Department of Energy
Office of Nuclear Physics Report

Addendum II

Response to DOE Recommendations

Nose Cone Calorimeter Detector (NCC) Upgrade Proposal

Attachment C

Excerpts of the Reviewer's evaluation of the PHENIX NCC Collaboration's response to DOE Science Review Recommendations are presented in this Attachment.

Reviewer:

In the July 2007 review of the NCC, the committee made two recommendations which can be summarized as:

I. Show what the NCC adds to the physics of PHENIX, in detail, for two or more topics and

II. Show via simulation that the proposed geometry of the NCC will not hinder its abilities.

In the PHENIX NCC response, several points still need clarification. These were items that were perhaps done correctly; although, it wasn't entirely clear from the response document. The response to further questions from reviewers (referred to as Q. xx below) did go a long way to clarifying many of these issues, however, but there are still a few things left to consider.

Recommendation II: Will the non-projective geometry work?

To show that the geometry will work, the responses for single γ, *e* and π^0 particles were generated in Monte Carlo. These signals were embedded into Monte Carlo background events generated with HIJING and PYTHIA for *p-p*, *d-Au* and *Au-Au* events, after which an attempt was made to reconstruct the embedded γ, *e* or π^0. The primary difficulty appears to be in reconstructing low energy γ, *e* or π^0's at very high η in central *Au-Au* events, as can be seen in many figures.

I have several concerns about the procedures which were used. They are partially answered in the response to reviewer's questions:

A. The response didn't specify how the embedding was done, but in answer to Q. 2, it was done correctly—the energy deposition was what was embedded and then the electronic response was digitized.

B. The description of the reconstruction of single-track π^0's in central Au-Au events in p. 3-25 seemed to be a cheat, by using the underlying HIJING event. This was partially answered in Q. 6 and Q. 7. Here the "search-and-rescue" procedure seems inadequate as a true simulation. As they point out, however, the full reconstruction CPU intensive, but I am still skeptical that this is a good approximation in the high occupancy areas. Perhaps they could do a "classical" reconstruction at lower η where there is less occupancy and demonstrate that you

get the same result at the "search-and-rescue", and try to find at what η this approximation breaks down.

What they have shown is

C. Good single photon efficiency for *p-p* and *d-Au* events at all η and for *Au-Au* events at low η and high photon energy (Figs. 2.7 and 2.8). In the "physics case" they limit the region of interest for *Au-Au* events to $\eta<1.5$ to compensate for this inefficiency.

D. Good double track π^0 reconstruction efficiency in *p-p* (Fig. 2.12 and 2.13) and *d-Au* events (Fig. 2.13). For *Au-Au* events a peak is still reconstructable. The statistical precision of the "postage stamps" in Fig 2.13 leave something to be desired. If this is just Monte Carlo statistics and not "real running" statistics, this is fine. (The statistics question is partially answered by Q. 4.)

E. The NCC is able to successfully reconstruct single track π^0's in central *Au-Au* events up to 20% of the time, depending on η and p_T (Fig. 3.4) subject to the criticism in B. above. *D-Au* and *p-p* events are presumably easier (*p-p* events are in Fig. 2.15). The opposite of this is also a concern for the $R_{AA}(\pi^0)$ measurement; that is, how many non-π^0's are reconstructed as π^0's? This is shown, without centrality binning in Fig. 3.5.

Except for point B, PHENIX did a reasonable job in showing that the non-projective geometry will work within specific kinematic regions (due to occupancy in *Au-Au*). However, point B is a serious concern. This could be addressed with additional simulation work, but that has yet to be done. Also, the limitations in kinematics need to be evaluated in terms of the physics impact. This is partially addressed in answering the first recommendation.

Recommendation I: Physics Cases

For the physics cases, PHENIX chose to look at $R_{AA}(\pi^0)$ and $R_{AA}(\chi_c)$ and chose to mention heavy ion γ, jet identification and direct-photon spin measurements.

$R_{AA}(\pi^0)$

$R_{AA}(\pi^0)$ is an important measurement, so the question to be answered is what the NCC can add to the measurements which have already been made (specifically, PHENIX arXiv:0801.4020).

