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HARD PROBES AND SPIN PHYSICS AT STAR

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1 Introduction

Primary goal of all new accelerators is to discover new physics phenomena. Relativistic Heavy Ion Collider (RHIC) located at Brookhaven National Laboratory is aimed to create and study properties of new state of nuclear matter - Quark Gluon Plasma and resolve the "spin crisis" in high energy particle physics. The first task requires the collisions of heavy ions and the second one - the collisions of polarized protons at high energies. RHIC is capable to collide gold ions from $\sqrt{s_{NN}} = 20$ up to 200 GeV and polarized protons up to 500 GeV.

Spin is one of the fundamental quantum particle properties [1]. It has not a classical analog. Its nature is believed to be connect with space-time structure itself. The basic information on the proton spin structure have been obtained from numerous experiments performed at SLAC, Fermilab, CERN and DESY on deep-inelastic scattering (DIS) of polarized leptons on polarized proton, neutron and deuteron. A global analysis of experimental data on asymmetries of DIS in the framework of Quantum Chromodynamics shown that only small fraction (part) of the proton spin is carried by quarks. Decomposition of the proton spin is usually presented as follows

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_{q+g} \tag{1}$$

Contributions to the proton spin arising from gluons ΔG and orbital angular momentum of quark L_q and gluons L_g could be significant. To extract direct information on gluon and valence and sea quark of different flavour contributions to proton spin the measurements of asymmetries of semi-inclusive DIS should be done. They will be measured at CERN, Jefferson Laboratory and DESY. Similar information can be obtained from double A_{LL} and single A_L asymmetries in the interactions of longitudinally polarized protons at RHIC.

The single (A_L) and double (A_{LL}) longitudinal spin asymmetries are written as:

$$A_L = \frac{1}{P_1}\frac{N^{\uparrow} - R_L N^{\downarrow}}{N^{\uparrow} + R_L N^{\downarrow}}, \qquad A_{LL} = \frac{1}{P_1 P_2}\frac{N^{\downarrow\uparrow} - R_{LL} N^{\uparrow\uparrow}}{N^{\downarrow\uparrow} + R_{LL} N^{\uparrow\uparrow}} \tag{2}$$

Here $N^{\uparrow}, N^{\downarrow}, N^{\downarrow\uparrow}, N^{\uparrow\uparrow}$ are the spin-dependent yields of process, P_1, P_2 are the beam polarizations and $R_L = L^{\uparrow}/L^{\downarrow}$, $R_{LL} = L^{\downarrow\uparrow}/L^{\uparrow\uparrow}$ are the relative luminosities.

The measurement of A_{LL} for direct photon and jet production in coincidence in $\vec{p}-\vec{p}$ collisions is of more preferable to determine the spin-dependent gluon distribution $\Delta G(x, Q^2)$ and integral gluon contribution to proton spin. The Compton scattering $g + q \to \gamma + q$ of elementary constituents is the dominant process in the LO perturbative QCD. The contribution of quark-quark annihilation is negligible. The inclusive direct photon, single jet and back-to-back dijet production in $\vec{p}-\vec{p}$ collisions are also acceptable to extract $\Delta G(x, Q^2)$ over a wide kinematic range.

To separate valence and sea quark contributions in $\Delta\Sigma$ and to determine spin-flavor content of polarized sea in the proton the measurement of the parity violating spin asymmetry A_L of $W^{\pm}$ production in $\vec{p}-p$ collisions should be done.

The hard regime of quark and gluon interactions is under control of perturbative QCD. Therefore cross sections of hard probes like direct photons, jets, high-p_T

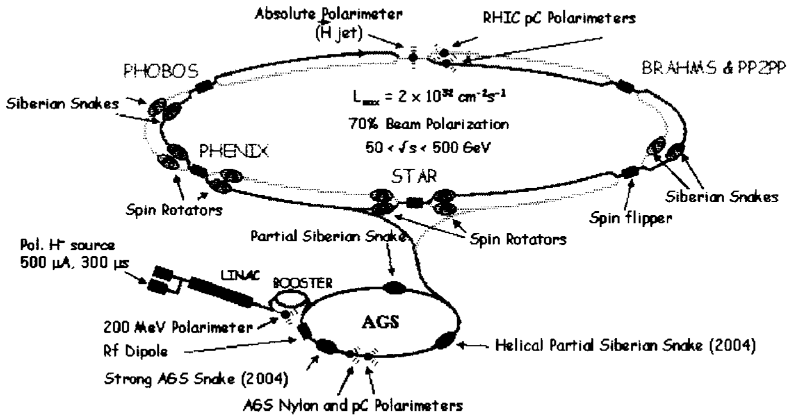


Fig. 1. RHIC Spin accelerator complex.

hadrons, Drell-Yan pairs, heavy quarkonium and $W^{\pm}, Z^0$-bosons can be estimated in LO and NLO QCD with high accuracy. Quark chirality is conserved at all QCD and electroweak vertices, however quark chirality can flip in distribution function because they probe the soft regime where chiral symmetry is dynamically broken in QCD [1].

