



# Scanning the initial jet production points with dijet tomography in heavy-ion collisions

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QM at Houston, Sep. 5th, 2023

# Outline

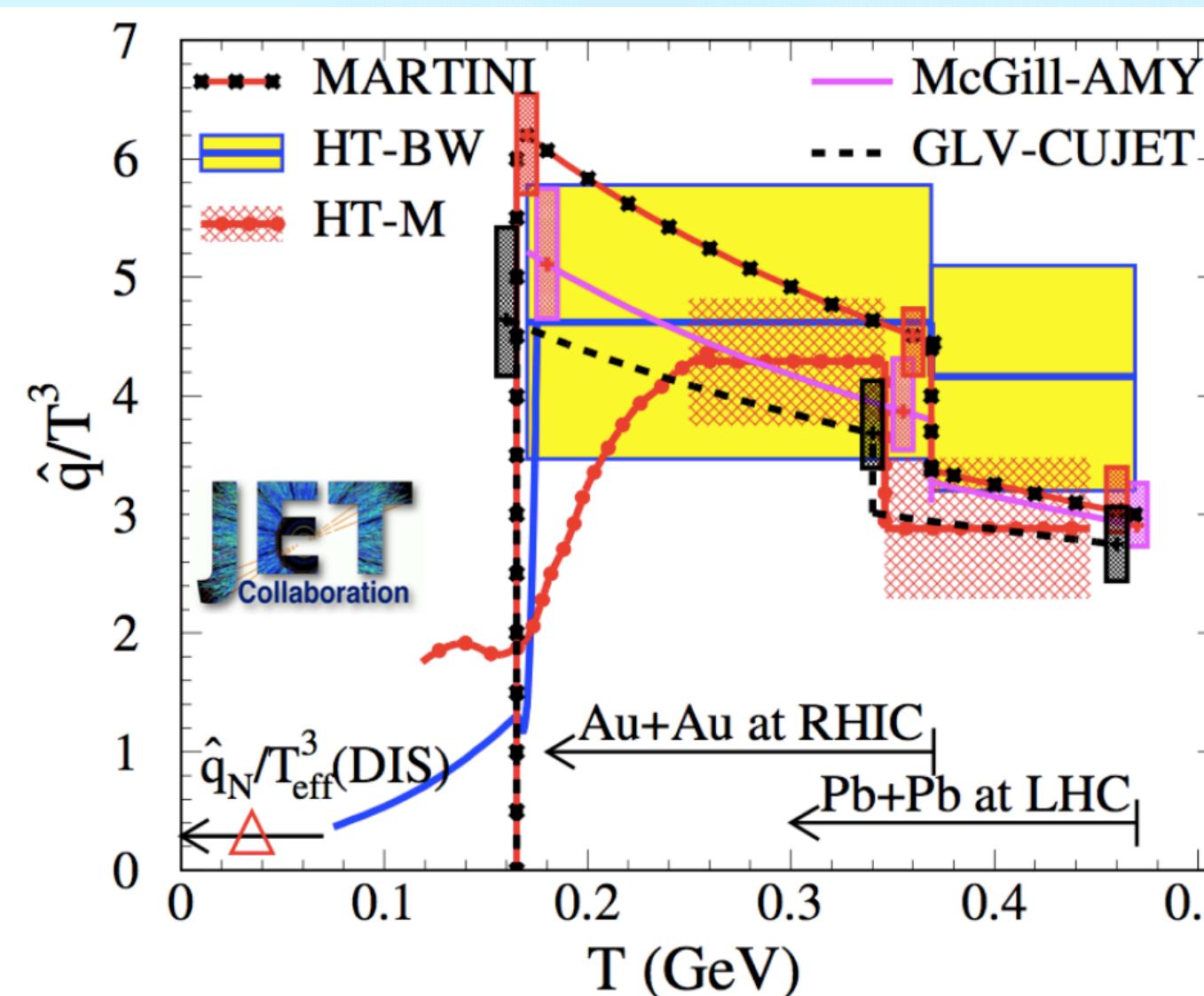


- ◆ Motivation
- ◆ The linear Boltzmann transport (LBT) Model
- ◆ Dijet tomography
- ◆ Summary

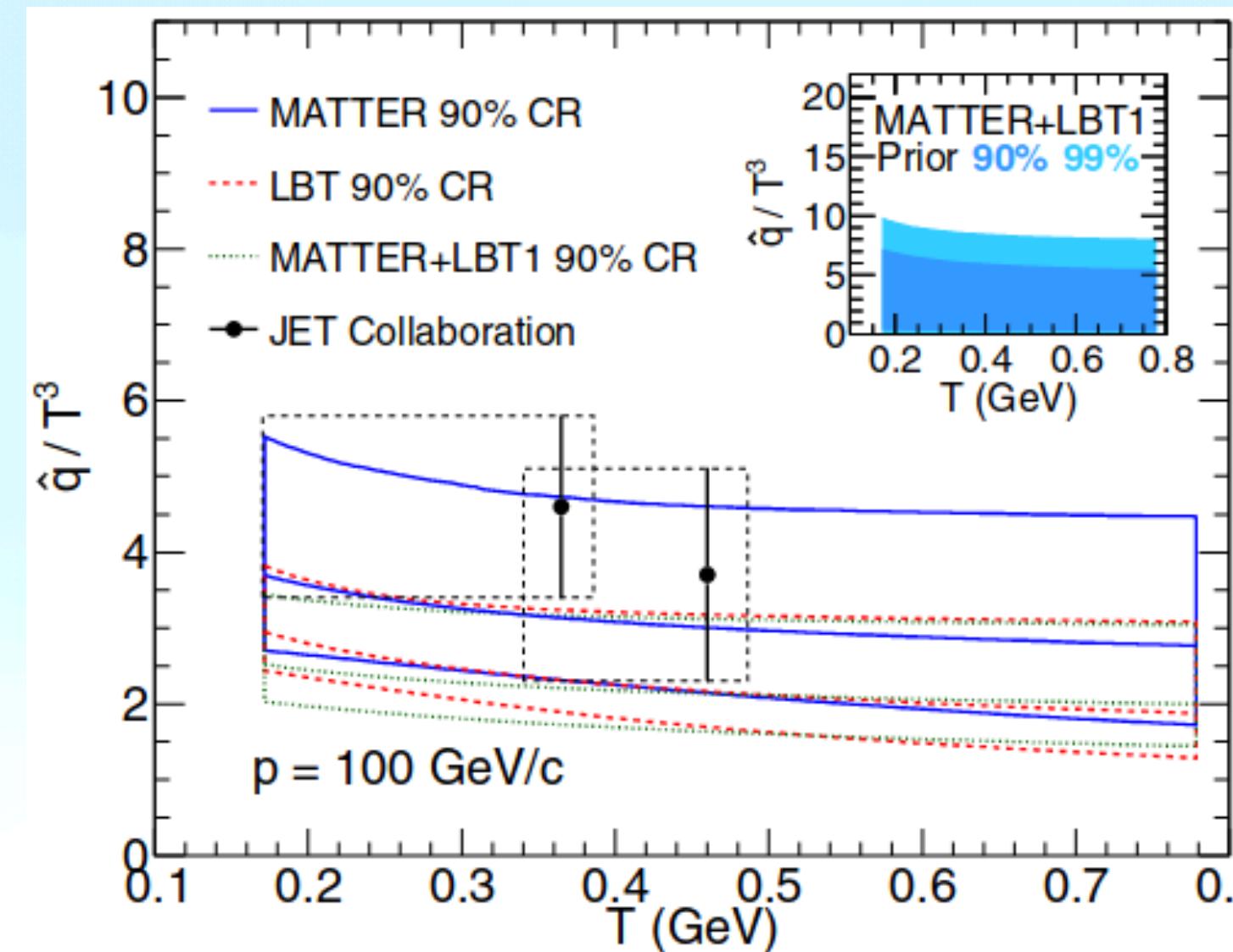
# Motivation



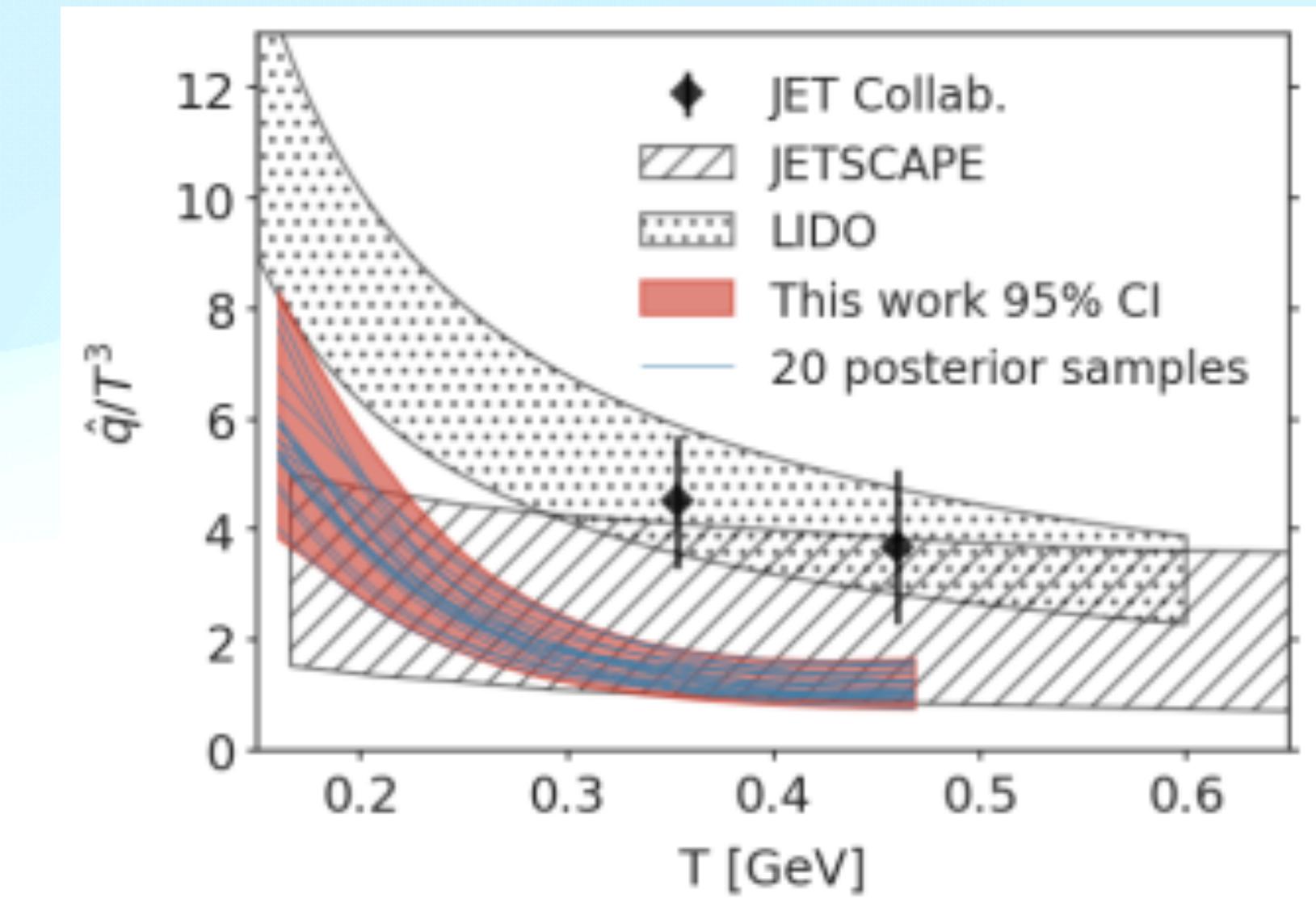
**Jet transport coefficient**  $\hat{q}_a(x) = \sum_{bcd} \rho_b(x) \int d\hat{t} q_\perp^2 \frac{d\sigma_{ab \rightarrow cd}}{d\hat{t}} = \frac{\langle q_\perp^2 \rangle}{\lambda}$



JET Collaboration, PRC 90, 014909 (2014)



JETSCAPE Collaboration, PRC 104, 024905 (2021)



Xie, Ke, Zhang & Wang, PRC 108, 1, L011901 (2023)

$$\hat{q} \approx \begin{cases} 1.2 \pm 0.3 & \text{GeV}^2/\text{fm} \text{ at } T=370 \text{ MeV} \\ 1.9 \pm 0.7 & \text{GeV}^2/\text{fm} \text{ at } T=470 \text{ MeV} \end{cases} \begin{matrix} \text{RHIC} \\ \text{LHC} \end{matrix}$$

