Jet Wake from Linearized Hydrodynamics

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arXiv: 2010.01140

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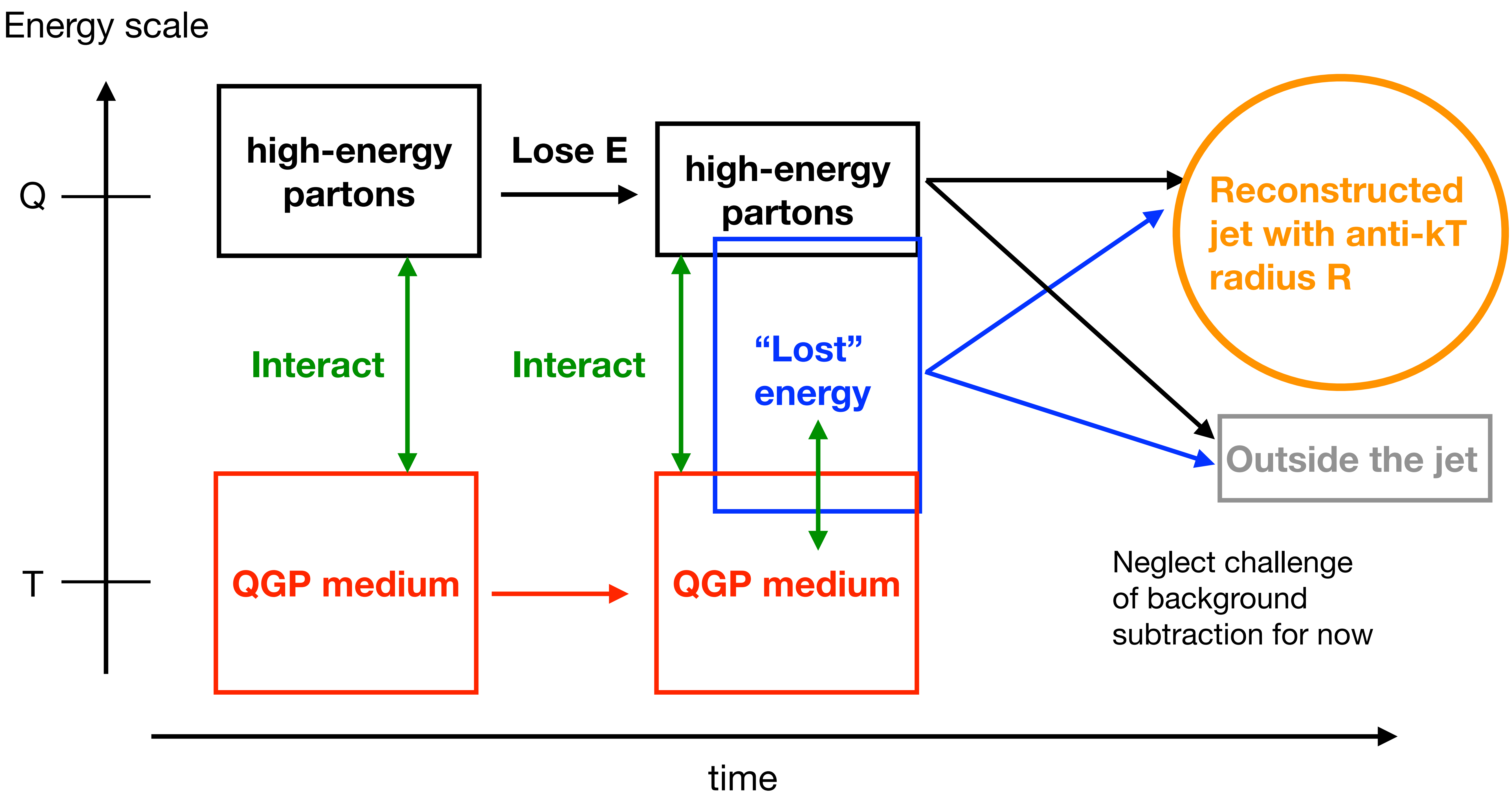
Jet Evolution in QGP and Reconstruction



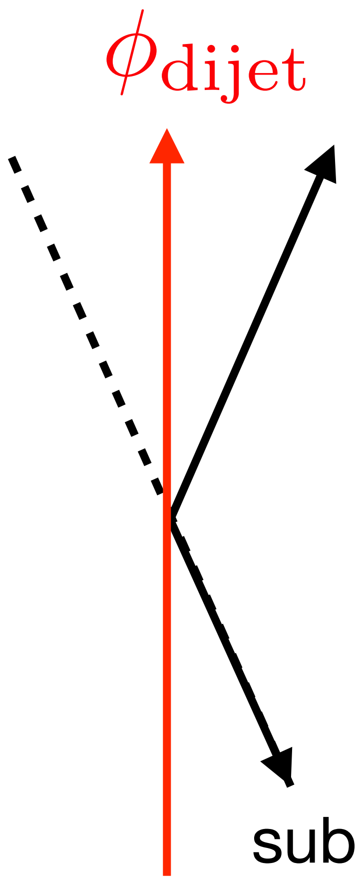
Need to understand evolution of deposited energy and how particles are produced from the deposited energy and reconstructed into jets

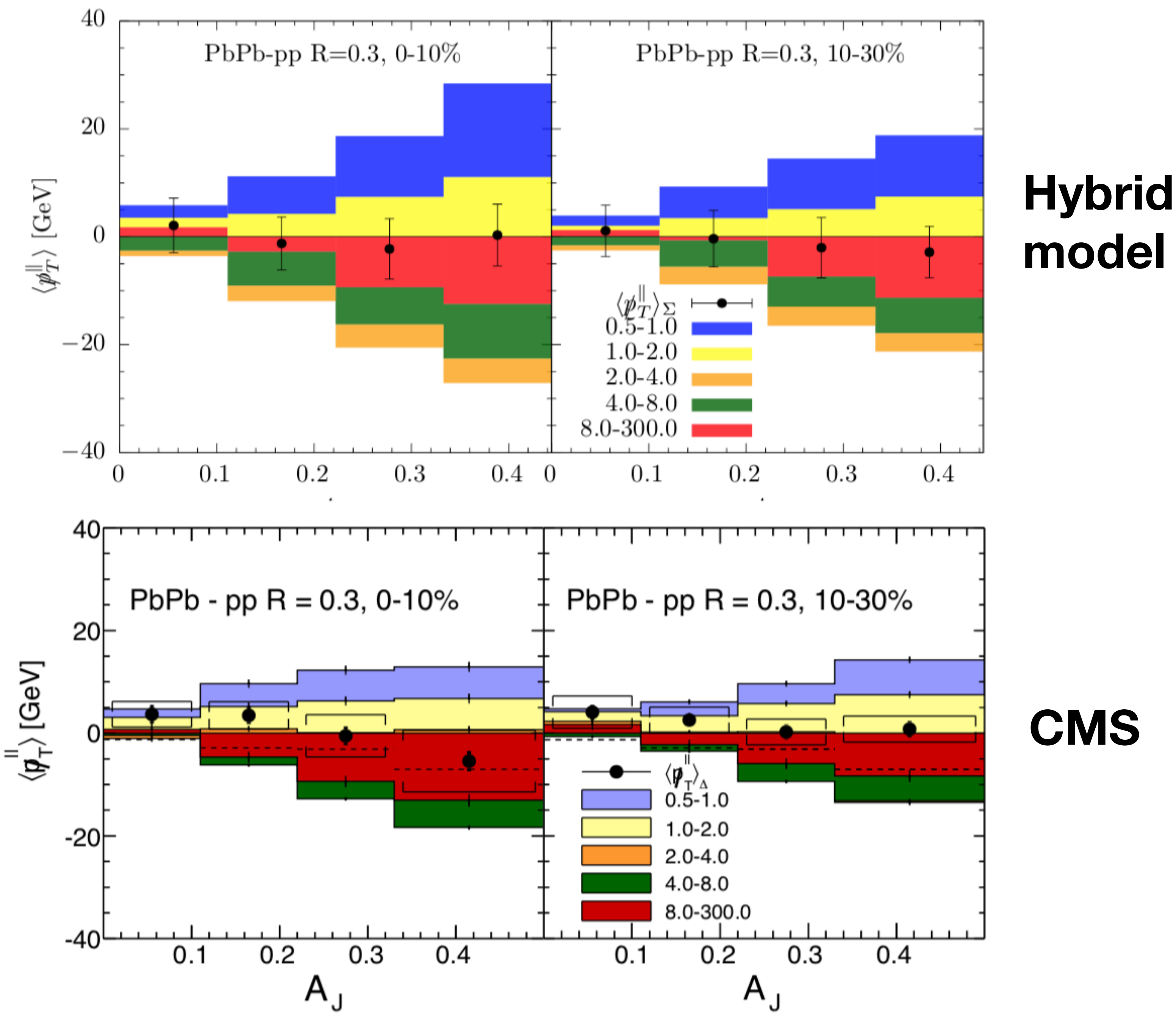
Observables Sensitive to Dynamics of Deposited Energy

- Missing-pT observables:

Calculate for all tracks in the event

$$\not{p}_{\mathrm{T}}^{\parallel} \equiv -p_{\mathrm{T}} \cos\left(\phi_{\mathrm{dijet}} - \phi\right)$$





arXiv:1609.05842 J.Casalderrey-Solana, D.Gulhan, G.Milhano, D.Pablos, K.Rajagopal

- Medium response in hybrid model has too many pT<1 GeV particles, too few pT = 2-4 GeV particles

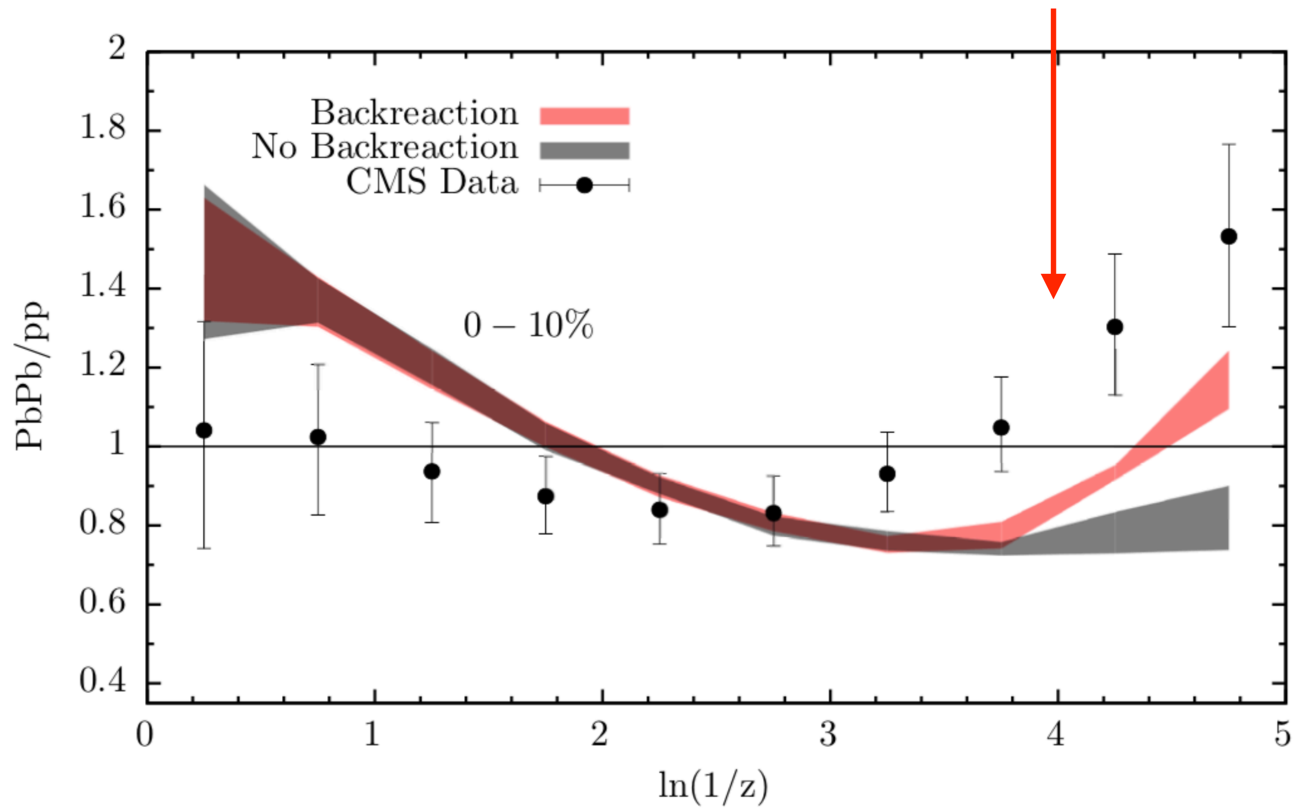
Observables Sensitive to Dynamics of Deposited Energy

- Jet Raa not sensitive, since recovered “lost” energy << E(jet)

- Fragmentation function f(z) at low z sensitive

Medium response in hybrid model lacks particles with pT = 2-4 GeV

Fragmentation function ratio



arXiv:1609.05842 J.Casalderrey-Solana, D.Gulhan, G.Milhano, D.Pablos, K.Rajagopal

- Improve hybrid model: use hydrodynamics to describe evolution of deposited energy

Linearized Hydrodynamics

- Decompose: background + perturbation for Bjorken flow

$$u^\mu = u_0^\mu + \delta u^\mu$$
$$\epsilon = \epsilon_0 + \delta\epsilon$$
$$P = P_0 + \delta P$$

$$u_0 = (u_0^\tau, u_0^x, u_0^y, u_0^{\eta_s}) = (1,0,0,0)$$
$$u = (1, \delta u^x, \delta u^y, \delta u^{\eta_s})$$

$$\nabla_\mu T^{\mu\nu}_{(0)} = 0$$ Background

$$\nabla_\mu \delta T^{\mu\nu} = J^\nu$$ Expand to linear order in perturbation

$$\partial_\tau \delta\epsilon + \frac{\delta\epsilon + \delta P}{\tau} + \partial_x\Big((\epsilon_0 + P_0)\delta u^x + \frac{4\eta}{3\tau}\delta u^x\Big) + \partial_y\Big((\epsilon_0 + P_0)\delta u^y + \frac{4\eta}{3\tau}\delta u^y\Big) + \partial_{\eta_s}\Big((\epsilon_0 + P_0)\delta u^{\eta_s} - \frac{8\eta}{3\tau}\delta u^{\eta_s}\Big) = J^\tau$$

$$\Big(\partial_\tau + \frac{1}{\tau}\Big)\Big((\epsilon_0 + P_0)\delta \boldsymbol{u}^\perp + \frac{2\eta}{3\tau}\delta \boldsymbol{u}^\perp\Big) + \boldsymbol{\partial}^\perp \delta P - \eta\Big(\partial^{\perp 2} + \frac{\partial^2_{\eta_s}}{\tau^2}\Big)\delta\boldsymbol{u}^\perp - \frac{1}{3}\eta\boldsymbol{\partial}^\perp\Big(\boldsymbol{\partial}^\perp\cdot\delta\boldsymbol{u}^\perp + \partial_{\eta_s}\delta u^{\eta_s}\Big) = \boldsymbol{J}^\perp$$

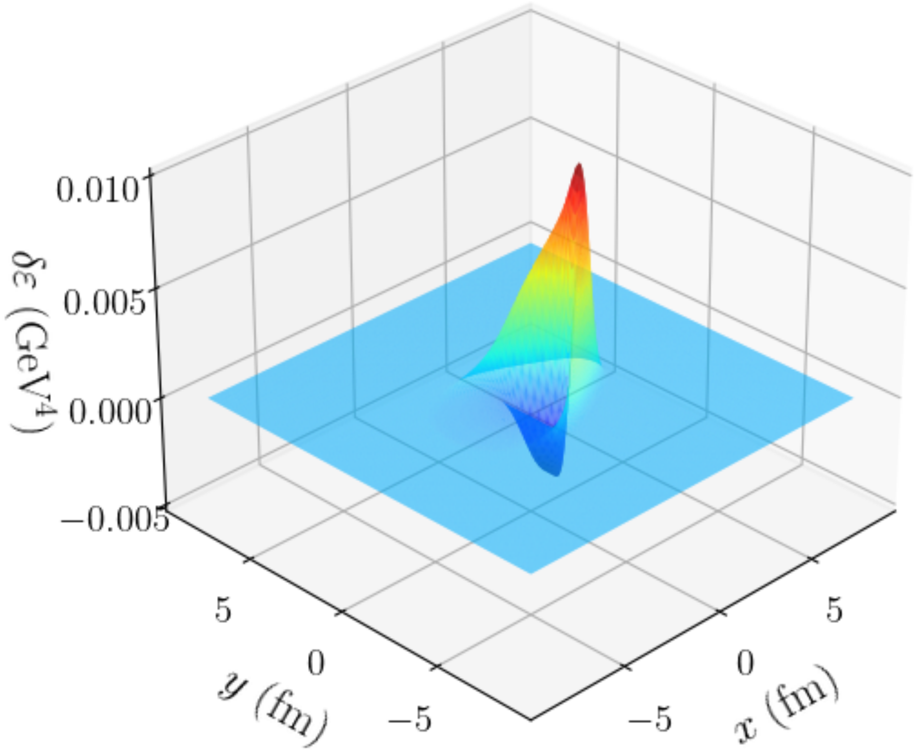
$$\Big(\partial_\tau + \frac{3}{\tau}\Big)\Big((\epsilon_0 + P_0)\delta u^{\eta_s} - \frac{4\eta}{3\tau}\delta u^{\eta_s}\Big) + \frac{1}{\tau^2}\partial_{\eta_s}\delta P - \eta\Big(\partial_x^2 + \partial_y^2 + \frac{\partial^2_{\eta_s}}{\tau^2}\Big)\delta u^{\eta_s} - \frac{1}{3\tau^2}\eta\partial_{\eta_s}\Big(\boldsymbol{\partial}^\perp\cdot\delta\boldsymbol{u}^\perp + \partial_{\eta_s}\delta u^{\eta_s}\Big) = J^{\eta_s}$$

