Hybrid approach at low energies: dynamical fluidization

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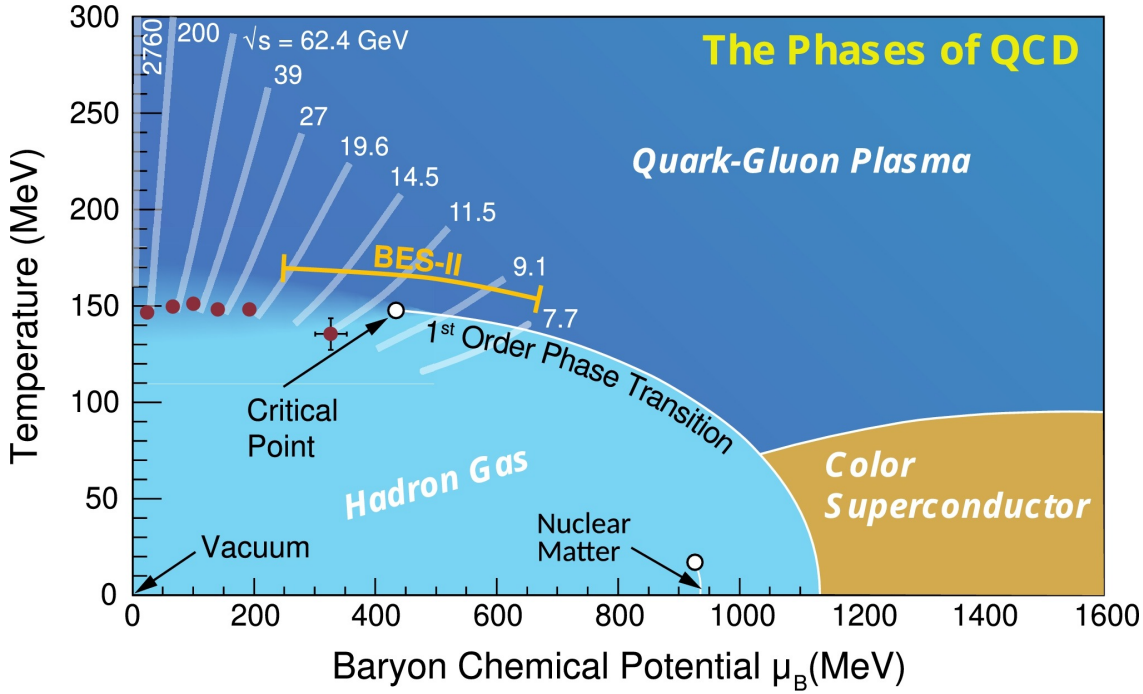
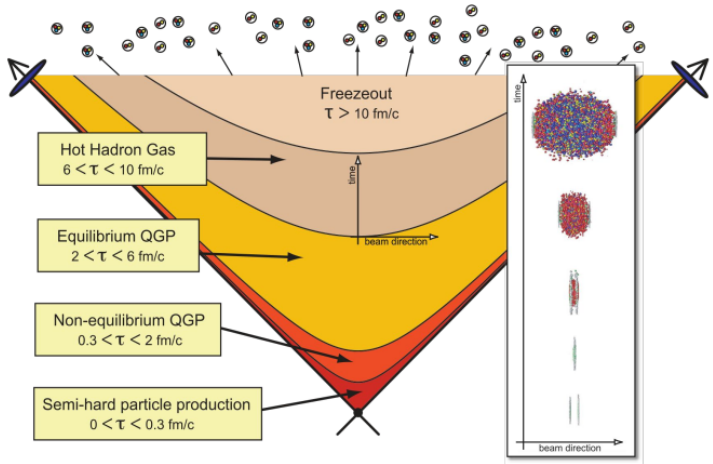
Based on: R.Hirayama, J.Egger, Z. Paulinyova et al.: 2507.19389

