

The shapes of the multiplicity distributions in 7.7-200 GeV Au+Au collisions at STAR

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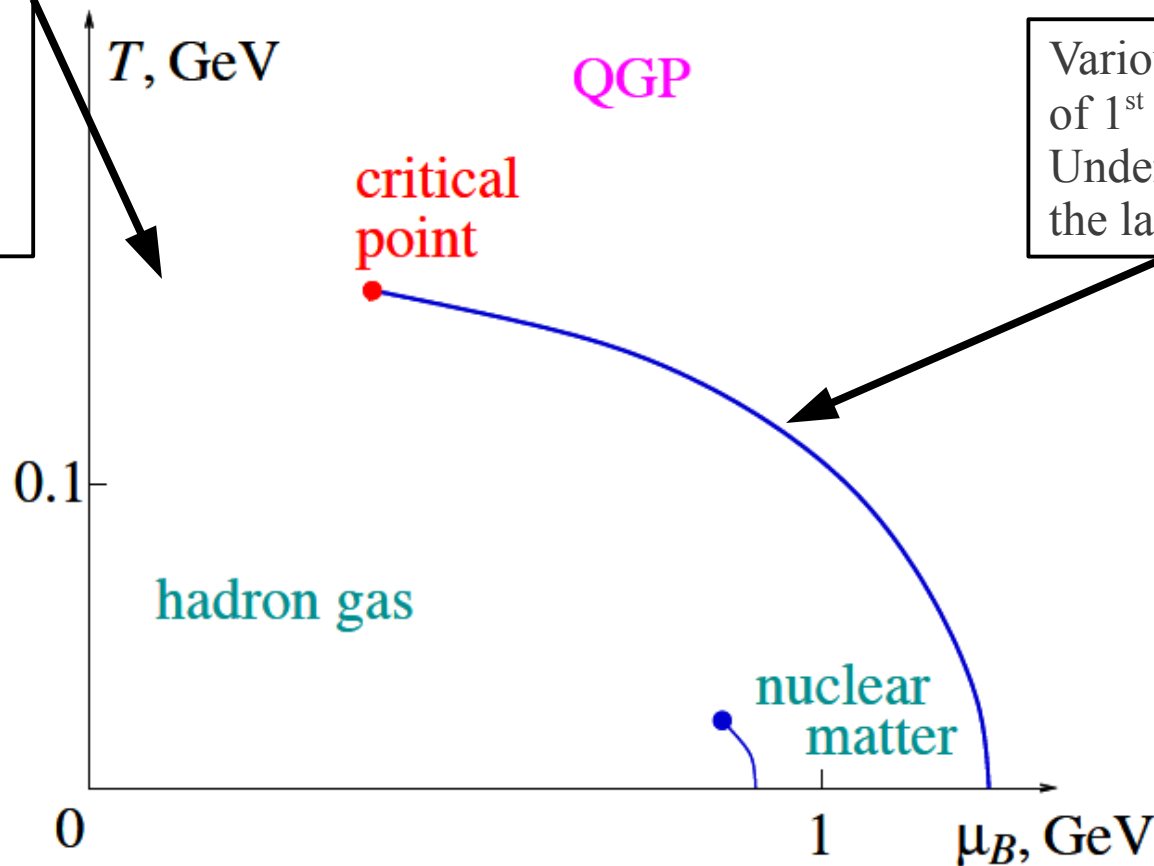
For the STAR Collaboration
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Brookhaven National Laboratory

QCD phase diagram

STAR, arXiv:1007.2613 [nucl-ex]

- Top RHIC energies
- baryochemical potential is small
- crossover transition



Various indirect suggestions of 1st order phase transition. Under heavy discussion in the lattice theory community.

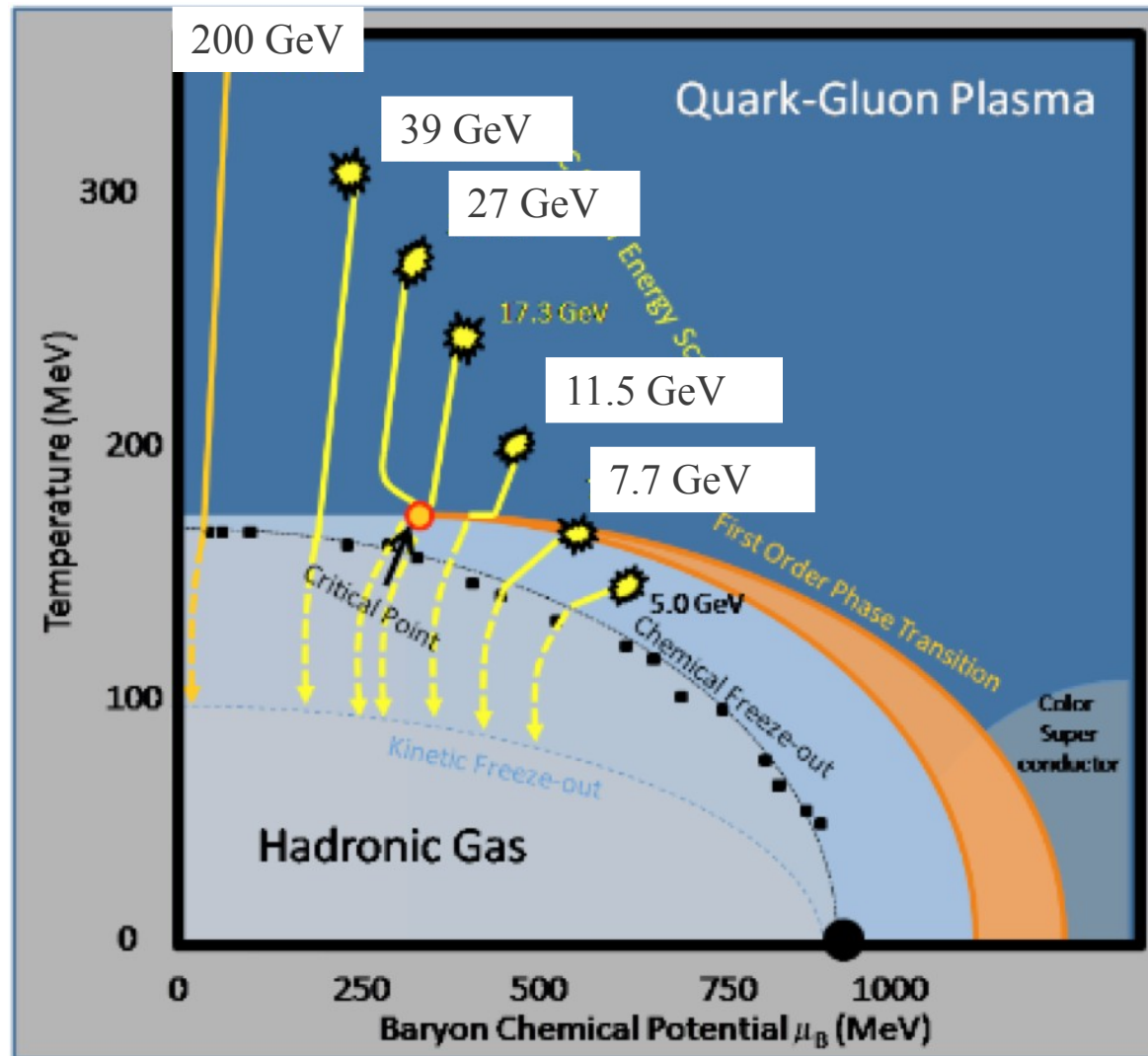
Lattice QCD is difficult. However, this topic can be addressed experimentally.

