Understanding the Gluon's Contribution to the Spin of the Proton using a π^0 A_{LL} Measurement with the STAR Experiment at RHIC

Adam Gibson
Valparaiso University

For the STAR Collaboration

DNP 2019

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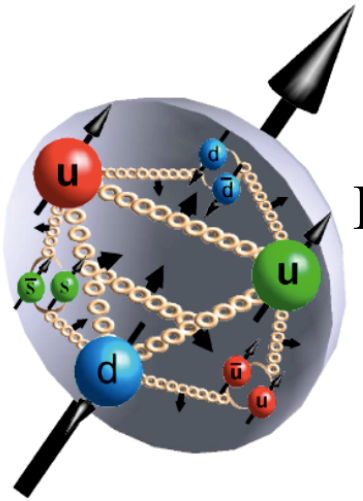
Contributions to the Proton's Spin



Polarized e/μ + p: ~0.3
Puzzling for ~30 years

Relatively poorly constrained but S_g coming into focus.

Proton spin sum rule: $\frac{1}{2}\hbar = \frac{1}{2}\sum_q S_q^z + S_g^z + \sum_q L_q^z + L_g^z$

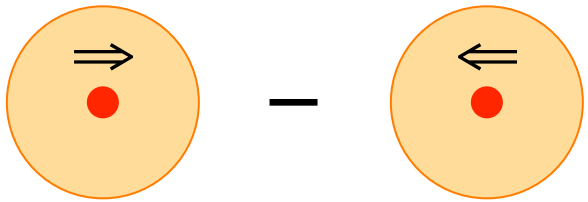
$$S_g^z = \Delta G = \int_0^1 dx \Delta g(x)$$

Gluon's contribution to the proton's spin

Proton momentum ⇒

Proton spin ⇒

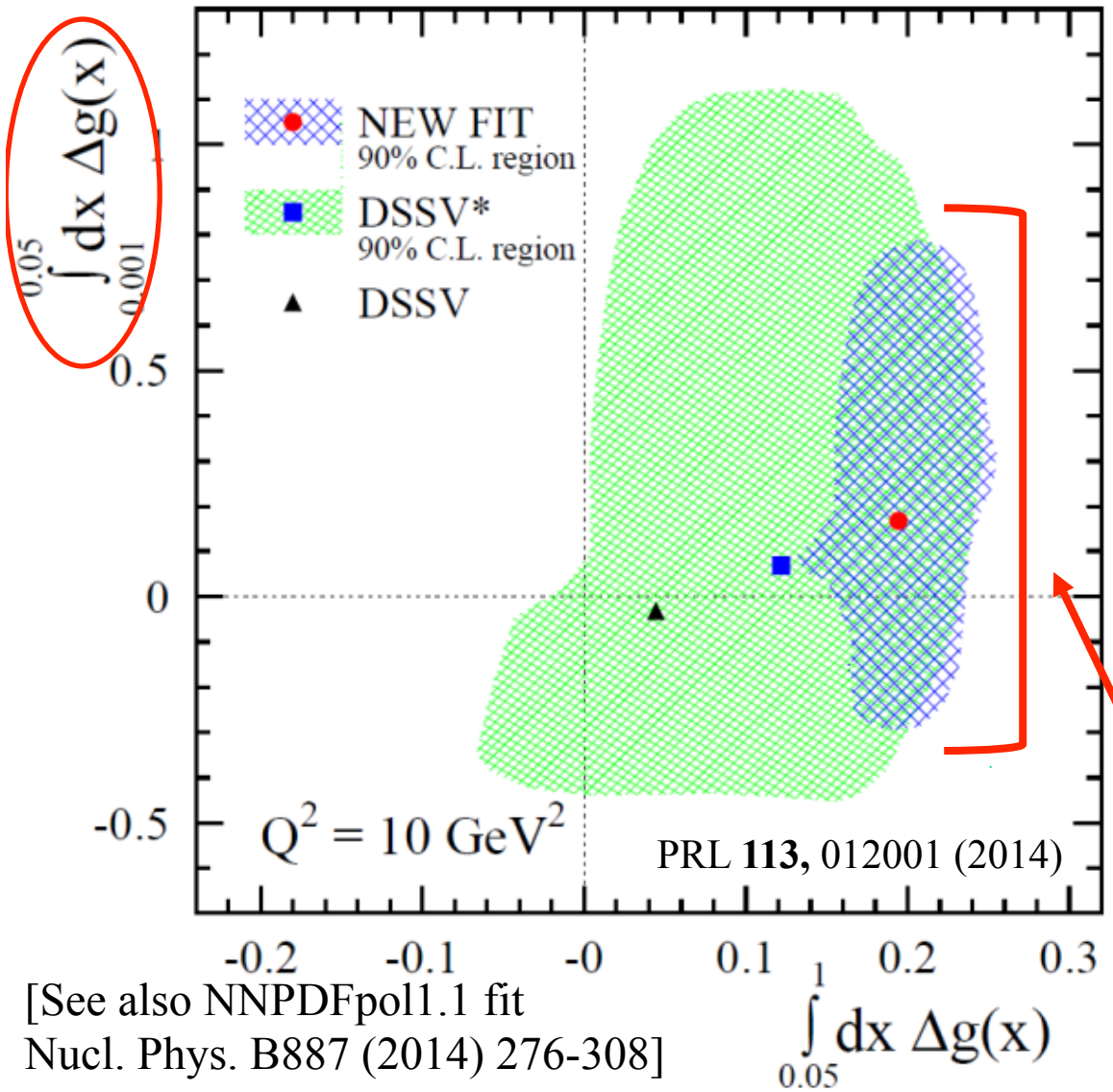
$\Delta q(x)$
$\Delta g(x)$



Longitudinal Polarization

See also Y-B Yang et al χQCD Collaboration Phys. Rev. Lett. 118, 102001 (2017) for ΔG on the Lattice

DSSV14 Fit – ΔG Comes into Focus
Low *x* Remains Blurry



[See also NNPDFpol1.1 fit
Nucl. Phys. B887 (2014) 276-308]

- With input from PHENIX π^0's and STAR 2009 jets
- Integral of Δg(x) in range $0.05 < x < 1.0$ increases substantially, now significantly above zero.
- Uncertainty shrinks substantially from DSSV* to DSSV14 fit
- Uncertainty on integral over low *x* region is still sizable

