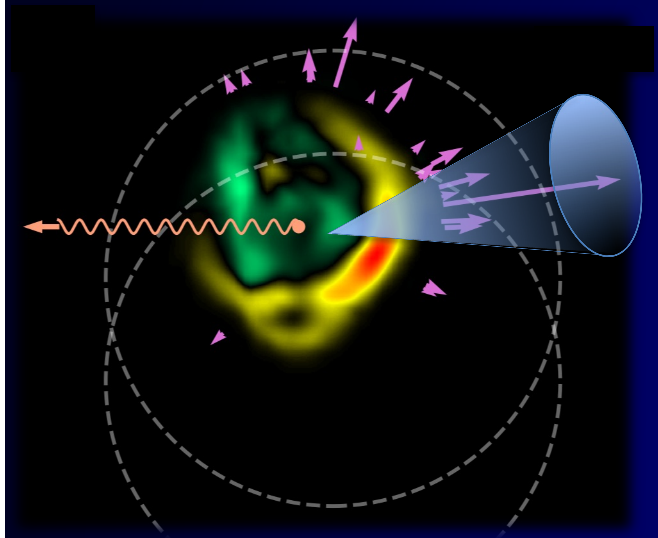
Hot Jets: Advancing the Understanding of High Temperature QCD with Jets

UIUC, Jan. 8-10 , 2025

Asymmetrical Jet Shape due to jet-flow interaction & Diffusion wake in di-jets



In collaboration with H. Zhang, Y. Xiao, Z. Yang …

Xin-Nian Wang

Central China Normal University

Institute of Particle Physics
粒子物理研究所

Jet-induced medium excitation

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

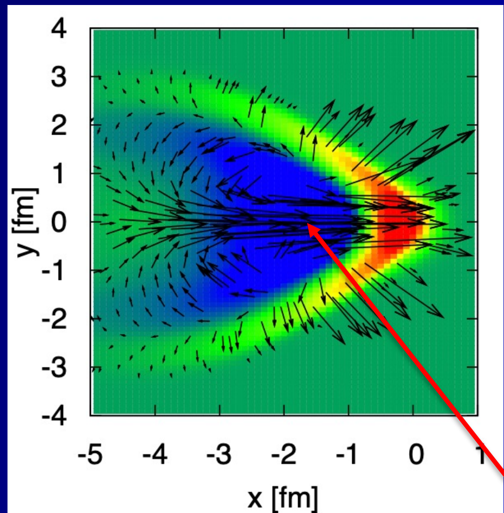
Jet induced Mach-cone in QGP

$$v = p/E > c_s$$

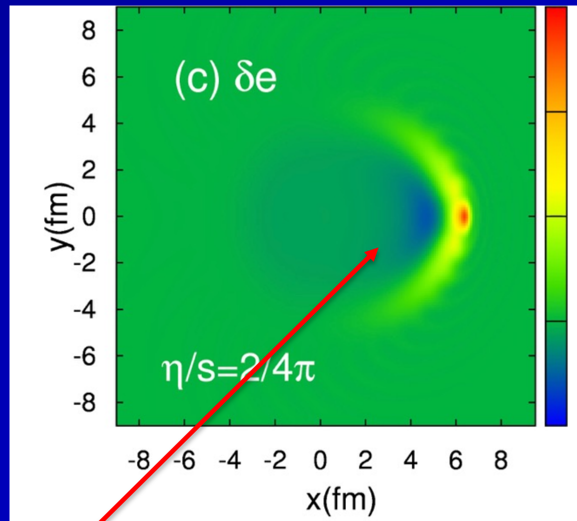
Hydrodynamic approach

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

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

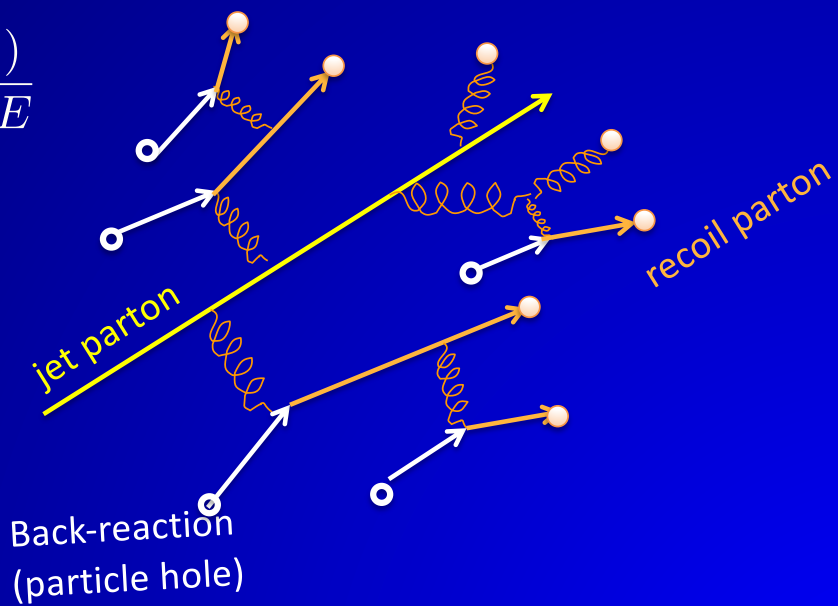
LBT: Linear Boltzmann Transport

$$p_1 \cdot \partial f_1 = -\int dp_2 dp_3 dp_4 (f_1 f_2 - f_3 f_4) |M_{12\to 34}|^2 (2\pi)^4 \delta^4 (\sum_i p_i) + \text{inelastic}$$

Induced radiation

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

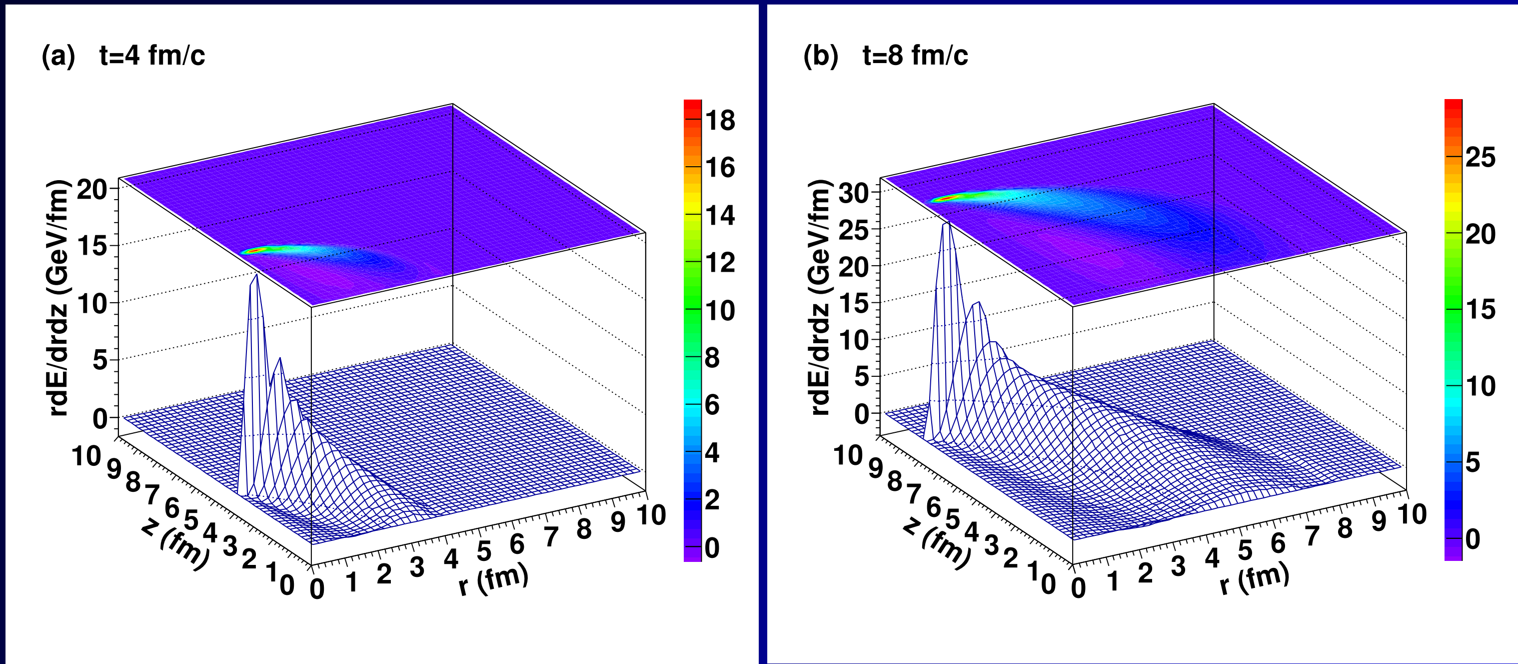
- pQCD elastic and radiative processes (high-twist)
- Transport of medium recoil partons (and back-reaction)
- CLVisc 3+1D hydro bulk evolution



