Overview of the PHENIX Experiment

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Abstract. PHENIX is an large nuclear physics experiment at the Relativistic Heavy Ion Collider located at Brookhaven National Laboratory. The multi-kiloton detector is designed to address a spectrum of physics topics that range from quark-gluon plasma formation to spin structure of the nucleon and structure function physics. PHENIX is composed of a set of subdetectors that allow for a wide variety of spectrometry, calorimetry and event characterization measurements.The experiment has just completed its third year of data taking.

INTRODUCTION

PHENIX is a large, multi-purpose nuclear physics experiment located at one of the intersection regions of Brookhaven National Lab's Relativistic Heavy Ion Collider (RHIC). The 3.5 kiloton detector is composed of four spectrometer arms: two forward muon spectrometers covering the full azimuth and $1.1 \leq |\eta| \leq 2.4$ North (2.2 South) and two central spectrometer arms each covering $\pi/2$ in azimuth and $\eta \leq 0.35$ in pseudorapidity. Additional detectors at small radii cover a large rapidity range for both vertex determination and event characterization [1].

The experiment has been designed to work in conjunction with the RHIC accelerator to investigate a broad range of nuclear physics topics including the observation and characterization of the Quark-Gluon Plasma, spin structure of the nucleon, structure function physics, initial and final state cold nuclear effects. PHENIX has been designed, built and is operated by over 450 scientists and engineers from 56 institutions in 13 countries.

PHENIX resides in the 8 o'clock hall of the RHIC accelerator complex. The Relativistic Heavy Ion Collider has two counter-circulating rings 3.83 km in circumference. Each ring can be filled with a maximum of 120 equally spaced bunches of nuclei that cross the six machine intersection regions every 106 nanoseconds. The machine has the potential to collide any nuclear species with any other ranging from protons to fully stripped Au ions. The maximum machine energy is $\sqrt{s_{NN}}$ = 200 GeV for AuAu collisions and $\sqrt{s}$ = 500 GeV for p-p collisions. At the end of May 2003, RHIC had completed its third year of operation. During the machine's three physics runs it has delivered long data runs with beams of AuAu $\sqrt{s_{NN}}$ = 130 GeV, AuAu $\sqrt{s_{NN}}$ = 200 GeV, pp $\sqrt{s}$ = 200 GeV and dAu $\sqrt{s_{NN}}$ = 200 GeV.

PHYSICS PROGRAM

The PHENIX experiment has been designed with the ability to measure a large variety of physics signals over a broad momentum, energy and eta range [2]. The versatility of the RHIC accelerator to deliver collisions for a large variety of beam species challenges the experiment to handle luminosities and particle multiplicities ranging from AuAu ($\mathscr{L} = 2 \times 10^{26} cm^{-2} sec^{-1}$ with $dN_{charged}/dy \cong 700$) [3] to pp ($\mathscr{L} = 2 \times 10^{32} cm^{-2} sec^{-1}$ with $dN_{charged}/dy \cong 3$). In addition, the physics program of the experiment requires that p and p_T resolutions are maintained at the few percent level or less for identified hadrons (0.3 GeV/c $\leq p_T \leq$ 5.0 GeV/c), inclusive charged hadrons (0.3 GeV/c $\leq p_T \leq$ 20 GeV/c), and charged leptons ($p_T \leq$ 50 GeV/c). Similarly the detector must maintain good M_{inv} resolution for pair reconstruction of particles with masses ranging from the π^o to the Υ.

The PHENIX physics program includes at least three major components.

1. The observation and characterization of the quark-gluon plasma (QGP) [4]: This is a deconfined state of quarks and gluons that is potentially produced when the high temperatures and matter densities created in a HI collision cause hadronic matter to go through a phase transition to a QGP. Initially the heaviest and most energetic beams at RHIC (AuAu at $\sqrt{s_{NN}} = 200\ GeV$) will be used in an attempt to observe this state of matter. Later systematic scans of collision energies and species will be used to detail physical characteristics of the phase transition.
2. Measurements of the spin structure of nucleons [5]: The spin of the proton has significant contributions from both the gluon and sea quarks. Colliding beams polarized in both the transverse and longitudinal direction will be used to measure the contributions of gluons and anti-quarks to nucleon spin.
3. Systematic studies of structure function physics and cold nuclear physics: These effects provide a nuclear physics baseline needed to disentangle QGP effects from more conventional nuclear physics. Nuclear physics topics including structure function saturation, gluon and quark shadowing, anti-shadowing, and Cronin effect. This physics is studied through pAu and dAu collisions, light ion collisions and energy scans of heavy ions.

