Conception and design of a control and monitoring system for the mirror alignment of the CBM RICH detector

J. Bendarouach for the CBM collaboration
Justus-Liebig-University Gießen, Germany – contact: *Jordan.Bendarouach@exp2.physik.uni-giessen.de*

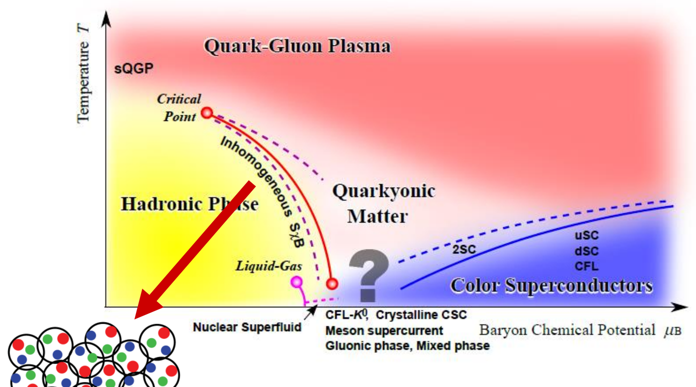
Introduction

CBM at FAIR

Explore the QCD phase diagram in the region of high net-baryon density with A+A collisions at energies from 2 to 11 AGeV (at SIS100)

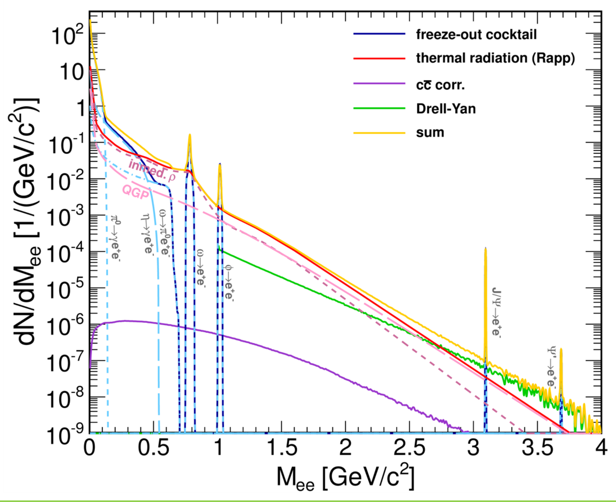
Phase diagram at high μ_B ?

- Quarkyonic phase?
- Phase transition(s)?
- Critical point/ triple point?
- **Need for high precision data including rare probes**



EM probes

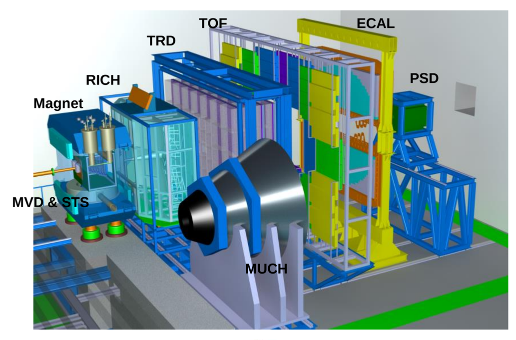
- Low-mass region
  Photons: early temperatures of the fireball
  Low mass vector mesons: hadron dynamics
- Intermediate-mass region
  Slope: indicates thermal radiation of the fireball
  Also hints for a quarkyonic phase?
- High-mass region (SIS 300?)
  J/Ψ: investigation of the charm quark propagation



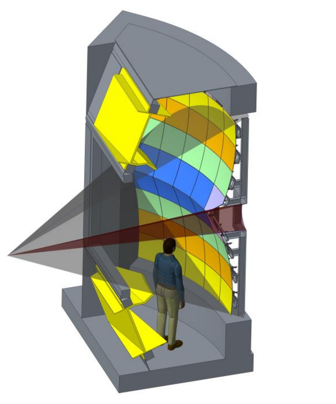
Efficient and clean electron identification together with a combined pion suppression factor of 1000 to 5000 (using in addition a Transition Radiation Detector) are required in a wide acceptance.

