Nuclear and Particle Physics at Valparaiso University - Summer 2022

Peyton Grimm, Emily Nelson, Madison Wallner, Roshan Gautam
Mentors: Adam Gibson-Even, David Grosnick, Donald Koetke, Paul Nord, Shirvel Stanislaus
(Department of Physics and Astronomy, Valparaiso University), Nguyen Phan (Los Alamos National Laboratory)

Analyzing the Gluon Contribution to Proton Spin at STAR

Emily Nelson, Madison Wallner, Peyton Grimm

- The intrinsic spin of the proton is known to be ½ ħ.
  - We know that the valence quarks contribute ~30% to the spin.
  - We believe that the gluon contributes ~35% to the spin, but need more data.
  - We don't know the gluon or quark orbital momentum contributions.
- At STAR (Solenoidal Tracker At RHIC), we collide longitudinally polarized protons at 500 GeV center of mass energy.
- For this analysis, we use a 2013 data set from STAR's Endcap Electromagnetic Calorimeter (EEMC).
- We are interested in the neutral pions (π^0s) produced from the collisions.
  - π^0s decay into two photons which the EEMC can detect.
- With the known polarization of the beams and the number of pions produced, we can calculate the asymmetry of π^0 production (A_{LL}). **This is a major goal of STAR as A_{LL} relates to the gluon spin contribution to proton spin**.

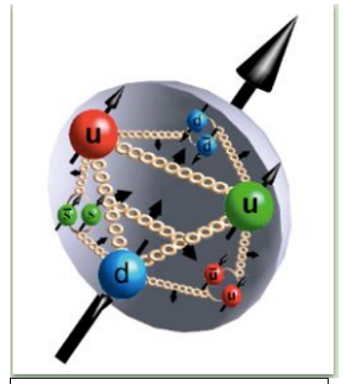

Figure 1: A diagram of the proton's composition.

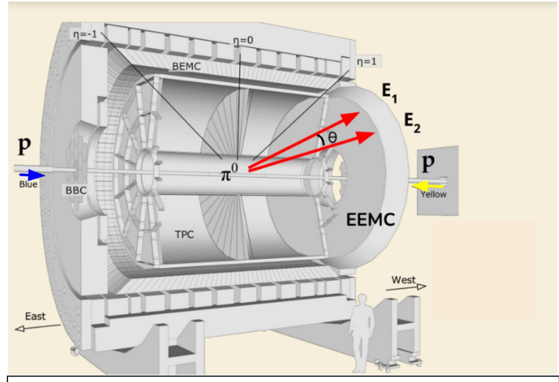

Figure 2: A digital model of STAR. The EEMC is shown to the right. Both proton beams are shown.

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

Equation 1: The spin of the proton (½ ħ) as a sum of four components. Starting from the left, the components are quark intrinsic spin, gluon intrinsic spin, quark orbital angular momentum, and gluon orbital angular momentum.

nEDM Experiment at Los Alamos National Laboratory

Roshan Gautam

- The search for the neutron Electric Dipole Moment (nEDM) is an important test of the Standard Model (SM) of particle physics, as well as proposed extensions to the model.
  - The SM predicts the value of the nEDM to be ~ 10^{-31} e·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·cm.
- One observable that is sensitive to the nEDM is the precession frequency of ultracold neutrons in a strong electric field (75 KV/cm) 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 to 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.

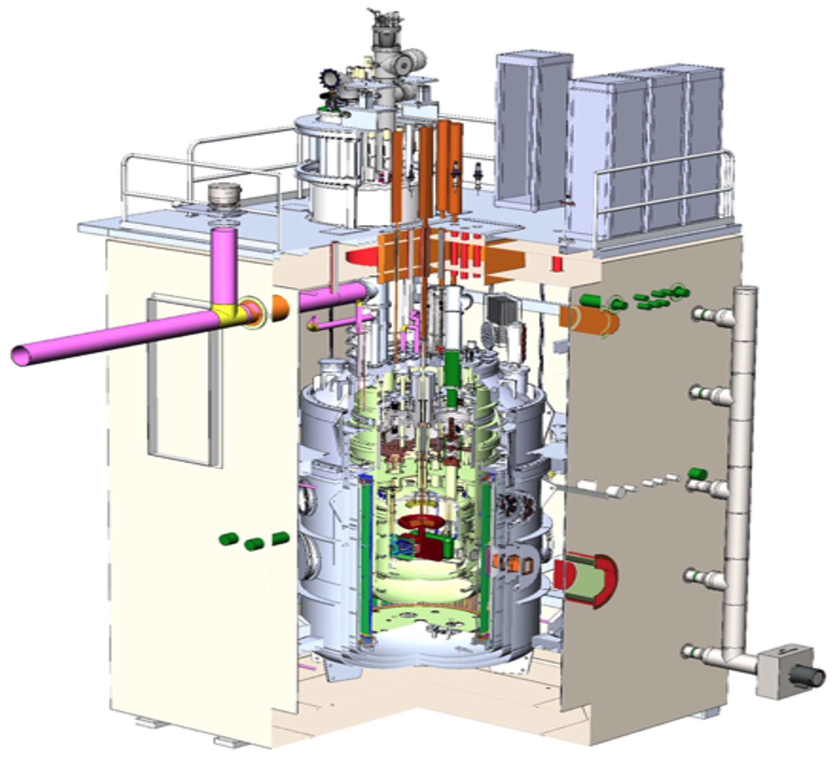

Figure 6: The nEDM apparatus.

