Bridging the gap between theoretical and experimental results on higher moments

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The Plan

- Not actually going to bridge the gap
  - Just going to talk about it
- What does the data tell us so far?
- What progress have we made already?
- Where can we go from here?

Why higher moments?

If we start with the log of the QCD partition function

$$\frac{p}{T^4} \equiv \frac{1}{VT^3} ln\left[Z\left(V,T,\mu_B,\mu_S,\mu_Q\right)\right]$$

then take derivatives with respect to the chemical potential

$$\chi_n^x \equiv \left.\frac{\partial^n p/T^4}{\partial \hat{\mu}_x^n}\right|_{\mu=0}$$

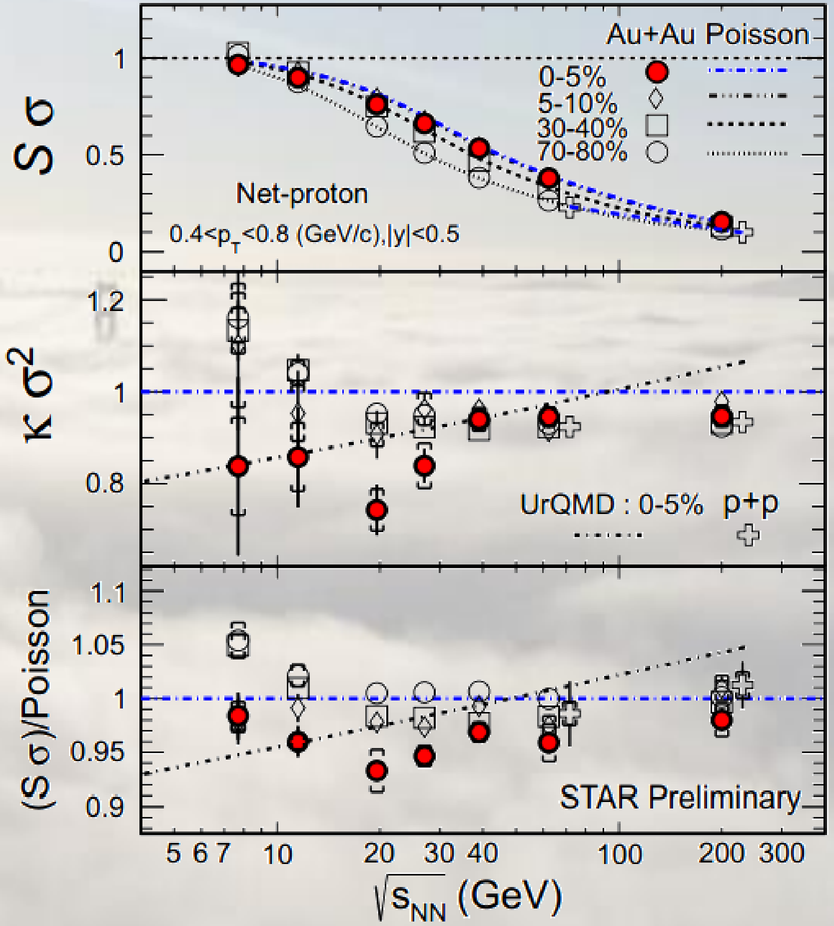
we find that the cumulants of conserved quantities give us the susceptibilities

$$\chi_n^x = \frac{1}{VT^3}\langle(\delta N_x)^n\rangle = \frac{1}{VT^3}\kappa_n$$

Critical point fluctuations would cause these to diverge.
Values relate to locations on the phase diagram.

The Data (Net Proton)

