PHENIX Beam Use Proposal for RHIC Runs 5-9

The PHENIX Collaboration

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Abstract

This document updates the previous 5-year "PHENIX Beam Use Proposal for RHIC Runs 4-8" (submitted 03-Sep-03). The focus is on a revised request for RHIC Run-5 consistent with the improved understanding of RHIC performance as described in the most recent guidance from the Collider-Accelerator Department. Information on the current status of the experiment, on the data sets recorded to date, and the program of proposed upgrades is also provided.

Executive Summary

The PHENIX Collaboration proposes a continued program of exploration based on the development of the highest possible luminosities in ion-ion, "proton"-nucleus and polarized proton collisions. Building on the successes of Runs 1-4, the requested running conditions are designed to maximize the discovery potential at RHIC via extended measurement of rare probes and hard processes in various systems, with an emphasis in Runs 5-9 on mapping the dependence of these phenomena versus system size and beam energy. An intensive program of luminosity and polarization development is requested for polarized protons, including timely development of 500 GeV operations, leading to quality measurements of ΔG in various production channels.

1 Introduction

The PHENIX goals for future RHIC running have been clearly delineated in our previous submissions to the Program Advisory Committee[1, 2, 3, 4, 5, 6]. In Runs 1-4, 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 the J/ψ . The cross section for charmonium production is sufficiently small that such integrated luminosities also provide superb results for single particle hadron yields to very high transverse momenta, thereby significantly extending the systematic studies of the suppression patterns measured in RHIC Run-1 (Ref. [11]), Run-2 (Ref. [21]) and Run-3 (Ref. [33]). The superior performance of RHIC in Run-4 allowed PHENIX to record an integrated luminosity in excess of 240 μb^{-1}, over an order-of-magnitude larger than our Run-2 data sample for the same system (and a very substantial fraction of our long-standing request for 300 μb^{-1} of Au+Au at 200 GeV.)

In this Beam Use Proposal we provide an update to our previous 5-year request[6]. We focus here specifically on Run-5 and on updates to the latter years due to more refined guidance from CAD; the reader is referred to the previous document for all supporting details for Run 6 and beyond.

1.1 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 systems for Run-3 to an enhanced detector for Run-4. Three additional "beyond the baseline" components were installed for Run-3:

1. The Zero-Degree Calorimeters were augmented by a Shower-Max Detector (SMD), which was of crucial importance in providing local polarimetry capabilities during the commissioning of the spin rotators at IP8.
2. Two Forward Calorimeters (FCAL's) were installed to provide event characterization for d+Au collisions.

3. A New Trigger Counter (NTC) was used during p+p running to extend the fraction of minimum bias cross section accessible to the PHENIX Level-1 trigger system.

For Run-4, the capabilities of the PHENIX central spectrometer were significantly extended through the addition of an Aerogel Cerenkov Counter (ACC). This detector, consisting of 160 elements of hydrophobic aerogel installed in the West arm of PHENIX(Figure 1), provides additional particle identification capabilities illustrated in Figure 2, which will permit a crucial test of quark recombination models[7, 8] for $p_T > 5$ GeV/c.

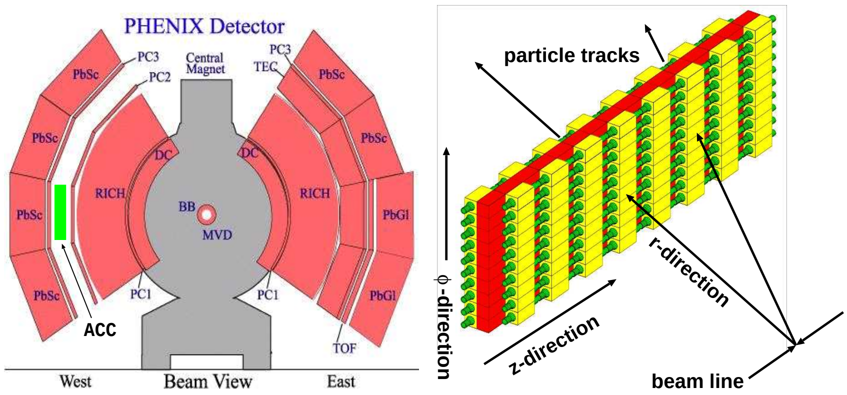

Figure 1: The aerogel detector in the west arm between pad chamber 2 (PC2) and 3 (PC3) in the W1 sector (left) and the aerogel detector structure and orientation with respect to the beam line (right) are shown.

Each of the configurations used for Runs 1-4 was capable of using the delivered luminosity from RHIC to explore both heavy ions (Runs 1, 2 and 4), polarized proton collisions (Runs 2, 3 and 4) and deuteron+Au collisions (Run 3). Table 1 shows the statistics on the total number of events, total archived data volumes, and integrated luminosities achieved by PHENIX in Runs 1 through 4. During the 200 GeV Au+Au portion of RHIC Run-4 the PHENIX DAQ system recorded data at event rates as high as 1700 event/s and with aggregate data rates as high as 400 MByte/s[1]. This very high throughput allowed PHENIX to collect approximately 1.5 billion 200 GeV minimum-bias Au+Au events during Run 4.

[1]As far as we know, this data recording rate is by far the highest archiving rate ever achieved by a particle physics experiment.

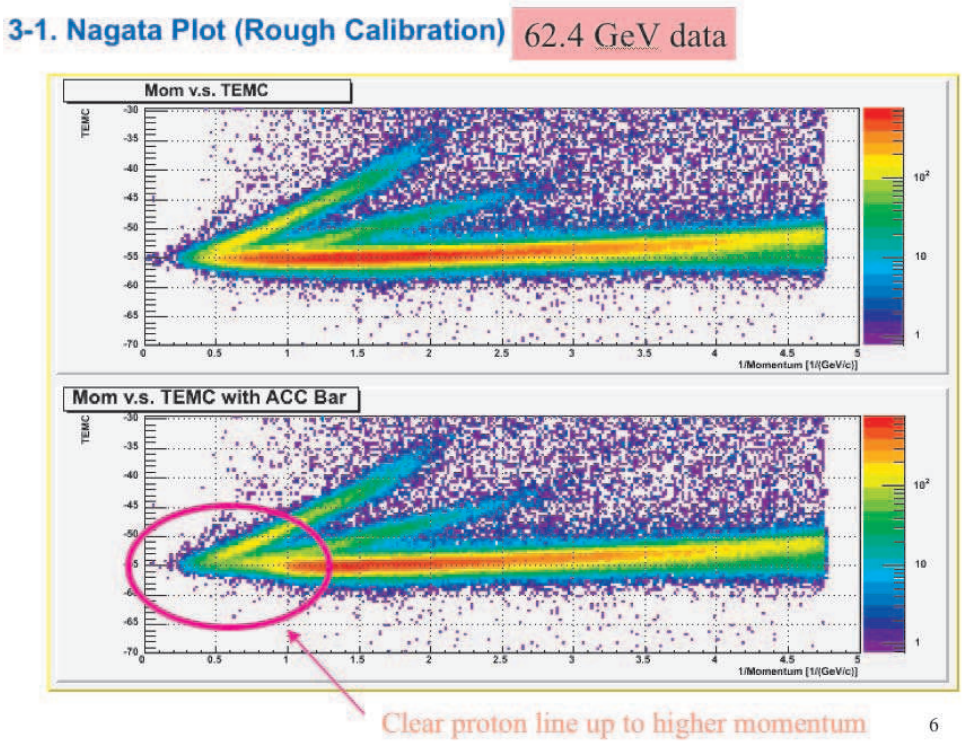

Figure 2: Hadron identification in the PHENIX Central Arms with the Aerogel Cerenkov Counter system. The time-of-flight is plotted versus 1/momentum for charged tracks without (top) and with (bottom) an aerogel signal. The pion band is effectively vetoed for momenta $> \sim 1.5$ GeV/c.

