A Silicon-Tungsten Electromagnetic Calorimeter for the PHENIX Experiment at RHIC

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Abstract.
A proposed Silicon Tungsten Calorimeter for the PHENIX Experiment at RHIC will increase the calorimetric of the experiment by over an order of magnitude. The physics and design of the calorimeter is described.

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The initial round of RHIC experiments has yielded a rich panoply of results[1] which indicate that a strongly interacting Quark-Gluon Plasma (sQGP) has been formed. The high multiplicities in relativistic heavy ion collisions have required that the detectors be very highly segmented. In the case of the PHENIX detector the initial design was a compromise between coverage and granularity - the coverage was chosen to be in the mid-rapidity region. In order to make further progress, it becomes necessary to use probes with smaller cross sections requiring large acceptance detectors covering the forward and backward rapidity regions. This necessarily requires that PHENIX significantly expand its coverage for calorimetry in the region $1<|\eta|<3$. The only space for such a calorimeter is on the pole tips of the magnet at a distance of 40 cm from the interaction region (Fig. 1). Two shower separation is critical for the extraction of the direct photon signal, particularly in a heavy ion environment. Given the geometrical constraints, a silicon tungsten calorimeter which provides a compact solution because of the small Moliere radius - provides the best, and probably only solution. The small Moliere radius is a result of the small radiation length together with the possibility of a high density readout via silicon pads and strips. The PHENIX upgrades program includes just such a device - the Nose-Cone Calorimeter (NCC)[2].

PHYSICS GOALS

The physics program at RHIC, includes: 1) heavy ion collisions to study high energy density, large volume, hadronic systems - i.e. the sQGP, 2) proton-nucleus (or deuteron nucleus) collisions to examine the properties of nuclei at very low x-Bjorken, i.e. the region of the Colored Glass Condensate (CGC), and 3) polarized pp collisions to measure the spin structure of the nucleon. The NCC will play a critical role in each of these.

One of the most remarkable phenomena observed at RHIC has been the suppression of high momentum particles in central Au-Au Collusions, when compared to a suitably scaled pp reference[3]. This presumably results from the loss of energy by fast partons

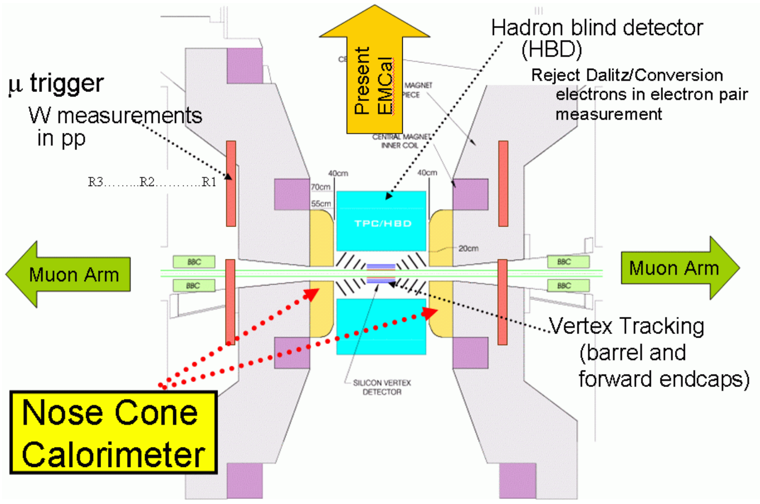

FIGURE 1. A schematic view of the central region of the PHENIX detector showing the proposed location for the NCC. The beam comes in from the left and right.

traversing the sQGP, where the detected particles are the leading fragmentation products. In the analysis of present experimental data assumptions have been made about the initial momentum spectrum of the hard partons before energy loss. However in the future, photon-jet events can be used to "calibrate" the initial momentum of the parton. Of course, the cross section for such events is significantly reduced because of the electromagnetic coupling constant. The NCC would increase the acceptance for such events by more than an order of magnitude. In addition, the rapidity and azimuthal coverage would allow one to construct a tomographic map the the energy density vs rapidity and reaction plane. Similar measurements can be made in proton-nucleus collisions to examine the effects of the saturation of the gluon structure function at low x-Bjorken as a function of rapidity and centrality. In polarized pp collisions, direct photon-jet events can be used on an event by event basis to extract the kinematical quantities, x and Q^2 and directly measure the spin dependent gluon structure function. The NCC can also assist in the measurement of the W boson in sea quark polarization measurements by providing the possibility to use isolation cuts. In heavy ion collisions, one of the most important measurements to be made is the measurement of the suppression of charmonium. This has traditionally been thought to be a indication of deconfinement - though this interpretation has been called into question[4]. Lattice calculations, indicate that a measurement of the suppression of various quarkonia states, may be indicative of the critical temperature of QCD. In particular, the χ_c may "melt" at a temperature close to T_c. The NCC, together with the muon spectrometer already operational in PHENIX, provides a unique opportunity to measure the χ_c, via its decay to $J/\psi+\gamma$.

