ΔG and A_{LL} measurement in π± production at RHIC p-p collider

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Abstract. The measurement of double longitudinal asymmetry in inclusive hadron production in polarized proton-proton collisions, A_{LL}, provides insight into the gluon spin contribution to the total proton spin. One particularly interesting channel is through charged pions as it gives sensitivity to the sign of ΔG. A brief overview on what can be learned from this measurement and analysis methods will be provided. Recent preliminary results from RHIC in p+p collisions at √s = 200 GeV are shown and discussed.

1. Introduction
The first effort to decompose the contributions to the total proton spin from different constituents dates back several decades ago. Two prominent results from European Muon Collaboration (EMC)[1] and Spin Muon Collaboration (SMC)[2], with the former being inconclusive due to large uncertainties and yet foreseeing the proton spin crisis, the latter conclusively showed that quark components alone only contribute ~25% of the total proton spin leaving gluon one of the potential contributors along with orbital angular momenta. These inclusive measurements with an observable g_1, however, could not tell us much about gluon spin contribution as this information only could be obtained through Q^2 evolution and the kinematic range of Q that could be reached by these experiments were limited at a given x. To get around this limit, there have been and are attempts to directly measure gluon polarization by hadron pairs or open charm production via photon-gluon fusion processes.[3] The uncertainties on the measurements from these experiments, however, do not yet constrain gluon polarization well. Thus, with its ability to directly probe gluons inside a proton via quark-gluon scattering, the proton-proton collider is a promising machine that provides an independent approach to access gluon polarization. And after having seen an indication of insignificant contribution of gluon polarization from the first few successful measurements through single inclusive neutral pion and jet measurements[4], in the Relativistic Heavy-Ion Collider (RHIC) there are still active research going on to further constrain gluon polarization through other different channels. One interesting channel that this paper concerns is through charged pions as it is a abundant channel that offers sensitivity to the sign of gluon polarization along with direct photons.

2. Double longitudinal asymmetry A_{LL} and gluon polarization ΔG
It is long well known that the double longitudinal asymmetry defined in Eq.(1) is an observable that can be translated into polarized parton distribution functions (pPDFs) in a certain formalism [5]. When the cross sections for initially polarized protons are expressed in terms of helicity parton densities that are defined so as to distinguish contributions from 4 different combinations of proton-parton helicity,
the double longitudinal asymmetry can be written as the ratio of convoluted polarized distribution functions to convoluted unpolarized parton distribution functions as shown in Eq.(2). As explained below, what it tells us about gluon polarization becomes clear upon investigation of all three parts in the cross section in a factorized form.

\[
A_{\text{LL}} = \frac{d\sigma(p(+)p(+)\rightarrow \pi^\pm + X) - d\sigma(p(+)p(-)\rightarrow \pi^\pm + X)}{d\sigma(p(+)p(+)\rightarrow \pi^\pm + X) + d\sigma(p(+)p(-)\rightarrow \pi^\pm + X)}
\]  (1)

The FFs were initially extracted from $e^+e^-$ annihilation data and has been much improved in recent years with inclusion of DIS/SIDIS data [6]. The recent results of polarized PDFs are shown in full global analysis that incorporates p-p data with the calculation of hard scattering cross sections at next leading order in $\alpha_s$ [6]. The hard scattering cross section $\hat{a}_{\text{LL}}$ of processes that have quark-gluon in the initial state - the most dominant process in pion production at relevant rapidity and $p_t$ range - and the sub-leading processes except for the quark-antiquark annihilation is all positive. Gluons do not have any preference in fragmenting into $\pi^+$ or $\pi^-$. The probability of $u$ quark fragmenting into $\pi^+$, $D_u^{*+}$, however, is greater than the one for $\pi^0$, $D_u^{*0}$, which is followed by $D_u^{*-}$ in magnitude. One can finally conclude that if $\Delta G$ is positive, $A_{\text{LL}}^{\pi^+} > A_{\text{LL}}^{\pi^0} > A_{\text{LL}}^{\pi^-}$ and vice versa.