Concept of the CBM RICH Detector

Ring Imaging CHerenkov (RICH) detector for electron identification (p<8GeV/c):



- Gaseous RICH detector for electron identification, with CO_2 as radiator gas ($p_{\pi,th}$=4.65 GeV/c)
- 2 photodetector planes (MAPMTs, Hamamatsu H12700) with approx. 55.000 channels
- 2 large spherical mirrors (R=3m) as focusing optics, Al+MgF_2 reflective coating
- Vertical splitting of RICH geometry because CBM dipole magnet is located in front of the RICH (photodetector planes shielded by magnet yoke; particle tracks horizontally spread)
- RICH and MUCH detectors will be exchanged approximately once every year. During this process the RICH will be craned out to the MUCH parking position → need for an alignment control system



In case of mirrors misalignment:

- Efficiency losses in ring reconstruction: ring splitting, ring distortion, double rings, ring-track mismatches
- Misidentification due to distorted ring parameters, too large ring-track distances
- Perfectly aligned and stable mirror system is required for accurate and highly efficient ring reconstruction

Development of an alignment correction cycle:

- Monitor misalignment qualitatively
- Determine misalignment quantitatively
- Apply corrections at the reconstruction level

Qualitative control of mirror alignment

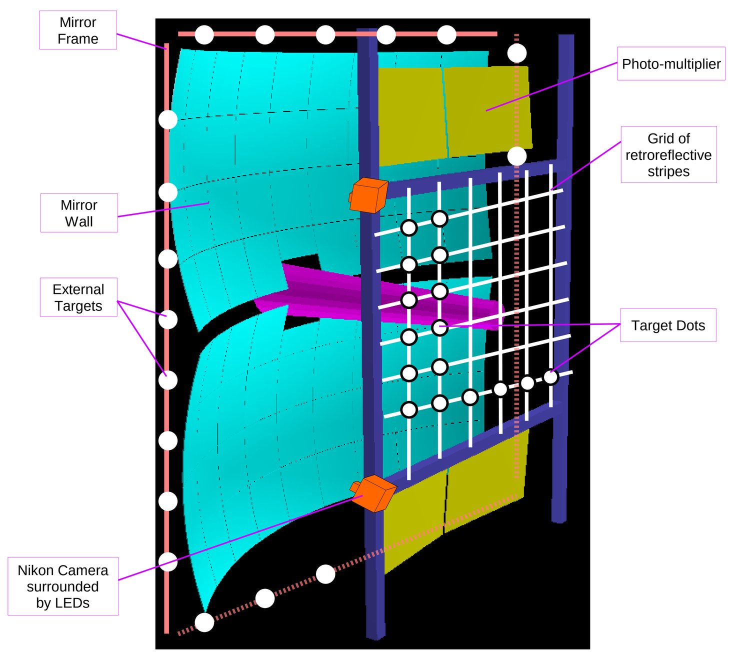
Principle of Continuous Line Alignment Monitoring Method (CLAM)[1,2]

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



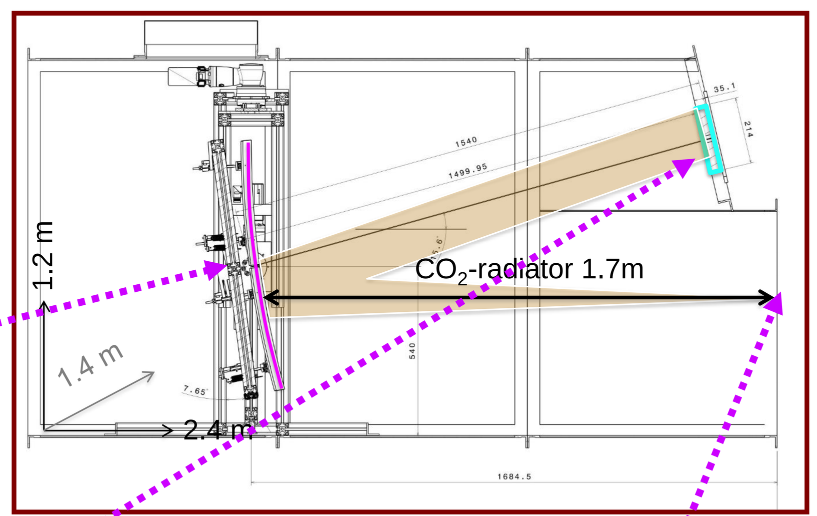
[1]: Alexeev M et al (COMPASS) 2008 Nucl. Instr. Meth. Phys. Res. A 595 194-6
[2]: Alexeev M et al (COMPASS) 2011 Nucl. Instr. Meth. Phys. Res. A 639 219-21

