Determining the Longitudinal Double-Spin Asymmetry (A_{LL}) in π^0 Production from 2013 STAR Endcap Calorimeter Data

Sam Starkenburg
Valparaiso University
For the STAR Collaboration

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Background - Proton Spin

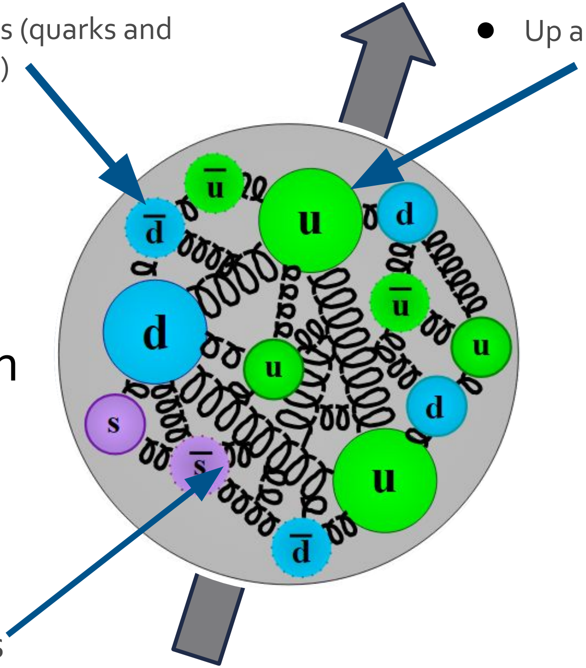
- Spin is the intrinsic angular momentum of a particle
- The proton has spin ½ ħ
- Quarks are elementary particles which make up composite particles called hadrons (e.g. protons, neutrons, pions, etas)

$$\frac{1}{2}\hbar = \underbrace{\frac{1}{2}\Delta\Sigma}_{\text{Quark spin} \sim 30\%} + \overbrace{\Delta G}^{\text{Gluon spin}} + \underbrace{L_q}_{\text{Quark orbital angular momentum}} + \overbrace{L_g}^{\text{Gluon orbital angular momentum}}$$

Sea Quarks
- Quark pairs (quarks and antiquarks)

