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Influence of conservation laws on higher moments of the net proton and net charge distribution

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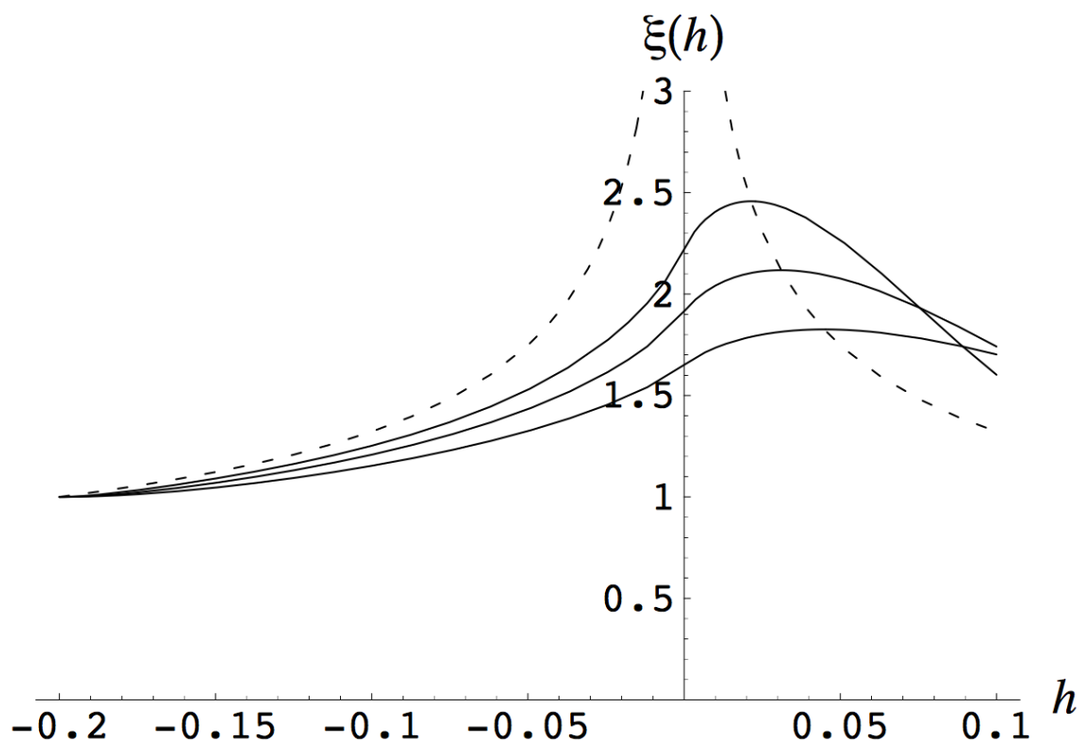
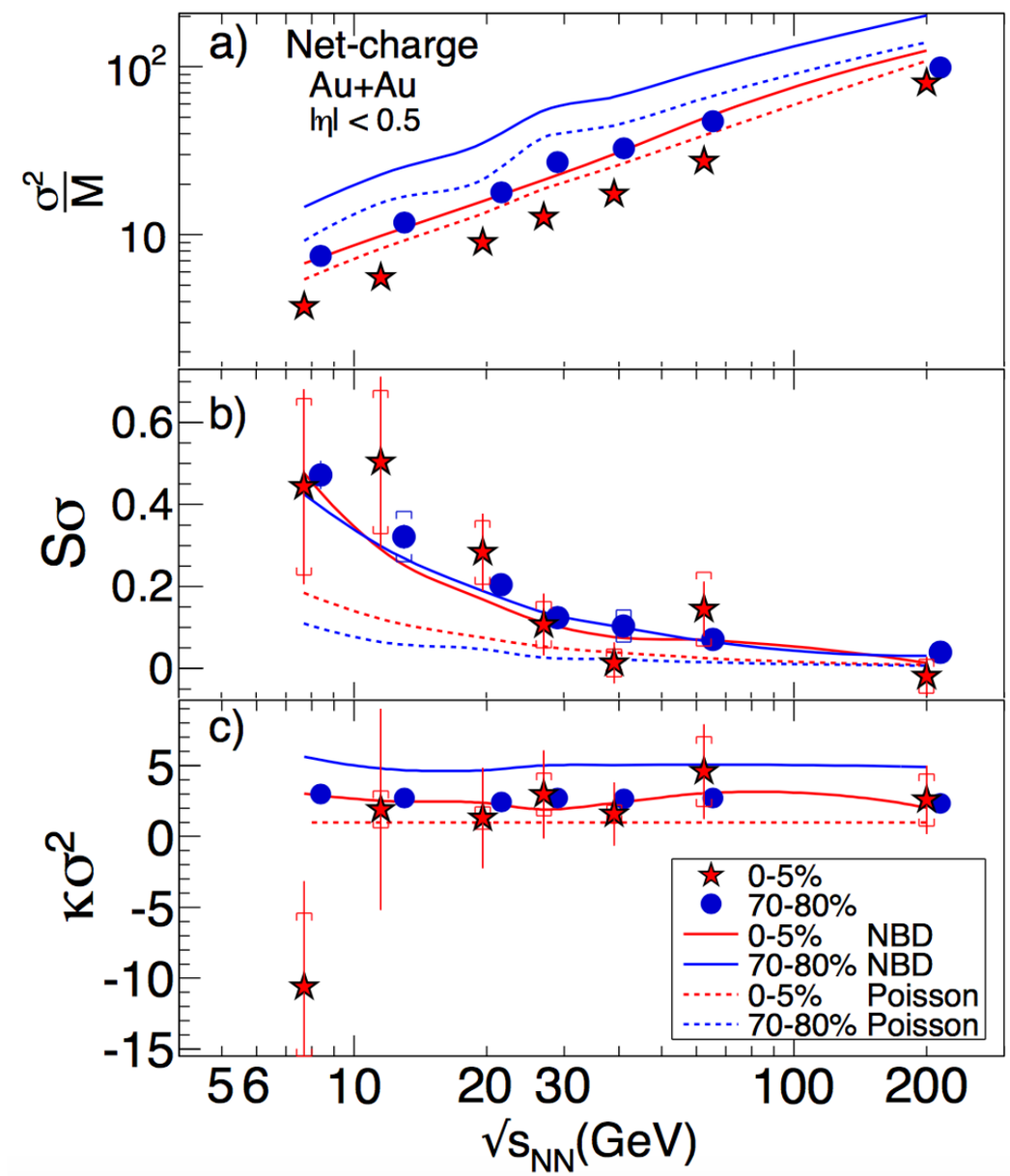
Why higher moments?