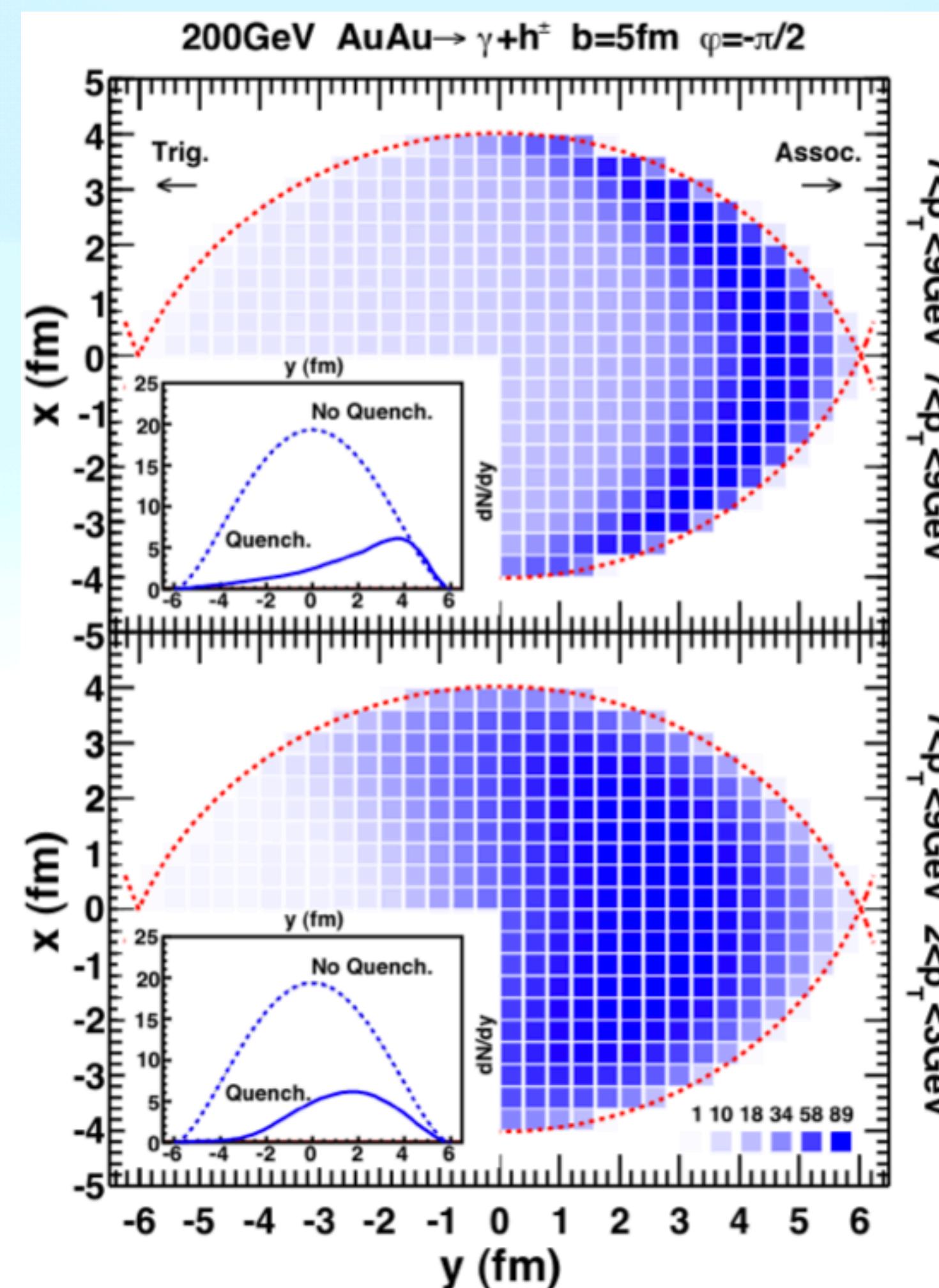
Jet transport coefficient is crucial for jet quenching calculations

# Motivation



## Longitudinal jet tomography in heavy-ion collisions

length dependence  
of parton energy loss



$$p_T^h/p_T^\gamma \sim 0.9$$

less energy loss:  
surface emission

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

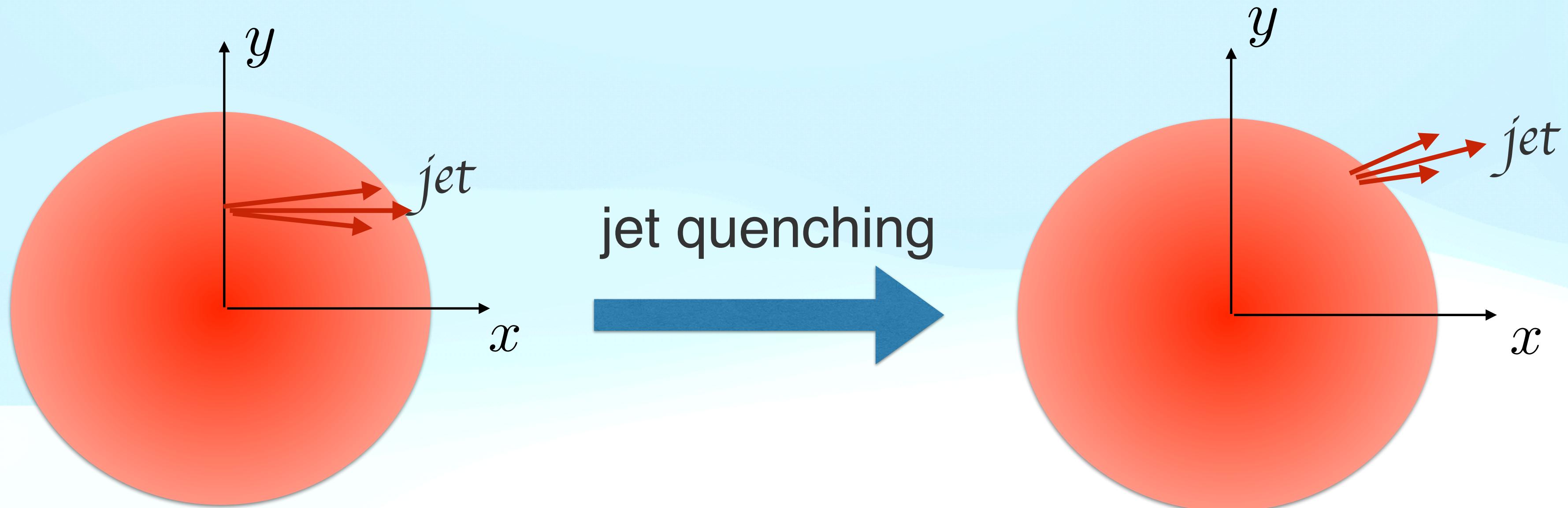
more energy loss:  
volume emission

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

# Motivation



What about the transverse jet tomography?



jet quenching leads to:

- ✓ jet energy loss
- ✓ transverse momentum broadening.

# Motivation



Boltzmann equation for an elastic scattering:

Small angle scattering, and neglect the effect of flow and drag term:

$$\frac{k^\mu}{\omega} \partial_\mu f_a(\vec{k}, \vec{r}) = \frac{\hat{q}_a}{4} \vec{\nabla}_{k_\perp}^2 f_a(\vec{k}, \vec{r})$$

$$\hat{q}_a = \sum_{bcd} \prod_{i=b,c,d} \int \frac{d^3 k_i}{2E_i (2\pi)^3} f_b(k_b) (\vec{k}_{a\perp} - \vec{k}_{c\perp})^2 \times |\mathcal{M}_{ab \rightarrow cd}|^2 \frac{\gamma_b}{2} (2\pi)^4 \delta^4(k_a + k_b - k_c - k_d)$$

For,  $\hat{q}_a = \text{constant}$        $f_a(\vec{k}, \vec{r}, t) = 3 \left( \frac{4\omega}{\hat{q}_a t^2} \right)^2 e^{-(\vec{r}_\perp - \frac{\vec{k}_\perp}{2\omega} t)^2 \frac{12\omega^2}{\hat{q}_a t^3} - \frac{k_\perp^2}{\hat{q}_a t}}$

Diffusion width:  $\sqrt{\langle k_\perp^2 \rangle} = \sqrt{\hat{q}_a t}$  and  $\sqrt{\langle r_\perp^2 \rangle} = t \sqrt{(\hat{q}_a t / 3)} / \omega$

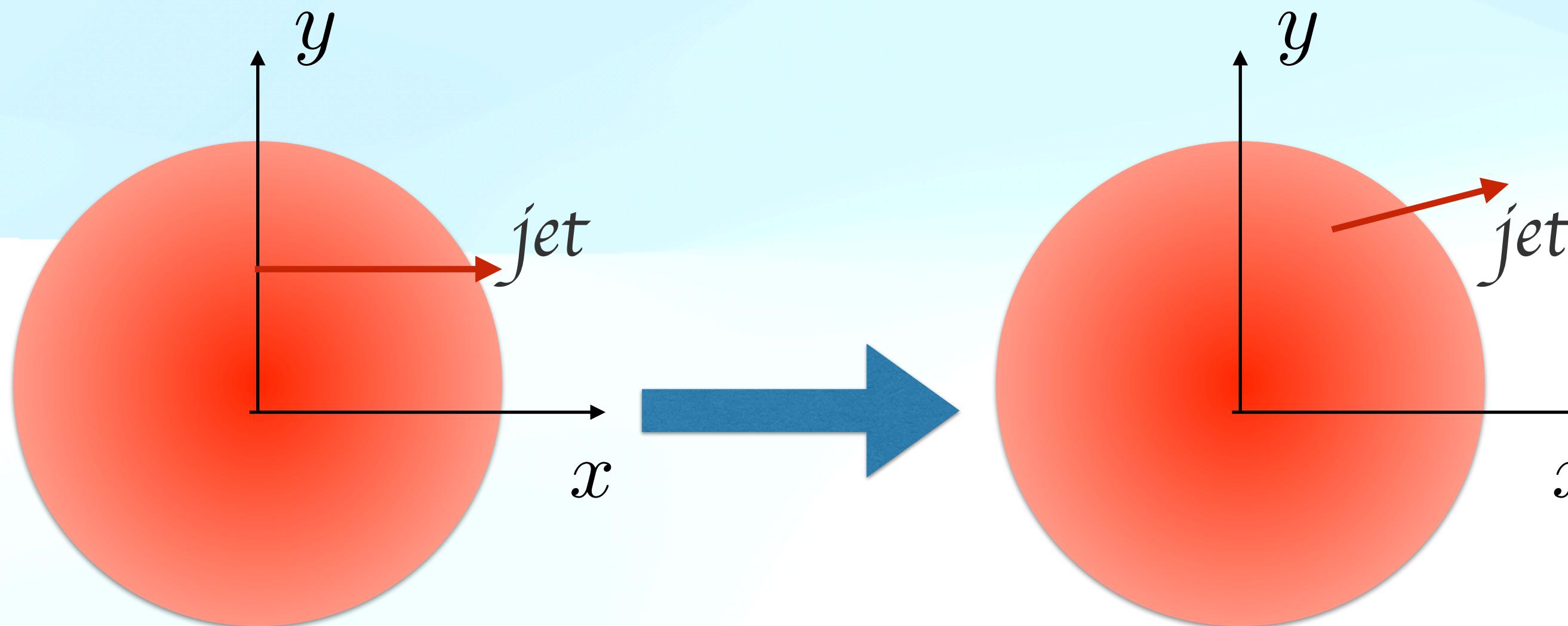
Drift:  $\vec{r}_\perp = (\vec{k}_\perp / 2\omega) t$

