Hard Probes, 2016

Probing Transverse Momentum Broadening via Dihadron & Hadron-jet Angular Correlations

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arXiv:1607.01932

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- Extract $\hat{q}$ from dihadron & hadron-jet correlations
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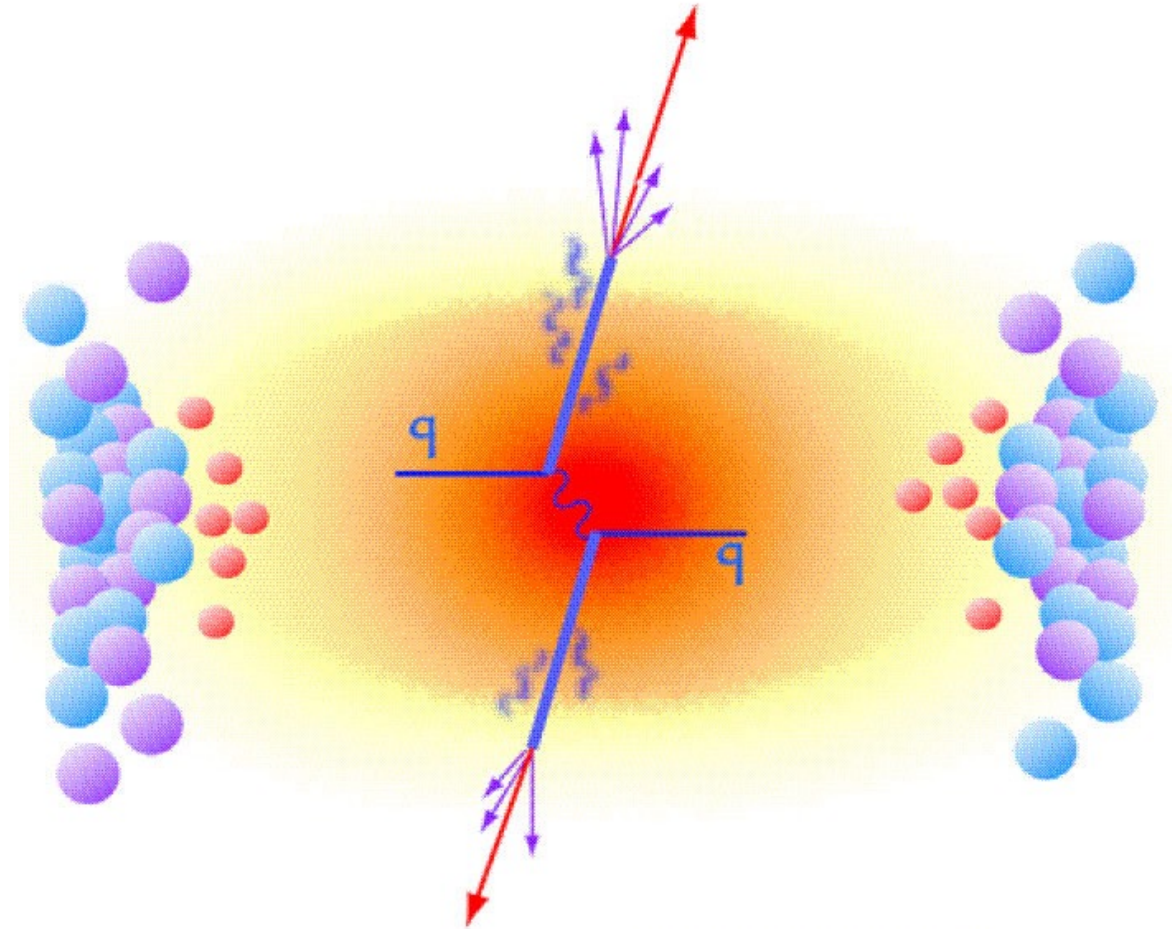
Introduction: Jet Quenching

Jet-medium interaction

- ☑ $k_\perp$ broadening
- ☑ Energy loss

Two sides of the same coin.



BDMPS approach

Jet transport parameter $\hat{q} = \frac{\Delta k_\perp^2}{L}$

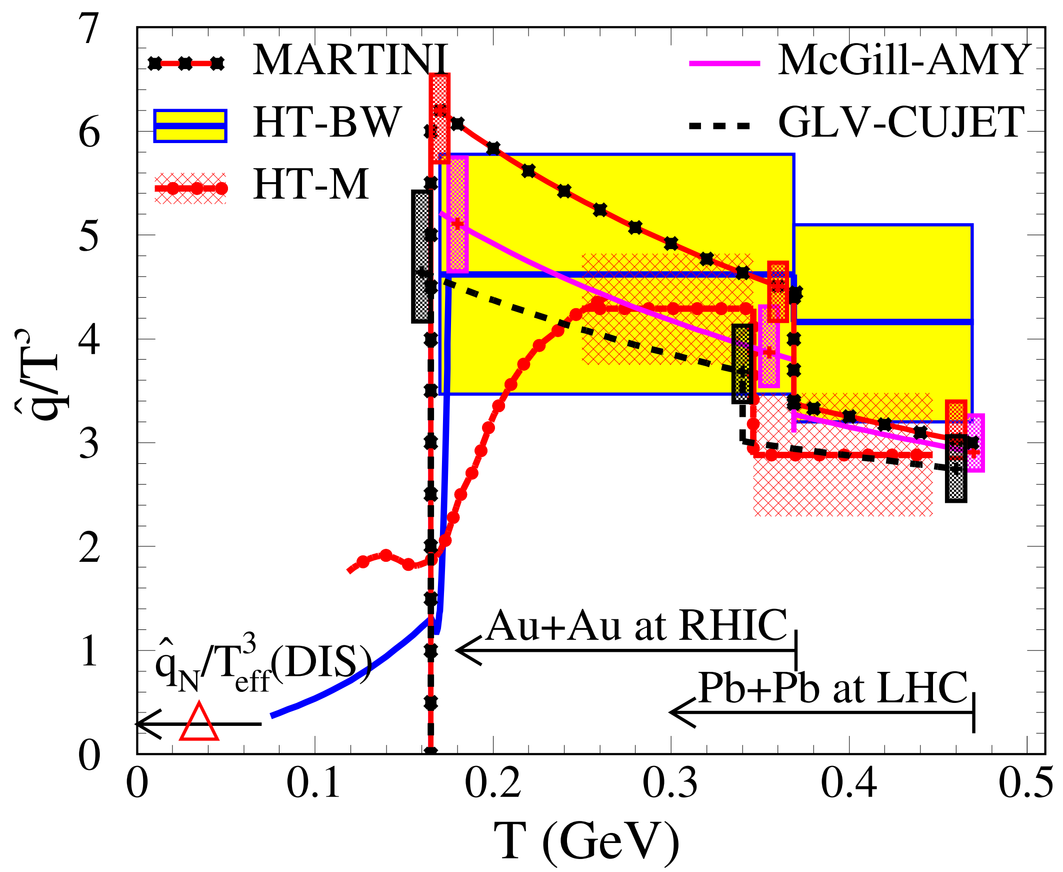
$$-\frac{dE}{dx} = \frac{\alpha_s N_c}{4}\hat{q}L$$

☑ $\hat{q}$ reflects the density of QGP

Baier, Dokshitzer, Mueller, Peigne, and Schiff
NPB 483 (1997), 484 (1997), 531(1998).

