sPHENIX status and updated run plan

David Morrison (BNL)
Gunther Roland (MIT)
co-spokespersons
sPHENIX presentations at this meeting

1. Earlier today: sPHENIX project status (Ed O’Brien)
2. sPHENIX status and updated run plan (GR, DM)
   - Collaboration overview and recent progress
   - Recall key considerations connecting sPHENIX science mission and design, commissioning and operations
   - 2023-2025 beam use proposal
3. sPHENIX TPC Outer Tracker (Hugo Pereira da Costa)
   - Proposed upgrade to complement existing solutions for TPC distortion monitoring and corrections
sPHENIX Science mission

sPHENIX was designed as a state-of-the-art jet detector at RHIC to explore the properties of the QGP at very short scales, and its scientific program was endorsed by the 2015 NSAC Long Range Plan for Nuclear Science. The PAC considers the completion of the sPHENIX scientific program as the highest priority of the RHIC program after the completion of BES-II and before the transition to the EIC facility.

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.
sPHENIX Science

Mission: **Study QCD phenomena discovered at RHIC** with unprecedented precision

- Focus on **hard probes** (jets and heavy flavor)
- Kinematic reach and capabilities to allow **direct comparison with LHC**
- Affirmed by **Hot QCD white paper → LRP → sPHENIX CD-0 → ECFA → PAC**
- more than **100 (!) PRL/PLB** from RHIC, LHC on these topics since LRP (2015)

**Jet cor. & substructure**
Vary momentum/angular size of probe

**Parton energy loss**
Vary mass/momentum of probe

- $g$
- $u,d,s$
- $c$
- $b$

**Upsilon spectroscopy**
Vary size of the probe

$\Upsilon(2S) - 0.56 \text{ fm}$
$\Upsilon(3S) - 0.78 \text{ fm}$
$\Upsilon(1S) - 0.28 \text{ fm}$

**Cold QCD**
Vary temperature of QCD matter
sPHENIX science mission and schedule

• ’15 LRP recommended installation of a new detector at existing collider
  • this is unusual (vs LEP, Tevatron, LHC,…)
  • realized as upgrade to PHENIX

• needs to significantly advance HI physics vs prior 20 years of data taking

• EIC @BNL reference schedule implies end of RHIC operations after 2025 run
  • this is unusual (vs prior colliders)
  • no opportunity for do-overs

• Need to complete science mission on a 3-yr schedule guides construction, commissioning and running schedule and physics focus
sPHENIX: the detector

n.b., every subdetector you see on this picture is new
sPHENIX calorimeters

First @ RHIC: Full calorimeter stack incl. hadronic calo

Challenge:
- Absolute calibration of jet response (JES, JER)
sPHENIX tracking

Continuous readout TPC (R = 20-78cm)
- shares many concepts with ALICE TPC upgrade

Si strip intermediate tracker (INTT, R = 7-11cm)
- based on ALICE ITS IB detector

3 layer MVTX vertex tracker (R = 2.3, 3.1, 3.9cm)

First @ RHIC: Large acceptance high-rate tracking

Challenges:
- Track reconstruction CPU time
- TPC distortion correction
The PAC supports the sPHENIX project management proposal to use the contingency funds to find ways to ensure meeting the construction schedule. The PAC considers the timely startup of sPHENIX physics data-taking as the highest priority of the RHIC program after completion of BES-II. The PAC recommends the sPHENIX and RHIC managements to work together to meet the schedule requirements of the sPHENIX project.

Collaboration and project are committed to sPHENIX being ready for data taking in early 2023
Possible b/c of extraordinary effort by project, collaboration and support by BNL/DOE
sPHENIX collaboration

- 82 institutions (22 new since CD-0)
- world-class expertise in physics, silicon, TPCs, calorimetry, electronics, computing
- about 25% non-US institutions
- \( \approx 330 \) participants (\( \Rightarrow 400-500 \) by 2023)
- Steady evolution of collaboration organization
sPHENIX organization

Co-Spokespersons
D. Morrison, G. Roland

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V. Greene (chair)

Speaker's Bureau
M. Rosati (chair)

Publication policy TF
A. Sickles (chair)

Bylaws TF
R. Belmont (chair)

Beam Use Request TF
J. Nagle (chair)

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M. Purschke

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Jet TG
D. Perepelitsa, R. Reed

