Division of Nuclear Physics 2024

Probing the Path-Length Dependence of Jet Energy Loss in $\sqrt{s_{NN}} = 200$ GeV/c^2 Au-Au Collisions

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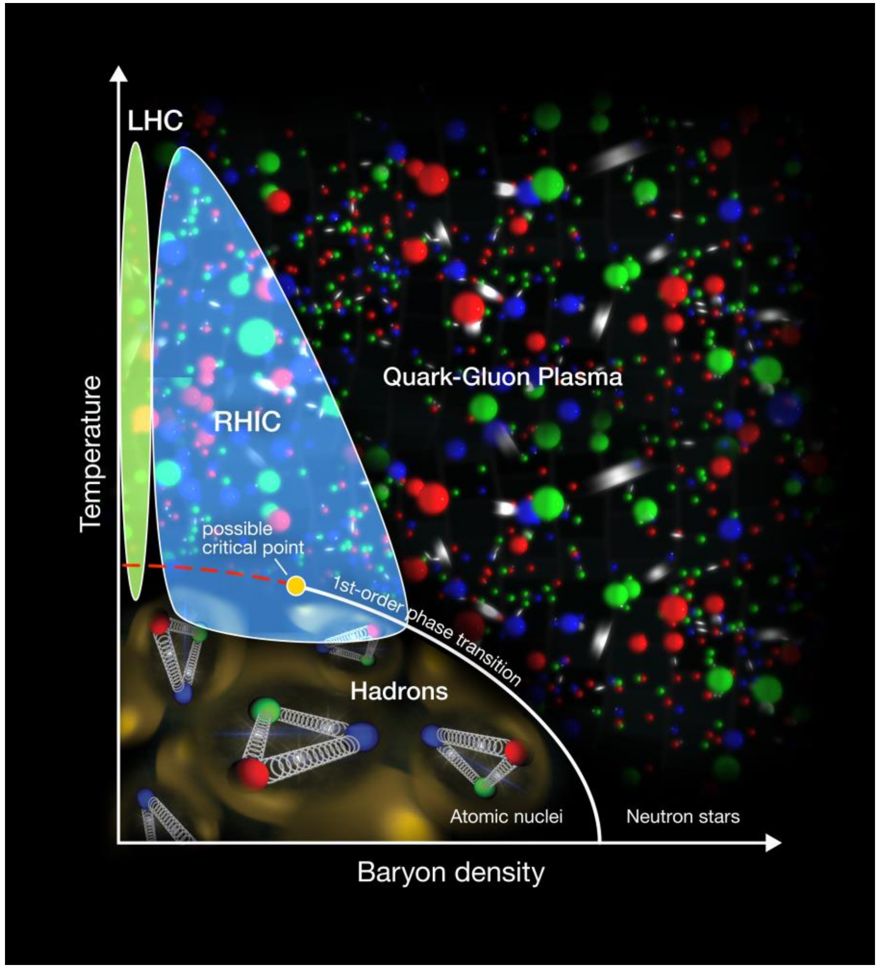
Quark-Gluon Plasma (QGP)

Soup of **deconfined strongly interacting quarks and gluons** that gives rise to a liquid-like matter with the **lowest specific shear viscosity** (η/s) known to man

Forms **~1 fm/c** after a collision surpassing a **critical temperature** T_C ~155 MeV (~2 trillion °C)

Lifetime of **~10 fm/c** (10^{-23} seconds)