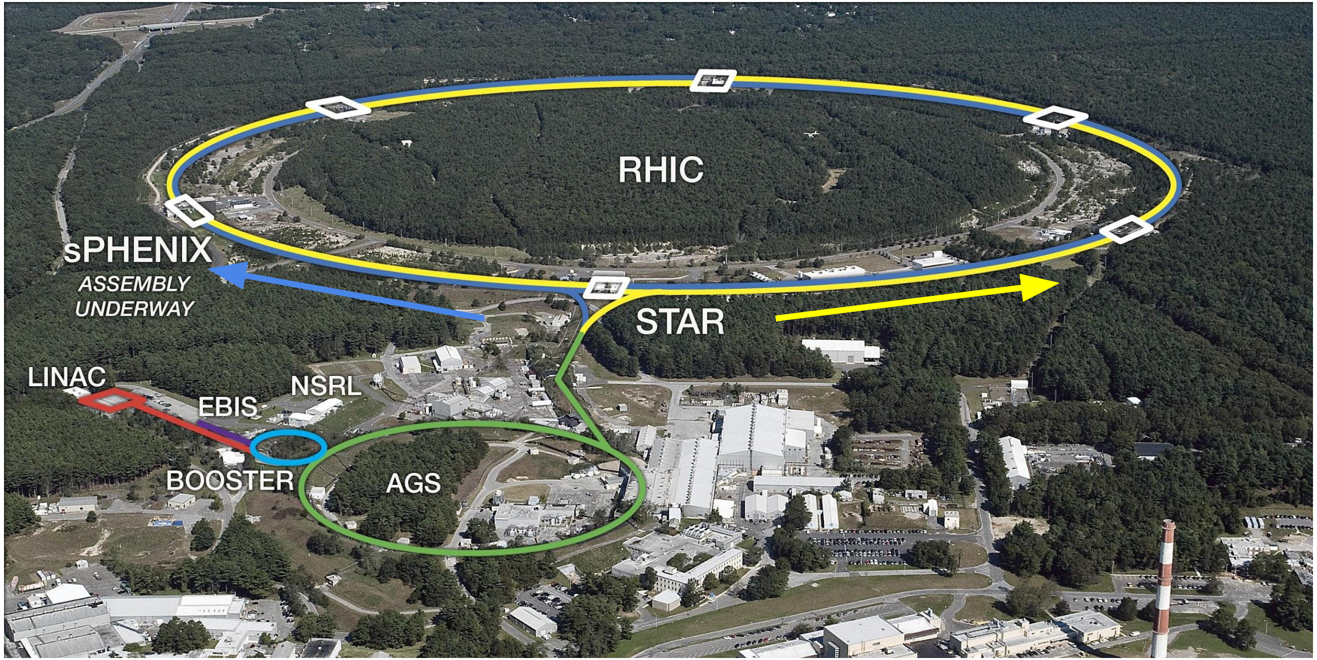
Valence Quarks
- Up and Down

Proton (uud)



