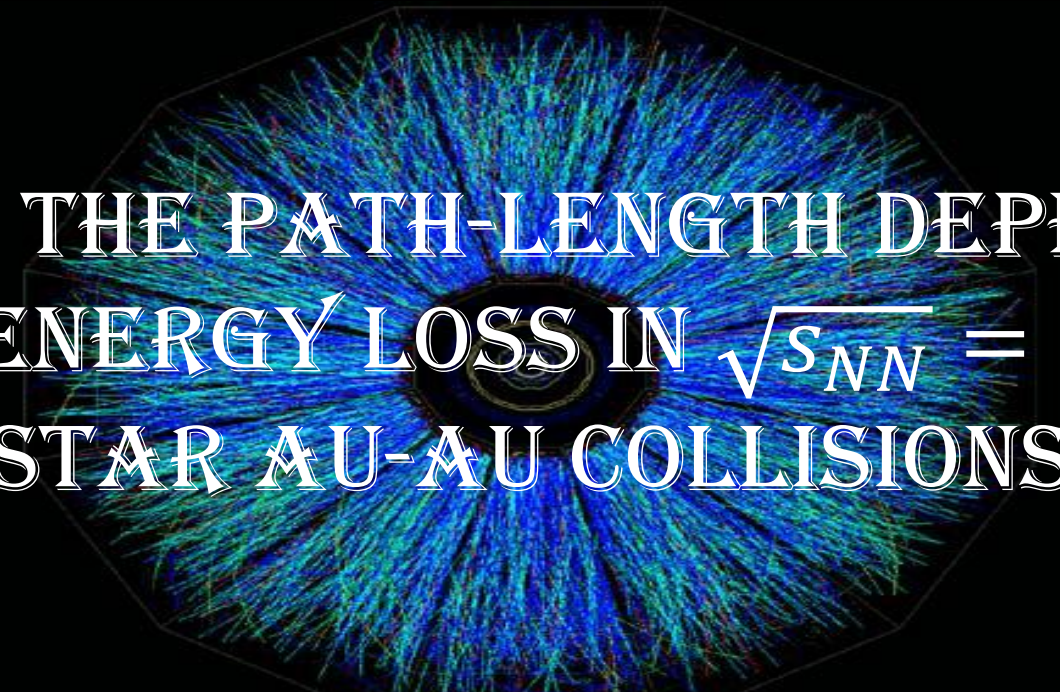
Yale

Wright Lab

DIVISION OF NUCLEAR PHYSICS OCT. 10, 2024



PROBING THE PATH-LENGTH DEPENDENCE OF JET ENERGY LOSS IN $\sqrt{s_{NN}} = 200$ GeV STAR AU-AU COLLISIONS

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ON BEHALF OF THE STAR COLLABORATION

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Supported in Part By:

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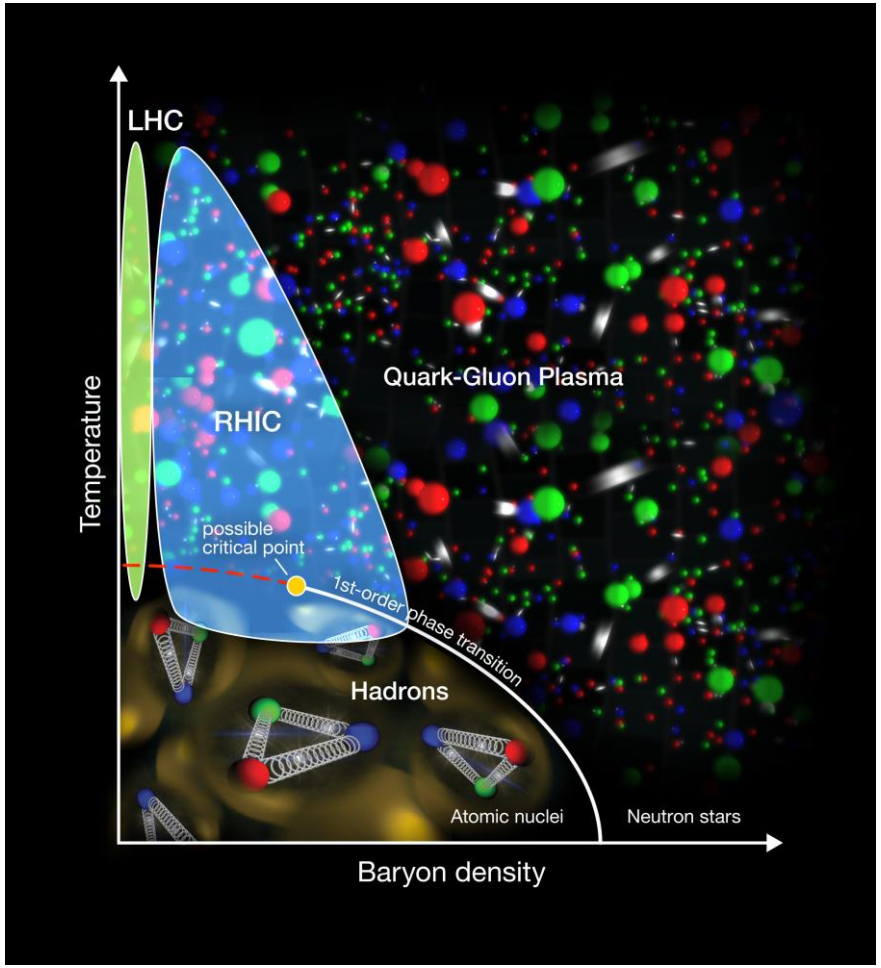
LEHIGH

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) in nature

Forms after a collision surpassing a **critical temperature** $T_C \sim 155\ MeV$ (~2 trillion ℃) occurring at $\mu_B = 0$