Motivation

Dynamical evolution in a HIC

- modeling: IC $\rightarrow$ hydro $\rightarrow$ final state hadron interactions



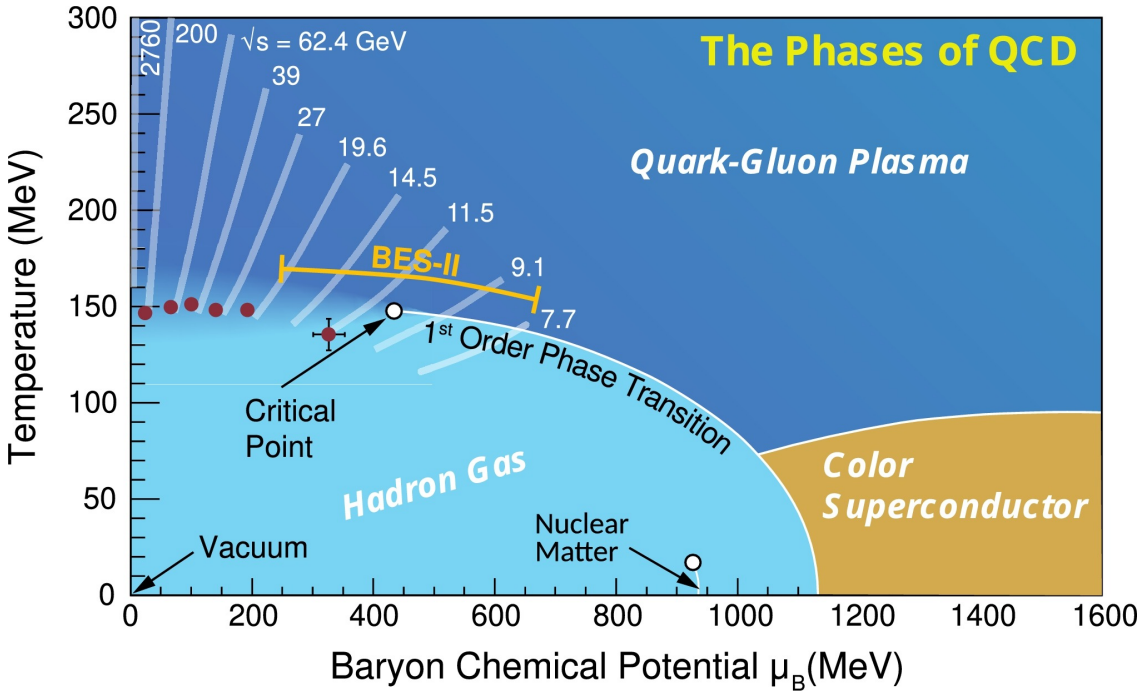


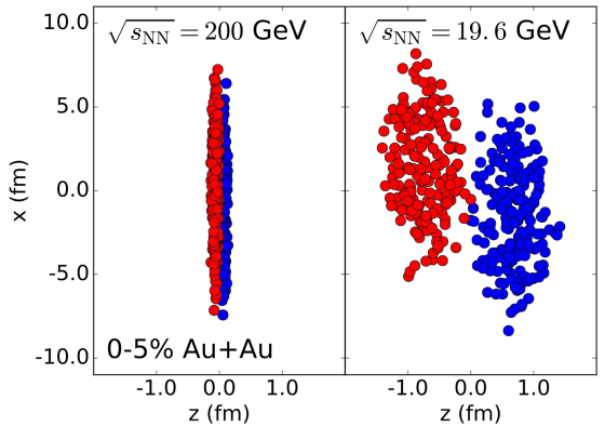
figures from Xin An et al.: Nucl.Phys.A 1017 (2022) 122343, M. Strickland, A Phys. Pol. B 45, 2355(2014)

Motivation

Dynamical evolution in a HIC

- modeling: IC $\rightarrow$ hydro $\rightarrow$ final state hadron interactions
- the picture changes from high to low energies





figures from Xin An et al.: Nucl.Phys.A 1017 (2022) 122343, C. Shen & B. Schenke, Phys.Rev.C 97, 024907 (2018)

Motivation

Modeling different stages

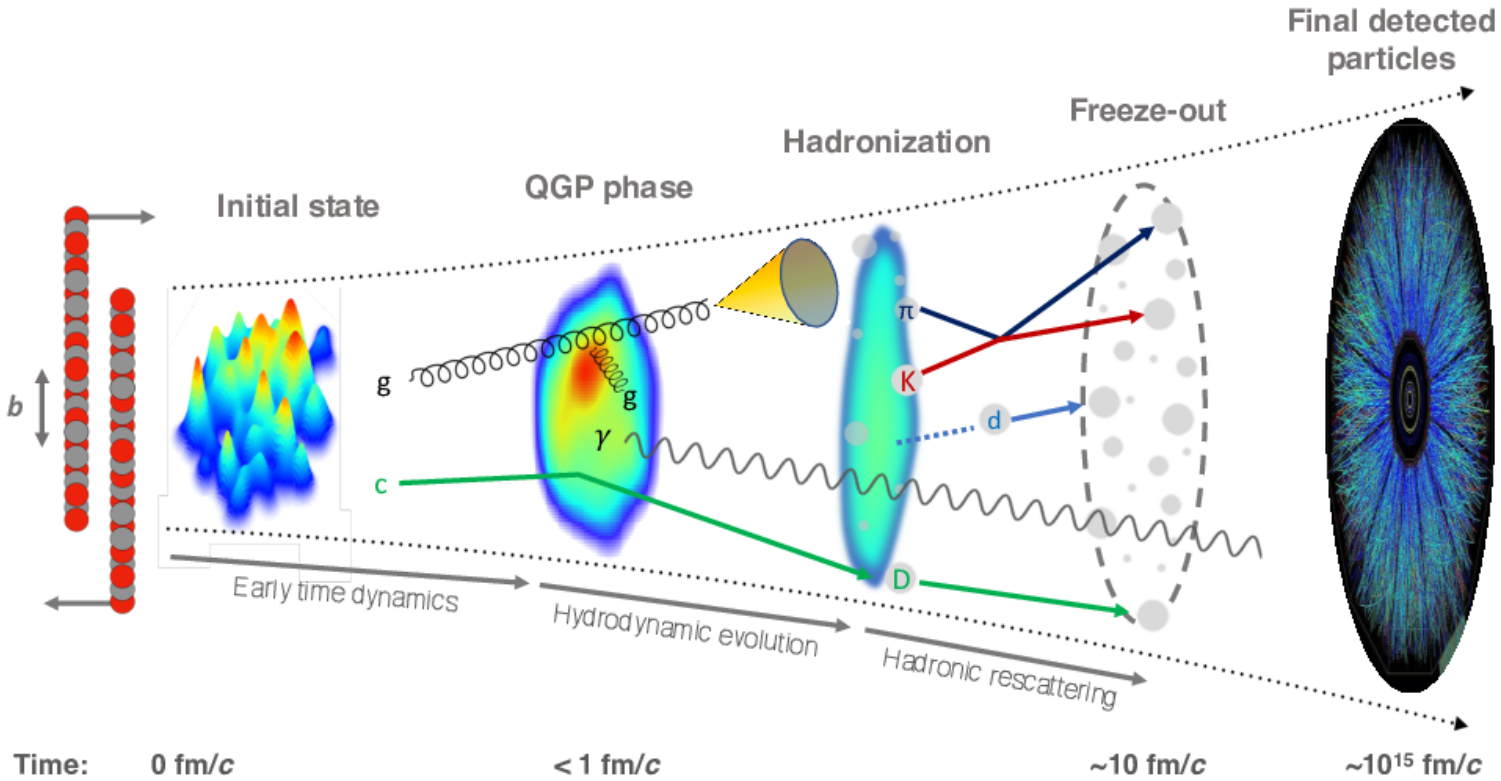
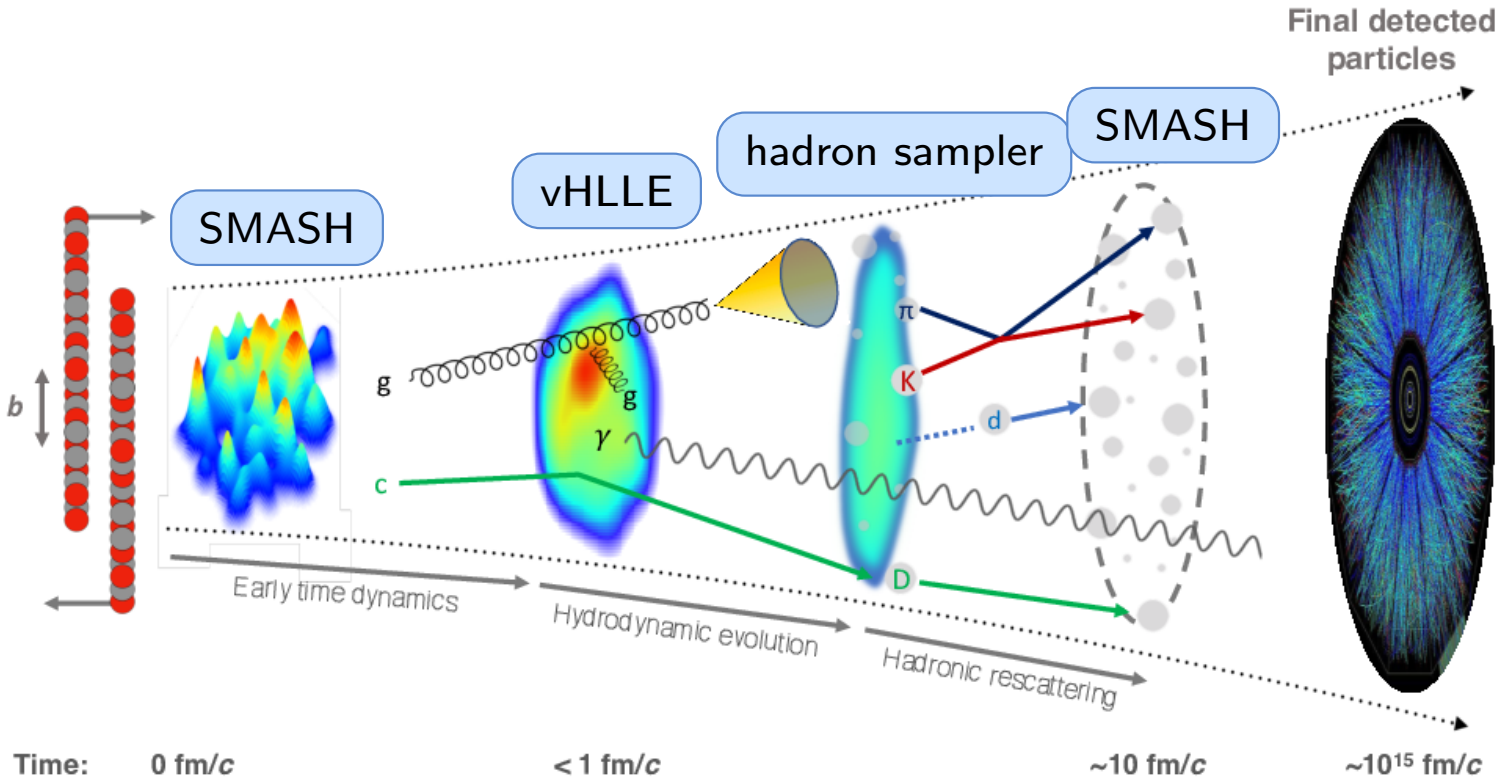