Institute of Particle Physics
粒 子 物 理 研 究 所

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

Jet-induced medium response in LBT



Energy distr. of medium response in a static medium

He, Luo, XNW & Zhu, PRC91 (2015) 054908

CoLBT-hydro

(Coupled Linear Boltzmann Transport hydro)

Concurrent and coupled evolution of bulk medium and jet showers

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

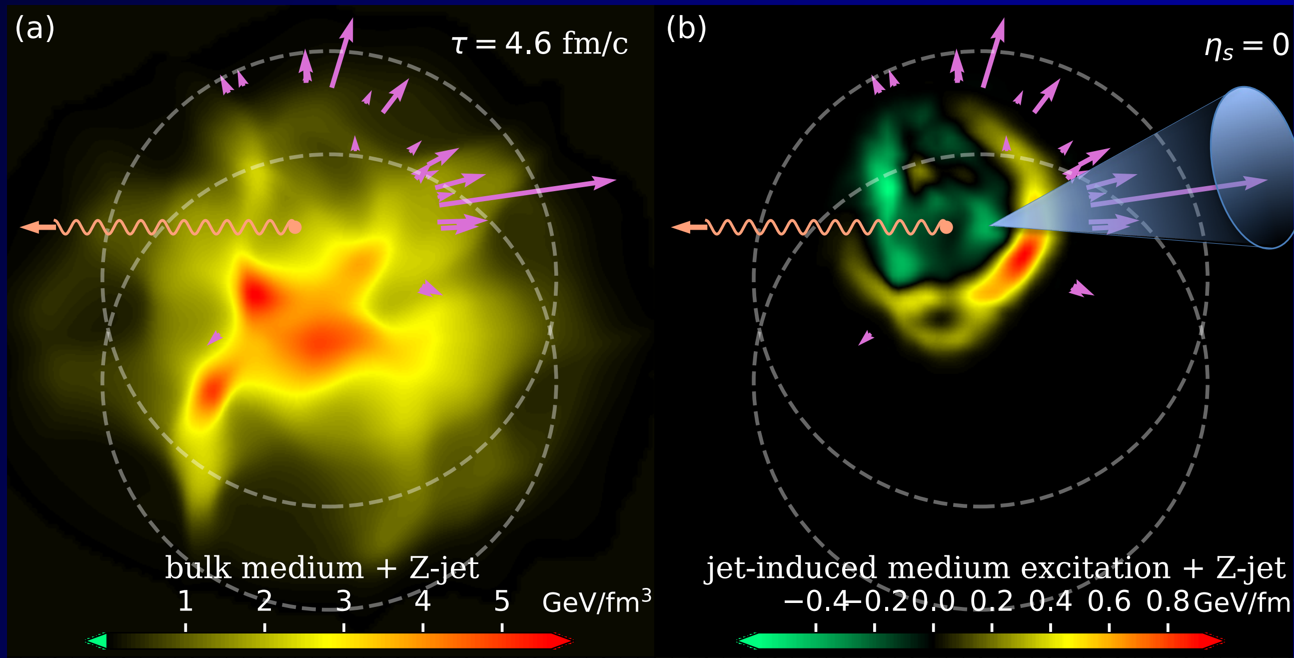
$$\partial_\mu T^{\mu\nu}(x) = j^\nu(x)$$

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

- 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

Medium response of Z/γ-jet in CoLBT-hydro



Before

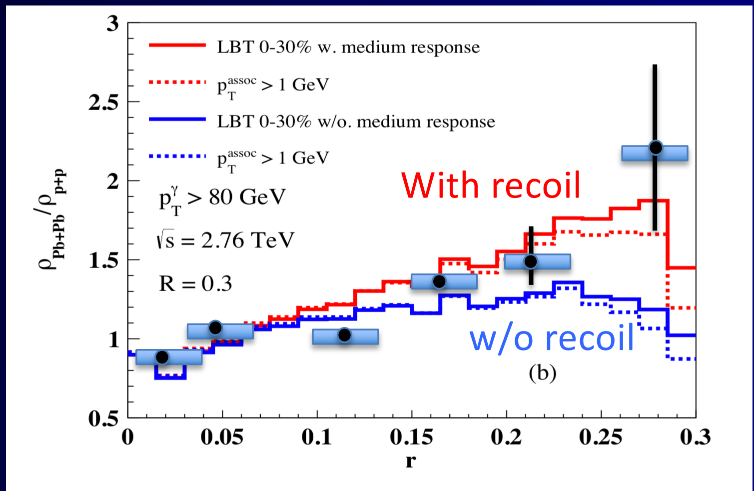
After hydro background subtraction

Medium modification of γ-jets

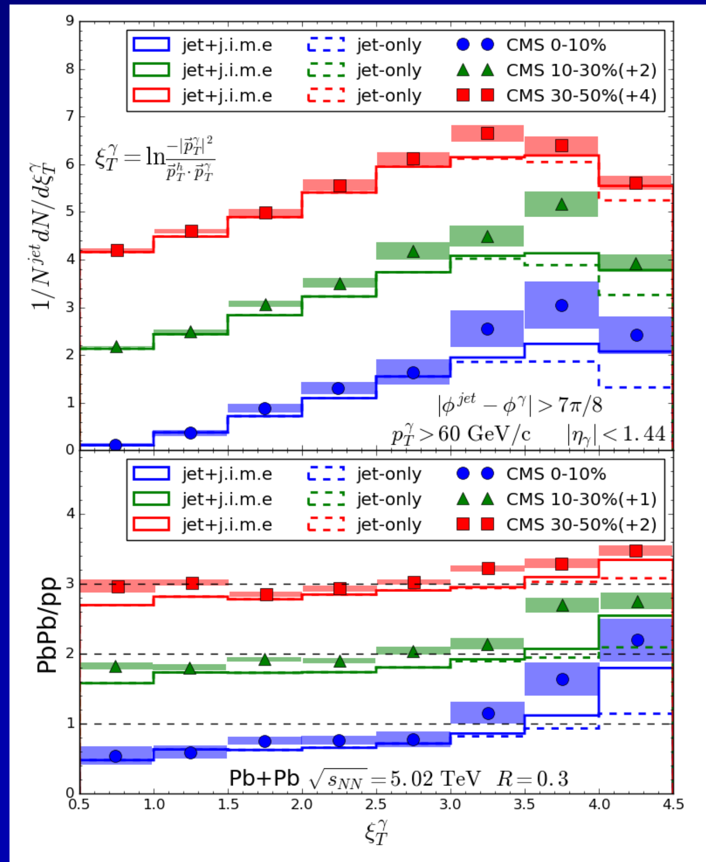
Enhancement of soft hadrons in large angles

