Prospects for the study of event-by-event fluctuations at MPD/NICA project

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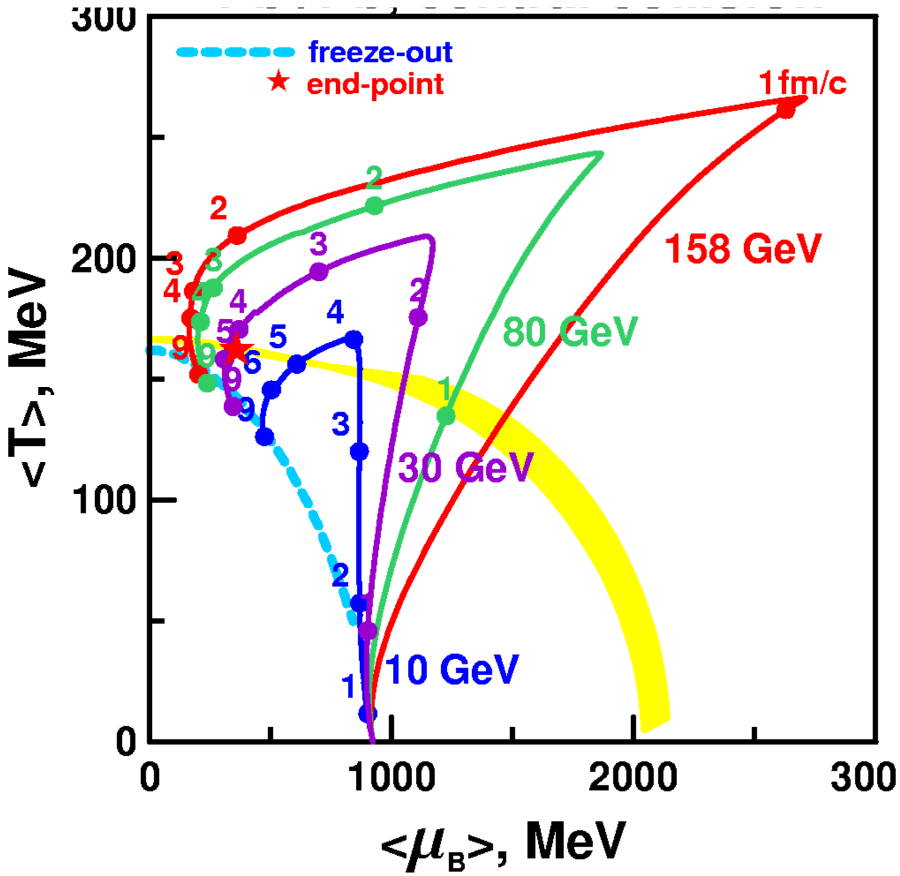
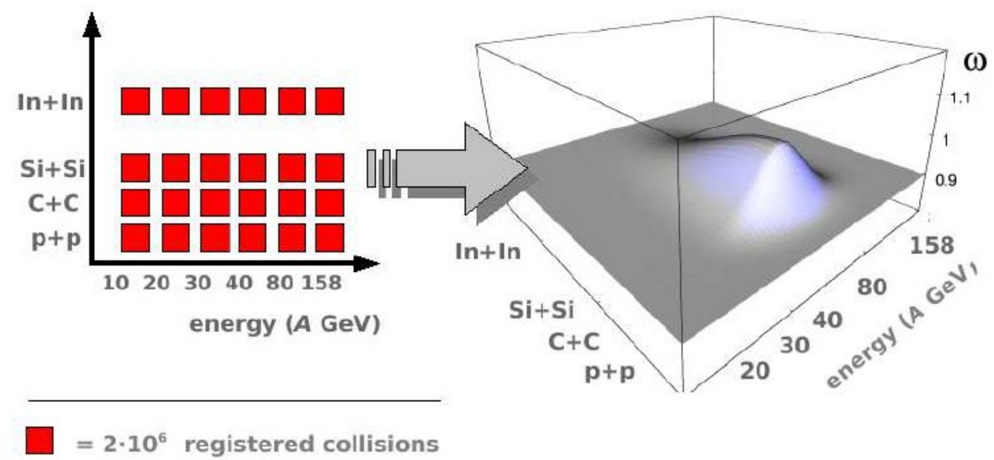
QCD phase diagram. Critical end point (CEP)

Trajectories calculated by a 3-fluid hydrodynamics model
Toneev & Ivanov



If the trajectory is in the vicinity of the critical endpoint – abnormal fluctuations can be observed



Observables - event-by-event fluctuations:

- multiplicity, charge number
- particle ratios
- mean pT, azimuthal angle
- baryon number

Experimental challenge: fluctuation signal may be suppressed due to final state interactions that washed out the signal. Real CEP signal should show consistency in several observables!

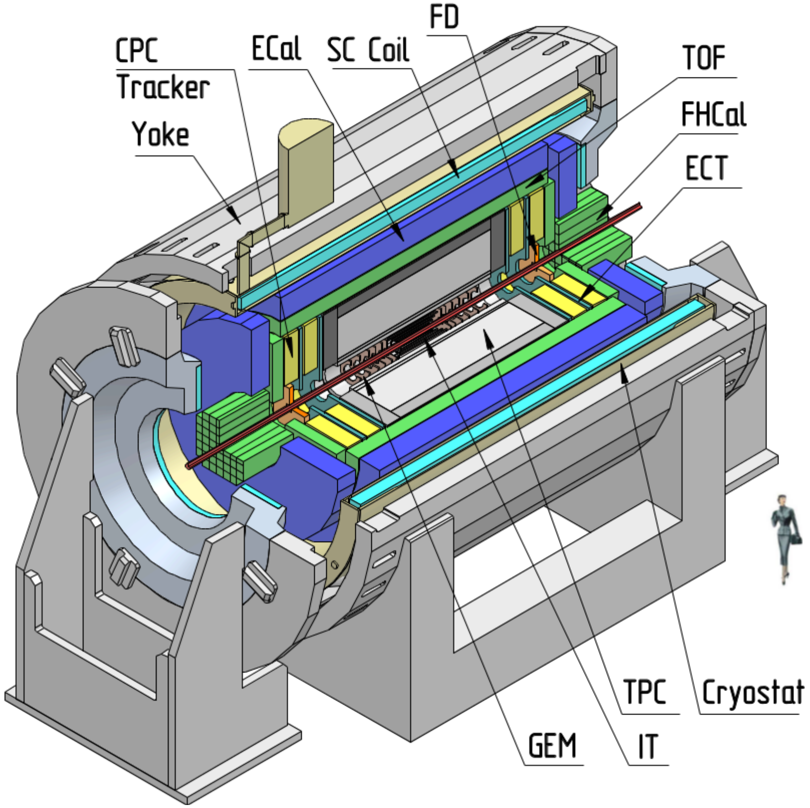
MPD detector: data set and selection criteria

