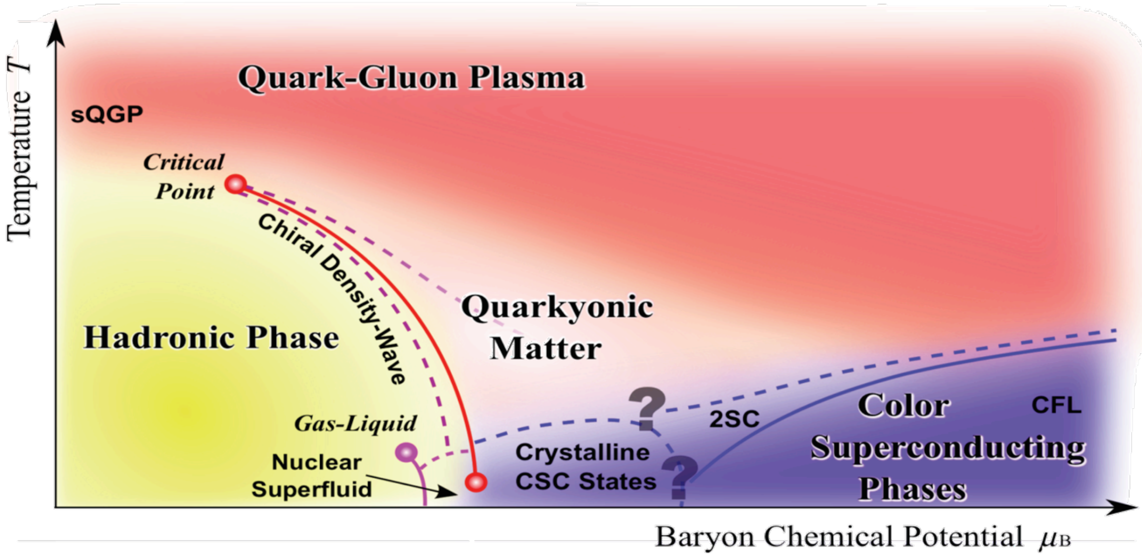
Heavy-Ion Collisions: study the properties of nuclear matter under extreme conditions and map the QCD phase diagram

Different T-μ_B regimes:

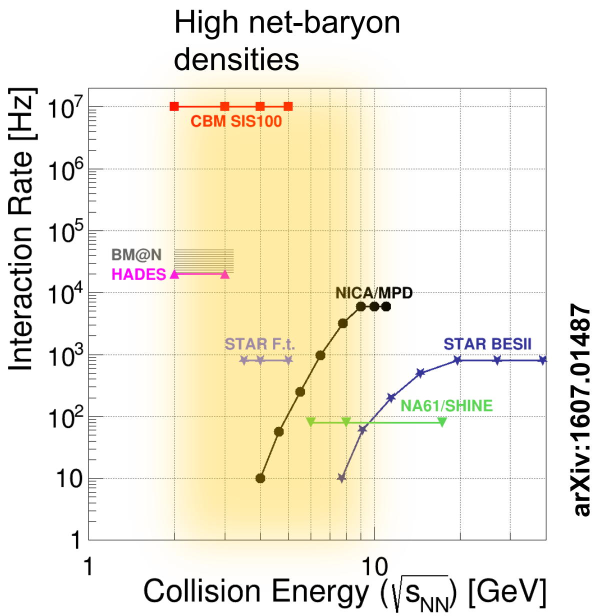
- **High T, low μ_B:** lattice QCD and high quality data RHIC and LHC
- **Low T, high μ_B:** largely unknown structures:

① New phases besides QGP and HG (Quarkyonic)
② Nature of phase transitions
③ Existence and location of CP

→ new experimental campaign in Dubna, RHIC, SPS, J-PARC, and FAIR(**CBM**)

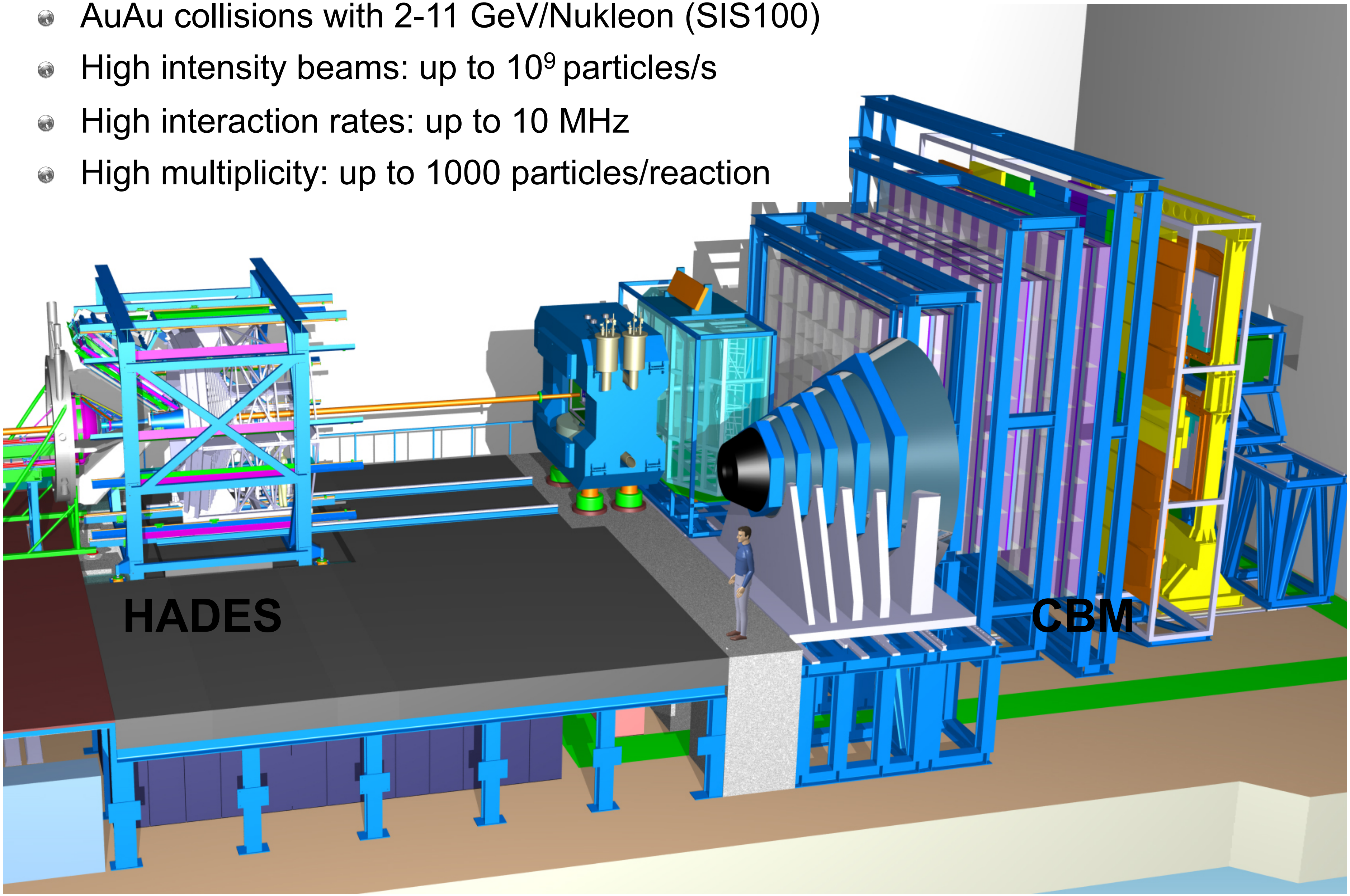


K. Fukusihma and T. Hatsuda, Rept. Prog. Phys. 74 (2011) 014001

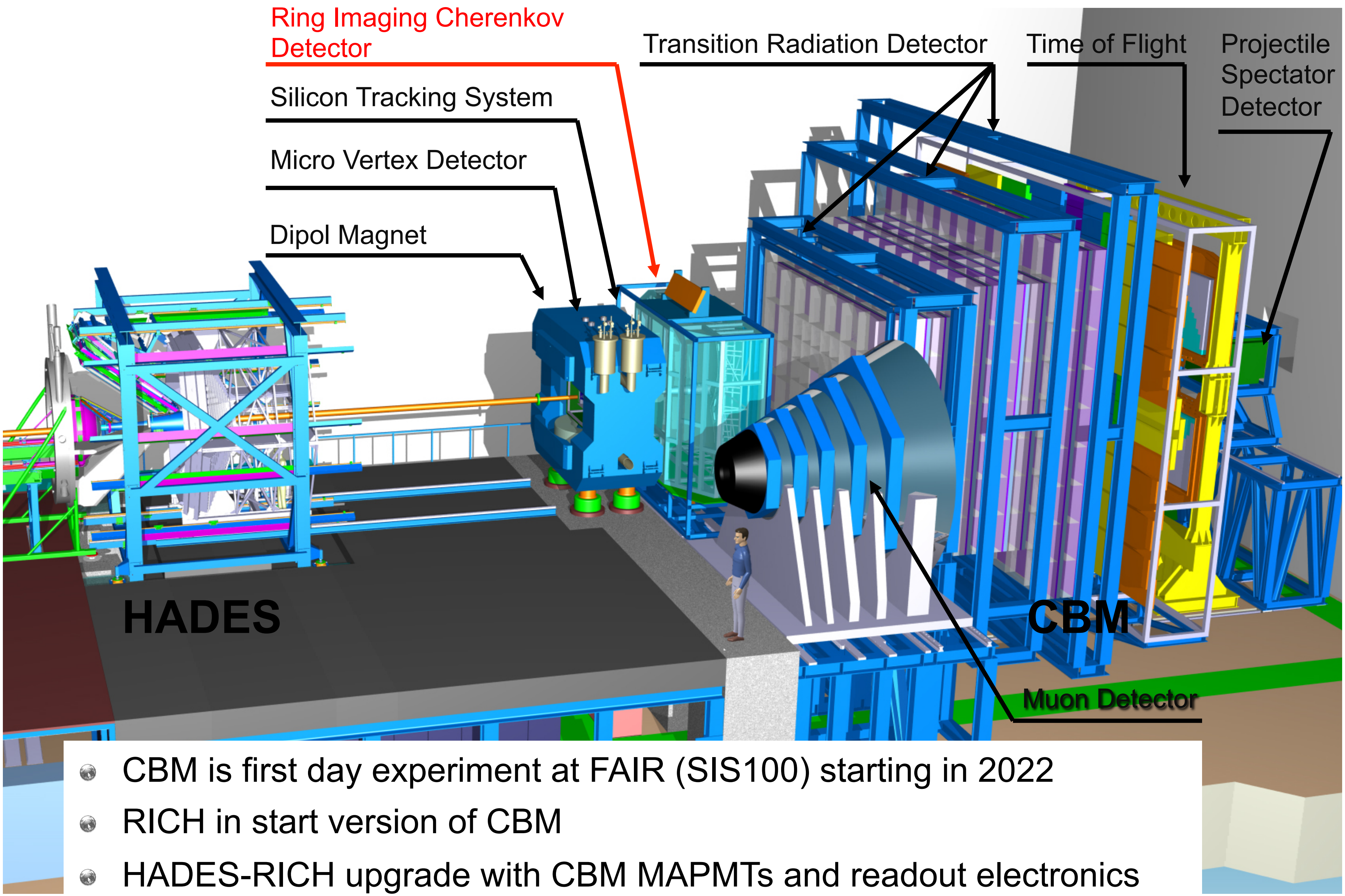


THE CBM EXPERIMENT @ FAIR

- AuAu collisions with 2-11 GeV/Nukleon (SIS100)
- High intensity beams: up to 10^9 particles/s
- High interaction rates: up to 10 MHz
- High multiplicity: up to 1000 particles/reaction



THE CBM EXPERIMENT @ FAIR



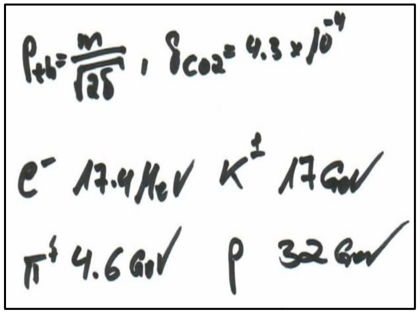
- CBM is first day experiment at FAIR (SIS100) starting in 2022
- RICH in start version of CBM
- HADES-RICH upgrade with CBM MAPMTs and readout electronics

THE RICH CONCEPT

Aim: efficient and clean electron identification for momenta below 8GeV/c

Challenges: ① high rates and high particle density ② located directly behind magnet

Strategy: build a stable, robust and fast detector relying on components from industry



Radiator

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

Mirror

- SIMAX-glass with Al+MgF_2 coverage
- R = 3m, d ≤ 6mm, 11.8 m^2
- 72 tiles of 40×40 cm^2

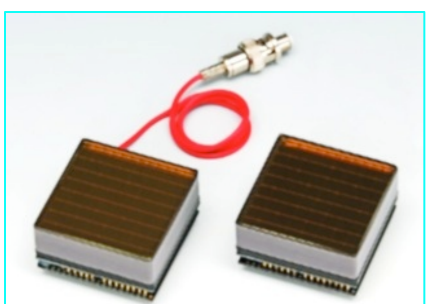
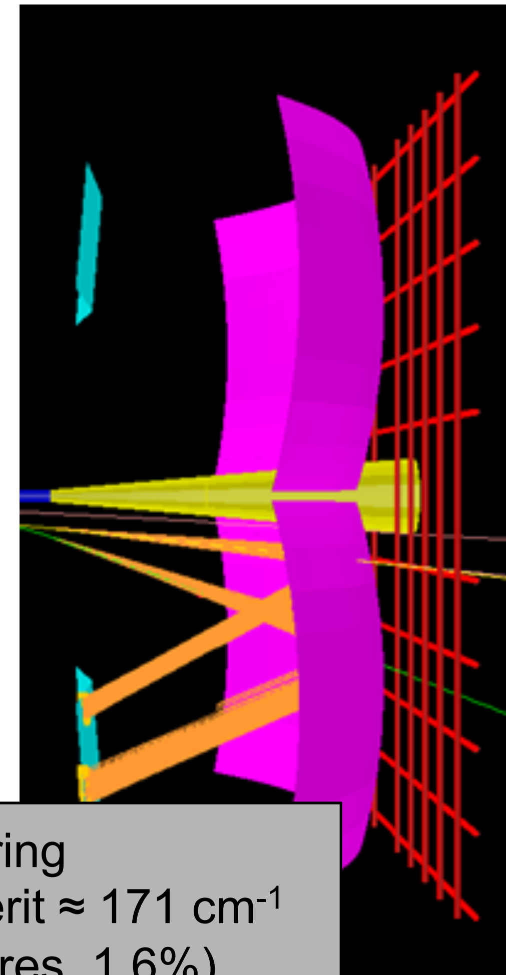


Photo Detector

- 2.4 m^2, 55k Ch.
- MAPMT: H12700 series
- Enhance sensitivity in the UV with WLS

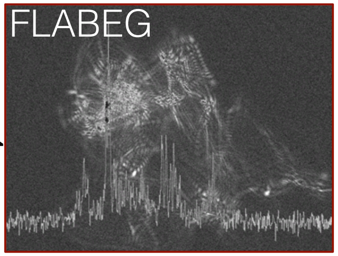


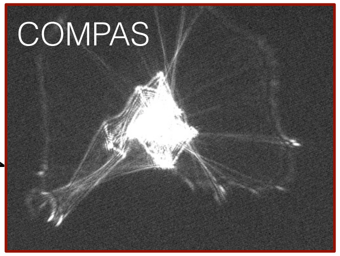
- 28 photons/ring
- Figure of Merit ≈ 171 cm^{-1}
- r_e=4.56 cm (res. 1.6%)

