1 Experiments

1.1 PHENIX

1.1.1 Detector overview

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In this section we discuss the current and proposed capabilities of the PHENIX detector in the context of meeting the challenges of the spin program. Already, RHIC has made great strides towards providing high luminosity beams of highly polarized protons. To make statistically sensitive asymmetry measurements with low systematics requires well understood detectors; clean, highly selective triggers, reliable measurements of beam luminosity and polarization, and the ability to take and analyze data at high rates. PHENIX has already demonstrated these abilities, and is prepared for the years ahead.

Central Arm The EMCal consisted of two subsystems: a six sector, lead scintillator (PbSc) calorimeter and a two sector, lead glass (PbGl) calorimeter. Located at a radial distance of ∼5 m from the beam line, each of these sectors covered the pseudorapidity range of $|\eta|<0.35$ and an azimuthal angle interval of $\Delta\phi \approx 22.5°$. Each of the towers in the calorimeter subtended $\Delta\phi \times \Delta\eta \sim 0.01 \times 0.01$, thus ensuring that the two photons from a decayed π° were clearly resolved up to a p_T of 12 GeV/c. Shower profile analysis can extend this p_T range beyond 20 GeV/c. The energy calibration was corroborated by the position of the π° invariant mass peak, the energy deposit from minimum ionizing charged particles traversing the EMCal (PbSc), and the correlation between the energy deposit in the EMCal and the measured momentum for electrons and positrons identified by the ring-imaging Čerenkov detector. These studies showed that the accuracy of the energy measurement was within 1.5%. At a p_T of ∼11 GeV/c, this uncertainty translates into a systematic error on the π° yield of ∼12%. The effective energy resolution for the dataset was deduced from the widths of the π° mass peaks, which varied with p_T from 7% to 10% (PbSc) and 12% to 13% (PbGl), and a comparison of the measured energy and momentum for identified electrons and positrons.

The number of recorded high-p_T π°'s was enhanced by a high-p_T trigger (denoted as 2×2) in which threshold discrimination was applied independently to sums of the analog signals from non-overlapping, 2×2 groupings (called tiles) of adjacent EMCal towers. During this run, the thresholds corresponded to a deposited energy of 0.75 GeV. The efficiency of this trigger for π° detection, $\varepsilon_{\pi^\circ}^{2\times2}(p_T)$, was obtained from the MB data. As shown in Fig. 1, this efficiency reached a plateau at a p_T of ∼3 GeV/c. This dependence was reproduced by Monte Carlo calculations which included the tile threshold curves, the EMCal detector response, and the geometry of the active trigger tiles. The plateau level, 0.78 ± 0.03 for both PbSc and PbGl, was consistent with the geometrical acceptance of the active trigger tiles.