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

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



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

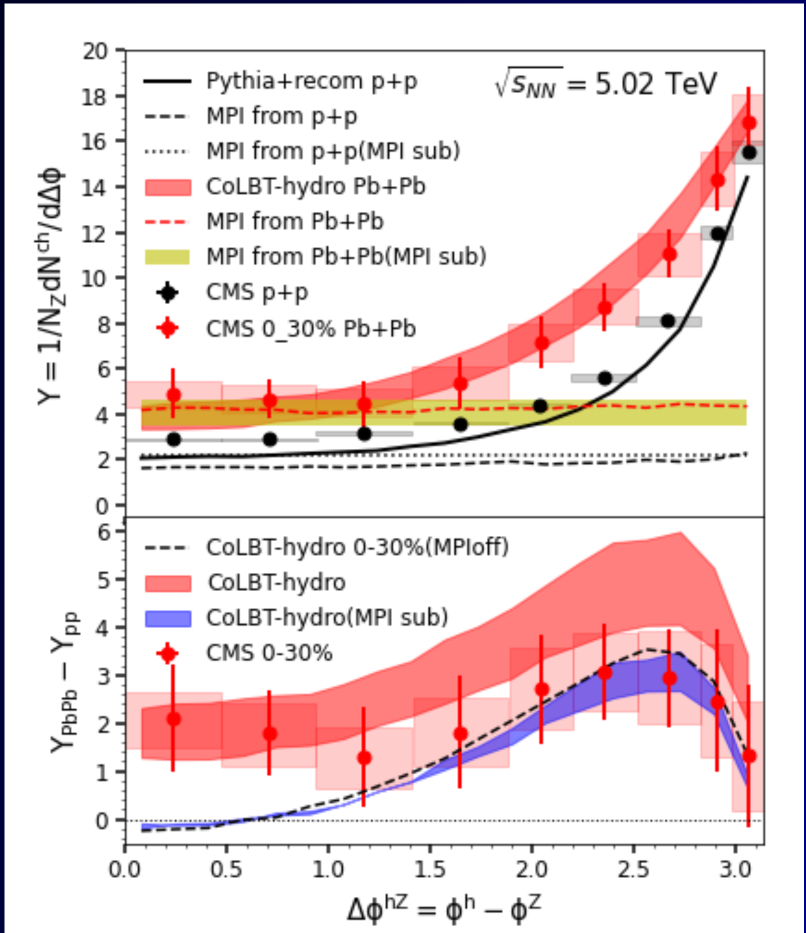


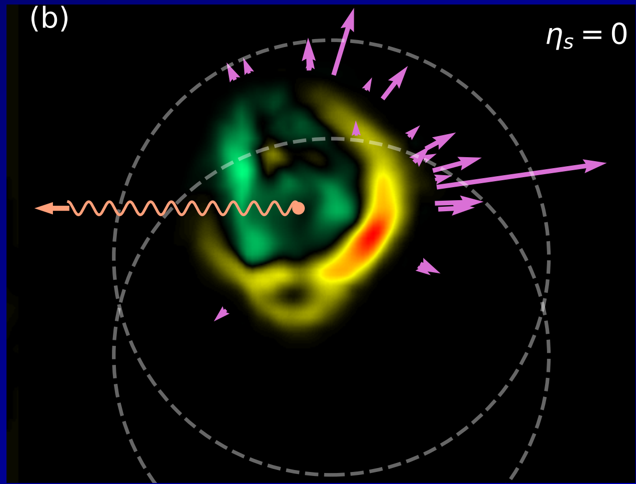
Luo, Cao, He & XNW, arXiv:1803.06785

Chen, Cao, Luo, Pang & XNW, 2005.09678

Institute of Particle Physics
粒 子 物 理 研 究 所

MPI background and diffusion wake in Z-jets



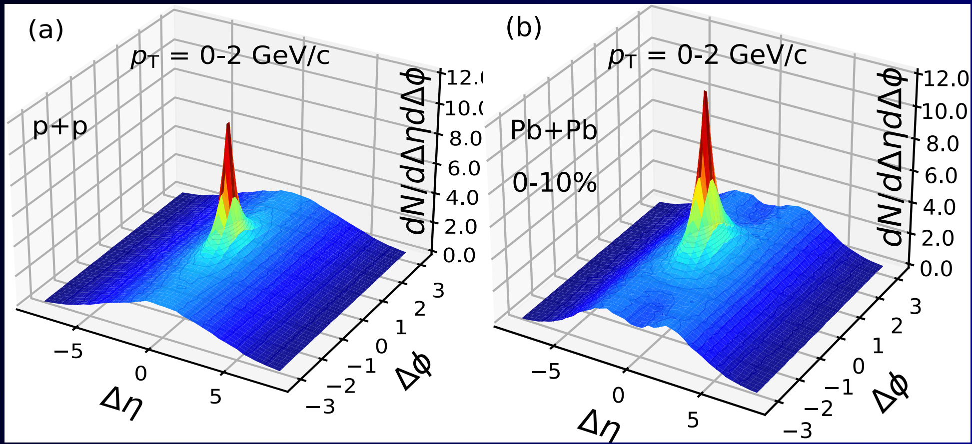


Mixed event subtraction

$$\frac{dN^{hZ}_{\rm MPI}}{d\phi} = \frac{dN^{hZ}_{\rm mix}}{d\phi} - \int_1^\pi \frac{d\phi}{\pi}\left(\frac{dN^{hZ}}{d\phi} - \frac{dN^{hZ}}{d\phi}|_{\phi=1}\right)$$

Chen, Yang, He, Ke, Pang and XNW, *PRL* 127 (2021) 8, 082301

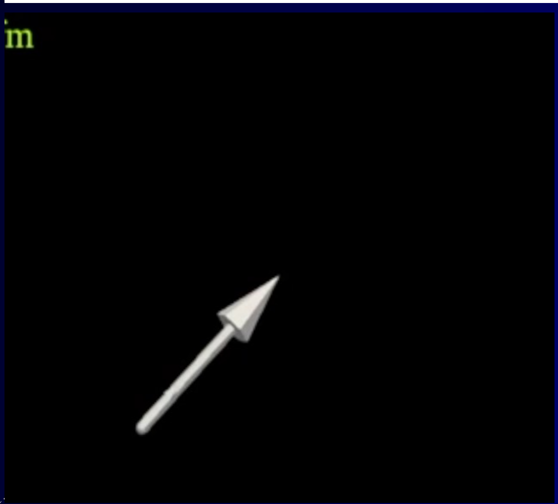
3D structure of diffusion wake

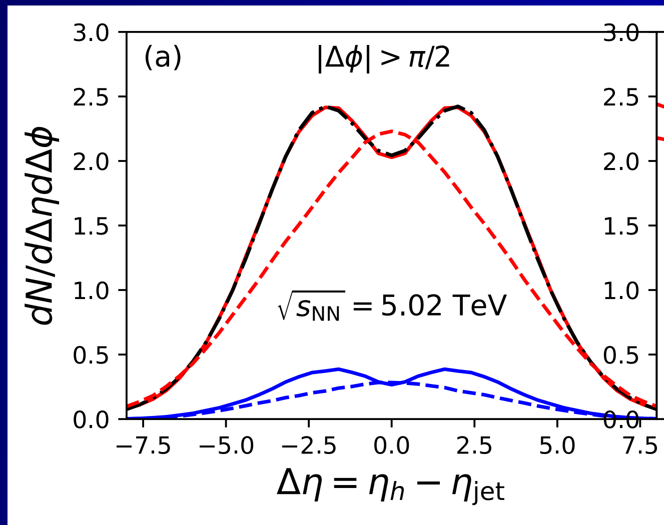


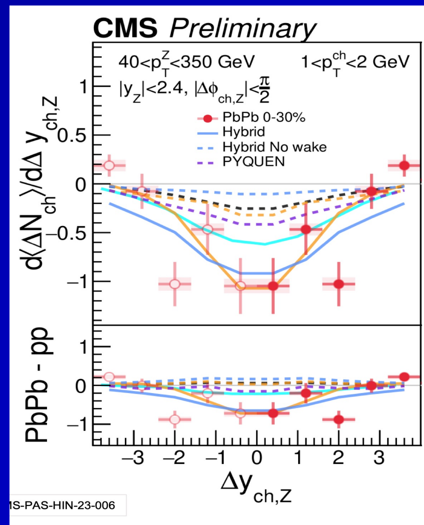
Jet-hadron correlation in γ/jet events

Diffusion wake → rapidity valley
on top of the MPI ridge

Yang, Luo, Chen, Pang and XNW, PRL 130, 052301 (2023)





