sPHENIX: Design, Status, Schedule

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UTFSM, Valparaiso, Chile

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large-scale structure

small-scale structure

High-density, high-temperature regime of QCD matter: (near) perfect fluidity
QGP at different scales...

short-distance, asymptotically free quarks and gluons

collective, strongly-coupled, long-distance behavior

need multi-scale, internally generated probes of the QGP medium...
Multi-scale probes

Kurkela, Weidemann, PLB 740 (2015) 172

DGLAP

LPM

Medium cascade

Late DGLAP

Jets and jet structure

Upsilon spectroscopy

\( Y(3s) \quad Y(2s) \quad Y(1s) \)

Parton flavor/mass
Context within U.S. nuclear physics

The 2015 LONG RANGE PLAN for NUCLEAR SCIENCE

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.**
Jet probes of Pb+Pb @ LHC
(also high-statistics Upsilon measurements)

Jet Grooming and Substructure

- JEWEL: enhancement of low Zg jets (due to medium response)
- SCET: modification due to medium induced splitting function
- HT & Coherent antenna BDMPS: Coherent energy loss

Jet structure/sub-structure

broad kinematic range w/ systematic control
jets produced

(adopted from PHOENIX proposal)

microscope resolving power \([1/\text{fm}]\)

jets evolve in QGP at the LHC

jets evolve in QGP at RHIC

early universe

medium coupling

perfect liquid

1s, 2s, 3s

10 weeks p+p

\(\sigma_{1s} = 99 \text{ MeV} \)

Y(1s)

Y(2s)

Y(3s)
• QGP at RHIC is closer to transition temperature, better access to strong coupling regime

⇒ Larger fraction of evolution is dominated by “QGP medium length scales” at RHIC
sPHENIX Timeline
(slides from T. Hallman, DOE Nuclear Physics)

RHIC / LHC Timeline

- **2015**
  - 1 Month Ion Running
    - 11/2015, 11/2016, 6/2018
  - End of Long Shutdown 1
  - Long Shutdown 2
    - 7/18-12/19
  - Stochastic e-Cooling
  - Chiral Magnetic Effect Confirmation
  - Install LEReC

- **2020**
  - 1 Month Ion Running
    - 11/2020, 11/2021, 12/2022
  - Long Shutdown 2021
  - Installation
  - sPHENIX

- **>2025**
  - Electron-Ion Collider
    - (Notional BNL Plan)

- **2014-2017**
  - Heavy Flavor Probes of QGP
  - Origin of Proton Spin

- **2019-2020**
  - Beam Energy Scan II

- **2022-2025**
  - Precision jets and quarkonia

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**CD-0 Status, Sept. 2016**
sPHENIX Scientific Collaboration formed Dec. 2015 >70 institutions

https://indico.bnl.gov/conferenceTimeTable.py?confId=3822
The Hadronic Calorimeter Detector Concept

Figure 3.7: Cross section of sPHENIX. The outer hadronic calorimeter surrounds the solenoid cryostat.

Figure 3.8: Scintillating tiles in the sampling gap of sPHENIX hadronic calorimeter, showing the transverse segmentation into elements 0.1 units of pseudorapidity wide.

Detector design

1.4 Tesla magnet, from BaBar expt.

tracking detectors (to measure charged particles)

electromagnetic calorimeter (to measure photons & electrons)

hadronic calorimeters (to measure jets)

DAQ / trigger system (to record large Au+Au and reference pp samples)
Detector design

1.4 Tesla magnet, from BaBar expt.

Tracking detectors (to measure charged particles)

Electromagnetic calorimeter (to measure photons & electrons)

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sPHENIX Tracking

**MVTX** (based on ALICE ITS upgrade):
- 3-layer MAPS vertex tracker, $R = 2.3$, 3.1, 3.9 cm
- excellent 2-D DCA resolution, $<25 \mu m$ for $p_T > 1$ GeV

**INTT**:  
- 4-layer Si strip intermediate tracker  
- pattern recognition, connects tracking systems, $R = 6$, 8, 10, 12 cm

**TPC**:  
- continuous readout, $R = 20-78$ cm  
- good momentum resolution $p_T = 0.2-40$ GeV
Upsilon spectroscopy

- Momentum resolution sufficient to separate 2S and 3S states, \( \sigma(M_{ee}) < 100 \text{ MeV}/c^2 \) at \( p_T \sim 4.5 \text{ GeV} \)
- Substantial work on TPC design & performance in high-luminosity \( p+p \) running: simulation of in-time pileup, etc.

