Track Reconstruction and Muon Identification in the Muon Detector of the CBM Experiment at FAIR

Andrey Lebedev [1,2]
Claudia Hoehne [1]
Ivan Kisel [1,3]
Anna Kiseleva [1]
Gennady Ososkov [2]
and the CBM collaboration

ACAT
November 3-7, 2008
Erice, Sicily

[1]_Gesellschaft für Schwerionenforschung, Darmstadt, Germany_
[2]_Laboratory of Information Technologies, Joint Institute for Nuclear Research, Dubna, Russia_
[3]_Kirchhoff Institute for Physics, University of Heidelberg, Germany_

Outline

- Introduction of CBM
- The CBM muon identification system
- Track reconstruction
  - challenges
  - solution
  - results
- Results on muon identification; feasibility studies

CBM at FAIR
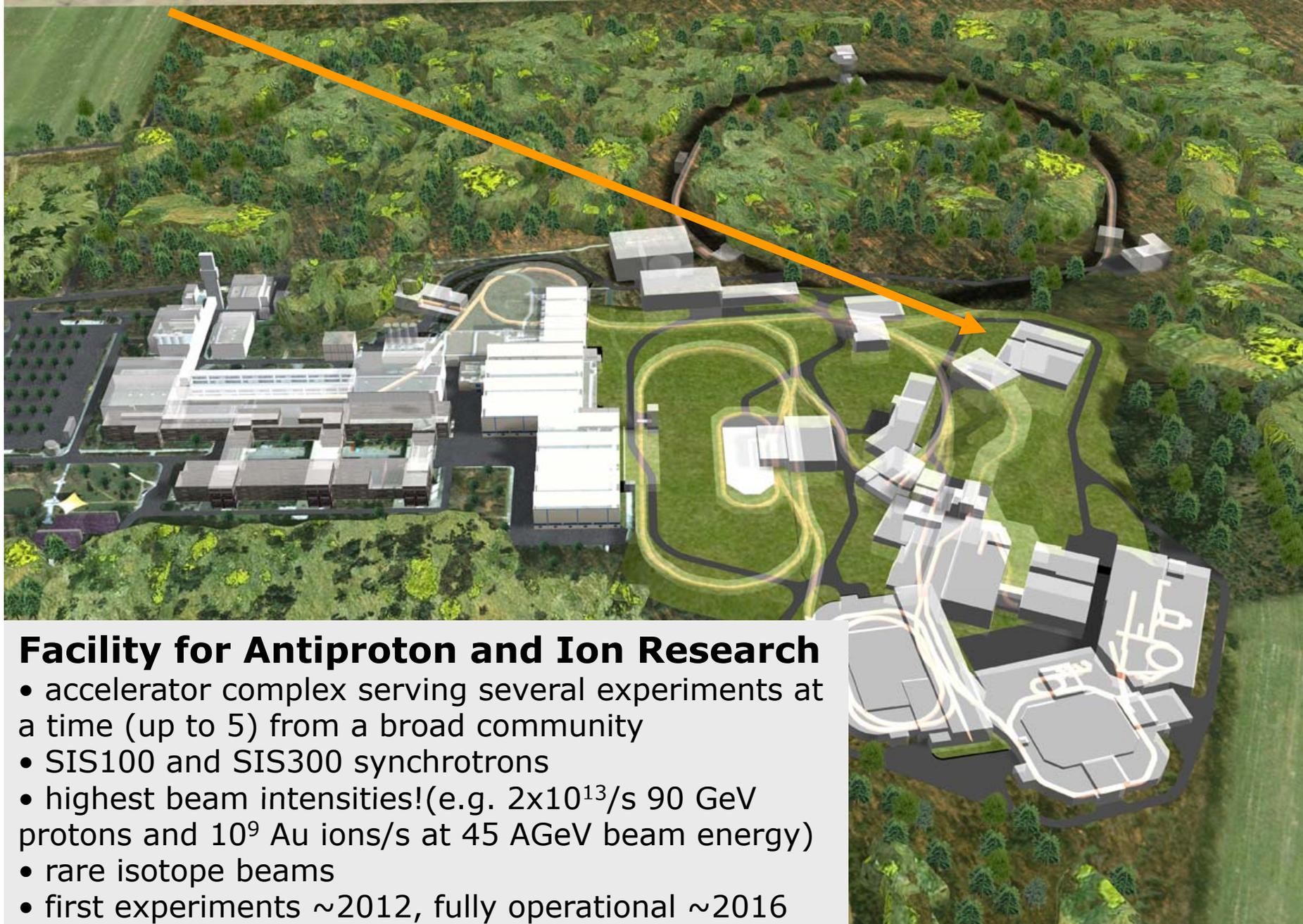
Facility for Antiproton and Ion Research
• accelerator complex serving several experiments at a time (up to 5) from a broad community
• SIS100 and SIS300 synchrotrons
• highest beam intensities!(e.g. 2×10^{13}/s 90 GeV protons and 10^9 Au ions/s at 45 AGeV beam energy)
• rare isotope beams
• first experiments ~2012, fully operational ~2016

CBM physics topics
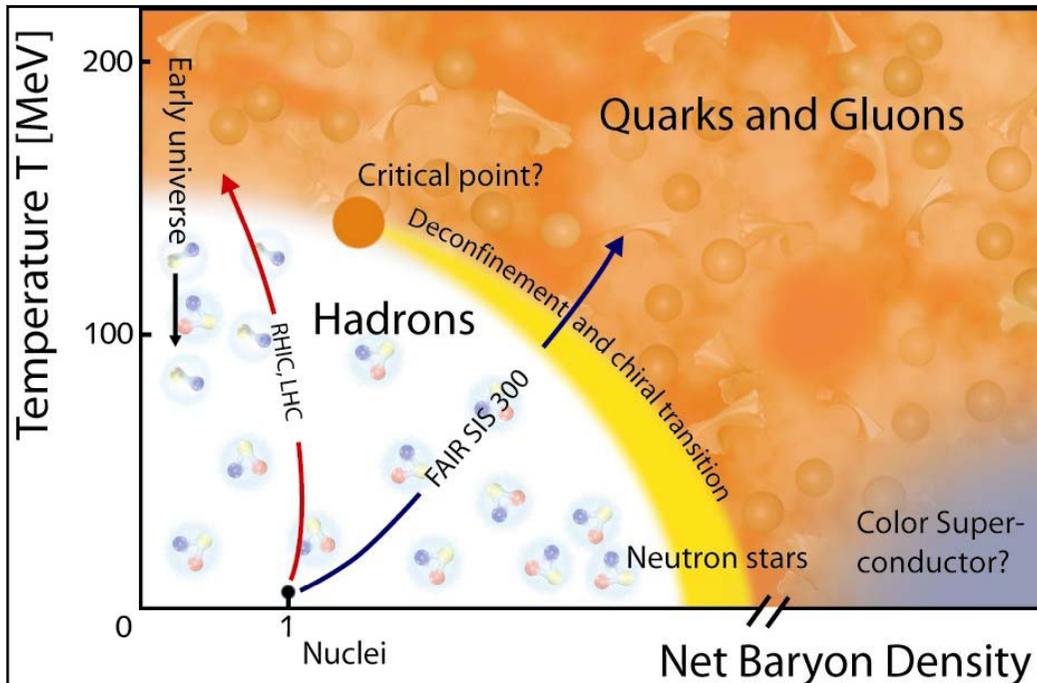
Exploration of the QCD phase diagram in regions of high baryon densities and moderate temperatures.