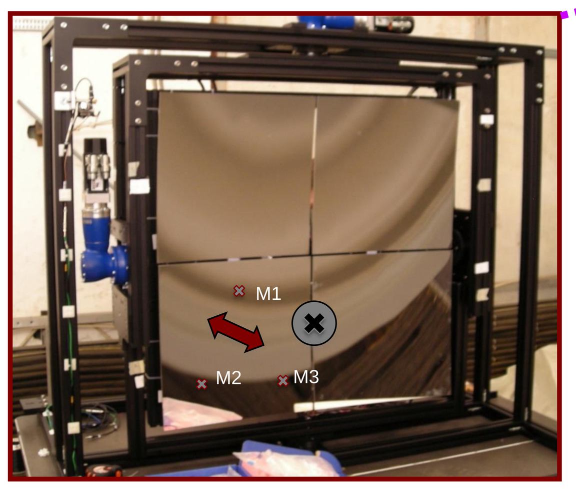
Prototype set-up and equipment

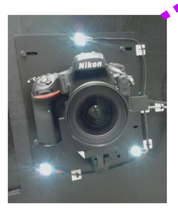
This method has been implemented in a downscaled prototype of the CBM RICH detector and tested under real conditions at the CERN PS/T9 beamline in Nov 2014, with electron and pion beams and momenta ranging between 1 and 10 GeV/c.

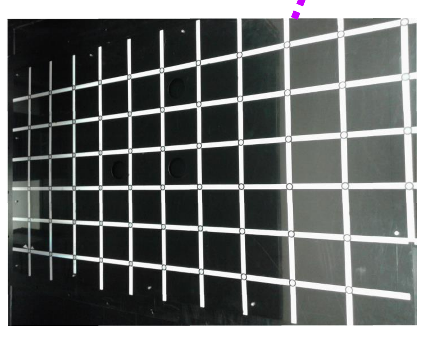
Prototype:

- Sketched side view of the prototype
- Four-mirror system remotely controlled
- CLAM camera surrounded by three LEDs
- Photomultiplier plane
- Retro-reflective grid and target dots at the entrance window



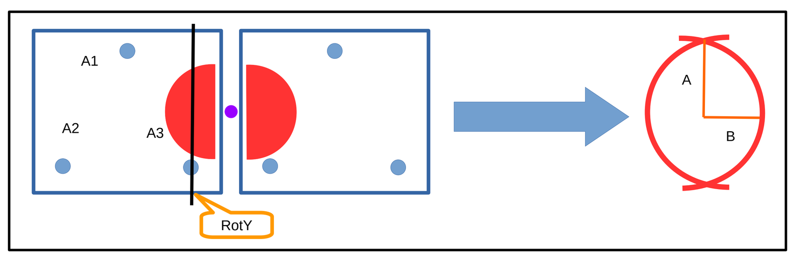






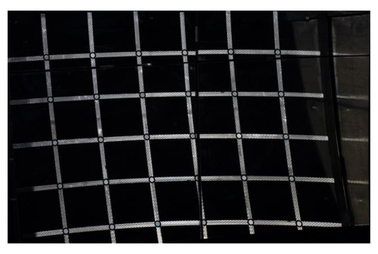
Sketch of the setup:

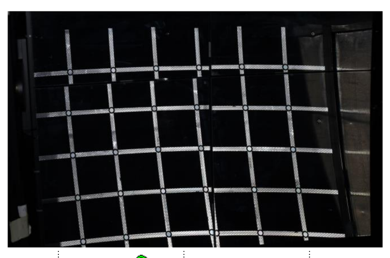
- Blue squares: two lower mirrors
- Red: half rings reflected on the mirrors
- Purple circle: beam traversing the two lower mirrors
- Blue circles: mirror actuators, for remote control
- Definition of A and B axes of the ellipse

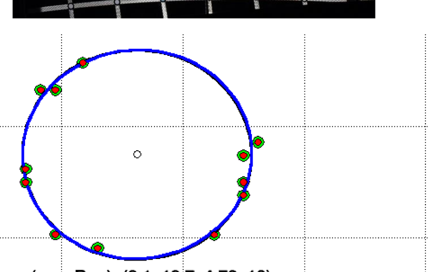


Mirror system viewed by the CLAM camera and corresponding reconstructed rings below:

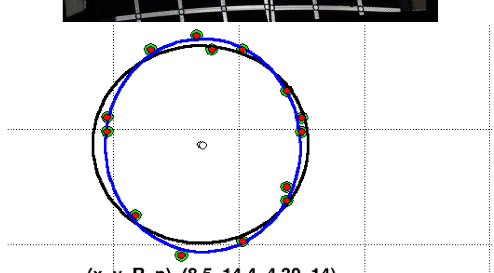
- Upper left and right pictures:
  - Left: system after the initial alignment. The beam is traversing in between the two lower mirror tiles
  - Right: system after artificial misalignment of 4 milliradians has been applied to the lower left mirror
- Lower left and right pictures correspond to single event rings in these configurations:
  - Left: Very nice ring (black)
  - Right: elliptical shape (blue)







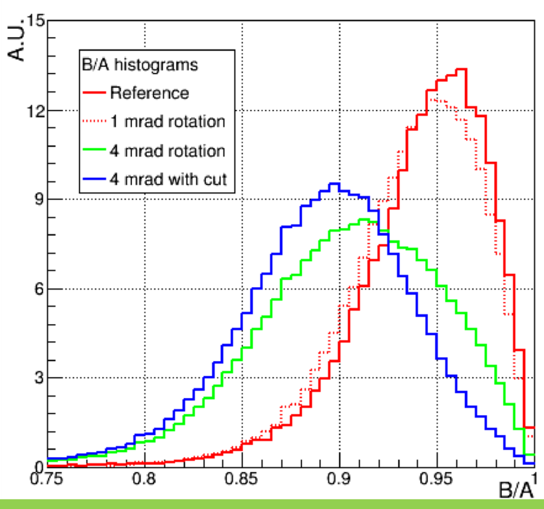
(x, y, R, n)=(8.1, 13.7, 4.72, 12)
(x, y, A, B, ϕ, n, B/A)=(8.1, 13.8, 4.75, 4.69, 0.69, 12, 0.99)



(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)

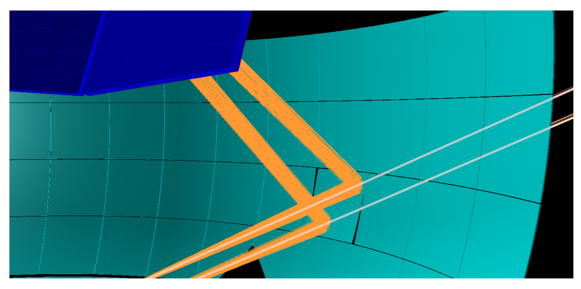
Impact of misalignments on ring parameters:

- Ring ellipticity distributions for various misalignments.
- Ellipticity defined as B/A
- 4 different cases are illustrated:
  - Distribution after initial reference alignment in red
  - Misalignment of 1 mrad on one tile in dashed red
  - Misalignment of 4 mrad on one tile in green
  - Cut enhancing the 4 mrad misaligned data sample (better event selection, for tracks running between the lower mirrors)
- Mean ellipticity of blue curve below 0.9
- Drop in reconstruction efficiency from close to 100% down to 90%



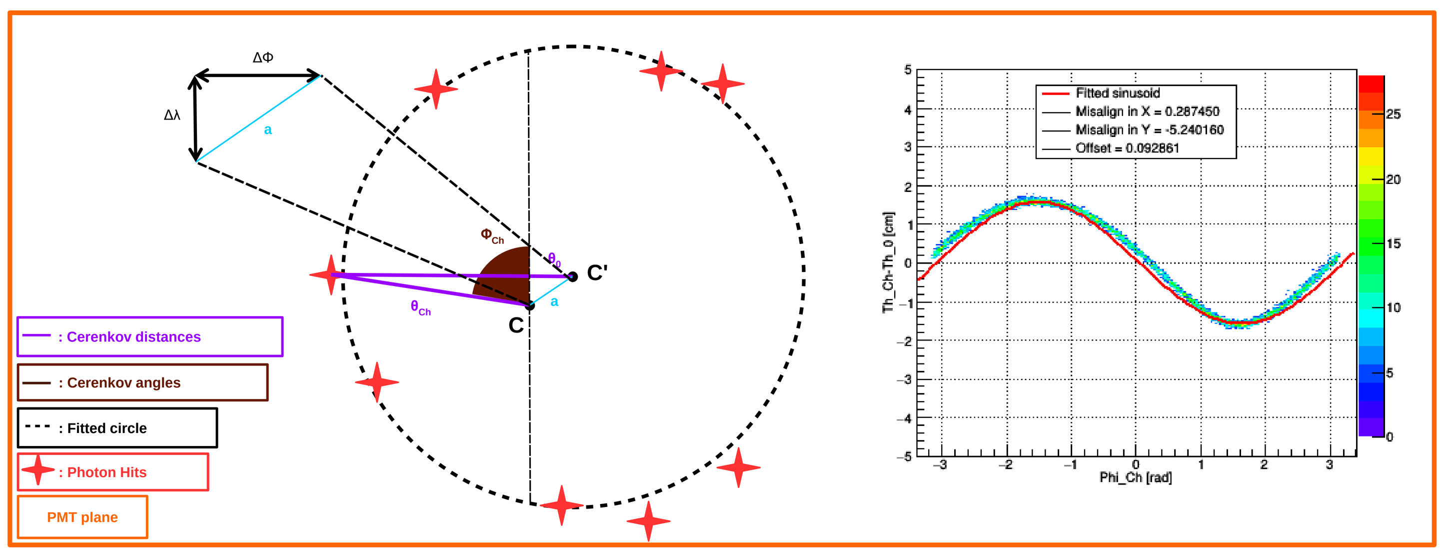
Quantitative control of mirror alignment

