Recent developments of event-by-event fluctuations study at MPD

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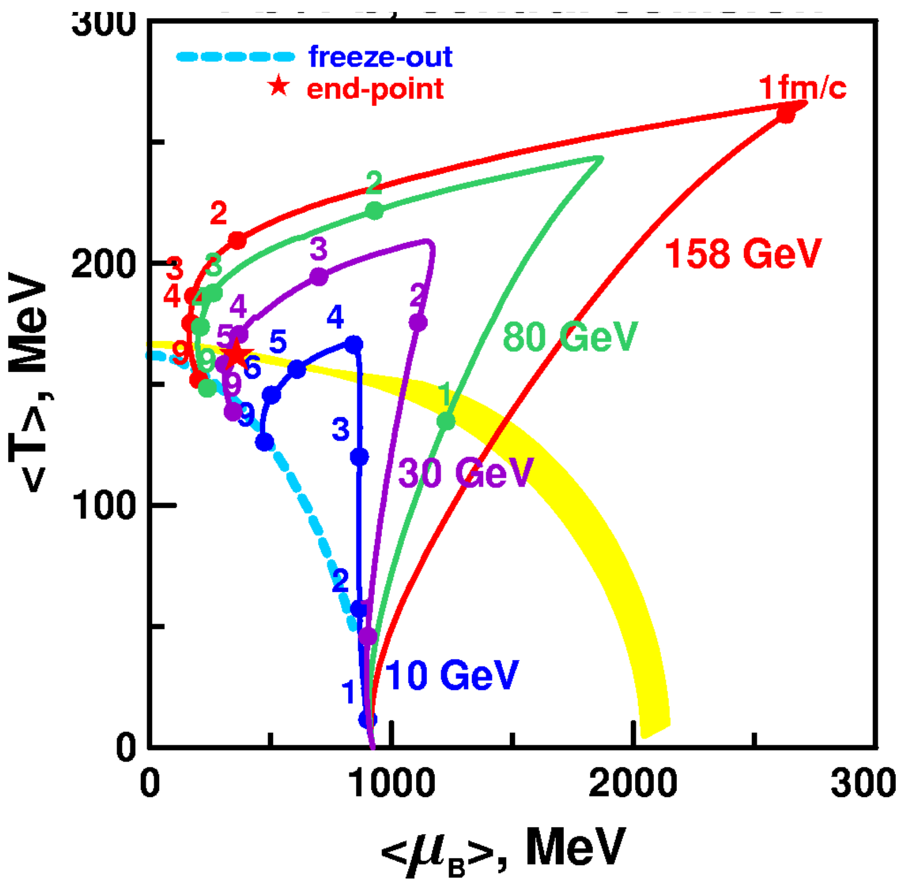
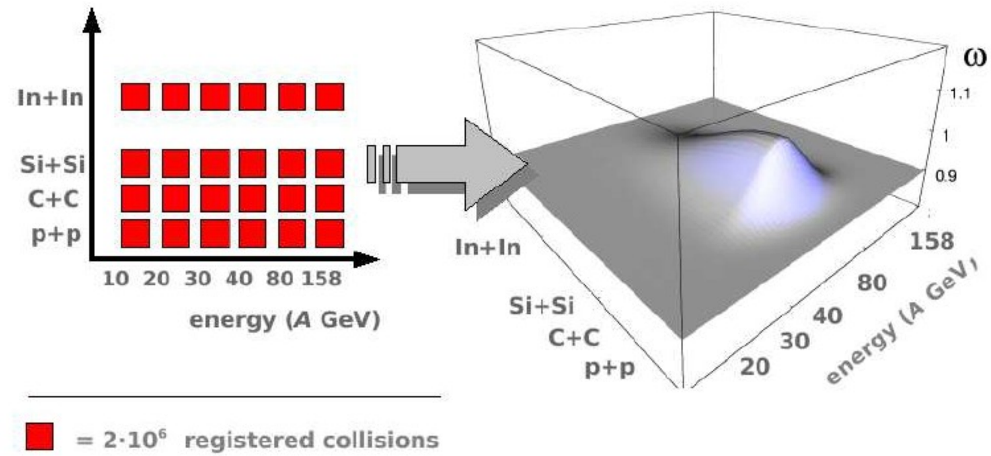
on behalf of the MPD team

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!