Introduction

Energy loss - Single hadron R_{AA}



$$\hat{q} \approx \begin{cases} 1.2 \pm 0.3 \\ 1.9 \pm 0.7 \end{cases} \text{GeV}^2/\text{fm at} \begin{array}{l} T{=}370 \text{ MeV}, \\ T{=}470 \text{ MeV}, \end{array}$$

for a 10 GeV quark JET

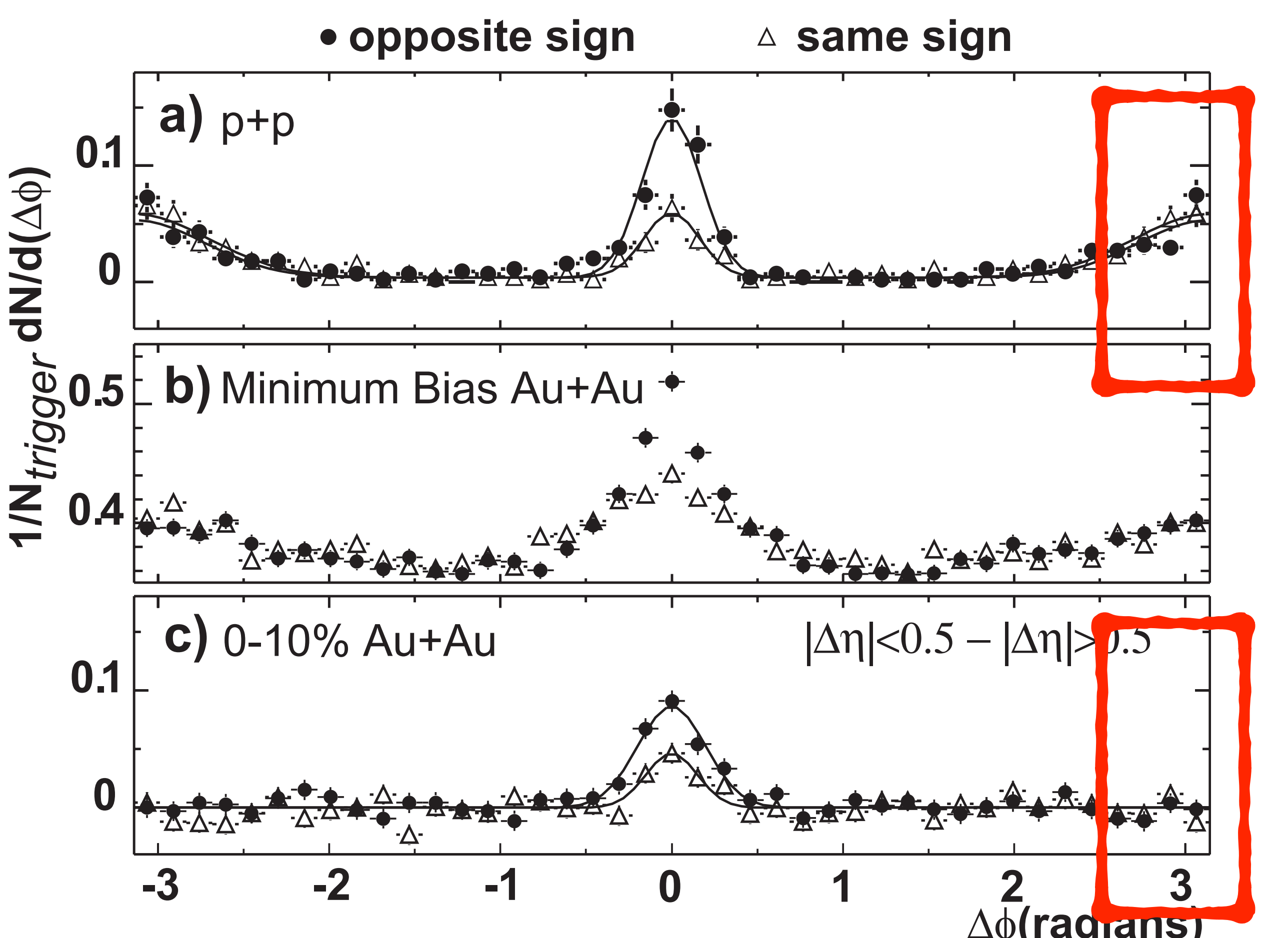
Jet Collaboration. PRC 90, 014909, (2014)

Angular decorrelation - New and complimentary method

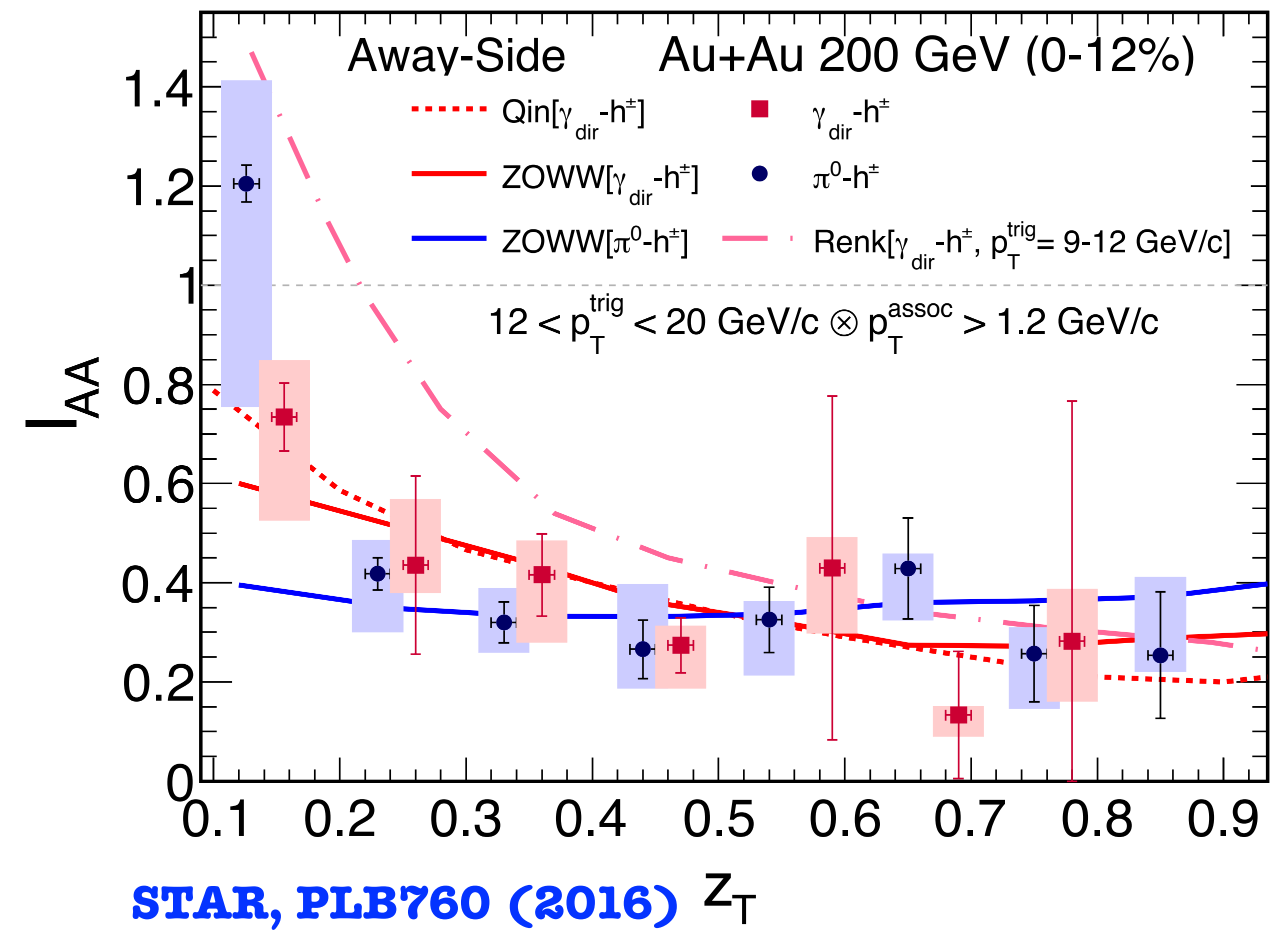
☑ Extract $\hat{q}$ via angular decorrelation in the back-to-back region.

