Determining the Longitudinal Double-Spin Asymmetry (A_{LL}) for π^0 and η Production from STAR 2013 Endcap Calorimeter Data

Emily Nelson, Madison Wallner, and Roshan Gautam on behalf of the STAR Collaboration
Mentors: Profs. Shirvel Stanislaus, Adam Gibson, David Grosnick, Donald Koetke, Paul Nord

Proton Spin and the STAR Experiment

- The intrinsic spin of the proton is known to be ½ ħ.
  - Quark spins contribute ~30% of the spin.
  - Gluon spins appear to contribute significantly.
- At RHIC (Relativistic Heavy Ion Collider) we collide longitudinally polarized protons.
- For this analysis, we use the 510 GeV data set taken in 2013 with the Endcap Electromagnetic Calorimeter (EEMC) of the STAR (Solenoid Tracker at RHIC) detector.
- We are interested in the neutral pions (π^0s) and η particles produced from the collisions.
  - π^0s and ηs decay into two photons which the EEMC can detect.
- With the known polarization and luminosity of the beams and the number of π^0s and ηs detected, we can calculate the asymmetry of π^0 and η production (A_{LL}). This is one of the goals of the STAR spin program as A_{LL} can be related to the gluon spin contribution to proton spin.

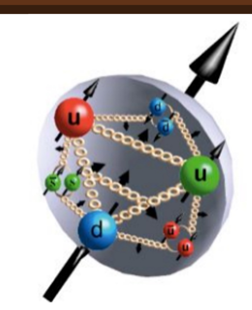

Figure 1: A diagram of the proton's composition.

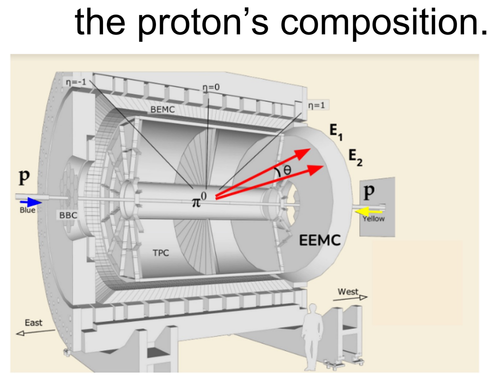

Figure 2: The STAR detector.

$$\frac{1}{2}\hbar = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$

quark spin — gluon spin — quark angular momentum — gluon angular momentum

Equation 1: The spin of the proton (½ ħ) as a sum of four components.

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π^0 and η Extraction

- The invariant mass of π^0 (η) particles can be calculated from the energies of the two photons into which they decay, and the angle between the two photons (Equation 2).

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

Equation 2: The invariant mass ($M_{\gamma\gamma}$) of a π^0 (η) calculated based on the two photon energies (E_1 and E_2) and the angle between them θ.

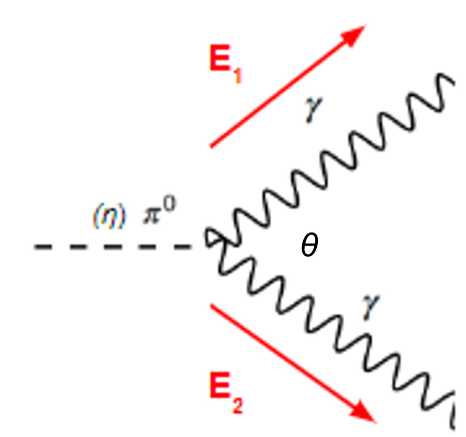

Figure 3: A Feynman diagram depicting a π^0 (η) decaying into two photons (γ). The red lines represent E_1 and E_2, the momentum/energy of each photon.

- The mass of a π^0 particle is known to be 0.135 GeV/c^2
- The mass of an η particle is known to be 0.548 GeV/c^2
- Using this information, we can measure the number of π^0s (ηs), an essential factor in calculating the asymmetry of π^0 (η) production (A_{LL}).

