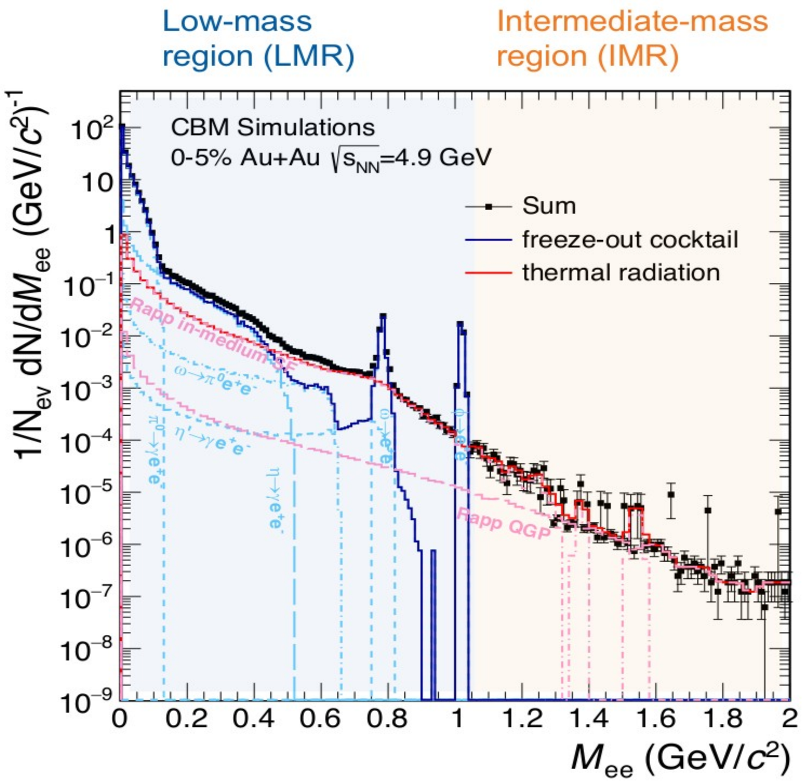
Status of the CBM RICH detector -

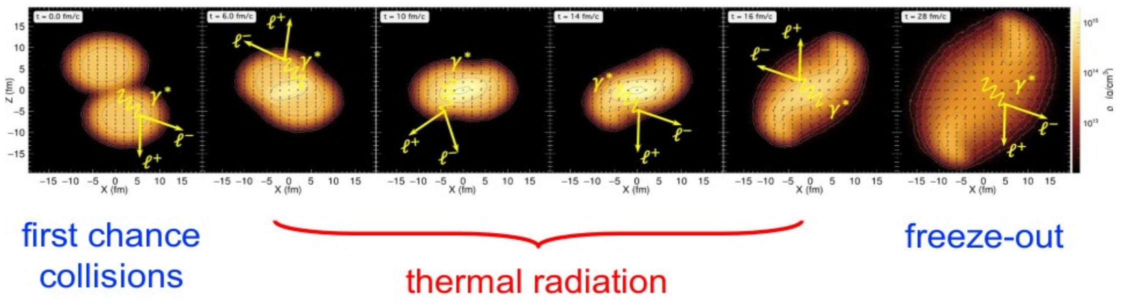
towards first beam in 2028

C. Pauly, BU Wuppertal
for the CBM RICH collaboration

- Overview
- Status CBM RICH
  - the CBM RICH photon detector
  - mirrors and mirror wall
  - other components
- Towards first upgrade:
  - SiPMs instead of MAPMTs ?
- Summary

Dileptons – one of CBM's key observables





Electromagnetic radiation as multi-messenger of fireball

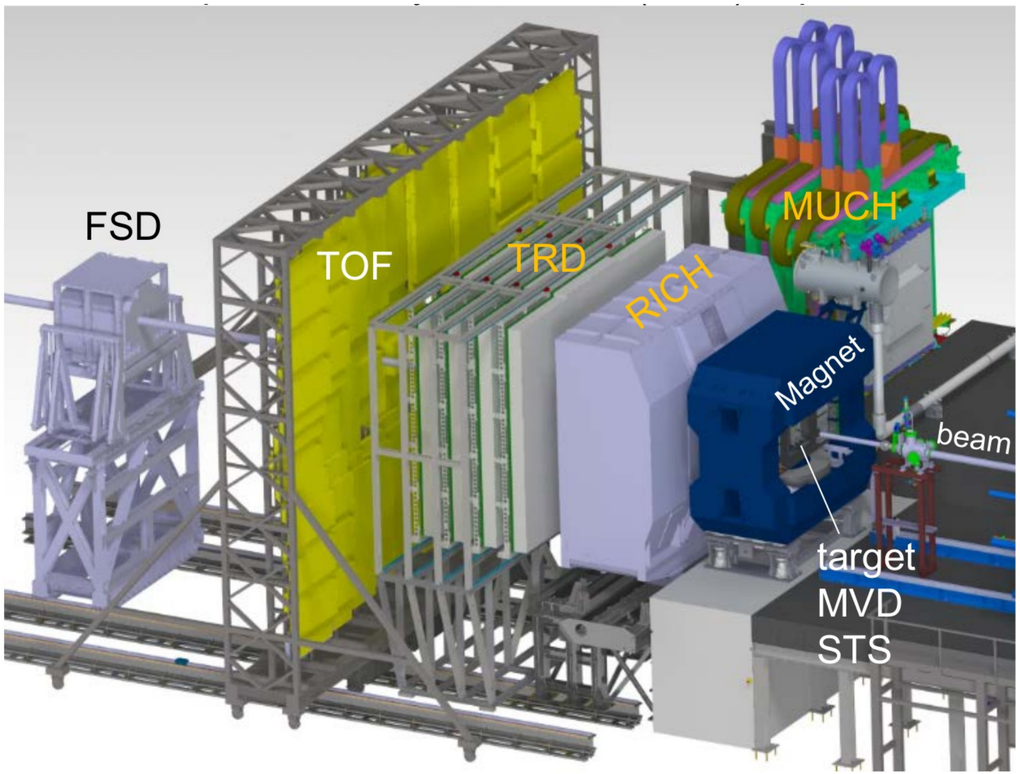
- No strong final state interaction
  → leave interaction volume undisturbed
  → reflect the whole history of HI collision

- Encodes information of matter properties
  – degrees of freedom of the medium
  – fireball lifetime, temperature, polarization
  – restoration of chiral symmetry

LMR → "Chronometer" : total yield ~ fireball lifetime
IMR → "Thermometer" : slope ~ emitting source temperature

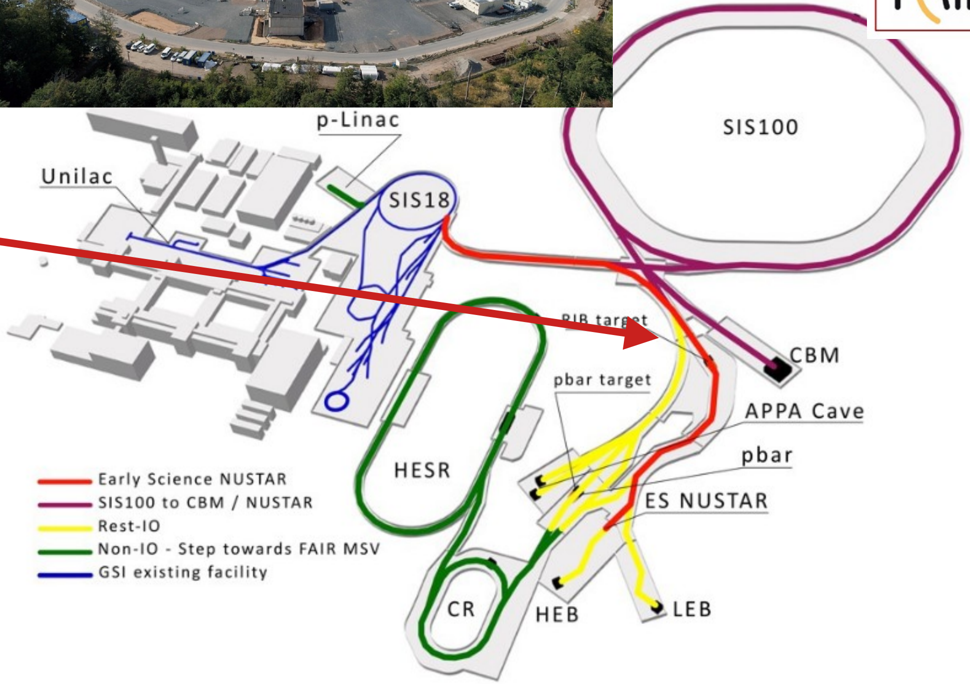
The CBM Experiment

- Fixed target experiment
  - tracking acceptance : 2.5° < Θ_{lab} < 25°
- 2 interchangeable detector setups:
  - electron setup : RICH detector for e / π separation
  - muon setup : MUCH- instrumented absorber
- Peak interaction rate : 10 MHz (Au+Au)
  (300 kHz with MVD)
- Free-streaming, self-triggered DAQ system
- Online event reconstruction and selection
- Fast and radiation hard detectors
- 4D tracking (space + time)
- Data rate : up to 1 TB/sec



FAIR facility and CBM cave

RICH group in CBM cave at RICH position



- CBM cave ready (painted and pretty...)
- RICH EDR mirror + mirror wall : next month
- RICH EDR + PRR mechanics next year
- **Installation in cave -> 2027**
- **First beam in cave -> end 2028**

The CBM RICH detector

- **CO_2 gas radiator**
  - pion threshold 4.65 GeV/c, n=1.00045
  - UV cutoff < 190 nm
  - 70 m^3 radiator gas volume, ~1.7 m radiator depth
  - good quenching of scintillation light

