Physics via Lepton Channels at RHIC/PHENIX

Kenta Shigaki* for the PHENIX Collaboration

*High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan

Abstract. The first physics data taking has started at Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. The physics goal of RHIC is to investigate QCD in extreme conditions and scales, and ultimately to create, to observe, and to understand the nature of a deconfined quark-gluon plasma phase. Experimental approaches and physics prospects via lepton channels at RHIC are discussed along with strategies and capabilities of the PHENIX experiment.

INTRODUCTION

Heavy ion programs at CERN SPS suggested possible onsets of the QCD phase transition [1]. It has been generally agreed that various signatures have to be combined to understand the whole picture of relativistic heavy ion reactions: hadrons to probe the boundary conditions of collision dynamics, photons to trace the evolution of the system, and leptons to probe the early stage of the collisions. Among these the particular importance of lepton channels was endorsed.

Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, which started its first physics operation in 2000, will create a much higher energy density and clearer environment due to the center-of-mass collision energy 12 times higher than at SPS. It has comprehensive and complementary programs to achieve conclusive experimental results on the physics goals to investigate QCD in extreme conditions and scales, and ultimately to create, to observe, and to understand the nature of a new phase of matter predicted by QCD, *i.e.* a deconfined quark-gluon plasma phase. In particular the PHENIX experiment [2,3] uniquely features systematic studies of penetrating probes via single- and di-lepton channels in conjunction with photon and hadron measurement in the single experiment. We will discuss experimental approaches and physics prospects via lepton channels at RHIC along with strategies and capabilities of PHENIX.

PHENIX EXPERIMENT AT RHIC

The basic strategy of PHENIX is to utilize a wide variety of probes with the single detector and trigger system. It is designed for sensitivity to as many signatures of the QCD phase transition as possible and to essentially all the time scales of relativistic heavy ion reactions. The signatures in the scope of PHENIX include strangeness and heavy flavor production, jet quenching, color Debye screening, chiral symmetry restoration via vector meson properties and perhaps disoriented chiral condensation, and thermal radiation from hot hadron gas. With the emphasis on penetrating probes, *i.e.* real and virtual photons and single- and dileptons, PHENIX is characterized with the high particle identification capability, high momentum and mass resolution, and broad kinematic coverage. The high rate capability with selective multi-level triggering plays another vital role to access the rare physics probes.

As shown in Figure 1, PHENIX consists of four arms of magnetic spectrometers along with a set of global detectors for event characterization: two central arms to measure photons, electrons and hadrons, and two forward arms for muon measurement.

PHENIX measures electrons in the two central arms covering a pseudo-rapidity range $-0.35 < \eta < 0.35$ and azimuthally $d\phi = \pi/2$ each. Charged particles are

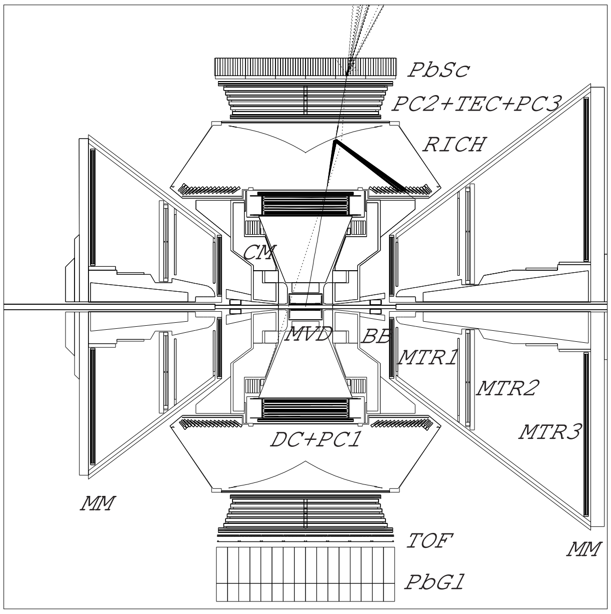

FIGURE 1. A plan view of the experimental apparatus of PHENIX and a simulated single-electron event. BB: beam/beam counter. MVD: silicon multiplicity and vertex detector. DC: drift chamber. PC1–3: pad chambers. TEC: time expansion chamber. RICH: ring imaging Čerenkov counter. TOF: time-of-flight wall. PbSc: lead-scintillator calorimeter. PbGl: lead-glass calorimeter. MTR1–3: muon trackers. CM: central magnet. MM: muon magnets.