- Energy dependence of higher moments as a promising signal of the QCD critical endpoint



B. Berdnikov, K. Rajagopal, Phys.Rev. D61 (2000) 105017,
V. Skokov, B. Friman, C. Redlich, Phys.Rev. C88 (2013) 034911
M. Nahrgang et al, Phys.Rev. C84 (2011) 024912

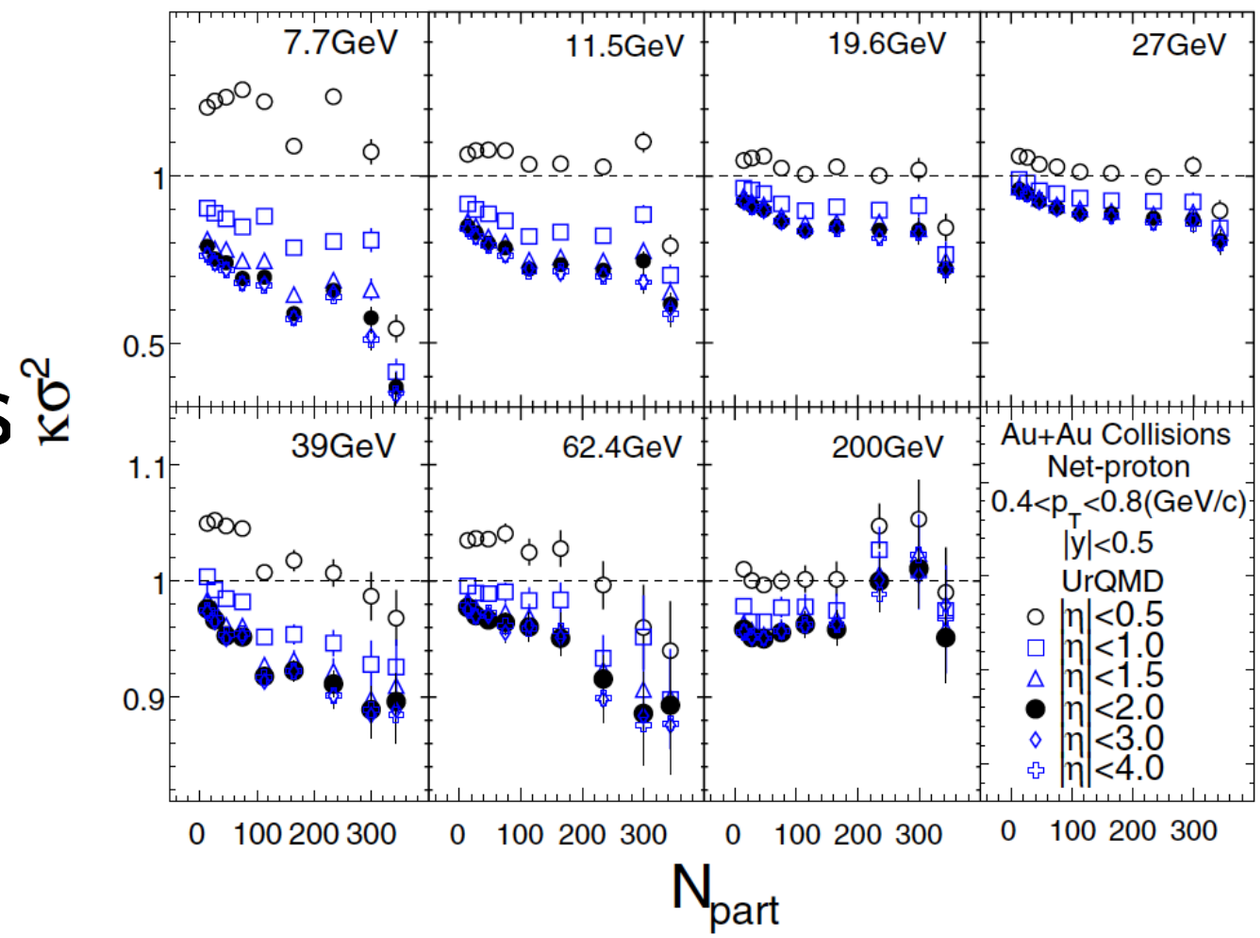
BES I at RHIC



STAR, Phys. Rev. Lett. 113 (2014) 92301

Fluctuations in Heavy Ion Collisions

- What fluctuates?
  - Multiplicities, Conserved charges (due to acceptance)
- Challenges:
  - Volume fluctuations
  - Conservation law effects
  - Kinematic Cuts
  - Detector Efficiencies
  - Finite Statistics



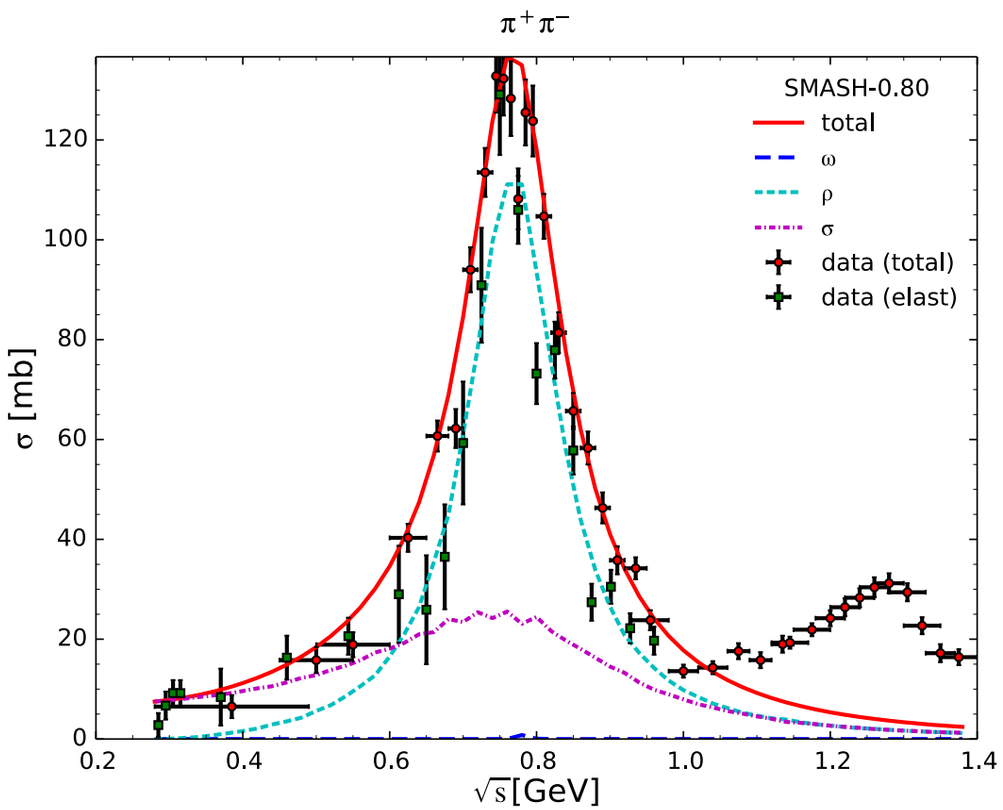
A. Bzdak and V. Koch, Phys. Rev. C 86 (2012) 044904,
A. Bzdak and V. Koch, Phys.Rev. C91 (2015) 2, 027901
A. Bzdak, V. Koch, V. skokov, Phys.Rev. C87 (2013), 014901

