PHENIX Beam Use Proposal for RHIC Run-3 and Beyond

The PHENIX Collaboration

16-Aug-02

Executive Summary

The PHENIX Run-3 request is predicated on a multi-year strategy of discovery and consolidation, emphasizing the pursuit of rare probes and hard processes in both nucleus-nucleus and proton-nucleus collisions, together with fundamental measurements using polarized protons.

The PHENIX Collaboration request for RHIC Run-3 is

- 10 weeks of physics running with high intensity d-Au collisions at $\sqrt{s_{NN}} = 200$ GeV.
- 3 weeks of physics running with polarized protons at $\sqrt{s} = 200$ GeV and polarization P$\geq$ 40%.
- Up to one week of dedicated machine studies in preparation for Run-4.

The Run-3 request is made under the assumption of a Run-4 consisting of

- 11 weeks of physics running with high intensity Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV.
- 3 weeks of physics running with polarized protons at $\sqrt{s} = 200$ GeV and polarization P$\geq$ 40%.

Completion of this program will provide an extensive characterization of nuclear collisions in the RHIC energy regime, an initial measurement of ΔG in various production channels, and a set of control measurements in p-p and d-Au collisions against which new phenomena in Au-Au collisions may be measured. We would then envision a Run-5 request with lighter species to continue the systematic exploration of nuclear collisions at $\sqrt{s_{NN}} = 200$ GeV, along with additional spin running to explore further the spin structure of the proton.

1 Introduction and Assumptions

The PHENIX goals for future RHIC running remain unchanged from those described in our previous submissions to the Program Advisory Committee[1, 2, 3, 4]. Briefly stated, PHENIX has consistently requested Au-Au collisions at the highest possible energy, polarized proton collisions, and proton or deuteron collisions on Au all at the same per nucleon energy, with integrated luminosities sufficient to measure systematic trends in the production of J/Ψ . The production cross section for charmonium is sufficiently small that such integrated luminosities also provide for observation of single particle hadron yields to very high transverse momenta, thereby permitting study of both hard and soft phenomena in the RHIC environment.

1.1 PHENIX Status

The Run-1 data set of $\sim 1\ \mu\text{b}^{-1}$ Au-Au at $\sqrt{s_{NN}} = 130$ GeV was obtained with a partially instrumented subset of the PHENIX Central Arms, as shown in Figure 1. In Run-2, $\sim 24\ \mu\text{b}^{-1}$ of Au-Au at $\sqrt{s_{NN}} = 200$ GeV and $\sim 130\ \text{nb}^{-1}$ of polarized proton data at 200 GeV were recorded. The detector configuration, data acquisition and triggers were significantly upgraded in Run-2. All central arm detectors were read out, and the South Muon Arm was installed (Figure 2). The published results from Run-1 Au-Au collisions[5]-[14] and the preliminary results from Run-2 Au-Au collisions and proton-proton collisions at 200 GeV[15] clearly demonstrate that PHENIX has the capability to make high quality measurements in both hadronic and leptonic channels, thereby probing the complete range of timescales in the collision. Beginning with RHIC Run-3, the entire PHENIX detector will be available. The improvements from the Run-2 configuration include additional readout planes for the Time Expansion Chamber (TEC) along with its upgrade to transition radiation detector, the installation of the North Muon Arm, the installation of calorimeters to measure the number of “gray” protons, and corresponding improvements in data acquisition and triggering.

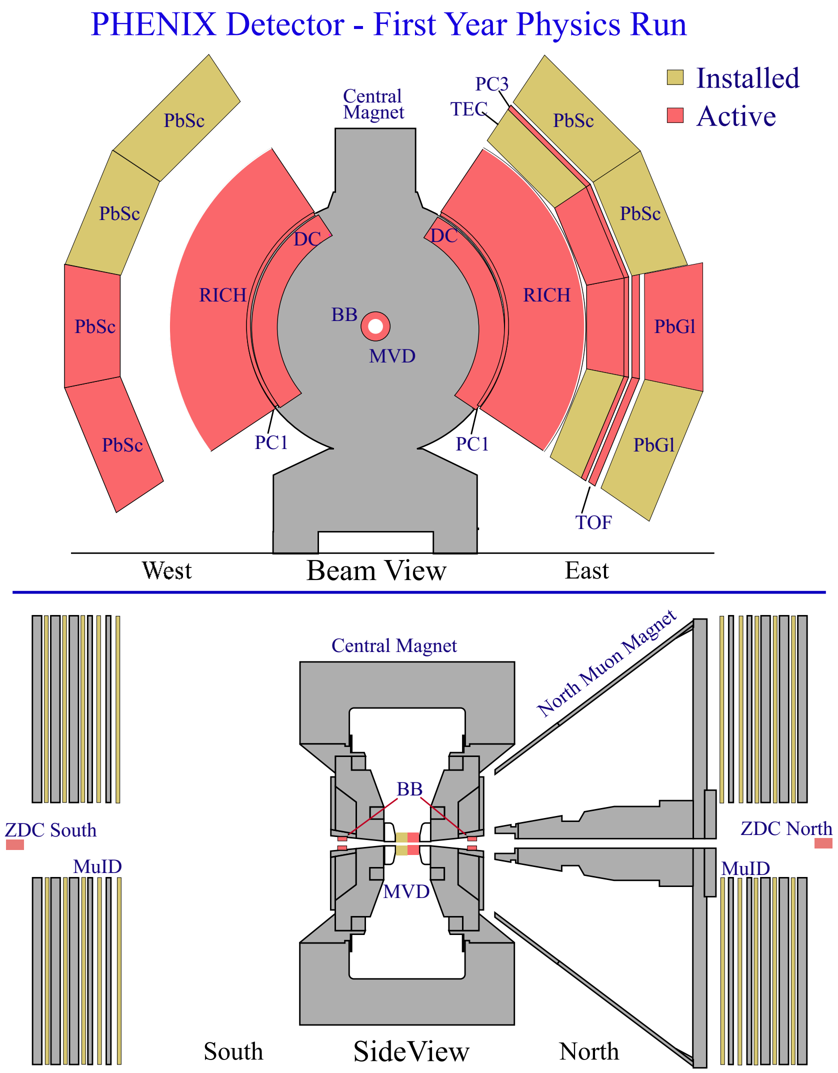

Figure 1: Installed and active detectors for the RHIC Run-1 configuration of the PHENIX experiment.

