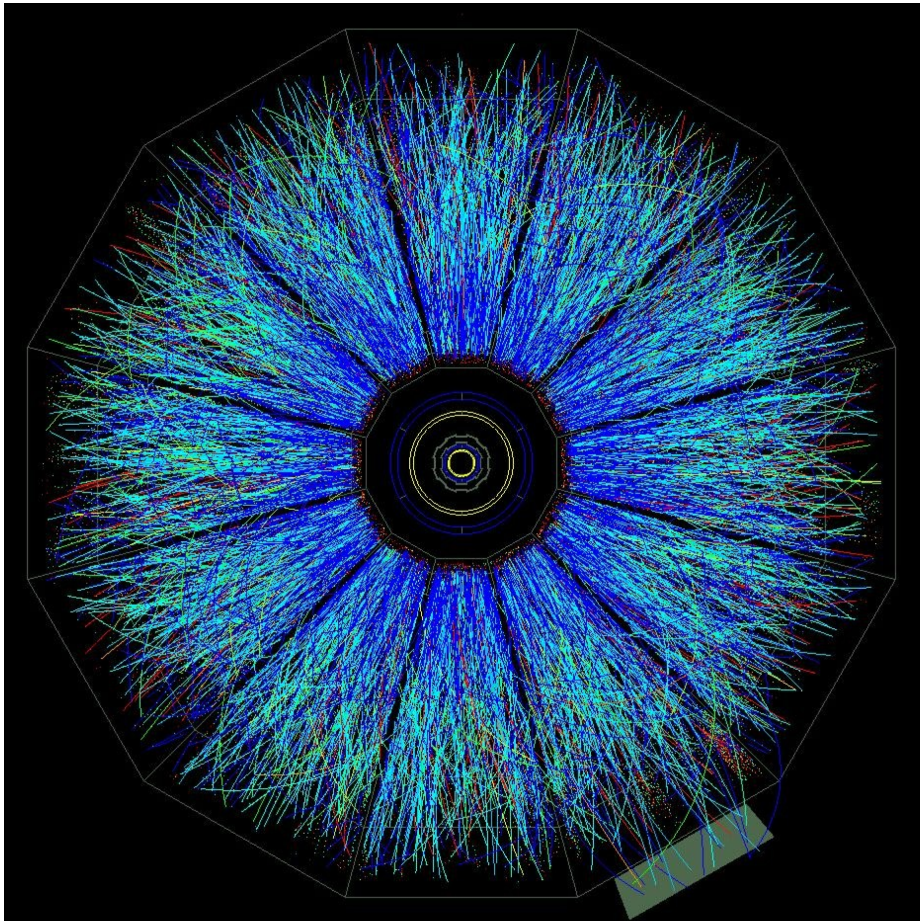
Jet-Hadron Correlations in STAR

Alice Ohlson (Yale University)
for the STAR Collaboration

Winter Workshop on Nuclear Dynamics
February 8, 2011

Outline

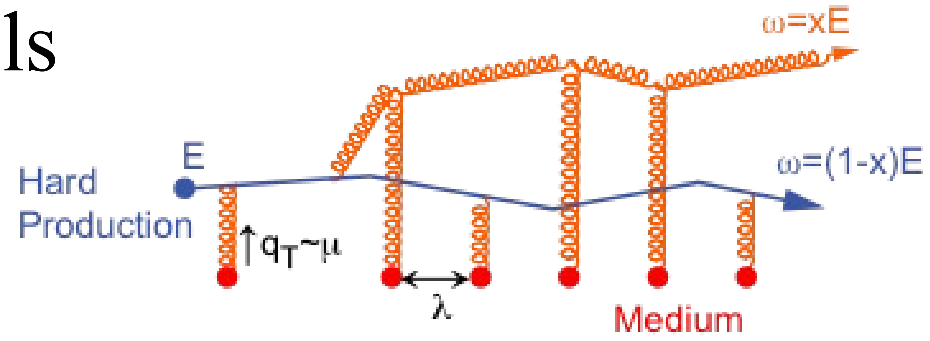
- Jet Quenching
- Jet Reconstruction in STAR
- Jet-Hadron Correlations
  - Issues of background subtraction
  - Gaussian widths, I_{AA}, D_{AA}
- Connection to 2+1 Correlations
- Jet-Hadron Correlations with Respect to the Event Plane
  - Issues of Jet v_2 and Event Plane Reconstruction
- Conclusions



Jet Quenching

- Radiative energy loss models
  - Partons lose energy and are scattered as they traverse the medium
  - What would we see in angular correlation studies?

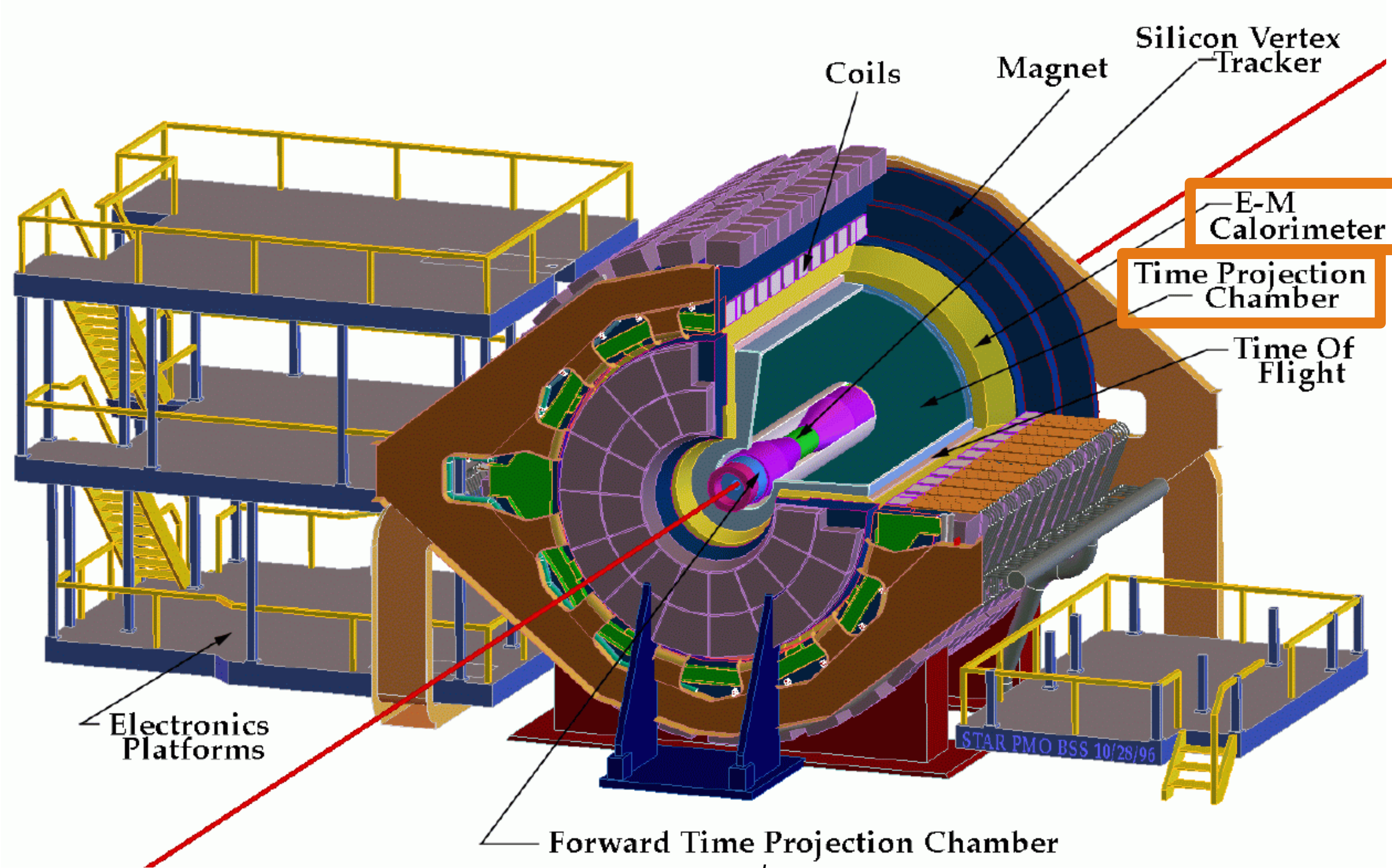
    Softer and broader distribution of hadrons around the jet axis than seen in p+p

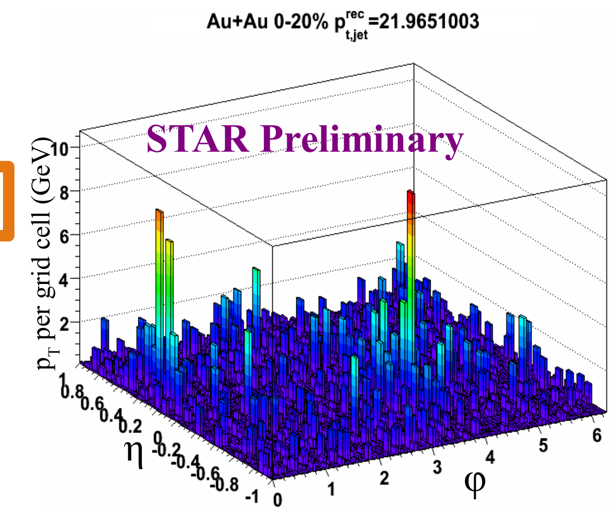


- "Black-and-white" models
  - Partons either escape the medium unmodified or are entirely thermalized/absorbed
  - Unmodified jet shapes compared to those in p+p collisions

We can use jet-hadron correlations to study jet quenching!

Jet Reconstruction at STAR





Online Trigger
E_T > 5.4 GeV in one tower
$\Delta\varphi \times \Delta\eta = 0.05 \times 0.05$

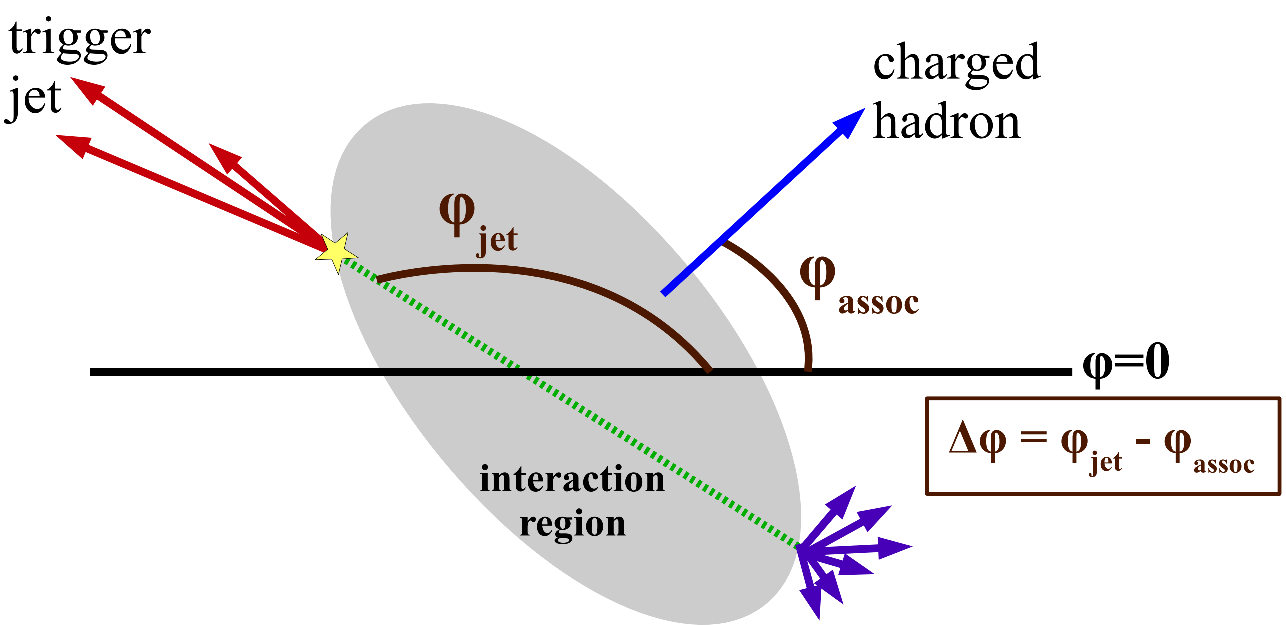
Data set: Run 7, AuAu, $\sqrt{s_{NN}}$ = 200 GeV, High Tower (HT) Trigger.