Particle Reconstruction

- The mass of π^0 particles can be calculated from the energy of the two photons they decay into and the angle between them. (equation 2)

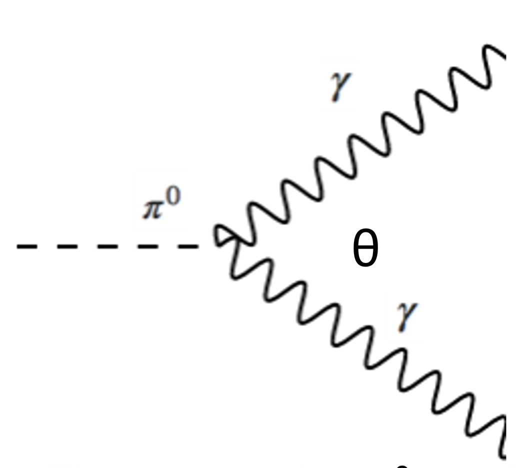

Figure 3: A Feynman diagram depicting a π^0 decaying into two photons (γ).

Equation 2: The invariant mass of two photons ($M_{\gamma\gamma}$) as a function the energies of the two photons (E_1 and E_2) and the angle between them θ.

Invariant Mass

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

- The mass of a π^0 particle is known to be 0.135 GeV/c^2
- From the measured values of $M_{\gamma\gamma}$ the number of π^0s can be obtained to calculate the asymmetry of π^0 production (A_{LL}).

$$A_{LL} = \frac{(N^{++} - N^{+-})}{P_b P_y (N^{++} + N^{+-})}$$

Equation 3: An approximation of the Asymmetry (A_{LL}) where P_b and P_y are the polarization of the beams and N^{++} and N^{+-} are the number of pions for each polarization orientation.

Data Processing

- Data collected by the STAR detector are subdivided into fills and runs.
  - A 'Fill' is a set of protons in the RHIC rings that collide many times over ~ 6 hours
  - Each run is roughly 30 minutes of data taking. Multiple runs make up a fill.
- From the raw data, we produce trees, a hierarchical collection of information.
  - trees → branches → leaves
  - Each leaf contains some information gathered by the detector such as the energy in each photon, the positions of photons, and more.
- For each run, we do a series of QA tests to make sure that the data is of good quality.
  - We look at the mean π^0 mass, mean number of towers (segments in the detector) hit, and the signal to noise ratio, and remove runs that have QA parameters greater than 4σ from the mean.

Fill-Level Quality Assurance

- π^0 Reconstruction
  - The two-photon invariant mass spectrum is plotted to find the number of π^0s
  - To identify the π^0s and remove the random two-photon background, we fit the $M_{\gamma\gamma}$ spectrum (histogram in Fig. 4) with the sum of two functions.
  - A skewed Gaussian function represents the π^0 signal
  - A 5th order Chebyshev polynomial characterizes random two-photon background

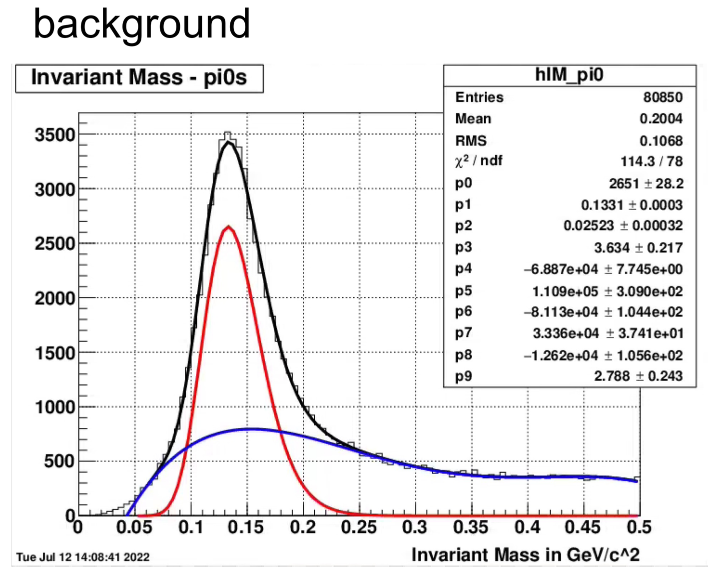

Figure 4: π^0 candidates vs. invariant mass for one fill. Chebyshev polynomial for background fit (blue) and Skewed Gaussian fit for the signal (red). The sum of the signal and background is the black curve that matches the data (histogram).