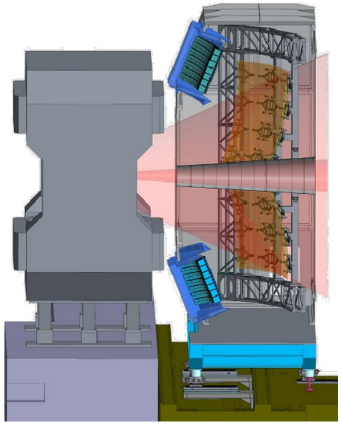
- **13m^2 segmented mirror, upper+lower half**
  - 80 spherical lass tiles 40x40 cm^2, d=6mm, R=3.0 m
  - Al + MgF_2 (+ HfO_2) coating

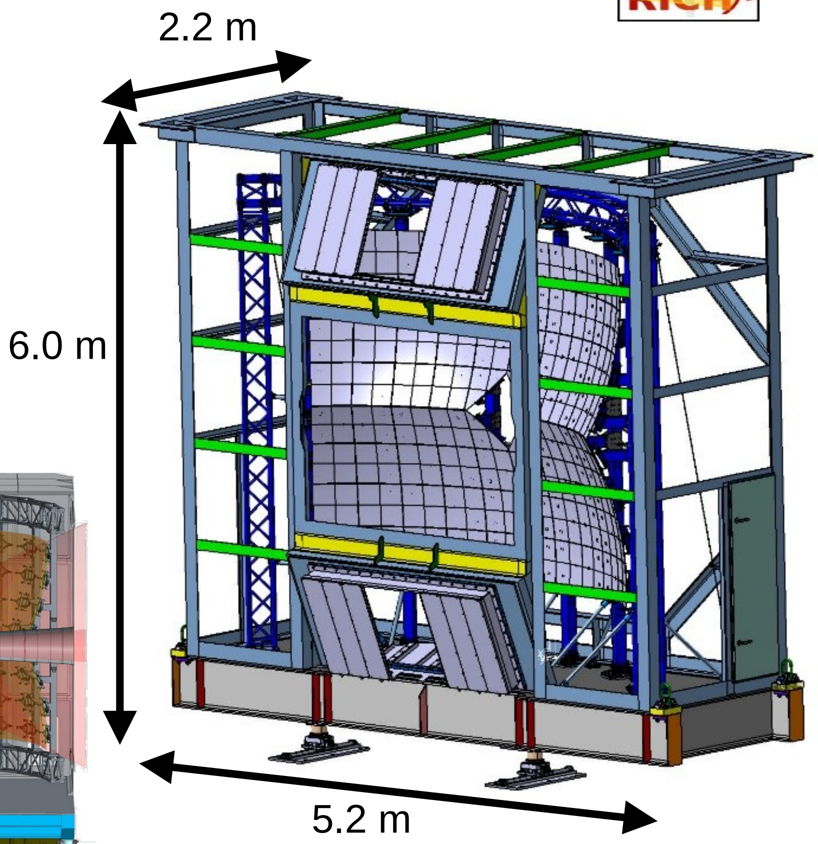
- **MAPMT readout**:
  - 1100 Hamamatsu H12700 MAPMTs
  - FPGA-TDC based readout chain, 64k channels
  - excellent photon timing precision (< 300 ps RMS)

Challenges:

- high rate (up to 300 kHz photon rate per pixel)
- quasi free-streaming readout
- RICH downstream of tracking system
- magnetic stray field from CBM magnet (shielding box)
- RICH movable by crane

- since 2022: cooparation with PNPI St. Petersburg ceised





Weight : **~15 t**

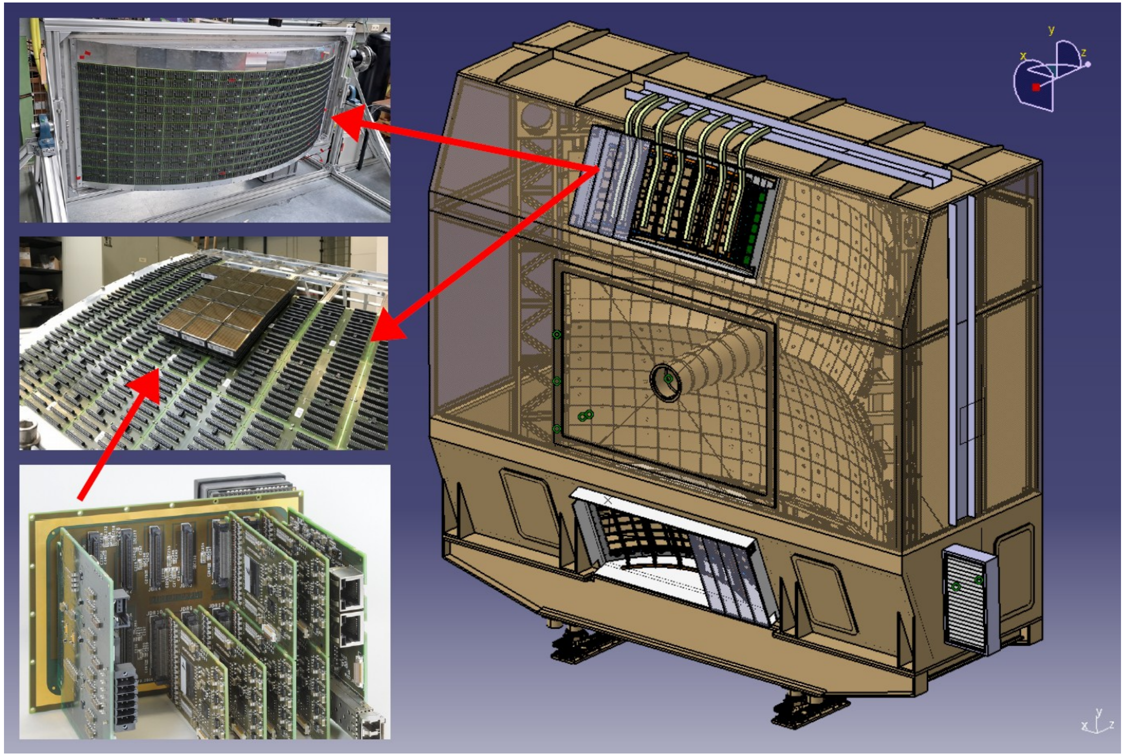
The CBM RICH photon detectors

- **Two separate photon detectors**
  - 1100 Multi-anode PMTs Hamamatsu H12700
  - 65000 individual readout pixel, 6x6 mm²
  - protected by magnetic shielding boxes

- **Electronic readout chain**
  - FPGA-TDC based “DIRICH” readout chain
  - TDC timing precision : <20 ps RMS
    (leading+trailing edge -> ToT)

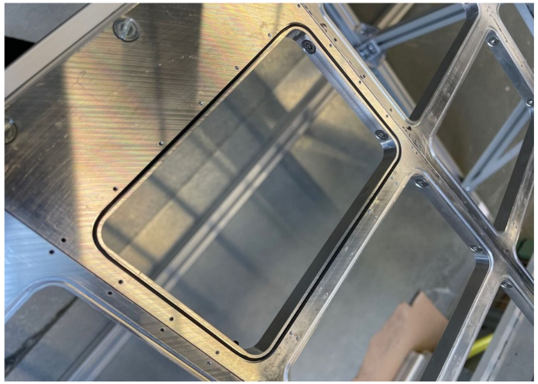
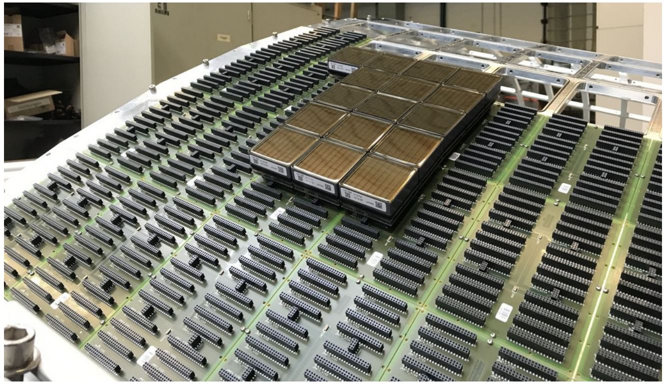
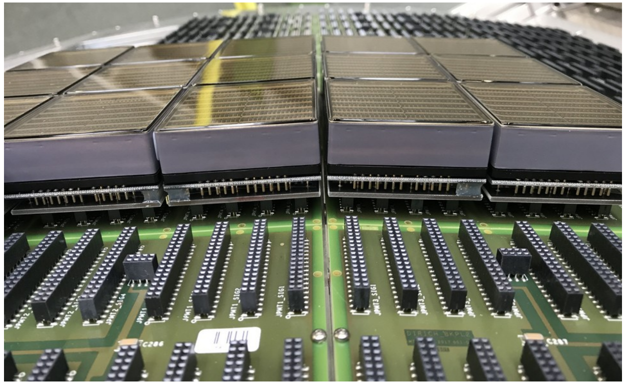
  - organized in modules :
    6 MAPMTs → 12+2 FE modules

