12th MPI at LHC

12th International workshop on Multiple Partonic Interactions at the LHC

LIP Lisbon, 11-15 October 2021

MPI and Jet Physics in Heavy-ion Collisions

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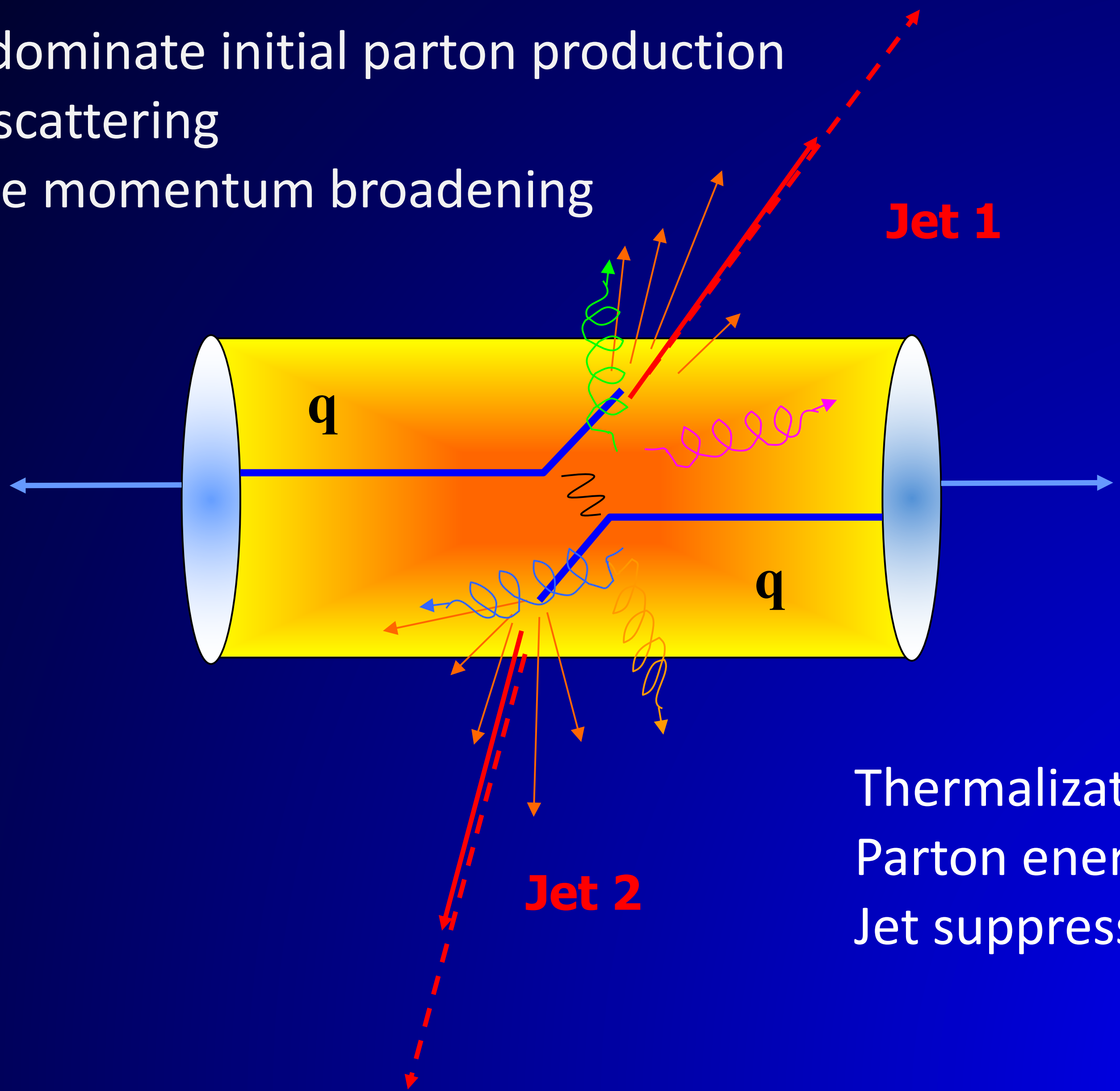
Jets in heavy-ion collisions

Minijets dominate initial parton production
Multiple scattering
Transverse momentum broadening



Thermalization
Parton energy loss
Jet suppression

Multiple jet production in pp

Probability of multiple jet production:

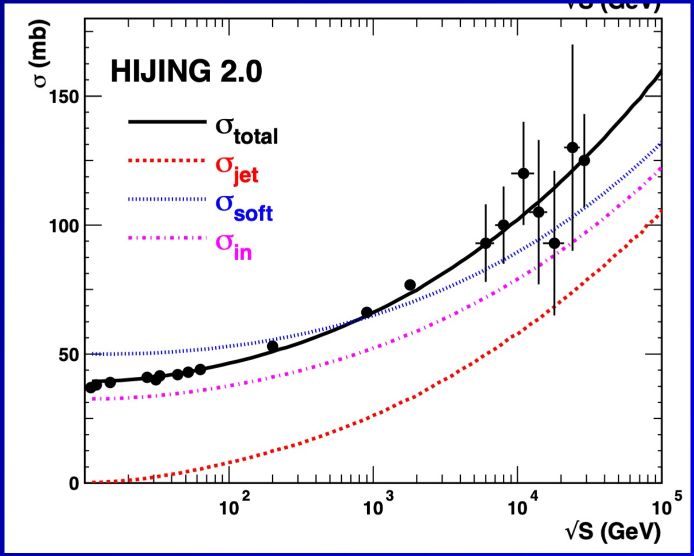
$$g_j(b) = \frac{[\sigma(p_0)T(b)]^j}{j!} e^{-\sigma(p_0)T(b)}$$

$$g_0(b) = [1 - e^{-\sigma_{\rm soft}T(b)}]e^{-\sigma(p_0)T(b)}$$

Total inelastic cross section

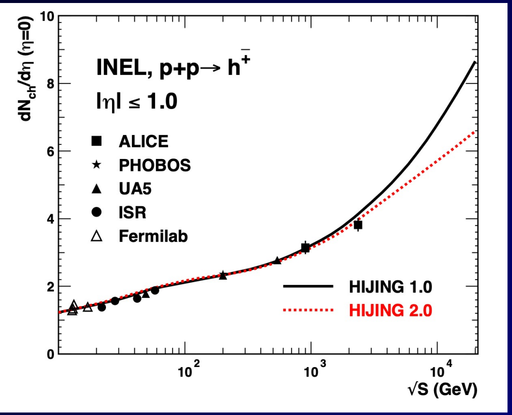
$$\sigma_{\rm in} = \int d^2b[1 - e^{-(\sigma_{\rm soft}+\sigma(p_0))T(b)}]$$

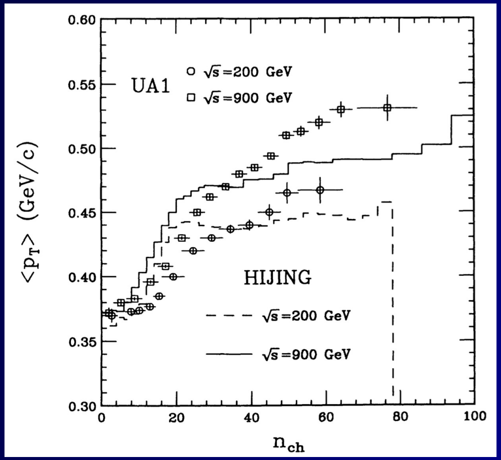
$$\sigma_{\rm el} = \int d^2b[1 - e^{-(\sigma_{\rm soft}+\sigma(p_0))T(b)/2}]^2$$

