Chapter 1

THE PHENIX EXPERIMENT

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Abstract The PHENIX experiment at RHIC is currently under construction with data collection planned to start in 1999. The heavy ion and spin physics goals of PHENIX are described. We discuss the experiment's capabilities to address these physics goals. Highlights of the present status of construction and installation are presented.

Keywords: PHENIX, RHIC, quark gluon plasma, heavy-ion collisions, muons, spin

1. INTRODUCTION

The PHENIX experiment [1, 2] is currently under construction at the BNL Relativistic Heavy Ion Collider (RHIC). Data collection is planned to start in 1999. We describe the physics goals of the experiment and how they lead to its design philosophy. These physics goals consist of two broad complementary programs of experimental investigation, namely the PHENIX heavy ion and spin physics programs. We separately discuss these experimental programs and emphasize the experiment's capabilities to address them. In particular, the experiment is able to identify and trigger on exclusive leptons, photons, and high p_T hadrons with excellent momentum and energy resolution. Highlights of the present status of construction and installation are presented.

*For the complete PHENIX Collaboration author list, please refer to Ref. 1. See *http://www.phenix.bnl.gov* for extensive current information about PHENIX.

2. HEAVY ION PHYSICS PROGRAM

The primary purpose of the PHENIX experiment is to detect and characterize a predicted new state of matter, the Quark Gluon Plasma [3] (QGP), via simultaneous measurement of various signatures as a function of energy density in $A+A$, $p+A$, and pp collisions.

These signatures include deconfinement as manifested in differential suppression of J/ψ and ψ' production; chiral symmetry restoration as manifested in a modification of the effective ϕ meson mass, width, and branching ratios; thermal radiation of real and virtual photons from a hot initial state; enhanced production of strangeness and charm; and hard scattering processes which serve as good primordial probes such as high p_T leptons, high p_T photons, and high p_T jets identified by their leading particle.

Debye screening due to the presence of a QGP can be systematically studied by measurements of J/ψ, ψ', and Υ production due to their different respective bound state radii: $R_{\Upsilon}(0.13\text{ fm}) < R_{J/\psi}(0.29\text{ fm}) < R_{\psi'}(0.56\text{ fm})$. In a sense, the Υ serves as an "experimental control" since it is unlikely to be screened at energy densities attainable at RHIC collision energies.

During the first year of RHIC operations, the luminosity will initially be 1% and grow to 10% of the design luminosity of $2\times10^{26}\text{ cm}^{-2}\text{s}^{-1}$. The experiment expects to record 20 μb^{-1} to tape of $Au+Au$ collisions at a center-of-mass energy of 200 GeV per nucleon pair. Physics measurements that will be performed in the first year include measurement of global event properties such as N_{ch}, $<p_T>$, $dN_{ch}/d\eta$, E_T, and $dE_T/d\eta$, and fluctuations in these quantities. PHENIX will study the energy density and geometry of the collisions. Other early measurements include hadronic spectra and inclusive photon and π^0 measurements.

As the RHIC luminosity increases, feasible measurements next include open charm production (via single high p_T leptons as well as unlike-flavor lepton pairs), the Drell-Yan continuum, $\phi\to e^+e^-$, and $J/\psi\to e^+e^-$.

3. SPIN PHYSICS PROGRAM

RHIC will be able to produce longitudinally or transversely spin-polarized $p+p$ collisions at center-of-mass energies ranging from 50 to 500 GeV. It will provide two months of spin physics running per year beginning with the year 2000. The expected luminosity at $\sqrt{s}=200$ GeV is $8\times10^{31}\text{cm}^{-2}\text{s}^{-1}$. The luminosity at $\sqrt{s}=500$ GeV is $2\times10^{32}\text{cm}^{-2}\text{s}^{-1}$. PHENIX's initial request is for an integrated luminosity of 800 pb^{-1} collected at $\sqrt{s}=500$ GeV and 320 pb^{-1} at $\sqrt{s}=200$ GeV.

