VIth MPD Collaboration meeting
22-24 April 2021,JINR, Dubna

Femtoscopy correlations with MPD at NICA

on behalf of PWG3 (Correlations and Fluctuations)
Supported by the RFBR grant 18-02-40044

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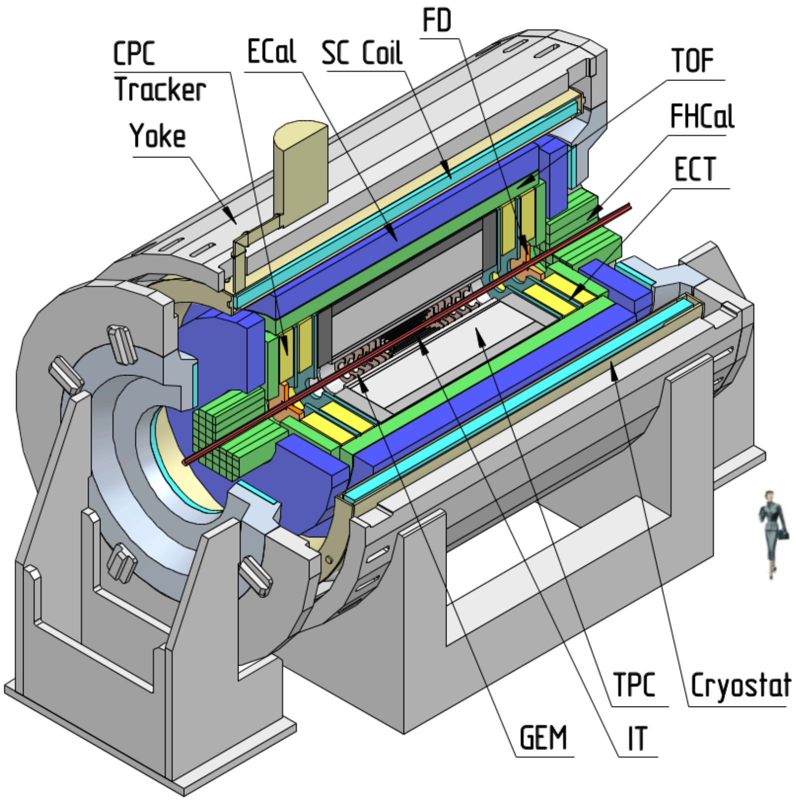
Outline

- Activities
- Femtoscopy
- Femtoscopy and methodical aspect
- Two track effects
- Factorial moments status
- Conclusions



Activities within RFBR grant 18-02-40044

- Three Master and 1 PhD student in Femto group

- PWG3 Femto Meetings: about 20 events(2020-201) → https://indico.jinr.ru/category/346/

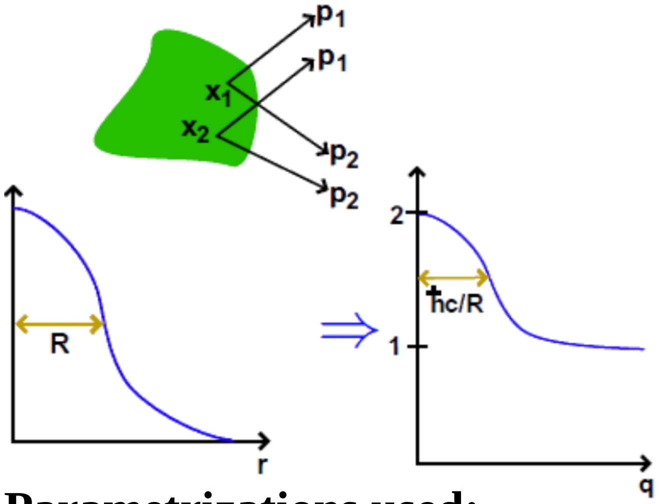
- MPD Physics Seminars(+5 in 2019,2020):
  G.Nigmatkulov. «Energy for the first collisions in MPD at NICA». 04 Feb 2021

- Conferences(+10 in 2019, 2020):
  plan a few talks in 2021

- Publications(since last CM):

  P. N. Batyuk, L. V. Malinina, K. R. Mikhaylov, and G. A. Nigmatkulov,
  «Femtoscopy with Identified Charged Particles for the NICA Energy Range», Physics of Particles and Nuclei, 2020,Vol. 51, No. 3, pp. 252–257
  Grigory Nigmatkulov et al.. "Measurements of the like-sign pion and kaon femtoscopic correlations at NICA Energies. ", J.Phys.Conf.Ser. 1690 (2020) 1, 012132

Femtoscopy



Correlation femtoscopy :

Measurement of space-time characteristics **R**, **cτ** of particle production using particle correlations due to the effects of quantum statistics (QS) and final state interactions (FSI)

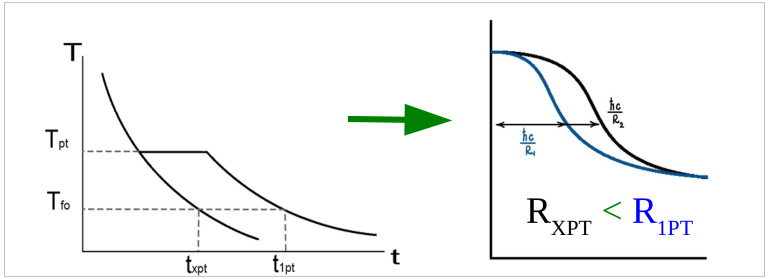
Two-particle correlation function:

theory: $$C(q)=\frac{N_2(p_1,p_2)}{N_1(p_1)\cdot N_2(p_1)},\; C(\infty)=1$$

experiment: $$C(q)=\frac{S(q)}{B(q)},\; q=p_1-p_2$$

$S(q)$ – distribution of pair momentum difference from same event

$B(q)$ – reference distribution built by mixing different events



Parametrizations used:

1D CF: $$C(q_{inv})=1+\lambda\, e^{-R^2 q_{inv}^2}$$

R – Gaussian radius in PRF,

λ – correlation strength parameter

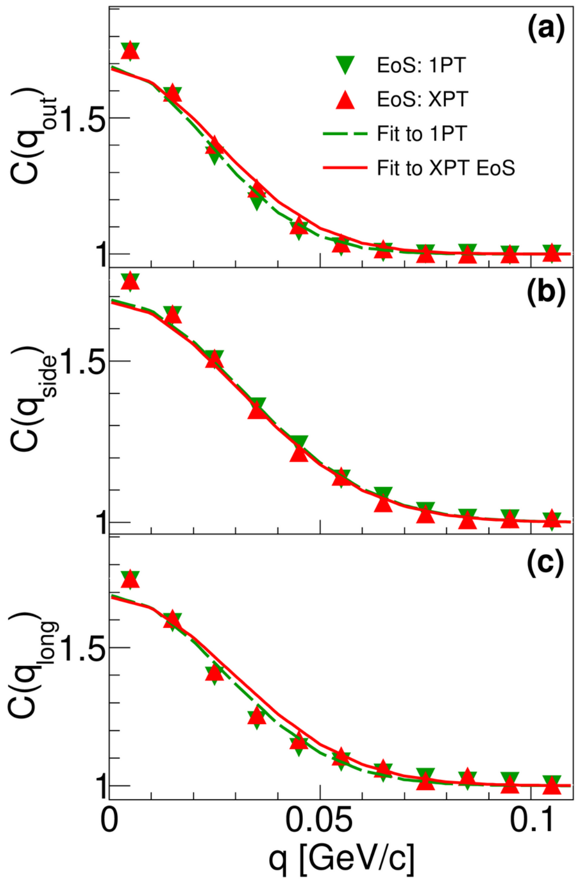
3D CF: $$C(q_{out},q_{side},q_{long})=1+\lambda\, e^{-R_{out}^2 q_{out}^2-R_{side}^2 q_{side}^2-R_{long}^2 q_{long}^2}$$

