PHENIX Beam Use Proposal Update
for RHIC Run-7 and Beyond
13-Mar-07

The PHENIX Collaboration

Abstract

A multi-year program to further elucidate the nature of nuclear matter at the highest temperatures and densities, and to increase our understanding of the spin structure of the proton was proposed in September 2006. The run plan presented in September remains the PHENIX plan, essentially unchanged. However, the number of weeks of running in FY07 is substantially less than foreseen. This document discusses the impact and updates our earlier proposal.

1 Introduction

The goals of the PHENIX Collaboration for future RHIC running have been clearly delineated in our previous Beam Use Proposals and presentations to the Program Advisory Committee. The deployment of new detector sub-systems significantly extends the physics reach of PHENIX, and opens new and important channels for detailed investigation. The baseline measurements in p+p collisions will result from the extended running requested in the polarized proton program, where improvements in luminosity and polarization will continue to provide advances beyond the current results. Both the heavy ion and polarized proton programs require the highest possible integrated luminosities (and polarizations in the case of p+p running) to explore fully the range of fundamental phenomena in nucleus+nucleus, "proton"+nucleus and proton+proton collisions at RHIC energies. The emphasis in Runs 7-10 is on achieving maximum physics sensitivity via an order-of-magnitude increase in integrated luminosity over current values.

Our previous request[1] laid out a plan for Au+Au, p+p and d+Au running over two years. Our goals remain unchanged. This document provides an update, in response to unforeseen budget issues curtailing RHIC running in 2007. These limit RHIC to a maximum of 12 weeks of 200 GeV/A Au+Au data taking in Run-7. Furthermore, the loss of time to run any other beams in Run-7 impacts the PHENIX Run-8 plans.

PHENIX has installed significant upgrades for Run-7: a new reaction plane detector, a time-of-flight detector in the west arm and a novel type of hadron blind detector. The north arm muon piston calorimeter was also installed, completing the construction of that detector system. As a result of these upgrades, our proposed program will provide the first definitive measurement of the low-mass dilepton spectrum at RHIC energies, will greatly extend our understanding of flow phenomena for rare probes, up to and including the J/ψ , and will continue our systematic attack on both single and double spin asymmetries in polarized proton collisions.

2 Status of the PHENIX Experiment

The PHENIX detector has evolved from a partial implementation of only the central arms in Run-1 to a completed installation of the baseline + AEE (Additional Experimental Equipment) systems for Run-3 to a significantly enhanced detector for Runs 4, 5 and 6. Crucial upgrades have been added for Run-7; additional strategic upgrades are planned.

Run	Year	Species	$\sqrt{s_{NN}}$ (GeV)	$\int L\,dt$	N_{Tot}	p+p Equivalent	Data Size
01	2000	Au+Au	130	1 μb^{-1}	10M	0.04 pb^{-1}	3 TB
02	2001/2002	Au+Au	200	24 μb^{-1}	170M	1.0 pb^{-1}	10 TB
		p+p	200	0.15 pb^{-1}	3.7G	0.15 pb^{-1}	20 TB
03	2002/2003	d+Au	200	2.74 nb^{-1}	5.5G	1.1 pb^{-1}	46 TB
		p+p	200	0.35 pb^{-1}	6.6G	0.35 pb^{-1}	35 TB
04	2004/2004	Au+Au	200	241 μb^{-1}	1.5G	10.0 pb^{-1}	270 TB
		Au+Au	62.4	9 μb^{-1}	58M	0.36 pb^{-1}	10 TB
		p+p	200	0.35 pb^{-1}	6.6G	0.35 pb^{-1}	35 TB
05	2004/2005	Cu+Cu	200	3 nb^{-1}	8.6G	11.9 pb^{-1}	173 TB
		Cu+Cu	62.4	0.19 nb^{-1}	0.4G	0.8 pb^{-1}	48 TB
		Cu+Cu	22.5	2.7 μb^{-1}	9M	0.01 pb^{-1}	1 TB
		p+p	200	3.8 pb^{-1}	85G	3.8 pb^{-1}	262 TB
06	2006	p+p	200	10.7 pb^{-1}	230G	10.7 pb^{-1}	310 TB
		p+p	62.4	0.1 pb^{-1}	28G	0.1 pb^{-1}	25 TB

Table 1: Summary of the PHENIX data sets acquired in RHIC Runs 1 though 6. All integrated luminosities listed are *recorded* values.

