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

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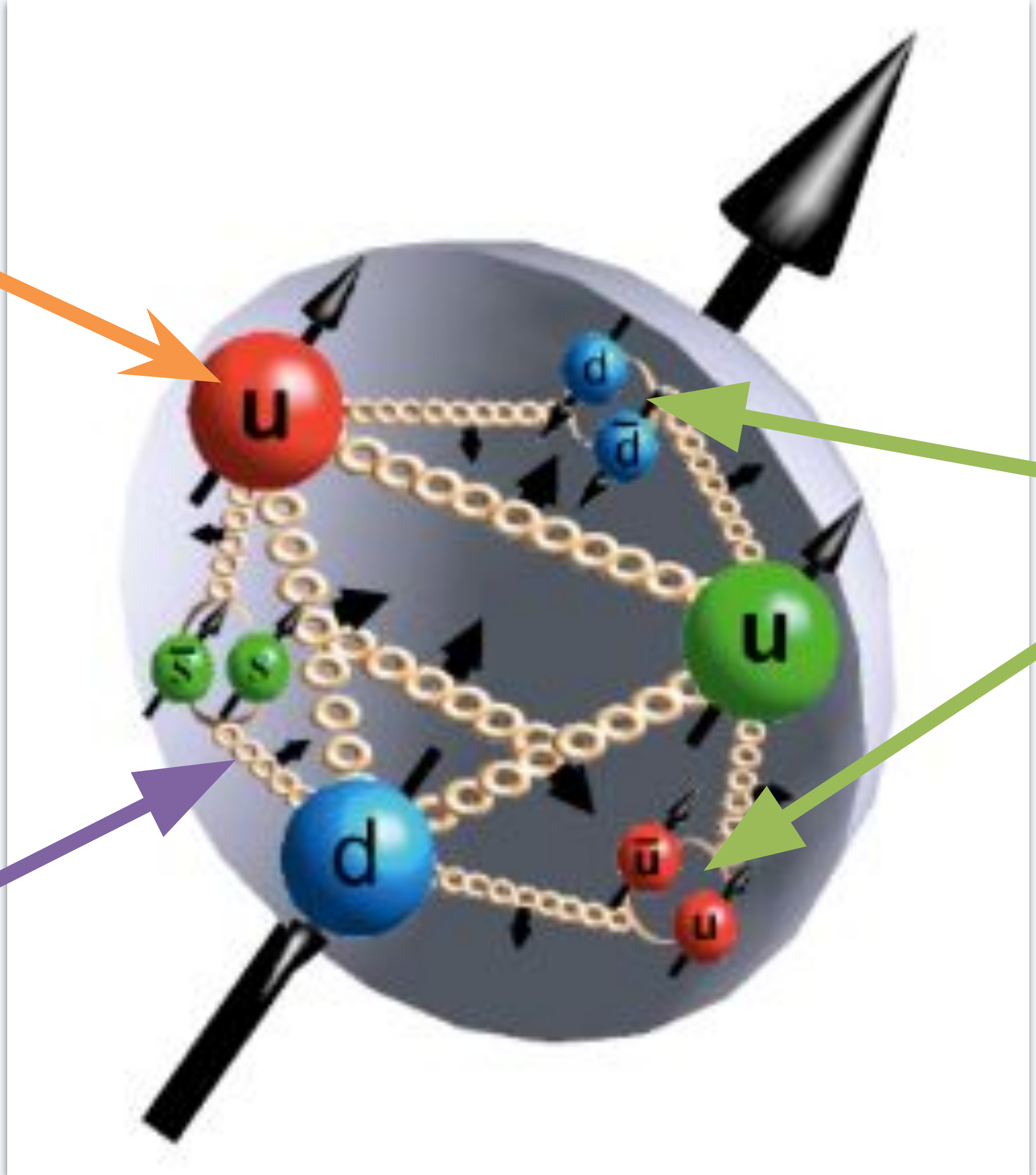
On Behalf of the STAR Collaboration
APS April Meeting

Supported in part by
U.S. DEPARTMENT OF ENERGY

Proton Composition

Valence Quarks
- Up, Up, Down
- Always present



Sea quarks

- Virtual particles
- Additional quark-antiquark pairs
- Pop in and out of existence in the proton

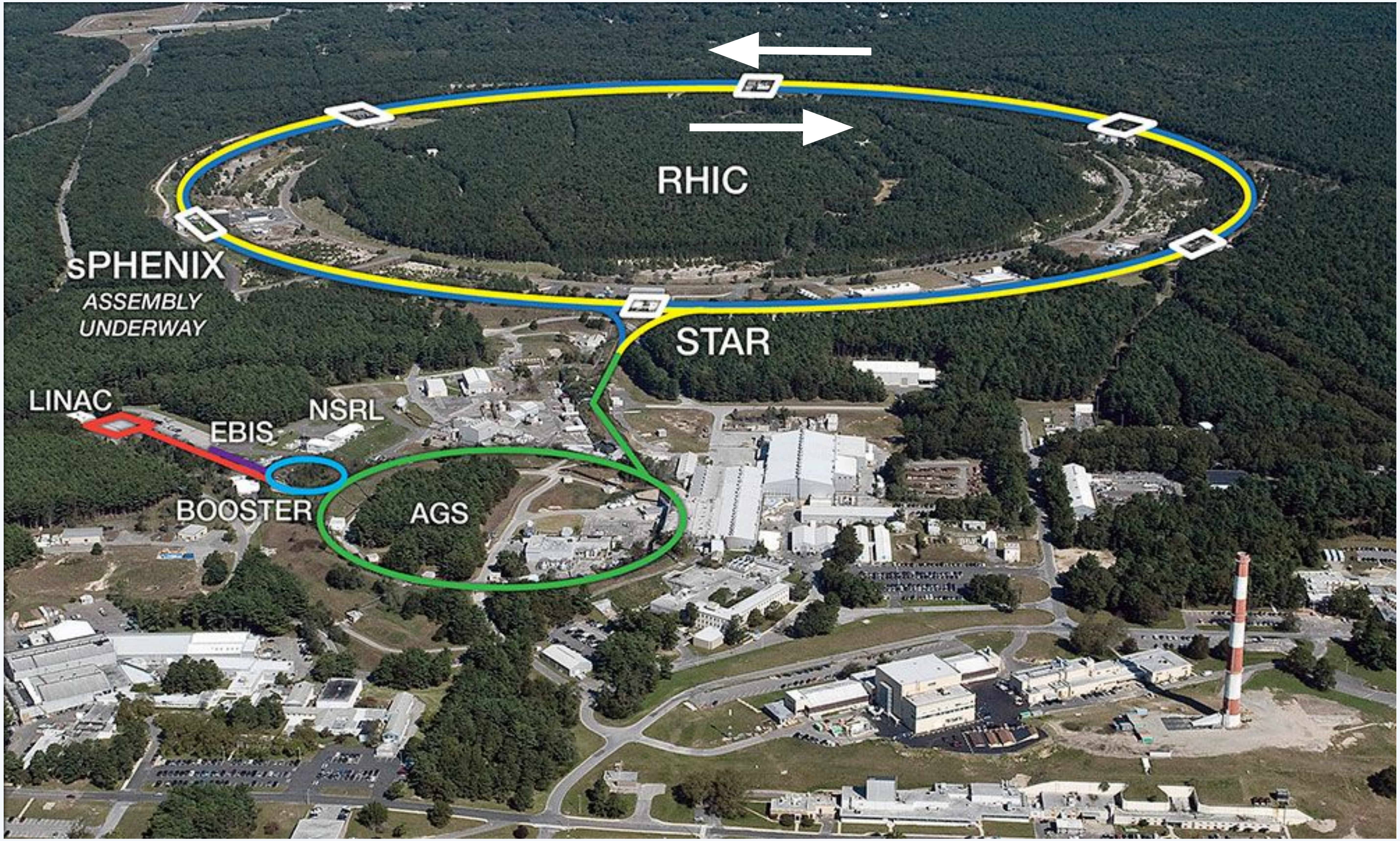
Gluons
- Carry the strong force
- Hold valence quarks together

