Recent Results on Jet Physics from STAR

The 35th Winter Workshop on Nuclear Dynamics (WWND 2019)

January 7, 2018

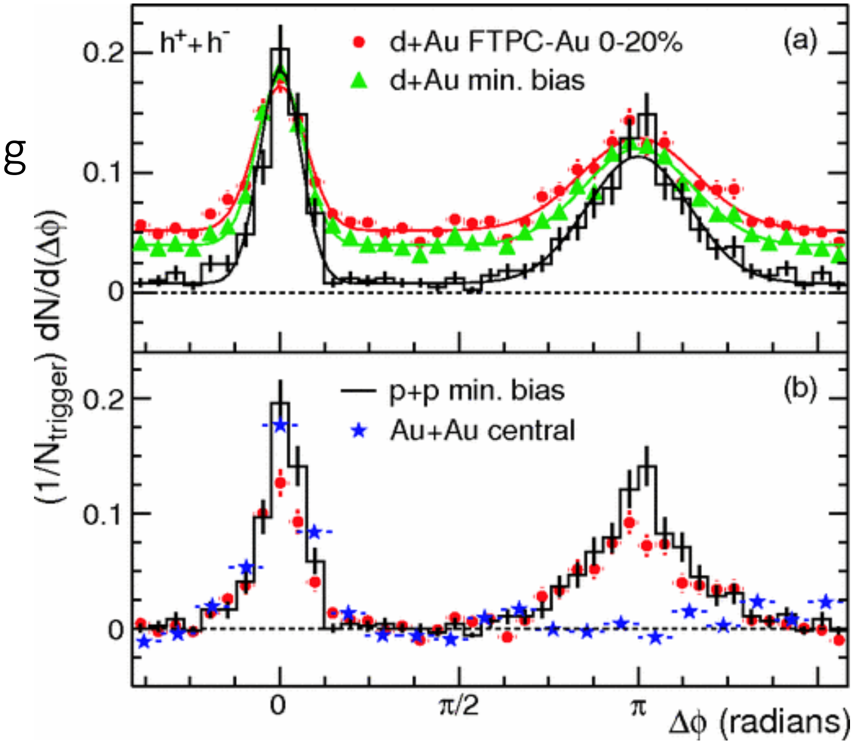
Saehanseul Oh for the STAR Collaboration

(Yale University - BNL)

Introduction

- Jets and high-p_T particles from hard scattering in heavy-ion collisions can probe the QGP
- The first experimental evidence of "*jet quenching*" from STAR

STAR, Phys. Rev. Lett. **91** (2003) 072304



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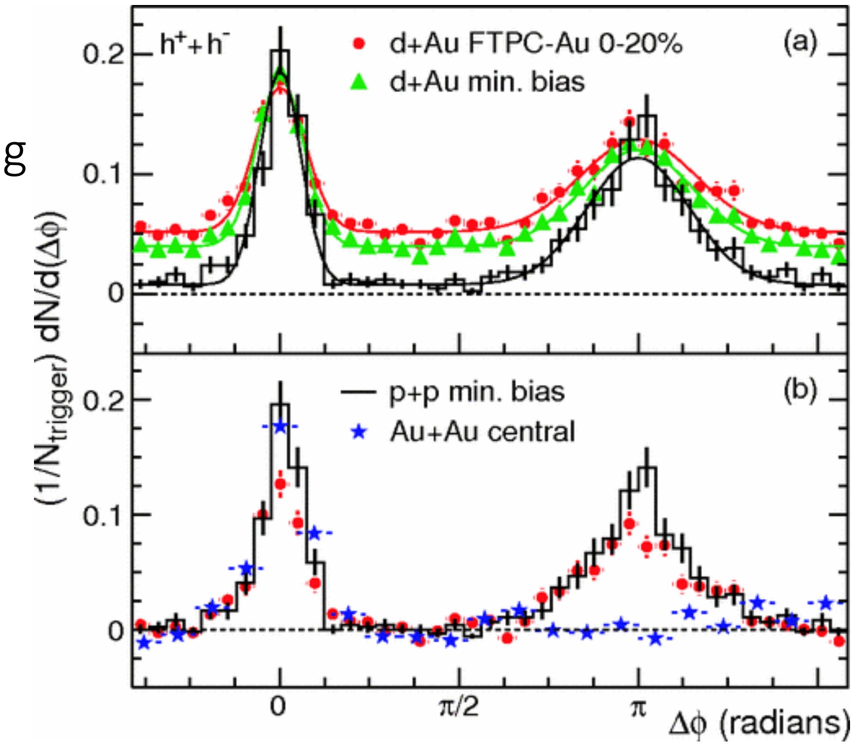

Most recent results on jet physics from STAR

- ✓ Di-jet imbalance
- ✓ Event-plane dependent measurements
- ✓ Semi-inclusive jet (triggered-jet)
- ✓ Jet flavor dependence
- ✓ Jet angular scale dependence

Various measurements can be connected to different aspects of jet properties

Introduction

Key Questions for more derivative jet-quenching observables

- Dependence on where the jet is produced inside of the medium?
- Path-length dependence in non-central collisions?
- Flavor dependence?
- Jet angular scale dependence?

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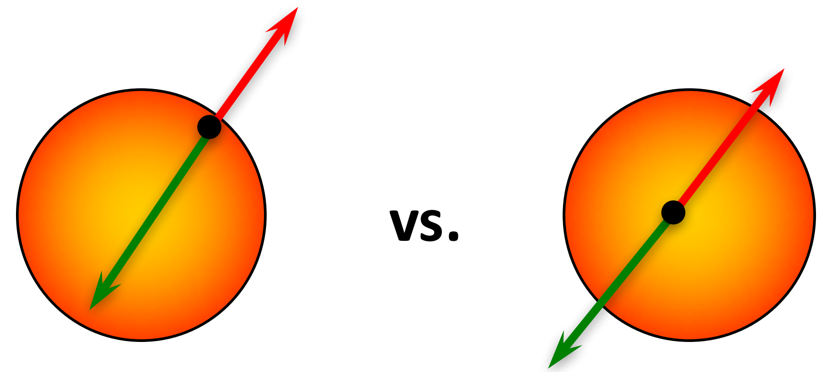

Di-jet imbalance from two situations?

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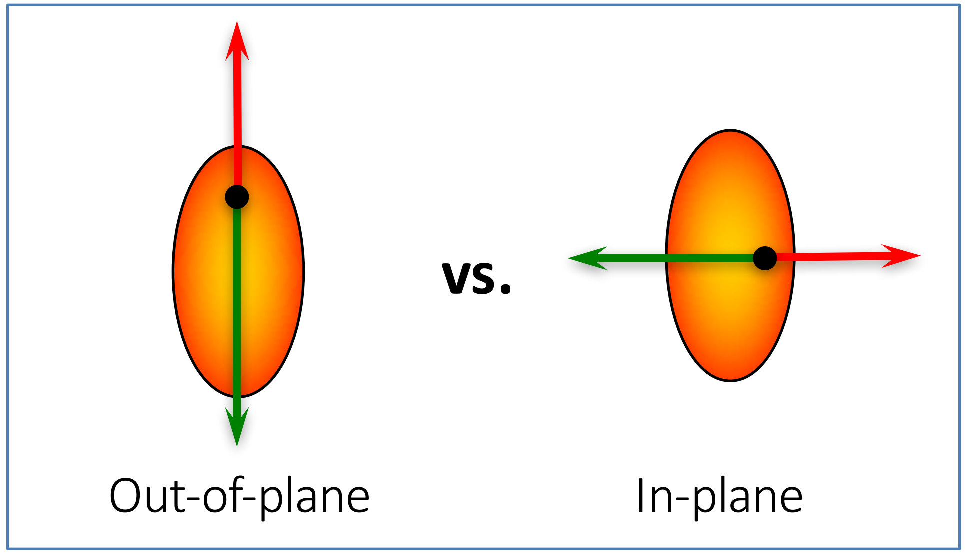

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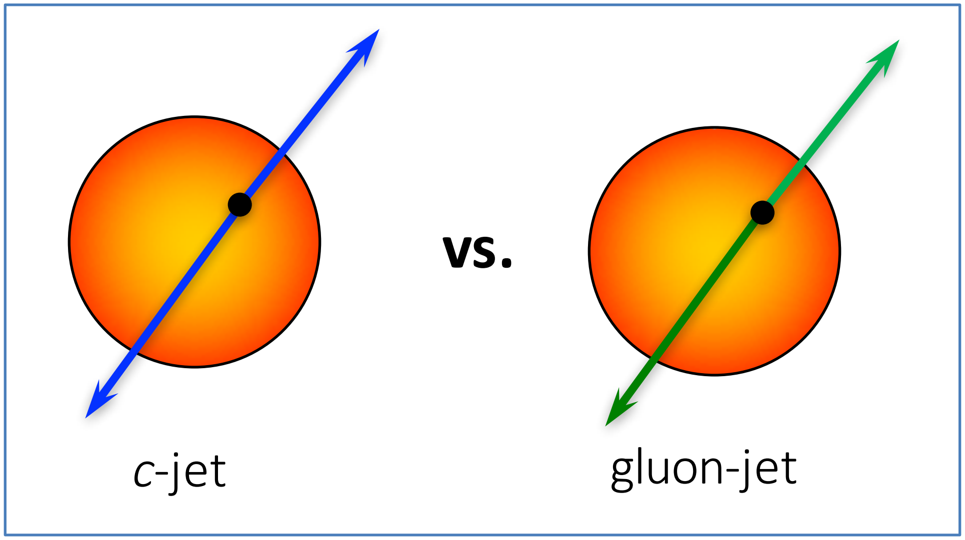

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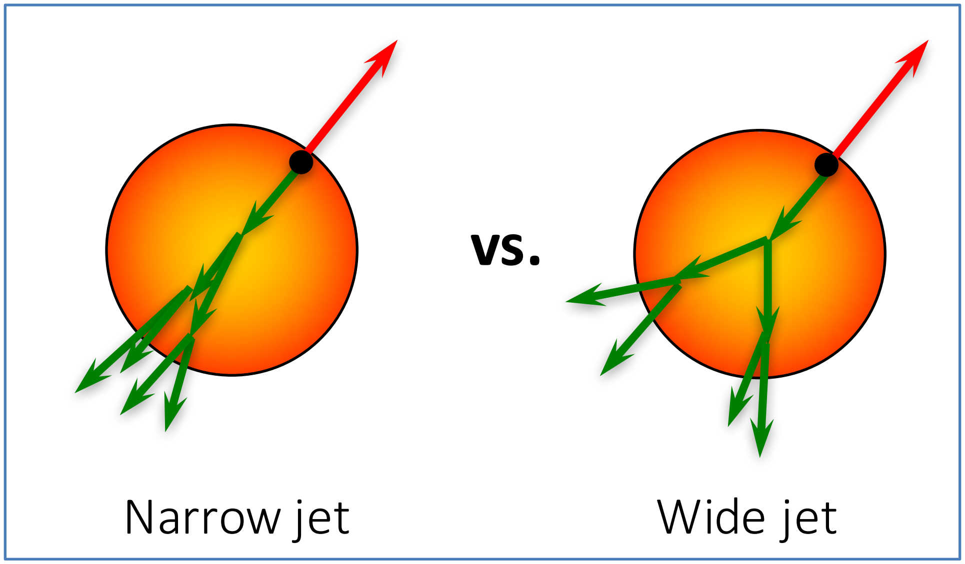
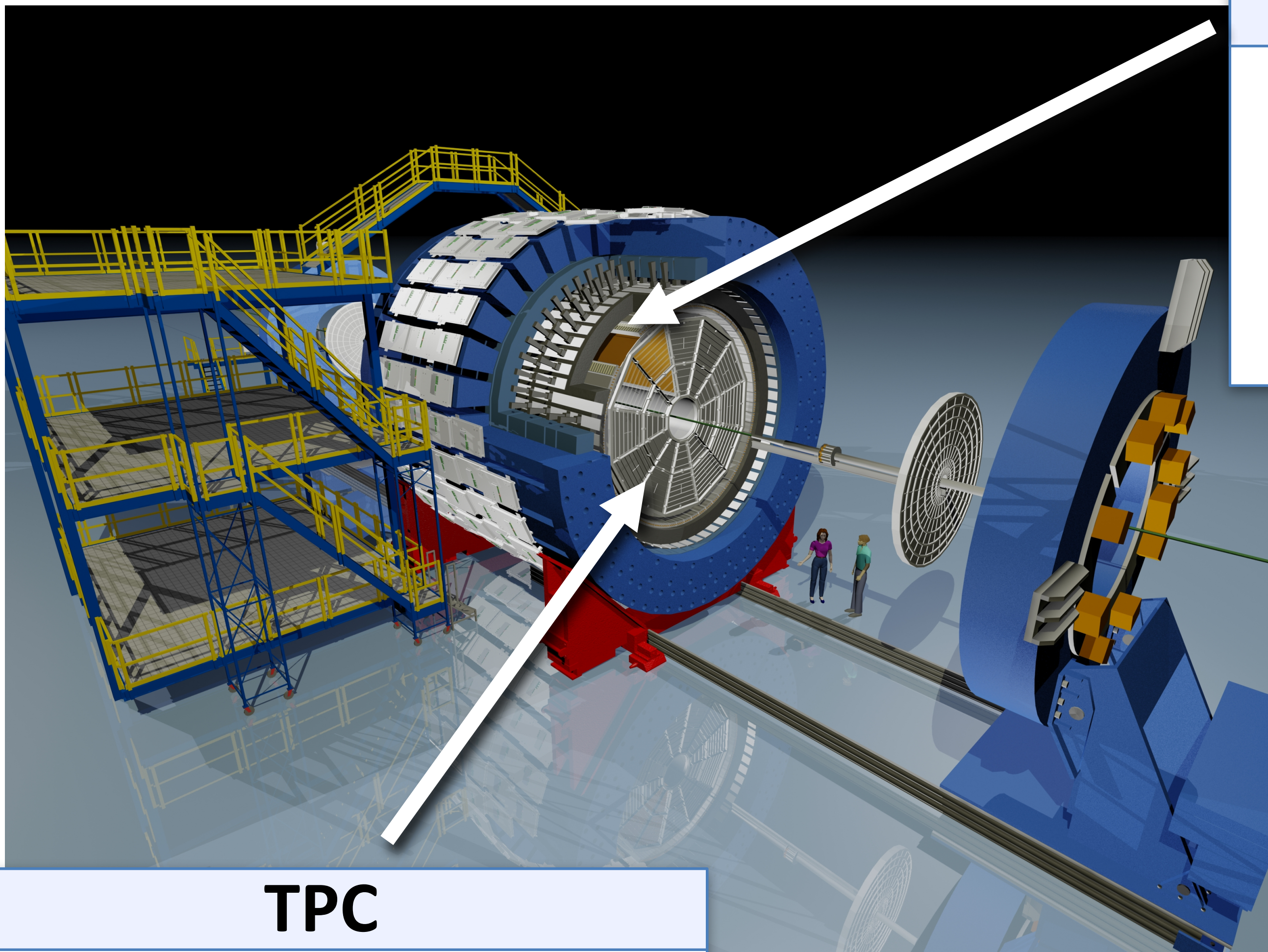


The Solenoidal Tracker At RHIC (STAR)



BEMC

- ✓ Barrel Electromagnetic Calorimeter
- ✓ $|\eta| < 1.0$, $0 < \varphi < 2\pi$
- ✓ Trigger

TPC

- ✓ Time Projection Chamber
- ✓ $|\eta| < 1.0$, $0 < \varphi < 2\pi$
- ✓ Tracking, momentum, dE/dx

