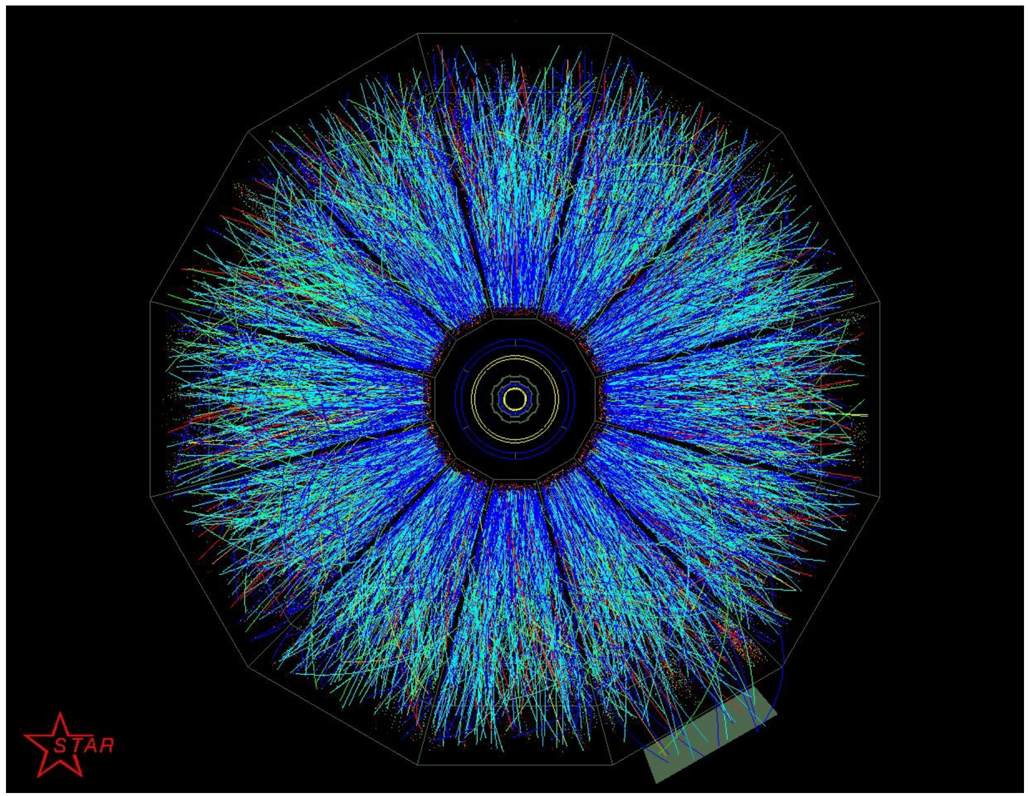
Joel Mazer

Rutgers University

"Event plane dependence of jet quenching studied via azimuthal correlations and differential jet shape in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV with the STAR detector at RHIC "



On behalf of the STAR collaboration

13th International Workshop on High p_T Physics in the RHIC/LHC era: March 19-22th 2019

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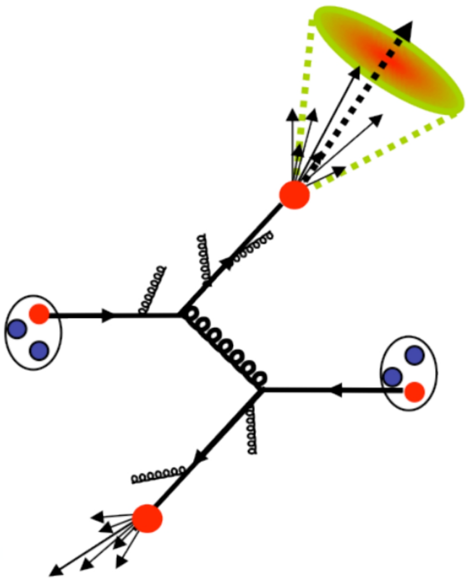
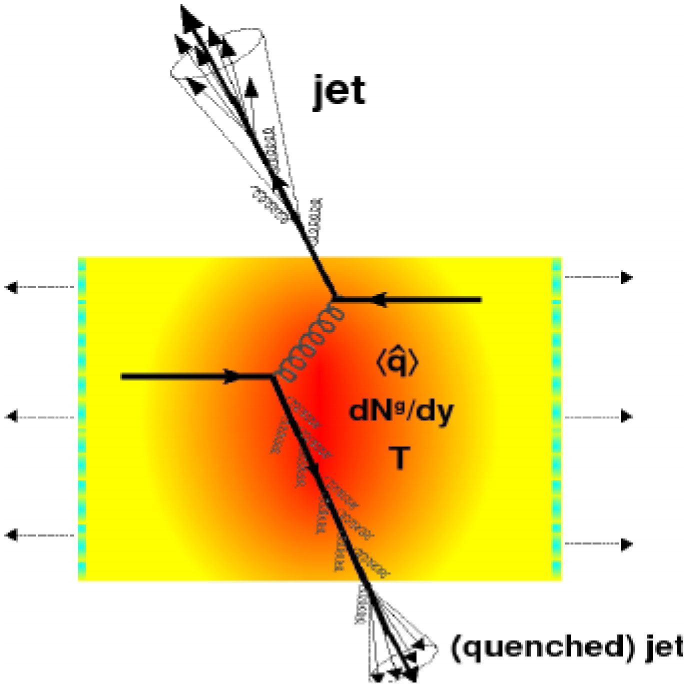
Jets in heavy-ion collisions



- Hard scattering ($Q^2 > 1$ (GeV/c)^2)
- Hadronization into colorless collimated spray of particles: ***'jets'***
- A+A collisions: scattered partons interact with medium

→ ***'jet quenching'***

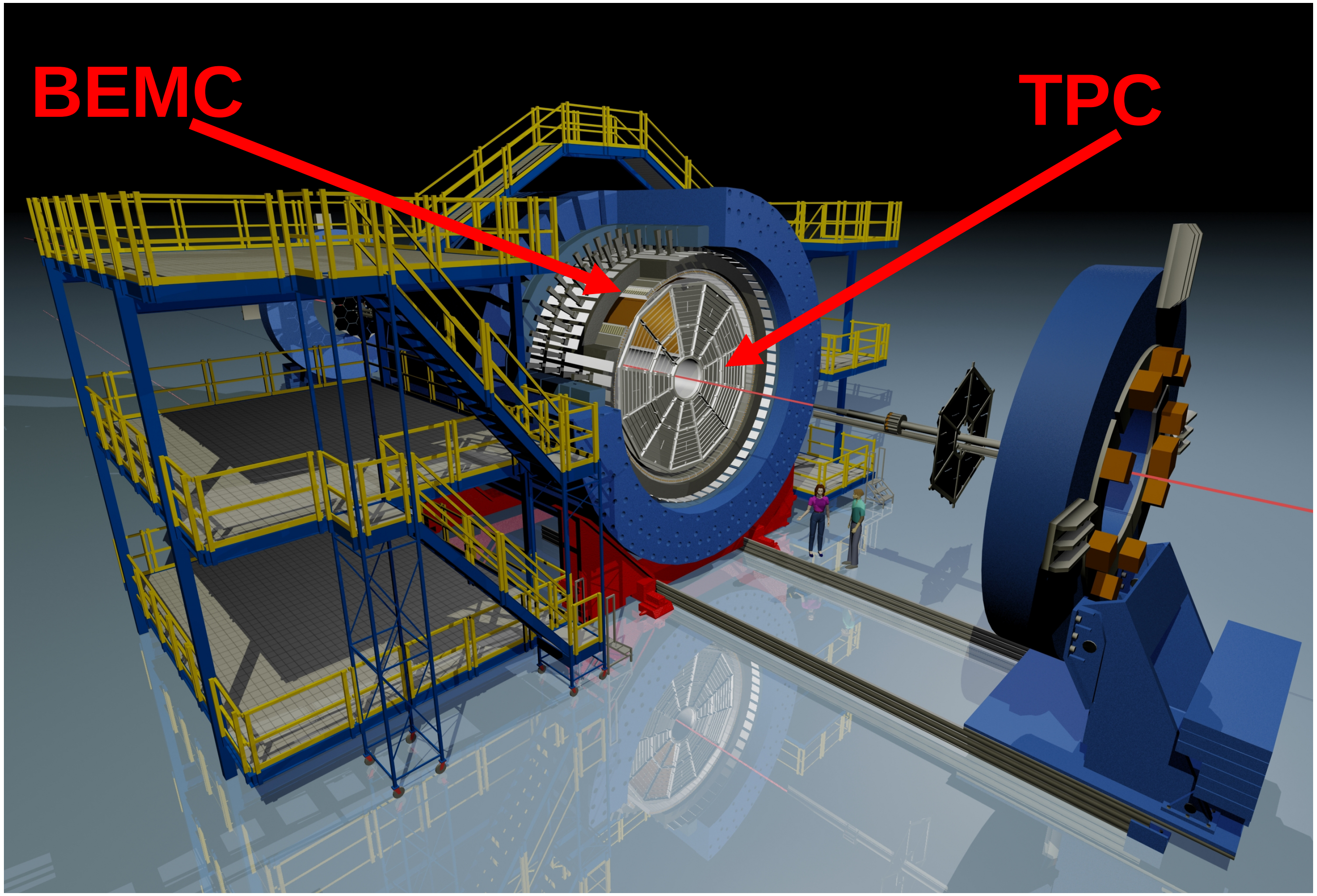
  – ***Jets can probe the QGP***



- Measure the jet in the form of quark and gluon remnants (hadrons etc. measured as tracks and towers in detector)
- Jet finder: groups final state particles into jet candidates
- Ideally reflect kinematics of partons (p_T, η, Φ)

Challenge in A+A analyses: <u>large fluctuating background</u>

The Solenoidal Tracker At RHIC (STAR)



- BEMC: lead-scintillator sampling calorimeter
  - $|\eta| < 1.0$, $0 < \varphi < 2\pi$
  - Resolution: 0.05x0.05
  - Study high p_T processes, triggering

Remove contamination from charged particles

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

Charged constituents → **Full JET** ← ***Neutral constituents***

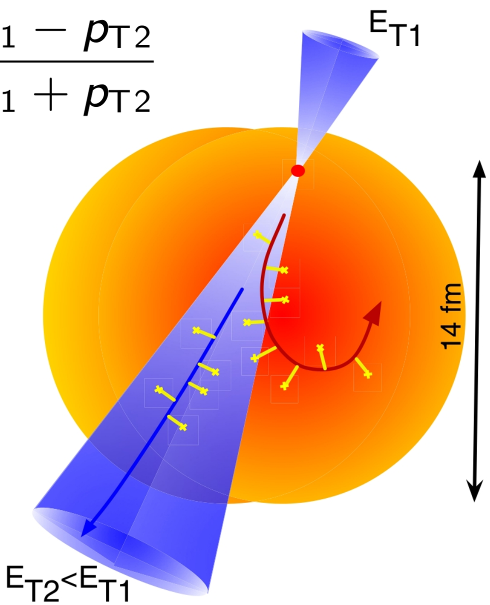
Full jet = charged + neutral

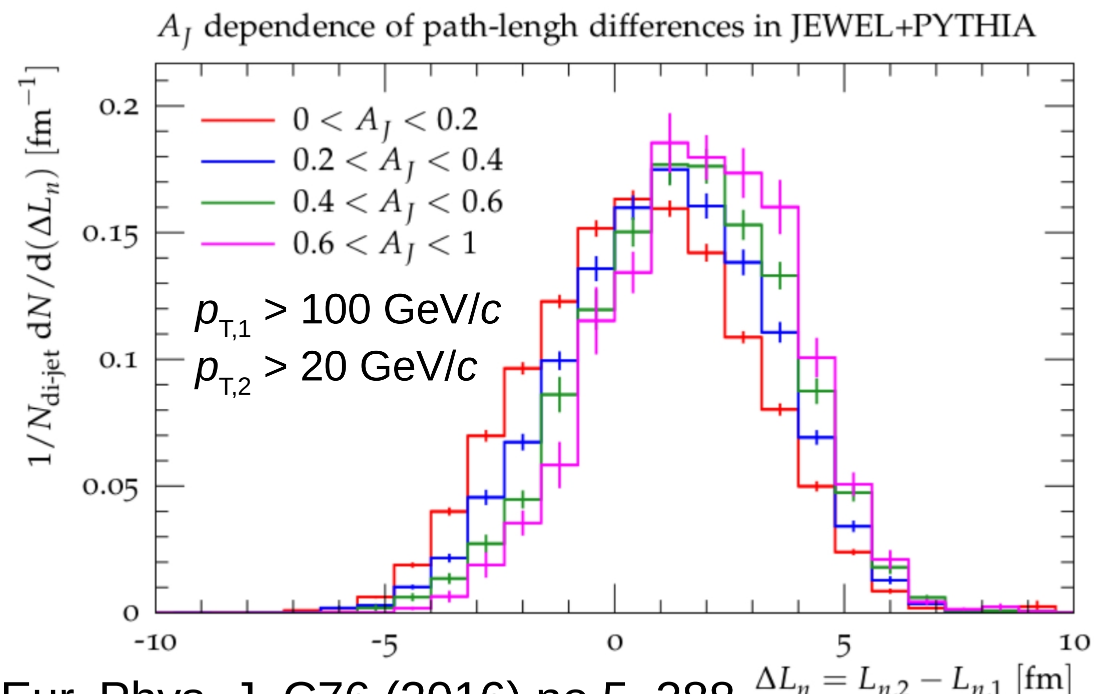
Modeling energy loss

Constraining QGP properties starts with **comparing** our data to **models**
Factorization is the basis for all parton energy loss models

$$\underbrace{\left.\frac{dN}{dp_T}\right|_{\text{hadrons}}}_{\text{final state}} = \underbrace{\left.\frac{dN}{dE}\right|_{\text{jets}}}_{\text{pQCD, nPDF's}} \otimes \underbrace{P(\Delta E)}_{\text{energy loss distribution}} \otimes \underbrace{D(p_T/E)}_{\text{fragmentation function}}$$

$$A_J = \frac{p_{T1} - p_{T2}}{p_{T1} + p_{T2}}$$





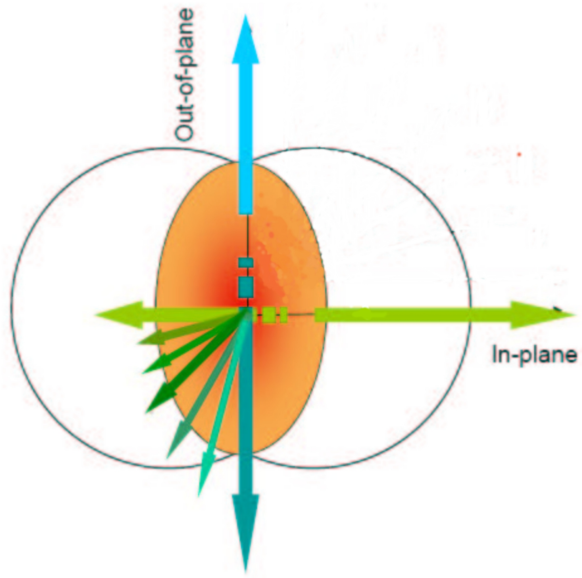
Milhano, Zapp: Eur. Phys. J. C76 (2016) no.5, 288

"Mean path-length difference shift is small compared to width of the distributions, which is a measure of the importance of fluctuations"

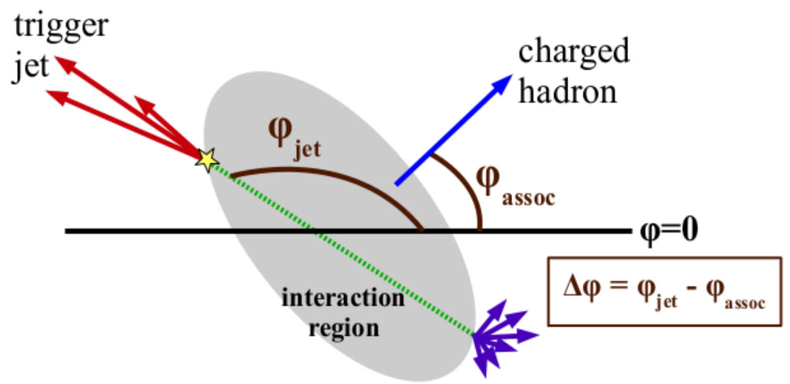
Can we experimentally distinguish between the effects of path-length dependence and the enhancement of vacuum-like fluctuations?

Jet-hadron vs EP correlation

Fix trigger jet relative to the "2nd order" event plane: $\Psi_{EP,2}$



Event plane reconstruction: similar approach to Phys. Rev. C89 (2014) 041901(R) (more on slide 11,12)



<u>Event plane dependence</u>

IN-plane: $0° < |\varphi_{jet} - \Psi_{EP,2}| < 30°$

MID-plane: $30° < |\varphi_{jet} - \Psi_{EP,2}| < 60°$

OUT-of-plane: $60° < |\varphi_{jet} - \Psi_{EP,2}| < 90°$

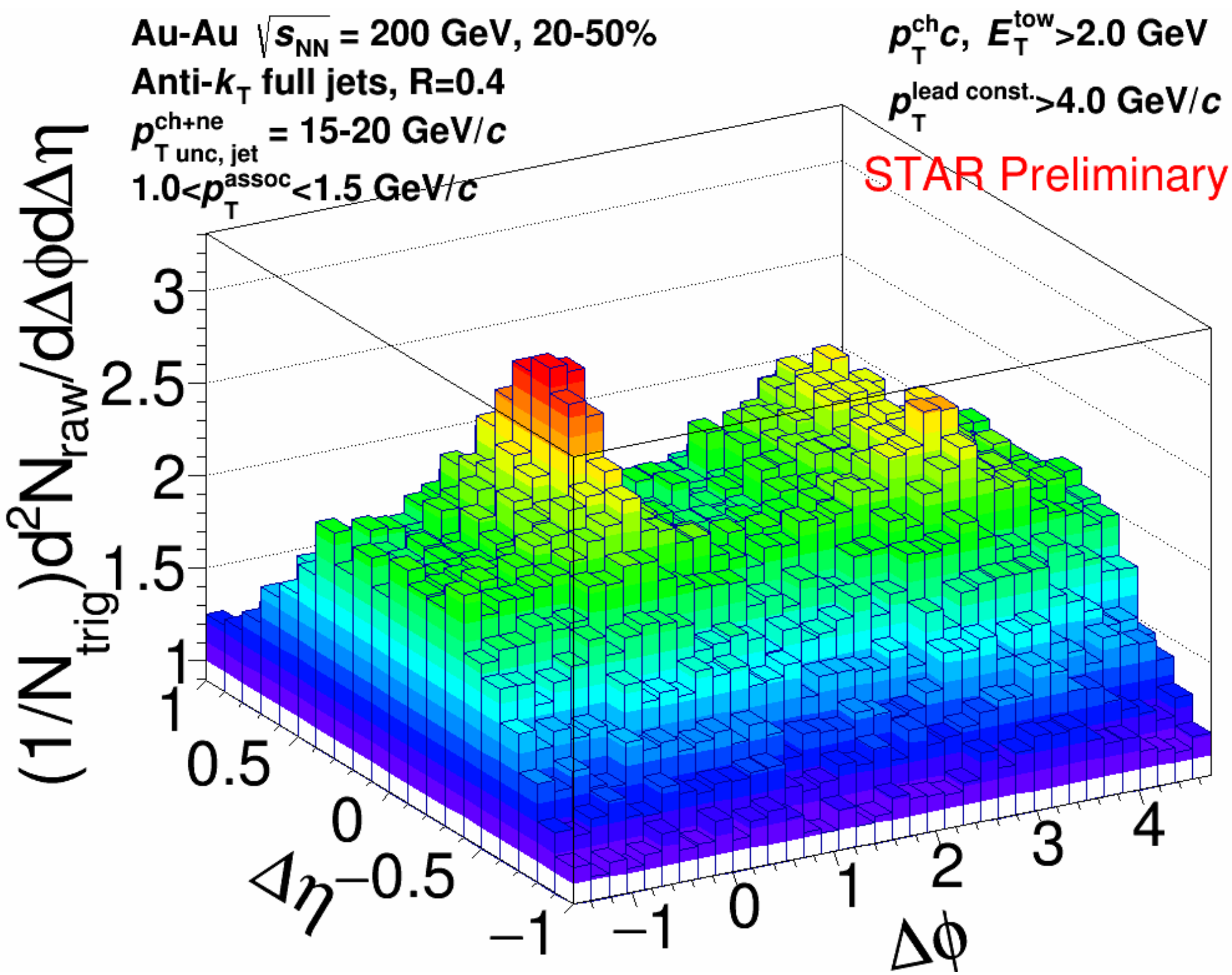
- Event plane (path-length) dependence of medium modifications?
- Are we sensitive enough?