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Asymmetry

- We use the following equation to calculate the asymmetry (A_{LL}) of π^0 and η production from collision of longitudinally polarized protons.

$$A_{LL} = \frac{1}{P_B P_Y}\frac{(N^{++} - R_3 N^{+-})}{(N^{++} + R_3 N^{+-})}$$

- N is the total number of π^0s (ηs) measured for different spin alignments
- N^{++} (N^{--}) = both colliding protons have their spin aligned (anti-aligned) with their momentum
- N^{+-} (N^{-+})= one colliding proton has its spin aligned with its momentum; the other proton has its spin anti-aligned with its momentum
- P_B = polarization of the RHIC "blue" beam
- P_Y = polarization of the RHIC "yellow" beam
- R_3 = luminosity ratio of the two spin configurations (N^{++} and N^{+-})

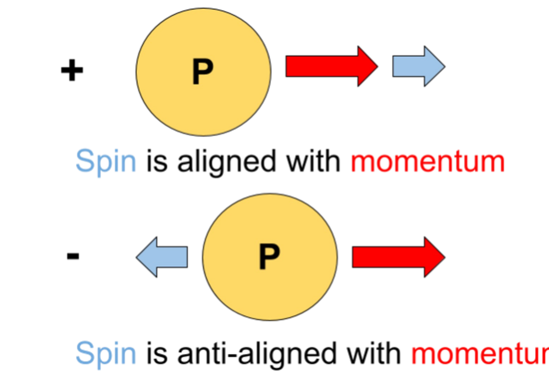

Figure 4: A visual representation of the spin of a particle being aligned or anti-aligned with its momentum

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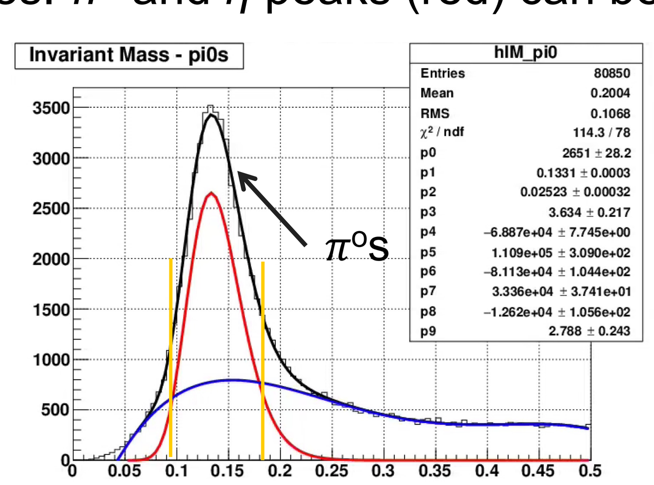
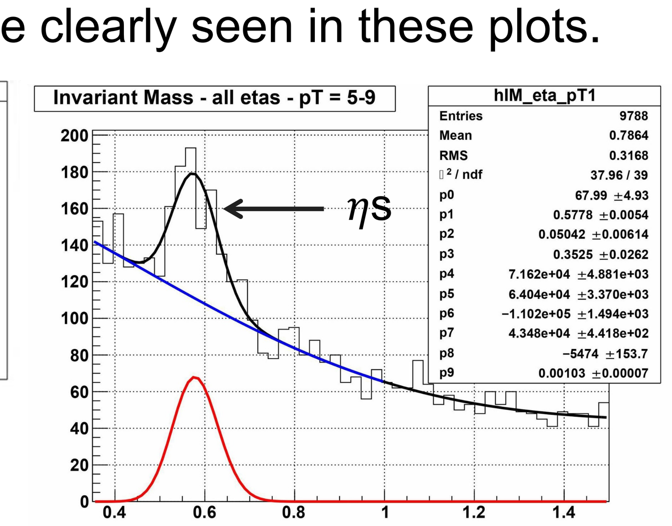
Quality Assurance (QA)

- A fill corresponds to bunches of protons injected into the two RHIC rings and left to collide until their numbers are too small (~6 hr). A data collection run lasts ~30 min; an average of ~12 runs from one fill.
- Quality assurance (QA) checks are done first at the run level and then at the fill level
  - In run-level QA we look at observables related to π^0 (η) mass and the signal to background ratio, and remove any outlier runs 4σ away from the mean of that observable for all runs.
  - In fill-level QA we fit the measured two-photon invariant mass spectrum with the sum of a π^0 (η) signal function (skewed Gaussian) plus a background function (5th order Chebyshev polynomial).
  - Figures 5 and 6 show two photon invariant mass spectra at different mass scales. π^0 and η peaks (red) can be clearly seen in these plots.

