Study Quark and Antiquark Contribution to Proton Spin Structure at RHIC

Wei Xie

Riken-BNL Research Center, Brookhaven National Lab, Upton, NY 11973

Abstract. Relativistic Heavy Ion Collider (RHIC) provides a unique opportunity for the direct measurement of quark and antiquark spin in proton utilizing the parity-violating feature of W boson production. Through probing the decay leptons from W bosons in the central and forward rapidity region, RHIC can dissociate contributions from different flavors of quarks to the proton spin with very high accuracy. The capabilities of the spin flavor dissociation at RHIC with current detector configuration and future upgrades are described.

Keywords: spin, RHIC, PHENIX, STAR, quark, upgrade, W boson, asymmetry, trigger, tracking, lepton.
PACS: 12.38.Aw

INTRODUCTION

In the late 80s, measurements from DIS experiment showed that the quarks and antiquarks contribute only ~ 20% of the proton spin [1]. To solve this "crisis", one needs direct measurement of the spin of different flavor of quarks and antiquarks. On the other hand, the unpolarized Fermilab E866 experiment discovered the flavor symmetry breaking in the quark sea [2]. It would be very interesting to see if similar flavor asymmetry exists in the polarized cases. The Semi-inclusive DIS experiment like HERMES [3] has made the first progress in this direction. The measurements are based on the assumption that the leading hadrons most likely come from the quarks hit by the virtual probe photons. The limitation is the low probe Q^2 where the quark fragmentation functions are not well measured and one has to rely on theoretical model calculations. RHIC can directly measure the quark sea flavor asymmetry *via* the decay leptons from W^+ and W^- bosons [4] based on the first principle and no model dependence. RHIC spin collaboration has the multi-year plan to do the W measurement with great sensitivity in $\sqrt{s} = 500\,GeV$ polarized p-p collisions. The capabilities of the measurements at RHIC with current detector configuration and future upgrades are described

SENSITIVITY OF QUARK AND ANTIQUARK SPIN MEASUREMENT AT RHIC

In the standard model, a W boson is produced *via* the V-A interaction and is directly coupled to the parent quark and antiquark with known helicity. Through studying the single longitudinal spin asymmetry of W-decay leptons, one can measure the participating quark and antiquark spin inside protons at large Q^2 ($\sim M_w^2$) without any knowledge of fragmentation functions [4]. RHIC has the muti-year plan to measure W boson in polarized p-p collision at $\sqrt{s} = 500\,GeV$ .The projected integrated luminosity is 800 pb^{-1}. One expect to have 8000 decay muons from W^+ and 8000 decay muons from W^- in PHENIX muon arms, 15000 decay electrons from W^+ and 2500 decay electrons from W^- in PHENIX central arms . Recently P.M. Nadoski and C.P. Yuan made predictions on the W boson production in polarized p-p collision at RHIC based on the resummation calculation [5]. They proposed the approach of measuring quark and antiquark spin *via* studying W-decay lepton asymmetry. Fig.1 shows the prediction of the lepton asymmetry as a function of lepton rapidity with 800 pb^{-1} p-p collisions at $\sqrt{s} = 500\,GeV$. A 20GeV p_T cut is applied to reduce the backgrounds. The error bars on the solid point is statistical only. One can see the sensitivity is different in central and forward rapidity region. RHIC experiment will be able to cover both regions.

