PHENIX Beam Use Proposal for RHIC Run-6 and Beyond

The PHENIX Collaboration

10-Oct-05

Abstract

A program of decisive measurements is proposed 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. Emphasis is placed both on the systematic development of data-sets of sufficient statistical precision to eliminate current ambiguities in the field, and on the need to extend various baseline measurements to complement existing data sets. Information on the current status of the experiment, on the data sets recorded to date, and on the program of proposed upgrades is also provided.

Executive Summary

The PHENIX Collaboration proposes a continued scientific program of increased precision based on the development of the highest possible luminosities in ion-ion, “proton”-nucleus and polarized proton collisions. Building on the successes of Runs 1-5, the requested running conditions for heavy ions are designed to extend the discovery potential at RHIC via extended measurement of rare probes and hard processes in the heaviest colliding system at the highest energy combined with corresponding baseline measurement in d+Au and p+p collisions. 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 lead to dramatic advances beyond the current results. For both programs, the emphasis in Runs 6-10 is on achieving maximum physics sensitivity via accumulation of data-sets with an order-of-magnitude increase in integrated luminosity over current values. 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 goals of the PHENIX Collaboration for future RHIC running have been clearly delineated in our previous Beam Use Proposals and in presentations to the Program Advisory Committee[1, 2, 3, 4, 5, 6, 7]. The consistent theme that emerges is the need to develop the highest possible integrated luminosities (and polarizations in the case of p+p running) to explore fully the range of fundamental phenomena in the nucleus+nucleus, "proton"+nucleus and proton+proton collisions at RHIC energies. The requested program has been designed to provide incisive measurements necessary to understand the spin structure of the proton and the nature of nuclear matter at the extremes of temperature and density, while performing the necessary baseline measurements for both the spin and the heavy ion programs. Every effort has been made to insure that PHENIX's triggering, data acquisition and archiving abilities meet or exceed those necessary to sample fully the delivered luminosity. A similar effort has been made to provide timely analysis of these data-sets using not only the RHIC Computing Facility (RCF), but also the very significant computing resources from PHENIX institutions in the United States (LLNL, New Mexico, ORNL, Vanderbilt), Japan ("CC-J") and France ("CC-F").

In this Beam Use Proposal we provide an update to our previous request[7]. We focus specifically here on Run-6 in light of ever-improved accelerator performance from RHIC (and ever-refined guidance on same from the Collider-Accelerator Department). The proposed program for Run-6 completes previous explorations necessary to make contact with results at lower energies, extends our physics reach in Au+Au collisions at the highest energies, and advances our understanding of single-spin asymmetries. We propose in Run-7 and beyond a continuing program based on systematic accumulation of increasingly rich data-sets in combination with a planned series of upgrades to greatly extend the physics reach in both the heavy ion and spin program.

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 (Additional Experimental Equipment) systems for Run-3 to a significantly enhanced detector for Runs 4, 5 and 6. A program of strategic upgrades will continue and indeed accelerate this continuing extension of PHENIX's capabilities in Run-7 and beyond.

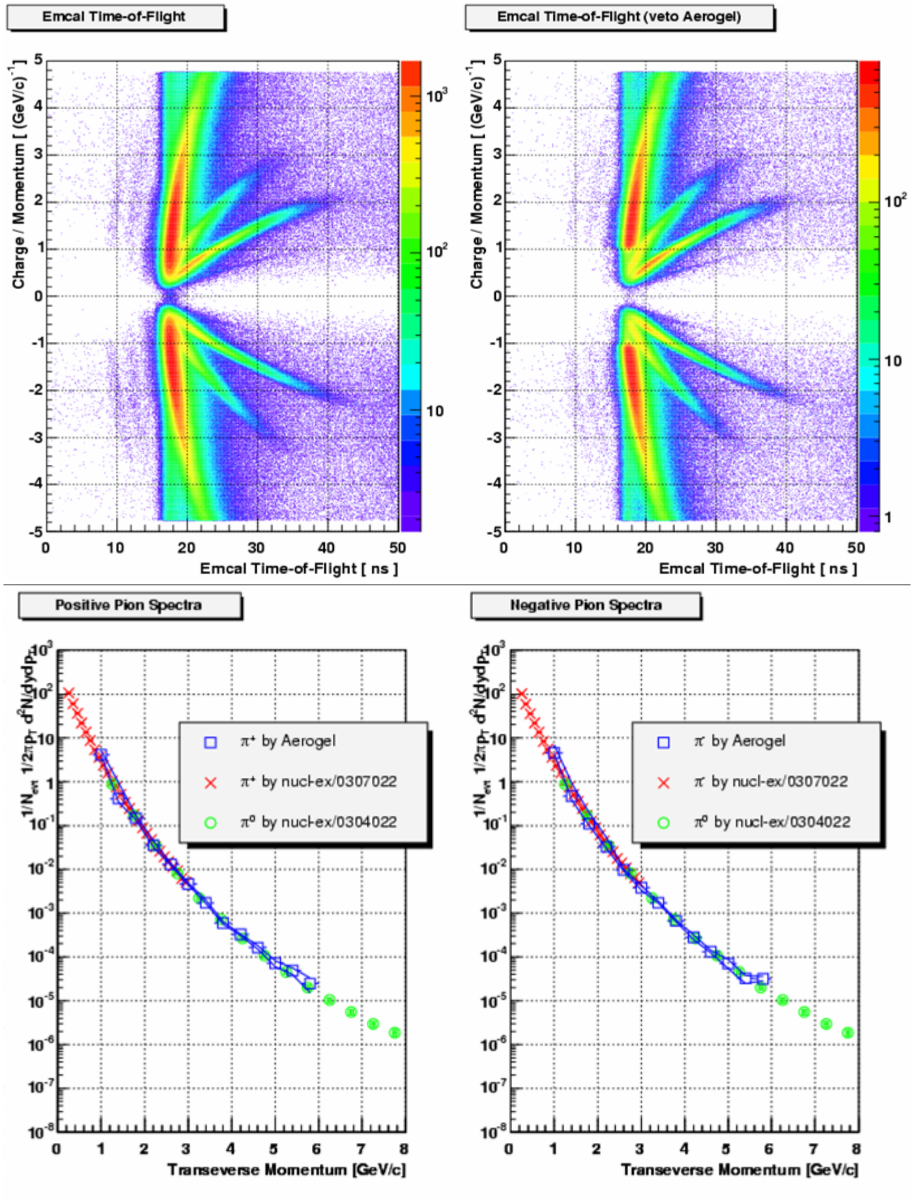

Figure 1: Top: Charge/momentum versus time-of-flight without (left) and with (right) a veto on the signal from the Aerogel subsystem. Note the removal of the pions for values of charge/momentum corresponding to momenta > 1 GeV/c. Bottom: Pion p_T spectra in Au+Au collisions showing the extended range (blue) for charged particles provided by the Aerogel subsystem.

Specific improvements to PHENIX in Run-5 included

- Installation and operation of the Aerogel sub-system, allowing charged particle identification up to ~ 6 GeV/c (see Figure 1).

- Installation and testing of prototype time-of-flight sub-system using multi-gap resistive plate chambers (RPC's) to provide full π/K/p identification to $\sim$ 9 GeV/c.
- Operation of all front-end electronics with multi-event buffering, combined with very significant advances in the Event Builder architecture, further extending PHENIX's world-record data acquisition throughput (see Figure 2).
- On-line filtering of Level-2 tagged events to provide fast-track analysis streams for rare probes (leading to physics results presented at Quark Matter '05).

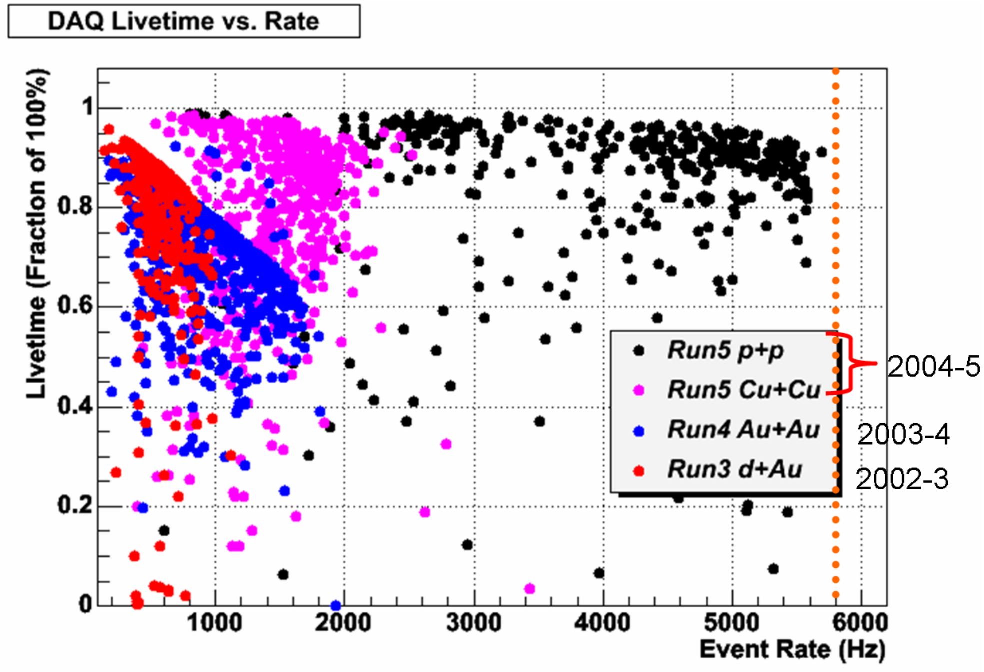

Figure 2: Evolution of the PHENIX Data Acquisition System performance over the past three RHIC runs.

The great increase for Run-5 in PHENIX's ability to record data is illustrated in Table 1, which shows the statistics on the total number of events, total archived data volumes, and integrated luminosities achieved by PHENIX in Runs 1 through 5. During the 200 GeV p+p portion of RHIC Run-5 the PHENIX DAQ system recorded data at event rates in excess of 5000 events/s while remaining at a livetime of greater than 90%.

The following should be noted regarding the values shown in Table 1: For each dataset 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*

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

Table 1: Summary of the PHENIX data sets acquired in RHIC Runs 1 though 5. All integrated luminosities listed are *recorded* values.

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

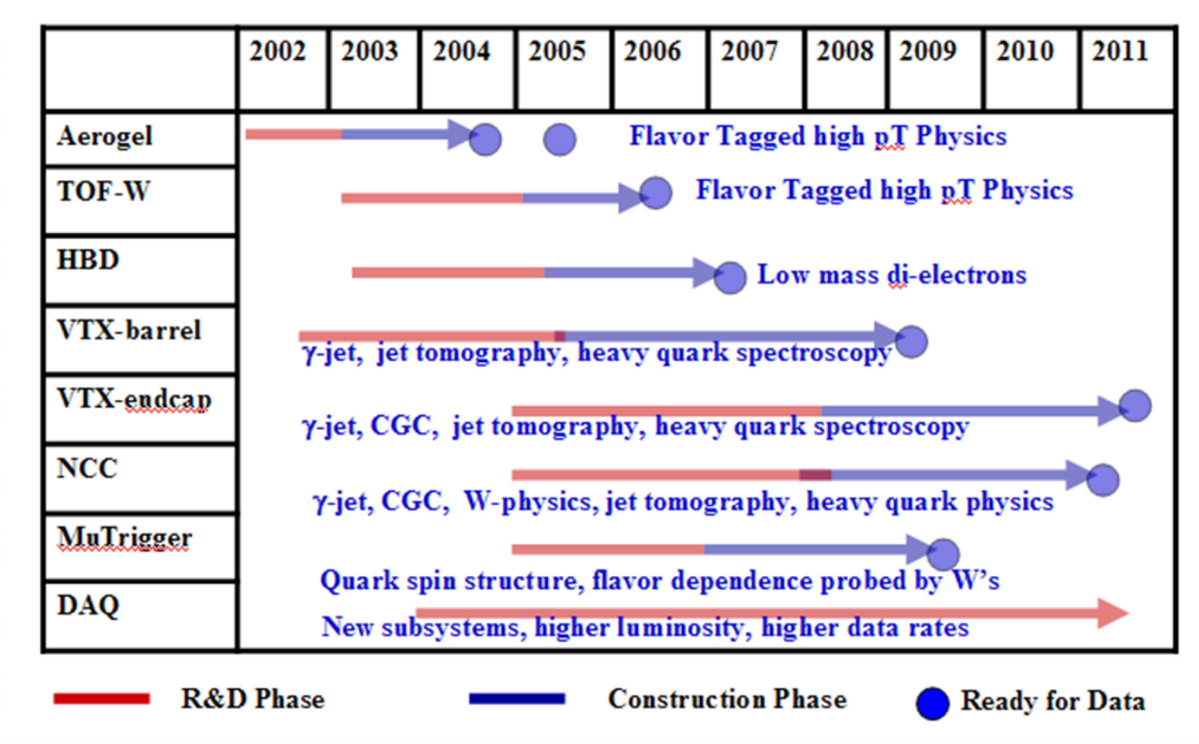

Figure 3: The technically-driven schedule for planned PHENIX upgrades together with physics extensions provided by same.