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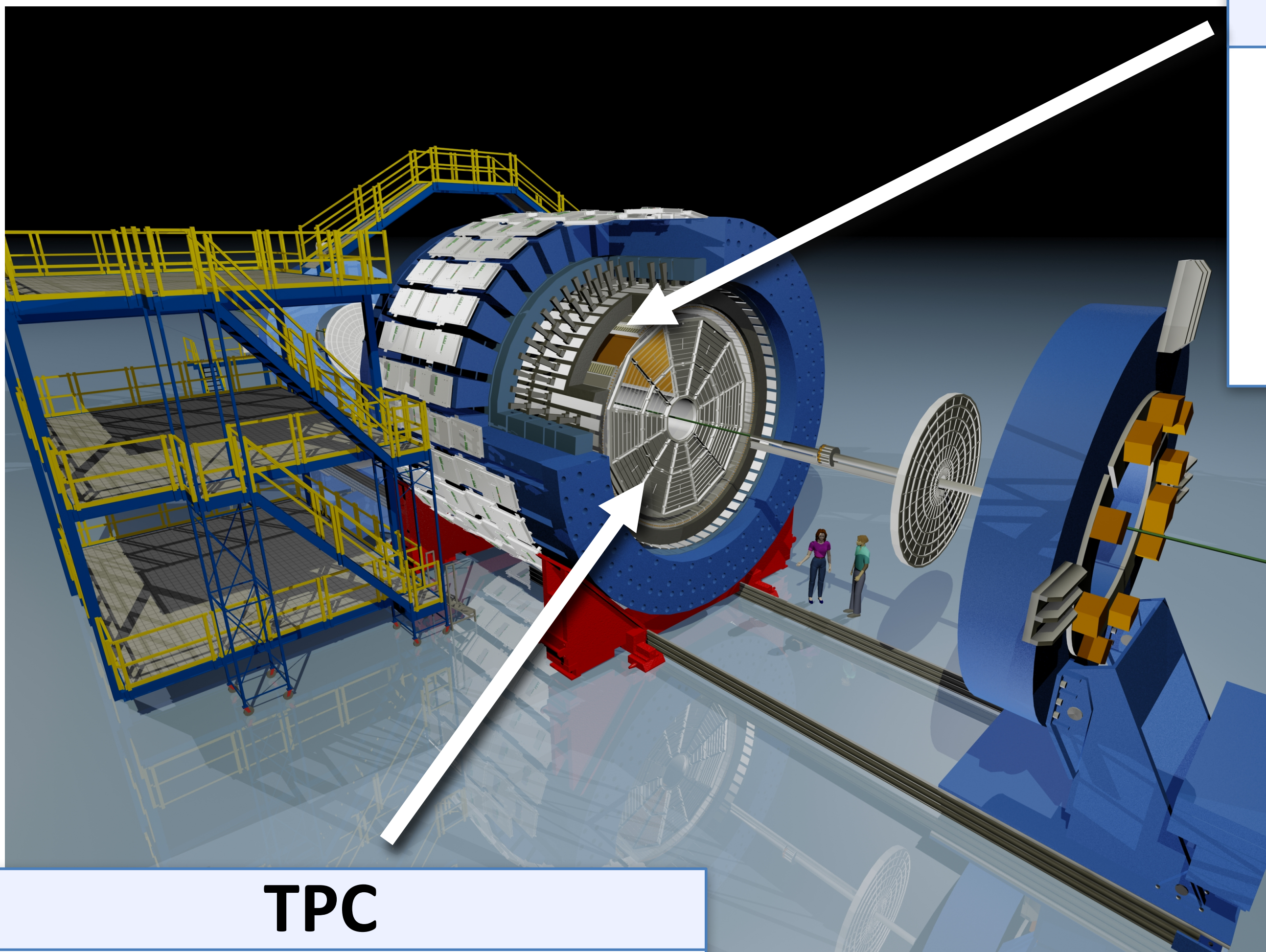

BEMC

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Neutral constituents

TPC

- ✓ Time Projection Chamber
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- ✓ Tracking, momentum, dE/dx

Charged constituents

Full Jet

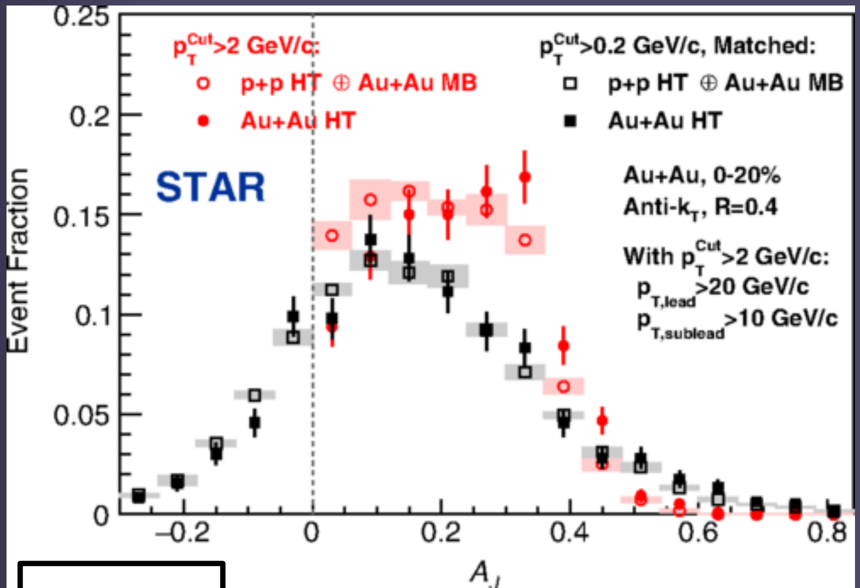
Charged Jet

Di-jet Imbalance

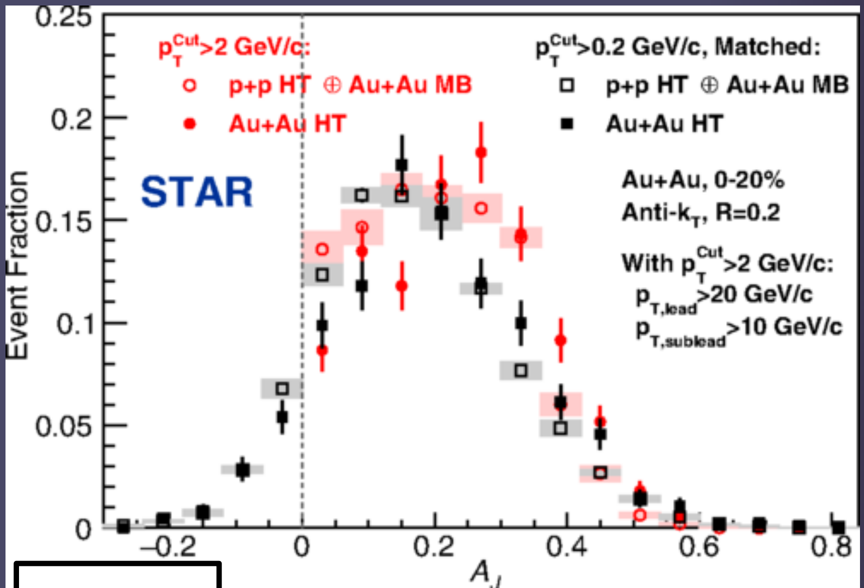
Di-jet Imbalance

- $A_J = \frac{p_T^{Lead} - p_T^{SubLead}}{p_T^{Lead} + p_T^{SubLead}}$
- **Hard-core jet** vs. **Matched jet**

STAR, Phys. Rev. Lett. **119** (2017) 062301



R=0.4



R=0.2

- For $R = 0.4$ hard-core jet, more di-jet momentum imbalance compared to p+p
- Balance recovered when soft constituents are included (matched-jet)
- For $R = 0.2$, balance no longer recovered in matched-jet
  - ✓ **Softening** of jet constituents and **Broadening** of the jet structure

Di-jet Imbalance

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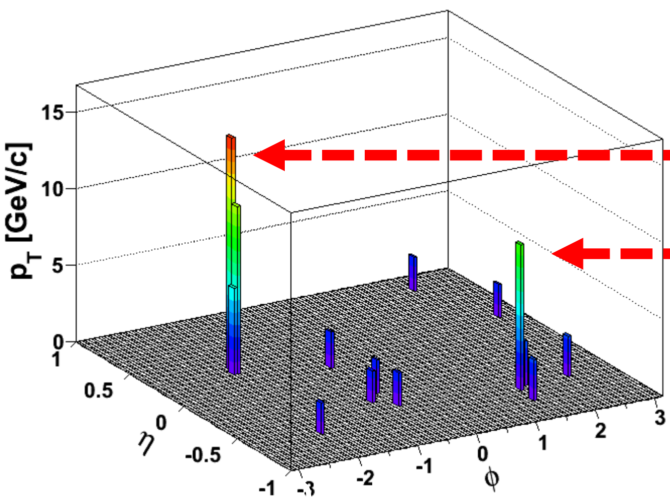
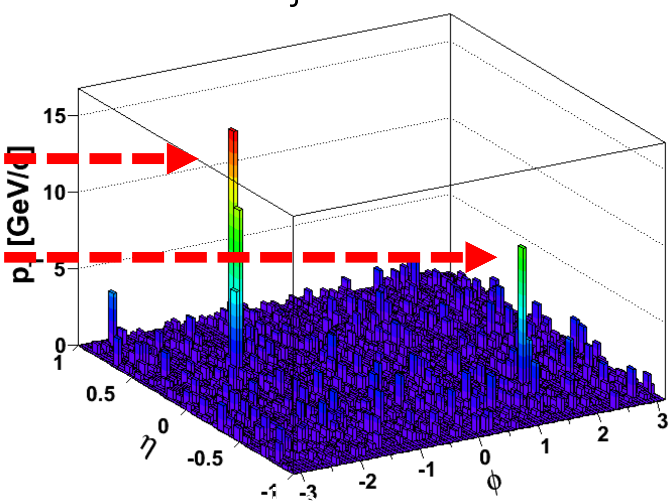
ST… Rev. Lett. **119** (2017) 062301

- Constituent p_T^{Cut} = 2 GeV/*c*
- Reduce BG and combinatorial jets



- Constituent p_T^{Cut} = 0.2 GeV/*c*
- Geometrically matched to the hard-core jet



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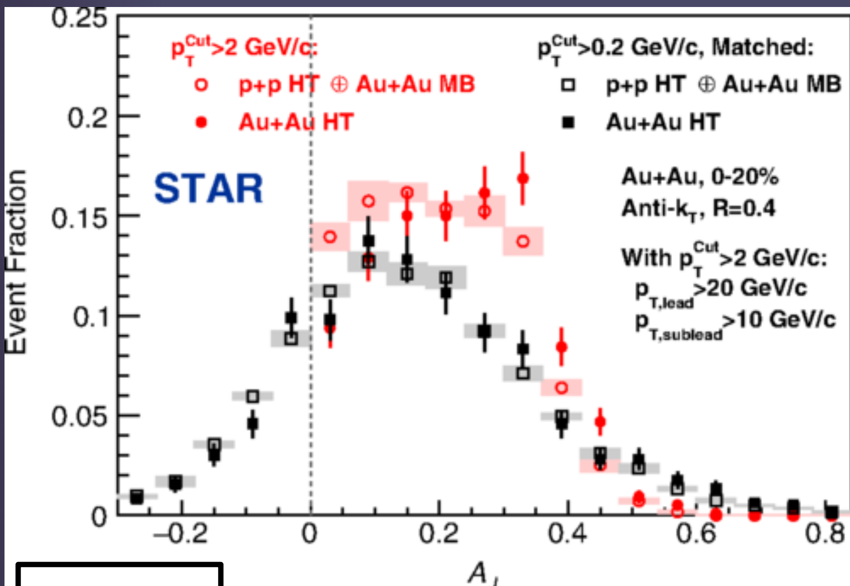

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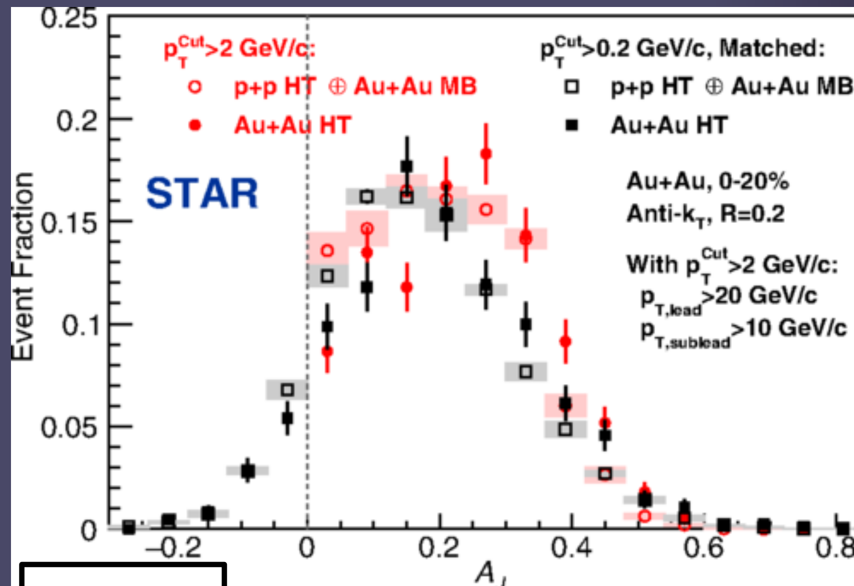

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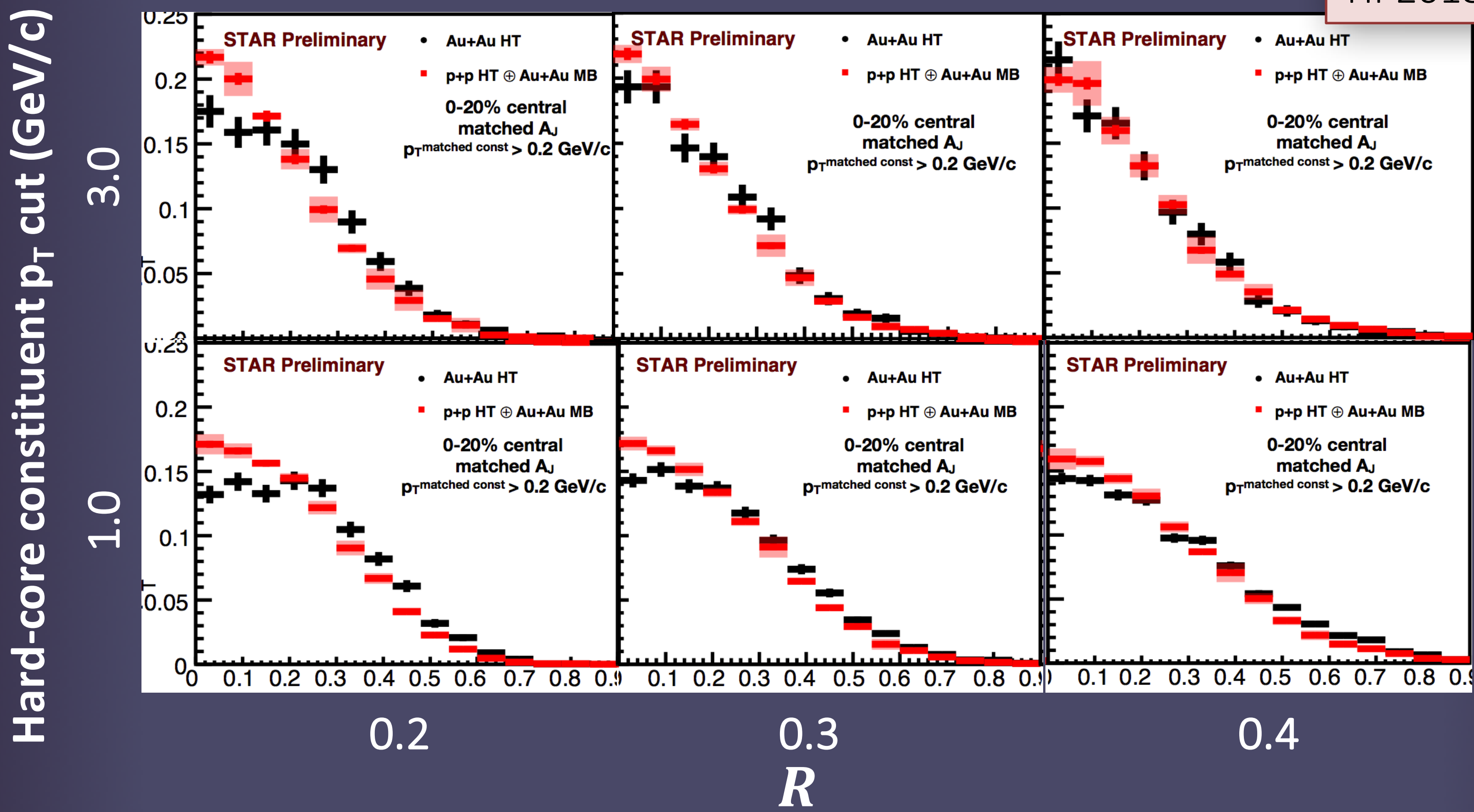
Di-jet Imbalance