PHENIX accesses these physics topics through a combination of spectrometer and calorimeter measurements. Physics quantities are derived from measurements using signals from photon, electron, muon, and hadron channels. A subset of the physics variables measured by the experiment is shown in table 1.

DESCRIPTION OF THE EXPERIMENT

The PHENIX detector is composed of two central spectrometer arms, two forward muon spectrometer arms and a set of subdetectors responsible for event characterization, triggering and global physics measurements .The central arms are optimized to measure photons,electrons and identified hadrons. They also have a good capacity for inclusive

TABLE 1. Physics Variables Measured by PHENIX

Signal	Physics Objective	Category
High pT π^o, hadrons from jets	Jet Quenching, parton dE/dx	QGP
dN/dy,E_T, inclusive hadron spectra	Temperature and Energy Density	QGP
Ident. hadron spectra, $\pi^\pm$,K,p,π^o,η..	Temperature and Energy Density	QGP
HBT($\pi\pi$,KK,pp), v2=Elliptic flow	Space-Time Evolution	QGP
Evt by evt fluctuations(p_T, E_T, net q)	Space-Time Evolution	QGP
J/ψ,ψ'$\rightarrow ee, \mu\mu$, $\Upsilon \rightarrow \mu\mu$	Deconfinement	QGP
ϕ $\rightarrow$ee,KK, ϕ,ω,ρ width/shift	Chiral Symmetry Restoration	QGP
Dis. Chiral Condensate $(\pi^+\pi^-)/\pi^o$	Chiral Symmetry Restoration	QGP
anti-nucleon production	Chiral Symmetry Restoration	QGP
K/π, ϕ, J/ψ,ψ',Υ, D, B mesons	Heavy Quark Production	QGP
Direct γ, $\gamma^* \rightarrow$ ee, $\mu\mu$	Thermal Radiation	QGP
Direct γ, high pT π's	Gluon spin ΔG	Nucleon spin
$W^+/W^- \rightarrow e\nu, \mu\nu$ DY	Sea quark spin,$\Delta\bar{u}, \Delta\bar{d}$	Nucleon spin
π,K,p, charged hadron spectra	Cronin effect	Struct. function phys
J/ψ,ψ', DY $\rightarrow ee, \mu\mu$, vs x, A	Shadowing, anti-shadowing, absorp.	Struct. function phys

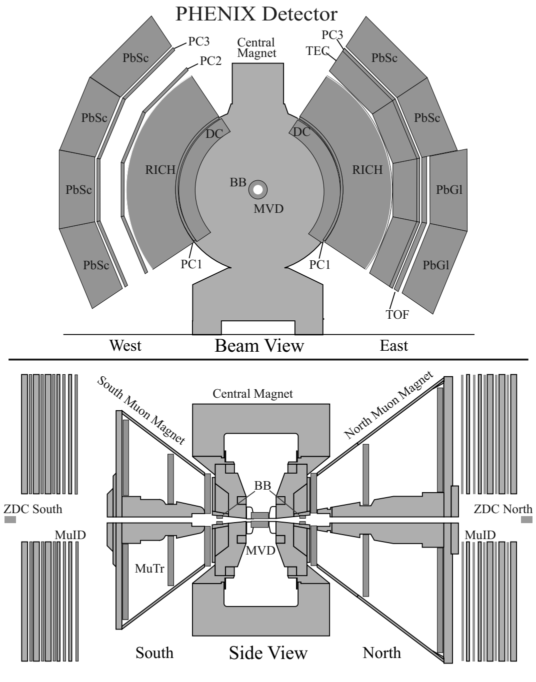

FIGURE 1. Top and side view of PHENIX detector.

hadron measurements. The forward muon arms are design to measure physics signals that produce either single muons or muon pairs such as open charm, ϕ, J/ψ, ψ'and Υ.

The two central arms are similar but not identical (Figure 1). The central arms contain subdetectors for charged particle tracking, particle ID devices and finely segmented calorimetry. The two central spectrometer arms are centered at y=0 and are built around an axial-field spectrometer magnet. The central magnet has a primary coil that can deliver a field integral of 0.78 T-m. A secondary inner coil also exists that allows the central magnet to be operated with an enhanced field integral 1.15 T-m or with the field bucked to provide essentially zero field integral within a radius of 70 cm from the first interaction point.