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

Table 1: Summary of the PHENIX data sets acquired in RHIC Runs 1 though 4. All integrated luminosities listed are *recorded* values.

1.2 Status of PHENIX Physics

1.2.1 Physics Yields from Runs 1-3

The published results from Run-1 Au+Au collisions[9]-[20], from Run-2 Au+Au collisions at 200 GeV[21]-[29] and Run-2 proton+proton collisions[30, 31, 32], and Run-3 d+Au collisions[33] clearly demonstrate that PHENIX has the capability to make high quality measurements in both hadronic and leptonic channels for collisions ranging from p+p to Au+Au. Together these 24 publications (which have generated over 1400 citations) encompass physics from the barn to picobarn level. We limit our presentation here to a few results representative of the PHENIX program in rare probes, as it is these channels that determine the thrust and scope of our beam request. The discussion will focus on yields per integrated luminosity rather than on physics content. Specifically, the yield is presented as a function of the "*proton+proton equivalent*" "*recorded*" integrated luminosity, as given by the corresponding column in Table 1. The *proton+proton equivalent* integrated luminosity in an A+B collision is given by

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

and clearly 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. For this discussion we focus on the recorded[2] values, in that it is directly proportional to the number of events examined for physics content (the number of events is also listed in Table 1).

The data sets obtained by PHENIX in Runs 1-3 for Au+Au, p+p and d+Au correspond to proton+proton equivalent values of 0.1 to 1 pb^{-1} . Figure 3 provides a convenient point of reference, in that it shows the transverse momentum obtainable (∼13 GeV/c) for $p+p \rightarrow \pi^0 + X$ with ∼0.1 pb^{-1} . However, as Figure 4 makes clear, this same value of integrated luminosity is completely inadequate for a quality measurement of direct photons. Nor does it suffice for a measurement[3] of the double spin asymmetry A_{LL} via π^0's at a level to distinguish between a range of gluon polarizations allowed by the previous world's data from DIS measurements (Figure 5). As shown in Figure 6 the ∼1 pb^{-1} proton+proton

[2] Note that in the case of minimum bias data sets, "recorded" is strictly accurate, while for triggered data "examined" or "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.

[3] The average polarization of the beams in this measurement was 27%.

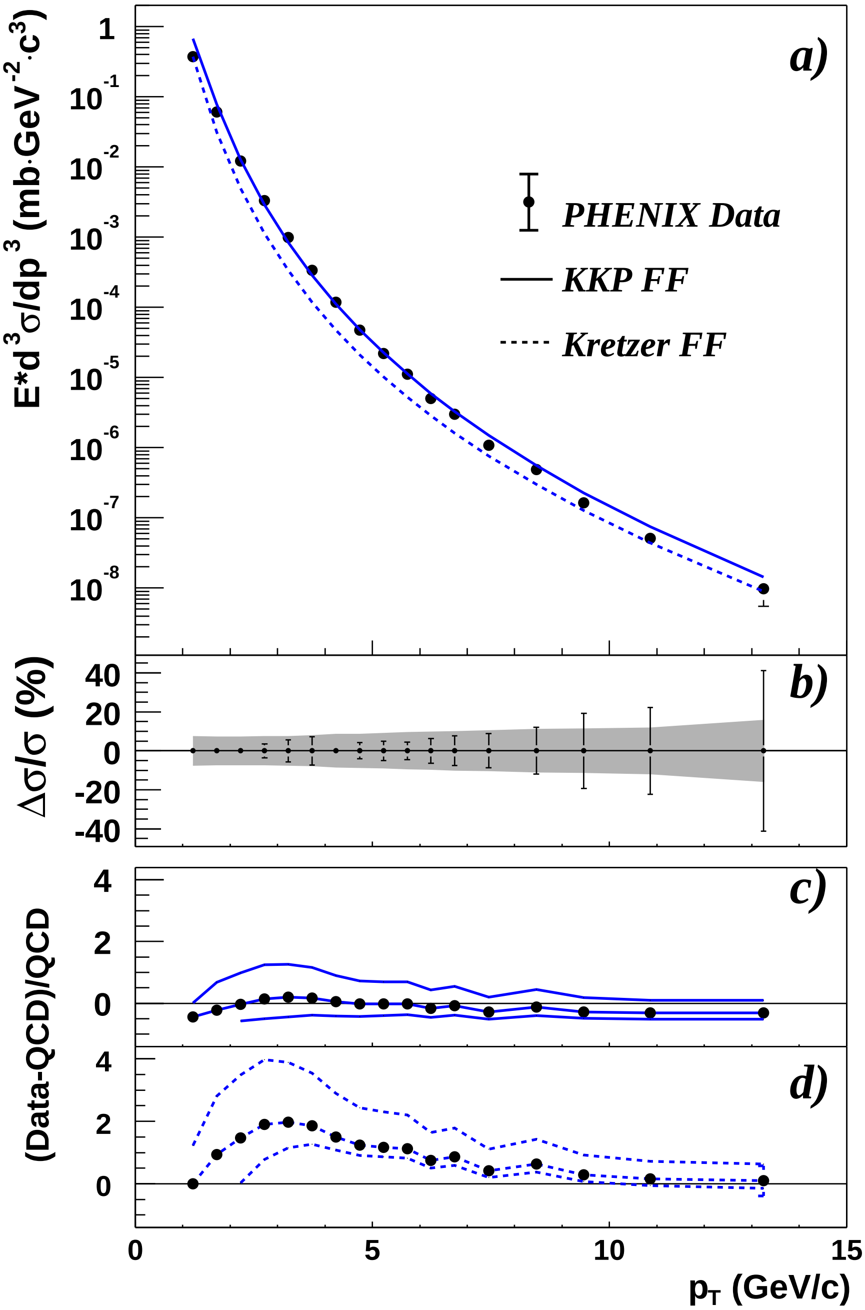

Figure 3: The cross section for $p + p \to \pi^0 + X$ measured by PHENIX in Run-2 200 GeV p+p collisions with $\sim$0.1 pb^{-1} . For details, consult Ref. [30].

equivalent yield in Run-3 d+Au collisions provides an adequate J/ψ p_T spectrum, but does not compare well with fixed target measurements of the A^α parameterization the nuclear yield dependence. As a final example, we present in Figure 7 the single-electron results obtained from $\sim$1 pb^{-1} of proton+proton equivalent in Run-2 Au+Au collisions.

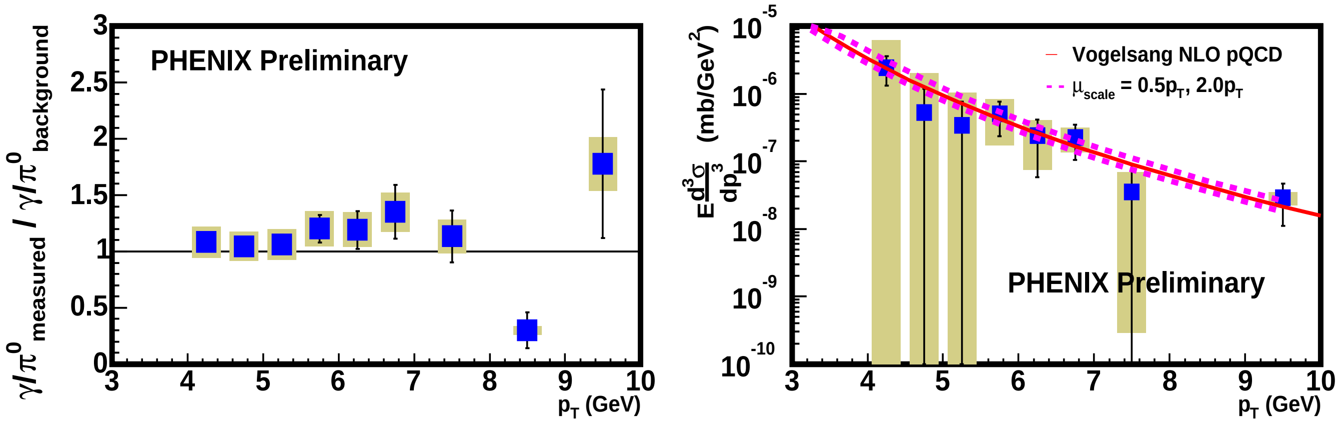

Figure 4: Direct γ excess double ratio and cross section measured by PHENIX in Run-2 200 GeV p+p collisions for a recorded integrated luminosity of approximately 0.1 pb^{-1} . The cross section is compared to pQCD [34] for scale factors $\mu = 0.5p_T, 1.0p_T, 2.0p_T$.