1.2 Run Assumptions

The PHENIX request is based on the planning document[16] provided by the Collider-Accelerator Department that explicitly accounts for setup (2 weeks) and commissioning time (3 weeks) for each mode of RHIC operation. Projected integrated luminosities are then based on previous experience where applicable (Au-Au and p-p), and extrapolation in the case of d-Au. The relevant results are the anticipated delivered luminosity per week:

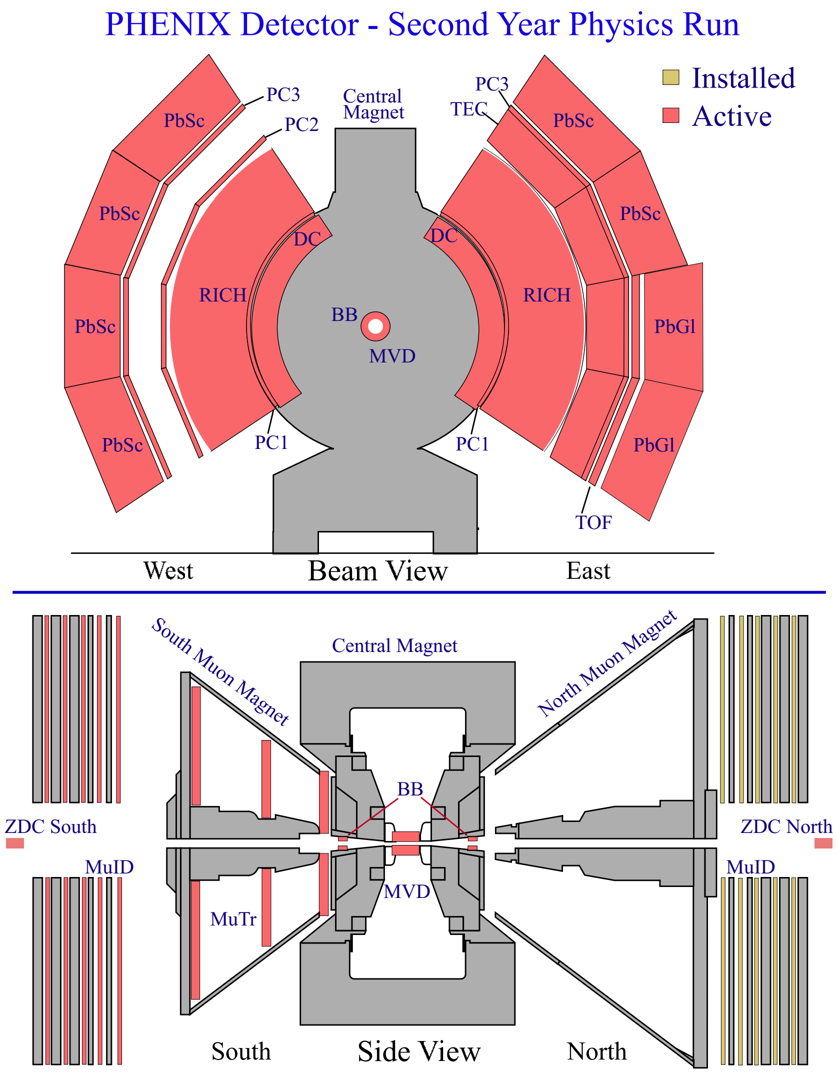

Figure 2: RHIC Run-2 configuration of the PHENIX experiment.

p-p: (0.3-2.8) pb^{-1} /wk
d-Au: 4 nb^{-1} /wk [scaled value: 1.6 pb^{-1} /wk]
Au-Au: (24-70) μb^{-1} /wk [scaled value: (1.1-2.8) pb^{-1} /wk]

For p-p and Au-Au, a range of values is provided, with the lower value corresponding to the “Minimum expectation” based on Run-2 experience, and the upper value (“Maximum expectation”) based on optimistic extrapola-

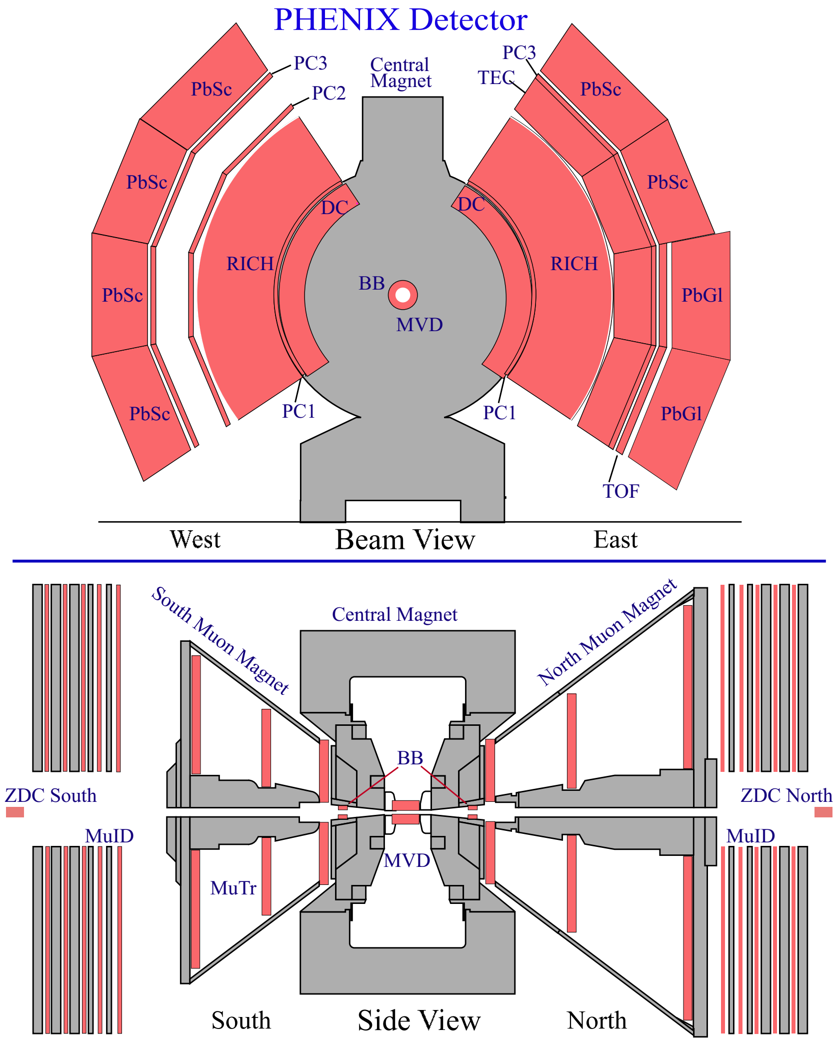

Figure 3: RHIC Run-3 configuration of the PHENIX experiment.

tions beyond the Run-2 values. It is important to note that the rates quoted for d-Au must necessarily be categorized as "Maximum expectations", since there is no previous experience with deuterons in the AGS or RHIC. The "scaled value" quantity in square brackets for the d-Au and Au-Au is the p-p luminosity required to deliver the same parton-parton flux (assuming no shadowing or other nuclear effects, i.e., a simple scaling going as $A \cdot B$ for the two species). This indicates that the anticipated per week yield of hard processes (absent suppression or enhancement effects) is roughly independent of the colliding species.