Total energy loss = collisional + radiative **~ L^n ?**

Jet-hadron correlation measurement steps

Jet-hadron correlations analysis steps:

- Signal events: jet-hadron pairs from the same event
  - Generated in $\Delta\eta$ and $\Delta\Phi$ bins

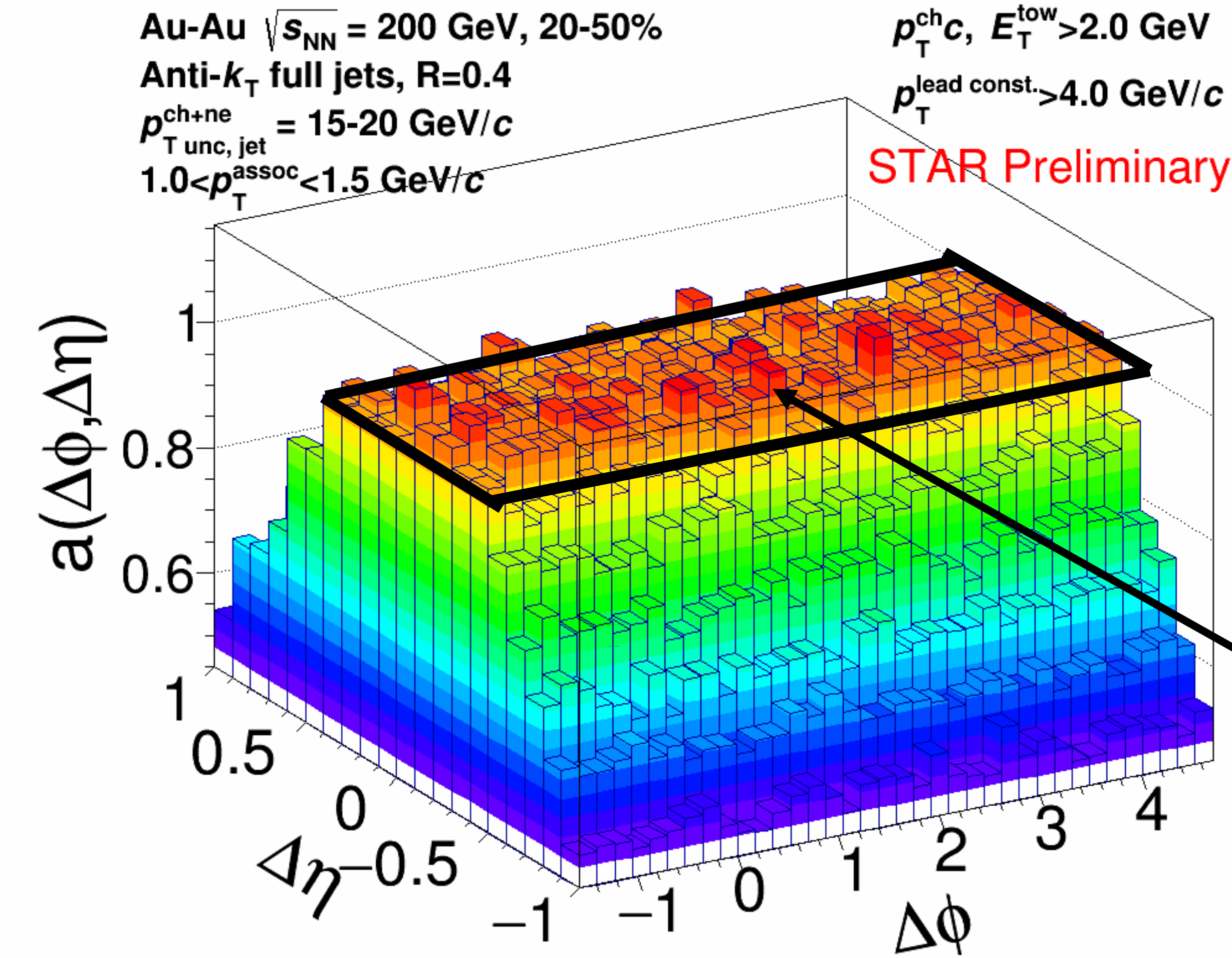


Trigger Object: “hard core” jets
- Tracks p_T >2.0 GeV/c,
- Towers E_T > 2.0 GeV
- Require high tower E_T > 4.0 GeV
- Anti-k_T, R=0.4, p_T = 15-20 GeV/c

Phys. Rev. Lett. 112 (2014) 122301

Jet-hadron correlations analysis steps:

- Mixed events used for our **acceptance correction:**
  - Jets from triggered events correlated with charged hadrons of minimum-bias events of a similar event class



Trigger Object: "hard core" jets
- Tracks p_T >2.0 GeV/c,
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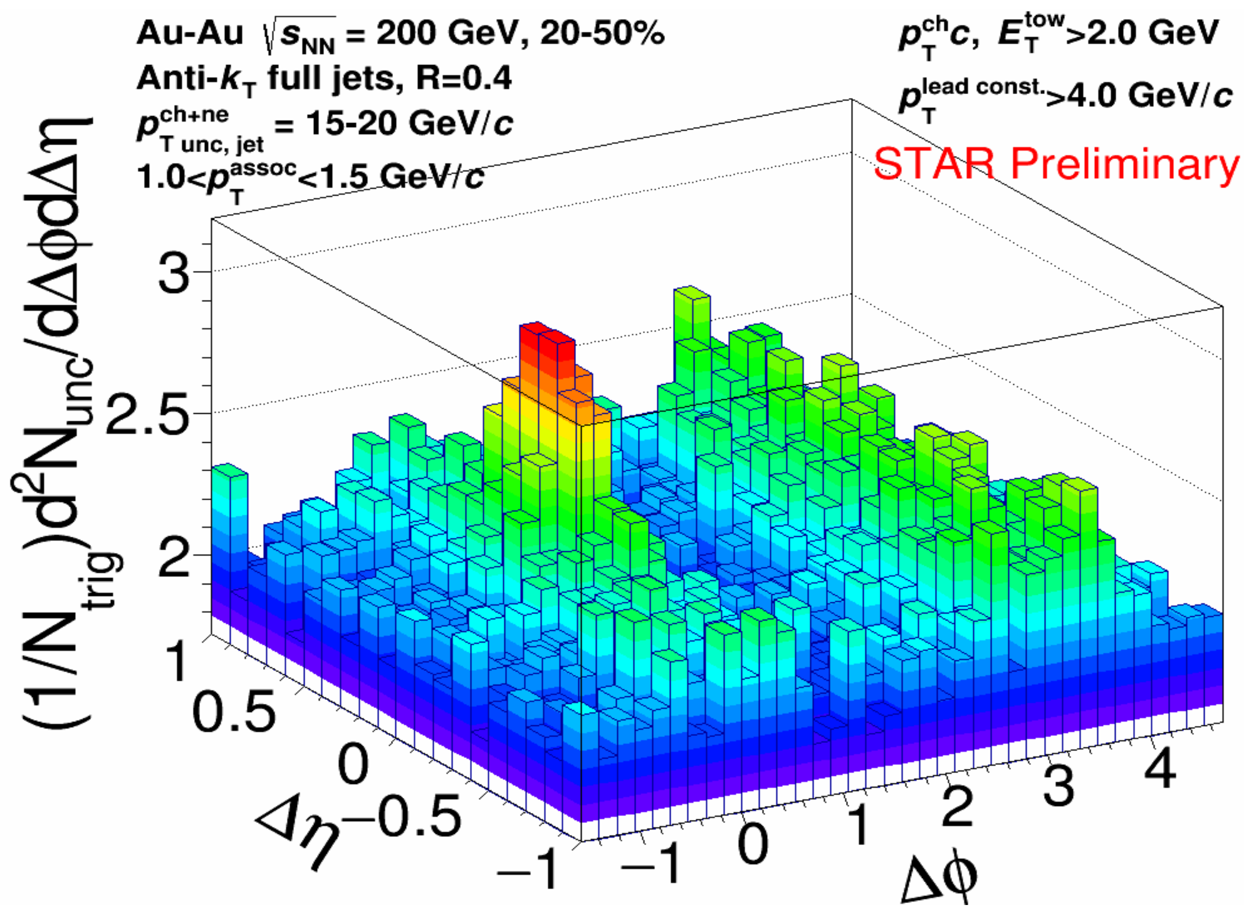
- Anti-k_T, R=0.4, p_T = 15-20 GeV/c

Phys. Rev. Lett. 112 (2014) 122301

Normalize mixed events peak region to 1

Jet-hadron correlations analysis steps:

- Correct same event pairs by mixed event pairs
  - **(same events) / (mixed events)**



N_{unc}: only pair acceptance correction was applied, not tracking efficiency (for all of talk)

- Correlation function = signal (jet) + underlying event
- Underlying event
  - Flat pedestal in pp
  - Flow modulated (initial collision geometry) in heavy-ion collisions

- Subtract (event plane dependent) background from correlation of form: $B\left(1+2v_2^{jet}v_2^{assoc}\cos(2\Delta\phi)+2v_3^{jet}v_3^{assoc}\cos(3\Delta\phi)+\ldots\right)$
  - Shape is dependent on the event plane resolutions: R_n

Removing background from correlations

Event plane dependence: background

- Background shape depends on angle relative to the event plane, need a different formula for each orientation
- All combined event plane angles:

$$B\left(1+\sum v_n^t v_n^a \cos(n\Delta\phi)\right)$$

- When trigger is restricted relative to the event plane:
  - Background level modified

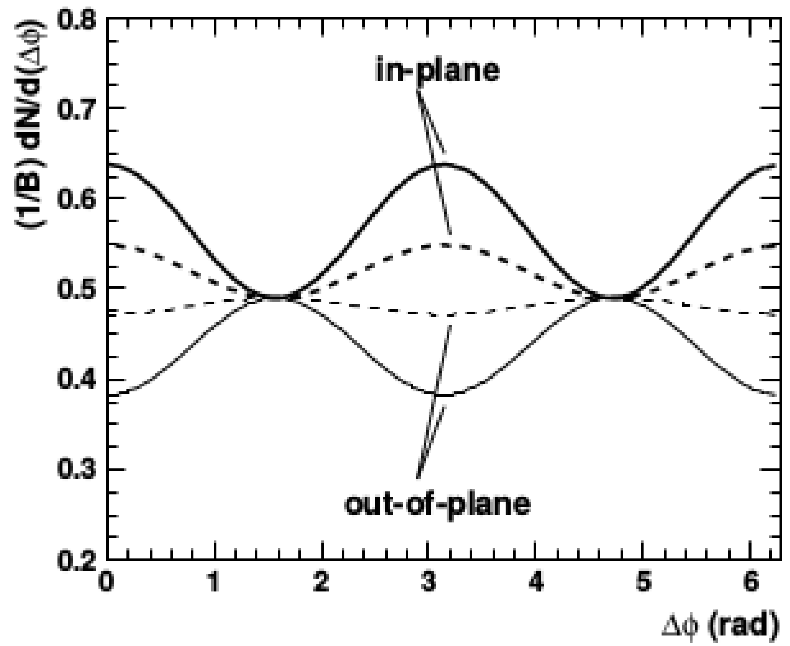
$$B=1+\sum 2 v_k^a v_k^{R,t} \cos(k\phi_S)\frac{\sin(kc)}{kc}R_n$$

  - Effective v_n modified

$$v_n^{R,t}=\frac{v_n+\cos(n\phi_S)\frac{\sin(nc)}{nc}R_n+\sum(v_{k+n}+v_{k-n})\cos(k\phi_S)\frac{\sin(kc)}{kc}R_n}{1+\sum 2v_k\cos(k\phi_S)\frac{\sin(kc)}{kc}R_n}, n=even$$

ϕ_S: center of angular window

2c: width of window



In-plane and **out-of-plane** correlation functions; ideal EP (FULL Lines); finite EP resolution (<cos(2ΔΨ)> = 0.3) (dashed Lines)

Event plane resolution

$$R_n=\langle\cos(n(\psi_{n,true}-\psi_{n,reco}))\rangle$$

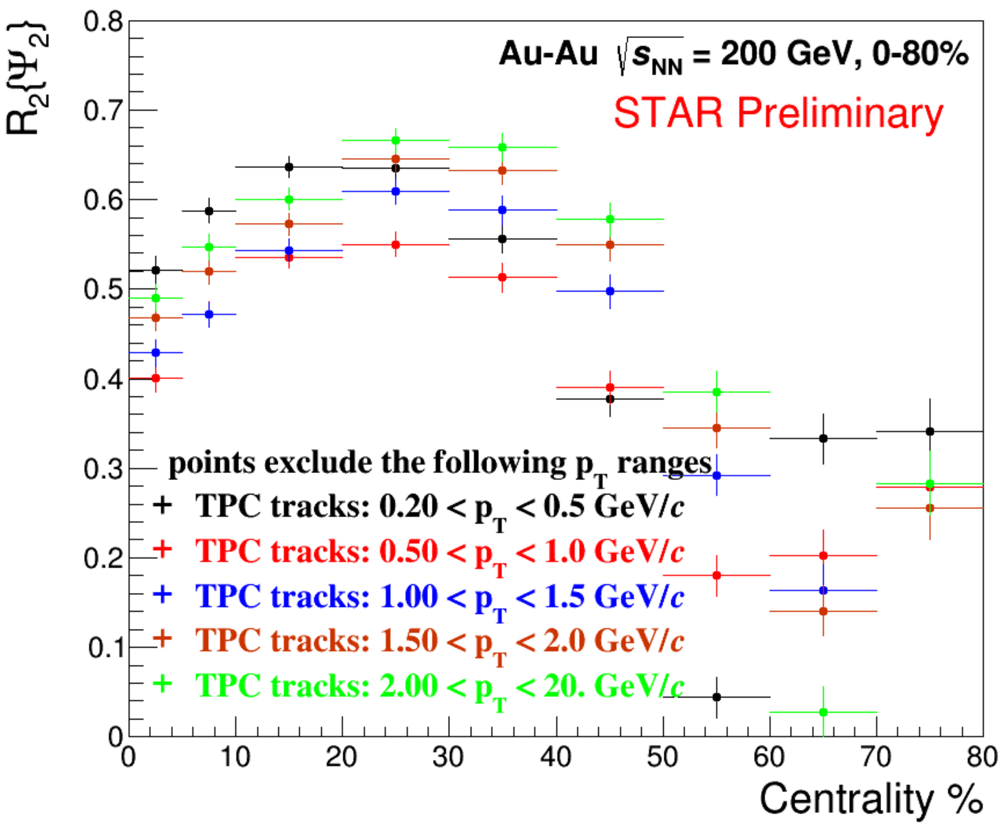
Nattrass & Todoroki, Phys. Rev. C97 (2018) 054911

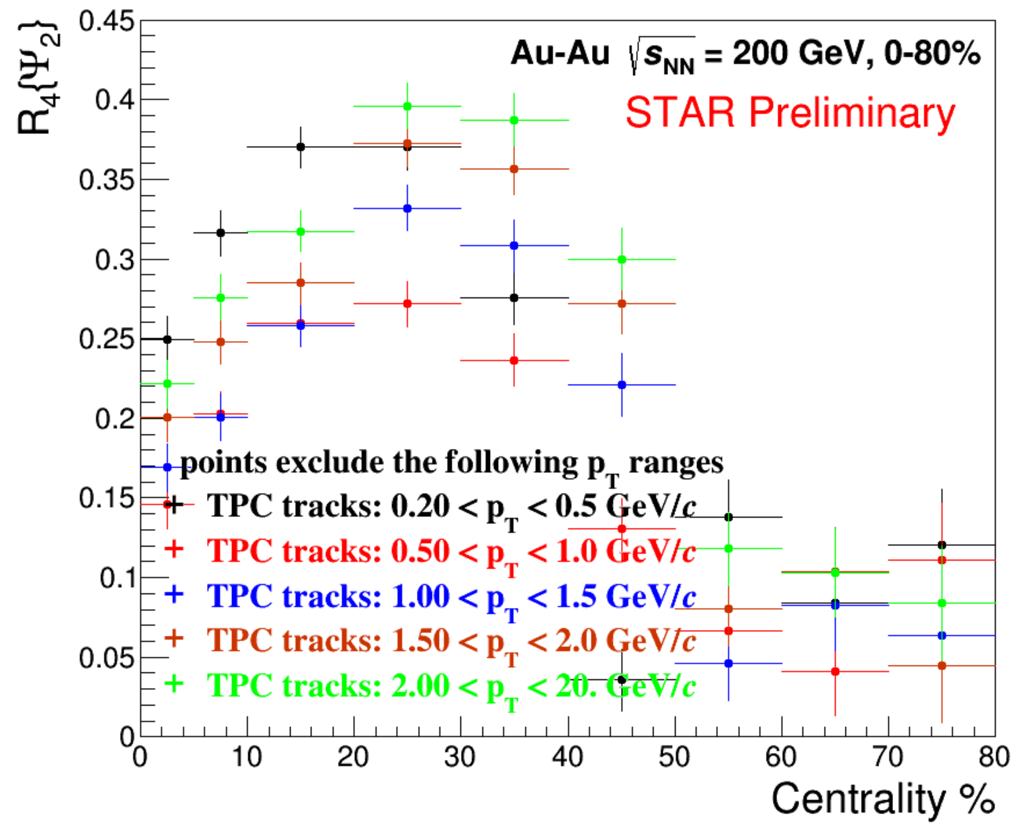
Bielcikova et al, Phys. Rev. C69 (2004) 021901

Event plane resolution

- Due to finite multiplicity of each event, there will be a difference between reconstructed event plane and underlying symmetry plane: ψ_n

$$R_n = \langle \cos\left(n\left(\psi_{n,true} - \psi_{n,reco}\right)\right)\rangle$$





- Using modified reaction-plane (MRP) method, for p_T associated bins
- Peak for 20-30% & 30-40% centrality
- Excluding 0.5 < p_T < 1.0 GeV/*c* tracks gives lowest R_n
  - Also seen by Phys. Rev. C89 (2014) 041901(R)

Near-side fit (NSF) method

30-40% central (simulation) TOY MODEL

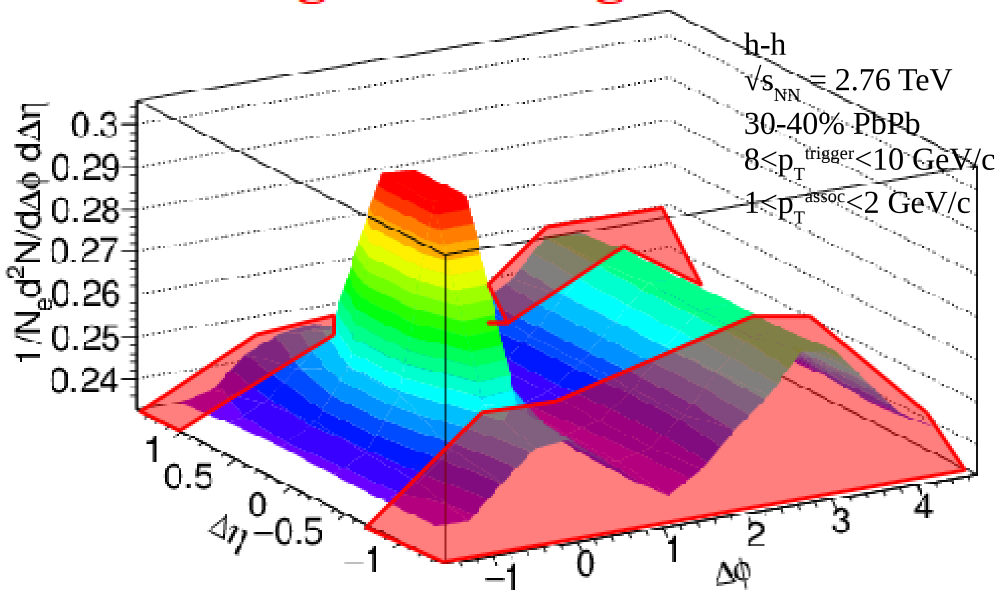
No reaction plane dependence

NOT used by this analysis

$$\frac{dN^{pairs}}{\pi d\,\Delta\Phi} = B\left(1+\sum_{n=1} 2\, v_n^{trigger} v_n^{assoc} \cos(n\Delta\phi)\right)$$

- Signal is negligible in large Δη and small Δφ region.