Table 1 summarizes the data collected in Runs 1-6. For each data-set the "*proton+proton equivalent*" "*recorded*" integrated luminosity is given by the corresponding column of the table. For an A+B collision the *proton+proton equivalent* integrated luminosity is given by

$$\int \mathcal{L}\, dt|_{p+pequivalent} \equiv A \cdot B \int \mathcal{L}\, dt|_{A+B} \quad ,$$

which corresponds to the integrated parton+parton luminosity, without taking into account any nuclear enhancement or suppression effects. The *recorded* integrated luminosity is the number of collisions actually examined by PHENIX, as distinguished from the larger value delivered by the RHIC accelerator. In the case of minimum bias data sets, "recorded" is strictly accurate, while for triggered data "sampled" more accurately describes the process. We use "recorded" as shorthand for either case to refer to the number of events examined by PHENIX for a given physics observable (the number of equivalent minimum bias events is also listed in Table 1). We note that ALL of these data, including Run-6, have already been reconstructed.

2.1 Upgrades in place for Run-7

The HBD is a proximity focused Cerenkov detector insensitive to the vast majority of charged hadrons created in the central rapidity region. Essentially all electrons from external and internal conversions are detected, allowing rejection of the majority of pairs that form the combinatoric background in analyses of low-mass e^+e^- pairs. Reduction of this background is of crucial importance in this sector in which the signal pairs are sensitive probes of thermal radiation, chiral symmetry restoration and medium modifications to hadron properties. The present result is severely limited by the low signal-to-background ratio. The HBD is designed to reduce the combinatorial background originating from Dalitz decays and photon conversions by a factor of ~ 100. Then the S/B will be dominated by combinatorial background originating from uncorrelated semi-leptonic decays of open charm; the ultimate improvement in the measured S/B should be a factor of ~ 20. The HBD was installed for Run-7, and is currently being commissioned. The novel readout technology, utilizing a stack of three GEM detectors with a CsI photocathode deposited on the top GEM, will be challenging to commission in the high multiplicity environment of Au+Au collisions.

In Run-6, the South Muon Piston Calorimeter (MPC) was installed; its North Arm counterpart was completed for Run-7. The MPC's provide high quality calorimetry in the region $3.1 < |\eta| <\sim 3.7$. This new coverage significantly enhances the forward physics program of PHENIX, particularly in p+p and d+Au collisions.

In the course of ongoing Run-4 and Run-5 analyses of the reaction-plane dependence of various rare probes, it became clear that the (lack of) reaction plane resolution was a major obstacle. PHENIX has therefore built a subsystem to measure the angular dependence of multiplicity in the pseudorapidity region $1 < |\eta| < 3$. The resulting RXNP detector, consisting of 48 scintillators with Pb converters, read out with wavelength-shifting fibers and phototubes into EmCal electronics, is now in place for Run-7. It will improve the PHENIX reaction plane resolution by a factor of two, providing comparable statistical precision with 1/4 the previously required integrated luminosity. The rapidity region spanned by the RXNP also makes it very attractive as a trigger counter during low-energy runs, where the reduced width of the pseudorapidity distribution creates inefficiencies for the current trigger based on the Beam-Beam Counters. The possibility of incorporating the RXNP into the Level-1 trigger is under active investigation.

The TOF-W is a highly segmented time-of-flight detector using multi-gap resistive plate chambers (MRPC's) and read out with a modification of PHENIX TOF electronics. In conjunction with the Aerogel-based Cerenkov detector already installed, it will provide complete π/K/p separation for p_T up to 10 GeV/c. Of particular interest will be particle identification in the region of the displaced peak observed in the away-side jets in Au+Au in Run-7.

We note that PHENIX's ability to archive Au+Au events has been increased by a factor of 3-5 from its already impressive capabilities demonstrated in Run-4.

