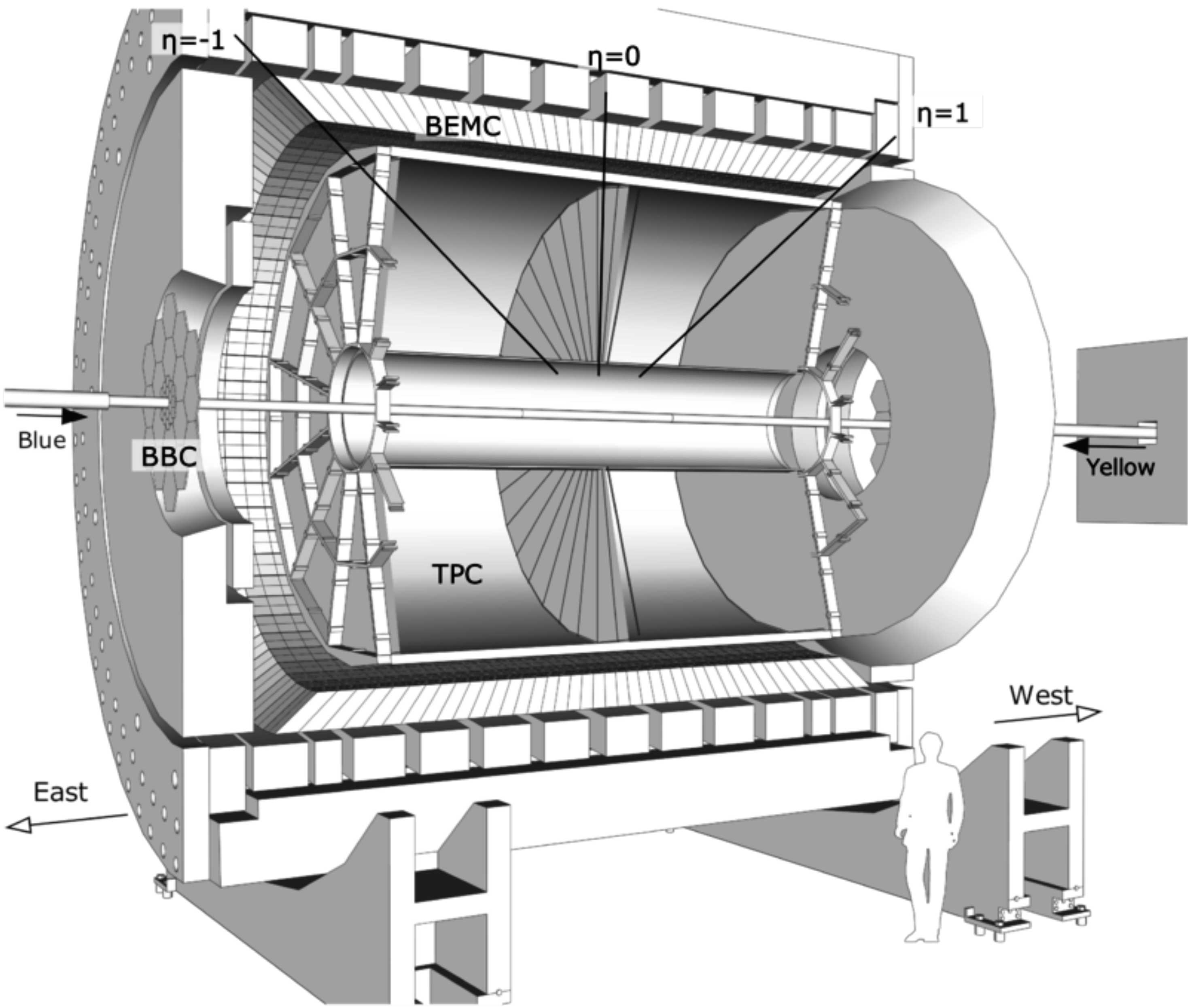

Jet Measurements with STAR

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BNL
for the STAR Collaboration

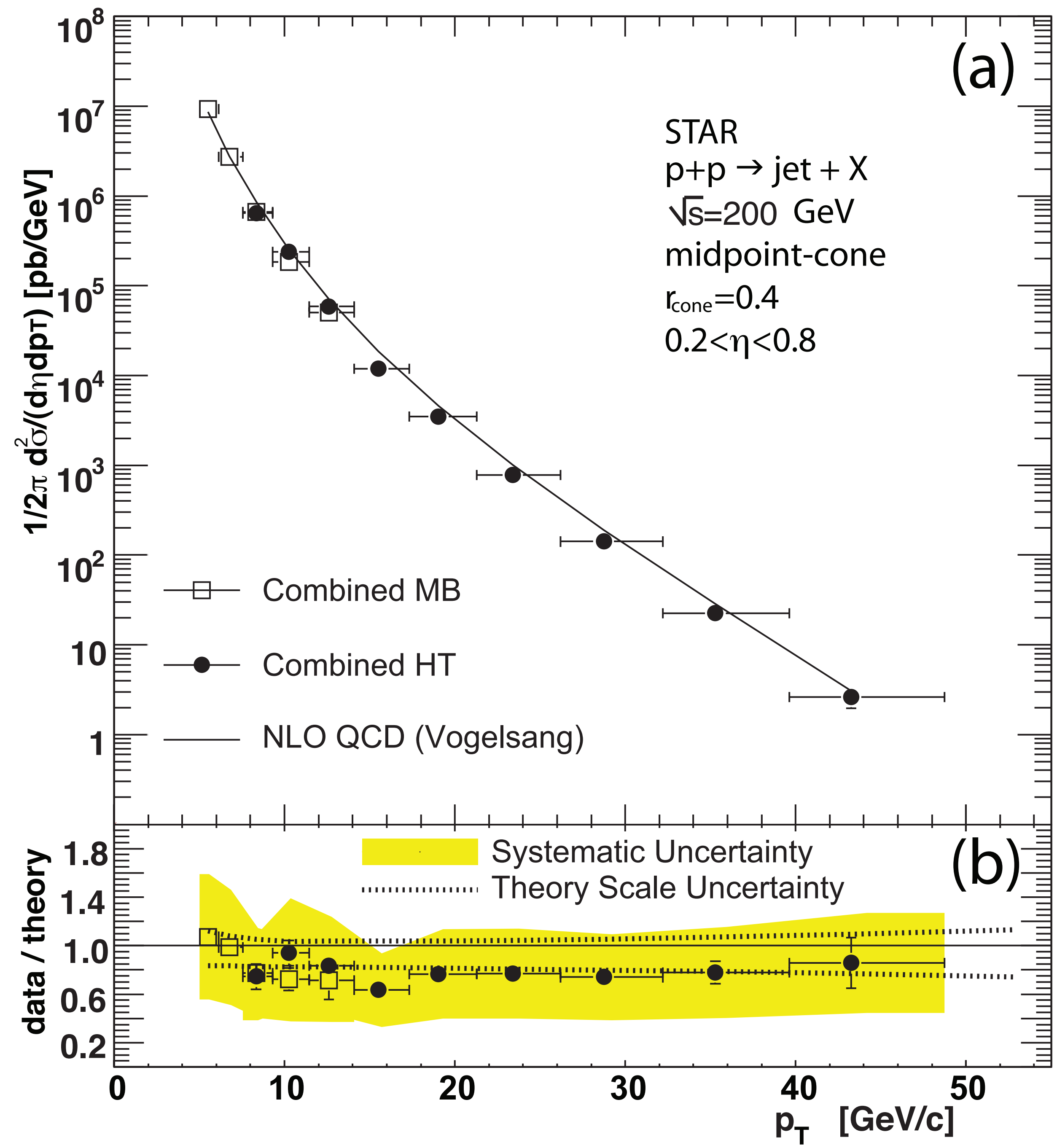
BROOKHAVEN NATIONAL LABORATORY

macl@bnl.gov: Moriond QCD 2015

U.S. DEPARTMENT OF ENERGY

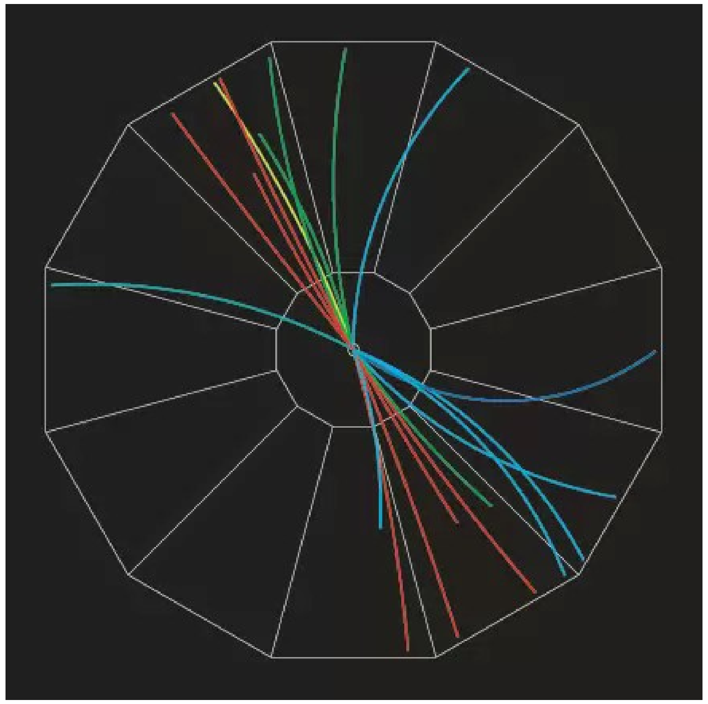
Jets in p+p

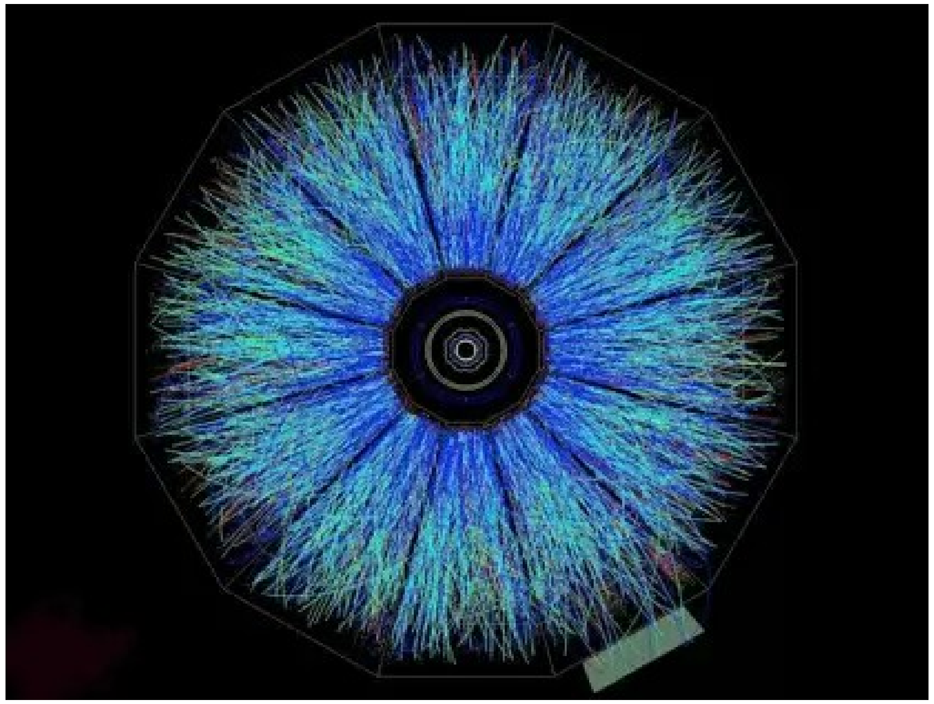
- A measurement of full jets in p+p is in good agreement with NLO QCD model
- Midpoint cone algorithm used (R=0.4)
- Both TPC tracks and EMC towers used in the measurement
- Higher-statistics measurement (with greater coverage in η), is underway



STAR: Phys. Rev. Lett. **97** (2006) 252001

Jets in p+p vs Au+Au





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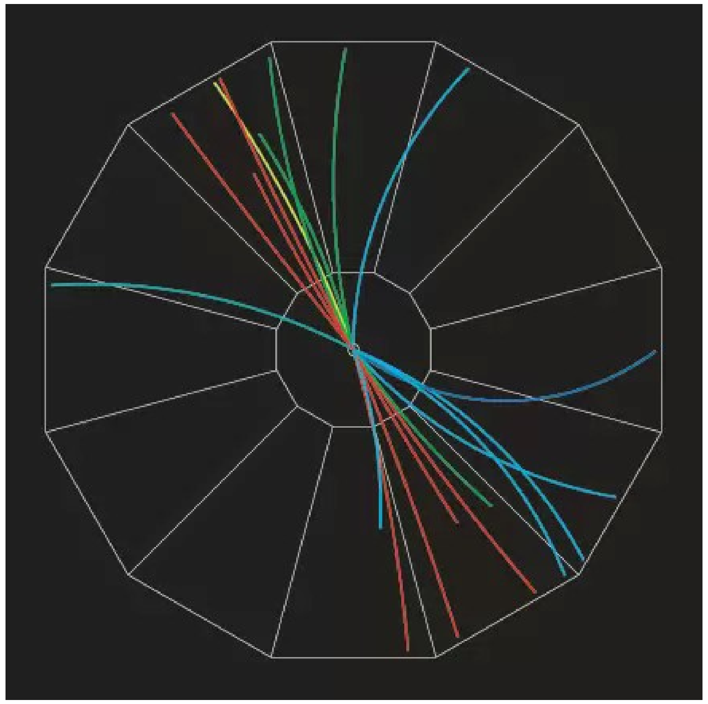

