# Answering the Baseline Scope Charge

### The sPHENIX Collaboration
### May 31, 2016

# Executive Summary

In this document the sPHENIX collaboration answers a charge (see Appendix A.2.3) from BNL ALD Berndt Mueller to detail a configuration for the sPHENIX detector that conforms to specific funding guidance and to describe the program of compelling physics accessible to that particular configuration.

sPHENIX is a next-generation RHIC experiment providing world-class measurement capabilities of key scale-sensitive observables to understand the dynamics of the strongly coupled quark gluon plasma. It uniquely provides measurements complementary to those being obtained at the LHC by working at a collision energy near $T_c$, where the medium coupling is believed to be strongest and the corresponding dynamical effects the most pronounced.

The physics aims of sPHENIX have been endorsed broadly and repeatedly. The top recommendation of the September 2014 Phases of QCD Matter Town Meeting at Temple University reads in part, "implementation of new capabilities of the RHIC facility (a state-of-the-art jet detector such as sPHENIX and luminosity upgrades for running at low energies) [is] needed to complete its scientific mission,". The top recommendation of "The Hot QCD White Paper: Exploring the Phases of QCD at RHIC and the LHC", includes the statement, "implementation of new capabilities of the RHIC facility needed to complete its scientific mission: a state-of-the-art jet detector such as sPHENIX and luminosity upgrades for running at low energies." Both of these documents provided carefully considered community input for the development of the most recent NSAC Long Range Plan, "The 2015 Long Range Plan for Nuclear Science," which was officially accepted by the DOE Office of Nuclear Phyics in October 2015, and reads in part:

> There are two central goals of measurements planned at RHIC, as it completes its scientific mission, and at the LHC: (1) Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of the two facilities is essential to this goal, as is a state-of-the-art jet detector at RHIC, called sPHENIX. (2) Map the phase diagram of QCD with experiments planned at RHIC.

In addition to these community-wide endorsements of the aims of sPHENIX, the detailed science case presented in the sPHENIX proposal had a successful science review in April 2015 conducted by the DOE Office of Nuclear Physics.

# sPHENIX configuration options

The discussion of cost changes is relative to the detector described in the sPHENIX pCDR. However, we also define a reference sPHENIX configuration to provide a baseline for discussion of the physics performance of various configuration alternatives.

## DAQ/Trigger

**Cost delta: -$1.5M**

The costs associated with the DAQ and Trigger are an area where significant reductions are very achievable. Although we think the $0.5M trigger detector is a suitable target for a non-DOE, possibly non-US, contribution, for the purposes of answering this charge, we do not assume that that will happen. Each of the RHIC experiments has built trigger detectors that would suit the needs of sPHENIX, and some of these detectors, such as the trigger detector used by PHOBOS, are currently unused and available. We would repurposed one of these detectors for use in sPHENIX and reduce the M&S costs accordingly.

We would reuse the infrastructure currently in place in the PHENIX counting house, consisting of data collection modules (DCMIIs), subevent buffers (SEBs), assembly and trigger processors (ATPs), a high throughput networking switch and several racks of computers. Some amount of new equipment would be needed, such as new level-1 and global trigger boards. There is some risk associated with this approach, as it means, absent funds to renew th computing infrastructure, starting a new experiment with computing that will be by then several years old.

## TPC

**Cost delta: -$0.5M**

We have considered the effect of instrumenting only alternate rows of the TPC readout plane, reducing the cost of the electronics by approximately a factor of two.

## Considerations

A number of people in the collaboration have expressed a very strong interest in maintaining the potential for $\pi$, $K$, $p$ particle identification through a $dE/dx$ measurement in the TPC. While we may already be driven to set the voltages on the TPC GEMs in a way that minimizes ion backflow at the expense of worsened $dE/dx$ resolution, the additional worsening that comes from not reading out half the pad rows will be taken as a very negative statement about their physics interests.

