Other Observables sensitive to the EoS/type of PT

”life beyond net proton/baryon cumulants”

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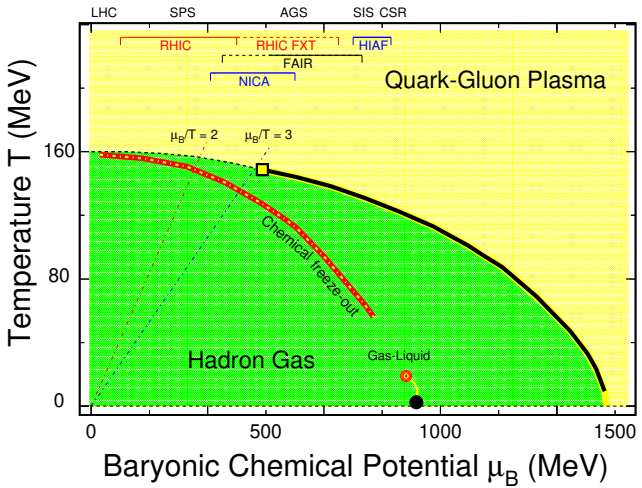
QCD Critical Point and Hydrodynamic Evolution, Yukawa Institute for Theoretical Physics, 1-4 June 2026

The idea:

Study not the observables sensitive to the CP
but observables sensitive to the kind of phase transition in the EoS
and see a change of patterns in them as sqrt(s) changes



Old phase transition signatures

Not criticality but softening of the EoS

HBT (time-delay signature of QGP formation)
Nucl.Phys.A 608, 479 (1996)

Directed Flow: Brachmann, et al,
Phys.Rev. C61 (2000) 024909

… do not hold water anymore, but the idea of a smoking gun signature is still tempting

A more recent motivation for directed flow observable

Ivanov, Soldatov, Phys. Rev. C 91, 024915 (2015)

Simulations in 3-fluid dynamics

Strong EoS dependence,
Crossover EoS preferred

Looks like directed flow has complex dependencies

J. Steinheimer, J. Auvinen, H. Petersen, M. Bleicher, H. Stöcker, Phys. Rev. C 89 (2014) 054913

An oversimplified simulation where v1 is sensitive to PT in the EoS

State-of-the-art simulation where v1 is sensitive to freezeout and also the EoS

Baryon stopping/transparency is driven by initial state

MUFFIN (3-fluid hydro) simulations:

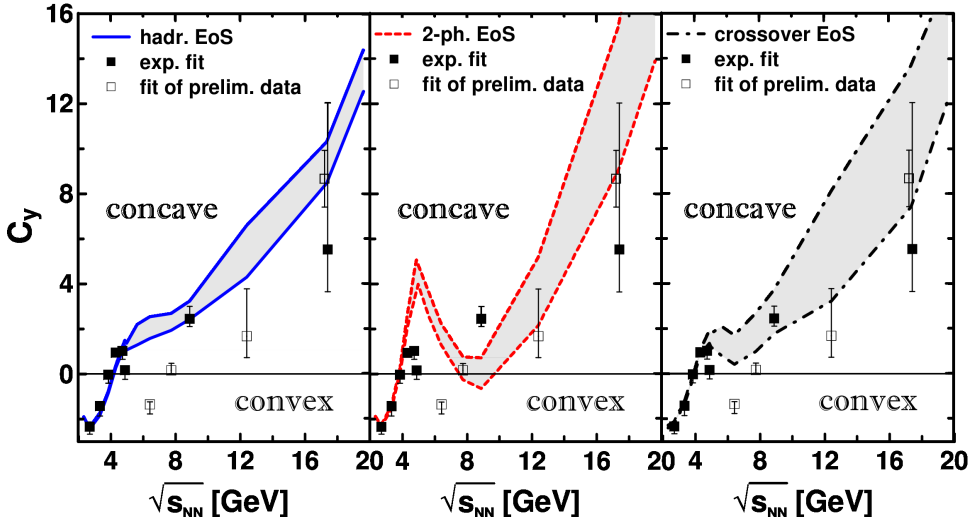
Werthmann, IK, Huovinen,
Phys.Rev.C 113 (2026), 034908

β => relative rapidity cut for initial state nucleons to melt into fireball or p/t fluids

Can result in very different shapes of net proton rapidity distribution

Sensitivity of the second derivative (curvature) of net proton distribution to the EoS "peak-dip-peak-dip" structure

Yu. Ivanov, arXiv:1302.5766



$$C_y = \left(y_{cm}^3 \frac{d^3N}{dy^3} \right)_{y=y_{cm}} \Big/ \left(y_{cm} \frac{dN}{dy} \right)_{y=y_{cm}} = (y_{cm}/w_s)^2 \left(\sinh^2 y_s - w_s \cosh y_s \right).$$

EoS sensitivity / constraints?

There is no simple answer for that yet, but we are slowly getting there.