R and q are in Longitudinally Co-Moving Frame (**LCMS**)

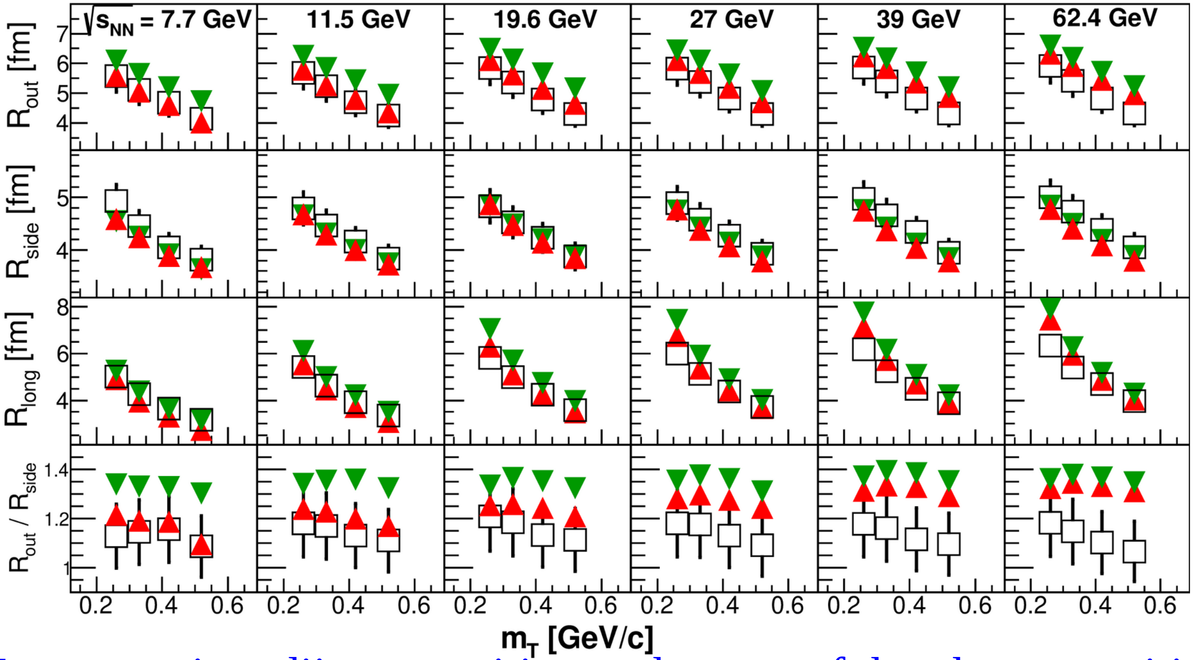
long || beam; out || transverse pair velocity $\boldsymbol{v}_T$; side normal to out,long

3D Pion radii versus m_T with vHLLE

Model CF



Comparison of extracted radii with the STAR data [PRC 96, 024911(2017)]



- Femtoscopic radii are sensitive to the type of the phase transition
- Crossover EoS does better job at lowest collision energies.
- R_{out} (XPT) at high energies and R_{out} (1PT) at all energies are slightly overestimated
- $R_{out,long}$ (1PT) > $R_{out,long}$ (XPT) by value of ~1-2 fm.

Femtoscopic Radii of Pions and Kaons from vHLLE

- AuAu $\sqrt{s_{NN}}$ = 11.5 GeV
- Pion and kaon results for the cross over (XPT) and 1st-order (1PT) phase transitions

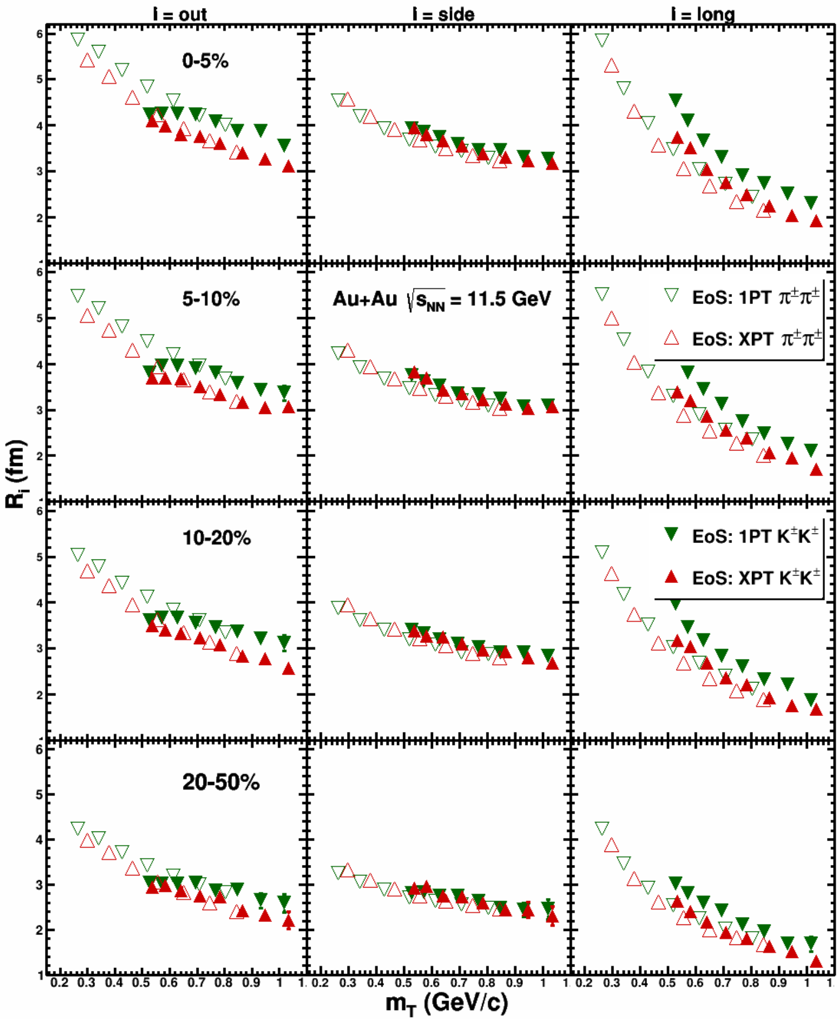
- Femtoscopic radii of π and K decrease with increasing transverse mass → Influence of radial flow

- R_{side} values for π and K are similar
  → Similar size of the particle-emitting region

- R_{out} for both π and K show similar behavior
  → Similar particle emission duration

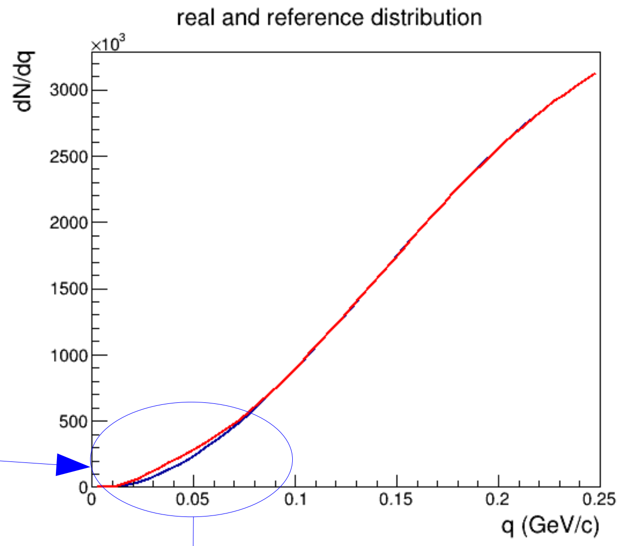
- R_{long} for K is generally larger than that for π at the same m_T
  → Influence of resonances, K*

