Seeking the Magnitude of the Gluon Contribution to Proton Spin with STAR Endcap π^0s

By Nicholas Gilles and Marcus Engstrom on behalf of the STAR Collaboration

With Acknowledgements and Thanks to Professor Adam Gibson-Even and Mr. Paul Nord

ABSTRACT: The spin of the proton is known to be ½ ħ. It arises from the spin and orbital angular momenta of the proton's constituents: quarks and gluons. The relative contributions of various components remain uncertain, with the quark spin contribution significantly lower than once anticipated. We seek to quantify the gluon spin contribution, in particular. At the RHIC-STAR experiment at Brookhaven National Laboratory (BNL), we observe collisions between spin-polarized beams of protons. In this measurement, our probe of initial-state gluons will be the neutral pion (π^0), abundantly produced in such collisions. The π^0s rapidly decay into two photons, which we can detect with STAR's Endcap Electromagnetic Calorimeter (EEMC). We have been calibrating and reconstructing the 2013 data, from proton-proton collisions at 510 GeV center-of-mass energy, to form both photon and π^0 candidates and storing this information in data structures called trees. We track the reconstruction process and assure its quality. We will describe our efforts to identify bad data using quantities including π^0 mass distributions and the signal to background ratio. We will present the status of the EEMC π^0 measurements using the 2013 dataset and our quality assurance analysis.

Brief Description of Proton

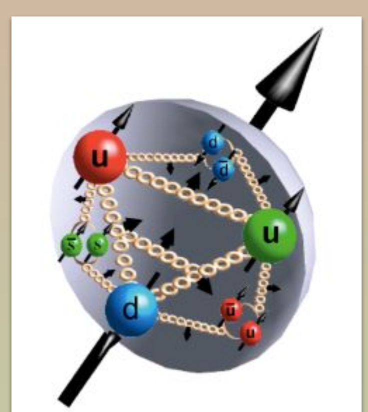


Figure 1. The proton and its constituents.

- Proton made of:
  - Valence quarks (up, up, down)
  - Gluons (hold quarks together)
  - Sea quarks
    - Particle-antiparticle pairs that come into and out of existence
- Goal: measure the gluon spin contribution to the proton spin

$$\frac{1}{2}\hbar = \frac{1}{2}\Sigma_q + \Sigma_g + L_q + L_g$$

Equation 1. Contributions to proton spin. Quark spins (Σ_q) contribute roughly 30%, the gluon spin contribution (Σ_g) is also significant, and the orbital angular momentum contributions (L) are unknown.

Asymmetry A_{LL}

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}$$

Equation 2. Definition of A_{LL}.

- Longitudinal double spin asymmetry (A_{LL}) helps constrain the gluon spin contribution
- Measured using the number of π^0s (related to σ) produced in ++ vs +- configuration of polarized proton collisions
  - Will be calculated from π^0 mass plots similar to Fig. 5
  - ++: both protons in collision have spin and momentum aligned
  - +-: one proton in collision has spin and momentum aligned, and the other is anti-aligned

