Recommendations of the Nuclear and Particle Physics Program Advisory Committee, Brookhaven National Laboratory
June 16 – 17, 2016

1. Introduction

The Program Advisory Committee (PAC) convened on June 16, 2016, to hear presentations from STAR, PHENIX and RHICf. STAR presented an overview of their data-taking, analysis progress and key publications from Runs 14 and 15. PHENIX presented an overview of their data-taking, analysis progress and key publications through run 16 as well as their data release plan. The STAR Beam Use Request for Runs 17 and 18 was presented. The PAC also heard presentations summarizing the Report from the Chiral Magnetic Effect Task Force and the Cold QCD Plan for 2017 – 2023. The following day, June 17, updates were presented on sPHENIX, and the STAR BES-II and iTPC. In addition, a summary of Run 16 was requested by the PAC and presented by C-AD.

The PAC thanks the collaborations and the C-AD for their input and congratulates them for their effective operation of the detectors and collider for physics. Run 16 has been successful even with the 20-day downtime due to the RHIC magnet failure, with PHENIX in its final RHIC run exceeding its proposed integral luminosity goals for $\sqrt{s}$ = 200 GeV Au+Au and for $\sqrt{s}$ = 19, 62 and 200 GeV d+Au. With the run still being completed at the time of the PAC Meeting, only an integral luminosity projection for the final energy $\sqrt{s}$ = 39 GeV (80% of the proposed goal by the end of the run) of the d+Au beam energy scan could be reported. In all the PAC deems this a very successful final PHENIX run and anticipates it will produce considerable physics on heavy flavors from the top energy Au+Au run, as well as address questions on the initial state and anisotropic flow harmonics from the d+Au beam energy scan.

STAR highlighted results from Runs 14 and 15, including its continuing implementation of new detector systems to increase its physics scope. The Muon Telescope Detector was installed permanently before Run 13 and has begun to provide new quarkonium data at RHIC. The Heavy Flavor Tracker, which was installed and took data in Runs 14 and 15, will produce significantly new results on heavy flavors. The 14.5 GeV Au+Au data represent the end of the first phase of the RHIC Beam Energy Scan, and have produced exciting results on the energy dependence of flow and fluctuation observables and the di-electron mass spectra. The Forward Meson Spectrometer (with pre-shower detector) and the Roman Pots expand the forward physics capabilities in STAR. The PAC commends STAR for its continual detector upgrade program and anticipates considerable additional physics from STAR from these runs.

The STAR and PHENIX measurements of a large transverse single-spin asymmetry A_N in p+p and p+A provide new information and a challenge for models on the gluon nuclear wave function.

1.1 Beyond the Beam Use Requests

STAR will be the only detector taking data at RHIC over the next four years. BNL and STAR should investigate ways to optimize the effectiveness of their ongoing physics and analysis programs. The PAC urges the STAR collaboration to work with RHIC management and other possible funding sources to secure the support for the iTPC and EPD upgrade projects and to carry out these upgrades as planned to enable a vibrant BES-II physics program.

The STAR collaboration has expressed concern about continuation of their limited computing resources and disk storage, which the PAC considers to be a very serious issue. In order to enable the timely reconstruction and release of STAR data, BNL management is urged to find ways to improve on the current constrained resources and to seriously consider the following recommendations:

- BNL Management should immediately commission a panel of local computing experts to evaluate the STAR needs for computing resources, review the current practices, investigate possible optimization of the use of the local RCF resources, and report within three months.
- BNL Management must look into the potential availability and use of additional computing resources within the laboratory, such as the Institutional Cluster within the BNL Computational Science Initiative, or seek additional computing resources, to enable timely reconstruction of STAR data.

The STAR collaboration is urged to adopt their newly developed pico-DST data format before the end of the calendar year, in order to reduce significantly the footprint of the data sets being produced and enable their timely analysis.

The PAC encourages the management and the collaborations to consider a potential (polarized) p+p and/or p+A program before 2023. In addition to the scientific benefits pointed out in the Cold QCD Report, this would help to keep the Cold QCD community active and engaged at RHIC, which might be important for the activities at BNL aiming at an EIC. It would also be helpful to further prioritize measurements by considering both the scientific impact as well as budget constraints. In this context we encourage the Cold QCD community to further elaborate the physics that can and must be done prior to EIC in order to aid in optimization of the future EIC science program.

The PAC is seriously concerned about the impact of budgetary constraints on the physics program envisaged for sPHENIX. We urge the BNL Management and the sPHENIX collaboration to work together closely to seek other possible funding sources in order to reach an optimal detector configuration that will meet not only the challenges of the detector construction schedule but, more importantly, its intended science program.

2. RHIC Runs 2017 and 2018

2.1 Executive summary

The PAC recommendations for Run 17 *in priority order* (all in STAR):

1. $\sqrt{s}$ = 500 GeV p+p with transverse polarization for 400 pb^{-1} with 55% polarization, which is projected to encompass 13 weeks of running, with the luminosity throughout the fill optimized to yield a roughly constant ZDC event rate of 330 +/- 10 kHz as requested by STAR. Collection of this set of data is essential and, if necessary, should supersede any other running during this period.
2. $\sqrt{s}$ = 500 GeV p+p for RHICf and RHICf with fixed target for a maximum of 1 week, if solutions for the setup, installation and data-taking are agreeable to STAR and RHIC and in the simplest agreeable configuration.
3. $\sqrt{s_{NN}}$ = 62 GeV Au+Au is viewed as low priority

BNL management should consider how best to utilize resources for the 2017 run after the p+p run goals are met.

The PAC sees the $\sqrt{s}$ = 500 GeV p+p with transverse polarization run as an opportunity to make a landmark measurement and recommends this run with the highest priority. The PAC is aware of the large number of additional spin observables that can be addressed in parallel. The experiment should take full advantage of this opportunity to extend these unique spin measurements to the extent possible.

