



**Faculty
of Physics**

WARSAW UNIVERSITY OF TECHNOLOGY

Feasibility studies of femtoscopy at CBM

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21st ZIMÁNYI SCHOOL

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Outline

The CBM experiment

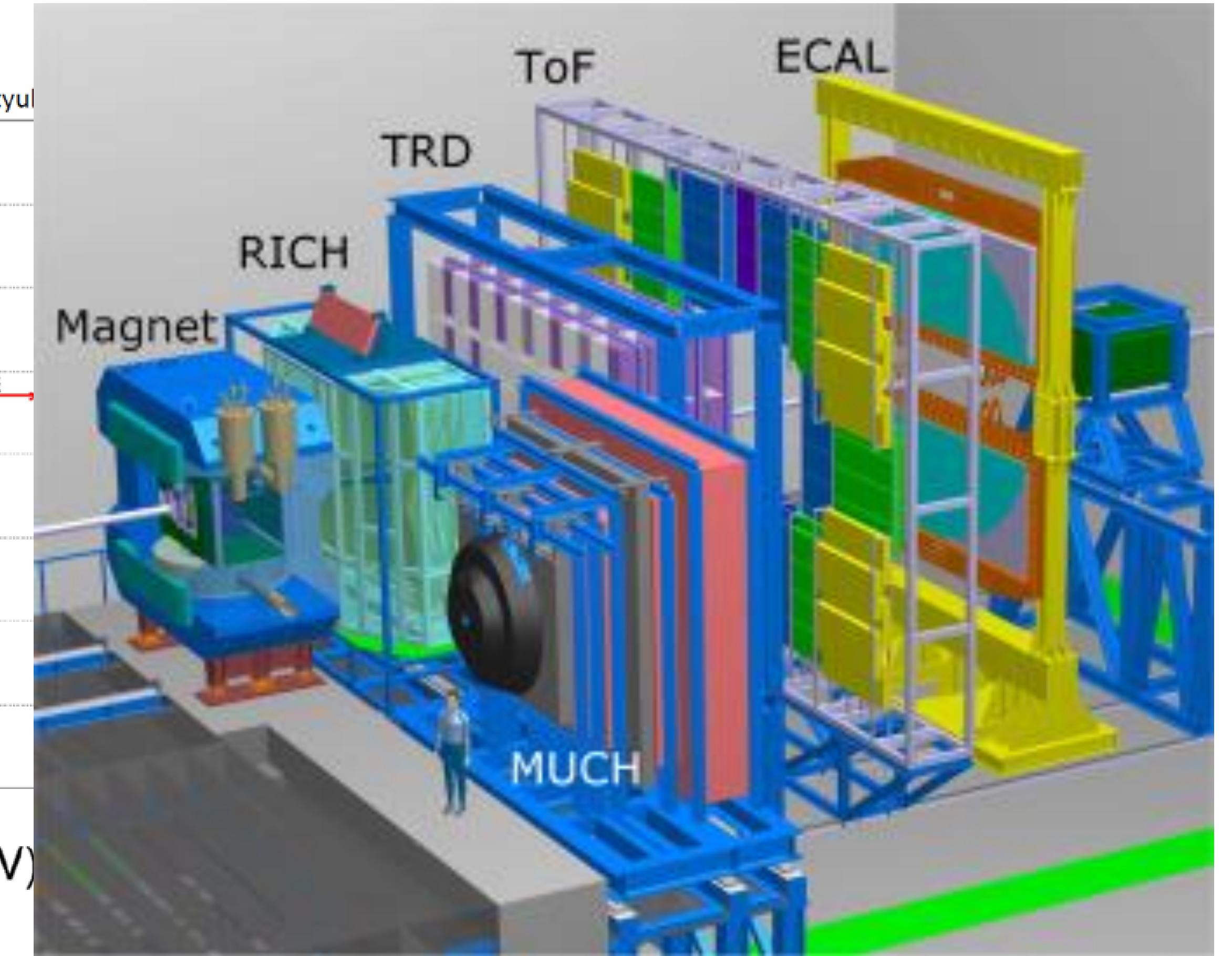
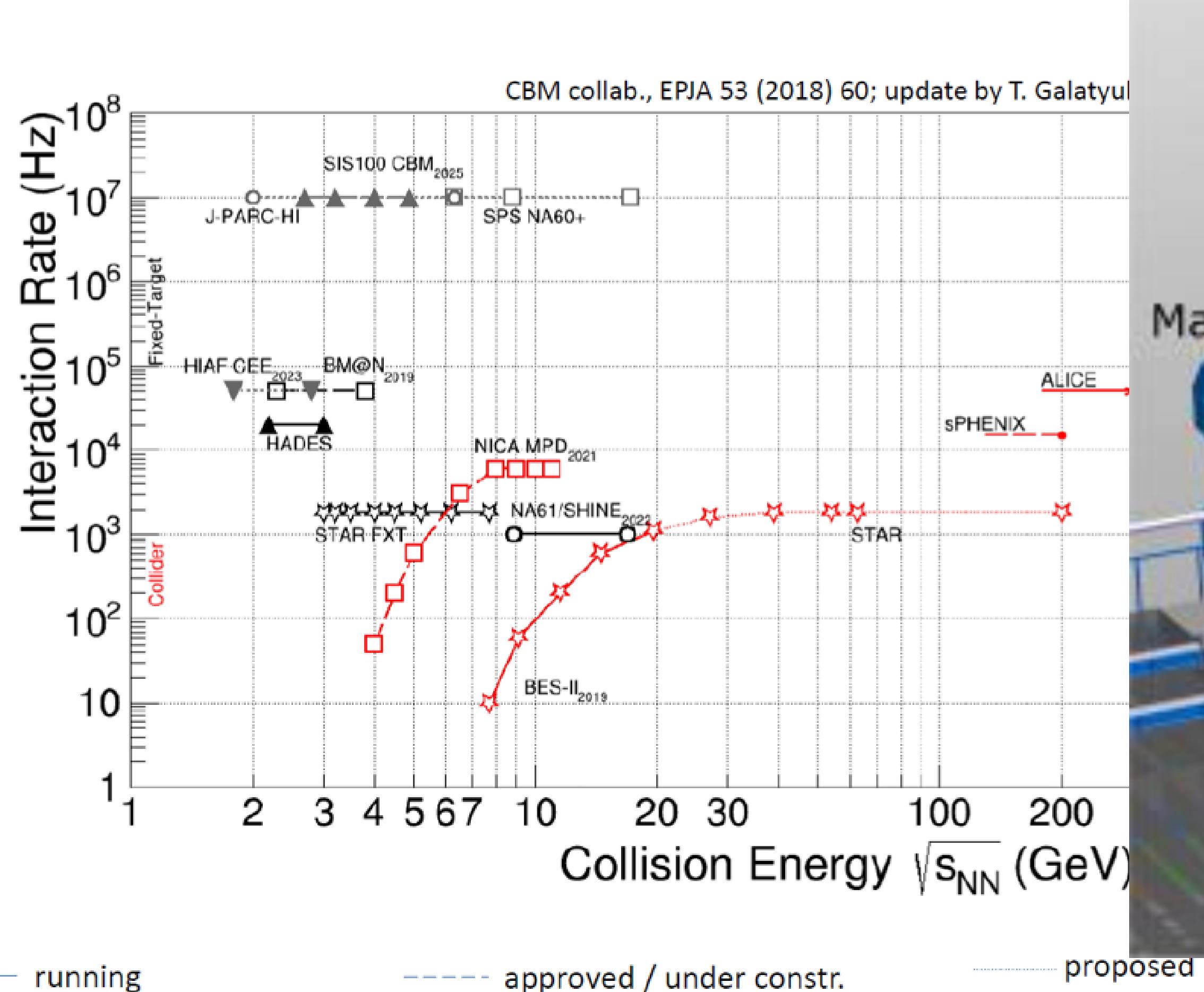
The femtoscopy

Pion Femtoscopy

Proton Femtoscopy

Summary

The CBM detector



Femtoscopy

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

Base on two particle correlations

Correlation function defined as

$$C(q) = \frac{P(p_1, p_2)}{P(p_1)P(p_2)} = \frac{N_{\text{correlated}}(q)}{N_{\text{uncorrelated}}(q)}$$

where $q \equiv q_{inv} = \sqrt{(p_1 - p_2)^2 - (E_1 - E_2)^2}$ (for nonidentical correlations we use $k^* = 0.5 q$)

$\rho(x_i, p_i)$ – probability of emission of i -th particle with momentum p at x

The CF can be also expressed as:

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

$|\Psi(x_1, p_1, x_2, p_2)|^2$ = quantum statistic (identical particles only) + interactions

Theoretical shape of the CF

Example: non-interacting identical bosons with spin = 0

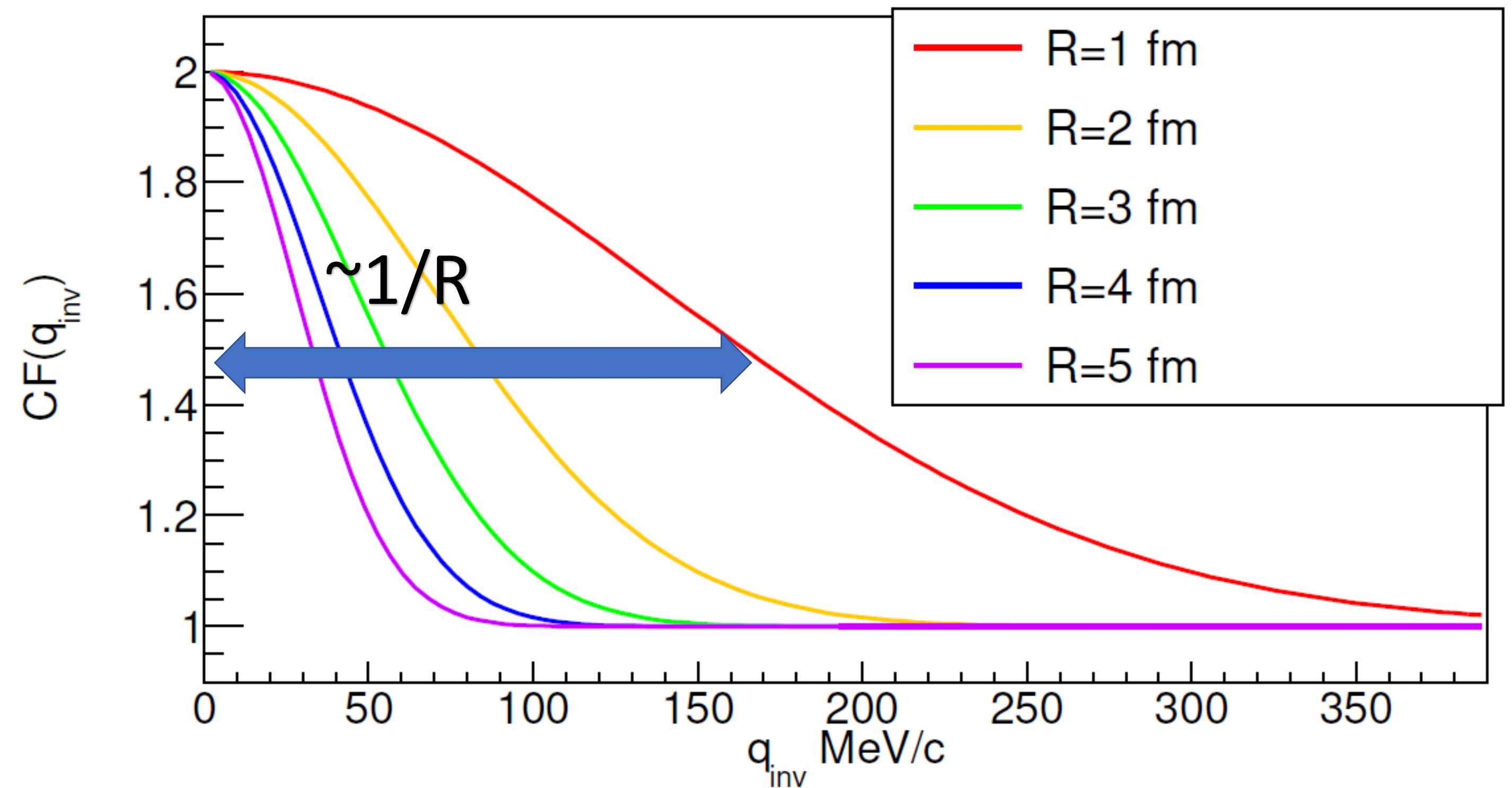
$$\rho(x) \approx e^{-\left(\frac{x^2}{2R^2}\right)}$$

$$\rho(x_1, p_1)\rho(x_2, p_2) = \rho(\Delta x = x_1 - x_2) \approx e^{-\left(\frac{(\Delta x)^2}{4R^2}\right)}$$

$$|\Psi(\Delta x, \Delta p = q)|^2 = 1 + \cos(\Delta x q)$$

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

$$C(q) = 1 + \lambda e^{-q^2 R^2}$$

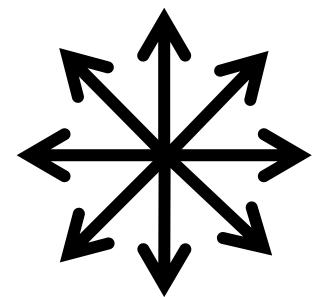


Femtoscopy

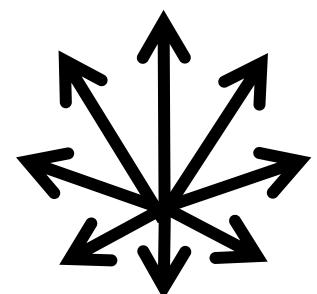
How useful is this method?

