Search for the critical point through the rapidity dependence of cumulants

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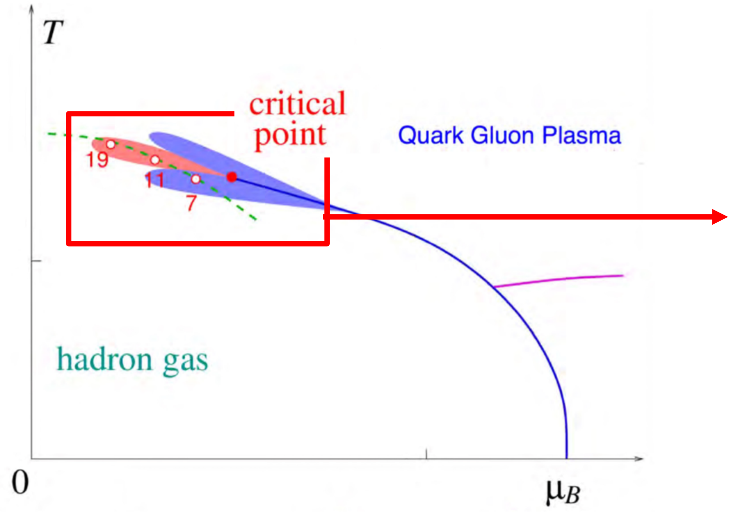
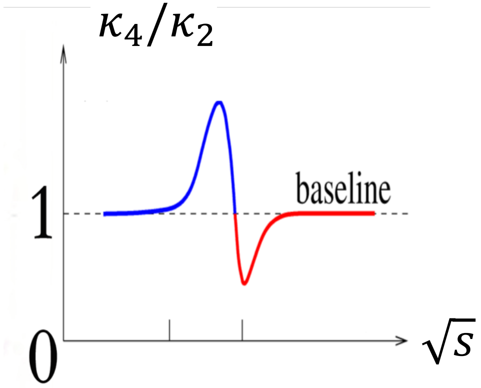
arXiv: 1804.10215

Search for a critical point at the Beam Energy Scan

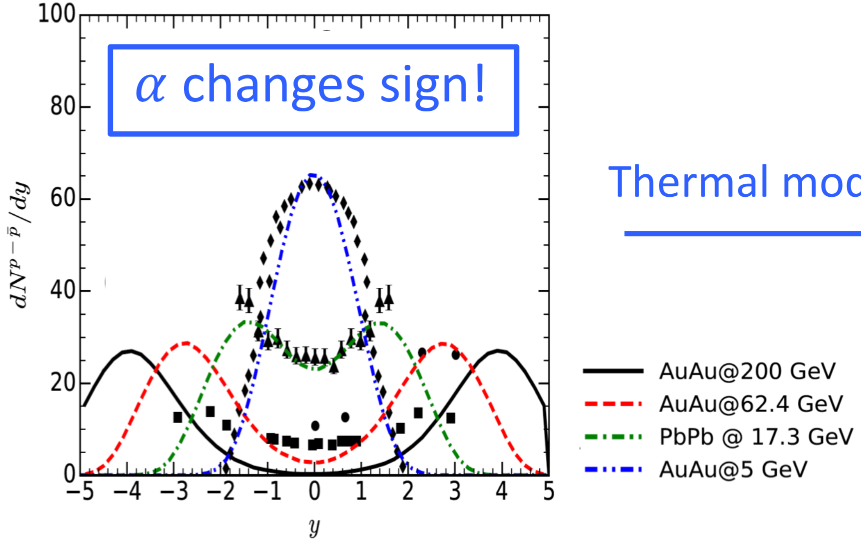
- characteristic signature: non-monotonicity and sign change of event-by-event fluctuations as a function of beam energy