tracked with drift chambers, pad chambers and time expansion chambers with a help from ring imaging Čerenkov counters, a time-of-flight wall and electromagnetic calorimeters. The ring imaging Čerenkov counters serve as the primary electron identification device providing hadron rejection at 10^4 level for single tracks and at 10^3 level in central Au+Au environment. The calorimeters provide additional hadron rejection via measured energy/momentum ratio especially at high momentum, and the time expansion chambers via dE/dx measurement at relatively low momentum. The combined electron identification capability stays above 10^4 up to the threshold momentum of pions in the Čerenkov counter, which is 3.5 GeV/c with CO_2 radiator and 4.7 GeV/c with C_2H_6. In the momentum range the momentum resolution dp/p is better than 2% in r.m.s..

Muons are measured in the two forward arms with full azimuthal coverage. Their pseudo-rapidity coverage is $1.2 < \eta < 2.4$ for the north arm and $1.2 < \eta < 2.2$ for the south. They are equipped with tracking chambers in the magnetic field followed by muon identifiers with the energy threshold at 2 GeV. The left panel in Figure 2 shows a simulated di-muon mass spectrum demonstrating the high mass resolution to separate not only J/ψ and ψ(2S) but even Υ(1S) and Υ(2S+3S).

PHYSICS VIA LEPTON CHANNELS

Quarkonium has been proved at SPS as a promising probe of the QCD phase transition. NA50 observed ψ(2S) strongly suppressed [4] and more interestingly a multi-step-like behavior of J/ψ possibly due to dissolution of χ_c and J/ψ [5]. If the quarkonium suppression is scaled to the energy density in the reaction system, J/ψ is expected to dissolve from semi-peripheral collisions in Au+Au reaction at the RHIC energy. On the other hand there exist many uncertainty factors to be cleared before understanding the so-called "anomalous" suppression, *e.g.* elemen-

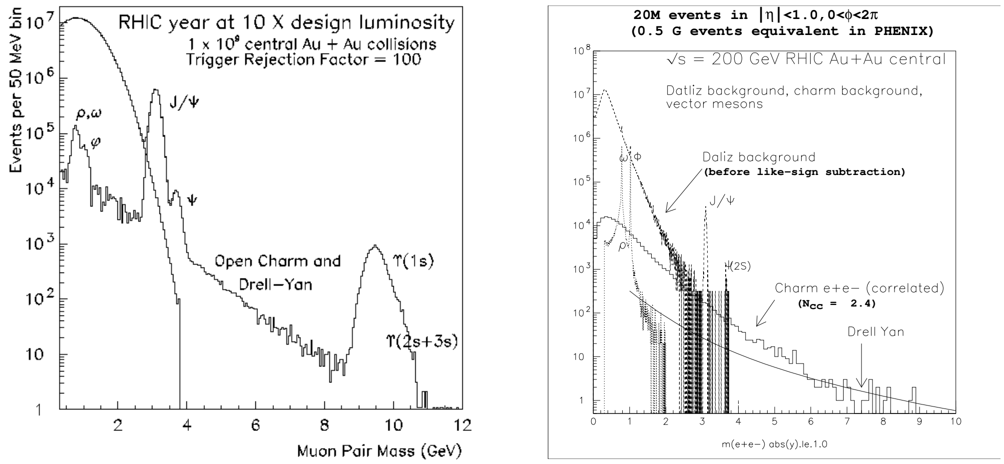

FIGURE 2. Simulated di-muon (left) and di-electron (right) spectra in PHENIX forward and central arms, respectively.

