Investigation of surface homogeneity of mirrors for the CBM-RICH detector and low-mass di-electron feasibility studies

Elena Lebedeva
Justus-Liebig-Universität, Giessen

HIC for FAIR Helmholtz International Center

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

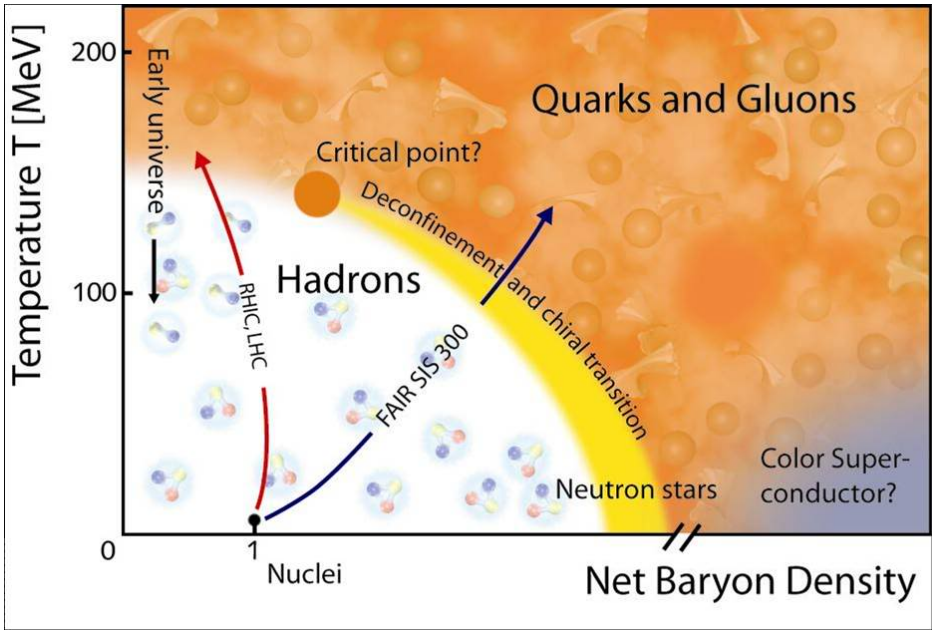
JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

CBM RICH

Agenda

- CBM experiment
- Surface homogeneity of mirrors for RICH detector
- Low-mass di-electrons

Motivation
Exploring the phase diagram of nuclear matter



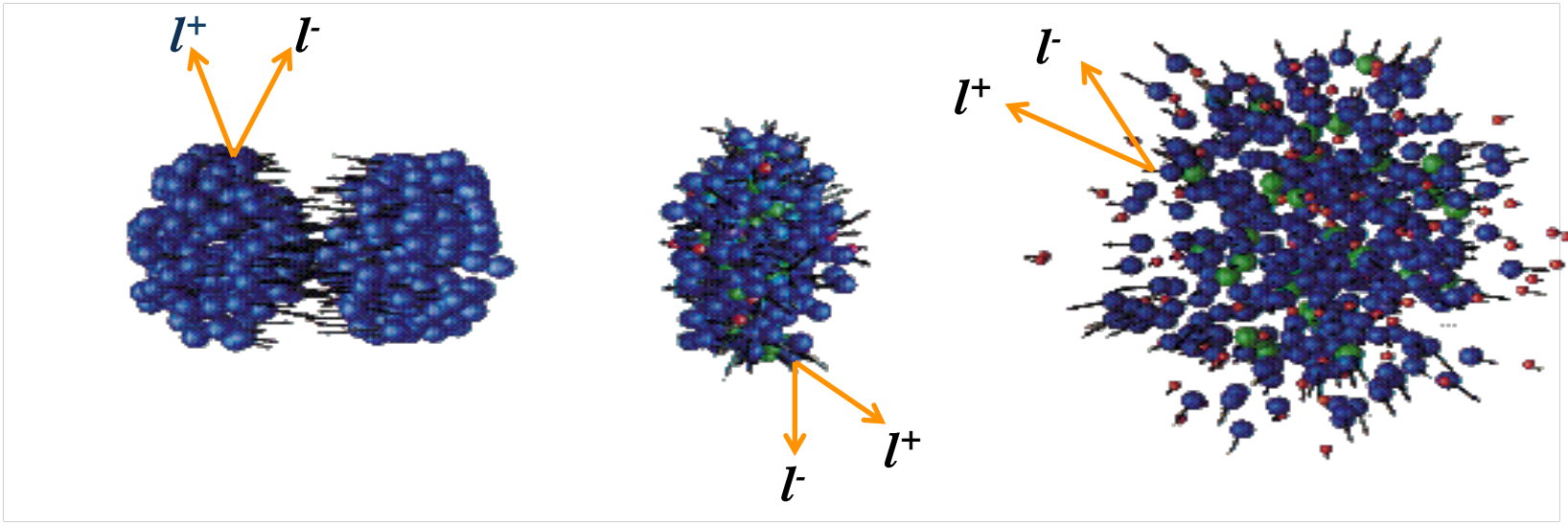
The CBM research program is focused on the following physics cases:

- The equation-of-state of baryonic matter at neutron star densities
- In-medium properties of hadrons ($\rho,\omega,\phi \longrightarrow e^+e^-(\mu^+\mu^-)$)
- Phase transitions from hadronic matter to quarkyonic or partonic matter at high net-baryon densities
- Hypernuclei, strange dibaryons and massive strange objects

Lepton pairs are one of the key signatures for CBM

Motivation

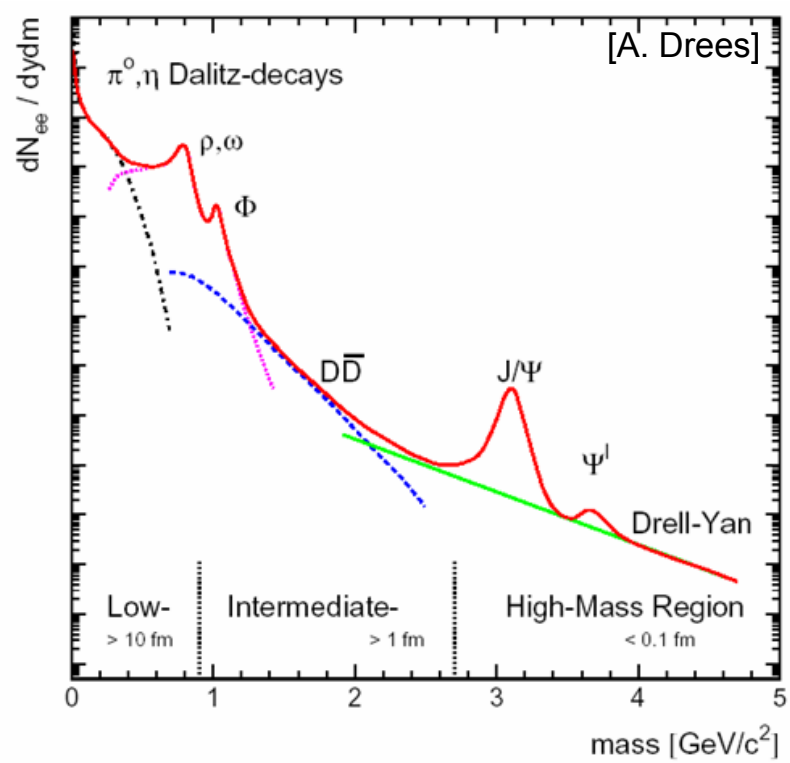
- Dileptons as ideal probes to study the properties of the matter created in heavy-ion collisions



- The dilepton signal contains contributions throughout the whole collision
- No strong final state interactions -> leave reaction volume undisturbed

Motivation

All di-electrons in all energy regimes are penetrating probes, i.e. face no strong final state interaction.



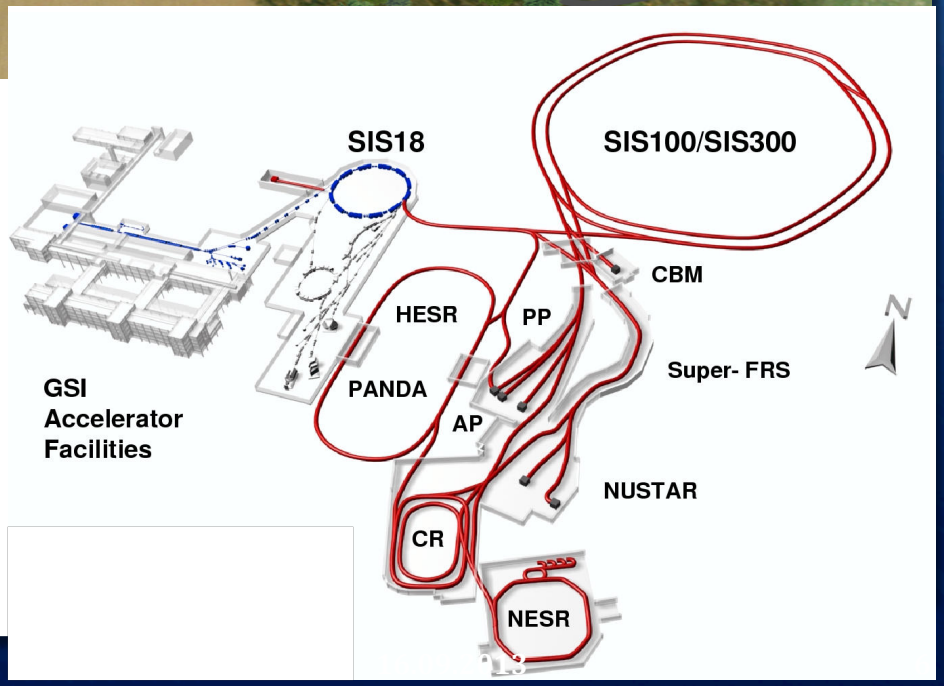
Measure electromagnetic radiation from the very dense baryonic matter at all energy ranges:

- Photons: get access to early temperatures
- Low mass vector mesons: get access to whole fireball evaluation and study in medium properties of ρ^0
  - short life time -> provide information about in-medium modifications
- Range 1 – 2.5 GeV/c^2 : get direct access to fireball radiation (QGP radiation? Temperature?)
- Charmonium: charm as a probe for dense baryonic matter

Facility for Antiproton and Ion Research

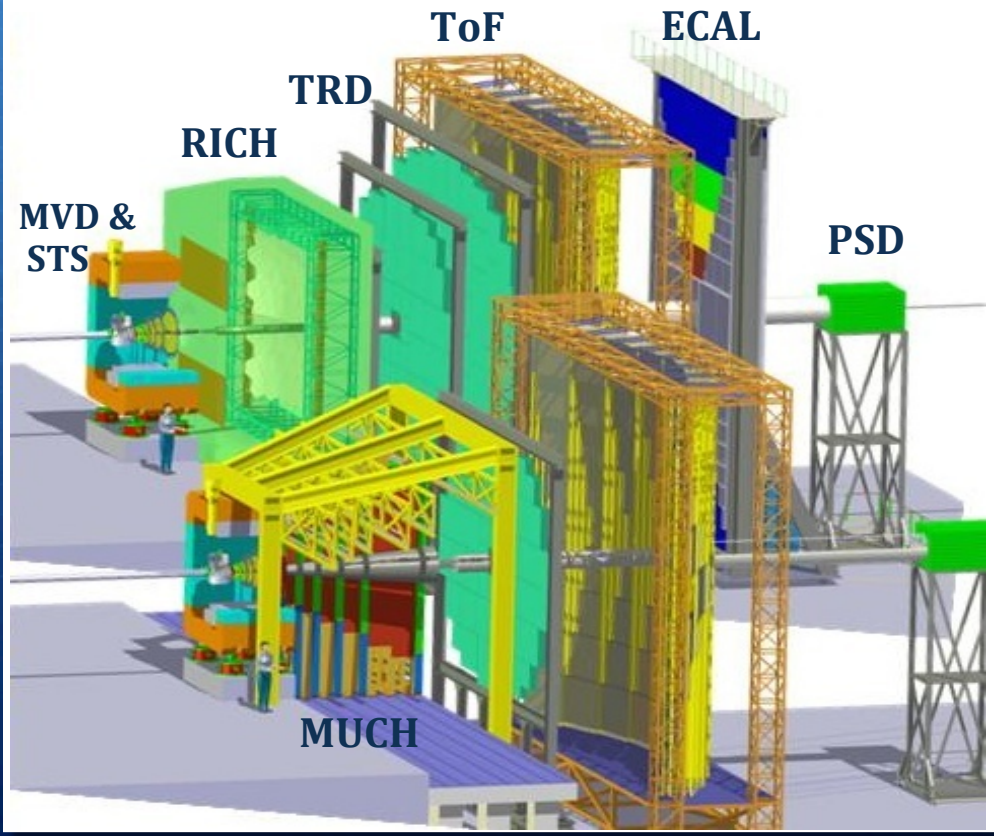
Accelerator complex serving experiments at a time (up to 5) from a broad community

- Beam availability for CBM:
  - SIS100 synchrotron:
    - Protons up to 29 GeV
    - Au-ions up to 11 AGeV
  - SIS300 synchrotron:
    - protons up to 90 GeV
    - Au-ions up to 35 AGeV



CBM experiment

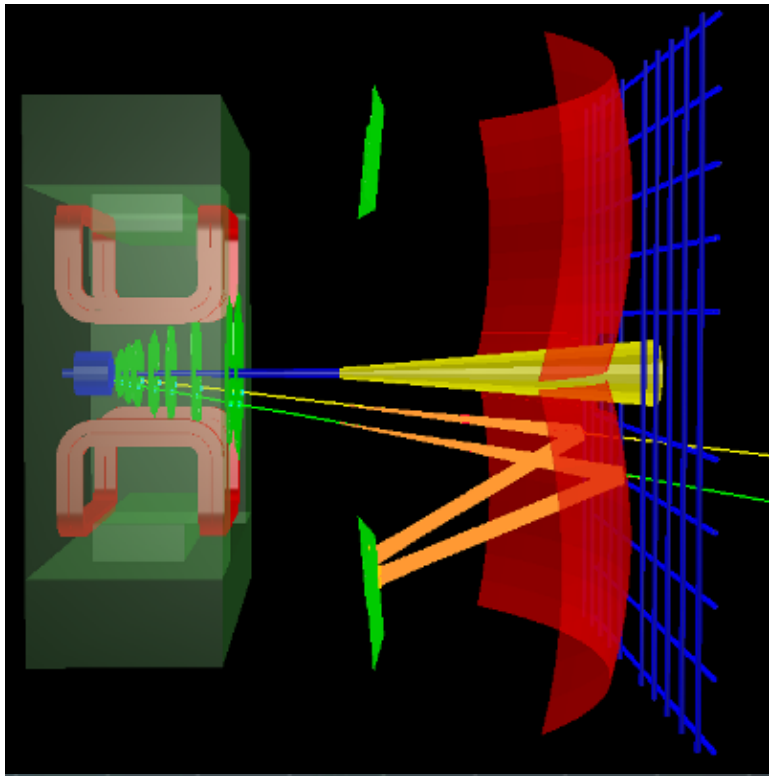
- Exploring the QCD phase diagram ⟶ measurement of hadronic and leptonic probes in large acceptance



- **MVD & STS** – tracking, momentum determination, vertex reconstruction
- **RICH & TRD** - electron identification ➔ pion suppression factor ≥ 10^4
- **MUCH** - muon identification
- **ToF** – hadron identification
- **ECAL** – photons, π^0
- **PSD** – event characterization

- Up to 10MHz interaction rate ➔ rare probes ➔fast reconstruction algorithms are essential!

The challenge (low-mass di-electrons)



- Lepton pairs are rare probes (branching ratio $<10^{-4}$)
- Large combinatorial background:
  - Dalitz decays (π^0)
  - Conversion pairs

1.2% $\gamma\, e^+e^-$

~350 π^0 $\longrightarrow$ 98.8% $\gamma\,\gamma$

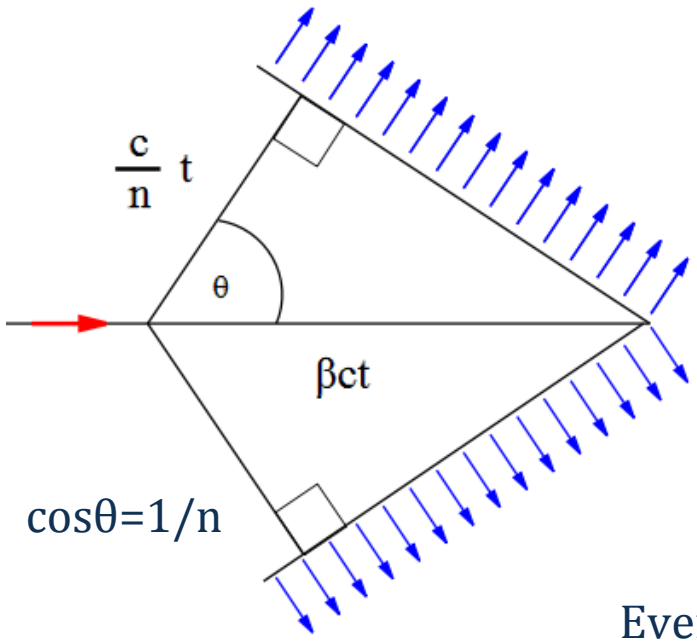
~3 γ $\longrightarrow$ e^+e^-

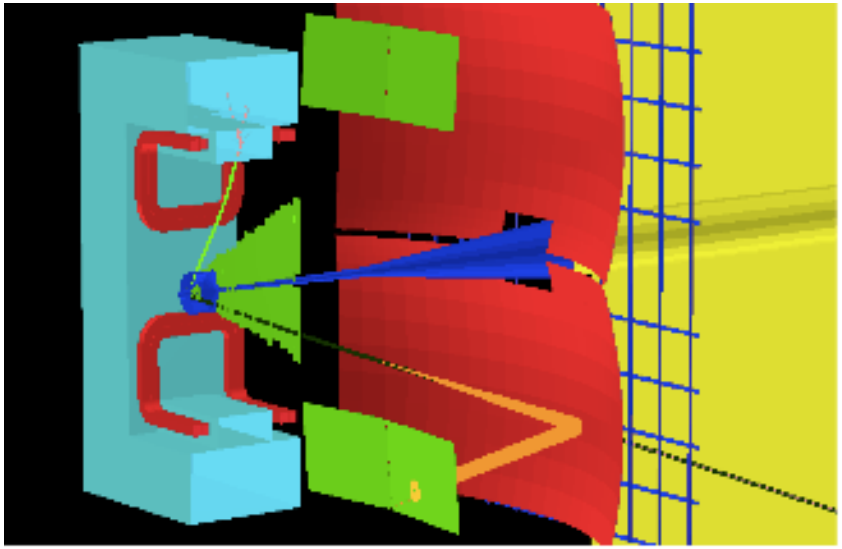
~700 $\pi^{+/-}$ could be identified as an electron

- Background due to material budget of the STS

Principle of Ring Imaging CHerenkov detectors (RICH)

- A cone of Cherenkov light is produced when a particle traverses a suitable medium (radiator), with a velocity greater than the speed of light in the medium (v>c/n, n being the refractive index of the medium).
- In RICH detectors this light cone is focused as ring on a position sensitive photon detector.

