Vertex Detector Upgrade Plans for the PHENIX Experiment at RHIC

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Abstract

The PHENIX experiment at the Relativistic Heavy Ion Collider has completed its baseline instrumentation for the start of the presently ongoing third physics run. In the next few years, PHENIX will focus on high-statistics measurements in this configuration. It is expected that the collider will reach full luminosity with heavy ion and polarized proton beams by the year 2006. An upgraded collider is intended for the second half of the decade, with a luminosity increase to about 20-40 times the design value of 8×10^{26} cm^{-2}s^{-1} for Au+Au, and 2×10^{32} cm^{-2}s^{-1} for polarized proton beams. The collision energies of $\sqrt{s_{NN}} = 200$ GeV will increase to $\sqrt{s_{NN}} = 500$ GeV for proton beams. The PHENIX collaboration plans to upgrade its experiment to exploit with an enhanced detector new physics then in reach. A silicon vertex detector comprising pixel and novel microstrip sensors in a new vertex spectrometer is the main new sub-system discussed. This paper overviews the physics motivation and the detector concept chosen, and explains the directions of the beginning research and development effort.

Key words: RHIC, PHENIX, Upgrade, Silicon Vertex Detector, Microstrip, Pixel
PACS: 25.75.-q, 07.77.-n

1 Introduction

The PHENIX experiment [1] is the large experiment at Brookhaven National Laboratory's Relativistic Heavy Ion Collider (RHIC) that was specifically designed to detect probes which sense the early phase of heavy ion collisions. It is expected that the formation of Quark Gluon Plasma (QGP) is most likely to occur then. This high-energy-density state of matter with freely moving quarks and gluons has never been clearly observed but is believed to have existed in the early universe when hadrons formed about 10 μs after the Big Bang. Probes of interest for the study of Quantum Chromo Dynamics (QCD), confinement of color charge in hadrons and the absence of chiral symmetry

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Preprint submitted to Elsevier Science *17 April 2003*

in nature, are electromagnetic radiation, jets of particles with high transverse momenta, and charmonium states from heavy flavor decays. Another physics programme at RHIC with important PHENIX involvement uses colliding polarized proton beams. It aims at the understanding of the complex internal spin and flavor structure of hadrons. For polarized proton physics, especially jet production, prompt photons and Drell-Yan lepton pairs provide information on the parton kinematics.

2 The PHENIX Experiment

The PHENIX detector comprises four spectrometer systems. A pair of "central" spectrometers covers mid-rapidities ($|\eta| < 0.35$, 2 × 90 degrees of azimuth). They are optimized to detect electrons, hadrons and photons over a large momentum range, outside an axial magnetic field that is created around the beam line with two sets of solenoidal coils. Vector mesons can be measured due to the high mass resolution achieved with tracking in drift chambers and pixel pad chambers. Electrons and photons are identified with ring imaging cherenkov counters and time expansion chambers. The identification of hadrons is realized via time-of-flight measurement in a scintillator wall. Energy is measured in two types of electromagnetic calorimeters. Two muon spectrometers are located at forward rapidities ($1.2 < |\eta| < 2.2$). They consist of a hadron absorber, a muon tracker with radial magnetic fields and muon identifier stations. In the center of PHENIX, a multiplicity vertex detector measures the charged particle multiplicities and the position of the event vertices along the beam line. Beam-beam scintillator counters, zero-degree calorimeters and scintillator multiplicity counters allow to characterize the collisions and to trigger the data collection from the PHENIX sub-systems.

3 From RHIC I to RHIC II

The two physics runs performed at RHIC since its start-up in Fall 1999 were dominated by the commissioning and completion of the collider and the experiments. Already numerous PHENIX results were obtained from those runs [2]. Now that the PHENIX baseline detector systems are completed for the third run, the collaboration is able to start to exploit the ongoing first phase of RHIC that focusses on the confirmation of QGP creation in heavy ion collisions. A second phase of RHIC is anticipated to begin during the second half of this decade, with a luminosity increase to up to 40 times the design value in an upgraded collider. It will focus on the fundamental properties of QCD. A key requirement of that program will be the access to new observables, for which upgraded PHENIX detector systems are needed that add new capabilities to the baseline experiment [3].