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Fig.2

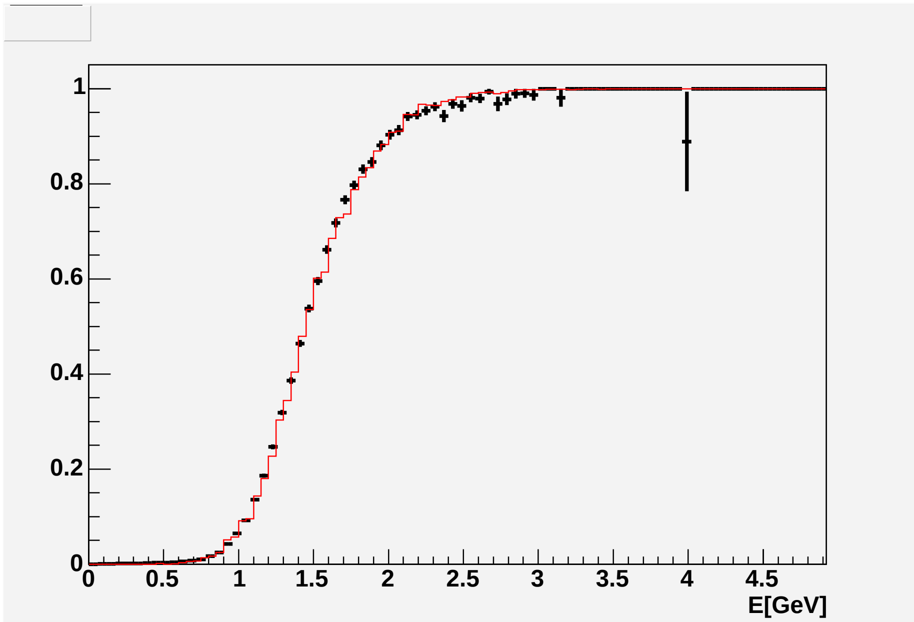

Figure 1: The efficiency of the 4$\times$4 hith-p_T trigger for photon as a function of the energy of photon. (west arm only) The geometrical limit is set to one. The red line shows the results of a Monte Carlo simulation based on the PMT gain variance and Gaussian assumption of trigger circuit variation.

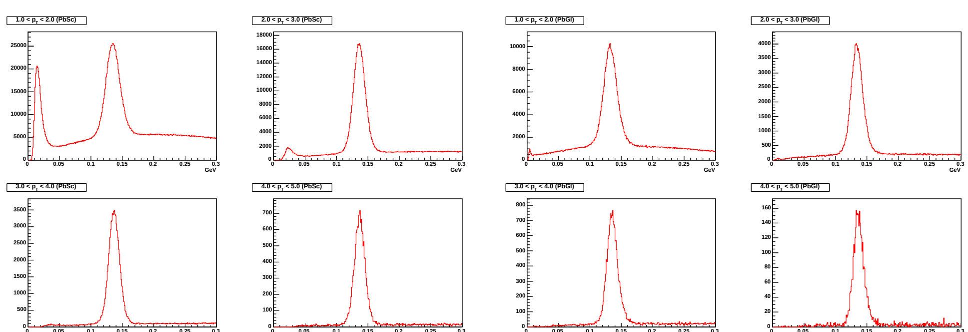

Figure 2: These plots shows π^0 mass spectrum for 4 p_T bins, 1-2 GeV/c, 2-3 GeV/c, 3-4 GeV/c and 4-5 GeV/c. Events are collected using high p_T photon trigger of the EMCal. The π^0 mass peak can be seen clearly and the background is mainly combinatorial background. The background contribution is $\sim$30% in the p_T from 1 to 2 GeV/c, and $\sim$5% more than 5 GeV/c in p_T. The mass resolution at π^0 mass peak is 8.5% in the first p_T bin and 6.4% in the last p_T bin.

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Ref. to Fig.3, page 12 of the combined report.

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Ref. to Fig.7, page 17 of the combined report.

The transverse single-spin asymmetries of neutral pions and non-identified charged hadrons, shown in Fig.21 (page 28 of the combined report), have been measured at mid-rapidity ($x_F \approx 0$). The asymmetries seen in this previously unexplored kinematic region are consistent with zero within statistical errors of a few percent. The dominant partonic processes in both π^0 and charged hadron production in the current kinematic region are gluon-gluon and gluon-quark scattering. This gluon dominance suggests that any potential contribution from mechanisms involving transversity [1] should be significantly suppressed, and the current measurement is probing gluon-sensitive models such as that given in [2, 3].

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Ref. to Fig.4, page 13 of the combined report.

Electrons are measured by the Central arms and well identified by RICH detector (Cherenkov threshold for p1 being 4.9 GeV/c) and the EMCal. The yield of electrons can be categorized into nonphotonic and photonic sources. Photonic electrons are mainly from decays of semi-leptonic decays of charm and beauty, nonphotonic electrons are from gamma conversion and Dalitz decays of neutral mesons such as π^0 and η. This picture shows the decomposed nonphotonic spectrum using the converter method. Luminosity $\sim$20 pb^{-1} and just using 1 arm.