# Motivation

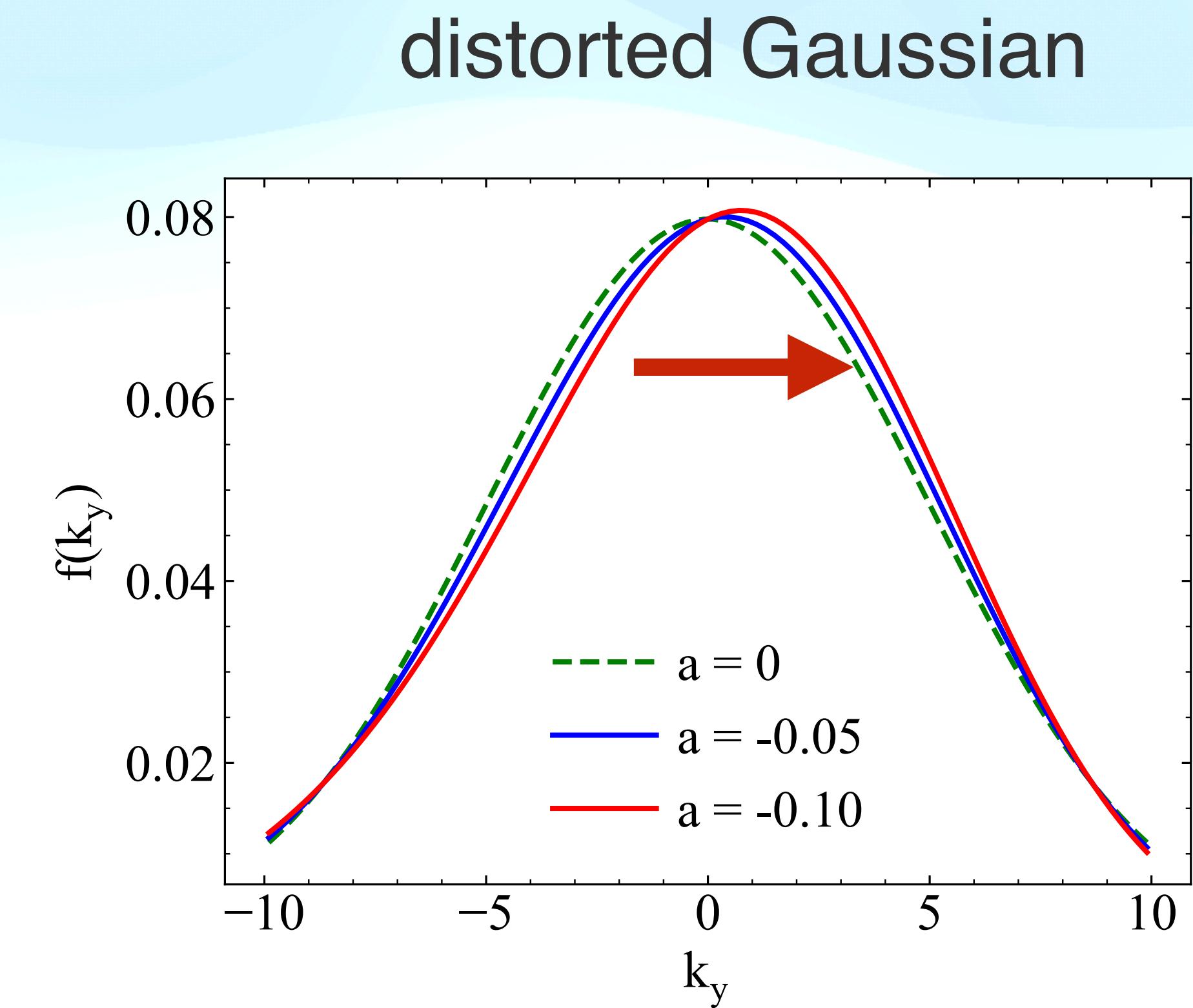


For  $\hat{q} = \hat{q}_0 + \vec{a} \cdot \vec{r}_\perp$        $f(\vec{k}_\perp, t) = [1 - \frac{t}{5q_0 w} \vec{a} \cdot \vec{k}_\perp (1 - \frac{1}{2\hat{q}_0 t} \vec{k}_\perp^2)] f_s(\vec{k}_\perp, t)$

If  $a$  is small enough, linear dependence



Jets tend to propagate to lower- $\hat{q}$  region!



# Motivation



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Other theoretical developments on gradient jet tomography:

Fu, Casalderrey-Solana, and Wang, PRD 107, 5, 054038 (2023)

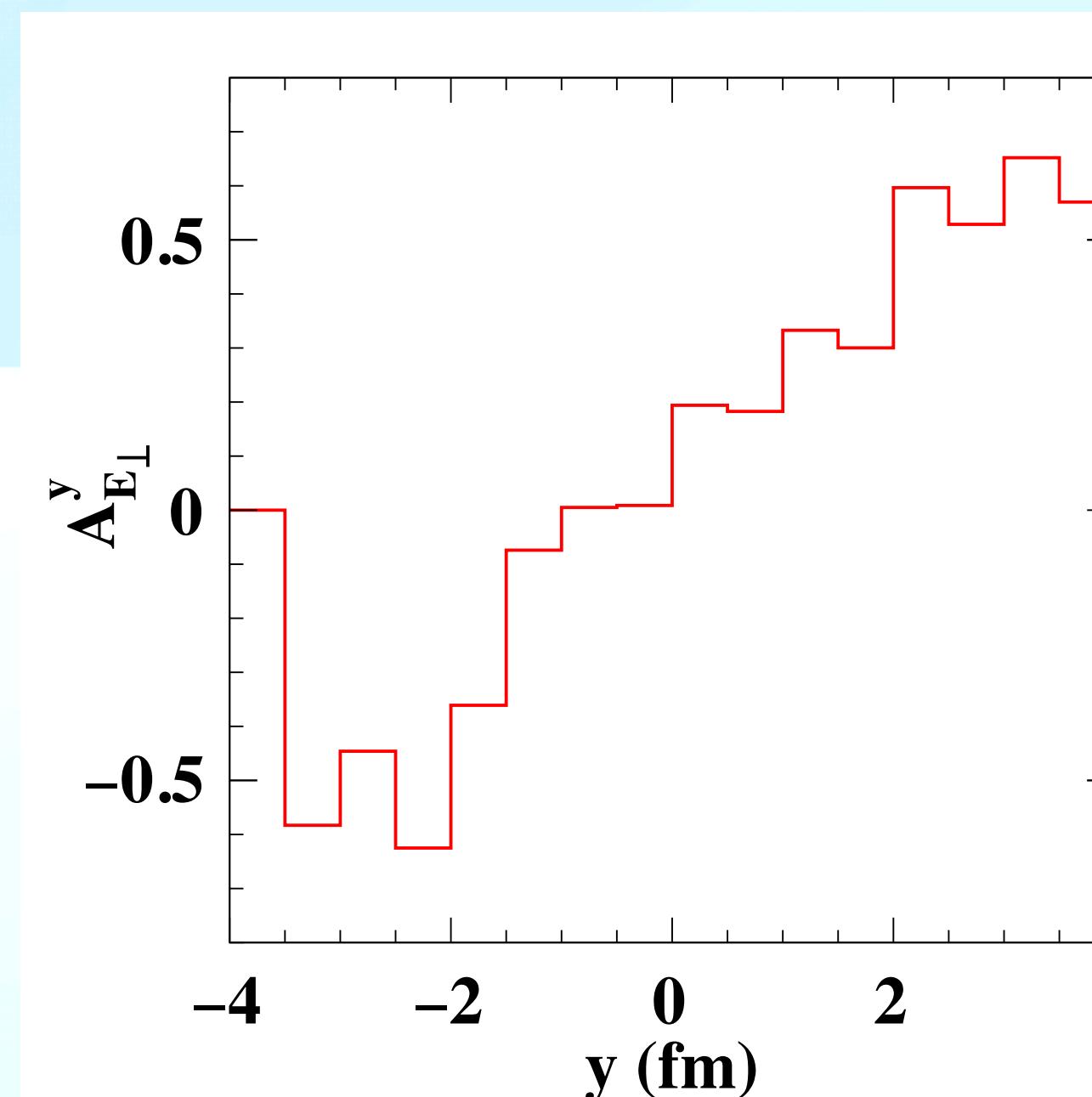
Barbara, Sadofyev, and Wang, PRD 107, 5, L051503 (2023)

# The transverse tomography: $\gamma + \text{jet}$



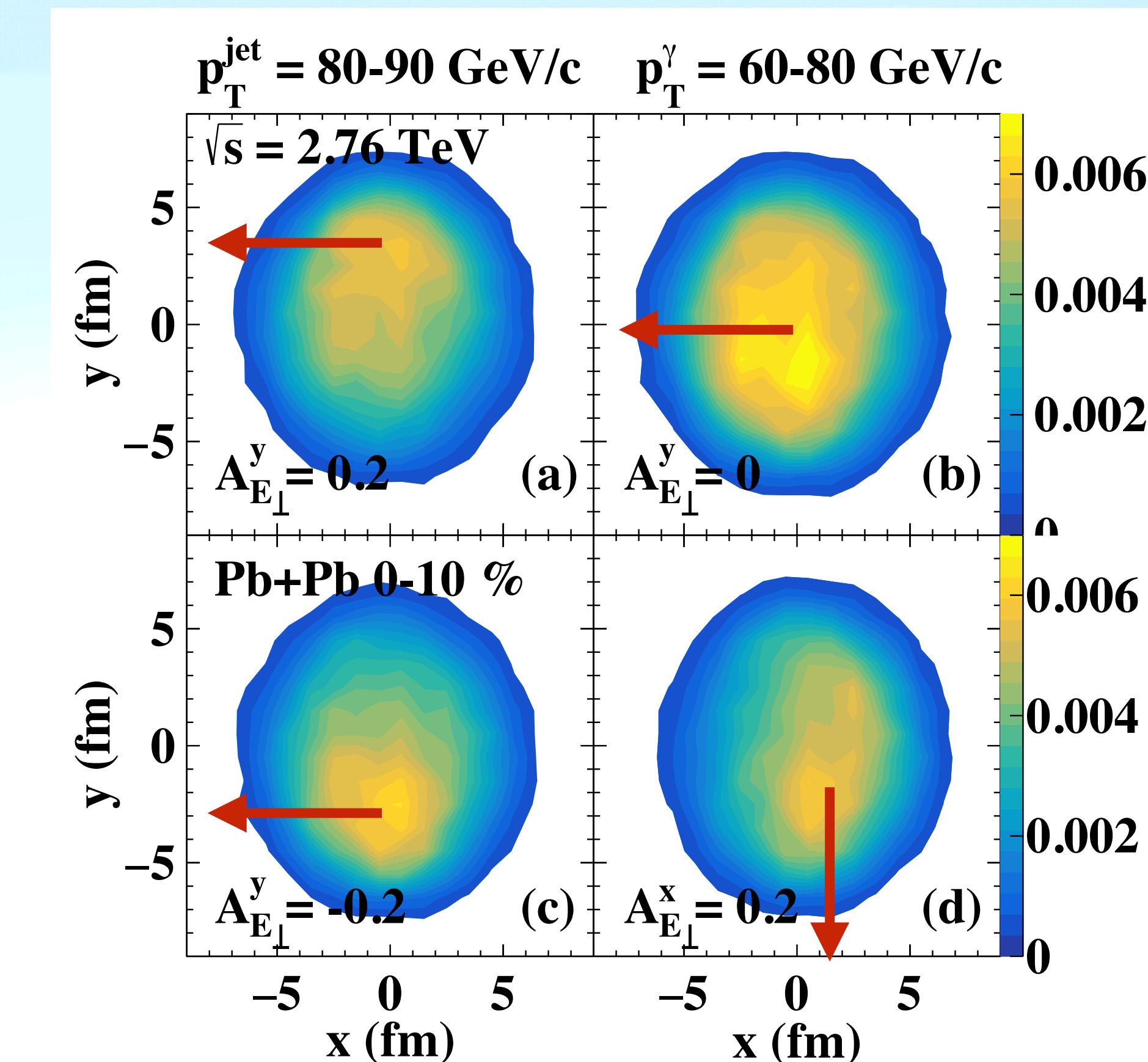
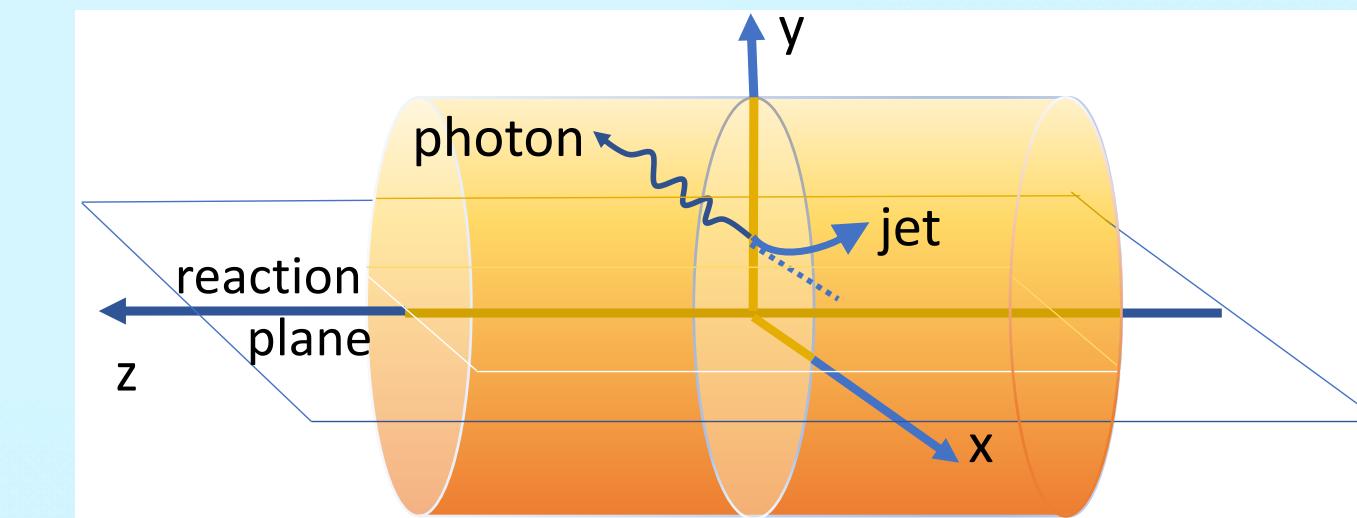
transverse energy asymmetry:

$$A_{E_\perp}^{\vec{n}} = \frac{\int d^3r d^3k f(\vec{k}, \vec{r}) \vec{k} \cdot \vec{n}}{\int d^3r d^3k f(\vec{k}, \vec{r}) |\vec{k} \cdot \vec{n}|}$$