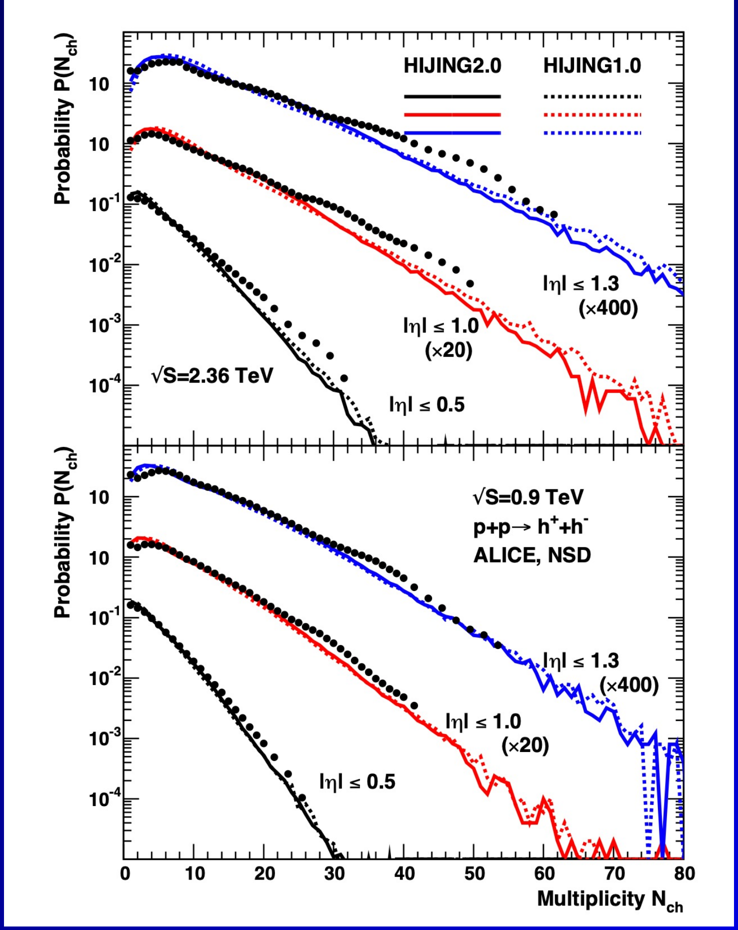


XNW & Gyulassy (1991);
Deng, XNW & Xu (2010)

Jets and particle multiplicity in p+p







XNW & Gyulassy (1991);
Deng, XNW & Xu (2010)

Associated multiple parton production

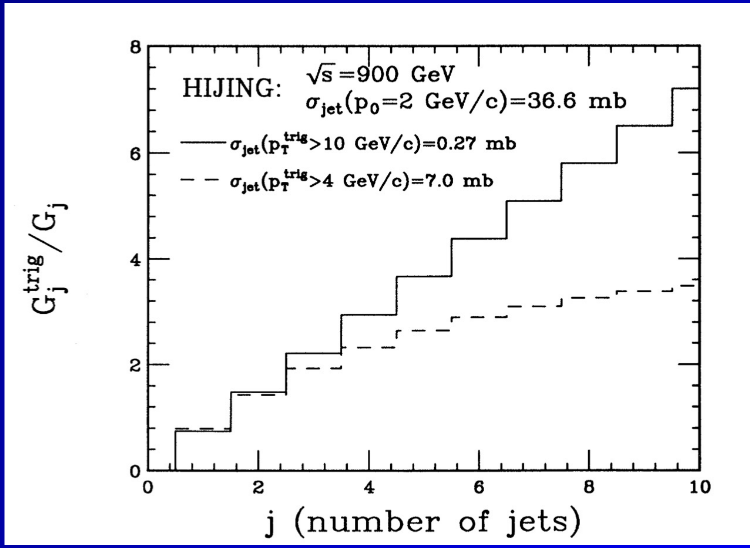
XNW & Gyulassy (1991)

Probability of multiple jets ($p_T > p_0$) with at least one jet with $p_T > p_T^{trig}$

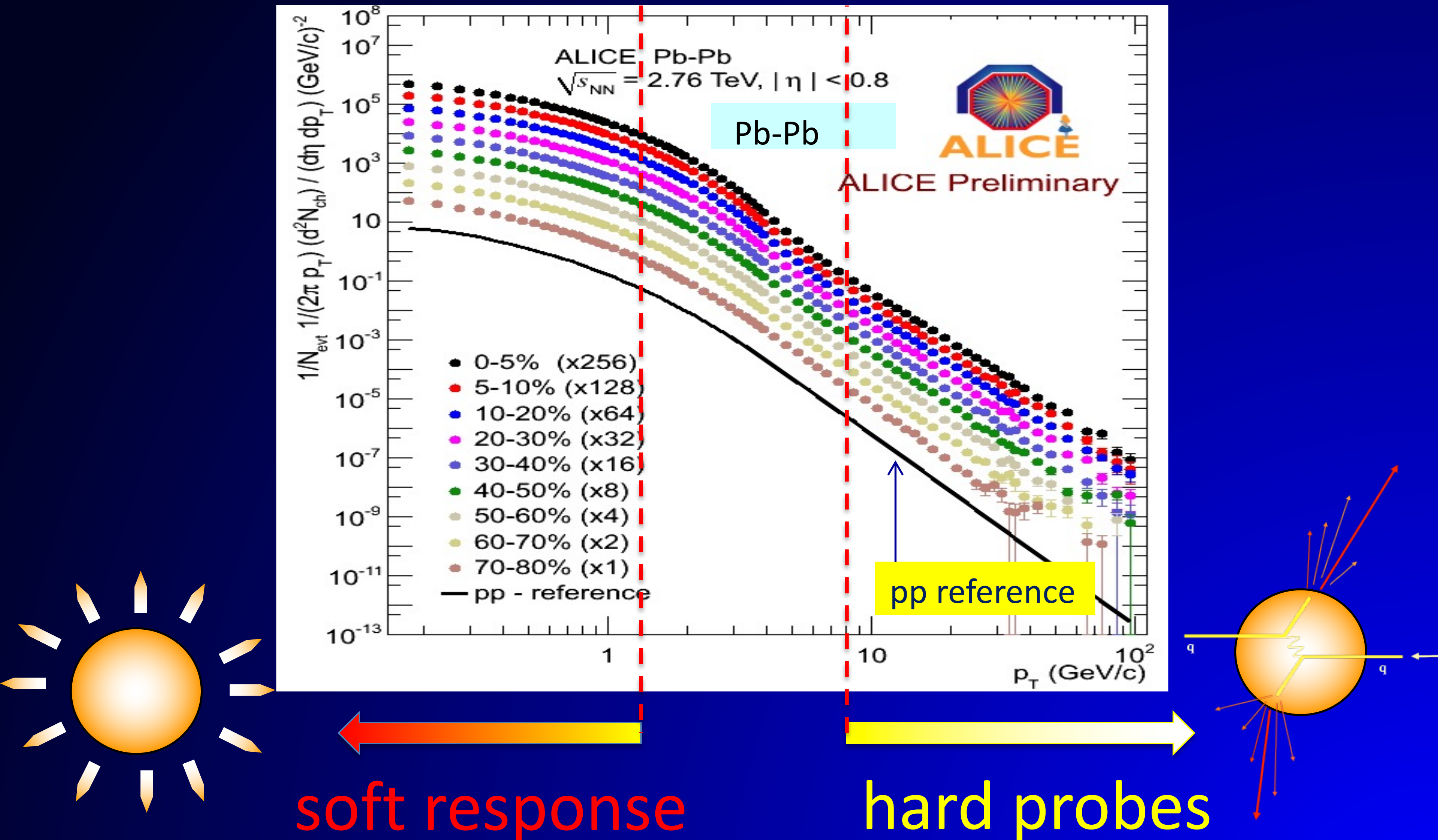
$$g_j^{\rm trig}(b) = \frac{[\sigma(p_0)T(b)]^j}{j!}\left\{1 - \frac{[(\sigma(p_0) - \sigma(p_T^{\rm trig})]^j}{\sigma(p_0)^j}\right\} e^{-\sigma(p_0)T(b)}$$

