Study of strongly-interacting matter properties at the energies of the NICA collider using the methods of factorial moments

Egor Alpatov, Pavel Batyuk, Mariya Cheremnova, Aleksey Chernyshov, Eugenia Khyzhniak, Olga Kodolova, Igor Lokhtin, Ludmila Malinina, Konstantin Mikhaylov, Grigory Nigmatkulov, Gleb Romanenko

Introduction

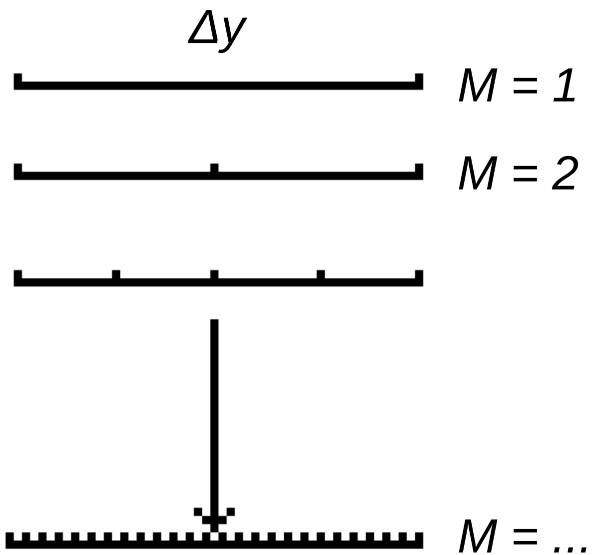
It was proposed by A. Bialas and R. Peschanski (Nucl. Phys. B 273 (1986) 703) to study the dependence of the normalized factorial moments of the rapidity distribution on the bin size δ*y*:

1. if fluctuations are purely statistical no variation of moments as a function of δ*y* is expected
2. observation of variations indicates the physics nature of the fluctuations

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

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

Note: there is a set of definitions of moments and cumulants.



What do we see with factorial moments: simplified case

Mathematical model:

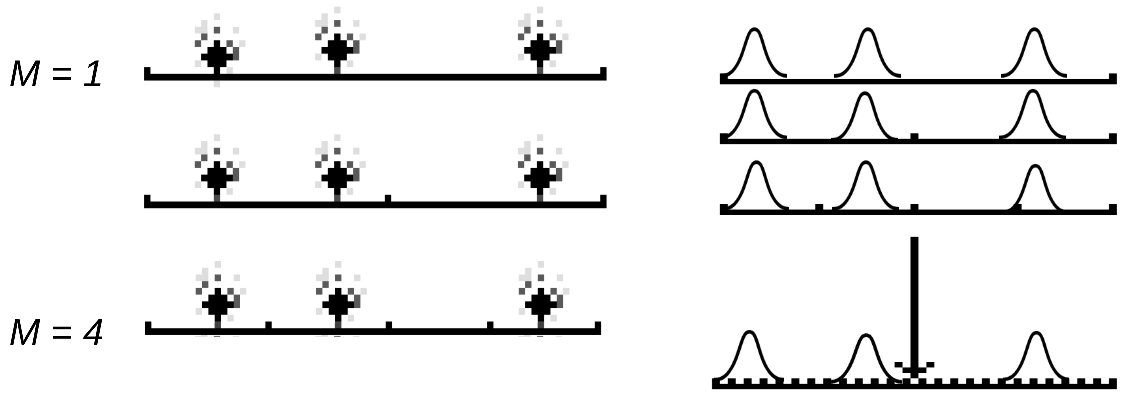
- **An random number of particles per event organized in groups**
- **Groups are distributed uniformly along *Δy* interval**.
- **Each group has the random number of particles.**
- **Consider two cases:**
  - **Point-like group** - all particles inside group have the same y,
  - **Non-point-like group** - particles are distributed over y with respect to the group center

➢ number of groups per event is Poissonian

➢ number of particles per group has geometrical distribution.

Multiplicity distributions of particles in Δy interval is:

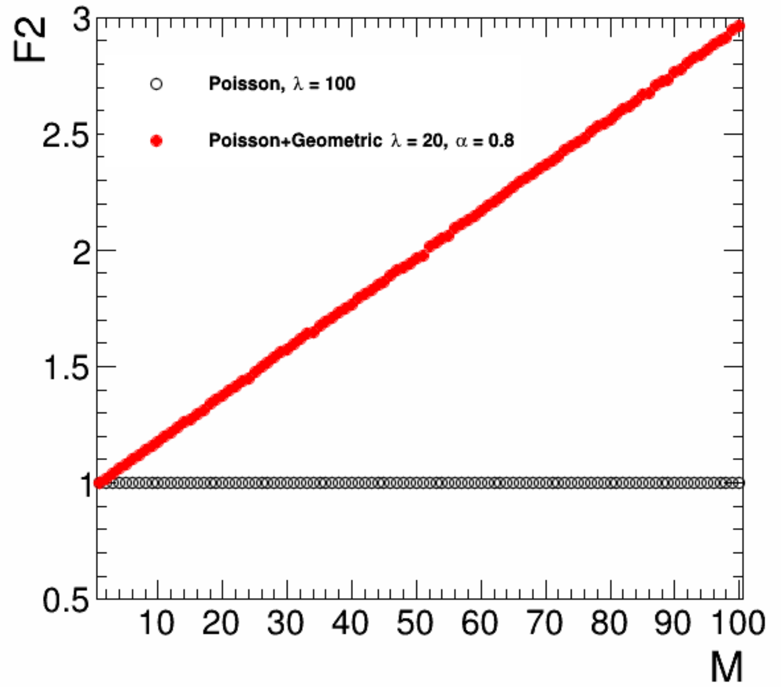
$$P(l) = \sum_{m=0}^{l} \frac{e^{-\lambda}\lambda^m}{m!} \binom{l-1}{m-1} \alpha^{l-m}(1-\alpha)^m$$

