1. Cover Sheet

05-515 (program announcement/solicitation number)

Directorate for Mathematical and Physical Sciences
(NSF unit consideration)

Development of a Fast Trigger System for the PHENIX Forward Detector Upgrade (title)

2. Project Summary (1 page, Hill, referee Seto)

We propose to develop and build a fast trigger for the forward spectrometer upgrade of the PHENIX detector at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL). The motivation of this upgrade is to study how contributions from various quarks and gluons add together to produce the proton spin. We will use the RHIC high energy polarized proton beams especially designed for this study. Our method involves the isolation of high-energy interactions between the proton's quarks and gluons. Of special interest for us is collisions in which a W boson is formed. The proposed instrument will permit measurement of the direction and momentum of the W with good efficiency and resolution.

The fast trigger will be installed as an upgrade to the two PHENIX forward muon spectrometers. We propose to build Resistive Plate Chambers (RPCs) to track muons from W decay through the forward spectrometers. The RPCs will employ fast readouts to create a signal that the level-1 trigger can use to indicate the presence of the rare W particles but reject the much more numerous muons from hadron decays and beam interactions In addition the RPCs will employ a slower readout with high spatial resolution to accurately determine the W-boson trajectory. It will therefore be necessary to build fast and slow RPC readout electronics. An essential component of the upgrade is a Local Level-1 (LL1) trigger that takes the data from the RPCs in real time and decides on-line in a few microseconds to accept or reject the collision event. The proposal to develop this trigger was reviewed and approved by PHENIX in July, 2004.

A total of five U.S. universities, namely Illinois at Urbana-Champaign, Colorado California at Riverside, Iowa State and Abilene Christian will participate in this project. All of these universities will contribute graduate and undergraduate students as well as postdoctoral fellows to work on this project. This will involve projects in building and testing of detectors and electronics and writing of software to process output signals from the detectors and the trigger. Also additional software will be needed to simulate the collision environment expected with the higher beam intensities resulting from the planned RHIC luminosity upgrade. The students involved will thus gain experience in the design, construction and testing of state-of-the-art radiation detectors and readout electronics and the creation of the software needed to obtain physics results.

A fundamental goal of nuclear physics and the RHIC spin program is to understand the quark-gluon structure of the fundamental bound state of QCD, namely the nucleon. Thus upgrade of the PHENIX forward spectrometers to study W spin physics using the weak interaction, which has several advantages over previous experiments, is needed. In addition to the advantage of large Q^2, “u-quark dominance” is eliminated resulting in more accurate study of the role of the d and s quarks. The parity violating nature of the weak interaction provides a natural polarization measurement requiring only a single spin asymmetry measurement. Once the forward upgrade and the upgrade of RHIC luminosity is completed the PHENIX collaboration will undertake precision measurements of W particles produced in collisions of polarized beams to gain a more complete understanding of the roles of various factors producing the proton's spin.

3. Project Description

3. a) Research Activities (3.5 pages, Kinney, referee Saito)

While the instrumentation we propose to develop may have a number of applications both within the PHENIX spectrometer as well as more generally in any apparatus requiring fast, compact, ionizing particle triggering and tracking, the scientific purpose in the present case is the determination of the spin contributions of the sea and valence quarks to the spin of the proton, as described below.

The Spin Structure of the Nucleon: Present Understanding

A central goal of high-energy nuclear physics is to determine and understand the quark-gluon structure of the nucleon, the fundamental bound state of QCD. (Ref NSAC LRP). The present understanding is largely empirical and rudimentary. A prime example of this is the surprising fact, now well established from inclusive polarized deep inelastic lepton scattering experiments,(Ref Spin review) that only 20-30% of the spin of the nucleon arises from the spins of the quarks. While one would expect a significant contribution from the gluon field, this contribution remains almost completely undetermined. Possible contributions from orbital angular momentum are even less well understood, both experimentally and theoretically, although there are recent hints that this contribution is not small(Refs Jlab Ge/Gm, Sivers).

The PHENIX experiment, along with the STAR and COMPASS experiments, will make the first direct measurements of the gluon contribution to the nucleon spin, $\Delta G(x)$, over a significant range in momentum fraction x (Refs RHIC Spin program, COMPASS). The basic processes are polarized gluon-gluon and polarized quark-gluon hard scattering leading to different final states, as shown in Fig. 3.1. First results from PHENIX Run 3 and 4 (Ref A_LL) have already been produced which constrain models with different gluonic spin contributions. With data from future running periods (Ref decadel plan?), the variety and power of these measurements will greatly increase.

