Faculty of Physics
WARSAW UNIVERSITY OF TECHNOLOGY

Feasibility study of femtoscopic measurements in CBM

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Warsaw University of Technology

Outline

The femtoscopy

Physics at CBM

Perspectives on pion femtoscopy

Perspectives on baryon femtoscopy

Summary

Femtoscopy

Technique used to extract information about spatio-temporal structure of event

Base on two particle correlations

Correlation function defined as

$$C(q) = \frac{P(p_1, p_2)}{P(p_1)P(p_2)}$$

where $q = \sqrt{(p_1 - p_2)^2 - (E_1 - E_2)^2}$

CF is calculated usually as a function of:

- centrality (more central events -> larger system -> larger radius)
- m_T or k_T (average transversal mass/momentum of the pair)

Theoretical shape of the CF

Let's consider noninteracting bosons

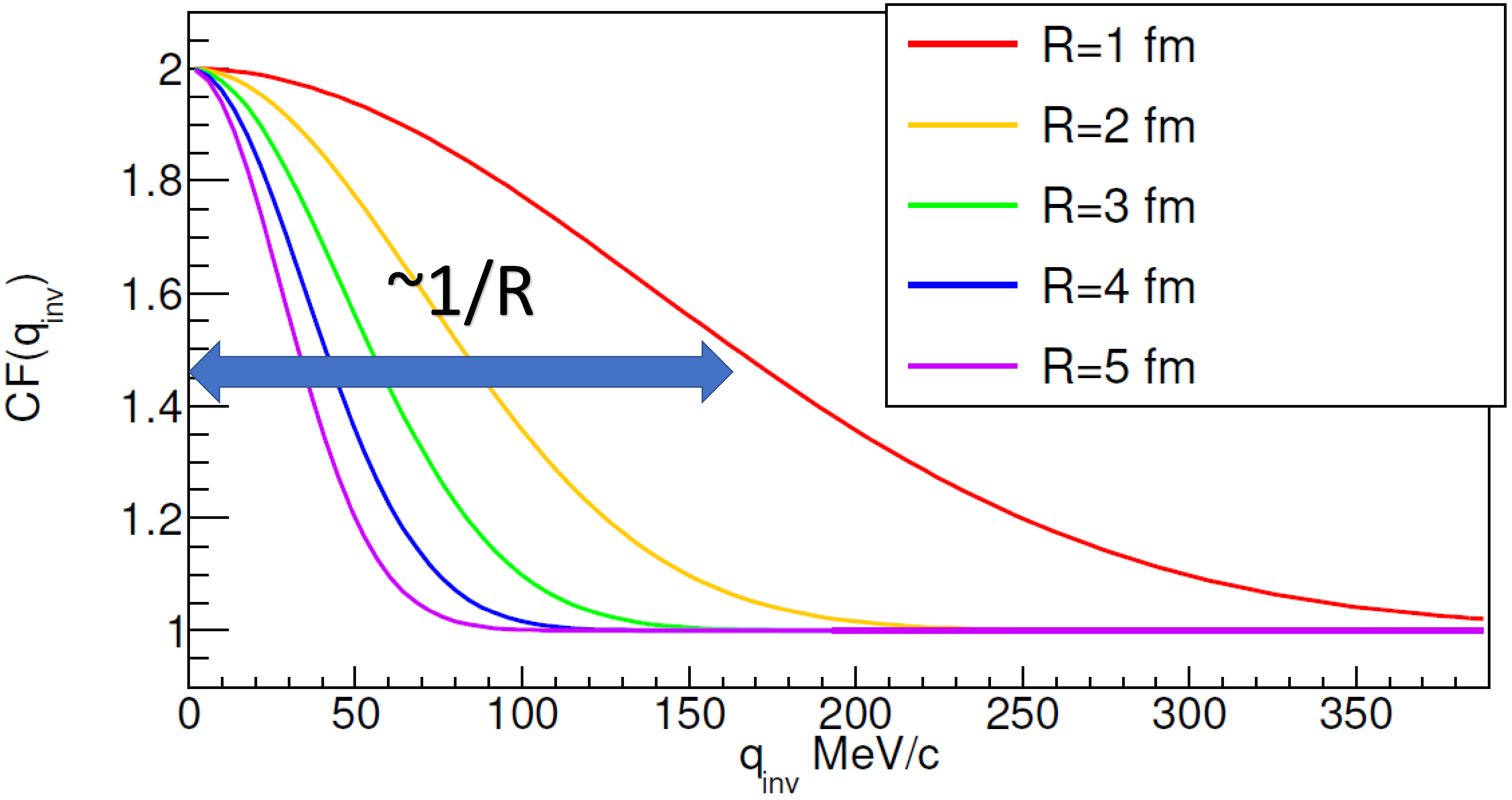
Probability of pair emission is:

Influence of quantum statistic term:

$|\Psi$

Correlation function

$C(q) = \int \rho(x_1, p_1)$



Femtoscopy

Known interactions ($|\Psi(x_1, p_1, x_2, p_2)|^2$)e.g. proton-proton:

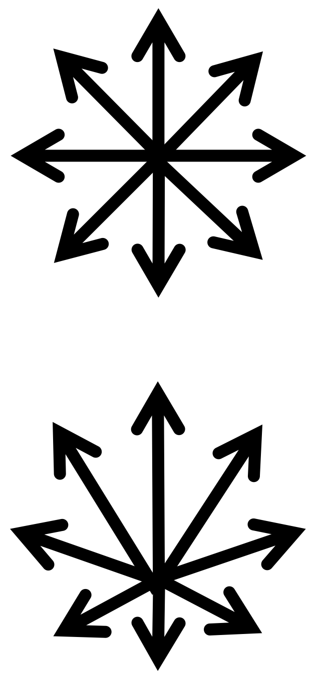
$$C(q) = \int \rho(x_1, p_1)\rho(x_2, p_2)|\Psi(x_1, p_1, x_2, p_2)\Big|^2 dx_1 dx_2 \to \rho(x_1, p_1)\rho(x_2, p_2)$$

Unknown interactions, known/assumed size of the source ($\rho(x_1, p_1)\rho(x_2, p_2)|$) e.g. lambda-lambda:

$$C(q) = \int \rho(x_1, p_1)\rho(x_2, p_2)|\Psi(x_1, p_1, x_2, p_2)\Big|^2 dx_1 dx_2 \to |\Psi(x_1, p_1, x_2, p_2)\Big|^2$$

Femtoscopy

Femtoscopic measurements are sensitive to dynamics of the source:



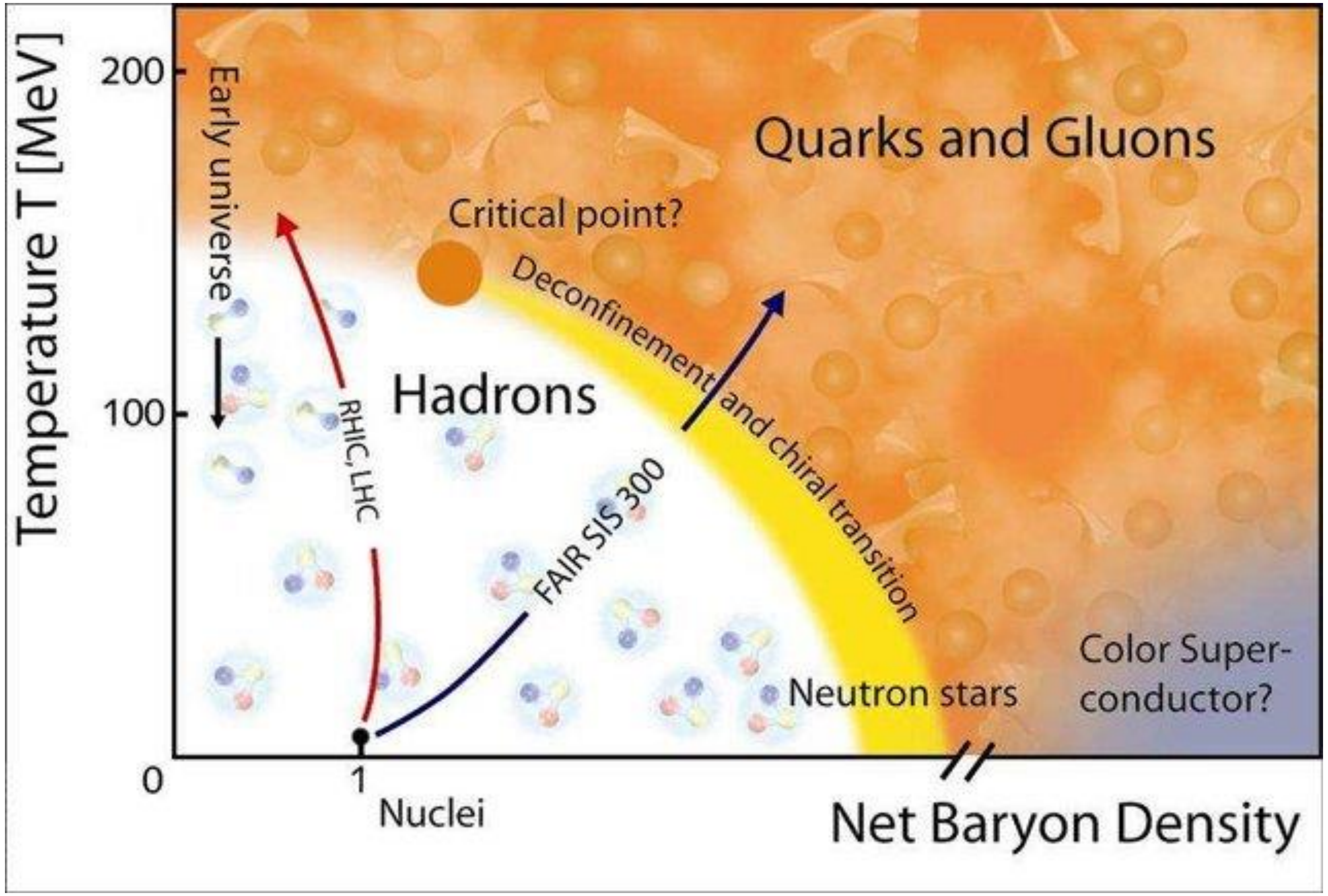
Lack of collectivity

Collectivity

Small k_T/m_T

Large k_T/m_T

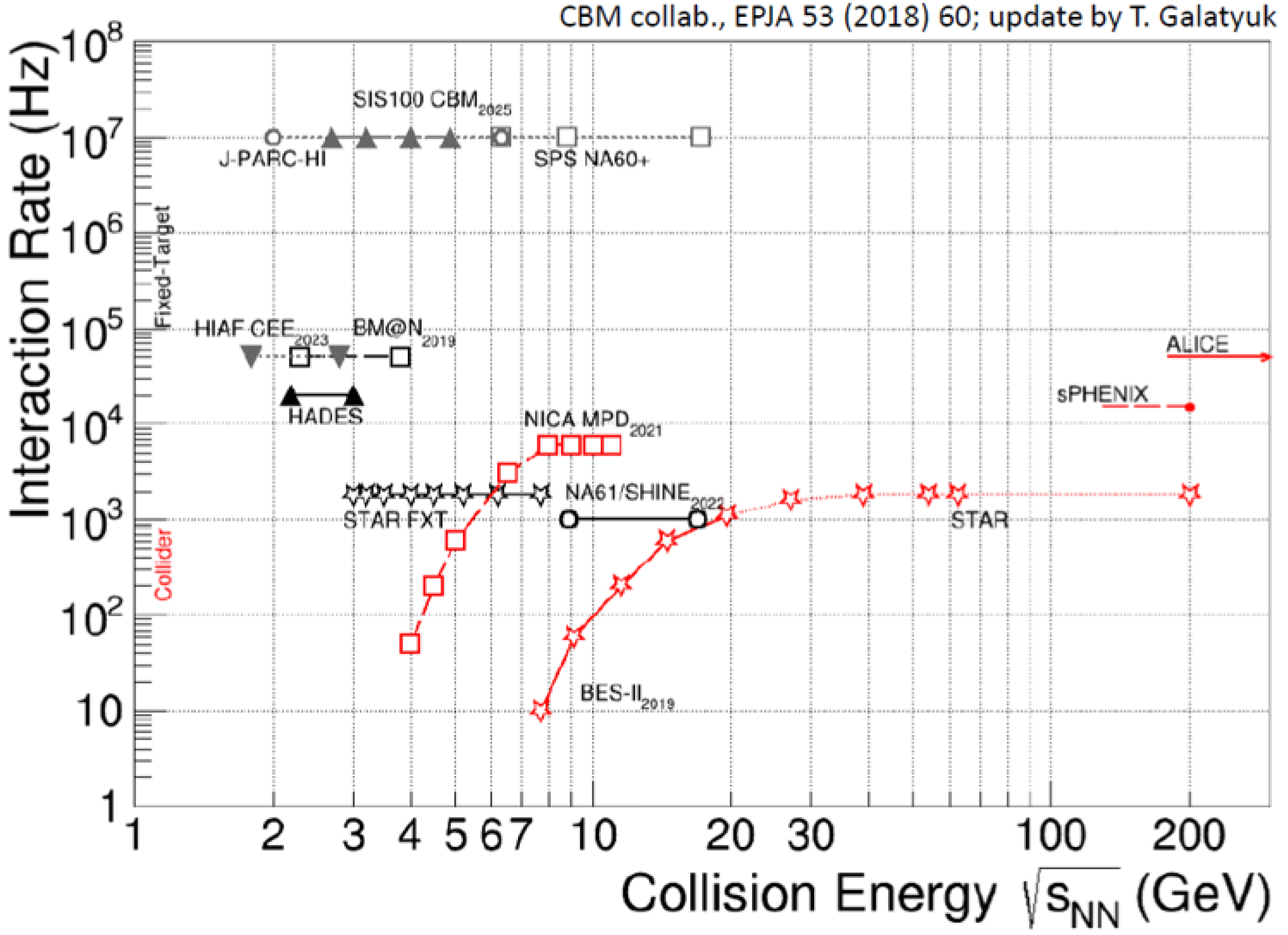
Physics in CBM



More info:
See P. Senger
talk at 14:00

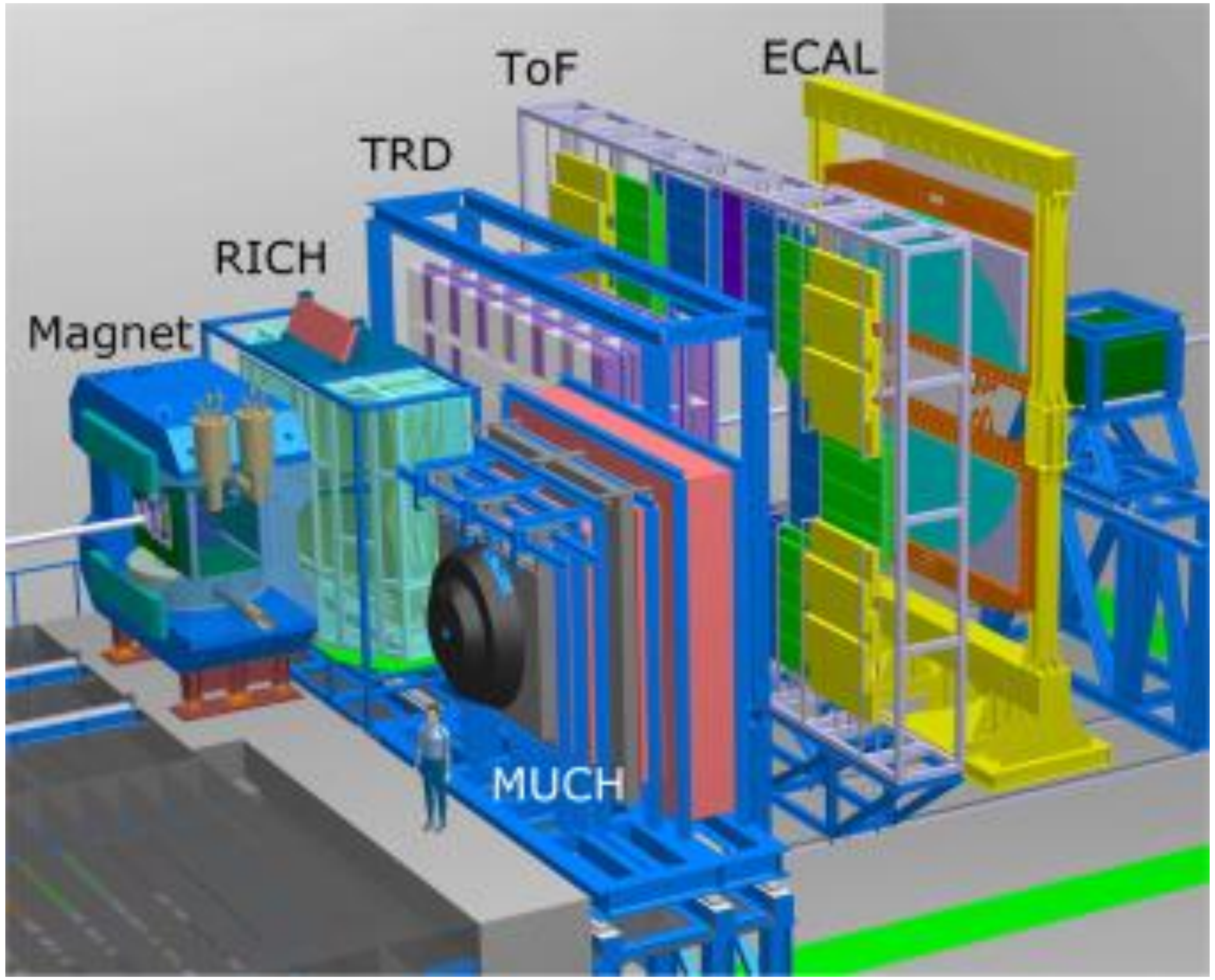
Introductory lectures on lattice QCD at nonzero baryon number, December 2015
•Journal of Physics Conference Series 706(2)

