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Upgrade Plans for PHENIX

Craig Woody for the PHENIX Collaboration
Physics Department
Brookhaven National Lab
Upton, New York

Abstract. The PHENIX experiment has just completed its second data taking run at RHIC and is now in the process of installing the final components of its baseline detector. In addition, RHIC will soon begin a series of upgrades to the collider leading eventually to RHIC II which will increase the luminosity by up to a factor of 40 above the design luminosity. As a result, PHENIX is starting to plan for possible detector upgrades which will make use of this higher luminosity, and to add new detectors which will enhance the physics capabilities and extend the physics reach of the present detector. This paper describes some of the ideas being discussed as a part of these upgrade plans.

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1. Introduction

The PHENIX experiment at RHIC is a large multipurpose detector designed to discover and explore new states of matter produced in relativistic heavy ion collisions in a new energy regime, and to study the spin structure of the nucleon in polarized proton interactions. It has a wide range of capabilities that allows it to make detailed measurements of the production of leptons, photons, jets, high p_T particles, transverse energy, flow, and numerous other quantities of physics interest in these types of collisions. The RHIC collider has now had two successful physics runs, including the most recent run in which the design luminosity was reached for Au+Au collisions, along with the first polarized proton run. During these first two runs, the PHENIX detector was only partially complete. However, many new and interesting results have already been produced with the data obtained thus far [1–6]. The final major components of the detector will be installed during the 2002 RHIC shutdown period, which will complete the baseline configuration of the detector in time for the third physics run at RHIC starting in the fall of 2002.

With the successful startup of RHIC and its four experiments, there are now plans to increase the luminosity of the machine by a factor of 40 above the design value through its

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proposed upgrade to RHIC II. This will open up many new possibilities for exploring new physics, particularly those involving rare processes in both heavy ion and polarized proton collisions. The PHENIX experiment has also begun to make plans to enhance the physics capabilities and extend the physics reach of its present baseline detector to meet these new challenges as the experimental program moves from the initial "discovery" phase to one of a detailed study of matter at extreme temperatures and densities, and of the spin structure of the nucleon. This paper discusses the present status of these plans along with some of the new physics topics that could be studied with an upgraded detector.

2. PHENIX Baseline Detector

The PHENIX baseline detector consists of three main spectrometers. The Central Spectrometer is divided into East and West Arms, each covering 90° in azimuth and $|\eta| < 0.35$ in rapidity, and contains a central axial field magnet. Each arm contains a drift chamber, pad chambers, a ring imaging Cherenkov counter (RICH), and an electromagnetic calorimeter. In addition, the East Arm contains a Time Expansion Chamber (TEC) and a high resolution Time-of-Flight counter. The North and South Muon Spectrometers cover the forward and backward directions, each having an acceptance of 2π in azimuth and $1.2< \eta <2.4$. They consist of a set of muon tracking chambers, muon identifier detectors, and a series of hadron absorbers.

During the first RHIC run in 2000, only the Central Spectrometer was in place and was only partially instrumented. For the second run in 2001, the South Muon Spectrometer was installed, and the Central Spectrometer was nearly fully instrumented. The North Muon spectrometer will be installed during the 2002 shutdown period, and the PHENIX baseline detector, as shown in Figure 1, will be essentially complete in time for the third RHIC run in fall of 2002.

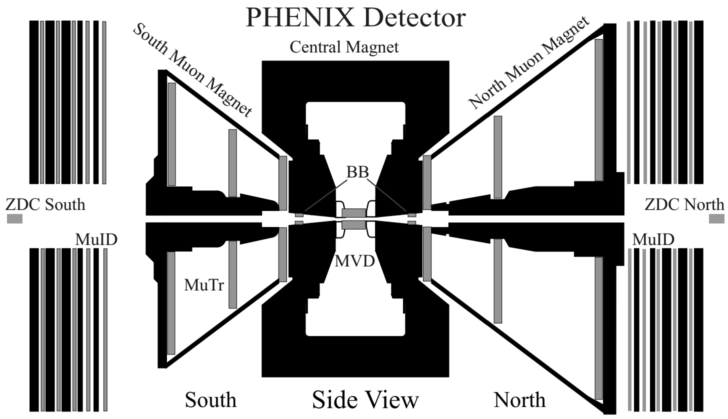

Fig. 1. PHENIX Baseline Detector as it will be instrumented for Run 3 at RHIC in 2002