  - up to 300 kHz photon rate / pixel

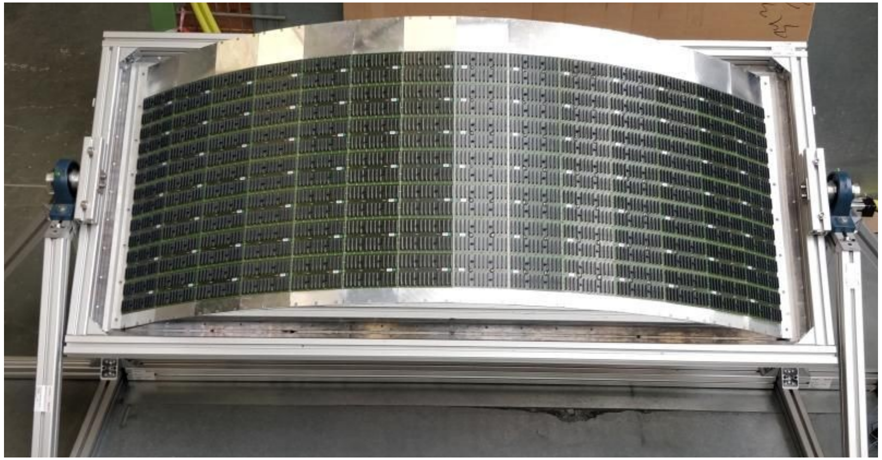


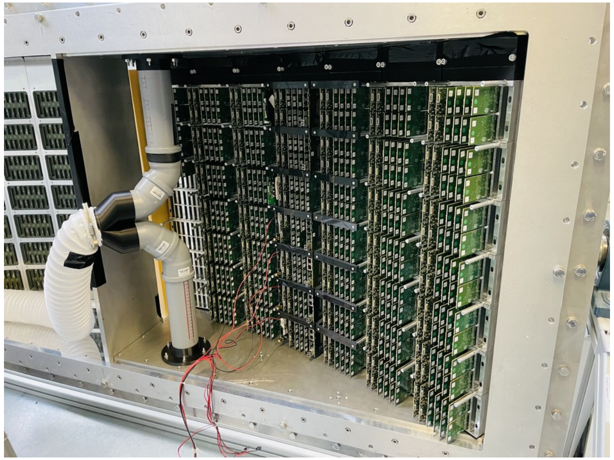
Photon camera design – some pictures

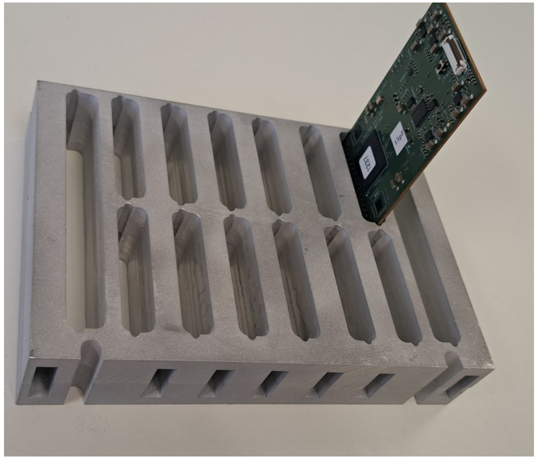


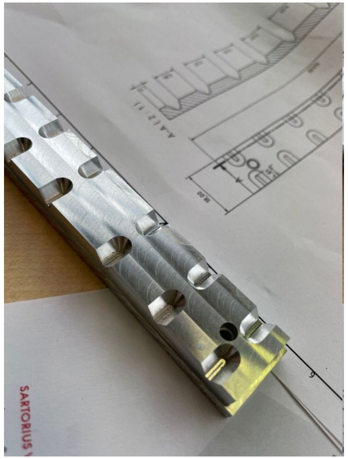





Photon camera design – some more pictures









CBM RICH Front-end Electronics

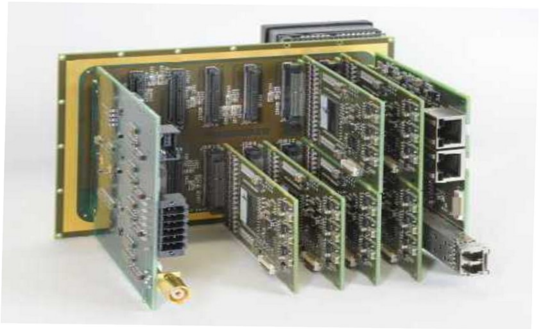
- **FPGA-TDC based readout chain “DIRICH”**
  - developed at GSI, already used in HADES
  - also used in many other applications (eg. PANDA DIRC)

- **Electronic module production far advanced:**
  - **2500 DIRICH TDC modules :   45% produced   (GSI)**
  - **210 DIRICH Concentrator :   100% produced   (GSI)**
  - **210 DIRICH Power modules : 100% produced   (GSI)**
  - **220 Backplane PCBs :   100% produced   (extern)**

- **Dedicated series testing of each produced module**
  - < 10 % faulty modules on first test
  - most of them can be reworked

- Qualification of free-streaming readout chain:
  → **mini-CBM mRICH detector**

poster: **“The mRICH detector [...]”**
Abhishek Deshmukh
this conference



CBM RICH readout module for 6 MAPMTs :
- Backplane PCB
- 12x DIRICH TDC modules
- 1x Data Concentrator module
- 1x Power Module

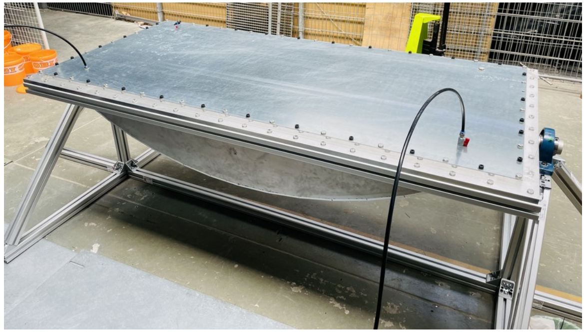
meanwhile 7 such boxes...

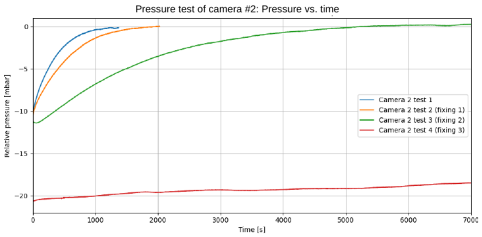
Pressure leak test of camera modules

- Photon sensors inside CO_2 radiator volume
- Front end electronics outside radiator volume

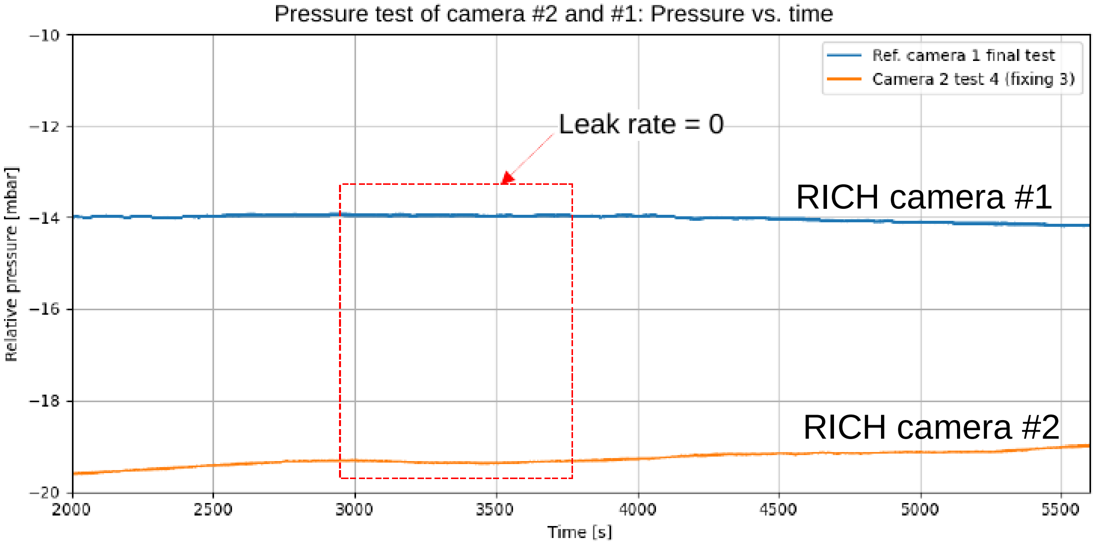
- Over / Underpressure test up to 20 mbar measured over 90 min
  ⇨ **leak rate < 1x10^{-4} mbar m³/s**

- Also serves as test of mechanical stability (20 mbar ~ 200 kg load on PMT plane !)
  ⇨ **< 0.2 mm deformation**





after fixing few initial leaks…
(using CO_2 sniffer)

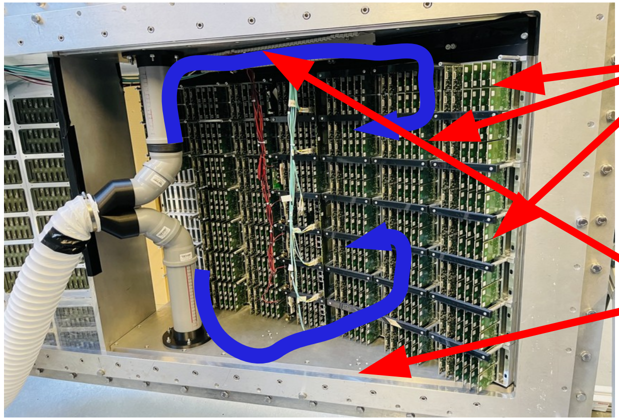


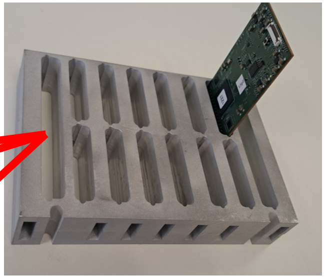
Camera air cooling concept

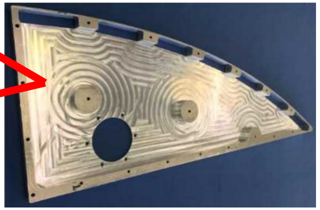
Around **3kW heat dissipation per camera**
Camera **volume enclosed by shielding box**