Thus, a critical point (CP) might exist somewhere in between these extremes at the end of the 1st order phase transition...

QCD phase diagram

STAR, arXiv:1007.2613 [nucl-ex]

- Varying the beam energy results in different search trajectories through this space. Decreasing the beam energy results in larger μ_B values, as shown in the cartoon below.



- We will be describing data collected by the STAR experiment at:

$$\sqrt{s_{NN}} = 7.7, 11.5, 19.6, 39, 62.4, 200 \text{ GeV}$$

Correlation length divergence near the critical point

At the critical point the correlation length, ξ , should diverge.

- “critical opalescence”

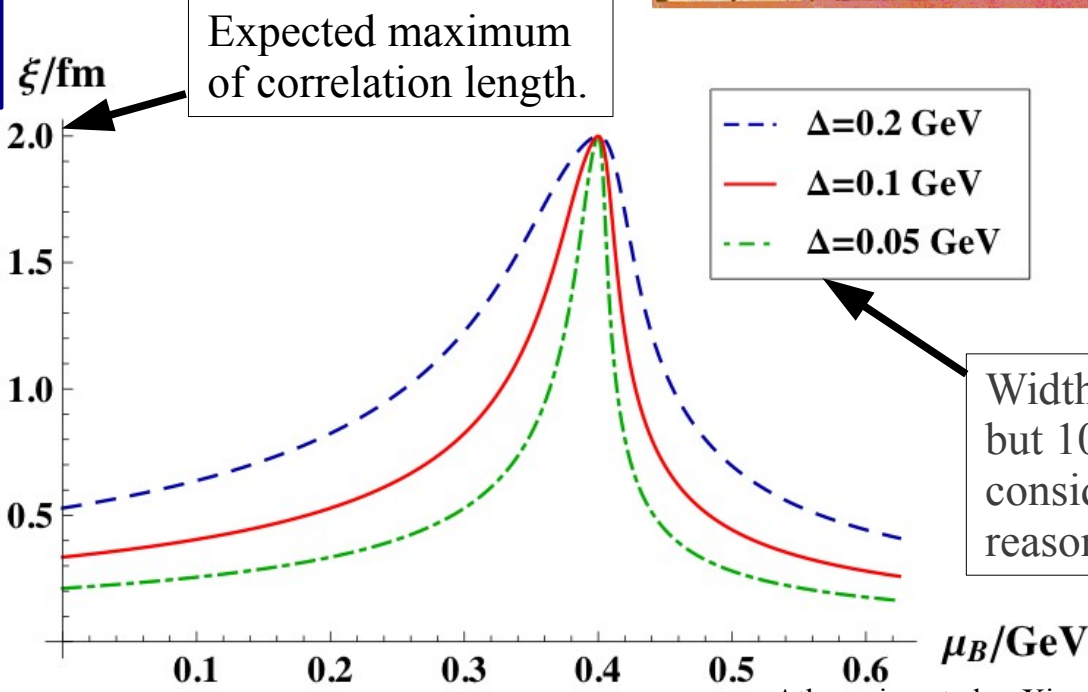
For $T \sim T_c$, substance becomes “cloudy,” indicating long-range density fluctuations.



T. Andrews, Phil. Trans. Royal Soc., 159:575, 1869

A similar increase in the correlation length is expected in the hot and dense nuclear systems formed at RHIC.

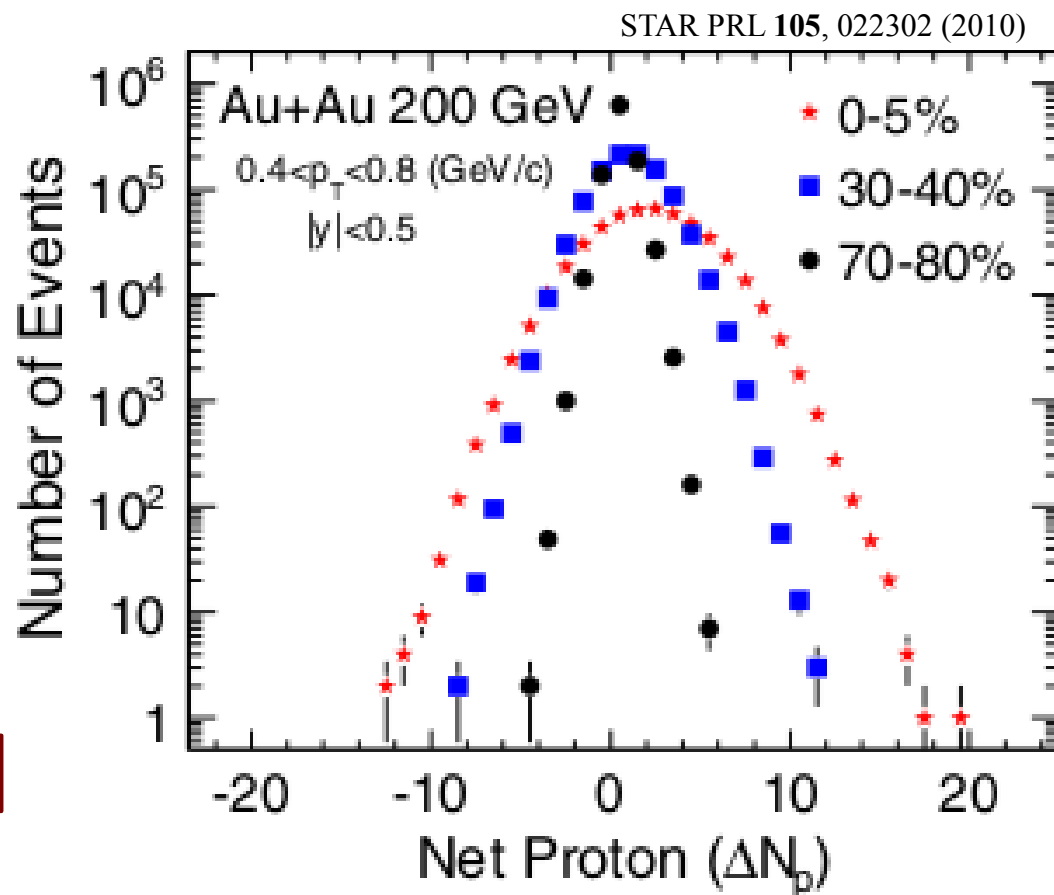
An *ansatz* reproducing the expected trends of the correlation length versus the baryo-chemical potential.