1.1.1 Upgrades in Run-6 and beyond

The TOF-West will be installed in the fall, commissioned during the early part of Run-6, and fully operational as Run-6 progresses. We will also be testing the Hadron-Blind Detector (HBD), which will greatly extend PHENIX's ability to measure low-mass e^+e^- pairs as probes of thermal radiation, chiral symmetry restoration and medium modifications to hadron properties. The HBD prototype will also be installed in the fall and commissioned with the final detector support systems during early Run-6. When the production HBD (with CsI-coated GEM sensors funded by the NSF and the Weizmann Institute in FY06) becomes available in the middle of Run-6, we plan to install a subset of the detector during machine maintenance periods to complete a comprehensive HBD engineering run in Run-6. This approach will enable PHENIX to have the first physics run of the high p_T detector (Aerogel+ TOF-W) in Run-6 and the first physics run of the

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[1] Note that 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.

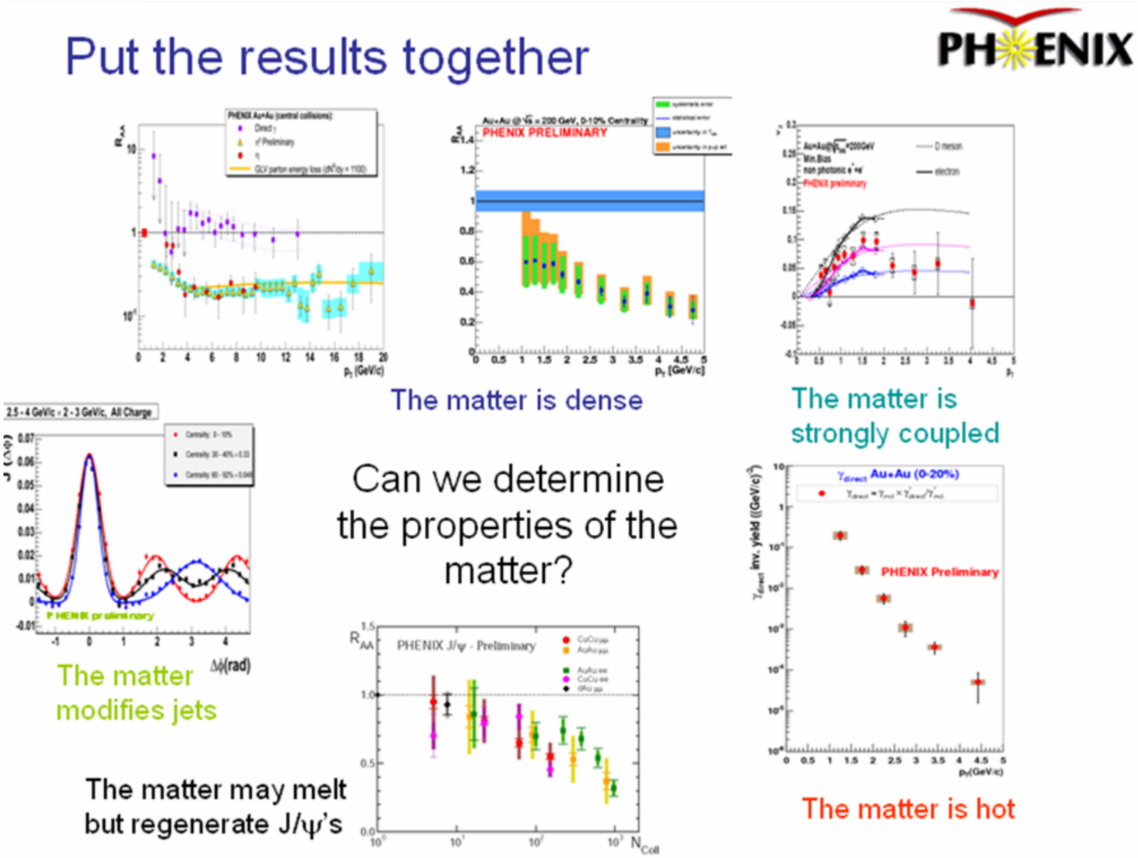
complete Hadron Blind Detector in Run-7.

The TOF-W and HBD detectors are elements of a coordinated series of planned upgrades to the PHENIX detector designed to improve its sensitivity and extend its physics reach for both heavy ion and spin physics[8]. As shown in Figure 3, a program of phased upgrades is being planned. In addition to those sub-systems already discussed, it includes

- **VTX-barrel**, an inner silicon pixel and strip detector in the central region of PHENIX (anticipated as part of the DOE FY07 budget, and with ∼$3M of existing funding from RIKEN).
- **VTX-endcap**, a silicon mini-strip detector to cover the muon-arm apertures (prototype funded as a LANL LDRD).
- **Nose-Cone Calorimeter (NCC)**, a Si-W calorimeter replaces the current PHENIX "nose-cones" in the region $0.9 < |\eta| < 3.0$.
- **MuTrigger**, a set of RPC stations that will provide a clean trigger on the highest p_T muons from W decays, and improve the pattern recognition capabilities of the muon spectrometers (approved and funded as an MRI by the National Science Foundation).
- **DAQ**, a program of ongoing improvements to the PHENIX Data Acquisition system.

1.2 Status of PHENIX Physics

1.2.1 Heavy Ion Physics from Runs 1-5



Put the results together

The matter is dense

The matter is strongly coupled

Can we determine the properties of the matter?

The matter modifies jets

The matter may melt but regenerate J/ψ's

The matter is hot

Figure 4: Summary from the "Focus" talk[10] on PHENIX results presented at Quark Matter 2005 .

The PHENIX “White Paper”[9] provides a comprehensive review of the PHENIX results from Au+Au, d+Au and p+p baseline collisions in RHIC Runs 1 to 3. Rather then repeat its arguments here, we will instead focus on characteristic measurements from the Run-4 and Run-5 heavy ion program as points of reference for our proposed program.

1.2.2 Results from Runs 4 and 5

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 our previous Au+Au data sets.

First results from that data set were presented at Quark Matter 2005 in August, and formed the basis for the "PHENIX Focus Talk" presented on the last day of the conference, and, as shown in Figure 4, highlighted the new results from both Run-4 and Run-5 on jet properties, heavy flavor suppression and flow, J/ψ yields and direct photons[10].

A concerted effort was made by PHENIX not only to analyze the entire Run-4 data set for Quark Matter 2005, but to also perform data production and analysis on the Run-5 heavy ion data sets (Cu+Cu collisions at $\sqrt{s_{NN}} = 200$, 62 and 22 GeV). This was achieved by starting production in February, 2005, roughly midway the full-energy Cu+Cu running period. Both the Level-2 filtering and the online calibrations tasks were sufficiently automated that these tasks were performed by the shift crews as part of routine operations. A multi-pronged strategy was deployed, using computing resources in the PHENIX counting house (calibrations, Level-2 filtering), RCF (reconstruction of minimum bias streams) and off-site resource (all Level-2 triggered data were reconstructed at the the computing farm of the PHENIX ORNL group.) In addition to providing timely release of physics results at the Quark Matter meeting[2], the quasi-realtime aspect of this production effort provided superb feedback on the quality and physics content (for example J/ψ yields) during the actual course of Run-5.

To assess the physics content of the more than 100 new data plots presented by PHENIX at Quark Matter 2005, we recapitulate here the main points made in the "PHENIX Focus Talk", while noting that this represents only a small subset of the results presented in the 18 PHENIX talks at the conference:

- **The matter is so opaque that even a 20 GeV/c π^0 is stopped.** This is illustrated in Figure 5, which shows that the large suppression for π^0's extends to the highest measured momenta. The common pattern observed for η mesons strongly suggests that this suppression is established at the partonic phase, while the near-unity value of the direct photon yield demonstrates that the binary scaling from p+p yields to the Au+Au system is well-calibrated.
- **The matter is so dense that even heavy quarks are stopped.** Figure 6 shows that the strong suppression extends to single electrons from the semi-leptonic decays of heavy flavor (predominantly charm in this p_T range).

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[2] An equally important effort (described later in this section) using the resources of the RIKEN computing center in Japan was made to complete the production for the Run-5 p+p data-set in time for presentation at the October 2005 PANIC meeting.

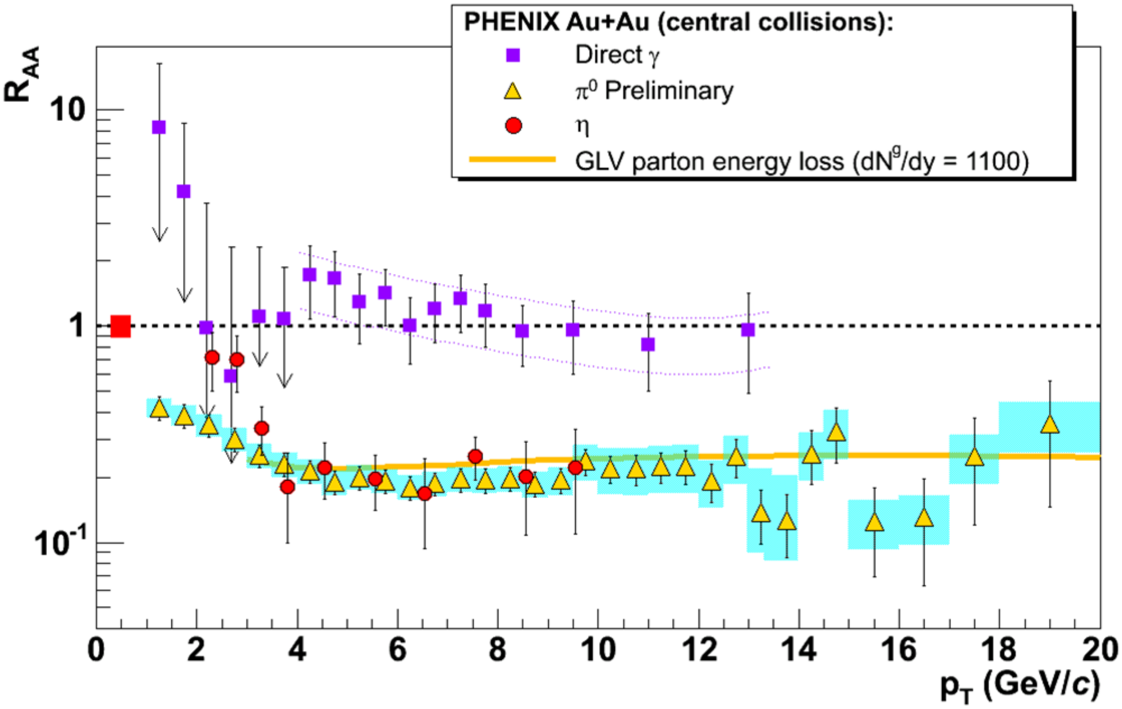

Figure 5: Preliminary results on the nuclear modification factor R_{AA} as a function of transverse momentum for π^0's, η's and direct photons from central Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV.

- **The matter is so strongly coupled that even heavy quarks flow.** The analysis of the flow properties of single electrons provides clear evidence for a non-zero value of v_2 (Figure 7), indicating substantial coupling of the charm quarks to the bulk dynamics of the medium.

- **The matter is so hot that it emits (thermal?) photons copiously.** A new analysis using low-mass virtual photons (measured as electron pairs) suggests an enhancement of the photon yield above that expected from pQCD in the region $p_T < 3$ GeV/c (Figure 8). Models assuming thermal radiation from a quark-gluon plasma are able to reproduce this excess.

