

Jet acoplanarity in vacuum at RHIC to EIC

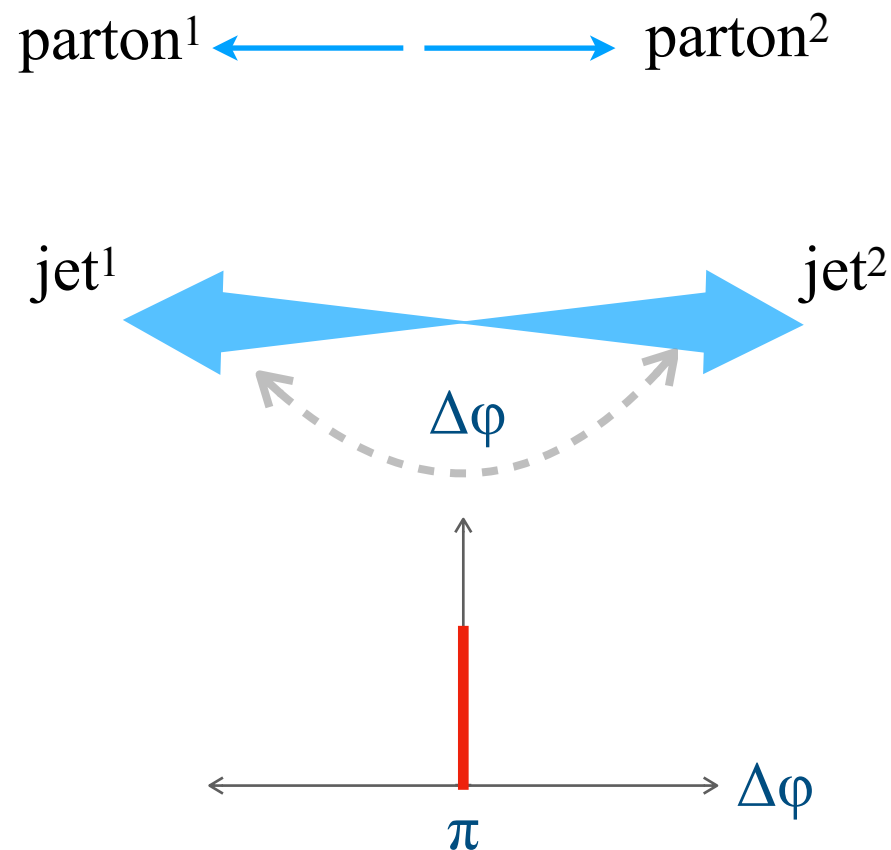
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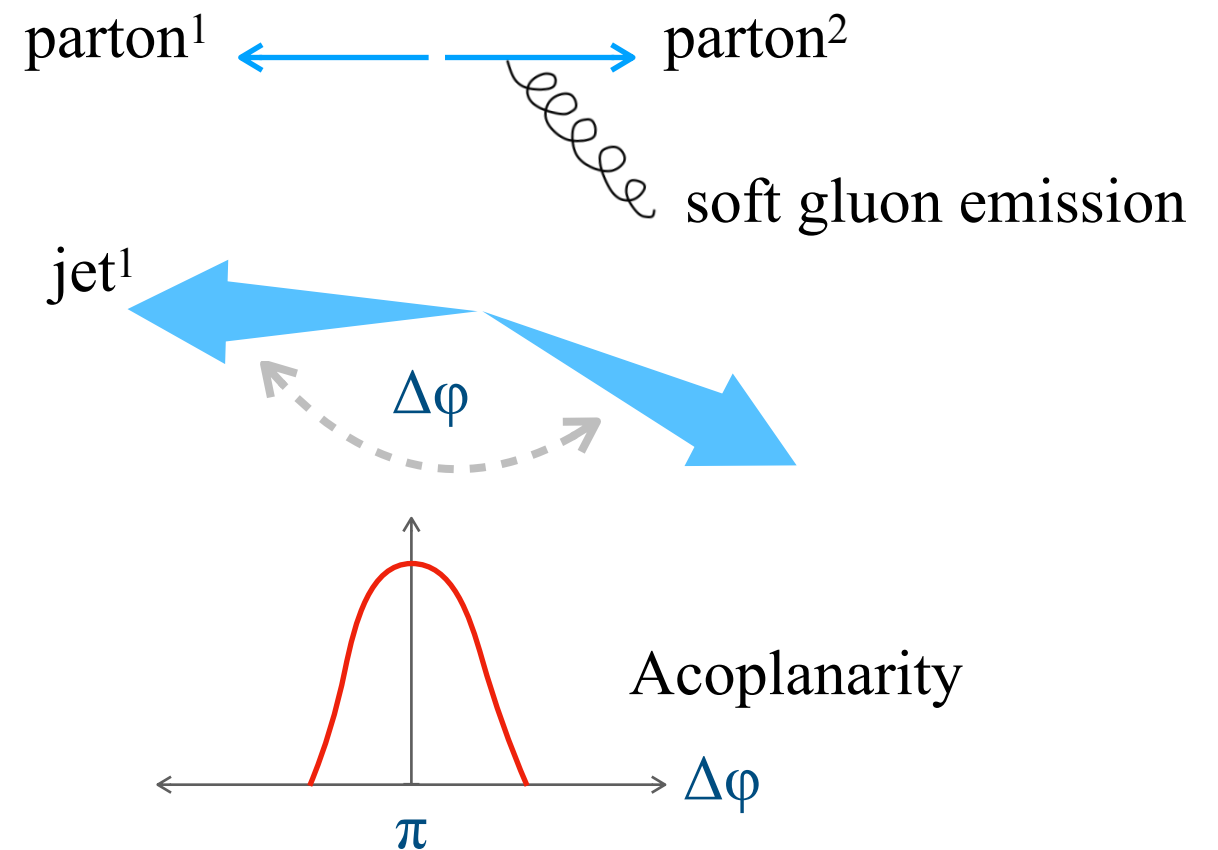
Advancing the Understanding of Non-Perturbative QCD Using Energy Flows, Sep 19-22, 2022

