Critical *vs.* spurious fluctuations in the search for the QCD critical point

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Outline

The QCD critical point

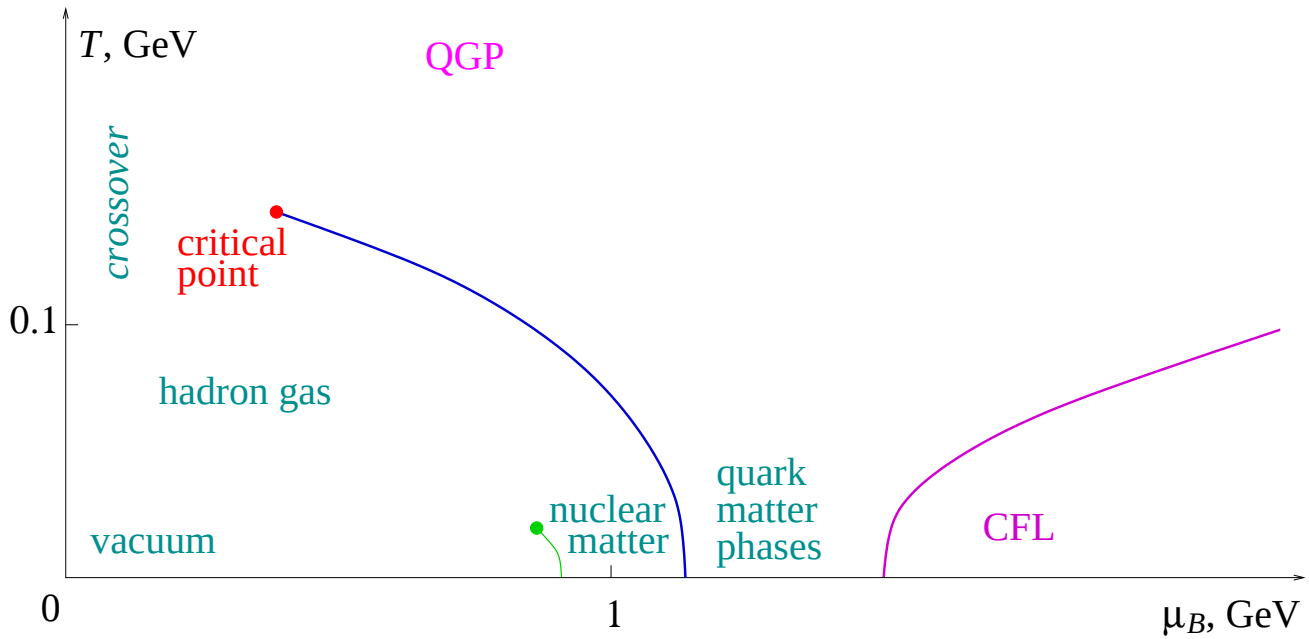


Figure: A semiquantitative representation of the QCD phase diagram. Ref.: M. Stephanov (2006).

Can heavy ion collisions reach the neighborhood of the critical point? Is it there? What would its signatures be?

Experimental signatures

Theory

- "$\xi \to \infty$": long range fluctuations (pions, protons ...).
- Statistical moments of observables (e.g. $\langle (\Delta N)^3 \rangle$) as signatures in HICs (focus: multiplicity).

Reality (HICs)

- Spurious contributions, finite size/duration: $\xi \nrightarrow \infty$...
- Do signatures "survive", even in a simplified model?
- Need to test basic realistic ingredients!

