Longitudinal Double-Spin Asymmetries for Dijet Production at Intermediate Pseudorapidity in Polarized Proton-Proton Collisions at $\sqrt{s}$ = 510 Gev

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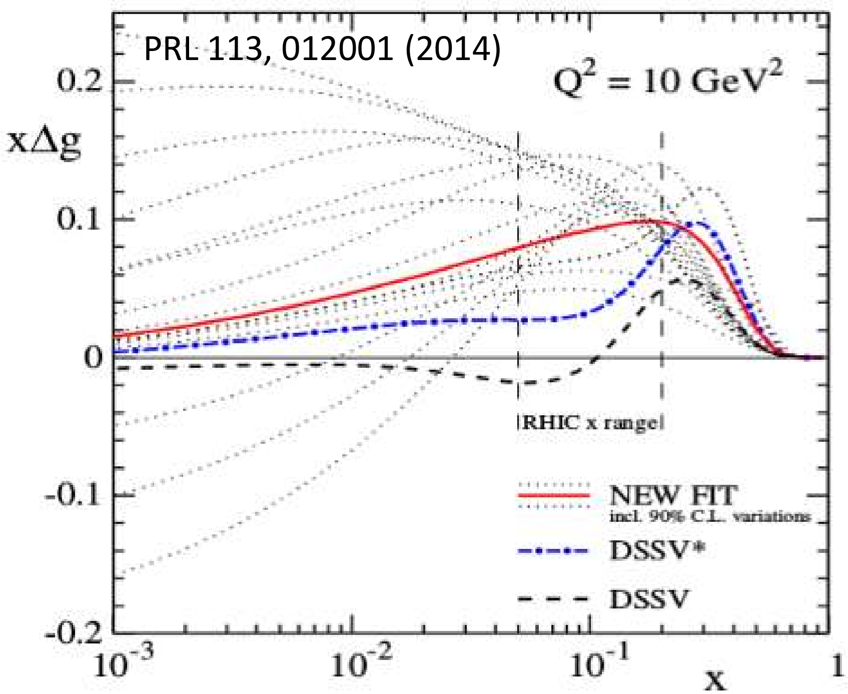
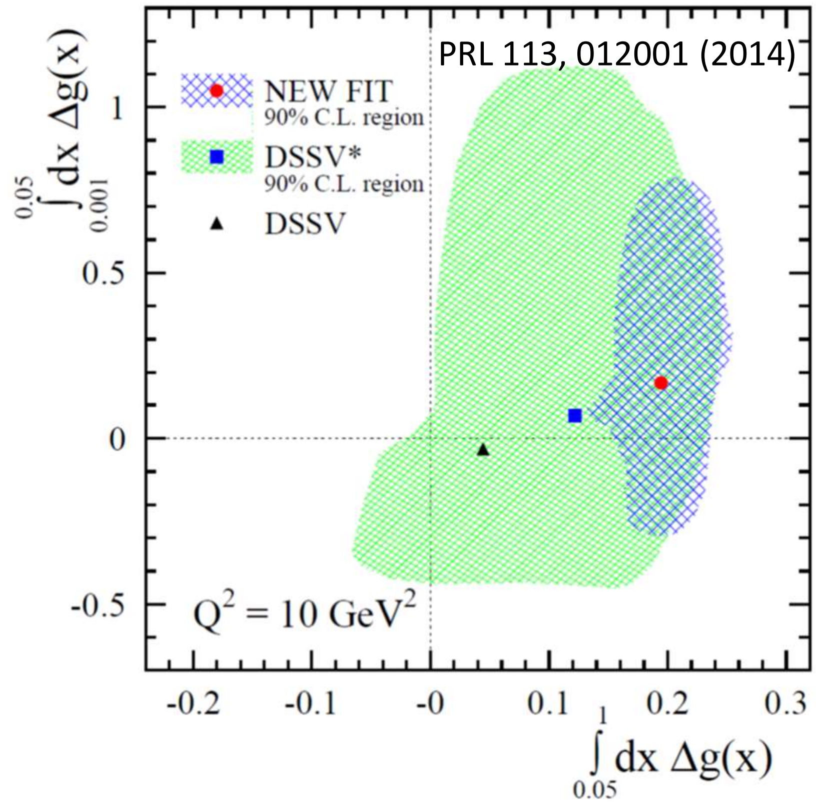
Gluon Contribution to Proton Spin

