Evolution of jet shapes in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV with the STAR experiment at RHIC

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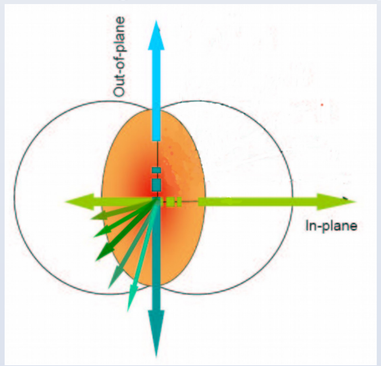
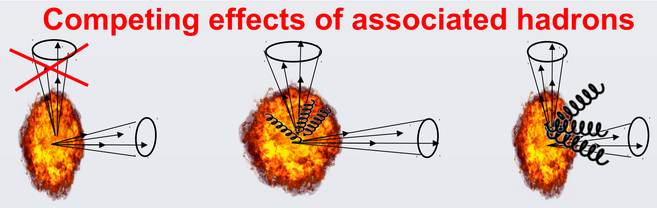
Introduction

- Control **path-length** of jet quenching with centrality and **event plane angle**
- Path-length dependence of medium modifications can be studied by reconstructing jets relative to second-order harmonic event plane. Average path length OUT > average path length IN.



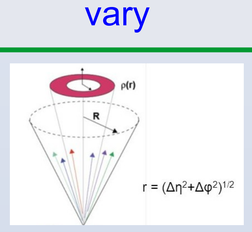
Motivation:

Competing effects of associated hadrons



Equilibration in medium	Bremsstrahlung	Fluctuations
Fewer jets, lower high-p_T yield out of plane	Softer, higher yield out of plane	Individual jets' energy loss may vary

Sensitive probe: differential **jet shape**
- Radial momentum distribution of the constituents
- Discriminate **quenching models**
- Discriminate **quark v. gluon** energy loss [1]



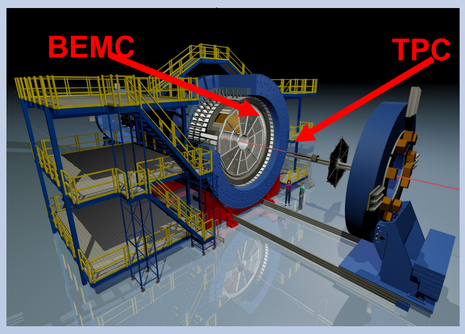
Event selection and jet reconstruction

- Au+Au @ $\sqrt{s_{NN}}$ = 200 GeV, mid-luminosity events, -28 < z_{vtx} < 28 cm
- Anti-k_T jet algorithm with a resolution parameter R=0.4 ([2, 3]):
  - Charged tracks with p_T > 2 GeV/c
  - Hadronically corrected BEMC towers with E_T > 2.0 GeV
- High p_T constituent cut:
  - Selects hard scatters and reduces fluctuations
  - Obviates underlying event background subtraction
- "Leading jet": the most energetic jet in each selected event is analyzed

Detector setup

The Solenoidal Tracker At RHIC (STAR)

- **Time Projection Chamber (TPC)**:
  - $|\eta|$< 1.0, 0<φ<2π
  - Tracking, momentum, dE/dx
- **Barrel Electromagnetic Calorimeter (BEMC)**:
  lead-scintillator sampling calorimeter
  - $|\eta|$< 1.0, 0<φ<2π
  - Resolution: 0.05x0.05
  - Study high p_T processes, triggering



Remove contribution from charged particles

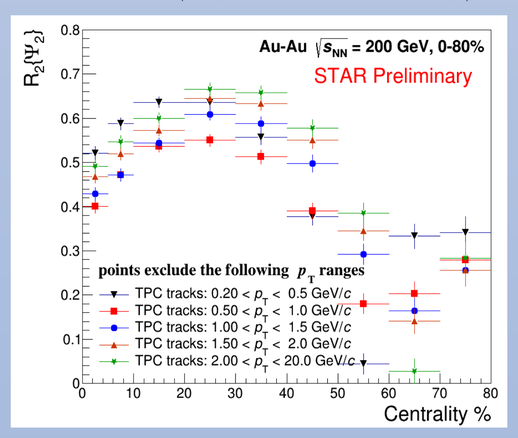
Charged constituent + Neutral constituent = **Full jet**

- High-tower trigger (at least one BEMC tower with E_T > 5.4 GeV) selects jetty events

Event plane reconstruction

- Reconstructed with charged tracks excluding p_T^{assoc} ranges from 2 randomized sub-events (expected to be similar estimates of the event plane)
- Similar procedure as [4] - Modified Reaction Plane (MRP) method
  - ➢Improvement over traditional TPC and BBC methods
- Event plane resolution:

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



Trigger jets labeled by following conditions:

in-plane: $0 < |\Phi_{jet} - \psi_{EP,2}| < \pi/6$

mid-plane: $\pi/6 < |\Phi_{jet} - \psi_{EP,2}| < \pi/3$

out-of-plane: $\pi/3 < |\Phi_{jet} - \psi_{EP,2}| < \pi/2$

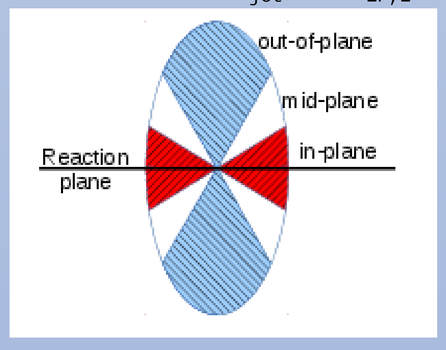


Fig. 1: **Left**: Event plane resolutions, shown for p_T^{assoc} ranges, for the 2nd-order event plane. **Right**: Cartoon depiction of in-, mid-, and out-of-plane regions relative to the event plane [5].

- Highest event plane resolution in 20-50% central region
  - ➢Gives maximal path length, on average, between in-plane and out-of-plane due to the initial collision geometry

Jet shape function, ρ(Δr)

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

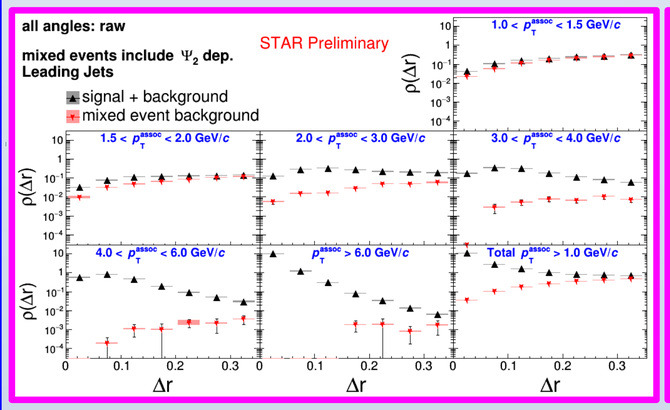
- Radial annulus size: $\Delta r = \sqrt{[(\eta_{trk} - \eta_{jet})^2 + (\Phi_{trk} - \Phi_{jet})^2]}$
- Inner and outer radius: $r_a = r - \delta r/2$, $r_b = r + \delta r/2$
- Transverse momentum of track and jet: p_T^{trk}, p_T^{jet}
- Normalization of trigger jets, annulus size: N_{jets}, δr

Background subtraction

- Uses mixed minimum bias (MB) events matched in centrality, event plane, z-vertex

Results

Fig. 2: **Left**: Signal+background and mixed event background differential (leading) jet shape distributions for the 20-50% most central events. **Right**: Background subtracted differential (leading) jet shape as a function of Δr. Shown are 20-40 GeV/c, R=0.4 full jets at all inclusive angles.



- The differential jet shape at low-p_T^{assoc} (1.0-2.0 GeV/c) is dominated by background particles
- With increased associated transverse momenta, the jet shape changes from a relatively flat distribution across Δr to a sharply falling distribution at high-p_T

Event plane dependent differential jet shapes

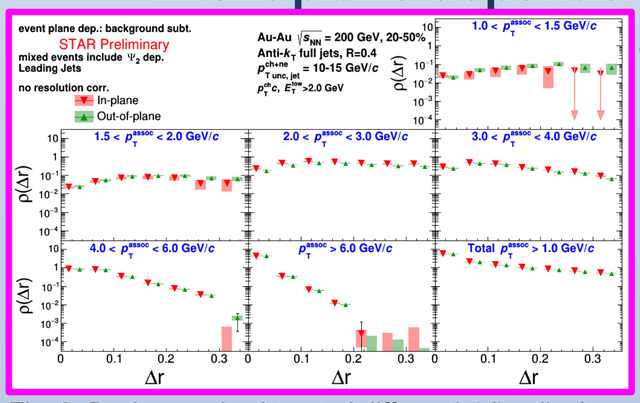


Fig. 3: Background subtracted differential (leading) jet shape as a function of Δr and compared for in- and out-of-plane jets from the 20-50% most central events.

