Measuring Longitudinal Double-Spin Asymmetry A_{LL} for η Mesons with 2012 STAR Endcap Calorimeter Data

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STAR Project

We at STAR (Solenoidal Tracker At RHIC) are exploring the contribution of the spin of the gluon to the proton's spin. A proton is made up of both quarks and gluons, with total spin known to be ½ ħ. The intrinsic spin of quarks (Σ_q in Eq. 1) has been measured to contribute approximately 30% to the total spin, while the gluon intrinsic spin contribution (Σ_g) and orbital momentum contributions (L_q, L_g) are not well known. To study this contribution, we use data from the longitudinally polarized proton beams collided at RHIC (Relativistic Heavy Ion Collider) at Brookhaven National Lab. We measure the longitudinal double spin asymmetry (A_{LL}) in production of neutral pions (π^0) and eta (η) particles in proton-proton collisions at 510 GeV.

A_{LL} is the primary goal of this research because it is proportional to the gluon spin contribution. At STAR, we specifically use the Endcap Electromagnetic Calorimeter (EEMC, Fig. 1) to identify photons from particle decays and determine the number of particles as a function of spin state.

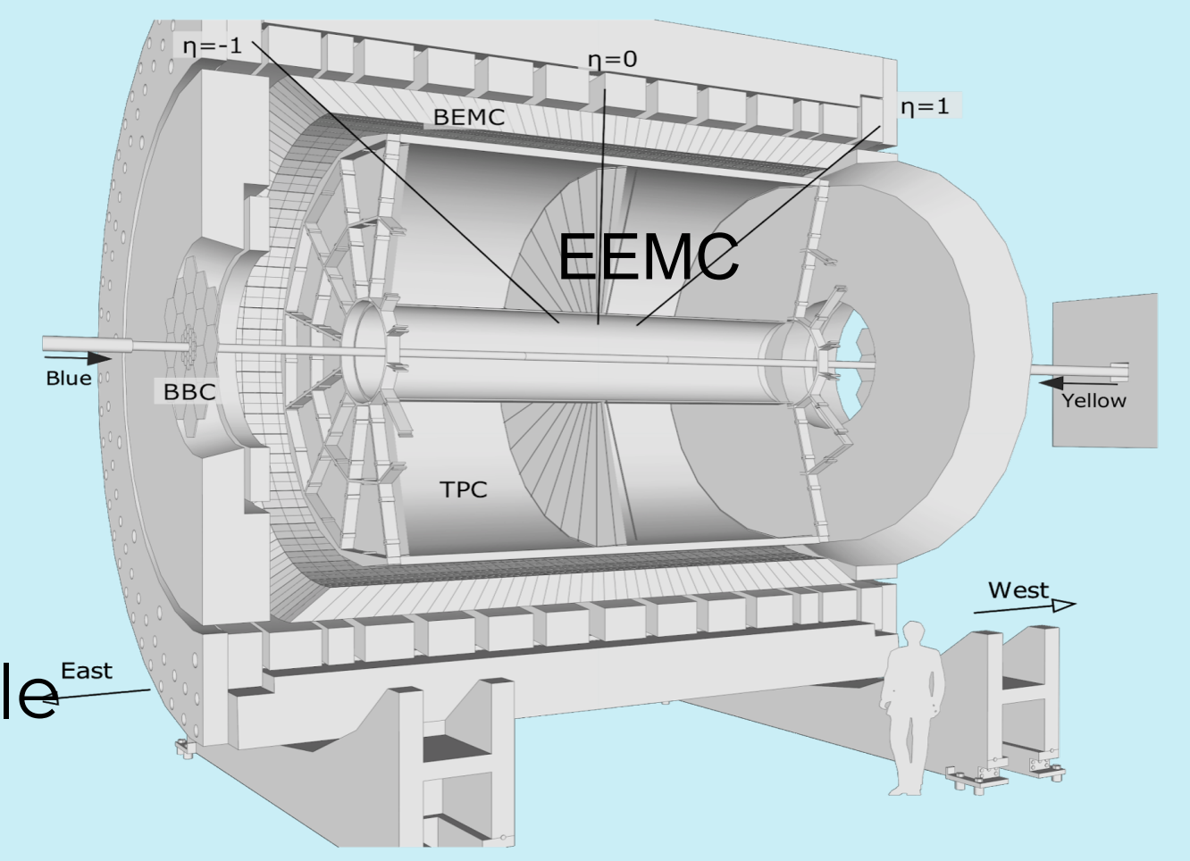


Fig. 1: The STAR Detector

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

Eq. 1: The composition of a proton's spin

Asymmetry (A_{LL})