$$\approx j\,\frac{\sigma(p_T^{\rm trig})}{\sigma(p_0)}\, g_j(b)$$

Enhanced multiple minijet production in triggered jet events



Jets and collective flow in A+A



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

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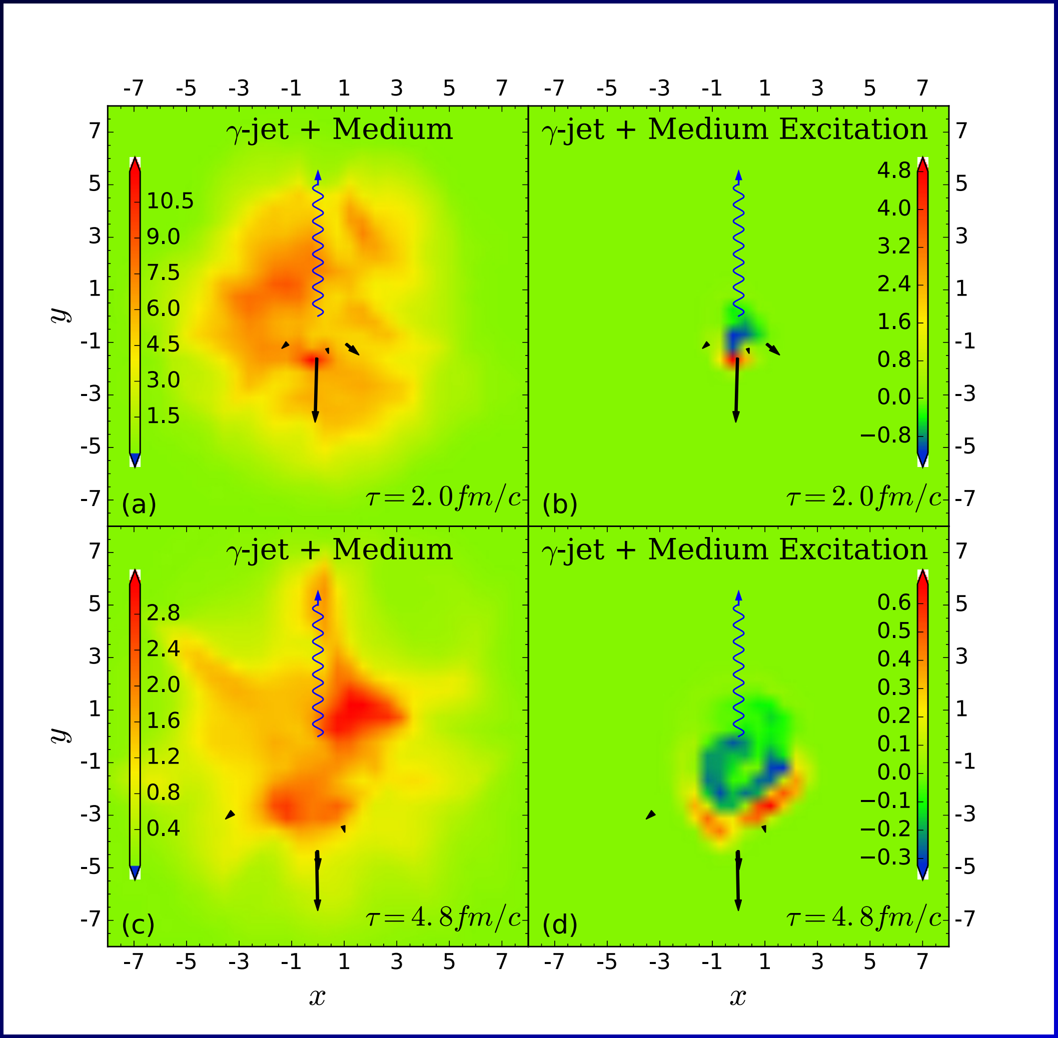
γ-jet propagation within CoLBT-hydro

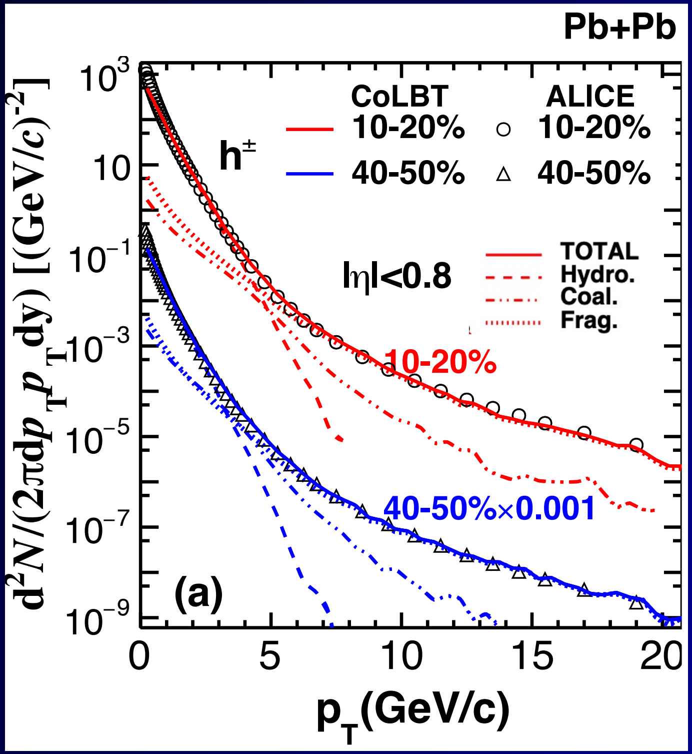


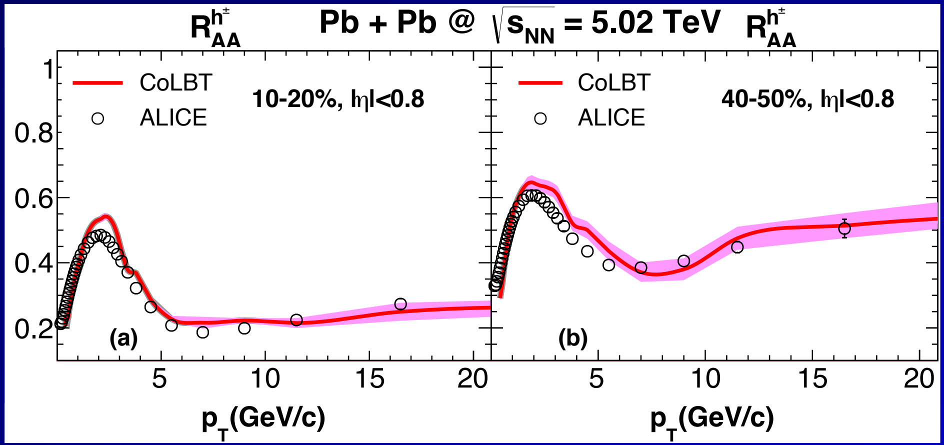
Chen, Cao, Luo, Pang & XNW, PLB777(2018)86

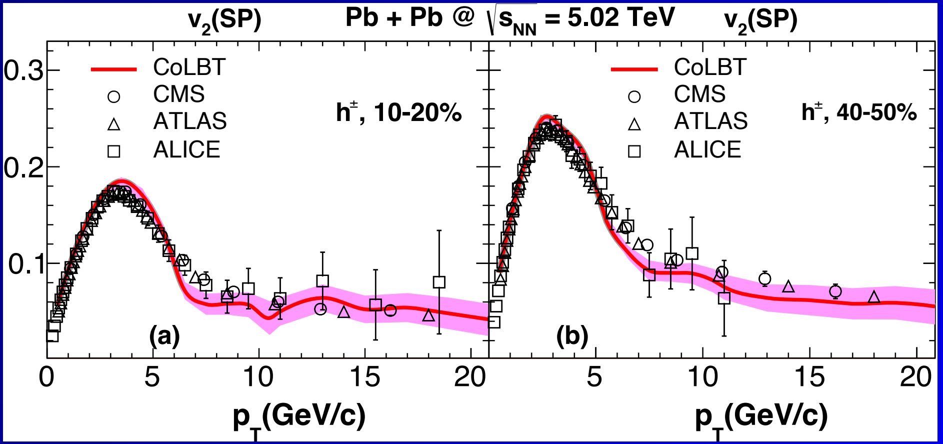
Hadron spectra: from low to high pt

Interplay of hydro, jet quenching, parton coalescence, fragmentation and hadron cascade

R_{AA}&v_2 puzzle resolved !