Physics Topics	Observables
In medium modifications of hadrons	ρ, ω, ϕ $\rightarrow$ $\mu^+\mu^-$ (e^+e^-) D^0, $D^{\pm}$, $D^{\pm}_s$, Λ_c
Deconfinement phase transition, charm production at threshold	K, Λ, Σ, Ξ, Ω D^0, $D^{\pm}$ J/Ψ, Ψ' $\rightarrow$ μ^+ μ^- (e^+e^-)
Critical point	Event by event fluctuations

The CBM detector

STS

beam

MUCH

TRD

TOF
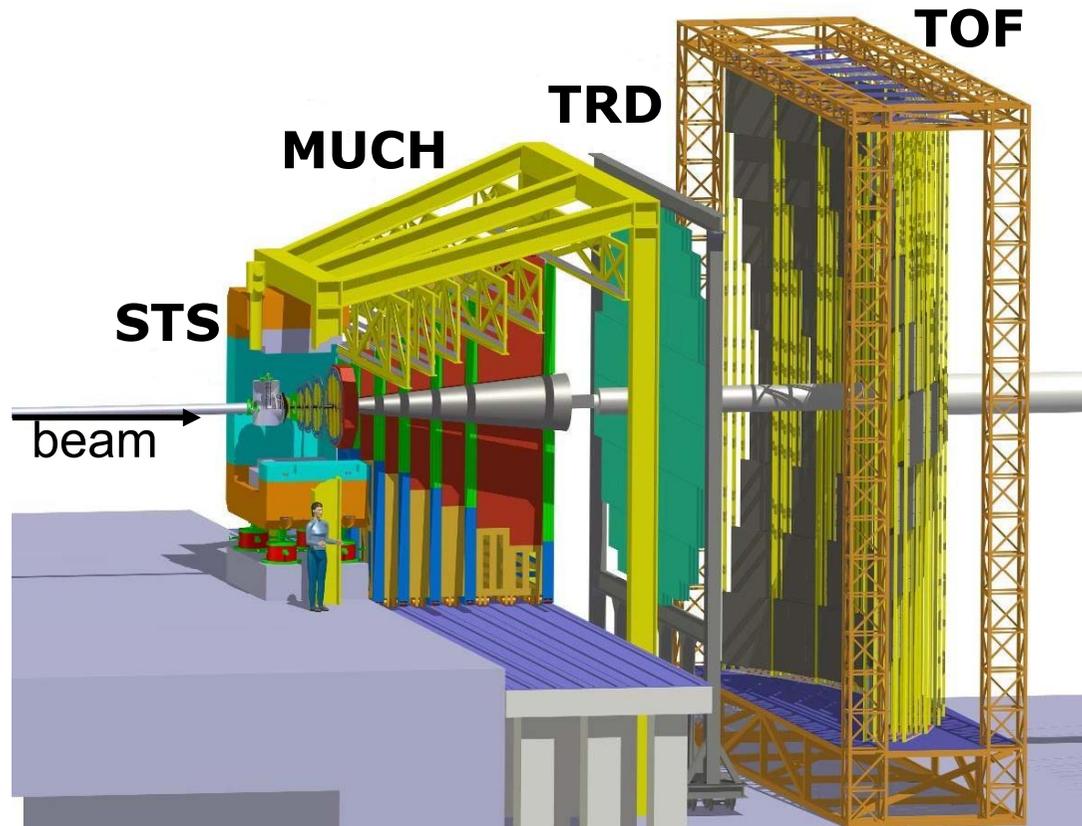
STS: track, vertex and momentum reconstruction

MUCH: muon identification

TRD: global tracking

TOF: time of flight measurement

- comprehensive measurement of hadron and lepton production in *pp, pA* and *AA* collisions from **8-45 AGeV** beam energy
- fixed target experiment

Challenges for muon id

standard: muon identification by absorber technique

however, for CBM:
- up to 1000 charged particles per reaction
- major background of muons from pion and kaon decay
- signal muons very rare ($<J/y> \sim 10^{-6}$, branching ratio of low-mass vector mesons $\sim 10^{-5}$)
- reconstruction of low momentum muons (p>1.5 GeV/c)
- punch through of hadrons, track mismatches