2.2 Timing of Near-Term Upgrades

The structure of the PHENIX Beam Use Proposal is guided by the carefully structured, ongoing program of upgrades. In particular, the request is predicated on making all necessary measurements in Au+Au with the HBD in Runs 7, 8 and 9. Following that, the HBD will be removed from its data-taking position (along with the RXNP) in order to install the VTX detector, together with mechanical infrastructure to support the FVTX. Accordingly, we have requested Au+Au, d+Au and p+p collisions at 200 GeV in proportions designed to give roughly equivalent proton+proton luminosities, thereby assuring appropriate baseline and cold nuclear matter measurements for the HBD physics program.

3 Beam Use Proposal for Run-7 and Beyond

3.1 Planning Assumptions and Methodology

The Interim Associate Laboratory Directory for Nuclear and High Energy Physics requested short updates of the September 2006 Beam Use Proposals, in light of the budget uncertainty-driven late start of Run-7. We assume 12 weeks of *physics running* in Run-7, and 25 weeks per year in subsequent years. Given expectations for decreased start-up times, the ALD has advised that this should be feasible with 30 cryo weeks per year in the case of two-mode operation.

Detailed guidance provided by the Collider-Accelerator Department (C-A D) describes the projected year-by-year luminosities for various species, along with the expected time-development of luminosity in a given running period. This guidance remains the same as for September 2006. Perhaps the single most important piece of guidance from C-A D regarding luminosity development is their emphatic statement *"To reach the luminosities projected in the Research Plan for Spin Physics at RHIC[2] it is necessary to have a long polarized proton run in every year."* Our ambitious goals for spin observables have led PHENIX to request the annual opportunity to further develop luminosity and polarization. Run-8 is impacted by the lack of p+p running in Run-7.

The now rather extensive experience with operating RHIC in a variety of modes and in understanding luminosity limitations provides some confidence in the projected minimum luminosities, which are based on either actual experience or achieving the same charge per bunch as for Au beams. Maximum projected luminosities are based on current understanding of the accelerator limits. In past Beam Use Proposals, we have used the geometric mean of the minimum and maximum projected luminosities, except in those cases where we believe (based on documented C-AD performance) that this results in an overly conservative estimate. For this update, we are hampered in our planning for Run-8 and beyond by lack of knowledge of luminosity development impact from Run-7. We believe that assuming NO improvement from the Run-7 experience is overly conservative. However, banking upon a 1-2 week dedicated luminosity development period in Run-7 is excessively optimistic, given the likely total length of Run-7 cryo operations. Consequently for Run-8 we specify target integrated luminosities to achieve our physics goals. We estimate the time split between two beam species based upon the mean of the minimum and the maximum projected luminosities for d+Au. In this scenario, it will be possible to achieve our Run-8 physics goals if RHIC delivers a d+Au integrated luminosity 10% larger than the mean between the minimum and maximum projected luminosity. The p+p goal is attainable in Run-8 if the currently projected maximum delivered p+p luminosity and 65% polarization are delivered.

Delivered luminosities are converted to PHENIX-recorded luminosity assuming a PHENIX integrated live-time from all sources of 60%, and that 70% of the delivered luminosity will satisfy our vertex requirement of $|z| < 30$ cm.

3.2 Beam Use Proposal Summary

This proposal aims to maintain the program of discovery physics that has attracted worldwide attention to the RHIC heavy ion program, *while maintaining* the progress in both polarized proton performance and in the spin physics program. This is best accomplished by

- Continued enrichment of existing data sets that are statistically sparse in essential physics channels (which requires accumulation of data over multi-year periods)
- Continued development of luminosity and polarization to stay on schedule for deci-

sive measurements with polarized protons.

- **Completing** surveys by securing requisite baseline data in a timely fashion, so that comparison data sets are obtained with essentially the same detector configuration.

Table 2: The PHENIX Beam Use Proposal for Runs 7-10.