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

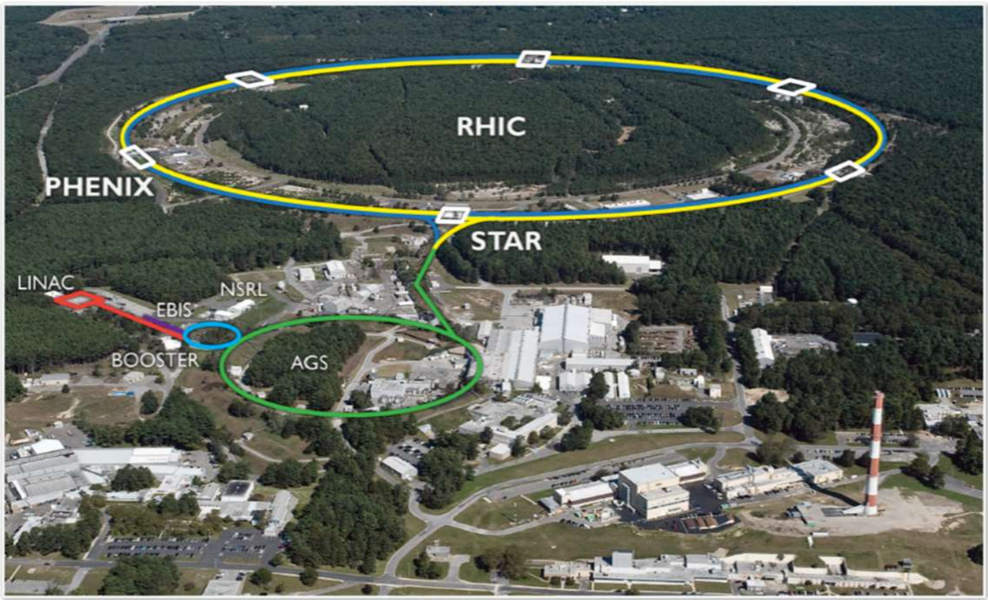
- The spins of the quarks ($\frac{1}{2}\Delta\Sigma$) contribute ~30% of the total spin of the proton
- Gluon contribution $\Delta G = \int \Delta g(x) dx$ less well constrained, especially at low *x*



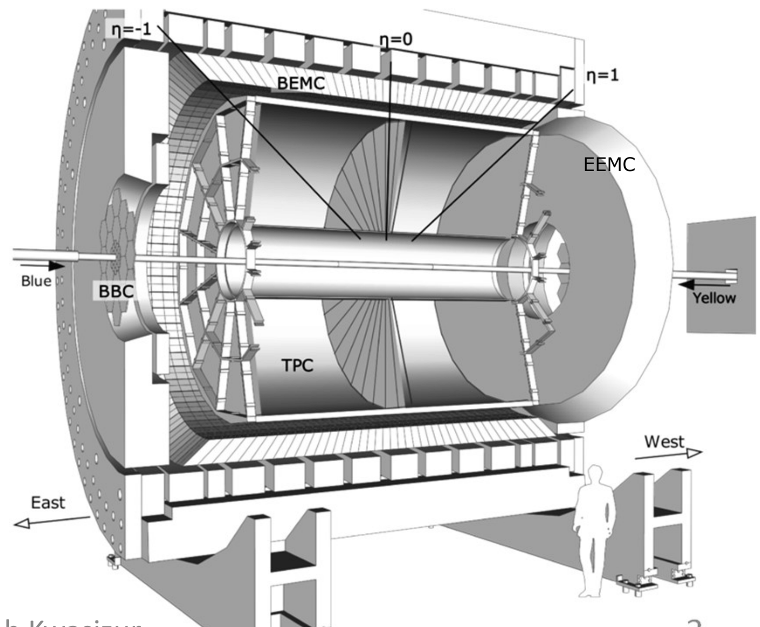


- Inclusion of 2009 STAR data to global fits gave a non-zero value of ΔG for the first time

RHIC and the STAR Detector



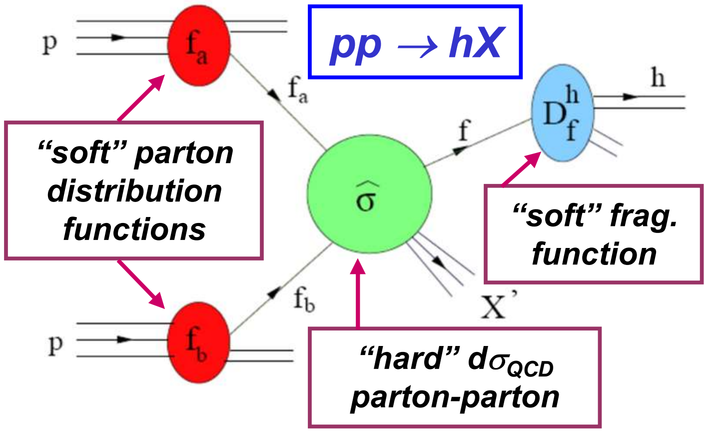
- The Solenoidal Tracker at RHIC (STAR) features charged particle tracking and electromagnetic calorimetry
- Time Projection Chamber (TPC) provides tracking for $|\eta| < 1.3$
- Barrel (BEMC) and Endcap (EEMC) Electromagnetic Calorimeters measure EM particle energies for $-1 < \eta < 2$

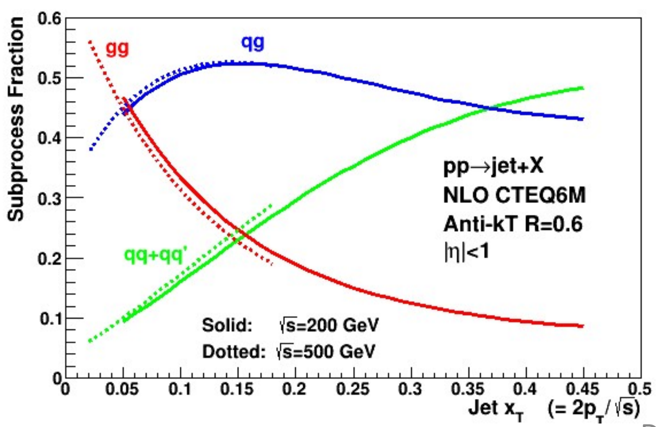


- The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory is the first and only particle accelerator capable of colliding polarized protons
- Collides transversely or longitudinally polarized protons at center-of-mass energies of (typically) 200 GeV and 510 GeV