Gluons
- Mediates the strong nuclear force

RHIC



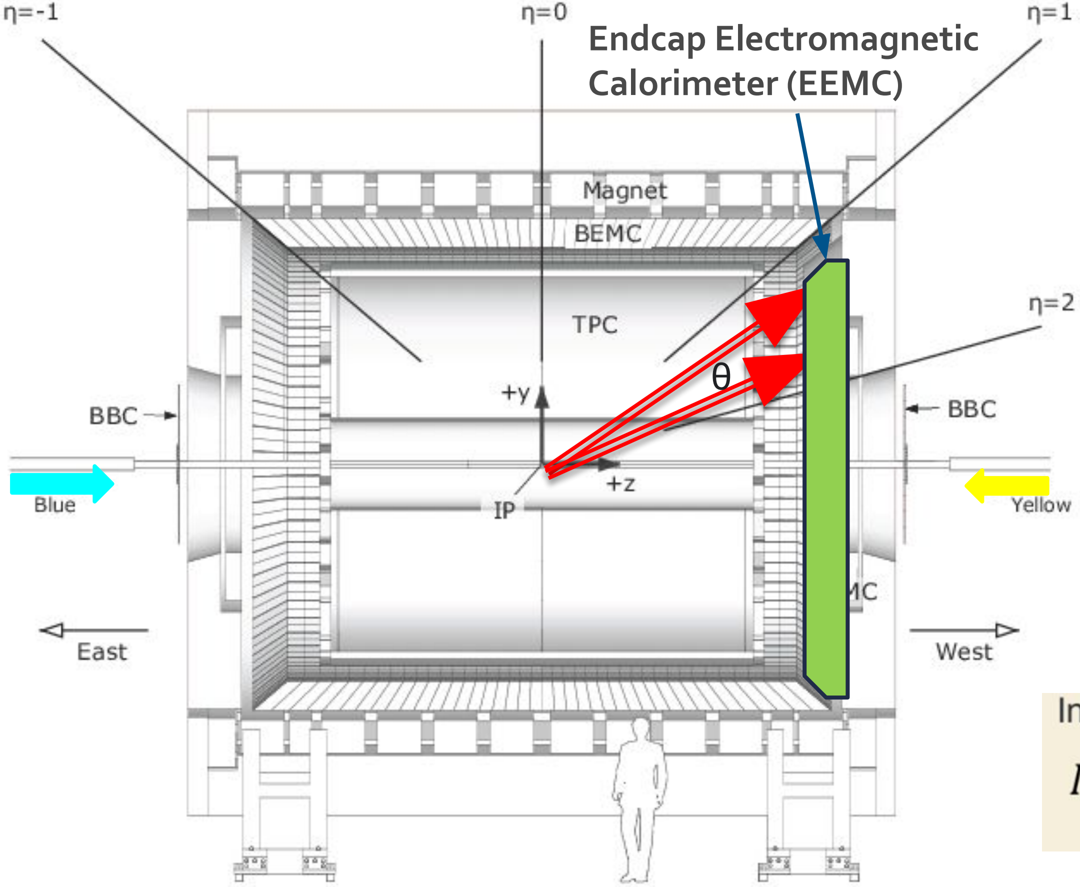
Relativistic
Heavy
Ion
Collider

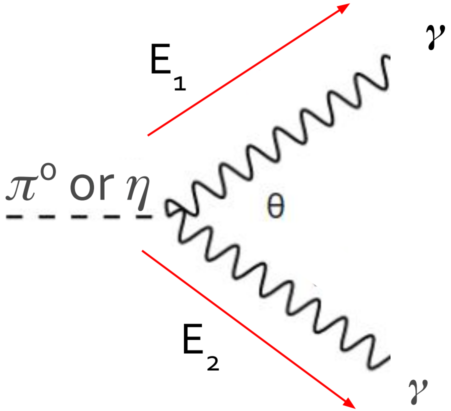
Located at Brookhaven National Lab in New York

Protons are collided with a center-of-mass energy of 200 and 500/510 GeV

Only collider that can collide spin-polarized protons
Average polarization: 50-60%

STAR - Solenoidal Tracker at RHIC





Neutral pion (π^0) and eta (η) particles decay rapidly into two photons

π^0 mean lifetime: $8.5*10^{-17}$s

Invariant Mass

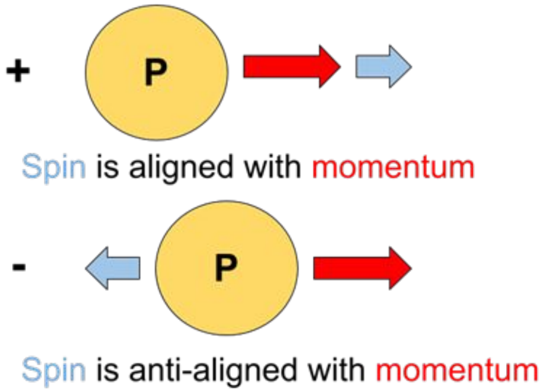
$$M_{\gamma\gamma} = (E_1 + E_2)\sqrt{1 - \left(\frac{E_1 - E_2}{E_1 + E_2}\right)^2 sin\left(\frac{\theta}{2}\right)}$$

Asymmetry (A_{LL})

- Using the number of the π^0 particles and the known polarization of the beams, we can calculate the asymmetry of π^0 production from different spin states of the protons

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

- The asymmetry formula:
  - P_b and P_y are the polarization of the blue and yellow beams
  - N^{++} and N^{+-} are the number of π^0 in the respective spin state
  - R is the relative luminosity ratio
- If A_{LL} is nonzero, then there is a sensitivity to π^0 production from spin of the proton

