

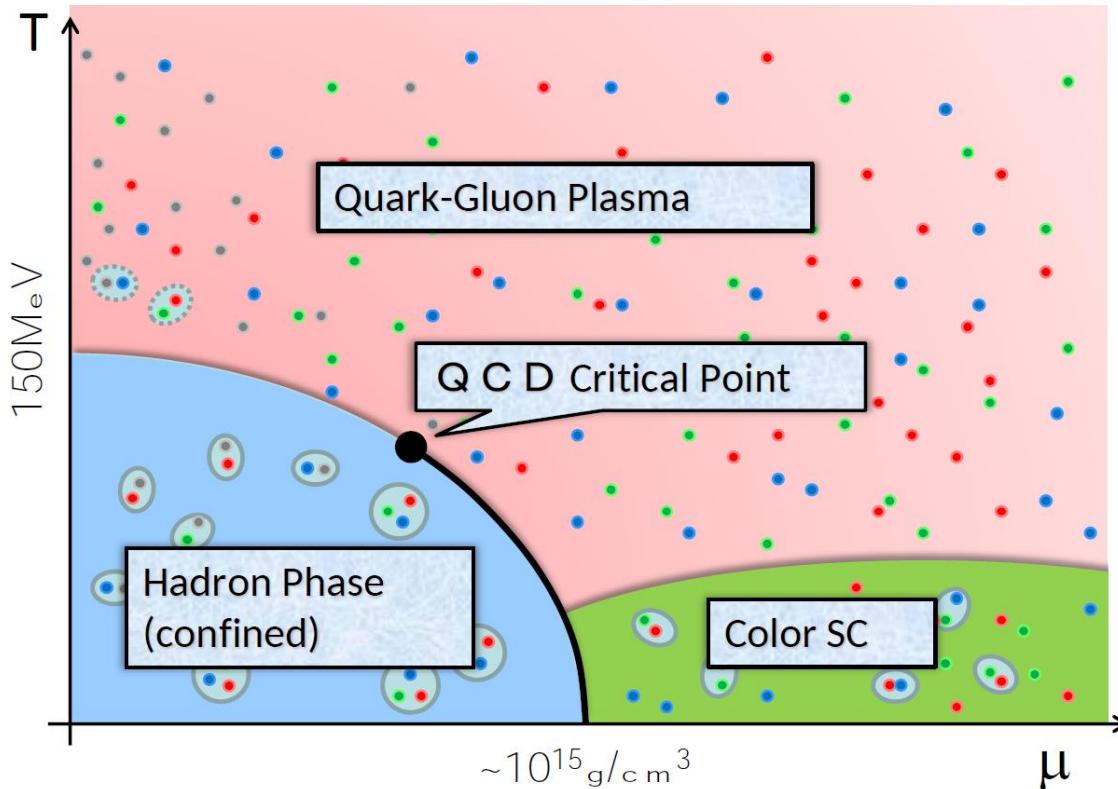
Signals of the QCD critical point in an expanding medium

Grégoire Pihan, Marlène Nahrgang, Marcus Bluhm, Masakiyo
Kitazawa, Taklit Sami, Nathan Touroux