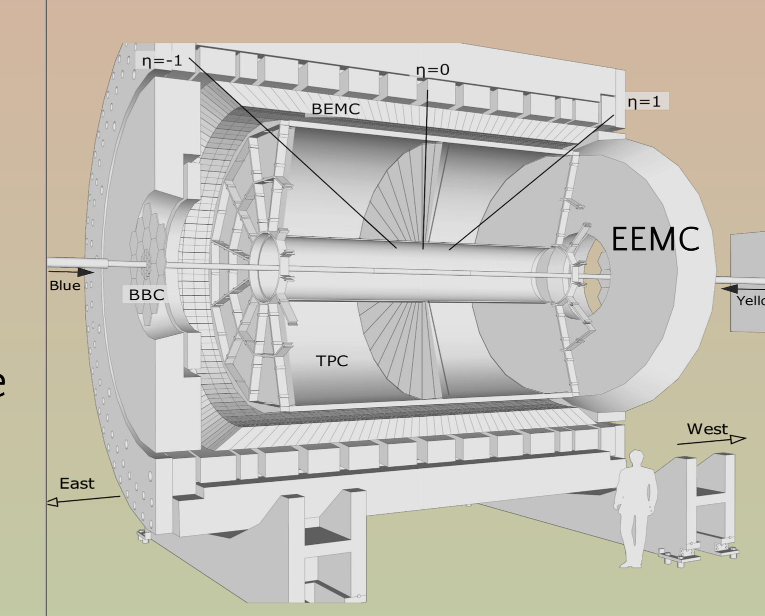


Figure 2. The STAR detector at BNL-RHIC. The EEMC is used for this analysis. It detects the energies and positions of photons to reconstruct π^0 candidates. A tower is 1 of 720 segments of the EEMC, and a tower hit means the energy detected in the tower is above the threshold.

π^0 Reconstruction

- Mass of π^0 reconstructed using:
  - Energies and positions of two photons and their opening angle
  - Conservation of energy and momentum

Invariant Mass

$$M_{\gamma\gamma} = (E_1 + E_2)\sqrt{1 - \left(\frac{E_1 - E_2}{E_1 + E_2}\right)^2 sin\left(\frac{\theta}{2}\right)}$$

Equation 3. Equation derived to calculate two-photon invariant mass.

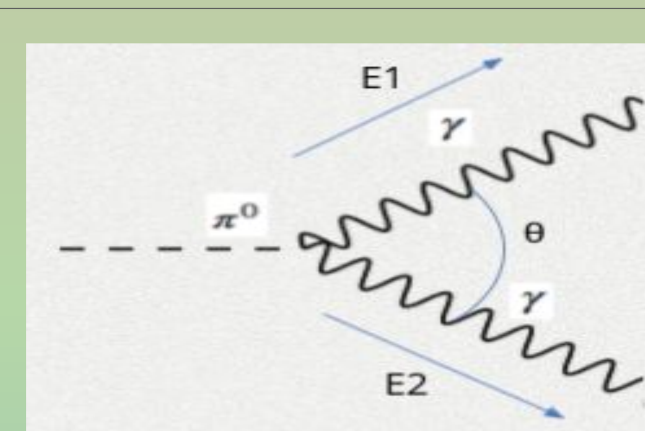


Figure 3. Feynman diagram of the neutral pions (π^0) decaying into two photons (γ) along with the resultant photons' respective energies (E1 and E2) and the angle between them (θ).

Data Reconstruction

- Raw data gathered from EEMC
  - Initially registered as electric signals
  - A more "human readable" format is imperative for physics interpretation: identified photons with momenta in appropriate units
- Data reconstruction – a multi-step process
  - Calibrate electric signal into energy (GeV)
  - Energies and positions used to reconstruct photon candidates
    - π^0s reconstructed from pairs of photons (Fig. 3)
    - Number of reconstructed π^0s allows us to calculate A_{LL}
  - Store in ROOT objects called trees

