Studying Elliptic Flow in High Energy Nuclear Collisions at RHIC

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Abstract

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) in Upton, New York is a heavy ion collider capable of producing Au-Au collisions with a center of mass energy as high as 200 GeV. The purpose of the project is to gain a deeper understanding of the structure and properties of matter; in particular properties of the quark-gluon plasma (GQP), a phase of quantum chromodynamics (QCD) which is thought to have existed during the first 20 to 30 microseconds after the big bang. Elliptic flow analysis is one of the major tools for gaining knowledge about the QGP and how it transitions into hadrons.

1 Background

It may not be immediately obvious to someone outside the field of nuclear physics why exactly one would want to collide heavy ions rather than protons. The charge to mass ratio is significantly higher for protons than for heavy ions so proton-proton collisions with far greater center of mass energies could be produced using the same magnets. One of the main reasons for using nuclei is that nuclear collisions produce a larger number of scattering particles (there are usually thousands of particles detected by STAR in each collision). The vast magnitude of scattering particles can be seen in figure 1. The abundance of particles offers insight into bulk properties of the collision, a concept of immense importance in studying and substantiating the QGP.

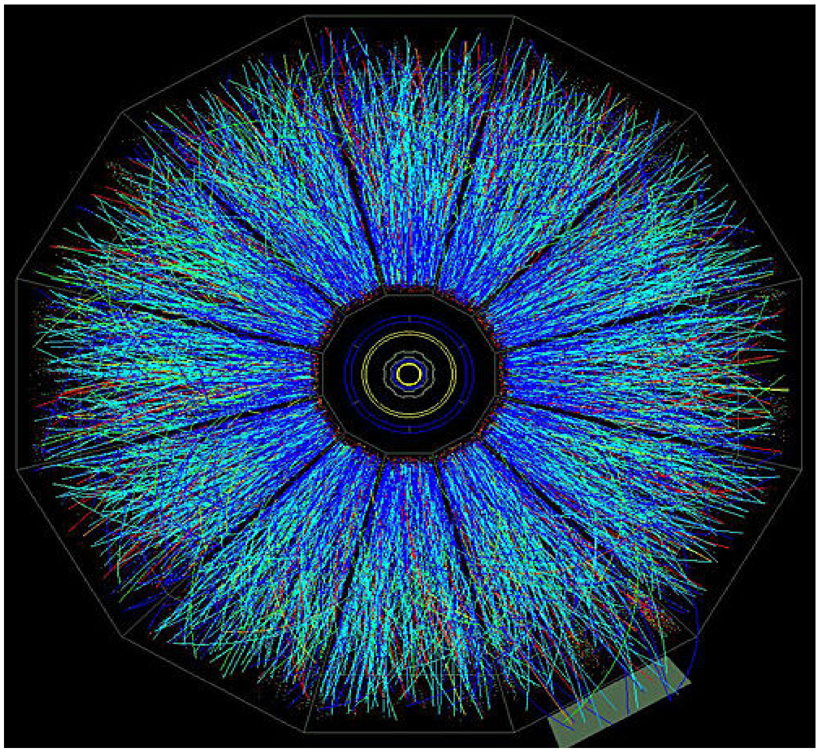

Figure 1: The classic image of the particles detected in one of the first Au-Au collisions at RHIC's STAR detector. There are on the order of several thousand tracks in this image. [1]

One of the primary bulk properties of the collision, and the one that my work is centered around, is anisotropic elliptic flow. The flow exhibited is consistent with almost ideal fluid-dynamical collective behavior which is very suggestive of a well-developed quark-gluon plasma. The anisotropy of the flow is mass dependent which offers insight into the QGP's equation of state and the process of hadronization.

2 Methods

My work over the summer centered around the azimuthal anisotropy of the flow. This flow anisotropy arises from the initial spatial anisotropy which can be seen in figure 2. After the collision there is a pressure gradient which transforms this anisotropy in the coordinate space into one in the momentum space along the reaction plane.