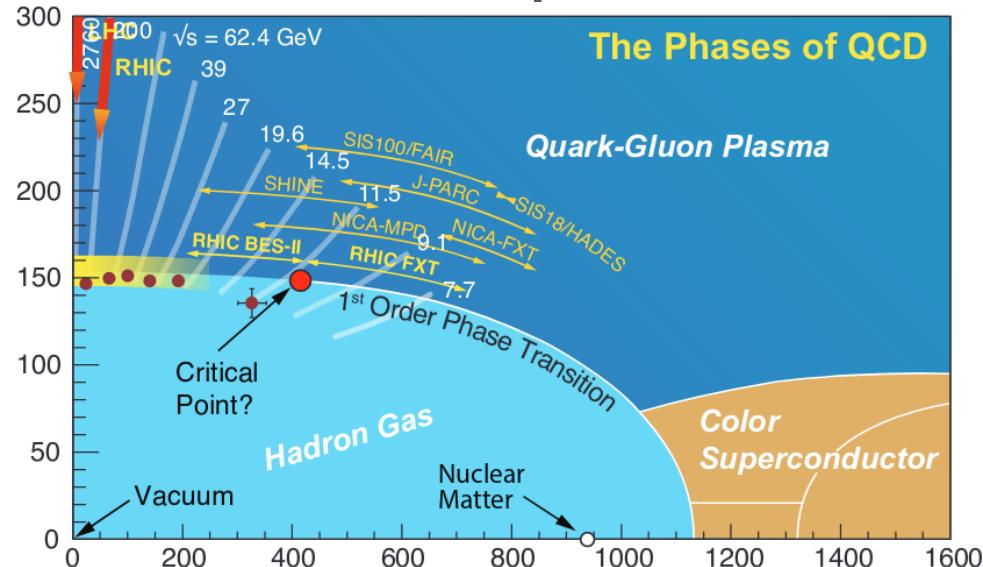
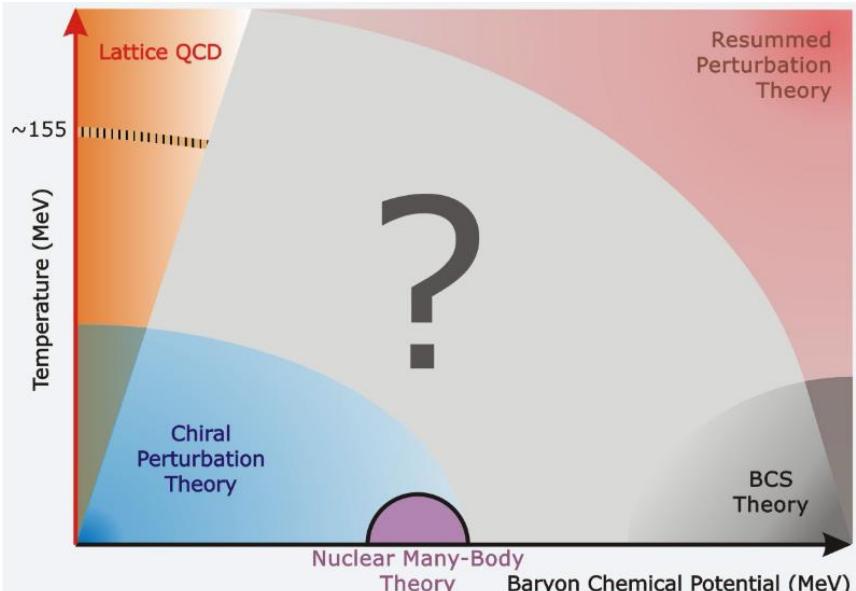
ZIMÁNYI Winter School 2019, Budapest, Hungary, 5. Dec 2019

Search for the QCD critical point



QCD Critical point ?