Physics in CBM



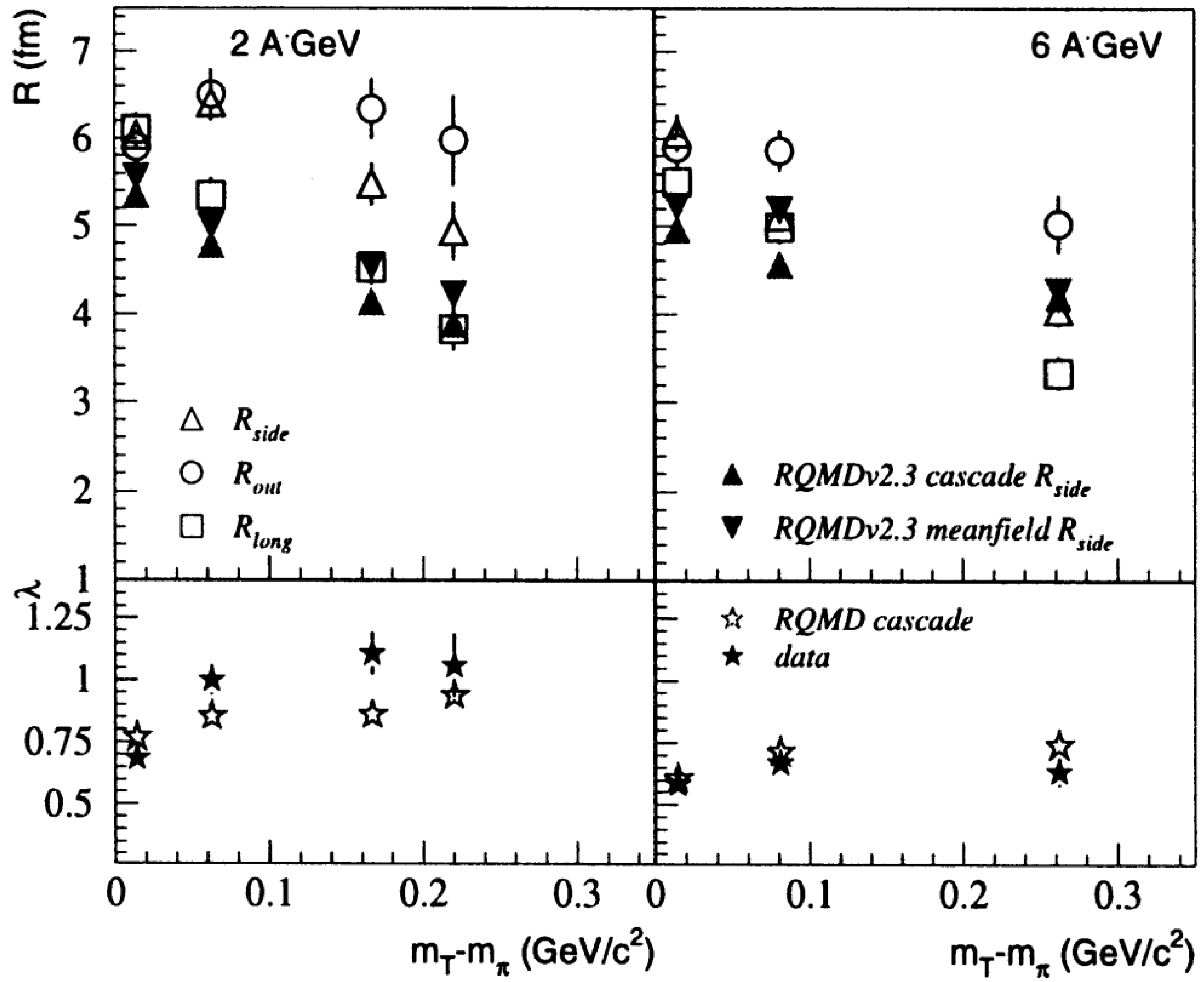
running
approved / under constr.
proposed

Physics in CBM

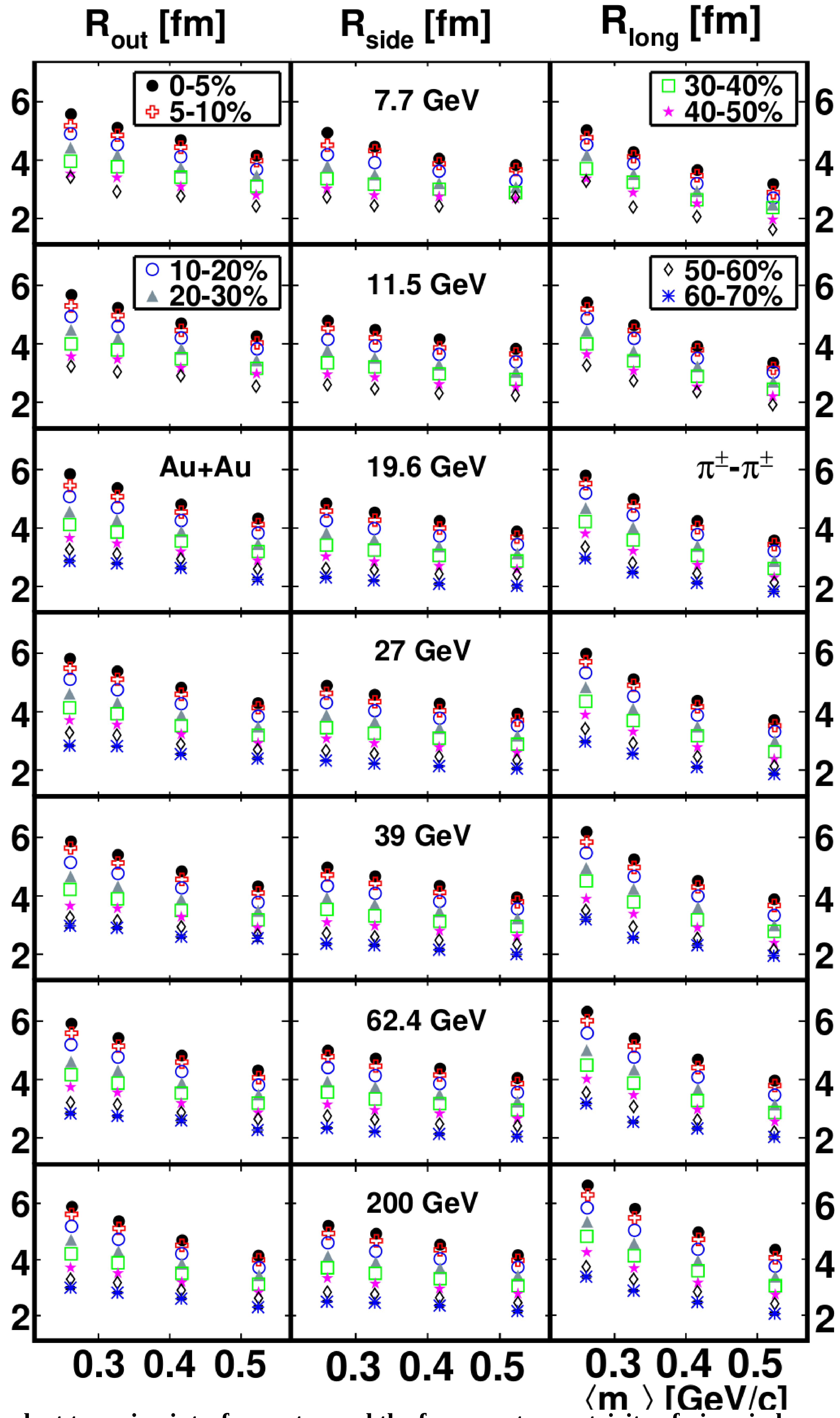


Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2017

Physics in CBM



Advances in nuclear dynamics 5 , W. Bauer G. d. Westfall
THE BOMBARDING ENERGY
DEPENDENCE OF 1r INTEFEROMETRY
AT THE AGS, M. Lisa et al..



Beam energy dependent two-pion interferometry and the freeze-out eccentricity of pions in heavy ion collisions at STAR, Physical Review C 92, 2014, L. Adamczyk et al..

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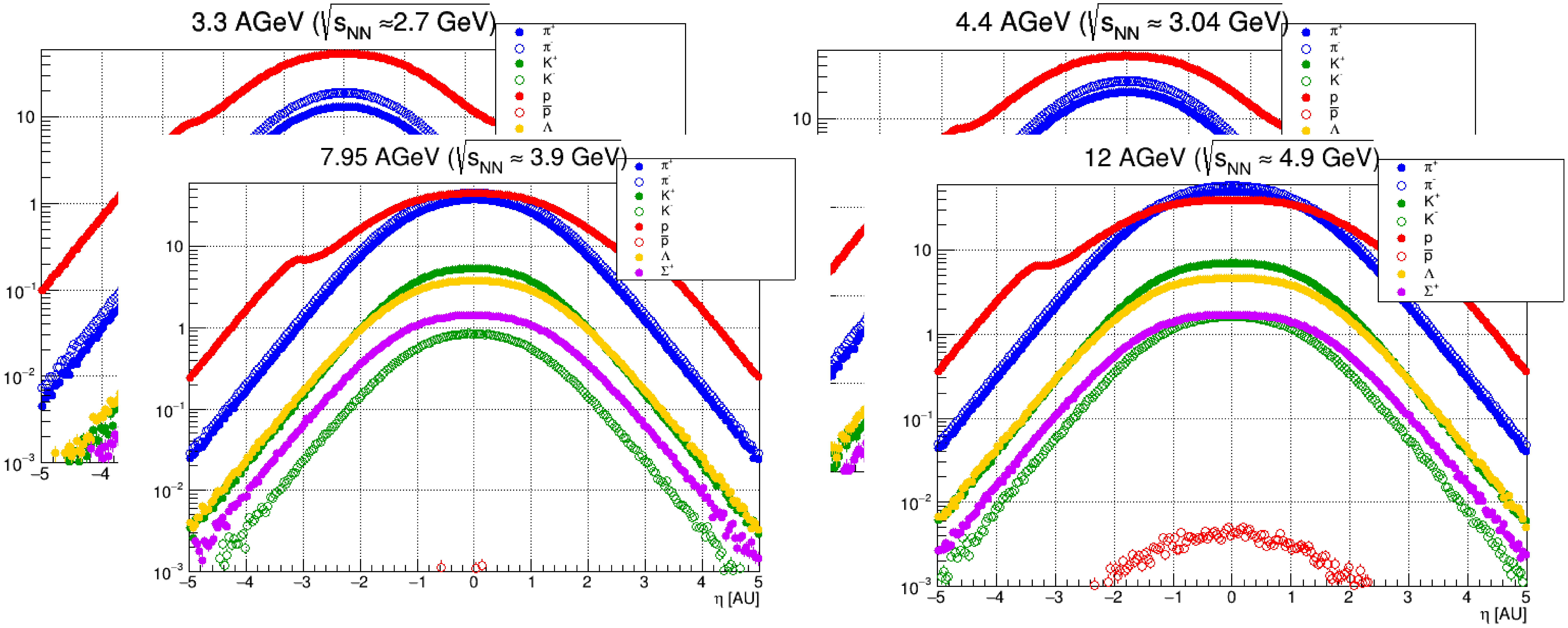
Physics in CBM – model predictions

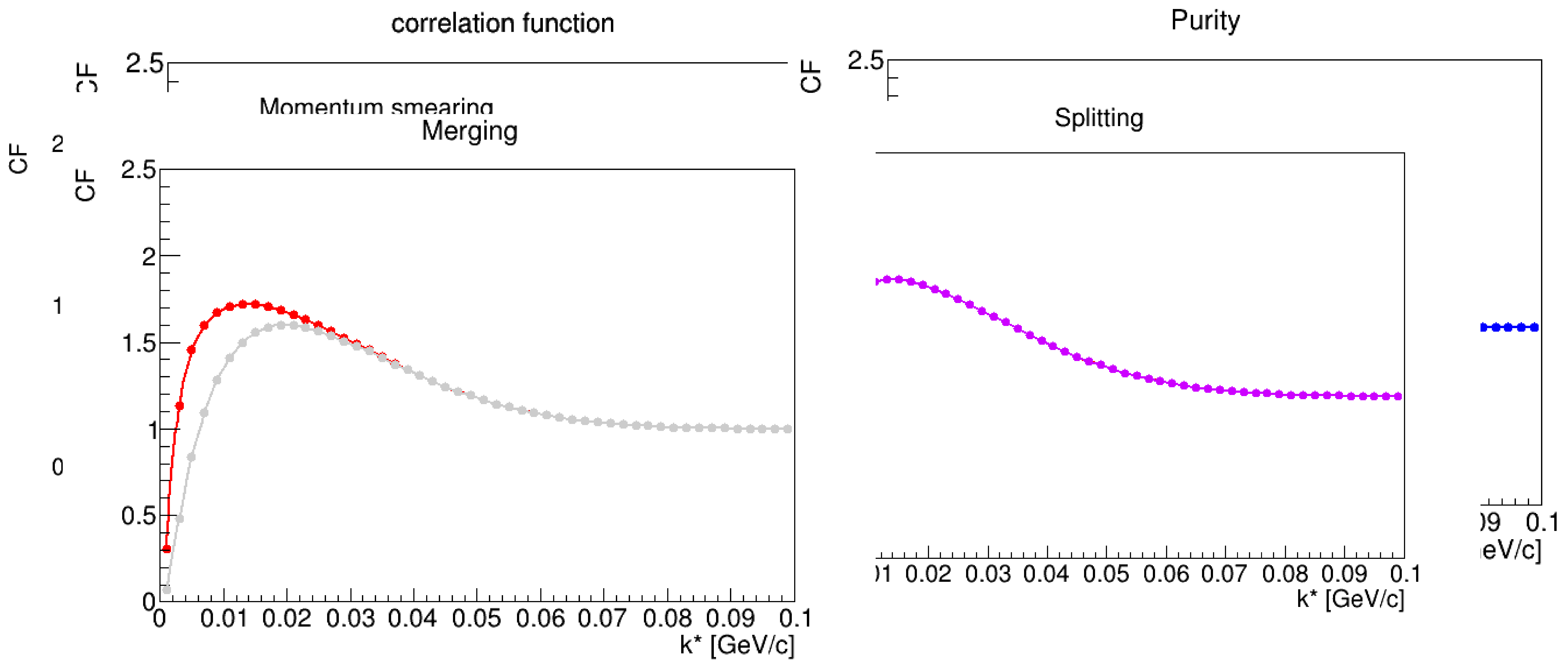


Femtoscopy in CBM

Problems with CF in experiment:

- Identification of particles (type, primary/secondary)
- Momentum resolution
- Two-track effects
- Residual correlations

