Chapter 1

Physics Goals And Detector Overview

The primary physics goals of the PHENIX Muon Arms are to contribute to both the Relativistic Heavy Ion Physics program and to the Spin Physics program of the PHENIX Experiment. This chapter will describe the physics goals of both of those programs in as much as they relate to the Muon Arms. However, since the Relativistic Heavy Ion Physics program has been described in considerable detail in supplementary documents, it will only be summarized there.

1.1 Relativistic Heavy Ion Physics

The Relativistic Heavy Ion Physics goals of the PHENIX Experiment are described in both the PHENIX Conceptual Design Report (CDR) [1] and the CDR Update [2]. This section will, therefore, only summarize what is presented in those documents about the PHENIX Muon Arms.

The primary goal of the Relativistic Heavy Ion Physics program of PHENIX is to detect the quark-gluon plasma (QGP) and measure its properties with as many different experimental probes as the detector will allow. Those measurements are shown in an updated version of Table 1.1 of the CDR and shown here as Table 1.1. As the table clearly indicates, the Muon Arms are a major contributor to the total physics program. Muon pairs are measured in order to study properties of the vector mesons (e.g., mass, width, and yield) and to study the continuum spectra in different regions of rapidity and mass from what is accessible with the Central Arms alone. Additionally, the $e\mu$ coincidence will probe charm production and aid in the understanding of the shape of the continuum dielectron spectrum. During the last two years, the potential for making measurements of heavy-flavor production in pA and AA running utilizing single muons has been recognized [4]. That single muons are useful for such measurements can be seen from Figure 1.1. The figure shows the momentum spectra of muons which come from heavy-flavor production followed by semileptonic decay and muons from π and K decays. When $p_\mu > 2\ GeV$, muons from heavy-flavor production dominate background muons. Because this physics requires only the detection of a single muon it can

QGP Physics Issues	Probes
Debye Screening of QCD Interactions	
• $r(\Upsilon) = 0.13$ fm $< r(\mathrm{J}/\psi) = 0.29$ fm $< r(\psi') = 0.56$ fm	
$\mathrm{J}/\psi \rightarrow e^+e^-$ at $y \simeq 0$.	Electrons
$\mathrm{J}/\psi \rightarrow \mu^+\mu^-$ at $y \simeq 2$.	
$\psi', \Upsilon \rightarrow \mu^+\mu^-$ at $y \simeq 2$.	Muons
Chiral Symmetry Restoration	
• Mass, Width, Branching Ratio: $\phi \rightarrow e^+e^-$, K^+K^-	Electrons
with $\Delta m \leq 5$ MeV.	Hadrons
• Baryon Susceptibility: Production of antinuclei.	
• Narrow σ-meson?	
Thermal Radiation of Hot Gas	
• Prompt γ, Prompt $\gamma^* \rightarrow e^+e^-$.	Photons, Electrons
Deconfinement: Nature of the Phase Transition	
• First-order: Entropy Jump $\rightarrow$ Second rise in the $< p_T >$	Hadrons
spectra of π, K, p.	
• Second-order: Fluctuation $\rightarrow N(\pi^0)/N(\pi^+ + \pi^-), d^2N/d\eta d\phi$.	Hadrons, Photons
Strangeness and Heavy-Flavor Production	
• Production of K^+, K^-, K^0_L.	Hadrons
$\phi \rightarrow e^+e^-$, K^+K^- at $y \simeq 0$,	Electrons
$\phi \rightarrow \mu^+\mu^-$ at $y \simeq 2$.	Muons
D-meson: $e\mu$ coincidence.	
Open c- and b-production: high-p_t muons	Muons
Jet Quenching	
• High p_T jets via eading particle spectra.	Hadrons
Space-Time Evolution	
• HBT correlations for $\pi\pi$ and KK.	Hadrons

Table 1.1: Physics Issues Related to Quark-Gluon Plasma

be expected to be some of the first physics produced by the PHENIX Muon Arms.

For further details on the Relativistic Heavy Ion Physics goals consult the CDR Update. Chapter 2 of this report presents the detector design specifications which must be met in order to carry out the physics programs.