Jet acoplanarity in vacuum

In Born diagram, dijet production is back-to-back in transverse plane



One single gluon emission, dijet no longer back-to-back in vacuum



1. To study jet acoplanarity in vacuum (p+p, e+p) at RHIC (relatively lower Q^2 than the LHC/Tevatron)
Associated TMD resummation (small imbalance relative to individual jet momentum)
2. As a baseline for hot-dense (A+A) and Cold QCD (p+A, e+A) environment

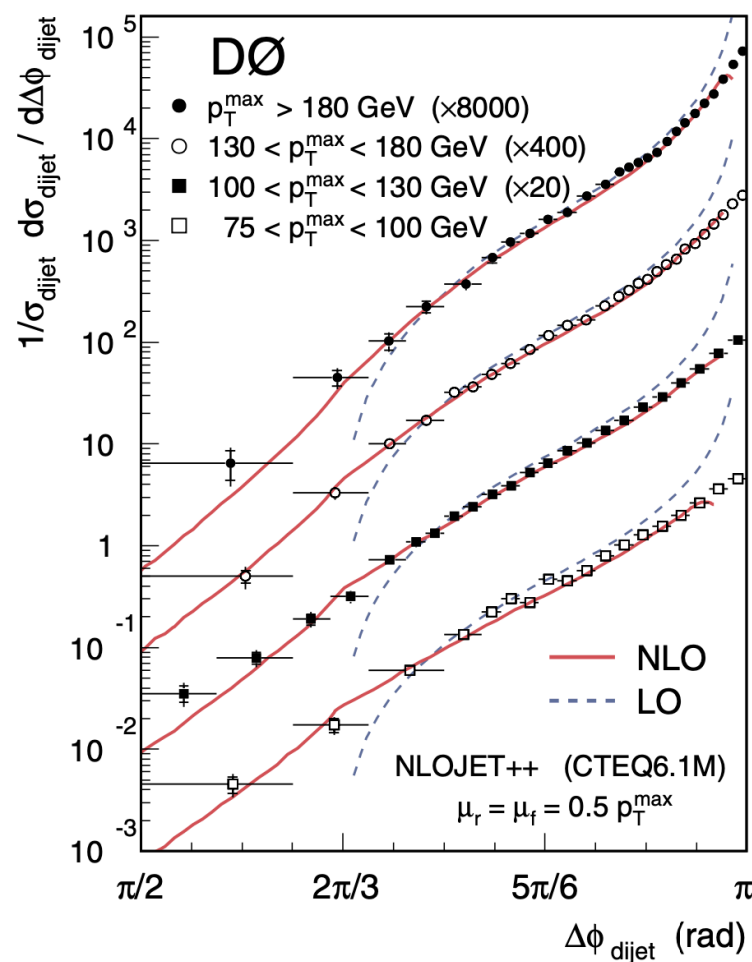
Dijet acoplanarity (correlation) measurement at mid-rapidity

Previous measurements at LHC and Tevatron

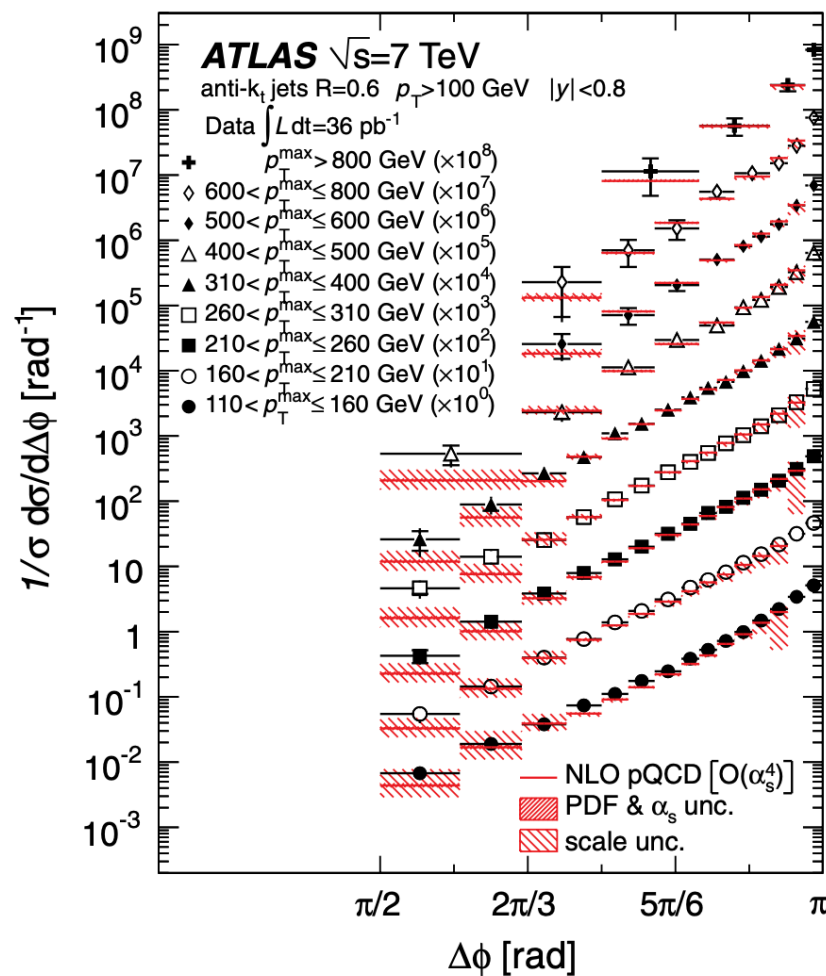
Tevatron: $p + \bar{p}$ at $\sqrt{s} = 1.96$ TeV