Dihadron Angular decorrelation @ RHIC

back-to-back region



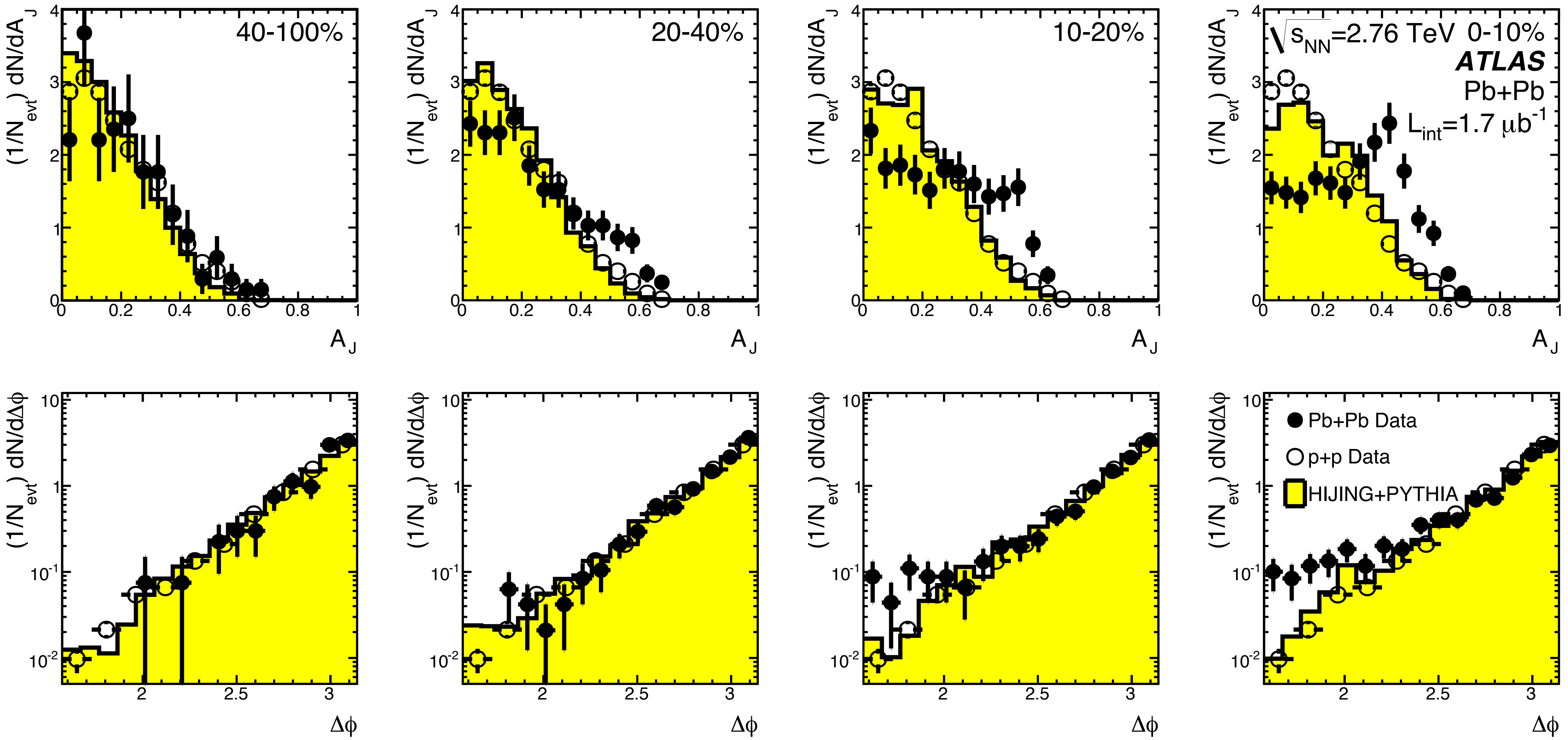
STAR, PRL 90, (2003)



STAR, PLB760 (2016)

- ☑ Yield suppression
- ☑ Angular decorrelation: quantitative calculation is lacking

ATLAS [PRL 105, (2010)] & CMS [PRC 84, (2011)]



$$A_J \equiv \frac{p_T^1 - p_T^2}{p_T^1 + p_T^2}$$

peripheral → central

- ☑ Energy imbalance increases: Energy Loss
- ☑ No clear sign of angular decorrelation

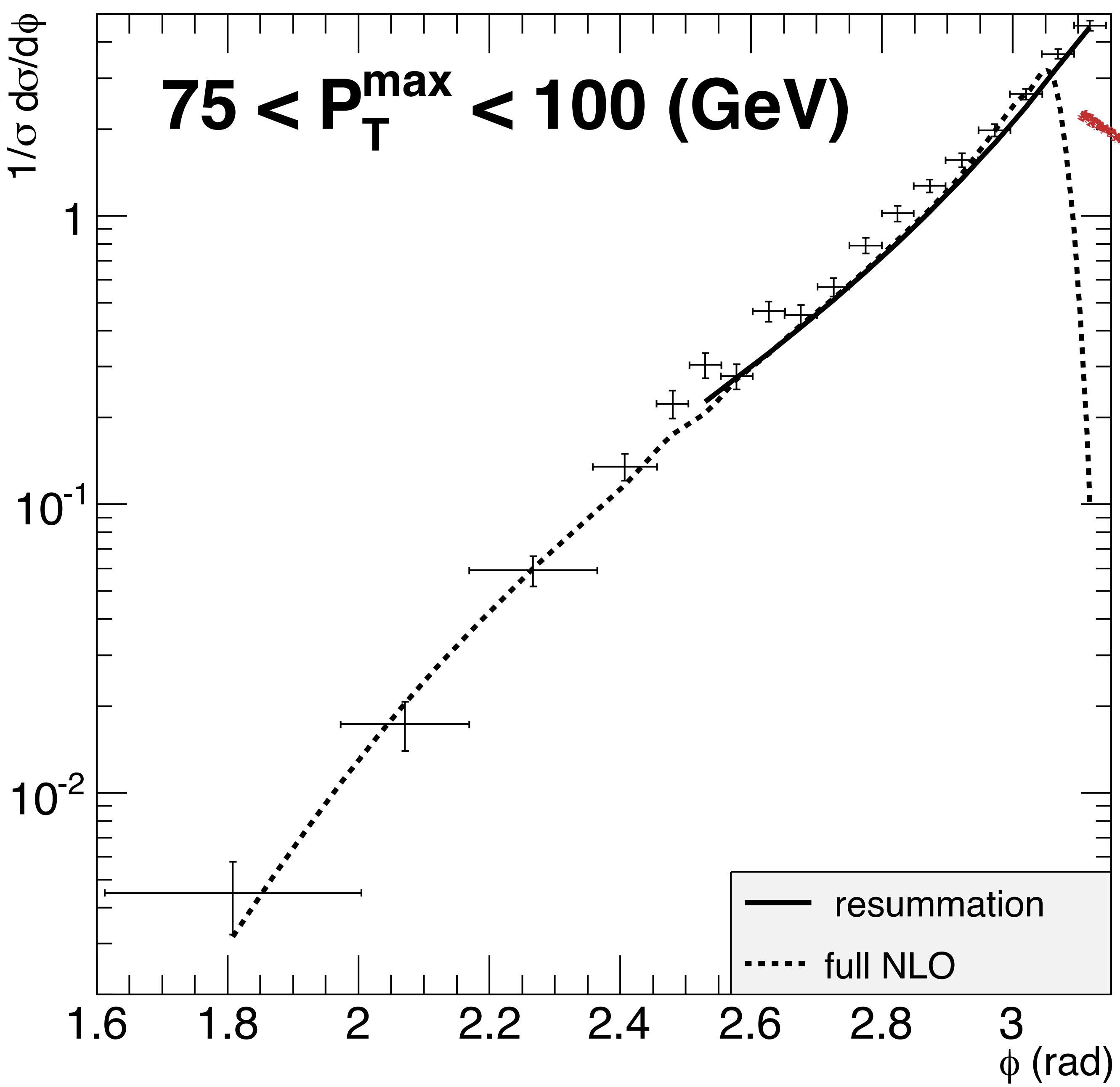
Qin, Muller, PRL 106 (2011)

Is $\hat{q} \simeq 0$?

Puzzle: Large Energy Loss, Small p_T Broadening?

