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Simulating UR HICs:

EPOS $^1$ and Hydro $^2$

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$^1$with Tanguy Pierog, Sarah Porteboeuf
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EPOS is a parton model, with many binary parton-parton interactions, each one creating a parton ladder.

\[ 0.5 \, \log(x^+/x^-) \]

ladder splitting in case of nuclei

longitudinal electric field decaying via pair production into segments \[ \Rightarrow \text{hadrons} \]
Early stage ($\tau \leq \tau_0$): EPOS

freeze–out hypersurface

At $\tau = \tau_0$: core - corona separation
(core: high density of string segments; we include inwards moving corona segments)

Need: Link of EPOS core at $\tau = \tau_0$ to the freeze-out hyper-surface

(assuming strongly interacting matter inside)
First option:

- Parameterization of the freeze-out properties

Second option:

- Run hydro based on average EPOS initial conditions
- Tabulate results such that they can be used to treat the core evolution and hadronization (event by event).
- Compare the two procedures
In any case, the initial mass will be partly transformed into flow, characterized (at given $\eta$) by the **transverse rapidity**

$$y_{FO} = y_0(\tau) + y_2(\tau) \cos(2\varphi)$$

on the **FO hypersurface** given as

$$r_{FO} = r_0(\tau) + r_2(\tau) \cos(2\varphi).$$

What we need is the **FO rate**

$$w_{FO} = \frac{dM}{d\eta d\varphi d\tau} = w_{FO} = w_0(\tau) + w_2 \cos(2\varphi)$$

All quantities depend on $\eta$. 

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An effective invariant mass $M$ (in a given $\eta$ range) is given as

$$M = \int w_{FO} d\tau d\varphi,$$

the energy is

$$E = \int \cosh(y_{FO}) w_{FO} d\tau d\varphi,$$

which must be equal to the initial invariant mass $M_0$ at $\tau = \tau_0$.

Only $M$ and not $M_0$ is available for particle production!
Provided the FO conditions are known, we suppose that the effective invariant mass $M$ decays according to the covariant microcanonical phase space.

The particles adopt the flow according to the corresponding position on the FO hypersurface.
Changing FO hypersurface parameters

Useful to employ the transverse rapidity \( y_0 \) rather than \( \tau \) to parameterize the FO hypersurface.

(two branches!)

We define

\[
    w_i(y_0) = \int w_i(\tau) \delta(y_0(\tau) - y) d\tau.
\]

And we consider \( y_2 \) as well as \( r_0, r_2 \) as functions of \( y_0 \) (and also \( \tau \)).
Advantage:

investigate the different FO characteristics one after the other, looking at different observables.

- Particle spectra → we just need \( w_0(y_0) \).
- Looking a elliptic flow → consider \( w_2(y_0) \) and \( y_2(y_0) \)
- HBT → consider \( \tau(y_0) \) as well as \( r_0(y_0) \) and \( r_2(y_0) \)
Procedure

- Generate events using EPOS, do string formation & splitting into string segments as usual
- For a given event, at given $\tau = \tau_0$ consider string segments within transverse slices in some space-time rapidity interval $[\eta - \Delta \eta, \eta + \Delta \eta]$
- Separate core from corona
- Determine the core Mass $M_0$ at $\tau = \tau_0$, and its net flavor.
• Get FO properties for the centrality class corresponding to the centrality of the current event, namely
  \[ w_0(y_0), \; w_2(y_0), \; y_2(y_0), \; \tau(y_0), \; r_0(y_0), \; r_2(y_0) \]

• Compute effective mass \( M = M_0 f \) with
  \[ f = \frac{\int w_{FO} d\tau d\varphi}{\int \cosh(y_{FO}) w_{FO} d\tau d\varphi}. \]

• Decay the mass \( M \) according to micro-canonical phase space (conserving energy, momentum, flavor)
For each particle, generate randomly a transverse rapidity $y_0$ according to $w_0(y_0)$

Generate randomly an angle $\varphi$ according to

$$w_0(y_0) + w_2(y_0) \cos(2\varphi)$$

Assign $y$, $r$, and $\tau$ to each particle as

$$y_{FO} = y_0 + y_2(y_0) \cos(2\varphi),$$

$$r_{FO} = r_0(y_0) + r_2(y_0) \cos(2\varphi),$$

$$\tau = \tau(y_0).$$

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First option: simply parameterize FO

We use

\[ w_0(y_0) \propto \begin{cases} y_0 & \text{if } y_0 \leq y_{\text{max}} \\ 0 & \text{otherwise} \end{cases} \]

with \( y_{\text{max}} \) equal to 0.75 for RHIC and 0.55 for SPS.