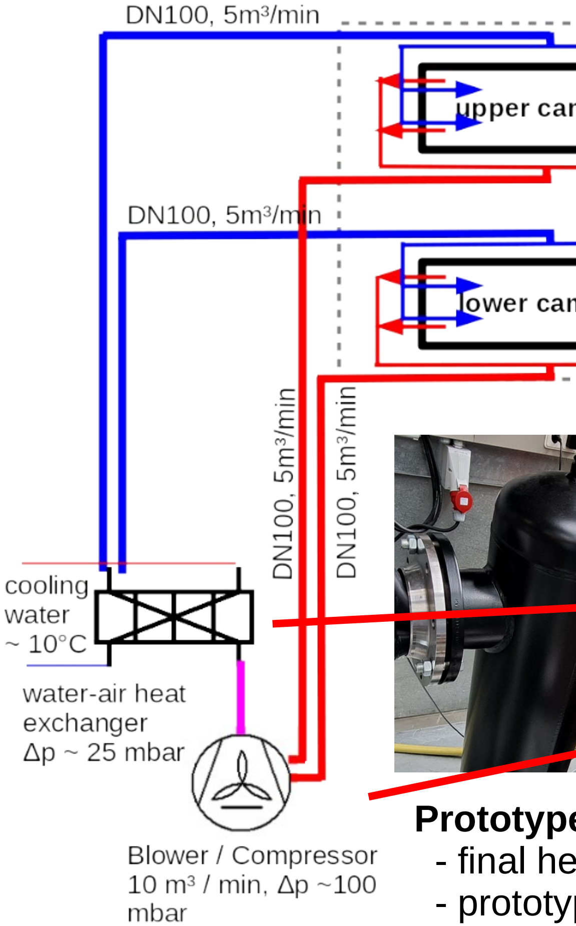
Closed-loop air circulation cooling

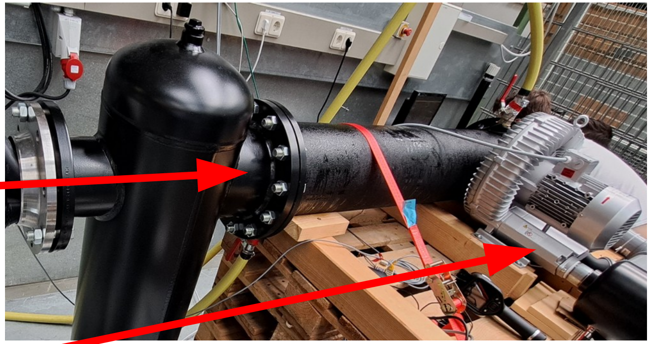
- Heat exchanger to cooling water (cave)
- Electric blower for enforced air circulation
- “Reverse” air-flow, away from photon sensors ! (important lesson from HADES RICH upgrade)
- CNC-milled air distribution parts (“mask”)







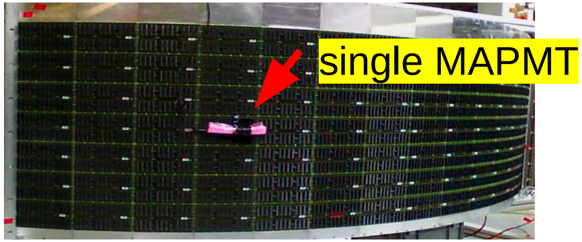


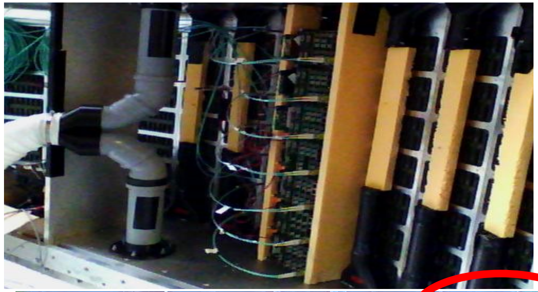


Prototype cooling system
- final heat exchanger
- prototype blower (single camera)

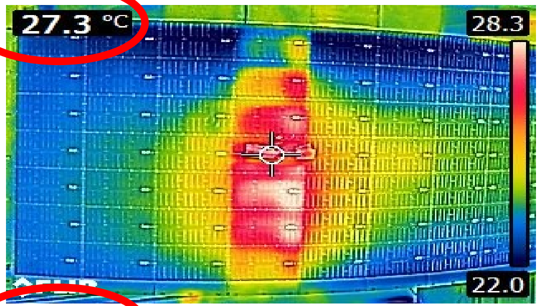
First test – Single column, 7 readout modules powered

goal:
Keep MAPMT cathode temp < 30°C
despite heat load from front-end electr.

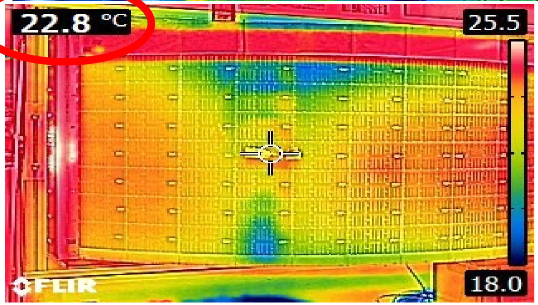




Blower freq. : 10 Hz
Air flow (per column): **54 kg/h**
T_{air}: 11.3 °C
→ **MAPMT Temp: 27 °C**
→ **Electronics Temp: 47 °C**



Blower freq. : 20 Hz
Air flow (per column): **105 kg/h**
T_{air}: 10.5 °C
→ **MAPMT Temp: 23 °C**
→ **Electronics Temp: 33 °C**

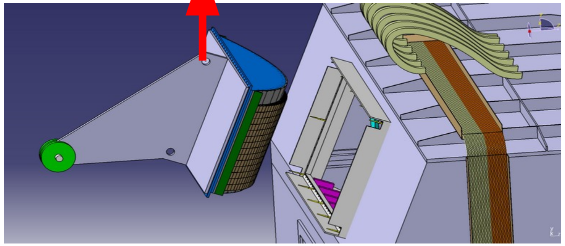


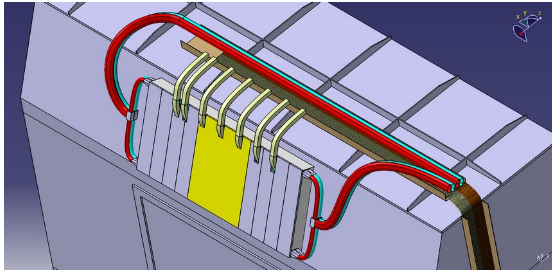
Room Temperature:
T_{room} ~ 25 °C

Mind change in color range...

crane

Maintenance access for photon cameras





mounting flange

camera flange

- **Maintenance access in-situ difficult**
  - camera enclosed by iron shielding box
  - upper camera at a height of ~6 m
  - access from inside radiator vessel difficult due to mirror wall

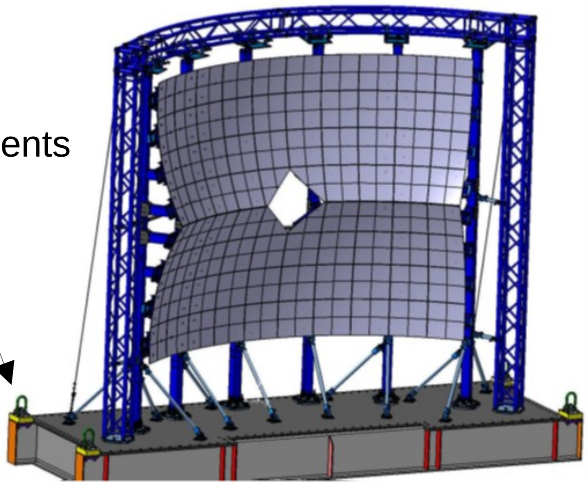
remove (upper) camera for maintenance

- **Special crane tool for camera (de)installation**
  - precise tilt angle (+/- 24 °) achieved using counter weight
  - protective covers for MAPMTs
  - crane weight-scale to ensure force-less removal
  - cameras only fixed via mounting flange

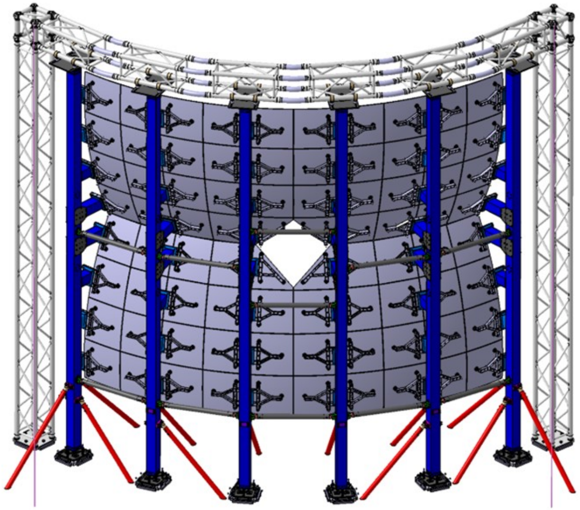
- **All connecting cables will stay with RICH detector**
  - removable cable trays for easy (un)cabling

The CBM RICH mirror wall

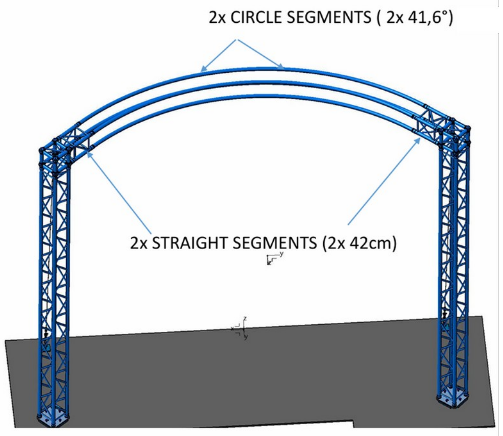
Crane attachments



Front view – with platform



Back view



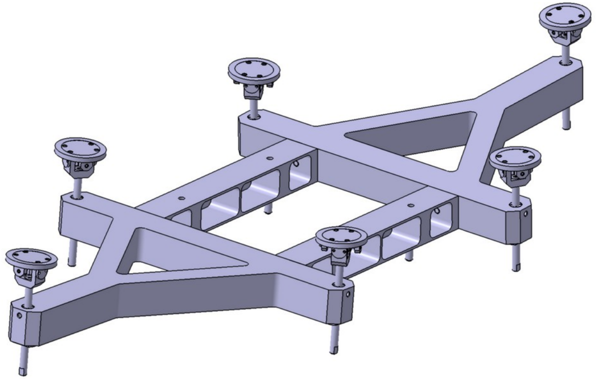
Outer frame structure

Engineering desing review
Mirror wall : next month

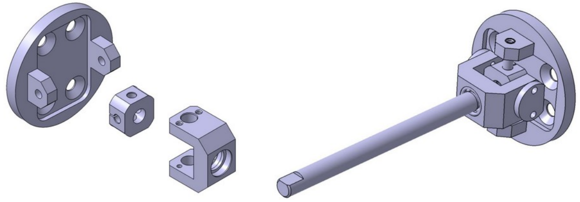
- **Engineering design review mirror wall : next month**
- Mirror wall only attached to massive RICH platform (→ crane operations...)
- 6 aluminum pillars, 100 x 100 mm² x 2 mm, each carrying 2 (1) columns of 8 mirror tiles
  - 3-4 mm gap between mirrors
  - < 1 mrad / < 1 mm alignment / position accuracy
- Adjustable pillar feet for alignment

