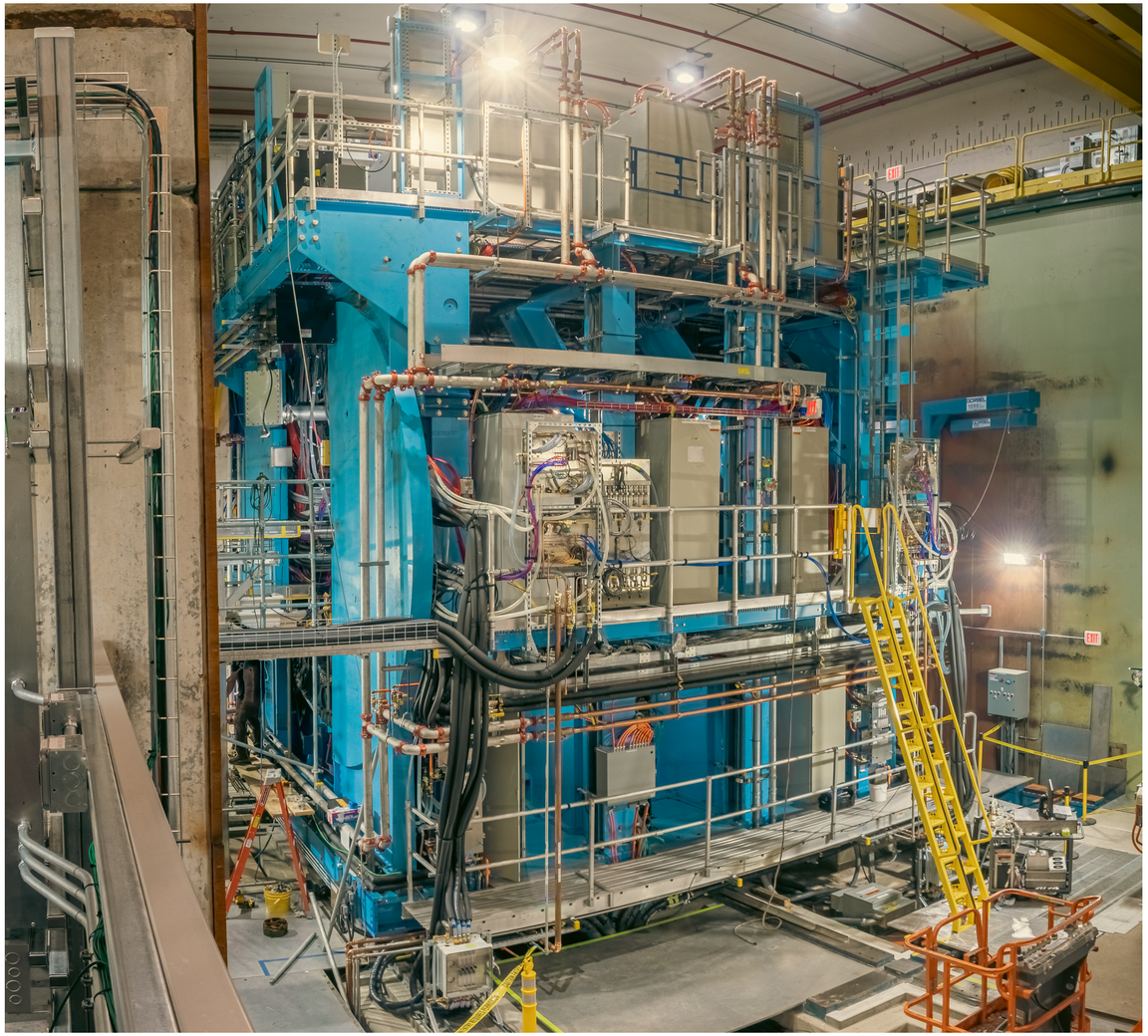
sPHENIX

Beam Use Request for Runs 24-25



BNL NPP Physics Advisory Committee (PAC) Meeting

11 September 2023

Dennis V. Perepelitsa (University of Colorado Boulder)

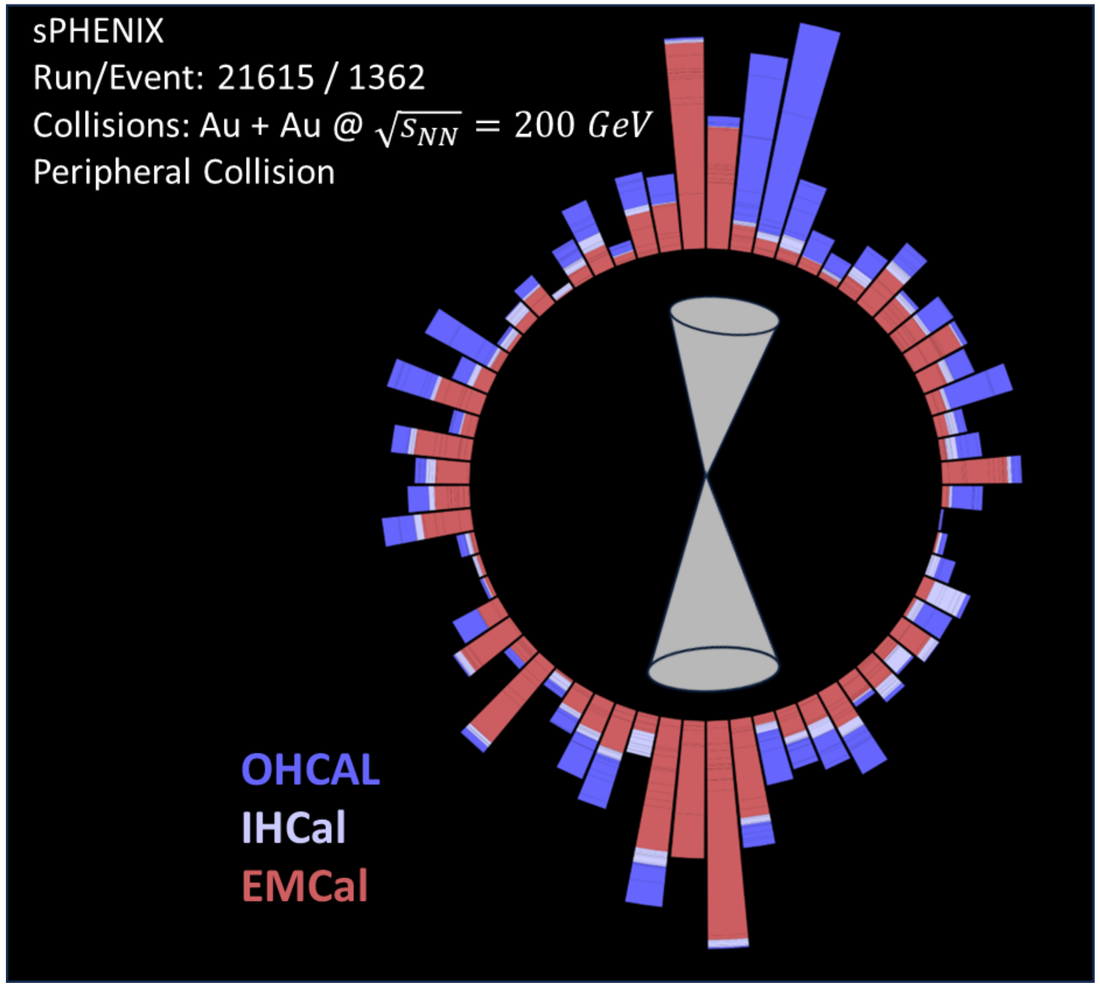
sPHENIX science

sPHENIX is the first new detector at *any* hadron collider in over a decade!

sPHENIX has unique, purpose-built capabilities never before deployed at RHIC

sPHENIX is going to put the remarkable QGP under a state-of-the-art microscope …

…and complete the scientific journey started at RHIC over twenty years ago!



sPHENIX science

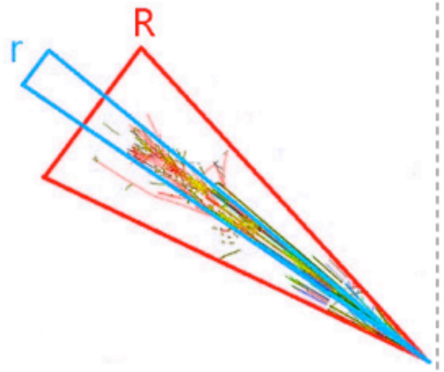
There are two central goals of measurements planned at RHIC, as it completes its scientific mission, and at the LHC: **(1) Probe the inner workings of QGP by resolving its properties at shorter and shorter length scales. The complementarity of the two facilities is essential to this goal, as is a state-of-the-art jet detector at RHIC, called sPHENIX.** **(2) Map the phase diagram of QCD with experiments planned at RHIC.**

2015 US NP LRP

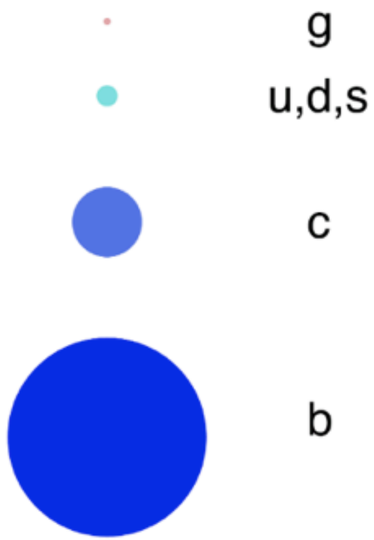
sPHENIX recognized by the U.S. Nuclear Physics community as the *essential* tool for QGP microscopy at RHIC

sPHENIX science program

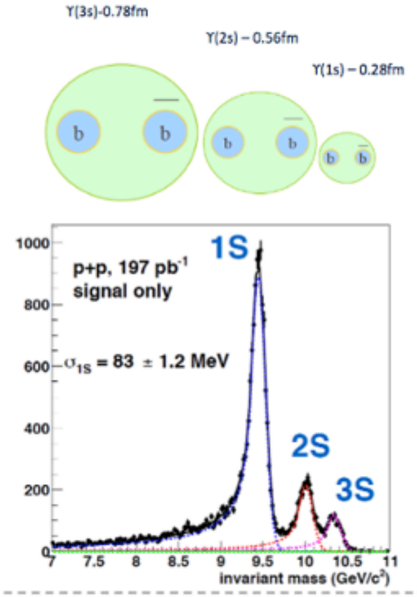
Jet Correlations
Jet Substructure
Vary momentum/
angular size of probe



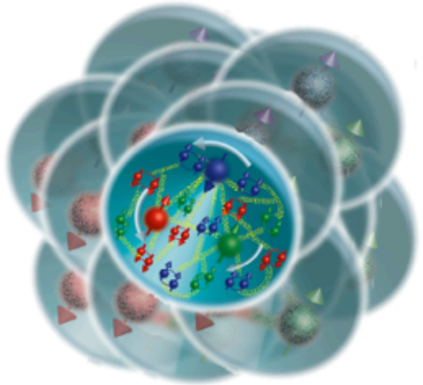
Heavy Flavor
Vary momentum/
mass of probe



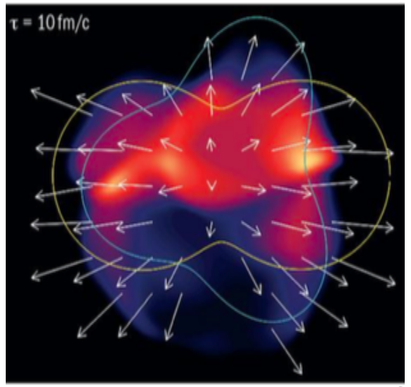
Quarkonia
Vary size of probe



Cold QCD
Study Proton spin, p_T,
cold nuclear effects



Bulk
Study global, local
medium properties



BUP charge

sPHENIX has prepared quantitative run plans for all cryo-week scenarios:

- 20/24/28 weeks in 2024

  ➡ including potential configurations for the additional “six Au+Au weeks from Run 2023 […] carried forward into Run 2024”

- 24/28 weeks in 2025

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STAR: Beam Use Requests for Runs 24-25
sPHENIX: Beam Use Requests for Runs 24-25

The Beam Use Requests should be submitted in written form to PAC by August 25, 2023
by emailing Fran and copy me and John the BUR directly or provide a link to access
the BUR before the due date.