Figure 3.1 Basic processes sensitive to $\Delta G(x)$.

Given these measurements, a fundamental question will be how the quark and gluon contributions mutually arise in the nucleon bound state. In particular, how is the polarization of the sea quarks, which are formed from the gluon field, affected by the gluon polarization. In order to answer this more detailed question, experiments at CERN (SMC(ref), COMPASS(ref)) and DESY(HERMES(ref)) have and are attempting to determined the spin contributions of the different quark flavors separately, especially the contributions from the sea quarks. The technique used is so-called “hadron tagging” based on the measurement of semi-inclusive asymmetries, in which a leading hadron (i.e., a hadron containing a large fraction of the energy transferred to the nucleon) is detected in coincidence with a deep-inelastically scattered lepton. Using a statistical analysis and empirical fragmentation models, one can exploit the greater than random probability that the leading hadron contains the struck quark (calculated in a fragmentation model), and use the hadron species to limit the possible flavor of the struck quark. Measuring concurrently a sufficient number of semi-inclusive asymmetries with identified leading pions and kaons allows an extraction of the spin contributions from the different quark and anti-quark (sea) flavors. The results of the analysis(ref-HERMES-dq) of the HERMES data are shown in Fig. 3.2.

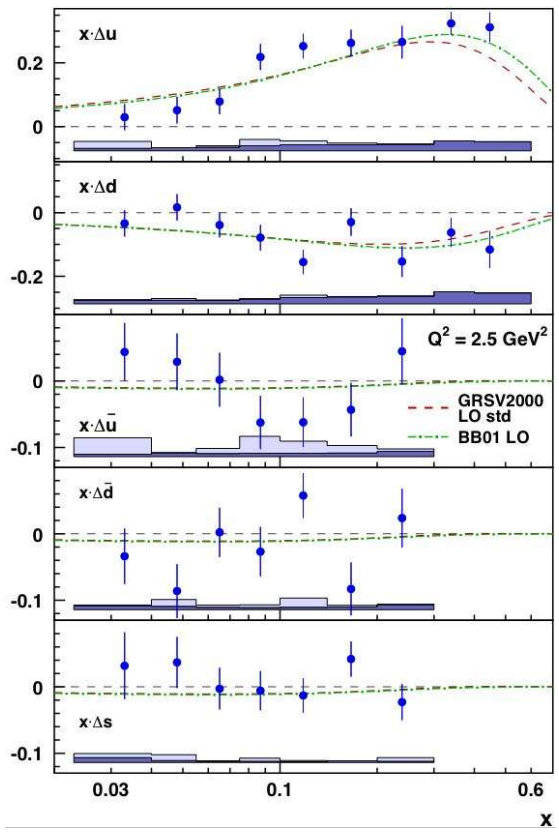

Figure 3.2 Results of HERMES spin-flavor decomposition using a leading order analysis of semi-inclusive deep-inelastic electron scattering. Taken from Ref. (HERMES-dq)

To date, this extraction has only been performed within a leading order (LO) QCD "framework", that is, with the effects of the Q^2 evolution only minimally included and no attempt at inclusion of higher twist effects. The limited statistical accuracy of the data allows no strong conclusions about the polarization of the sea quarks. Several theoretical programs(refs-NLO-SIDIS) to extend the semi-inclusive analysis procedure to next-to-leading order (NLO) are underway, but progress has been slow. A chief concern with the HERMES analysis is the relatively low Q^2 (average about 2.5 GeV^2) of the data, which may result in large NLO corrections. The forthcoming analysis from COMPASS will certainly use a data sample with significantly higher Q^2 which will likely have smaller NLO corrections. Furthermore, it will extend the determination to almost an order of magnitude smaller x value than HERMES. Because COMPASS only will use a polarized deuterium target, some additional assumptions about the proton and neutron parton distributions will be required (Ref DIS04). Nonetheless, the HERA collider experiments have

shown just how strongly coupled the resolution of the sea distributions are to the Q^2 of the probe, so it remains important to measure the spin-flavor composition of the nucleon up to the highest Q^2 possible.

Despite these efforts with lepton scattering, a common systematic uncertainty to both experiments' analyses is the hadron-tagging technique itself, which relies on the use of fragmentation function models which in some cases (e.g., s quark fragmentation to kaons) are not well known due to a general lack of data, especially at lower energies. While there is hope that new (and voluminous) data from the Belle experiment (ref. Belle) will significantly improve this situation, there will remain issues related to possible differences in how the fragmentation process occurs starting from the initial quark-antiquark pair of e+e- colliders and the process starting from a quark struck from a nucleon. Furthermore, both COMPASS and HERMES suffer from the "u-quark dominance" caused by the weighting of the fundamental photon-quark interaction by the square of the quark charge as well as the intrinsic inability of electromagnetic probes to distinguish quarks and antiquarks. Hence it will remain difficult to extract precise information about the up, down and strange sea quark (and anti-quark) polarized distributions. Since the weak interaction lacks this bias, intense high energy neutrino beams would be ideal for this type of semi-inclusive analysis.

