Determining π^0 A_{LL} from STAR 2012 Endcap Calorimeter Data

Claire Kovarik (Valparaiso University) for the STAR Collaboration

Mentors: Shirvel Stanislaus, Adam Gibson, David Grosnick, Donald Koetke

Background

The STAR Experiment, located at the Relativistic Heavy Ion Collider (RHIC) at the Brookhaven National Laboratory, uses longitudinally polarized proton-proton collisions to produce neutral pions (π^0) whose production exhibits an asymmetry (A_{LL}). By measuring A_{LL} the gluon contribution to the spin of the proton can be studied. The STAR detector (Fig 1) is located along the 2.3 mile RHIC circumference (Fig.2). As seen in Fig 4, the neutral pion decays into two photons essentially immediately (~10^{-16}s). The analysis reported here is based on data taken in 2012 for 500 GeV center of mass energy of the colliding protons.

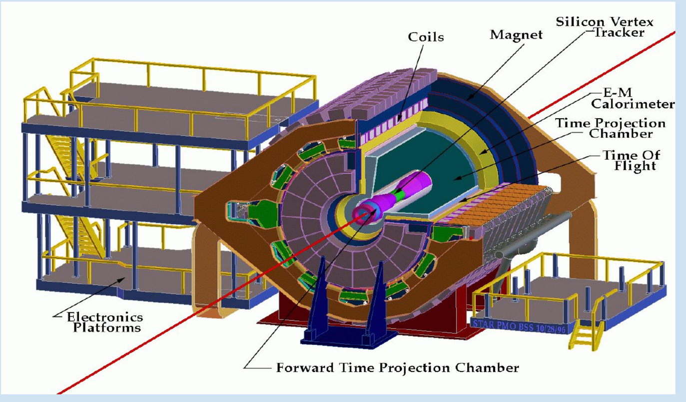


Fig 1. STAR Detector at Brookhaven National Laboratory
Photo Credit: *The STAR Experiment*

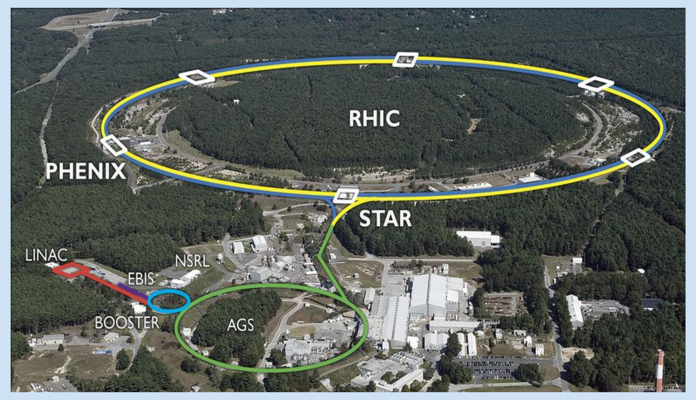


Fig 2. Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory
Photo Credit: *Brookhaven National Laboratory*

Determining A_{LL}

The π^0 asymmetry (A_{LL}) is an imbalance in the π^0 production in the different spin states of the colliding protons. There are four spin states the beam could have, but they can be grouped based on the longitudinal polarization direction that is either parallel or antiparallel to the beam momentum (Fig. 3). Using the following formulas, the A_{LL} can be calculated.

$$A_{LL} = \frac{\sum_{runs} P_Y P_B (N^{++} - R_3 N^{+-})}{\sum_{runs} P_Y^2 P_B^2 (N^{++} + R_3 N^{+-})}$$

$$R_3 = \frac{L^{++} + L^{--}}{L^{+-} + L^{-+}}$$

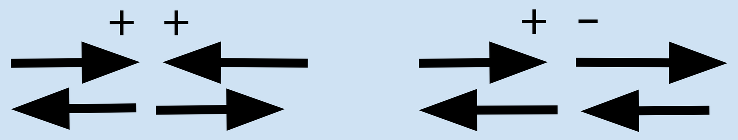
N^{++} = number of π^0s in an antiparallel spin state

N^{+-} = number of π^0 in a parallel spin state

L = luminosities at different spin states (see Fig 3).