Athanasiou et al, arXiv: 1006.4636v2 [hep-ph]

Experiment observables

At STAR, we measure the multiplicity distributions of identified particles, such as net-protons (shown to the right).



number in an event

“deviate” ← $\delta x \equiv x - \langle x \rangle$

average number in an ensemble of events

$$\kappa_{2x} \equiv \langle \langle x^2 \rangle \rangle \equiv \langle (\delta x)^2 \rangle$$

$$\kappa_{3x} \equiv \langle \langle x^3 \rangle \rangle \equiv \langle (\delta x)^3 \rangle$$

$$\kappa_{4x} \equiv \langle \langle x^4 \rangle \rangle \equiv \langle (\delta x)^4 \rangle - 3 \langle (\delta x)^2 \rangle^2$$

“cumulants” ←

Experiment observables

Near the critical point, the **cumulants** will diverge with large powers of the correlation length (ξ).

$$\kappa_{2x} = \langle (\delta x)^2 \rangle \sim \xi^2 \quad \kappa_{3x} = \langle (\delta x)^3 \rangle \sim \xi^{4.5}$$

$$\kappa_{4x} = \langle (\delta x)^4 \rangle - 3\langle (\delta x)^2 \rangle^2 \sim \xi^7$$

Stephanov PRL **102**, 032301 (2009)

Higher moments scale with higher powers of the correlation length.

The final observable needs to have volume normalization. This presentation will concentrate on the intensive normalized cumulants ω_3

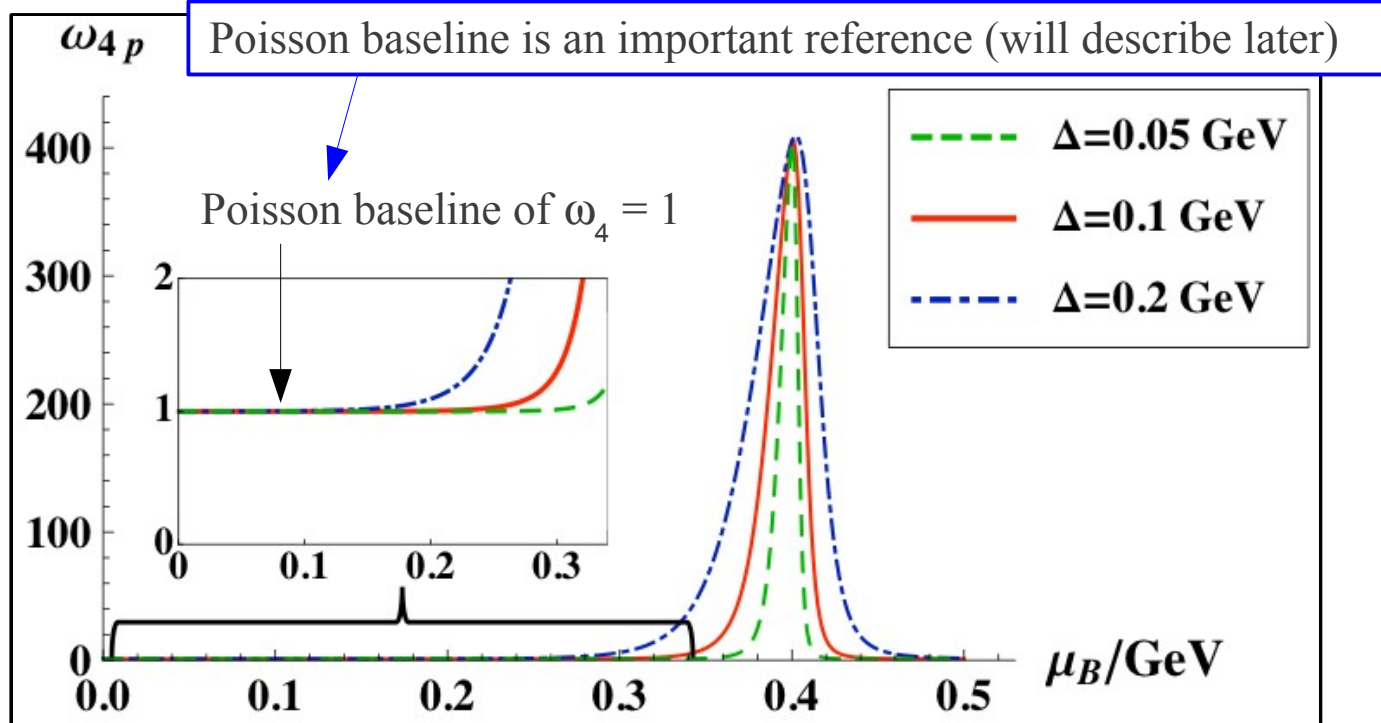
and ω_4 .

$$\omega_{ix} = \kappa_{ix} / \langle N_x \rangle$$

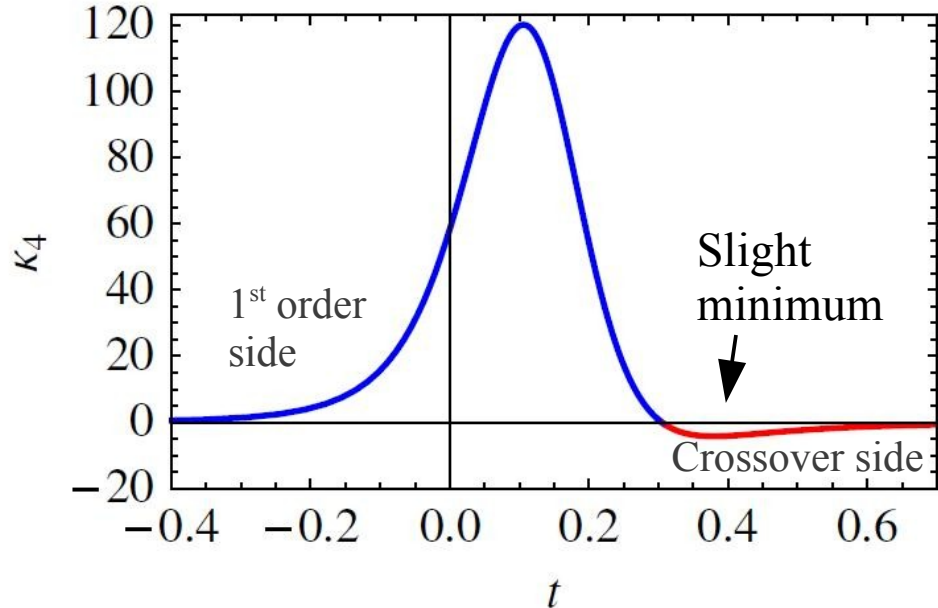
← volume normalization is the average number of particles.