A new polarized quark distributions, transversity [2], describing the transverse relative to momentum direction of the proton spin quark distributions can be studied in the collisions of transversely polarized protons $p \uparrow -p \uparrow$. The transverse asymmetry A_{TT} of dijets, $\gamma + jet$ and Drell-Yan pairs l^+l^- production should be measured.

The difference between longitudinal and transverse quark distributions is considered as an effect of non-perturbative interactions of quarks and gluons. Single spin pion asymmetry of the process $p \uparrow +p \to \pi + X$ is one of the best test to verify perturbative regime predicted by QCD [3, 4, 5, 6].

2 RHIC is First Polarized Proton Collider

Relativistic Heavy Ion Collider is the first collider of ultra-relativistic ions and polarized protons. Schematic view of the RHIC spin accelerator complex is shown in Figure 1. It is designed to accelerate and collide ions of Au and polarized protons up to 500 GeV. A system of regulating magnets (Siberian snakes and spin rotators) will allow to obtain a stable beams of longitudinal and transverse polarized protons.

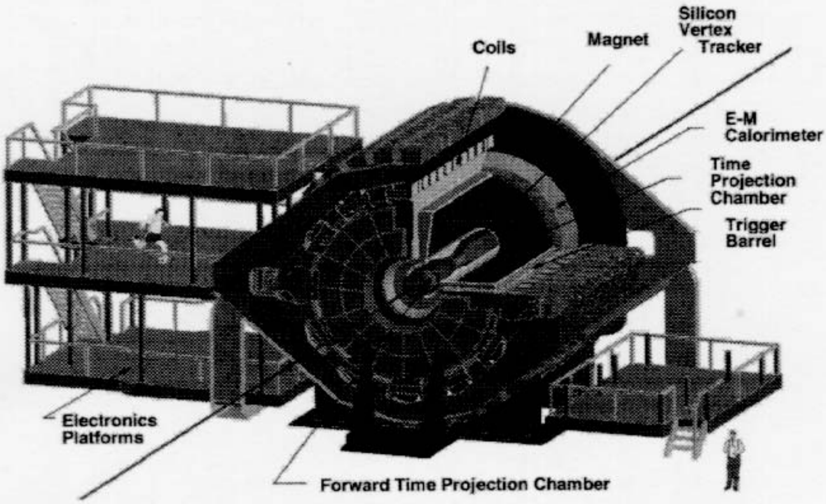


Fig. 2. Schematic view of the STAR detector.

The design luminosity and beam polarization in $p-p$ collisions are expected to be $2 \cdot 10^{32}\ cm^{-2}s^{-1}$ and 70%. A control of beam polarization will be performed by AGS and RHIC polarimeters and luminosity monitors [7, 8].

3 STAR Detector

The Solenoidal Tracker at RHIC (STAR) (Fig.2) is one of two large detector systems constructed at Brookhaven National Laboratory to investigate the behavior of strongly interacting nuclear matter at high energy density and search for signature of new state matter formation - Quark Gluon Plasma (QGP). The primary goal is to create such new state of matter colliding ions of gold at RHIC, to measure many observables simultaneously and to obtain a fundamental understanding of the microscopic scenario of ultra-relativistic heavy ion collisions.

The other part of the STAR physics program at RHIC is the Spin physics program [9, 10]. RHIC is the first polarized proton collider. Therefore it is the unique tool to search for and investigate physics phenomena in new kinematic domain. Spins of colliding protons allow to select a mechanisms of underlining constituent interactions. That is impossible to do in collisions of unpolarized particles.

The heart of the STAR detector is the large Time Project Chamber (TPC) [11] destinated for charged particle tracking and particle identification with the magnetic field of 0.5 T. The TPC covers a pseudo-rapidity $|\eta| \leq 1.8$ and full azimuthal $\Delta\phi = 2\pi$ range. It is 4 meters long and from 50 to 200 cm in the radial direction