figure from M.Arslandok et al.: Hot QCD White Paper, arXiv:2303.17254

Motivation

Modeling different stages

- hybrid modeling: hadron transport + hydrodynamics: https://github.com/smash-transport/smash-vhlle-hybrid



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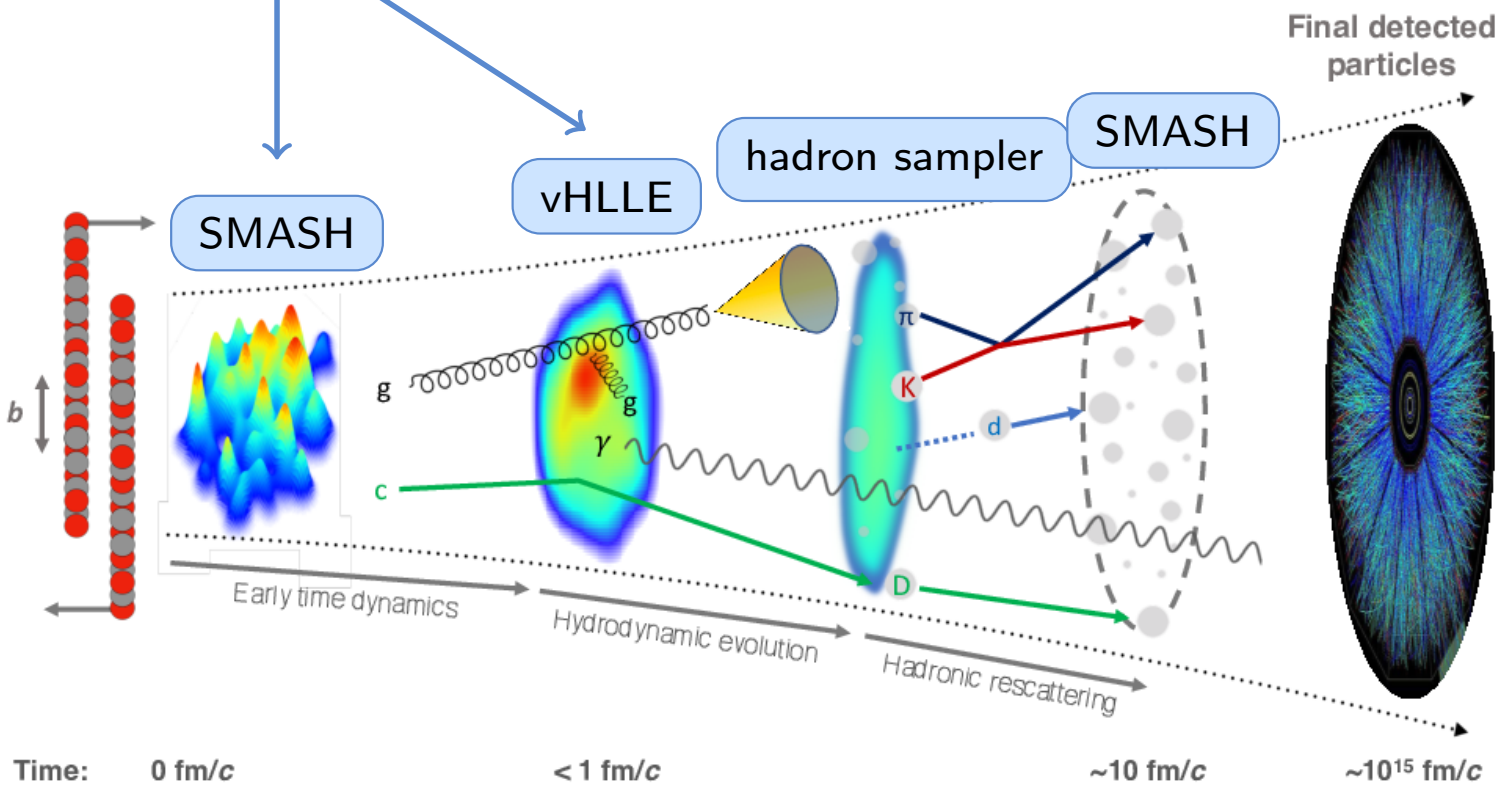
Motivation