Principle of the correction using data[3,4]



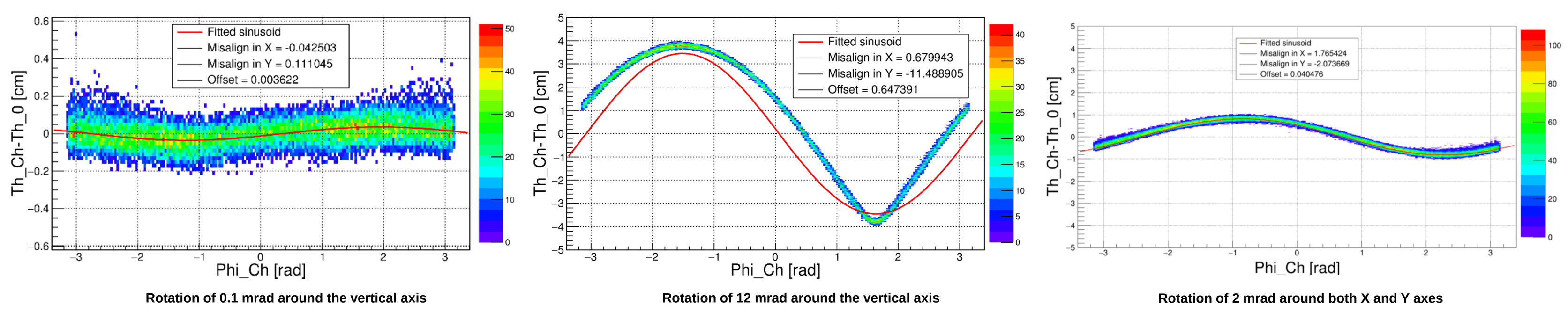
- Fitted ring center C' and extrapolated track hit C
- Calculation of Cerenkov distances θ_{ch} and angles Φ_{ch}
- Sinusoidal behavior: $\theta_{Ch} = \theta_0 + \Delta\Phi * cos(\Phi_{Ch}) + \Delta\lambda * sin(\Phi_{Ch})$

[3]: Gorisek A, Krizan P, Korpar S and Staric M (HERA-B) 1999 Nucl. Instr. Meth. Phys. Res. A 433 408-12
[4]: Staric M and Krizan P (HERA-B) 2008 Nucl. Instr. Meth. Phys. Res. A 586 174-9



Performances of the method

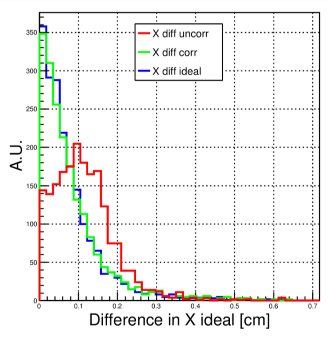
- Simulation of a 5 mrad misalignment around the horizontal axis of one tile
- Minimum detectable misalignment: 0.1 mrad & maximum detectable misalignment 12 mrad. For larger misalignments, C is outside of the ring
- Detection of misalignment on both rotation axes simultaneously
- In principle misalignments on four different mirror tiles at the same time can be detected