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

Eq. 2: The equation to calculate asymmetry A_{LL}

- Defined in Eq. 2
- Proportional to the gluon spin contribution
- Calculated using the number of particles resulting from a collision (N)
  - N^{++} refers to that spins of the protons are aligned in the direction of their momenta (Fig. 2). N^{+-} is when one proton is aligned and other is anti-aligned
  - N is obtained from particle reconstruction
- P is the beam polarization and R_3 is the luminosity ratio of the two spin configurations.
  - Polarization at RHIC is around 50-60%

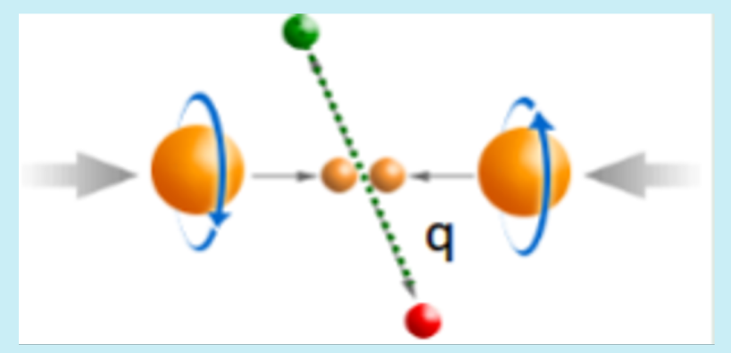


Fig. 2: A cartoon of alignment of proton spin with momentum. The image pictured has both protons aligned.

Endcap Electromagnetic Calorimeter

- The EEMC is made up of 720 towers, located at one side of the STAR detector
- The towers are made up of layers of lead and scintillator (Fig. 3)
- The photons that result from η decay are neutral particles and cannot be detected directly
  - Photons undergo pair production and Bremsstrahlung, producing electrons and positrons, which can be detected
  - This process creates an electromagnetic shower (Fig. 4)
- Positioned within the lead scintillator sandwich is the Shower Maximum Detector (SMD)
  - The SMD is positioned where the most particles are produced, and records their positions, which are used to calculate the invariant mass