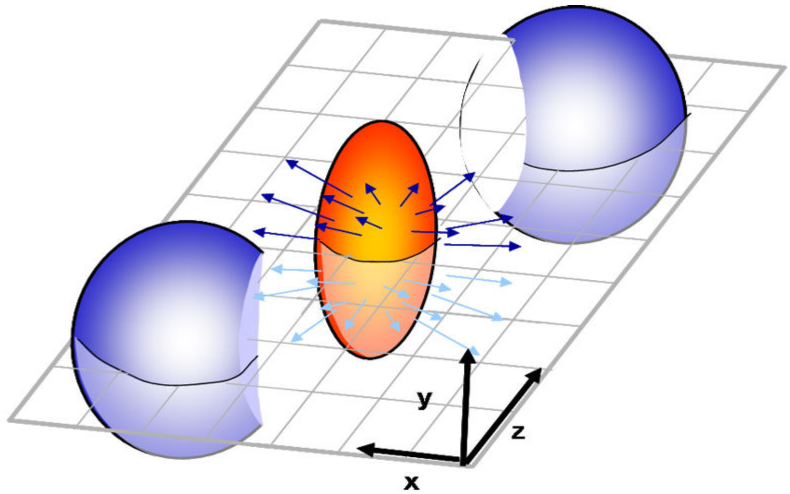

Figure 2: Two ions collide leaving an almond-shaped overlap region. The pressure distribution in this overlap region results in increased hydrodynamic flow along the minor axis. [2]

The azimuthal anisotropy of the flow can be expressed as a Fourier series

$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1+\sum_{n=1}^{\infty} 2v_n \cos[n(\phi-\Psi_r)]\right),$$

where Ψ_r represents the angle of the reaction plane. The anisotropy is most prominent in the second harmonic, which was the focus of my work over the summer. I was primarily concerned with using the second harmonic to calculate the reaction plane

$$\Psi_2 = \left(\tan^{-1}\frac{\sum_i w_i \sin(n\phi_i)}{\sum_i w_i \cos(n\phi_i)}\right) \Big/ 2,$$

where the sums cover each detected particle in a collision and w_i is a weight for each particle.

3 Data Analysis

My data analysis programs were written in ROOT, an object-oriented software package developed by CERN. The documentation for ROOT is somewhat lacking and it took more time to gain any fluency in the program than I would have liked. The largest obstacle that I faced in my project's development was learning to work within the framework of STAR's "chains" and "makers" to access raw data files. The system is relatively simple in hindsight, but I spent several frustrating weeks reading poorly or not at all commented header files before forming that conclusion.

A brief overview of my data analysis process can be described as follows. First a chain must be created along with several makers including a maker specific to the format of the raw data files and a maker designed for my specific analysis. These makers are then added to the chain. Each maker in the chain is initialized before each event in the data files is successively passed to all of the makers. My analysis maker makes track and event quality cuts as well as performing whatever analysis it's programmed for. Finally, each maker is shut down and the results of the data analysis are written to file.

4 Results

Once I had developed an understanding of the maker system and how to implement it I was able to make rapid progress with my analysis. Unfortunately, due to my struggles with some of the more poorly documented features of root, delays in getting computing accounts on the facilities at Brookhaven and Berkeley, and a bad motorcycle accident, it wasn't until my last few weeks that I made it to this point.

I did have time to briefly explore the resolution of my calculation of the event plane. This was done by randomly subdividing each event into two subevents of equal multiplicity and looking at the difference between the calculated event planes for each subevent. In figure 3 it can be seen that the correlation is roughly Gaussian and it is the width of this Gaussian that determines with what resolution the event plane is being found.

