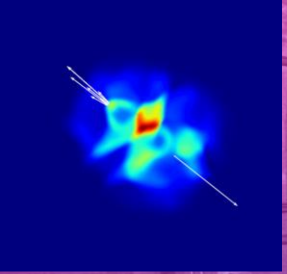


ICHEP2024, July 17-24,2024, Prague

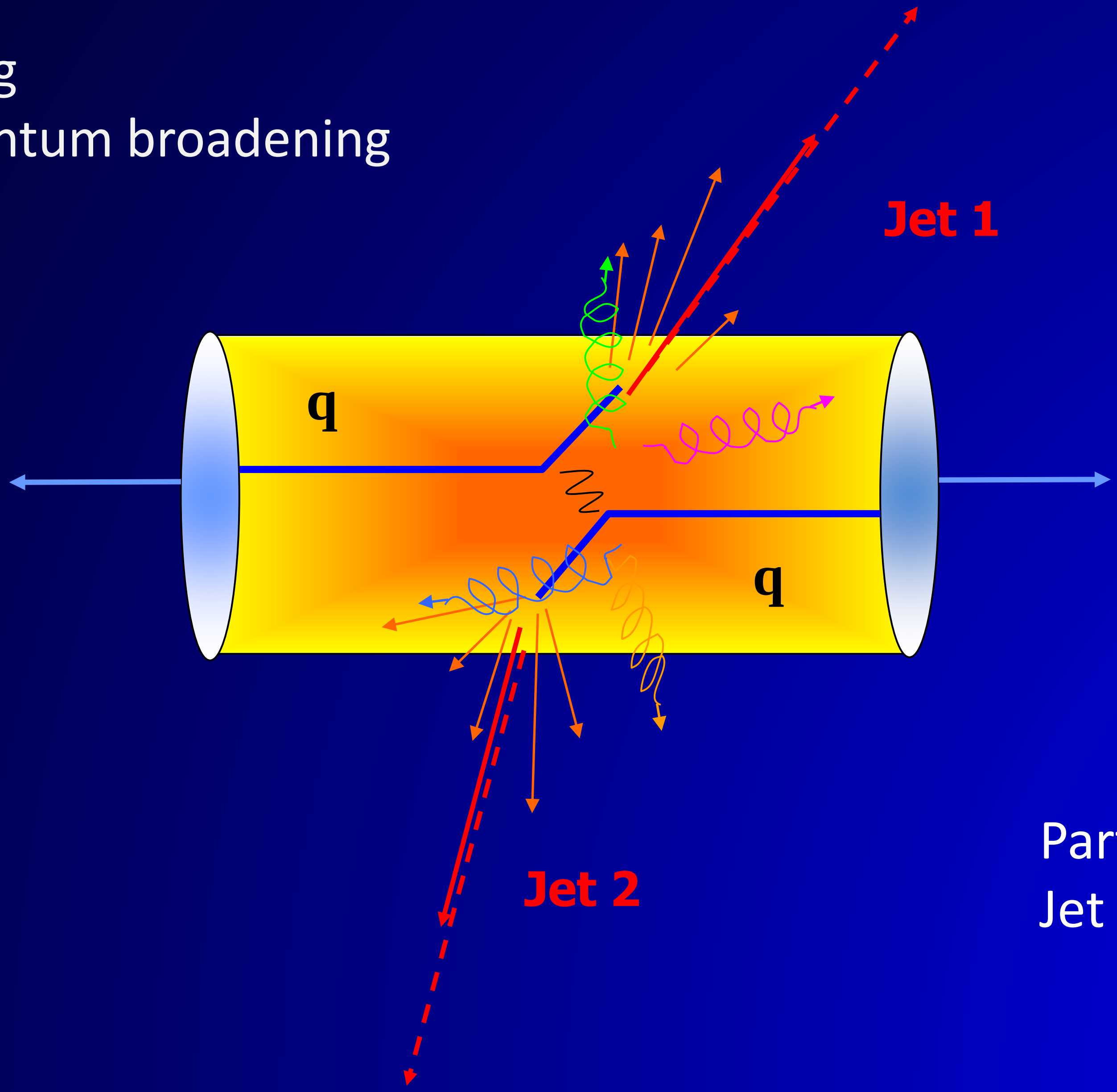
Jet tomography of QGP and medium response

Xin-Nian Wang

Central China Normal University/Lawrence Berkeley National Laboratory

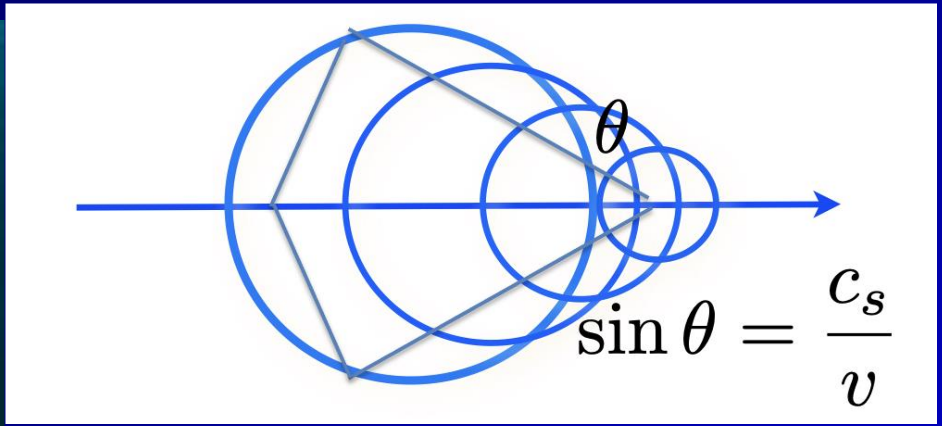
Jets in heavy-ion collisions

Multiple scattering
Transverse momentum broadening



Parton energy loss
Jet suppression

Bow waves, Mach waves



Jet-induced medium excitation

Casalderrey-Solana, Shuryak & Teaney (2005), Stoecker (2005)

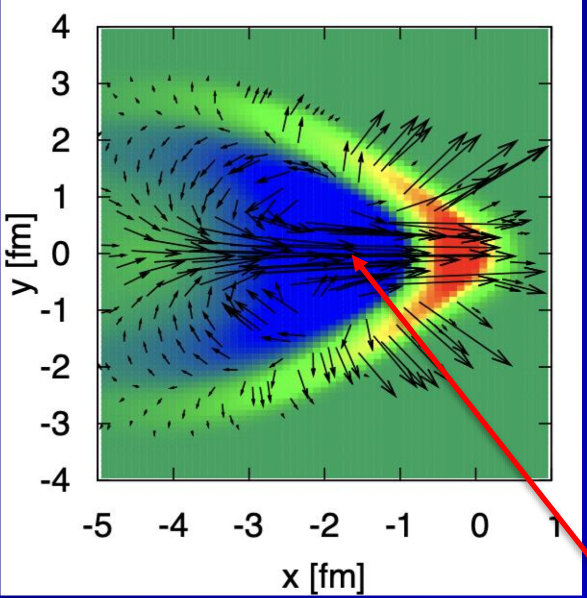
Jet induced Mach-cone in QGP

$$v = p/E > c_s$$

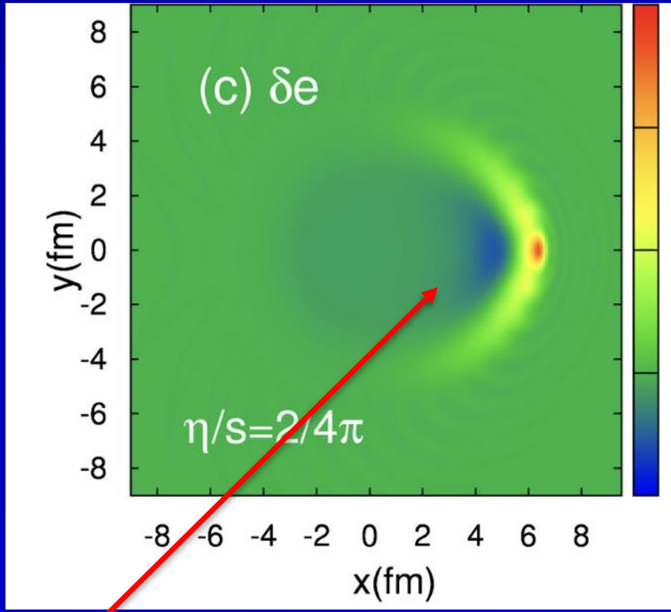
Hydrodynamic approach

$$\partial_\mu T^{\mu\nu} = J^\nu$$

J^ν : energy-momentum deposited by jet



Betz, Noronha, Giorgio, Gyulassy, Mishudtin, Rischke (2009)



Li Yan, S. Jeon, C. Gale (2018)