The PAC recommends for Run 18 the following *in priority order* (all in STAR):

1. $\sqrt{s_{NN}}$ = 200 GeV ^{96}Ru+^{96}Ru and ^{96}Zr+^{96}Zr, 1.2 billion minimum bias events in each system. This program represents an opportunity to clarify a central puzzle in the field and thus is of high scientific priority.
2. 2 weeks of $\sqrt{s_{NN}}$ = 27 GeV Au+Au collisions if RHIC operates with 13 weeks of cryogenic running in 2018.

The experimental isobar (Ru+Ru and Zr+Zr) program proposed initially by STAR last year and since bolstered by simulations and the Report of the Chiral Magnetic Effect (CME) Task Force is a compelling program that takes advantage of the flexibility of RHIC and the capabilities of the STAR detector. It should be able to unravel a signal from the CME out of background contributions from flow through measurement of the difference between charged particle correlations across the reaction plane in Ru+Ru and Zr+Zr collisions.

The proposed Lambda and anti-Lambda global polarization measurement is exploratory and may be related to the vorticity of the QCD fluid formed in non-central heavy ion collisions. The PAC considers the 27 GeV Au+Au running higher priority than the 62.4 GeV Au+Au running that was proposed for Run 17. The PAC encourages the STAR collaboration to continue to sharpen the physics case quantitatively for the proposed 27 GeV Au+Au running.

2.2 Recommendations for 2017 (Run 17)

2.2.1 STAR Run with √s = 500 GeV p+p with Transverse Polarization

The PAC sees the proposed run as an opportunity to make a landmark measurement and recommends with the highest priority the run to collect data for 400 pb^{-1} with 55% polarization for √s *= 500 GeV p+p with transverse polarization.*

By measuring single spin asymmetries in different channels and for different kinematics ($W^{+/-}$ and Z, Drell-Yan and prompt photons) the measurement will check the predicted sign change linked to the naïve T-odd nature of the relevant correlator. The PAC congratulates the collaboration for their achievement of making such a comprehensive program possible, in particular with respect to the Drell-Yan channel.

The PAC is aware of the large number of additional spin observables that can be addressed in parallel. The experiment should take full advantage of this opportunity to make measurements to extend unique spin measurements to the extent possible.

2.2.2 RHICf with STAR – Run with √s = 500 GeV p+p with Radial Polarization

Following the recommendation of the previous PAC report, the collaboration signed an MOU with STAR and received endorsement for the two proposed measurements. While the cross section part of the program is straightforward, there are potential issues with the required vertical detector motion and radial polarization for the A_n measurement. If that is not an issue and solution for installation is agreed upon with STAR and BNL, then the requested beam-time should be allocated. *Since resources are limited, the PAC recommends to run the experiment in the simplest possible configuration.*

2.2.3 RHICf with Fixed Target in STAR – Run with √s = 500 GeV p+p with Radial Polarization

The proposed configuration for the RHICf fixed target measurement is relatively new, and has not been fully vetted by the STAR collaboration. There is a concern expressed by some STAR collaborators about possible radiation damage to the STAR Forward Meson Spectrometer. There is also an important issue with the presented fixed-target design that allows the use of three solid targets, a design that is different from the existing STAR fixed target configuration. A safety review of the proposed fixed-target design will be required to make sure that the failure mode of the target will not interfere with nor damage the RHIC program.

Again as resources are limited, if the solutions for the setup, installation and data-taking are agreed upon with STAR and BNL, then the requested beam-time can be allocated. We note the proposed experiment also requests a radial polarization. The two lowest p_T

values of the proposed data points cannot be taken with only a vertical polarization.

2.2.4 **$\sqrt{s_{NN}}$ = 62 GeV Au+Au running in STAR**

STAR proposes 4 weeks of Au+Au running at $\sqrt{s_{NN}}$ = 62 GeV to collect 1 - 1.5 B minimum bias events and perform measurements of jets, non-photonic electrons, and direct (thermal) photons. *The PAC views running Au+Au collisions at $\sqrt{s_{NN}}$ = 62 GeV as low priority.*

The goal is to probe the partonic coupling to the medium at temperatures closer to Tc. While measurements at this energy exist from Run 10, the proposed data set will represent a significant improvement in statistics for the STAR experiment. These improvements must be considered in the context of existing measurements from Run 10 in both STAR and PHENIX. Some of the proposed measurements, non-photonic electron R_{AA} and v_2, have already been published by PHENIX with reasonable statistical uncertainties. Others, like the thermal photons, are limited by systematics, rather than statistics. The R_{AA} measurements of jets and non-photonic electrons are also limited by the fact that p+p measurements are not available from RHIC at the same energy. The PAC finds that the proposed measurements present incremental improvements to the existing published or preliminary results from Run 10 and are not definitive.

BNL management should consider how best to utilize resources for the 2017 run after the p+p run goals are met.

2.3 Recommendations for 2018 (Run 18)

2.3.1 STAR Isobaric Run Program: $\sqrt{s_{NN}}$ = 200 GeV ^{96}Ru+^{96}Ru and ^{96}Zr+^{96}Zr

The PAC endorses a program of isobaric running in which 1.2 billion minimum bias Ru+Ru collisions and 1.2 billion minimum bias Zr+Zr collisions at $\sqrt{s_{NN}}$ = 200 GeV *are recorded.* This program represents an opportunity to clarify a central puzzle in the field and thus is of high scientific priority.

2.3.2 STAR $\sqrt{s_{NN}}$ = 27 GeV/n Au+Au Run

The PAC endorses running 2 weeks of 27 GeV Au+Au collisions if RHIC has 13 weeks of cryogenic running in 2018 and if time remains after the requested number of isobar collisions have been recorded. The proposed Lambda and anti-Lambda global polarization measurement may be related to the vorticity of the QCD fluid formed in non-central heavy ion collisions. The PAC considers the 27 GeV Au+Au running interesting and exploratory. The PAC ranks this as second priority for Run 18, and sees it as being a higher priority than the 62.4 GeV Au+Au running proposed for Run 17. The PAC encourages the STAR collaboration to continue to sharpen the physics case for the exploration of global Lambda polarization and to make the arguments for what can be learned from 2 weeks of running at 27 GeV more quantitative.