The charged particle tracking in the central arms is handled by three subsystems. The Drift Chamber is a multi-wire proportional chamber with its anode -cathode wires configured as a focusing jet-chamber. It provides a single-wire track resolution of better than 150 μm and a two-track separation of 1.5 mm. The Pad Chambers are cathode-readout wire chamber. Their fine-granularity pixel pad readout provides non-projective track information with a few mm precision. The Time Expansion Chamber is a radial drift wire chamber that measures charged track positions to 270 μm and dE/dx information in the chamber gas for particle ID.

Four different subsystems contribute to particle identification in the central arms. The PHENIX Time-of-Flight wall combines with a start counter, the Beam Beam, to obtain $\sigma_t < 96$ ps. The central arm ToF can separate $K/\pi \leq 2.5$ GeV/c, $p/K \leq 4.2$ GeV/c. The Ring Imaging Cerenkov Counter is optimized for e/π separation. The RICH uses CO2 as a radiator gas and is readout with 5100 phototubes. The Time Expansion Chamber has been equipped with transition radiation radiator packs. When it is filled with a xenon gas mixture it will operate as a tracking Transition Radiation Detector.

The central spectrometer arms are instrumented with over 24k modules of electromagnetic calorimetry segmented 0.01 $\Delta\Phi$ x 0.01 $\Delta\eta$. There are two calorimeter technologies in the central arms. Pb-scintillator modules are arranged in a shishkabob-geometry with wave-length shifting fiber running longitudinally through the alternating Pb-scintillator layers and into the phototubes. The Pb-scintillator modules have a timing resolution σ_t= 340 ps and an energy resolution of $\sigma_E = 10\%\sqrt{E} + 6.5\%$. The Pb-glass modules make up 25% of the central arm calorimetry. The Pb-glass has an energy resolution of $\sigma_E = 8.5\%\sqrt{E} + 9.0\%$.

The forward muon spectrometer arms each have a piston-lampshade magnet that produces a radial magnet field and a 0.72 T-m field integral (at $\eta = 2.0$). The muon magnets are each instrumented with three stations of cathode-strip tracking chambers (CSCs). A CSC station has a charged track position resolution of 100 μm. Following the forward spectrometer magnet is the muon identifier. The MuID is 5 layers of steel absorber plate interleaved with 5 layers of Iarocci tubes (2X,2Y 4 planes/layer), 10 m $\times$ 10 m in active cross section. The MuID has a low energy cutoff of 1.9 GeV/c.

The PHENIX event characterization and global detectors consist of the beam-beam counters, zero-degree calorimeter, normalization trigger counter, multiplicity vertex detector and forward calorimeters. The beam-beam counters are two sets of quartz radiator-phototubes arranged symmetrically around the beam pipe and located 144 cm forward from the IR collision point. They provide input to the Level1 trigger and a start time for the PHENIX high-precision timing subsystems. The zero-degree calorimeters are tungsten calorimeters with fiber readout. They are an important Level1 trigger device and contribute to the absolute luminosity measurement. The normalization trigger counters are scintillator arrays which also contribute to the Level1 trigger. The MVD is a combination Si-strip/Si-pad detector which provides vertex, charged-track multiplicity and reaction plane information. The forward calorimeter is two arrays of Pb-scintillating fiber hadronic calorimeters located in the forward direction, 18m from the interaction region vertex point. They are used to characterize collision centrality in dAu and pAu running at RHIC by measuring forward protons near beam rapidity.