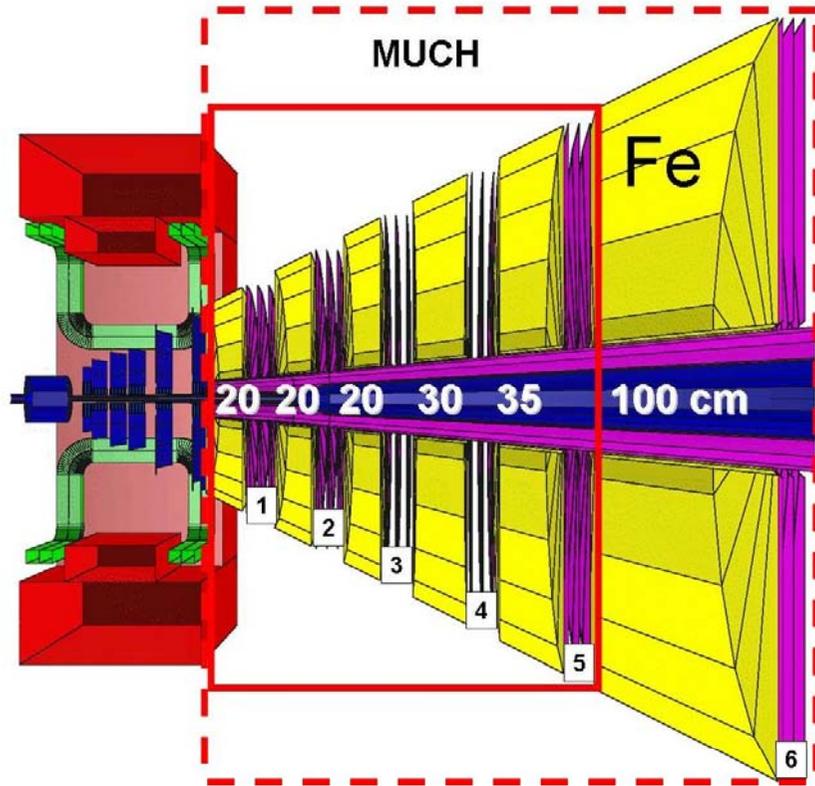$\rightarrow$ choose compact setup
$\rightarrow$ absorber-detector sandwich for continuos tracking
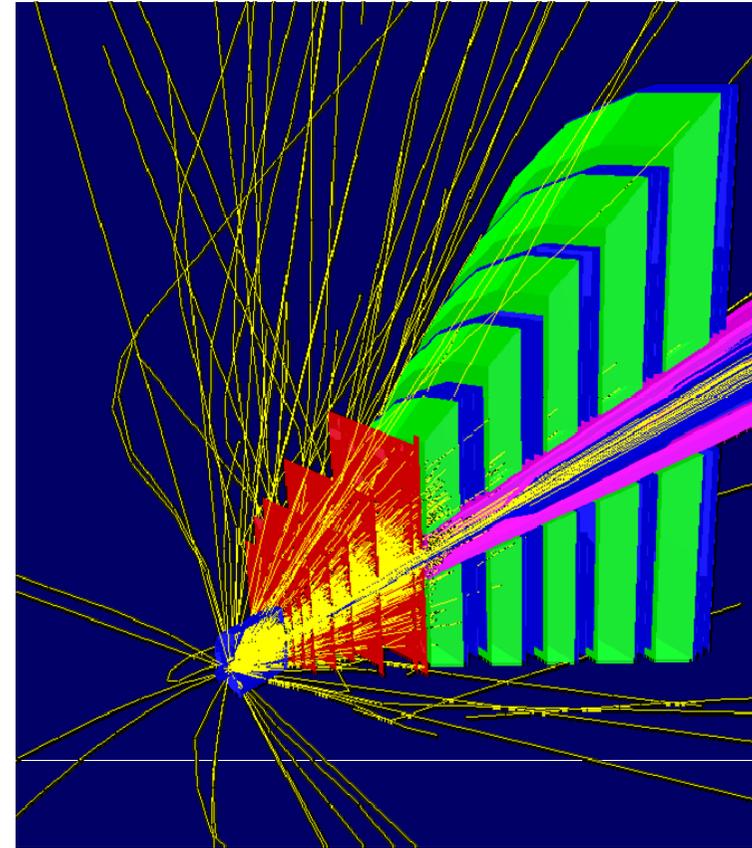
Central Au+Au
collision at 25 AGeV
(UrQMD + GEANT3)

The Muon detector (MUCH)

Choose alternating detector-absorber layout for continuos tracking of the muons through the absorber

Measurements of:

————— *Low mass vector mesons*
5 Fe absorbers (**125 cm**)
7.5 λ_I, p> 1.5 GeV/c

– – – – *Charmonium*
6 Fe absorbers (**225 cm**)
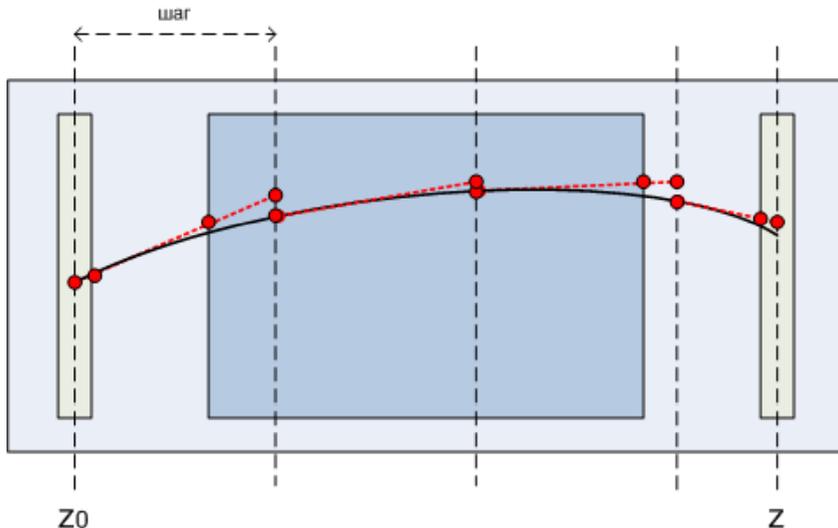13.5 λ_I, p> 2.8 GeV/c

2(3) detector stations between the absorbers

Detector challenges:
- High hit density (up to 1 hit per cm^2 per event)
- High event rates (10^7 events/s)
- Position resolution < 300 µm
$\rightarrow$ use pad readout (e.g. GEMs), minimum pad size 1.4x2.8 mm^2.

Track propagation

- ## _Extrapolation._ Two models:
  - Straight line in case of absence of magnetic field.
  - Solution of the equation of motion in a magnetic field with the 4th order Runge-Kutta method, with a parallel integration of the derivatives.