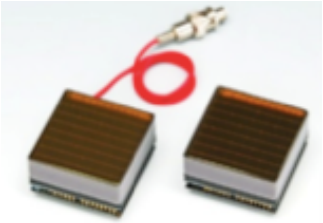




Event display for simulation of di-electron decay from ρ

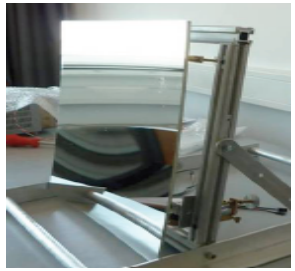
CBM-RICH detector

- The CBM-RICH detector is designed to provide electron identification in the momentum range up to 8 GeV/c.



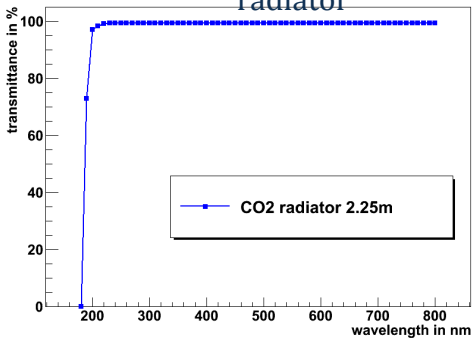
Hamamatsu H8500

- It will be operated with:
  - 1.7m long CO_2 radiator gas (n=1.00045, threshold for pions 4.65 GeV/c)
  - MAPMTs (Multi-Anode Photo Multiplier) as photodetector
  - Spherical glass mirrors as focusing element (70 mirror tiles)

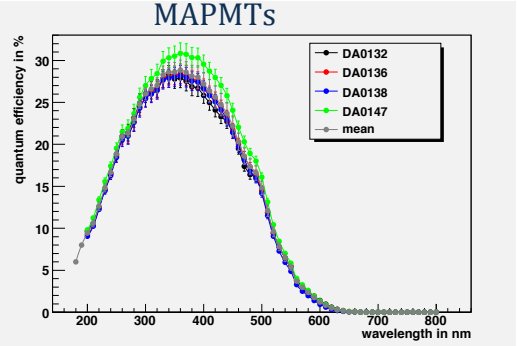


SLO Olomouc

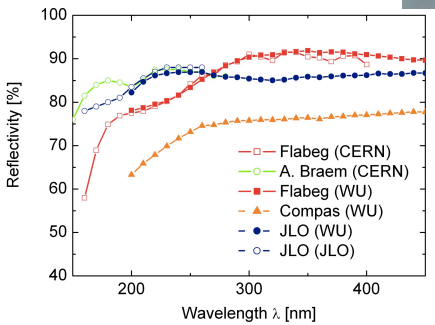
radiator



MAPMTs



mirrors



These foreseen detector components work well together in terms of the covered wavelength range

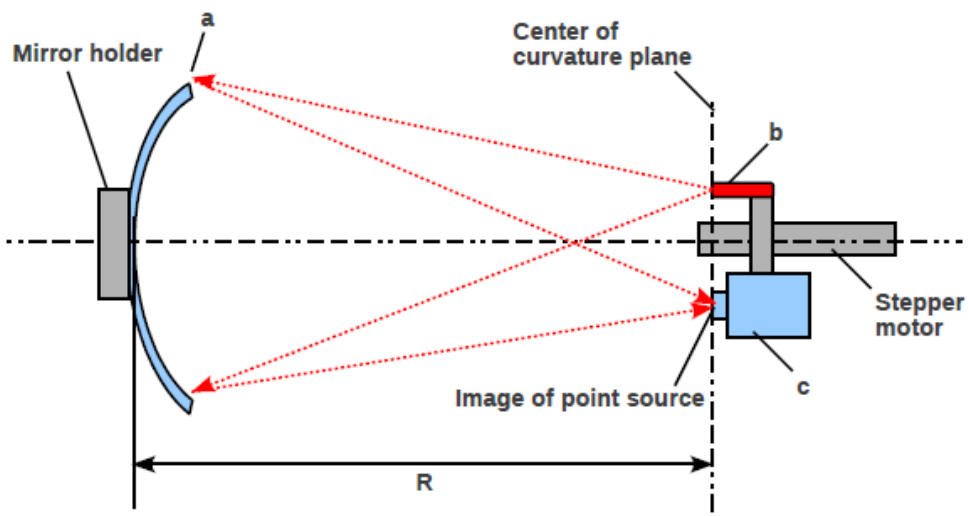
Mirror surface homogeneity

A good optical quality of the spherical focusing mirror, in particular in terms of reflectivity and surface quality (homogeneity), is essential for the performance of the RICH detector.

- The optical surface quality determines the imaging quality or "sharpness" of the projected Cherenkov rings and has direct influence on the ring-fitting performance.
- To quantify the surface non-homogeneity the D_0 measurement is used.
- D_0 is defined as diameter of the circle, which contains 95% of the total light intensity reflected by the mirror when illuminated with a point source.
- D_0 is expected to be the smallest at a distance which is the radius of the mirror curvature.

Measurement setup

Experimental setup for D_0 measurements



a – spherical mirror
b – laser point source
c – CCD camera
R – radius of curvature

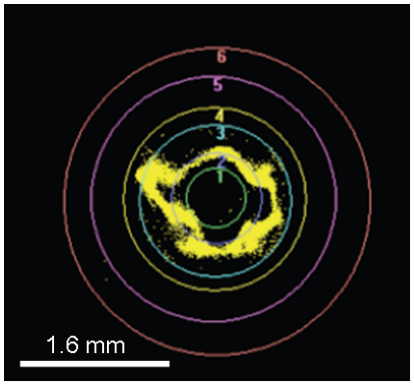
- Andor iKon CCD camera with 1024×1024 pixels (13.3×13.3 mm^2)
- Laser point source with wavelength 650nm
- 4 mirror prototypes from SLO Olomous 40×40 cm^2 with radius of curvature 3m; SIMAX glass (6mm), polished, Al+MgF_2 reflective and protective coverage

Results of the measurements

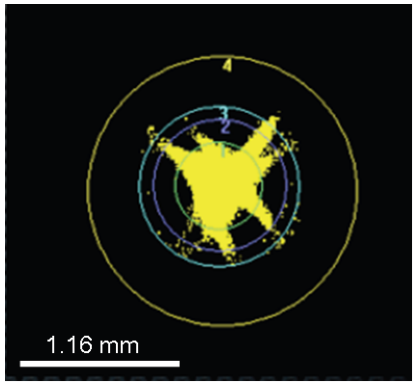
- Two different measurements were done for each mirror:
  - at the nominal radius
  - for the smallest spot of reflected light
- Ideally both measurements give the same results.
- But due to manufacturing process the mirrors lose some of their concavity leading to a larger radius.

Mirror	$D_{0,min}$ [mm]	ΔR [mm]	D_0 (R=3m) [mm]
SP01	1.16	+5	1.60
SP02	1.42	+12	2.58
SP03	0.88	+5	1.81
SP04	1.3	+13	2.89
Mounted	0.98	+3	1.4

CCD camera view



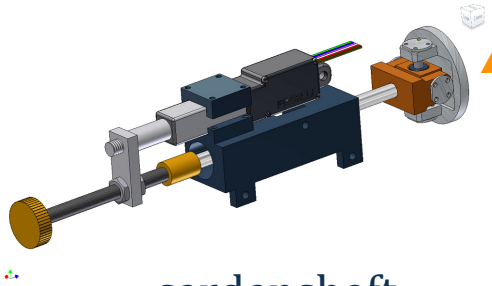
R = 3m



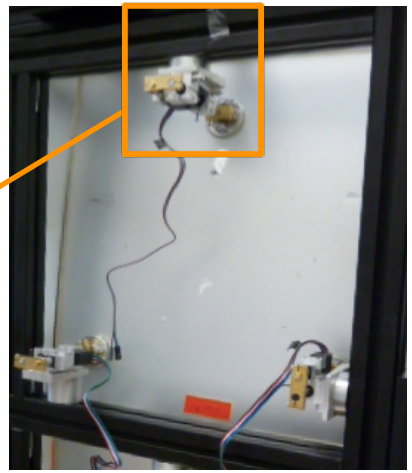
for smallest spot

Ongoing work and plans

- Preparing the program for automatization of the measurement process -> fast measurements and more precise analysis, quality control for the 70 mirror tiles.
- Other methods for study the mirror surface -> see local inhomogeneities (from gluing the mirror mounts):
  - Ronchi test
  - Shark-Hartmann test