HF TG
J. Huang, H. Okawa

Quarkonia TG
T. Frawley, M. Rosati

Cold QCD TG
S. Bazilevsky, R. Seidl

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C. Roland, T. Sakaguchi

TPC Calibration
R. Corliss, H. Pereira da Costa

Calo Calibration
J. Frantz

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Framework
C. Pinkenburg

Simulations
J. Huang

Computing Plan
R. Soltz

Tracking
T. Frawley

Calo reco
D. Perepelitsa, S. Bazilevsky

= new since 2020
Commissioning taskforce (est. 2021)

Led by Caroline Riedl (UIUC) and John Haggerty (BNL)

- Charge is to develop detector commissioning plan
- Covers both ~now to beginning of data taking and commissioning with beam in 2023-2025 runs

Draft beam commissioning plan informs run plan

<table>
<thead>
<tr>
<th>Weeks</th>
<th>Designation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>Cool Down from 50 K to 4 K</td>
</tr>
<tr>
<td>2.0</td>
<td>Set-up mode 1 (Au+Au at 200 GeV)</td>
</tr>
<tr>
<td>0.5</td>
<td>Ramp-up mode 1 (8 h/night for experiments)</td>
</tr>
<tr>
<td>11.5</td>
<td>sPHENIX Initial Commission Time</td>
</tr>
<tr>
<td>9.0 (13.0)</td>
<td>Au+Au Data taking (Physics)</td>
</tr>
<tr>
<td>0.5</td>
<td>Controlled refrigeration turn-off</td>
</tr>
<tr>
<td>24.0 (28.0)</td>
<td>Total cryo-weeks</td>
</tr>
</tbody>
</table>
Software/Computing

- **Key principle:** Reconstruction with fixed, short latency
  - Rapid diagnosis of rare failures
  - Timely completion of science program
  - → Reconstruction time budget of 5s/event

- **Challenges**
  - Reconstruction time performance
  - TPC distortion correction
  - Jet energy calibration

- **Collaboration on common software:**
  - Workfest w/ ALICE/STAR (July ’19)
  - Workfest w/ ALICE/STAR/CBM/ATLAS (Jan ’20)
  - ACTS tracking, CA seeding (ATLAS, ALICE, STAR
  - KFParticle 2ndary vertex reco (CBM)
  - TPC distortion correction (ALICE)
  - Particle flow jet reconstruction (CMS/ATLAS)
The PAC endorses the plans of the sPHENIX Collaboration to initiate a Mock Data Challenge (MDC). This is timely and it is important to have in place a software project with appropriate project structure, responsibility and review processes associated with a project. The goals and milestones of the MDC project should be defined to enable the collaboration to assess the software readiness for the start-up of the sPHENIX detector. The MDC project will be essential to shape up the sPHENIX software towards the commissioning of the detector in 2023.

MDC-1 led by Camelia Mironov (MIT) and Chris Pinkenburg (BNL)

- **Exercise full chain** from large scale simulation, reconstruction in production environment to analysis of reconstructed data
- Effort involving **software teams and analysis groups** from Nov 2020 - March 2021
- Results reported at 2021 Software & Computing review (March 2021)
- Catalyzed **major progress in all areas** of sPHENIX computing effort
MDC-1 results

- Sustained MDC simulation and reconstruction effort
- Valuable lessons about interaction w/ scheduling system

Mock data challenge, planning for convergence

Findings

1. The experiment has successfully conducted the first simulation campaign organized as a Mock Data Challenge (MDC1). The data production/processing chain was executed. Full simulation was done.
2. Several new software tools, including job management PanDA as proof of concept and MC production tools, file catalog, parallel file reading and performance profiling (memory, time) were used or at least tested. Jenkins integration for Quality Assurance was in place during MDC1.
3. First full simulation using ACTS was carried out and reached the reconstruction performance goals.

Flagship measurements performed on MDC-1 simulated/reco’d data
Preventing for MDC-2, starting in late 2021

- Include distortions and distortion correction as well as calo calibration workflows
- Production workflow management and database software (PanDa/Rucio, Belle-2 database)
- Receiving strong support from NPPS and SDCC - most welcome!
- Exercise day physics analyses in “blind” mode (w/ truth information propagated separately)
2021 PAC charge and sPHENIX