- ## _Material Effects._

  Track propagation components

  - _Energy loss_ (ionization: Bethe-Bloch, bremsstrahlung: Bethe-Heitler, pair production)

  - _Multiple scattering_ (Gaussian approximation)

- ## _Navigation._
 - Based on the _ROOT TGeoManager_.
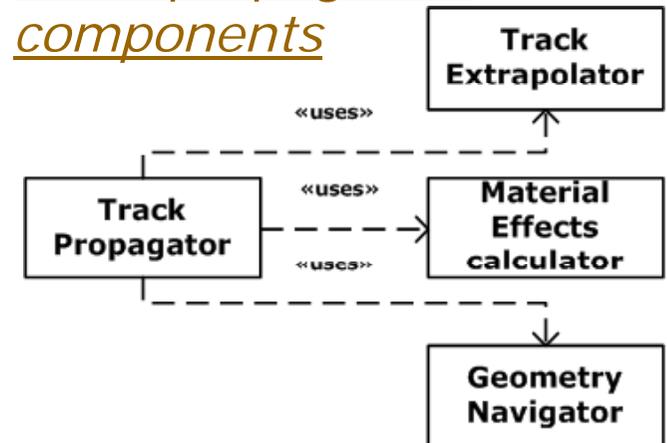
The Algorithm:
Trajectory is divided into steps. For each step:

– – – Straight line approximation for finding intersections with different materials (geometry navigator)

—— Geometrical extrapolation of the trajectory

Material effects are added at each intersection point

Track finding

- Based on **track following** and the **Kalman filter**
- Uses **branching**: Branch is created for each hit, has to pass a test to be assigned to the track segment, check for missing hits.
- Initial seeds are tracks reconstructed in STS.
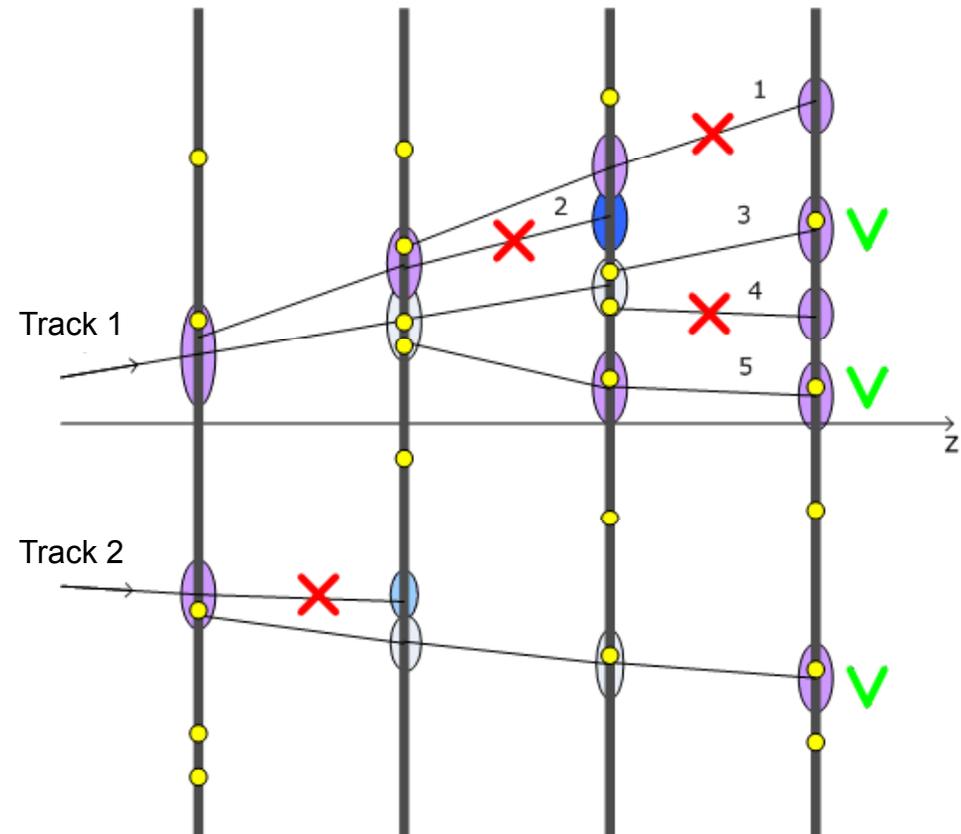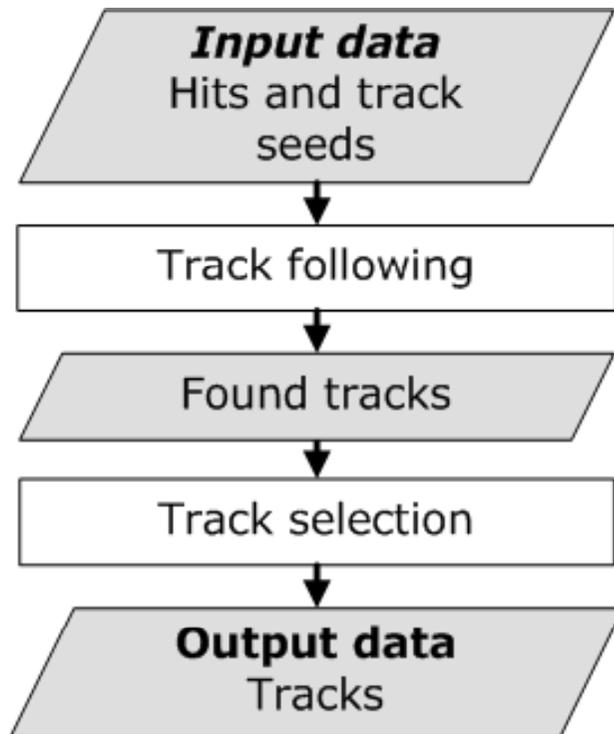
The main components of the track finding algorithm are **track following** and **track selection**.
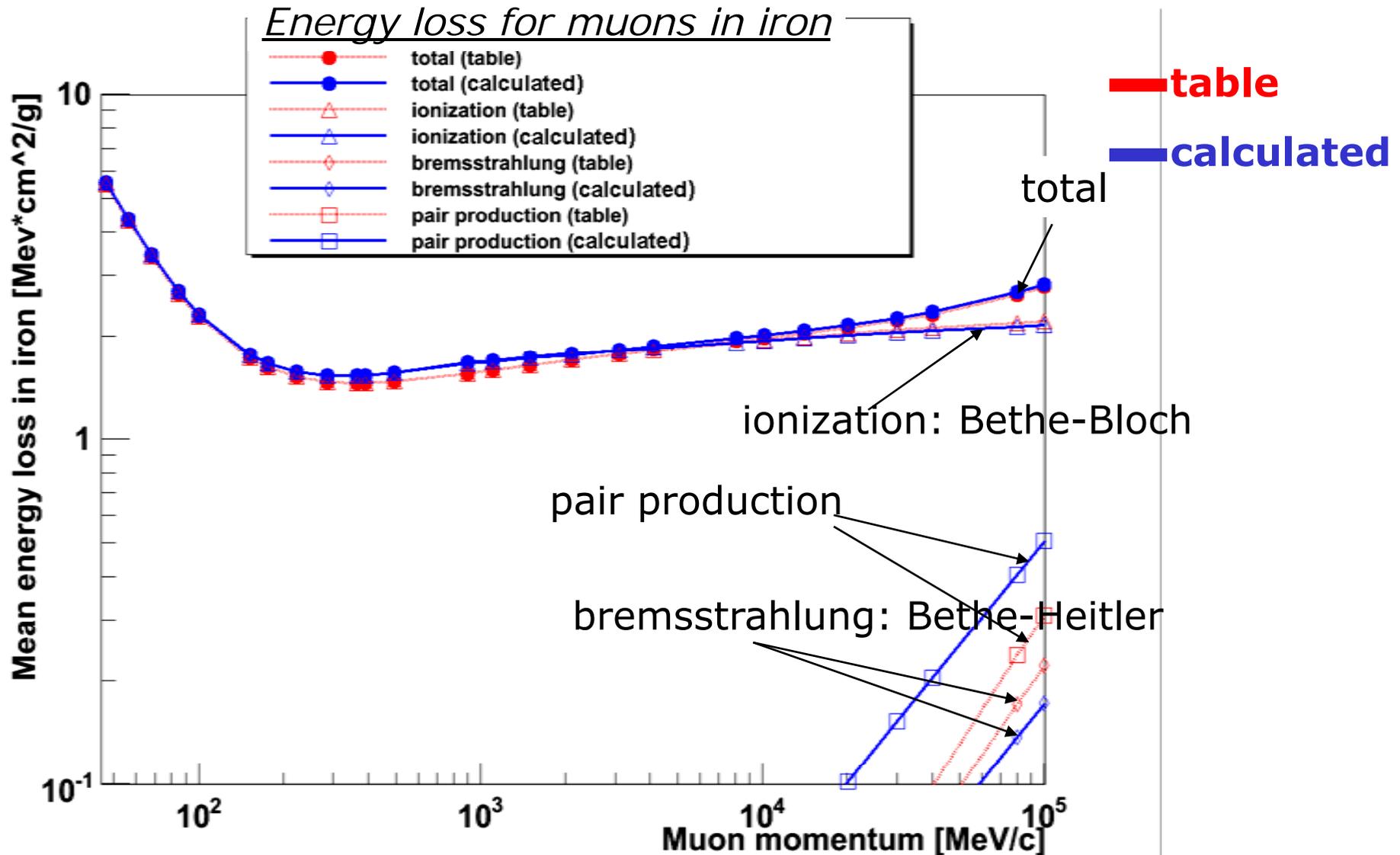
Track selection