Sudakov Resummation

Dijet angular correlation in *pp*



Perturbative Expansion

$2 \to 2,\ 2 \to 3$
$2 \to 4,\ \ldots\ldots$

large logarithms

$$(\alpha_s \ln^2 \frac{p_T^2}{q_\perp^2})^n$$

Not Stable

paradigm shift

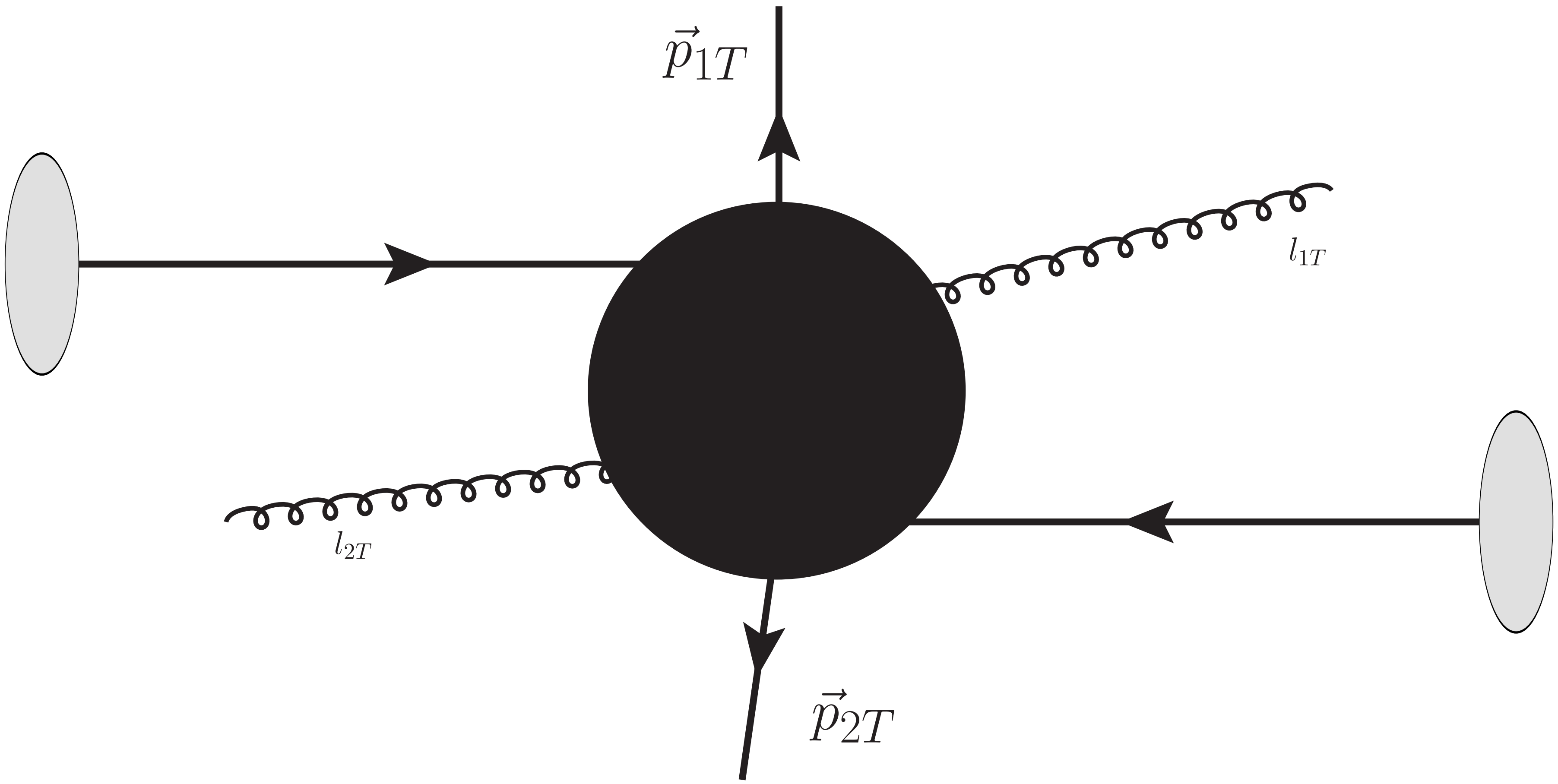
Sudakov Resummation

$2 \to 2 + n$ Soft gluon radiations (parton shower)

$p\bar{p}$ at $\sqrt{s} = 1.76$ TeV Tevatron

Sun, Yuan, Yuan, PRL113 (2014), PRD92 (2015)

Central rapidity back-to-back dijet production



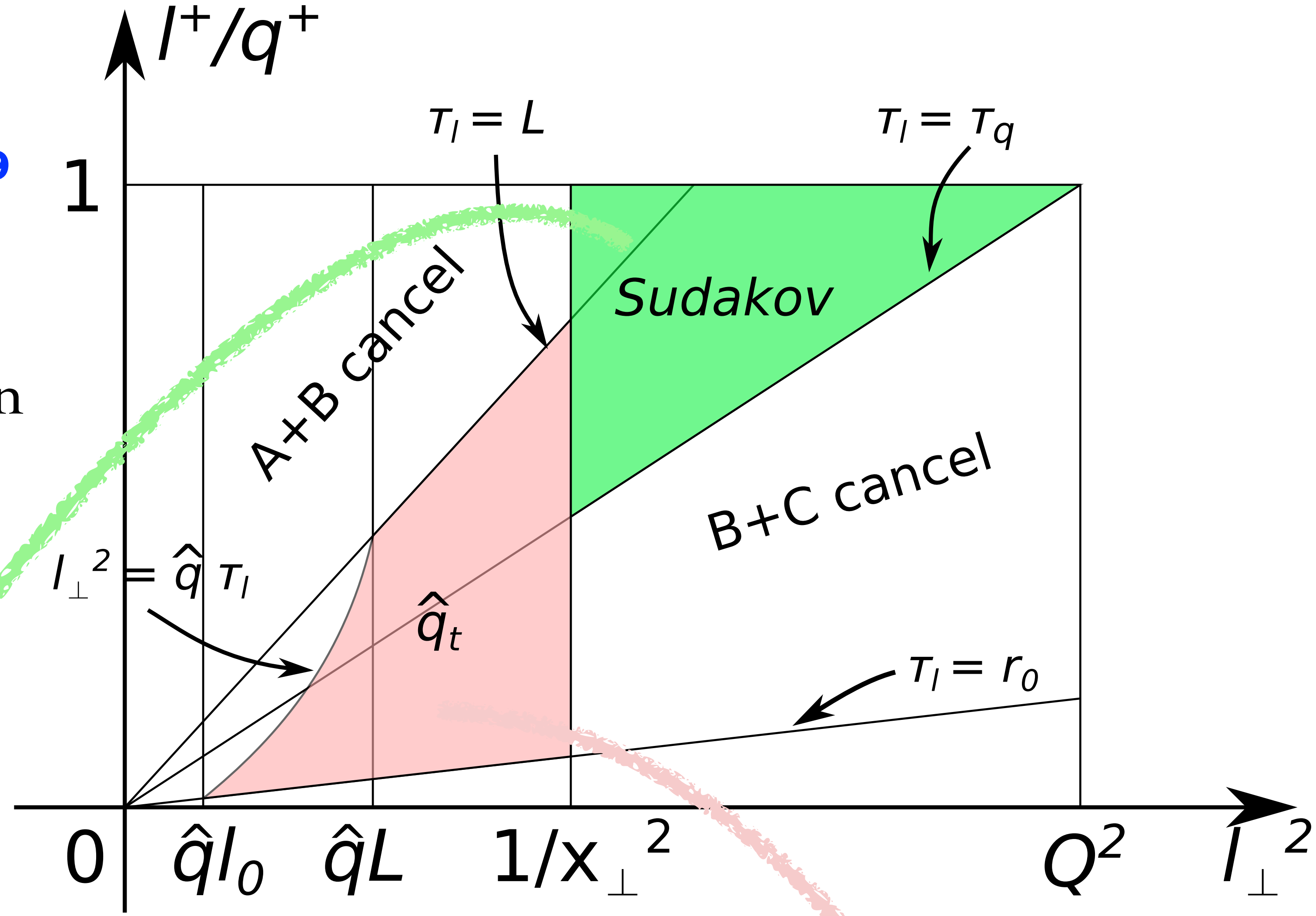
Picture: Inertia

Kinematic region: $|\vec{q}_\perp| = |\vec{p}_{1T} + \vec{p}_{2T}| \ll |\vec{p}_{1T}| \simeq |\vec{p}_{2T}|$ small angle

Back-to-back correlations are very sensitive to the soft gluon radiations.