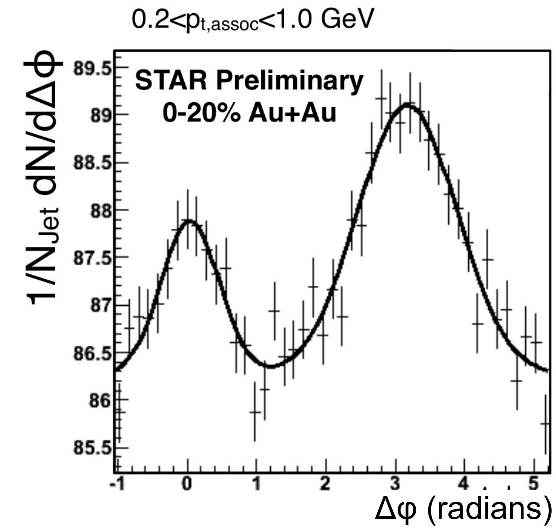
Trigger Jets found with Anti-kT algorithm [1]
($R = 0.4$, $p_T^{track,tower} > 2$ GeV/c).

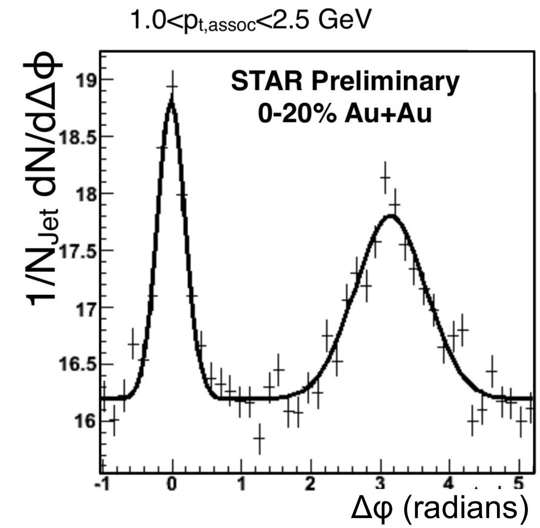
[1] M. Cacciari and G. Salam, Phys. Lett. B **641,** 57 (2006)

Jet-Hadron Correlations

- Study azimuthal angular correlations of associated particles (all charged hadrons in an event) with respect to the axis of a reconstructed HT trigger jet.







- Jet reconstruction increases the kinematic reach compared to dihadron correlations.

Issues: ZYAM, jet v_2

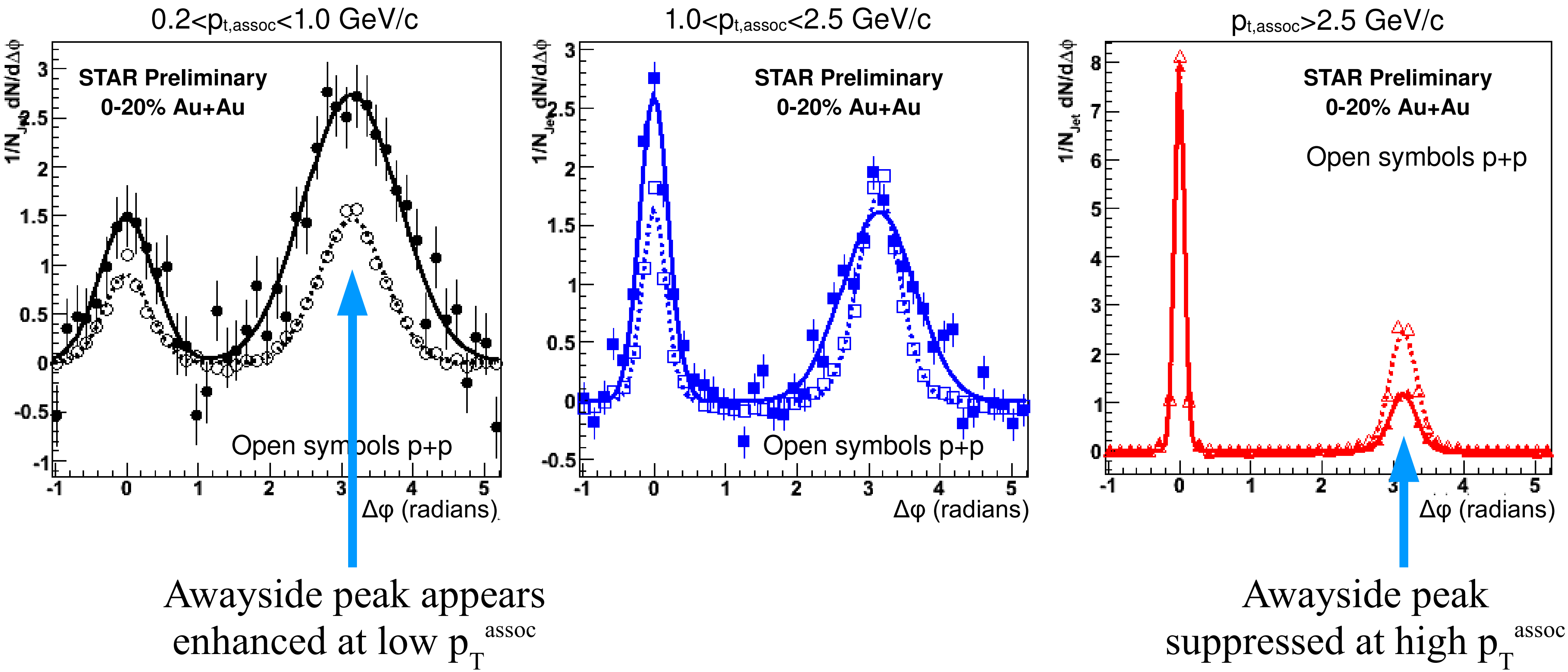
- In the presence of broad jet peaks (i.e. central collisions, low p_T^{assoc}), ZYAM overestimates background levels.
  "Zero Yield At Minimum"
- Jet v_2 is *a priori* unknown (studies in progress).
- In this analysis:
  - background levels estimated by fitting

    $$2 \text{ Gaus} + B*(1+2*v_2^{assoc}*v_2^{jet}*\cos(2\Delta\varphi))$$

  - $v_2^{assoc} = (v_2\{2\}+v_2\{4\})/2$ (as a function of p_T)
  - $v_2^{jet} = v_2\{2\}(p_T = 6 \text{ GeV/c})$
  - maximum v_2 uncertainties: no v_2 and +50% of $v_2^{jet}*v_2^{assoc}\{2\}$

Jet-Hadron Correlations

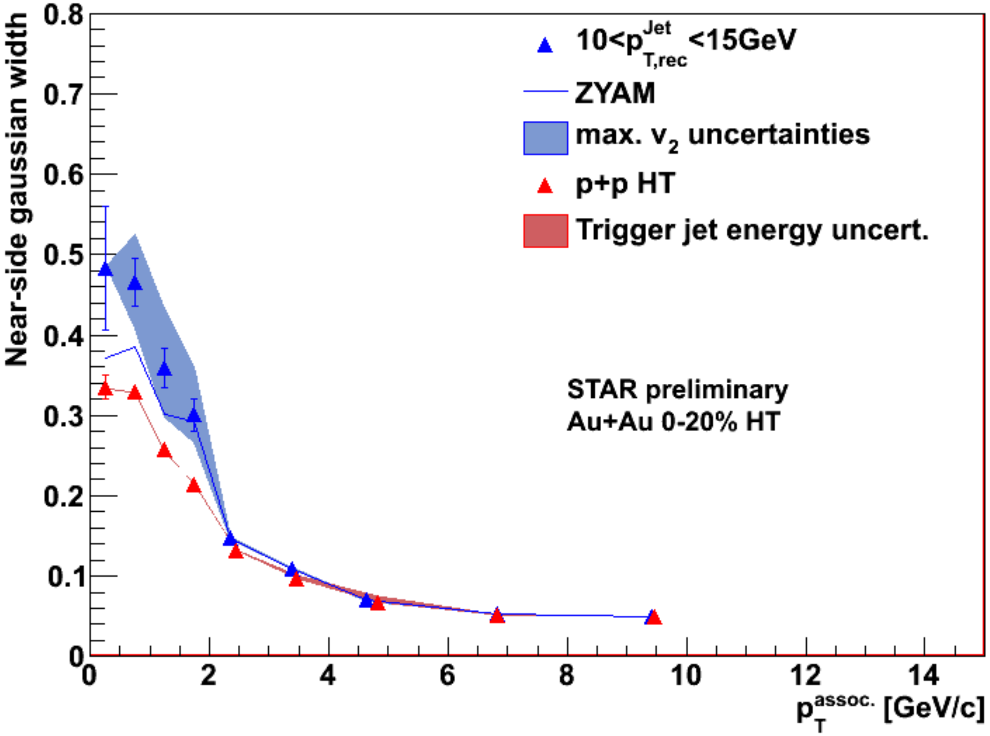
$p_T^{jet} > 20$ GeV/c

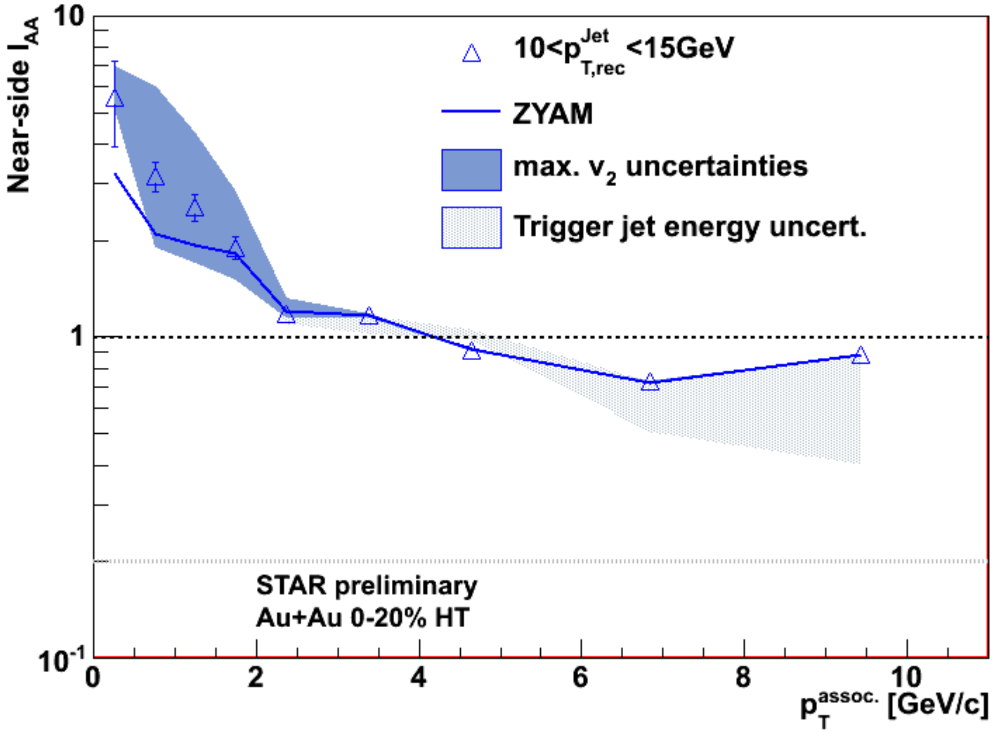


Note: Here a flat background is subtracted (no v_2)

A comparison of jet-hadron correlations in p+p and Au+Au indicates a softening and broadening of jets which traverse the QGP.