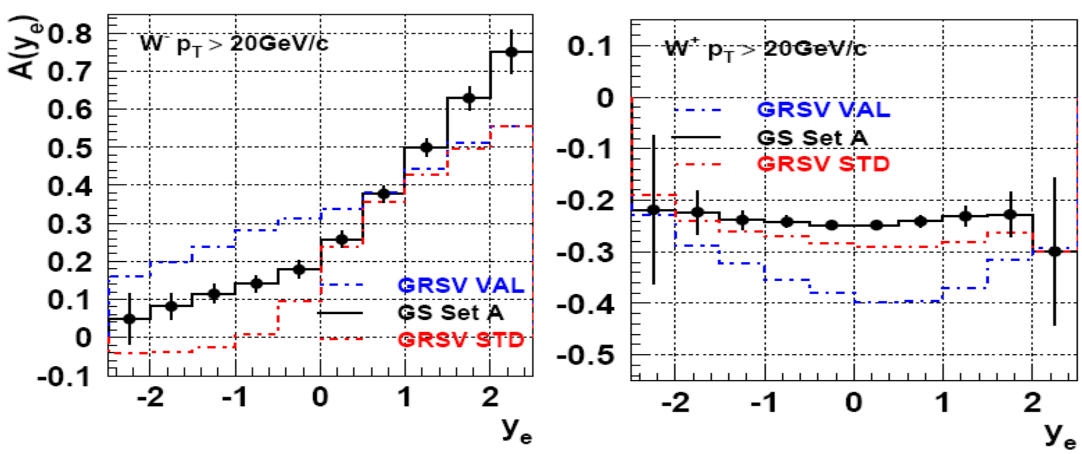


FIGURE 1. Asymmetries of decay leptons from W^- boson (left) and W^+ boson (right) predicted by resummation calculations using RhicBos [6]. Results shown are from GRSV VAL (blue) [7], GS Set A (black) [8] and GRSV STD (red) [9].

EXPERIMENTAL CAPABILITIES OF MEASURING QUARK AND ANTIQUARK SPIN AT RHIC

In order to successfully measure the quark and antiquark spin through W-decay leptons at RHIC, the experiments are required to have:

- Good charge sign identification at very high momentum. One can see from fig.1 that the decay lepton asymmetry from W^+ and W^- are quite different. Mixing them together will significantly deteriorate the sensitivity of the measurement.
- High performance level-1 trigger. In the $\sqrt{s} = 500\,GeV$ p-p runs at RHIC, the expected collision rate is 12 MHz. We need a single lepton level-1 trigger with very high rejection and efficiency to collect all the W-decay leptons through the limited trigger bandwidth in the RHIC experiments.
- Good hadron rejection factor or being able to measure the charged hadron asymmetry that can be subtracted to achieve the asymmetry of W-decay leptons.

Fig.2 shows the PYTHIA simulation on the p_T distribution of decay leptons from different sources in the central and forward rapidity region inside PHENIX acceptance. Keeping in mind the large uncertainties of the estimate, one can see the dominant background is the charged hadrons. We need either to reject them or be able to measure its asymmetry and subtract it later to get the W-decay lepton asymmetry. A rejection factor of at least 1000 is needed to bring down the charged hadrons to the level comparable to other backgrounds.

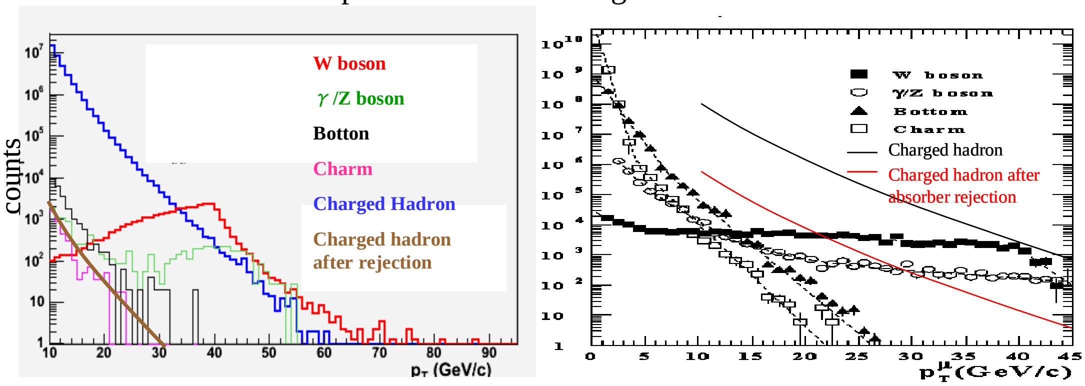


FIGURE 2. Yields of decay leptons from various sources in $\sqrt{s} = 500\,GeV$ p-p collisions with 800 pb^{-1} integrated luminosity inside PHENIX central arm (left) and muon arm (right) acceptance. Both raw charged hadron yield and the one after rejection are shown in the plots. For muon arm, the result from absorber rejection alone is shown and further rejection power can be achieved from shower profile cut.