Data set:

1) **UrQMD v3.4 generator**
2) **Au + Au**
3) **√s: 4, 7, 9 and 11 GeV**
4) **Impact parameter: 0..1 fm**

Track selection criteria:

1) **|η| < 1.6**
2) **nHits ≥ 20**
3) **TPC edge cut** *(removes tracks with significant difference between simulated and reconstructed momenta)*



PID is based on the latest version of the realistic tracking. It takes into account as many TPC response details as possible.

General idea of Particle Identification (PID)

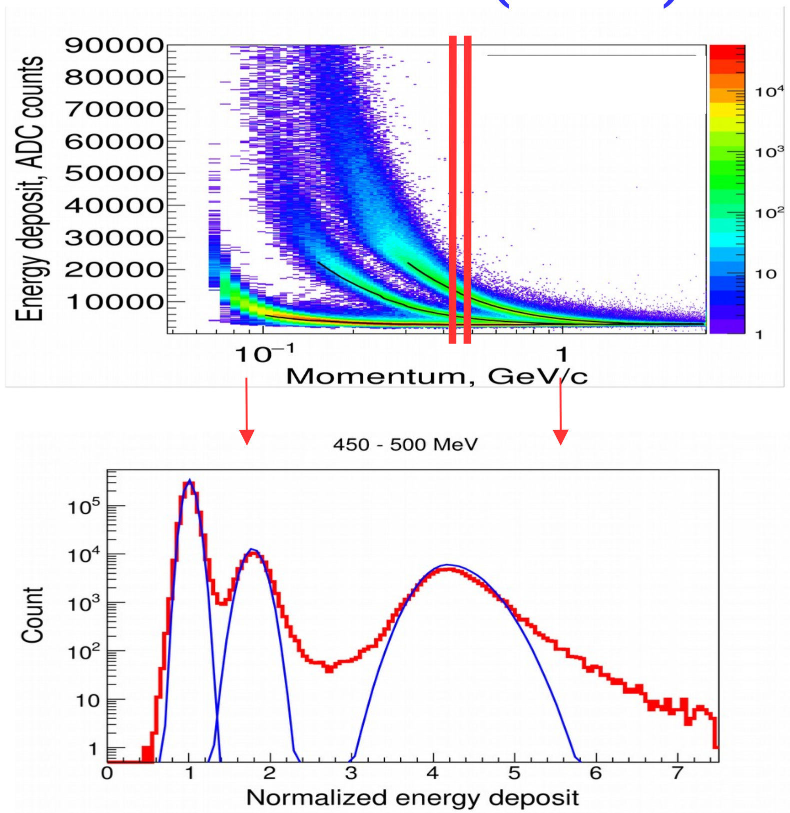
TPC partial probability

TOF partial probability

ECAL partial probability

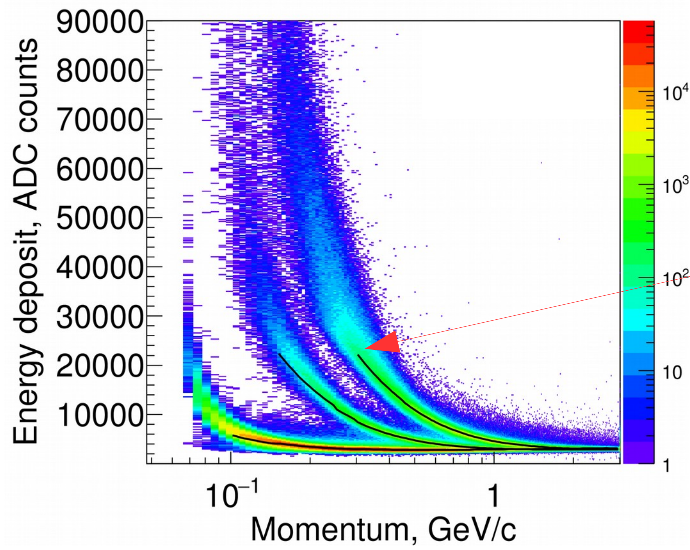
...

