PHENIX R&D proposal

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1. Introduction

We request funding of a research and development (R&D) program for PHENIX over the period of three years, FY03 to FY05. The R&D is required to prepare future improvements of the PHENIX experiment, which will substantially enhance its physics capabilities beginning in the near future and continuing beyond the end of this decade. A total funding through the DOE of $ 3.58 M is required to support the necessary R&D.

PHENIX has developed an upgrade plan and initiated some R&D projects funded through institutional contributions. A broad-based R&D program with sufficient funding is now necessary to make further progress. This document lays out the proposed R&D projects. These projects are embedded in an overall upgrade plan for PHENIX and will be supplemented by R&D funds from collaborating institutions which draw upon non-DOE sources such as NSF, as well as RIKEN, US-Japan and other non-US funding agencies.

In Sections 2 to 4 we briefly formulate the main physics goals and the planned detector upgrades. The specific detector components and R&D needs are discussed in Section 5. In order to give a complete picture of PHENIX's future plans, all components of the PHENIX upgrade program are listed and discussed. However, the projects for which we seek DOE funding are emphasized and discussed in more detail. The last section summarizes the R&D program that we propose to be carried out with DOE support.

2. RHIC and the PHENIX experiment

RHIC is a unique facility for studying strongly interacting matter under extreme conditions and to test fundamental properties of QCD, the underlying theory of the strong interaction. Strongly interacting particles, hadrons, confronts us with three main puzzles: (i) confinement of color, the "charge" of QCD, (ii) apparent absence of chiral symmetry which results in large masses typically ~1 GeV/c^2, and (iii) the complex internal spin and flavor structure of hadrons. All three phenomena first appeared about 10 μs after the Big Bang when hadrons were formed. The goal of heavy ion physics is to recreate energy densities present at that moment by colliding ions like gold nuclei at the highest available energy. QCD predicts that matter will then change its state from hadrons to a system of freely moving quarks and gluons. The hope is that studies of this state, the Quark Gluon Plasma (QGP), will unveil mysteries related to confinement and chiral symmetry breaking. Collisions of elementary beams like p-p are more suited to study hadron structure. In particular, with polarized beams new insight can be gained. RHIC is ideally suited for these studies of QCD since it provides the highest energy ion beams and the only high energy polarized proton beams worldwide.

In order to study QCD at high densities the PHENIX experiment was specifically designed to detect penetrating probes - electromagnetic radiation and hard scattering processes - which are produced in heavy ion collisions at the early stage where the formation of QGP is most likely. The reason is simple: Electromagnetic radiation – both real photons and virtual photons materializing as electron- and muon-pairs - does not interact strongly, and thus carries unperturbed information from the time of emission to the detectors. While such radiation is emitted at all times of the space-time evolution during the collision, the reaction dynamics favors emission from the hot and dense phase. So-called hard scattering processes are those collisions between partons in the initial state, presumably before the QGP is formed. In vacuum these collisions produce either jets of particles with high transverse momenta or heavy flavor quarks like charm or bottom, of which a small fraction materialize in charmonium states. Since the initially scattered partons will traverse the full space-time evolution of the reaction the abundance and properties of the emerging high-p_T hadrons may indicate whether QGP was created.

The PHENIX emphasis on measuring electromagnetic probes resulted in a detector configuration that is also well matched to the requirements for studying the spin structure of the nucleon. For spin physics it is essential to know the kinematics of the parton reaction. One of the most important variables is the momentum fraction *x* carried by the colliding partons. Photons and leptons, especially prompt photons and Drell-Yan lepton pairs, provide precise information on the parton kinematics. Photons and leptons can be detected with better energy resolution than other hard scattering processes such as jet production, yielding a better resolution in *x*.

The PHENIX physics programs therefore require a detector able to measure electrons, muons, photons and high momentum charged particles combined with the a high rate capability. In PHENIX this is realized in two independent but complementary detector systems: A pair of mid-rapidity spectrometers with electron, photon and hadron identification capabilities and a set of two muon spectrometers located at more forward rapidities. In addition, a vertex detector provides the event vertex and charged particle multiplicity. All detector components will be completed and operational by the end of 2003, in time for the next RHIC run.

Since the start of RHIC operation two years ago, many interesting results have already emerged from two runs with gold beams and one with polarized protons. Among the various results published in PRL and other journals PHENIX has discovered the first hints for jet suppression and an unexpected and puzzling enhancement of baryon production with large transverse momentum. Other important results PHENIX uniquely contributed are the first measurement of open charm and charmonium states (J/ψ) as well as a measurement of the initial energy densities. While many of these results are consistent with the Production of Quark Gluon Plasma in Au-Au collisions at RHIC, more extensive measurements with gold and other beams, including protons, deuterons and lighter ions will be required to fully establish the creation of Quark Gluon Plasma at RHIC and to study the spin structure of the nucleon. PHENIX has a detailed physics program for this exploratory phase of RHIC operation, which we expect to complete within the next few years.

Following the completion of this exploratory phase, PHENIX plans to commence detailed investigations to characterize the QGP and advance our understanding of QCD. The second phase at RHIC, beginning during the second half of this decade will focus on the study of QGP and a broader and deeper exploration of the fundamental properties of QCD. A key to the success of such a program will be to access new observables, presently unavailable to experiments at RHIC, and to perform accurate measurements. PHENIX has developed a plan to gradually upgrade the experimental setup to enhance and fully exploit its strengths. Timely implementation of these upgrades for the second phase of RHIC requires that a broad-based R&D effort be initiated now.

3. Goals and strategy of PHENIX upgrades

In this section we discuss the enhancements of the physics program of PHENIX planned plan to begin in the second half of this decade and the detector upgrades necessary to realize this program. PHENIX was designed to detect rare events in heavy ion and pp collisions. It combines a large bandwidth DAQ and trigger system with a highly granular detector optimized to measure photons, electrons/positrons, muons and high p_T hadrons. The goal of the proposed physics program is to provide key measurements that reach beyond the capabilities of the present PHENIX detector. The measurements will complement and enhance the present physics program and will fully exploit the strength of the PHENIX setup. PHENIX anticipates the proposed upgrades will smoothly integrate into the experiment with no major disruptions to either the current PHENIX configuration or yearly RHIC running schedules. The main issues PHENIX wants to address are:

1. Complementary study of QCD at high temperatures with heavy ion, p-nucleus, and pp collisions
    - High p_T phenomena including identified hadrons and γ-jet correlations
    - Electron-pair continuum, in particular at low masses (<1 GeV/c^2)
    - Heavy flavor production
    - Quarkonia including excited states, J/ψ, ψ', $\Upsilon(1s)$, $\Upsilon(2s)$, and $\Upsilon(3s)$

2. Extended exploration of the spin structure of the nucleon
    - Gluon spin structure ($\Delta G/G$) with heavy flavor and γ-jet correlations

- Quark spin structure ($\Delta q/q$) with W-production
- Transversity

3. Exploration of the nucleon structure in nuclei
   - A-, p_T -, x-dependence of the parton structure of nuclei

3.1 Complementary study of QCD at high temperatures

Data from the first two Au-Au runs at RHIC have unveiled several interesting high p_T phenomena, perhaps the most exciting discovery is the significant suppression of charged hadrons and identified π^0 with high p_T. This has been discussed as an indication of jet quenching due to QCD energy loss in dense colored matter. The suppression is significantly larger for π^0 's than for charged hadrons, and since the proton and antiproton yields exceed the pion yield above 2 GeV/c, this difference may be due to a large proton and antiproton contribution at high p_T. This result is surprising and cannot be explained in terms of conventional jet fragmentation. New baryon production mechanisms based on gluon junctions rather than diquarks in dense gluonic matter have been proposed. Also large azimuthal asymmetries in the emission of charged particles have been observed at high p_T. Again differences between pions and protons are observed. A detailed exploration of high p_T phenomena at RHIC has just begun and one can expect many interesting results in the next years. However, to shed light on the apparent puzzles related to the particle composition will require more extensive particle identification above 5 GeV/c that is not provided by the current detectors.