2 Run Request and Supporting Details

The model provided by C-A D imposes a significant (but realistic) 'penalty' of 5 weeks for the setup and commissioning of each mode. The implications of this, together with the following considerations, have shaped our request for Run-3 and the following years:

- The need for stable operations, development of triggers, and the exciting physics provided by rare probes argues against running three modes in any given RHIC year.
- The necessary restriction of two modes per RHIC run, combined with the many intriguing directions of investigation, argues strongly for a multi-year strategy.
- The need from the spin program for factors of 10^{3-4} improvement in $\mathcal{P}^2\mathcal{L}$ and/or $\mathcal{P}^4\mathcal{L}$, along with the necessity of developing rare triggers and precision polarimetry, argues for one mode per RHIC run dedicated to polarized proton running.
- The striking pattern of suppression of high p_T particle production, now extending to the highest measured transverse momenta, is very intriguing. To establish that this effect is truly unique to the nucleus-nucleus environment requires a control measurement in d-Au collisions.

The PHENIX request that emerges from these considerations is:

- **Run-3:**
  - Cool-down: 4 weeks
  - d-Au at $\sqrt{s_{NN}} = 200$ GeV (See Note #1 below)
    - Set-up: 2 weeks
    - Ramp-up: 3 weeks
    - Background studies: 1 week (See Note #2 below)
    - Data-taking: 10 weeks

  - p-p (polarized) at $\sqrt{s} = 200$ GeV
    - Set-up: 2 weeks
    - Ramp-up: 3 weeks
    - Data-taking: 3 weeks
  - Warm-up: 1 week

- **Run-4:**
  - Cool-down: 2 weeks (See Note #3 below)
  - Au-Au at $\sqrt{s_{NN}} = 200$ GeV
    - Set-up: 2 weeks
    - Ramp-up: 3 weeks
    - Data-taking: 12 weeks (See Note #4 below)
  - p-p (polarized) at $\sqrt{s} = 200$ GeV
    - Set-up: 2 weeks
    - Ramp-up: 3 weeks
    - Data-taking: 4 weeks (See Note #4 below)
  - Warm-up: 1 week

- **Run-5:**
  - At least one light species (e.g.,Si-Si) with sufficient integrated luminosity to obtain a J/Ψ data set suitable for comparison to the Run-4 results from Au-Au.
  - A period of dedicated spin running.

The following notes are of relevance to this plan:

1. We request that deuterons be injected into the Blue ring.
2. A dedicated period of one week is requested in Run-3 for background studies. Of particular concern are machine backgrounds that produce large rates in the Local Level 1 trigger for muons. Signficant progress was made in Run-2 in understanding such backgrounds both in Au-Au

and p-p collisions and in controlling them via shielding. Nonetheless, it is anticipated that additional investigations may be necessary both for efficient triggering in d-Au, and to allow time to mitigate against them for Au-Au running in Run-4. Our current understanding suggests that these backgrounds are beam-related rather than collision-related, so that the backgrounds in the South Muon Arm from Au ions in the Yellow ring will be indicative of those expected in Au-Au running in Run-4. However, to the extent that the optics in the Blue ring differs from that in the Yellow ring, we wish to allow for the possibility of time dedicated to such study with Au ions in the Blue ring as well. It would not be necessary to bring the beams into collision for such studies.

3. Note that in Run-4 we have assumed the same 29 weeks of RHIC operations, but have assumed that two additional weeks are available for physics, due to more efficient cool-down due to the newly commissioned LN_2 cooling system.

4. The precise partitioning between Au-Au and polarized proton running in Run-4 remains to be determined; the values provided above serve to indicate our desire for 'long' runs for both modes.

2.1 d-Au Physics

It has long been recognized that p-A collisions[1] serve an important role in the search for quark-gluon plasma (QGP) in relativistic heavy-ion collisions. While the QGP is in general not expected to be produced in p-A collisions, a comparison of the A-A with p-A data at identical kinematic conditions is nonetheless crucial for understanding potential modifications to signatures for QGP formation that are already present in the proton-nucleus environment. This was demonstrated in the AGS and SPS heavy-ion programs, which benefited greatly from the p-A measurements for interpreting the A-A results. This important role of p-A collisions is clearly valid at RHIC too.

In addition to their connection to A-A physics, p-A measurements are

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[1] In this discussion the generic label 'p-A' is used, where appropriate, rather than the specific 'd-Au' version.

important in their own right. Many outstanding questions in hadron physics can be well addressed with a p-A program at RHIC. It is important to note that RHIC provides unprecedented opportunities for exploring proton-nucleus collisions. The center-of-mass energy reached at RHIC in p-A collisions is roughly an order of magnitude higher than any existing fixed-target proton-nucleus experiments. Moreover, the large-acceptance collider detectors are capable of measuring many particles produced in the p-A collisions simultaneously, which could provide qualitatively new information not accessible in previous fixed-target experiments.

Thus, the data from d-Au collisions will both play an essential role for interpreting the Au-Au data and also provide unique information on the partonic structures in the nuclei and the propagation of partons in a cold nuclear medium. Some specific physics results which could be obtained by PHENIX in this initial d-Au run include:

- A study of parton energy-loss and jet quenching in cold nuclear matter via the measurement of high-p_T single hadrons.
- A measurement of J/Ψ production in the nucleus covering a wide kinematic regime including small Bjorken-x and negative x_F. As a result, nuclear shadowing of gluons at small x can be studied.
- A measurement of open-charm production and heavy-quark propagation in cold nucleus via the detection of high-p_T single leptons.
- A study of the correlation of various observables with the number of “grey tracks” detected with the forward-angle calorimeter.

In addition, an extensive list of physics topics at relatively low p_T such as $dN/d\eta$, $dE_T/d\eta$, elliptic flow, HBT, particle/antiparticle ratios, medium effects on Φ production, event-by-event fluctuation, etc., can be well studied in the proposed d-Au run.

It is also important to note that this initial d-Au commissioning and running is important for demonstrating the capability of colliding asymmetric species at RHIC as well as for collecting important first data on d-A. Futhermore, the d-Au run is also crucial for planning future runs to realize the full potential of a p-A program at RHIC.

2.1.1 Physics Justification

We briefly summarize some of the physics justifications for a d-Au run. The expected event rates for some measurements are also presented. These rates are calculated based the C-A D model [16] that the length of the data-taking period will be 10 weeks with an average luminosity of 4 $(\mathrm{nb})^{-1}$ per week. We also assume that 50% of the collisions survive the PHENIX interaction vertex cut, and an average up-time of 50% for PHENIX. These are conservative estimates. The trigger and reconstruction efficiencies of various events are also taken into account.