\[
\sigma_{1S} = 83 \pm 1.2 \text{ MeV}
\]

Upsilon state separation in \( p+p \) collisions

Statistical 1S/2S/3S projections
Heavy flavor reconstruction

Measure identified $D$ and $B$ hadrons in Au+Au

- use precision tracking & high statistics, without PID
- also, $b$- and c-jet tagging

Projected statistical uncertainties for Prompt & Non-Prompt $D\,v_2$

Fully reconstructed low-$p_T\,B^+$ mesons

$S/\sqrt{(S+B)}$ figure of merit in central Au+Au
sPHENIX calorimetry

- **EMCal**: scintillating fibers embedded in W powder
  - $\Delta\eta\times\Delta\phi = 0.024\times0.024$, $\sigma_E/E = 15\%/\sqrt{E}$
- **HCal**: plastic scintillating tiles + tilted steel plates
  - Inner (1\(\lambda\)) and Outer (3.5\(\lambda\)) sections
  - $\Delta\eta\times\Delta\phi = 0.1\times0.1$, $\sigma_E/E = 100\%/\sqrt{E}$
Calorimeter test beams

Proof of principle, Feb 2014

$\eta \sim 0$ Geometry, Feb 2016

physics.ins-det/1704.01461,
submited to IEEE TNS

$\eta \sim 0.9$ Geometry, Feb 2017

Combined test of improved large-$\eta$ calorimetry design,
Feb-March '18 @ Fermilab
Test beam: EMCal

**Linearity and resolution vs. Electron Energy**
(different tower designs & incidence angles)

**GEANT4 simulation of 8 GeV electron incident on EMCal**
(in test beam configuration)
Test beam: HCal

Reconstructed hadron energy distribution, different incident energy (data/sim comparison)

Linearity and resolution for electrons and hadrons in the HCal
DAQ & Trigger

- Large 15 kHz DAQ rate allows recording of Au+Au dataset minimum bias
- Efficient triggering for photons, jets, hadrons, Upsilon in $p+p$ and $p+Au$
- Possible 5-year run plan with 200 GeV $p+p$, $p+Au$, Au+Au running

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<td>Au+Au</td>
<td>200</td>
<td>16.0</td>
<td>7 nb$^{-1}$</td>
<td>8.7 nb$^{-1}$</td>
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<td>Year-2</td>
<td>$p+p$</td>
<td>200</td>
<td>11.5</td>
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<td>48 pb$^{-1}$</td>
<td>267 pb$^{-1}$</td>
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<td>Year-2</td>
<td>$p+Au$</td>
<td>200</td>
<td>11.5</td>
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<td>0.33 pb$^{-1}$</td>
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<td>23.5</td>
<td>14 nb$^{-1}$</td>
<td>26 nb$^{-1}$</td>
<td>88 nb$^{-1}$</td>
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<td>149 pb$^{-1}$</td>
<td>783 pb$^{-1}$</td>
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<tr>
<td>Year-5</td>
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<td>200</td>
<td>23.5</td>
<td>14 nb$^{-1}$</td>
<td>48 nb$^{-1}$</td>
<td>92 nb$^{-1}$</td>
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sPHENIX Magnet

- Formerly Babar magnet, 1.4 T solenoid
- Successful low-field test, full-field tests imminent
Simulations & Software

- Increasingly sophisticated GEANT-based description of detector & development of reconstruction software
  - track and vertex finding
  - electromagnetic and hadronic showering & clustering
  - jet finding in AA collisions

![Raw EMCal](image)

![Raw Inner HCal](image)

![Raw Outer HCal](image)

![Jets in HI collisions after UE subtraction](image)
sPHENIX in “Cold QCD” context

(slides from EIC UG Detector Discussion Mtg, Nov-Dec ’17)

• Dedicated “Cold QCD” topical group for medium-energy physics
  ➤ transition to Day-1 Electron Ion Collider (EIC) detector
  ➤ physics with sPHENIX barrel in 2022-2025

One (possible) evolution to a BNL-EIC detector

Studies of an “ePHENIX” for EIC physics

Numerous studies of detector & physics
thank you for your attention!