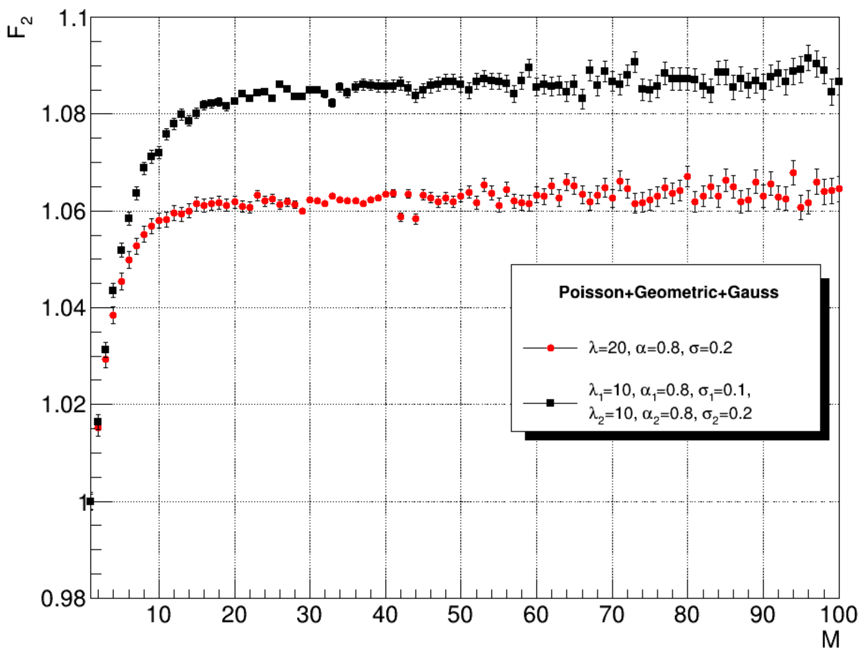


Point-like groups

Non-point-like groups with width σ

Simple examples: point-like and non-point-like groups





The power of growth depends on

- Mean number of groups
- Mean number of particles per group
- Characteristic widths of groups

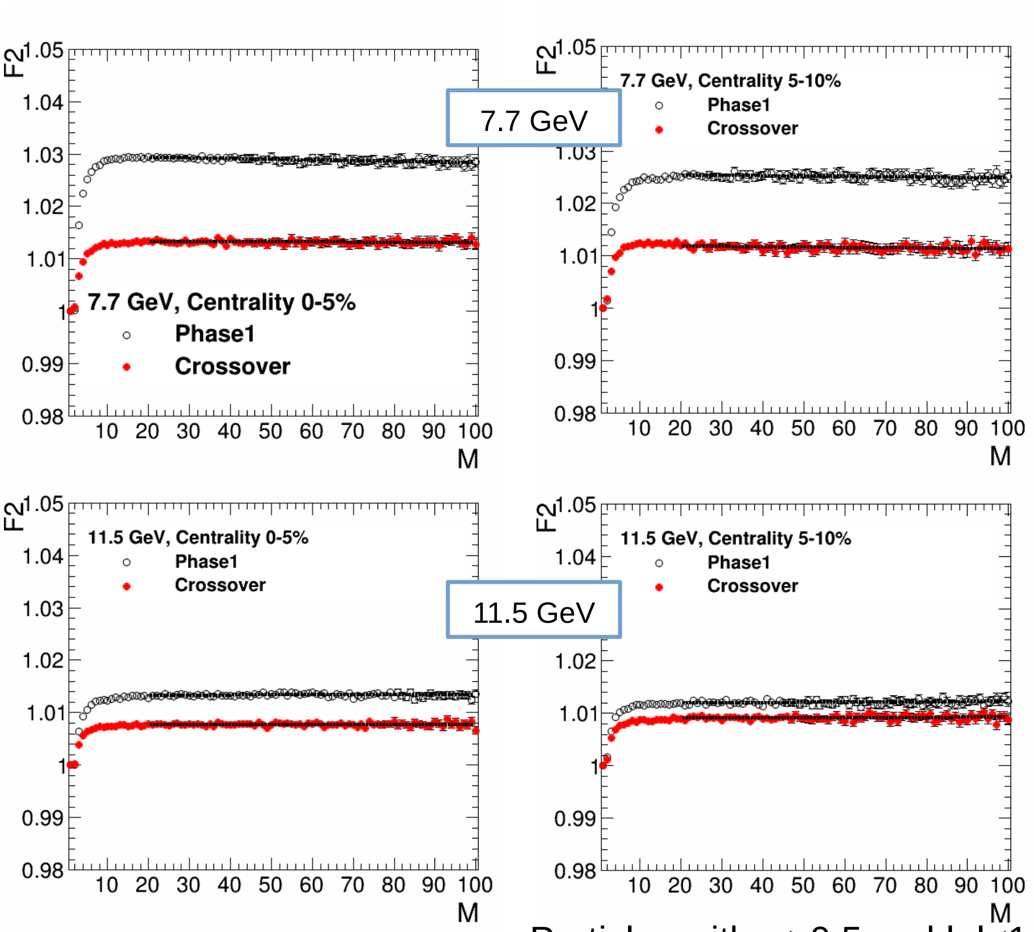
Independent production of particles with Poisson distribution leads to $F_i(M) = 1$.