DESIGN

The physics goals - that of large coverage including forward rapidities, with fine segmentation - have driven the design of the NCC. One of the most challenging aspects

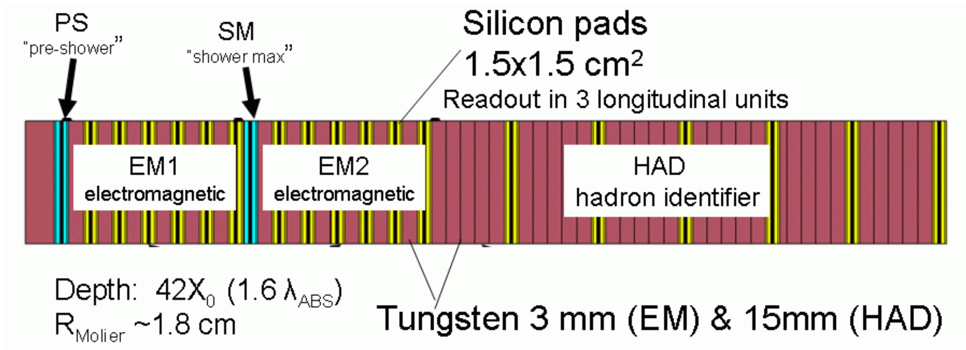

FIGURE 2. A schematic of the longitudinal segmentation of the NCC.

of this detector is the requirement of good two shower separation for an accurate measurement of the π^0 spectrum. Such a measurement will allow the extraction of the direct photon spectrum. This technique has been well tested by the PHENIX collaboration in heavy ion collisions[5]. Such techniques can be extended, given high statistics, to yield measurements of the direct photon spectrum, in correlation with opposite high momentum particles to make a "calibrated" measurement of the energy loss of partons though the medium, as mentioned in the previous paragraph. It is this measurement that drives much of the design of the detector.

The detector, shown in Fig. 2 is composed of silicon pads 1.5x1.5 cm^2 interleaved between layers of tungsten. The readout is in 3 longitudinal sections, effectively dividing the detector into "compartments": EM1, EM2 and HAD. The tungsten thickness is 3mm in the EM1 and EM2 sections and 15 mm in the HAD section for a total depth of 42 L_{rad}, or about 1.6 λ_{abs}. The effective Moliere radius is about 1.8 cm. The readout is then in towers, 1.5x1.5 cm^2 divided into the 3 longitudinal compartments. The electronics in each tower is simply passively ganged together in each compartment. The energy resolution from simulations is expected to be $\frac{18\%}{\sqrt{(E(GeV)}} + 4\%$.

In addition, there are two layers of specialized elements: the preshower (PS) and shower-max (SM) detectors to be used for two shower separation. The proposed technology will be a layer of "StriPixel" detectors[6] for x-y readout, with 500 μm pitch. These detectors make it possible to reconstruct neutral pions, even if two showers overlap. The strategy is as follows: The PS detector is at a depth of 2L_{rad} - a depth optimized such that two photons from a neutral pion will give a MIP signal in the PS detector. If two tracks are seen in the PS detector, this information, together with the vertex of the event, will give the opening angle of the two photons. The information from the pads is used to measure the total energy of the overlapping showers. The profile as seen in the SM can then be fit to a double peak, where the area under each peak used to obtain the energy asymmetry of the two showers. Using the opening angle, the total energy, and the energy asymmetry, the π^0 mass can be reconstructed. Fig. 3(left) shows an example of this technique from a simulation of 1-30 GeV pions in which the showers were overlapping.

An initial prototype without the PS and SM detectors was exposed to 10 GeV positrons at the Protvino proton sychrotron (Russia) to obtain an energy resolution. The results, shown in Fig. 3(right) give a width of 10%, consistent with the simulated en-

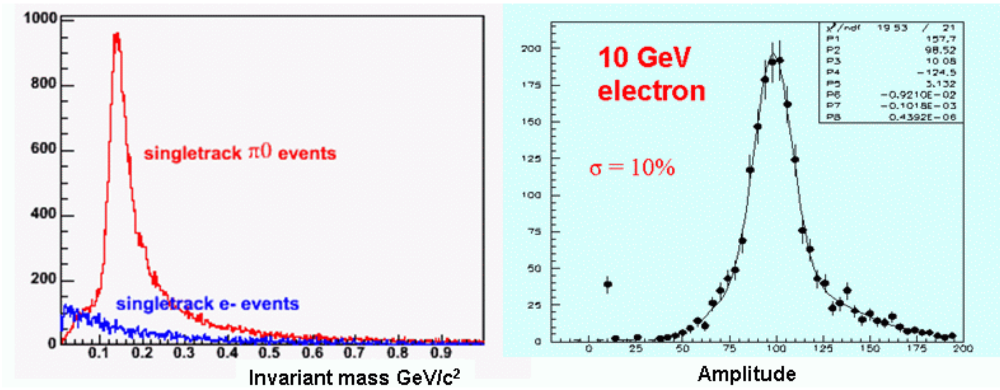

FIGURE 3. (**left**)Simulation of the $\gamma\gamma$ invariant mass reconstructed from overlapping showers in the NCC as explained in the text. For comparison, showers from electrons, misidentified as two overlapping showers are also shown. (**right**)The amplitude as measured by the NCC prototype from 30 GeV electrons in the test beam. The width of the distribution is 10%, consistent with the expected energy resolution of the NCC.

ergy resolution mentioned above. An extensive test beam measurement is scheduled for 2007 in which a several subunits of the detector, including the PS and SM detectors, and prototype electronics will be exposed to a variety of particles including neutral pions at various energies and angles to map out the performance of the device and to obtain a detailed understanding of the neutral pion reconstruction efficiency.

STATUS AND CONCLUSION

The schedule calls for the installation of the first NCC in 2010, and the second in 2011. As mentioned above, a major prototype will be tested in 2007 will a final design review at the end of that year. An initial review of the NCC took place in March 2006 at BNL, which recommended a start of funding in FY 2008. Production should then begin in January 2008.

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