Modeling at low energies

- in fact these two stages: initial hadron state and QGP fluid are simultaneous



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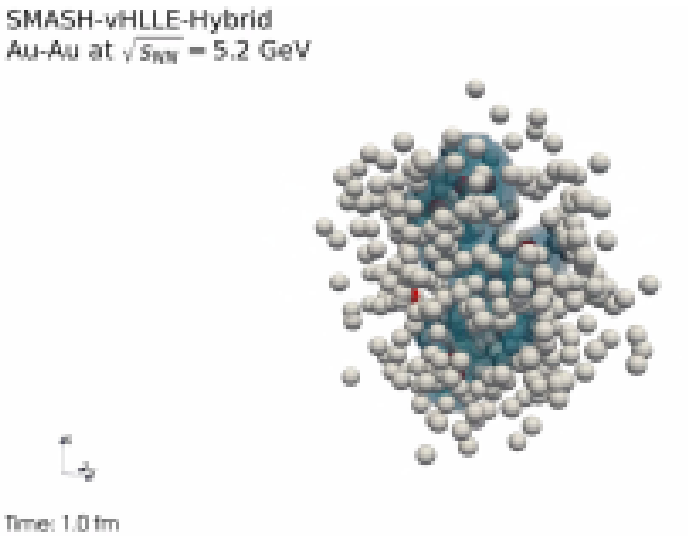
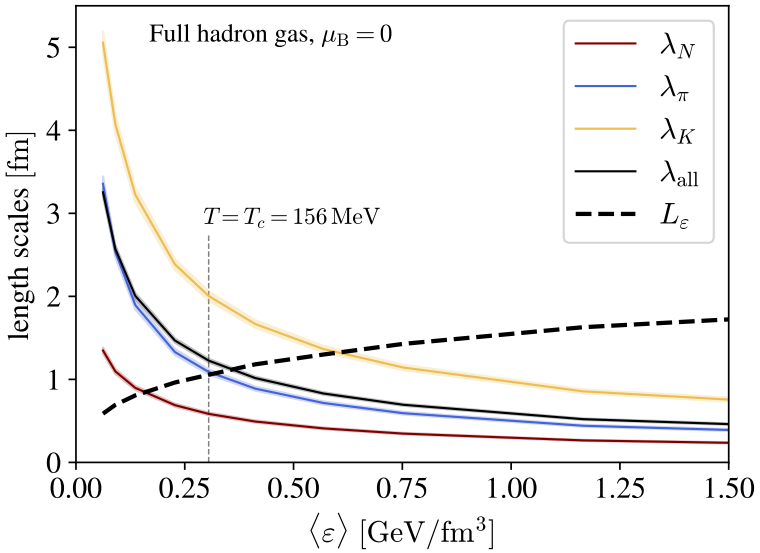
Dynamical fluidization



- main idea: dense systems thermalize
- fluidization criterion: threshold energy density $\epsilon_{th} = 0.5\ \mathrm{GeV}$ **and** at least one inelastic collision or two elastic collisions
- fluid is not created at once, it is rather built up gradually $\rightarrow$ hydro has source terms