Femtoscopy

Femtoscopic measurements are sensitive to dynamics of the source:



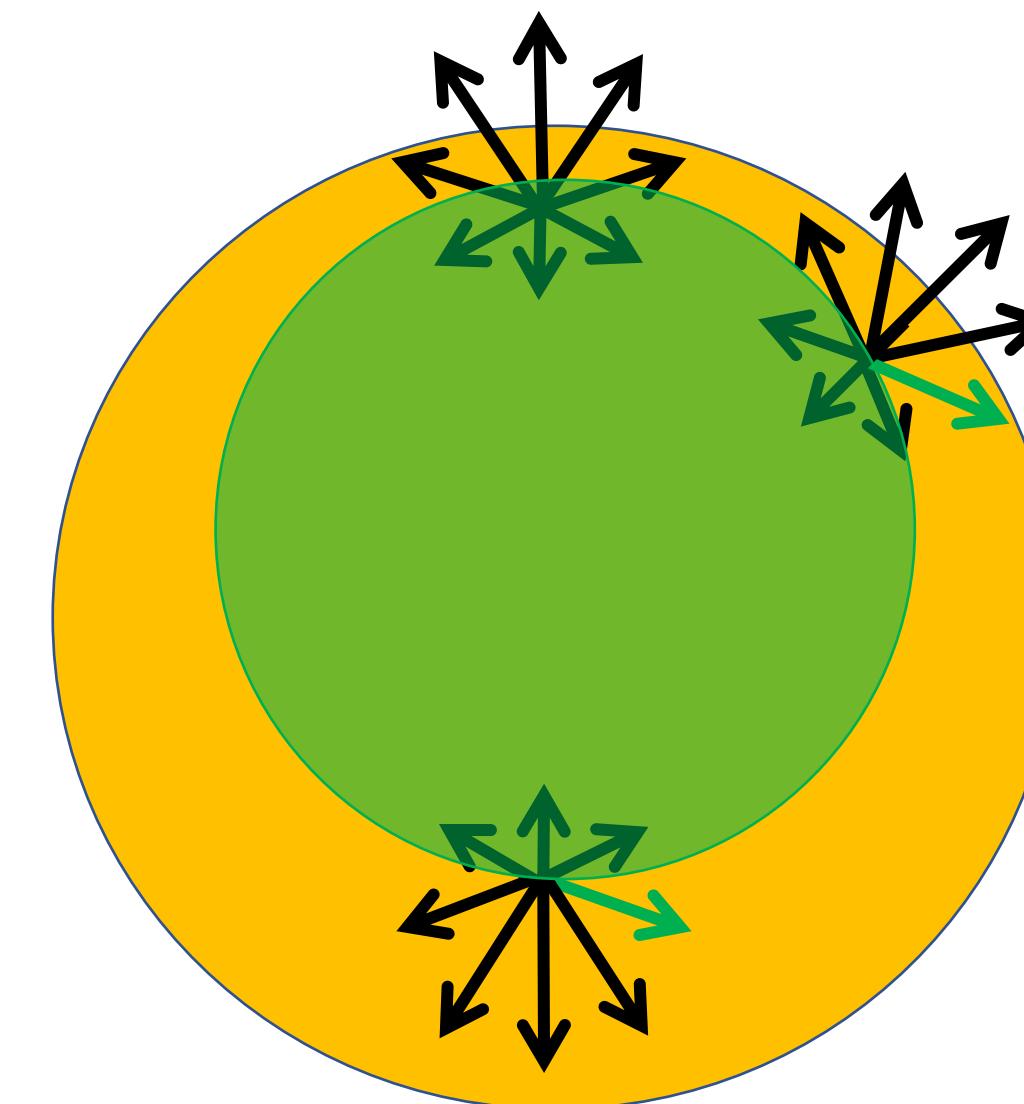
Lack of collectivity



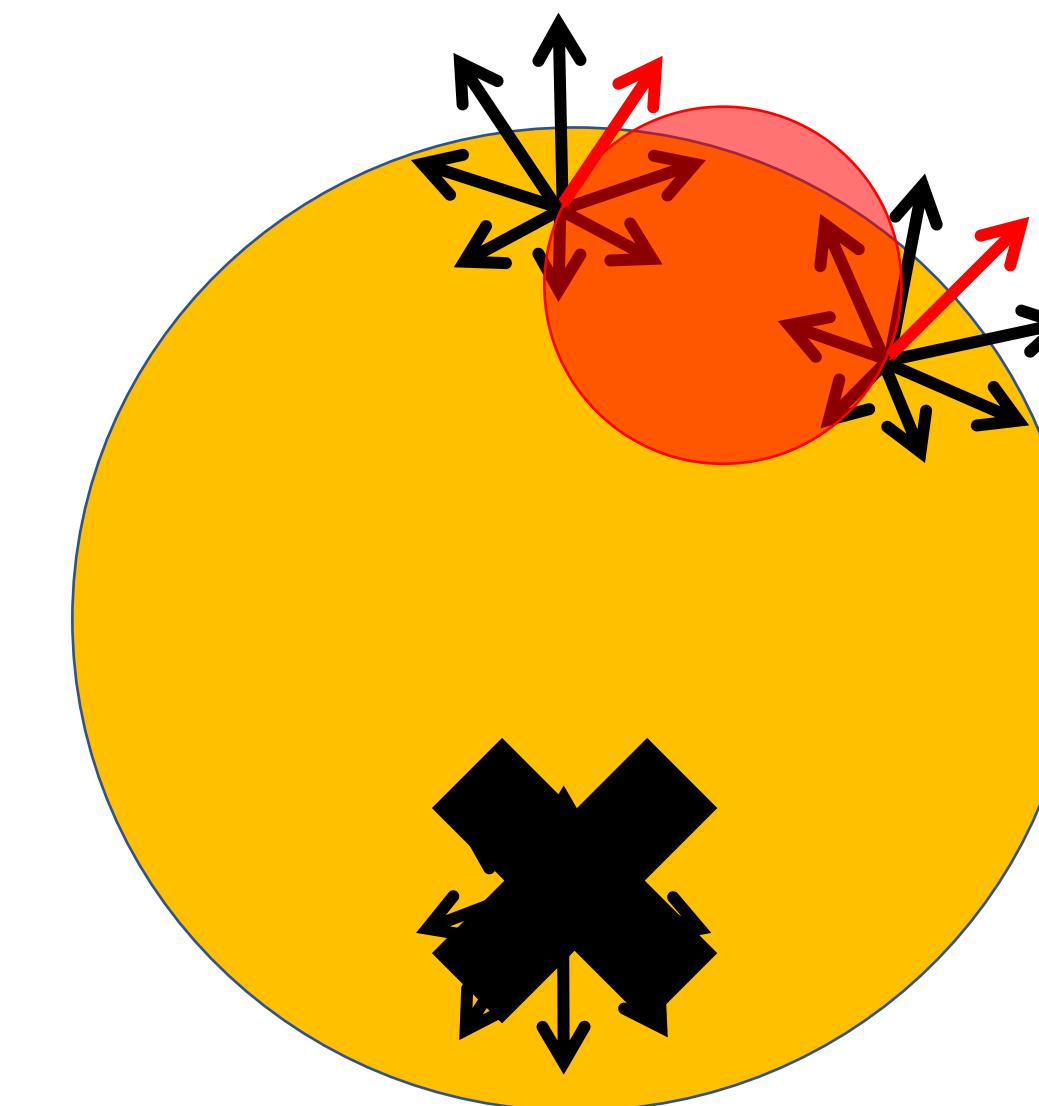
Collectivity

Femtoscopy doesn't measure the actual geometrical size of the source

We measure the „homogeneity length” – the range of the correlations !



Small k_T/m_T



Large k_T/m_T

k_T – average transverse momentum of the pair , m_T – av. transverse mass of the pair

Femtoscopy

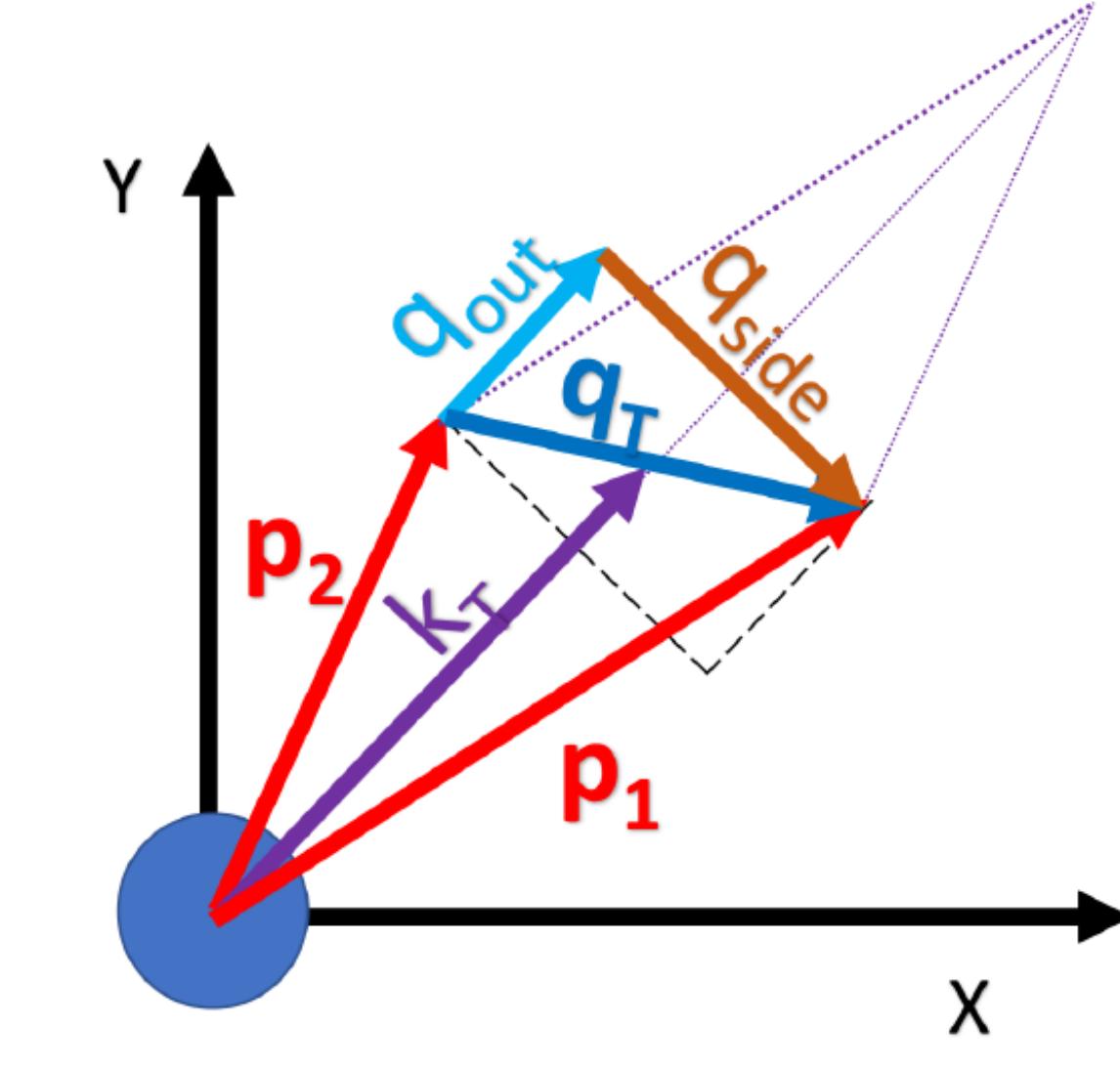
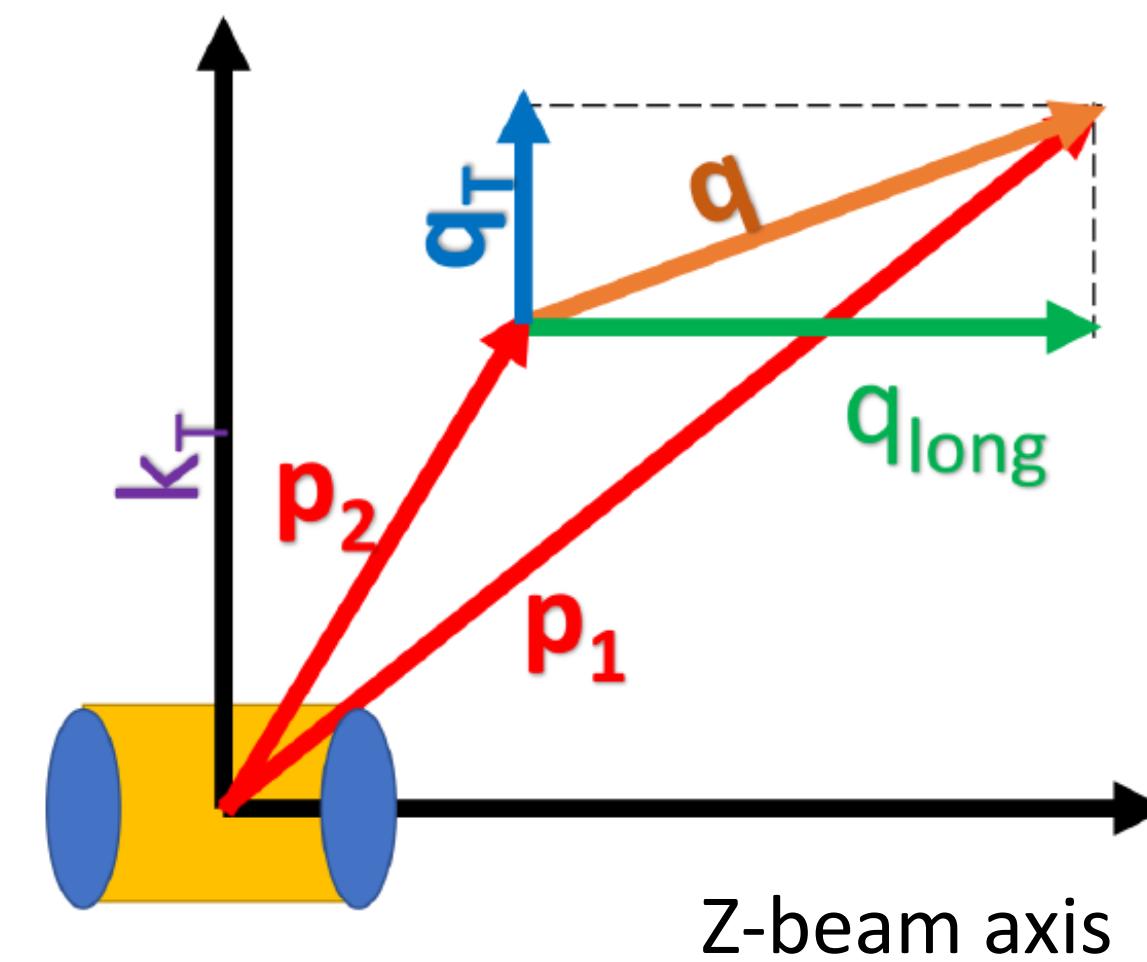
One dimensional CF – measuring the „general” size of the source