– aim: remove clone and ghost tracks
– Tracks are sorted by their quality, obtained by chi-square and track length
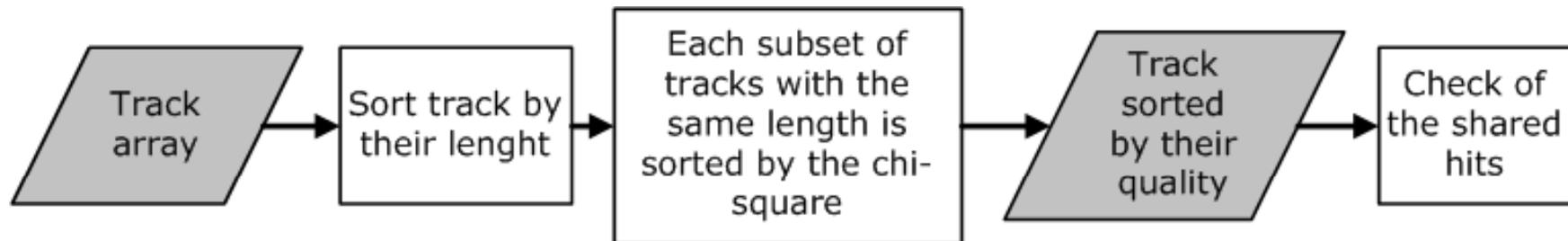
– Check for shared hits
  • loop over tracks list which is sorted by quality
  • collect used hits
  • check for each new track the number of shared hits: if too many – reject track

Energy loss for muons in iron

D.E.Groom, N.V.Mokhov and S.I.Striganov, Muon stopping power and range tables 10 MeV-100 TeV, Atomic Data and Nuclear Tables, 78, 2001

Energy loss for muons in iron

total (table)
total (calculated)
ionization (table)
ionization (calculated)
bremsstrahlung (table)
bremsstrahlung (calculated)
pair production (table)
pair production (calculated)

