# PHENIX RHIC Beam Use Proposal

submitted by the PHENIX Collaboration

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# 1 INTRODUCTION

## 1.1 PHENIX Overview

The PHENIX physics program is devoted to the systematic exploration of nucleus-nucleus, proton-nucleus, and (polarized) proton-proton collisions at RHIC. The study of each of these reactions classes has a particular goal. Specifically, the nucleus-nucleus (A-A) program is focused on the creation and detection of quark-gluon plasma (QGP); the proton-nucleus (p-A) program will explore baseline phenomena in cold nuclear matter necessary to the quantitative understanding of A-A collisions, and polarized p-p ($\vec{\mathrm{p}}$-$\vec{\mathrm{p}}$) collisions will measure various contributions to the spin of the proton (while again providing baseline data against which to compare the p-A and A-A measurements).

This ambitious and varied program is made possible by the tremendous flexibility of RHIC and its injectors. The design of the PHENIX detectors and readout has been optimized across this very broad dynamic range from A-A collisions (low rate, large events, high occupancy) to $\vec{\mathrm{p}}$-$\vec{\mathrm{p}}$ collisions (high rate, small events, low occupancy). The result of this optimization is a detector with the ability to measure both large cross section hadronic phenomena and rare processes[1]. The rare probes in A-A collisions are particularly intriguing, since they address some of the most pressing questions in heavy ion physics (charmonium production and suppression, energy loss of high $p_T$ partons, direct photon production, etc.) It is therefore of paramount interest to PHENIX that the highest priority in the initial running of RHIC be given to the development of stable running conditions for Au-Au collisions, followed by a steady period of luminosity growth.

## 1.2 Executive Summary

The PHENIX Beam Use Proposal, in priority order, is:

1.) Sufficient Au-Au running to

  A. Commission and calibrate our Year-1 detector elements.

  B. Record 20 $\mu b^{-1}$ of Au-Au collisions at $\sqrt{s} = 200$ A $\cdot$ GeV.

2.) Spin commissioning of one ring.

3.) A p-p comparison run at $\sqrt{s} = 200$ GeV.

As described below, this program will allow us to

- Understand basic reaction dynamics through global variables
- Understand flavor dynamics through identified (charged and neutral) particles
- Embark on rare physics investigations:
  - Direct photons
  - Hard scattering
  - Pair decays
  - Charm production
- Measure and cross-correlate all QGP signatures permitted by the integrated luminosity.
- Explore *terra incognita.*

The sensitivity and flexibility of PHENIX, coupled with a steady increase in RHIC luminosity, will provide an extensive characterization of the properties of heavy ions (Au) colliding at the highest energies ($\sqrt{s} = 200$ A $\cdot$ GeV) yet observed. The high bandwidth of the PHENIX data acquisition system will allow recording of an unbiased data set, which will permit the systematic study of both large and small cross-section phenomena as a function of centrality. Such a study will provide a unique insight into the dynamics of RHIC heavy ion collisions at all timescales, from the high-$Q^2$ perturbative regime to the soft hadronic scale. At the same time, the unbiased nature of the data set, together with its high statistics, are necessary inputs to the trigger studies needed for later running of RHIC and PHENIX at high luminosities.

# 2 PHENIX Beam requests

## 2.1 Assumptions

The following assumptions have been used in deriving our request:

### 2.1.1 RHIC Parameters

- A total RHIC running period of **30 weeks**.
- The total time devoted to Au-Au running is **20 weeks** (the remainder being used for spin commissioning, a p-p comparison run, and planned accesses).
- A **linear increase** of the Au-Au luminosity from $\sim 0\%$ to **10% of the design value** of $2 \times 10^{26}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ over the 20 week period of Au-Au running. That is,

$$\mathcal{L}(t) \approx \frac{t}{T} \cdot (10\% \times \mathcal{L}_{DESIGN}) \quad ,$$

  with $T = 20$ weeks.
- All Au-Au running is at $\sqrt{\mathbf{s}} = \mathbf{200}$ A $\cdot$ GeV.
- The RHIC duty factor is **50%**.
- The PHENIX duty factor is **50%**.

### 2.1.2 PHENIX Parameters

Unless otherwise noted, the PHENIX configuration for Year-1 is assumed to consist of

1.) The Zero-Degree Calorimeters (ZDC)

2.) The Beam-Beam Counters (BBC)

3.) The Multiplicity and Vertex Detector (MVD), covering the central five units of pseudo-rapidity.