Mission: Test signatures under the most optimistic scenario

Critical fluctuations

Critical mode

- Classical treatment with homogeneous approximation [a]

$$\mathcal{P}_{\sigma_0}[\sigma_0] \propto \exp\left(\frac{-\Omega[\sigma_0]}{T}\right), \tag{1}$$

$$\Omega[\sigma_0] = V\left(\frac{m_\sigma^2}{2}\sigma_0^2 + \frac{\lambda_3}{3}\sigma_0^3 + \frac{\lambda_4}{4}\sigma_0^4 + \cdots\right), \tag{2}$$

with $\quad m_\sigma \sim \xi^{-1}, \qquad \lambda_3 \sim T\,(T\,\xi)^{-3/2}, \qquad \lambda_4 \sim (T\,\xi)^{-1}.$

[a] Stephanov, Rajagopal, Shuryak (1999); Stephanov (2009); Tsypin (1996).

Distribution changes at the CEP $\Rightarrow$ change in cumulants!

Framework

Interaction

- Mass correction

$$\delta m_\pi^2 = 2\,G\,\delta\sigma_0\,, \qquad \delta m_p = g\,\delta\sigma_0 \qquad (G \approx 300\text{MeV},\ g \approx 10). \quad (3)$$

- Fluctuations of σ change m, change distribution of particles.
- Freeze-out near the CEP $\Rightarrow$ possible observation.
- Correlated fluctuations of observables $\Rightarrow$ **signal**.
- Analytically, expansion in $\delta\sigma_0$ followed by average.

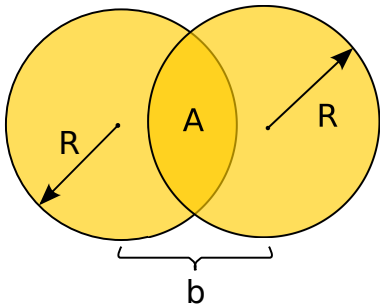
Framework for Monte Carlo simulations!
Background can be added!

HICs' background contributions

In HICs, not everything is under control

1. Gaussian temperature fluctuations ($\sigma_T = 5\%$)
2. Geometrical fluctuations (below)

Geometric fluctuations

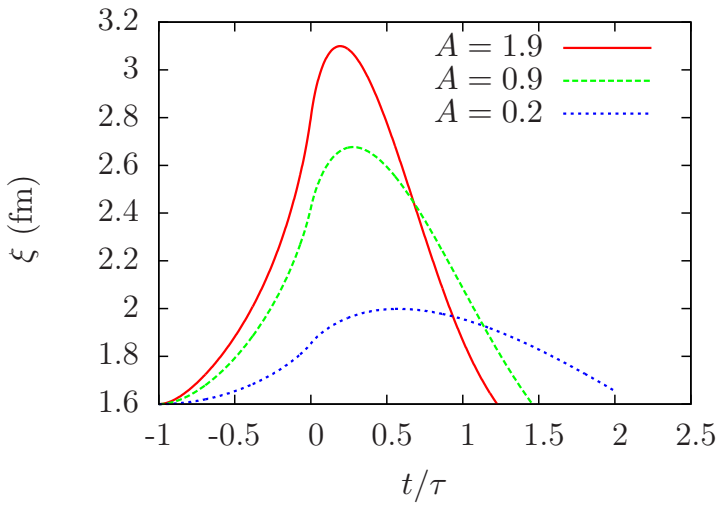


- Impact parameter distribution $\Rightarrow$ Overlap area.
- Assumption $V(b) = C\ A(b)$.
- Fix $R_p = 6.8$ fm for $0 - 5\%$ centrality.
- Analytically, expansion of $p_i = \dfrac{\alpha_i}{R_p + \delta R_p}$.

HICs' inherent limitations

Also, no thermodynamic limit or equilibrium.