TABLE 1. PHENIX acceptance and resolution for quarkonium measurement.

	central arms	forward arms
pseudo-rapidity coverage	$-0.35 < \eta < 0.35$	$1.2 < \eta < 2.4$ (north) $-2.2 < y < -1.2$ (south)
J/ψ acceptance	0.8% of $B_{ee}\sigma$ (4% of $B_{ee}\sigma$ in $\lvert y\rvert < 0.5$)	4.3% of $B_{\mu\mu}\sigma$ (per arm)
Υ acceptance	1.7% of $B_{ee}\sigma$ (5% of $B_{ee}\sigma$ in $\lvert y\rvert < 0.5$)	3.0% of $B_{\mu\mu}\sigma$ (per arm)
J/ψ mass resolution	20 MeV	105 MeV
Υ mass resolution	160 MeV	180 MeV

tary J/ψ production cross section, initial state suppression or gluon shadowing, and nuclear absorption. PHENIX attacks these problems to understand the whole picture of quarkonium production/suppression in relativistic heavy ion reactions through systematic measurement of quarkonia.

On the accelerator side, RHIC is capable of colliding any combination of ions from proton to ^{197}Au in the independent two rings, and at any energy from the injection energy to 500 GeV per nucleon per rigidity (200 A GeV for heavy ions). It allows us p+p and p+A measurement as a function of $\sqrt{s}$ as the baseline. Note that the elementary cross section of J/ψ production at the RHIC energy presently has uncertainty of a factor of ~ 2.

The basics of PHENIX capability in quarkonium measurement is summarized in Table 1. The central and forward arms look into kinematic regions with substantially different local energy densities, as demonstrated in Figure 3 using the rapidity density of produced particles as a measure. Simultaneous access to the two regions provides a good test whether the quarkonium suppression is a function of local energy density. The transverse momentum coverage for di-electron also spans widely from 0 to above 5 GeV/c. As another key systematics, PHENIX can identify several members of J/ψ and Υ families, namely J/ψ, ψ(2S), Υ(1S) and Υ(2S+3S) separately (see Figure 2). It is also capable to measure many reference channels such as di-lepton continuum from charm and Drell Yan, single leptons and single photons.

The expected statistics for one year of RHIC Au+Au running are shown in Table 2 with following assumptions: (1) 1.6 nb^{-1} of integrated luminosity, corresponding to 27 weeks of running with a 50% experimental duty factor at the RHIC nominal Au+Au luminosity of 2×10^{26} cm^{-2} s^{-1}, and (2) 400 nb of $B_{ll}\sigma_{NN}(J/\psi)$ at $\sqrt{s} = 200$ GeV. Nuclear absorption or any further suppression is not included in the calculation. NA50 estimates the factor in Pb+Pb reactions at $\sqrt{s} = 17$ GeV to be ~ 0.31 for J/ψ in minimum-bias events, ~ 0.27 for J/ψ in central events, and ~ 0.06 for ψ(2S) [4,5]. High statistics data from the high rate capability with selective triggering open a possibility of further systematics, *e.g.* quantitative evaluation of χ_c contribution to J/ψ and detailed study of centrality dependence of quarkonium behavior.

TABLE 2. Expected quarkonium statistics in PHENIX for one year of RHIC running. See text for details of assumptions.

	central arms		forward arm (per arm)	
	10 % central	minimum-bias	10 % central	minimum-bias
J/ψ †	$\sim$ 70,000	$\sim$ 200,000	$\sim$ 350,000	$\sim$ 1,000,000
ψ (2S) †	$\sim$ 1,400	$\sim$ 4,000	$\sim$ 7,000	$\sim$ 20,000
Υ †	$\sim$ 80	$\sim$ 250	$\sim$ 160	$\sim$ 500
Drell Yan (> 4 GeV)	$\sim$ 250	$\sim$ 700	$\sim$ 1,500	$\sim$ 4,000

† Nuclear absorption and "anomalous" suppression factor are not included.

Open heavy flavor production is a probe of the initial state and also serves as a good reference to quarkonium production. PHENIX addresses it via single leptons at high momentum, high-mass di-leptons, and more sophisticatedly electron-muon coincidence. As an example the right panel in Figure 2 shows a simulated di-electron spectra at $\sqrt{s} = 200$ GeV. Contribution of open charm will dominate single electrons above 2 GeV/c and di-electrons above the J/ψ mass.