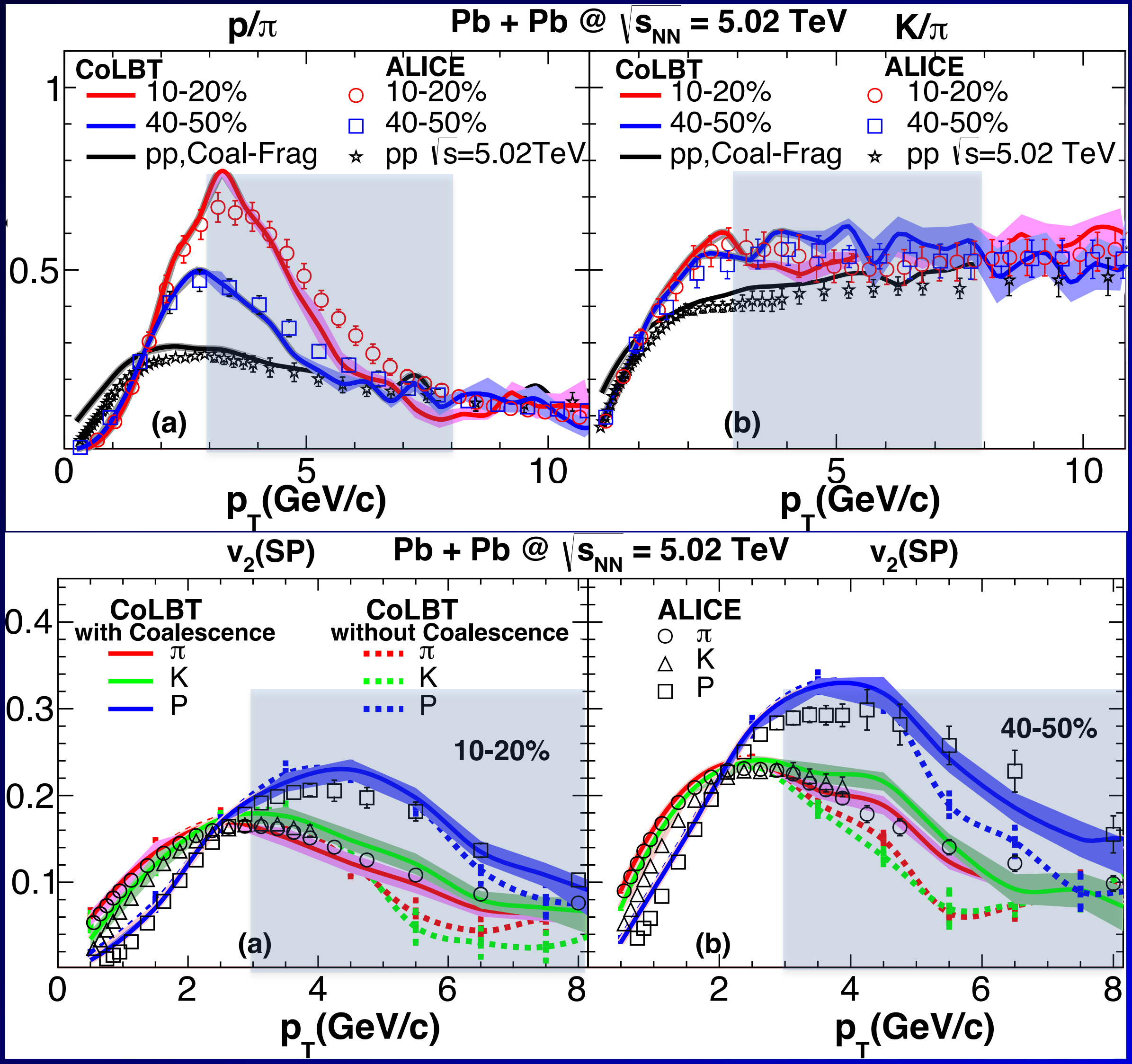






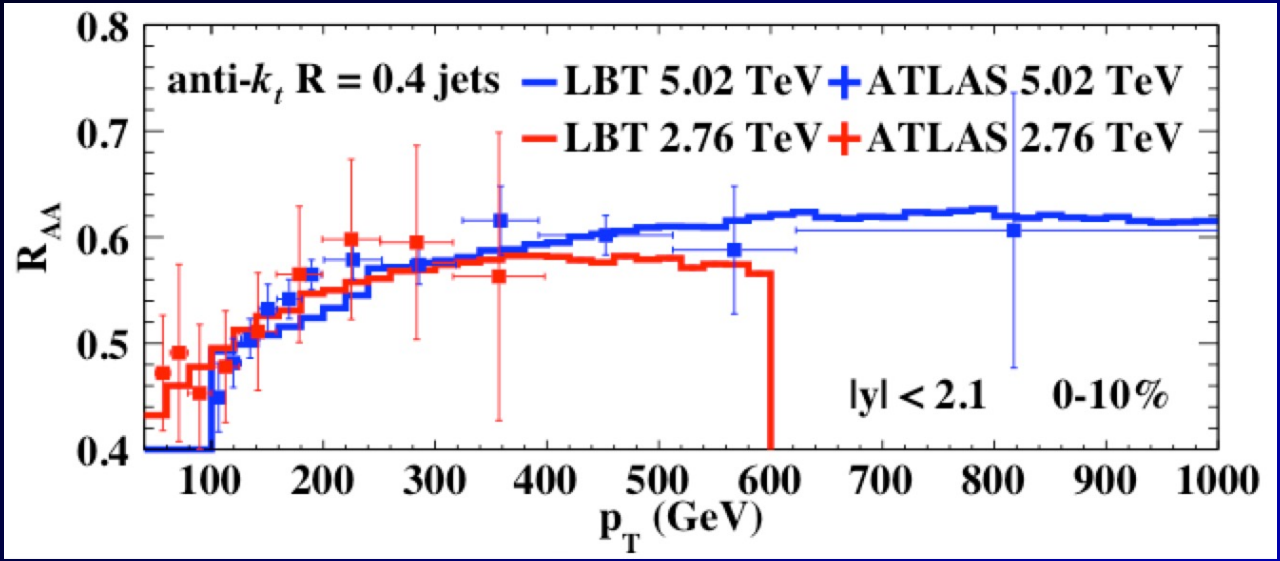
Zhao, Ke, Chen & XNW 2103.14657

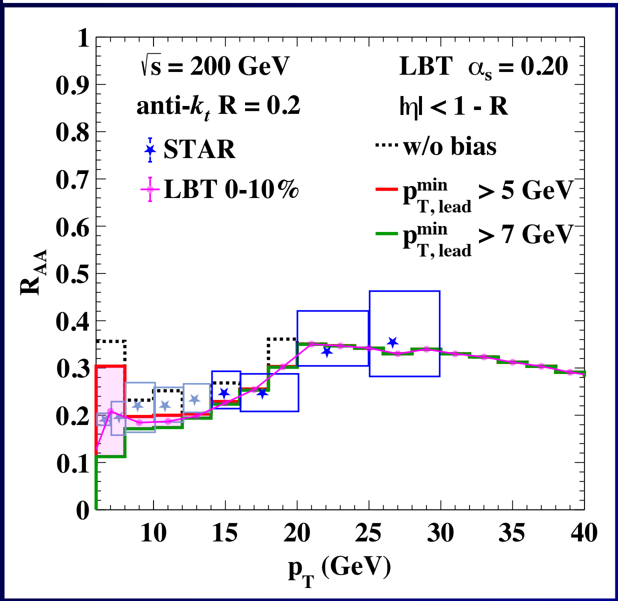
Coalescence & hadron cascade



Zhao, Ke, Chen & XNW 2103.14657

Jet suppression and energy loss





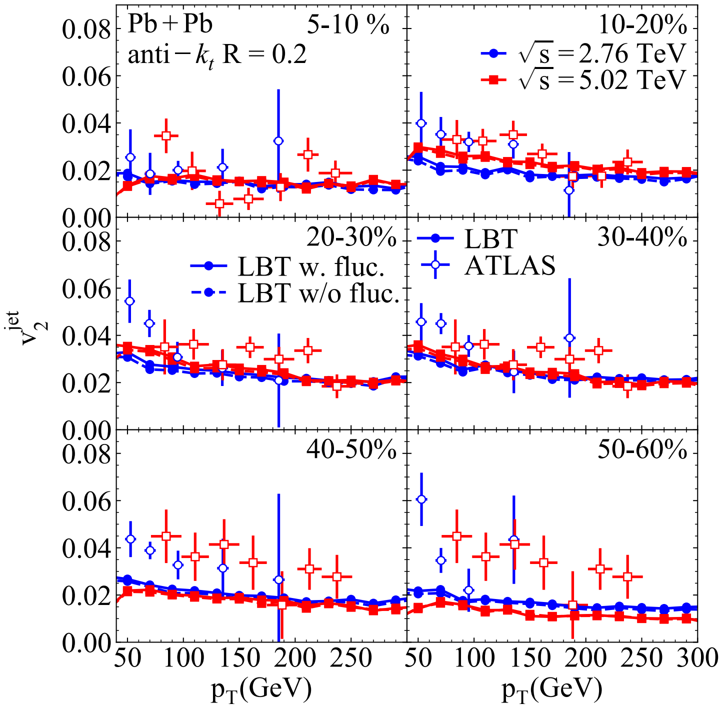
He, Cao, Chen, Luo, Pang & XNW 1809.02525

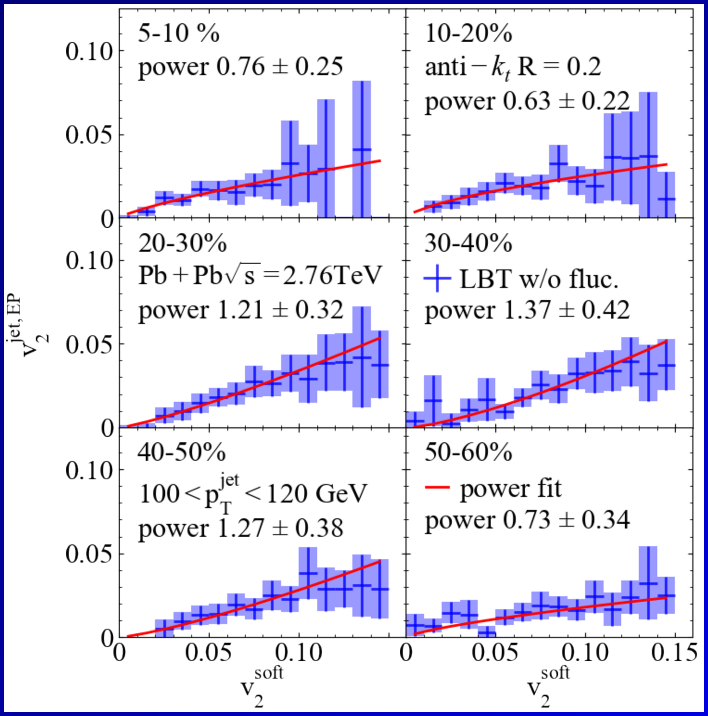
- p_T dependence: initial jet spectra and p_T dependence of energy loss ΔE
- energy dependence: increase of jet energy loss and the slope of initial spectra
- Medium response reduce jet net energy loss