Electron pairs are the most promising observable in the quest for the restoration of chiral symmetry expected to take place in the early stages of heavy ion collisions. CERN experiments have confirmed the unique physics potential of the electron pair continuum. The continuum in the mass range from 200 - 600 MeV/c^2 has been systematically studied by the CERES experiment. The most prominent result is the observation of a strong enhancement of low-mass electron pairs in all observed heavy ion collisions. This enhancement has triggered a wealth of theoretical activity, which indicate that agreement with the CERES data is only achieved by invoking in-medium modification of the intermediate ρ meson, as a precursor of chiral symmetry restoration, in the $\pi\pi$-annihilation channel ($\pi\pi \rightarrow \rho \rightarrow \gamma^* \rightarrow e^+e^-$). Recent theoretical predictions that incorporate the acquired knowledge from the first year of RHIC running, show that the enhancement of low-mass e^+e^- pairs should persists at RHIC. The extension of the pair continuum studies under the much better conditions offered at RHIC -- higher initial temperature, larger energy density, larger volume and longer lifetime of the system -- promises to be very interesting. This challenging measurement will require adding the capability to reject electrons from Dalitz decays and photon conversion as well as an accurate measurement of the open charm decay contribution.

In recent years, more and more interest has focused on open heavy flavor production in heavy ion physics. Charm and bottom quarks are ideal probes to study the flavor dependence of QCD energy loss. In a QGP, charm and bottom can be produced thermally, and although significant effects are only predicted at LHC energies, first hints of thermal c-quark production might be visible at RHIC. In addition, open charm is the best reference for charmonium production, and once both charm and bottom production are established, Drell-Yan pair production will become accessible at RHIC in heavy ion collisions. PHENIX has measured charm production through single electrons in the p_T range from 1 to 3.5 GeV/c and will complement these by measurements based on single muons and electron-muon pairs in the future. These measurements will give initial results on heavy flavor production, but a clear separation charm from bottom will be problematic. Also whether there is any contribution from thermal lepton pair production will remain inconclusive. To provide a more robust and accurate measurement that can separate charm and bottom, precision tracking close to the interaction point which is capable of identifying displaced decay vertex of charm and bottom flavored hadrons will be essential. A large acceptance particle identification system would provide additional capabilities to tag heavy flavor with kaons.

Color screening effects associated with QGP production give the prime motivation to study J/ψ production in heavy ion collisions. Studying a full suite of heavy quarkonium states, the J/ψ, ψ' and $\Upsilon(1S)$, $\Upsilon(2S)$ and

ϒ(3S) will provide detailed information about the QCD potential in colored matter. Since all states have different size and binding energies their simultaneous observation will permit mapping the QCD potential in colored matter. All ϒ states are smaller and more tightly bound than the J/ψ and thus probe the QCD potential at shorter distances than the J/ψ. The 1S state should not disintegrate at energy densities reached at RHIC, while the larger and less bound ϒ(2S) and ϒ(3S) states should be affected. Separating the ϒ(1S) from the ϒ(2S), ϒ(3S) requires improving the invariant mass resolution to better than 100 MeV (about 1%). Long runs at high luminosity will be required for this measurement.

3.2 Extended exploration of the spin structure of the nucleon

Understanding the structure of the nucleon in terms of quarks and gluons is one of the outstanding problems of nuclear physics. Spin-dependent deep inelastic scattering experiments have revealed that only 30% of the proton spin is carried by quarks. A centerpiece of the PHENIX spin physics program will be the first precise measurement of the gluon polarization. At present we can exploit the measurement of double spin asymmetries in inclusive hadron production. This method seems promising, since first data on inclusive π^0 production from PHENIX is consistent with next to leading order QCD predictions. In a limited kinematic region $0.01<x<0.3$, PHENIX will measure prompt photon production from quark-gluon Compton scattering and provide the most direct access to the gluon polarization. Because of the fundamental importance of the measurement of the gluon polarization, a measurement with different experimental and theoretical systematic will be critical. Measuring the double-spin asymmetry of charm and bottom flavored quarks will not only provide the necessary verification but also extend the kinematic coverage substantially to $0.001<x<0.3$.

Recent measurements of the quark flavor dependent polarized parton distribution $\Delta q(x)$ by the HERMES experiment indicate that the light-quark sea polarization are small. The HERMES measurement is carried out at low Q^2 and the interpretation of the result depends on the validity of the factorization ansatz between quark distributions and fragmentation functions at low scales. A second independent measurement at hard scales is urgently required. PHENIX can provide such a measurement by extracting the longitudinal single spin asymmetry in W- and W+ production. Recent work by Yuan and Nadolsky using modern re-summation techniques will permit a clean interpretation of the W-asymmetries in NLO pQCD from first principles. At $\sqrt{s}$ = 500 GeV RHIC will copiously produce W bosons. However, the collision rates at luminosities of $2\text{x}10^{32}\text{cm}^{-2}\text{s}^{-1}$ will be as high as 12 MHz. At this rate, it poses a significant experimental challenge to select muons from W-decays over the very large background of low momentum muons from hadron decays in jets. Before successful measurements can be carried out a substantial upgrade of the existing first level muon trigger is required.

In addition to the quark structure functions $q(x)$ and $\Delta q(x)$ a third class of distributions, transversity $\delta q(x)$, is needed for a complete description of nucleon structure at leading twist. Transversity distributions are experimentally unknown and offer a new window on nucleon spin structure with distinct advantages: Transversity involves a helicity spin flip amplitude and therefore is free of admixtures from gluons. The first moment of transversity distributions is a tensor charge and thus strictly a valence quark. The measurement of transversity distributions through spin-dependent fragmentation of hadrons requires the knowledge of the jet-axis. For example, in Collins-Heppelman fragmentation the sensitivity to the transverse quark spin results from the azimuthal distribution of hadrons around the jet-axis. The present geometric acceptance ($\Delta\eta < 0.7$) of the PHENIX central arms is to small to permit a sufficient reconstruction of the jets-axis, since jets typically extend over about one unit in pseudo rapidity. However, a new tracking device close to the interaction region would extend the geometric acceptance ($\Delta\eta < 2.0$) and provide the necessary jet reconstruction.

3.3 Exploration of the nucleon structure in nuclei

Proton-nucleus collisions not only provide important key baseline information for the study of QCD at high temperatures, they also address the fundamental issues of the parton structure of nuclei. Since the discovery of the EMC effect in the 1980's, it is clear that the parton structure of a nucleon changes if it is bound in a nucleus. It is still unclear why the rather weak nuclear binding force can have such pronounced effects on the parton distributions. With the advent of RHIC, high-energy p-nucleus collisions will give access to structure functions in nuclei in a completely new region. The prime objectives for us are to measure the gluon and antiquark distributions in nuclei. In general all processes suitable to measure the gluon structure in nucleons are also ideal for probing gluon and antiquark distributions in nuclei. Therefore, this part of our physics program will also profit greatly from the anticipated upgrades to PHENIX.

3.4 Upgrade Strategy

All of the proposed measurements have low cross sections and require taking data at high luminosity over extended periods of time. We anticipate that a luminosity of 8×10^{26} $cm^{-2}s^{-1}$ for Au-Au and 2×10^{32} $cm^{-2}s^{-1}$ for polarized proton beams will be reached over the next several years. These luminosities will be sufficient for most of the measurements listed above, but some of them (specifically upsilon spectroscopy, γ-jet coincidences, and the Drell-Yan continuum) would benefit greatly from a further increase of the Au-Au luminosity by a factor of 10 through electron cooling. Each of the detector upgrades will make important physics measurements without this ultimate luminosity increase, but the upgrade plan includes increasing PHENIX's data rate capabilities to fully utilize such an increase in luminosity when it becomes available.