Search for the QCD critical point

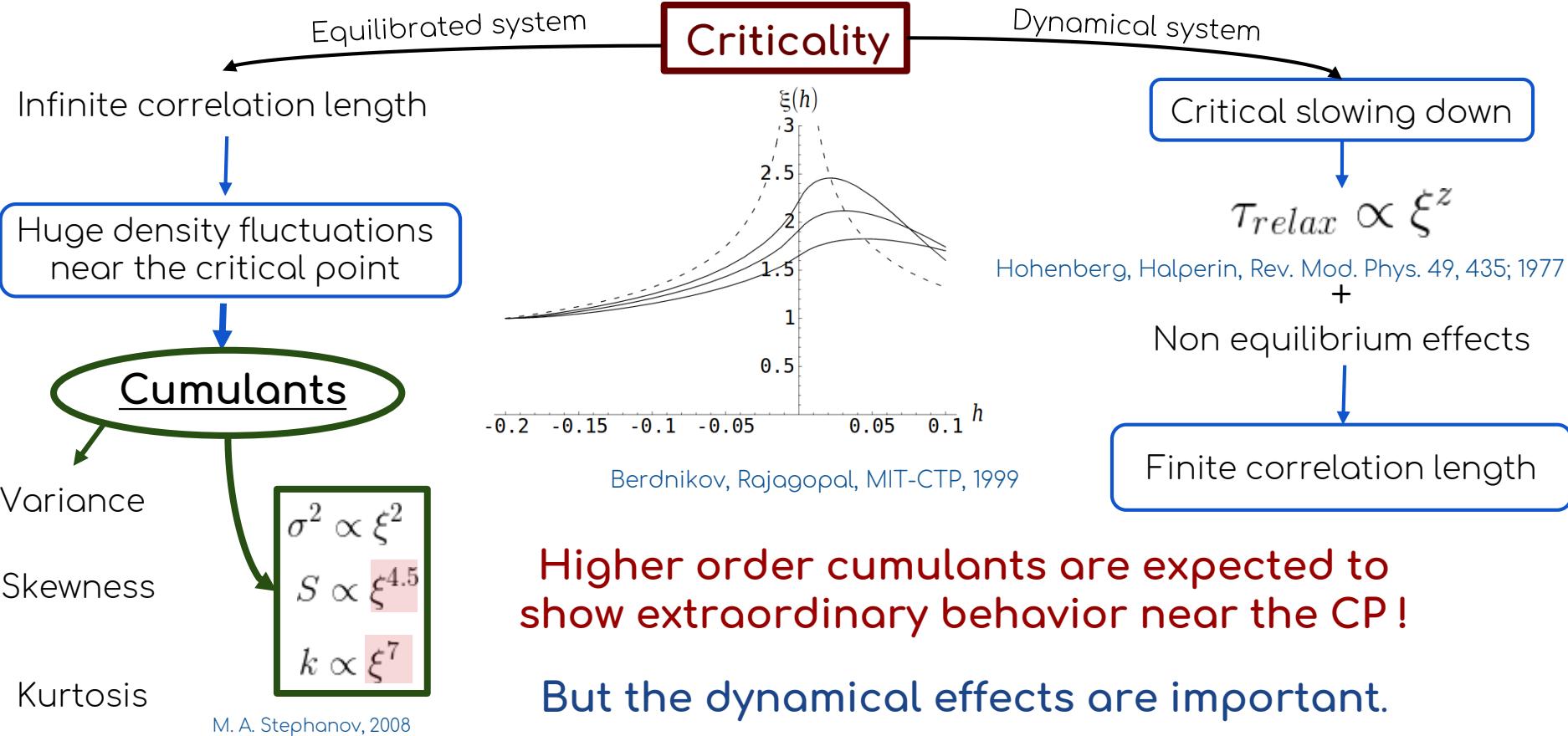


A. Steidl, Goethe University Frankfurt am Main.