Determination of Sea and Valence Polarized Quark Distributions using W Boson Production

The collision of high-energy polarized protons at RHIC provide a completely new means to use the weak interaction as a probe of the polarized parton distributions, namely $W^{\pm}$ production, leading to a very high energy muon or electron, of the same charge as the W and with an energy of roughly half the W mass, as shown in Fig 3.3. This measurement and estimates of the sensitivity are described thoroughly in Refs. 1, 2, and 3, so we here recall the major points (more here?).

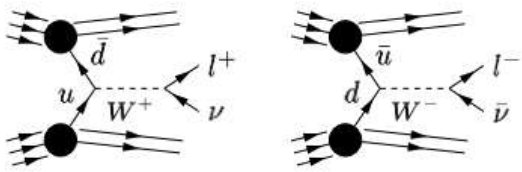

Figure 3.3 $W^{\pm}$ production in polarized pp scattering.

This reaction mechanism offers a number of advantages over deep-inelastic scattering: there are no systematic uncertainties from fragmentation models, there is no u-quark dominance arising from the intrinsic vertex coupling strength, the parity violating nature of the weak interaction provides a natural polarization measurement so that only a single spin asymmetry is required, and the Q^2 of the measurement is very high, essentially at the mass squared of the W boson. Because the neutrino is not detected, one actually measures the single spin asymmetry in the production of the charged lepton as a function of rapidity and p_T, and then via relates these asymmetries to those of the parent W bosons. Calculations of these asymmetries, including the effects of NLO QCD and resummation, have been performed by Nadolsky and Yuan (Ref. 3). Figure 3.4 shows the results at forward rapidity in the PHENIX acceptance

(More here on kinematics, explanation of Fig 3.4)

Since the instantaneous rate of observed W decay leptons is not high, it is critical that the muon trigger have both high efficiency and discrimination. Specifically, it should be sensitive to the higher average momenta of the W decay muons and insensitive to muons resulting from hadron decay, especially from hard jets.

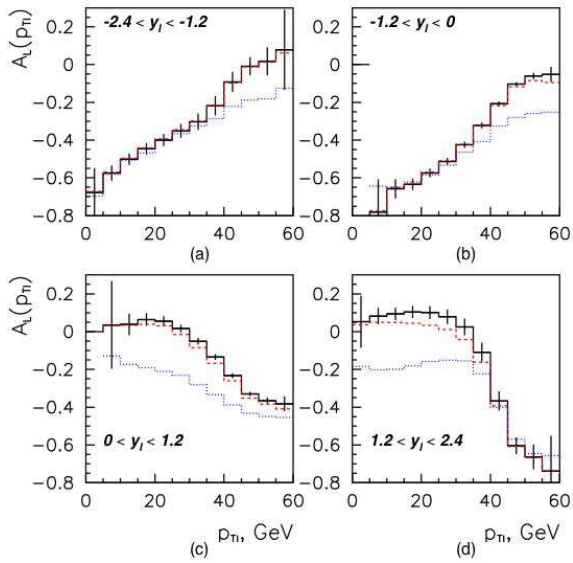

Figure 3.4 Expected single spin asymmetries for leptons from W production as a function of p_T for different regions in rapidity.

(0.5 pages, Hill, description on numbers of people using the facility)

A large number of people will be involved in the development of the fast trigger system for the forward detector upgrade. This includes persons in addition to those from the four universities submitting the proposal. The total includes __ senior personnel, ___ postdoctoral fellows, ___ graduate students and ___ undergraduate students. Many of these people will then use this system for research and training for students. Once the system is built and in operation it will be used by the whole PHENIX detector collaboration for a number of different experiments. PHENIX is a large collaboration of over 400 scientists and students. The exact numbers are continually in flux but representative numbers of people using the facility are ___ senior personnel, ___ postdoctoral fellows, ___ graduate students and ___ undergraduate students.