PHENIX is presently developing a detailed plan of detector upgrades necessary for the proposed physics program. The plan is based on the recognition that the three broad research areas suggested above require similar detector upgrades. All planned measurements exploit the robust features of the existing PHENIX detector, either of the central arms, or of the muon spectrometers. We plan to augment these detector systems by a new vertex spectrometer with a flexible magnetic field configuration, high precision vertex tracking with silicon detectors, and with a compact TPC combined with hadron blind electron detection, along with Aerogel Cherenkov detectors in one of the central arms, which when combined with the existing RICH and TOF, will provide continuous π-K-p separation out to 10 GeV. The upgrades rely on the large bandwidth DAQ of PHENIX, which is capable of utilizing ~12kHz event rates by higher level triggers. Improved first level trigger capabilities (specifically to detect single muons) will enable PHENIX to make full use of the anticipated luminosity.

The development of the PHENIX upgrade program was launched in response to the recent NSAC long-range plan which was developed in 2000. The strategy was consolidated at a workshop in Montauk, NY from March 21-23, 2001 and since then has been worked out in detail within four PHENIX study groups.

4. Overview of PHENIX upgrades

The main new detector system is a vertex spectrometer, which combines a flexible magnetic field configuration, high precision vertex tracking in the central and forward region, and electron identification and tracking. The layout of this new system is shown in Fig.4-1.

The addition of a second inner coil to the PHENIX central magnet in the summer of 2002 will provide the flexible magnetic field. The second coil, which was already foreseen in the original design of the magnet yoke, may be operated in two modes: a (+ +) mode in which the inner field is in the same direction as the field of the outer coil, and a mode where the inner field is in the opposite direction to the field of the outer coil. In the (+ +) configuration the field integral is increased by a factor of ~1.7 to 1.2 Tm. Combined with the tracking near the beam axis, the mass resolution for reconstructing the Υ via the $\Upsilon \rightarrow e^+e^-$ decay is reduced to ~60 MeV/c, which will enable PHENIX to separate the 1S, 2S, and 3S exited states of the Υ, (provided there is sufficient luminosity). In the (+ –) mode, a region with zero field integral can be created around the beam axis, which when combined with electron identification and tracking, will open the avenue towards a low-mass dilepton measurement.

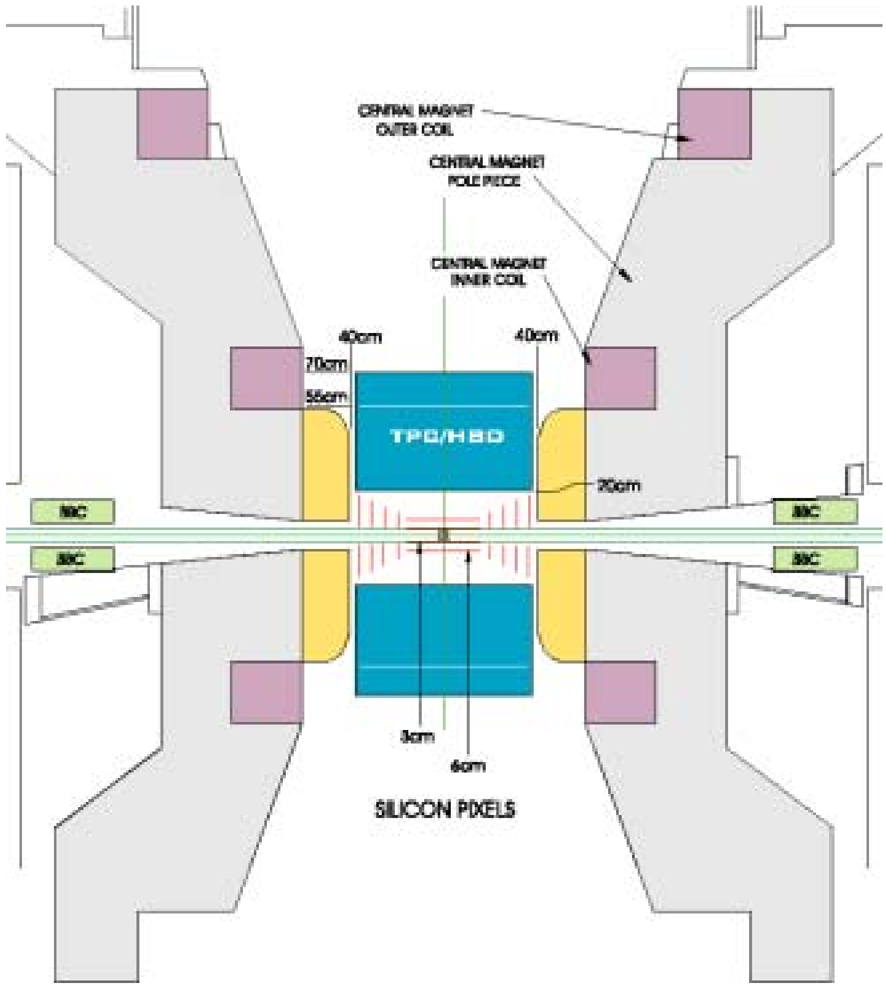


Fig.4-1. Overview of the new detector system in the PHENIX interaction region.

The vertex tracking is based on highly segmented silicon strip or pixel detectors at mid rapidity and silicon pixel detectors in the forward direction. The central detectors (silicon barrel) cover $-1.2 < \eta < 1.2$ and almost 2π in azimuth and provide a single-track resolution of ~ 50 μm at the vertex. The forward silicon detectors are designed to provide coverage in the angular acceptance of the forward Muon Arms. The forward silicon cover $1.2 < |\Delta\eta| < 2.7$ and the almost full azimuth angle with a resolution of ~150 μm. Both systems provide sufficient resolution to measure electrons and muons from semi-leptonic decays of D or B mesons, which carry open charm or bottom respectively. A robust measurement of open charm and bottom will provide two new channels for the $\Delta G/G$ measurement with a substantial kinematic coverage from $0.002 < x < 0.3$. Data from this subsystem on heavy flavor production in nuclear collisions will provide one of the missing keys to a full picture of QCD at high temperatures. Besides tagging inclusive electrons from charm and bottom decays, many other measurements become available with this device. For example, the forward detectors will also provide tagging of J/ψ's from B decays, and due to the large rapidity acceptance of the silicon tracker, it will be possible to reconstruct D-mesons via the $D \rightarrow \pi K$ decay mode in AA and pp collisions. In addition, jet tagging in pp will be possible, which is essential for a transversity measurement.

A compact hadron blind detector (HBD) combined with a micro-TPC completes the vertex spectrometer. The device is based on micro-pattern detectors (GEMs) for both the TPC and HBD. It covers $-1<\eta < 1$ and almost 2π in azimuth and has the primary function to detect and track electrons. Electron identification and tracking in a low field region, provided by the (+ –) field mode, is the key for the measurement of the low mass dilepton continuum. The central problem of this challenging measurement is the large combinatorial pair background stemming from electron and positrons of different physics origin. The most important source of such background electrons are photon conversions and Dalitz decays. In both processes, electron-positron pairs of small opening angle are produced for which typically only one of the two particles is reconstructed in the central arm acceptance. In the absence of a strong magnetic field, and with electron identification and tracking, the background can be reduced by more than an order of magnitude and the low mass dilepton continuum becomes accessible. It is important to note that RHIC might provide the highest beam energies where such a measurement is feasible, since at higher beam energies, the irreducible background from uncorrelated semi-leptonic charm decays will dominate.

An Aerogel Cherenkov detector in the west arm provides another important enhancement to PHENIX's capabilities. Together with the already existing RICH detector and the time-of-flight measurement provided by either the electromagnetic calorimeter or TOF, full π-K-p separation will be available up to transverse momenta of 10 GeV/c. This particle identification, along with charm and bottom measurements and γ-jet coincidences, will allow a detailed and comprehensive study of jet production at RHIC.