A. For two track π^0's as a function of p_T, a comparison of Fig. 3.7a and arXiv:0801:4020 Fig. 2 shows that the main uncertainty in the $p_T<5$ region is systematic, not statistical. The discussion in the response focuses on statistics, which appear to be qualitatively similar to the already published data.

B. For single track π^0's, the same comparison again shows that the existing data appear qualitatively on par with Fig. 3.7b. Showing additional centrality bins in Fig. 3.7b

might make the case clearer. (There could be some argument about the exact size of the uncertainties and number of points, but PHENIX will also be accumulating more data for the existing central measurements.) Again, improvements in systematic uncertainties would be better.

C. For the NCC, the effects of occupancy on the systematic uncertainties in $R_{AA}(\pi^0)$ need to be demonstrated. The occupancy is clearly different in *p-p*, *d-Au* and *Au-Au* events and this will affect the reconstruction efficiency and photon misidentification.

D. The NCC contributes additional η coverage to this measurement. ArXiv:0801:4040 only covers $|\eta|<0.35$, while the NCC covers $1.0<\eta<1.5$ for double track events and $\eta<2.5$ (Fig. 3.4) for single track events in *Au-Au*, although with a p_T dependent efficiency. Again, however the single-track π^0's in *Au-Au* need better simulation (point II.B). In addition, there is no discussion about what is expected for $R_{AA}(\pi^0)$ vs. η or what additional physics interpretation it will add.

In conclusion, the primary contribution of the NCC to the $R_{AA}(\pi^0)$ measurement is additional η coverage. What was missing was the physics-case that required the additional η coverage and whether or not $\pi^{\pm}$ data could measure this physics case equally well.

$R_{AA}(\chi_c)$

$R_{AA}(\chi_c)$ is also an important measurement for the QGP, giving clues to the pattern of Charmonium suppression and color screening.

E. This measurement depends only on single photon identification, using events already filtered by having an identified J/ψ and then has a mass cut which can be applied to the χ_C, making this a cleaner measurement. Fig. 3.15 shows nice mass peaks in *p-p*, and *d-Au* events. These peaks are not as clear in *Au-Au* events, but this apparently is an effect of Monte Carlo statistics. Because of the peak, systematic effects should be (relatively) easily controlled.

F. The measurement has a reasonable reach in η for the χ_c, even though the photon η may be restricted, since the photon is recoiling against a J/ψ.

G. The key to achieving this measurement will with the proposed NCC lies in statistics, and here the picture is not clearly presented. A detailed estimate of the expected number of reconstructed χ_c's should have been presented. An estimate can be made based on the PHENIX J/ψ yields in PRL 98, 232301 (2007). This estimate shows that for large $N_{participant}$ and low p_T there are sufficient χ_c's, but moving to less central bins or higher p_T these yields rapidly decline. Because of this, determining $R_{AA}(\chi_c)$ as a function of $N_{participant}$ and p_T becomes marginal. A p_T-integrated (equivalent to low p_T) may be possible, with a limited number of centrality bins.

In conclusion, the NCC may be able to make a p_T-integrated measurement of $R_{AA}(\chi_c)$. Studying color screening effects through $R_{AA}(\chi_c)$ is very interesting, but it appears that it will be statistically challenging with the proposed NCC, especially if the p_T dependence is needed.

Additional Physics

The NCC will clearly have a role in γ and jet identification. This role was discussed in Sec. 3.3.4 and 3.3.5. Through this, the NCC could have an impact on other physics programs of PHENIX, but these were not discussed (except for $\Delta G(x)$ in polarized *p-p*). It is clear that particle-jet and γ-jet correlations are useful in leading order to resolve the kinematics of the interacting partons. Again, this will be especially useful for $\Delta G(x)$.

Finally, the measurement of $\Delta G(x)$ through direct photon measurements in polarized *p-p* is discussed. Again, this is a very important measurement that can only be done at RHIC at the current time. The response only contained limited information on this analysis.