LHC : $p+p$ at $\sqrt{s} = 7$ TeV

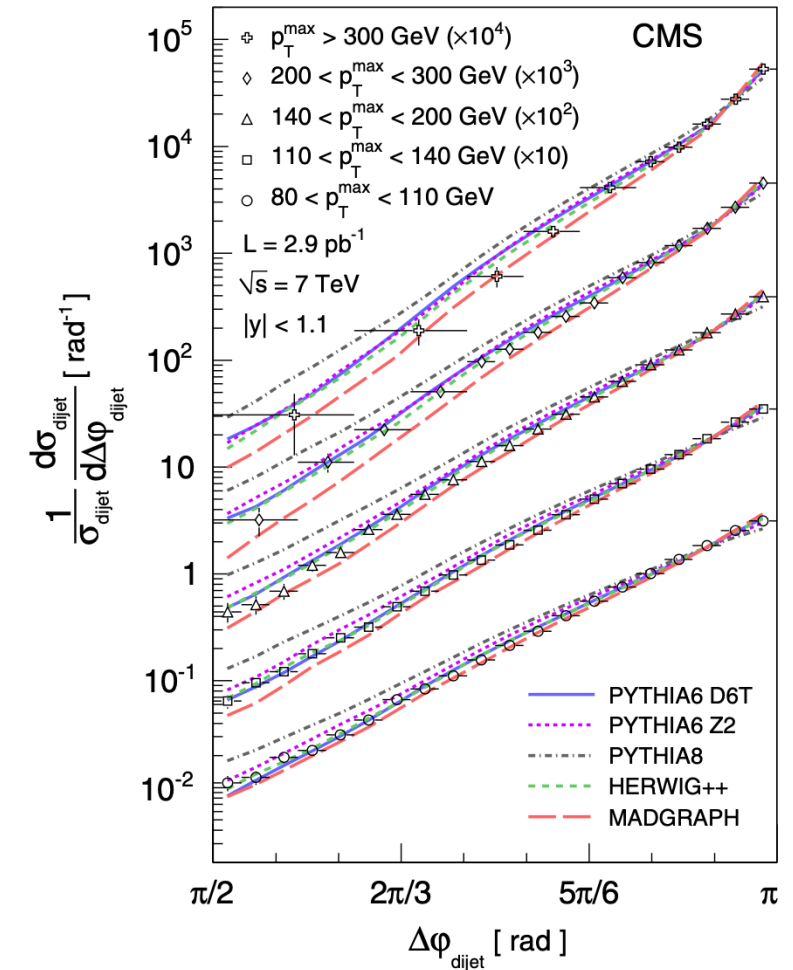
DØ: PRL **94**, 221801 (2005)



ATLAS: PRL **106**, 172002 (2011)



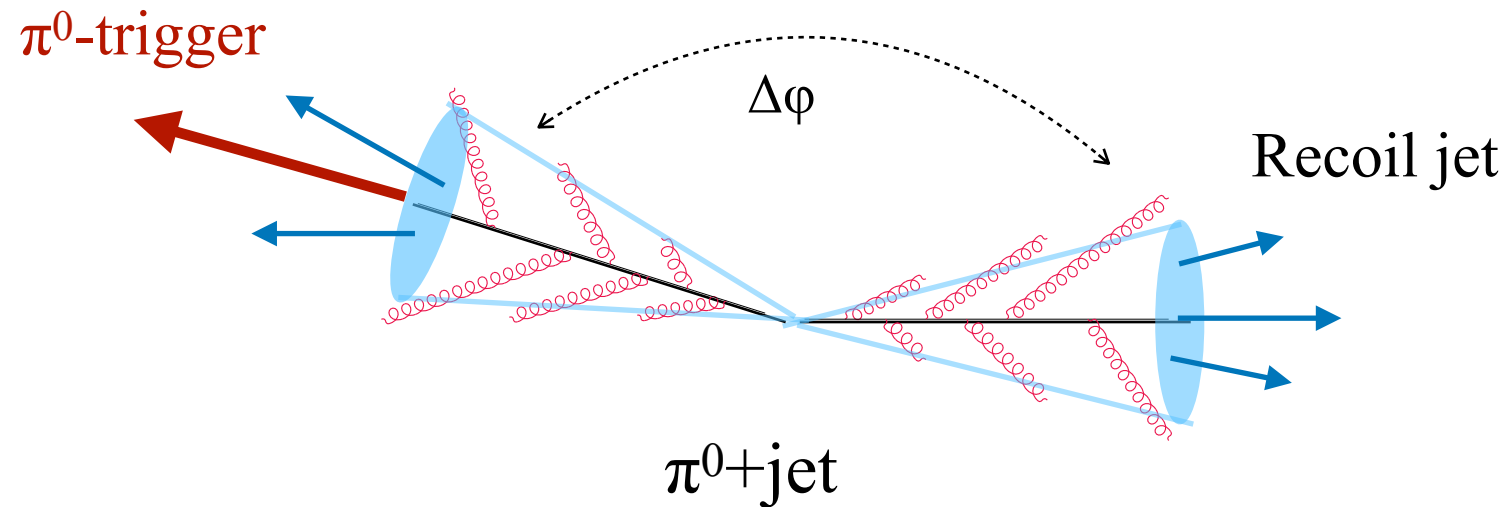
CMS: PRL **106**, 122003 (2011)