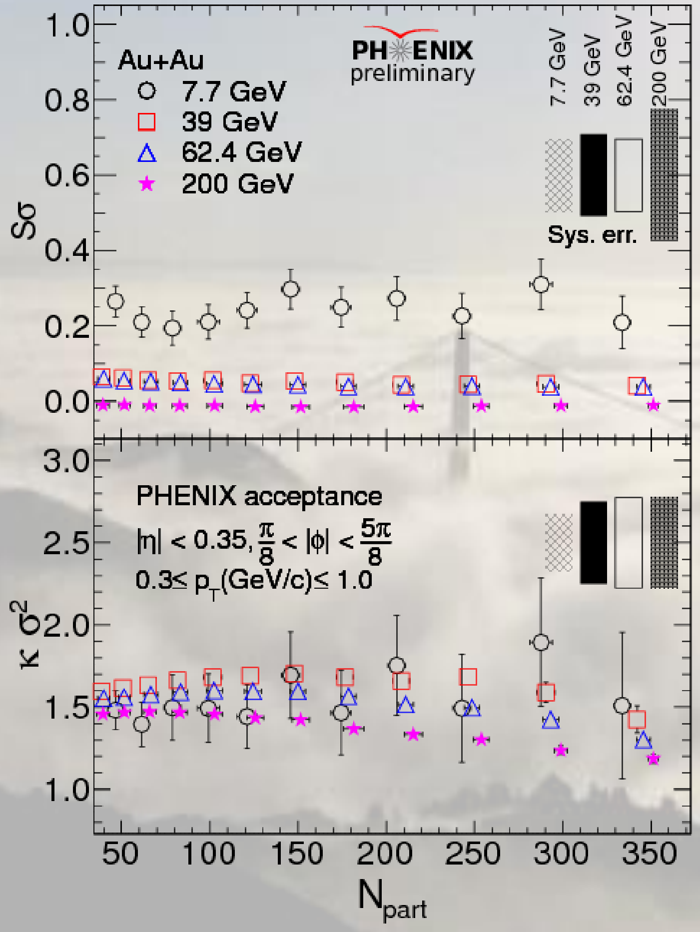
X. Lou for STAR, arXiv:1306.3106



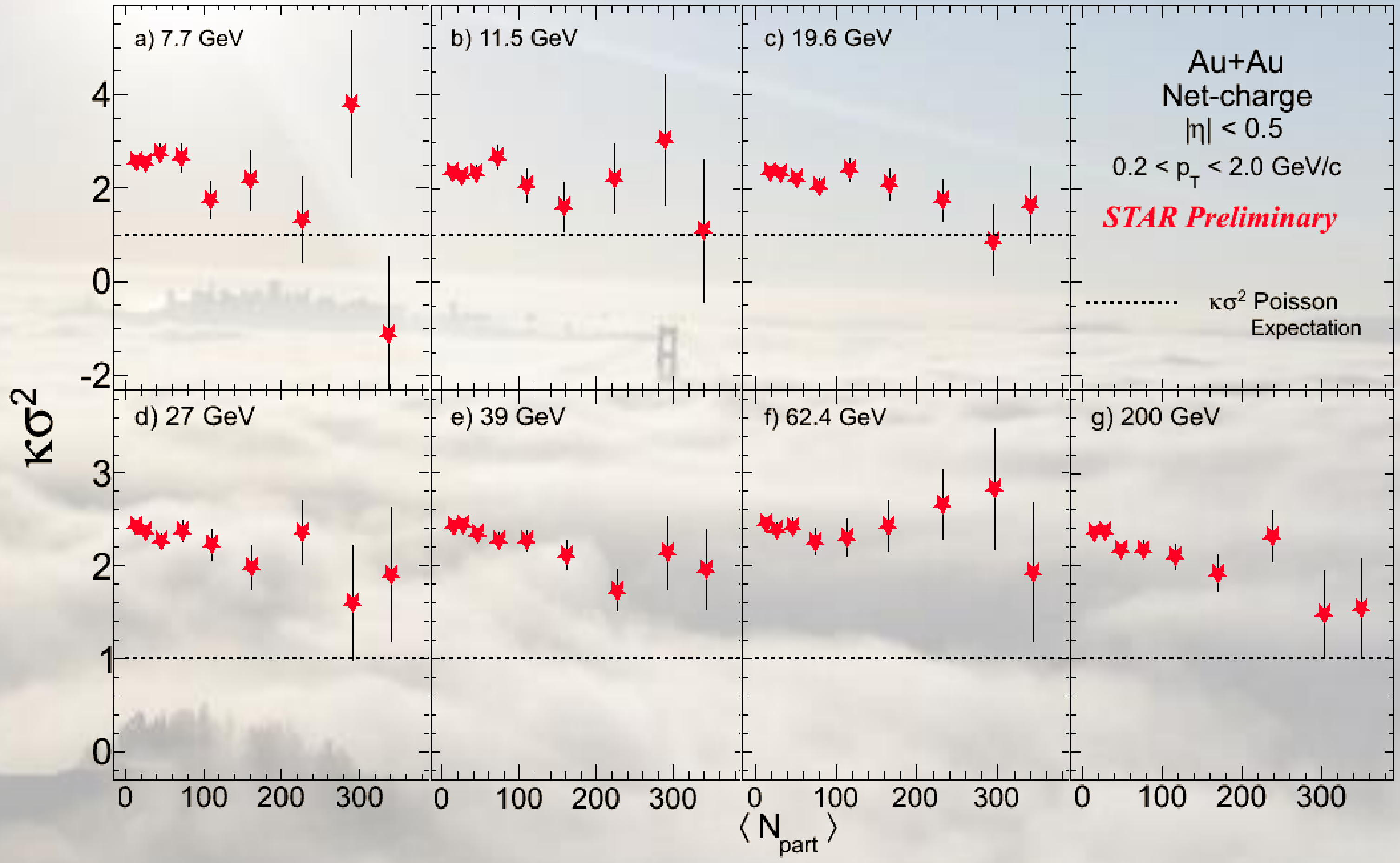
- ❖Very little energy/centrality dependence beyond the changing $N_p/N_{\bar{p}}$ ratio
  - ❖Features are on order of 5-10%
- ❖No compelling evidence for critical point fluctuations