Jet Quenching

Recent results from PHENIX [12] showed a prominent suppression of high-p_T hadrons in central Au-Au collision at $\sqrt{s} = 130$ GeV. This striking result is consistent with a calculation performed by Wang and Wang [17] incorporating a large rate of energy loss for partons traversing a dense nuclear medium. These authors conclude that the initial gluon density in Au-Au collision at $\tau_0 = 0.2$ fm/c is ~ 15 times higher than that in a cold Au nucleus. Figure 4 shows the prediction of Wang and Wang on the nuclear modification factors of π^0 p_T spectra at $\sqrt{s_{NN}} = 200$ GeV for both d-Au and central Au-Au collision. With a ten-week d-Au run, a reach in p_T in excess of ∼15 GeV/c can be readily accomplished. These d-Au data will shed much light on the origins of the suppression of large p_T hadrons observed at RHIC energies.

J/Ψ Production

An important physics topics which can be studied with a d-Au run is J/Ψ production. A comparison of the J/Ψ production in p-p, d-Au, and Au-Au is crucial for studying possible evidence for quark-gluon plasma formation.

A calculation for J/Ψ cross section in p-p collision at $\sqrt{s} = 200$ GeV using

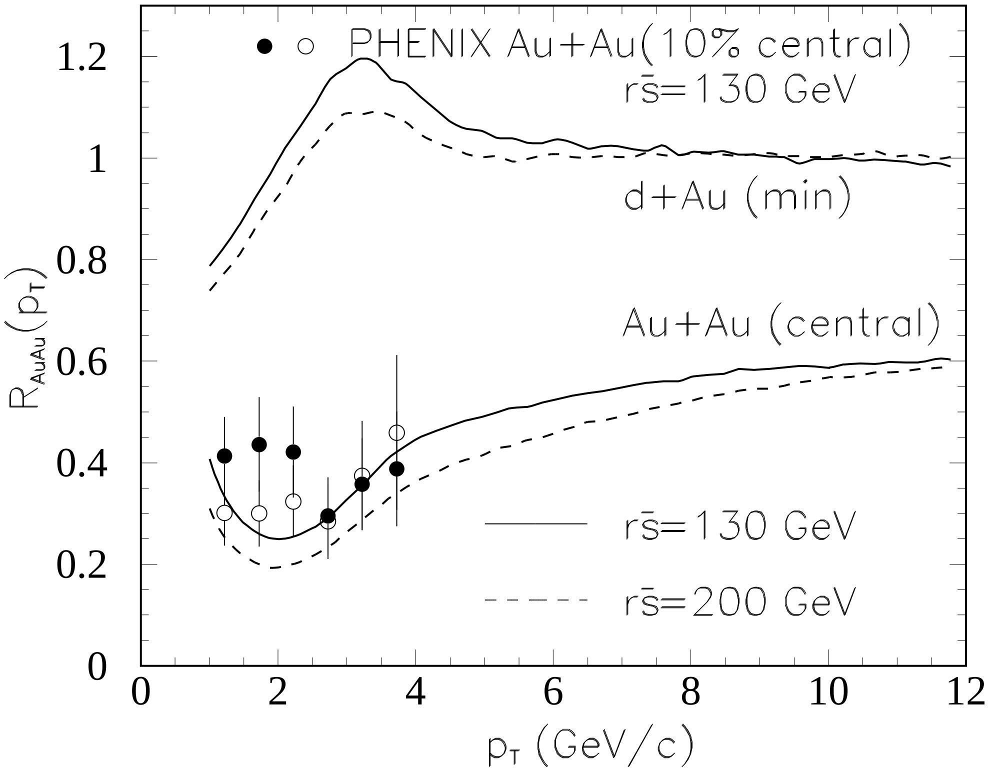

Figure 4: Prediction of nuclear modification factor of π° p_T spectra for d-Au and central Au-Au collisions at $\sqrt{s}$ = 130 and 200 GeV [17].

a color-evaporation model is shown in Figure 5. The preliminary PHENIX result [18] is also shown for comparison. The normalization factor is adjusted to fit the PHENIX preliminary data, giving a total p-p J/Ψ production cross section of 4.01 μb.

Figure 5 also shows the prediction of the J/Ψ cross section per binary collision in d-Au at $\sqrt{s_{NN}}$ = 200 GeV. The nuclear effect is calculated by using the parametrization of Eskola et al. [19] for nuclear shadowing of the quark and gluon distributions. It is interesting to note that the nuclear shadowing effect causes some asymmetry in the x_F distribution. The J/Ψ cross sections at positive x_F, corresponding to small x_2, are suppressed relative to

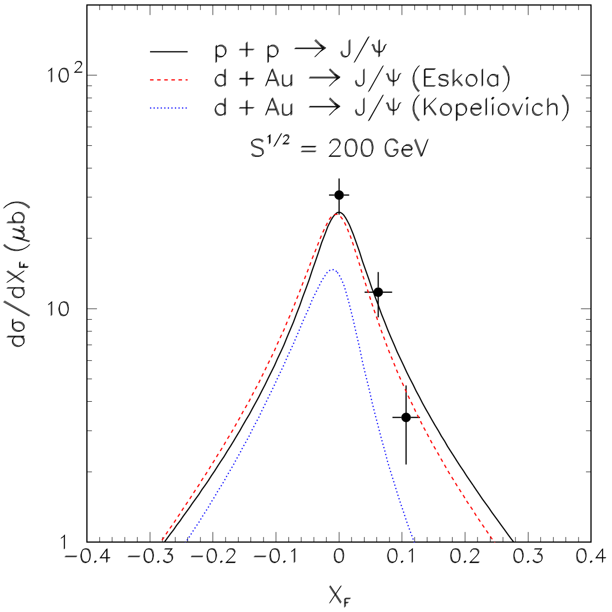

Figure 5: Comparison of the calculation of the color-evaporation model with the p-p preliminary PHENIX data at $\sqrt{s} = 200$ GeV [18]. The dashed curve is a calculation for d-Au using the parametrization of Eskola et al. [19] for quark and gluon shadowing in nuclei. The dotted curve is a prediction for d-Au using the nuclear J/Ψ suppression calculations by Kopeliovich et al. [20].

those at negative x_F. The J/Ψ cross section per binary collision is 3.91 μb (or a total d-Au J/Ψ cross section of 1540 μb).

Kopeliovich et al. recently predicted a strong nuclear shadowing effect for J/Ψ production in p-Au collision [20]. Assuming the same shadowing effect for d-Au collision, the predicted J/Ψ cross section is shown in Figure 5 as the dotted curve. A comparison of the dashed and dotted curves in Figure 5 clearly shows that the J/Ψ data from the d-Au collision can readily distinguish the shadowing model of Eskola et al. from the model of Kopeliovich et al.