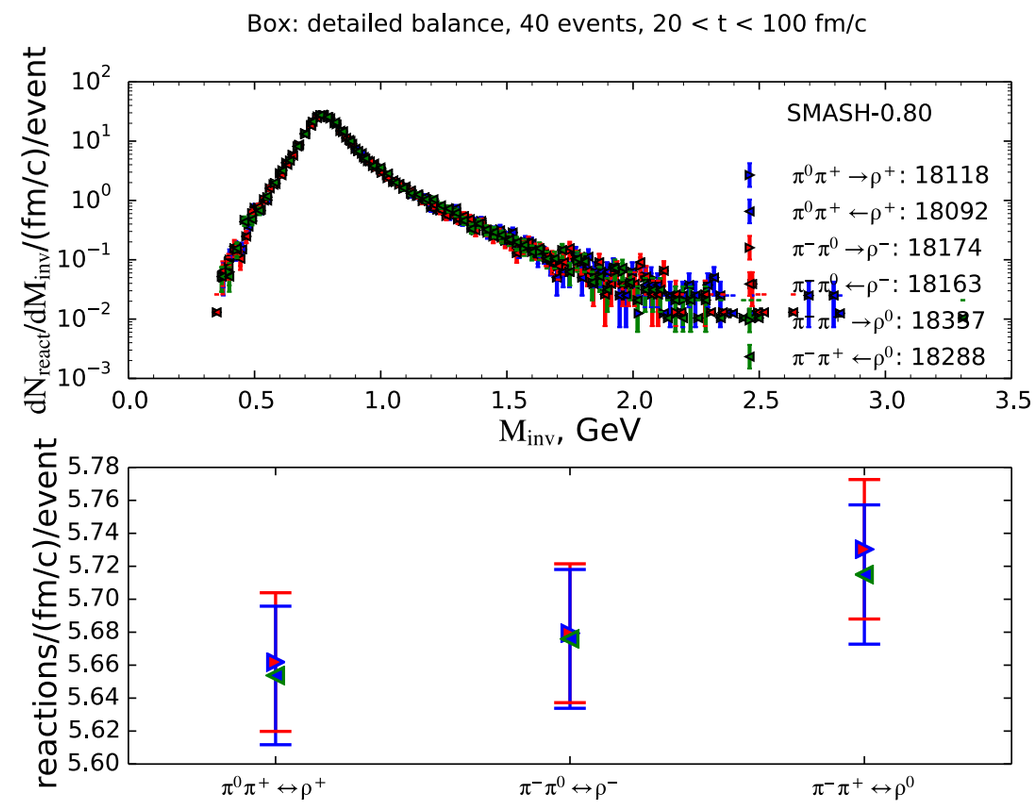
X.Luo et al, J. Phys. G: Nucl. Part. Phys. 40 (2013) 105104

- Investigation in a hadronic transport approach

Transport Approach

- SMASH: Non-equilibrium hadronic transport
- Geometrical cross section criterion is employed



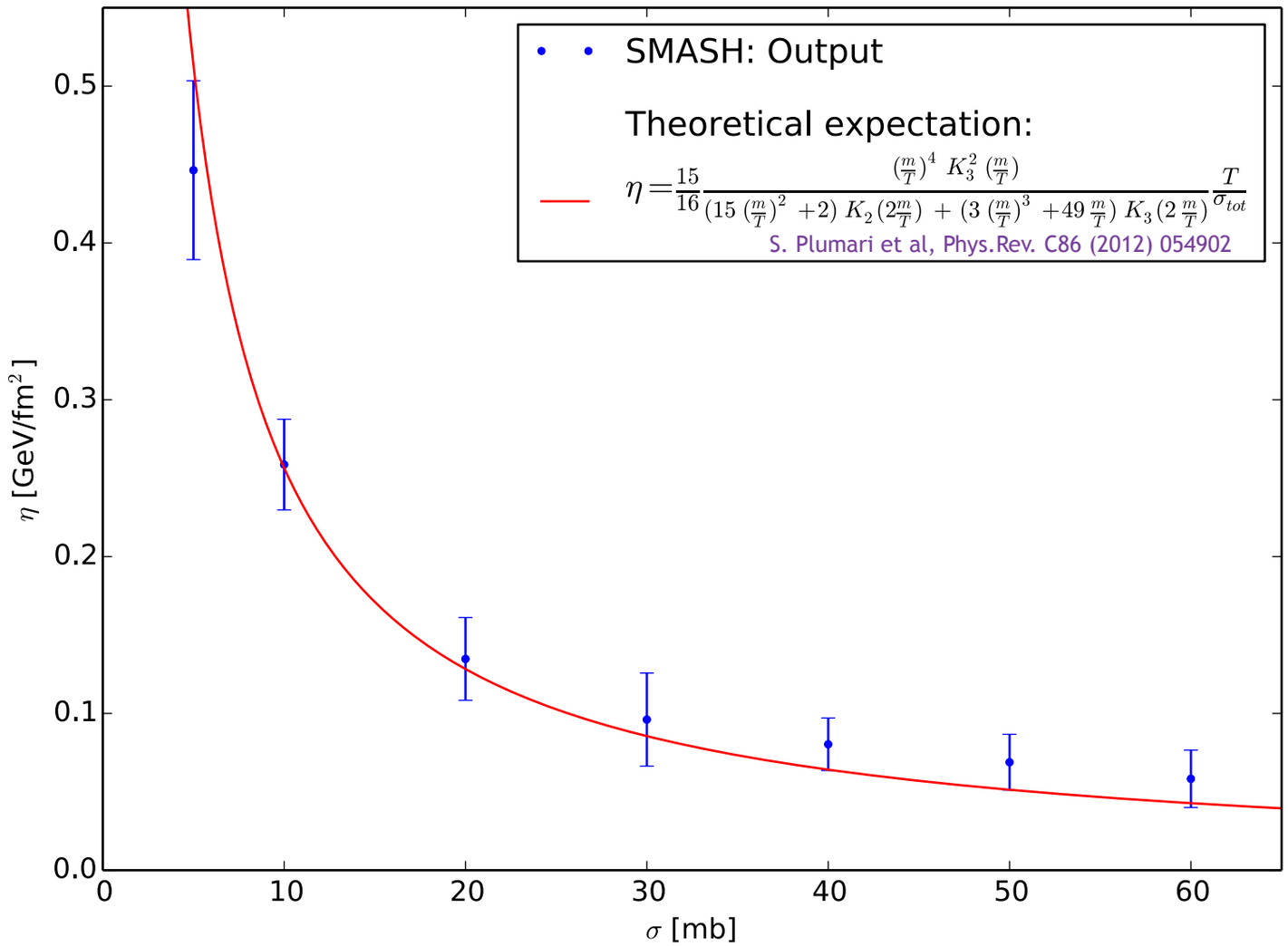


- $\pi^+\pi^-$ cross section and full detailed balance in π-ρ box
- Goal: Investigate conservation laws and kinematic cuts with full non-trivial resonance dynamics

Infinite Matter Calculations

- Pion gas with different elastic cross sections (T=200 MeV)