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

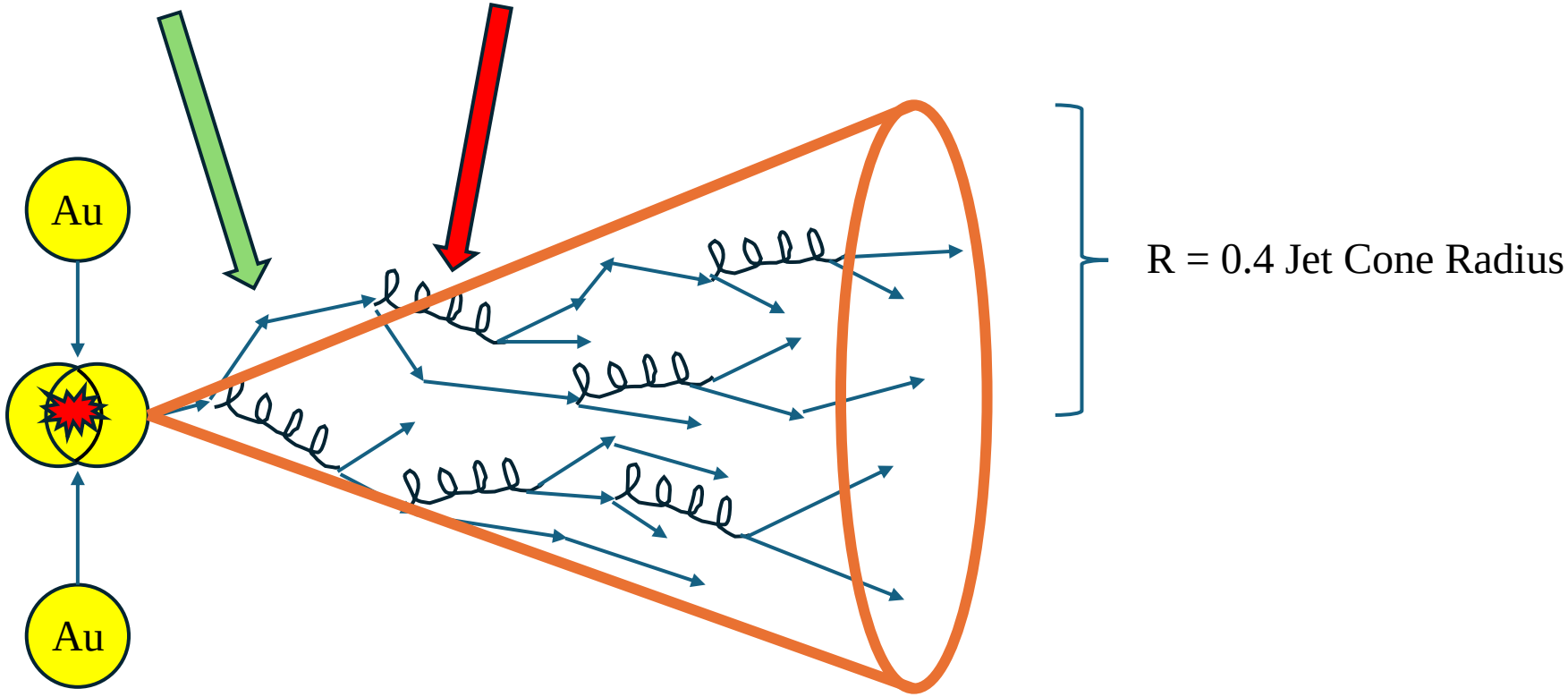


Jets in the QGP

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



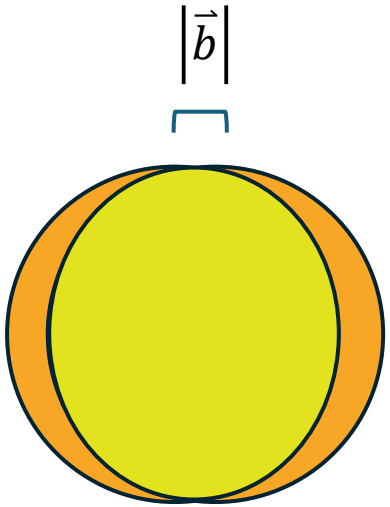
Interaction Region Geometry

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

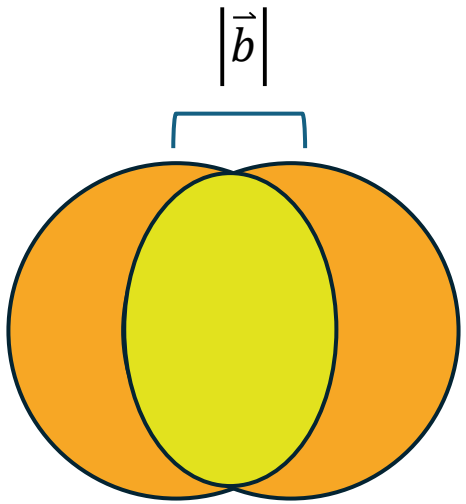
Central Collision



Beam Axis $\hat{z}$ in ⊗

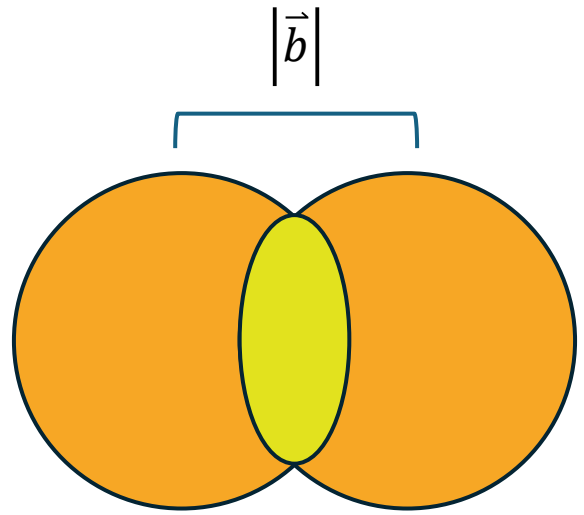
20-60% Centrality

Mid-Central Collision



60-80% Centrality

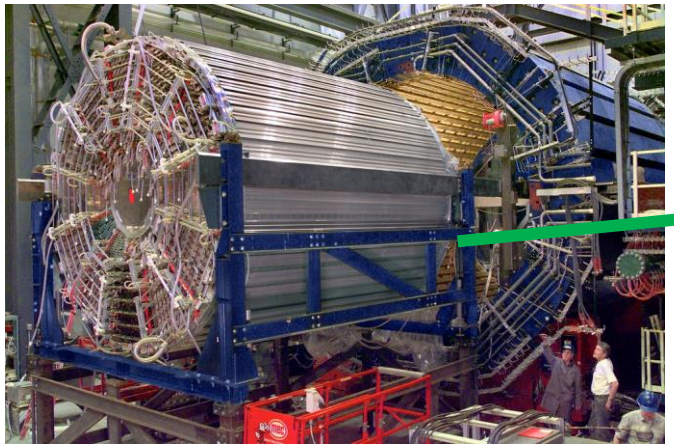
Peripheral Collision

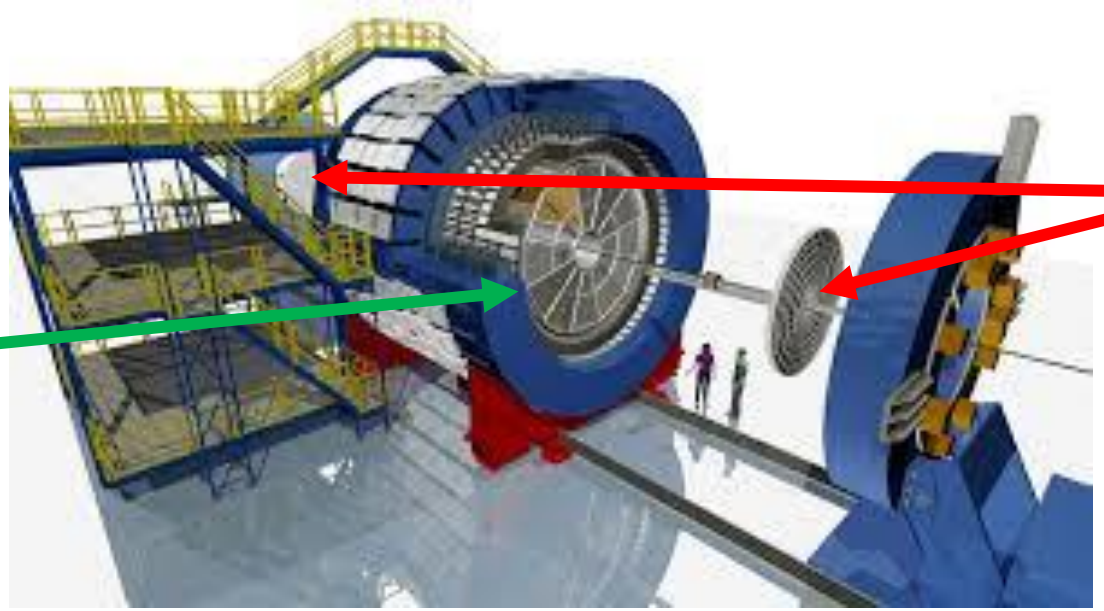


The STAR Experiment: Solenoidal Tracker at RHIC