poster:
“Mirror system of the CBM RICH”
Sven Peter, this conference

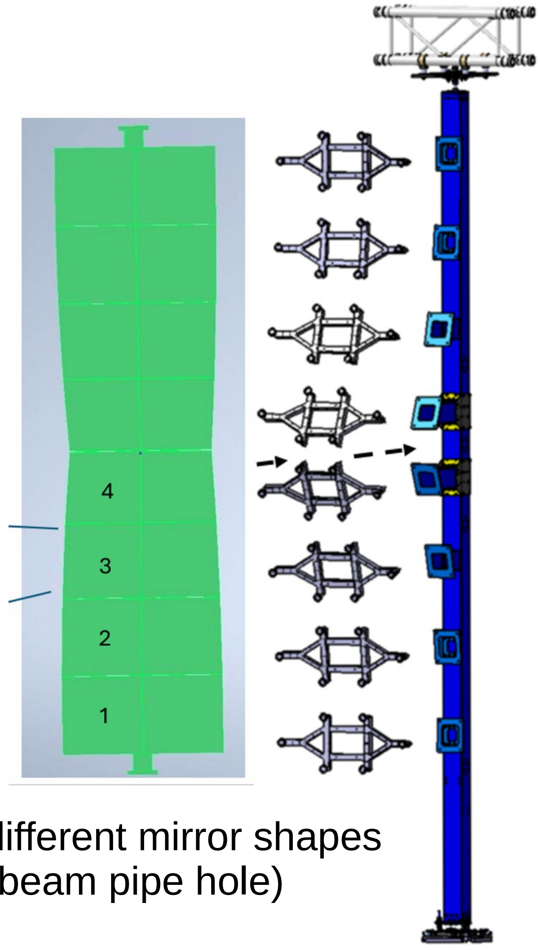
Elements of the mirror wall



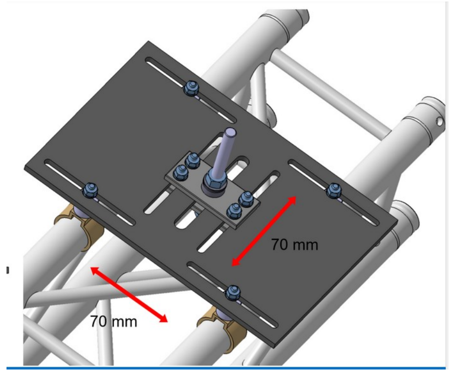
Mirror mounting bracket
carrying two mirrors each



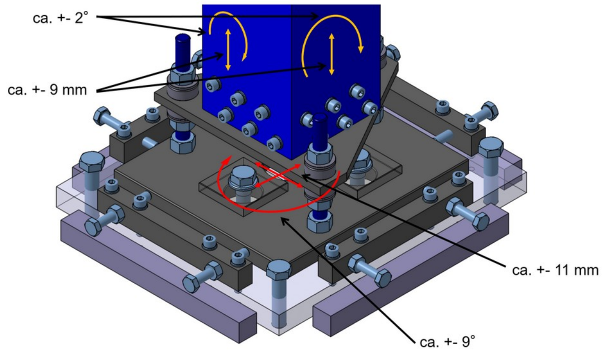
Mirror cardan joints -
3 mounts per tile



4 different mirror shapes
(+ beam pipe hole)

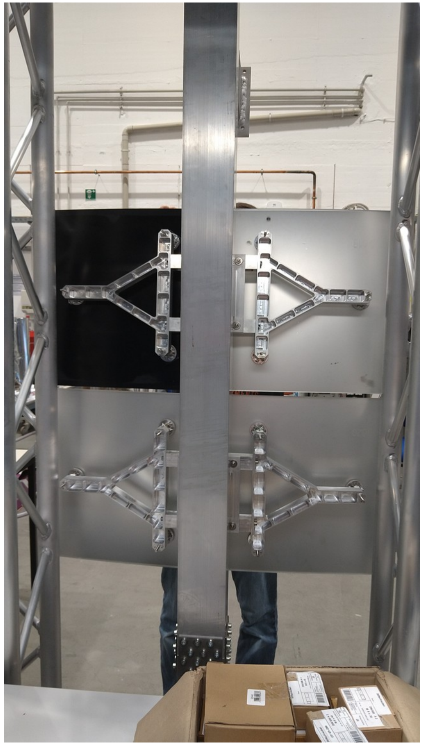


Upper pillar fixation+alignment

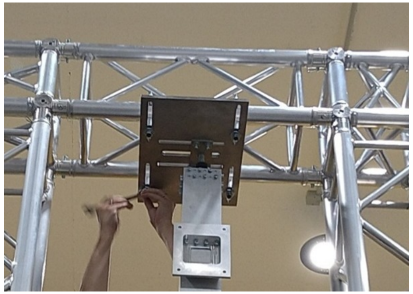
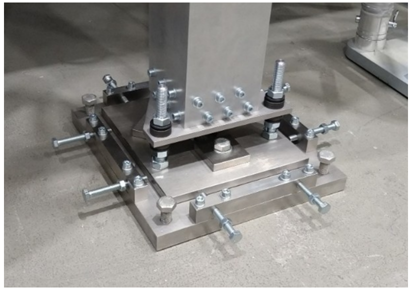


Lower pillar alignment foot

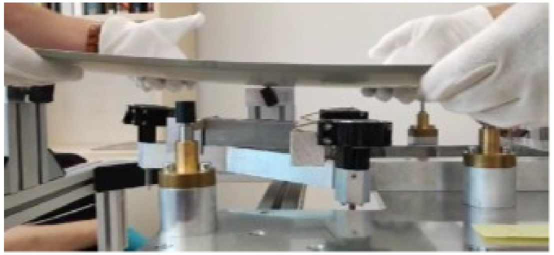
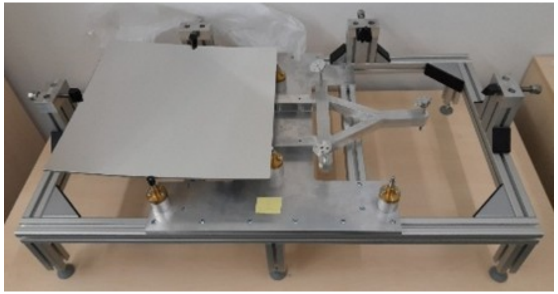
Mirror pillar prototype at JLU Gießen

Single pillar + frame prototype
with 4 mounted mirror tiles

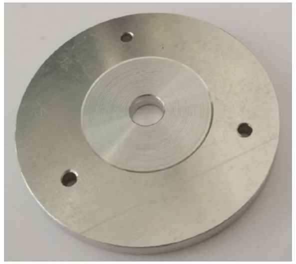
Prototype of pillar
alignment fixations

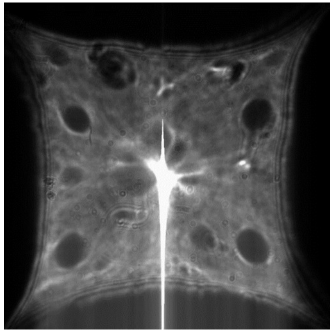

Mirror glueing procedure
special glueing table
for precise alignment

Mirror glueing and possible distortion

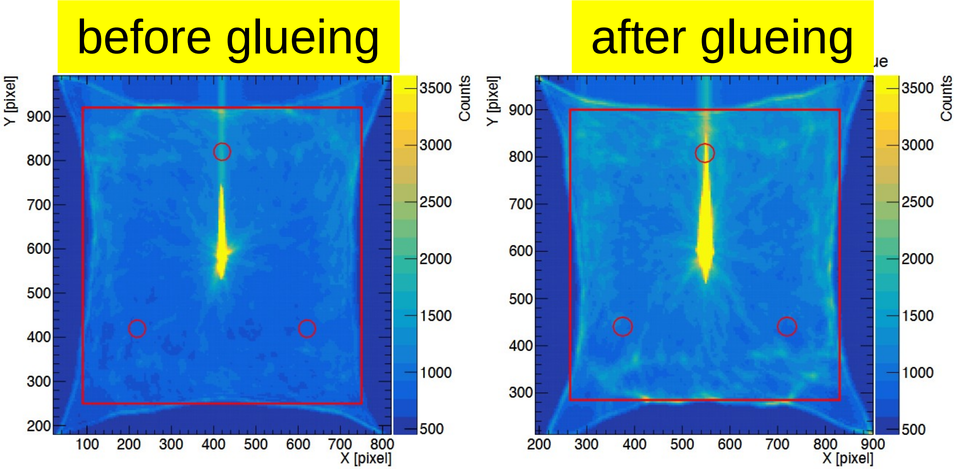
- Mirrors fixed by 3 glue pads each
- Detailed studies on optimum glue, pad shape, procedures, …
- Glue : **Momentive RTV 157** 1-component silicone
  - radiation hard according to CERN yellow report (DOI: 10.5170/CERN-1982-010)