Diffusion wake

Microscopic picture of Mach wave

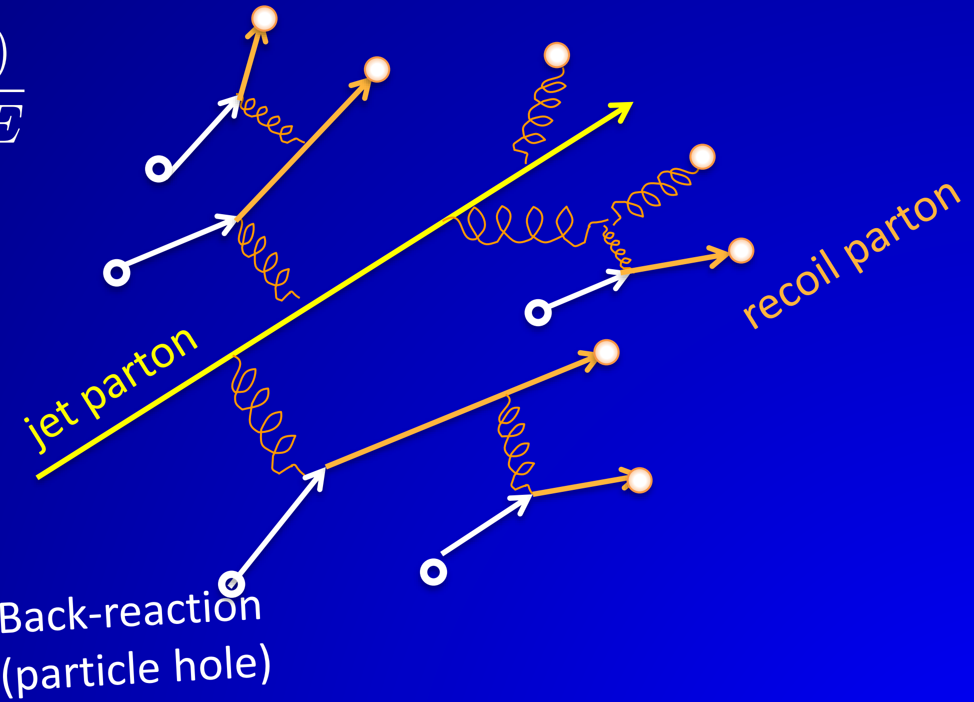
LBT: Linear Boltzmann Transport

$$p_1 \cdot \partial f_1 = -\int dp_2 dp_3 dp_4 (f_1 f_2 - f_3 f_4)|M_{12\to34}|^2 (2\pi)^4 \delta^4(\sum_i p_i) + \text{inelastic}$$

Induced radiation

$$\frac{dN_g}{dz d^2k_\perp dt} \approx \frac{2C_A \alpha_s}{\pi k_\perp^4} P(z) \hat{q}(\hat{p}\cdot u) \sin^2 \frac{k_\perp^2 (t-t_0)}{4z(1-z)E}$$

- pQCD elastic and radiative processes (high-twist)
- Transport of medium recoil partons (and back-reaction)
- CLVisc 3+1D hydro bulk evolution



He, Luo, Zhu & XNW, *PRC* 91 (2015) 054908

CoLBT-hydro
(Coupled Linear Boltzmann Transport hydro)

Concurrent and coupled evolution of bulk medium and jet showers

$$p \cdot \partial f(p) = -C(p) \quad (p \cdot u > p^0_{cut})$$

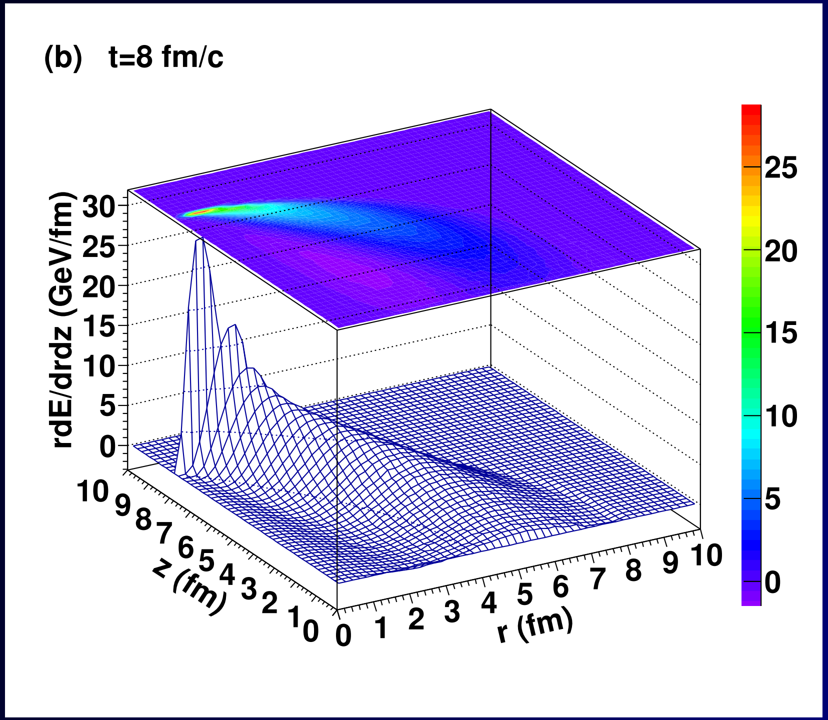
$$\partial_\mu T^{\mu\nu}(x) = j^\nu(x)$$

$$j^\nu(x) = \sum_i p_i^\nu \delta^{(4)}(x - x_i)\theta(p^0_{cut} - p \cdot u)$$

- LBT for energetic partons (jet shower and recoil)
- Hydrodynamic model for bulk and soft partons: CLVisc
- Parton coalescence (thermal-shower)+ jet fragmentation
- Hadron cascade using UrQMD

Chen, Cao, Luo, Pang & XNW, PLB777(2018)86

LBT & CoLBT: Jet-induced medium response

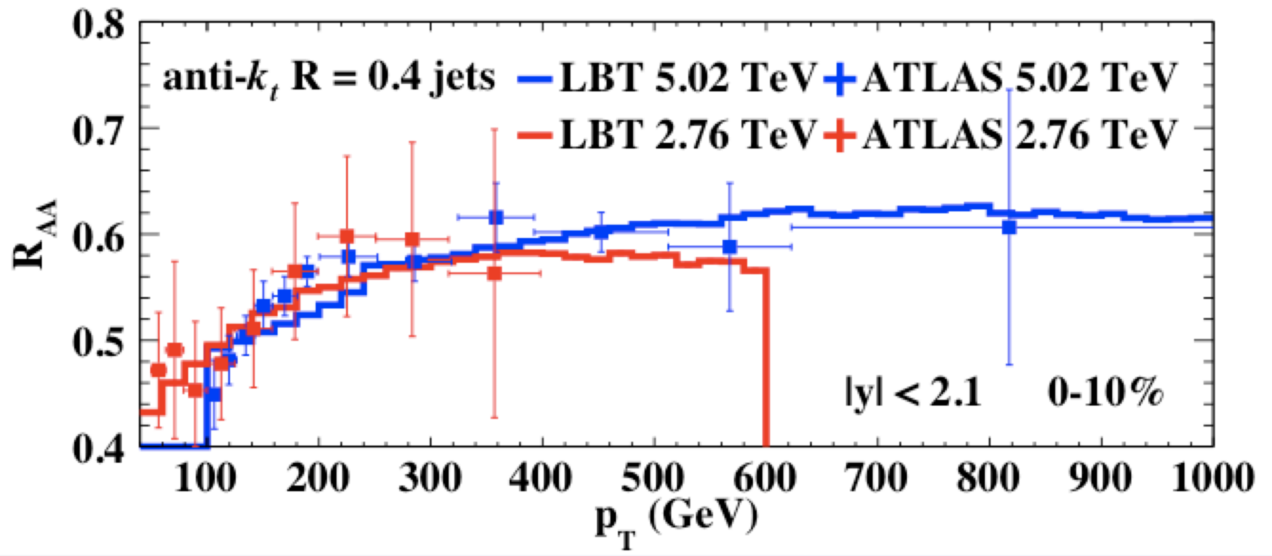


Energy transverse distribution of medium response in a static medium

3D energy density distribution of the medium response induced by a γ-jet in a 0-10% Pb+Pb event