MIRRORS

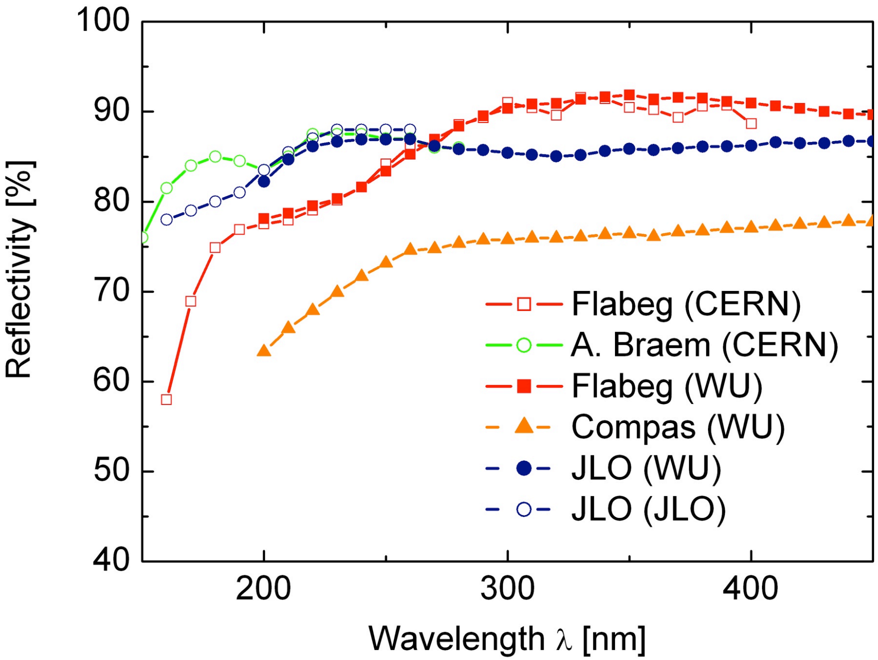
Mirrors from three manufacturers were tested upon surface homogeneity and reflectivity

D_0 is a measure for the surface homogeneity





	required	FLABEG	COMPAS	JLO
D_0 [mm]	≤3	--	2.3	2.3



Best results with JL OLOMOUC

PHOTON DETECTORS (MAPMT)

HAMAMATSU: Multi-anode Photomultiplier Tubes (MAPMT)

① **H10966**: 8-dyn., SBA photo cathode — good QE but bad single photon response

② **R11265**: 12-dyn., SBA photo cathode — best results but small & expensive

③ **H8500**: 12-dyn., BA photo cathode — best choice

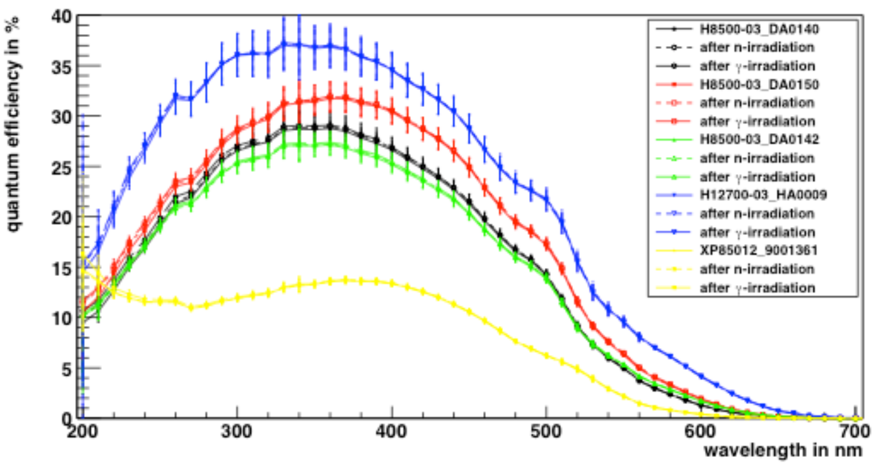
④ **H12700**:

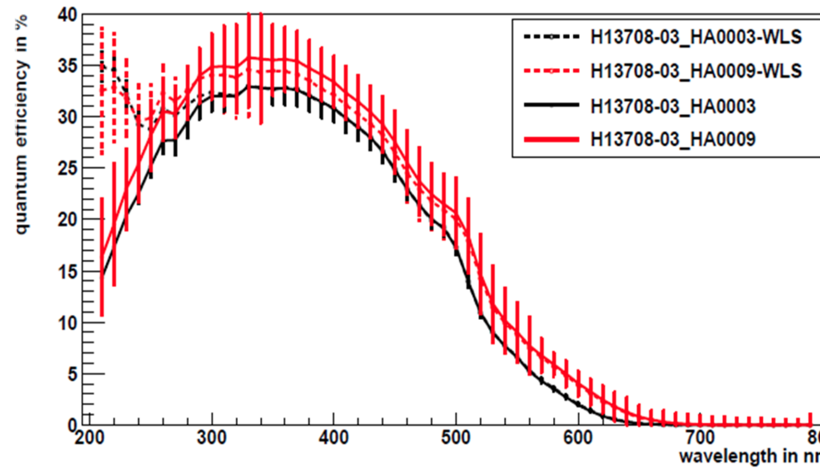
- 10-dyn.., dyn. system as in R11265,
- geometry of H8500,
- *advanced* BA photo cathode

- 1100 pcs ordered in Sept 2015
- Up to now about 500 pcs delivered

- Pixel resolution
- Single photon response
- Noise
- Quantum efficiency w/ & w/o WaveLength-Shifting films

WLS: NIM A 783 (2015) 43-50





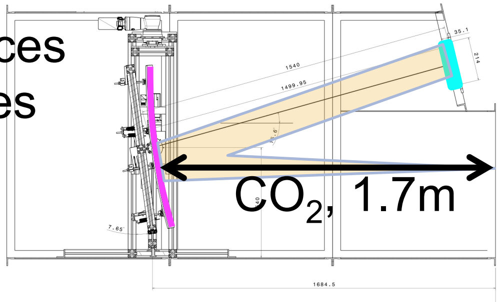
PHOTONIS (XP85012): Micro Channel Plate (MCP)

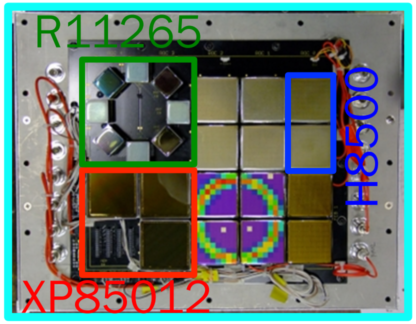
Poster: J. Förtsch (B4)

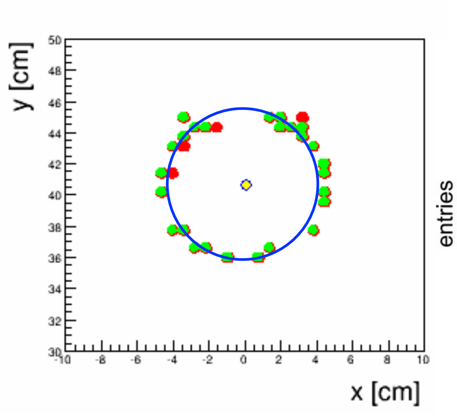
THE RICH PROTOTYPE

Laterally scaled prototype: Modules have the same dimensions and properties as foreseen in the RICH concept.

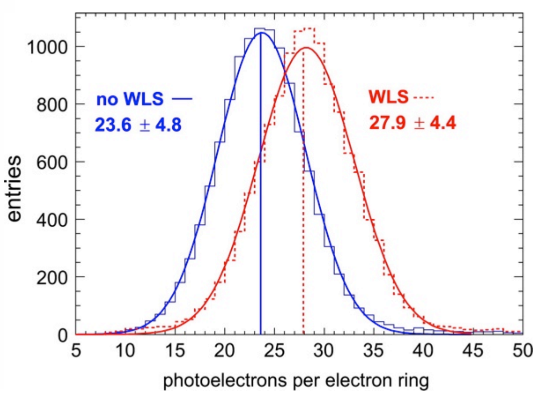
① Verified RICH concept & gained experiences
② Determined components & fixed tolerances
③ Tested software and gas system
④ Test of electronics and DAQ



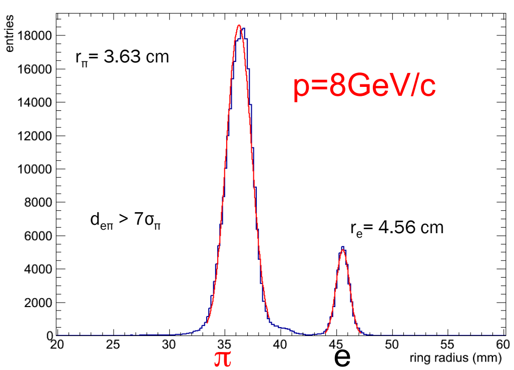


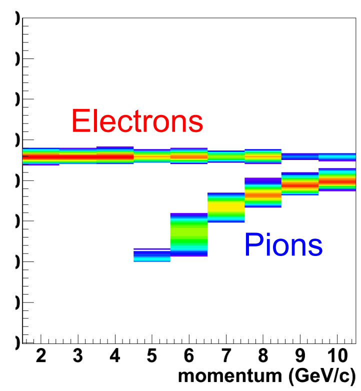


Single (fitted) ring



# of hits per ring





ring radius

Poster: S. Lebedev (A25)

Poster: E. Ovcharenko (A11)

Pion suppression factor = 3500 @ p=8 GeV/c

CONCEPT APPROVED

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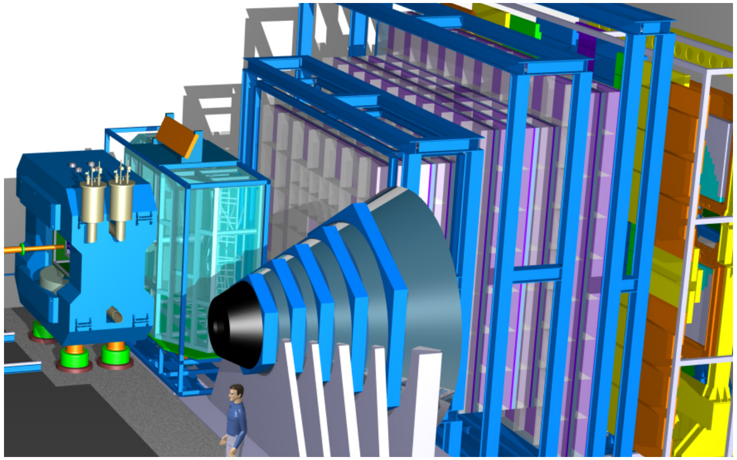


Besides electronics …
Three issues kept open:

RICH is located …

① not far from IP → high radiation environment
→ Test PMTs upon radiation hardness

② directly behind the magnet → stray field
→ re-optimise geometry to escape the field influence; shielding box

③ in front of other sub-detectors (TRD, TOF)
→ Holding structure with low radiation length

Compressed Baryonic Matter Experiment

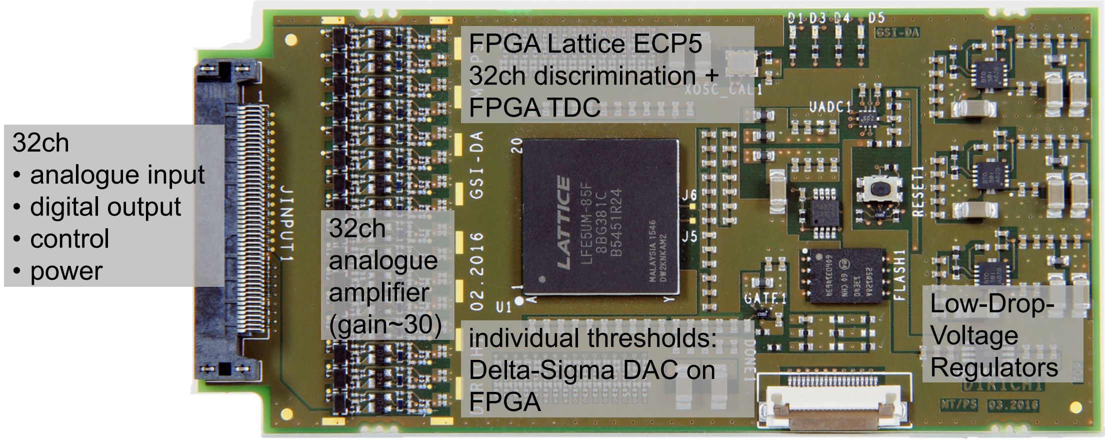
Technical Design Report for the CBM

Ring Imaging Cherenkov (RICH) Detector

The CBM Collaboration

April 2013

READOUT CONCEPT



DiRICH:

- Combined development between PANDA, HADES, and CBM
- FPGA-TDC readout based on HADES TRB3 board
- Excellent time resolution: limits by sensor
- Limited amplitude information via Time-over-Threshold

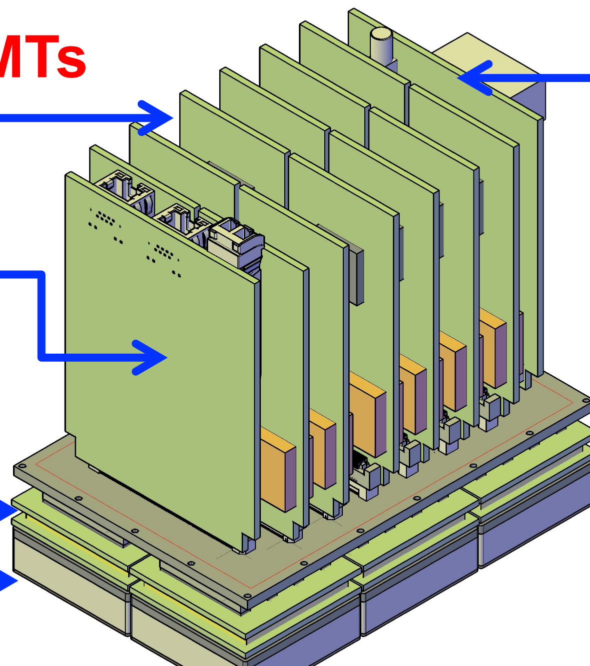
Modules with 2x3 PMTs

12x DiRICH

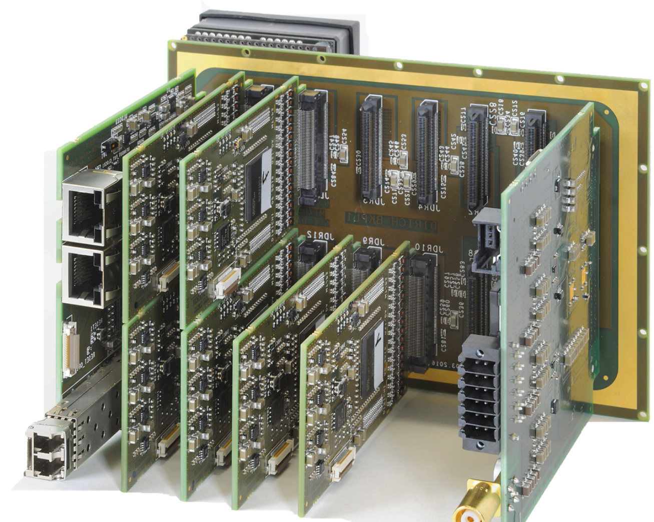
Data combiner module

Backplane

6x H12700 MAPMTS



Power module

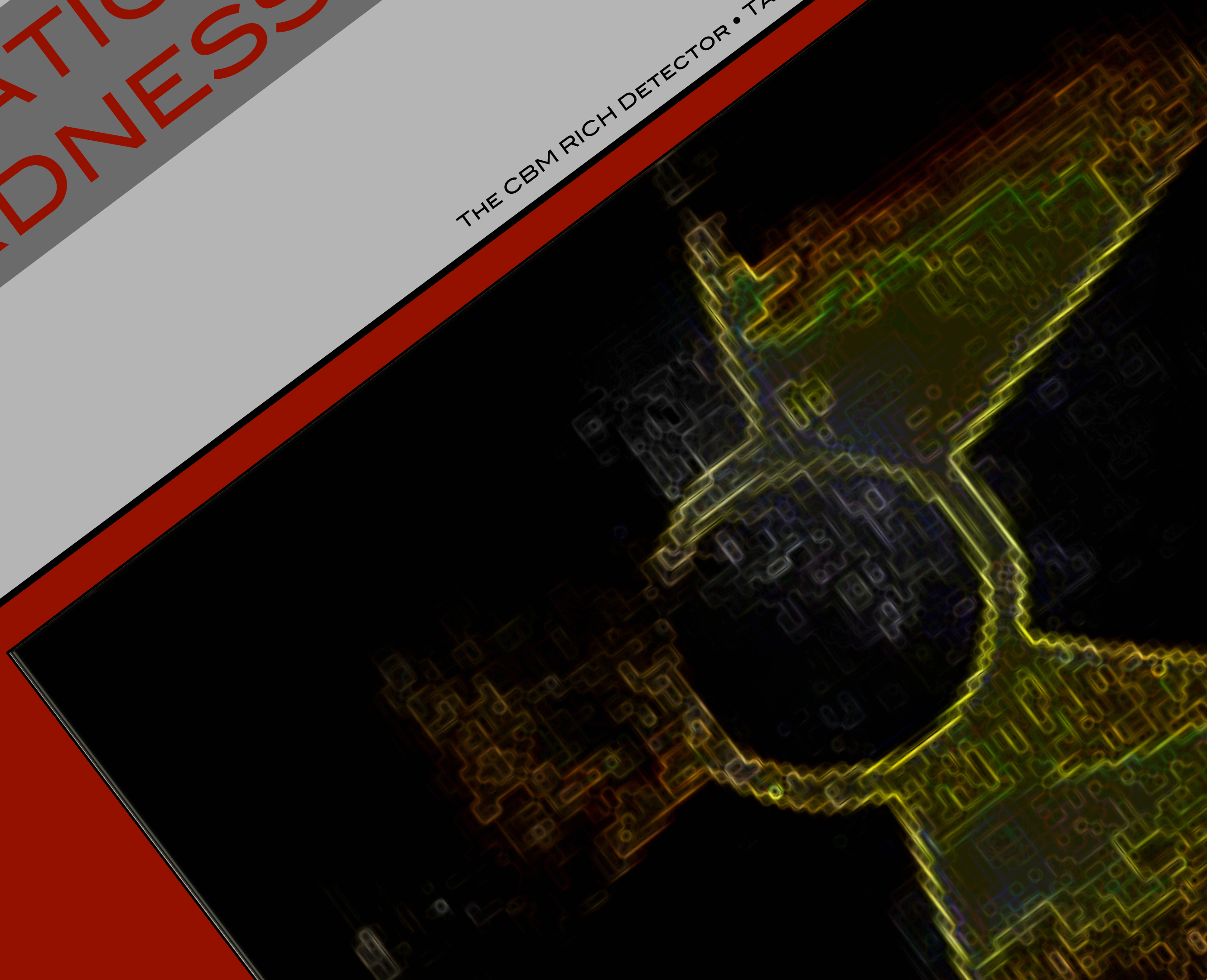


Photos: G. Otto (GSI)