Figures 5 (left) and 6 (right): Two photon invariant mass spectra showing the π^0s and ηs





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Invariant Mass

- Figure 7 shows the reconstructed π^0 mass from fitting for all analyzed fills
- The trend lines show a gradual drop in the detector gains
  - This could be due to a degradation of the detector performance with time.
  - The sudden rise is due to that the detector response was recalibrated.

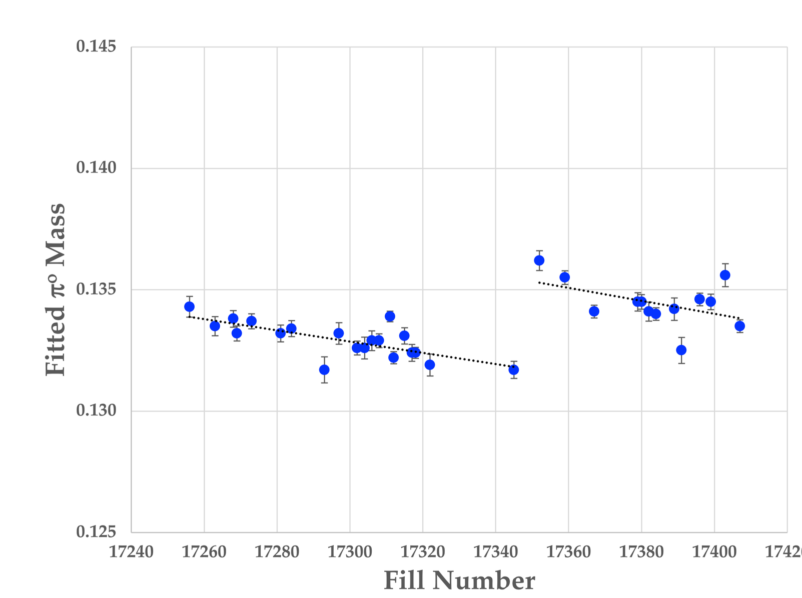

Figure 7: Fitted π^0 mass vs Fill Number

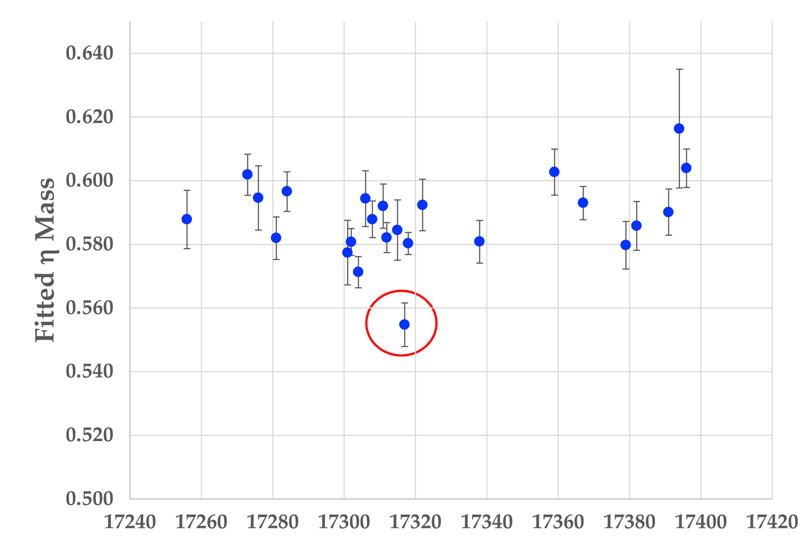

Figure 8: Fitted η mass vs Fill Number

- Figure 8 shows the reconstructed η mass from fitting for all analyzed fills
- Fills that have significantly different values, such as the fill circled on figure 8, are closely examined.
- Larger error bars are due to fewer ηs produced in the collisions.