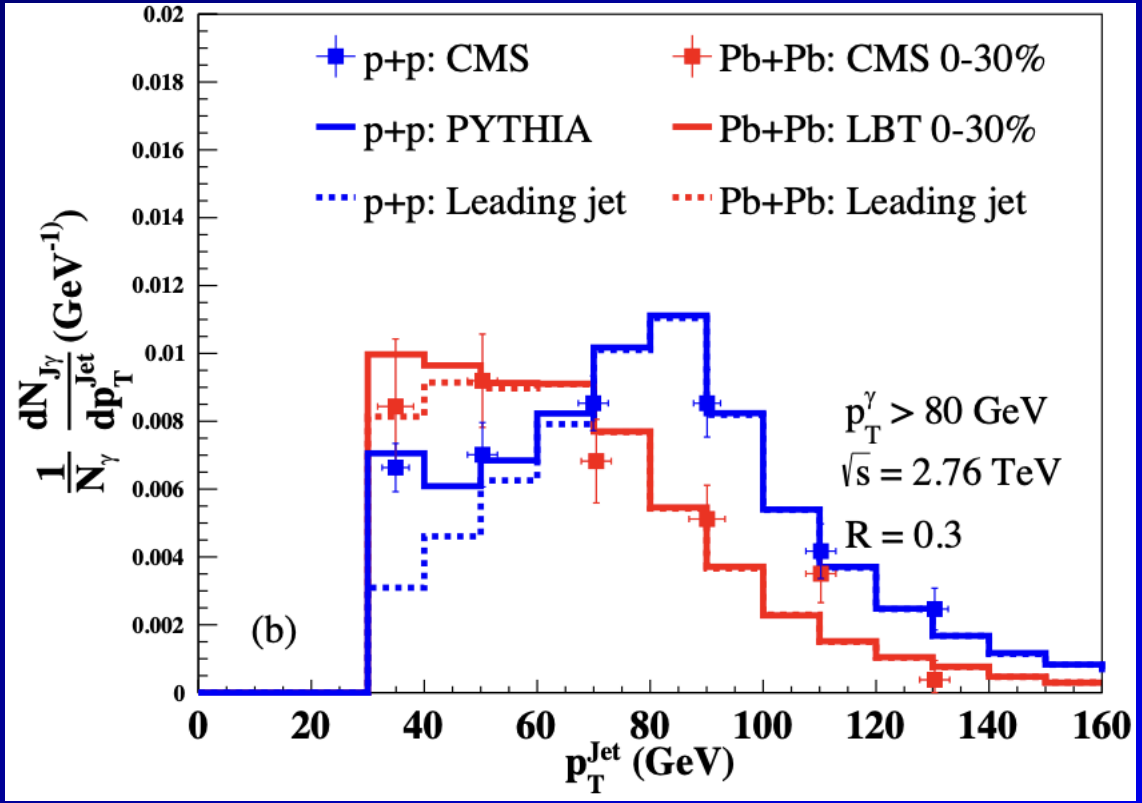
Jet suppression and energy loss

Single inclusive jets



- Weak p_T dependence: initial jet spectra and p_T dependence of energy loss ΔE
- Week energy dependence: increase of jet energy loss and the slope of initial spectra
- Medium response reduce jet net energy loss

γ - jets

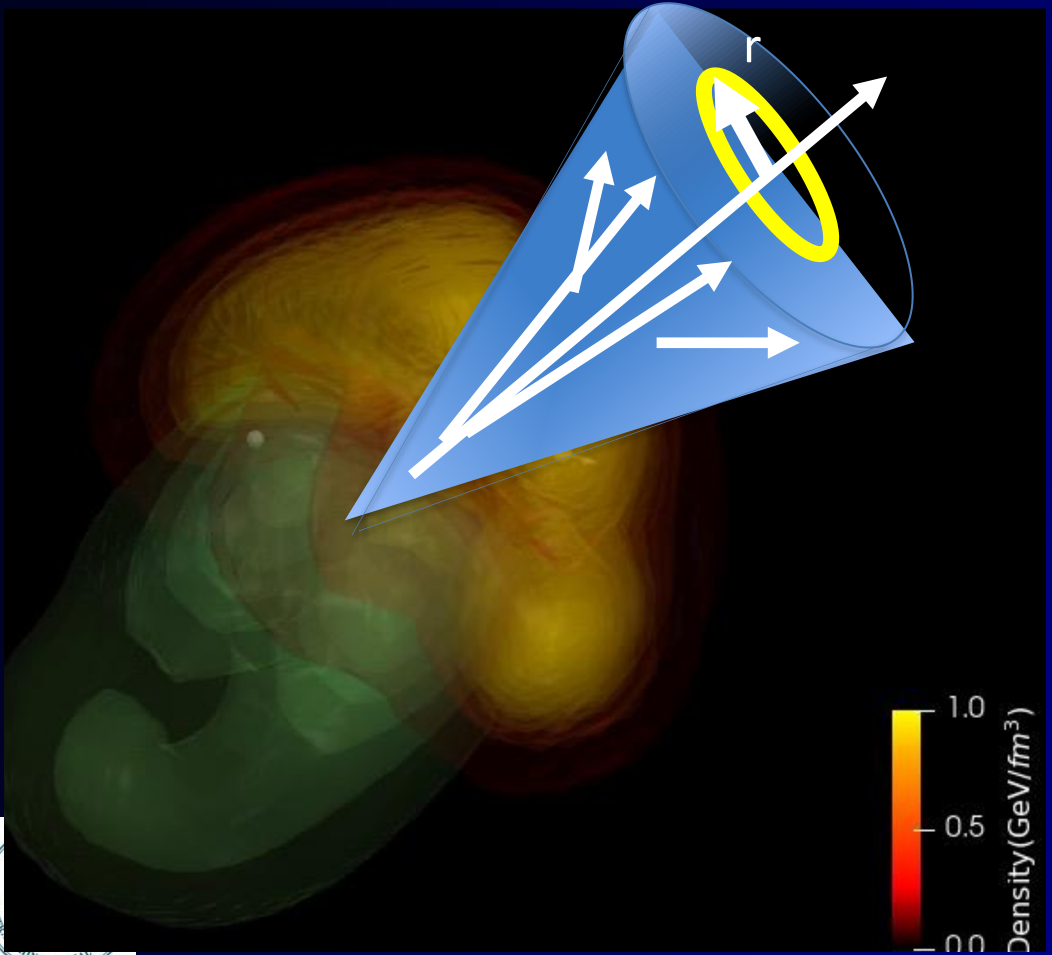


Luo, Cao, He & XNW, arXiv:1803.06785

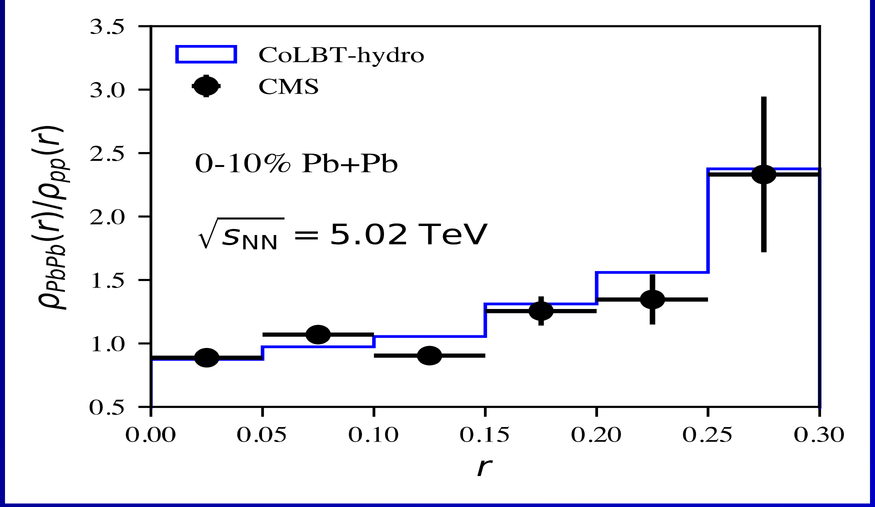
He, Cao, Chen, Luo, Pang & XNW 1809.02525

Modification of jets and medium response

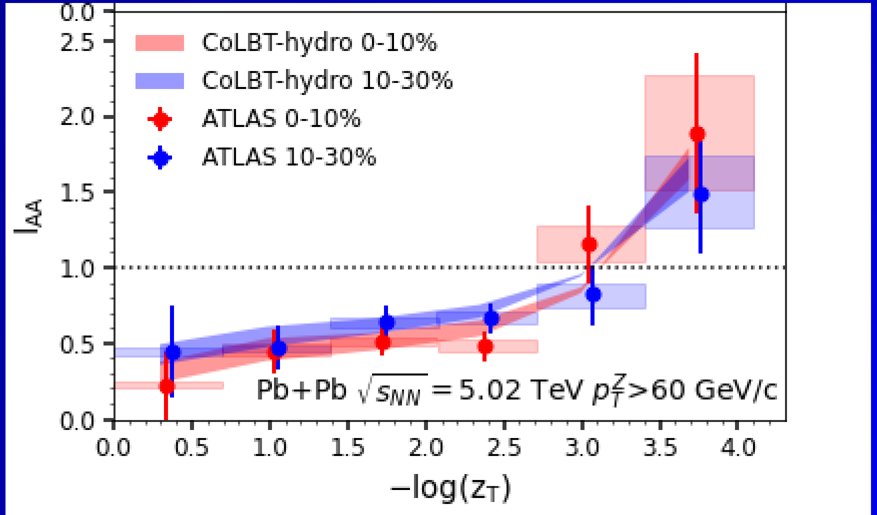
$$\rho(r) = \frac{1}{\Delta r}\frac{1}{N_{jet}}\sum_{jet}\frac{p_T^{jet}(r-\Delta r/2, r+\Delta r/2)}{p_T^{jet}(0,R)}$$