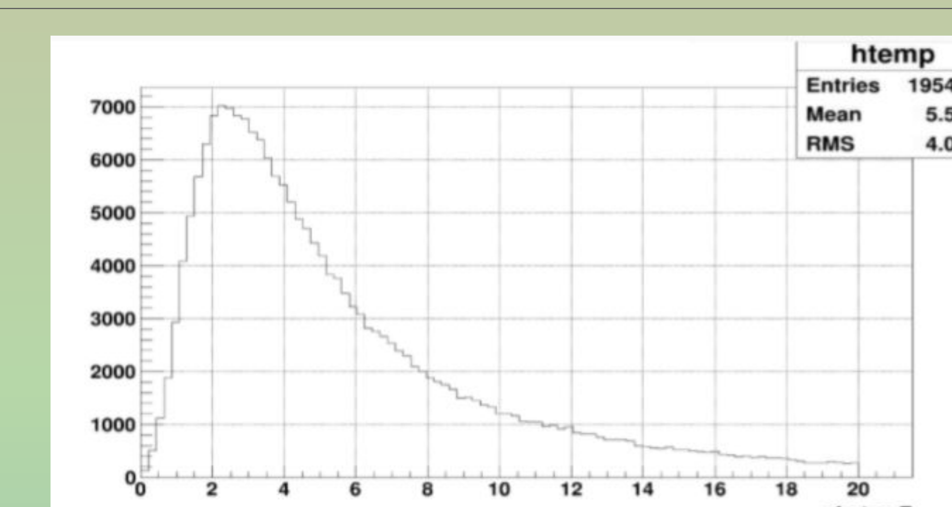


Figure 4. Number of photons vs. energy (GeV). We reconstruct π^0s from pairs of photons.

- What are trees?
  - Hierarchical structures of information
    - Trees >> Branches >> Leaves
  - Over 2000 produced for 2013 data

Run by Run Quality Assurance (QA)

- Run: data collected from about 30 minutes of collisions
- Select quality data for analysis, looking at signal fraction (Fig. 5), mean mass (Fig. 6), and number of tower hits (Fig. 7) as a function of run number
  - Flag outliers for further QA investigation
- Plot two photon invariant mass (Fig. 5) to identify signal π^0s
  - Estimate background from side band and calculate signal fraction
    - Signal fraction = S/(S+B)
    - Part of the background arises from random combinations of photons

Figure 5. Two Photon Invariant Mass (GeV/c^{2}). The peak is close to the expected π^0 mass.

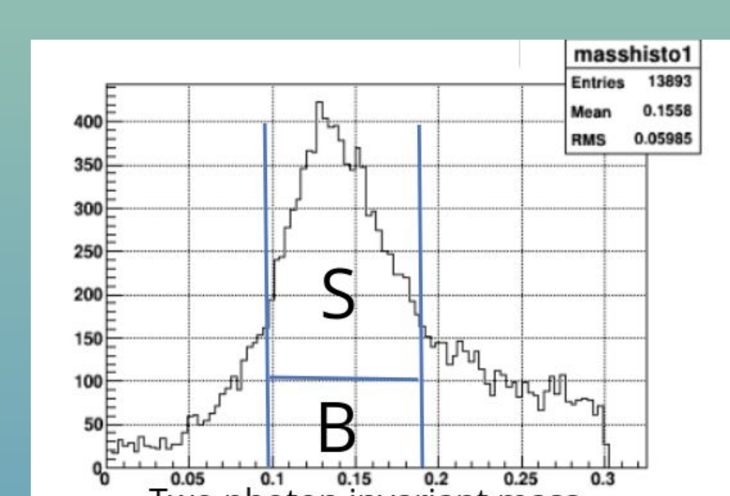
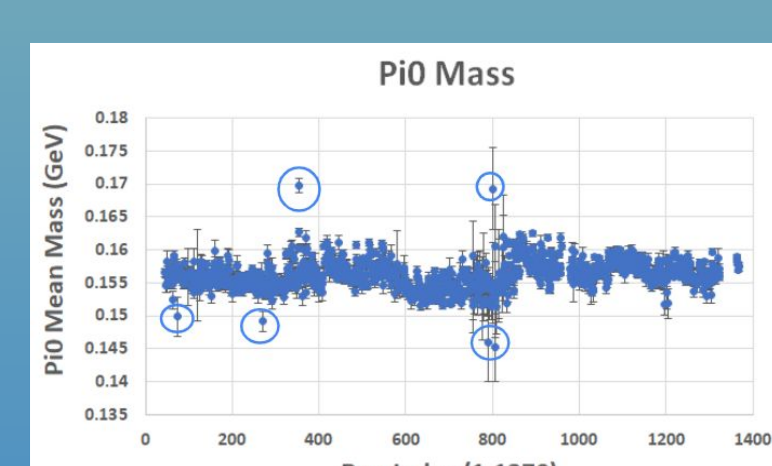
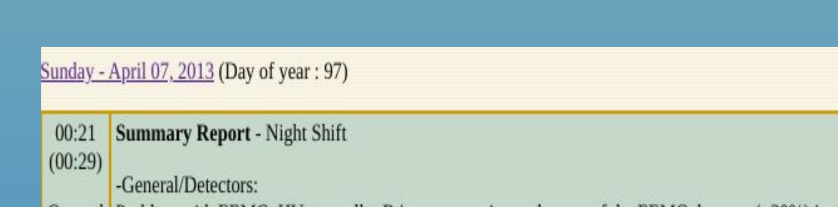


Figure 6. Plot of mean π^0 candidate mass vs. run index. The circled runs are outliers. The mean mass includes backgrounds, and is thus higher than the expected π^0 mass.