Under hypothesis of independent point-like groups $F_i(M)$ grows as polynomial of order (i-1)

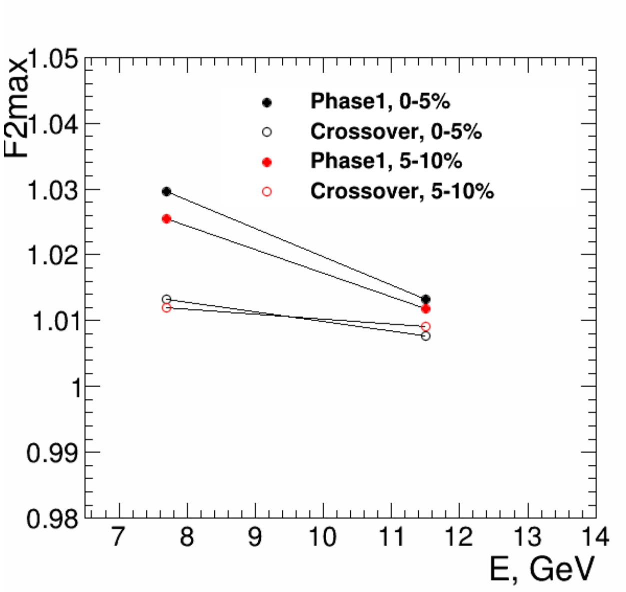
For non-poin-tlike group with width σ.
F_i (M) = constant when $\delta y = \Delta Y/M \ll \sigma$

Several processes with different characteristic widths ($\sigma_1 > \sigma_2 > .. > \sigma_N$) the factorial moments are increasing untill $\delta y = \Delta Y/M \ll \sigma_N$

Factorial moments: AuAu, UrQMD+vHLLE



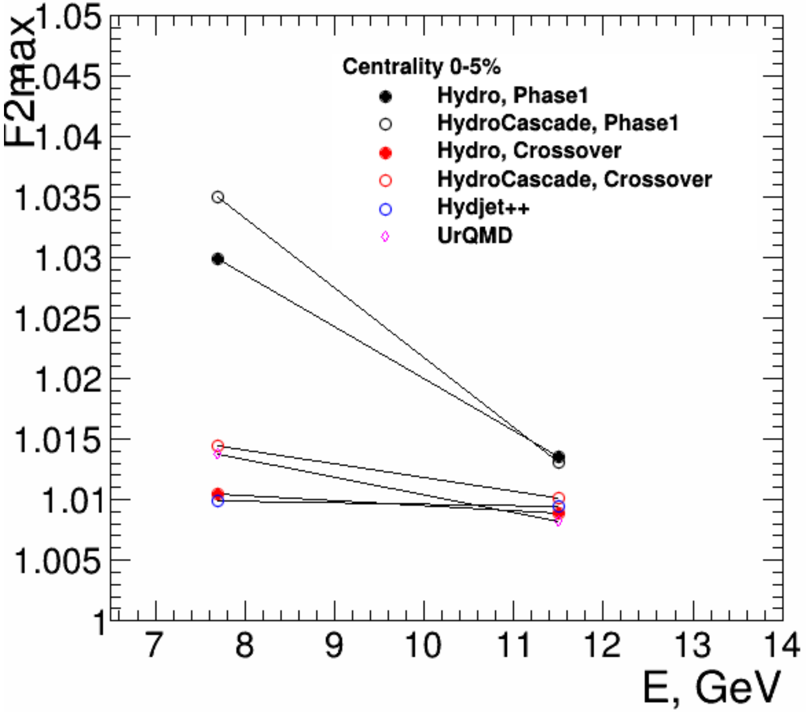
F2Max



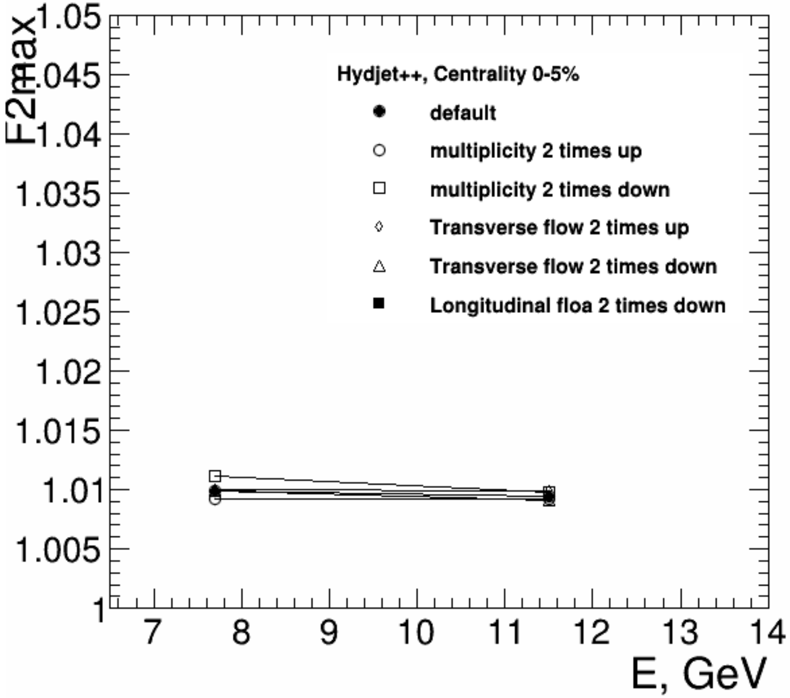
Particles with p_t>0.5 and $|\eta|$<1

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

Models comparison: UrQMD, UrQMD+vHLLE, HYDJET++



- UrQMD, HYDJET++ are comparable with vHLLE+UrQMD crossover
- Change of
  - Multiplicity
  - volume size