Behaviour of experiment observable near critical point

Non-linear sigma model from:
Athanasίου et al, hep-ph: 1006.4636v2



M.A. Stephanov, PRL 107, 052301 (2011)



This model predicts **large enhancements** of the 4th cumulant and other cumulants near the critical point.

Charged particle groups

Experimentally, we measure the following particle groups as possible proxies of conserved quantities:

Baryon number	→ Net-protons	[p-pbar]	(B)
Strangeness	→ Net-Kaons	[K ⁺ -K ⁻]	(S)
Charge	→ Net-charge		(Q)

and study the beam-energy dependence of the moments values. The beam energy is our “knob” of the baryo-chemical potential.

Net-charge has been proposed to have a strong sensitivity to chiral symmetry breaking and deconfinement and is related to the net-baryon and isospin fluctuations. Skokov 1108.3231v1

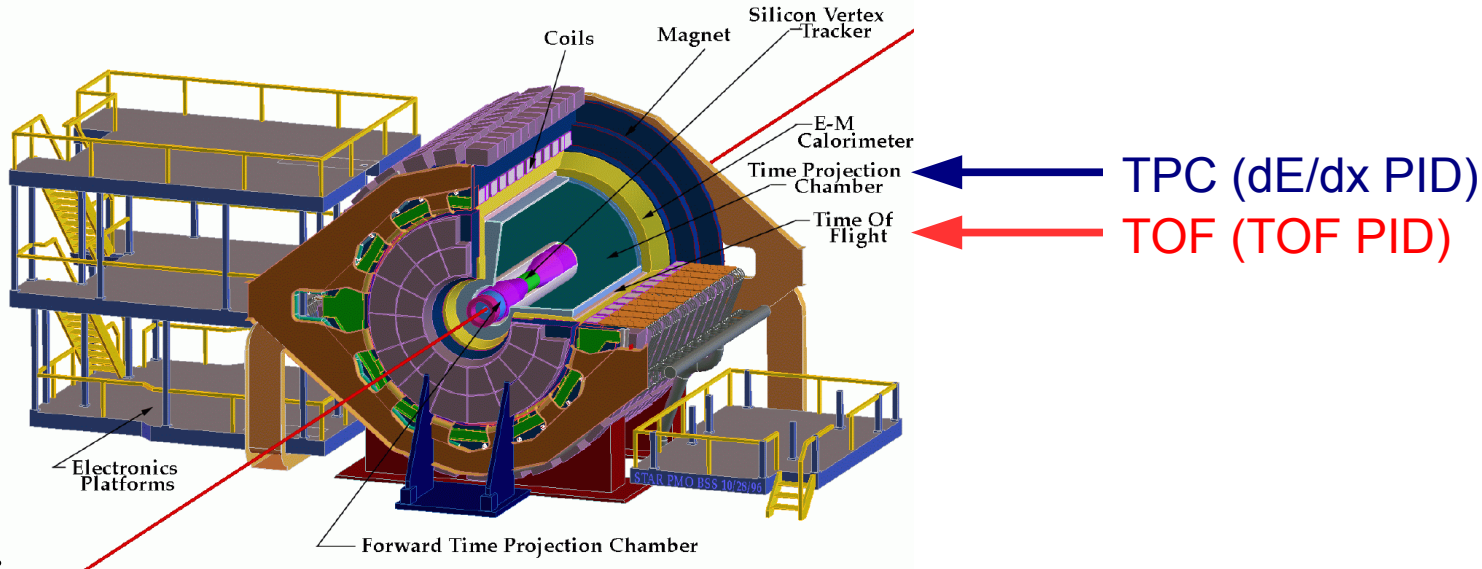
“Sigma field is isospin blind” → moments of the total multiplicity (e.g. p+pbar) might be more sensitive to the critical phenomena than are the moments of the net multiplicity (e.g. p-pbar). We will present both the total- and net-multiplicity moments of protons.

Athanasίου et al. hep-ph: 1006.4636v2

Analysis Details: Detectors and Cuts

Third and fourth moments are very sensitive to possible critical fluctuations, but are also very sensitive to experiment effects (background, drift, etc). It is important to remove these experimental effects via careful data QA and cuts.

Solenoidal Tracker at RHIC (STAR)



Good event cuts:

- all beam energies: $|Z_{vtx}| < 30$ cm, $R_{vtx} < 1.2$ cm, $TOF_{match} \geq 5$ & other cuts on global observables
- careful bad run rejection performed

Good track cuts:

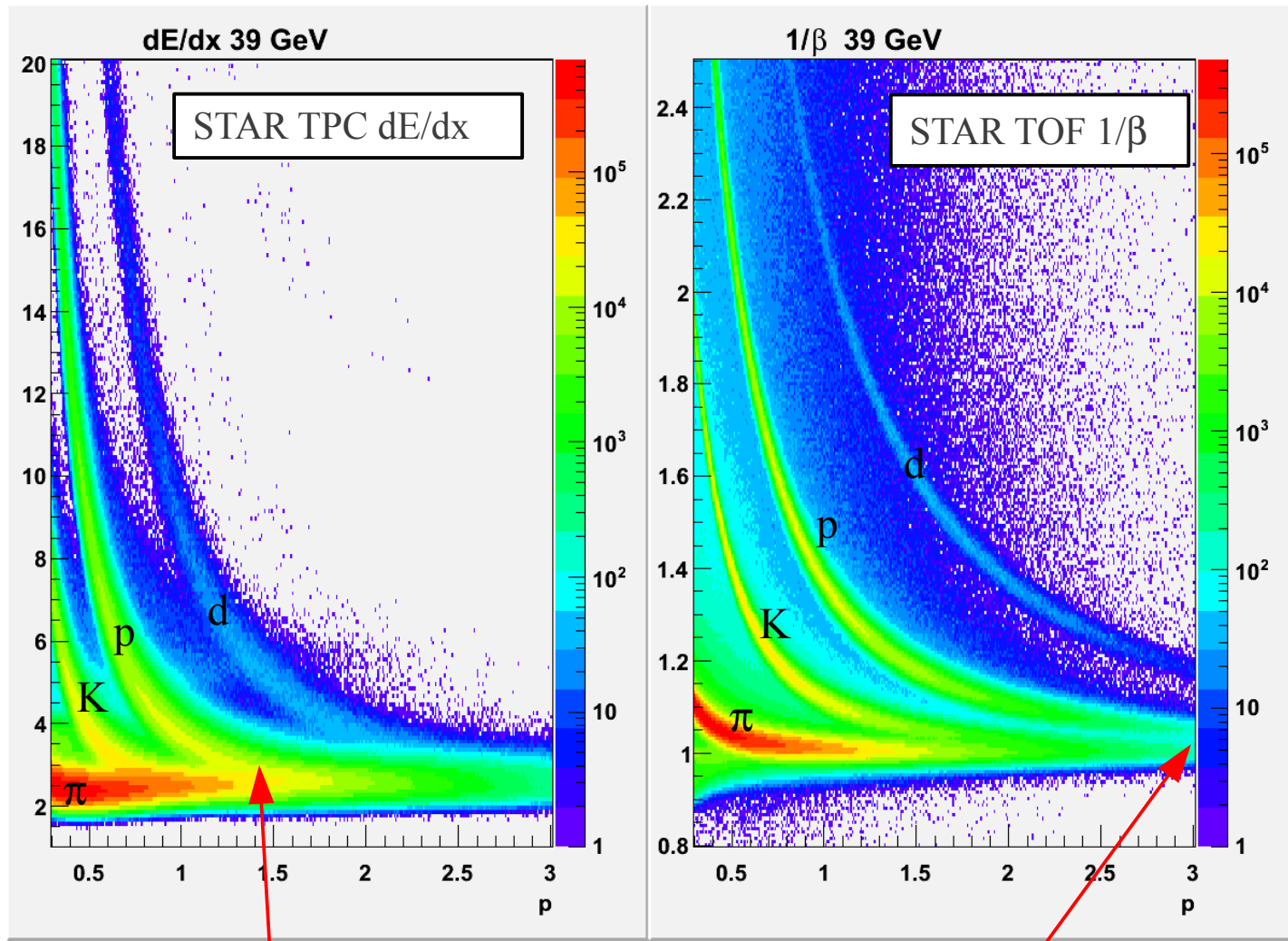
- $N_{hitsfit} > 15$, $N_{hitsdE/dx} > 10$, $|\eta| < 0.5$, $globaldca < 1.0$ cm, $N_{hitsratio} > 0.52$
- $0.2 < p_t < 1.0$ GeV, $p < 1.6$ GeV for π, K $0.4 < p_t < 1.0$ GeV, $p < 2.8$ GeV for protons