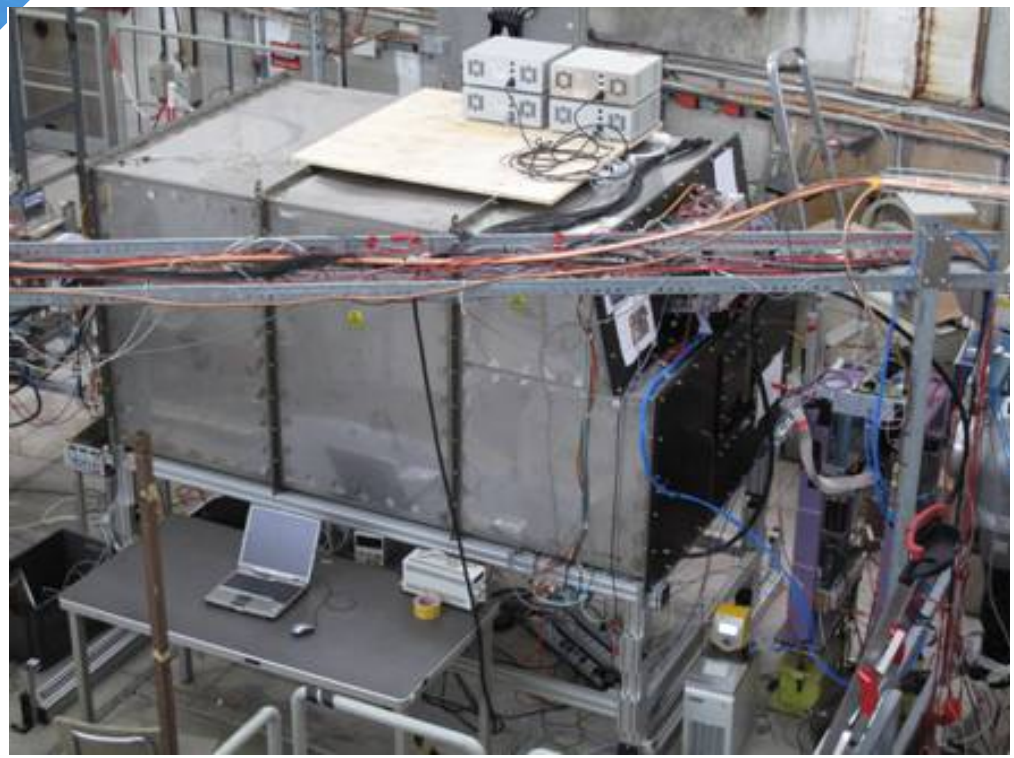


cardanshaft



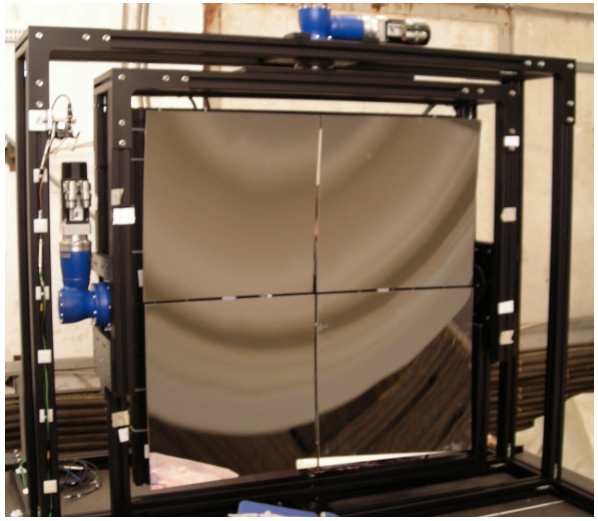
mount system

RICH prototype

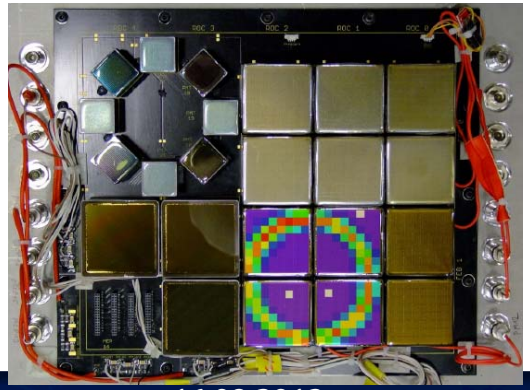


Real dimension prototype in test beam at CERN in 2011 and 2012

Movable mirror frame



Photocamera with various MAPMTs



Agenda

- CBM experiment
- Surface homogeneity of mirrors for RICH detector
- Low-mass di-electrons

Input to the simulation

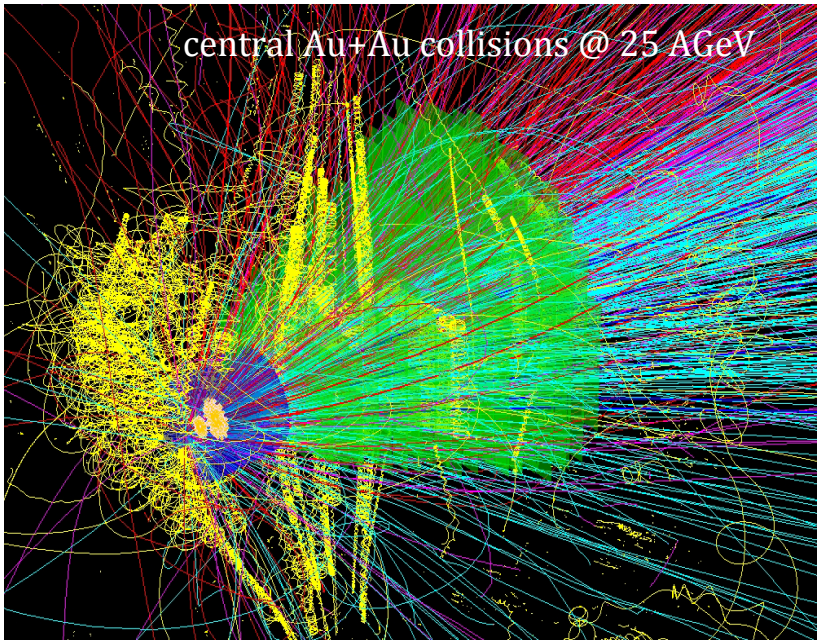
- CbmRoot, GEANT3 package
- Central Au+Au collisions at 25 AGeV and 8 AGeV beam energies
- Background – UrQMD events ($e^{\pm}$ from γ-conversion, π^0, η-Dalitz decays)
- ρ, ω, ω-Dalitz, ϕ decays generated by PLUTO
- Multiplicity – HSD
- Most up-to-date realistic detector descriptions partially including passive materials such as cables (STS), mirror mount structure (RICH), mount structure (TRD)
- 25 μm gold target

Mean multiplicities

	8 AGeV	**25AGeV**
ρ	9	23
ω	19	38
ϕ	0.12	1.28

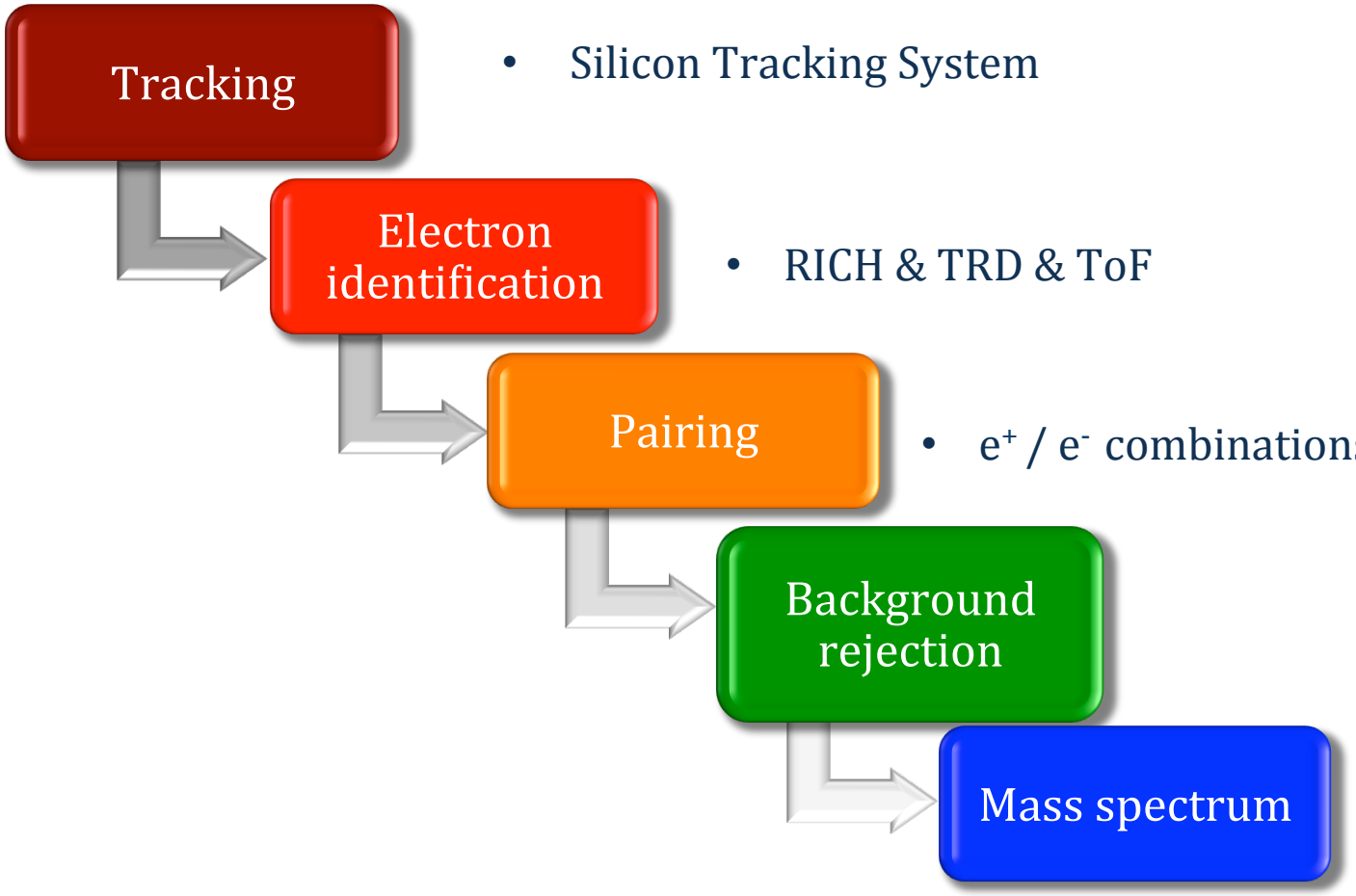
Event reconstruction

- STS – Celular Automaton method (CA) and L1 tracking
- RICH – Hough Transform
- TRD – Kalman Filter
- Global tracking – LIT method