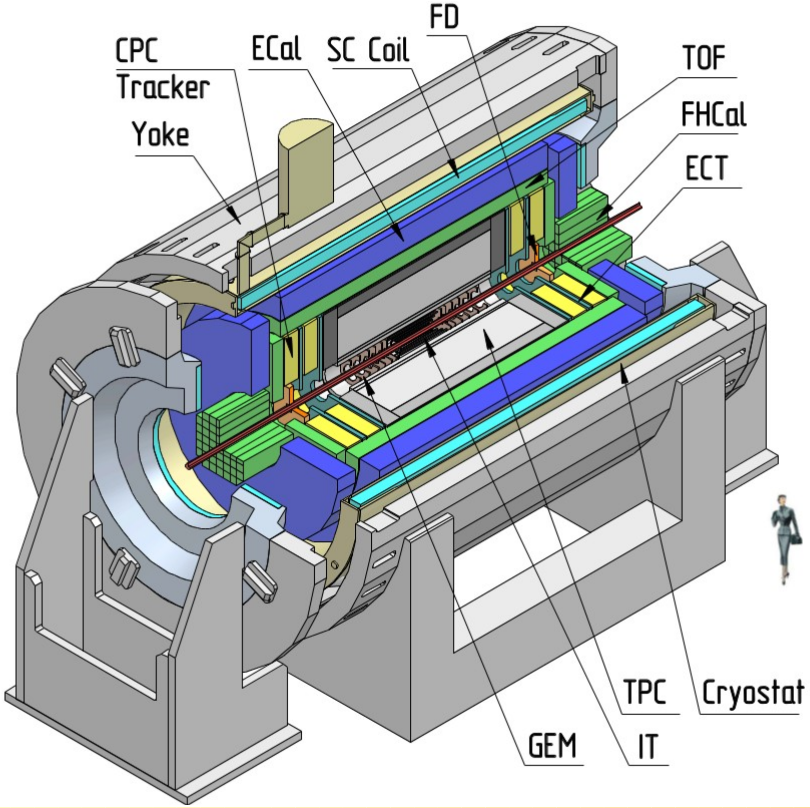
MPD detector: data set and selection criteria

Data set:

1) **UrQMD v3.4 generator**
2) **Au + Au**
3) **√s: 4, 7, 9 and 11 GeV (50k events)**
4) **Impact parameter: 0..1 fm**

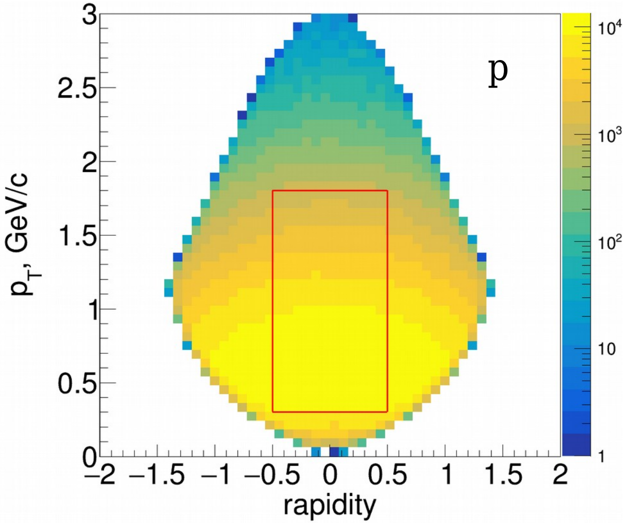
Track selection criteria:

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

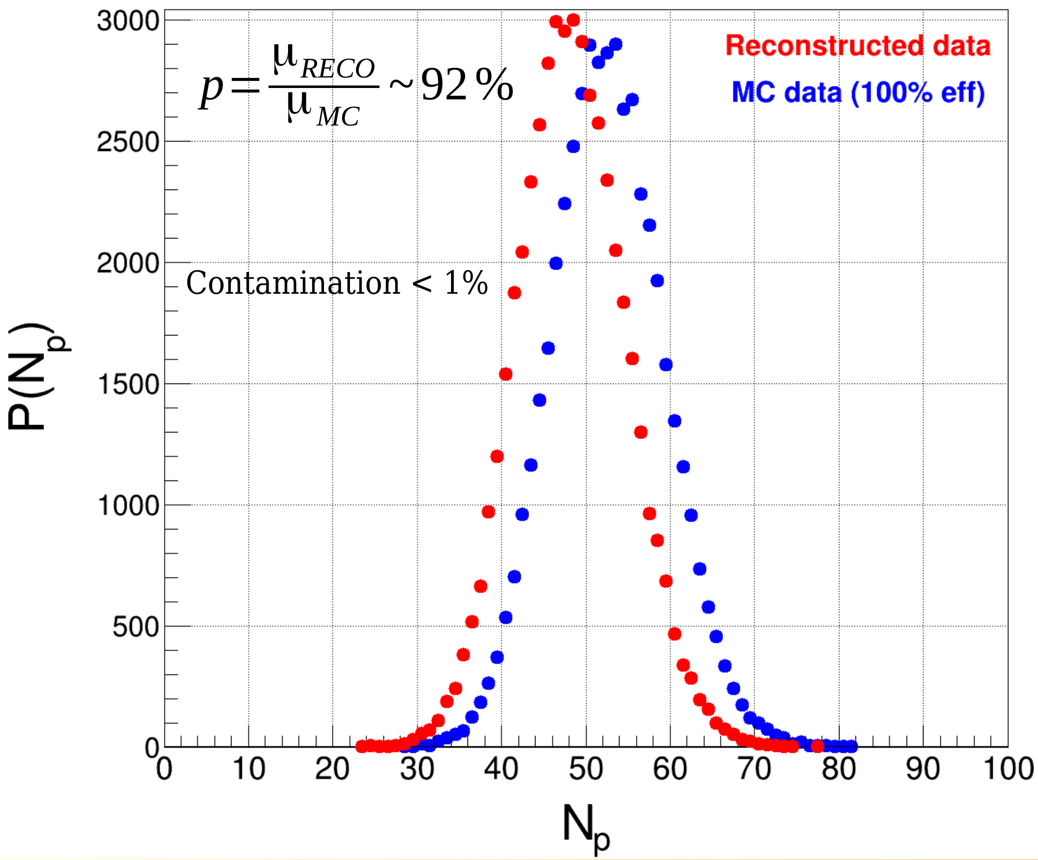


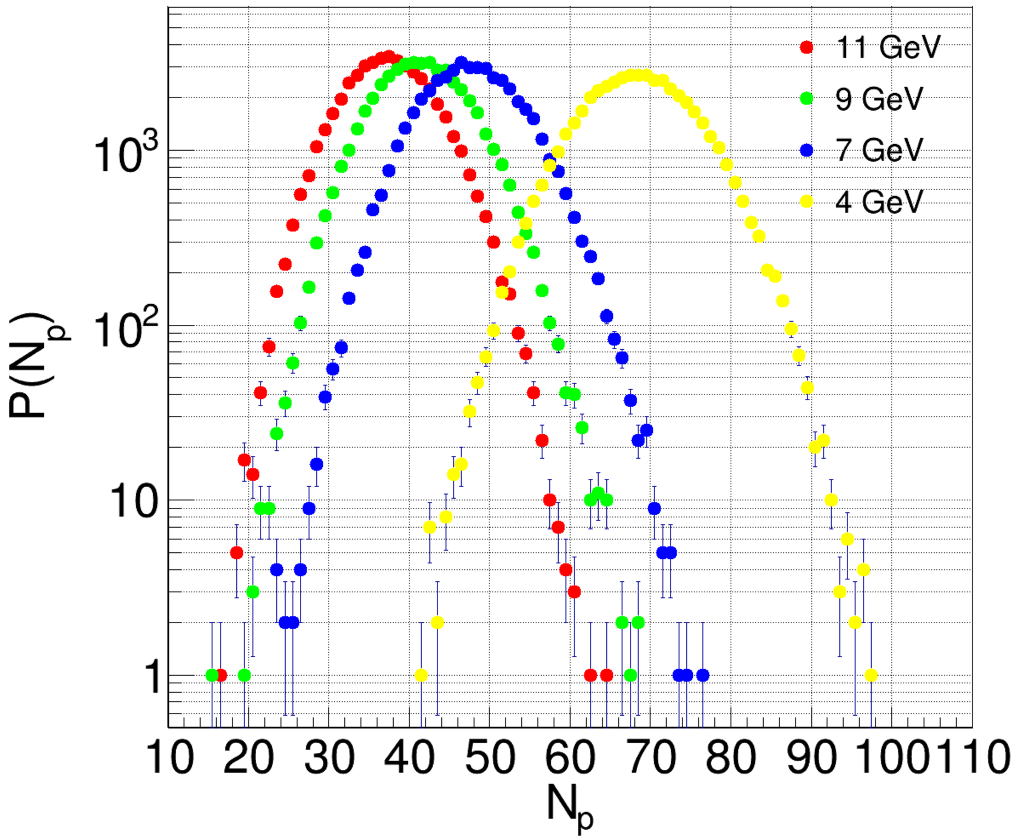
PID is based on the latest version of the realistic tracking.
It takes into account as many TPC response details as possible.

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 modes 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:

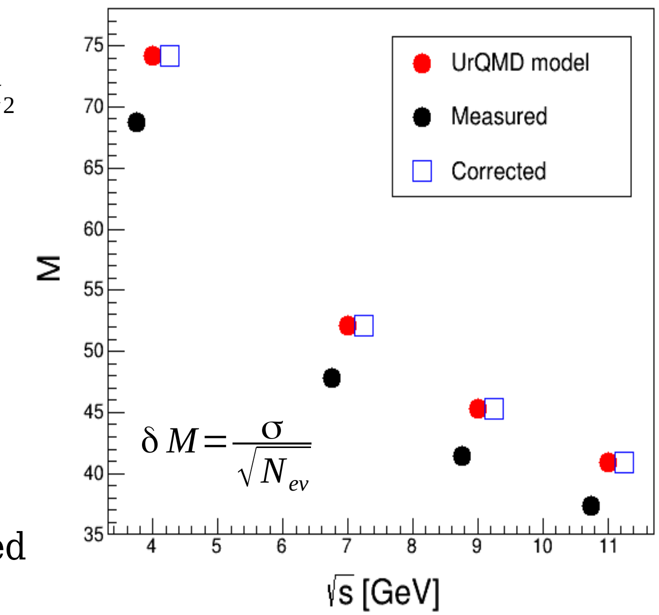
$$pK_1 = c_1$$

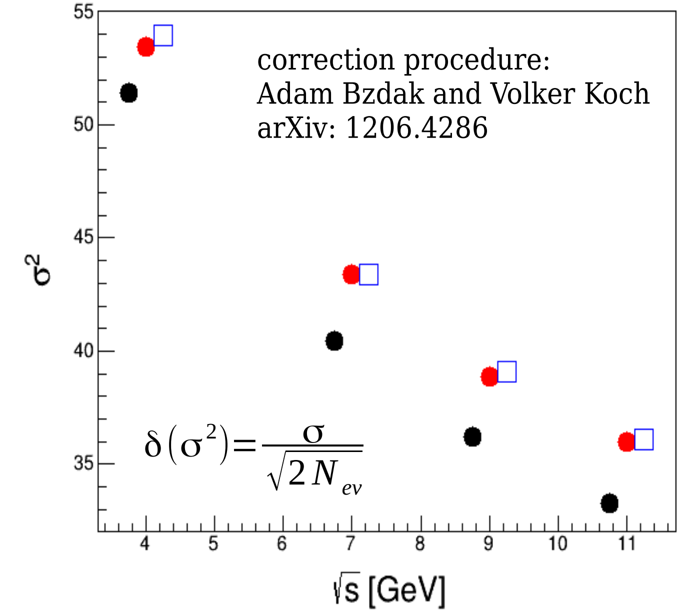
$$p^2 K_2 = c_2 - c_1(1-p)$$

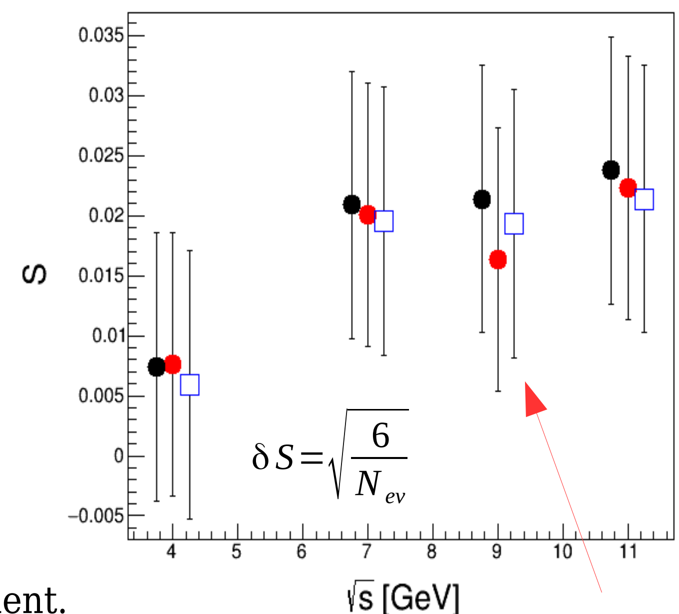
$$p^3 K_3 = c_3 - c_1(1-p^2) - 3(1-p)(f_2 - c_1^2)$$