P_Y= polarization of yellow beam

P_B=polarization of blue beam



Antiparallel Parallel

Fig 3. The four different spin states can be grouped as protons with parallel spin or antiparallel spin.

π^0 Reconstruction

The Endcap Electromagnetic Calorimeter (EEMC) of the STAR detector (Fig 1) is able to measure the energy (E) and positions of each photon's electromagnetic shower. By using the energy and the opening angle (Θ) between the two photons (Fig. 4), the two photon invariant mass can be calculated using the following equation:

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

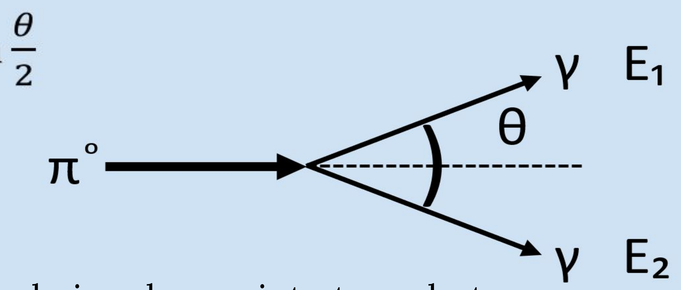


Fig 4. The neutral pion decays into two photons.

Fitting Invariant Mass Spectra

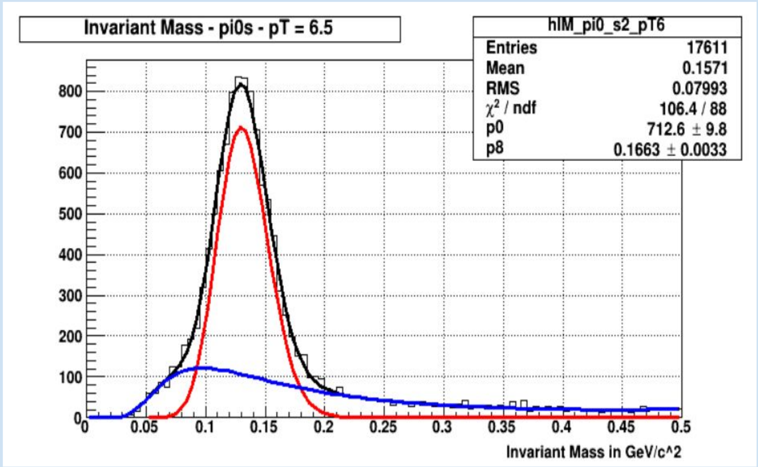
The two photon invariant mass histograms were fitted with a skewed gaussian for the π^0 peak and a background function. Two different background functions were compared; a Chebyshev function and a modified Planck function. Fitting is done in two steps: (1) Fit spin combined histograms to determine the signal and background parameters (2) Fit spin sorted histograms with the above parameters fixed, to determine the normalizations. The number of π^0s in each spin state is found by integrating the fitted Gaussian function within ± 3 sigma of the mean. This information can then be used to find the π^0 asymmetry (A_{LL}).