The Data (Net Charge)

J. Mitchel, Quark Matter 2012



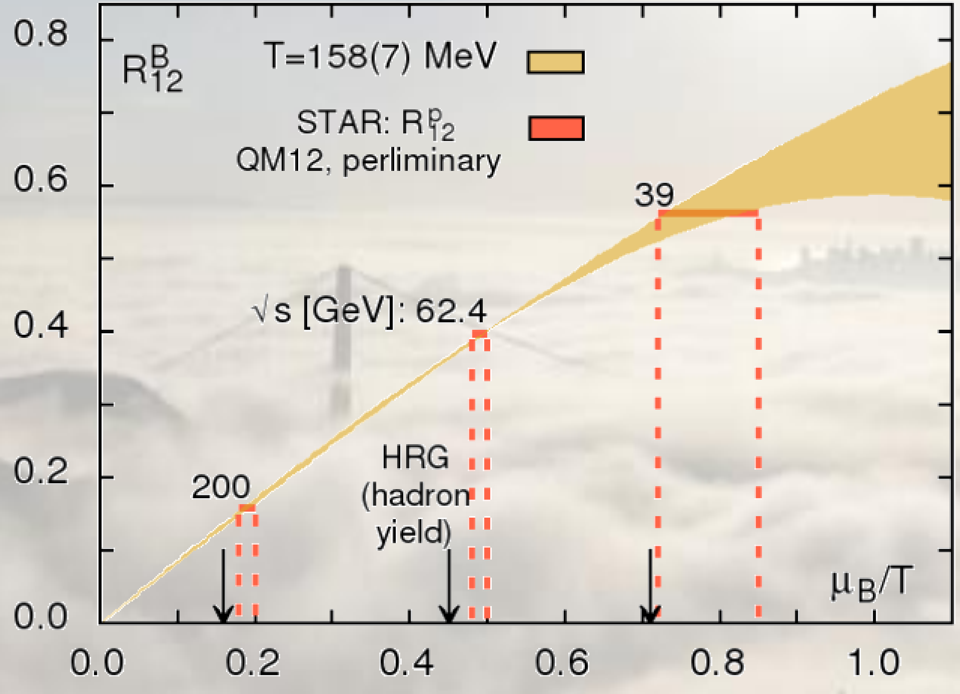
N. Sahoo, Quark Matter 2012



PHENIX results are systematically lower than STAR's.

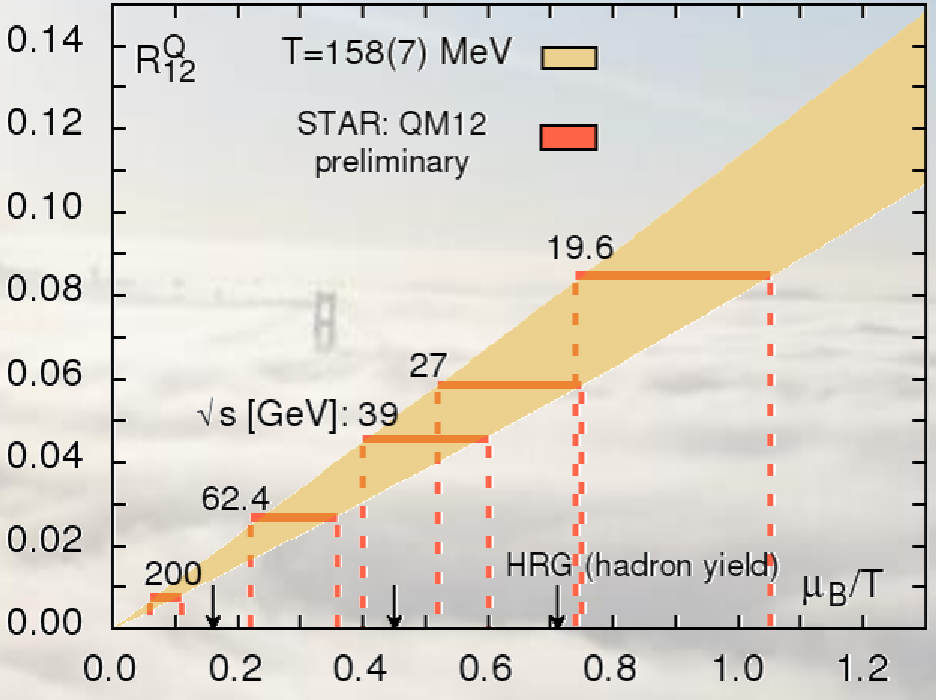
The Data (Coupled w/ Lattice)

