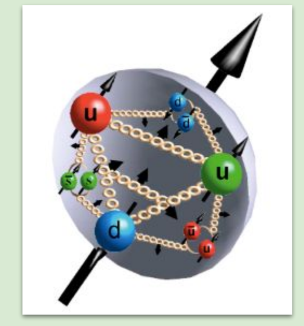
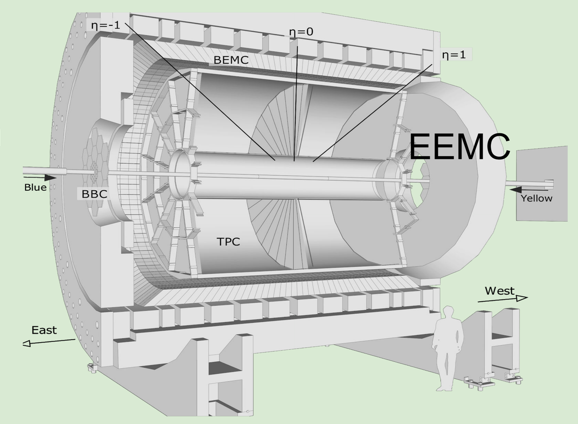
Nuclear and Particle Physics at Valparaiso University Summer 2021

Analyzing Proton Spin Contribution with STAR



One goal of STAR (Solenoidal Tracker At RHIC) is exploring the contributions to the proton's spin. A proton is made up of both quarks and gluons (pictured at right), which must contribute to its spin. The spin of a proton is known to be ½ ħ, with the intrinsic spin of quarks (Σ_g below) contributing approximately 30% of the total spin, while the gluon intrinsic spin contribution (Σ_g) and orbital momentum contributions (L_q, L_g) are unknown. To make these measurements, we use data from the longitudinally polarized proton beams collided at RHIC (Relativistic Heavy Ion Collider) at Brookhaven National Lab. From there we measure the asymmetry (A_{LL}) in particle production of neutral pions (π^0) and eta (η) particles from differently spin aligned collisions. A_{LL} is the primary target of this research because it is proportional to the gluon spin contribution. At STAR, we specifically use the Endcap Electromagnetic Calorimeter (EEMC, right) to identify photons from the particle decays and determine the number of particles as a function of spin state.

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



The Search for the Neutron Electric Dipole Moment (nEDM)

The search for the nEDM is an important test of the Standard Model (SM) of particle physics, as well as the many proposed extensions to the model. The SM predicts the value of the nEDM to be ~ 10^{-31} $e \cdot$cm. However, in extensions of the SM, such as supersymmetry, larger values are predicted. The experiment at Oak Ridge National Laboratory (ORNL) expects to search for the nEDM at the level of ~ 3 × 10^{-28} $e \cdot$cm. One observable that is sensitive to the nEDM is the precession frequency of ultracold neutrons in a strong electric field and a weak magnetic field. The change in frequency when the electric field is reversed is proportional to the value of the nEDM and the strength of the electric field. By using a stronger electric field and reducing background noise, the collaboration expects lower the current experimental limit by two orders of magnitude. This new experimental limit will provide a rigorous test of extensions to the SM that predict a larger nEDM.

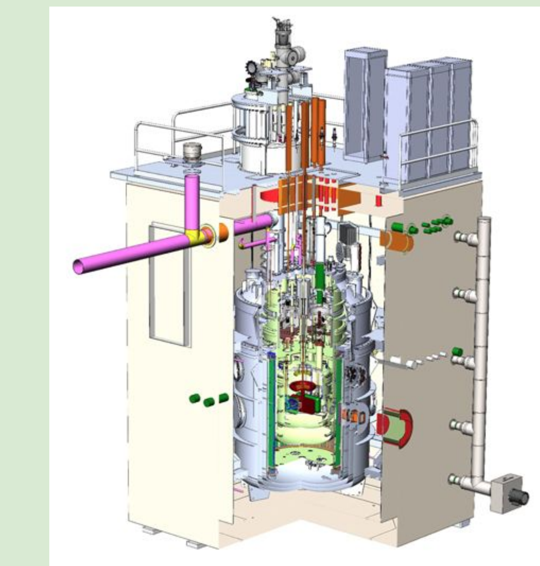


Fig. 1: The proposed design of the nEDM apparatus.