PMTS and readout will be operated in upgraded HADES RICH starting 2018

Poster: C. Pauly (A19)

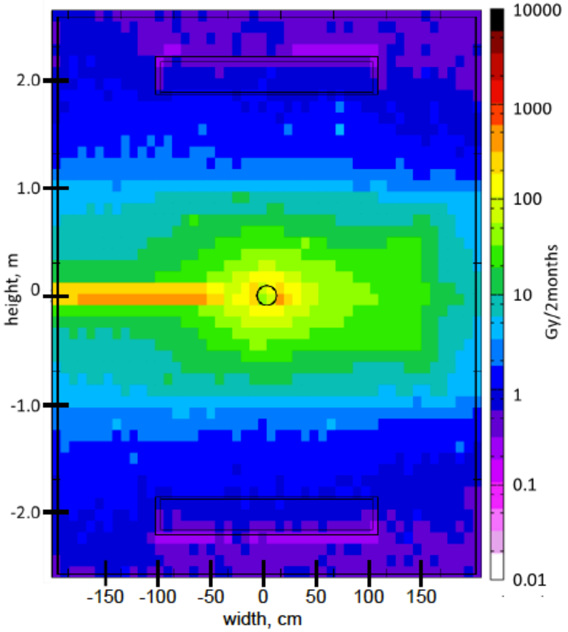
RADIATION HARDNESS



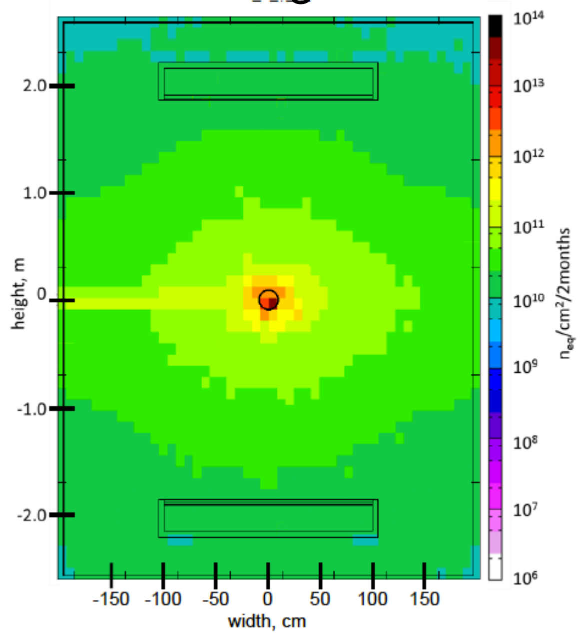
RADIATION DOSE AT PMT VICINITY

Simulations with FLUKA

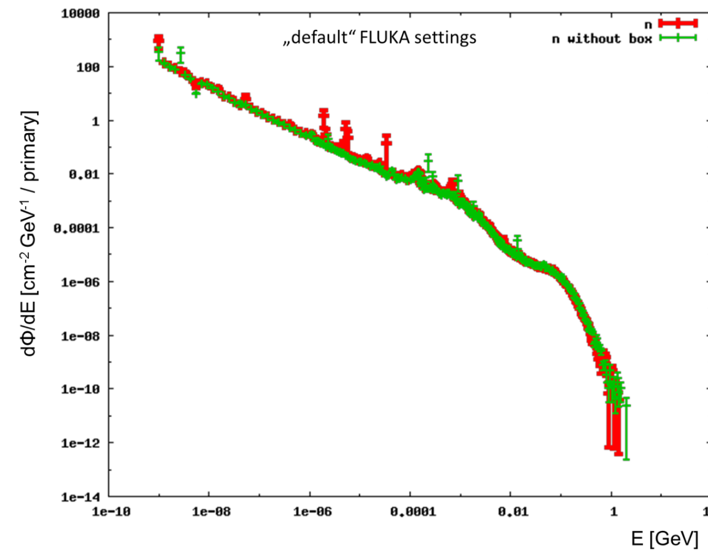
Ionising radiation



Non-ionising radiation



Mainly thermal neutrons are expected



Expected dose rate at PMT plane

per 2 months operation at maximum intensity …

with 35 AGeV AuAu collisions:

IR ~5 Gy

NIR ~5×10^{10} n_{eq}/ cm² (mainly thermal neutrons)

PMT sensors should survive **1×10^{12} n_{eq} / cm²** and **100 Gy**

(CBM life time: dose rate about 20x higher)

POTENTIAL DAMAGE

PMT component	Effect
PMT entrance window	loss of transmittance → loss of hits
WLS	change of structure → loss of hits
Whole PMT	activation of material (ca. 70% kovar) → higher dark rate, lower QE, loss of gain and detection efficiency

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

Irradiate samples and compare results before and after irradiation

SAMPLES & DOSES

None ionizing radiation: TRIGA nuclear reactor, Jozef Stefan Institute, Ljubljana: high flux of thermal neutrons

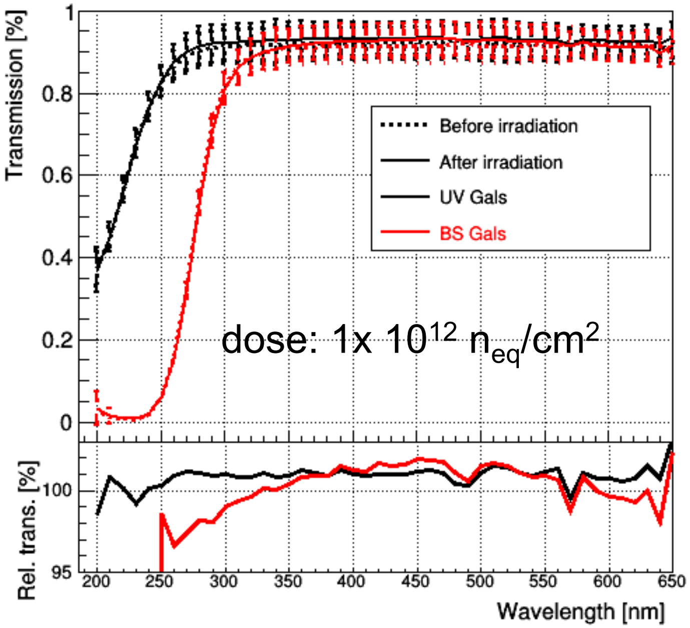
Ionizing radiation: ^{60}Co source, *Strahlenzentrum* Giessen: gammas of 1.2 MeV-1.3 MeV

Sample	Neutron dose $[n_{eq}/cm^2]$	Gamma dose [Gy]
BS-window 1	$1x\ 10^{12}$	
UV-window 1	$1x\ 10^{12}$	
BS-window 2	---	20-32000
UV-window 2	---	20- 32000
Quartz with WLS 1	$(1\text{-}3)\ x\ 10^{11}$	---
Quartz with WLS 2	---	~ 50 & 100
H12700	$3x\ 10^{11}$	145,7
H8500-D	$1x\ 10^{11}$	45,8
H8500-D	$3x\ 10^{10}$	12,5
H8500-D	$1x\ 10^{10}$	
MCP	$1x\ 10^{11}$	145,7

ENTRANCE WINDOW

Measured transmittance of BS and UV glass samples before and after irradiation

- For both samples the most noticeable loss of transmittance occurs in the UV region
- The reduction is more pronounced for the BS sample



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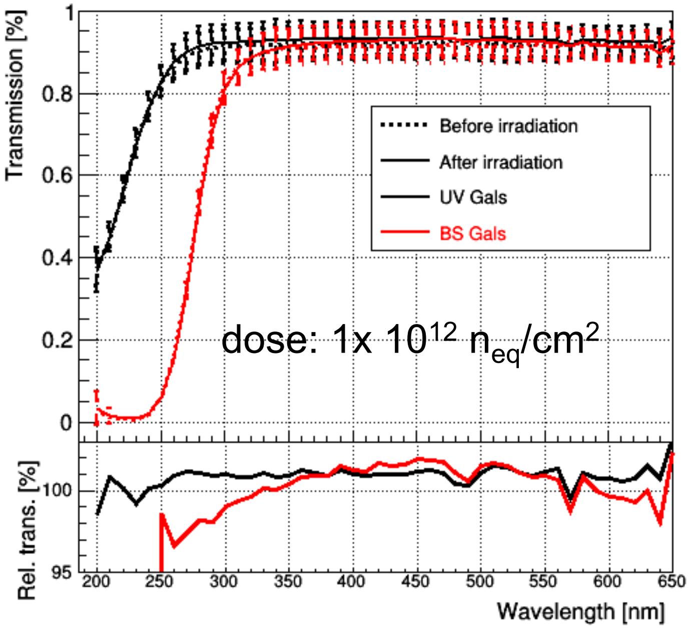

Neutron irradiation
None of the samples is affected with neutron irradiation up to 1x 10^{12} n_{eq}/cm^2

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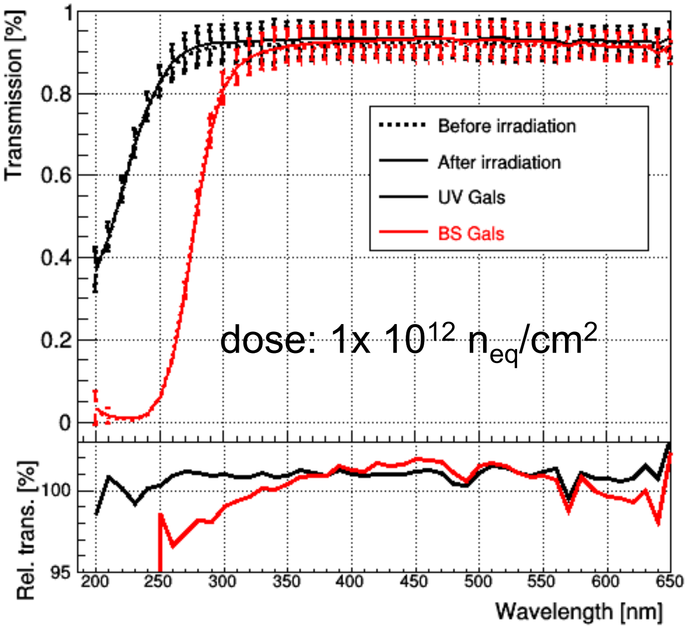
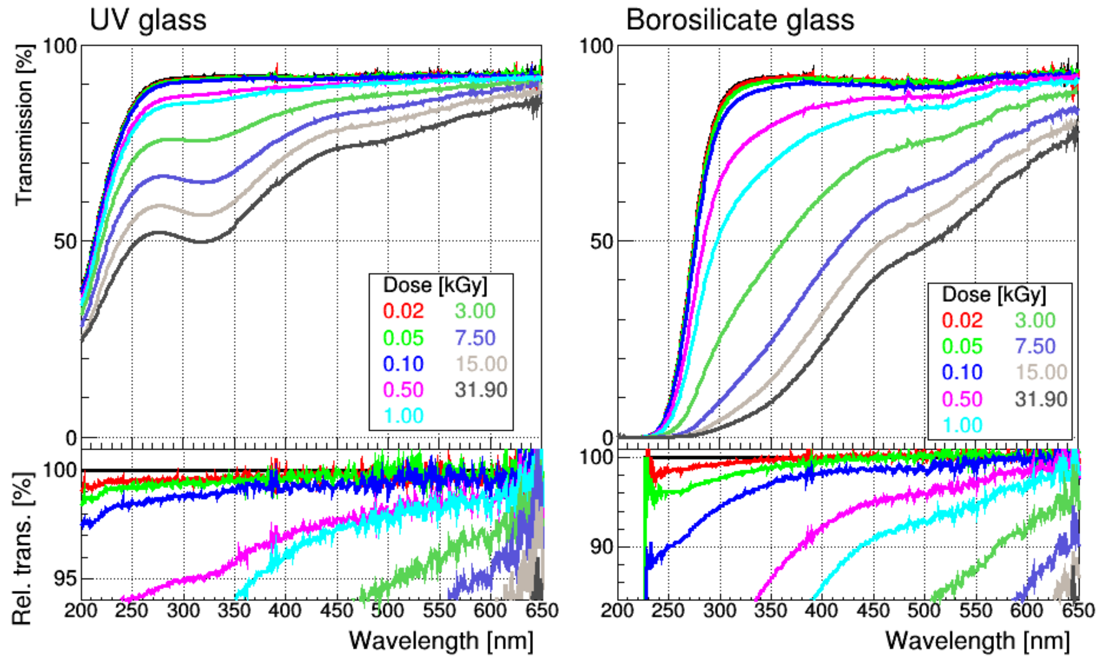




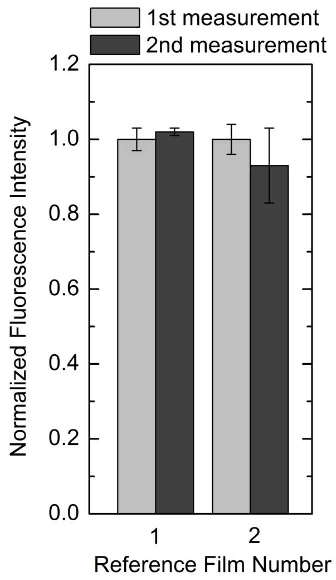
Neutron irradiation

None of the samples is affected with neutron irradiation up to $1\times 10^{12}\ n_{eq}/cm^2$

Gamma irradiation

- After 100 Gy the UV window loses less than 3% of its transparency (200nm)
- After irradiation of 3 kGy the UV glass loses only 16% of its transparency but the BS glass is opaque

WAVELENGTH SHIFTING FILM



Without radiation:

Up to **10% fluctuation** between different measurements with the same sample

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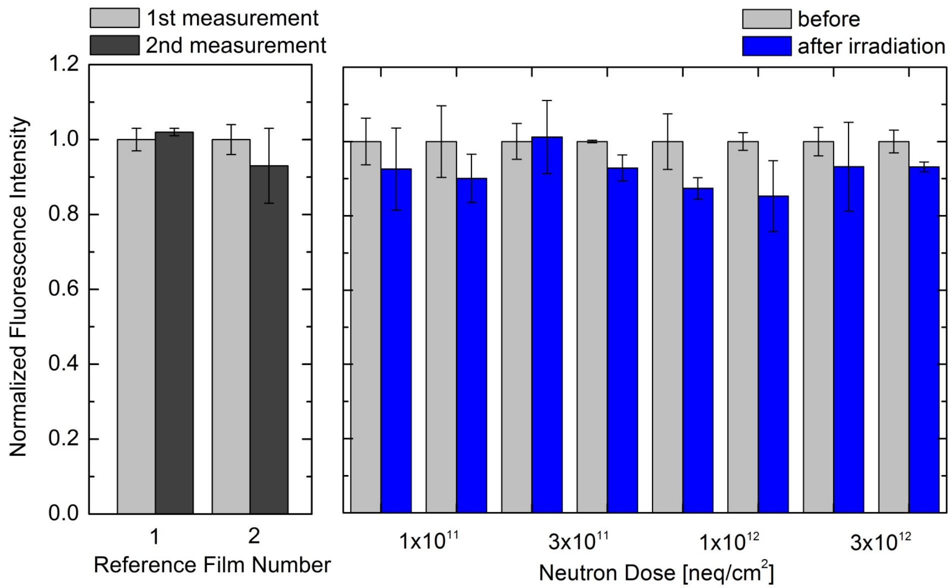