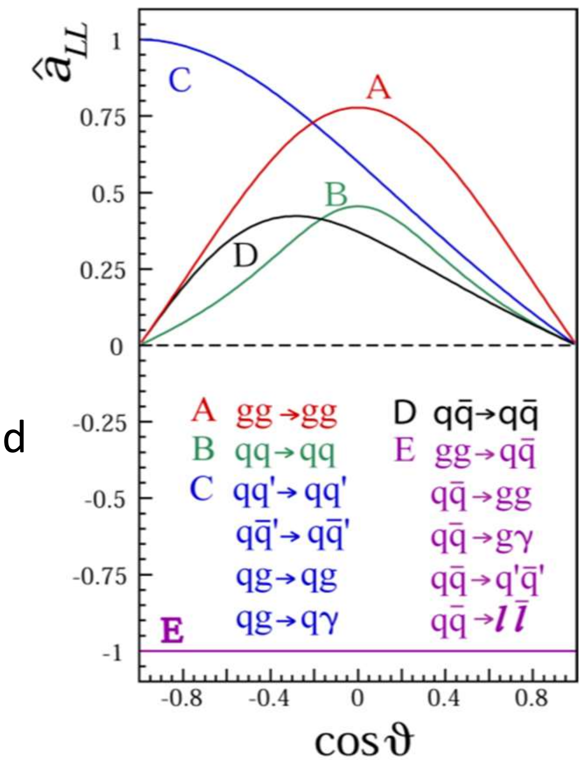
Probing Gluon Polarization at RHIC

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} = \frac{\sum_{a,b,c} \Delta f_a \otimes \Delta f_b \otimes d\hat{\sigma}^{f_a f_b \to f_c X} \cdot \hat{a}_{LL}^{f_a f_b \to f_c X} \otimes D_{f_c}^h}{\sum_{a,b,c} f_a \otimes f_b \otimes d\hat{\sigma}^{f_a f_b \to f_c X} \otimes D_{f_c}^h}$$

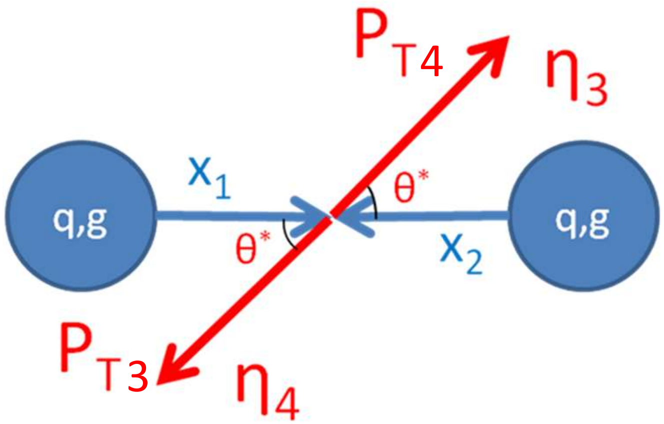




- Quantity of interest is longitudinal double-spin asymmetry A_{LL}
- Spin-dependent cross-sections for partonic scattering processes are well determined in perturbative QCD
- For RHIC energies, *gg* and *qg* are the dominant partonic scattering processes, making A_{LL} sensitive to gluon polarization



Dijet Kinematics



$$x_1 = \frac{1}{\sqrt{s}}\left(p_{T3}e^{\eta_3} + p_{T4}e^{\eta_4}\right)$$

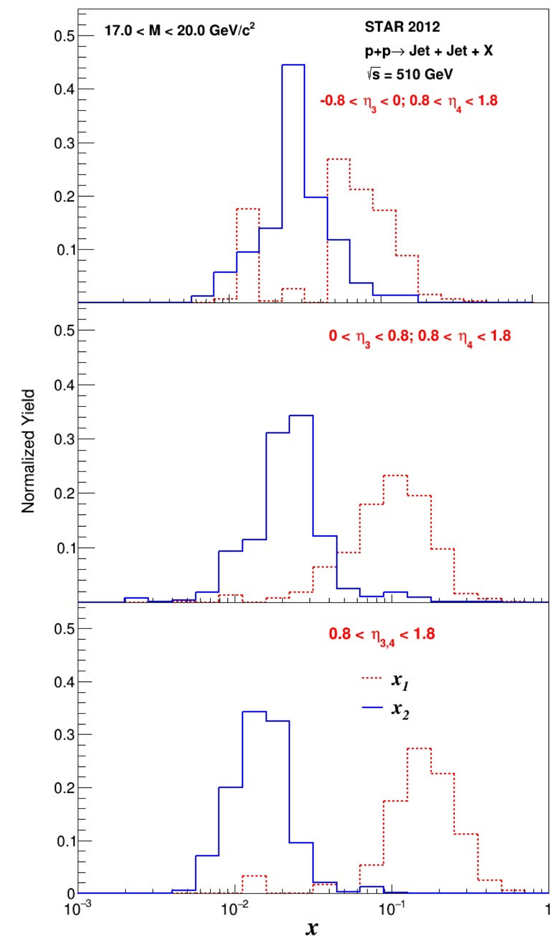
$$x_2 = \frac{1}{\sqrt{s}}\left(p_{T3}e^{-\eta_3} + p_{T4}e^{-\eta_4}\right)$$