The primary goal of the PHENIX Spin Physics program is to use polarized proton-proton collisions to measure the helicity distributions of flavor separated quarks and antiquarks and gluon polarization in the nucleon. This information is obtained by studying the polarized Drell-Yan process, vector boson (J/ψ, W, Z) production, polarized gluon fusion, and polarized gluon Compton scattering (leading to direct photon production). Antiquark structure function measurements rely on analyzing Drell-Yan and vector-boson production data. Gluon polarization measurements rely on analyzing heavy quark, J/ψ, and prompt photon data. Efforts to understand the contributions of the spin of sea quarks and the polarization of gluons to the total nucleon spin may help explain the lack of agreement between experimental data and the Ellis-Jaffe sum rule. A further major goal of the PHENIX spin program is to perform precise tests of fundamental symmetries such as parity violation.

RHIC is expected to make important contributions to this field in ways that have not been possible historically via polarized deep inelastic scattering experiments. In essence, those experiments have used virtual photons to probe the nucleon. Such photons couple to the square of the electric charge and can not be used to distinguish quarks from antiquarks or to separate flavors. By using a proton beam to probe the nucleon, one can, through an appropriate program of measurements of helicity and transversity-dependent cross sections, untangle these quark-spin distributions as well as measure the gluon polarization in the nucleon.

An early study of particular interest is to study W boson production via a single μ tag. Fig. 1.1 demonstrates that this is very feasible for muons with $p_T > 20$ GeV/c. This allows measurement of a parity violating longitudinal spin asymmetry which can be optimized by selecting particular kinematic regions. This measurement is important to address the antiquark helicity distributions in the nucleon. These, and other, aspects of the spin program represent a very different, and fundamental, physics topic addressed using data from PHENIX. Work done commissioning, understanding, calibrating, and simulating the performance of PHENIX in support of the heavy ion program has immediate benefits to these spin studies.

4. EXPERIMENTAL OVERVIEW

PHENIX consists of eleven different detector subsystems. Fig. 1.2 provides a schematic drawing of PHENIX. The design philosophy of the experiment is to identify and trigger on exclusive leptons, photons, and high p_T hadrons with excellent momentum and energy resolution. This requires flexibility, multiple technologies, and the ability to handle

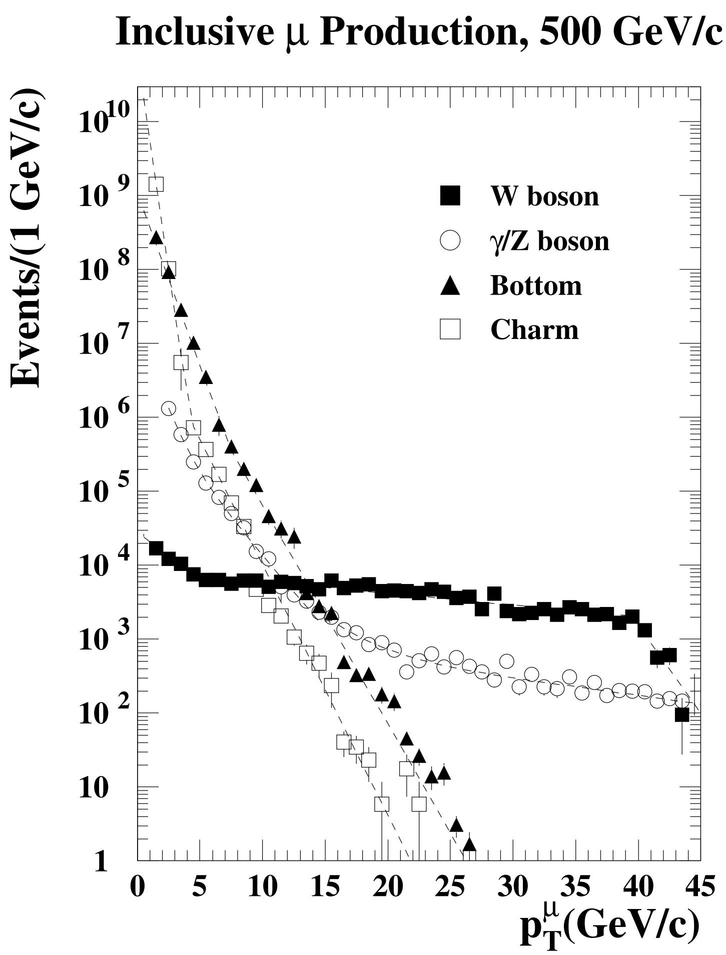

Figure 1.1 Simulated single muon transverse momentum distribution due to various decay processes. Distribution corresponds to an integrated luminosity of 2 fb^{-1} (one year of running at design luminosity) of $p + p$ collisions at $\sqrt{s} = 500$ GeV.