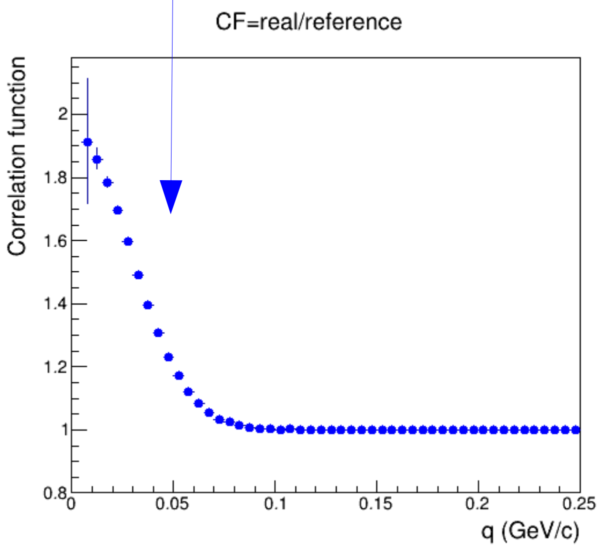
- *We have to study femtoscopy in very wide pair transverse momentum region to see all above!*



Features of reconstruction for femtoscopy

- The signal is in small phase space
- Close track reconstruction is very important
- Momentum resolution
- Particle identification in pair (e.g. e+e- could destroy K+K-)





Detector effects affecting the correlation function *

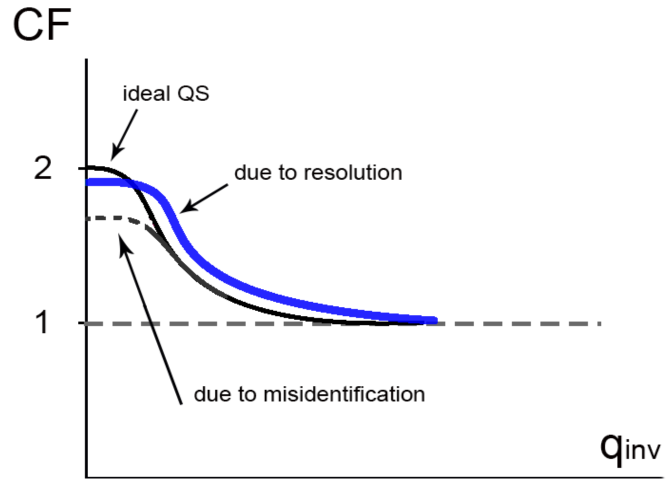
- Single track effects:

  → the momentum resolution effects smear CF, making it wider and extracted radii smaller

  → CFs should be corrected by resolution

  → the particle misidentification influences only λ-parameter of CF, radii do not change.

  → CF should be corrected by pair purity.

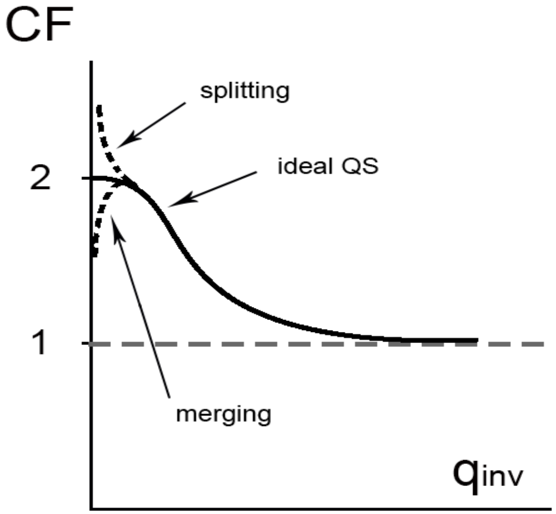


- Two track effects:

  → track splitting (one track is reconstructed as two)

  → track merging (two tracks are reconstructed as one)

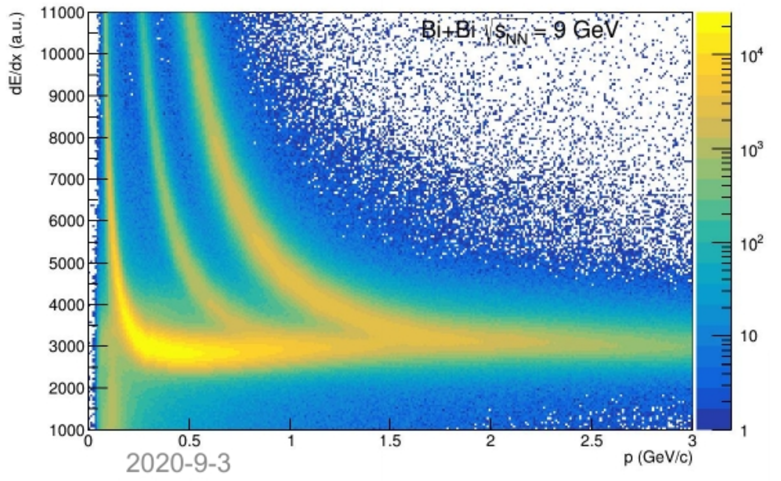
  These effects are studied and the special pair selection are used in the analysis.



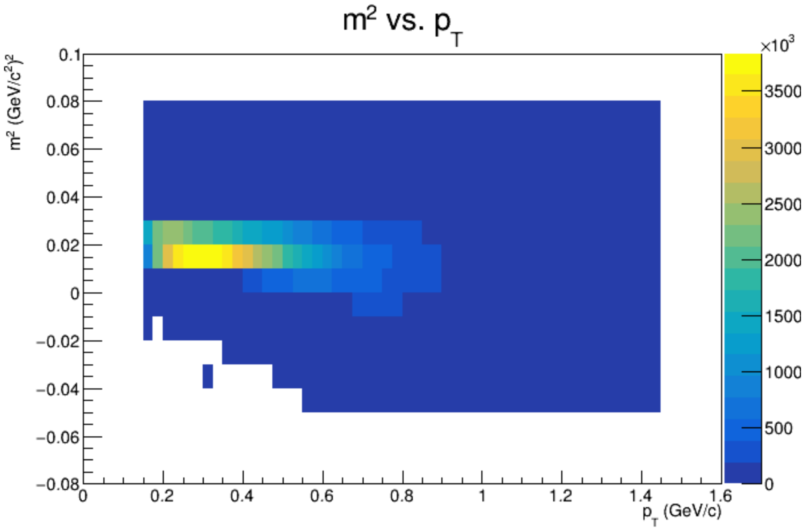
* *see Ludmila's talk today*

Monte-Carlo data

- Monte Carlo simulation request
- UrQMD Minimal Bias 10 million evens
- BiBi at $\sqrt{s_{NN}}$=9 GeV
- MiniDst format
- See Ludmila's talk

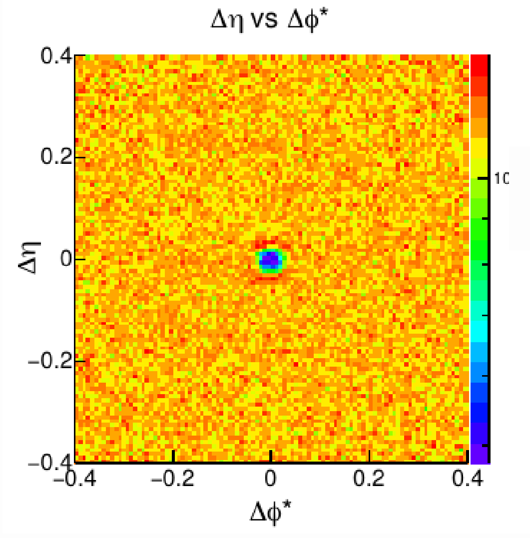


- Kinematic conditions for pions
  $0.05<p_T<2$ GeV/c
  |eta|<1.0



- Nhits TPC > 15
  DCA < 3 cm
  |VertexZ| < 75
  PID : Select poin track by PDG code (tests)
  (Nsigma for pion selections in TPC & TOF = 2)