Signal+background



Background dominated region

Near-side fit (NSF) method

30-40% central (simulation) TOY MODEL

No reaction plane dependence

NOT used by this analysis

$$\frac{dN^{pairs}}{\pi d\Delta\Phi} = B\left(1+\sum_{n=1} 2 v_n^{trigger} v_n^{assoc} \cos(n\Delta\phi)\right)$$

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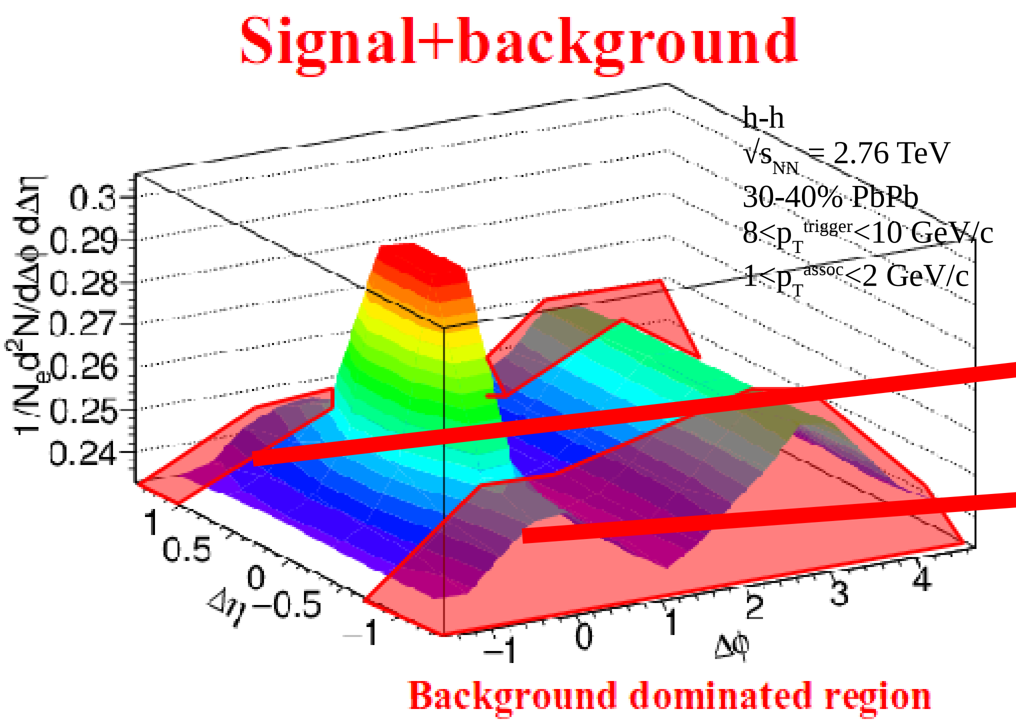
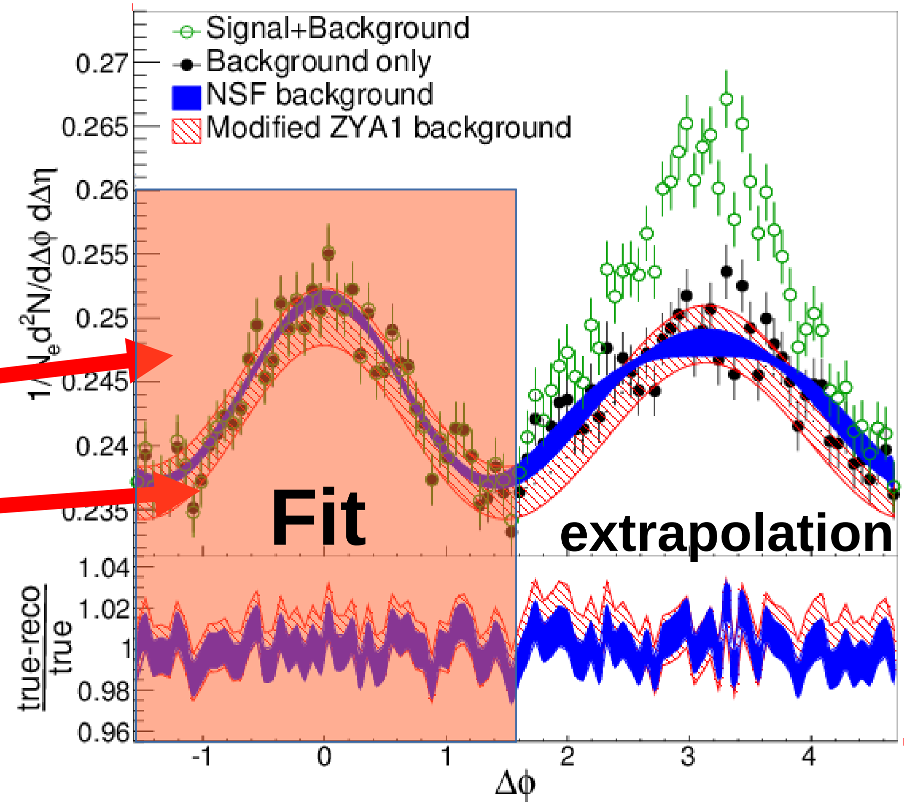
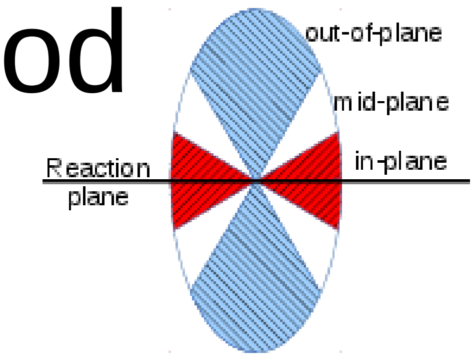




- NSF for 1.0< | Δη | < 1.4 and | ΔΦ | < π/2
- Fit up to 4th order v_n term, total 6 fit parameters: B, v_2^{assoc}, v_2^{trig}, $v_3^{assoc}\times v_3^{trig}$, v_4^{assoc}, and v_4^{trig}

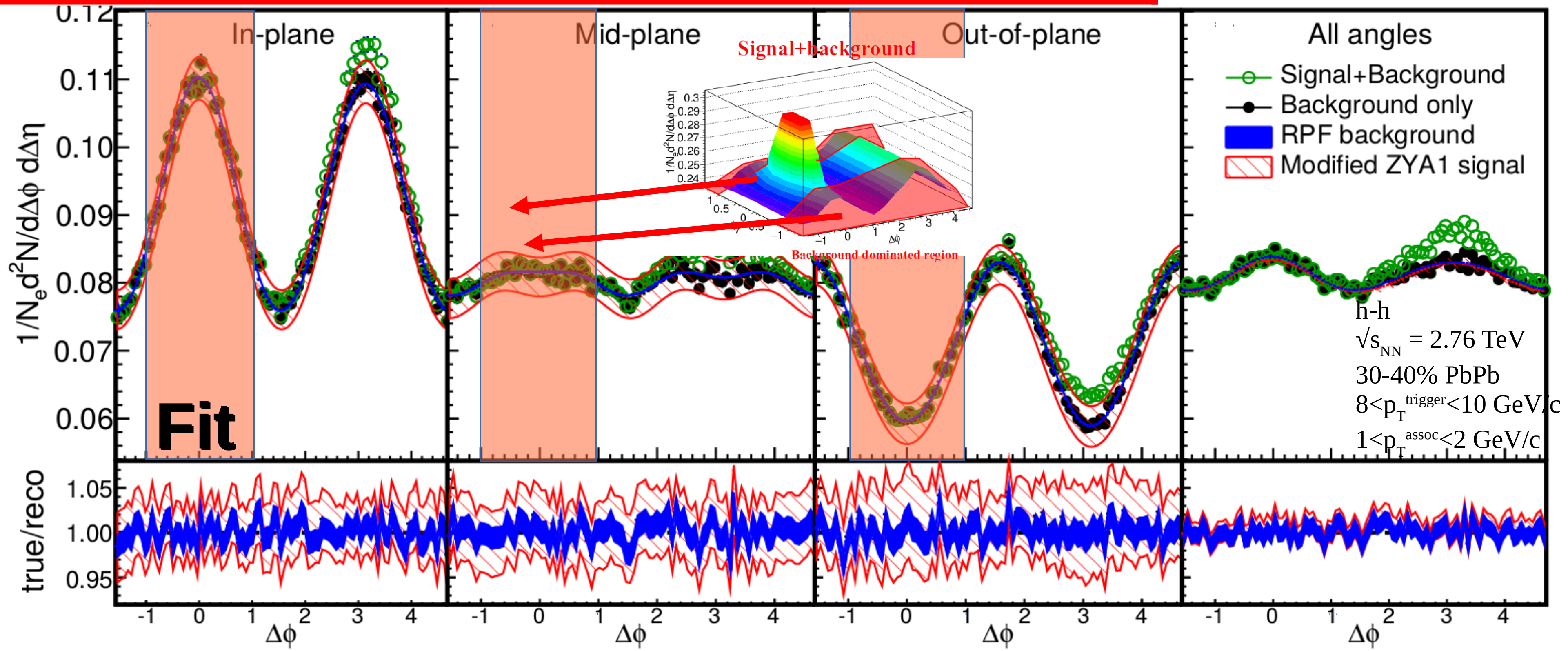
Sharma, Mazer, Stuart, Nattrass: Phys. Rev. C93 (2016) 044915

Reaction plane fit (RPF) method



30-40% central (simulation) TOY MODEL

- The background shape in the correlations depends on the angle of trigger relative to the event plane - different functional form: require same parameters
- RPF is more robust of a method, more information going in to give a more constrained background fit



- v_n and B extracted from fit

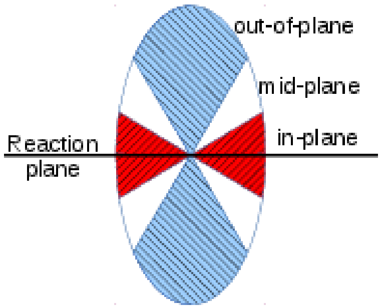
Phys. Rev. C93 (2016) 044915

- Fewer assumptions and less bias than ZYAM while having much smaller errors

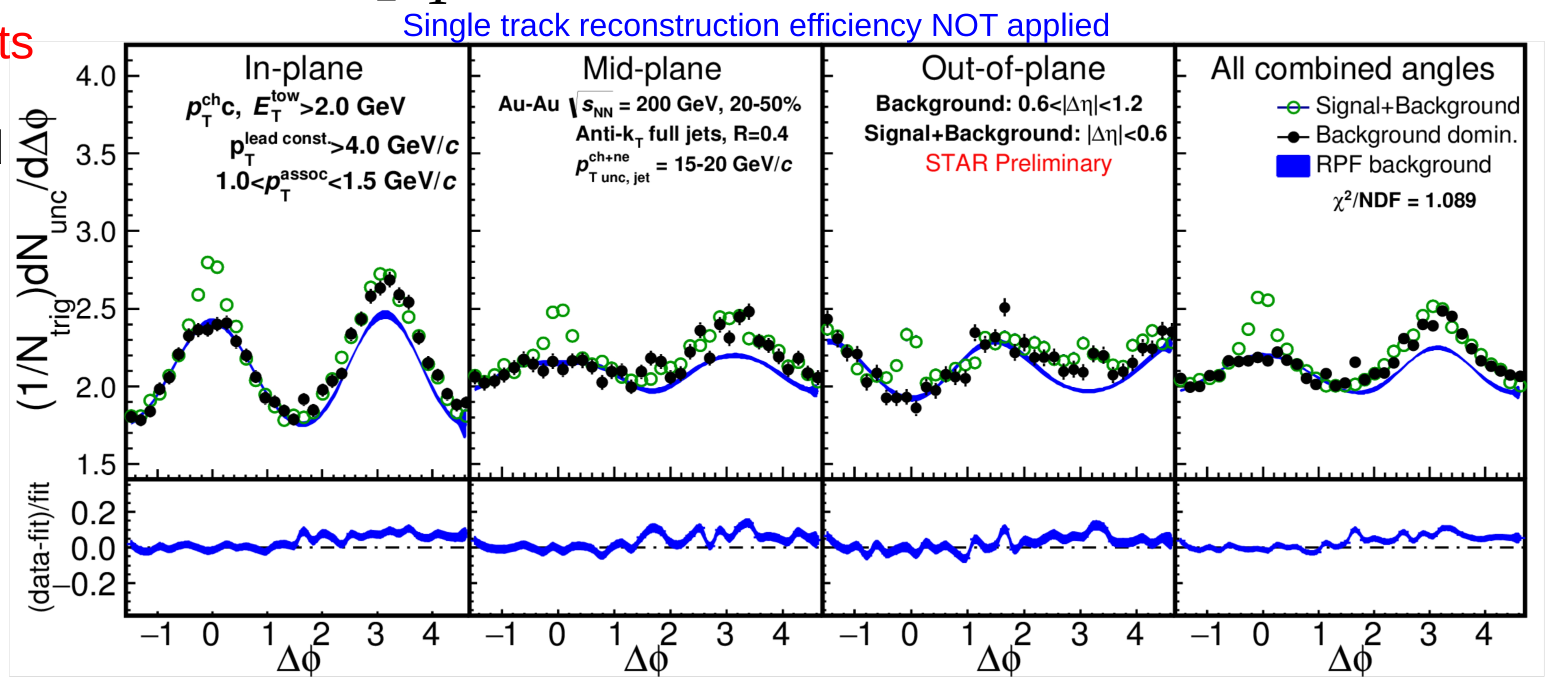
Correlation Results

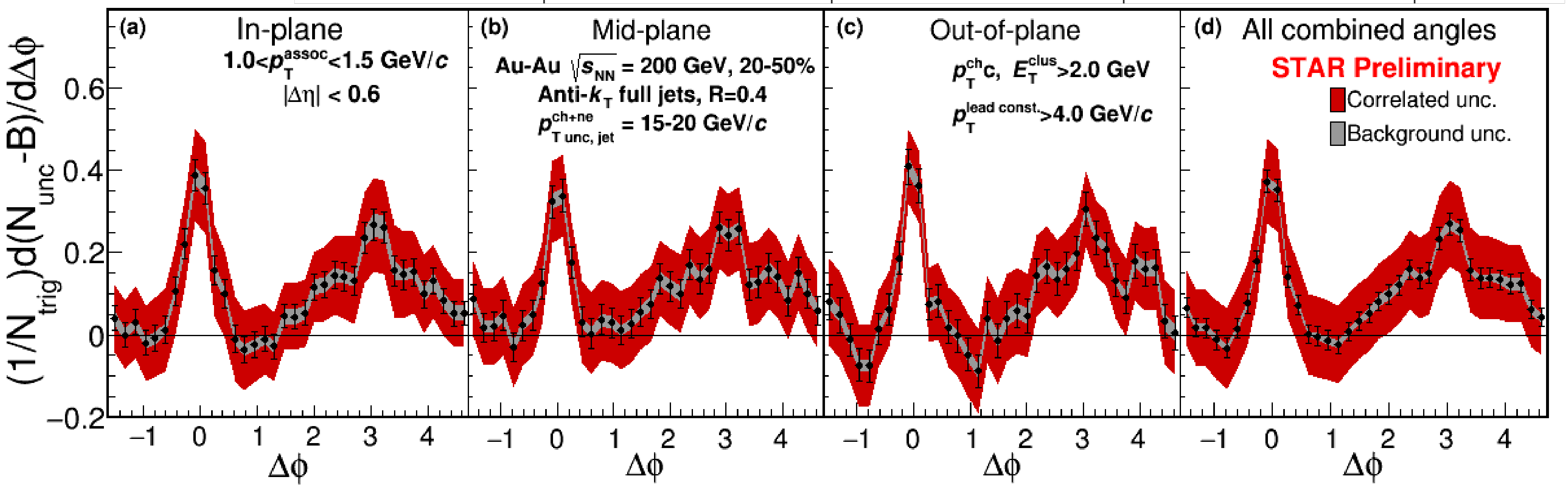
Data results: p_T^{assoc} 1.0-1.5 GeV/c

15-20 GeV/*c* R=0.4 full jets
1) signal+background
2) background dominated
3) background RPF fit



Correlation function





- v_3 and v_4 components important
- Background uncertainty is non-trivially correlated point-to-point