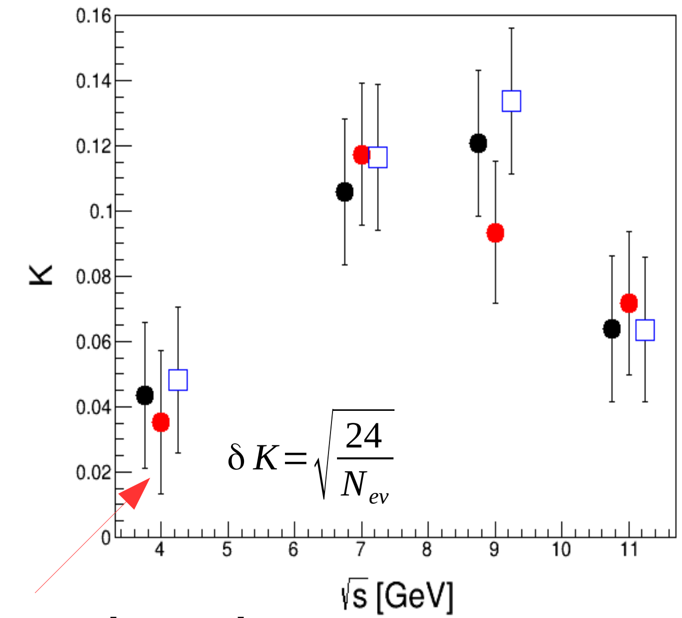
$$p^4 K_4 = c_4 - c_1 p^2 (1-p) - 3 c_1^2 (1-p)^2 - \\ - 6p(1-p) f_2 + 12 c_1 (1-p) f_2 - \\ - (1-p^2)(c_2 - 3c_1^2) - 6 c_1 (1-p)(c_1^2 - c_2) - \\ - 6(1-p)(f_2 + f_3)$$