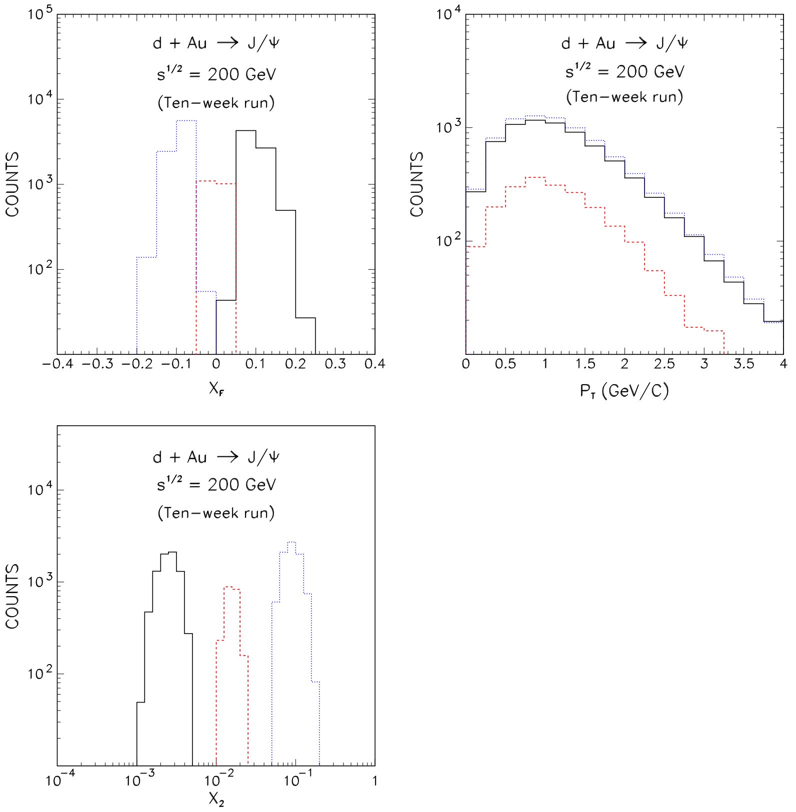

Figure 6: Expected event distributions for J/Ψ in a 10 week d-Au run at $\sqrt{s} = 200$ GeV. The solid, dashed, and dotted histograms correspond to the North muon arm, central arm, and South muon arm detection, respectively.

Simulation studies [21] indicate that the total number of $J/\Psi \rightarrow \mu^+\mu^-$ reconstructed events for the South and North Muon Arms will be 8200 and 7500, respectively. The total number of $J/\Psi \rightarrow e^+e^-$ events reconstructed in the central arm is roughly 2100. The event distributions as a function of x_F, p_T and x_2 are shown in Figure 6. The coverage in p_T and x_2 is quite broad, allowing a detailed study of the J/Ψ production as a function of these variables. It should be noted that it is precisely the need for such quality data in d-Au that determines the length of our request for this mode, since comparable statistics for J/Ψ observables are anticipated from the Run-4 Au-Au data set. By comparing the J/Ψ production cross sections of d-Au versus p-p, one can determine the nuclear-dependence parameter α as a function of x_F, p_T, and x_2. The nuclear dependence is parametrized as A^α. Figure 7 shows the expected statistical accuracy for α in the proposed d-Au run. We assume the corresponding p-p run has an integrated luminosity comparable to that of d-Au. Also shown in Figure 7 are the data obtained at the Fermilab fixed-target experiment E866 [22].

2.2 Tagging with Gray Tracks

The E910 experiment at the AGS showed that the centrality and the number of collisions in p-A interaction can be well characterized by the number of "gray" tracks emitted in a given event [23]. Many physics observables were found to correlate strongly with the multiplicity of the "gray" tracks. The detection of "gray" tracks will be performed using a forward-angle calorimeter being installed at PHENIX for the d-Au run. With a 10-week d-Au run, we expect to have sufficient statistics to measure many soft and some hard processes as a function of the number of "gray" tracks detected in the PHENIX forward-angle calorimeter. This will permit the same detailed analysis in terms of the number of participants and the number of binary collisions that has proven so useful in analyzing the Au-Au data from from the first two RHIC runs.

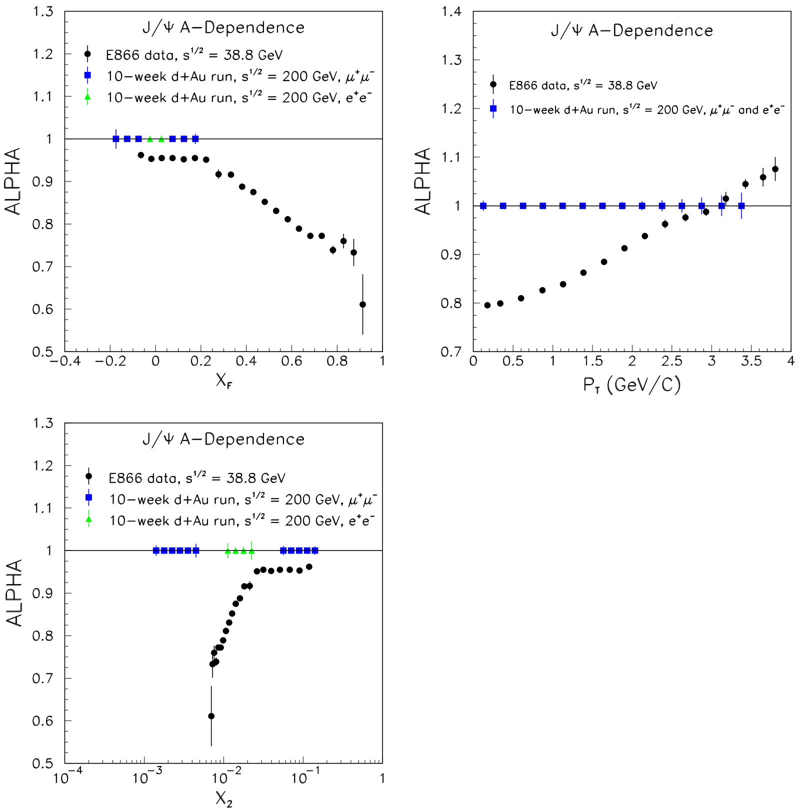

Figure 7: Expected statistical accuracy for measuring the nuclear dependence parameter α from a 10 week d-Au run at PHENIX. Data from a fixed-target experiment [22] at $\sqrt{s} = 38.8$ GeV are also shown.

2.3 $\vec{p}$-$\vec{p}$ Physics

The anticipated results described in this section assume an 8-week period of spin commissioning and running at $\sqrt{s} = 200\,\mathrm{GeV}$, which in the C-A D model corresponds to 3-weeks of production data. The assumed luminosity is $1\,\mathrm{pb}^{-1}$/week. Commissioning includes the newly installed spin rotators, which of course allow independent selection of the polarization at each IR. The results described here are for longitudinal polarization in PHENIX.