- **The matter is so dense that it melts(?) J/ψ 's (and regenerates them?)** New results from PHENIX show that while J/ψ 's are suppressed in Cu+Cu and Au+Au collisions, the suppression is considerably less than what would be expected from extending screening models developed for SPS energies. In contrast, models which provide for J/ψ regeneration via a recombination mechanism[11, 12, 13, 14] show qualitative if not quantitative agreement with the data.

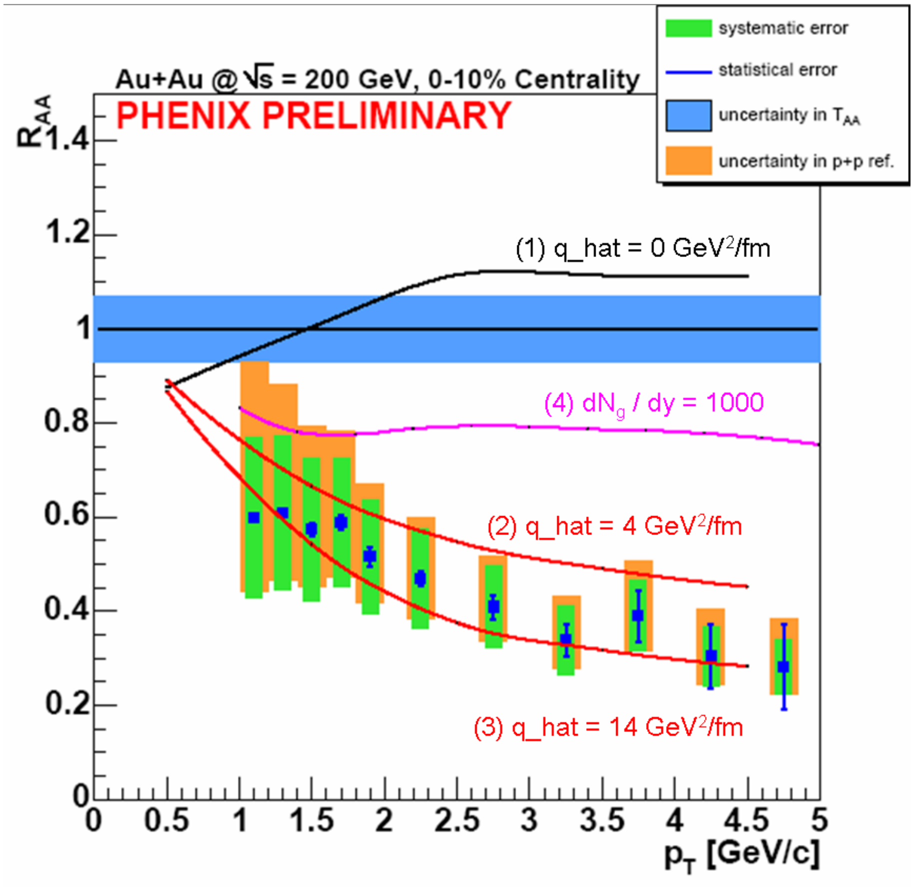

Figure 6: Preliminary results on the nuclear modification factor R_{AA} for single electrons as a function of transverse momentum from central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

- **The matter is so dense that it modifies the shape of jets.** PHENIX established early in the RHIC program that the yield of high p_T particles was suppressed[15]. New results show modest changes to the *shape* of the near-side jet, but dramatic modifications to the away-side shape (Figure 10).

This sampling of the physics derived from RHIC Runs 4 and 5 is indicative of the tremendous discovery potential provided by the PHENIX program of rare probes accessed via physics-sensitive triggers coupled with a world-leading high bandwidth data acquisition system. At the same time, it should be noted that the distributions shown in Figures 5 through 10 in most cases represent the full statistics available from the analysis of the data sets tabulated in Table 1. The need to advance these discoveries as rapidly as possible to the next level of sensitivity determines the strategy of the beam request to follow in this proposal.

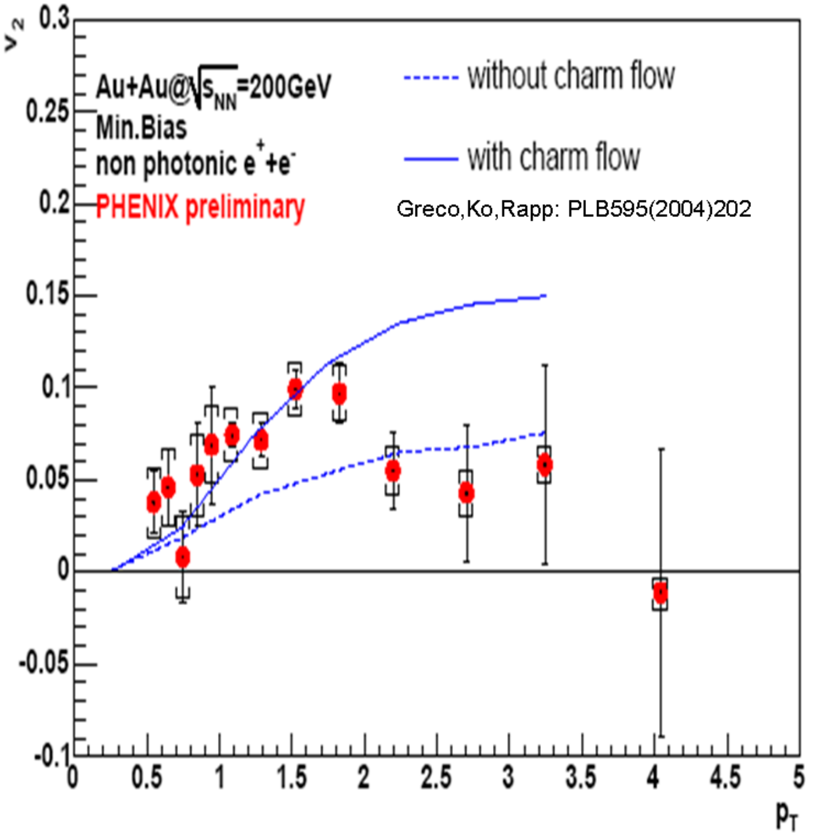

Figure 7: Preliminary results on the elliptic flow coefficient v_2 for single electrons as a function of transverse momentum from central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

1.2.3 Spin Physics from Runs 3-5

Run 3: The Run-3 polarized proton run obtained an average luminosity of 3×10^{30} cm^{-2}s^{-1} and mean polarization values of 27%. In this 10 week run PHENIX recorded 0.35 pb^{-1}, and achieved the following milestones:

- Commissioning of the PHENIX Spin rotators to obtain and confirm longitudinal polarization using the ZDC/SMD based local polarimeter (realized utilizing the analyzing power in very forward neutron production in single spin pp scattering) leading to fill by fill monitoring of the proton spin direction during collisions.

- Established that A_{LL} of the luminosity monitor in PHENIX (BBC) is consistent with zero within the measurement accuracy of $\delta A_{LL} < 2 \times 10^{-3}$.

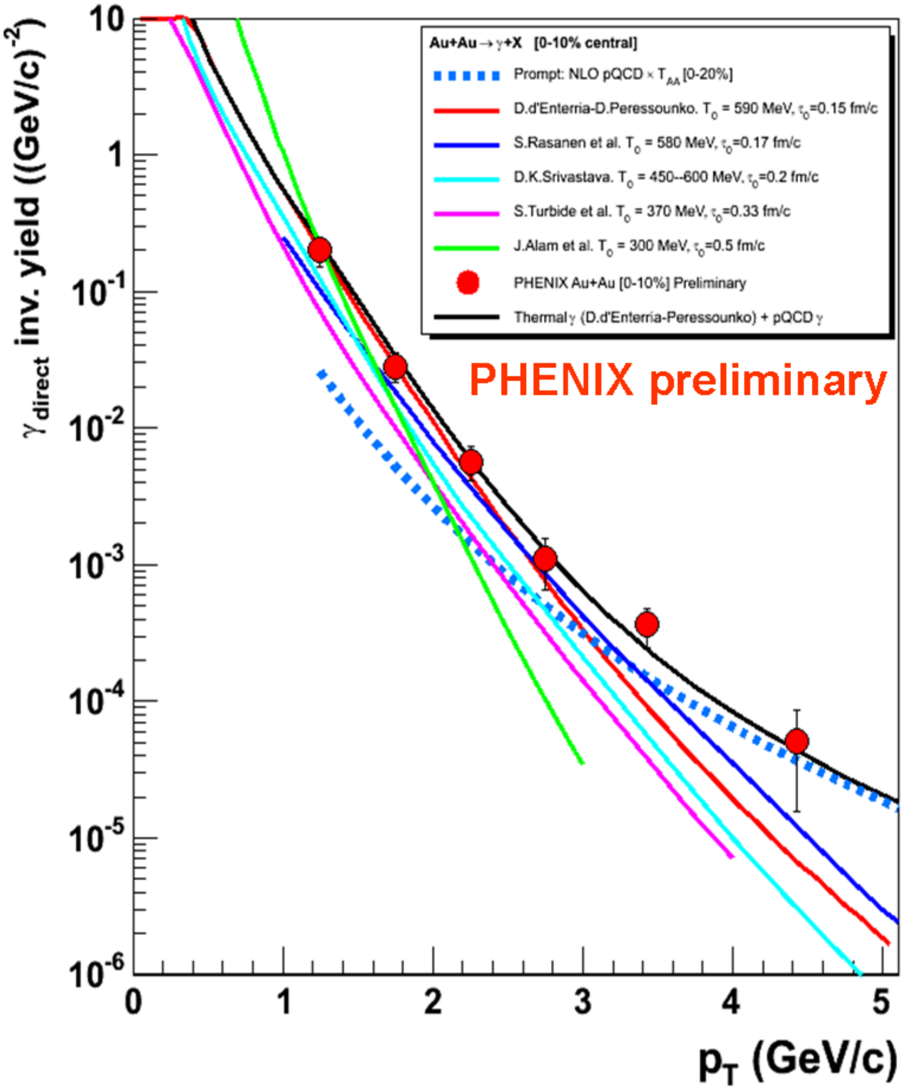

Figure 8: Preliminary results on the yield of virtual photons measured via low-mass electron pairs as a function of transverse momentum from central Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. The results are compared to the contributions from pQCD and various models of thermal production from a quark-gluon plasma.

- Comparison of relative number of hits (bunch-to-bunch) from BBC and ZDC, established that relative luminosity uncertainty for Run-3, $\delta(L_{++}/L_{+-})$, was less than 2.5×10^{-4}.

- First measurement[16] of $A_{LL}(\pi^0)$, $A_L(\pi^0)$. This result, obtained at mid-rapidity and low p_T is nonetheless of fundamental importance since $A_{LL} \sim (\Delta G/G)^2$. The enormous potential of the RHIC collider to measure and control systematic uncertainties by mixing bunch crossings (++, +-, -+, –) was demonstrated in this

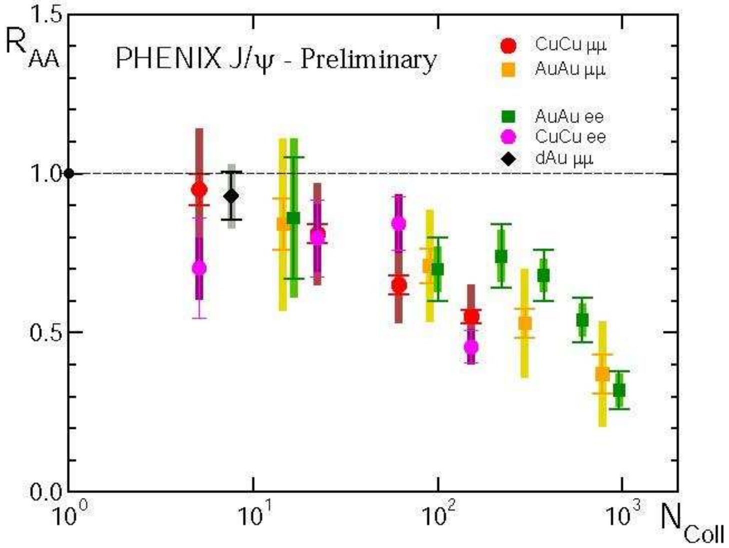

Figure 9: Preliminary results on the yield of J/ψ 's from d+Au, Cu+Cu and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV as a function of the number of binary collisions N_{Coll}.

measurement, and comparisons to NLO pQCD results for large and small $\Delta G(x)$ were made.