Stephanov 0809.3450, 1104.1627

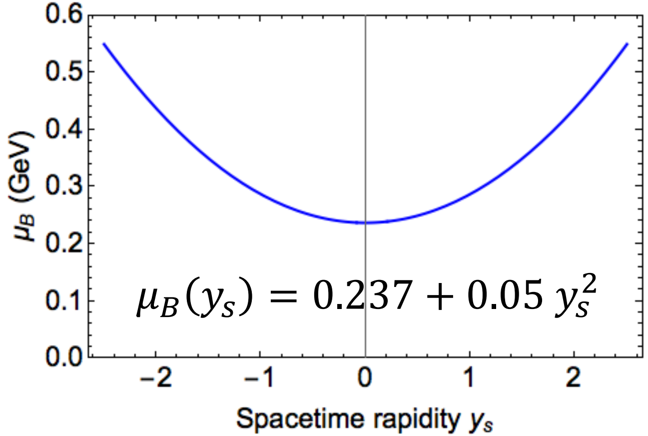
At RHIC energies, μ_B has non-trivial rapidity dependence



Shen and Schenke, 1710.00881

Thermal model fit →

$\sqrt{s} = 17.3$ GeV

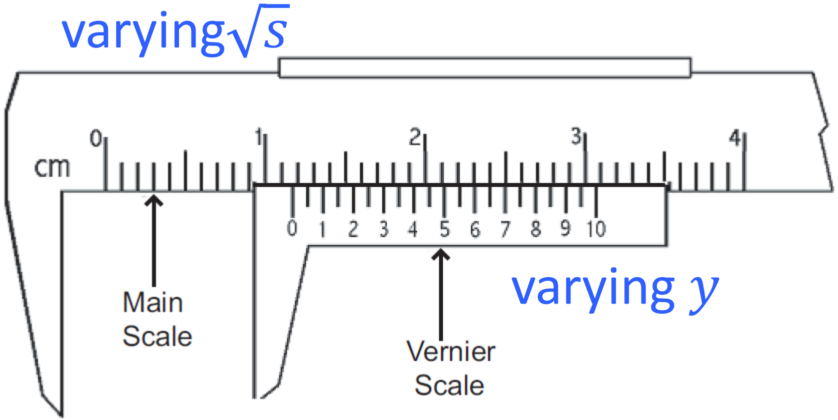


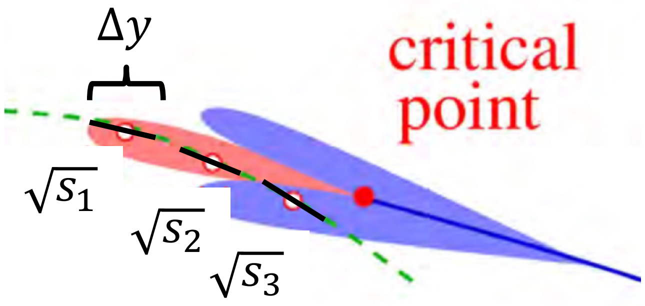
Beccatini et. al. 0709.2599

$\alpha \approx 50\ MeV$

Simplest parameterization near mid-rapidity: $\mu_B(y_s) = \mu_{B,0} + \alpha\, y_s^2$

Rapidity is a finer-resolution probe of the critical regime than $\sqrt{s}$





"mini-scan" in y can be used to give additional signatures of a CP

Cumulants near a critical point

Higher cumulants scale with higher powers of the correlation length

$\kappa_2 \sim \xi^2$ $\kappa_3 \sim \xi^{9/2}$ $\kappa_4 \sim \xi^7$

$$\kappa_{4,\sigma} = \int_{\mathbf{x}} \overbrace{\underbrace{K_4 \xi^7 T^2}_{\text{controls sign change}}}^{\text{critical fluctuations}} \Bigg(\underbrace{g_p \int_{\mathbf{p}} \frac{\chi_{\mathbf{p}}}{\gamma_{\mathbf{p}}}}_{\text{protons coupling to fluctuations}} \Bigg)^4$$

$$\chi_{\mathbf{p}} \equiv \frac{\partial f_{\mathrm{eq}}}{\partial \mu_B} \approx f_{\mathrm{eq}}/T$$

