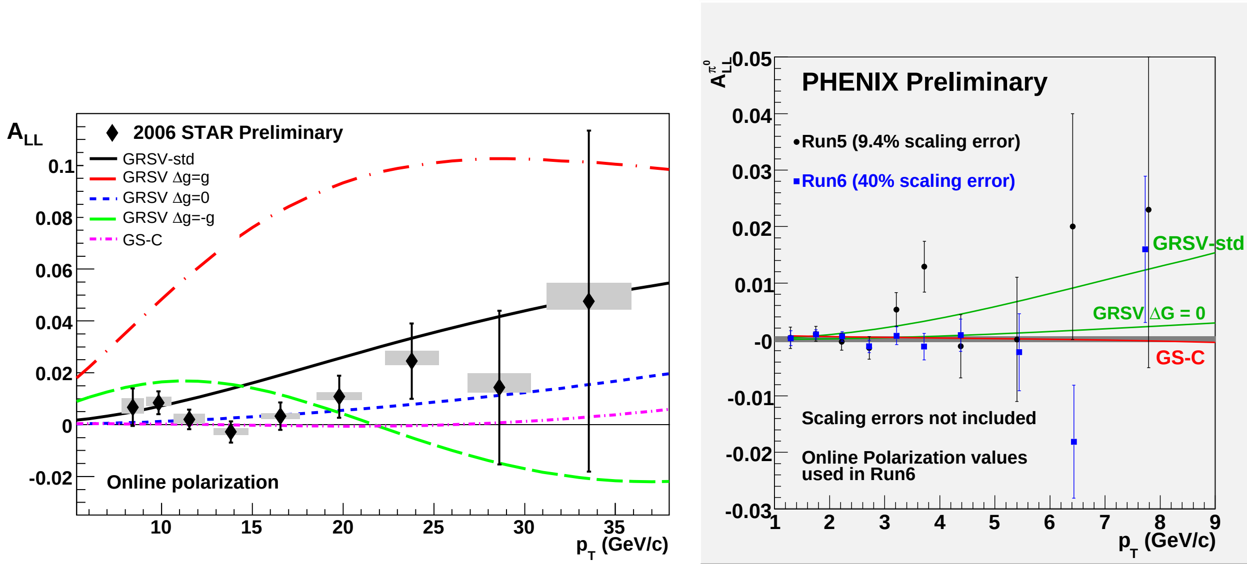

Figure 1: *A_{LL} for 2006 inclusive jet data from STAR (left) and π^0 data from PHENIX (right). The theoretical curves are based on different models of gluon polarization from GRSV [REF] including their best fit "GRSV-std" and the GS-C fit [GS] characterized by a node in the x-shape but still a large integral Δg. The other GRSV results refer to extreme assumptions about $\Delta g(x)$ at the input scale of their fit.*

1 RHIC Spin program & polarized gluon distribution *5/3/08 draft*

One of the main motivations for the RHIC spin program is to determine the contribution of gluonic spin, Δg(x) to the proton spin as related above. In the following, we present the most recent data, show its important impact on the first global (hadronic plus DIS) fits, and describe how our future measurements will provide important leaps in our understanding of the role of the gluon's spin in the proton.

1.1 Current status of the data

1.1.1 Recent results: Inclusive π^0s and jets

The 200 GeV run in 2006 produced about 8 pb^{-1} of integrated luminosity with longitudinal polarization resulting in large improvement on the inclusive measurements made by the two experiments in previous years. Shown in Fig. 1.1.1 are the double spin asymmetries A_{LL} for inclusive jets at STAR and inclusive π^0s at PHENIX. Shown also on the figures are curves generated from a number of parton distribution functions. The curves correspond to theoretical calculations of A_{LL} for a range of gluon polarization models [GRSV,GS], from large and positive, "GRSV Δg=g", to large and negative, "GRSV Δg=-g". The GS-C gluon has a node in the region of x subtended by the measurement leading to almost vanishing predictions for A_{LL} despite having a large and positive integral.

