A Study of Heavy Quark and Quarkonium Production in Polarized p-p collisions at RHIC

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Abstract.
At RHIC, heavy quark production is sensitive to the gluon distribution inside the proton. The expected integrated luminosity of $3pb^{-1}$ from this year's first longitudinally polarized proton beams will provide an opportunity to study the helicity dependent heavy-quark and quarkonium production that could lead to direct measurement of gluon polarization in the polarized proton. I discuss the experimental sensitivity of such measurements with the PHENIX detector. New ideas to explore physics beyond the Standard Model with heavy quarks in the future high energy polarized p-p collisions are also discussed.

INTRODUCTION

The surprising result from the EMC experiment 15 years ago at CERN showed that the sum of the quark's spin only accounts for a small fraction of the proton's total spin[1]. Tremendous progress has been made in both experimental measurements and theoretical studies since then, however the origin of the proton's spin still remains an outstanding puzzle. One very likely candidate to solve this "missing" proton spin problem is the gluon polarization.

RHIC-SPIN is the first high-energy polarized proton-proton collider where hard gluon-gluon and gluon-quark scattering processes can be studied at leading order. It opens up a new frontier for the study of the gluon distribution inside the polarized proton.

PHENIX EXPERIMENT

The PHENIX experiment at RHIC is designed for a broad spectrum of physics for involving both Heavy Ion collisions and Spin[2]. The excellent capability for lepton measurements allows the PHENIX experiment to have a rich program in heavy-quark physics, as has already been demonstrated in recent publications on open charm and J/ψ production through electron and muon measurements[3]. Here, I highlight selected topics from heavy-quark measurements with the PHENIX detector.

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[1] for the PHENIX Collaboration

Heavy quark production and parton distribution

In the study of parton structure of the nucleon, perturbing QCD plays an critical role. The nucleon's structure functions measured in hard processes can be written as a sum of parton distributions $f_a(x,q^2)$ for each quark and gluon, where a is the index of parton flavor, x represents parton's momentum fraction in the nucleon, and q^2 is the energy scale at which it is measured. In the parton model, the heavy quark production process $a+b \rightarrow Q+\bar{Q}$ is given by,

$$E\frac{d^3\sigma}{d^3p} \propto f_a(x_a,q^2)f_b(x_b,q^2)\frac{d\hat{\sigma}(a+b\rightarrow Q\bar{Q})}{dt} \tag{1}$$

where $\frac{d\hat{\sigma}(a+b\rightarrow Q+\bar{Q})}{dt}$, the parton scattering cross section, can be calculated with perturbative QCD. At RHIC energy, $\sqrt{s} = 200$ GeV, it is expected that charm and bottom quarks are predominately produced through the gluon fusion process. A simple simulation estimation with PYTHIA [4] shows that about 95% and 85% are from the gluon fusion process in open charm and open bottom production, respectively. So the the spin-dependent asymmetry A_{LL} from heavy-quark production in polarized p-p collisions, is given by,

$$A_{LL} = \frac{\sigma(++)-\sigma(+-)}{\sigma(++)+\sigma(+-)} \simeq \frac{\Delta G(x_1)}{G(x_1)}\frac{\Delta G(x_2)}{G(x_2)}\hat{a}_{LL}(g+g\rightarrow Q\bar{Q}) \tag{2}$$

where $\Delta G(x) = G^+(x) - G^-(x)$ is the longitudinally polarized gluon distribution inside the proton, and $\hat{a}_{LL}$ is the asymmetry in the partonic process $g+g \rightarrow Q+\bar{Q}$. The latter has been computed at LO and NLO[5, 6].

Open heavy quark and quarkonium measurements in the PHENIX

In PHENIX, open heavy-quark production is measured with high P_T single leptons and dilepton pairs. For heavy quarkonium such as the J/ψ, it is fully reconstructed in its dilepton decay mode. PHENIX also has a plan to upgrade its inner tracking system to include a silicon vertex detector to explicitly detect heavy-quark decays.

By studying the spin-dependent asymmetry A_{LL} in heavy-quark production, the polarized gluon distribution $\frac{\Delta G(x)}{G(x)}$ can be extracted from equation (2). Fig. 1 show the expected asymmetry A_{LL} from single muon and J/ψ measurements in PHENIX for various projected luminosities.