- Varying the jet definition (R, constituent p_T cut, …) effectively controls the path length of jets in the medium (Jet Geometry Engineering)

HP2018



- Matched jet with various hard-core constituent p_T cut and R
  - ✓ Imbalance at small R
  - ✓ Balance ONLY restored with increased R (~0.35) when soft particles are included

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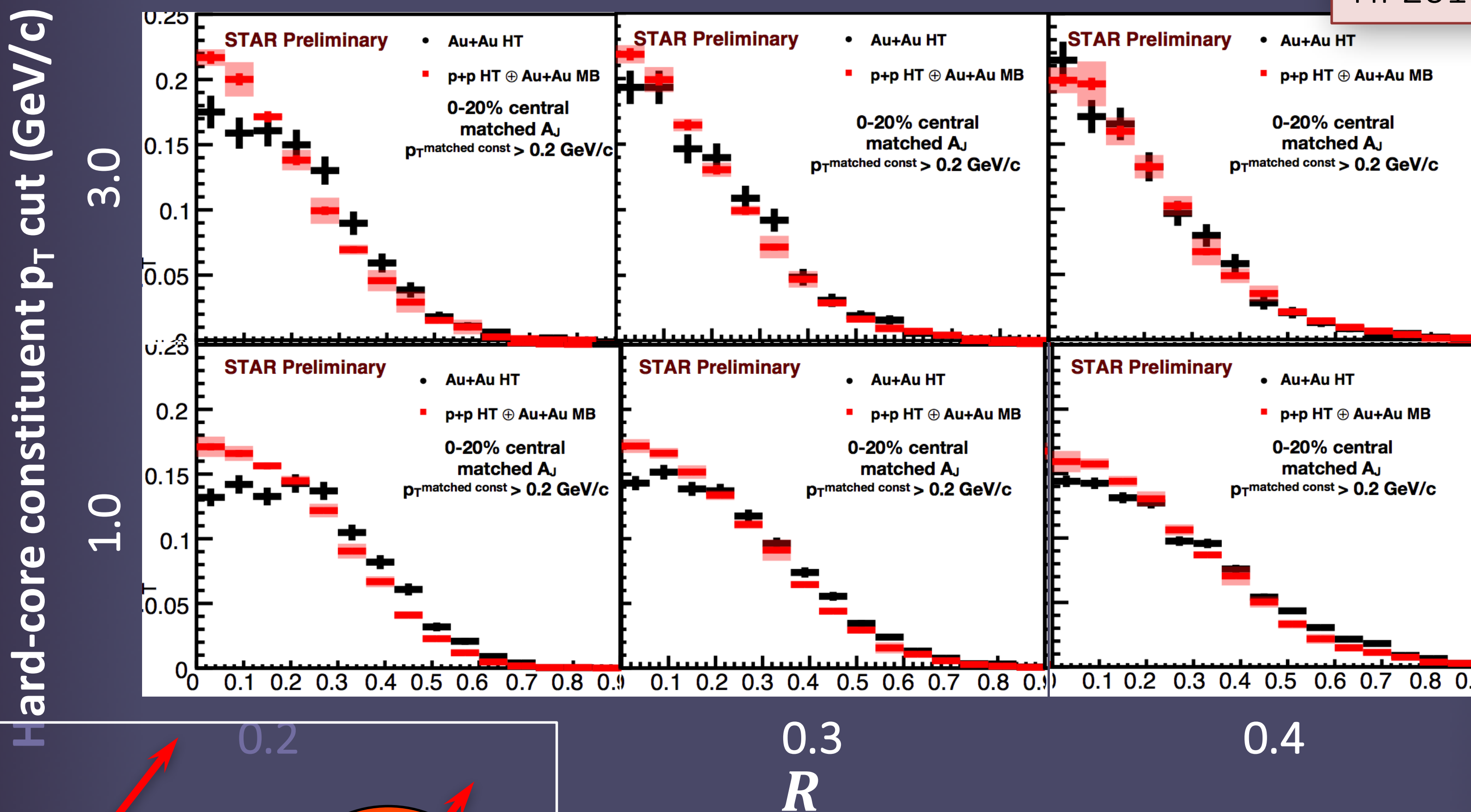
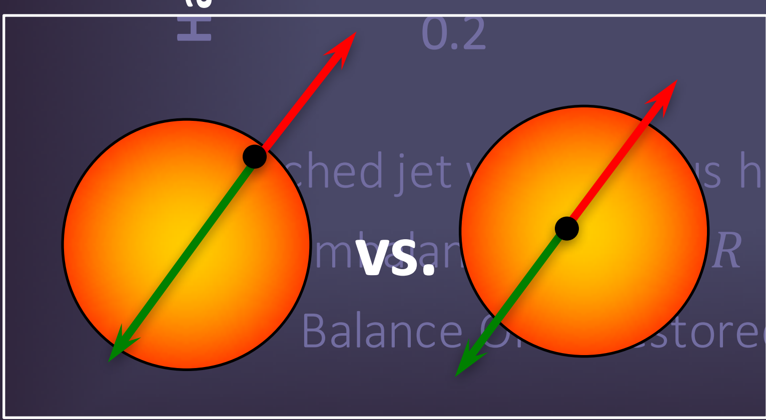
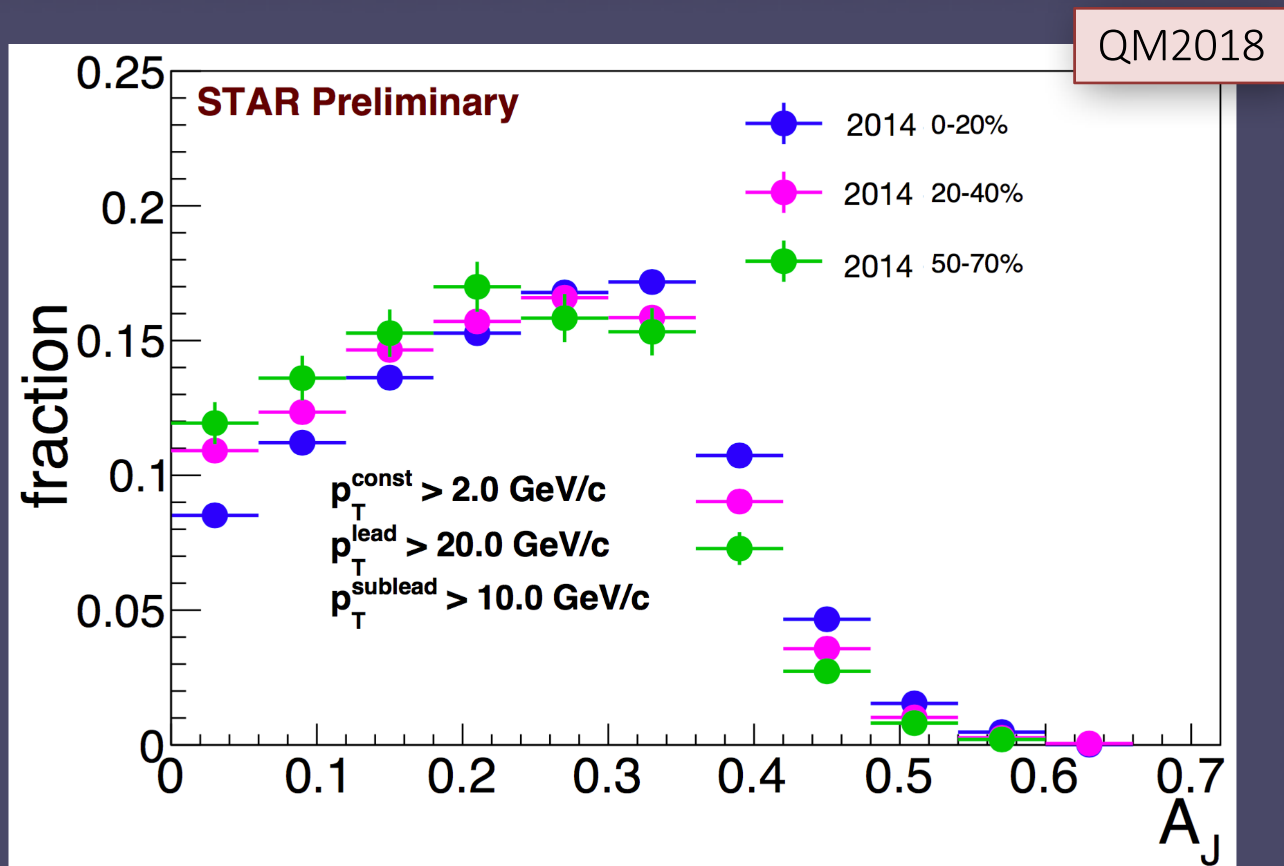




Balance … stored with increased R (~0.35) when soft particles are included

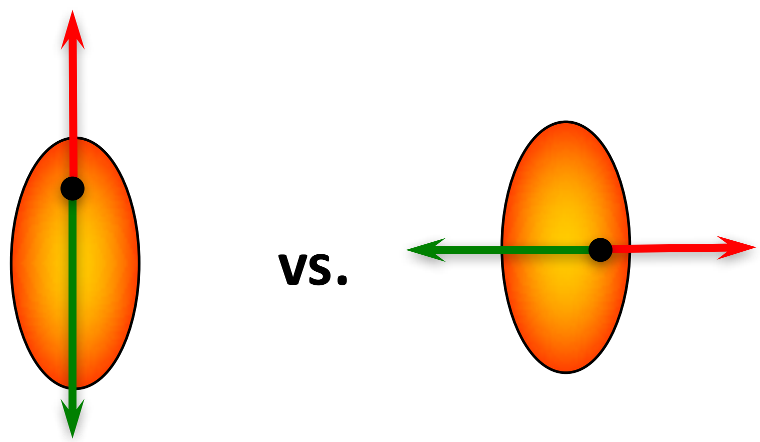
Jet Geometry Engineering Works!

Di-jet Imbalance



- More differential measurements with the help of increase in statistics with recent RHIC runs
- Centrality dependence of A_J – More balanced in peripheral Au+Au collisions

Event-plane Dependent Measurements

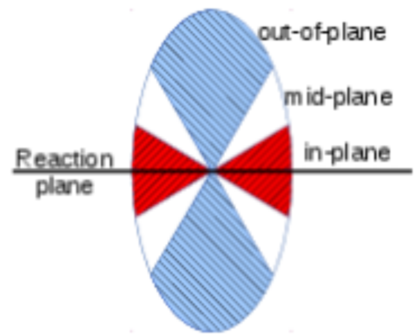


Out-of-plane In-plane

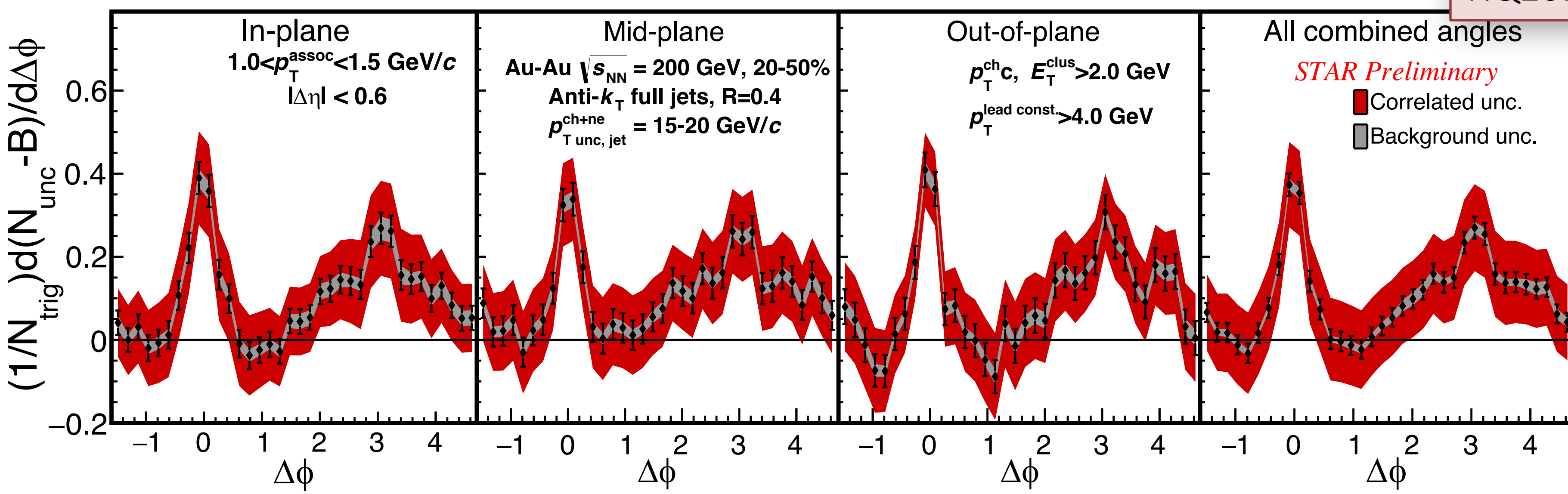
Event-plane Dependent Jet-hadron Correlations

- Previous jet-hadron correlations by STAR (Phys. Rev. Lett. 112 (2014) 122301)
  - ✓ Suppression of high-p_T associated particle yield is balanced by low p_T associated particle enhancement

- More differential measurement using the trigger jet angle with respect to the event plane
  - ✓ In-plane, mid-plane, and out-of-plane