TABLE 2. Summary of the PHENIX Detector

Subsystem	$\Delta\eta$	$\Delta\phi$	#Chan.	Electronics	Characteristics
Central magnet	$\pm$ 0.35	2π			$Bdl \leq 1.15$ T-m
Muon magnet S	-2.25$\leq \eta \leq$-1.15	2π			0.72 T-m η=-2
Muon magnet N	1.15$\leq \eta \leq$2.44	2π			0.72 T-m η=2
Silicon(MVD)	$\pm$2.5	2π	34,720	ADC	Si strip + pad
Beam Beam Counter	$\pm$(3.1-3.9)	2π	128	ADC/TDC	quartz + PMT
Normal. Trigger Countr	$\pm$(1.2-2.4)	2π	16	ADC/TDC	scin slat + PMT
Zero Degree Calorimtr	$\pm$2 mrad, $\|\eta\| >6$	2π	6	ADC/TDC	W+scin fiber
Forward Calorimeter	$\|\eta\| \geq 5.3$		180	ADC	Pb+scin fiber
Drift Chamber	$\pm$0.35	2xπ/2	12,800	TDC	MWPC Ar+C_2H_6
Pad Chamber	$\pm$0.35	2xπ/2	172,800	Discrim.	pixel cath readout
Time Expansion Chmbr	$\pm$0.35	π/2	20,480	FADC	MWPC P-10 or Xe
Ring Imaging Cerenkov	$\pm$0.35	2xπ/2	5,120	ADC/TDC	CO2 + PMTs
Time of Flight	$\pm$0.35	π/4	1,920	ADC/TDC	scin slat+ PMT
EM Calorimeter	$\pm$0.35	2xπ/2	24,768	ADC/TDC	Pb Scin/Pb Glass
Muon Tracking S	-2.25$\leq \eta \leq$-1.15	2π	21,984	ADC	Cath strip chambr
Muon Tracking N	1.15$\leq \eta \leq$2.44	2π	21,984	ADC	Cath strip chambr
Muon ID S	-2.44$\leq \eta \leq$-1.15	2π	3,170	TDC	Iarocci tube+steel
Muon ID N	1.15$\leq \eta \leq$2.44	2π	3,170	TDC	Iarocci tube+steel

PHENIX OPERATIONS

When the experiment is operational, the detector timing, control, synchronization, monitoring, event selection, data collection, event building and archiving is all managed by the PHENIX Data Acquisition and Trigger systems [6]. RHIC design luminosities result in an interaction rate that varies from a few kHz in central AuAu to over 1MHz in pp minimum bias. The wide variety of data rates and event sizes is accommodated by a design that features a significant amount of parallelism and data buffering at every stage of the DAQ system. All data is digitized on the detector by front-end electronics that is pipelined with multi-event buffering. Zero-suppression is accomplished in the counting house at the data collection stage just prior to event building. The DAQ is fully partitioned with 32 partitions available.

PHENIX has two levels of triggering. A hardware LVL1 trigger operates as a synchronous pipeline with a latency of $\sim 40\mu$s. A software LVL2 trigger operates in a few dozen parallel cpu's on fully assembled events immediately after the event building stage. The prescales are adjusted for each type of LVL1 and LVL2 trigger to create a archived mix of min bias, large cross-section and rare triggered events. Events can be built by the PHENIX DAQ at a rate of 1.5 kHz ($\sim$100 kB/evt) and archived at a rate of 100 MB/s. Near term upgrades are expected to increase event building and archiving rates to 8 kHz and 250 MB/s. Summary of PHENIX runs to date is shown in table 3.

TABLE 3. PHENIX Data in the first 3 RHIC Runs

Run #	Year	Species	$\sqrt{s}$(GeV)	$\int \mathscr{L} dt$	N_{TOT}
Run1	2000	Au-Au	130	1 μb^{-1}	10M
Run2	2001/02	Au-Au	200	24 μb^{-1}	170M
		p-p	200	0.15pb^{-1}	3.7G
Run3	2002/03	d-Au	200	2.74 nb^{-1}	5.5G
		p-p	200	0.35pb^{-1}	6.6G

SUMMARY

PHENIX has just completed its third year of operations at the RHIC accelerator. The experiment has a broad physics program encompassing the physics of the quark-gluon plasma, nucleon spin structure, structure functions, and cold nuclear physics topics. The program is carried out with a complex, multi-kiloton detector that combines excellent charged particle tracking, calorimetry, particle ID and event characterization subdetectors with a wide-bandwidth DAQ and multi-level triggering system. Even though RHIC has only operated for a few years, the experiment and accelerator have combined to produce a number of interesting results for a variety of running configurations in AuAu, pp and dAu. PHENIX has had significant physics production to date and intriguing physics effects are already being observed [7].

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REFERENCES

1. K. Adcox et al., NIMA 499(2003)469.
2. PHENIX Conceptual Design Report, BNL, 1993, unpublished
3. K. Adcox et al., Phys. Rev. Lett. 86(2001)3500.
4. D.P. Morrison et al., Nucl. Phys. A 638(1998)565c.
5. N. Saito et al., Nucl. Phys. A 638(1998)575c.
6. S.S. Adler et al., NIMA 499(2003)560.
7. S.S. Adler et al., Phys. Rev. Lett. 91(2003)072303.