3. b) Description of the Research Instrumentations and Needs
(6 pages, Matthias, referee Kinney, O'Brien)

3.c) Impact of Infrastructure Projects (2 pages)

This should be divided into 2 parts as explained below:

Impact on nation's academic research infrastructure. We should discuss relevance to PHENIX, RHIC, DOE, NSAC etc. This is asked by NSF to be here and we need to say something, Suggestion:

(1 page, Barish, referee Seto, I think we agreed on this Friday)

How students involved and education enhanced. Also we have no private sector partners.

(1 page, Celia, referee Hill,

3.d) Management Plan (3 pages, Seto, Hill referee)

(The material below contains elements of management plan 3d and budget and funding 6. I leave it all together now but will work on separation soon.)

The overall responsibility of the experiment is PHENIX management, led by the spokesperson of PHENIX, Zajc together with the project manager Edward Obrien, and upgrades manager Axel Drees. Mathias Grosse Perdekamp of UIUC, one of the deputy spokepersons of PHENIX has the responsibility of coordinating the muon trigger upgrade. The detailed design of the detector has been led by Perdekamp and Wei(of RBRC) who is in charge of simulations. The hardware design and construction phase has three essential components.

First are the RPC detectors themselves which will be the responsibility of UIUC, PKU, and RBRC will be under the coordination of Perdekamp of UIUC and Mao of PKU. PKU brings a great deal of expertise on the construction of RPC's having constructed detectors for the CMS detector at CERN. A small prototype has been completed and is now undergoing testing at PKU. It will be shipped to BNL to be in the beam by February. We plan to construct a full scale module (?x? in size) for testing next year. Full production which will take place at PKU will begin in late 2006 for installation in the third quarter of 2007.

The second major component is the electronics which will be coordinated by Kinney of the University of Colorado and Barish of the University of California, Riverside. Since there is a low level granularity set of readout electronics for triggering, and high granularity electronics for tracking, Colorado will take primary charge of low granularity readout and UCR will take primary charge of the higher granularity readout. As mentioned previously in the description of the electronics, it is possible to use electronics used in other parts of PHENIX, thereby significantly reducing design costs and time (EDIA). There is a great deal of expertise in the collaboration for both the Read Out Cards for the muon ID system which will be used as the low granularity readout (ORNL- Vince Cianciolo) and Pad chamber electronics (LUND – Sivermeyer and Oskarsson, one of the primary designers of the system). A prototype readout system is now being developed which will be used in the full scale prototype to be testing in 2006

The final component is the LVL-1 triggering system which takes the signals from the low granularlity electronics and forms the trigger. This will be coordinated by John Lajoie of ISU. ISU has been responsible for the PHENIX level -1 trigger for all of the PHENIX detector and are well suited for this project.

Electrical engineering support will come from ISU, ORNL, Nevis, and BNL . BNL, PKU and UIUC will provide mechanical engineering. BNL operations will be responsible for the integration of the detector into the PHENIX experiment. Before the final construction phase – PHENIX management will convene a

TAC (Technical Advisory Committee) of outside reviews to review the design.

Detail design and construction phases.

x Technical expertise needed each activity.

x Risks and how confront.

x Staff organization and performance evaluation.

x Team responsibilities and rationale various positions.

Stuff from matthias

(I) rough layout:

RPC I (upstream of muTr, replacing one muTr module)

RPC II (downstream of muTr)

RPC III (gap 5)

upgrade muTr station II FEE for input into trigger.

technology choice: 2 gap RPC from CMS/PKU
with modified chathode strips.
Each RPC has two cathods one
with square pads and a second with
phi pads.

readout: square pads --> modified muID ROCs
phi pads high
granularity --> pad chamber FEE
phi pads low
granularity --> modified muID ROCs

(II) Channel counts

RPC I RPC II RPC III

acceptance	full	full	3x3m2
# of square pads	800 (4x4cm2)	400	90
# of phi-l pads	720	720	0
# of phi-h pads	8640	8640	0

total #/arm for uiD ROCs 2730
for pad chamber 17280

total # of LL1 2 (1 square pads, 1 phi-l)

(III) phi-cathode carry pre-amps + logic to configure
low granularity phi pads

(IV) Possible projects

a) 4 LL1 + 0.5 years of engineering $40k + $60k = $100k
b) 5460 channels of muID ROCs + 0.5 eng. $290k + $120k = $410k
c) 34560 channels of pad chamber + 0.5 eng.$350k + $120k = $470k
d) cathodes $400k + $120k = $520k
e) RPC hardware $250k = $250k
f) gas system $50k 50k
g) HV $100k $100k
h) mechanical integration (labor: PHENIX) $300k $300k

$1950k

Responsibilities

Iowa State University (Local-Level 1)