Net Proton k_1/k_2



Net Charge k_1/k_2

S. Mukherjee, WWND 2013



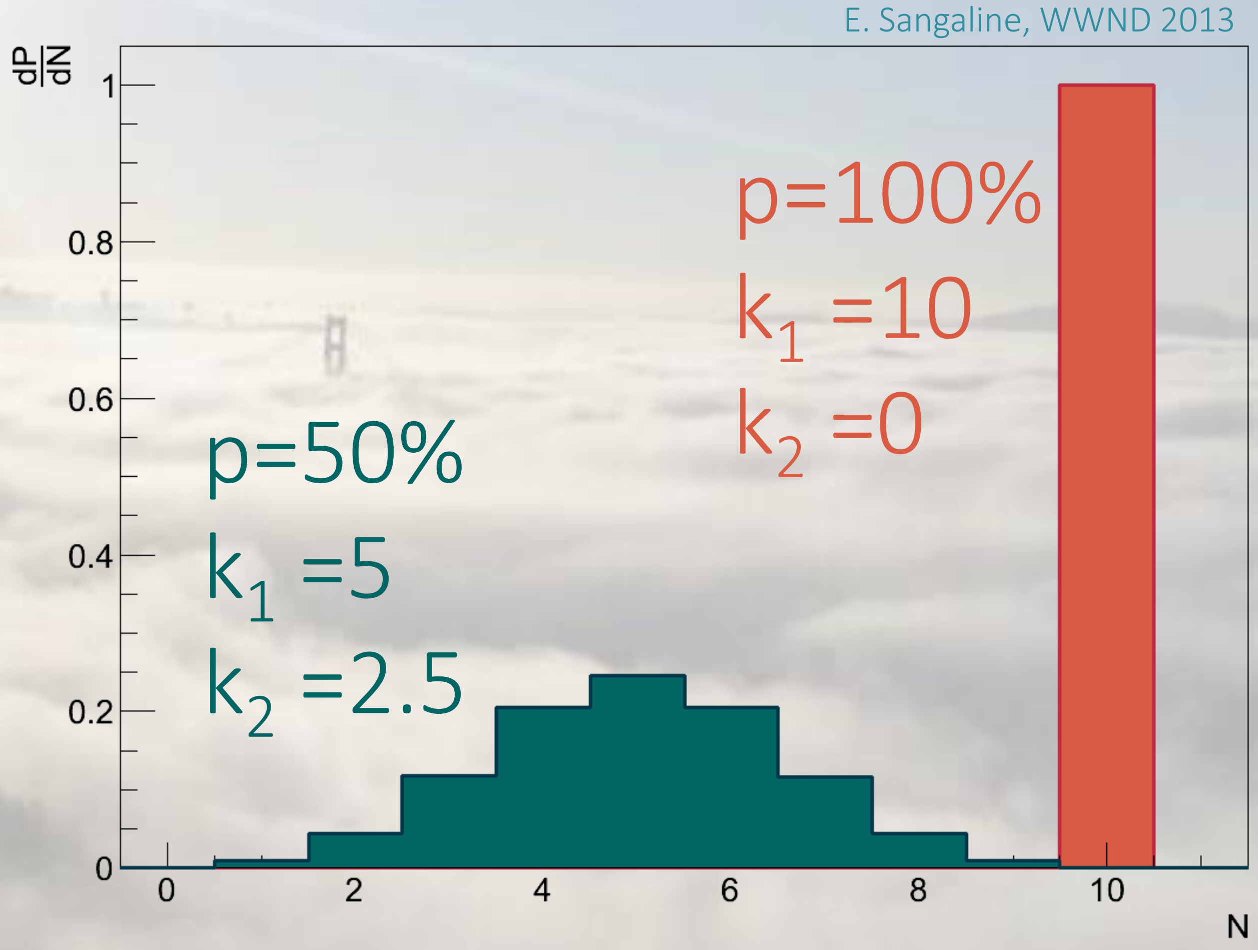
STAR Net Charge and Net Proton results give inconsistent values of μ_B/T?

What Does the Data Tell Us?

- We see no compelling evidence for a critical point
  - Little energy/centrality dependence of k_4/k_2
- Possible systematic issues affecting STAR and PHENIX in different ways
- Current lattice results seem inconsistent with “lower” moments
- **There is more work that needs to be done in order to understand these results…**