Time Projection Chamber (TPC)

Acceptance
$0 < \phi < 2\pi$
$-1 < \eta < 1$



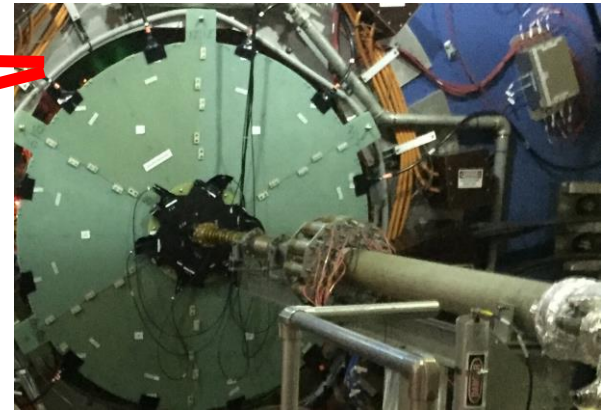


Detects tracks of charged particles

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

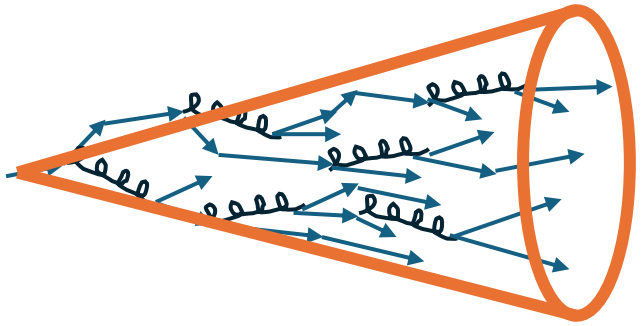
Event Plane Detector (EPD)

Acceptance
$0 < \phi < 2\pi$
$2.14 < |\eta| < 5.09$

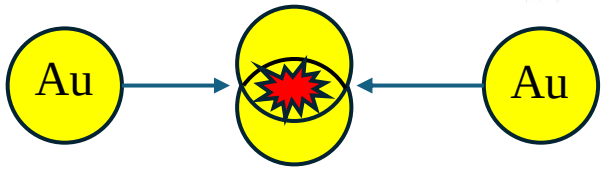


Detects the azimuthal distribution of final state charged particles

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
- ✓ $(\rho_{background} \cdot A_{jet})$-subtraction applied to jets
- ✓ Jets have one or more $p_T > 2$ GeV/c track
- ✓ $|\eta_{jet}| < 0.6$