For a 3 week run with 40% polarization and $3\,\mathrm{pb}^{-1}$, PHENIX will make the first sensitive measurements of gluon polarization in the pion channels. This would represent a major contribution towards solving the proton spin puzzle, and allow PHENIX to provide results on this important issue competitive (indeed, considerably better than, but in a similar time frame) with the COMPASS experiment at CERN. The interpretation of the expected results in the framework of perturbative QCD is on solid grounds as recently confirmed by the good agreement between the PHENIX result on inclusive π° cross sections and next-to-leading-order QCD calculations by W. Vogelsang[24].

In addition, a successful 2003 commissioning and run is crucial to develop the PHENIX and RHIC spin program to reach full potential in 2005 and beyond. Many issues need to be successfully addressed. In RHIC, the issues on this learning curve include increasing luminosity 10-fold, bringing the spin rotators on-line, successfully locking the betatron tune on ramp and storage (which will also be used for heavy ions), spin-flipping the stored beam, and downramping the beam to calibrate the polarimeters at full energy. For PHENIX, the issues will be handling the factor of 10 increase in luminosity, successful spin-independent measures of relative luminosity by crossing, level 1 and 2 triggers at very high rate, *etc.* The 2004 luminosity is expected to increase an additional factor of 8, to reach design.

2.3.1 PHENIX 2002 Spin Run

The RHIC spin run in 2002 was very successful in all areas but two: 1) The polarization from the AGS was very low, which resulted in the decision to focus only on transverse spin for the run; 2) Attempts to downramp back to injection energy got only halfway. The commissioning otherwise was very successful: the Siberian Snakes were shown to work well up to 100 GeV, the polarimetry (by Kazu Kurita *et al.*) performed admirably, the spin flipper was demonstrated to work, beam lifetime was excellent, and the luminosity reached the predicted level. (The PHENIX Run-2 plan was based on significantly higher luminosity, but the RHIC plan/goal was subsequently changed from 4×10^{30} to 1.5×10^{30}. This revised luminosity goal was reached, but with a long interaction diamond. The PHENIX effective luminosity in 2002 was a factor 8 below our beam use proposal.)

The PHENIX level 1 triggers worked beautifully, and PHENIX obtained a data set on transverse polarization at midrapidity with sensitivity 10x better than previous polarized proton experiments, and at 10x higher energy, with p_T for π° reaching up to $\sim$12 GeV/c. There is considerable physics interest in this coming from recent work on transversity (the extent to which a transversely polarized proton carries transversely polarized quarks), prompted by the recent observation of large azimuthal asymmetries from the HERMES experiment at DESY and SMC at CERN. However, our plan to make the first measurements of gluon polarization using longitudinally polarized protons was not accomplished. This is the plan now being proposed for 2003.

2.3.2 PHENIX 2003 Spin Run

The expected performance in Run-3 is summarized in the Table 1. The peak luminosity is expected to increase by a factor of 10, and PHENIX will need to improve its rate handling capability accordingly. This includes completion of the Muon Level-1 trigger, the EMC-RICH trigger, GL1-P, and level-2 filtering. In addition, for tuning the spin rotators, we will be installing a ZDC-based local polarimeter. All will need to be in place and be commissioned for this run.

Item	2002 Run	2003 Run	Design 2004
Ions/bunch	$< 0.8\times10^{11}$	1.0×10^{11}	2.0×10^{11}
Number bunches	55	110	110
$\beta*$	3 m	1 m	1 m
Emittance (mm·mr)	25π	25π	15π
$\mathcal{L}_{\rm avg}$(wk)(RHIC)	0.2pb^{-1}	2.8pb^{-1}	$32\ \text{pb}^{-1}$
$\mathcal{L}_{\rm avg}$(wk)(PHENIX)	$.08\text{pb}^{-1}$	1pb^{-1}	
$\mathcal{L}_{\rm avg}$(store)	1×10^{30}	1×10^{31}	8×10^{31}
$\mathcal{L}_{\rm peak}$	1.5×10^{30}	1.6×10^{31}	
Polarization	$< 25\%$	$> 40\%$	$> 40\%$

Table 1: RHIC performance for polarized proton collisions in 2002 and expectation for future runs.

In 2004, a polarized jet target at the 12:00 interaction region is expected to provide absolute polarization to ±5%. For 2005 and beyond, we expect that a new strong snake in the AGS will improve the AGS polarization to 70%. (This will require a significant commissioning effort since the spin entering the AGS will need to be tilted from vertical, and the spin will also need to be rotated to vertical before injection into RHIC.)

2.3.3 Physics Case for 2003 Spin Run

Electron and muon experiments have shown that on average only about 25% of the proton spin is carried by the quarks and antiquarks in the proton. New facilities such as RHIC-PHENIX and STAR, E161 at SLAC, and the COMPASS experiment at CERN are focused on measuring the gluon contribution, which may be the missing part. If the gluon is highly polarized, it will produce clear asymmetries at PHENIX for high p_T pions, and for direct photon production. Heavy quark production should also be very sensitive to the gluon polarization. At RHIC, these probes are at first order. The COMPASS experiment, using muon probes, will indirectly observe gluons by looking at the production of pairs of “jets/pions” or open charm. These graphs are second order, and the experiment is done at fixed target energies where interpretation of the processes involved is not clear. Nevertheless, COMPASS has started taking data on these processes in July, 2002.

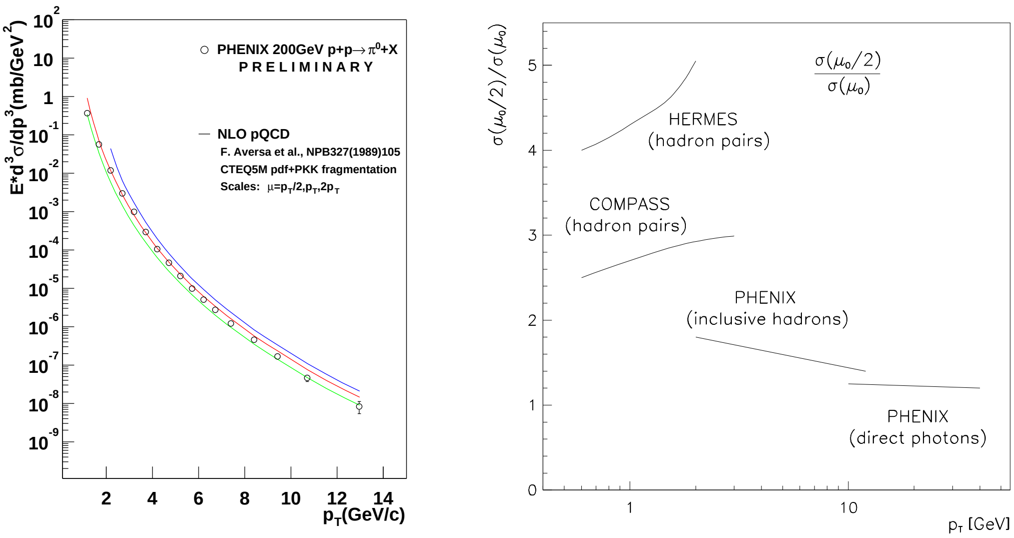

Figure 8: Left panel: PHENIX π° cross section from proton proton collisions in Run-2 overlaid with a NLO pQCD calculation. Right panel: Scale dependence (factorization and renormalization scale are chosen to be identical) of NLO pQCD calculations for different processes in accessing ΔG (Courtesy M. Stratmann and W. Vogelsang).