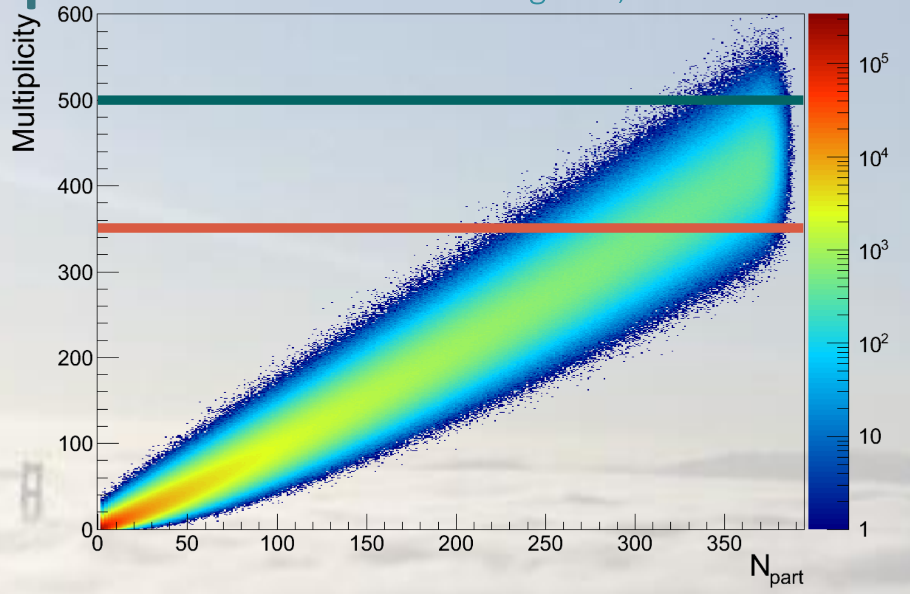
Efficiency Losses

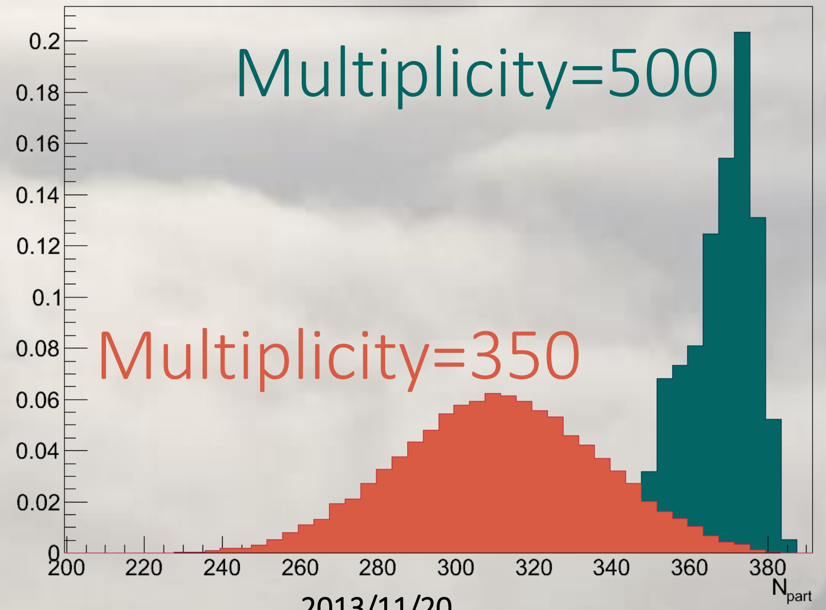
- Push results toward Poissonian expectations
- Cause artificially small statistical and systematic errors
- Can be corrected analytically
  - Derivation: http://nuclear.ucdavis.edu/~sangaline/research/papers/efficiency_corrections.pdf
  - Generally accepted by the community
    - Will be included in the final STAR and ALICE results