Skewed Gaussian = $a e^{-0.5\left(\frac{x-b}{c(1+d(x-b))}\right)^2}$

b= mean

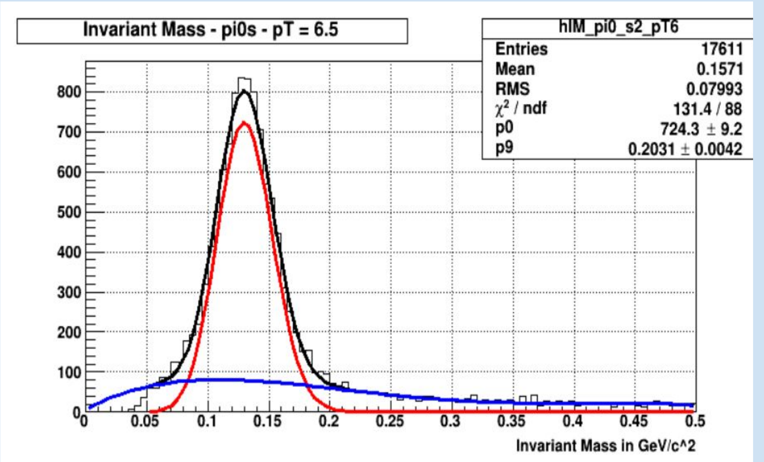
c= sigma

d= 'skewing' parameter



Chebyshev Function= $c_0+c_1(x)+c_2(2x^2-1)+c_3(4x^3-3x)+c_4(8x^4-8x^2+1)$

Fig 5. Invariant mass plot at an average p_T (transverse momentum of the of the π^0) of 6.5 GeV/c fitted with a Chebyshev background function (blue) and a skewed Gaussian for the π^0 peak (red).



Modified Planck Function= $\frac{1}{(x-c_1)^5 e^{\left(\frac{c_2}{x-c_3}\right)}-c_4}$

Fig 6. Invariant mass plot at an average p_T of 6.5 GeV/c fitted with a modified Planck background function (blue) and a skewed Gaussian for the π^0 peak (red).

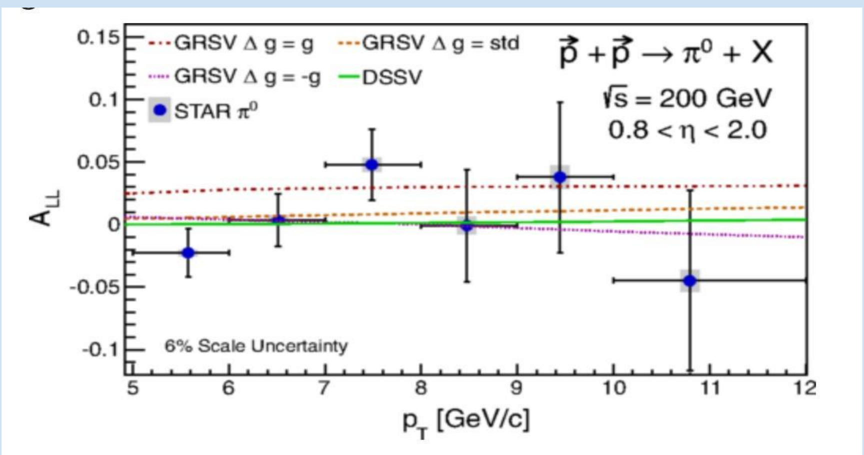


Fig 10. Published data[1] from 2006 at a lower energy level than the 2012 data. Statistical errors are given by the error bars while systematic errors are given by the shaded boxes.

[1] Adamczyk, et al. (STAR Collaboration), Phys. Rev. D 8A9, 012001 (2014).

Grouping

The 2012 data set contains over 500 runs. If each run was analyzed individually, the statistics would be really low. In order to increase statistics, the data were divided into 16 groups. Fig 7 shows the number of π^0s vs p_T for a single group. This demonstrates that the number of π^0s depends strongly on p_T. Dividing the data into groups gives more events especially in the lowest and the highest p_T bins. Similarly, Fig 8 demonstrates how as p_T changes, the background changes. Two different methods of grouping was used in order to correct for any systematic error that might have occurred do to the grouping. The first method of grouping was created based on fill number and luminosity (Fig 9). The relative luminosity remained relatively constant across each fill, so fills with similar luminosity values were grouped together. The second method of grouping placed runs together based on their polarization. Invariant mass plots were created using the 16 groups at each p_T (ranging from 3.5-15.5 GeV/c) and fitted to find the A_{LL}.