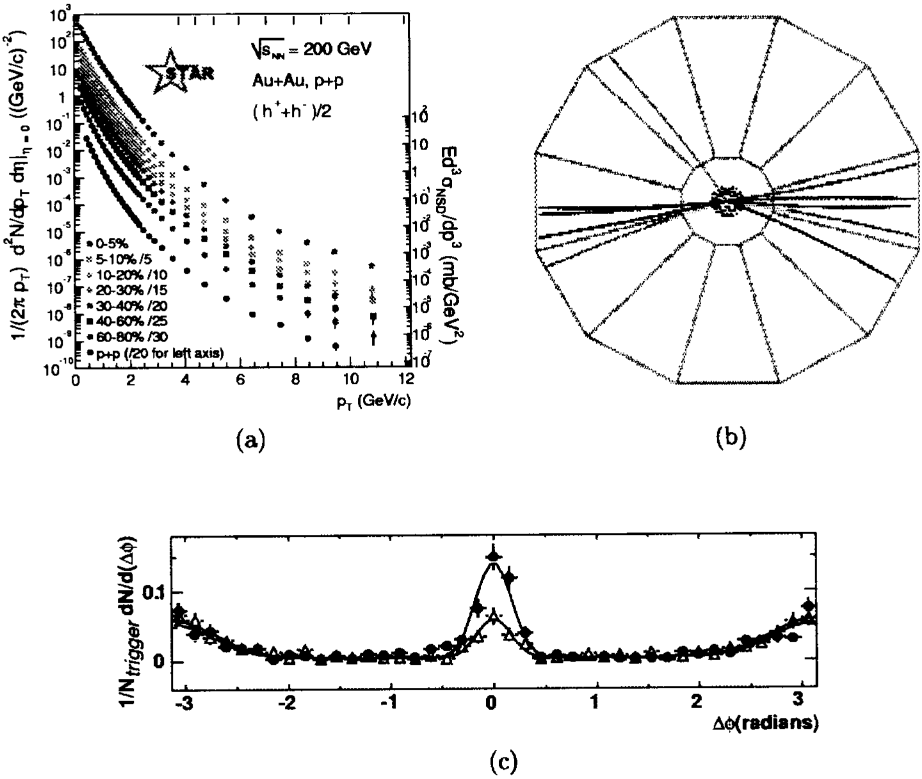


Fig. 3. (a) Charged particle spectra in $p-p$ and $Au-Au$ collisions [14]. (b) Dijet event display view in STAR TPC for $p-p$ collisions at $\sqrt{s}$ = 200 GeV [15]. (c) Azimuthal opposite (•) and same (Δ) sign charge high-p_T hadron correlations.

from the beam axes. The Selicon Vertex Tracker (SVT) and Silicon Strip Detector (SSD) allow to precisely localize the primary interaction vertex and secondary vertices from weak decays of short-lived particles (for example, hyperons) in the range $|\eta| \leq 1.$, $\Delta\phi = 2\pi$. Two radial drift Forward TPC cover the high pseudo-rapidity range $2.5 < |\eta| < 4$.

The fast detector that provide input to trigger system are the Central Trigger Barrel (CTB) [12] and Zero Degree Calorimeter (ZDC) [13] located at $|\eta| < 1$ and $\theta < 2$ mrad, respectively. The CTB surrounds the outer cylinder of the TPC and triggers on the flux of charged-particles in the midrapidity region. The two ZDCs are used to determine the energy of neutral particles in forward direction.

Particle production at high transverse momentum is due to hard collisions of quarks and gluons. Figures 3a and 3b demonstrate the charged particle spectra in $p-p$ and $Au-Au$ collisions [14] and dijet event display view in STAR TPC for $p-p$

collisions at $\sqrt{s} = 200$ GeV [15]. Star results for azimuthal correlations between high-pT charged hadrons produced in $p-p$ collisions are shown in Figure 3c. The opposite ($\bullet$) and same (Δ) charge sign correlations are between a trigger particle with $4 < p_T^{trig} < 6$ (GeV/c) and associated particles with $2 < p_T < p_T^{trig}$ (GeV/c). Near side ($\Delta\phi \simeq 0$) and away side ($|\Delta\phi| \simeq \pi$) correlations are in consistent with expectation from jet and dijet events. Charged high-p_T hadrons from parton fragmentation carry only some part of total jet energy which is measured by TPC. The other fraction is carried out by neutral component. The last will be measured and studied by the using of the STAR Barrel and Endcap Electromagnetic Calorimeters (BEMC and EEMC). This system will allows to measure the transverse energy of events, trigger on and measure high transverse momentum photons, electrons, electromagnetically decaying hadrons.

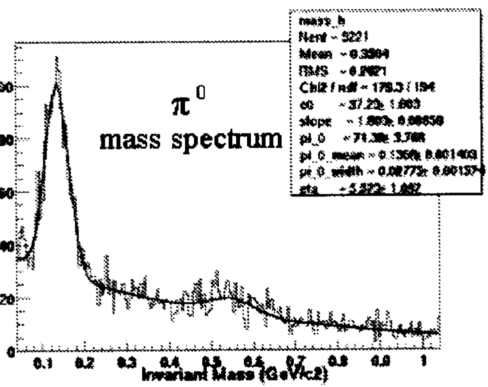


Fig. 4. Spectrum of π^0-mesons produced in $p-p$ collisions at $\sqrt{s} = 200$ GeV and reconstructed in STAR BEMC.