This situation shall be illustrated in Fig. 1 which shows an example of the present central spectrometers' track and vertex reconstruction capabilities along with one of the important recent PHENIX measurements. The measurement of open charm and open beauty as well as the total charm and bottom production belongs to the very important measurements of leptonic observables in heavy ion collisions. Their direct detection, never achieved so far in those conditions, requires the identification of secondary vertices of charm and beauty meson decays, i.e. electron or muon track reconstruction with spatial resolution of the order of a few tens of micrometers at the collision vertex. Though the central detectors can handle well the particle multiplicity even in central Au+Au collisions, the vertex measurement based on the reconstructed tracks and information from the multiplicity vertex detector is not of sufficient resolution for this task. So far, PHENIX followed two different inclusive approaches to measure electron production from non-photonic sources. In a first measurement the vast background was subtracted using a Monte Carlo "cocktail" simulation of all known electron sources. In the second measurement the most significant background (photon conversion from π^0 Dalitz decays) was measured in PHENIX itself by addition of a photon converter of known thickness to the detector material [4]. The measured electron spectra are in good agreement with expected charm production. Future direct measurements will have to support the result and are required to separate the contributions of charm and beauty to the electron production at higher transverse momenta.

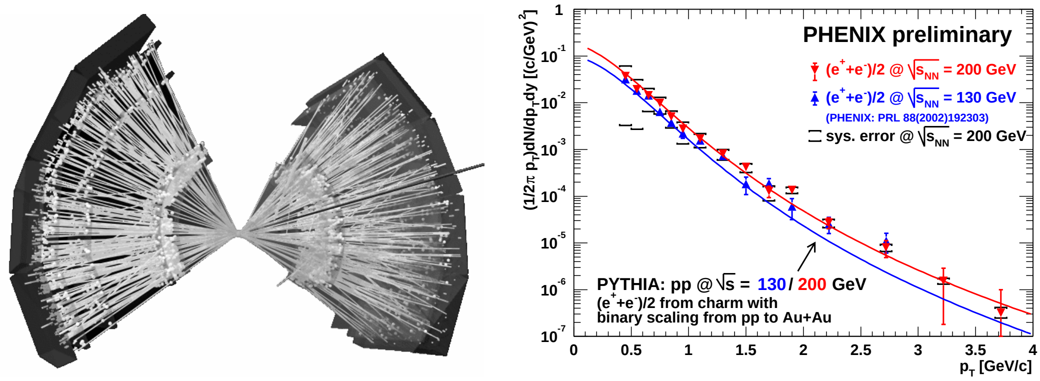

Fig. 1. Tracks of charged particles produced in a central Au+Au collision at $\sqrt{s_{NN}}$ = 200 GeV, reconstructed in the central spectrometers of PHENIX. The charged particle density is $dN_c/dy \approx 700$ (left). Two indirect measurements of electron production from non-photonic sources in min. bias Au+Au collisions using the PHENIX central spectrometers. The measurements are compared with expectations from semi-leptonic D meson decays (right).

4 Upgrade of PHENIX with a Vertex Detector and Spectrometer

The main PHENIX upgrade foreseen is a new vertex spectrometer that will be installed in the space presently used by the multiplicity vertex detector. It combines high precision tracking for jet and heavy-flavor decay vertex measurement with electron identification and charged particle tracking. Figure 2 shows the spectrometer with its three planned sub-systems between the pole faces of the central magnet.