Strategy for probing lower *x* gluons

- Larger datasets: reduce our statistical uncertainty
  - 2006 6.8 pb^{-1} longitudinally polarized data collected at STAR, 2009 25 pb^{-1}, 2012 82 pb^{-1}, 2013 300 pb^{-1}
- Higher Center-of-Mass Energy
  - For similar p_T reconstructed particles, naturally probe lower *x* partons
  - 2006 and 2009 200 GeV CoM
  - 2012 and 2013 510 GeV CoM
- Forward detectors
  - Collisions with low *x* gluon, high *x* quark send particles to forward detectors
  - Jets at STAR historically mid-rapidity – lately pushing jets further forward
  - Use π^0s where we have EM calorimetry, but no tracking for jets
- Also, aim to use STAR detector comprehensively
  - Make measurements with all subsystems

Solenoidal Tracker at RHIC

Inclusive hadron (e.g. π^0) measurements:

Barrel ElectroMagnetic Calorimeter (BEMC),

Endcap ElectroMagnetic Calorimeter (EEMC),

and

Forward Meson Spectrometer (FMS)

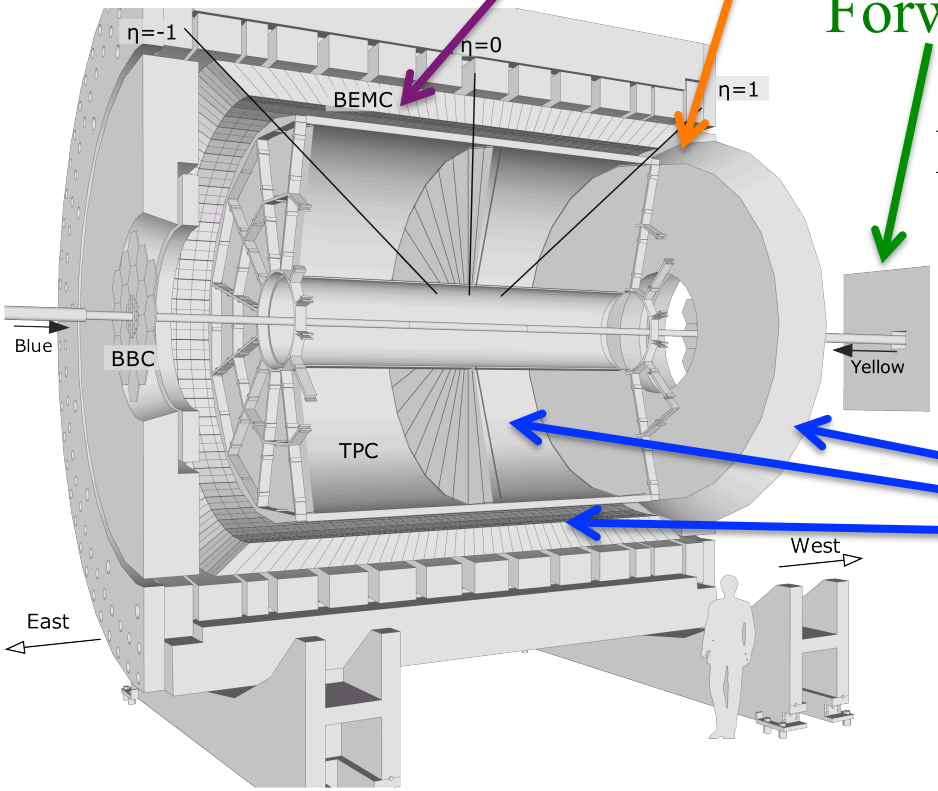
Relative luminosity measurements:

Beam Beam Counters (BBC) etc.

Jet measurements:

TPC +

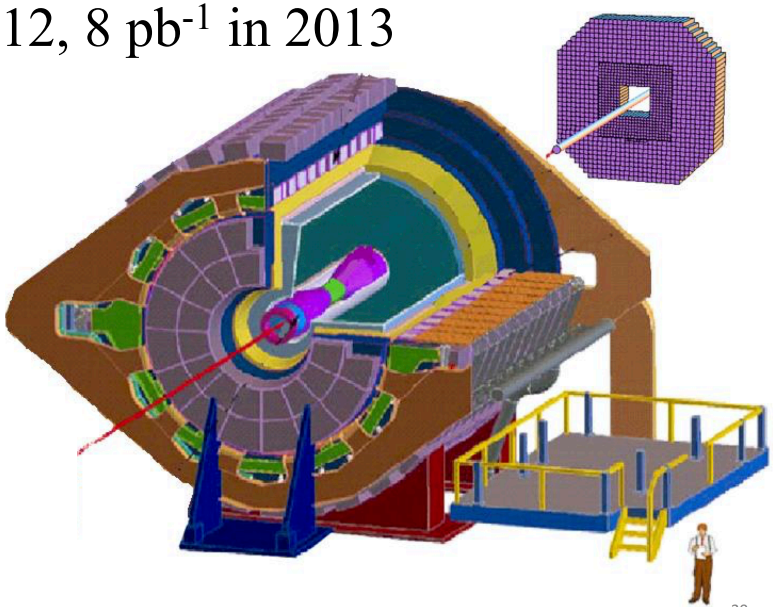
Barrel + Endcap EMC

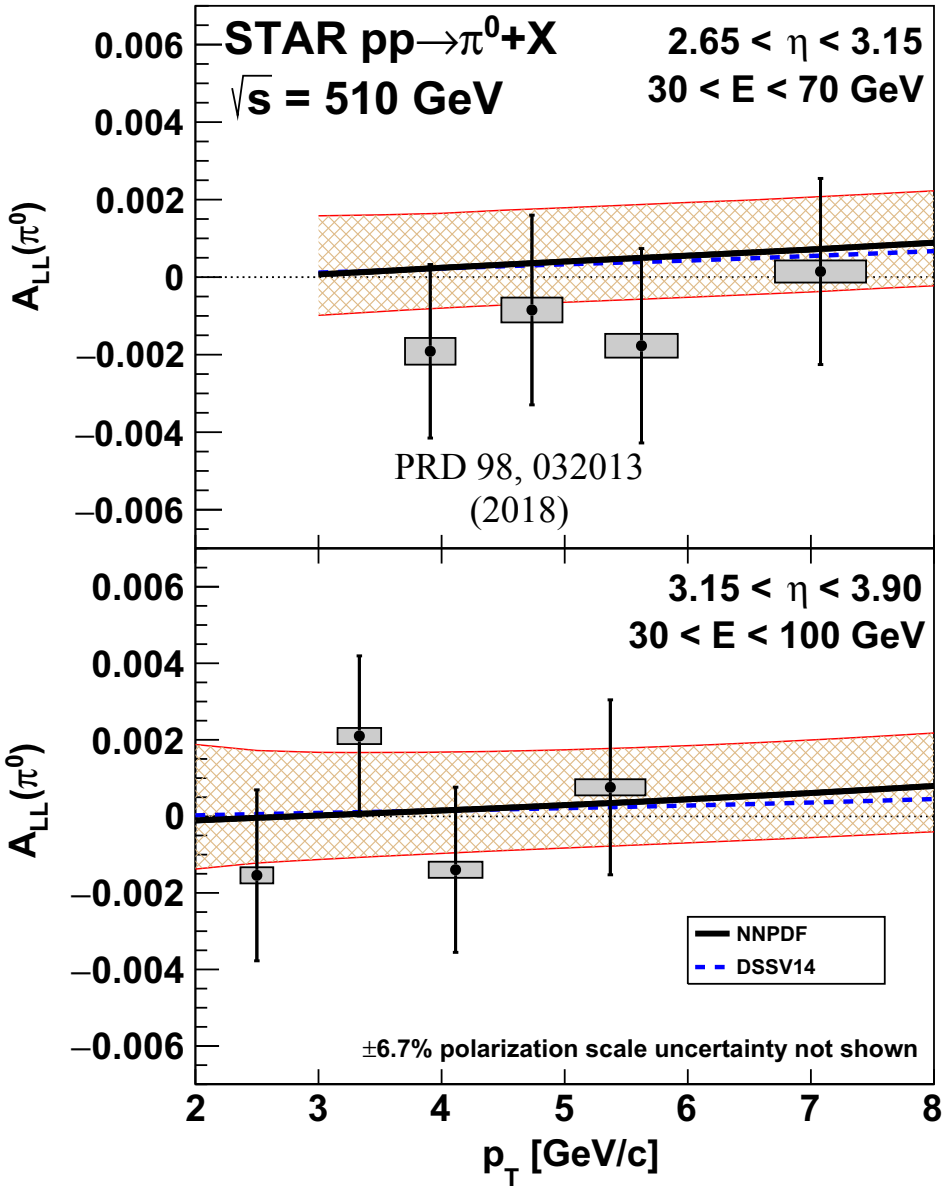


π^0 A_{LL} in Forward Calorimeters: FMS

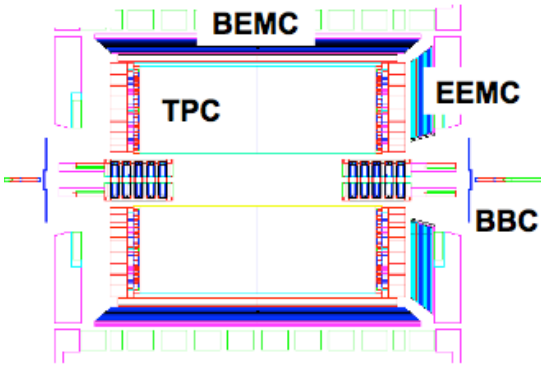
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \propto \frac{\Delta f_a \Delta f_b}{f_a f_b} \hat{a}_{LL}$$

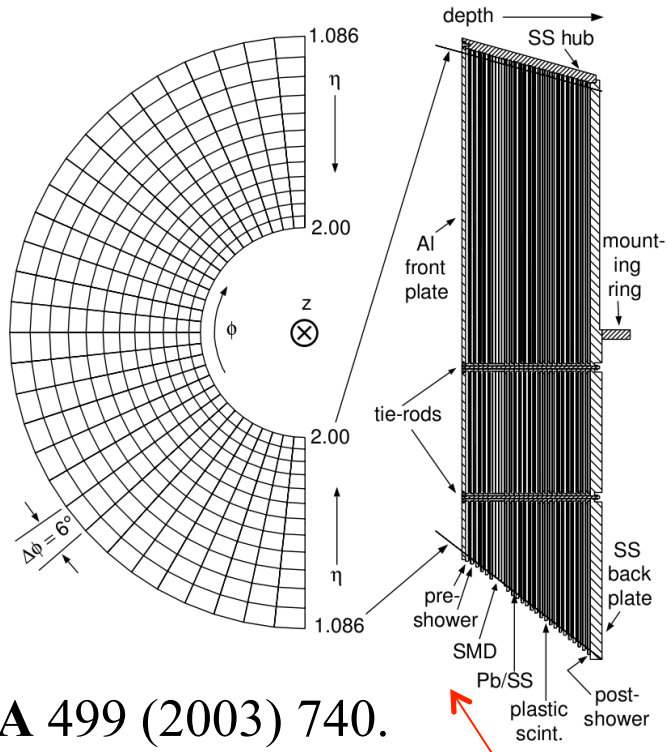
- qg scattering dominates at high η with high *x* quarks and low *x* gluons
- Highest η calorimeter at STAR recently is lead-glass Forward Meson Spectrometer (FMS)
- After prescales, effectively 46 pb^{-1} in 2012, 8 pb^{-1} in 2013





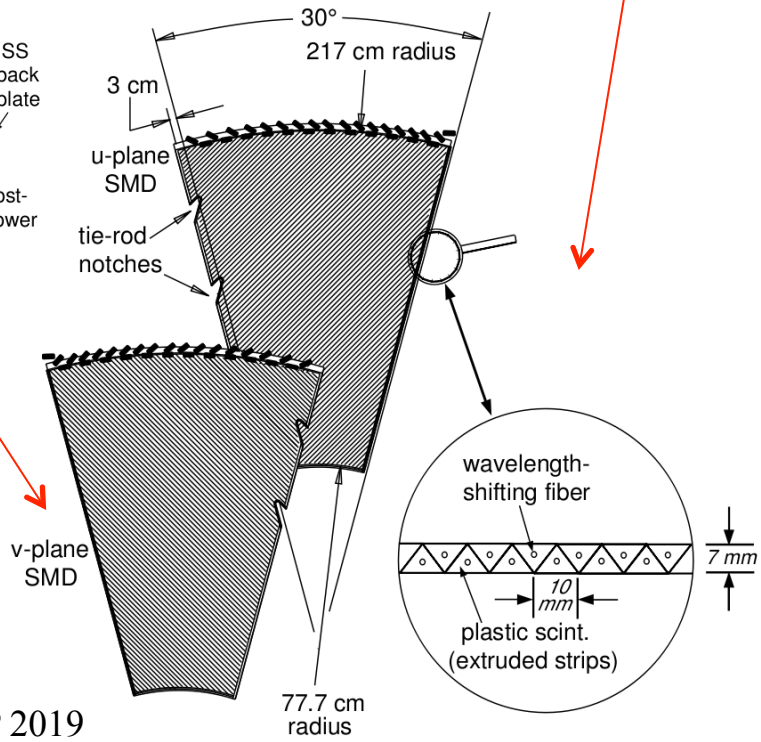
STAR's Endcap Electromagnetic Calorimeter