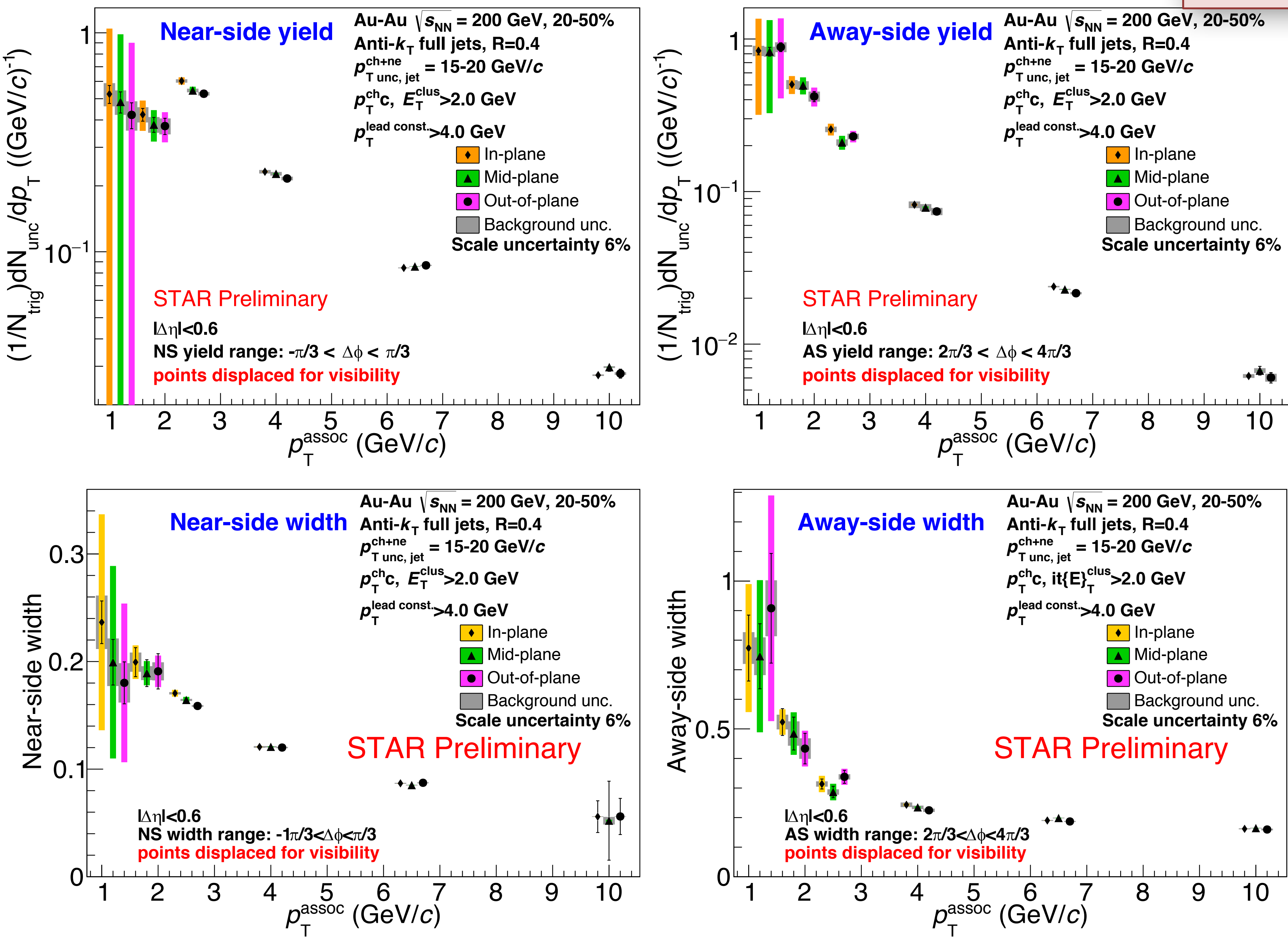


HQ2018



Event-plane Dependent Jet-hadron Correlations

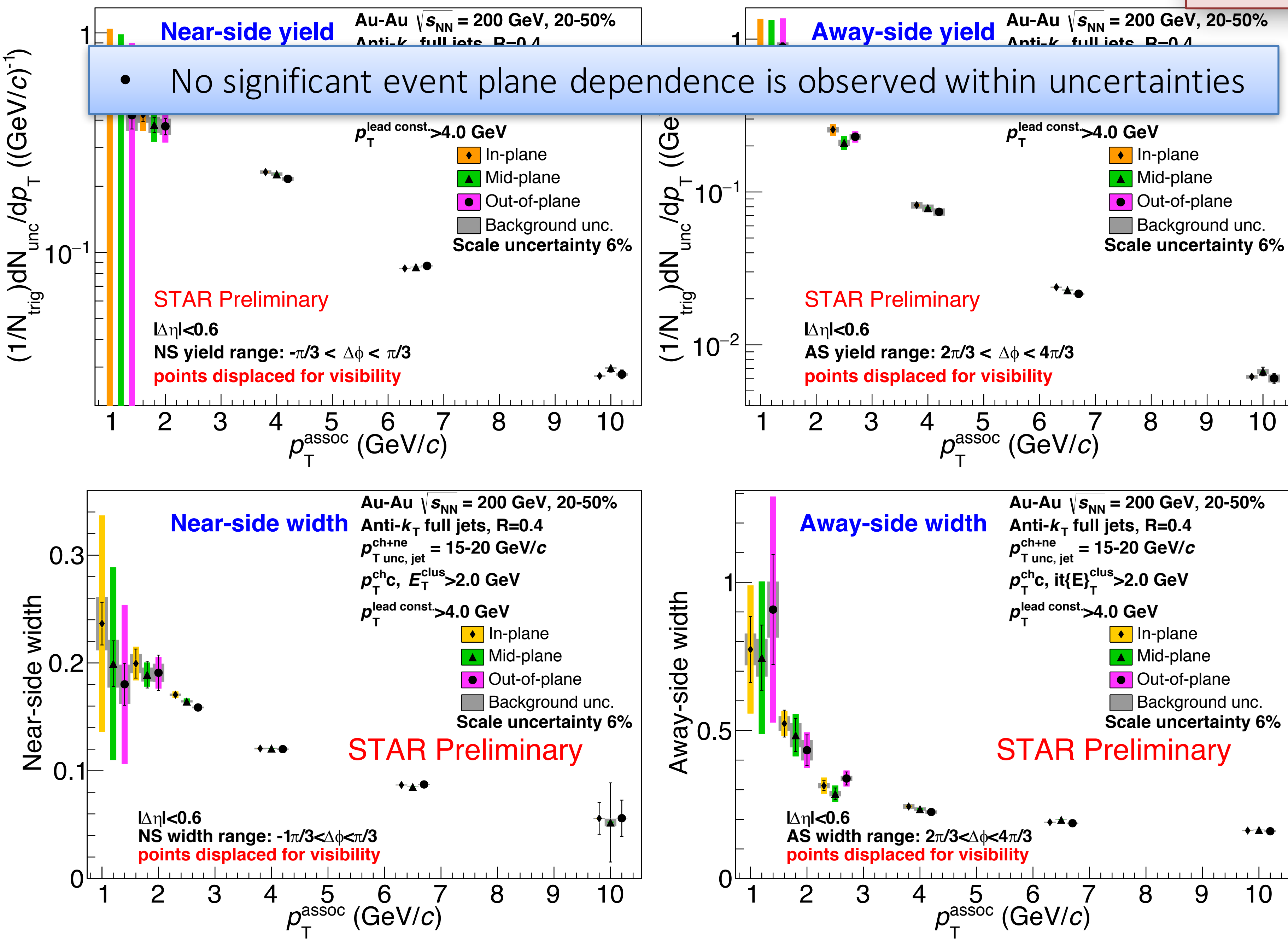
HQ2018



Event-plane Dependent Jet-hadron Correlations

HQ2018

- No significant event plane dependence is observed within uncertainties



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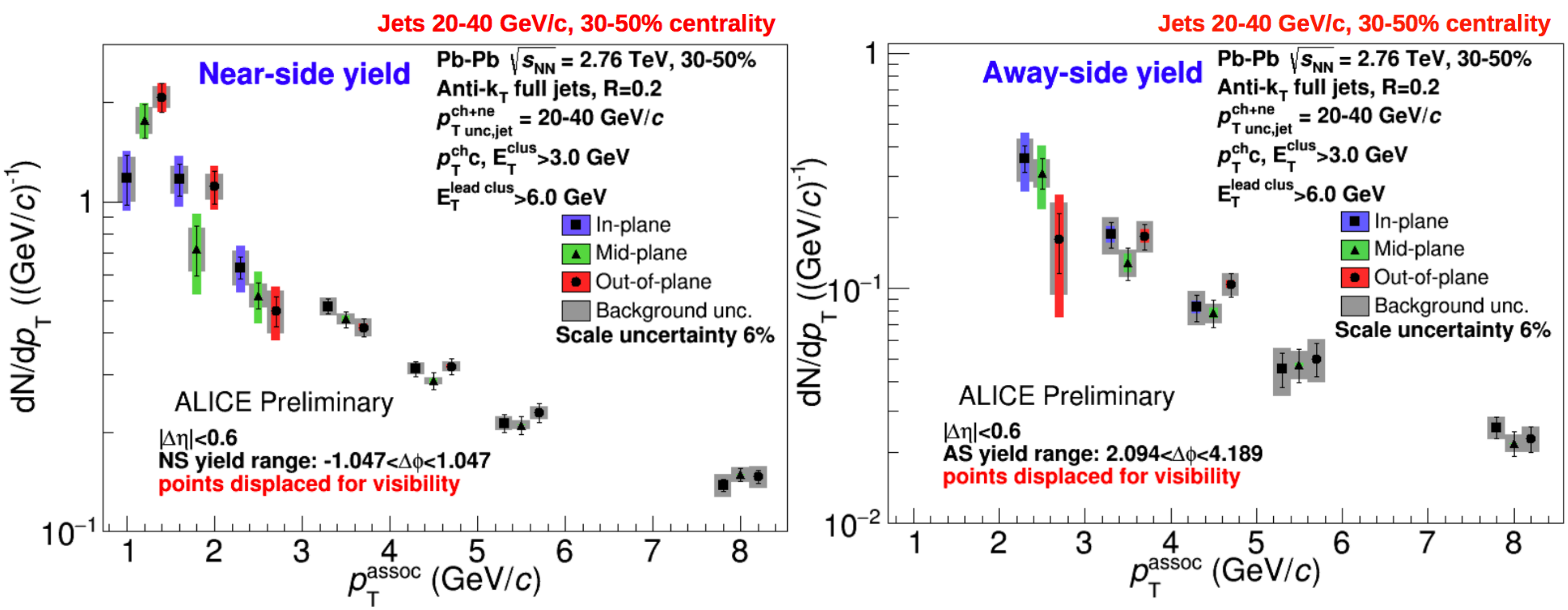
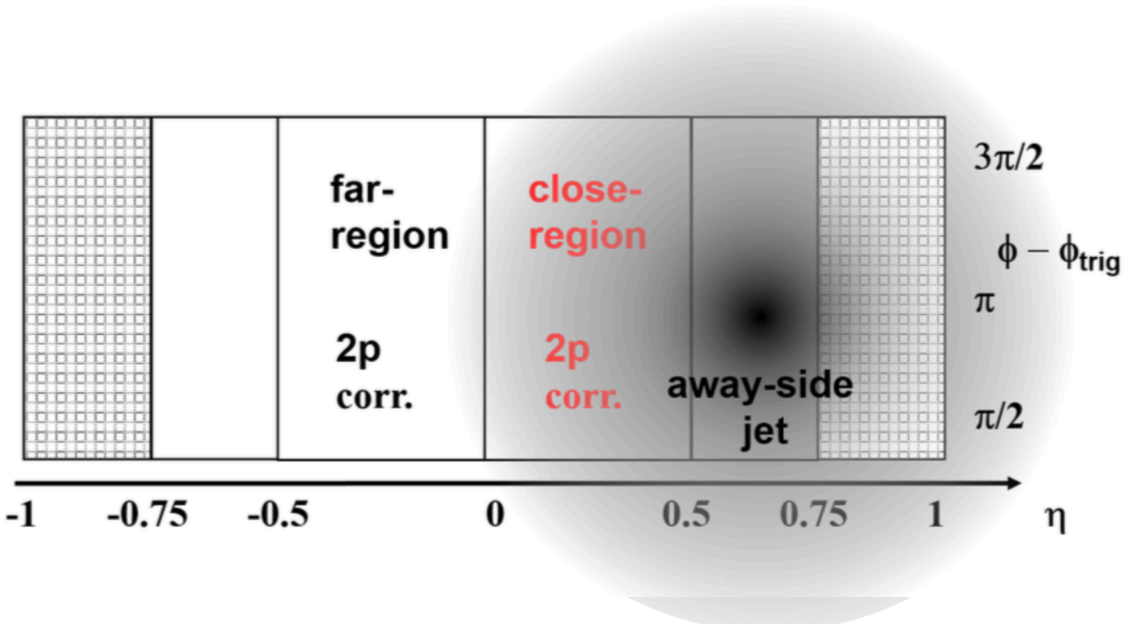
Consistent with LHC results



Event-plane Dependent Di-hadron Correlations – Recoil Width

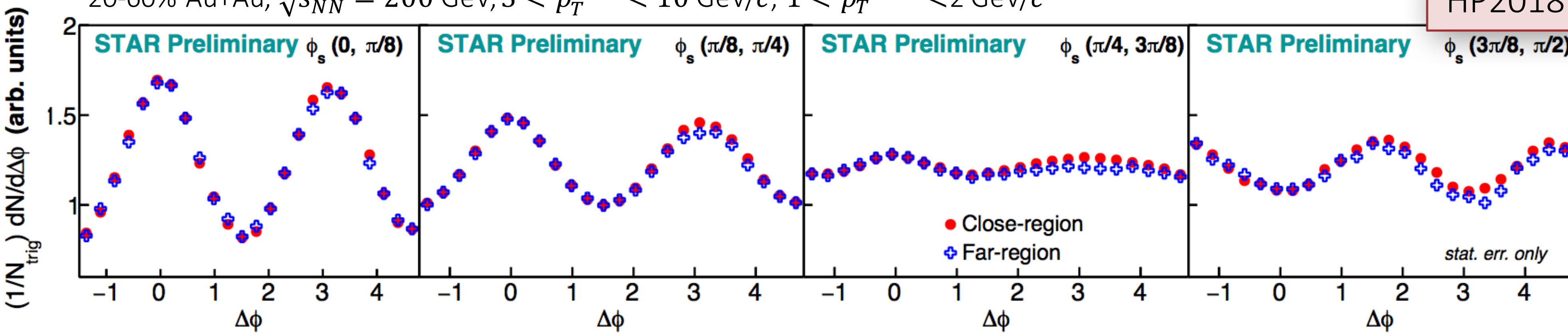


- After selecting events with high recoil momentum within $0.5 < \eta < 1.0$, two-particle correlation functions in **close-region** and **far-region**, separately

- Under the assumption that the flow contribution is equal in two regions, the difference between **close-region** and **far-region** correlation functions provides information on **away-side width** of jet-like correlations without the flow contribution

20-60% Au+Au, $\sqrt{s_{NN}} = 200$ GeV, $3 < p_T^{trig} < 10$ GeV/c, $1 < p_T^{assoc} <$ 2 GeV/c

HP2018



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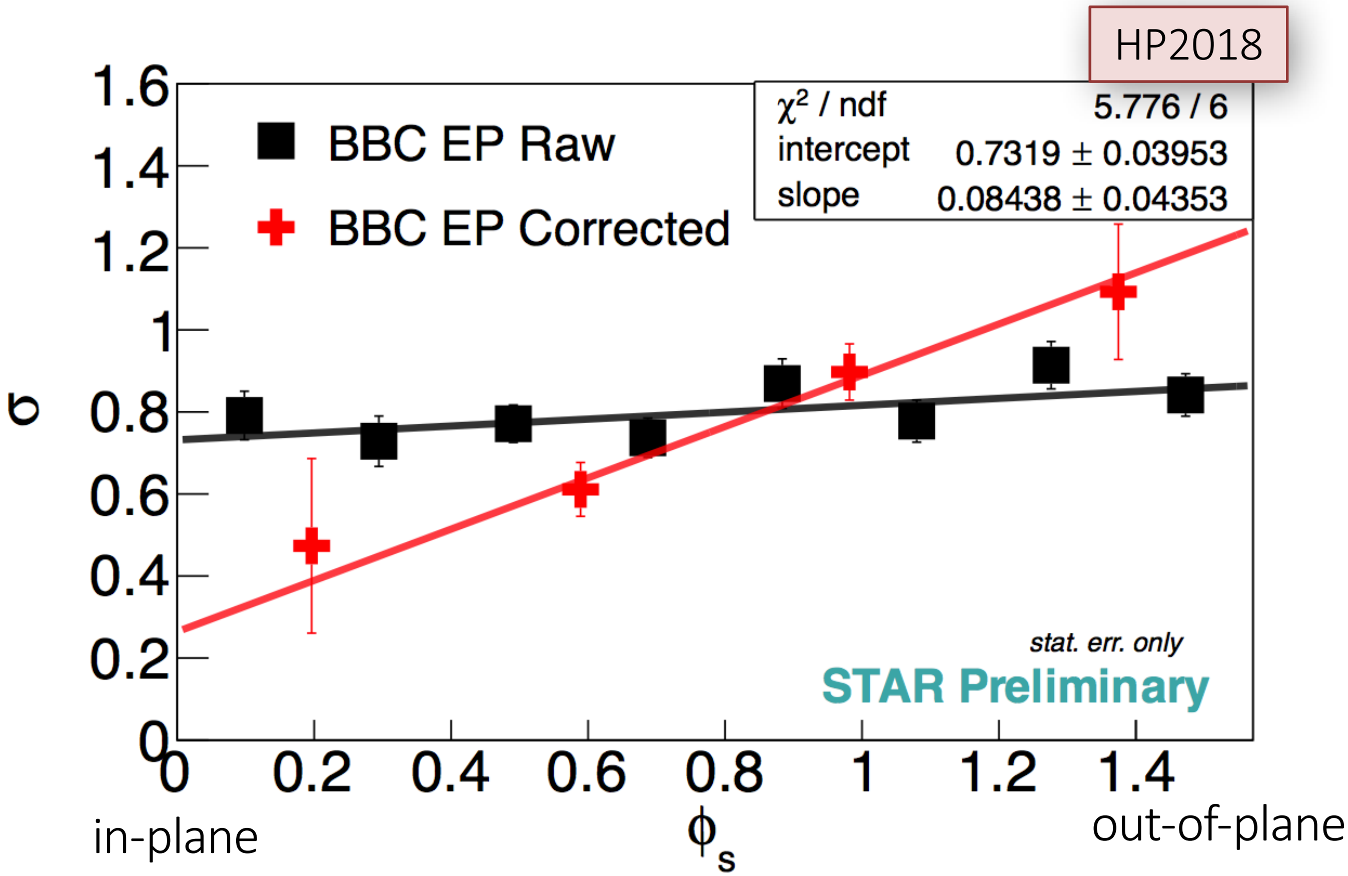
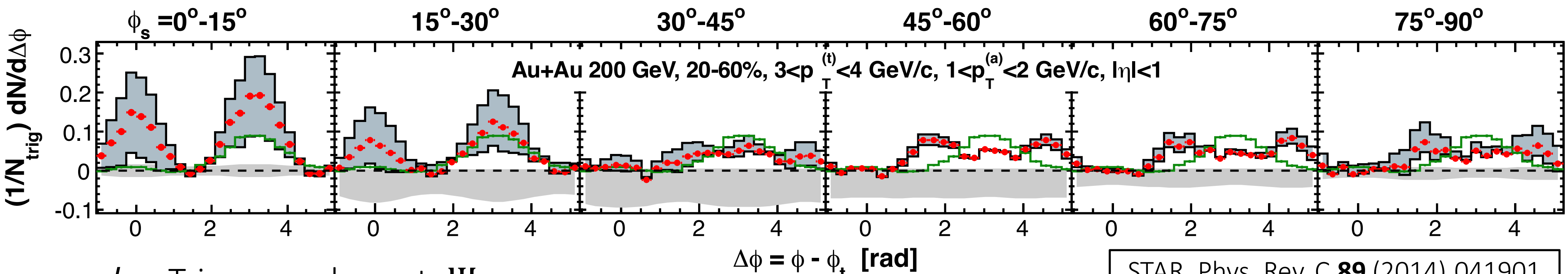