2.4 Discussion of Run 17 Priorities

2.4.1 Discussion of $\sqrt{s}$ = 500 GeV p+p with Transverse Polarization ($W^{+/-}$, Z, Drell-Yan, Prompt γ) in STAR

Transverse-momentum dependent parton distributions (TMDs) provide a 3-D image of strongly interacting systems in momentum space. As such, they generalize the ordinary collinear 1-D parton distributions, which merely contain information on the longitudinal momentum of partons. TMDs are complementary to generalized parton distributions (GPDs) which describe the distribution of longitudinal momentum and transverse position of partons. In general, TMDs can be measured in reactions that involve at least two momentum scales. Important examples are semi-inclusive deep-inelastic lepton-nucleon scattering (SIDIS) and the Drell-Yan (DY) process. In the latter case the two scales are given by the (sufficiently) large invariant mass of the dilepton pair as well as its transverse momentum.

QCD factorization in terms of TMDs is more complicated than factorization for collinear leading-twist parton distributions. The most crucial test of TMD factorization would be a check of the predicted sign change of one of the TMDs, the Sivers function, between SIDIS and DY. In general, the Sivers function enters the QCD description of transverse single-spin asymmetries (SSAs). While the Sivers function has been measured in SIDIS, data for DY are not yet available. The importance of the experimental test of the sign change is widely recognized and consequently became the DOE HP13 performance milestone in hadronic physics.

In p+p collisions, the sign change of the Sivers function can also be checked through measuring the transverse SSA A_N for $W^{+/-}$ and Z production. The STAR Collaboration has already published pioneering results for these observables. They are indicative of the expected sign change though not conclusive. Data with higher precision are required.

The PAC considers transversely polarized p+p running at $\sqrt{s}$ = 510 GeV as an opportunity to make a landmark measurement via checking the sign change of the Sivers function. The measurement should be done as precisely as possible. Therefore, the PAC recommends collecting a minimum of 400 pb^{-1} at 55 % polarization. This would give a decisive measurement with regard to the sign change, provided that TMD evolution does not reduce the asymmetry by more than a factor of 5.

The current theoretical predictions for the magnitude of A_N for the production of heavy gauge bosons in p+p collisions have significant uncertainties, mostly due to uncertainties related to the evolution of TMDs which is sensitive to non-perturbative physics. At present, TMD evolution, in particular its numerical impact, is one of the hot topics in hadron physics. The STAR measurement of A_N in Run 17 can provide a benchmark constraint in this area. Moreover, the PAC recognizes the sensitivity of this observable to the antiquark Sivers function which currently is only poorly constrained.

The PAC believes that measuring A_N for DY should also be pursued, even though this channel might be challenging. The PAC congratulates the collaboration for tremendous progress, which seems to make possible the required huge suppression of the background. It is understood that a successful DY measurement would provide crucial additional insights, not the least due to the much lower scales where TMD evolution effects should be strongly suppressed compared to that in W or Z production.

The PAC is also supportive of measuring A_N for prompt photon production, $p+p \rightarrow \gamma+X$. This observable has a large potential as well. First, it allows one to study the relation between the Sivers function and its collinear (twist-3) counterpart, the Qiu-Sterman function. Second, it is sensitive to the same physics that underlies the sign change of the Sivers function, that is the rescattering of the active partons with the proton remnants. Third, it can discriminate between two widely used theoretical approaches to SSAs in single-scale reactions --- the generalized parton model and collinear twist-3 factorization. It therefore can also give critical new insights into the large transverse SSAs observed in, for example, $p+p \rightarrow \pi+X$ which were key observables in transverse spin physics at RHIC in the past. The present theoretical projections for A_N in prompt photon production show that a measurement at the aforementioned integrated luminosity and polarization would be required in order to draw unambiguous conclusions.

The PAC welcomes and encourages the analysis of additional observables as outlined in the RHIC BUR for Run 17. While they should not have the same priority as the transverse SSAs discussed above, they will contain a wealth of new physics information. One example is di-hadron production which, for a transversely polarized proton, gives access to the transversity distribution of the nucleon. In order to use the full potential of this final state it would be interesting to analyze the cross section for unpolarized di–hadron production also, since a sufficiently precise knowledge of unpolarized di-hadron fragmentation functions is needed for a reliable extraction of the transversity distribution. Another example is the study of fragmentation functions, like the Collins function, by measuring hadrons inside jets. This is an emerging research area with considerable recent theoretical and experimental activity that is worthwhile pursuing. In addition, it would be interesting to explore the possibility for measuring other TMDs, for instance through gauge boson production. The PAC trusts that the STAR Collaboration will take full advantage of the data from the high-statistics polarized p+p Run 17.

The PAC also believes that the results that can be obtained from Run 17 will be important for the physics program at a future electron-ion collider (EIC).

2.4.2 Discussion of RHICf with STAR: $\sqrt{s}$ = 500 GeV p+p with Radial Polarization

The proposal on ``Precise measurements of very forward particle production at RHIC'' was presented to the PAC in June 2015. It consists of two measurements: (i) cross section measurement from proton-proton collisions at 510 GeV to improve the existing hadronic interaction models used in simulations of cosmic-ray air showers using one of the LHCf detectors; (ii) single spin asymmetry (A_n) measurement for neutrons at forward angles, which was first discovered in the RHIC IP12 experiment, later by PHENIX with a p_T scaling of A_n suggested by the data. The PAC in June 2015 recommended the approval of the cross section measurement under the condition that the installation of the RHICf would not impact the STAR experiment in any significant way, and conditionally approved the asymmetry measurement with the condition that minimal beam time will be required to set up the radial polarization. Details can be found in the 2015 PAC report. RHICf submitted a RHIC beam use request to the PAC in June 2016.

Major progress has been made since the 2015 PAC meeting, including the fact that the RHICf detector has arrived at the STAR workshop. Following the recommendation of the previous PAC report, the collaboration signed a MOU with STAR and received an endorsement for the two proposed measurements from the STAR collaboration. The cross section part of the program seems straightforward, but there are potential issues with the required vertical detector motion and radial polarization needed for the A_n measurement.