Charged Hadron Rejection

For an experiment with calorimeters and tracking chambers, the usual ways to reject hadrons are through the cut on the ratio of energy over momentum (E/p cut) and shower profiles. In the case of measuring W bosons, its high p_T decay leptons should be isolated from charged hadrons and therefore an isolation cut is effective to reject hadrons. On the other hands, the p_T of W boson is much smaller than its decay leptons, an event containing a W boson decay must have very high p_T since the decay neutrino can not be detected. One therefore can reject any events with missing large p_T.

The STAR experiment [10] contains Electromagnetic Calorimeters (EMCal) and Time Projection Chambers (TPC) covering both central ($|\eta|<1$) and forward rapidity ($1<|\eta|<2$) region. The total hadron rejection factor is more than 10^3 and it comes equally from the E/p, isolation and large missing p_T cut. STAR is also equipped with a pre-shower detector in its forward calorimeter. A longitudinal shower profile cut should produce more hadron rejection powers.

The PHENIX [11] central arm detector contains EMCal and a drift chamber for track reconstruction covering $|\eta|<0.35$ region. The total rejection factor is between 2000 to 10^4 where E/p cut contributes ~40 to 200 depending on different arm and different tracking algorithm, shower profile and isolation cut contribute another factor of 50. A TEC/TRD detector is equipped in the east central arm and will be used for high p_T electron identification. It is expected to produce an additional rejection factor of 30 once its operation is stable.

The PHENIX Muon arm detector contains a muon tracking chambers (MuTr) and muon identification chambers (MuID) covering $1.2<|\eta|<2.4$ region. The total hadron rejection of ~100 comes mainly from the thick steel absorber located in front of MuTr. Further rejection power can be achieved *via* shower profile cut at MuID. Future PHENIX forward calorimeter upgrade will help reject hadrons through isolation and large missing p_T cut. The possibilities of measuring the large p_T hadron asymmetry that can be used for subtraction to get the W-decay lepton asymmetry are also being studied.

Charge Sign Identification

Both the PHENIX central and muon arm have very good charge sign identification capabilities. Only a few percent of charge sign misidentification is observed in p_T ~ 40GeV region with current detector setup. Further improvement is expected when the ongoing silicon vertex detector upgrade is finished.

STAR TPC has coarse pad readout granularity in the region of $|\eta|>1.0$. The charge sign misidentification is up to ~15% at p_T ~ 40GeV as shown from the simulation neglecting the huge event pile-up effect in the coming $\sqrt{s} = 500\,GeV$ high luminosity p-p run. The event pile-up effect is expected to further seriously deteriorate charge sign identification. An ongoing forward tracking upgrade project will be able to solve the problem and will be described briefly in one of the following sections.

Level-1 Trigger Performance

PHENIX central arm has built a powerful electron trigger using EMCal and Cerenkov detectors. The rejection factor can go well beyond 10^4 at reasonable trigger threshold where the efficiency is high. This satisfies the requirement for trigger performance in the high luminosity 500GeV run for PHENIX experiment.

STAR can trigger on electrons efficiently using the barrel and endcap EMCal by setting a certain energy threshold. The rejection factor is expected to be high enough to meet their requirement for detecting W bosons in the high luminosity 500GeV run.