Hardware for 4 LL1	$ 40K	
0.5 years of engineering	$ 60K	
Iowa TOTAL		$100K

University of Colorado (low granularity trigger readout)

0.5 year at engineer			$120K
parts		$170K	
board		$60K	
board assembly (SMD)		$60K	
Colorado TOTAL		$410K	

UC Riverside (High granularity RPC readout for offline)

0.5 year of engineer			$120K
Parts			$200K
Boards Manufacturing		$80K	
Assembly		$70K	
UCR TOTAL		$470K	

PKU + UIUC + RBRC (cathodes for RPC's)

Parts		$400K	
Boards / Mechanics	$120K		
RPC hardware		$250K	
TOTAL (UIUC+PKU+RBRC)	$770K		

RBRC (gas system)

parts			$50k
labor à DOE operations			

ACU (High Voltage)

CAEN			$100k

BNL (as host lab, not a cost to NSF grant)

mechanical integration		$300k	

TOTAL for NSF Proposal		**$1,900K**	
TOTAL for project		**$2,200K**	

Project schedules (tasks, and costs).

Construction parts and costs.

Timelines and deliveries.

Fig. 7. An estimated project timeline assuming funding beginning in the ???

Costs

(IV) Possible projects

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Iowa State University (Local-Level 1)

Fiber optics systems:	$25,000.
FPGA chips:	$60,000.
Fabrication of circuit boards:	$15,000.
Engineering design labor:	$70,000.
Total project cost:	$170.000.

Budget Explanation

Need 20 fiber optic links at $250/link for one circuit board for a total of $5,000/board.

Need 6 FPGA chips at $2,000/chip for a total of $12,000/board.

Cost for fabrication of boards commercially at $3,000/board.

Total cost per board is $20,000.

Total cost for 5 boards is $100,000.

Engineering design labor for 1000 hours at $70/hour at the Electronics Design Center in the ISU Department of Physics and Astronomy is a total of $70,000.

Hardware for 4 LL1	$ 40K
0.5 years of engineering	$ 60K

Iowa TOTAL			$100K
University of Colorado (low granularity trigger readout)			
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ACU (High Voltage)			
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How make instrument design available others and possible commercialization.

Notes:

Management Plan (3 pages for instrument development)

Detail design and construction phases.
Technical expertise needed each activity.
Risks and how confront.
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ISU revised budget

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h)	mechanical integration (labor: PHENIX)	$300k $300k
		$1950k

4. References Cited

(Hill will organize results from individual writers)
(Use GPG guidelines for references)

5. Biographical Sketches

(limit 2 pages per person)
(Hill will gather, sent out sample (Matthias) and sample on web)
(Are there others that should be included??)

Biographies needed:

RBRC:	Xie
Beijing:	Mao
Kyoto:	Saito
ACU:	Towell
Iowa State:	Hill, Lajoie
Riverside:	Seto, Barish
Colorado:	Kinney, Nagle
Illinois:	Matthias, Peng, Makins

6. Budget and Funding

(This consists of 2 parts, budget and budget explanation)

Budget (1 page, Celia, Matthias, referees Seto, Hill)

(This is limited to one page using a standard NSF format)

(Some of this in 3d and I will work on separation soon)

Budget Explanation (3 pages maximum for whole proposal)
(referees Seto, Hill)
(Some of this in 3d and I will work on separation soon)

Each institution needs to write a justification for their part of the budget. I suggest the following writers agreed upon Friday:

UCIC + Integration:	Matthias
UCR:	Seto
Colorado:	Kinney
Iowa State:	Hill
Abilene C. U.:	Towell

7. Current and Pending Support.

(All who submit biographical sketch must submit this if have support. See section 5 to see if you need to do this. Not clear if non-U.S. Collaborators included here.)

(Hill sent out example earlier using himself as example. This can be combined for one grant, ex. (Hill & Lajoie)).

8. Facilities, Equipment and Other Resources.

(This section is not required for MRI proposals.)

(We decided to include something here. Matthias will send Hill a list of things to be included and Hill will write this section)

9. Supplementary Documents.

(Statement to classify submitting organization, UIUC. UIUC is "Ph.D. granting organization".)

(List all partners and subawardees. Hill can write this once the situation is clear.)

Here is where you can attach supporting documents. I suggest that the following documents may be needed. Please indicate any other documents that are needed:

1. Document from Iowa State.
2. Document from Colorado.
3. Document from Riverside.
4. Document from Beijing.
5. Document from Kyoto?
6. Document from Nevis?

10. List of Suggested Reviewers (optional)

(We decided on Friday to make a list for this.)