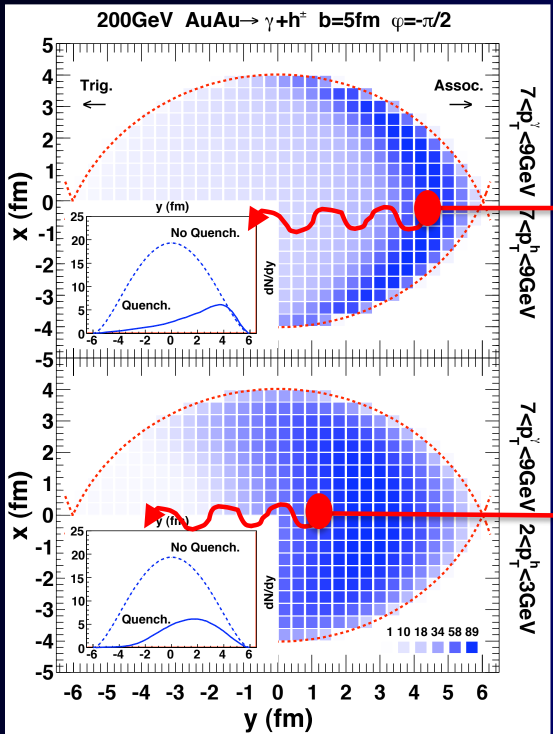


Y. Lee talk at HP24

Institute of Particle Physics
粒 子 物 理 研 究 所

Diffusion wake and jet energy loss

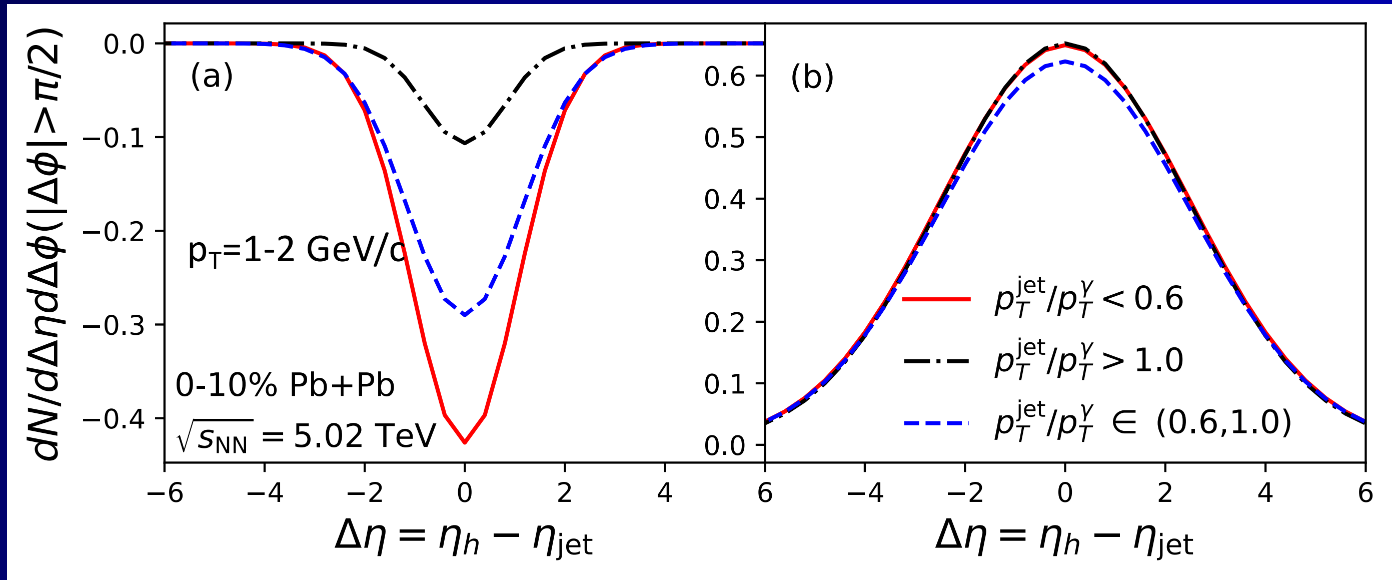
$p_T^h/p_T^\gamma \sim 1$



$p_T^h/p_T^\gamma \sim 0.3$

Longitudinal tomography

γ-jet asymmetry p_T^{jet}/p_T^γ : proxy of jet energy loss



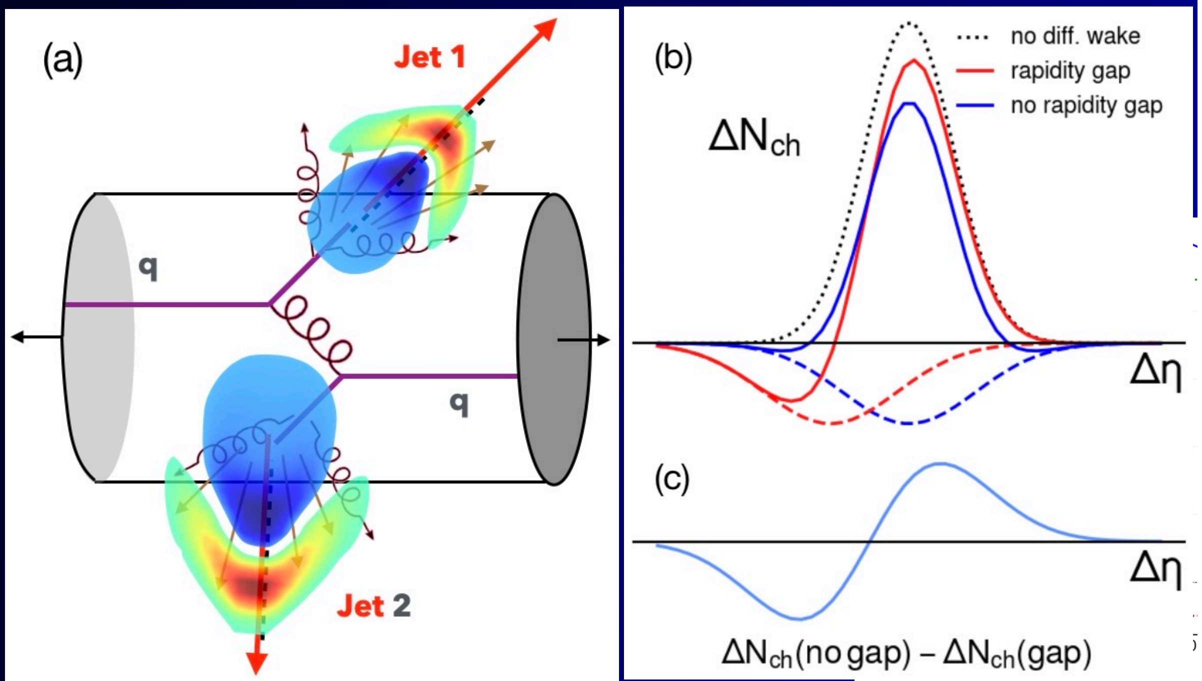
Yang, Luo, Chen, Pang and XNW, PRL 130, 052301 (2023)