Selection conditions

The consideration included events under the conditions:

- Impact parameter < 3.3
- Number of tracks > 500

Generated:

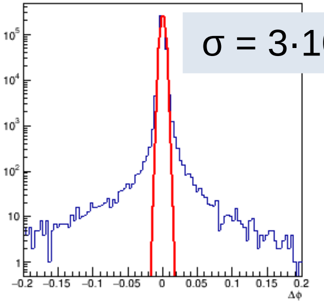
- $p_t>0.5$, $|\eta|<1$
- Tracks from Primary Interaction
- p, π, k, Σ

Reconstructed:

- $p_t>0.5$, $|\eta|<1$
- π: $m_{TOF} < 0.4$
- K: $0.4 < m_{TOF} < 0.8$
- p: $0.8 < m_{TOF}$
- In case the track has no m_{TOF}, it was assumed that $m=m_\pi$

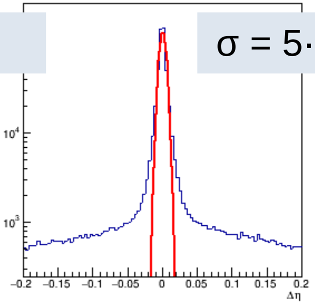
Tracking resolution

φ resolution for p



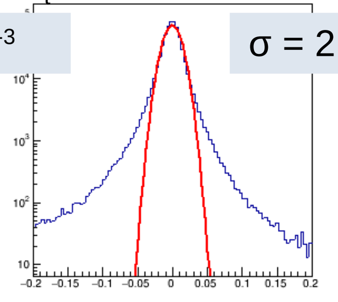