Fig.3

Ref.[4] (charm of AuAu, ref. of converter method)

Muon Arm PHENIX has two forward spectrometers devoted to the characterization of single and di-muon events in the forward rapidity regions. The central magnet poles act as a hadron absorber in front of a radial field magnet with acceptance from $1.2 < \eta < 2.2$ (2.4) in the South (North) spectrometer. Inside the magnetic field, there are three high resolution cathode strip tracking chambers capable of determining space point position to < 100 microns. Downstream of each spectrometer magnet is a Muon Identifier (MuId) which covers the same rapidity region. They consist of five layers of steel absorber sandwiching both horizontal and vertical proportional tubes, with the total thickness of the absorber material of 60 cm. The minimum muon momentum able to penetrate all 5 gaps is 2.7 GeV/c, and the pion rejection factor at 3 GeV/c is 2.5×10^{-3}. The MuId is also used as trigger counter as well as identifying the muon. It uses full hit information of the detector, 9 cm in horizontal and vertical direction for each gap, and determines whether a muon candidate road exists for each beam crossing. Triggers on single and double tracks with sufficient depth in the MuId are passed to the global level-1 trigger of PHENIX. J/ψ mass resolution of 160 MeV/c^2 in p-p collisions has been achieved. Together with the di-electron measurement in the central arm, PHENIX has published the p_T, rapidity and total cross-sections for J/ψ at $\sqrt{s}$ = 200GeV.

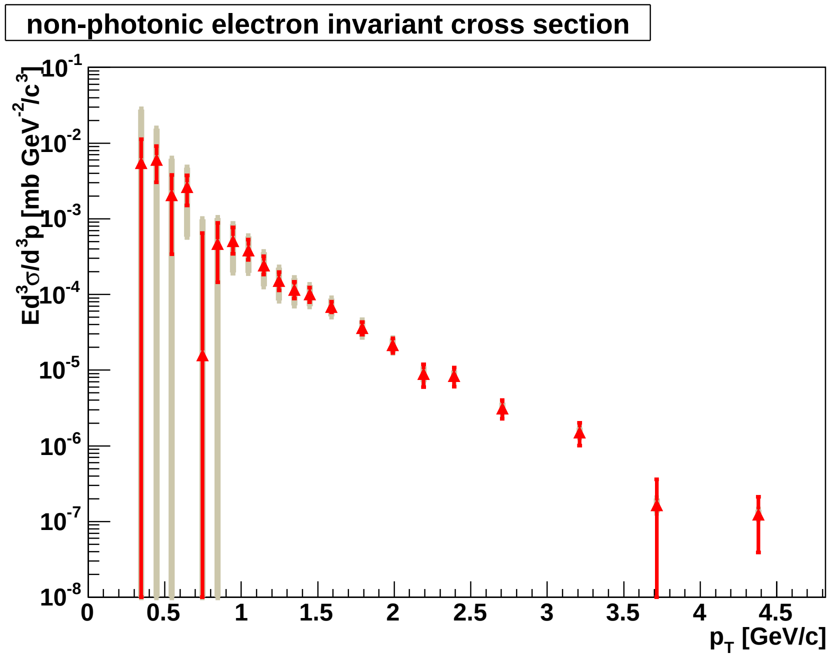

Figure 3:

Fig.4

Spin- and pp-specific detectors Local polarimeters, sensitive to the transverse polarization at collision, were used to set up the spin rotators, and to monitor the beam polarization direction at the PHENIX experiment. The local polarimeters utilized a transverse single spin asymmetry in neutron production in p-p collisions at $\sqrt{s} = 200$ GeV [5]. For vertically polarized beam a left-right asymmetry is observed for neutrons produced at very forward angles, with no asymmetry for production at very backward angles. A fully longitudinally polarized beam produces no asymmetry.