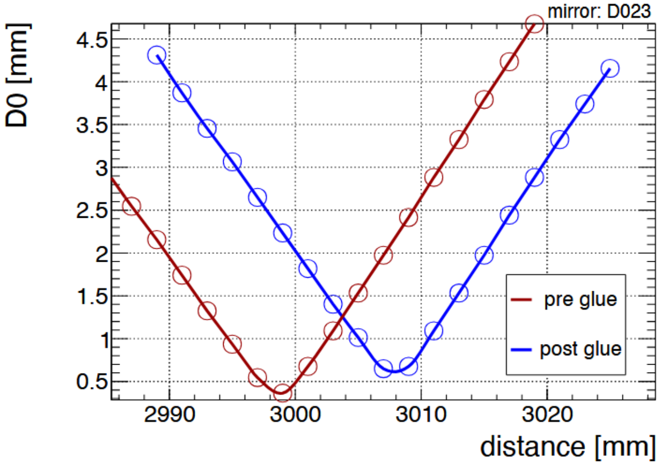
Optimized aluminum pads



Ronchi-like test image revealing glue deformation

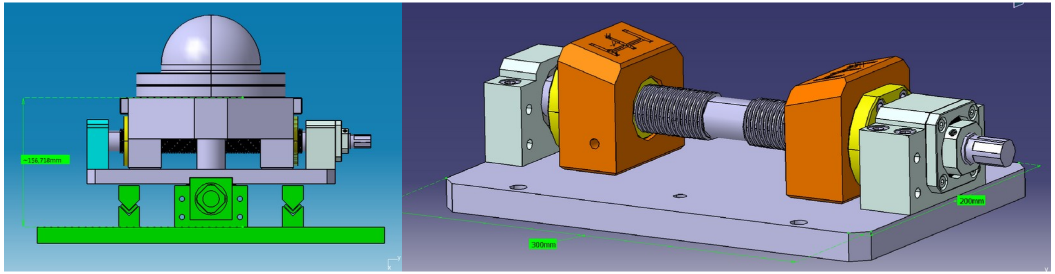


Comparison: before- vs after glueing
applying **optimized glueing precedure**
using **optimized aluminum pads**



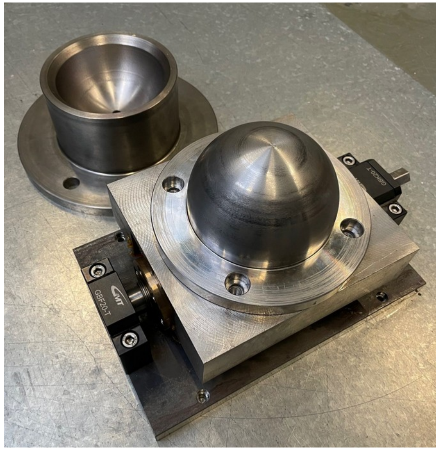
D_0 test for local change in R_0 due to glueing deformation:
→ **deformation < 1 cm in R_0**

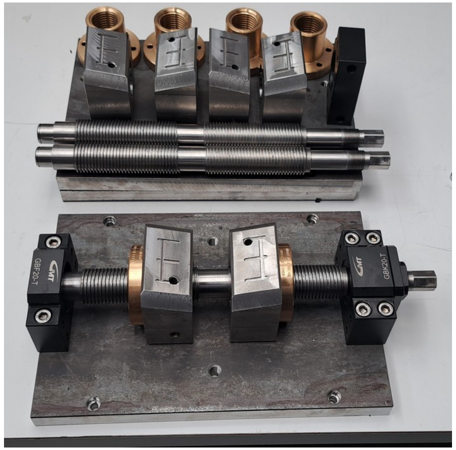
Other components: RICH alignment feet

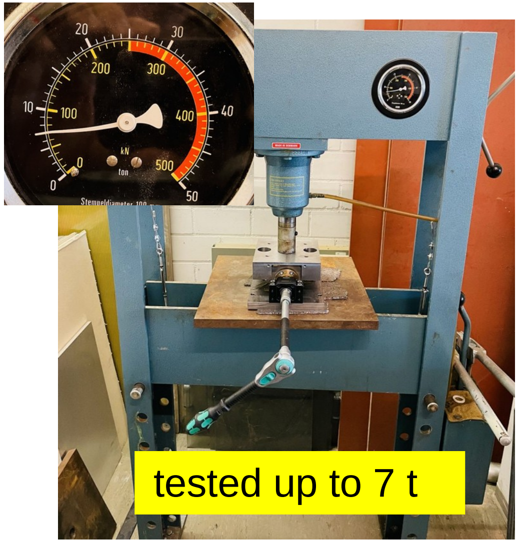


Requirements:

- Full RICH ~15t – resting on 3 feet (+...)
- Load capacity : 5-7 t / foot
- Height adjustment: Δ = 3 cm
- Movable in beam-direction: ~ 40 cm
- Reproducible detector positioning for crane ops.



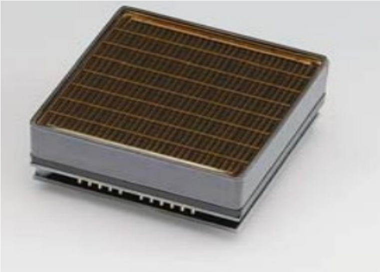




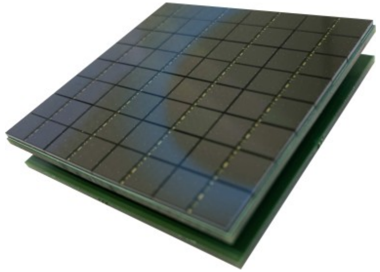
First studies towards a possible future upgrade with SiPM-MPPCs

SiPM MPPCs – a possible upgrade for CBM RICH ?

CBM-RICH day 1:
H12700 Multi-anode PMT



Multi-pixel MPPC SiPM



MAPMTs: current “state-of-the-art” in RICH

- $3x3\ mm^2$ / $6x6\ mm^2$ pixel size
- Hamamatsu only manufacturer
  - market+pricing driven by medical applications (PET scanners)

- Good efficiency (30+ % peak)
- Good timing (350 ps FWHM)
- Radiation hard
- Very robust, durable
- Low dark rate (<< 100 Hz / pixel)

- Better efficiency (up to 65% peak PDE)
- Better resolution (3x3 mm pixel and less)
- Better timing precision (typ. 50 ps)
- Much larger dark count rate : MHz / pixel
- Low radiation hardness

Particular challenges in CBM:

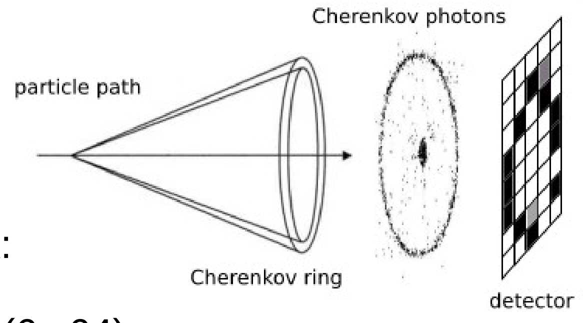
- Free-streaming, self-triggered DAQ
- **SiPM Pixel dark rate : ~ MHz / pixel**
- Radiation: 2 months CBM SIS100 HI run
  1 – 20 Gy
  $0.8 – 5\ x\ 10^{10}\ n_{eq}/cm^2$

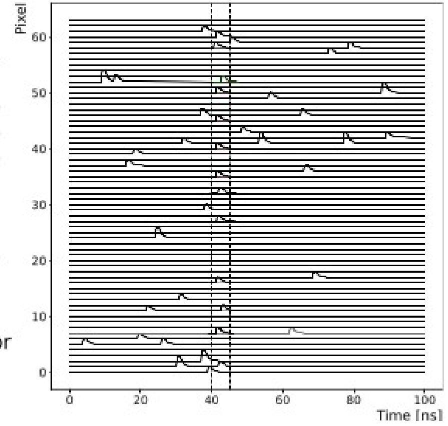
SiPMs @ CBM RICH:
Local coincidence triggering on DIRICH front-end FPGA

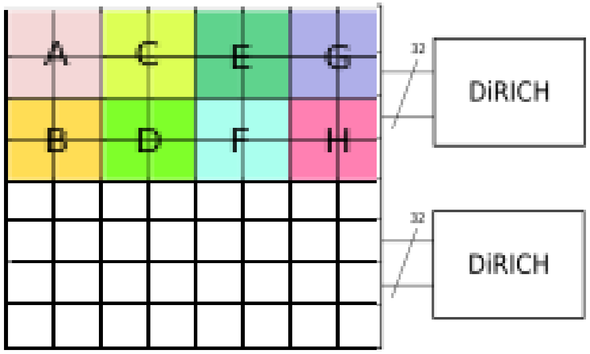
Strategy:

- Use existing DIRICH front-end + adapter
- Keep (start…) with same form factor as MAPMTs:
  6x6 mm² pixel size
- Signal shaping / tail cancellation of SiPM signals

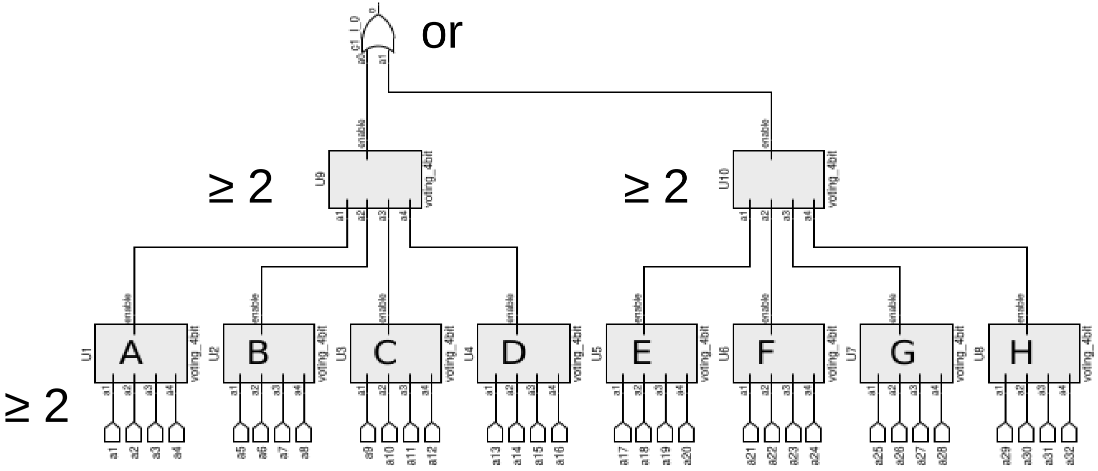
- Implement local coincidence logic on DIRICH FPGA:
  4-pixel coincidence + majority logic
- Possible 2nd step : extend over full readout modules (6x 64)