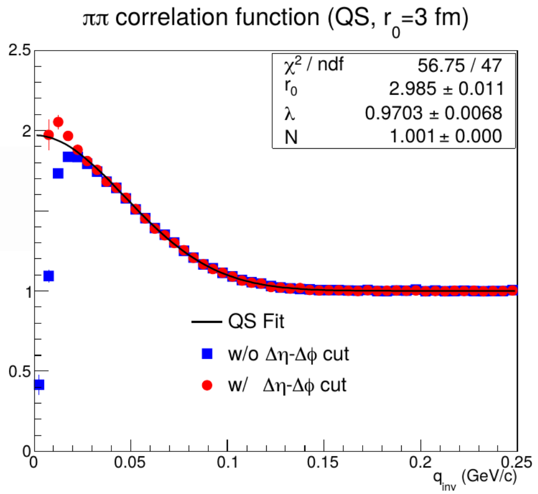
Two-track selection criteria

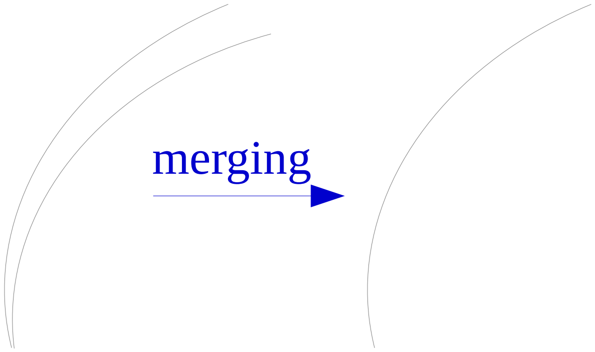


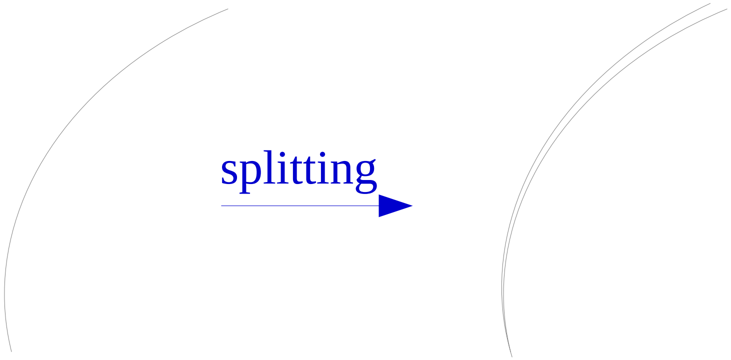
- Δη-Δφ* cut:

$$\Delta\phi^* = \phi_1 - \phi_2 + \arcsin\left(\frac{z \cdot e \cdot B_z \cdot R}{2p_{T1}}\right) - \arcsin\left(\frac{z \cdot e \cdot B_z \cdot R}{2p_{T2}}\right)$$

R is a given cylindrical radius,
$\phi_{1,2}$ are azimuthal angles of track at reconstructed vertex



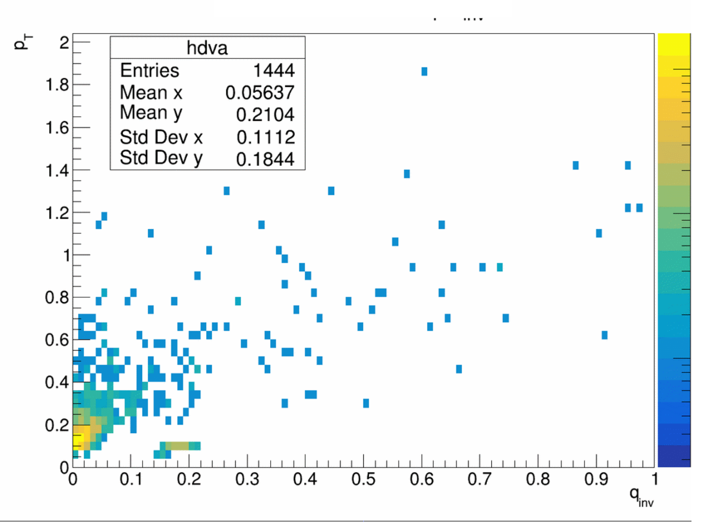


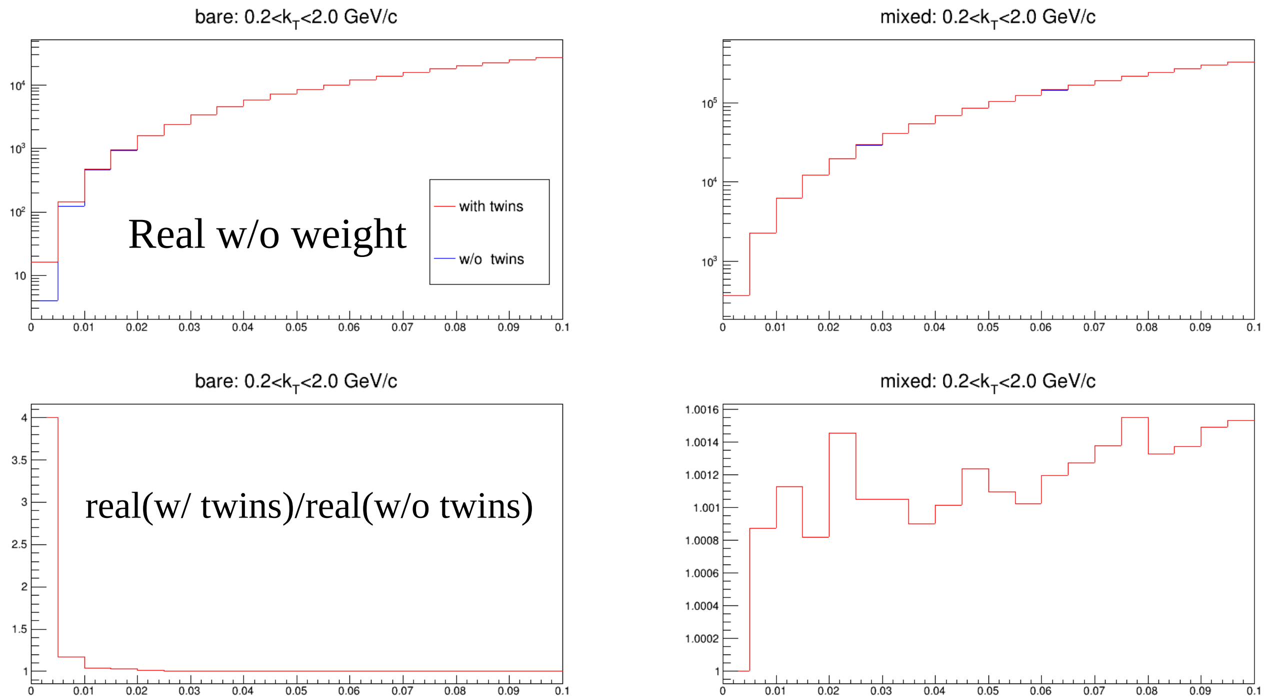


Reconstructed tracks with the same MC index (splitting)

Red – both reco tracks, blue – only first one
Ratio=Twins/Total =4 at first bin !
This huge effect comes from 0.1% tracks from same MC track