Proton Spin Composition

- Proton spin is known to be ½ ħ
  - Quark spin contributes ~30% of proton spin
  - Gluon spin contributions could be substantial
  - There could be additional contributions from quark and gluon orbital angular momenta

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

RHIC Ring

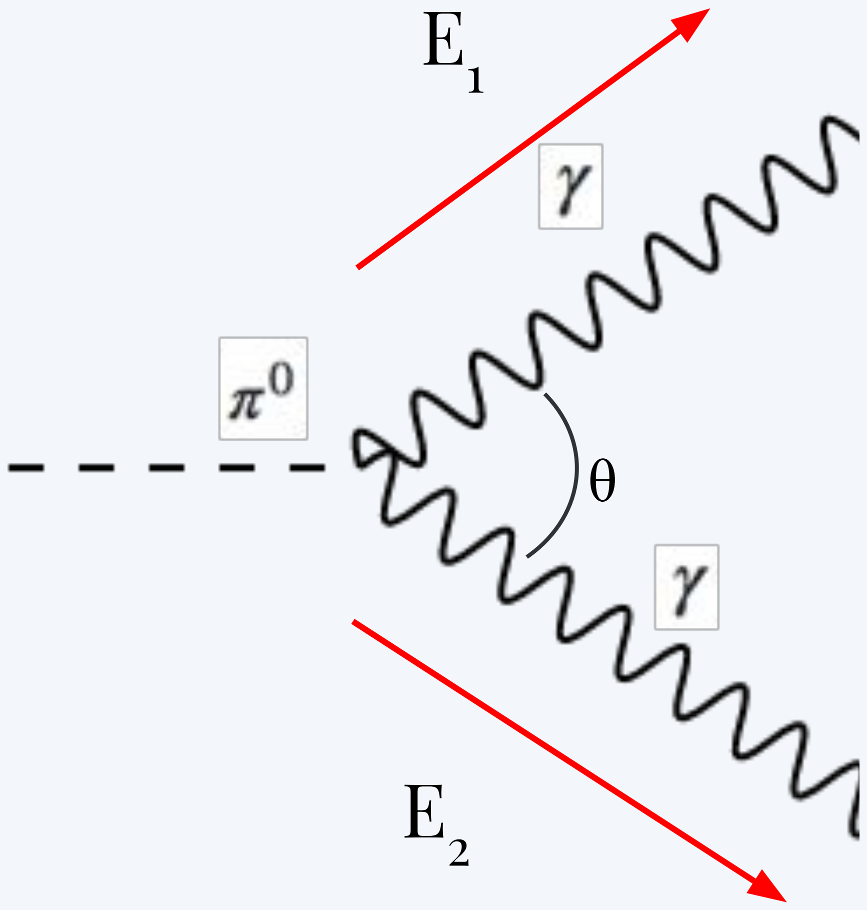


Relativistic
Heavy
Ion
Collider

Solenoidal
Tracker
At
RHIC

Particle Reconstruction

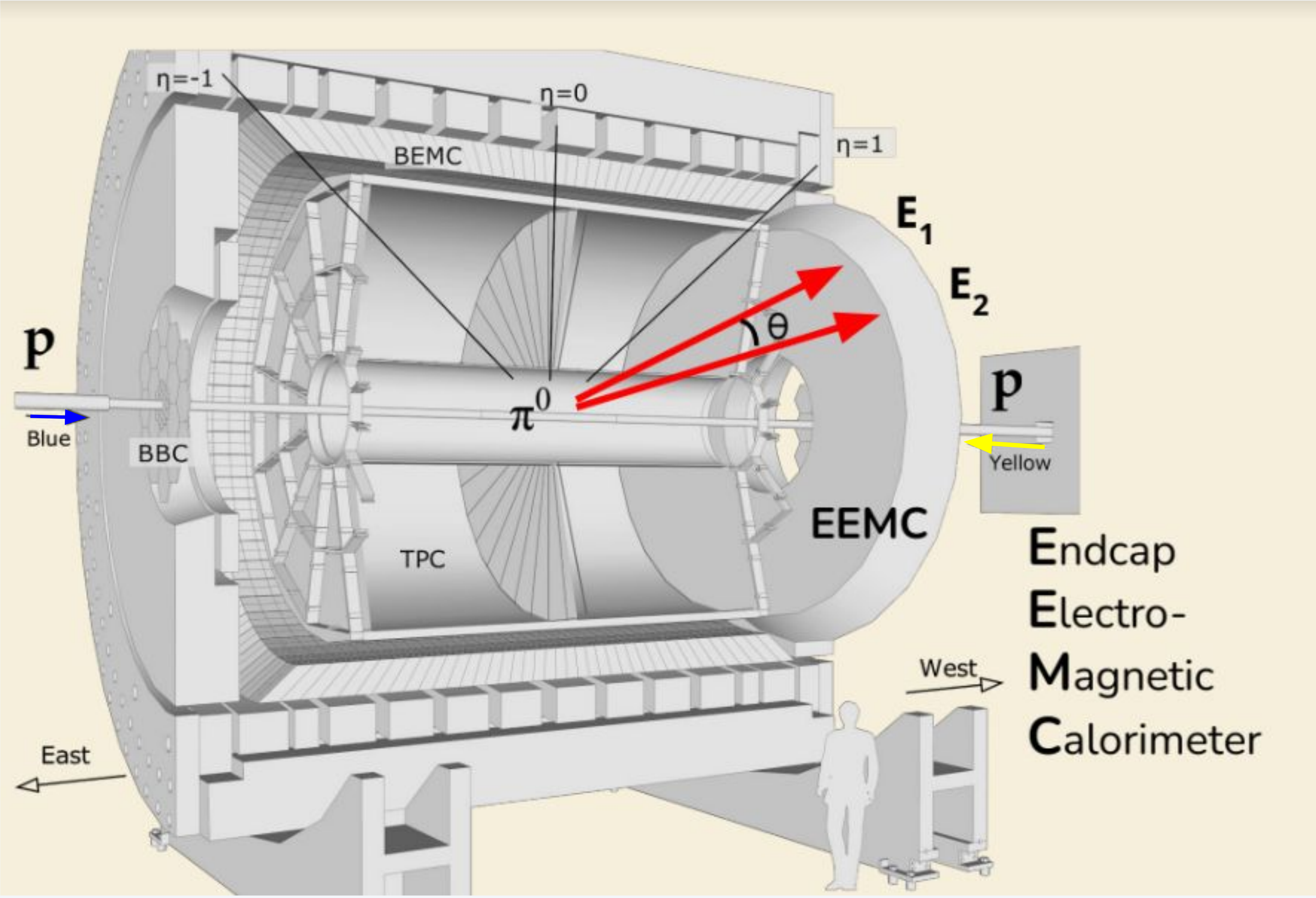
- π^0s (neutral pions) and ηs (eta mesons) are two of the many particles produced in the collisions
- π^0s and ηs rapidly decay into 2 photons
- The energy and position of the photons are measured by the Endcap Electromagnetic Calorimeter (EEMC)
- If the two photons come from a π^0 or η, the invariant mass ($M_{\gamma\gamma}$) will be equal to the mass of the π^0 or η particle
  - π^0 mass = 0.135 GeV/c² (~14% proton mass)
  - η mass = 0.548 GeV/c² (~58% proton mass)