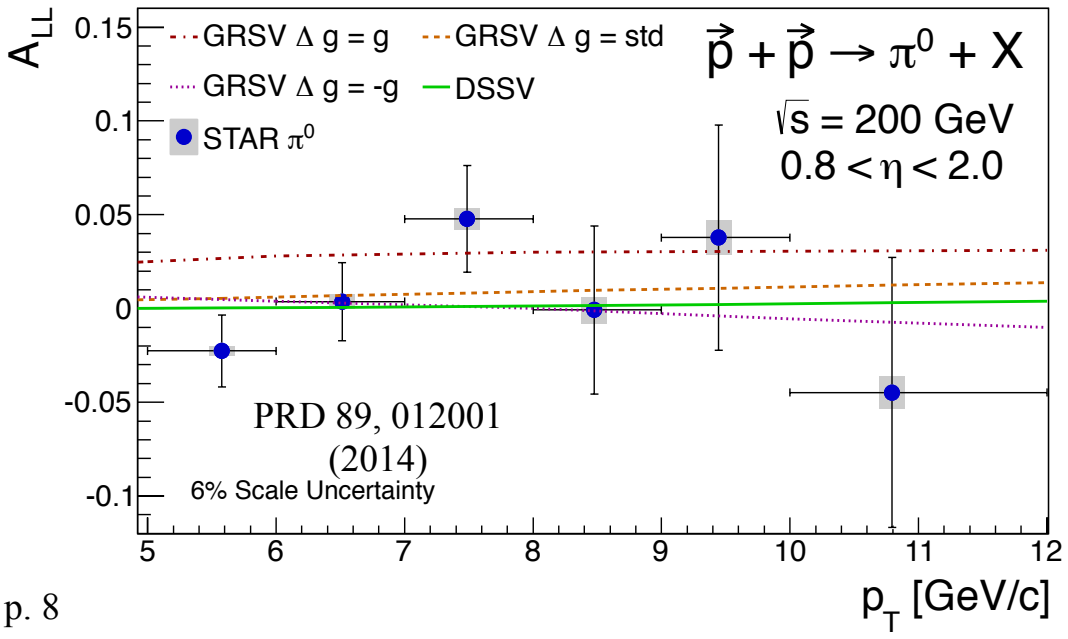
- Scintillating strip SMD
  - ϕ segmented into 12 sectors
  - Two active planes
  - 288 strips per plane
- Resolution of a few mm

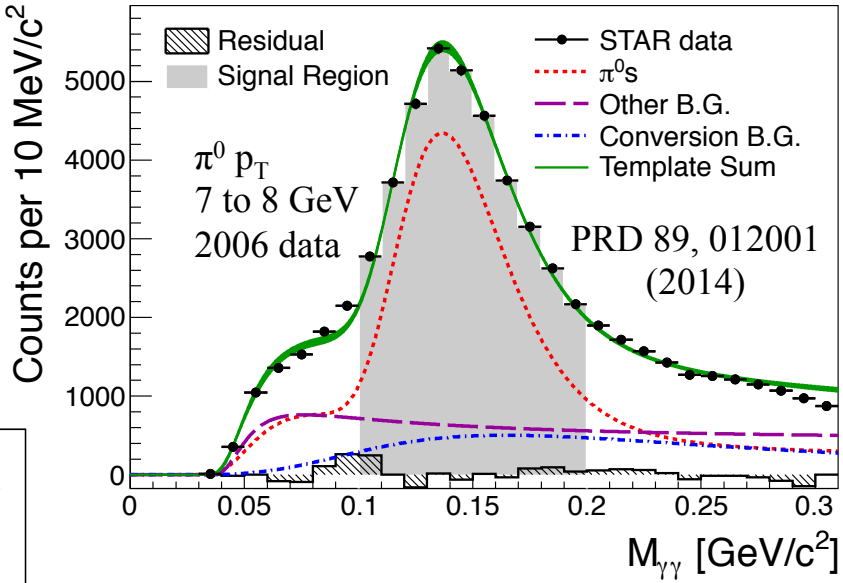
- Nucl. Instrum. Meth. **A** 499 (2003) 740.
- Lead/scintillator sampling EM calorimeter
  - Covers $1.09 < \eta < 2.00$ over full 2π azimuth
  - 720 optically isolated projective towers (~22 X_0)
  - 2 pre-shower, 1 post-shower layers, and an additional shower maximum detector (SMD)
- High Tower and Jet Patch triggers



A_{LL} in π^0 + X at STAR for $0.8 < \eta < 2.0$

- Published measurement with the 2006 dataset in the Endcap Calorimeter (EEMC)
- Push to (reasonably) low *x* (to ~0.01) by going (relatively) forward
  - η region unique at RHIC
- **MC-based templates for shapes**
  - Signal
  - Conversion BG (π^0 candidate is from $\gamma \rightarrow e^+e^-$)
  - All other BG (extra or missing photons, π^0 candidate is γe, etc.)