RUN	**SPECIES**	$\sqrt{s_{NN}}$ **(GeV)**	**PHYSICS WEEKS**	$\int \mathcal{L}dt$ **(recorded)**	**p+p Equivalent**
7	Au+Au	200	12	1.1 nb^{-1}	44 pb^{-1}
8	d+Au	200	10	58 nb^{-1}	23 pb^{-1}
	p+p	200	15	71 pb^{-1}	71 pb^{-1}
9	Au+Au	TBD	25-M		
	p+p	500	M		
10	heavy ion	200	25-N		
	p+p	500	N		

Table 2 summarizes the current PHENIX Beam Use Proposal. This plan is the same as our previous request[1], but the times requested are modified to take into account the following:

- Au+Au running at $\sqrt{s_{NN}} = 200$ GeV to significantly advance the statistical precision and physics reach of our existing Run-4 data set, given the limitation of a maximum of 12 weeks of Physics running in Run-7.
- Loss of polarized proton running originally requested for Run-7. We still need proton collisions with transverse (radial) polarization to perform a measurement of the gluon Sivers function, and sufficient integrated luminosity with longitudinal polarization to provide a sensitive measurement of the gluon polarization of the proton via 200 GeV p+p collisions. This measurement is required to meet a DOE Milestone in 2008.
- A d+Au run, taking advantage of significant advances in luminosity and data acquisition throughput to refine our knowledge of this essential baseline system by more than an order-of-magnitude in integrated luminosity.

The Run-4 data set for full energy Au+Au collisions resulted in critical new observations. However, over substantial regions of interest the statistical errors exceed the systematic errors. Correspondingly, the ability to address fundamental questions (e.g., does the flow extend to bottom quarks?) is limited by the statistical reach of the existing data sets; increased statistics will also help decrease a number of the systematic uncertainties. Crucial rare event physics that we have yet to address include the flow of J/ψ 's (perhaps a critical test of regeneration mechanisms), photon+jet measurements, direct photon flow (again, which may be a critical test for QGP-induced bremsstrahlung and/or conversion mechanisms) and 3-particle jet correlations. Consequently, an order of magnitude increase in integrated luminosity by adding together Run-7 and Run-9 data sets is proposed.

While there is great value to be derived from the multi-year planning process, we are also aware of the intrinsic limitations when such plans are confronted with ongoing discovery physics. Accordingly, we have left the energy for the Au+Au segment of Run-9 in Table 2 as "TBD" (To Be Determined). It is expected that some fraction of this running will be at lower energies, with the precise allocation depending on results from our analysis of the Run-7 data set and on C-A D progress in establishing collisions at low-energy. As always, the decision will be made by the standard PHENIX practice of discussion in the Executive Council, based on input from the Physics Working Groups.

The particular sequence of Au+Au in Run-7, d+Au in Run-8 and Au+Au in Run-9 is motivated by and coordinated with the program of upgrades. In particular, this three-year segment will provide robust data-sets in Au+Au, d+Au and p+p collisions for the low-mass dilepton physics made possible by the HBD. It is worth noting that upon completion of the 200 GeV polarized proton program, this plan will achieve comparable sensitivity in terms of the p+p equivalent integrated luminosity for Au+Au, d+Au and p+p collisions, thereby assuring adequate baseline data for the heavy ion program as well as achieving our goals for spin measurements at this energy.

3.3 Run-7

The geometric mean of the minimum and maximum C-AD guidance for Au+Au running at $\sqrt{s_{NN}} = 200$ GeV corresponds to 215 μb^{-1} per week of delivered luminosity. Allowing for a 4 week ramp to this value, 12 weeks of running corresponds to 2620 μb^{-1} delivered, and 950 μb^{-1} recorded. Our initial request was for 1100 μb^{-1} recorded, which represents approximately a factor of 4 increase over our Run-4 data set for this system. This number can be achieved, if the delivered luminosity exceeds the geometric mean of the minimum and maximum by approximately 15%. Failure to do so implies a longer period of running at full energy in Run-9. For discussion of representative measurements from this run, please refer to our previous Beam Use Proposal [1].

3.4 Run-8

In Run-8 we focus on d+Au and p+p running. As budget uncertainties shortened Run-7, we will need to make up for the missed p+p running, and have changed our requested time split accordingly. We propose 15 weeks of polarized p+p at 200 GeV; both longitudinal and transverse spin running are needed.