The BURs should be based on the following number of cryo-weeks. For Run 2024, we
ask that you consider three scenarios for 20, 24 and 28 cryo-weeks each, given the
uncertain budgetary situation. Additionally due to the recent Blue Ring valve box
event, we ended Run 2023 in August so six Au+Au weeks from Run 2023 will be carried
forward into Run 2024

For Run 2025, the first number is the proposed RHIC run duration for scenario 1 and
the second number corresponds to optimal duration (scenario 2) presented to the
DOE-ONP in BNL’s FY25 Lab Managers’ Budget Briefing:

2024:  20/24/28 + six weeks of Au+Au
2025:  24 (28)
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Updated charge from ALD, August 2023

Updated guidance from C-AD (1/2)

- The sPHENIX scientific case, including the Beam Use Proposals 2020-2022, have been based on a stable set of quantitative guidance from C-AD
- In August 2023, the C-AD projections were updated in response to what was learned during the 2023 RHIC run

  ➡ sPHENIX is grateful to C-AD for their quick turnaround and clear guidance

  ➡ sPHENIX is continuing close discussions with C-AD to optimize the delivered luminosity to the experiment

Updated guidance from C-AD (2/2)

- The updated guidance results in significantly lower rates of luminosity production *p+p* and Au+Au per running week, although there are uncertainties in the projections

  ➡ Timing has not permitted us to update our broad set of physics projection plots

  ➡ Discussion in sPHENIX has continued after submission of the BUP, leading to serious concerns about the impact on core elements of the RHIC science mission

  ➡ In the following, we will discuss C-AD guidance, updated luminosities, recall some essential physics goals and illustrate the impact of the reduced luminosity on some key measurements

Overview of updated run plan

- Run-2024: transversely polarized *p*+*p* running, with a few options for short Au+Au running
  - ➡ finish commissioning, ColdQCD *p*+*p* program, crucial reference data for AA program
  - ➡ the luminosity projections do not allow for a *p*+Au run in 2024 w/o jeopardizing the core science mission based on *p*+*p* and Au+Au data
- Run-2025: high-luminosity Au+Au running
  - ➡ measurements of jets and heavy flavor observables with unprecedented statistical precision

Table 2.2: Summary of the sPHENIX Beam Use Proposal for 2024 and 2025, as requested in the charge. The values separated by slashes correspond to different cryo-week scenarios (20/24/28 in 2024 and 24/28 in 2025). The 10%-*str* values correspond to the modest streaming readout upgrade of the tracking detectors.

Species	$\sqrt{s_{NN}}$ [GeV]	Physics Weeks	Min. Bias Rec. Lum. $\lvert z\rvert$ <10 cm	Calo. Trigger Lum. $\lvert z\rvert$ <10 cm
Run-2024, Scenario A, 6 cryo-weeks Au+Au + 20/24/28 cryo-weeks *p*+*p*				
Au+Au	200	n/a	n/a (Commissioning running)	
p+*p*	200	13/17/21	0.34/0.44/0.54 pb^{-1} [@ 5kHz] 2.3/3.1/3.9 pb^{-1} [10%-str]	23/31/39 pb^{-1}
Run-2024, Scenario B, 20/24/28 cryo-weeks *p*+*p* + 6 cryo-weeks Au+Au				
p+*p*	200	9/13/17	0.23/0.34/0.44 pb^{-1} [@ 5kHz] 1.5/2.3/3.1 pb^{-1} [10%-str]	15/23/31 pb^{-1}
Au+Au	200	3	0.4 nb^{-1} (3B events)	not needed
Run-2025, 24/28 cryo-weeks				
Au+Au	200	20.5/24.5	5.2/6.3 nb^{-1} (35B/43B events)	not needed

Considerations and Proposal for Run-2024

C-AD guidance for 2024

- Due to the RHIC experience in 2023, C-AD projects that delivered *p+p* luminosity / week will be no better than that achieved in 2015 *p+p*

  ➡ The 2015-best used to be the “2024-worst-case” but is now the “2024-best-case”

  ➡ Approximately a factor of 2 decrease in luminosity production / week

To meet the ColdQCD & AA reference luminosity goals of the sPHENIX science mission, it will be necessary to devote every available* cryo-week in 2024 to *p+p* running

* - except those carried over for Au+Au running

C-AD Projections for *p+p*, pre-2022

Parameter	Unit	FY2015	2022E	2023E	2024E	2025E	2026E	2027E
No of colliding bunches k_b	…	111	111	111	111	111	111	111
Protons/bunch, initial N_b	10^{11}	2.25	2.8	3.0	3.0	3.0	3.0	3.0
Average beam current/ring I_{avg}	mA	312	389	418	418	418	418	418
Stored beam energy	MJ	0.40	0.50	0.54	0.54	0.54	0.54	0.54
Envelope function at IP β^*	m	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Hour glass factor H	…	0.75	0.84	0.84	0.84	0.84	0.84	0.84
Beam-beam parameter ξ/IP	10^{-3}	-9.7	-12.1	-14.9	-14.9	-14.9	-14.9	-14.9
Initial luminosity L_{init}	**10^{30} cm^{-2}s^{-1}**	**115**	**203**	**268**	**268**	**268**	**268**	**268**
Events per bunch-bunch crossing μ	…	0.7	1.2	1.5	1.5	1.5	1.5	1.5
Average/initial luminosity	%	55	60	65	65	65	65	65
Average store luminosity L_{avg}	**10^{30} cm^{-2}s^{-1}**	**63**	**122**	**175**	**175**	**175**	**175**	**175**
Time in store	%	64	60	60	60	60	60	60
Max. luminosity/week	pb^{-1}	25	44	64	64	64	64	64
Min. luminosity/week	pb^{-1}		25	25	25	25	25	25
L within $\|z\|<10$ cm, $\theta = 0$ mrad*	%	16	19	19	19	19	19	19
L within $\|z\|<10$ cm, $\theta = 1$ mrad*	%	15	18	18	18	18	18	18
L within $\|z\|<10$ cm, $\theta = 2$ mrad*	%	14	16	16	16	16	16	16
AGS extraction, P_{max}	%	68	70	70	70	70	70	70
RHIC store average, P_{max}	**%**	**57**	**60**	**60**	**60**	**60**	**60**	**60**
RHIC store average, P_{min}	%		57	57	57	57	57	57

* Luminosity within vertex cut $|z|$ for full crossing angle θ.

C-AD Projections for *p+p*, May ‘22

		p↑+p↑					p↑+Au	
Parameter	Unit	FY2008	2009	2012	2015	2024E	FY2015	2024E
No of colliding bunches k_b	…	109	109	109	111	111	111	111
Protons/bunch, initial N_b	10^{11}	1.5	1.3	1.6	2.25	2.5	225/1.6	250/2.4
Average beam current/ring I_{avg}	mA	198	179	214	312	347	313/176	348/266
Stored beam energy	MJ	0.25	0.23	0.27	0.40	0.45	0.40/0.56	0.45/0.84
Envelope function at IP β^*	m	1.00	0.70	0.85	0.85	0.85	0.85/0.70	0.85/0.70
Hourglass factor H	…	0.77	0.72	0.74	0.75	0.84	0.72	0.72
Beam-beam parameter ξ/IP	10^{-3}	-5.3	-6.3	-5.8	-9.7	-11.7	-5.3/-4.1	-11.7/-4.3
Initial luminosity L_{init}	**10^{30} cm^{-2}s^{-1}**	**35**	**50**	**46**	**115**	**176**	**0.88**	**1.68**
Events per bunch-bunch crossing μ	…	0.2	0.3	0.3	0.7	1.1		
Average/initial luminosity	%	65	56	71	55	57	51	54
Average store luminosity L_{avg}	**10^{30} cm^{-2}s^{-1}**	**23**	**28**	**33**	**63**	**100**	**0.45**	**0.90**
Time in store	%	60	53	59	64	60	65	60
Max. luminosity/week	pb^{-1}	7.5	8.3	9.3	25	36	0.140	0.326
Min. luminosity/week	pb^{-1}					25		0.140
L within $\|z\|<10$ cm, $\theta = 0$ mrad, r_0/r_0*	%					22/22		29/29
L within $\|z\|<10$ cm, $\theta = 2$ mrad, r_0/r_θ*	%					19/69		24/75
AGS extraction, P_{max}	%	55	65	72	68	68	68	68
RHIC store average, P_{max}	**%**	**45**	**56**	**59**	**57**	**60**	**60**	**60**
RHIC store average, P_{min}	%					57		57

* Luminosity $L(z,\theta)$ within vertex cut $|z|$ for full crossing angle θ. The values r_0/r_θ are $r_0 = L(z,\theta)/L(10\text{ m},0)$ and $r_\theta = L(z,\theta)/L(10\text{ m},\theta)$.