Numbers of events surviving cuts (0-80%)

	7.7 GeV	11.5 GeV	19.6 GeV	39 GeV	62.4 GeV	200 GeV
# events	1.74 M	6.12 M	14.3 M	22.6 M	39.5 M	45.0 M

Analysis Details: Particle Identification

Plots of dE/dx and TOF versus momentum results in distinct bands for the different pion, Kaon, and proton particle species.



Protons merge with π/K at around 1.5 GeV

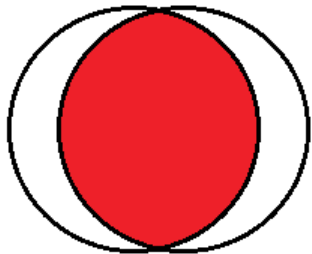
Protons merge with π/K at around 3 GeV. The TOF detector dramatically extends the reach of particle identification.

PID used here:

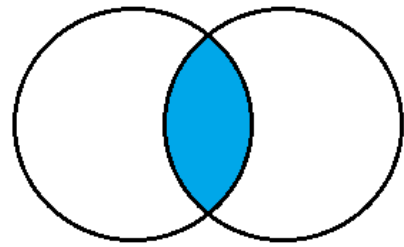
- A 2σ cut on dE/dx_{expected} for identified charged particles with a minimum momentum cut
- Reconstruct $Mass^2$ using $1/\beta$ from TOF detector, and cut on $Mass^2$ for identified charged particles with a maximum momentum cut.
- Momentum cuts prevent contamination where particle bands merge

Analysis Details: Centrality

Centrality is a measure of how “head-on” a collision is.



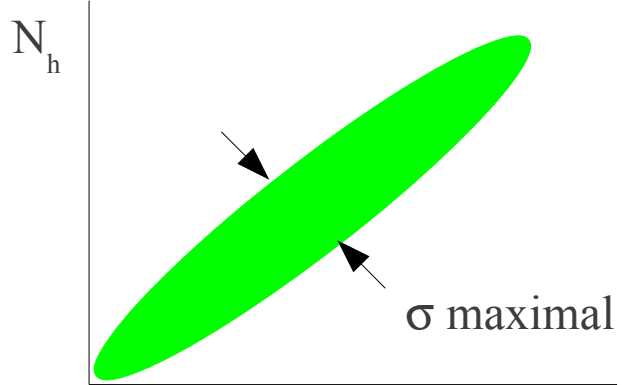
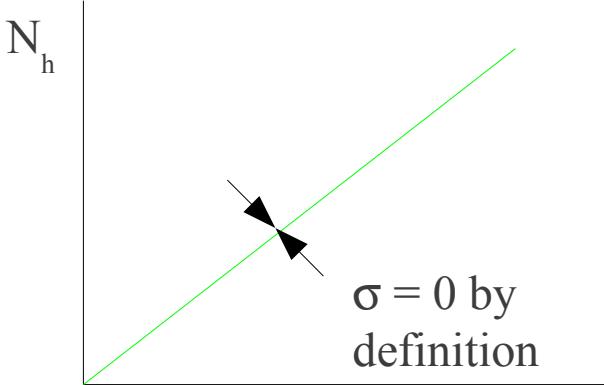
Central



Peripheral

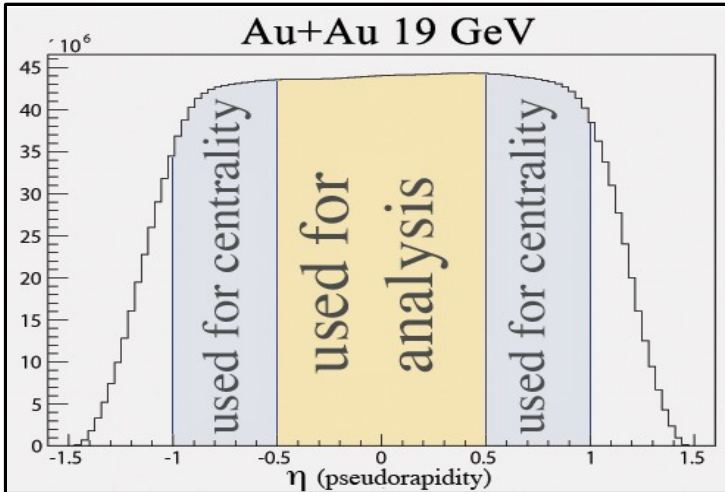
Views of collision along beam axis

Using (some of) the same particles to define centrality and measure the moments suppresses variances mathematically (autocorrelation).



Centrality (N_h)

Centrality



Centrality bin limits defined by a Glauber simulation.

- To avoid autocorrelations with the centrality definition:
- analyze moments for $|\eta| < 0.5$
 - determine centrality using $0.5 < |\eta| < 1.0$

Final details of analysis

Moments are corrected for centrality bin-width effects by using the weighted average of the moments inside each centrality bin.