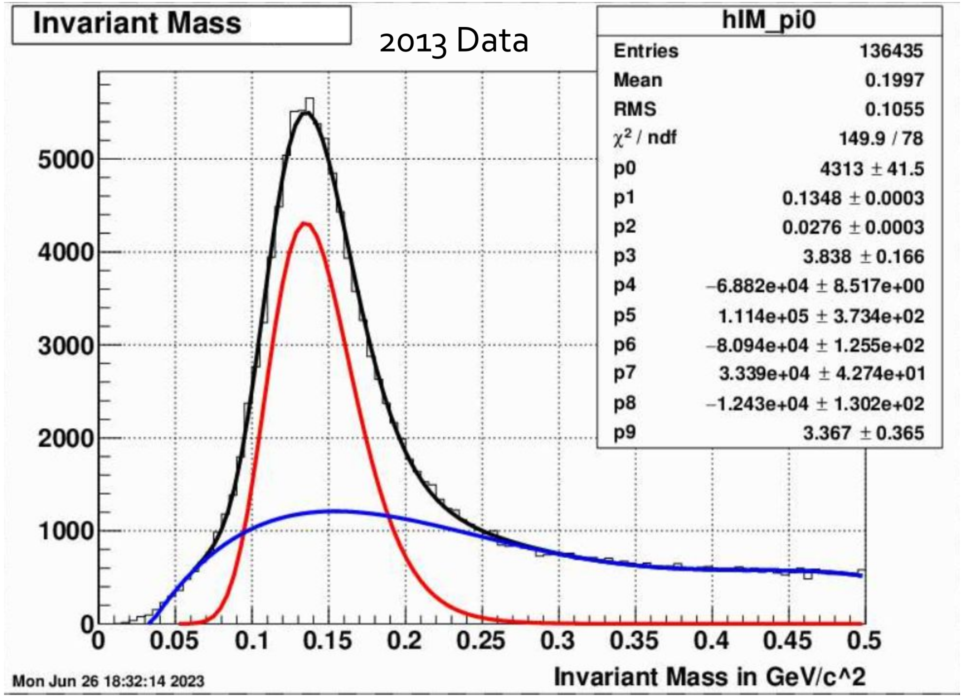


Asymmetry is related to the gluon contribution to the spin of the proton

Data Quality Assurance (QA)

- To make sure we are using the best data available, we use quality assurance tests at the run and fill level
- A fill is a set of data collected from when the beam is injected to when it is dumped
- My research is π^0 Fill Level QA for the 2013 dataset ($\sqrt{s}$ = 510 GeV)
- For fill level QA, we investigate:
  - Invariant mass
  - Signal to background ratio
  - Width of π^0 signal

Fitting the π^0 Histogram



- This is a histogram of the invariant mass of all two photon combinations in a fill
- Histogram is fit using:
  - A Skewed Gaussian function to represent the signal (π^0 particles):

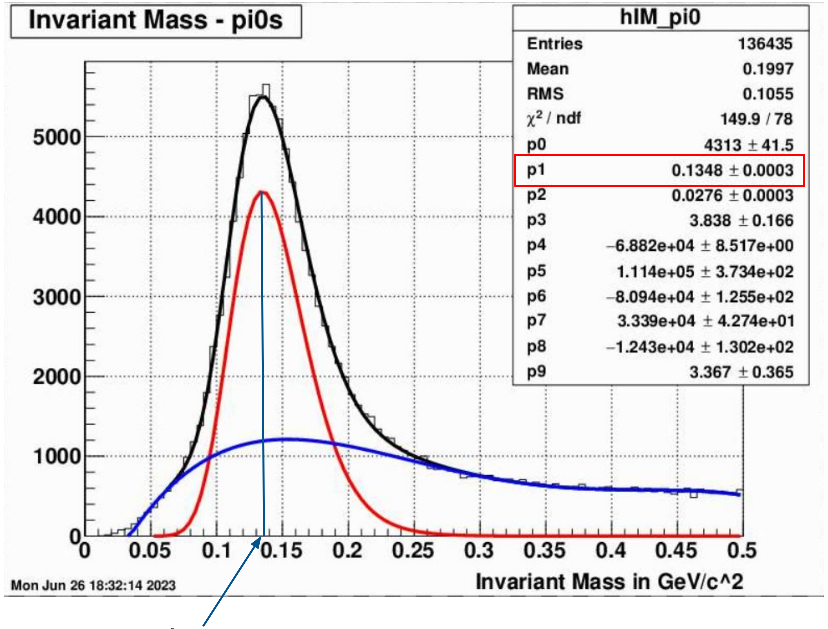
$$f(x) = p_0 * exp(-0.5(\frac{x - p_1}{p_2(1 + p_3(x - p_1))})^2)$$