C-AD Projections for *p+p*, Aug ‘23

		p↑+p↑					p↑+Au	
Parameter	Unit	FY2008	2009	2012	2015	2024E	FY2015	2024E
No of colliding bunches k_b	…	109	109	109	111	111	111	111
Protons/bunch, initial N_b	10^{11}	1.5	1.3	1.6	2.25	2.5	225/1.6	225/1.6
Envelope function at IP β^*	m	1.00	0.70	0.85	0.85	0.85	0.85/0.70	0.85/0.70
Beam-beam parameter ξ/IP	10^{-3}	-5.3	-6.3	-5.8	-9.7	-9.7	-5.3/-4.1	-5.3/-4.1
Initial luminosity L_{init}	**10^{30} cm^{-2}s^{-1}**	**35**	**50**	**46**	**115**	**115**	**0.88**	**0.88**
Average/initial luminosity	%	65	56	71	55	55	51	51
Average store luminosity L_{avg}	**10^{30} cm^{-2}s^{-1}**	**23**	**28**	**33**	**63**	**63**	**0.45**	**0.45**
Time in store	%	60	53	59	64	64	65	65
Max. luminosity/week	pb^{-1}	7.5	8.3	9.3	25	25	140	140
Min. luminosity/week	pb^{-1}					17		100
$L_{avg}(\theta)/L_{avg}(0)$, full crossing angle $\theta = 1$ mrad	%					0.45		0.37
Max. luminosity/week, $\theta = 1$ mrad						11		51
$L_{avg}(\theta)/L_{avg}(0)$ for full crossing angle $\theta = 2$ mrad	%					0.25		0.19
Max. luminosity/week, $\theta = 2$ mrad						6		27
AGS extraction, P_{max}	%	55	65	72	68	68	68	68
RHIC store average, P_{max}	**%**	**45**	**56**	**59**	**57**	**57**	**60**	**60**

Concluding sPHENIX Commissioning

- sPHENIX made significant progress on commissioning a variety of subsystems in 2023
- Due to the early end of RHIC Run-2023, sPHENIX will need dedicated weeks to finish commissioning ahead of physics data-taking
  - ➡ No expectation of physics at any IP - sPHENIX will need full control over machine (single-beam backgrounds, crossing angle, β^*, lumi ramping, etc.)
  - ➡ This includes *p*+*p*-specific commissioning (local polarimetry, calo trigger, etc.), and potentially short Au+Au fills to prepare for later Au+Au running

System	Before Run 2024	During Run 2024
Trigger	Firmware and software development of calorimeter triggers	First operation of calorimeter triggers with beam
TPC	• FEE firmware completion • tests of zero suppression • completion of MJACK to mitigate SEU • development of digital current • cosmic ray data with and without zero suppression	• Stable operation with HV • collision data with and without zero suppression • testing of digital current and SEU mitigation
DAQ	• Tests with zero suppression in calorimeters and TPC • Throughput and livetime tests with multievent buffering • Development of offline event building • Any additional development needed to achieve routine 15 kHz • Improvements in reliability, data integrity, and error handling	• Tuning of zero supression • Timing of detectors to new triggers • Spin: integrate ZDC, SMD and MBD digital scaler information into GL1
MVTX	• Field off cosmic data for tracking development and alignment • Development of mitigation strategies for background and lock-up	• Field off and field on collision data for tracking development and alignment • Tests of mitigation strategies for background and lock-up
INTT	Field off cosmic data for tracking development and alignment	Field off and field on collision data for tracking development and alignment
EMCal HCal	(HCal) tower-by-tower cosmics analysis	Demonstration of design energy resolution and response uniformity

Table 6: Overview of major commissioning tasks needed with and without beam.

Run-2024 request

The sPHENIX request is for high-luminosity *p+p* running

We consider data recorded via:

1. minimum-bias trigger for all subsystems at fixed rate
2. "streaming readout" of tracking detectors only at fixed fraction of full MB rate
3. calorimeter-triggered readout of rare events, sampling full luminosity

We considered two example Scenarios for including six weeks of Au+Au running (at the start/end of Run-24)

Table 2.2: Summary of the sPHENIX Beam Use Proposal for 2024 and 2025, as requested in the charge. The values separated by slashes correspond to different cryo-week scenarios (20/24/28 in 2024 and 24/28 in 2025). The 10%-*str* values correspond to the modest streaming readout upgrade of the tracking detectors.

Species	$\sqrt{s_{NN}}$ [GeV]	Physics Weeks	Min. Bias Rec. Lum. $\lvert z\rvert$ <10 cm	Calo. Trigger Lum. $\lvert z\rvert$ <10 cm
Run-2024, Scenario A, 6 cryo-weeks Au+Au + 20/24/28 cryo-weeks *p+p*				
Au+Au	200	n/a	n/a (Commissioning running)	
p+p	200	13/17/21	0.34/0.44/0.54 pb^{-1} [@ 5kHz] 2.3/3.1/3.9 pb^{-1} [10%-str]	23/31/39 pb^{-1}
Run-2024, Scenario B, 20/24/28 cryo-weeks *p+p* + 6 cryo-weeks Au+Au				
p+p	200	9/13/17	0.23/0.34/0.44 pb^{-1} [@ 5kHz] 1.5/2.3/3.1 pb^{-1} [10%-str]	15/23/31 pb^{-1}
Au+Au	200	3	0.4 nb^{-1} (3B events)	not needed
Run-2025, 24/28 cryo-weeks				
Au+Au	200	20.5/24.5	5.2/6.3 nb^{-1} (35B/43B events)	not needed

Run-24 request - Scenario A

Species	$\sqrt{s_{NN}}$ [GeV]	Physics Weeks	Min. Bias Rec. Lum. $\lvert z\rvert$ <10 cm	Calo. Trigger Lum. $\lvert z\rvert$ <10 cm
Run-2024, Scenario A, 6 cryo-weeks Au+Au + 20/24/28 cryo-weeks p+p				
Au+Au	200	n/a	n/a (Commissioning running)	
p+p	200	13/17/21	0.34/0.44/0.54 pb^{-1} [@ 5kHz] 2.3/3.1/3.9 pb^{-1} [10%-str]	23/31/39 pb^{-1}
Run-2024, Scenario B, 20/24/28 cryo-weeks p+p + 6 cryo-weeks Au+Au				
p+p	200	9/13/17	0.23/0.34/0.44 pb^{-1} [@ 5kHz] 1.5/2.3/3.1 pb^{-1} [10%-str]	15/23/31 pb^{-1}
Au+Au	200	3	0.4 nb^{-1} (3B events)	not needed

Weeks	Designation
0.5	Cool Down from 50 K to 4 K
2.0	Set-up mode 1 (Au+Au at 200 GeV)
0.5	Ramp-up mode 1 (8 h/night for experiments)
3.0	Outstanding sPHENIX Au+Au Commissioning Time
2.0	Set-up mode 2 (p+p at 200 GeV)
0.5	Ramp-up mode 2 (8 h/night for experiments)
4.0	Dedicated sPHENIX p+p Commissioning Time
13/17/21	Data taking mode 2 (p+p Physics)
0.5	Controlled refrigeration turn-off
20/24/28 (+6 Au+Au)	Total cryo-weeks

Table 2.3: Year 2024 run plan for 20/24/28 (+6 Au+Au) cryo-weeks, Scenario A.

- Begin Run-24 with six weeks of Au+Au
  - ➡ No expectation of Au+Au physics data due to ongoing commissioning
  - ➡ Reserve 4 weeks at start of p+p running for additional system-dependent commissioning

Run-24 request - Scenario B

Note: previous typo in live presentation here, now fixed

Species	$\sqrt{s_{NN}}$ [GeV]	Physics Weeks	Min. Bias Rec. Lum. $\lvert z\rvert$ <10 cm	Calo. Trigger Lum. $\lvert z\rvert$ <10 cm
Run-2024, Scenario A, 6 cryo-weeks Au+Au + 20/24/28 cryo-weeks p+p				
Au+Au	200	n/a	n/a (Commissioning running)	
p+p	200	13/17/21	0.34/0.44/0.54 pb^{-1} [@ 5kHz] 2.3/3.1/3.9 pb^{-1} [10%-str]	23/31/39 pb^{-1}
Run-2024, Scenario B, 20/24/28 cryo-weeks p+p + 6 cryo-weeks Au+Au				
p+p	200	9/13/17	0.23/0.34/0.44 pb^{-1} [@ 5kHz] 1.5/2.3/3.1 pb^{-1} [10%-str]	15/23/31 pb^{-1}
Au+Au	200	3	0.4 nb^{-1} (3B events)	not needed

Weeks	Designation
0.5	Cool Down from 50 K to 4 K
2.0	Set-up mode 1 (p+p at 200 GeV)
0.5	Ramp-up mode 1 (8 h/night for experiments)
8.0	Dedicated sPHENIX p+p Commissioning Time
9/13/17	Data taking mode 1 (p+p Physics)
2.0	Set-up mode 2 (Au+Au at 200 GeV)
0.5	Ramp-up mode 2 (8 h/night for experiments)
3.0	Data taking mode 2 (Au+Au Physics)
0.5	Controlled refrigeration turn-off
20/24/28 (+6 Au+Au)	Total cryo-weeks

Table 2.4: Year 2024 run plan for 20/24/28 (+6 Au+Au) cryo-weeks, Scenario B.

- End Run-24 with six weeks of Au+Au

➡ Reserve 8 weeks at start of *p+p* running to finish sPHENIX commissioning

➡ Opportunity to take Au+Au data with full physics readiness

Run-24 request - other scenarios

- Other possibilities, not explicitly listed in BUP 2023, including:

  ➡ switch to 3-6 weeks of Au+Au running in the middle of the run (avoid summer heat load)

  ➡ under Scenario B, can choose to continue running *p+p* if needed (no Au+Au)

  ➡ half *p+p* / half Au+Au running in both Run-24 and Run-25

Species	$\sqrt{s_{NN}}$ [GeV]	Physics Weeks	Min. Bias Rec. Lum. $\lvert z\rvert$ <10 cm	Calo. Trigger Lum. $\lvert z\rvert$ <10 cm
Run-2024, Scenario A, 6 cryo-weeks Au+Au + 20/24/28 cryo-weeks *p+p*				
Au+Au	200	n/a	n/a (Commissioning running)	
p+p	200	13/17/21	0.34/0.44/0.54 pb^{-1} [@ 5kHz] 2.3/3.1/3.9 pb^{-1} [10%-str]	23/31/39 pb^{-1}
Run-2024, Scenario B, 20/24/28 cryo-weeks *p+p* + 6 cryo-weeks Au+Au				
p+p	200	9/13/17	0.23/0.34/0.44 pb^{-1} [@ 5kHz] 1.5/2.3/3.1 pb^{-1} [10%-str]	15/23/31 pb^{-1}
Au+Au	200	3	0.4 nb^{-1} (3B events)	not needed

We ask the PAC to endorse a flexible approach to Au+Au running in Run-24, depending on machine performance and sPHENIX commissioning progress