## EMCal Ganged Towers

**Cost delta: -$1.7M**

We have studied the effect of ganging together the electronic outputs of groupings of four nominally-sized EMCal towers. This has several effects of this modification are a reduction in the $e/\pi$ separation performance in Au+Au collisions

## EMCal Coarsened Segmentation

**Cost delta:** $-\$1.8M$

We have investigated reducing the number EMCal towers from $256 \times 96 = 24576$ ($\Delta\eta \times \Delta\phi = 0.024 \times 0.024$) to $192 \times 80 = 15360$ ($\Delta\eta \times \Delta\phi = 0.033 \times 0.028$) a reduction of tower numbers by 37.5%.

## Thinned Outer HCal

**Cost delta: -$0.4M**

We investigated reducing the thickness of the outer HCal (nominal depth of 82.5 cm) by 20 cm, or approxiately one nuclear interaction length. Several possible effects were investigated through full GEANT4 simulations of the calorimeter response. It should be noted that the calorimeter simulations have recently been compared to data from the FNAL test beam and ahve been found to reproduce the measured response quite well (put a number in here). We looked at the effect of thinning on the jet energy response, high-$z$ fragmentation functions, and triggering in $pp$ and $pAu$.

From a physics perspective, the effect of thinning the outer HCal by this amount seems to be moderate, and considered by itself, a thinner outer HCal would still enable the core elements of the sphenix physics program to be carried out.

From the perspective of the project, the effect of this modification would be extremely significant. The OHCal is the structural backbone of the sPHENIX structure. Reducing the radial thickness will significantly reduce the ability of the OHCal to support the detector. The finite element analysis would need to be redone. The tilt angle reanalyzed and likely changed. The prototyping and test beam would have to be redone. It would make no sense to build the full scale mechanical prototype

now. The IHCal will still need some redesign due to the changes in the EMCal. Well want the $\phi$ segmentation to match between the two for mechanical reasons.

Sets the OHCal engineering back as much as twelve months and requires R&D be redone.

## Considerations

In the nominal design, the $5.5\lambda$ total depth of the calorimeter stack (at $\eta = 0$) is distributed as $1\lambda$ (EMCal), $1\lambda$ (inner HCal), and $3.5\lambda$. If the outer HCal is reduced to $2.5\lambda$, one has to consider the effects if one or more of the other calorimeters in the stack is also modified. If the inner HCal is not installed, the depth of the calorimeter stack is reduced by an additional $1\lambda$ over the whole acceptance, falling to $2.5\lambda$ at midrapidity.

If the EMCal acceptance is cut to $|\eta| < 0.7$, the thickness of the calorimeter stack in the range $0.7 < \eta < 1.1$ becomes thinner by $1\lambda$, but the effect in that range (aside from the lack of EMCal coverage) is moderated by the increasing thickness of the calorimeters along lines of constant $\eta$ due to their rectangular profile.

## Shortened HCal

**Cost delta: –\$0.7M**

We investigated shortening the outer HCal (nominal length 631 cm) to 541 cm. For an HCal of the nominal length, the outer corner of the HCal lies along $\eta = 1.0$ while then inner corner of the HCal is at $\eta = 1.3$. For a reduced length calorimeter, the outer corner of the HCal lies along $\eta = 0.89$ while then inner corner of the HCal is at $\eta = 1.19$. This is a minimum length for the outer HCal, as supporting the weight of the calorimeter requires it to extend beyond the end of the solenoid cryostat.

The effect on sphenix physics stems directly from the reduced acceptance. The smaller acceptance catches fewer jets and high $p_T$ hadrons and dijets, and it also reduces the acceptance for systematic studies of the response. The former issues can be determined in a straightforward manner; the effect of the latter issue is guided by relevant experience.

From the perspective of the project, save on not only mechanics but also scintillator tiles and electronics channels. The shorter OHCal will be easier to make, handle, transport and assemble. It will be more rigid. The detector cross section will be unchanged so engineering revisions will be minimal (the project estimates that it would take four weeks). The R&D done to this point will be valid. We can advance to the next step in prototype work. Restoring the acceptance with endcap calorimeters is conceivable, but would require immediate consideration in the engineering of the main part of the detector. In addition, the procurement process for the endcap steel would need to begin very soon, as it would have the similar long lead-time issues as the steel for the current design.