The BEMC [16] is a lead-scintillator, tile geometry, sampling calorimeter with fiber readout covering $-1 < \eta < 1$ and $0 < \phi < 2\pi$ with 4800 segments each covering $(\Delta\phi, \Delta\eta) = (0.05, 0.05)$. A preshower layer with the same segmentation allows improved h/e suppression as well as providing π^0/γ discrimination. The high spatial resolution provided by the shower maximum detector with 36000 channels of fine grained wire chamber readout is essential for π^0 reconstruction, direct γ and electron identification. STAR will utilize the BEMC to trigger on and study rare, high-p_T-processes (production of direct photons, jets, leading hadrons, heavy quarks) and provide a large acceptance for photons, electrons, π^0 and η^0 mesons produced in $p-p$ and $Au-Au$ collisions. Mass spectra of π^0-mesons produced in $p-p$ collisions at $\sqrt{s} = 200$ GeV and reconstructed in STAR BEMC is shown in Figure 4.

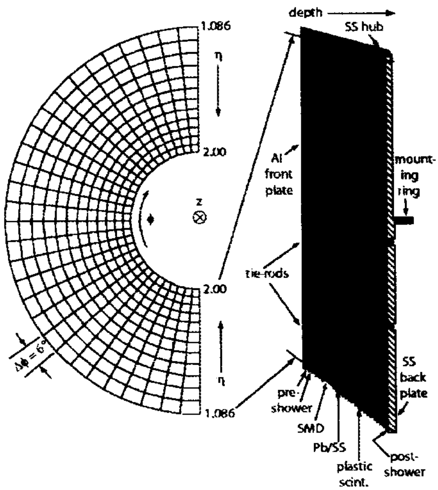


Fig. 5. Schematic EEMC tower structure.

The EEMC [17] covers the west endcap of STAR just inside the magnet pole tip. The schematic view of the EEMC structure is shown in Figure 5. It is 21 radiation lengths deep and spans $1.086 < \eta < 2.0$ and $0 < \Delta\phi < 2\pi$ with 6^o segmentation in ϕ and 12 radial segments varying from $\Delta\eta = 0.057$ to 0.099. It is also a sampling Pb-scintillator tile geometry detector with fiber readout and has preshower, shower maximum and post shower layers. In the endcap region, the added e/h discrimination from the post shower layer helps to compensate for the degraded E/p constraint from the poorer momentum measurement in the TPC at larger η. The SMD is designed to provide the fine granularity crucial to distinguish the transverse shower profiles characteristic of single phorons and the closing photon pairs from π^0 and η^0 meson decay. This SMD will also be useful for e/h discrimination and the matching of $e^{\pm}$ hits to TPC tracks. The global energy resolution of both calorimeters is about 17%.

The prototype of the Forward Pion Detector (FPD) [17, 18, 19] consisted of one module of EEMC was installed near the beam pipe at 750 cm from the STAR interaction point. The pFPD has a shower-maximum detector (SMD), preshower detector, and three similarly Pb-glass detectors. The primary goal of pFPD installation in STAR to measure the single-spin asymmetry for leading π^0 mesons [18, 19] produced in $\vec{p}-p$ collisions at $\sqrt{s} = 200$ GeV. The FPD is capable of triggering and reconstructing neutral pions of 15 to 80 GeV produced at forward pseudo-rapidity $3 < \eta < 4$ and transverse momentum of 1 to 4 GeV/c.

The Beam-Beam Counters (BBC) [19, 20] are the fast, highly-segmented scintillation counters installed around the beam pipe, on the east and west poletips of the STAR magnet at ~ 3.5 m from IR. BBC covers the range $3.4 < |\eta| < 5$, $\Delta\phi = 2\pi$. It is used as the main trigger detector and to monitor the overall luminosity, the relative luminosity during the polarized proton-proton runs and to tune the STAR spin rotators.

4 STAR spin program

The first priority goals of STAR experiment in the polarization program at RHIC [9] are to measure spin-dependent quantities of polarized proton-proton collisions and to understand the fundamental physics problem - the origin of the proton spin in the framework of Quantum Chromodynamics.

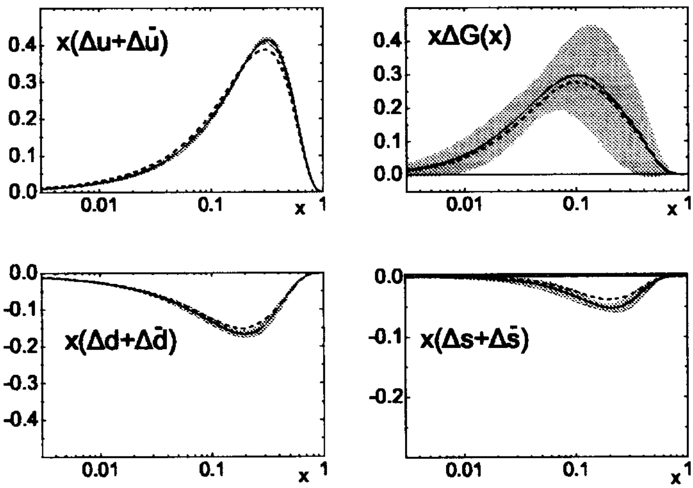


Fig. 6. Polarized quark and gluon distribution functions. Results of the NLO QCD analysis [21] of SLAC, CERN and DESY experimental data on the DIS structure functions $g_1^{p,n,D}$.