In addition to the installation of the North Muon Spectrometer during the 2002 shutdown, the TEC will be upgraded to a Transition Radiation Detector (TRD) in order to provide better electron identification at high p_T. This will require installing polypropylene fiber radiators in existing compartments of the TEC and implementing a recirculating xenon gas system. Figure 2 shows the pion misidentification probability as a function of momentum for an electron efficiency of 90% using the various PHENIX detectors. At low momentum, the e/π rejection is provided mainly by the RICH, EMCAL (using both time of flight and E/p matching), and by dE/dx in the TEC. At high momentum, particularly above the pion threshold in the RICH, the rejection is provided by E/p matching and the TRD, which allows one to maintain an overall rejection factor on the order of 10^{-3} over the entire p_T range.

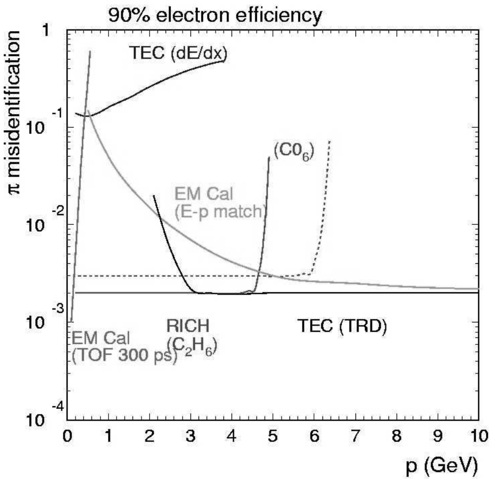

Fig. 2. Pion misidentification probability versus momentum for an electron efficiency of 90% utilizing various PHENIX detectors

3. PHENIX Upgrades

The upgrades for PHENIX will add additional capabilities to the baseline detector in order to explore new physics with both heavy ions and polarized protons. This will build on the extensive existing capabilities of the present detector, and will make use of the much higher luminosity expected for the collider with RHIC II. Some of the physics topics which will be addressed by the PHENIX upgrades are:

- Low mass electron pairs
- Improved measurements of heavy flavor production

- Jet studies and γ-jet correlations
- High p_T identified particles
- Studies of rare processes requiring high luminosity (e.g.,measurement of inclusive particle spectra and direct γs out to high p_T, the Drell-Yan continuum above the J/Ψ, Upsilon spectroscopy, W production in polarized proton collision, etc.)

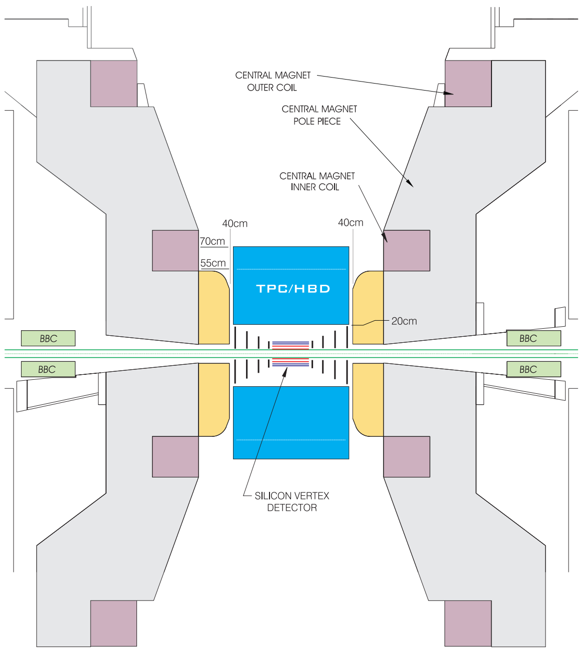

Fig. 3. Inner region of the Central Spectrometer with second inner coil, TPC/HBD and Silicon Vertex Detector

