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Recent STAR Measurements to Constrain the Polarized Gluon Distribution Function of the Proton

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Motivation



The simplest model of proton structure (3 valence quarks only), fails to explain early results of polarized DIS.

The proton spin sum rule:

$$< S_p >= \frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_q + L_g$$
Polarized DIS results $\Delta\Sigma \approx 0.3$
(B. Surrow's talk on constraining sea quarks)
Polarized DIS results $\Delta\Sigma \approx 0.3$

What is the contribution of gluon polarization (ΔG) to the spin of the proton?



 For most RHIC kinematics, gg and qg scattering dominate.

Gluon polarization can be measured

using longitudinally polarized

 STAR A_{LL} inclusive jet results (2009) at 200 GeV, provide the first evidence of non zero gluon polarization at x > 0.05 (Phys. Rev. Lett. 115, 092002).

$$\Delta G = \int dx \Delta g(x)$$

DSSV⁽¹⁾ : $0.19 \pm 0.06 (0.05 < x)$ NNPDF⁽²⁾: $0.23 \pm 0.07 (0.05 < x < 0.5)$

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Motivation

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









Motivation

- Uncertainty of gluon polarization points to a positive value, in the high x region.
- Need to increase precision in the currently sampled region to consolidate the observation of non zero gluon polarization.
- Uncertainties in the low x region are still very large.
- Need to extend sensitivity to lower x to further constrain global fits in this region.







Relativistic Heavy Ion Collider



Polarized proton runs at RHIC

Longitudinally polarized runs

Year	√s (GeV)
2009	200
2012	510
2013	510
2015	200









STAR Experiment

- One of the largest experiments at the Relativistic Heavy Ion Collider (RHIC).
- The main tracking device is a Time Projection Chamber (TPC) at |η| ≤ 1.3.
- Electromagnetic calorimeters (-1 ≤ η ≤ 2) are used to trigger high momentum particles and measure neutral component of jets.
- Forward Meson Spectrometer (FMS) is a lead-glass EM calorimeter to detect π^0 at 2.5 $\leq \eta \leq$ 4.2.





Previous STAR Results





Inclusive Jets at Vs=200 GeV in 2009

- Increase statistical precision compared to earlier STAR measurements in 2006.
- Results were systematically above the DSSV 2008 global fit.
- These results strongly suggest a positive gluon polarization value after inclusion in DSSV14 and NNPDF1.1 fits.







Di-jets at √s=200 GeV in 2009



- Di-jets measurements allows to probe a narrower x region.
- Results are consistent with 2014 global fits.





Forward Di-jets at Vs=200 GeV in 2009



- Forward di-jets at $\eta < 2$, allows reaching lower and narrower x region.
- Forward upgrades will reach $x \sim 10^{-3}$ (E. Aschenauer's talk on STAR future program).





Inclusive and Di-jets at Vs=510 GeV in 2012



Publication in preparation

- Increased center of mass energy allows probing lower x values.
- Final di-jets result will be presented with finer binning in pseudorapidity.
- Details in Z. Chang's talk on inclusive jet measurements (next talk).

Latest Measurement





Run 2013 data

- Figure of Merit relevant for double spin asymmetry: almost three times greater than the previous year.
- Average beam polarization 53%.
- STAR installed the Heavy Flavor Tracker (HFT) in the middle of the run.
- The extra material affects the reconstruction of events (e.g. average η).







Jet Reconstruction and Simulation





- Jets were reconstructed using the anti-kt jet finding algorithm with R=0.5.
- Embedded simulations (in data) are used to quantify the detector response and estimate systematic uncertainties.
- Embedded simulation sample for the 2012 run agrees with data for the 2013 run (before HFT).





Inclusive Jets 2013 Preliminary Results



- Run 2009 (200 GeV), Run 2012 and the newest Run 2013 (510 GeV) A_{LL} measurements show good agreement in x overlap region.
- The inclusion of the STAR Run 2009 results to the newest global fits provides better control of the systematics (e.g. trigger and reconstruction bias), allowing to improve these errors.
- The full data sample of Run 2013 (510 GeV) is already processed and simulation is being produced to finalize systematic uncertainty studies for final result.





Di-jets 2013 Preliminary Results





- Preliminary di-jet asymmetries results for 2009, 2012 and 2013 are in agreement.
- Reduced statistical and systematic uncertainties for 2013 compared to 2012.
- Preliminary results are in agreement with 2009 results in the overlap region.