- Large track density
  ➔ complicated event reconstruction

Simulation steps

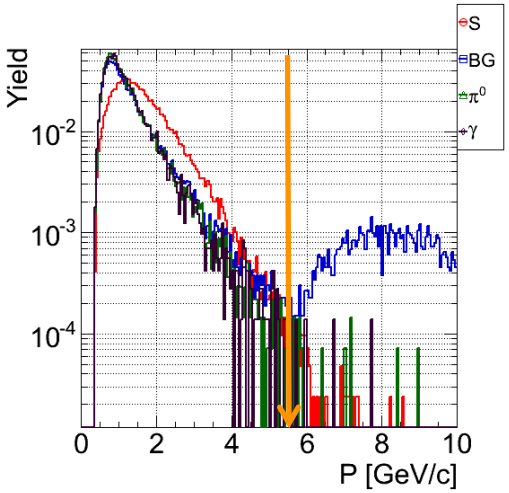


- Silicon Tracking System
- RICH & TRD & ToF
- e^+ / e^- combinations

Electron identification

Electron must be identified in all detectors

- **RICH** - Artificial Neural Network + momentum cut (for 8 AGeV as TRD is not used)
  - Input parameters:
    - A-axis and B-axis;
    - Number of hits in ring,
    - Momentum
    - Position of ring on PMT plane

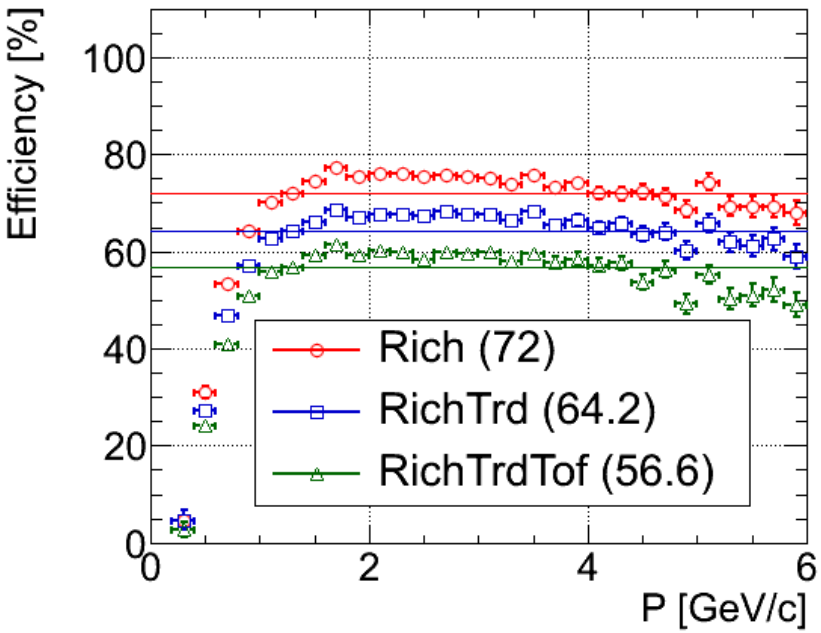


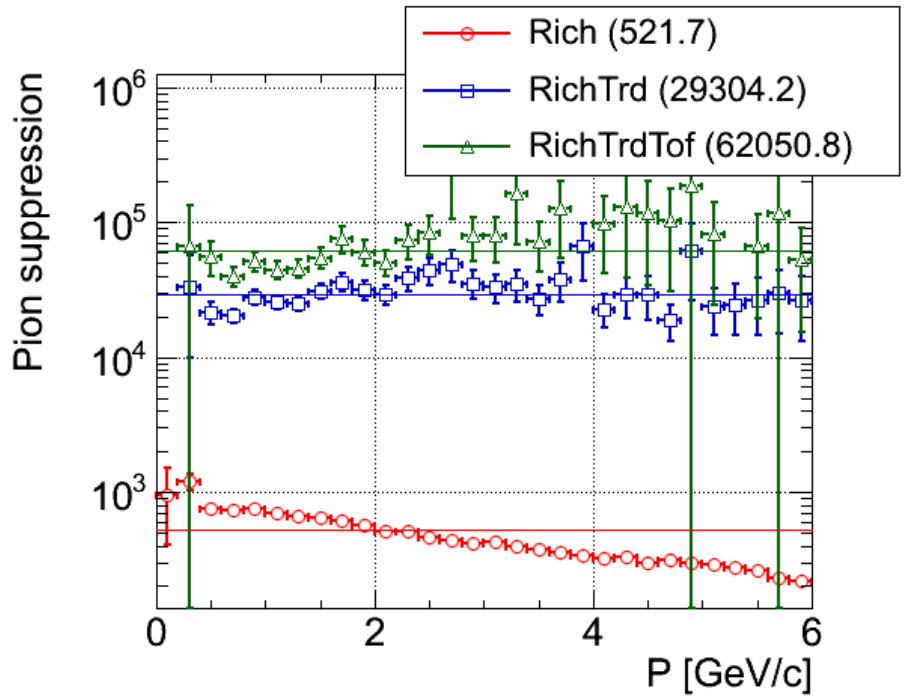
- **TRD** - Artificial Neural Network
  - Input parameters: energy loss measurements

- **ToF** - m^2 vs. momentum

Electron identification performance

- **Central Au-Au collisions at 25 AGeV**





- **El. id. eff.** = identified electrons / electrons accepted in STS+RICH+TRD+TOF

- **Pion supp.** = reconstructed pion in STS+RICH projection / pions identified as electrons

Background rejection strategy

Dominant sources

- Random combinations of e^+ and e^- from π^0-Dalitz decay and γ-conversion

Strategy

- Use tracking in STS to reject those pairs even if only partially reconstructed

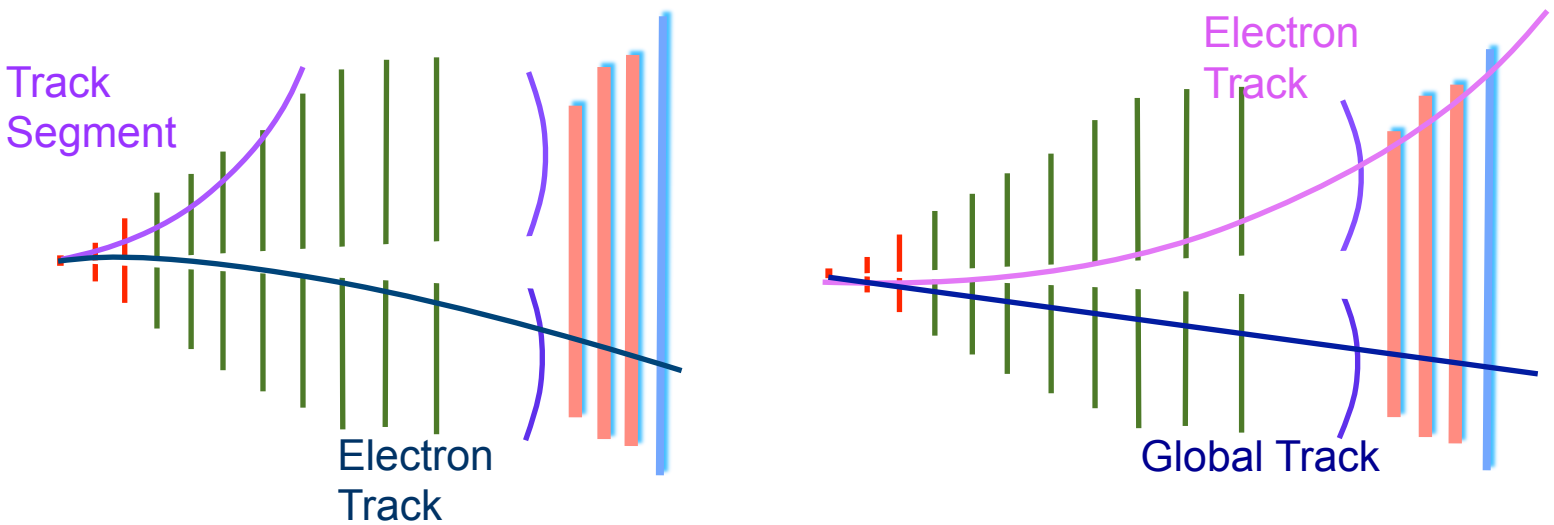
Rejection cuts

- **γ-conversion cut**: all reconstructed pairs with m_{ee} <25MeV/c^2 are removed from combinatorics
- **Track topology cuts**: combine fully identified e-tracks with tracks having momentum information only: cut on combination of opening angle and combined momentum
- **Transverse momentum cut**: cut p_t < 0.2 GeV/c