Critical Slowing Down

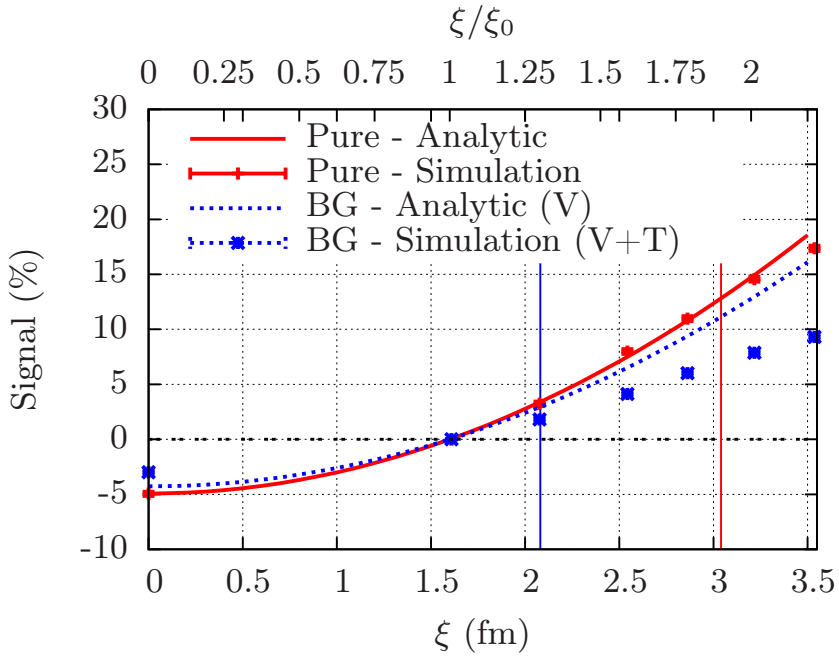


- $\xi \nrightarrow \infty$
- Equilibration is slow near the critical point.
- ξ does not reach its equilibrium value.
- Speed-of-light limit

Berdnikov, Rajagopal (2000),
MH, Fraga, Santos (2015).

Signatures of pions

- Signal in $\langle(\Delta N_\pi)^2\rangle/\langle N_\pi\rangle$.
- Excellent agreement with analytic calculations!



MH, Fraga, Santos (2015).

Final remarks

Conclusions:

- Theoretical expectations *vs.* reality!
- Simplified model + noise $\Rightarrow$ visible signatures?
- Background contributions can be **very relevant**.

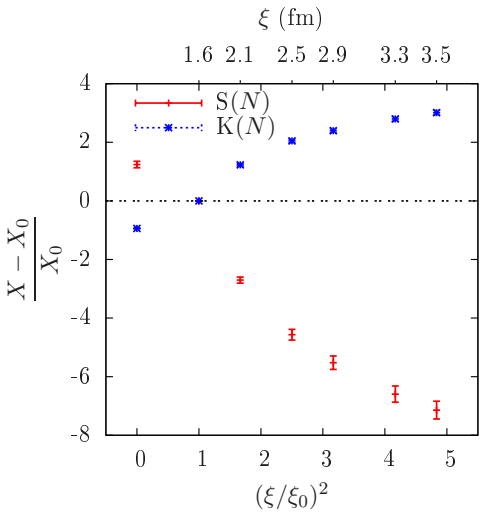
Perspectives:

- Other signatures to be tested (soon, higher-order and proton).
- More background/limitations.
- Parameter estimation: τ, V_p?
- Dynamics beyond $\xi(t)$.
- Resonance decay contributions.

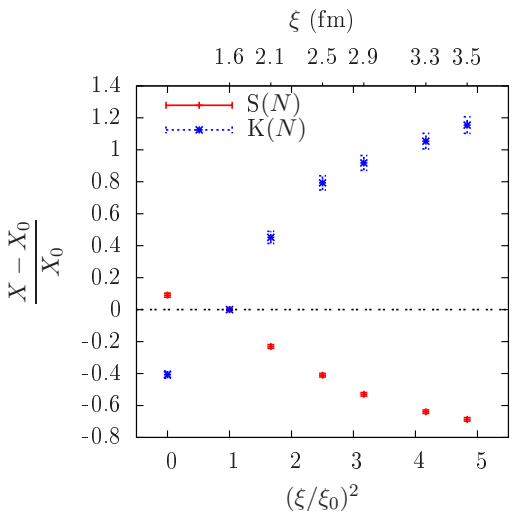
In progress: higher-order signatures

- Our code is ready for higher-order moments (skewness and kurtosis).
- Should yield stronger signals. Results coming soon.