Invariant Mass Formula

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

STAR Detector

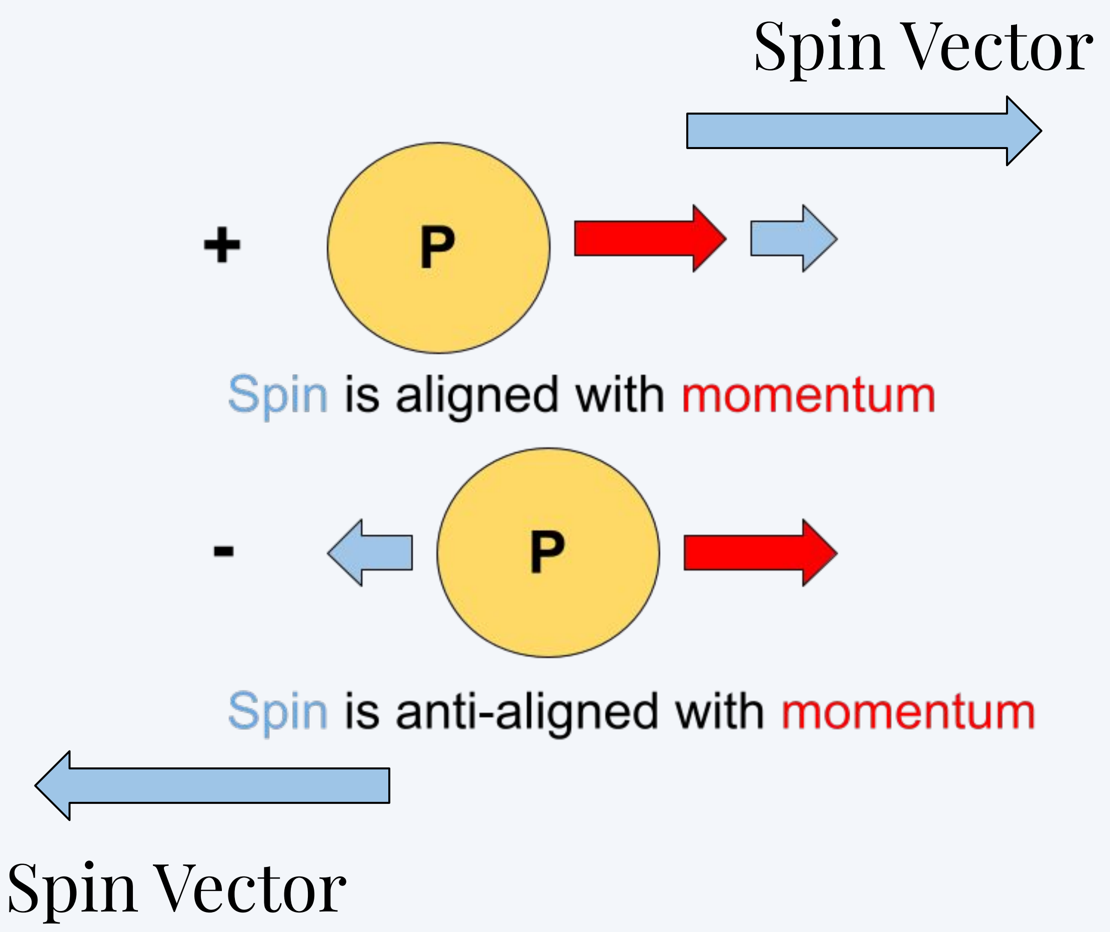


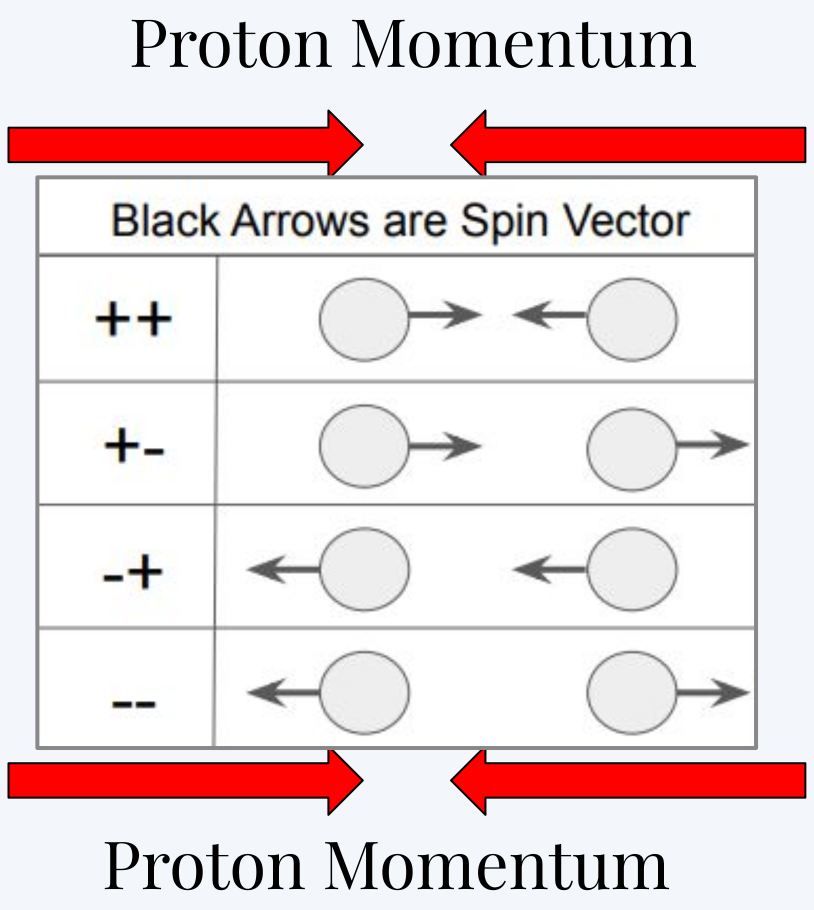
Asymmetry

- This is one of the goals of STAR's physics program as A_{LL} can be related to the gluon spin contribution to proton spin.
- Asymmetry is given by:

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

- where:
  - N = Total number of π^os (ηs) measured for different spin alignments
  - P_B = "Blue" beam polarization
  - P_Y = "Yellow" beam polarization
  - R3 = Luminosity ratio
  - N^{++} includes both N^{++} and N^{--}
  - N^{+-} includes both N^{+-} and N^{-+}





Fills and Runs

Fill:

- A number of bunches of protons that travel through the accelerator rings
- When the polarization and number of protons become lower than a certain point, the current fill is dumped and a new fill is started
- Each fill lasts roughly 6 hours

Run:

- Subset of a fill that contains a certain number of proton-proton collisions
- Breaks data into manageable pieces
- Many runs make up a fill (usually from 2-20, averaging around 12)
- Each run is comprised of roughly 30 minutes of data-taking within a fill

Two Photon Invariant Mass Fitting

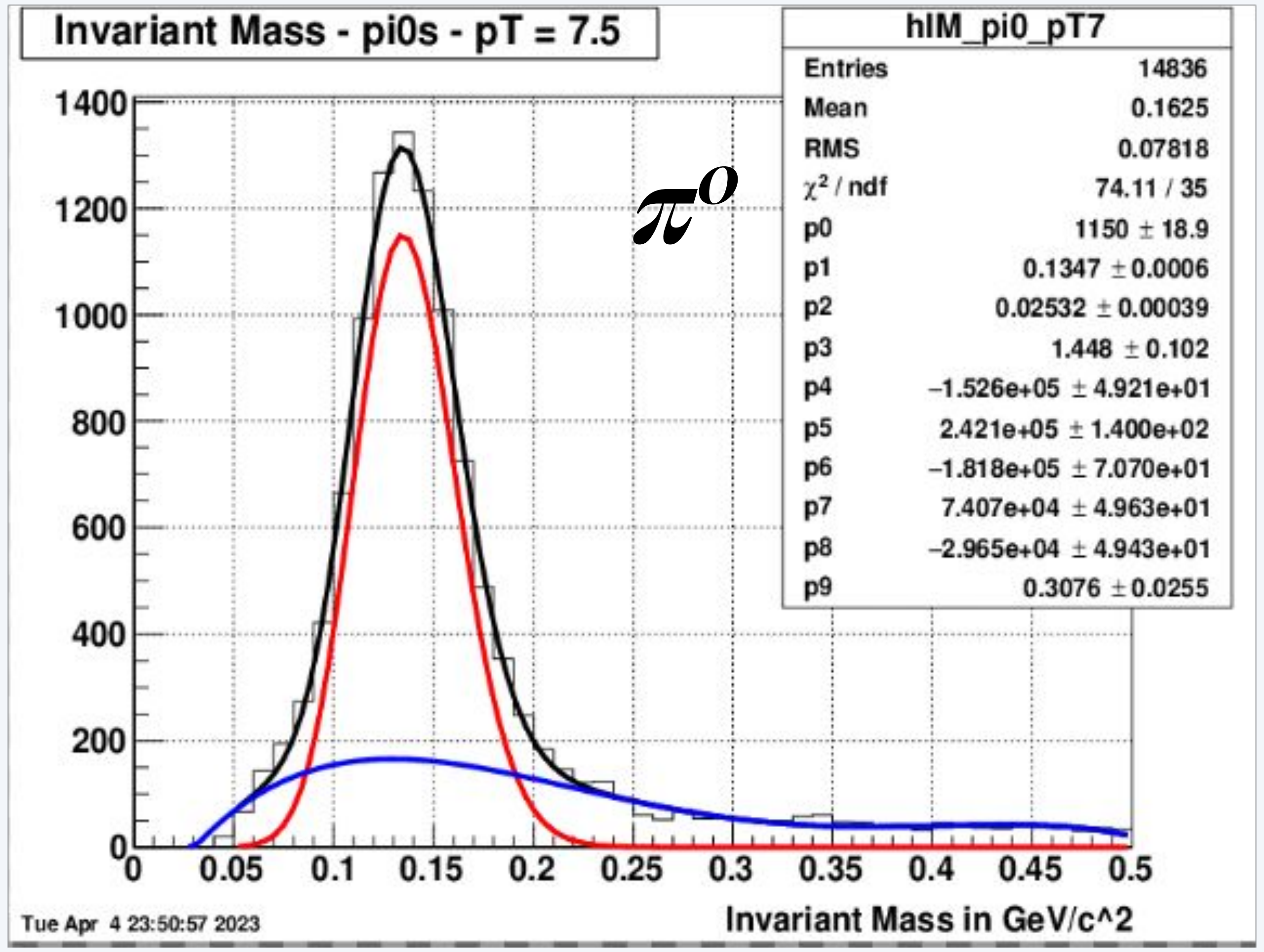
- Signal (π^o or η) is fit using a skewed Gaussian function (red line)

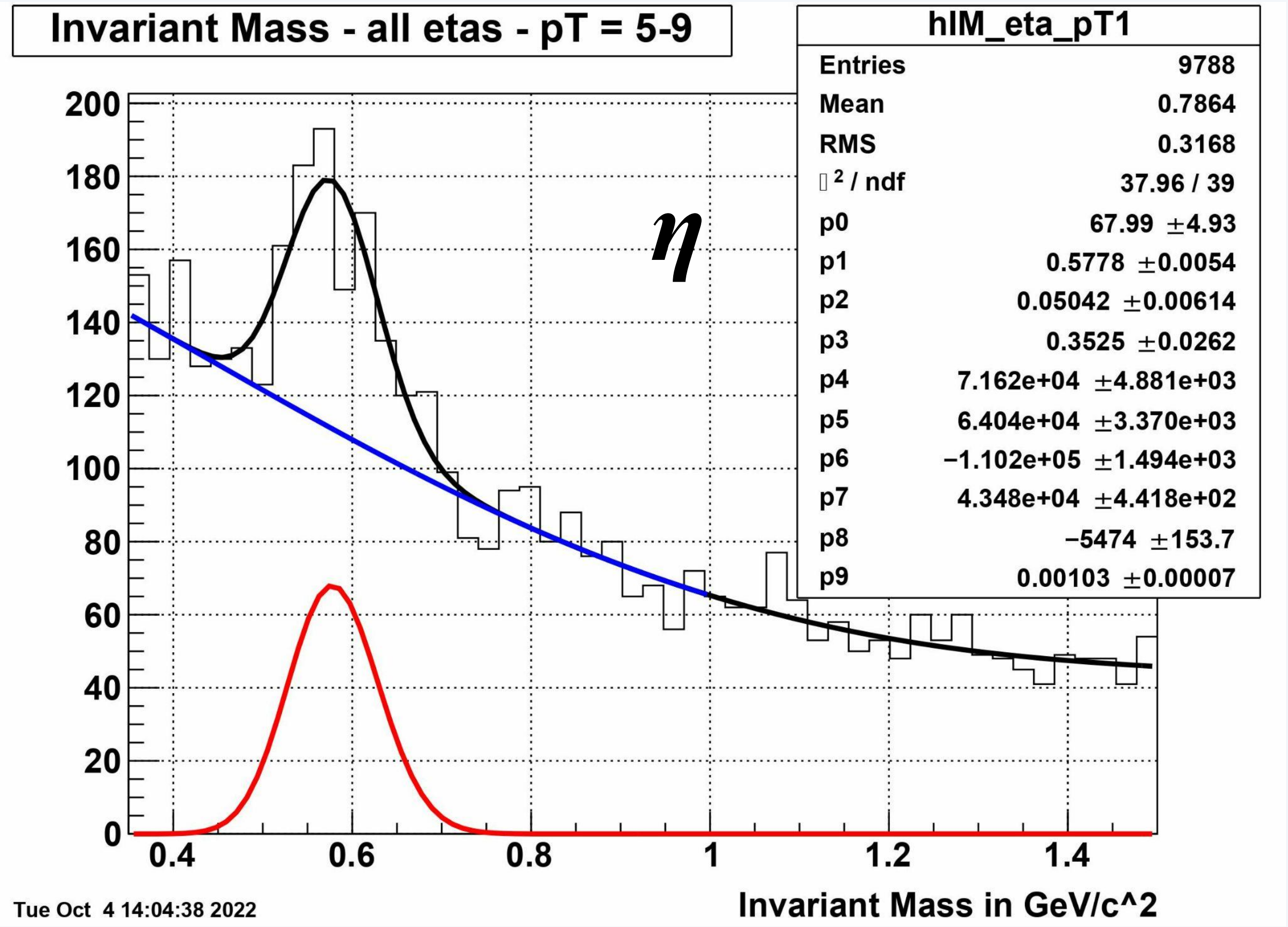
$$f(x) = p0 \cdot exp\left(-0.5\left(\frac{x - p1}{p2(1 + p3(x - p1))}\right)^2\right)$$