The first full-fledged global analysis at next-to-leading order accuracy of all currently

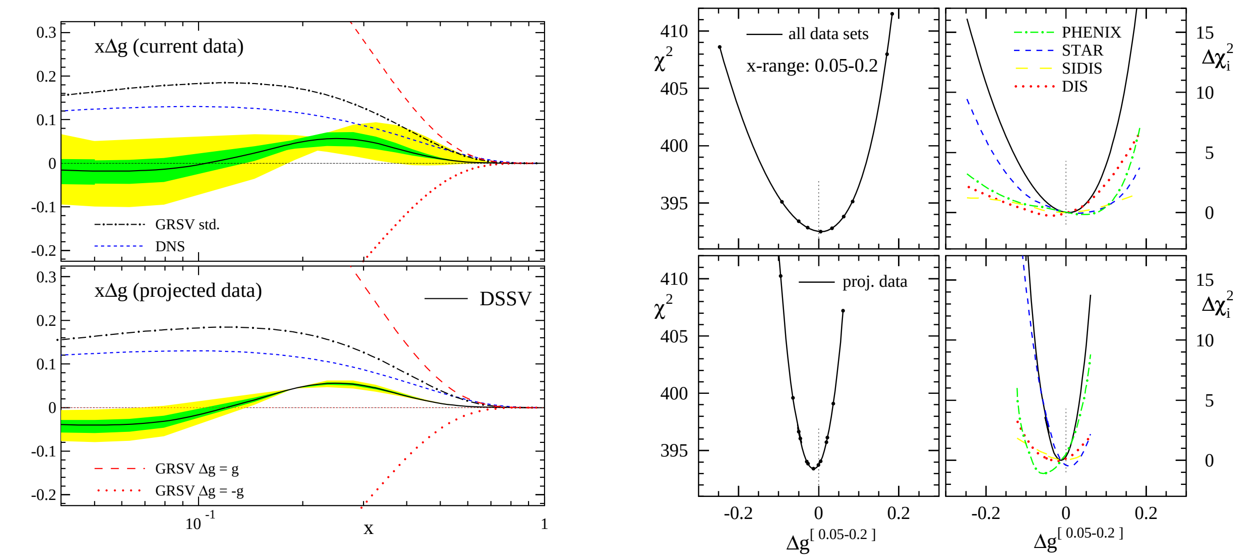

Figure 2: *Upper row:* $x\Delta g$ *(*$Q^2 = 10\,\mathrm{GeV}^2$*) from the global NLO QCD analysis by DSSV [REF] (left) and partial contributions* $\Delta\chi^2$ *of the fitted data sets to the total* χ^2 *for variation of the integral* Δg *computed in the range 0.05* $< x <$ *0.2 (right). The uncertainty bands correspond to* $\Delta\chi^2 = 1$ *(green) and* $\Delta\chi^2/\chi^2 = 2\%$ *(yellow). Also shown are results for* $\Delta g(x)$ *from previous GRSV [ref] and DNS [ref] fits. Lower panels: same as above when the RHIC data errors are scaled down by a factor of 4 as expected from the next long RHIC pp run at 200 GeV (50 pb*$^{-1}$*).*

available spin-dependent data, including the 2006 RHIC preliminary results for inclusive jets and π^0s, was completed very recently by DSSV[ref]. The resulting polarized gluon density is depicted in the upper left panel of Fig. 2 together with estimates of the typical uncertainties involved in the analysis procedure based on a common approach using "Lagrange multipliers". The DSSV result is compared to previous fits of GRSV[ref] and DNS[ref] based on DIS data only and, in particular, to two extreme gluon polarization models from the GRSV analysis which are now clearly outside the uncertainties estimated by DSSV. For $x \lesssim 0.05$ the uncertainties in Δg(x) are still sizable, and the full integral, $\int_0^1 \Delta g(x)dx$, which represents the contribution of gluons to the spin of the nucleon, is still not determined. The impact RHIC data have on the determination of Δg(x) is clearly visible in the upper right panel where the partial contributions $\Delta\chi_i^2$ of the individual data sets for variations in the integral of Δg over the range Δg for 0.05 $<$ x_g $<$ 0.2 are shown. RHIC data currently provide the best limit on negative values of this integral and are comparable to DIS for positive values.