Without radiation:

Up to **10% fluctuation** between different measurements with the same sample

Neutron irradiation (four doses):

- Up to 10% fluctuation between irradiated and non-irradiated samples
- No dependence on irradiation dose

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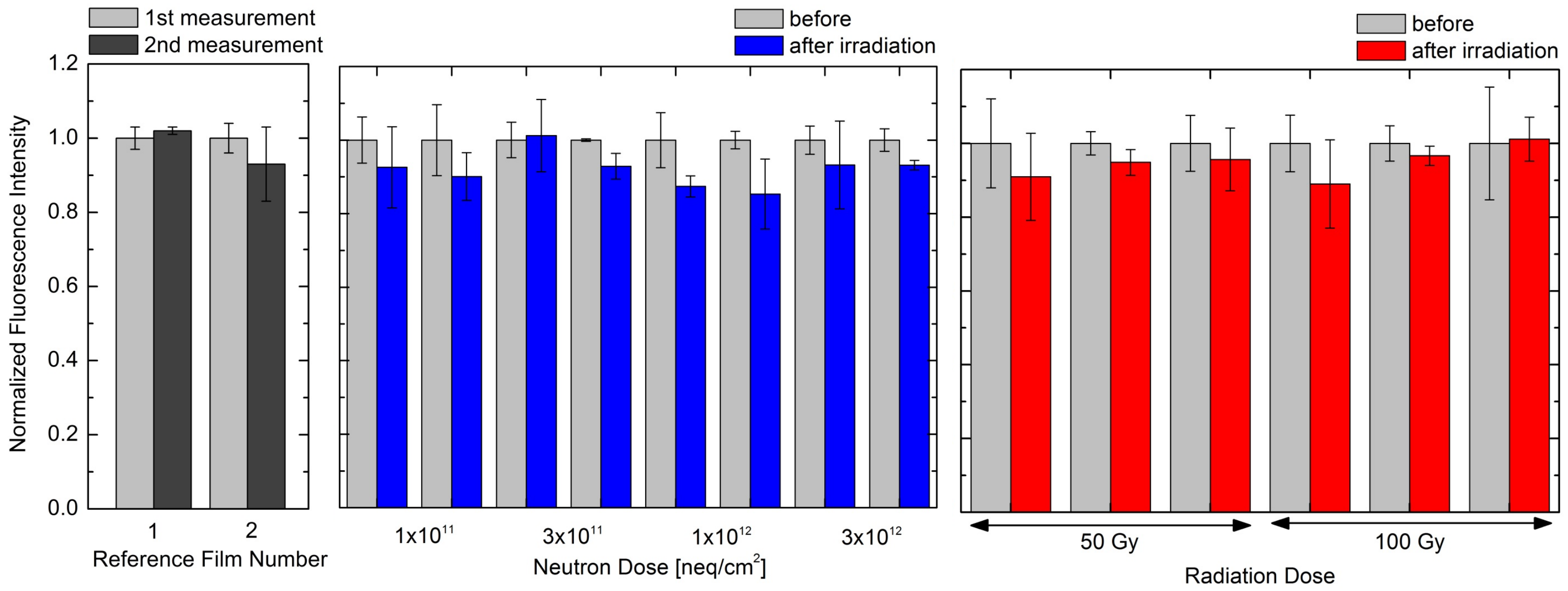


Without radiation:

Up to **10% fluctuation** between different measurements with the same sample

Neutron irradiation (four doses):

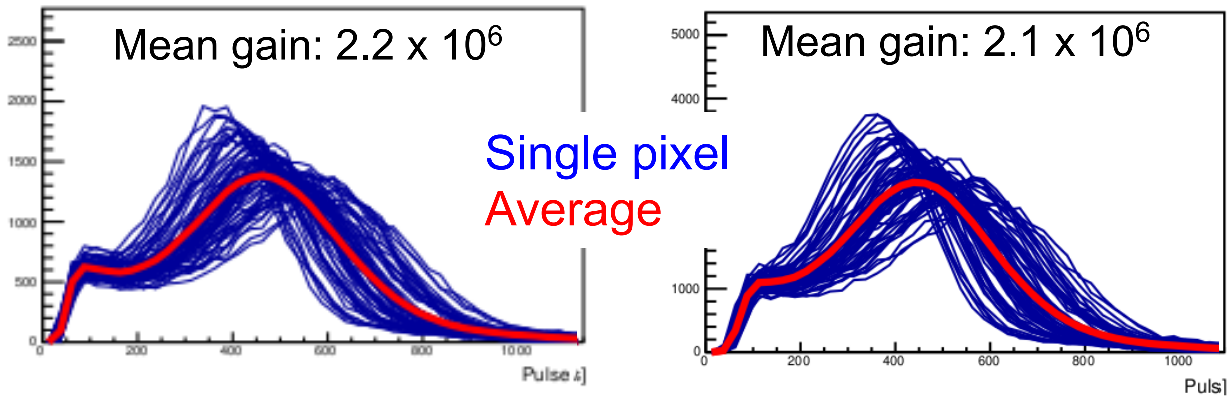
- Up to 10% fluctuation between irradiated and non-irradiated samples
- No dependence on irradiation dose

Gamma irradiation (two doses)

- Up to 10% fluctuation between irradiated and non-irradiated samples
- No dependence on irradiation dose

SING. PH. SPECTRA & DETEC. EFFICIENCY

Before irradiation | **After n-and γ-irradiation**



H12700

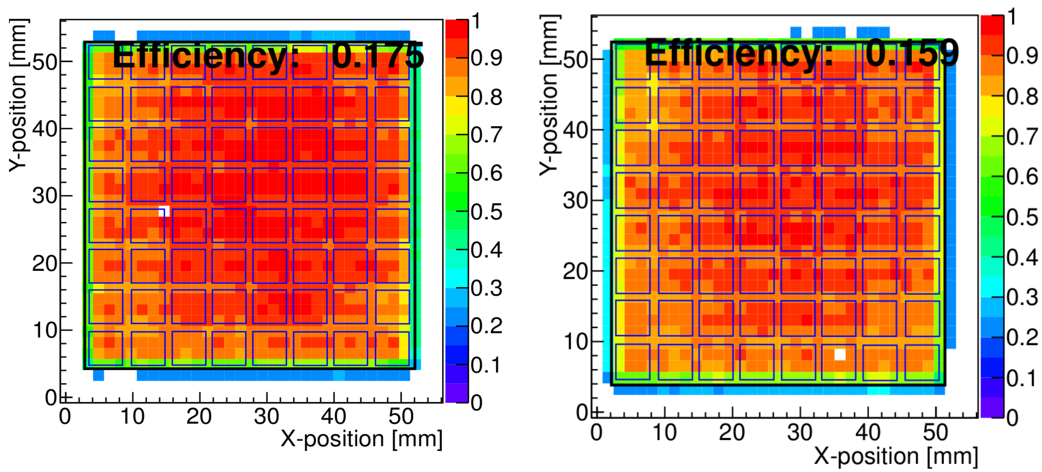
n-dose=3x 10^{11} n_{eq}/cm^2
gamma-dose = 145,7Gy

Single photon spectra:

- Neither the n- nor the gamma-irradiation affects the single photon spectrum
- Sensors survive: $1x10^{12}$ n_{eq}/cm^2 and 100 Gy

Single photon detection efficiency:

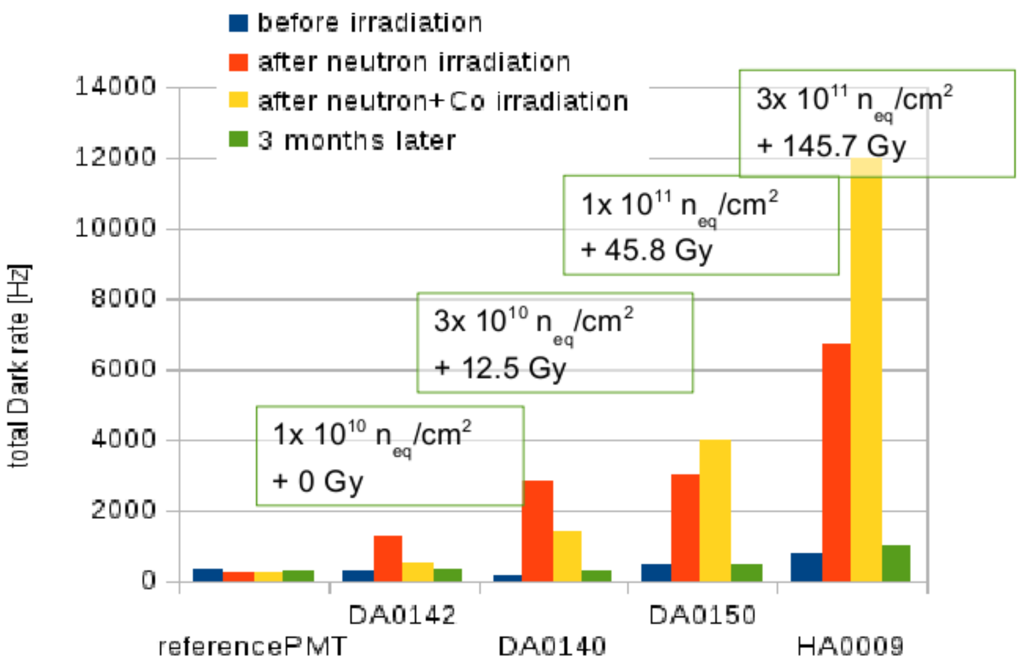
- No effect from n-irradiation
- About 6% loss of efficiency by gamma-irradiation. *Probably* caused by the UV window



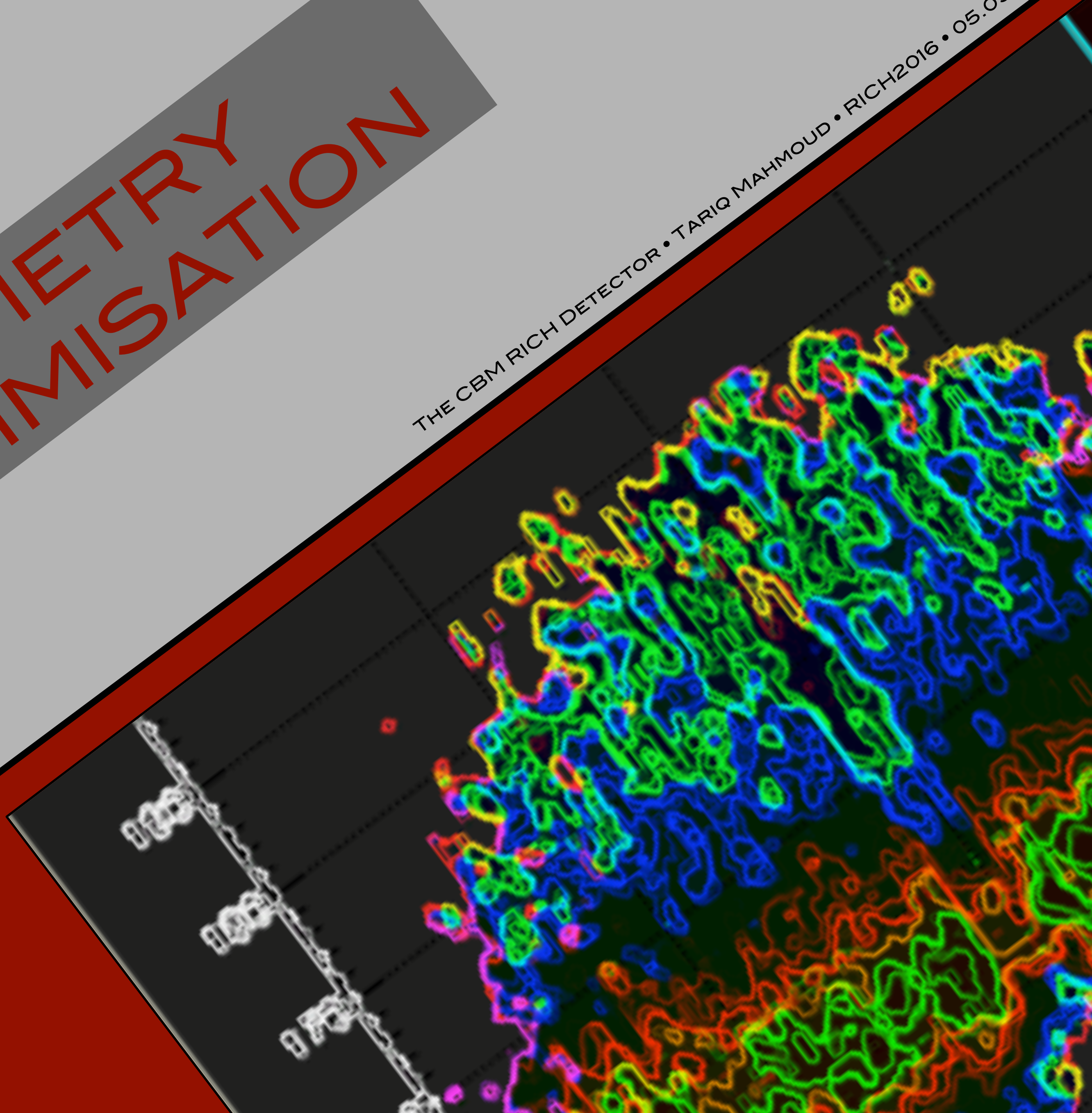
GAMMA SPECTROSCOPY

Gamma spectroscopy results measured **24h after irradiation**: **H8500**

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



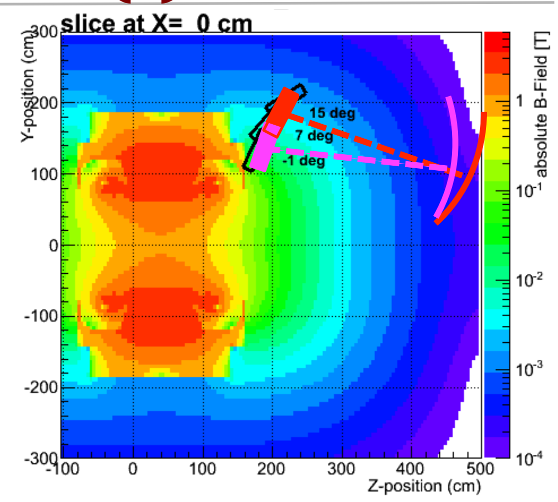
GEOMETRY OPTIMISATION



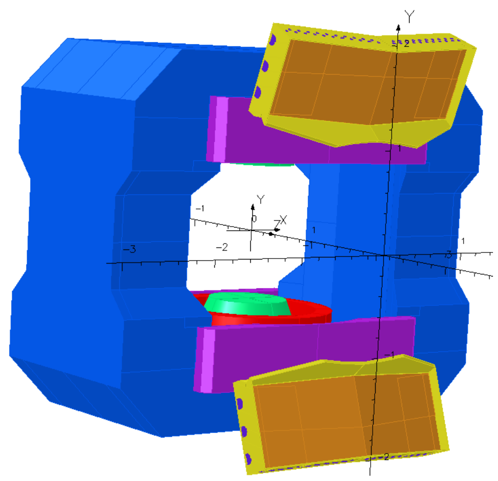
GEOMETRY OPTIMISATION (I)

① Stray field at the PMT position is about 100mT!