- Background of the graph is fit using the Chebyshev polynomial (blue line)

$$B = p9 \cdot (p4 \cdot T_o + p5 \cdot T_1 + p6 \cdot T_2 + p7 \cdot T_3 + p8 \cdot T_4)$$

- The black line is the sum of the two functions and represents the fit to the data





Quality Assurance (QA)

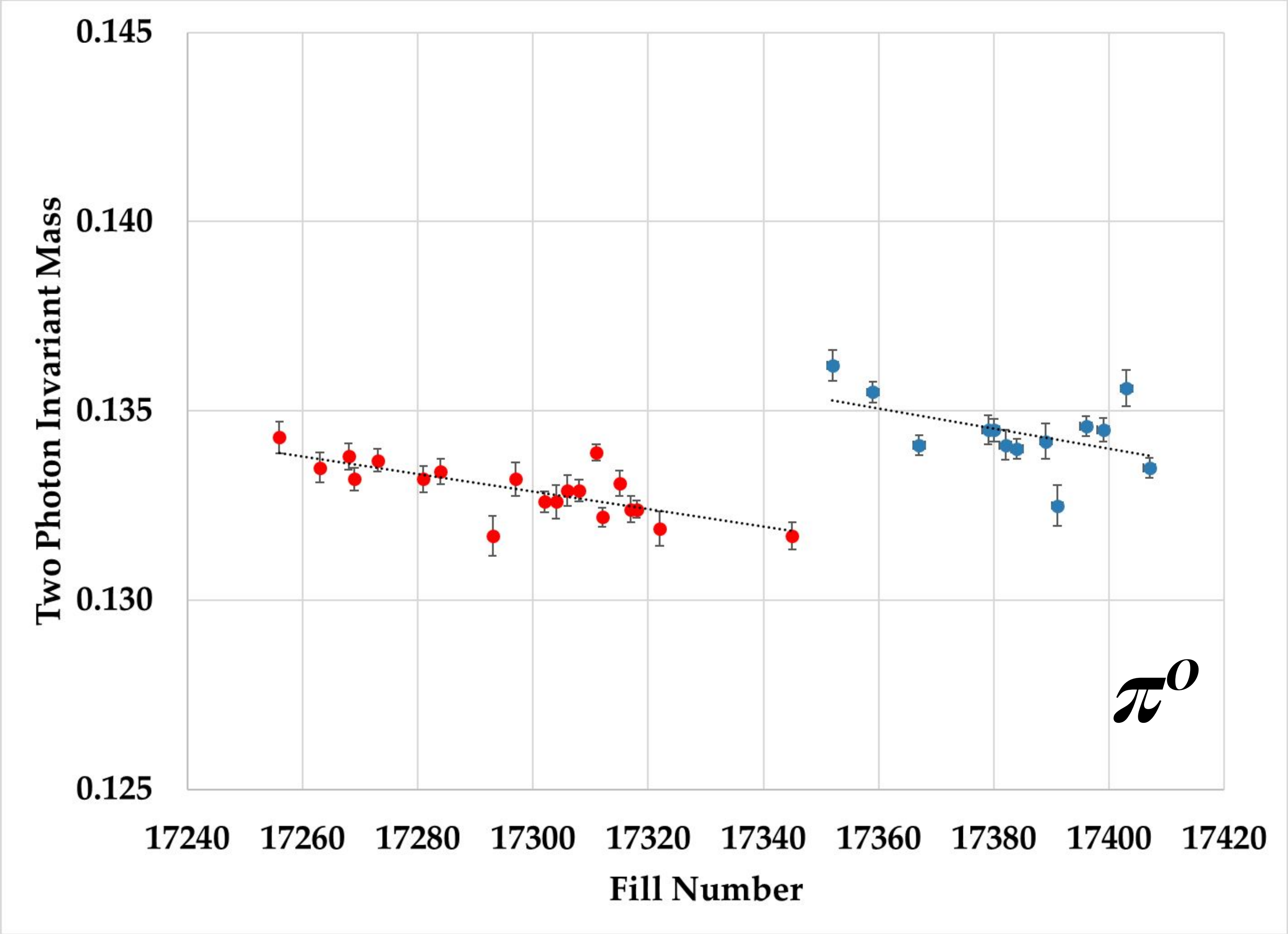
- Done first at the run level and then at the fill level