Neutrons with $E_n > 20$ GeV and production angle $0.3 < \theta_n < 2.5$ mrad were observed by two hadronic calorimeters located ± 18 meters from the interaction point (ZDC or Zero Degree Calorimeter [6]) . Scintillator hodoscopes at 1.7 interaction length provided the neutron position at the ZDC, and thus the neutron production angle and azimuthal angle $\phi = \arctan(x/y)$ with $\hat{y}$ vertically upward. The $\hat{x}$ axis forms a right handed coordinate system with the $\hat{z}$ axis defined by the beam direction for forward production. Figure 5 shows the observed asymmetry, for the spin rotators off and on, for the blue and yellow beams. With the spin rotators off, a left-right asymmetry is observed from the vertically polarized beam. With the spin rotators on, the measured transverse polarization, averaged over the run, was $\langle P_{Bx} \rangle = 0.033 \pm 0.019$, $\langle P_{By} \rangle = 0.008 \pm 0.020$, $\langle P_{Yx} \rangle = -0.020 \pm 0.013$ and $\langle P_{Yy} \rangle = 0.054 \pm 0.017$, out of $\langle P \rangle = 0.27$. The double spin transverse polarization was $\langle P_{Bx} P_{Yx} \rangle = (0.4 \pm 1.1) \cdot 10^{-3}$ and $\langle P_{By} P_{Yy} \rangle = (-0.2 \pm 0.8) \cdot 10^{-3}$, compared to $\langle P_B P_Y \rangle = 0.07$. Therefore, with the spin rotators on, the transverse asymmetry is greatly reduced, indicating a high degree of longitudinal polarization: the longitudinal fraction of the beam polarization was 0.99 and 0.98 for the blue and yellow beams, respectively.

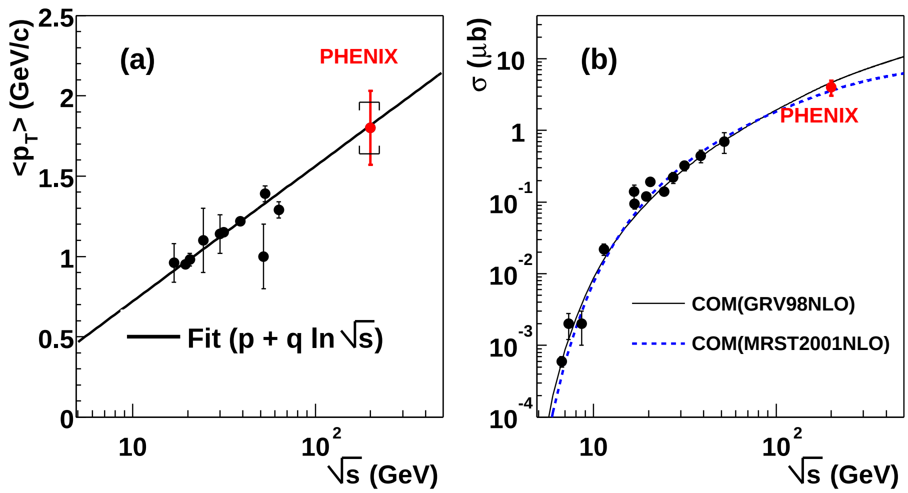

Figure 4:

A separate run with the spin rotators set to give radial polarization confirmed the direction of the polarization for each beam.