Single jet anisotropy

$$v_n^{\text{jet}} = \frac{\langle\langle v_n \cos[n(\phi^{\text{jet}} - \Psi_n)]\rangle\rangle}{\sqrt{\langle v_n^2 \rangle}}$$

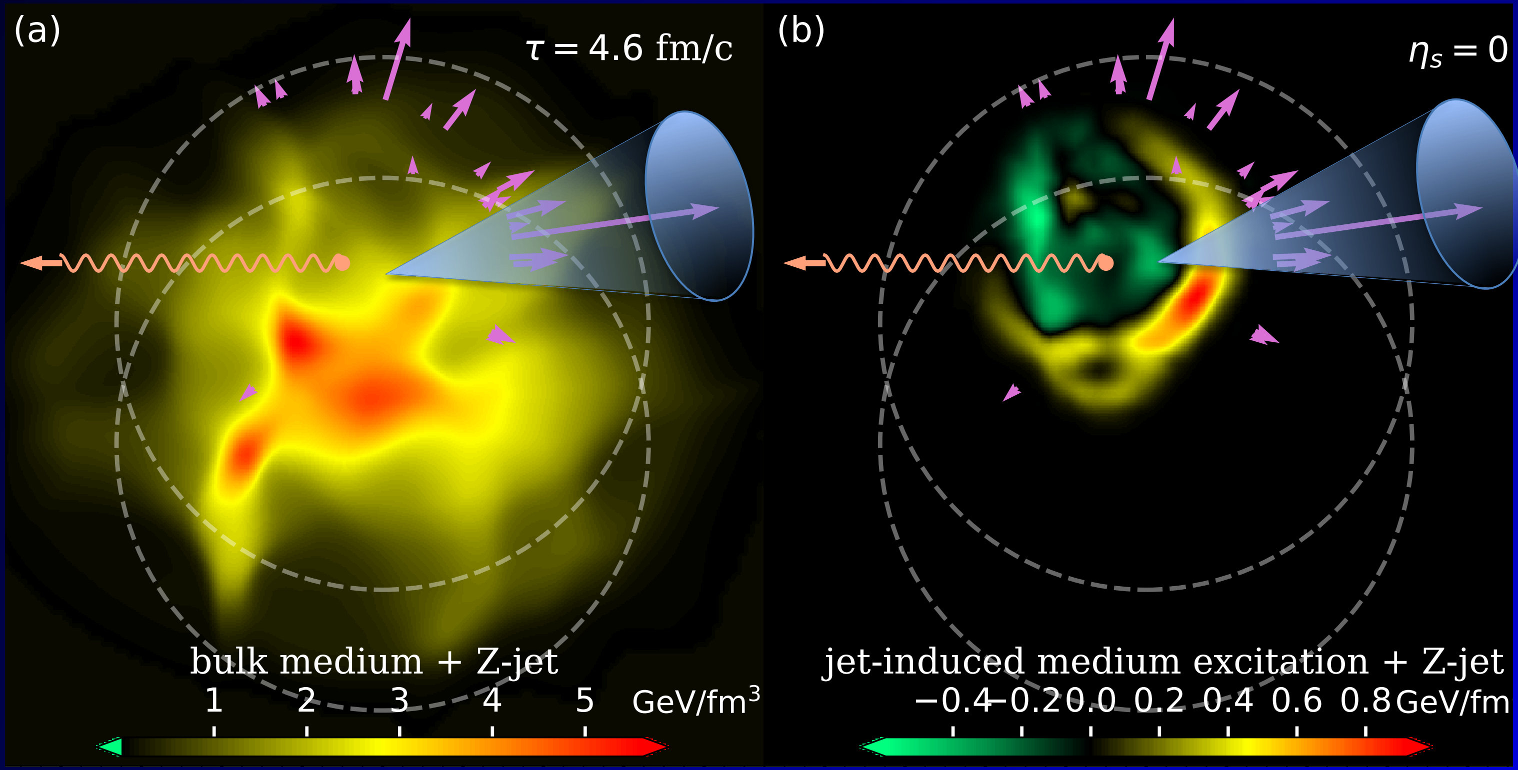
(1) Finite jet v2 at very large pt (2) Linear e-by-e correlation btw jet and bulk v2
(3) Effect of bulk v2 fluctuation on jet v2 negligible





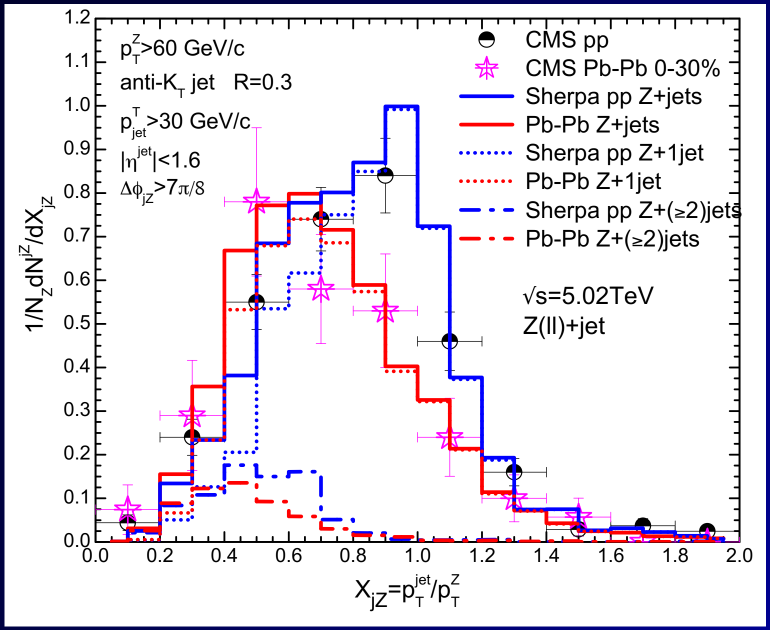
He, Cao, Luo, Pang & XNW, in preparation