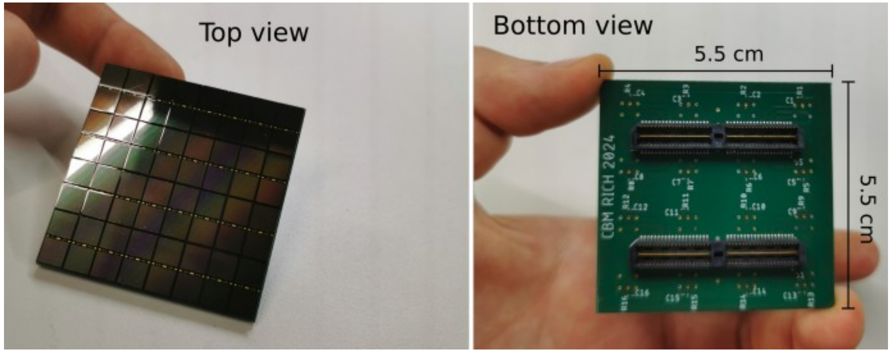




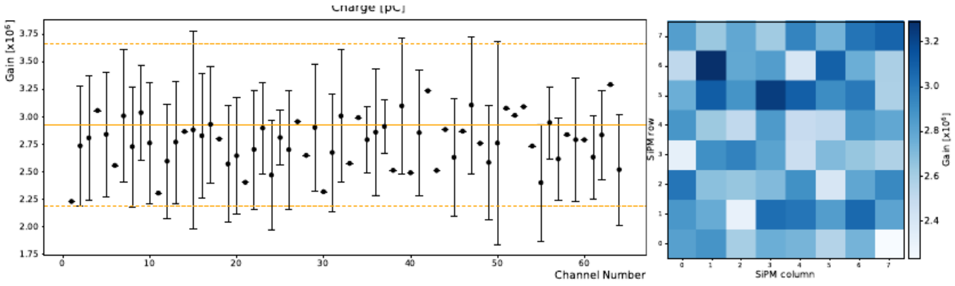
8x8 SiPM pixel MAPMT equivalent



First SiPM array prototype

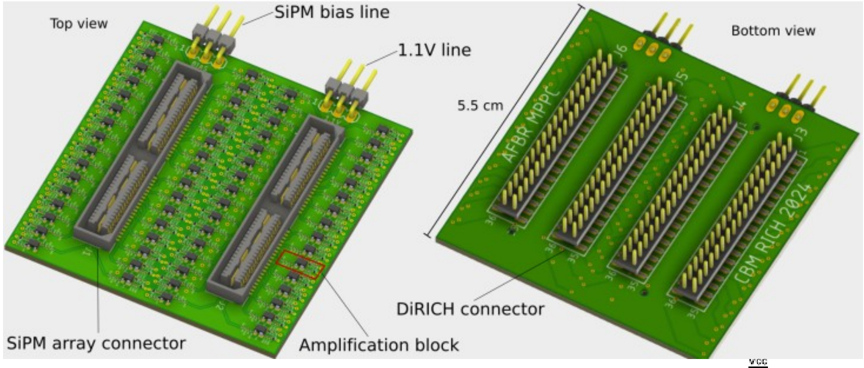


8x8 SiPM prototype:
manufacturing : GSI
64x **Broadcom AFBR – S4N66P024M**
gain : ~ 2.6 x 10^6
DCR: 150 kHz / mm², ~5 MHz / pixel
PDE: 63% peak

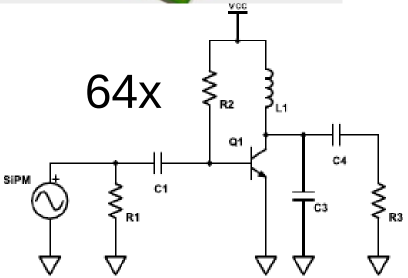


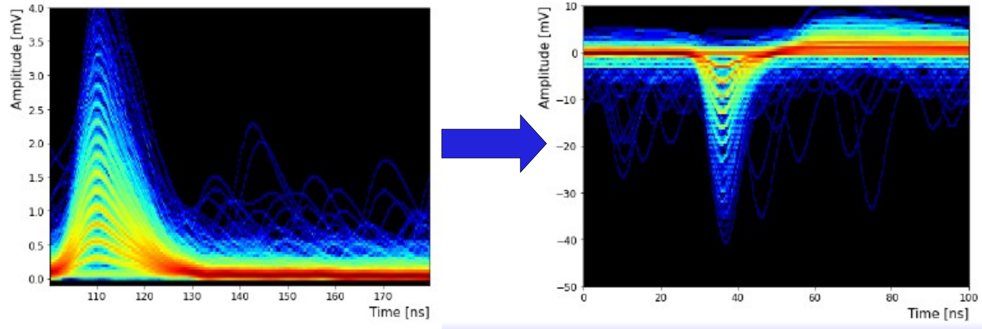
SiPM array gain variation

+

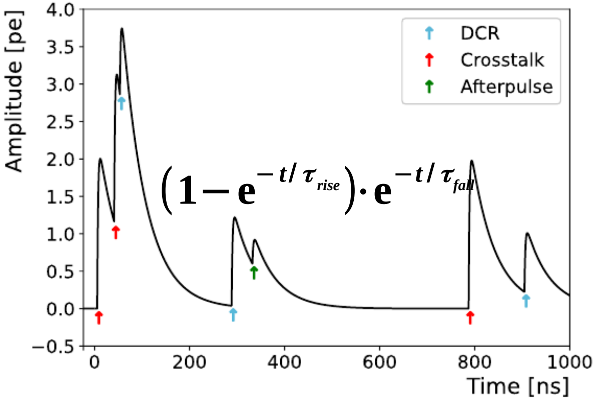


Preamp + Adapter board:
64x shaper+amplifier
pinout identical H12700
match CBM RICH readout
gain : ~ x12
1.1 V / 12 mA per channel

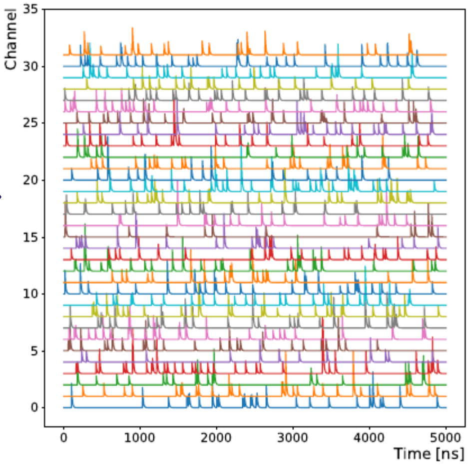




First simulations on trigger performance

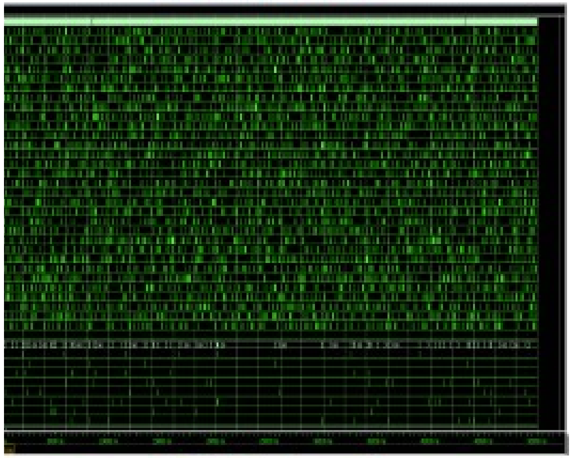


Realistic SiPM signal simulation including
- Signal shape (rise / fall time)
- Dark count rate (DCR)
- Cross talk
- Afterpulsing



32x individual SiPM pixel
+ correlated (cherenkov) signal

200 kHz/mm²



32x
discriminated
input pulses

8x
group
coincidence

FPGA signal simulation

First results:
- 2 MHz/channel DCR → output rate ~ 1 kHz / DIRICH
- 7 MHz/channel DCR → output rate ~20 kHz / DIRICH

- Strong dependence on coincidence window...