Numerical Solutions: Energy

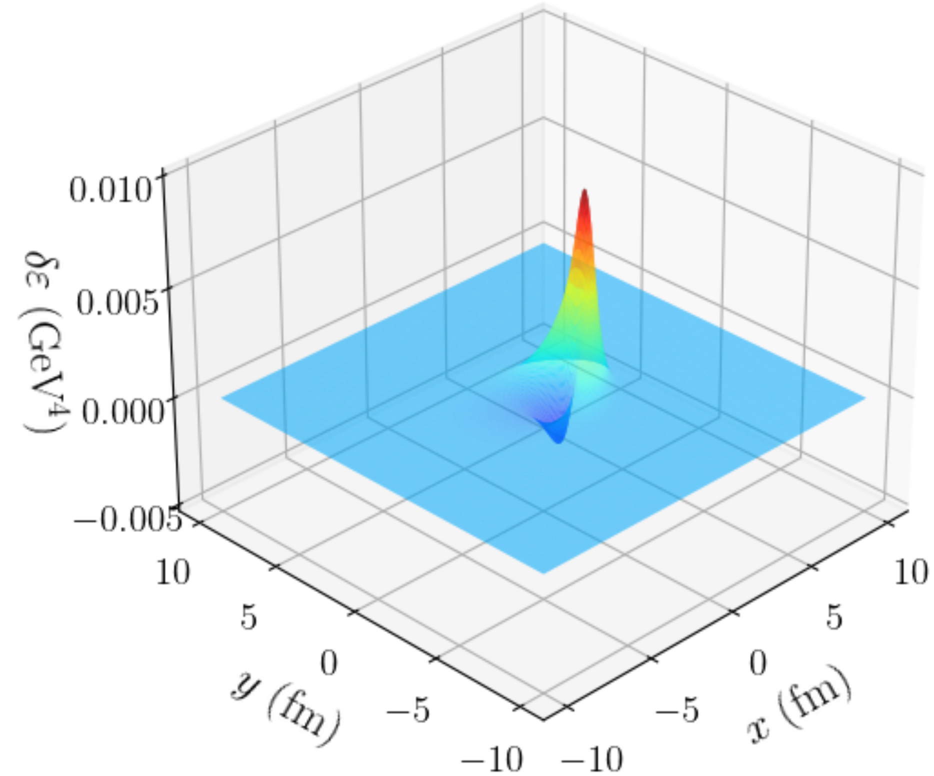
100 GeV parton moving along x loses energy from x=0.6 to x=4.6fm/c