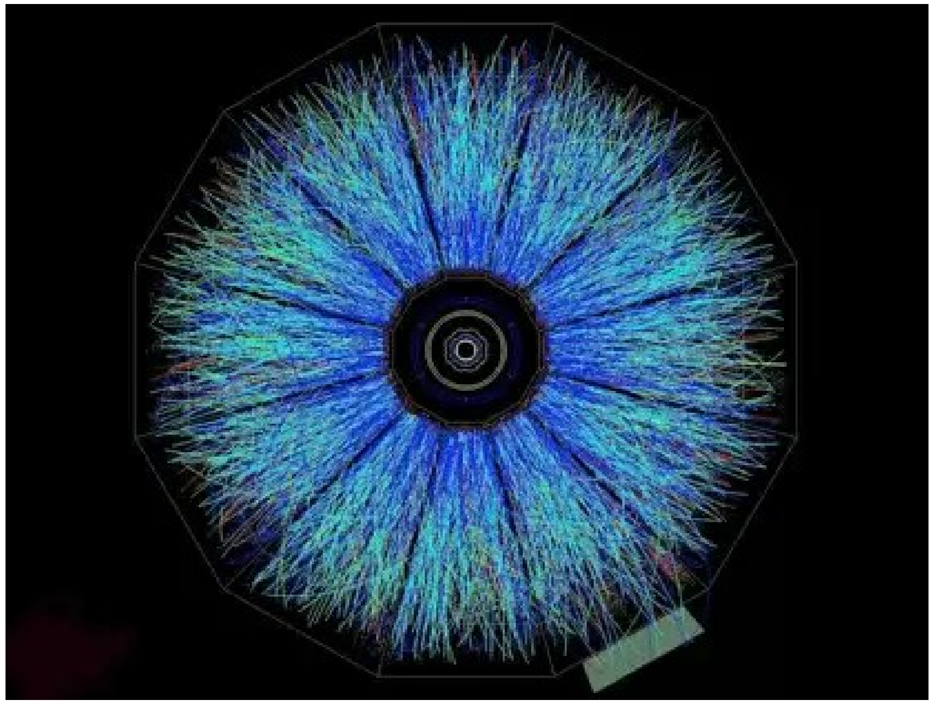

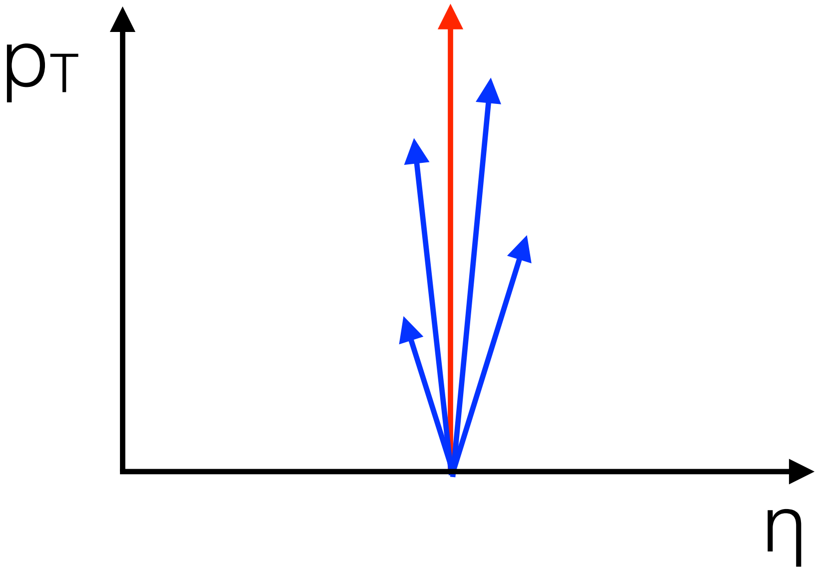

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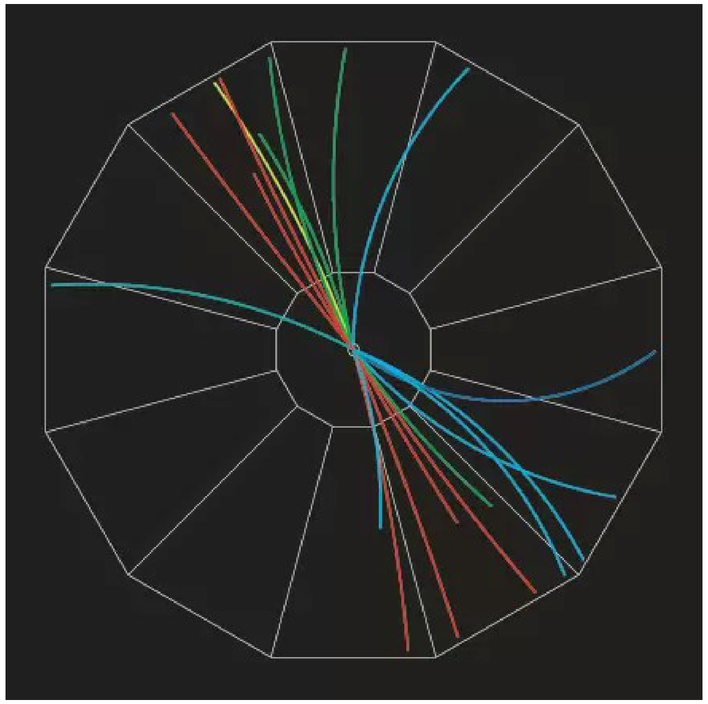
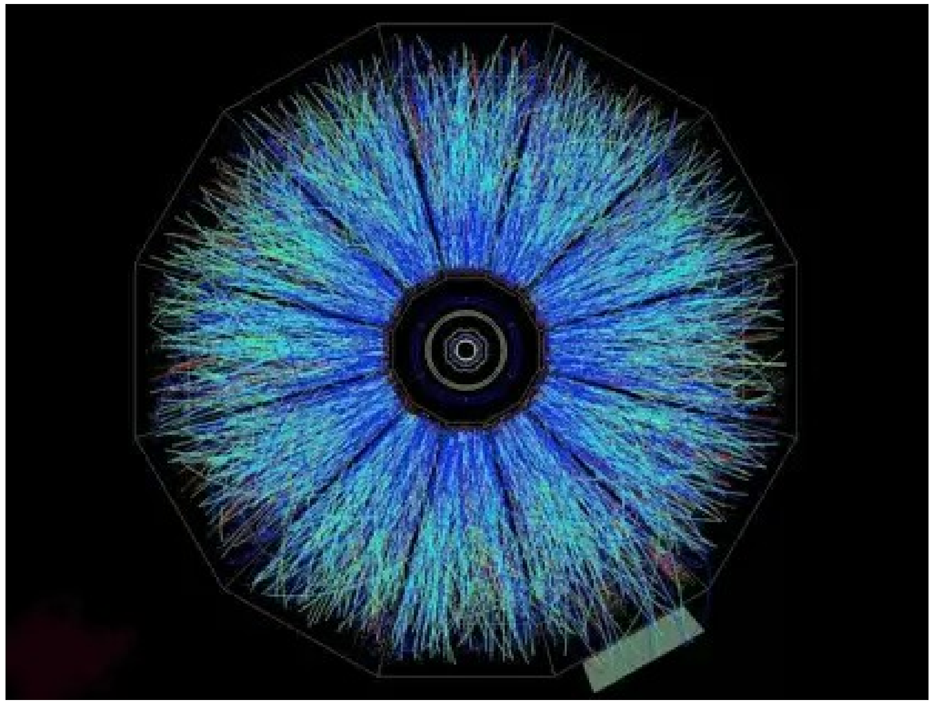
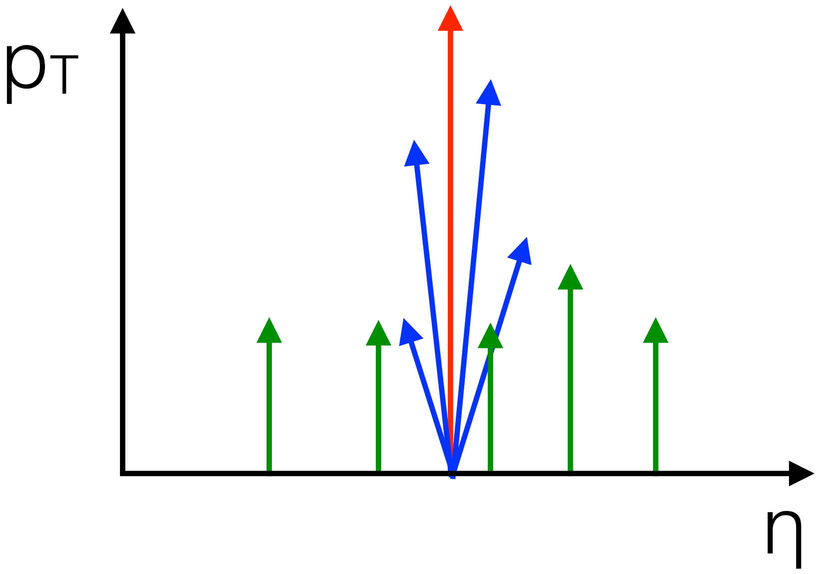
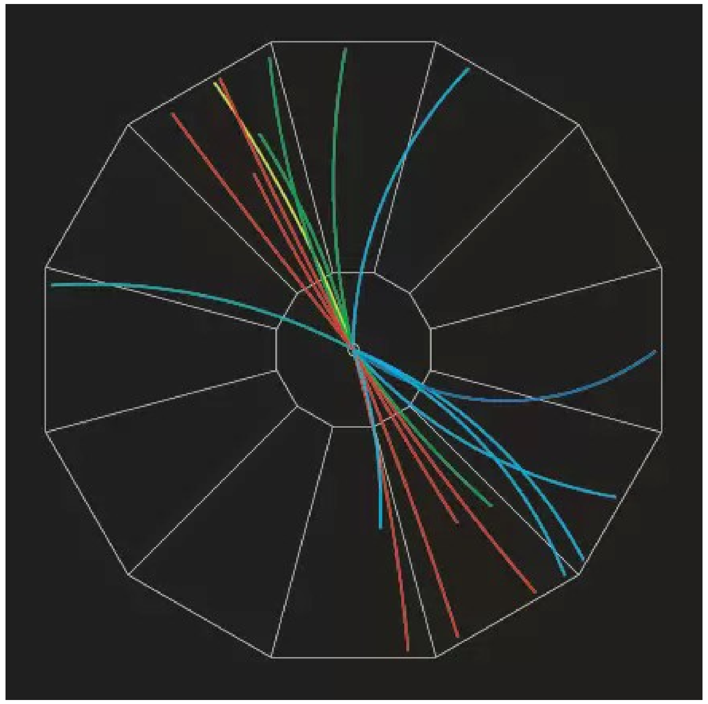
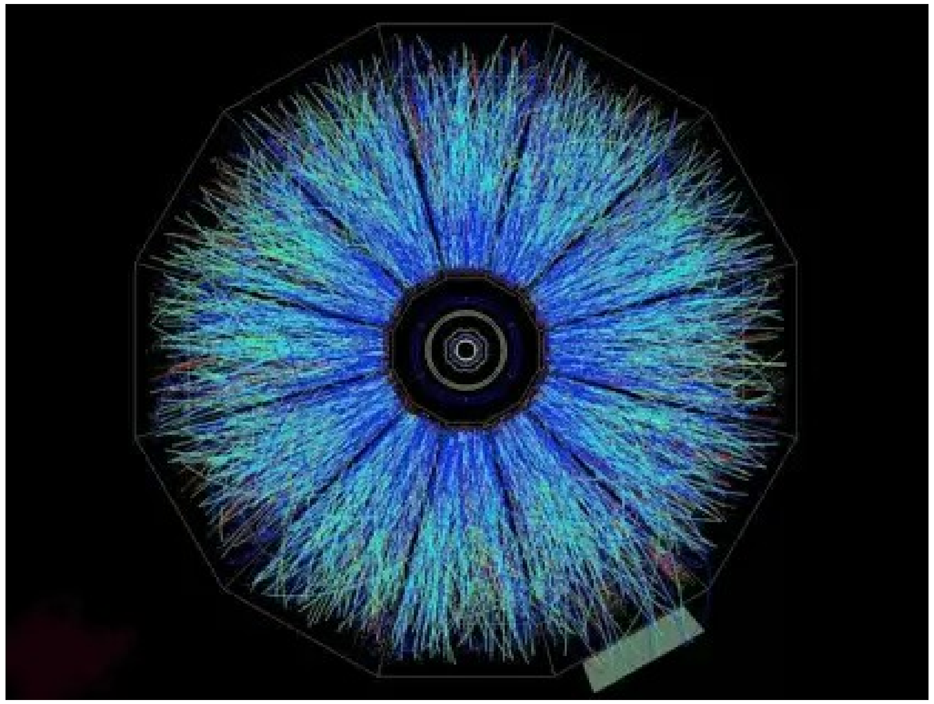