Again, while the current data suffice to establish the N_{coll} scaling of the inferred charm yields, they provide no resolution to the crucial question of the flow dynamics for charm quarks[37].

1.2.2 Run-4 Status

As indicated in Table 1 , the Run-4 Au+Au data set provides an order-of-magnitude improvement ($\sim$10 pb^{-1} proton+proton equivalent) on all previous Au+Au data sets. The ongoing analysis of this data set should provide the long-anticipated first quantitative results on J/ψ 's from 200 GeV Au+Au collisions, and should also greatly extend the precision of measurements such as direct photons and elliptic flow of charmed mesons. It is also clear from Table 1 that a corresponding order-of-magnitude increase in the p+p data set is required in order to have comparison data with the same equivalent luminosity. This requirement is reflected in our Run-5 request for a significant p+p run at 200 GeV, and provides maximal overlap between the goals of the heavy ion and polarized proton program.

Not apparent in Table 1 is the very substantial progress made in the spin program during the Run-4 period of machine development for polarized protons. The following achievements were made by PHENIX and CAD in Run-4:

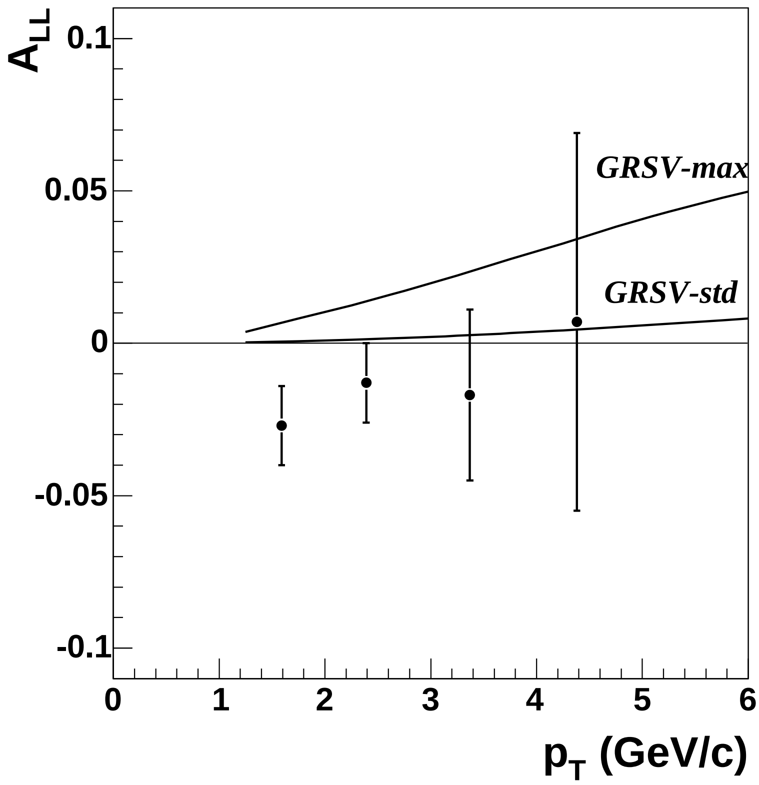

Figure 5: The double spin asymmetry $A_{LL}^{\pi^0}$ measured by PHENIX[32] via $p+p \rightarrow \pi^0 + X$ with $\sim$0.2 pb^{-1} versus mean p_T of the π^0's in each bin. A scale uncertainty of $\pm$65% (due to the absence of an absolute calibration for the RHIC beam polarimeters in Run-3) is not included. Two theoretical NLO pQCD calculations[35] for the nominal and maximal gluon polarization allowed by the previous world data set are also shown for comparison with the data.

- Improved the Figure of Merit $\mathcal{P}^4 \int \mathcal{L}dt$ by a factor of ~ 2 over the Run-3 result (this due to the greatly improved working point with 45% polarization).
- Installation of new muon shielding (leading to significantly improved trigger efficiency) and automatic beam scraping work.
- A conceptual design for a new luminosity telescope was tested, with excellent prospects for improved monitoring in future high luminosity runs.
- Commissioned new custom scalers for future monitoring of bunch-by-bunch lumi-

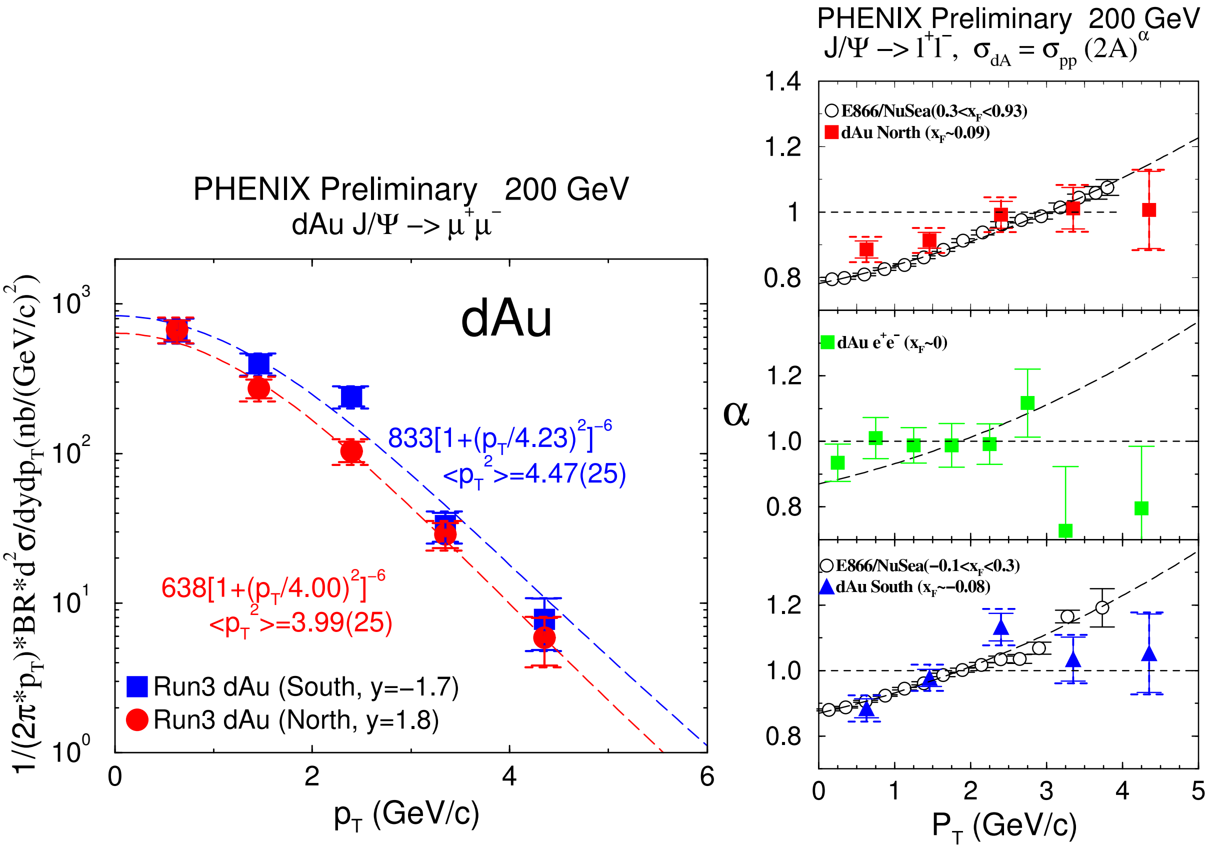

Figure 6: Left-hand plot: The transverse momentum spectrum for J/ψ 's measured by PHENIX in Run-3 200 GeV d+Au collisions for a proton+proton equivalent recorded integrated luminosity of approximately 1 pb^{-1} . Right-hand plot: A comparison of the corresponding A^{α} dependence of the J/ψ yield versus p_T to fixed target results[36].

nosity variations.