H. The statistical significance appears to be enough to distinguish between two vastly different models of $\Delta G(x)$, namely GS(a) and GS(c), one of which contains a zero-crossing. The anticipated precision will do little to distinguish anything but this gross feature, however and cannot distinguish between, for example GS(a) and GS(b).
I. Point H above is based on Fig. 3.14(left). There is a major caveat to that figure that the dilution do to background is not included in the uncertainties. This could completely invalidate even the ability to distinguish between GS(a) and GS(c). It must be quantified.
J. Identification of direct photons depends on statistically subtracting photons from other sources, making this measurement more difficult, and the background more important.
K. The NCC may allow a significant increase in η coverage for this measurement. The additional coverage is needed to determine the presence of a node in distribution.
L. In the end, the *x*-dependence is desired. To obtain meaningful data for this, the p_T spectrum is marginal and γ-jet correlations are needed. This was not discussed.

In conclusion, $\Delta G(x)$ is a very important measurement, but the response did little to show that the NCC would be able to contribute to a significant measurement here. This is not to say that it cannot do this, only that it was not clearly shown. This conclusion is primarily based on point I above.

Conclusions

PHENIX responded to our recommendations by first attempting to show in more detail that the NCC will work and what the efficiency will be; then by showing the physics case for two measurements.

Their response showed that NCC will work and is reasonable efficient (within certain kinematic ranges for Au-Au). The one caveat is that for Au-Au events, the reconstruction which was done depended on knowledge of the underlying event—this was due to a limitation in computing time. It should be demonstrated that, at least in a limited kinematic range, this reconstruction gives the same efficiency as a real reconstruction without knowledge of the underlying event.

The NCC contributes to an $R_{AA}(\pi^0)$ measurement over a larger range in η. The response lacked the physical interpretation for what the additional η coverage would provide. It also lacked a comparison of what could be learned from $R_{AA}(\pi^{\pm})$ that could be available without the NCC upgrade.

The study of color screening through the measurement of $R_{AA}(\chi_c)$ is a very interesting. The primary question here is one of statistical significance. This measurement cannot be done without the NCC, however, even with the NCC, it appears to suffer from lack of statistical significance. Information from the collaboration and the committee's calculations differ on this. It is the critical point in determining if the measurement is exciting or will not work.

Finally, PHENIX showed some information on the NCC and $\Delta G(x)$. This is a very interesting and crucial measurement, but the response did little to show what was really achievable.

The PHENIX NCC may enable some interesting physics, but there are significant concerns if it will be able to perform these measurements with the statistical significance that is needed. In addition, for some of the physics topics, it was not clear what additional information was provided with the additional coverage. In summary, the response left some significant unanswered questions.

<u>Reviewer</u>:

PHENIX was asked to show that the detector could work with non projective geometry and to illustrate its potential with two physics cases. For the physics cases I will concentrate on the R_{AA} measurements of π_0 and χ_C PHENIX also presented studies on photon-jet correlations and polarization measurements but the first seems to have very limited statistics and the polarization measurements limited leverage on disentangling competing physics mechanisms.

Non Projective Geometry:

The NCC has very little space to work in, which has driven PHENIX to a tungsten/silicon design. The granularity of the detector is well matched to the Molaire radius. The length of the collision diamond is not negligible compared to the distance from Z=0 to the start of the NCC and I was concerned that all of PHENIX's events were at Z=0. However, to first order the variation of the collision vertex is cancelled out by the shift in the $dN/d\eta$ distribution so I do not think that this is a grave problem with the simulation.

In their response PHENIX has delimited the limits of design in multiplicity, eta, and pT. As the multiplicity goes up the useable eta range shrinks and it becomes harder to find small energies in the calorimeter. This is particularly limiting for the χ_C where a soft photon has to be found in coincidence with a J/psi in the muon spectrometers.

PHENIX has done a detailed simulation of the detector with a proper embedding of the energy responses of photons and underlying events. However because of limited computing time they have had to use some information from the Monte Carlo in their reconstruction. This "search and rescue" method seems reasonable but could be improved upon.

Overall I am reasonably confident that the non-projective geometry can be made to work with when hard cuts are made on multiplicity and pseudo-rapidity.

π_0

The rapidity coverage, up to y<2.5, is very welcome. However similar measurements have already been made with charged pions. It seems to me that by the time the NCC is built the pt coverage at central and forward rapidity will be comparable. The response did not say how these new data might disentangle possible effects from saturation effects and jet quenching.