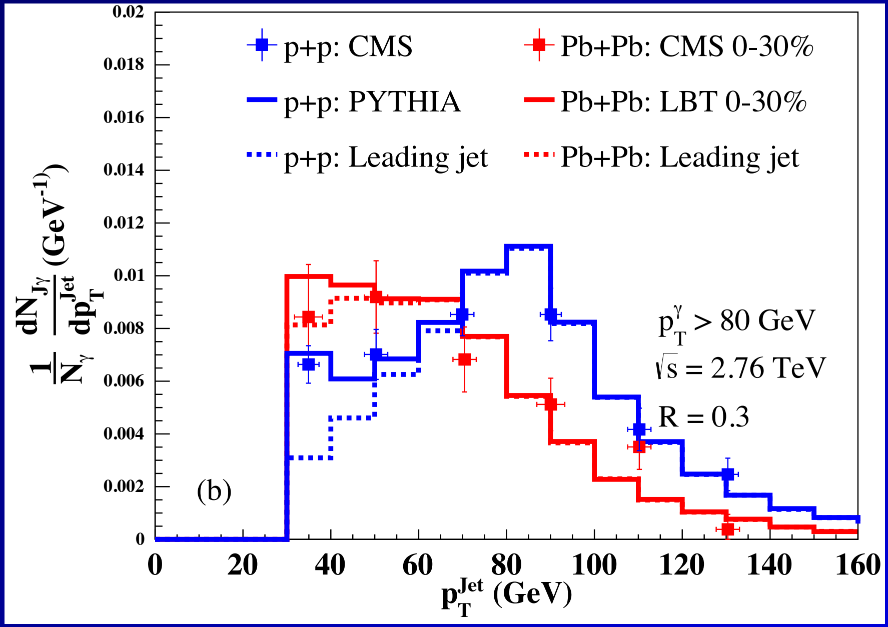
Medium response in Z/γ-jet



Energy loss in γ/Z-jet at LHC

Suppression of leading and multiple jets



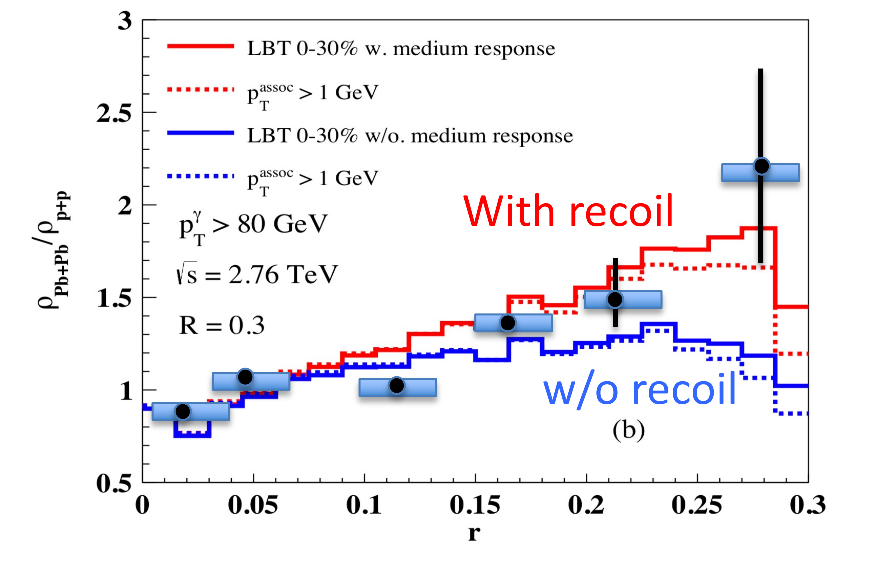


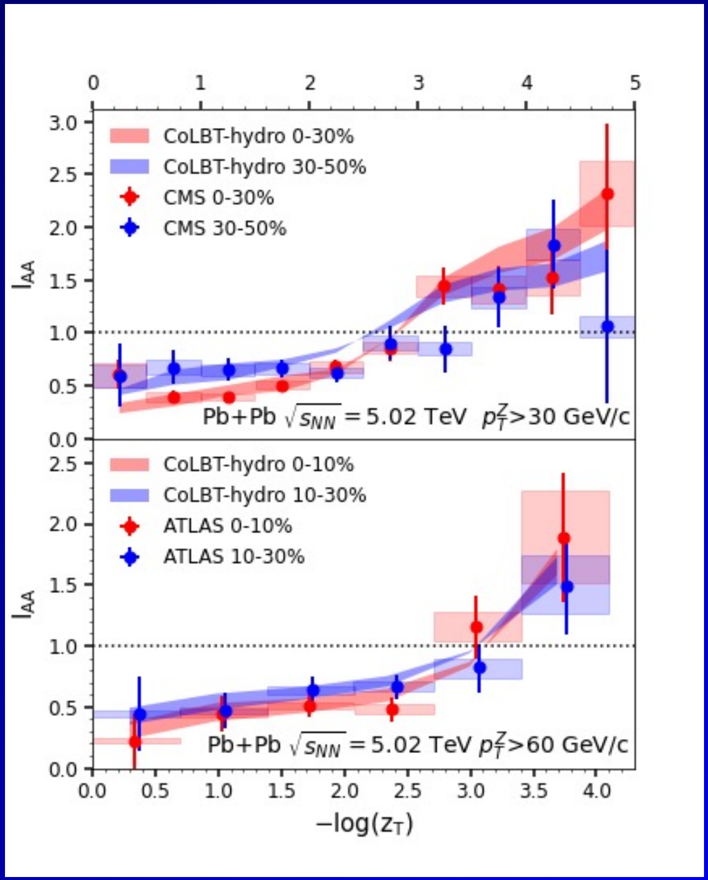
Zhang, Luo, XNW, Zhang, arXiv:1804.11041

Luo, Cao, He & XNW, arXiv:1803.06785

Medium modification of γ/Z-jets

Enhancement of soft hadrons
in large angles





Luo, Cao, He & XNW, arXiv:1803.06785

Chen, Cao, Luo, Pang & XNW, 2005.09678

Chen, Yang, He, Ke, Pang and XNW, 2101.05422

Medium response & soft gluon radiation

Medium response:

$$\delta f(p) \sim e^{-p\cdot u/T}$$

Medium-induced gluon radiation:

Formation time:

$$\tau_f = \frac{2\omega}{k_T^2} \quad k_T^2 \approx \tau_f \hat{q}$$

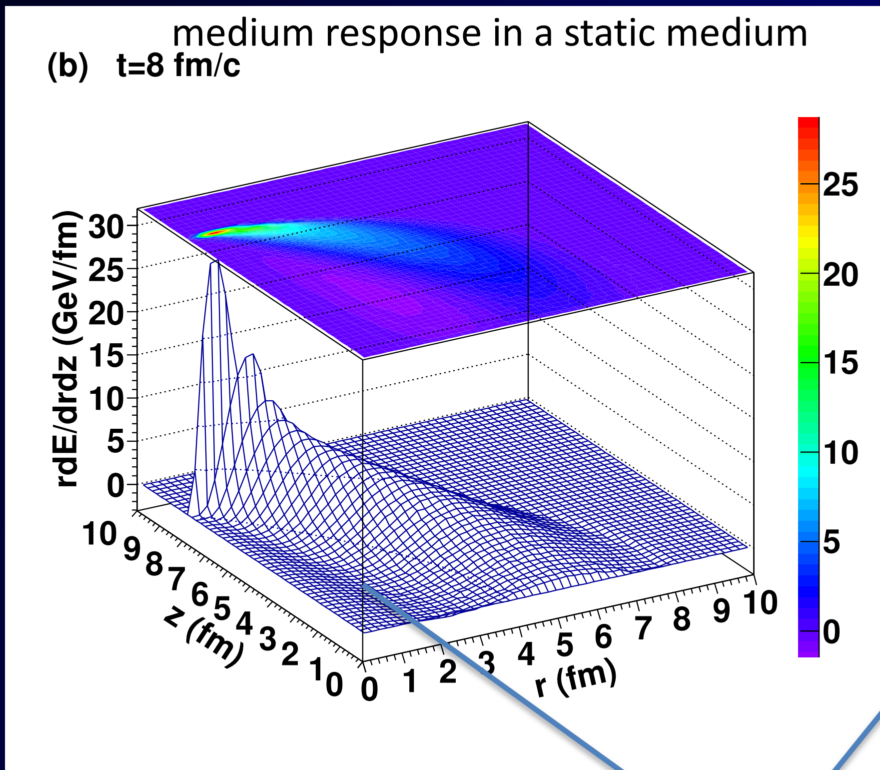
$$\tau_f \approx \sqrt{2\omega/\hat{q}}$$

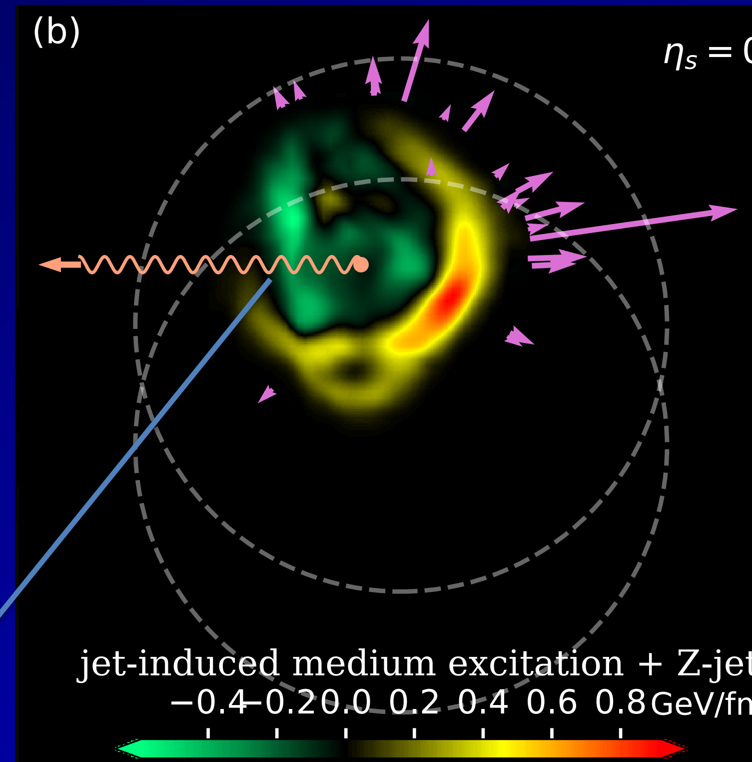
Mean-free-path limits the formation time

$$\tau_f \leq \lambda \sim 1/T \quad \hat{q} \sim T^3$$

$$\omega \approx \lambda^2 \hat{q}/2 \sim T$$

Signal of the diffusion wake





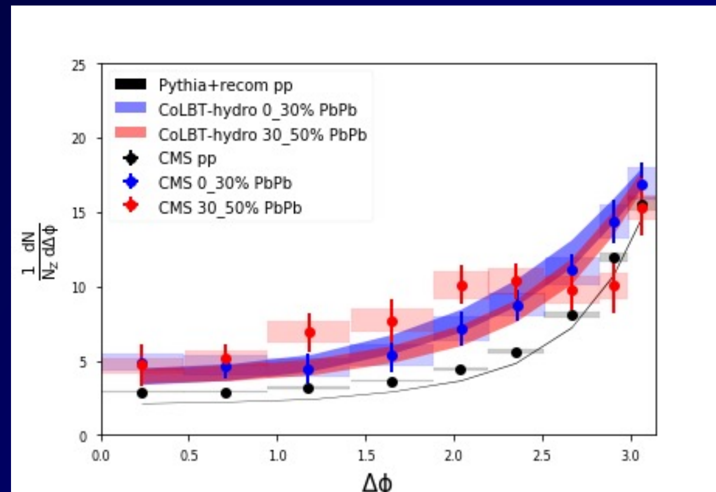
Diffusion wake: propagation of “particle holes” depletion of phase-space