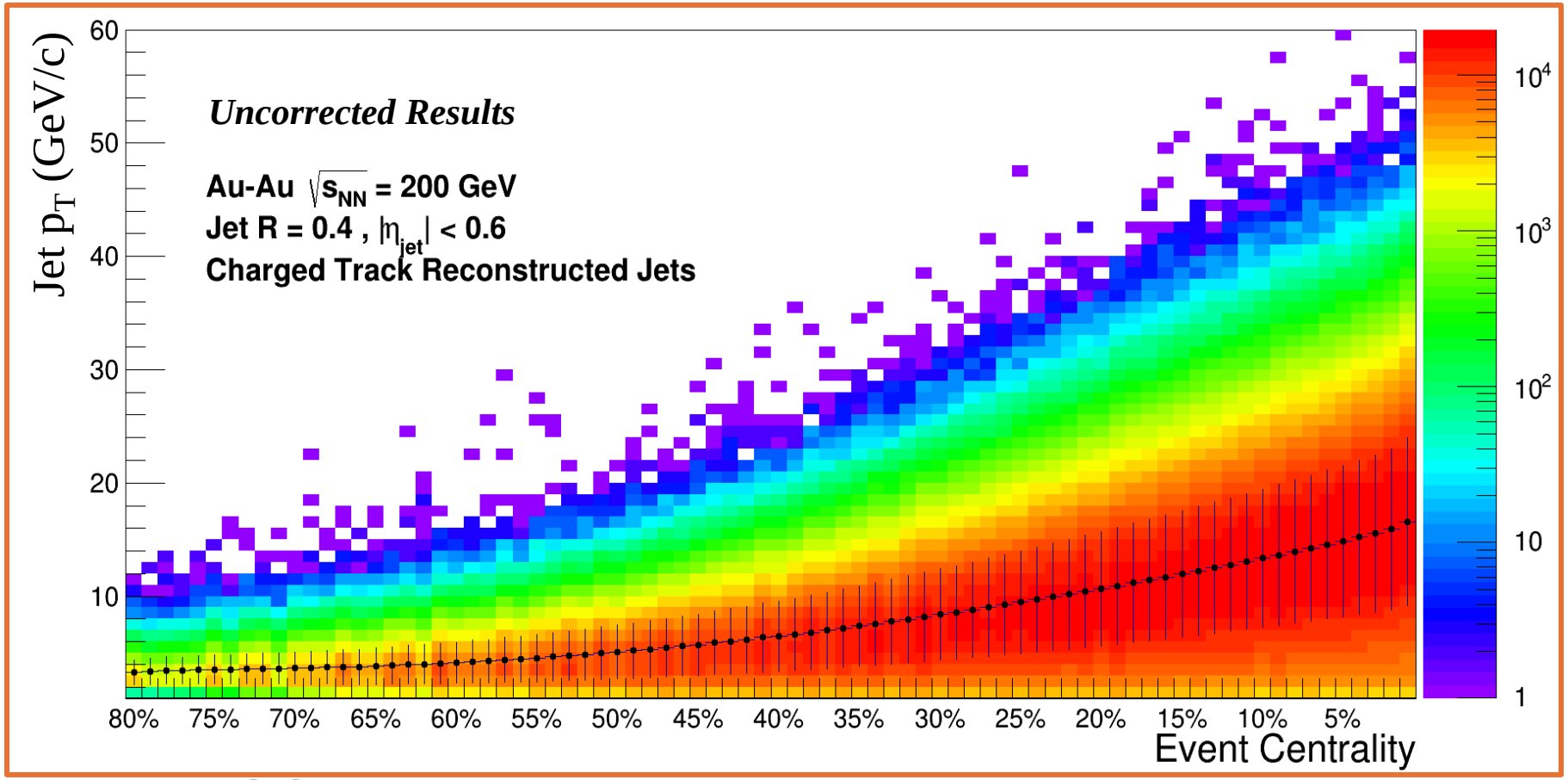
Events

- ✓ 4.76 million events, 2019 Au-Au
- ✓ $\sqrt{s_{NN}} = 200$ GeV Center of Mass Energy
- ✓ Minimum Bias Trigger
- ✓ z-Vertex Cut: $-30 < v_z < 20$ cm
- ✓ Primary Vertex Radial Distance from Beam Axis < 2 cm

Jet p_T Dependence on Centrality

Larger energy contribution from the underlying event as the centrality of the collision **increases**

More jets in central collisions due to **greater number of nucleon-nucleon collisions** occurring in the event



Note: Jet p_T is uncorrected, clustered raw charged particle p_T after ($\rho \cdot$Area)-subtraction
Only statistical errors accounted for in error bars