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



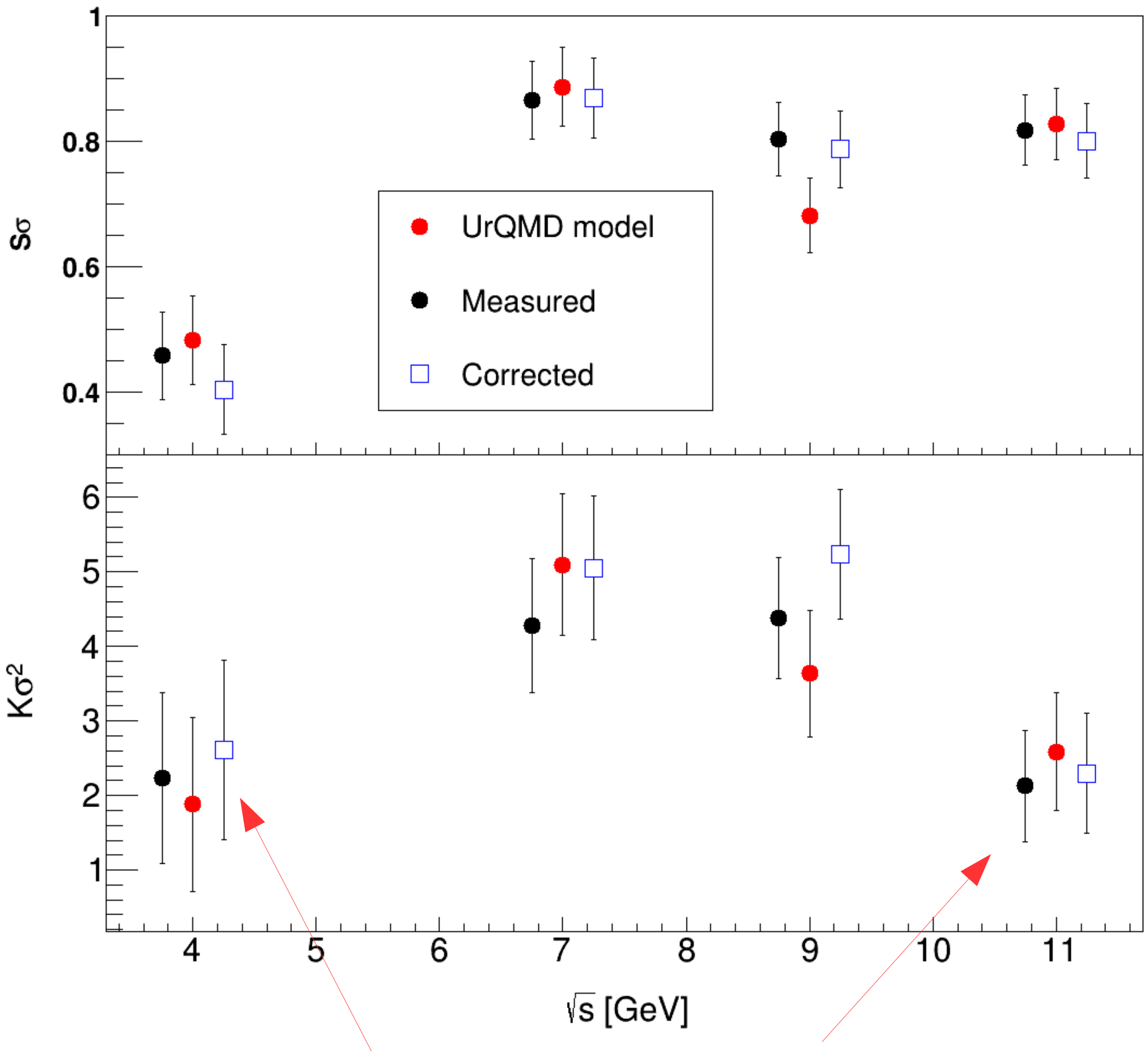






Statistical error bars only

Corrections to cumulants and moments (very preliminary)