For the W-measurements in p-p and for Υ spectroscopy in A-A at the anticipated luminosities the selectivity of the existing first level single muon and muon pair triggers need to be increased by a factor of ~50. Making a rough momentum measurement available at the trigger level can provide this increase of selectivity. This requires new dedicated muon level-1 trigger detectors, which will be integrated into the two PHENIX muon spectrometers.

Finally, all new detector systems will require an expansion of the present data acquisition (DAQ) system to cope with the additional data volume. PHENIX expects that an upgrade of the DAQ and trigger will be required.

5. Specific Detector Components and R&D needs

5.1 Silicon vertex detector

5.1.1 Overview

The present strawman design foresees four layers of silicon detectors in the central region and four layers in both forward directions. Each layer should not exceed a thickness of ~ 1% of a radiation length per layer. These detectors would be an immediate benefit to the program, not only for its heavy flavor tagging capabilities but also as a tool for reducing backgrounds at high transverse momentum from decays in flight. Fig. 5-1 shows a schematic layout of the silicon vertex detector system.

The inner one or two layers are envisioned to be silicon pixel detectors, while the outer layers utilize silicon strip detector technology. These detectors are well matched to the highest anticipated RHIC luminosities. PHENIX has been investigating the CERN/ALICE hybrid pixel devices and started a joined R&D effort. For PHENIX the R&D will need to focus on reducing the thickness of these devices to the desired level, on reliable and efficient assembly of the hybrids, as well as on matching their readout to the PHENIX DAQ system requirements. Monolithic Active Pixel Sensors developed by the LEPSI group are an alternative development that could produce ultra-thin detectors. The PHENIX Iowa State group has been actively pursuing the development of this technology.

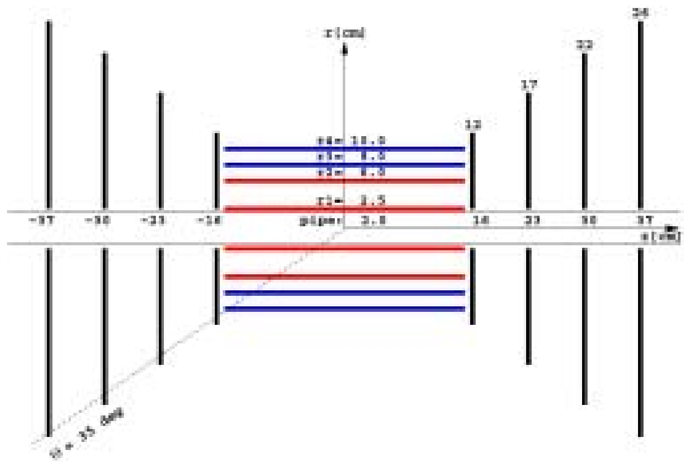


Fig. 5-1 Schematic layout of the silicon vertex detector indicating approximate dimensions of the detectors

The first prototypes of the planned silicon strip detectors are currently being designed by the BNL and RIKEN research groups in close collaboration with BNL's Instrumentation Division. The main R&D issues for the silicon strips are the design of the readout electronics and system integration with the existing PHENIX DAQ, both of which are being addressed by ORNL. For the central silicon pixels, sensor development and readout electronics, together with mechanical system integration, are the central R&D issues. The LANL group has recently started R&D on the forward silicon pixel detectors. At present this work is focused on specifying the detector requirements and will extend to reconfiguring the layout of the readout electronics to match the layout of the pixels on the endcaps.

5.1.2 R&D program

Over the past year several key R&D areas have been identified in order to make progress towards completing the proposed silicon vertex tracker. Preliminary work has been started on each of the following:

Primary issues for the R&D program:

- Silicon strip integration of readout electronics with PHENIX DAQ
- Hybrid-pixel readout electronics, and subsequent bump-bonding and thinning.
- Development of ultra-thin monolithic active pixel sensors
- Design of lightweight support structure with capability of installing detector components in different stages, e.g. first silicon strips in barrel, followed by silicon pixels on barrel and finally endcap pixels.

Silicon strips will instrument the outer two or three barrel layers of the silicon detector. Silicon strip detectors are used in numerous high energy and nuclear physics experiments. Several suppliers of single sided detectors are available worldwide. PHENIX is considering a new form of strip detectors developed and fabricated by BNL Instrumentation. The detectors are 3x6cm single-sided sensors. Two sets of read-out strips are placed longitudinally and diagonally, providing simultaneous x-u readout from a single surface. At low-occupancies this projective geometry localizes a hit to within a pad of 80μx1mm. A first prototype of this new sensor will be tested in Fall 2002. The fallback position is to use silicon strip detectors that are commercially available, e.g. from Hammamatsu.

In the present design, each strip detector has ~ 1500 channels (375 channels per end, 2-readouts per end and two ends per detector). Depending on the final layout plan, the total number of channels is 200 to 300K, so we will need on the order of 2000 readout chips, assuming 128 channels per chip. Since it is planned to implement the silicon strips on a short time scale a suitable choice needs to be made from existing readout electronic designs that match the PHENIX readout criteria.

The main R&D issue for FY03 and FY04 is how to integrate these chips into the PHENIX DAQ. The leading candidate is the SVX4 chip developed at Fermilab. The SVX4 uses 0.25μm CMOS technology which is broadly available. It is a 128 channel chip with a 46 deep pipeline cycled by the beam-crossing clock. The rise time is on the order of 60 ns. A second option is to use a modified form of the Oak Ridge 32-channel TGV preamp/analog pipeline storage /ADC chip. The TGV family of chips was designed specifically for PHENIX and has an architecture that will, without doubt, work well for any proposed application involving silicon within PHENIX. The present version of TGV and AMU/ADC has a 64-deep pipeline, 60 ns rise time, low power, and are matched to the PHENIX DAQ. They were designed for 1.2 μm nwell CMOS as was available when they were fabricated for PHENIX. In order to update the fabrication and physical format of the chipset to match current technology, we will reimplement the preamplifier in the TSMC 0.35 μm CMOS process. This will likely have an expanded channel count (128 channels/chip) and involve removal of the multiplicity discriminator.

For the silicon strip electronics the key R&D items covered by this proposal are:

- Conduct a study to determine if the SVX-4 can be interfaced to the PHENIX online system.
- Development of a modified version of the TGV preamplifier/AMU/ADC chipset.

Hybrid pixel detectors consist of two silicon layers; a sensor made of high resistivity silicon and a readout chip that is bump-bonded to the sensor. The leading readout chip is the ALICE/LHCb chip developed by the CERN EP microelectronics group. Systems based on this chip are developed for the inner tracking of the ALICE experiment and the photon detector of the RICH of the LHCb experiment. It is also the building block of the silicon pixel telescope of the NA60 experiment at the SPS that is presently being constructed. Detectors from the first production are currently used in the NA60 experiment at CERN. The RIKEN Institute and SUNY Stony Brook have joined an R&D effort with NA60 to obtain experience with this technology. First results from a run in the summer of 2002 look very promising.

Important remaining R&D issues focus on reducing the thickness of these devices to the desired level, and a reliable and efficient assembly of the hybrids. On these issues we plan to work closely together the ALICE pixel group. The RIKEN institute is currently negotiating an agreement for this technical collaboration with the CERN/ALICE group. The bump-bonding and thinning procedures are the critical step in the development of hybrid pixel detectors, we therefore want to investigate alternative options to the CERN development. Our plan is to participate in FNAL trials of commercial thinning tests in 2003 and to trial our own chip-set in 2004. Another R&D project aims at integrating the ALICE pixel chip into the PHENIX DAQ. A backup option for readout electronics could be the FPIX2 chip used at the BTEV experiment at FERMILAB, and the ATLAS experiment at CERN.