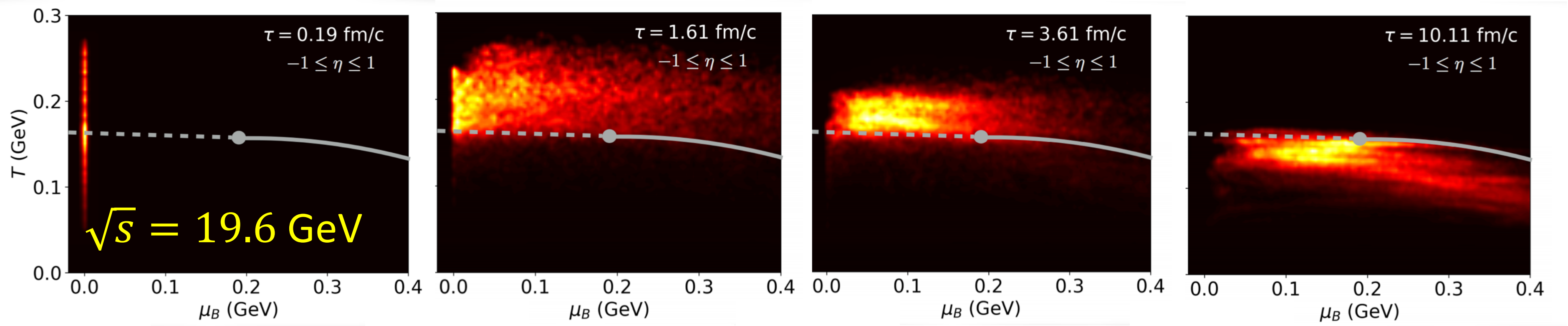
$$f_{\mathrm{eq}} \sim \exp\left(\frac{\mu_B - u \cdot p}{T}\right)$$

Hydro input: $\int_{\mathbf{x}}, \int_{\mathbf{p}}, f_{\mathrm{eq}}$ calculated on the freezeout surface

This work: blast wave

Caveats…

- Freezeout curve may be significantly smeared in a heavy ion collision



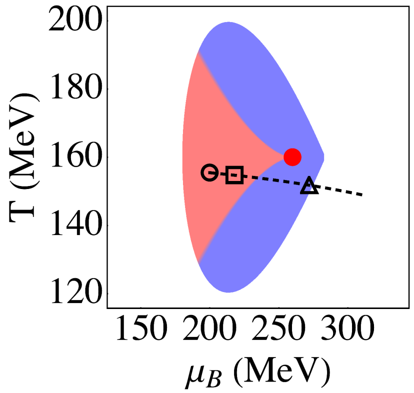
Schenke and Shen, APS 2018

- Non-equilibrium effects of the critical regime could be significant

This work: equilibrium features given average μ_B

Can the rapidity scan help discover a critical point?

Consider a hypothetical heavy ion collision which freezes out near a hypothetical critical point:



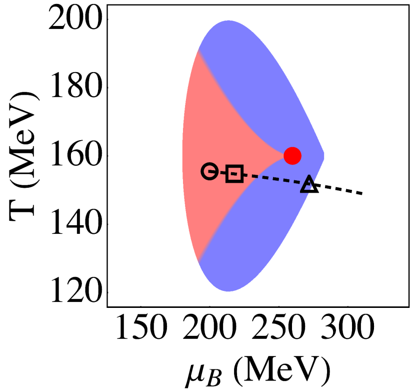
freezeout curve is extended in the critical regime due to

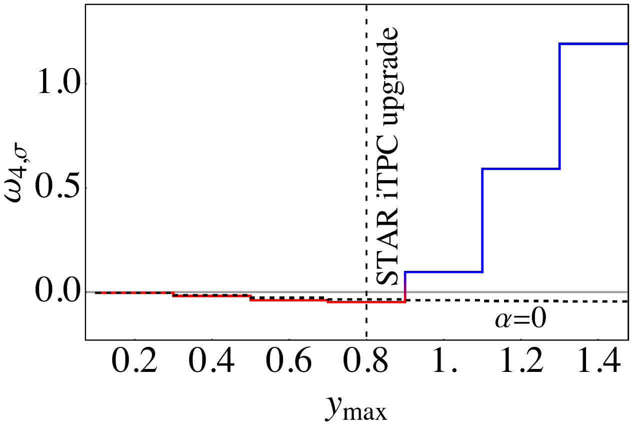
$$\mu_B = \mu_B(y_s) = \mu_{B,0} + \alpha\, y_s^2$$