$\sigma = 3 \cdot 10^{-3}$

η resolution for p



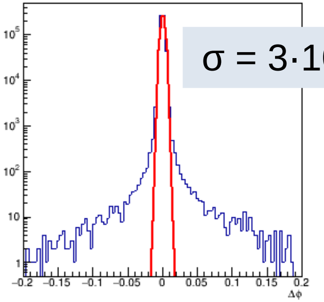
$\sigma = 5 \cdot 10^{-3}$

p_t resolution for p



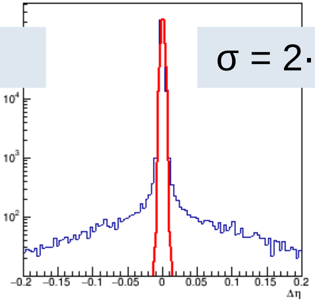
$\sigma = 2 \cdot 10^{-2}$ GeV

φ resolution for π



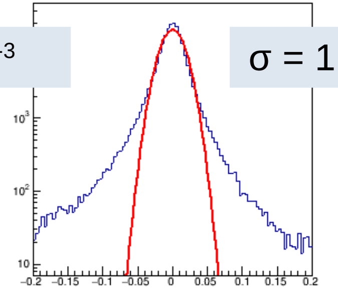
$\sigma = 3 \cdot 10^{-3}$

η resolution for π



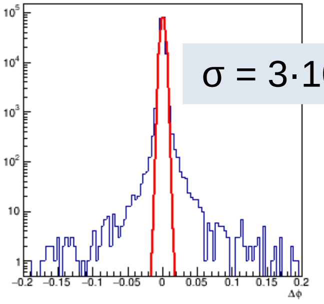
$\sigma = 2 \cdot 10^{-3}$

p_t resolution for π



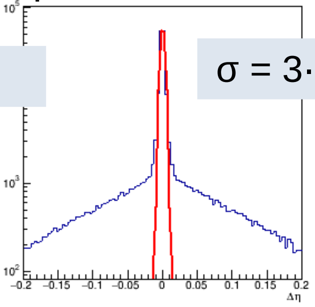
$\sigma = 1 \cdot 10^{-2}$ GeV

φ resolution for K



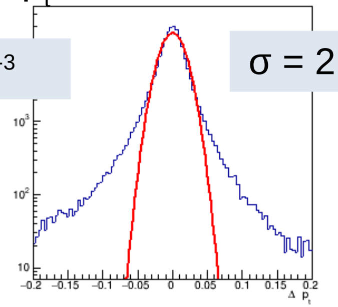