- Well-described by NLO pQCD
- Multi-parton radiation dominates at small angle

RHIC/STAR measurements

Semi-inclusive π^0 +jet azimuthal correlation in $p+p$ collisions in STAR

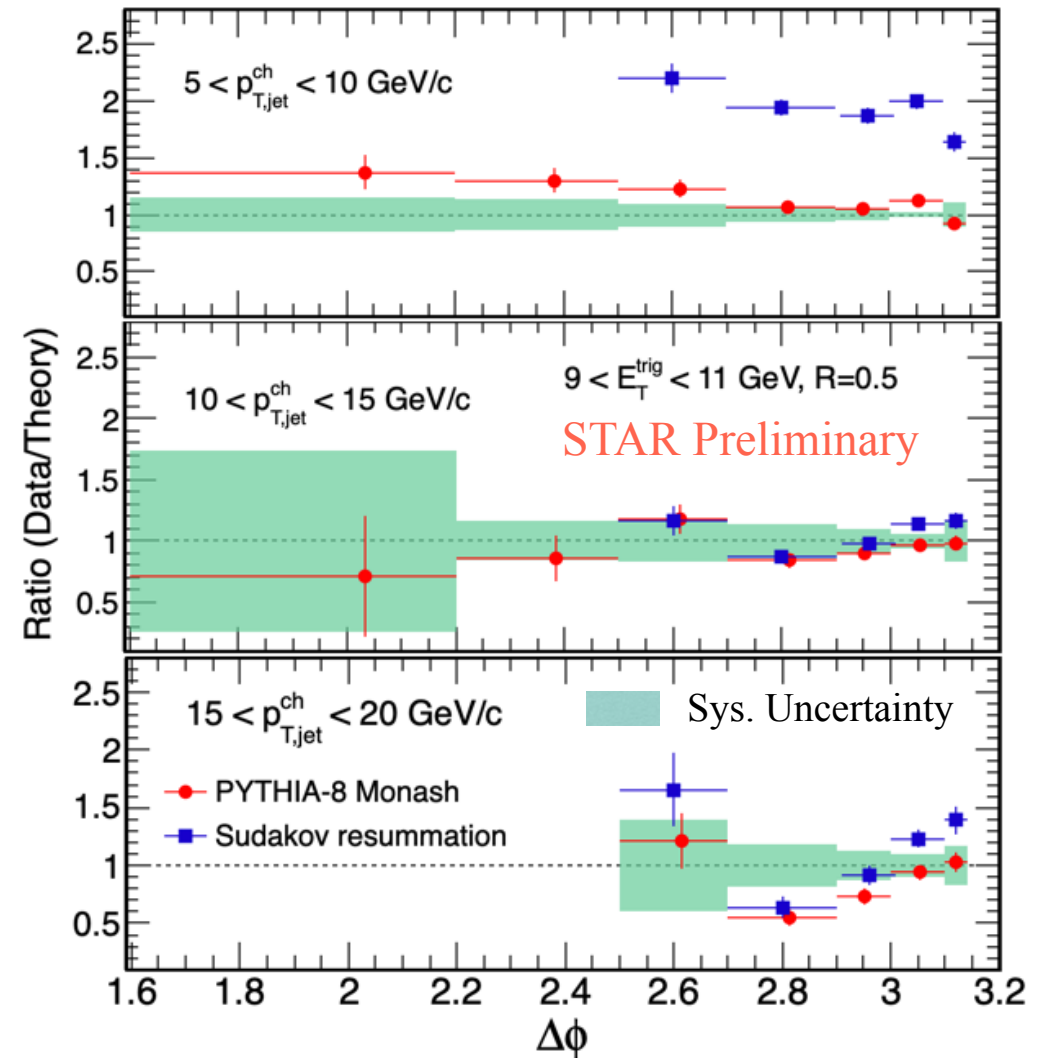
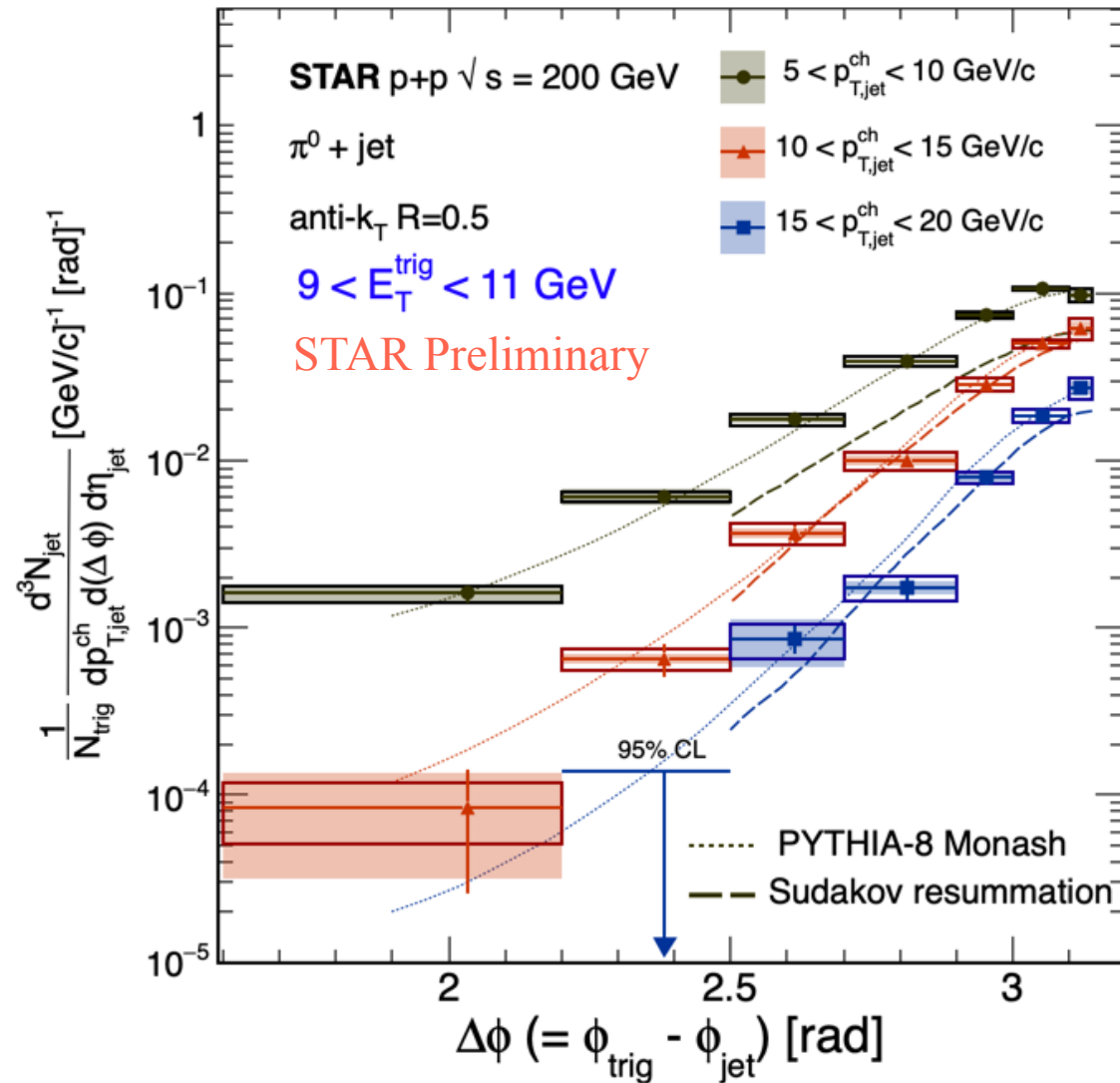