Quark transversity distribution functions remain the last unmeasured leading twist distribution functions in the nucleon. As they are chiral-odd they have not been measured in inclusive deep inelastic scattering experiments in the past. In p+p transversity can be accessed in combination with either the Collins- or the interference fragmentation functions. With transverse polarization in RHIC we aim to measure transversity distributions and the Sivers function in short but dedicated parts of the spin operations time. The cleanest channels for these two measurements are:

- A_T for interference fragmentation function
- A_N for back to back di-hadrons produced in p+p collisions

Determination of the polarized gluon distribution is of paramount importance to the RHIC spin program. The DOE milestone for this goal is 2008, and the operations schedule in the RHIC Spin Research Plan[2] are needed to accomplish this. PHENIX plans to do this measurement using two main physics channels: π^0 and direct photon production. Due to increasing statistical samples accumulated by other physics channels, we would have multiple handles on this determination of polarized gluon distribution. In the case of inclusive neutral pion asymmetries, the resolving power between the various polarized gluon scenarios is strongest in the low p_T region. However, this is also the kinematic region in which the partonic interaction for neutral pion production is mostly gluon-gluon scattering, and as such does not give a unequivocal handle on the sign of the polarized gluon distribution. There are several options, namely,

1. Measure neutral pion A_{LL} at $p_T > 6$ GeV/c, where the qg subprocess dominates, with good accuracy.
2. Measure charged pion double longitudinal asymmetry in this kinematic region, where the values of $A_{LL}^{\pi^\pm}$ are more or less than the other depending on the sign of the polarized gluon distribution. To achieve that we need significantly larger data samples than those achieved so far.

We have used the Collider-Accelerator Department guidance for luminosity[3]. Furthermore, we assume that the experience of operating RHIC in Run-7, potentially coupled with the C-A D request for beam development time, allows us to expect RHIC performance in Run-8 at or near the maximum predicted delivered luminosity per week. Consequently, we assume the following figures on luminosity and polarization:

- The estimate for the delivered (integrated) luminosity ranges from 70 pb^{-1} to 170 pb^{-1} for 15 weeks. We use 170 pb^{-1} in this proposal, consistent with the maximum estimate of 14 pb^{-1} per week.
- Applying the standard factors for data-taking efficiency and vertex cuts leads to 71 pb^{-1} recorded.
- The proposed breakdown is $\sim 25\%$ transverse and $\sim 75\%$ longitudinal polarization. The ratio of the time actually spent on the two will somewhat different due to the assumed ramp-up from the initial luminosity.
- We assume 65% polarization, again as per the supplied guidance.

For a detailed discussion of the measurements with both transverse and longitudinal polarizations, please refer to our previous Beam Use Proposal [1]

The remaining 10 weeks of Run-8 should then be used to study d+Au at $\sqrt{s_{NN}}$ = 200 GeV. We expect to develop an integrated luminosity in this period that exceeds our Run-3 d+Au value of 2.7 nb^{-1} by more than an order-of-magnitude. Given the significant increase now made available by our Run-5 p+p data-set of 3.8 pb^{-1} , and the additional 10.7 pb^{-1} Run-6, the Run-3 d+Au data-set is now very much the limiting factor in our ability to make precision measurements of the relatively small but crucial nuclear modifications that occur in cold nuclear matter.

A 10 week run of d+Au collisions, assuming maximum (25 nb^{-1} per week) C-A D guidance will result in a recorded sample of 58 nb^{-1} , i.e., a factor of > 20 increase over the existing d+Au data-set. This will provide much greater precision in determining the absorption cross section in cold nuclear matter, which is of critical importance to a quantitative understanding of J/ψ yields in Au+Au collisions at RHIC energies. It is also essential for the low-mass dilepton program.

Two additional points are worth noting here. First, due to extensive studies conducted by PHENIX, we were able to identify sources of background in the muon arms and develop a shielding plan that has greatly improved the Signal/Background since Run-3. Therefore, the improvement in our understanding of the d+Au data in the muon channels will exceed the simple factor in integrated luminosities. Second, we have argued that greater precision is required for understanding the role of absorption in cold nuclear matter. This of course is the simplest such model of nuclear effects. Quantitative investigation and incisive tests of other effects such as Sudakov suppression[4], gluon saturation[5], etc. can be made only with the substantially increased data set we are requesting in Run-8.