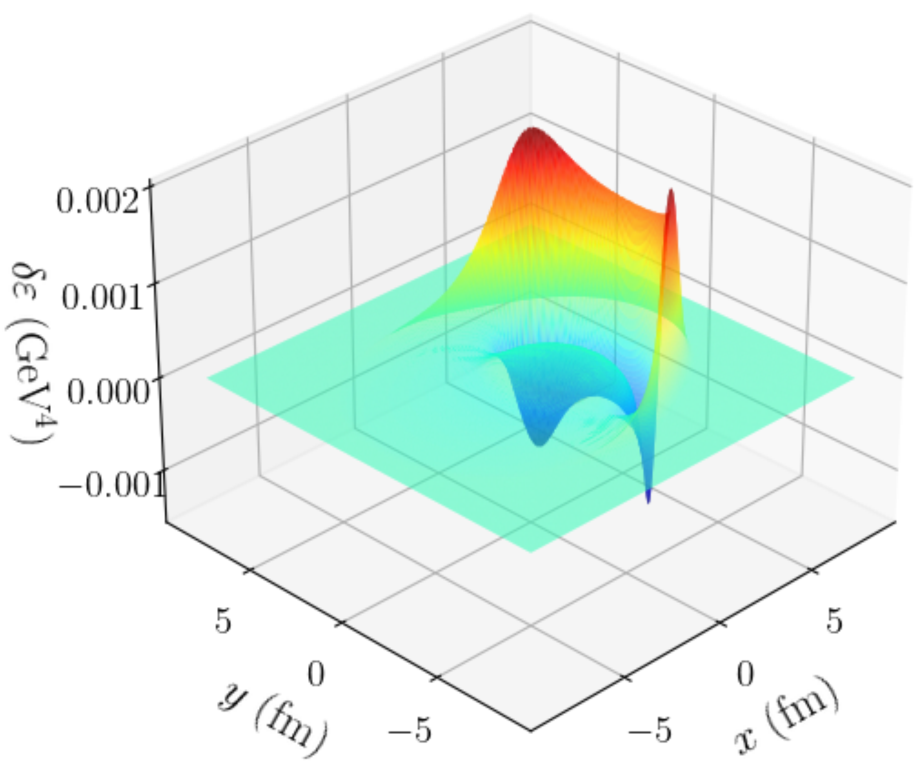
Ideal hydro

Viscous hydro

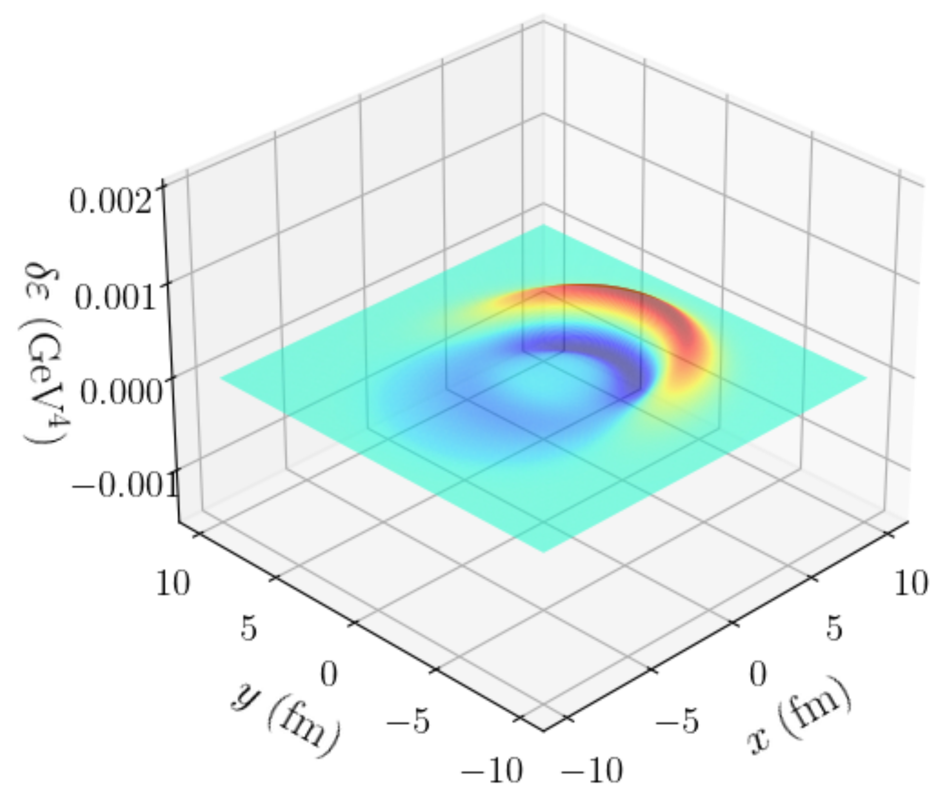


tau=4.6 fm





tau=10.5 fm



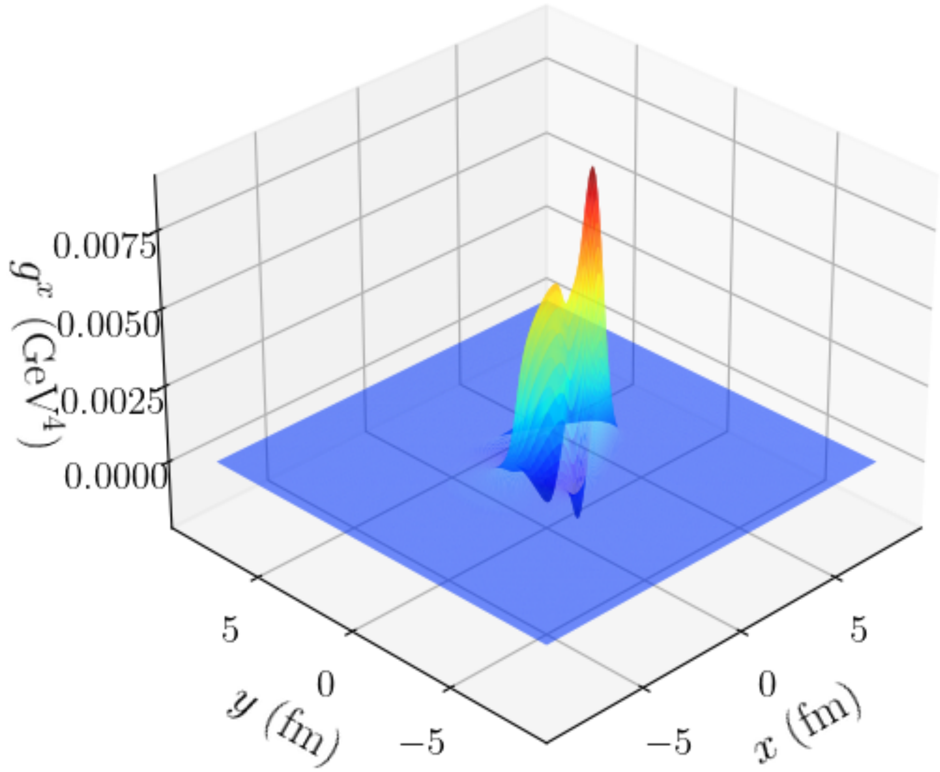
Numerical Solutions: Momentum

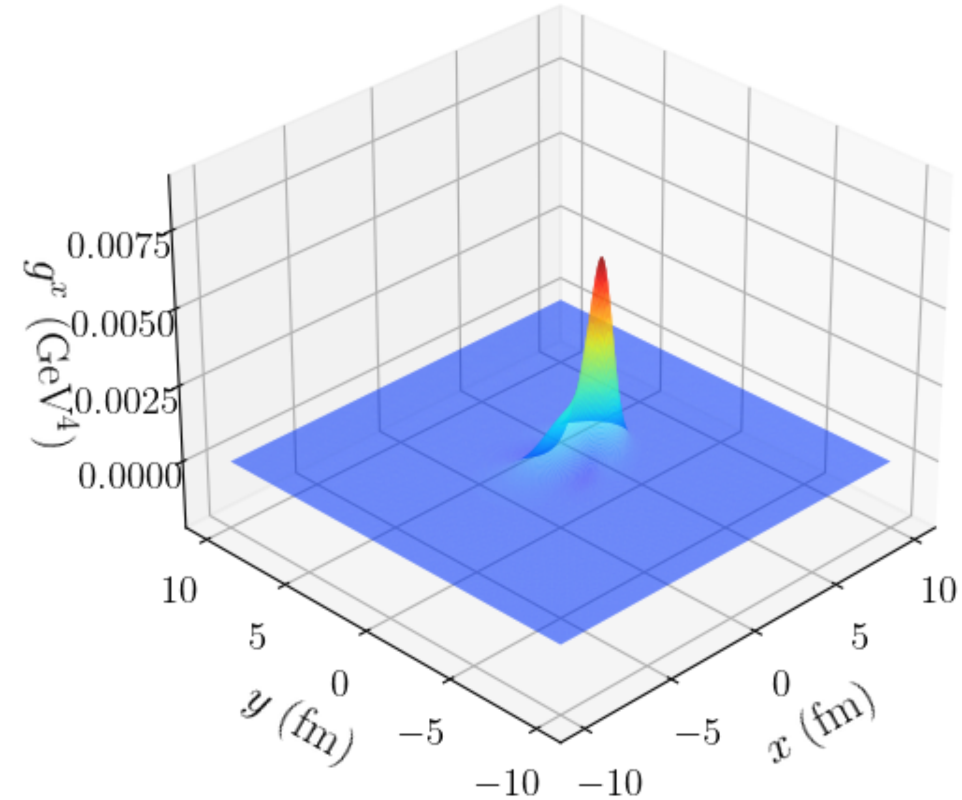
100 GeV parton moving along x loses energy from x=0.6 to x=4.6fm/c

