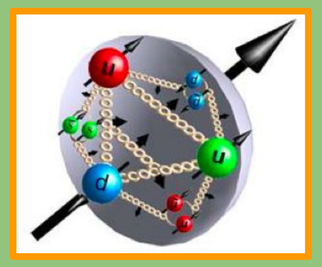
Gluon Contribution to Proton Spin and the Connection to Forward Calorimetry at STAR

Miya Bailey (Valparaiso University) for the STAR Collaboration

Mentors: Professor Adam Gibson and Professor Shirvel Stanislaus

Proton Spin Distribution

- Protons have intrinsic spin: ħ/2
- Protons composed of quarks and gluons, which contribute to its spin
- Quark spin responsible for ~30% of proton spin
- Gluon contribution not as well constrained, particularly gluons with a small fraction of the proton's momentum (low *x*, e.g. $x < 0.05$)



(**Above**) A model of the proton

Quark Spin | Gluon Spin

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

Proton Spin | Quark Orbital Momentum | Gluon Orbital Momentum

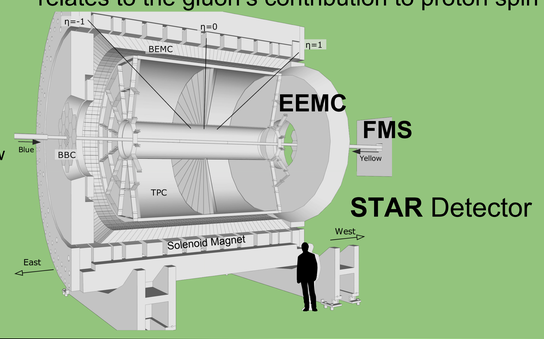
Investigation of Spin at STAR

- **S**olenoidal **T**racker **a**t **R**elativistic Heavy Ion Collider
- RHIC the only collider in the world capable of producing spin-polarized collisions

(**Left**) Aerial view of RHIC at Brookhaven National Laboratory in Upton, NY

EEMC and FMS

- **E**ndcap **E**lectro**m**agnetic **C**alorimeter and **F**orward **M**eson **S**pectrometer detect the number of π^0's from spin-polarized collisions
- Allow us to calculate an asymmetry which relates to the gluon's contribution to proton spin



STAR Detector

π^0 Reconstruction

- Jets of particles, including π^0's, are produced from proton collisions
- EEMC and FMS detect the photons from π^0 decays
- Measure photon energy and position (for opening angle θ)
- Calculate the diphoton mass, expected to be ~135 MeV/c^2, the invariant mass of the π^0

$$M_{\gamma\gamma}^2 = 2E_1E_2(1-\cos\theta)$$

π^0 Asymmetry

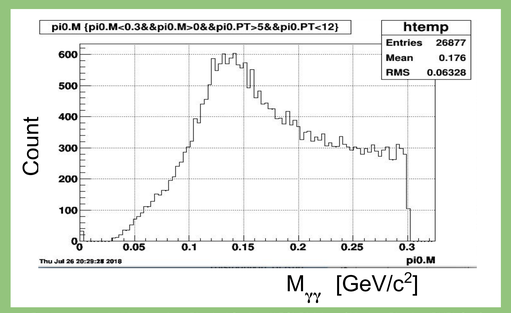
- A_{LL} is proportional to the gluon's contribution to the proton spin
- Spin is aligned when spin and momentum vectors are aligned; Spin is anti-aligned when the vectors are opposed.

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}}$$

Asymmetry equation where σ^{++} is the pion or di-jet production cross section for collisions with both protons aligned

2013 EEMC π^0 Analysis

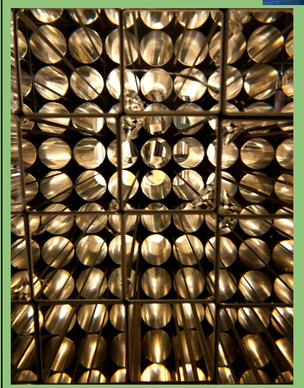
- Measure π^0's in the EEMC ($1 < \eta < 2$) to probe relatively low momentum (*x)* gluons
- Using dataset from 2013 (integrated luminosity 300 pb^{-1}), ~3 times larger than 2012 dataset (82 pb^{-1})
- Analysis proceeds through 3 parts
  - Part 1: Calibrated energies for different parts of the EEMC
  - Part 2: Strip clustering and other elements of photon reconstruction
  - Part 3: Final photons and π^0's
- Analyzed 105 runs (a small fraction of the 2013 dataset), including some for comparison with work from another student last summer
- Few small discrepancies (i.e. slightly different entry and RMS values) noted in the comparison, under investigation.
- Each run had a mass peak in the 135 MeV/c^2 range!