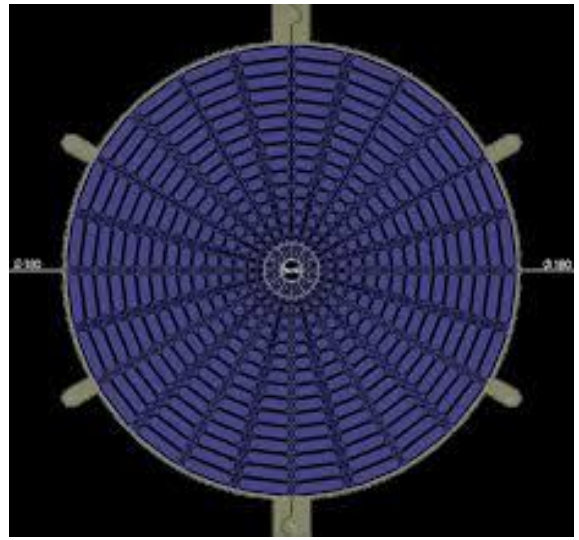
Quantifying Ellipticity

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

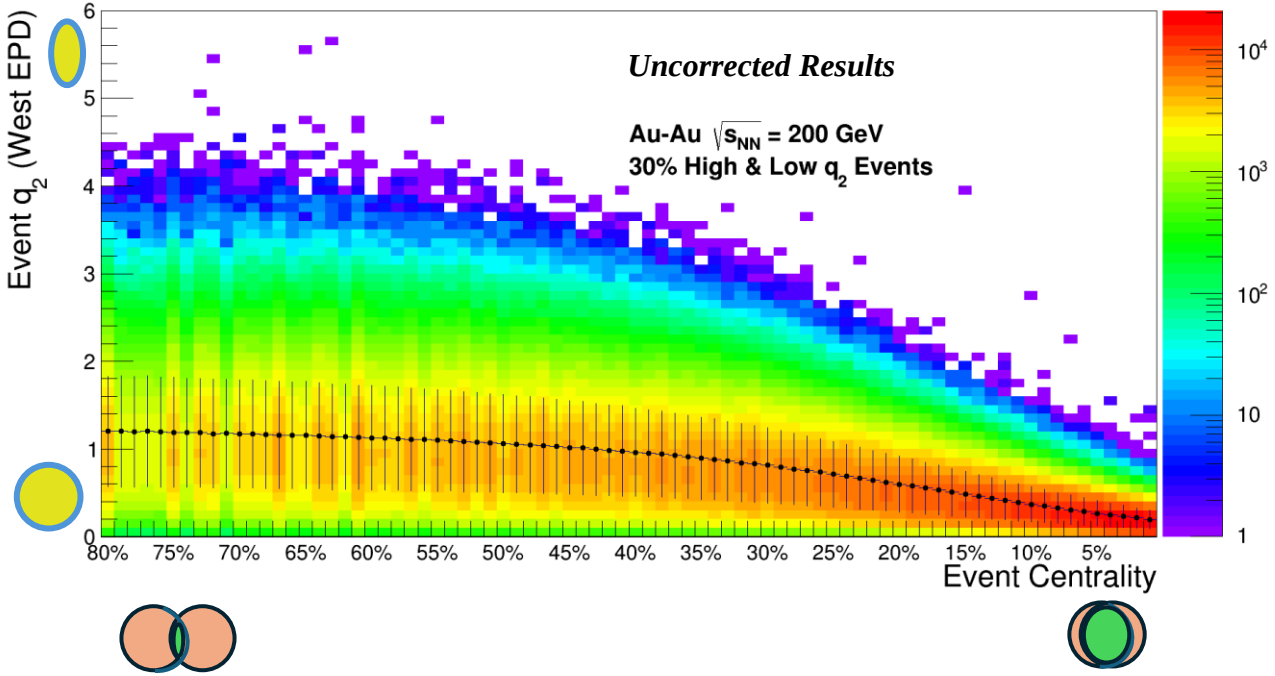


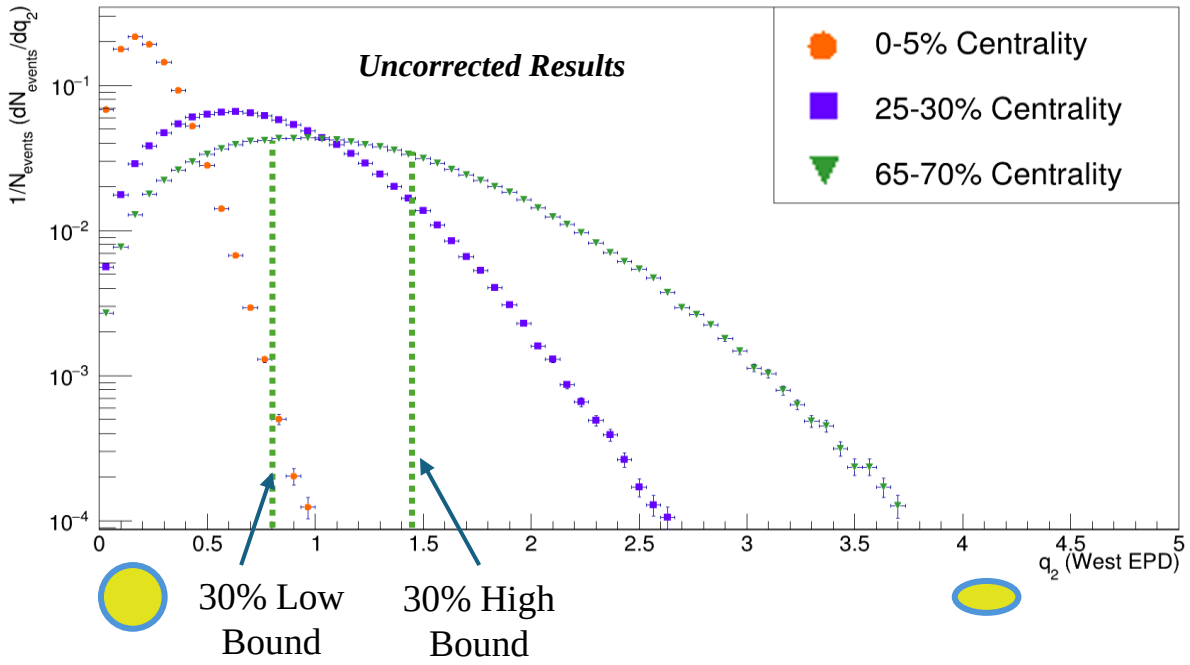
A perfectly azimuthally symmetric event has $\mathbf{q_2 = 0}$