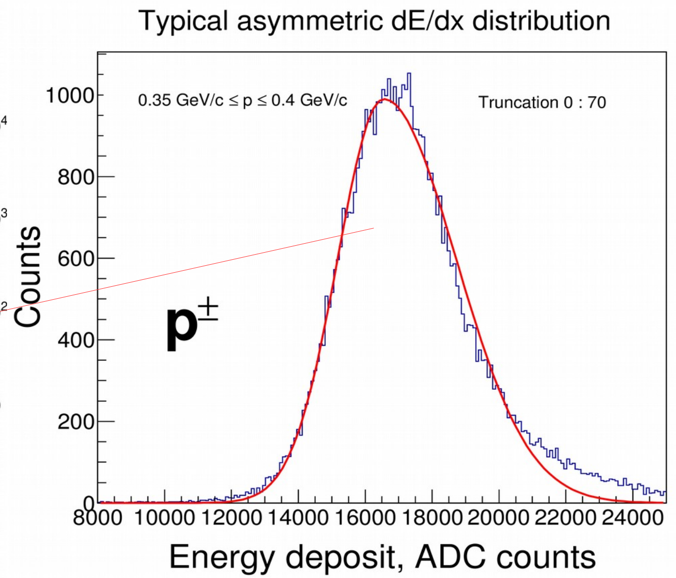
Combined probability

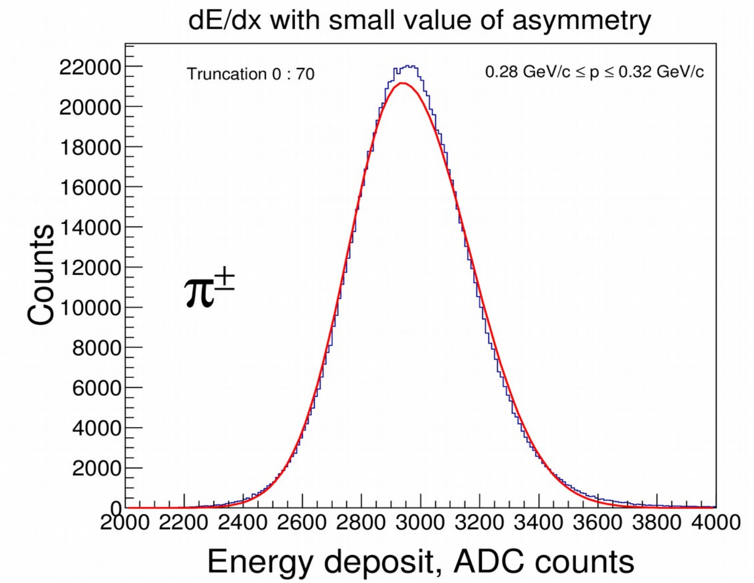


Parameterizations:
dE/dx (mean, sigma, delta and amplitude vs momentum)
m^2 (mean, sigma and amplitude vs momentum)

dE/dx parameterization







Bethe-Bloch function (5 parameters) to associate with the average dE/dx:

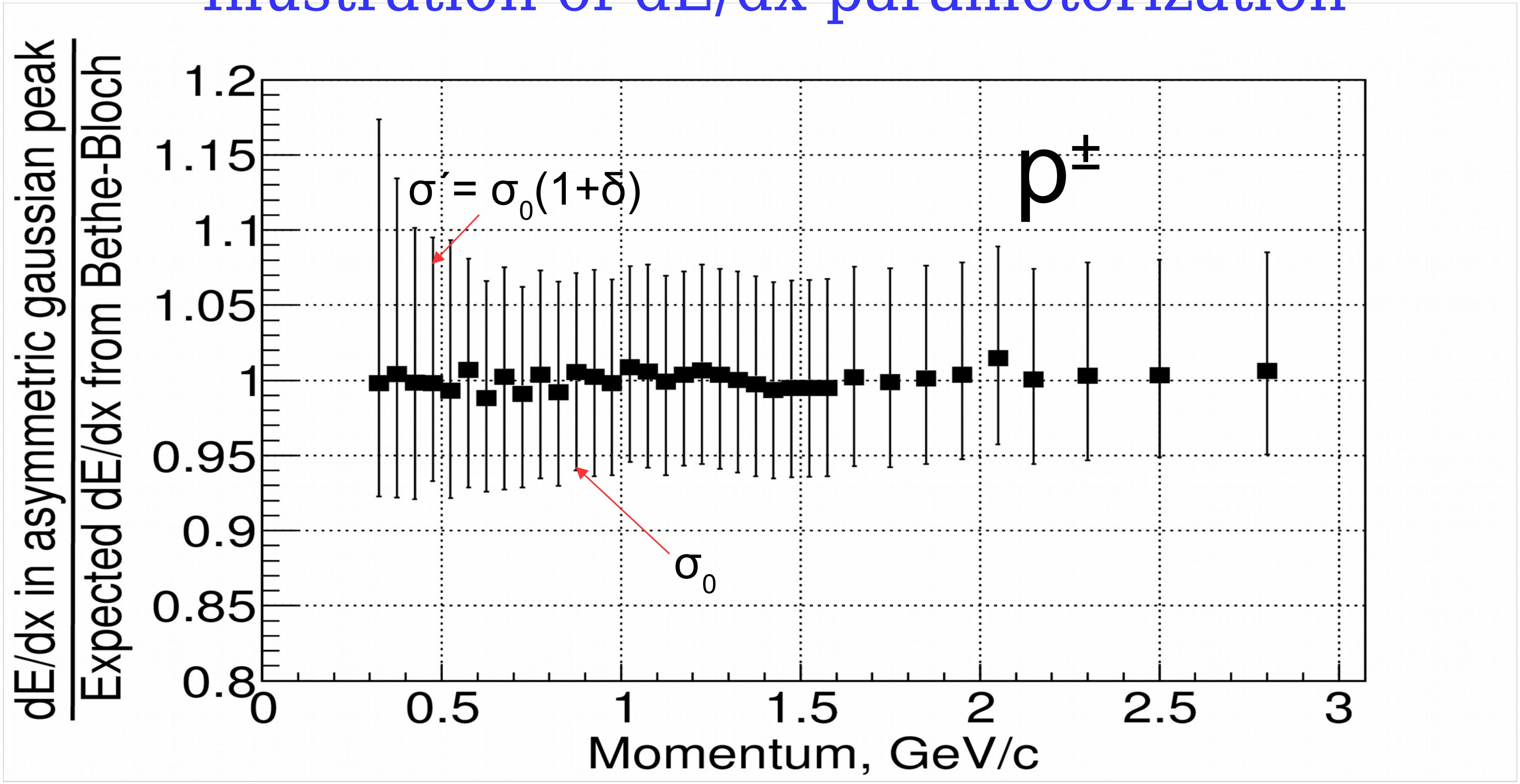
$$\frac{dE}{dx} = \frac{a_0}{\left(\frac{p}{E}\right)^{a_3}} \cdot \left(a_1 - \left(\frac{p}{E}\right)^{a_3}\right) - \ln\left(a_2 + \left(\frac{m}{p}\right)^{a_4}\right)$$

Asymmetric gaussian function:

$$f(x) = \begin{cases} A \cdot e^{\frac{-(x-\bar{x})^2}{2\sigma_0^2}} & x < \bar{x} \\ A \cdot e^{\frac{-(x-\bar{x})^2}{2(\sigma_0 \cdot (1+\delta))^2}} & x \geq \bar{x} \end{cases}$$