The spin structure information of interest is manifested in correlations between the rate or angular distribution of specific final states and the spin direction(s) of the colliding protons. However, spin correlated differences in the production rate of particular final states may appear even in the absence of a physics asymmetry simply because the luminosities of the colliding bunches are different. This necessitates measurements of the relative luminosities of the colliding bunches which are insensitive to the beam polarization to greater precision than the smallest physics asymmetry to be measured. PHENIX is currently equipped with two forward detectors, the BBCs and ZDCs [references], which are primarily sensitive to minimimum bias pp inelastic and double-diffractive cross-section respectively. They have demonstrated an insensitivity to the colliding bunch polarization at the level of 2×10^{-3} and have a high rejection of backgrounds. Scalars attached to these detectors which can count a single event per crossing form the successful foundation of the relative luminosity measurements suitable for the current pp luminosity. As RHIC approaches its design luminosity, 2×10^{32} cm^{-2}s^{-1}, there will be multiple pp interactions per bunch crossing, and ambiguities in determining whether the event vertices lay within the PHENIX acceptance. We believe these complications may be overcome by incorporating additional information from the detectors which are linear in the rate such as phototube charge and multiplicity. Bunch profile information from existing RHIC intrumentation, new analysis techniques and trigger logic will be used to minimize the effects of vertex ambiguities on the determination of relative luminosity. Also, a dedicated low cost, small acceptance detector is being considered to address these issues.

The PHENIX DAQ has been designed from inception as a parallel pipelined buffered system capable of very high rates of nearly deadtime-less data-taking. In this kind of design, data is sent from each detector element in multiple parallel streams, buffered at each stage in the chain to smooth out fluctuations in rate, and then uses simultaneous read and write for the highest possible throughput with existing technology. At present, PHENIX has achieved data rates of

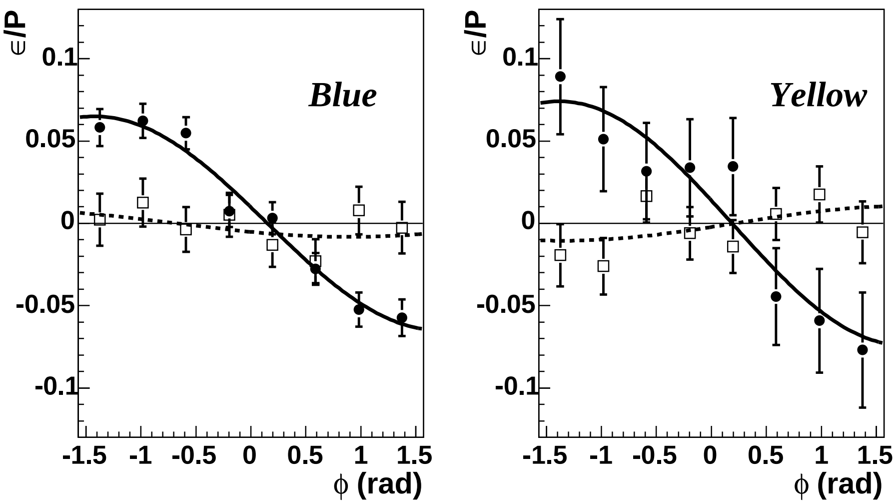

Figure 5: The raw asymmetry normalized by the beam polarization, ϵ/P, as a function of azimuthal angle ϕ, for forward neutron production. The solid points and curve correspond to the spin rotators off (transverse polarization) and the open points and dashed curve correspond to the spin rotators on (longitudinal polarization). Curves are sine function fits to the data, representing possible transverse polarization. The data are for special runs used to set up the spin rotators, where the blue (yellow) polarization was 0.24 and 0.33 (0.08 and 0.28), for spin rotators off and on, correspondingly.

over 4 kHz, and with improvements in noise reduction PHENIX should be able to approach the peak design interaction trigger rate of 12.5 kHz. Such high DAQ rates are crucial for providing the capability and flexibility to record the many different kinds of interesting rare events at RHIC.

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1.1.2 Detector upgrades

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muon trigger for W physics and figure of muon trigger to be inserted ...