3.5 Run-9

With the anticipated recording of an additional 1.1 nb^{-1} of Au+Au data at $\sqrt{s_{NN}}$ = 200 GeV, PHENIX will have reached several important goals. First, we will have extended our Run-4 Au+Au data-set by a factor of four, with upgraded detectors leading to an order-of-magnitude improvement in sensitivity, thereby accessing the many statistics-limited observables. Second, we will have commissioned the HBD. It is very likely that we would request further running at this energy in order to achieve our goal of an order of magnitude increase in statistics using the combined Run-7 and Run-9 data sets, and to make precision measurements at RHIC of the low-mass dilepton spectrum. Of course, we are also aware of the substantial potential of RHIC for low-energy running, and the great physics interest in same. As Run-9 would be the last year for HBD running before insertion of the VTX detector, we wish to leave open the possibility of using a significant fraction of Run-9 for running Au+Au at lower energies. Consequently, we expect to spend 25-M weeks running Au+Au in Run-9. M is the number of weeks dedicated to 500 GeV p+p. We note that should Run-8 provide insufficient p+p data at 200 GeV, we may request more running at the lower energy in Run-9.

As noted above, we prefer to specify the precise length of the Run-9 Au+Au segment and its energy (energies) when the physics from Runs 7 and 8 is in hand. This of course impacts in turn our ability to specify the length of the polarized proton segment, hence the algebraic nomenclature. However, we wish to emphasize the crucial aspect of having a 500 GeV polarized proton segment in Run-9. This is necessary both as per C-A D guidance, and to commission the Muon Trigger in an engineering run. A significant fraction of the South Arm trigger capability will be installed prior to Run-9. This is an essential step in PHENIX's progress towards W physics in the next decade.

3.6 Run-10

We propose (25-N) weeks "heavy ion" running at $\sqrt{s_{NN}}$ = 200 GeV As noted in our previous Beam Use Proposals, the resolution on assumed heavy ion species more than three years from the time of writing is quite limited. Nonetheless, we have left this item as placeholder, to indicate continued running for this aspect of the program as various upgrades further extend PHENIX's ability to make incisive measurements. Of particular interest will be the first opportunity in Run-10 to perform physics measurements using the Si-VTX tracker, which would provide intrinsically new results from either Au+Au or d+Au collisions on displaced vertices from heavy flavor decays to provide qualitatively new data on the production, energy loss and flow of charm and beauty.

The complete Muon Trigger will be available for Run-10, and we anticipate a major data-taking run for W physics using longitudinally polarized p+p at 500 GeV.

3.7 Run-11

Once again cautioning about the difficulty with long-baseline projections, we nonetheless note that completion of the EBIS project in this period will provide the unprecedented opportunity to study U+U collisions. The static quadrupole deformation of the uranium nucleus will lead to collisions (in some orientations) with significantly greater initial densities than those found in Au+Au collisions, presenting new challenges to both theory and experiment to extract and understand the influence of the initial geometry on the subsequent dynamics. Consequently, we propose (25-X) weeks "heavy ion" running at $\sqrt{s_{NN}} = 200$ GeV.

As in the 200 GeV polarized proton program, we project steady accumulation of integrated luminosity at 500 GeV over a multi-year period. X weeks p+p longitudinal polarization at 500 GeV will contribute to this program. The Nose Cone Calorimeter and the Forward Vertex detectors could also be available at this time, once again extending the PHENIX physics reach.

References

[1] PHENIX Beam Use Proposal for RHIC Run-7 and Beyond, Sep-06; avalable from http://www.phenix.bnl.gov/phenix/WWW/publish/zajc/sp/presentations/RBUP06/ProposalText/RBUPforRun7andBeyond.pdf

[2] Research Plan for Spin Physics at RHIC, submitted to U.S. Department of Energy February, 2005; available from http://spin.riken.bnl.gov/rsc/report/masterspin.pdf.

[3] RHIC Collider Projections (FY2007-FY2008), W. Fischer *et al.*, last updated June 1, 2006, available from http://www.agsrhichome.bnl.gov/RHIC/Runs/RhicProjections.pdf.

[4] S. Catani, M. L. Mangano, P. Nason, C. Oleari and W. Vogelsang, JHEP **9903**, 025 (1999) [arXiv:hep-ph/9903436].

[5] For a comprehensive review see E. Iancu and R. Venugopalan, *"The color glass condensate and high energy scattering in QCD,"* in QGP3, Eds. R.C. Hwa and X.N.Wang, World Scientific, 2004. arXiv:hep-ph/0303204.