Change in properties of light vector mesons, such as mass, decay width and/or branching ratio, is proposed as a probe of chiral symmetry restoration. NA45 reported enhancement of low-mass di-electrons which could be attributed to enhancement and melting of ρ [6]. PHENIX addresses it with the high electron identification capability and resolution. With the mass resolution better than 5 MeV in r.m.s., ϕ and ω will be clearly separated as shown in Figure 2. Without like-sign subtraction signal-to-noise ratios of $\sim 1/10$ and $\sim 1/15$ will be achieved for ϕ and ω, respectively.

Thermal di-lepton is another probe of interest to access radiation from the hot gas state as a complement to direct photon measurement. At RHIC there is a possible invariant mass window to look into thermal di-electrons from 1 to 2 GeV.

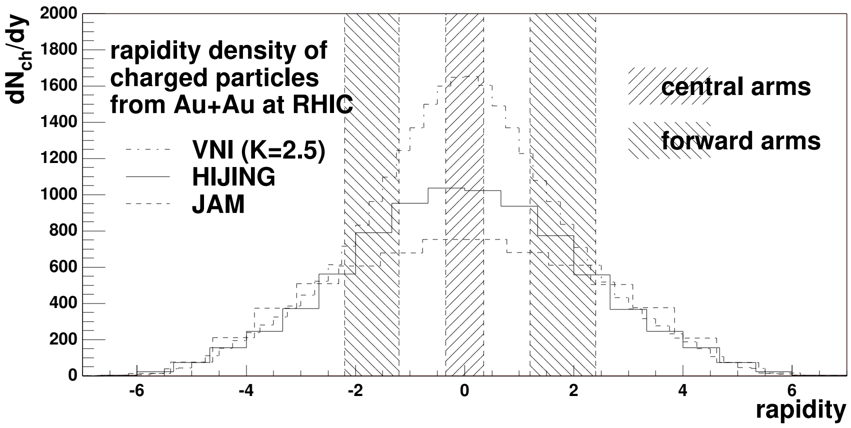

FIGURE 3. Expected produced particle density, as a measure of local energy density, in kinematic coverage of PHENIX central and forward arms.

UPCOMING PHYSICS

In the programs at RHIC in 2000, the first priority is placed to record at least 1 μb^{-1} of Au+Au reactions at $\sqrt{s} = 130$ GeV. First physics results via photon, electron and hadron channels will come out of PHENIX. It should be stressed that PHENIX is capable of accessing most of the physics probes and essentially all time scales of the reaction already in the first year: initial hard processes via jet, hard photon and hadrons at high transverse momentum; deconfinement via heavy quarkonium; chiral restoration via light vector mesons; thermalization via soft photons, non-resonant di-electrons, single electrons from open charm and photons at high transverse momentum; hadronization via hadron spectra, strangeness and interferometry; and final-state hydro-dynamics via transverse energy distribution and produced particle density.

In the following year, Au+Au running at the full energy of $\sqrt{s} = 200$ GeV is planned, along with p+p running to characterize the baseline and for spin physics programs. PHENIX will also add the muon measurement capability. A greater sensitivity to rare probes from relativistic heavy ion reactions, as well as first results from spin physics, is expected in 2001.

SUMMARY AND CONCLUDING REMARKS

RHIC, a unique and versatile facility to investigate QCD in extreme conditions and scales, has started its operation. The PHENIX experiment at RHIC is suited for systematic studies of relativistic heavy ion reactions, notably via lepton channels with the high particle identification capability, high resolution, broad kinematic coverage and high rate/statistics capability. Utilizing a wide variety of physics probes, it covers many signatures of the QCD phase transition and accesses essentially all time scales of relativistic heavy ion reactions. First physics results via photon, electron and hadron channels will come out of PHENIX in 2000, followed by more systematic data including muon channels in 2001. The longstanding search for the QCD phase transition and a deconfined quark-gluon plasma phase is expected to reach conclusive experimental results.

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