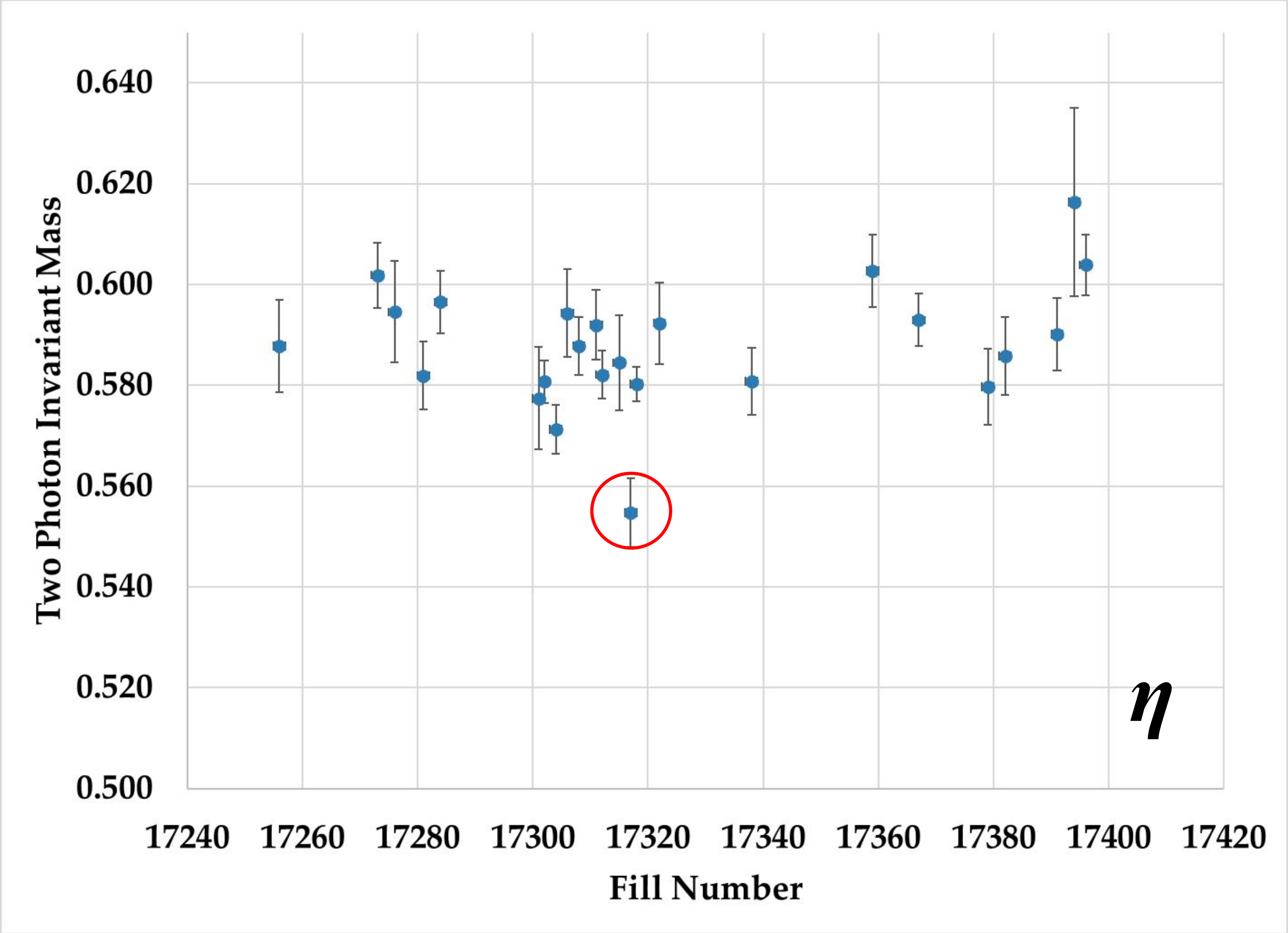
- QA on the runs ensures quality data
  - Gather all runs from all fills (~ 12 runs per fill)
  - Look at values related to π^o (η) mass, segments in the detector hit, and the signal to background ratio
  - Remove any outlier runs 4σ away from the mean of that value for all runs

- QA on the fills takes place after run QA with remaining data
  - Remove fills that are “bad” or inconsistent with the data set
  - Fit the measured two-photon invariant mass spectrum with the sum of two functions: a π^o (η) signal function (represented by a skewed gaussian) plus a background function (5th order Chebyshev polynomial).

Fitted Invariant Mass Spectrum

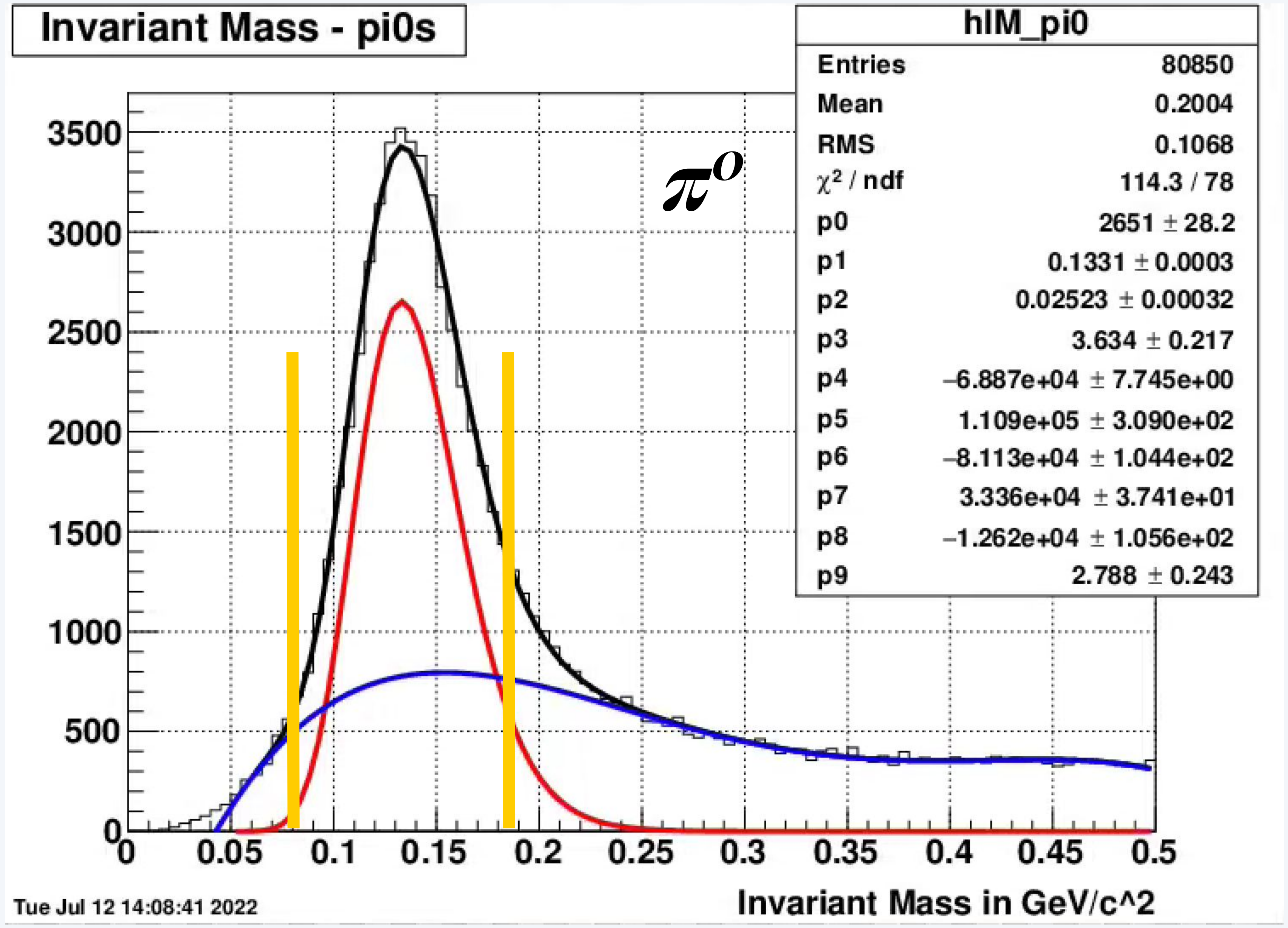
- Plot important information such as π^o (η) mass, π^o (η) width, number of π^os (ηs), etc.
  - Look for deviations from the norm
  - The plots show the mean of the signal portion of the two photon invariant mass vs fill number