$$\frac{\rho_{AA}(r)}{\rho_{pp}(r)}$$



$$I_{AA} = \frac{D_{AA}(z_T)}{D_{pp}(z_T)}$$



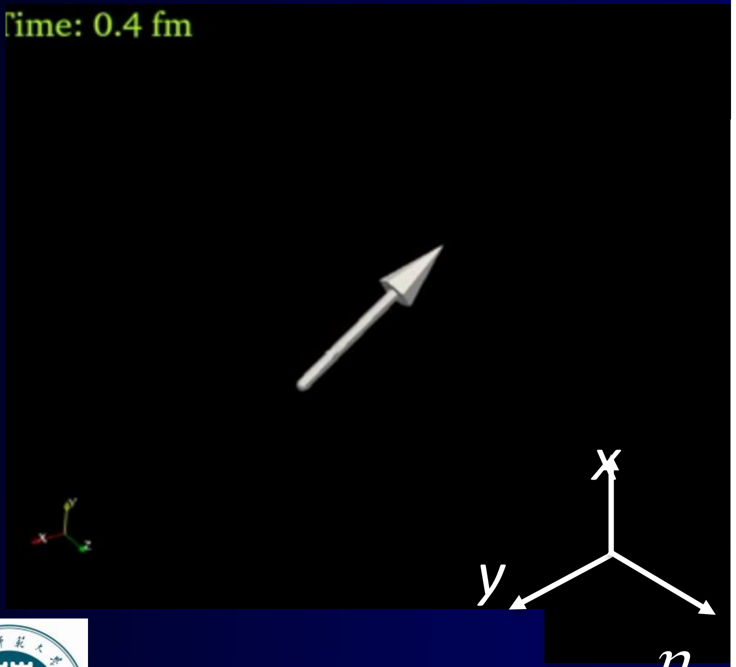
CoLBT

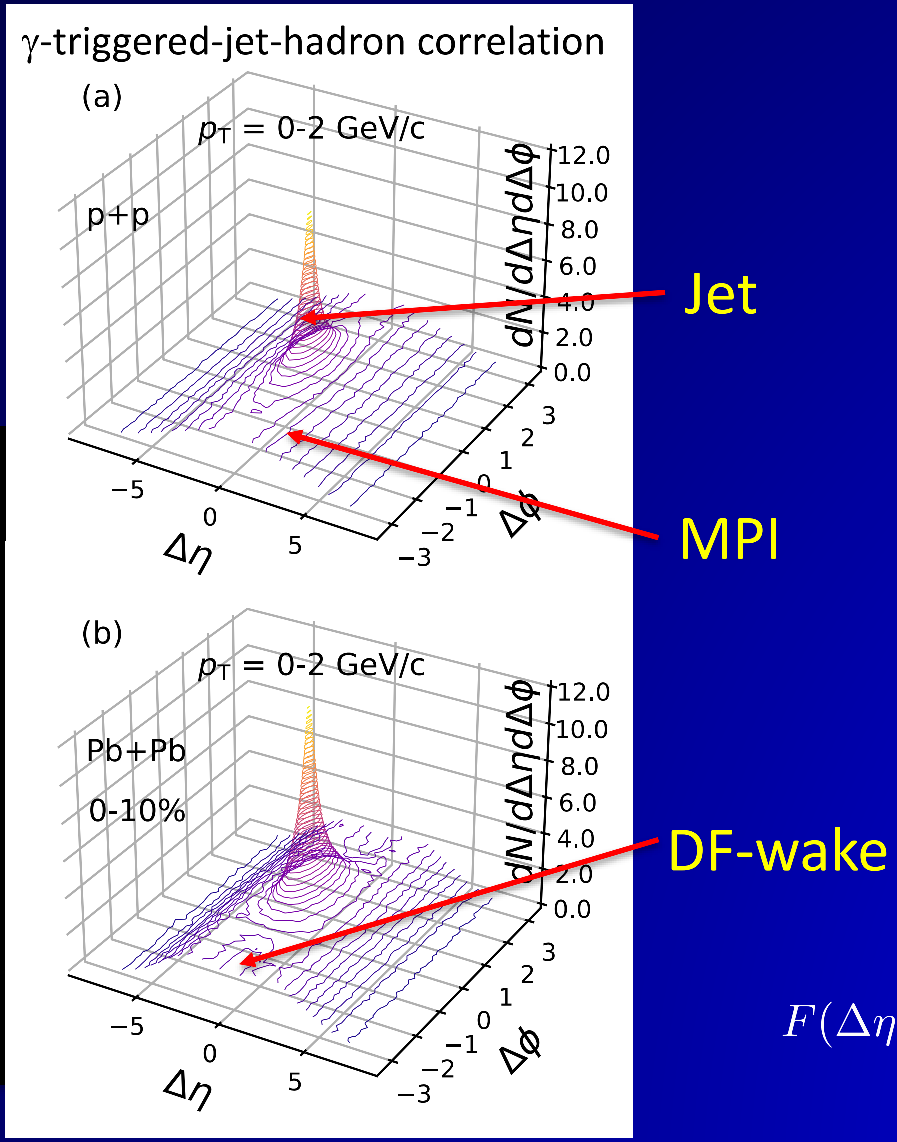
e-Print: 2101.05422

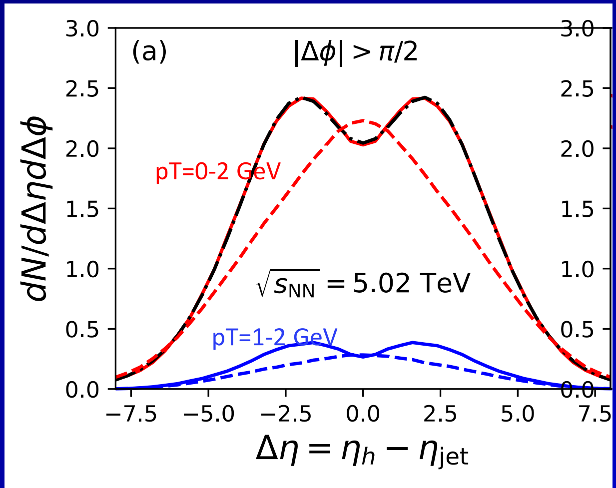
Search for jet-induced diffusion wake

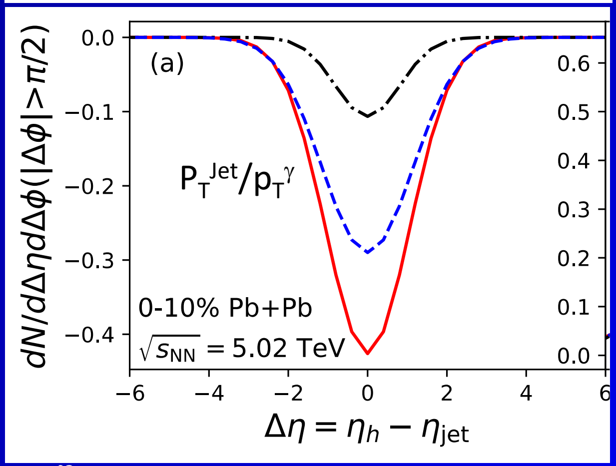
Diffusion (DF) wake leads to depletion of soft hadron yield in the back of jet direction