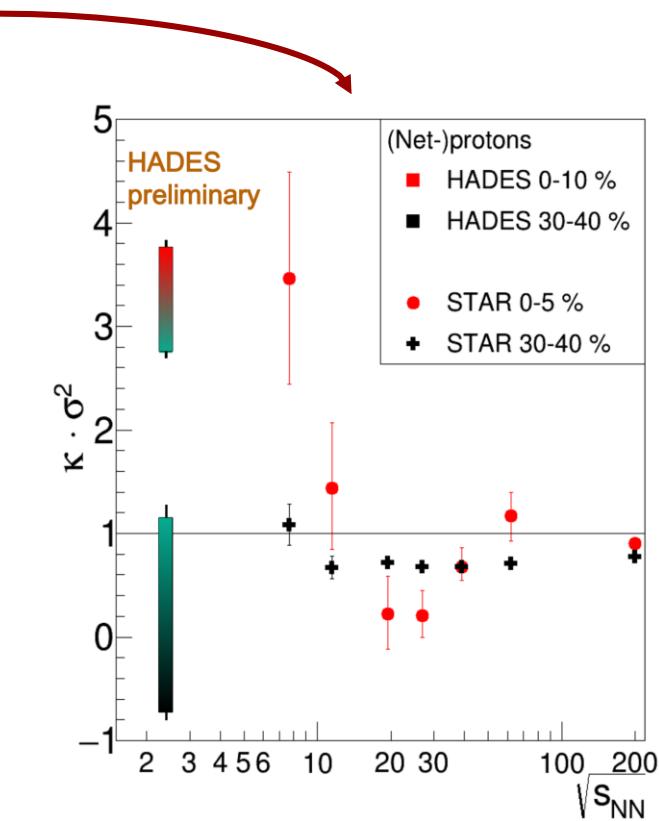
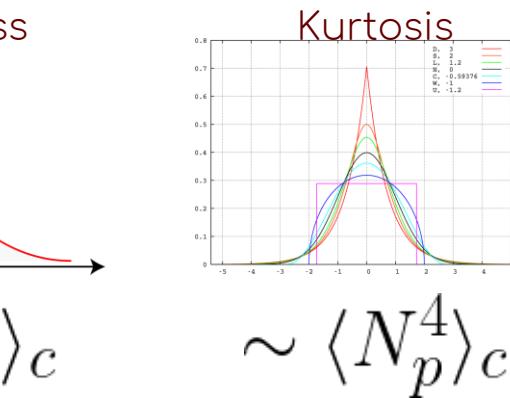
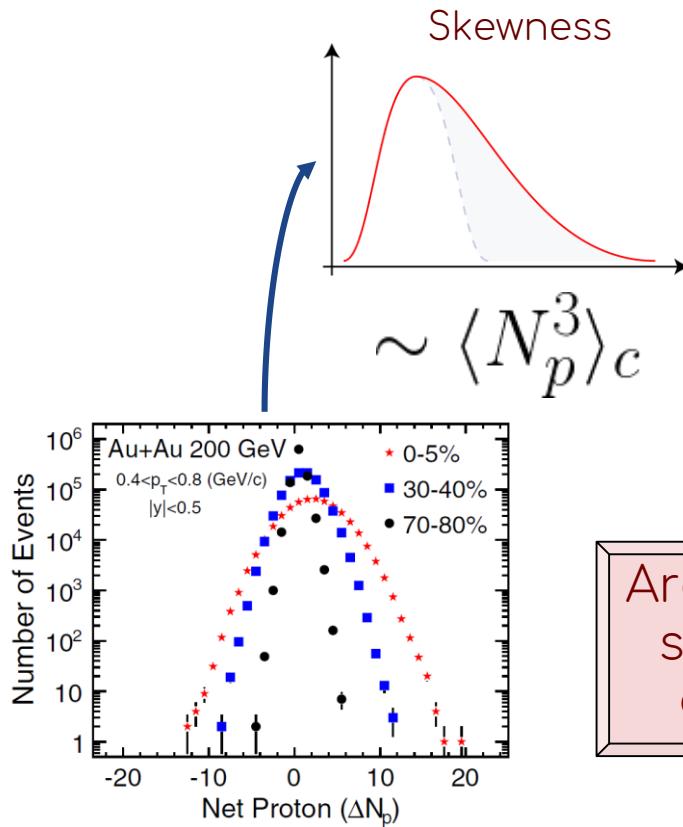
H. Caines, Quark Matter 2017.