Run-2024 request - comparison

sPHENIX BUP 2023

Species	$\sqrt{s_{NN}}$ [GeV]	Physics Weeks	Min. Bias Rec. Lum. $\lvert z\rvert$ <10 cm	Calo. Trigger Lum. $\lvert z\rvert$ <10 cm
Run-2024, Scenario A, 6 cryo-weeks Au+Au + 20/24/28 cryo-weeks p+p				
Au+Au	200	n/a	n/a (Commissioning running)	
p+p	200	13/17/21	0.34/0.44/0.54 pb^{-1} [@ 5kHz] 2.3/3.1/3.9 pb^{-1} [10%-str]	23/31/39 pb^{-1}
Run-2024, Scenario B, 20/24/28 cryo-weeks p+p + 6 cryo-weeks Au+Au				
p+p	200	9/13/17	0.23/0.34/0.44 pb^{-1} [@ 5kHz] 1.5/2.3/3.1 pb^{-1} [10%-str]	15/23/31 pb^{-1}
Au+Au	200	3	0.4 nb^{-1} (3B events)	not needed
Run-2025, 24/28 cryo-weeks				
Au+Au	200	20.5/24.5	5.2/6.3 nb^{-1} (35B/43B events)	not needed

sPHENIX BUP 2022

Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\lvert z\rvert$ <10 cm	Samp. Lum. $\lvert z\rvert$ <10 cm
2023	Au+Au	200	24 (28)	9 (13)	3.7 (5.7) nb^{-1}	4.5 (6.9) nb^{-1}
2024	$p^{\uparrow}p^{\uparrow}$	200	24 (28)	12 (16)	0.3 (0.4) pb^{-1} [5 kHz] 4.5 (6.2) pb^{-1} [10%-*str*]	45 (62) pb^{-1}
2024	$p^{\uparrow}$+Au	200	–	5	0.003 pb^{-1} [5 kHz] 0.01 pb^{-1} [10%-*str*]	0.11 pb^{-1}
2025	Au+Au	200	24 (28)	20.5 (24.5)	13 (15) nb^{-1}	21 (25) nb^{-1}

- Under the most favorable circumstances (Scenario A, 28 cryo-weeks, no p+Au running), sPHENIX will sample ~39 pb^{-1} of p+p data
  - ➡ c.f. 45 pb^{-1} under previous conservative projections (24 cryo-weeks, which includes five weeks of p+Au running)

p+p as reference for Au+Au

Species	Relevant Luminosity	$\langle N_{coll} \rangle$	Effective-$p+p$
$p+p$	39 pb^{-1} (sampled)	1	1.6×10^{12}
Au+Au (min. bias.)	6.3 nb^{-1} (recorded)	250	11×10^{12}

Table 2.6: Comparison of the effective number of $p+p$ collisions from the full data sets from Years 2024 and 2025, assuming the 28 cryo-week scenarios for each. The Au+Au values correspond to the minimum bias case (i.e. all centralities).

- The ratio of expected partonic luminosity between centrality-integrated Au+Au data and *p+p* data is ~6:1

  ➡ Between central Au+Au and *p+p*, it is ~2:1

  ➡ For hadronic final states (R_{AA} ~ 1/2), the ratio in central events is ~1:1

- We therefore stress that any reduction in *p+p* data directly translates into increased uncertainties in the R_{AA}!

Loss of *p*+Au physics in 2024

- Many flagship sPHENIX measurements (γ+jet, *b*-jets, family of Upsilon states) critically rely on large integrated luminosities
- A large *p*+*p* data-set is also needed to reduce systematic uncertainties via, e.g., *in situ* detector studies (track-calo response, γ+jet balance, etc.)
- In 2021, sPHENIX was asked to prepare a BUP under a 20 cryo-week scenario in 2024. Under that scenario, sPHENIX was forced to remove all *p*+Au running to preserve the needed *p*+*p* luminosity.
- The reduced projections now preclude *p*+Au running even in 28wk scenario

  ➡ There is a significant cost to switching species & the projected *p*+Au luminosity/week has also decreased significantly (> factor of 2)

  ➡ Splitting 2024 running between *p*+*p* and *p*+Au will result in not meeting the luminosity target for either system

Loss of *p*+Au physics in 2024

- Many flagship sPHENIX measurements (γ+jet, *b*-jets, family of Upsilon states) critically rely on large integrated luminosities
- A large *p*+*p* data-set is also needed to reduce systematic uncertainties via, e.g., *in situ* detector studies (track-calo response, γ+jet balance, etc.)
- In rio in g to pr

We ask the PAC to encourage Brookhaven to look broadly and aggressively for an opportunity for high-luminosity *p*+Au data-taking beyond the currently considered 2024 and 2025 cryo-week allocations

  - ➡ The reduced projections now preclude *p*+Au running even for the 28wk scenario.
  - ➡ Significant cost to switching species & *p*+Au lumi projections have decreased
  - ➡ Splitting 2024 running between *p*+*p* and *p*+Au will result in not meeting the luminosity target for either system

Considerations and Proposal for Run-2025

C-AD guidance for 2025

- Due to the RHIC experience in 2023, C-AD projects that delivered luminosity / week will be no better than that achieved in 2016 Au+Au

  ➡ Factor of ~2.3 reduction from 2022 projections

- Additionally, the luminosity decrease under a finite crossing angle (previous sPHENIX plan $\theta = 2$ mrad) was found to be significantly lower than expected

  ➡ Another factor of ~2.6 reduction

C-AD Projections for Au+Au, Dec '22

Parameter	Unit	FY2007	2010	2011	2014	2016	2023E	2025E
No of bunches k_b	…	103	111	111	111	111	111	111
Ions/bunch, initial N_b	10^9	1.1	1.1	1.3	1.6	2.0	2.4	2.90
Average beam current/ring I_{avg}	mA	112	121	147	176	224	265	319
Stored beam energy	MJ	0.36	0.39	0.47	0.56	0.71	0.84	1.0
Envelope function at IP β^*	m	0.85	0.75	0.75	0.70	0.70	0.70	0.65
Beam-beam parameter ξ/IP	10^{-3}	-1.7	-1.5	-2.1	-2.5	-3.9	-4.6	-5.6
Initial luminosity L_{init}	**10^{26} cm^{-2}s^{-1}**	**30**	**40**	**50**	**80**	**155**	**215**	**336**
Events per bunch-bunch crossing μ	…	0.08	0.10	0.13	0.21	0.40	0.55	0.86
Average/initial luminosity	%	40	50	60	62	56	58	60
Average store luminosity L_{avg}	**10^{26} cm^{-2}s^{-1}**	**12**	**20**	**30**	**50**	**87**	**125**	**200**
Time in store	%	48	53	59	68	65	60	60
Max. luminosity/week	μb^{-1}	380	650	1000	2200	3000	4530	7260
Min. luminosity/week	μb^{-1}						3000	3000
L within $\|z\|$<10 cm, θ = 0 mrad, r_0/r_θ*	%						39/39	39/39
L within $\|z\|$<10 cm, θ = 2 mrad, r_0/r_θ*	%						31/81	31/81

* Luminosity $L(z,\theta)$ within vertex cut $|z|$ for full crossing angle θ. The values r_0/r_θ are $r_0 = L(z,\theta)/L(10\text{ m},0)$ and $r_\theta = L(z,\theta)/L(10\text{ m},\theta)$.

C-AD Projections for Au+Au, Aug '23

Parameter	Unit	FY2007	2010	2011	2014	2016	2023E	2025E
No of bunches k_b	…	103	111	111	111	111	111	111
Ions/bunch, initial N_b	10^9	1.1	1.1	1.3	1.6	2.0	1.65	1.8
Envelope function at IP β^*	m	0.85	0.75	0.75	0.70	0.70	0.70	0.70
Beam-beam parameter ξ/IP	10^{-3}	-1.7	-1.5	-2.1	-2.5	-3.9	-3.2	-3.5
Initial luminosity L_{init}	**10^{26} cm^{-2}s^{-1}**	**30**	**40**	**50**	**80**	**155**	**101**	**120**
Average/initial luminosity	%	40	50	60	62	56	56	60
Average store luminosity L_{avg}	**10^{26} cm^{-2}s^{-1}**	**12**	**20**	**30**	**50**	**87**	**57**	**72**
Time in store	%	48	53	59	68	65	50	60
Max. luminosity/week	μb^{-1}	380	650	1000	2200	3000	1700	2600
Min. luminosity/week	μb^{-1}							1820
$L_{avg}(\theta)/L_{avg}(0)$, full crossing angle θ = 1 mrad	%						30	30
Max. luminosity/week, θ = 1 mrad							510	780
$L_{avg}(\theta)/L_{avg}(0)$ for full crossing angle θ = 2 mrad	%						15	15
Max. luminosity/week, θ = 2 mrad							255	390

However, impact to sPHENIX science is smaller due to mitigating factors (next slides)

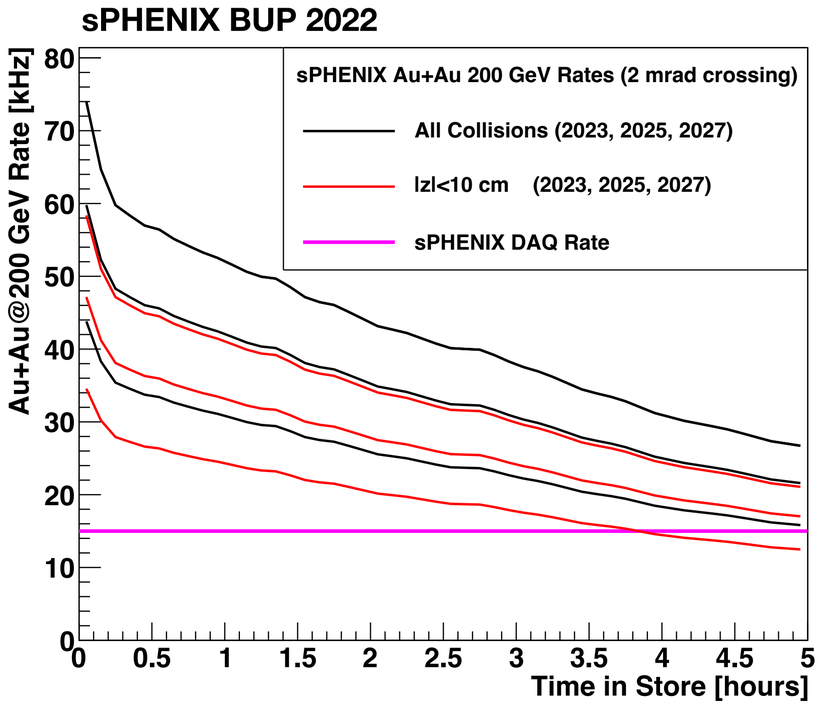
Re-optimizing Au+Au crossing angle

Crossing angle θ	$L(\theta,\ \text{all } z)/L(\theta = 0,\ \text{all } z)$	$L(\theta, \lvert z\rvert < 10\ \text{cm})/L(\theta,\ \text{all } z)$	σ_z in sPHENIX [cm]	Lumi/Week all z [μb^{-1}]	Lumi/Week ($\lvert z\rvert < 10$ cm) [μb^{-1}]
0 mrad	1.0	0.30	26	2210	660
1 mrad	0.30	0.52	14	660	340
2 mrad	0.15	0.79	8	330	260