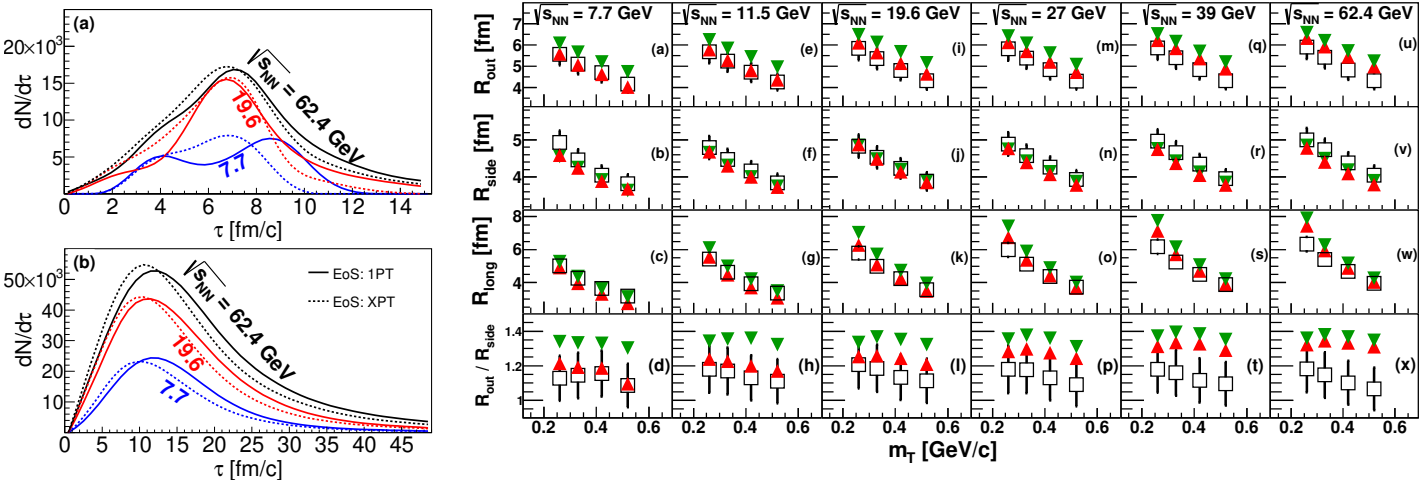
- EoS sensitivity in the models can be obscured by other sensitivities (just like at high energies); parameter space is complex but there is hope.
- E.g. EoS constraining via directed flow or HBT does not seem to be a straightforward procedure.
- State-of-the-art EoS with CP location as a free parameter are started to be applied in *some* fluid-dynamic models (MUSIC code, NEOS).
- But there is no BA constraining the EoS at non-zero baryon density yet.

EoS/PT sensitivity via HBT/femtoscopy

Initial idea: enhancement of $R^2_{\text{out}} - R^2_{\text{side}}$ would signal a passage through the mixed phase.

"Reality check":
UrQMD (initial state) + fluidisation at fixed τ_0 + vHLLE (hydro) + UrQMD

Batyuk, IK, Lednicky, Malinina, Mikhaylov, Rogachevsky, Wielanek, Phys. Rev. C 96, 024911 (2017)



1PT = 1st order PT, XPT = crossover; crossover EoS is red, 1PT EoS is green

There is weak EoS sensitivity, crossover EoS is preferred.

A path forward

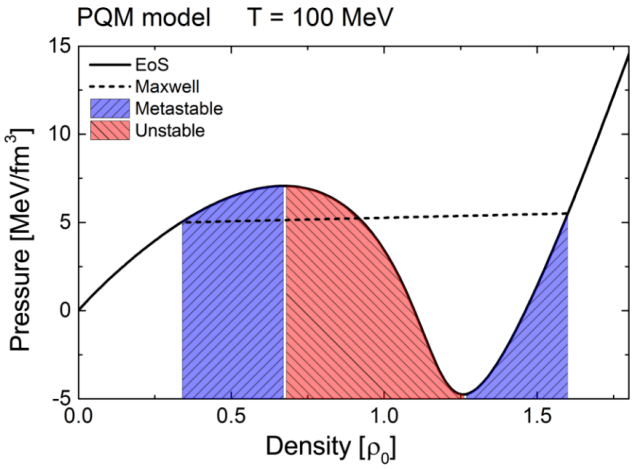
- Figure out discrepancies between the models (wherever possible)
  E.g. parametrized initial state vs. initial state from transport (at fixed τ_0)
  vs. dynamical fluidization from transport vs. multi-fluid vs. hadron(-parton)
  cascade

- Bayesian analysis to provide constraints on the EoS
  For that, one needs an EoS with parametrized location of CP

- Get more consistent experimental data (depends on experimental collaborations)

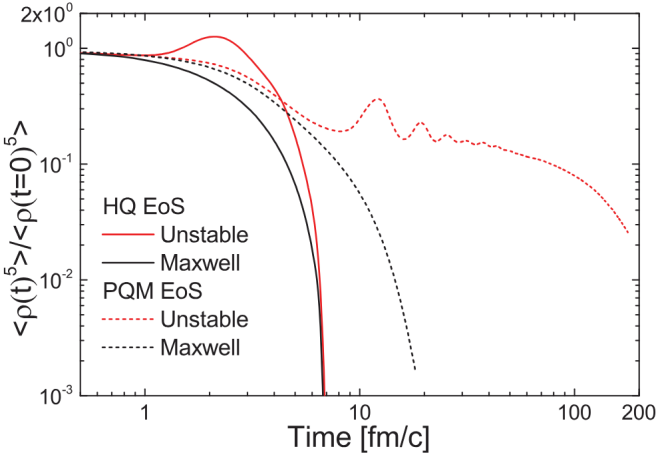
Fluid dynamics with spinodal decomposition in the EoS

Steinheimer, Randrup, Koch, Phys. Rev. C 89, 034901 (2014),



EoS w/ Mechanically unstable region (phase coexistence with hadronic med.)

translates into clumping in coordinate space



But intuitively sensitive observables show little sensitivity.

A follow-up JHEP 12, 122 using machine learning