Since statistical errors are large, the additional simulation has to be carried out to increase the number of events

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

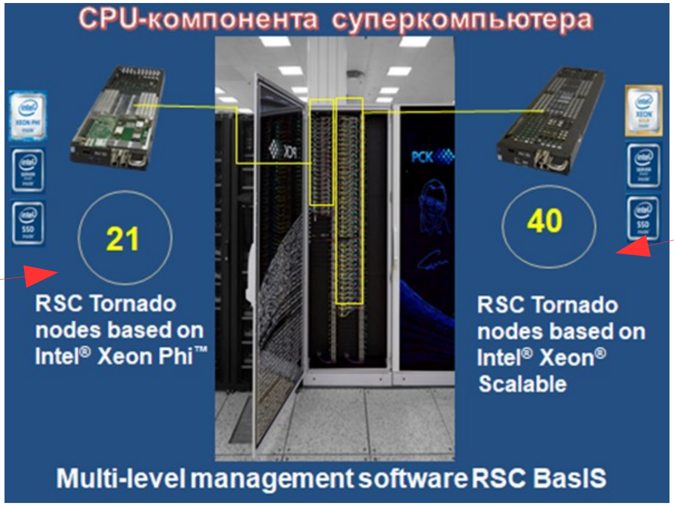
σ^2, S (skewness) and K (kurtosis) have been calculated for proton distributions in Au + Au collisions (UrQMD generator, impact parameter 0..1 fm, ~50K events). Such combinations of moments (see Figure) are directly related with the thermodynamic susceptibilities in lattice QCD.

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.

Hybrilit and NICA clusters



“knl” queue

(is using now)

“skylake” queue

(more productive)

Data set:

√s = 4 GeV, 0 < b < 1 fm

To calculate average time, 100 events per each node have been reconstructed.

The time spent on the reconstruction at Hybrilit is 3 times less than at NC if one uses 1000 parallel tasks.

	Hybrilit	NICA Cluster
Maximum number of parallel tasks	6048	60
Average reconstruction time per 1 event	460 s	75 s

Hybrilit: 1M events can be reconstructed in 1 – 3.5 week

Hybrilit cluster: parallel tasks at GOVORUN

1) ssh USERNAME@hydra.jinr.ru
2) use hybrilit modules:
    a) module load FairSoft/oct17p1
    b) module load FairRoot/oct17p1
    c) module add GVR/v1.0-1
3) use SLURM task manager

example of config-slurm.sh :

```
#!/bin/bash

export Linux_Flavour_="Scientific Linux release 7.5
(Nitrogen)"

export System_="x86_64"

#. /path/to/mpdroot/build/check_system.sh

#if [ $same_system -eq 1 ]; then

< bla – bla – bla >

#fi
```

example of batch script (SLURM) :

```
#!/bin/sh
#SBATCH -p knl
#SBATCH --array=1-1000
#SBATCH -t 10-05
#SBATCH -J dst-b

echo "  Start date: `date` (`hostname`)"

# Type correct paths
export MACRO_DIR=/path/to/macro/directory
export BUILD_DIR=/path/to/build/directory
export OUT=/path/to/output/directory

. ${BUILD_DIR}/config-slurm.sh

root -b -q '${MACRO_DIR}/reco.C("INPUTFILE", "OUTPUTFILE",
                                        nStartEvent, nEvents)'

echo "  End date: `date`"
```

Summary

- 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.

  The additional simulation is doing at both NICA and Hybrilit clusters. Hybrilit allows submitting at least 1000 parallel tasks. It makes simulations at least 3 times faster.