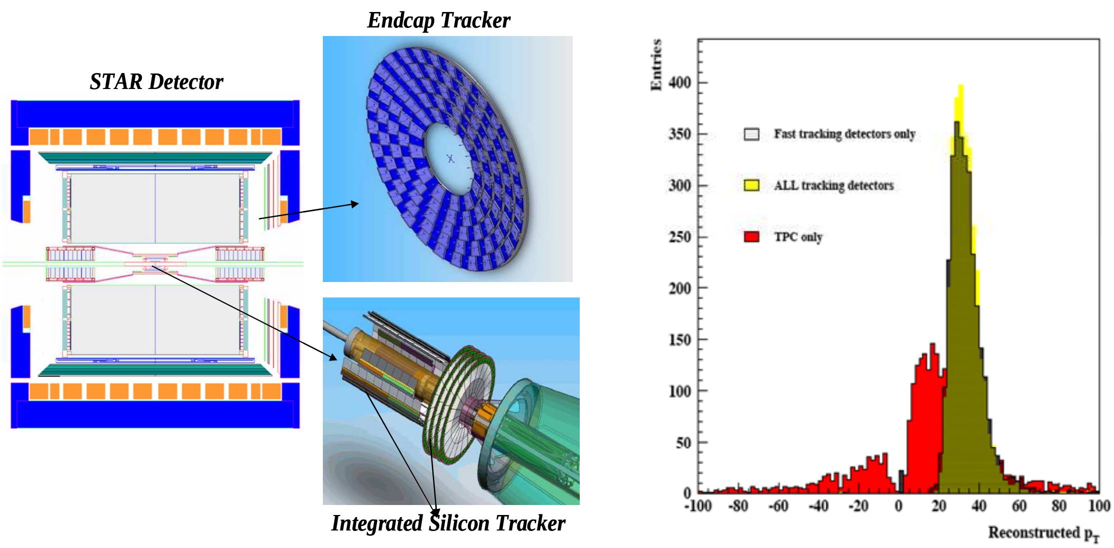
PHENIX muon arm has a single muon trigger that has been used to successfully trigger on the muons decay from heavy flavor mesons. However, the rejection factor is about 20-50 times lower than that is required for W boson measurement at RHIC. A trigger upgrade project is ongoing to build a powerful momentum sensitive muon trigger to solve the problem. The project will be described briefly in one of the following sections.

FUTURE DETECTOR UPGRADE FOR QUARK AND ANTIQUARK SPIN MEASUREMENT AT RHIC

As we see from previous sections, to successfully measure the quark and antiquark spin at RHIC, STAR experiment needs a forward tracking upgrade to solve the charge sign identification problems and PHENIX need to upgrade the muon trigger to adapt to the coming high luminosity p-p collisions.

Forward Tracking Upgrade for STAR Experiment

The forward tracking upgrade will include 4 silicon disks with 50μm resolution in the inner region and a 3-layer GEM detector with 100μm resolution between endcap EMCal and TPC pad readout plane as shown in fig.3 (a). Fig.3 (b) shows the simulated results of new tracker performance with p_T=30GeV electrons. One can see the new tracking system alone has very little charge misidentification and much better momentum resolution compared to the TPC. The performances are comparable with and without adding the TPC. The proposal is planned to be submitted after FY06 run and the detectors are to be installed in the summer of 2009. Simulation and R&D efforts are ongoing actively.