1.1.2 Other experiments in the world

The broad interest in understanding the nucleon's spin structure has led to a world-wide experimental program in polarized DIS. The efforts of the COMPASS experiment at CERN, the recently completed HERMES experiment at DESY, and many experiments at Jefferson Laboratory are well documented elsewhere[PREV SPIN UPDATE] and we provide only a brief update on the status from the lepton scattering experiments.

First and foremost, deep inelastic lepton scattering provides information on the polarized gluon distribution via evolution in x and Q^2 of the structure function g_1. Experimental results from COMPASS, HERMES and Jlab are an integral part of a global analysis [DSSV] and their impact on determining Delta g(x) is also shown in the upper right panel of Fig. 2. The analysis of DIS data is well developed and there are many practitioners.[list of recent references]. These most recent fits show considerable progress but still substantial uncertainty in the shape and sign of the integral Δg remain.

COMPASS has also pursued Δg via photon-gluon fusion detected as high p_T hadron pairs[ref] and open charm production[ref]. Although their results still lack a proper NLO analysis, the obtained Δg/g is consistent with 0 near x$\sim$0.1. While they still have 2006 data taken on a proton target to add to the analysis, the current spin program is complete. HERMES has also extracted Δg/g from semi-inclusive DIS[ref HEP conf 07]. These results are again consistent with 0 but at a slightly higher average x of $\sim$0.2. The HERMES experiment concluded last June. Jlab also has proposals on the books to pursue semi-inclusive measurements in pursuit of Δg/g mostly at large x.

The overall conclusion is that results from lepton-nucleus scattering experiments are in agreement with those of the RHIC program. Large contributions from the gluonic spin to the proton spin at the large to moderate x values tested so far is unlikely. However there are still significant uncertainties in the magnitude of the integral Δg due to uncertainties in constraining the shape of Δg(x) and the possibility of negative portions of Δg(x).

1.2 Δg and RHIC spin: next five years 2009-2013

With newly completed or proposed upgrades, increased luminosity and runs at 500 GeV, RHIC and its two experiments STAR and PHENIX are uniquely positioned to add significant new constraints on the magnitude and shape Δg(x) and thereby zero in on the integral value Δg. In this section we describe these new capabilities, measurements and their expected impact.

1.2.1 Inclusive Channels

Inclusive channels, with π^0s and jets being the most sensitive, have been the workhorse of the program to date. With increased luminosity expected in the coming years these measurements will be extended to higher p_T into regions where qg scattering is known to dominate giving sensitivity to negative values of Δg(x). Existing measurements have been dominated by gg scattering where sensitivity to the sign of the distribution is poor. The impact of including simulated data for approximately another 50 pb^{-1} of inclusive π^0 data from PHENIX and jet data from STAR are shown in the lower portion of Fig. 2. Substantial improvements in the integral Δg in the region $0.05 < x_g$ <0.2 are seen.

There are two principle inclusive channels, charged pions and direct photons, whose impact has been limited by statistics with the luminosities delivered so far. With an additional 20-30 pb $^{-1}$ these will start to play an interesting role. The production of charged pions at high p_T is dominated by gluon-quark scattering. For positive polarized gluon distributions it has been suggested [ref] that $A_{LL}^{\pi^+} > A_{LL}^{\pi^0} > A_{LL}^{\pi^-}$. However, if the gluon polarization is negative the opposite hierarchy in their magnitude holds. Such measurements, along with the increased p_T range accessible with the larger luminosity will allow us to access not only the size but also the sign of Δg(x).