-0.04

0.05

0.1

0.15

0.2

Parton Invariant Mass//s

0.25





Status of run 2015 (200 GeV) analyses

- Average beam polarization 55%.
- Test of tracking, jet reconstruction and triggering software: complete.
- STAR TPC and BEMC calibration: finalizing.
- QA of jet analyses: in progress.
- MC / Embedding comparison using previous sample: initial testing.
- Systematic uncertainty studies: initial testing.
- These measurements will reduce uncertainties by a factor of ~1.6, compared to 2009 results.



Jets Transverse Momentum

Pion Analysis





Forward π^0 analysis



- The A_{LL} measurement of π^0 at $\sqrt{s} = 510$ GeV allows reaching the lowest x values at STAR (2012 and 2013).
- Requiring 2-photon isolation cones: 35 mr and 100 mr around π^0 .



- Preliminary results are consistent with zero.
- Final results will be using a modified cone method for pion identification.







Summary and Projections

- The STAR spin program provided evidence of nonzero gluon polarization.
- Results of A_{LL} for inclusive jet, di-jets and π^0 are consistent and agree with the global fits DSSV14 and NNPDFpol1.1.
- Run 2013 embedding studies are ongoing. The path to final results is well established after completion of MC sample.
- STAR took additional 200 GeV pp data during 2015, to consolidate previous measurements in 2009.
- These high precision measurements motivate the natural step forward to the STAR forward upgrade program and an Electron Ion Collider.







All quantities studied (34):

- Vertex Z
- Bunch Crossing
- Asymmetry
- Each False Asymmetry (4) (for Asymmetries took the ->Integral(3,15), not mean)
- Each Relative Luminosity (6)
- Each Polarization (2)
- Jets per Event, Pt, Rt, Eta, Phi, Det Eta, Underlying event
- Tracks per jet, Pt, DcaXY, Eta, Phi, DcaZ
- Tower multiplicity, Et, Energy, Eta, Phi, Adc

Runs QA

Procedure:

- 1.- Divide Period 1 in four sub-periods A, B, C, D.
- 2.- Calculate the average of each quantity per run per period.
- 3.- Plot versus ZDC rate.
- 4.- Fit a 2nd order polynomial per quantity.
- 5.- Calculate RMS of sample respect to the pol2 fit.
- 6.- Runs outside 3*RMS per quantity, are removed.



Showing all period 1. The RWS lines match each sub-period.

Comparison of data and simulation (run 13)



False asymmetries



Jet Energy Scale systematic

- 1. P_T shift: is the statistical error of each bin obtained for the ProfileX of the p_T shift (appendix).
- 2. BEMC track:

 $p_{T,avg} * \sqrt{((1-R_T)*trk_p)^2 + ((1-R_T)*(NH-trk_eff*trk_dep)*BEMC_trk*BEMC_unc/trk_eff)^2}$

Trk_p = Track momentum uncertainty as 1% NH = Scale up for neutral hadrons 1.1628 Trk_eff= Track efficiency 55% Trk_depTrack deposition in projected tower 50% BEMC_trk = BEMC resp to track 30% BEMC_unc = BEMC resp to track uncertainty 9%

3. BEMC neutral:
$$p_{T,avg} * R_T \sqrt{(gain)^2 + (eff_unc)^2}$$

gain= 8% (5% run 13 + 3% Run12 emb) and Eff_unc= 1%

- 4. 7% track loss: sqrt ((pt-pt7%)^2 + 0.01^2)
- 5. UE shift: difference between Profile of UE in data and UE in simulation.
- 6. Pt tune: extrapolate Zilong results to my pt bins. Tune13 = (Pt13/Pt12) *Tune12

A_{LL} systematic uncertainty

A_{LL} diff.

 -0.00°

-0.002 -0.003 -0.004

-0.005

-0.007

-0.008

-0.009

10

20

Dots: average of detector – parton (100 rep.) Lines: same average in detector binning.

30

40

50

60

- 1.- Relative luminosity systematic: 5.6E-4.
- 2.- UE systematic: 1E-4.
- 3.- Trigger Bias:
 -Use NNPDF1.1 100 replicas.
 -Take the diff Detector Parton for each replica.
 -The Mean is the A_{LL} correction.
 - -The RMS is the systematic.
- 4.- The RMS of NNPDF1.1 best fit Detector Parton is the systematics.
- 5.- Track 7% loss:
 - -Take the average of 100 rep. nominal and 7% loss.
 - -The difference of Detector Nominal Detector 7% loss is the systematic.

Final systematic, add everything in quadrature

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70

80

p_ (GeV/c)

Correlation Measurements