The PAC remains enthusiastic about the proposed measurements and was pleased with the closer collaboration and communications established between the STAR and RHICf collaborations, and with the proposed back-up plan to carry out the A_n measurement with vertical polarization only in the event that setting up a radial polarization turns out to be challenging and time consuming. The PAC recommends the running of the experiment in the simplest possible configuration since resources are limited. If that is not an issue and solution for installation is agreed upon with STAR and BNL, then the requested beam-time should be allocated.

2.4.3 Discussion of RHICf with Fixed Target in STAR: $\sqrt{s}$ = 500 GeV p+p with Radial Polarization

The RHICf collaboration proposed a measurement of ``Transverse Single Spin Asymmetry of Forward Neutron Production in p+A using Fixed Targets at STAR'', motivated by an interesting but also unexpected nuclear dependence suggested by the preliminary results from the PHENIX measurement of this SSA of neutrons at very forward angles in Run 15 data. The proposed RHICf measurement aims at addressing a number of physics questions that arose from the observed nuclear dependence such as whether the nuclear dependence (A- or Z-dependence) is linear or not, whether diffractiveness plays a role, and also what roles hadronic and electromagnetic amplitudes play.

The proposed configuration for the RHICf fixed target measurement is relatively new, and has not been fully vetted by the STAR collaboration. There is a concern expressed by some STAR collaborators about possible radiation damage to FMS. There is also an important issue with the presented fixed target design that allows the use of three solid targets, which is different from the existing STAR fixed target design. A safety review of the proposed fixed target design will be required to make sure that possible failure modes of the target would not damage the RHIC program. If the solutions for the setup, installation and data taking are agreed upon with STAR and BNL with limited resources, then the requested beam-time can be allocated. We note the proposed experiment also requests a radial polarization. The two lowest P_T values of the proposed data points would be lost if data were taken only with a vertical polarization.

2.4.4 Discussion of $\sqrt{s_{NN}}$ = 62 GeV Au+Au Running in STAR

STAR proposes 4 weeks of Au+Au running at $\sqrt{s_{NN}}$ = 62 GeV to collect 1 - 1.5 B minimum bias events and perform measurements of jets, non-photonic electrons, and direct (thermal) photons. The goal is to probe the partonic coupling to the medium at temperatures that are closer to the phase transition than for the medium produced at $\sqrt{s_{NN}}$ = 200 GeV. While measurements at this energy exist from Run 10, the new data set will represent a significant improvement in statistics for the STAR experiment. These improvements have to be considered in the context of existing measurements from Run 10 in both STAR and PHENIX and their potential impact.

Semi-inclusive jet spectra and nuclear modification factor:
The proposed jet measurement would extend the p_T reach of the preliminary STAR results from Run 10. The goal is to measure the jet energy loss at $\sqrt{s_{NN}}$ = 62 GeV and map out the temperature dependence of the jet quenching transport coefficient $\hat{q}$ by adding these proposed results to earlier measurements at higher center-of-mass energy from RHIC and LHC. The major challenge in achieving this goal is the lack of high-statistics pp reference data at 62 GeV that can be used to construct the jet nuclear modification factors. The STAR experiment is proposing to use peripheral Au+Au events as a substitute, but this inevitably introduces additional uncertainties. Considering that there are also large theoretical uncertainties, the improvement in determining the temperature dependence of $\hat{q}$ by including the new data set is likely to be limited.

Non-photonic electron spectra, nuclear modification factor, and v_2 :
Within the proposed 4-week period, STAR expects to collect about 400M to 600M events that could be used for these measurement within the TPC acceptance, which is a large improvement over the 67.3M such events collected by STAR in Run 10. The goal is to study simultaneously the nuclear modification factors and collective flow of heavy quarks, and determine their coupling to the medium. Recently, PHENIX published R_{AA} and v_2 of non-photonic electrons in several centrality classes and up to p_T = 5 GeV/c (Phys. Rev. C 91, 044907 (2015)). These results indicate non-zero v_2 and some enhancement in R_{AA}. The measurements were based on 400 M events recorded by PHENIX during Run 10 within a smaller acceptance than that of STAR. The proposed measurements from STAR would improve the statistical uncertainties but, unfortunately, the major uncertainty in the R_{AA} measurement is systematic, due to the lack of a pp measurement at this energy, and cannot be reduced with new Au+Au data. In addition, with the removal of the HFT in Run 17, the separation of electrons originating from charm and bottom decays would not be possible, which is a shortcoming in the era when precise measurements of this kind are becoming available from both STAR and PHENIX

for the top RHIC energy.

Direct (thermal) photons:
STAR proposes to use the measurement of low-mass dileptons to extract the thermal photon spectrum in Au+Au collisions at $\sqrt{s_{NN}}$ = 62 GeV. This is a challenging measurement, because the low-p_T (1-3 GeV) photons are dominated by hadronic decay photons. It can be performed either using internal conversions (virtual photons) or external conversions. It requires detailed understanding of all sources of hadronic decay photons, and in the case of external conversions – a well calibrated converter. In both cases, earlier measurements at $\sqrt{s_{NN}}$ = 200 GeV (from PHENIX) have been dominated by systematic rather than statistical uncertainties. Analysis in $\sqrt{s_{NN}}$ = 62 GeV based on the 400 M events collected by PHENIX in Run 10 is already underway, and an additional measurement from STAR would be a desirable cross check. The lack of pp data at the same energy presents a caveat, since in the 200 GeV data the direct photon spectrum measured in pp collisions has been used to subtract the prompt (pQDC) component in order to reveal the thermal component. One would have to rely completely on theoretical calculations to do this for the 62 GeV data, which may limit the accuracy with which the temperature of the system could be extracted.