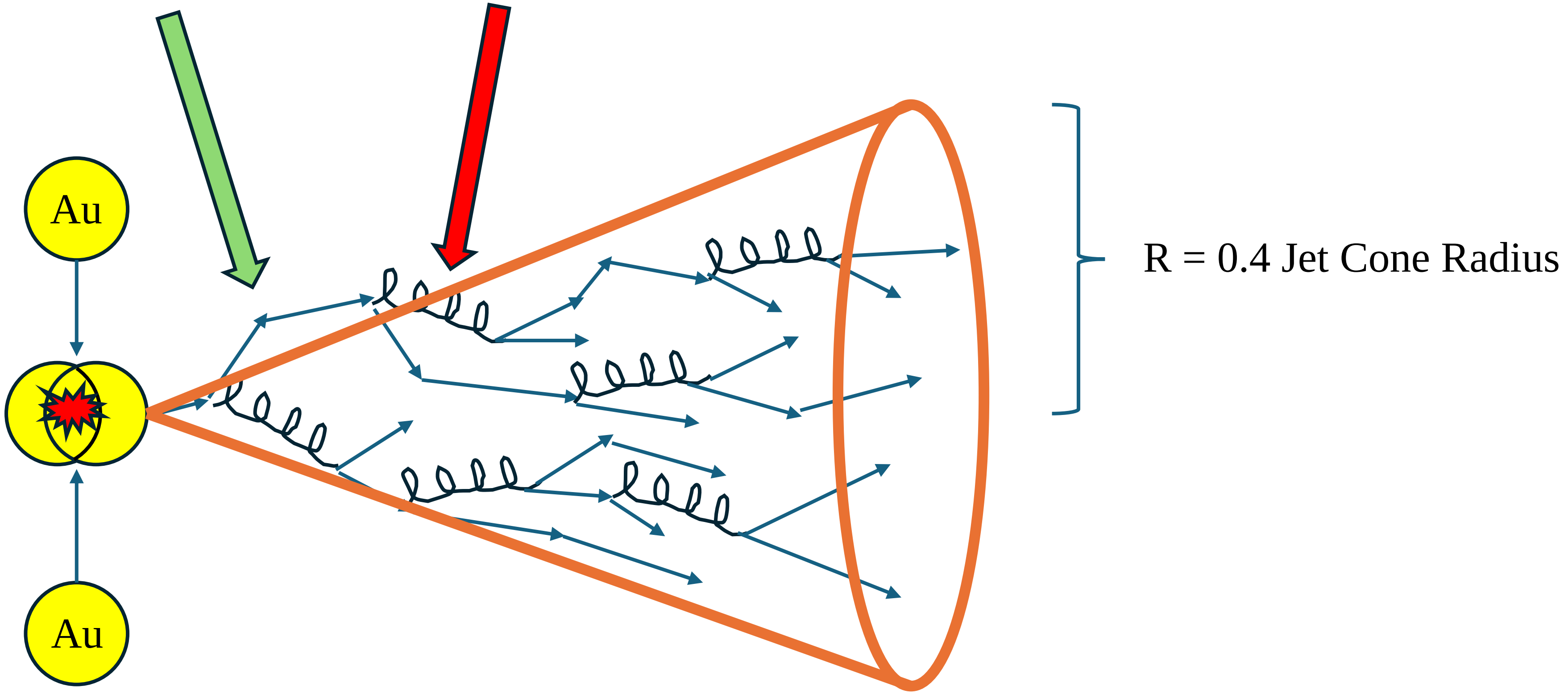


Jets in the QGP

Jets are **collimated streams** of highly energetic particles

Serve as a **proxy for the initial hard quark or gluon** kinematics

Undergo **collisional** & **radiative** energy loss within the medium



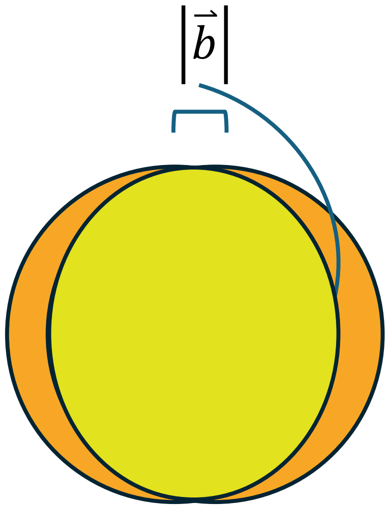
Interaction Region Geometry

Centrality is a quantifier of the impact parameter between two colliding nuclei (how “head-on” an event is)

For this analysis: 0% (most central) … 80% (most peripheral)

0-20% Centrality

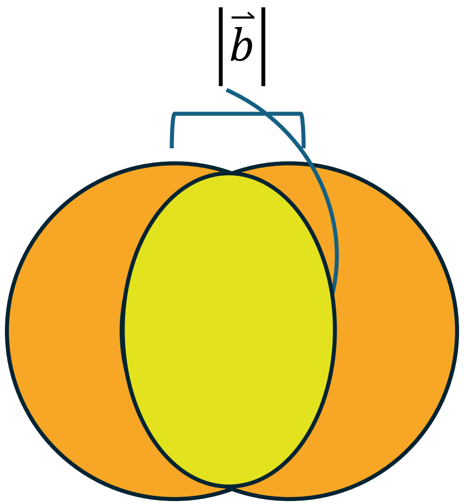
Central Collision



Beam Axis $\hat{z}$ in ⊗

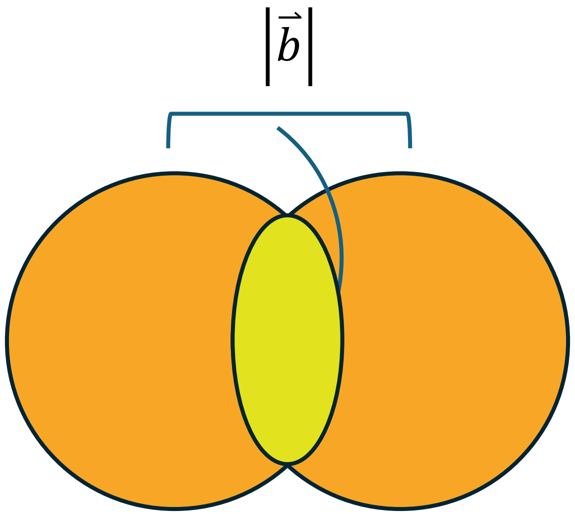
20-60% Centrality

Mid-Central Collision



60-80% Centrality

Peripheral Collision



The STAR Experiment: Solenoidal Tracker at RHIC

Time Projection Chamber (TPC)