For the Hybrid pixel detectors the main R&D funded through this proposal are:

- Test ALICE/LHCb sample chip
- Develop the interface between ALICE/LHCb chip and the PHENIX DAQ
- Investigate alternative options for bump-bonding/thinning
- Optimize the layout and pixel-size for the endcap silicon pixels.
- Modify the pixel readout electronics to match the sensor pitch of the endcap pixels

Monolithic active pixel sensor (APS) technology combines the sensor and readout electronics in one chip and hence has the potential advantage of producing an ultra-thin detector. By eliminating the need for bump-bonding there is also a reduction in complexity and possibly cost. In recent years progress has been driven by commercial applications rather than physics applications. Active Pixel Sensors are monolithic optical sensors developed for digital cameras. In these optical sensors the epitaxial layer is only a few microns, and it needs to be increased to at least 20 microns for use as a detector in heavy-ion experiments.

The Iowa State group is collaborating with LBNL and LEPSI, Strasbourg to develop monolithic pixel detectors with thick (~20 micron) epitaxial layers. As a first step the LEPSI design of on-chip electronics has been modified to increase its speed and to perform a pre minus post subtraction to reduce noise.

The main R&D items for the monolithic pixels are:

- Test the prototype readout chip designed by Iowa State
- Design and develop a version of the chip with a pipelined event buffer to match the requirements of PHENIX
- Partner with silicon CMOS foundries to produce sensors with thick epitaxial layers with high resitivities.
- Prototype a combined sensor and electronics in one CMOS manufacturing step

The mechanical requirements for a silicon vertex detector are derived from the spatial resolution needed, heat load of the electronics, radiation length restrictions, utility routing, and maintainability. A complicating issue is the plan to stage the implementation of the strip detectors, barrel pixels and endcap pixels over a period of a few years. The LANL group has initiated contact with the firm HYTEC to discuss the conceptual design. HYTEC are the mechanical design team for the ATLAS silicon vertex detector. For PHENIX they have designed the station 1 muon detectors and the station 2 spider and also did the finite element analysis of the station 3 octants.

The main R&D items for the mechanical design are

- Conceptual design for an endcap and barrel space frame to support the staged arrival of silicon strips, barrel and endcap pixels, including the constraints of existing PHENIX infrastructure.
- Establish cooling and cabling requirements

5.1.3 Budget and Milestones

FY03

- Investigate two options for Si strip readout and make a recommendation to PHENIX to proceed with either the SVX4 or TGV preamplifier chip
- Test ALICE/LHCb sample chip
- Begin to develop pixel FEM, the interface between pixel readout electronics and the PHENIX DAQ
- Coordinate with FNAL/CERN R&D programs on thinning bump-bonded detectors
- Test the prototype monolithic readout chip for performance and extend to include a pipelined event buffer to match the requirements of PHENIX
- Fabricate test thick epitaxial layers for the monolithic sensor
- Develop a conceptual design for an endcap and barrel space frame

FY04

- Develop silicon strip readout (based on SVX4 or TGV) and FEE interface with PHENIX
- Finalize pixel FEM, the interface between pixel readout electronics and the PHENIX DAQ
- Thin and test sample bump-bonded pixel detector
- Modify the pixel readout electronics to match the sensor pitch of the endcap pixels.
- Test the prototype pipelined monolithic readout electronics
- Develop detailed design for an endcap and barrel space frame

FY05

- Thin and test sample bump-bonded pixel detector
- Finalize pixel readout electronics that match the sensor pitch of the endcap pixels.
- Fabricate and test monolithic sensor with pipelined electronics.

Silicon Tracker R&D budget	Description	FY03	FY04	FY05
Salaries (incl. Fringe)	Post doc	$60,000	$60,000	$30,000
	Elec. Engineer	$175,000	$175,000	$100,000
	Mech. Engineer	$50,000	$100,000	$50,000
	Mech. Designer	$20,000	$40,000	-
Supplies & Electronics	Wafer fabrication	$20,000	$40,000	$40,000
	Prototype fabrication	$40,000	$60,000	-
	Equipment	$20,000	-	-
Total		$385,000	$475,000	$220,000
Total (incl. 40% overhead)		$539,000	$665,000	$308,000

Tab. 5-1 Budget Request for silicon vertex tracker R&D. Overhead is assumed to be 40%. Yearly salaries are assumed to be $60k for postdocs, $100K for engineers, $80K for all others.

5.2 Dalitz Rejector and Inner Tracker

5.2.1 Overview

Fig. 5-2 shows a conceptual design of the TPC/HBD detector. The HBD is a Cherenkov detector that utilizes a gas radiator with good transparency into the deep UV and a large area CsI photocathode to detect Cherenkov light from electrons with high efficiency, while having very low sensitivity to charged hadrons. The TPC acts as a tracking device with a short drift region and utilizes a fast drift gas that limits the drift time to 4 μsec such that the detector can be operated at the highest rates anticipated at RHIC for both heavy ion and pp running. It would provide the ability to track electrons through the inner magnetic field and make associations with Cherenkov light hits in the HBD, as well as provide additional electron identification by dE/dx. In addition, it would allow the measurement of jets in the rapidity range $|\eta| \sim \pm 1$ and $\Delta\phi \sim 2\pi$ in azimuth, and would provide an independent measurement of charged tracks through the inner magnetic field with a momentum resolution of ~2%.

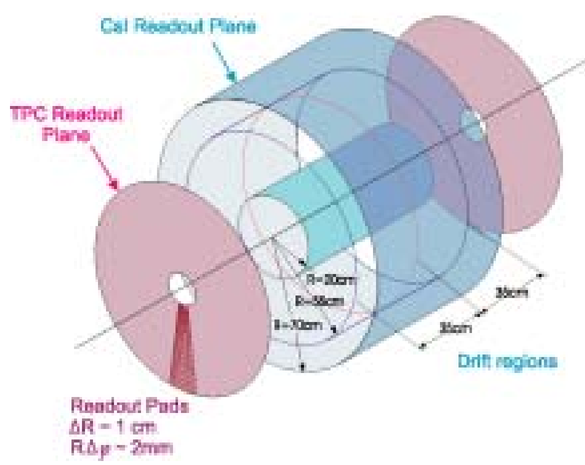


Fig. 5-2 Conceptual design of a combined TPC and HBD detector for PHENIX

The benefits and system specifications of the HBD have been extensively studied in detailed Monte Carlo simulations. The results of this study are given in a PHENIX technical note [PHENIX Technical Note 391, available at: http://www.phenix.bnl.gov/phenix/WWW/forms/info/view.html]. It showed that a detector providing electron identification with a very high efficiency is required (> 90%), along with a double (electron) hit recognition at a comparable level. A moderate π rejection factor of a few hundred is adequate.

Possible implementations of the HBD were also considered in this study. In particular, various options of the key elements (gases, detector configuration and readout chambers) were analyzed. The choice that emerges is a windowless Cherenkov detector in a special proximity focus configuration, with a CsI photocathode and Gas Electron Multiplier (GEM) readout chambers. Since a mirror-type RICH detector in the center of PHENIX is very difficult or nearly impossible to implement, we consider instead a scheme without mirrors and without windows in which Cherenkov light from particles passing through the radiator is directly collected on a CsI photosensitive cathode plane, forming a roughly circular blob image with a radius ~2 cm, rather than a ring as in a RICH detector.

There are a limited number of gases that have enough transparency in the VUV to transmit sufficient photons to provide good electron detection efficiency. One of the most promising choices is CF_4 because of its very high energy cutoff (E_{cutoff} = 11.5 eV), which results in a large number of UV photons. Taking into account the quantum efficiency of the CsI photocathode and realistic losses, we would expect CF_4 to produce ~40 photoelectrons in a 50 cm long radiator. This large number of photoelectrons ensures a very high electron efficiency, which is important to achieve a double hit recognition larger than 90%. As a detector element, we envision GEMs in a multistage configuration. The layout of such a detector with a triple GEM or a double GEM + MWPC is shown in Fig. 5-3. With the windowless geometry, it would also imply that CF_4 would also be used as the operating gas for the GEM detectors. In this arrangement, the CsI photocathode is deposited directly on the surface of the outer GEM foil. This configuration has been studied on a small scale and shown to produce very encouraging results [A.Breskin et al., NIM A483 (2002) 670], but more R&D is needed in order to demonstrate that this type of device can be used in a practical detector.