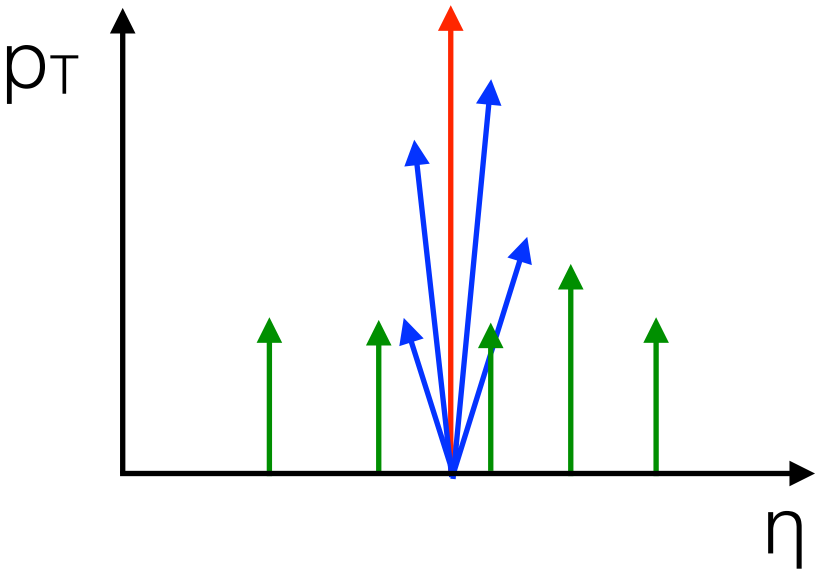


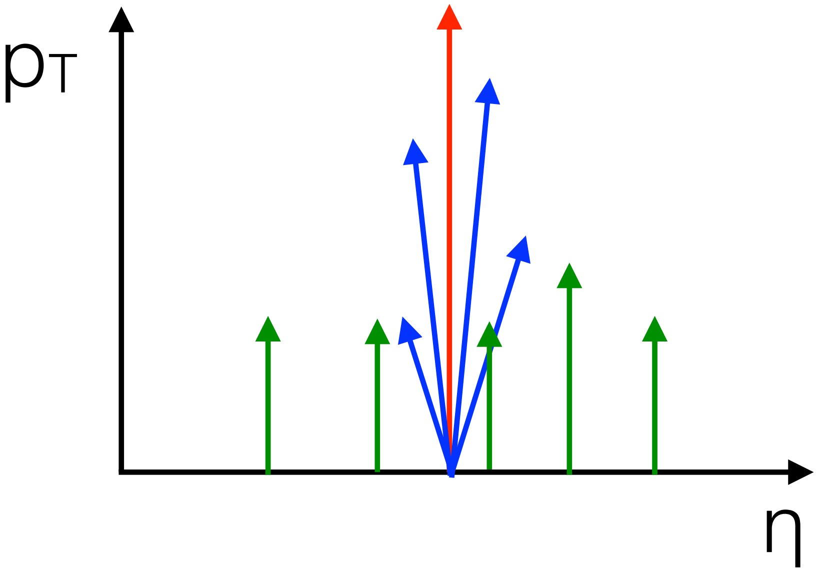


Jets in p+p vs Au+Au

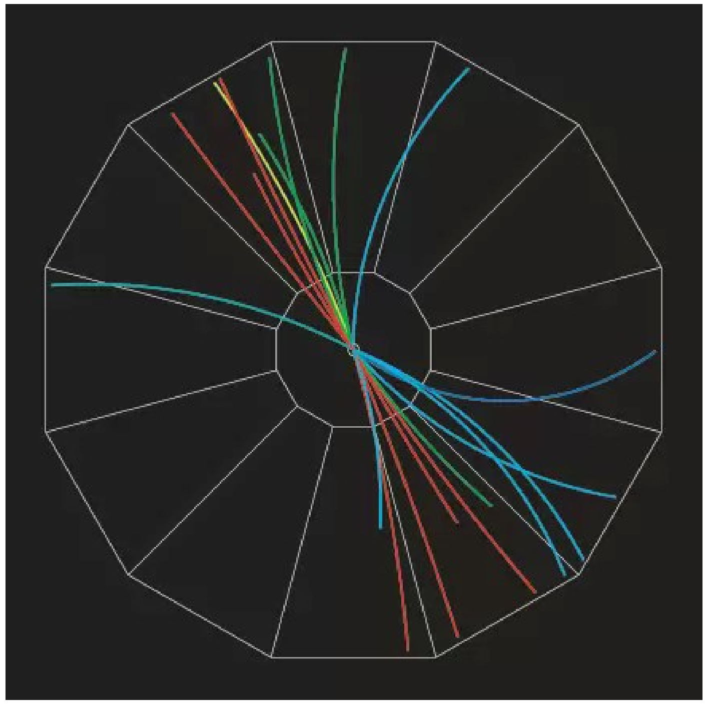


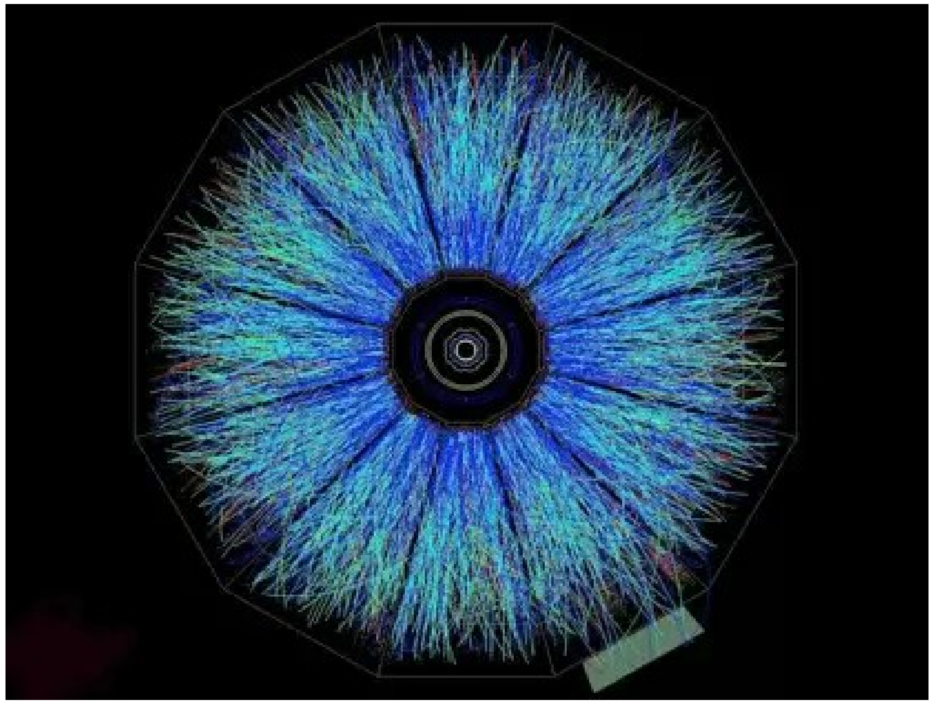


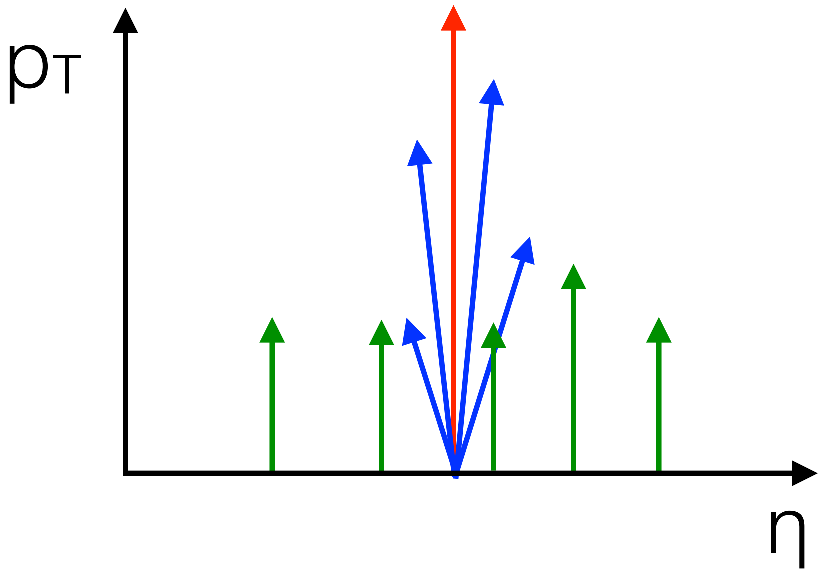


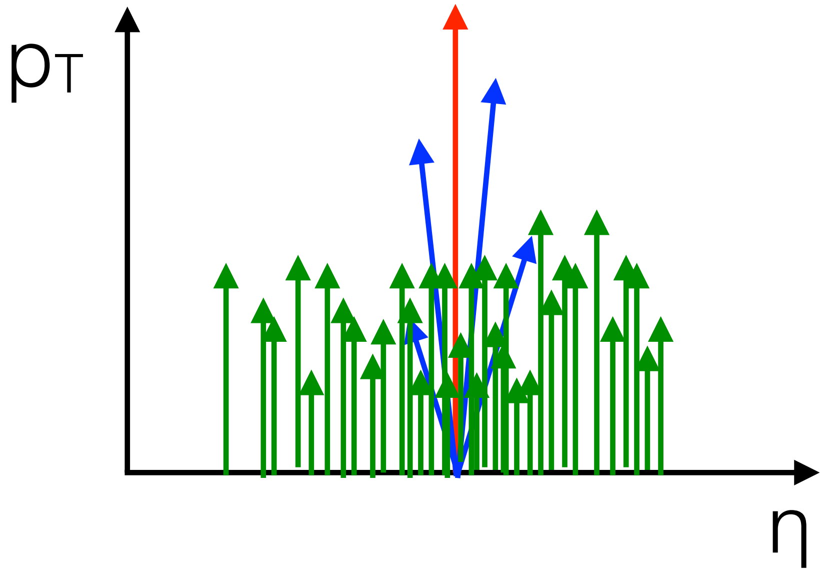


Jets in p+p vs Au+Au

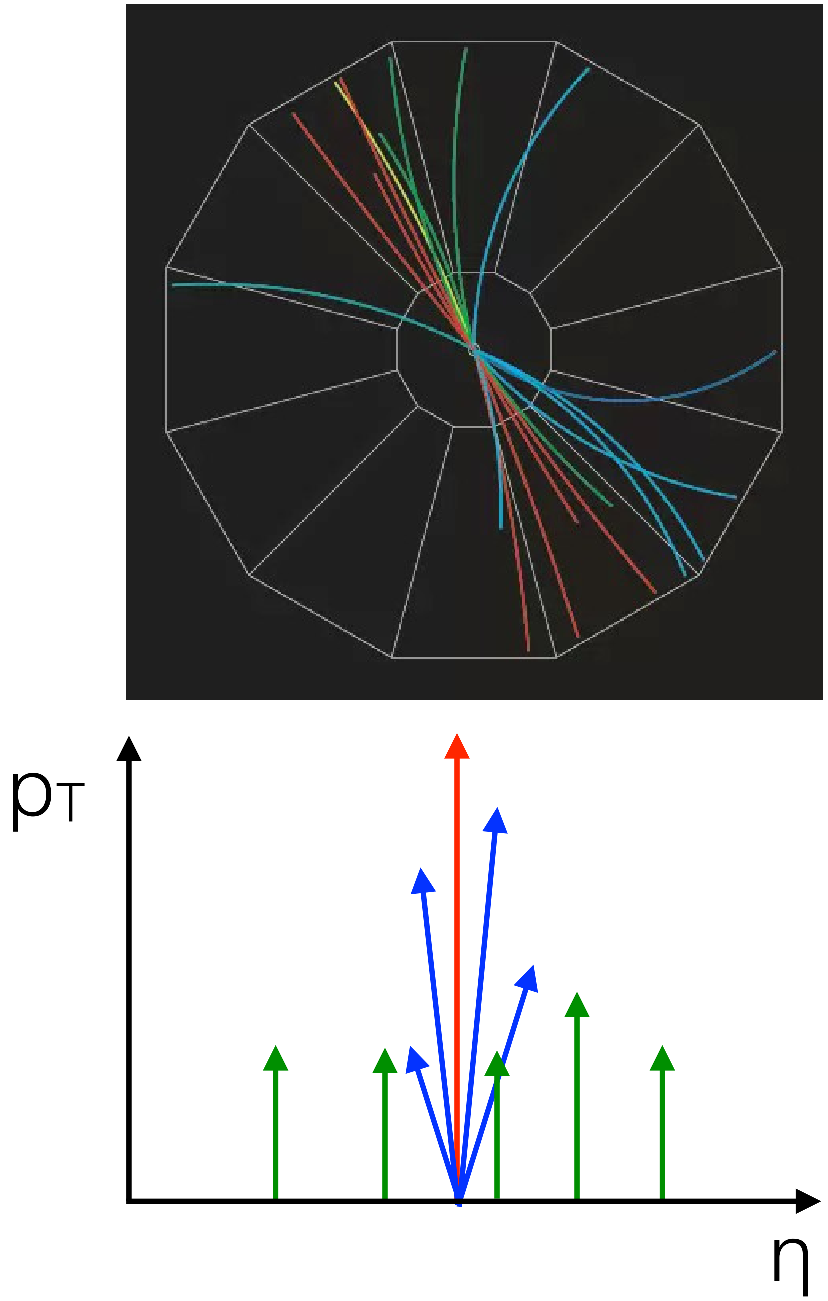


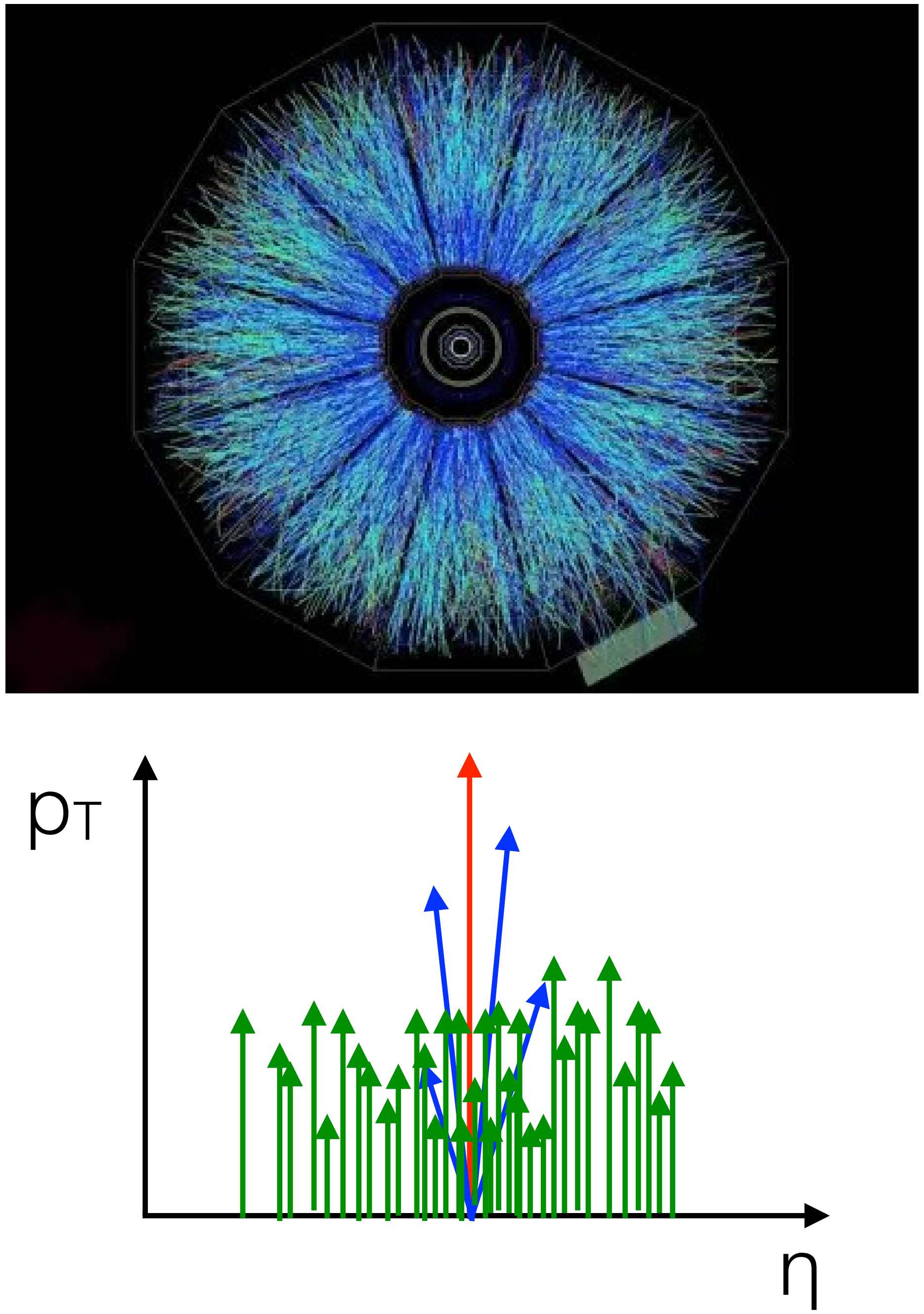






Jets in p+p vs Au+Au

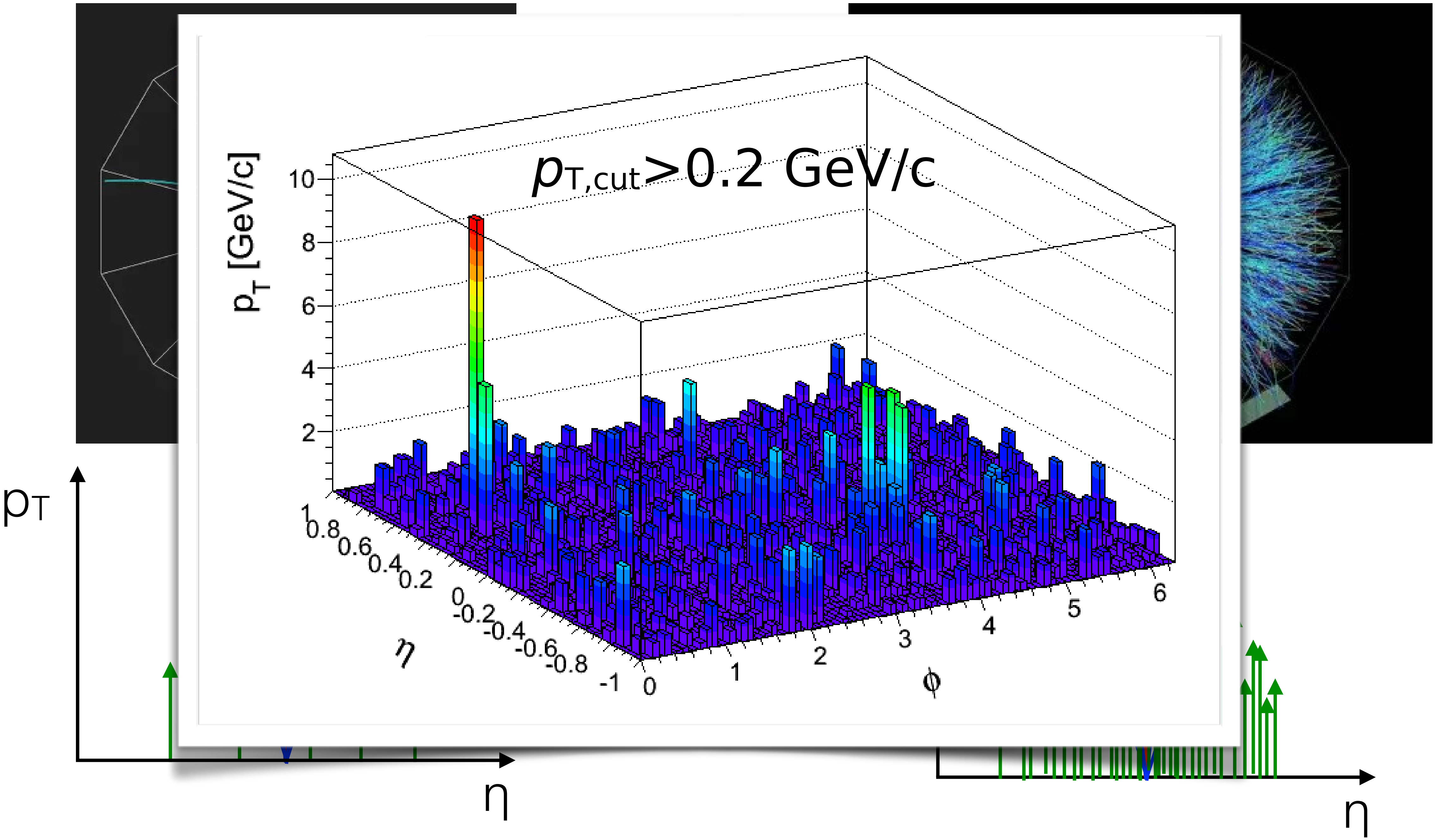




- Heavy-ion collisions have much greater multiplicity than in p+p

➡ Jet-finding in heavy-ions at RHIC is a very difficult task!

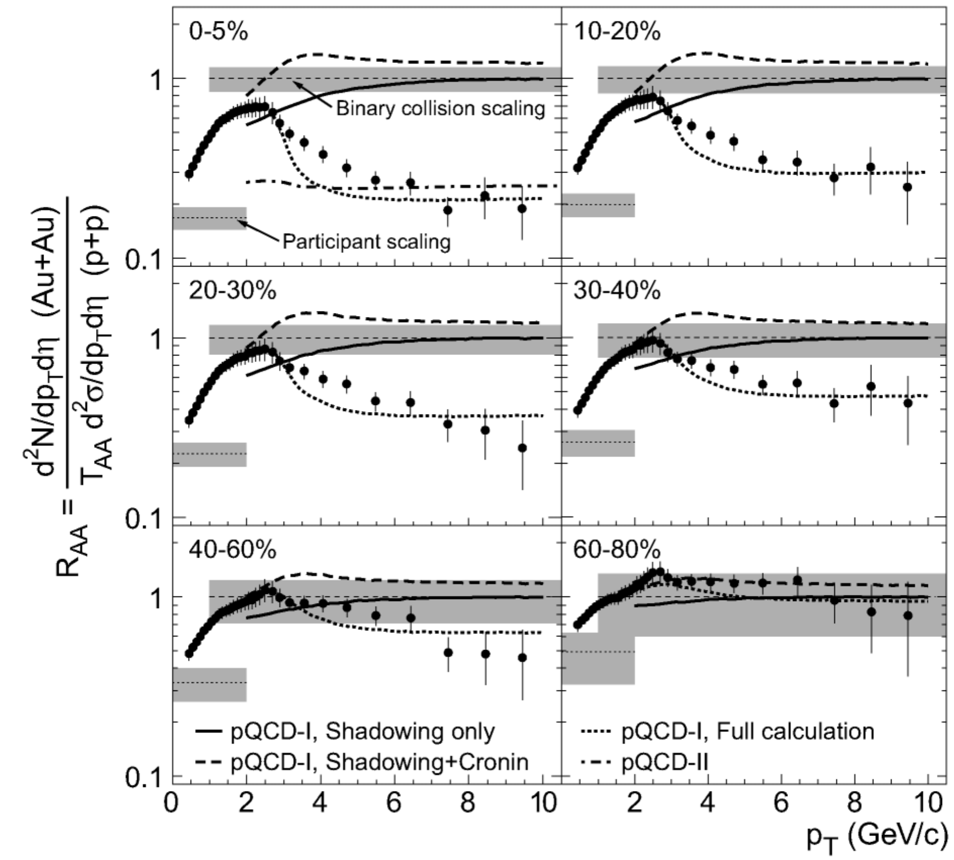
Jets in p+p vs Au+Au



- Heavy-ion collisions have much greater multiplicity than in p+p
    - ➡ Jet-finding in heavy-ions at RHIC is a very difficult task!

High-p_T in Au+Au

- Jet physics measurements in Au+Au collisions are motivated by 2 distinct proxy measurements in STAR:
  - ➡ The measurement of R_{AA}
    - Ratio of single particle spectra relative to p+p
    - Shows a suppression at high p_T in the more central collisions
    - Can only be described by energy loss