Ideal hydro

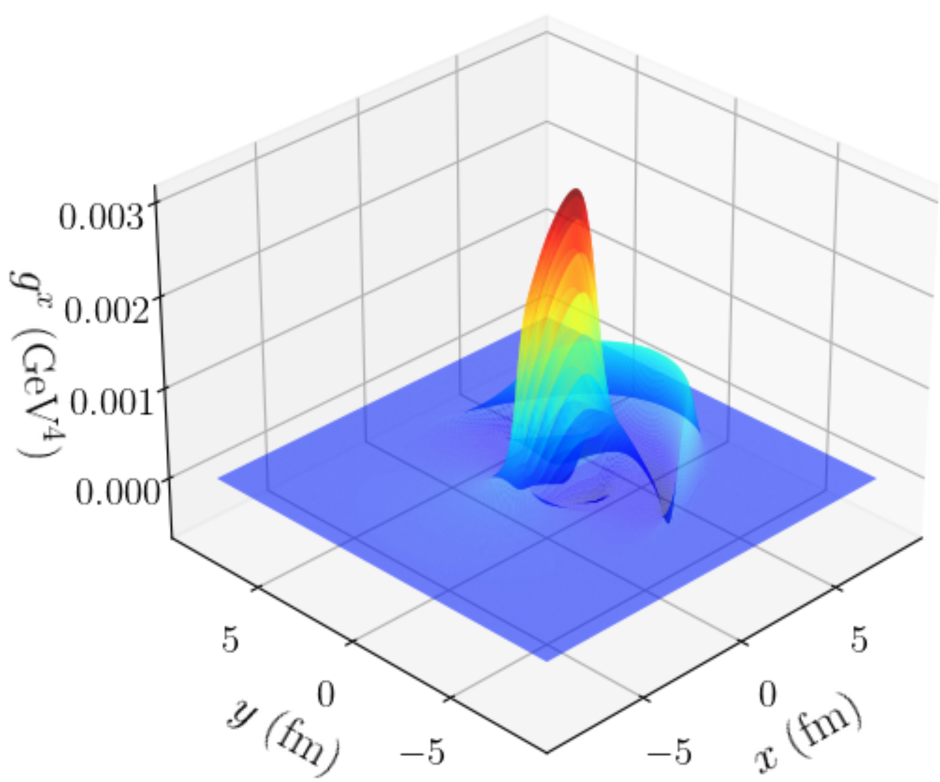
Viscous hydro

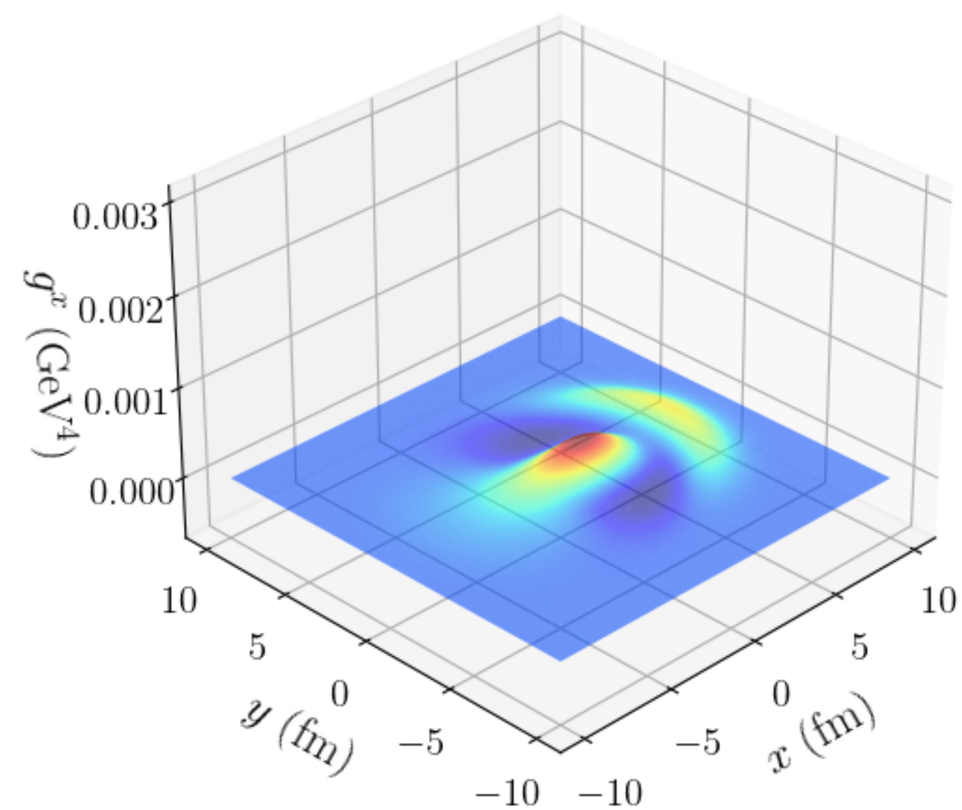
tau=4.6 fm





tau=10.5 fm





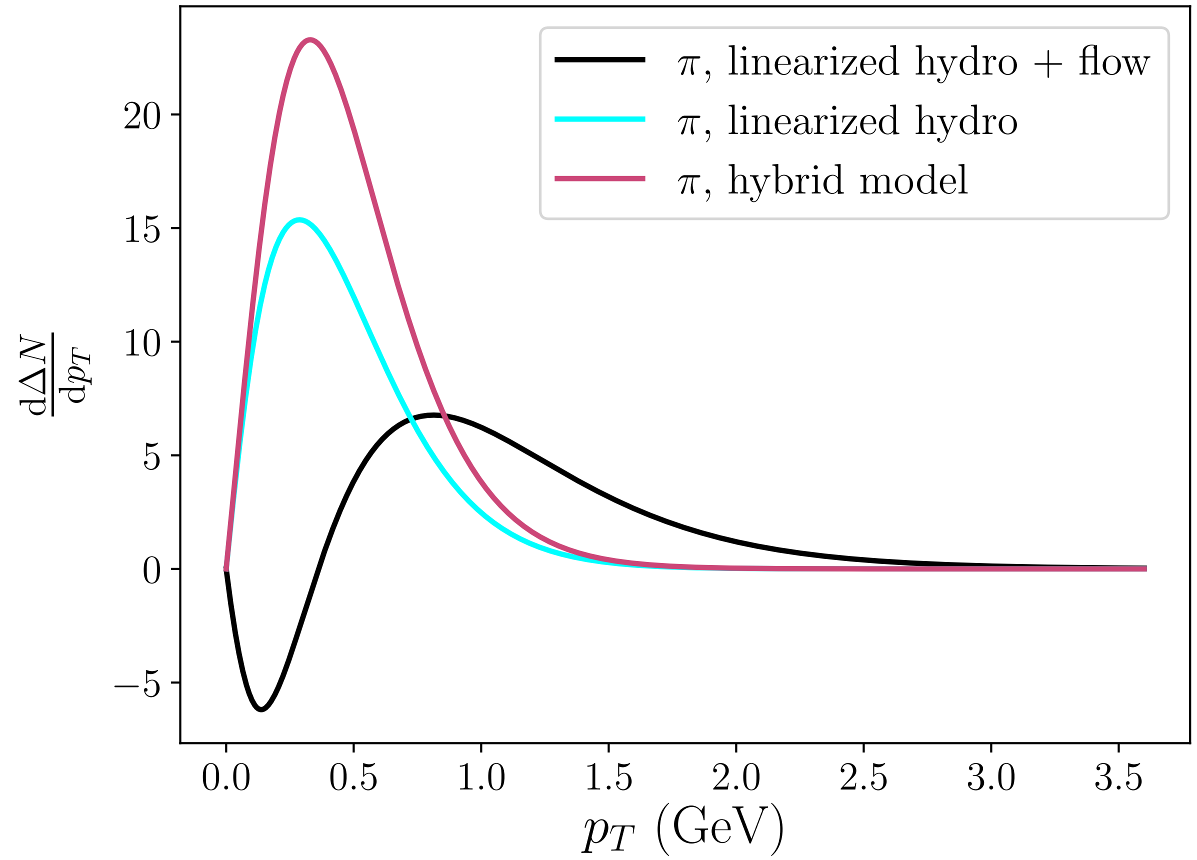
Particle Distribution & Transverse Flow Effect

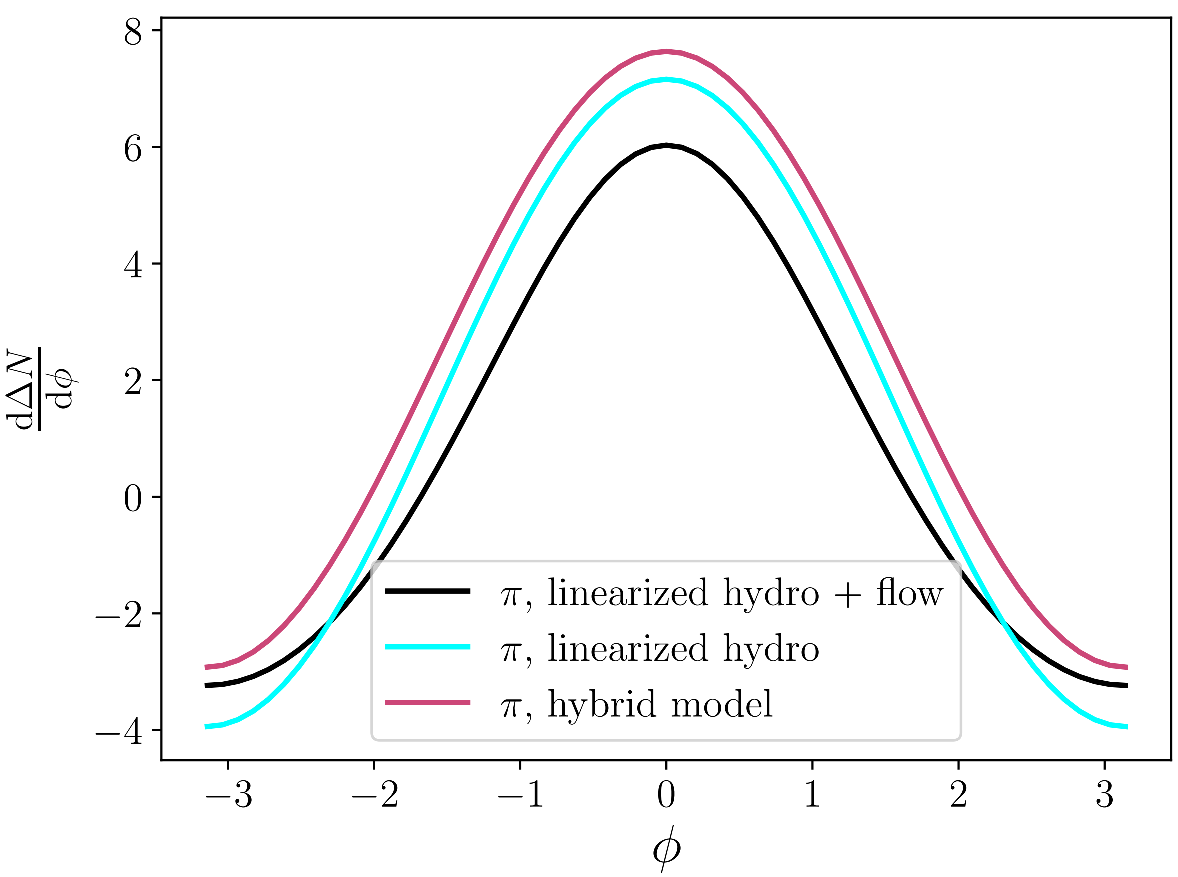
Cooper-Frye formula

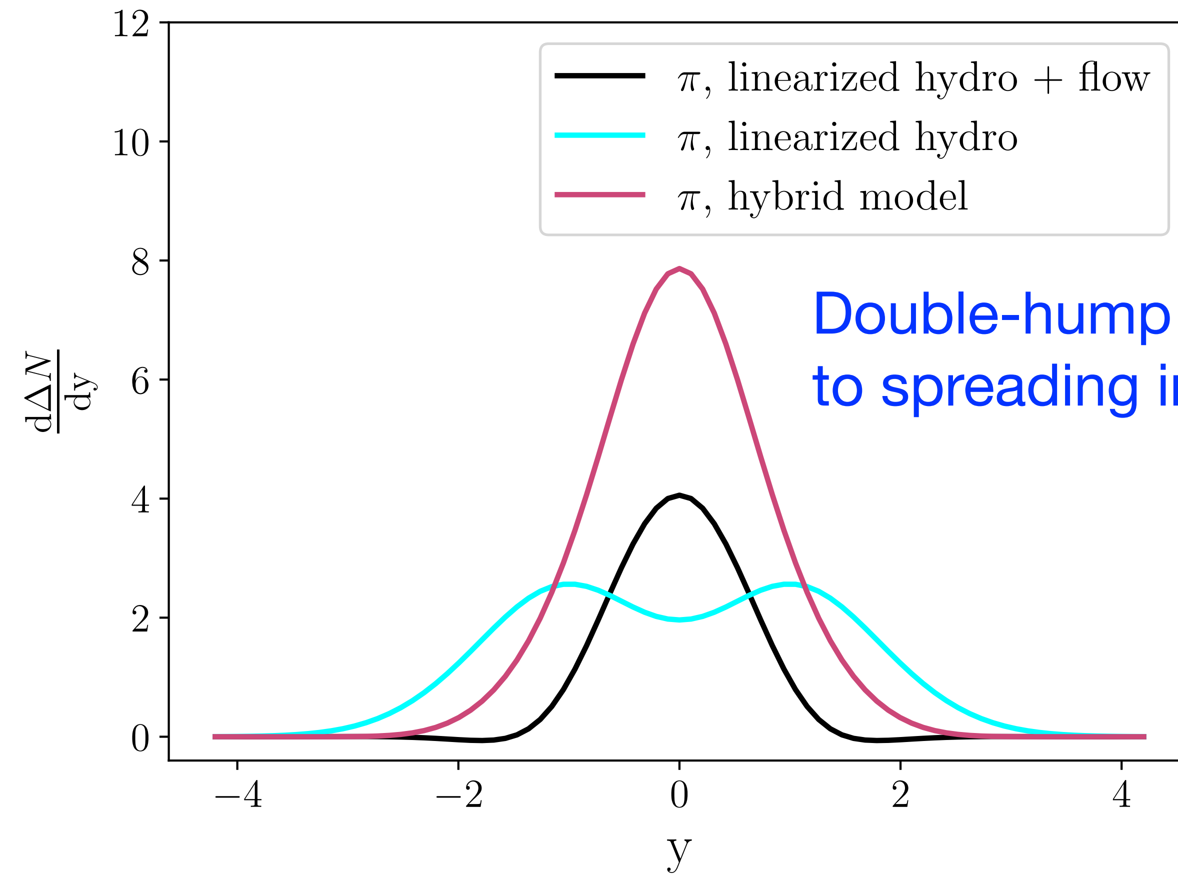
$$E\frac{d\Delta N}{d^3p} = \frac{1}{(2\pi)^3}\int d\sigma^\mu p_\mu \Big(f\big(\frac{u^\mu p_\mu}{T}\big) - f\big(\frac{u_0^\mu p_\mu}{T}\big)\Big)$$