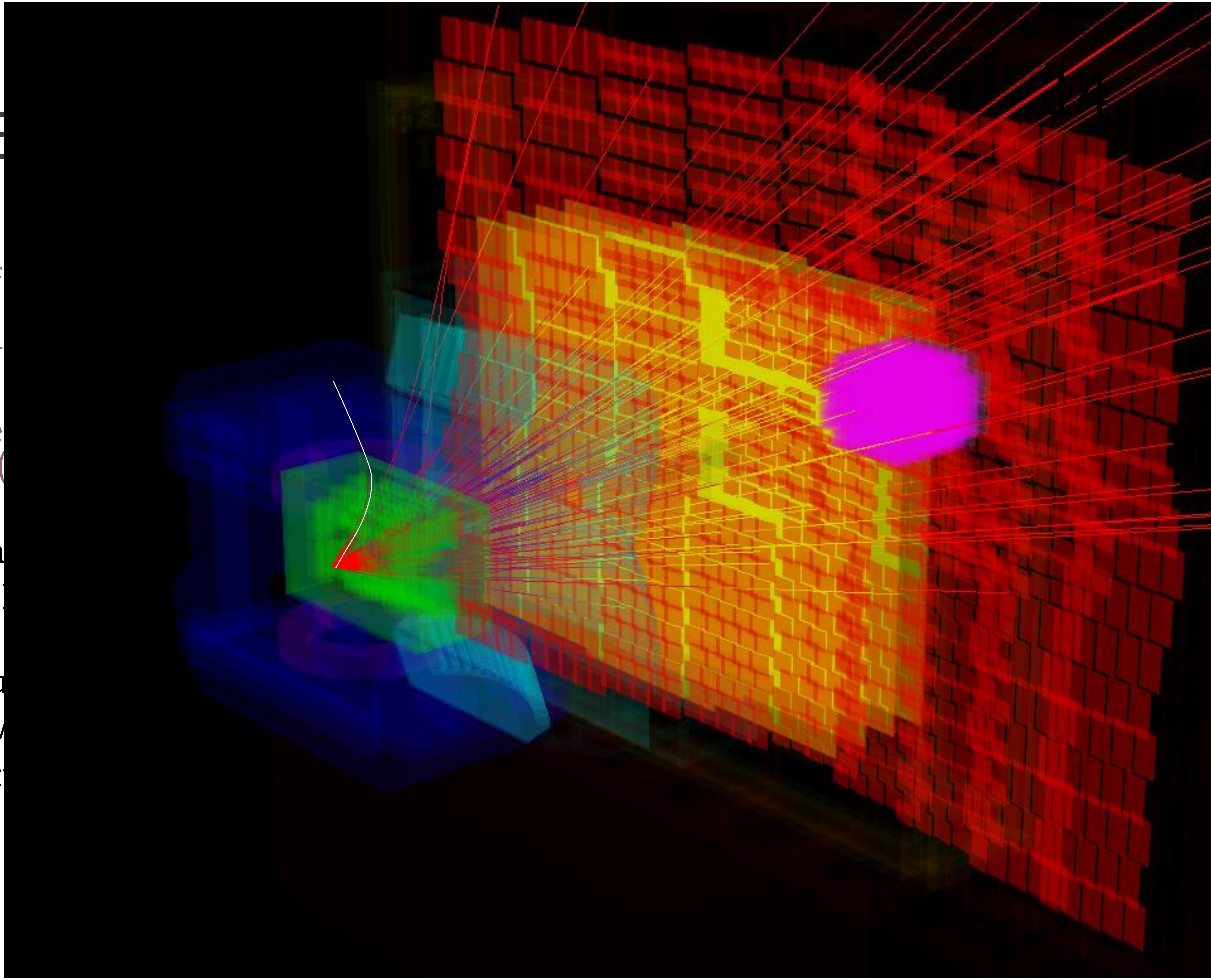
Femtoscopy in CBM



Femtoscopy in CE

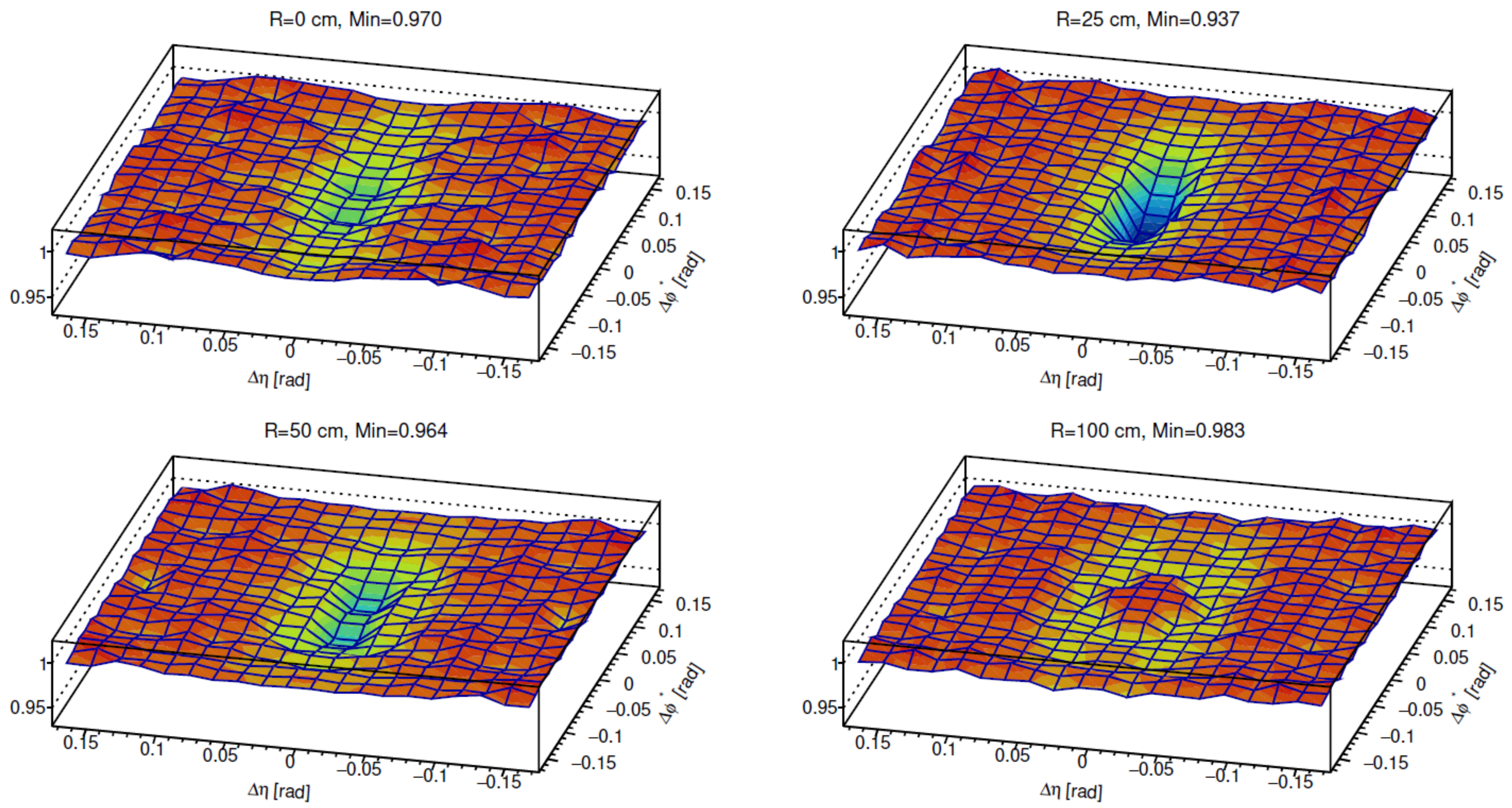
How to deal with two-particle eff

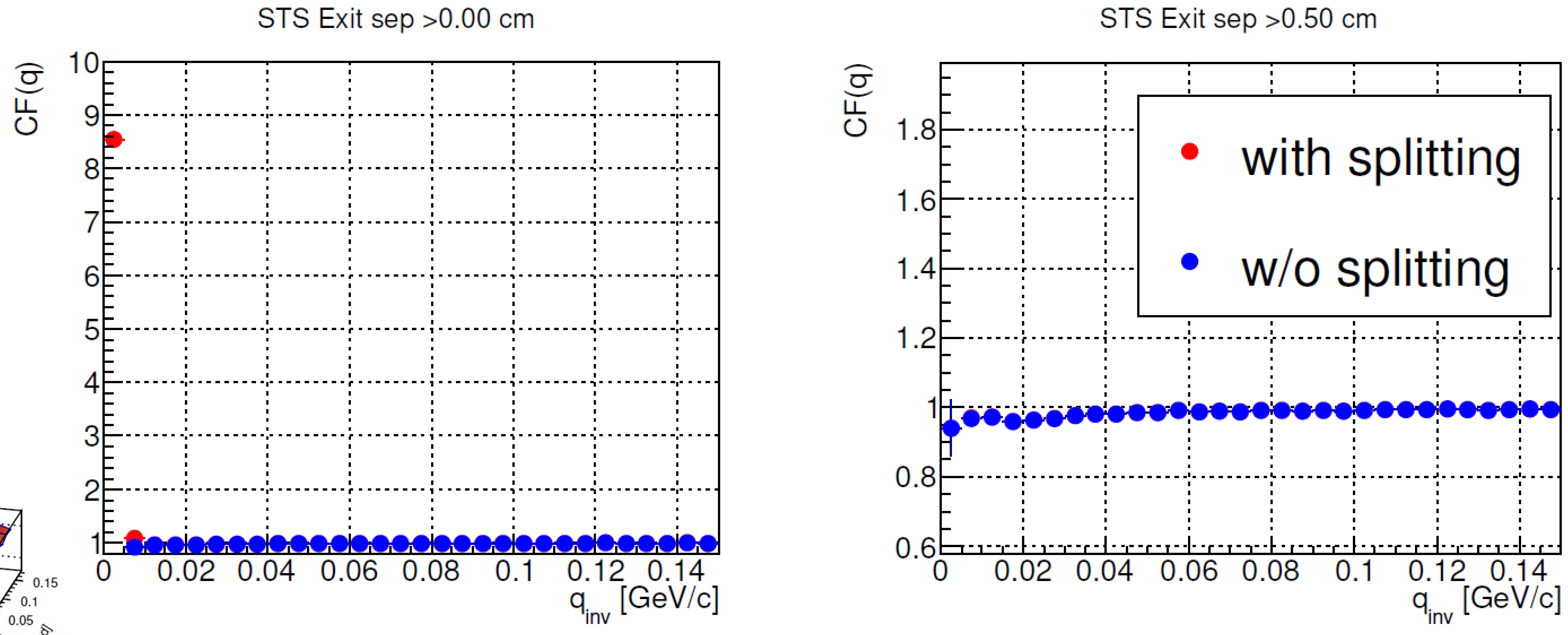
- Apply the cuts on pure MC mod function will be achieved
- Two-track cuts that remove me splitted but cannot base on q_{inv} (particle cuts:
    - STS exit separation – distan
    - N_{STS} hits it's less probable t merging/splitting
    - X,Y – position of particle du
    - $\Delta\eta^*\Delta\varphi^*$ - $\Delta\eta$ $\Delta\varphi$ between tw
    - ΔX ΔY – distance between t



Femtoscopy in CBM – negative pions

Anti-splittng cut – STS exit separation





Anti merging cut – Δη*Δφ* cut

Femtoscopy in CBM

Fraction of correlated pairs

$$C(q) = N\left(1 + \lambda C_{purity}(q)\left(C_{map}(q,R) - 1\right)\right)$$

Normalization

Fraction of pion-pion pairs

CF for gaussian source
- Spherically symmetrical
- PRF frame
- Numerical map

Impurity

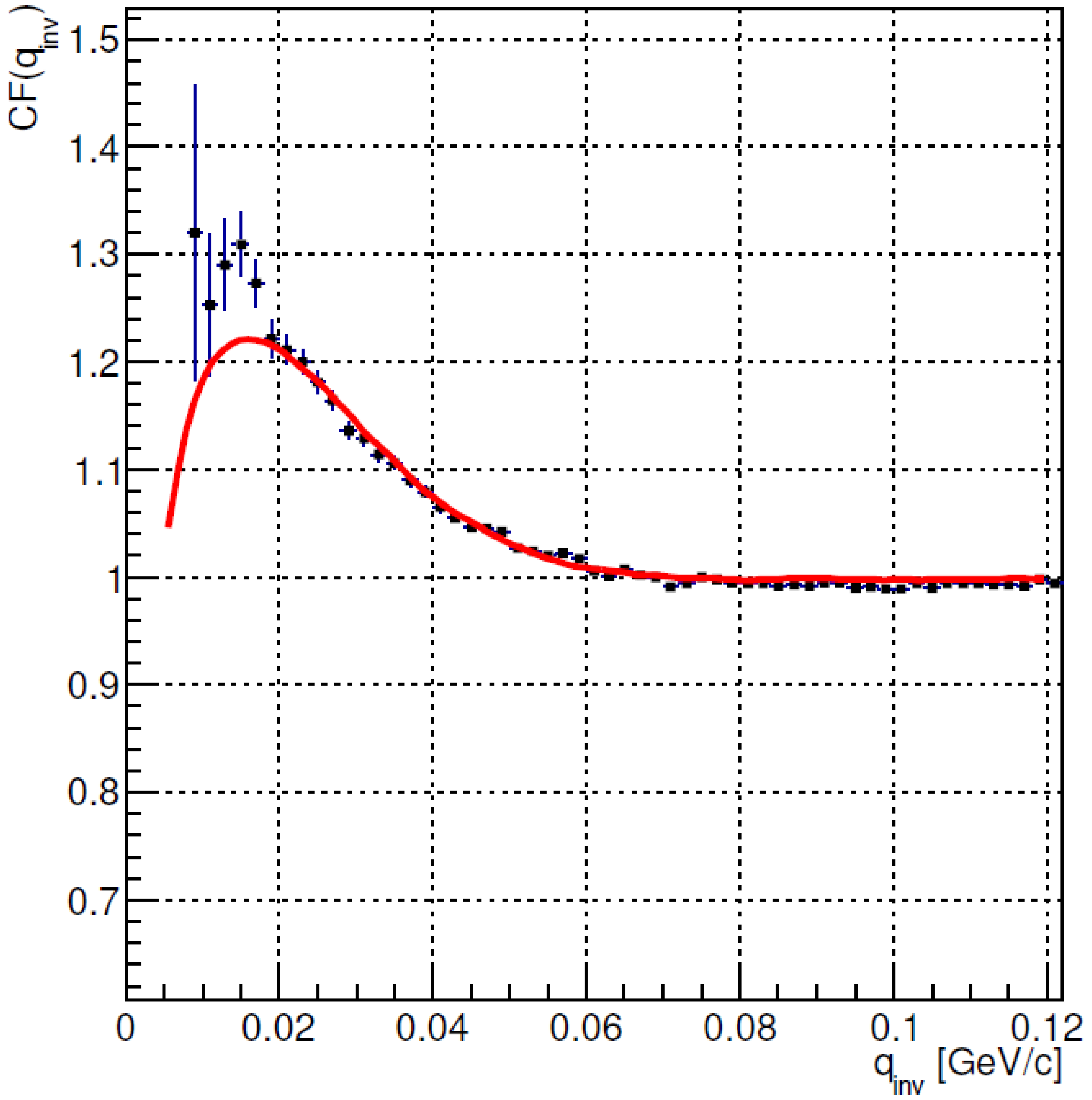
$$C_{purity}(q) = 1 - \left(\mathrm{A} + \mathrm{B}e^{-qC}\right)$$