LBT+CLVisc hydro  $p_T > 3$  GeV/c

He, Pang, and Wang. PRL 125 (2020) 122301



# The LBT Model



$$p_a \cdot \partial f_a = \int \sum_{bcd} \prod_{i=b,c,d} \frac{d^3 p_i}{2E_i(2\pi)^3} (f_c f_d - f_a f_b) |\mathcal{M}_{ab \rightarrow cd}|^2 \times \frac{\gamma_b}{2} S_2(\hat{s}, \hat{t}, \hat{u}) (2\pi)^4 \delta^4(p_a + p_b - p_c - p_d) + \text{inelastic}$$

$$S_2(\hat{s}, \hat{t}, \hat{u}) = \theta(\hat{s} \geq 2\mu_D^2) \theta(-\hat{s} + \mu_D^2 \leq \hat{t} \leq -\mu_D^2), \quad \mu_D^2 = \frac{3}{2} g^2 T^2$$

Elastitic:

$$\Gamma_a^{\text{el}} \equiv \frac{p \cdot u}{p_0} \sum_{bcd} \rho_b(x) \sigma_{ab \rightarrow cd}$$

LO perturbative QCD

*J. Auvinen et al, Phys.Rev. C 82(2010) 024906*

Inelasitic:

$$\frac{d\Gamma_a^{\text{inel}}}{dz dk_\perp^2} = \frac{6\alpha_s P_a(z) k_\perp^4}{\pi(k_\perp^2 + z^2 m^2)^4} \frac{p \cdot u}{p_0} \hat{q}_a(x) \sin^2 \frac{\tau - \tau_i}{2\tau_f}$$

High twist approach

*Guo and Wang, PRL 85 (2000) 3591*

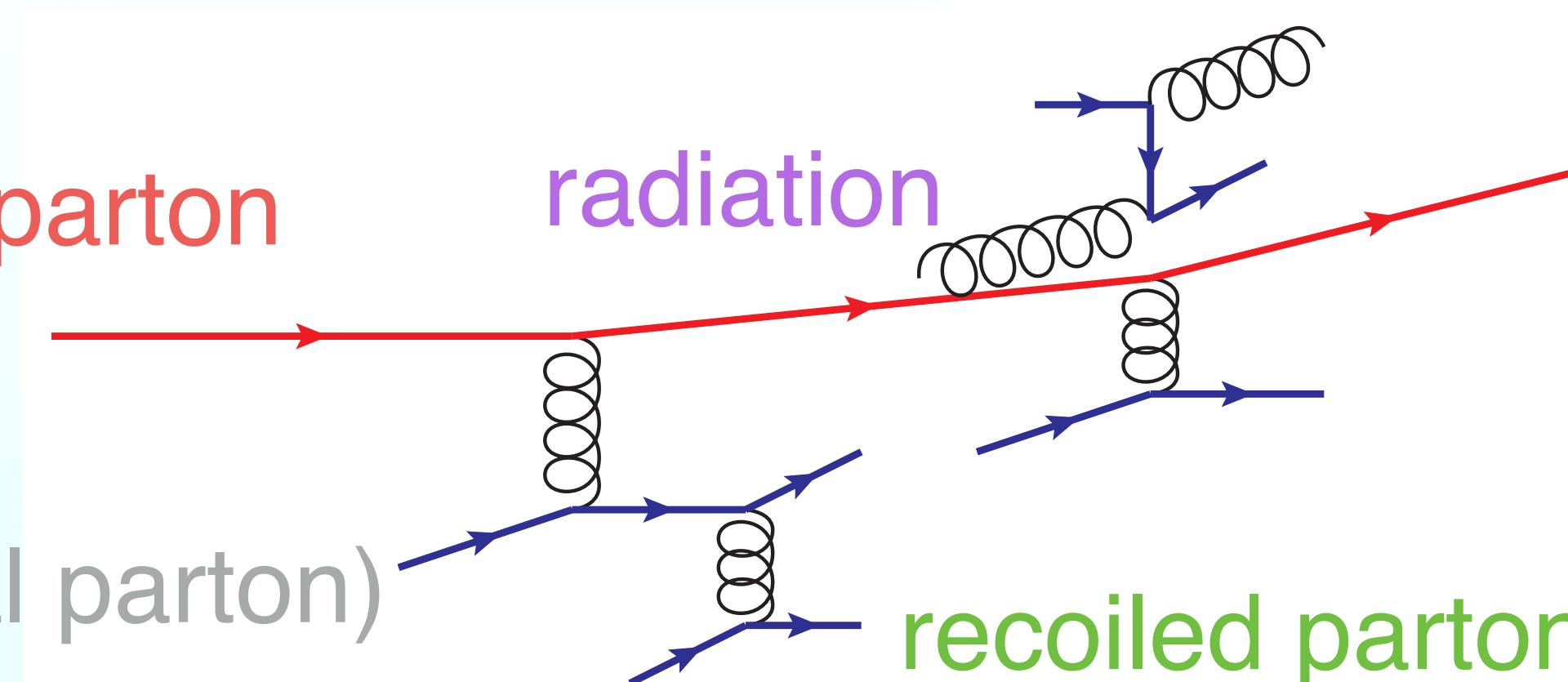
*Zhang, Wang and Wang, PRL 93 (2004) 072301*

shower parton

radiation

(thermal parton)  
back reaction

recoiled parton



Model features:

- ◆ re-scattering
- ◆ back reaction
- ◆ Linear approximation, and valid for  $\delta f \ll f$

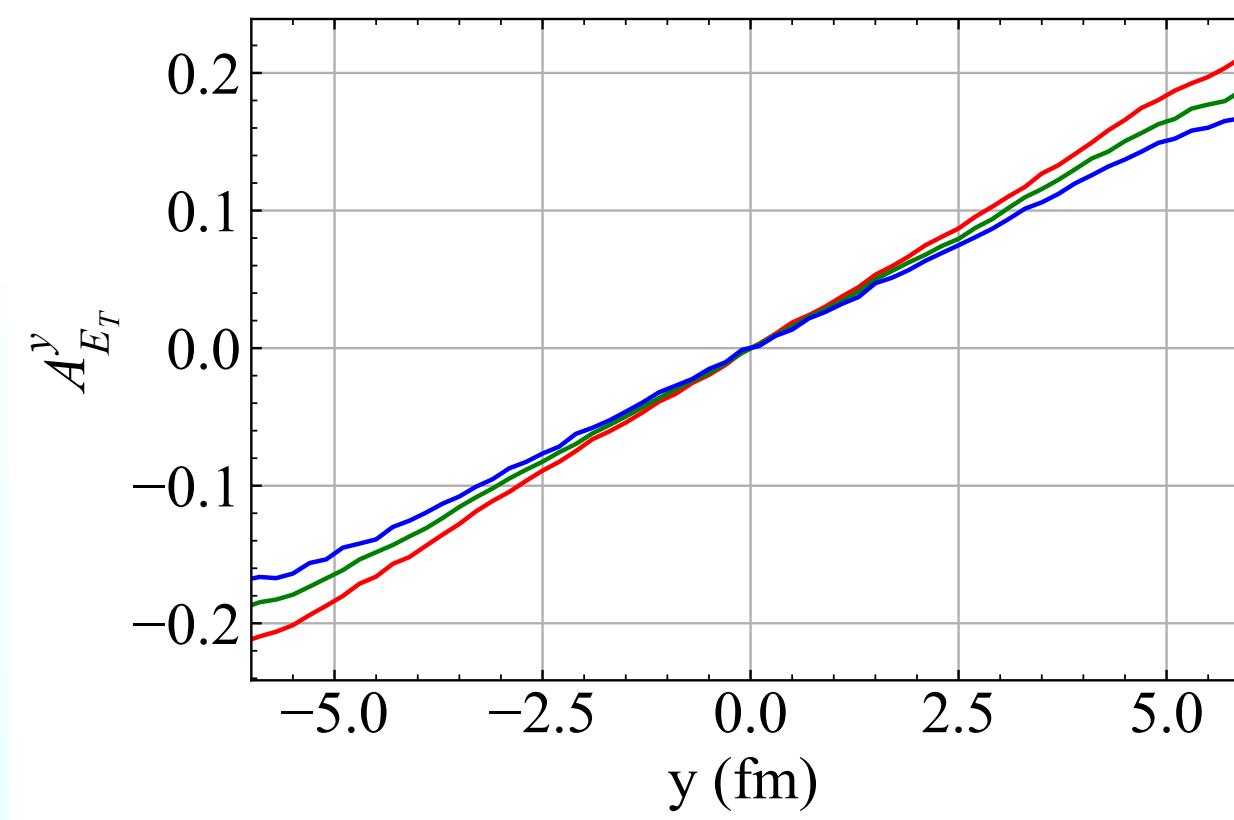
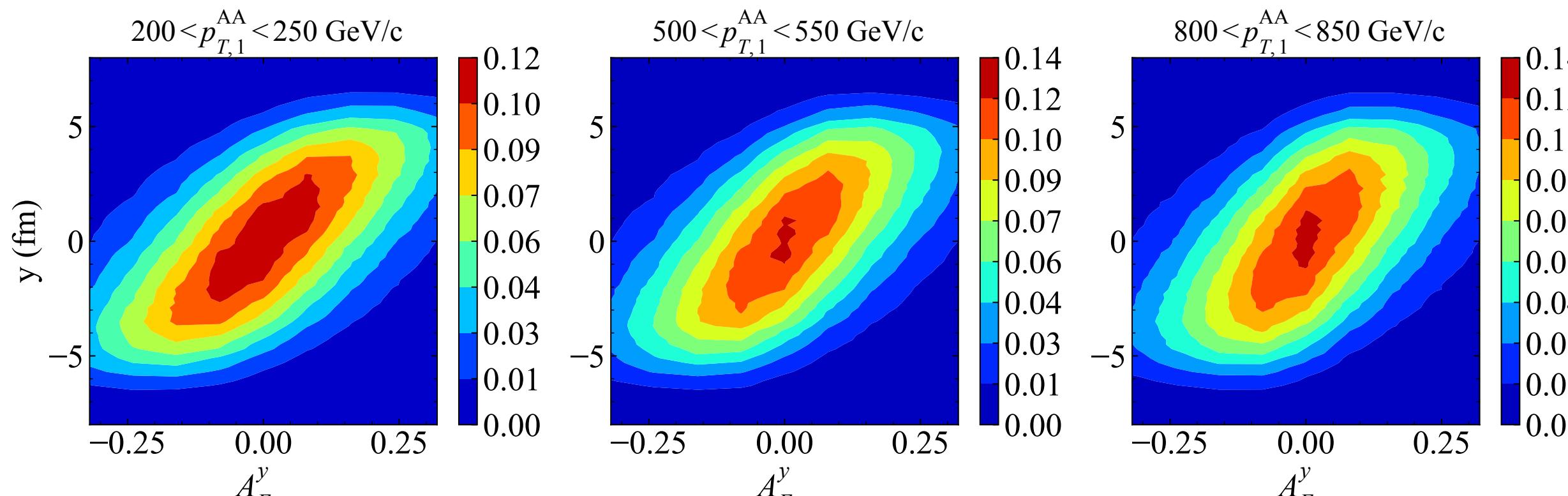