Considerations

Shortening the outer HCal steel also implies moving the flux doors at each end of the experiment inward by the same 45 cm. This is needed so that the strong magnetic field is well-contained and kept away from the electonics racks on the carriage, allowing personnel to get to those racks for routine or exceptional maintenance during the run without requiring the magnet to be deenergized. Moving the flux doors inward by this amount significantly reduces the space potentially available for instrumentation beween the end of the TPC and the flux door, as would be required for forward spin and cold QCD measurements. This would be seen particularly negatively by the members of the collaboration interesting in spin physics and by those intereseted in the use of sPHENIX as a day-1 EIC detector.

## MAPS

# Appendix A

# Physics performance studies

Below we describe the simulation studies performed to evaluate the impact of the re-scoping options we identified on the three science drivers. We first compare each change individually to the performance of the reference configuration, and then study a select set of changes in combination to evaluate their combined effect on the physics performance. For each option we describe the simulations employed, ranging from generator level evaluations of count rates to single particle and single jet GEANT simulations + reconstruction to full HIJING central Au+Au GEANT simulations and reconstruction. All studies were performed for 200 GeV Au+Au collisions.

## A.1   Hadronic calorimeter changes

### A.1.1   Outer HCAL thinning

The main impact on the science program from thinning the outer HCAL is expected in areas:

- Reduced jet energy containment leading the larger systematic uncertainties in the jet energy scale and larger fluctuations in the jet-by-jet energy measurement.

- Increased punch-through of high momentum particles leading to a fragmentation function bias

The impact was studied with full GEANT simulations and jet reconstruction using the anti-$k_T$ algorithm for single jets for the reference configuration, the 20cm thinner oHCAL and the minimal outer HCAL.

### A.1.2   Outer HCAL shortening

For the shortened outer HCAL (reducing the pseudorapidity coverage from $\|\eta\| <$ FIXME to $\|\eta\| <$ FIXME), all measured at the outer corner of the calorimeter) the expected impact is in the statistics of jet related probes. The 20% reduction in coverage will predominantly affect lower $p_T$ jets ($p_T <$

FIXME), as jets at the highest $p_T$ have a narrow rapidity distribution that falls within the remaining acceptance. From generator level studies, we expect the following loss of statistics: FIXME

Some of the physics impact can be recovered using tracker + EMCal reconstruction of jets, although reduced control over the jet energy scale and increased jet-by-jet fluctuations will limit the precision that can be achieved with such studies.

**Figure A.1:** EMCal coverage VS tower counts. With half tower produced to cover from central pseudo-rapidity, 2D SPACAL cover to an eta of 0.55 (quite linear in eta coverage) and 1D SPACAL cover to eta of 0.63 (forward tower has less eta-bite) at its outer radius and 0.70 at its inner radius (clip into forward acceptance). Nevertheless, EM shower coverage to —eta—¡=0.6 is a good approximation.

**Figure A.2:** For 2x2-ganging EMCal + inner HCal, inclusive charged hadron rejection is plotted as function of electron ID efficiency, for negatively charged tracks of three choices of momentum and for middle and edge rapidity in 10% most central Au+Au events.

### A.1.3 Removal of the inner HCAL

The impact on jet energy scale and fluctuations for this option is expected to be larger than for the outer HCAL thinning, with major impact on engineering of the inner detector mechanical design leading to expectations of minimal overall savings. We therefore did not perform detailed studies of this option.

## A.2 EMCal

### A.2.1 2×2 ganging of EMCal channels

The reduced EMCal segmentation from 2x2 ganging of readout channels is expected to affect three physics areas: jet finding and jet energy reconstruction, electron/hadron separation for the Υ to $e^+e^-$ channel and photon identification. We performed full GEANT and reconstruction studies of the effect on the single jet response and full GEANT simulations for Au+Au HIJING events for electron identification. Studies of the effect on photon identification are ongoing.