table
calculated

total

ionization: Bethe-Bloch

pair production

bremsstrahlung: Bethe-Heitler

Multiple scattering

Theta angle of the multiple scattering for muons passing 10 cm of iron
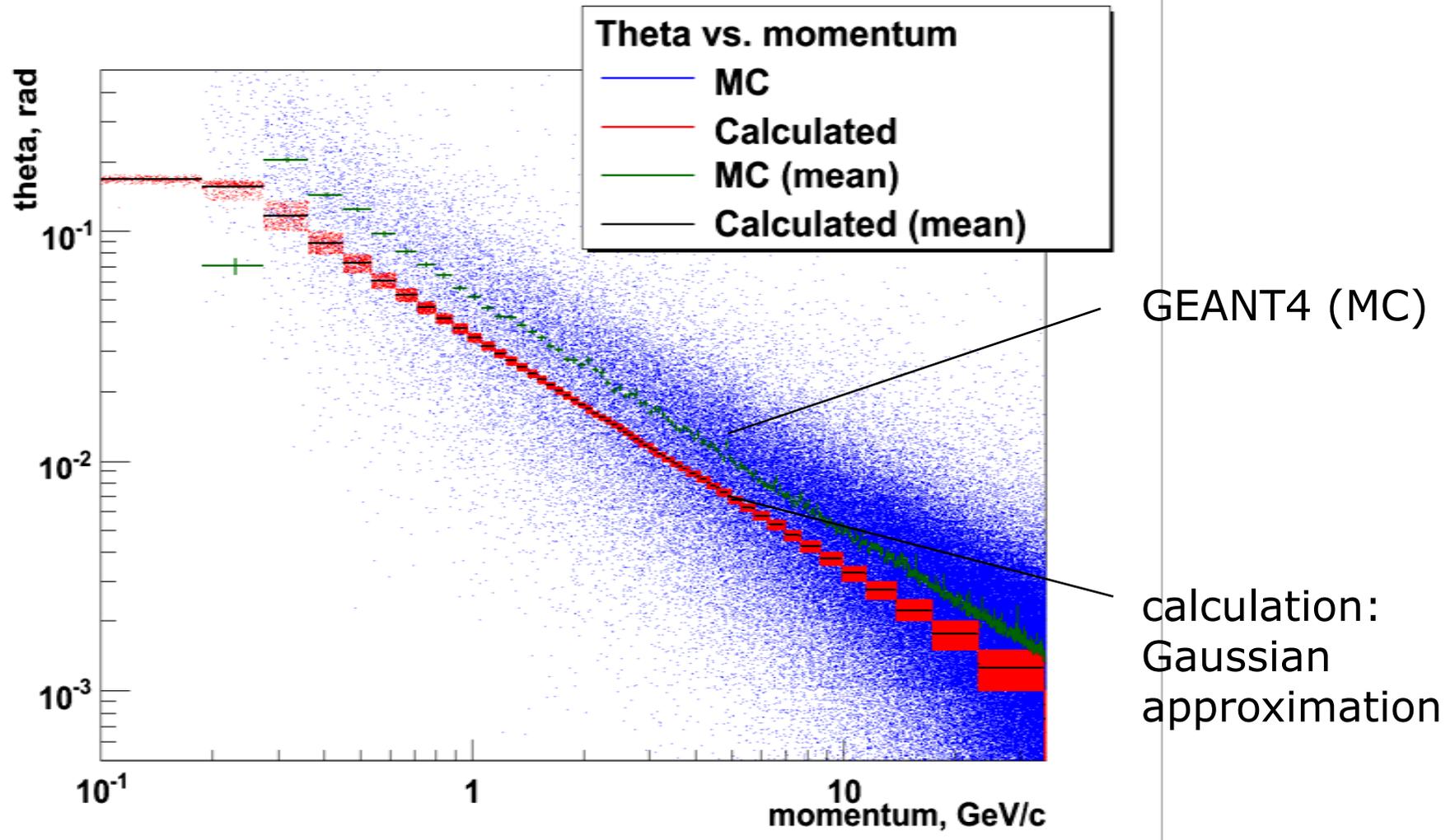
Performance of the track propagation

Simulated data: 100k mu+ and mu- with momentum range 1-10 GeV/c.
Track parameters are updated with the Kalman filter on each station.
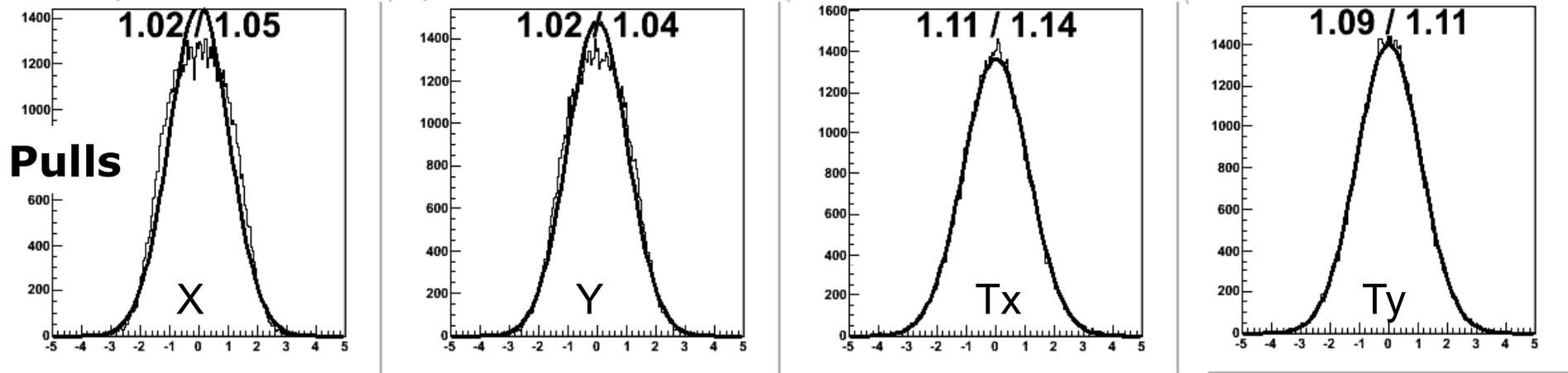
Pulls

Residuals   **Bold** – sigma of the Gauss fit, (in brackets) – RMS value.

	x		y		tx * 10^{-2}		ty * 10^{-2}		q/p * 10^{-2}		res. p, %
F	**0.17**	0.17	**0.17**	0.17	**1.06**	1.06	**1.07**	1.07	**0.27**(0.66)	**0.28**(0.67)	**1.51**(2.43)	**1.60**(2.44)
M	**0.36**	0.36	**0.64**	0.62	**1.41**	1.40	**1.62**	1.61	**0.53**(1.46)	**0.59**(1.63)	**2.78**(4.11)	**3.19**(4.23)
L	**0.20**	0.20	**0.53**	0.52	**1.17**	1.17	**1.64**	1.63	**1.06**(2.39)	**1.23**(2.48)	**5.17**(6.93)	**6.12**(7.73)

Pulls   F – first, M – middle, L – last station | **GEANE** | **our calc.** |

	x		y		tx		ty		q/p	
F	**1.32**	0.98	**1.33**	0.98	**1.04**	1.06	**1.04**	1.07	**0.82**(1.14)	**0.78**(1.00)
M	**1.00**	1.05	**1.09**	1.07	**1.01**	1.09	**1.04**	1.10	**0.77**(1.19)	**1.02**(1.27)
L	**0.98**	1.01	**1.02**	1.01	**0.95**	1.11	**0.99**	1.08	**0.74**(1.04)	**1.49**(1.88)