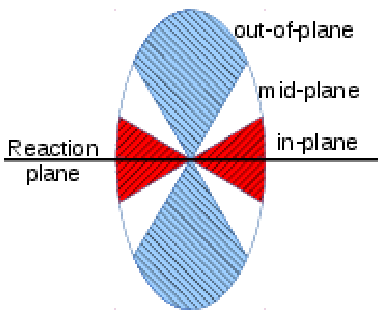
Data results: p_T^{assoc} 2.0-3.0 GeV/c

15-20 GeV/c R=0.4 full jets

1) signal+background

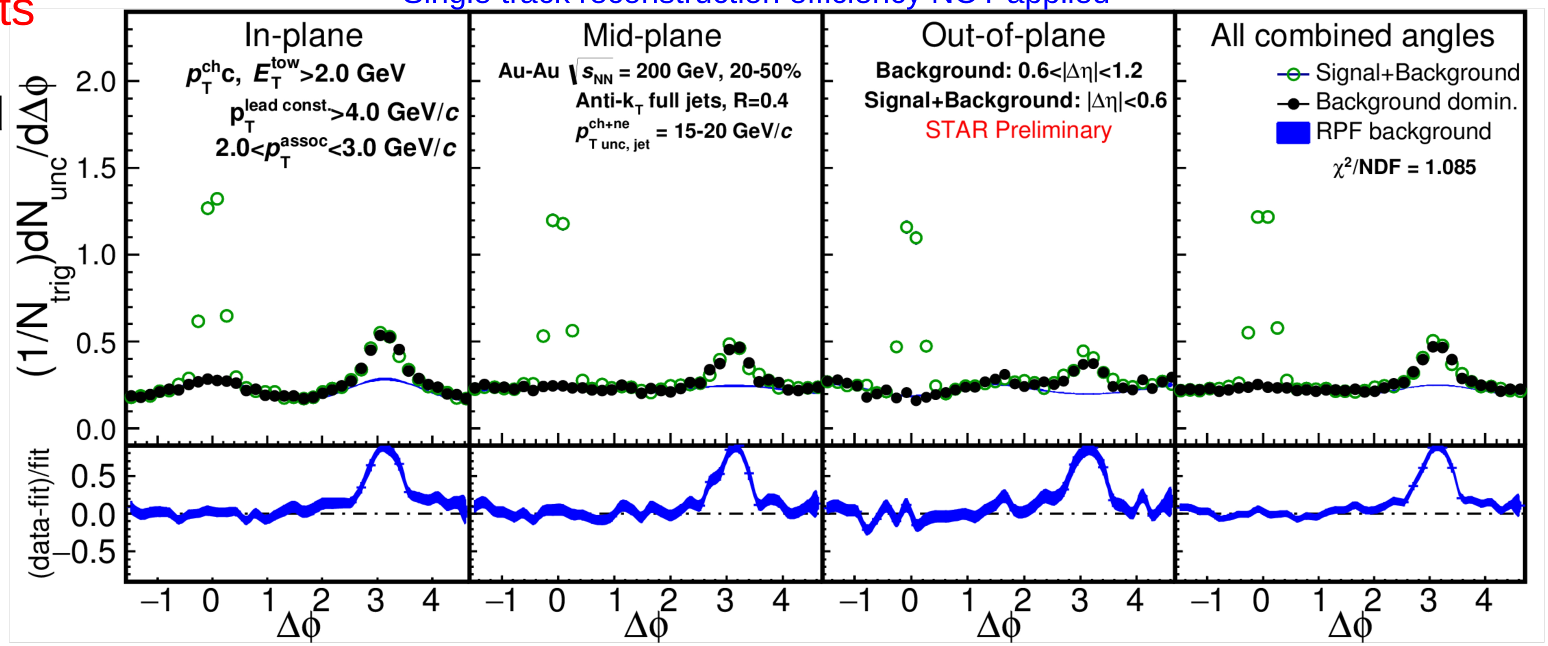
2) background dominated

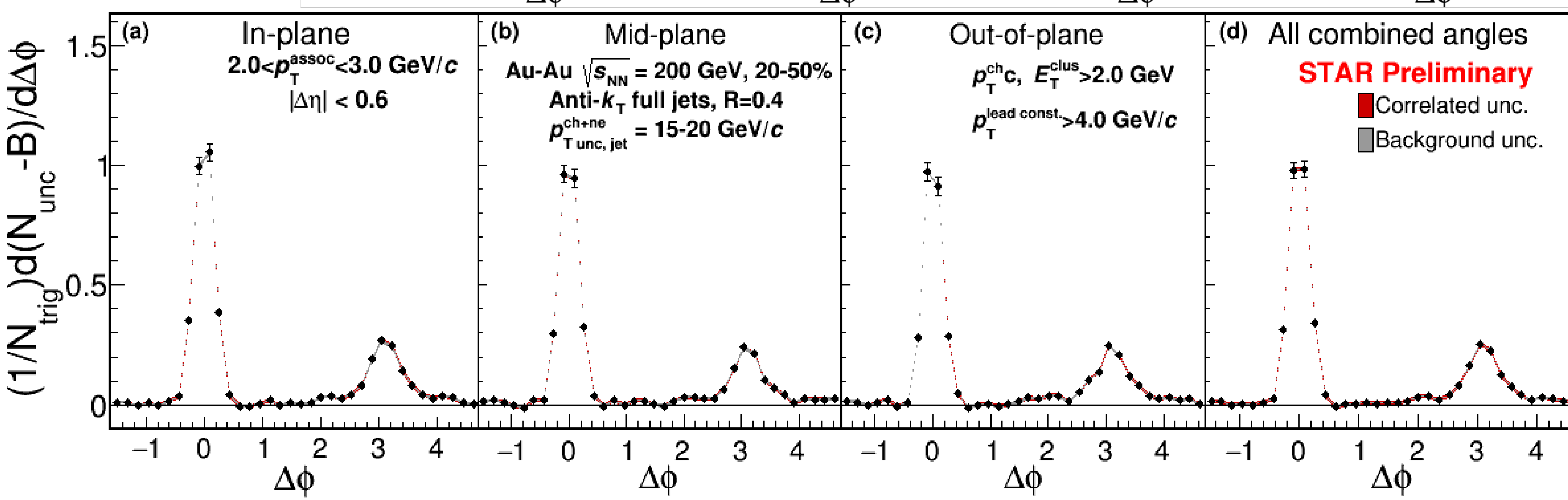
3) background RPF fit



Correlation function

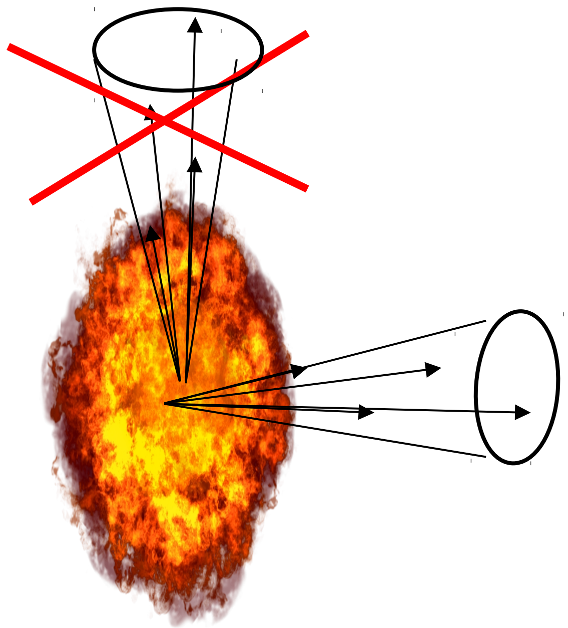
Single track reconstruction efficiency NOT applied





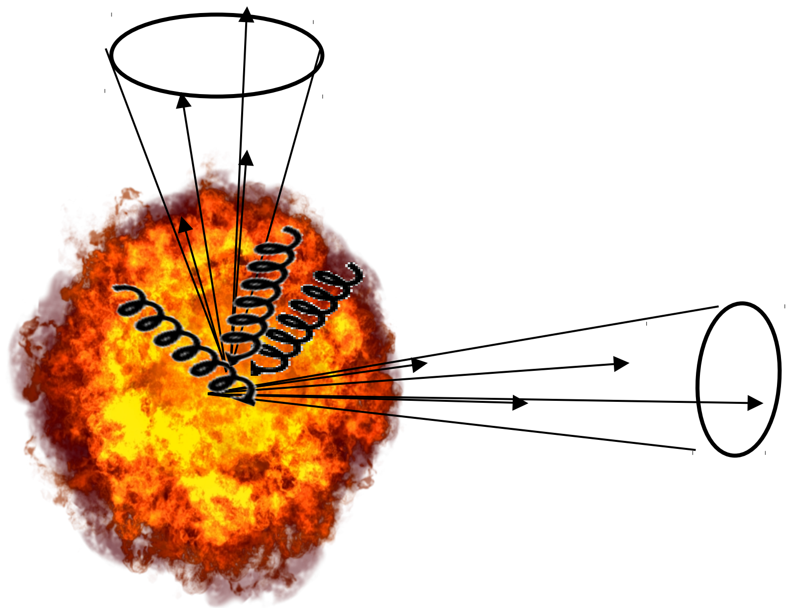
- Signal/background level increasing
- Background uncertainty is non-trivially correlated point-to-point

Competing effects of associated hadrons



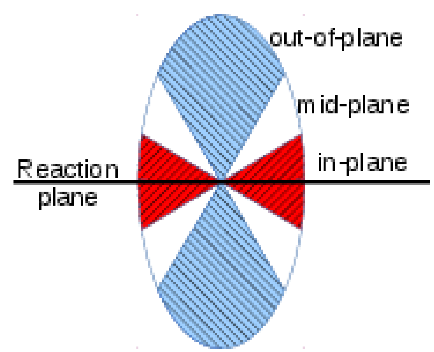
Equilibration in medium

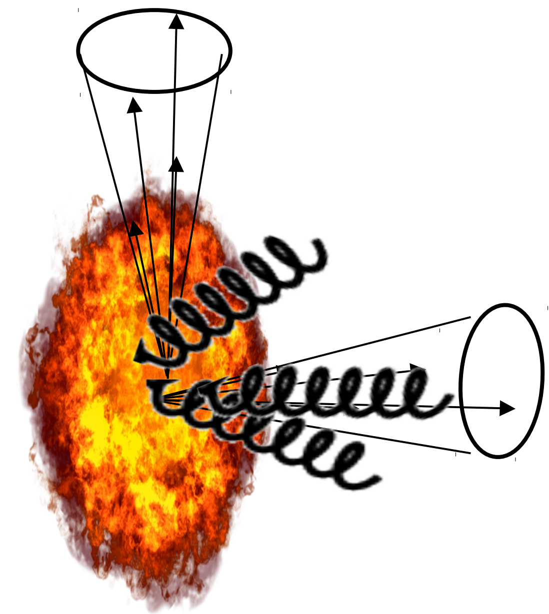
Fewer jets, lower high-p_T yield out of plane



Bremsstrahlung

Softer, higher yield out of plane





Fluctuations

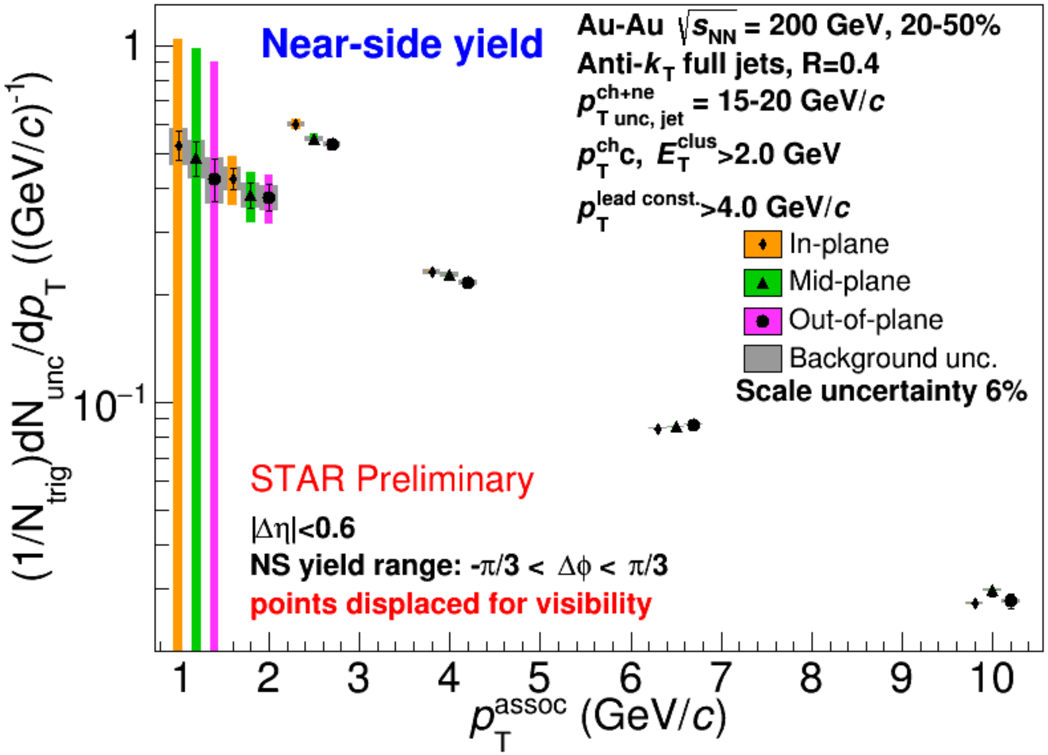
Individual jets' energy loss may vary

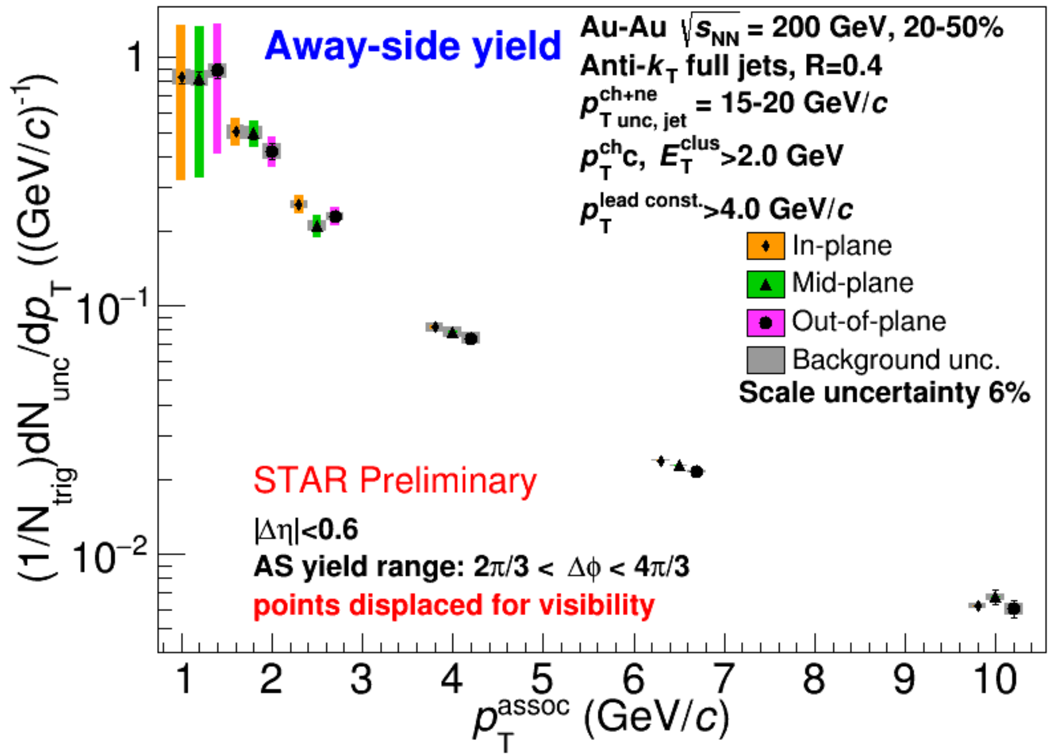
Yields

Near-side and away-side yields vs. EP

Single track reconstruction efficiency NOT applied

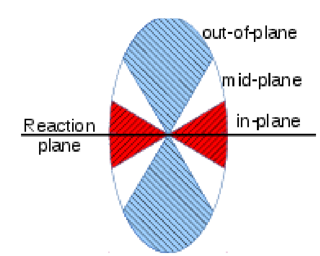
R=0.4 full Jets 15-20 GeV/*c*, 20-50% centrality





- NS should be EP-independent due to surface bias – focus on AS
- Within uncertainties of current statistics, no event plane ordering
- Different levels of (competing) effects in different p_T associated bins

1) Equilibration in the medium (decrease yield from in → out)
2) Bremsstrahlung (increase yield from in → out)

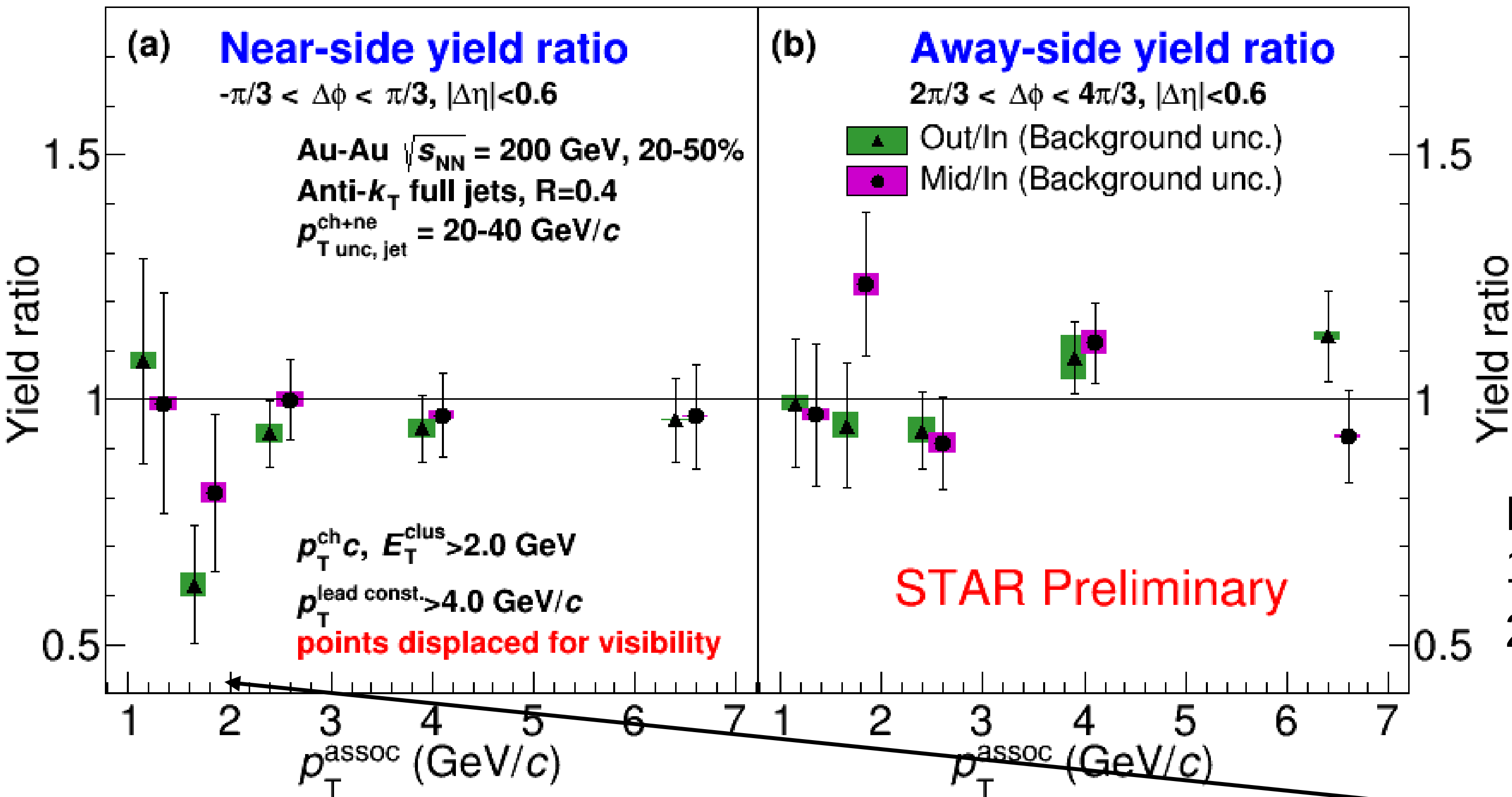


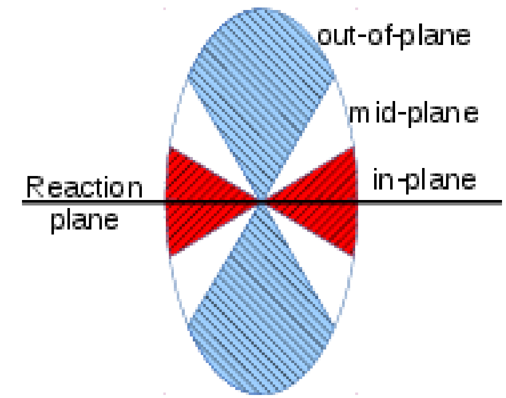
Quantifying the event plane dependence

Yield ratio

Single track reconstruction efficiency NOT applied

R=0.4 full Jets 20-40 GeV/*c*, 20-50% centrality





If in-plane jets interact less:
1) ratios < 1 at high p_T
2) ratios > 1 at low p_T

constituent cut

- Dominated by statistical uncertainties
- ***Within current uncertainties, don't observe significant path-length dependence (same jet p_T as ALICE)***
- **Indication that path-length is a secondary effect to fluctuations of jet energy loss in the medium**

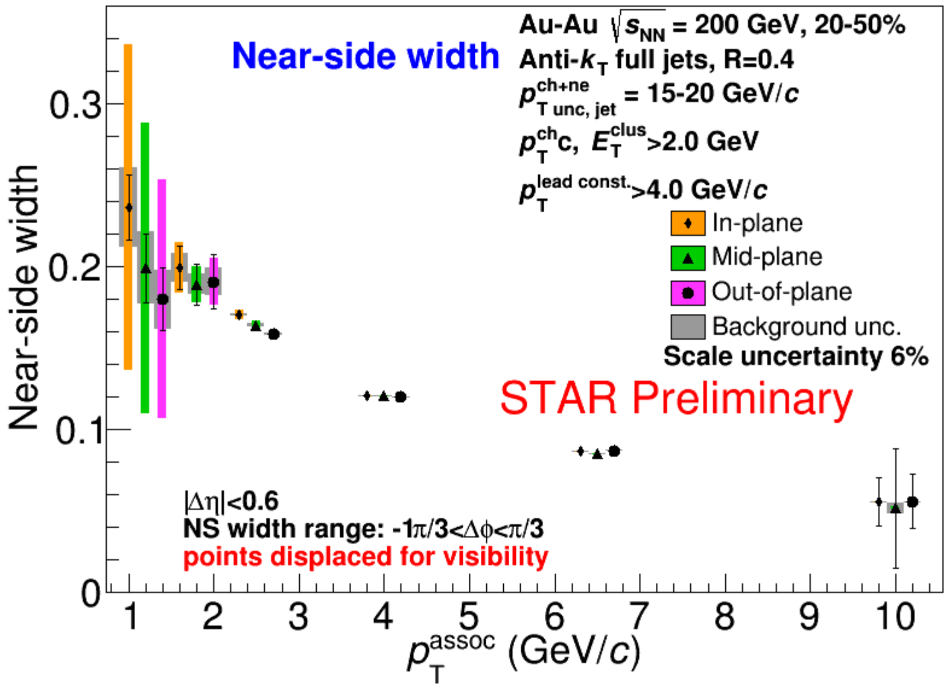
Not sensitive enough?