high data rates. The experiment is divided into central subsystems, east and west central arms, and north and south muon arms with each arm covering roughly one steradian. The magnetic field is axial in the central region and radial in the muon arms. PHENIX has a deadtime-less first-level trigger system to cope with background processes while measuring rare signal processes.

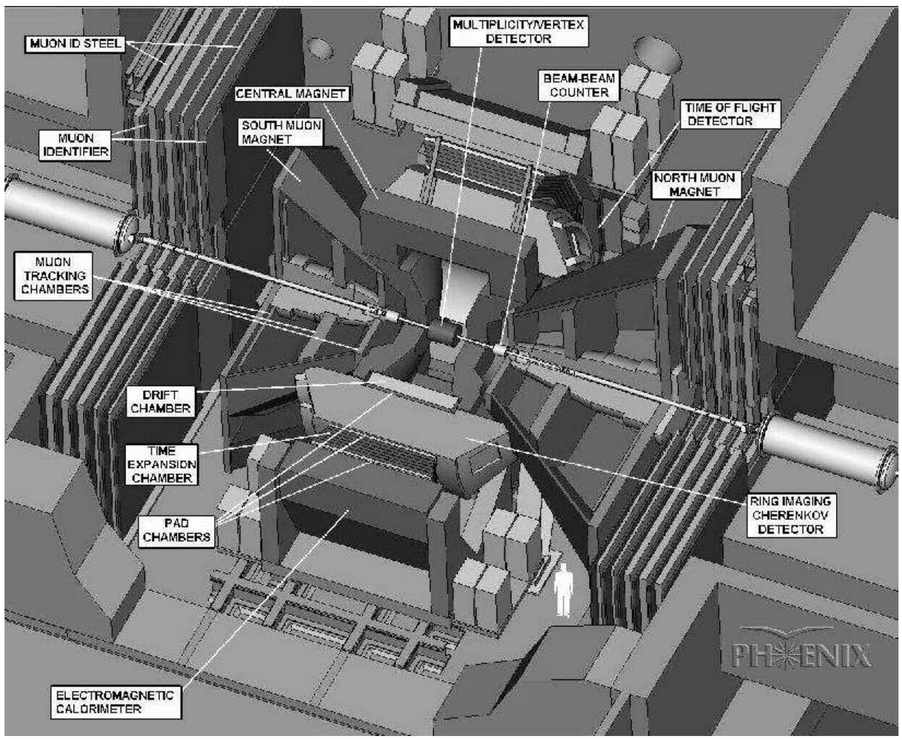

Figure 1.2 Schematic drawing of the PHENIX Experiment.

The central subsystems consist of the beam-beam counter and the multiplicity vertex detector. The beam-beam counter provides the time and longitudinal position of the interaction. It consists of two arrays of quartz Cerenkov telescopes. The multiplicity vertex detector is a 64 cm long silicon strip detector with silicon pad endcaps covering pseudorapidity from -2.5 to 2.5. It has approximately 35 thousand channels and a position resolution of 200 μm. It measures the collision vertex position in three dimensions as well as N_{ch} and $d^2N_{ch}/d\eta d\phi$.