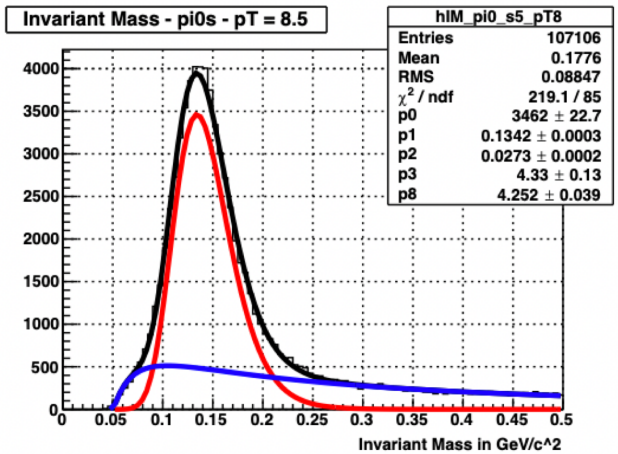


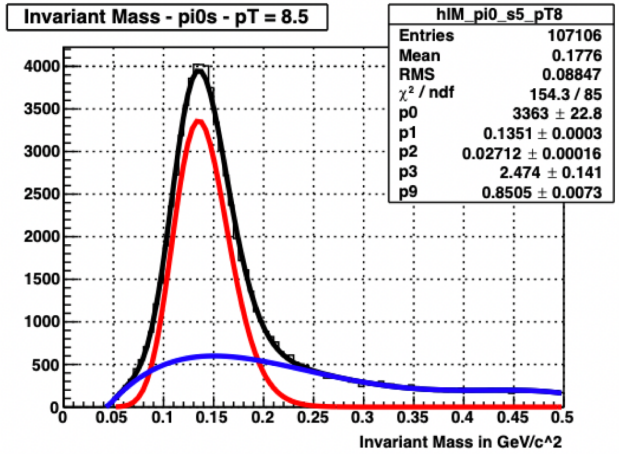


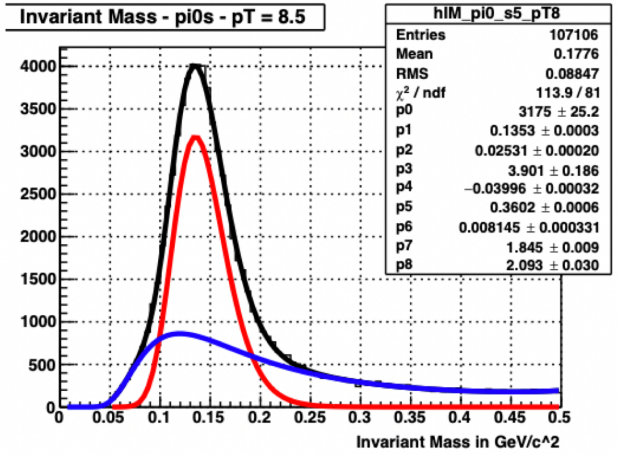
4.8 pb^{-1} for A_{LL} after prescales
~56% polarization
Statistical error (bars) dominate
Systematic error (boxes)

A_{LL} in Endcap π^0s with Larger Dataset

- 2012 dataset being analyzed now
  - x10 the 2006 statistics; ~80 pb^{-1}, ~50% polarization
  - 510 GeV CoM energy w/ similar trigger and reconstruction thresholds allows access to **lower *x* gluons**
- Pursuing a data-driven background model; skewed Gaussian for signal
  - Several background models considered; comparable quality
  - Chebyshev polynomial current default







Polynomial in 1/x

$$B = c_1 + \frac{c_2}{x} + \frac{c_3}{x^2} + \frac{c_4}{x^3}$$

Chebyshev polynomials

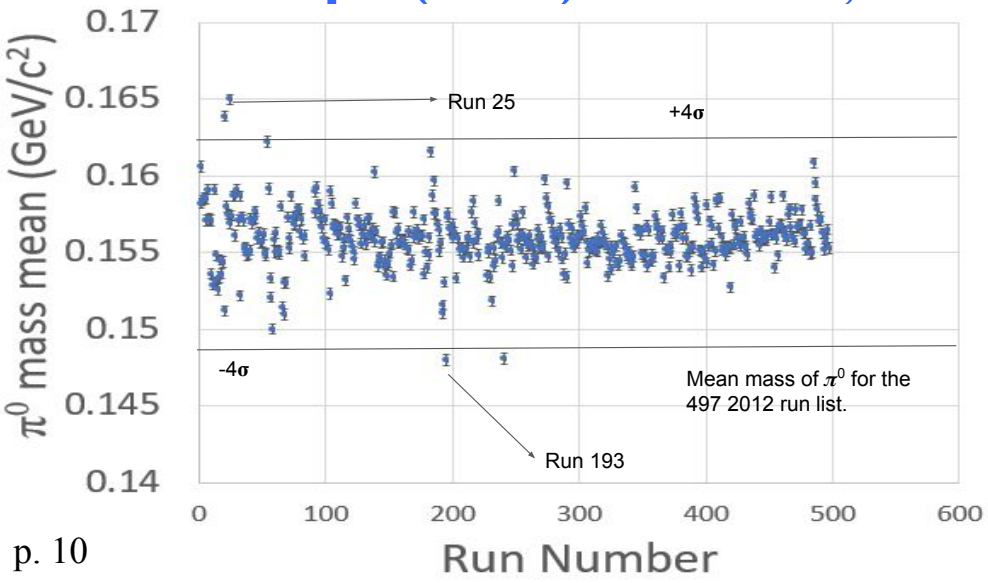
$$B = c_0 + c_1(x) + c_2(2x^2-1) + c_3(4x^3-3x) + c_4(8x^4-8x^2+1)$$

Planck function

$$B = \frac{1}{(x-c_1)^5\left(exp\left(\frac{c_2}{x-c_3}\right) - c_4\right)}$$

Endcap π^0-Specific QA

- Other analyses published with 2012 data and overlapping requirements e.g. 2012 inclusive jets
  - Polarization, relative luminosity, some use of endcap
- Take advantage of their Quality Assurance (QA), but add some analysis-specific QA
  - π^0- and endcap calorimeter-specific quantities
- **See "Quality Assurance of the 2012 Endcap π^0 data at STAR", Joseph (J. D.) Snaidauf, Thursday 11:54 AM for details**