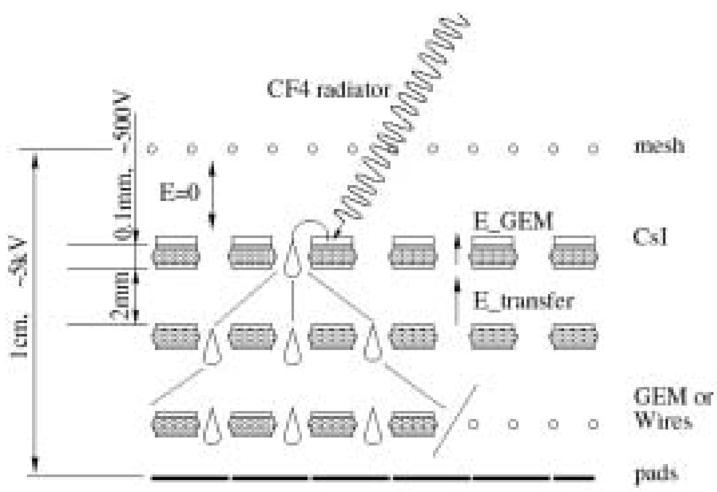


Fig. 5-3 Possible detector configuration with triple GEM or double GEM + MWPC

The TPC part of the detector would use the HBD radiator as an ionization gas volume. Charge produced in this region would be drifted over a distance of ~35 cm to readout planes on both ends of the detector where it would be amplified and detected on a high-resolution pad plane. We envision that multistage GEM detectors, similar to those used in the HBD, but operating at somewhat lower gain would provide the gas amplification. The radiator gas must have a high drift velocity and low diffusion in order to provide both the speed and spatial resolution required for operating in both a high rate and high multiplicity environment. For this, CF_4 again seems to be an attractive choice. The drift velocity and diffusion coefficient for CF_4 have been measured in [J.Va'vra et al., NIM A324 (1993) 113] , and it is possible to achieve a drift velocity of ~10 cm/μsec with a diffusion coefficient of ~100 μm/√cm with drift fields on the order of 1 kV/cm. This would result in a drift time of < 4 μsec and a spatial diffusion limit of ~500 μm. In addition, the readout plane must have sufficient segmentation to provide the necessary spatial resolution in the transverse direction, and the readout electronics must have sufficient speed to provide the necessary resolution in the longitudinal direction. These are both areas where significant R&D will be required.

The concept of combining the features of the HBD and TPC into the same detector configuration is clearly an ambitious proposition. Each detector in itself involves a number of new technologies which require substantial development before they can be implemented into a real device that can be used for physics measurements. While the construction of a small TPC of this size would not be considered a difficult task compared to other TPCs which have been built, the fact that it must operate in an environment of extremely high track density and at very high rates does represent a significant challenge. In particular, to achieve the necessary spatial resolution and readout speed requires a substantial effort in both the design of the detector and the readout electronics. On the other hand, while the HBD may be simpler in terms of its readout, it also presents many challenges in terms of detector design. We therefore envision a staged approach for implementing such a detector in PHENIX, in which the detector would first be installed with only the functionality of the HBD, and would then later be upgraded to incorporate the features of the TPC. This clearly requires a carefully coordinated design of both features of the detector from the very beginning, and an R&D program which would lead to the final detector on a reasonable time scale.

5.2.2 R&D program

There are a number of questions and issues in the proposed detector design that require substantial R&D. Many of these items were identified at last year's RHIC Detector Workshop (BNL Nov. 13/14, 2001) as areas where advances in detector technology is required to go beyond the present state of the art in order to meet the requirements for upgraded RHIC detectors.

These R&D areas include:

- Studies of gases with fast electron drift, which will have sufficient UV transparency for combined TPC-HBD operation and good gain properties for stable operation with micropattern electrodes.
- Micropattern gas electrode design with stable gain and very low positive ion transmission into the drift volume of the TPC.
- Readout electrode ("anode") design with a granularity optimized for double track resolution and for minimum number of signal channels.
- Microelectronics for fine-grain, low-mass detectors.

Our R&D program follows very much along these lines. One of the main items of interest is the study and development of micropattern detectors, such as GEMs, which would be used in both the HBD and TPC. For the HBD, this involves depositing CsI photocathodes over large area GEM foils and studying the quantum efficiency, gain and operating parameters of structures such as those shown in Figure 3. In particular, we must study the response of the detector to both Cherenkov photons and ionizing particles to determine the degree of "hadron blindness" one can achieve. In addition, it will be required to operate such a detector at reasonably high gain in order to detect the number of photoelectrons expected, so one must also determine the gain stability over long periods of operation.

Other issues regarding the HBD include:

- The effect of impurities on the VUV transparency of the radiator gas.
- Scintillation light produced in the radiator gas and the design of detector structures which minimize sensitivity to the scintillation.

For the TPC, it will be necessary to achieve a spatial resolution of ~200-300 μm at the readout plane. While this is easily achievable with the GEM detectors, it could potentially result in a very large number of readout channels. We must therefore study ways of minimizing the channel count while maintaining the desired spatial resolution (we have so far assumed a pad size of ~2 x 10 mm, resulting in ~80K readout channels). This can be achieved using various types of interpolating readout structures, such as chevrons strips, floating pads, or resistive layers. In addition, good gain uniformity over the entire area of the detector is required in order to have good dE/dx resolution. Both of these requirements will necessitate a careful design of the readout plane.

Other issues that must be studied for the TPC include:

- Studies of the drift properties of gases such as CF_4 , including drift velocities, diffusion parameters, dE/dx, charge collected as a function of drift length, effects of impurities, etc. A test drift cell will be constructed to study these effects.
- Ion feedback - this should be significantly reduced using a GEM detector compared with a conventional MWPC, but must be studied in detail in order to understand the level of space charge effects in the detector.
- Design the field cage - this must be designed in such a way that it will produced a uniform drift field, but not compromise the operation of the HBD.
- $E \times B$ effects inside the PHENIX central magnet, and how this will affect the position resolution

There are also numerous issues regarding the design of the electronics for both the TPC and HBD. The TPC will require a new, dedicated design of readout electronics involving several new ASICs for both the front end analog readout, as well as new digital electronics for transmitting the data off the front end to new data collection modules (DCMs), which would be part of an upgraded PHENIX data acquisition and triggering system. One major issue is the level of power consumption and cooling required for the electronics which is mounted on the readout plane. This will require a low power ADC and a very high level of integration. In addition, because of the potentially large number of readout channels, it is assumed that one would have to perform some level of zero suppression in the front end module. We expect that all of this will require a substantial R&D effort.

While the HBD readout electronics may be simpler than that of the TPC, and will have fewer readout channels due to the coarser segmentation required, it must be designed with very low noise in order to minimize the gain required in the GEM, and also have sensitivity to the relatively small number of photoelectrons. In addition, it must have very low power and mass, since it will be located in the main part of the PHENIX acceptance.

Finally, there are numerous issues regarding the mechanical design and installation of the detector, including space, cooling, power, cabling, support, and other infrastructure. This will require a dedicated engineering study to address these issues in order to design the detector.

We estimate that the R&D program for the combined detector, along with the associated readout electronics, will require approximately three years to complete, starting in FY03. However, we expect that the R&D for the HBD and its readout electronics could be completed in 1-2 years, while the TPC R&D will require an additional year. The following gives a list of milestones for the R&D effort over the next three years, along with a table which gives the budget request and level of support required to carry out this program.