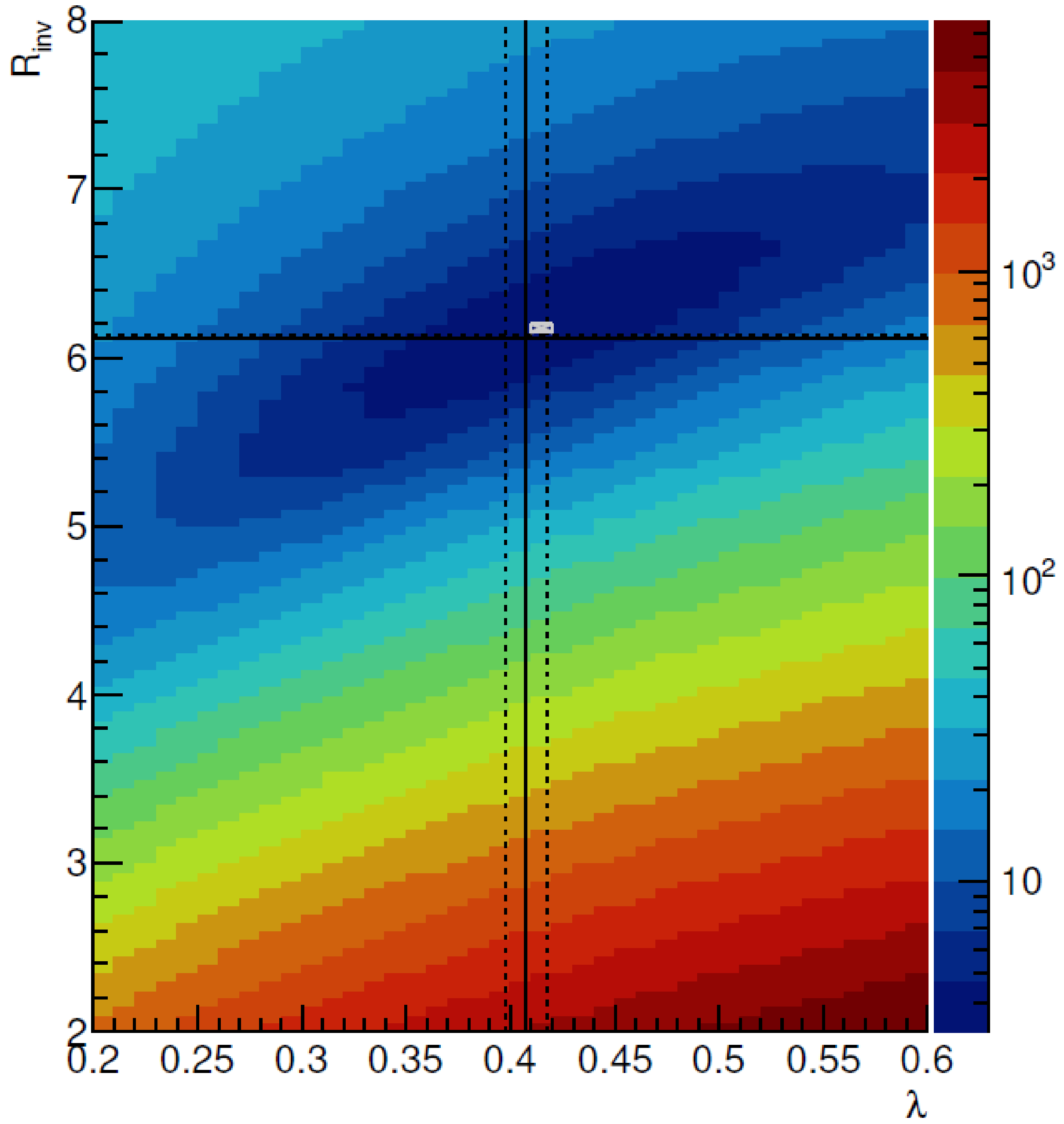
Femtoscopy in CBM – negative pions

After analysis of 1M central AuAu events

Systematic uncertainty is estimated to be around 9-10%

It's worth to stress that assumed source (3-dimensional gaussian) is not well described by 1-dimensional gaussian model.





Femtoscopy in CBM: protons

Similar sample of data – central UrQMD events, 1M of events. Track cuts optimized to select primary protons.

Input – gaussian source with R=3.5 fm and lambda = 1 – radius taken from UrQMD model.

Femtoscopy of protons (WIP)

Warning: in contrast to mesons, in baryon-baryon correlations there are significant residual correlations. It means that instead fitting CF by this formula where M is theoretical function for proton proton

$$C_{experiment}(q) = M_{pp}(q)$$

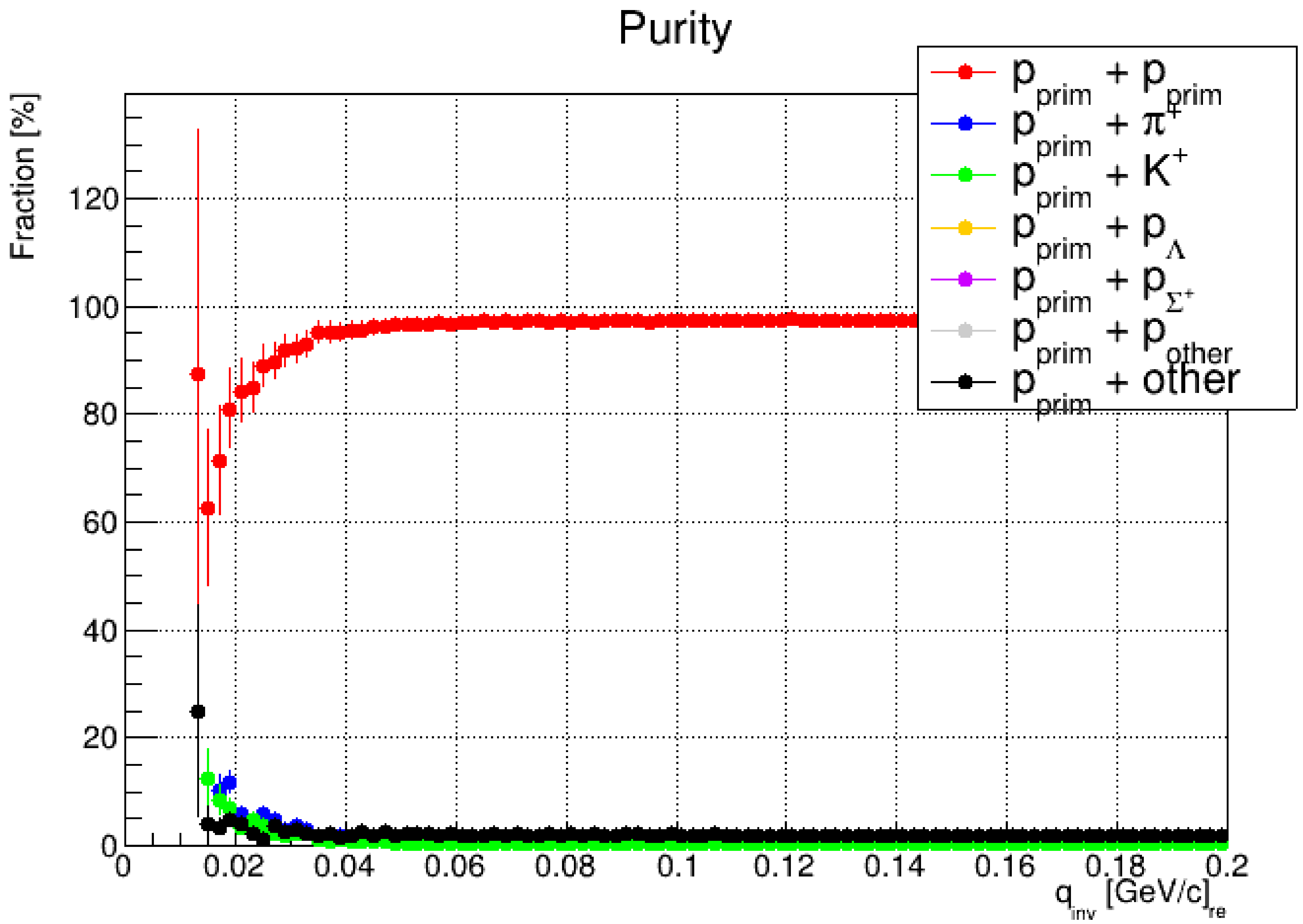
We should you this equation:

$$C_{experiment} = F_{pp}M_{pp}(q) + F_{p\Lambda}(q)\widehat{M}_{p\Lambda}(q) + F_{\Lambda\Lambda}(q)\widehat{M}_{\Lambda\Lambda}(q) + \cdots$$

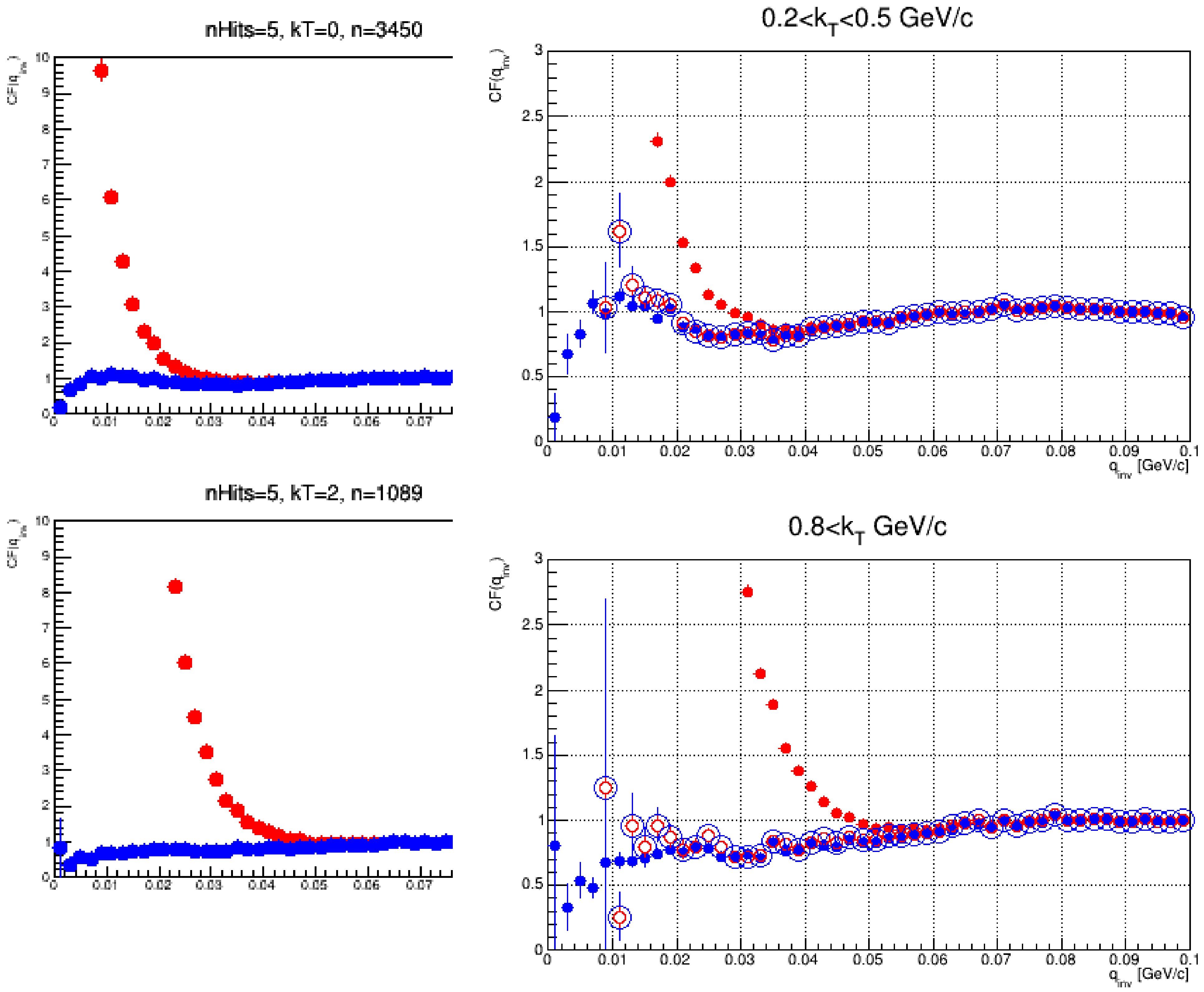
where the $\mathrm{M_{XY}}$ is contribution from X and Y baryons that decays in the protons

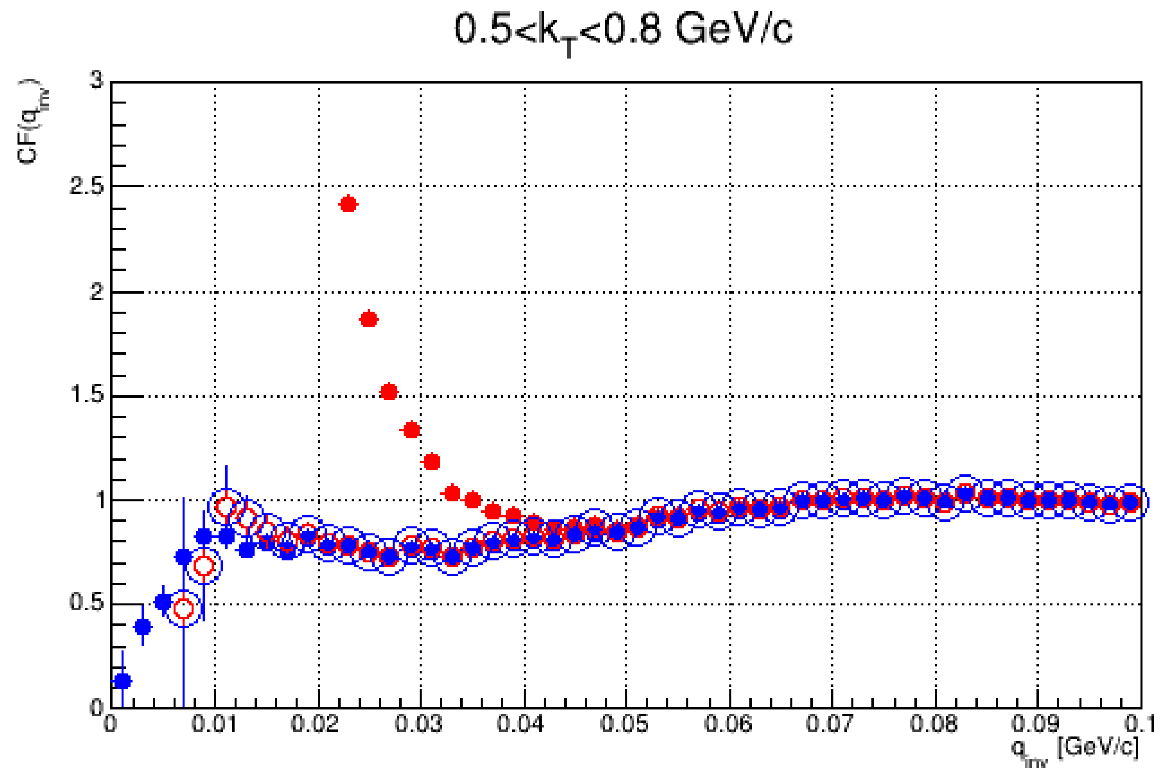
Femtoscopy of protons

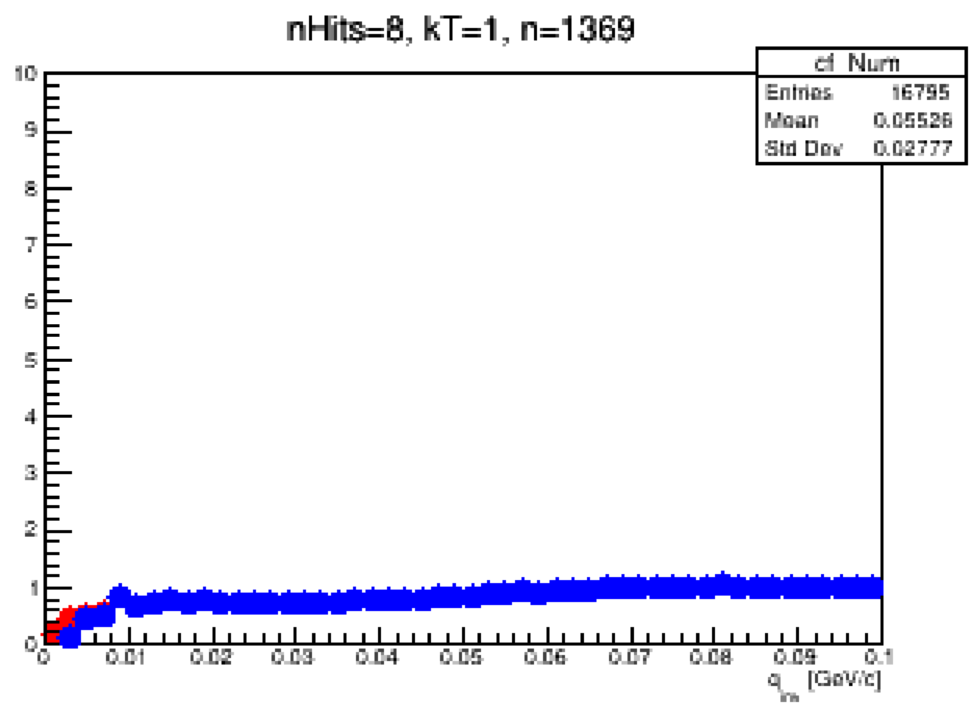
The good news – there is no significant contribution from residual correlations in CBM!