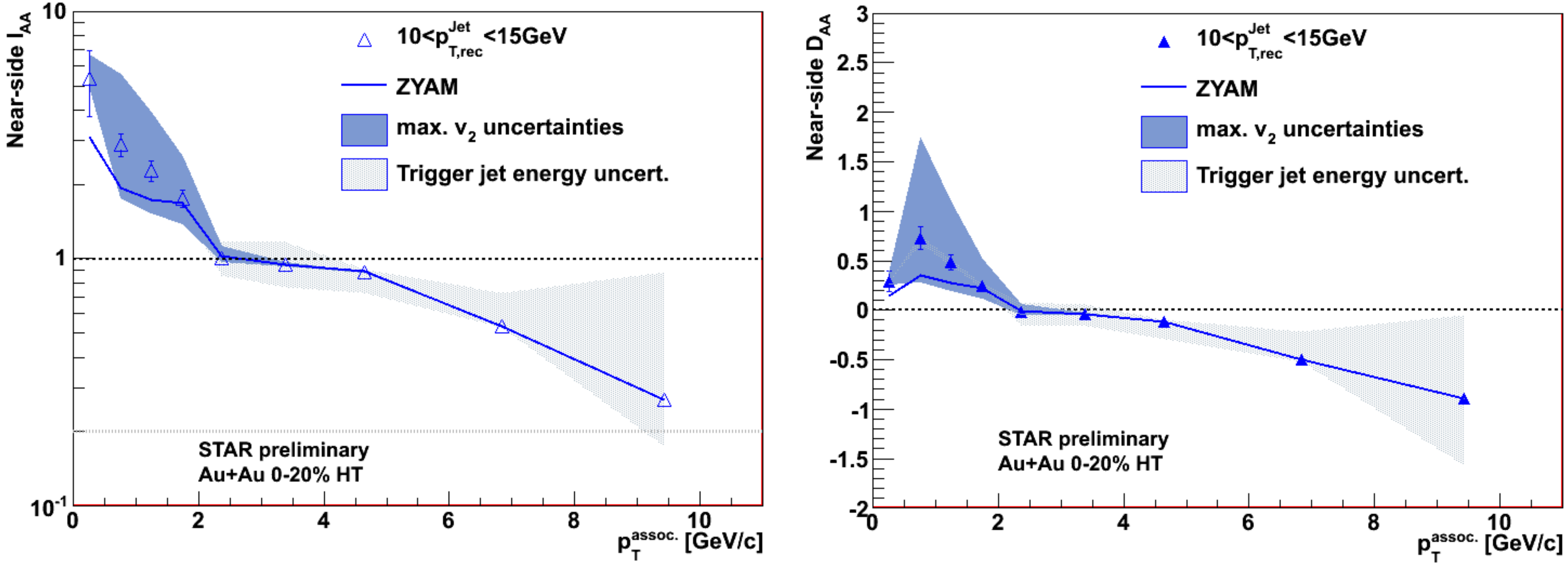
Nearside Gaussian Width and I_{AA}





- Gaussian broadening of nearside jet peak?!
- Enhancement of low p_T yield → Due to ridge, v_3, other bulk effects?
- Assumption: What if there is energy loss (ΔE~2GeV) on the nearside? → Adjust the p+p reference (+ΔE*3/2)

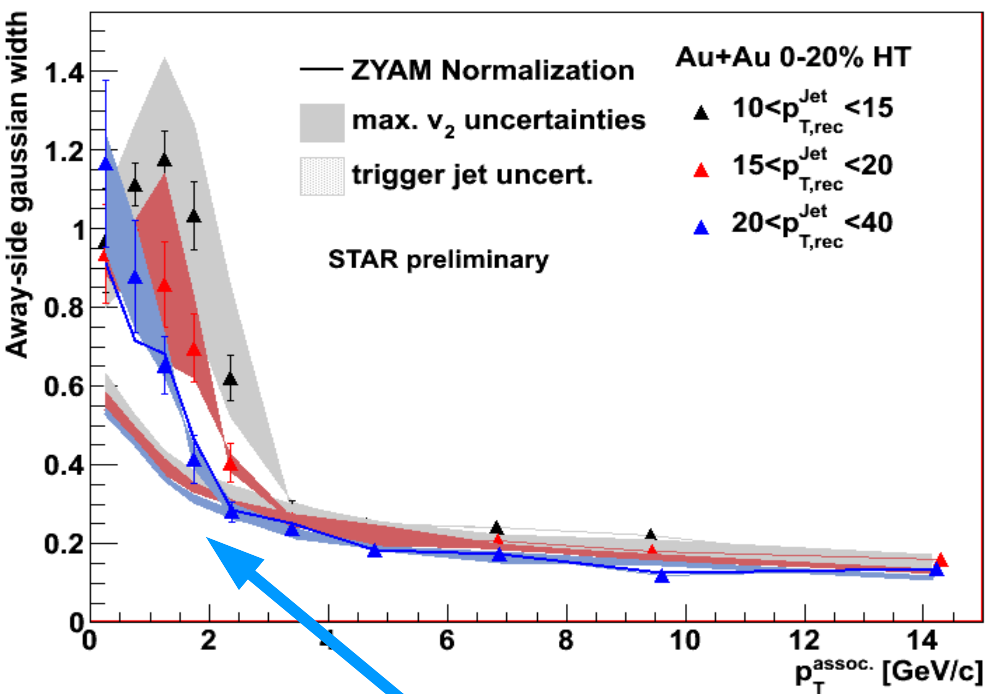
Nearside Energy Balance (D_{AA})

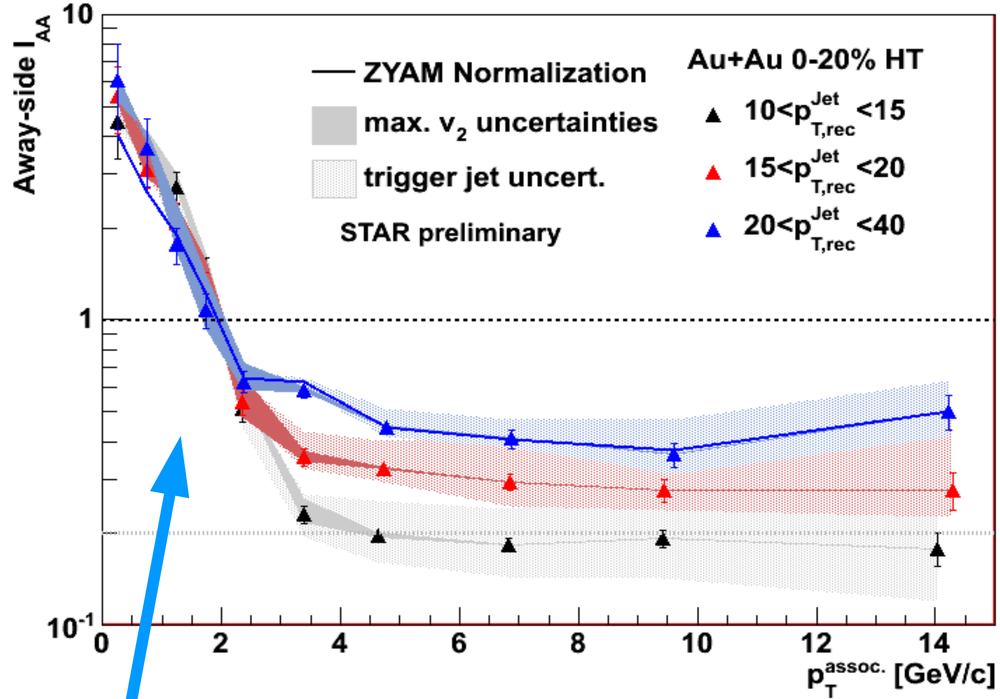


$$D_{AA}(p_T^{assoc}) = Y_{AA}(p_T^{assoc}) \cdot p_{T,AA}^{assoc} - Y_{pp}(p_T^{assoc}) \cdot p_{T,pp}^{assoc} \qquad \Delta B = \int dp_T^{assoc} D_{AA}(p_T^{assoc})$$

- Is enhancement at low p_T being compensated for by suppression at high p_T?
  - After p+p energy shift: $\Delta B \sim 0.4 \pm 0.2$ (stat.) GeV for $10 < p_T^{jet} < 15$ GeV
  - Before p+p energy shift: $\Delta B \sim 1.6$ GeV
- Are we seeing energy loss even in high tower trigger jets with stringent jet-finding criteria?