- No reliable approach from first-principle QCD calculations, dynamical effect → **Phenomenological study**
- Experimental measurements → **RHIC-BES II, HADES GSI, NA 61 CERN**. Future : FAIR, NICA, J-PARC...

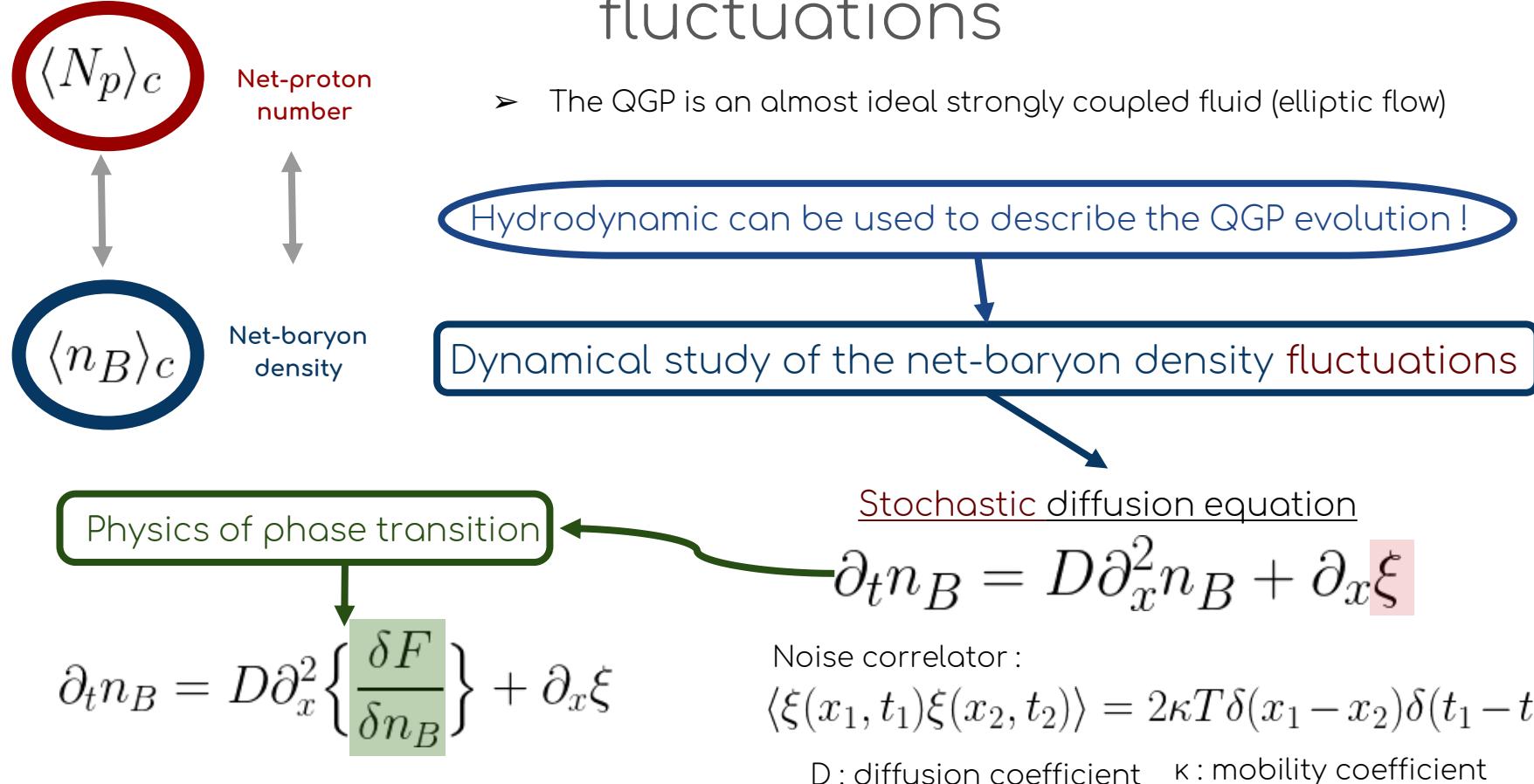
Relevant phenomenological observables



Relevant phenomenological observables



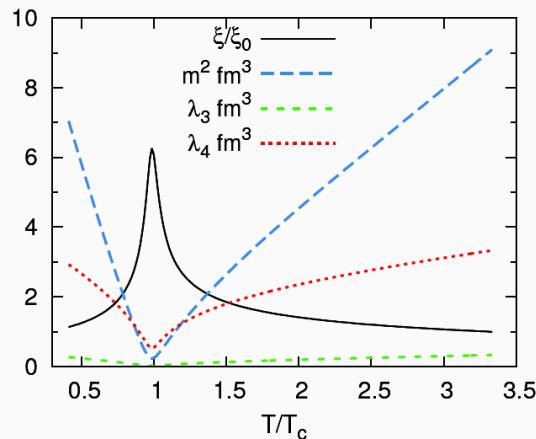
Evolution of the net-baryon density fluctuations



Physics of the phase transition

Ginzburg-Landau free-energy functional

$$F(T, n_B) = T \int \left[\frac{m^2}{2n_c^2} n_B^2 + \frac{K^2}{2n_c^2} (\nabla n_B)^2 + \frac{\lambda_3}{3n_c^3} n_B^3 + \frac{\lambda_4}{4n_c^4} n_B^4 + \frac{\lambda_6}{6n_c^6} n_B^6 \right] dx^3$$



in this Fig.: $\tilde{\lambda}_3 = 1$, $\tilde{\lambda}_4 = 10$

Temperature dependance:

$$m^2 = 1/(\xi_0 \xi^2)$$

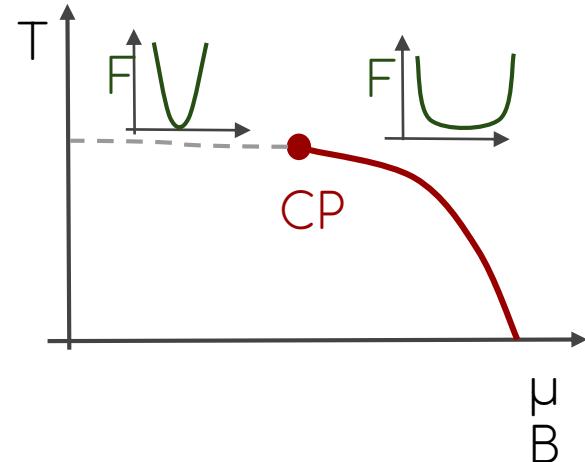
$$K = \tilde{K}/\xi_0$$

$$\lambda_3 = n_c \tilde{\lambda}_3 (\xi/\xi_0)^{-3/2}$$

$$\lambda_4 = n_c \tilde{\lambda}_4 (\xi/\xi_0)^{-1}$$

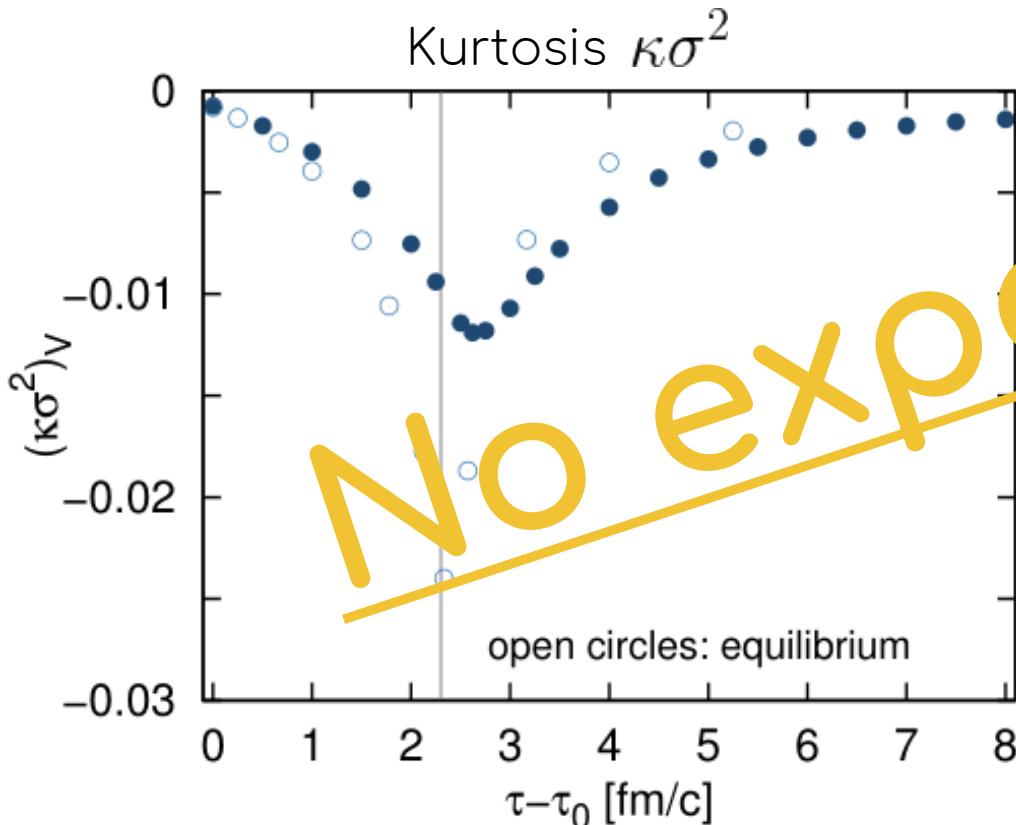
$$\lambda_6 = n_c \tilde{\lambda}_6$$

M. Tsypin PRL73 (1994); PRB55 (1997)



- Gaussian approximation + surface tension
- Non-linear terms → higher order cumulants!

First approach on the cumulants



Equilibrium : open circles

- Simulations at fixed T
 - Total System length : 20 fm
 - Coarse-grained : $V = 1.95$ fm
- Dynamical evolution : circles
- Hubble like temperature profile

$$T(t) = T_0 \left(\frac{t_0}{t} \right)$$

Smaller extremal values
Retardation effects

Evolution of the net-baryon density fluctuations in an expanding medium

Dynamical study of the net-baryon density fluctuations

Stochastic diffusion equation

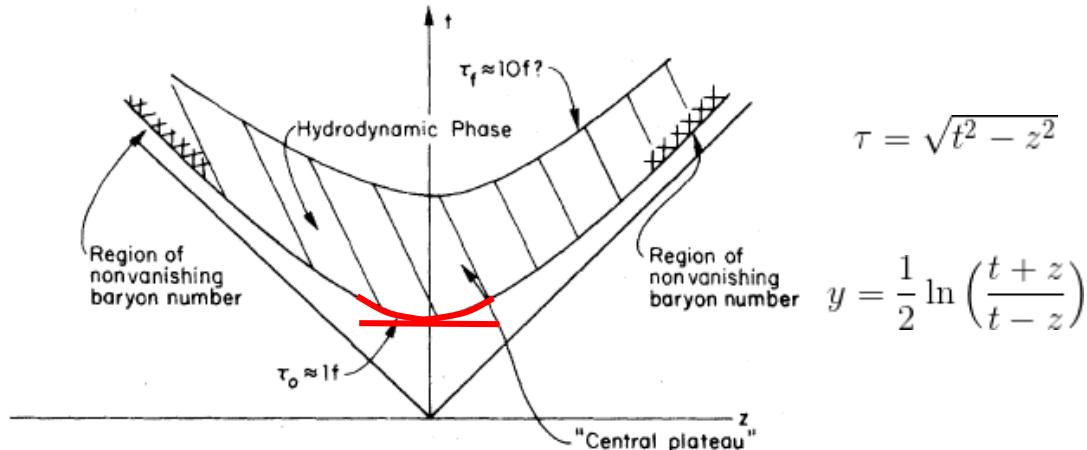
$$\partial_t n_B = D \partial_z^2 \left\{ \frac{\delta F}{\delta n_B} \right\} + \partial_z \xi$$

More realistic model!

Bjorken expansion

$$\partial_\tau n_B = D(\tau) \partial_y^2 \left\{ \frac{\delta F}{\delta n_B} \right\} + \partial_y \xi$$

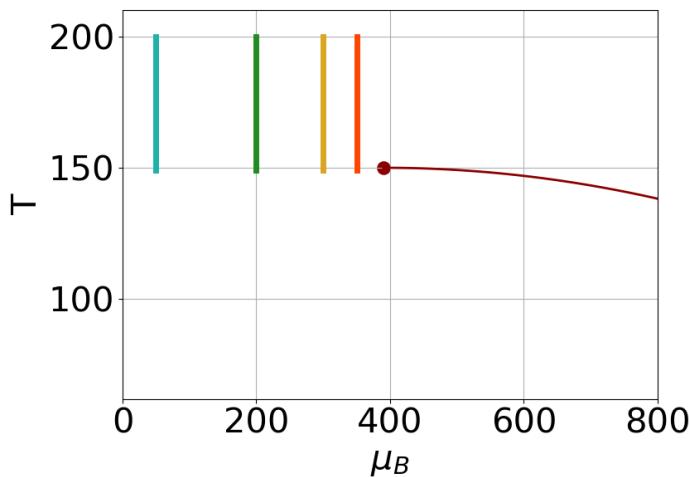
- Critical baryo-chemical potential : 390 MeV
- Hubble temperature profil : initial temperature : 200 MeV
- Gauss approximation and non-linear terms