2.5 Discussion of Run 18 Priorities

2.5.1 Discussion of STAR Isobaric Run Program ^{96}Ru+^{96}Ru and ^{96}Zr+^{96}Zr

The proposed $\sqrt{s_{NN}}$ = 200 GeV Ru+Ru and Zr+Zr isobar running is intended to measure the possible magnetic field dependence of charged particle correlations across the reaction plane that may be due to the chiral magnetic effect, disentangling this signal from background contributions that are intertwined with collective flow. This is a new and clever experimental program that takes full advantage of the flexibility of the RHIC accelerator and the capabilities of the STAR detector. It was devised by the STAR collaboration and proposed to the PAC last year. As we describe in Section 7 of this document, last year the PAC asked for further guidance with regards to the state of current understanding of the chiral magnetic effect and for as quantitative a demonstration as possible of how a program of isobar collisions could clarify that understanding. Between last year and now, the case for this experimental program has been made compelling by the work done by a Chiral Magnetic Effect Task Force, formed by BNL, consisting of several key members of the STAR collaboration and several theorists including one member of the PAC. The PAC reviewed the report of this Task Force and heard a presentation by one of its co-chairs. We describe our response to the work and the report of the Task Force in Section 7. The discussion that we provide here is brief; Section 7 provides further context.

The isobaric nuclei Ruthenium-96 and Zirconium-96 have the same mass but have charge Z=44 and 40, respectively. Ru+Ru collisions will therefore generate magnetic fields that are about 10% larger (and magnetic fields squared that are about 20% larger) than in Zr+Zr collisions. The CME Task Force has quantified this expectation and has quantified the (small) impact of present uncertainties in the shapes of the two isobars on this expectation and shown how flow measurements in the most central collisions will further reduce these uncertainties. Comparisons of the charge separation observable in mid-central Ru+Ru and Zr+Zr collisions will isolate the magnetic field dependence of the observed charge separation, thereby yielding a direct constraint on the contribution of the chiral magnetic effect to this observable.

The CME Task Force has done simulations that demonstrate that if 20% or more of the effect presently seen in the charge separation observable is due to the CME, an isobar run with 1.2 billion minimum bias Ru+Ru collisions and 1.2 billion minimum bias Zr+Zr collisions will yield a 5 sigma measurement of a difference between the charge separation observable in the collisions of the two isobars with 20-60% centrality. This means that this experimental program will either demonstrate that more than 80% of the presently observed charge-dependent two-particle correlation across the reaction plane comes from backgrounds or quantify the CME contribution to the observed effect, cementing a fundamental discovery that will be high on the list of RHIC accomplishments.

The principal measurements that motivate the isobar program, as sketched above and as analyzed quantitatively in the report of the CME Task Force, are those of charged particle correlations across the reaction plane as well as of flow observables. It is these measurements that motivate the experimental program and that provide the compelling case for the proposed Run 18 program. Once the data is taken, though, many other observables can also be explored, in each case seeking and quantifying any possible Z-dependence. We are happy to see that the STAR Beam Use Request already provides one such example and we would like to encourage the STAR collaboration to explore further possibilities, including via further engaging the theory community. STAR plans to measure the dielectron mass spectrum in the hope of shedding light on the source of the dielectron excess seen in peripheral U+U collisions. The two possible sources that have been discussed, namely photonuclear processes and two-photon processes, scale like Z^2 and Z^4 respectively. This means that measuring the difference between the dielectron mass spectrum in Ru+Ru and Zr+Zr collisions, although expected to be only 2 or 3 sigma, may be rather informative.

2.5.2 Discussion of Au+Au collision running for Global Hyperon Polarization

The proposal for a 27 GeV Au+Au run was motivated by the preliminary STAR result that both Lambda and anti-Lambda hyperons are produced with a global polarization with respect to the reaction plane and that the magnitude of the polarization increases with decreasing collision energy. In a thermal statistical model for particle production from a rotating droplet of Quark-Gluon Plasma (QGP), the global polarization can be related to the vorticity of the QGP fluid from which the Lambda's and anti-Lambda's freeze out. If the difference in the magnitude of the polarization between anti-Lambda's and Lambda's if confirmed in the higher statistics measurement that the proposed 2 week run would provide, within the context of a thermal statistical model for particle production this would be attributable to the presence of a magnetic field at the time of Lambda and anti-Lambda formation.

The selection of the 27 GeV beam energy was based on balancing two competing requirements: (i) a larger vorticity is expected for the fluid formed in lower beam energy collisions; and (ii) higher collision energies are required in order to have a sufficient anti-Lambda yield to make an accurate polarization measurement.

The STAR Event-Plane Detector (EPD) would significantly improve the resolution for reaction plane determination and would enhance the signal strength in the global polarization measurement as a result. The EPD is expected to be ready for Run 18. This favors scheduling the 27 GeV Au+Au run in 2018 rather than in 2017.

The presence of fluid vorticity or magnetic field are prequisites for possible Chiral Vortical Effects or Chiral Magnetic Effects in heavy ion collisions. Because the scientific goals of the 27 GeV Au+Au run include demonstrating the existence of observable consequences of vorticity or magnetic field, these goals align well with the goals of the isobaric running. However, the 27 GeV Au+Au run is not necessary to achieve the goals of the program of isobar collisions. The PAC ranks the 27 GeV Au+Au run as the second priority for Run 18.

The PAC considers a 2 week 27 GeV Au+Au run a higher priority than the 62.4 GeV Au+Au run proposed for Run 17.

The PAC encourages the STAR collaboration to continue to sharpen the physics case for the 27 GeV Au+Au run, and further quantify it, in advance of next year's meeting of the PAC.

3. STAR BES-II and iTPC Upgrade

The PAC was very pleased to see that the STAR collaboration has made significant progress and the BES-II scientific program was presented well. Likewise, the iTPC project is strongly motivated scientifically. The PAC commends the STAR collaboration for progress made in the last year and is pleased that the iTPC upgrade is an approved ongoing project. The construction/installation schedule for the iTPC project seems very challenging given the current RHIC running plan. The verification and test of installation tooling and procedure during the 2017 shutdown will be an important step for the iTPC project, though the planned exchange of one outer sector and the possible installation of one new inner sector could be a risk for the scientific program of run 2018 as well. The PAC recommends the STAR collaboration to monitor the schedule diligently and work with CA-D to possibly allow for more schedule contingency of the installation and commissioning of the iTPC prior to the start of Run 19.