Semi-inclusive π^0 +jet measurement:

$$\frac{1}{N_{\text{trig}}} \cdot \frac{d^2 N_{\text{jet}}}{dp_{T,\text{jet}} d(\Delta\phi)} \bigg|_{E_T^{\text{trig}}} = \left(\frac{1}{\sigma^{A+A \rightarrow \text{trig}}} \cdot \frac{d^2 \sigma^{A+A \rightarrow \text{trig}+\text{jet}}}{dp_{T,\text{jet}} d(\Delta\phi)} \right) \bigg|_{E_T^{\text{trig}}}$$

π^0 +jet acoplanarity measurement at $\sqrt{s} = 200$ GeV

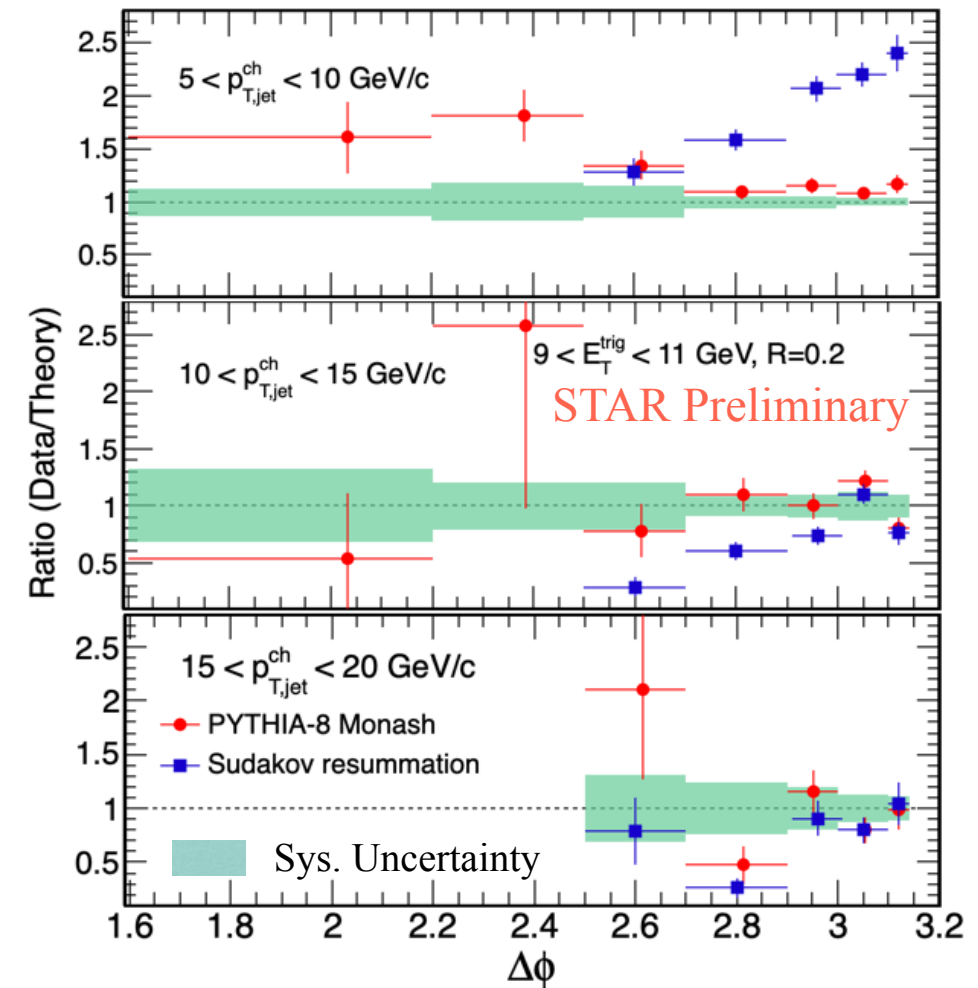
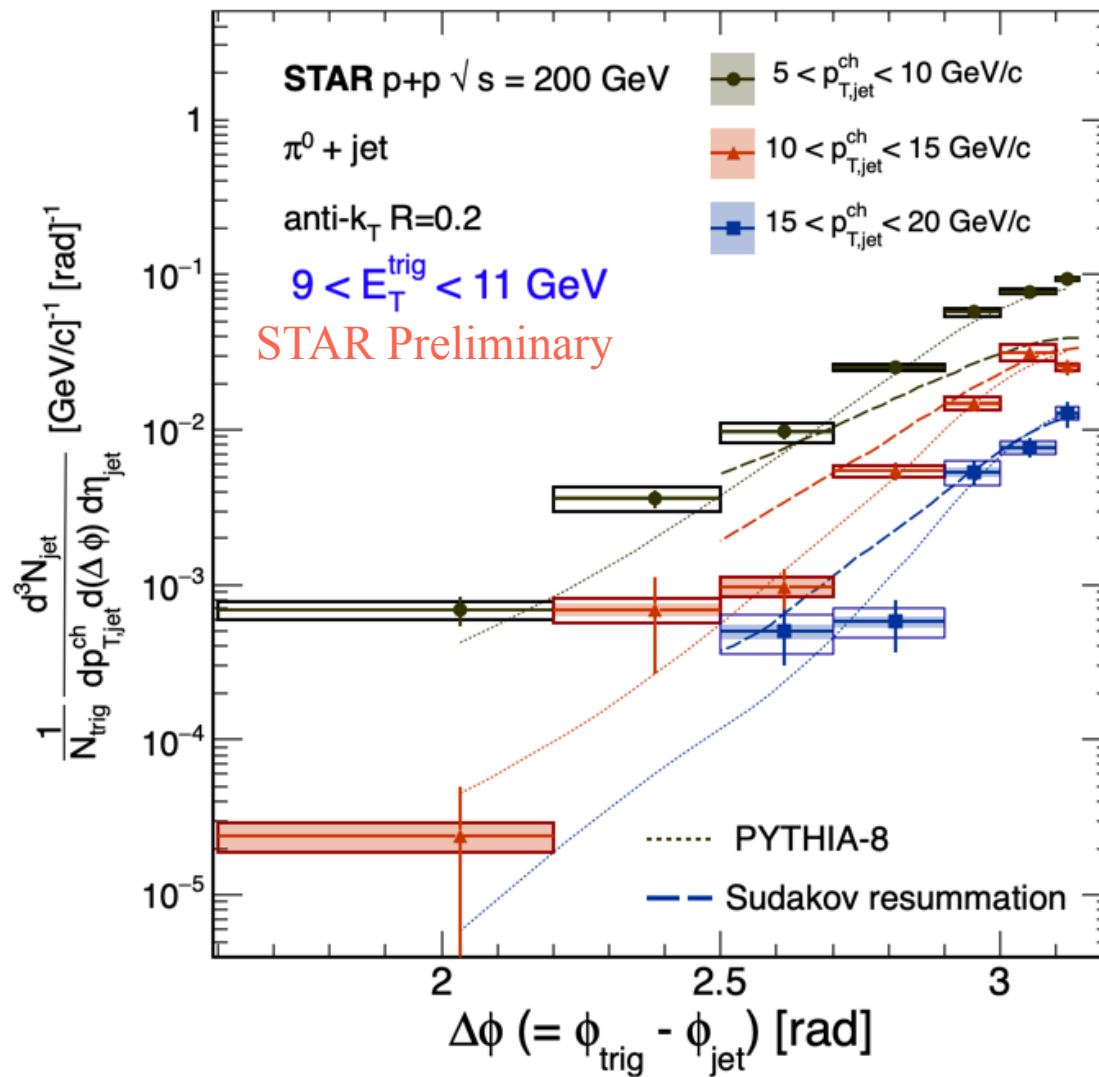
$$9 < E_T^{\text{trig}} < 11 \text{ GeV, jet } R=0.5$$