Awayside Gaussian Width and I_{AA}

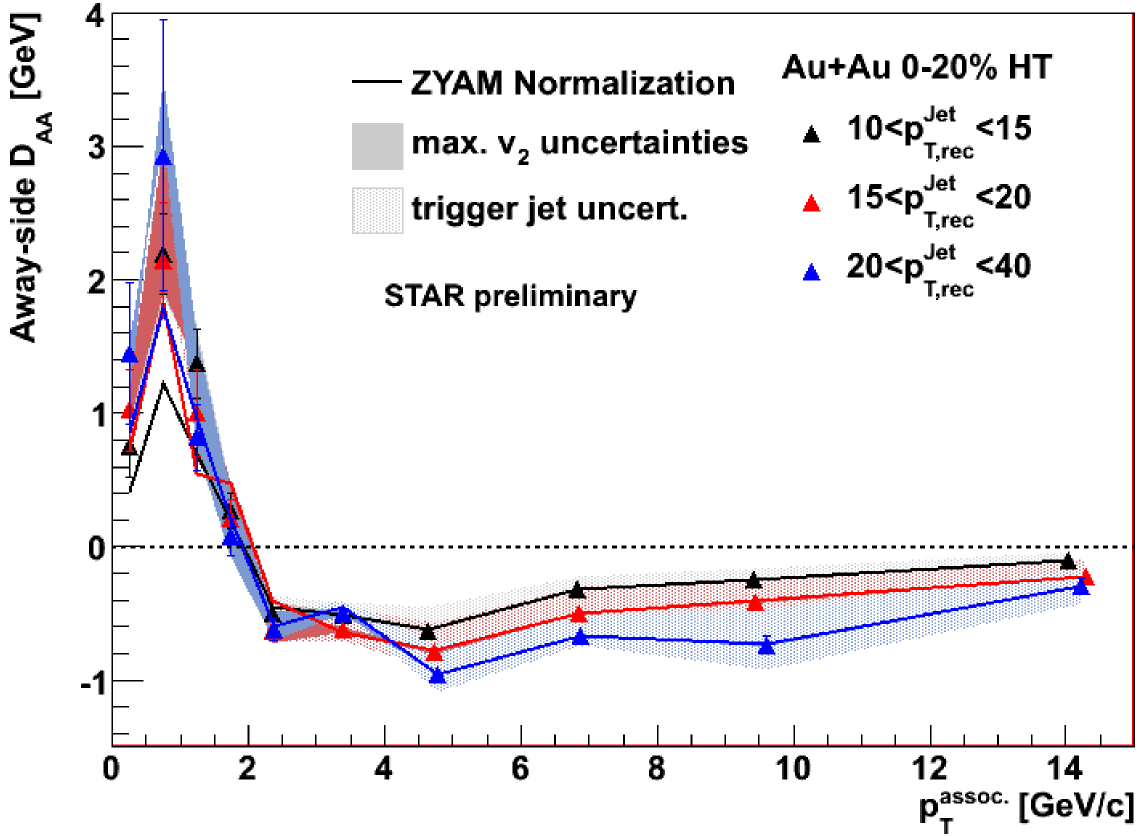




Significant broadening and softening of awayside peak.
Less modification of jets with higher p_T.

Awayside Energy Balance (D_{AA})

$$D_{AA}(p_T^{assoc}) = Y_{AA}(p_T^{assoc}) \cdot p_{T,AA}^{assoc} - Y_{pp}(p_T^{assoc}) \cdot p_{T,pp}^{assoc}$$



- Significant amount (but not all) of energy at low p_T compensated for by high p_T suppression ($\Delta B \sim$ 1-2 GeV).

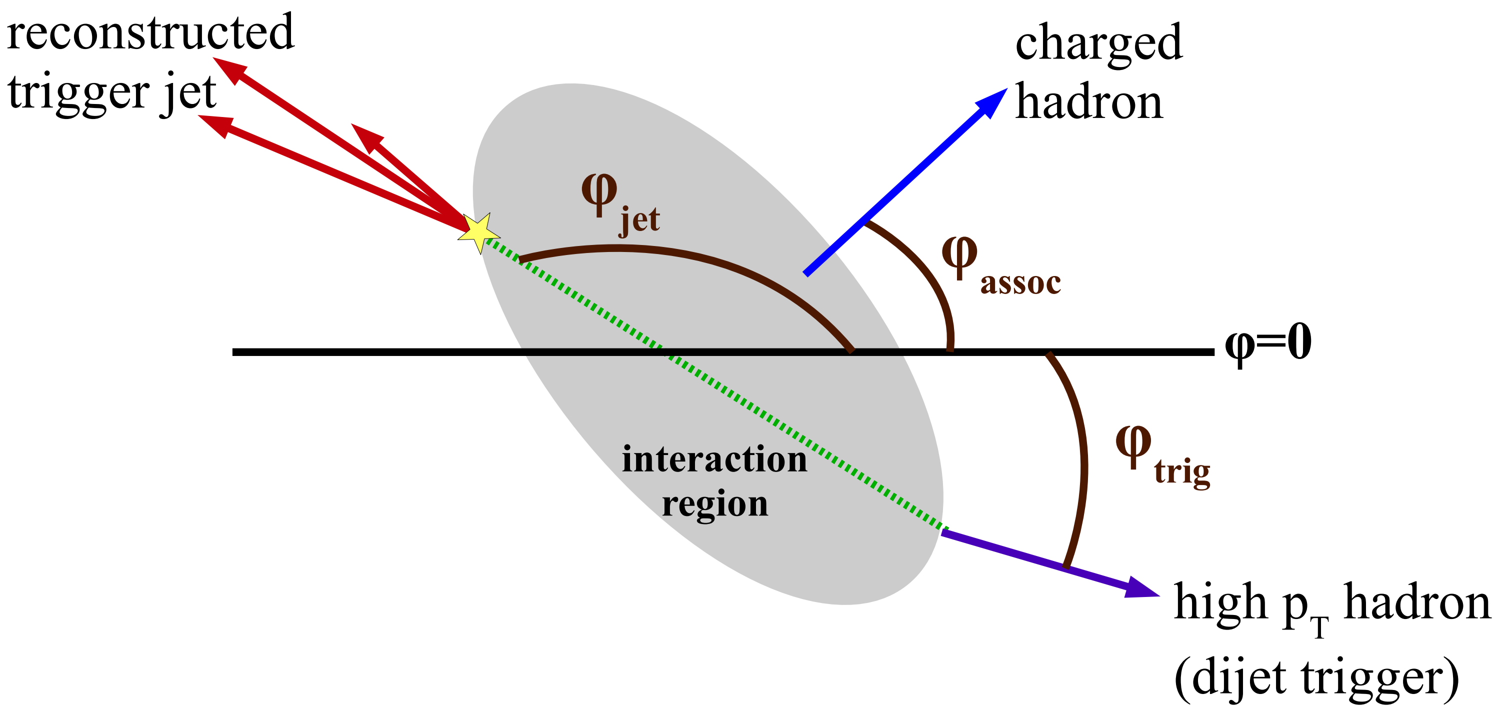
→ Jet quenching in action!

"2+1" and Jet-Hadron Correlations

- "2+1" Correlations: A pair of back-to-back high p_T hadrons is a dijet proxy. Do dihadron correlations with respect to both trigger particles.

see talk by H. Pei later

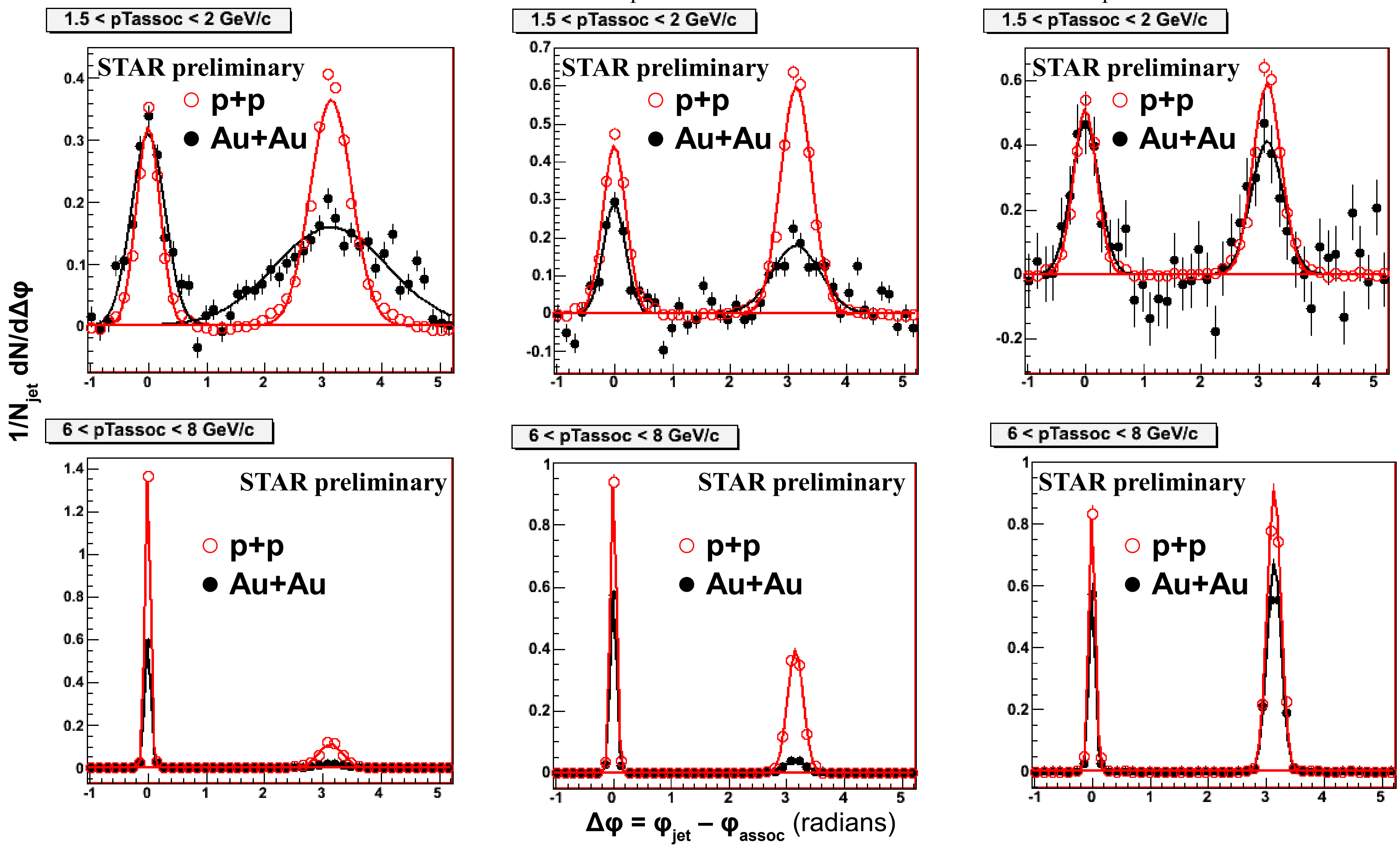
- Do jet-hadron correlations in events where there is a high-p_T hadron opposite the reconstructed jet.