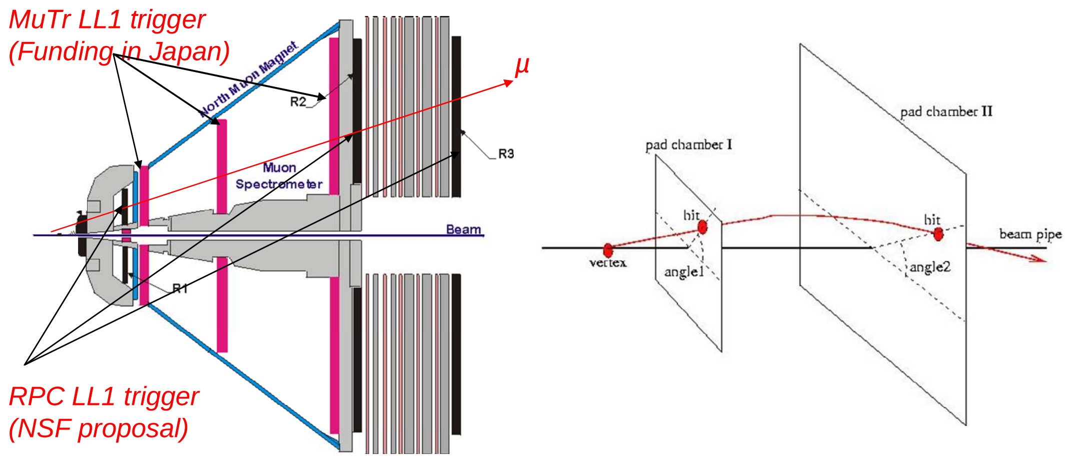


(a) (b)

FIGURE 3. STAR forward tracking upgrade detectors (a) and performance (b). Right hand side plot shows reconstructed momentum of p_T=30GeV electrons with TPC only (red), TPC plus new forward tracking system (yellow) and forward tracking system only (brown).

Muon Level-1 Trigger Upgrade for PHENIX Experiment

There are two proposals for trigger upgrade. One is to install three resistive plate chambers (RPC) inside the muon arm. The trigger requires that the RPC hits are associated with the muon candidates of the existing muon trigger and apply an angle cut between hits in the two front RPCs to reject low momentum muons. The principle is illustrated in fig.3 (b). A proposal of two million dollars has been submitted to NSF. The other one is similar but MuTr hits are used for the angle cut and the association with muon candidates from current trigger and it requires upgrade of MuTr front end electronics. Efforts are being made to seek funding in Japan. Both proposals provide sufficient rejection factor (> 10^4) for W boson measurement in the coming high luminosity p-p run. If both proposals succeed in getting funding, their combination will produce an even more powerful trigger that can be used in the future higher luminosity RHICII environment. The installation of new RPC trigger detectors and electronics is planned to be finished before early 2009. Simulation and R&D work are ongoing actively on both fronts.



(a) (b)

FIGURE 4. PHENIX forward muon trigger upgrade detectors (a) and working principle (b). In the left hand side plot, the proposal of RPC trigger is illustrated in back color and the proposal of MuTr trigger is illustrated in pink color.

SUMMARY

RHIC provides a unique opportunity for the direct measurement of quark and antiquark spin in proton utilizing the parity-violating feature of W boson production. With the successful upgrade of forward tracking system in STAR and forward muon trigger in PHENIX, RHIC will be able to dissociate contributions to proton spin from different flavors of quarks and antiquarks with very high accuracy through probing the decay leptons from W bosons in the central and forward rapidity region,

ACKNOWLEDGMENTS

The author expresses full thankfulness to B. Sorrow and A. Bazilevsky for providing many materials for the proceeding.

REFERENCES

1. Ashman J, et al [European Muon Collaboration (EMC)]. *Phys. Lett.* B206:364 (1988)
2. FNAL E866/NuSea Collaboration, E.A. Hawker *et al.*, Phys. Rev. Lett. 80 (1998) 3715
3. HERMES Collaboration, Phys.Rev. D71 (2005) 012073
4. G. Bunce *et al.*, Annu. Rev. Nucl. Part. Sci. 2000. 50:525-75
5. P.M. Nadolsky *et al.*, Nuclear Physics B 666 (2003) 31-55
6. P.M. Nadolsky *et al.*, http://hep.pa.msu.edu/people/nadolsky/RhicBos/index_frames.html
7. M. Gluck *et al.*, Phys. Rev. D 63 (2001) 094005
8. T. Gehrmann *et al.*, Phys. Rev. D 53 (1996) 6100
9. M. Gluck *et al.*, Phys. Rev. D 53 (1996) 4775
10. STAR Collaboration, NIM A 499 (2003) 624-813
11. PHENIX Collaboration, NIM A 499 (2003) 469-602