Performance of the track finder

125 cm iron absorber

225 cm iron absorber
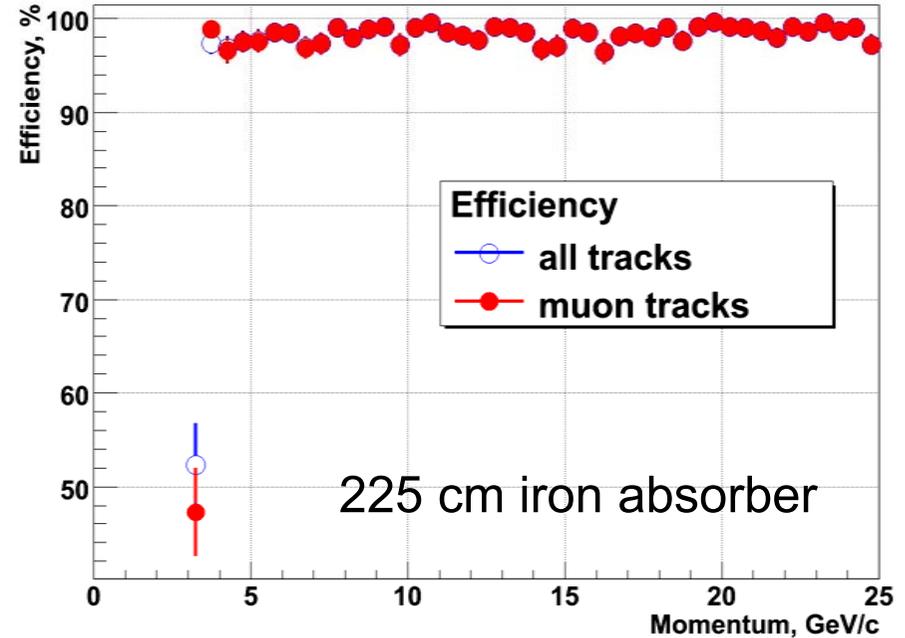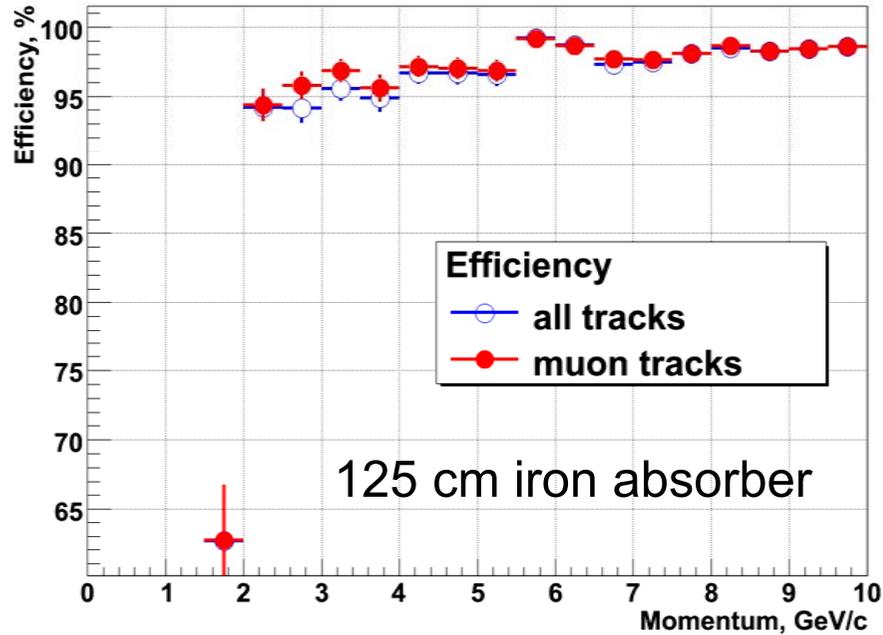
	125 cm Fe	225 cm Fe
all	96.2%	97.5%
ref	97.1%	97.6%
prim	96.4%	97.5%
sec	89.2%	89.0%
muons	96.8%	97.5%
ghost	1.5%	0.21%
clone	0.0%	0.0%

Events:

URQMD central Au+Au at 25 AGeV

+

5 mu+ and 5 mu-

efficiency for tracks passing through the whole absorber

A.Lebedev et al, Track Reconstruction and Muon Identification in the Muon Detector of the CBM experiment at FAIR

Muon identification

Cuts:

- select primary vertex tracks (impact parameter)
- cut on χ^2 of reconstructed MUCH tracks

Reconstructed background per central Au+Au collision at 25 AGeV beam energy

RECO bg (pID_{MuCh}):