5.2.3 Milestones and Budget

FY03

- Complete TPC drift cell (including readout plane)
- Gas studies with TPC, HBD
- Photocathode studies with CsI
- Design TPC field cage and HBD electrode structure
- Begin engineering design study of TPC/HBD detector system
- Begin design of HBD & TPC readout electronics

FY04

- Build and test TPC/HBD prototype detector
- Complete design of HBD readout electronics
- Complete engineering design of TPC/HBD detector system

FY05

- Complete TPC detector design
- Complete design of TPC readout electronics

TPC/HBD R&D budget	Description	FY03	FY04	FY05
Salaries (incl. Fringe)	Postdoc	$45,000	$45,000	$45,000
	Elec. Engineer	$100,000	$125,000	$125,000
	Elec. Technician	$20,000	$20,000	$20,000
	Mech. Engineer	$25,000	$25,000	$25,000
	Mech. Designer	$20,000	$20,000	$20,000
	Mech. Technician	$20,000	$20,000	$20,000
Supplies & Electronics	Lab equipment	$30,000	$20,000	$15,000
	ASIC fabrication	$30,000	$60,000	$75,000
	Test equipment	$15,000	$25,000	$15,000
Total		$305,000	$360,000	$360,000
Total (incl 40% overhead)		$427,000	$504,000	$504,000

Tab. 5-2 Budget Request for TPC/HBD Detector R&D. Overhead is assumed to be 40%. Yearly salaries are assumed to be $60k for postdocs, $100K for engineers, $80K for all others.

5.3 High p_T particle identification

In the present setup of PHENIX charged pion, kaon and protons can be identified by a measurement of momentum and time-of-flight. Intrinsically this measurement is limited to moderately low p_T. At high p_T, pions can be identified with the gas Cherenkov detector designed for electron identification. The addition of an aerogel Cherenkov counter with an index of refraction of ~1.01 will provide a particle identification (PID) system with seamless pion, kaon, and proton separation up to p_T of almost 10 GeV/c.

Aerogel has undergone substantial improvements over the past years and it is now reliably used for large area detectors in high-energy physics experiments such as BELLE. The Tsukuba group, together with collaborators from BNL and Dubna, has studied several 12x12x12 cm^3 aerogel detectors read out by one or two photo-multipliers. In a sequence of test beam experiments at KEK, a configuration was developed which gives a uniform light output of about 15 photoelectrons independent of the impact angle, position and direction. The R&D for this detector is essentially completed. A full-scale prototype with a size of 2x2 m^2 is under design. With the help of the Tokyo and Dubna group, the prototype may be ready for tests in PHENIX within 2 years. The production of the detector is primarily supported through US-J funding. Sources to support integration and infrastructure are yet to be determined.

The benefits of a large acceptance aerogel detector to tag heavy flavor with kaons are under discussion. Several interesting new options could be considered. These include increasing the solid angle coverage using a large area photocathode readout, such as CsI or CVD diamond, or increasing the solid angle coverage outside the present PHENIX acceptance by implementing a highly segmented detector inside the PHENIX central magnet using a hybrid photo-multiplier tube readout. Either of these options would require additional R&D beyond the scope of this proposal.

5.4 Ultra high rate muon trigger

In p-p collisions the bandwidth available to the PHENIX first level trigger limits the data-taking rate. At luminosities of $2\times10^{32}cm^{-2}s^{-1}$ the current first level single muon trigger will fire at a rate of about 20 to 60 kHz. This rate is dominated by hadron decays into muons and beam-related backgrounds. It exceeds the available bandwidth for the single muon trigger channel by a factor ~50. The upgrade plans largely exploit the difference between the momentum spectrum of muons from hadron decays at lower momenta and the spectrum of signal muons from W and Υ decays. Three possible components of the trigger upgrade are being studied: (i) Momentum measurements using a new scintillator hodoscope upstream of the muon magnet and anode information from the upstream muon tracker station in combination with a road from the existing muon identifier level-1 trigger. (ii) Matching threshold information from a segmented Cherenkov-counter to muon roads from the muon identifier. (iii) The use of an electromagnetic nosecone calorimeter to exploit topology differences between background jet production and signal events.

The two scintillator hodoscopes – one for each muon arm - will be placed on the back-leg of the central magnet iron yoke. GEANT simulations of occupancies and tracking resolution suggest that each hodoscope should consist of a horizontal and a vertical plane of 1 cm wide and 90 cm long scintillator elements. The simulation studies indicate that a rejection factor of 4 will be reached. RIKEN, Kyoto University and University of Illinois (UIUC) collaborators have started an R&D effort to measure the actual occupancies in the next RHIC run starting in November 2002.

Reading out the muon tracker anodes will provide access to muon tracker information for level-1 decisions. The anodes are tangential to the bending direction and provide limited momentum information. However, they are instrumental in resolving soft secondary background. Different hardware options for the anode readout are presently investigated at the Ecole Polytechnique in Paris.

The Cherenkov detector will be placed between the muon arm magnets and the upstream muon identifier walls. The integration issues in the north muon arm are difficult and are presently being investigated by collaborators at RBRC, BNL and UIUC. GEANT simulations of soft electron background indicate that a modest segmentation, e.g. 5 by 5 elements would result in rejection factors of about 30. An effort is underway to survey the relevant backgrounds in the coming RHIC run.

The nosecone electromagnetic calorimeter requires high segmentation and material with a small Molière radius. A solution based on $20x20x200mm^3$ PbWO (2.2cm Molière radius) is being studied at RIKEN and University of California at Riverside.

The integration of the new trigger detectors will require a new set of local level-1 processors. A new regional trigger processor will combine and analyze the information from the local level 1 processors before passing the muon trigger decision to the PHENIX global level-1 system. Possible solutions are presently being discussed at Nevis and Iowa State University.

Due to the different level of R&D required for the individual detector components we foresee a staged construction. The hodoscopes would be built in FY04 followed by the Cherenkov counters in FY05 and all other components would be completed in FY06.

The ongoing R&D has been funded through institutional contributions. We plan to fund further R&D and construction of the muon trigger upgrade through a MRI grant request to NSF and several foreign sources in Japan and France. The MRI grant request is planned through a consortium of University of Illinois at Urbana-Champaign and Iowa State University, Ames. A detailed funding plan is not available at this time as the funding load distribution between the different groups and funding agencies is presently being negotiated.

5.5 DAQ and Trigger

5.5.1 Overview and R&D program

In the current PHENIX online system front-end modules (FEMs), which control detector front-end electronics, send uncompressed events of fixed length to Data Collection Modules (DCMs) through a gigabit optical link upon receiving a level 1 trigger (L1) accept signal. On each DCM four sets of optical receivers, FPGAs and digital signal processors (DSP) zero suppress and buffer the events from four FEMs. An additional DSP is used to merge the data from the four chains. DCMs and FEMs pipeline events with the capability to buffer at least 5 L1 triggers. Since the FEM data is of known length no data flow control between FEMs and DCMs is necessary in this design and only the DCM participates in the busy logic. The system is designed for a bandwidth corresponding to 12.5 kHz L1 trigger rate.

Most of the detector systems planned to upgrade PHENIX will deliver substantially larger data volumes than the currently operated detectors and thus it will be necessary to zero suppress the data from the new detectors at the front-end before it is transmitted to DCMs. As a consequence a part of the current DCM functionality must be taken over by the FEMs. In particular, after the zero suppression, the FEM data will no longer be of fixed length and therefore the FEMs must participate in the busy logic. This requires a major change of the PHENIX DAQ system. In order to cope with the requirements of the new detector systems R&D is needed in three areas:

- system architecture
- optical technology
- development of new DCMs

The system architecture needs to be modified to take into account the new relation between buffers on the FEM, the data transfer speed between FEM and DCM, and zero suppression efficiency in the FEM. Of critical importance is the minimum buffer length required on the FEMs, which depends on the transfer speed and zero suppression efficiency. Also how to integrate the FEMs into the current busy logic needs to be investigated.

The optical technology has changed significantly since we produced our electronics 4-5 years ago. 10 Gigabit Ethernet and parallel optical links are commercially achievable today. Faster data transfer will reduce the necessary buffer length for the new FEM. It is very important to understand how these technologies can be applied to our new FEMs.