Recover narrow-vertex luminosity while keeping all-vertex lumi below TPC limit

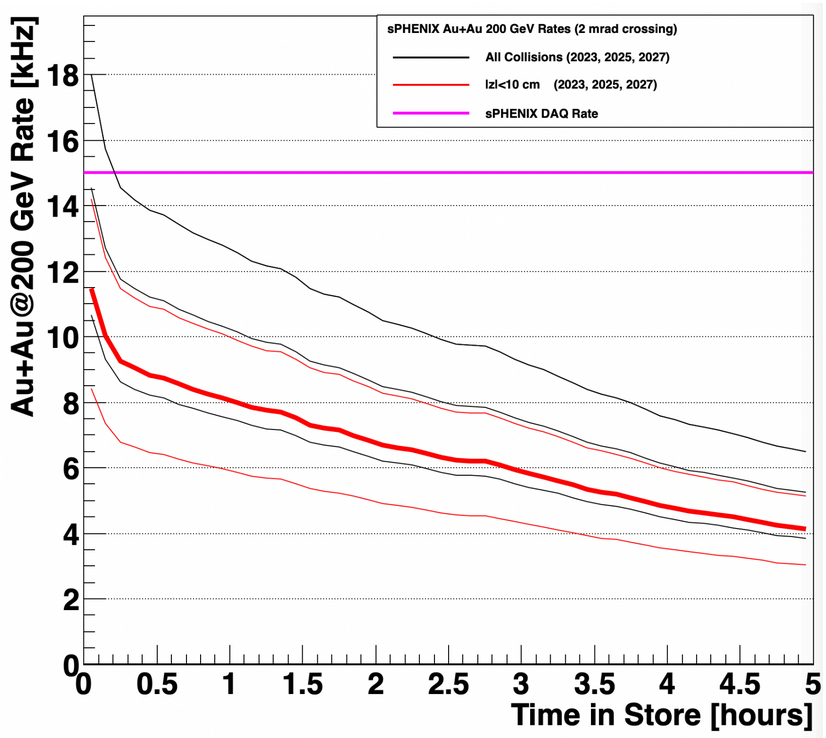
- Previous sPHENIX BUP used $\theta = 2$ mrad beam-beam crossing angle to greatly decrease the rate of large-z_{vtx} interactions (which contribute to TPC IBF but are not usable for physics) with respect to those in $|z_{\text{vtz}}| < 10$ cm
- Given the overall lower rates, this choice could be re-optimized to recover luminosity in the narrow vertex ($|z_{\text{vtz}}| < 10$ cm)
- In the BUP 2023, we use $\theta = 1$ mrad (recover +30%), but exact value to be optimized in discussions with C-AD and TPC sub-system experts

Au+Au trigger strategy



Previous sPHENIX strategy: saturate 15kHz DAQ bandwidth to record min bias collisions (& sample others with EM trigger for γ physics)

Preliminary study by J. Nagle



However, the lower rates will fall within the DAQ limit (TBC with detailed luminosity profile from C-AD)

$\Rightarrow$ thus, for pure min-bias collisions, the impact to sPHENIX is partially mitigated

Run-2025 Au+Au request

sPHENIX BUP 2023

Weeks	Designation
0.5	Cool Down from 50 K to 4 K
2.0	Set-up mode 1 (Au+Au at 200 GeV)
0.5	Ramp-up mode 1 (8 h/night for experiments)
20.5/24.5	Au+Au Data taking (Physics)
0.5	Controlled refrigeration turn-off
24/28	Total cryo-weeks

Table 2.5: Year 2025 run plan for 24/28 cryo-weeks with Au+Au 200 GeV collisions.

sPHENIX BUP 2023

Species	$\sqrt{s_{NN}}$ [GeV]	Physics Weeks	Min. Bias Rec. Lum. $\lvert z\rvert$ <10 cm	Calo. Trigger Lum. $\lvert z\rvert$ <10 cm
Run-2024, Scenario A, 6 cryo-weeks Au+Au + 20/24/28 cryo-weeks p+p				
Au+Au	200	n/a	n/a (Commissioning running)	
p+p	200	13/17/21	0.34/0.44/0.54 pb^{-1} [@ 5kHz] 2.3/3.1/3.9 pb^{-1} [10%-str]	23/31/39 pb^{-1}
Run-2024, Scenario B, 20/24/28 cryo-weeks p+p + 6 cryo-weeks Au+Au				
p+p	200	9/13/17	0.23/0.34/0.44 pb^{-1} [@ 5kHz] 1.5/2.3/3.1 pb^{-1} [10%-str]	15/23/31 pb^{-1}
Au+Au	200	3	0.4 nb^{-1} (3B events)	not needed
Run-2025, 24/28 cryo-weeks				
Au+Au	200	20.5/24.5	5.2/6.3 nb^{-1} (35B/43B events)	not needed

- Run full-energy Au+Au collisions for the entire duration
- Collect ~6.3 nb^{-1} / ~43B min-bias Au+Au events in a 28 cryo-week scenario

Run-2025 Au+Au request - comparison

sPHENIX BUP 2023

Species	$\sqrt{s_{NN}}$ [GeV]	Physics Weeks	Min. Bias Rec. Lum. $\lvert z\rvert$ <10 cm	Calo. Trigger Lum. $\lvert z\rvert$ <10 cm
Run-2024, Scenario A, 6 cryo-weeks Au+Au + 20/24/28 cryo-weeks p+p				
Au+Au	200	n/a	n/a (Commissioning running)	
p+p	200	13/17/21	0.34/0.44/0.54 pb^{-1} [@ 5kHz] 2.3/3.1/3.9 pb^{-1} [10%-str]	23/31/39 pb^{-1}
Run-2024, Scenario B, 20/24/28 cryo-weeks p+p + 6 cryo-weeks Au+Au				
p+p	200	9/13/17	0.23/0.34/0.44 pb^{-1} [@ 5kHz] 1.5/2.3/3.1 pb^{-1} [10%-str]	15/23/31 pb^{-1}
Au+Au	200	3	0.4 nb^{-1} (3B events)	not needed
Run-2025, 24/28 cryo-weeks				
Au+Au	200	20.5/24.5	5.2/6.3 nb^{-1} (35B/43B events)	not needed

sPHENIX BUP 2022

Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\lvert z\rvert$ <10 cm	Samp. Lum. $\lvert z\rvert$ <10 cm
2023	Au+Au	200	24 (28)	9 (13)	3.7 (5.7) nb^{-1}	4.5 (6.9) nb^{-1}
2024	$p^{\uparrow}p^{\uparrow}$	200	24 (28)	12 (16)	0.3 (0.4) pb^{-1} [5 kHz] 4.5 (6.2) pb^{-1} [10%-*str*]	45 (62) pb^{-1}
2024	$p^{\uparrow}$+Au	200	–	5	0.003 pb^{-1} [5 kHz] 0.01 pb^{-1} [10%-*str*]	0.11 pb^{-1}
2025	Au+Au	200	24 (28)	20.5 (24.5)	13 (15) nb^{-1}	21 (25) nb^{-1}

- Collect ~6.3 nb^{-1} / ~43B min-bias Au+Au events in a 28 cryo-week scenario
  - ➡ c.f. 15 nb^{-1} / 100 B under previous projections — x2.4 reduction
  - ➡ For photon-triggered observables specifically, x4 reduction

Run-2025 Au+Au request - comparison

sPHENIX BUP 2023

Species	$\sqrt{s_{NN}}$ [GeV]	Physics Weeks	Min. Bias Rec. Lum. $\lvert z\rvert$ <10 cm	Calo. Trigger Lum. $\lvert z\rvert$ <10 cm
Run-2024, Scenario A, 6 cryo-weeks Au+Au + 20/24/28 cryo-weeks p+p				
Au+				
p+				
Run-				
p+				
Au+				
Run-2025, 24/28 cryo-weeks				
Au+Au	200	20.5/24.5	5.2/6.3 nb^{-1} (35B/43B events)	not needed

