Investigating π^0 and η Production From STAR Endcap Calorimeter Data

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Proton Spin and the STAR Experiment

- A major goal of the STAR Experiment at Brookhaven National Laboratory is understanding the **gluon spin contribution to the proton's spin**
  - **A proton contains quarks and gluons whose individual spins contribute to an overall spin of ½ ħ**
- At the Relativistic Heavy Ion Collider (RHIC), high-energy polarized proton beams are collided, producing a large number of pions (π^0) and eta (η) mesons
- These particles promptly decay into two photons whose energies and positions are measured by the Endcap Electromagnetic Calorimeter (EEMC), which has a pseudorapidity range of $1.1 < \eta < 2.0$
  - Within the EEMC, pairs of photons are **combined** to calculate the **invariant mass** of the particles from which they decayed

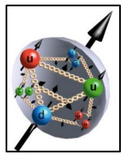


Fig. 1: A diagram of the proton's composition

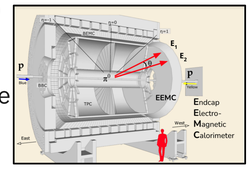


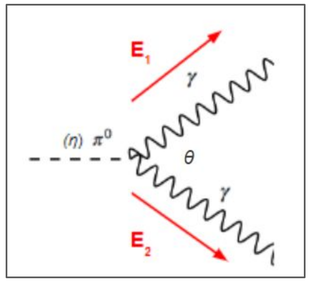
Fig. 2: The STAR detector with EEMC labeled

Fig. 3: Proton spin sum: A proton's spin is the sum of the spins and orbital angular momenta of its constituents

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

π^0 and η Extraction

- The invariant mass of π^0 and η particles can be reconstructed from the **energies** and **opening angle** of the two photons which they decay from



$$M_{\gamma\gamma} = 2\sqrt{E_1 E_2}\,\sin\left(\frac{\theta}{2}\right)$$

Fig. 4: The invariant mass of a π^0 and η is calculated using the two photon energies and the opening angle between them

Fig. 5: A Feynman diagram depicting a π^0 decaying into 2 photons (γ). The red lines represent the momentum and energies of each photon

- The mass of a π^0 particle is known to be **0.135 GeV/c²**
- The mass of an η particle is known to be **0.548 GeV/c²**
- 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})**

Asymmetry

- **Asymmetry:** The fractional difference of π^0 cross-sections in the collision between polarized proton beams with differing helicity (spin) states
- If the asymmetry is **nonzero**, then the production of π^0s and ηs depends on the **spin alignment of the protons at collision**
- We use the following equation to calculate the asymmetry (A_{LL}) of π^0 and η production from the collision of longitudinally polarized protons

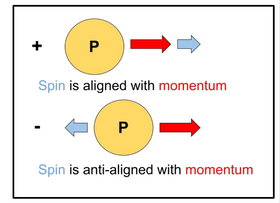


Fig. 6: A visual representation of the spin of a particle being aligned or anti-aligned with its momentum

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

- **N** = total number of π^0s (ηs) measured for different spin alignments
- $\mathbf{P_B}$ = polarization of the RHIC "blue" beam
- $\mathbf{P_Y}$ = polarization of the RHIC "yellow" beam
- $\mathbf{R_3}$ = luminosity ratio of the two spin configurations (N^{++} and N^{+-})

Fill-Level Quality Assurance (QA)

- The **main goal** of Fill-Level Quality Assurance is to ensure that **fill data** is **good enough** to be used in **asymmetry calculations**
  - A "fill" is a physical batch of protons that is loaded into the RHIC rings
  - These batches must be periodically dumped and reloaded to **maintain polarization**
- Invariant mass histogram fits are created for **control** and **outlier** fill data sets
  - These fits are then **compared** between each other in order to determine the overall quality of the histograms
  - π^0 and η fits are created using a **skewed Gaussian** (red lines) with a 5th order **Chebyshev polynomial** (blue lines) that fits the background

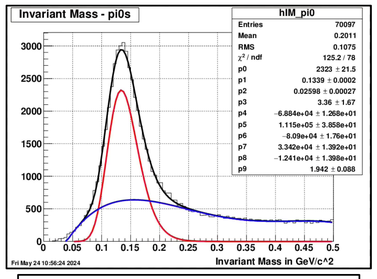


Fig. 7: A fit π^0 invariant mass histogram

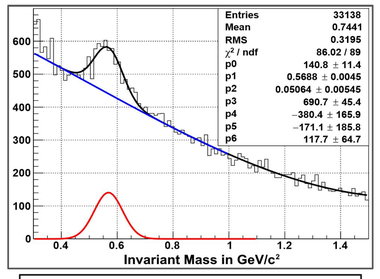


Fig. 8: A fit η invariant mass histogram

Invariant Mass

- Fig. 9 displays the **fitted π^0 invariant mass** for each investigated fill (from *pp* collisions at √s = 510 GeV) in the 2013 dataset
- The trend lines show **detector degradation** over time
  - Sudden changes in the π^0 invariant mass show **recalibration** of the EEMC

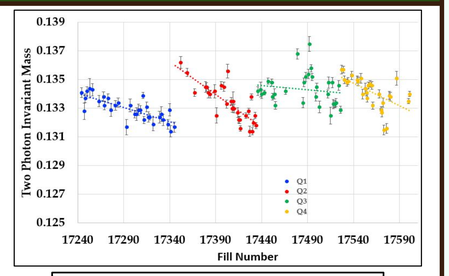


Fig. 9: π^0 Invariant Mass v. Fill Number

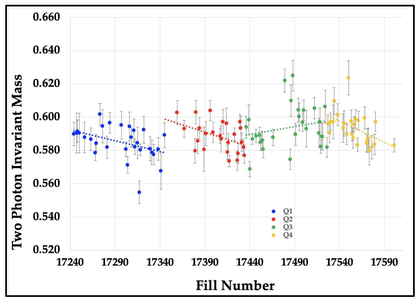


Fig. 10: η Invariant Mass v. Fill Number

- Figure 10 is an invariant mass vs. fill number plot for the ηs of the **2013** data set
- Notice in Fig. 10 the error bars are much larger than in Fig. 9, this is due to there being **much less η production** in the collisions of protons

Signal Fraction

- Signal fraction refers to the **number** of π^0s and ηs **within 2σ** of the fitted peak **divided** by the **total number of candidates** within this region
- Data from the 2013 data set shows that the signal fraction for π^0s typically resides around **0.75** while the signal fraction for ηs lies just under **0.2**
  - η signal fraction tends to be **lower** due to a larger background

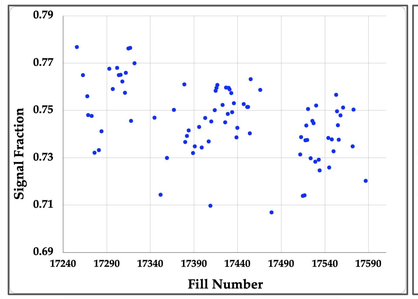


Fig. 11: Signal Fraction v. Fill Number for π^0s in 2013 data set

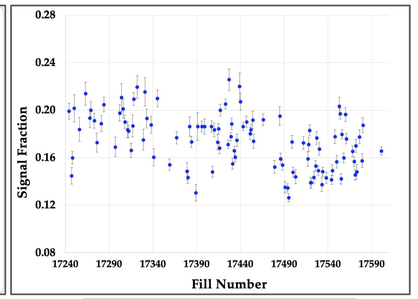


Fig. 12: Signal Fraction v. Fill Number for ηs in 2013 data set

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Supported in part by U.S. DEPARTMENT OF ENERGY | Office of Science