Heavy quarks as a probe for new physics

Besides the importance in their own right in determining the spin structure of nucleon, study of the spin-dependent heavy-quark production will also provide a critical test of the QCD, and may eventually lead us to search for new physics beyond the standard

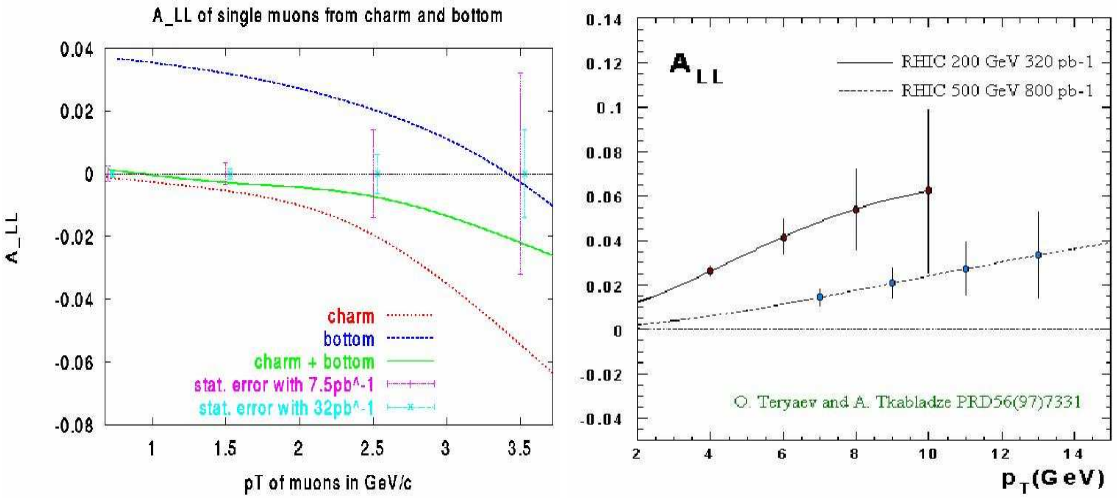

FIGURE 1. Left: Expected A_{LL} in open charm and open beauty production from single muon measurement. Right: Expected A_{LL} from J/ψ measurement.

model. The planned $\sqrt{s} = 500$ GeV polarized p-p collisions at RHIC will certainly open up a new window for such physics. Several ideas have already been proposed to probe new physics at RHIC-SPIN[7, 8]. Here we discuss one example where contributions from new heavier particles, such as light gluinos studied by E. Berger et al. in unpolarized $p\bar{p}$ collisions at the Tevatron[9], could be probed for beauty-quark production in polarized p-p collisions at RHIC. In the paper, Berger et al. showed that the creation of light gluinos of mass ~ 15 GeV at the Tevatron would produce more bottom quarks and thus bring the theoretical expectation into good agreement with the experimental measurements. Other models are also proposed to explain the excess of beauty production at Tevatron, including the use of improved B-hadron fragmentation functions and modified parton distribution functions[10]. However, in general, it is hard to disentangle these different contributions in unpolarized collisions.

We argue that if indeed there exist such new particles of mass ~ 15 GeV that contribute significantly to the beauty production at high energy p-p collisions, it is possible to directly probe them at RHIC in the beauty-quark A_{LL} measurement if gluons have a sizable polarization inside the proton. The modified asymmetry A_{LL} is given by,

$$A_{LL} = \frac{\Delta\sigma_{SM} + \Delta\sigma_{NEW}}{\sigma_{SM} + \sigma_{NEW}} \tag{3}$$

where σ_{NEW} is the contribution from new processes such as light gluino production. Fig. 2 shows the LO calculation of A_{LL} as a function of $\sqrt{\hat{s}}/2M$. At high $P_T \geq 15$ GeV, the standard model process $g + g \to b + \bar{b}$ gives $A_{LL} \sim -1$ while the gluino processes $g + g \to \tilde{g} + \tilde{g}$, followed by $\tilde{g} \to b\tilde{b}$, will yield $A_{LL} \sim +1$ if the gluino has a large mass ~ 15 GeV. Detailed studies are underway to include NLO corrections.

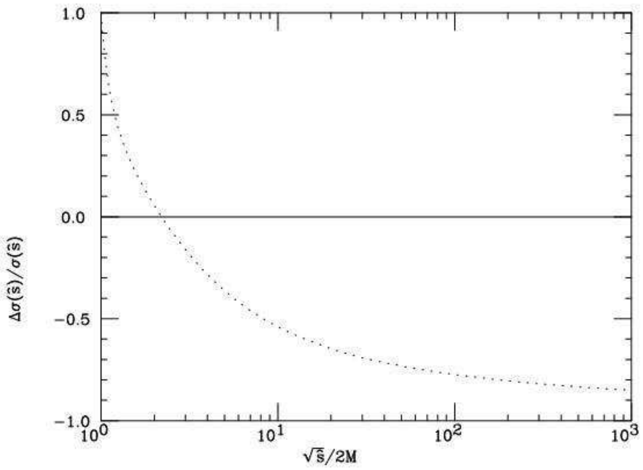

FIGURE 2. Parton level a_{LL} as a function of $\sqrt{\hat{s}}/2M$ in heavy-quark production, from LO calculation.

SUMMARY

We discussed the possibility to use heavy-quark measurements to study the polarized gluon distribution inside the proton, and to probe new physics beyond the standard model. We expect with improved luminosity and beam polarization in the future, heavy-quark measurements will produce exciting results for the physics outlined above. The RHIC-SPIN program opens up a new frontier for nucleon structure physics and allows the search for new physics beyond the standard model.

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