### A.2.2 Changing EMCal segmentation

The reduced EMCal segmentation from increasing the tower dimensions from $d\eta \times d\phi = 0.024 \times 0.024$ to FIXME × FIXME was not evaluated with full GEANT simulations, as time did not permit implementing the corresponding detector geometry. However, as the change in tower area is only FIXME % compared to a factor of 4 for the 2x2 ganging, the expect impact can be well estimated based on the 2x2 ganging full simulations. For the jet response, the 2x2 ganging did not show any noticable effect, implying that the FIXME % increased tower size will also have no effect on jets. For e/h separation, the effect of the 2x2 ganging of about a factor of two suggests scaling with

the $\sqrt{\text{area}}$, i.e., the fluctuations in the background energy. This implies a FIXME % change in e/p separation in central Au+Au collisions for the FIXME % increase in tower size, which is well within the projected safety margin for the measurement.

### A.2.3   Reduced EMCal pseudorapidity coverage

Reducing the EMCal coverage will directly affect the expected statistics for Y to $e^+e^-$ and photon-based measurements. The corresponding loss in statistics is summarized in the table below, based on generator level studies. For jet measurements,

To keep the discussion of options in the preceedings pages as brief as possible, we collect here the performance plots detailing the effects of various changes to a reference design.

**Figure A.3:** EMCal coverage VS tower counts. With half tower produced to cover from central pseudo-rapidity, 2D SPACAL cover to an eta of 0.55 (quite linear in eta coverage) and 1D SPACAL cover to eta of 0.63 (forward tower has less eta-bite) at its outer radius and 0.70 at its inner radius (clip into forward acceptance). Nevertheless, EM shower coverage to —eta—¡=0.6 is a good approximation.

**Figure A.4:** For 2x2-ganging EMCal + inner HCal, inclusive charged hadron rejection is plotted as function of electron ID efficiency, for negatively charged tracks of three choices of momentum and for middle and edge rapidity in 10% most central Au+Au events.

**Figure A.5:** Ratios of inclusive charged hadron rejection of $2 \times 2$ ganged EMCal to the reference design, as functions of electron ID efficiency. This is evaluated for negatively charged tracks of three choices of momentum and for middle and edge rapidity in 10central Au+Au events.

# Charge
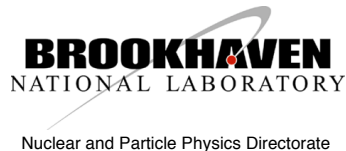
**BROOKHAVEN**
NATIONAL LABORATORY

Nuclear and Particle Physics Directorate

**Memorandum**

*From: Berndt Mueller*
*To:     David Morrison, Gunther Roland*
*Cc:     Ed O'Brien, James Dunlop*
*Date:  March 30, 2016*


Dear Dave and Gunther:

In discussions since the November 2015 Cost and Schedule Review for sPHENIX, it has become clear that further work is needed to develop a plan for the construction of the sPHENIX detector within the constraints of possible DOE funding redirected from RHIC Operations.

I have therefore requested that sPHENIX Project Management, in close collaboration with the sPHENIX Collaboration, develops a credible plan encompassing an option of baseline design scope, cost, and schedule that will allow the detector to be completed on schedule for data taking in the FY2022 RHIC run within the presently foreseen DOE funding profile, and that the sPHENIX Project Management present this plan to BNL management no later than May 31, 2016. The plan should maintain the 40% contingency requested by the cost and schedule review. This plan should not assume the availability of additional funding from non-DOE sources, but may describe which elements would be added to the baseline scope of sPHENIX if additional funding became available.

I am aware that design scope choices will likely require making priority choices with respect to the scientific scope of the sPHENIX physics program. The sPHENIX collaboration and project management team should work closely in establishing these priority choices as needed.  I trust that you understand that the sole purpose of my request is to ensure the success of sPHENIX and its future science program. I will be happy to answer any questions you may have at our bi-weekly sPHENIX spokespersons meetings.