Finite Centrality Resolution

E. Sangaline, WWND 2013

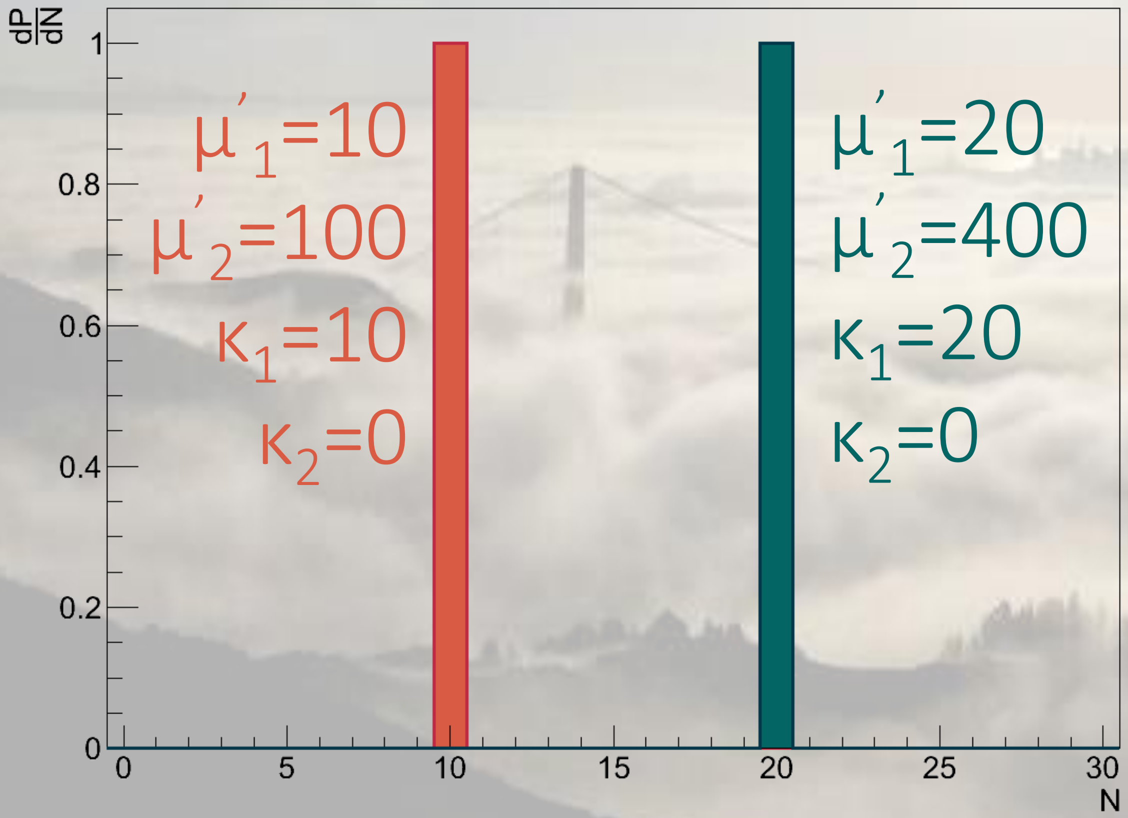


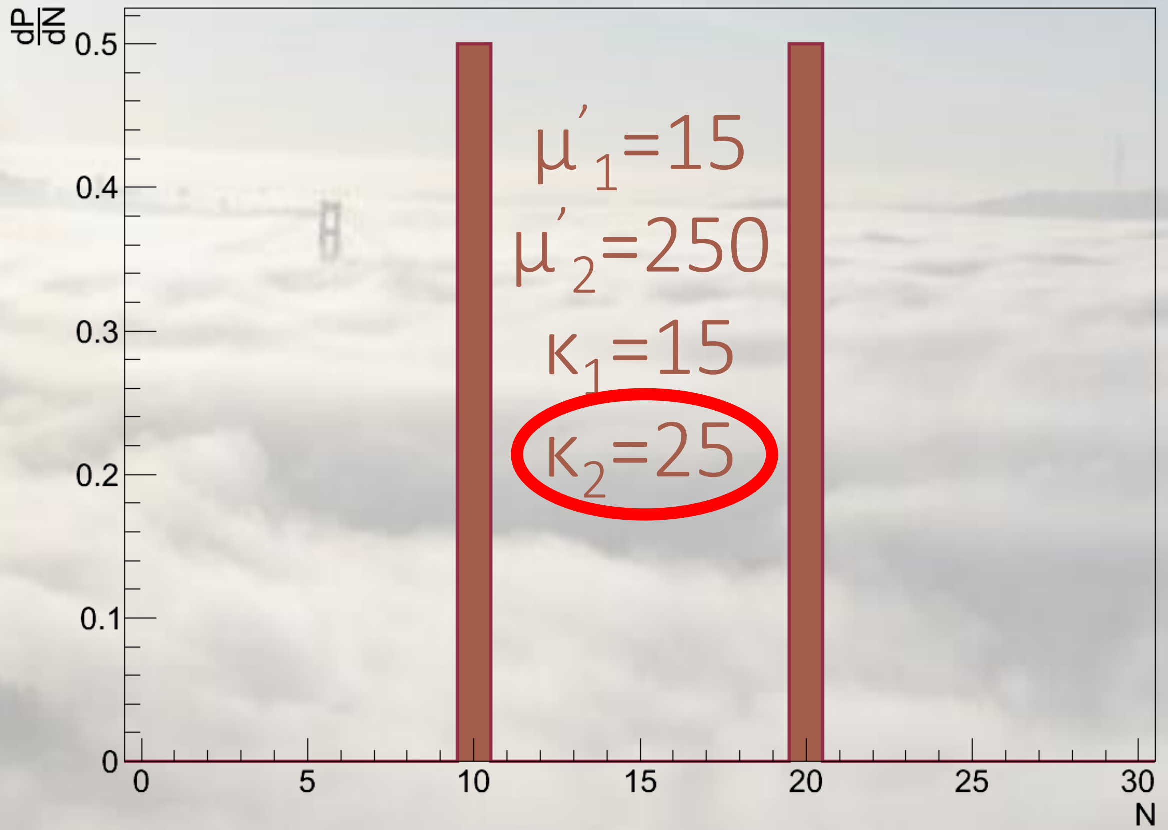


- Introduces centrality, collision energy, and experiment dependent biases
- Analytical corrections exist if the volume distribution is known
  - Model dependent (e.g. Glauber)
  - No plans for publication in either STAR or PHENIX
- Reduced by maximizing phase space used in centrality determination
  - Still a large effect, especially in net charge analyses

Centrality Resolution

Multiple distributions with the same cumulant ratios → Convoluted distribution with different cumulant ratios