X. Luo arXiv: 1106.2926 [nucl-ex]

Cumulants

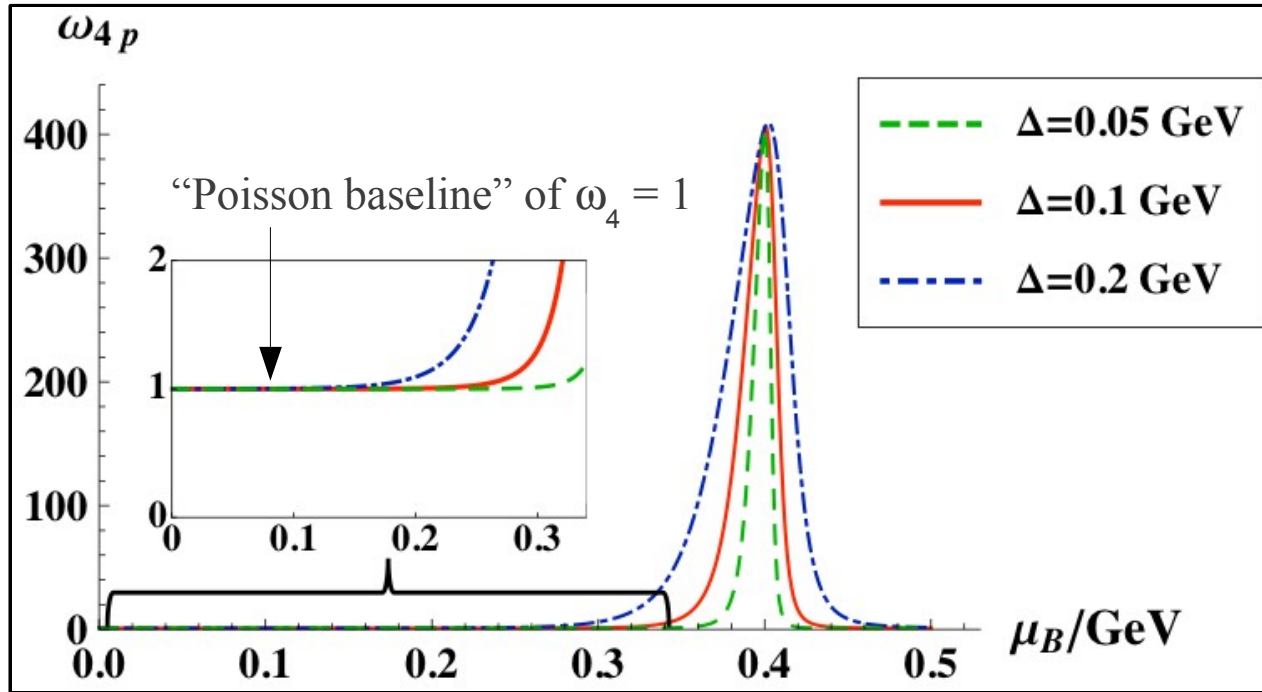
- Will show cumulants for 4 particle groups:

p-pbar	net-protons	proxy of net-baryon number
K^+K^-	net-Kaons	possible proxy of net-strangeness
pos-neg	net-charge	
p+pbar	total-protons	

Error bars shown are from an analytical calculation and are statistical only.

The results to be shown for ω_3 and ω_4 are from the 0-5% centrality bin.

Poisson baseline



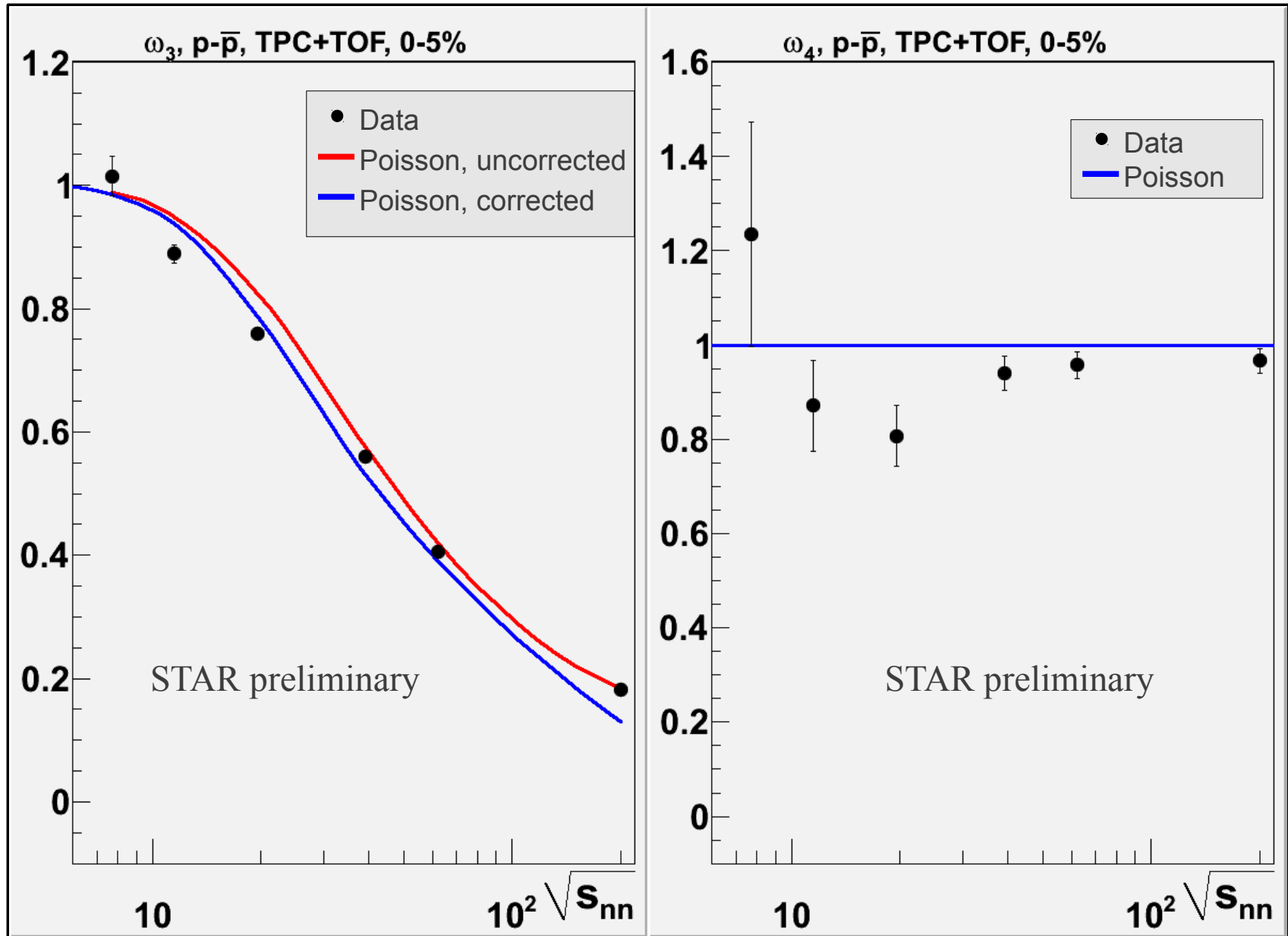
To the extent that the multiplicity distributions are poisson, there are very simple relations based only on the average number of particles that allow a prediction for ω_3 and ω_4 , where $\mu_+ = \langle N_+ \rangle$, $\mu_- = \langle N_- \rangle$

$$\omega_{3,\text{poisson}} = (\mu_+ - \mu_-) / (\mu_+ + \mu_-) \quad \omega_{4,\text{poisson}} = (\mu_+ + \mu_-) / (\mu_+ + \mu_-) = 1$$

