MC-EKRT event generator for initializing 3+1 D hydrodynamics

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In collaboration with
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- Problem: So far at midrapidity only, cannot study y-dependent observables! Overall E-conservation?

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8. Compute observables.

Minijets from nucleon-nucleon pairs

- For nucleons $a \in A$ and $b \in B$, the probability to produce $n \geq 0$ minijet pairs:

$$P_n^{ab}(\bar{b}_{ab}) \equiv \frac{\left(T_{NN}(\bar{b}_{ab})\, \sigma_{\text{jet}}^{ab}\right)^n}{n!} \mathrm{e}^{-T_{NN}(\bar{b}_{ab})\, \sigma_{\text{jet}}^{ab}},$$

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- Dijets' transverse momentum p_T and rapidities y_1, y_2 sampled from $\frac{d\sigma_{\text{jet}}^{ab}}{dp_T^2 dy_1 dy_2}$, and spatial coordinates sampled from $T_N(\bar{s} - \bar{s}_a) * T_N(\bar{s} - \bar{s}_b)$.

Minijet cross section with spatial nPDFs

- LO differential cross section of hard parton production:

$$\frac{d\sigma_{\text{jet}}^{ab}}{dp_T^2 dy_1 dy_2} = K \sum_{ijkl} x_1 f_i^{a/A}(\bar{s}_a, x_1, Q^2) x_2 f_j^{b/B}(\bar{s}_b, x_2, Q^2) \times \frac{d\hat{\sigma}^{ij \to kl}}{d\hat{t}}.$$

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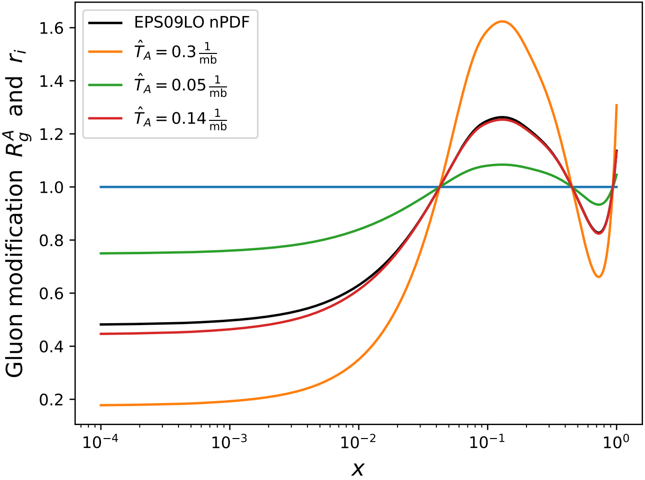
- Solution: Define the EbyE fluctuating spatially dependent nPDF of the proton a bound in a nucleus A as

$$f_i^{a/A}(\bar{s}_a, x, Q^2) \equiv \exp\Big(c_A(x, Q^2) \hat{T}_A^a(\bar{s}_a) \Big) f_i^p(x, Q^2),$$

where $c_A(x, Q^2)$ is set by normalizing to the global averaged nuclear modification $R_A^i(x, Q^2) = f_i^A(x, Q^2)/f_i^p(x, Q^2)$ (EPS09LO).

Spatial nPDFs



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- Filter in the order of the formation time $\tau = 1/p_T$:
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$$\|\bar{s} - \bar{s}^{\text{cand}}\| < \frac{1}{\kappa_{\text{sat}}}\left(\frac{1}{p_T} + \frac{1}{p_T^{\text{cand}}}\right) \qquad \Rightarrow \qquad \text{Reject the candidate.}$$

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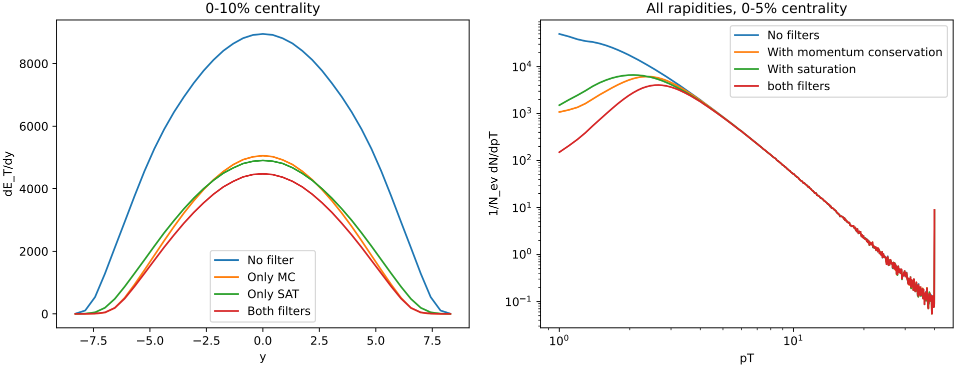
- Momentum conservation at nucleon level: A candidate dijet process with momentum fractions x_1 and x_2 is accepted if