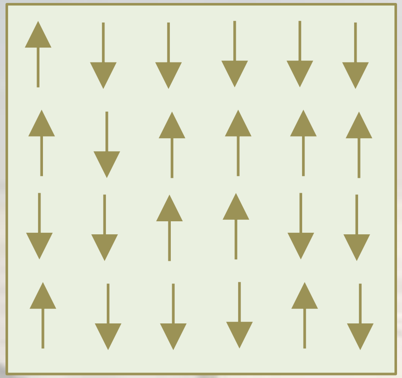


Other Effects

- Acceptance
  - Conservation suppresses fluctuations for larger acceptances
  - Small acceptances exclude particles and have an efficiency-like effect
    - Depends on relationship between position and momentum space
  - Likely explanation of STAR/PHENIX net charge results
- Autocorrelation in centrality determination from resonance decays and jets
- Impact of jets with partial acceptance on charge fluctuations
- Time evolution of μ_B and T
  - How much does history of the collision affect measurements?
- Finite size effects
  - Limited volume
  - Limited equilibration

The 2D Ising Model

A 2D Lattice of Dipole Spins



Hamiltonian Given By

$$H = \sum_{i,j} \sum_{k,l \in neighbors_{i,j}} -s_{ij}s_{jk}$$

Magnetic Susceptibility Given By

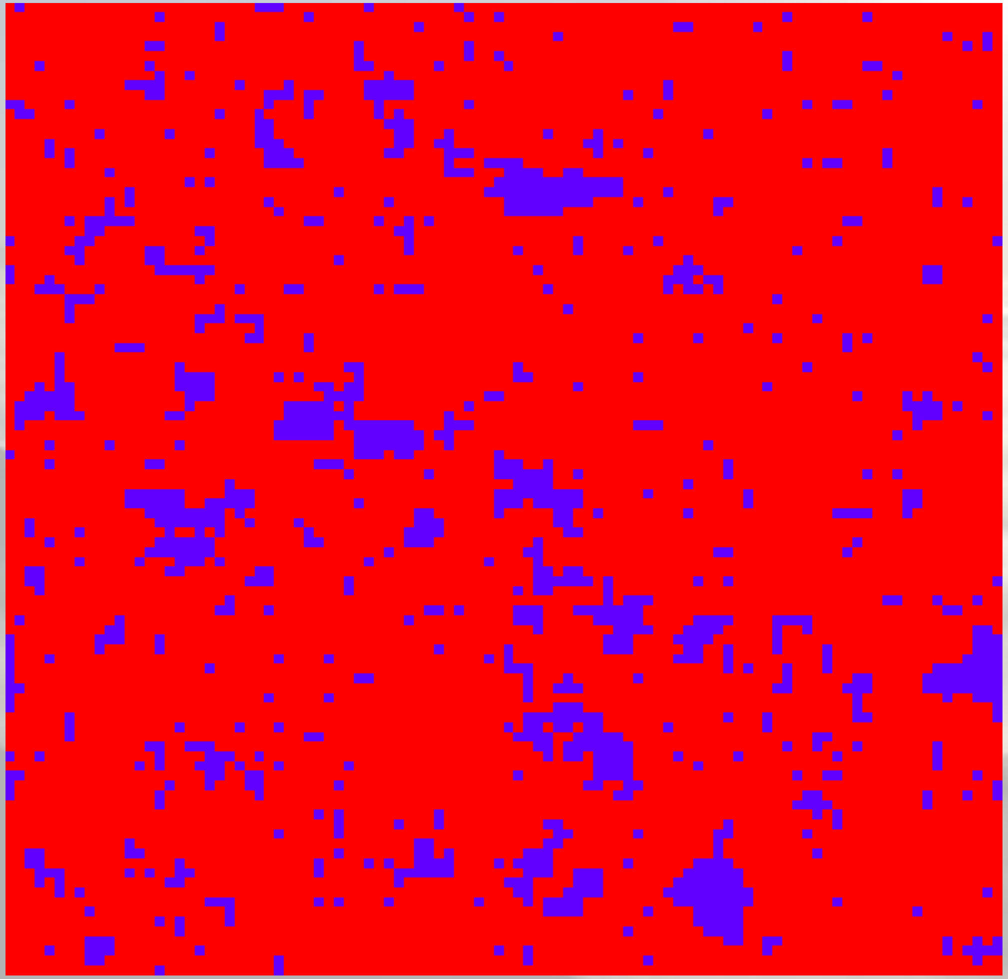
$$\chi = \frac{\partial M}{\partial T} = \frac{\langle M^2 \rangle - \langle M \rangle^2}{T}$$

Diverges at T_C for an infinite lattice, analogous to the goal of higher moments analysis.

One of the simplest thermodynamic systems with a phase transition. Useful for a qualitative understanding of some effects.