- Depending on the trigger particle angle with respect to the event plane ($= \phi_s$), the difference of two-particle correlation functions shows different away-side widths ($= \sigma$) after correcting for the EP resolution
- Larger width for out-of-plane triggers – indication of jet-medium interactions

Event-plane Dependent Di-hadron Correlations with ESE

- Previous event-plane (EP) dependent di-hadron correlations
  - ✓ Implication of path-length dependence of energy loss in the medium (**shorter** path-length for in-plane trigger and **longer** path-length for out-of-plane trigger)

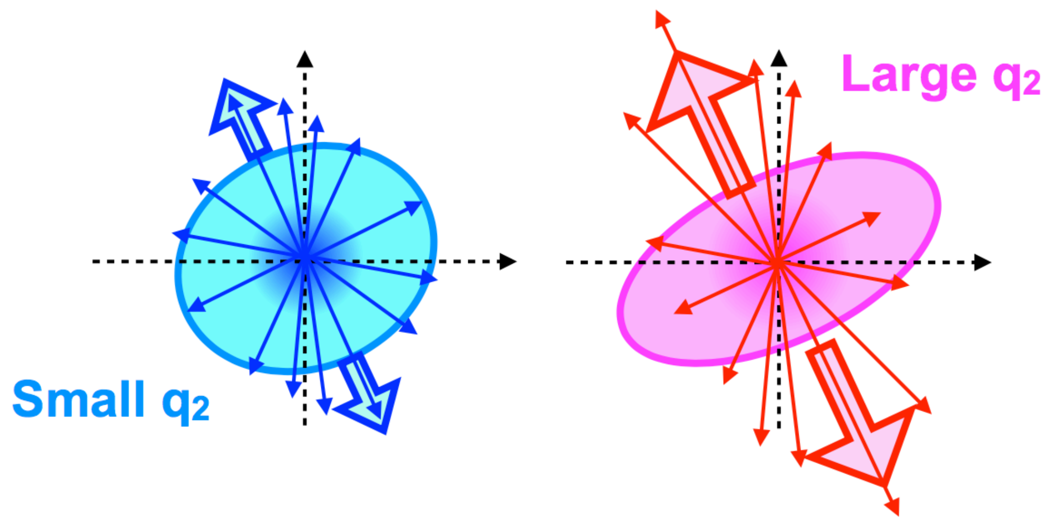
in-plane ⟷ out-of-plane



STAR, Phys. Rev. C **89** (2014) 041901

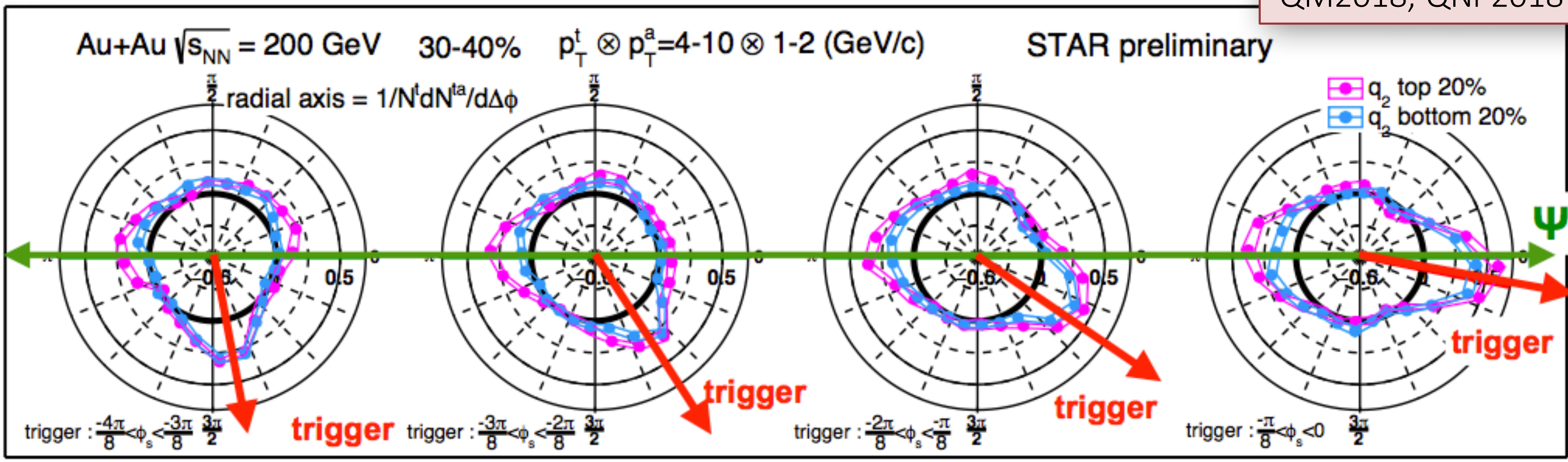
ϕ_s : Trigger angle w.r.t. Ψ_{EP}

- Event shape engineering (**ESE**) can further control the initial geometry with the fixed average energy density – Measurements in small-q_2 and large-q_2 events separately

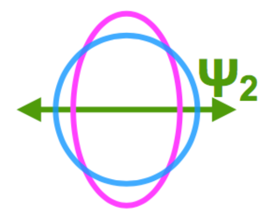


Event-plane Dependent Di-hadron Correlations with ESE

QM2018, QNP2018



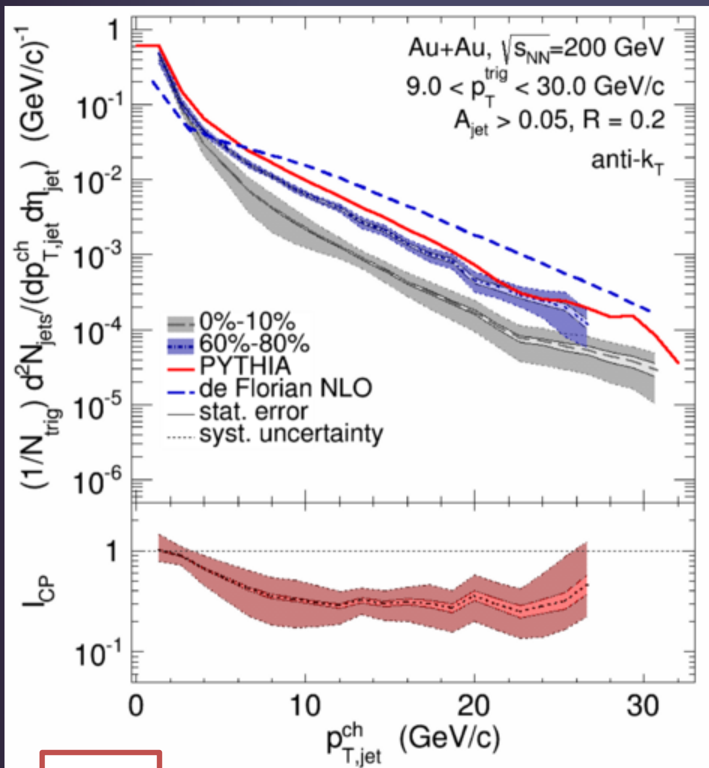
- Polar representation of two-particle angular correlations
- **Near-side** – Higher peak in large-q_2 events with **in-plane** trigger
- **Away-side**
  - ✓ Larger associated particle yields toward in-plane direction
  - ✓ Higher peak in large-q_2 events with **in-plane** trigger
    - ➪ Consistent with path-length dependent picture?



Semi-inclusive Spectra

h-Triggered Recoil Jets

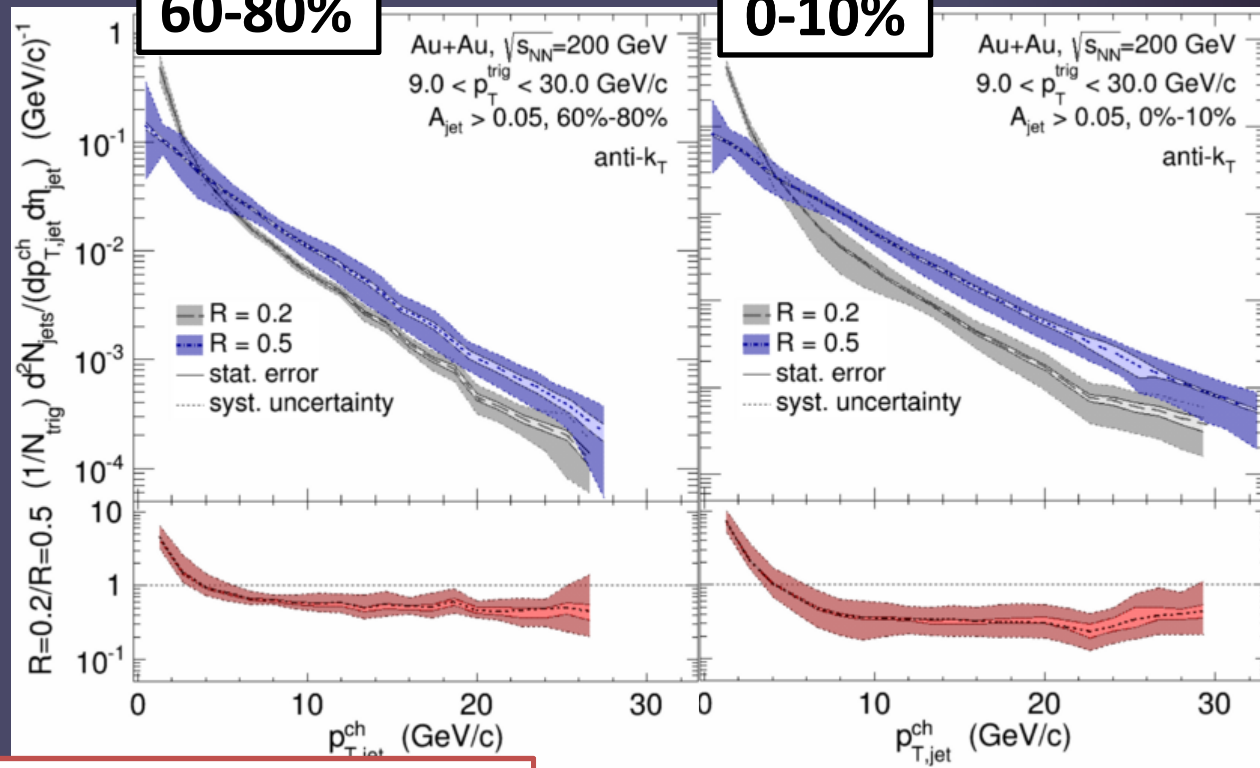
STAR, Phys. Rev. C **96** (2017) 24905



I_{CP}

60-80%

0-10%



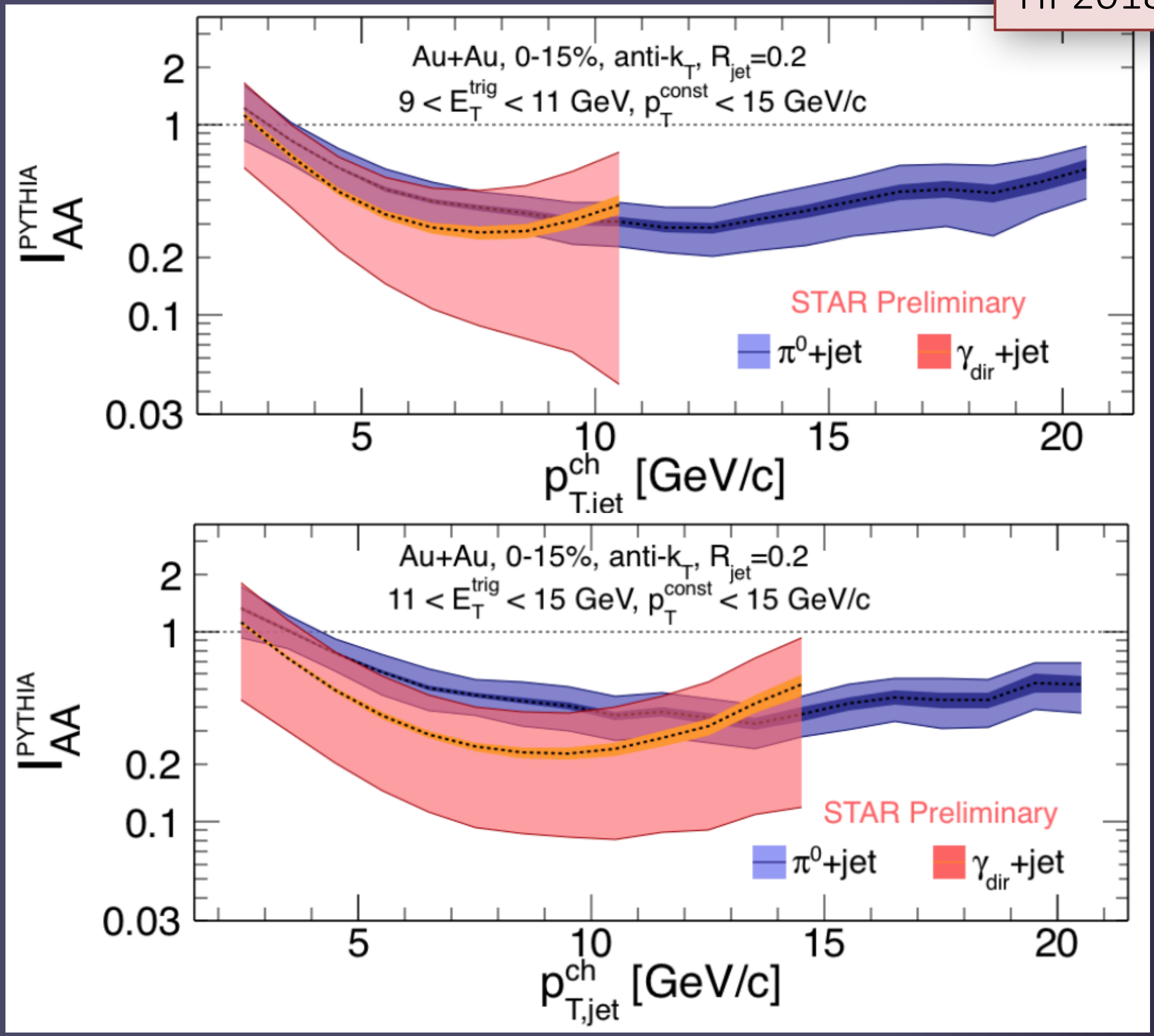
R=0.2 vs. R=0.5

- Fully corrected $h^{\pm}$-triggered charged recoil jet
  - ✓ Strong suppression via I_{CP}
  - ✓ Medium-induced broadening ⇦ Comparison between $R = 0.2$ and $R = 0.5$