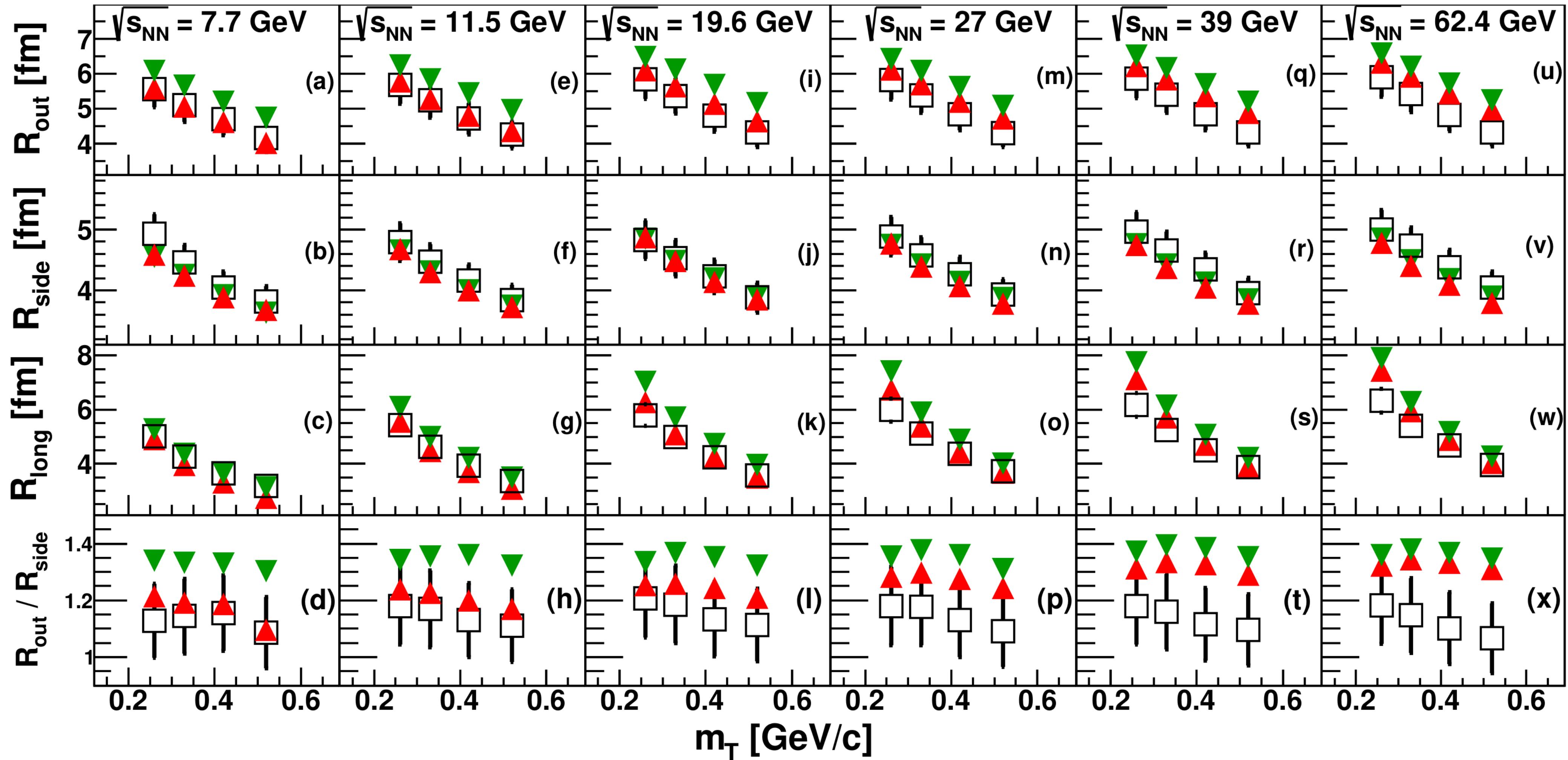
3-dimensional Femtoscopy ($q_{inv} \rightarrow (q_{out}, q_{side}, q_{long})$):

$R_{side} \approx$ geometrical size of the source

$R_{out} \approx R_{side} +$ time of emission of the particles

$R_{long} \approx$ lifetime of the source



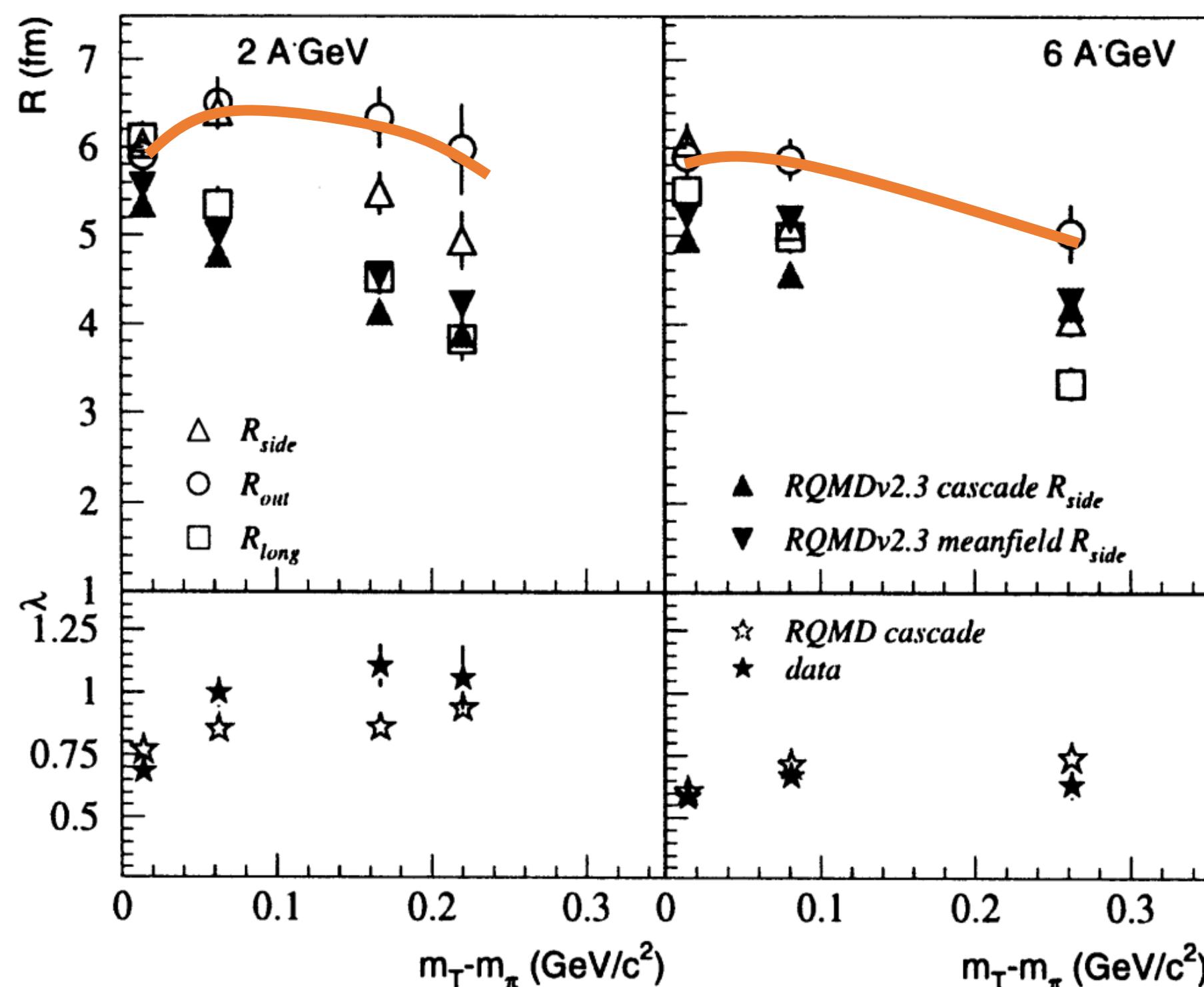


Crossover Eos
1st order Eos

Correlation femtoscopy study at energies available at the JINR Nuclotron-based Ion Collider fAcility and the BNL Relativistic Heavy Ion Collider within a viscous hydrodynamic plus cascade model, Phys. Rev. C 96, 024911, 2017, P. Batyuk, Iu. Karpenko, R. Lednický, L. Malinina, K. Mikhaylov, O. Rogachevsky, D. Wielanek

Femtoscopy

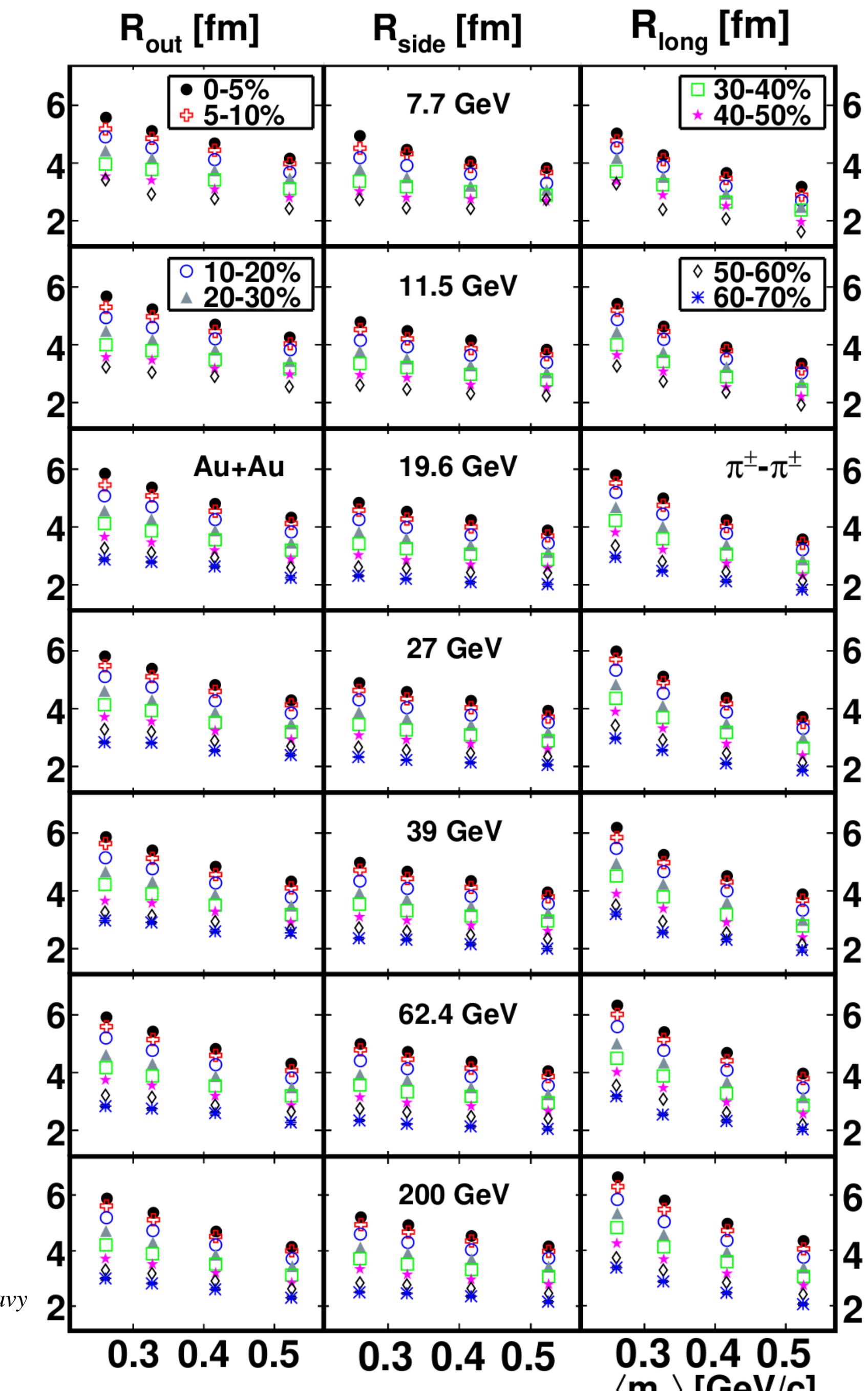
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THE BOMBARDING ENERGY DEPENDENCE OF l_π INTERFEROMETRY AT THE AGS, M.Lisa et al. 199 Book advances
In Nuclear Dynamics

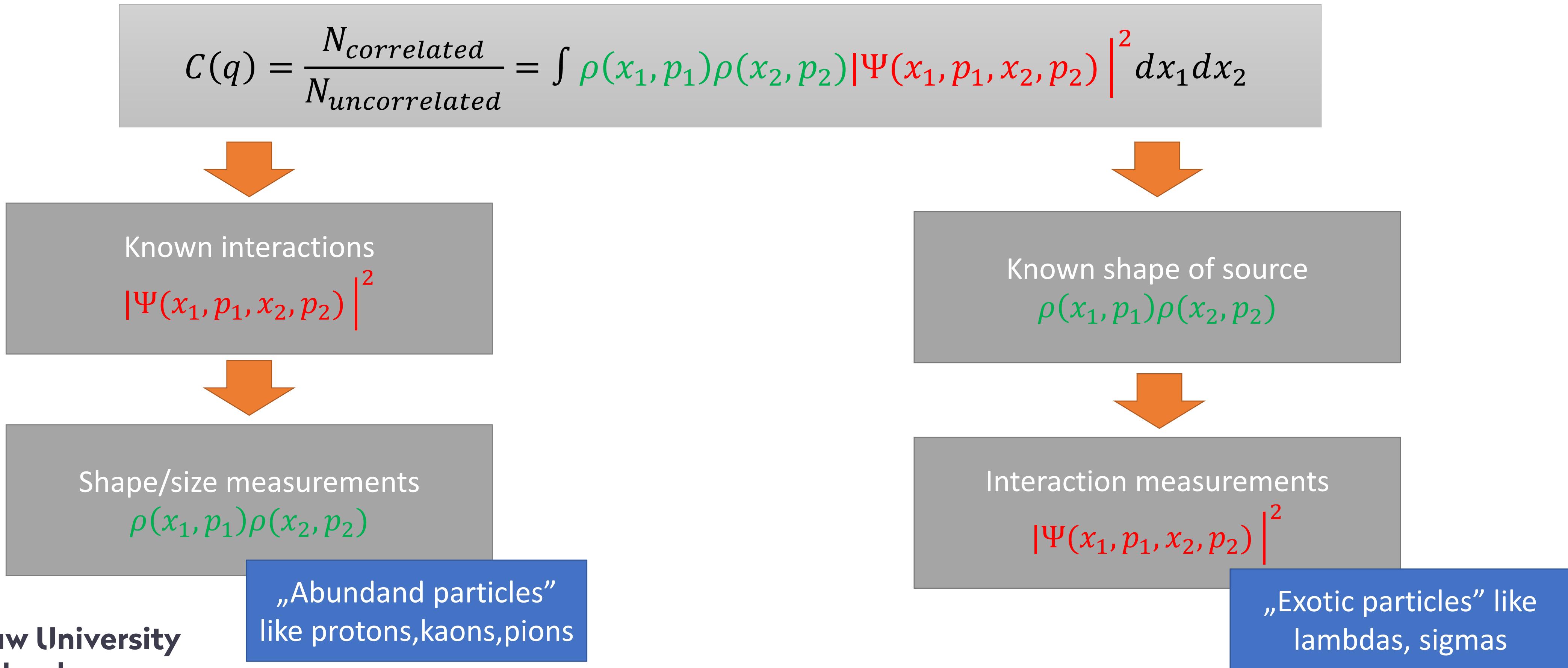
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Beam energy dependent two-pion interferometry and the freeze-out eccentricity of pions in heavy ion collisions at STAR – STAR collaboration, 2014 Physical Review C 92(1)