Yang, Tan, Chen, Pang & XNW, *PRL,* 130 (2023) , 052301





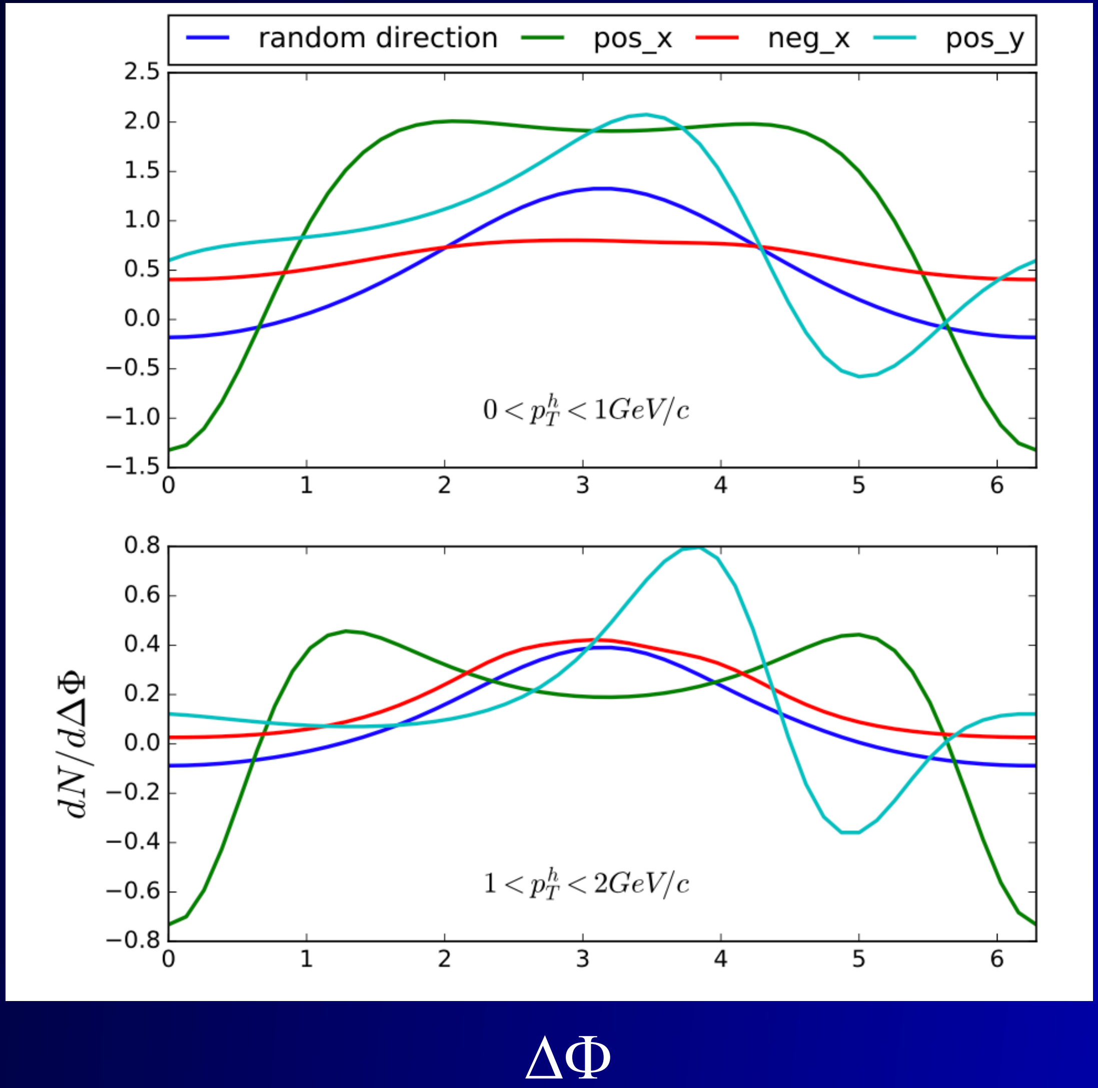




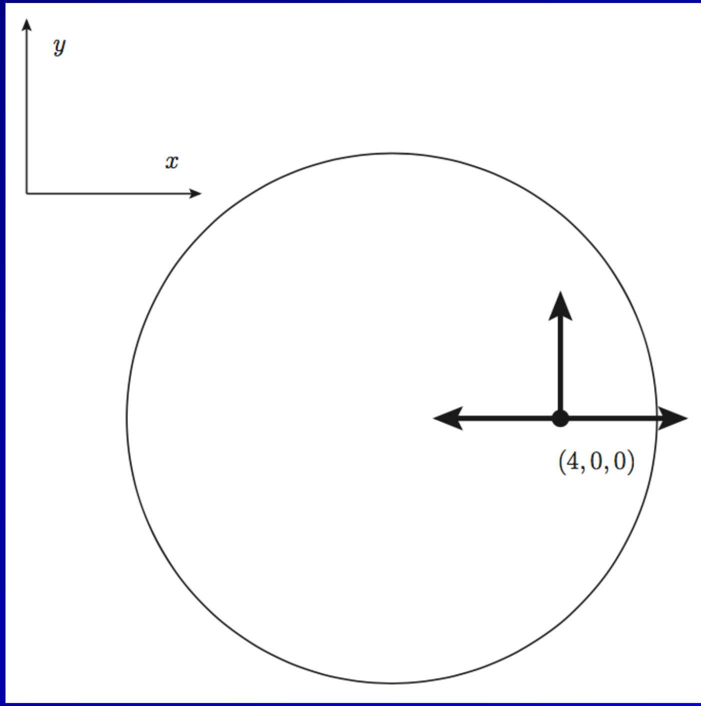
$$F(\Delta\eta) = \int_{\eta_{j1}}^{\eta_{j2}} d\eta_j F_3(\eta_j)(F_2(\Delta\eta, \eta_j) + F_1(\Delta\eta)),$$

Jet-distr MPI DF-wake

Initial position & azimuthal correlation



γ-hadron correlation



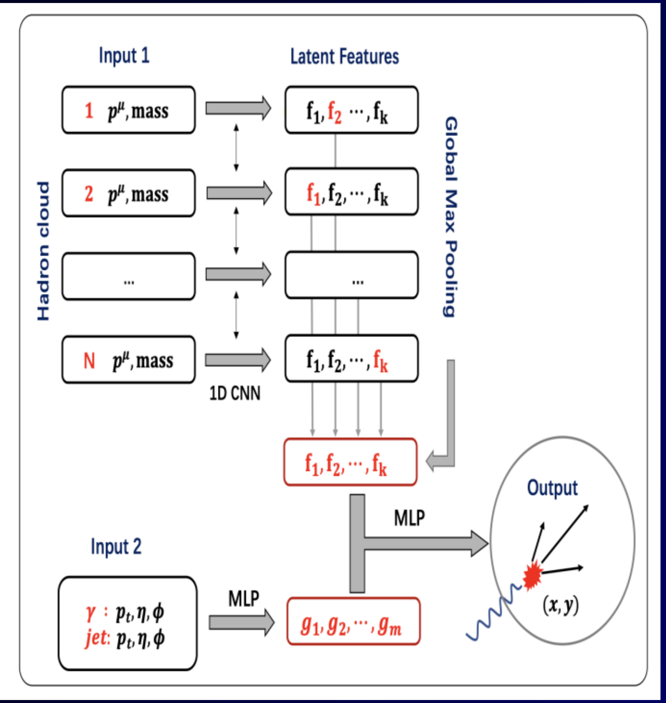
W Chen & XNW (2018)

Li, Liu, Ma, XNW and Zhu, Phys. Rev. Lett. 106, 012301 (2011)

Tachibana, Shen & Majumder 2001.08321 (2020)

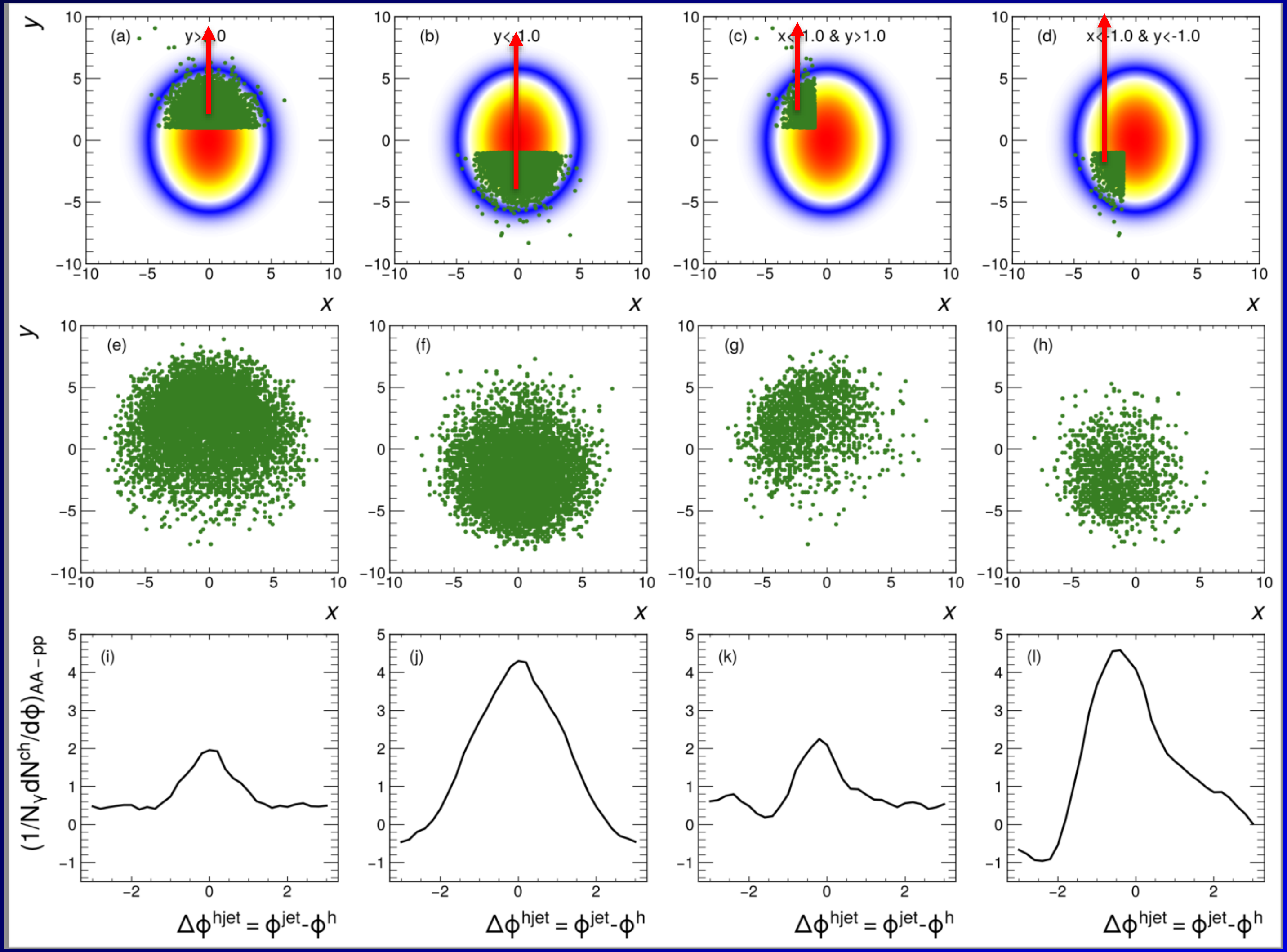
Deep learning assisted jet tomography

PCN (point cloud network)