In addition to the approved iTPC upgrade project, the planned Event-Plane Detector (EPD) will cover a pseudo-rapidity window 2.1 to 5.0 on both directions of the beam and will significantly enhance the reaction plane resolution. The expectation is that the detector will be ready for run 2018 where the scientific program can benefit greatly from the improved reaction plane resolution. The Endcap Time-Of-Flight (eTOF) upgrade will use the Multi-gap Resistive Plate Chamber (MRPC) modules from the Compressed Baryonic Matter (CBM) experiment to configure a STAR endcap TOF detector. This addition could significantly enhance the Particle IDentification (PID) capability of the STAR experiment for its proposed fixed-target running with the RHIC beam. The funds needed for the EPD and the eTOF project seem to be modest. The PAC urges the STAR collaboration to work with the RHIC management and other possible funding sources to secure the support for these upgrade projects and carry out these upgrades as planned.

The PAC commends the STAR collaboration for quantitative evaluations of its measurement capabilities for key observables in the BES-II era with the planned iTPC, EPD and eTOF upgrade projects. These observables included the precise measurement of dv_1/dy as a function of collision centrality, critical fluctuations with a large rapidity coverage, precise dilepton spectra, and global polarization measurement. The cases for both the BES-II scientific program and the detector upgrades have been made stronger.

4. STAR and PHENIX Computing and Data Production

Key information presented to the PAC on data release projections

STAR has estimated the following timelines for full production of data from the 2014, 2015 and 2016 data-taking runs at RHIC:

- 2014 Au+Au data to be fully processed by September 2016. ^{3}He+Au data is still in preview production and no estimate was given of when it will be fully produced.
- 2015 p+p data to be processed by August 2016 ; p+Au and p+Al production is queued and estimated to take 5.5 months at 50% farm occupancy
- 2016 Au+Au data production is estimated to take 8 months at 100% farm occupancy; no estimate was given for the production of the d+Au BES data.

The STAR collaboration has expressed concern about continuation of their limited computing resources and disk storage, which the PAC considers to be a very serious issue.

PHENIX has fully processed the ^{3}He+Au (Run 14), p+Au and p+Al (Run 15), and has finished online production of the d+Au BES data from Run 16. The Au+Au data (Run14) and p+p data (Run 15) will undergo a second pass for improved performance. The Au+Au data from Run 16 will take about 6 months to process. PHENIX stated that all data taken would be processed by the end of 2017. Presently, PHENIX stores all data sets since Run 3 in a compact form, nDST, on disk and available for fast analysis access. With the two large Au+Au data sets from Run 14 and Run 16 adding 2PB, this may not be feasible and further optimization and filtering is being considered.

Discussion

Both STAR and PHENIX have maintained a strong publication record in the last year and the PAC commends them for their efforts. Although the large Au+Au data sets from Run

14 and Run 16 present computing challenges, the PAC is not concerned with the PHENIX data release plan. There are, however, remaining and deepening concerns that insufficient computing resources may limit the timely production and release of STAR data. A hallmark of the RHIC scientific program is the versatility of the collider, giving it the flexibility to pose, and answer, important new questions. Realizing this unique advantage, using the world's most versatile collider to best achieve scientific impact, requires the timely production and analysis of data sets taken with varied running conditions. For example, the recent data taken in small collision systems with a variety of initial geometries and collision energies give the STAR and PHENIX collaborations unique opportunities to address questions that are presently of great interest in the field world-wide, such as the question "what is the smallest possible droplet of liquid QGP?" and how the answer to this question depends on the collision energy and the QGP temperature. The PHENIX collaboration has taken the lead in exploring this physics, while the STAR collaboration is forced to make choices due to limited resources, and therefore is missing the opportunity to release such results at a time when they are most impactful. STAR management is encouraged to be proactive in attracting effort and allocating resources to all current physics topics.

STAR has taken a number of steps aimed to improve the computing bottlenecks within their limited resources:

- During the last year, STAR user jobs have taken advantage of unused CPU cycles in the PHENIX computing farm.
- Effort has been made to involve facilities outside the lab (e.g. Dubna and LBNL-NERSC), which are expected to have up to a 20% impact on the current projection.
- To mitigate problems in storage, a more compact data format is being developed that would reduce the footprint of the data sets by a factor of 5-10.
- A tracking focus group has been investigating possible optimization of the tracking software.

The PAC commends the collaboration for taking these steps and encourages them to take these projects to completion as well as continue to investigate new opportunities. For example, they may evaluate what changes would be needed in the production software, such that production jobs may also use opportunistic CPU cycles in the PHENIX computing farm. The BNL management is urged to find ways to improve on the current constrained resources in order to enable the timely reconstruction and release of STAR data.

Recommendations

- BNL Management should immediately commission a panel of local computing experts to evaluate the STAR needs for computing resources, review the current practices, investigate possible optimization of the use of the local RCF resources, and report within three months.
- BNL Management must look into the potential availability and use of additional computing resources within the laboratory, such as the Institutional Cluster within the

BNL Computational Science Initiative, or seek additional computing resources, to enable timely reconstruction of STAR data.

- The STAR collaboration is urged to adopt their newly developed pico-DST data format before the end of the calendar year, in order to reduce significantly the footprint of the data sets being produced and enable their timely analysis.

5. sPHENIX

The PAC commends the sPHENIX collaboration for the progress made last year in the formation of the collaboration organization and leadership team, as well as in the detector prototype and the development of the scientific program of the experiment.

The recent exercise of deliberation on possible detector descoping options, and the cost reductions associated with these options, requested by the BNL ALD has been very informative. The tracker options remain a major uncertainty and will be reviewed in September 2016. The PAC looks forward to seeing the final sPHENIX detector configuration which will deliver the exciting physics capability for jets and Upsilon measurements at RHIC foreseen in the 2015 nuclear science long range plan.