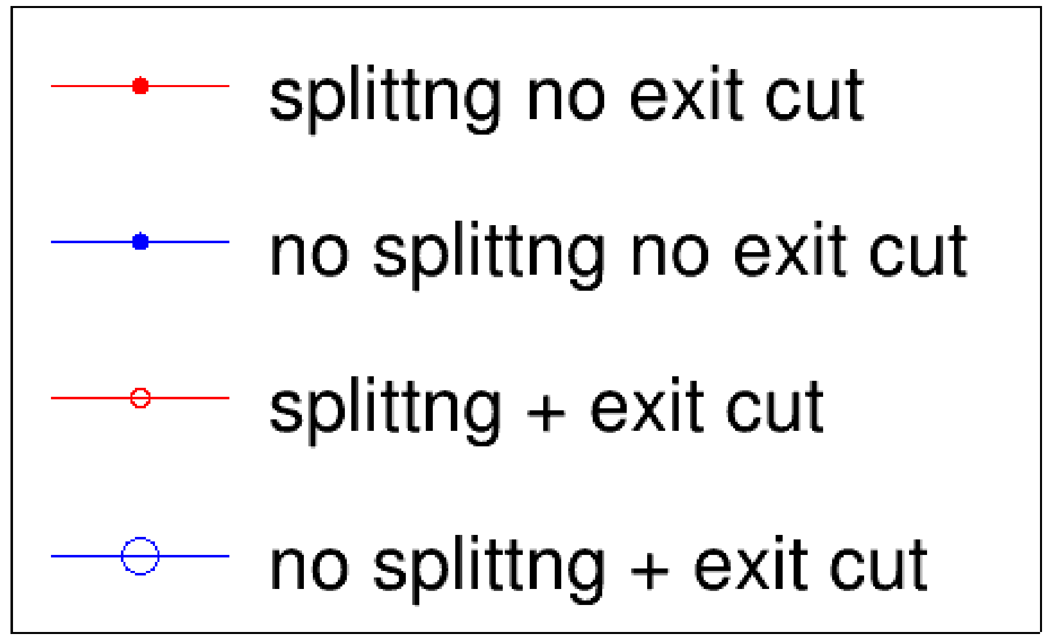


Anti splitting cut





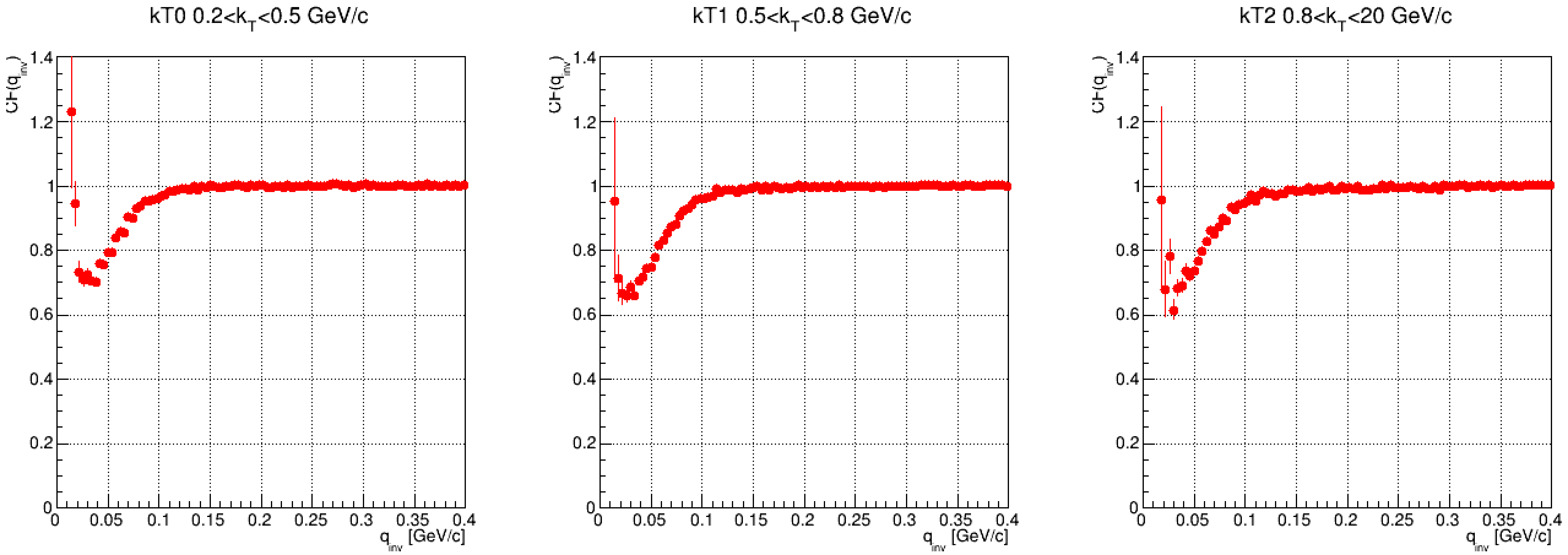




STS hits >=8

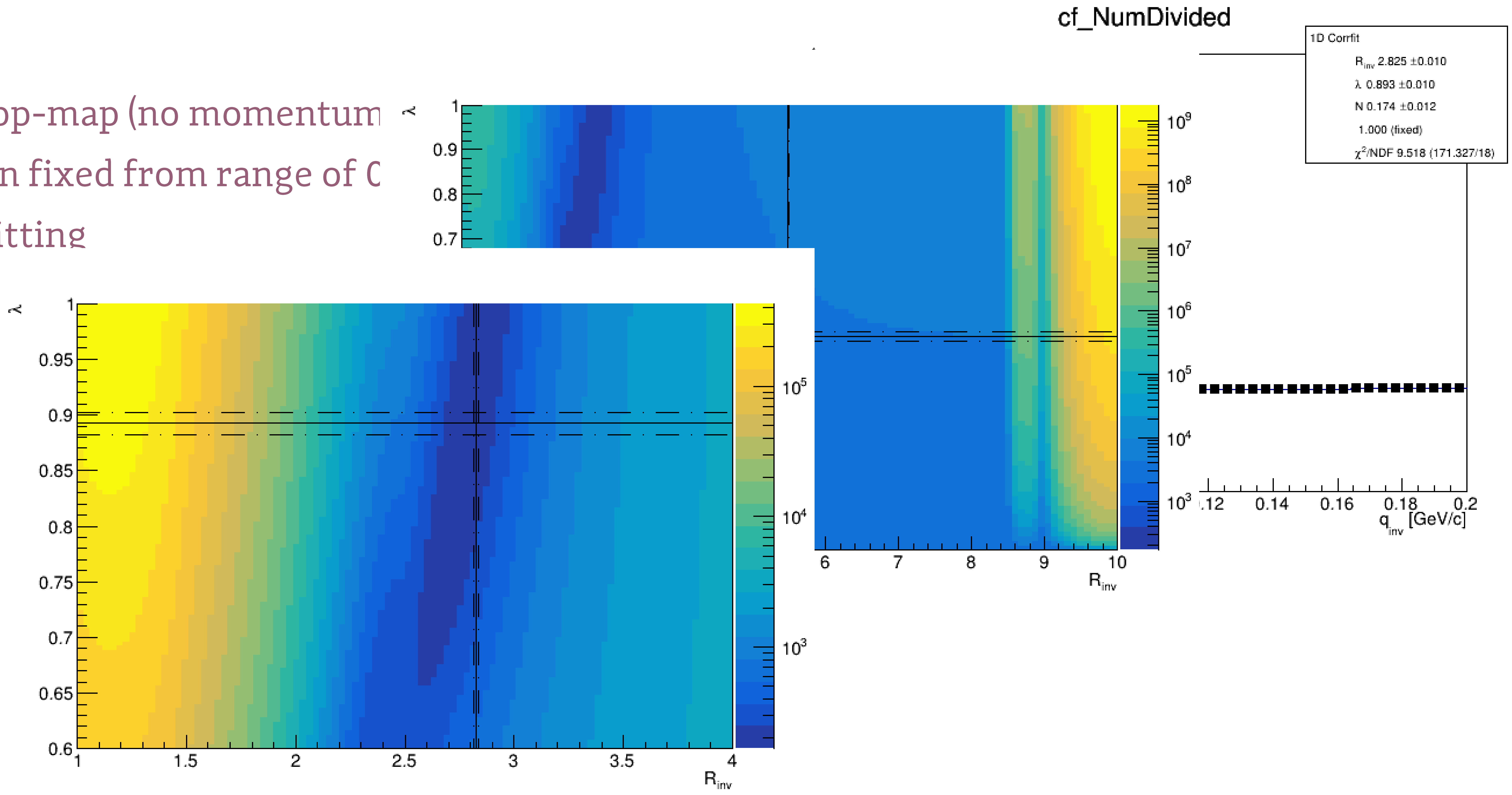
STS exit cut = 1 cm
(for pions it was 0.5 cm)

Merging – corrected by dividing the denominator



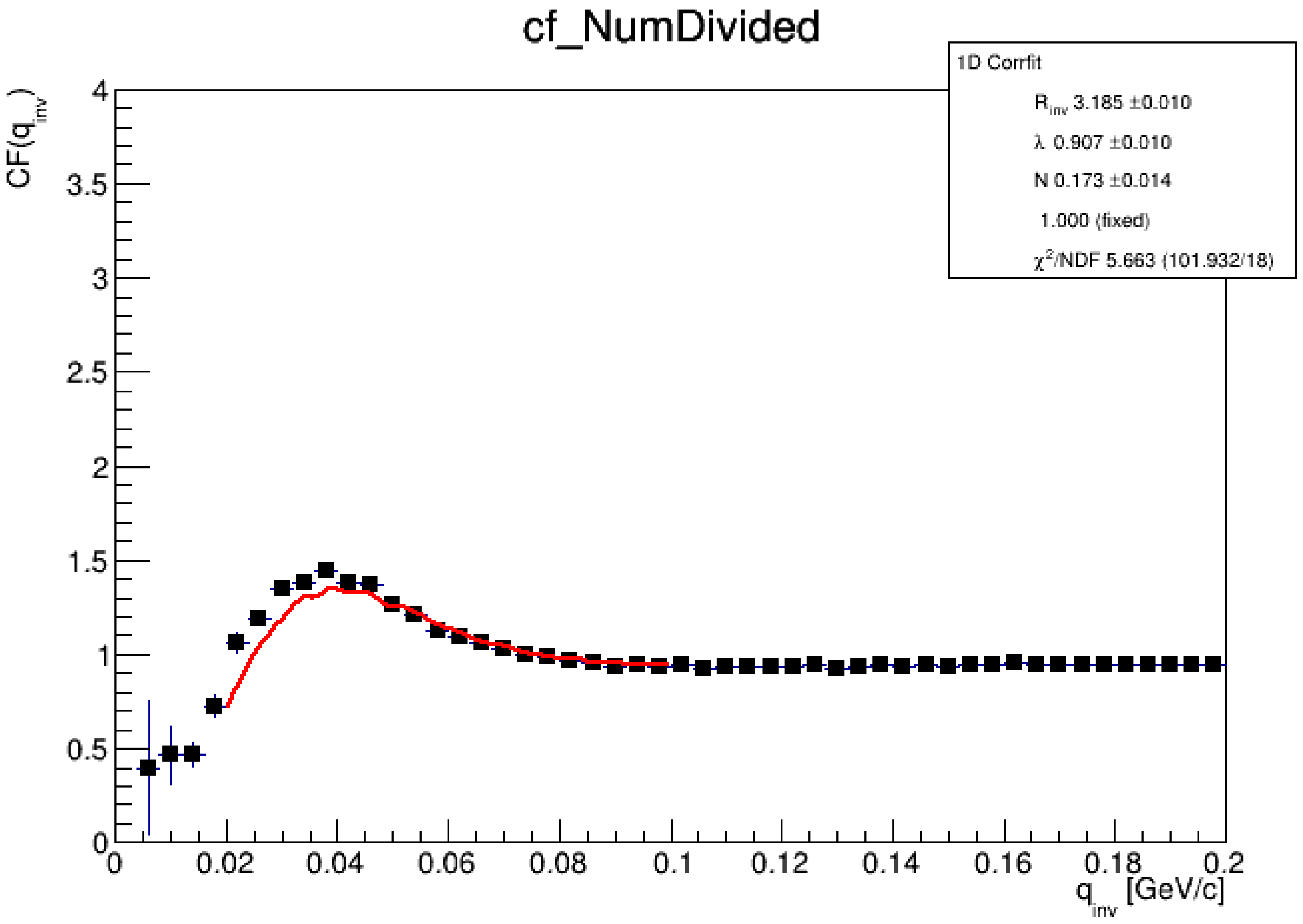
Fitting

- NicaFemto + pp-map (no momentum
- Normalization fixed from range of C
- Two step of fitting
- Process is au



Results

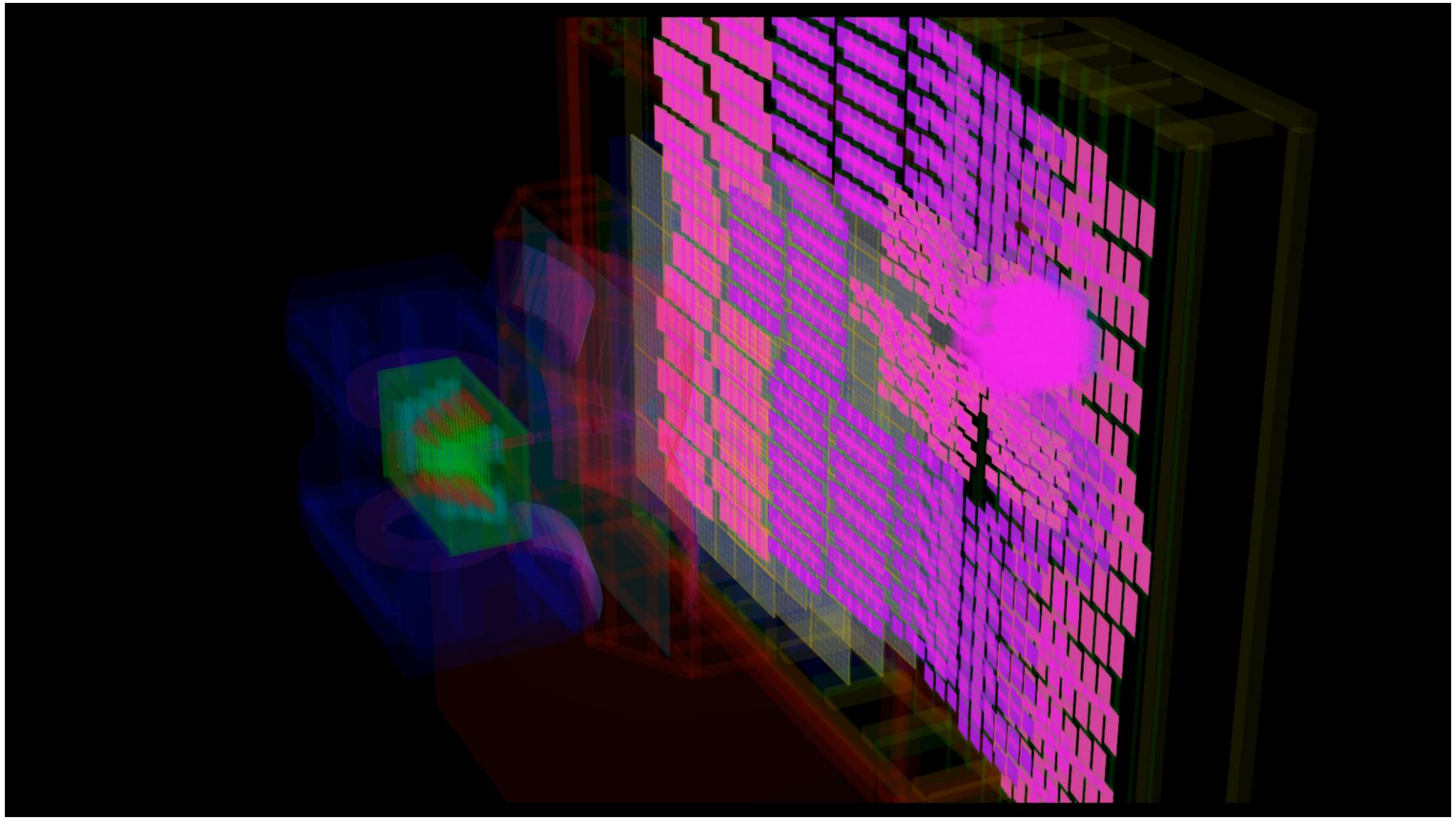
- Obtained radius are smaller (≈ 2.8 instead of 3.5 :
- Lambdas are also smaller (0.85-0.9 instead of 1)
- Relatively small statistical uncertainty (ΔR≈0.3%
- Large systematical uncertainties - ΔR≈55% - the „background”