BNL Nuclear Physics PAC 2021 Charge and Agenda
March 16, 2021

Charge
STAR: Beam Use Requests for Runs 22–25
sPHENIX: Beam Use Requests for Runs 23–25
CeC: Beam Use Requests
The Beam Use Requests should be submitted in written form to PAC by May 14, 2021
The BURs should be based on the following number of expected cryo-weeks.
First number is minimal expected RHIC run duration and second number is optimal duration:
2022: 18 (20)
2023: 20 (28)
2024: 20 (28)
2025: 20 (28)

Presentations:
STAR: Update on spin physics and isobar analyses
PHENIX: Update on ongoing analysis efforts and data archiving effort
sPHENIX: Installation status and schedule
Each of run period has distinct, critical role for sPHENIX science mission

- **2023** - **commissioning** of detector, RHIC and data operations with Au+Au
- **2024** - **high statistics p+p** reference and **p+Au** cold QCD data
- **2025** - **high statistics Au+Au** data

This is the **minimal “safe” schedule**

- ensure safe combined operation of detector and collider
- provide development time for calibration and reconstruction to ensure successful completion of science mission before transition to EIC

For successful completion of sPHENIX science mission, **each of these runs needs to be successful**
Run plan for 28 week scenario

<table>
<thead>
<tr>
<th>Year</th>
<th>Species</th>
<th>$\sqrt{s_{NN}}$ [GeV]</th>
<th>Cryo Weeks</th>
<th>Physics Weeks</th>
<th>Rec. Lum.</th>
<th>Samp. Lum.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>24 (28)</td>
<td>9 (13)</td>
<td>3.7 (5.7) nb$^{-1}$</td>
<td>4.5 (6.9) nb$^{-1}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.3 (0.4) pb$^{-1}$ [5 kHz]</td>
<td>4.5 (6.2) pb$^{-1}$ [10%-$str$]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20 (28)</td>
<td>12 (16)</td>
<td>0.003 pb$^{-1}$ [5 kHz]</td>
<td>0.11 pb$^{-1}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>13 (15) nb$^{-1}$</td>
<td>21 (25) nb$^{-1}$</td>
</tr>
</tbody>
</table>

Unchanged compared to 2020 BUP

- **Focus on core science** mission
- **Minimization of risk** guides ramp-up, commissioning and running conditions
- **Maximize science output** for investment
  - MIE, 1008 upgrade, research effort, RHIC ops, US HI research workforce
Run plan for 20 week scenario

Compared to 28 week scenario

- **Loss of p+Au** science program
- **Increased risk** to core science (e.g., commissioning, detector or machine delays)
- Significant **loss of science output** (precision!) for **minimal savings** on investment

<table>
<thead>
<tr>
<th>Year</th>
<th>Species</th>
<th>$\sqrt{s_{NN}}$ [GeV]</th>
<th>Cryo Weeks</th>
<th>Physics Weeks</th>
<th>Rec. Lum.</th>
<th>Samp. Lum.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2023</td>
<td>Au+Au</td>
<td>200</td>
<td>20</td>
<td>5</td>
<td>1.7 nb⁻¹</td>
<td>2.1 nb⁻¹</td>
</tr>
<tr>
<td>2024</td>
<td>$p^+p^+$</td>
<td>200</td>
<td>20</td>
<td>16</td>
<td>0.4 pb⁻¹  [5 kHz]</td>
<td>6.2 pb⁻¹ [10%-str]</td>
</tr>
<tr>
<td></td>
<td>$p^+\text{Au}$</td>
<td>200</td>
<td>–</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2025</td>
<td>Au+Au</td>
<td>200</td>
<td>20</td>
<td>16.5</td>
<td>10 nb⁻¹</td>
<td>16 nb⁻¹</td>
</tr>
</tbody>
</table>
Comparison of 28 vs 20 week scenarios

Run 23

28 wk
Cooldown | ramp-up | set-up | commission w/ beam

20 wk
Cooldown | ramp-up | set-up | commission w/ beam

Run 24

28 wk
Cooldown | ramp-up | set-up | p+p physics | DX move/set-up | p+Au physics | warm-up

20 wk
Cooldown | ramp-up | set-up | p+p physics

Run 25

28 wk
Cooldown | ramp-up | set-up | commission w/ beam

20 wk
Cooldown | ramp-up | set-up | Au+Au physics | warm-up

n.b., 28wk→ 20wk savings amount to 2% of total investment

55% loss for p+Au
35% loss

no!
Comparison of 28 vs 20 week scenarios

Run 23
- 28 wk
  - Cooldown
  - Ramp-up
  - Commission w/ beam
  - Au+Au physics
  - Warm-up