inspired by: Y.Akamatsu et al.: Phys.Rev.C 98 (2018) 2, 024909

Dynamical fluidization



- main idea: dense systems thermalize
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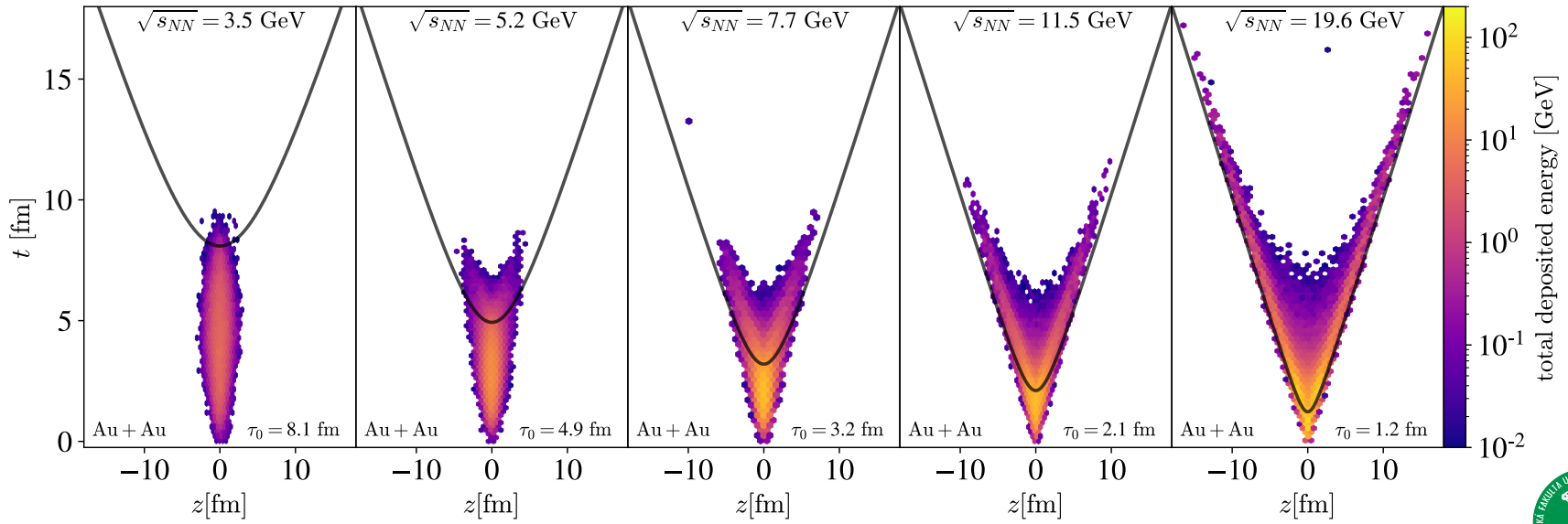
- fluid is not created at once, it is rather built up gradually $\rightarrow$ hydro has source terms
- test: mean free path of hadrons in a dense system

Dynamical fluidization

Hadron transport

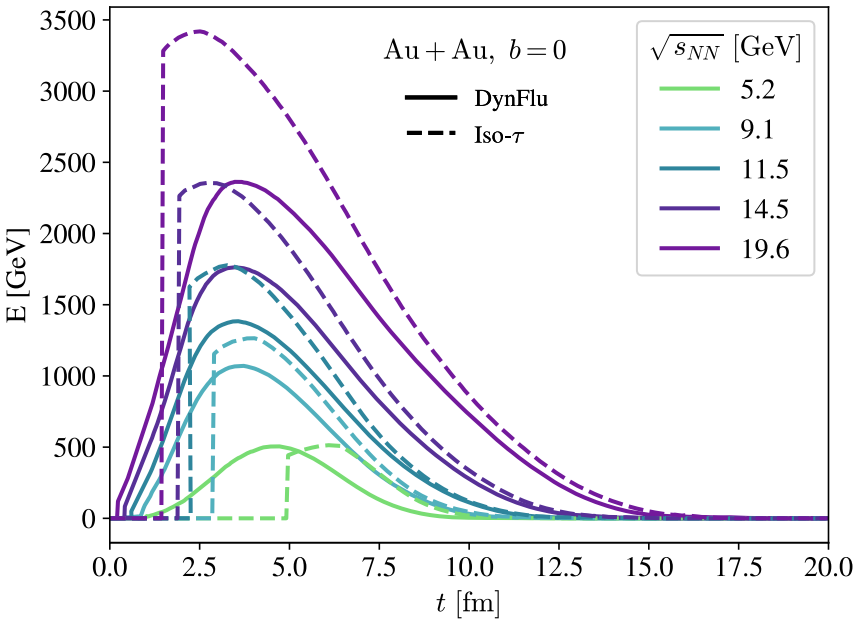
- we show how hadrons are entering fluid
- for low energies, the fluid is initialized much sooner than in a conventional approach

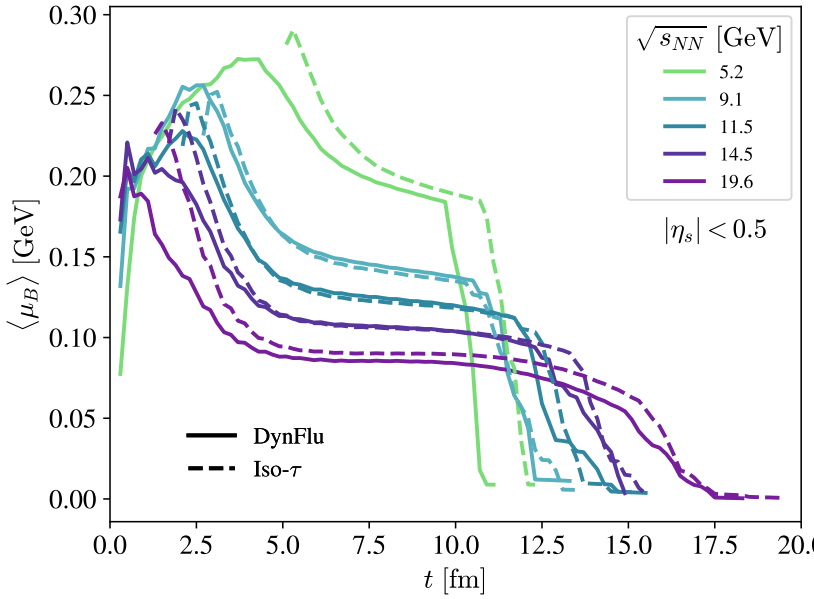


Dynamical fluidization

Fluid

- the fluid is created earlier than in iso-tau picture, but it is smaller - hadrons stay in the corona