$$M = \sqrt{x_1 x_2 s}$$

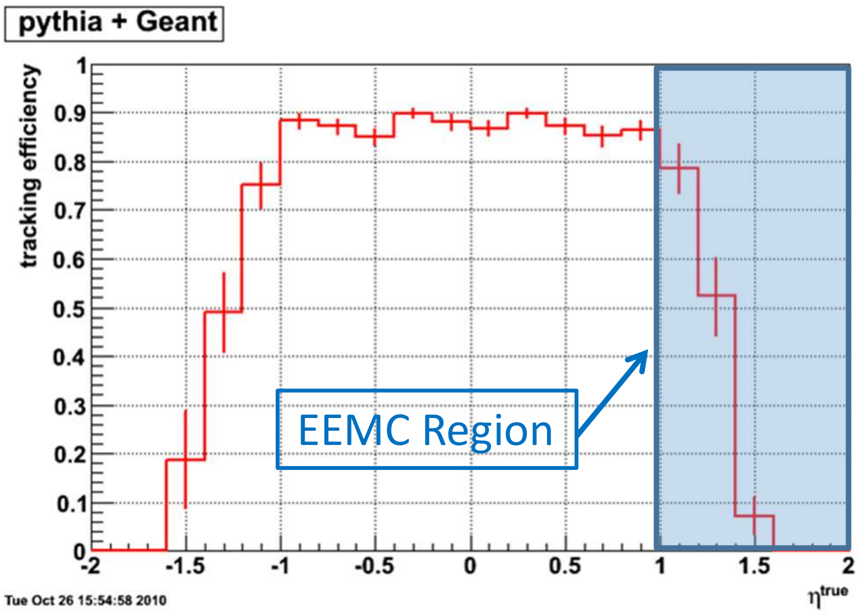
$$\eta_3 + \eta_4 = \ln\frac{x_1}{x_2}$$

$$\left|\cos\theta^*\right| = \tanh\left|\frac{\eta_3 - \eta_4}{2}\right|$$

- Dijets are correlation measurements which capture more information on the hard-scattered outgoing partons, making them more sensitive to the initial state parton kinematics
- Forward rapidity jets ($\eta > 1$) arise from asymmetric partonic collisions, allowing access to low-*x* region where gluon contribution to proton spin is poorly constrained
- Can also increase collision center-of-mass energy to probe lower *x* gluons