Phys. Rev. Lett. **91** (2003) 172302

High-p_T in Au+Au

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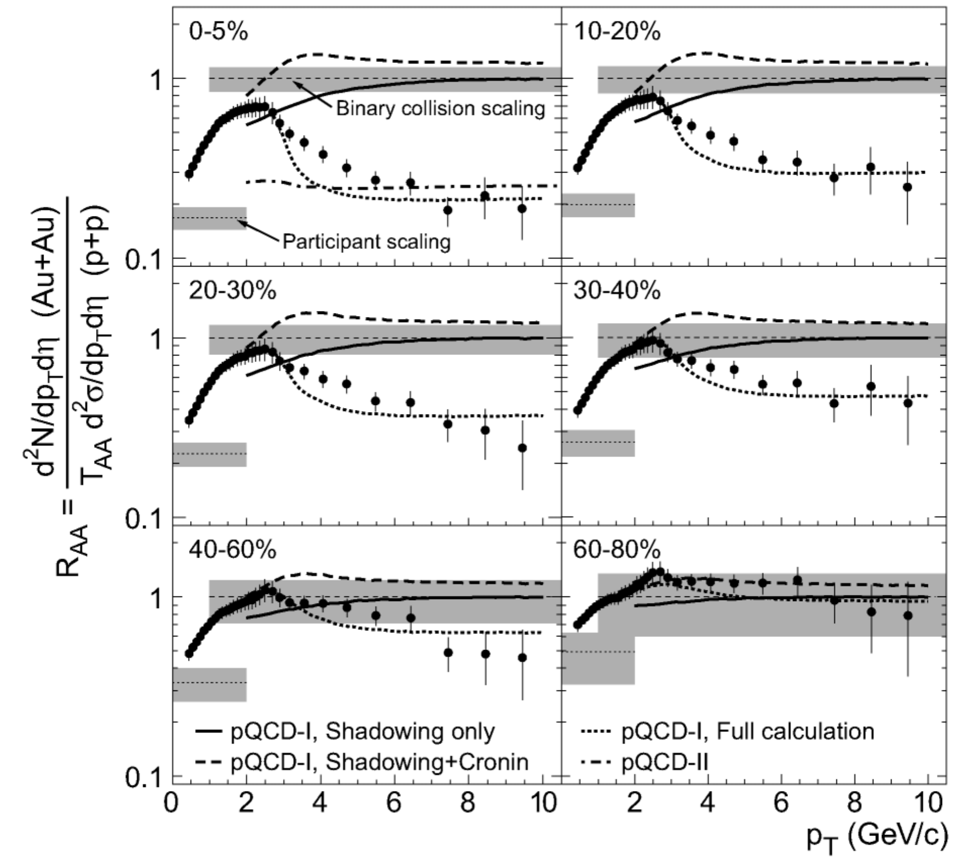
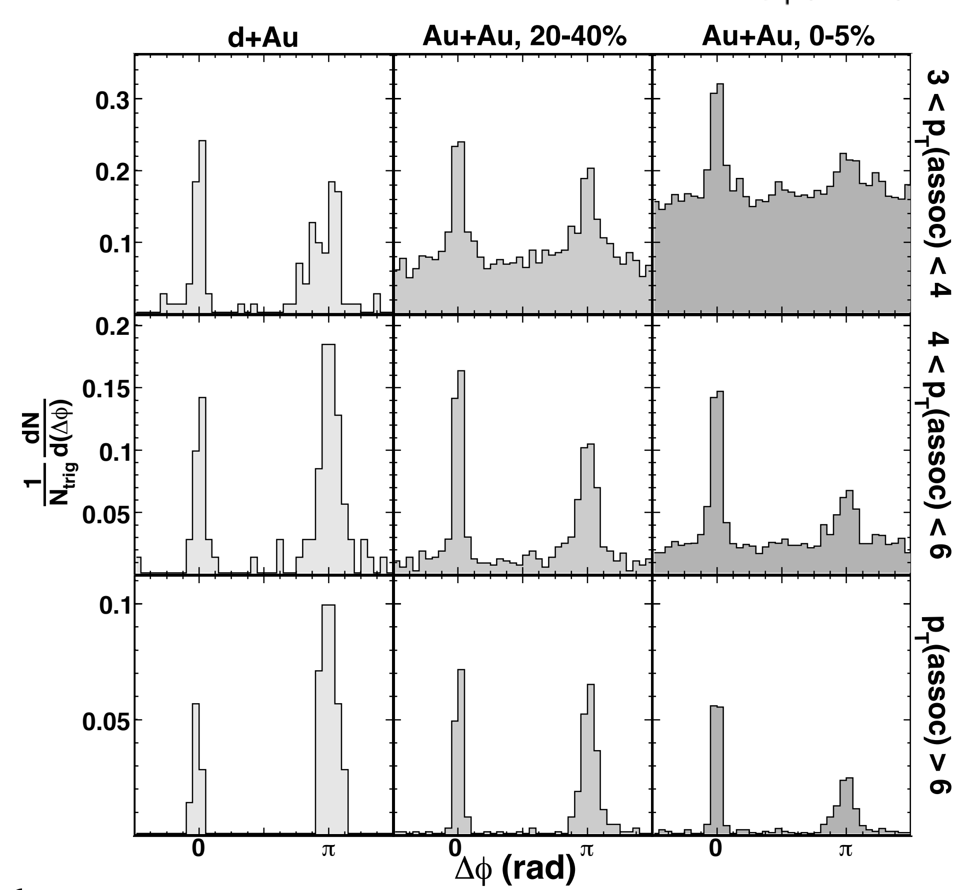
  - ➡ The measurement of R_{AA}
    - Ratio of single particle spectra relative to p+p
    - Shows a suppression at high p_T in the more central collisions
    - Can only be described by energy loss
  - ➡ Back-to-back correlations of high-p_T hadrons
    - Show a loss on the away-side in central Au+Au collisions.
    - Correlation persists in d+Au collisions
      - Final-state effect
- In order to quantify the energy loss on a partonic level, need to measure the jet quenching with real jets



Phys. Rev. Lett. **91** (2003) 172302

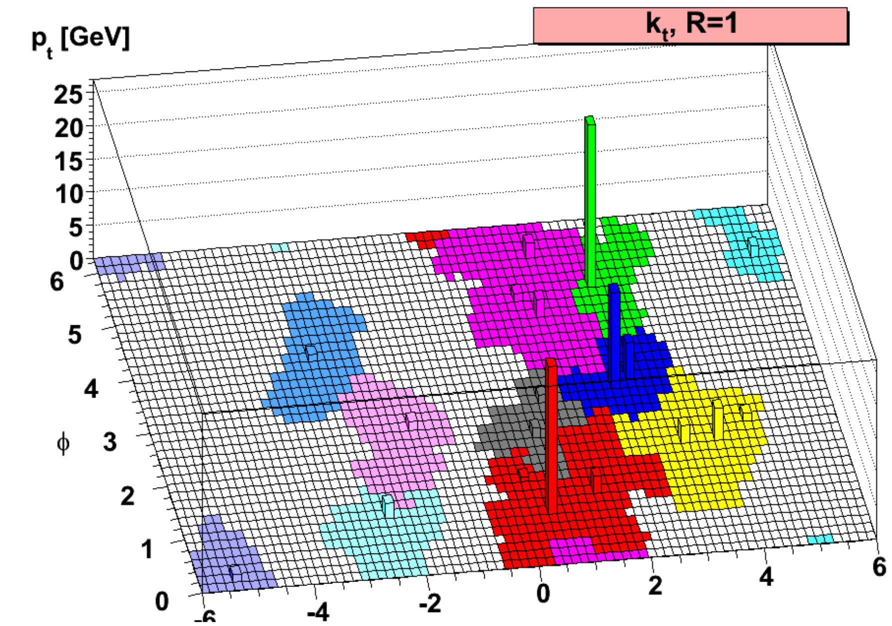


Phys. Rev. Lett. **97** (2006) 162301

Jets in A+A Collisions

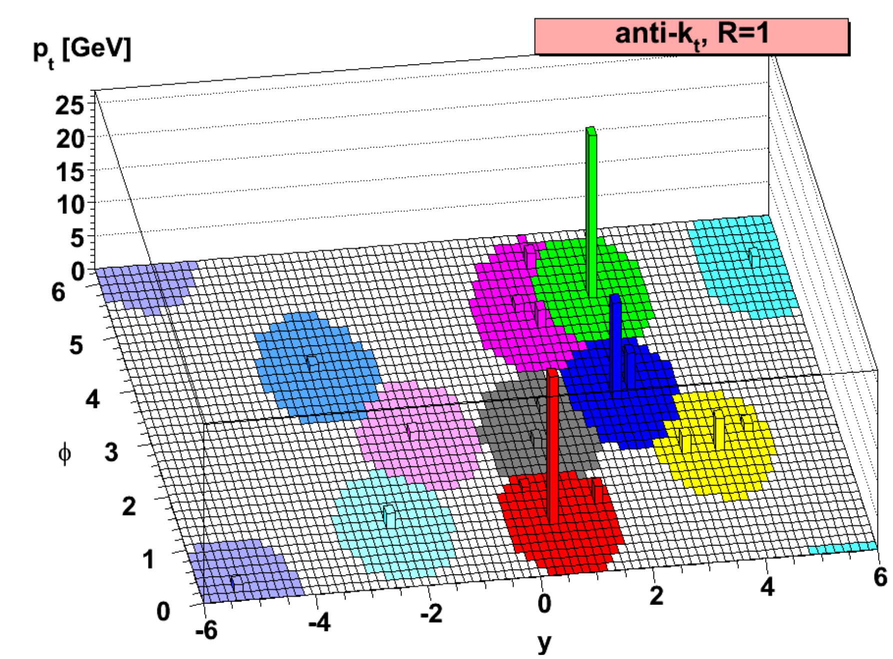
- One of the biggest difficulties in jet finding in A+A collisions is the large background - have to subtract correctly
- Use the Fastjet reconstruction algorithms (Eur. Phys.J C72 1896 (2012))
- Jet reconstruction uses the anti-kT algorithm
- Correction for background energy:
  - ➡ density: $\rho = med\{\frac{p_{T,i}}{A_i}\}$

$p_{T,corr} = p_T - A_{jet} \times \rho$



Simulation: Cacciari – arXiv:0906.1598

kT algorithm starts clustering from low-p_T particles



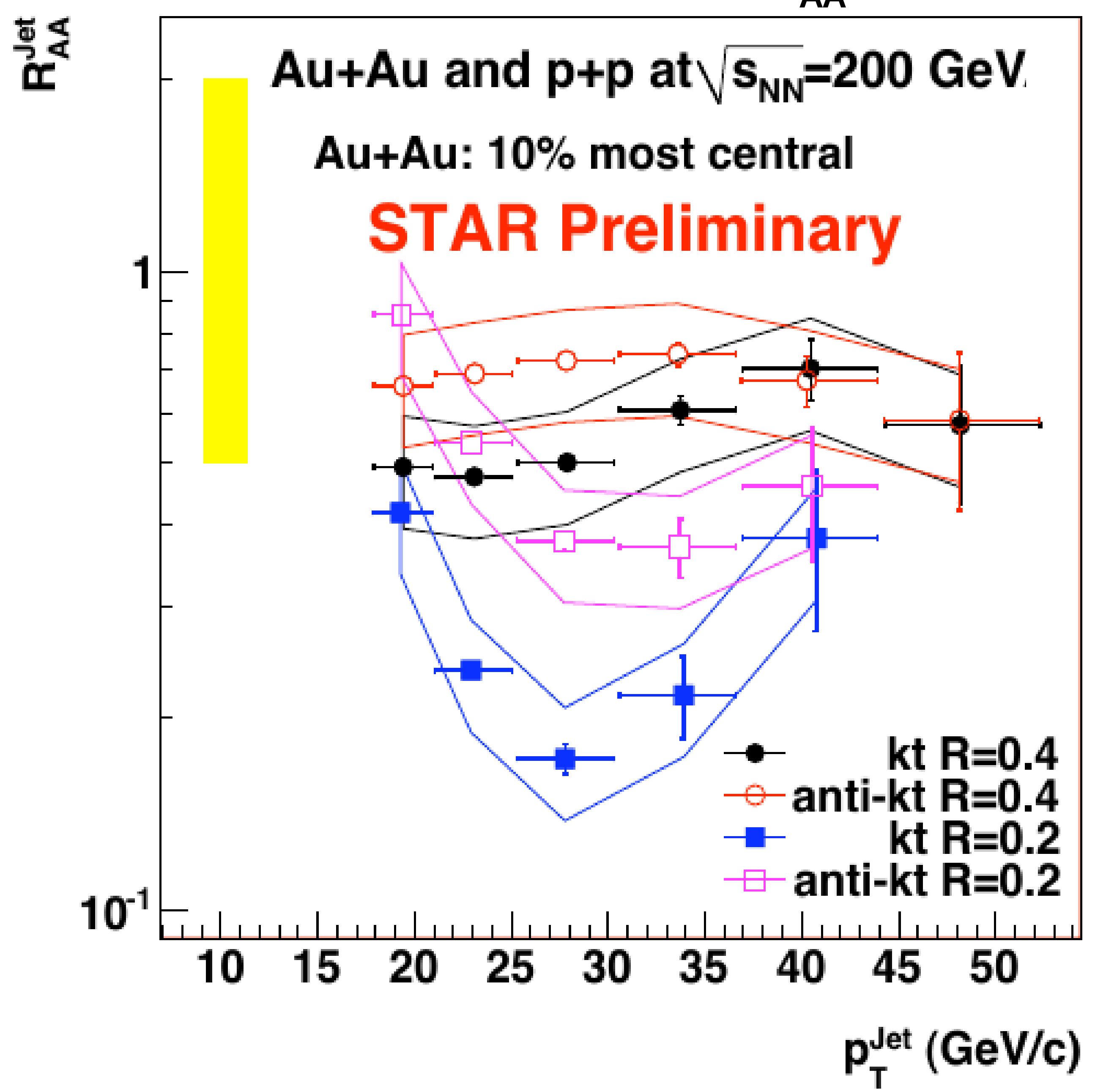
anti-kT algorithm starts clustering from high-p_T particles

Existing Preliminary Results

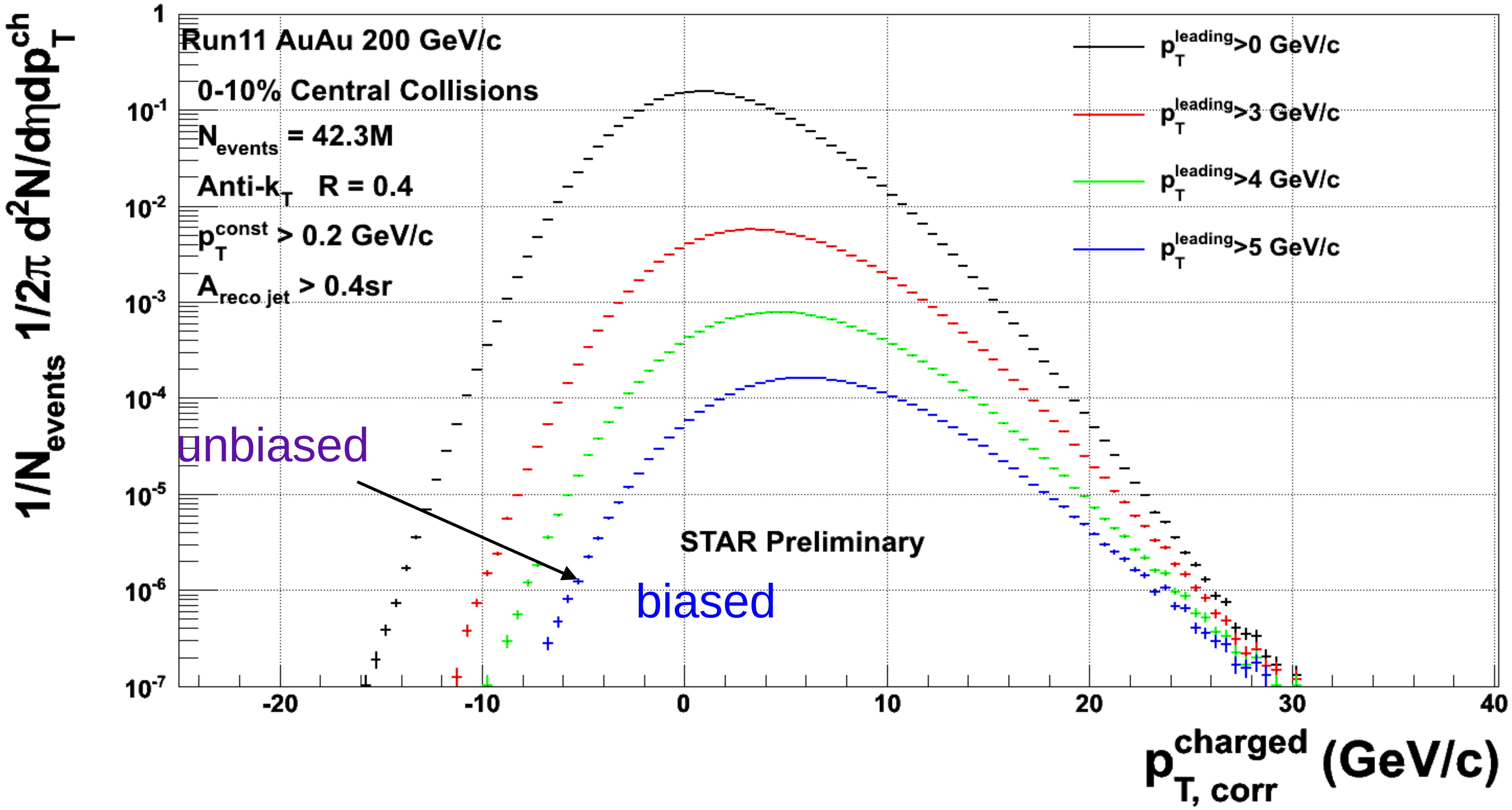
- STAR has existing results for Full-Jet R_{AA}
  - ➡ Large systematic uncertainties make it difficult to make a conclusion
- Higher statistics have since been recorded
  - ➡ Smaller uncertainties
- New techniques have since been developed
  - ➡ First attempt in the new analysis uses only TPC charged tracks

Nucl. Phys. A 830, 255c, (2009)

