Using π^0's to Understand Proton Spin Structure through Polarized p+p Collisions at $1 < \eta < 2$ and $\sqrt{s} = 200$ GeV at STAR

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STAR

Abstract

Measurements of spin dependent observables at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory provide unique insight into the contribution of a proton's constituents to its spin. The Solenoidal Tracker at RHIC (STAR) can be used to measure effects of the quark and gluon spins in the proton by observations of neutral pions that result from longitudinally and transversely polarized proton-proton collisions in STAR. The neutral pions (π^0's) decay into two photons that, for pseudorapidity (η) 1 to 2, can be observed in the endcap electromagnetic calorimeter in STAR. These are used to reconstruct the kinematic properties of the π^0's and we can then look for spin asymmetries in π^0 production. Measurements of both the longitudinal and transverse spin asymmetries in the production of π^0's from data taken in 2006 have made some contributions to our understanding of the structure of the proton. New data taken in 2009, in a longitudinal spin run with greater luminosity, will provide greater precision to the final results. Results from 2006 (STAR's most recent spin paper, submitted to Phys. Rev. D: arXiv:1309.1800) and preliminary work on 2009 data are shown.

Fig. 1: RHIC Collider

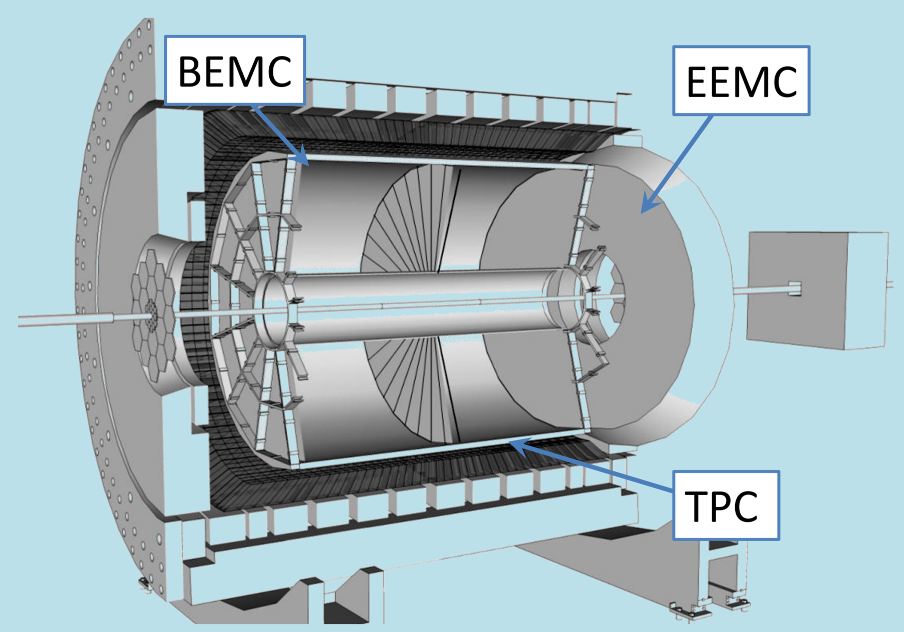


Fig. 2: The STAR Detector; the Barrel and Endcap ElectroMagnetic Calorimeters are highlighted, as well as the Time Projection Chamber.

Spin Studies in STAR

The Relativistic Heavy Ion Collider (RHIC) (Figure 1), located at Brookhaven National Laboratory is the world's only machine capable of colliding high-energy beams of polarized protons. The Solenoidal Tracker at RHIC (STAR) detector (Figure 2) utilizes these polarized-proton collisions to explore the origin of the proton spin in terms of its constituent parts.