All of these items argue for an extended period of polarized proton running in Run-5, with the goal of making a major extension of the first results presented in Figure 5.

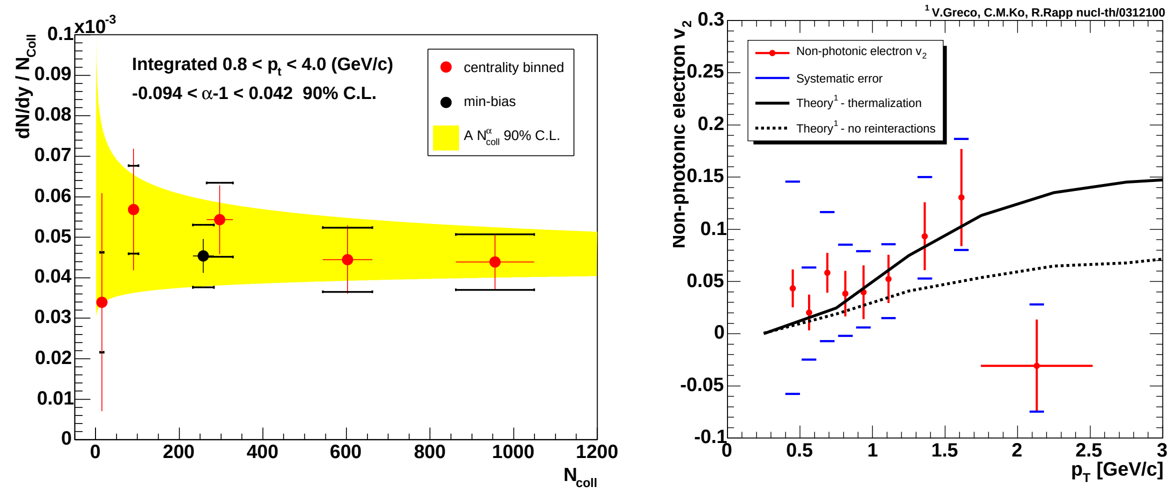

Figure 7: PHENIX results on non-photonic electrons (i.e., those electrons from charm and beauty decays). Left-hand plot: per collision yield for non-photonic electrons $dN/dy/N_{coll}$ versus the number of collisions N_{coll}. Right-hand plot: PHENIX Preliminary data for the non-photonic electron v_2. Both results were obtained by PHENIX in Run-2 200 GeV Au+Au collisions for a proton+proton equivalent recorded integrated luminosity of approximately 1 pb^{-1} .

2 Run Planning Assumptions and Methodology

2.1 ALD Input

The call for Beam Use Proposals issued 12-Jun-04 by the Associate Laboratory Directory for High Energy and Nuclear Physics requested updates of the previously submitted 5-year plans, with the following new guidance:

1. A specific focus on Run-5.
2. For Run-5, 31 weeks of cryogenic operations should be taken as the default assumption.
3. A fall-back scenario should also be developed for the case of 27 cryo weeks in Run-5.
4. Luminosity assumptions should be consistent with the latest Collider-Accelerator Department guidance.

While not explicitly specified, for the out-years presented here we have assumed (only) 27 cryo weeks per year of operation, based on recent communications with NSAC and DOE review committees.

2.2 CAD input

Detailed guidance was provided by the Collider-Accelerator Department (updated on 28-Jun-04) describing the projected year-by-year luminosities for various species, along with the expected time-development of luminosity in a given running period[38]. Here we briefly summarize the parameters most relevant to our planning process:

2.2.1 Overheads

- **Cooldown**: 2 weeks
- **Warm-up**: 1 week
- **Set-up**:

  - 2 weeks ≡ time required to set-up machine for a given species.
  - 1 week required in the case of a second mode in same run-year (2 weeks in the case of polarized protons).

- **Ramp-up**:
  - 2 weeks ≡ time required to achieve stable operations with useful (initial) luminosities.
  - 1 week required in the case of a second mode in same run-year

- **Energy Changes**: 2-3 days required to achieve stable operations at a lower energy for a given species.

Thus, 27 weeks of cryo operations translates into 27 - 2 - (2+2) - 1 = 20 weeks of stable operations for physics when running one mode, and 27 - 2 - (2+2) - (2+1) - 1 = 17 weeks for the case of two modes.

2.2.2 Luminosity Development

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 were also provided, based on current understanding of the accelerator limits. In both cases, an "8 week linear growth" model was applied to model the time development of the initial luminosity value achieved at the end of "ramp-up" to the final value. Guidance was also provided for anticipated year-by-year of the maximum luminosity which would result from various planned improvements in accelerator operations.

2.3 PHENIX Input and Assumptions

The detailed parameterizations of anticipated physics yields per recorded luminosity[39] developed in the course of the previous Beam Use Proposal[6] have proven to be sufficiently accurate and flexible for our planning purposes. Accordingly, the same methodology has been applied for this year's request, after appropriate modifications to reflect the updated guidance from CAD. As in the previous request, we have quantified the expected physics for a given integrated luminosity in terms of three characteristic measurements: The number of J/ψ 's measured in the North Muon Arm, the p_T reach for π^0's in the central arms, and the reach in p_T for A_{LL} measured via π^0's (again, in the central arms). The reliability of the estimates for these figures-of-merit has been borne out by all measurements to date.

In the following sections, we have taken as our baseline (where applicable) the geometric mean of the CAD maximum and minimum projections for delivered luminosity per week. The same algorithm was used in our previous proposal prior to Run-4, and under-predicted the actual recorded data set by roughly a factor of two[4]. However, since the guidance has been revised accordingly to reflect the CAD achievements in Run-4, and since this has resulted in a smaller dynamic range between the maximum and minimum projected values, we think it likely that our prescription for using an average of the two remains an appropriate estimator. A similarly conservative approach has been taken when applying the CAD-supplied estimates for possible luminosity growth in latter years. Here we have taken half of the projected growth factors from Runs 6, 7 and 8. Finally, to convert the resulting delivered luminosities to PHENIX-recorded luminosity, we have assumed 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.

[4]We note that in a similar footnote in last year's proposal we stated "PHENIX also found it unrealistic to use the conservative guidance in that it would ignore not only the physical capabilities of the accelerator but also the demonstrated ability of CAD staff to make year-by-year improvements in the delivered luminosity."

3 Beam Use Proposal for Runs 5-9

Table 2: The PHENIX Beam Use Proposal for 31 cryo weeks in Run-5, and 27 cryo weeks in latter years.