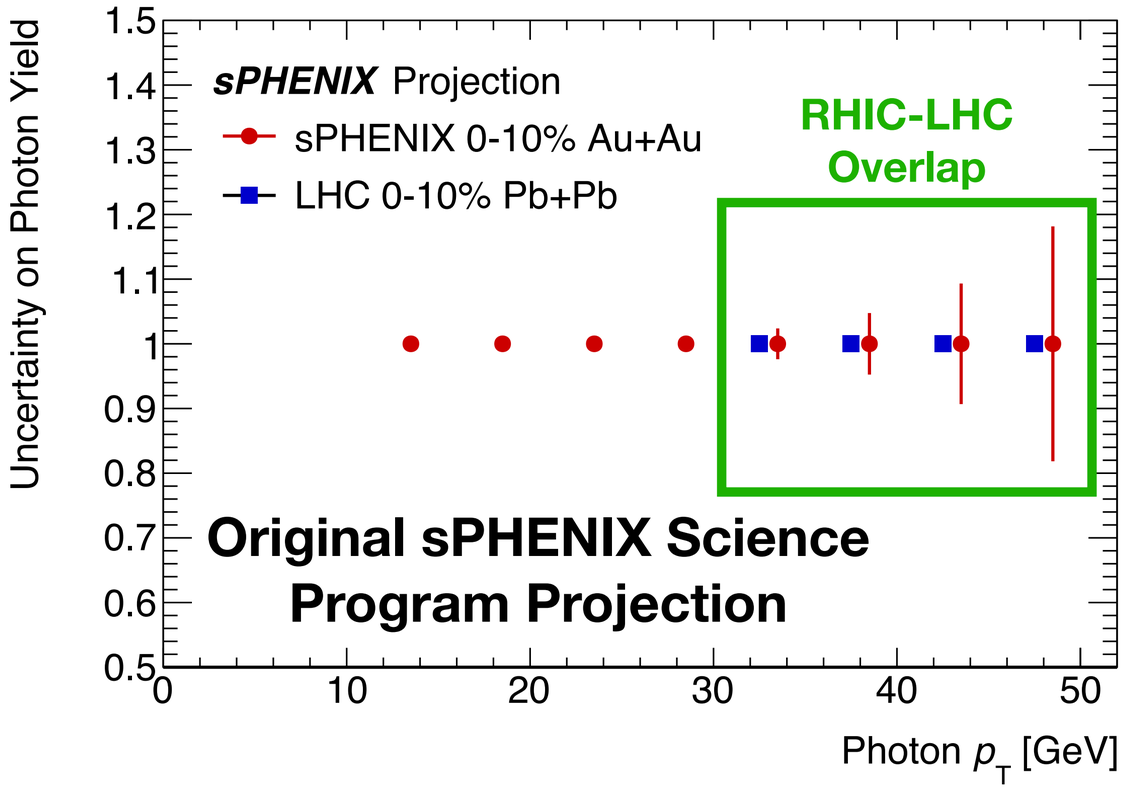
sPHENIX BUP 2022

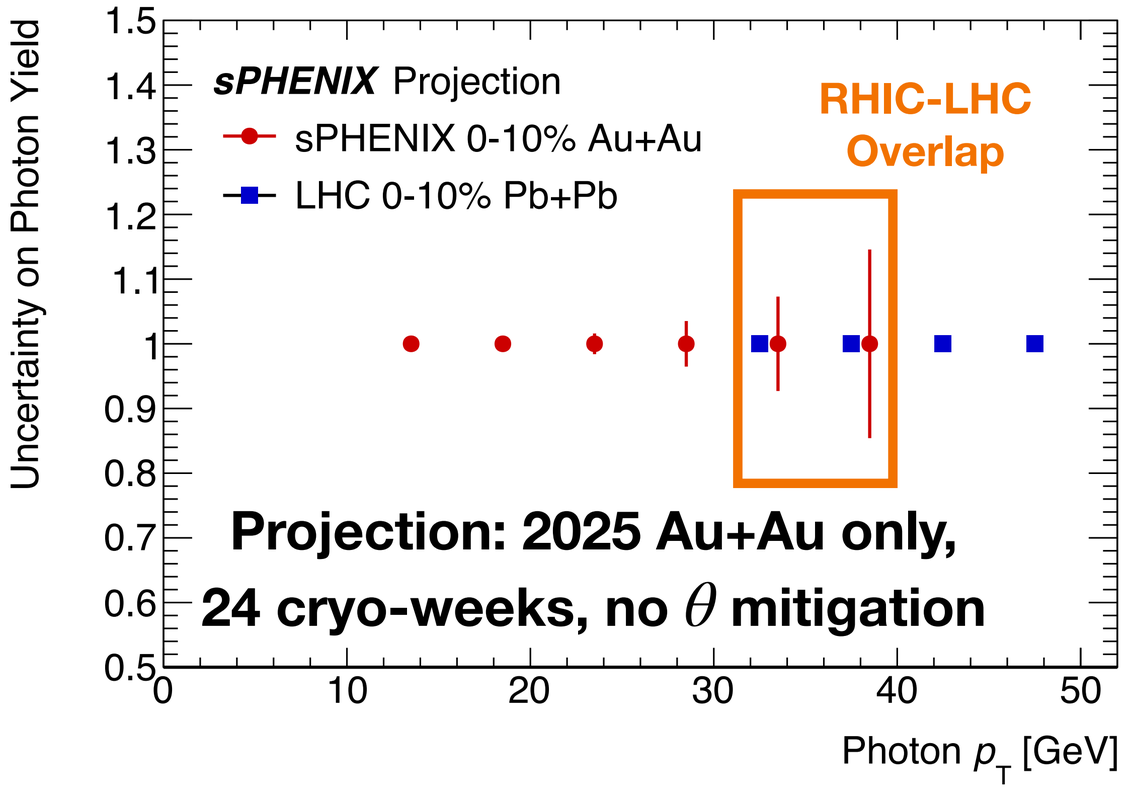
Year	Species	$\sqrt{s_{NN}}$ [GeV]	Cryo Weeks	Physics Weeks	Rec. Lum. $\lvert z\rvert$ <10 cm	Samp. Lum. $\lvert z\rvert$ <10 cm
						9) nb^{-1}
						) pb^{-1}
						pb^{-1}
						21 (23) nb^{-1}

- We ask the PAC to encourage Brookhaven to look broadly and aggressively for ways to provide additional integrated Au+Au luminosity
- In the next two slides, we give examples of flagship measurements (γ+jet and Υ production) and discuss the severe impact a failure to recover the expected luminosity can have

- Collect ~6.3 nb^{-1} / ~43B min-bias Au+Au events in a 28 cryo-week scenario
  - ➡ c.f. 15 nb^{-1} / 100 B under previous projections — x2.4 reduction
  - ➡ For photon-triggered observables specifically, x4 reduction

Impact on RHIC science mission (1/2)

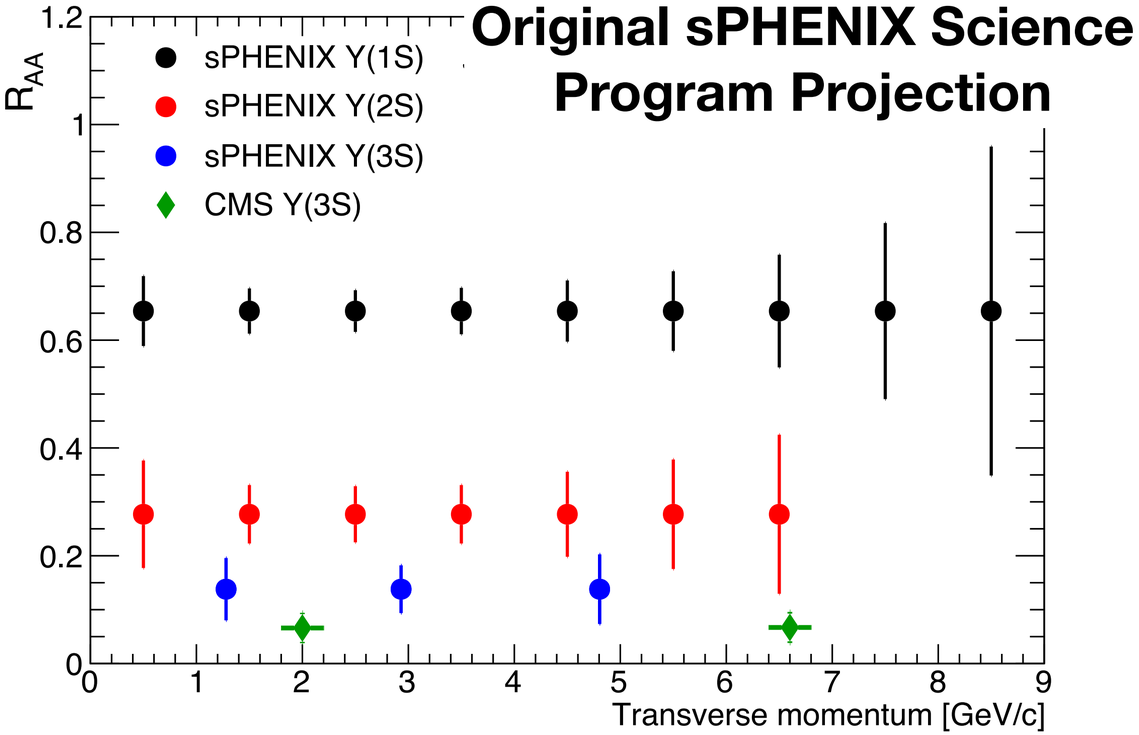


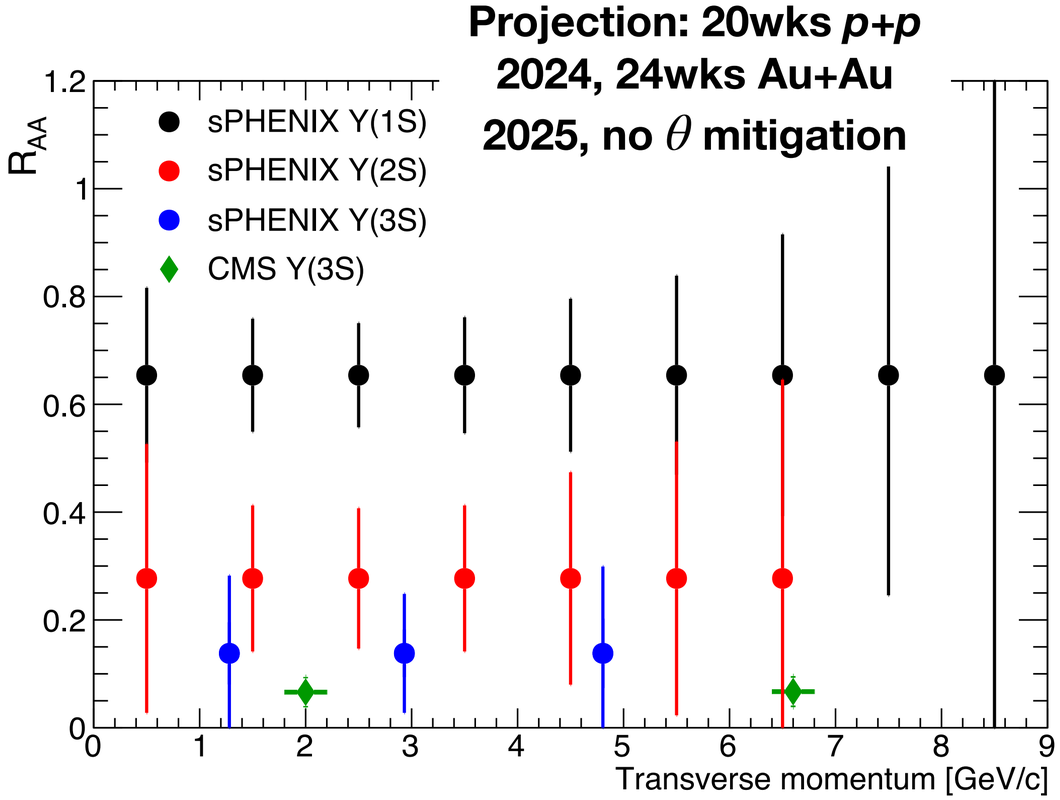


- Key mandate of the Long-Range Plan: large kinematic overlap between RHIC and LHC to constrain temperature-dependence of the QGP in detail

  ➡ For photon+jets (flagship LHC HI and sPHENIX measurement), the worst case projections threaten to cut this overlap range to only 10 GeV

Impact on RHIC science mission (2/2)





➡ For Upsilon suppression, greatly degrade kinematic dependence for $\Upsilon(1S)$ and $\Upsilon(2S)$, lose ability to distinguish surviving $\Upsilon(3S)$ above background

➡ These examples illustrate the risk to the "essential" [2015 LRP] complementarity between RHIC and LHC (c.f. CMS $\Upsilon(3S)$)

CMS: nucl-ex/2303.17026

Selected physics projections

Hard process yields

Signal	Au+Au 0–10% Counts	p+p Counts
Jets $p_{\mathrm{T}} > 20$ GeV	6 800 000 ($R_{\mathrm{AA}} = 0.4$)	6 700 000
Jets $p_{\mathrm{T}} > 40$ GeV	20 000 ($R_{\mathrm{AA}} = 0.4$)	19 000
Direct Photons $p_{\mathrm{T}} > 20$ GeV	9 200 ($R_{\mathrm{AA}} = 1$)	3 700
Charged Hadrons $p_{\mathrm{T}} > 25$ GeV	1 300 ($R_{\mathrm{AA}} = 0.2$)	2 600