3. Data and Analysis

3.1. Dataset

The dataset was taken by the PHENIX at RHIC at $\sqrt{s} = 200\,\text{GeV}$ in 2009. About 15 pb$^{-1}$ were seen and the beam polarization was measured to be $\approx 56\%$. EMCal-RICH Triggered (ERT) data were used for this analysis in addition to requiring hits in Beam Beam Counter (BBC), and the triggering required coincidence of hits in Ring Image Cherenkov (RICH) and shower in Electromagnetic Calorimeter (EMCal) Detector with the nominal energy threshold of 1.4GeV. ERT triggered dataset allowed us to collect much larger sample of charged pions than the one without it, despite of the inefficiency caused by requiring hadronic shower of which probability is only $\approx 2/3$ for hadrons in EMCal.

3.2. Detectors

The central arm detectors and the Beam Beam Counter (BBC) at the PHENIX are the relevant detectors. Each arm of the former covers $\Delta \phi = 2\pi$ and $-0.35 < \eta < 0.35$. The drift Chambers (DC) and Pad Chambers (PC) are used to track charged particles and determine transverse momenta of particles. The RICH counter vetoes heavier hadrons. EMCal provides position and energy information. BBC counter is a global detector that consists of Photo Multiplier Tubes (PMT) and is used to determine luminosity and where and when an event occurs. In 2009, additionally Hadron Blind Detector (HBD)
was placed very near the beam pipe. Full description of the rest of PHENIX detectors is shown in [8].

3.3. Analysis

Charged pions radiate Cherenkov radiation leaving photoelectron hits in RICH at above its threshold \( p_t > 4.7 \text{GeV/c} \). At this \( p_t \) range electrons also leave hits and thus are one of main sources of background. EMCal is designed in such a way that electrons tend to deposit all their energy while charged pions deposit significantly smaller fraction with differentiable shower shape. The cut performed to require the resemblance of typical electron shower shape removes \( \sim 80\% \) of electrons and requiring the energy deposited be comparable to its momentum further reduces electron contamination, given that its momentum is correctly reconstructed. Due to absence of magnetic field for tracking outside the radius of \( \sim 2 \text{m} \) from the beam pipe, where the central arm tracking starts, electrons created by photo conversion prior to this region have severely incorrect reconstructed momenta and therefore can be significantly reduced. Other potentially remaining sources of background are, photo conversion electrons and light/heavy meson decay electrons generated away from interaction vertex.

The overall background contamination is estimated to be as high as 10\% at lower \( p_t \) range \((7 < p_t < 9 \text{ GeV/c})\) and as high as 25\% at higher \( p_t \) range \((9 < p_t < 12 \text{ GeV/c})\) with the method described above. With Hadron Blind Detector (HBD)[9] in place in 2009, the backgrounds from different processes and geometrical position are further broken down and quantified and a study on this is under way.

4. Results and discussion

Results of double longitudinal asymmetry measurement for data taken in 2009 as well as for combined data for several years are shown in Fig. 1 and Fig. 2 respectively. There has been some improvement, for example, the \( p_t \) range has been extended to 12 GeV/c and the statistical uncertainties become smaller when the datasets were combined. The uncertainties, however, are not yet at the level where one can make a conclusion on the sign of \( \Delta G \) based on the prediction described in section 2. Furthermore, recent results of \( \Delta G \) measurement through neutral pion channel show \( \Delta G \) is insignificant rendering determining the sign challenging in theoretical aspects in as well. Nonetheless, what impact this measurement will have in global analysis to extract \( \Delta G \) is of great interest.

![Figure 1](image.png)

**Figure 1.** Double longitudinal asymmetry for positive charged pions(Left) and negative charged pions(Right) produced at midrapidity in p+p collision at \( \sqrt{s} = 200 \text{ GeV} \) from data taken in 2009.
Figure 2. Double longitudinal asymmetry for positive charged pions (Left) and negative charged pions (Right) produced at midrapidity in p+p collision at $\sqrt{s} = 200$ GeV from combined data taken in 2005, 2006 and 2009.

Figure 3. Comparison of double longitudinal asymmetry for three isospin-symmetric pion species. The data sets from 2005, 2006 and 2009 are combined. [10]
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