To carry out these physics measurements will require new and enhanced detector capabilities. One of the main areas of focus for the PHENIX upgrades will be the inner region of the Central Spectrometer. This will include a new detector for rejection of Dalitz pairs and conversions, a 2π inner tracker for improved momentum resolution and jet measurements, a new high precision vertex detector for measuring charm and bottom decays, and an inner coil for the central magnet which will allow the possibility of creating a low field in the central region for measuring low mass electron pairs. Figure 3 shows the inner region of the Central Spectrometer with one possible upgrade configuration. In addition, a second Cherenkov counter made of aerogel is being considered which will provide better π/K separation at low momentum, and will extend the K/p separation out to $\sim$ 9 GeV/c. PHENIX is currently carrying out an extensive R&D program to develop new technologies required to design and implement these new detectors, along with plans to upgrade the PHENIX DAQ and trigger systems in order to deal with the higher luminosities expected in both heavy ion and pp collisions. A brief description of some of these ideas is given below.

3.1. Fast, Compact TPC/HBD

There is considerable interest in the study of low mass dilepton pairs in heavy ion collisions, which could indicate the production of thermal radiation from a hot hadron gas, or the onset of chiral symmetry restoration. However, in order to carry out this measurement in the environment of high energy heavy ion collisions, it is necessary to have extremely good rejection of low momentum electrons produced by Dalitz pairs and conversions which produce a large combinatorial background in the electron pair mass spectrum. An improvement in the signal to background of least two orders of magnitude is required, along with an electron detection efficiency greater than 90%.

The strategy for achieving this in PHENIX is to create a low field region in the Central Spectrometer using a second inner coil, which would allow the measurement of low momentum electrons ($p < 200$ MeV/c) that would normally curl up and be lost in the normal field configuration. Higher momentum electrons would be measured in the higher field outside this region, and identified using the full complement of outer PHENIX detectors (RICH, EMCAL, TEC/TRD).

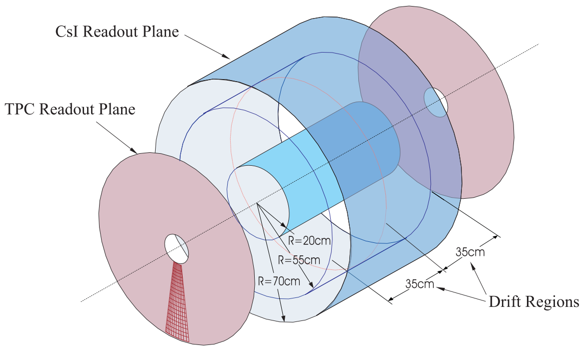

Fig. 4. Dalitz rejector and tracking detector with combined features of a small, compact TPC and Hadron Blind Detector

Electrons would be tracked and identified in the inner region using a combination of a small, compact Time Projection Chamber (TPC) and a Hadron Blind Detector (HBD). As a TPC, this detector would also provide full tracking coverage over 2π in azimuth and $|\eta| < 1.0$. A possible design of such a detector is shown in Figure 4. Low momentum electrons would be identified by dE/dx in the TPC and by detection of their Cherenkov light by the HBD. The HBD would have a large area photocathode (such as CsI) on its outer surface and utilize the TPC gas volume as a radiator. The TPC would drift charge towards the readout planes on each end of the detector over a distance of $\sim$ 35 cm, and would use a fast drift gas to limit the drift time. It is possible that a fast, UV transparent gas such as CF_4 could be used for both purposes. Both the TPC and HBD would also use some form of micropattern detector (such as a GEM or MicroMega) as a readout device, which could also operate with the same common gas.

3.2. High Precision Silicon Tracker and Vertex Detector

Another area of great interest in heavy ion and spin physics is the production of heavy flavors. While the first measurements of charm production has already been made by PHENIX [6] and can be studied to a consider degree with the PHENIX baseline detector, it would be a great advantage to be able identify individual charm and bottom decays by measuring their displaced secondary vertex. This would not only enhance the capability for flavor tagging of jets, improve the measurement of the charm and bottom cross sections, and improve the resolution for measuring upsilons, but would also permit further studies, such as separating charm and bottom decays as a function of p_T and allow a direct measurement of D meson production. Given the charm and bottom lifetimes ($c\tau$) in the range of a few hundred microns, it is necessary to have a vertex detector with a resolution on the order of 30-50 μm in order to cleanly separate the secondary decay vertex from the primary vertex. However, a significant limitation in this measurement is the multiple scattering produced in the beam pipe and in the vertex detector itself.