$$\eta = \frac{V\, C^{xy}(0)}{T}$$



thanks to A. Schäfer

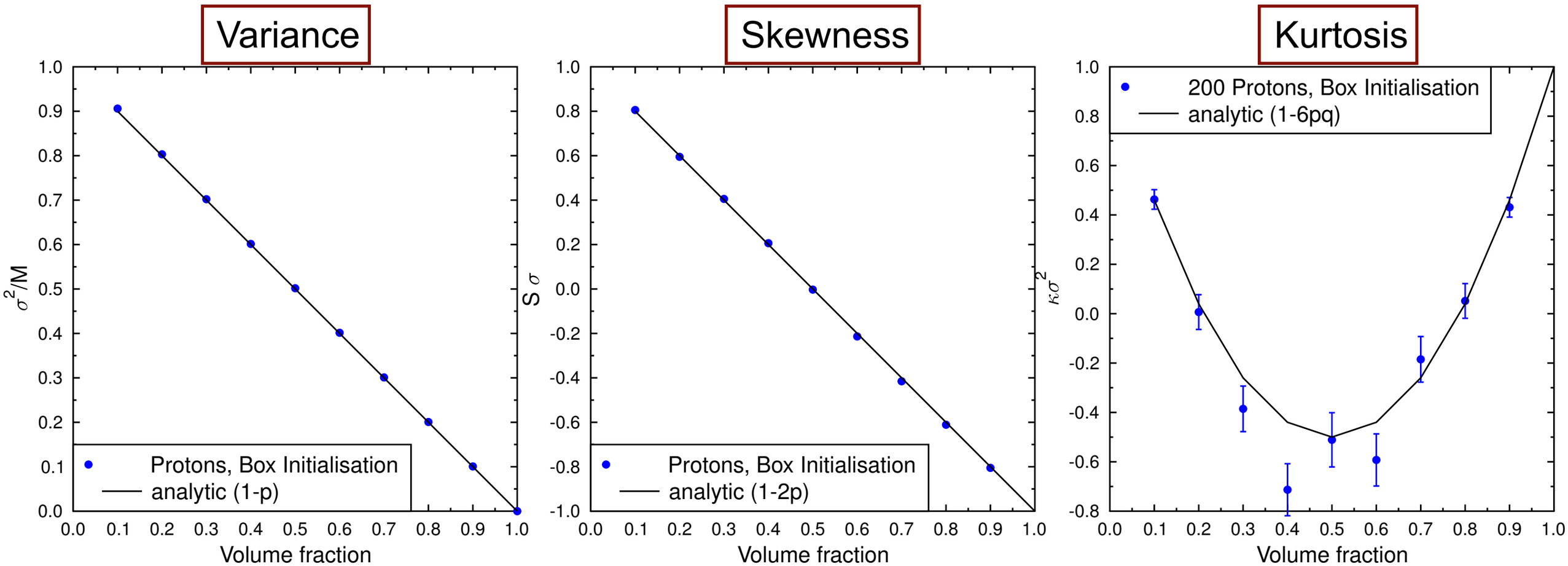
- Results for viscosity agree with theoretical expectation for 1000 π^0 in $(10\ \mathrm{fm})^3$ box

Higher Moments

- ~5 Mio Events for each calculation
- Sub-Volumes of size p = v/V, q=1-p
- Moments of the Poisson distribution:
  - Calculate $$\mu_r \equiv \langle (n - \langle n \rangle)^r \rangle$$
  - and compare to $$\sigma^2/M \equiv \mu_2/M = q$$ $$S\sigma \equiv \mu_3/\sigma^2 = 1 - 2p$$ $$\kappa\sigma^2 \equiv (\mu_4/\mu_2^2 - 3)\mu_2 = 1 - 6pq$$
- Statistical error bars: $$Var(\kappa\sigma^2) = \frac{24\sigma^4}{N_{\mathrm{Events}}}$$ X. Luo, J. Phys. G 39, 025008, 2012
  - For all other quantities: smaller than symbol size

Initialization (200 p)

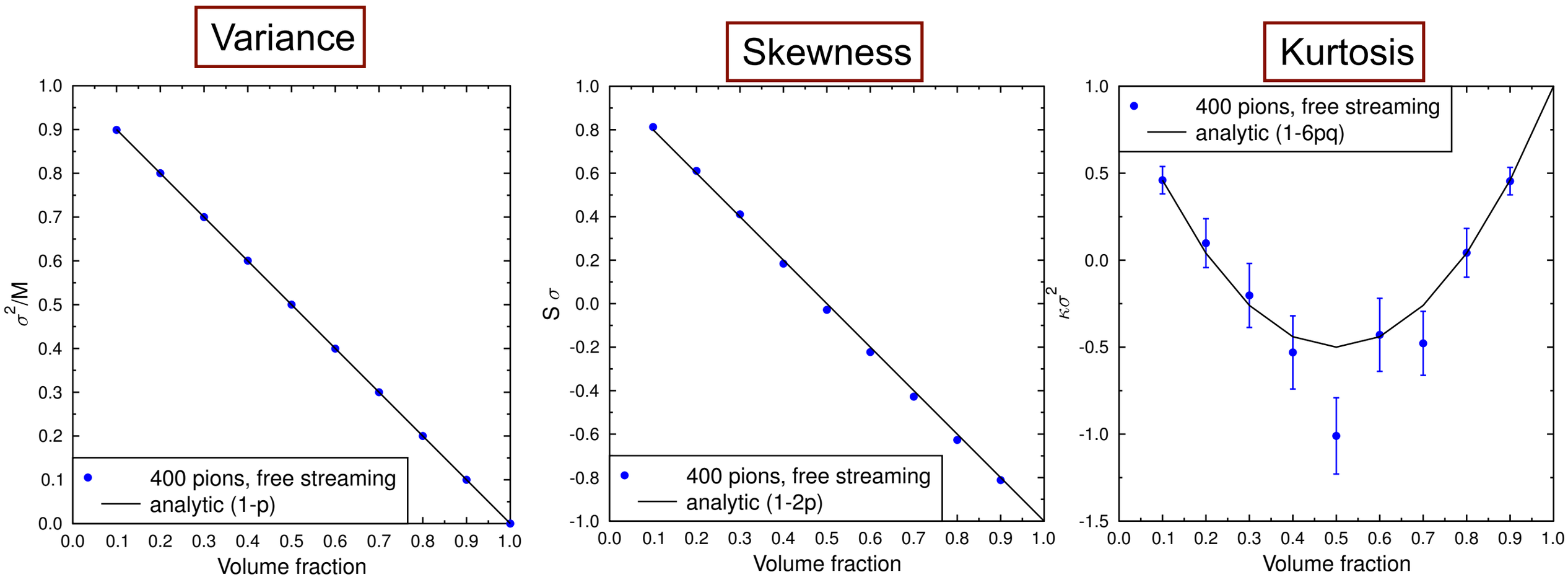
- 200 protons uniformly distributed in space



- Results agree with Poisson expectation
- Random number generator (Mersenne-Twister) is stable enough

Free Streaming

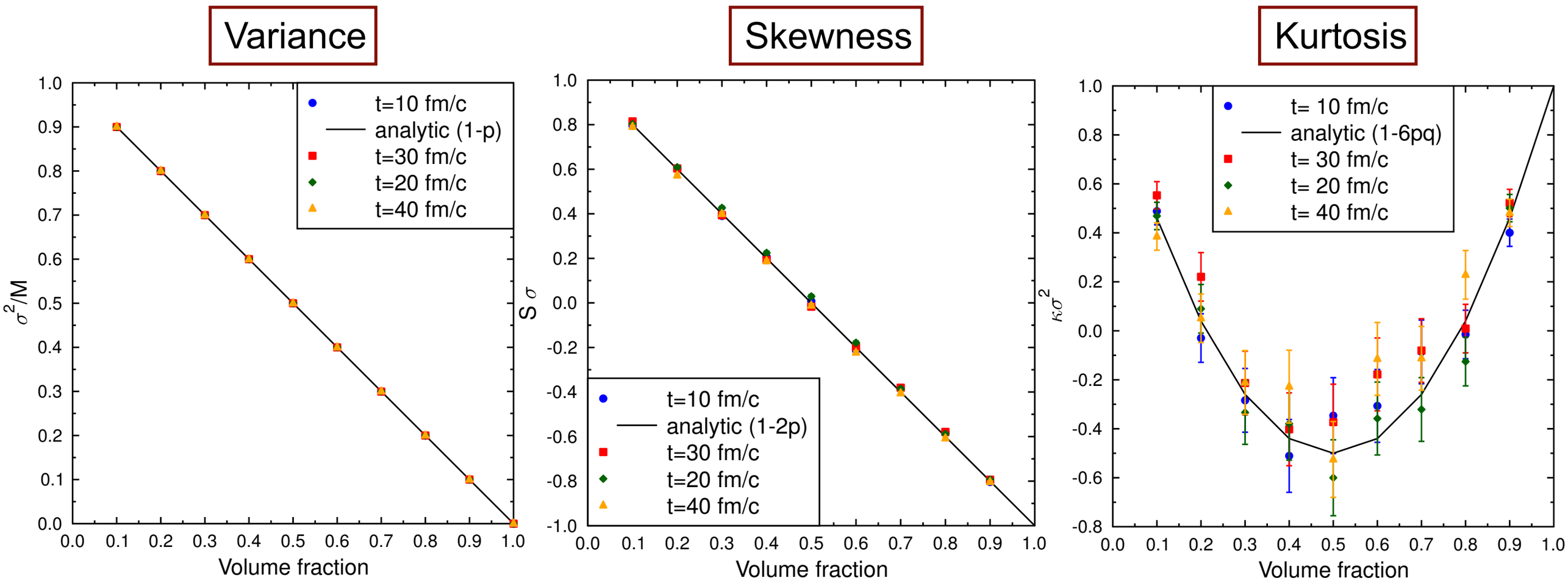
- Box with 400 pions, free propagation, t=10 fm/c