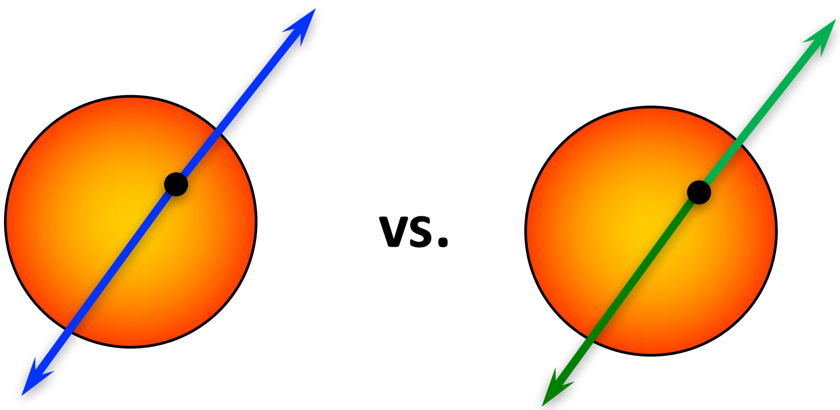
γ-Triggered Recoil Jets

- γ_{dir}+jet and π^0+jet
  - ✓ Path length
  - ✓ Color factor
  - ✓ Parton energy
- Similar level of suppression observed

HP2018



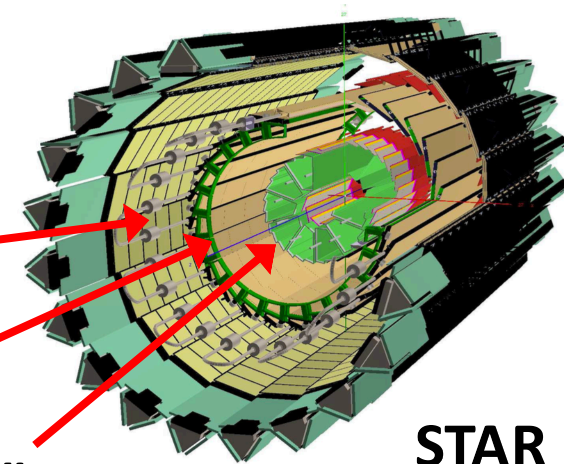
Jet Flavor Dependence



c-jet gluon-jet

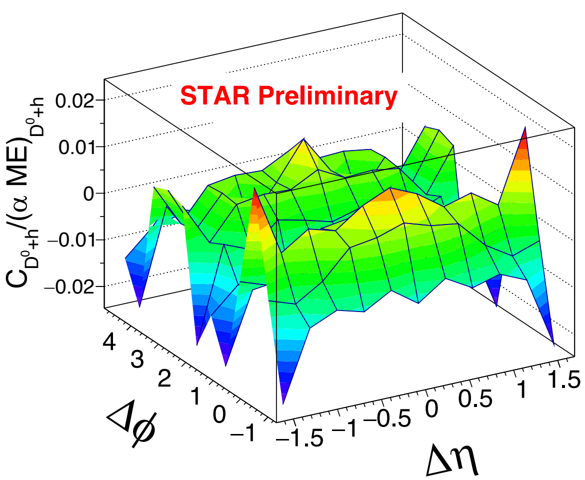
D^0-hadron Correlations

- Heavy Flavor Tracker (HFT) provides significantly better identification of heavy-flavor particles
- D^0-hadron two-particle angular correlations with $D^0 \rightarrow \pi^{\pm}K^{\mp}$ channel

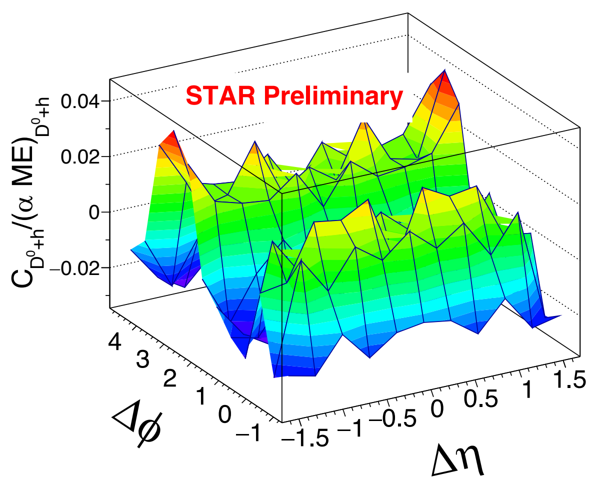


HP2018

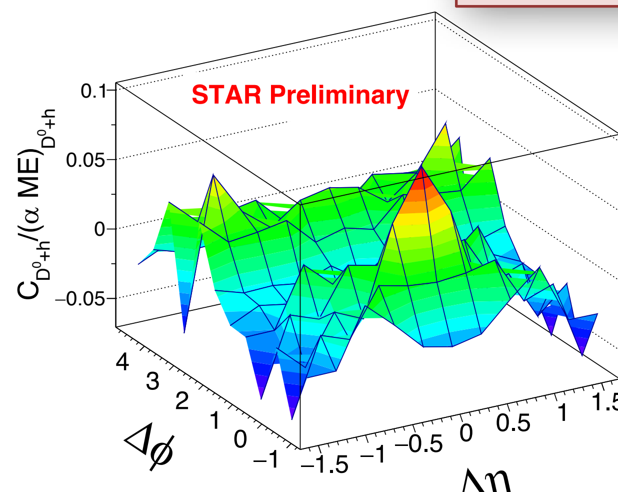
Au+Au, $\sqrt{s_{NN}} = 200$ GeV, D^0 $p_T = 2$–10 GeV/c, $h^{\pm}$ $p_T > 0.15$ GeV/c



0-20%

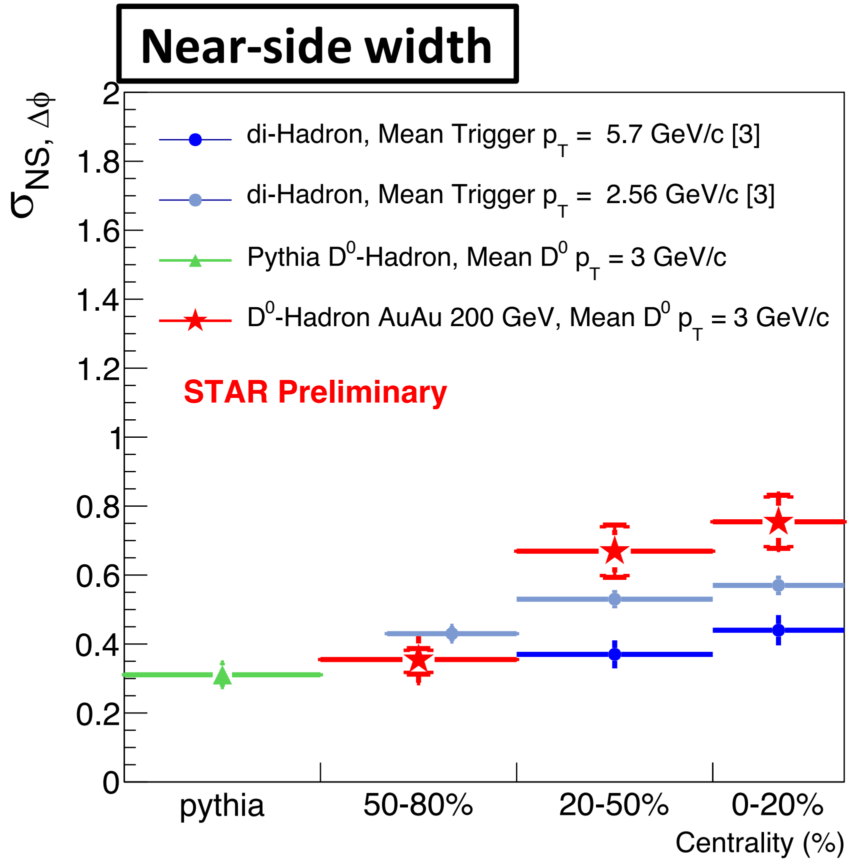


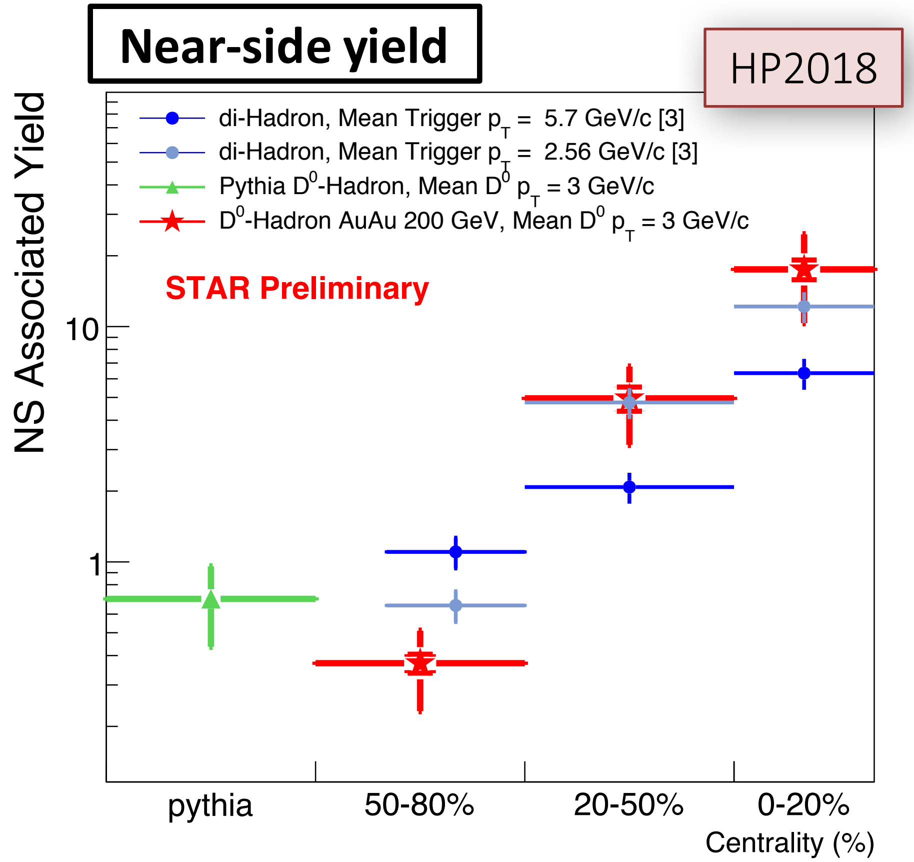
20-50%



50-80%

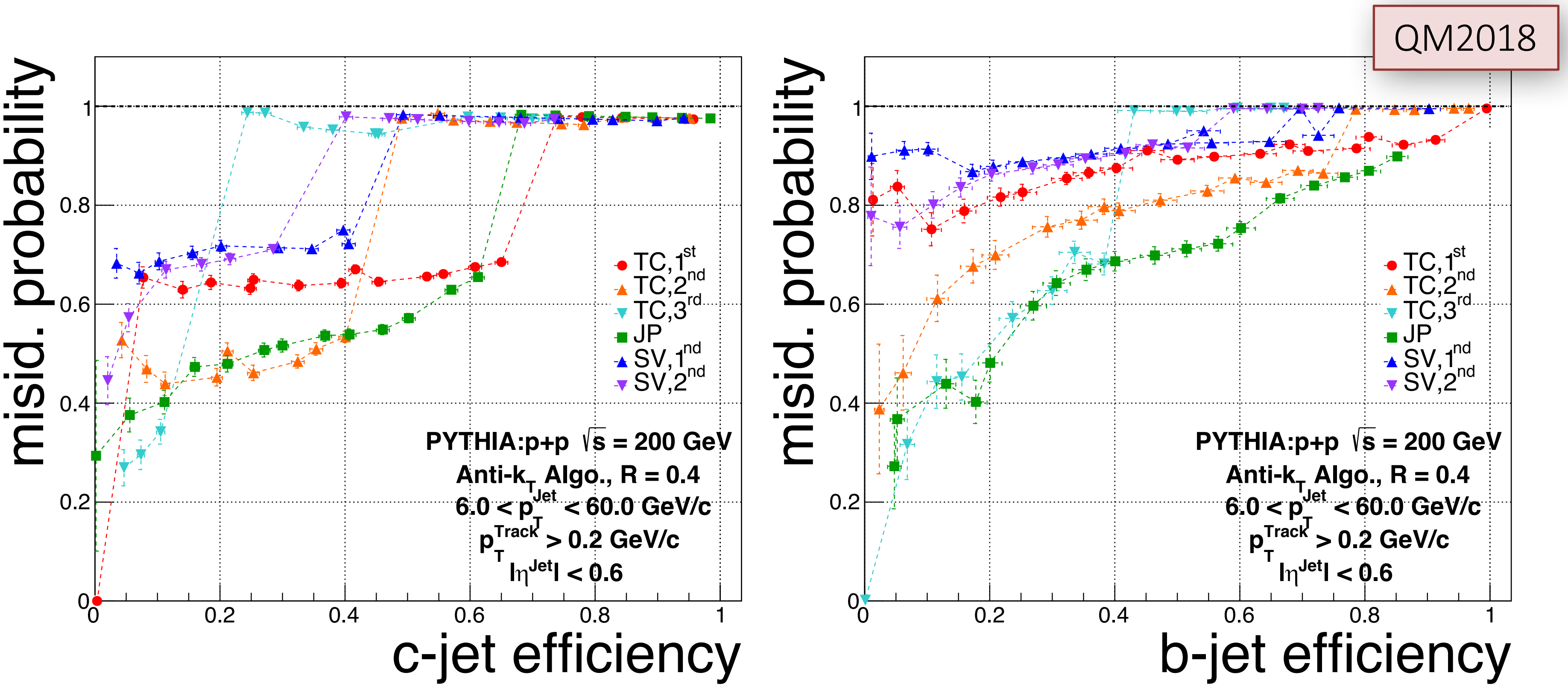
D^0-hadron Correlations





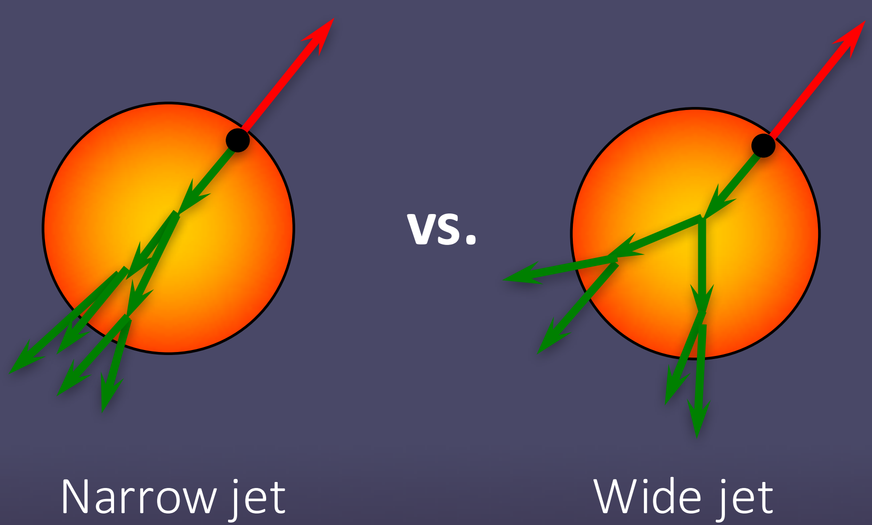
- Similar width and yield results to light-flavor correlations – Indication of similar behavior of correlations between light-flavor and *c*