$\sigma = 3 \cdot 10^{-3}$

η resolution for K



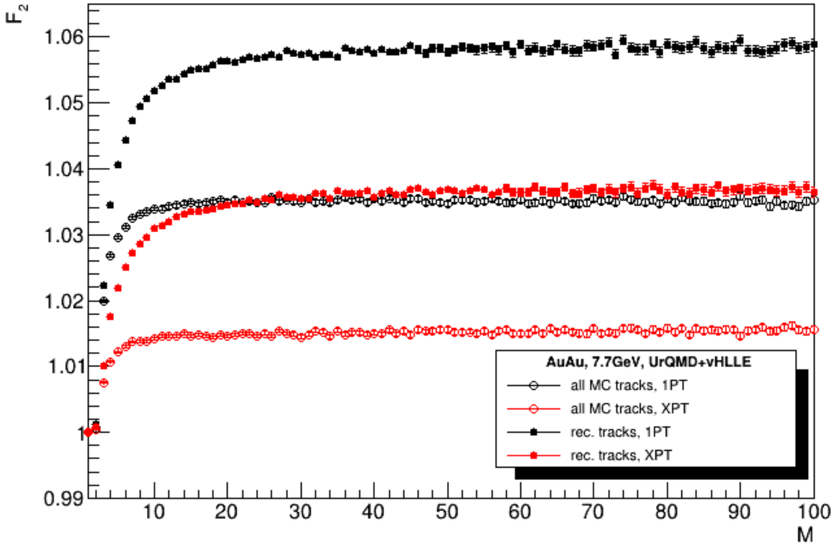
$\sigma = 3 \cdot 10^{-3}$

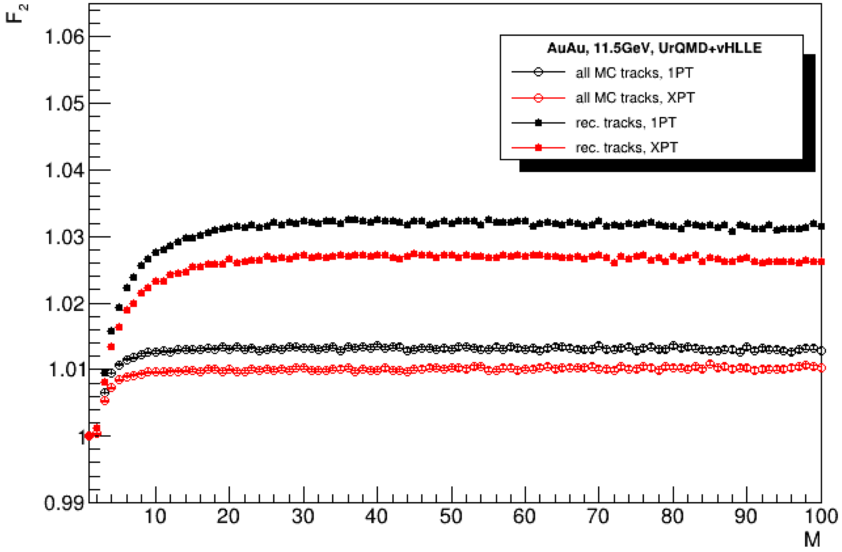
p_t resolution for K

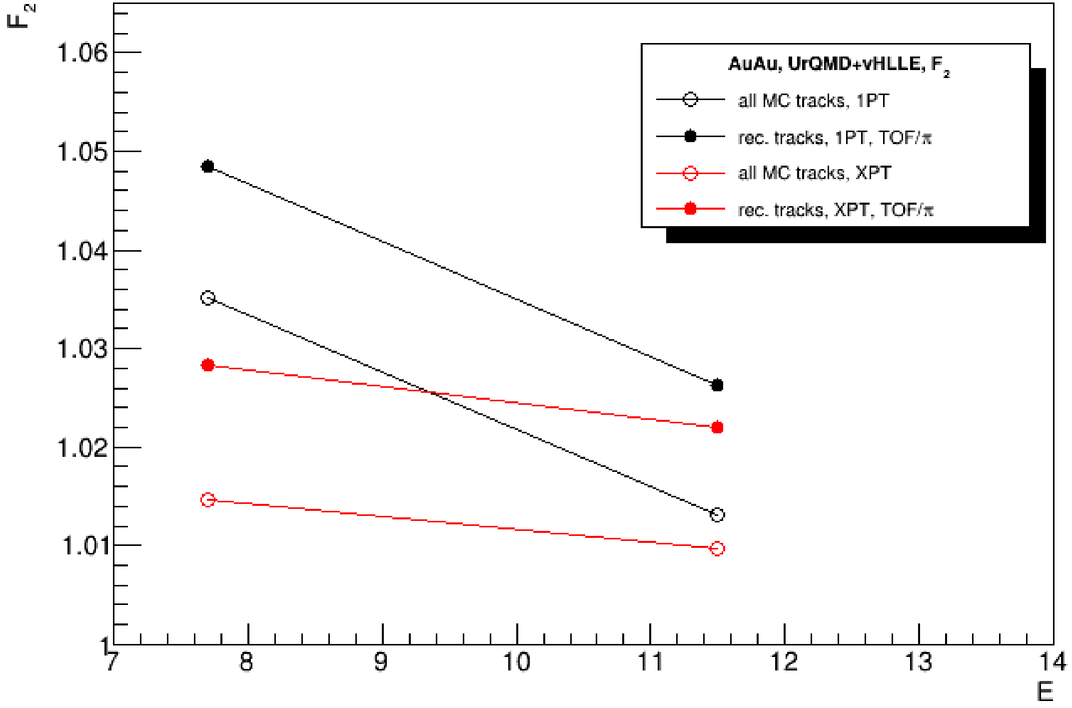


$\sigma = 2 \cdot 10^{-2}$ GeV

Factorial moments: generated vs reconstructed tracks

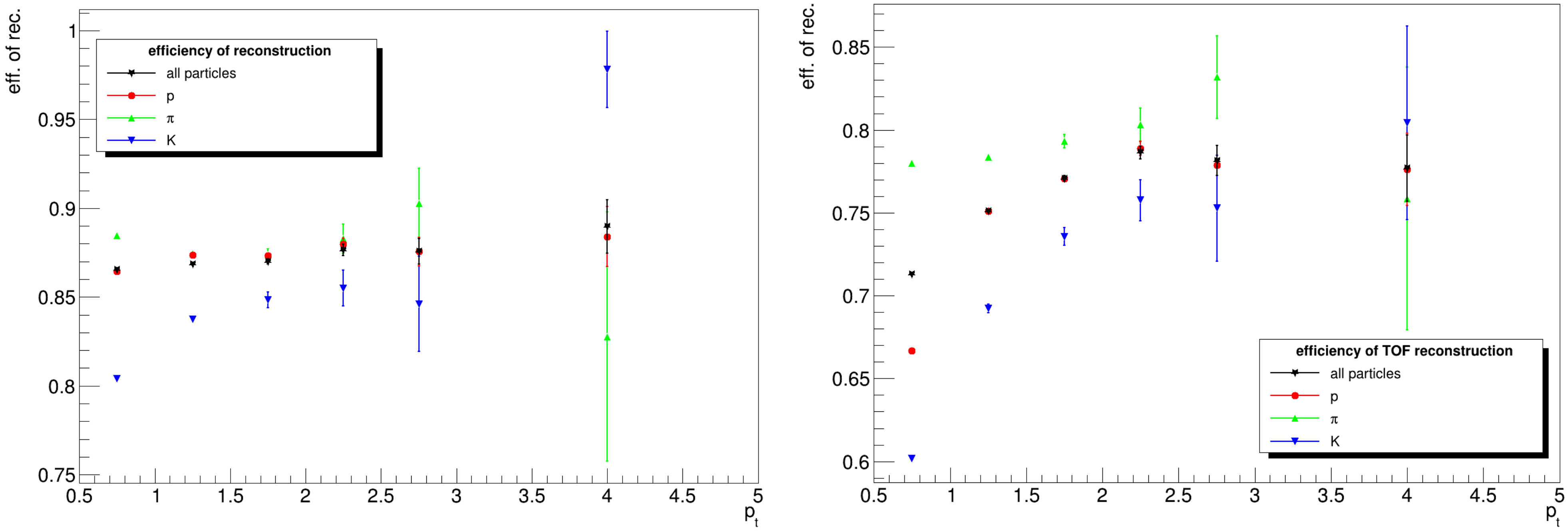






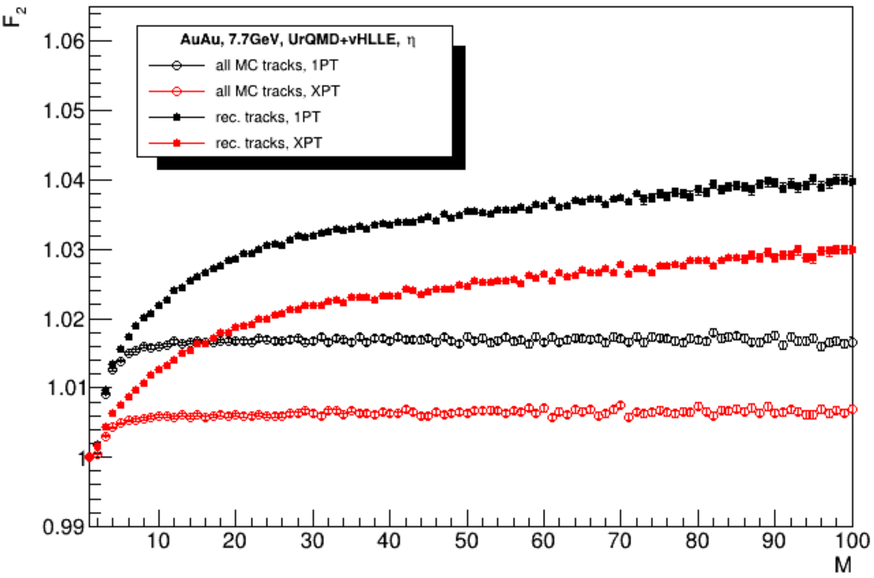
Factorial moments of multiplicity distribution in the ***rapidity*** interval [-1,1]

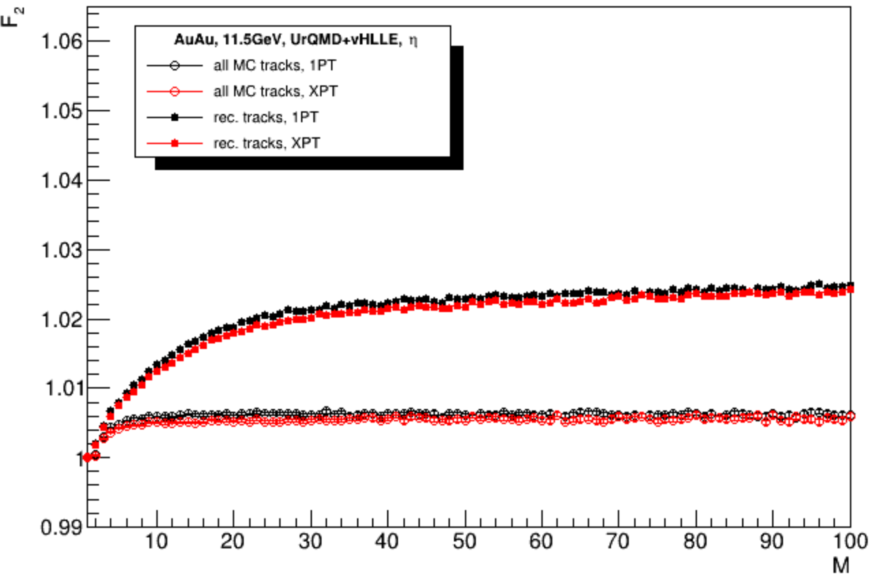
Reconstructed tracks: efficiency of reconstruction