From *pp* to *AA*

Mueller, Wu, Xiao, Yuan, arXiv:1608.07339



hot medium

Considering one gluon radiation in the large medium,
Medium Induced Radiation and
Vacuum Parton Shower
can be separated.

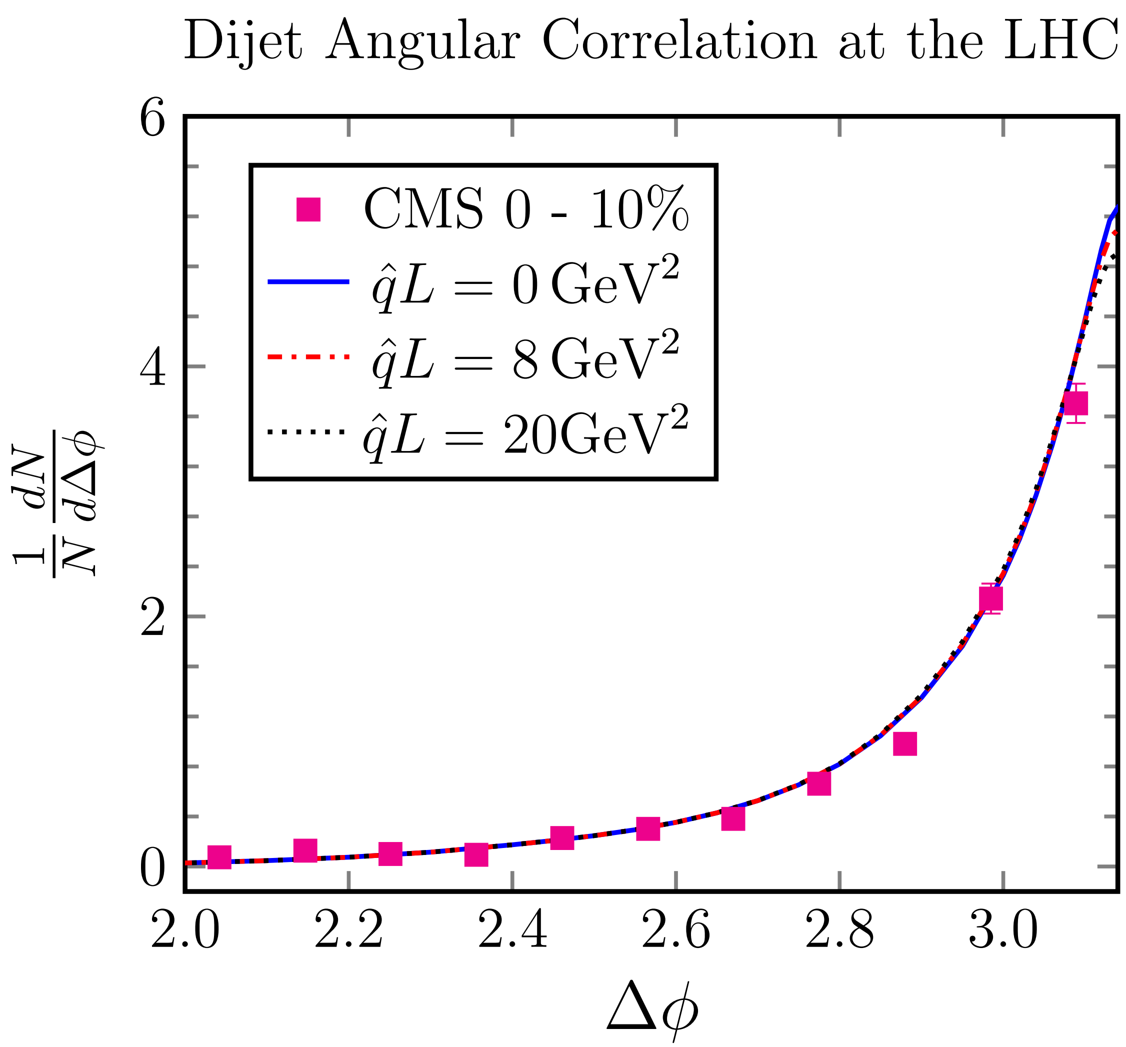
$$S_{AA}(Q,b) = S_{pp}(Q,b) + \frac{\langle \hat{q}L \rangle b^2}{4}$$