Reco tracks with same mcindex

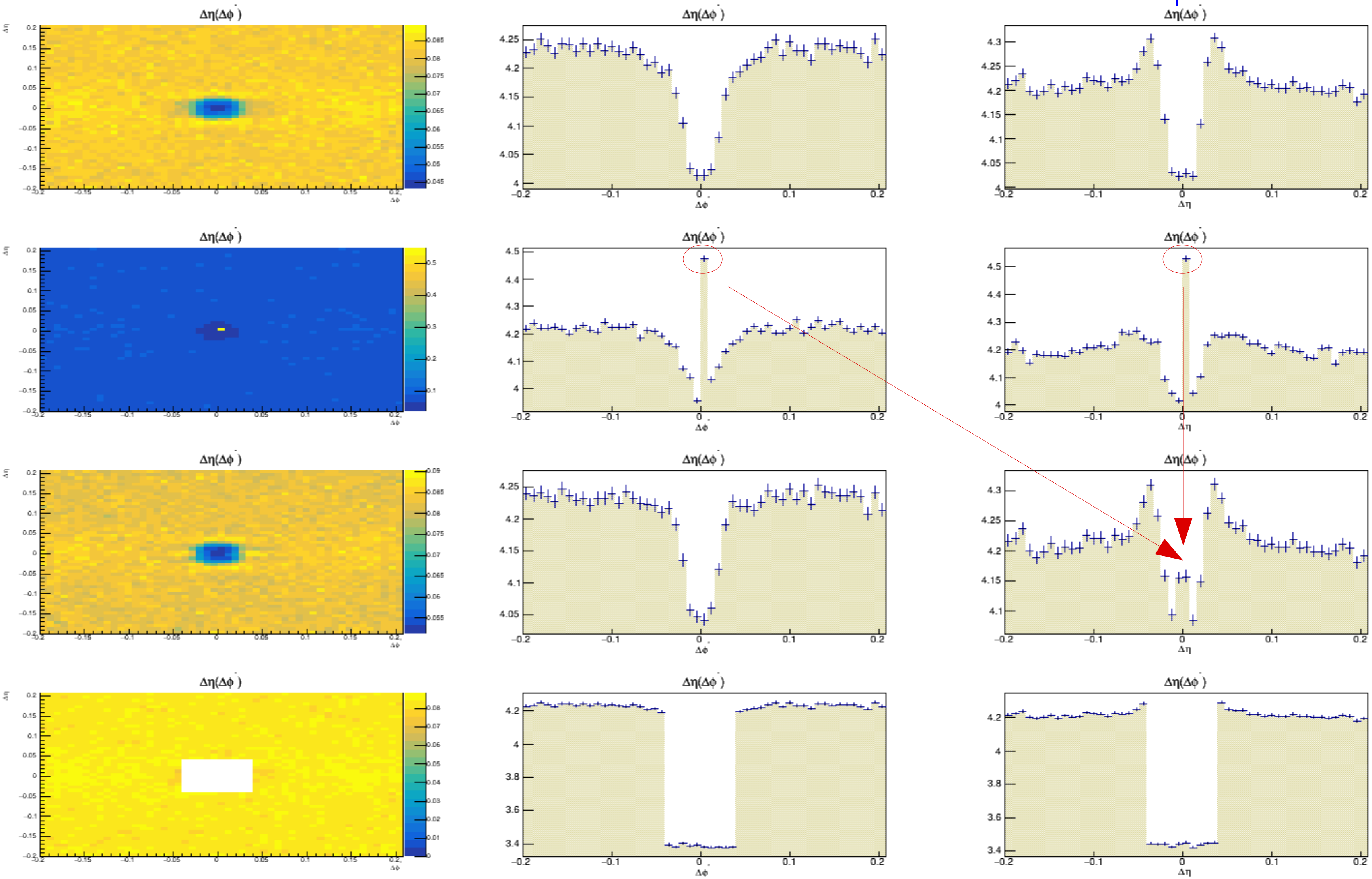




Δη-Δφ* selection criteria

Δη

Δφ*



No twins (removed by hand)