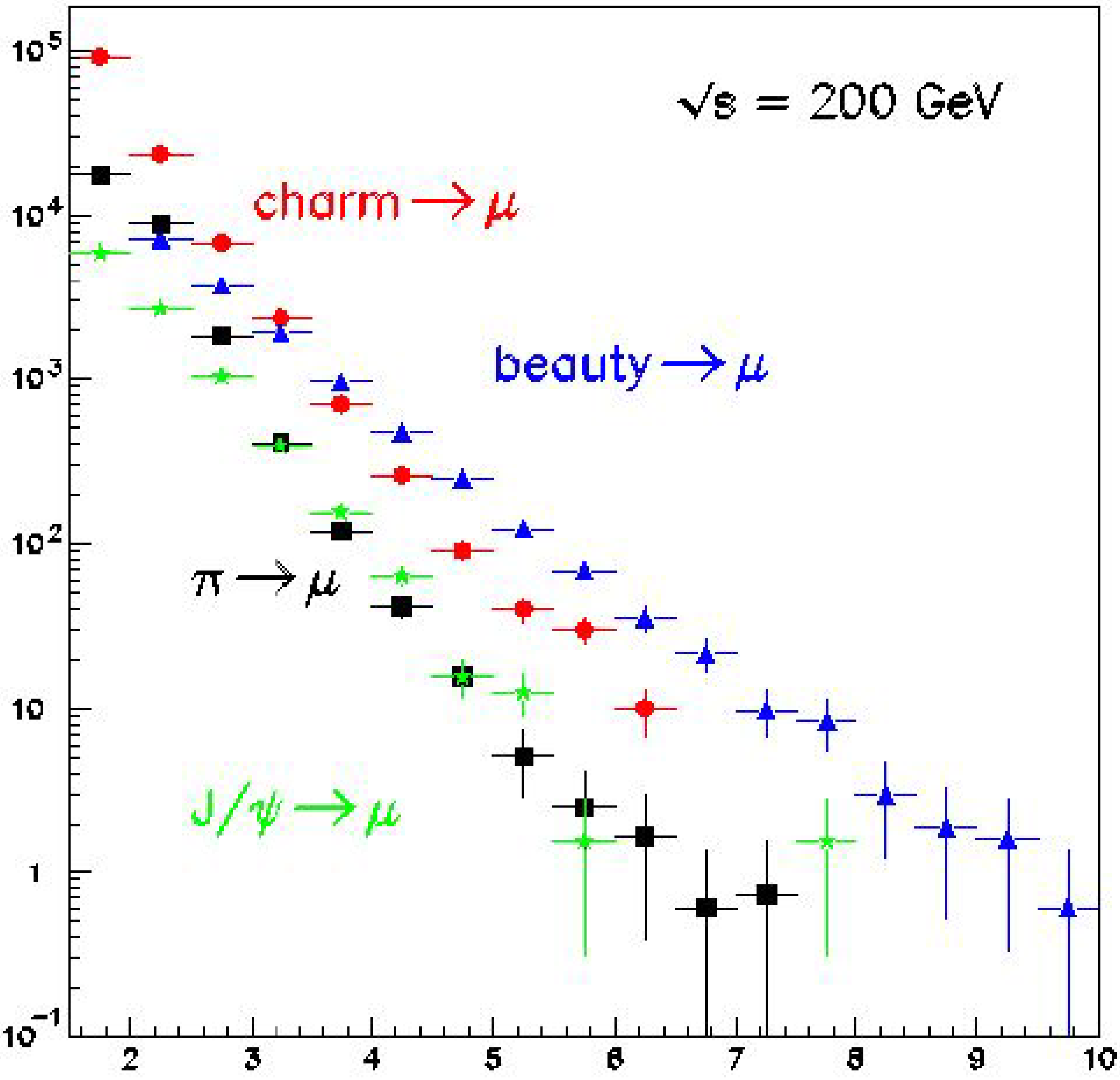

Figure 1.1: Spectrum of single muons into the South Muon Arm of PHENIX [4].

1.2 Spin Structure of the Nucleon

A major resurgence of interest in the spin structure of the nucleon followed the 1988 publication [3] of small-x measurements of $g_1^p(x)$ by the European Muon Collaboration (EMC). Analysis of the EMC data and larger-x deep-inelastic scattering (DIS) data from SLAC [5] gave rise to the so-called "spin crisis" – the observation that the integral contribution of the up and down quarks to the proton's helicity was small [6].

The past eight years has seen an enormous effort to acquire more precise DIS data using polarized electron and muon beams. New measurements of $g_1^p(x)$ confirm [7] the earlier EMC results, and new data on the neutron from DIS on polarized ^2H [8] and polarized ^3He [9] add significantly to our knowledge of quark polarization in the nucleon system. The search for new understanding continues. A major effort is underway at DESY where the HERMES [10] experiment will extend DIS to more exclusive channels. Experiments are also envisioned at SLAC using 50 GeV polarized electrons and at CEBAF exploiting parity violation.