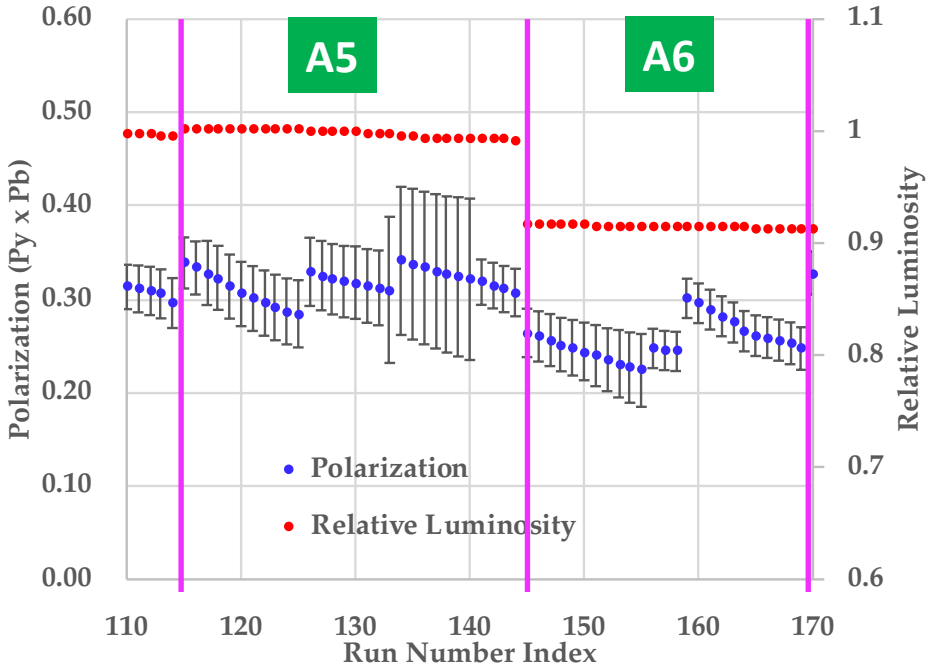
Moving Towards Endcap A_{LL}

- A_{LL} requires relative luminosity and beam polarizations (Yellow, Blue)
- Considering grouping similar runs
  - Allows use of short runs
- Keeping accelerator fills together (as shown)
  - Or splitting them to group even more similar runs
- May end up fitting single runs, instead

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

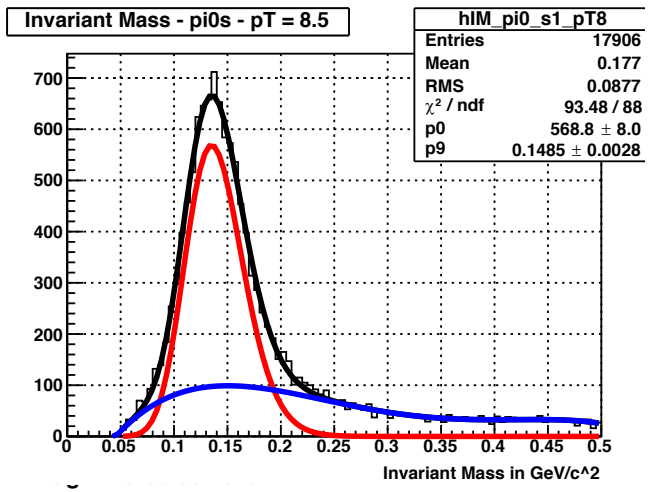
$$A_{LL} = \frac{\sum_{runs} P_Y P_B (N^{++} - R_3 N^{+-})}{\sum_{runs} P_Y^2 P_B^2 (N^{++} + R_3 N^{+-})}$$

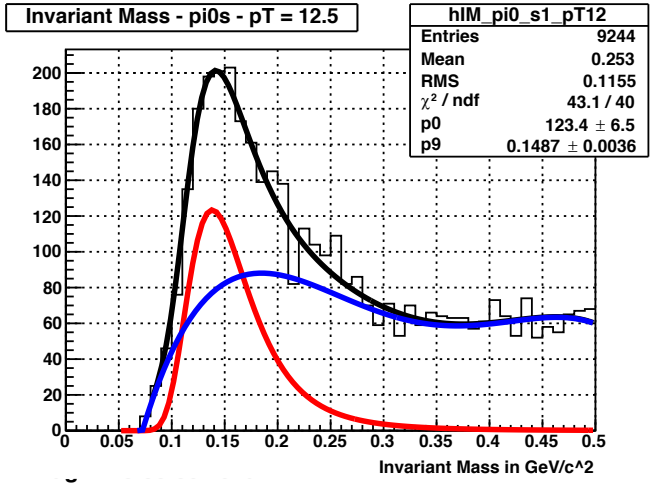
Set A: Keep fills together and combine fills with similar properties into groups.

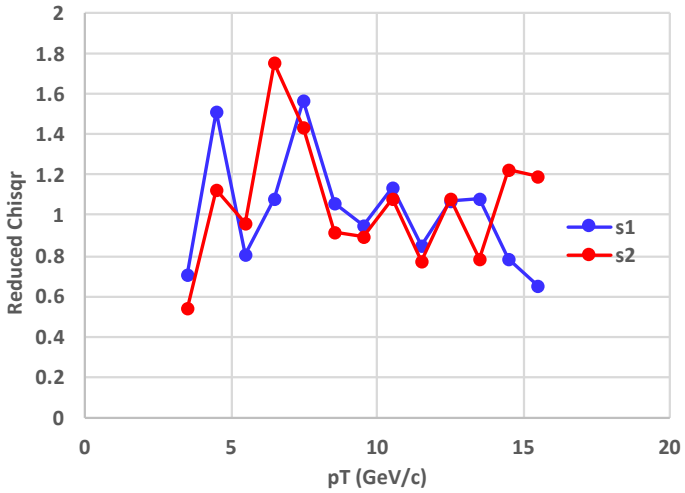


Moving Towards Endcap A_{LL}

- Using background and signal shapes from spin-combined data we separate the data by spin, and fit for signal fraction
- Fits work for a wide range of p_T bins
- Shown here for a subset of the data