The development of new DCMs is a critical R&D project for the DAQ system. Since the zero suppression at the FEMs must be on the single channel level, both the silicon vertex detectors and the inner tracker and Dalitz rejector could generate large amounts of data if the detectors become noisy or in individual events may channels fire. Based on the current FPGA and DSP technology, it seems feasible that the DCM could perform a hit or cluster recognition which analyses the information from several neighboring channels and suppresses isolated noise hits.

Depending on the additional trigger requirements the global level 1 system (GL1), which combines information from different detector systems, will need to be upgraded. At this time the amount of triggers one can combine in the GL1 system is limited. The system is not easily scalable and a redesign will become necessary. At that point we would also upgrade the GL1 to work with a much faster system clock. This will allow us to do more calculations within the current L1 latency of 4 μs. We will closely examine these issues when the needs of the new local level 1 triggers are clear.

5.5.2 Milestones and budget

FY03

- Start development of system architecture
- Survey high speed optical data transfer technology
- Start DCM conceptual design

FY04

- Complete design of system architecture
- Select optical data transfer technology
- Finalize conceptual DCM design
- Start DCM prototype development

FY05

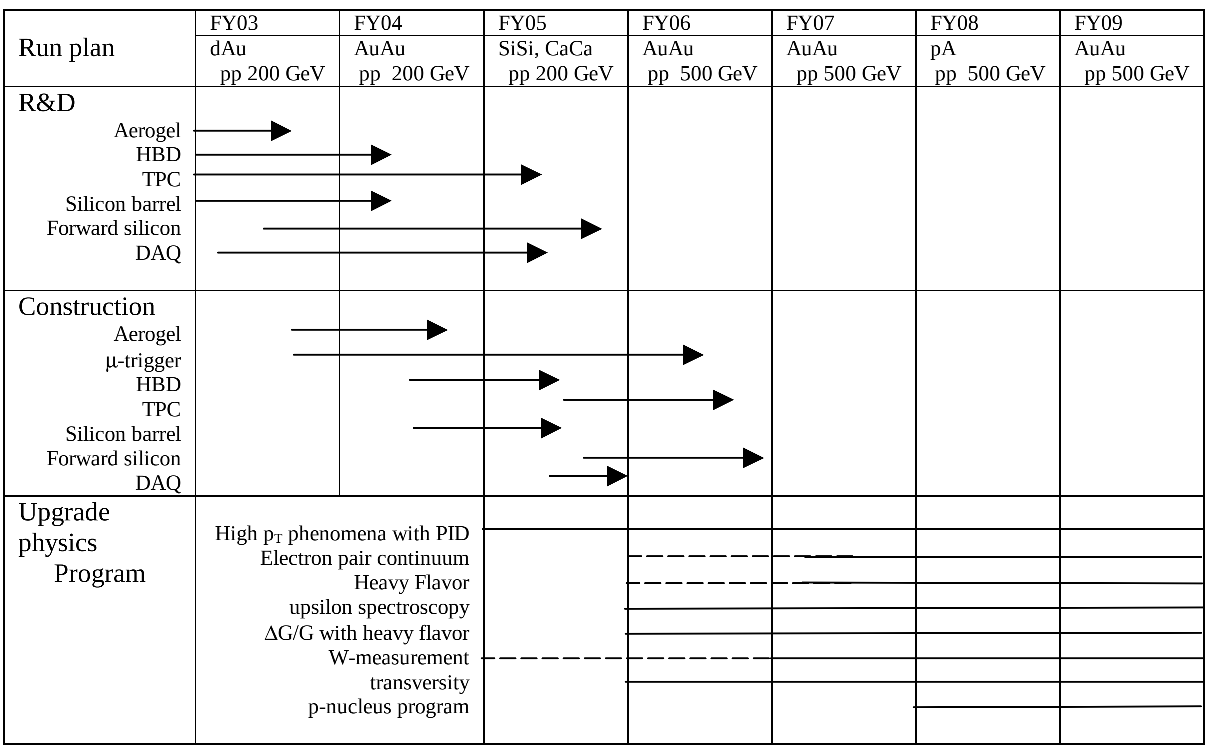
- Complete DCM prototype

DAQ R&D budget	Description	FY03	FY04	FY05
Salaries (incl. Fringe)	Elec. Engineer	$50,000	$75,000	$50,000
	Elec. Technician	$20,000	$75,000	$40,000
Equipment		$40,000	$30,000	$10,000
Prototype Fabrication		$10,000	$30,000	$20,000
Total		$120,000	$210,000	$120,000
Total (incl. 40% overhead)		$168,000	$294,000	$168,000

Tab. 5-3 Budget Request for DAQ R&D. Overhead is assumed to be 40%. Yearly salaries are assumed to be $60k for postdocs, $100K for engineers, $80K for all others.

6. R&D proposal summary

PHENIX is developing a plan for upgrades of the experimental setup to extend the physics reach of the experiment well beyond the discovery phase of RHIC. Tab. 6-1 illustrates how this plan could be realized over the next years, starting from initial R&D, leading to construction and operation of new detector components. The time line shown intimately links to the RHIC running schedule and to the actually achieved luminosities. We show a hypothetical schedule till the end of this decade and assume that the anticipated average luminosity of $8x10^{26}$ $cm^{-2}s^{-1}$ for Au-Au and $2x10^{32}$ $cm^{-2}s^{-1}$ for polarized proton beams will be reached by FY06. PHENIX would evolve gradually while maintaining an exciting physics program initially focused on exploratory studies shifting with time towards a broader and deeper exploration of QCD phenomena in A-A, p-A and polarized p-p collisions. The enhanced physics program would begin in the second half of this decade and reach well into the next decade.



Tab. 6-1 Time line for an optimal PHENIX upgrade schedule showing the R&D program and a possible detector construction scenario. Both are related to a hypothetical running schedule of RHIC and it is shown when specific parts of the enhanced physics program would become available. The time lines for the physics program end without arrow to indicate that they extend beyond FY09.

According to this schedule: (i) an extended program for high p_T phenomena could start as early as FY05, (ii) the construction of the muon trigger upgrade ends in FY06, but since it follows a staged approach physics measurements will start earlier as luminosity permits, (iii) the silicon vertex tracker and the Dalitz rejector also follow a staged approach such that most of the new spin physics measurements and a first electron pair measurements could be done in FY06 when high luminosities are reached, and (iv) the full capabilities of the upgrades program would unfold around FY07.

In the past year PHENIX has been able to initiate a small scale R&D program funded mostly through institutional contributions. Many of the PHENIX institutions have joined the R&D or expressed interest in it. Tab. 6-2 gives a list of the institutions presently participating and their prime interest or current involvement.

Silicon vertex tracker	BNL, Iowa State, LANL, ORNL, RBRC, RIKEN, SUNY SB
HBD/TPC	BNL, Columbia, SUNY SB, Tokyo, Weizmann
DAQ	BNL, Columbia
Aerogel	BNL, Dubna, Tokyo, Tsukuba,
μ-trigger	Iowa Sate, Kyoto, RBRC, RIKEN, Riverside, UIUC

Tab. 6-2 Institutions presently involved in the different PHENIX upgrade projects.

To make further progress a broad-based R&D effort over the next three years is essential. This effort exceeds the possibilities of the contributing institutions and requires a broader funding through DOE. We request a total of about ~ $3.58 M funding from DOE over the next three years to support R&D for the Dalitz rejector and inner tracker, the silicon vertex tracker and the DAQ system. The year-by-year funding profile for the individual projects is summarized in Tab. 6-3 (a more detailed breakdown can be found in Section 5). The costs shown include support of engineering and scientific personal, equipment and prototype fabrication.

R&D for	FY03	FY04	FY05
Dalitz rejector/ tracker	$427,000	$504,000	$504,000
Silicon vertex tracker	$539,000	$665,000	$308,000
DAQ	$168,000	$294,000	$168,000
Total	$1,134,000	$1,463,000	$980,000

Tab. 5-3: Proposed funding profile for PHENIX R&D program. All numbers include 40% overhead.