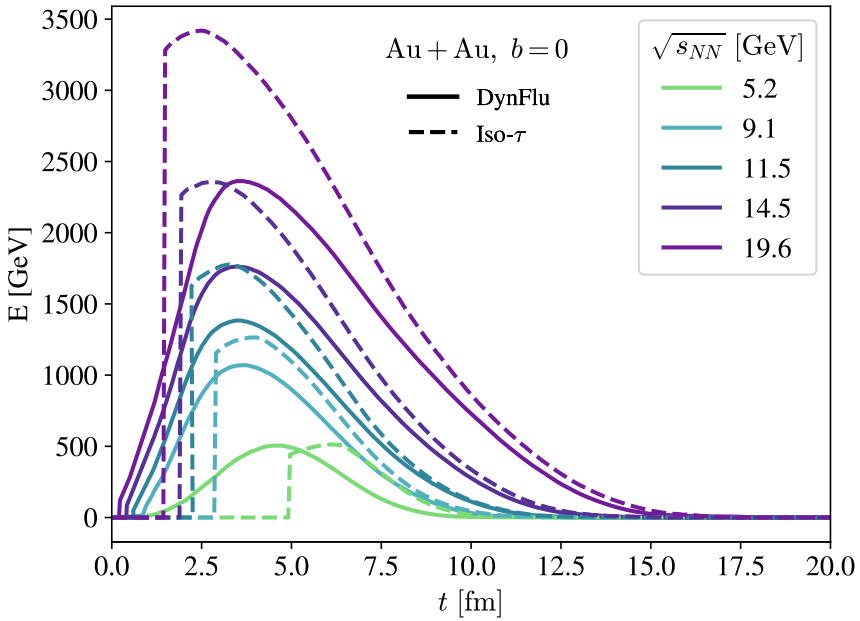


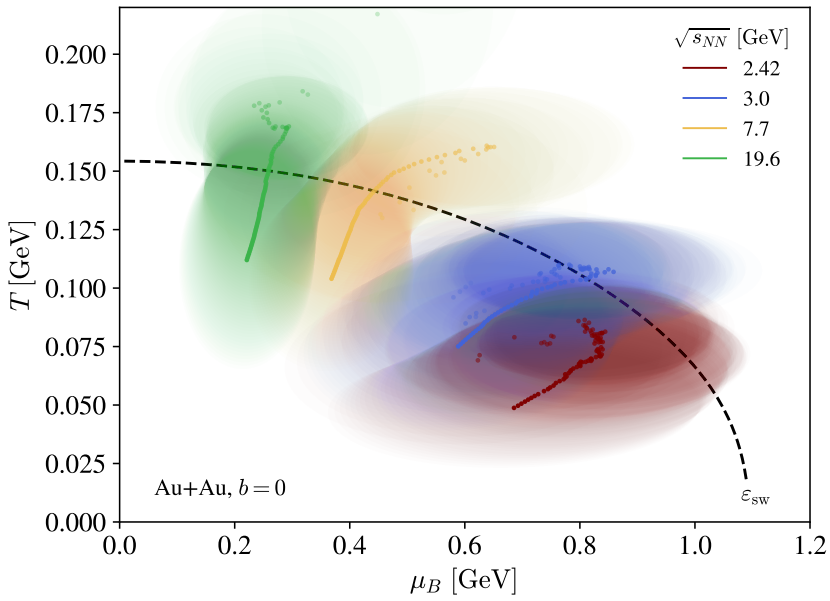


Dynamical fluidization

Fluid

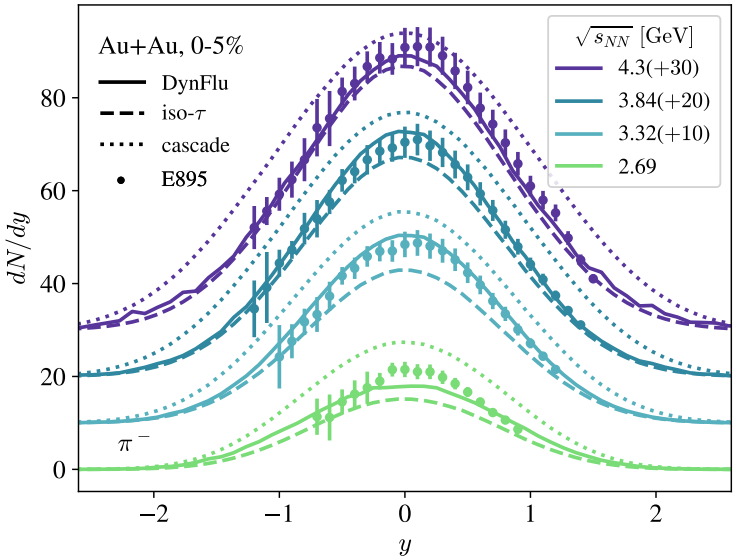
- the fluid is created earlier than in iso-tau picture, but it is smaller - hadrons stay in the corona
- trajectories of the fluid in (T, μ_B) plane suggest the model is relevant for $\sqrt{s_{NN}} > 3$ GeV