RUN	SPECIES	$\sqrt{s_{NN}}$ (GeV)	PHYSICS WEEKS	$\int \mathcal{L}dt$ (delivered)	p+p Equivalent
5	Cu+Cu	200	10	7.0 nb^{-1}	27.6 pb^{-1}
	p+p	200	11	13.1 pb^{-1}	13.1 pb^{-1}
6	Au+Au	62.4	9	111 μb^{-1}	4.3 pb^{-1}
	p+p	200	8	15.0 pb^{-1}	15.0 pb^{-1}
7	p+p	200	20	122 pb^{-1}	122 pb^{-1}
8	Au+Au	200	20	4140 μb^{-1}	161 pb^{-1}
9	p+p	500	20	359 pb^{-1}	359 pb^{-1}
10	d+Au	200	20	91.6 nb^{-1}	36 pb^{-1}

3.1 Executive Summary

Table 2 summarizes the current PHENIX Beam Use Proposal[5]. This plan incorporates the major features from our previous request[6]:

- A light-ion run at 200 GeV, to examine both J/ψ production and jet production and possible quenching in a lighter system.
- Au+Au at 62.4 GeV to investigate the energy dependence of the high p_T suppression pattern observed at 200 GeV.
- Continued development of polarized proton luminosity and polarization leading to a sensitive measurement of the gluon polarization of the proton via 200 (and 500)

[5] For planning purposes, and to avoid "end effects" on the five-year interval, it was found useful to project beyond the range of the Runs 5-9, hence the additional entry for Run 10.

GeV p+p collisions.

- A desire, whenever possible, to match the growth in A+A data with corresponding baseline p+p measurements of comparable sensitivity.

3.2 Revisions from Run 4-8 Proposal

The following revisions have been made to the previous Beam Use Proposal:

1. Our choice for light-ion running is now a species in the mass range of atomic number 50-70. The precise element should be chosen by CAD to provide the highest reliable luminosity; in what follows we use Cu for the sake of definiteness. The reasons for this choice are presented in Section 4.1.1.

2. We have identified the possibility of two "conditional" measurements in Run-5:

   A. A Cu+Cu run at 62.4 GeV

   B. A p+p run at 62.4 GeV.

   The motivations for and the conditions on these items along with their relative priorities are presented in Section 4.1.3.

3. A polarized proton run is now requested in Run-6, which previously had been devoted exclusively to a Au+Au run at 62.4 GeV. The latest CAD guidance now makes it possible to perform the lower energy Au+Au measurement in 9 weeks rather than the 19 weeks based on guidance prior to Run-4. This has the added advantage of providing timely access in Run-6 to the higher polarizations which should be available from the newly-commissioned cold snake in the AGS.

4. We now explicitly mention the possibility of using a portion of Run-7 to pursue beam development for 500 GeV polarized proton operations.

5. The beam energy for the d+Au run in Run-10 has been changed from 62.4 GeV to 200 GeV. Given the very long lead time for this request, this change is largely for illustrative purposes. It is intended to demonstrate the need to re-visit d+Au collisions with much higher luminosities to fully access the heavy flavor signals in cold nuclear matter. The precise allocation of time between 62.4 GeV and 200 GeV can of course be determined at a much later date.

3.3 Physics Yields

Table 3: Physics yields from the PHENIX run plan for 27 cryo weeks per year

RUN	**SPECIES**	$\sqrt{s_{NN}}$ **(GeV)**	**PHYSICS WEEKS**	$\int \mathcal{L}dt$ **(recorded)**	J/ψ **'s N. Arm**	π^0 p_T^{max} **(GeV/c)**	$A_{LL}(\pi^0)$ p_T^{max} **(GeV/c)**
5	Cu+Cu	200	10	2.9 nb^{-1}	9080	19.9	
	p+p	200	11	5.5 pb^{-1}	8830	18.2	7.1
6	Au+Au	62.4	9	47 μb^{-1}	127	10.5	
	p+p	200	8	6.0 pb^{-1}	9760	18.4	8.6
7	p+p	200	20	51 pb^{-1}	81,800	23.7	11.5
8	Au+Au	200	20	1740 μb^{-1}	23,200	24.6	
9	p+p	500	20	151 pb^{-1}	675,000	37.8	18.2
10	d+Au	200	20	38.5 nb^{-1}	15,000	20.5	

The proposed run plan provide a comprehensive investigation of both rare and global processes over the broadest possible range of species. The components include

- Cu+Cu at $\sqrt{s_{NN}}$=200 GeV, to study jet quenching and charmonium production in a lighter system, together with global properties such as flow and strangeness production.
- Au+Au at $\sqrt{s_{NN}}$=62.4 GeV, with sufficient integrated luminosity to investigate the energy dependence of both global and rare phenomena.
- A re-investigation (in Run-8) of $\sqrt{s_{NN}}$=200 GeV Au+Au collisions, to take advantage of both expected enhancements in machine performance and the planned upgrades to the PHENIX detector.
- An aggressive program of development for luminosity and polarization in p+p collisions, followed by production running at both 200 and 500 GeV to measure ΔG over a broad range in x, and quark and anti-quark polarizations in W-production at the higher center-of-mass energy.

Whenever possible, the various running modes in this program have been designed to provide roughly comparable parton-parton luminosities, and thus comparable sensitivities to rare processes. This may be seen by examining the "p+p equivalent" columns of Table 2 and the physics yields columns of Table 3. The integrated luminosities quoted in Table 2 are calculated according to the linear-ramp model provided by CAD and the PHENIX modeling assumptions described in Section 2.3. Additional discussion on the physics motivations for the Run-5 ion-ion and polarized proton request may be found in Sections 4.1.1 and 4.1.2, respectively.

4 Discussion

This section provides specific remarks for the various components of our plan. These will of course be most detailed for the Run-5 discussion, both due to its proximity and because the discussion of Run-5 physics yields is readily extensible to the latter runs by straightforward scaling of the p+p equivalent luminosities[6]. A general discussion of key points and critical observations is provided in Section 4.7.

4.1 Run-5

4.1.1 10 weeks Cu+Cu at $\sqrt{s_{NN}}$=200 GeV

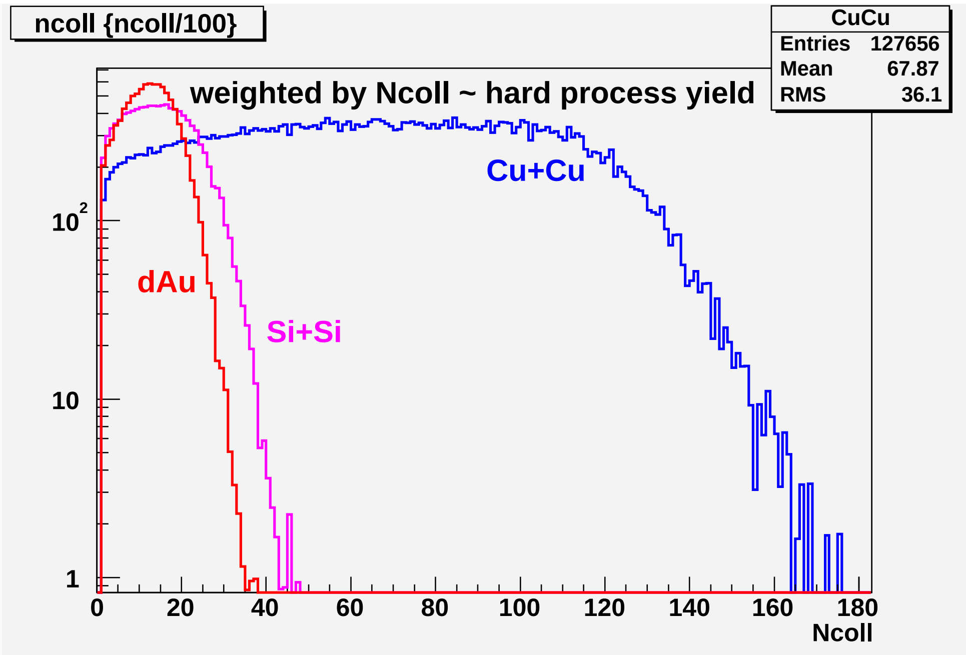

Figure 8: The distribution in the number of binary nucleon-nucleon collisions N_{coll}, weighted by N_{coll}, is plotted for d+Au, Si+Si and Cu+Cu collisions.