Full jet R_{AA}

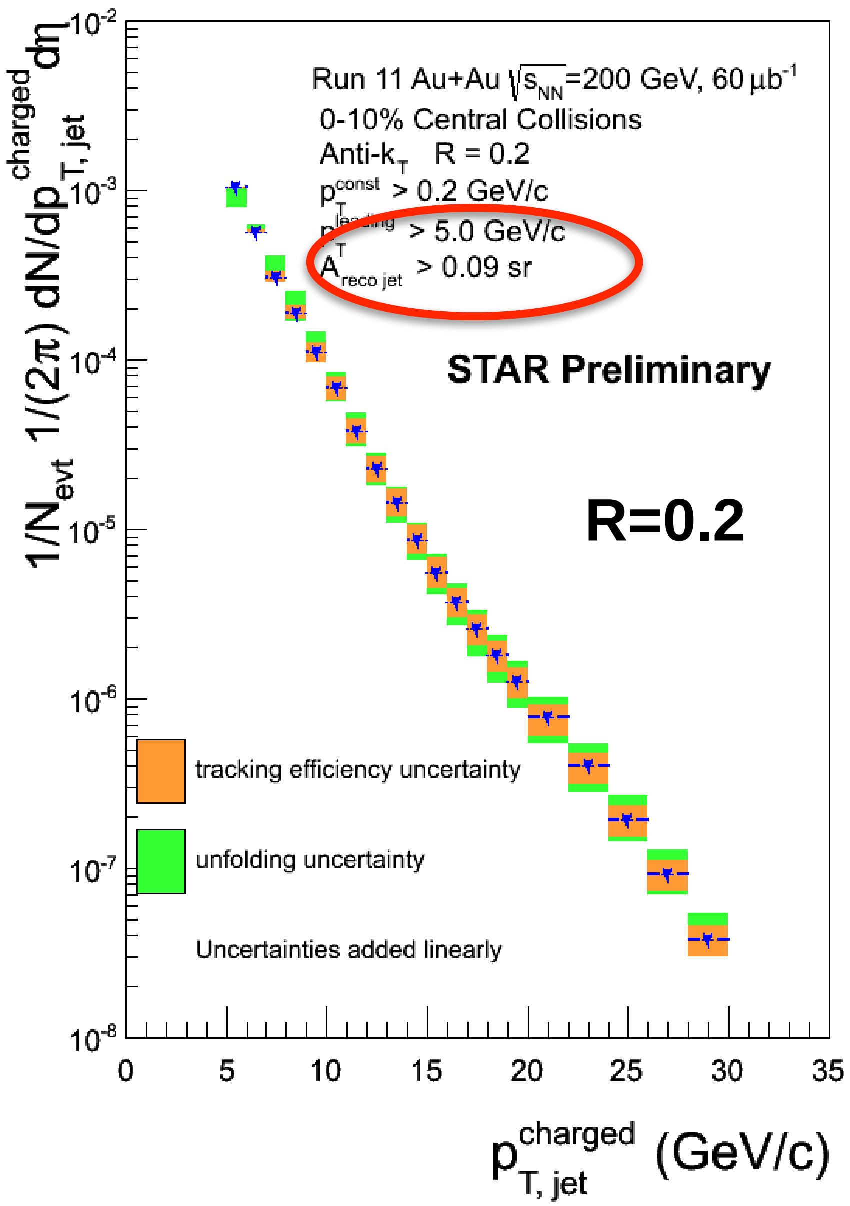


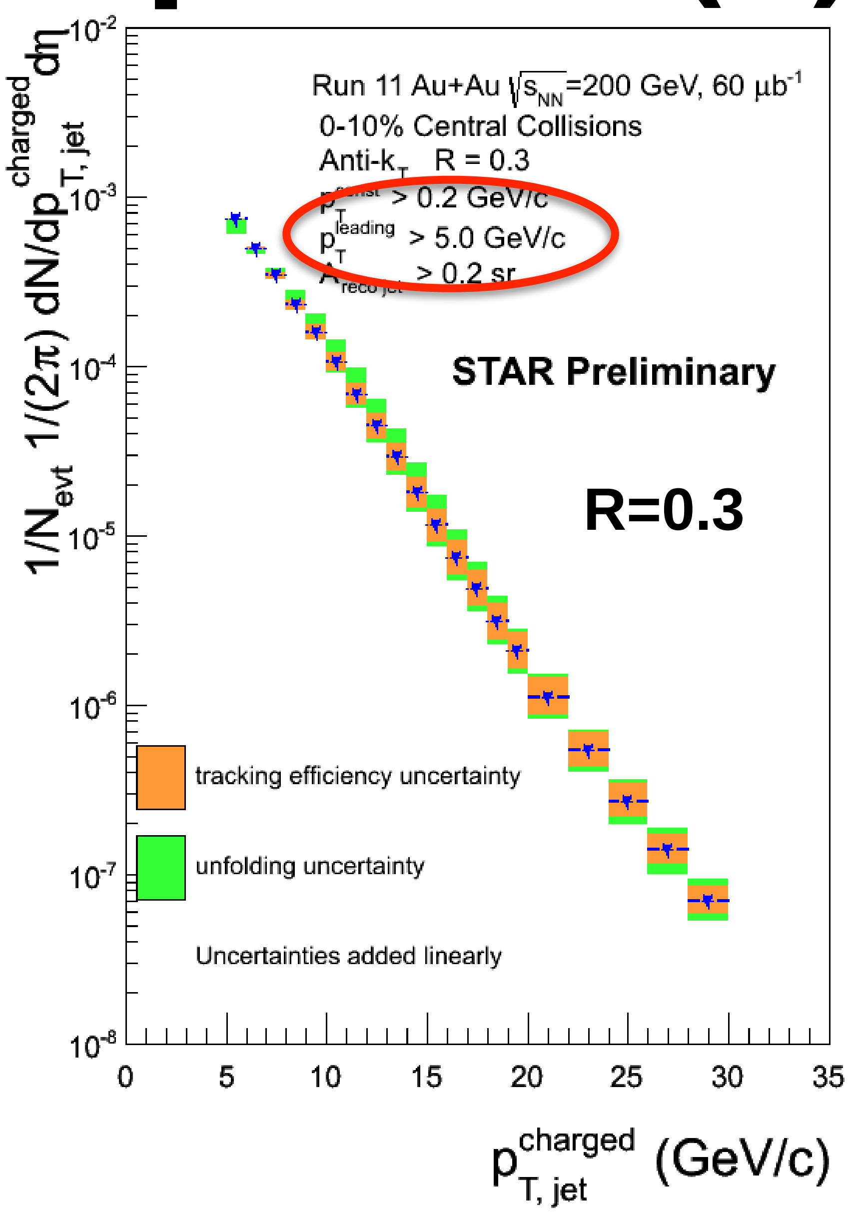
Inclusive Jet Spectra (i)



- Combinatorial background can be reduced by applying a cut on the leading hadron p_T in the jet candidate
    - ➡ This introduces a bias, although the jet can still contain many soft particles

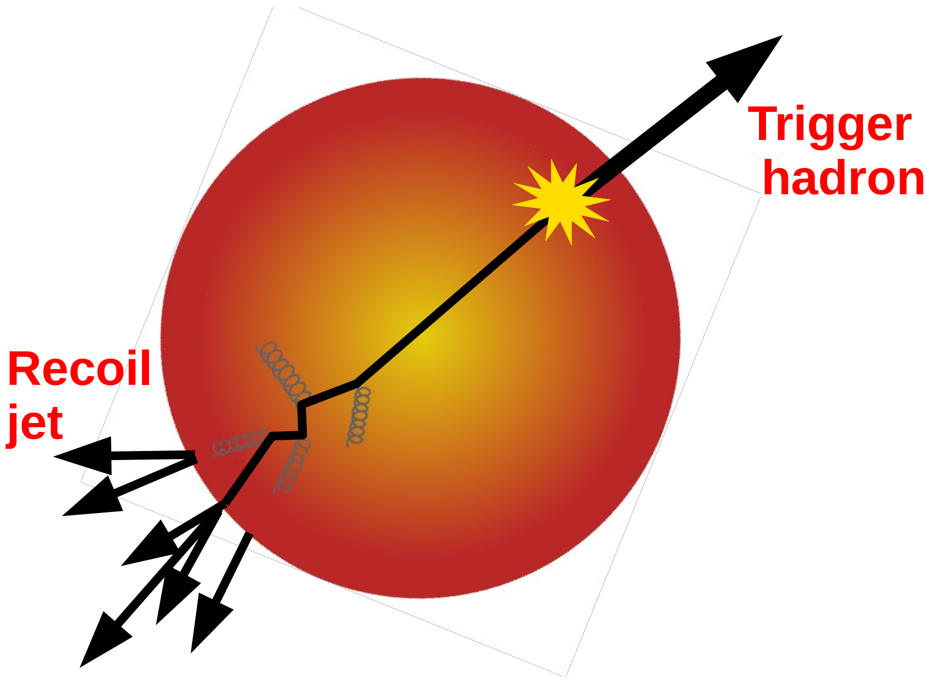
Inclusive Jet Spectra (ii)





- Measured spectra are corrected using Bayesian unfolding
- Different radii contain differing amounts of the jet energy
  - ➡ Ideally, a high radius is wanted but this is determined by the stability of the unfolding
- R_{AA} is a work in progress
  - ➡ Work ongoing on p+p baseline
  - ➡ Full systematic uncertainty study is underway

Semi-inclusive Recoil Jets



Trigger: high-p_T hadron
⇒ selects hard events

Recoil jet: no further cuts
⇒ unbiased

- STAR analysis:
  - Recoil jet azimuth: $|\Delta\phi-\pi| < \pi/4$
  - No rejection of jet candidates on jet-by-jet basis
  - Collinear safe jet measurement with low infra-red cutoff (200 MeV/c)
  - Background subtraction:
    - Mixed events

Observable:
Recoil jets per trigger

$$\frac{1}{N^h_{trig}}\frac{dN_{jet}}{dp_{T,jet}} = \frac{1}{\sigma^{AA\rightarrow h+X}}\frac{d\sigma^{AA\rightarrow h+jet+X}}{dp_{T,jet}}$$

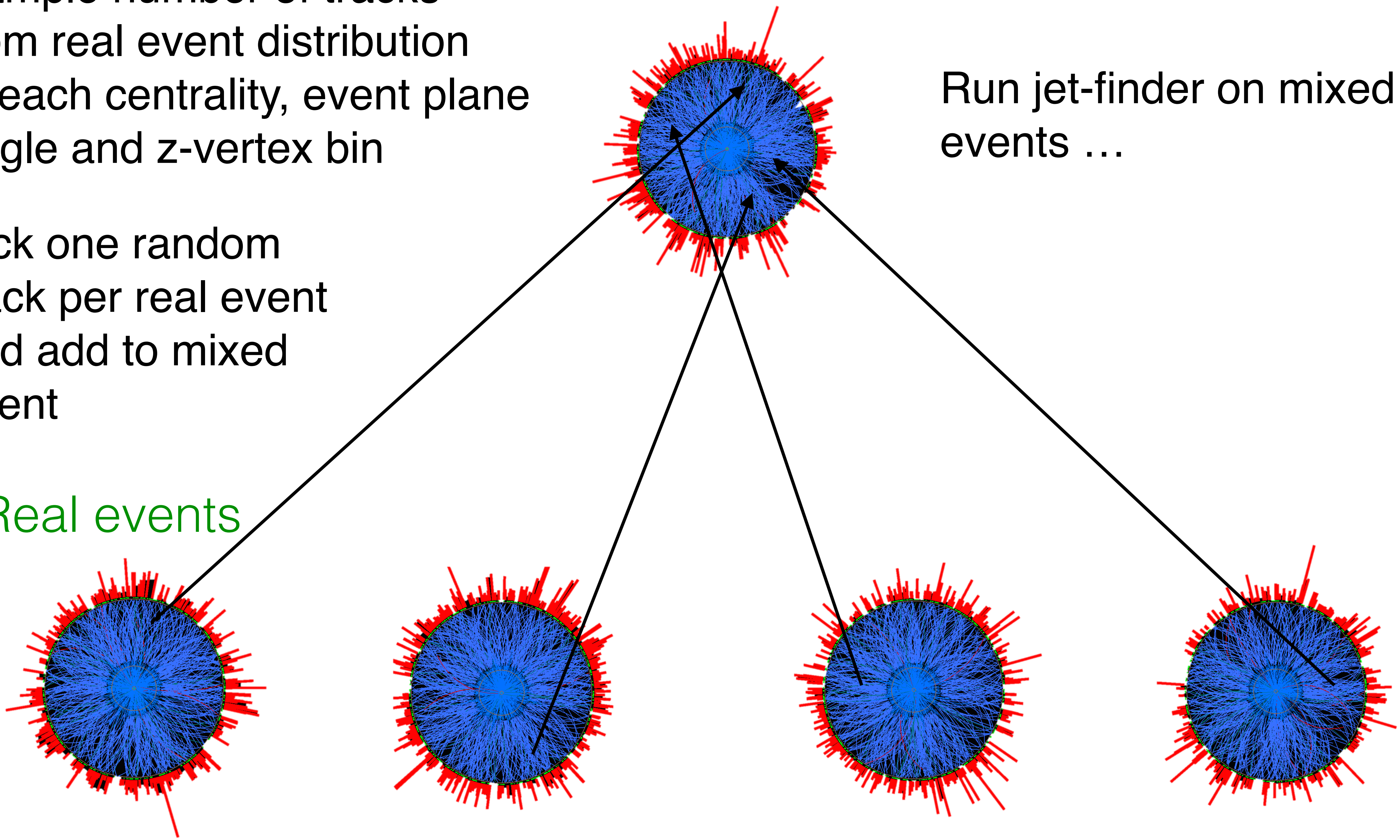
Measured   Calculable in NLO pQCD

Semi-inclusive Recoil Jets - background estimation

Sample number of tracks from real event distribution in each centrality, event plane angle and z-vertex bin

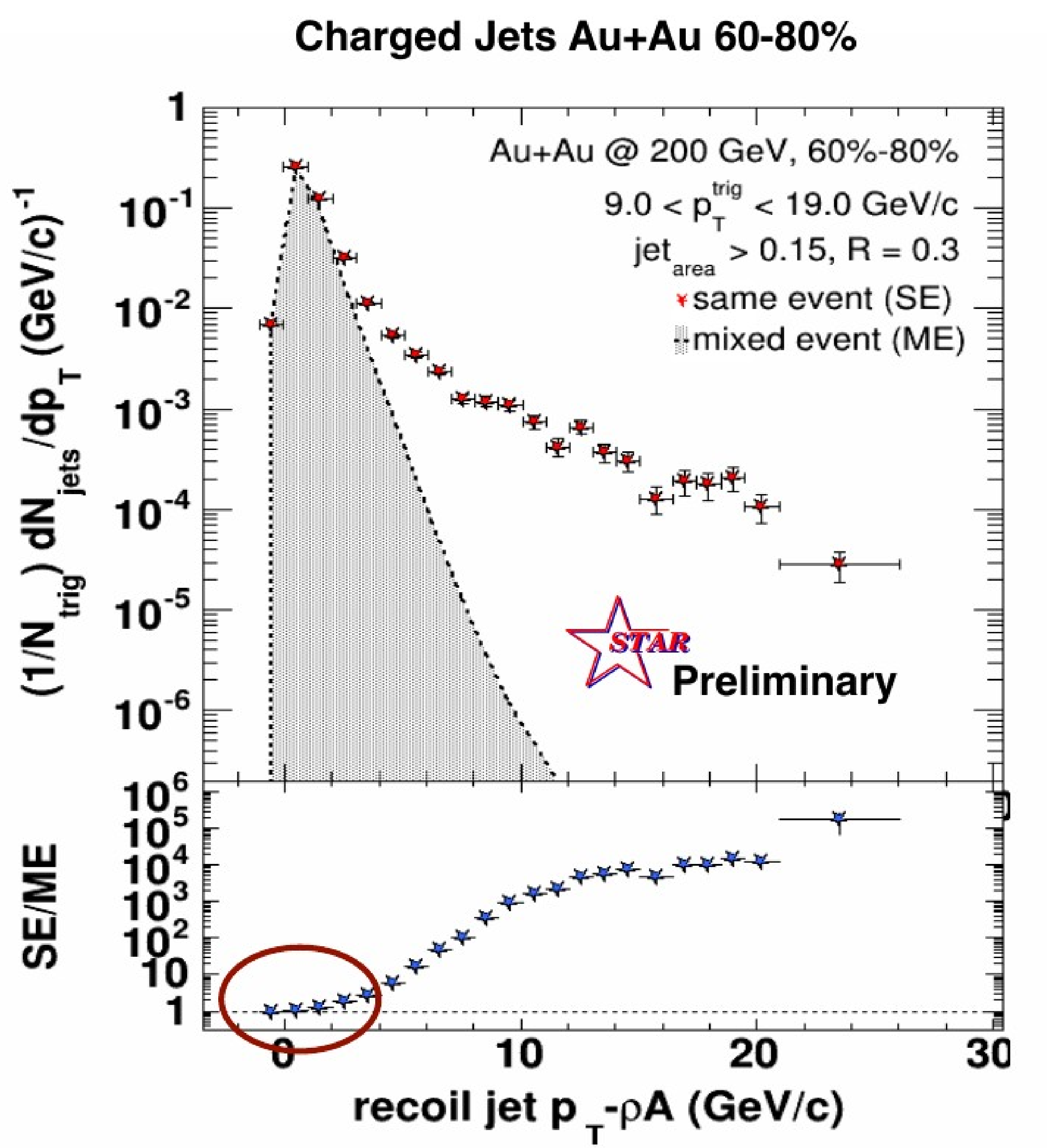
Pick one random track per real event and add to mixed event