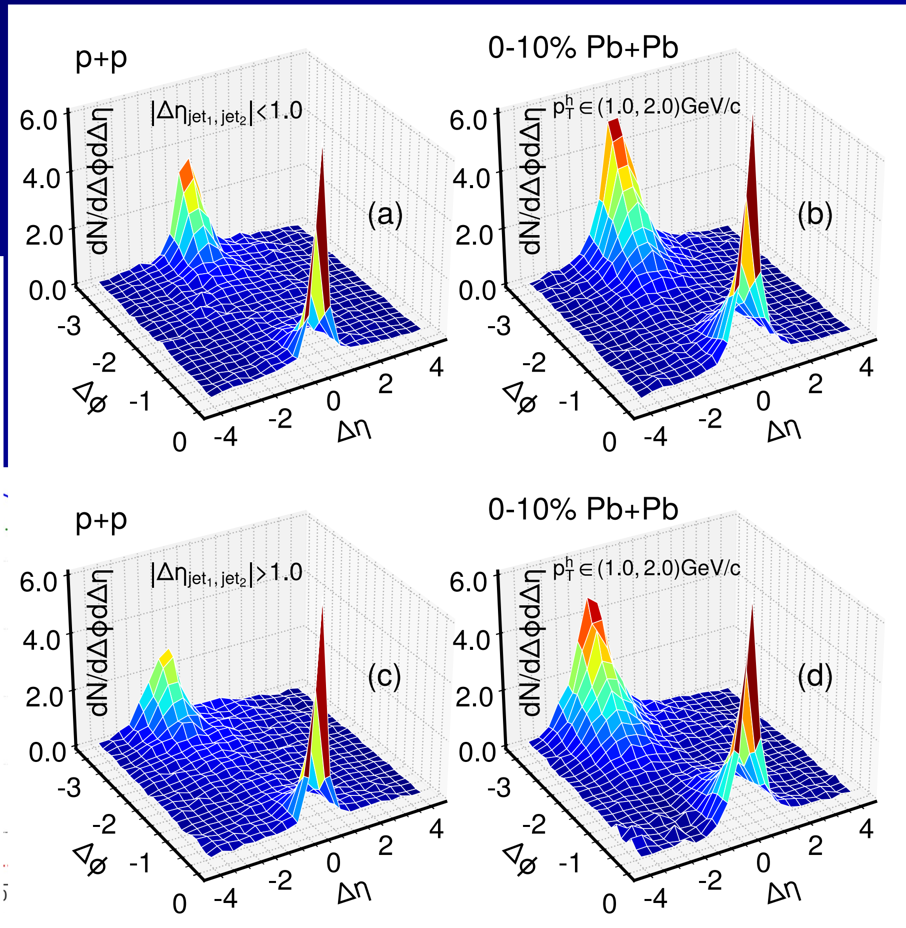
Zhang, Owens, Wang and XNW, PRL 103, 032302 (2009)

Diffusion wake in di-jets

Jet-hadron correlation in di-jets with rapidity gap

Rapidity ordering convention: $\eta_{\mathrm{jet}_1} > \eta_{\mathrm{jet}_2}$





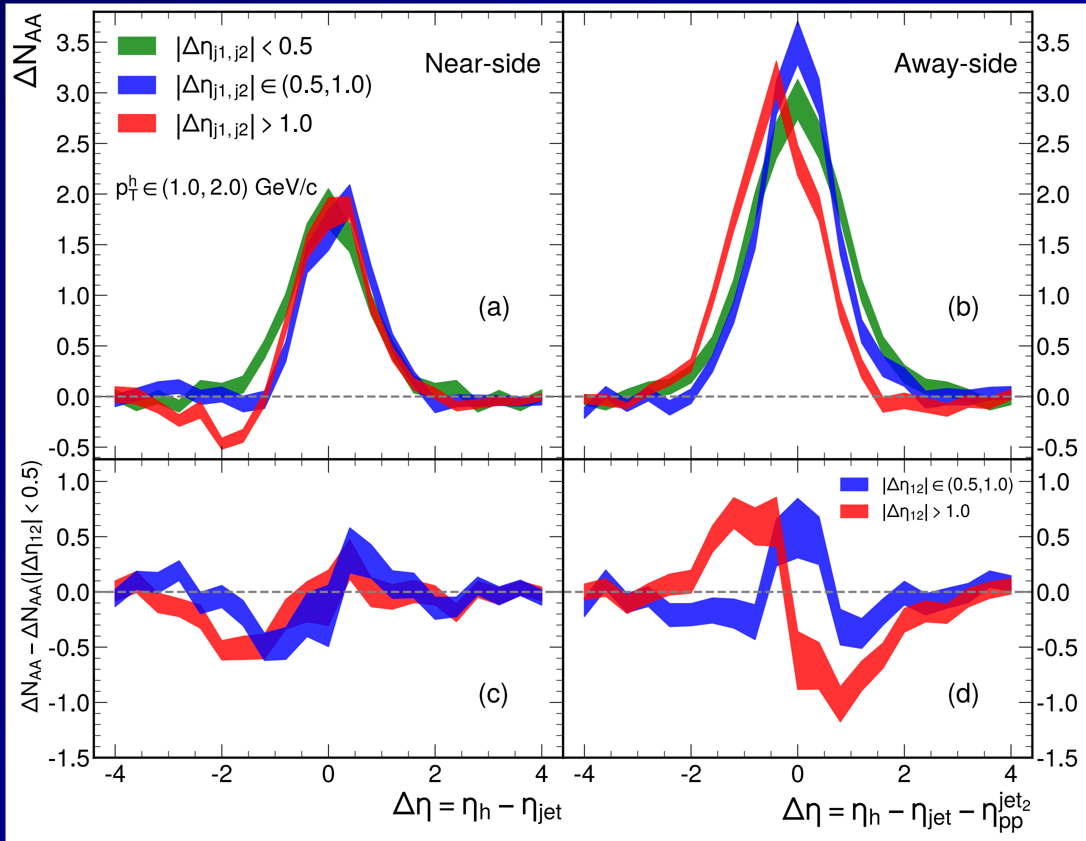
Rapidity asymmetry as robust signal of diffusion wake

Medium modification of jet-hadron correlation

$$\Delta N_{\mathrm{AA}} = \int d\Delta\phi \left[\frac{dN_{\mathrm{AA}}}{d\Delta\phi d\Delta\eta} - \frac{dN_{\mathrm{pp}}}{d\Delta\phi d\Delta\eta} \right]$$

Rapidity Asymmetry

$$\Delta N_{\mathrm{AA}} - \Delta N_{\mathrm{AA}}(\Delta\eta_{\mathrm{jet_1,jet_2}} < 0.5)$$



Zhong Yang and XNW, 2501.03419

Institute of Particle Physics
粒子物理研究所

Rapidity asymmetry with mix-event subtraction

Same-hemisphere di-jet:

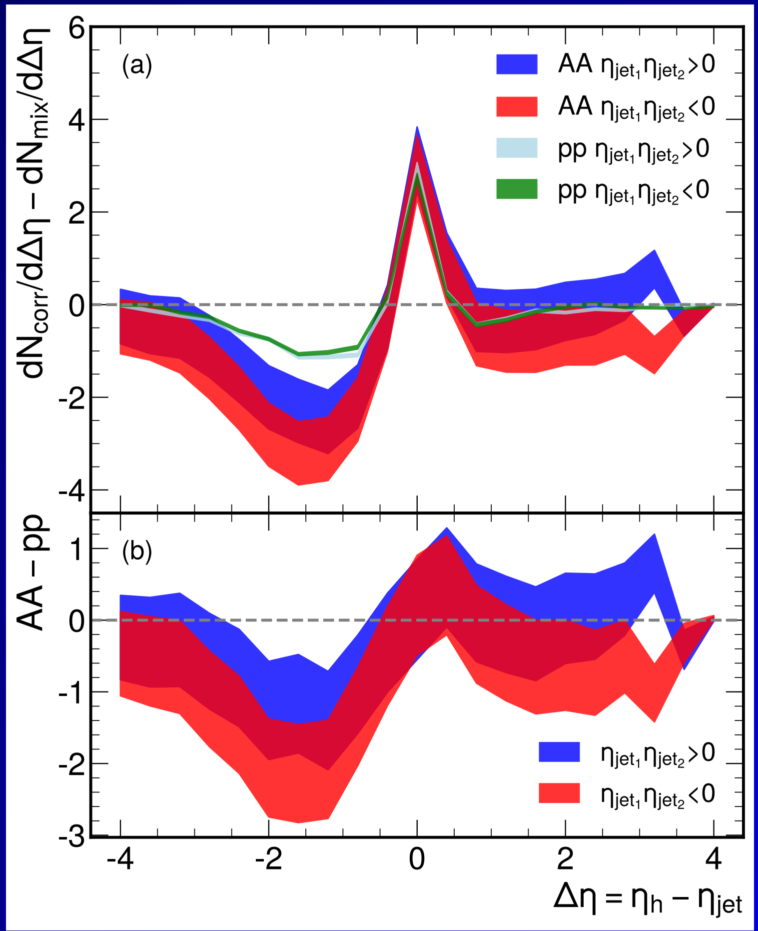
$$\eta_{\text{jet}_1} \times \eta_{\text{jet}_2} > 0$$

Opposite-hemisphere di-jet:

$$\eta_{\text{jet}_1} \times \eta_{\text{jet}_2} < 0$$

Rapidity ordering in all events

$$\eta_{\text{jet}_1} > \eta_{\text{jet}_2}$$



Zhong Yang and XNW, 2501.03419

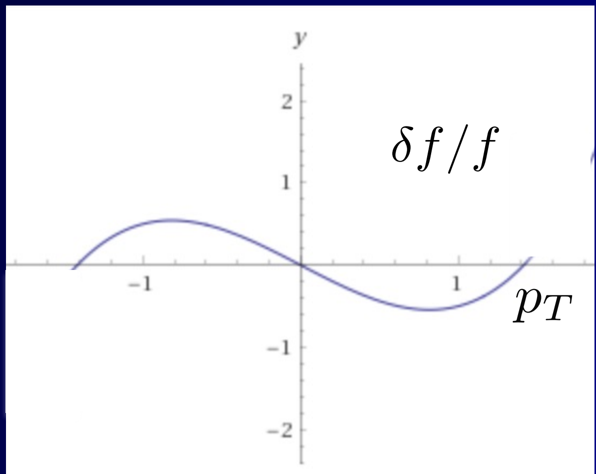
Institute of Particle Physics
粒 子 物 理 研 究 所

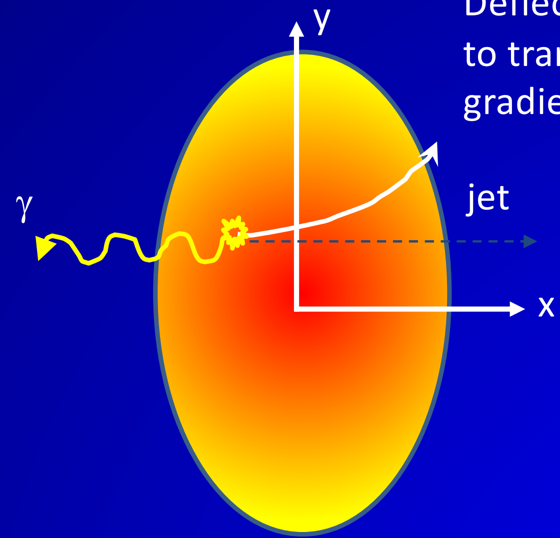
Asymmetric p_T broadening in non-uniform medium

$$\frac{\partial f}{\partial t} + \frac{\vec{p}_\perp}{E} \cdot \frac{\partial f}{\partial \vec{r}_\perp} = \frac{\hat{q}(\vec{r}_\perp)}{4} \vec{\nabla}^2_{p_\perp} f(\vec{p}, \vec{r})$$

$$\hat{q} = \hat{q}_0 + \vec{x}_\perp \cdot \vec{a}$$

Momentum asymmetry





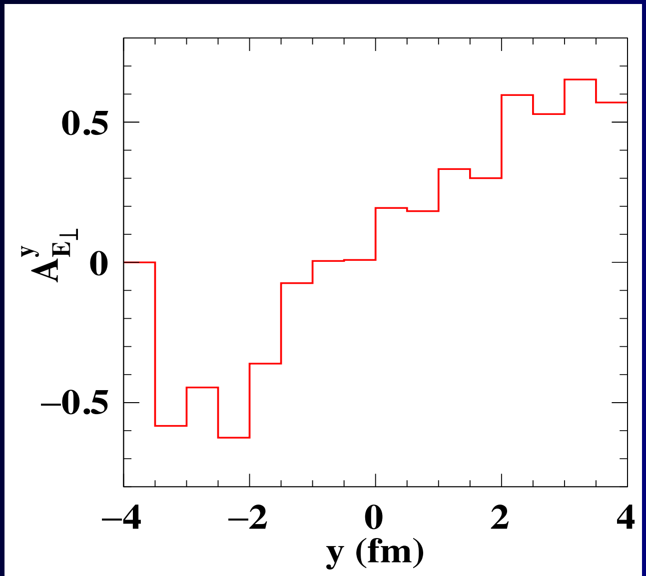
Deflection due to transverse gradient along y

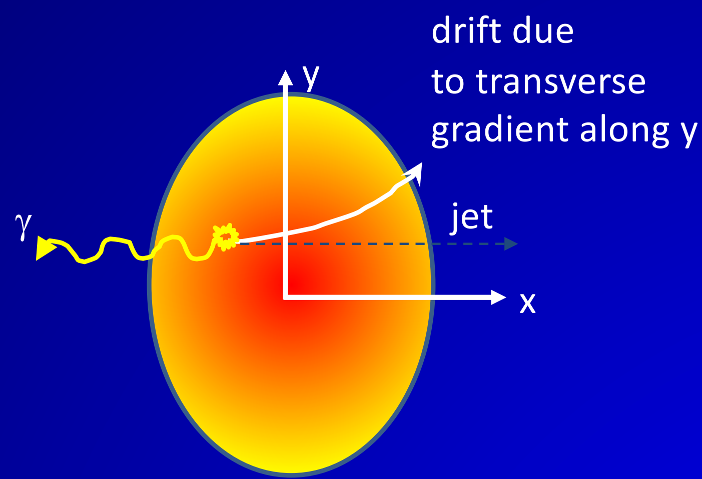
$$\delta f(\vec{p}_\perp) = -\frac{t}{3\omega \hat{q}_0} \vec{a} \cdot \vec{p}_\perp \left(1 - \frac{p_\perp^2}{2\hat{q}_0 t}\right) f_s(\vec{p}_\perp, t) + \mathcal{O}(a^2)$$

Transverse gradient tomography

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

(p_T>3 GeV/c)