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

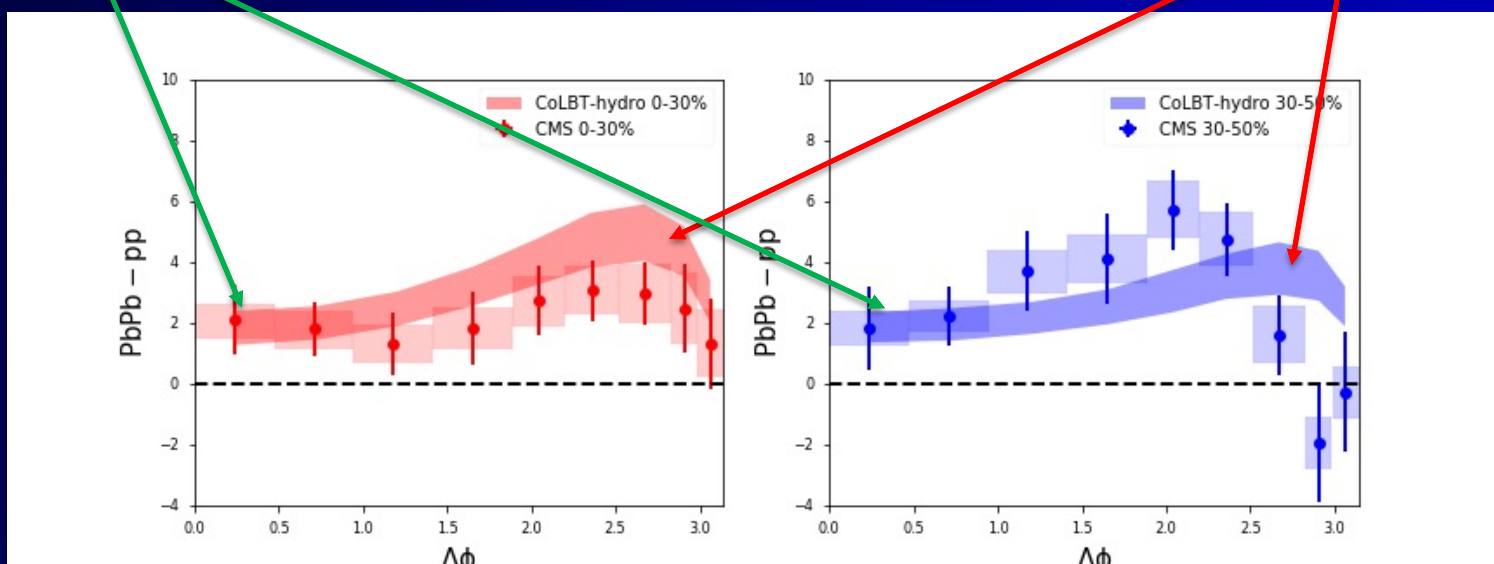
Chen, Yang, He, Ke, Pang and XNW, 2101.05422

Z-hadron correlation

enhancement of the away-side background



enhancement and broadening of the jet peak

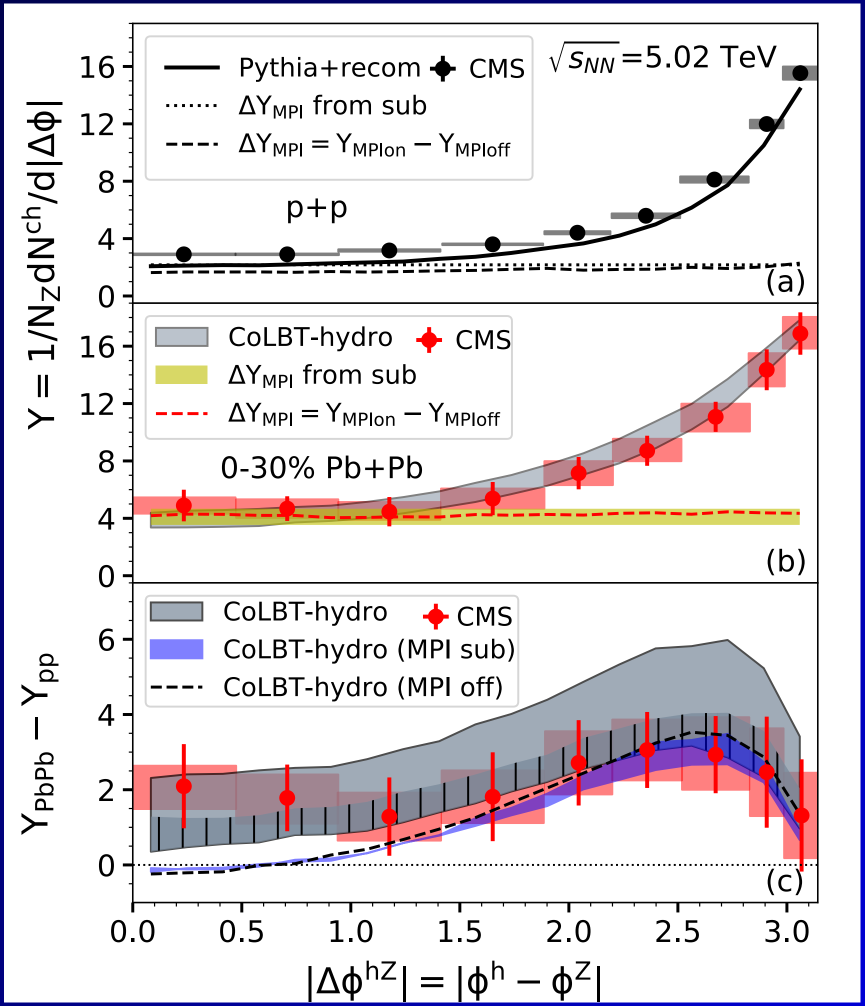


Chen, Yang, He, Ke, Pang and XNW, 2101.05422

MPI subtraction in Z-hadron correlation

Medium modification of MPI: low pT enhancement and high pT suppression

No correlation with Z/γ-jet



Mixed event subtraction

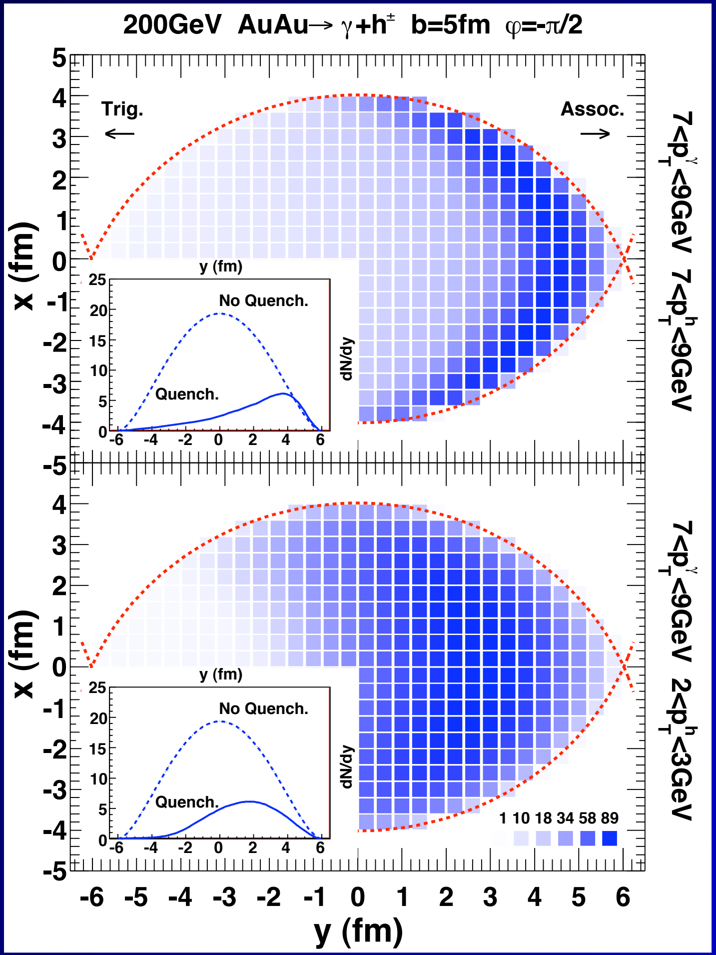
$$\frac{dN^{hZ}_{\rm MPI}}{d\phi} = \frac{dN^{hZ}_{\rm mix}}{d\phi} - \int_1^{\pi} \frac{d\phi}{\pi} \left(\frac{dN^{hZ}}{d\phi} - \frac{dN^{hZ}}{d\phi}\Big|_{\phi=1} \right)$$