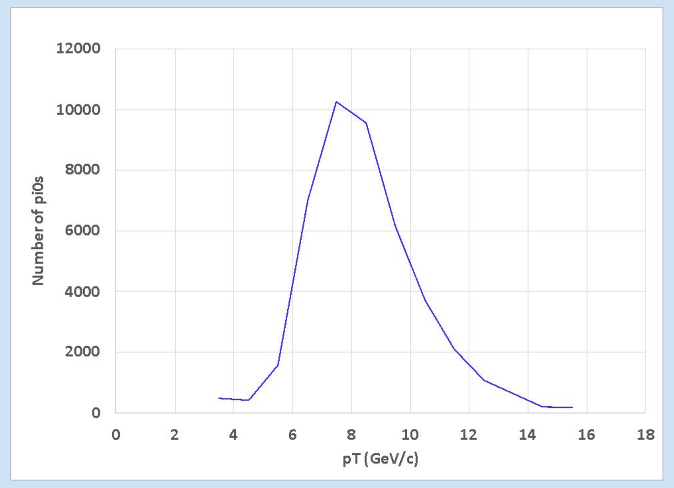


Fig 7. Graph of the number of π^0s vs p_T for one group.

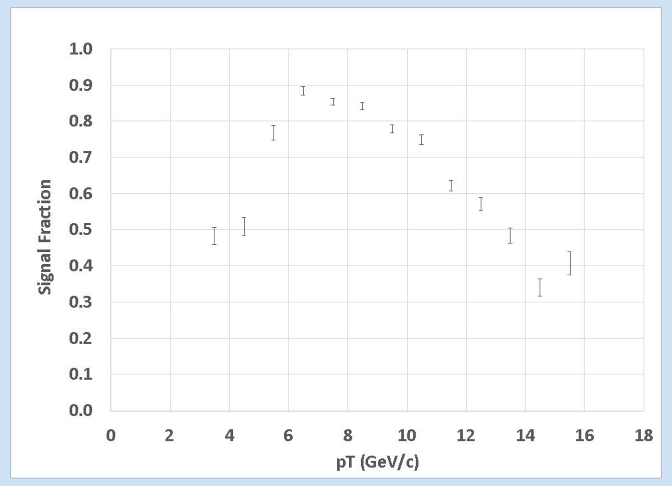


Fig 8. Graph of the number of the signal fraction (π^0s/(π^0s + background π^0s)) vs p_T for one group.

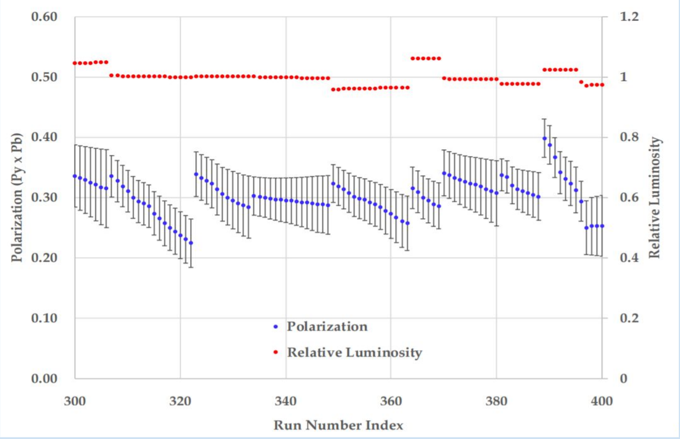


Fig 9. Graph showing polarization and relative luminosity of some of the runs in the 2012 data set. The polarization within each fill decreases over time while the relative luminosity remains relatively constant across each fill.

Future Work

Further work includes analyzing the second method of grouping (based on polarization) in order to better understand any systematic errors that occured from grouping the runs. In addition, the data set may be looked at run by run in order to avoid error that may occur by using averages from each group. We expect the 2012 data set to significantly reduce the error bars when compared to the published results from work done with data from 2006[1] (Fig 10).

Additional presentations on the STAR Experiment and the work on the Endcap Electromagnetic Calorimeter:
Andrew Edwards: Thursday 10:30-10:42 (Salon 5)
Joseph (JD) Snaidauf: Thursday 11:54-12:06 (Salon 6)