Uncertainties in the theoretical interpretation of results are exemplified in Figure 8. In the left panel, a perturbative QCD calculation from W. Vogelsang is compared with the PHENIX π° cross section which was obtained from the polarized proton data collected in Run-2. This calculation agrees with the data within 50% for $p_T > 2\,\mathrm{GeV}$. In the right panel of Figure 8, we compare the scale dependence of perturbative QCD calculations for hadron pair production at COMPASS (factor 2.5 to 3) to hadron production (factor 1.4 to 1.8) and direct photon production at PHENIX (factor 1.2). While the shown scale dependence in the absolute cross section is expected to largely cancel in the asymmetry, it is still desirable to build the theoretical interpretation of the results on good agreement between data and theory for both the spin averaged and the spin dependent cross sections.

The prompt photon channel is an extremely clear process to select gluon reactions (only 10% is expected to be from quark-antiquark annihilation), and is our golden channel for measuring the gluon polarization. However, the rate is low, and this channel is planned to be used to measure the gluon polarization for 2004 and beyond at high luminosity and beam polarization. It is a multi-year measurement even at high luminosity.

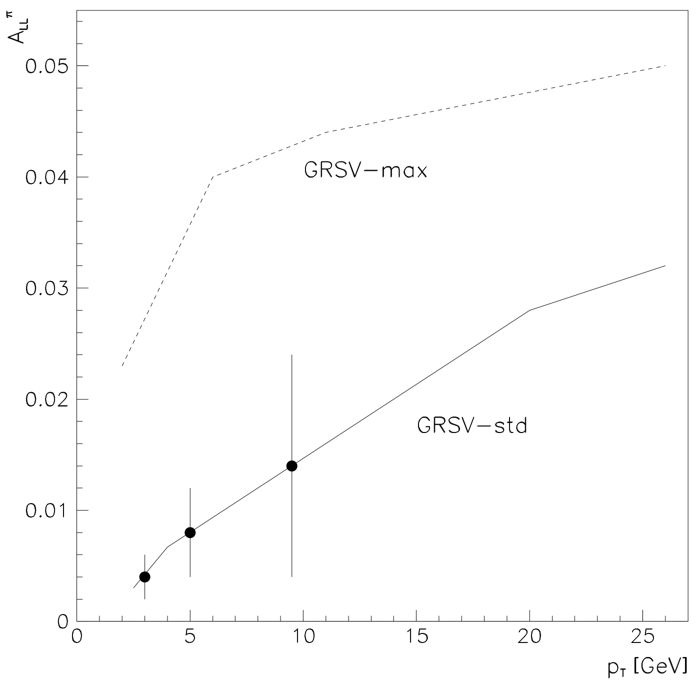

Figure 9: Projected sensitivities for longitudinal π° double spin asymmetries for a polarization of $P = 40\%$. The statistical errors correspond to an integrated luminosity of $\int \mathcal{L} dt = 3\,\mathrm{pb}^{-1}$ at $\sqrt{s} = 200\,\mathrm{GeV}$.

Pion production at accessible transverse momentum is very sensitive to gluon polarization through quark-gluon and gluon-gluon subprocesses, with these processes responsible for more than half the production of π°'s from $3 - 10\,\mathrm{GeV/c}$ p_T. Figure 9 is a calculation from W. Vogelsang in which we have scaled the error bar to the relevant luminosity and polarization values anticipated for Run-3. The figure shows the predicted asymmetries for π° production and compares the asymmetries and their errors with a range of possible values for the gluon polarization (allowed within the lepton measurements of quark polarization); there is a significant and measurable (in PHENIX 2003 running) difference. This figure is based on $3\,\mathrm{pb}^{-1}$ and 40% polarization.

An important cross check that we are really seeing gluon polarization is from a paper by Saito and Jaffe. If we do see an asymmetry for pions with longitudinal polarization, the asymmetry should be much less for transverse polarization where polarized gluons cannot contribute. We would only do this test if we see an asymmetry with longitudinal polarization, and would probably then do this in Run-4 for a short run with transverse polarization.

On model dependence of the pion measurements, Vogelsang and Stratmann have studied this issue for us by using a range of structure functions and fragmentation functions which fit the large body of unpolarized ep, e^+e^- and $p\bar{p}$ data, and find only small variation in the predictions for asymmetry.

To summarize: gluon polarization has been the focus of much speculation for solving the proton spin puzzle. PHENIX is in position to make a measurement with major impact. The measurement will also prepare both PHENIX and RHIC for the next order of magnitude on the learning curve to full luminosity and polarization.

2.3.4 Some comments on prospects for polarization and luminosity

The main difficulty for AGS polarization was the slow ramp rate from the back-up Westinghouse motor generator power supply. The Siemens is expected to be available by fall, and the spin resonances will be half the strength in Run-3 as compared to Run-2. This will significantly reduce the polarization losses in the AGS. A recent breakthrough in the polarized source, identification of molecular hydrogen background with 1.5 keV lower energy and reduction by a factor 5, have increased the source polarization from 70% to 80%. More improvement on the source performance is expected. A new CNI (RHIC-type) polarimeter is being prepared for the AGS which will make measurements in a minute instead of 1/2 hour for the pp polarimeter. This is expected to greatly improve diagnostics, for identification of problems, and for reliability. A polarization of $>40\%$ is likely.

To first order, polarization was changed little or not at all during the ramp and storage in RHIC. However, there were many cases of lost polarization. This is a commissioning issue: the betatron tunes must be kept close to design during ramp and storage, and the rings must be very flat vertically (to better than 1 mm). Also, the snakes must be set to be orthogonal. This is all in the plan: using tune lock (a.k.a. phased-lock loop or PLL), resurvey of the rings, studies using the spin flipper to set up the snakes. This requires commissioning time. Further, a major unique part of the PHENIX spin program is from parity violating W production at $\sqrt{s} = 500\,\mathrm{GeV}$. To reach this energy (the heavy ion rigidity), several large spin resonances need to be crossed during the ramp from 100 GeV and 250 GeV. This study is also planned.