- Studied backgrounds both for future muon trigger upgrade and for the (now implemented) background shielding plan.
- In progress: exploratory cross section measurements of direct photons, electrons, muons, J/ψ .

The first measurement of $A_{LL}(\pi^0)$ was published in Physical Review Letters[16]. The data seem to prefer a small value of $\Delta G/G$ at $x \sim$ 0.03-0.1. It has been argued that the sensitivity to $\Delta G/G$ from this result is already at level of that coming from global fits to spin structure function data obtained by DIS experiments over the last 30 years[17].

Run-4: The primary goal of polarized proton running in Run-4 was to provide 6 weeks of R&D towards understanding (and overcoming) the luminosity and polarization limitations experienced in Run-3, thereby establishing the basis for a long pp run in Run-5[3]. Although not intended for physics measurements, data with an average luminosity 5×10^{30} cm^{-2}s^{-1}, integrated luminosity 0.35 pb^{-1} and average polarization 40% were

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[3] Run-4 was also very successful from the view of the Collider-Accelerator Department: a) A new working point with minimal polarization loss in RHIC was developed which led to repeated stores with

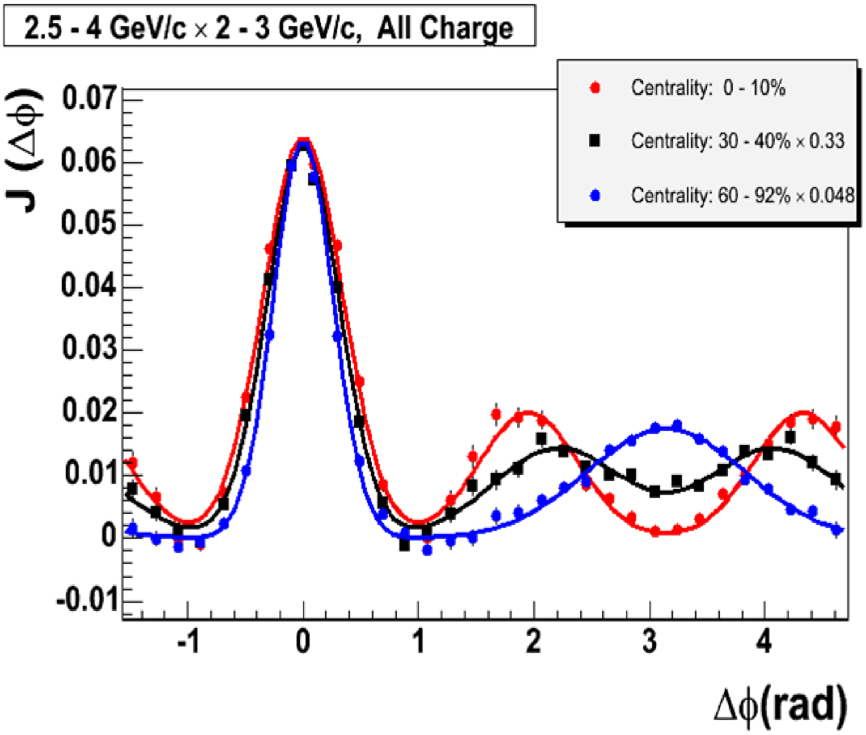

Figure 10: Preliminary results on the correlation function $J(\Delta\phi)$ from various centralities in $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions for charged particles with $2 < p_T < 3$ GeV/c associated with a trigger particle in the range $2.5 < p_T < 4$ GeV/c as a function of the relative angle $\Delta\Phi$.

obtained and written to tape in PHENIX in the last week of this run. These data were combined with the results of Run-3 to produce a more precise measurement of $A_{LL}(\pi^0)$ shown in Figure 11a.

PHENIX achieved the following in its polarized proton program during Run-4:

- Improved the figure of merit of the π^0 result by a factor of ~ 2.
- New muon shielding was installed and automatic beam scraping work was performed.
- Developed and installed a conceptual design for a luminosity telescope monitor (as

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$> 45\%$, b) The warm snake in the AGS provided robust higher polarization than before (45-50%) c) The hydrogen gas jet target was commissioned and data were collected which will lead to a significant reduction in the beam polarization measurement uncertainty, with online results indicating absolute $\delta P/P_{beam} < 10\%$.

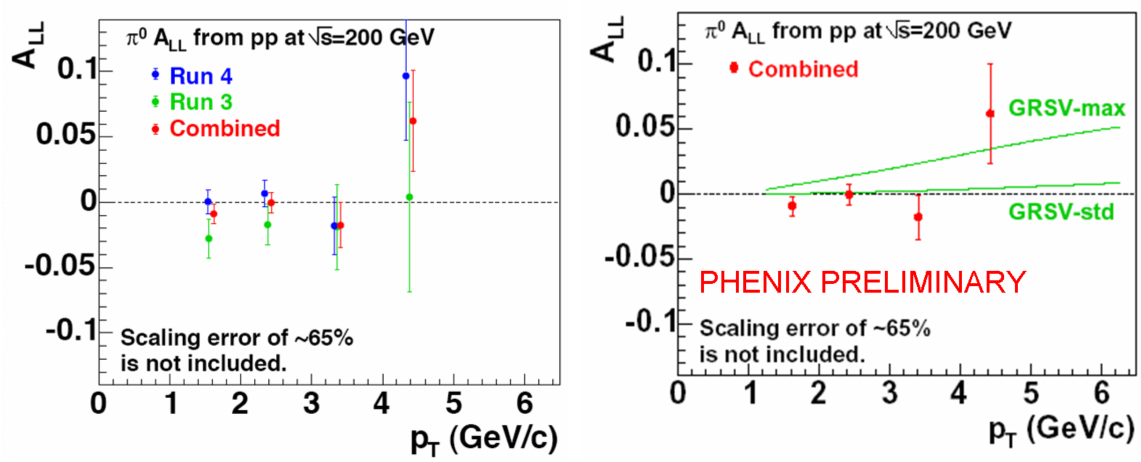

Figure 11: a) The published Run-3 results[16] on $A_{LL}(\pi^0)$ from PHENIX are shown together with Preliminary results on the same quantity from PHENIX for Run-4. b) The combined Run-3 + Run-4 data are compared to two theoretical calculations[18] based on NLO pQCD (both presently in agreement with the world DIS data).

a R&D project) with vertex cuts for future high luminosity runs.

- Commissioned bunch-sorted scaler boards (produced by LBNL) for future use in monitoring the bunch crossing luminosity variations.

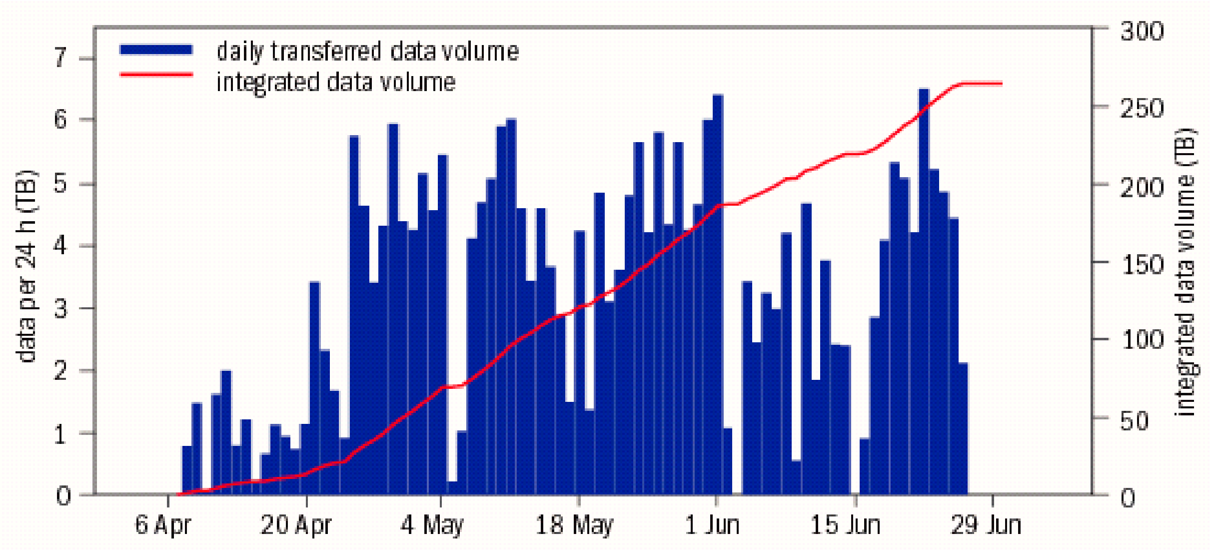

Figure 12: Daily rates (blue) and integrated total (red) of Run-5 polarized proton data transferred via the Grid from PHENIX to the CC-J computing center in Japan.

Run-5: In Run-5 PHENIX recorded 3.8 pb^{-1} with a mean polarization of $\sim 50\%$ in p+p collisions at 200 GeV[4]. The 262 TB of data were successfully transferred via the Grid (see Figure 12) to the PHENIX Analysis Center "CC-J" located on the Wako campus of RIKEN[19]. A fast-track production of the central arm data was completed in early September, with the goal of having preliminary data available for the PANIC conference in late October. In particular, PHENIX will significantly extend our measurement of the gluon polarization $A_{LL}(\pi^0)$ in central rapidity to a transverse momentum of ∼8 GeV/c with ∼6 times better accuracy than the Run-3+Run-4 result (illustrated schematically in Figure 13). Since this observable is presently the most sensitive measured probe of the magnitude of the gluon polarization, we expect this result to have a major impact.

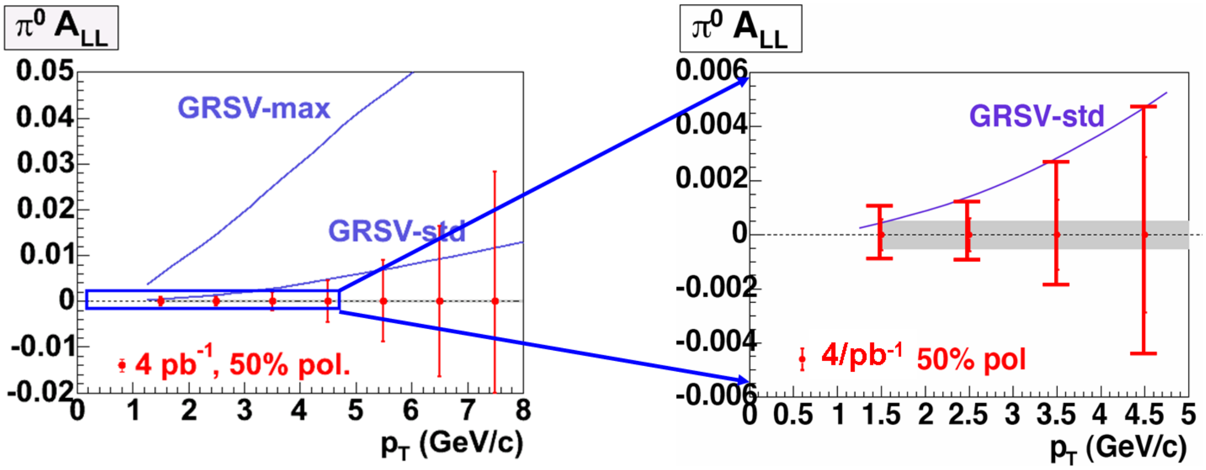

Figure 13: Expected statistical precision for the longitudinal double-spin asymmetry A_{LL} to be obtained from the (ongoing) analysis of the PHENIX Run-5 p+p data set.

In addition to this major Run-5 achievement in the PHENIX program of double-spin asymmetry measurements, we also acquired 0.16 pb^{-1} of transversely polarized data, which is the same integrated luminosity as our (accepted for publication[20]) Run-2 result, but the much higher Run-5 polarization (∼50%) provides a factor of three improvement in the figure of merit $\int \mathcal{P}^2 \mathcal{L}\, dt$.