“2+1” and Jet-Hadron Correlations

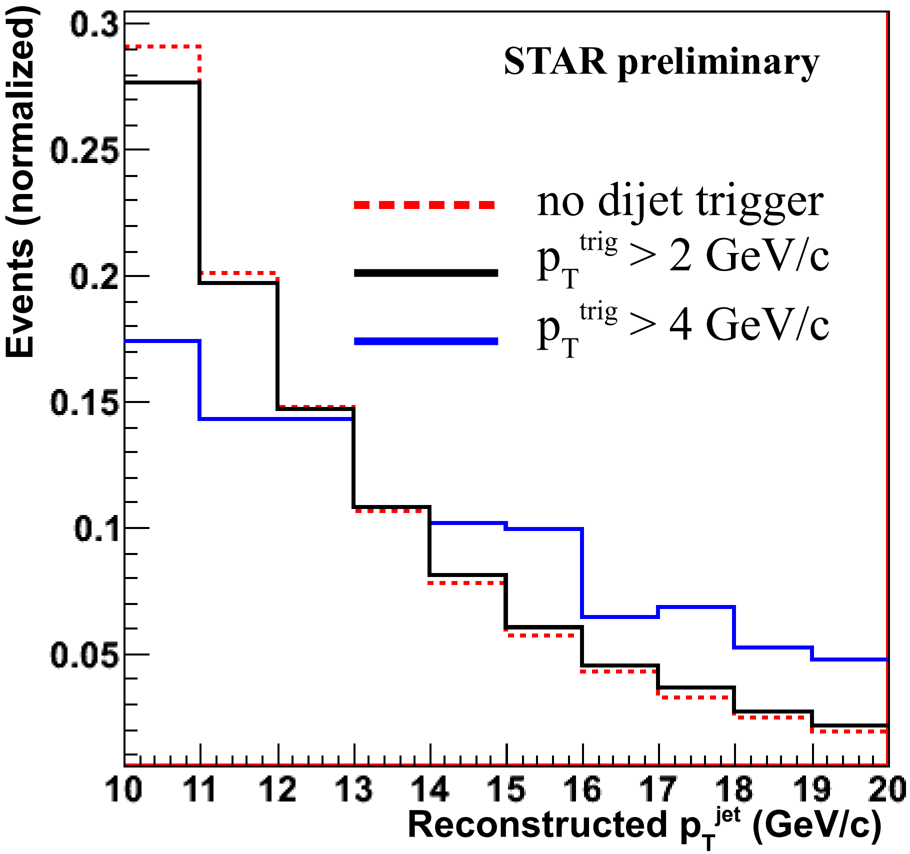
$10 < p_T^{jet} < 20$ GeV/c $|\varphi_{jet} - \varphi_{trig}| > \pi - 0.2$

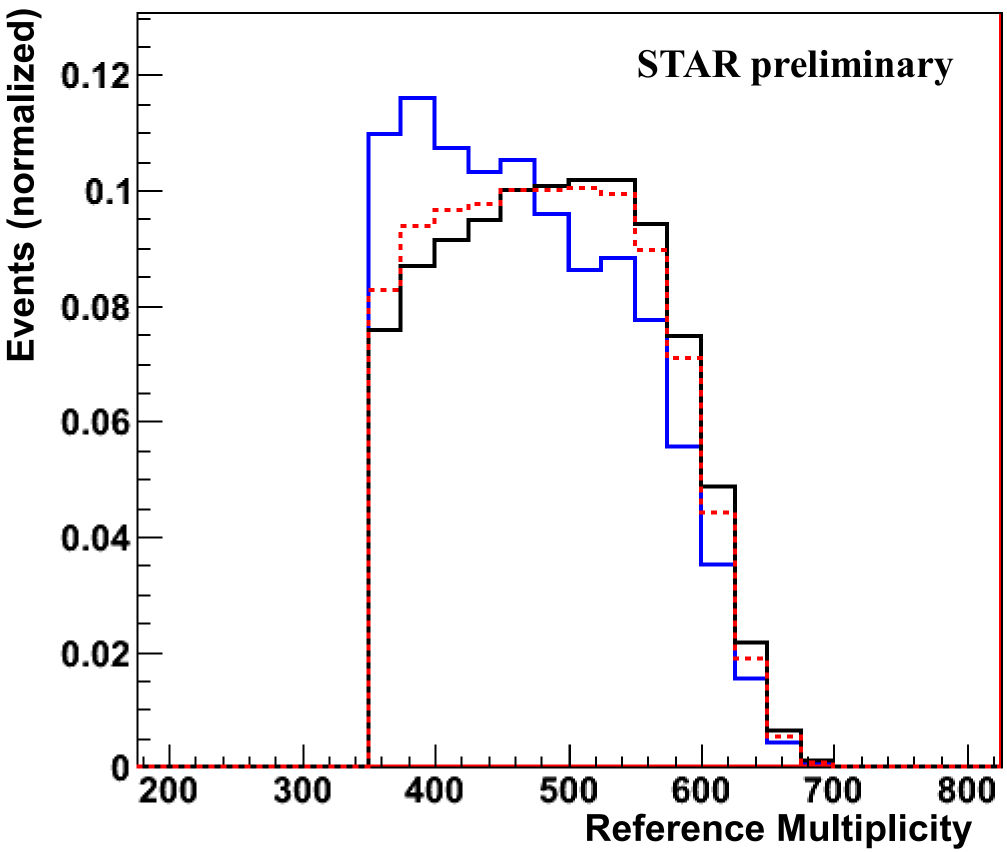
no dijet trigger $p_T^{trig} > 2$ GeV/c $p_T^{trig} > 4$ GeV/c



When a high-p_T dijet trigger is required, the jets look more like those in p+p collisions.

"2+1" and Jet-Hadron Correlations

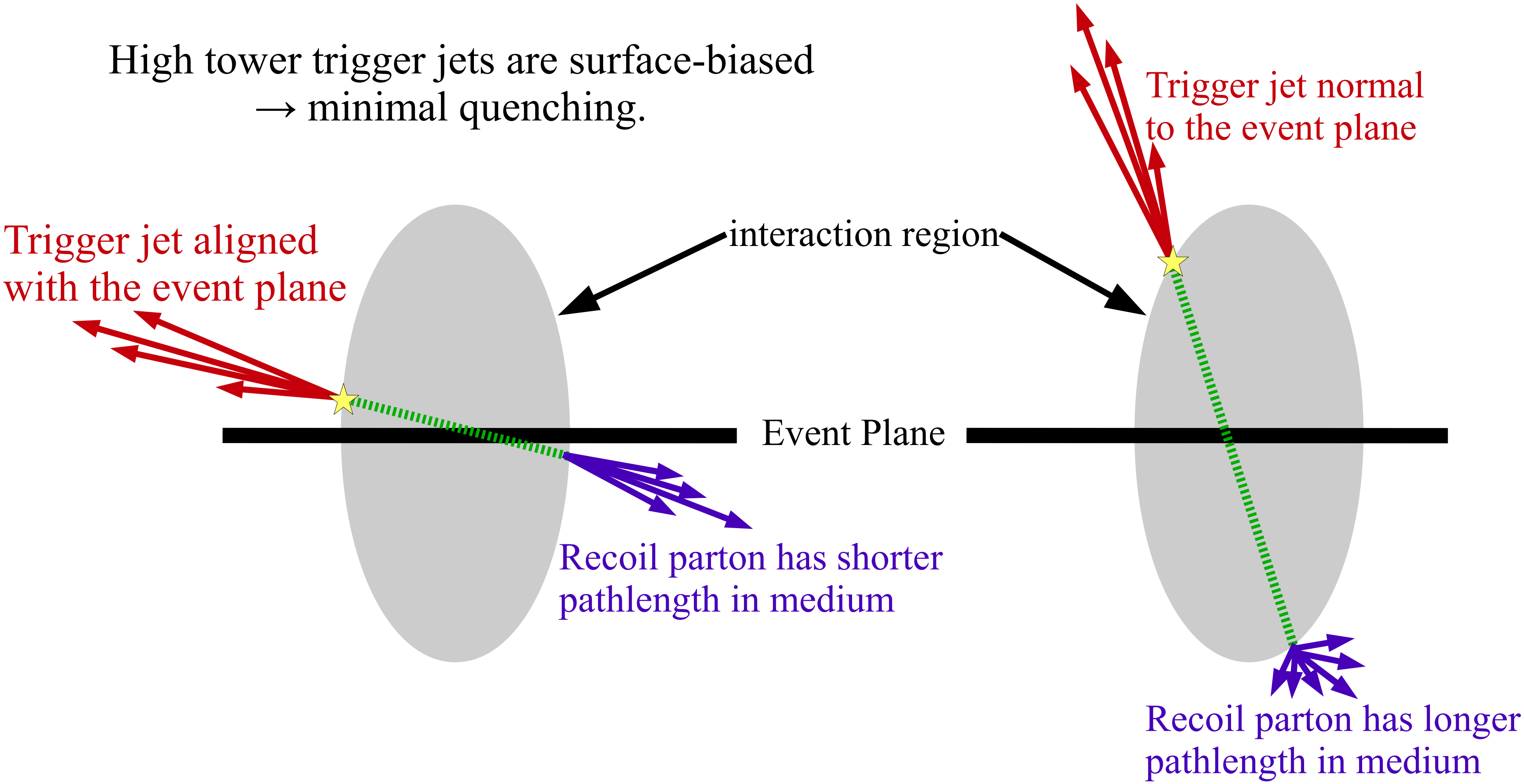




The high-p_T dijet trigger requirement seems to select harder jets and more peripheral events.

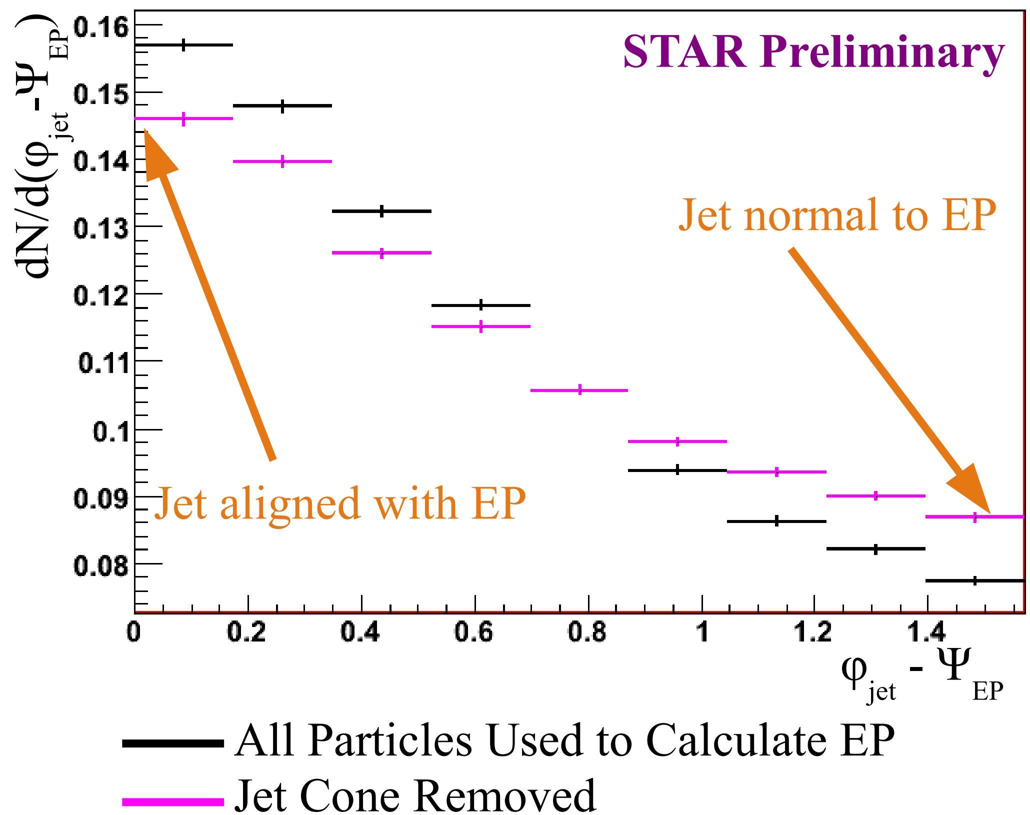
Why Study Jets w.r.t. the Event Plane?

High tower trigger jets are surface-biased
→ minimal quenching.



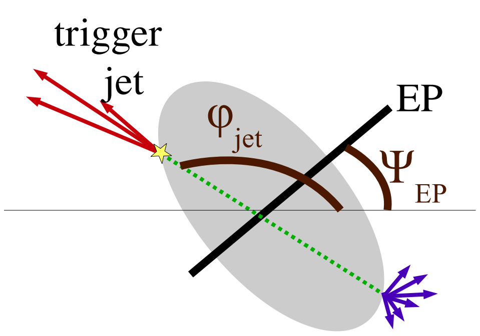
Jet quenching with respect to the event plane → pathlength-dependent energy loss of partons traveling through the QGP.