Topological cuts

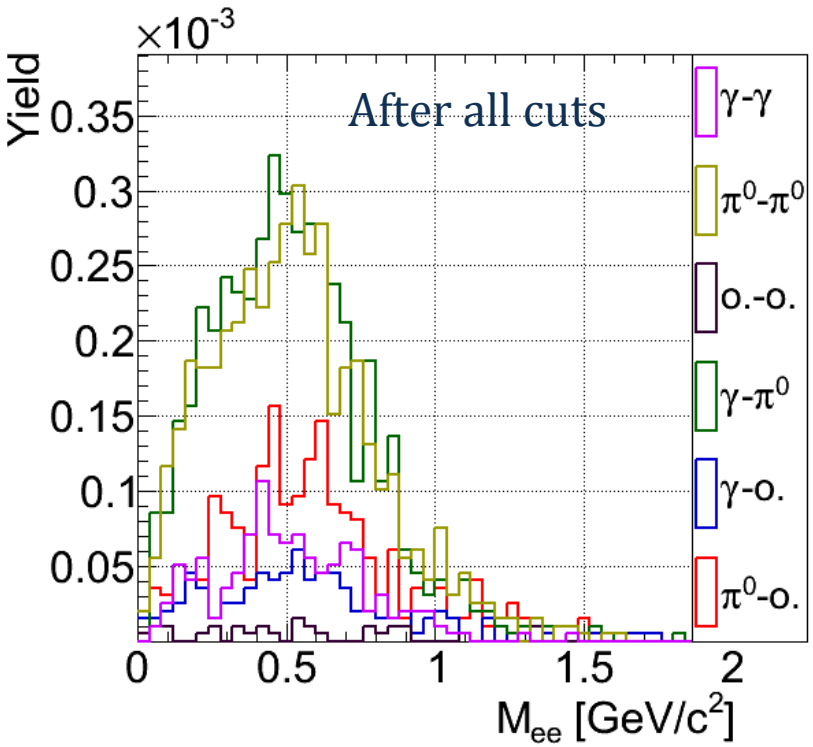
Combine $e^{\pm}$ candidates with all other tracks potentially being also an $e^{\pm}$ (may be the lost partner of a γ-conversion or π^0-Dalitz decay):

- Track segment (ST) = track escaping the identification detectors because being bent off by the magnetic field
- Global track (TT) = track reaching all detectors but escaping e-ID because of the limited efficiency

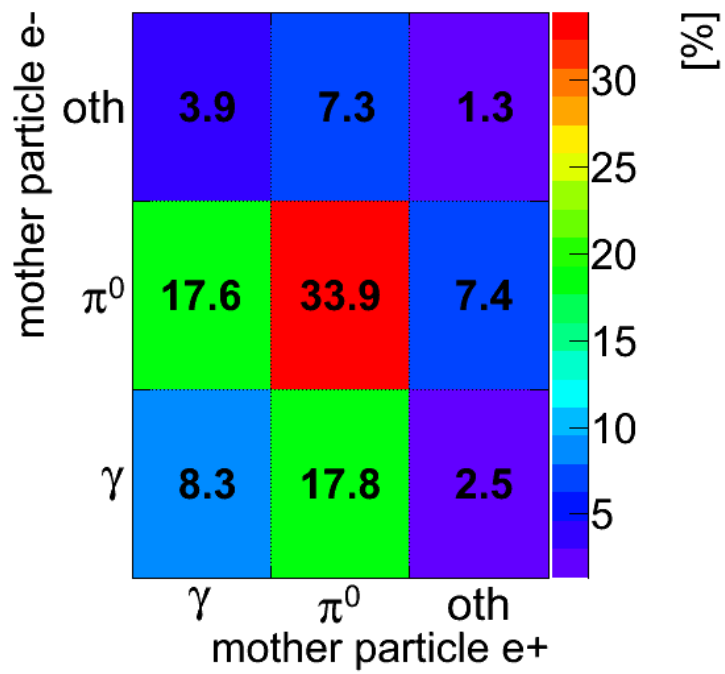


BG contributions

- **Central Au-Au collisions at 25 AGeV**



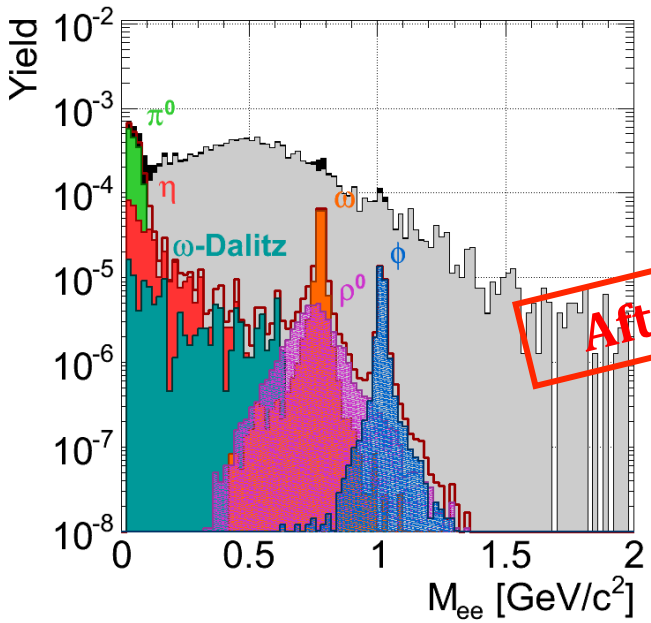
Percentage of the different sources of background pairs



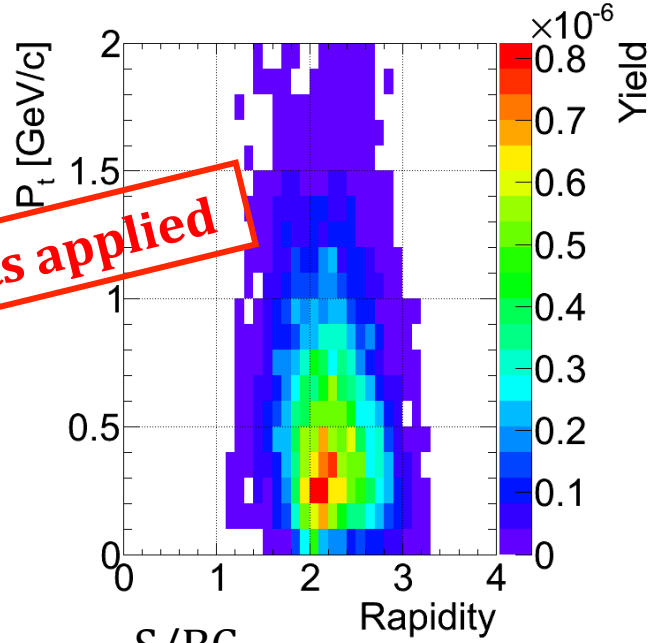
- γ-γ – e^+ and e^- from different γ-conversions
- π^0-π^0 – e^+ and e^- from different π^0-Dalitz decays
- o. - $e^\pm$ from other sources including misidentification

Results,
central Au+Au at 25 AGeV

Invariant mass spectra



Transverse momentum versus rapidity distribution for ρ^0



After all cuts applied

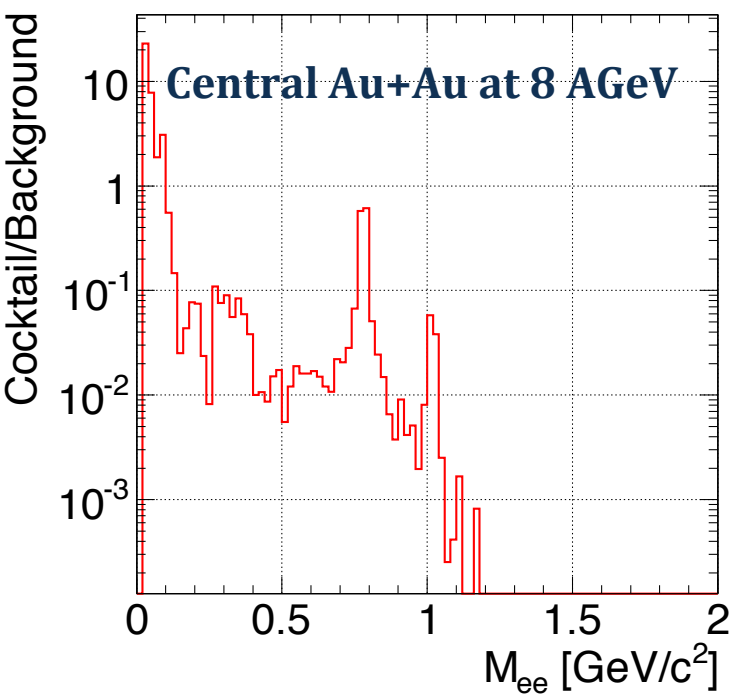
	ρ	ω	φ
eff. [%]	4.39	5.53	7.08
S/BG	-	0.31	0.11