PHENIX Collaboration proposes to construct a Silicon Vertex Tracker (VTX) in the next few years. The VTX will substantially enhance the physics capabilities of the PHENIX central arm spectrometer. Our prime motivation is to provide precision measurements of heavy-quark production (charm and beauty) in A+A and p(d)+A collisions, and polarized p+p collisions. In addition, addition of a large acceptance central detector capable of monitoring multiplicities of hadronic final states along with their directions, will enhance PHENIX's capability to study Jets in hadron-hadron collisions. These are key measurements for future RHIC program, both for heavy ion physics which intends to study the properties of dense nuclear medium created in their collisions, and for the exploration of the nucleon spin-structure through polarized pp collisions. While the detailed list of physics measurements possible with the VTX detector are discussed elsewhere [1], the the principle measurements associated with polarized pp program are:

- $\Delta G/G$ from charm and beuty production in polarized pp scatterin
- x dependence of $\Delta G/G$ from γ-Jet correlations

The PHENIX detector has been described before in Section**??**. The heavy quark production has been measured by PHENIX only indirectly through the observation of inclusive (decay) electrons. These measurements are limited in accuracy by the systematic uncertainties resulting from possible large electron backgrounds originating from Dalitz Decays and photon coversionsaThe measurements are statistical in nature, and one uses different models to distinguish between charm and beuty contributions. The VTX detector will provide tracking with a resolution of $< 50\mu$m over a large coverate both in rapidity $|\eta| < 1.2$ and in azimuthal angle ($\Delta\phi \sim 2\pi$). A significantly improved measurement of heavy quarks in pp collisions is deemed possible over a wide kinematic range with the VTX.

The proposed VTX detector will have four tracking layers. For the inner two laters we propose to use silicon pixel devices with 50x425 μm channels that were developed for the ALICE experiment at CERN/LHC. Our preferred technology for outer two detector layers is a silicon strip detector developed by the BNL instrumentation division which consists of 80μm x 3 cm strips layed to achieve an effective pixel size of 80 x 1000 μm. We plan to use SVX4 readout chip developed at FNAL for the strip readout. The main aim in using ready technology has been to shorten the cost and the time for the R&D that for such a project could ordinarily be rather high and long, respectively.

PHENIX anticipates that the project will be mainly funded by two agencies: the DOE Office of Nuclear Physics and RIKEN Institute of Japan. While RIKEN funding has been available since 2002, it is anticipated that the construction funds for the Strip Layers will be available from DOE starting FY06 and the project will get constructed and commissioned in the RHIC - Run 8 which presently is expected to be a long Au+Au run.

The PHENIX detector at RHIC has been designed to study hadronic and leptonic signatures of the new states of matter in heavy ion collisions and polarized proton collisions. The baseline detector measures muons in two muon spectrometers located forward and backward of mid-rapidity, and measures hadrons, electrons, and photons in two central spectrometer arms each of which covers 90 degrees in azimuth and 0.35 unit of rapidity where the existing electromagnetic calorimeters are installed. Further progress requires extending rapidity coverage for hadronic and electromagnetic signatures beyond the limits set by already built central spectrometer, in particular upgrading the functionality of the PHENIX forward spectrometers to include photon and jet measurement capabilities.

A forward spectrometer upgrade is being proposed with the objective of introducing new detector capabilities and greatly enhancing present capabilities for PHENIX in the forward direction. When completed it will result in a nearly ten-fold increase to its rapidity coverage for photons and to some extent for hadrons, jet detection and better triggering capabilities. Newly acquired access to forward production of inclusive jets, direct photons or Drell-Yan pairs at large xF in nucleon-ion collisions at RHIC will provide a new window for the observation of saturation phenomena expected at high parton number densities and its importance in the evolution of the partonic distribution functions.