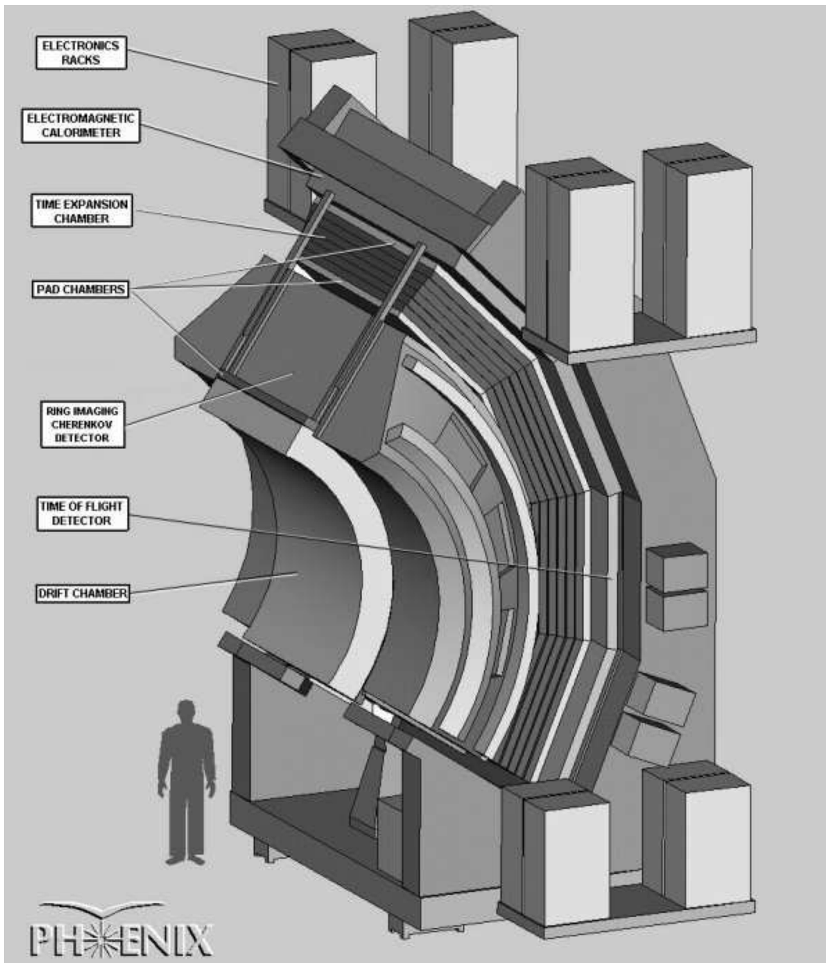

Figure 1.3 One of the two PHENIX Central Arms.

5. PHENIX CENTRAL ARMS

A schematic of one of the two PHENIX central arms is shown in Fig. 1.3. The central arms cover pseudorapidity $-0.35 < \eta < 0.35$. Tracking in a central arm is provided by means of the drift chambers, pixel-pad chambers, and time expansion chambers (TEC). The drift chambers provide projective measurement of particle trajectories (with a position resolution of 150 μm) to yield a transverse momentum measurement. The pad chambers provide 3-dimensional space points which are critical for pattern recognition. Particle identification is provided by means of the time of flight (TOF) and Ring Imaging Cerenkov (RICH) subdetectors supplemented by the TEC. The TOF consists of 1056 scintillator slats. It provides 85 ps resolution time-of-flight information and can separate pions from kaons up to 2.5 GeV/c. This π/K particle identification separation is available for 30° of azimuth. The separation extends up to 1.4 GeV/c for the rest of the azimuthal coverage (using time-of-flight information provided by the electromagnetic calorimeter). The mass resolution for $\phi \to e^+e^-$ is 0.5% for $p_T < 2$ GeV/c. The π/e rejection factor for identified electrons is 10^{-4}.

The electromagnetic calorimeter has high resolution, high granularity, and provides timing information. It consists of approximately 25 thousand cells located 5 m from the interaction diamond. Each is about 15 to 18 radiation lengths long with a cross sectional area of about one Moliere radius square. It has a position resolution of a few mm/$\sqrt{E}$ and an energy resolution of 6–8%/$\sqrt{E}$, which has been tested extending up to 70 GeV. It can reliably separate π^0 mesons from single photons up to $p_T = 20$ GeV/c.