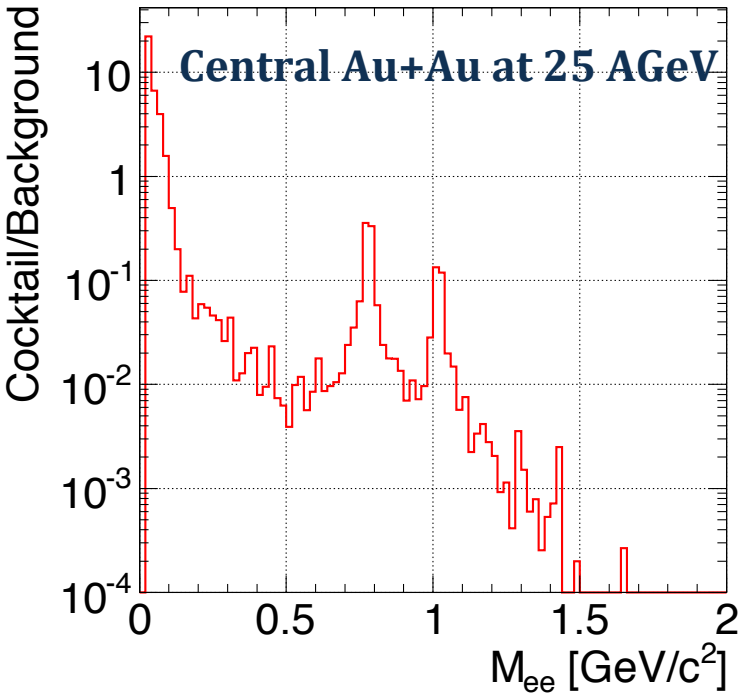
S/BG

M_{ee}: 0.0-0.2 [GeV/c^2]	1.44
M_{ee}: 0.2-0.6 [GeV/c^2]	0.019
M_{ee}: 0.6-1.2 [GeV/c^2]	0.053

cocktail/background vs. minv

After all cuts applied





The cocktail-to-background ratio around 100 for masses around 0.5 GeV/c^2 is very well compatible with existing di-lepton experiments and will allow for a precise investigation of low mass di-electron pairs.

Summary

- very good optical surface quality of the mirrors from Olomouc with $D_0 < 3mm$ - well below the anticipated photon detector pixel granularity of 5-6mm.

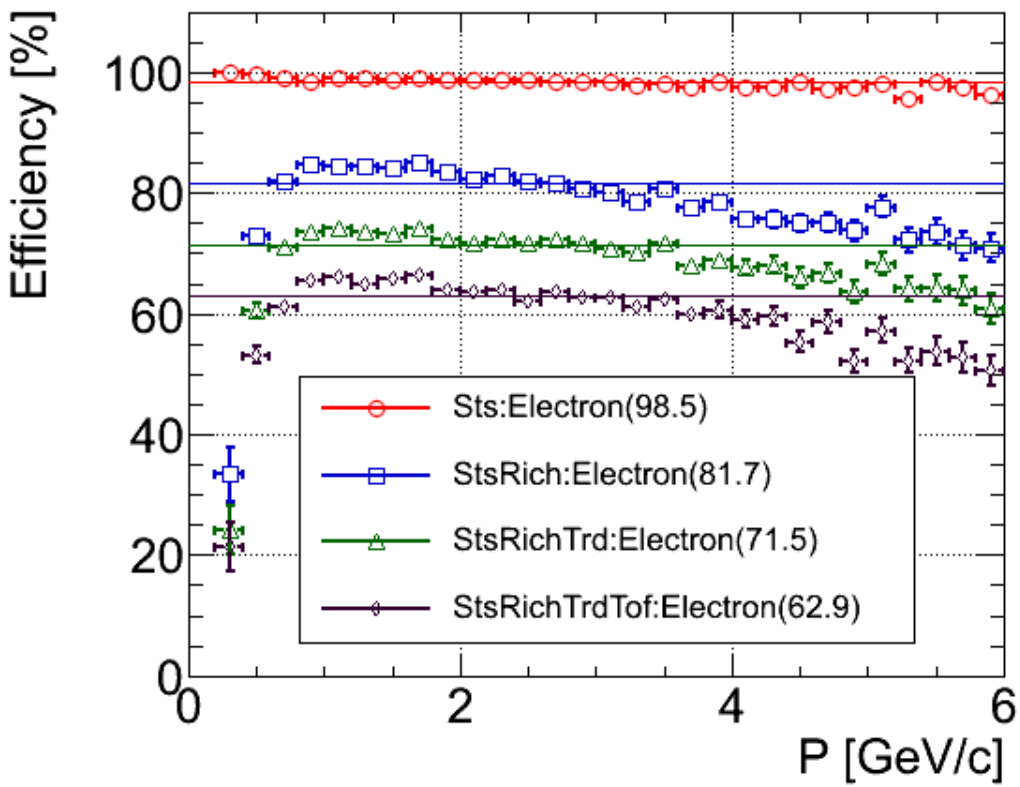
- Feasibility studies showed that CBM setup will allow the precise investigation of low-mass di-electrons.

Thank you for your attention

Back-up

Global tracking performance for $e^{\pm}$ from ρ

- **Central Au-Au collisions at 25 AGeV**



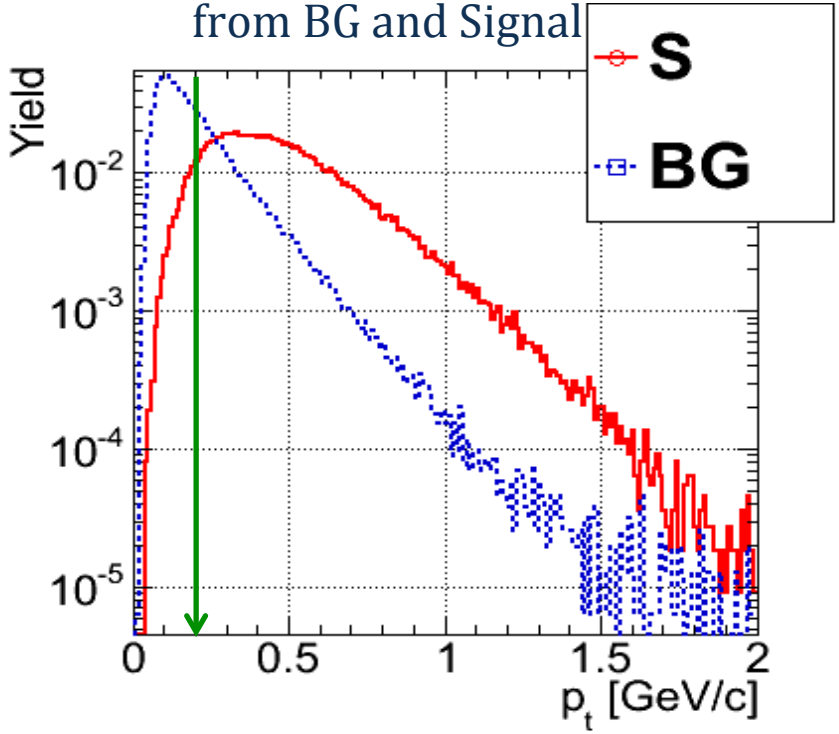
- **Global eff.** = reconstructed electron tracks in detector(s) / electron tracks with 4 consecutive points in STS, with 7 hits in RICH ring, with 6 points in TRD and 1 point in ToF

Transverse momentum cut

Central Au+Au at 25 AGeV

Single electron cut

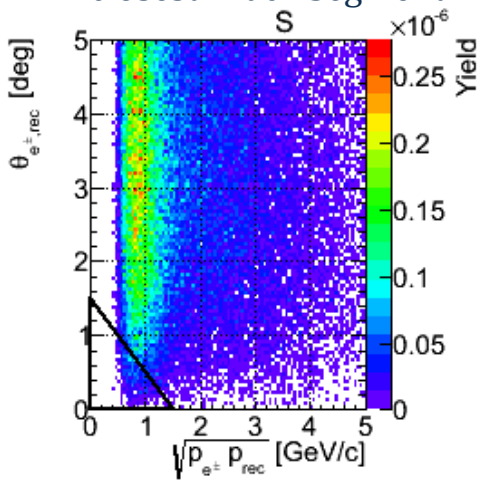
p_t distribution of e^+/e^- from BG and Signal



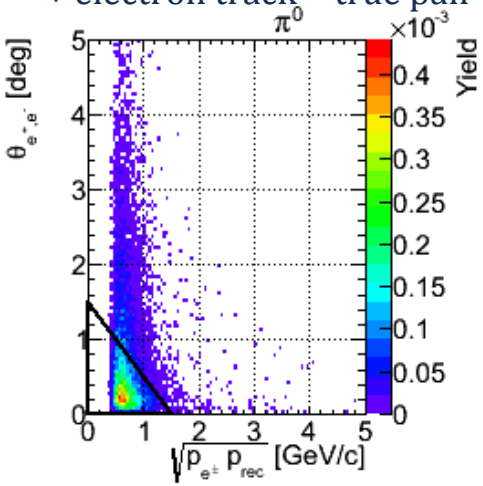
Topological cuts

- Select **closest neighbor track** and plot opening angle $\theta_{e,rec}$ versus $\sqrt{p_e p_{rec}}$
- Track segment cut, 25 AGeV : reject only 1.3% of ρ^0, but for 14% of $e^\pm$ pairs from γ-conversion and 13% from π^0-Dalitz decays the true partner is found
- Global track cut, 25 AGeV: reject only 0.6% of ρ^0, but 6% of $e^\pm$ pairs from γ-conversion and 6% from π^0-Dalitz decays

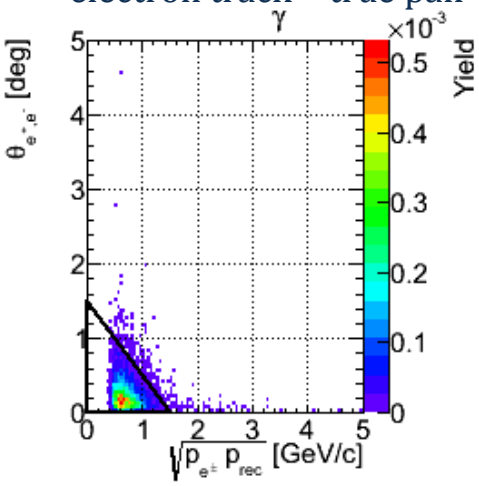
$e^\pm$ from **ρ**
+ closest Track Segment