The basic information on spin proton content are obtained from numerous experiments performed at SLAC, CERN, Fermilab and DESY on deep-inelastic scattering of leptons on nucleons. The results of the global NLO QCD analysis [21] of DIS data for spin-dependent quark and gluon distributions are shown in Figure 6. This analysis allows to determine the sign and shape of the quark and gluon distributions and their integral contributions to proton spin with taking into account experimental errors and theoretical uncertainties. It should be noted that the gluon distribution $\Delta G(x,Q^2)$ is not well constrained and the sea quark distributions $\Delta\bar{u}$ and $\Delta\bar{d}$ are not extracted at all from the DIS data. The orbital momentum contribution of quarks and gluons to the proton spin based on the NLO QCD analysis of DIS data is estimated to be large and negative ($\simeq -0.5$). Recent results obtained by HERMES [22] give some indications to consider that the shape and sign of the distributions also can be different from standard PDFs [21, 23, 24, 25].

Therefore the experiments to directly measure the gluon ΔG and flavor spin-dependent valence and sea quark distributions Δq_f, $\Delta\bar{q}_f$ $(f = u, d, s)$ are necessary to resolve the problem of "spin crisis".

Such experiments will be performed by the STAR collaboration using high energy polarized proton beams at RHIC. The STAR spin program includes:

1. the measurement of the double longitudinally asymmetry A_{LL} of direct photon, direct photon in coincidence with jet, single and dijet production in $\vec{p}-\vec{p}$ collisions to determine the gluon polarization ΔG;

2. the measurement of the parity violating single longitudinally asymmetry A_L

of $W^{\pm}$ boson production in $\vec{p}-p$ collisions to determine the quark $(\Delta u, \Delta d)$ and anti-quark $(\Delta \bar{u}, \Delta \bar{d})$ polarizations;

3. the measurement of the single asymmetry of π^0-meson and charged hadron production in collisions of transversely polarized protons $p\uparrow -p$ to determine the mechanism of large polarization observed for a first time by E704 Collaboration at $\sqrt{s}=20$ GeV and verify the perturbative regime of QCD at RHIC energy $\sqrt{s}=200$ GeV;

4. the measurement of the double transversely asymmetry A_{TT} of Drell-Yan pair, dijet and direct photon in coincidence with jet production in $p\uparrow -p\uparrow$ collisions to determine the transverse polarization of quarks (δq) and anti-quarks $(\delta\bar{q})$;

5. the measurement of the spin-transfer asymmetry of the process $\vec{p}+p\rightarrow\vec{\Lambda}+X$ to determine the spin-dependent fragmentation function ΔD_q^{Λ};

6. the measurement of parity-violating spin asymmetry A_{LL}^{PV} for one jet production in $\vec{p}-\vec{p}$ collisions to search for effects of new short-range interactions could lead to large modifications of the SM predictions expected from $g-Z^0$ interference.

4.1 Gluon polarization ΔG

It is usually assumed that high-p_T regime of particle (high-p_T hadrons, direct photons and jets) production is well controlled by perturbative QCD. Therefore basic parton processes contain information on the ratio $\Delta G/G$ are the Compton $(gq\rightarrow\gamma q)$ and quark-gluon $(gq\rightarrow gq)$ scattering. Other processes like quark-quark annihilation and scattering and gluon-gluon fusion are background. Their contributions are estimated to be small enough in the studied kinematic range.

In LO pQCD the asymmetry A_{LL} is expressed via the gluon $\Delta G/G$ and quark $\Delta q/q$ ratios and partonic asymmetry a_{LL}

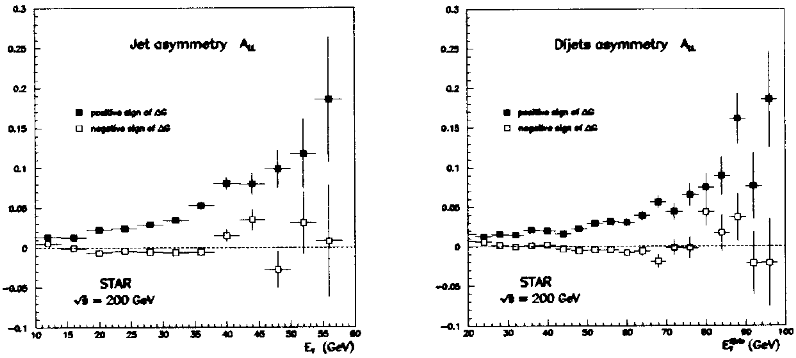
$$A_{LL}\simeq\frac{\Delta G(x_g,Q^2)}{G(x_g,Q^2)}\times\frac{\Delta q(x_q,Q^2)}{q(x_q,Q^2)}\times\hat{a}_{LL}. \tag{3}$$