Eur.Phys.J.C 83 (2023) 7, 652

Yang, He， Chen， Ke， Pang & XNW

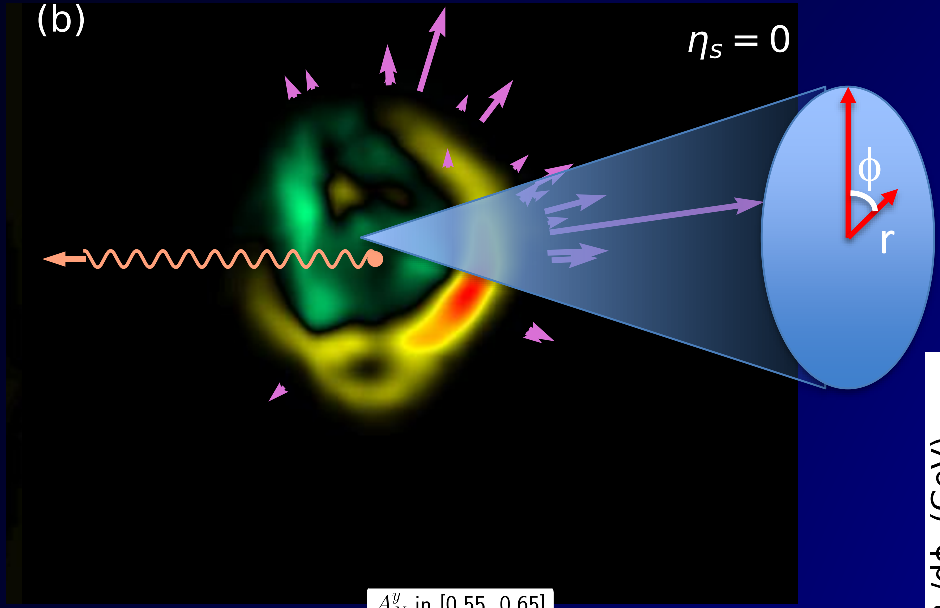


DL network selection

Actual distribution

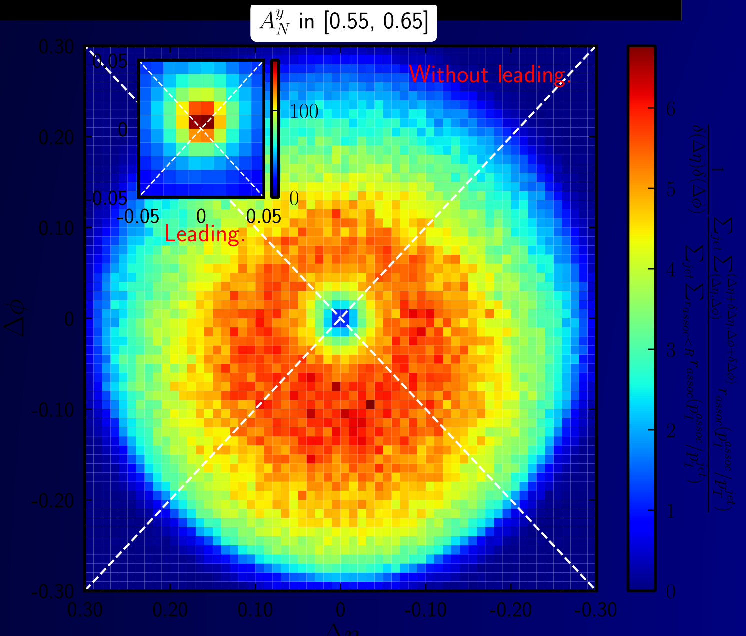
γ-soft hadron correlation

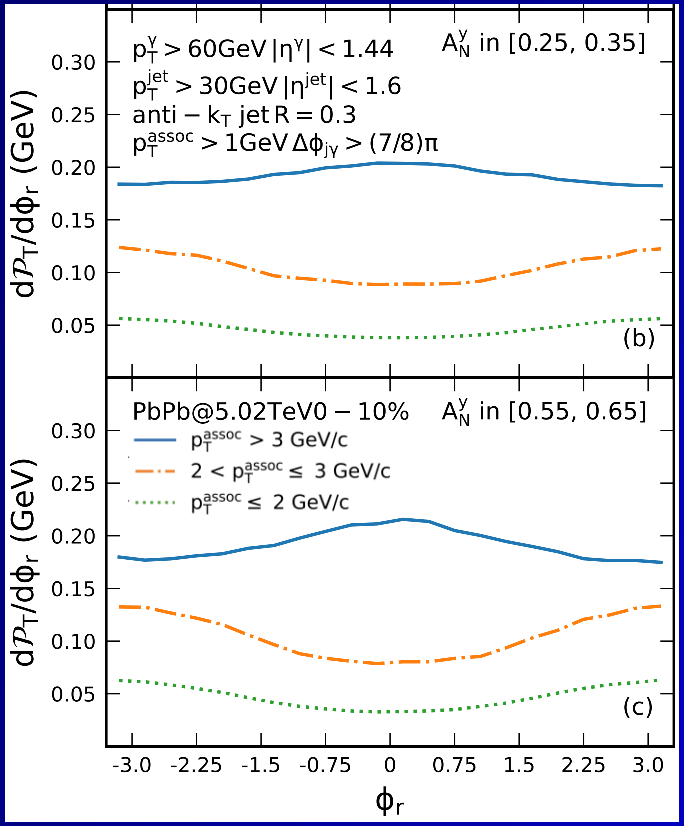
Asymmetric jet shape

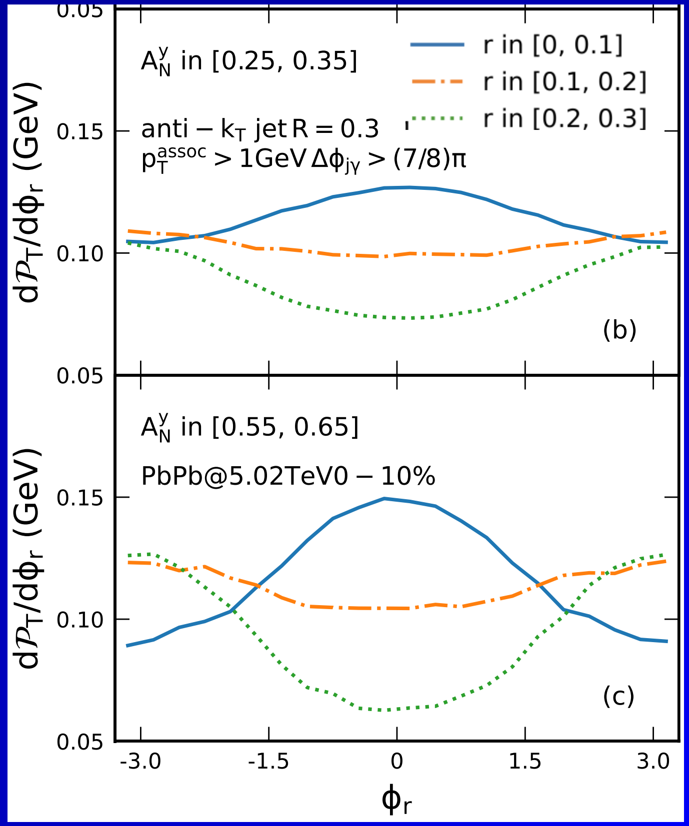


Energetic hadrons at the core of jet deflected away from center
Soft hadrons from medium response at large angle flow into center

$$A_{E_\perp}^{\vec{n}} = \frac{\int d^3r d^3p f_a(\vec{p},\vec{r}) \vec{p}_T \cdot \vec{n}}{\int d^3r d^3p f_a(\vec{p},\vec{r})}$$