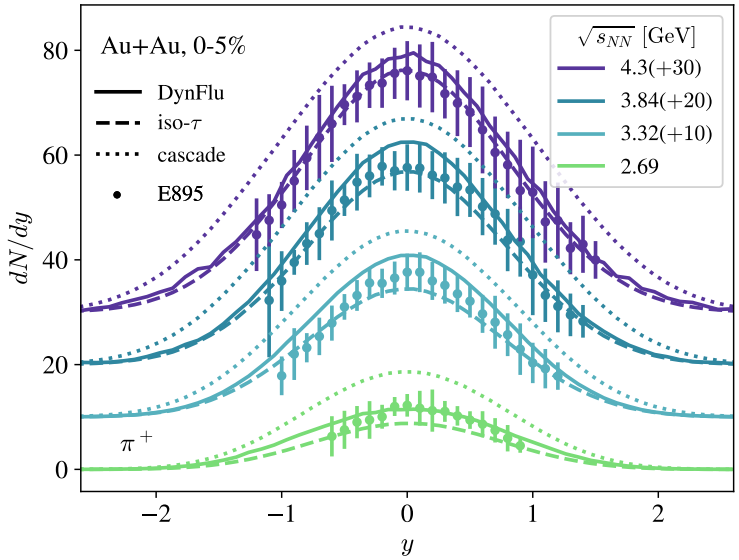


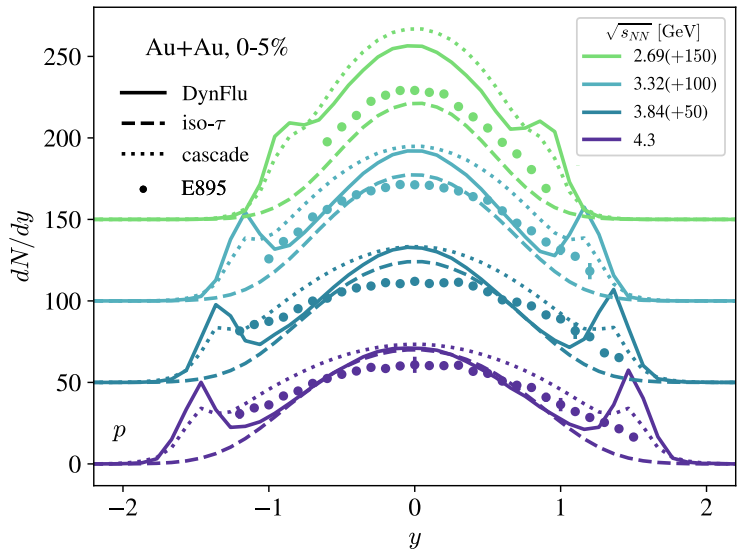


Comparison of initialization models

Rapidity distributions



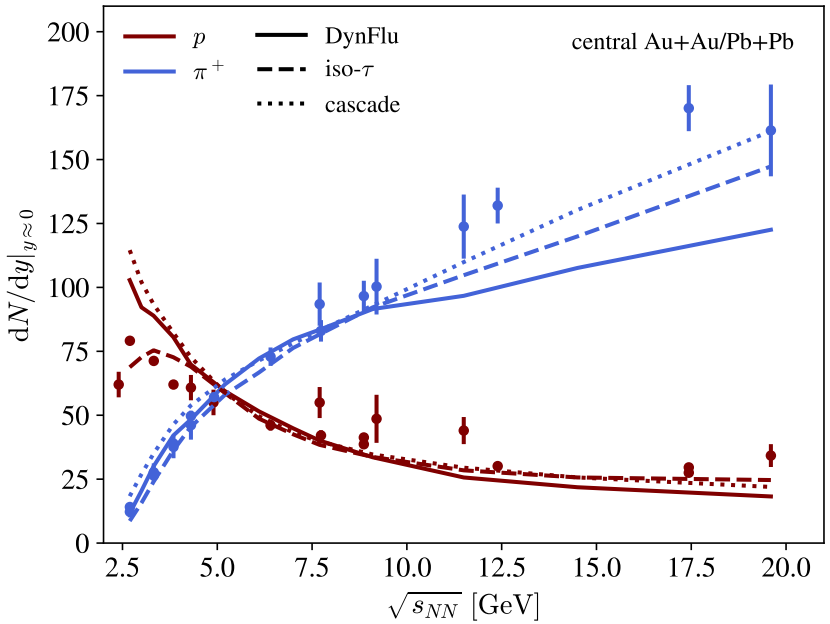


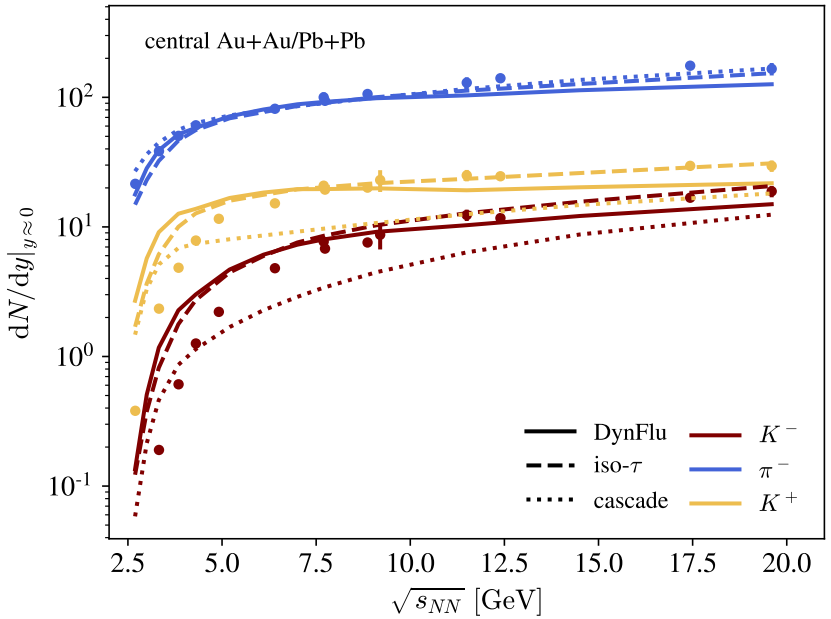


Comparison of initialization models

Particle production at midrapidity

- pion production suggests the limits of the dynamical fluidization scenario → there might be need to vary parameters with $\sqrt{s_{NN}}$