- all reconstructed: 0.245
- μ: 0.130
- π: 0.019
- K: 0.069
- p: 0.009
- ghost: 0.019
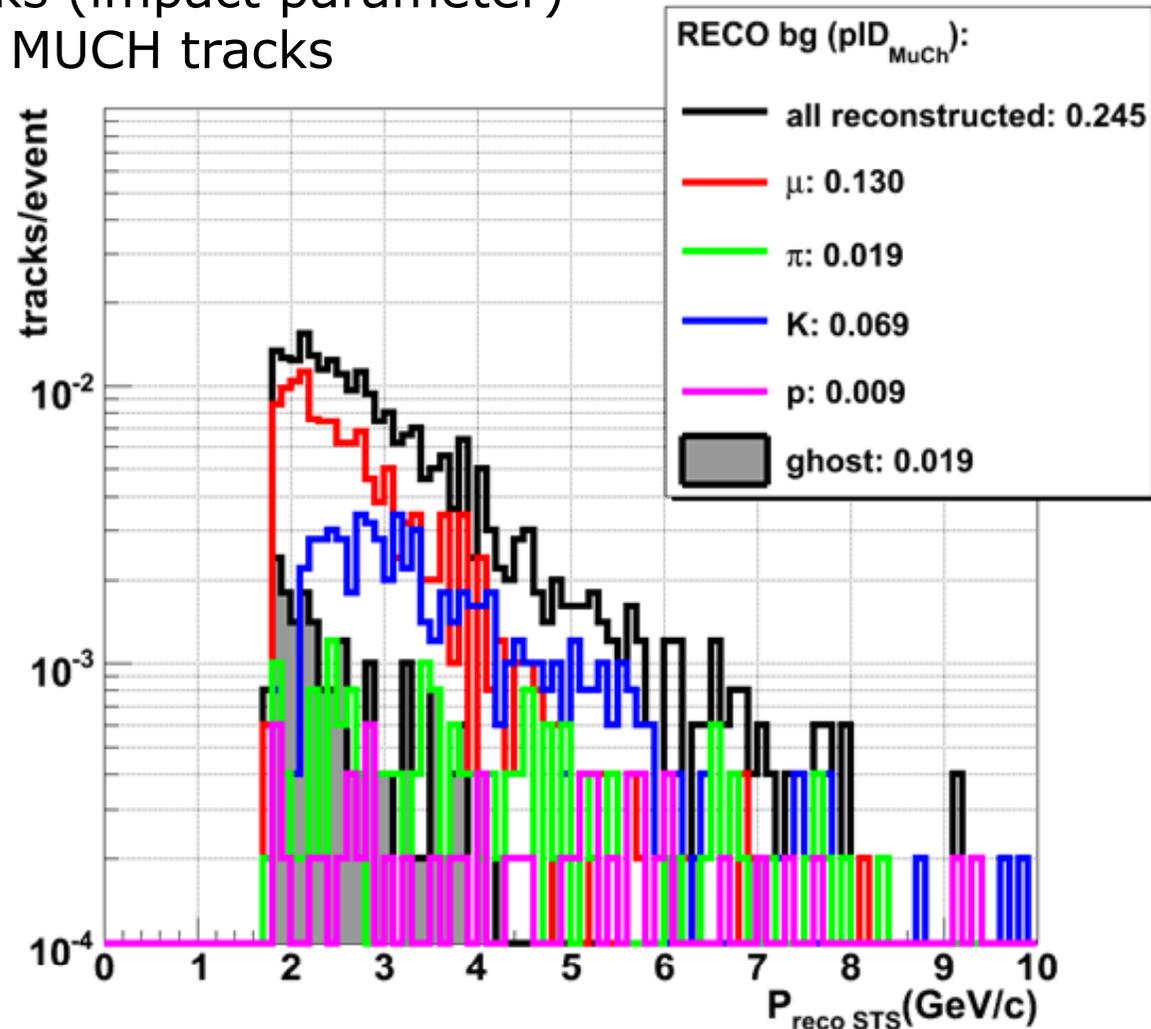
Muon identification

Physics feasibility study for low-mass vector mesons and J/ψ reconstruction in central Au+Au collisions at 25 AGeV beam energy

	Signal-to-Background (S/B) ratio	Efficiency (%)	Mass resolution (MeV)
ω	0.09	2	10
φ	0.03	4	12
J/ψ	18	13	21
Ψ'	0.8	16	27
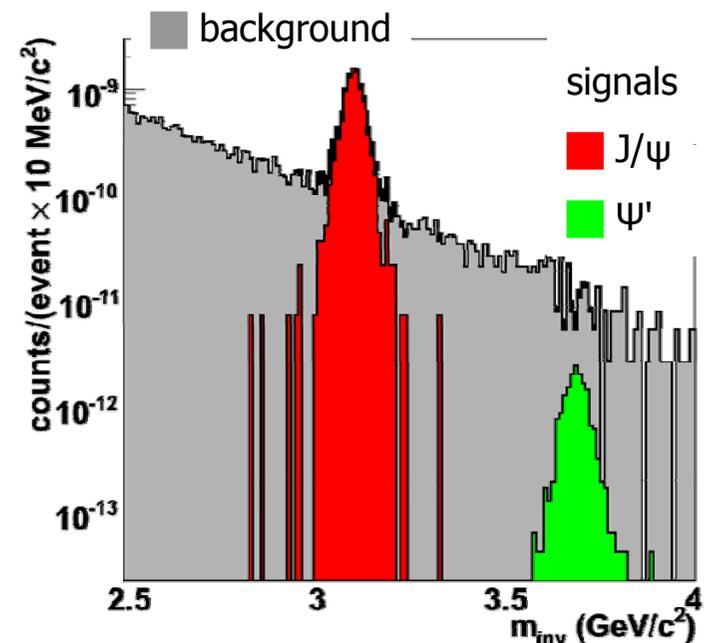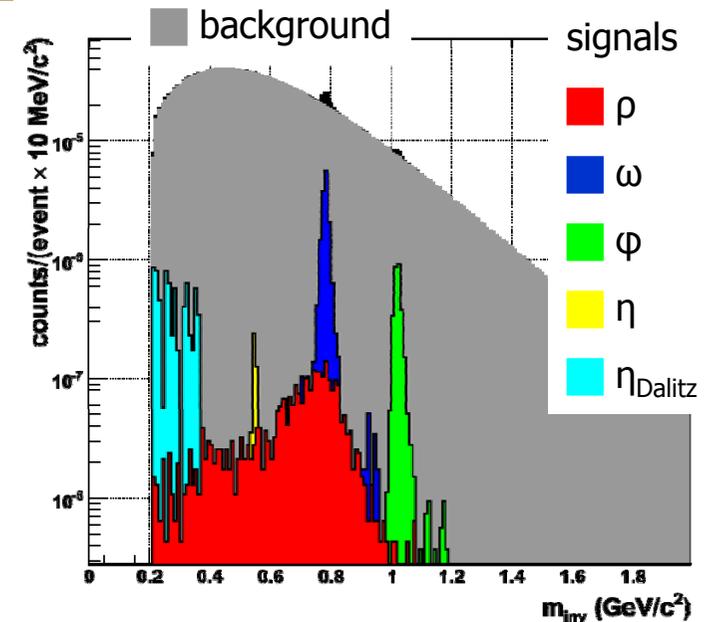
Summary & Outlook

- proposed detector layout of alternating absorber-detector layers for muon identification in CBM studied

- succesful demonstration that tracking through the absorber is feasible with such a layout in a high track density environment:

  - 97% tracking efficiency for muons passing the absorber

  - low rate of ghosts, clones and track mismatches: 0.25 backgrounf tracks reconstructed per central Au+Au collision at 25 AGeV beam energy

  - main background are muons from π, K decay

- physics feasibility studies on J/ψ and low-mass vector meson reconstruction promising

$\rightarrow$ use established tracking routines for layout optimization

$\rightarrow$ develop fast tracking algorithms for trigger