  - A Chebyshev Polynomial to represent the background:

$$f(x) = p_9 * (p_4 T_0 + p_5 T_1 + p_6 T_2 + p_7 T_3 + p_8 T_4)$$

- We can find number of π^0s by integrating the signal function

π^0 Fit Parameters



Measured mass

π^0 invariant mass: 0.135 GeV/c^2

- Skewed Gaussian function to represent the signal (π^0 particles):

$$f(x) = p_0 * exp(-0.5(\frac{x-p_1}{p_2(1+p_3(x-p_1))})^2)$$

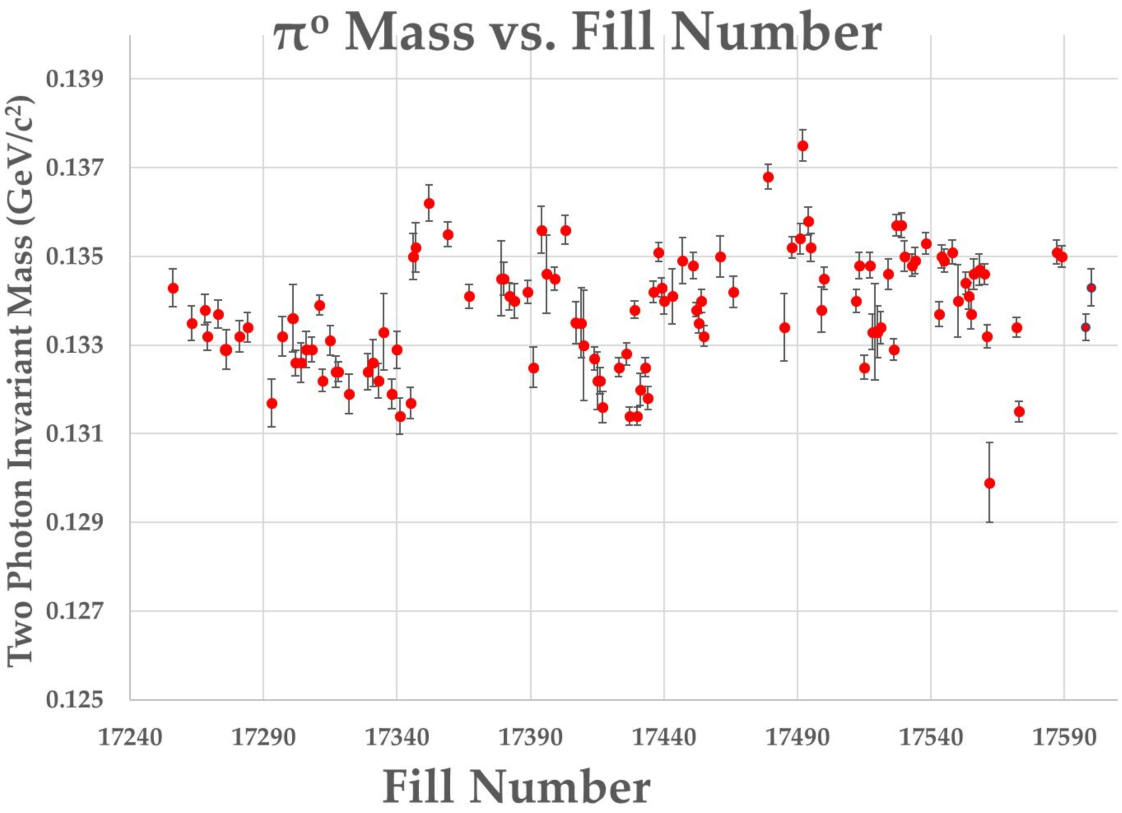
- Chebyshev Polynomial to represent the background:

$$f(x) = p_9 * (p_4T_0 + p_5T_1 + p_6T_2 + p_7T_3 + p_8T_4)$$

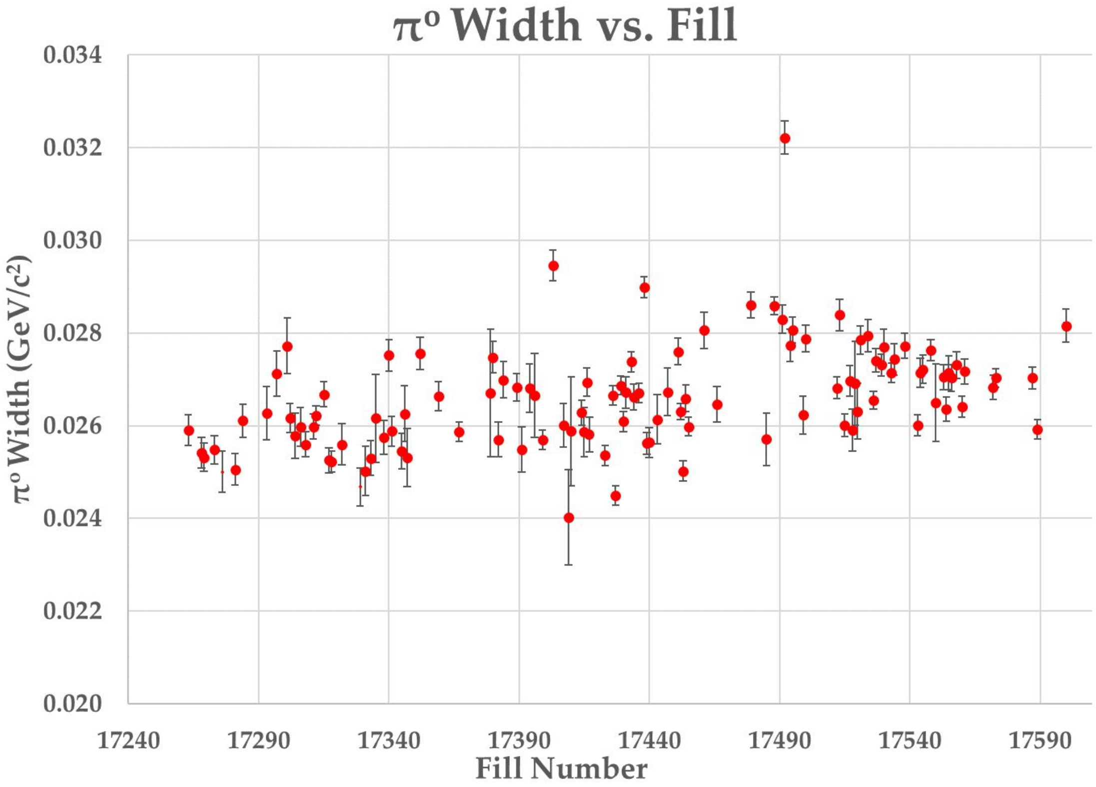
$$T_0(x) = 1$$
$$T_1(x) = x$$
$$T_2(x) = 2x^2 - 1$$
$$T_3(x) = 4x^3 - 3x$$
$$T_4(x) = 8x^4 - 8x^2 + 1$$

- Background could also be fit with regular polynomial or “modified planck function”