# *How about the **transverse tomography** in dijet production?*

# Dijet transverse tomography

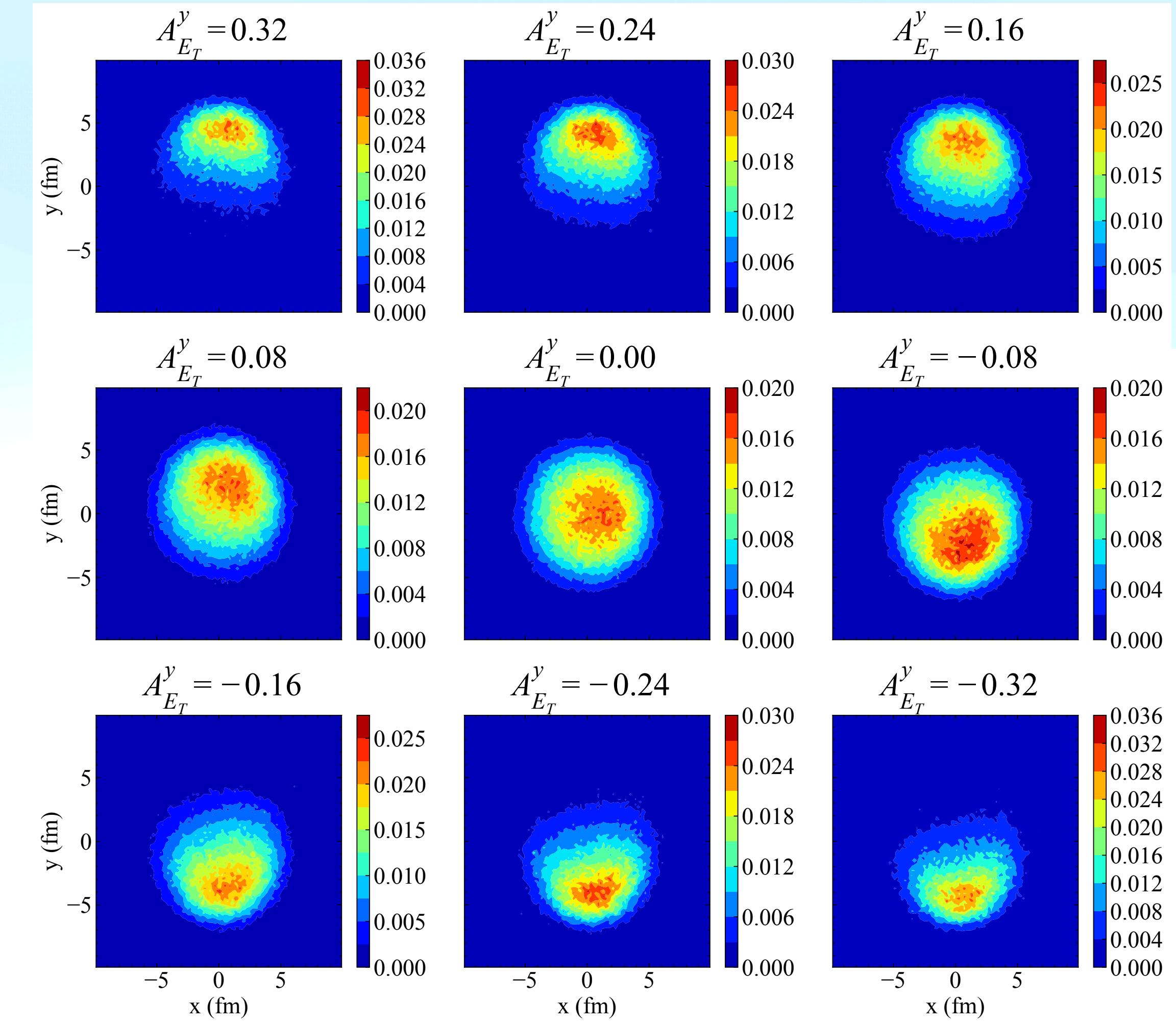


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LBT+CLVisc hydro  $p_T > 3$  GeV/c

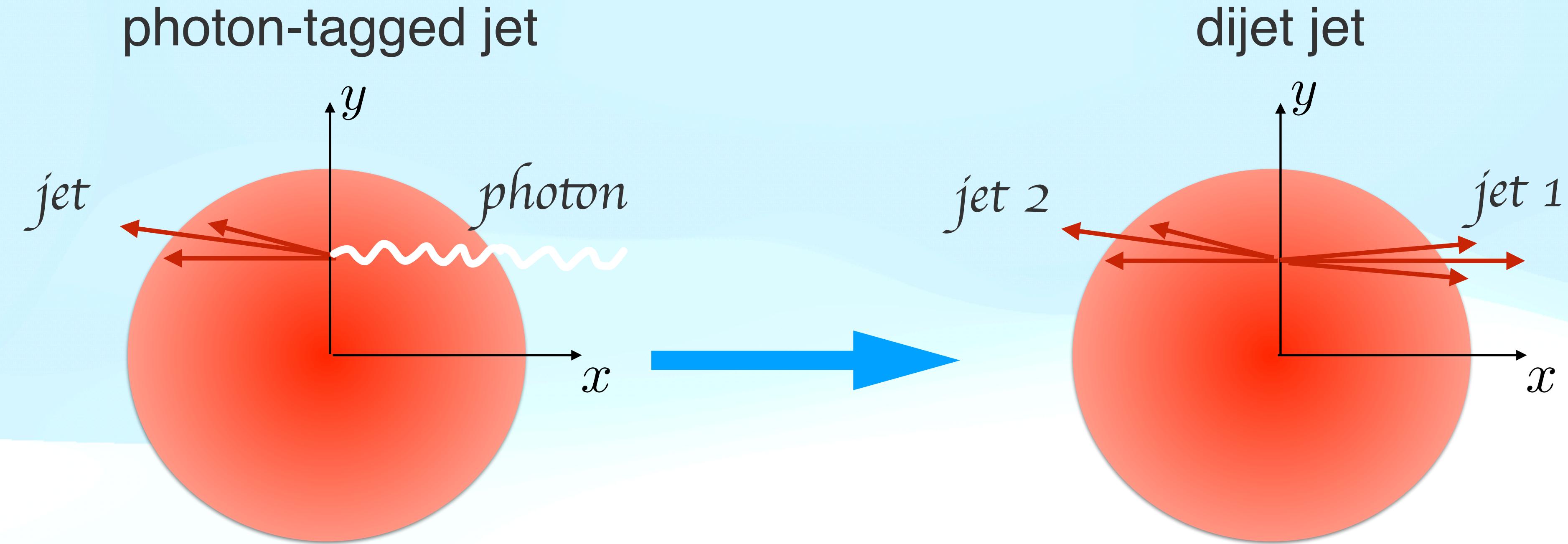
$500 < p_{T,1}^{\text{AA}} < 550 \text{ GeV}/c$





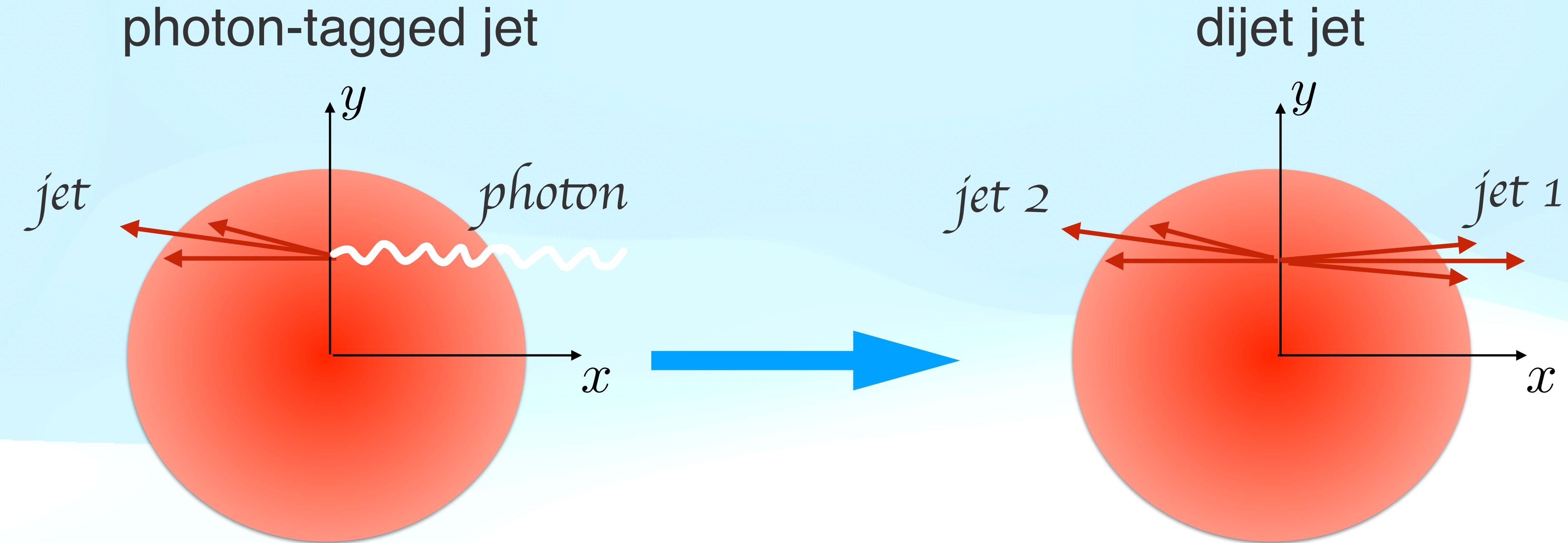
# *What's the **longitudinal** tomography in dijet production?*

# Dijet tomography: trigger bias



- The trigger propagates along  $x$  direction initially
- photon-tagged jet: photon as the trigger
- dijet: leading jet as the trigger

# Dijet tomography: trigger bias



- photon-tagged jet is free of bias, emitted mainly from the center.
- dijet is biased, the leading jet also has energy loss, emitted mainly from the right region.