Sources of asymmetry:
1) Strong dE/dx dependence in low momenta
2) Truncation cannot remove asymmetry
3) Etc…

Illustration of dE/dx parameterization

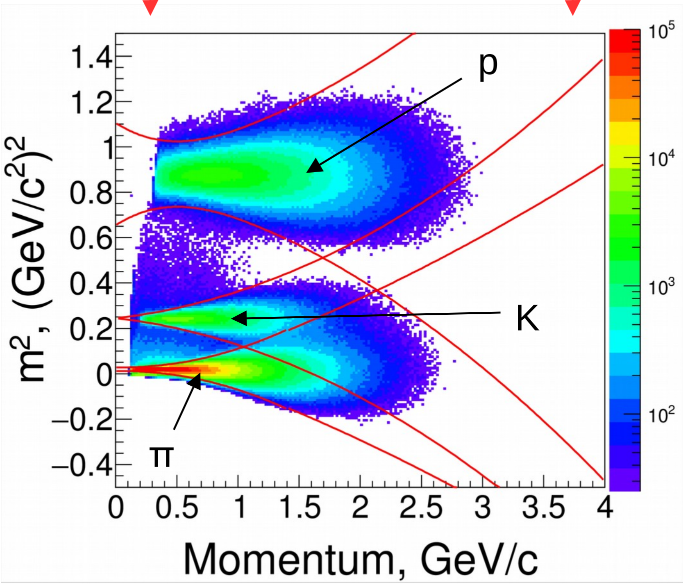


The ratio of dE/dx value in asymmetric gaussian peak over dE/dx value expected from Bethe-Bloch is used to estimate the PID parameterization quality. It has been performed for all types of particles included in MPD PID.

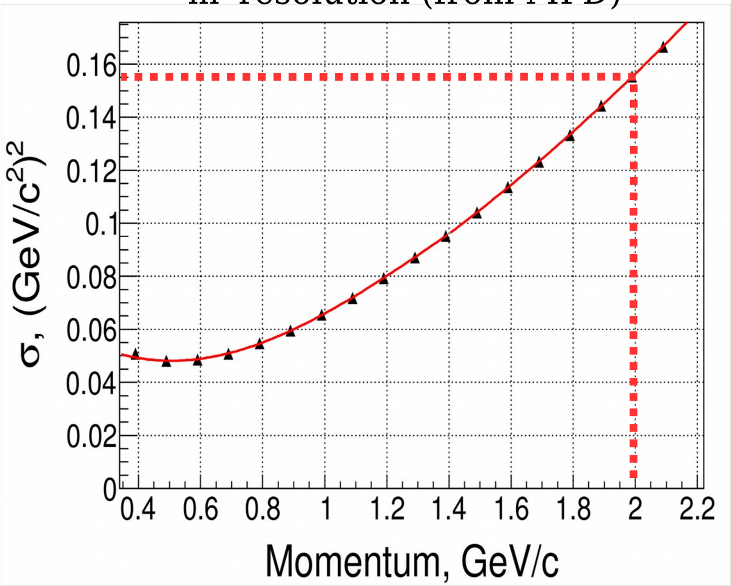
Typical value of σ_0 is 6%, σ' is 8%

m^2 parameterization

Red lines depict 3σ bands

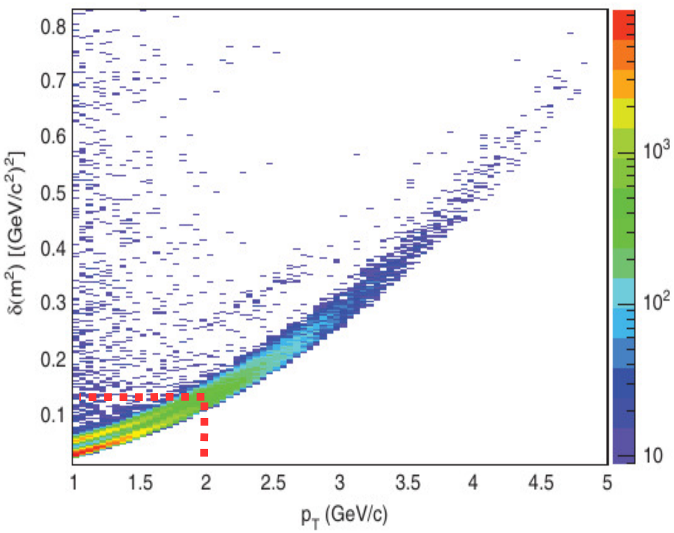


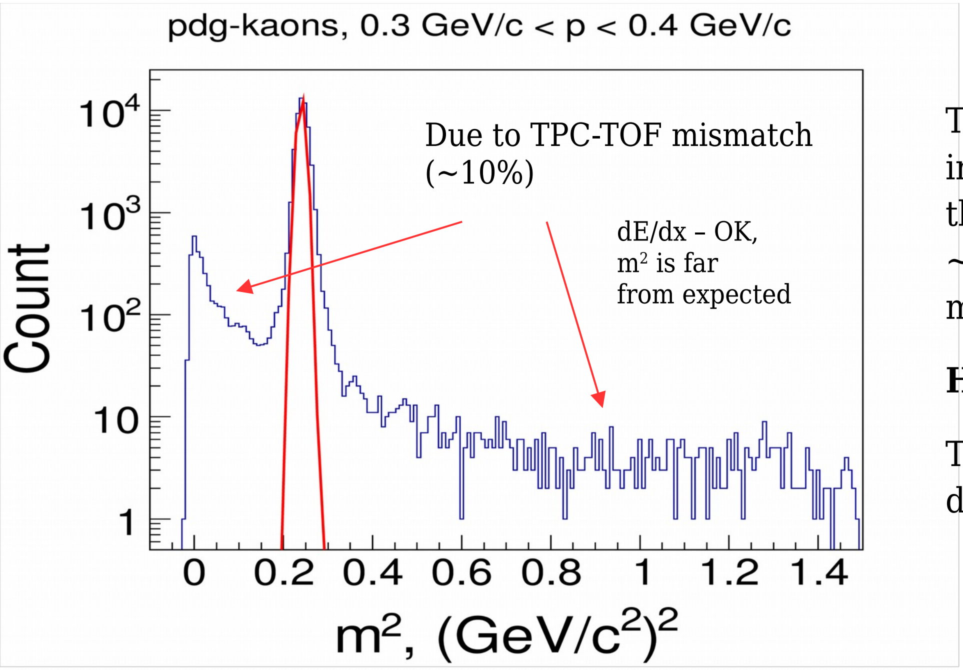
m² resolution (from MPD)



doi:10.1016/j.nima.2005.11.251

m² resolution (from STAR)