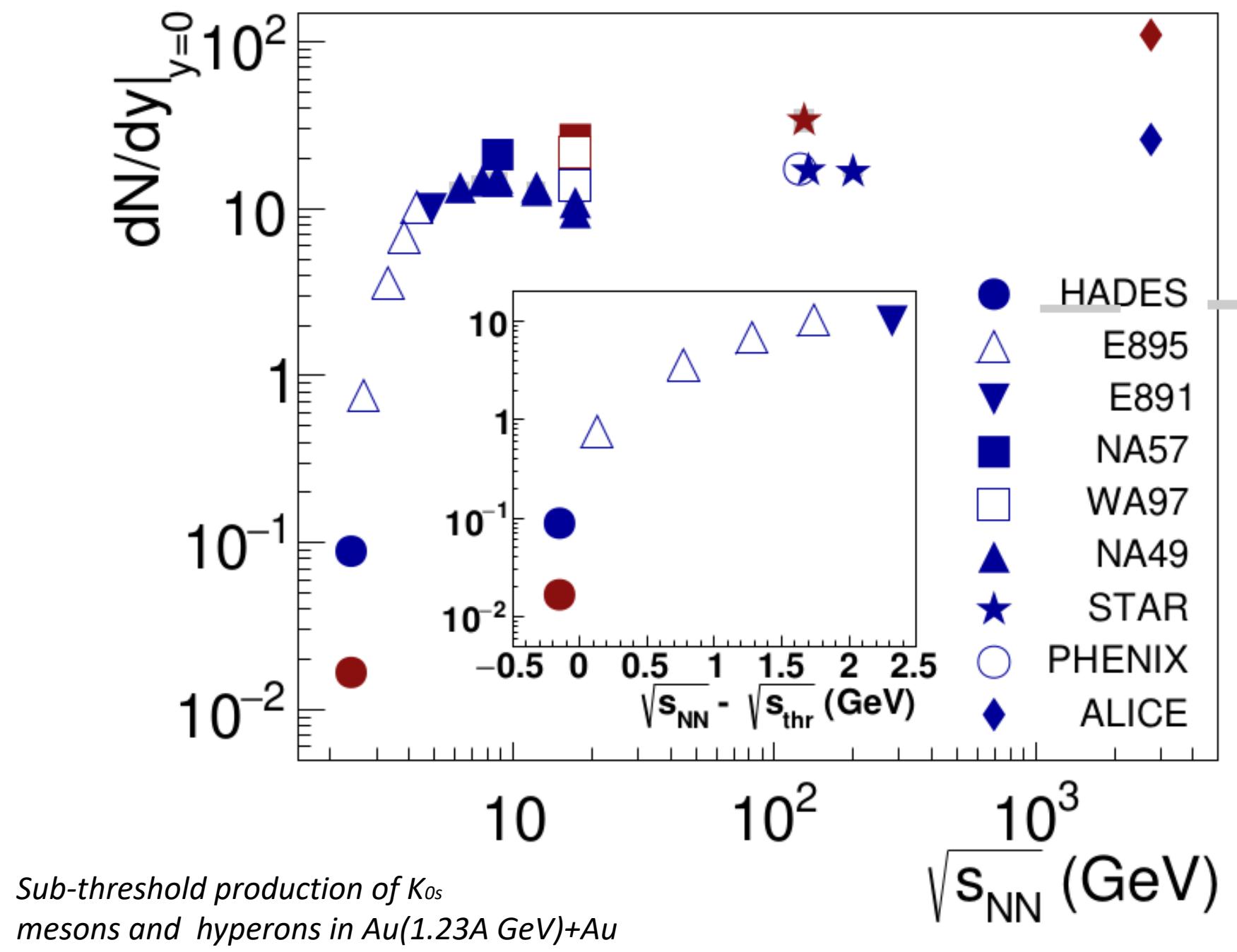


Femtoscopy

Femtoscopy can be used for measurements of interaction between exotic particles:



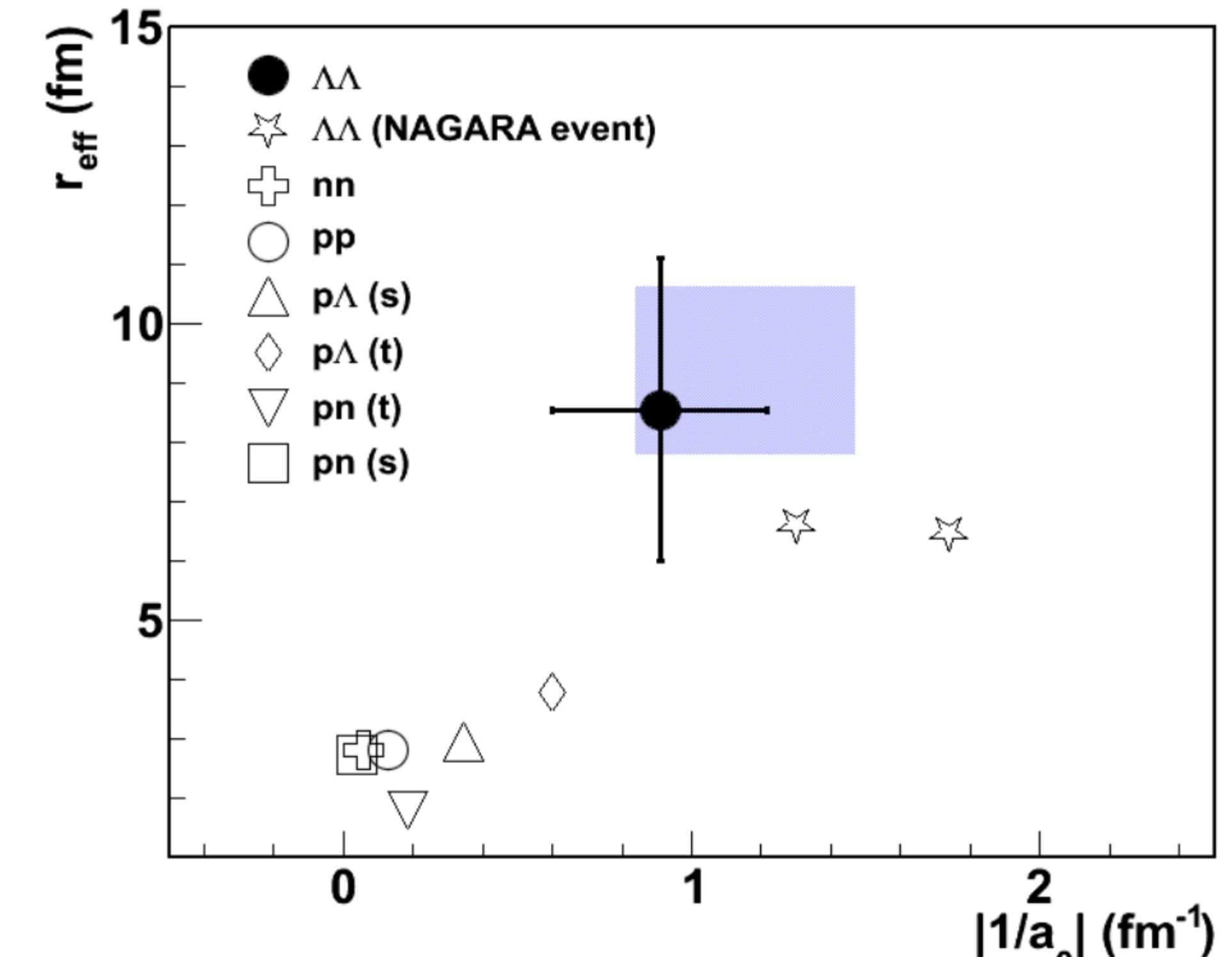
Femtoscopy



$$\frac{N_{\Lambda STAR}}{N_{\Lambda CBM}} \approx \frac{16.7}{10.8} \approx \frac{17}{10}$$

$$\frac{N_{\Lambda STAR}^2}{N_{\Lambda CBM}^2} \approx \frac{17^2}{10^2} \approx 3$$

..but CBM is MUCH faster!



$\Lambda\Lambda$ Correlation function in $Au+Au$ collisions at $\sqrt{S(NN)}=200$ GeV
,January 2015, Physical Review Letters 114(2)

Femtoscopy

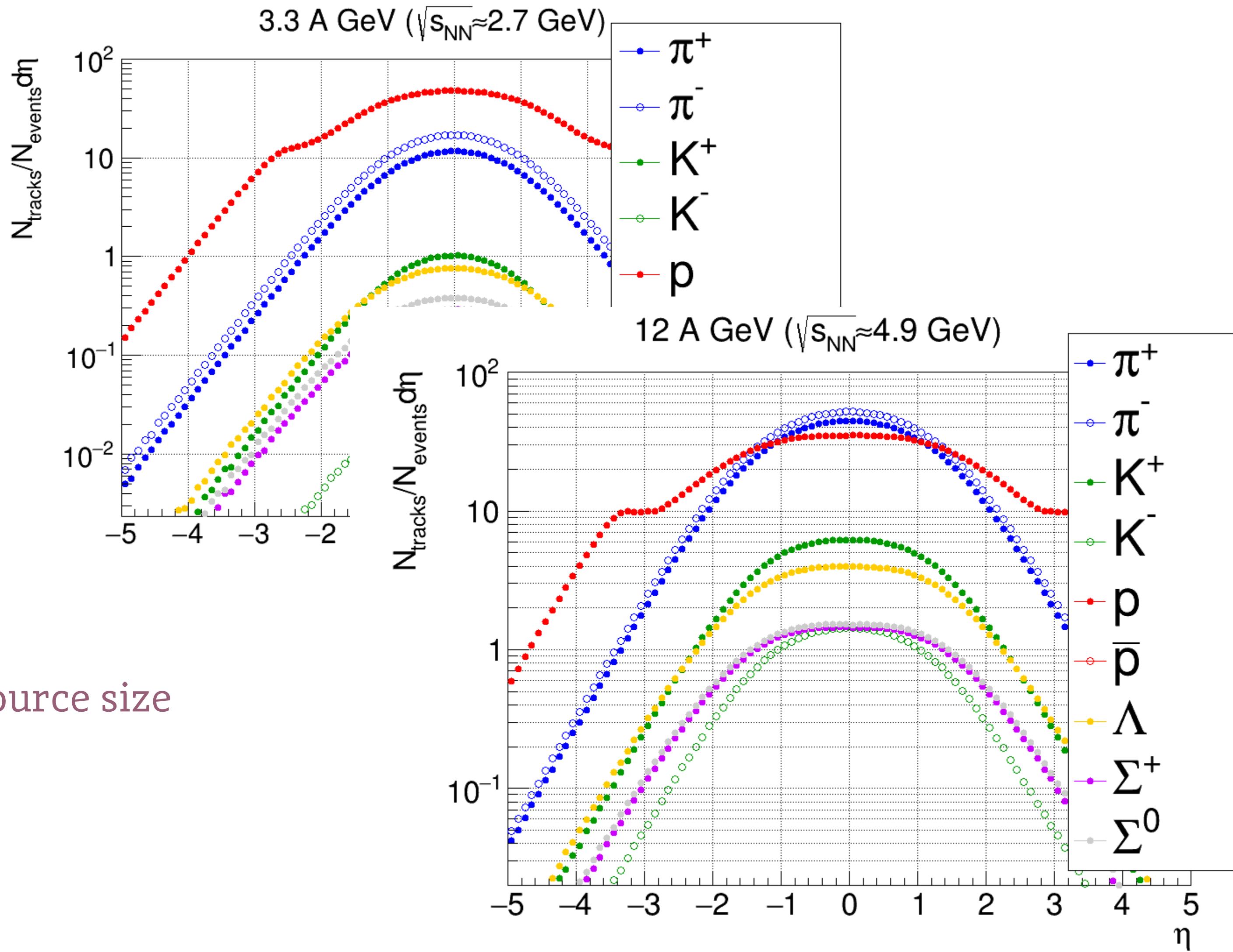
Pions

- Abundant
- Easy for identification
- No problem with residual cor

Mesons

Protons

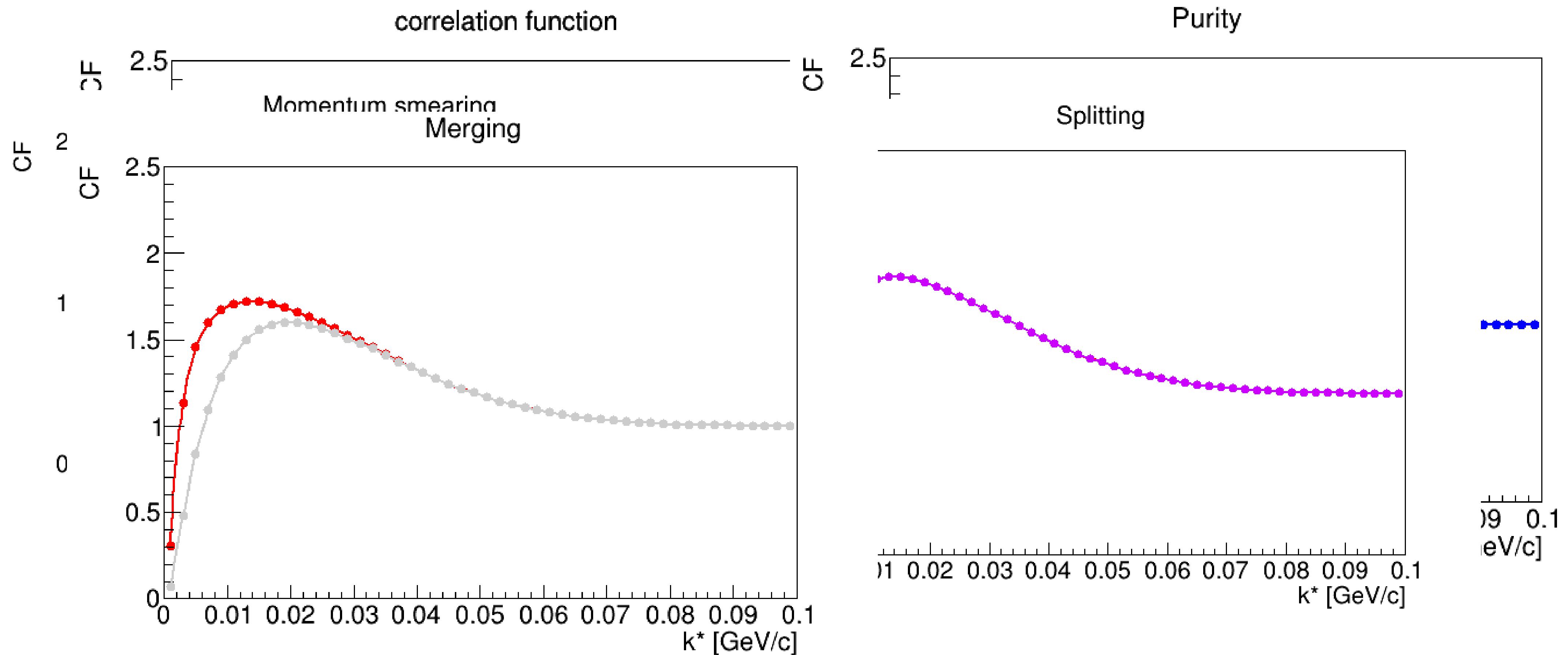
- Abundant
- Easy for identification
- Needed for lambda-lambda (source size estimation)
- Baryons