② Rotation of the mirrors by 10° outwards and …



Position optimisation



③ Shielding the PMT plane with steal

GEOMETRY OPTIMISATION (I)

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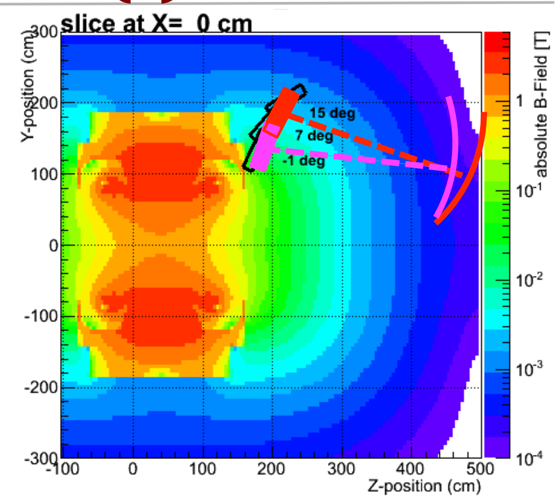
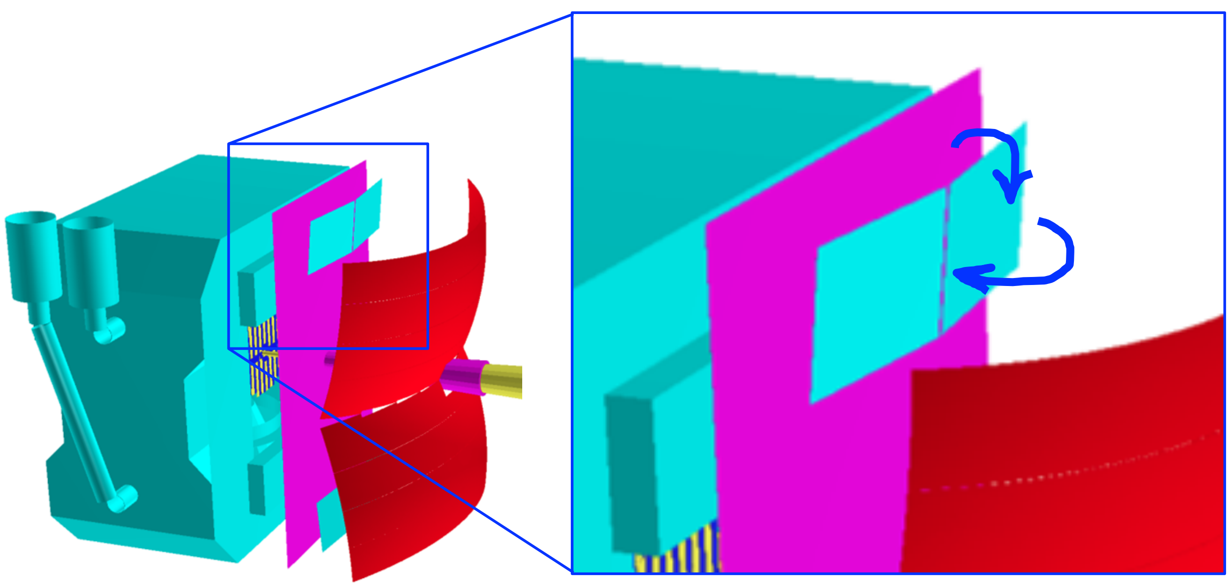


- Optimisation of position and dimensions of the PMT-plane
- Segmentation of the PMT-plane to cope with the electronics concept within the CBM acceptance →

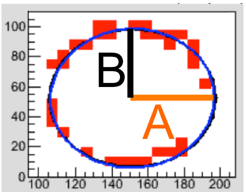
7 x 7 modules (14 x 21 MPTs → 742 mm x 1113 mm)



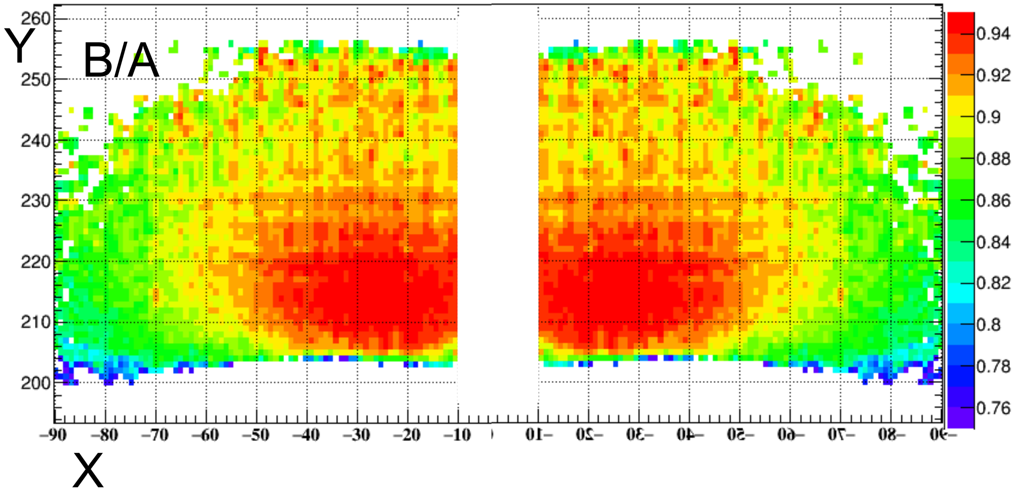
- In a first step for a two-wings geometry
- In a second step for a curved geometry

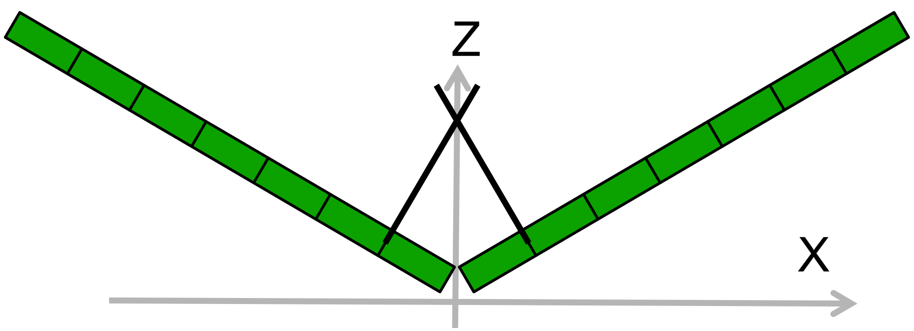
GEOMETRY OPTIMISATION (II)

Best position in space is that with the highest resolution of an elliptic fit upon the rings and the highest B/A



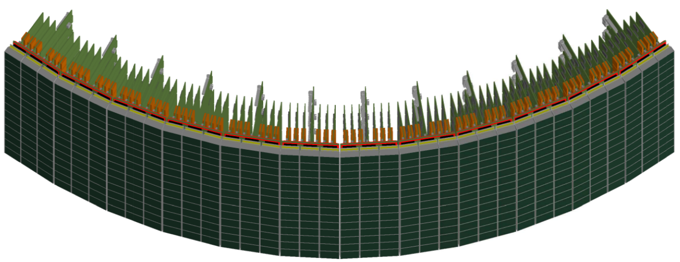
① Two wing geometry





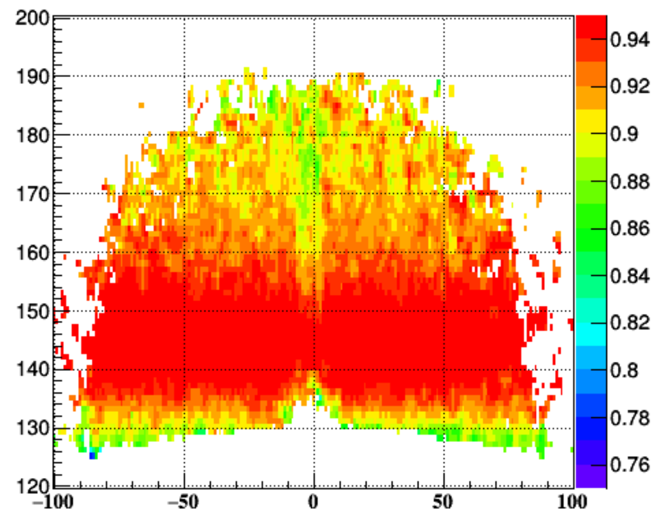
Loss of efficiency

② Curved geometry



BoA: $\Delta_y = 0$, $\Delta_z = -20$, $\theta_x = 18$, $r_y = 1650$

Aa = 0.36, Ba = 0.36, BoA = 0.93, dR = 0.28, Eff = 92.86,



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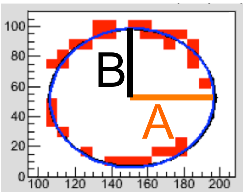
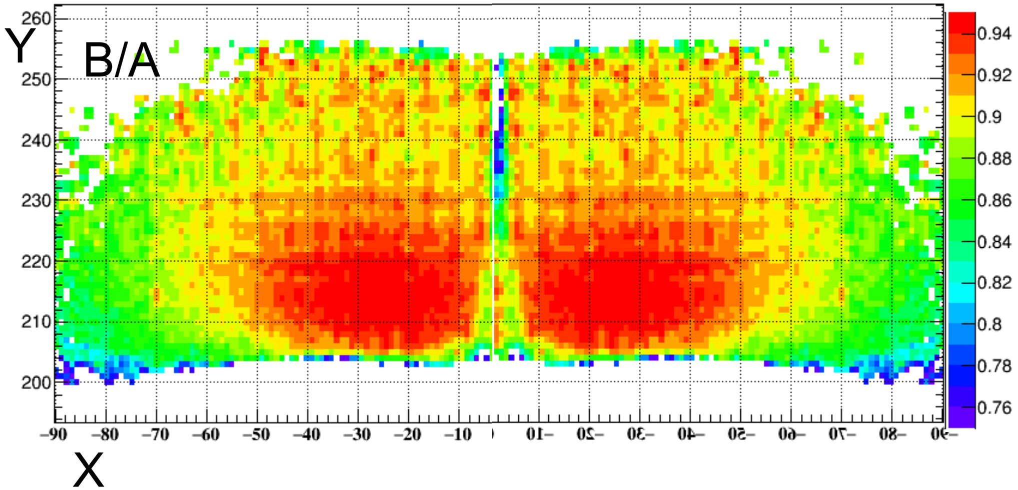
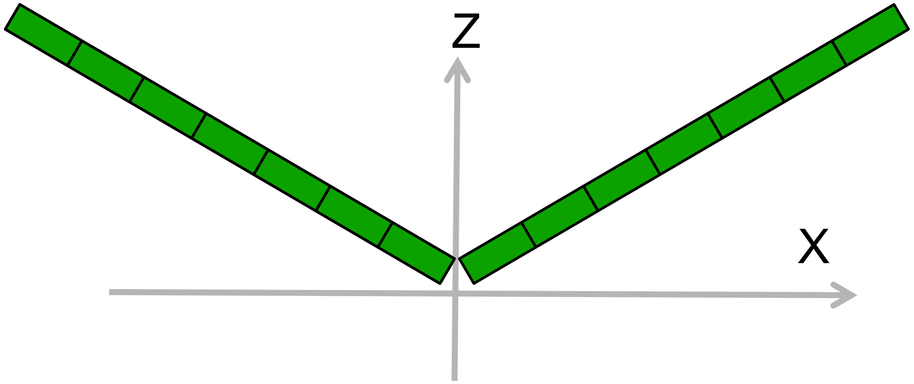


① **Two wing geometry**





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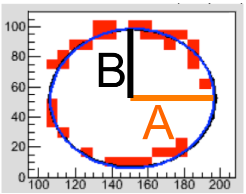

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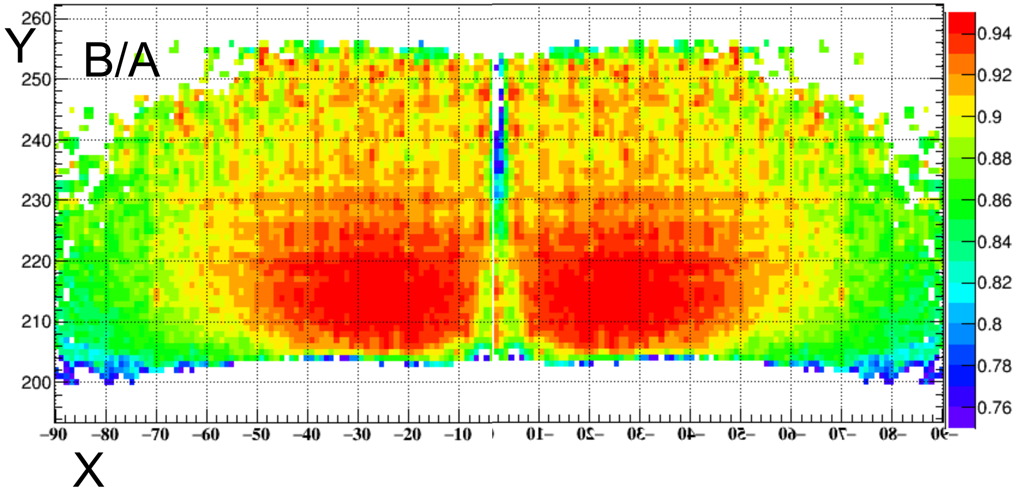

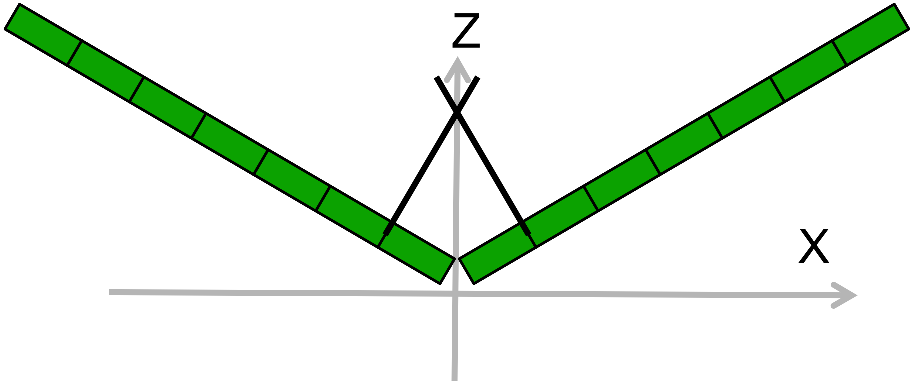

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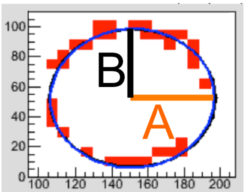

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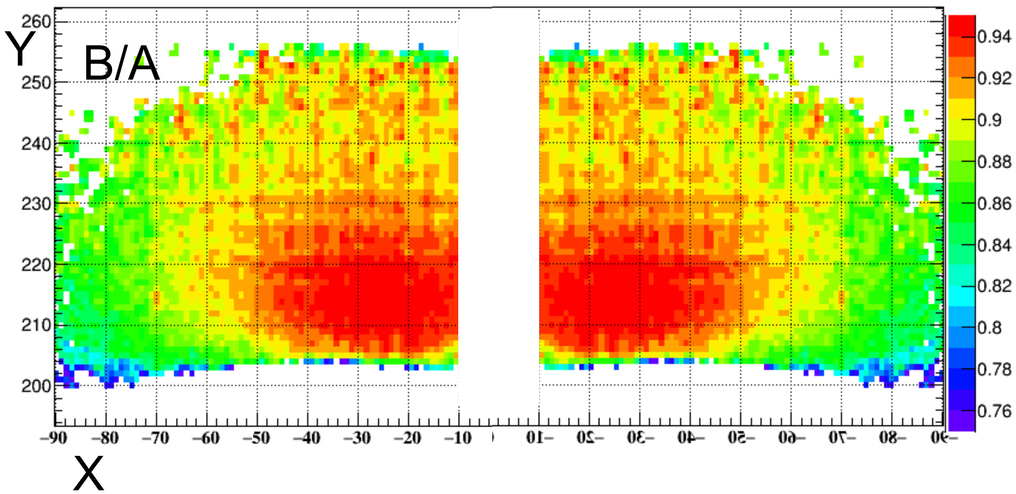
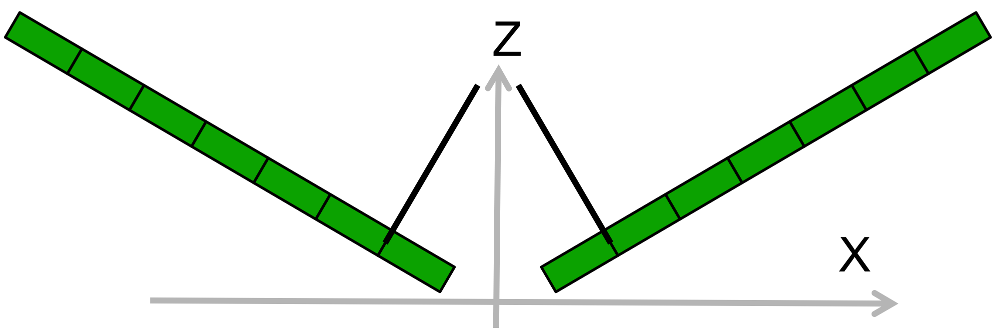
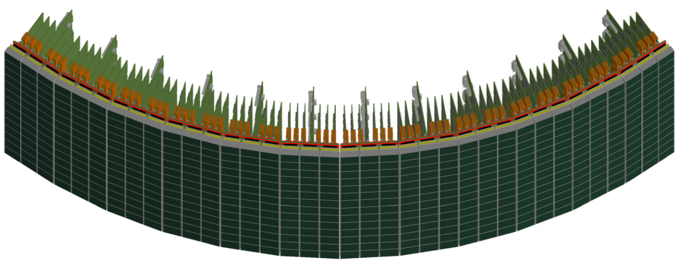