- $e^\pm$ from **π^0**
  + electron track = true pair



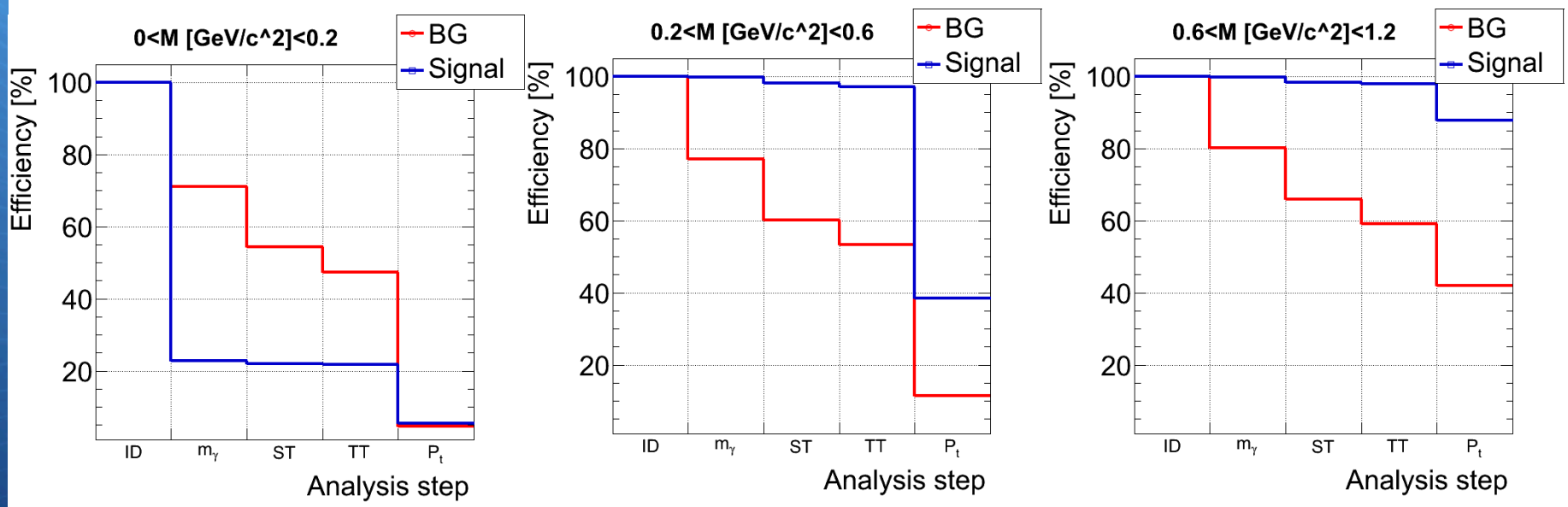
- $e^\pm$ from **γ**
  + electron track = true pair



- The triangle shows the cut area

Efficiency of cuts

- **Central Au-Au collisions at 25 AGeV**



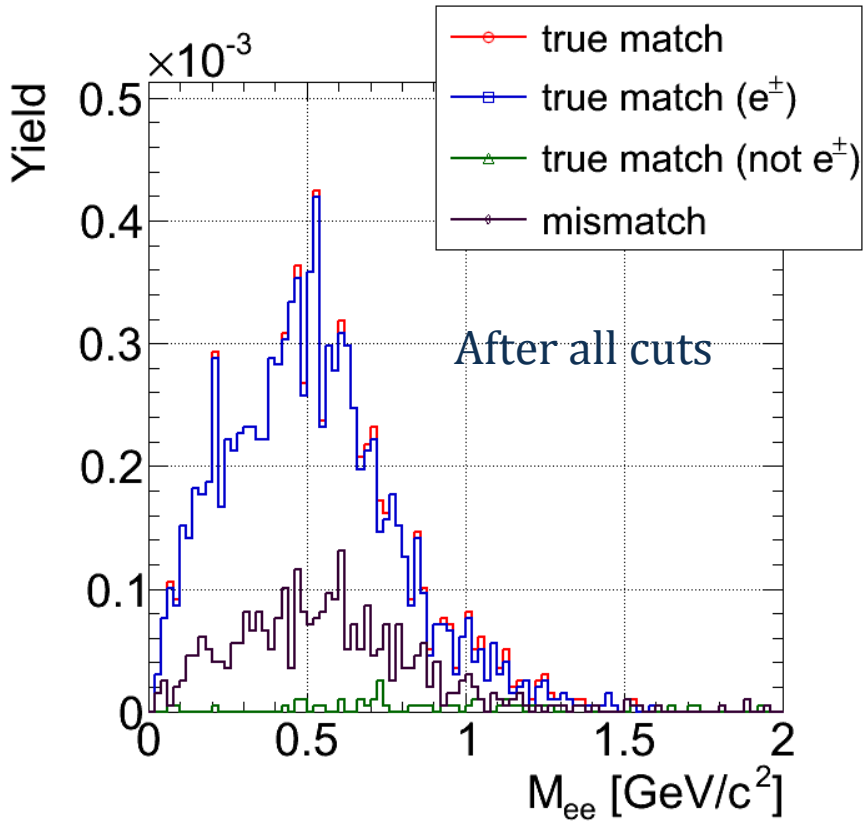
Eff = N_{cuts}/N

N_{cuts} – signal (background) after cuts
N – signal (background) after ID

Signal – all pairs originating from one source (π^0, η, ω Dalitz decay, ρ, ω, ϕ direct decay)
Background – random combinations between e+ and e- from different sources

*Pairs from γ-conversion (M_{ee}<0.2GeV/c^2) are counted as signal

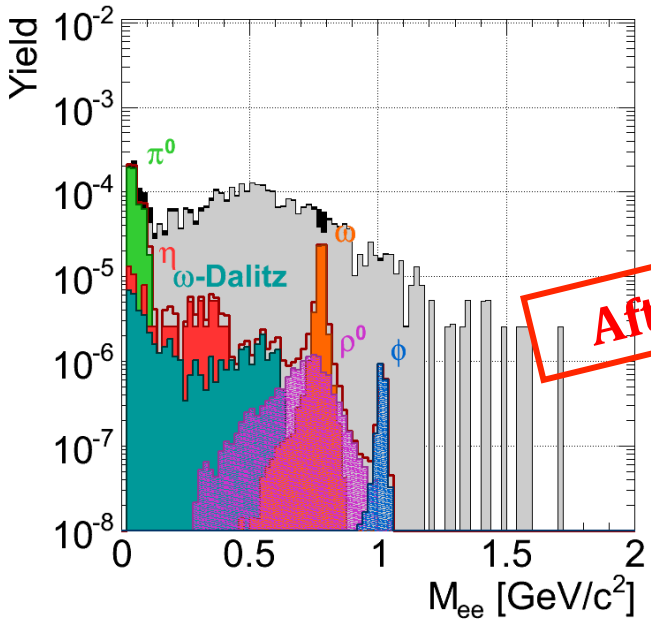
Mismatches contributions



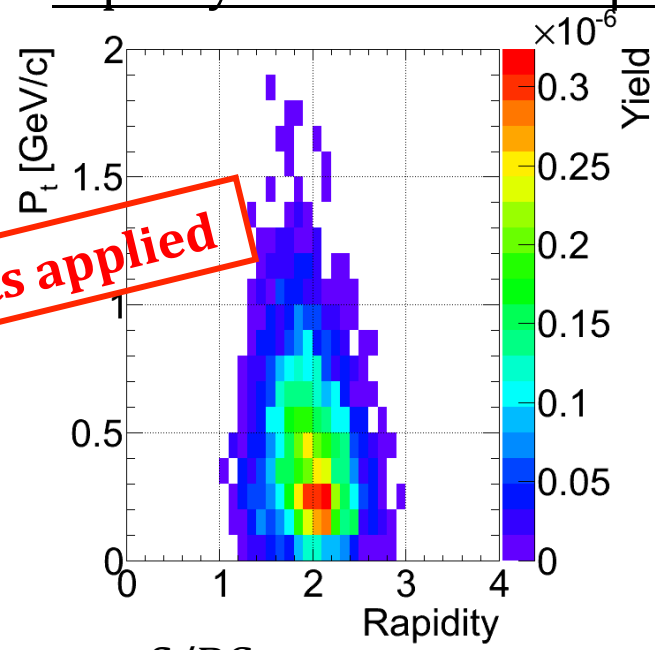
- True match – both tracks from BG pair were correctly matched in all detectors
- True match ($e^{\pm}$) – both tracks from BG pair are $e^{\pm}$ and were correctly matched
- True match (not $e^{\pm}$) – both tracks were correctly matched and at least one of the track from BG pair is not $e^{\pm}$, but was identified as $e^{\pm}$
- Mismatch – one of the track from BG pair was not correctly matched in one of detectors

Results
central Au+Au at 8 AGeV

Invariant mass spectra



Transverse momentum versus rapiditydistribution for ρ^0



After all cuts applied

	ρ	ω	φ
eff. [%]	3.12	4.10	4.89
S/BG	-	0.65	0.04

S/BG

M_{ee}: 0.0-0.2 [GeV/c^2]	2.04
M_{ee}: 0.2-0.6 [GeV/c^2]	0.033
M_{ee}: 0.6-1.2 [GeV/c^2]	0.067