3.) The PHENIX East Arm. Unless otherwise noted, this arm covers $|\Delta\eta| < 0.35$ and is divided into four azimuthal sectors, with each sector spanning $22.5^o$ of azimuth. The East Arm consists of:

a. The drift chamber (DC), with the full azimuth ($\Delta\phi = 90^o$) instrumented.

b. Two instrumented sectors of Pad Chamber 1 (PC1).

c. The Ring Imaging Cherenkov (RICH), with the full azimuth ($\Delta\phi = 90^o$) instrumented.

d. Two instrumented sectors of the Time Expansion Chamber (TEC).

e. Two instrumented sectors of Pad Chamber 3 (PC3).

f. One full sector of Time-Of-Flight (TOF), combined with a second sector covering $|\Delta\eta| < 0.08$.

g. One sector of PbGl Electromagnetic Calorimeter (PbGl EmCal).

h. One sector of Pb-Scintillator Electromagnetic Calorimeter (PbSc EmCal).

These detector elements are read out with a data acquisition system capable of recording 100 events/second, and triggered with an interaction trigger (BBC's), and (if needed) a charged multiplicity trigger (MVD). It is important to emphasize that PHENIX is capable of triggering on, digitizing and recording *all* Au-Au collisions for machine luminosities below $\sim 10\%$ of the design value[1].

## 2.2 Requested Beam Segments

The specific segments requested by PHENIX are listed here. An important adjunct to these is the request for flexibility in the RHIC running schedule. To realize the full physics potential of PHENIX in Year-1, it may be necessary to install the East Arm after the start of RHIC running (currently planned to start on 01-Nov-99). We have discussed this possibility with RHIC management, and are meeting with them on a regular basis to keep them informed on the PHENIX progress towards completion of the East Arm.

[1] This capability could be degraded if there are large machine backgrounds that satisfy the PHENIX Level-1 trigger criteria. However, it is expected that such backgrounds can be eliminated with only a modest trigger requirement away from minimum bias.

### 2.2.1 Au-Au running

The first beam segment requested by PHENIX is Au-Au running to commission and calibrate the detector, leading into a physics run at $\sqrt{s} = 200\ \mathrm{A \cdot GeV}$of duration sufficient to record an integrated luminosity of $20\ \mu\mathrm{b}^{-1}$. Using the assumptions stated in Sections 2.1.1 and 2.1.2, the physics portion of this segment would require the last 9 weeks of the Au-Au running period, beginning at roughly 5% of design luminosity $\approx 1 \times 10^{25}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, and finishing at twice this value. During this 9 weeks of calendar time, the assumed RHIC duty factor is 50%, so the requested beam hours are equivalent to 9 weeks $\times$ 168 hours/week $\times$ 0.5 = 756 hours at an average luminsoity of $\approx 1.5 \times 10^{25}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

The $\sim$ 11 weeks preceeding the "physics" portion of this run would serve as the commissioning period for PHENIX. During this time it is desirable but not essential that the beam energy be the same as that for the physics portion of the segment. However, it is important that the beams for this commissioning period be Au-Au, since only then will the multiplicities (and dynamic range of same) be sufficient to stress both the detectors and the readout chain.

### 2.2.2 Spin commissioning

PHENIX requests that sufficient time be allocated in the RHIC schedule for Year-1 to commission one ring of the accelerator for spin operations with protons. This is essential to understand the issues required for a succesful spin physics run in Year-2. It is our understanding that 4 weeks would be required for this work. Since PHENIX will request $\sqrt{s} = 200$ GeV for the Year-2 spin run, it would be most advantageous if the Year-1 commissioning work could establish spin operations for (at least) this beam energy. During this period we expect no collisions, and have no requirements on luminosity or beam hours of operation.

### 2.2.3 p-p

Any quantitative understanding of the Au-Au events observed in the first year of RHIC running depends critically on comparison to p-p data at the same energy per nucleon[2] To do this, PHENIX requests a p-p comparison run at $\sqrt{s} = 200$ GeV. Two weeks of running at a very modest luminosity ($\sim 10^{27}\mathrm{cm}^{-2}\mathrm{s}^{-1}$) is sufficient to acquire 10M events, which would allow a thorough exploration of minimum bias physics. Higher luminosities would of course be acceptable, although values beyond ($\sim 10^{29}\mathrm{cm}^{-2}\mathrm{s}^{-1}$) would saturate the DAQ and therefore require development of specialized triggers, which is not a PHENIX priority in Year-1.

### 2.3 Relative Priorities

The above beam segments are listed in priority order, as in Section 1.2. It should be noted that the p-p running is viewed as a natural evolution of the single-ring spin-commissioning studies, and therefore one could anticipate modest trade-offs between spin studies and p-p running.