In the approximation the kinematic of parton subprocess is directly related with the kinematic of hadron process. The quark x_q and gluon x_g fractions of the hadron momentum can be reconstructed on an event-by-event basis when the photon and the jet $(qg\rightarrow\gamma q\ )$ or jet and jet $(qg\rightarrow qg)$ are detected in coincidence. The procedure is to associate the larger of the x_1,x_2 values

$$x_1=\frac{2p_T}{\sqrt{s}}\cdot\frac{e^{+\eta_{\gamma,jet}}+e^{+\eta_{jet,jet}}}{2}, \qquad x_2=\frac{2p_T}{\sqrt{s}}\cdot\frac{e^{-\eta_{\gamma,jet}}+e^{-\eta_{jet,jet}}}{2} \tag{4}$$

with the quark (x_q) and the smaller one (x_g) with the gluon momentum fractions

$$x_q=max(x_1,x_2), \qquad x_g=min(x_1,x_2). \tag{5}$$



(a) (b)

Fig. 7. Double spin longitudinal asymmetry A_{LL} of jet (a) and dijet (b) production in $\vec{p}-\vec{p}$ collisions at $\sqrt{s}=200$ GeV as a function of jet transverse energy [26]. The parton distributions with the positive and negative ΔG are taken from [27].

Here η_γ and η_{jet} denote the observed photon and jet pseudo-rapidities, p_T is the observed transverse momentum of the photon or the jet.

Figure 7 demonstrates the Monte Carlo simulations [26] of asymmetry A_{LL} for jet (a) and back-to-back dijet (b) production in $\vec{p}-\vec{p}$ collisions at $\sqrt{s}=200$ GeV and $-1<|\eta|<2$. The values of jet-finder parameters were $E_\perp^{cell}=1.5$ GeV and $R=\sqrt{\Delta\eta^2+\Delta\phi^2}=0.7$. Energy resolution of the STAR Electromagnetic Calorimeter (BEMC and EEMC) were taken to be $\Delta E/E \simeq 0.16/\sqrt{E}$. The luminosity $\mathcal{L}=8\times10^{31} cm^{-2}s^{-1}$ at $\sqrt{s}=200$ GeV and the polarization $P=0.7$ of the beams were used in the calculation. As seen from Figure 6 the asymmetry A_{LL} in the region $20<E_T<50$ GeV for jet and $30<E_T<70$ GeV for dijet production is sensitive to the sign of the $\Delta G(x,Q^2)$. STAR is able to reconstruct the ratio $\Delta G/G$ over the range $x_g=0.01-0.3$ [28].

4.2 Antiquark polarizations $\Delta\bar{u}$ and $\Delta\bar{d}$

The independent information on the spin-dependent quark and antiquark distributions of different flavors is necessary to understand the origin of proton's spin composition.

The measurement of the single longitudinally parity violating asymmetry A_L for $W^\pm$ boson production in $\vec{p}-p$ collisions at $\sqrt{s}=500$ GeV can be possible at STAR [28].

Within the Standard Model (SM), W bosons are produced through pure $V-A$ interaction. The helicity and flavor structures of quarks and antiquarks are strongly correlated. Therefore $W^\pm$ production via quark-antiquark fusion ($u+\bar{d}\to W^+,\ d+\bar{u}\to W^-$) is an unique and ideal tool to study the spin-flavor nucleon structure.

In the leading approximation the parity violating asymmetry for W^+ and W^- boson production are expressed via quark $\Delta u, \Delta d$ and antiquark $\Delta\bar{u}, \Delta\bar{d}$ distributions

$$A_L^{W^+} = \frac{\Delta u(x_1)\bar{d}(x_2) - \Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2) + \bar{d}(x_1)u(x_2)}, \quad A_L^{W^-} = \frac{\Delta d(x_1)\bar{u}(x_2) - \Delta\bar{u}(x_1)d(x_2)}{d(x_1)\bar{u}(x_2) + \bar{u}(x_1)d(x_2)}. \tag{6}$$