Mimic transverse flow effect by locally boosting lab momentum into hydro cell that is flowing transversely with v_{cell}

$$u_0^\mu p_\mu \rightarrow u_0^\mu \Lambda_{\mu\nu}(\boldsymbol{v}_{\text{cell}})p^\nu$$
$$u^\mu p_\mu \rightarrow u^\mu \Lambda_{\mu\nu}(\boldsymbol{v}_{\text{cell}})p^\nu$$



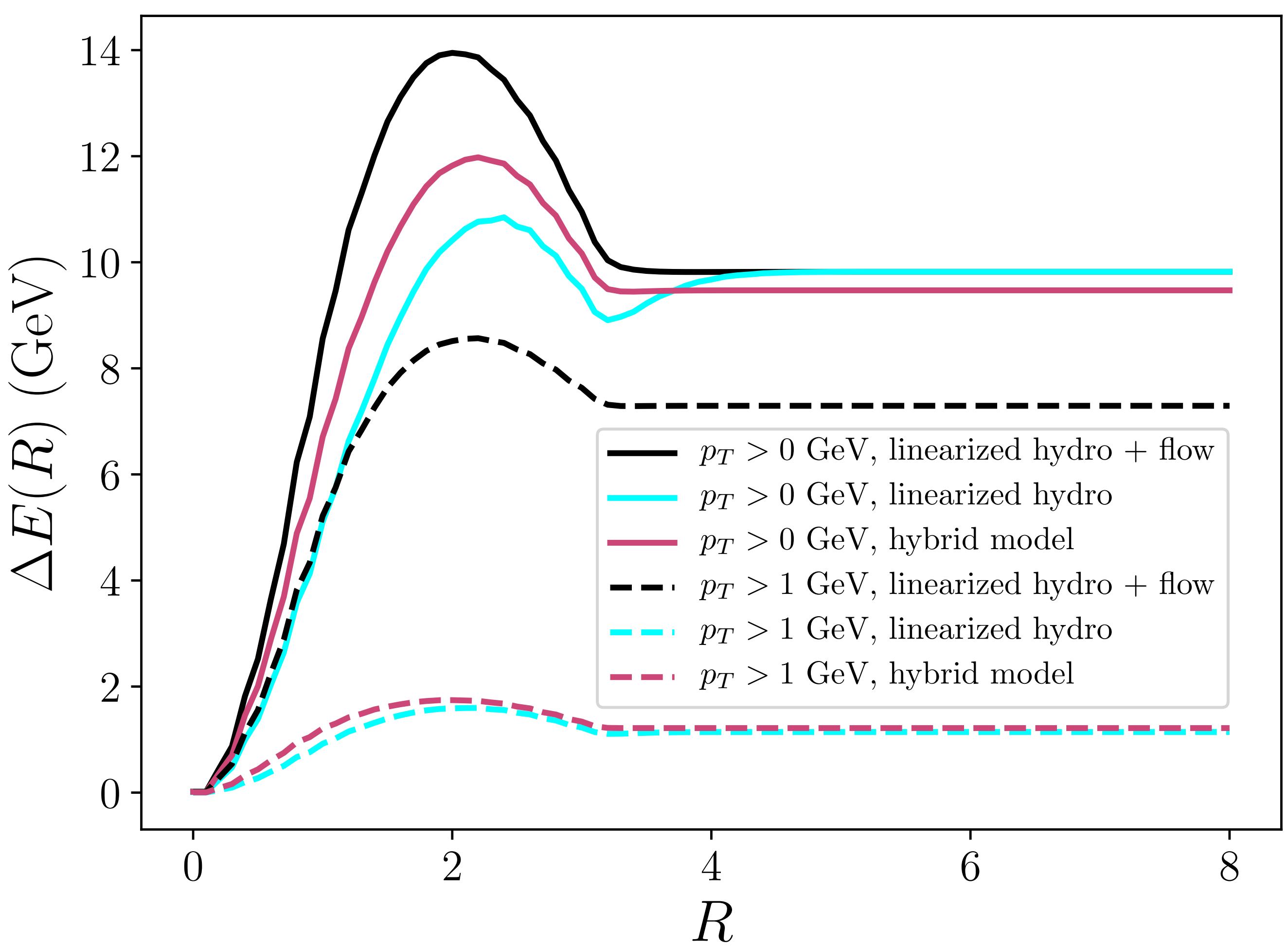




Double-hump due to spreading in eta

Towards Jet Observable: Cone Energy

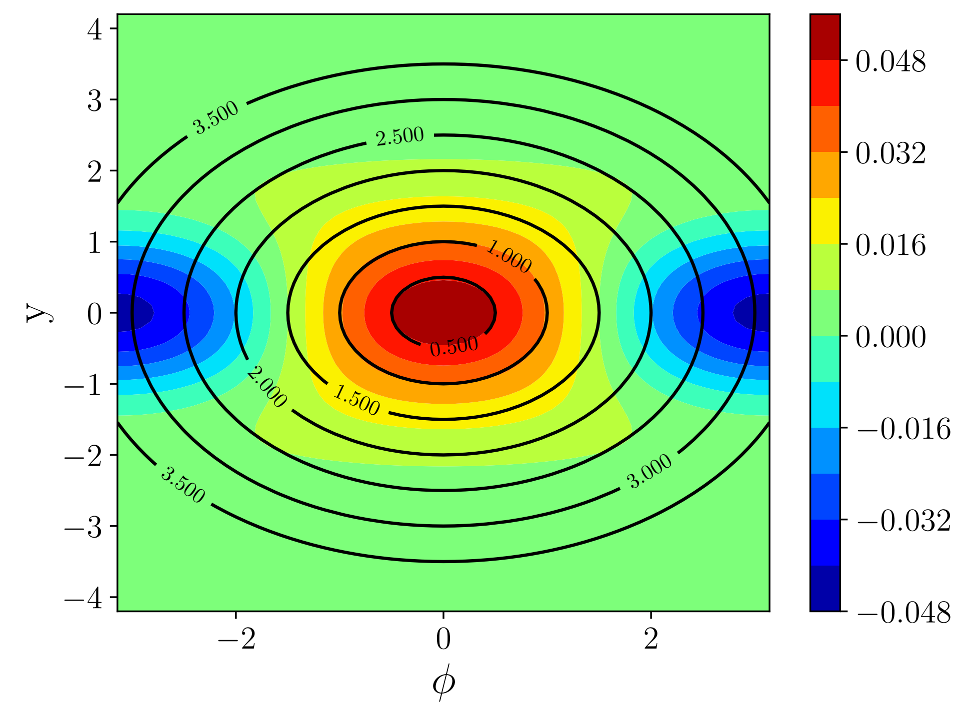
$$\Delta E(R) \equiv \int_{\sqrt{\phi^2+\mathrm{y}^2}<R} d\phi d\mathrm{y} \int dp_T \sqrt{p_T^2+m^2} \cosh \mathrm{y} \, \frac{d\Delta N}{dp_T d\phi d\mathrm{y}}$$

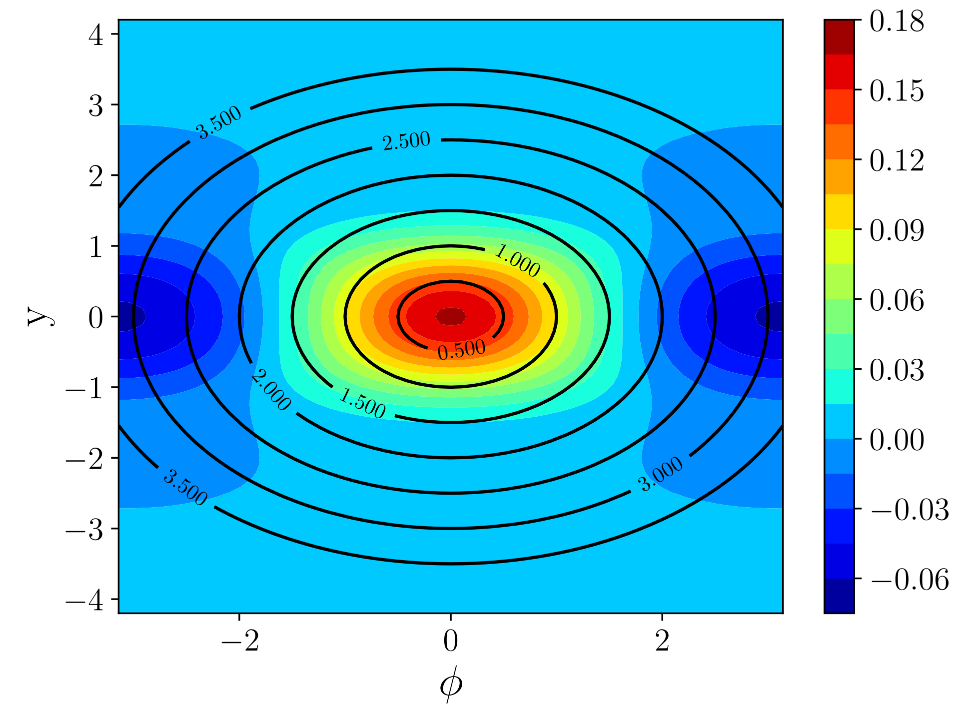


Could recover more than lost due to kinematic regions in (ϕ, y) with particle depletion (see right plots)