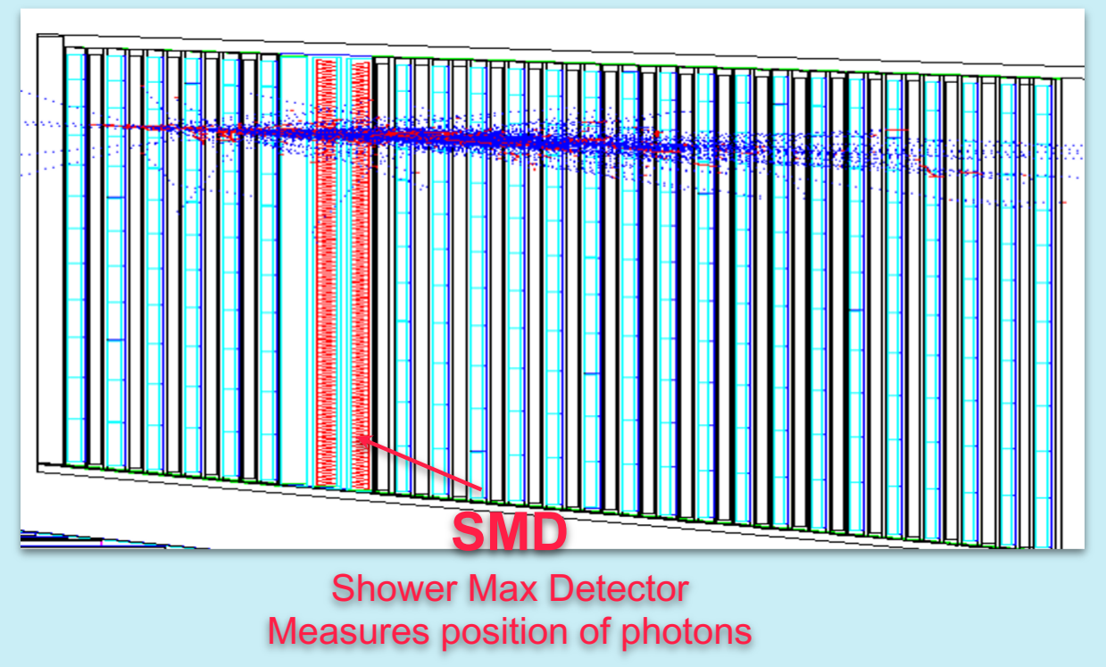


Fig. 3: The SMD and representation of a EM shower within the lead scintillator sandwich in each tower of the EEMC.

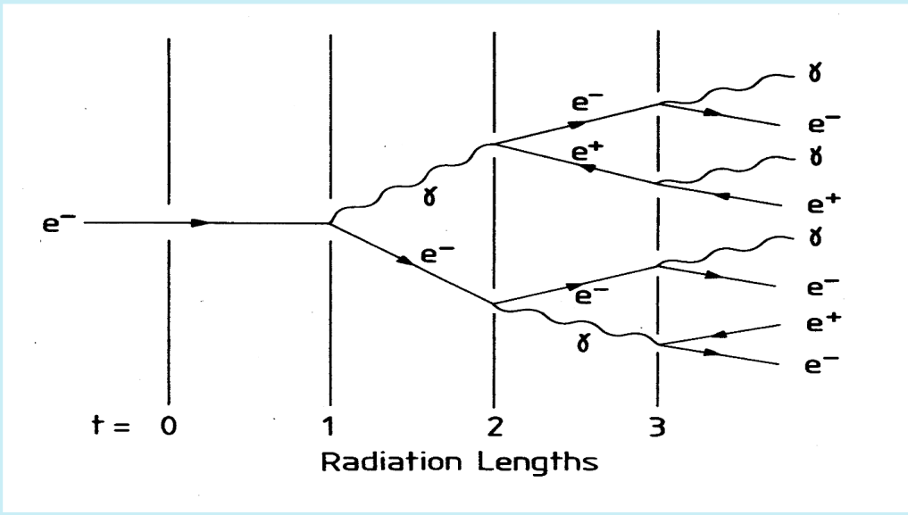


Fig. 4: A diagram showing pair production, Bremsstrahlung radiation, and the chain reaction relationship between them.