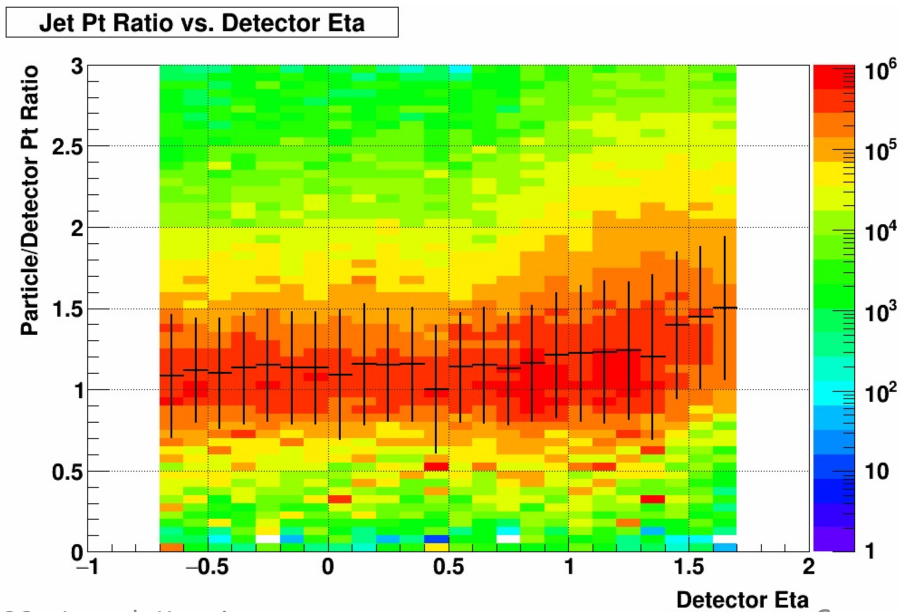


Challenges at Forward Rapidity

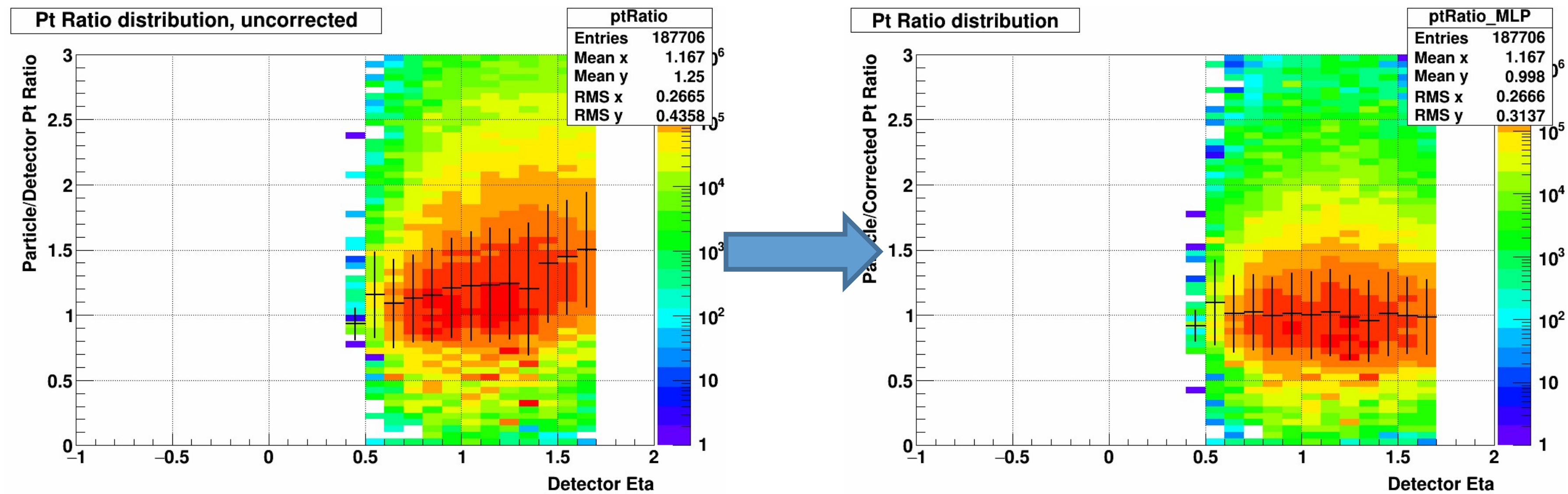


- TPC efficiency decreases in forward region
- Fewer tracks means reconstructed jets have lower p_T on average

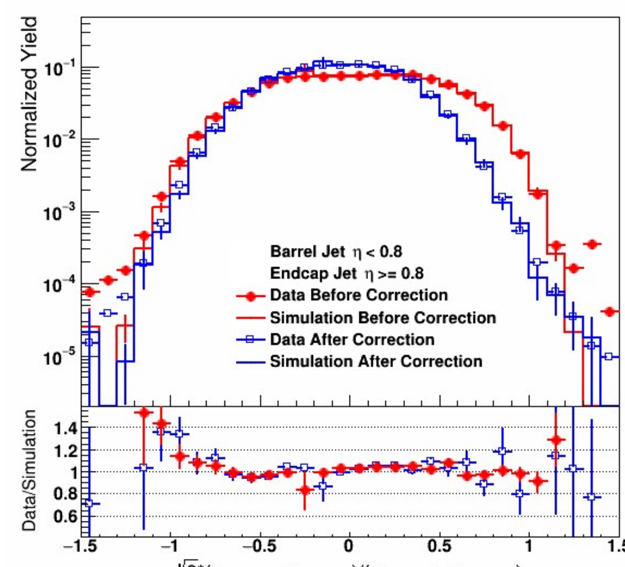
- Less tracking information also leads to biased sample of jets
- Jets with high percentage of neutral energy will be preferentially selected in the EEMC



Machine Learning Correction

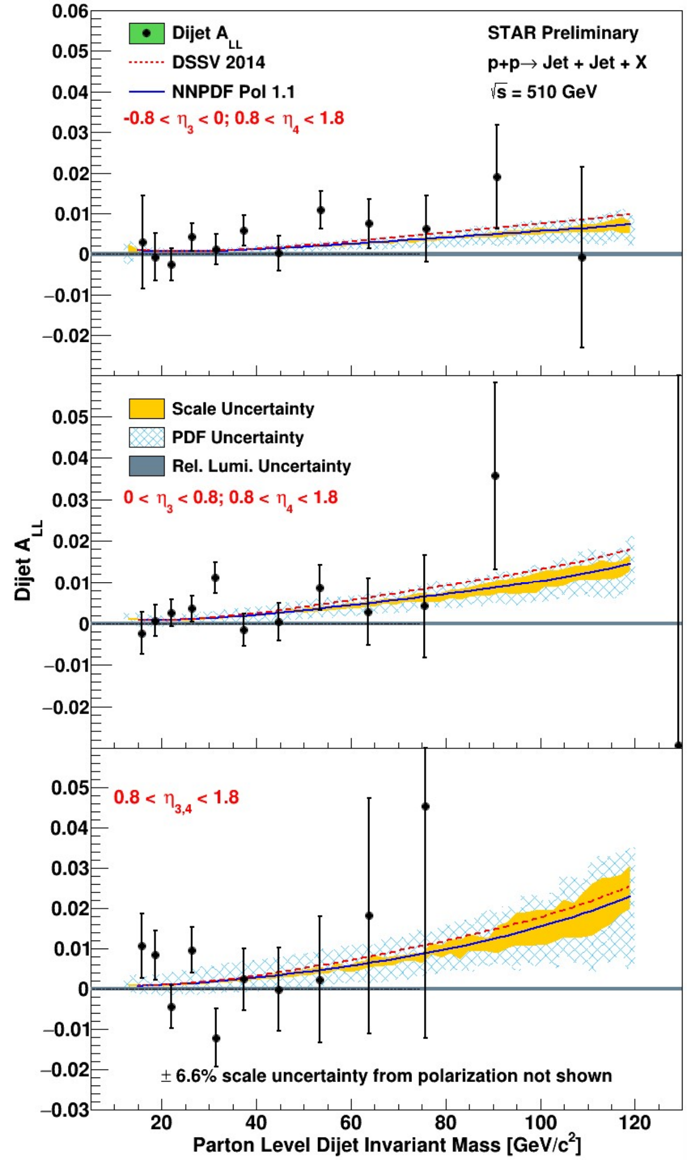


- Supervised regression algorithm: Multilayer Perceptron (MLP)
- Algorithm is trained on simulation, using detector level p_T, detector η, and neutral fraction as input information
- Corrects detector level p_T and jet invariant mass back to particle level on a jet-by-jet basis
- Trained network is then applied to data