χ_C

The χ_C is an important part of the quarkonia puzzle. They plan to measure a soft photon recoiling off a J/psi that is measured in the muon spectrometers. They then construct an invariant mass distribution which has a peak at the χ_C mass. In order to find the photon in a large background of pions they have to limit the pseudo rapidity of the χ_C to y=1 to 1.5. For this study they assumed a large improvement in their yield of J/psi s due increased RHIC luminosity and better reconstruction because of the forward vertex detector.

The NCC will not allow a study of rapidity dependence which is unfortunate since one of the most interesting results of PHENIX is that J/psi suppression is stronger at forward rapidity. However it is still useful. I believe that PHENIX can do this measurement for some class of AuAu events. Both the statistics and background make the measurement for 10% central events challenging. I expect that ALICE will also reconstruct the χ_C on the same time scale as the NCC. This is actually an advantage to PHENIX since their data will be part of an excitation function.

In my mind the case for building the NCC rests almost entirely on the χ_C. If things go well with the FVTX, and RHIC II the detector should be able to measure the χ_C produced

between y=1 and y=1.5 from Au+Au collisions. It is not clear whether this will be possible for the most central collisions.

Reviewer:

I was originally asked to review the PHENIX NCC upgrade proposal in July 2007. From that review, our committee made two recommendations to both the DOE and the proponents. They were.

- Demonstrate what the NCC upgrade adds to the physics of PHENIX, in detail, for two or more topics and
- Show via simulation that the proposed geometry of the NCC will not hinder its abilities.

I felt that the response document was incomplete and difficult to fully understand. However, based on discussions with the committee a consistent picture did emerge.

The decision to upgrade the detector is not clear cut. The improvements offered by this new piece of apparatus are marginal at best. For me, given the limitations with evaluating the pi-zero reconstruction efficiency and in estimating the expected data volume for the χ_C as a function of centrality, transverse momentum and rapidity, the investment both in time and effort to build this piece of apparatus is marginal at best.

The detailed simulations provided indicate that the performance of the NCC is severely compromised Au-Au collisions. While the lower rapidity range of 1 to 1.5 seems to work, the upper end of the rapidity range from 1.5 and above does not.

$R_{AA}(\pi^0)$

Based on the documentation we were given, the NCC will only be able to reconstruct pizero's in a limited kinematics region of phase space; namely in 1<rapidity<1.5 and Pt< 5 for the most challenging central gold on gold collisions. As one moves outside of this phase space, reconstruction get much more challenging. Thus given the limited rapidity extension compared to the existing measurements, this aspect of the NCC physics program offers only incremental value.

$R_{AA}(\chi_c)$

This is a very challenging measurement and its success will depend on whether PHENIX can gather sufficient number of events to make a statistically significant measurement. The committee struggled with this issue. Based on the plots in 3.15, it looked

challenging at best. [Two Reviewers] did quick estimates of what could be expected. Both concluded that it was unlikely that PHENIX could gather sufficient numbers of events over a sufficiently large centrality and pt range in order to achieve the desired precision. Thus while the NCC will allow them to make this measurement, it is doubtful that it will be successful.

Final Comment

The PHENIX collaboration did a lot of work to try to address the concerns of the committee based upon last years review. The NCC may allow the collaboration to access some physics that is currently unavailable to them. However, there are significant concerns among the committee as to how successful the physics measurements presented to us might be given the constraints in running time and ultimately limited statistics. Thus, the proposal as presented offers marginal value to the experiment.

<u>Reviewer</u>:

The NCC group apparently chose to concentrate on R_{AA} for π^0 and χ_c in heavy ion experiments as their "physics" signals. They did not quantify what we would learn from these measurements, so it is difficult to say whether they can gain sufficient statistics or cleanliness of signal to satisfy their desires.

The proposal does not tell us what their measurement adds to the already well documented π^0 R_{AA} data that has been published. Both Star and Phenix have reported to Pt=20 GeV for π^0 and will go higher. The NCC increases the η reach for Phenix, but is silent on why the larger η region is compelling.

The proposal does not tell us how well we have to measure χ_c R_{AA} to quantify any physics conclusion. How well do we have to measure the yield of χ_c, and what else do we have to measure to interpret the result? Over what Pt range? What role do the excited states play?