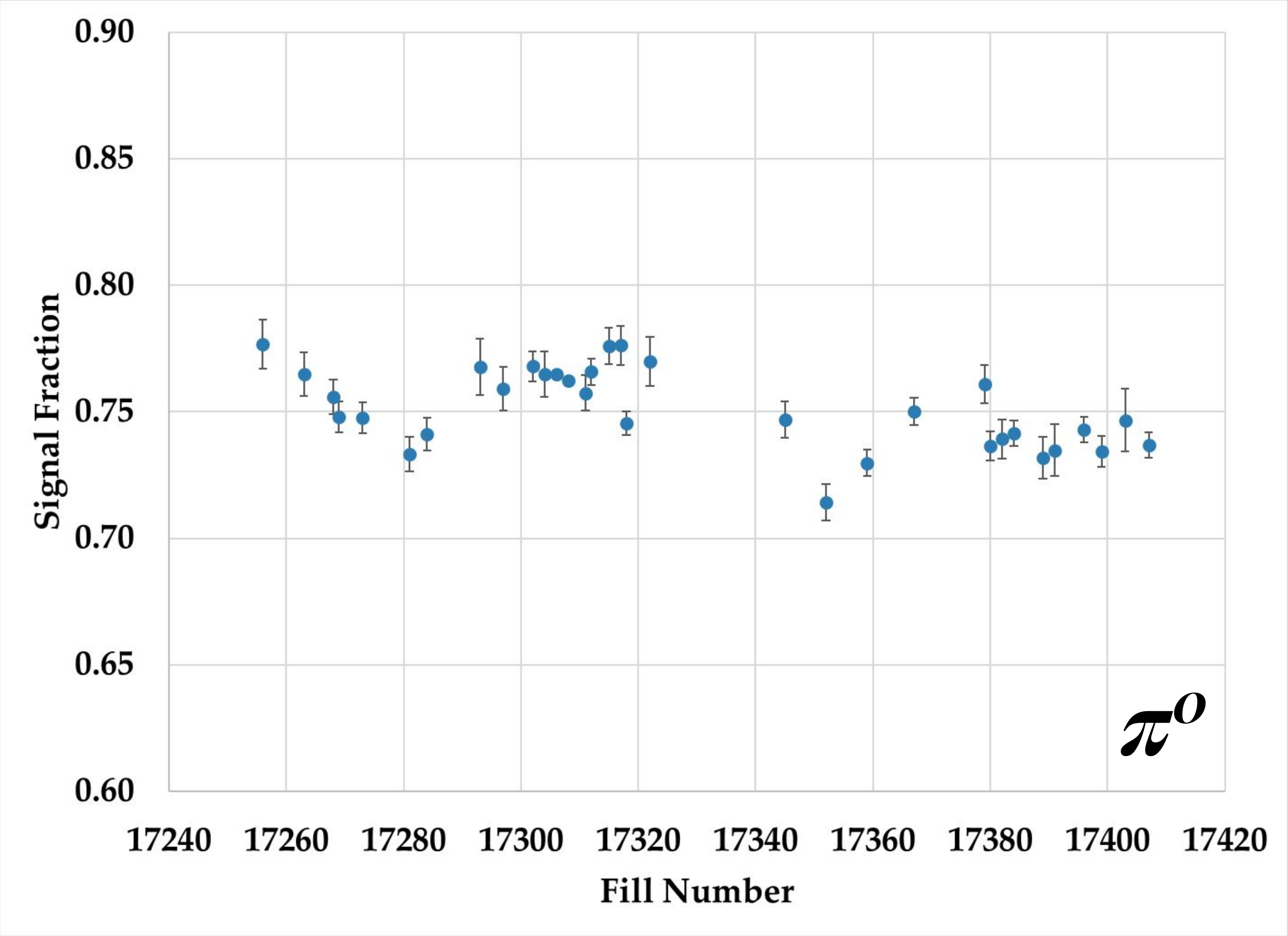
Signal Fraction

- The signal fraction is the number of π^os (ηs) within 2σ of the π^o (η) peak divided by the total number of events in this region.
- π^o candidates that are within 2σ of the mean (gold lines)
- The signal fraction is used as an analysis tool to ensure a good ratio of the signal to the background noise