Acceptance

$0 < \phi < 2\pi$

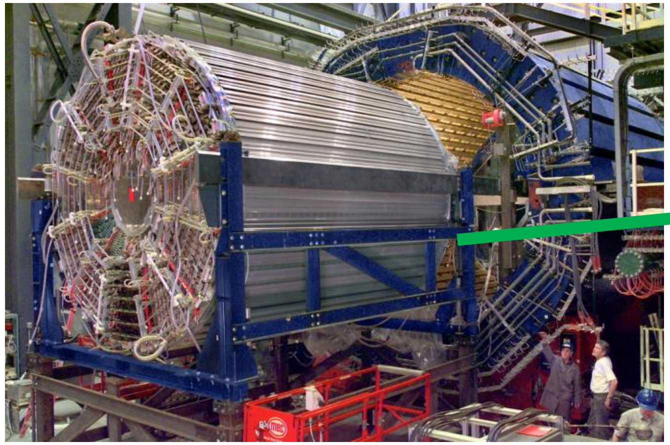
$-1 < \eta < 1$

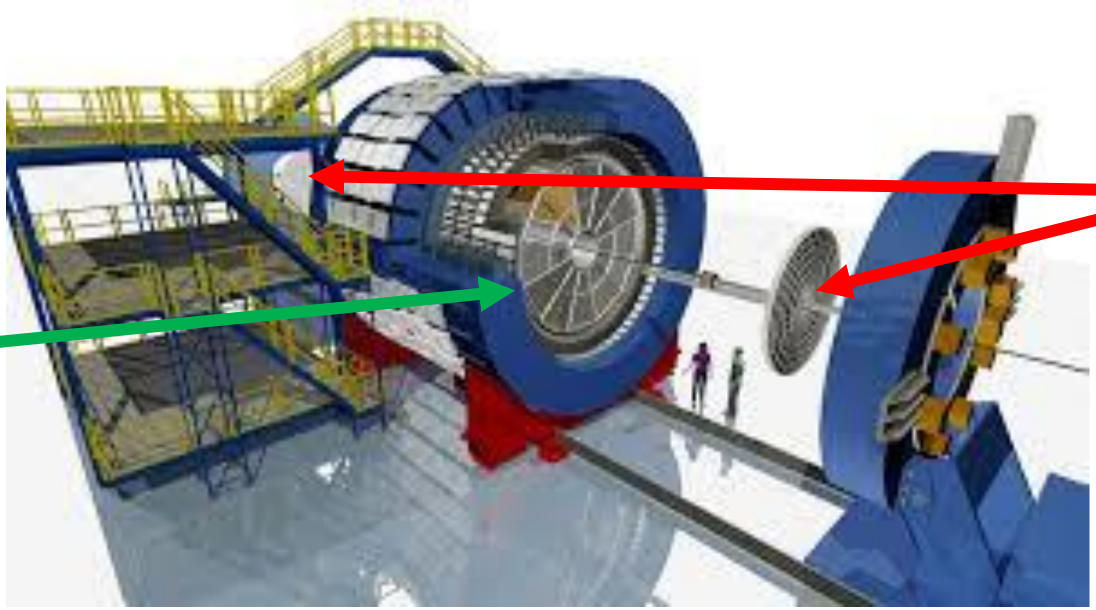
Event Plane Detector (EPD)

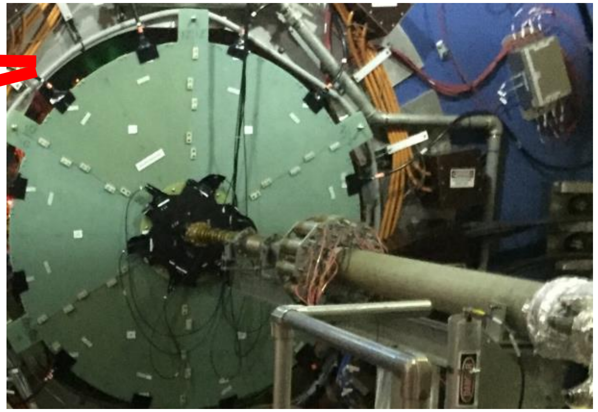
Acceptance

$0 < \phi < 2\pi$

$2.14 < \eta < 5.09$







Detects tracks of charged particles

Used to measure **charged track p_T spectra** for clustering into jets

Detects the azimuthal distribution of final state charged particles

Used to determine **initial collision geometry**

Analysis Specifications

Jets

- ✓ R = 0.4 jet radius
- ✓ Charged, primary tracks
- ✓ Clustered with the FastJet anti-k_T algorithm
- ✓ ρ-subtraction applied to background
- ✓ Jets have one p_T > 2 GeV/c track
- ✓ $|\eta_{jet}| < 0.6$