Various physics analyses of the Run-5 data are in progress. A partial list would include:

- A_{LL} of neutral pions, to determine the magnitude of polarized gluon distribution precisely.

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[4] In addition, collisions of polarized pp beams at 410 GeV were achieved in a small R&D run.

- A_{LL} of charged pions, which play an important role in understanding the sign of the gluon contribution.
- Direct-photon cross section measurement and a first look at the A_{LL} in this channel.
- A_{LL} of η mesons, as a secondary measure of the magnitude of ΔG.
- A_{LL} of J/ψ mesons, an alternative reaction sensitive to ΔG. Both di-muon and di-electron final states are under study.
- Measurement of single (inclusive) muons as a signal of charm physics at large rapidity.
- An exploratory measurement of single (inclusive) electrons at central rapidity, also a signal of charm physics.
- A_N of both charged and neutral pions.

2 Run Planning Assumptions and Methodology

2.1 Input from the Associate Laboratory Director for HENP

The call for Beam Use Proposals from the Associate Laboratory Directory for High Energy and Nuclear Physics requested updates of the previously submitted Beam Use Proposals, with the following new guidance:

1. A specific focus on Run-6.
2. For Run-6, 29 weeks of cryogenic operations should be taken as the default assumption.
3. Luminosity assumptions should be consistent with the latest Collider-Accelerator Department guidance.

The number of cryo weeks in the out-years was not explicitly specified. For our planning purposes, we have assumed a slightly larger value, with 25 weeks of *physics running* per year. Naively, this would correspond to 34.5 cryo weeks per year in the case of two-mode operation. However, we very much hope that the ever-increasing understanding of RHIC performance can lead to decreased start-up times and further increases in operational efficiency, such that 25 physics weeks per year may be possible in future years in (say) a 31 cryo week scenario. In particular, we expect this to be the case when species and energies that have previously been run are revisited, as is in the case in much of our request.

2.2 C-AD input

Detailed guidance provided by the Collider-Accelerator Department describes the projected year-by-year luminosities for various species, along with the expected time-development of luminosity in a given running period[21]. Here we briefly summarize the parameters most relevant to our planning process:

2.2.1 Overheads

- **Cool-down**: 2 weeks
- **Warm-up**: 0.5 weeks
- **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**:
  - 1 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, 29 weeks of cryo operations translates into 29 - 2 - (2+1) - (2+1) - 0.5 = 20.5 weeks for the case of two modes, with an additional reduction of 2-3 days per energy change.

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. The dynamic range between minimum and maximum values is considerably smaller than in past years, due to increased experience with actual operating parameters and increased understanding of intrinsic limits. In either case, a “4 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 growth of the maximum luminosity which would result from various planned improvements in accelerator operations.

The specific assumptions regarding the luminosity for a given species will be detailed in the individual subsections of Section 3 that follow. In general, we will adhere to our previous methodology of using 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. A specific instance where a different methodology is used is in estimating the delivered luminosity for polarized protons beyond Run-6. Here we have adopted the assumption of 70% of the C-AD maximum, in order to be consistent with the projections found in the Spin Research Plan[22] that was submitted to DOE in February, 2005. In either case, 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 Beam Use Proposal for Runs 6 and Beyond

Some general considerations concerning the RHIC program guided the development of our request. Chief among these is the desire to maintain the program of discovery physics that has attracted world-wide attention to the RHIC heavy ion program, *while maintaining* the progress in both polarized proton performance and in the spin physics program. At the same time, we are painfully aware of the highly constrained funding environment which both reduces flexibility in operations and restricts the available weeks for physics operations. Given these observations as input, we assume that, absent compelling arguments for investigating new systems and species, scarce resources are best utilized by

- Continued enrichment of existing data sets that are statistically sparse in essential physics channels (accepting that this may in fact require accumulation of data over multi-year periods)
- Continued development of luminosity and polarization to maximize efficient usage of scarce weeks
- **Completing** surveys by securing requisite baseline data in timely fashion, so that comparison data sets are obtained with essentially the same detector configuration.

3.1 Executive Summary

Table 2 summarizes the current PHENIX Beam Use Proposal. This plan incorporates the major features from our previous request[7]:

- Additional Au+Au running at $\sqrt{s_{NN}} = 200$ GeV to significantly advance the statistical reach and physics precision of our existing Run-4 data set.
- Two comparison runs:
  - p+p collisions at 62.4 GeV to complete the investigation of the energy dependence of the high p_T suppression pattern observed at 200 GeV.
  - p+p collisions at 22.5 GeV to complete the Run-5 low energy studies in the Cu+Cu system, and to make valuable comparisons between RHIC and SPS measurements of the nuclear modification factor.

- A period of polarized proton running with transverse (radial) polarization, to perform a measurement of the gluon Sivers function.
- Continued development of polarized proton luminosity and polarization leading to a sensitive measurement of the gluon polarization of the proton via 200 (and 500) GeV p+p collisions.
- A d+Au run, again to take advantage of significant advances in luminosity and data acquisition throughput to refine our knowledge of this essential baseline system.

The proposed plan emphasizes increasing the statistical reach of existing data-sets by one (Au+Au) to two (polarized protons) orders-of-magnitude, through the year-by-year accumulation of data, coupled with (ongoing) advances in accelerator performance and (existing) improvements to the PHENIX triggering and data acquisition systems. In particular, it should be noted 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.

Table 2: The PHENIX Beam Use Proposal for Runs 6-10.

RUN	**SPECIES**	$\sqrt{s_{NN}}$ **(GeV)**	**PHYSICS WEEKS**	$\int \mathcal{L}dt$ **(recorded)**	**p+p Equivalent**
6	Au+Au	200	13	1 nb^{-1}	40 pb^{-1}
	p+p	200	4	7 pb^{-1}	7 pb^{-1}
	p+p	62.4	2	0.6 pb^{-1}	0.6 pb^{-1}
	p+p	22.5	0.5	4 nb^{-1}	4 nb^{-1}
	p+p	500	1	NA	NA
7	d+Au	200	10	28 nb^{-1}	11 pb^{-1}
	p+p	200	15	57 pb^{-1}	57 pb^{-1}
8	Au+Au	200	15	1.5 nb^{-1}	60 pb^{-1}
	p+p	200	10	52 pb^{-1}	52 pb^{-1}
9	TBD	200	10		
	p+p	200	5	22 pb^{-1}	22 pb^{-1}
	p+p	500	10		
10	U+U?	200	15		
	p+p	500	10		

That such a strategy is warranted for Au+Au collisions may be seen by examining the PHENIX preliminary results on the nuclear modification factors for direct photons, π^0's and η's (Figure 5) or heavy flavor flow (Figure 7). Over substantial regions of interest, the statistical errors still exceed the systematic errors, that is, 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. Additional 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.

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 entry for the “heavy ion” segment of Run-9 in Table 2 as “TBD” (To Be Determined). The precise decision is expected to be taken when the status of the physics, upgrades and funding are much better understood, and will be determined 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-6, d+Au in Run-7 and Au+Au in Run-8 is motivated by and coordinated with the program of upgrades delineated in Figure 3. Specifically:

- Au+Au in Run-6 is our last opportunity to extend the measurement of low-mass virtual photons (Figure 8) before the introduction of the HBD (to be followed by the Si-VTX detector) into the PHENIX central aperture. As shown in Figure 14, there is a need to reduce the statistical errors in the transverse momentum region where the measurement of the real and virtual photons overlap, both to provide an assessment of the systematic error on the two approaches and to establish the origin of this photon “excess” in the region of thermal radiation from the QGP.
- Following Run-6, PHENIX will have data-sets for Au+Au and p+p each in excess of 10 pb^{-1} proton+proton equivalent in integrated luminosity. Consequently, our ability to compare effects observed in Au+Au to cold nuclear matter effects will be limited by the relatively small Run-3 sample of 1.1 pb^{-1} proton+proton equivalent for d+Au collisions, making a re-examination of this system in Run-7 an important physics priority. In addition, the HBD will be available, so that, following its

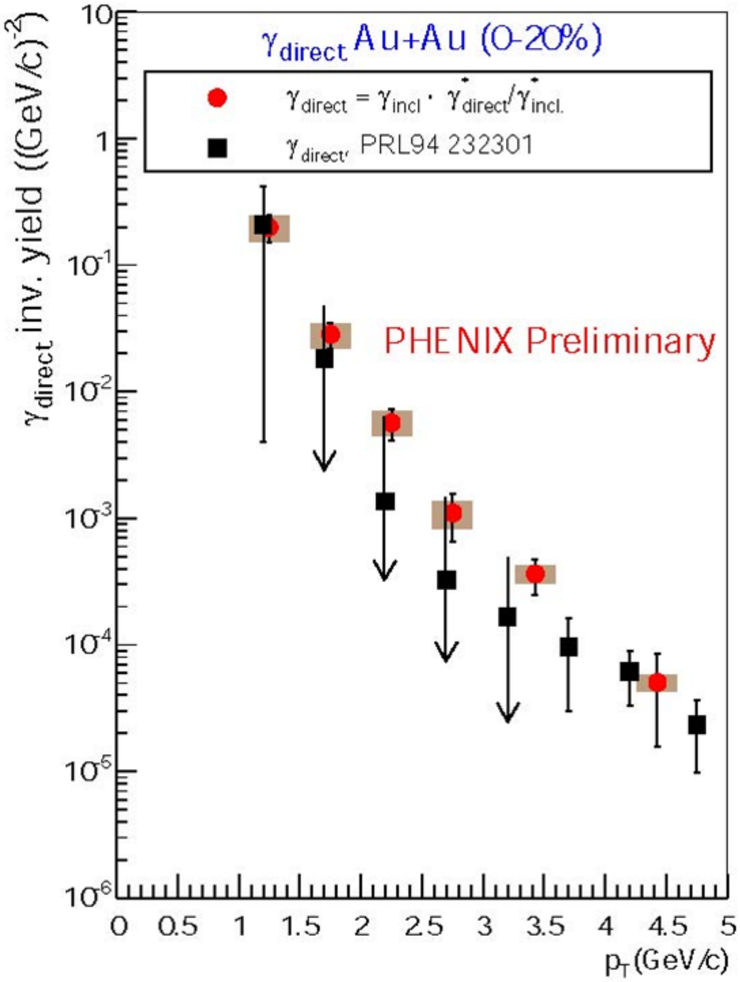

Figure 14: The published PHENIX transverse momentum spectrum of real direct photons from central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV (black points)[23] compared with the preliminary results from Run-4 for virtual photons (red points).

first confrontation with Au+Au collisions in Run-8, a complete baseline data-set from d+Au and p+p collisions will already be available from Run-7 for comparison purposes[5].

- Au+Au running in Run-8 will provide the order-of-magnitude (cumulative) increase requested over our current Run-4 data-set, while also using the huge improvement on Signal/Background in the di-electron provided by the HBD to probe medium modifications of vector mesons and chiral symmetry restoration.

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[5] Similar arguments were used to motivate the Run-3 d+Au run in advance of the (then) large-statistics Au+Au run planned for Run-4.

4 Discussion

This section provides specific remarks for the various components of our plan. These will of course be most detailed for the Run-6 discussion, as appropriate due to its proximity.

4.1 Run-6

In this section we present the PHENIX Beam Use Proposal for Run-6. The various run segments appear in the desired time sequence, which is designed to provide a long period of Au+Au and unpolarized p+p running before beginning operations with polarized beams in RHIC. As in the past, it is our expectation that such a period will be used to maximize polarization in the AGS behind RHIC stores. This is of particular interest in Run-6, in order to provide sufficient time to commission the cold snake before the polarized operations begin.

4.1.1 13 weeks Au+Au at $\sqrt{s_{NN}}$=200 GeV

The geometric mean of the minimum and maximum C-AD guidance for Au+Au running at $\sqrt{s_{NN}} = 200$ GeV corresponds to 192 μb^{-1} per week of delivered luminosity. We have instead chosen to use the maximum value of 230 μb^{-1} per week, noting that in Run-4, a best value of 180 μb^{-1} was delivered in one week with 45 bunches per ring and a β^* of 1.0 m. The planned increases to more (78) bunches and lower β^* (0.9 m) lead to values well in excess of the maximum guidance. However, we note that, since Au+Au is particularly well-understood species in RHIC, the dynamic range between the minimum and maximum is quite small, that is, the maximum guidance is reasonably near our standard geometric mean prescription.