- Sudakov resummation (single-gluon emission, $\alpha_s^i \ln^{2i-1}(P_T^2/q_\perp^2)$): private communication with Bowen Xiao, Feng Yuan et al., [PRL 113, no.23, 232001 (2014), PRD 92, no.9, 094007 (2015), PLB 773, 672-676 (2017)]
- Sudakov resummation explains for $R=0.5$, but deviates from data at low recoil jet p_T
- LO QCD process in PYTHIA-8 reproduces the shape of the data and quantitatively reproduces within uncertainty

π^0 +jet acoplanarity measurement at $\sqrt{s} = 200$ GeV

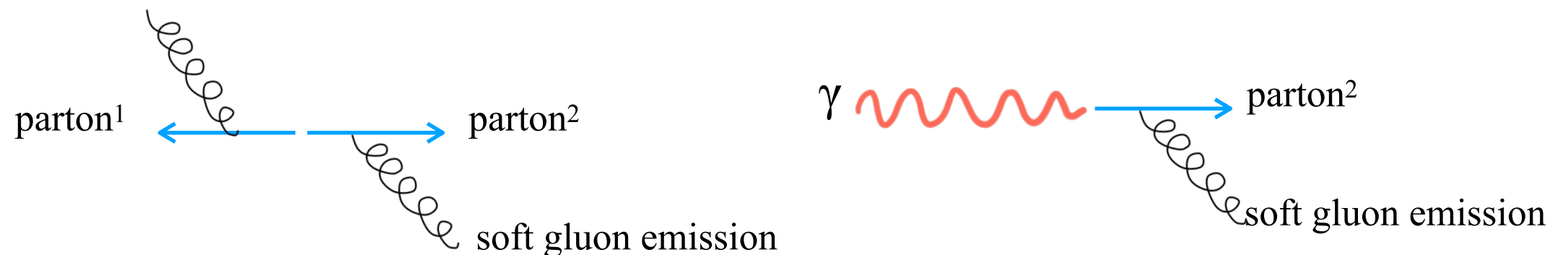
$$9 < E_T^{\text{trig}} < 11 \text{ GeV, jet } R=0.2$$



- Sudakov resummation (single-gluon emission, $\alpha_s^i \ln^{2i-1}(P_T^2/q_\perp^2)$): private communication with Bowen Xiao, Feng Yuan et al., [PRL 113, no.23, 232001 (2014), PRD 92, no.9, 094007 (2015), PLB 773, 672-676 (2017)]
- Sudakov resummation deviates from data at low recoil jet pT
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Ongoing and upcoming RHIC/STAR measurements and physics

Semi-inclusive π^0 +jet (dijet) and γ +jet measurement in pp 200 GeV



In resummation, double logarithms are related to incoming parton's color factor

- $qq \rightarrow qq, gg \rightarrow gg$, etc., vs. $qg \rightarrow \gamma q, q\bar{q} \rightarrow \gamma g$
- Plan to explore with upcoming high statistics pp data in STAR (Run23-25)

Hatta, Xiao, Yuan, and Zhou, PRD 104, 054037 (2021)

In Au+Au (finite temp. QCD) and p+Au (cold QCD) collisions

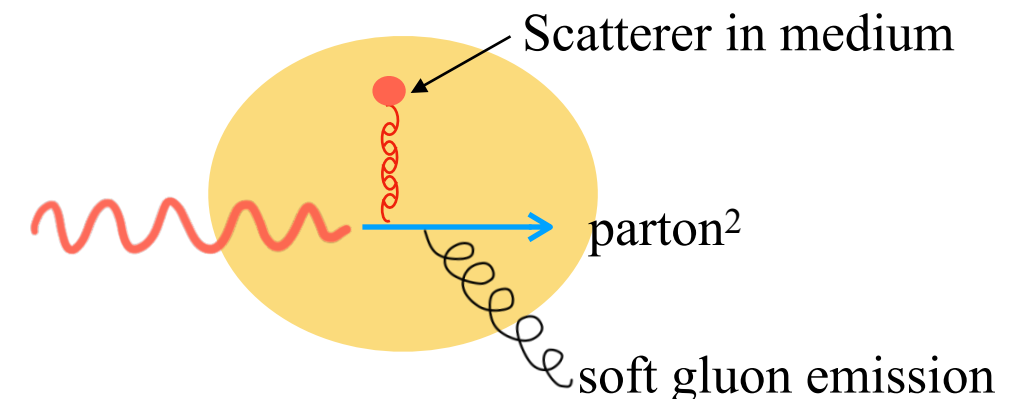
Two competing effects:

1. p_T -broadening

$$Q_s^2 = \hat{q}L \rightarrow e^{q_\perp^2/Q_s^2} \text{ (BDMPS, Gaussian like distribution)}$$

2. Sudakov

Muller et. al, PLB 763 (2016) 208; Collin et. al, NPB 250 (1985)199



Hot QCD
Cold QCD
Medium

Ongoing STAR measurements in A+A collisions

In Au+Au (finite temp. QCD) and p+Au (cold QCD) collisions

- Two competing effects:

1. p_T -broadening

$$Q_s^2 = \hat{q}L \rightarrow e^{q_{\perp}^2/Q_s^2} \text{ (BDMPS, Gaussian like distribution)}$$

2. Sudakov

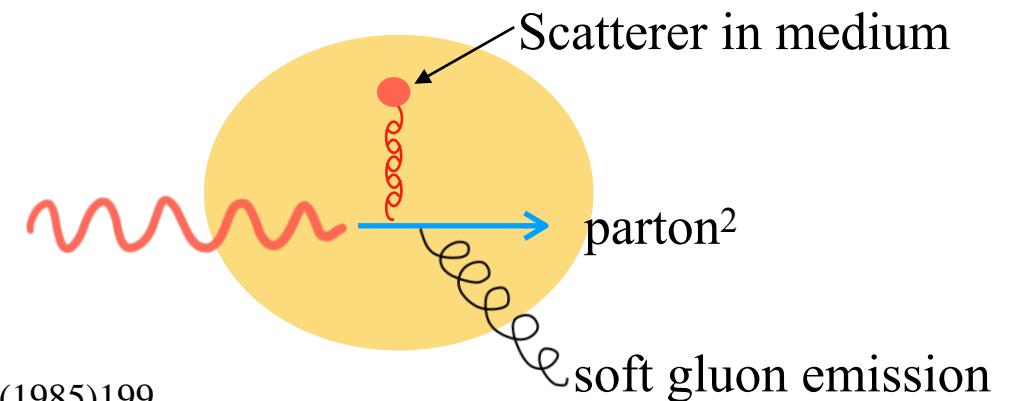
Muller et. al, PLB 763 (2016) 208; Collin et. al, NPB 250 (1985)199

- Rutherford Scattering: Energetic parton resolves microstructure of QGP

Large-angle deflection of hard partons off quasi-particles

D'Eramo, Rajagopal, Yin, JHEP 01 (2019) 172;

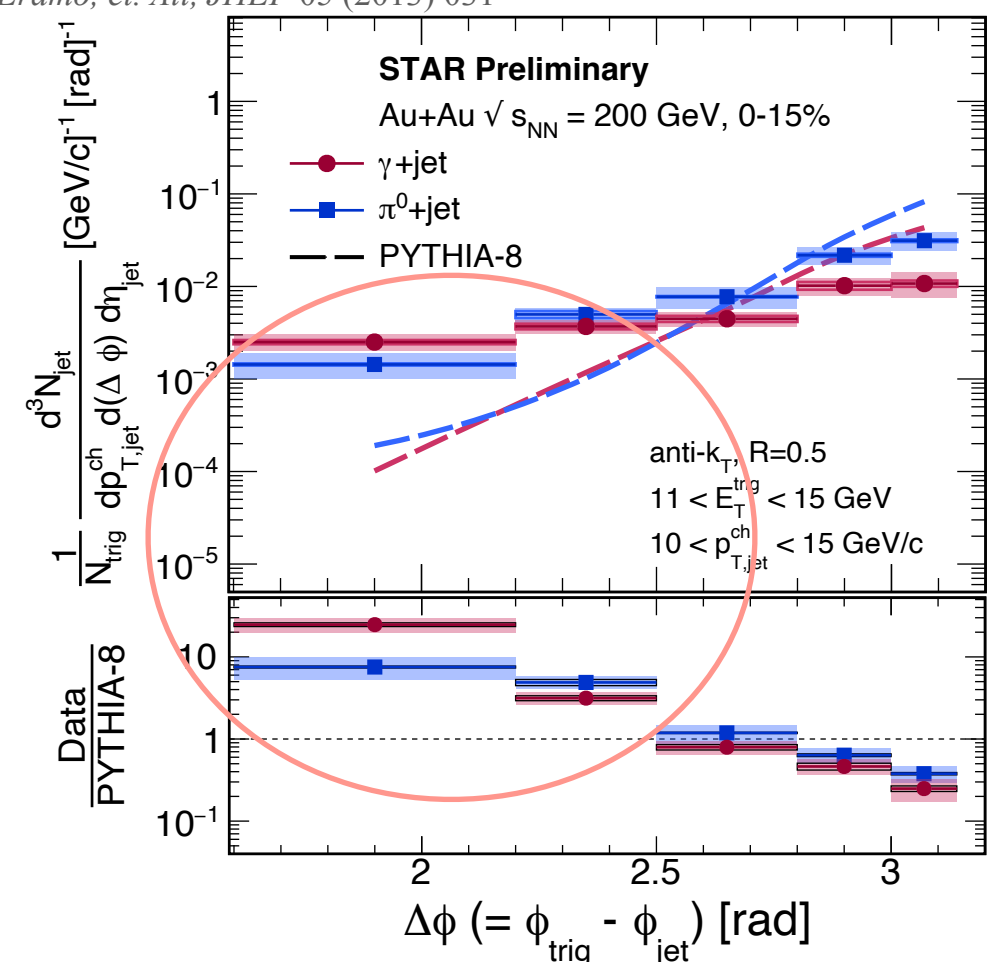
D'Eramo, et. All, JHEP 05 (2013) 031



Semi-inclusive γ +jet and π^0 +jet measurement in central Au+Au 200 GeV:

First evidence of significant medium-induced jet acoplanarity in QGP for jets with $R=0.5$

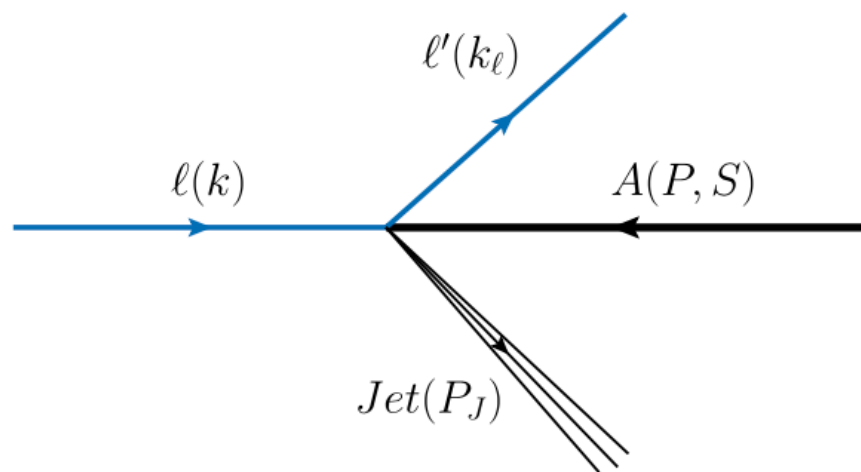
Cold QCD medium needs to be explored using p+A and e+A collisions...



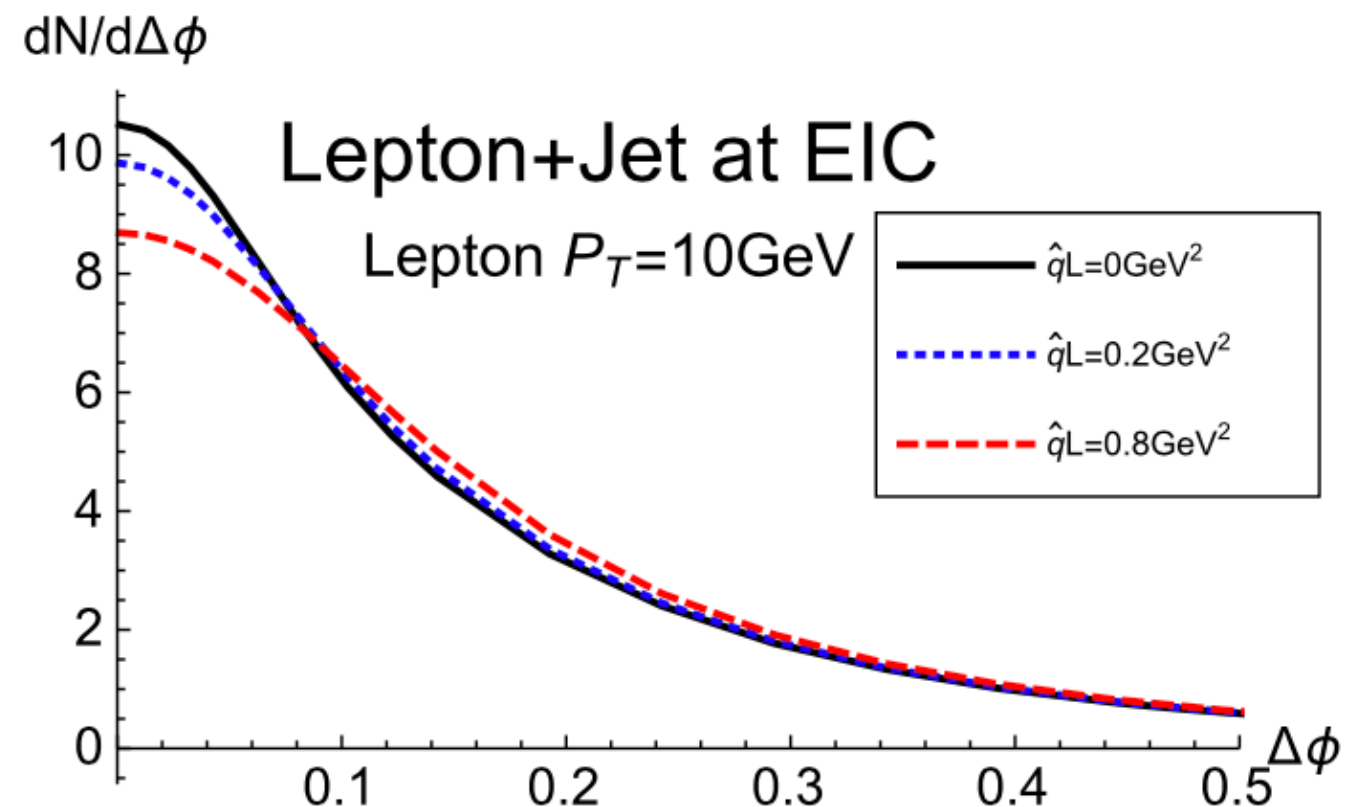
EIC measurements

Liu, Ringer, Vogelsang, Yuan; PRL 122, 192003 (2019)

lepton+jet correlation in $e+p$ and $e+A$



TMD resummation: $\tilde{W}_q \rightarrow \tilde{W}_q e^{\frac{-\hat{q}Lb_\perp^2}{4}}$



Summary and outlook

In STAR, semi-inclusive π^0 +jet acoplanarity at $\sqrt{s} = 200$ GeV in p+p collisions

- Sudakov results are comparable at high p_T recoil jets
- LO QCD process in PYTHIA-8 reproduces the shape of the data quantitatively
- π^0 +jet (dijet) and γ +jet measurement in pp 200 GeV important to study QCD resummation (Run23-25 data taking)

Semi-inclusive γ +jet and π^0 +jet measurement in central Au+Au 200 GeV

- First evidence of significant medium-induced jet acoplanarity in QGP for jets with $R=0.5$

In EIC era, Cold QCD medium (e+A relative to e+p)

To explore the competing effects of Sudakov and p_T -broadening ...