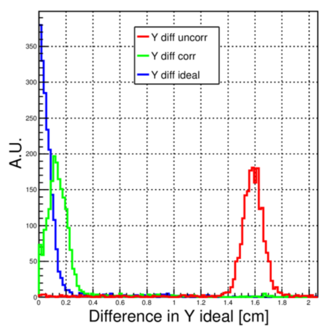


Correction routine development

Correction on one tile

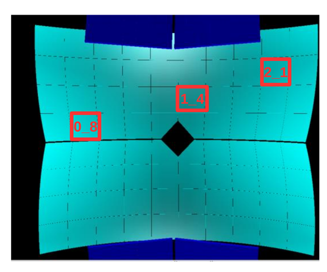
- 5 mrad misalignment around horizontal axis
- Determination of the misalignment, using the quantitative method described above:
  - 5.24 mrad misalignment around horizontal axis
  - 0.37 mrad misalignment around vertical axis
- Correction of the extrapolated track hit onto the photomultiplier plane
- Calculation of the distances between the extrapolated track hit and the fitted ring center ; in red without corrections ; in green using the corrected values from the method ; in blue with ideal corrected values
- Method used to determine correction values on different misaligned tiles at the same time

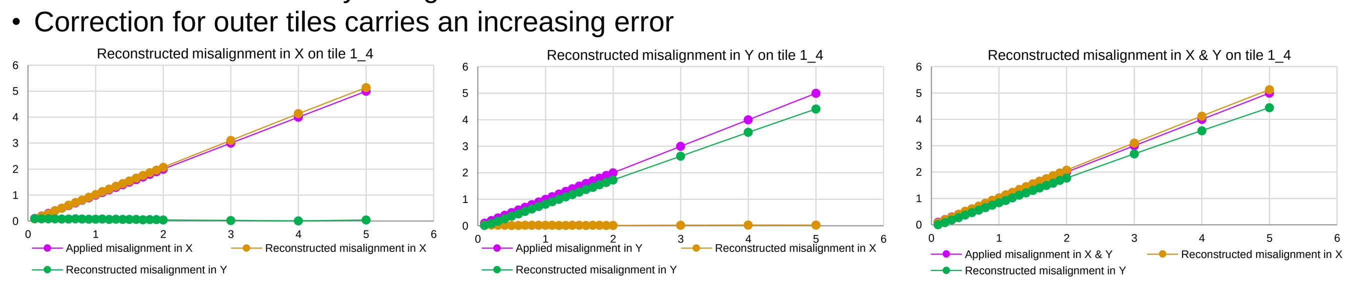


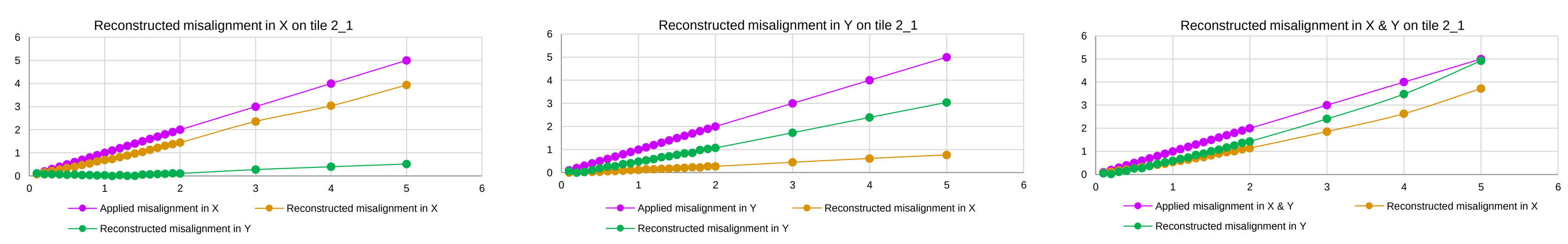


Performances of the correction method

- Misalignments applied on tiles located at different places on the mirror wall
  - Tile in the inner region (i.e. close to the beam pipe, going through the black rhombus)
  - Tile in the outer region
- Correction for inner tiles yields good results
- Correction for outer tiles carries an increasing error







Outlook

Presentation of an alignment correction cycle for the CBM RICH detector. The system is able to detect misalignments qualitatively for monitoring purposes and to quantify them with data. A correction routine is also implemented and shows promising results.

HIC for FAIR Helmholtz International Center

HGS-HIRe for FAIR Helmholtz Graduate School for Hadron and Ion Research

JUSTUS-LIEBIG-UNIVERSITAT GIESSEN

GSI

Supported by the Helmholtz International Center for FAIR, the GSI Helmholtzzentrum für Schwerionenforschung F&E cooperation with Gießen, the Helmholtz Graduate School for Hadron and Ion Research and the BMBF grants 05P15RGFCA and 05P12RGFCG