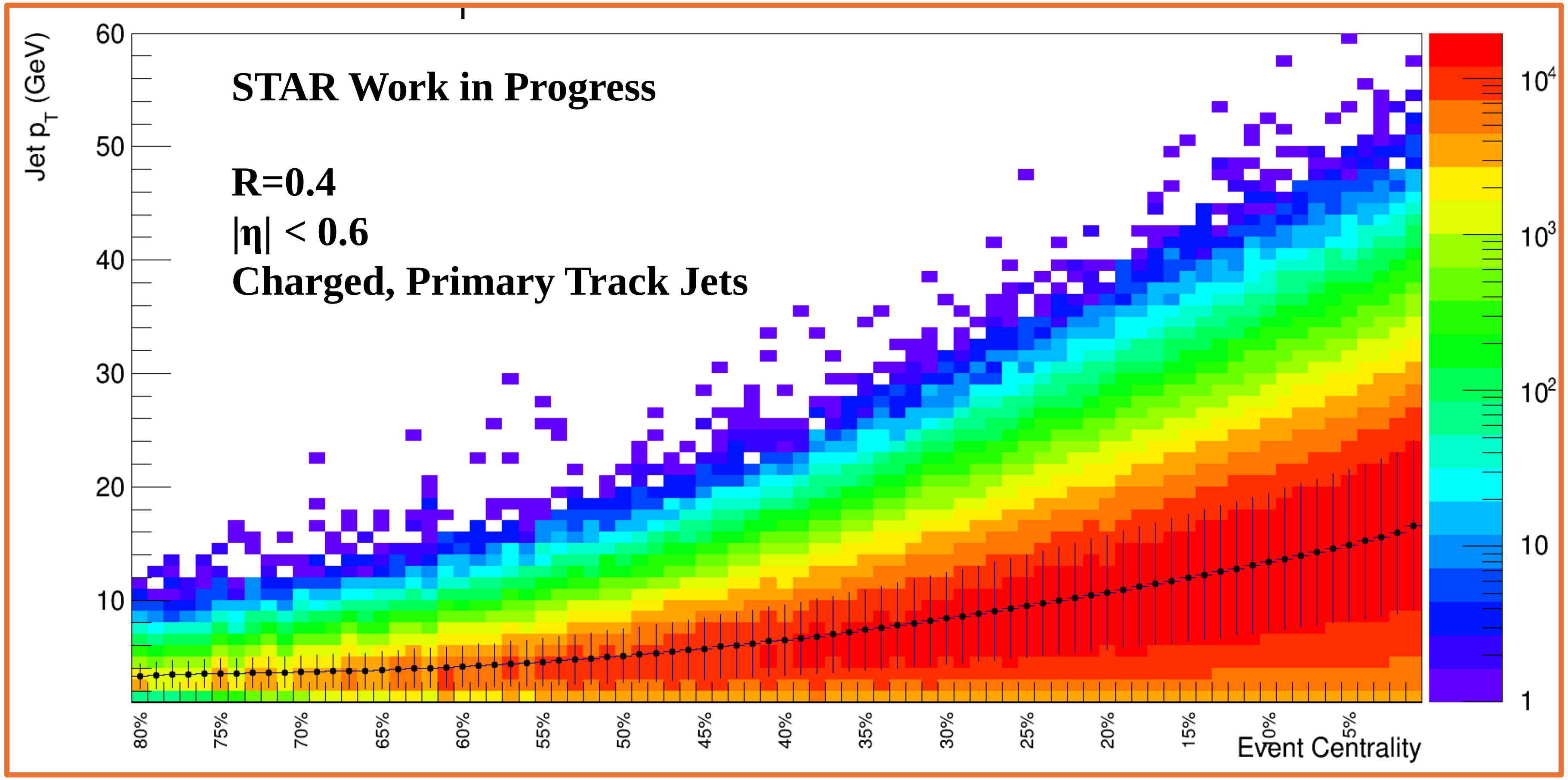
Events

- ✓ 4.76 million events
- ✓ $\sqrt{s_{NN}} = 200$ GeV/c^2 Center of Mass Energy
- ✓ Minimum Bias Trigger
- ✓ z-Vertex Cut: $-30 < v_z < 20$ cm

Jet p_T Dependence on Centrality

More energy available in the QGP medium as the centrality of the collision **increases**

Due to **more nucleon-nucleon collisions** occurring in the overlap region & increased **soft collision contribution**



Quantifying Ellipticity

2nd Order Reduced Flow Harmonic Vector: $\mathbf{q_2}$

$$q_2 = \frac{1}{\sqrt{M}}\left|\sum_{i=1}^{M}\cos(2\varphi_i), \sum_{i=1}^{M}\sin(2\varphi_i)\right| = \frac{1}{\sqrt{M}}\left|\sum_{i=1}^{M} e^{2i\varphi_i}\right| = \frac{1}{\sqrt{M}}|\boldsymbol{Q_2}|$$

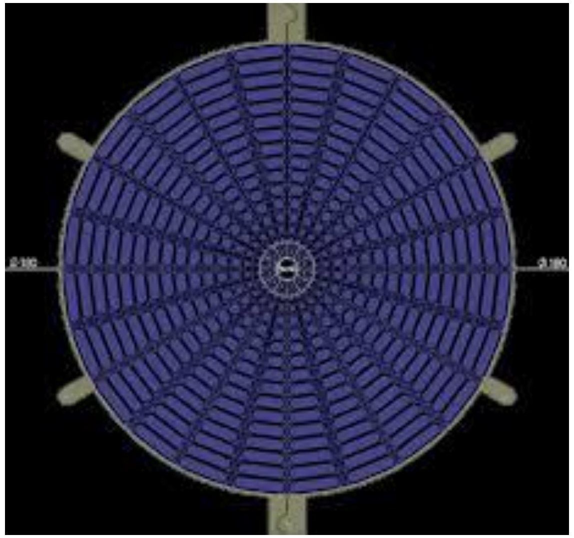
M: Charged Particle Multiplicity of Event