○ □ △ $\rightarrow y_s = 0, 0.6, 1.2$

$\alpha = 50\ MeV$

Distinctive signatures of criticality arise in the dependence of the kurtosis on the total rapidity acceptance

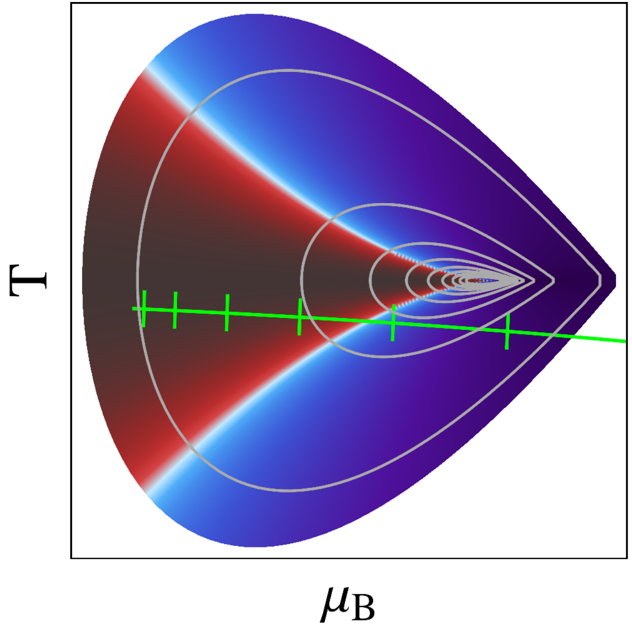




Including contributions from total rapidity acceptance $|y| < y_{max}$ averages over details of the critical regime

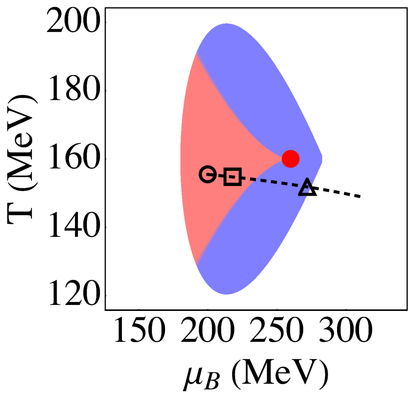
○ □ △ $\rightarrow y_s = 0, 0.6, 1.2$

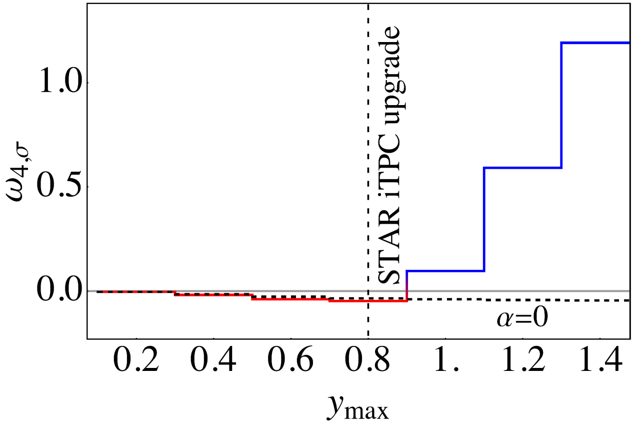
Cumulants localized in rapidity probe localized area in phase diagram

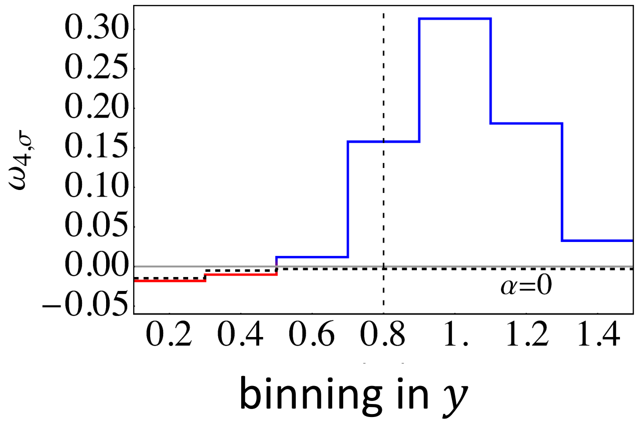


Gives more crisp picture of the critical region

For $\sqrt{s}$ near a critical point, how does the kurtosis depend on rapidity?