Run jet-finder on mixed events …

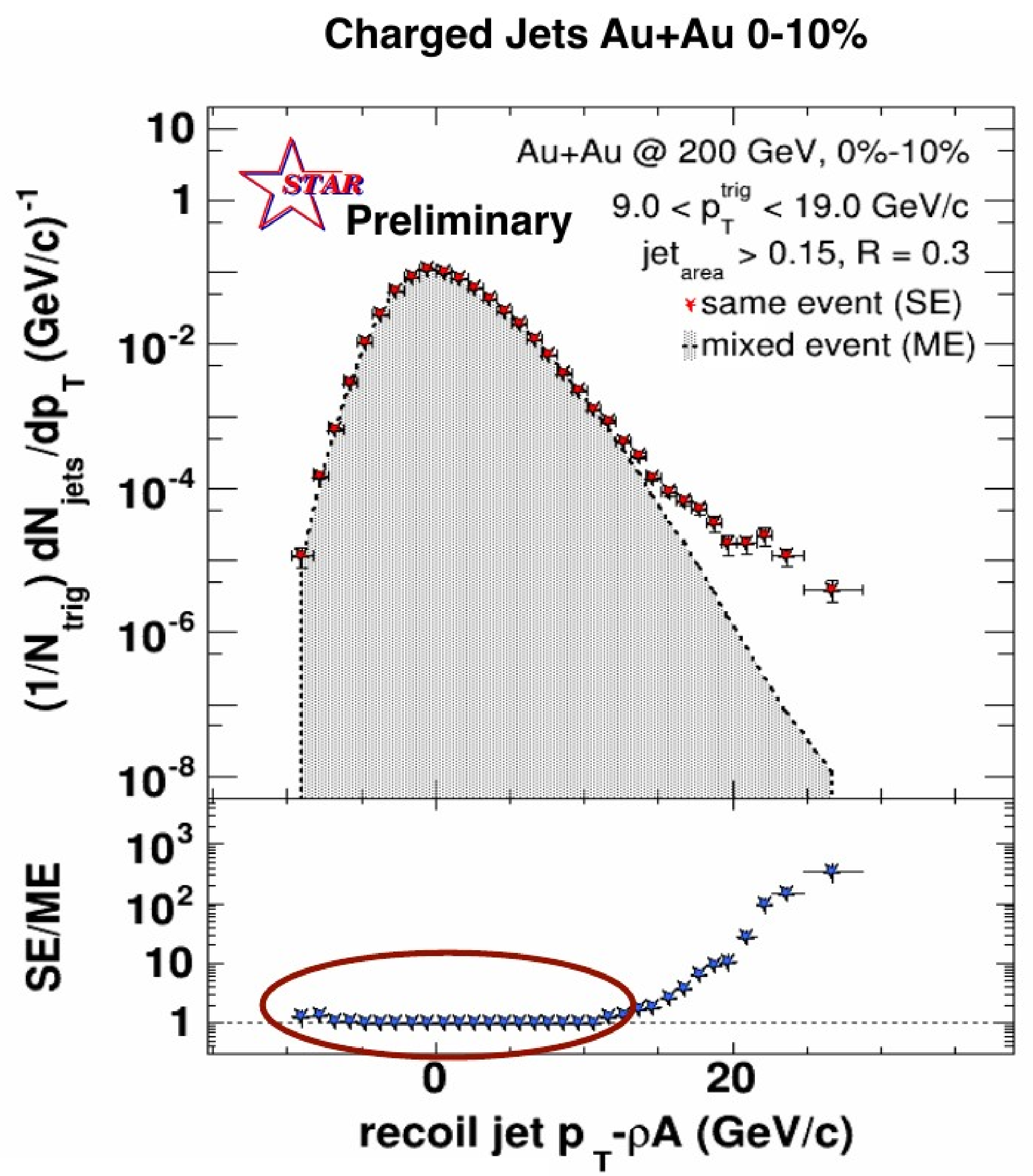


Semi-inclusive Recoil Jets: same- and mixed-event

peripheral

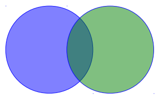


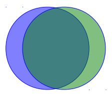
central

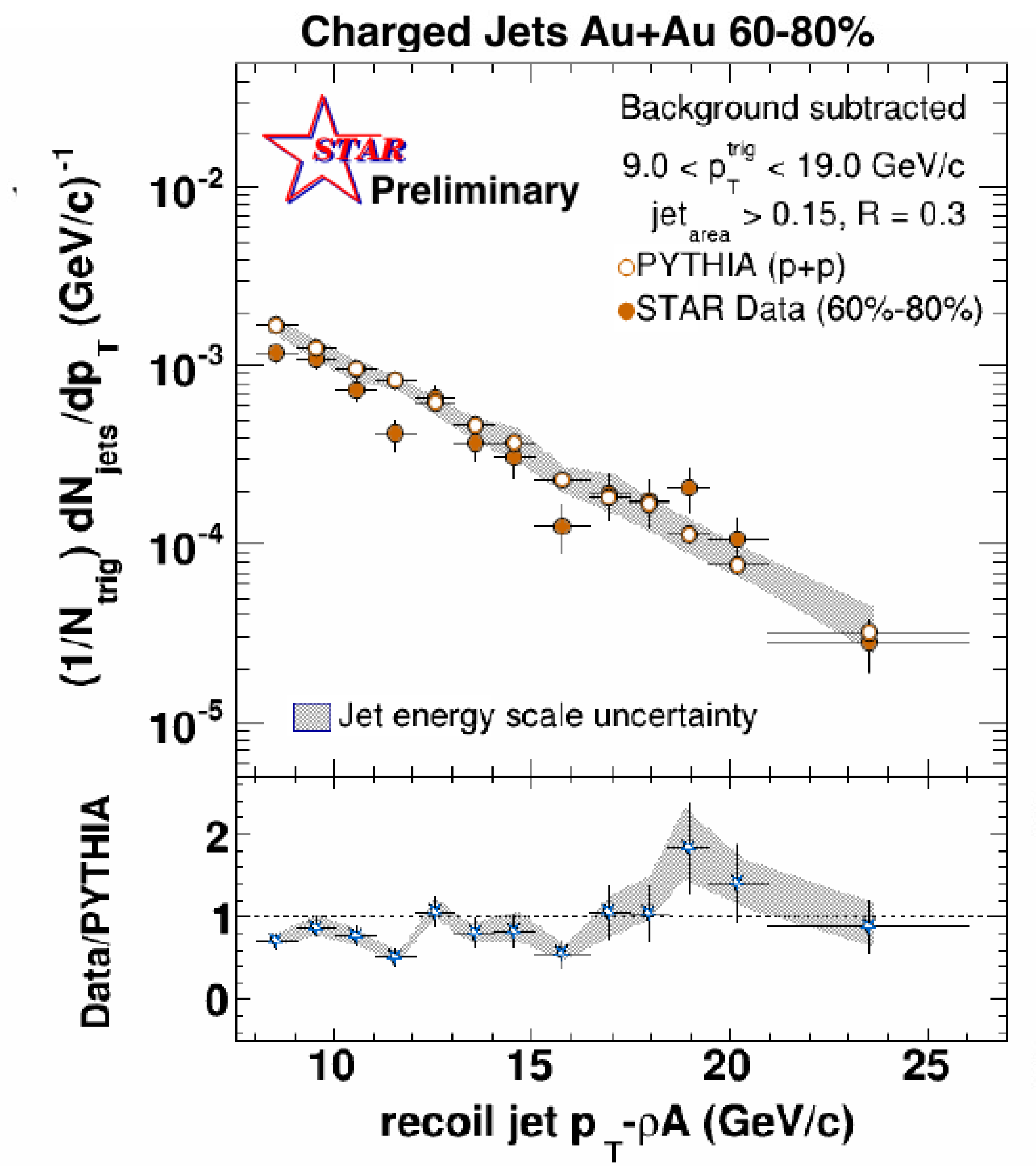


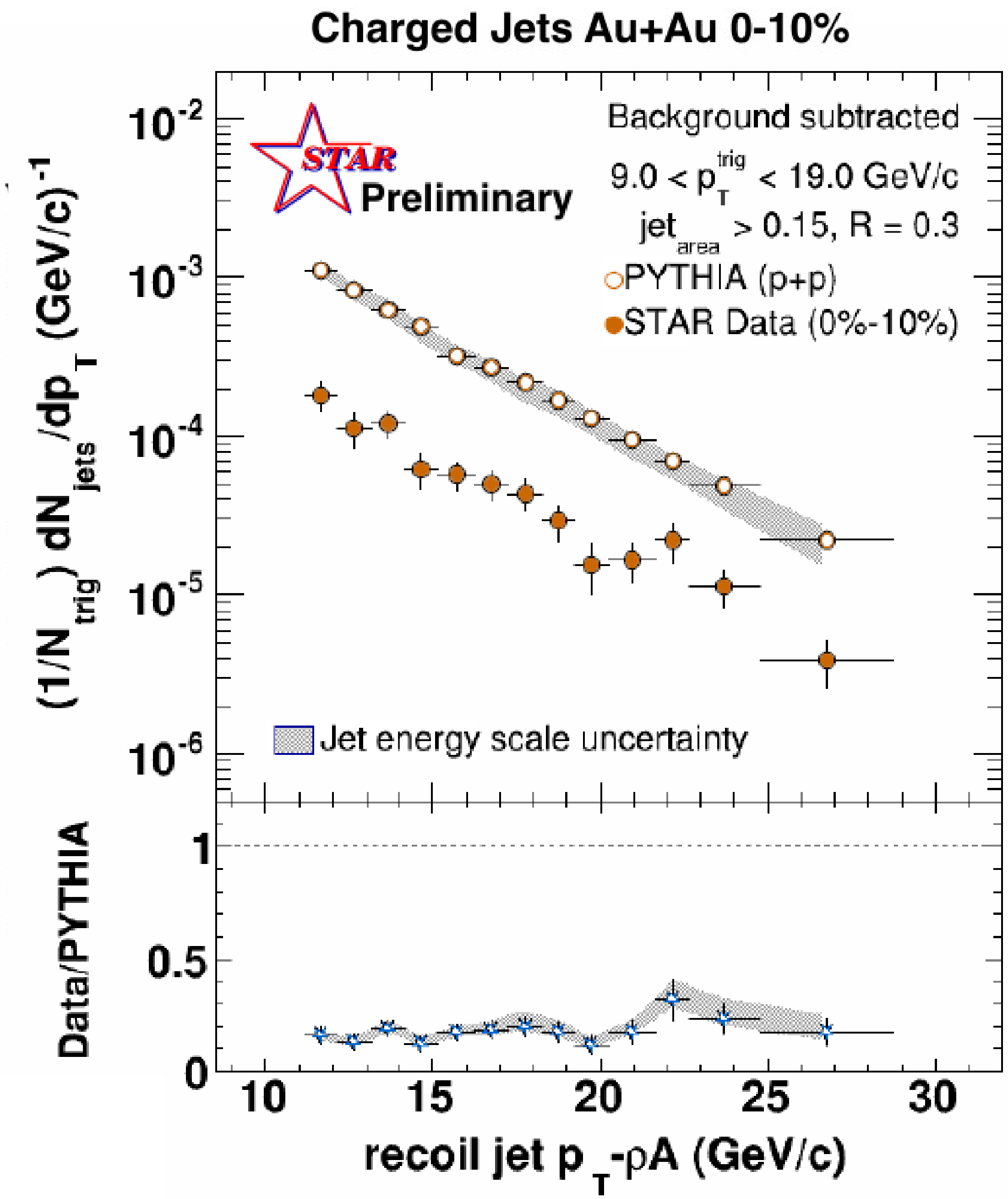
- Normalisation performed at negative $p_{T,corr}$
  - ➡ Mixed event describes the combinatorial background well
- Signal = Same Event (SE) - Mixed Event (ME)

Semi-inclusive Recoil Jets: same- and mixed-event

peripheral 

central 





- PYTHIA reference is smeared by a simulation of detector effects and background fluctuations
  - ➡ Unfolding is on the way
- Central collisions show a strong suppression with respect to the peripheral collisions

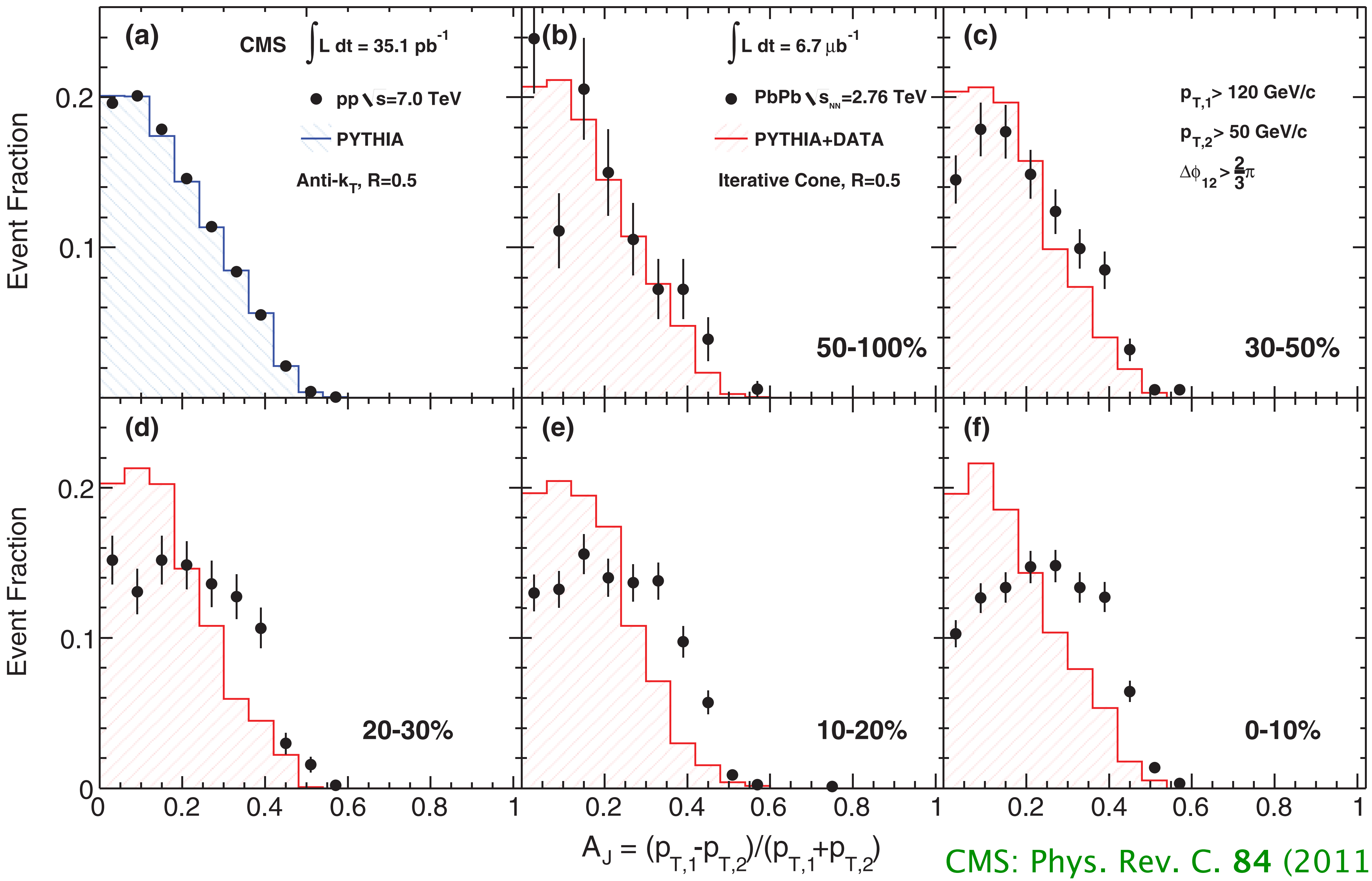
Summary and Conclusions

- Using the high-acceptance of the STAR experiment, it is possible to measure jets in high-multiplicity Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV
- Inclusive charged-jet spectrum extracted
  - ➡ Work ongoing to calculate the R_{AA} ratio
- Semi-inclusive recoil charged jets:
  - ➡ New technique using mixed events for the background estimation
  - ➡ Central Au+Au collisions show a strong suppression compared to PYTHIA, peripheral collisions are comparable to PYTHIA
- Also made a measurement of the di-jet asymmetry, A_j (not shown due to lack of time)
- Will extend the analyses to full-jets, including the calorimeter information.

Backup

Di-jet imbalance

A_J at the LHC

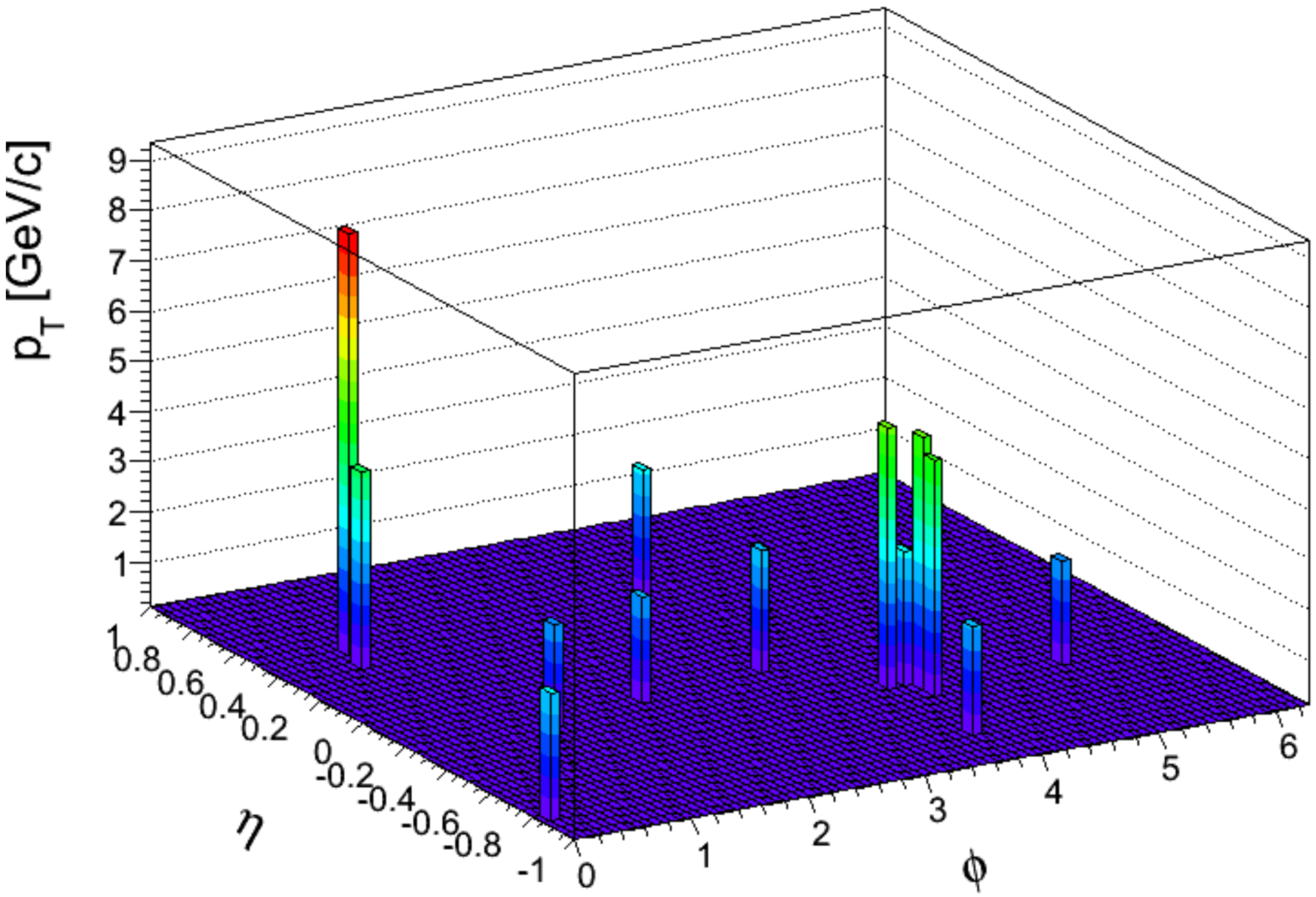


CMS: Phys. Rev. C. **84** (2011) 024906

- Significant di-jet momentum imbalance is observed for high-p_T jets in central Pb+Pb collisions

A_J in STAR

$p_{T,cut}$=2 GeV/c
p_T^{Lead}>20 GeV
$p_T^{SubLead}$>10 GeV
$\Delta\Phi_{Lead,SubLead}$ > 2/3 π