The π^0 R_{AA} measurement requires identifying $\pi 0$ from $\gamma\gamma$ decays in AuAu collisions. Figure 3-2 shows the not-so-good efficiency for reconstruction of 2-"track" and single-"track" π^0 for min bias pp collisions (Fig. 3.2); Figure 3-4 indicates that they will have pretty low efficiency for reconstructing π^0 in AuAu. From Fig. 3.6 we are to believe that error bars on π^0 R_{AA} will be "small" up to about 10 GeV - what do we learn from this?

The proposal does not tell me how good their "prompt photon" measurement will be, nor what we will learn from it. How good is their hadronic suppression? It is not clear from the caption of Fig. 2-11 or from the text what conditions this represents. What is their prompt-photon contamination from unreconstructed π^0 and other decays? What

processes contribute to their "direct photon" signal in 3.1? There must be a mixture from QCD Compton and fragmentation – what do we learn from the mixture?

They say (p.3-28) that the direct photon signal below 10 GeV is "probably not measurable" in AuAu. Above 10 GeV they can't identify π^0 decays very well, and their efficiency for finding π^0 is down around 10-15% in AuAu – how can they expect to identify photons? Figure 2-12 does not make a good case for their ability to identify direct photons, especially in AuAu collisions.
What would Fig.15 look like for AuAu rather than pp? I conclude that their results will be difficult to interpret at best.

Figure 3-14 tells us that they cannot make a significant measurement of χ_c in the central AuAu environment, yet this is one of their benchmark goals. How do branching ratios and excited states fold into their conclusions? If you start with Hijing AuAu collisions, and put χ_c particles into them, with realistic noise, what fraction of them are identified?

What is their false ID rate, for events that do not have a χ_c embedded (i.e., J/ψ in coincidence with forward γ)? Given the limited η coverage for a marginal signal they have not convinced me that they can make a significant measurement of χ_c, let alone make a significant interpretation of the physics underlying the production process.

I do not believe that this proposal with the response to the questions justifies construction of the calorimeter.

<u>Reviewer</u>:

General comments:

The physics issues addressed by the heavy ion component of the proposal include the study of energy loss mechanisms and attenuation of charm meson yields with a focus on possible effects of color screening. The proposed goals are significant and would have important impact on our understanding of the collision environment produced in the RHIC experiments. The experimental study requires high quality data for pp, d-Au, and AA from peripheral to most-central collisions. The latter presents the most challenging conditions, therefore I have considered the NCC's physics capabilities only with respect to most-central Au-Au at the top RHIC energy.

The key issue which remained to be resolved from the original proposal and DOE review in summer of 2007 was for the proponents to demonstrate via detailed simulations and reconstruction analysis that the NCC design, particularly its non-projective geometry, would enable the physics goals to be achieved. The NCC proponents have done full Geant simulations of EM and hadronic showers using realistic detector geometries; the embedding was done realistically; the detector response was realistic as far as possible in

lieu of further test beam data; the event reconstruction was realistic. Problems appear to remain with evaluating the π^0 reconstruction efficiencies and in estimating the expected data volume for the χ_c as a function of centrality, transverse momentum and rapidity.

The detailed simulations show that the performance of the NCC is severely compromised for more central Au-Au collisions at larger rapidity, leaving only the lowest half unit of rapidity coverage (from y = 1 to 1.5) available for most central Au-Au collisions. In the following I summarize the simulation/analysis results and the physics capabilities for the two analysis topics selected by the proponents in the response document. I also comment on the γ-jet analysis.

π^0 R_{AA}:

The response document indicates that the NCC will only be able to successfully reconstruct π^0s for $p_t < 6$ GeV/*c* and $\eta = 1.0$ to 1.5 for most-central Au-Au using a two-track EM shower and invariant mass reconstruction method. Although the photon backgrounds in Fig.2.12 appear formidable the response document demonstrates that by applying a number of cuts reasonable invariant mass plots with manageable backgrounds can be achieved (see Fig.2.13).

However, the π^0 capabilities for $p_t > 6$ GeV/*c* are problematic based on the efficiencies in Fig.3.4 (zero for lower p_t and η), the discussion on pg. 3-25 of the unusual method required for embedding and efficiency studies, and the answers to questions 6 & 7 (listed in Attachment B). The single EM track π^0 reconstruction does not appear to be under control.