$$\frac{d\Delta E}{dy d\phi}$$

without transverse flow



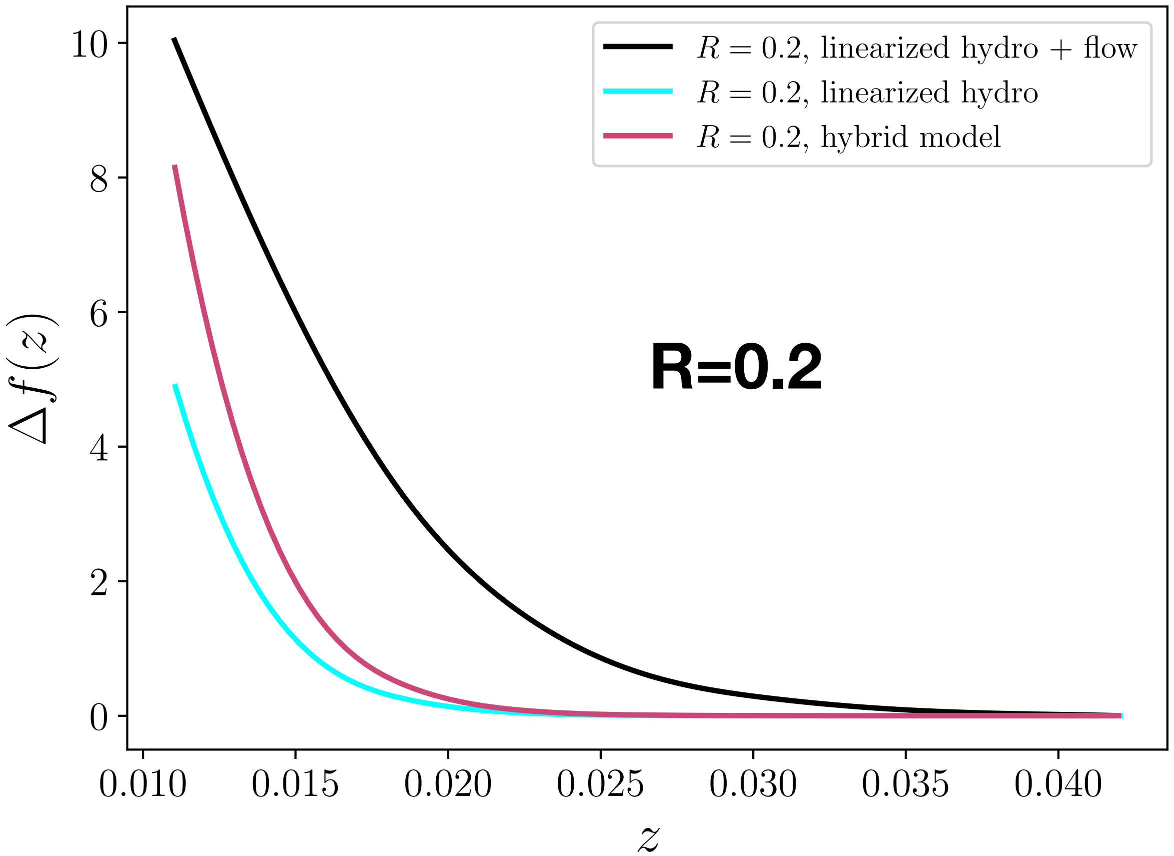


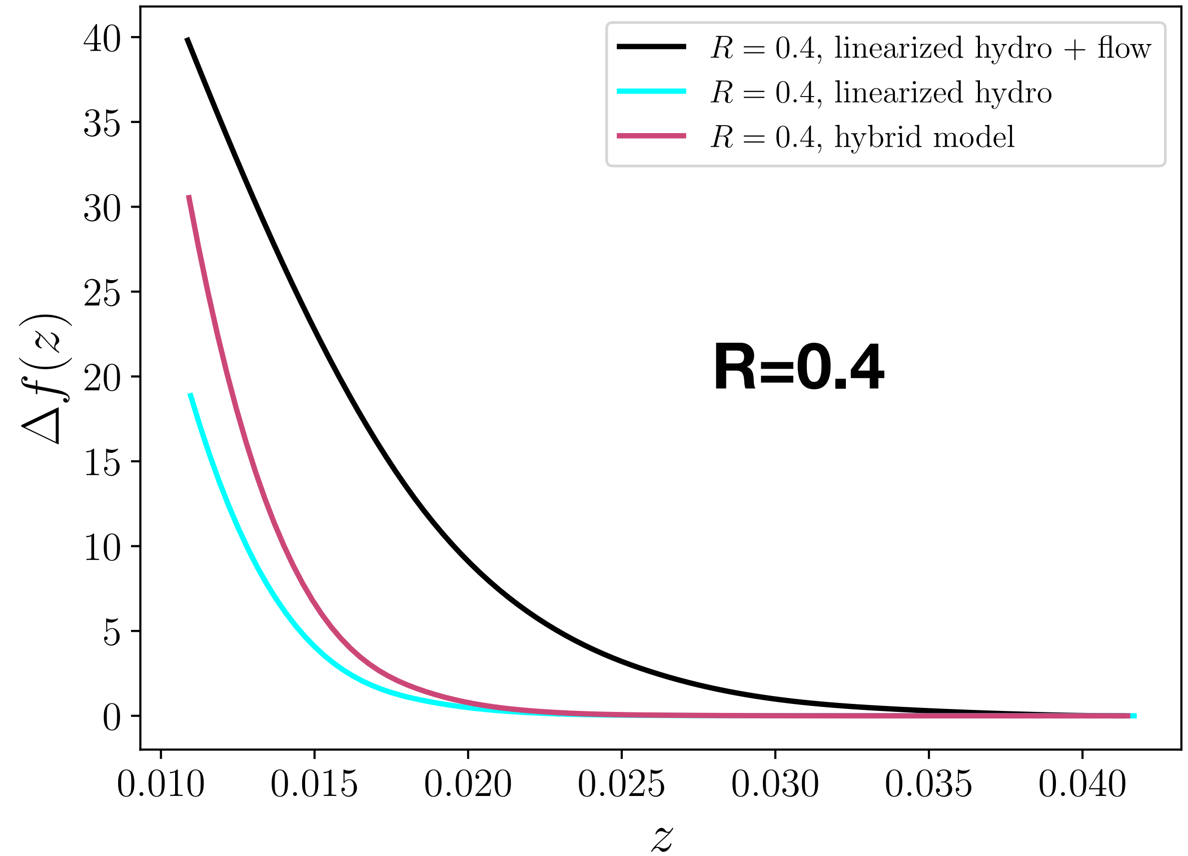
with transverse flow

Towards Jet Observable: “Fragmentation Function”

$$\Delta f(z) \equiv \int dp_T \int_{\sqrt{\phi^2+\mathrm{y}^2}<R} d\phi dy \frac{d\Delta N}{dp_T d\phi dy} \delta\Big(z - \frac{p_T \cos\phi}{E(R)}\Big)$$