The momentum fractions carried by the quark and antiquark can be determined from the equations

$$x_1 = \frac{M_W}{\sqrt{s}} \exp(y_W) \quad \text{and} \quad x_2 = \frac{M_W}{\sqrt{s}} \exp(-y_W), \tag{7}$$

where the rapidity of W can be determined from the observed rapidity y_e of the electron. The transverse momentum of the W is neglected. The choose of the asymmetric kinematic ($x_1 >> x_2$ or $x_1 << x_2$) for $q-\bar{q}$ collisions provides the correctly relation with momentum of W reconstructed in the $W \to e\nu$ decay. It corresponds to the assumption that the transverse momentum of W is small enough. Event selection requires that transverse momentum of $e^\pm$ in the acceptance of the STAR BEMC and EEMC should be larger than 10 GeV/c. The asymmetric kinematic of W^+ and W^- production allows to connect asymmetries $A_L^{W^+}$ and $A_L^{W^-}$ with direct measures of the quark and antiquark polarizations of separated flavors

$$\begin{aligned} A_L^{W^+} &\simeq +\frac{\Delta u(x_1)}{u(x_1)} & A_L^{W^-} &\simeq +\frac{\Delta d(x_1)}{d(x_1)}, & x_1 >> x_2 \\ A_L^{W^+} &\simeq -\frac{\Delta\bar{d}(x_1)}{\bar{d}(x_1)} & A_L^{W^-} &\simeq -\frac{\Delta\bar{u}(x_1)}{\bar{u}(x_1)}, & x_1 << x_2 \end{aligned} \tag{8}$$

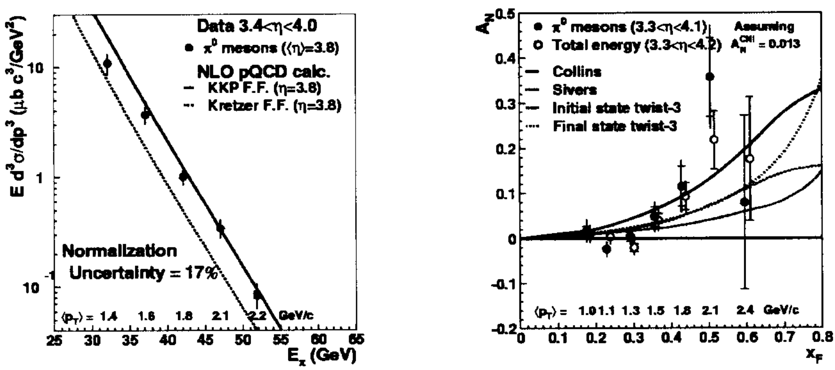
We would like to note that $W^\pm$ production in unpolarized $p-p$ collisions probes the d/u and $\bar{d}/\bar{u}$ ratios. Thus the Gottfried [29] and Bjorken [30] sum rules could be complementary to DIS verified at RHIC.

4.3 Transverse quark δq and antiquark polarization $\delta\bar{q}$

The transverse double-spin asymmetry A_{TT} for Drell-Yan lepton pair production in $p\uparrow -p\uparrow$ collisions

$$A_{TT} = \frac{\sum e_q^2[\delta q(x_1,Q^2)\delta\bar{q}(x_2,Q^2) + \delta\bar{q}(x_1,Q^2)\delta q(x_2,Q^2)]}{\sum e_q^2[q(x_1,Q^2)\bar{q}(x_2,Q^2) + \bar{q}(x_1,Q^2)q(x_2,Q^2)]} \times a_{TT}, \tag{9}$$

are expressed via the quark transversely densities δq and $\delta\bar{q}$. They describe the differences of probabilities to find quarks with transverse spin aligned and anti-aligned with transverse spin of the nucleon [2]. Similar distributions can be studied in the processes $p\uparrow +p\uparrow\to \gamma + jet + X$ and $p\uparrow +p\uparrow\to jet + jet + X$ using the STAR BEMC [16] and EEMC [17] for direct photon and jet reconstruction.



(a) (b)

Fig. 8. Invariant differential cross section (a) and analyzing power A_N (b) for forward π^0-meson production in proton-proton collisions at $\sqrt{s} = 200$ GeV [39].

4.4 Transverse single spin hadron asymmetry

The dynamic origin of the transverse single spin asymmetry A_N of pion production in $p\uparrow -p$ collisions at large x_F is of interest during the long time [31]-[36].

The prominent properties of A_N for $\pi^{\pm,0}$ mesons produced in $p\uparrow -p$ interactions at $\sqrt{s} = 20$ GeV were observed by the E704 collaboration at FNAL [37]:

1. the growth of A_N with x_F up to 40%;
2. the asymmetry is compatible with zero in the central range $x_F \simeq 0$;
3. the correlation between the sign of A_N and pion charge, $A_N^{\pi^+} \simeq -A_N^{\pi^-}$;
4. the correlation of A_N for $\bar{p}\uparrow -p$ and $p\uparrow -p$ collisions $A_N(pp) \simeq -A_N(\bar{p}p)$.