Updated w/ August 2023 projections

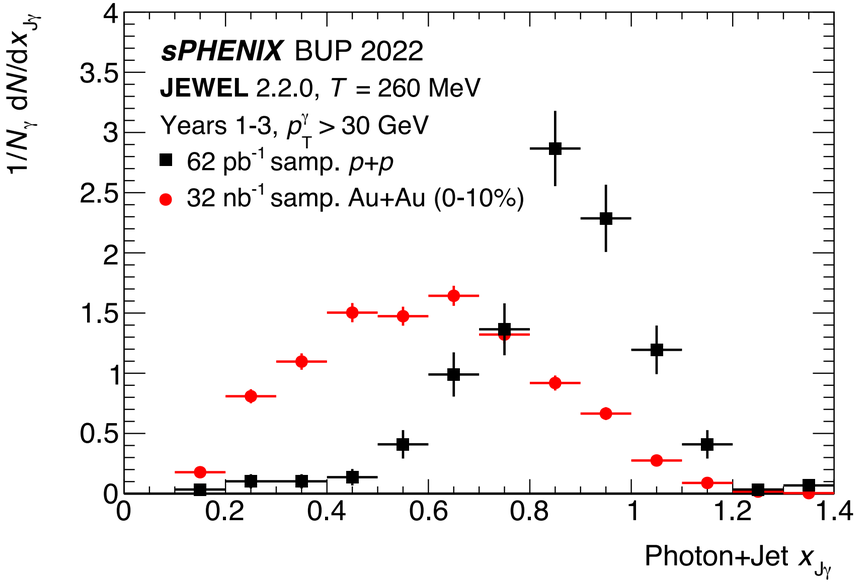
The projected luminosity provides for inclusive R_{AA} measurements over a wide range, and large samples of final states for detailed study

The Figures of projected measurements in BUP 2023 are unchanged from the BUP 2022. To account for the reduced luminosity projections:

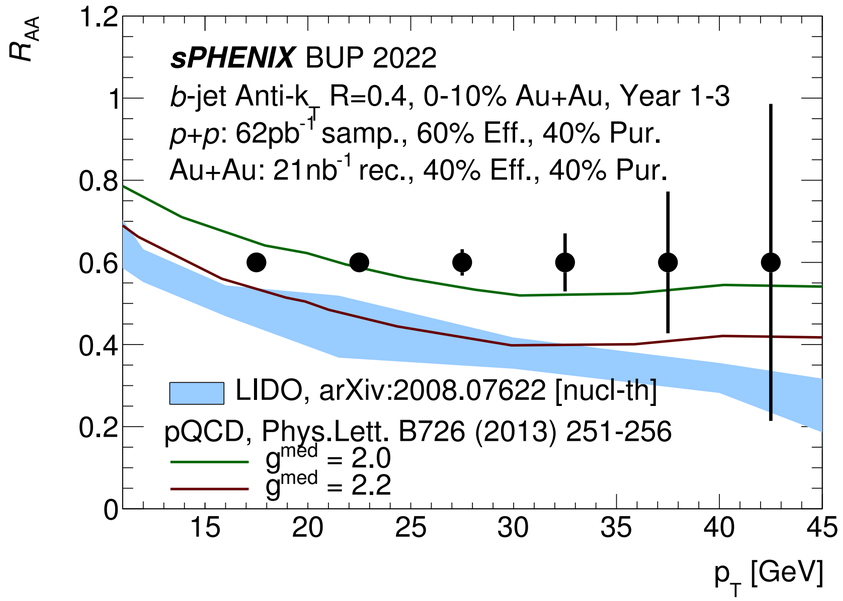
- For measurements in p+p data only: statistical uncertainty x1.25
- Most measurements in Au+Au data: statistical uncertainty x1.8
- For photon/photon+jets in Au+Au data: statistical uncertainty x2.4

Note: not updated for August 2023 luminosity projections!

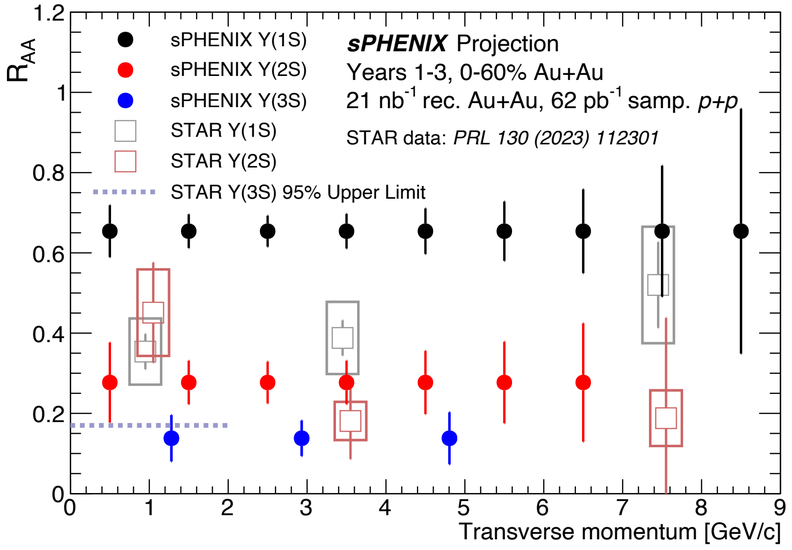
Flagship measurements



γ+jet "golden channel" for calibrated study of jet-medium interaction!



Fully reconstructed *b*-jet tagging - completely new channel at RHIC!

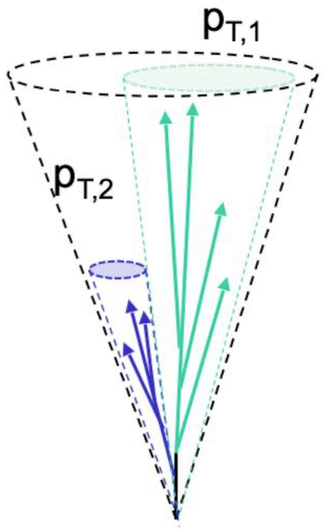


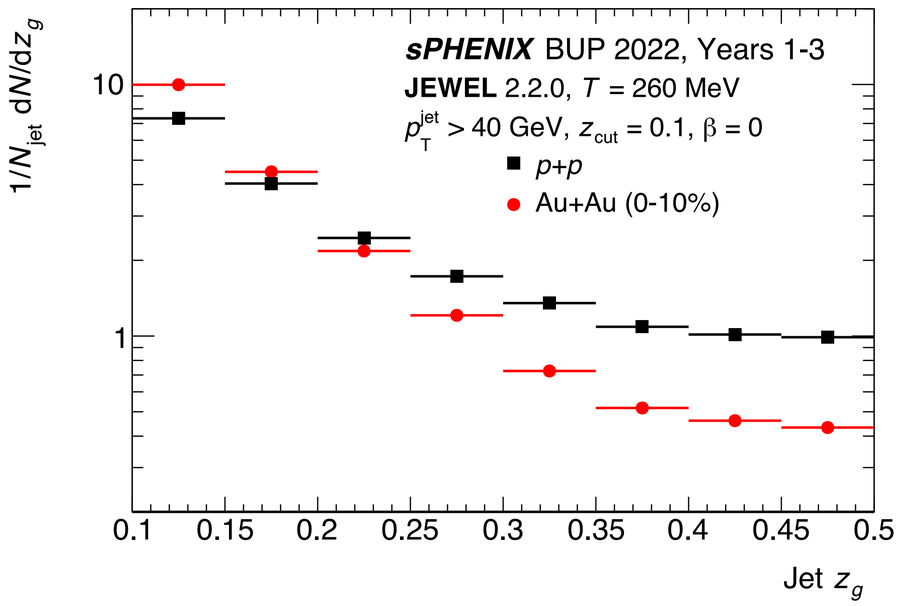
Opportunity to make definitive observation of surviving $\Upsilon(3S)$!

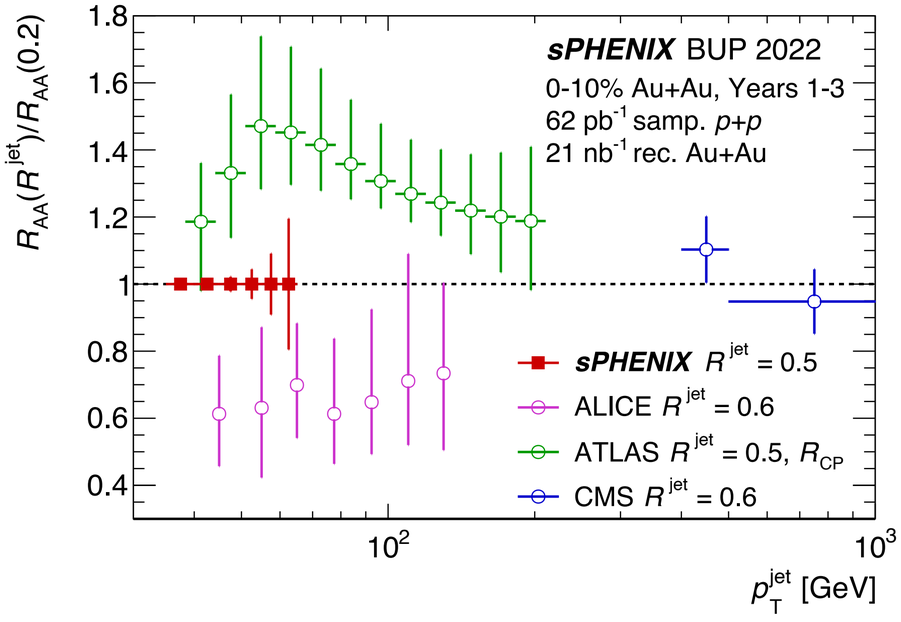
All of these crucially rely on the highest possible *p*+*p* and Au+Au luminosities

Note: not updated for August 2023 luminosity projections!

Jet physics







Sub-jet fraction z_g for >40 GeV jets

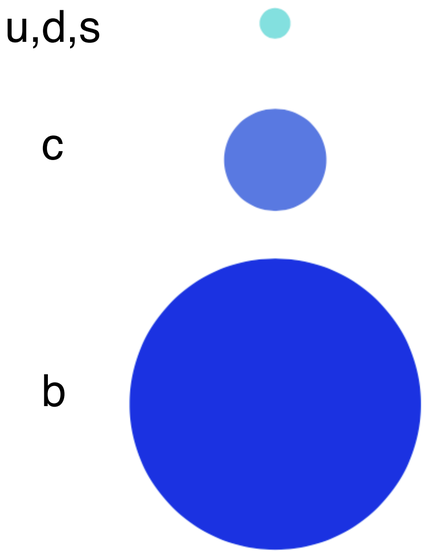
Very large yield for inclusive jet (sub-)structure - full variety of measurements limited only by creativity!

Double-R_{AA} ratio for Large-R jets

Resolve LHC tension in this key observable - in the region where physics effects are largest

Note: not updated for August 2023 luminosity projections!