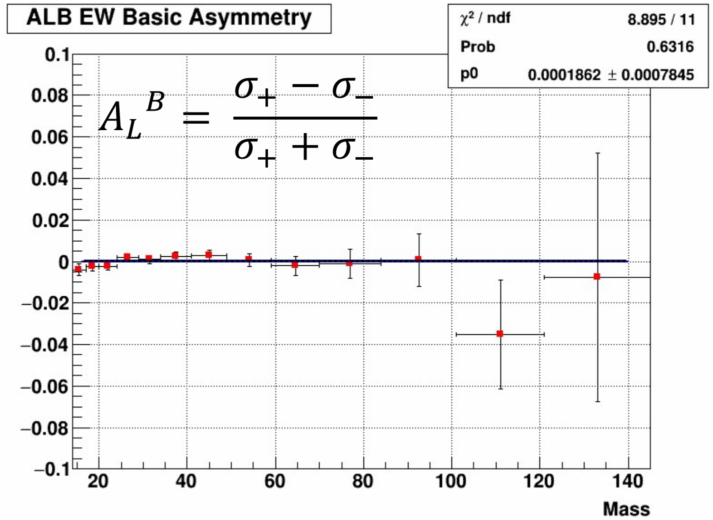


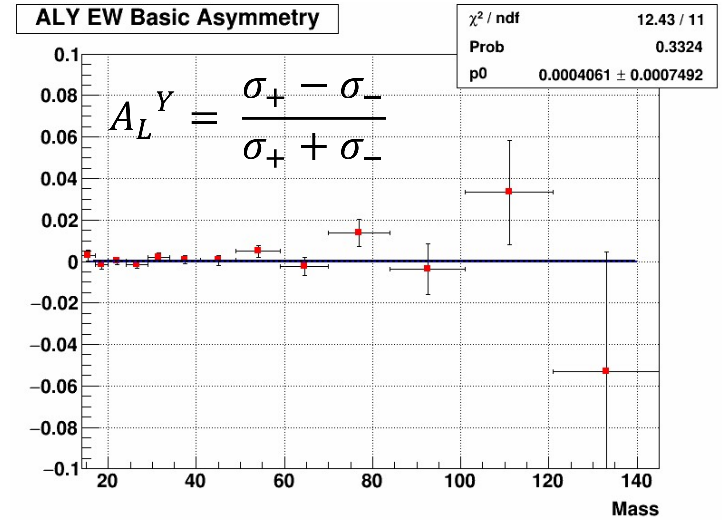
Dijet Asymmetry Results, 2012

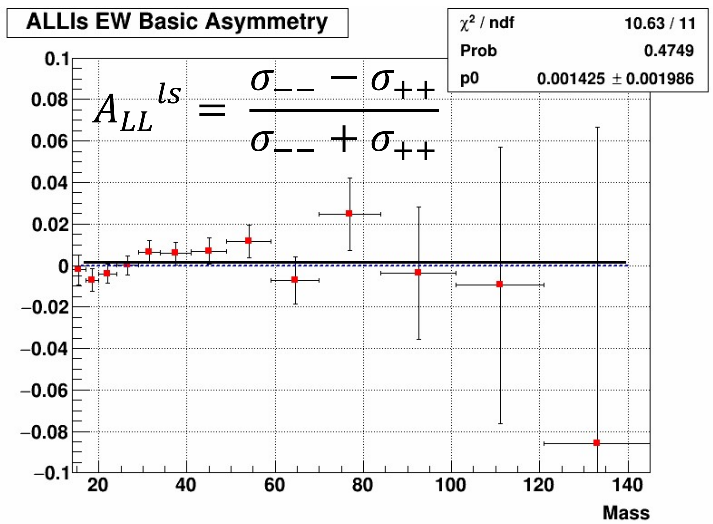
- Machine learning correction is trained and applied separately for three different dijet topologies
- Corrected jet transverse momenta and masses are used to calculate dijet invariant mass
- Error bars are statistical; calculation of systematic uncertainties is ongoing
  - Systematics separated into two categories: uncertainties on dijet invariant mass and uncertainties on A_{LL}
  - Dominant systematics expected to be Jet Energy Scale uncertainty and Pythia tune uncertainty
  - Systematic uncertainties are expected to be smaller than statistical errors at all points