Trigger Strategy: PHENIX has developed and demonstrated the ability to maintain full physics sensitivity at the highest RHIC Au+Au luminosities for rare physics with triggers to select

- $J/\psi \rightarrow e^+e^-$
- $J/\psi \rightarrow \mu^+\mu^-$

- High p_T photons (and hence π^0's and η's)
- High p_T single electrons

Correspondingly, it is not possible to develop triggers with sufficient rejection to select

- Single muons
- Light vector mesons decaying to either di-electrons or hadrons.
- Low mass di-electron (or di-muon) continuum physics.
- Low and intermediate p_T photons.
- Charged hadrons with particle identification (particularly important when performing jet correlations).

This second set of observables is therefore obtained via our minimum bias trigger, and will be incorporated into the stream of recorded data at the level permitted by the data acquisition system. The success of such a strategy is already apparent from our Run-4 Au+Au data-set, in that we have presented preliminary results for observables in all of these channels.

4.1.2 4 weeks p+p transverse (radial) polarization at 200 GeV

Stimulated by increased theoretical understanding[24] of single spin asymmetries in deep inelastic scattering measurements, and by the discovery by STAR of their persistence at RHIC energies[25], Boer and Vogelsang have proposed that a sensitive measurement of the gluon Sivers function could be obtained via azimuthal correlations of jets produced in collisions of transversely polarized protons with unpolarized protons[26]. The effect, which would manifest itself as a non-zero value of A_N for such correlations, is proportional to the T-odd quantity $\vec{S}_T \cdot (\vec{P} \times \vec{k}_T)$, which naively was thought to vanish prior to the discovery by Brodsky, Hwang and Schmidt[24] of the essential role of final-state interactions from gluon exchange between the outgoing quark and the spectators. This quantity is at the center of intense theoretical debate focusing on transverse spin phenomena in QCD and on related questions of factorization and the universality of distribution and fragmentation

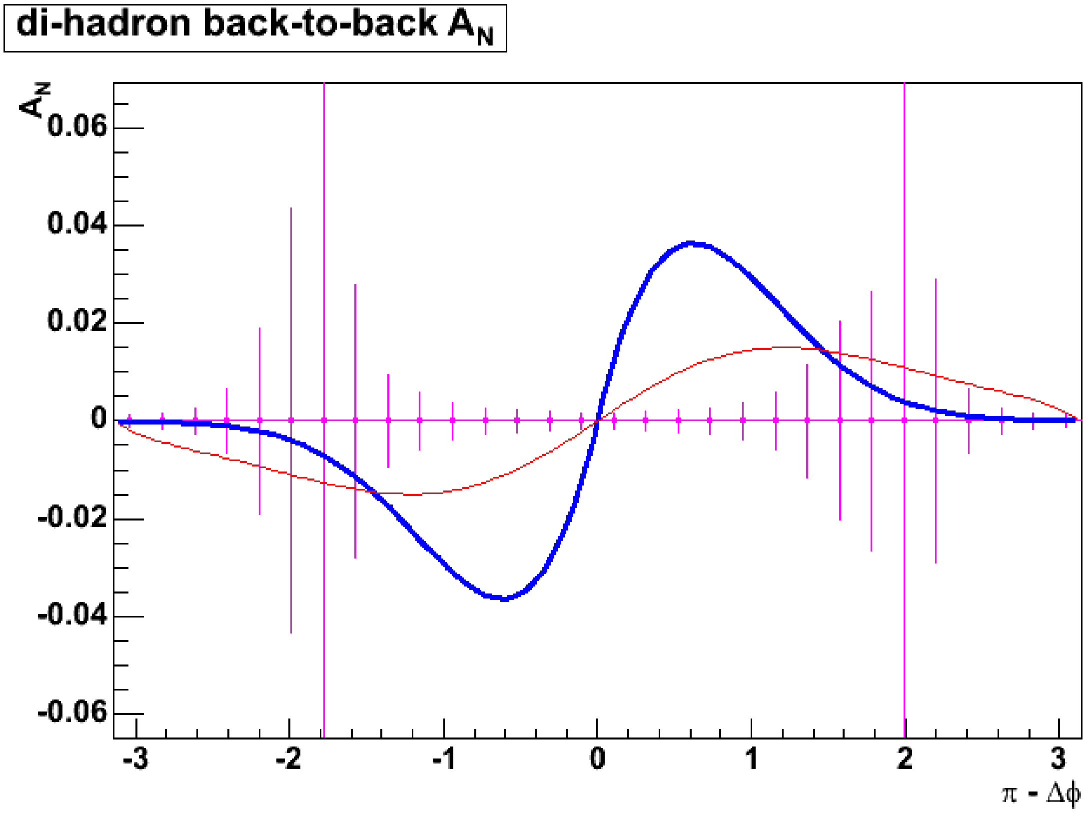

Figure 15: The statistical sensitivity (violet bars) as a function of azimuthal angle in the single-spin asymmetry A_N for back-to-back di-hadrons expected from 4 weeks of transverse running with $\sqrt{s} = 200$ GeV polarized p+p collisions. The blue curve shows the spin asymmetry resulting from one version of the gluon Sivers function in the calculations of Boer and Vogelsang[26]; the red curve shows the same after accounting for resolution smearing in the di-hadron system.

functions in hard-scattering processes. Sivers distributions play a key role in gaining first insight in the origin of transverse spin phenomena in QCD processes.

Given ongoing efforts to measure this function in semi-inclusive deep inelastic scattering measurements, it is essential to make a timely measurement in Run-6. We have determined that, following an appropriate period of luminosity and polarization development (in particular, commissioning of the cold snake), a 4 week run with transverse (radial) polarization will result in 7-10 pb^{-1} of integrated (recorded) luminosity, which will provide a sensitive measure[6] in this channel (see Figure 15). Note that measurement

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[6] During a brief period of transverse running in Run-5, PHENIX recorded 0.15 pb^{-1} at 50% polarization, which is currently being analyzed. The proposed Run-6 measurement would result in a factor of

will be with di-hadron pairs as a proxies for the full jet, and that the request is for radial polarization to maximize the rate into the asymmetric PHENIX acceptance. These effects have been fully incorporated into the study shown in Figure 15. We also note that these studies have been conducted for the central arms only, and that it may be possible to obtain additional information using the PHENIX muon arms.

It is expected that this measurement will have a major impact.

4.1.3 2 weeks p+p at $\sqrt{s}$=62.4 GeV

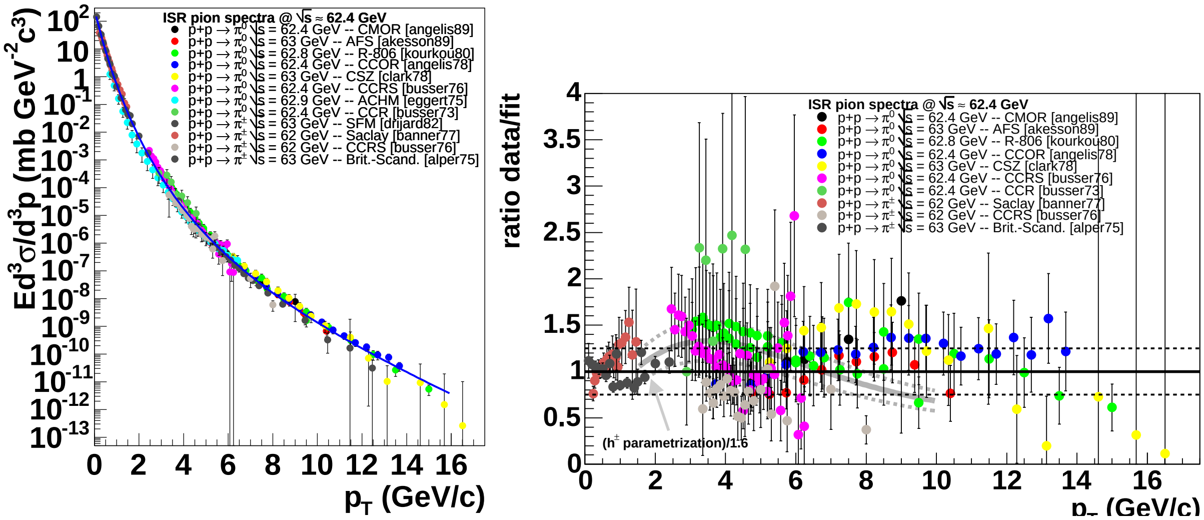

Figure 16: Left: World's data for $p + p \rightarrow \pi^0 + X$ at $\sqrt{s}$=62.4 GeV. Right: The ratio of the individual data sets to a global fit.

In the PHENIX Beam Use Proposal for Run-5[7], we noted

> *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,*

6-8 improvement in statistical accuracy.

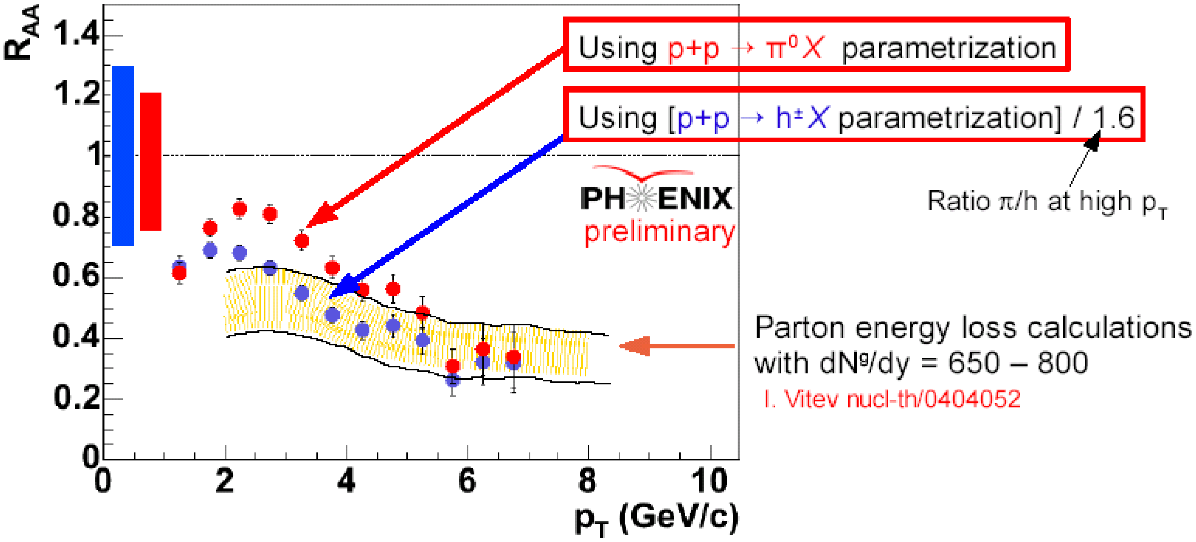

Figure 17: The change in the nuclear modification factor R_{AA} due to two different parameterizations of the world's data on pion production at 62.4 GeV.

> *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.*

That is, the current request precisely reflects the foreseen modification to our Run-6 request, and remains driven by the uncertainties in the world's data set for particle production at 62.4 GeV. As shown in Figure 16, 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 17). Note also that because the deviations are p_T-dependent, they can mimic true physics effects such as the Cronin enhancement. Similar 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, along with a general desire to completing all baseline measurements implicitly required by energy surveys in a timely way, motivates our request for a period of p+p running at 62.4 GeV.

The C-AD guidance states the luminosity for lower energy p+p running should scale as γ^2_{BEAM} or s, leading us to expect a reduction by a factor of 10 from the 4 pb^{-1} per week assumed for 200 GeV running. Since these values are for asymptotic performance after a suitable period of beam development, we request that this segment follow the p+p running at 200 GeV. However, we note that the luminosities projections supplied by C-AD are for polarized proton collisions. A factor of ~ 2 improvement is possible if polarization is not a goal[27]. This would indeed be our request, i.e., to optimize luminosity by developing unpolarized beams. In this mode we would expect a recorded integrated luminosities of order 0.6 pb^{-1} , which exceeds the existing p+p equivalent for our Au+Au 62 GeV data-set and compares well with that for Cu+Cu at 62 GeV (see Table 1).