Jets w.r.t. the Event Plane – Data



Data Set:
AuAu, 200 GeV
HT Trigger
All Centralities (0-70%)

Jet Reconstruction:
Anti-k_T, R = 0.4
$p_T^{track,tower} > 2$ GeV/c
$p_T^{jet} > 10$ GeV/c



EP calculation:
TPC tracks, $p_T < 2$ GeV/c
no p_T weighting

Note: Error bars represent statistical uncertainties only.

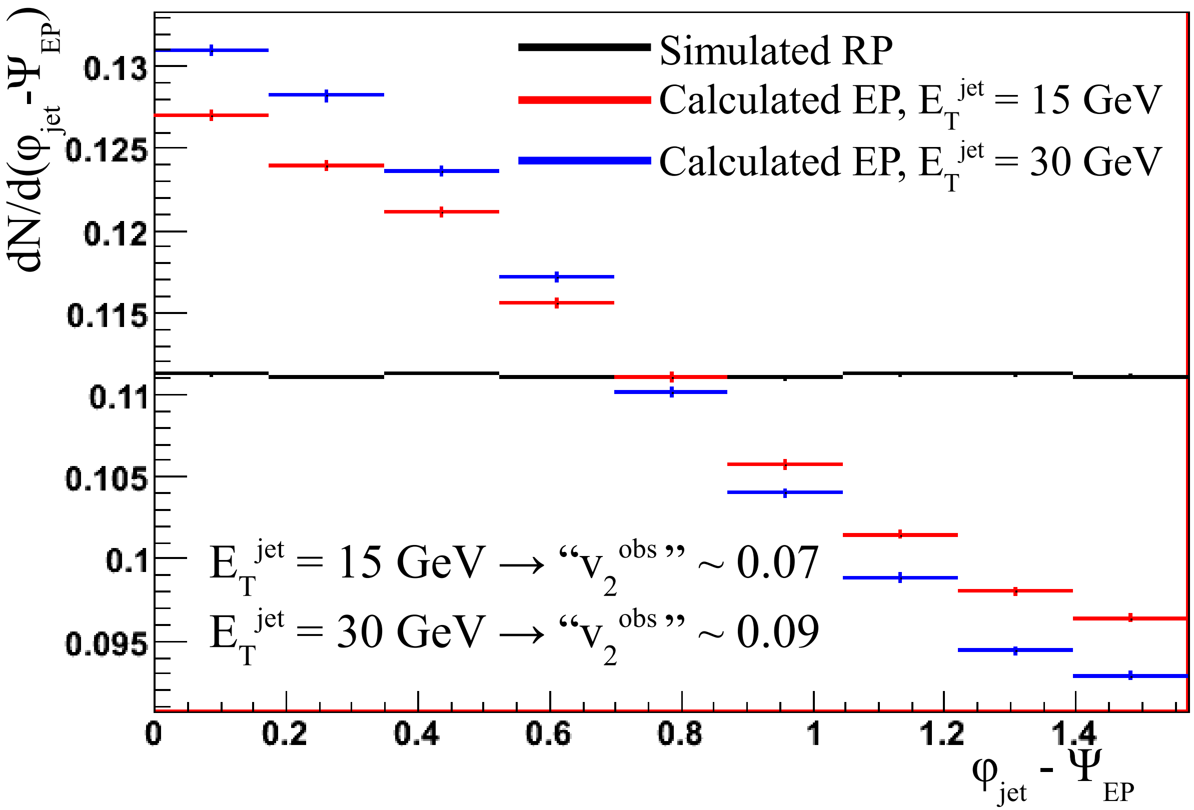
The presence of a jet affects the calculation of the event plane.
→ Is there a jet v_2 beneath the jet-event plane bias?

Jets w.r.t. the Event Plane – Simulation

Thermal background (T=0.291GeV) with p_T- and centrality-dependent v_2

Embed PYTHIA (p+p) jets

Reaction planes and jet axes are randomly distributed → entirely uncorrelated



Jet Reconstruction:

Anti-k_T, R = 0.4

$p_T^{track,tower} > 2$ GeV/c

EP calculation:

TPC tracks, $p_T < 2$ GeV/c

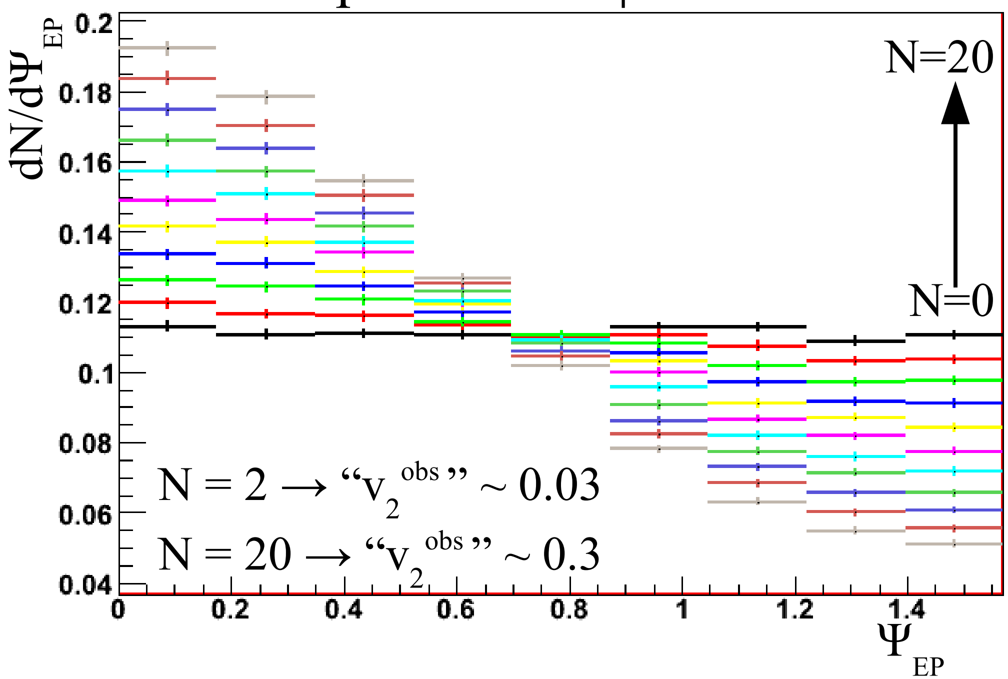
no p_T weighting

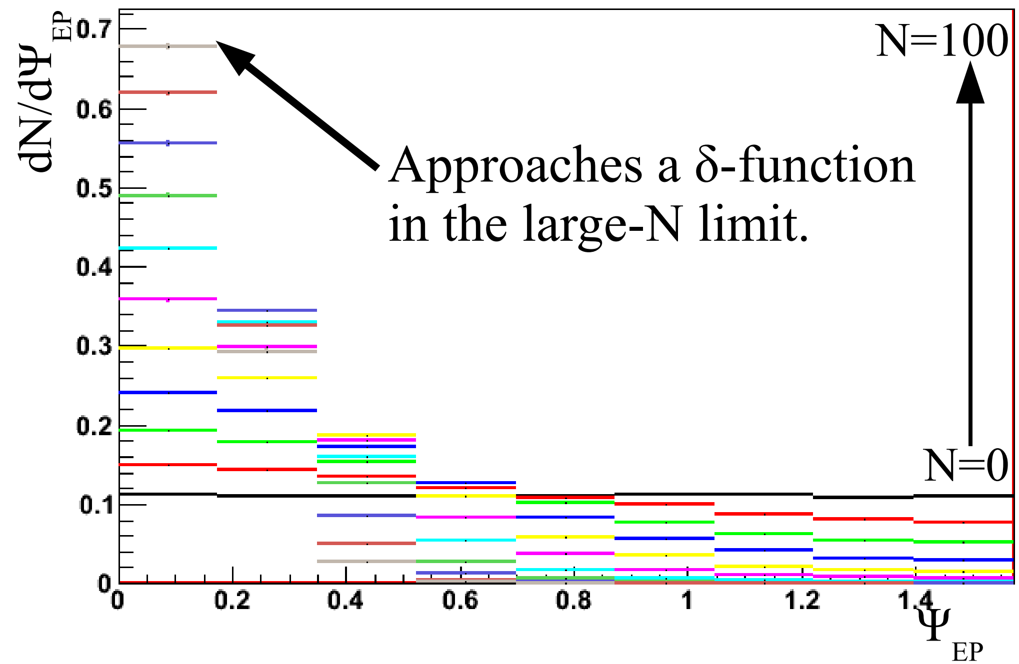
Centrality bin: 10-20%

The jet pulls the event plane significantly!

How many particles can pull an event plane?

Simulate thermal background with $dN_{ch}/d\eta$=370 (10-20% centrality bin, with p_T- and centrality-dependent v_2) and randomly distributed reaction planes. Embed N particles at φ=0.





Even small numbers of particles can pull the event plane enough to produce a significant effective v_2.

How can we solve the Jet-EP bias?

Data

- Use forward detectors to calculate event plane (FTPC, BBC, ZDC-SMD)
  - Caveat: Long-range correlations (e.g. the ridge) may affect EP calculation

Simulation

- Investigate ways of removing the jet from the event plane calculation
  - Remove particles in jet cone **X**
  - η wedge **X**
  - Lee-Yang Zeros **X**
  - other ideas.... **?**

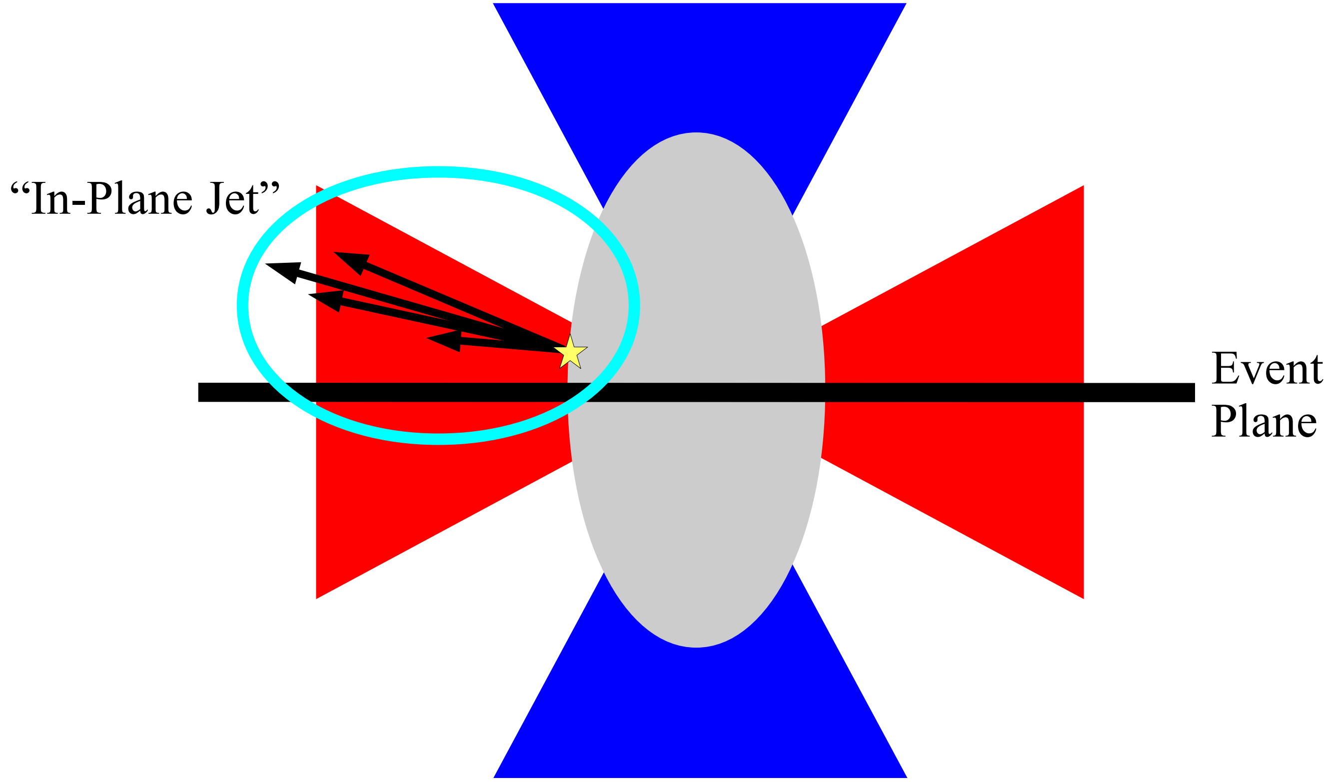
Jet-Hadron Correlations w.r.t the Event Plane

Separate events based on relative angle between jet and event plane.