## 3 Physics Goals

### 3.1 Nominal Configuration

The major goals of the PHENIX physics program for Year-1 are to measure phenomena from all timescales in Au-Au collisions, to correlate the greatest possible variety of such observables, and to thereby characterize dense nuclear matter and search for quark-gluon plasma[2]. Since initial formation timescales $\sim 0.01$ fm translate into high-$Q^2$ scales in momentum space, this program necessarily involves measurement of rare probes. Such processes make contact with pertubative QCD, and as a result allow direct testing of current theoretical predictions for the behavior of high-$p_T$ partons in deconfined matter[3, 4, 5, 7, 6].

In Year-1, the high bandwidth of the PHENIX DAQ system allows the study of rare signals *while running an unbiased interaction trigger.* This provides a unique ability to completely characterize the baseline physics of RHIC by systematically studying the various signatures as a function of event multiplicity and/or transverse energy in a very high statistics data set. (The requested 20 $\mu\mathrm{b}^{-1}$ corresponds to roughly 120M Au-Au events.) An event sample of this size will permit extensive studies of the hadronic final state

[2]Note that the highest energy p-p data now available are from the CERN ISR at 63 GeV; the existing data at 200 GeV are $p\bar{p}$ collisions.

through “global” quantities such as $dN_{ch}/d\eta$, spectral observables such as $p_T$-spectra for identified $\pi^{\pm}$, $K^{\pm}$, p’s, $\bar{p}$’s, ... for $p_T < 2$ GeV/c, and two-particle HBT measurements. The very clean $\pi/K$ separation of the PHENIX TOF, combined with the high mass resolution of the tracking also allows study of the $\phi \rightarrow K^+K^-$ decay, leading to an expected sample of $\sim$ 200K $\phi$ decays, which should be sufficient to begin the search for modifications of the production and/or decay of the $\phi$ due to medium effects[8, 9].

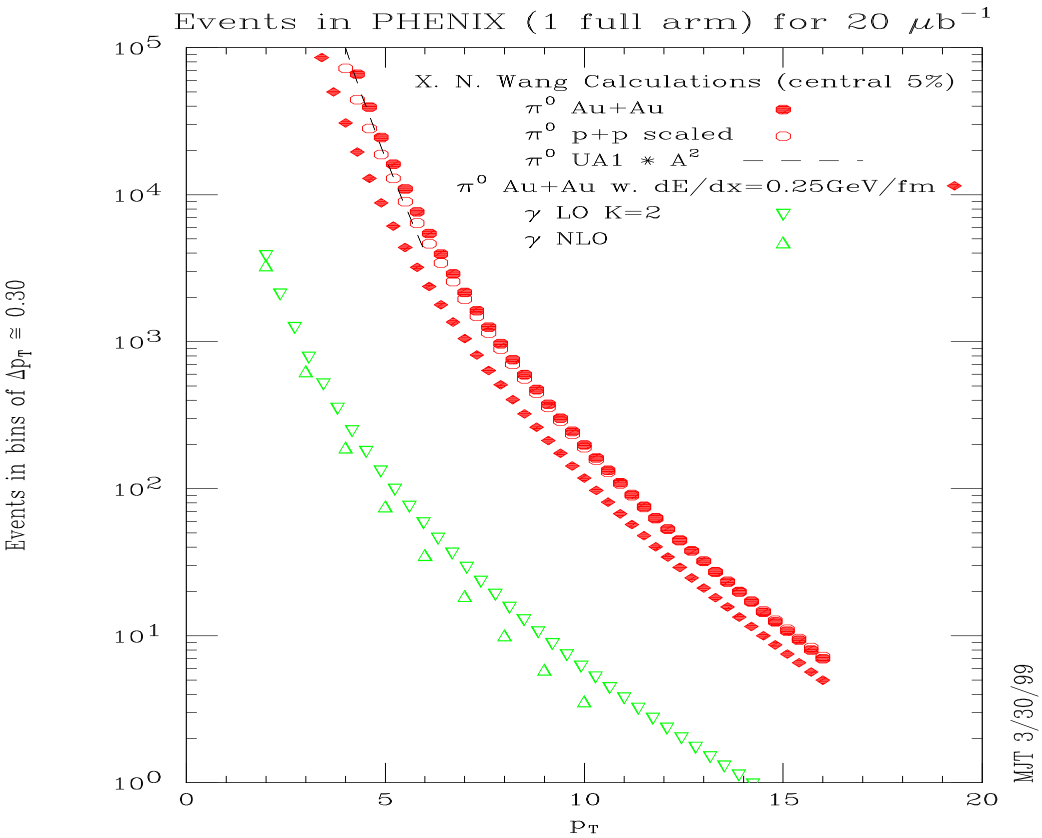


Figure 1: The number of $\pi^0$’s per 0.3 GeV/c $p_T$ bin expected in PHENIX for 20 $\mu b^{-1}$ of Au-Au running. Predicted spectra are shown with and without (modest) jet-quenching.