The most important subsystem of the STAR detector, for this analysis, is the **E**ndcap **E**lectro**M**agnetic **C**alorimeter. The EEMC, composed of alternating lead and scintillator layers, detects, along with other particles, photons resulting from the proton-proton collision in the pseudorapidity range of $1 < \eta < 2$. In the analysis of the data collected by STAR, event triggers are used to selectively save information from p + p collisions that are of specific interest based on physics goals. These are selections that are made electronically at the time the data are collected and archived.

Triggers are an essential component of any collision experiment. Triggers allow for only the events of interest to be analyzed, based upon the characteristics of the event that one wants to examine. Each trigger is tailored for the analysis that is desired, by changing the criteria that each of the events must have in order to be included in the data to be analyzed. For my summer research, I looked at several individual triggers that had already been created, in the hope that they (or triggers like them) may potentially be used for analysis in the STAR Collaboration's ongoing proton spin research.

The proton is known to contain two up quarks and a down quark, which contribute to the properties of the proton, such as charge. There are also the sea quarks and anti-quarks in the proton at any given time. It might be intuitive to suppose that the valence quarks and the sea-quarks and anti-quarks would make up the spin of the proton which is experimentally known to be ½ ħ. However, deep inelastic scattering experiments show that the quarks only contribute ~36% of the spin of the proton. This is the "spin crisis," who's complexity can be demonstrated in Figure 3. To account for the rest of the proton spin, we must consider the gluonic contribution and orbital angular momentum contribution of the proton's constituents. The polarization capabilities of the RHIC proton collider allow for STAR to probe the gluonic contribution to the spin of the proton.

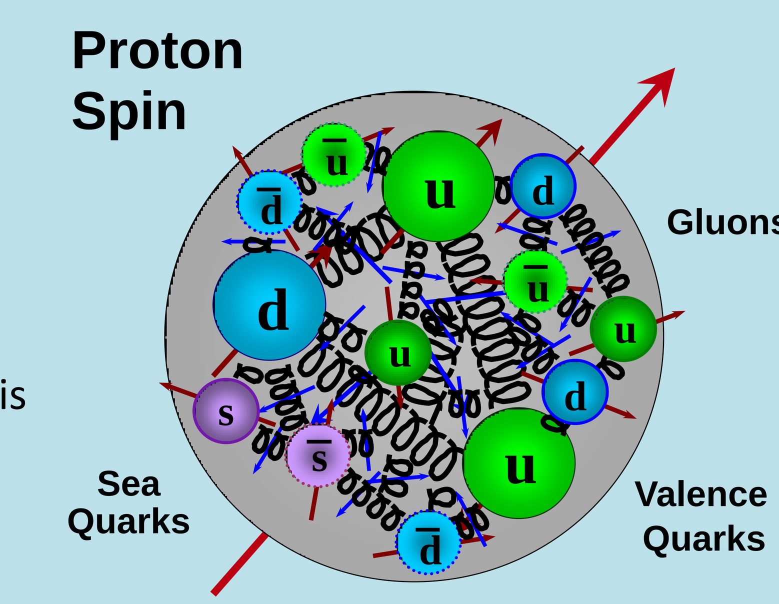


Fig. 3: A quark model of the proton, to show the complexity of the proton constituent's contribution to the spin of the proton.

Double Longitudinal Asymmetry

Neutral pions (π^0's) are a product of the collision of two protons. The neutral pions most likely decay into two photons, which can then be detected by the EEMC within the pseudorapidity range of 1 to 2. The EEMC is used to find the neutral pion cross section and measure the longitudinal and transverse spin asymmetries in the production of π^0's.

The double longitudinal asymmetry is sensitive to the gluonic contribution to the spin of the proton, which allows for it to be useful in this analysis. Figure 4 shows longitudinal asymmetry results from 2006.