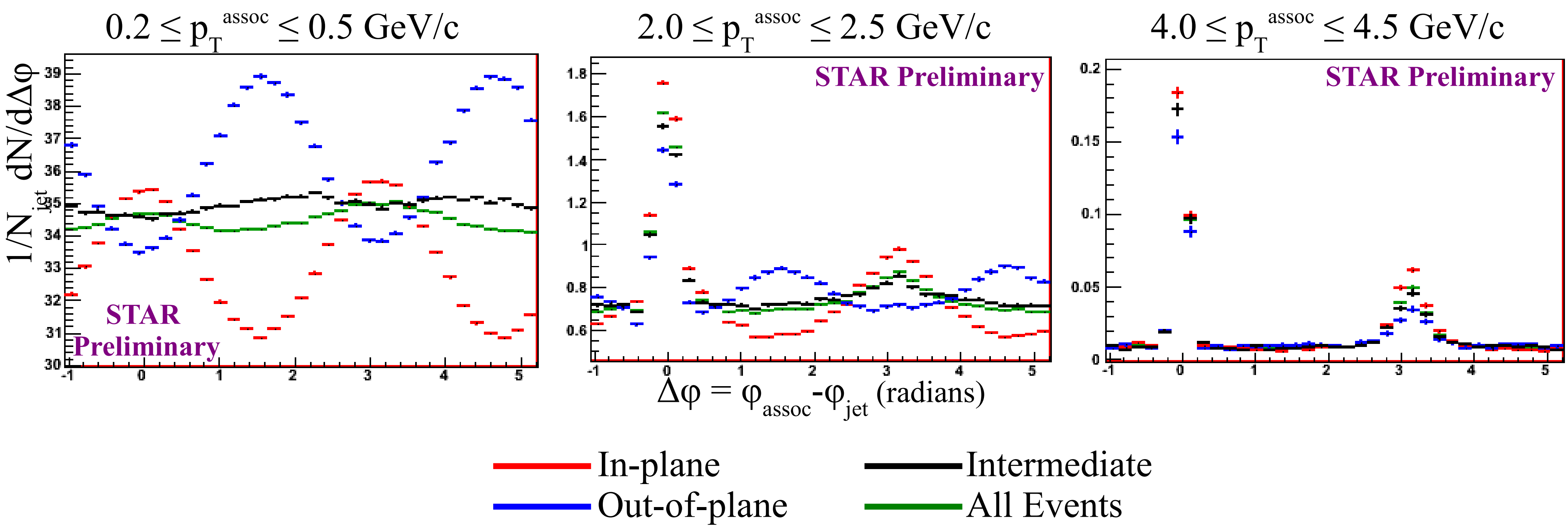
"In-plane" $|\varphi_{jet} - \Psi_{EP}| < 30^\circ$

"Intermediate" $30^\circ < |\varphi_{jet} - \Psi_{EP}| < 60^\circ$

"Out-of-plane" $60^\circ < |\varphi_{jet} - \Psi_{EP}|$



Jet-Hadron Correlations w.r.t. the Event Plane

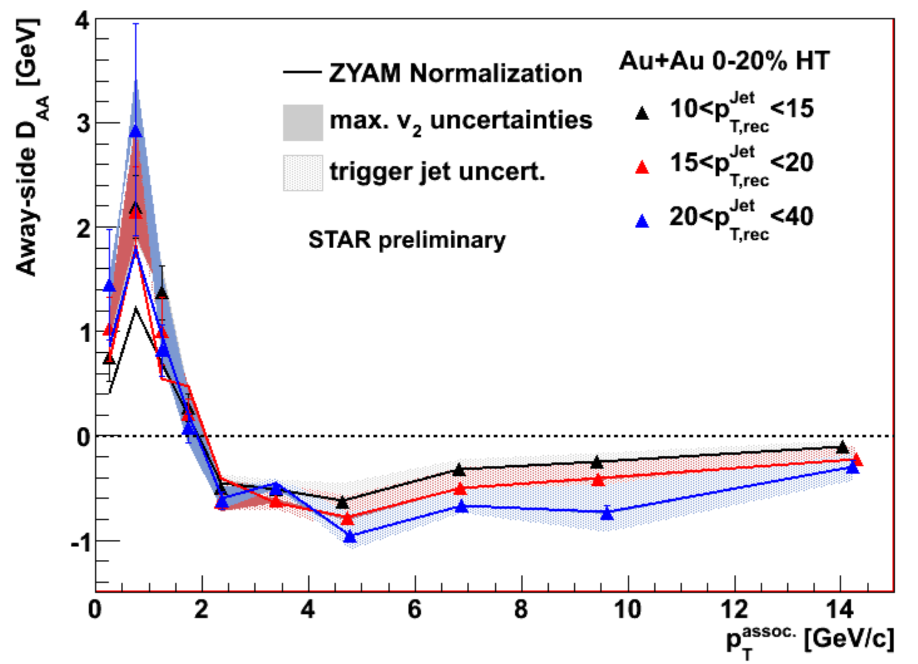


Elliptic flow background dominant. → Elliptic flow background decreases, jet signal becomes visible. → Jet signal dominant.

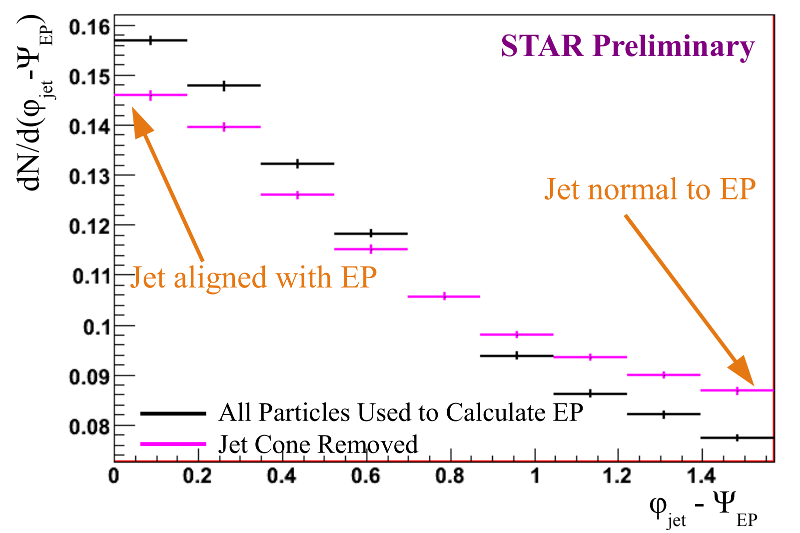
So far background subtraction is not done... issues of jet v_2 and event plane reconstruction are being addressed.

Conclusions

- Jet-hadron correlations are being used to study jet quenching.
  - Observed: softening, broadening, p_T redistribution of awayside jets

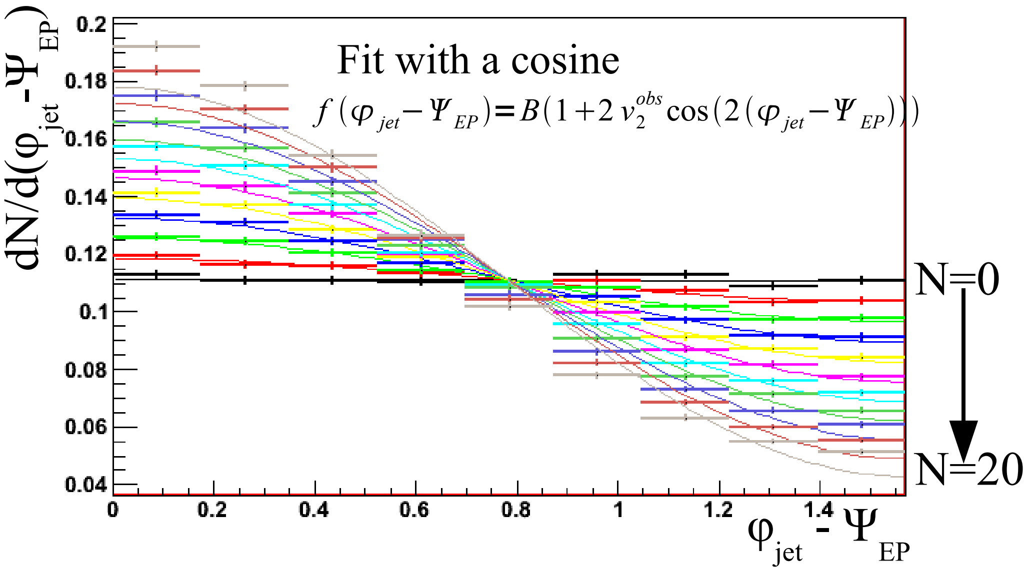


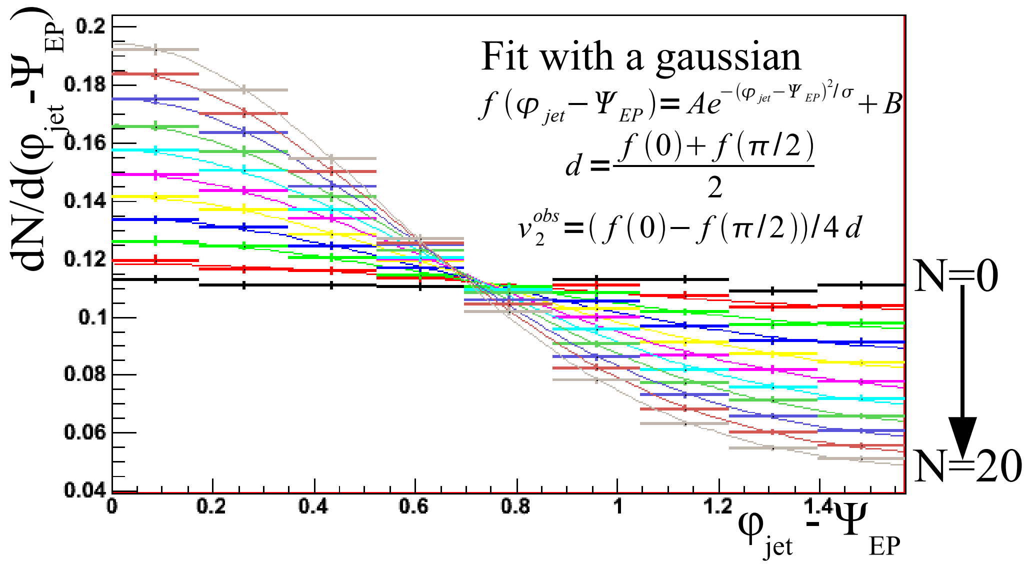
- Analysis of jet-hadron correlations with respect to the event plane is in progress
  - Jet v_2 is under investigation.

