Investigating the Path-Length Dependence of Jet Energy Loss in the Quark-Gluon Plasma

- Austin Rosypal -
The STAR Experiment

Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL)

Solenoidal Tracker at RHIC (STAR)
A Typical Collision
For the STAR 2019 Au-Au data used in this analysis, COM energy is $\sqrt{s_{NN}} = 200 \text{ GeV}$.
A Typical Collision
Quark-Gluon Plasma

Past a critical temperature $T_C \sim 155 \text{ MeV}$ (2 trillion °C), confined hadronic matter transitions to a soup of quasi-free colored partons.

This plasma, forming only 1 fm/c after the collision, can be modeled as a strongly coupled, relativistic hydrodynamic fluid.

Hard probes, spurred by the initial collision, traverse the entire medium, acting as excellent energy loss proxies.
Mid-Central Collision with some Impact Parameter vector $\vec{b}$

Quantum Uncertainty

$$\Delta E \Delta t \geq \frac{\hbar}{2}$$
The quark-gluon plasma produced expands \textit{anisotropically}.
Path Length Dependence

More quark-gluon plasma = More potential color interaction sites

Particles travelling out-of-plane through the QGP will lose MORE energy than those traversing in-plane

Studying yields and energies of particle sprays in relation to the anisotropy of the QGP will probe the path length dependence theory
STAR TPC & EPD

Time Projection Chamber

 Measures the 4-momentum of charged particles
 Used to produce the jet & track $p_T$ spectra

Event Plane Detector

 Detects the azimuthal distribution of emitted particles
 West EPD: Used to calculate $q_2$
 East EPD: Used to calculate the event plane

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Austin J. Rosypal
Jets

Jets are highly energetic, collimated sprays of particles that are a result of the fragmentation and subsequent hadronization of quarks and gluons.

Transverse Momentum: \( p_T = \sqrt{p_X^2 + p_Y^2} \)

Jet \( p_T \) as a Function of Event Centrality

Counts

R=0.4 Jets
Anti-\( k_T \) Algorithm
Event Shape Engineering

Method that grants the ability to select on the characteristic shape of an event in given centrality and eccentricity bins
2\textsuperscript{nd} Order Reduced Harmonic Flow Vector

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

- \( M \): Particle multiplicity of the event
- \( \varphi_i \): Azimuthal angle of \( i^{th} \) particle

Quantifies \textit{ellipticity} of the event (and of the QGP produced)

- High \( q_2 \) = Large Ellipticity
- Low \( q_2 \) = Radial Symmetry
There exist a range of probable $q_2$ values per centrality class, despite the monotonic decrease in average ellipticity.

$q_2$ Dependence on Collision Centrality

Central collisions are spherically symmetric
Peripheral collisions can attain high anisotropy in momentum space
Jet Yield with Respect to the Event Plane

\[ \Delta \varphi = 30^\circ \]

- In-Plane
- Out-of-Plane

Event Plane Angle \( \Psi_2 \)
Jet Yield with Respect to the Event Plane

Initial indication of a dominance of in-plane jets per event

20-60% Centrality Jets with $p_T > 5$ GeV

Number of Jets in Event

N_{events}
Jet Yield Ratios

A ratio less than unity signifies a suppression of out-of-plane jet yields, due to the larger amount of QGP traversed with respect to in-plane jets.
Comparison to Computational Simulation

Computational work of Ryan Hamilton

Au-Au Data Event Shape Engineering Results

Eccentricity from: Geometric Grid

$q^2$ Distributions of Different Centralities
Comparison to Computational Simulation

Glauber Model results from Ryan Hamilton

Au-Au Data Event Shape Engineering Results

Event $q_2$ as a Function of Collision Centrality
Charged Track Spectra Ratio

Ratio of charged track spectra from the 10% highest and lowest $q_2$ events is compatible with unity.

Working towards replicating this relationship with jets: Would indicate a full reconstruction insensitivity to the underlying radial event.
The State & Future of Jet ESE...

Current Status

- Track spectra align, within error, to Isaac Mooney’s 2023 Au-Au charged hadron ESE analysis
- Centrality & shape correlations align with models
- Ratios indicative of pathlength dependence are in the right ballpark, though limited by low statistics and bounded by uncertainty

Coming Weeks

- Ensure that jet statistics are comparable to recent analyses
- Boost statistics to increase measurement uncertainties
- Implement statistical uncertainties
- Compare with further theoretical and simulation expectations
## Acknowledgements

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