In spite of the large body of new data and the promise of even better experiments in the near future, polarized DIS measurements have major limitations. They do not directly provide any information about antiquark or gluon helicity distributions. Neither can they probe the potentially equally interesting, and completely unknown, chiral-odd quark structure functions [11,12,13,14,15,16,17]; hence the interest in polarized hard-hadronic processes which could offer new physics insight, complimentary to polarized DIS [18,19].

1.2.1 PHENIX Spin Structure Program

The spin structure function program of the PHENIX detector, described in the RHIC Spin Proposal [19], includes measurements of direct photon, Drell-Yan, $W^{\pm}, Z^0$, and jet production through the detection of π^0. These measurements address gluon and antiquark polarization using the PHENIX baseline detector.

1.2.2 Spin Structure Physics With a Two-arm Muon Spectrometer

In 1994, when it became apparent that the newly formed PHENIX/RIKEN collaboration would permit a substantial upgrade of the muon subsystem, PHENIX submitted a new document [20] to BNL's HENP Advisory Committee describing the enhanced capabilities for spin physics achievable with a two-arm muon spectrometer. In brief the two-arm muon subsystem greatly enhances the detection of large $\sqrt{\tau} = M/\sqrt{s}$ muon pairs as is shown in Figure 1.2.

It is at large values of $\sqrt{\tau}$ where polarization effects are likely to be maximal. For a complete description of the spin structure function physics program, the reader is refered to the upgrade document [20] and a brief note summarizing more recent simulations of single-muon detection as a signature of $W^{\pm}$ and heavy-quark production [21].

Finally, it is important to note that the spin-structure function physics program with the muon subsystem makes use of the muon pair spectrum above $M = 3$ GeV in much the

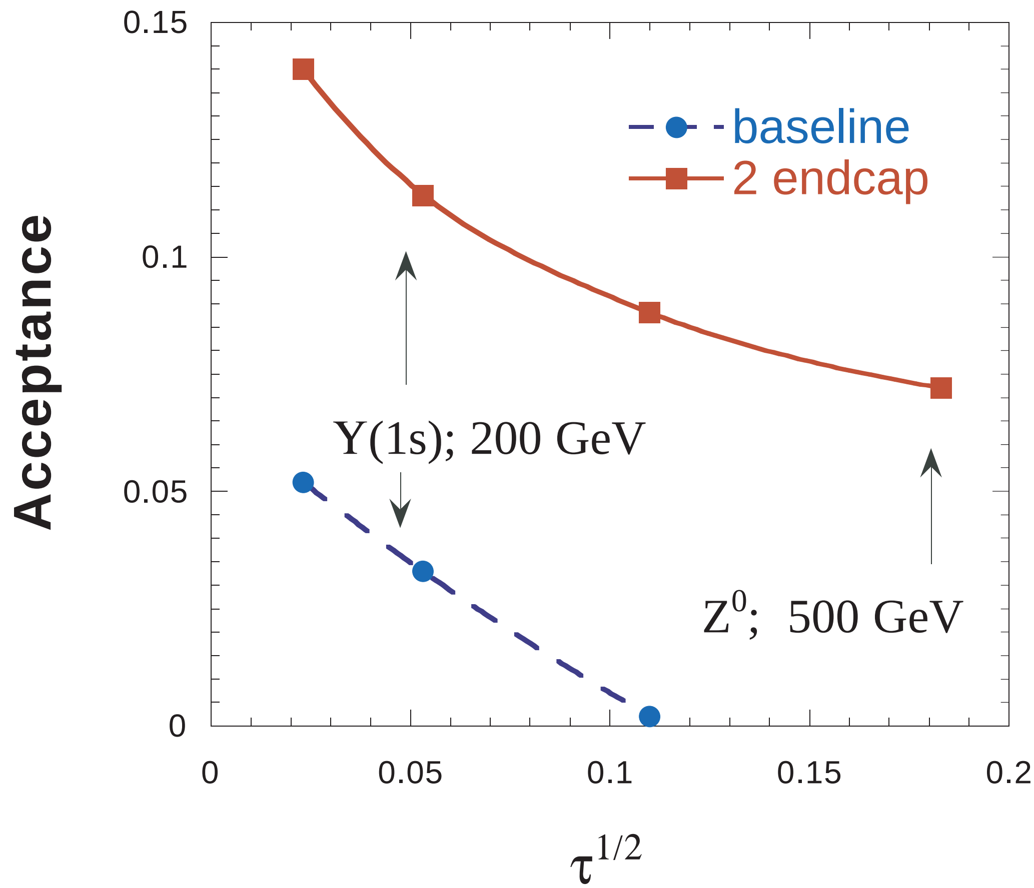

Figure 1.2: Acceptance of the baseline (one endcap) and upgrade (two endcap) versions of the PHENIX muon spectrometer. Calculations were performed at 200 GeV but are approximately valid at other energies as well.