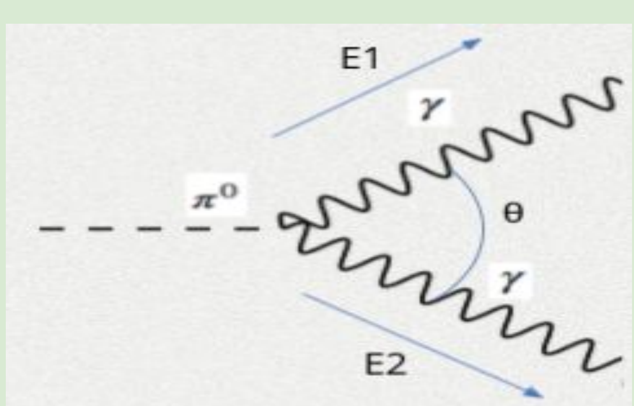
Tree Production of 2013 Neutral Pions Data

Nick Gilles

Mentors: Dr. Adam Gibson-Even and Mr. Paul Nord

- Raw data gathered from EEMC
  - Initially registered as electric signals
  - A more "human readable" format is imperative for physics interpretation
- Trees - two step process
  - Calibrate data into energy units (GeV)
  - Energy quantities used to find number of photon candidates
    - Neutral pion reconstructed from two photons

Fig 2: Feynman diagram of the neutral pion's (π^0) decay into two photons (γ). The mass of the neutral pion is found using the energies of the two photons (E1 and E2) and the angle between them (θ).



- The number of photon candidates per spin state lets us calculate A_{LL}
  - Related to the gluon spin contribution to the proton's spin

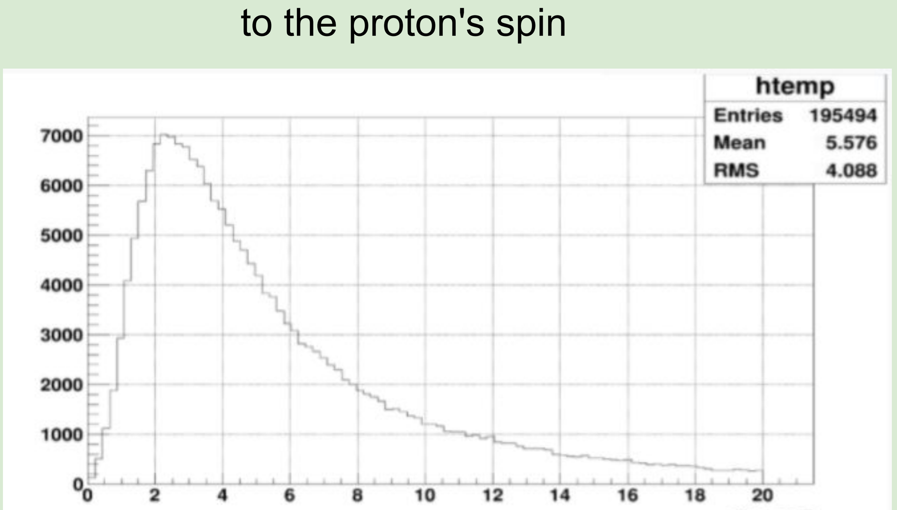


Fig 3: Number of photons vs. energy (GeV). We reconstruct neutral pions from pairs of photons.