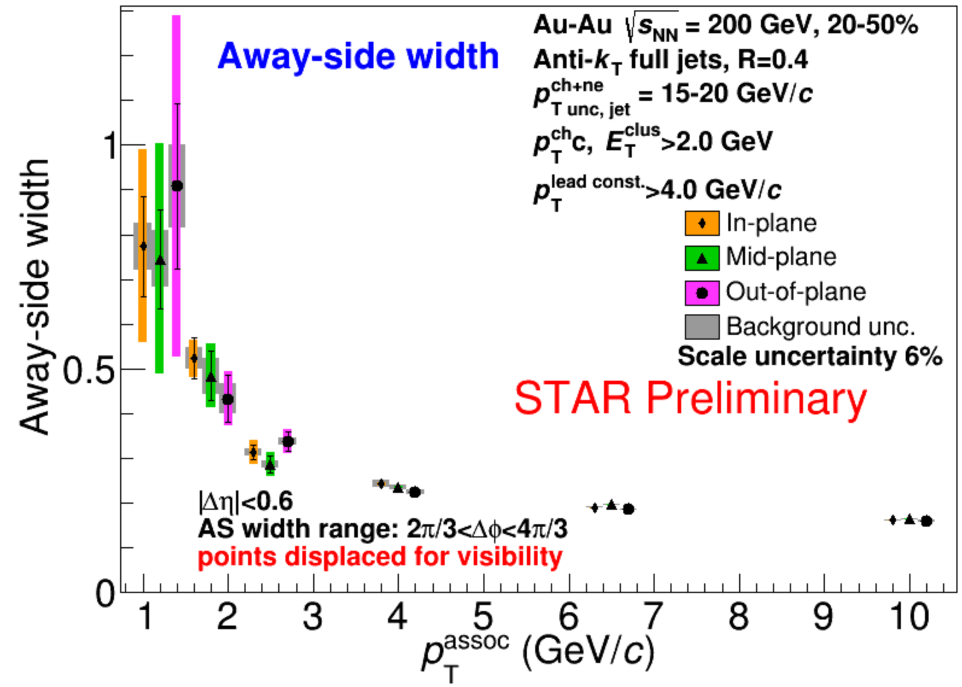
Widths

Near-side and away-side widths vs. EP

Single track reconstruction efficiency NOT applied

R=0.4 full Jets 15-20 GeV/*c*, 20-50% centrality





- Large uncertainties at low p_T
- Broadening seen for decreasing associated momenta
  - Expected from either collisional energy loss or gluon bremsstrahlung
  - Path-length dependent energy loss would lead to greater width for jets out-of-plane than in-plane
- No significant path-length dependence of widths seen within uncertainties

Jet-hadron summary

- Event plane dependence of jet-hadron correlations
  - Another tool for exploring path-length dependent modifications to jets in medium

- No significant event plane dependence seen within uncertainties of the measurement – on yield ratios or widths
  - path-length dependence → secondary effect
  - Event-by-event fluctuations play important role to jet energy loss
  - consistent with: ALICE results, JEWEL studies at LHC energies, re-analysis of STAR, Phys. Rev. C94 (2016) 011901(R)

Exploring Differential Jet Shape

Jet Shape

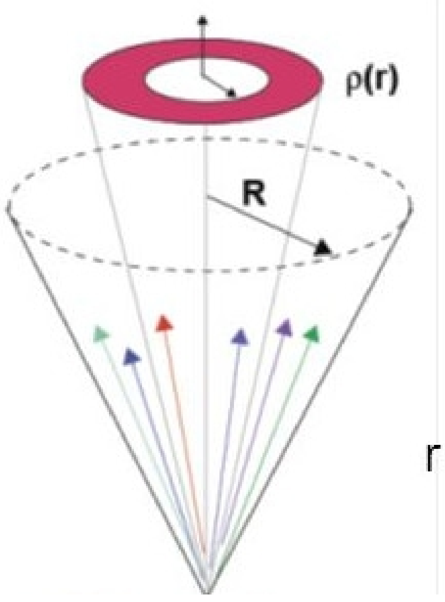
Motivation:

- Jet shapes measure the average distribution of jet energy as a function of distance from the jet axis
- It can discriminate between different models of jet quenching
- It can distinguish physics mechanisms of quark and gluon energy loss in medium

<u>Averaged over many jets</u>

Differential jet shape:

$$\rho(\Delta r) = \frac{1}{\delta r}\frac{1}{N_{\text{jets}}}\Sigma_{\text{jets}}\frac{\Sigma_{\text{tracks}\in(r_a,r_b)}\,p_{\text{T}}^{\text{trk}}}{p_{\text{T}}^{\text{jets}}}$$

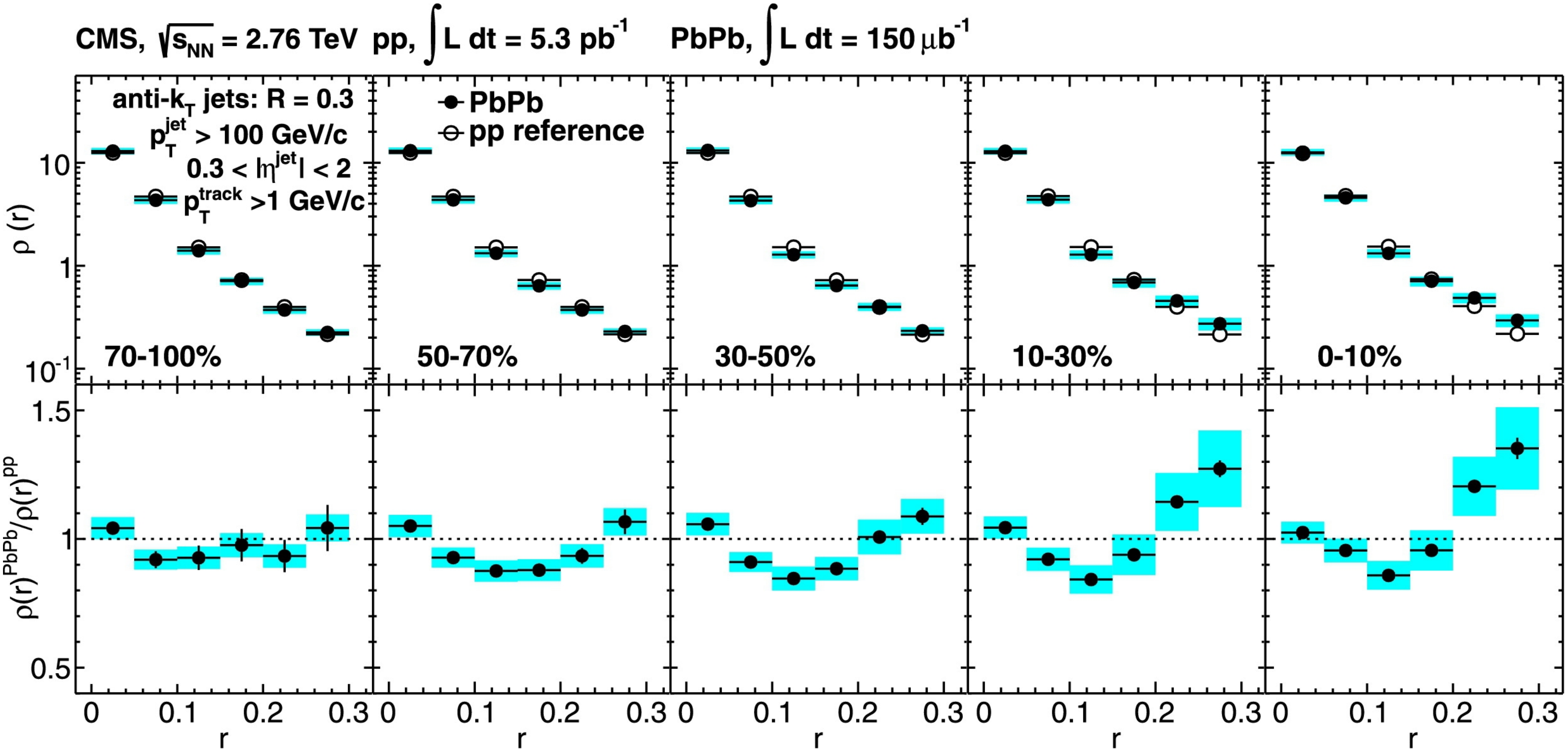


$r = (\Delta\eta^2+\Delta\varphi^2)^{1/2}$

<u>Jet shape function</u>: provides information about the radial distribution of the momentum carried by the jet constituents (fragments)

LHC Jet Shape studies

LHC differential jet shape results

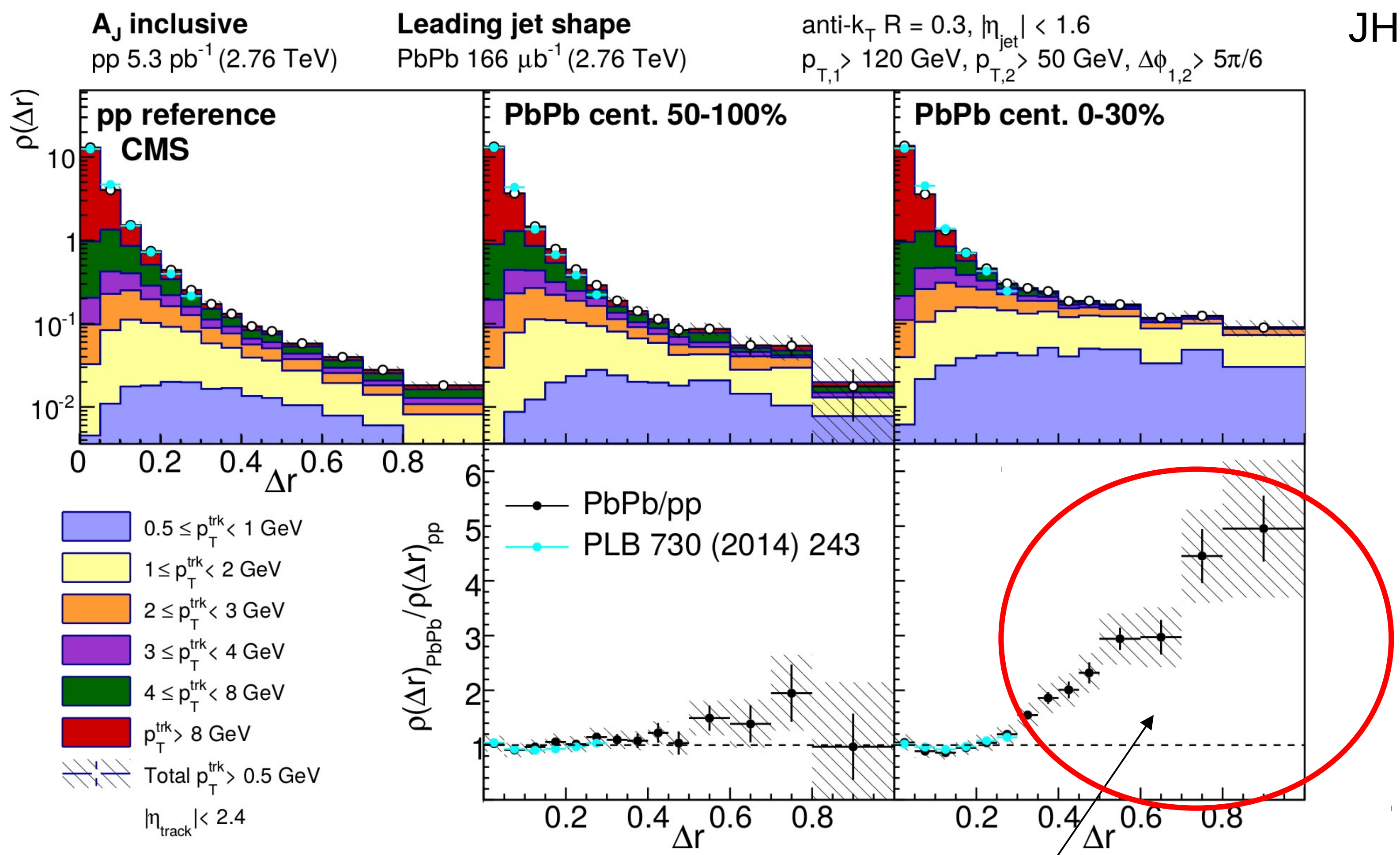


Phys. Lett. B 730 (2014) 243

- Significant modification at large radius (r) with respect to the jet axis, looking at tracks with p_T > 1 GeV/c
- Consistent with expectations from jet quenching models

LHC: decomposing transverse momentum balance contributions

JHEP 11 (2016) 055

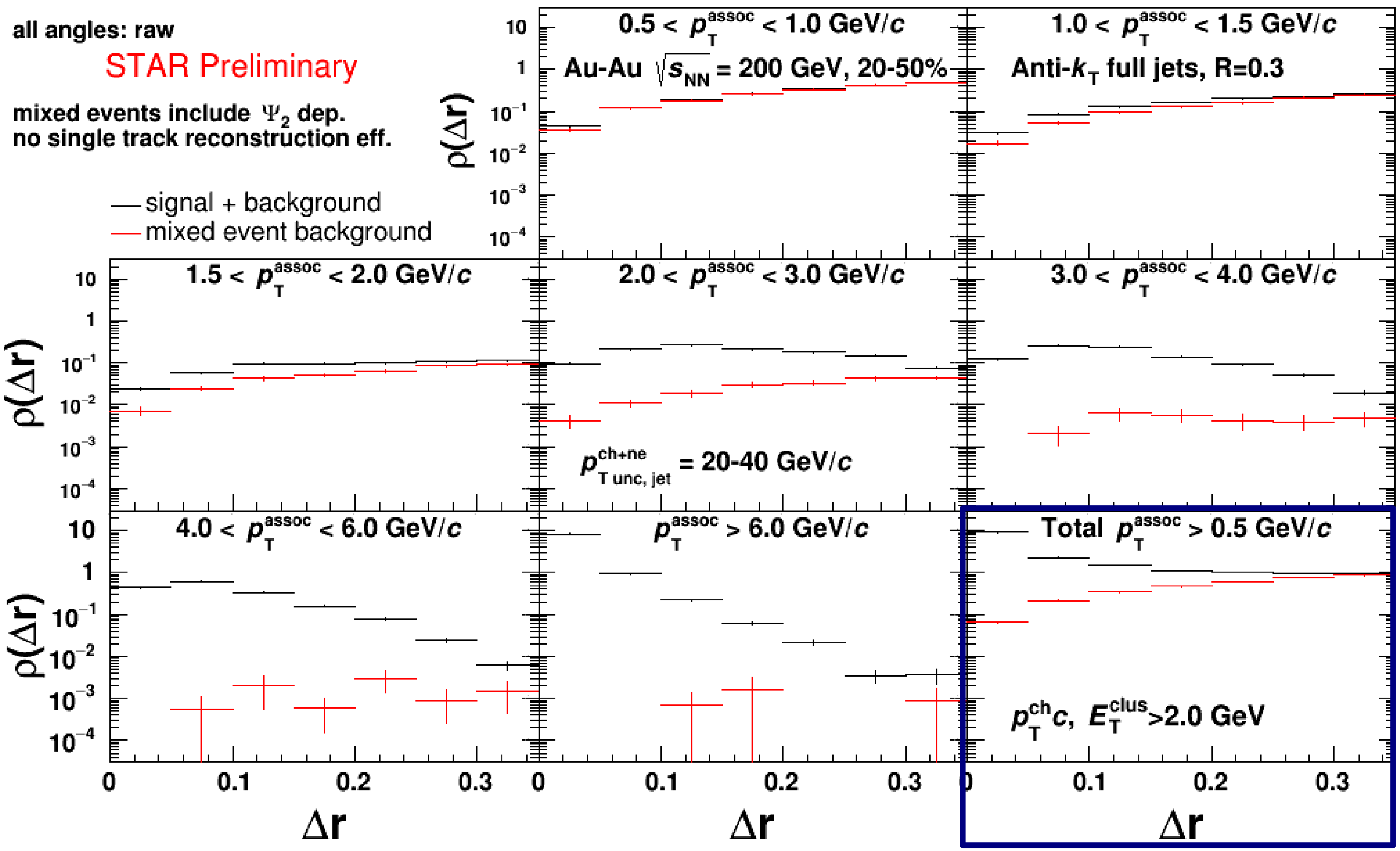


- Clear broadening that increases with centrality
- Significant modification at large r relative to the jet axis
- Where does the radiated energy go?
  - seen at large distances from jet, mainly in form of low-p_T particles

STAR
differential jet shape

Raw Jet shape: Au+Au

p_T increasing



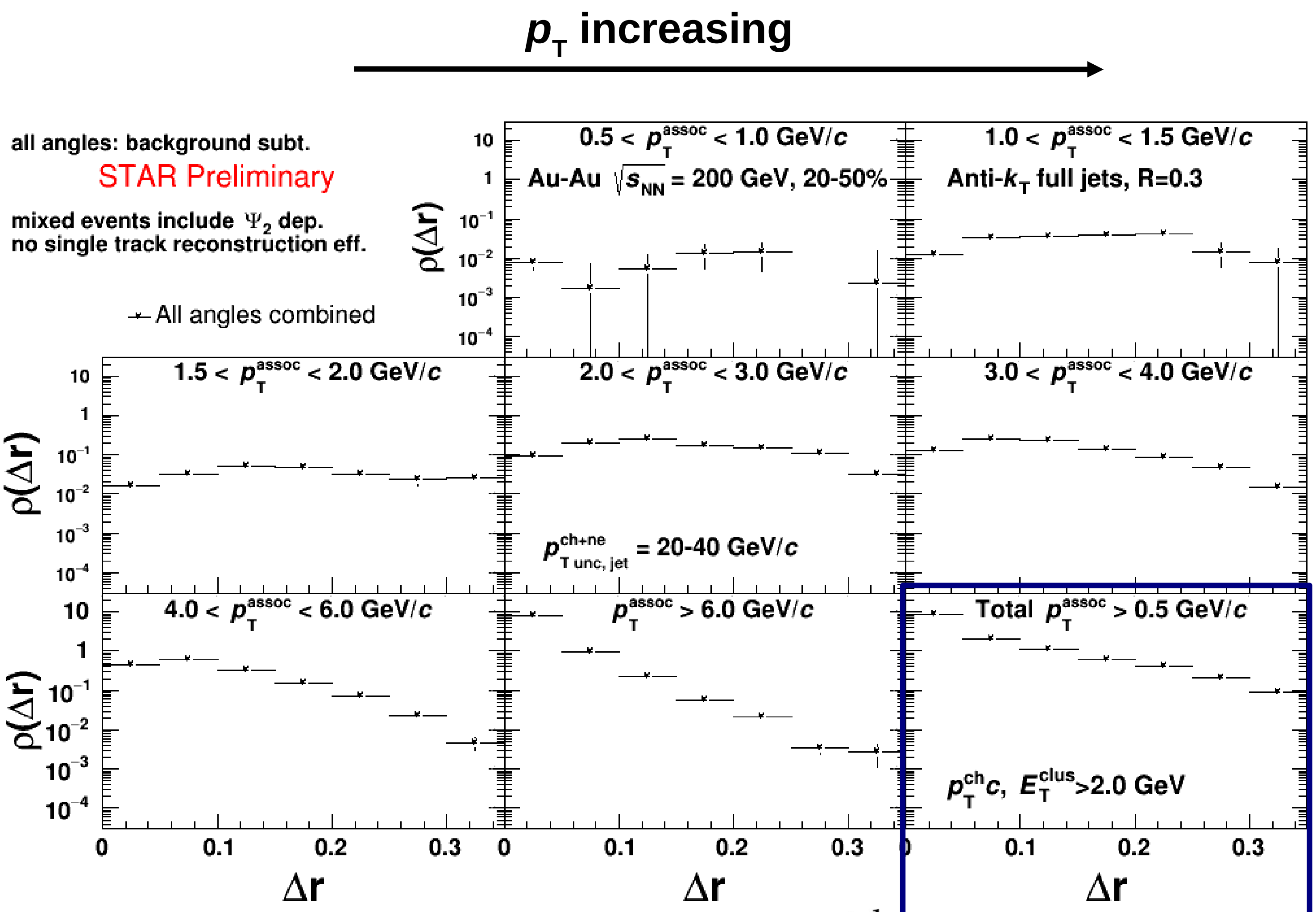
- **20-50% centrality**
- Leading jets
- R=0.3 full jets
- **20-40 GeV/*c* Jets**
- Jet Constit. 2.0+GeV/*c*

- Background:
  - Event mixing

p_T increasing

- Sum up charged track p_T in Δr bins from the trigger jet axis
- Sum up charged track p_T in Δr bins from background jet axis in mixed events from minimum bias events of similar event class (centrality, z-vertex, event plane angle)

Differential jet shape (inclusive angle)



