



# Jets at RHIC



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### REACHING FOR THE HORIZON





The 2015 LONG RANGE PLAN for NUCLEAR SCIENCE



To this day, nobody understands this dichotomy: how do quarks and gluons conspire to form strongly coupled, nearly perfect liquid QGP?

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.

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## Jet physics at RHIC in 2023-2025

**Table 8.2:** Summary of Au+Au at 200 GeV running in the sPHENIX Beam Use Proposal. The recorded luminosity (Rec. Lum.) and first sampled luminosity (Samp. Lum.) values are for collisions with z-vertex |z| < 10 cm.

Year	Species	$\sqrt{s_{NN}}$	Cryo	Physics	Rec. Lum.	Samp. Lum.
		[GeV]	Weeks	Weeks	z  <10 cm	z  < 10  cm
2023	Au+Au	200	24 (28)	9 (13)	3.7 (5.7) nb <sup>-1</sup>	4.5 (6.9) nb <sup>-1</sup>
2025	Au+Au	200	24 (28)	20.5 (24.5)	13 (15) nb <sup>-1</sup>	21 (25) nb <sup>-1</sup>

**Table 8.3:** Summary of p+p at 200 GeV running in the sPHENIX Beam Use Proposal. The recorded luminosity (Rec. Lum.) and sampled luminosity (Samp. Lum.) values are for collisions with z-vertex |z| < 10 cm.

Year	Species	$\sqrt{s_{NN}}$	Cryo	Physics	Rec. Lum.	Samp. Lum.
		[GeV]	Weeks	Weeks	$ z  < 10 { m cm}$	z  < 10  cm
2024	$p^{\uparrow}p^{\uparrow}$	200	24 (28)	12 (16)	0.3 (0.4) pb <sup>-1</sup> [5 kHz]	45 (62) pb <sup>-1</sup>
					4.5 (6.2) pb <sup>-1</sup> [10%- <i>str</i> ]	

Table 4: Proposed Run-23 - Run-25 assuming 24 (28) cryo-weeks of running every year, and6 weeks set-up time to switch species in 2024. Sampled luminosities assume a "take all" triggers.

$\sqrt{s_{\rm NN}}$	Species	Number Events/	Date
(GeV)		Sampled Luminosity	
200	Au+Au	$10B / 38 \text{ nb}^{-1}$	2023
200	p+p	$235 \text{ pb}^{-1}$	2024
200	$p{+}\mathrm{Au}$	$1.3 {\rm ~pb^{-1}}$	2024
200	Au+Au	$10{ m B}~/~52~{ m nb^{-1}}$	2025

Proposed running plan from <u>STAR</u>

## Proposed running plan from <u>sPHENIX</u>

Focus of this talk: selected higlights from recent Beam Use Proposals

- focus on complementarity / differences between experiments
- point out areas where there is overlap with LHC program, but also those particularly accessible / unique to RHIC!

## STAR detector

The STAR Beam Use Request for Run-21, Run-22 and data taking in 2023-25

The STAR Collaboration

Recent publications of semi-inclusive recoil jets, di-jets, inclusive charged-jet *R*<sub>CP</sub>, and groomed jets (in *p*+*p*) using 2014+2016 data

Expect large statistical increase from 2023-2025 data + continued development of analysis methods!



## **sPHENIX** Detector



BaBar Magnet



First run year	2023
$\sqrt{s_{NN}}$ [GeV]	200
Trigger Rate [kHz]	15
Magnetic Field [T]	1.4
First active point [cm]	2.5
Outer radius [cm]	270
$ \eta $	≤1.1
$ z_{vtx} $ [cm]	10
N(AuAu) collisions*	1.43x10 <sup>11</sup>

\* In 3 years of running

July 28, 2020

sPHENIX at RHIC

sPHENIX is a purpose-built jet physics detector: (1) large, hermetic acceptance, (2) huge data rate, (3) hadronic calorimeter-based energy measurement, (4) unbiased triggering

#### Prototype EMCal towers









sPHENIX Installation Workflow — still on track to collect first data in 2023!

### **GEANT4** simulation of Au+Au event in sPHENIX



Challenge for sPHENIX: jet reconstruction in large, dynamic background with completely new detector!

### γ+jet probes of QGP at RHIC



### event recorded by STAR in 2014



STAR Experiment Au+Au  $\sqrt{s_{NN}} = 200 \text{ GeV}$ Apr 06, 2014 09:22:51 EDT Run Number: 15096026 Event ID: 2056716  $\gamma$  + jet event E<sub>T</sub>: 17.6 GeV

 $\Delta \phi (= \phi^{\gamma} - \phi^{\text{recoil jet}}) \text{ [rad]}$ 



11x increase in statistical power compared to 2014+2016 data, with possible additional reduction in systematics

Gain in discriminating power compared to example models above

Significant increase in ability to construct *p*+*p* data reference important for STAR!

# y+jet projections: sPHENIX



Narrower  $x_{Jy}$  distribution in p+pcollisions at **RHIC** than **LHC** due to smaller ISR/FSR rate

Along with lower- $p_T$  reach, greater sensitivity to *E*-loss!



# Jet sub-structure: STAR



- Jet sub-structure physics systematically connect observables to space-time development of parton shower — RHIC sub-jets much closer to medium scale!
- Use observables as "jet tagger": see how jets with a particular radiation pattern interacts with the medium (color coherence, dead cone, etc.)
  - big focus in 2023-2025 for STAR: decrease resolution on θ<sub>SJ</sub> from ~0.1 to ~0.025 - and increased projected statistics above!

## Jet sub-structure: sPHENIX



Challenging measurement with only calorimeter information (given subjet kinematics at RHIC)





# Large-angle scattering: STAR



Measurement likely unique to RHIC:

smaller rate of ISR/FSR to distort vacuum Δφ shape

access to lower-*p*<sub>T</sub> jets (compare solid to dashed lines)

Statistical projection from STAR - reach down to three orders of magnitude in  $\Delta \phi$ 





### Energy loss in O+O collisions at RHIC



#### 2007.13754, Huss et al.

sufficient theoretical & experimental control to see jet quenching signal in O+O collisions at RHIC Statistical projection for **jet**, **hadron**, **photon** *R*<sub>AA</sub> from sPHENIX, given only two weeks of O+O (or Ar+Ar) data-taking

steeper spectrum at RHIC than at LHC - a given E-loss results in a bigger effect in the RAA!

### Energy loss in O+O collisions at RHIC



Statistical projection for v<sub>2</sub><sup>hadron</sup> from sPHENIX, given only two weeks of **O+O** (or **Ar+Ar**) data-taking



Expected RHIC-LHC overlap from:

- → technical developments + rare channels at LHC enabling low- $p_T$  reach
- increased luminosity + new capabilities at RHIC

# $R_{AHC}$ measurements at low- $p_T$



# STAR + LHC



STAR has similar overall instrumentation and physics analysis focus as ALICE — great synergy for RHIC-LHC comparisons!



CERN-LPCC-2018-07 February 26, 2019

Future physics opportunities for high-density QCD at the LHC with heavy-ion and proton beams

Report from Working Group 5 on the Physics of the HL-LHC, and Perspectives at the HE-LHC



### sphenix + lhc



#### Coherence between LHC Run 3+4 Heavy Ion jet and sPHENIX jet physics programs in 2023+





# Jets at RHIC: Outlook

- Well-motivated and exciting jet physics programs at sPHENIX and STAR in 2023+
- Complementary with LHC programs, but can also explore physics particularly accessible (or even unique!) to RHIC
- Very interesting few years ahead!