η Particles

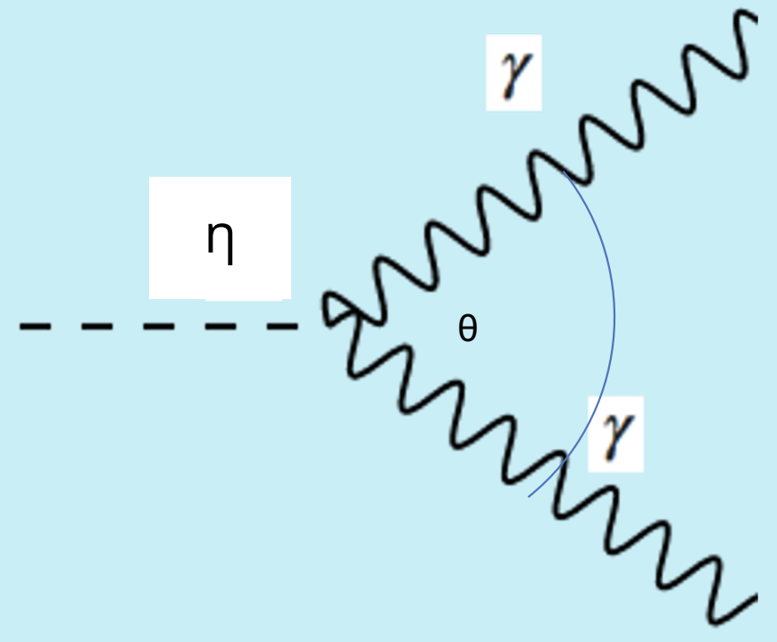


Fig. 5: The decay of an η particle

- Mass: 547.862 ± 0.018 MeV/c²
- Mean lifetime: (5.0 ± 0.3) ×10^{-19} s
  - Decays almost instantaneously into two photons (Fig. 5)
  - Photons' positions and energies measured by the EEMC
- Photons are paired up and their energies (E_1 and E_2) and opening angle (θ) are used to calculate the invariant mass (Eq. 3)

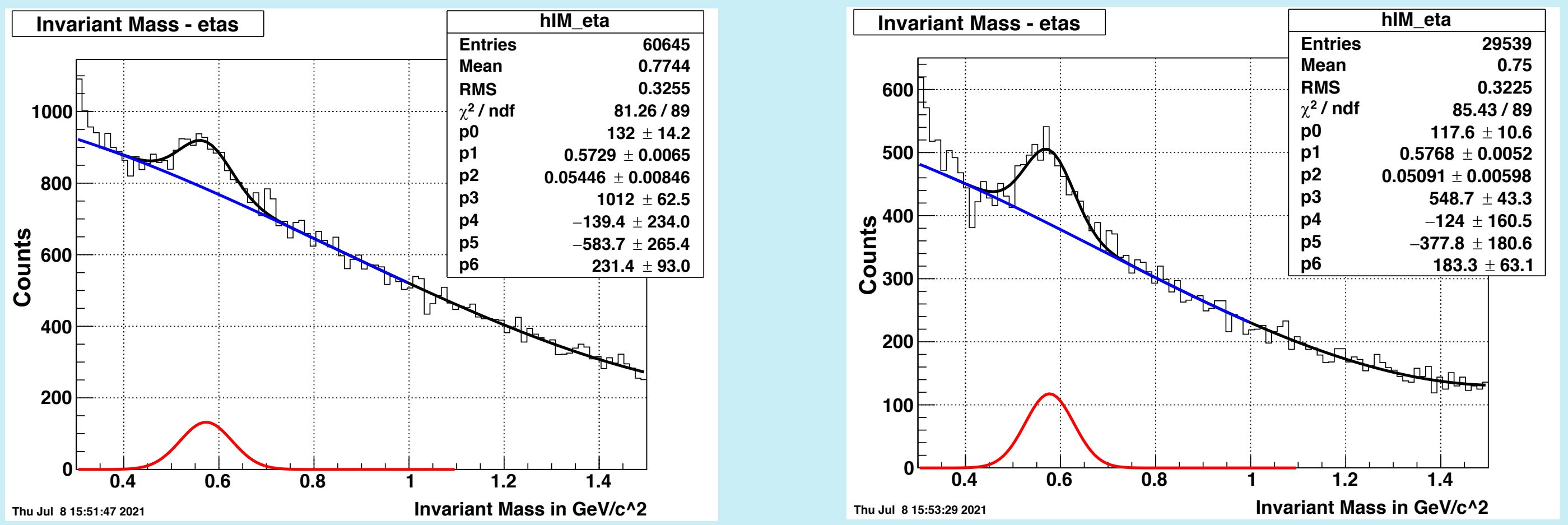
$$M_{\gamma\gamma} = (E_1 + E_2)\sqrt{1 - \left(\frac{E_1 - E_2}{E_1 + E_2}\right)^2}\,\sin\left(\frac{\theta}{2}\right)$$