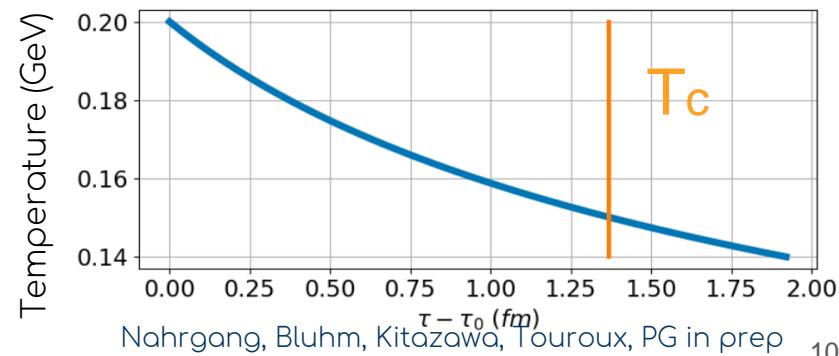
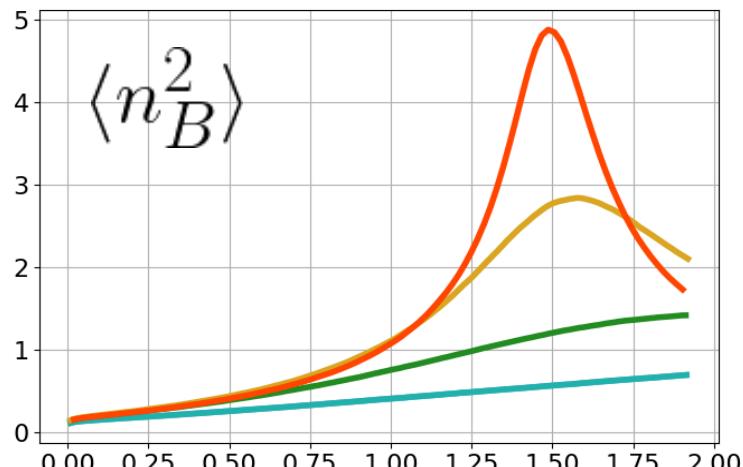
Bjorken, PRD 1983

Gaussian model in Bjorken expansion

Trajectories in the QCD Phase diagram



— $\mu_B = 50\text{MeV}$
— $\mu_B = 200\text{MeV}$
— $\mu_B = 300\text{MeV}$
— $\mu_B = 350\text{MeV}$

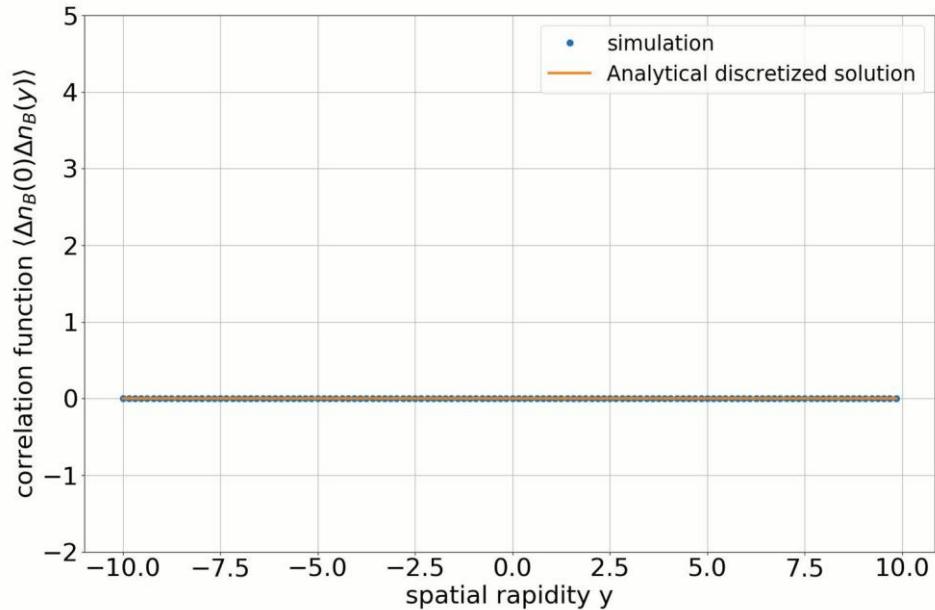
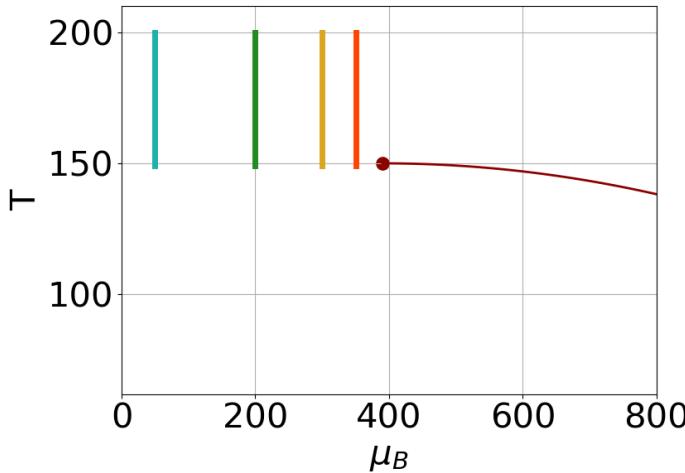