QA Investigation

- Investigate outliers (Fig. 6, 7)
  - Check error bars for low statistics
  - Check STAR run log and shift log QA plots for detector issues
- White space (Fig. 8): no EEMC tower hits
  - Small white regions: low statistics
  - Large white regions: indicates section of EEMC was off



Sunday - April 07, 2013 (Day of year : 97)

00:21 (00:29) **Summary Report** - Night Shift

-General/Detectors:

General Problem with EEMC: HV controller B is unresponsive and a part of the EEMC detector (~30%) is off.

Figure 9. STAR run log entry confirming ⅓ EEMC was off for Fig. 8.

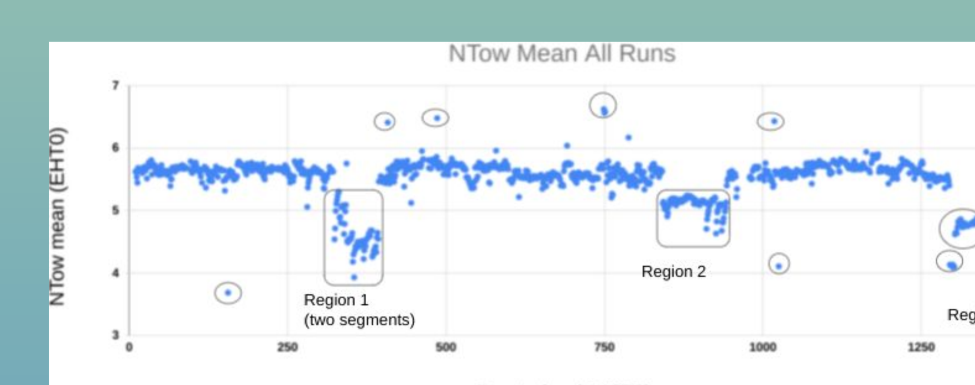


Figure 7. Number of EEMC Tower Hits vs Run Index. There are three regions with a lower mean number of tower hits. Sections of the EEMC were off during those periods.

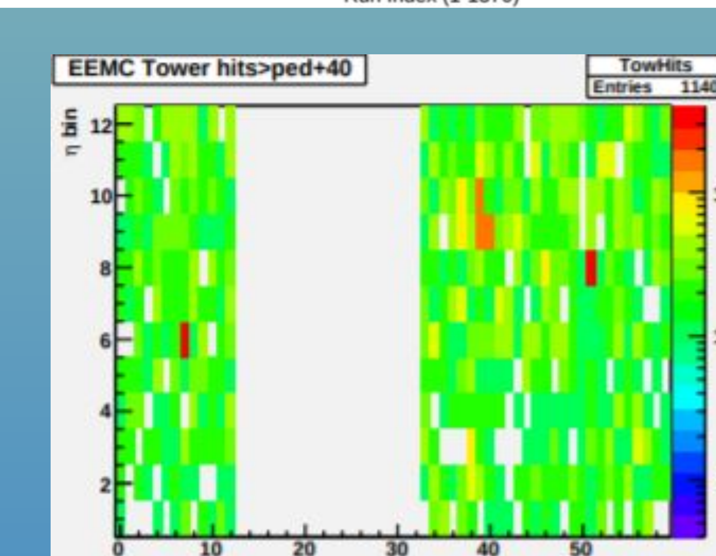


Figure 8. EEMC tower hits from run log QA plot. In this plot, ⅓ of the EEMC was off.

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