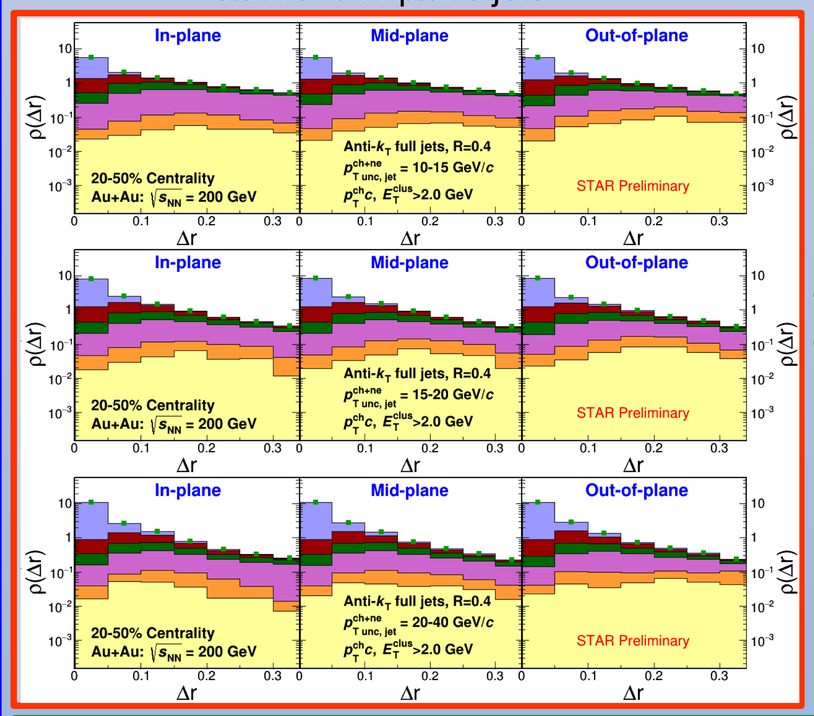
- More low-p_T associated hadrons at large Δr for out-of-plane jets relative to in-plane jets

Unfolding methods on data

Unfold event plane dependent results to correct for available event plane resolution. Uses a response matrix generated from data along with RooUnfolds' Iterative Bayes Method [6,7].
- Unfold N_{jets} in 3 regions: in/mid/out
- Unfold in Δr bins separately
- Re-normalize by unfolded N_{jets} distributions

Smearing function: $\frac{dN}{d\phi_S} \approx \left(1 \frac{+v_{2,jet}}{R}\cos\left(2\phi_S\right)\right)$

- Φ_s: separation angle between trigger particles and event plane
- R: event plane resolution



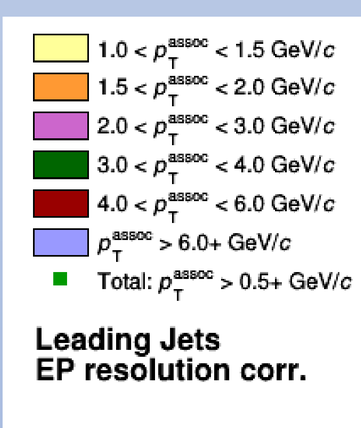


Fig. 4: Differential (leading) jet shape stacks corrected for event-plane resolution as a function of Δr and compared for in-, mid-, and out-of-plane jets for the 20-50% most central events for 3 different jet momentum regions. **Top**: 10-15 GeV/c, **Middle**: 15-20 GeV/c, **Bottom**: 20-40 GeV/c

Summary

- Low-p_T (1.0-2.0 GeV/c) associated hadrons are dominated by background at Δr > 0.1
- High-p_T hadrons are located closer to jet core
- Below 2 GeV/c: event plane ordering: out > mid > in-plane
  - out-of-plane jets have more low-p_T hadrons than in-plane jets
- Above 2 GeV/c: in-, mid-, and out-of-plane jet shape results are consistent with each other
- Jets with higher momentum are more collimated

Outlook

- Radial scan comparing the differential jet shape for various jet size, R
- Comparison of leading jet shape to that of inclusive and sub-leading jets
- Comparison of different centrality jet shapes to that of the baseline pp dataset at √s = 200 GeV

References

[1] CMS, JHEP **05** (2018) 006.
[2] M. Cacciari, G. P. Salam and G. Soyez, Eur. Phys. J. **C72** (2012) 1896.
[3] M. Cacciari, G. P. Salam, and G. Soyez, JHEP **0804** (2008) 063.
[4] STAR and STAR-RICH, Phys. Rev. C. **72** (2005) 014904.
[5] N. Sharma, J. Mazer, M. Stuart, C. Nattrass, Phys. Rev. C. **93**, (2016) 044915.
[6] The RooUnfold package and documentation are available from: http://hepunx.rl.ac.uk/~adye/software/unfold/RooUnfold.html

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