Mass distribution of Run 14082034. Peak is in the 135 MeV/c^2 range, which is the invariant mass of a neutral pion.

Forward Meson Spectrometer Decommissioning

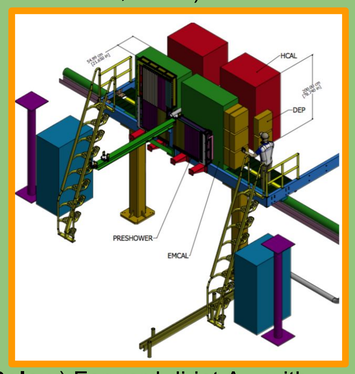
- The FMS ($2.5 < \eta < 4.0$) was a STAR detector used to measure forward π^0's to probe even lower *x* gluons
- Decommissioned for replacement by a Forward Calorimeter System (FCS)
- FMS made of 1,264 lead glass blocks of two different sizes
  - 476 3.8 x 3.8 x 45 cm^3 smaller blocks
  - 788 5.8 x 5.8 x 60 cm^3 larger blocks.
- Each lead glass block attached to one photomultiplier tube (PMT), and two cables
- VU physics research team traveled to BNL to dismantle FMS (7/8/18-7/28/18)
- Removed all cables, removed PMTs from fragile mounts and casings connected to the lead glass, and unstacked each lead glass block
- Carefully stacked and packed lead glass blocks into crates for safe storage until ready for use in other experiments



(**Above**) Team that deconstructed the FMS, from VU, Abilene Christian University, Yale, and UC-Riverside
(**Left**)The FMS with all of the photomultiplier tubes removed, looking west from the interaction point
(**Right**) Side view of the pre-deconstructed FMS

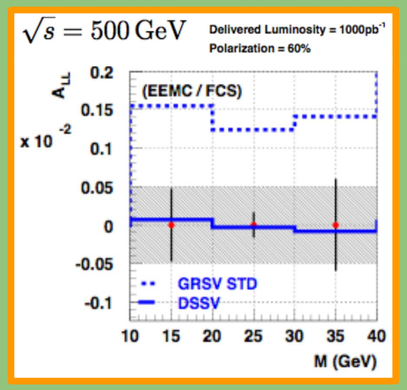
Proposed Forward Calorimeter System Upgrade

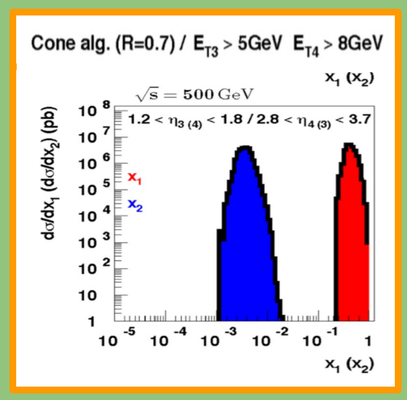
- Proposed for the years beyond 2020, covering $2.5 < \eta < 4.0$
- Refurbished portion of the PHENIX EMCAL (Pb-scintillator) and new HCAL (Fe-scintillator), with same newly designed readout
- Will allow forward jet measurements (not just π^0's), as in the di-jet measurement illustrated below (from "A polarized p+p and p+A program for the next years", STAR Note 605, 2014, and "The STAR Forward Calorimeter System and Forward Tracking System", STAR Note 648, 2017)



(**Left**) A diagram of the proposed FCS upgrade in its home, the previous position of the FMS.

(**Below**) Forward di-jet A_{LL} with projected statistical and systematic uncertainties and model calculations.





(**Above**) x-coverage for di-jet configurations involving one jet in the EEMC and one in the FCS. This configuration (and FCS/FCS) probes x values as low as 10^{-3}

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