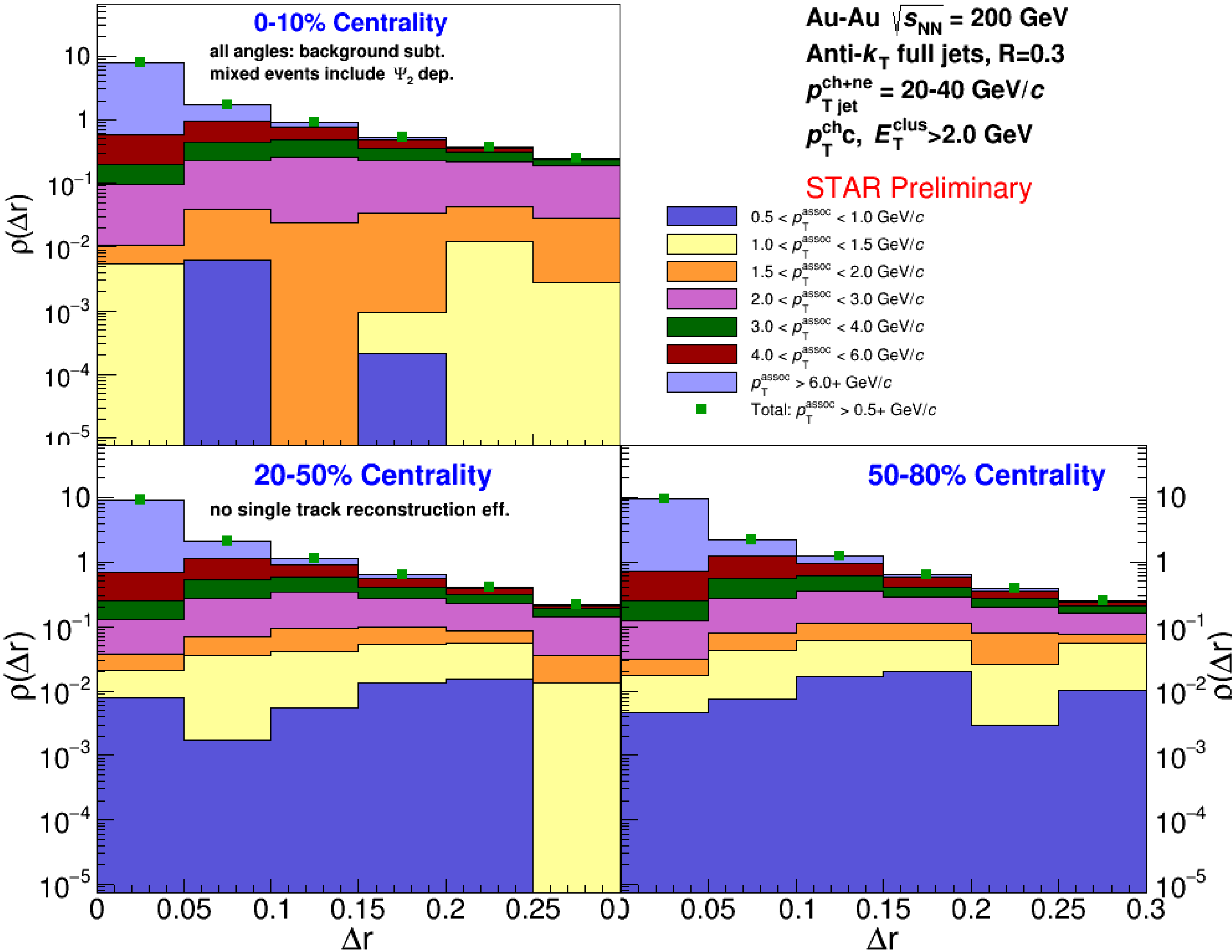
- **20-50% centrality**
- Leading Jets
- R=0.3 full jets
- **20-40 GeV/*c* Jets**
- Jet Constit. 2.0+GeV/*c*

Background removed from jet cone

$$\rho(\Delta r) = \frac{1}{\delta r}\frac{1}{N_{\rm jets}}\Sigma_{\rm jets}\frac{\Sigma_{{\rm tracks}\in(r_a,r_b)}p_{\rm T}^{\rm trk}}{p_{\rm T}^{\rm jets}}$$

- Normalize per trigger: N_{jets} and Δr bin width = 0.05
- High-p_T particles located near jet core

Decomposing transverse momentum contributions: RHIC

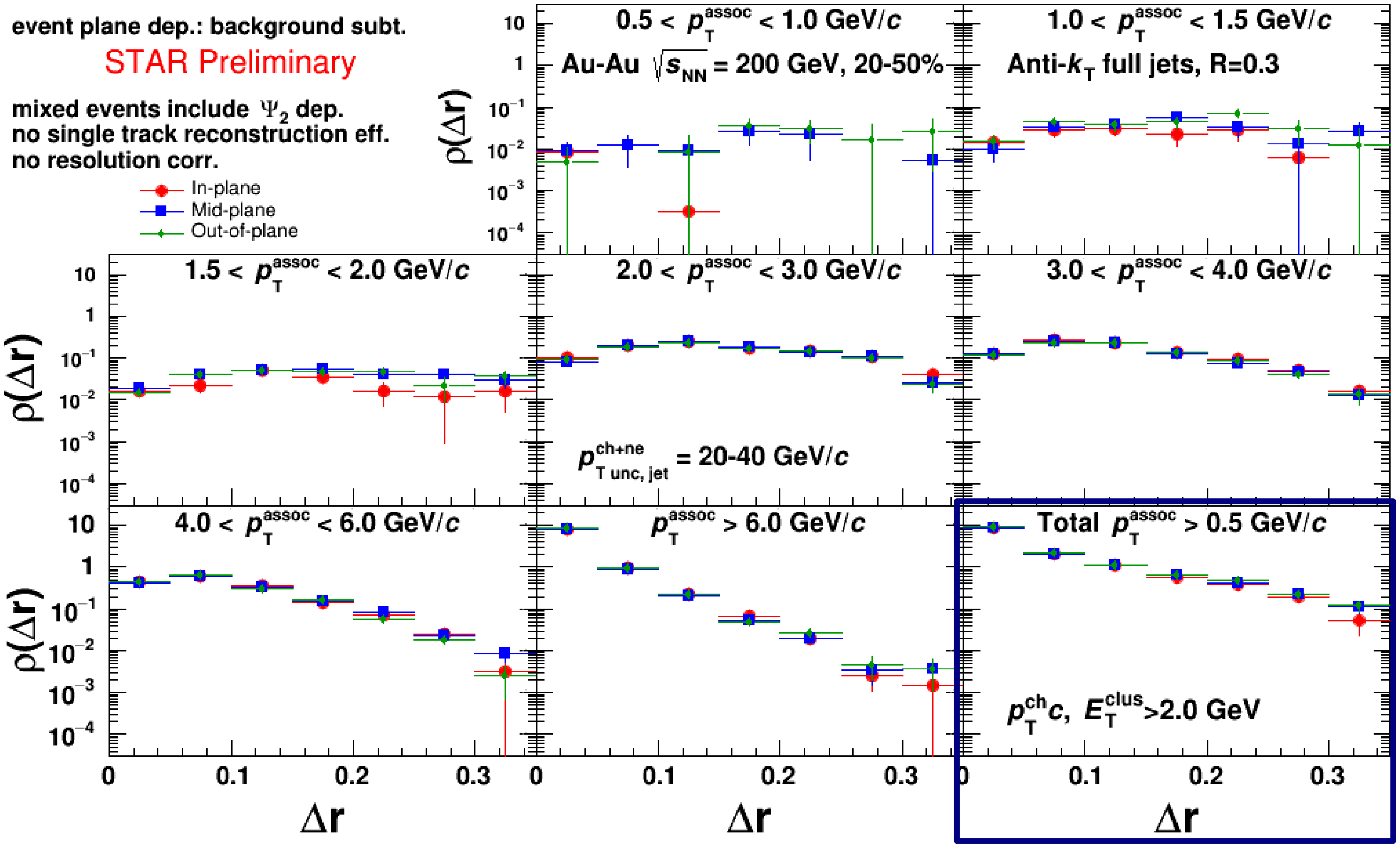


- Leading jets
- R=0.3 full jets
- **20-40 GeV/*c* Jets**
- Jet Constit. 2.0+GeV/*c*

- Increase in jet momentum leads to more collimated jets with high p_T tracks closer to jet core (10-15 GeV/*c* jets in backup)

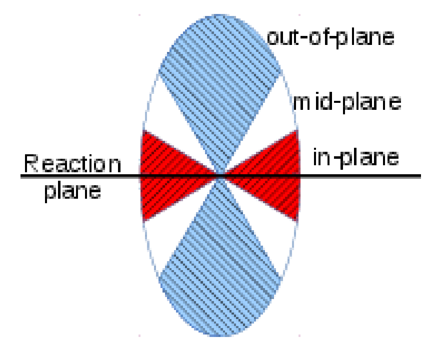
Event plane dependence

p_T **increasing**



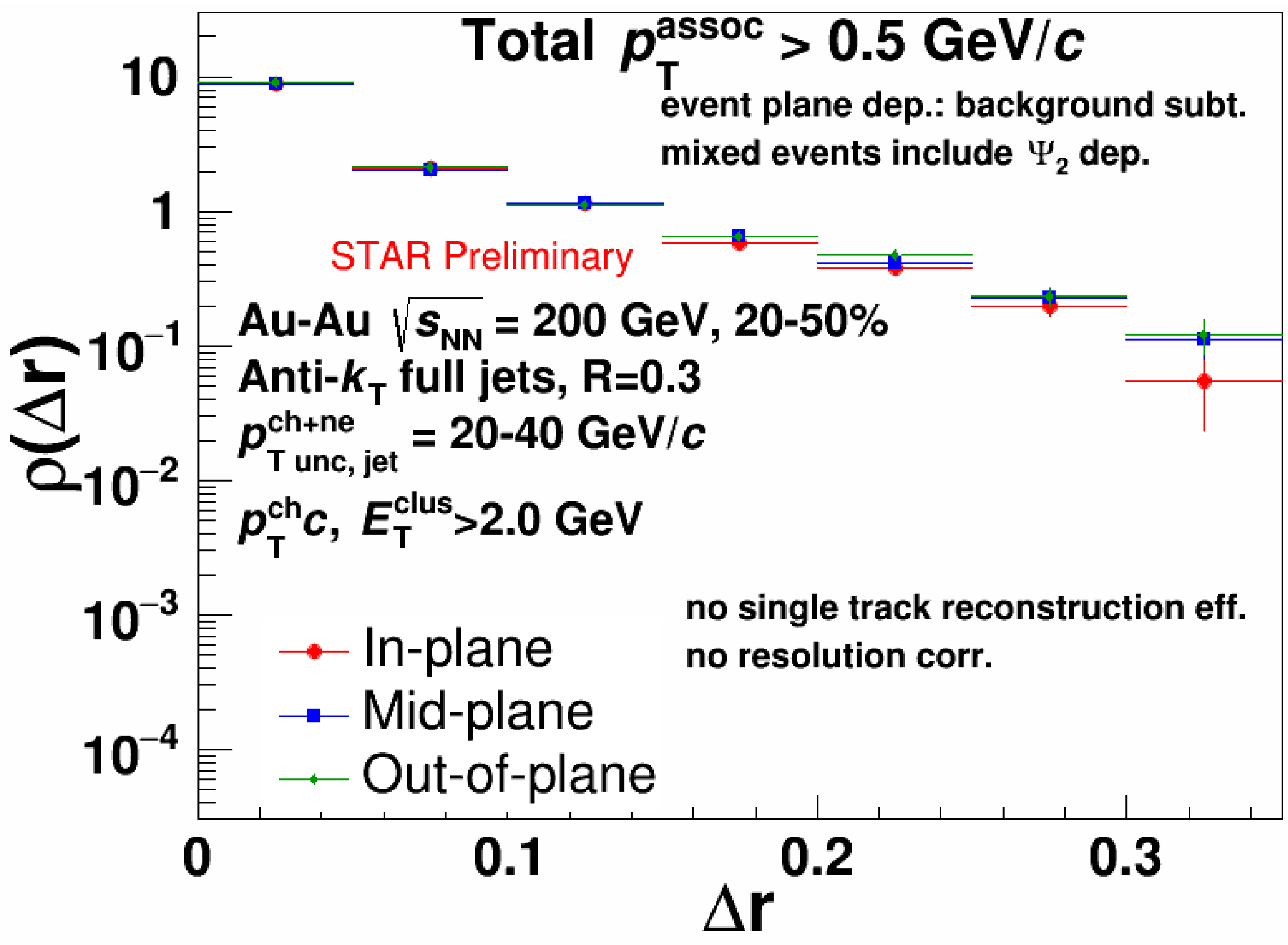
- **20-50% centrality**
- R=0.3 full jets
- **20-40 GeV/*c* Jets**
- Jet Constit. 2.0+GeV/*c*
- Background via: mixed events

p_T **increasing**



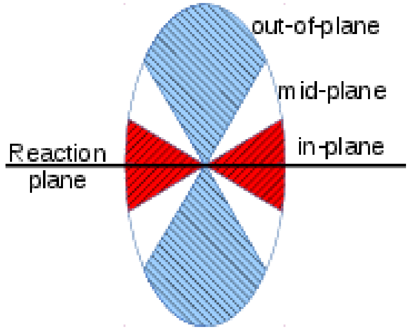
- Need to correct for the event plane resolution
- Hint of event plane ordering at low p_T
- Above 2 GeV/*c*, results are consistent with each other

EP-dependent differential jet shape: 0.5+ GeV/c tracks



- **20-50% centrality**
- R=0.3 full jets
- **20-40 GeV/c Jets**
- Jet Constit. 2.0+GeV/c
- Background via: mixed events

Sum of all 0.5+ GeV/c tracks



- Negligible jet shape differences over full momentum to within uncertainties
- Need to look to large R for full recovery of redistributed energy

Phys. Rev. Lett. 119 (2017) 062301

Phys. Rev. C84 (2011) 024906

Differential jet shape summary

- Event plane dependence of differential jet shape shown
  - Promising tool to study the energy loss mechanism and discriminate between different models of quenching

- Differential jet shape ρ(r):
  - Gets broader for less energetic jets
  - High p_T tracks closer to jet core (low Δr)

- Differential jet shape - relative to the event plane:
  - Need to look to large jet R for full recovery of redistributed energy
  - Hint of event plane ordering at low-p_T
  - General ordering trend to within uncertainties – evidence of path length dependent energy loss?

Conclusions

- No significant event plane dependence seen within uncertainties of the measurement – on yield ratios or widths
  - path-length dependence → secondary effect
  - Event-by-event fluctuations play important role to jet energy loss
  - consistent with: ALICE results, JEWEL studies at LHC energies, re-analysis of STAR, Phys. Rev. C94 (2016) 011901(R)

- Differential jet shape at RHIC: *FIRST LOOK*
  - Higher p_T jets are more collimated
  - Harder jets are shown to survive more out-of-plane
  - Hint of event plane ordering at low p_T

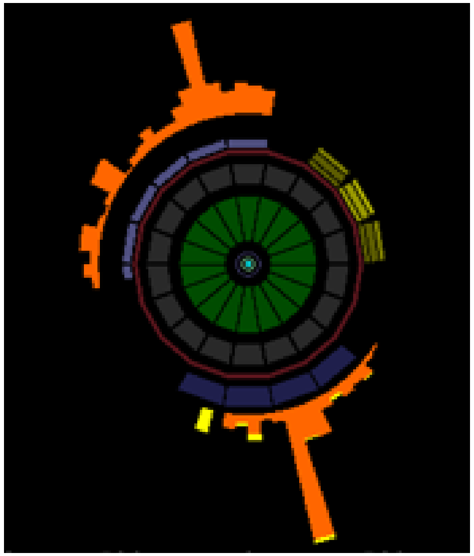
Moving forward

- Single track reconstruction efficiency
- Compare to pp (in-progress!)
- Centrality ratios (in-progress!)
- Event plane resolution correction (in-progress!)
- Applying systematics

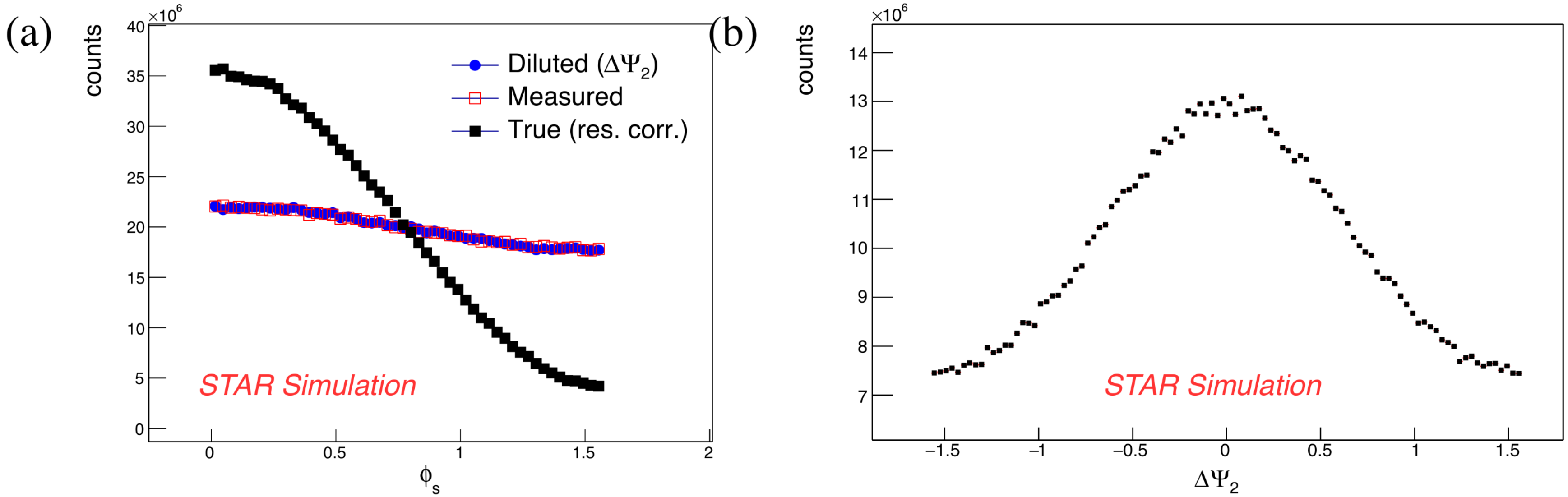
Happy Birthday Miklos!!

1983 Quark Matter

Backup



Resolution correction



$$\frac{dN}{d\phi_s} \propto \left(1 + \frac{2v_2}{\mathcal{R}}\cos(2\phi_s)\right),$$

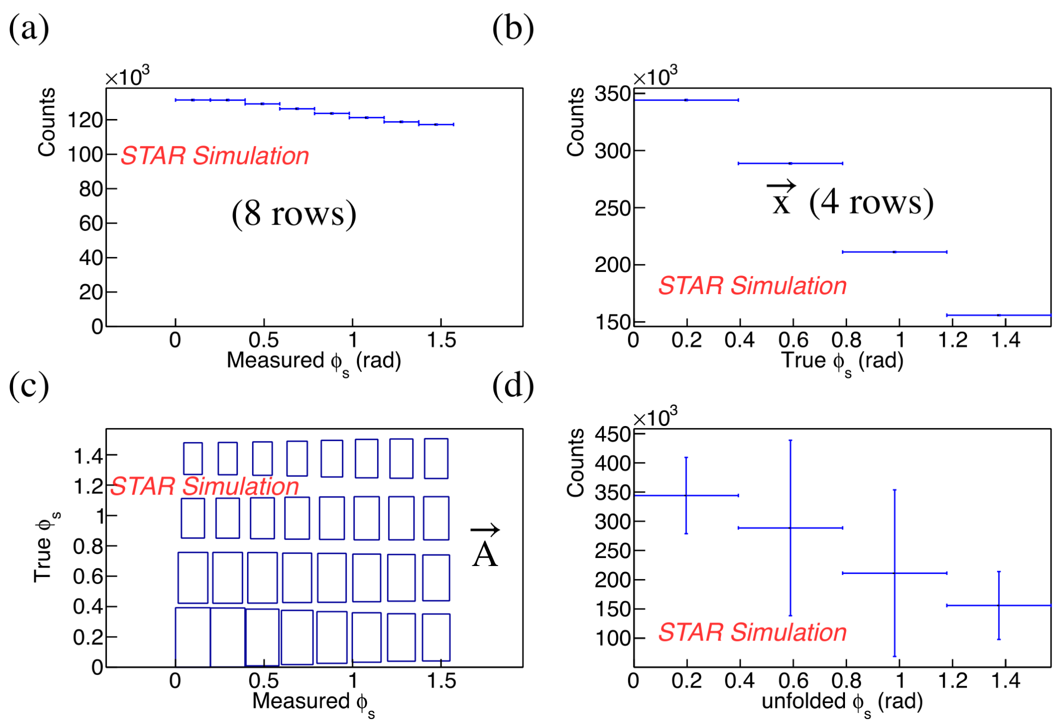
ϕ_s: The separation angle between trigger particles and EP

$$f(\chi, \Delta\Psi_2) = \frac{1}{\pi}\left[e^{-\frac{\chi^2}{2}} + \sqrt{\frac{\pi}{2}}\chi(\cos 2\Delta\Psi_2)e^{-\frac{\chi^2 \sin^2 2\Delta\Psi_2}{2}}\left(1 + \mathrm{erf}\left(\frac{\chi\cos 2\Delta\Psi_2}{\sqrt{2}}\right)\right)\right],$$

and $\chi = \mathcal{R}/\sqrt{\frac{\pi}{8}}$.