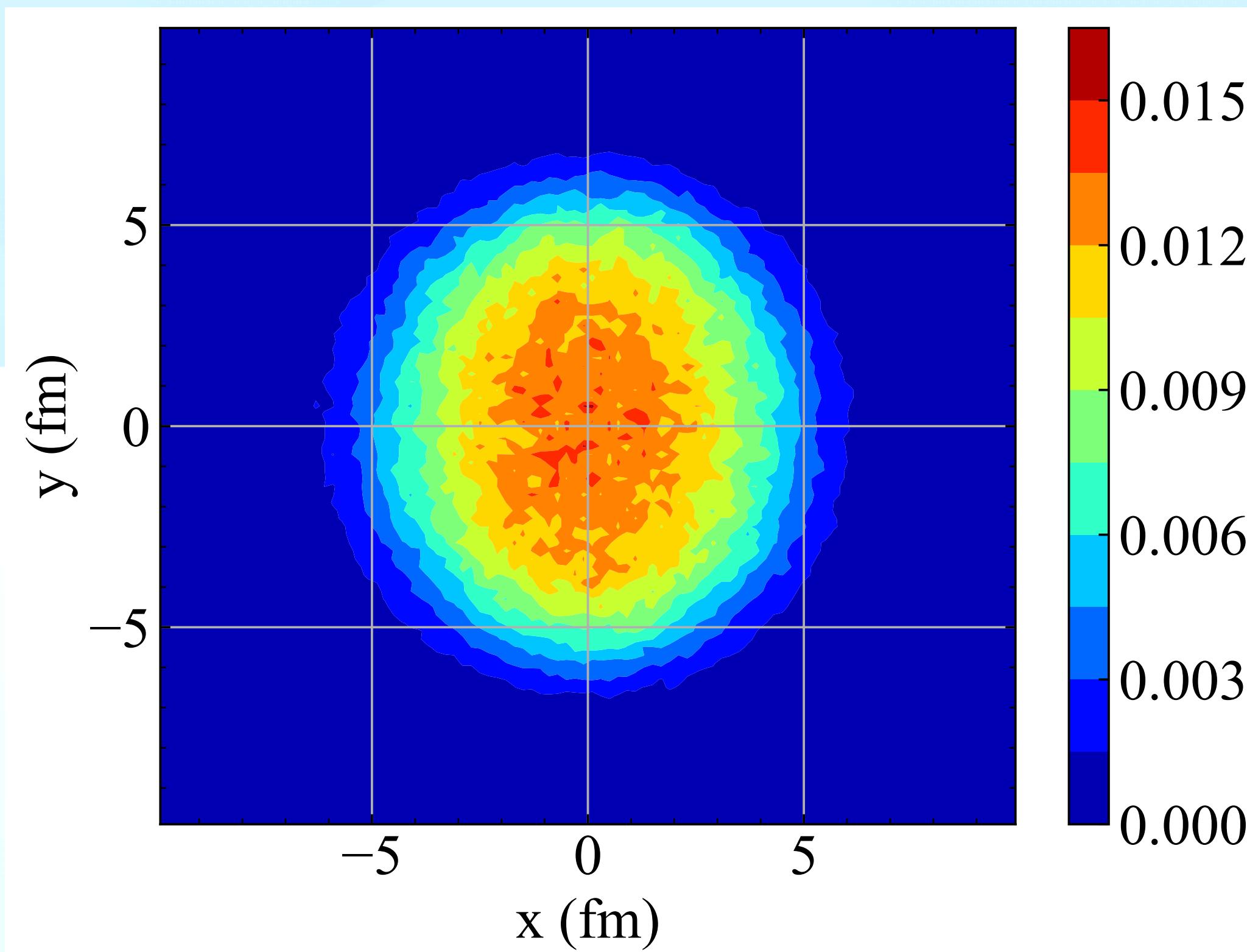
# Dijet tomography: trigger bias



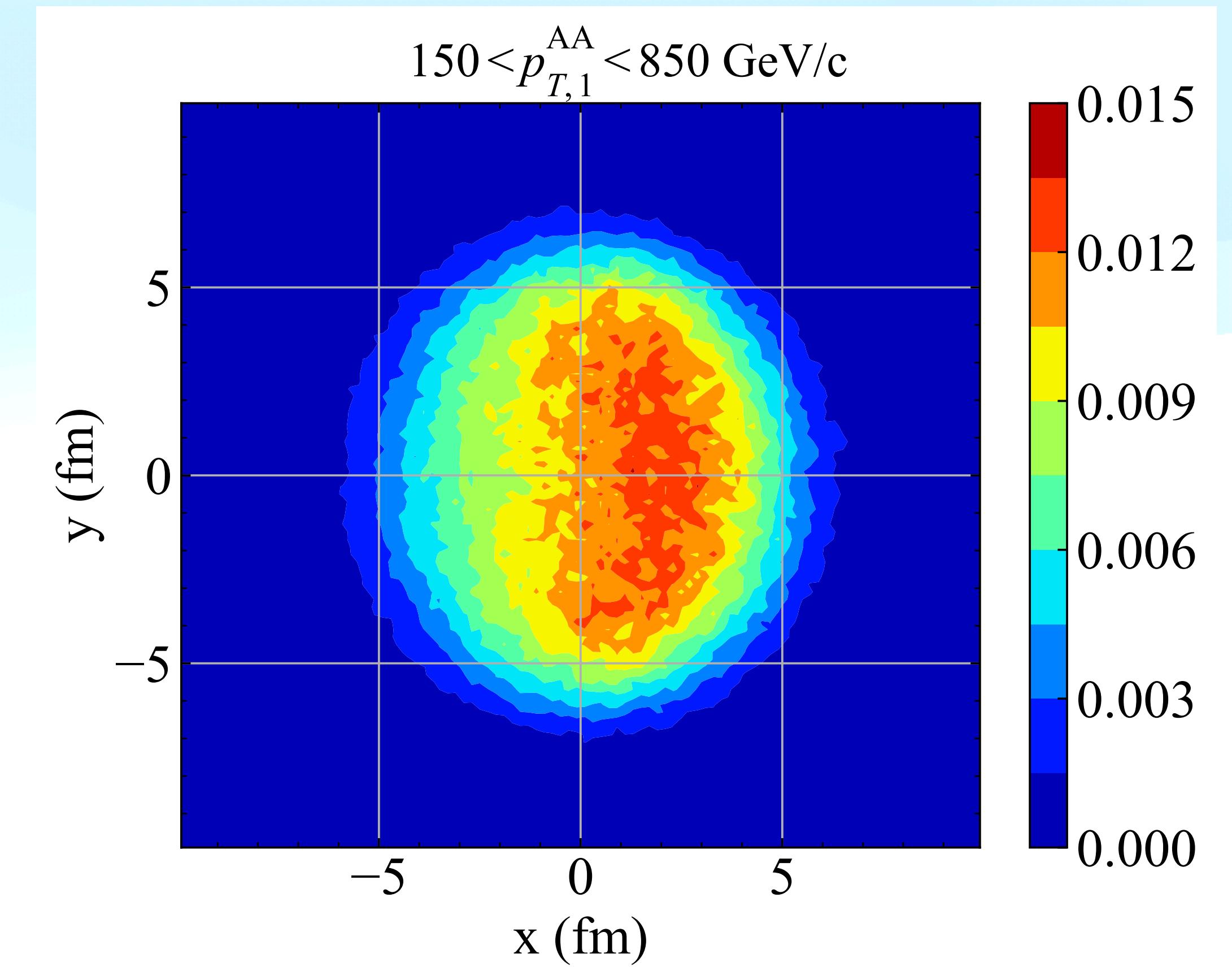
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Pb+Pb 0-10% 5.02 TeV

Initial production without jet quenching



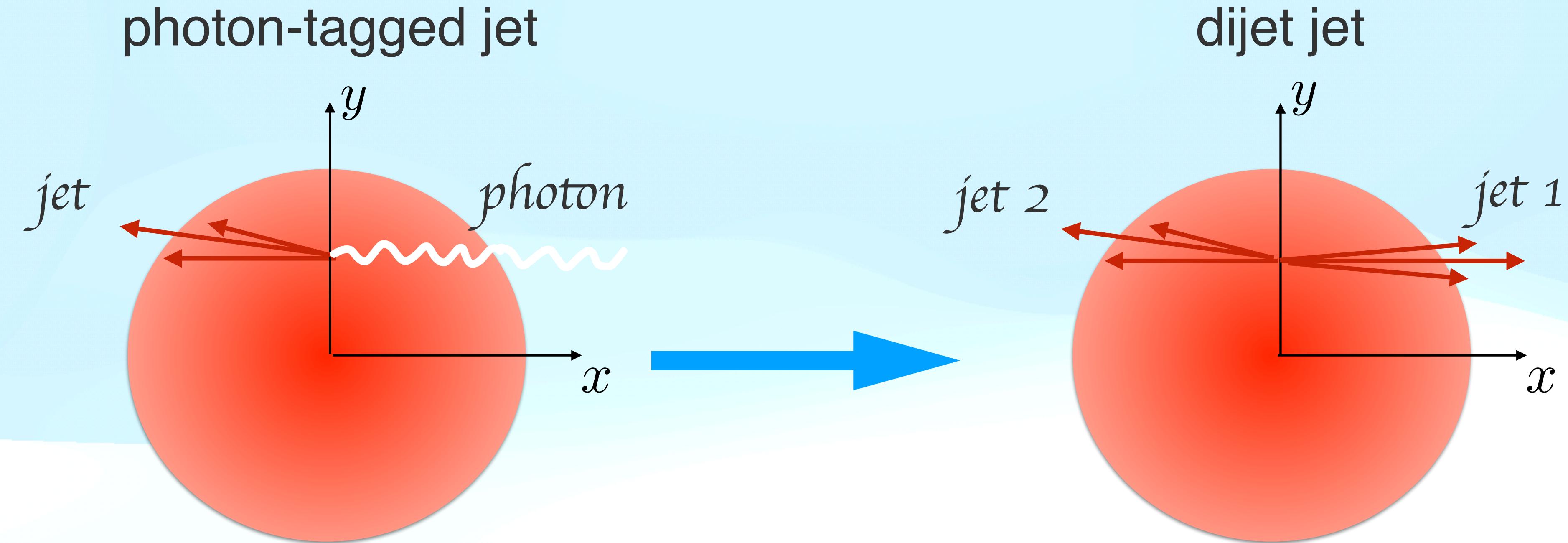
with jet quenching



# Dijet tomography: trigger bias



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The leading jet initially from pp collisions could become the final subleading jet in AA collisions due to energy loss, “**id exchange**”



# *How much does the trigger bias affect the dijet tomography?*

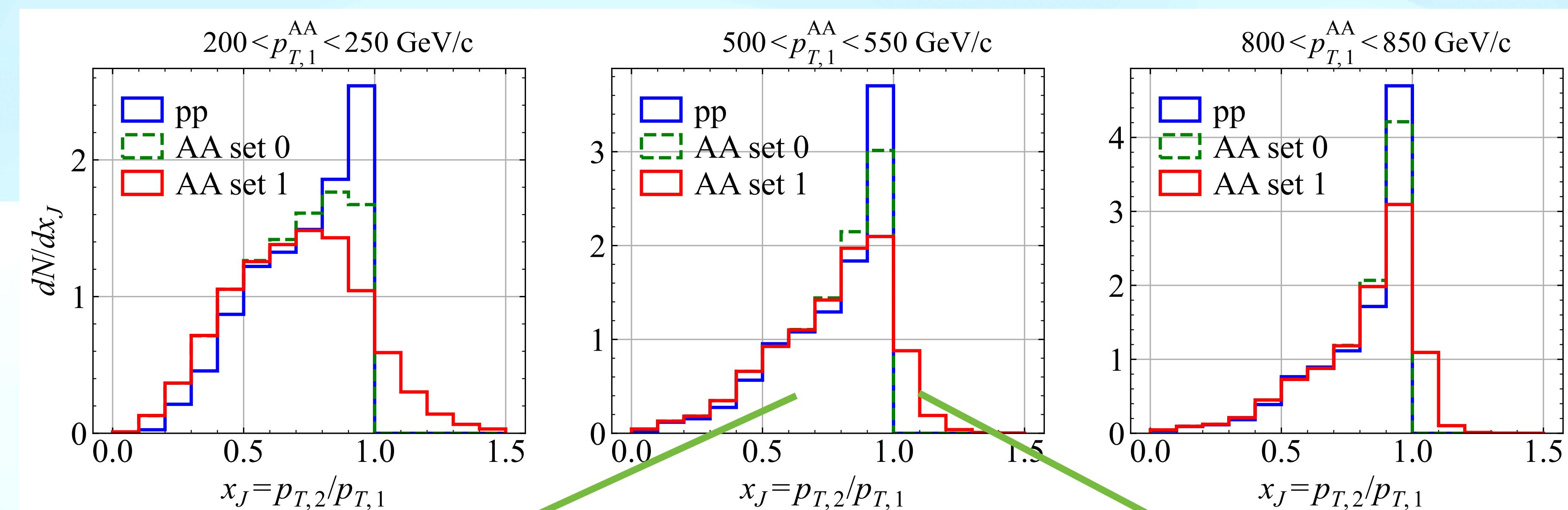
# Dijet tomography: trigger bias



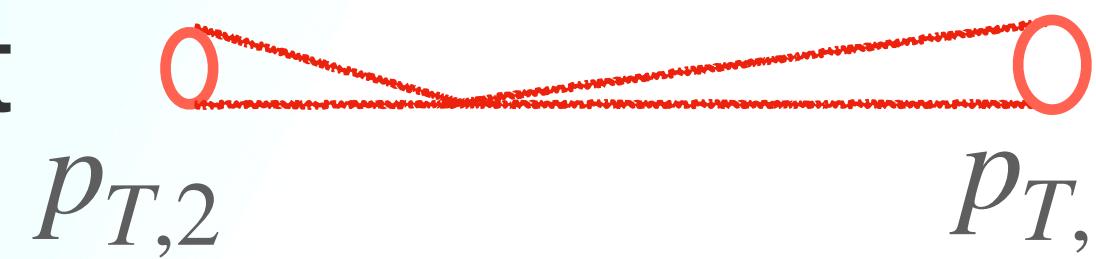
pp:  $p_{T,1}$  is leading,  $p_{T,2}$  is subleading

AA set 0:  $p_{T,1}$  is leading,  $p_{T,2}$  is subleading; potential id exchange