$$x_1 + \sum_{i=1}^{n} x_1^{(i)} \leq 1 \qquad \text{and} \qquad x_2 + \sum_{i=1}^{m} x_2^{(i)} \leq 1,$$

  where the summations are over the previously accepted processes from nucleons 1 and 2.

The effect of the filters



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- The accepted minijets are propagated as free particles to the proper time surface $\tau_0 = 1/p_{T0}$ $(= 0.2\,\mathbf{fm/c})$ and spacetime rapidity $\eta = y$.

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$$e(\bar{s}, \eta) = \frac{1}{\tau_0\, \mathrm{d}^2 \bar{s} \mathrm{d}\eta} \sum_{i=1}^{N_{\text{jet}}} g_i(\bar{s}, \eta, \sigma_L, \sigma_T) p_{Ti} \cosh(\eta - \eta_i),$$

where $g_i(\bar{s}, \eta, \sigma_L, \sigma_T)$ is a Gaussian-type smearing function.

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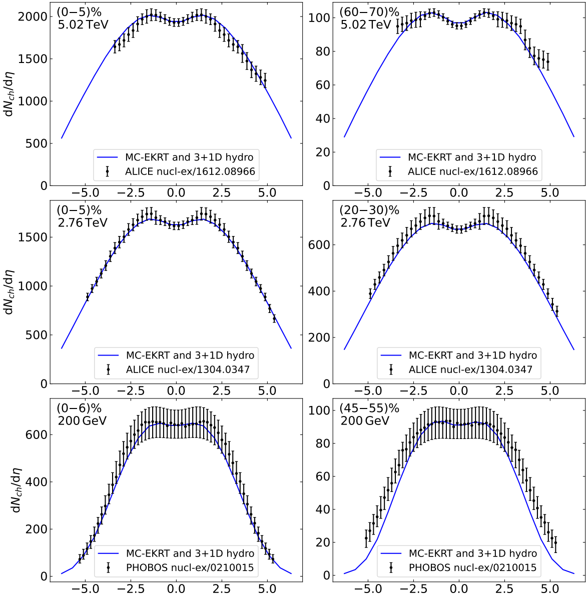
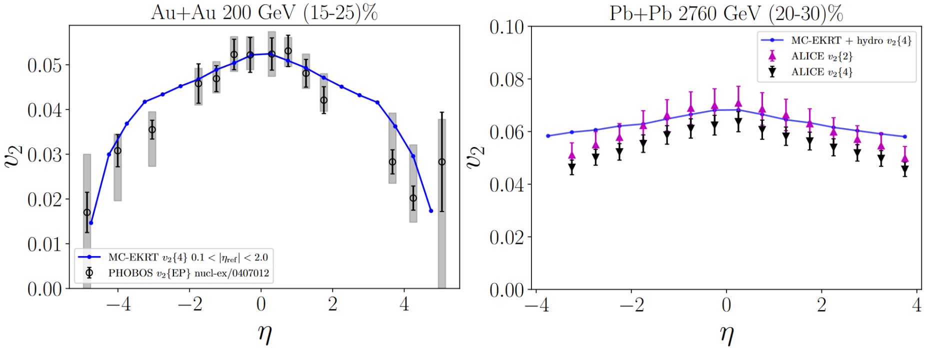
- In this exploratory work: Constant value $\eta/s = 0.12$ for the specific shear viscosity; no bulk viscosity; EoS *s95p-PCE* with $T_{chem} = 150$ MeV; kinetic freeze-out at $T_{kin} = 130$ MeV; resonance decays with PYTHIA; averaged initial states for each centrality class.