Femtoscopy in CBM

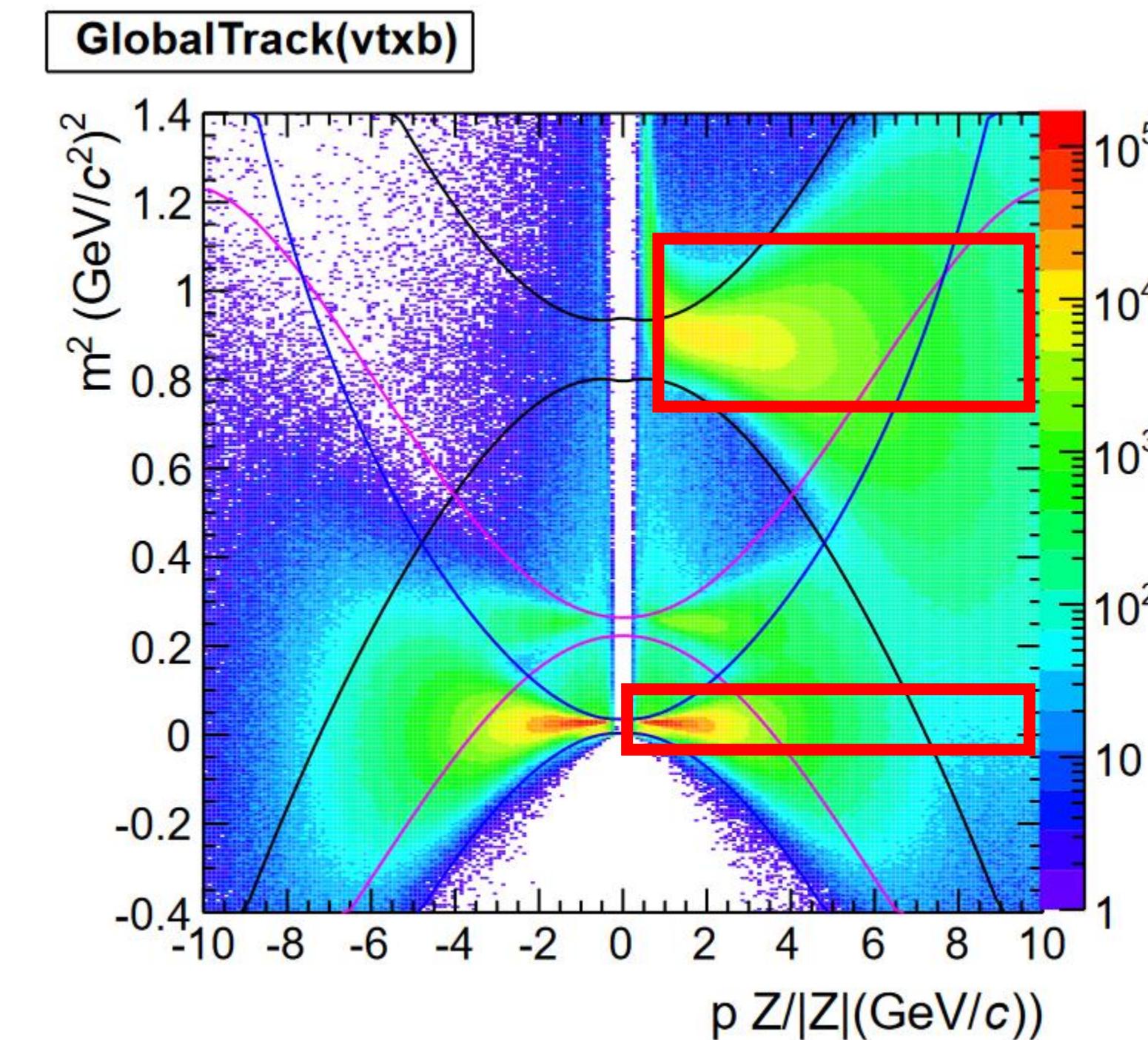
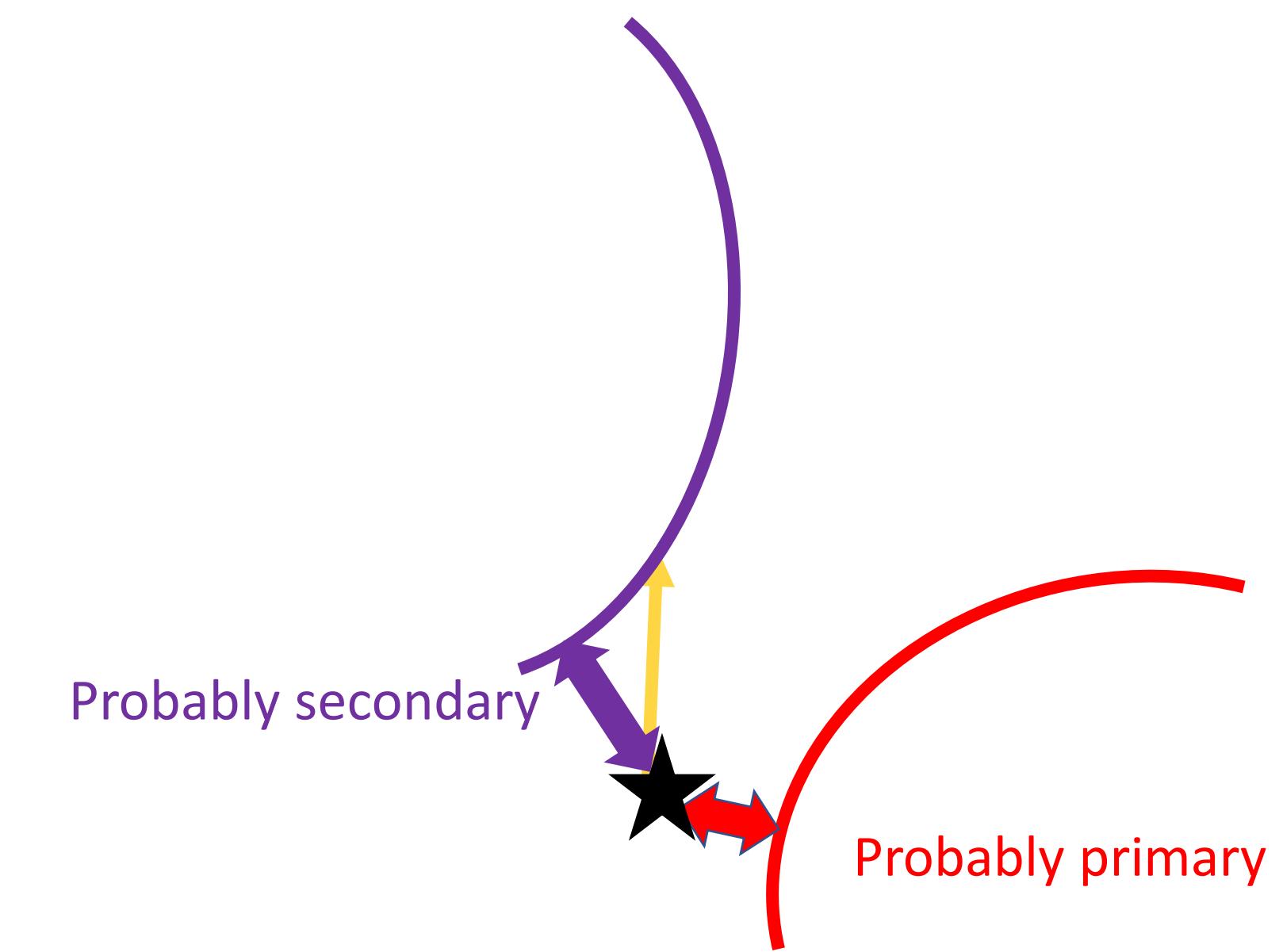
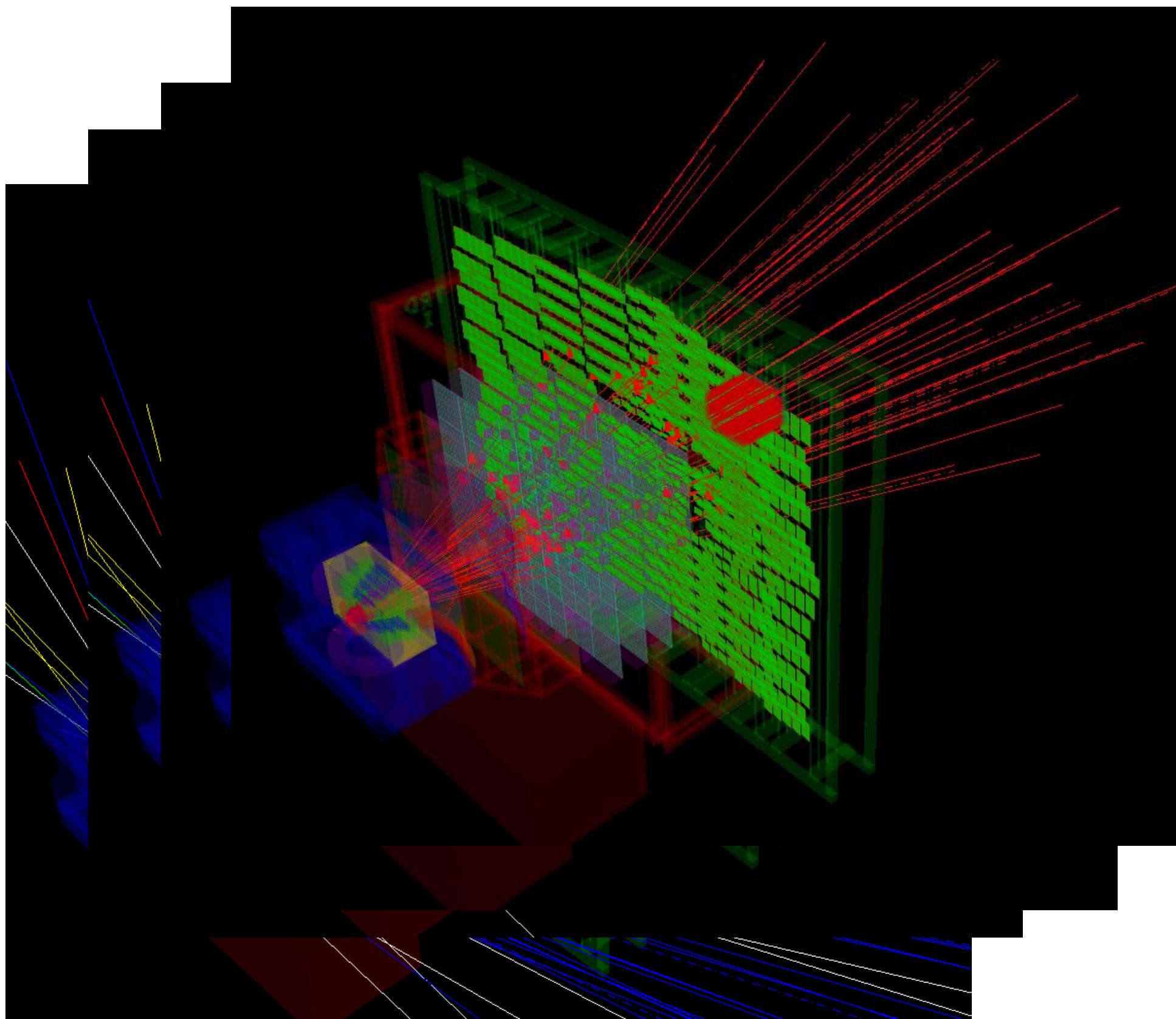
- Requirements for femtoscopic measurements:
 - Good identification of particles
 - Good momentum resolution (remember: $q_{inv} = p_1 - p_2$)
- Potential additional problems:
 - Two-track effects
 - Residual correlations

Femtoscopy in CBM



Selection of particles

- DCA – selecting primary particles
- m2 – selecting given type of particles
- nHits – selecting particles with good quality

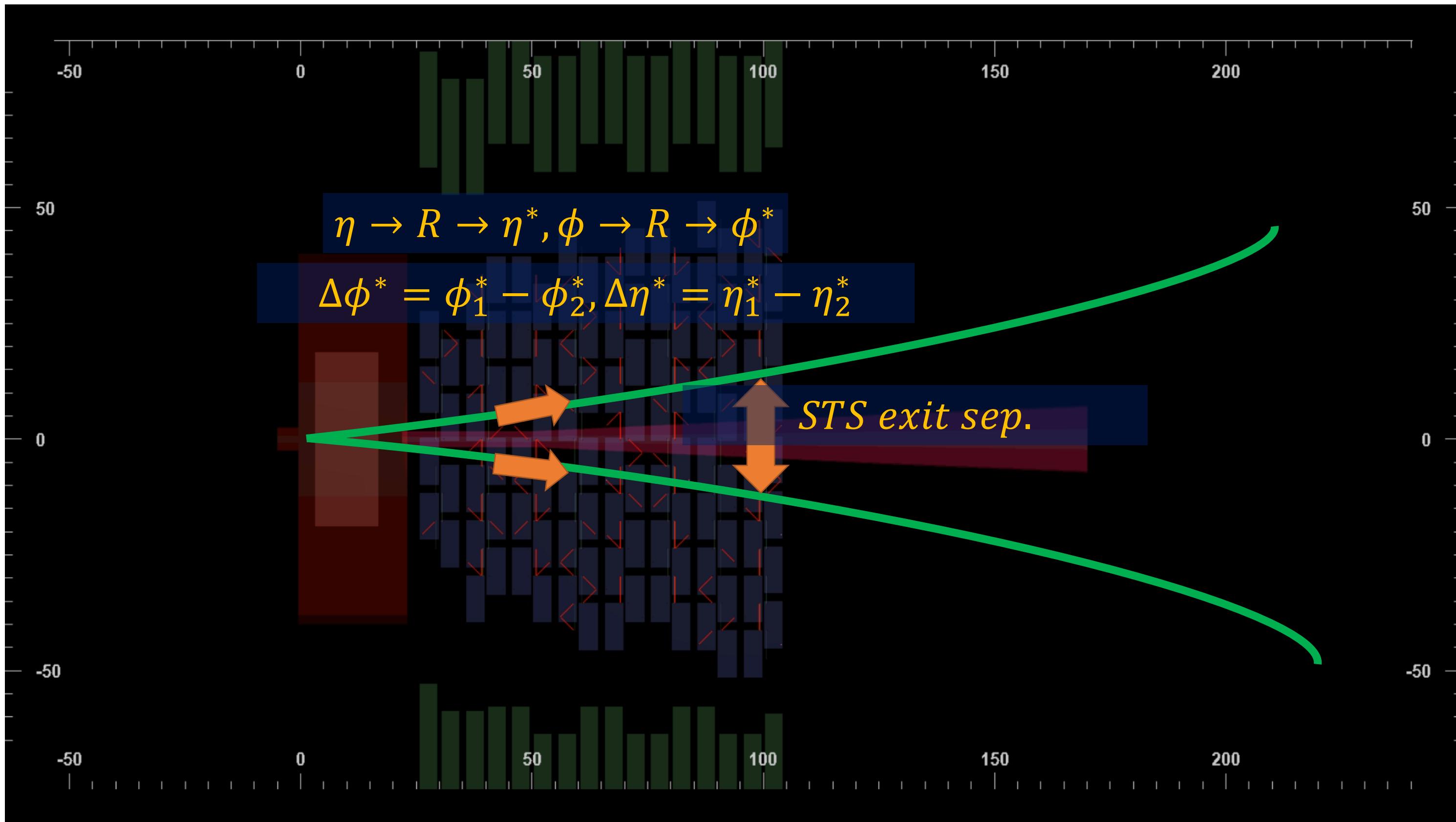


Femtoscopy in CBM

Two-particle selection

- We have the merging and splitting
- They affect pairs of particles with low q (q_{inv}) but we cannot remove pairs of particles with low q – we remove the correlation peak also!
- We need something like q but not q !