AA set 1:  $p_{T,1}$  is leading from pp,  $p_{T,2}$  is subleading from pp; no id exchange



id kept



id exchanged



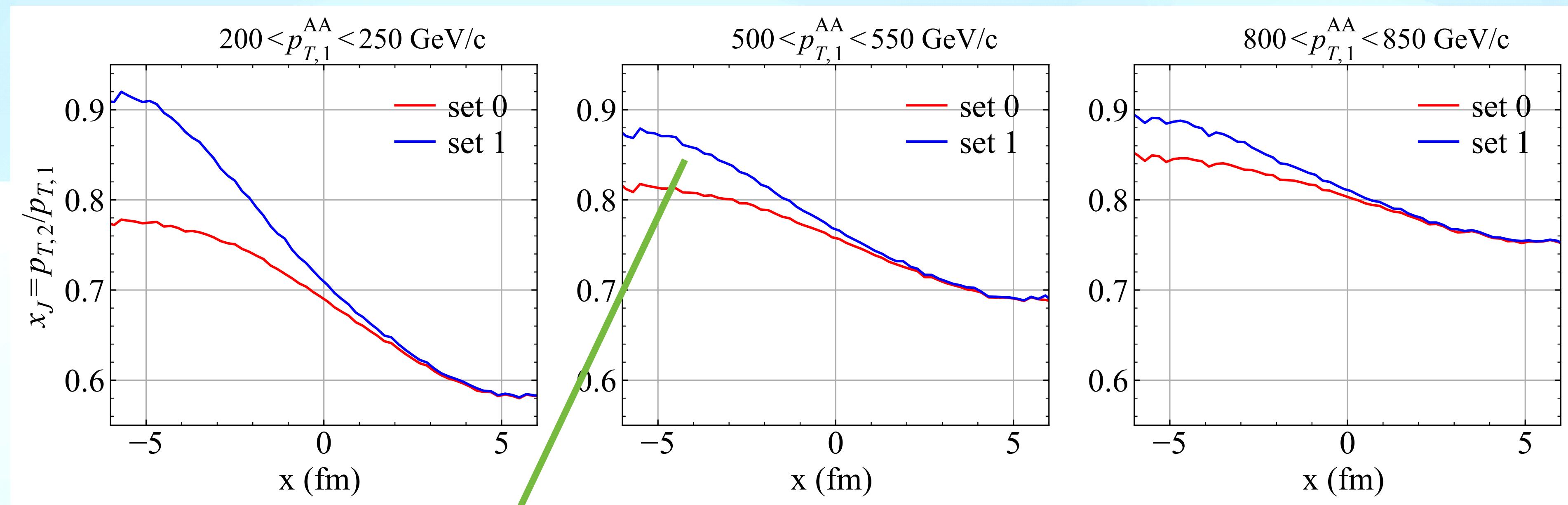
# Dijet tomography: trigger bias



pp:  $p_{T,1}$  is leading,  $p_{T,2}$  is subleading

AA set 0:  $p_{T,1}$  is leading,  $p_{T,2}$  is subleading; potential id exchange

AA set 1:  $p_{T,1}$  is leading from pp,  $p_{T,2}$  is subleading from pp; no id exchange



More energy loss for  $p_{T,1}$  at this initial production region leads to the id exchange

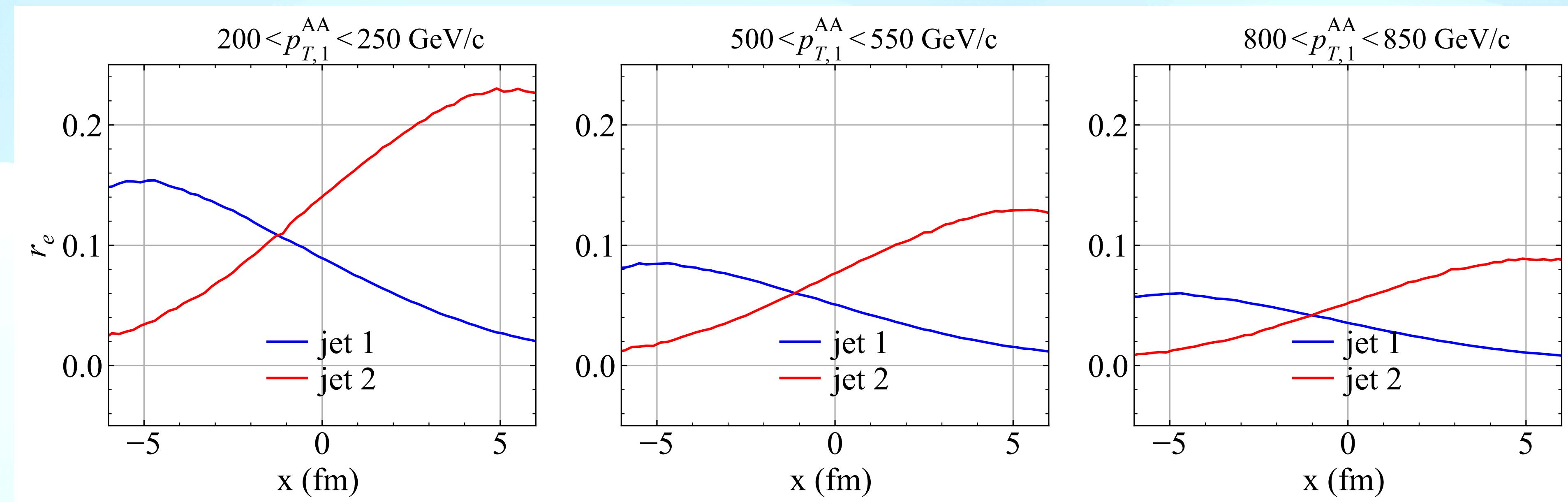
# Dijet tomography: energy loss ratio



Track the leading and subleading jet from pp

leading jet energy loss ratio:  $r_{e,1} = (p_{T,1}^{\text{pp}} - p_{T,1}^{\text{AA}})/p_{T,1}^{\text{pp}}$

subleading jet energy loss ratio:  $r_{e,2} = (p_{T,2}^{\text{pp}} - p_{T,2}^{\text{AA}})/p_{T,2}^{\text{pp}}$

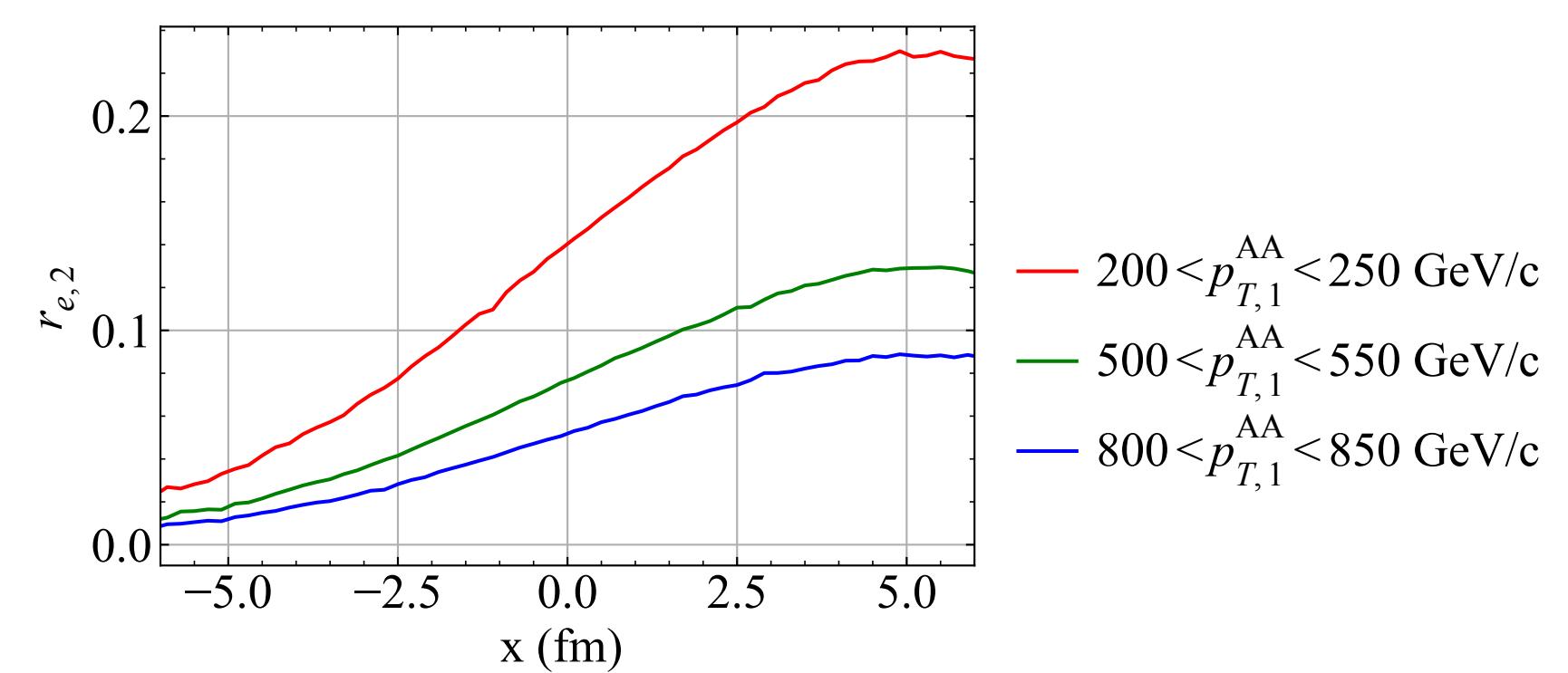
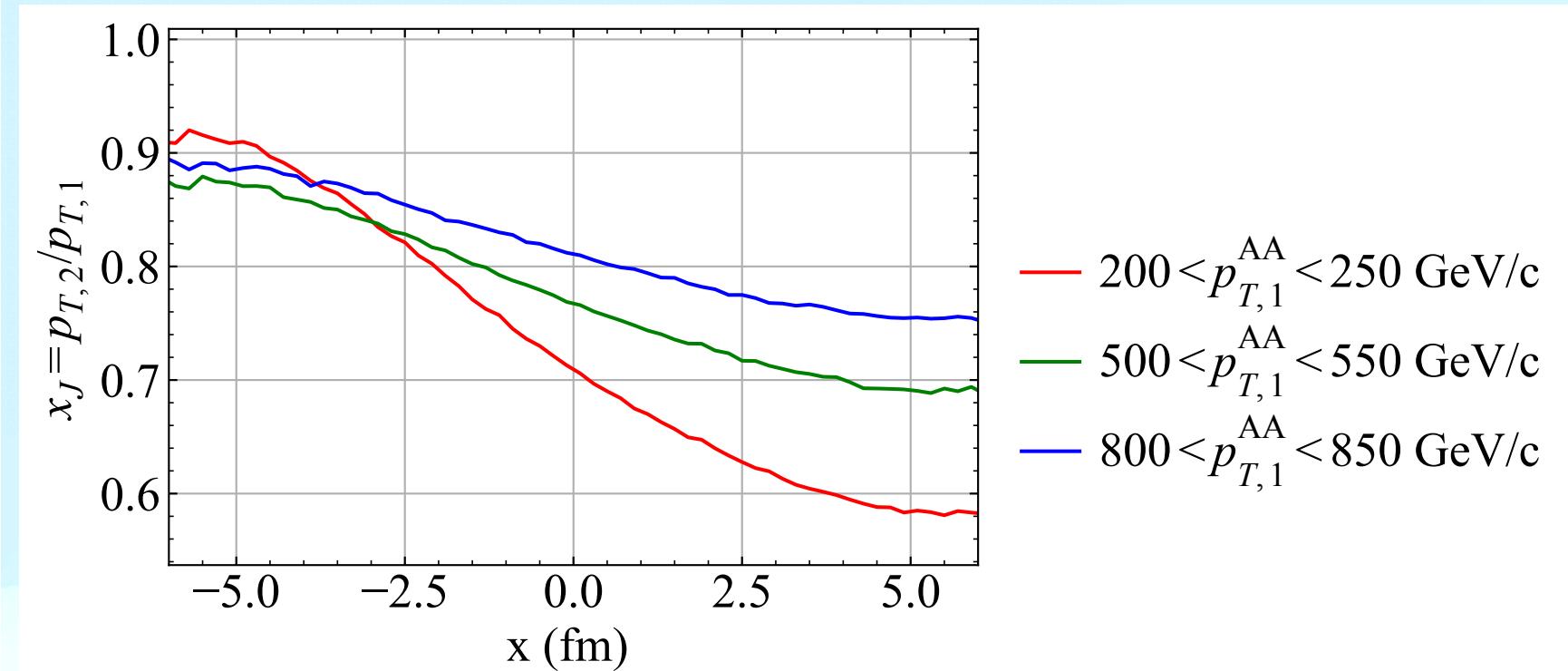
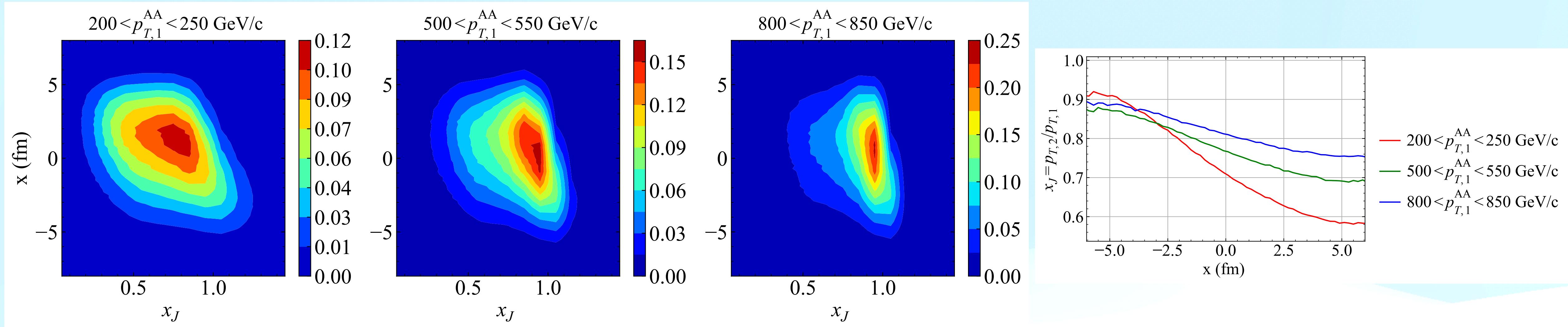