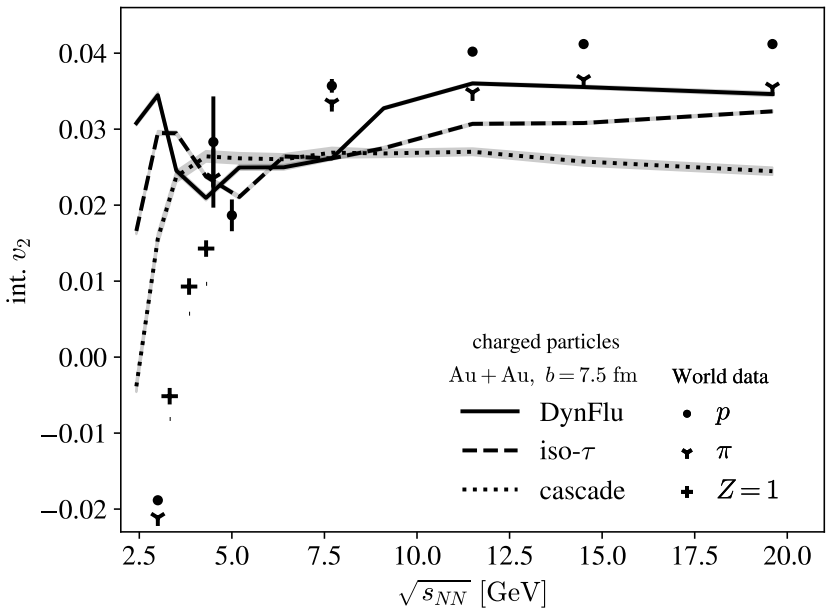


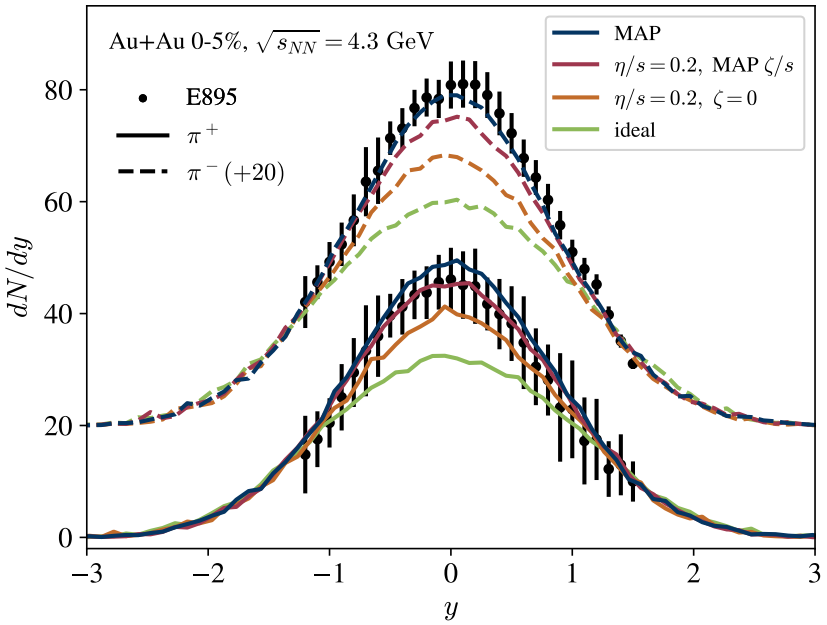


Comparison of initialization models

Elliptic flow and viscous effects

- longer hydrodynamic evolution produces more flow
- viscosity plays an important role in the description of the yield at midrapidity

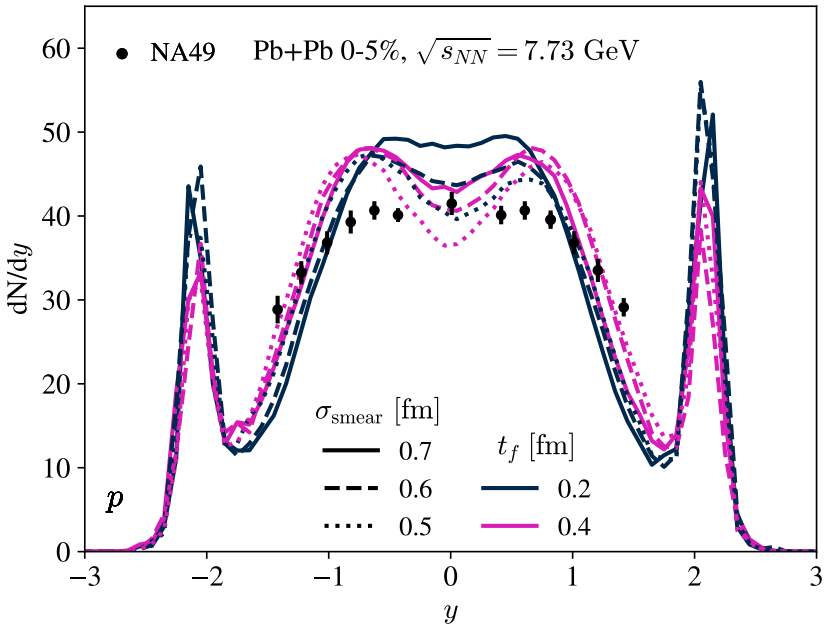
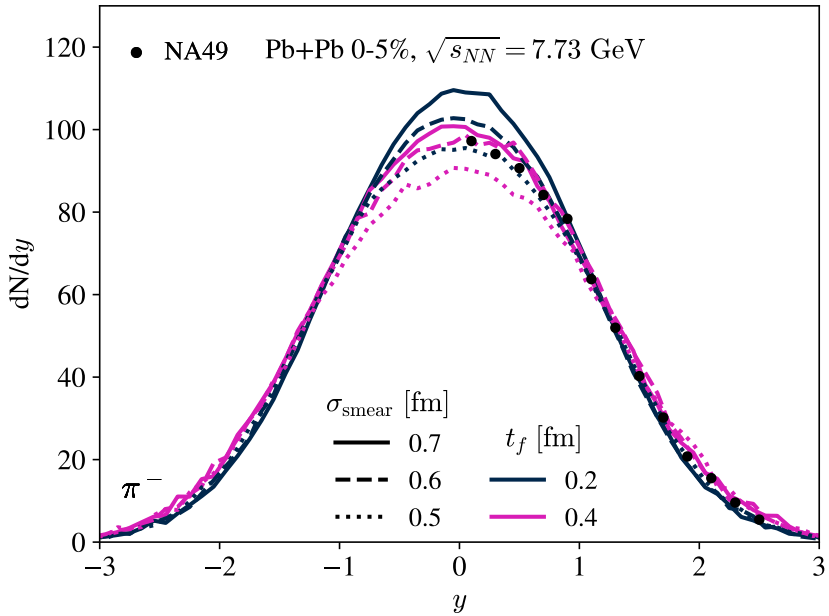




Summary

- at lower energies there is no clear separation of hadronic initial state and fluid $\rightarrow$ dynamical fluidization extends the applicability of the hybrid model to these energies
- first results for bulk observables, flow and dileptons (see https://arxiv.org/abs/2510.02862)
- preparing public release of the codes
- plans: concurrent running of transport and hydrodynamics

Back-up

Parameter space

- most parameters of the model are fixed in the *iso-τ* picture by a recent Bayseian analysis (see N. Götz et al.: Phys.Rev.C 112 (2025) 1, 014910, https://arxiv.org/abs/2503.10181)
- remaining parameters we fix: *gaussian smearing parameter* $\sigma = 0.7$ fm and *string fluidization time* $t_f = 0.4$ fm/c