Works quite well for all RHIC and SPS pt spectra, all centralities, all particle species.

\(^3\)compare blast wave fit
not only pt spectra at $y = 0$,
also rapidity dependence, also light systems
(here CC, SiSi at SPS)
Second option: FO from hydro

Initial conditions
averaged EPOS distribution \( dE/rdr \ d\varphi \ d\eta \) at \( \tau_0 \)
parameterized as

\[
A \exp \left( -\left( \frac{r}{B + 2|\varphi|/\pi(C - B)} \right)^{2+0.3r} \right) \left( 1 - (0.25|\eta|)^D \right)
\]

for \( |\eta| \leq 4 \) and zero otherwise.

No initial transverse flow
Energy at $\tau = \tau_0$ from EPOS (central)

red: EPOS simulations, average over many events
blue: fit
red, blue: EPOS simulations, average over many events
green, yellow: fit
Energy at $\tau = \tau_0$ from EPOS (semiperiph)

red: EPOS simulations, average over many events
blue: fit

green, yellow: fit

red, blue: EPOS simulations, average over many events
Initial energy: single event and average

Single event (lines) compared to average results (dots)

0-5% centrality
same but semiperipheral

Single event (lines) compared to average results (dots)

40-45% centrality
Hydro

Hydro done by Y. Karpenko

Freezeout condition:

\[ \varepsilon = \varepsilon_{\text{FO}} = 0.22 \text{GeV/fm}^3 \]
Time evolution of energy density

\[ \varepsilon(\tau, \eta, \phi, r) \text{ (GeV/fm}^3) \]

- \[ \phi = 0 \ldots \phi = \pi/2 \]
- \[ \eta = 0.00 \]
- \[ \tau - \tau_o = 0.2 \ldots \text{fm/c} \]

0-5%
Time evolution of the flow velocity

\[ \frac{v(r, \eta, \phi, \tau)}{c} \] (comov)

\[ \phi = 0 \ldots \phi = \pi/2 \quad \eta = 0.00 \]

\[ \tau - \tau_0 = 0.2 \ldots \text{fm/c} \]

0-5%
Time evolution of energy density

\[ \varepsilon(\tau, \eta, \phi, r) \text{ (GeV/fm}^3) \]

\[ \phi = 0 \ldots \phi = \pi/2 \quad \eta = 0.00 \]

\[ \tau - \tau_0 = 0.2 \ldots \text{fm/c} \]

40-50%
Time evolution of the flow velocity

\[ v_r(\tau, \eta, \phi, r)/c \text{ (comov)} \]

- \( \phi = 0 \ldots \phi = \pi/2 \)
- \( \eta = 0.00 \)
- \( \tau - \tau_o = 0.2 \ldots \text{fm/c} \)
- 40-50%

r (fm)
Which provides for different centrality classes and different space-time rapidities $\eta$ the **FO hypersurface**,\

$$r_{\text{FO}} = r_0(\tau) + r_2(\tau) \cos(2\varphi),$$

and the **transverse rapidity** at FO,

$$y_{\text{FO}} = y_0(\tau) + y_2(\tau) \cos(2\varphi).$$

We compute the **FO mass rate** as

$$w_{\text{FO}} = \frac{d}{d\tau} \int_{\varepsilon<\varepsilon_{\text{FO}}} \varepsilon dV^*.$$
red: zeroth harmonics
blue: second harmonics
$w_0, w_2$ (GeV/c/fm) vs $\tau$ (fm/c)

freeze out $\eta=0.00$ 40-50%

$y_0, y_2$ vs $\tau$ (fm/c)

freeze out $\eta=0.00$ 40-50%

red: zeroth harmonics
blue: second harmonics

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Transform to $y_0$ as basic variable

red: hydro results

blue: $w_0/y_0 = 1$ for $y_0 < y_{\text{max}}$

with the $y_{\text{max}}$ which provides the best fit to data

(as discussed earlier)

hydro curves are much too narrow, too little flow

$\Rightarrow$ does not work
Next steps

- **Take different EoSs**
  (work in progress with Yuri Karpenko and Yuri Sinyukov)

- **Consider HBT data**

- **Investigate effect of final state hadronic interactions**
  (work in progress with Stephane Haussler et Marcus Bleicher)