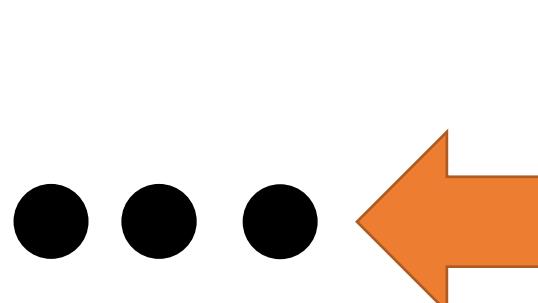
Two particle cuts



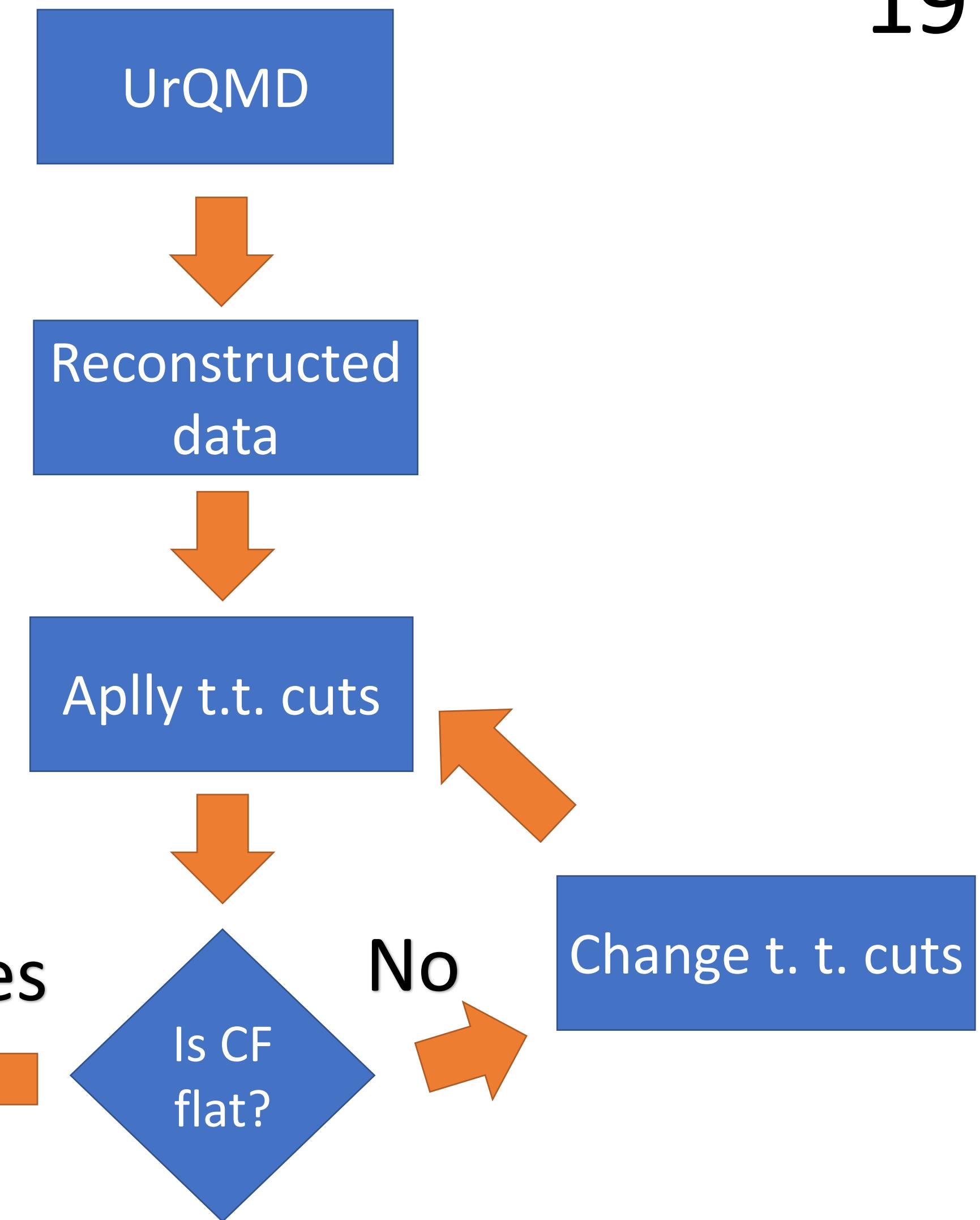
Femtoscopy in CBM

For simulations I used UrQMD model

UrQMD model doesn't contain the correlation effect, obtained CF is flat
(tested on pure UrQMD model)



Adding
femtoscopic
correlations



Femtoscopy in CBM

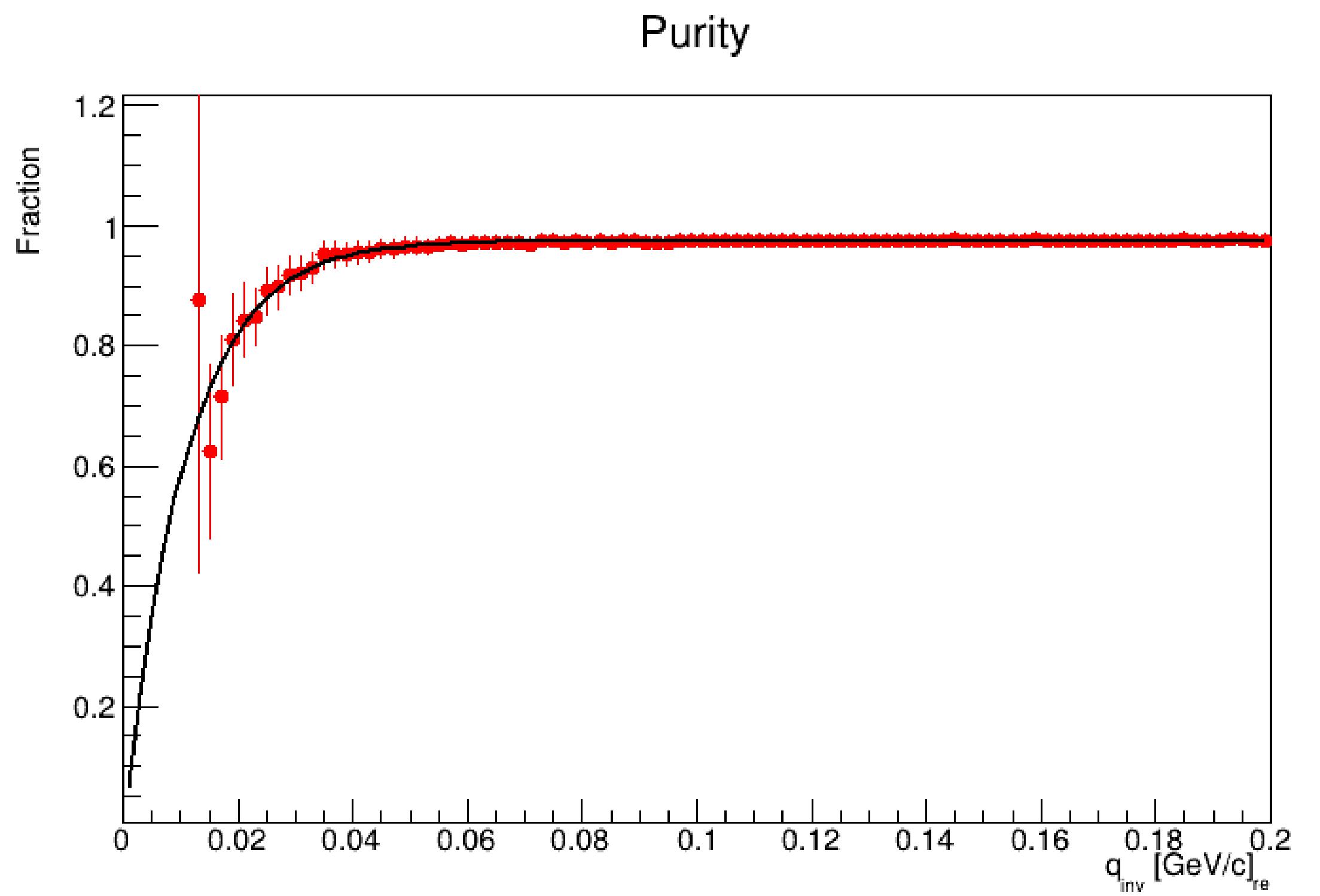
$$C(q) = N \left(1 + \lambda C_{purity}(q) \right)$$

Normalization Fraction of correlated pairs

Fraction of desired pairs

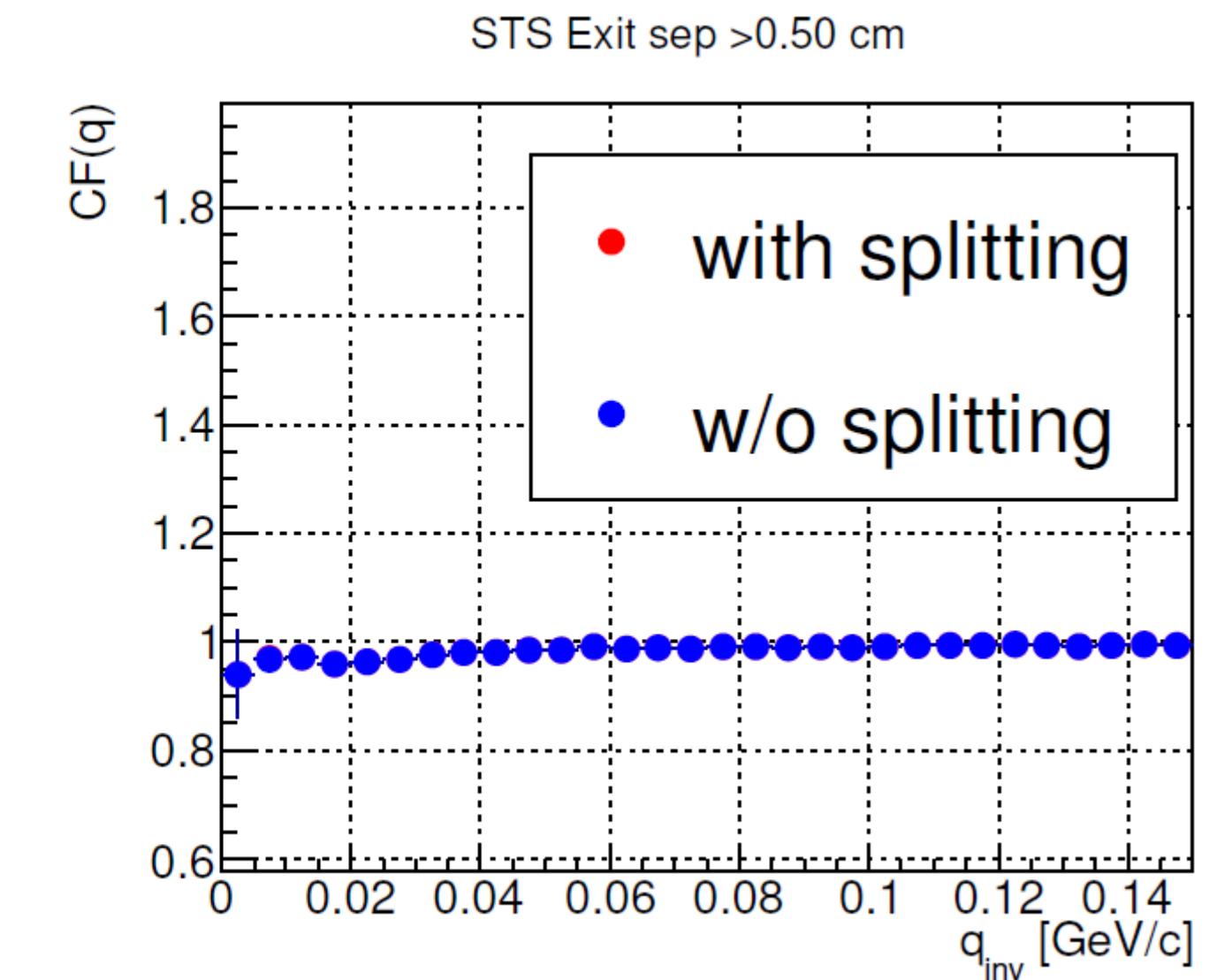
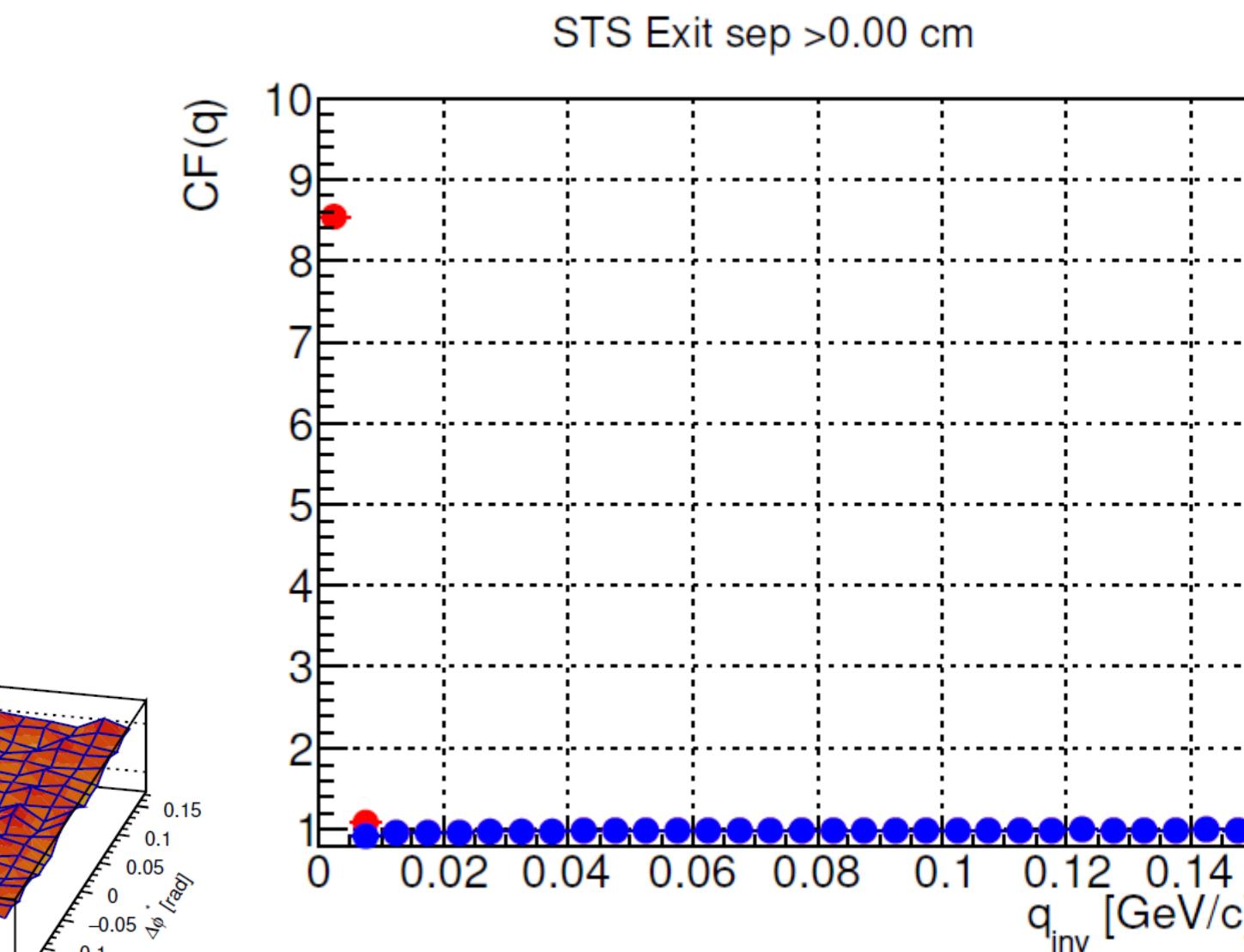
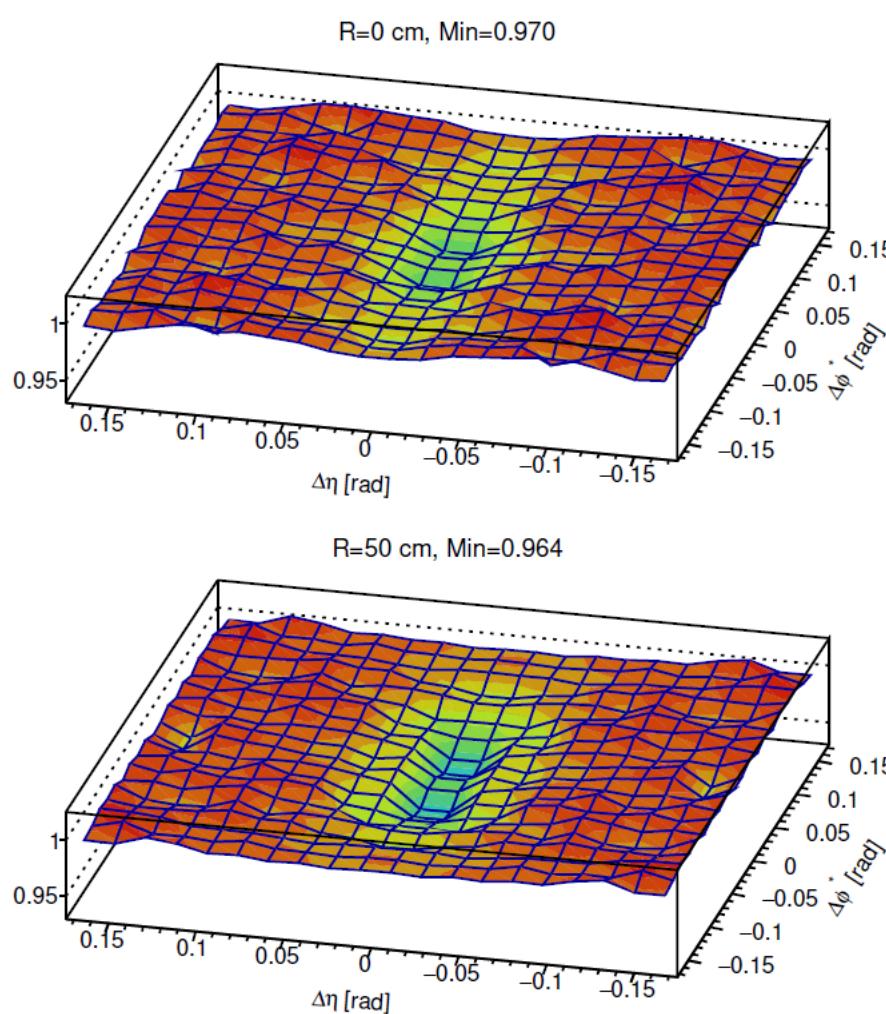
Impurity