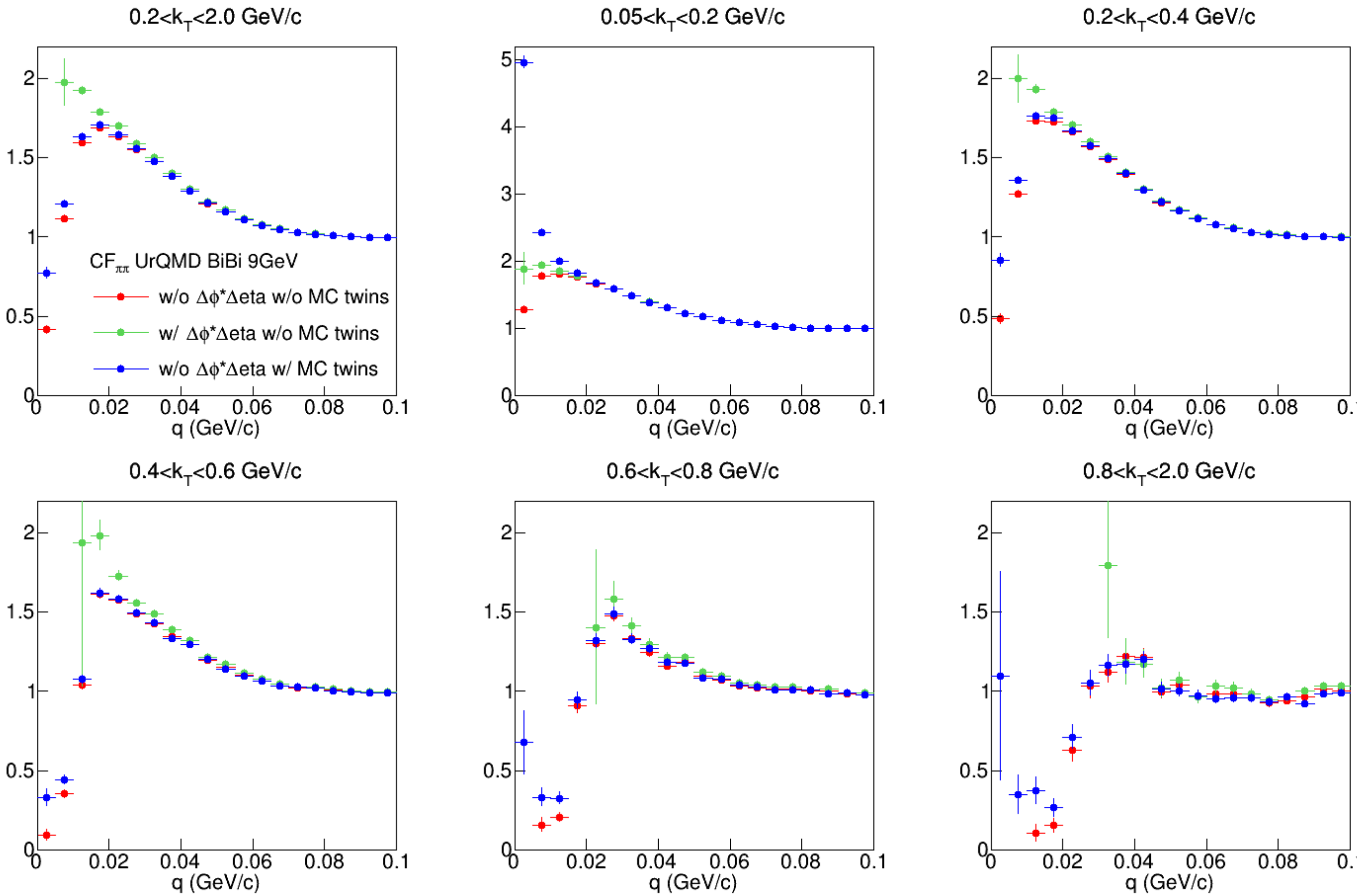
Twins
MC tracks
Δφ*Δη

Twins
Reco tracks
Δφ*Δη

Reco tracks
No twins
Δφ*,Δη<0.04

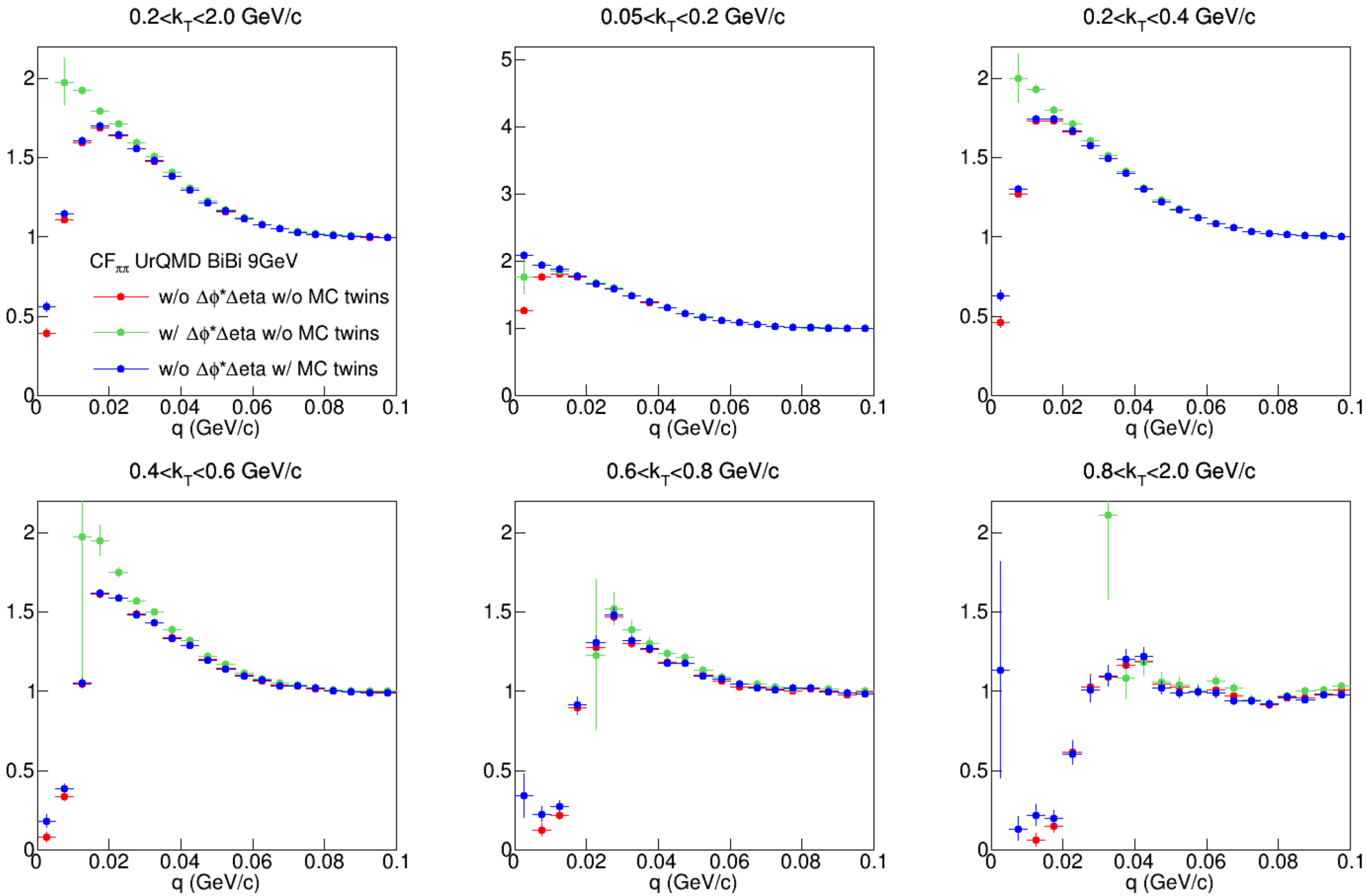
Two-pion CFs versus kT (#hits>15)

- k_T inclusive CF looks good
- The track-spitting effect is small as compared to the track merging
- Width of merging increases with increasing of k_T
- Unfortunately, we can't measure k_T-dependence due to the track-merging effect coming from reconstruction



Two pion CFs vs kT (#hits>20)

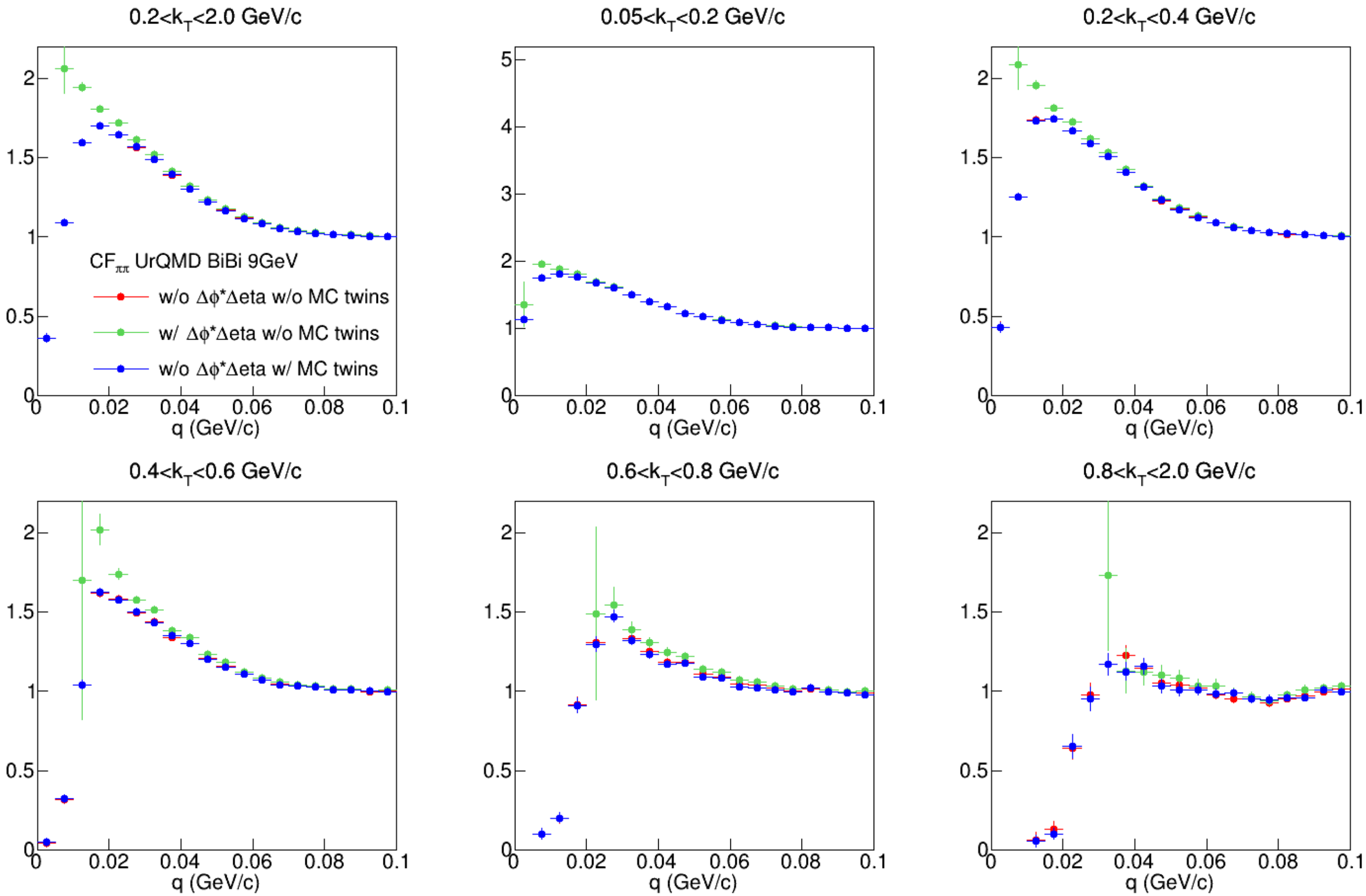
- Good news: splitting effect decreases with increasing number of hits per track
- Bad news: merging effect is approximately the same