E(R) ~ 100 GeV





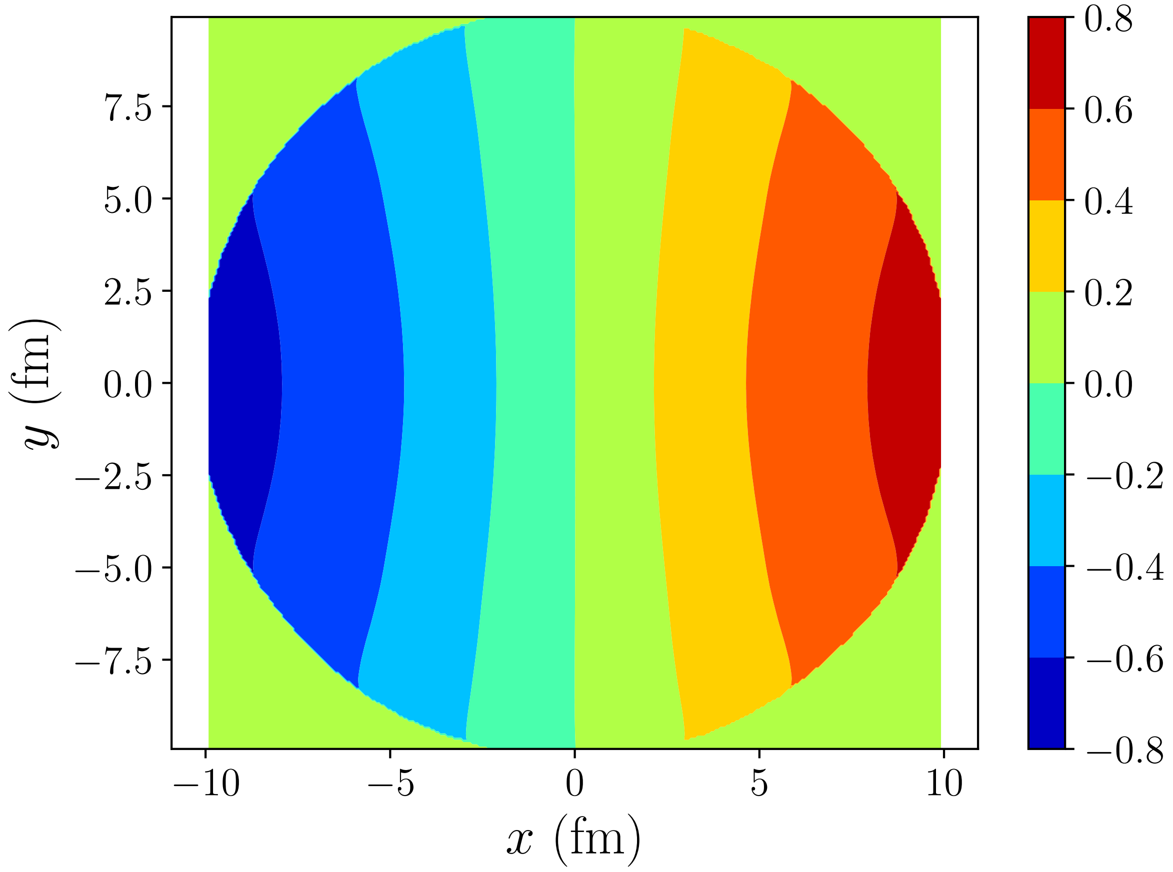
More semi-hard particles, will improve the hybrid model compared with data

Summary

- Backreaction of medium to jet energy loss: jet wake
- Linearized hydrodynamics on a Bjorken flow background
- Particle production from jet wake, effect of transverse flow
- Influence on jet observables: cone energy, fragmentation function
- Improve hybrid model: (1) transverse flow (2) spread-out in rapidity

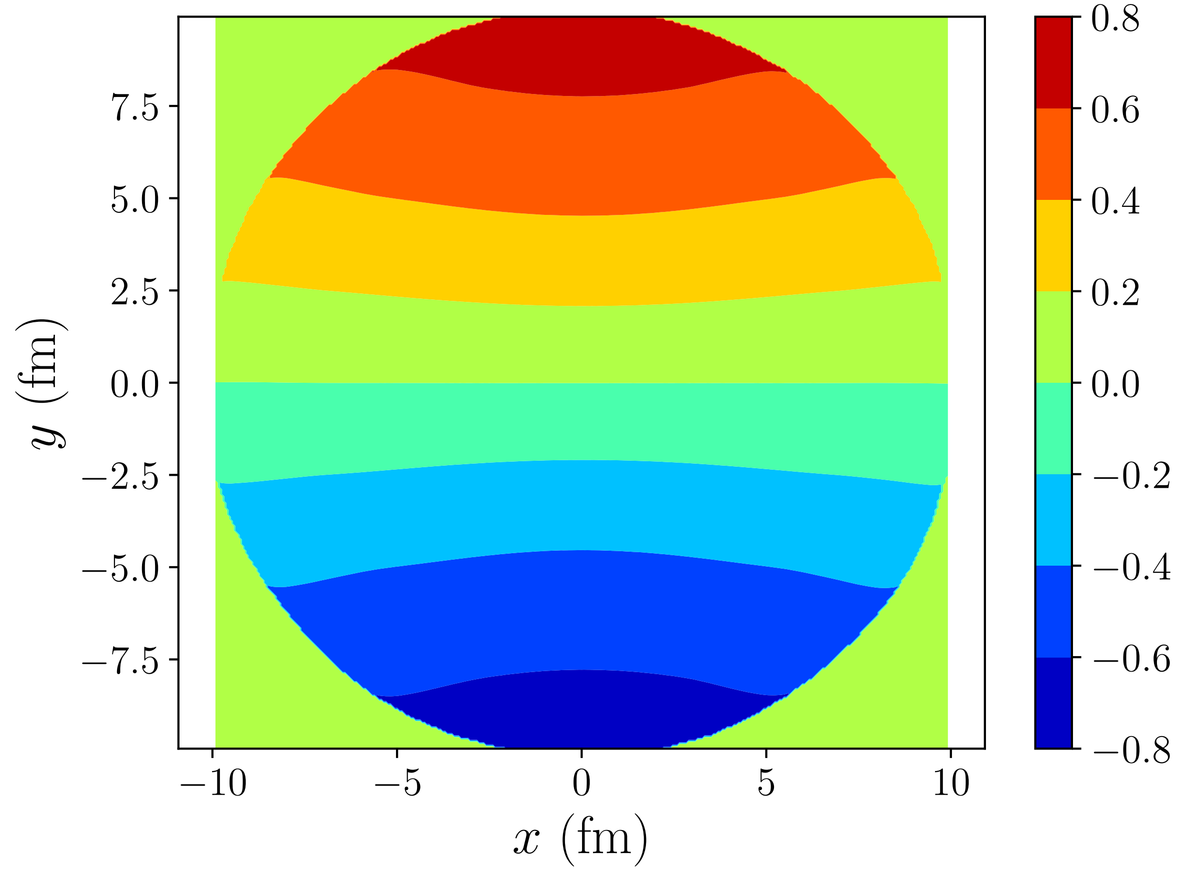
Backup

Vx

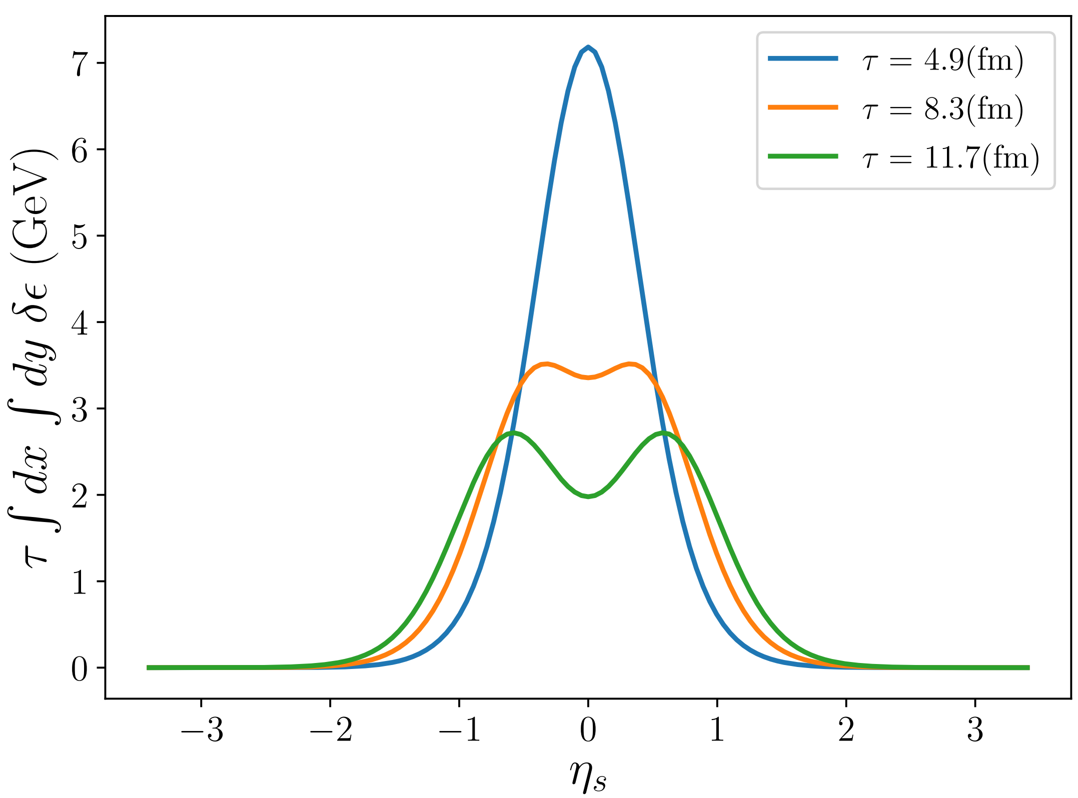


y (fm)
x (fm)
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8

Vy



y (fm)
x (fm)
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8



$\tau = 4.9$(fm)
$\tau = 8.3$(fm)
$\tau = 11.7$(fm)
$\tau \int dx \int dy\, \delta\epsilon$ (GeV)
η_s