- Over 1200 trees produced for 2013 data so far

Run-by-Run Quality Assurance of 2013 Neutral Pions Data

Marcus Engstrom

Mentor: Dr. Adam Gibson-Even

- Select good data for analysis
- Plot two photon invariant mass (Fig. 4)
  - Invariant mass is to identify signal π^0s
- Calculate a rough estimate of the signal fraction
  - Signal fraction = S/(S+B)
  - Part of the background is photons from different π^0s

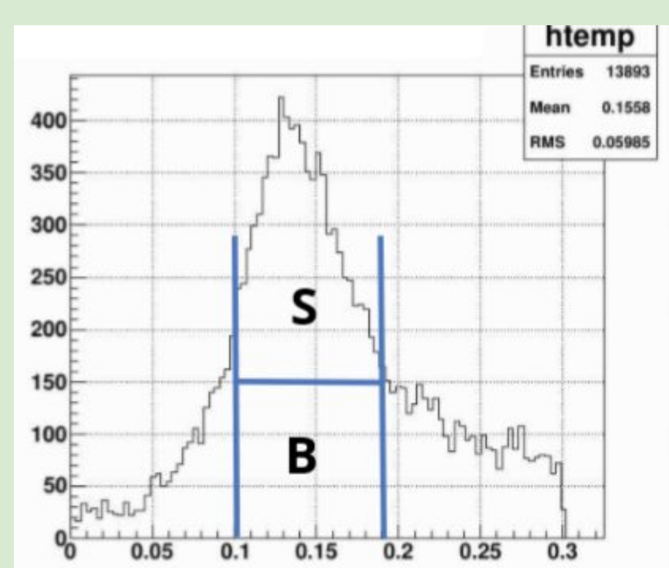


Fig. 4: Two Photon Invariant Mass
The peak is the close to the expected π^0 invariant mass.

- Plot π^0 mean mass run by run
- Run: Data for about 30 minutes of collisions
- Identify outliers
  - Flag for further investigation

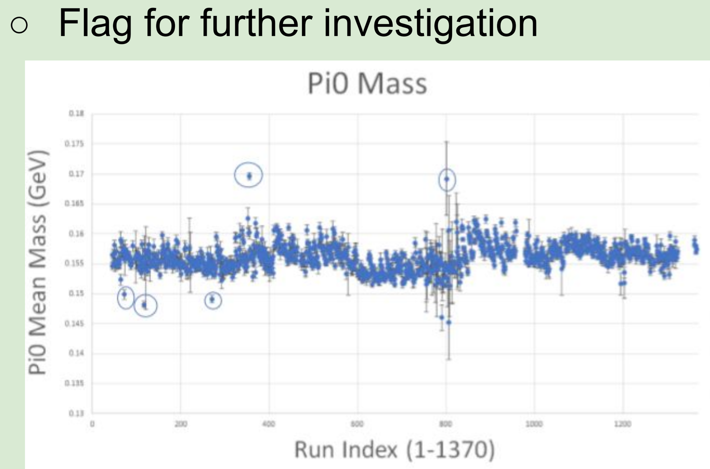


Fig. 5: Mean π^0 Mass vs. Run Index Number
The circled runs are outliers. The mean mass ignores backgrounds, and is thus higher than the expected π^0 mass.

Fill-by-Fill Quality Assurance of 2013 Neutral Pions Data

Brook Burbridge

Mentor: Dr. Shirvel Stanislaus

- Fill: Given set of protons to be collided in the RHIC rings
- Analyze data from 2013 longitudinally polarized proton-proton collisions
- Two photons produced from π^0 decay
  - Two-photon invariant mass spectrum is reconstructed to find number of π^0s created
- Skewed Gaussian function represents the π^0 signal
- Chebyshev polynomial characterizes random two-photon background

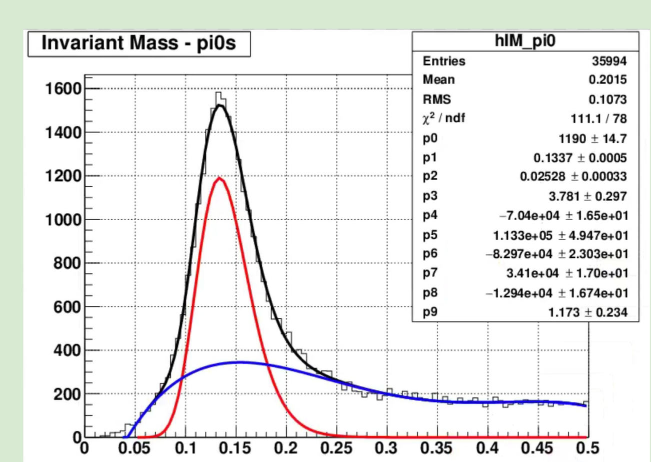


Fig. 6: Plotting invariant mass vs. number π^0s. Chebyshev polynomial for background fit (blue) and skewed Gaussian for data (red).

