Future Cold-QCD Physics Program with sPHENIX

Jin Huang (BNL)

For the sPHENIX collaboration
Core physics programs

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

Parton energy loss
Vary mass/momentum of probe

Upsilon spectroscopy
Vary size of the probe

ϒ(2s) – 0.56fm
ϒ(3s) – 0.78fm
ϒ(1s) – 0.28fm

Cold QCD
Vary temperature of QCD matter

See also talks: C. Dean on Wed, E. Umaka on Thu

This talk
15 kHz calo trigger + 10% streaming DAQ
10 GB/s data logging

Also proposed upgrades of event plane detector, Micromegas outer tracker
Spin workshop, RHIC AGS AUM2021

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< 2 years!
From now to first data

- 2010: sPHENIX proposed as upgrade / replacement of PHENIX
- 2012: Initial proposal
- 2014: Full proposal
- 2015: BaBar magnet arrives from SLAC
- 2016: Collaboration formed
- 2016: Final PHENIX run
- 2016: Test beam HCal, EMCal
- 2018: CD-0 (mission need)
- 2018: CD-1/3a (begin final design, place long lead-time procurements)

Sept 2019
PD2/3 (review complete)
Begin construction...

Aug 2020
Beam-use proposal

Oct 2020
Transition from MIE detector pre-production to production

Dec 2021
End of construction

Dec 2022
Installation

Dec 2023
Run 2023 Commis & AuAu candles

Dec 2024
Run 2024 pp ref. & cold QCD
Data Campaign 1

Dec 2025
Run 2025 AuAu high/stat
Data Campaign 2?

Dec 2027
Towards a potential relationship with the EIC

Data Campaign 2?
Outer Hadronic Calorimeter

1.4T magnet, tested at BNL

Detector support cradle

EMCal half sector

Inner HCal

TPC endcap support

TPC field cage

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All sPHENIX tracker support streaming readout → Plan to archive 10% all pp collisions in streaming mode:

- Allowing un-triggerable measurement, e.g. low $p_T$ HF→h
- Increasing spin-tagged M.B. p+p/p+A collisions by 2 to 3 orders of magnitude
- Data preservation from the collection stage for the last high-energy polarized hadron collisions → new analysis w/ EIC
TPC data stream in sPHENIX triggered DAQ

What detector sends out: Continues readout data stream

What we write to disk: 20% data @ 200 Gbps Each seg. corresponding to a calorimeter trigger
Extending streaming time window, a partial triggerless DAQ → \( \times O(100) \) gain in statistics!

What we write to disk, 40 Gbps
15kHz triggered events, 0.1% of all collisions

+ Streaming 10% of all collisions, 60Gbps
50% more data but \( \times O(100 - 1000) \) \( p + p \) events!
### Proposed run schedule, year 1-3

**sPHENIX BUP2021 [sPH-TRG-2021-001]**, 24 (& 28) cryo-week scenarios

<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>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>2024</td>
<td>$p^\uparrow p^\uparrow$</td>
<td>200</td>
<td>24 (28)</td>
<td>12 (16)</td>
<td>0.3 (0.4) pb$^{-1}$ [5 kHz]</td>
<td>0.11 pb$^{-1}$</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>4.5 (6.2) pb$^{-1}$ [10%-str]</td>
<td></td>
</tr>
<tr>
<td>2024</td>
<td>$p^\uparrow$+Au</td>
<td>200</td>
<td>–</td>
<td>5</td>
<td>0.003 pb$^{-1}$ [5 kHz]</td>
<td>0.11 pb$^{-1}$</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>0.01 pb$^{-1}$ [10%-str]</td>
<td></td>
</tr>
<tr>
<td>2025</td>
<td>Au+Au</td>
<td>200</td>
<td>24 (28)</td>
<td>20.5 (24.5)</td>
<td>13 (15) nb$^{-1}$</td>
<td>21 (25) nb$^{-1}$</td>
</tr>
</tbody>
</table>

sPHENIX asked to consider 20-28 week runs in 2024
- (Trans-)polarized $p + p$, $p + A$ with streaming readout for 28 weeks in Run24
- But short Run24 would endanger the $p + A$ data!
sPHENIX cold QCD observables and opportunities

- **Transversely polarized observables**
  - Sievers-type tri-gluon correlation: $\gamma$, HF
  - Hadron AN, pp vs pA: $h$
  - Sivers effects: $\gamma$-jet, di-jet
  - Transversity via Collins FF & IFF: $h$ in jet, di-h

- **Spin-averaged observables**
  - Quarkonia polarization: $J/\psi$, $\Upsilon$
  - nPDF: $h$, jet, di-jet, $\gamma$-jet
  - Hadronization, pp vs pA: $h$ in jet, $\gamma$-jet, di-jet
Gluon dynamics via $\gamma$, HF TSSA

**TSSA of prompt photon EMCal-based trigger**

$sPHENIX$ Projection, Years 1-3
62 pb$^{-1}$ samp. $p^+p \rightarrow \gamma + X$, $P=0.57$

$qgq$ Contribution (D. Pitonyak)
Trigluon Contribution Model 1 (S. Yoshida)
Trigluon Contribution Model 2 (S. Yoshida)

**TSSA of prompt $D^0 \rightarrow \pi K$**
Enabled by streaming readout

$6.2$ pb$^{-1}$ str. $p+p$, Years 1-3
Kang, PRD78, $\lambda_f = \lambda_d = 0$
Kang, PRD78, $\lambda_f = -\lambda_d = 70$ MeV

[see also current PHENIX results in talk by B. Mulilo]
PHENIX and STAR show significant different suppression of hadron $A_N$ from pp to pA in distinct kinematic regions [see talks B. Mulilo & X. Chu]

- sPHENIX hadron $A_N$ will explore wider region to help disentangle initial/final state effects
- Enabled by streaming recorded $p + p$ collision from far vertex collisions

See also current data. talks B. Mulilo & X. Chu
PHENIX, PRL123, 122001
STAR, PRD103 (2021) 072005

`sPHENIX BUP2021 [sPH-TRG-2021-001]`
Nature of hadron $A_N$ in pp and its nuclear modification

Tremendous improvement comparing to the published PHENIX data
Sivers effects via γ-jet, di-jet

- Enabled by high stat. calorimetric jet/photon detection provided by sPHENIX
- Exploring ideas of spin dependent γ-jet, di-jet correlation observables e.g. $p_{\text{out}}$, co-planarity, charge-tagged jets
Transversity via charged particle IFF

- Tremendous stat. enabled by both calorimetric jet trigger and streaming readout
- Need theory collaboration in the treatment of no-PID charged tracks & multi-dim binning
Fragmentation in p+A

- Access gluon fragmentation function (FF) in $p + p$, $p + A$ via jet FF
- Calorimetric triggered jet + precision tracking

Kaufmann et al. Phys.Rev.D 92 5, 054015
sPHENIX and EIC

sPHENIX, under construction

ECCE EIC exp. proposal [See talk by J. Lajoie, Wed]
Summary

- A rich data set of transversely polarized $p + p$, $p + A$ data planned in sPHENIX Run24
  - Importance of a long Run24 for completing both $p + p$, $p + A$ program
- High stat. observables uniquely enabled by high rate calo trigger and tracker’s streaming capability
- Address puzzles and explore new directions: gluon dynamics, origin of $A_N$, spin/nuclei as tool to study QCD