φ_i: Azimuthal Angle of ith particle

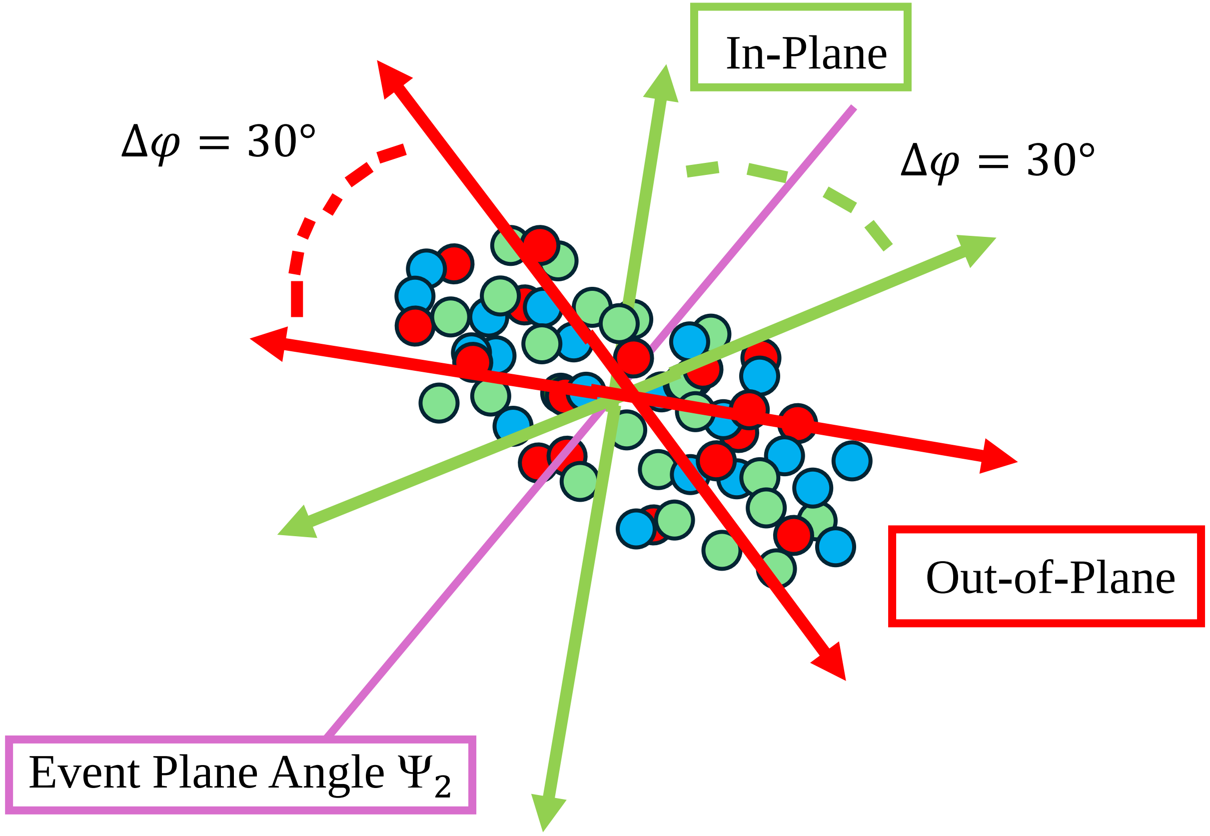
A perfectly azimuthally symmetric event has $\mathbf{q_2 = 0}$

q_2 **increases with more elliptically** shaped events

Measured with the West Event Plane Detector



Defining Regions About the Event Plane



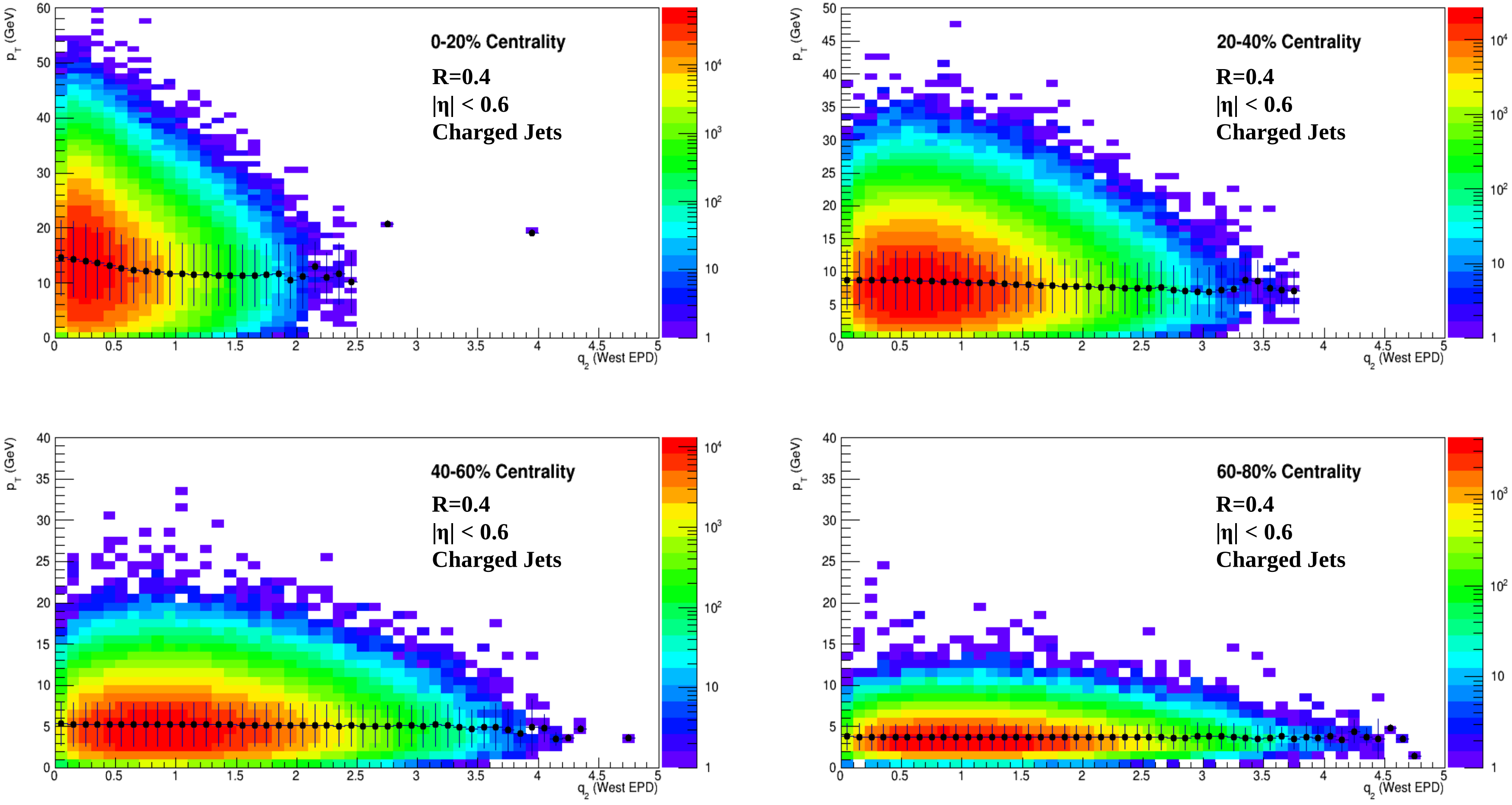
Event Plane approximates, at the detector level, the **reaction plane**: Plane spanned by the beam axis vector $\hat{\boldsymbol{z}}$ and the impact parameter vector $\widehat{\boldsymbol{b}}$