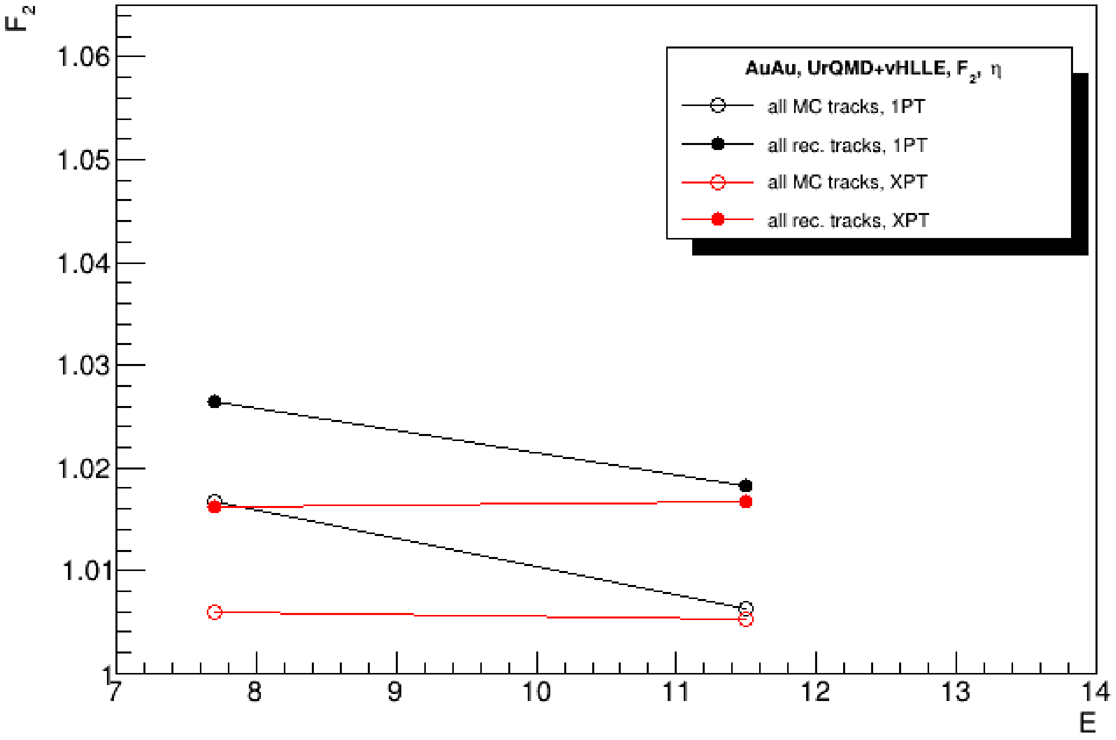


Since the height of the F_2 plateau when working with the rapidity interval depends on the accuracy of the mass reconstruction using TOF, it was decided use pseudorapidity notation instead.

Factorial moments: generated vs reconstructed tracks







Factorial moments of multiplicity distribution in the ***pseudorapidity*** interval [-1,1]

Unfolding

1) Main problems:
   - Tracking inefficiency
   - Tracking purity
   - Particles migration between bins due to η finite resolution
2) Unfold $<n(n-1)>(\eta)$ and $<n>(\eta)$ for each binning
3) Use package TUnfold for unfolding. Methods for regularization:
   - SVD
   - d'Agostini
4) Construct $F_2(M)$ for unfolded distributions

$$\frac{< n_i(n_i - 1) >}{< N(N-1) >}$$

Preparation for unfolding procedure

1) Match reconstructed and generated tracks

2) Prapare responce matrix $F(\eta_{gen}, \eta_{rec})$ for matched tracks – generated particles, *purity* = $N_{rec\ matched} / N_{rec}$, *efficiency* = $N_{gen\ matched} / N_{gen}$ for each binning.