Two pion CFs vs kT (#hits>30)

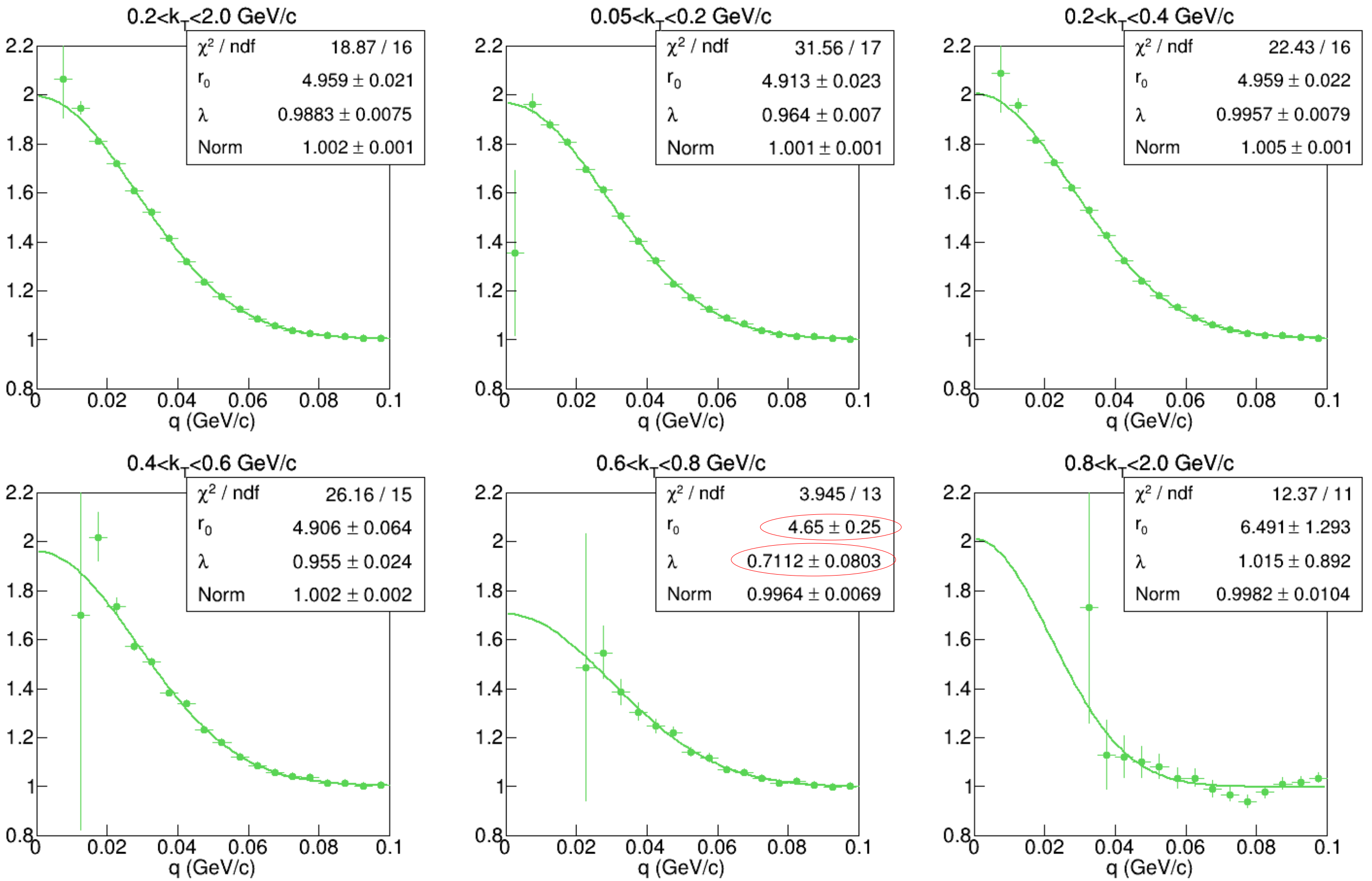
- Good news: splitting effect disappears starting from number of hits per track is higher 30

- Bad news: merging effect is approximately the same



Parameters R and λ from fitting function (#hits>30)

- Fit QS: $N[1+\lambda\cdot\exp(-q^2r^2_0)]$
- We should get
  $\lambda=1$ and $r^2_0=5$ fm
- Unfortunately, we can't measure k_T-dependence even in 1d case



Factorial moments*

$$F_i = M^{i-1} \times \left\langle \frac{\sum_{j=1}^{M} k_j \times (k_j - 1) \times \ldots \times (k_j - i + 1)}{N \times (N-1) \times \ldots \times (N - i + 1)} \right\rangle$$

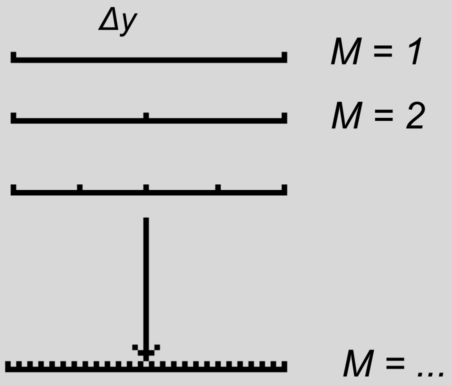
It was proposed by A. Bialas and R. Peschanski (Nucl. Phys. B 273 (1986) 703) to study the dependence of the normalized factorial moments of the rapidity distribution on the bin size δ*y*:

1. if fluctuations are purely statistical no variation of moments as a function of δ*y* is expected

2. observation of variations indicates the presence of physics origin fluctuations

$\delta y = \Delta y / M$
M — number of bins
Δy — size of mid rapidity window
N — number of particles in Δy
k_j-the number of particles in bin j

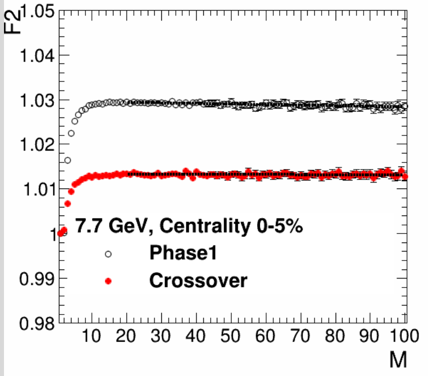
<u>Note:</u> there is a set of definitions of moments and cumulants.

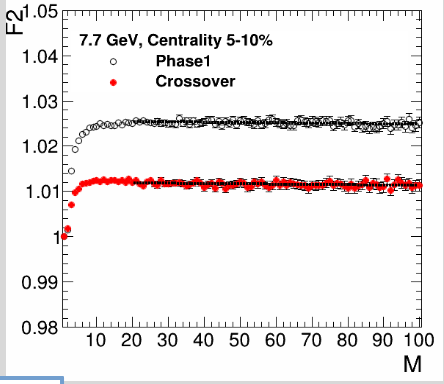


* Olga Kodolova and Maria Cheremnova

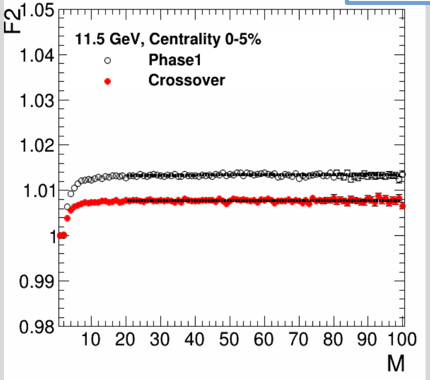
Au-Au, UrQMD+vHLLE: generator information