Calculate A_j with constituent $p_{T,cut}$>2 GeV/c

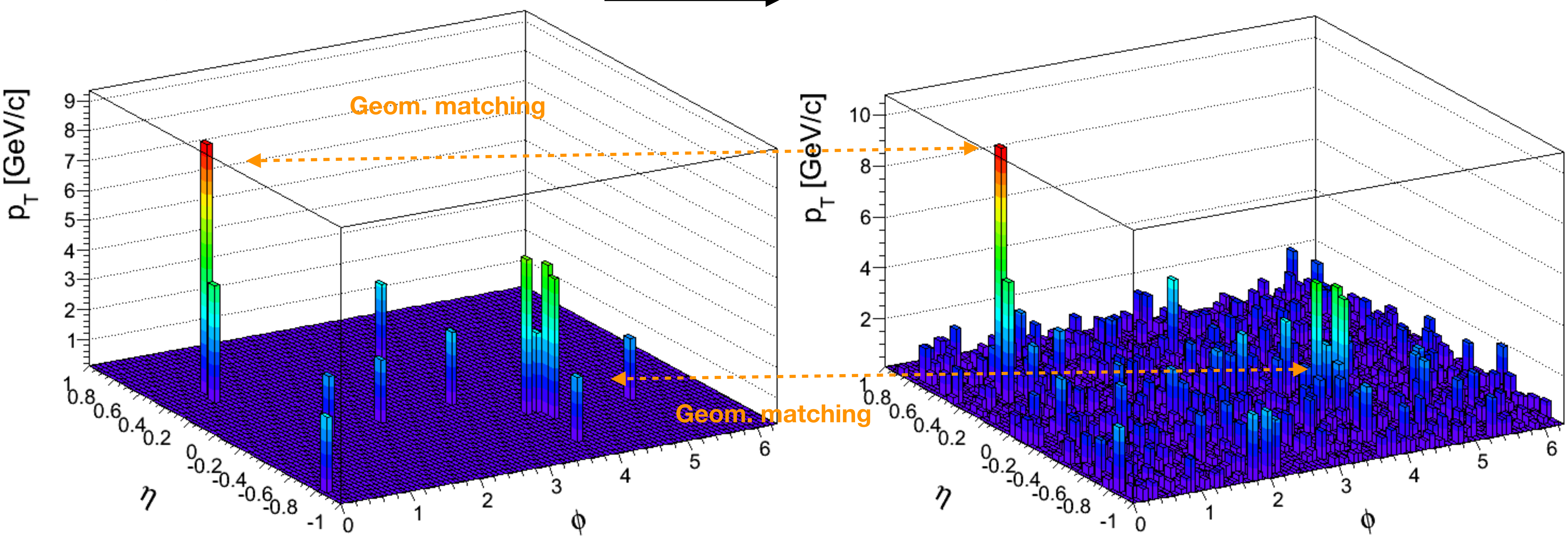
$$A_J = \frac{p_{T,1} - p_{T,2}}{p_{T,1} + p_{T,2}} \quad p_T = p_T^{rec} - \rho \times A$$

A_J in STAR

$p_{T,cut}$=2 GeV/c
p_T^{Lead}>20 GeV
$p_T^{SubLead}$>10 GeV
$\Delta\Phi_{Lead,SubLead}$ > 2/3 π

Re-run jet-finding algorithm
anti-k_T on these events ...

$p_{T,cut}$=0.2 GeV/c
p_T^{Lead}>20 GeV ($p_{T,cut}$=2 GeV/c)
$p_T^{SubLead}$>10 GeV ($p_{T,cut}$=2 GeV/c)

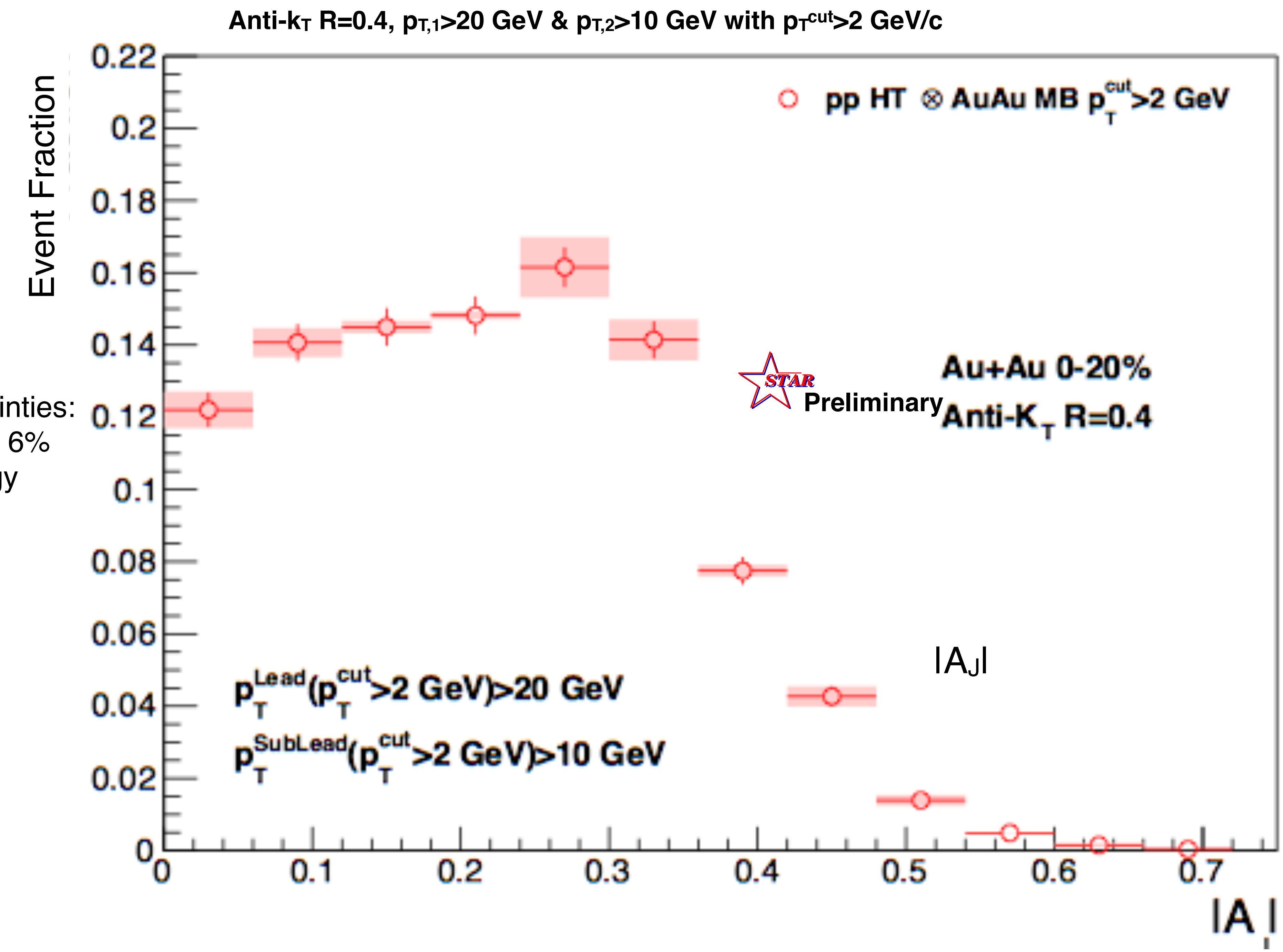


Calculate A_j with constituent $p_{T,cut}$>2 GeV/c

$$A_J = \frac{p_{T,1} - p_{T,2}}{p_{T,1} + p_{T,2}} \quad p_T = p_T^{rec} - \rho \times A$$

Calculate "matched" $|A_j|$ with constituent $p_{T,cut}$>0.2 GeV/c.

A_J in Au+Au 0-20%, R=0.4



Sys. Uncertainties:
- tracking eff. 6%
- tower energy scale 2%

A_J in Au+Au 0-20%, R=0.4

Sys. Uncertainties:
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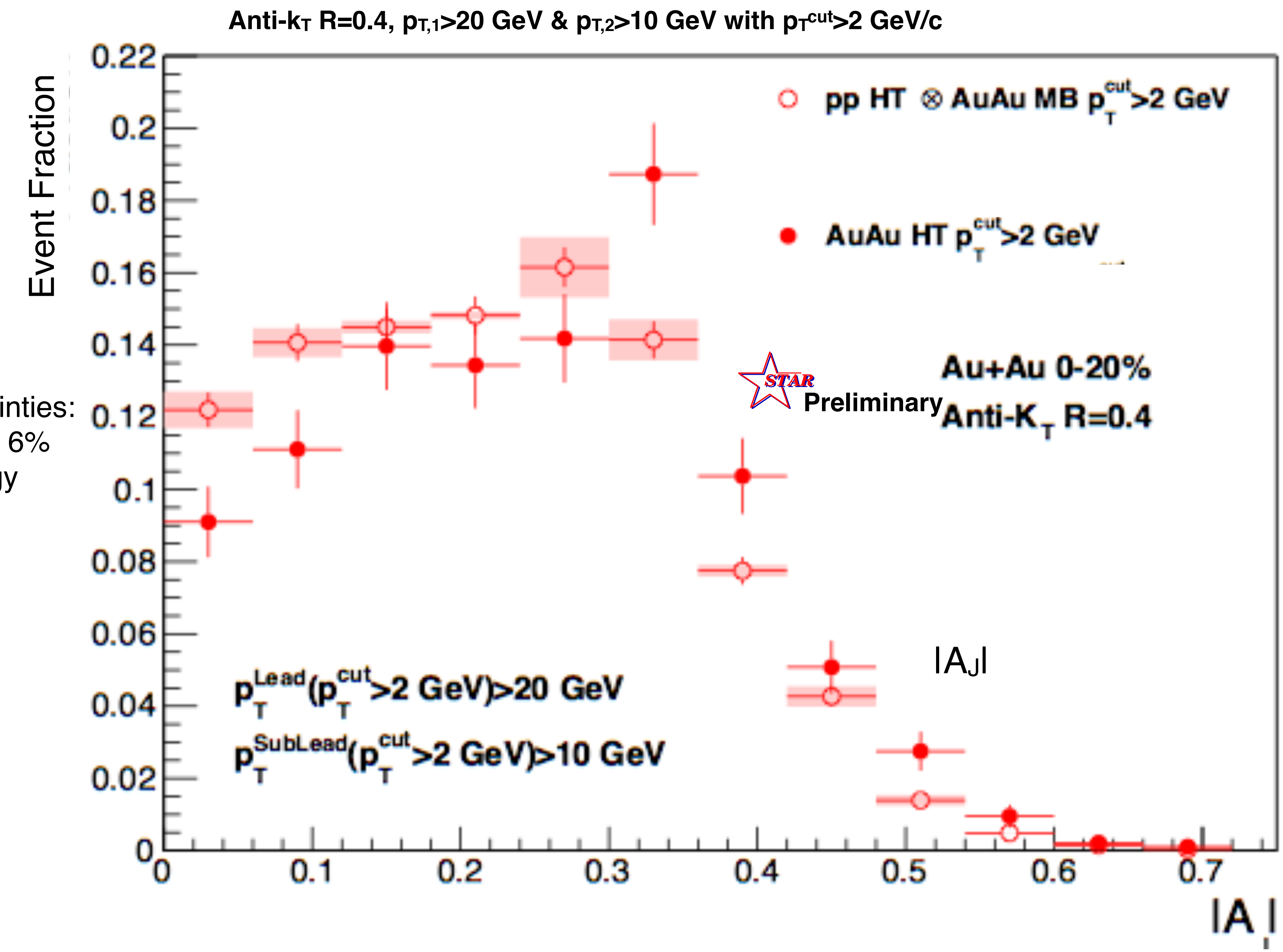
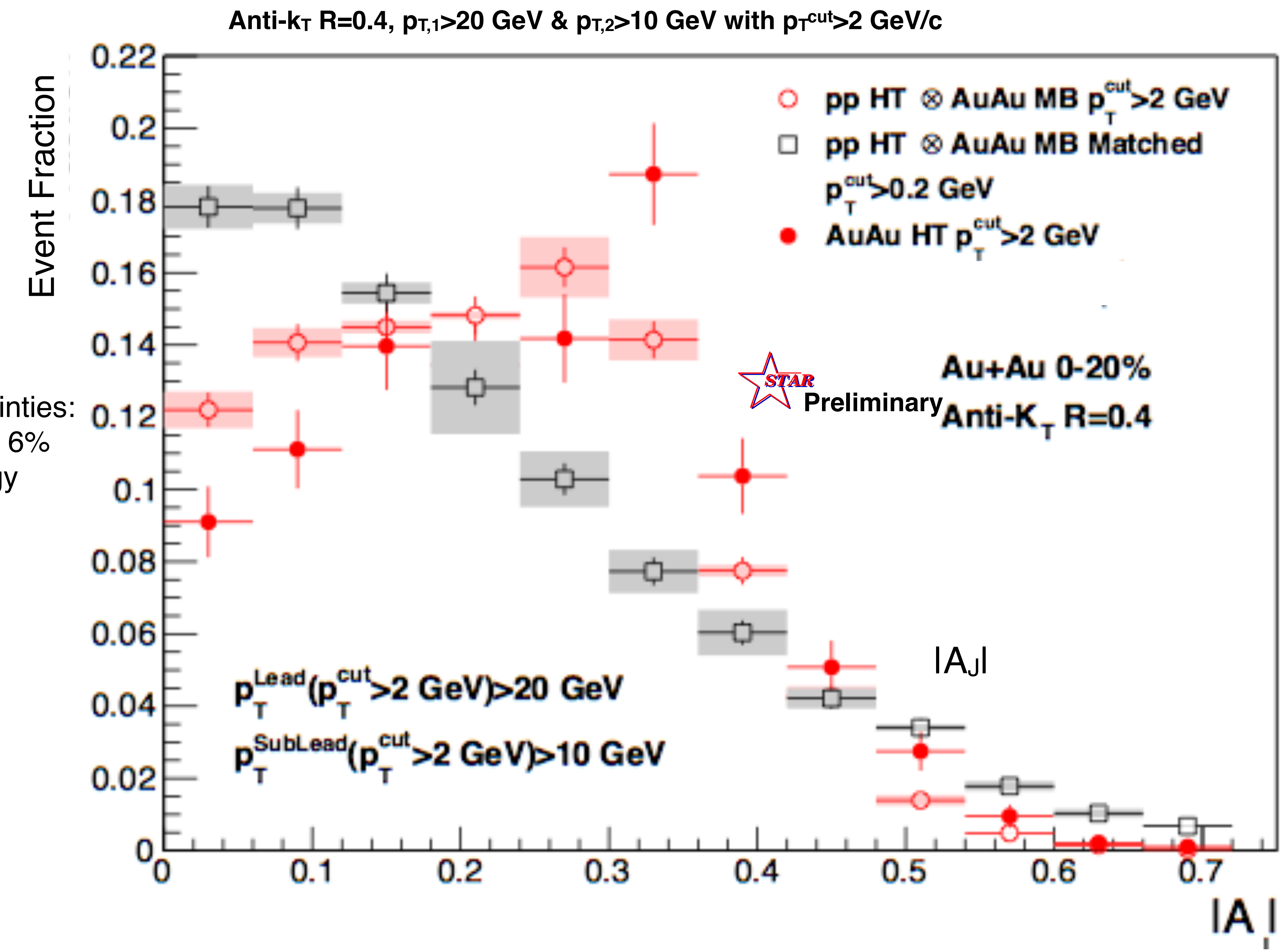
- tower energy scale 2%



p-value<10^{-5}
(stat. error only)

Au+Au di-jets more imbalanced than p+p for p_T^{cut}>2 GeV/c

A_J in Au+Au 0-20%, R=0.4



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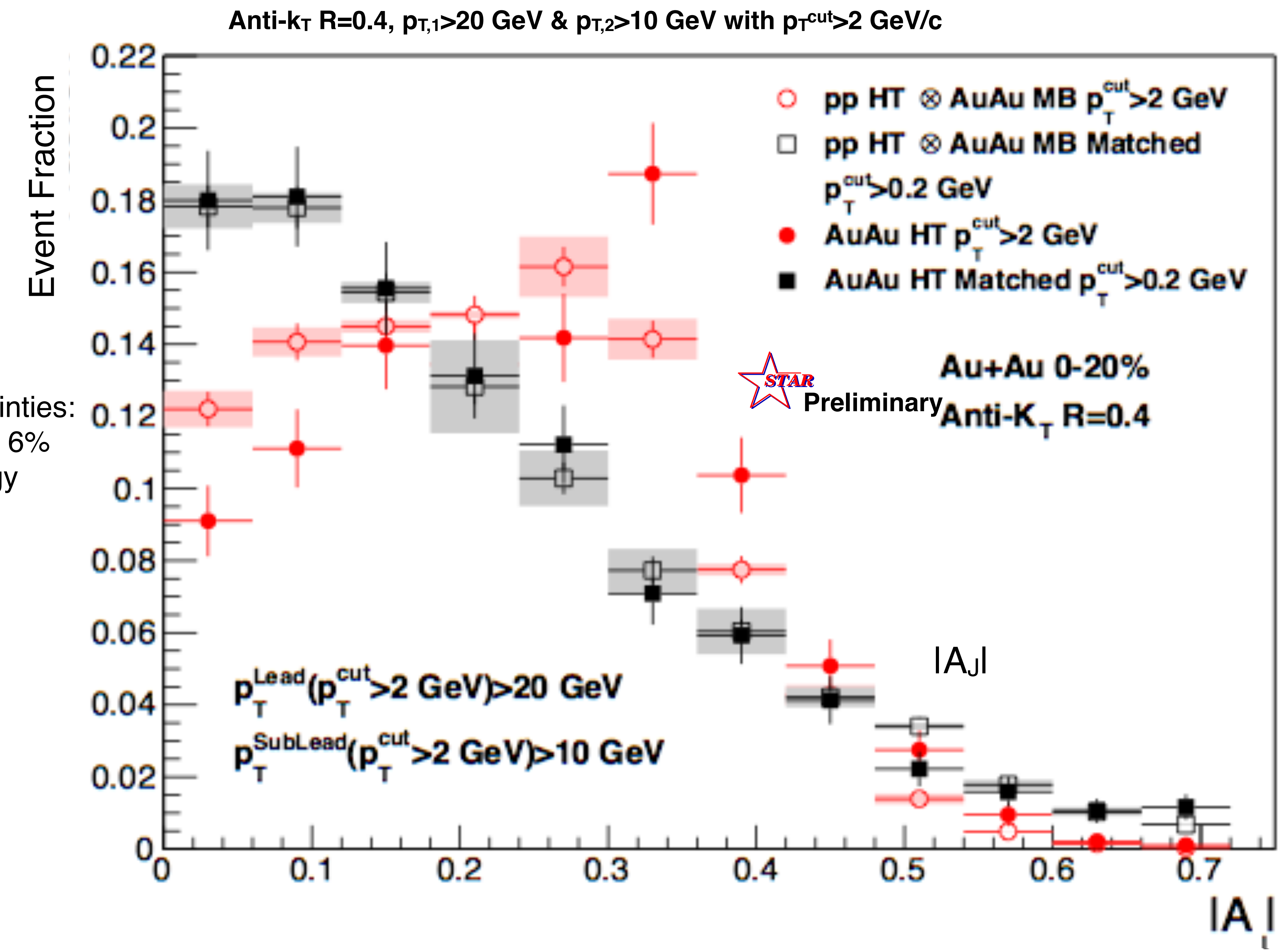