The physics reach of the requested PHENIX program is best illustrated by focusing on the sensitivity to rare probes. For example, Figure 1 shows the expected number of events in a PHENIX central arm for 20 $\mu b^{-1}$ of Au-Au at $\sqrt{s} = 200$ A $\cdot$ GeV, along with a comparison to the predicted effects of (mild) jet quenching[10].

A particular strength of PHENIX is the ability to very cleanly identify electrons in a high multiplicity environment. This can be used to study the crucial question of charm production rates in Au-Au collisions[11, 12] through single electrons at $p_T >$ 2 GeV/c, where HIJING studies indicate that the signal will be comparable to or larger than the expected backgrounds from Dalitz pairs. The central-most 10% of the 120M event date set will produce $\sim$1000 electrons in this momentum range. This central sample is sufficiently large to allow systematic studies necessary to determine the various contributions to the background to this measurement. For example, simulations indicate that extending the region of interest to $p_T > 1$ GeV/c increases the charm yield by more than an order-of-magntude while increasing the background by a factor of less than four. However, there is little doubt that a large data set is required to perform such variations as part of the careful studies required to quantitatively determine the contributions from $\pi$ and $\eta$ Dalitz decays to the charm signal in this region.

## 3.2 Extended Configuration

The very substantial physics program described above is obtainable with the PHENIX East Arm alone. There is a strong interest in extending this capability even further by implementing a corresponding aperture of the PHENIX West Arm in Year-1. All detector components will be complete; the major challenge is one of infrastructure and installation on a schedule that does not conflict with the higher priority that has been assigned to completion of the PHENIX East Arm.

The major addition to the PHENIX physics program in the East Arm alone is access to pair physics. The ability to study the "away-side" distributions in coincidence with a high $p_T$ particle in the opposite sector will extend the exploration of the energy loss mechanisms. Even more intriguing will be the first glimpse of the $\omega, \phi$ and J/$\psi$ decays to $e^+e^-$. The yield of these processes from our requested sample are presented in Table 3.2. These results are also notable in that the backgrounds and efficiencies are estimated using the full PHENIX reconstruction and particle identification chain from Monte Carlo events analyzed in the recently (24-Mar-99) completed Mock Data Challenge 2 (MDC2). The cuts used in the analysis have not yet been optimized, and there is the possibility for additional background rejection (and hence smaller errors for the $\omega$ and $\phi$).

| Meson | Signal | Signal/Background | Error |
|---|---|---|---|
| $\omega$ | 300 | 0.010 | 240 |
| $\phi$ | 180 | 0.024 | 180 |
| $J/\psi$ | 130 | (negligible background) | 11 |

Table 1: Yields of vector mesons to $e^+e^-$ pairs expected in a Year-1 two arm configuration of PHENIX for 20 $\mu b^{-1}$ of Au-Au collisions at $\sqrt{s} = 200\ \mathrm{A} \cdot \mathrm{GeV}$.

# 4 Collaboration Resources

A task force was convened by the PHENIX spokesperson in December 1998 to develop procedures for operating the experiment. The report from that task force was finalized in Feb-99 and endorsed by the PHENIX Executive Council in Mar-99. Implementation of its recommendations will be discussed at the Jun-99 meeting of the PHENIX Institutional Board. The report is attached to this proposal. It establishes a well-defined hierarchy for coordinating the activities of all PHENIX shift personnel and for insuring that the PHENIX physics goals are pursued in a coherent and safe fashion during the course of a running period. PHENIX management has also conducted a staffing survey to determine availability of critical personnel for each sub-system. The results indicate that there will be adequate coverage of all sub-systems.

The ability to perform the subsequent data analysis depends critically on the availability and reliability of the RHIC Computing Facility. A linear extrapolation of the PHENIX experience in MDC2 (loss of 5 out of 14 days due to hardware failures) would not permit an unequivocal statement in this regard. However, if one accepts this as a valuable lesson towards developing a fault tolerant system, there is a basis for cautious optimism. Reinforcing this is the very short turn-around time for the analyses cited in Section 3.2, which were completed with the full PHENIX analysis chain in spite of these difficulties.

# References

[1] Current information concerning the PHENIX experiment may be found at *http://www.phenix.bnl.gov/*.

[2] For a general review of QGP signatures, see S.A. Bass *et al.*, J. Phys. G **G25**, R1 (1999) hep-ph/9810281.

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