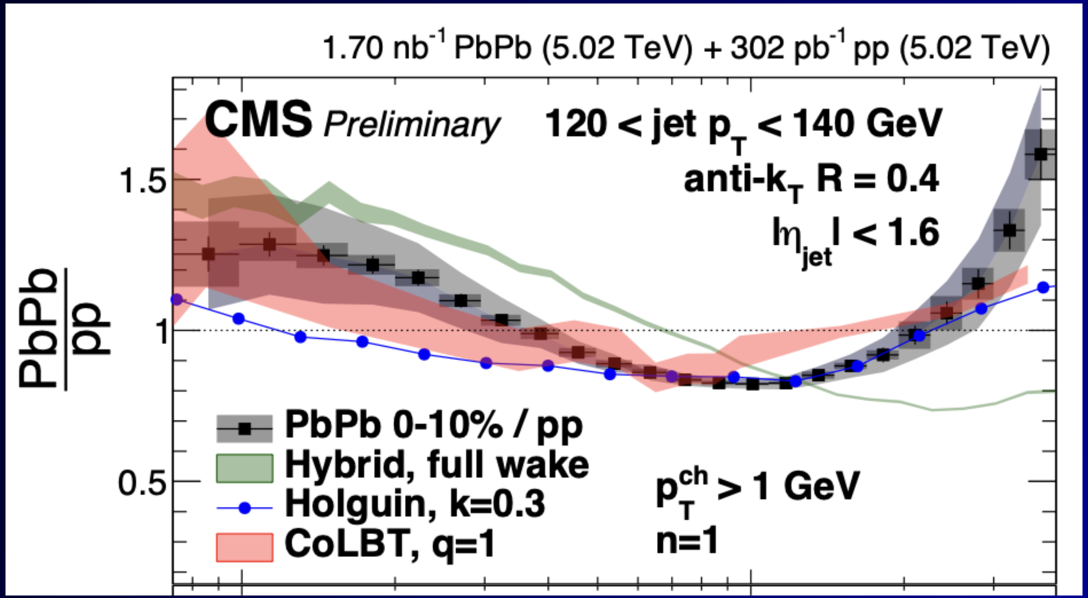


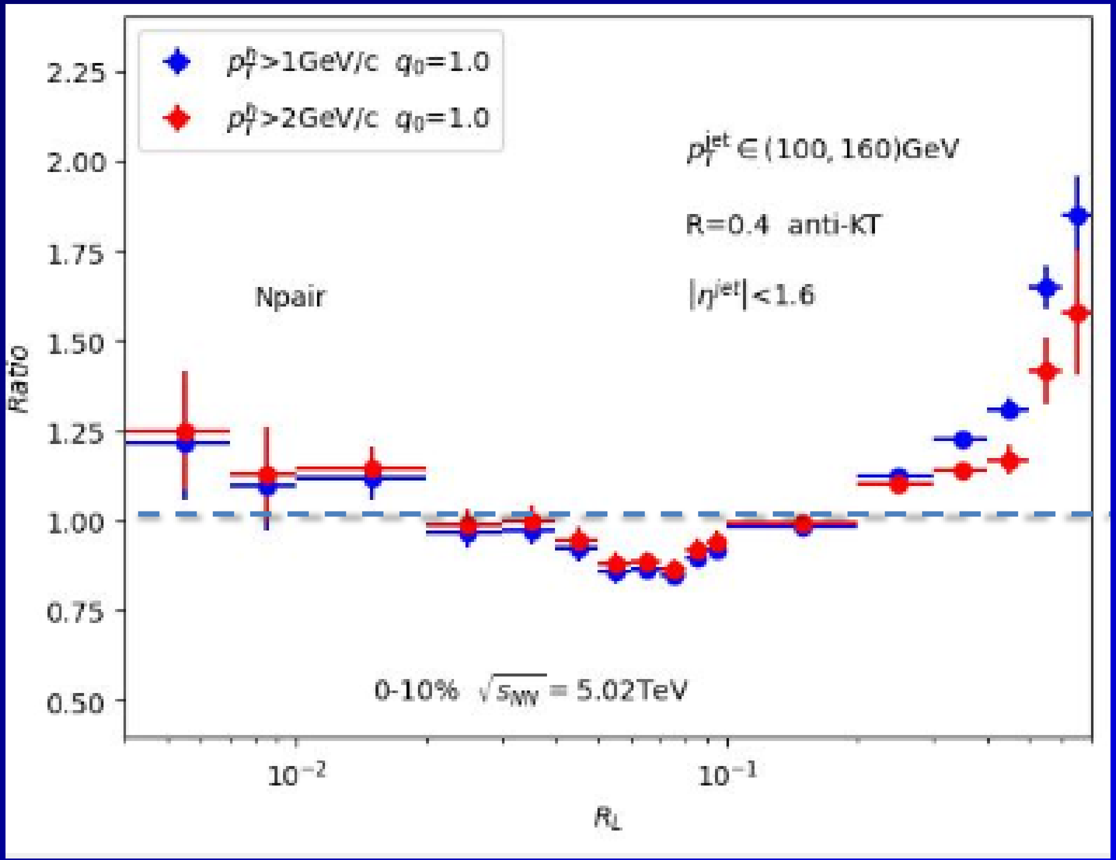




Single jet energy-energy correlator from CoLBT

$$\frac{d\Sigma^{(n)}}{d\theta} = \frac{1}{\sigma}\sum_{i\neq j}\int d\vec{n}_{i,j}\frac{d\sigma_{ij}}{d\vec{n}_{i,j}}\frac{E_i^n E_j^n}{Q^{2n}}\delta(\vec{n}_1\cdot\vec{n}_2-\cos\theta)$$

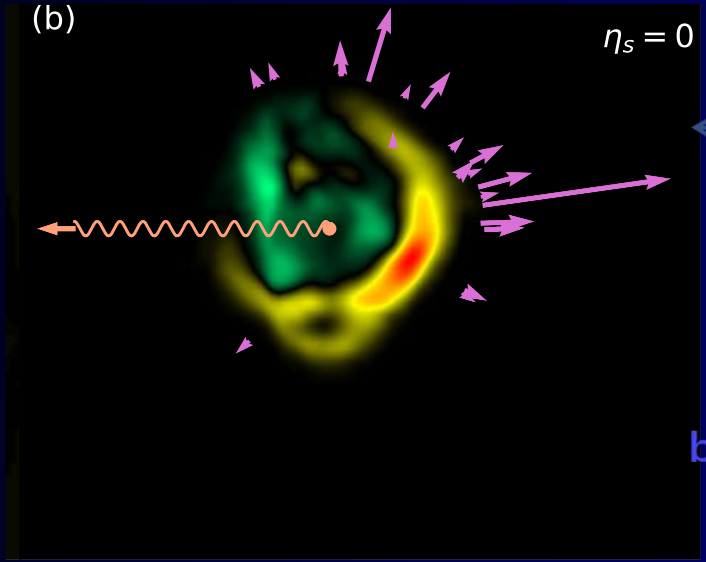


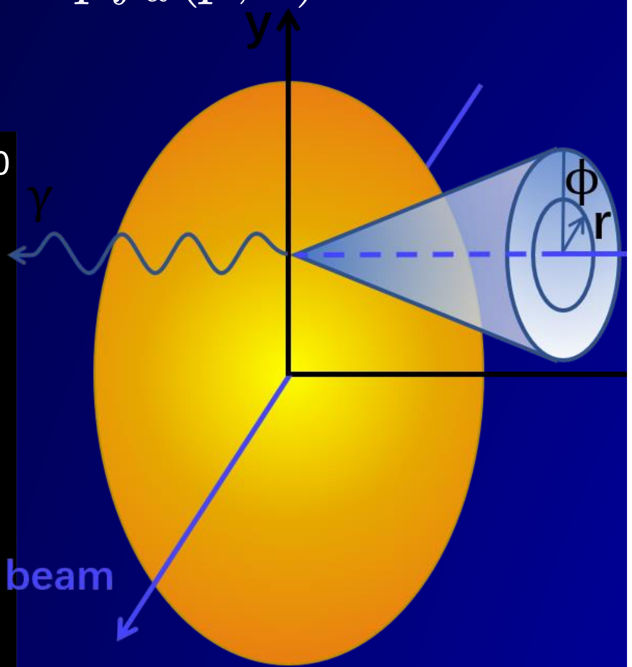


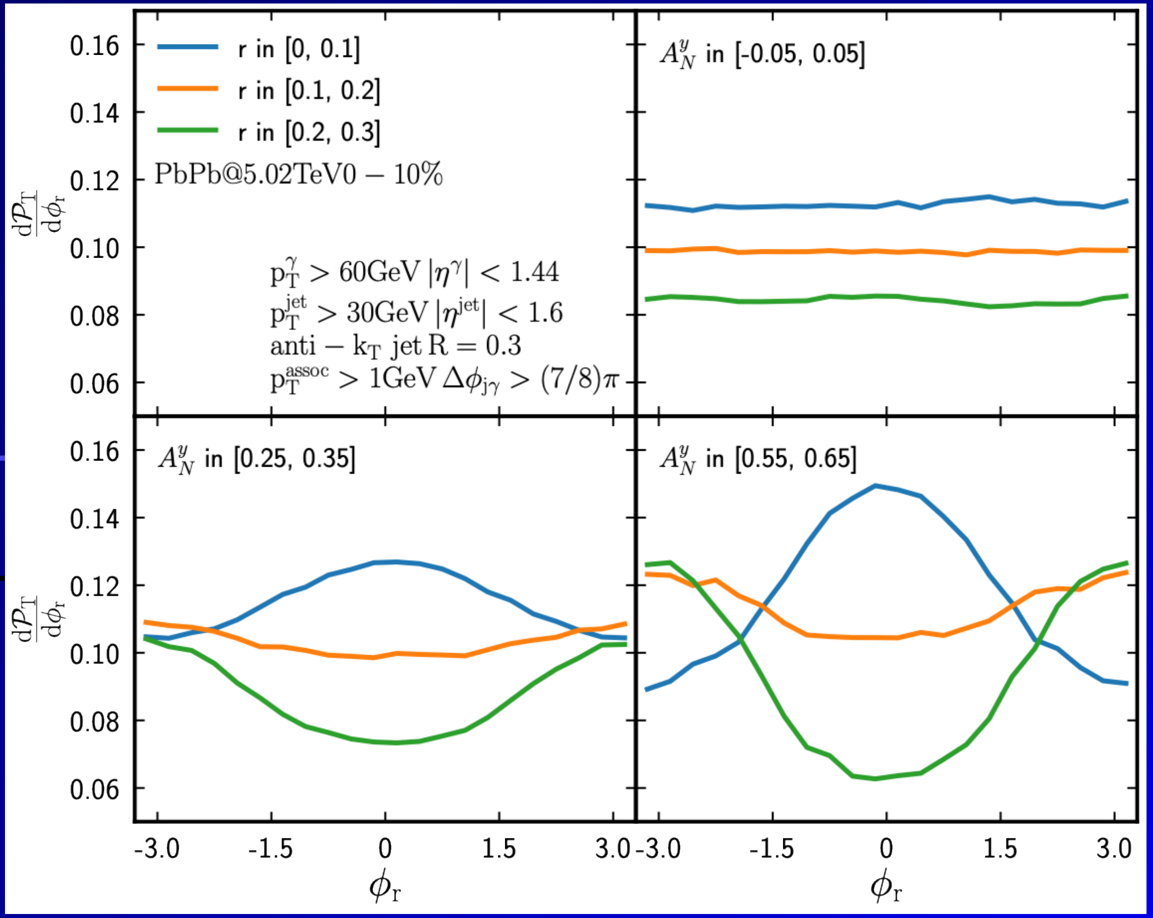
- Increased virtuality scale in medium leads to enhancement of EEC at small angle
- Medium response leads to enhancement at large angle R_L>0.3