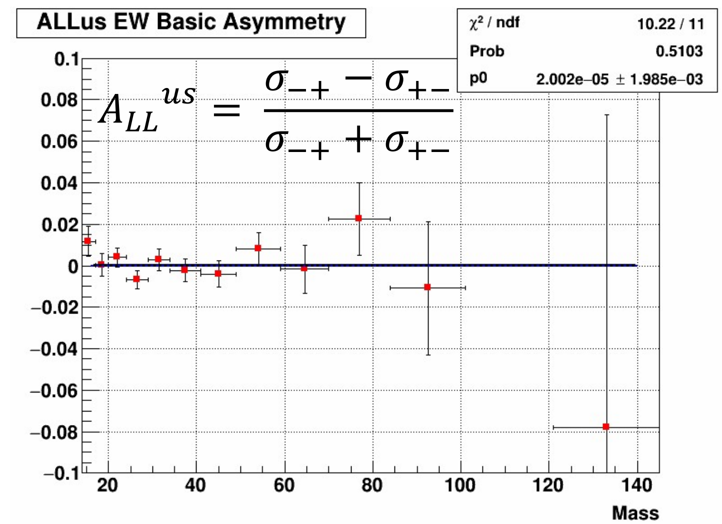


False Asymmetries





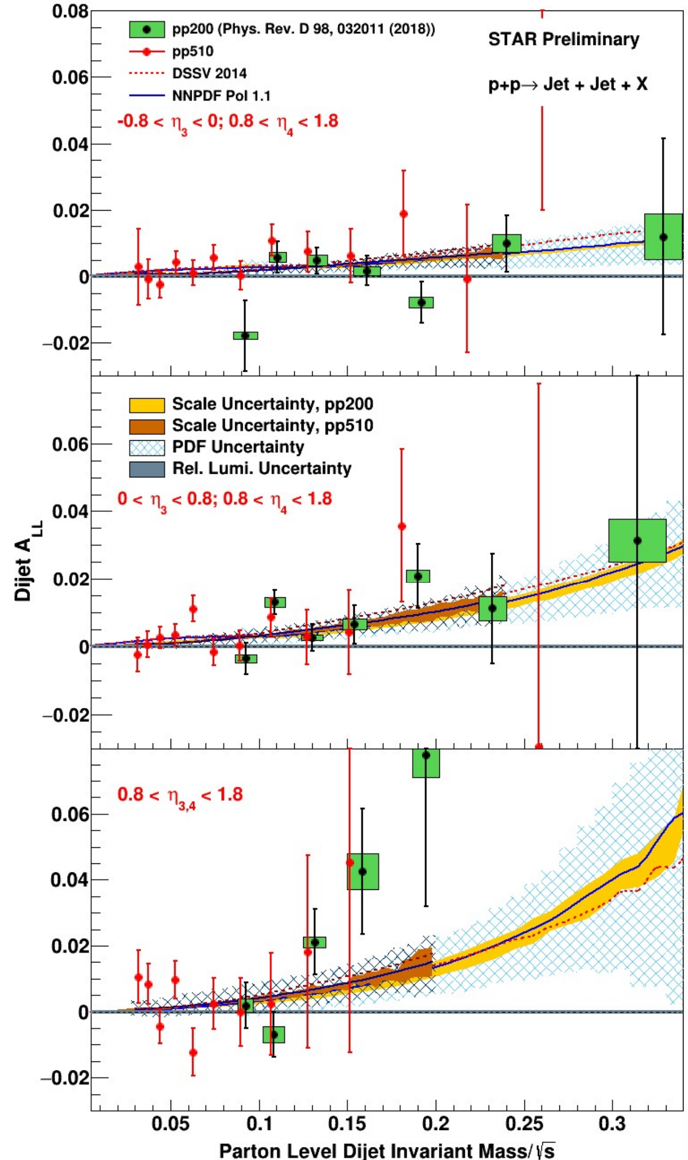




- Dijet false asymmetries provide checks on analysis, and are expected to be consistent with zero within statistical precision