Without spurious contributions:

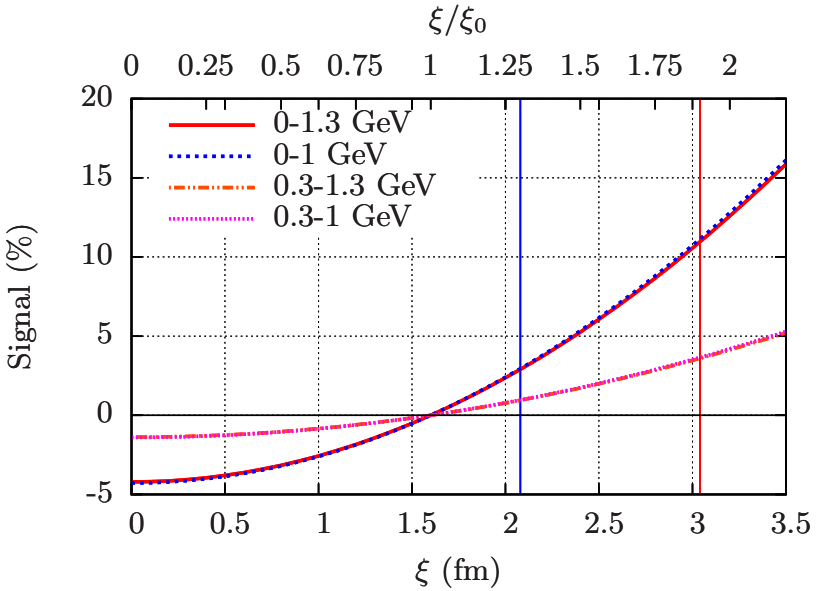


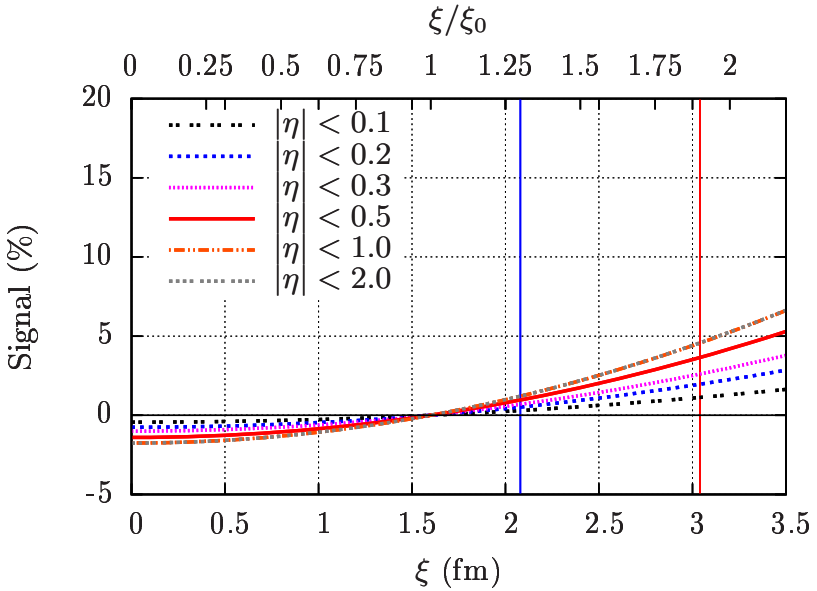
Temperature and volume fluctuations included:



In progress: acceptance effects

- Acceptance effects can also be introduced.
- For now only approximate results.





Preliminary: *MH, Fraga, in preparation.*

Acknowledgements

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