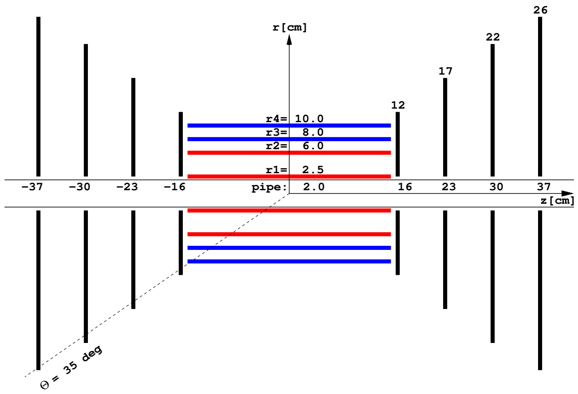

Fig. 5. High resolution silicon tracking and vertex detector. The two inner barrel layers and endcap disks are silicon pixels and the outer two barrel layers are silicon strips

A proposed silicon tracking and vertex detector is shown in Figure 5. It consists of an inner barrel with two layers of silicon pixel detectors, followed by two layers of silicon strips covering $|\eta| < 1.2$, along with a set of silicon pixel disk detectors which cover $1.2 < |\eta| < 2.4$. The pixel detectors would have pixels on the order of 50 μm $\times$ 425 μm and would provide a vertex resolution on the order of 35 μm. Monte Carlo simulations have shown that this would allow a cut on the distance between the primary and secondary vertex on the order of 100 μm, which would improve the signal to background ratio for D $\rightarrow$ eX decays from 1:1 to better than 10:1 for $p_T > 1$ GeV/c. Combined with the silicon strips in the outer two layers, it would provide both a precision vertex measurement and tracking information close to the vertex.

There are several technology choices for both the silicon strip and silicon pixel detectors. For the pixel detectors, the are two main options. The first option would be to use hybrid pixel detectors, which consist of a silicon sensor layer that is bump bonded to a readout layer containing the front end readout electronics. These detectors, along with the readout chip, and have been developed and are being tested for use in NA60[7] and ALICE. A second option would be to use Active Pixel Sensors (APS), which integrate the sensor and readout functions onto a single layer of silicon. These detectors, which can have pixel sizes on the order of 20 μm $\times$ 20 μm, are being developed by the LEPSI group [8, 9] and by the STAR group at LBL [10]. They offer the significant advantage of providing very high spatial resolution and less material to reduce multiple scattering. The silicon strips detectors could be standard $\sim$ 100 μm strips, or they could be elongated pad arrays with dimensions comparable to the pixels, which are currently being developed at BNL.

3.3. Aerogel Cherenkov

The first data from RHIC have indicated a number of very interesting effects involving high p_T particles and jets. Some of the most interesting have been the possible suppression of jets in dense nuclear matter, the copious production of protons and antiprotons at high p_T, and the p_T dependence of various particle ratios. To further study these phenomena, it is extremely important to have good particle identification over as large a p_T range as possible. For example, one would like to study the flavor dependence of jet suppression, which requires the identification of the leading charged particle in the jet at high p_T. In addition, studies of strangeness production, proton and antiproton production, particle composition within jets, and the study of particle ratios requires good particle identification.