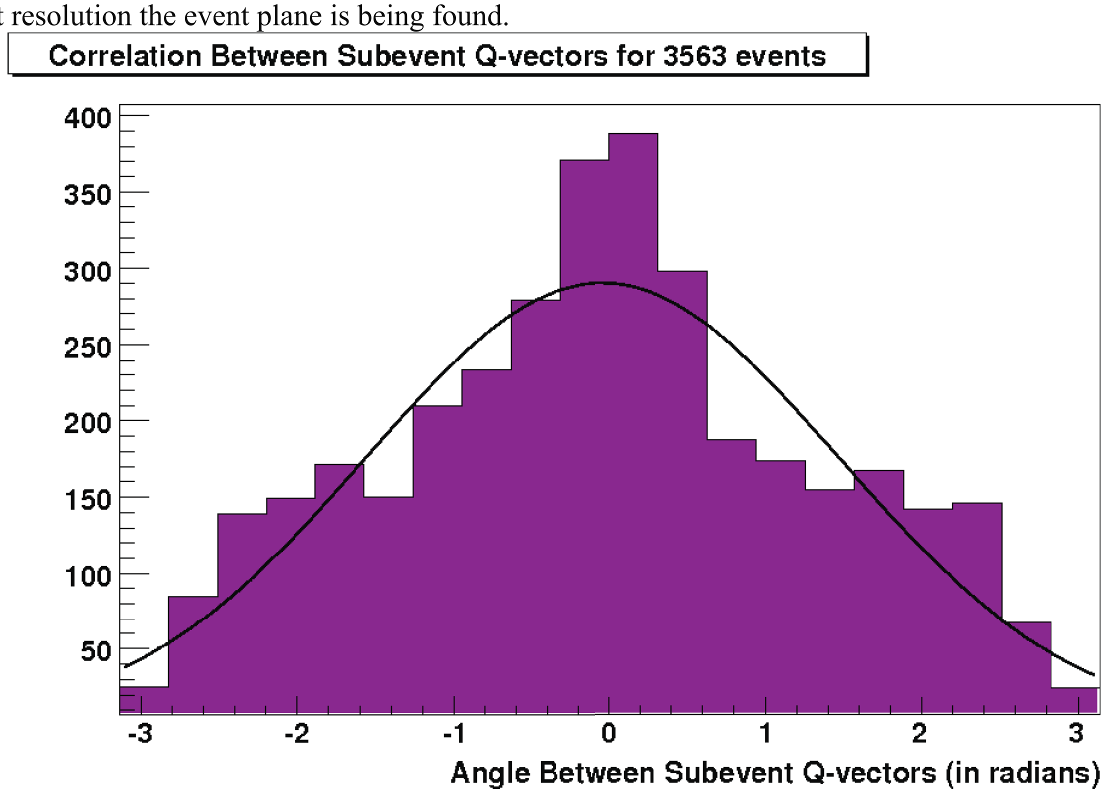

Figure 3: A histogram detailing the multiplicity for different angles between two subevent event planes. The term Q-vector simply refers to the vector on the event plane and perpendicular to the z-axis.

I attempted to investigate how different track and event quality cuts, as well as corrections, effect the resolution of the Q-vector. In figure 1 it can be seen that the time projection chamber (TPC) in the STAR detector is not entirely azimuthally symmetric. There are 12 equally spaced areas around the detector where there is no TPC resolution. This introduces a subtle bias into the calculation of the event plane which can be corrected for by weighting tracks according to the actual resolution of the detectors. The data sets that I used were too small to get an accurate depiction of the TPC resolution, but it is something that I investigated.

Although I couldn't correct for the TPC's resolution I was able to come to an interesting conclusion in regards to the forward time projection chambers (forward TPCs). In flow analysis it is typical to introduce a theta cut of about 45° because lower P_T particles are less effected by the anisotropy of the flow and introduce unwanted noise to the harmonic analysis. I looked at the relationship between event plane resolution and imposed theta cuts and unsurprisingly found that a mid-rapidity cut was appropriate. What was a little bit surprising was how poor the resolution was if tracks from the forward TPCs were included in the calculations. After looking at the theta distribution of tracks over a large number of events it became obvious that there was a huge and unexpected asymmetry (see figure 4). After talking to my professor I was informed that the forward TPC's had a number of dead sectors which were responsible for the lack of symmetry. The tracks from the forward TPCs wouldn't have contributed anything even with a correction, but the fact that they performed so differently from how I expected was an important reminder of the importance of understanding the resolution of the detectors.