Longitudinal jet tomography

length dependence of parton energy loss

Surface emission
Less energy loss

Volume emission
More energy loss



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

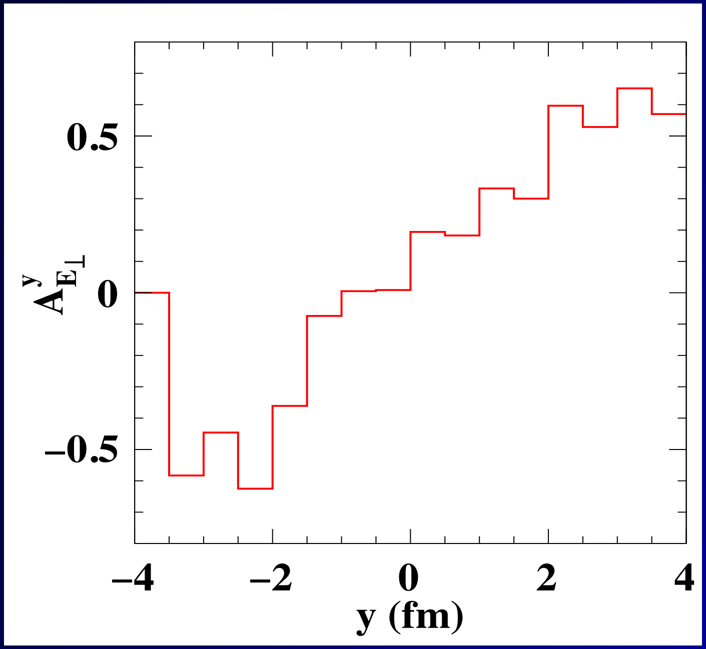
$p_T^h/p_T^\gamma \sim 0.3$

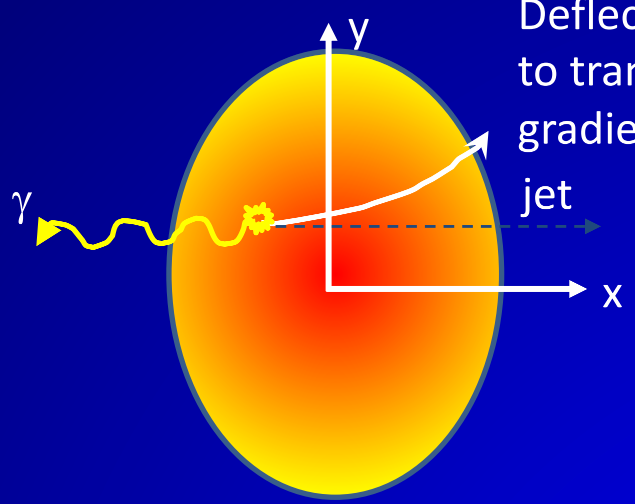
Zhang, Owens, Wang and XNW, PRL 103, 032302 (2009)

Transverse asymmetry

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

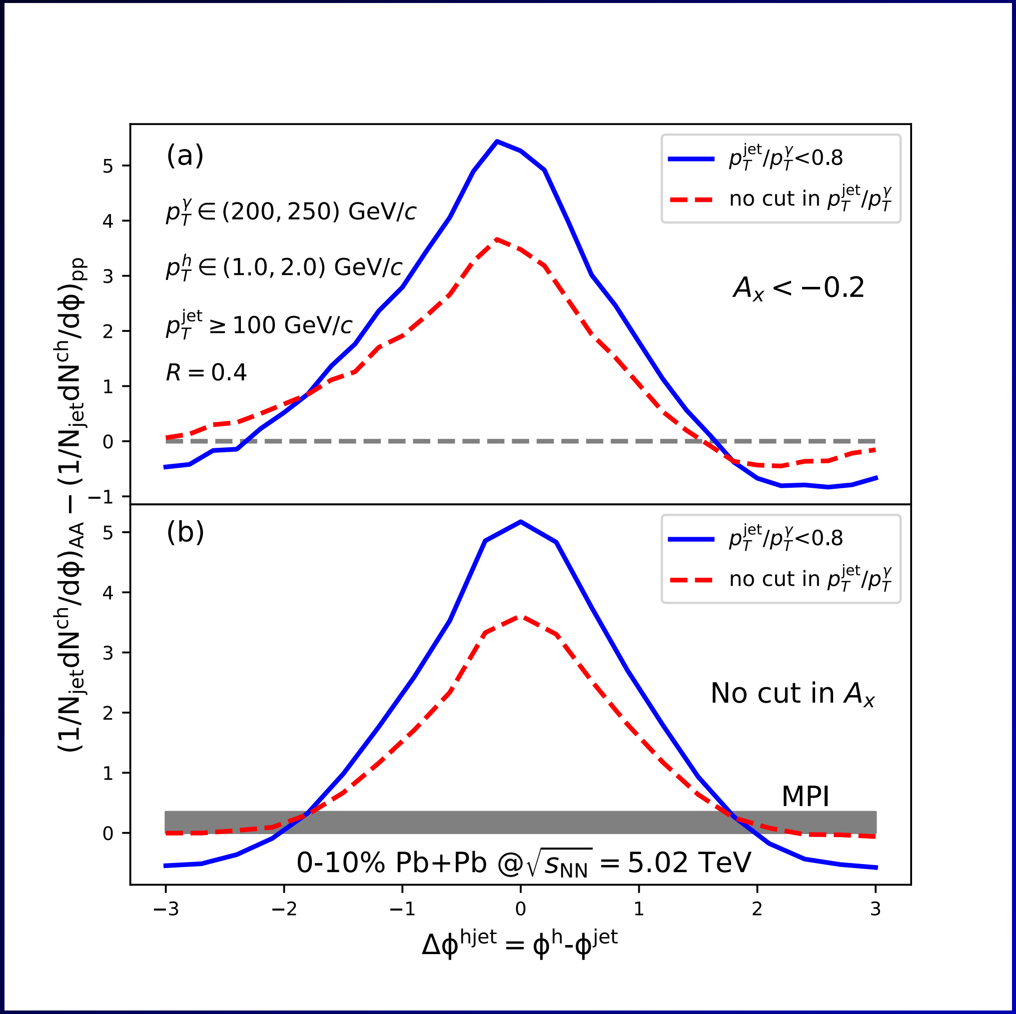
p_T>3 GeV/c

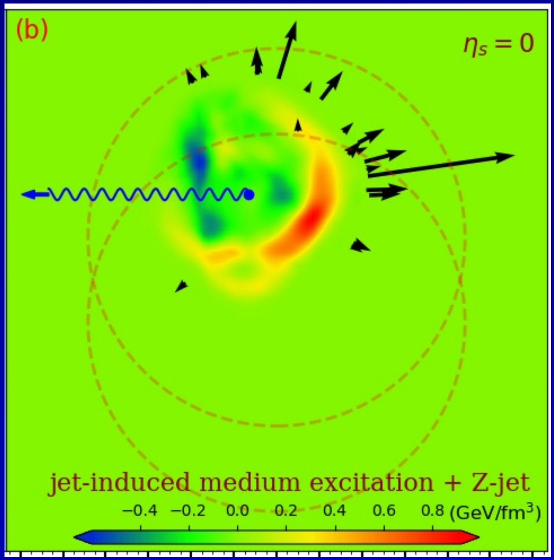




He, Pang & XNW, *PRL* 125 (2020) 12, 122301

Enhancing the diffusion wake





Summary

- Multiple jets dominate particle production in pp and AA collisions at LHC
- Coalescence at intermediate p_T solves R_{AA} v_2 puzzle
- Medium response leads to
  - enhancement of soft hadrons in jet direction
  - depletion of soft hadron on the away side
- MPI contribute to γ/Z-hadron correlation
- Use 2D jet tomography to reveal the angular structure of Mach-cone excitation

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