The focus in this run is the study of nuclear collisions at the same energy but in a

[6]In this section, all luminosities quoted will be *PHENIX recorded luminosities*; weeks refer to physics production weeks *after* ramp-up and set-up.

significantly smaller system. We have selected Cu for this purpose, in order to provide smooth contact with the lower limit of the number of participants $N_{part} \sim 70$ which can reliably be studied in the most peripheral Au+Au collisions[9]. At the same time, Cu+Cu collisions provide a broad distribution in the number of binary collisions N_{coll}, as shown in Figure 8, where the distribution in N_{coll}, weighted by N_{coll}, is plotted. This weighting, which is directly proportional to the production rate of hard processes, is clearly significantly broader in Cu+Cu than in d+Au or Si+Si collisions, and again will provide maximal overlap with the lower values of N_{coll} probed in Au+Au collisions. These general conclusions are supported by recent work from Grandchamp and Rapp[41], shown in Figure 9, which demonstrates that the range of N_{part} accessible in Cu+Cu collisions is precisely the region in which the different contributions from dissociation and recombination in J/ψ production are most clearly separated.

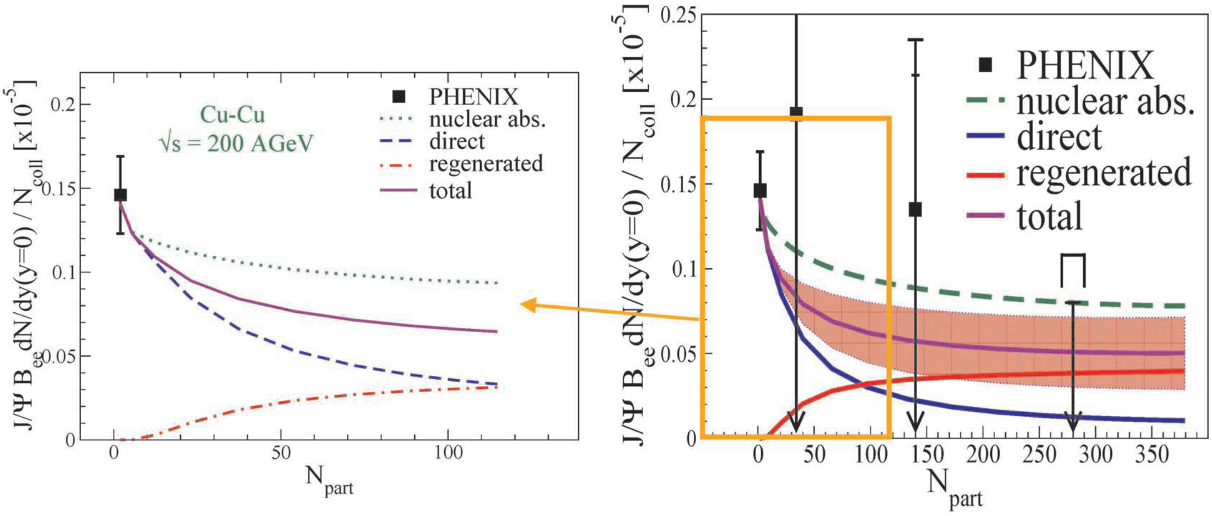

Figure 9: Theory calculations of absorption and recombination contributions to J/ψ yields per binary collision in Au+Au collisions versus the number of participants[40] compared to PHENIX Run-2 data[23] (right-hand plot) and predictions of same for Cu+Cu collisions[41].

Our implementation of the CAD guidance predicts a PHENIX recorded luminosity of 2.9 nb^{-1}, equivalent to a p+p sample of 11.6 pb^{-1}. This parton-parton flux is slightly larger than that of the Run-4 Au+Au data sample, thereby permitting direct comparisons to a rare probes in this lighter system, as well as the corresponding global features such as flow and strangeness production.

4.1.2 11 weeks p+p at 200 GeV

Following the proton development work in Run-4, this is anticipated as the first major spin physics production run. We have assumed that the average polarization will be 45%, as per the CAD guidance. Combined with the predicted luminosity growth, this provides a PHENIX recorded luminosity of 5.5 pb^{-1} leading to a more than a factor of 100 improvement in $\mathcal{P}^4 \int \mathcal{L}dt$ over the Run-3 result shown in Figure 5. Our goal is to make the first high sensitivity physics measurements of the gluon polarization using $A_{LL}(\pi^0)$ in central rapidity. This channel is presently the most sensitive accessible probe of the magnitude of the gluon polarization. It is expected that this measurement will have a major impact.

The complete set of observables to be examined by PHENIX in Run-5 include

1. A_{LL} *of neutral pions*, first measurement of the magnitude of polarized gluon distribution.
2. A_{LL} *of charged pions,* which play an important role in understanding the sign of the gluon contribution. Run-5 will be an exploratory measurement leading to a physics measurement in Run-6.
3. *Direct-photon cross section* measurement and possibly a first look at $A_{LL}(\gamma)$.
4. *An exploratory measurement* of single (inclusive) electrons, which will lead in future to the *charm physics* program in PHENIX.

We wish to emphasize the importance of developing adequate integrated luminosity and polarization for these measurements. The value of 5.5 pb^{-1} for recorded integrated luminosity is based on our standard geometrical mean of the minimal and maximal guidance. The corresponding value for the maximal guidance is 10 pb^{-1} , a value we have identified as of particular value in making a clear distinction between contributions to the double-spin asymmetry from g+g versus g+q. Note in particular that measurements at higher momenta $p_T >$ 6-8 GeV/c are dominated by g+q scattering, and therefore are sensitive to the sign of the gluon polarization, as opposed to the g+g mechanism dominant at lower momenta, where of course the sign if the gluon polarization is squared and therefore not accessible.

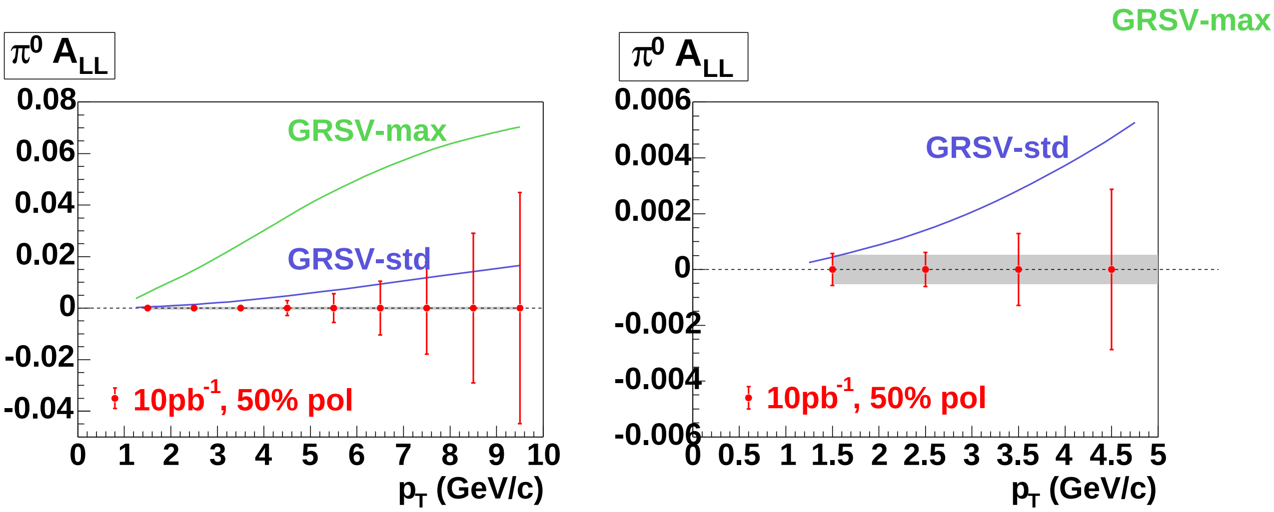

Figure 10: Left: Expected statistical precision versus transverse momentum of the double spin asymmetry measured in π^0 production from 10 pb^{-1} of polarized p+p collisions at central rapidity. Right: An expanded view of the low-momentum region of the left-hand plot. The shaded area indicates the region $p_T <$ 6 GeV/c which is expected to be dominated by contributions from g+g scattering.