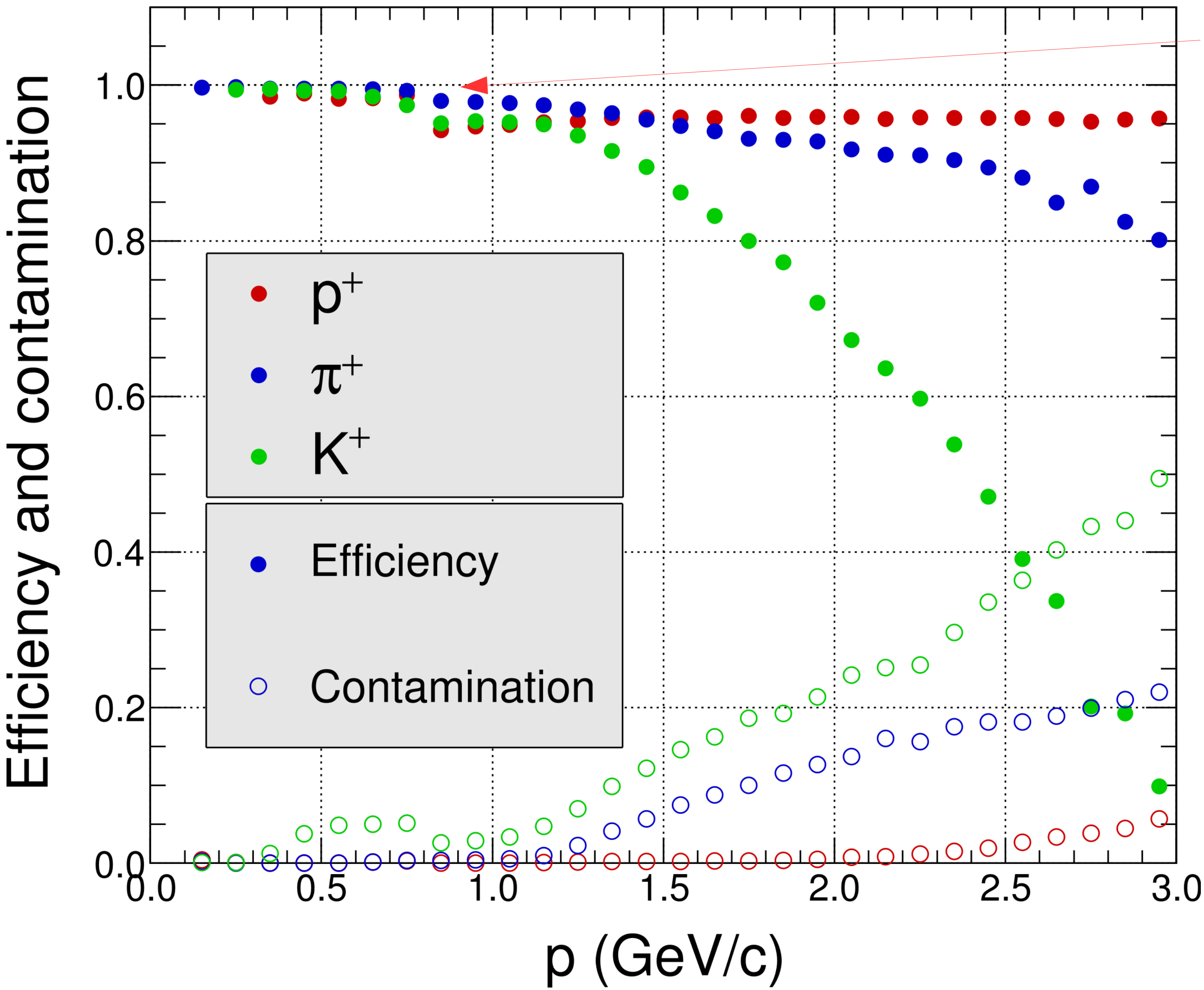
TPC-TOF mismatch:

TPC tracks and TOF hits can be mismatched. This effect is significant in low momenta. Typical example of TPC-TOF mismatch is shown on the left. PDG-kaon m^2 value has been incorrectly reconstructed for ~10% of tracks with $0.3 < p < 0.4$ GeV/c. The fraction of the mismatched tracks decreases to ~2% in high momenta region.

How to deal with mismatches?

The suggestion is to ignore the TOF information and identify them by dE/dx value,**but only for low momenta particles (p < 0.8 GeV/c).**

Combined PID efficiency and contamination, $0 < |\eta| < 1.6$

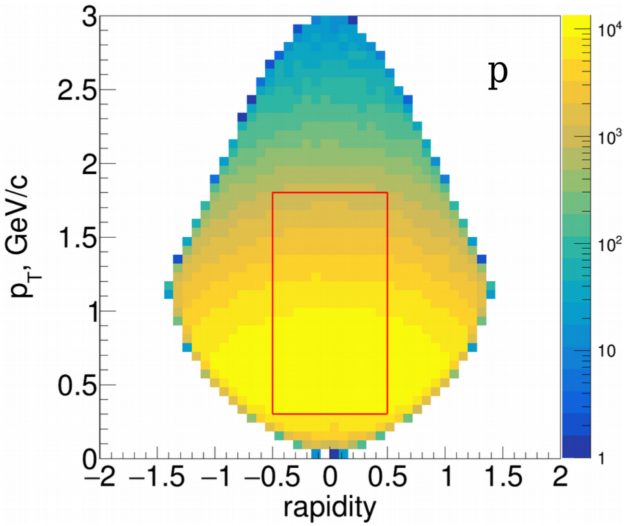


Step-like behavior of the efficiency and contamination arises as a result of redirection to the dE/dx identification