Eq. 3: Two-photon invariant mass

- If the resultant invariant mass equals the expected mass of an η particle (within resolution) the two photons could have originated from the same η particle

Reconstruction of η

- We are analyzing the 510 GeV data taken in 2012 with the STAR detector.
- The two-photon invariant mass is plotted as a histogram, which is fit for the background and η signal (Fig. 6 and 7)
  - The signal is fit with a Gaussian function $f = ae^{-0.5\left(\frac{x-b}{c}\right)^2}$ plotted in red
  - The background is fit with a polynomial $f = a + bx + cx^2 + dx^3$, plotted in blue
  - The fit to the data is the sum of these functions, plotted in black
- These fits are performed in two different ways
  - One fit allowed all photons in each sector of the EEMC
  - The second fit allows a max of two photons in each sector of the EEMC
- The all-photon fit yields more signals, but a lower signal fraction (~12%) because of higher background
- The two-photon fit provides a higher signal fraction (~20%), but fewer particles, because of the reduction in photon count



Figs. 6 (left) and 7 (right): Examples of fits of the η particle signal. Figure 6 demonstrates the all-photon fit, with a higher number of signals, but more background. Figure 7 demonstrates the two-photon fit, with a lower background.

Code Optimization and QA

- Particle reconstruction code is written and optimized for π^0 particles
- Several parameters (minimum energy of a photon, minimum energy of a SMD cluster, energy in the pre shower) needed to be optimized for η particles
- Each parameter is optimized separately, keeping the others constant
- The results are used to select optimum values for maximizing the number of η particles and signal fraction (particle signal / total signal) (Figs 8 and 9)