In-plane jets will traverse the **minor axis** of the QGP ellipsoid created in mid-peripheral collisions

Out-of-plane jets will traverse the **major axis**, encountering more QGP

Event Shape Engineering

STAR Work in Progress



Central Events

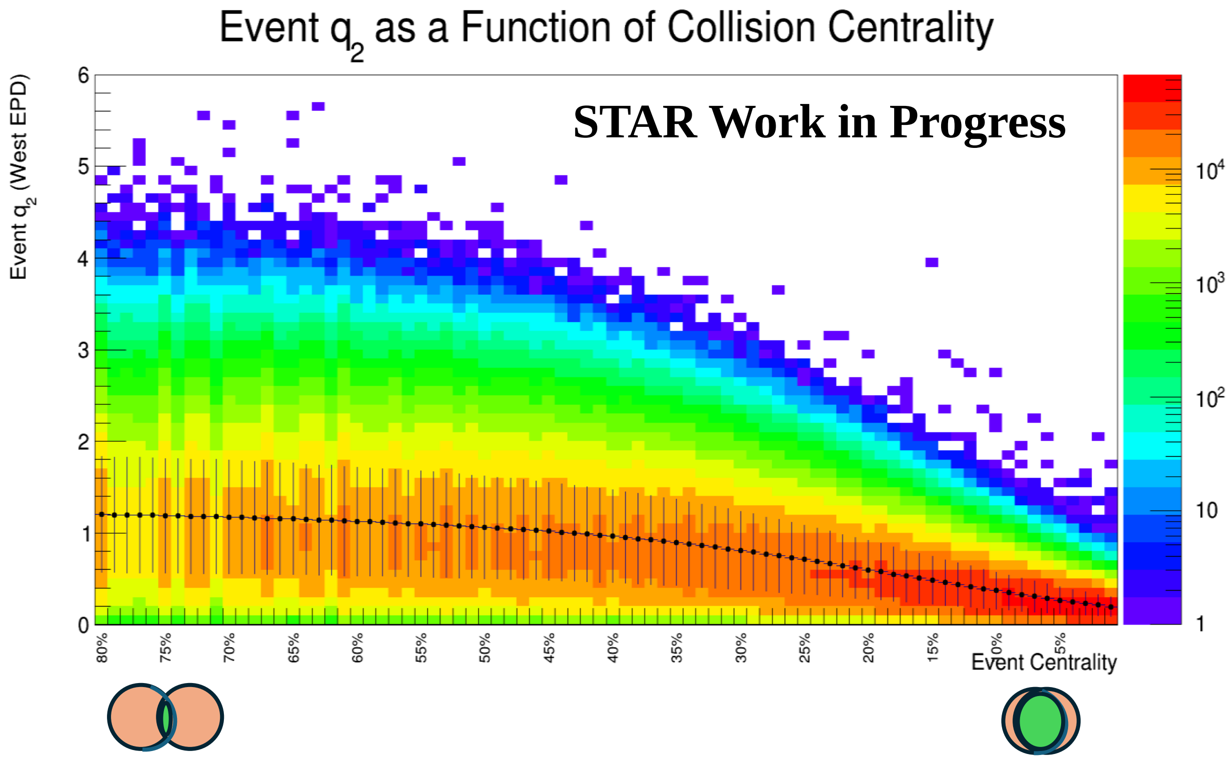
- ➢ Cause increased medium temperature, leading to more energy clustered in jets
- ➢ Limited q_2 range, low ellipticity

Peripheral Events

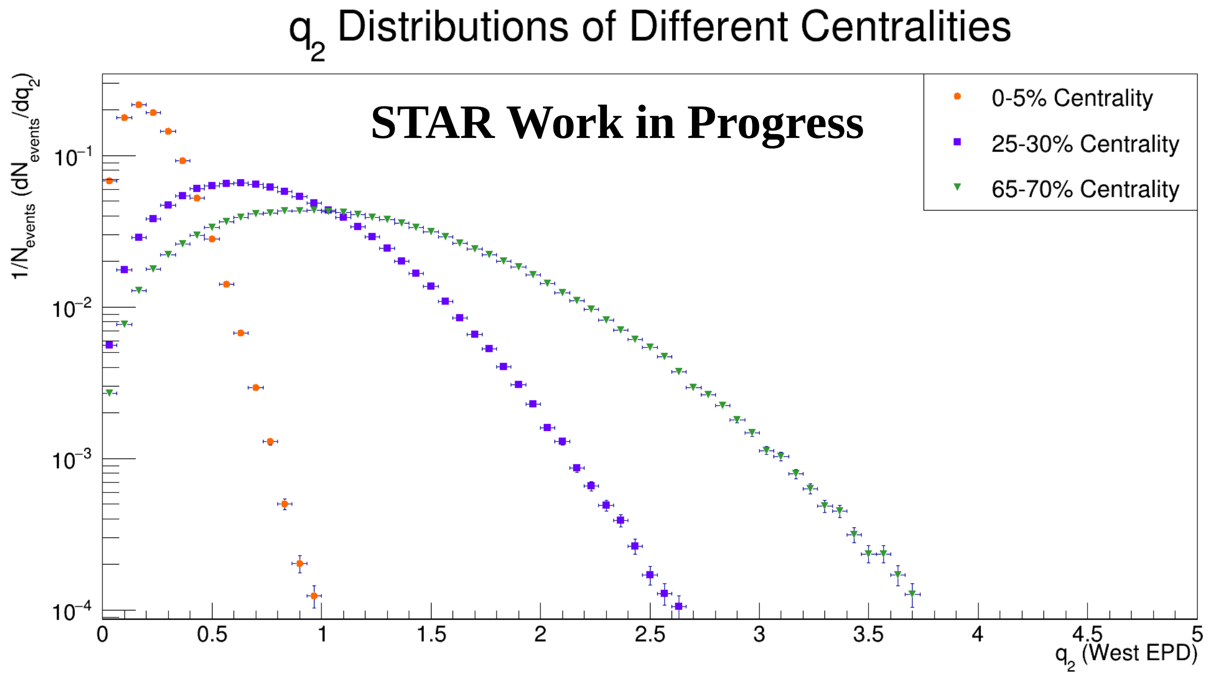
- ➢ Less energy clustered into jets
- ➢ Experience higher ellipticity