A fast and compact time projection chamber with an integrated hadron blind detector is foreseen to track and identify electrons over the full azimuth in the central acceptance. An inner pair of magnet coils that is already installed can

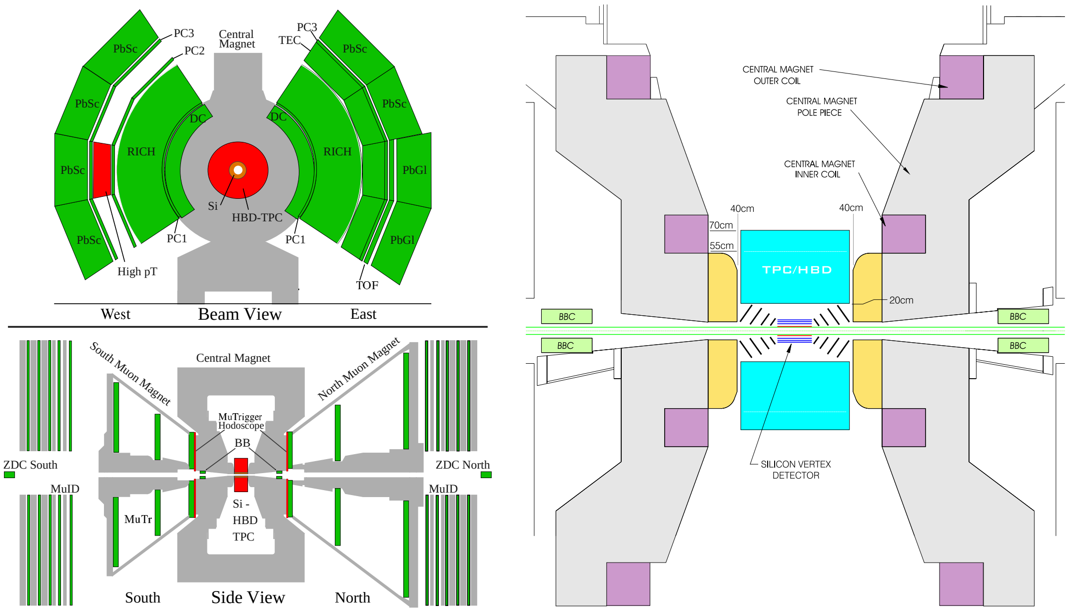

Fig. 2. The planned Vertex Spectrometer in PHENIX.

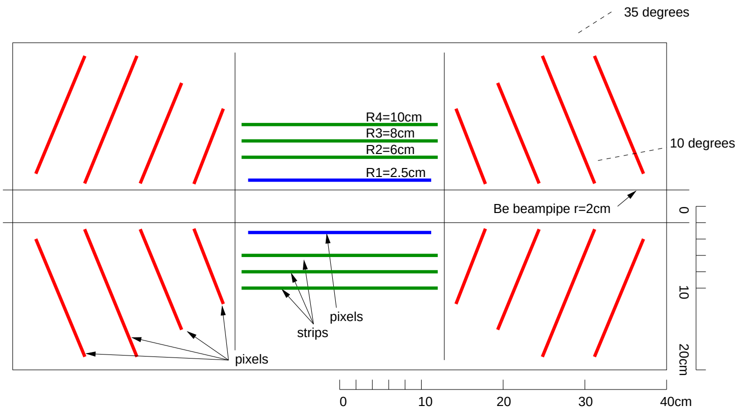

Fig. 3. Schematic layout of the proposed Silicon Vertex Detector, indicating the approximate positions and dimensions of the central and end-caps detector layers.

create a low-field environment in the vertex region. This will allow to detect in the vertex spectrometer low-momentum electrons (p $<$ 200 MeV) produced in photon conversions and Dalitz decays, which are not reconstructed in the central spectrometers.

The vertex tracking will be based on highly segmented silicon pixel and microstrip detectors at mid-rapidity, and further silicon pixel detectors in the forward direction. The schematic layout of the vertex detector in the available space is shown in Fig. 3. The central silicon detectors are planned to be built from an internal layer pixels and three outer layers strips. They will be arranged in two half-shells and will cover approximately $-1.2 < \eta < 1.2$ and almost 2π in azimuth. Pixel sensor technology is essential for the resolution of the high track density in heavy ion collision in the internal layer. Microstrip sensors can be used in the more outward layers where the occupancies are less severe. In proton-proton collisions with generally much lower occupancies, the pixel detectors of the internal layer help to constrain the vertex candidates found with the microstrip sensors. The forward silicon detectors will consist of four pixel cones per side that match the geometrical acceptance $1.2 < |\eta| < 2.7$ of the muon spectrometers.