The PHENIX Forward Upgrade is constrained by the existing muon spectrometer configu-

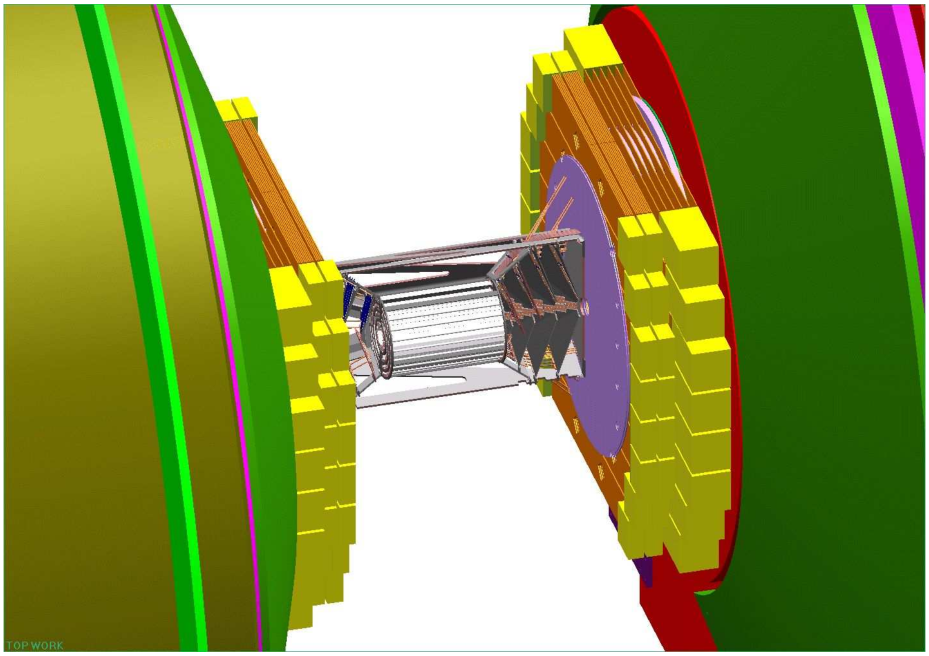

Figure 6: Longitudinal structure of a single NCC tower.

ration including its wire chambers, hadron absorber walls and magnet yokes. The core element of the proposed upgrade are compact tungsten calorimeters with silicon pixel readout and fine transverse and longitudinal segmentation built to identify and measure forward electromagnetic activity and provide jet identification and coarse jet energy measurements. The principal performance aspect of the NCC is its ability to run in the unassisted mode (without upstream tracking).

The NCC is extremely dense sampling calorimeter using tungsten absorber interleaved with silicon readout layers. Geometrical constrains of the PHENIX detector call for a very nontraditional and challenging design. Tungsten has a very short radiation length and a large absorption/radiation length ratio. The electromagnetic shower develops in the very first few cm of the calorimeter depth thus allowing the implementation of both electromagnetic and shallow hadronic compartments within the available 20 cm of space. To further suppress the hadronic contribution to the energy seen in the electromagnetic compartment the electromagnetic calorimeter will be only $\sim$10 radiation length deep. The tungsten in the first 16 layers has a thickness of 2.5 mm ($\sim$0.7 X0), and 1.6 cm in the remaining 6 layers serving as hadron rejecter - shower tail catcher (Fig.6).

Limiting the depth of the electromagnetic compartment to $\sim$10 Lrad serves to improve the em/hadron shower discrimination but will also result in the loss of resolution for high energy showers. To minimize the potential negative impact of this decision on the performance of the energy measurements the same lateral granularity will be retained in both electromagnetic and hadronic compartments (1.5×1.5 cm^2 pixels). Measurements in both compartments will combine to recover the resolution.

plan for high luminosity (relative luminosity, trigger rates, bandwidth, backgrounds, crossing ambiguities, vertex, ... to be inserted ...

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1.1.3 Projection for future measurements

In the PHENIX, single electrons from semi-leptonic decays from charm and beauty meson are measured in mid-rapidity region. These 2 sources will be decomposed by VTX upgrade (looking at DCA distribution). This picture shows the ALL error of electrons from charm and beauty. Each points shows ALL error of the pT region above pTmin.

Ref. to Fig.8, page 19 of the combined report.

Ref.[8]

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