- Tests authenticate the quality of the data being analyzed

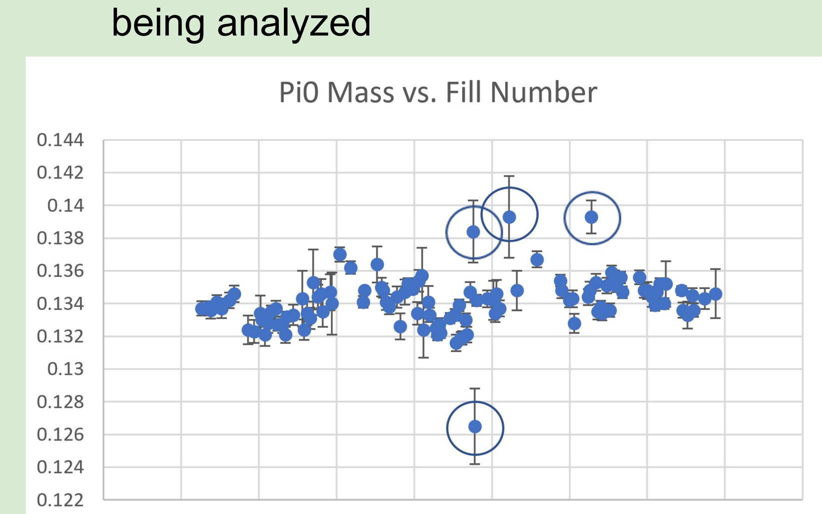


Fig. 7: Average π^0 Mass vs. the Fill Number. Outliers are circled.

Eta Particle Analysis With 2012 EEMC Data

Maggie Bliese

Mentor: Dr. Shirvel Stanislaus

- Eta (η) particles produced in the proton-proton collision decay into two photons
- Energy and position of these photons are measured by the EEMC
- Two-photon invariant mass spectrum was reconstructed, where the η peak can be seen at ~547 MeV/c^2

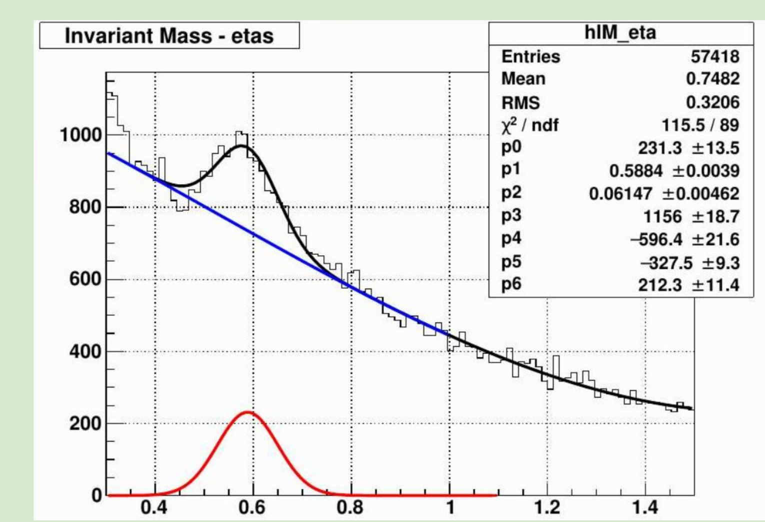


Fig. 8: Number of events vs. Invariant mass for η particles. The original data is plotted in black, the background in blue, and the η peak (data with background subtracted) is in red.