same way as it is used in the PHENIX heavy-ion program. Mass resolution requirements are essentially indentical to those described in Section 2.1. Mass resolution at the the Z^0 is $\approx$ 8 GeV [22] – quite acceptable for physics in this region.

Event multiplicities are substantially lower in spin structure function running conditions than those encountered central $Au - Au$ collisions. Thus pattern recognition and background considerations for the muon pair spectrum in the spin program add no new design requirements.

1.3 Other Physics Opportunities–Symmetry Tests

Test of symmetries is of fundamental interest to all physicists. The role of spin in such tests has been recognized for a long time. Other opportunities should not be ruled out by our designs, if possible.

For hadron-hadron collisions at high energies, an extensive review can be found in Ref. [23,

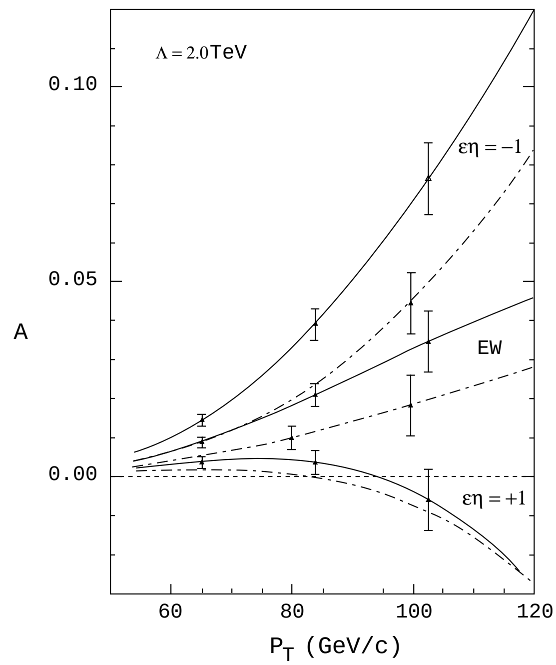

Figure 1.3: A_{LL}^{PV} for one-jet inclusive production from pure QCD-EW interference.

24]. Most of the studies in Ref. [23] were for the LHC and SSC, and the energy scale studied was the multi-TeV region including possible implications of physics beyond the standard model; supersymmetry, compositeness, etc. Of course, no positive signature of new physics has been seen. On the other hand, we should not miss the chance of a discovery and should be ready to detect those signals within the boundary conditions of the current detector.

The capability of the polarized proton acceleration up to $\sqrt{s} = 500$ GeV at RHIC is now widely known[1], and previous efforts now focuses on the possible discovery of the new physics at RHIC. For example, Taxil and Virey [25] have predicted sizable parity-violating asymmetry for inclusive one-jet production in pp collisions at $\sqrt{s} = 500$ GeV, as shown in Figure 1.3. For PHENIX, however, the reconstruction of jet-momentum using only the electromagnetic part of the fragments is rather model-dependent, incomplete, and challenging.

[1]But RHIC is not on the table of hadron colliders in the Particle Data Book.

1.4 Detector Overview

A cutaway view of the PHENIX detector is shown in Figure 1.4. It shows that the Muon Arms are end-cap spectrometers. They cover $10° < \theta < 35°$ for the North Muon Arm and $12° < \theta < 35°$ for the South Muon Arm. Both arms cover $0° < \phi < 360°$ and consist of tracking chambers inside of spectrometer magnets followed by the muon identification sections. Chapter 3 presents the details of the detector design as well as the results of R&D studies and the construction status. Chapter 4 presents the results of simulations of the performance capabilities of the Muon Arms. Chapter 5 describes some of the integration issues, and Chapter 6 presents a top-level cost and schedule summary.

A drawing of PHENIX goes here

Figure 1.4: Isometric view of the PHENIX Detector showing both the North and South Muon Arms.