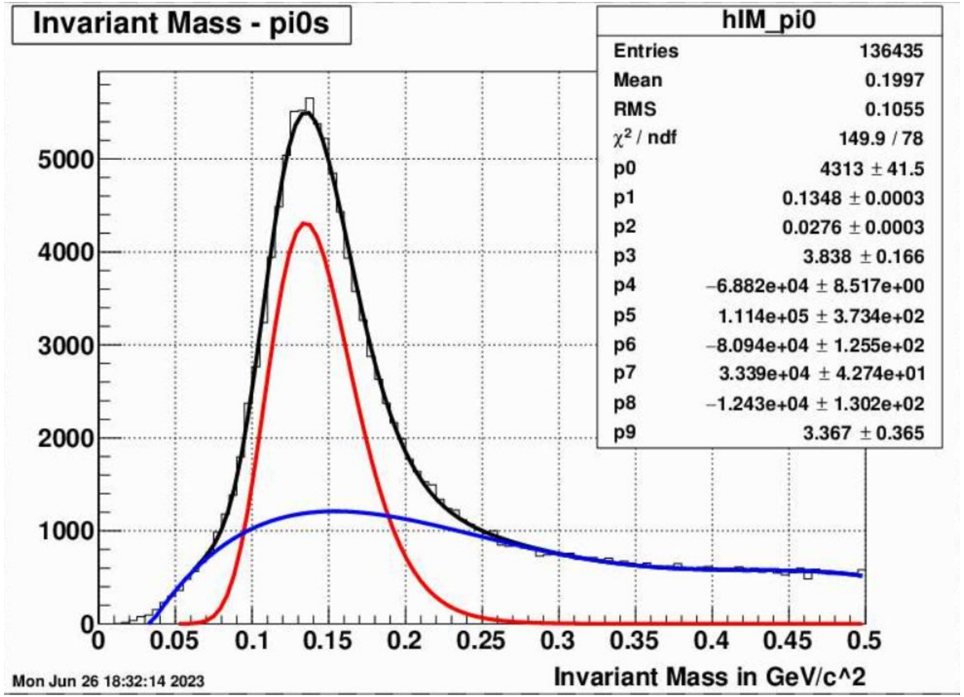
π^0 Fill Level Quality Assurance - Invariant Mass



