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The Nose-Cone Calorimeter: a forward upgrade to PHENIX

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Abstract. PHENIX is efficient at measuring processes involving rare probes, but has limited acceptance in azimuth and pseudorapidity (η). The Nose Cone Calorimeter (NCC), a W-Si sampling calorimeter in the region of $0.9 < \eta < 3$, is one of the upgrades which will dramatically increase coverage in azimuth and pseudorapidity. The NCC will expand PHENIX's precision measurements of electromagnetic probes in η, reconstruct jets, and enhance triggering capabilities. It will significantly contribute to measurements of γ-jets, quarkonia, and low-x nuclear structure functions. Here details of detector design and performance and a sample of the physics topics which will benefit from the NCC are discussed.

Keywords: Silicon-Tungsten, Si-W, tracking calorimeter, PHENIX forward upgrade, simulations
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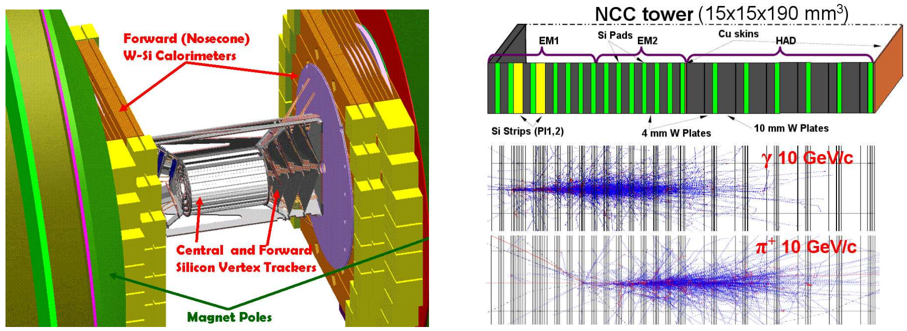
1. Introduction

The PHENIX electromagnetic calorimeter (EMC) [1] has been particularly important for various discoveries at RHIC, including high p_T suppression of both light[2] and heavy[3] hadrons, and direct γ measurements[4]. The NCC[5–8] will expand the pseudorapidity coverage to $0.9 < \eta < 3$ in each arm, allowing more detailed measurements of these observables. The NCC will lead to a better understanding of hot and cold nuclear matter and the spin structure of the proton through measurements of single hadrons, dihadrons, dileptons, direct photons, jets, and γ-jet correlations. Together with the muon arms, the NCC will enable studies of the χ_C, which could serve as a thermometer for the medium[13, 14]. The rapidity coverage is suitable for low-x and high Q studies of hot and cold nuclear matter, where saturation effects in gluon density are predicted for a Color Glass Condensate (CGC) [9, 10]. The NCC will also provide data for local level one (LL1) triggering, necessary at RHIC II luminosities. This report covers simulation efforts discussed in [11] for a single NCC arm, although a second arm would double sensitivity and significantly aid correlation and jet studies. Funding is being sought for a second arm.



(a) Schematic diagram showing the position of the NCC between the magnet poles and the Silicon Vertex Trackers

(b) Longitudinal structure of a single calorimeter shower and the response to a 10 GeV photon and a 10 GeV π^+

Fig. 1. Schematic depictions of the NCC

2. Nose Cone Calorimeter Design

The proposed NCC is a Si-W calorimeter with tracking capabilities. The NCC is 19 cm thick with a radius of 50 cm and will be mounted on the vertex magnet coils, replacing the copper nosecone, as shown in Fig. 1(a). There will be two finely segmented ($15{\times}15\,\mathrm{mm}^2$) sampling electromagnetic segments (EM1, EM2) and one coarse hadronic (HAD) segment. Tungsten was chosen for its high density and small Molière radius. Each EM segment is $8\,X_0$ and the HAD segment is $19\,X_0$ for a total of $35\,X_0$ or 1.3 nuclear interaction lengths. This means that most EM showers are extinct before they hit the HAD segment, allowing the measurement of EM probes in even the most central Au+Au collisions. The design enables the distinction of electromagnetic from hadronic signals as shown in Fig. 1(b).

High momentum π^0 identification The EM1 segment contains two layers of two perpendicular high resolution ($0.5{\times}60\,\mathrm{mm}^2$) position sensitive Si strip layers (photon identifiers PI1 and PI2), at depths of 2 and $3\,X_0$, as shown in Fig.1(b). The PI layers allow the identification of $\pi^0 \rightarrow \gamma\gamma$ from the separation and the energy distribution between two hits and the reconstruction of their invariant mass. This enables π^0 identification above 5 GeV.

Resolution of angle and energy measurement The HAD segment not only aids in hadron rejection for measurement of EM probes, but also improves hadronic energy resolution, aiding jet reconstruction. Energy resolution for jet reconstruction was estimated to be $\sigma_E^{jet}/E \approx 45\sqrt{E[GeV]}\,[\%]$ by reconstructing PYTHIA jets using a cone algorithm with dR$\,<0.5\,$rad. The angular resolution determined from simulation is $\lesssim$0.1 rad and contributes less than 10 % to the x resolution, below the amount expected from NLO radiative effects.