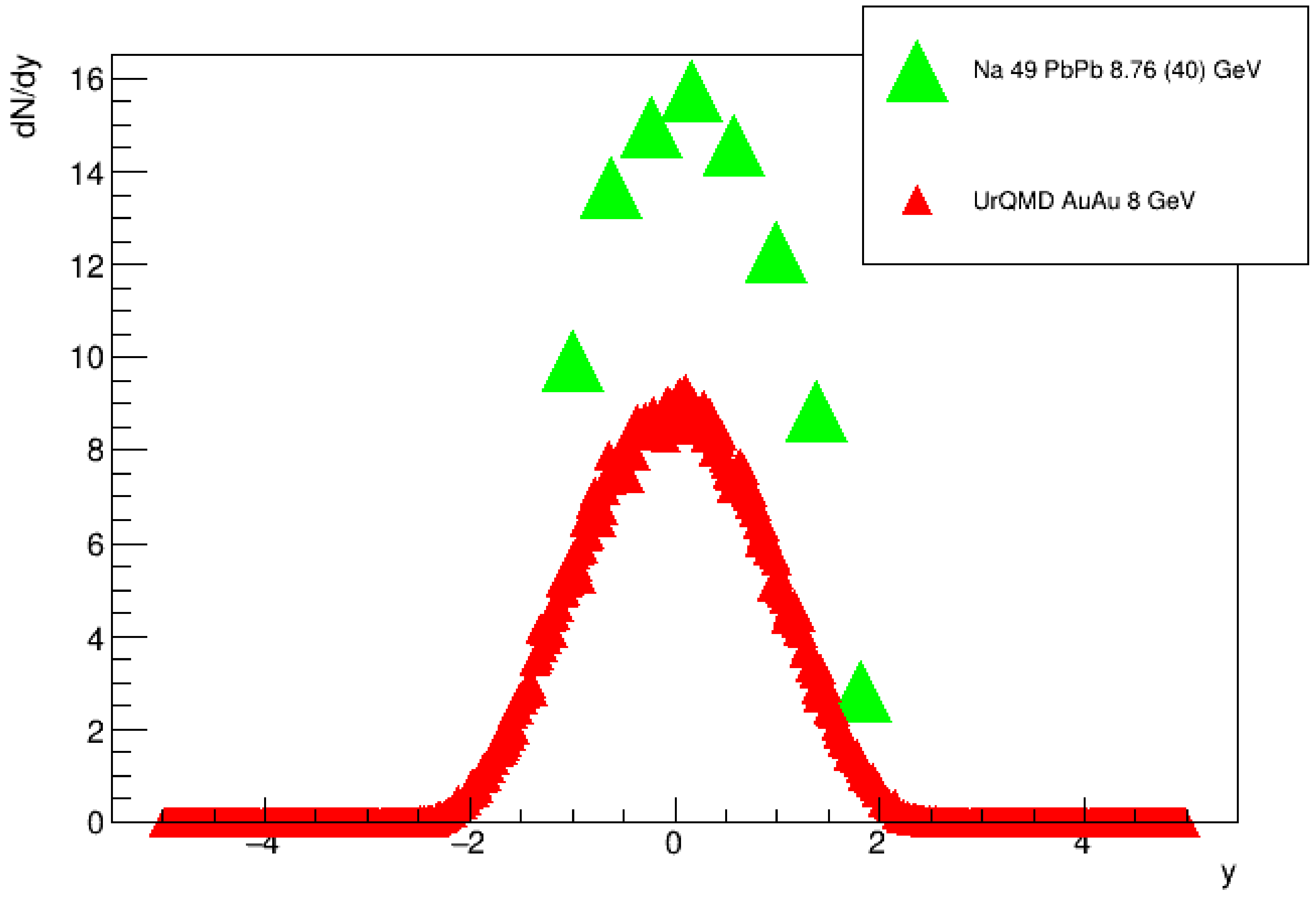
Summary & plans

- CBM seems to be very good detector for pion measurements
- Protons correlation – further studies needed
- There is no significant contribution of residual correlations into proton-proton HBT at 12 GeVA
- TODO:
  - Study the other correlations (exotic baryons, 3-dimensional femtoscopy etc.)
  - Testing model predictions
  - …

Thank you for your attention

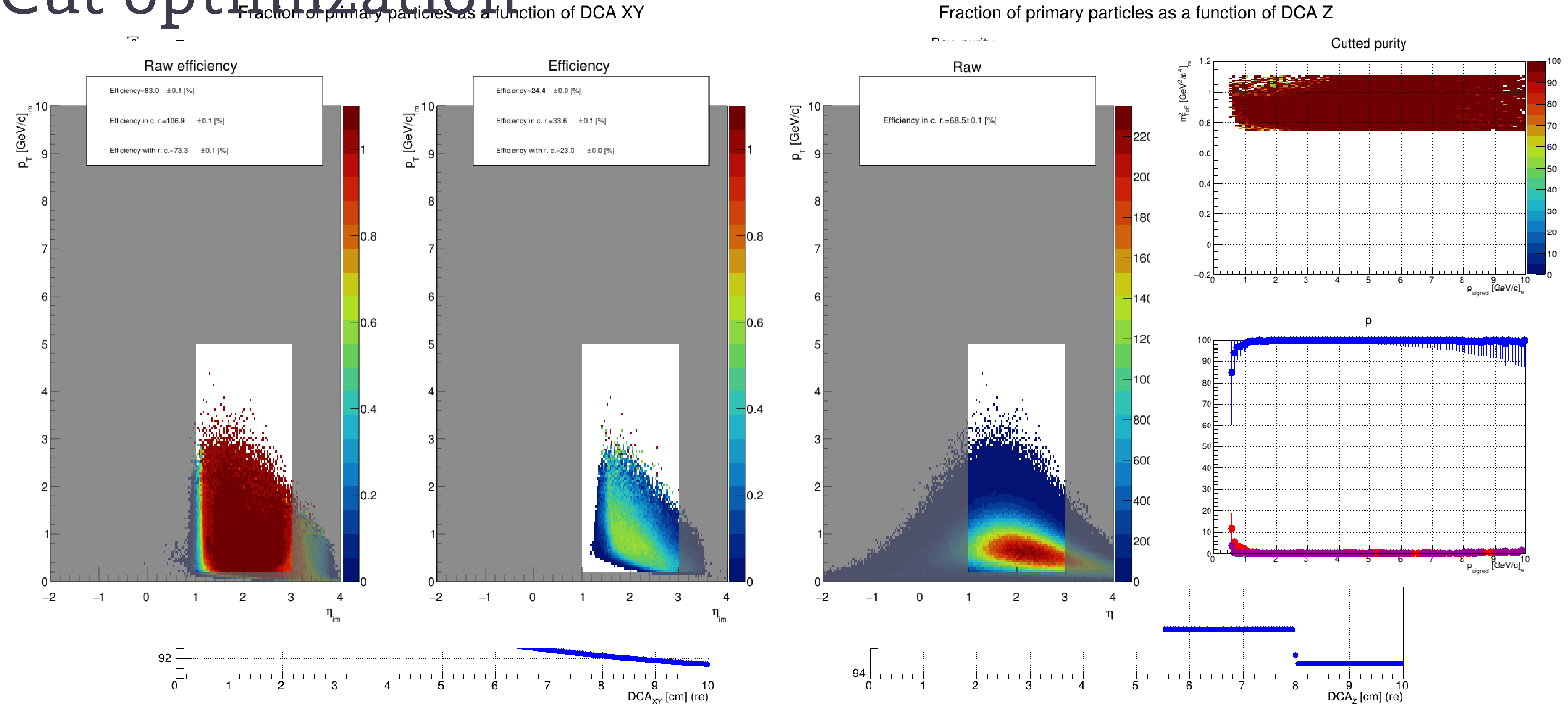


The interesting part ☺

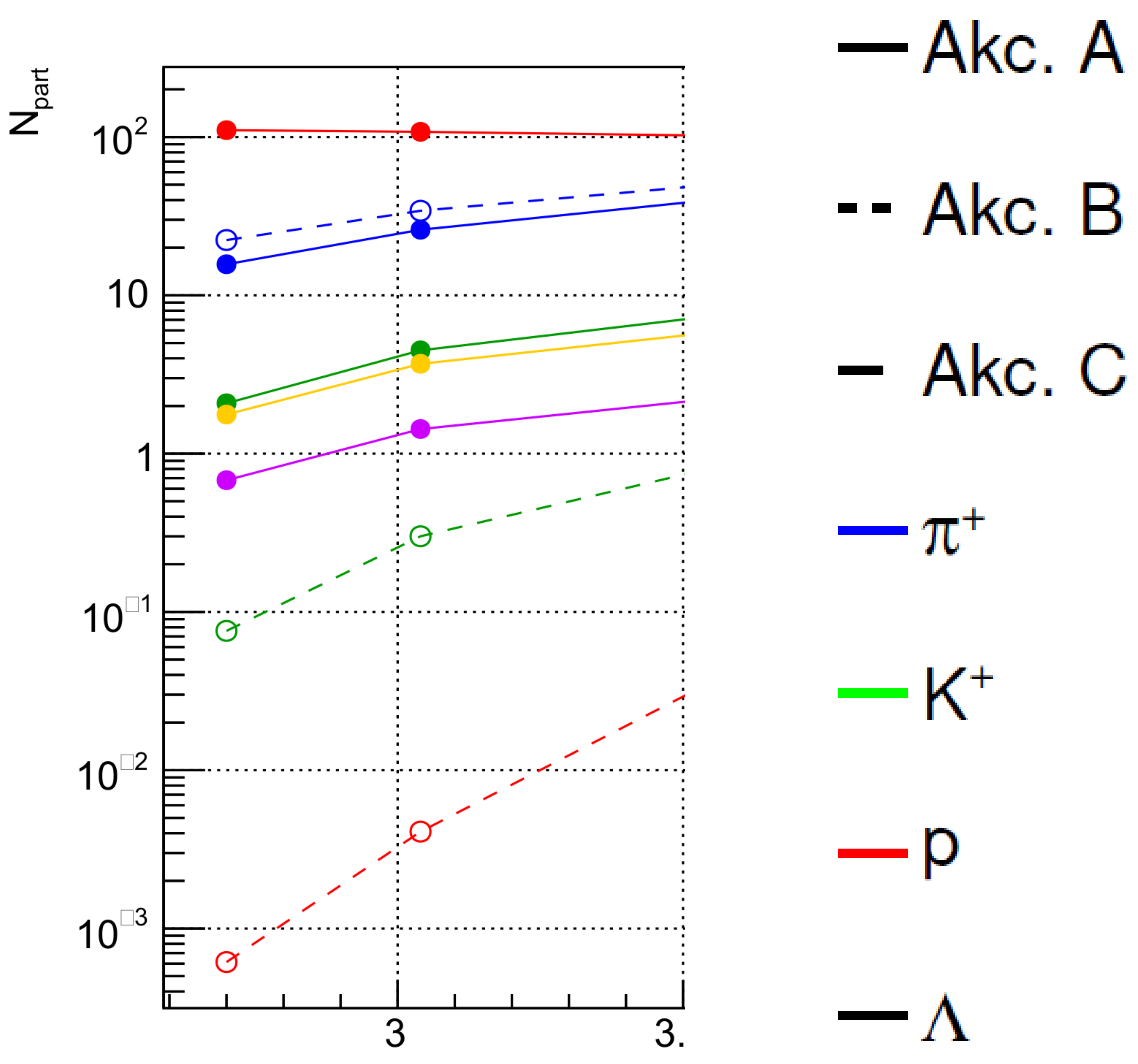


Na 49 PbPb 8.76 (40) GeV
UrQMD AuAu 8 GeV
dN/dy
16
14
12
10
8
6
4
2
0
−4
−2
0
2
4
y