Sys. Uncertainties:
- tracking eff. 6%
- tower energy scale 2%

p-value<10^{-5} (stat. error only)

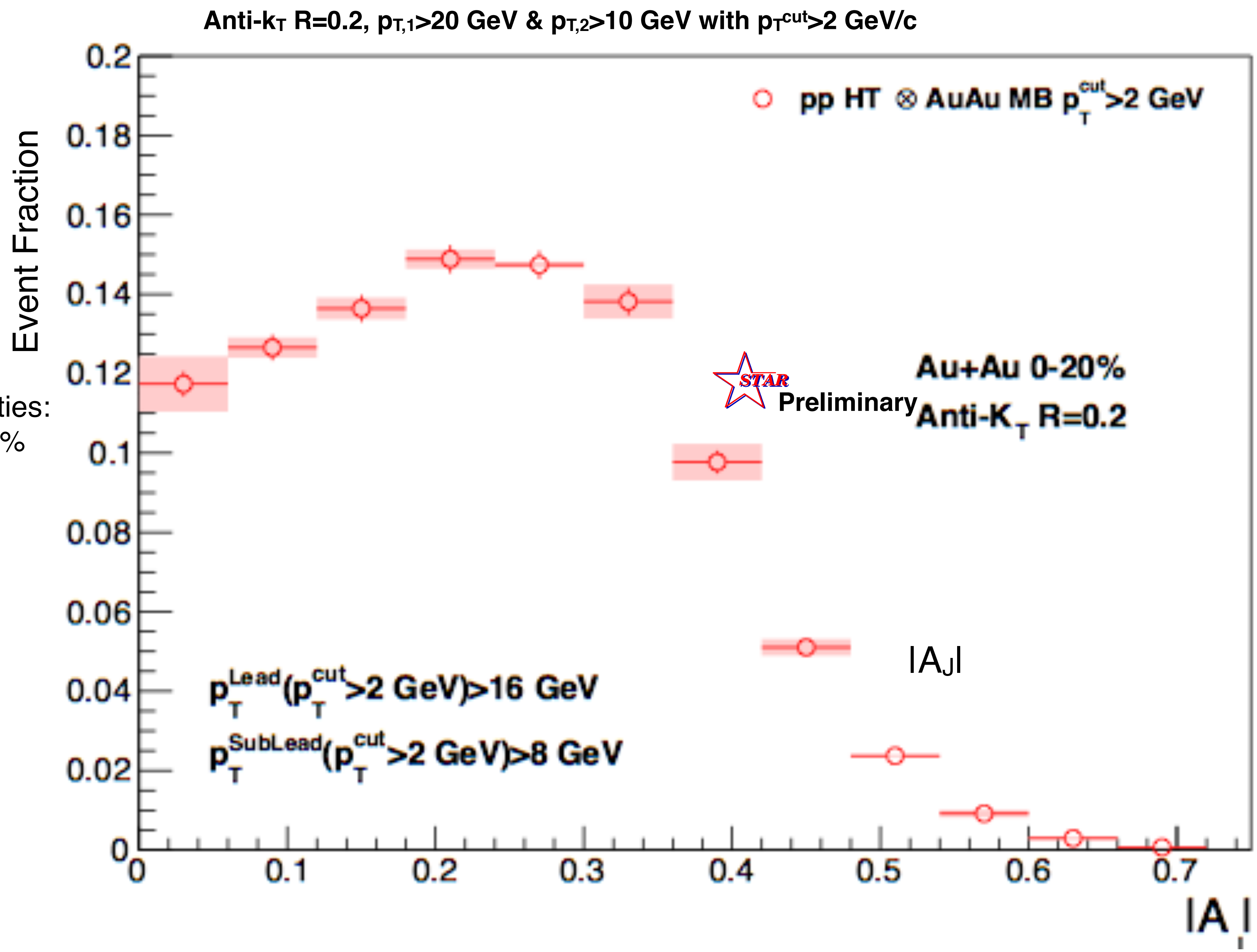
p-value~0.8 (stat. error only)

Au+Au di-jets more imbalanced than p+p for p_T^{cut}>2 GeV/c

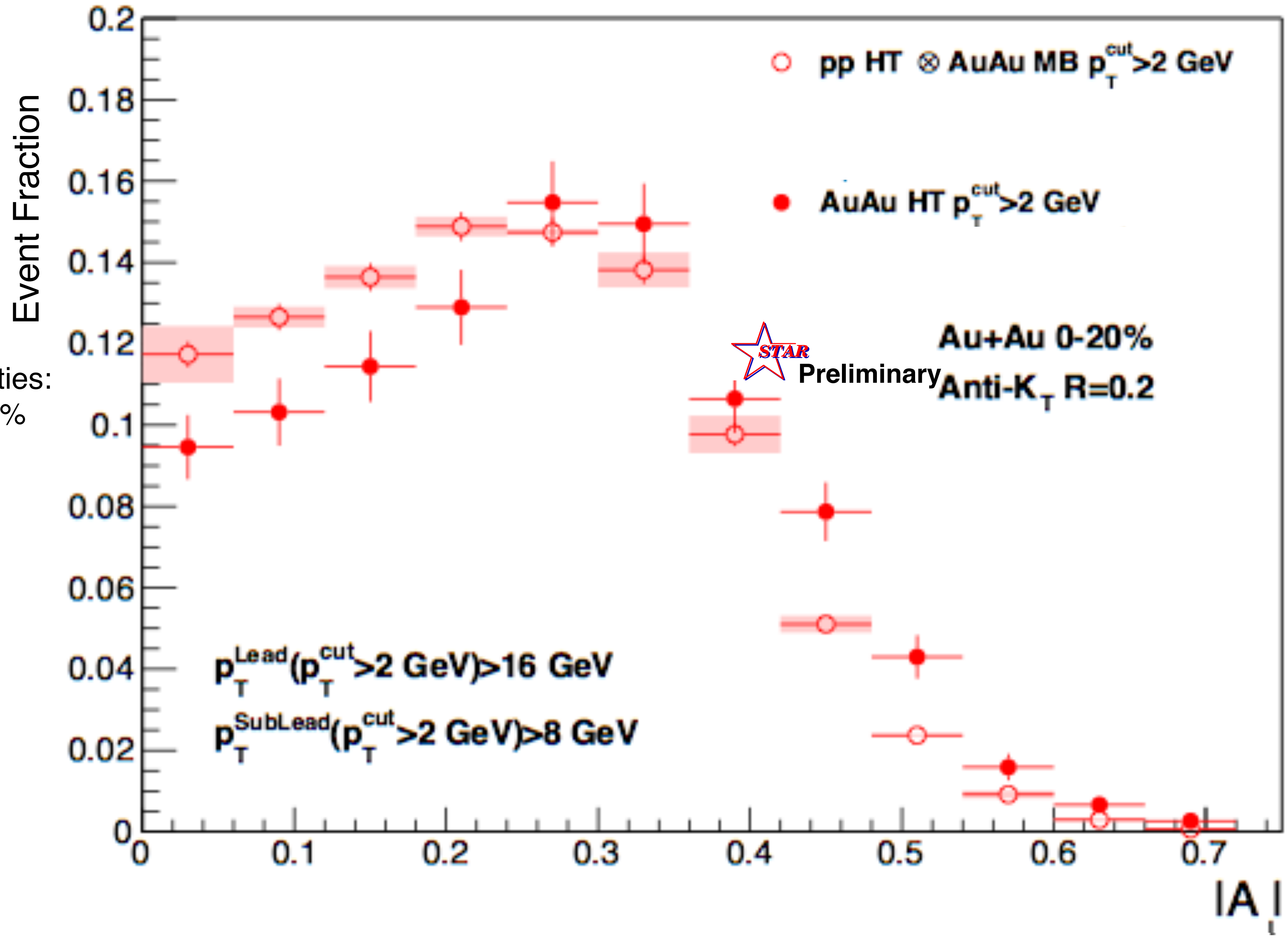
Au+Au A_J ~ p+p A_J for matched di-jets (R=0.4)

A_J in Au+Au 0-20%, R=0.2

Sys. Uncertainties:
- tracking eff. 6%
- tower energy scale 2%



A_J in Au+Au 0-20%, R=0.2



p-value<10^{-10}
(stat. error only)

Sys. Uncertainties:
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- tower energy scale 2%

A_J in Au+Au 0-20%, R=0.2

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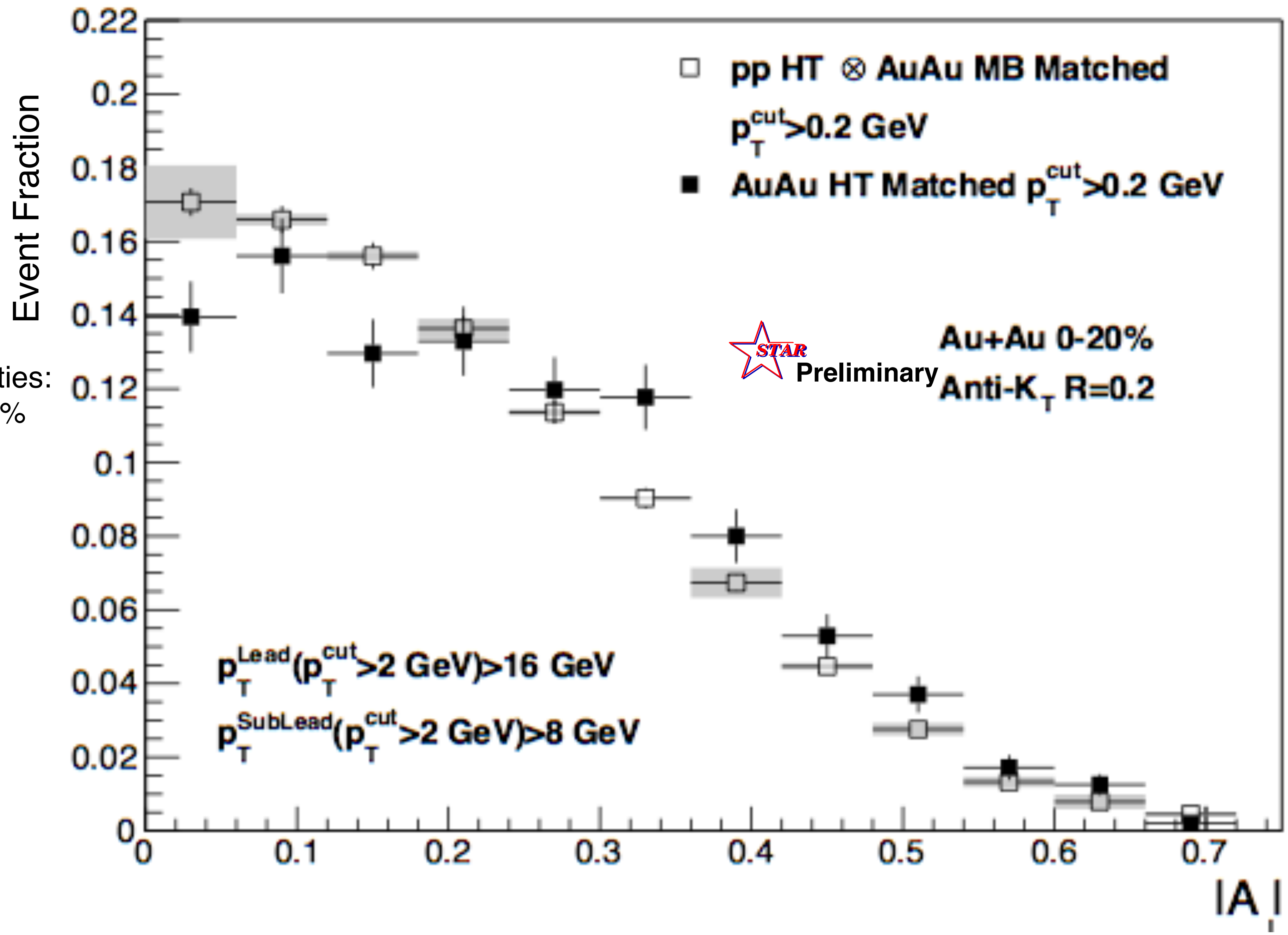
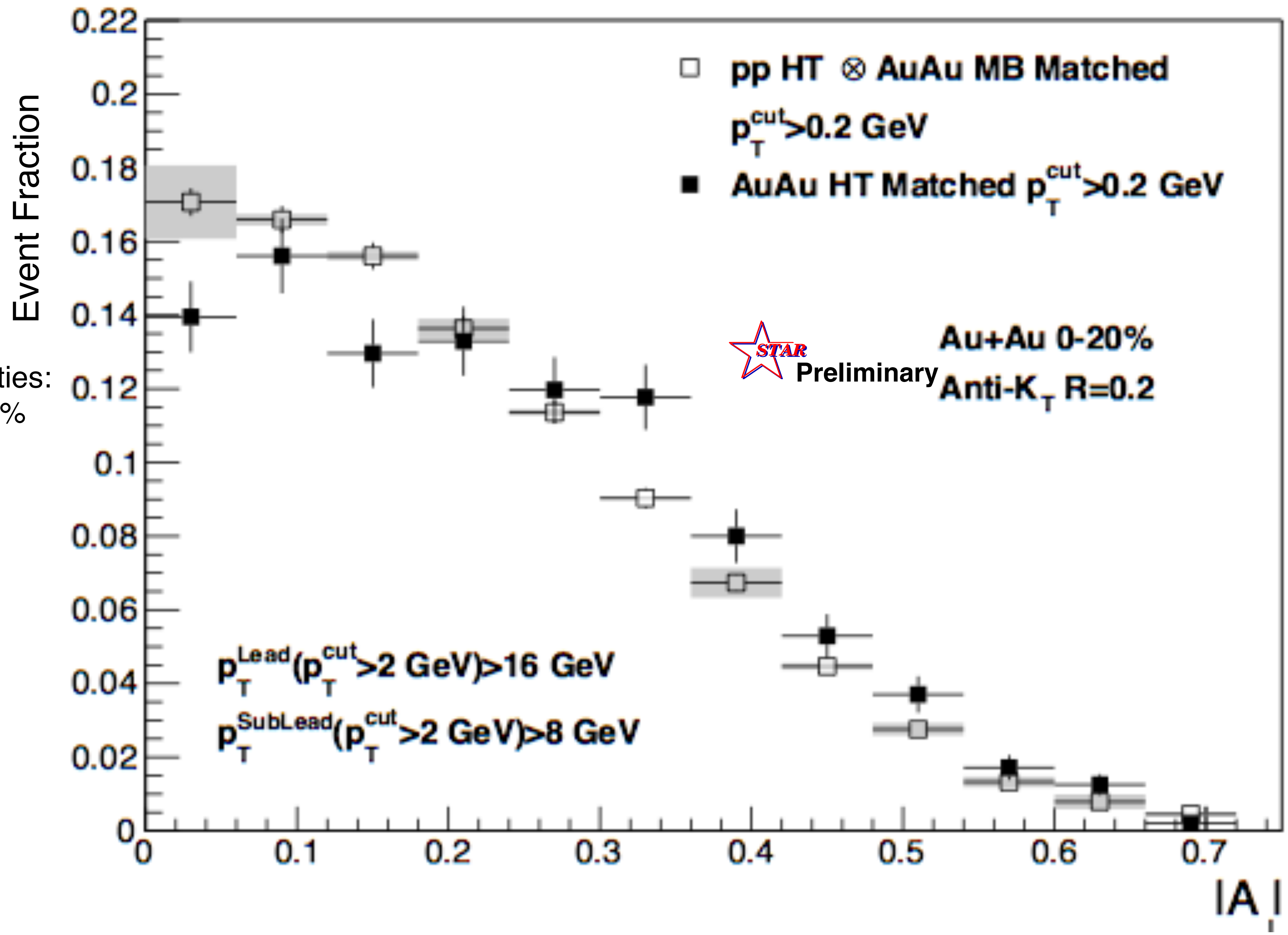


p-value<10^{-10}
(stat. error only)

p-value<10^{-4}
(stat. error only)

A_J in Au+Au 0-20%, R=0.2

Sys. Uncertainties:
- tracking eff. 6%
- tower energy scale 2%



p-value<10^{-10}
(stat. error only)

p-value<10^{-4}
(stat. error only)

Matched Au+Au A_J ≠ p+p A_J for R=0.2
→ (recoil) Jet broadening in 0.2 – 0.4