The sPHENIX collaboration identified a reference configuration consisting of three layers of MAPS inner tracker, TPC, EMCal, Inner HCal and Outer HCal detectors. Such a configuration is believed to be a scientifically viable option which will meet the requirements for the sPHENIX scientific program. The abandonment of the PHENIX VTX pixel detector for possible deployment in sPHENIX seems to be well justified given known technical and operational issues associated with the VTX detector. The addition of the MAPS detector is an important choice for Upsilon physics and for jet tagging, though it comes at a considerable increase in cost. The MAPS, TPC and other possible tracker options will be reviewed in September 2016. On the calorimeter front, much progress has been made as shown in preliminary results from the FNAL test beam run in the spring of 2016. The EMCal configuration with either 1-D or 2-D projective geometry remains a critical decision that will have a considerable impact on the cost and resources needed for its construction. Such a decision will presumably be made soon after the planned Jan 2017 test beam run and certainly should be made by early spring of 2017.

The preliminary results from the EMCal and HCal prototypes seem to satisfy the sPHENIX requirements. The collaboration has gained considerable experience with the construction of these prototypes. Based on the preliminary results for the EMCal prototype, it is not clear that the tested EMCal prototype will meet the EIC Barrel EMCal requirements. If the sPHENIX detector will be a possible day-1 detector at a future EIC facility, it is an important to consider whether the sPHENIX EMCal can be constructed with a performance that meets the more stringent EIC detector requirements, while maintaining approximately the same cost. We encourage the sPHENIX collaboration to address this question.

The options for descoping the sPHENIX detector from the reference configuration have consequences of varying degrees on the science program. The impact still remains to be evaluated quantitatively. The PAC commends the sPHENIX collaboration on the progress made and *urges the sPHENIX collaboration to work closely with BNL management on the budget constraints and to seek other possible funding sources in order to reach an optimal detector configuration that will meet the challenges of both construction schedule and scientific performance.*

6. Cold QCD Plan

The PAC commends the authors of the RHIC Cold QCD Plan for the large amount of work they have invested. The document lays out potential mid-term perspectives for p+p and p+A collisions at RHIC, including proton polarization. The overall result is impressive and justifies further studies, in addition to the recommended polarized p+p run during Run 17. Part of the Cold QCD Plan deals with the physics of Run 17 on which we have commented already above. Besides the key issues, the sign change of the Sivers function and TMD evolution which will be the focus of Run 17, the Cold QCD Plan addresses many other interesting measurements. Both parts could justify another spin run before 2023. To strengthen this case, it will be crucial that the data from Run 15 and Run 17 get analyzed and published in a timely manner so that they can serve as the basis for projections for future measurements and their impact. These analyses, and any resulting new understanding of physics questions for the EIC, could significantly impact the optimization of future EIC detectors and interaction regions for physics. The PAC advises the laboratory to work with the cold QCD community to highlight those cases in which pre-EIC running could significantly inform the EIC instrument design and luminosity needs.

In the following we address some of the measurements that were proposed for the year(s) 202X.

The Cold QCD Plan suggests to explore the origin of the large transverse SSAs A_N observed in reactions like p+p -> π+X. The PAC agrees that such a project addresses a long-standing puzzle in transverse spin physics. Recent studies have shown that there is tension between data for A_N and related spin-/azimuthal asymmetries in SIDIS and in electron-positron annihilation if one uses the standard hard scattering approach. Preliminary STAR data, however, indicate that A_N might be related to diffractive scattering where the proton stays intact. If this is indeed true, the main cause of A_N and the transverse SSAs in SIDIS are different. Clarifying this point before an EIC comes into operation would be important. A check of the potential diffractive nature of A_N for inclusive hadron production in p+p collisions requires installation of (updated) Roman Pots for detecting the final-state proton.

Another observable deals with the GPD E^g. The aim is to measure a transverse SSA for J/ψ production in ultra-peripheral p+p collisions and later also p+A collisions, where the p+A experiment would lead to higher count rates due to the (much) larger photon flux coming from the nucleus. Information on E^g is needed in order to get access to the total angular momentum of gluons inside the nucleon. At present this function is essentially unconstrained, and therefore the PAC welcomes this project. Measuring J/ψ production in lepton-nucleon scattering for a transversely polarized target is also considered a key observable of the EIC program.

It was also suggested to follow up on previous RHIC results on the contribution of the gluon spin Δg to the total spin of the nucleon. The observation of a nonzero Δg in single-inclusive production of jets and π^0 is likely to become part of the RHIC legacy. Future measurements of the longitudinal double-spin asymmetry A_{LL} at $\sqrt{s_{NN}} =$ 200 GeV can reduce the errors of Δg from previous extractions. The opportunity of measuring A_{LL} for dijet production at $\sqrt{s_{NN}} =$ 510 GeV is especially interesting. Such a study would allow one to constrain the gluon helicity distribution at smaller values of x, a kinematical region where currently the errors are very large. This measurement would require a forward upgrade.

A number of interesting observables that can be investigated in unpolarized p+A collisions were also proposed. Two possibilities are especially highlighted in the Cold QCD Plan, namely constraining further the nucleon PDFs as well as searching for signals of saturation. Both topics have a very long history. Nuclear modifications of PDFs, especially those known as the EMC effect, have intrigued theoreticians for 30 years. Also, the theoretical framework of the Color Glass Condensate (CGC), which predicts saturation, has been studied for decades. Despite these efforts, the situation in both cases has yet to be settled and the need for additional data is strongly motivated. On the other hand, this is not virgin territory and the added value of additional data must be evaluated carefully to judge the impact of such a program. In particular, such an evaluation should include a detailed comparison with the results of ongoing and planned measurements coming from all four detectors at the LHC. We encourage the Cold QCD community to further develop quantitative examples showing which measurements in such a p+A program can help to optimize the design of future EIC detectors. The PAC also notes that the success of a future p+A program at RHIC, as described in the Cold QCD Plan, relies partly on a successful reconstruction of the challenging DY channel.