- Fill Level Quality Assurance (QA)
  - Quality Assurance on the fills is done after the QA on the runs
  - Plot important parameters such as fitted π^0 mass, fitted π^0 width, number of signal π^0s, etc.
    - Look for outliers within the data

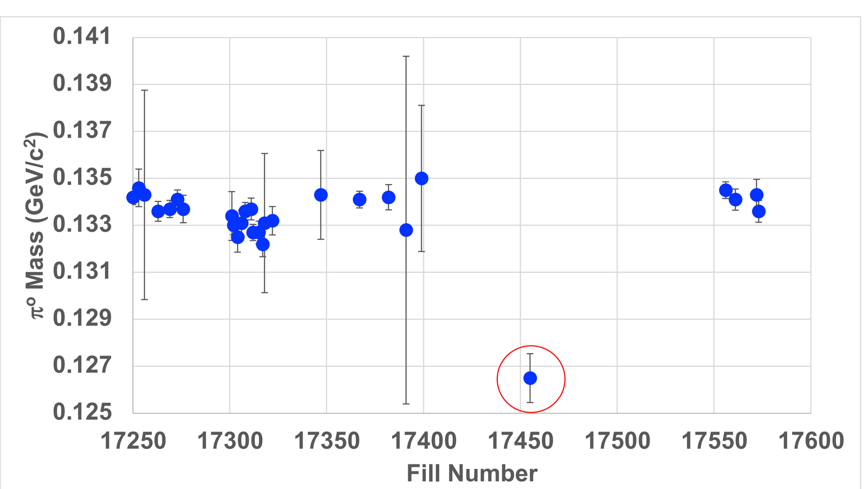

Figure 5: Average π^0 Mass (from signal fit) vs. the Fill Number. An example outlier (fake, for illustration) is circled. Larger error bars indicates less data in that particular fill.

Investigating High Voltage Breakdown

- To inform the design of the high voltage system in the final nEDM apparatus, many aspects of the HV breakdown phenomenon in liquid helium must be studied. These include parameters such as electrode materials, electrode surface quality, electrode area, liquid helium pressure and temperature, etc.
- The Half Scale High Voltage (HSHV) system is designed to study the high voltage (HV) breakdowns among other things. To carry out these tests, we need to transfer 200 kV from room temperature to liquid helium in the central volume. This transfer is done using a custom made stainless steel HV chain.
- The apparatus is designed with an outer volume which is vacuum and the central volume which contains 40 litres of superfluid helium below 2 K.
- We did multiple tests to identify the various factors that were preventing us from reaching the designed maximum voltage.

Tests

- In the first test, we were only able to reach 75 kV before breakdown.
- Afterwards we removed the chimney and long rods to simplify the chain and narrow down the problem.
- In the second test, we achieved 100 kV without breakdown but there was constant current draw due to field emission above 120 kV.
- We identified sharp edges and rough interior surface as likely causes of the unstable behavior at very high voltage.
- To solve the issue, we rounded off all the sharp edges and polished the interior surface.
- We plan to conduct additional testing with these and other improvements to bring the HV chain up to its full operating voltage.

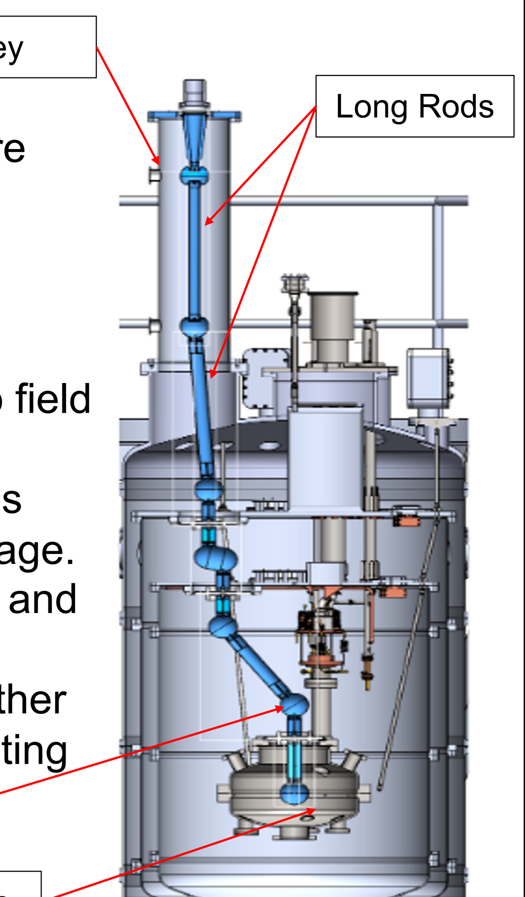

Figure 7: HSHV system showing the HV chain (blue) for transferring 200 kV from room temperature to the central volume (<2 K).

U.S. DEPARTMENT OF ENERGY Office of Science · STAR · VALPARAISO UNIVERSITY · NSF · nEDM · Los Alamos NATIONAL LABORATORY