Vacuum parton shower

k_T broadening

Multiple scattering
Medium induced radiation

Dijet angular correlation in *AA*



$$S_{AA}(Q,b) = S_{pp}(Q,b) + \frac{\langle \hat{q}L \rangle b^2}{4}$$

$$\sqrt{S_{NN}} = 2.76 \text{ TeV}$$

$$p_T^1 > 150 \text{ GeV}$$

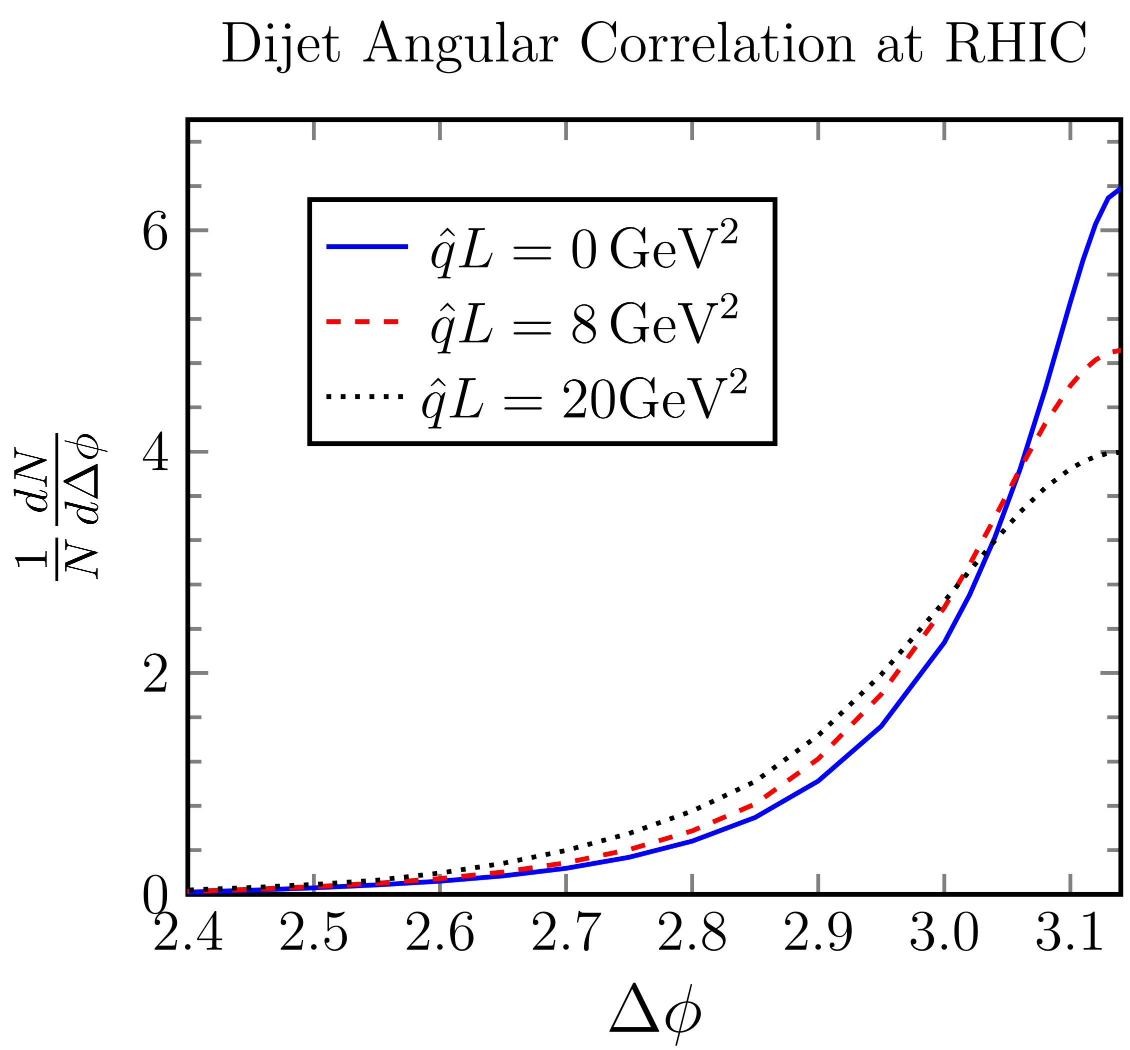
$$p_T^2 > 50 \text{ GeV}$$

Vacuum Sudakov Effect ≫ Medium Broadening Effect

This explains why the LHC did not observe the angular decorrelation.

Mueller, Wu, Xiao, Yuan, arXiv:1604.04250

Dijet angular correlation in *AA*



$$S_{AA}(Q,b) = S_{pp}(Q,b) + \frac{\langle \hat{q}L\rangle b^2}{4}$$

$\sqrt{S_{NN}} = 200$ GeV

$p_T^1 > 35$ GeV

$p_T^2 > 15$ GeV

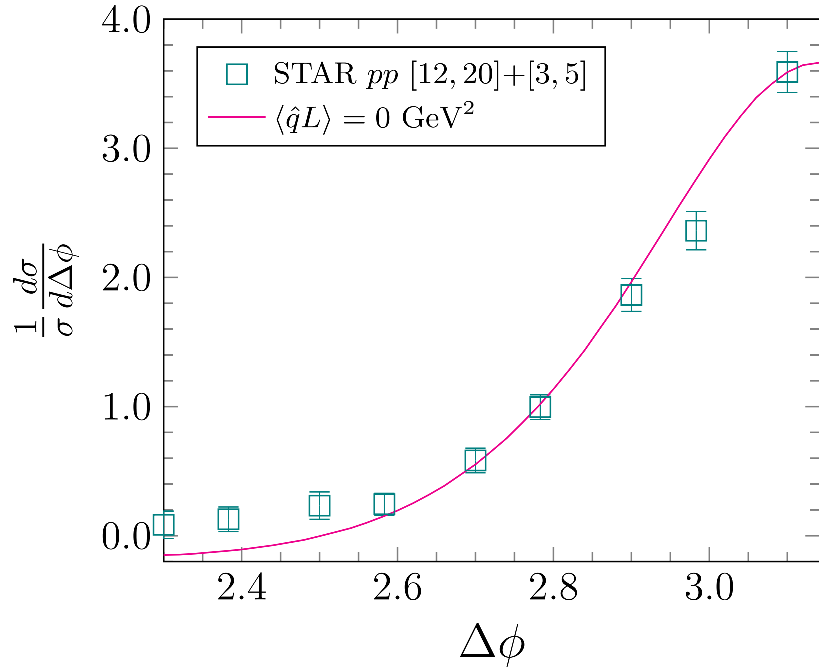
Vacuum Sudakov Effect ~ Medium Broadening Effect

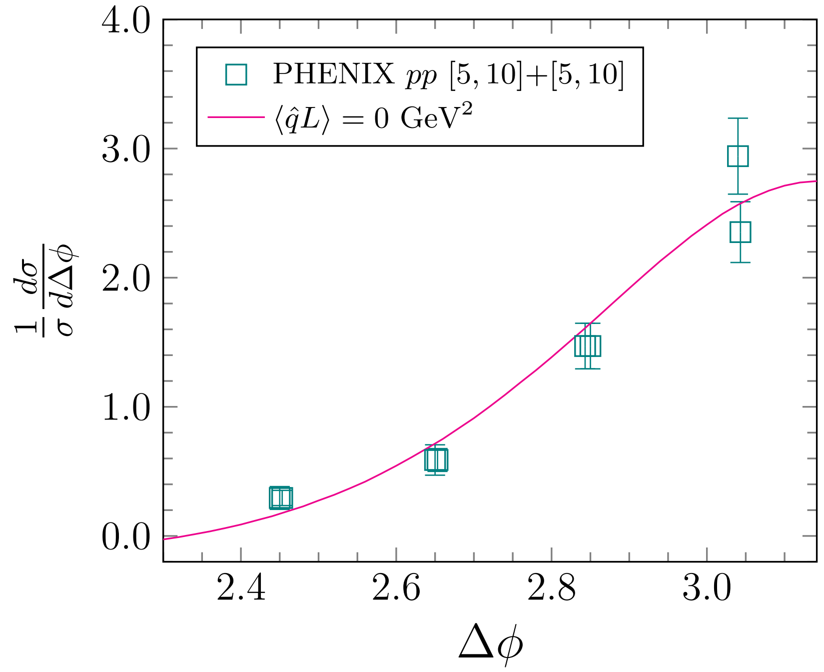
Decrease the center of mass energy or measure small p_{T} jet.

Mueller, Wu, Xiao, Yuan, arXiv:1604.04250

Dihadron & hadron-jet correlations

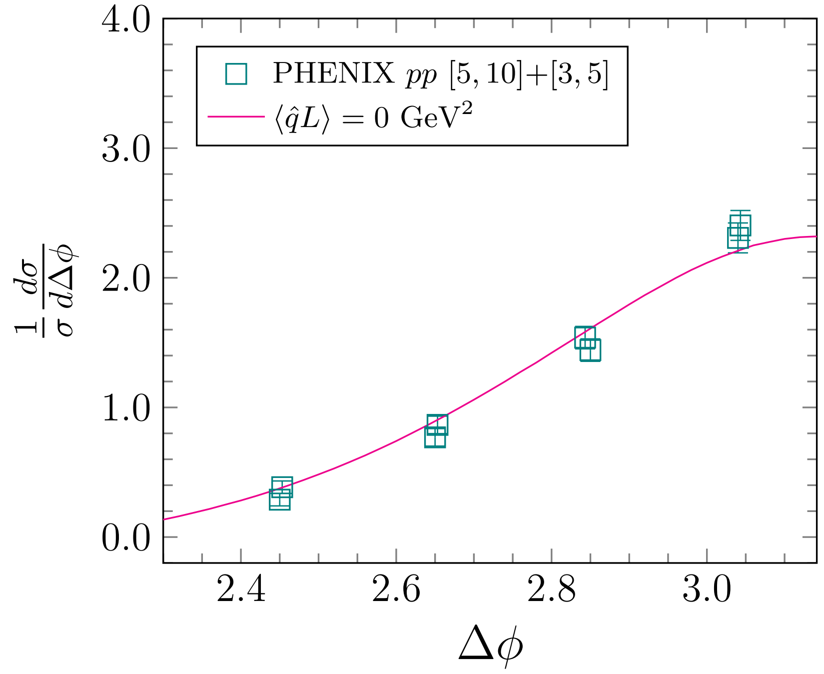
Dihadron correlations in *pp* - Establish Baseline