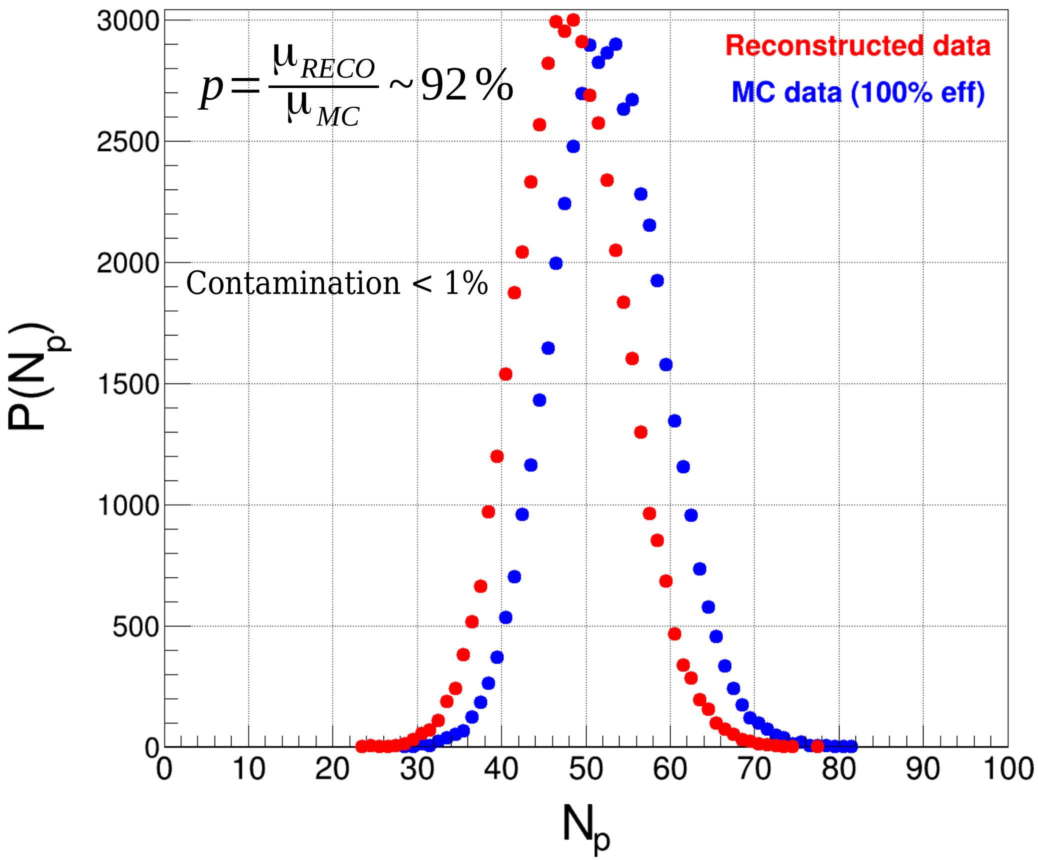
$$eff = \frac{correctly\ identified}{reconstructed}$$

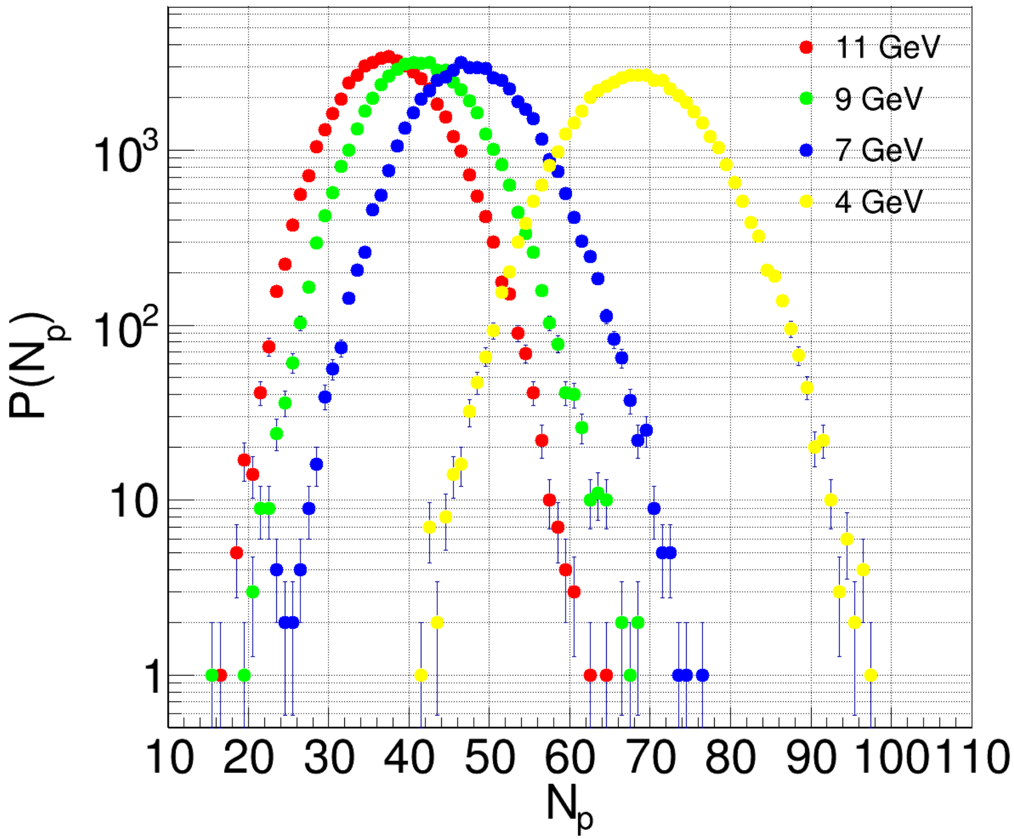
$$cont = \frac{incorrectly\ identified}{identified}$$

Conditions for cumulant measurements



- Cumulant measurements are carried out within $|y| < 0.5$ and $0.3 < p_T < 1.8$ GeV/c
- For event-by-event fluctuations study both dE/dx and dE/dx + TOF PID have been applied
- Only protons have been counted instead of “proton minus anti-proton” number (due to poor anti-p yield)
- Typical value of efficiency *p* in this region is 92% (protons are wasted due to tracking uncertainties, TPC-TOF mismatching, PID, cuts etc.)