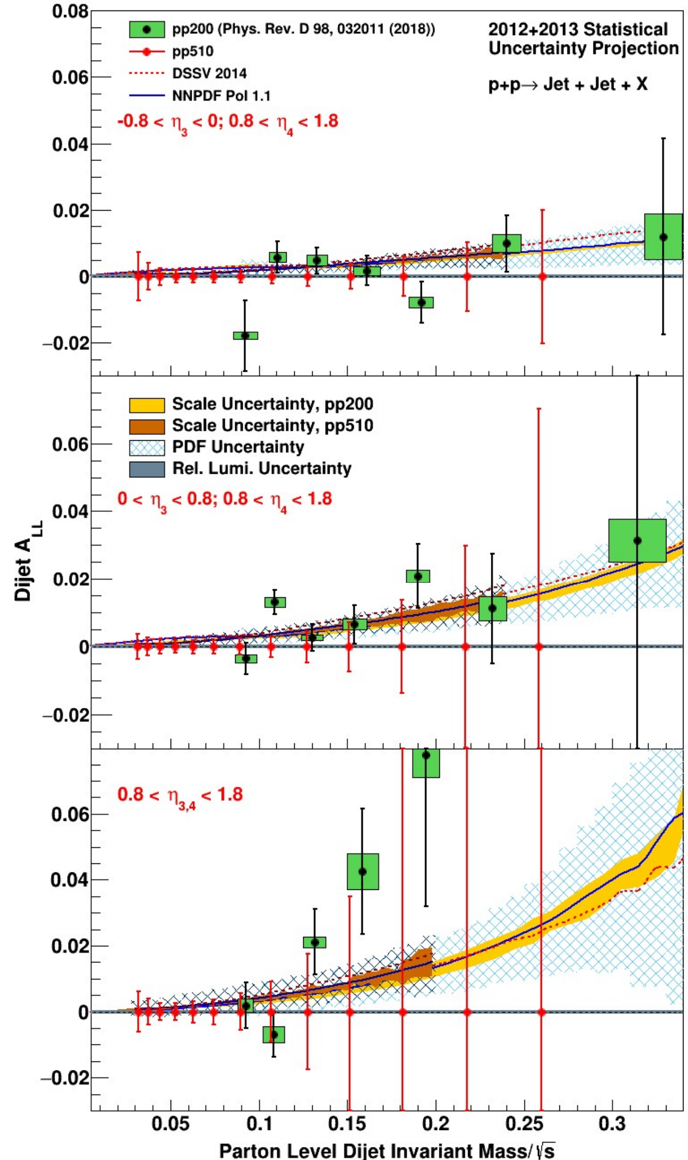
Comparison with Previous Results

- First measurement of forward dijet A_{LL}, using data from 2009 RHIC run at $\sqrt{s}$ = 200 GeV, was published in 2018
- Data taken at different center-of-mass energies can be compared by plotting asymmetries as a function of dijet invariant mass scaled by $\sqrt{s}$
- Lower kinematic reach in $M/\sqrt{s}$ of 510 GeV data allows one to probe lower initial-state partonic momentum fractions
- Green boxes on 2009 data show systematic uncertainties
  - ➢ Expect 2012 systematics to be comparable



Impact of 2013 Data

- Reduced error bars on red points (plotted at zero) illustrate the projected statistical impact of including data from the 2013 RHIC run at $\sqrt{s}$ = 510 GeV

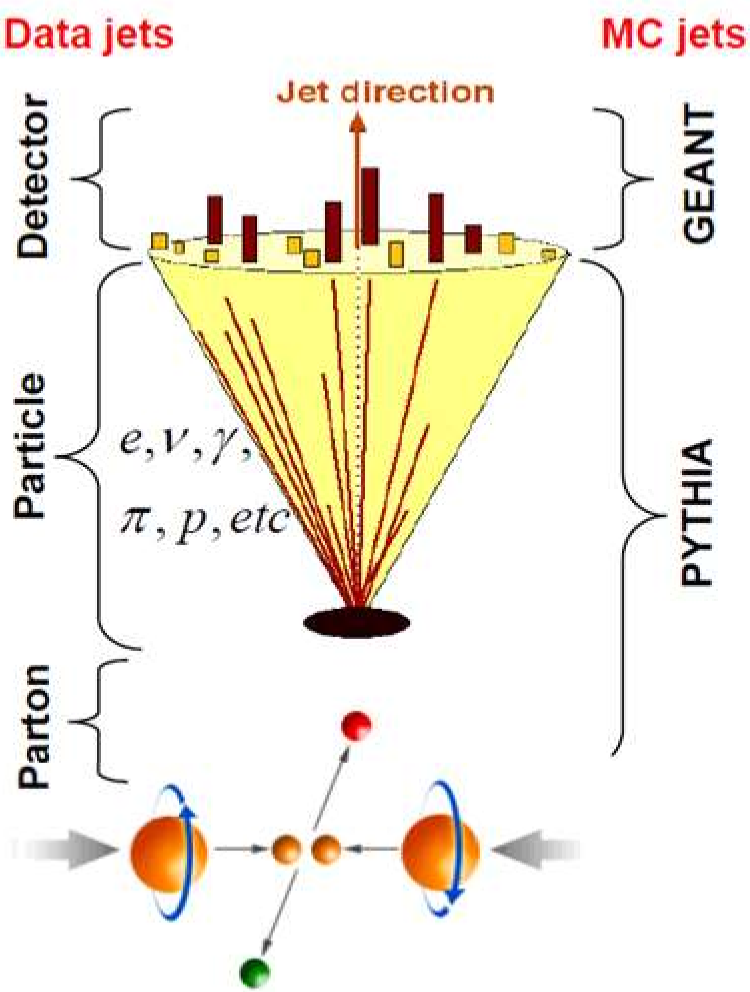


Conclusion

- Forward dijet A_{LL} at $\sqrt{s}$ = 510 GeV has been measured for the first time, using data from the 2012 RHIC run
- Calculation of systematic uncertainties is underway
  - Based on results of previous dijet analyses, systematic uncertainties expected to be smaller than statistical uncertainties
- 2013 dataset will provide approximately three times the statistics to further constrain low-*x* behavior of $\Delta g(x)$

Backup

Jet Reconstruction



- Large acceptance of STAR makes it ideal for jet measurements
- Anti-k_T algorithm for jet reconstruction
- Successive recombination method, with radius R = 0.6 in $\eta - \phi$ space:

$$d_{ij} = \min\left(\frac{1}{{k_{Ti}}^2}, \frac{1}{{k_{Tj}}^2}\right)\frac{{\Delta R_{ij}}^2}{R^2}$$

$$d_{iB} = \frac{1}{{k_{Ti}}^2}$$

- Pythia simulates parton scattering and hadronization, GEANT simulates detector response

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

- P_Y, P_B: polarizations of the proton beams
- $R_3 = \frac{\mathcal{L}^{++} + \mathcal{L}^{--}}{\mathcal{L}^{+-} + \mathcal{L}^{-+}}$: relative luminosity
- $N^{\pm\pm}$: spin-sorted yields for different beam polarization configurations