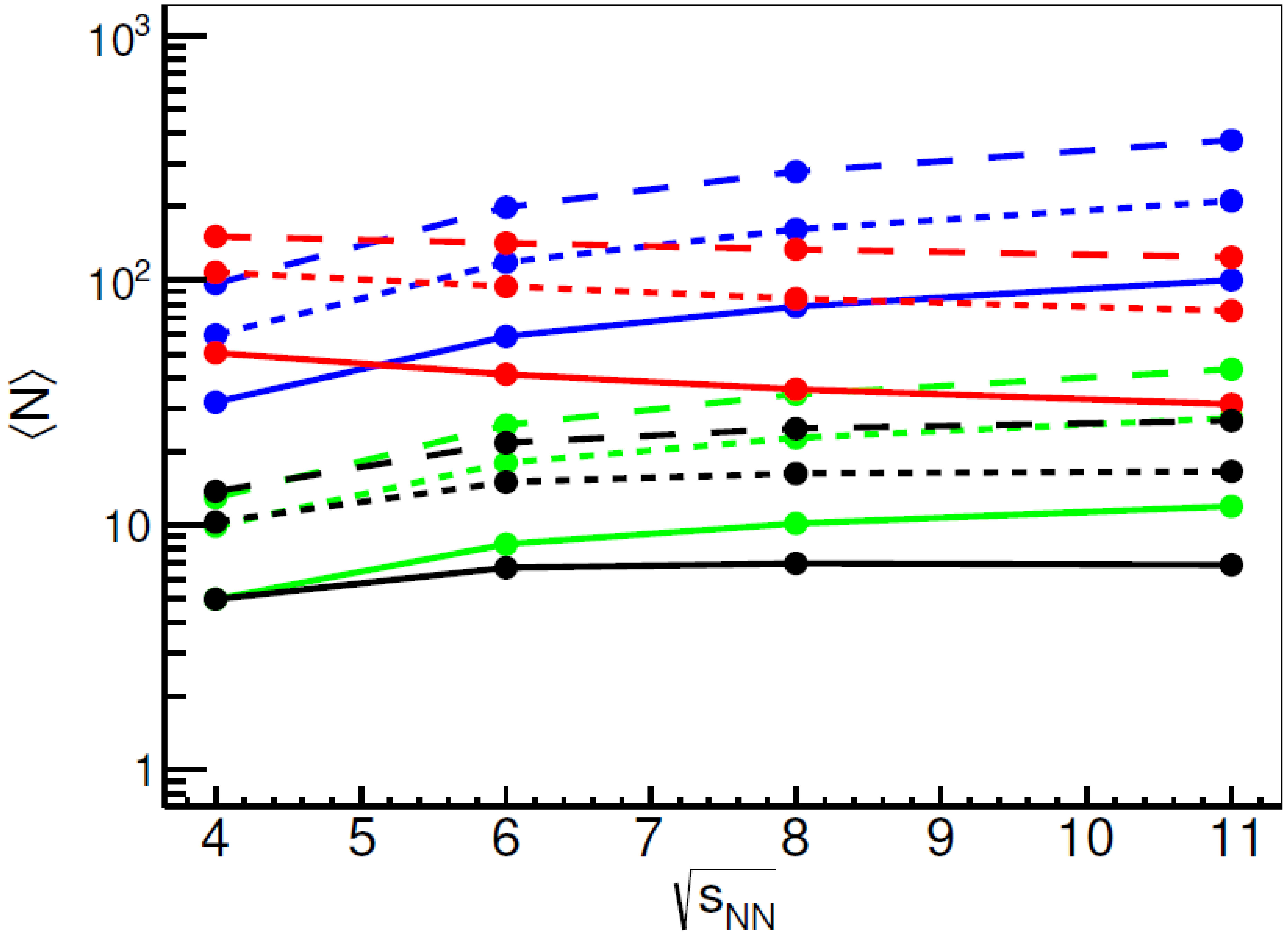
Cut optimization



Physics in CBM – model predictions



Central AuAu events (0-5%) production at midrapidity



D. Wielanek PhD Thesis

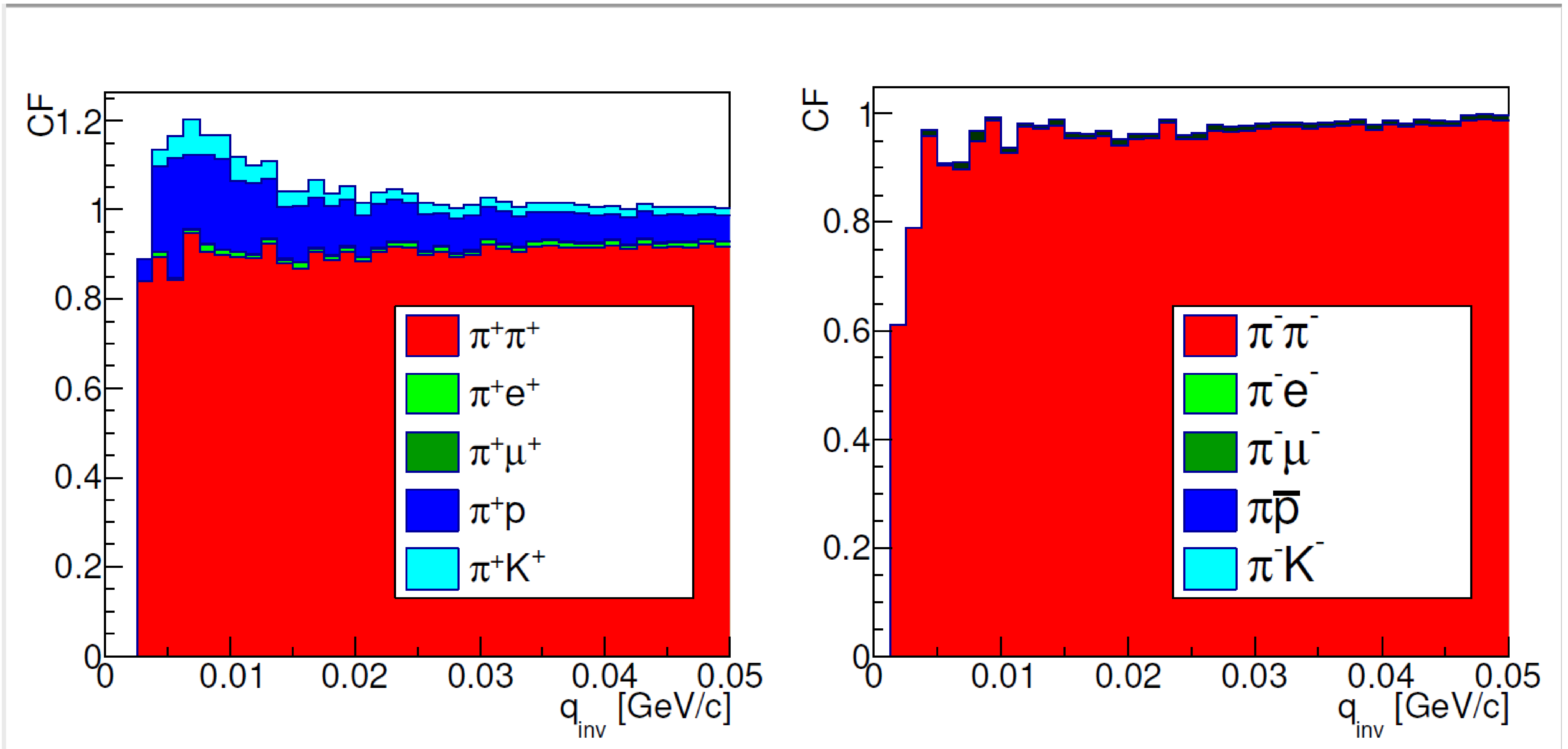
Warsaw University of Technology

Two particle cut monitors

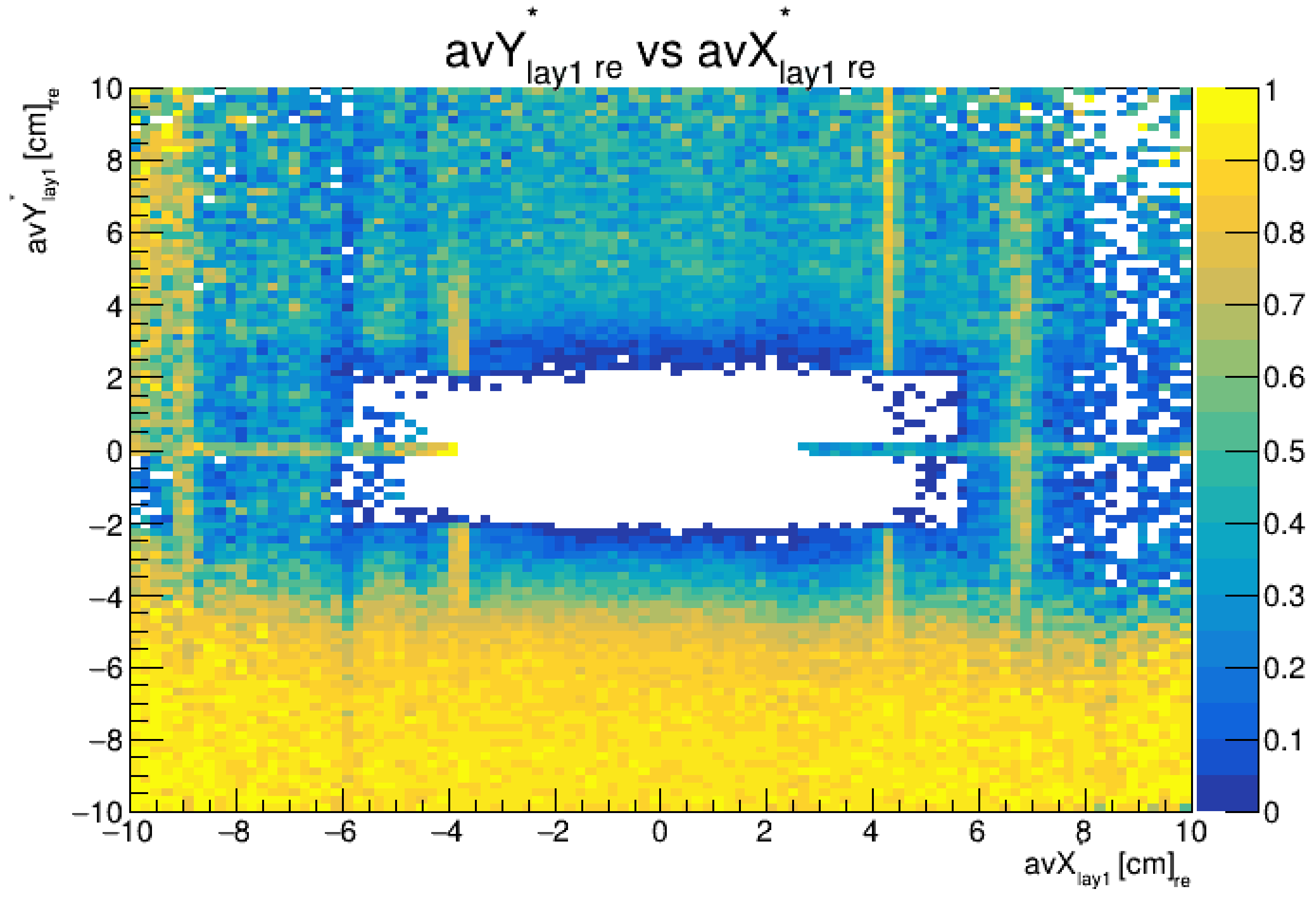
Femtoscopy in CBM

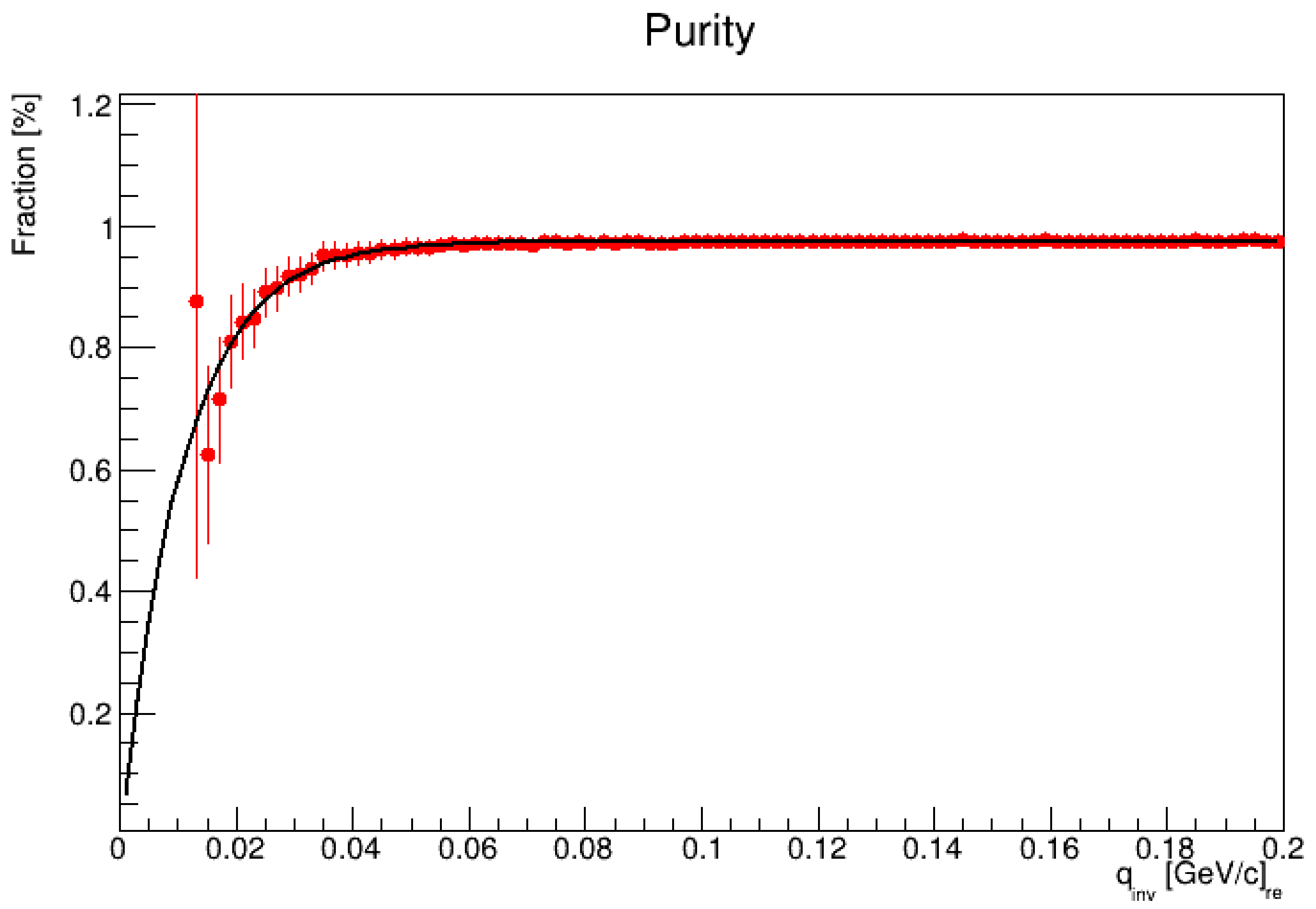
Pions:

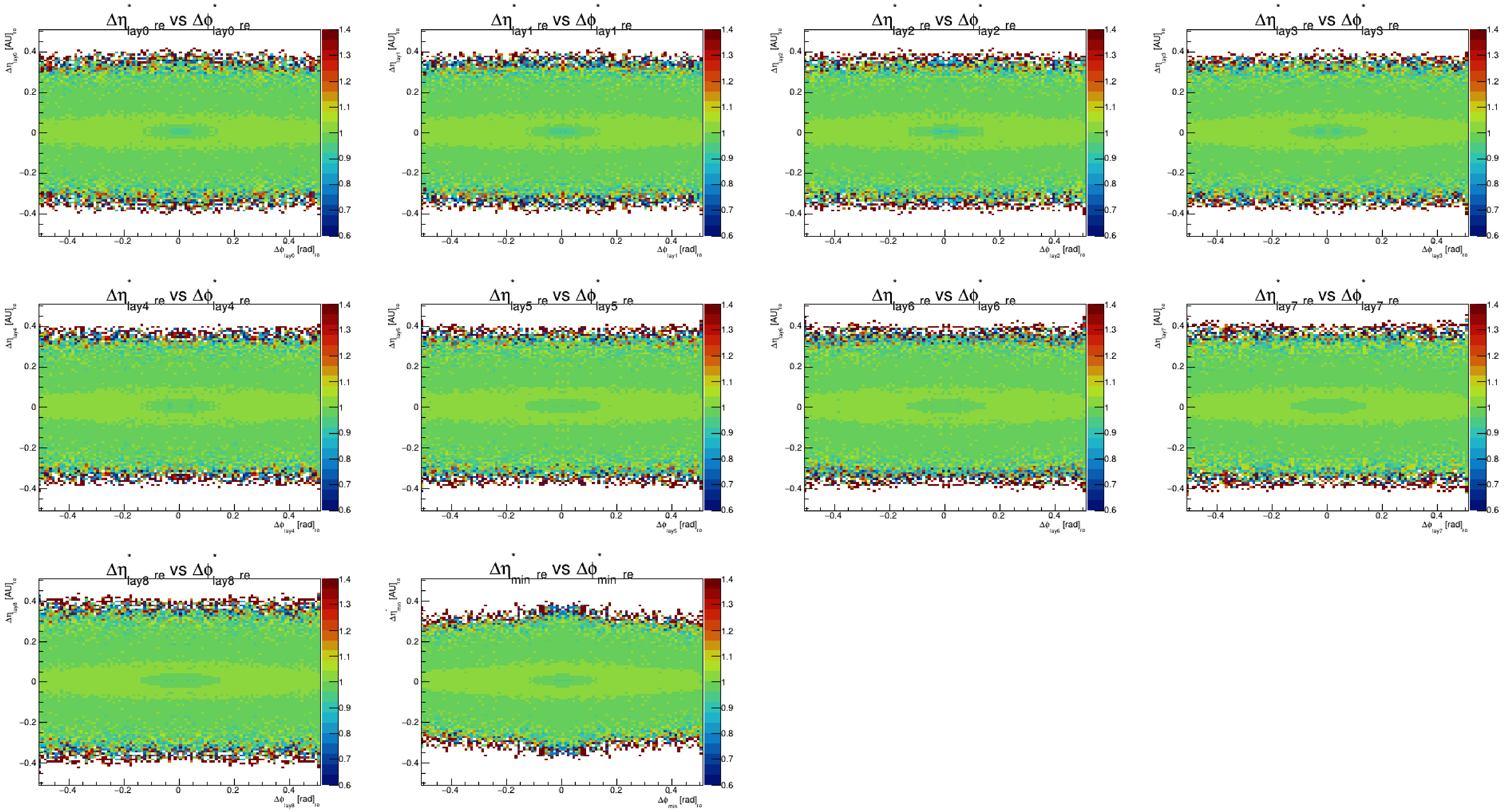
- Selected by m2 from TOF (negative pions chosen because positive one are strongly contaminated by protons)
- DCA used to rejection of secondary pions