The NCC can be used for tracking by using the center of gravity in each segment as measurement of particle position and combining this with information from the PI sensors, as shown in Fig. 2. For primary tracks, where the vertex position can be used, the angular resolution of the NCC is about 6 mrad; for global tracks it ranges from 10 to 18 mrad, depending on the impact angle. The energy of the particle is determined by summing the energies collected in each segment after correcting for the detector response. The NCC energy resolution is estimated to be $\sigma_E/E \approx 18\sqrt{E[GeV]}+4\,[\%]$.

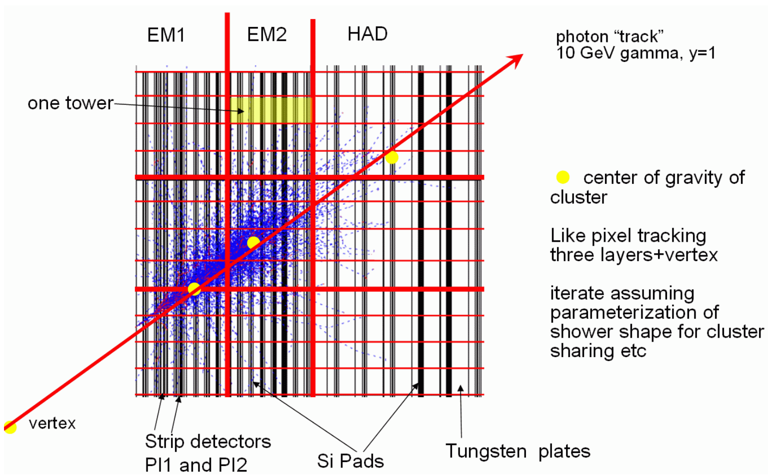


Fig. 2. Principles of tracking measurements in the NCC.

Prototypes Two NCC prototypes shown in Fig. 3 were constructed and tested. The first was used as a proof of principle and was used to test the design scheme and the robustness of the technology. It was exposed to 70 GeV/c protons and 10 GeV/c positrons at the IHEP U70 proton synchrotron in Protvino in Russia in November 2005, confirming that the design was sound and simulations describe the detector performance well. The second prototype was a 2x2 sensor module using the final stackable design, tower geometry, materials, and read-out electronics. It was used to test the design for the PI layers and the performance of the electronics. Tests were performed in September 2007 at CERN using electron beams at a range of energies up to 100 GeV.

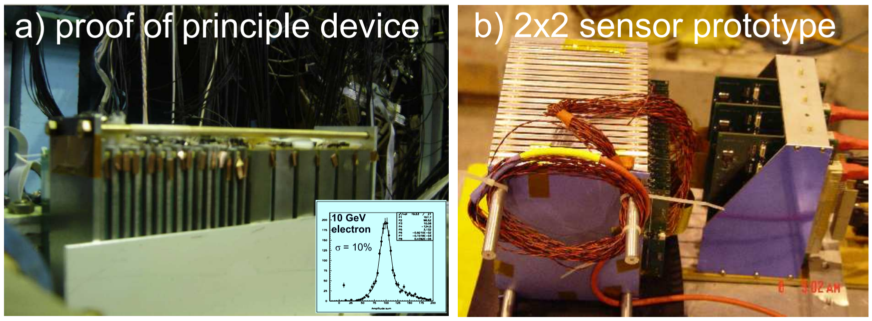
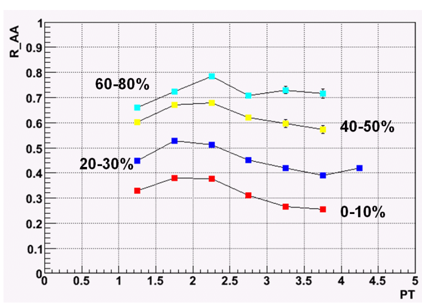


Fig. 3. NCC prototypes: (a) 2005 proof of principle, (b) 2007 final geometry.

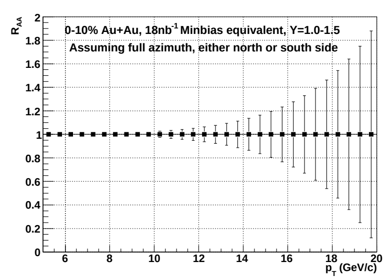
3. Simulations of detector performance

The NCC was modeled in GEANT-3, both as a stand-alone detector and integrated into the PHENIX Integrated Simulation Application (PISA) framework. The stand-alone simulation was used to establish detector sampling fractions, a parameterization of EM shower shape, and the energy calibration. The PISA simulation includes realistic descriptions of all components of the PHENIX detector and was used to estimate the sensitivity of the NCC to π^0s, single photons, and χ_Cs. All simulations were done to approximate ten weeks of running at $\sqrt{s_{NN}}$ of 200 GeV at RHIC-II luminosities.