S. Voloshin, Y. Zhang, Z. Phys. C 70 (1996) 665

Resolution correction (unfolding)



https://root.cern.ch/doc/master/classTUnfold.html

- Histogram (a) and (b) are filled by the data generated by MC
- 2D histogram (c) is regarded as the "probability matrix", boxes for each row of y can be understood as the probability to migrate to the bin of x
- We again use (a) but as the input. We can obtain the output (d)
- The number of bins after unfolding is half of the input. (8bins -> 4 bins)

$\chi^2_{unfold} = \chi^2_A + \tau^2\chi^2_L + \lambda\sum_i(\vec{A}\vec{x} - \vec{y})i,$

χ^2_A **is from a least square minimization**

τ^2: **regularization strength**

χ^2_L **for regularization**

λ: **Lagrangian parameter**

The best value of $\tau 2$ can be obtained from the L curve scan

Data Set and cuts

- Dataset: AuAu 200 GeV, Run14
- Jets taken from: HT2 triggered events
- Centrality determined using grefMultCorr: includes corrections for z-vertex + luminosity
  - Mid-peripheral collisions: Centrality 20-50%
- Z-vtx < 24 cm (statistics driven selection)
- Mixed events taken from: MB triggered events
  Event Pool: Centrality bins of 10%, Z-vertex bins of 4 cm
- R=0.4 and R=0.3 full (charged tracks + neutral towers)
- tracks + towers with $p_T > 2.0$ GeV/*c*
- Require bias Jet: max track/tower $p_T > 4.0$ GeV/*c*, tower constituent now
- Tower constituent required to have fired trigger

Reduces combinatorial background

Track / Jet quality cuts

Primary tracks

- Transverse momenta: $0.2 < p_T < 20$ GeV/c
- Eta acceptance: -1.0 < eta < 1.0, Azimuth: 0.0 < phi < 2*pi
- DCA: 3.0
- # of hits in track fit: require > 15
- # of hits in track fit / max # hits: require > 0.52
- Jet constituent towers:
  - $E_T > 0.2$ GeV after hadronic correction (100% fraction removed)
- Jet constituent tracks: same as regular tracks
  - Constituents: track $p_T > 2.0$ GeV/c
- Jets: Full anti-k_T jets
  - R=0.4 and R=0.3
  - -1.0+R < eta < 1.0-R, 0.0 < phi < 2*pi

Background jet cones

Case 1: -1 + R < eta,jet < 1 – R

- Eta reflection: eta,bgjet = -eta,jet
- Phi: phi,bgjet = phi,jet

Case 2: -R < eta,jet < +R

- Eta: eta,bgjet = eta,jet
- Phi shift: phi,bgjet = phi,jet + pi/2 (kept on cyclic coordinates)
  - This is be a problem for EP dependent jet shapes
  - Over estimate background for out-of-plane jets
  - Under estimate background for in-plane jets

Inclusive: combine the above 2 cases

Case 3: mixed events approach – 24 multiplicity bins, 14 - 4 cm z-vtx bins (same as correlation analyis): using kVPDMB5 || kVPDMB30 for mixing

- Eta,bgjet = eta,jet
- Phi,bgjet = phi,jet

Issues with ZYAM

- Tends to underestimate background level
  - Can use fixed point (e.g. $\Delta\varphi=1$) instead
- v_n for background may not be the same as independent measurements
  - Cumulant methods suppress fluctuations
  - Reaction plane measurements may include effects from jets
  - Events with jets may be different
  - High and low p_T reaction planes may be different
  - Effective v_n are average over particle pairs and includes background from other jets. Measurements of flow are averaged over events and the goal is to suppress contributions from jets.
- If jet peak is broadened, may overestimate background (underestimate signal)
- **Only v_2 measured for jets**

Background Subtraction Methods

- **Zero-Yield at Minimum (ZYAM):** Assumes v_n from other studies, assumes region around $\Delta\varphi \approx 1$ is background dominated
- **$\Delta\eta$ Method:** Project near-side signal onto $\Delta\eta$ and subtract constant background. Near-side only
- **$\Delta\eta$ Gap Method:** Use signal at large $\Delta\eta$ to determine background, assuming constant background in $\Delta\eta$. Near-side only
- **Near-Side Fit (NSF):** assumes small $\Delta\varphi$/large $\Delta\eta$ region background dominated, fits v_n and B
- **Reaction Plane Fit (RPF):** assumes small $\Delta\varphi$/large $\Delta\eta$ region background dominated, fits v_n and B using reaction plane dependence
- **Near-Side Subtracted NSF/RPF (NSS NSF/RPF):** fits v_n and B at small small $\Delta\varphi$ using reaction plane dependence after subtracting the near-side with a fit

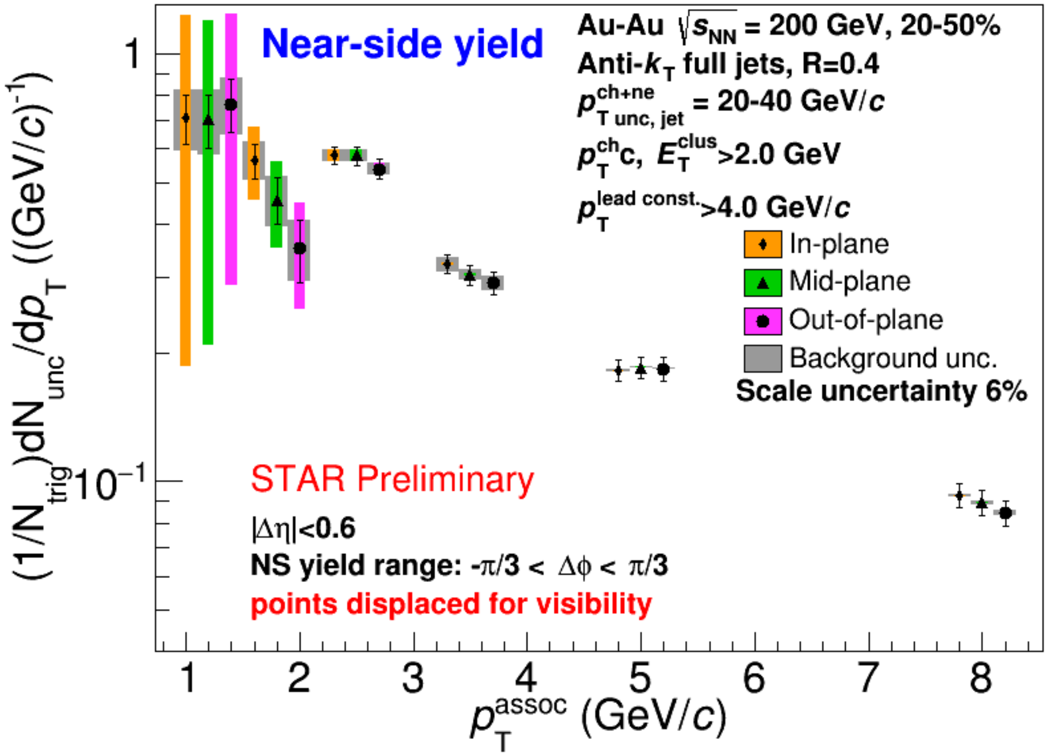
Little/no path length dependence?

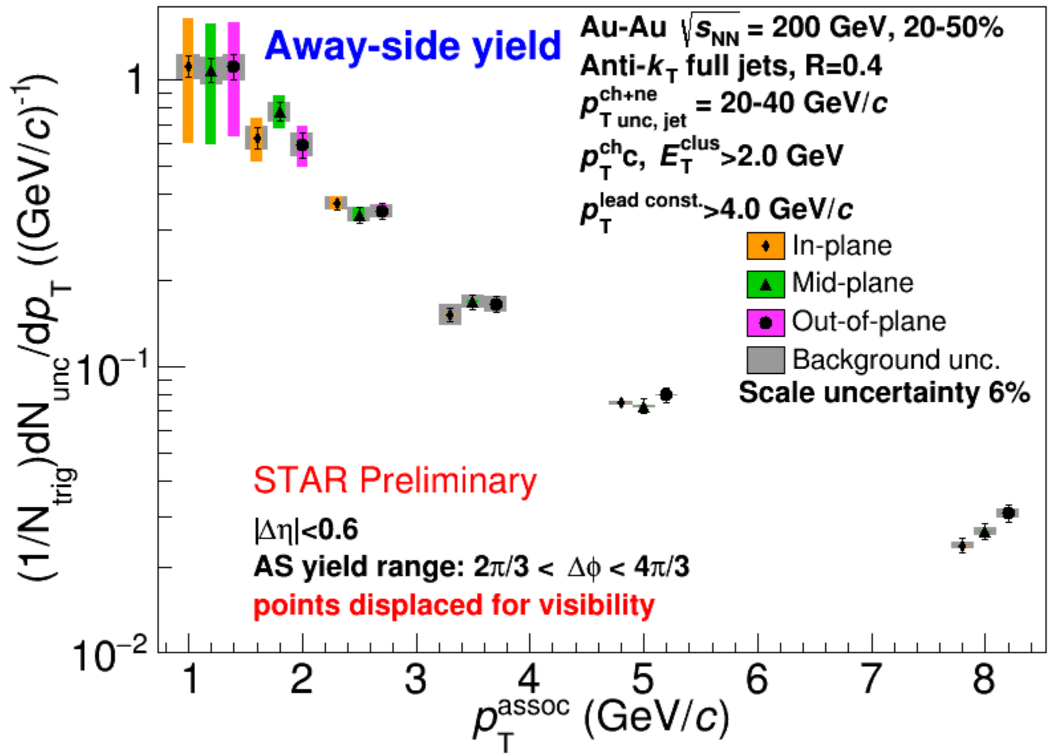
- Path length dependence naively predicted by every model
  - No path length dependence seen in rxn plane dependent A_j either
- Insufficient sensitivity?
- Statistical variation in energy loss is more important than path length dependence
  - J. G. Milhano and K. C. Zapp, "Origins of the di-jet asymmetry in heavy ion collisions," Eur. Phys. J. C76 (2016) no.5, 288
  - F. Senzel, O. Fochler, J. Uphoff, Z. Xu, and C. Greiner, "Influence of multiple in-medium scattering processes on the momentum imbalance of reconstructed di-jets," J. Phys. G42 no. 11, (2015) 115104.

Near-side and away-side yields vs. EP

Single track reconstruction efficiency NOT applied

R=0.4 full Jets 20-40 GeV/*c*, 20-50% centrality





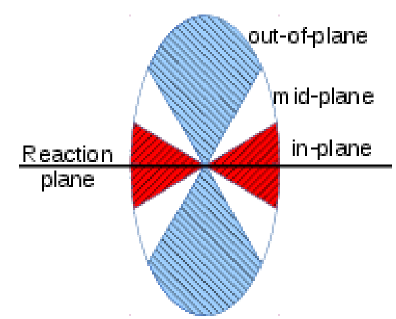
Within uncertainties of current statistics, no event plane ordering

Different effects in different p_T associated bins

Competing effects

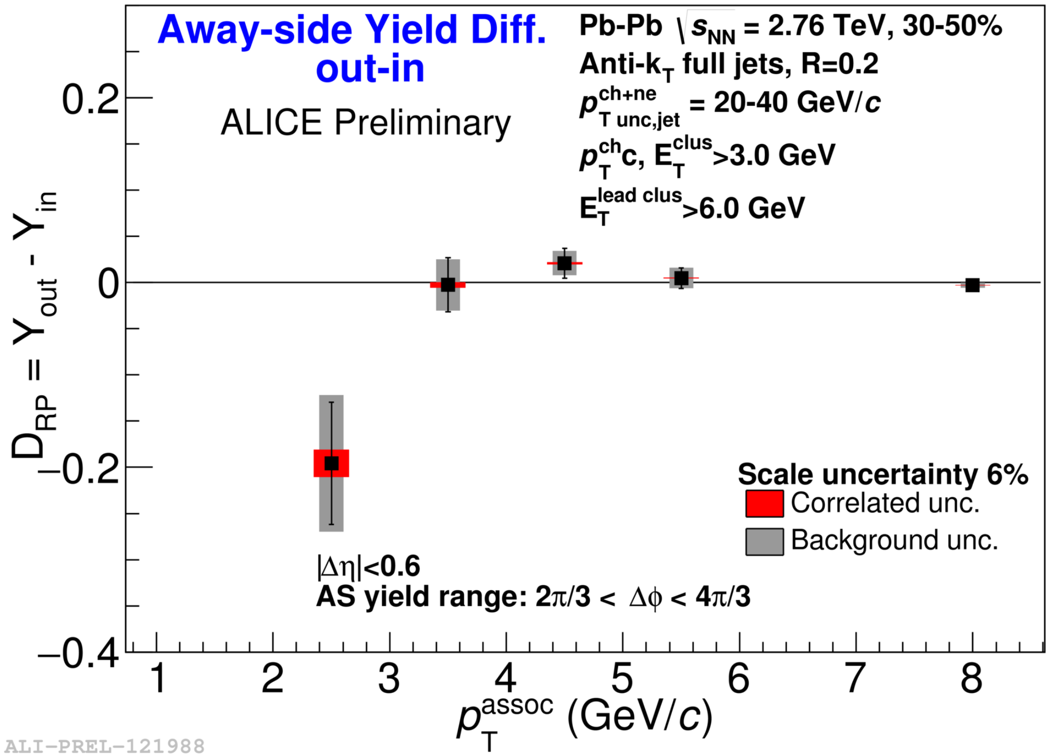
1) Quenching (decrease yield in → out)

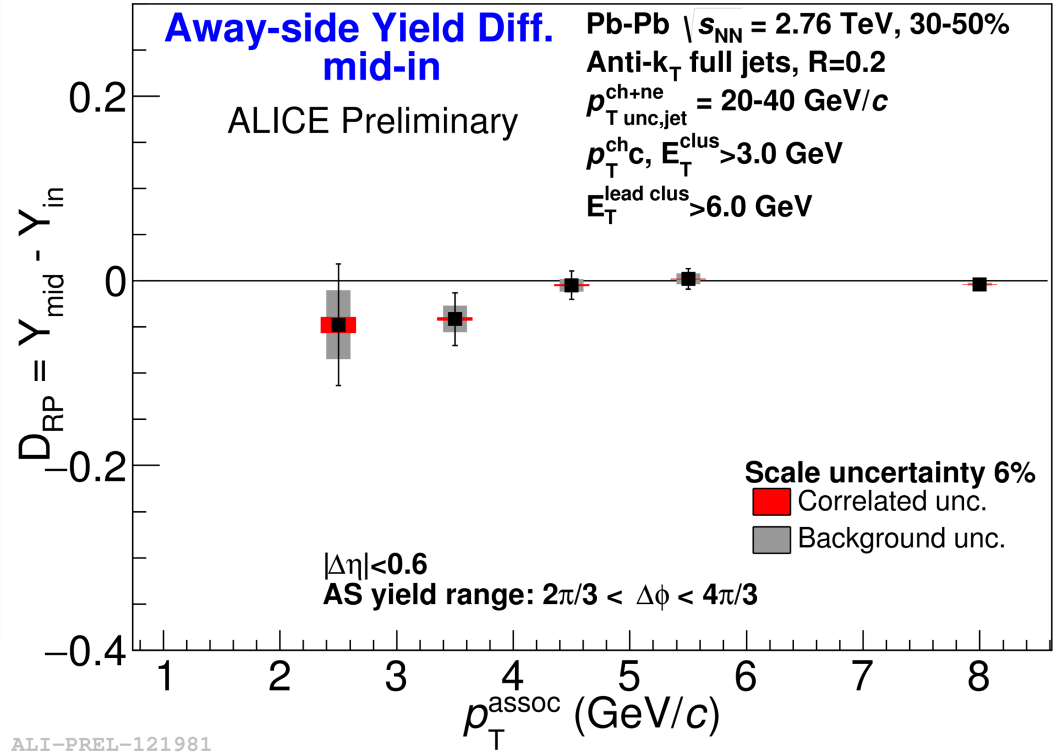
2) Bremsstrahlung (increase yield in → out)



ALICE Away-side yield diff.: 30-50%

$D_{RP} = Y_{out} - Y_{in}$ | $D_{RP} = Y_{out} - Y_{in}$



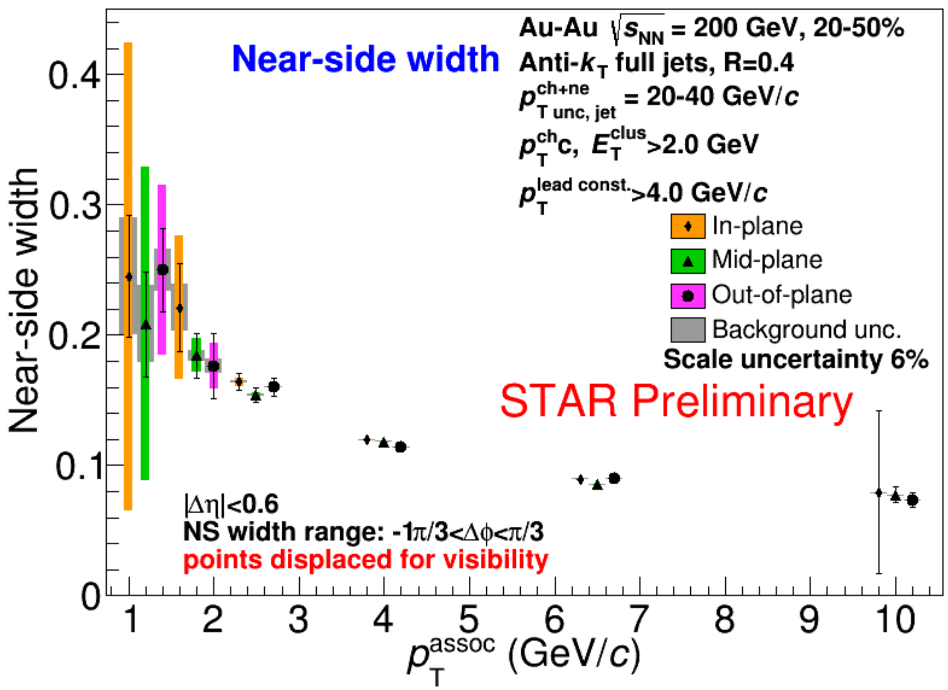


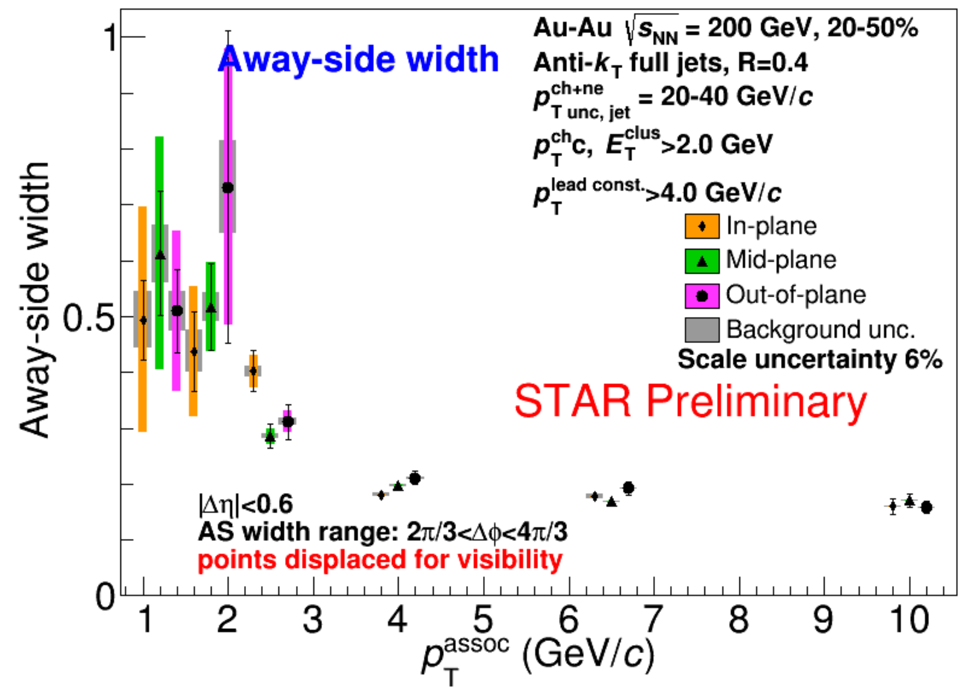
- **Within uncertainties, don't observe significant path-length dependence**
- Indication path-length is a secondary effect