Ising Model Simulations

- Metropolis algorithm for sampling
- Various lattice sizes
- Non-periodic boundaries
- Absolute magnetization measured (|M|)



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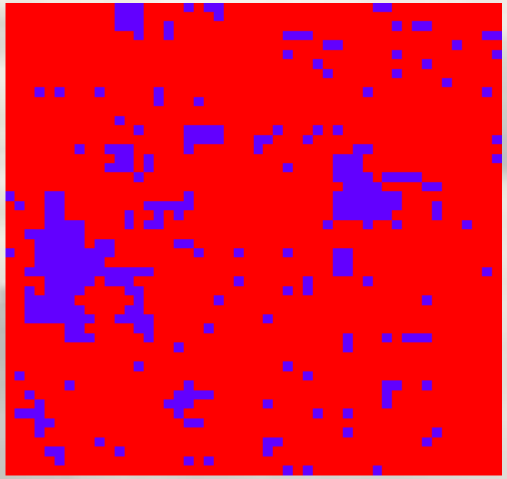

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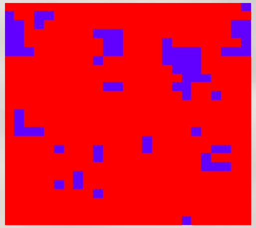

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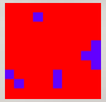

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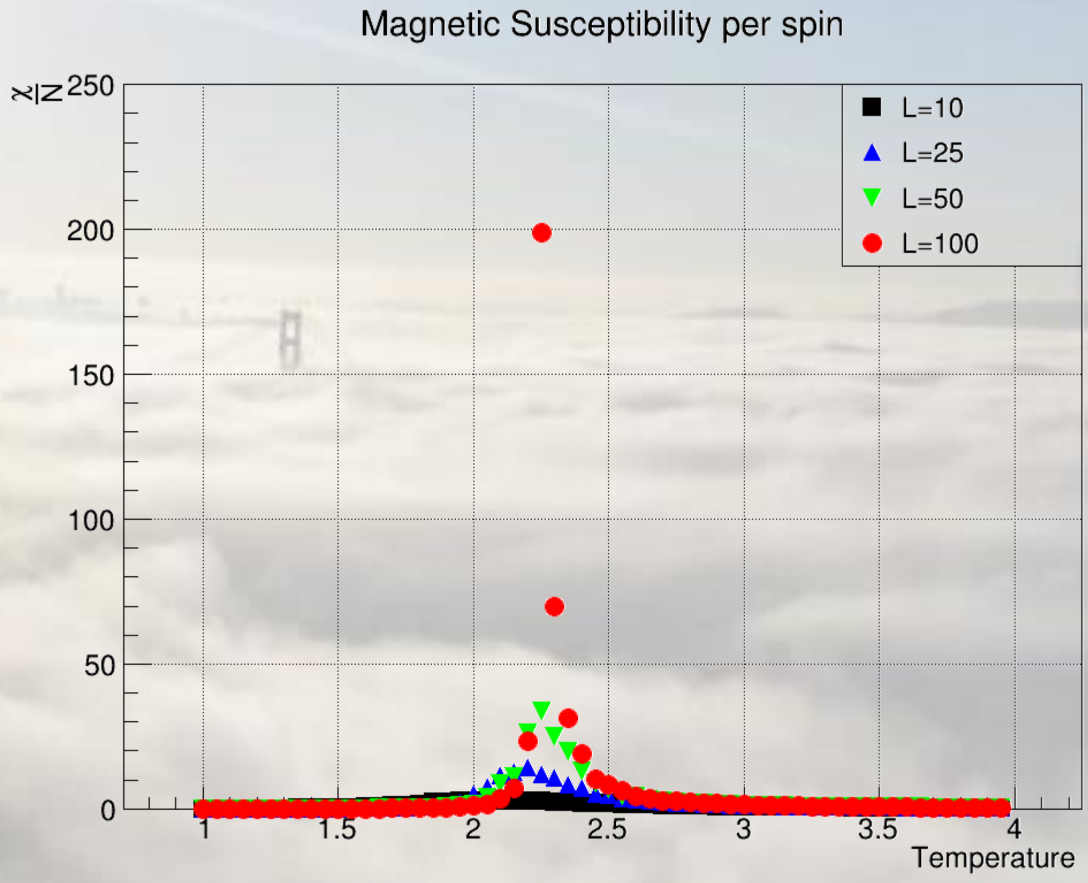
Magnet Susceptibilities and Finite Size

- Divergence rapidly disappears for small system sizes
  - Larger effect for higher order cumulants
- We only measure a handful of protons on average
  - **How much of a divergence should we expect if there is a critical point?**
    - And if the system isn't equilibrated at a large scale?



Conclusions

- We have a wide range of results from RHIC
  - Possible features are very subtle
- Experimental effects need to be eliminated as far as possible and expectations need to be made more realistic
  - A lot of progress has been made
  - A lot more needs to be made