Previous PHENIX and STAR publications report π^0 R_{AA} to 20 GeV/*c* at mid-rapidity. STAR data indicate that R_{AA} for π^0 approximately equals that for charged pions where the latter was measured in this region out to $\eta = 1$. It is not clear from the proposal what additional physics can be gained by extending R_{AA} π^0 measurements 1/2 unit in η.

Due to the limited rapidity extension compared to existing STAR and PHENIX measurements, I judge this aspect of the NCC physics program to be marginal.

γ-jet:

The physics of direct photon - charged hadron correlations was not emphasized in the response document but was a major component of the original proposal. Prompt photons cannot be distinguished from other photons and must therefore be estimated statistically via differences between the total observed photons and that expected from π^0 decays.

Most detected photons are from π^0s; direct photons are relatively suppressed by the EM coupling strength. Direct γ-jet correlations must therefore be constructed as the difference (or double ratio) between the total photon-hadron correlation and the π^0-hadron correlation. Both correlations are likely to be dominated by the jet-ridge structure which has been reported by STAR and PHENIX for higher p_t trigger and associated charged particles. A successful differential measurement of this sort is very challenging given the uncertainties in both the photon and π^0 data. Neither the proposal nor the response document provided simulations to support the claims in the proposal.

The NCC would increase the γ-jet acceptance. However, it would have helped the proponents' case if direct photon - charged hadron correlation results based on data from the central tracking and calorimeter arms of PHENIX were already in hand. I also judge this part of the NCC program to be marginal since it requires a delicate differential measurement which I expect exceeds the capabilities of the proposed detector and reconstruction methods within a RHIC II run-year.

χ_c:

I stipulate that the proposed measurement of R_{AA} for the χ_c together with previous measurements of R_{AA} for J/ψ and ψ' makes sense as a way to go about disentangling multiple sources of attenuation of charmed meson yields with increasing centrality in Au-Au collisions. Reconstruction of χ_c for p_t = 0.5 - 6 GeV/*c*, $\eta \sim 1$ - 2 for Au-Au collisions from peripheral to most-central could enable significant advances. However, the presented simulation and reconstruction analysis of the χ_c leave much to be desired. The simulated invariant mass peaks for Au-Au are unconvincing with respect to signal and backgrounds. Credible estimates of the statistics achievable in one run-year assuming RHIC II integrated luminosity were not provided. Vague statements about scaling the simulations by factors of 1000 were offered in place of reasonable rate and data volume estimates.

[Reviewers estimated]… the expected number of reconstructed χ_cs ($\chi_{c1}(1^{++},3511)$) within 10% centrality bins, 1 GeV/*c* wide p_t bins, y = 1 to 2 assuming the stated RHIC II run-year integrated luminosity. [They] used published branching ratios and estimated reconstruction efficiencies from PHENIX publications and the response document. From these estimates it appears reasonable that they can obtain a good χ_{c1} signal and yields for more-central Au-Au collisions at lower p_t. However, it is doubtful that sufficient quality data can be obtained over the required p_t and centrality ranges.

The physics program requires that the χ_c yields be measured well enough to allow differential comparisons with measured R_{AA} for J/ψ and ψ' over a wide range of centrality and p_t… estimates indicate that this physics program is unlikely to be successful. They have not made the case that they can achieve the necessary

measurement accuracy over a sufficient p_t and centrality range in a reasonable amount of run-time.

Conclusions:

Unfortunately the simulations and analysis presented in the response document, while representing a lot of work and being well done overall, indicate …that the NCC's measurement capabilities are seriously compromised for more central Au-Au collisions. As a result the cost/physics benefit of the NCC is severely degraded. Therefore the project as presented in these documents should not go forward.

Reviewer:

We are now one year after the initial review, and it seems that we are still trying to get information from the proponents to assess the science potential. I am impressed by the work done by [several reviewers] to analyze the details of likely results of the proposed PHENIX NCC upgrade. This is really work which should have been done by the proponents. The fact that the work by the proponents has been so slow does not bode well for the ability of the participating institutions to support the future RHIC program with this upgrade.

The impression I am getting is that the deeper the committee members dig, the "shallower" is the likely physics outcome.

I therefore would question the wisdom of approving the PHENIX NCC upgrade.