The R&D aspect of the run, developing luminosity and polarization in a longer run, is also of great importance. The cold (superconducting strong snake) will be installed and commissioned during Run-5, although it is not anticipated by CAD that it will be available for polarization increase in RHIC during this run. However, we have modified our previous Beam Use Proposal to include polarized proton running in Run-6, predicated on the success of this Run-5 commissioning effort.

4.1.3 Conditional Requests

As mentioned in Section 3.2, we have two conditional requests for Run-5, subject to achieving integrated luminosity targets in our primary request:

A. A Cu+Cu run at 62.4 GeV

B. A p+p run at 62.4 GeV.

The motivations, conditions and caveats for each of these supplemental requests are presented below.

Cu+Cu running at $\sqrt{s_{NN}}$ = 62.4 GeV: The motivation here is clearly one of program efficiency. Once the accelerator is in production-mode for Cu+Cu collisions at $\sqrt{s_{NN}}$ = 200 GeV, the 2-3 days change-over time to running at $\sqrt{s_{NN}}$ = 62.4 GeV is small compared to any set-up time necessary to revisit at some later date this species at a reduced energy. In our model using the geometric mean of the minimal and maximal guidance, RHIC is projected after the 8-week luminosity ramp to deliver $\sim$1 nb^{-1} per week at 200 GeV, which would translate to $\sim$0.1 nb^{-1} per week at 62.4 GeV. This would permit a measurement of comparable sensitivity to the Au+Au 62.4 GeV in approximately one week of production running. PHENIX would advocate such a period of running, **conditional** upon our achieving our request of (*at least*) 2.9 nb^{-1} recorded luminosity of Cu+Cu at $\sqrt{s_{NN}}$ = 200 GeV.

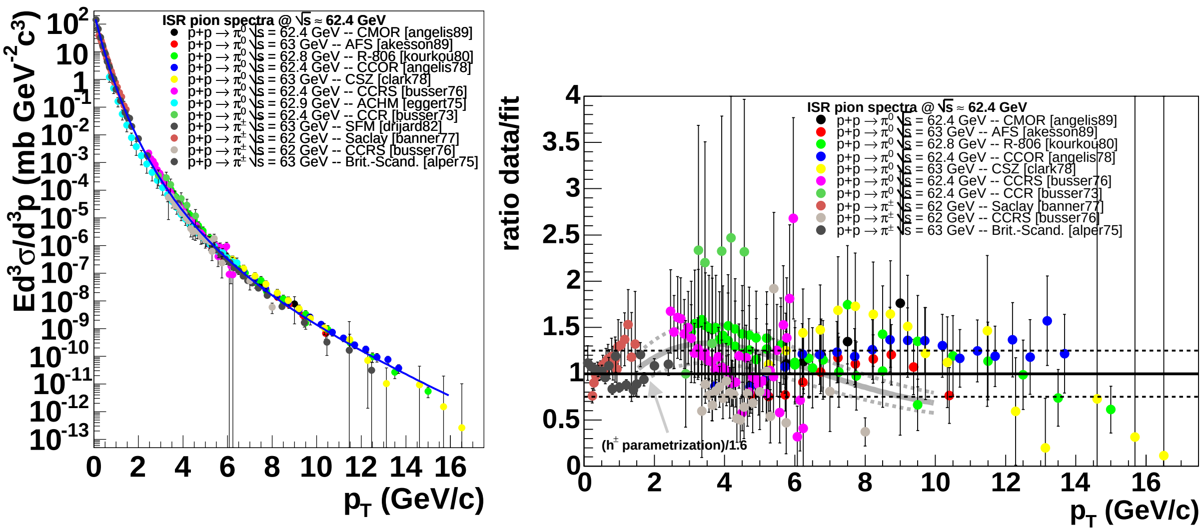

Figure 11: Left: World's data for $p + p \rightarrow \pi^0 + X$ at $\sqrt{s}$=62.4 GeV. Right: The ratio of the individual data sets to a global fit.

p+p running at $\sqrt{s_{NN}}$ = 62.4 GeV: This supplemental request is driven by the uncertainties in the world's data set for particle production at 62.4 GeV. As shown in Figure 11, there are substantial discrepancies between the various data sets measured at the ISR. Even after significant efforts at removing outlying data and post-correcting the ISR results for contributions from η's and direct photons, the residual uncertainties in the yields are the dominant source of systematic error in calculating the nuclear modification factor R_{AA} at 62.4 GeV (Figure 12). Note also that because the deviations are p_T-dependent, they can mimic true physics effects such as the Cronin enhancement. Similar

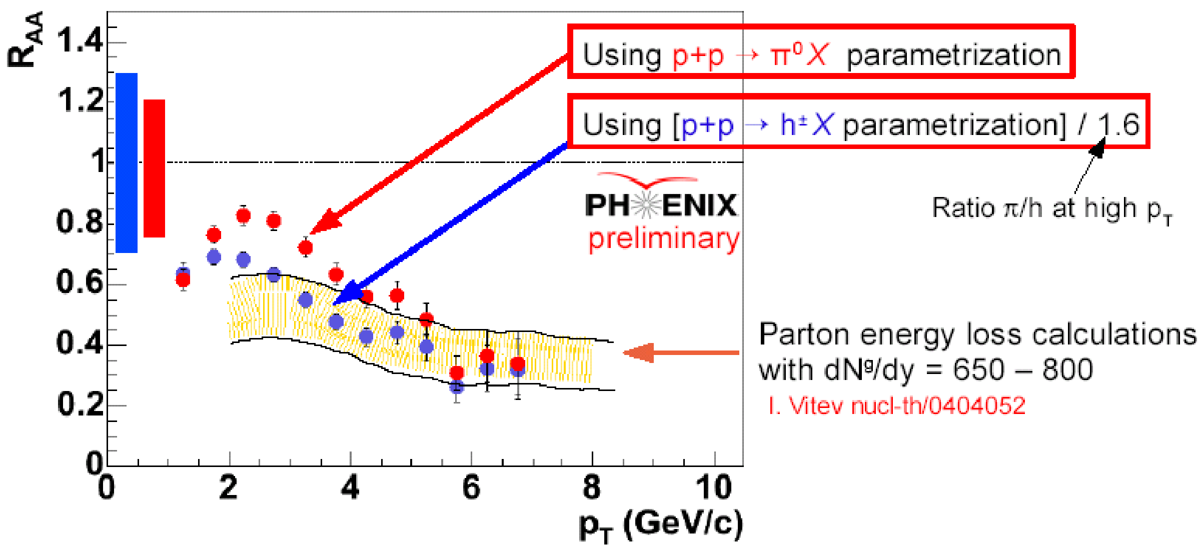

Figure 12: The change in the nuclear modification factor R_{AA} due to two different parameterizations of the world's data on pion production at 62.4 GeV.

uncertainties exist for data on the production of charged hadrons, which do not extend beyond $p_T \sim 3$ GeV/c (and were also measured slightly away from mid-rapidity).