- Fits are made with a polynomial background and a Gaussian for the data
- After fits, signal fraction, particle mass, and other qualities were calculated and plotted for quality assurance

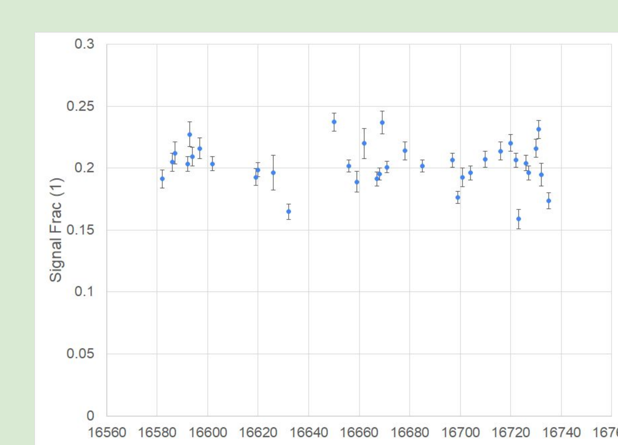


Fig. 9: Signal fraction vs. Fill number, which demonstrates that the eta signal is about 20% of the total data signal. These plots are made to identify outliers and data consistency and quality.

- Next steps will be to calculate A_{LL} for these particles

Construction of a High Voltage (HV) Chain

Lauren Kadlec

Mentors: Dr. Nguyen Phan (LANL) and Dr. Shirvel Stanislaus (VU)

- In the nEDM experiment conducted at ORNL, a strong electric field (75 kV/cm) is applied to ultra cold neutrons placed in liquid helium at 0.4K
- A HV chain was constructed to transport 200 kV of electricity from a room temperature power supply, through vacuum and liquid nitrogen, into a liquid helium compartment.
- In order to test this chain, HV components were configured in a Room Temperature High Voltage (RTHV) system and were introduced to HV incrementally. This was done using a python script.
- Defects in the system uncovered by these tests were corrected by re-engineering the components.
- When the system was deemed successful in the RTHV, the HV components were moved to the Half Scale High Voltage (HSHV) system to be tested in cryogenic temperatures with the rest of the system components. The system's cooling properties and ability to reach high voltages will be observed.

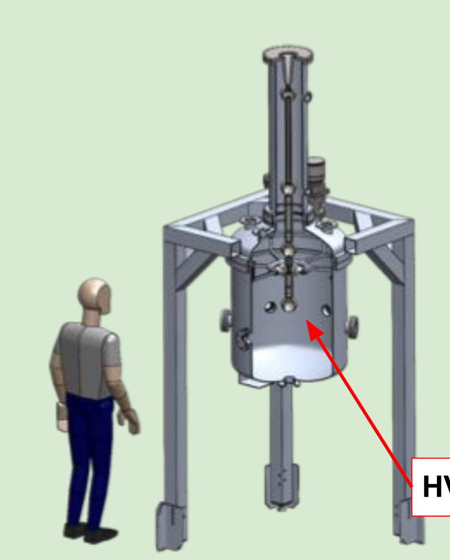


Fig. 10: The layout of the HV chain tested in the RTHV. The balls and rod inside the apparatus are the HV chain. The disc near the bottom surrounded by supports is a ceramic feedthrough.

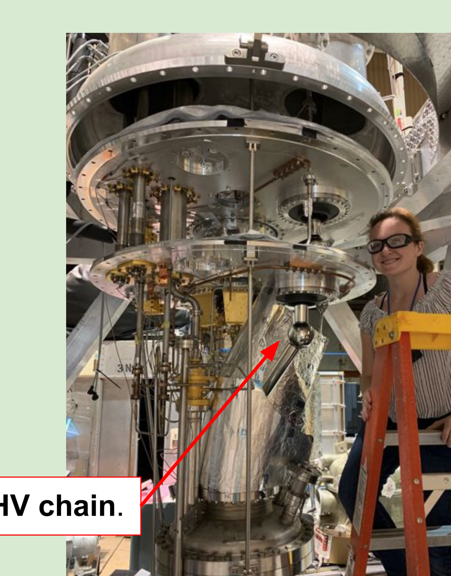


Fig. 11: The interior of the HSHV system showing the HV chain, multiple feedthroughs, plumbing, and the helium bath.

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