$$C_{purity}(q) = 1 -$$



Femtoscopy in CBM - negative pions

Anti-splitting cut – STS exit separation



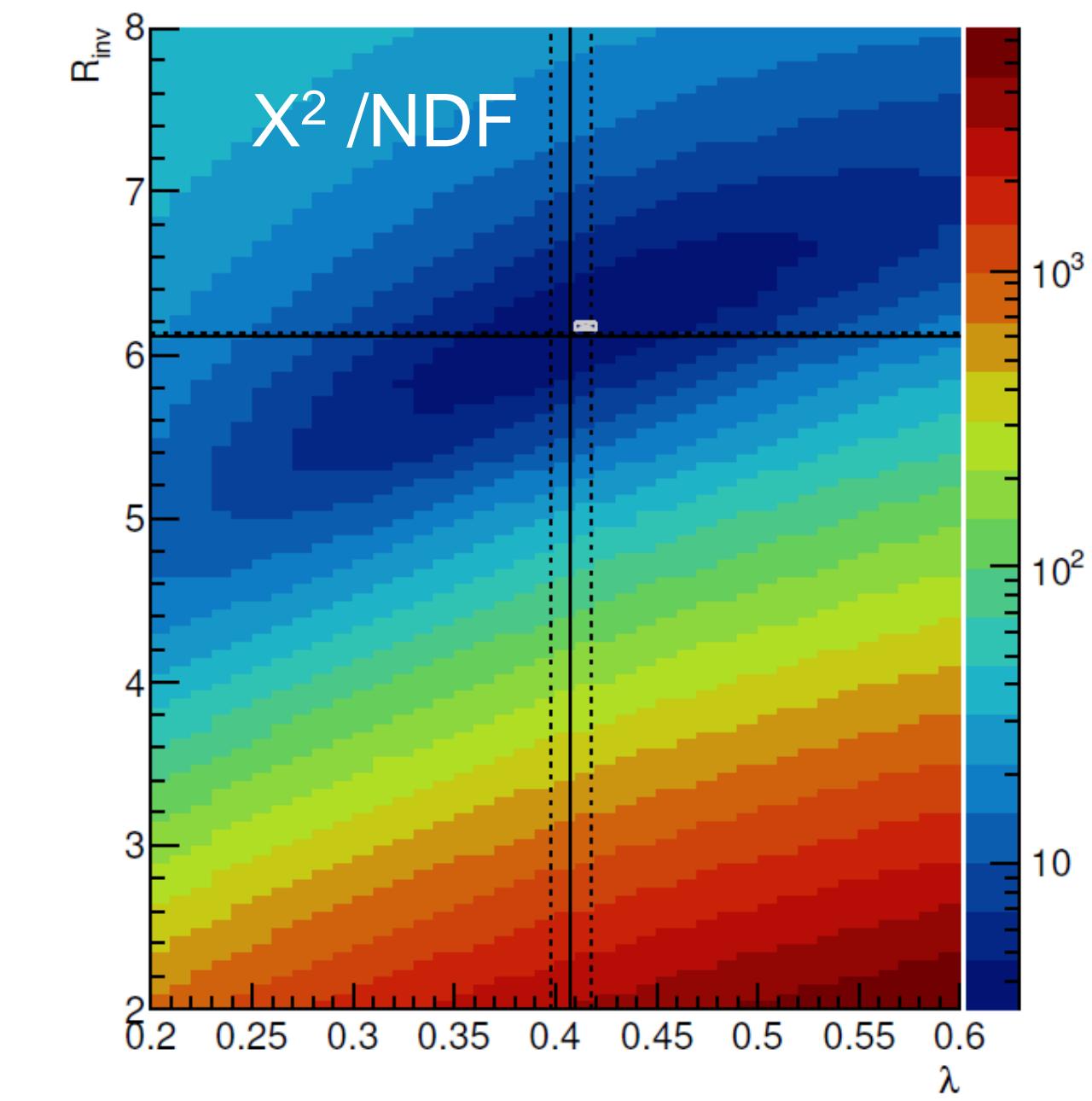
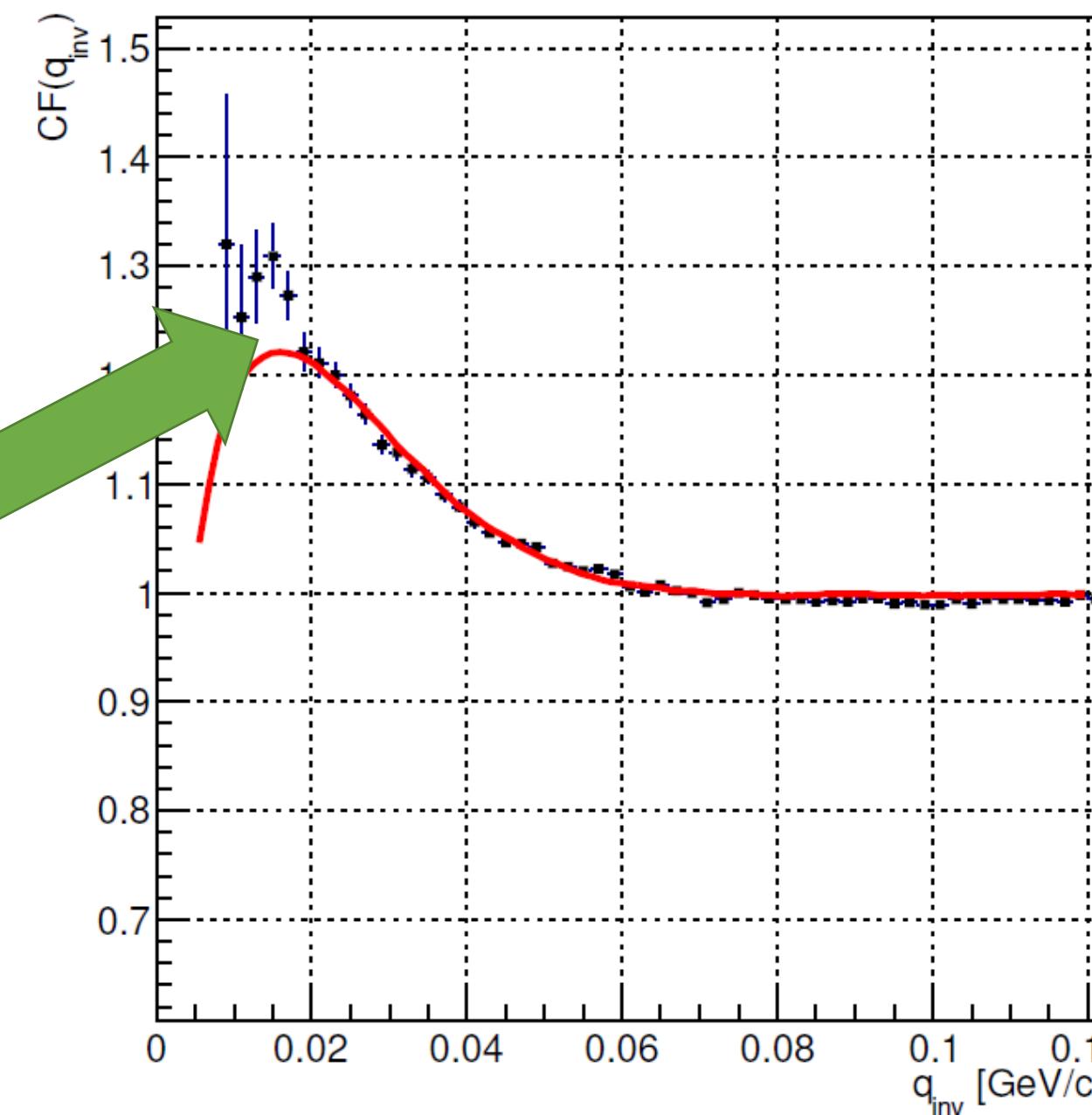
Anti merging cut – $\Delta\eta^*\Delta\phi^*$ cut

Femtoscopy in CBM - negative pions

After analysis of 1M central
AuAu events 10 A GeV

Systematic uncertainty is
estimated to be around 9-10%

Realistic shape of source in CF
Non-realistic shape of source
in fitting fuction



The feasibility of the femtoscopic measurements in CBM experiment

[Proceedings, Summer XLVI-th IEEE-SPIE Joint Symposium Wilga 2020 : Wilga, Poland, August 31- September 2, 2020](#)

D.Wielanek

Femtoscopy in CBM: protons

Similar sample of data – central AuAu collisions at 10 A GeV

Input parameters of source:

- Radius: 3.6 fm (estimated from UrQMD)
- $\lambda=1$ (all protons correlated)

Femtoscopy

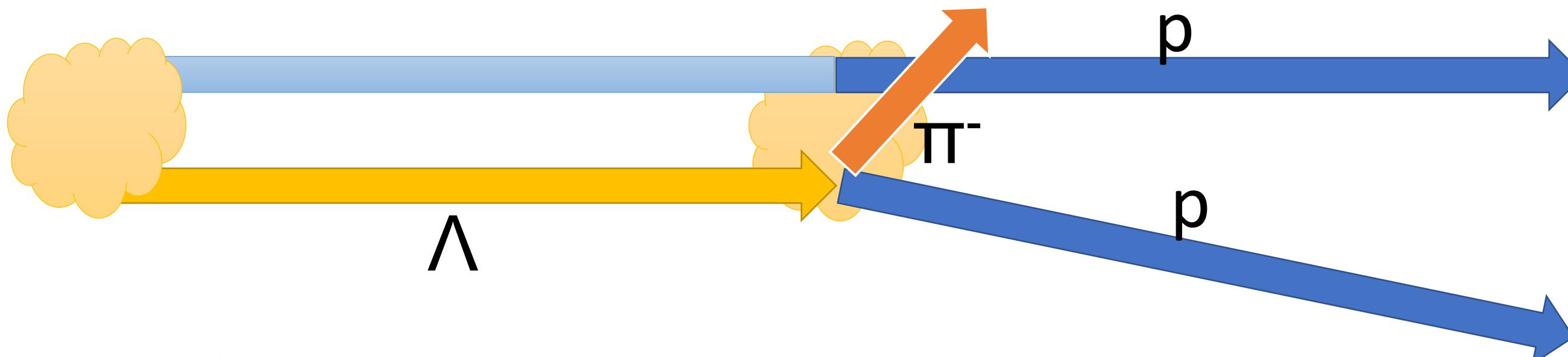
Warning: in contrast to mesons, in baryon-baryon correlations there are significant residual correlations. It means that instead of fitting CF by this formula:

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

We should you this equation:

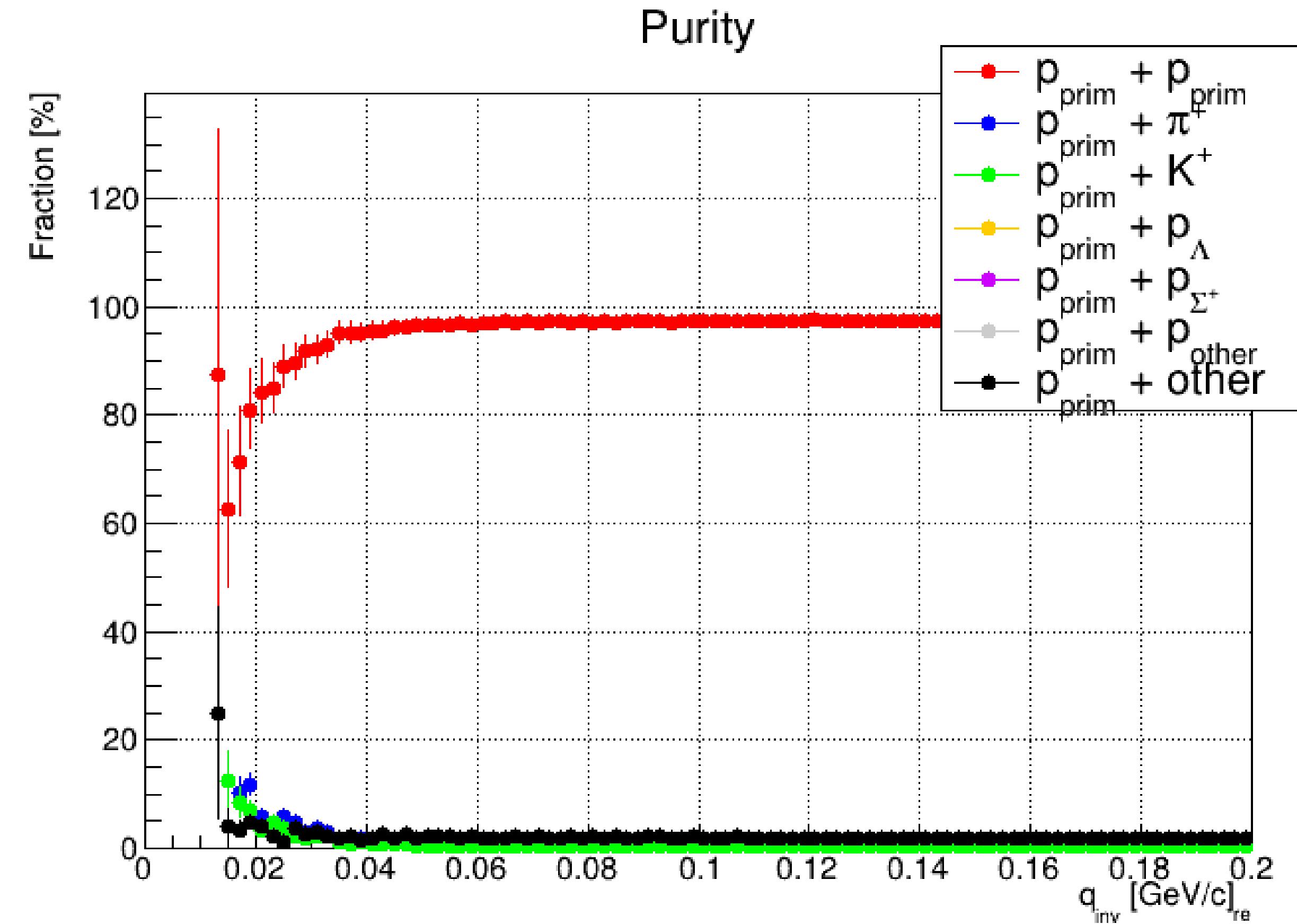
$$C_{\text{experiment}} = F_{pp}M_{pp}(q) + F_{p\Lambda}(\bar{q})\tilde{M}_{p\Lambda}(q) + F_{\Lambda\Lambda}(q)\tilde{M}_{\Lambda\Lambda}(q) + \dots$$

where the M_{XY} is contribution from X and Y baryons that decays in the protons, \tilde{M} denotes „transformed CF”