Allows for the **selection** of event geometry in centrality/ellipticity bins

q_2 Distributions by Centrality Class



Monotonic decrease in q_2 range with increasing event centrality



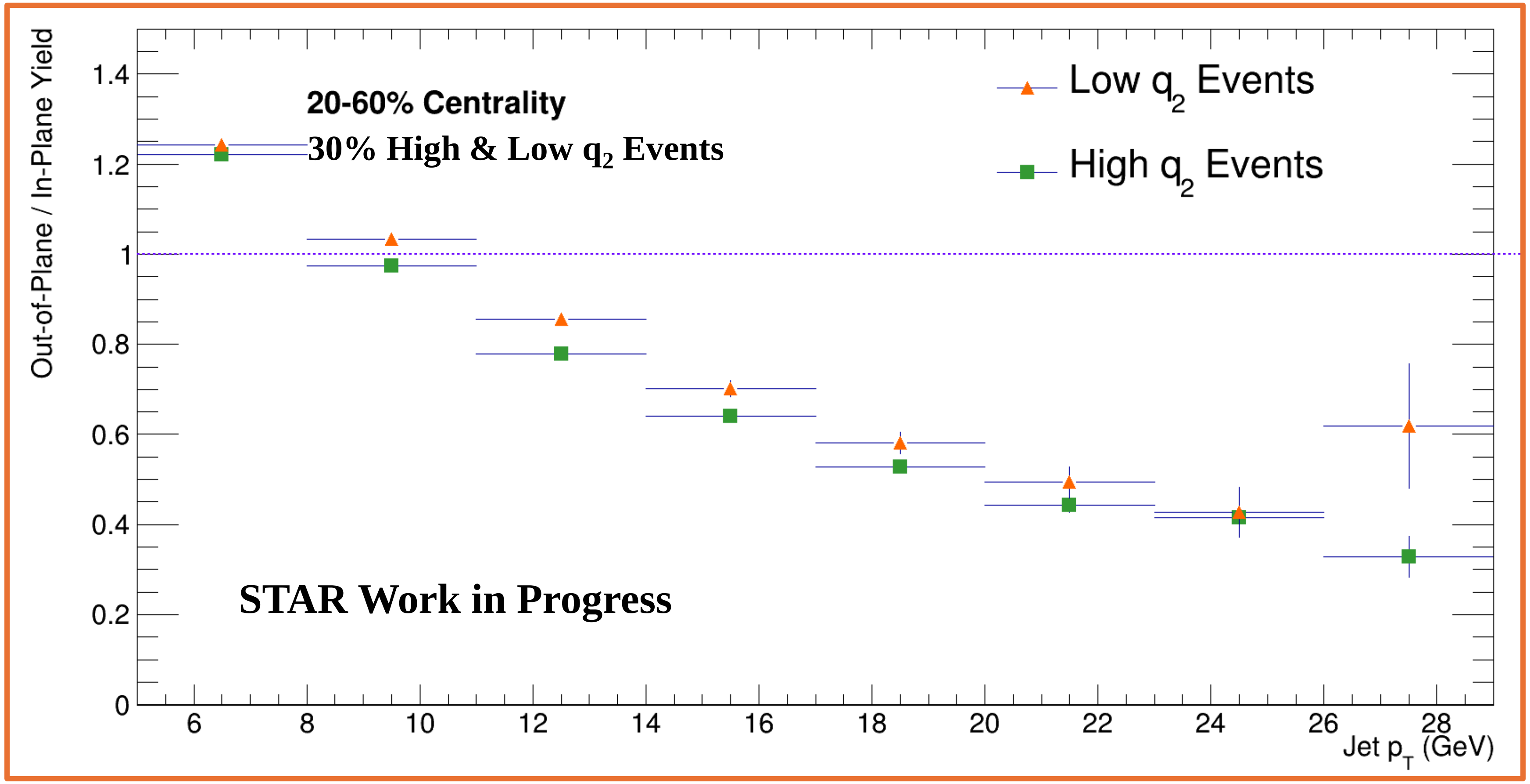
Peripheral events exhibit **highest ellipticity** of the shape of the particle distribution evolution