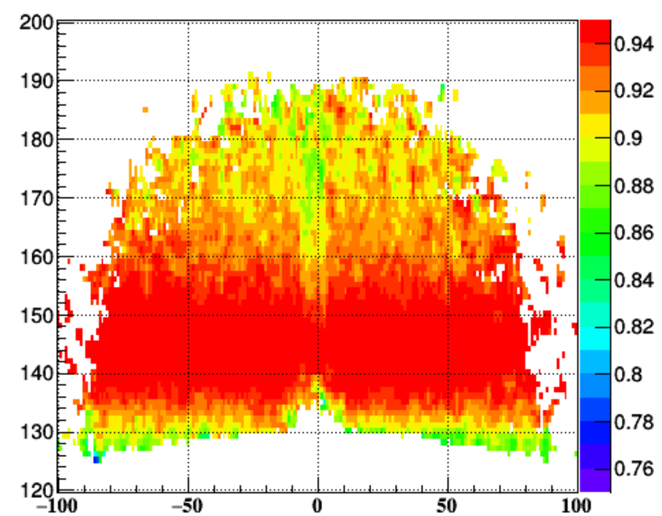
Loss of efficiency

② Curved geometry

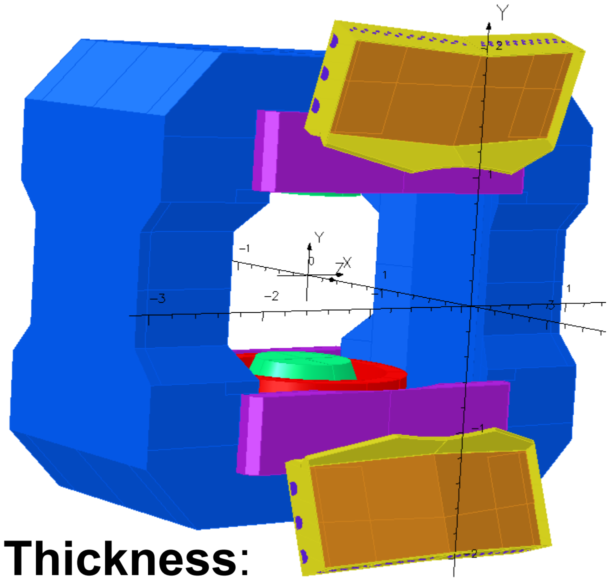


BoA: $\Delta_y = 0$, $\Delta_z = -20$, $\theta_x = 18$, $r_y = 1650$

Aa = 0.36, Ba = 0.36, BoA = 0.93, dR = 0.28, Eff = 92.86,



SHIELDING BOX



Thickness:

back & inner side: 3 cm

inner side extension: 3.5 cm

right, left, and outer sides: 1 cm

Volume:

V = 0.1087 m^3 → weight=850 kg

Holes on:

right and left sides for services

outer sides for cooling

Space to PMT-plane:

right, left, and outer sides: 5 cm

inner side: 2 cm

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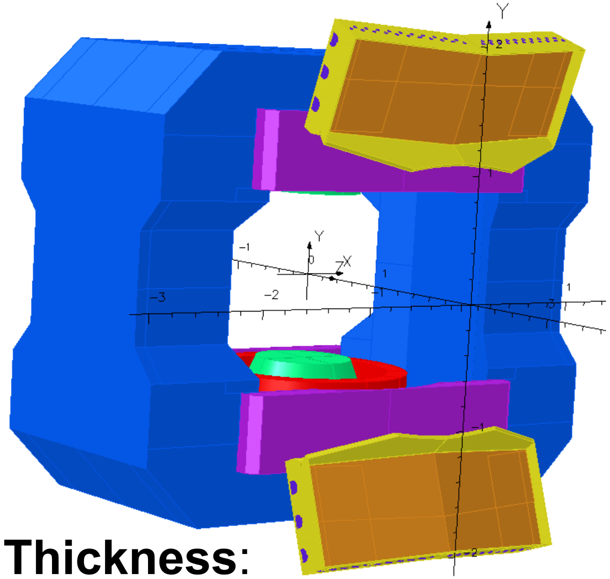

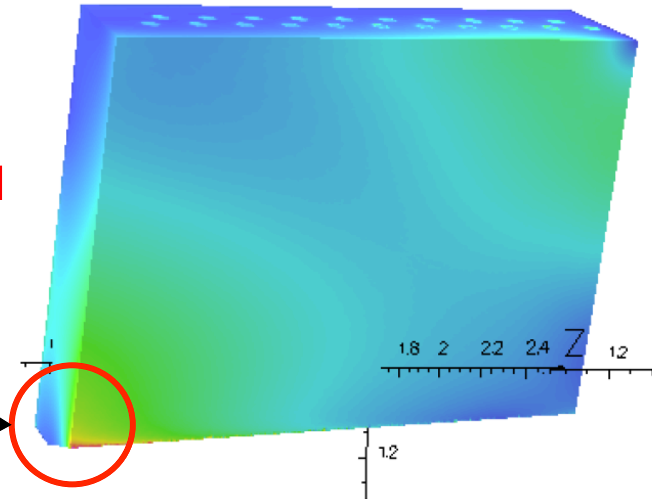

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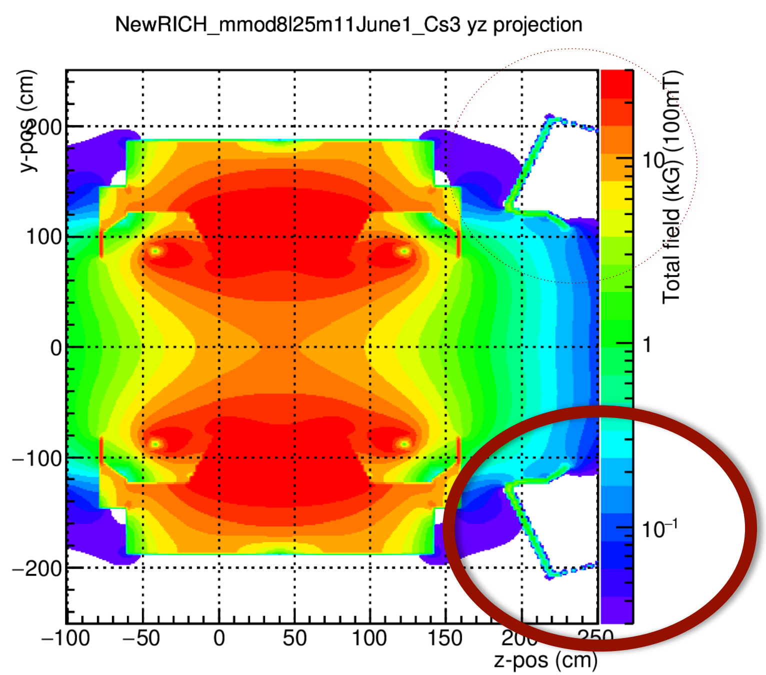
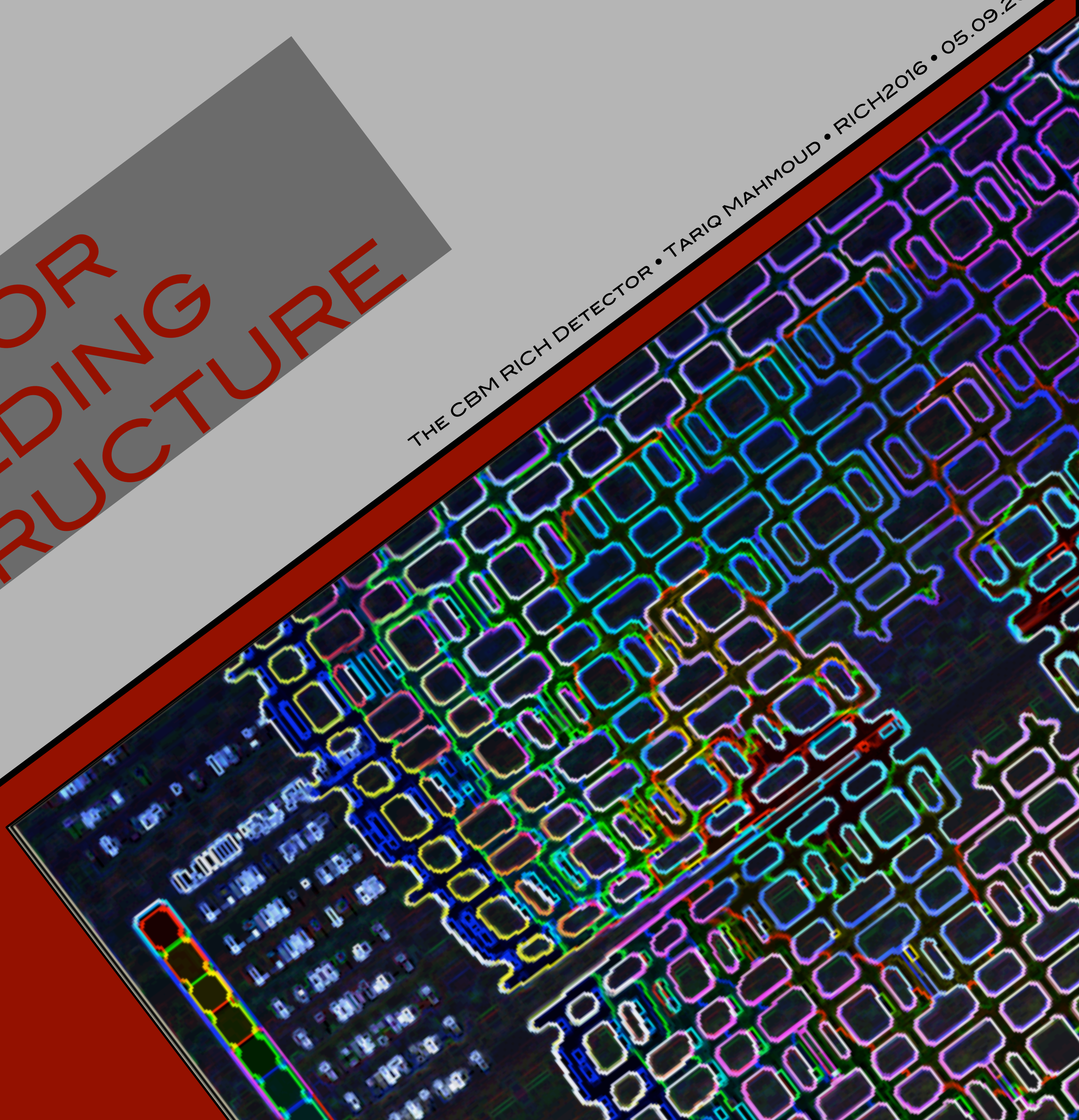
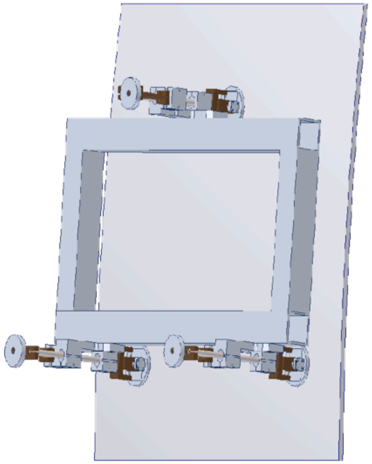


MIRROR HOLDING STRUCTURE



Justus-Liebig-Universität Giessen

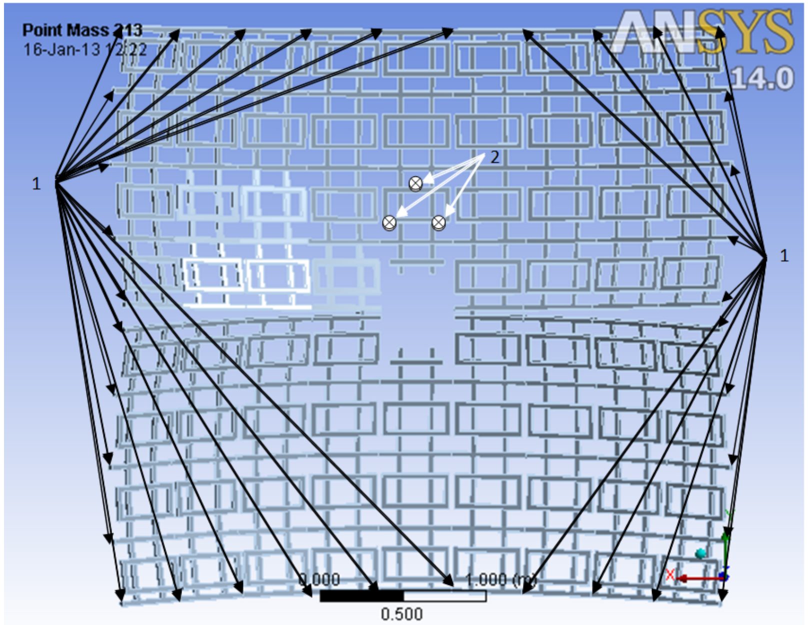
MIRROR MOUNT STRUCTURE (I)

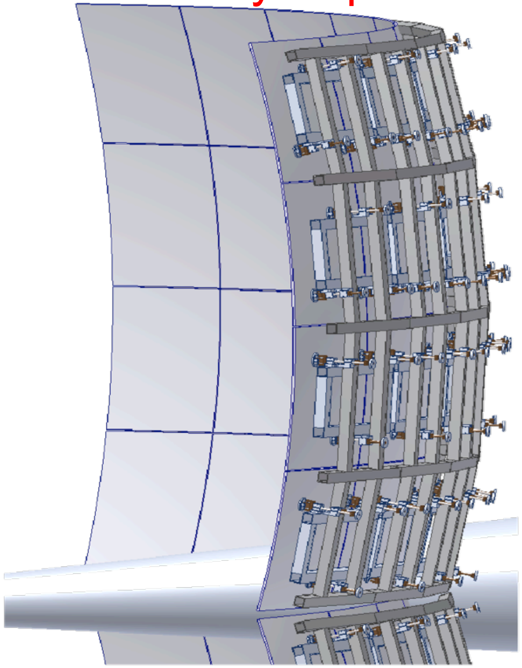


- Ensure high mechanical stability WITH low material budget
- **Basic structure:**
  - mount mirror tile to an aluminium rectangle with three actuators
  - 4 rows → 4 “belts” with 9 cells each
  - Weight = 197 kg + mounts, $X_0 \sim 6.35\%^*$

* relative to X_0 of an aluminum volume covering the CBM acceptance with 9 cm thickness.

  - Simulations with ANSYS: maximal deformation: 153 μm
  - Prototype was build and tested: design and materials fulfil stability requirements





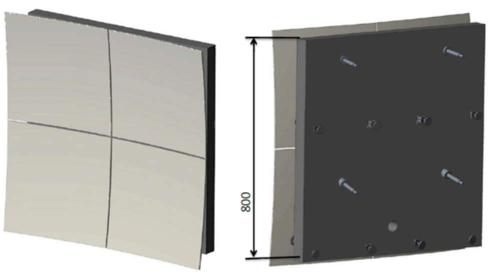
MIRROR MOUNT STRUCTURE (II)

Reduce material budget: → considered three new types of designs.