Run 24
- 28 wk
  - Cooldown
  - Ramp-up
  - Commission w/ beam
  - Au+Au physics
  - Warm-up

- 20 wk
  - Cooldown
  - Ramp-up
  - Commission w/ beam
  - p+p physics
  - Warm-up

Run 25
- 28 wk
  - Cooldown
  - Ramp-up
  - Commission w/ beam
  - Au+Au physics
  - Warm-up

- 20 wk
  - Cooldown
  - Ramp-up
  - Commission w/ beam
  - p+p physics
  - Warm-up

20wk scenario for Run 24 does not allow p+Au run. Shortening p+p run to ~8wks → unacceptable risk, loss of precision for core science program (p+p reference) → no!

28 wk scenario for Run 24 allows p+Au run. Shortening p+p run to ~8wks unacceptable risk, loss of precision for core science program (p+p reference) → no!

55% loss
100% loss for p+Au
35% loss
Comparison of 28 vs 20 week scenarios

Commissioning a new detector from initial turn-on to physics operations in ~12 weeks is ambitious

- c.f., LHC schedule for Run 3
  - 2-week pilot beam in Fall 2021
  - 4wk machine set-up → 9wk commissioning w/ beam → physics ramp up

- Expected lumi of 2022 LHC run is ~2/3 of run 2023 for same uptime

<table>
<thead>
<tr>
<th>Weeks</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>low rate, 6 bunches</td>
</tr>
<tr>
<td>2.0</td>
<td>low rate, 111 bunches, MBD L1 timing</td>
</tr>
<tr>
<td>1.0</td>
<td>low rate, crossing angle checks</td>
</tr>
<tr>
<td>1.0</td>
<td>low rate, calorimeter timing</td>
</tr>
<tr>
<td>4.0</td>
<td>medium rate, TPC timing, optimization</td>
</tr>
<tr>
<td>2.0</td>
<td>full rate, system test, DAQ throughput</td>
</tr>
<tr>
<td>11.5</td>
<td>total</td>
</tr>
</tbody>
</table>

2023 beam commissioning plan
20wk scenario: Rich p+Au program lost

Collectivity and jet quenching in p+Au

Over the last decade, many of the highest impact discoveries in the RHIC/LHC heavy ion program from p+Au

- Collectivity and nuclear geometry, nuclear PDFs, system size dependence on quarkonia and strangeness
- Unique opportunities in polarized proton-nucleus

sPHENIX presents unique capabilities for p+Au
20wk scenario: Impact on Au+Au program

- 20wk vs 28wk scenario implies loss of **40-50% of Au+Au statistics**
  - Optimal performance typically achieved towards end of collider run
  - Affects both statistical uncertainty and systematic uncertainty based on data-driven calibration (a la LHC)

- sPHENIX science mission is predicated on **precision of hard probes measurements**, enabled by higher rate and improved instrumentation

- Scale of loss is set by **two conditions**:
  - Need **decisive improvement** compared to existing RHIC data (x10, not x2-3)
  - **Comparison to LHC** data (“complementarity” in LRP mission statement)
    - will be limited by sPHENIX for most observables in overlapping kinematic range
    - loss of sPHENIX precision directly leads to loss of discriminating power/discovery potential
Direct comparison of **same probe** embedded in **different QGP** conditions

- LHC data has shown modifications of momentum balance, jet shapes and fragmentation functions
- sPHENIX tracking & calorimetry provide corresponding capability at RHIC

Need to **maximize precision in overlap region**: event statistics at sPHENIX!
Illustration: jet azimuthal correlations at LHC and sPHENIX

Molière Scattering in Quark-Gluon Plasma: Finding Point-Like Scatterers in a Liquid

At comparable jet energies, much smaller contribution from ISR/FSR at RHIC, as well as smaller smearing from UE fluctuations
Summary

• sPHENIX collaboration and project continue on path towards scheduled start of data taking in early 2023
  • Installation of full sPHENIX baseline detector now underway
  • Successfully completed first Mock Data Challenge
  • Preparations for MDC-2 underway
  • Expanding collaboration structure with emphasis on **commissioning, calibration and data operations**

• sPHENIX presents major investment by nuclear physics community, BNL, DOE:
  • MIE, 1008 upgrade, MVTX, iHCAL, SDCC, RHIC operations
  • Focus of a **majority of US HI research** groups

• Key concern is increased risk, irrecoverable loss of physics and damage to science return on investment in 20 cryoweek scenario