q_2 **increases with more elliptically** shaped events

Measured with the West Event Plane Detector

Event Shape Engineering

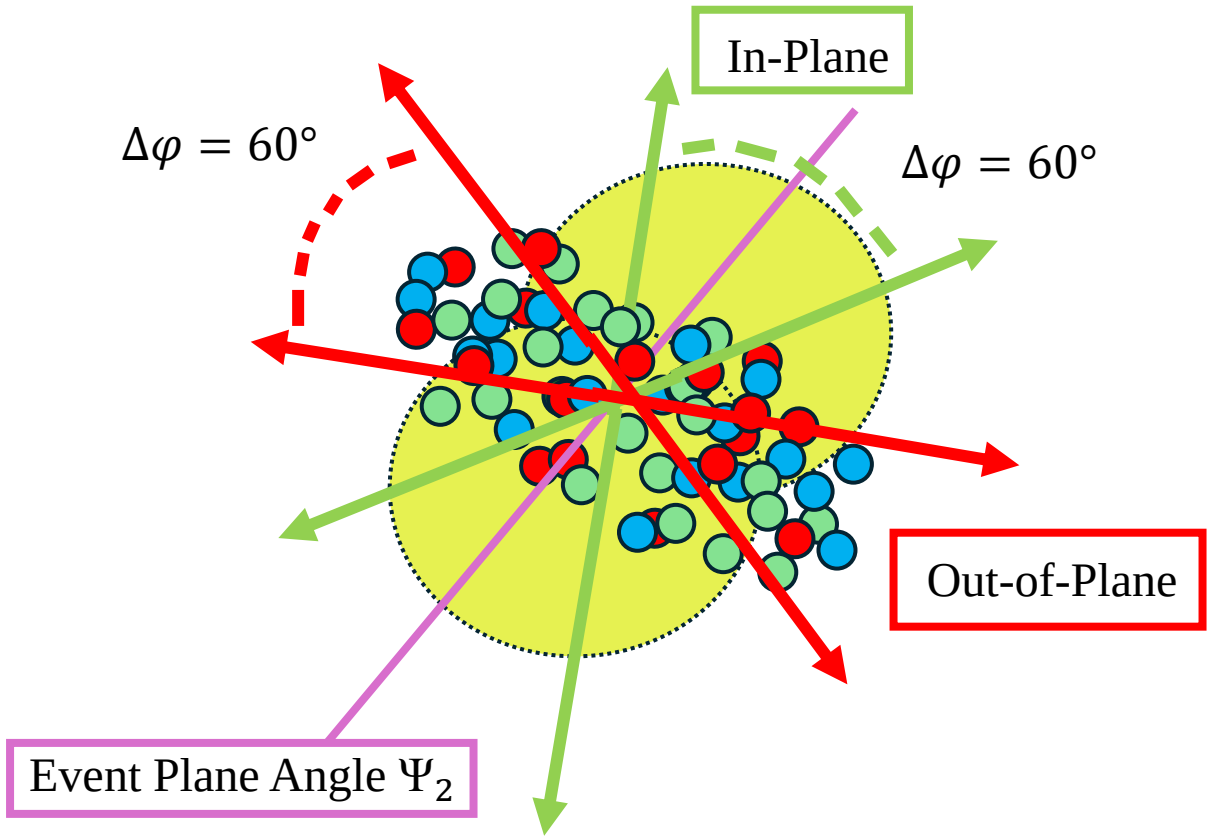




Monotonic decrease in q_2 range with increasing event centrality

Due to the distribution of q_2 values *within* a given centrality class, **30% high and low q_2 bounds** are imposed

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 $\hat{\boldsymbol{b}}$

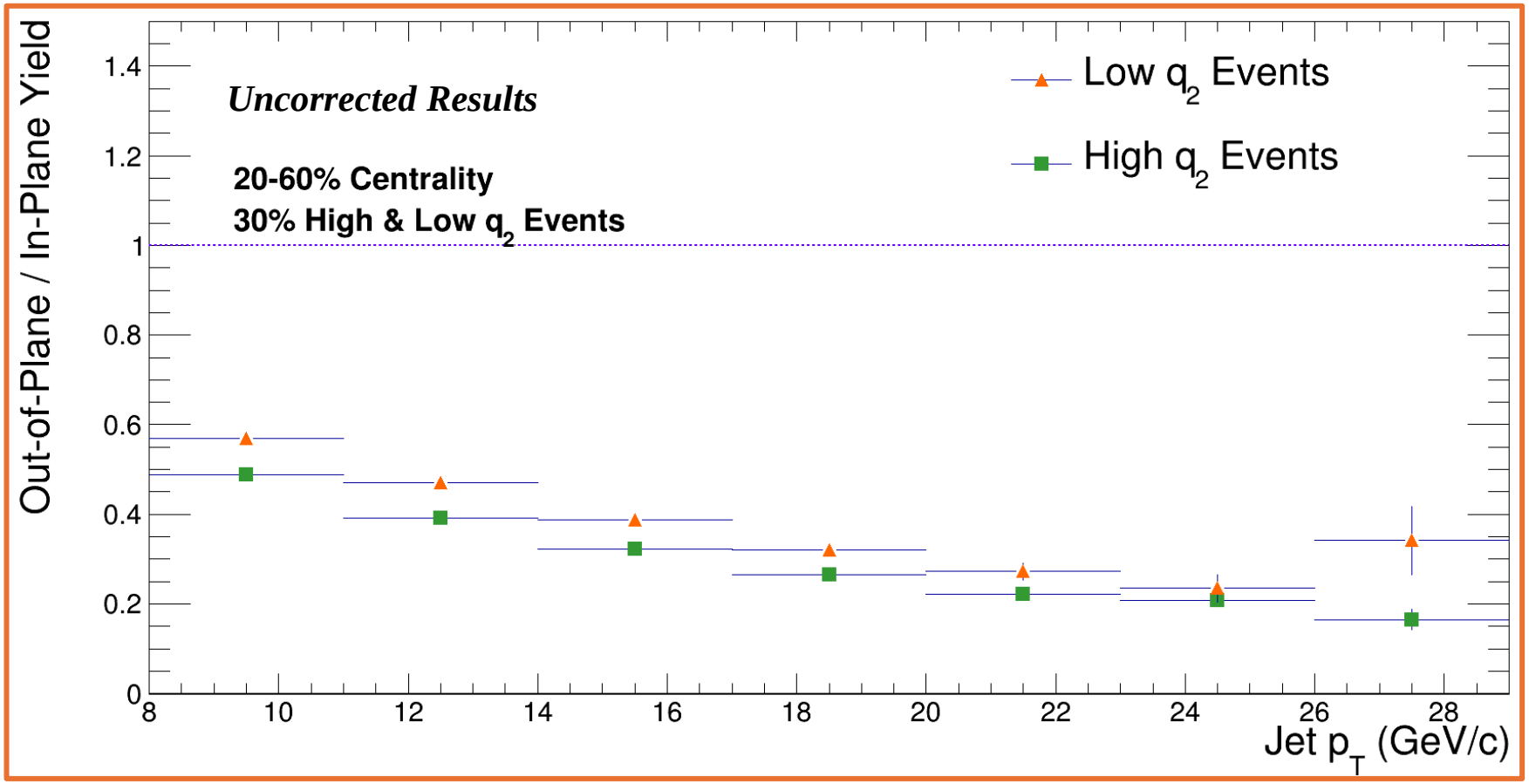
In-plane jets will traverse the **minor axis** of the QGP ellipsoid created in mid-peripheral collisions