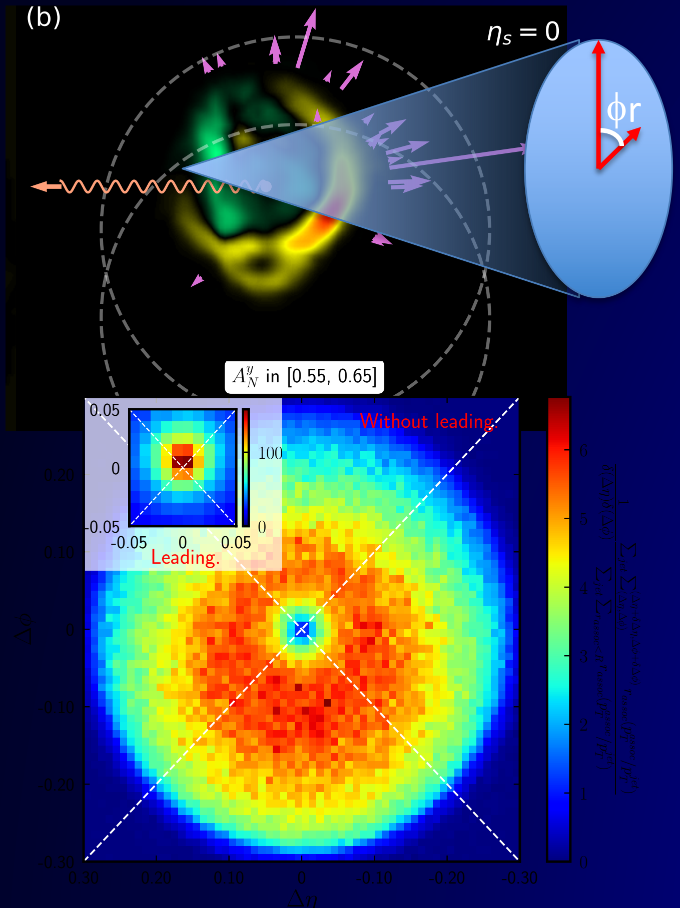




He, Pang & XNW, *PRL* 125 (2020) 12, 122301

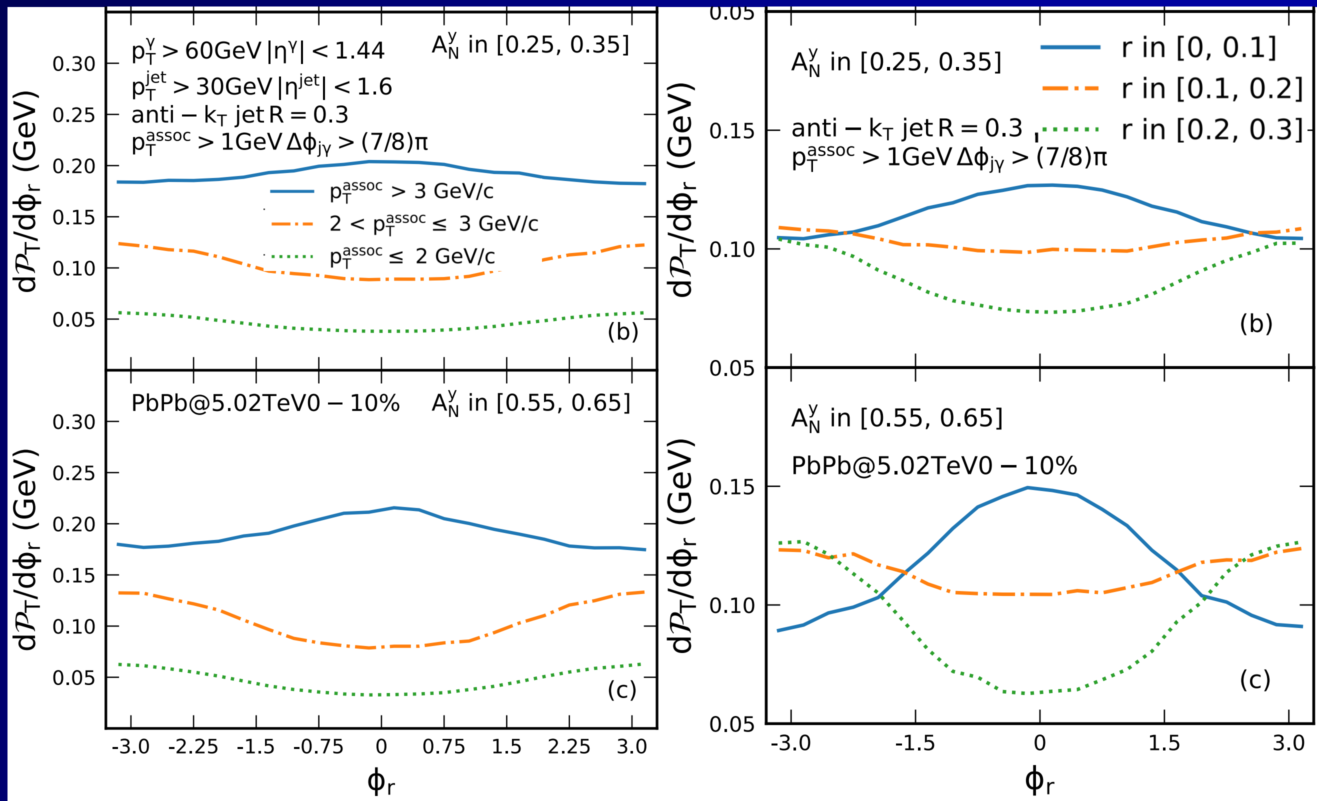
Jet energy loss → propagation length → initial jet position in x: Longitudinal tomography