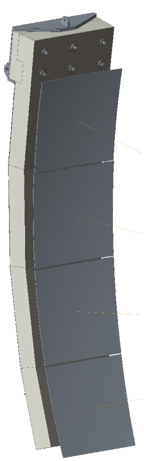
V1: Foam structure

Not sure that the design will keep the geometry over time

Module 2x2

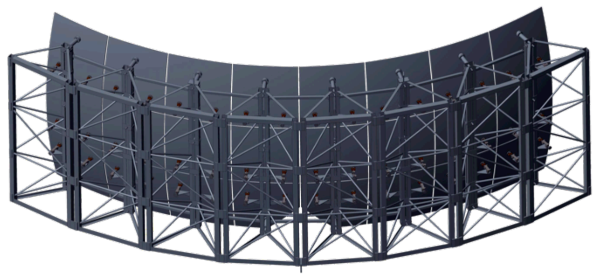


The mass of the mirrors ~10 kg
The mass of the foam ~ 3-6 kg



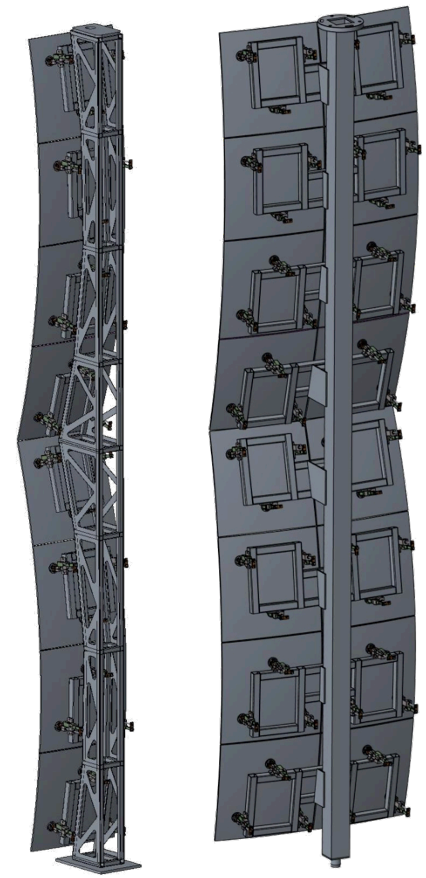
V2: Frame from light Al profile plus welding

Difficulties in manufacturing



V3: "Pillar" design

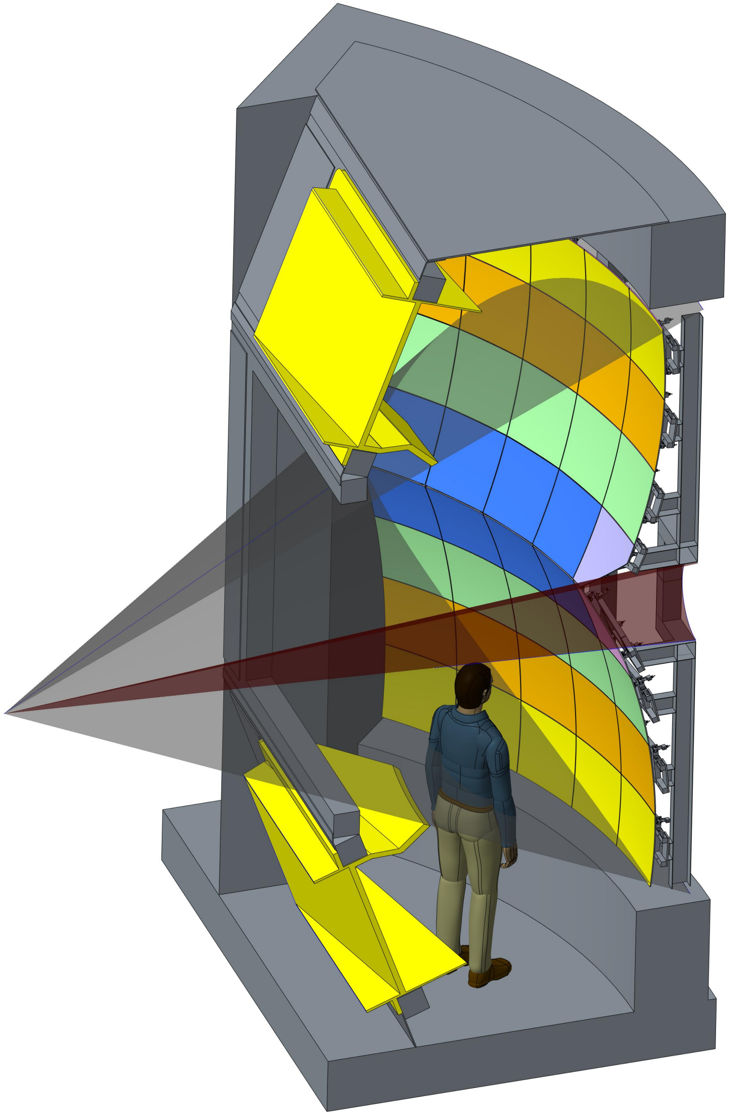
Two mirror columns per pillar

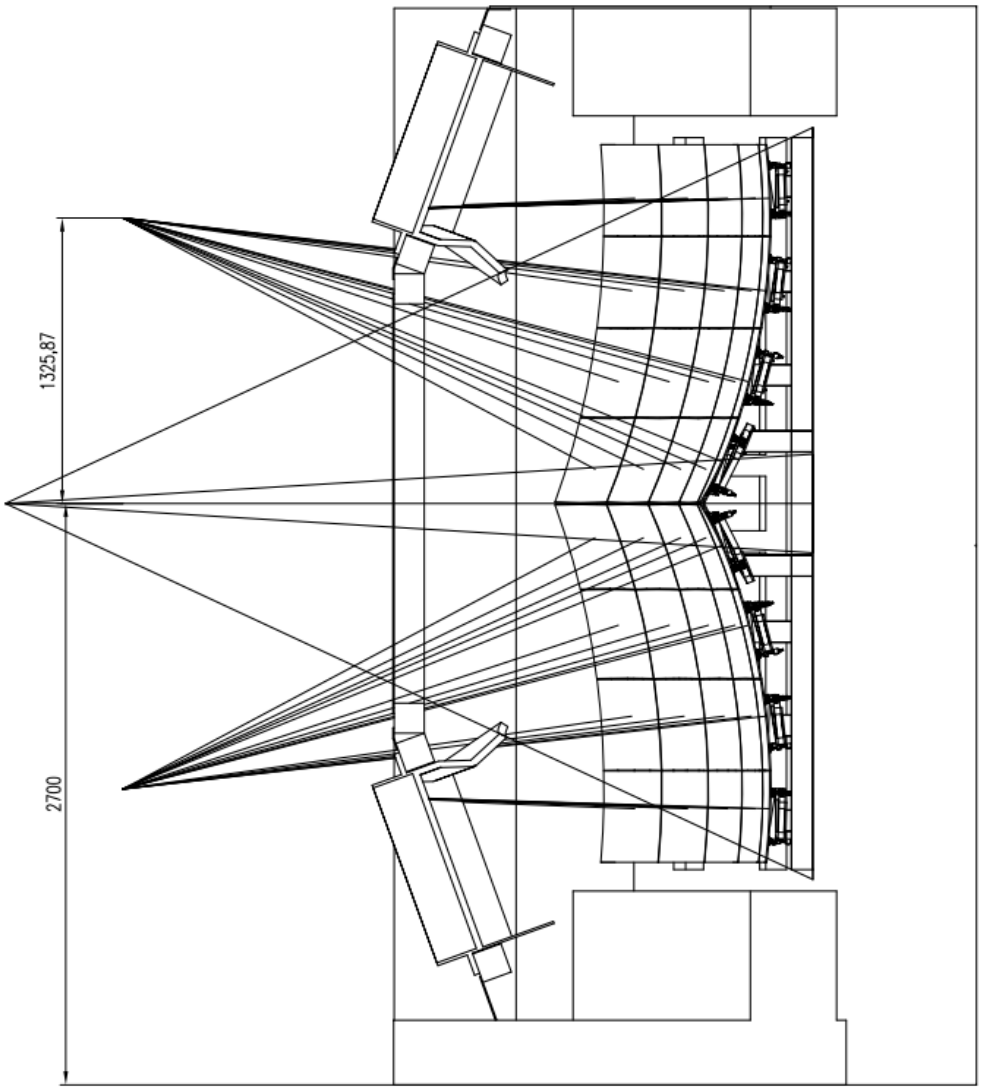


	Weight [kg]	X_0 [%]
Basic design	197 + mounts	~ 6.35
V1		~ 3.8
V2	140 + mounts	~ 4.8
V3	125 + mounts	~ 4.4

Potential reduction of X_0 with carbon fibre pillars

GEOMETRY OVERVIEW





Building the mirror structure and the shielding box does not pose any challenge

MIRROR ALIGNMENT

① Alternating usage of RICH with MUCH

→ potential mirror misalignment

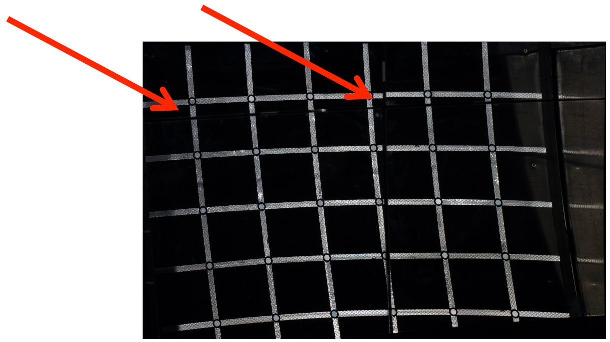
→ development of a mirror alignment system

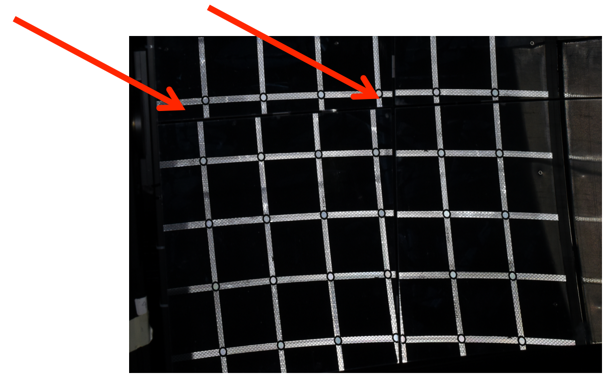
② **CLAM method:**

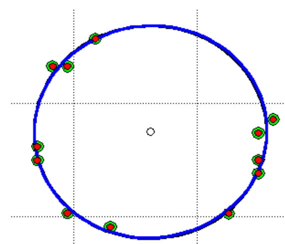
retro-reflective grid at entrance illuminated by LED, reflection “seen” via mirror and recorded with a camera

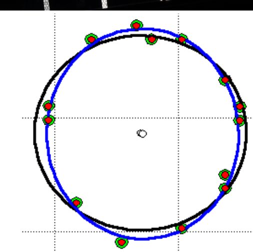
→ determine misalignment

COMPASS experiment, Nucl. Instr. Meth. Phys. Res. A 553 (2005) 135









③ **“Two ring centres”:** calculate difference between fitted and extrapolated ring centres HERA experiment, Nucl. Instr. Meth. Phys. Res. A 433 (1999) 408

→ correct for the misalignment

Poster: J. Bendarouach (A3)

SUMMARY

① The RICH concept was approved and accepted by the FAIR council

② Open items were studied carefully:

i. RICH geometry optimised to escape the influence of the stray field; shielding box designed

ii. PMTs tested on their radiation hardness for the duration of the CBM life time

iii. PMTs ordered and being delivered and tested

iv. Mirror holding structure developed to ensure mechanical stability with low material budget

v. Common readout development with PANDA and HADES: first readout board ready

③ Mirror alignment system established

④ Software developed and refined accordingly

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④ Software developed and refined accordingly **Poster: S. Lebedev (A25)**

⑤ Electronics and WLS tested in beam time **Poster: E. Ovcharenko (A11)**

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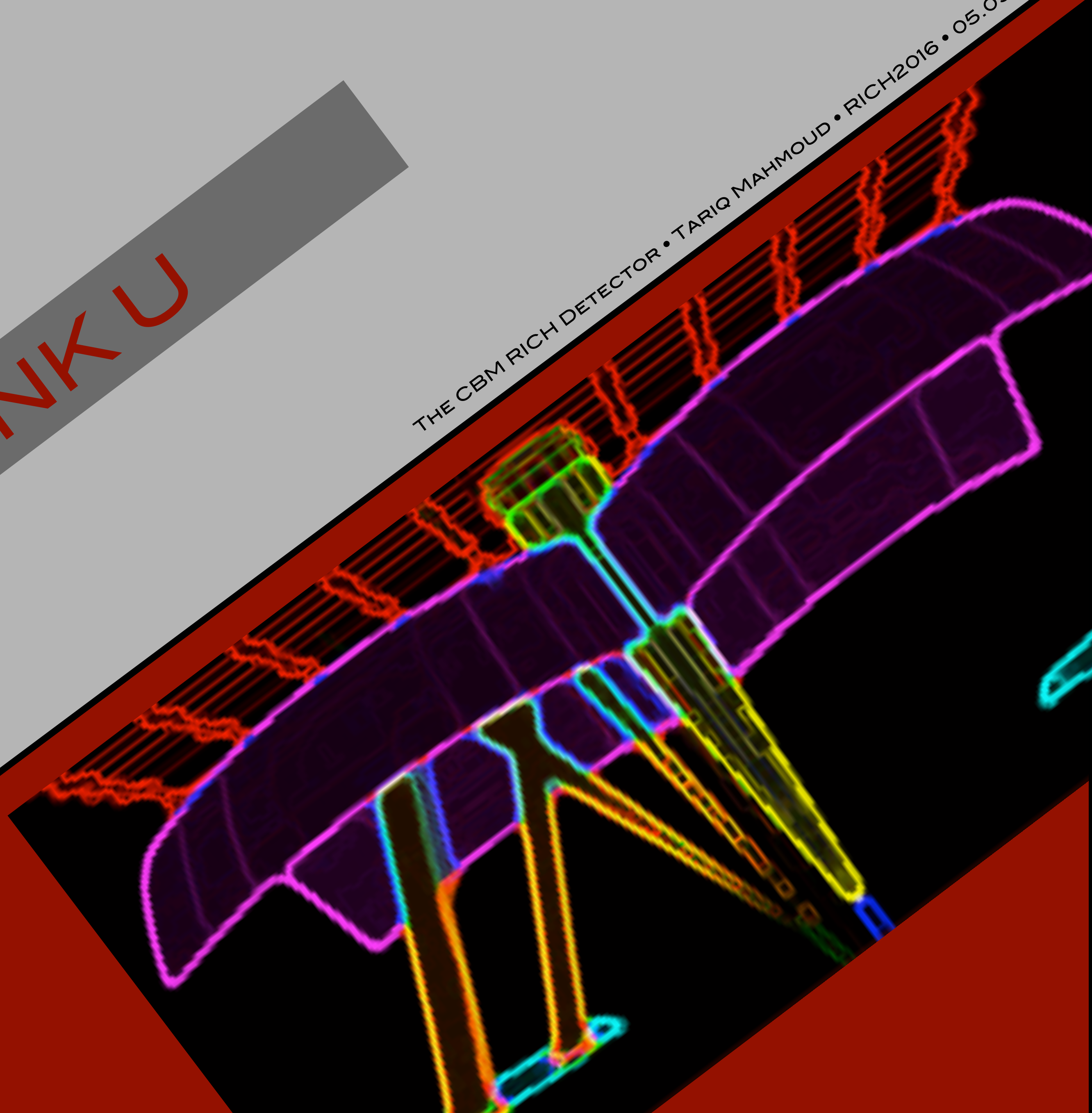
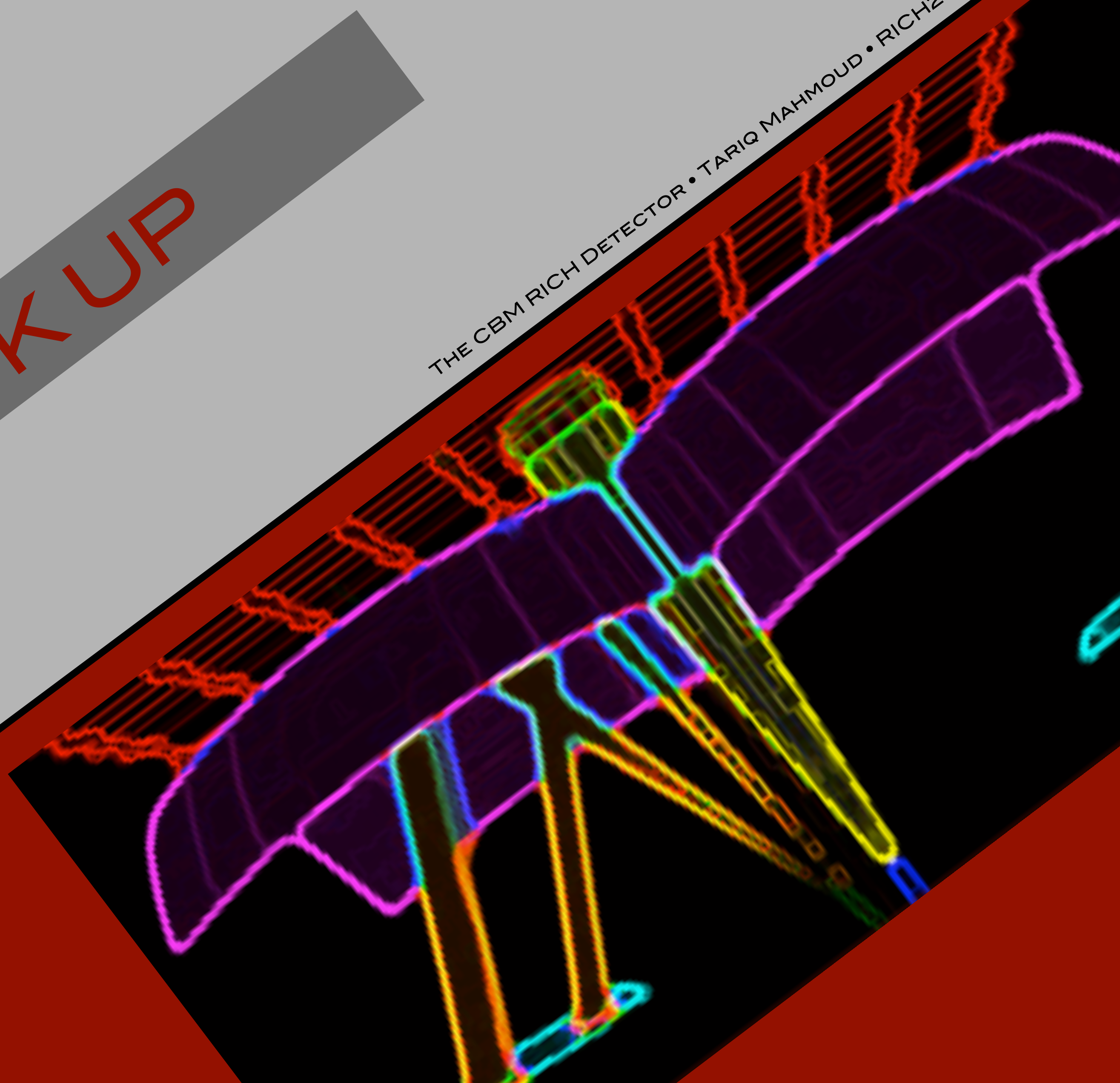
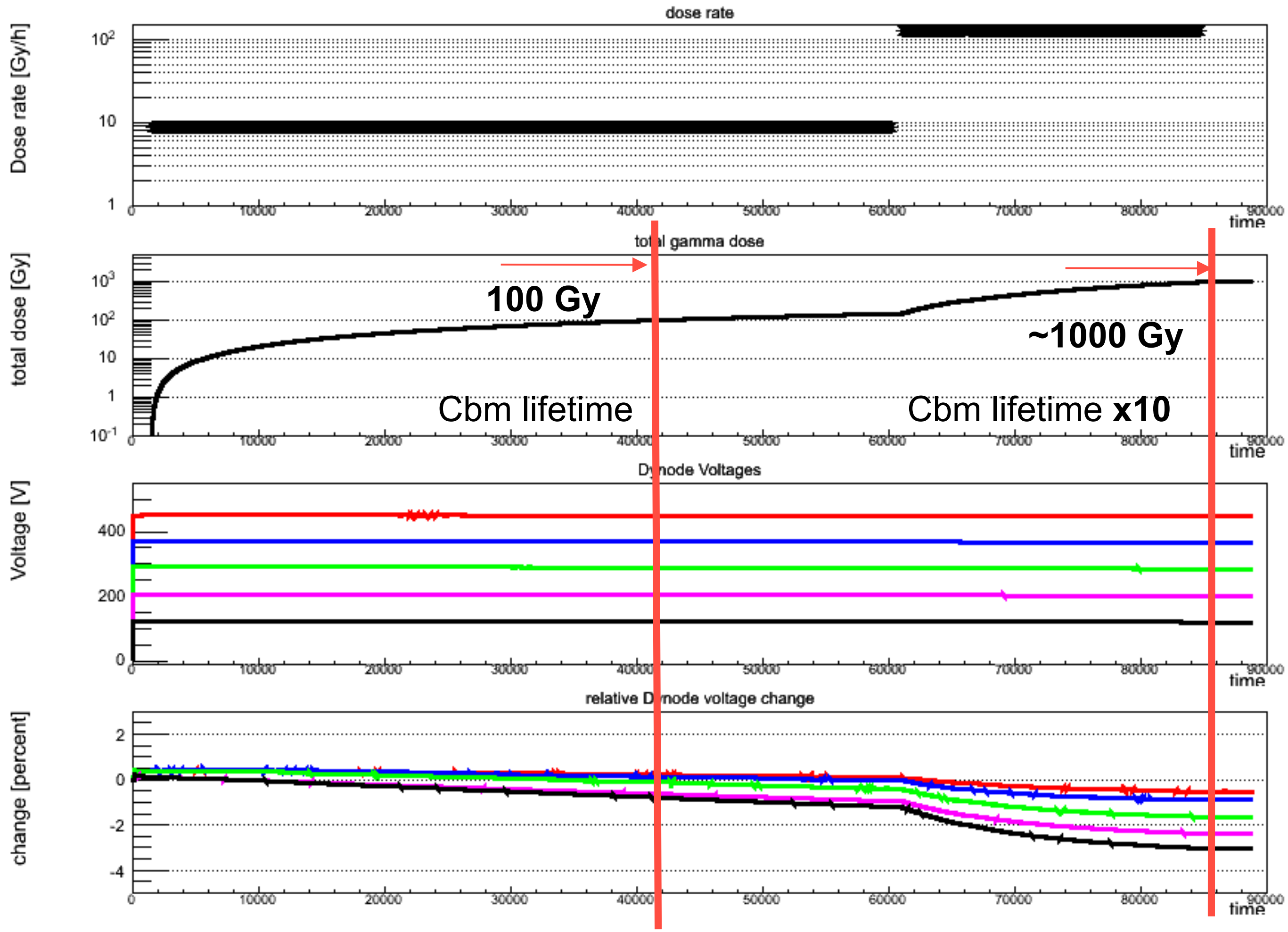
THANK U