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

In vs. Out of Plane Suppression

Initial indication of a **suppression** of *uncorrected* out-of-plane jets (ratio < 1)

High q_2 events may cause slightly more out-of-plane jet yield suppression (to be analyzed further after corrections applied)



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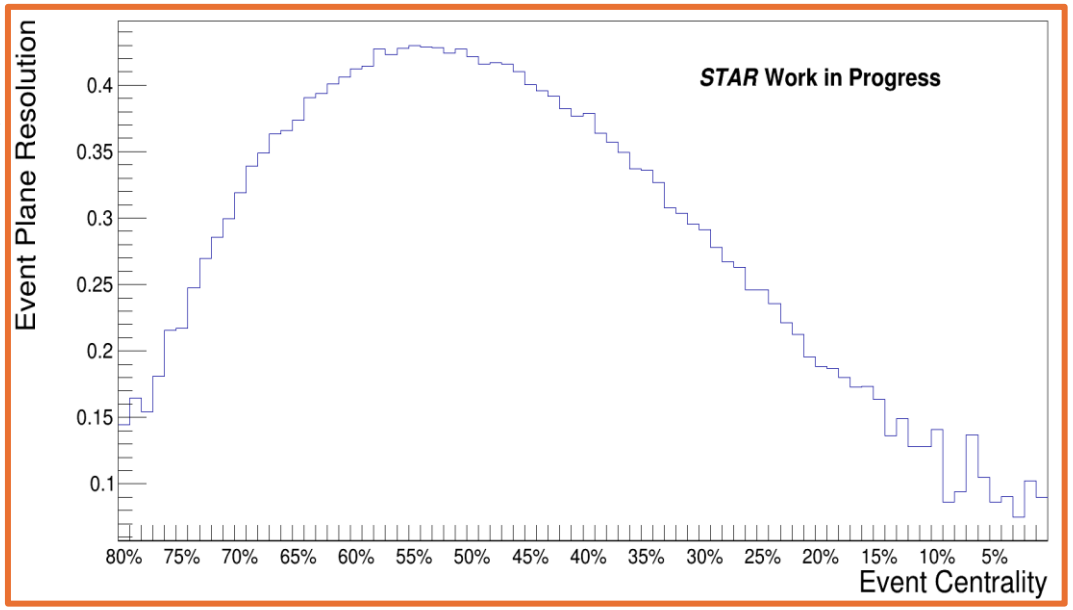
Only statistical errors accounted for in error bars

Event Plane Resolution Corrections



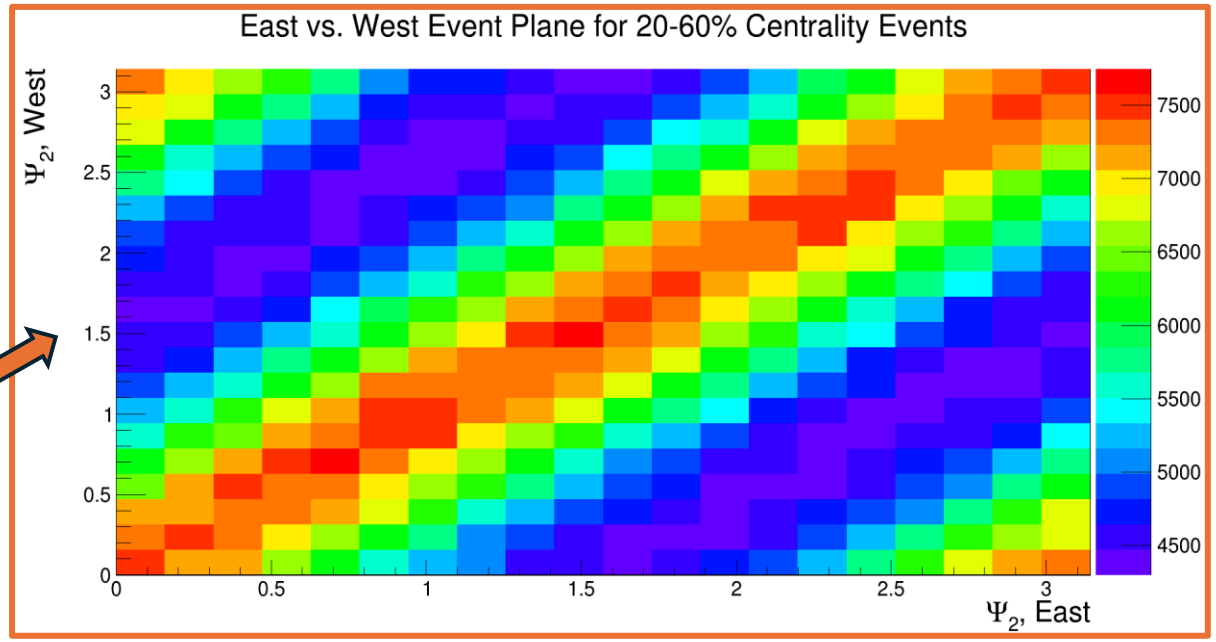
$$EP_{Resolution} = \langle \cos(2(\Psi_2^a - \Psi_R)) \rangle$$