Central events are consistently **radially symmetric**

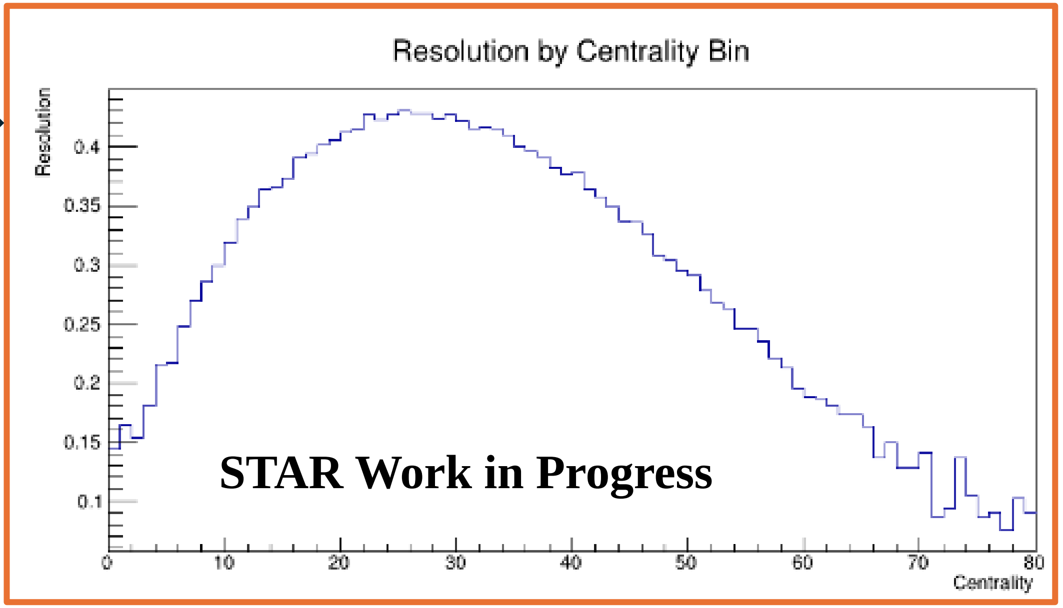
In vs. Out of Plane Suppression

Suppression of in-plane jets is evident (ratio < 1)

High q_2 events experience a slightly more enhanced suppression of jet yield in-plane



Event Plane Resolution Corrections



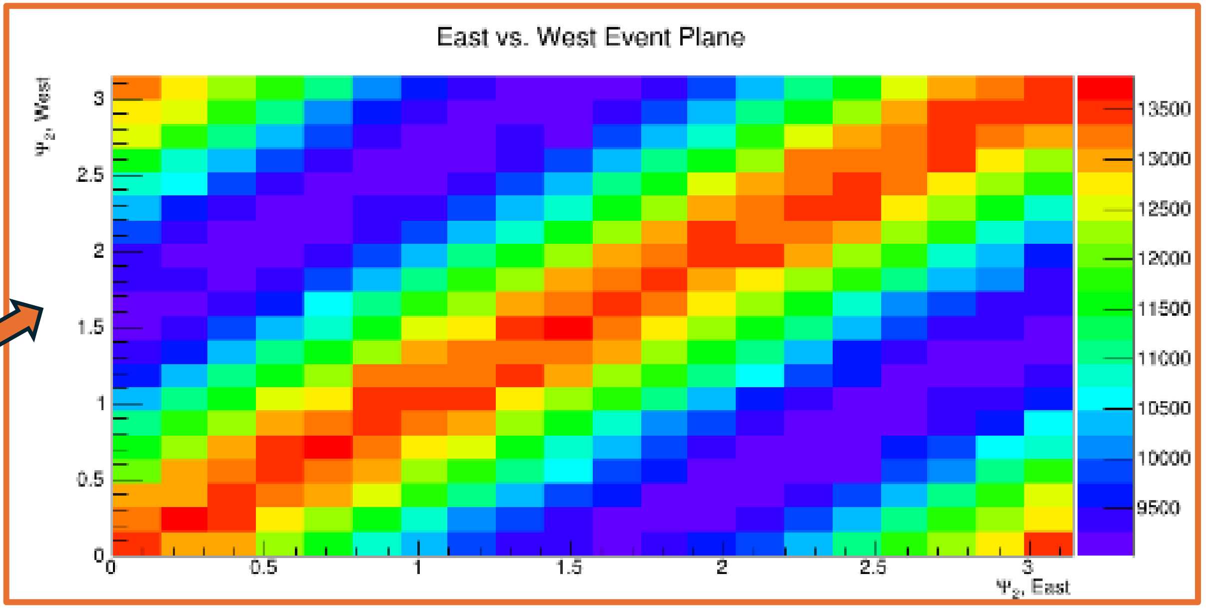
$$EP_{Resolution} = \langle \cos(2(\Psi_2^a - \Psi_R)) \rangle$$

$$= \sqrt{\langle \cos(2(\Psi_2^{East\ EPD} - \Psi_2^{West\ EPD})) \rangle}$$

Poskanzer & Voloshin, 1998

Highest event plane resolution measured between **20-30%** collision centrality. Beyond **25% centrality**, resolution decreases

Clear relationship between the event planes measured by the West and East EP Detectors on an event-by-event basis



STAR Work in Progress

Summary / Conclusion

Event-Shape Engineering can be utilized to study pathlength dependent jet quenching in STAR

A **suppression** of in-plane jet yield is observed over the measured jet p_T range

Future Endeavors:

Event plane **resolutions** must be applied to the observables

Study the event plane's resolution dependence on **q_2 resolution**

Jet p_T spectra must be **unfolded** to account for detector effects