Direct photon production is dominated by gluon-Compton scattering. The spin asymmetry is hence linear in gluon polarization and the quark polarization has already been measured accurately in the past DIS experiments. As such, it can be used to make a more direct evaluation of the polarized gluon distribution than with other processes. Thus the direct photon process should be an ideal method for the measurement of the polarized gluon distribution. However, the figure of merit for this process is low compared to the other inclusive channels described above. Nevertheless, with its different experimental and theoretical systematics, it maintains an important role of its own.

In the next few years the p-p running will turn to 500 GeV. It is fully expected that the inclusive channels will again provide the first results at this energy. A given p_T will naturally probe lower x for the gluon and thus be important in our effort to constrain Δg(x).

1.2.2 Semi-inclusive Channels

As the luminosity of RHIC grows, the already large STAR detector acceptance and the wider acceptance windows becoming accessible to PHENIX due to its detector upgrades (Si VTX tracker and Nose Cone Calorimeter) will allow measurements of two particle, jet-jet, hadron-hadron and photon-jet correlations. At leading order the hard scattering subprocess kinematics can be calculated on an event by even basis. This of course then leads to addressing one of the problems mentioned earlier, i.e. that of extracting Δg(x) directly. Of course such LO extractions must be followed up with full theoretical work associated with evaluation of cross sections and asymmetries at next to leading order, but they do give good guidance as to the reach of the measurements.

For example with completion of the FMS in the past year STAR now has coverage in pseudo-rapidity from -1 $< \eta <$ 4. Using the relationship $(\eta_3 + \eta_4) = ln(x_1/x_2)$ illustrates that highly polarized valence quarks can be used to probe a wide range of x values, as low as a few $\times\ 10^{-3}$ for $p_T >$ 2GeV in the FMS. This probed range, $\sim 3\times10^{-3} <$ x $< \sim 2\times10^{-1}$, far exceeds that of any other experiment in the near future. In addition, γ-jets inherently and di-jets with appropriate kinematic cuts can be used to emphasize the qg scattering subprocess. Since the q polarized PDFs are well known this can provide a clean measure of the gluon polarization including the sign.

While the γ-jets are cleaner in this regard and also provide a higher resolution measure of p_T, the di-jets have a large cross section and thus a strong advantage for much of the acceptance given the expected integrated luminosity. With realistic expectations on luminosity our best knowledge regarding Δg(x) will likely come from the di-jet channel with γ-jets supplying important independent information, although with less statistical precision. However, in the most forward regions, a combination of a rise in the underlying partonic asymmetry correlates with a rise in the back angle qg Compton scattering cross section making it the channel with best FOM.

With 2-body kinematics the data can be plotted vs. a number of different kinematic variables with cuts applied based on others providing near double differential distributions. Below we show the expected statistics for di-jets plotted vs. their invariant mass, $M_{inv} = \sqrt{x_1 x_2 s}$. Note that each panel represents a different combination of EM calorimeter sections