- Results agree with Poisson expectation

Time Evolution

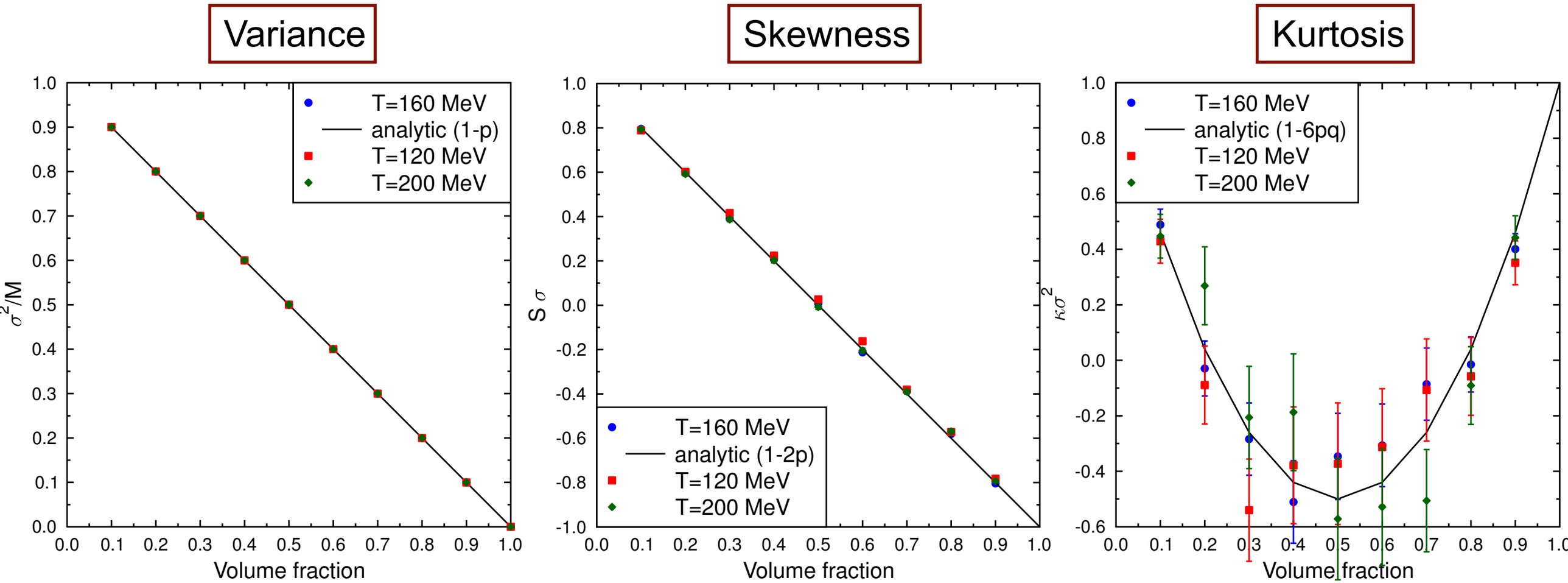
- Box with 400 pions, 10mb elastic cross section



- Results agree with Poisson expectation
- Stable results after 10 fm/c

Temperature Dependence

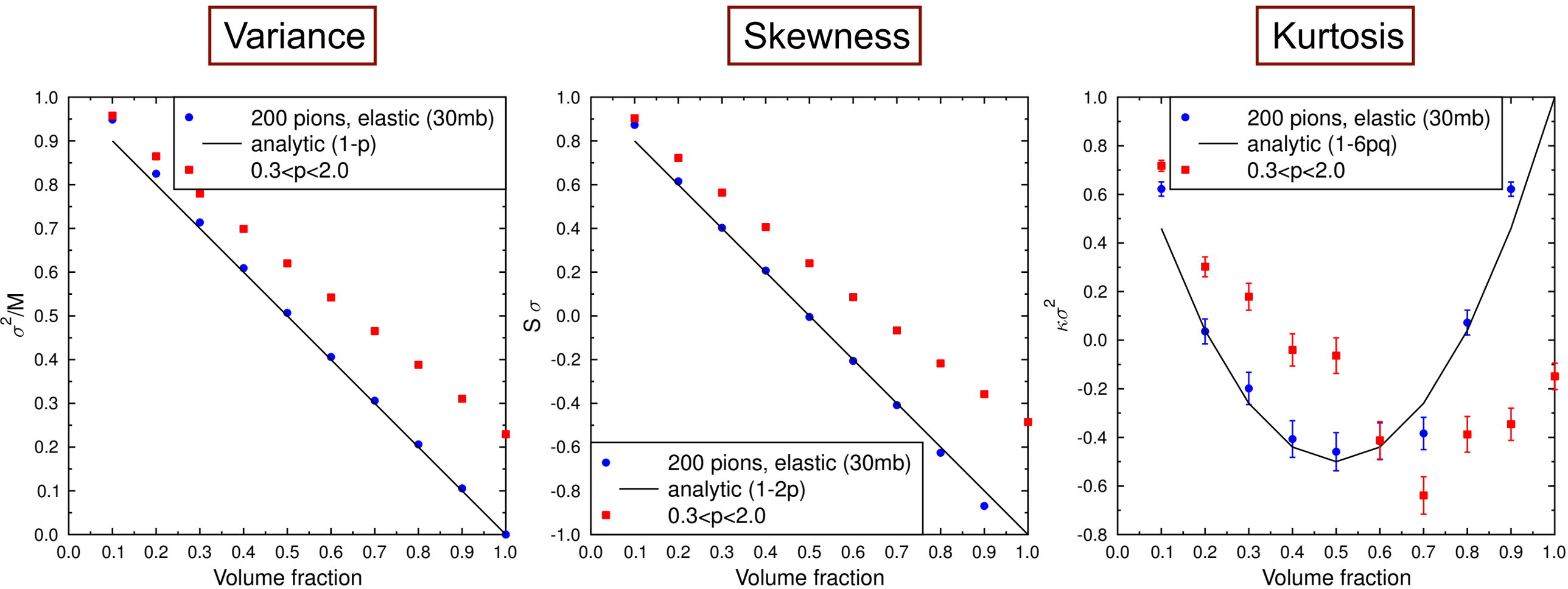
- Comparison of different temperatures in box with 400 pions, 10mb cross section