On luminosity, the estimate of $2.8\,\mathrm{pb}^{-1}$/week is estimated from runs showing availability in the last 2 weeks of 40%. We have used $1\,\mathrm{pb}^{-1}$/week. The factor of 10 improvement from 2002 is from higher intensity (x1.5), more bunches (x2), and smaller $\beta*$ (x3). Improvement of the diamond length (fitting all the beam into the 5 ns bucket of 200 MHz) is expected for Run-3.

3 Physics from Run-4 and Run-5

In this section we provide *brief* comments on the physics expected in the runs following Run-3. The primary goal in the extended high luminosity Au-Au run is a detailed measurement of J/Ψ production systematics in Au-Au collisions at the highest RHIC energy, as described in previous presentations to the Program Advisory Committee[2, 3]. The expected increase over the

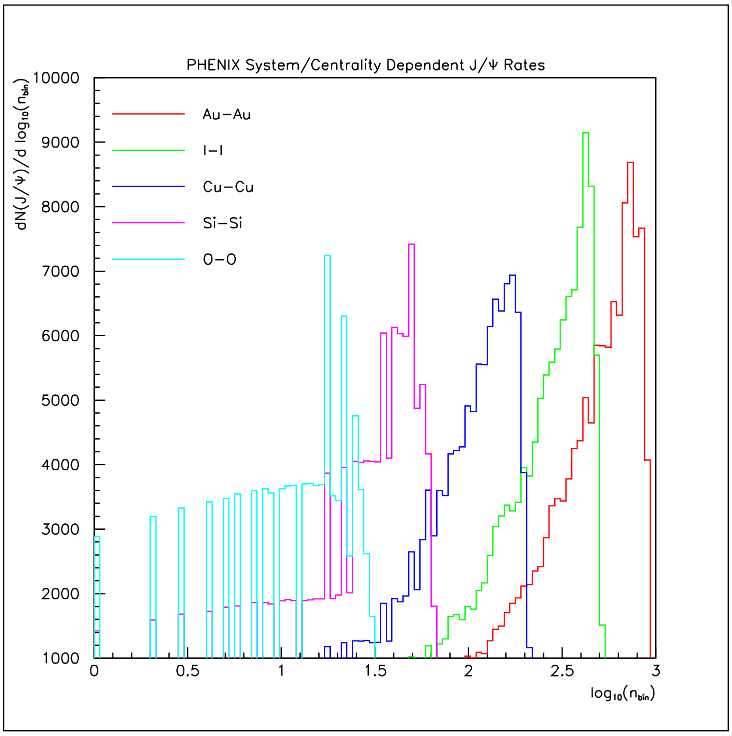

Figure 10: Relative yields in the number of binary collisions for various species in RHIC, based on a 6:1 ratio in running time between Au-Au and the lighter ions.

Run-2 results presented at QM02 will be 1.5 to 2 orders-of-magnitude, making it comparable to the J/Ψ yields from d-Au presented in Section 2.1.1. This large data set will also permit greatly increased statistical accuracy for the study of jet shapes and correlations, which may also extend to the very intriguing photon+jet channel.

The strategy for Run-5 calls for study of charmonium production in at least one light ion species at $\sqrt{s_{NN}} = 200$ GeV. Figure 10 shows the distribution in N_{Binary}, the number of binary nucleon-nucleon collisions, for various colliding species. The relative yields are based on a 6:1 ration between Au-Au and the other (lighter) species. This indicates that (at least in principle) lighter species provide the most effective way to reach truly low values in the number of binary collisions. While these expectations must be tempered by the learning curve required to introduce new species into RHIC, they indicate that once that setup time has been incurred, J/Ψ and other rare probes may be efficiently studied with moderate-length runs.

The PHENIX run plan also calls for continued development and measurements with polarized protons at 200 GeV. It is expected that these runs will allow PHENIX to both make a sensitive study of transversity and to begin measurement of ΔG with direct photons. These same runs will also provide superb comparison sets for the heavy ion program out to very high transverse momentum for both hadrons and direct photons.

References

[1] Initial PHENIX Run-1 request, 24-May-99, www.phenix.bnl.gov/phenix/WWW/publish/zajc/sp/presentations/rbup99/rbup99.htm

[2] PHENIX Run-1 presentation to PAC, 23-Mar-00, www.phenix.bnl.gov/phenix/WWW/publish/zajc/sp/presentations/rbup00/rbup00.htm

[3] PHENIX Run-2 presentation to PAC, www.phenix.bnl.gov/phenix/WWW/publish/zajc/sp/presentations/rbupnov00/RBUPNov00.htm

[4] PHENIX Run-2 proposal for extended running: www.phenix.bnl.gov/phenix/WWW/publish/zajc/sp/presentations/rbupsep01/RBUPSep01.htm

[5] K. Adcox *et al.* [PHENIX Collaboration], arXiv:nucl-ex/0207009.

[6] K. Adcox *et al.* [PHENIX Collaboration], arXiv:nucl-ex/0204007.

[7] K. Adcox *et al.* [PHENIX Collaboration], Phys. Rev. C **66**, 024901 (2002) [arXiv:nucl-ex/0203015].

[8] K. Adcox *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **89**, 082301 (2002) [arXiv:nucl-ex/0203014].

[9] K. Adcox *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **88**, 192303 (2002) [arXiv:nucl-ex/0202002].

[10] K. Adcox *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **88**, 192302 (2002) [arXiv:nucl-ex/0201008].

[11] K. Adcox *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **88**, 242301 (2002) [arXiv:nucl-ex/0112006].

[12] K. Adcox *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **88**, 022301 (2002) [arXiv:nucl-ex/0109003].

[13] K. Adcox *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **87**, 052301 (2001) [arXiv:nucl-ex/0104015].

[14] K. Adcox *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **86**, 3500 (2001) [arXiv:nucl-ex/0012008].

[15] Available from http://www.phenix.bnl.gov/conferences.html

[16] *"RHIC Run 3 (FY2003) Running Projections"*, T. Roser, June 28, 2002.

[17] E. Wang and X.-N. Wang, hep-ph/0202105.

[18] H. D. Sato and V. Cianciolo, PHENIX analysis note, July 10, 2002.

[19] K. J. Eskola, V. J. Kolhinen and P. V. Ruuskanen, Nucl. Phys. B535 (1998) 351.

[20] B. Kopeliovich, A. Tarasov and J. Hufner, Nucl. Phys. A696 (2001) 669.

[21] J.C. Peng, "J/Ψ Production for a d+Au Run at PHENIX", http://www.phenix.bnl.gov/WWW/publish/jcpeng/da/jpsi_10.ps,

[22] M. J. Leitch et al., Phys. Rev. Lett. 84 (2000) 3256.

[23] I. Chemakin et al., Phys. Rev. Lett. 85 (2000) 4868.

[24] W. Vogelsang, private communication.