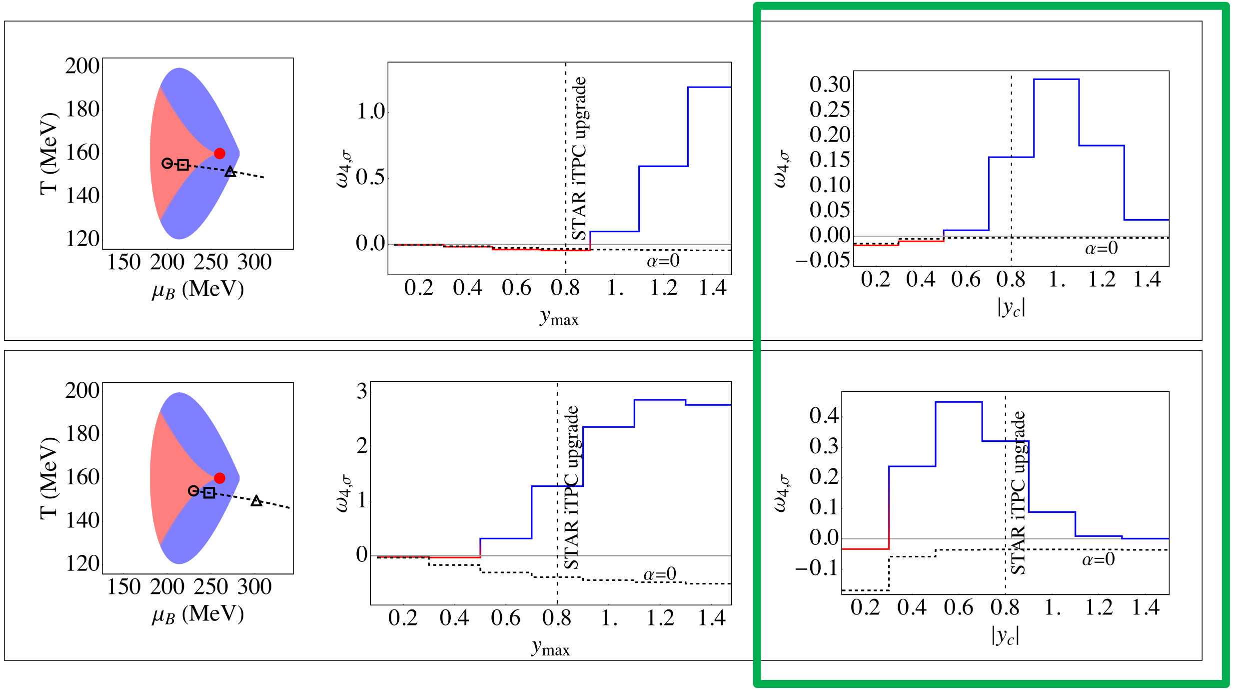




Sign change at lower rapidity

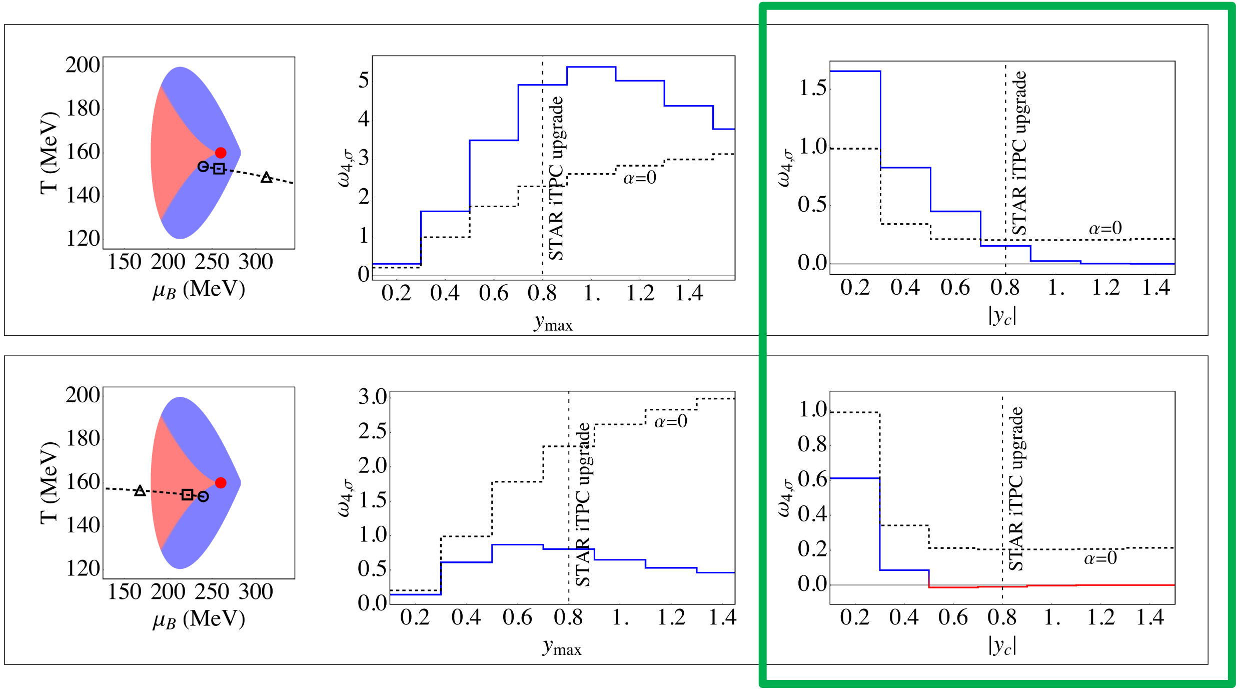
Critical signatures easier to detect at lower rapidity

Decreasing $\sqrt{s}$ to approach a critical point, binned cumulants increase with rapidity



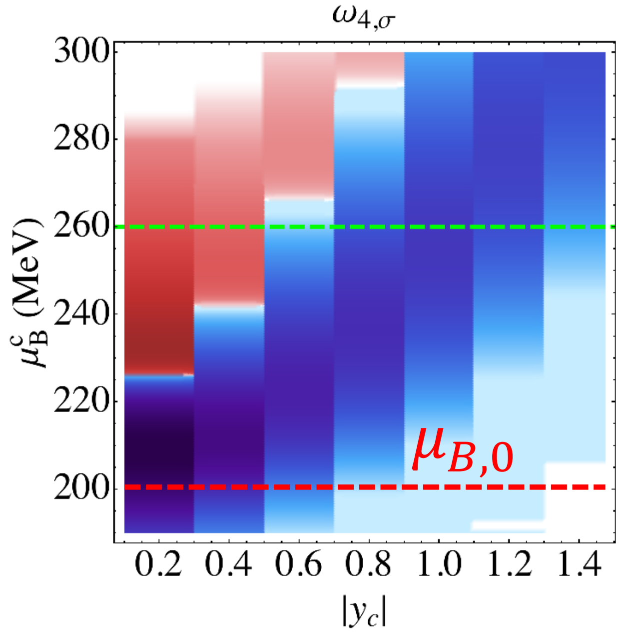
Increasing with rapidity near mid-rapidity

If a critical point is passed, binned cumulants switch to decreasing with rapidity



Decreasing with rapidity near mid-rapidity

Whether cumulants binned in rapidity increase or decrease as a function of rapidity **switches** when a critical point is passed



Independent test of critical behavior from $\sqrt{s}$-dependence of cumulants

What have we learned?

- Rapidity dependence of μ_B gives the rapidity dependence of cumulants characteristic signatures of criticality

- Binning cumulants in rapidity gives a more sensitive probe of the critical region than considering the full rapidity acceptance

- The rapidity dependence of binned cumulants changes qualitatively if the critical point is passed in the beam energy scan
    - Rapidity dependence gives independent test of location of critical point to $\sqrt{s}$ dependence