- No systematic differences:
  - 160 MeV in the following

Momentum Cut

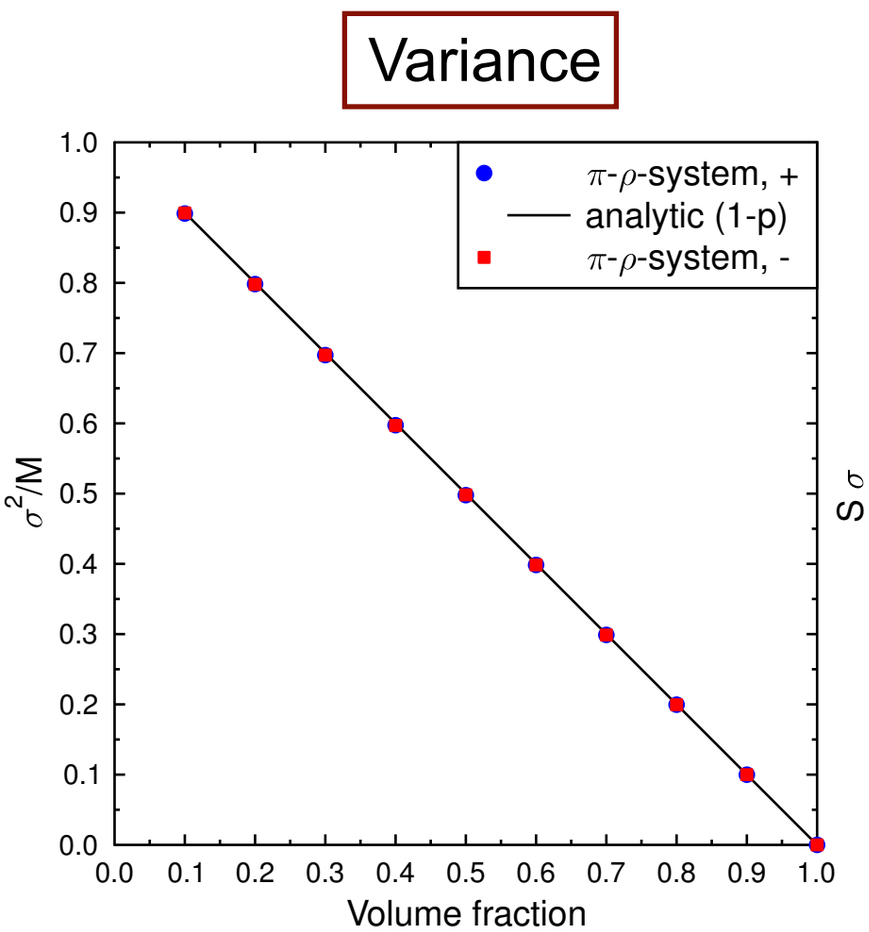
- Box with 200 pions with 30 mb cross section

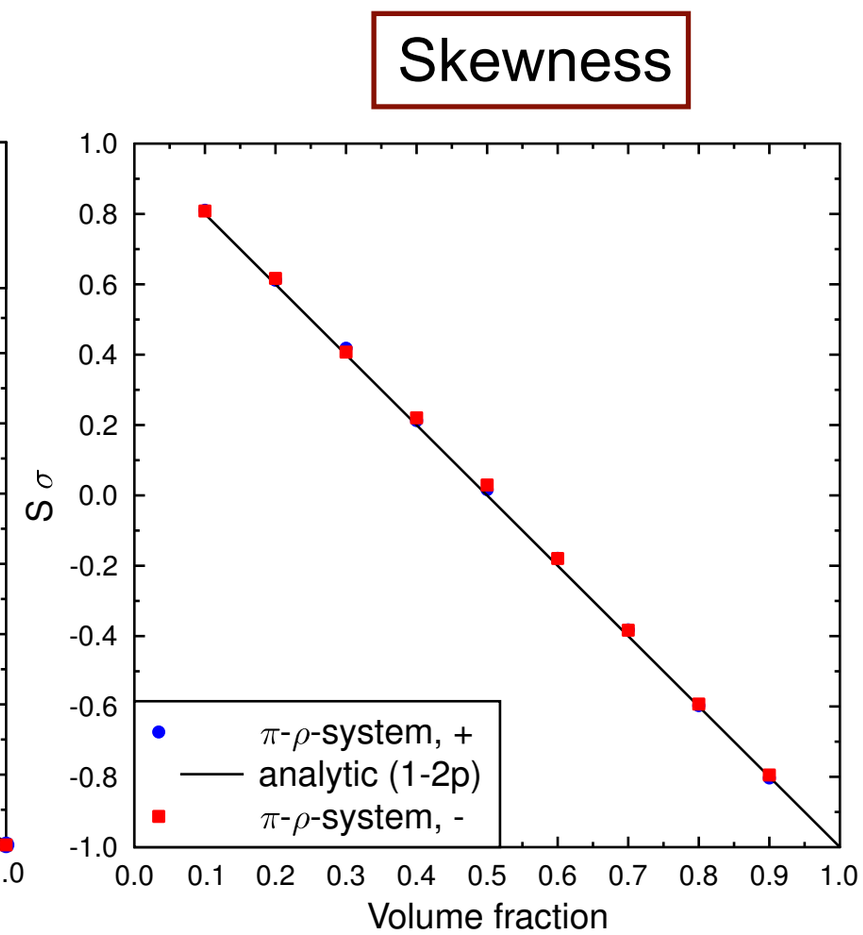


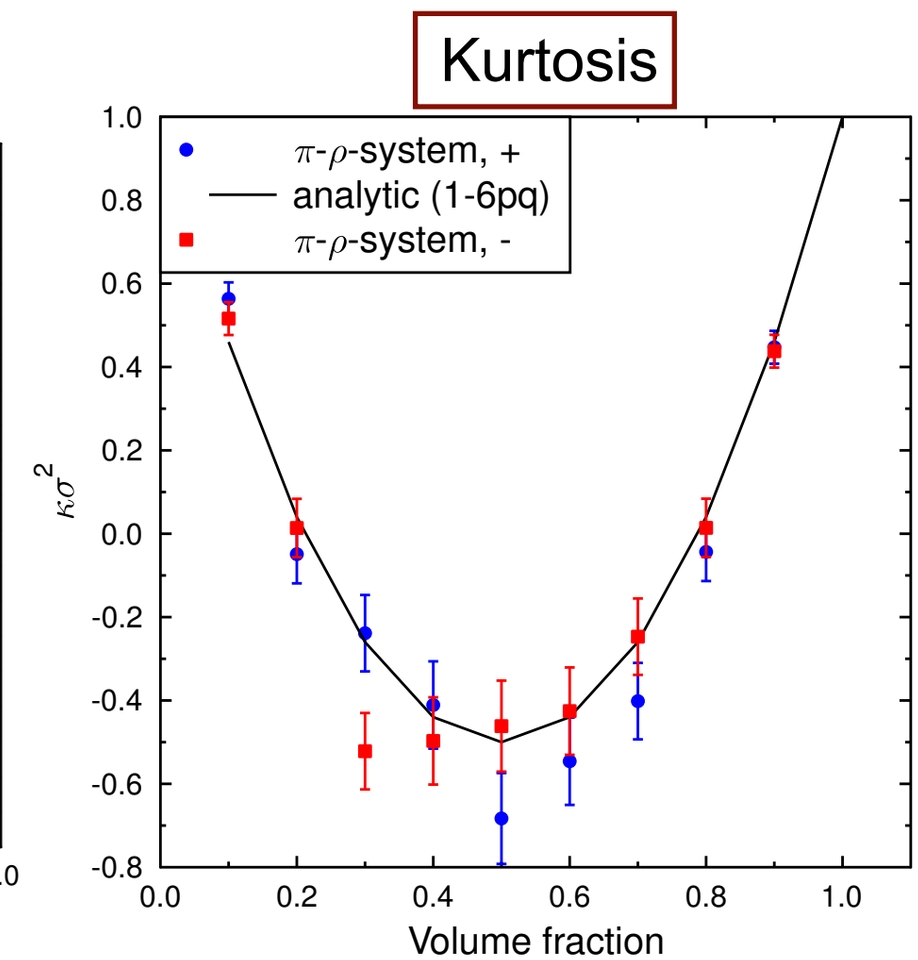
- Systematic deviations since particle number is not conserved anymore