It is clear that the precision study of nuclear modification factors which has been one of the hallmarks of the RHIC heavy ion program at $\sqrt{s_{NN}} = 200$ GeV will not be possible without a corresponding quality p+p data set measured in the same detectors. This motivates our request for a period of p+p running at 62.4 GeV, **conditional** upon a) completion of all necessary machine studies for luminosity and polarization development in Run-5 and b) the timely achievement of (*at least*) our minimal goals for polarized proton running in Run-5, i.e., 5.5 pb^{-1} with an average polarization of 45%. The potential to perform an effective measurement at the lower energy will depend critically on the ability of the accelerator to deliver near the maximal guidance. This is necessary both to achieve our requested goal for 200 GeV in less than the projected 11 weeks, and to demonstrate the capability of operating at 62.4 GeV near the upper end of the estimated 0.1 to 0.3 pb^{-1} per week for delivered luminosity[42]. Operation at 0.3 pb^{-1} per week would provide a comparison data set of the desired sensitivity in 2-3 weeks of running.

We have listed the two conditional requests in their potential time order. However, we wish to stress that a significantly greater *physics* priority is attached to the request for p+p running at 62.4 GeV, in that it is the comparison baseline for any additional studies at this energy. Since it is our position that a rigorous examination of all accessible probes at a second energy will be essential to understanding the discoveries made in Au+Au collisions at 200 GeV, failing to achieve a p+p reference sample of the requisite precision in Run-5 would necessitate modifications to our requested program in future years.

4.2 Run-6

4.2.1 9 weeks of Au+Au at $\sqrt{s_{NN}}$=62.4 GeV

As noted in Section 3.2, the revised CAD guidance now makes it possible to achieve our goal of $\sim$50 μb^{-1} recorded integrated luminosity in 9 weeks rather than last year's requested 19 weeks. Here again we are optimistic that values considerably higher than this value can be achieved, given the outstanding performance in Run-4 at 62.4 GeV. The goal would be to achieve a physics sensitivity an order-of-magnitude beyond what was obtained in the first measurement of Au+Au collisions at $\sqrt{s_{NN}} = 62.4$ GeV. This is consistent with our long-standing program to map each system with comparable levels of the parton-parton integrated luminosity. It will be crucial to understand in the greatest possible detail how the "discovery" phenomena measured at 200 GeV manifest themselves at another energy. Given the smooth evolution of all parameters studied to data with energy, PHENIX prefers an intensive study at one other energy, rather than an extensive series of superficial measurements at a variety of energies.

4.2.2 8 weeks of p+p at 200 GeV

This requested segment takes advantage of the cold snake commissioning in Run-5 to provide an extended period of polarized proton running at the substantially higher polarizations (65% versus 45%) it provides. By modifying our previous Beam Use Proposal to incorporate this run segment, we also accommodate the strongly expressed desire from CAD to have an annual period of polarized proton machine development and running. The improved luminosity and polarization leads to a factor of 5 improvement in the figure of merit $\mathcal{P}^4 \int \mathcal{L}dt$ over the requested Run-5 data set, and also provides momentum towards the following year's definitive measurement of polarized protons at 200 GeV.

4.3 Run-7

Our plan calls for dedicated production running for spin, i.e., the full period of 20 weeks used for p+p collisions at 200 GeV. The projected improvement in the figure of merit by another factor of nearly 5 over the Run-6 result should provide a superb measure of A_{LL} via π^0's as well as results on the same quantity via direct photons. These measurements, together with measurement of charm yields via both electron and muon channels, will allow an extraction of the gluon polarization ΔG with an unparalleled variety of probes.

It is also likely that we would call for a portion of this running period to be used for machine development work for operations at 500 GeV. This is clearly necessary prior to the requested first physics run at this energy in Run-9. It is also possible that even modest luminosities at this higher energy could lead to an improved understanding of the gluon polarization by varying the range of x. Finally, we note that any first examination of machine backgrounds at this higher energy would be most advantageous towards developing a trigger strategy for a subsequent dedicated physics run.

4.4 Run-8

We envisage a return to full energy Au+Au running, with the goal of exploiting the anticipated luminosity improvements in RHIC to substantially increase sensitivity in rare channels, even over the very robust Run-4 data set. However, the improved sensitivity is best realized in conjunction with the proposed upgrades[43] to the PHENIX detector, which will provide PHENIX with very substantial additional capabilities for charm measurements (via a Si-vertex counter) and low-mass dileptons (via a Hadron Blind Detector), greatly extending our understanding of in-medium effects in Au+Au collisions at RHIC. The precise scheduling of this high-luminosity Au+Au measurement will of course depend on the availability of these new systems.

4.5 Run-9

Continuing the pattern of dedicated runs to pursue rare physics, our plan calls for extended spin running at 500 GeV. The large integrated luminosity developed during this dedicated run, together with the high center-of-mass energy, will permit measurement of sea quark polarization via $W^{\pm}$ production. (A proposal for an improved muon trigger for W's is currently under preparation for submission to NSF, again the scheduling of this run will depend on the deployment of this trigger.)

4.6 Run-10

It should be clear from the above that the resolution of any beam use plan for five years in the future is extremely coarse. For illustrative purposes only, we have proposed a second, high-luminosity run with d+Au at 200 GeV, again with the goal of developing parton-parton integrated luminosity commensurate with the very robust Au+Au data sets that will be available in this period. As noted in Section 3.2, it may also be desirable to perform a portion of this running with d+Au at 62.4 GeV, a scenario consistent with the general argument that the low overhead for changing energies makes such a combined pair of segments quite efficient.

4.7 Discussion Summary

It is appropriate to augment the specific discussion of the previous section with some general observations derived from this multi-year planning process. We provide some of these below in itemized form:

- *The first, most obvious and most urgent point is that a steady-state situation of only 27 weeks of cryogenic operations will have a large and negative impact on the overall physics productivity of RHIC.* We note that even in the extended scope of this proposal, it is not possible to accommodate the entire spectrum of additional measurements (e.g., Si+Au, Si+Si, d+Cu) that could be of interest. Nor is it possible to achieve the goals for integrated luminosity in polarized operation originally envisaged by the RHIC Spin Collaboration. While world-class physics is produced by the 27 week scenario, the most efficient realization of the true potential of RHIC results for running periods of 32-37 weeks per year.
- To maximize the discovery potential so evident in the first four years of RHIC operations, it is advantageous to pursue each running mode to the limit of available luminosity, and whenever possible to balance the integrated luminosities between

modes to develop equivalent parton-parton flux (and thus p_T reach) in all comparison data sets.

- Momentum must be maintained not only for continued improvements in polarized operations at 200 GeV, but also towards early exploration of operations at 500 GeV. Again, this goal is severely threatened by "constant effort" budgets in the out-years of this proposal.

We conclude with a brief statement regarding upgrades. This is already an ongoing process in PHENIX, as is apparent from the discussion in Section 1.1 of added capabilities provided by the aerogel detectors added for Run-4. There is also an active R&D program[43] developing detailed proposals for Si-vertex detectors, a Hadron Blind Detector, an inner TPC, and a greatly enhanced muon trigger. The availability of these significant additions to PHENIX depend on the R&D efforts, the proposal process, and the subsequent funding. We have attempted to incorporate the planned delivery of these items into our planning process, but also realize that the detailed time sequence is subject to many as yet unknown constraints. The run plan developed here is possible without these additional systems[7], but made even more compelling should any or all of them become available over the scope of this plan.

[7] The muon trigger is an exception to this statement; it will be essential for efficient triggering in high luminosity p+p running at 500 GeV.

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