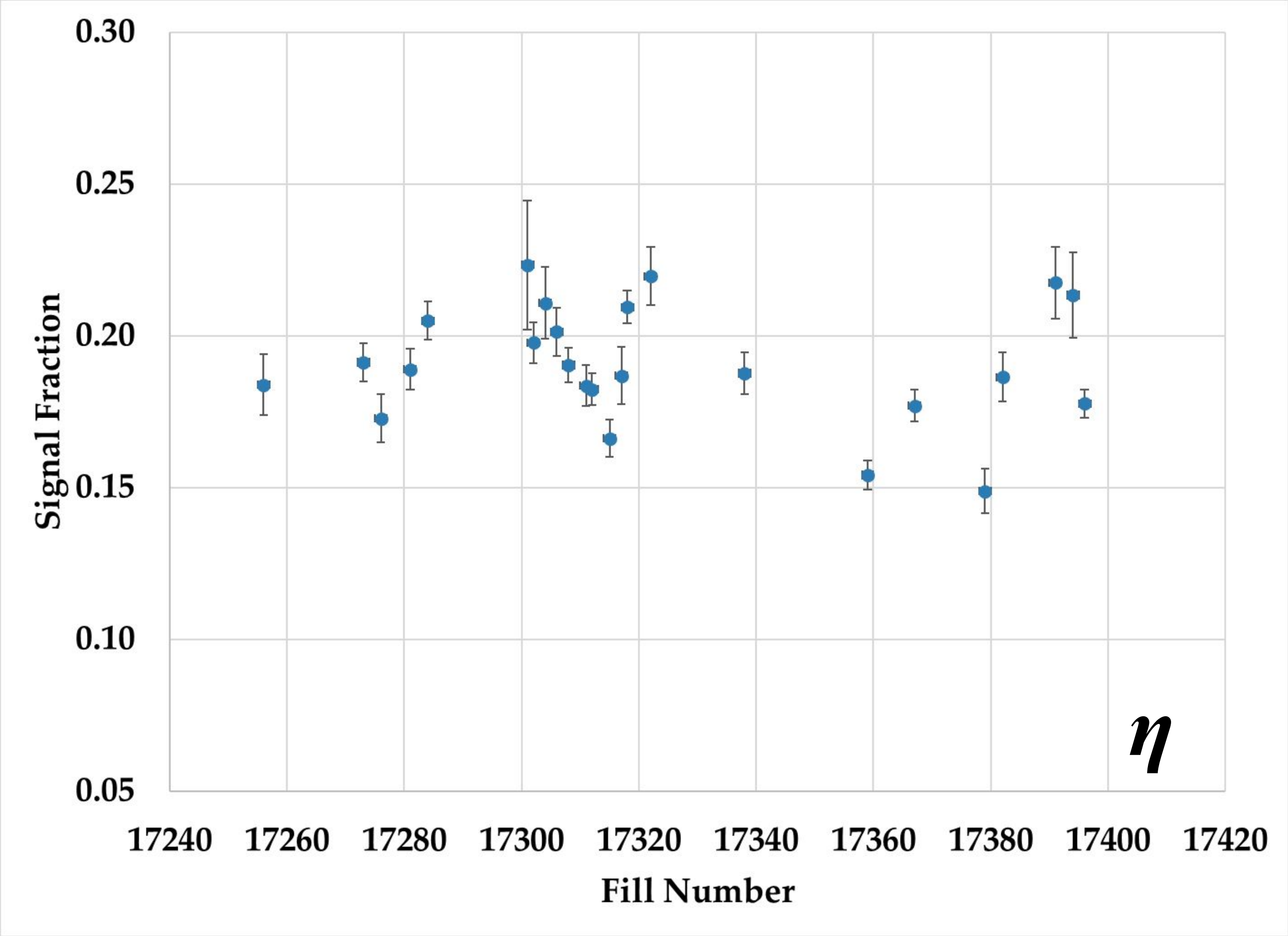


Signal Fraction vs. Fill Number

- The signal fraction is one of the parameters used to remove "bad" fills



π^o signal fraction vs. fill number, where the observed signal fraction is about 0.75



η signal fraction vs. fill number, where the observed signal fraction is about 0.20

Summary

- Run level QA has been completed for the 2013 data set
  - For both π^0s and ηs

- Fill level QA in progress
  - Total of 121 fills
  - ~30% fills analyzed for π^0s
  - ~25% fills analyzed for ηs

- Next steps:
  - Finish fill level QA for π^0s and ηs
  - Begin asymmetry (A_{LL}) analysis for π^0s and ηs to constrain gluon contribution to proton spin
  - To be completed in the summer of 2023

Acknowledgements

Dr. Stanislaus, Dr. Gibson-Even, Dr. Grosnick, Dr. Koetke, and Mr. Nord

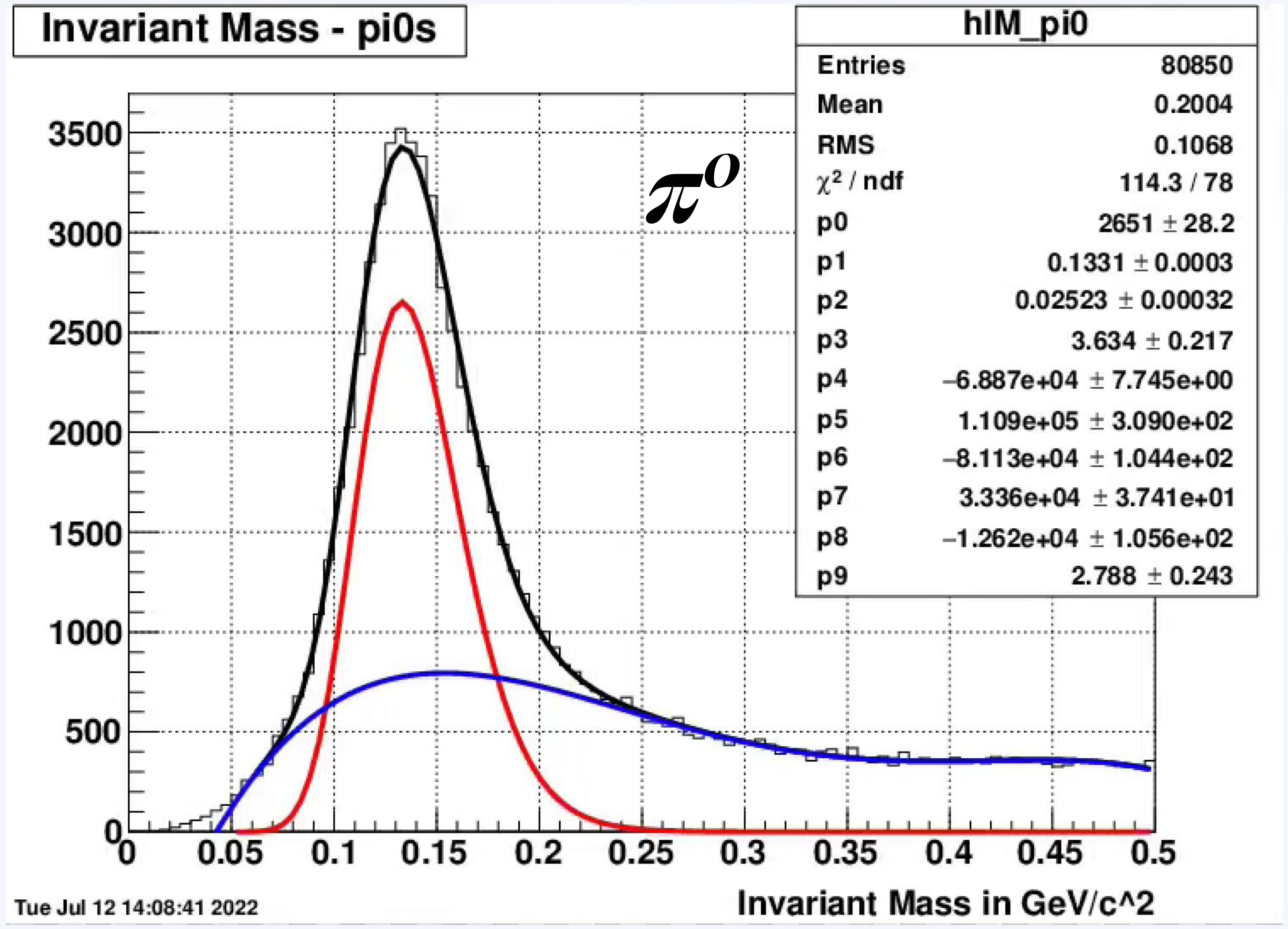
Valparaiso University Physics and Astronomy Department

Two Photon Invariant Mass Fitting

$$f(x) = a \cdot exp\left(-0.5\left(\frac{x-b}{c(1+d(x-b))}\right)^2\right)$$

$$B = c_0 T_0 + c_1 T_1 + c_2 T_2 + c_3 T_3 + c_4 T_4$$

p0 = related to the height (a)
p1 = related to the mass of pi0 (b)
p2 = related to width of graph (sigma) (c)
p3 = skewing parameter (d)
p4 = c0
p5 = c1
p6 = c2
p7 = c3
p8 = c4
p9 = moves the chebyshev polynomial (blue line) up and down to better match the function



$$T_0(x) = 1$$

$$T_1(x) = x$$

$$T_2(x) = 2x^2 - 1$$

$$T_3(x) = 4x^3 - 3x$$

$$T_4(x) = 8x^4 - 8x^2 + 1$$

b = mean
c = sigma
d = ‘skewing’ parameter

Eta Signal Fraction