We have two different choices for the values of μ_+ and μ_-

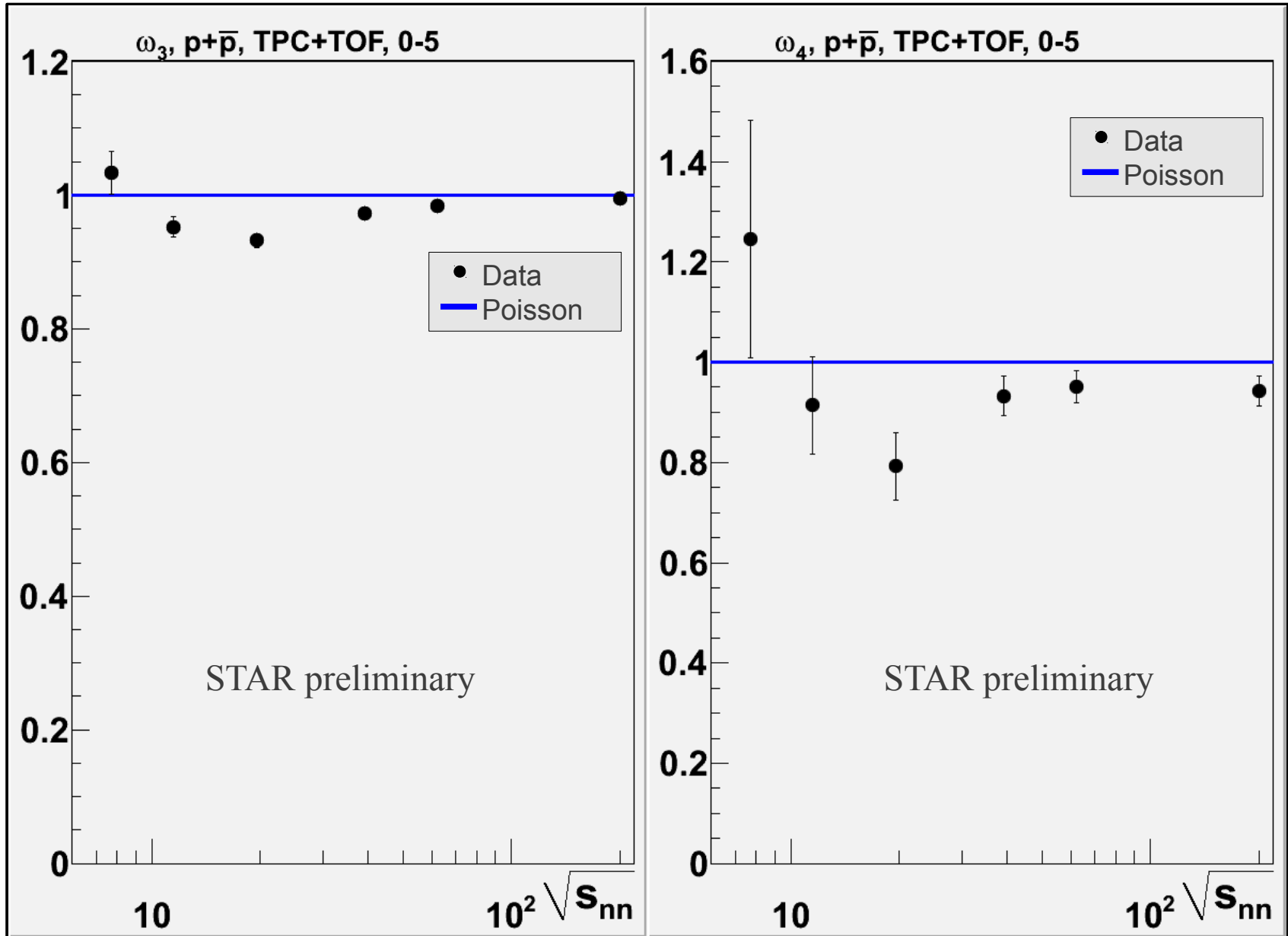
- 1) **efficiency-corrected** multiplicities, STAR published
- 2) **uncorrected** multiplicities, from this analysis directly

ω_3, ω_4 net-protons, proxy of net-baryon number



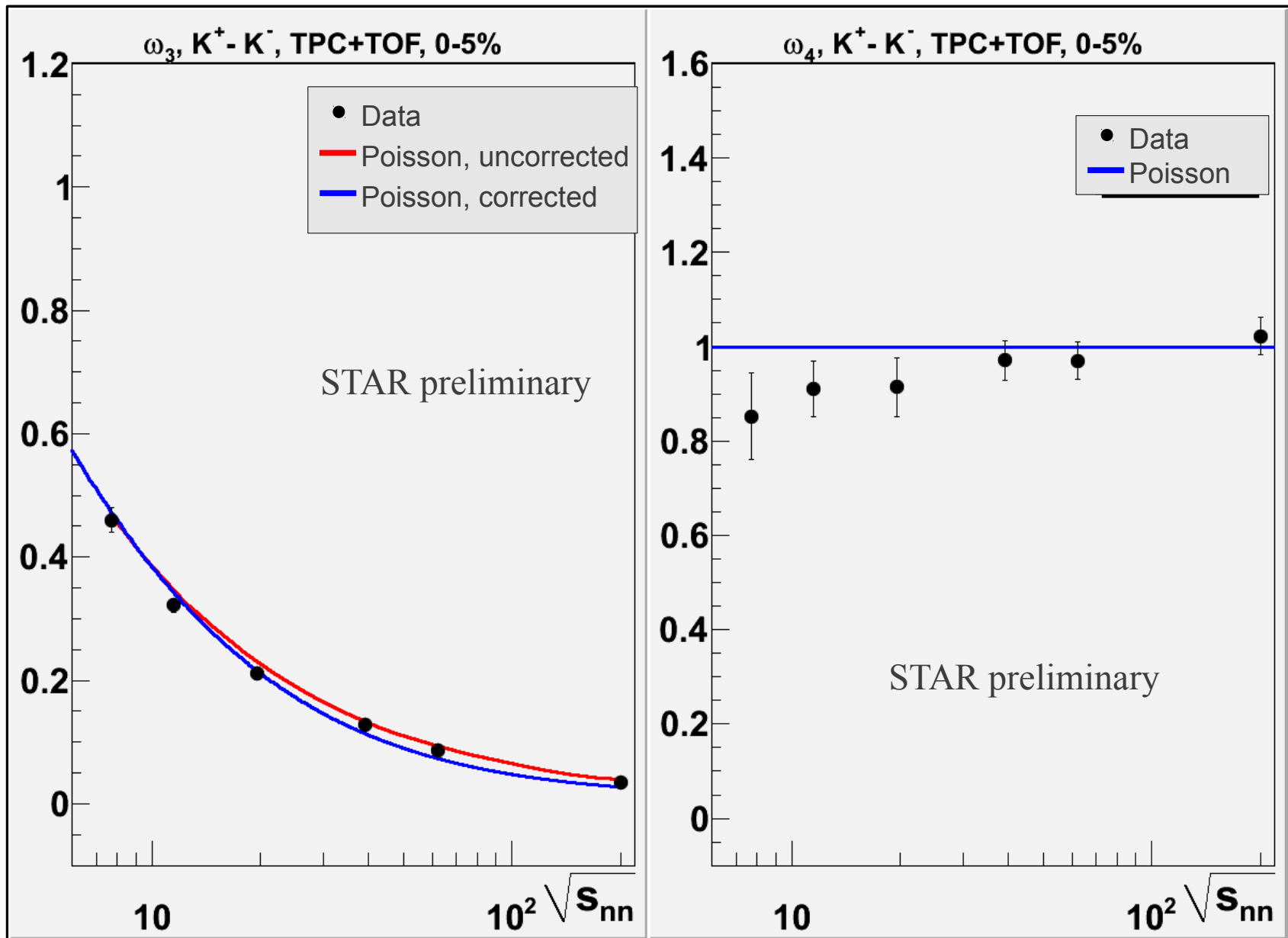
No enhancement relative to Poisson baseline observed.