Asymmetric jet shape: azimuthal dependent



Energetic hadrons at the core of jet are deflected away from center

Soft hadrons from medium response at large angle flow into center

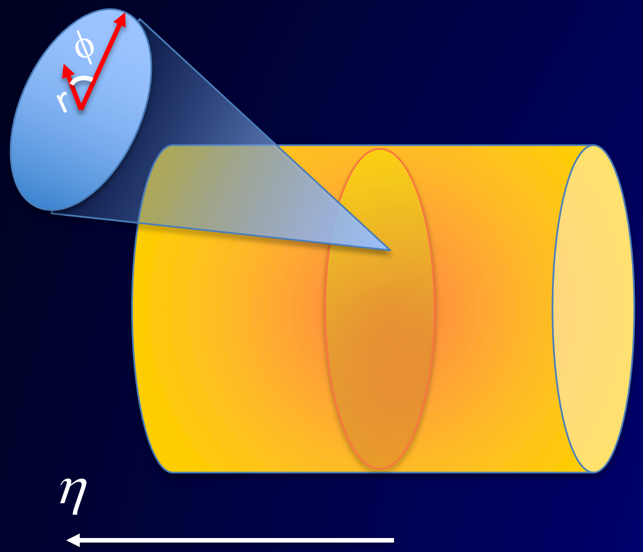


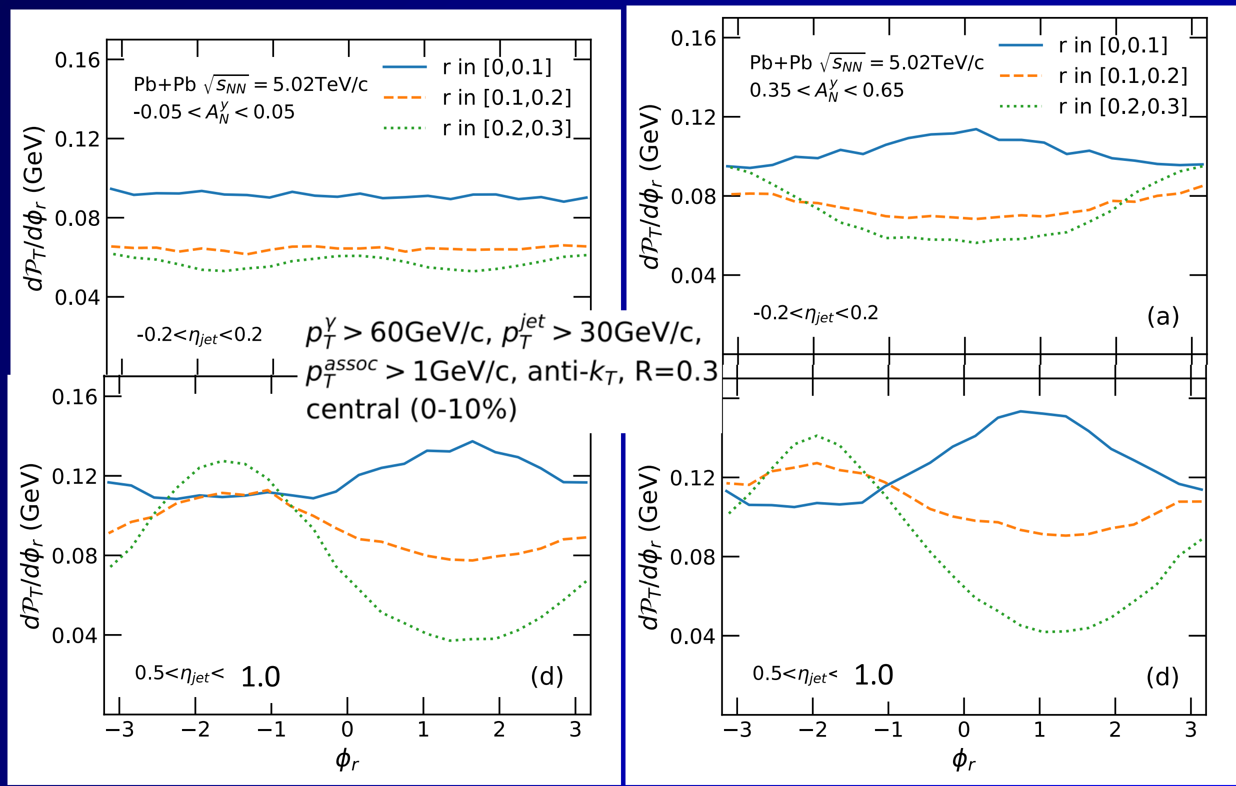
Xiao, He, Pang, Zhang and XNW *PRC* 109 (2024) 5, 054906

Institute of Particle Physics
粒 子 物 理 研 究 所

Asymmetric jet shape at finite rapidity

Jet and longitudinal-flow coupling





Xiao, Zhang and XNW to be published

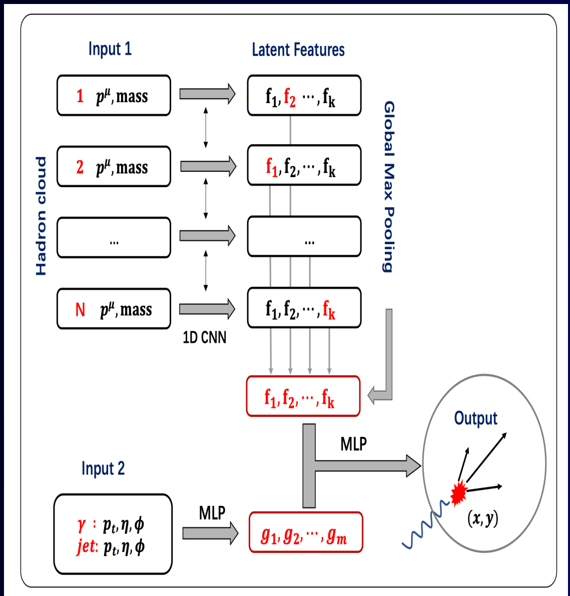
Against the longitudinal flow

Along the longitudinal flow

Institute of Particle Physics
粒 子 物 理 研 究 所

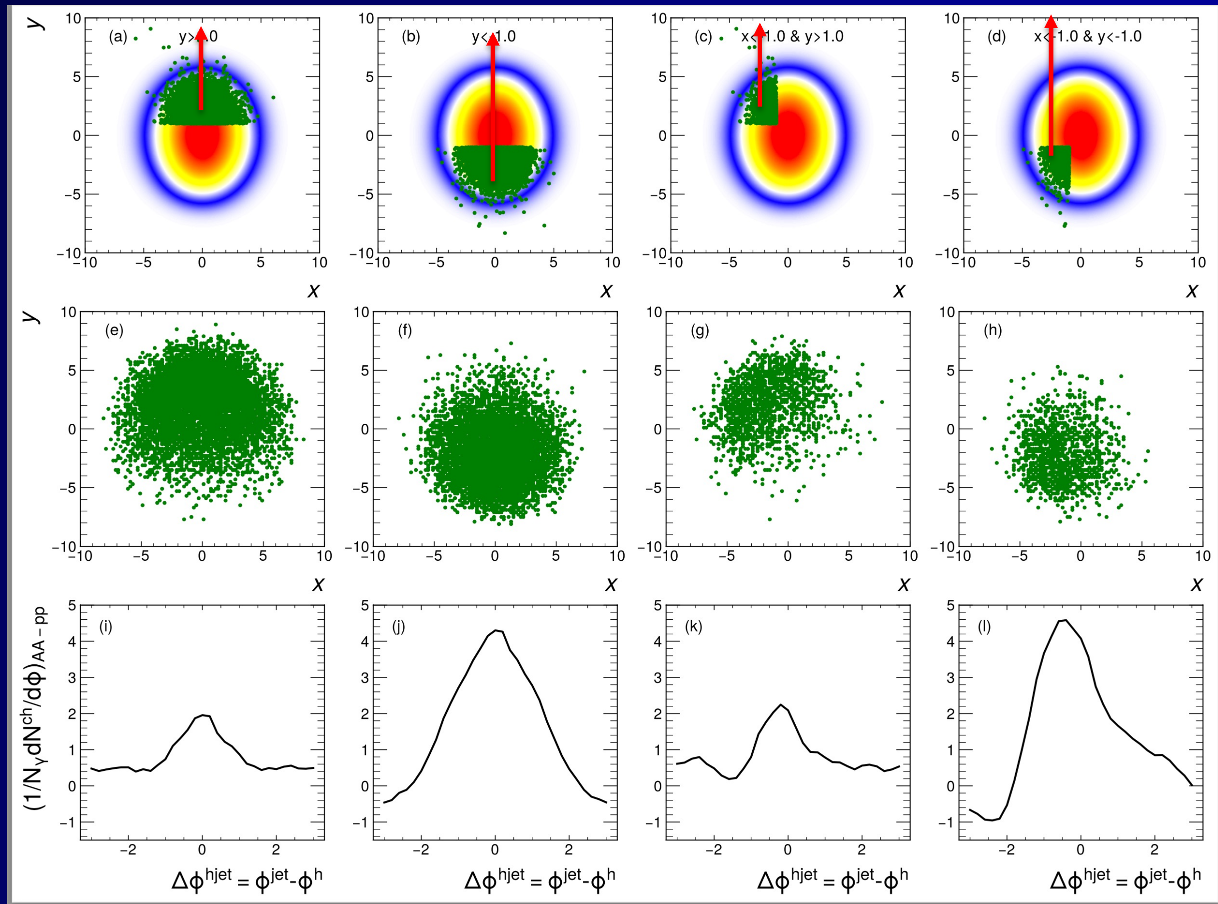
Deep learning assisted jet tomography

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

Institute of Particle Physics
粒 子 物 理 研 究 所

Summary

- 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
- Rapidity asymmetry as a robust signal of diffusion wake
- Future studies: ML improved 2D tomography and constraint on EoS, transport coefficients