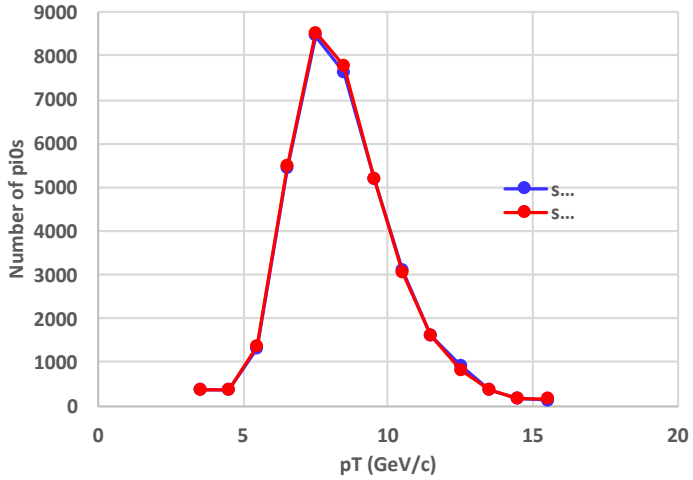






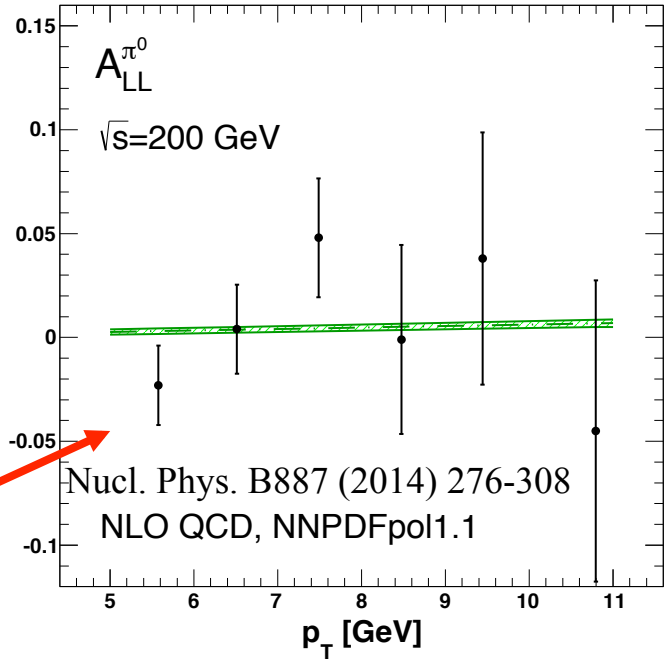
s1 = spin (++ and --)

s2 = spin (+- and -+)

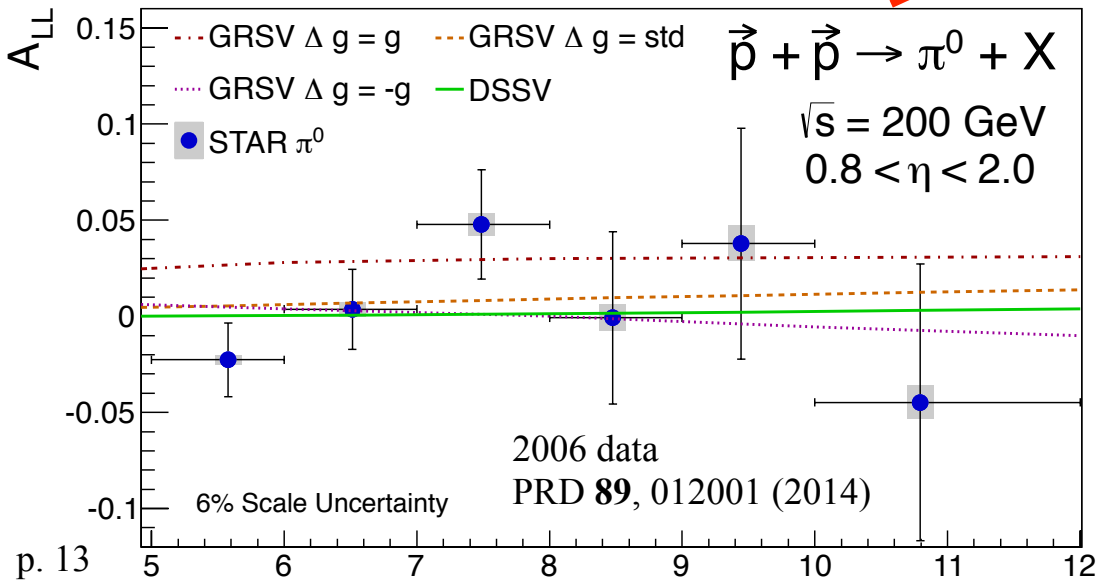


Updated Prediction for π^0 A_{LL} in Endcap (EEMC)

- Not ready to show 2012 A_{LL} yet, but can show projections
- Greater precision needed to constrain the NNPDF result