Charged hadron multiplicity



Elliptic flow v_2



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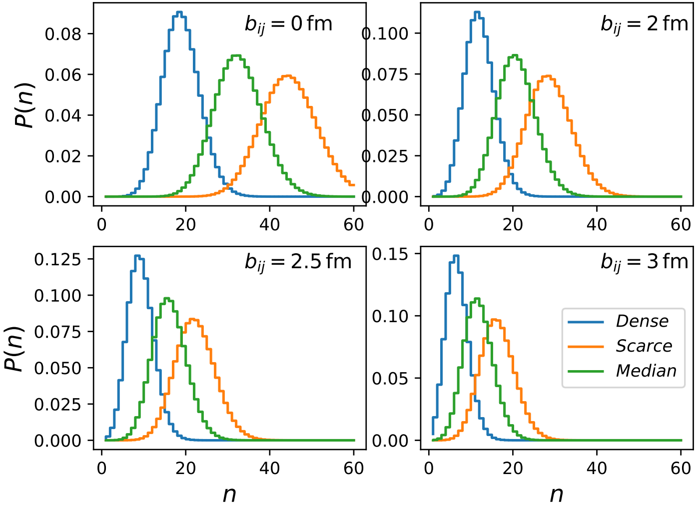
Thank you!

Minijet production probability



Spatial nPDFs with more detail

$$f_i^{a/A}(\bar{s}_a, x, Q^2) \equiv \exp\Big(c_A(x, Q^2)\,\hat{T}_A^a(\bar{s}_a)\Big)\, f_i^p(x, Q^2),$$

where $\hat{T}_A^a$ is a T_N-weighted average of the nuclear thickness function experienced by the nucleon a,

$$\hat{T}_A^a(\bar{s}_a) \equiv \sum_{b \neq a}^{A} T_{NN}\left(\bar{b}_{ab}\right).$$

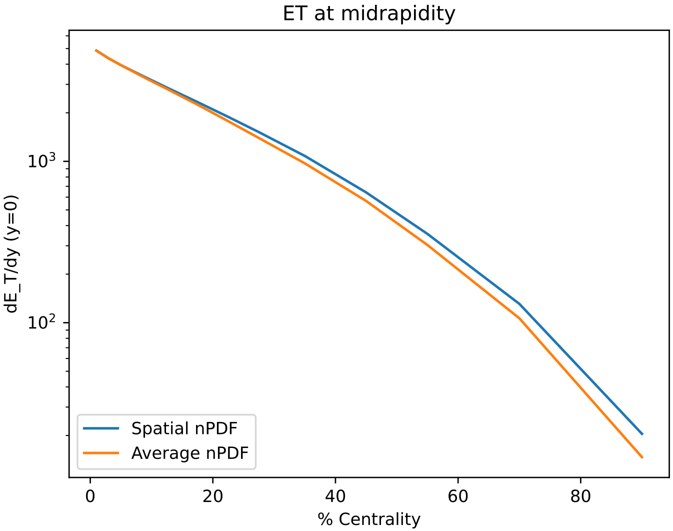
The coefficient $c_A(x, Q^2)$ is set by normalizing to the global averaged nuclear modification (EPS09LO):

$$R_i^A(x, Q^2) = \left\langle \int \mathrm{d}^2\bar{s}\, \frac{\sum_{a=1}^{A} f_i^{a/A}(\bar{s}_a, x, Q^2)}{A f_i^p(x, Q^2)} \right\rangle_{\{A\}} \equiv F\left(c_A(x, Q^2)\right),$$

where $\langle\cdot\rangle_{\{A\}}$ is an average over all the sampled nuclei. The function F can be inverted numerically:

$$c_A(x, Q^2) \equiv F^{-1}\Big(R_i^A(x, Q^2)\Big).$$

Spatial vs averaged nPDFs



3+1D viscous hydro with more detail

Gaussian-type smearing function

$$g_i(\bar{s}, \eta, \sigma_L, \sigma_T) = \frac{1}{N} e^{-\frac{1}{2}\frac{(\bar{s}-\bar{s}_i)^2}{\sigma_T{}^2}} e^{-\frac{1}{2}\frac{(\eta-\eta_i)^2}{\sigma_L{}^2}}$$

The events are divided into centrality classes according to the initial E_T. For each event, the energy density profile is converted to entropy density using the equation of state *s95p-PCE* with chemical freeze-out at $150\,$MeV. The event averaged entropy density is then converted back to energy density in each centrality class. The hydrodynamical evolution lasts until kinetic freeze-out temperature $T_{\text{kin}} = 130\,$MeV. We use a constant value $\eta/s = 0.12$ for the specific shear viscosity and omit the bulk viscous effects.

Proton-proton minimum bias