π-ρ-System

- Box with pseudo-elastic π-ρ scattering, 200 positive and 200 negative charges





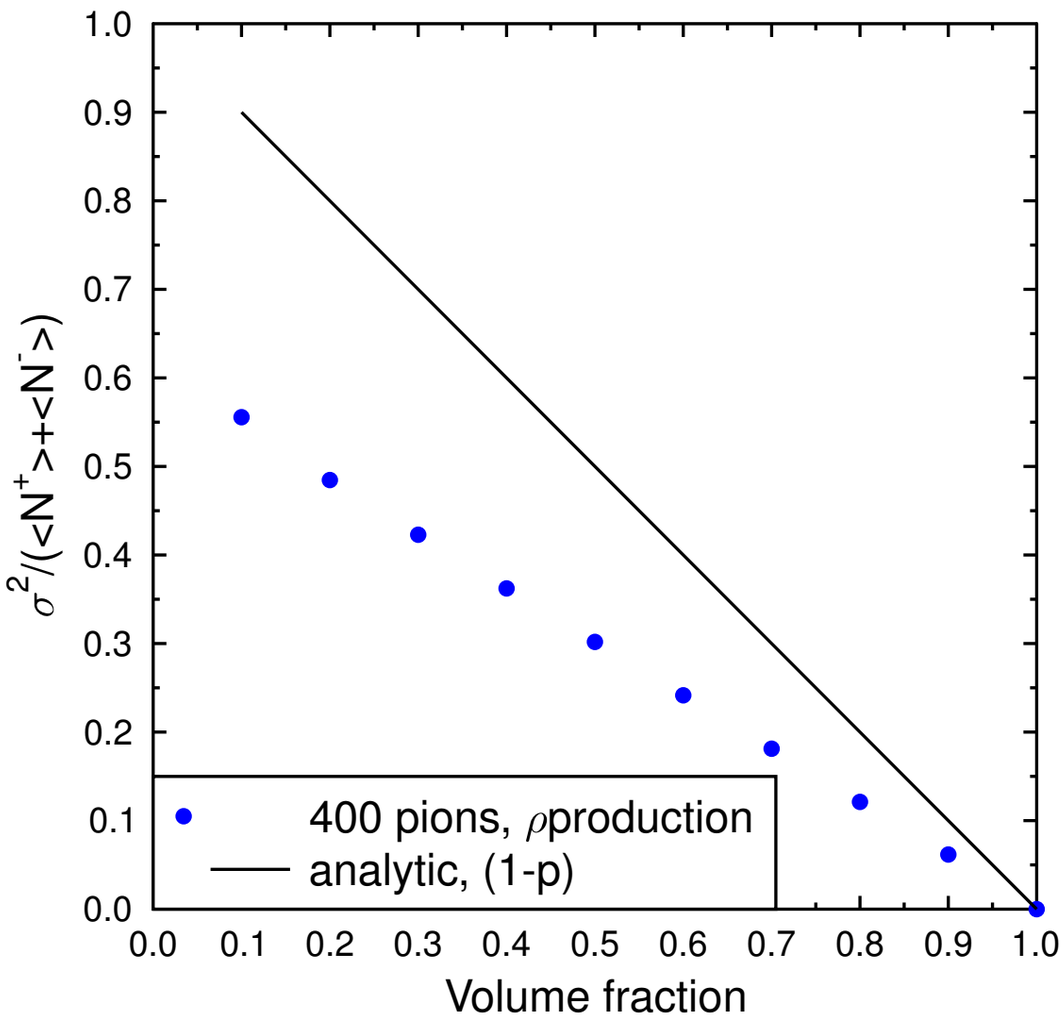


- Charges separately fulfill Poisson expectation

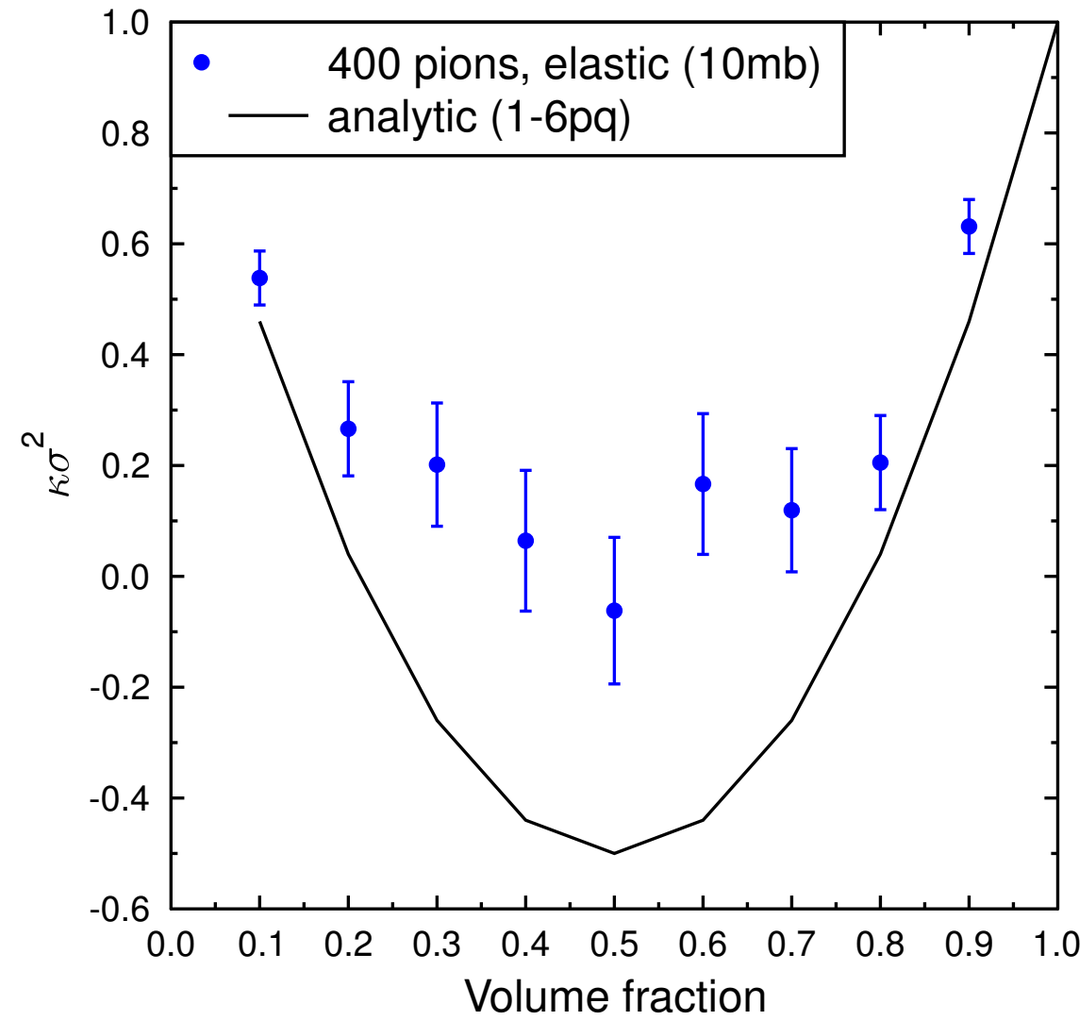
π-ρ-System: Resonances

- Net charge fluctuations, skewness is zero

Variance



Kurtosis

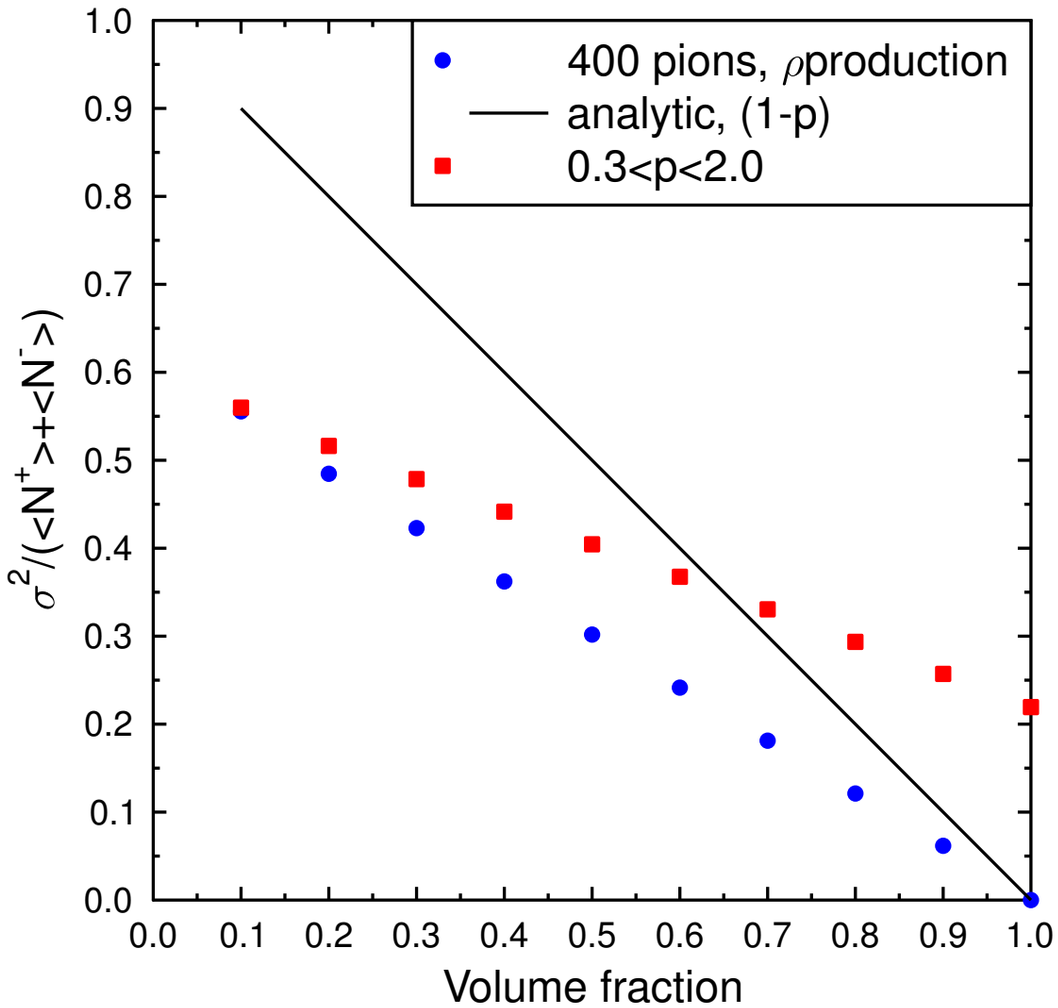


- Local charge conservation decreases fluctuations

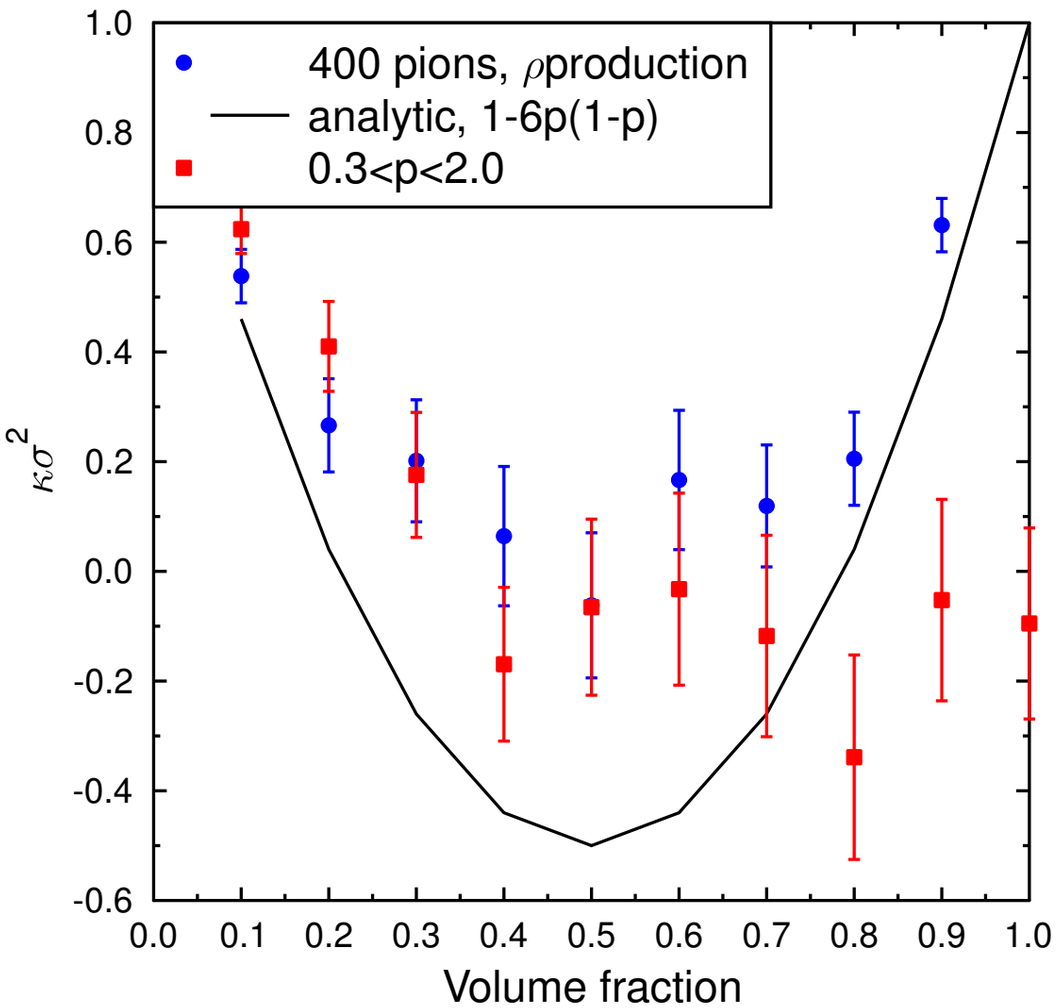
π-ρ-System: Momentum Cut

- Net charge distribution with p cut

Variance



Kurtosis



- Fluctuations are increased due to fluctuating particle number in the full volume

Summary & Outlook

- Higher moments of net charge/net proton distribution are observables for critical behavior
- Systematic study in a hadronic transport approach shows:
  - Initialization and free streaming confirm that RNG is good enough
  - No temperature/time evolution dependence
  - Resonances like ρ influence results due to local charge conservation
  - p cuts increase fluctuations
- Outlook: Net baryons with realistic interactions