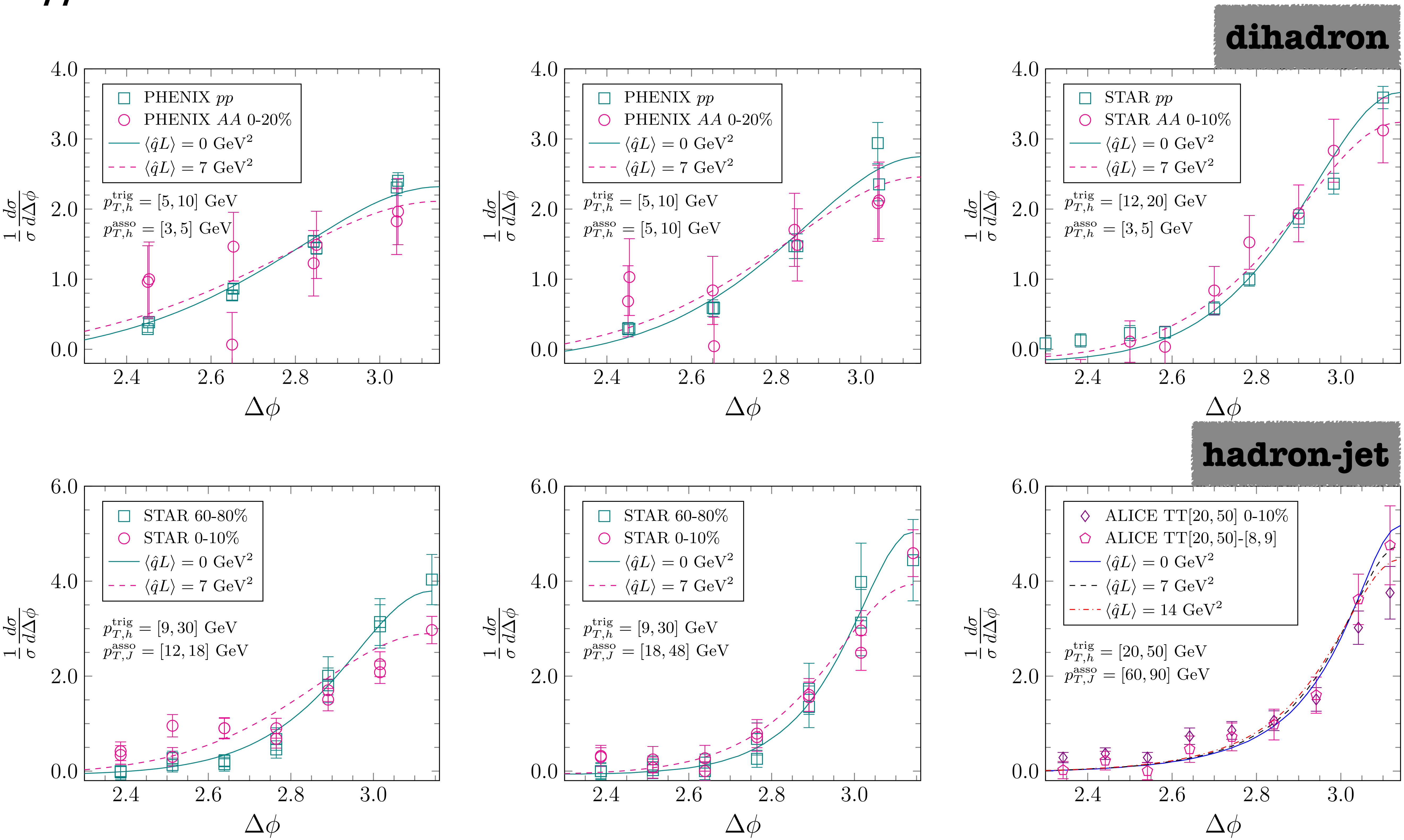


- ☑ For the first time we can describe the back-to-back angular correlation.

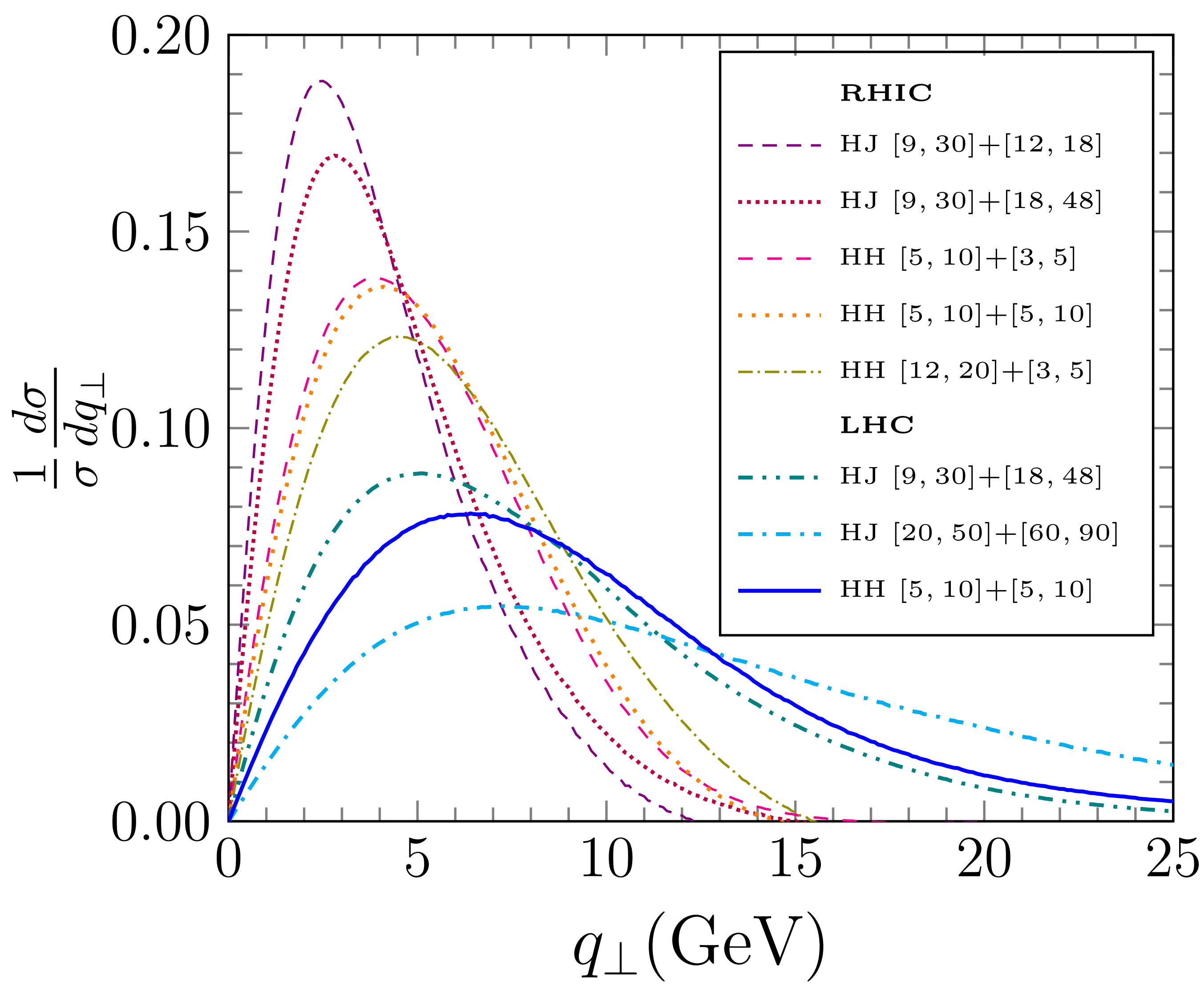
- ☑ Established a baseline to study the angular decorrelation in *AA* collisions.