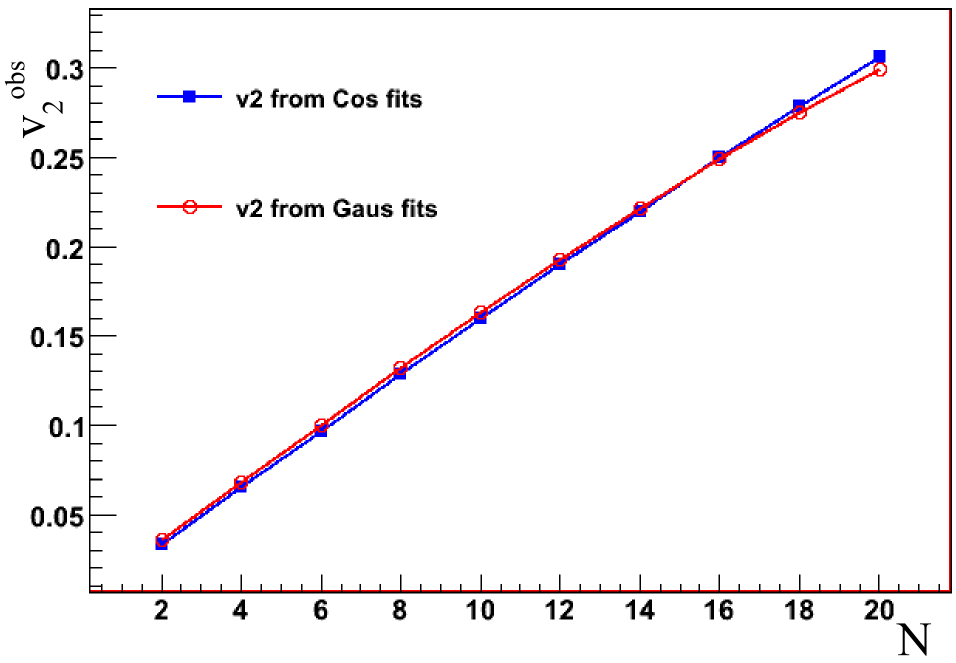


Backup

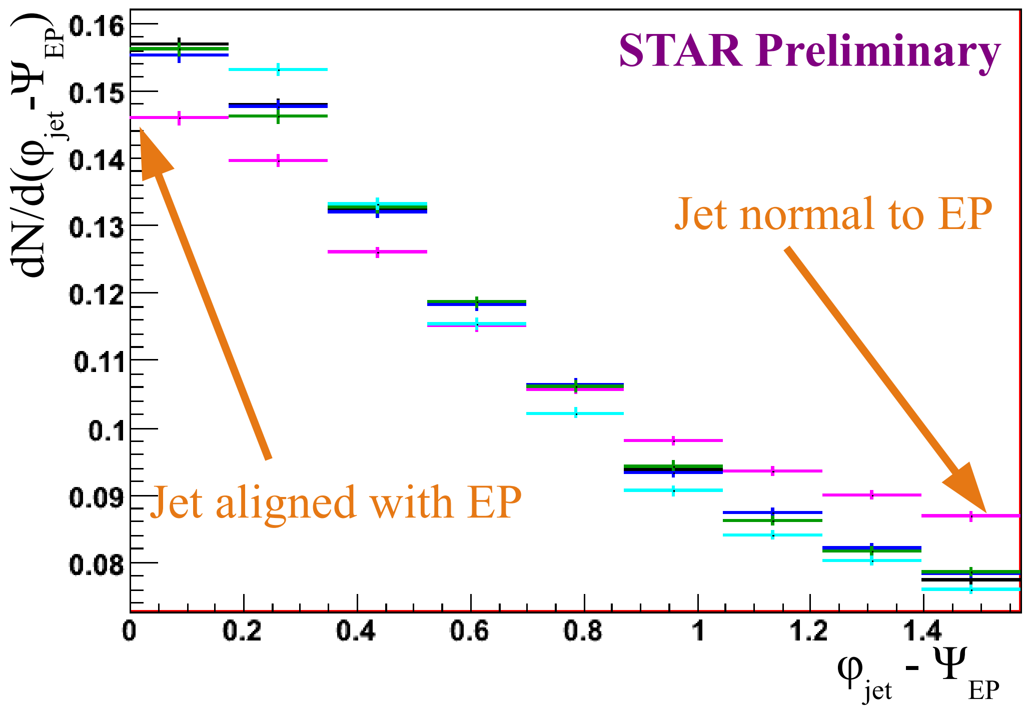
How is the effective v_2^{obs} calculated?







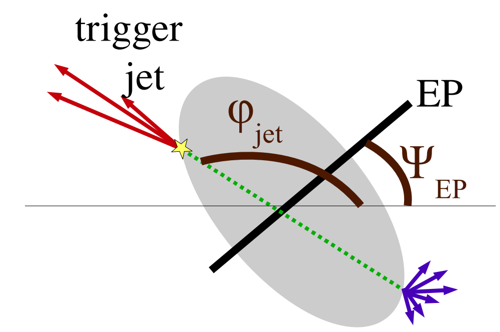
Jets w.r.t. the Event Plane – Data



- All Particles Used to Calculate EP
- Jet Cone Removed
- Random Cone Removed
- Same Cone Removed in Each Event
- Cone at (φ_{jet}, η_{jet}±0.6) Removed

<u>Data Set:</u>
AuAu, 200 GeV
HT Trigger
All Centralities (0-70%)

<u>Jet Reconstruction:</u>
Anti-k_T, R = 0.4
$p_T^{track,tower}$ > 2 GeV/c
p_T^{jet} > 10 GeV/c

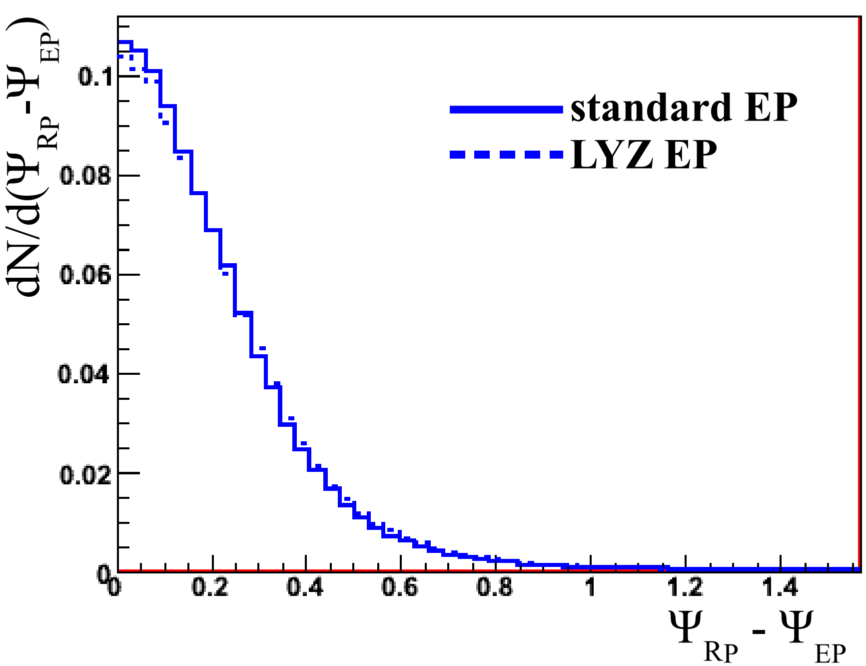


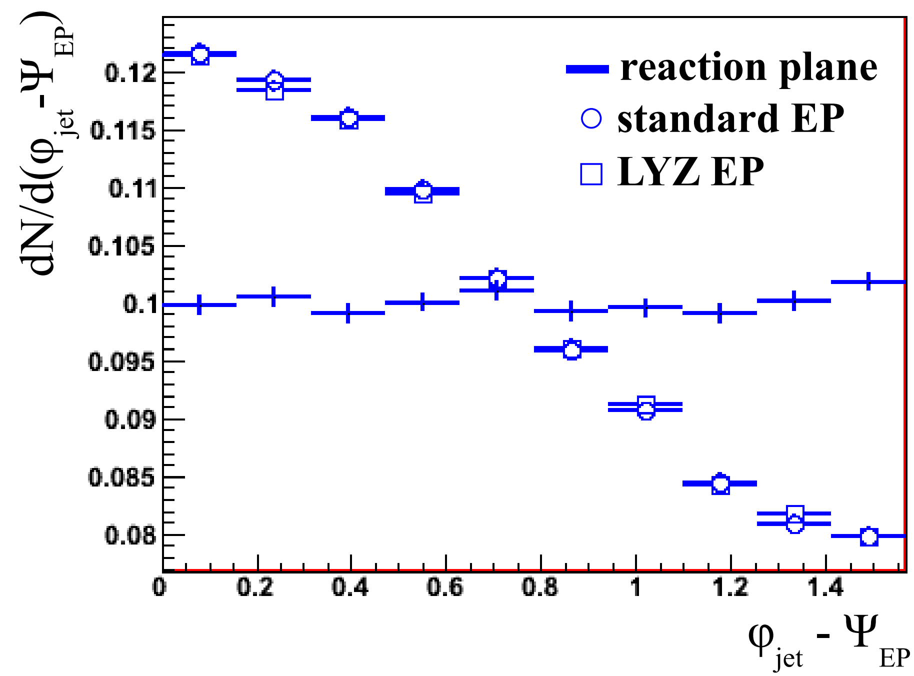
<u>EP calculation:</u>
TPC tracks, p_T < 2 GeV/c
no p_T weighting

Note: Error bars represent statistical uncertainties only.

LYZ Event Plane Calculation

Method from: A. Bilandzic, N. van der Kolk, J.Y. Ollitrault, and R. Snellings, arXiv:0801.3915 [nucl-ex]





Thermal background (T=0.291GeV) with p_T- and centrality-dependent v_2

Embed PYTHIA (p+p) jets, E_T^{jet} = 30 GeV.

Reaction planes and jet axes are randomly distributed → entirely uncorrelated

Using the LYZ EP method has been unsuccessful so far... studies are ongoing.

Relative Angle Between Dijets

Dijet Definition: Find jets with Anti-kT algorithm ($R = 0.4$, $p_T^{track,tower} > 2$ GeV/c), choose jet with highest p_T satisfying the requirement $|\varphi_{jet}-\varphi_{dijet}| > 2.6$