4.1.4 0.5 weeks p+p at $\sqrt{s}$ = 22.5 GeV

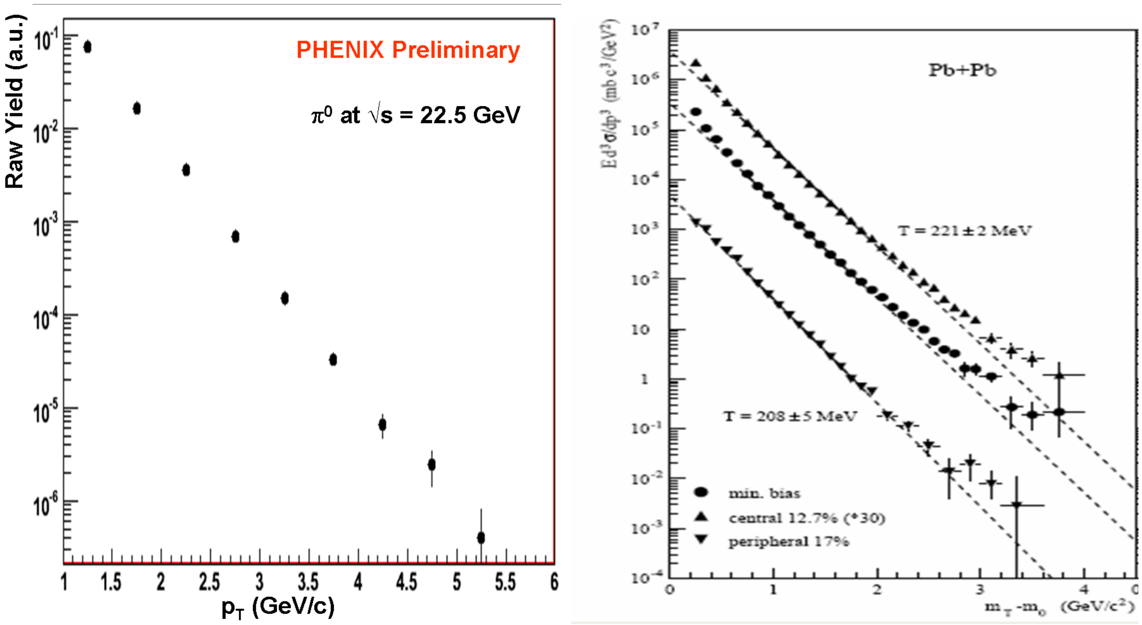

Figure 18: a) PHENIX preliminary results for the transverse momentum spectrum for π^0's from Cu+Cu collisions at $\sqrt{s_{NN}}$ = 22.5 GeV. b) Results[28] from the WA98 experiment at the CERN SPS for π^0's from Pb+Pb collisions at $\sqrt{s_{NN}}$ = 17.3 GeV.

In Run-5 PHENIX took Cu+Cu data at $\sqrt{s_{NN}}$ = 22.5 GeV for 39 hours. A minimum bias π^0 spectrum was obtained from that data-set which reaches $p_\mathrm{T} \approx 5\,\mathrm{GeV}/c$

(Figure 18a), which compares well with measurements from the CERN SPS program in Pb+Pb collisions at $\sqrt{s_{NN}} = 17.3$ GeV[28] (Figure 18b). We propose here a correspondingly brief run of p+p collisions at 22.5 GeV in order to provide a precise determination of the nuclear modification factor to address the crucial question whether jet quenching is already present in A+A collisions at CERN SPS energies.

Since operation at this energy is below the current injection energy for protons, we asked for additional C-AD guidance on this matter. Information from Wolfram Fischer reproduced below provided a basis for proceeding:

> At $\sqrt{s} = 22$ GeV we would be about a factor of two below the current injection energy. Operation should be possible, although the luminosity is certainly less than 1% of the luminosity at $\sqrt{s} = 200$ GeV, maybe even less than 10^{-3}. Bunches will fill the accelerating buckets, i.e. they are about 3.5x longer than at $\sqrt{s} = 200$ GeV.
>
> Time in store will be very good (about 80% I think) since we will not be accelerating, and it is close to impossible to quench a magnet. The store length will be adjusted so that we maximize the average luminosity.

Our ability to obtain baseline p+p data over the entire range of p_T spanned by the Cu+Cu data-set will depend critically on the value of luminosity obtained at this new energy. To set an upper limit, we assume that the luminosity for p+p collisions at 22.5 GeV is 0.1% of the luminosity for 200 GeV collisions, and require comparable statistics in our p+p baseline to the 10% most central class of the 22.5 GeV Cu+Cu data-set, which contains 6×10^5 events. For this centrality class, the number of binary collisions is $\langle N_{coll} \rangle \sim 150$. Thus, in order to match the complete statistics in Cu+Cu we would need to record $\langle N_{coll} \rangle \times 6 \times 10^5 = 9 \times 10^7$ p+p triggers at 22.5 GeV. This would require approximately 8-10 days, which is not possible to accommodate within our request. However, we note that considerable physics value is nonetheless obtained either by restricting attention to $p_T < 4$ GeV/c (a range which still exceeds that of the SPS data) or for minimum bias events only. Either approach requires a factor of 10 less p+p data, and indicates the feasibility of pursuing this critical overlap measurement between the SPS and RHIC programs.

We therefore propose a brief period of ~ 3 days to investigate this intriguing possibility. The measurement would be performed using the PHENIX "ERT" triggers to obtain the π^0 spectrum. We expect to coordinate with C-AD staff prior to this running period to further examine the feasibility of this measurement, and to use the demonstrated on-line monitoring features of the PHENIX analysis chain to determine and maintain data quality during this brief period.

4.1.5 1 week p+p development at 500 GeV

This request is as per C-AD guidance as to their needs to develop luminosity. It is not clear if collisions and stable physics running will be achieved; if so, PHENIX will be prepared to perform initial measurements at this new energy. We are also interested in measuring backgrounds and trigger performance at 500 GeV.

4.2 Run-7

4.2.1 10 weeks d+Au at $\sqrt{s_{NN}}$ = 200 GeV

As stated in Section 3.1, we can develop an integrated luminosity in this period that exceeds our Run-3 d+Au value of 2.7 nb^{-1} by 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 proposal to acquire an additional 7 pb^{-1} in Run-6), the Run-3 d+Au will be the limiting factor in our ability to make precision measurements of the relatively small but crucial nuclear modifications that occur in cold nuclear matter. This is demonstrated in Figure 19, which shows the data from our recent publication of the Run-3 data on J/ψ production[29], compared to both previous fixed-target data[30] and to models of initial and final state nuclear modifications[31, 32, 33]. It is clear that additional resolving power is needed to make rigorous distinctions between the various models. A 10 week run of d+Au collisions, assuming the geometric mean of the minimum (4.5 nb^{-1} per week) and maximum (15 nb^{-1} per week) C-AD guidance will result in a recorded sample of 28 nb^{-1} , i.e., an factor of 10 increase over the existing d+Au data-set.

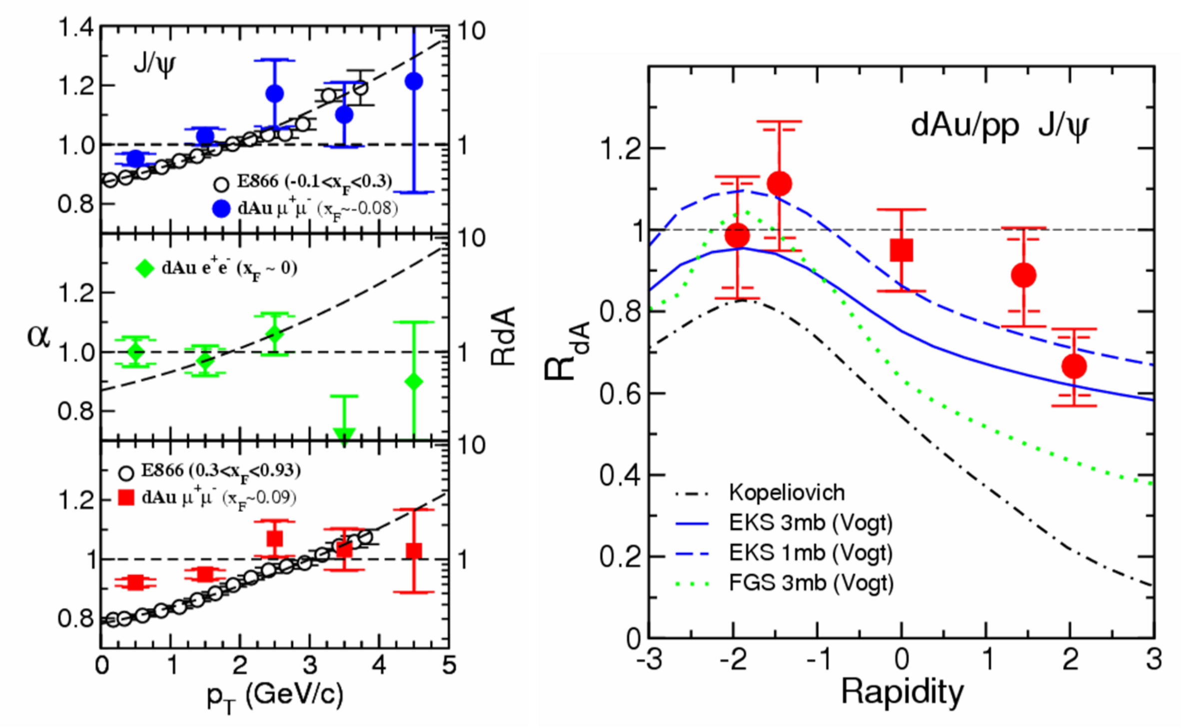

Figure 19: PHENIX Run-3 results[29] from $\sqrt{s_{NN}}$ = 200 GeV d+Au collisions for (Left) J/ψ yields parameterized as A^{α} as a function of transverse momentum compared to results from E866/NuSea[30] and (Right) the nuclear suppression factor R_{dAu} as a function of rapidity, compared to various models of initial-state shadowing and final-state absorption[31, 32, 33].

4.2.2 15 weeks p+p longitudinal polarization at 200 GeV

Following the expected major developments of polarization and luminosity in Run-6, PHENIX requests a major spin run of 15 weeks with longitudinal polarization to make a quality measurement of A_{LL} in a variety of channels (charged and neutral pions, η's, and first examination of J/ψ 's, single electrons, direct photons, Λ's and $\bar{\Lambda}$'s, etc.). As noted in Section 2.2.2, for these estimates we adopt the prescription used by BNL's Spin Planning Group of assuming 70% of the C-AD maximum guidance, which leads to a value for the weekly delivered luminosity of 0.70×15.2 pb^{-1}/week = 10.6 pb^{-1}/week. This, after accounting for PHENIX up-time, vertex cuts and a 4-week luminosity development ramp, in turn results in a PHENIX recorded value of 57 pb^{-1} . This, together with the assumed polarization of 65%, leads to a factor of 40 improvement in the figure of merit $\int \mathcal{P}^4 \mathcal{L}\, dt$ over the Run-5 data-set, resulting in the very significant extension of $A_{LL}(\pi^0)$ shown in Figure 20a and the first measurement via direct photons shown in Figure 20b.