Heavy-flavor Jet Tagging in p+p



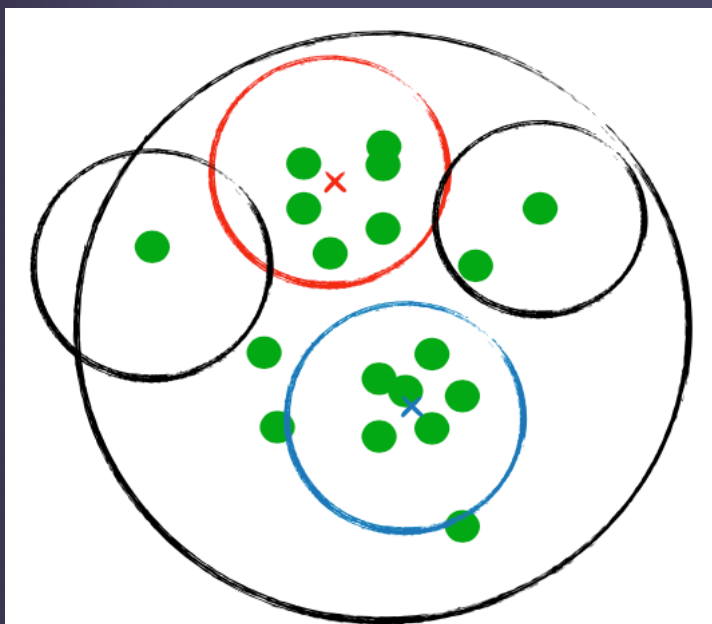
- Heavy-flavor jet tagging performance in p+p with low-level tagging algorithms
- Possibility of future heavy-flavor tagged jet analysis in STAR with HFT

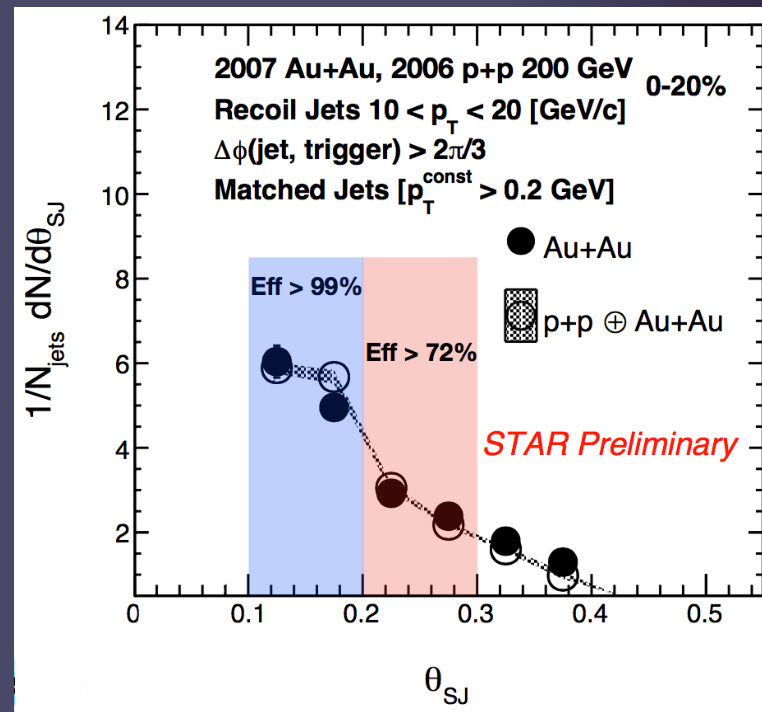
Jet Angular Scale Dependence



Jet Angular Scale Dependence

- Interaction of the jet with medium could depend on the jet's angular scale
  Majumder, A and Putschke, J Phys Rev C 93 054909
  Mehtar Tani, Y and Tywoniuk, K arXiv:1707.07361





- Clustering all constituents into smaller radius jets ($R = 0.1$) → leading and subleading subjets
- θ_{SJ} = ΔR(LeadingSJ axis, SubleadingSJ axis)

Jet classification based on θ_{SJ}

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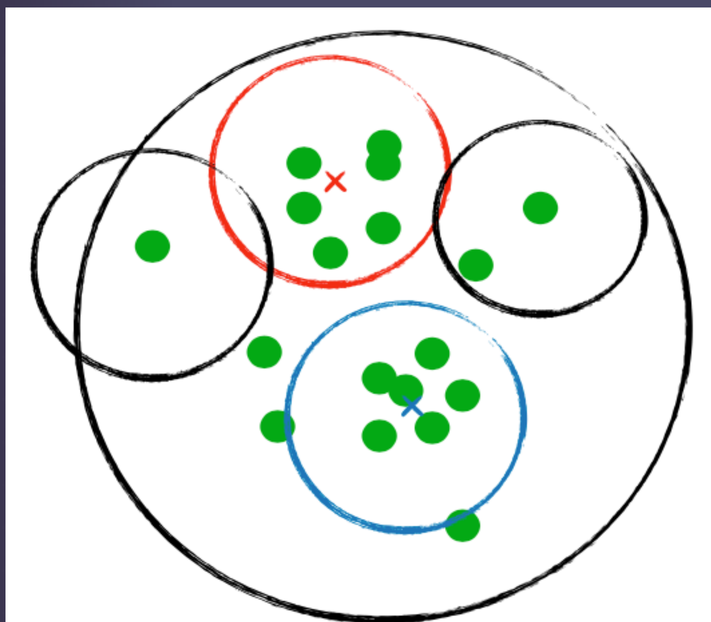

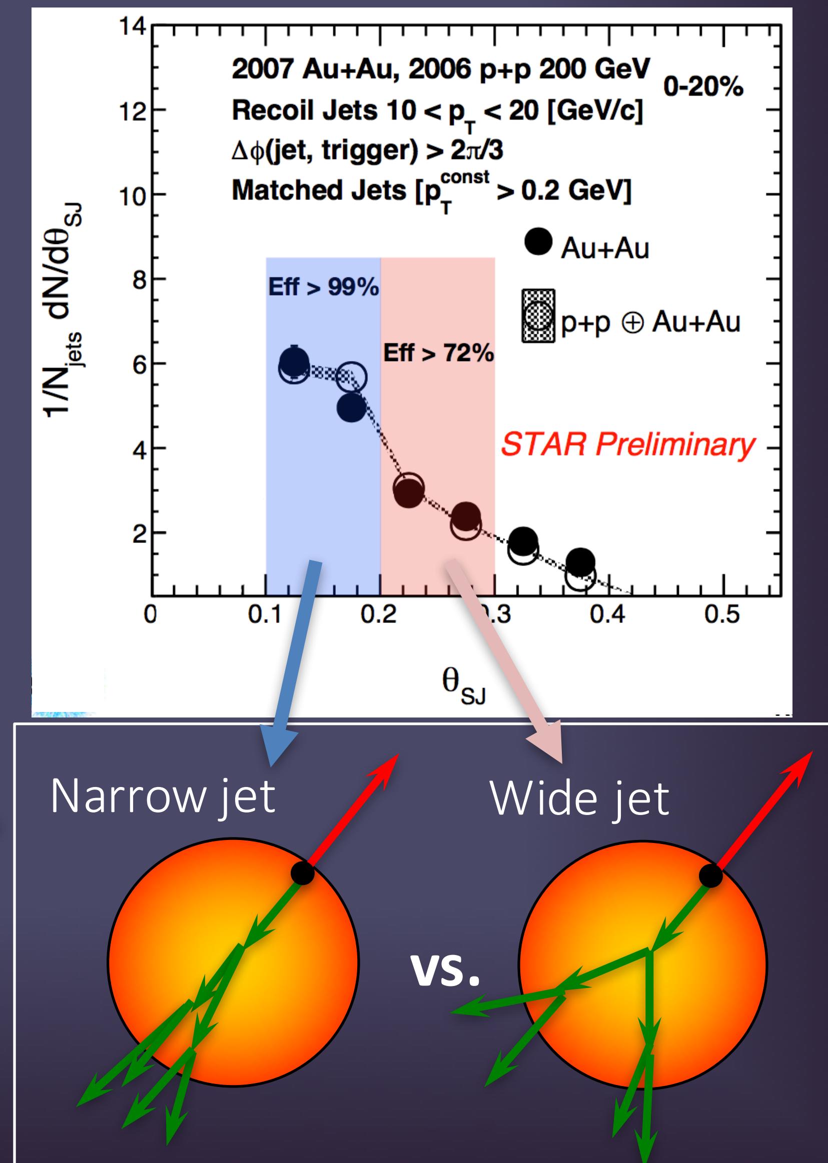

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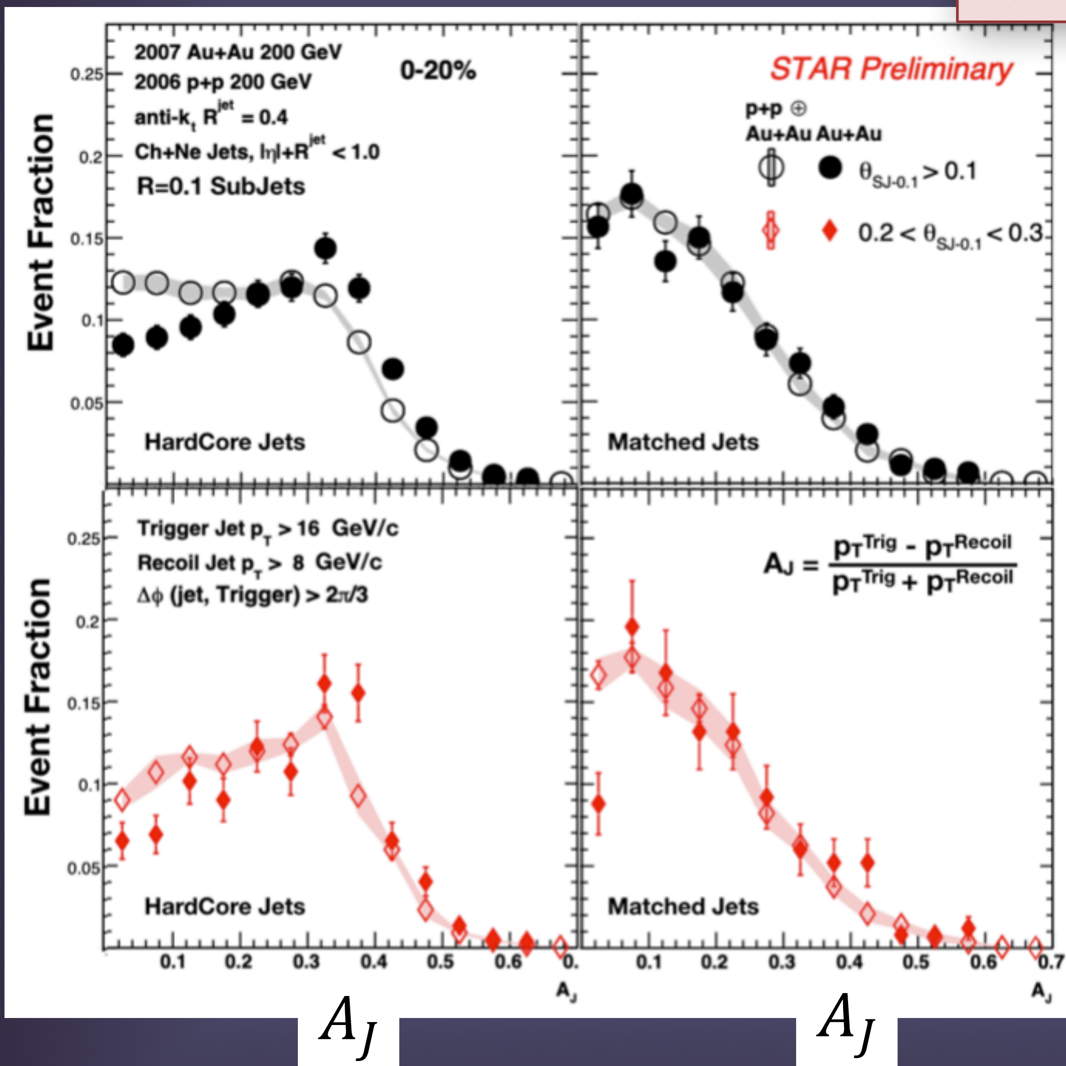
Jet Angular Scale Dependence

$\theta_{SJ} = \Delta R(\text{LeadingSJ axis, SubleadingSJ axis})$

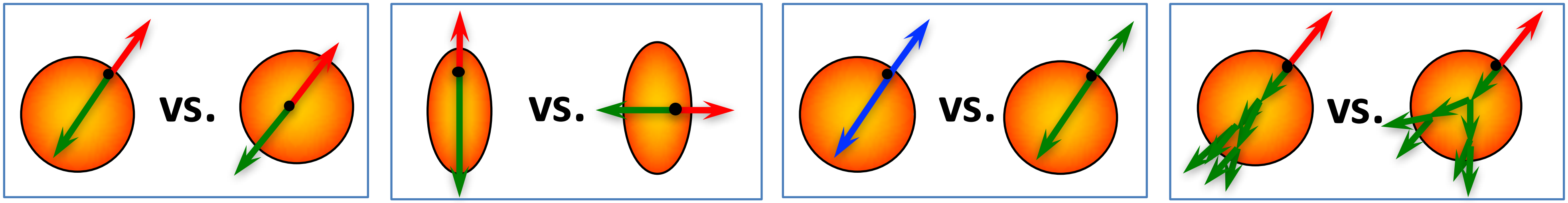
HP2018



- A_J measurements for hard-core and matched jets with different θ_{SJ} selections
- No significant difference between different θ_{SJ} selections