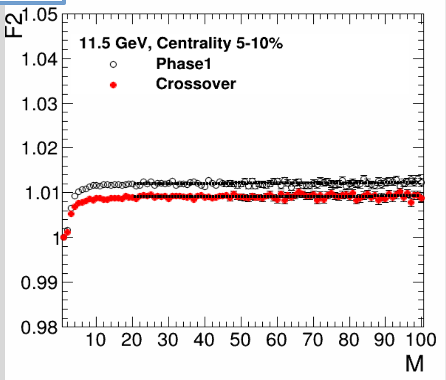
7.7 GeV

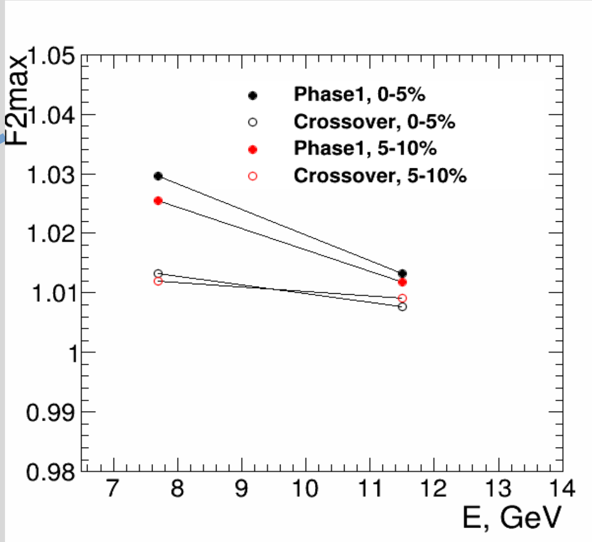




11.5 GeV







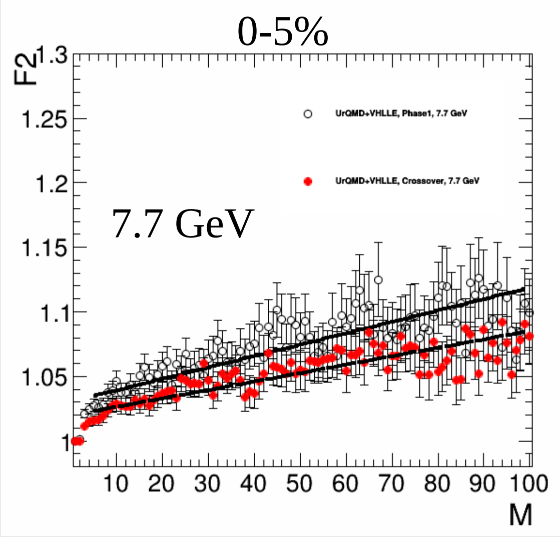
- Different energy dependence is expected for Crossover and 1st order phase transition
- There is a mild dependence on centrality for 1st order phase transition

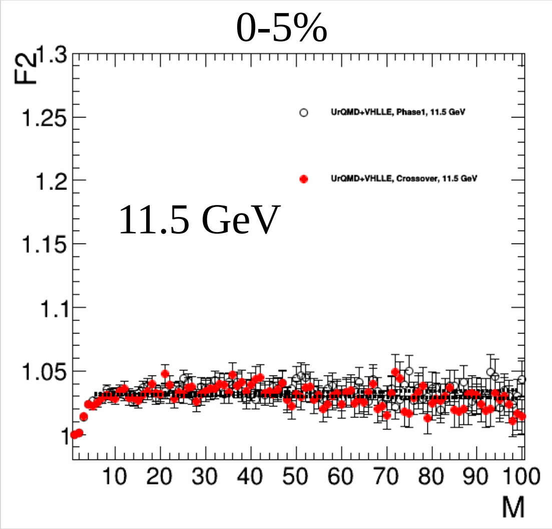
Factorial moments with reconstructed tracks

Use of reconstructed tracks
With p_T>0.5 GeV and $|y|$<1

ToF PID is used:
if particle fails ToF matching
it is considered being pion.

Factorial moments in rapidity bins are mostly affected by the ToF particle identification. Efficiency of particle -ToF matching is ~60%





Pre-production sample

Studies are on going.

1. Use pseudorapidity (instead of rapidity) –
   move away from particle identification problem
2. Take into account PID:unfolding to particle level
3. Add division in azimuthal angle

Conclusions

- The model shows that it is necessary to explore a wide range of the pair's transverse momentum
- Since the femtoscopy signal is found at small relative impulses,

  it is necessary to study in detail the two-track effects
- Huge effect (depends on #hits) at low q due to splitting of MC track into two reconstructed track
- Very wide close track inefficiency effect at k_T>0.4 GeV/c
- We can’t study CF versus k_T → high k_T CF has a big dip at the signal region
- We kindly ask tracking experts to help with this two-track problem
- See details in Ludmila Malinina talk today
- Factorial moments: work is in progress, detail study of PID is needed

Backup

Latest studies in the world: theory and experiments

- Intermittency (fluctuations of various different sizes in 1D, 2D and 3D phase space) have been studied at LEP, Tevatron, Protvino in ee, hh, hA, AA interactions at the various energies. There are plenty of interpretations including Clan Model proposed by L. Van Hove, intermittency and fractals of the different origin.
- Some latest studies for pp and AA (NA49, NA61, ALICE):
  - A Monte Carlo Study of Multiplicity Fluctuations in Pb-Pb Collisions at LHC Energies, Ramni Gupta, Journal of Central European Green Innovation 4(4) pp 116-126 (2016)
  - Search for the critical point of strongly interacting matter in NA49 Katarzyna Grebieszkow*a* for the NA49 collaboration, arXiv:0907.4101
  - **Scaling Properties of Multiplicity Fluctuations in the AMPT Model Rohni Sharma and Ramni Gupta, AHEP, v2018, AricleID 6283801**
  - **Searching for the critical point of strongly interacting matter in nucleus-nucleus collisions at CERN SPS,** Nikolaos Davis (for the NA61/SHINE Collaboration), arXiv:2002.06636

Femtoscopy with vHLLE

Iu. Karpenko, P. Huovinen, H.Petersen, M. Bleicher, Phys.Rev. C.91, 2015, 064901

Pre-thermal phase → Hydrodynamic phase → Hadronic cascade

UrQMD

Parameters τ_0, $R_\perp$, R_η and η/s adjusted using basic observables in the RHIC BES-I region.

$\sqrt{s_{NN}}$ [GeV]	τ_0 [fm/c]	$R_\perp$ [fm]	R_η [fm]	η/s
7.7	3.2	1.4	0.5	0.2
8.8 (SPS)	2.83	1.4	0.5	0.2
11.5	2.1	1.4	0.5	0.2
17.3 (SPS)	1.42	1.4	0.5	0.15
19.6	1.22	1.4	0.5	0.15
27	1.0	1.2	0.5	0.12
39	0.9	1.0	0.7	0.08
62.4	0.7	1.0	0.7	0.08
200	0.4	1.0	1.0	0.08

Model tuned by matching with existing experimental data from SPS and BES-I RHIC

vHLLE

(3+1)-D viscous hydrodynamics

EoS to be used in the model

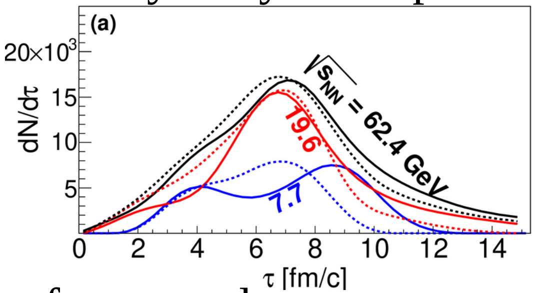
- Chiral EoS — crossover transition
  J. Steinheimer et al., J. Phys. G 38, 035001 (2011)
- Hadron Gas + Bag Model
  1st-order phase transition
  P. F. Kolb et al., Phys.Rev. C 62, 054909 (2000)

Hydrodynamic phase lasts longer with 1PT, especially at lower energies but cascade smears this difference.

UrQMD

Pion emission time

after hydrodynamic phase



after cascade