π^0 analysis Two techniques are used to reconstruct π^0s. The two-track method works best for energies below 5 GeV and involves looking at the invariant mass of all pairs of photons with energy greater than 0.5 GeV. Restrictions are placed on the longitudinal and lateral χ^2 for each photon, the photon pair's opening angle is restricted to < 50 mrad, and the energy asymmetry α was required to be < 0.8. The background subtraction is done by event mixing. The high detector occupancy in central Au+Au collisions limits this method to $\eta < 1.5$. For higher energies the two decay photons overlap, but π^0 candidates can be identified from the shape of the shower they leave in the calorimeter. In the NCC the PI detectors can be used to get an opening angle and energy asymmetry, and this is combined with information on the total energy in the shower to determine the invariant mass. For each of these single-track π^0 candidate in the mass region 135±50 MeV the probability that it is a π^0 is determined. Estimates for the uncertainties on π^0 R_{AA} is shown for the two-track method in Fig. 4(a) and for the single-track method in Fig. 4(b).



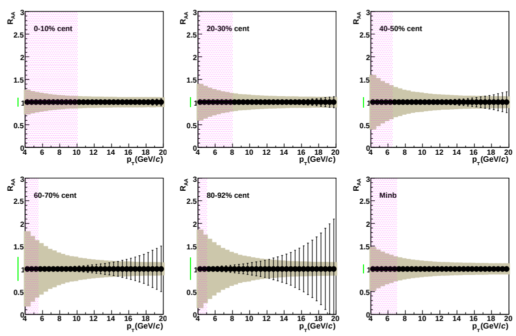
(a) R_{AA} for $\pi^0 \rightarrow \gamma + \gamma$ for various values of centrality. The value of R_{AA} is assumed to be the same as that seen in the central arms, the error bars reflect the precision possible from a one run at RHIC II luminosities.



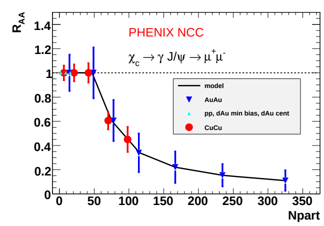
(b) R_{AA} for "single track" π^0's. The error bars reflect the precision possible in one run at RHIC II luminosities. We assume a suppression pattern similar to that seen in the central arms, hence statistics runs out at ∼15 GeV.

Fig. 4. π^0 analysis results

Direct photon analysis In heavy ion collisions, direct photons can only be measured by measuring the spectra of inclusive photons and subtracting contributions from hadron decays. Measurements of hadrons which decay into photons are used to simulate the contribution from decays. Below 5 GeV the direct photon signal is a few percent of the total photon spectrum in p+p and less than 10-20 % in central Au+Au. However above 5 GeV the signal to background (S/B) rises quickly, reaching $\sim$1 in central Au+Au collisions, largely due to the factor of 5 suppression of π^0 at mid-rapidity [12]. The increased S/B is concurrent with increased occupancy and overlap probability in the NCC. The expected sensitivity of the direct photon measurement is shown in Fig. 5(a). Shaded areas at low p_T indicate regions where the current method gives ambiguous results.



(a) Anticipated sensitivity for direct photon R_{AA} in several centralities Au+Au.



(b) Anticipated sensitivity for χ_C R_{AA} in Au+Au.

Fig. 5. Sensitivity for direct photons and χ_Cs in one RHIC-II run.

χ_C **analysis** With the NCC, PHENIX will be able to measure the χ_C through its decay $J/\psi + \gamma$ where the $J/\psi \rightarrow \mu\mu$ is detected in the muon arms. When both muons are detected in the muon arms, about 60 % of the photons are within the NCC acceptance. Dimuons are identified using the standard technique [15]. Photons are identified using a longitudinal χ^2 cut, and requiring an energy > 300 MeV. Fig. 5(b) shows the significance expected for the R_{AA} of the χ_C within $1 < \eta < 1.5$. The S/B for the most central Au+Au events used in this simulation is 1/400. Note that is other analysis, PHENIX has successfully identified signals using a mixed background subtraction of less that 1/1000. Therefore, using the NCC, PHENIX will be able to make an excellent measurement of the suppression factor for the χ_C.

4. Conclusions

The Nose-Cone Calorimeter (NCC) is a next generation Si-W sampling calorimeter with tracking capabilities, providing rapidity coverage about 10 times that of the central arms. When constructed and installed in 2011, the NCC will significantly enhance PHENIX's ability to measure properties of the sQGP medium produced in A+A collisions through measurements of the suppression of hadrons in forward direction, charmonium suppression, and γ-jet correlations. These measurements will lead to a better understanding of the temperature and more calibrated probes of the medium. In d+A collisions the NCC will help resolve the structure of high density nuclear matter. In particular it will enable studies of saturation effects down to low-x. In p+p collisions measurements at low-x will lead to a better understanding of the gluon and and sea polarization.

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