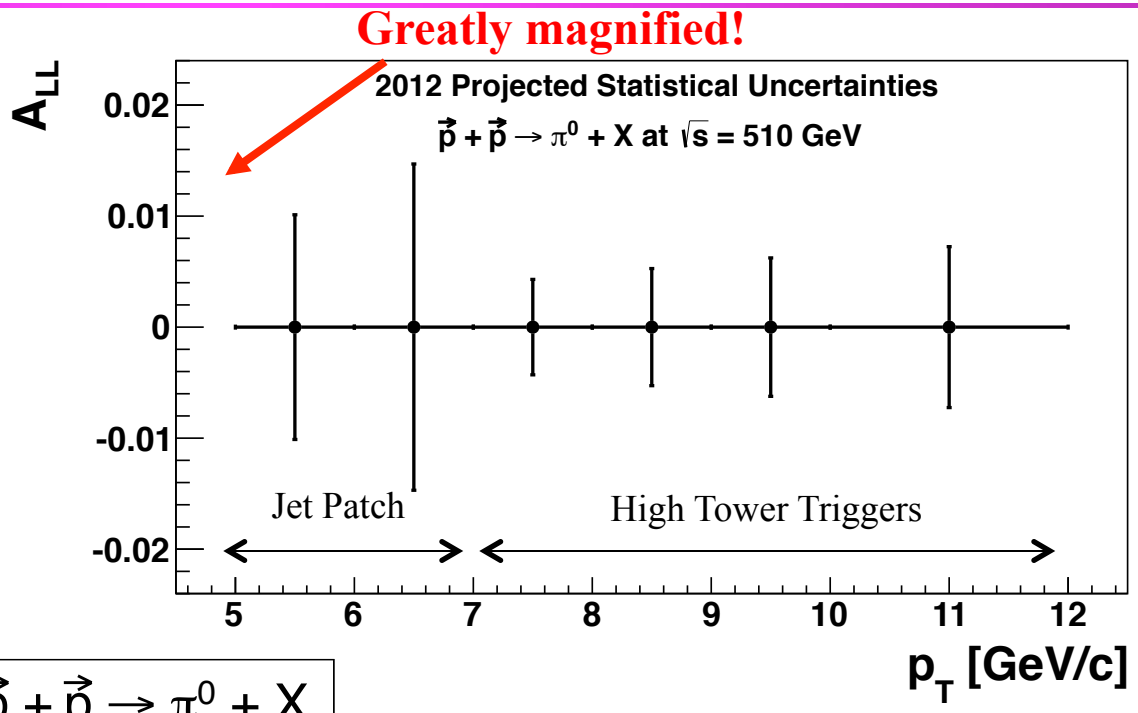


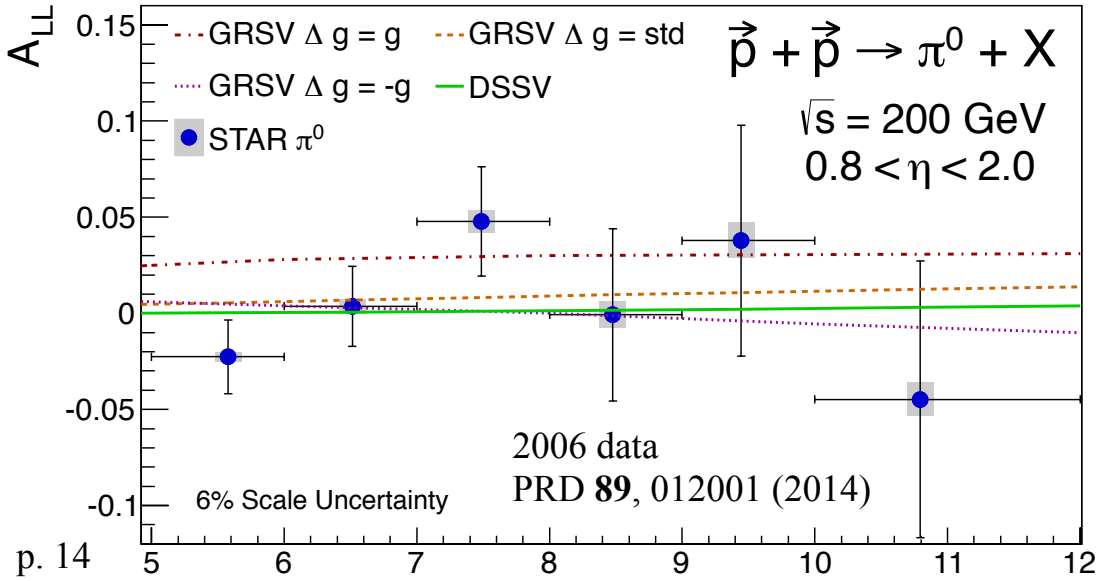
STAR data with NNPDF predictions



π^0 A_{LL} Prospects in 2012 Dataset

- Statistical projection from simplified, data-only fit
  - HT trigger above 7 GeV
  - JetPatch trigger 5-7 GeV
  - Large improvement in stat. uncertainty projected, as shown

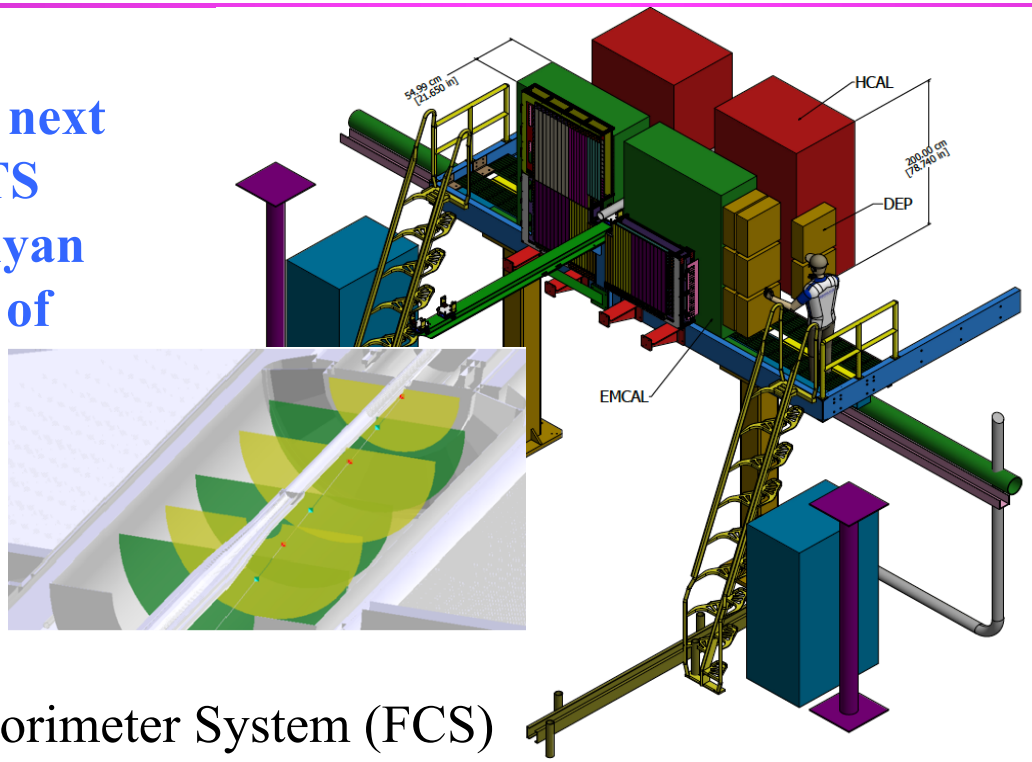




- Our 2012 analysis focuses on High Tower (HT) triggers, for now

Forward Upgrade for the 2020's

See T. C. Huang next for aspects of FTS and D. Kapukchyan after for aspects of FCS



P. Shanmuganathan 3:36 PM Tuesday for TGC

A. Edwards 10:30 AM Thursday (Undergrad Oral Session SE) for details of FCS assembly last summer

- Forward Calorimeter System (FCS)
  - Refurbish a portion of the PHENIX ECal, new Fe-scintillator HCal
  - Forward di-jets will extend gluon polarization to $x <\sim 10^{-3}$
- Forward Tracking System (FTS): Silicon discs and sTGC wheels
- Suite of measurements in longitudinal and transverse spin and p+A collisions
- First physics planned for 2021

Gluon Polarization and Endcap π^0's at STAR

- After 30 years, **evidence of non-zero gluon polarization** in the proton
- Pushing to **lower *x* gluons**
  - With forward detectors, $\sqrt{s}$ = 510 GeV, large datasets
- Work underway with **2012 dataset** at **$\sqrt{s}$ = 510 GeV**
  - **x10 statistics** compared to 2006 measurement**:** push to **lower x**
  - Data-driven background model
  - Run QA and strategy for A_{LL} calculation being finalized
- Return to 200 GeV CoM and/or transverse asymmetries in endcap π^0's possible
- Very large (x3.5 stats) 2013 longitudinal dataset also under study
- **Stay tuned!**

- CEU Poster session Tuesday 4-6 PM
- **Determining π^0 A_{LL} from STAR 2012 Endcap Calorimeter Data; Claire Kovarik**