The first measurement of invariant cross section (Fig.8a) and the transverse single spin asymmetry (Fig.8b) in inclusive π^0 production in proton-proton collisions at $\sqrt{s} = 200$ GeV and large $x_F = 0.2 - 0.6$ at STAR [18, 38, 39] using the Forward Pion Detector (FPD) confirmed that the asymmetry is significant and reaches $\simeq 20\%$. The average transverse beam polarization 16% and 25% in Run 2 and Run 3 was achieved. One considered that the asymmetry can be generated by k_T dependence of the parton distributions [3], spin-dependent fragmentation functions [4] and high twist effects [5, 6]. To distinguish the mechanisms the measurement of the single spin asymmetry will be continued by STAR at higher beam polarization and upgraded FPD and BBC.

The asymmetry of the Leading Charged Particles (LCP) reconstructed in TPC was found on the level $A_N \simeq (1\pm1)10^{-2}$ over the range $|\eta| < 1.4$ and $p_T = 0.5-4.5$ GeV/c [19]. The Beam-Beam Counters (BBC) [19] was used in STAR during proton run as the main trigger detector, to monitor the overall luminosity, and to measure the relative luminosities for different proton spin orientations. Azimuthal segmentation of BBC allows to measure the single transverse asymmetry of charged particles on the level $A_N \simeq (1.0 \pm 0.2)10^{-3}$ with statistical and systematic uncertainties estimated to be $\sim 10^{-4}$ and $< 3 \cdot 10^{-4}$.

5 Summary

The transversely and longitudinally collisions of polarized protons was observed at STAR. The first measurements of single transverse asymmetry A_L of π^0 with FPD and charged hadrons with BBC and TPC indicate that STAR would be able to perform a wide spin physics program using polarized protons at RHIC.

The upgrade programs (full installation and commission of BEMC, EEMC, FPD and BBC) at STAR crucial for beam luminosity and polarization monitoring and the measure of the double longitudinal and transversal asymmetries A_{LL} and A_{TT} of high-p_T charged hadron, direct photons, jet and dijet production in p–p collisions are underway.

The signals of the hard probes, the spectra of high-p_T π^0 mesons reconstructed in BEMC and FPD, charged hadrons reconstructed in TPC and first back-to-back jet events observed at STAR confirm the ability of a wide STAR detector performance.

The design luminosity $\sim 10^{32} cm^{-2} s^{-1}$, the beam polarization $\sim 70\%$, the RHIC running time $\sim 25\%$ and the energy $\sqrt{s} = 500$ GeV in $p - p$ collisions together with a control of local beam polarization and luminosity monitoring are crucial to successfully perform the STAR Spin Physics program at RHIC including the determination of the gluon contribution ΔG to the proton spin, the spin and flavor decomposition of sea $\Delta u, \Delta d, \Delta \bar{u}, \Delta \bar{d}$, the study of mechanism of polarization transfer and transversity and the search for new physics phenomena beyond SM using the unique tool such as spin.

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Жесткие пробники и спиновая физика на детекторе STAR E1-2003-202
Токарев М. В. и коллаборация STAR

Спин является одной из наиболее загадочных и наименее понятых характеристик элементарных частиц. Изучение природы спина составляет важную часть физической программы исследований на ускорителе релятивистских ядер и поляризованных протонов RHIC (Брукхейвен, США). STAR — один из двух больших детекторов, работающих на пучках RHIC, который обеспечивает хорошие возможности для проведения поляризационных экспериментов.

Представлена программа исследований по спиновой физике коллаборации STAR. Она включает приоритетные измерения одно- и двуспиновых асимметрий процессов с участием поляризованных протонов для выделения спин-зависимого глюонного распределения, разделения флэйворных вкладов поляризованных валентных и морских кварков и определения поперечной поляризации кварков. Также приводятся краткое описание ускорительного комплекса RHIC, основных компонентов детектора STAR и их характеристики.

Работа выполнена в Лаборатории высоких энергий им. В. И. Векслера и А. М. Балдина ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна, 2003

Hard Probes and Spin Physics at STAR E1-2003-202
Tokarev M. V. for the STAR Collaboration

Spin is one of the most enigmatic and least understandable properties of elementary particles. The study of the proton spin puzzle is an important part of the physics program at the Relativistic Heavy Ion Collider (RHIC) accelerating both nuclei and polarized protons. STAR is one of the two large detectors at RHIC. It has an excellent capability for spin physics.

In the present work the overview of the STAR spin physics program is given. It includes the highest priority measurements of single- and double-spin asymmetries allowing one to determine gluon contribution to proton spin, to separate sea and valence quark flavor polarizations, to measure quark transversity. A brief description of the RHIC accelerator complex, some detail of the STAR detector and its perfomance are presented.

The investigation has been performed at the Veksler–Baldin Laboratory of High Energies, JINR.

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