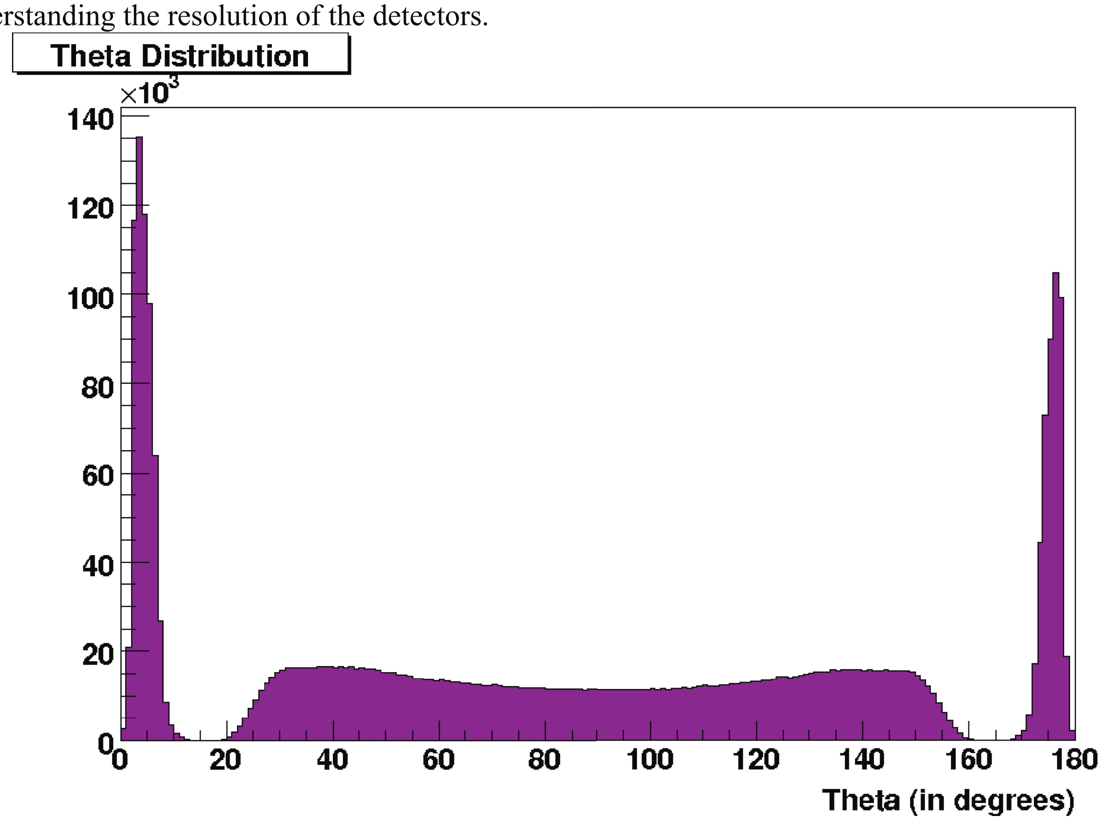

Figure 4: The theta distribution of tracks over a large number of events.

5 Future Work

I am fortunate enough to be continuing my research with the UC Davis Nuclear Group over the 2007-2008 academic year. My work over the summer was primarily a learning experience because so much must be learned before original research can be performed. I really look forward to applying what I've learned to performing actual research.

I will be performing a flow analysis on a 20GeV data set, but the full details of the project are not yet clear to me.

6 Acknowledgments

I would like to thank Daniel Cebra; not just for allowing me to work in his group but also for being such an incredible professor. The level of openness and community in the lab was stunning and I know that this is largely because Professor Cebra works hard to make it so. He spent more time with me than I could have possibly expected and made the summer one of the best learning experiences I've ever had. I'm also very grateful for him giving me the opportunity to continue working with the group.

Professor Manuel Calderon de la Barca Sanchez was a tremendous help to me as well. He organized several tutorials and lessons that were instrumental in me learning to use various scripts and software packages on the computing facilities at Brookhaven and Berkeley.

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And last but not least I'd like to thank the NSF and Rena Zieve for making the REU program at UC Davis happen.

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