Near-side and away-side widths vs. EP

Single track reconstruction efficiency NOT applied

R=0.4 full Jets 20-40 GeV/*c*, 20-50% centrality



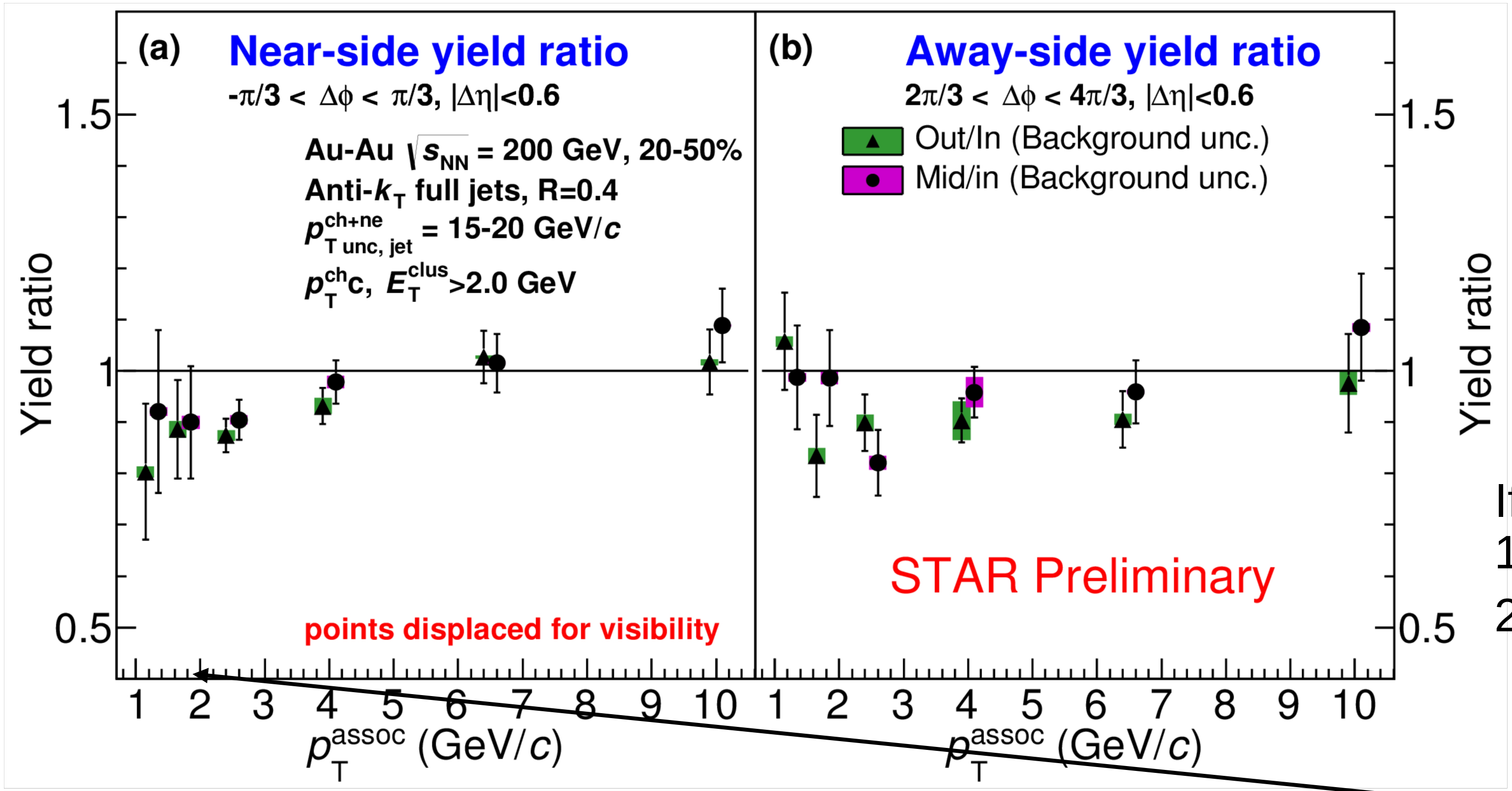


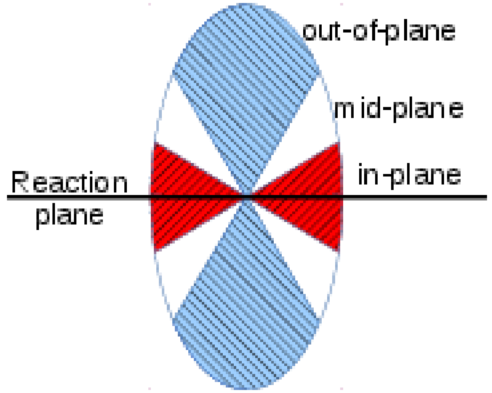
- Large uncertainties at low p_T
- Broadening seen for decreasing associated momenta
  - Expected from either collisional energy loss or gluon bremsstrahlung
  - Path-length dependent energy loss would lead to greater width for jets out-of-plane than in-plane
- No significant path-length dependence of widths seen within uncertainties

Yield ratio

Single track reconstruction efficiency NOT applied

R=0.4 full Jets 15-20 GeV/*c*, 20-50% centrality





If in-plane jets interact less:
1) ratios < 1 at high p_T
2) ratios > 1 at low p_T

constituent cut

- Don't expect much modification on NS
- Dominated by statistical uncertainties
- **Within current uncertainties, don't observe significant path-length dependence**

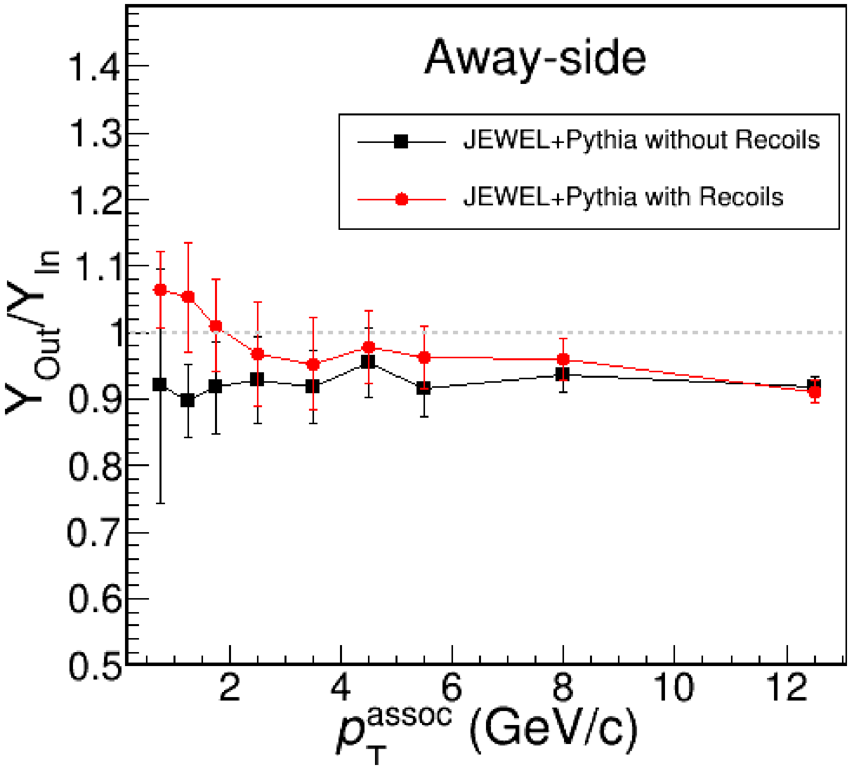
JEWEL comparison at LHC energies

Zapp, Eur. Phys. J. C74 (2014) Issue 2; Zapp, Eur. Phys. J. C60 (2009) 617-632

JEWEL: MC event generator simulating QCD jet evolution in heavy-ion collisions, treating interplay of collisional and radiative energy loss and including LPM interference

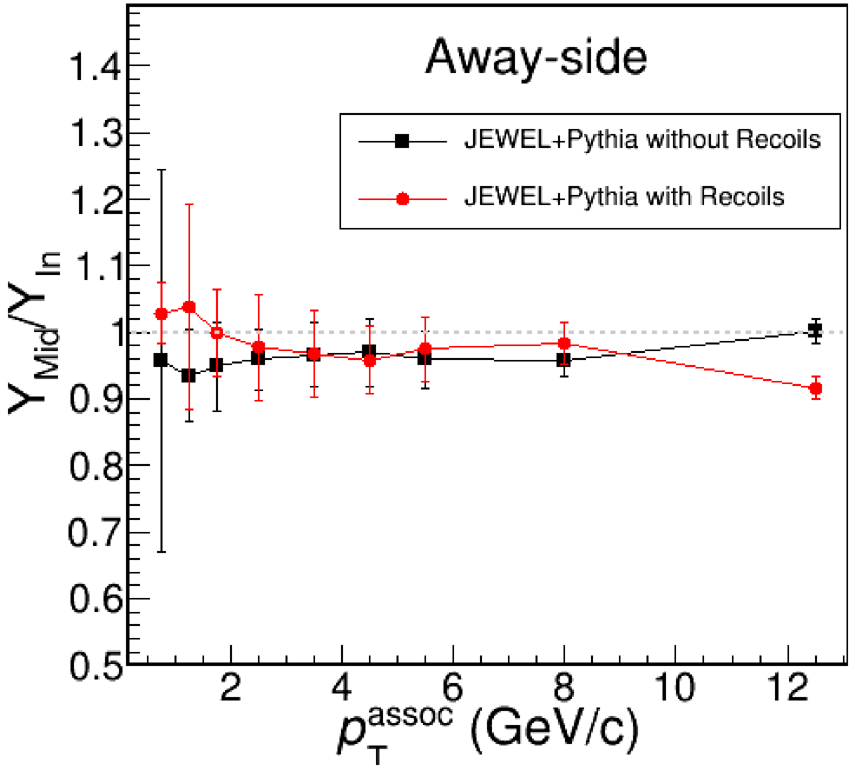
20-40 GeV/*c* full jets - Same cuts as ALICE analysis

$R = Y_{out} / Y_{in}$



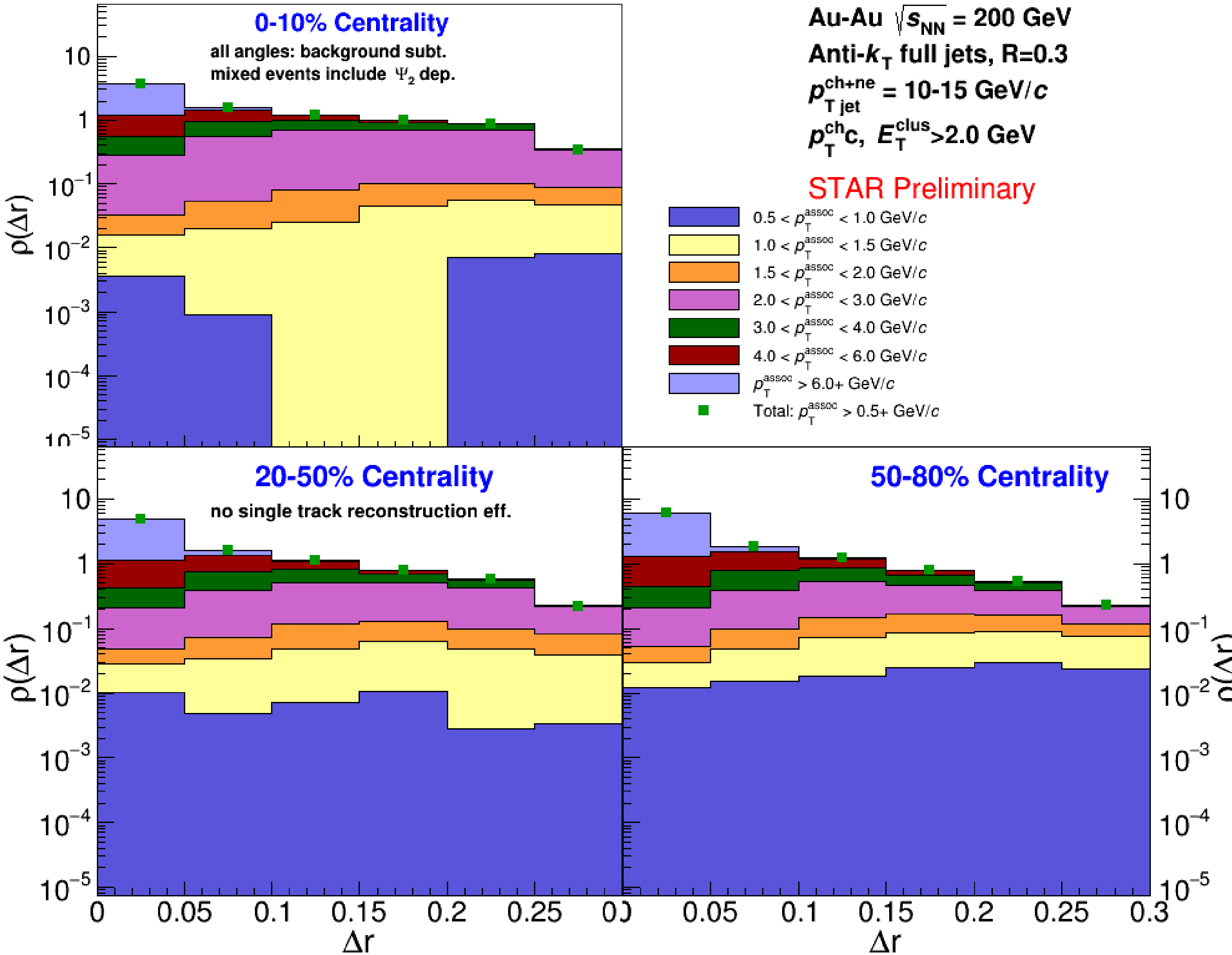
<u>Away-side</u>

$R = Y_{mid} / Y_{in}$



- Similar results seen in JEWEL
- ***Don't observe significant path-length dependence***
- Consistent with insignificant impact of path-length compared to jet-by-jet fluctuations in energy loss or fluctuations in the density of the medium

Decomposing transverse momentum contributions: RHIC



- Leading jets
- R=0.3 full jets
- **10-15 GeV/*c* Jets**
- Jet Constit. 2.0+GeV/*c*

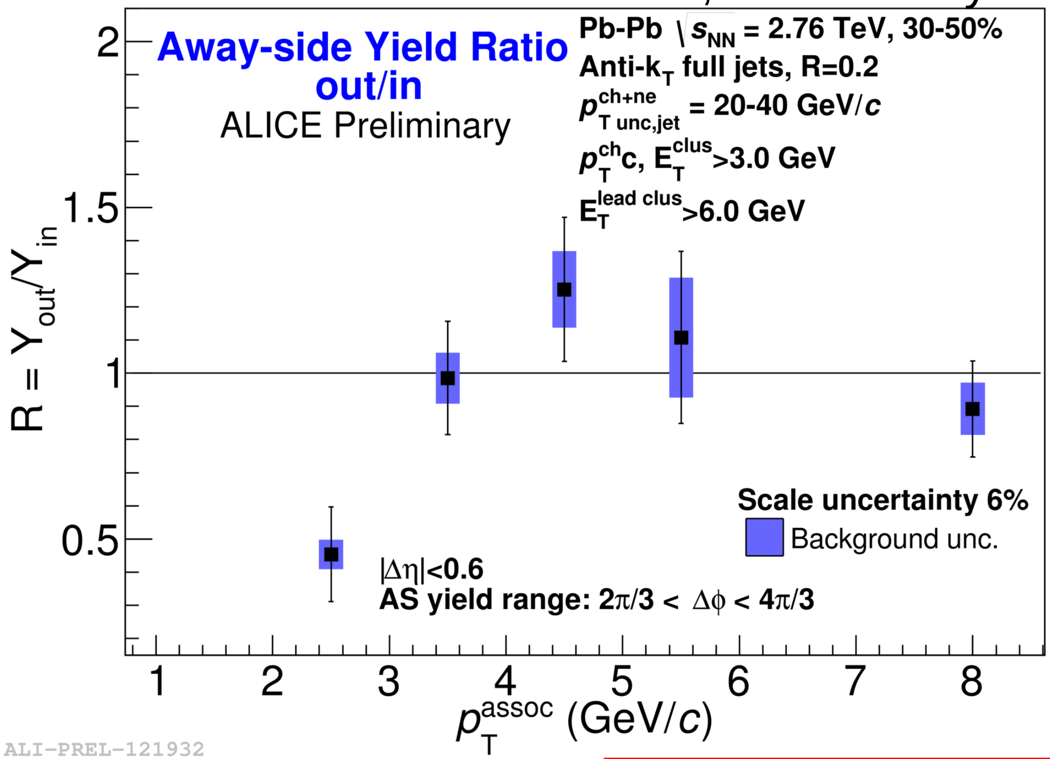
- Jet shape ρ(r): gets broader for more central events
- High p_T tracks closer to jet core (small r)

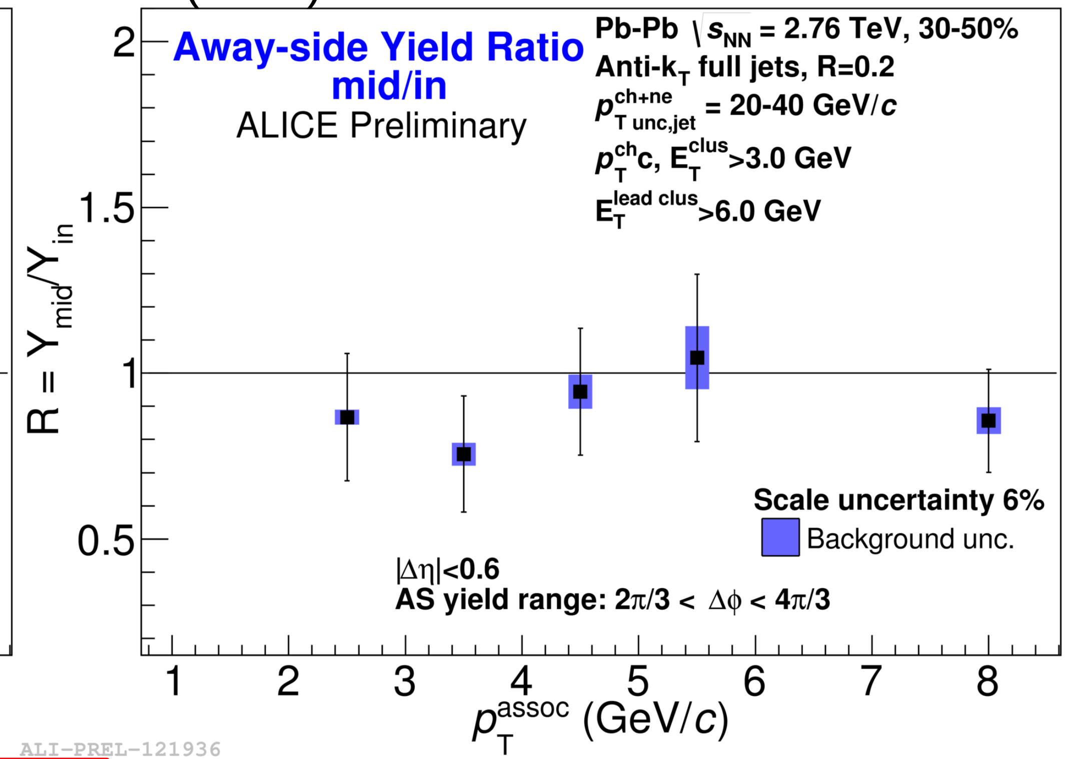
ALICE comparison yield ratio: 30-50%

$R = Y_{out} / Y_{in}$

QM 2017
Mazer, Nuclear Physics A 967 (2017) 500-503

$R = Y_{mid} / Y_{in}$





Anti-k_T R=0.2
full jets: 20-40 GeV/c
tracks/clusters > 3.0 GeV/c
leading cluster bias > 6.0 GeV

- Dominated by statistics
- Similar results to that of STAR with different collision system and energy