Corrections to cumulants and moments (very preliminary)

Cumulants:

$k_1 = \langle N \rangle$

$k_2 = \langle (\delta N)^2 \rangle$

$k_3 = \langle (\delta N)^3 \rangle$

$k_4 = \langle (\delta N)^4 \rangle - 3 \langle (\delta N)^2 \rangle^2$

Moments:

$\mu = k_1 \qquad \sigma^2 = k_2$

$S = \frac{k_3}{k_2^{3/2}}$

$K = \frac{k_4}{k_2^2}$

if $\boldsymbol{K_i}$ is a cumulant associated with MC-distribution and $\boldsymbol{c_i}$ with the measured one with detecting efficiency *p*, the relation between them is following:

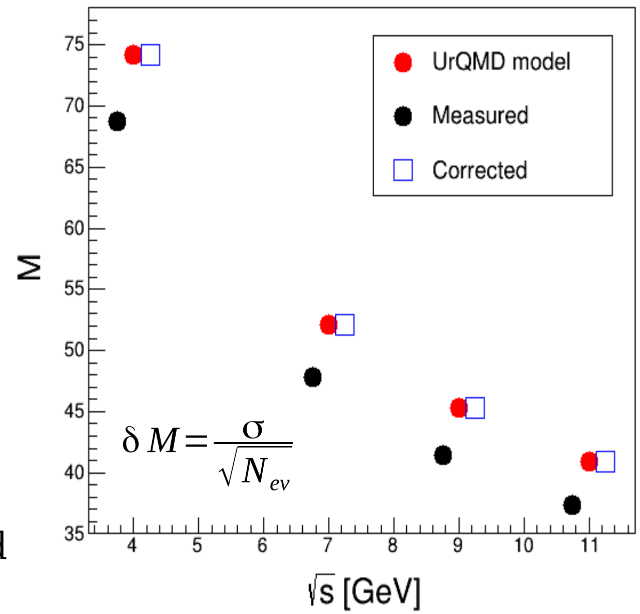
$pK_1 = c_1$

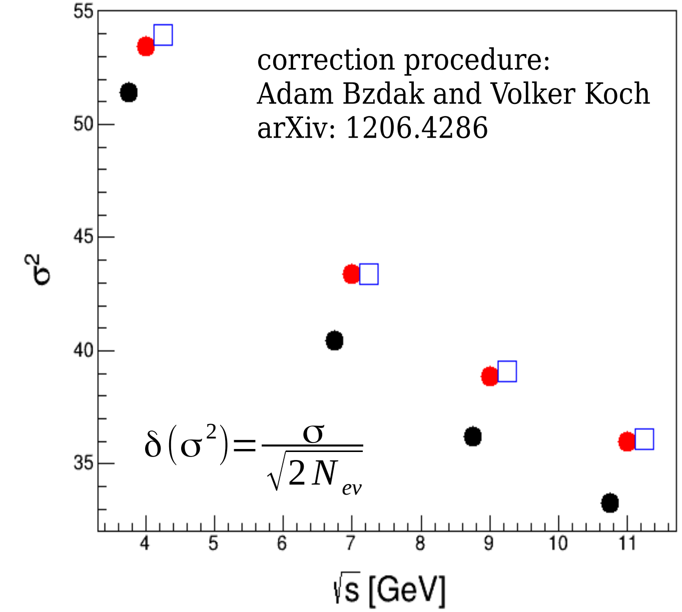
$p^2 K_2 = c_2 - c_1 (1-p)$

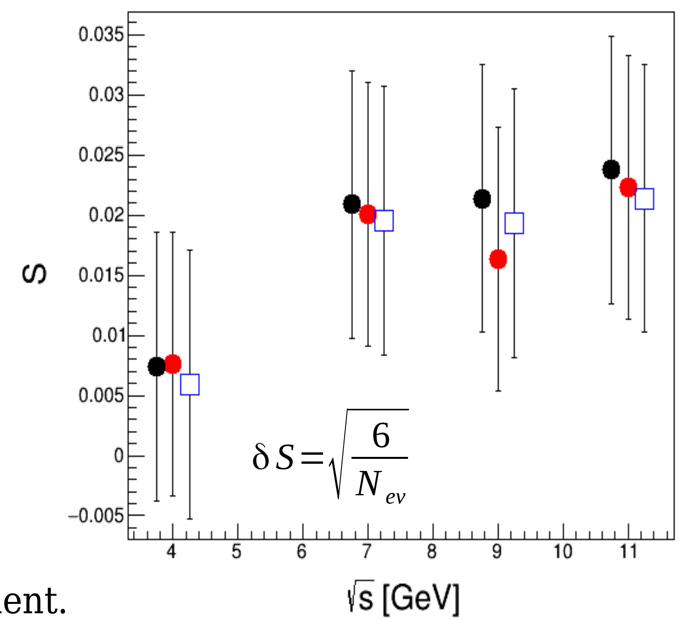
$p^3 K_3 = c_3 - c_1 (1-p^2) - 3(1-p)(f_2 - c_1^2)$