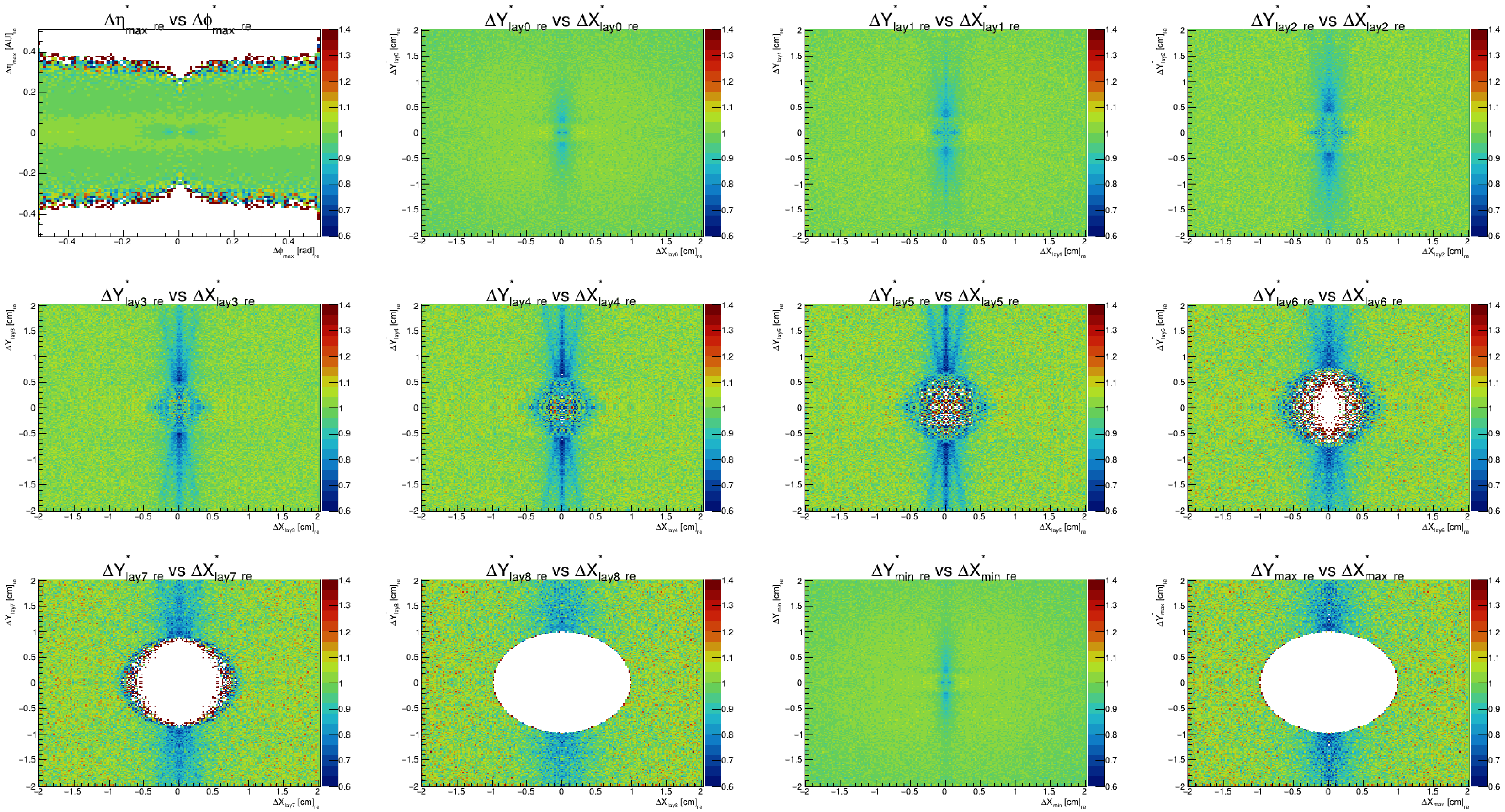


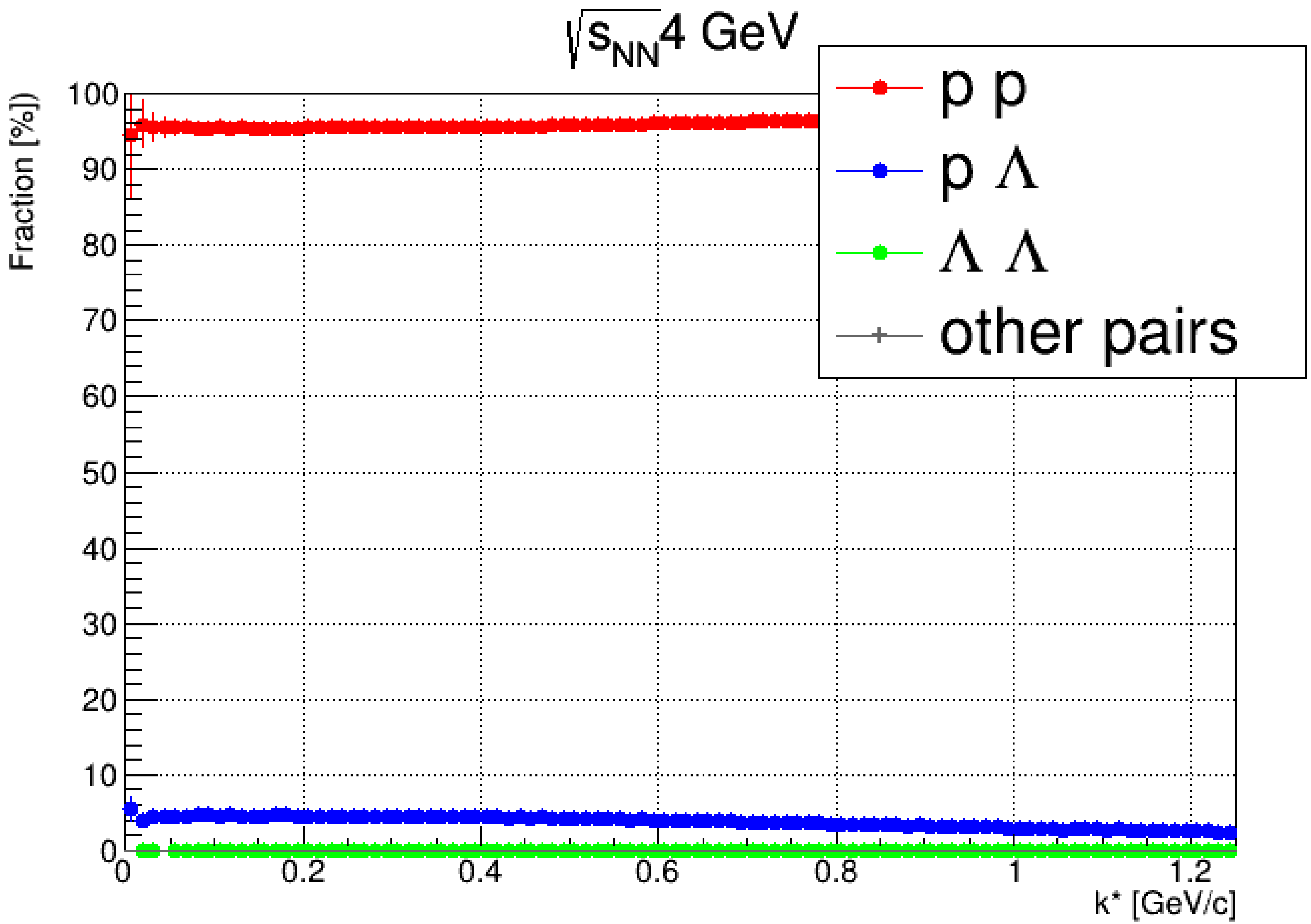
Strange splitting



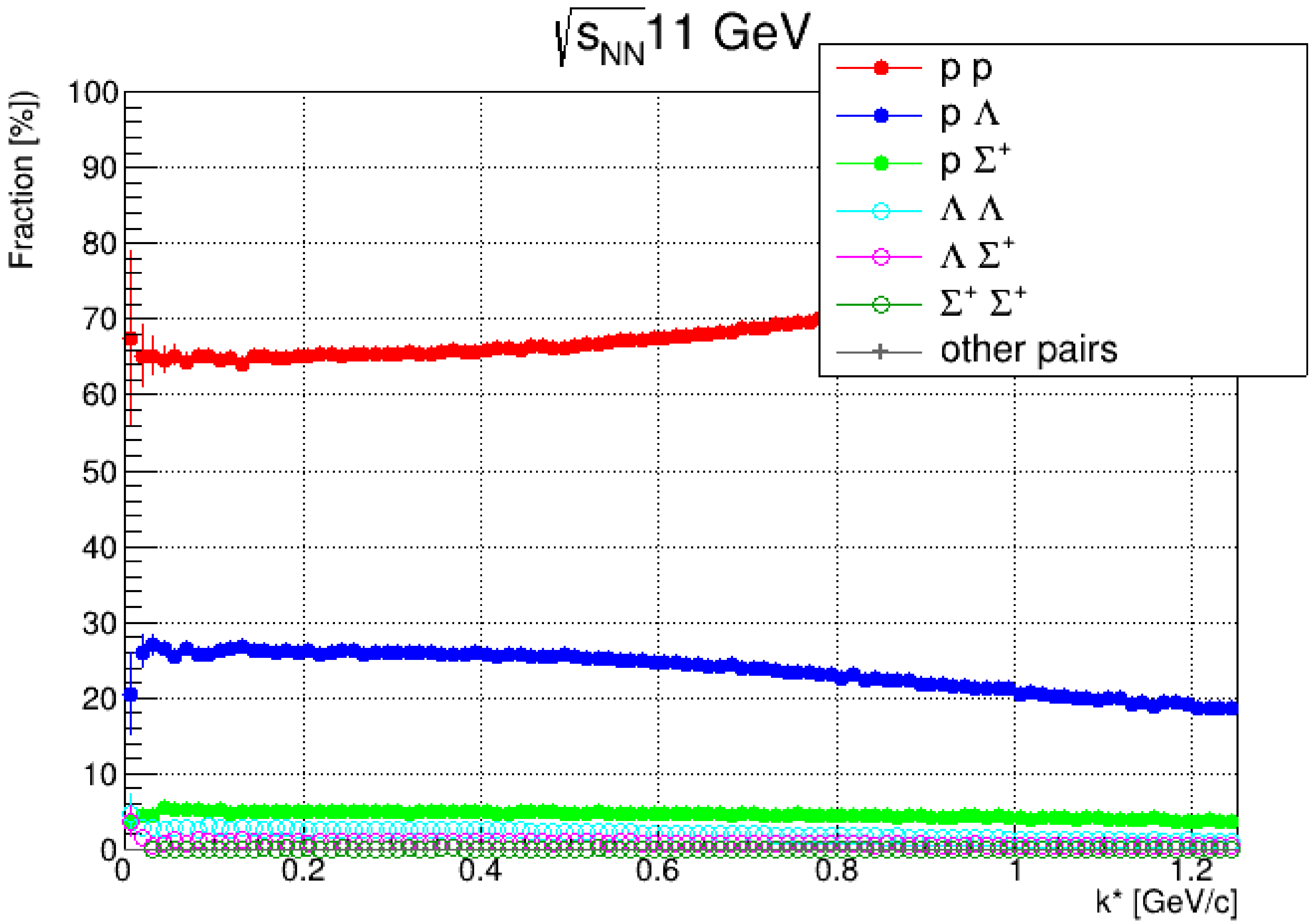

Purity
Fraction [%]
1.2
1
0.8
0.6
0.4
0.2
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
q_inv [GeV/c]_re


Δη*lay0 re vs Δφ*lay0 re
Δη*lay1 re vs Δφ*lay1 re
Δη*lay2 re vs Δφ*lay2 re
Δη*lay3 re vs Δφ*lay3 re
Δη*lay4 re vs Δφ*lay4 re
Δη*lay5 re vs Δφ*lay5 re
Δη*lay6 re vs Δφ*lay6 re
Δη*lay7 re vs Δφ*lay7 re
Δη*lay8 re vs Δφ*lay8 re
Δη*min re vs Δφ*min re

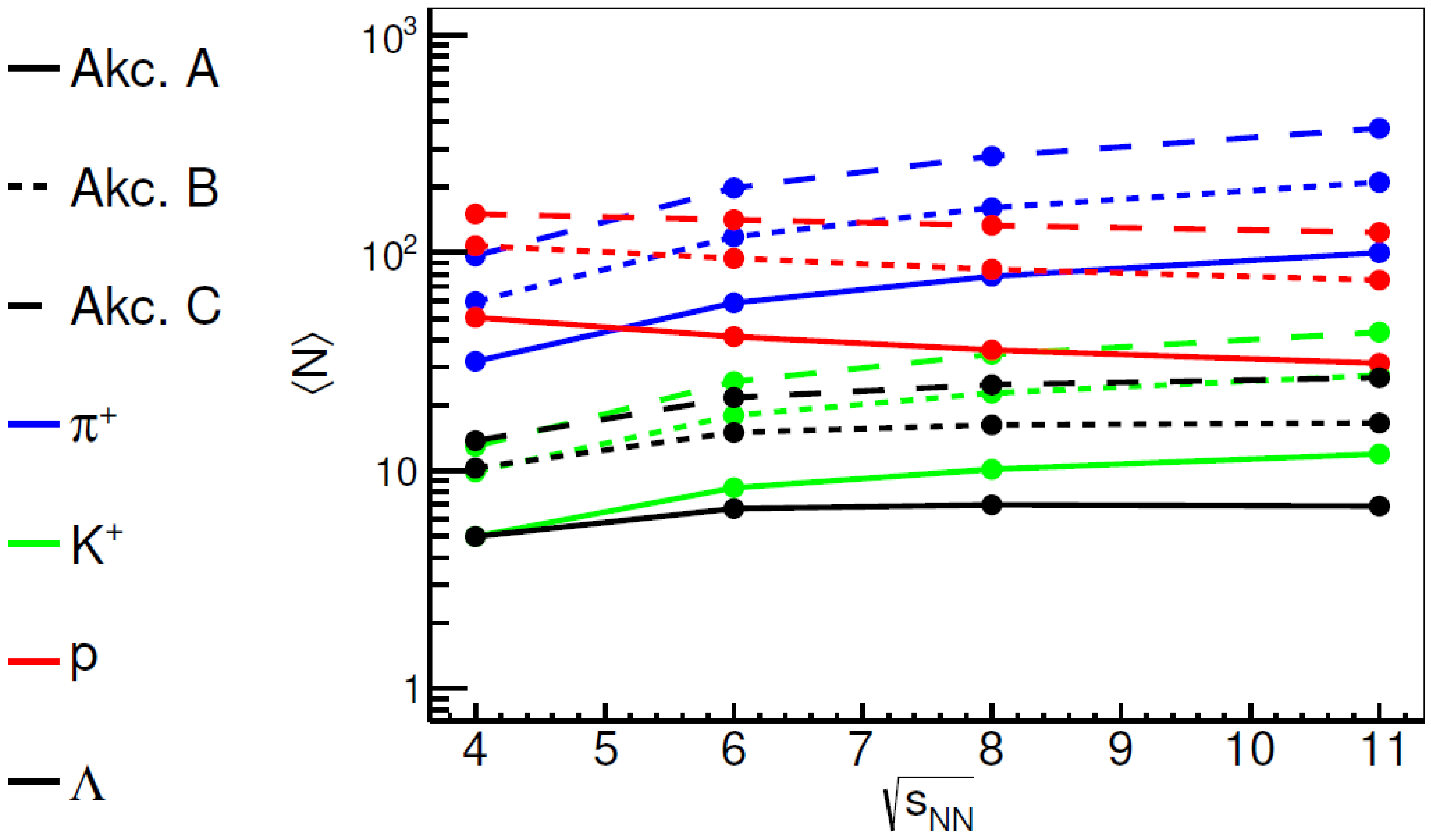

Δη*max_re vs Δφ*max_re
ΔY*lay0_re vs ΔX*lay0_re
ΔY*lay1_re vs ΔX*lay1_re
ΔY*lay2_re vs ΔX*lay2_re
ΔY*lay3_re vs ΔX*lay3_re
ΔY*lay4_re vs ΔX*lay4_re
ΔY*lay5_re vs ΔX*lay5_re
ΔY*lay6_re vs ΔX*lay6_re
ΔY*lay7_re vs ΔX*lay7_re
ΔY*lay8_re vs ΔX*lay8_re
ΔY*min_re vs ΔX*min_re
ΔY*max_re vs ΔX*max_re



$\sqrt{s_{NN}}$4 GeV
Fraction [%])
100
90
80
70
60
50
40
30
20
10
0
0
0.2
0.4
0.6
0.8
1
1.2
k* [GeV/c]
p p
p Λ
Λ Λ
other pairs



$\sqrt{s_{NN}}$11 GeV
Fraction [%])
k* [GeV/c]
0
0.2
0.4
0.6
0.8
1
1.2
10
20
30
40
50
60
70
80
90
100
p p
p Λ
p Σ+
Λ Λ
Λ Σ+
Σ+ Σ+
other pairs


Akc. A
Akc. B
Akc. C
π^+
K^+
p
Λ
10^3
10^2
10
1
$\langle N \rangle$
4
5
6
7
8
9
10
11
$\sqrt{s_{NN}}$