To find the longitudinal asymmetry value, the number of reconstructed neutral pions from the collision of the two proton beams that are aligned are compared to those from an anti-aligned collision. The same is done for the sampled luminosity in each of these cases. The asymmetry is then the difference divided by the sum of these two values, divided by the weighing of a factor of $\langle P_B P_Y \rangle$. This represents the luminosity weighted polarization factors due to the two beam lines used at RHIC; blue (B) and yellow (Y).

$$A_{LL} = \frac{1}{\langle P_B P_Y \rangle} \left(\frac{N^{++} - N^{+-} - N^{-+} + N^{--}}{N^{++} + N^{+-} + N^{-+} + N^{--}} - \frac{L^{++} - L^{+-} - L^{-+} + L^{--}}{L^{++} + L^{+-} + L^{-+} + L^{--}} \right)$$

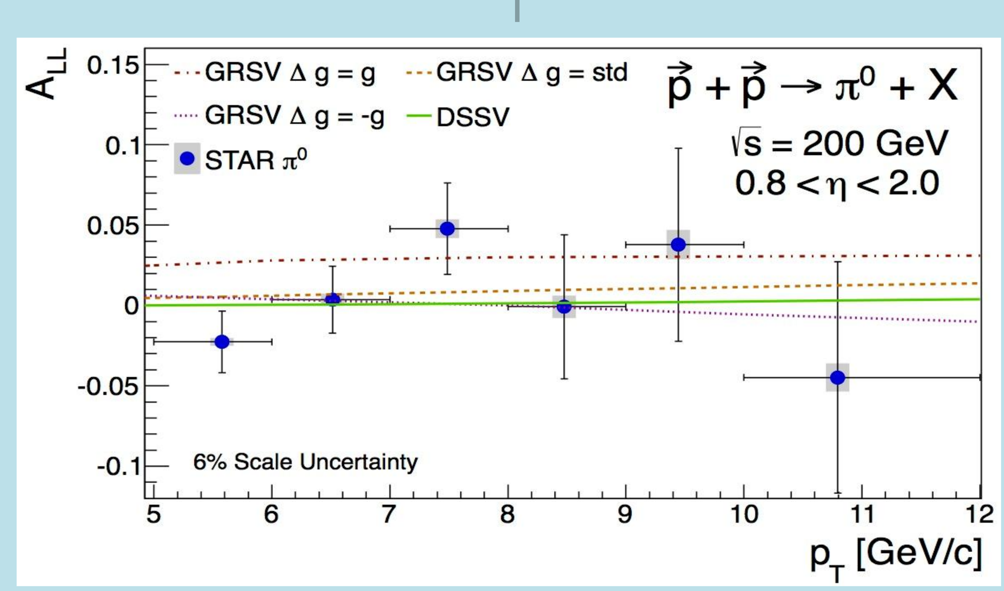


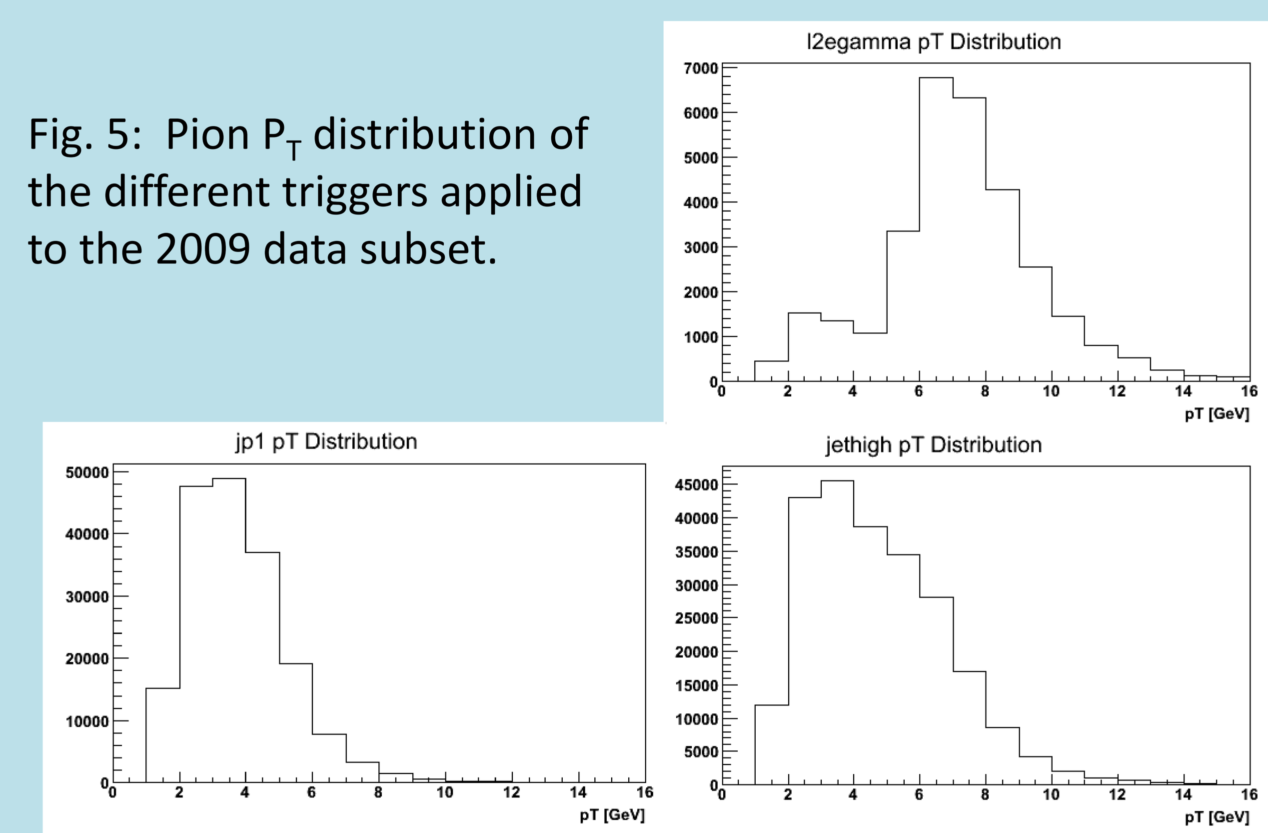
Fig. 4: Double longitudinal spin asymmetry vs. P_T alongside several theory curves. The theory curves show the expected asymmetry for various Δg scenarios. From the recent STAR paper based on 2006 data.

π^0 Reconstruction

The trigger that was used in the 2006 analysis was a photon trigger. This trigger was constructed to identify events with photons.

For the analysis of the data collected in 2009 we included events that passed the photon trigger as in 2006. However, in addition, we were able to include π^0 events that were triggered by a jet in the final state. (A jet is a cone of ejected particles resulting from the collision of quarks and gluons. Most of the ejected particles are charged and neutral pions.) In 2006 there were no jet triggers useful for the EEMC in π^0 events. Two jet triggers were examined for 2009 data. In all three triggers, we searched for photons in the EEMC that might have come from π^0 decays. The data collected in 2009, compared to 2006, had higher luminosity that is expected to lead to smaller uncertainties in the spin analyses.

Fig. 5: Pion P_T distribution of the different triggers applied to the 2009 data subset.



Using data from 2009, I studied 16 runs which is about a day's worth of data collection. The two jet triggers that were included were named "jp1" and "l2jethigh". My analysis did not study the jet, *per se*, but rather the photons from π^0's in these events. It was found that both of these jet triggers were able to probe lower π^0 transverse momentum (P_T) than could be obtained in the photon trigger, named "l2egamma." (See Figs. 5 and 6) Jethigh had the higher energy threshold. Including lower P_T values for the A_LL for inclusive π^0 events would help to better determine the gluonic contribution to the spin of the proton. It is hoped that these jet triggers will be able to be used for future analysis of π^0's, which would lead to better statistics.

Fig. 6: Trigger dependence of pion invariant mass curves for pion pT = 2-3 GeV/c.