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Signal Fraction

- The signal fraction (Figures 9 and 10) is the number of π^0s (ηs) within 2σ of the π^0 (η) peak divided by the total number of candidates in this region.
- Figures 5 and 6 show the results of the fit to the data:
  - π^0 candidates that are within 2σ (gold lines) in Figure 5
  - π^0 (η) signal function = red line
  - Background function = blue line
  - Sum of signal + background = black line (matches the measured data of the histogram)

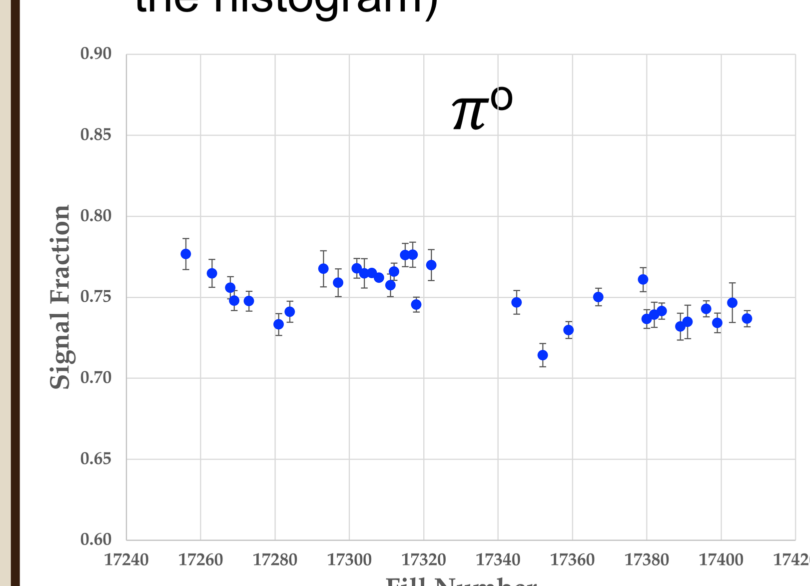

Figure 9: π^0 signal fraction vs. fill number. The signal fraction of π^0 production is around 0.75. This is similar to the results from the 2012 data set.

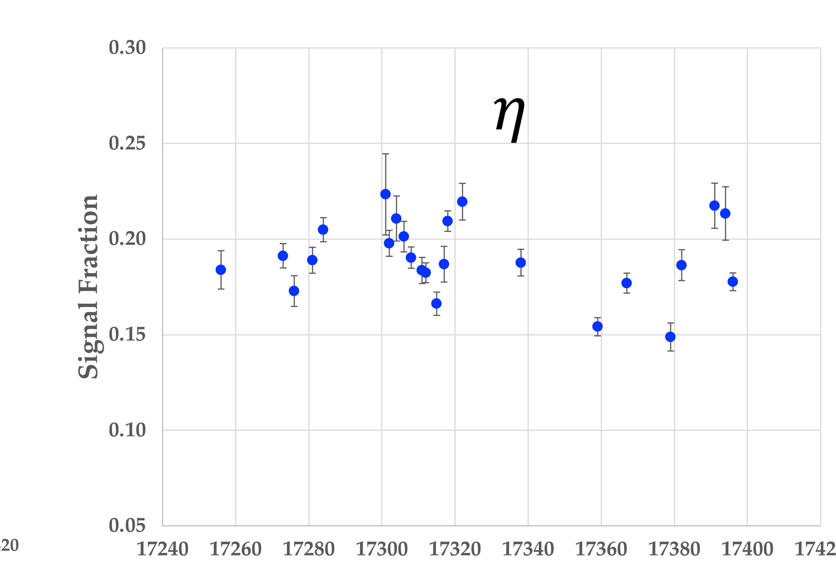

Figure 10: η signal fraction vs. fill number. The signal fraction of η production is around 0.2. It is lower than that for π^0s due to the larger background.

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