ω_3, ω_4 total-protons



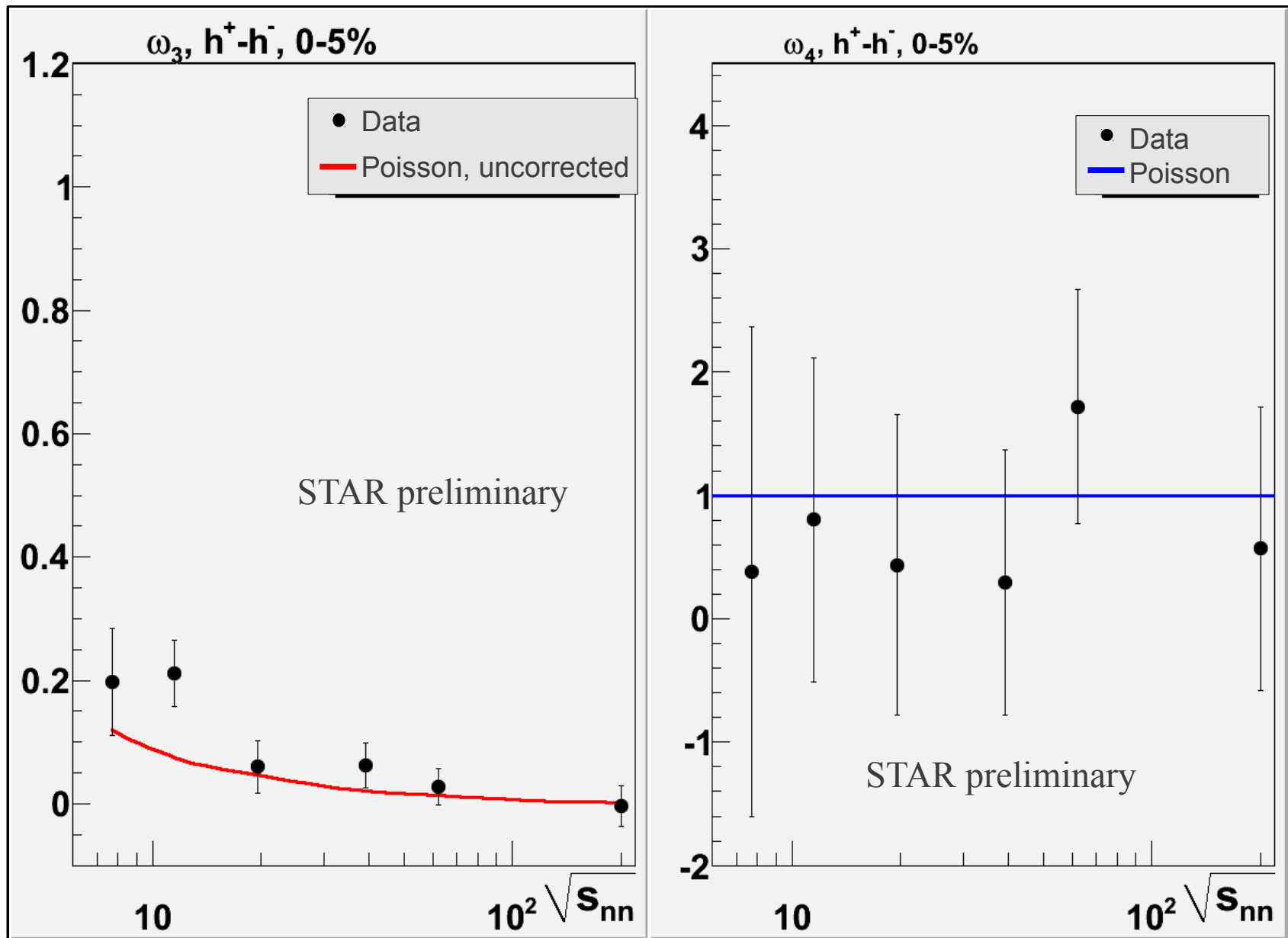
No enhancement relative to Poisson baseline observed.

ω_3, ω_4 net-Kaons, possible proxy of net-strangeness



No enhancement relative to Poisson baseline observed.

ω_3, ω_4 net-charge



No enhancement relative to Poisson baseline observed.

Summary

- Critical point would be a landmark measurement if it exists.
- Critical point might result in non-monotonic changes to the statistical moments of the multiplicity distributions of specific groups of identified charged particles.
- STAR studied Au+Au collisions over 7.7 - 200 GeV ($\sim 20 < \mu_B < \sim 420$ MeV).
 - Careful cuts applied to get clean data samples.
 - PID from a combination of TPC and TOF detectors.
- Calculated the intensive-normalized cumulants ω_3 and ω_4 for: p-pbar, p+pbar, K^+K^- , and net-charge and compared them to their respective Poisson baselines.
- At the presently available beam energies, **no enhancement of ω_3 and ω_4 cumulant values with respect to the Poisson baselines was observed.**
- It might be that the critical point is “in between” existing data sets. Largest unexplored gap is in between 11.5 and 19.6 GeV ($\Delta\mu_B = 110$ MeV). This gap is large relative to the expected width of the critical point signal.
- **Many thanks to CAD for delivering useful collisions at these low root-s values – which we understand was very technically challenging. Very interesting data was obtained!**
- **We hope to get new data sets at $\sqrt{s_{NN}}$ values near and below ~ 19.6 GeV.**
- Thank you!