- 2nd order cumulant shows a peak near T_c
- Retardation effect due to dynamical evolution

Gaussian model in Bjorken expansion

$$\tau - \tau_0 = 0.0 \text{ fm/c}$$

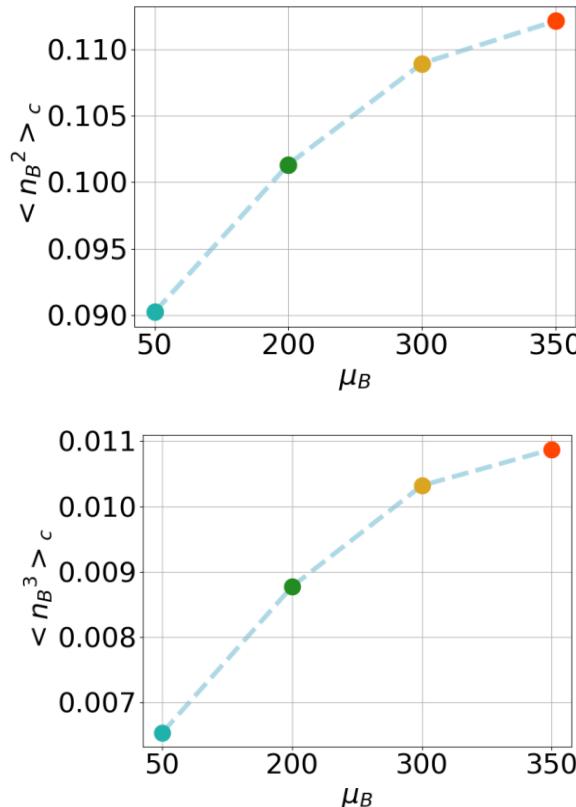
Trajectories in the QCD Phase diagram



- Numerics reproduces the analytical solution !

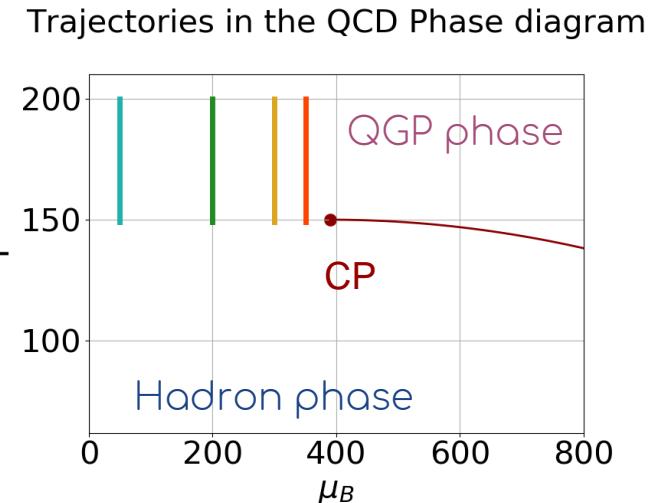
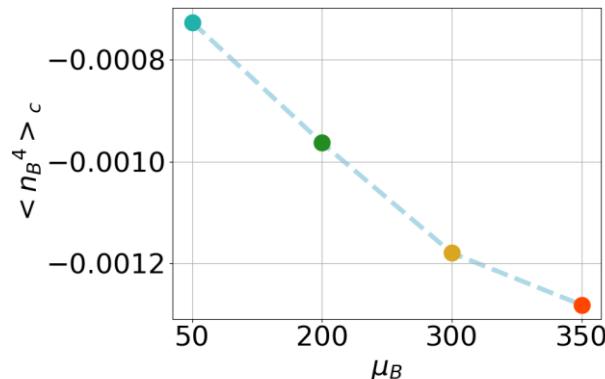
— $\mu_B = 50 \text{ MeV}$
— $\mu_B = 200 \text{ MeV}$
— $\mu_B = 300 \text{ MeV}$
— $\mu_B = 350 \text{ MeV}$

Full non-linear model in Bjorken expansion



Final temperature : 148 MeV
Just after the critical temperature

- $\mu_B = 50\text{MeV}$
- $\mu_B = 200\text{MeV}$
- $\mu_B = 300\text{MeV}$
- $\mu_B = 350\text{MeV}$



- Critical signal survives the expansion !

Conclusion

- ❑ QCD critical point ?

- Phenomenological study for the comparison with experimental results needed !
 - ❑ Study time evolution of net-baryon number fluctuations
- Stochastic diffusion in an expansion close to the critical point
- Agreement with the analytical expectations

Survival of the critical signal during the expansion !

- Future studies
 - ➔ Include regular part in the equation of state
 - ➔ Coupling with energy and momentum