An extensive research and development effort was initiated in the PHENIX collaboration to identify suitable technologies for the vertex detector components and the system integration. This work is presently ongoing and directions may change as progress is made.

Silicon microstrip detectors for the outer central layers are being developed based on a novel sensor design of the Instrumentation Division of Brookhaven National Laboratory [5]. In a projective readout, track points can be reconstructed in "pixels" of 80 μm × 1 mm size. First sensor prototypes were recently exposed to a test beam. Different readout chips are being evaluated.

The research on pixel detectors follows two paths, given the short time that remains until the new vertex detector is needed in the experiment. The general challenge we are facing is the necessity for thinnest possible detector modules. Multiple scattering in the material degrades the spatial resolution of the secondary vertex measurement and must be reduced as much as possible. Monolithic pixel detectors are attractive for their potentially very low thickness of a few tens of micrometers. Recent developments in this new field are followed-up and improvements studied to increase the readout speed of those structures [6]. Hybrid pixel detectors as developed at CERN during the last decade have already reached a high level of sophistication [7]. They are indispensable in the tracking systems of the next-generation experiments at the LHC. Attractive for PHENIX are the pixel detectors that will be used in the ALICE experiment [8]. The application in the ALICE inner tracking system is very similar to what PHENIX would need. A pixel detector module for PHENIX could be designed building on the ALICE concept. The pixel size of 50 μm × 425 μm would be compatible with the PHENIX requirements. Thin sensors and the thinning of front-end chips in the intrinsically thicker hybrid approach are a concern for ALICE as well as for PHENIX. A technical collaboration on the module development between PHENIX institutions and ALICE-CERN is aspired. Work has essentially started very recently. On a smaller scale, several members of a few PHENIX groups already gain experience with those detectors and participate in the NA60 experiment at CERN. The NA60 collaboration uses ALICE pixel detector components and is finalizing a vertex tracker for the measurement of prompt di-muon and charm production in proton and heavy ion beams at the CERN SPS [9].

Based on such silicon detectors, simulations of the expected vertex detector performance are performed. Both the central and the end-cap layers provide sufficient resolution to measure electrons and muons from semi-leptonic decays of D or B mesons. They will provide a single-track resolution of approximately 50 μm at the vertex. With a muon pair vertex resolution of about 130 μm, compared with the mean decay length of 1.1 mm, tagging of J/Ψ from B decays can be performed in the forward direction. In the central detector, D mesons can also be reconstructed via the D→ πK mode, and jet tagging will be possible as required in polarized proton physics. The inner magnet coils can be operated to produce a high field in the vertex spectrometer region. The momentum resolution achieved with the combined tracking of vertex detector and time projection chamber is then comparable with the present central spectrometer resolution, with the additional benefit of increased angular coverage.

5 Conclusion

With the baseline detector completed, the PHENIX experiment has reached full potential to explore the first phase of physics at RHIC. It will contribute to establish in detailed measurements the signatures of Quark Gluon Plasma creation in heavy ion collisions, and will measure the gluon polarization in the nucleon with polarized proton beams. In the next few years, increasing luminosities will allow to focus on rare electromagnetic probes and to distinguish spin assymmetries of different particle species. In the view of an upgraded RHIC machine that operates at much higher collision energy and luminosity, PHENIX prepares to enhance the capabilities of the experiment. Among the new detector systems foreseen, a vertex spectrometer upgrade is in the center of the interest. Vertex tracking is one of the important enhancements of PHENIX and will give access to exciting physics. We are designing a vertex detector that builds on silicon pixel and microstrip detector technology. The required performance has been identified, and we are working enthusiastically on the application of matching cutting-edge technologies to achieve that goal in the near future.

Acknowledgements

I would like to thank the organizors of VERTEX 2002 for the invitation and opportunity to speak about the vertex detector upgrade plans of PHENIX in front of an expert audience at a truly impressive location. I appreciate the contributions of my PHENIX colleagues to the exciting project and thank them for their confidence in me to present our work.

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