Despite of the bias,  $x_J$  and  $r_e$  can be good quantities to localize jet production regions

# Dijet tomography: localize x



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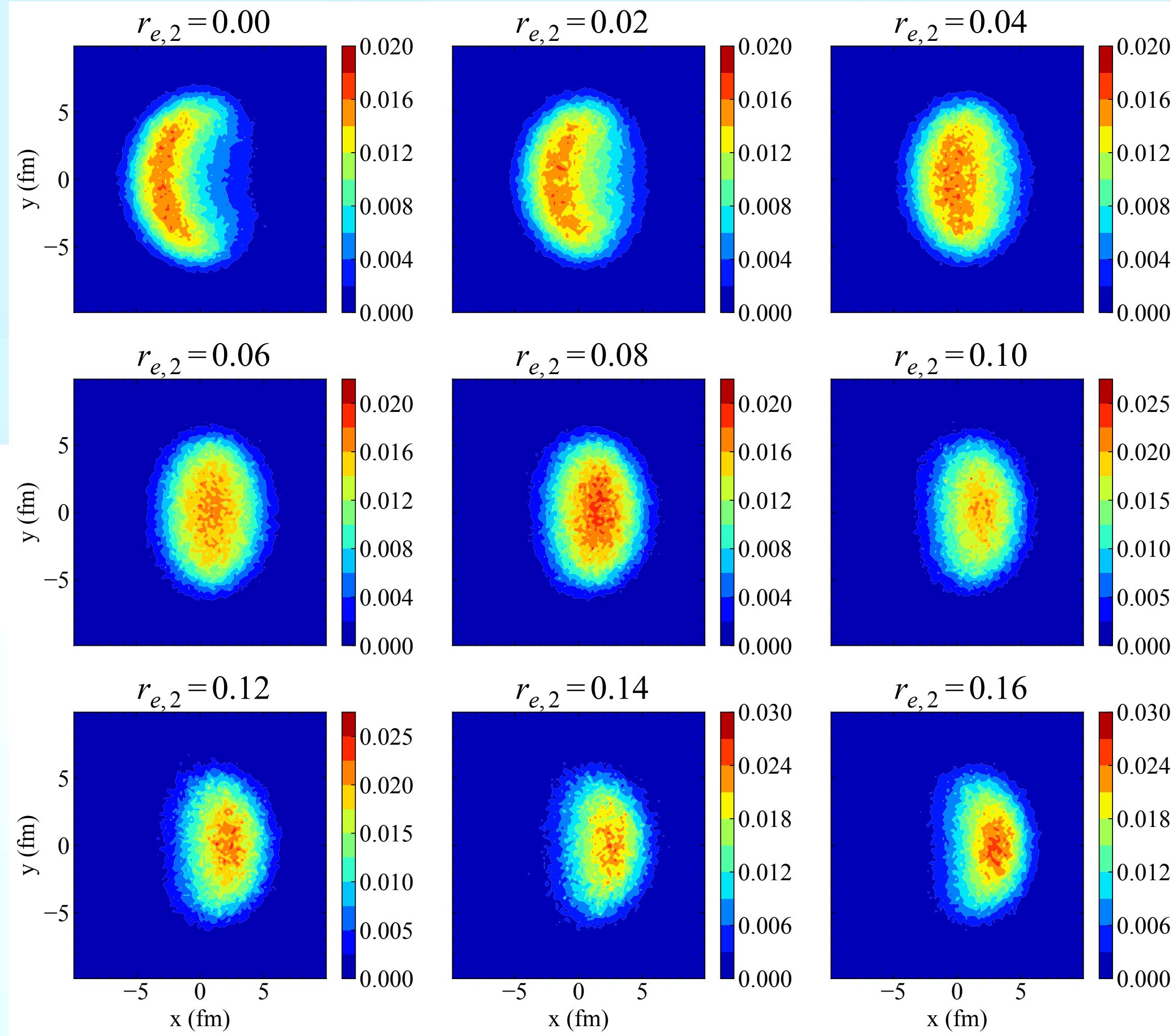


# Dijet tomography: localize x and y

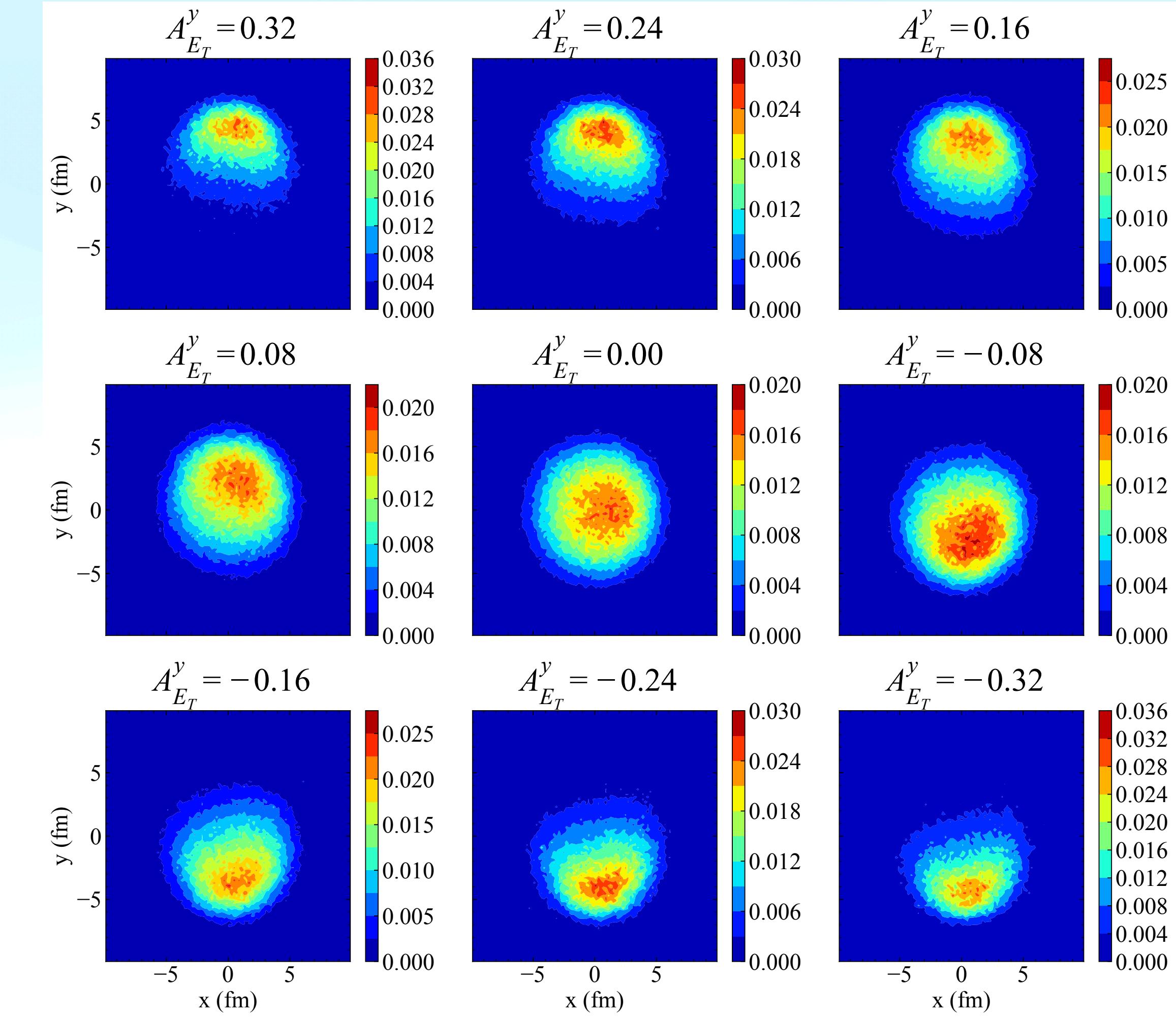


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$500 < p_{T,1}^{\text{AA}} < 550 \text{ GeV/c}$



$500 < p_{T,1}^{\text{AA}} < 550 \text{ GeV/c}$

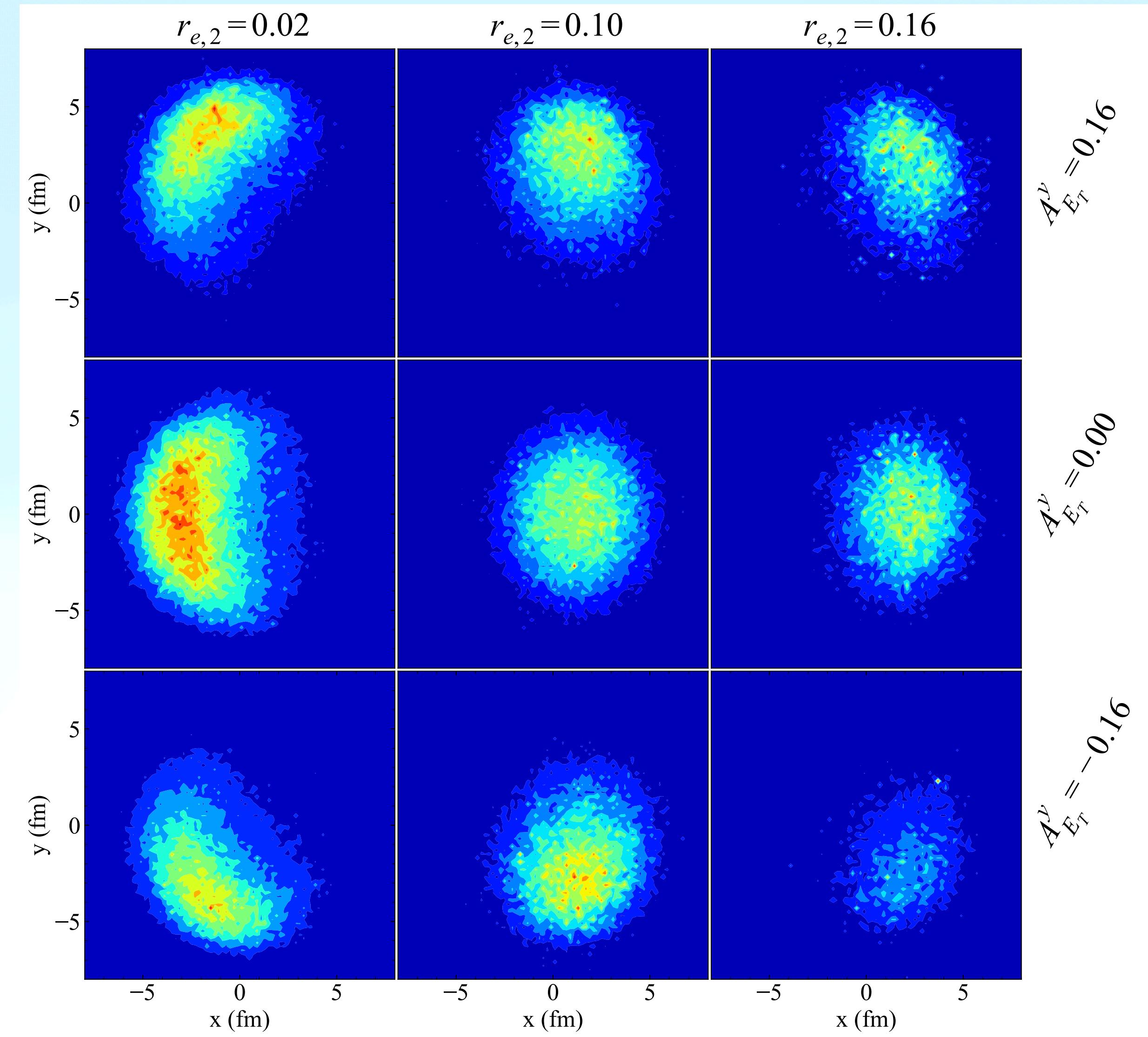


# Dijet tomography: scanning



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$500 < p_{T,1}^{\text{AA}} < 550 \text{ GeV}/c$



# Summary



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- The longitudinal and transverse jet tomography are studied simultaneously in dijet events.
- They are shown to strongly correlate with the initial jet production positions.
- The effect of dijet bias is also investigated.
- Jet tomography can be used to study jet-medium interactions in detail, especially at different production regions in the medium.

*Thanks for your attention!*