Particle identification in PHENIX is presently provided mainly by the high resolution Time-of-Flight counter and the RICH. However, the Time-of-Flight covers only a limited solid angle, and is limited to moderately low momenta by the time resolution ($\sigma < 100$ ps). The RICH provides π/K separation above $\sim$ 5 GeV/c, and K/p separation only above $\sim$ 17 GeV/c. The particle id capabilities of PHENIX could be considerably enhanced by the addition of a second Cherenkov counter having an aerogel radiator. With a refractive index in the range from 1.01-1.07, it could provide π/K separation in the range from $\sim$ 1-5 GeV/c and K/p separation from $\sim$ 5-9 GeV/c. Figure 6 shows the momentum range covered by each of the three particle id detectors, and indicates the more complete and extended range covered when the aerogel is added. PHENIX is presently exploring the possibility of building a Cherenkov counter using aerogel with a geometry similar to that used by the BELLE experiment [11] which would be mounted in front of the electromagnetic calorimeter in the West Arm that would provide high acceptance particle id over the full momentum range.

		Pion-Kaon separation	Kaon-Proton separation
TOF	σ~100 ps	0 - 2.5	0 - 5
RICH	n=1.00044 γth~34	5 - 17	17 -
Aerogel	n=1.007 γth~8.5	1 - 5	5 - 9

Fig. 6. Particle identification coverage using the Time-of-Flight, RICH, and Aerogel Cherenkov counters

3.4. High Rate DAQ and Trigger

One of the main goals of the PHENIX detector upgrade will be to make use of the increased luminosity expected for RHIC II. The PHENIX baseline detector has already been designed to deal with high luminosities, both in terms of the detectors themselves, as well as the DAQ and trigger system. During the past RHIC run, data was taken with a Level 1 trigger rate of up to 1.2 KHz in both heavy ion and proton-proton running. This rate is mainly determined by the readout time of the front end electronics, as well as the performance of the Local Level 1 and Level 2 triggers. Efforts are currently under way to enhance the performance of the DAQ for the next run, where the luminosity is expected to increase by an order of magnitude for both heavy ions and polarized protons, and the raw trigger rates are expected to be $\sim$ 11 KHz for heavy ions and up to 800 KHz for protons. With the planned upgrades, the PHENIX DAQ and trigger system should be able to take data at a Level 1 trigger rate of up to $\sim$ 8Kz. With further improvements, this could be increased to up to 12 KHz, or even up to 25KHz with demultiplexing of the front end electronics.

With higher trigger rates, the total amount of data produced by all of the detectors also increases, and any new upgrade detectors will certainly add to this data volume. PHENIX relies on its Level 2 trigger (Event Builder) to reduce the data rate and volume to a level suitable for archiving. At the present time, PHENIX can log data at approximately 40 MB/s, which is limited by the data transfer rate to RCF. With further improvements at RCF, this could possibly be increased to up to 100 MB/s for future RHIC II running. However, considerable effort will also have to be made to improve the Level 2 trigger, and possibly implementing a Level 3 trigger, to keep the data archiving rate to an acceptable level.

3.5. Other Possibilities

While it is important to have a plan which focuses on certain specific physics topics for the future, it is also important to maintain the flexibility to incorporate new ideas into the plan as experience is gained from present and future runs. This will be particularly important for certain running conditions for which there has not yet been a great deal of experience, such as proton-nucleus, deuteron-nucleus and lighter ion collisions. This may require new hardware for triggering and measuring centrality, which could utilize new hadronic calorimeters in the very forward direction, new trigger counters, or possibly a calorimeter in the region of the nose cone of central magnet. A nose cone calorimeter is also being considered to help distinguish single isolated muons from W-decays from muons contained in jets in polarized proton interactions. These, along with many other new ideas, will contribute to the overall upgrade plan for the PHENIX detector.

4. Conclusions

The PHENIX detector is just now reaching its full potential with the completion and installation of its three main spectrometer arms. The baseline detector will permit a very detailed and thorough study of heavy ion and polarized proton collisions which will surely produce a plethora of new and interesting physics results. The design of PHENIX detector permits a natural upgrade path which will build on its existing capabilities and the experience that will be gained over the next few years of running to explore many new areas of physics. This will involve a number of new detectors and technologies which are being developed, and will require devising new ways of operating the existing detectors to further improved their performance. It is hoped that these improvements and upgrades to the PHENIX detector, combined with those of the RHIC collider, will provide a tremendous opportunity for many new and exciting physics results in the future.

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