Asymmetric jet shape

$$A_{E_\perp}^{\vec{n}} = \frac{\int d^3r d^3p f_a(\vec{p},\vec{r})\vec{p}_T \cdot \vec{n}}{\int d^3r d^3p f_a(\vec{p},\vec{r})}$$





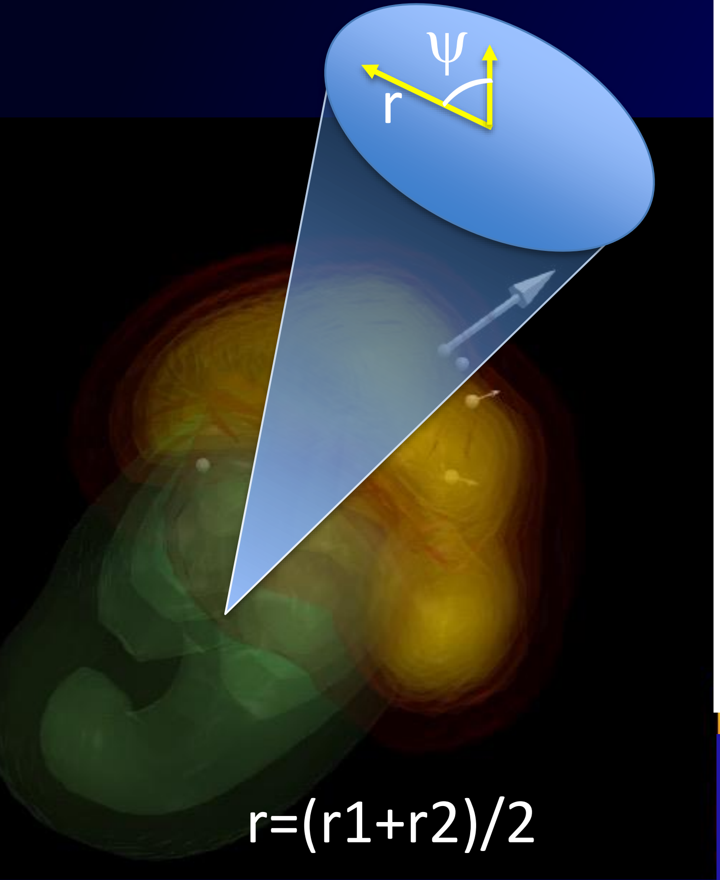


Energetic hadrons at the core of jet deflected away from center

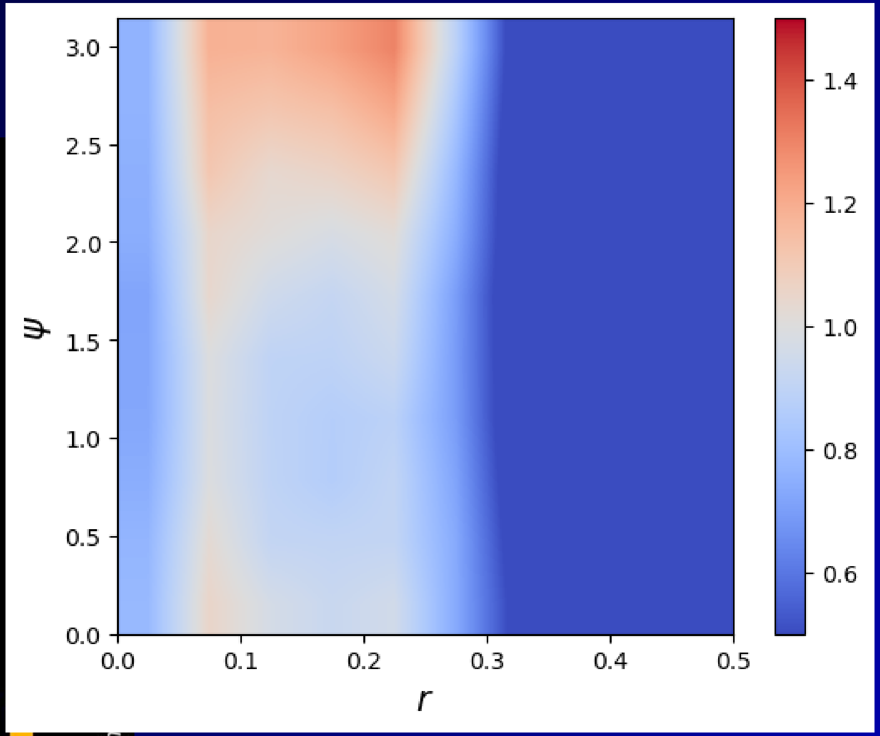
Soft hadrons from medium response at large angle flow into center

Xiao, He, Pang, Zhang & XNW, *PRC* 109 (2024) 5, 054906 (e-print: 2402.00264)

Seeing Mach-cone through 3p Azimuthal Correlation

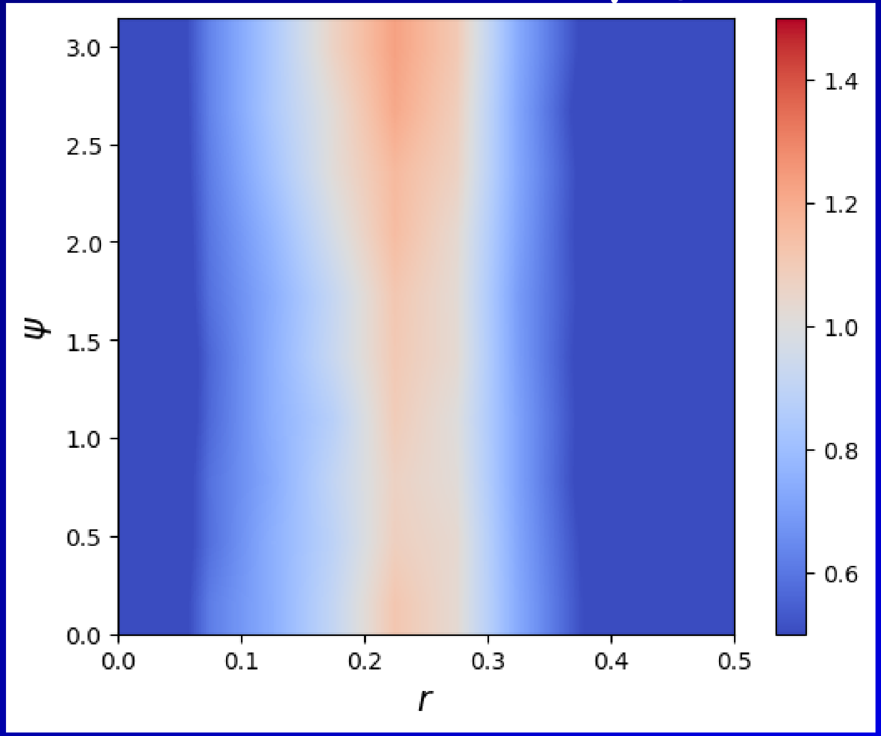


p+p (γ+jet) p_T>40 GeV/c



Back-to-back correlation due to momentum conservation of parton splitting

0-10%Pb+Pb (γ+jet)



Azimuthal uniform correlation due to medium-response: Mach-cone – sound velocity?

Summary

- Medium response reduces net jet energy loss
- Medium response leads to
  - enhancement of soft hadrons in jet direction
  - depletion of soft hadron on the away side
- Unique 3D structure of diffusion wake
- Use 2D jet tomography to reveal the angular structure of Mach-cone excitation
- Future studies: ML improved 2D tomography and constraint on EoS, transport coefficients