6. PHENIX MUON ARMS

The muon arms are a major contributor to the overall PHENIX physics program. The muon arms will be used to measure the production of vector mesons decaying into dimuons in heavy-ion collisions for masses ranging from that of the ϕ to the Υ. Measurement of the differential suppression of J/ψ, ψ', $\Upsilon(1S)$, and $\Upsilon(2S+3S)$ production will provide information concerning "deconfinement," *i.e.*, the Debye screening of the QCD potential. The muon arms also allow studies of the continuum dilepton spectrum in a much broader region of rapidity and mass than is accessible for e^+e^- in the central arms alone. In addition $e-\mu$ coincidences, using electrons detected by the central arms, will probe heavy-quark production and aid in the understanding of the shape of the continuum dielectron spectrum. This is feasible because unlike-sign $e-\mu$ pairs result primarily from $D\overline{D}$, while like-sign pairs are due to the combinatorial background arising predominantly from meson weak decays.

The muon arms consist of a muon tracker to track muons and provide sufficient mass resolution to separate the $\Upsilon(1S)$ from the $\Upsilon(2S+3S)$ and a muon identifier to provide an additional 100:1 $\pi{:}\,\mu$ rejection (beyond the factor of approximately 100 due to absorber material located before the muon identifier which filters out non-muons.) The muon tracker consists of three stations of cathode strip chambers per arm. The position resolution of the chambers is 100 μm. The muon identifier consists of 5 gaps per arm filled with planes of transversely oriented plastic proportional (Iarocci) tubes interleaved with layers of steel.

Table 1.1 Vector meson mass resolutions, acceptances, and expected number of particles per RHIC-year of minimum bias $Au + Au$ collisions (running at the design luminosity of 2×10^{26} cm^{-2}s^{-1}).

Particle	*Mass Resolution* *(MeV/c^2)*	*Acceptance* *(%)*	*Events/year*
ϕ	60	0.58	4×10^4
J/ψ	105	4.3	6.7×10^5
ψ'	105	4.3	1.2×10^4
Υ	180	3.0	382

The muon arms provide coverage from $\eta = -2.3$ to -1.1 and 1.1 to 2.4. This corresponds to $\theta = 168°$ to $145°$ and $\theta = 10° - 35°$. The mass resolution for reconstruction $J/\psi \rightarrow \mu^+\mu^-$ is about 100 MeV/c^2. Table 1.1 lists the mass resolution, geometric acceptance times reconstruction efficiency, and estimated number of respective particles collected per arm per year at design luminosity (2.2×10^{26}cm^{-2}s^{-1}). For example, an estimated 0.67 million J/ψ are expected to be collected per arm per RHIC-year of $Au + Au$ minimum bias collisions.

Not included in the table are the estimated approximately 290 Υ per year for which one muon goes into each arm. This corresponds to acceptance for Υ production at $y = 0$. This acceptance extends down to approximately 5 GeV/c^2 providing good coverage for Drell-Yan pairs at $y = 0$ (with a yield varying as $1/M^3$). Thus, the presence of *two* muon arms represents more than a factor of two in acceptance because they additionally provide coverage for production at $y = 0$. It is critical to have *two* muon arms in order to study Z production as part of the spin program.

7. CONSTRUCTION STATUS

The PHENIX experiment is currently under construction. The highlights of the current status of construction and installation as of early 1999 are as follows. The detector magnets have been installed and tested. All of the steel for the north and south muon arms is installed. The first drift chamber is mechanically complete, with the second chamber underway. The inner and outer pixel pad chambers have working prototypes and are in fabrication. The first ring imaging Cerenkov vessel is installed on the west arm, with the second in fabrication. The third sector of the time expansion chamber is in fabrication. The TOF counters are ready for installation. Four electromagnetic calorimeter sectors are installed on the west arm and those for the east arm are ready for installation. The muon identifier panels are all installed. The muon tracker cathode strip chambers are being fabricated. Working prototypes exist for all central arm front end electronics, global first-level trigger electronics, data acquisition systems, and online control systems. Advanced simulation, reconstruction, and analysis code has been developed and tested.

8. SUMMARY

The PHENIX experiment has been described both in terms of its physics goals and its technological implementation. The heavy ion and spin physics programs represent two broad programs of experimental endeavor to address fundamental physics questions. The experiment is comprised of multiple subsystems and detector technologies to address these physics goals. Important physics will be available beginning with the first year. The highlights of the present status of construction were presented.

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