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

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

An out-of-plane jet yield **suppression** will be examined *once corrections are applied* (event plane, jet spectra, statistical errors)

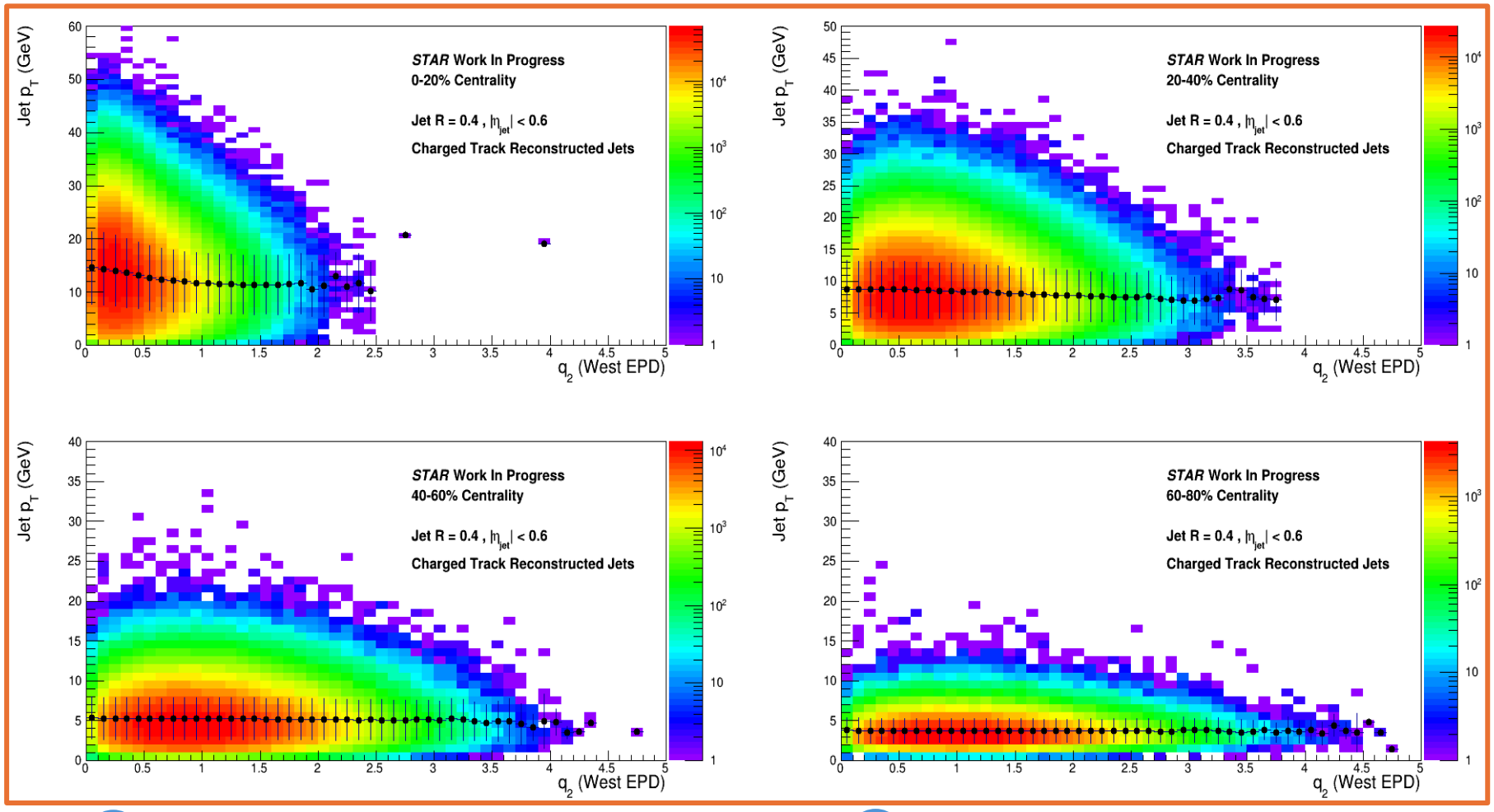
Future Endeavors:

- Event plane and q_2 **resolutions** must be applied
- Study the event plane's resolution dependence on **q_2 resolution**
- Jet p_T spectra must be **unfolded** to account for detector effects
- **Statistical Errors** will be calculated and applied

This study of path-length dependent jet energy loss at STAR is **motivated** by:

- Beattie, Nijs, Sas, van der Schee. 2023, PLB 836, 137596
- Beattie. arXiv:2210.02937 (2022)

Backup


STAR Work In Progress
0-20% Centrality
Jet R = 0.4 , |η_jet| < 0.6
Charged Track Reconstructed Jets
Jet p_T (GeV)
q_2 (West EPD)
STAR Work In Progress
20-40% Centrality
Jet R = 0.4 , |η_jet| < 0.6
Charged Track Reconstructed Jets
Jet p_T (GeV)
q_2 (West EPD)
STAR Work In Progress
40-60% Centrality
Jet R = 0.4 , |η_jet| < 0.6
Charged Track Reconstructed Jets
Jet p_T (GeV)
q_2 (West EPD)
STAR Work In Progress
60-80% Centrality
Jet R = 0.4 , |η_jet| < 0.6
Charged Track Reconstructed Jets
Jet p_T (GeV)
q_2 (West EPD)