3) Unfolding procedure for each binning

   - Multiply $n_{rec}(\eta_{rec})$ * *purity*

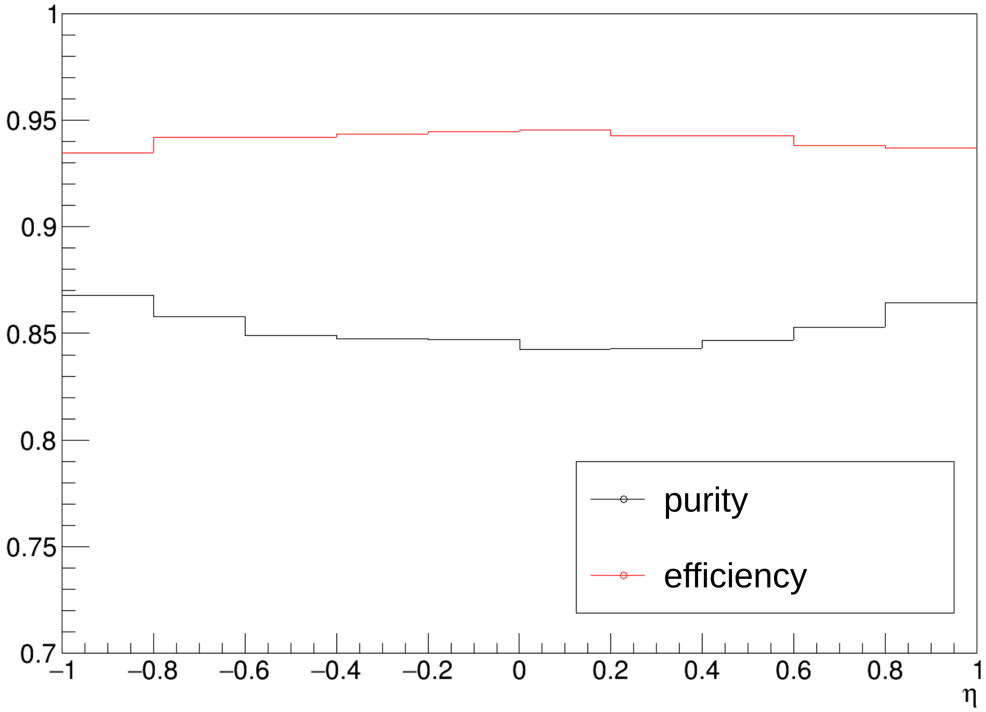
   - Unfold with responce matrix F to $n_{true\ matched}$

   - Divide $n_{true\ matched}$ on *efficiency*

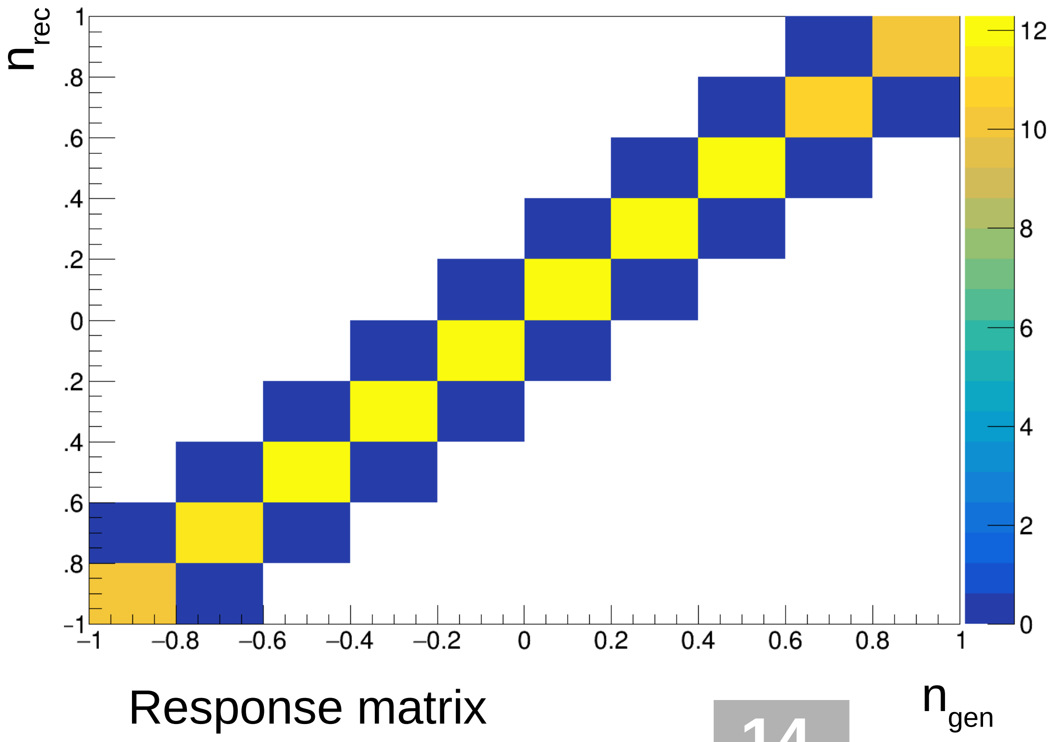
Preparation to unfolding

The pseudorapidity interval $|\eta|<1$ is divided into 10 bins.

Au-Au, XPT, 7.7GeV



Tracking efficiency and purity



Response matrix

Summary:

- It has been demonstrated that normalized factorial moments as a function of the size of the observation interval are sensitive to the type of phase transition.
  - We observe the different energy behaviour for the Crossover and 1st order phase transition in the frame of the URQMD+VHLLE model.
  - The energy behaviour is connected to the development of the phase transition and hydrodynamical phase itself. Cascade introduces the mild excess to the maximum of the normalized factorial moments.
- In the case of reconstructed tracks, the behavior of the distributions did not change. At the same time, the $F_2(M)$ values of the distribution reaching a plateau increased.
- Using the pseudorapidity interval to construct the factorial moments of the multiplicity distribution, it is possible to avoid the influence of the effects arising from particle identification. In this case, the behavior of the distributions did not qualitatively change in comparison with the case of rapidity.
- Work on the unfolding process has begun.