“A simulation framework for SiPMs”
J. Peña-Rodríguez et al.
JINST 20 (2025) P04031

poster: “SiPM-based RICH detector...”
J. Peña-Rodríguez
this conference

Summary

- Transition from design- to contruction phase

- Several crucial Design Reviews within next months
  - mirror + mirror wall (Oct 2025)
  - mirror alignment
  - RICH mechanics

- Both photon cameras fully assembled
  - large fraction of front-end electronics produced
  - full system cooling test upcoming

- RICH detector installation in cave : **2027**
  RICH ready for first beam : **end 2028**

- First R&D towards possible future SiPM upgrade

For further details:

poster: **“Mirror system of the CBM RICH”**
Sven Peter

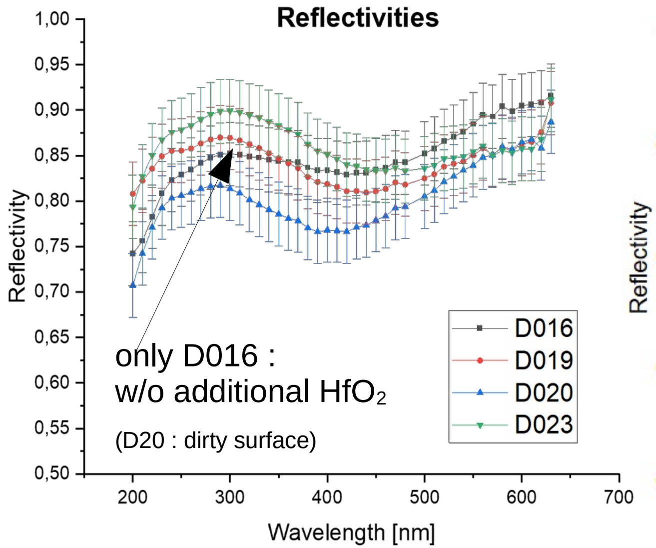
poster: **“The mRICH detector for the mCBM Prototype Experiment”**
Abhishek Deshmukh

poster: **“CBM RICH ring reconstruction using Machine Learning”**
Martin Beyer

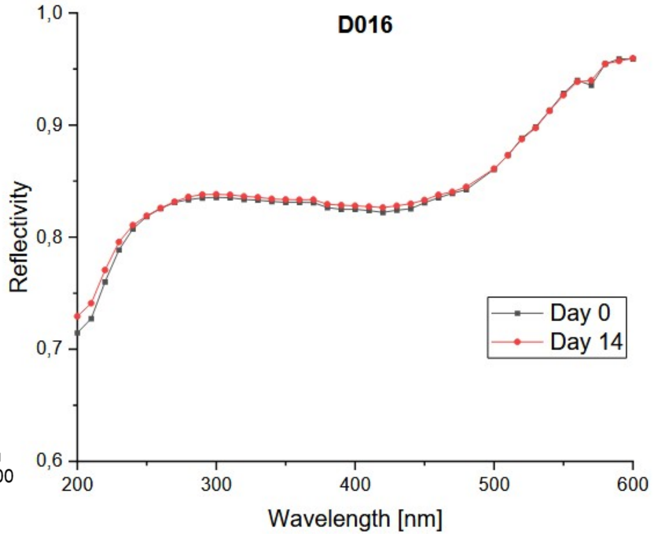
poster: **“SiPM-based RICH detector at an upgraded CBM experiment”**
J. Pena-Rodríguez

Mirror tiles

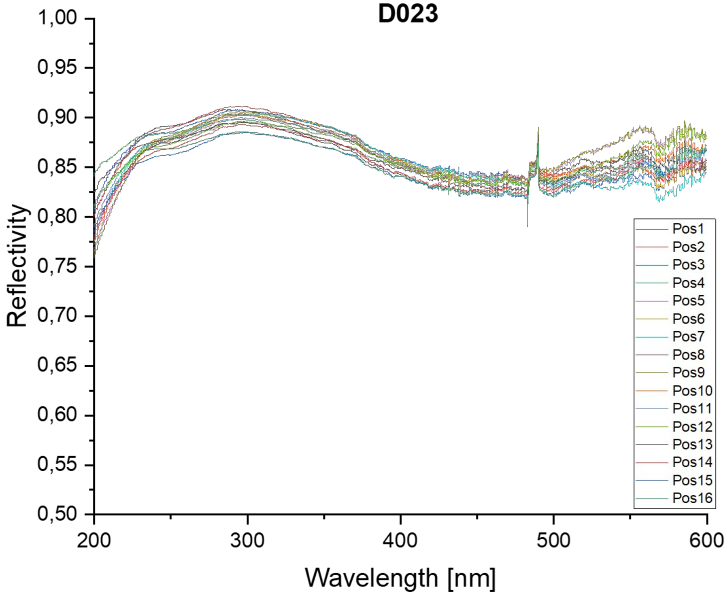
- Mirror tiles from **Fa. JLO Olomouc**
- 6mm Simax glass + MgF_2 (+HfO_2) coating
  additional HfO_2 : better stability, slightly better (+3%) overall reflectivity
- 80 tiles, 4 different trapezoidal shapes, + 4 special (beam pipe)
- stability of reflectivity and coating : tested in climate chamber



measured reflectivity on prototype tiles



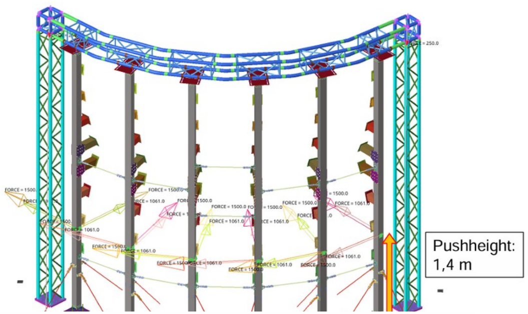
effect of humidity 70%,
14 days in climate chamber

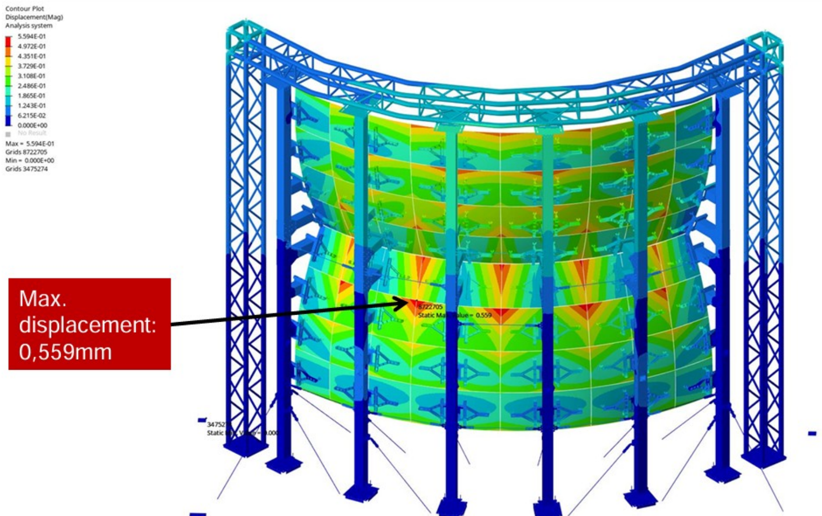


Reflectivity - surface homogeneity

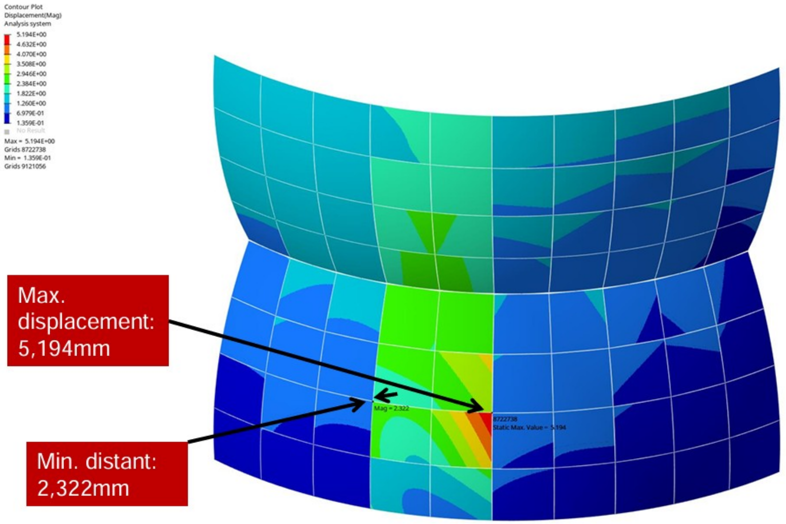
Mirror wall stability FEM simulations

- Comprehensive FEM stability simulations of mirror wall
  2D simulation, HyperMesh + OptiStruct
  - under influence of gravity
  - during crane operation
  - worst-case accidents (person stumbling against mirror pillar)
  - mild earthquakes (~ 1 m/s² acceleration)
- Mirror tiles must not touch under any circumstance !





maximum displacement of mirror tiles under gravity load

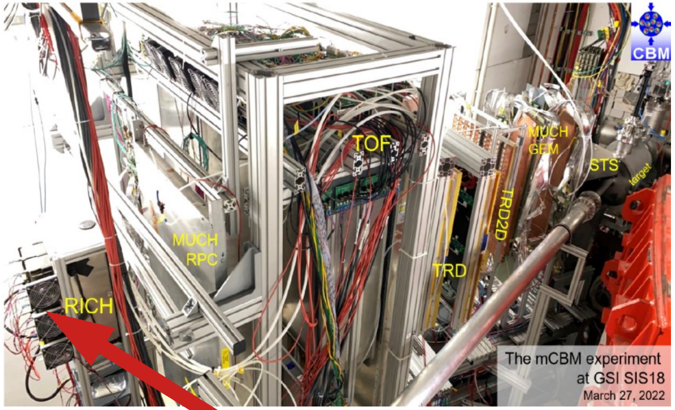


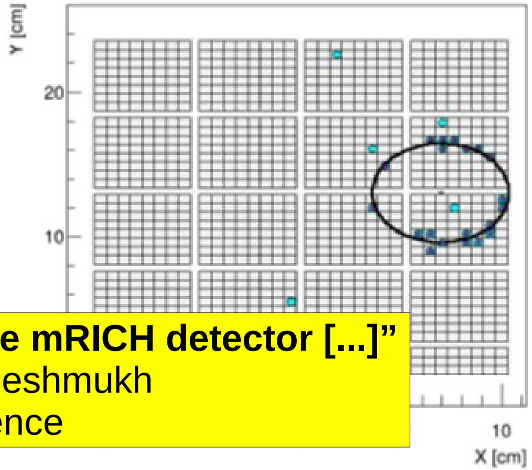
max. displacement and min. distance if person accidentally "pushes" against pillar with 1500 N

DIRCH readout chain within mRICH@mCBM operational !

- mRICH @mCBM detector:
  - 2 aerogel tiles, 36 MAPMTs, 6 readout modules
  - same DIRICH-MAPMT readout chain as in CBM RICH

- Successful integration of DIRICH into CBM CRI-based readout
- CBM-like free-streaming, triggerless readout already operational !
- Important test bed for further DAQ developments !
- Successful participation in 2024 and 2025 data runs





poster: **“The mRICH detector [...]”**
Abhishek Deshmukh
this conference