π^0 Fill Level Quality Assurance - Width



Signal Fraction

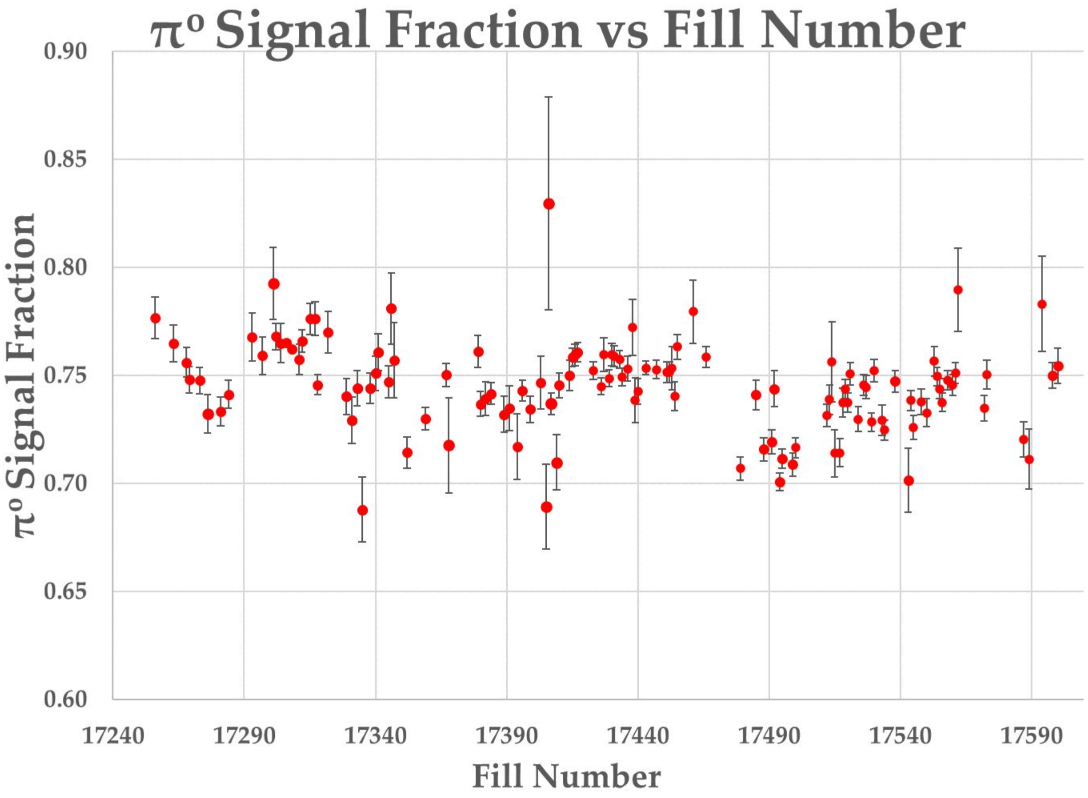


- Signal fraction is the fraction of **signal** to **signal + background** within 2 standard deviations

$$SF = \frac{signal}{signal + background}$$

- Typically ~.70-.80

π^0 Fill Level Quality Assurance - Signal Fraction



Summary

- QA testing was done on 2013 data at the fill level for π^0
- This data will be used to select good fills for the next step in the analysis of the 2013 data set to determine the π^0 A_{LL}

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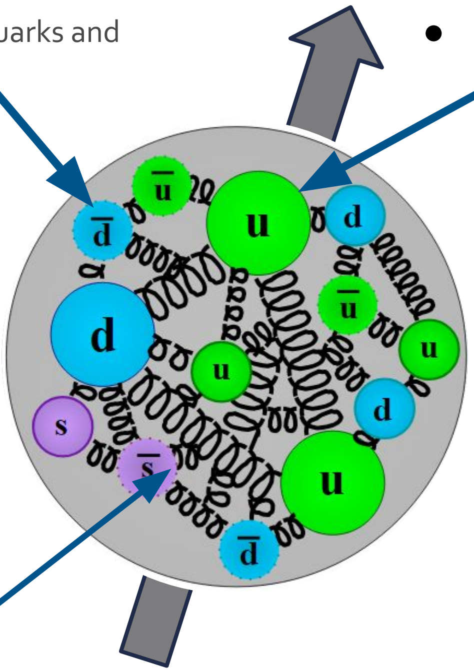

Gluons

- Mediates the strong nuclear force

Invariant Mass

- Invariant mass ($M_{\gamma\gamma}$) can be calculated from the energy and position of the photons

Invariant Mass

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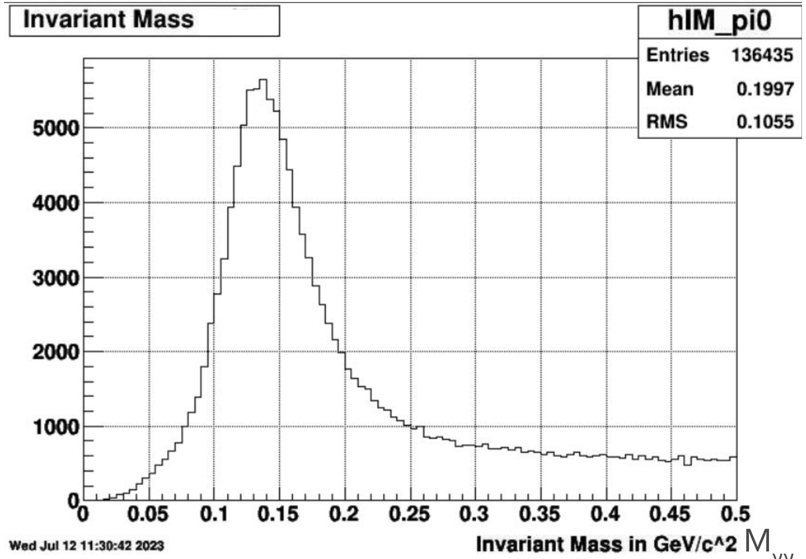
- The software package ROOT will take all of the invariant mass results and make a histogram
- The invariant mass plots help us identify particles and how many there are

π^0 Mass: 0.135 GeV/c^2

η Mass: 0.548 GeV/c^2



$M_{\gamma\gamma}$