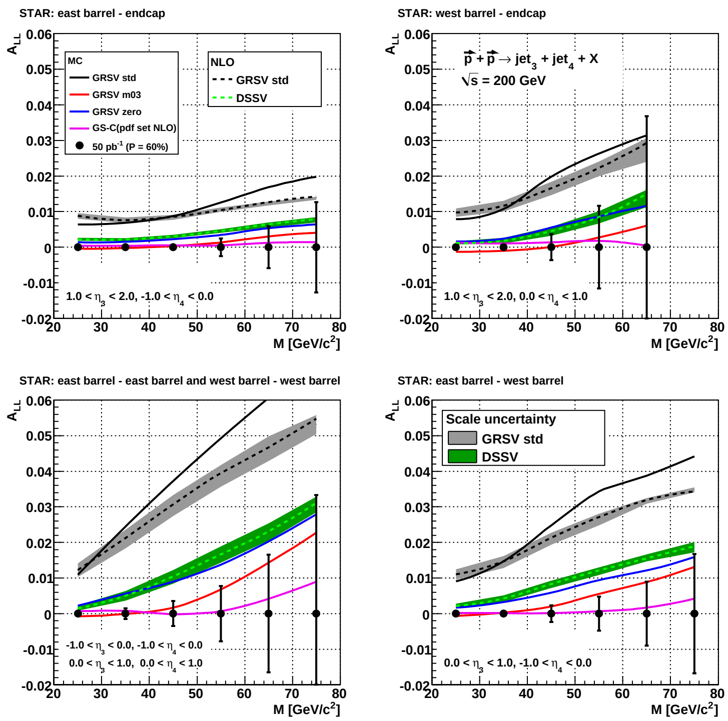

Figure 3: *A_{LL} vs. M_{inv} for di-jets based on an integrated luminosity of $50pb^{-1}$. Individual plots represent di-jets shared between various regions of the STAR EM calorimeters. The curves represent various PDFs, GRSV-std, GRSV=0 GRSV=-0.3 and GS-C discussed previously. In addition NLO calculations[ref] for two of the PDFs are also shown.*

contributing to the di-jet yield. Using the 2-body kinematics in leading order each panel represents a different combination of (x_1/x_2) and cosθ^*. By selecting a M_{inv} threshold in these plots they become a crude map in x. Note that the asymmetries are typically larger than for inclusive jets and that there is strong selectivity between solutions such as GRSV=0 and GS-C.

Despite the excellent constraints we expect to place on Δg(x) from di-jets it is still important to make statistically significant measurements in the γ-jet channel. This will provide independent information where the entrance channel is dominated by qg, the exit channel does not have strong final state interactions, and where theoretical concerns such as scale variations are in better control. Sufficient yield is produced with the luminosities expected in the next few years to make measurements with physics impact in the γ-jet channel. The crucial issue for the γ-jet program is cleanly identifying the direct photon in the presence of a much higher flux of π^0s in di-jets.

The yield of inclusive π^0's is a factor of $\sim$10 more than that of at γ's at p_T =10 GeV and worse as one goes lower. Initial simulations [ref] have identified that the signal to background could be reduced below 1:1 by the use of isolation cuts and selection on the shower shape in the shower maximum detector (SMD) for γ-jet coincident events. Such an analysis would also provide a background sample for subtraction. Over the past year efforts have been put into repeating these studies in the full Monte Carlo detector model of STAR and analyzing sample data sets taken in the 2006 run. These studies hope to verify the early simulations and provide yield information from the data. In addition, STAR is exploring the use of other observables in the calorimeter, e.g. pre- and post-shower detectors, to see whether the analysis might be pushed to lower p_T given the expected integrated luminosity. While huge progress has been made and is encouraging, we are not ready to quote specific numbers at this time. Based on the performance of the original simulations (1:1 signal:background with 80% retention of the signal) one would expect the statistical errors to grow by less than a factor of 2. Both experiments will be requesting long 200 GeV pp runs after various tracking upgrades for comparison to heavy ion data, providing an opportunity to enhance the statistics beyond that achieved in the next few years for this important channel.

The programs for di-jets and γ-jets will be extended to 500 GeV for both detectors. At this energy a given p_T will correspond to an x_g lower by a factor of 2.5. It is expected that luminosity requirements will be driven by the W program and sufficient statistics for $\Delta g(x)$ from these two body channels will not be an issue.

1.2.3 Heavy Flavor Physics

Both detector collaborations are working on silicon vertex trackers for central and forward rapidity regions to enhance their capabilities to access heavy quark physics, especially, charm and beauty physics in pp and heavy ion collisions[ref]. At any given center of mass energy, the heavy quark masses set the scale for determining the hardness of the event, i.e. for the reliable applicability of pQCD. When the experiments are equipped with these upgrades, heavy quarks along with the forward physics capabilities due to other upgrades will allow both experiments to make gluon polarization measurements at lower and higher x values than being pursued presently using the central barrels and 200 GeV center of mass operation of RHIC. These same ideas will apply for variations of the center of mass energy from 62 GeV to 500 GeV, provided sufficient integrated luminosity can be accumulated..