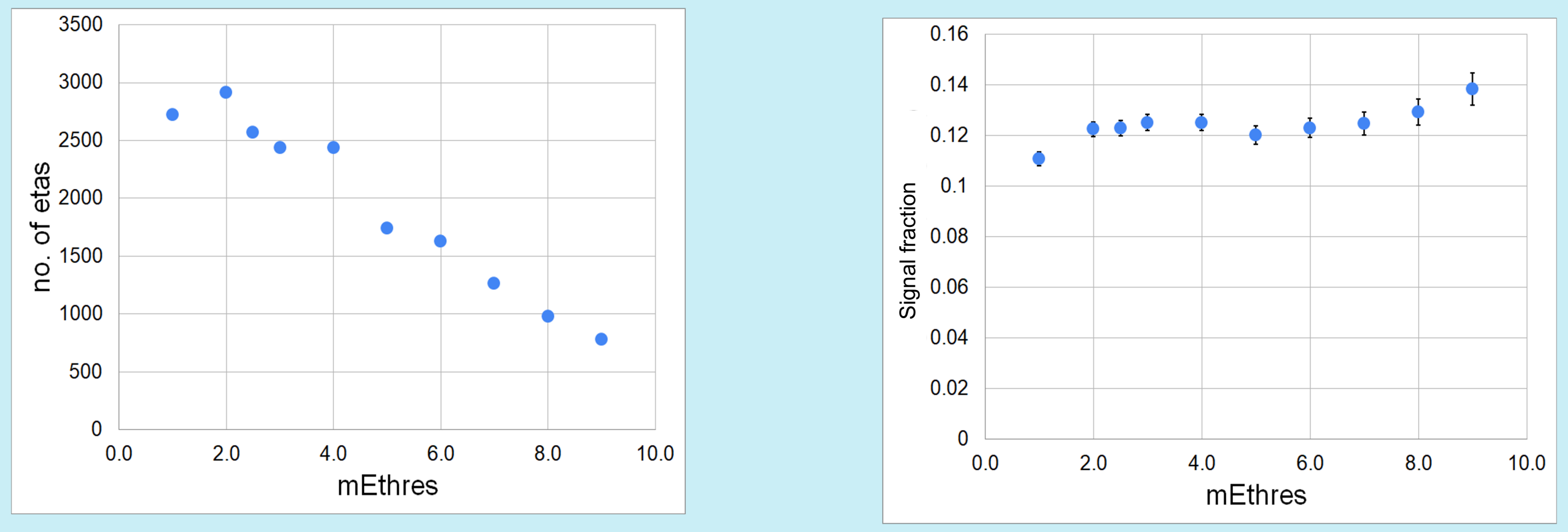


Fig. 8 (left) and 9 (right): Graphs of number of η particles and signal fraction vs the parameter mEthres, the minimum energy of a photon. Similar graphs are used for optimizing the other parameters.

- Fill-by-fill quality assurance is carried out to ensure the data was consistent between fills (Fig. 10 and 11)

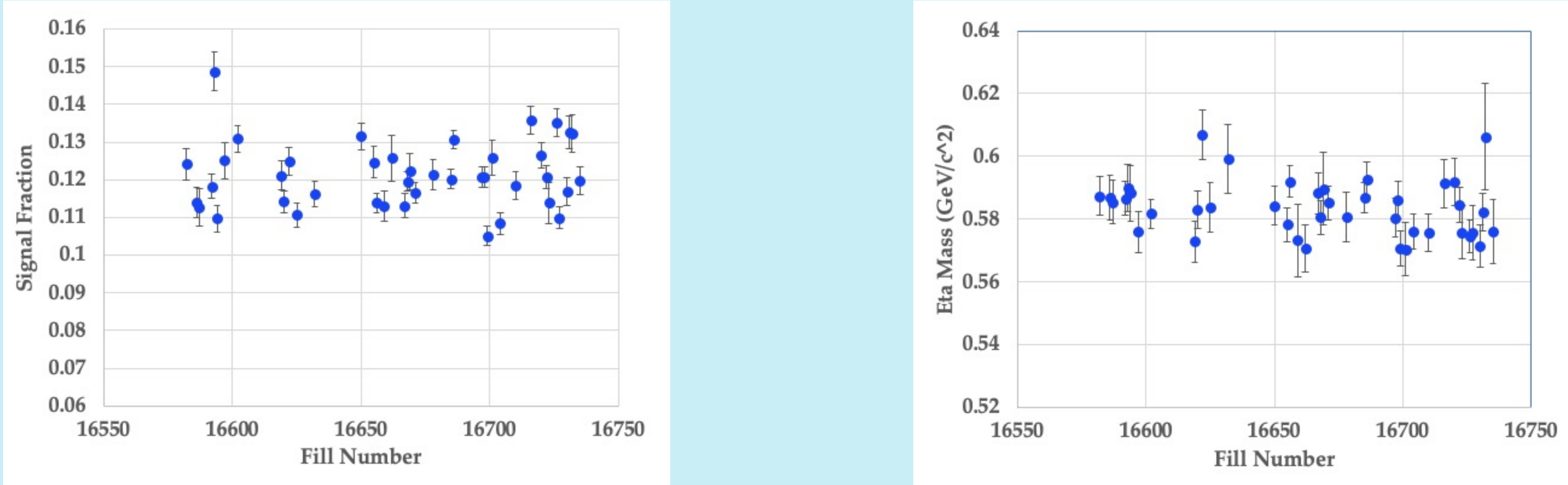


Fig. 10 (left) and 11 (right): Signal fraction and η mass vs fill number.

Acknowledgements

Valparaiso University Physics and Astronomy Department
U.S. Department of Energy STAR Collaboration

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

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