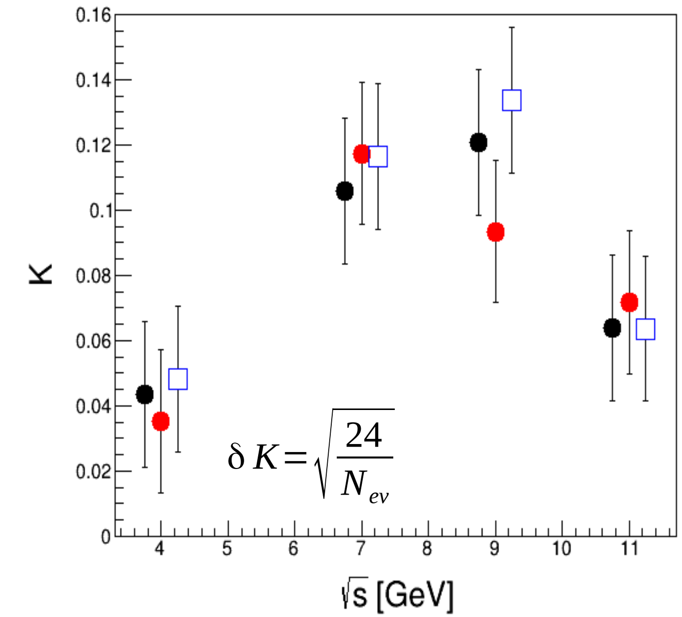
$$p^4 K_4 = c_4 - c_1 p^2 (1-p) - 3 c_1^2 (1-p)^2 - \\ - 6p(1-p) f_2 + 12 c_1 (1-p) f_2 - \\ - (1-p^2)(c_2 - 3c_1^2) - 6 c_1 (1-p)(c_1^2 - c_2) - \\ - 6(1-p)(f_2 + f_3)$$

where $f_i = \langle \frac{N_p!}{(N_p - i)!} \rangle$ – factorial moment.

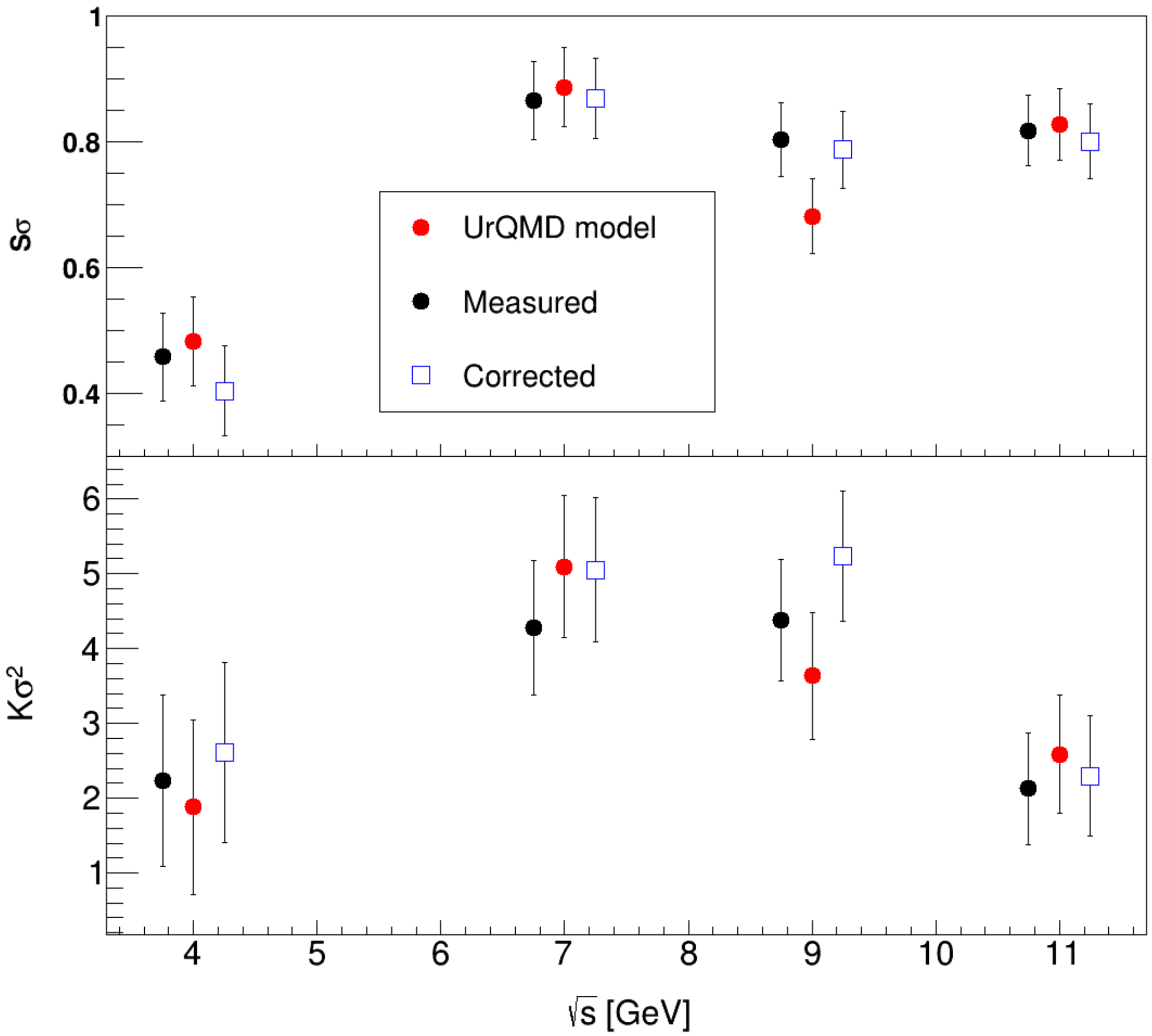








Corrections to cumulants and moments (very preliminary)



$$\frac{k_3}{k_2} = S\sigma \qquad \frac{k_4}{k_2} = K\sigma^2$$

σ^2, S (skewness) and K (kurtosis) have been calculated for proton distributions in Au + Au collisions (UrQMD generator, impact parameter 0..1 fm, ~50K events). Such combinations of moments (see Figure) are directly related with the thermodynamic susceptibilities in lattice QCD.

It is observed that this correction procedure does not work well. It can stem from our assumption that detection efficiency p is a single number. However, this does not imply that in each event i the number of observed particles is

$$n_i = pN$$

So, in order to improve correction results, local detection efficiency $p(y, p_T)$ has to be used instead of the global one.

Summary

- Particle identification (PID) based on Cluster Finder tracking has been developed and implemented within the MpdRoot software package. Effective π/K separation is working up to 1.5 GeV, π/p separation is working up to 3 GeV.
- Cumulants of proton distribution are calculated within $|y| < 0.5$ and $0.3 < p_T < 1.8$ GeV/c. Correction procedure has been applied to them, however, it can be improved.