pp collisions + *AA* collisions



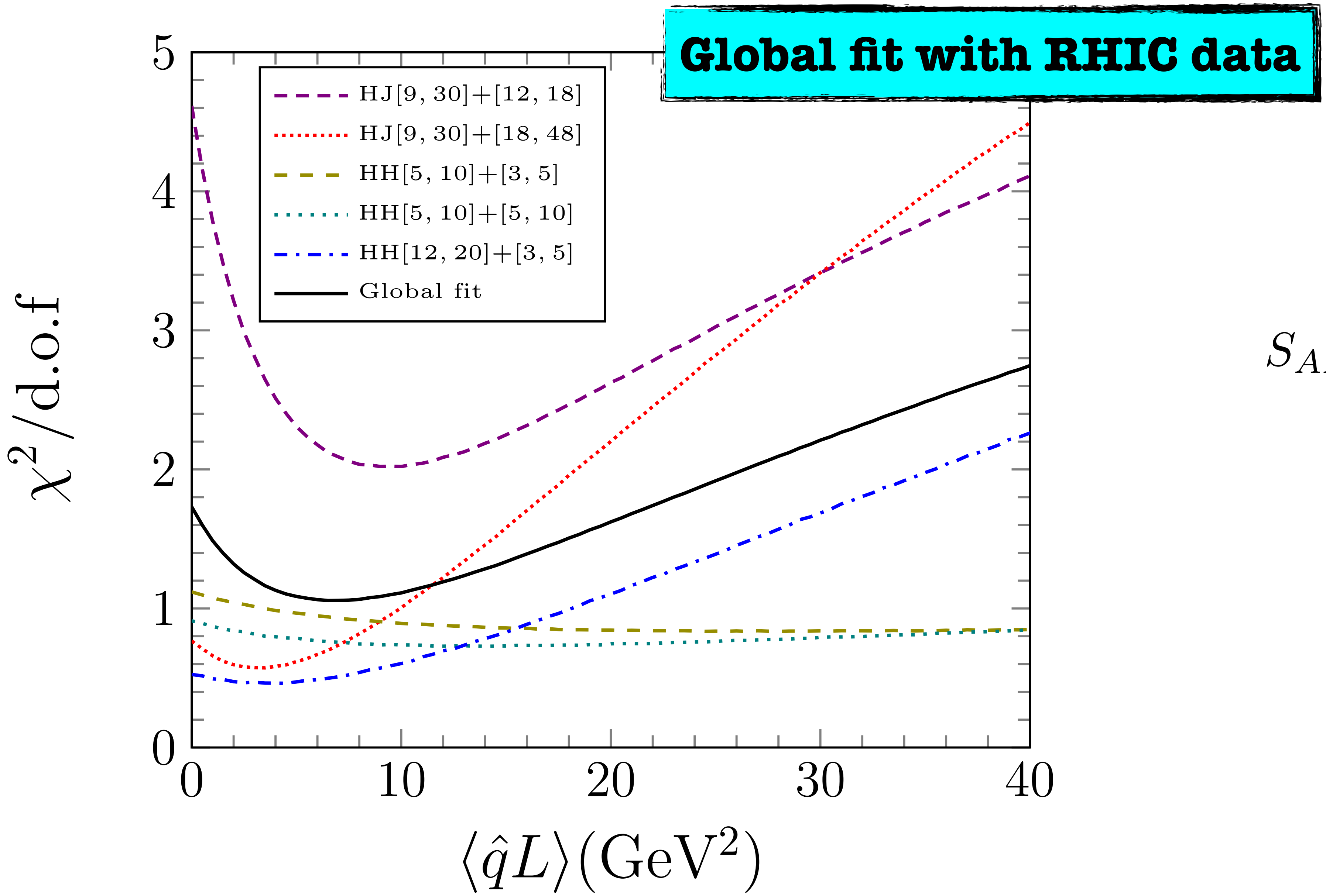
Normalized $q_\perp$ distributions



$$q^{*2}_{\perp\mathrm{AA}} \simeq q^{*2}_{\perp\mathrm{pp}} + \langle \hat{q} L \rangle$$

Large p_T events are not sensitive to the medium induced k_T broadening, since the vacuum Sudakov effect is too large.

Dihadron & hadron-jet correlations



$$S_{AA}(Q,b) = S_{pp}(Q,b) + \frac{\langle \hat{q} L \rangle b^2}{4}$$

$$\langle \hat{q} L \rangle_{\rm tot} = 14^{+42}_{-14}\ \mathrm{GeV}^2$$

larger than the value, $\hat{q} = 1.2 \pm 0.3\ \mathrm{GeV}^2/\mathrm{fm}$ extracted from single hadron R_{AA} by JET Collaboration

- ☑ Radiative correction
- ☑ Effective length

Summary

- For the first time we can describe the back-to-back dihadron/hadron-jet angular correlation measured at RHIC & LHC.
- The dijet, dihadron and hadron-jet angular correlations can provide a new gateway to quantify the medium induced k_T broadening.
- We extracted that $\langle \hat{q} L \rangle_{\rm tot} = 14^{+42}_{-14} {\rm GeV}^2$ for a quark jet at RHIC energy.

Outlook

- Energy loss.
- Dihadron per trigger yield.
- A_J distribution.

Summary

- For the first time we can describe the back-to-back dihadron/hadron-jet angular correlation measured at RHIC & LHC.
- The dijet, dihadron and hadron-jet angular correlations can provide a new gateway to quantify the medium induced k_T broadening.
- We extracted that $\langle \hat{q} L \rangle_{\rm tot} = 14^{+42}_{-14} {\rm GeV}^2$ for a quark jet at RHIC

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Thanks for your attention!

- Energy loss.
- Dihadron per trigger yield.
- A_J distribution.

The End

Sudakov Resummation

Dihadron azimuthal angle correlation (Chen, Qin, Wei, Xiao, Zhang, arXiv:1607.01932)

$$\frac{d\sigma}{d\Delta\phi} = \sum_{a,b,c,d} \int p_T^{h_1} dp_T^{h_1} \int p_T^{h_2} dp_T^{h_2} \int \frac{dz_c}{z_c^2} \int \frac{dz_d}{z_d^2} \int bdb \; J_0(q_\perp b) e^{-S(Q,b)}$$

$$x_a f_a(x_a, \mu_b) x_b f_b(x_b, \mu_b) \times \frac{1}{\pi} \frac{d\sigma_{ab\to cd}}{d\hat{t}} D_c(z_c, \mu_b) D_d(z_d, \mu_b)$$

Hadron-JET azimuthal angle correlation

$$\frac{d\sigma}{d\Delta\phi} = \sum_{a,b,c,d} \int p_T^{h_1} dp_T^{h_1} \int k_\perp^{j_2} dk_\perp^{j_2} \int \frac{dz}{z^2} \int bdb \; J_0(q_\perp b) e^{-S(Q,b)}$$

$$x_a f_a(x_a, \mu_b) x_b f_b(x_b, \mu_b) \times \frac{1}{\pi} \frac{d\sigma_{ab\to cd}}{d\hat{t}} D_c(z, \mu_b)$$

Sudakov factor

initial & final state parton shower

$$S(Q,b) = S_{\rm pert}(Q,b) + S_{\rm non-pert}(Q,b) + S_{\rm medium}(\langle \hat{q} L\rangle, b)$$

Broken universality

factorization breaks down
higher twist PDFs and FFs

Sudakov Resummation

Sudakov factor $S(Q,b) = S_{\rm pert}(Q,b) + S_{\rm non-pert}(Q,b) + S_{\rm medium}(\langle \hat{q}L \rangle, b)$

$$S^i_{\rm pert} = \sum_{i=a,b} \int_{\mu_b^2}^{Q^2} \frac{d\mu^2}{\mu^2} \left[A_i \ln\left(\frac{Q^2}{\mu^2}\right) + B_i \right]$$

initial state Sudakov factor

$$S^f_{\rm pert} = \frac{1}{2} \sum_{f=c,d} \int_{\mu_b^2}^{Q^2} \frac{d\mu^2}{\mu^2} \left[A_f \ln\left(\frac{Q^2}{\mu^2}\right) + B_f \right]$$

for f is a hadron

$$S^f_{\rm pert} = \sum_{f=c,d} \int_{\mu_b^2}^{Q^2} \frac{d\mu^2}{\mu^2} \left[D_f \ln \frac{1}{R^2} \right]$$

for f is a JET

Non-perturbative Sudakov factor

predictive power

- Not universal for dihadron, hadron-jet and dijet productions.
- Universal for different p_T regions or CME for the same process.

$S_{\rm np} = C \times S_{\rm np}{}^{\rm DIS}$

C = 5 for dihadron production
C = 2 for hadron-jet production