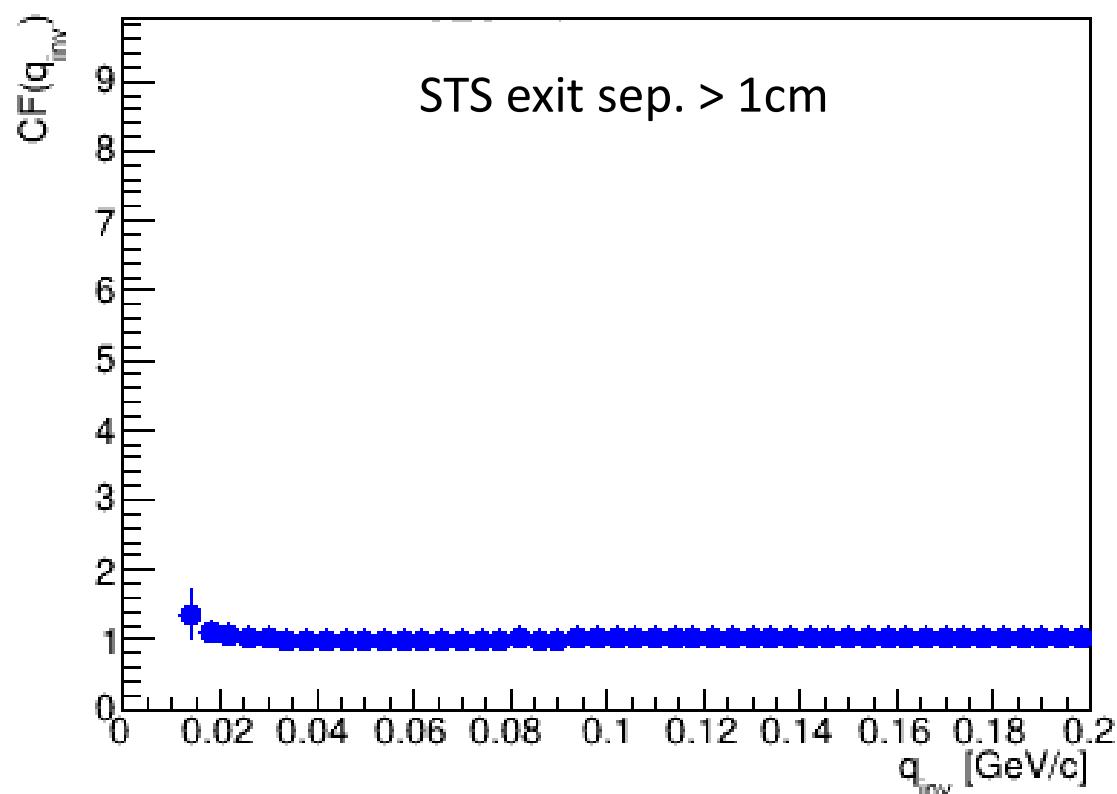
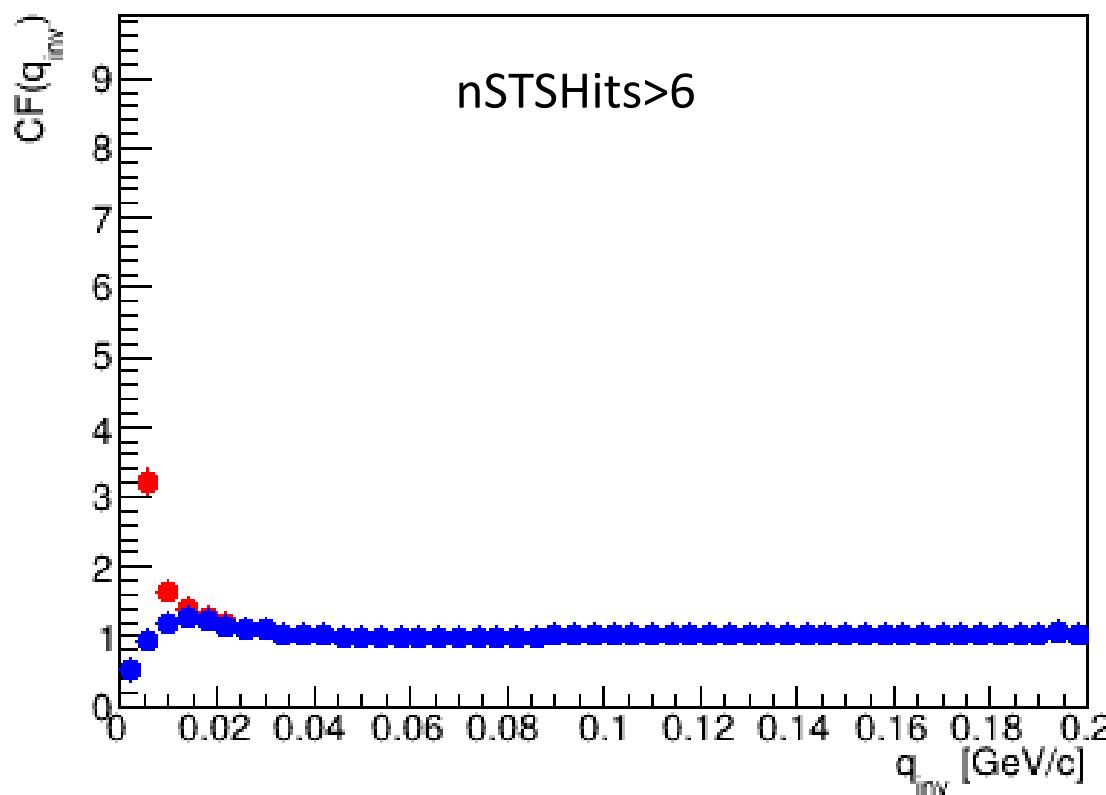
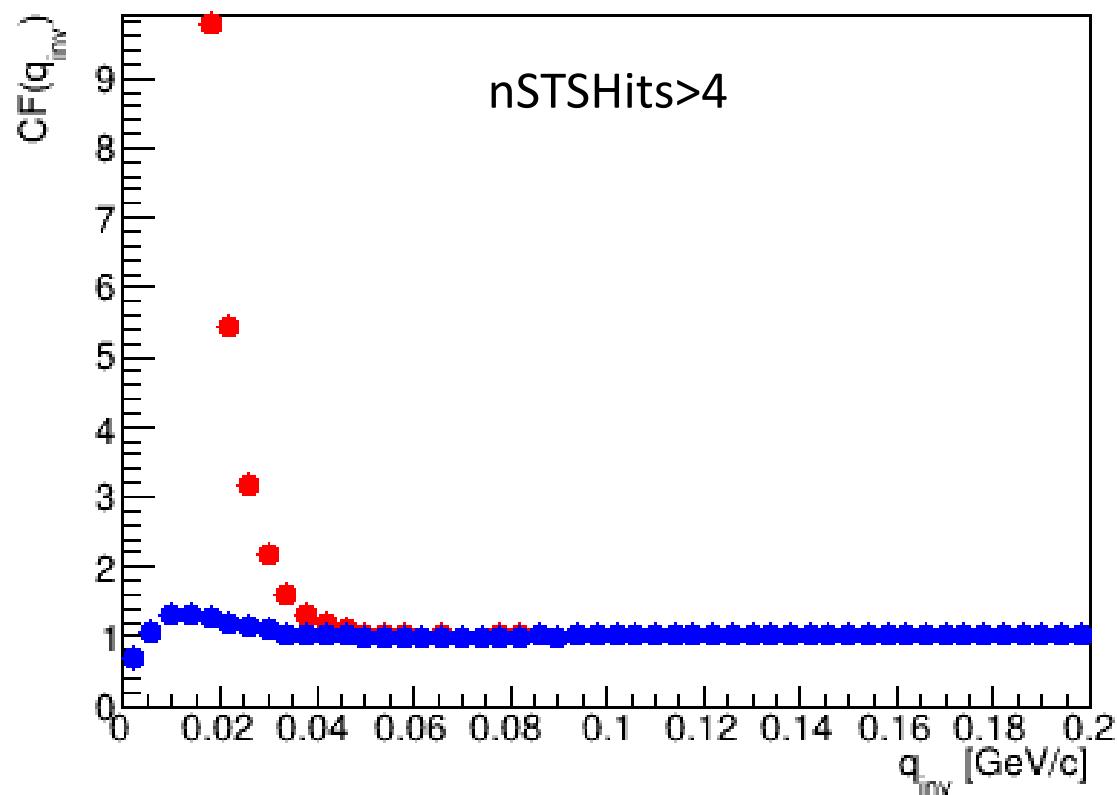


Femtoscopy of protons – WIP

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



Anti splitting cut

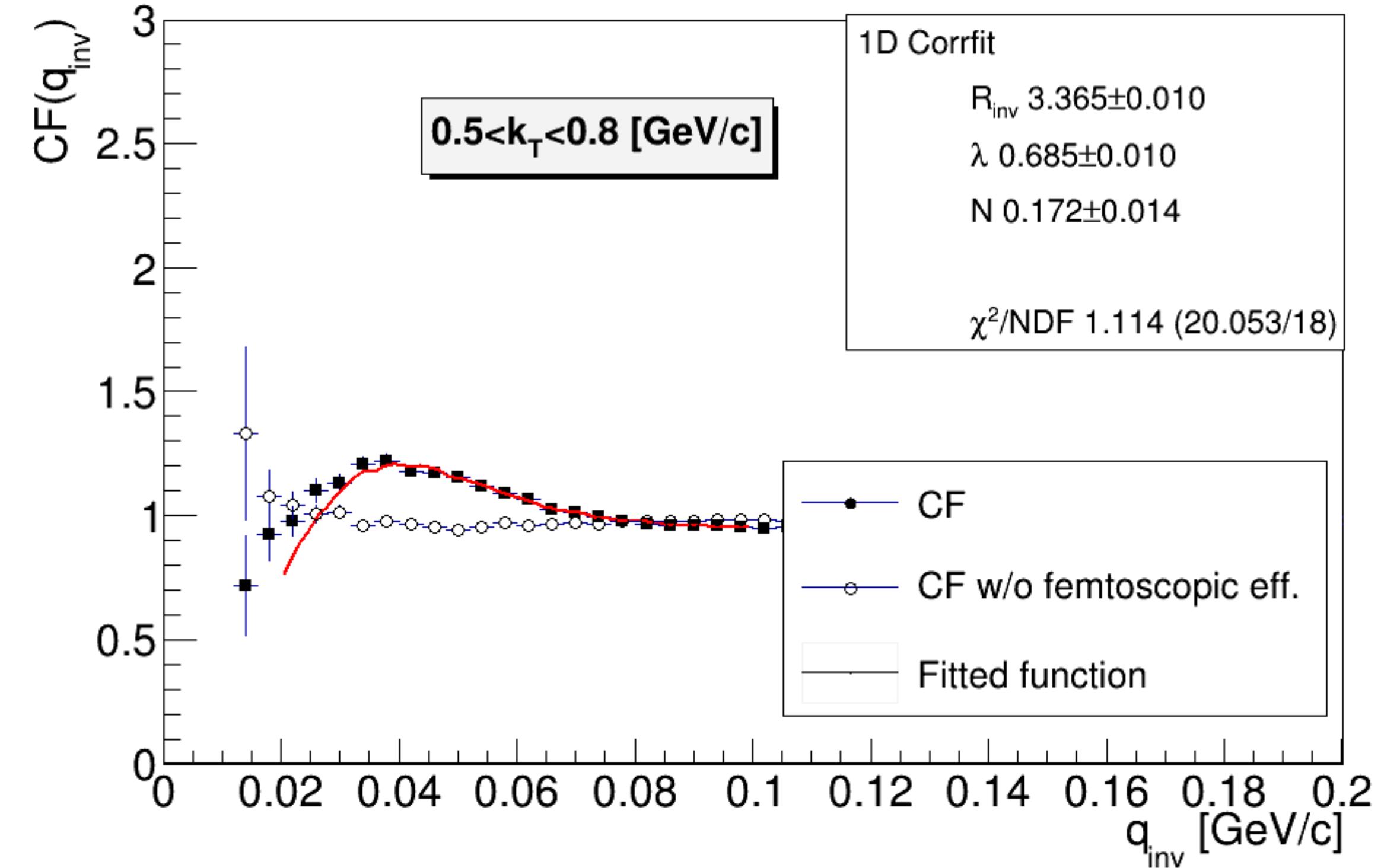


—●— Splitting on

—●— Splitting off

Results

- Obtained lambda – smaller than expected 0.65-0.7 instead of 1
- Obtained radius – smaller than expected 3.27-3.37 instead of 3.6 fm
- Cuts need to be improved – the background (CF without femtoscopic effects) is still not completely flat
- The biggest source of systematic uncertainty – range fit – around 18% of R uncertainty
- More detailed studies are needed
- 1M of events seems to be enough for calculation of p-p correlations at at least 3 k_T bins (stat. uncertainty $R \approx 0.3\%$, $\lambda \approx 1.5\%$)



Summary & plans

- CBM will be very good detector for pion measurements
- The feasibility study of proton-proton measurements – work in progress, looks very promising
- There is no significant contribution from residual correlations into proton-proton femtoscopic measurements at studied energies
- TODO:
 - „Get the full picture” – 3D Femtoscopy, exotic particles, testing model predictions etc. ..

Thank you for your attention