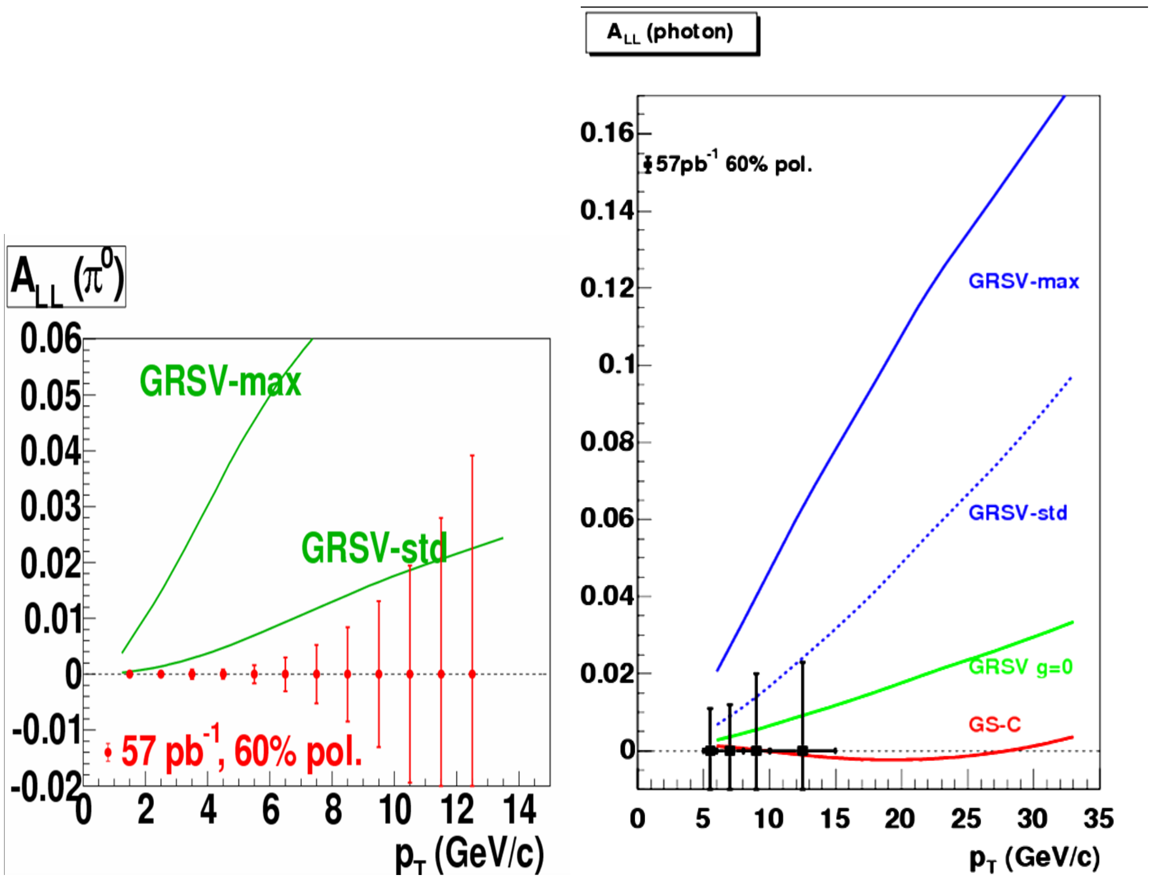

Figure 20: The expected sensitivity following accumulation of 57 pb^{-1} of (60%) polarized p+p collisions in Run-7 for a) $A_{LL}(\pi^0)$ and b) $A_{LL}(\gamma)$ (direct photons).

4.3 Run-8

4.3.1 15 weeks Au+Au at $\sqrt{s_{NN}}$ = 200 GeV

With the anticipated recording of an additional 1.5 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 an order-of-magnitude in sensitivity, thereby accessing the many observables listed above (Sections 3.1 and 4.1.1)that remain statistics-limited. Second, we will have used the HBD to make the first precision measurements at RHIC of the spectrum of low-mass di-electrons. The present result (Figure 21), even when using most of the Run-4 Au+Au data-set, is severely limited by the low signal-

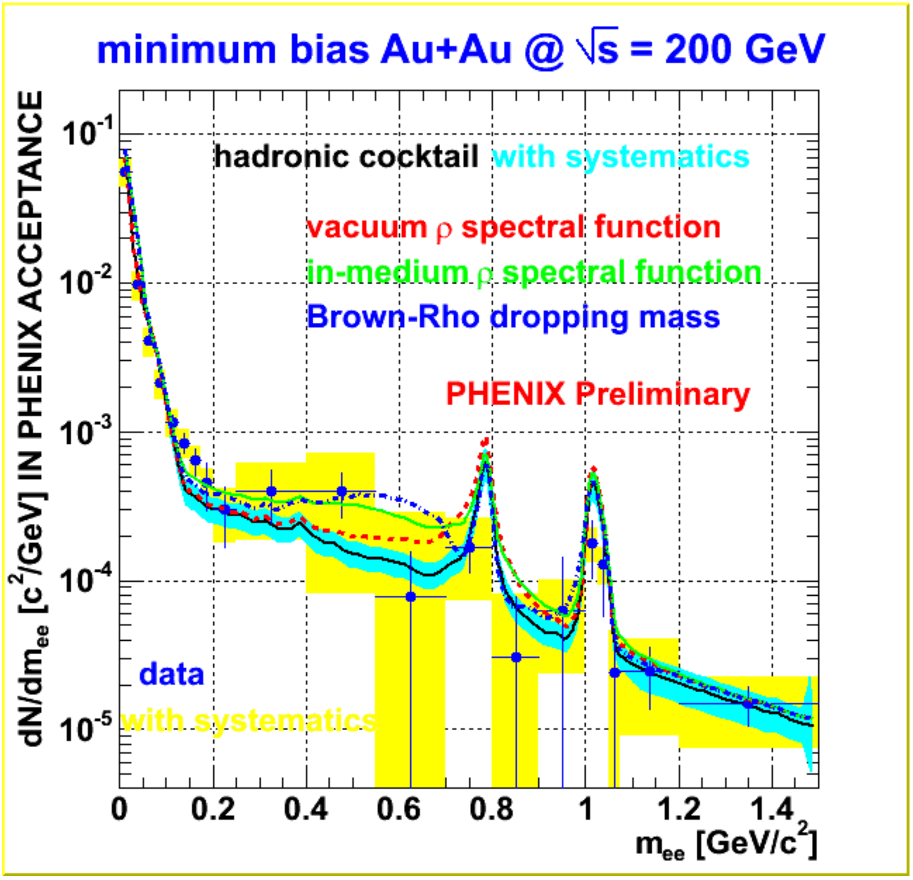

Figure 21: The invariant mass spectrum of e^+e^- pairs measured by PHENIX from the Run-4 data-set for Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. Also shown on the figure theoretical calculations[34, 35] using a ρ spectral function without (red) and with (blue and green) in-medium modifications.

to-background (S/B) ratio[7]. The HBD will improve this by a factor of ∼ 100, which, when combined with the significantly larger size of the Run-8 sample, will produce a qualitatively new result in this important sector. Finally, in Run-8, PHENIX will begin beam tests with the Si-VTX, which is a crucial step in our future program to identify displaced vertices from heavy flavor decays to provide qualitatively new data on the production, energy loss and flow of charm and beauty.

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[7] Note that the large systematic errors shown in Figure 21 are due to imperfect knowledge of the normalization for the combinatorial background, which in turn results from the small S/B ratio.

4.3.2 10 weeks p+p longitudinal polarization at 200 GeV

Here the reasoning closely follows that of Section 4.2.2, that is, the C-AD maximum value for Run-8 is 21.7 pb^{-1} per week, taking 70% of this value results in a PHENIX recorded integrated luminosity of 52 pb^{-1} . The somewhat higher polarization (70% versus 65% for Run-7) results in a figure of merit slightly in excess of the Run-7 value.

4.4 Run-9

4.4.1 10 weeks "heavy ion" running at $\sqrt{s_{NN}}$ = 200 GeV

As we have noted in 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 interest in this aspect of the program as the various upgrades continue to extend PHENIX's ability to make incisive measurements. Of particular interest will be the first opportunity in Run-9 to perform physics measurements using the Si-VTX tracker, which would provide intrinsically new results from either Au+Au or d+Au collisions.

4.4.2 5 weeks p+p longitudinal polarization at 200 GeV

Using the same assumptions as for Run-8 polarized proton running found in Section 4.3.2, this period of running in Run-9 will result in 22 pb^{-1} . This additional increment is intended to resolve any issues discovered in the analysis of the Run-7 and Run-8 data sets before embarking on the 500 GeV polarized proton program, and to provide overlap between the 200 and 500 GeV data-sets with an essentially identical configuration of the experimental apparatus. The total integrated luminosity from 200 GeV longitudinally polarized proton running is projected to be 131 pb^{-1} at polarizations $>$ 65%, and will result in a sensitivity for the direct photon signal as shown in Figure 22.

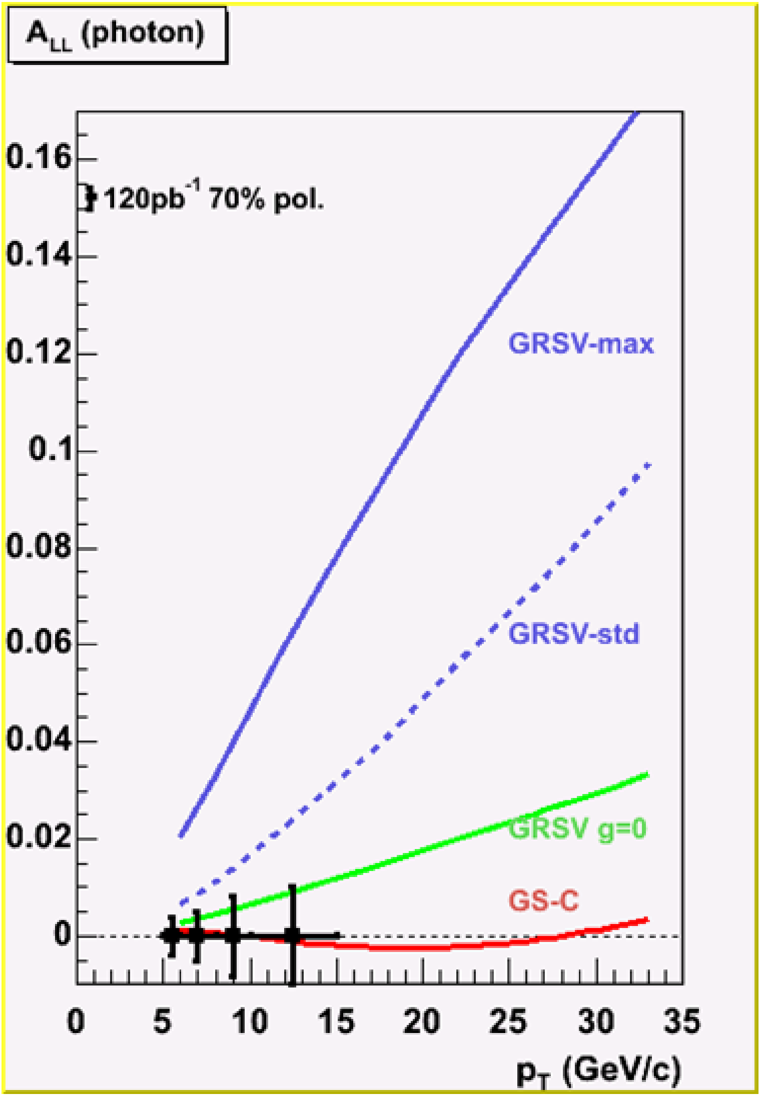

Figure 22: The projected sensitivity in A_{LL} for direct photons from 200 GeV p+p collisions following the Run-9 polarized proton run.

4.4.3 10 weeks p+p longitudinal polarization at 500 GeV

This is expected to be the first production run in the 500 GeV polarized proton program. The PHENIX muon trigger upgrade funded this year by the NSF will be in place to provide excellent trigger selection of high p_T muons from W decays, thereby allowing us to begin investigation of the sea quark contributions to the proton spin (as well as extending all of the 200 GeV measurements to this new kinematic regime).

4.5 Run-10

4.5.1 15 weeks "heavy ion" running at $\sqrt{s_{NN}} = 200$ GeV

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.

4.5.2 10 weeks p+p longitudinal polarization at 500 GeV

As in the 200 GeV polarized proton program, we project steady accumulation of integrated luminosity at this new energy over multi-year period.

4.6 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 the need to provide steady progress in both the heavy ion and the polarized proton program by continuing the impressive program of improvements in luminosity, polarization and reliability of operations demonstrated in RHIC Runs 1-5.* That progress is limited when funding falls below some critical value, so that the number of operating weeks becomes dominated by end effects. In fact, the current guidance for Run-6 is a case in point, and we have deliberately exceeded this value in our planning for the out-years, as evidenced in Table 2 and discussed in Section 2.1, in order to demonstrate the physics potential offered by modest increments to the number of physics weeks per year.
- 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. As previously noted, absent *compelling* arguments for investigating these systems, we believe great scientific value is obtained through significant extensions in the physics reach of the heaviest colliding system, coupled with corresponding additions to the d+Au and p+p baseline measurements.

- 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.

The plan proposed here incorporates these observations, and is intended to continue the program of discovery and precision physics that has become the definition of RHIC physics.

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