The PAC agrees that future measurements in p+p and p+A collisions can help to study the universality of non-perturbative parton correlators such as fragmentation functions, and may even allow one to quantify the impact of factorization breaking. This opportunity will be lost once the EIC is installed. It can be expected that further theoretical support and guidance for this part of the program will become available over the next years. Again, complementarity to LHC experiments for unpolarized measurements will need to be demonstrated.

As already indicated above, part of the physics program of the Cold QCD Plan requires detector upgrades in the forward region. This applies to both sPHENIX and STAR. The PAC is not in a position to discuss details of costs related to such upgrades.

In general, *the PAC encourages the management and the collaborations to consider a potential (polarized) p+p and/or p+A program before 2023*. In addition to the scientific benefits, this would help to keep the Cold QCD community at RHIC engaged, which might be important for the activities at BNL aiming at an EIC. It would also be helpful to further prioritize measurements by considering both the scientific impact as well as budget constraints.

7. Chiral Magnetic Effect (CME) Task Force

In chirally restored quark-gluon plasma, the handedness of quarks is conserved, but at the quantum level these conservation laws are modified by triangle anomalies. In the presence of an external magnetic field, such as the one generated by the current of the colliding charged ions, these anomalies – which are fundamental microscopic features of QCD – lead to novel macroscopic magneto-hydrodynamic effects, in particular the chiral magnetic effect (CME). These anomalous hydrodynamic effects can introduce charge-dependent correlations with observable consequences. However, possible significant background contributions to the charge-dependent correlations driven by bulk flow have also been pointed out in model calculations. The separation of the CME from potential background sources is challenging; the PAC commends STAR for its continuing progress towards a better understanding of the observables.

In its 2015 report, the PAC wrote that "given the importance and wide visibility of a potential claim for a CME-related observation, the PAC recommends that BNL convene a working group that includes experimentalists from STAR as well as theorists with expertise relevant to understanding CME and related phenomena and who are familiar with the challenges related to separating its observable consequences from possible backgrounds. This working group should both provide an agreed upon critical assessment of the present state of understanding and map out a strategy for how best to use the present suite of measurements (perhaps supplemented by other information that can be drawn from present data) to address open questions of interpretation. It should also help to sharpen the case for the isobar collisions that STAR has proposed."

The PAC commends BNL for forming such a Task Force, in a timely fashion. And, the PAC highly commends the Task Force itself for meeting the challenge posed last year, in full. Their report describes a considerable investment of effort by the Task Force over the past year, and this effort has paid off. Their report provides the requested critical assessment of the present state of understanding, and does so succinctly and incisively. It will provide essential guidance for next year's PAC as it has for us, and we hope that it is widely read within STAR and also within the community of theorists interested in the chiral magnetic and related effects.

Although it is not our focus as a PAC, we appreciate the way in which the Task Force report sets out the priorities for theory and modeling. We fully concur with the Task Force that it is important that the community of interested theorists take up the challenges described in this section of the report.

The report discusses further measurements that can be made with current data that show promise, stressing that such measurements should be shown to be interpretable, and either provide new information or be demonstrably better than previous methods. They suggest three measurements that meet these criteria. We look forward to seeing results from all three. Here we mention only one suggestion from the Task Force: by selecting U+U collisions in which the signals in the two zero degree calorimeters (ZDCs) are the most asymmetric, with one of them as small as possible while the other is large, it should be possible to select a data set in which collisions where the tip of one nucleus impinges on the side of the other are over-represented. In such collisions, v_2 should decrease while the magnetic field (and hence the CME-related component of the charge separation observable) should either increase or remain unchanged. (In the present data shown in Fig. 3 of the Task Force Report, when the response in both ZDCs is minimal both v_2 and the charge separation observable decrease.) We await results from this and the other proposed measurements with interest. But, we agree with the Task Force that, given the attendant complexities that they describe in their critical assessment, a conclusive interpretation of these and the present measurements will require more. (For the specific example that we have mentioned above, the most important complexity to be faced may be the effects of fluctuations on the determination of the reaction plane in tip-on-side collisions.)

The Task Force made a considerable effort to develop a compelling case for the isobar collisions, now proposed for Run 18. In particular, they did the simulations needed to show that if 20% or more of the effect presently seen in the charge separation observable is due to the CME, the proposed isobar run will yield a 5 sigma measurement of a difference between the charge separation observable in Ru+Ru and Zr+Zr collisions. These nuclei have the same mass but different charge, meaning that in collisions with the same centrality the magnetic field will be greater in Ru+Ru collisions than in Zr+Zr collisions. The Task Force has redone the calculation of the expected magnetic field in the two cases, making various improvements that they describe in their report. As a part of their analysis, they show that the present uncertainties in the quadrupole deformations of the two nuclei translate into little uncertainty in the difference between the magnetic fields in the collisions of the two isobars. The Task Force has also shown that measurements of v_2 in the most central Ru+Ru and Zr+Zr collisions will resolve the present uncertainties in the shapes of the two nuclei. Depending on the result of this measurement, the charge separation observable measured in 20-60% centrality collisions could turn out to be even a little more sensitive to the CME than in the baseline analysis of the Task Force. The Task Force concludes that the case for colliding nuclear isobars is compelling: it will either show that the CME contributes less than 20% to present measurements of charge separation observables or will allow a definitive separation of the CME from backgrounds and the quantification of the CME contribution to the charge separation observable. We concur with the Task Force that a program of isobar collisions is of high priority. It represents an opportunity to use the unparalleled flexibility of the RHIC accelerator and the capabilities of the STAR detector to clarify a central puzzle in the field.

We close with two further comments. We encourage the Task Force to consider making a version of their report public via posting it on the arXiv. And, we observe that if in future some other circumstance arises where challenges in the interpretation of extant data make it hard to evaluate the pros and cons of choices that must be made about the near-future experimental program, the formation of a Task Force constructed along the lines of this one, given a focused charge, and motivated to put in sustained effort, should be considered.