BACK UP

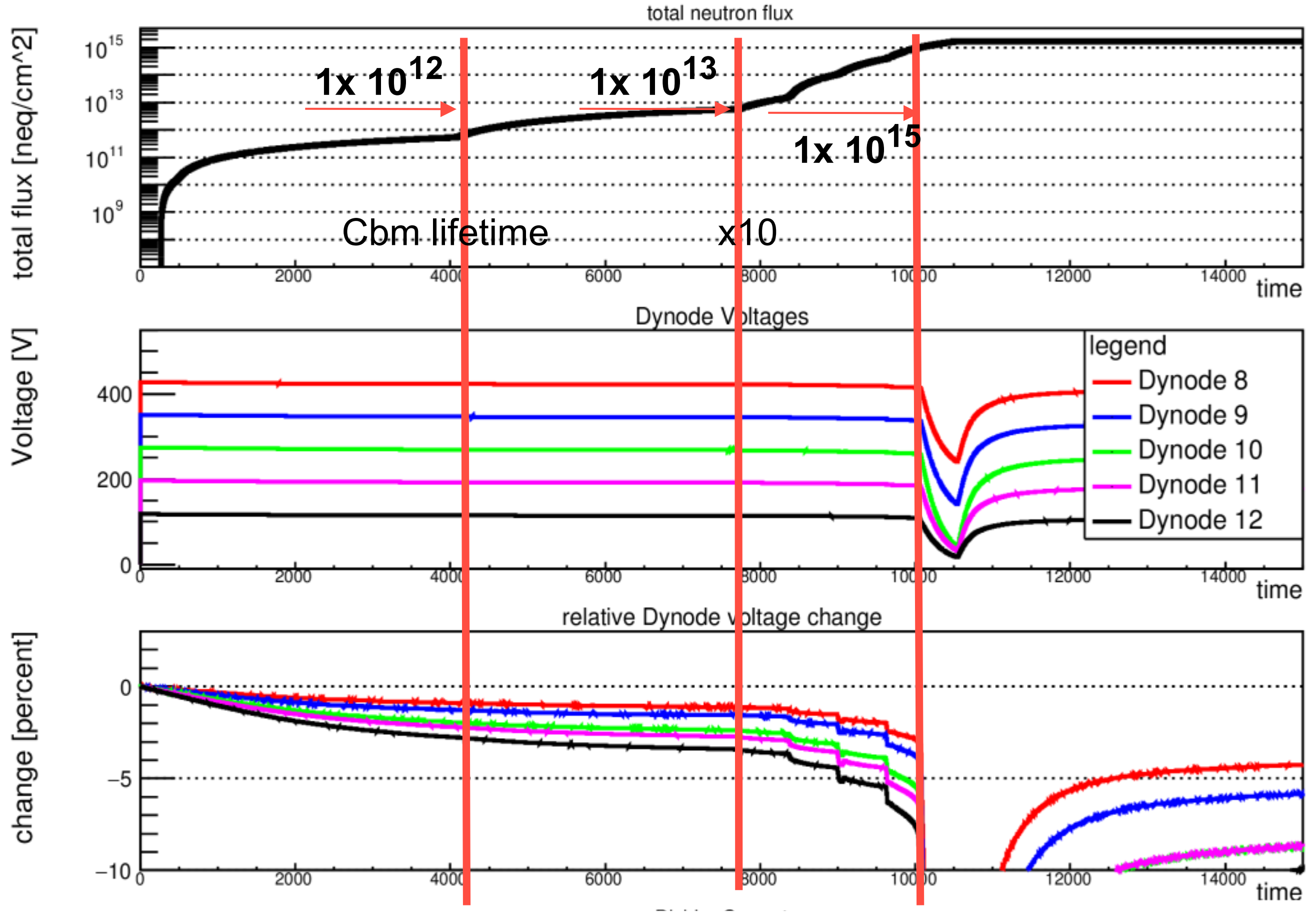


PMT VOLTAGE DIVIDER (GAMMA)



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

PMT VOLTAGE DIVIDER (NEUTRONS)



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

CBM RICH

Goal: separate electrons from pions with momenta up to 8 GeV →

Physics requirements:

need gas radiator (low *n*)

→ CO_2 or N_2

	N_2	CO_2	C_4F_{10}	Aerogil	C_5F_{10}	Quartz
δ [10^{-4}]	2.98	4.3	14	300	2700	4700
$p_{th}(e)$ [GeV]	0.02	0.017	0.01	0.002	$7 \cdot 10^{-4}$	$5 \cdot 10^{-4}$
$p_{th}(\pi)$ [GeV]	5.72	4.76	2.64	0.57	0.19	0.14

Practical considerations

$\delta = n-1$

	Radiator length [m]	Full length [m]	Mirror radius [m]	Mirror size [m^2]	Photon detector plane [m^2]	# of channels
CO_2	1.76	2.1	3	11.8	3.7	55k
N_2	2.5	2.9	4.5	22.8	9	200k

→ take CO_2

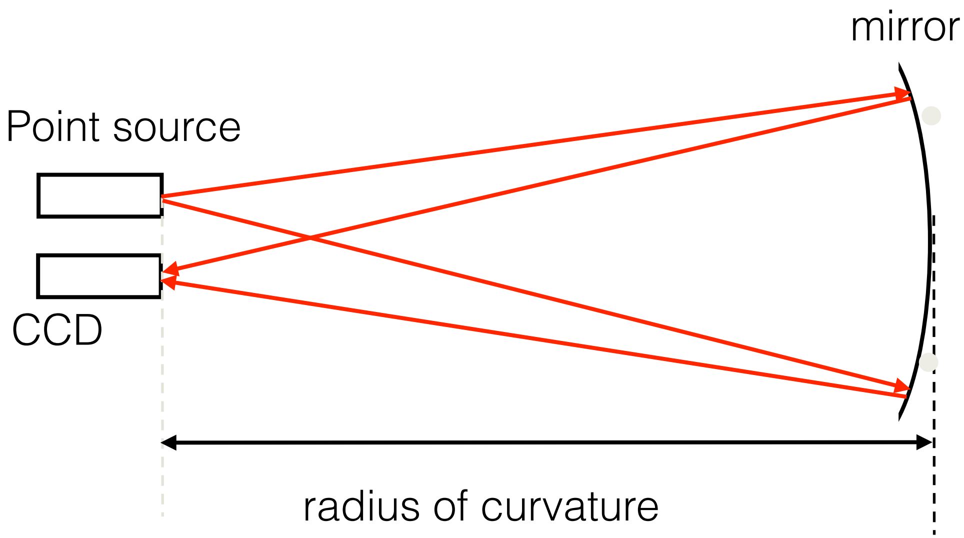
$$n_{CO_2} = 1.0004489 \rightarrow p_{th} = 33.37 * m/c^2$$

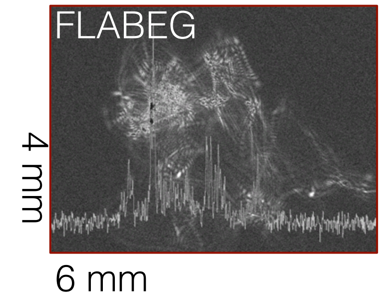
$$p_{th}(e-) = 17 \text{ MeV/c}$$

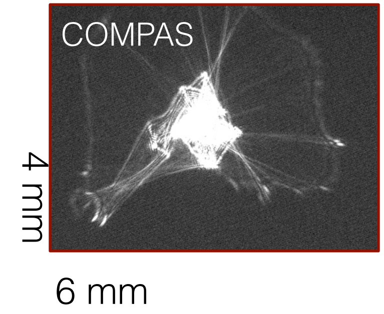
$$p_{th}(\pi) = 4658 \text{ MeV/c}$$

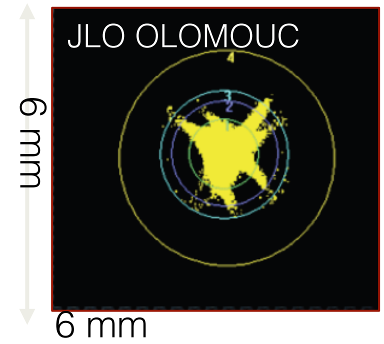
$$p_{th}(K) = 16474 \text{ MeV/c}$$

SURFACE HOMOGENEITY









Homogeneity:

- D_0 as a measure of the mirror homogeneity.
- Reflect a point-like source on the mirror and record its image.
- Ideally the image is also point-like. In Reality, inhomogeneity causes a non-homogenous spot (picture).
- D_0 is the diameter, of a circle, which contains 95% of the reflected light

	required	FLABEG	COMPAS	JLO OLOMOUC
D_0 (mm)	≤3	Very bad	2.3	2.3

RESOLUTION

$$\sigma = \frac{\sqrt{\sigma_{mirror}^2 + \sigma_{disp}^2 + \sigma_{pixel}^2 + \sigma_{MS}^2 + \sigma_B^2}}{\sqrt{N}}$$

Cherenkov angle resolution for N photons

σ_{mirror} due to mirror quality. It is negligible.

σ_{disp} due to chromatic dispersion. Can be estimated to 1 mrad.

P. Glässel. In: Nucl. Instr. Meth. A 433 17 (199

σ_{pixl} due pixel size. It is about 1 mrad.

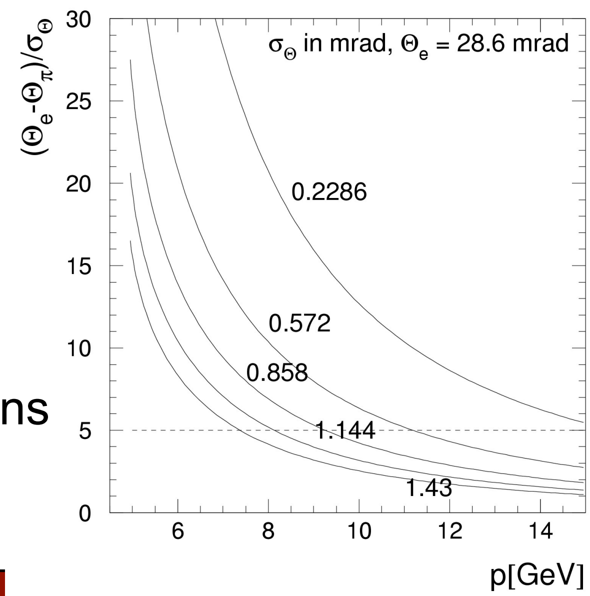
$$\sigma_{MS} = \frac{2}{3} MeV/c \bullet \sqrt{\frac{L}{X_0}} \bullet \frac{1}{p} = 0.874 MeV/c \bullet \frac{1}{p}$$

$$\sigma_B = 55.1 \frac{MeV}{Tm} \bullet \frac{LB_T}{p}$$

$B_T = 0.077 Tm$

p [GeV]	0.4	1	8
σ_{MS} [mrad]	2.2	0.9	0.1
σ_B [mrad]	18	7.2	0.9

$$\sigma(p = 8GeV, N = 20) = 0.38 mrad$$



For a σ = 0.572 mrad (2% resolution), pions and electrons are separated by 5 sigma up to about 11 GeV/c.