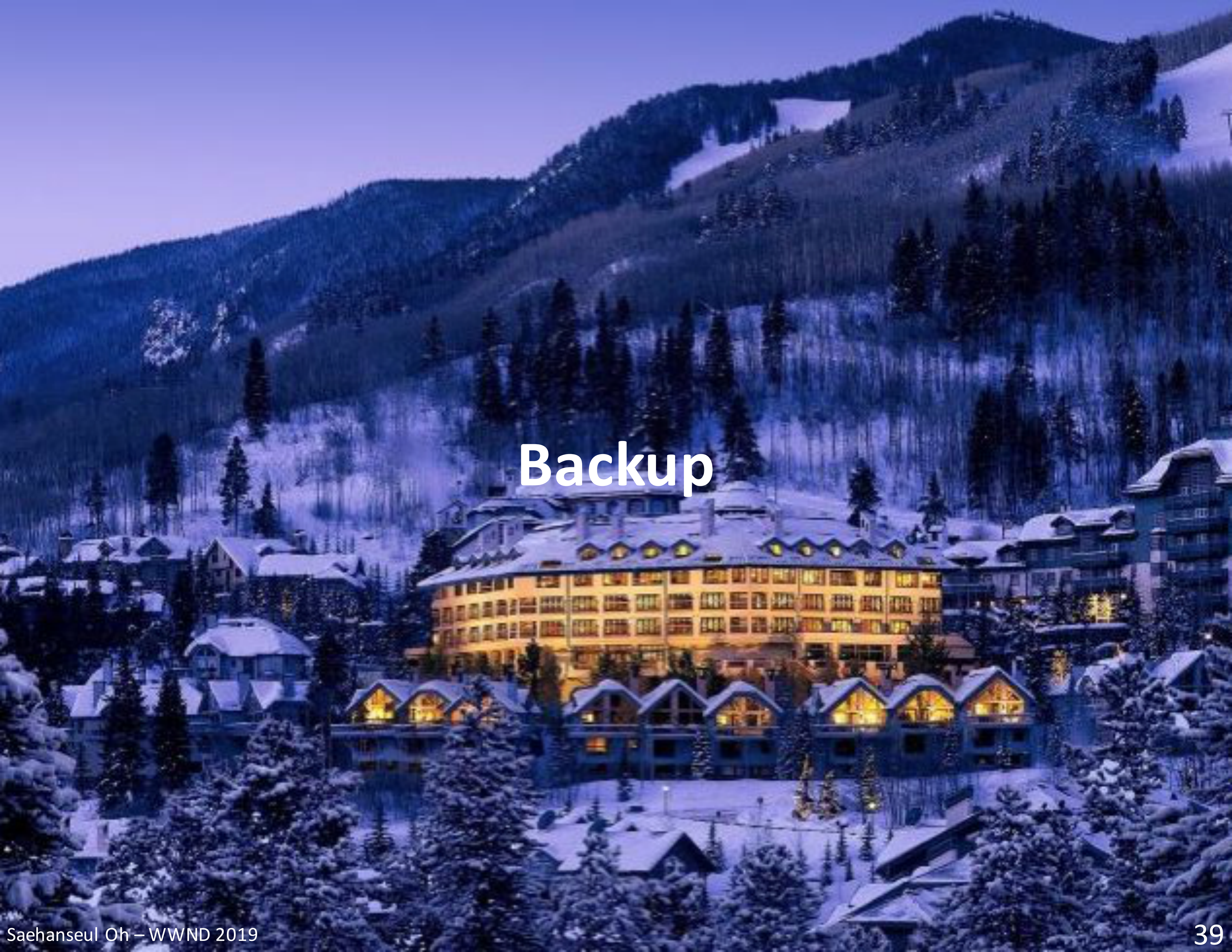
Summary

- Various jet measurements are on-going in STAR



- Di-jet imbalance for hard-core di-jets
  - ✓ Balance recovered with soft particles within $\mathrm{R} = 0.4$
  - ✓ More differential measurements (Centrality, jet reconstruction parameter)
- Event-plane dependent measurements
  - ✓ Indication of jet-medium interaction + path-length dependence
- Semi-inclusive measurements (h+jet, g+jet) and D^0-hadron measurements
  - ✓ Little flavor dependence of jet-quenching
- Jet angular scale dependent A_J - No significant dependence

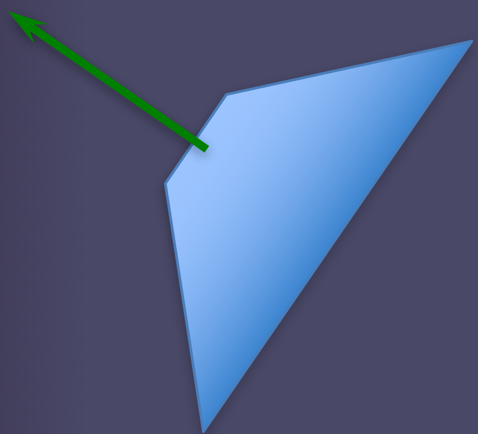
Stay tuned for upcoming Jet Results/Publications from STAR!



Backup

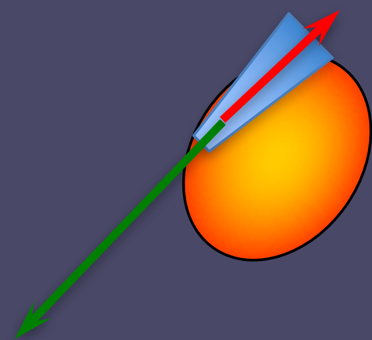
Jet Geometry Egineering at RHIC

- Steeply falling p_T spectrum at RHIC – good correlation between jet and parton energies

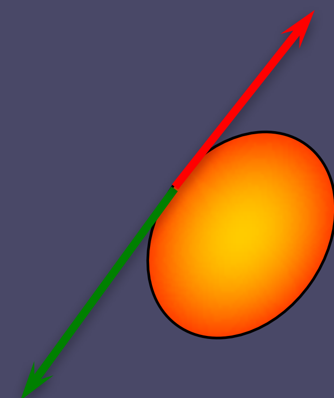


Leading trigger

- ✓ Jet+hadron correlation
- ✓ h+jet spectra



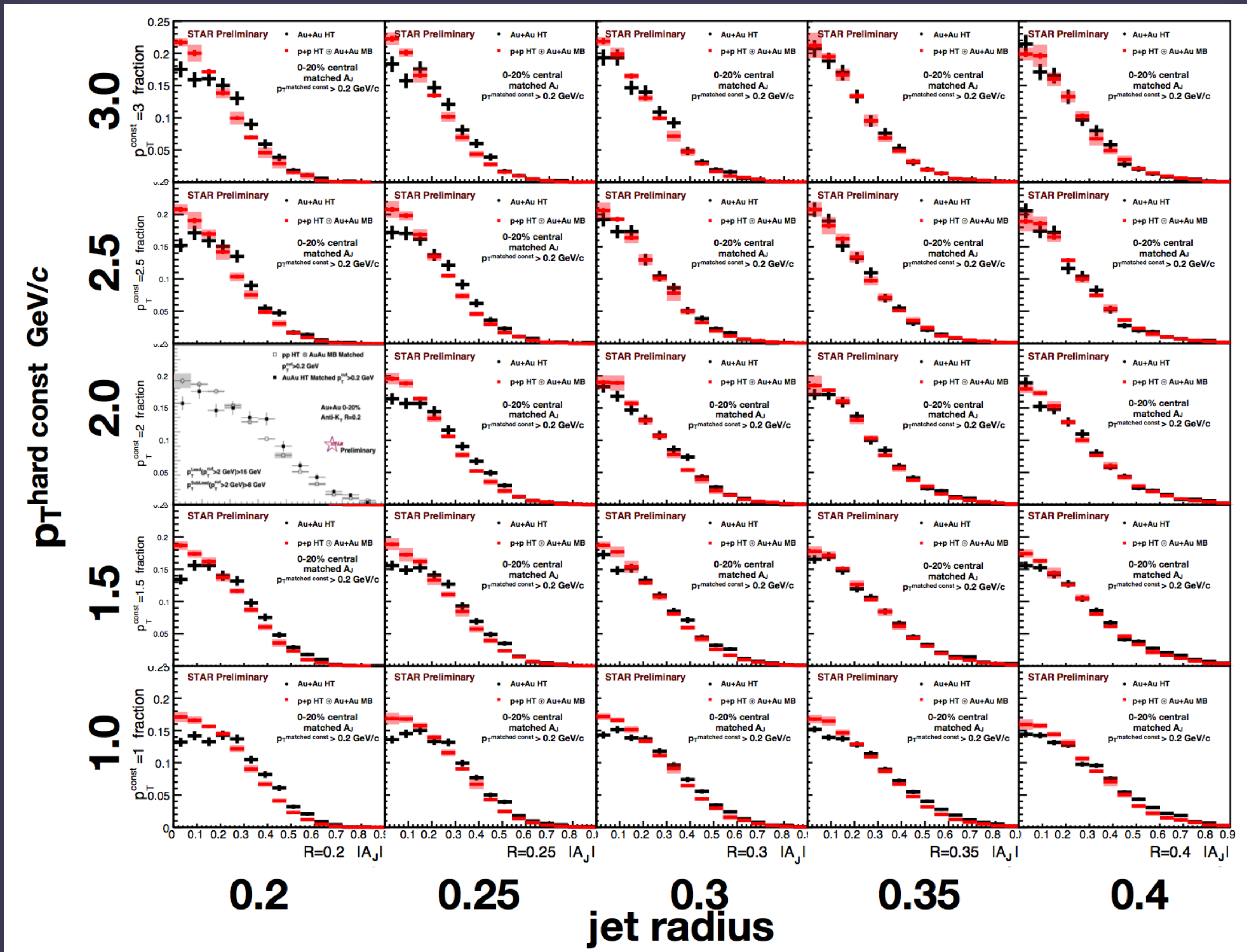
Di-jet imbalance



2+1 correlations

- Surface bias from trigger selection, particularly at RHIC energies, enables to use jet definition (R, constituent p_T cut, …) to select jet production vertex and di-jet origentation

Jet Geometry Egineering at RHIC



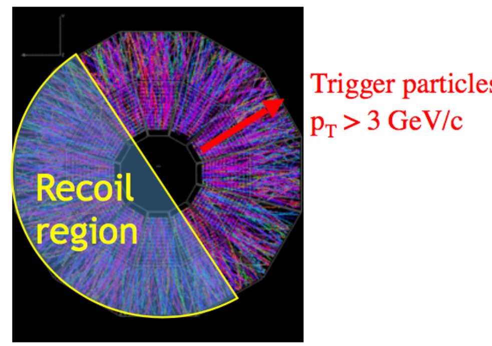
Event-plane Dependent Di-hadron Correlations – Recoil Width

- Event selection with high recoil momentum within $0.5 < \eta < 1.0$

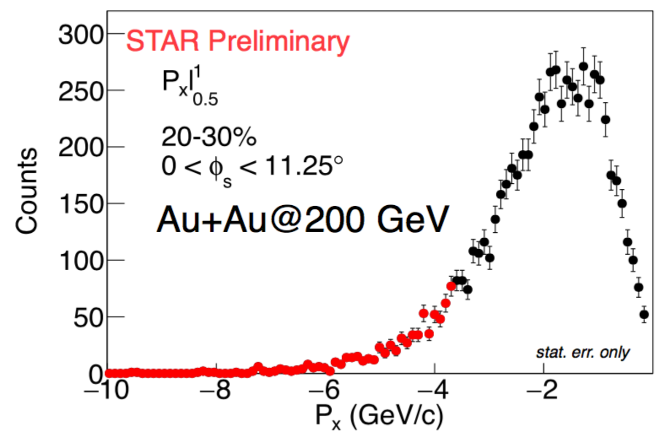
P_x : projection of away-side p_T onto trigger axis

$$P_x|_{\eta_1}^{\eta_2} = \sum_{\eta_1<\eta_a<\eta_2, |\phi_a-\phi_{trig}|>\frac{\pi}{2}} p_T^a \cos(\phi_a - \phi_{trig})\frac{1}{\epsilon}$$

ϵ:single-particle acceptance efficiency



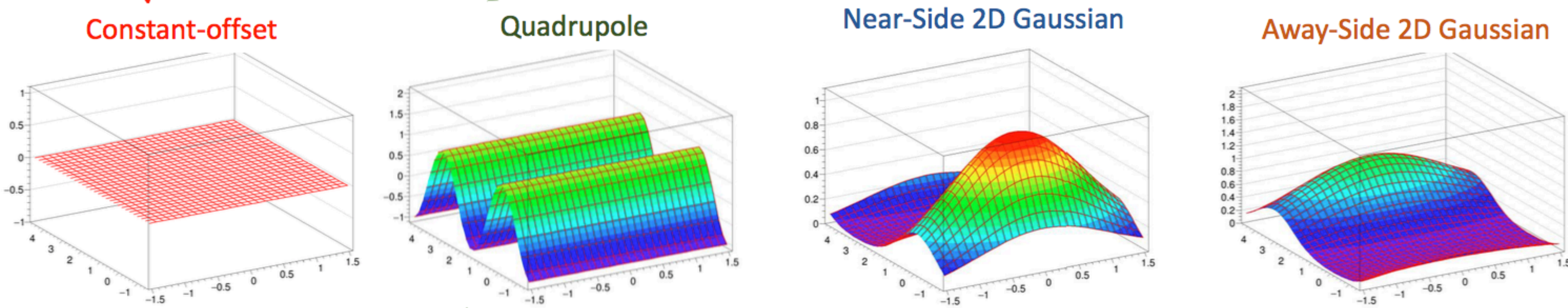
For each centrality,
cut on 10% left tail of P_x distribution to enhance away-side jet population in (η_1, η_2) acceptance



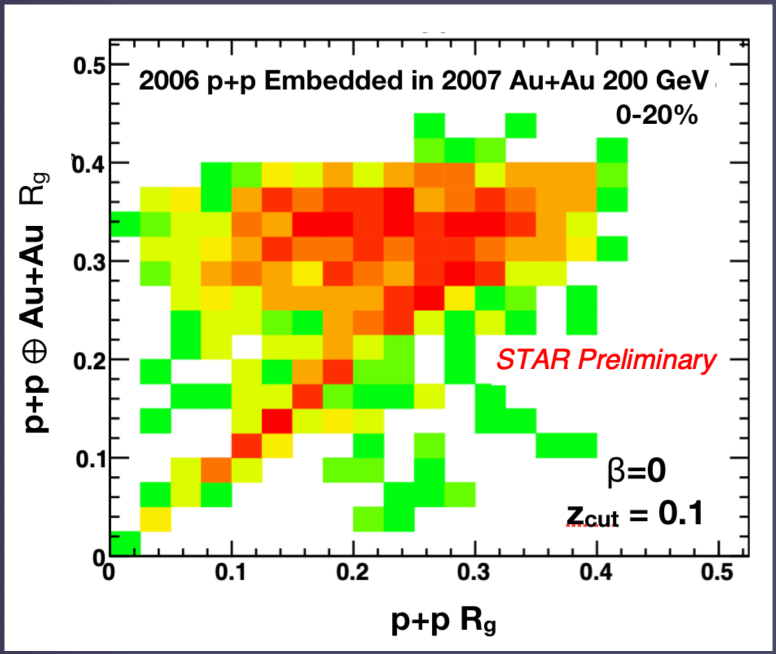
D^0-hadron Correlations

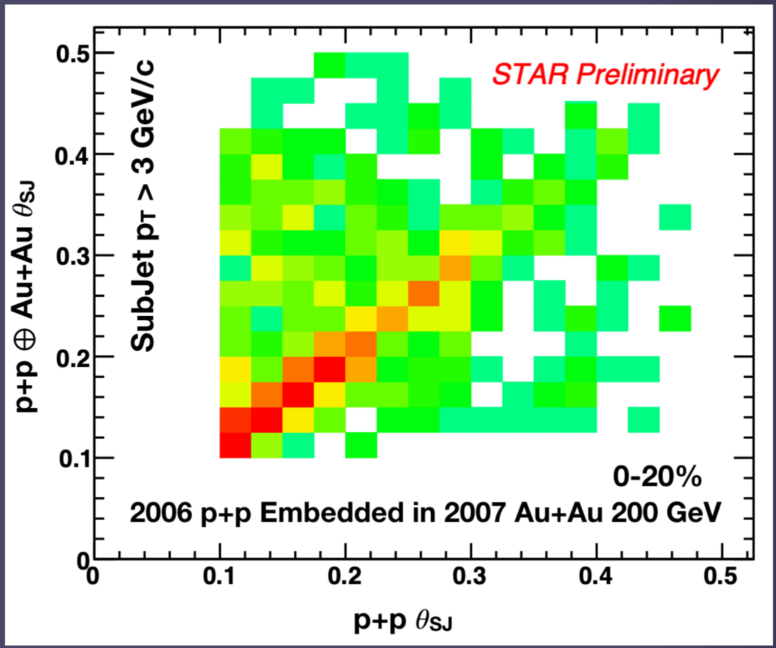
- Two-particle correlation functions are fitted with a model with 8 parameters

- $A_0 + 2A_Q\{2D\}Cos(2\Delta\varphi) + A_{NS}e^{-\frac{1}{2}\frac{\Delta\eta^2}{\sigma^2_{NS,\Delta\eta}}} * e^{-\frac{1}{2}\frac{\Delta\varphi^2}{\sigma^2_{NS,\Delta\varphi}}} + A_{AS}e^{-\frac{1}{2}\frac{\Delta\eta^2}{\sigma^2_{AS,\Delta\eta}}} * e^{-\frac{1}{2}\frac{(\Delta\varphi-\pi)^2}{\sigma^2_{AS,\Delta\varphi}}} + periodicity\ for\ \Delta\varphi\ Gaussian$



SoftDrop R_g vs. θ_{SJ}





SoftDrop R_g

θ_{SJ}

- SoftDrop R_g is more sensitive to background fluctuations

Jet Angular Scale Dependence

HP2018