Heavy flavor physics



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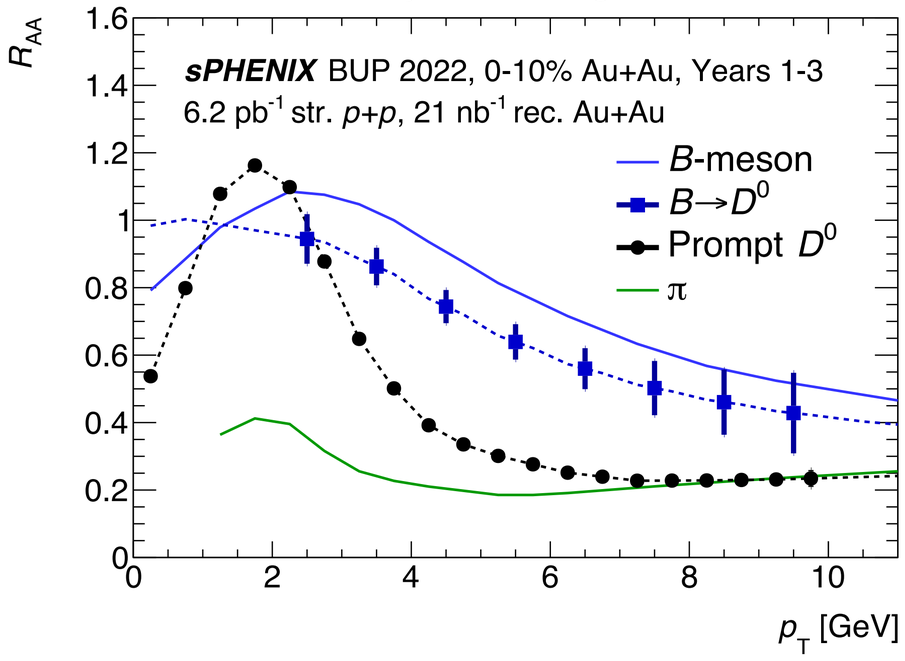

Prompt and non-prompt D^0 reconstruction over a wide kinematic range

Determine the mass effect & precision study of heavy quark diffusion

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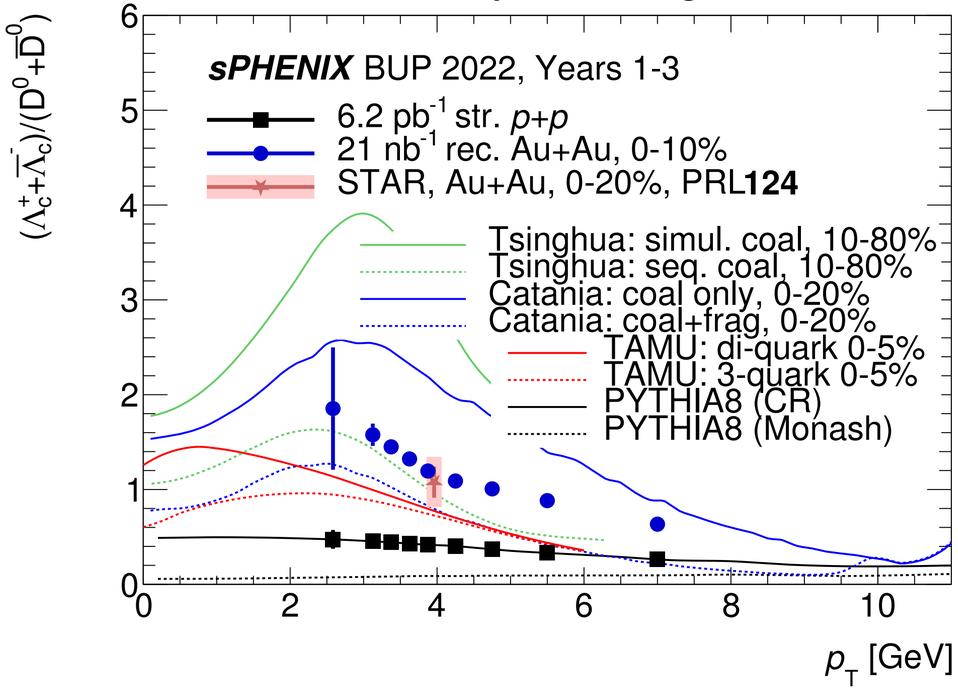
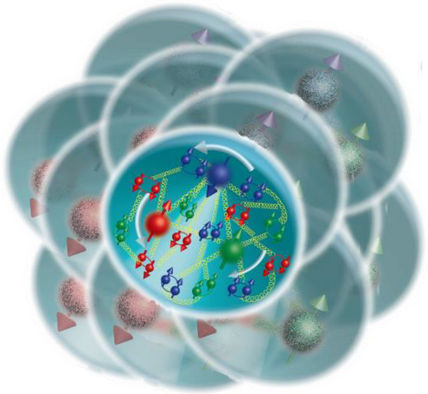


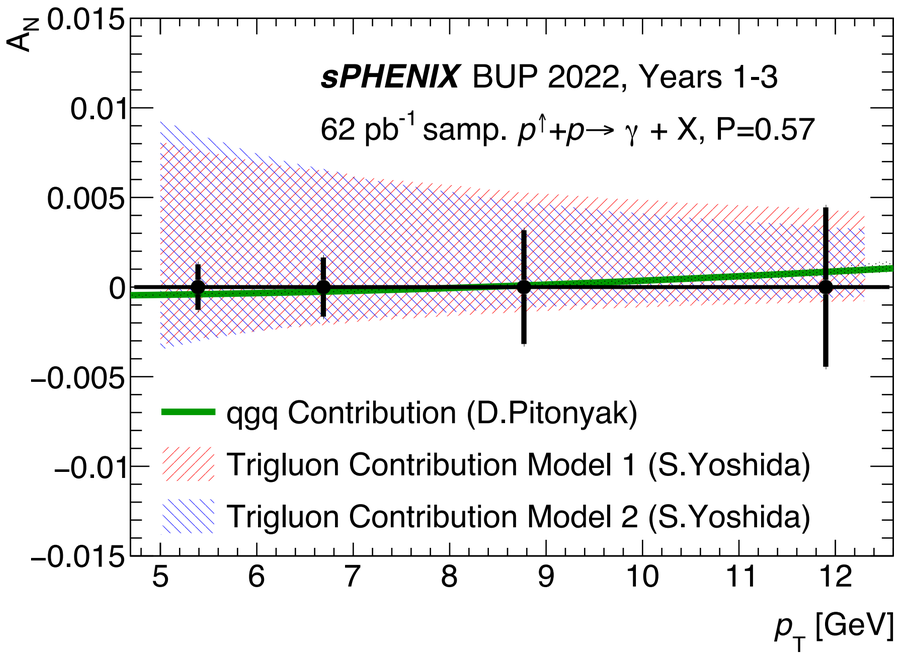
In-medium hadronization of heavy quarks

With measured *p*+*p* baseline

Note: not updated for August 2023 luminosity projections!

p+p: polarized observables





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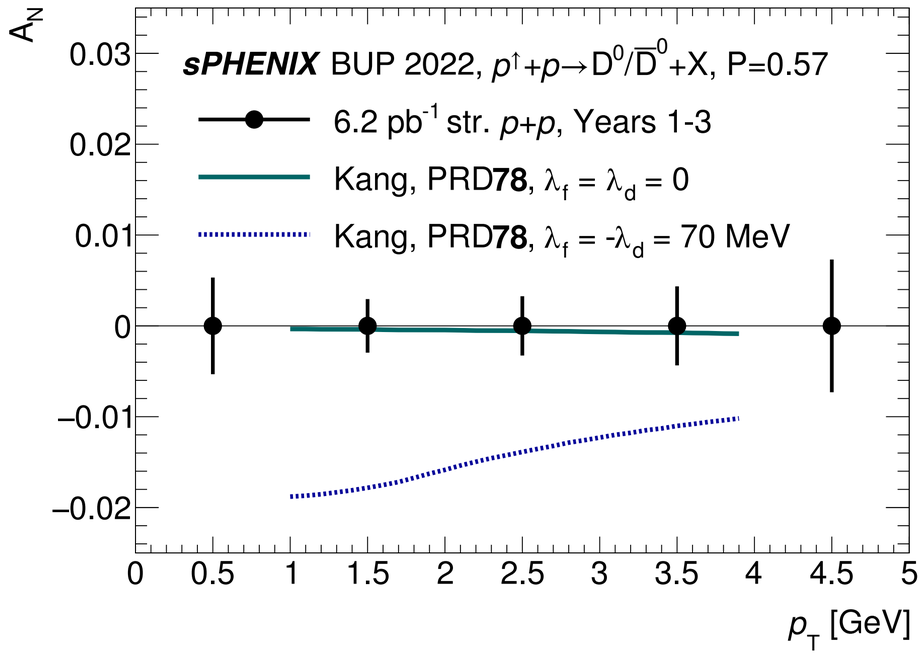


- Use sPHENIX capabilities for TSSA of direct photons (left) and heavy flavor hadrons (right) - probe gluon dynamics in transversely polarized nucleons through tri-gluon correlation function

  ➡connected with the poorly constrained gluon Sivers TMD function

  ➡check universality with HF A_N at the EIC

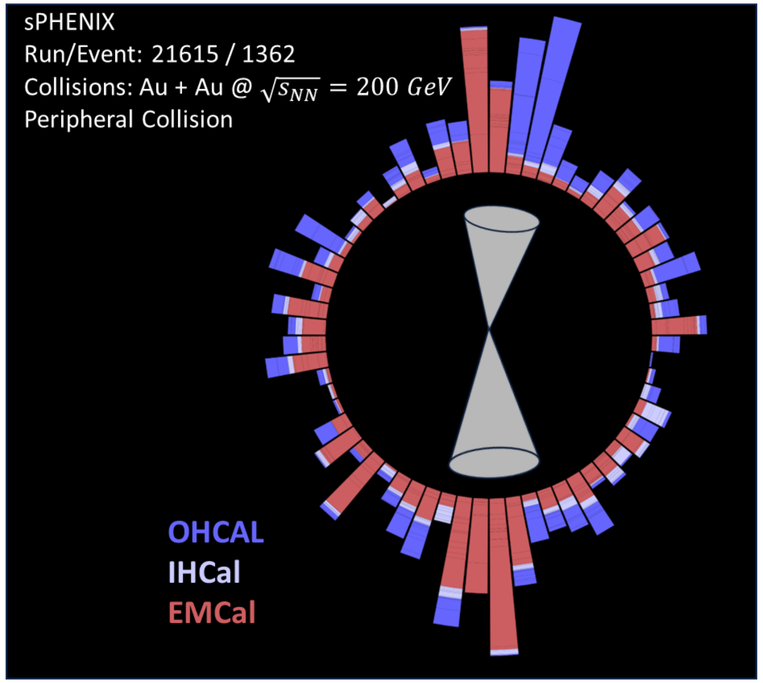
Outlook for PAC (1/2)

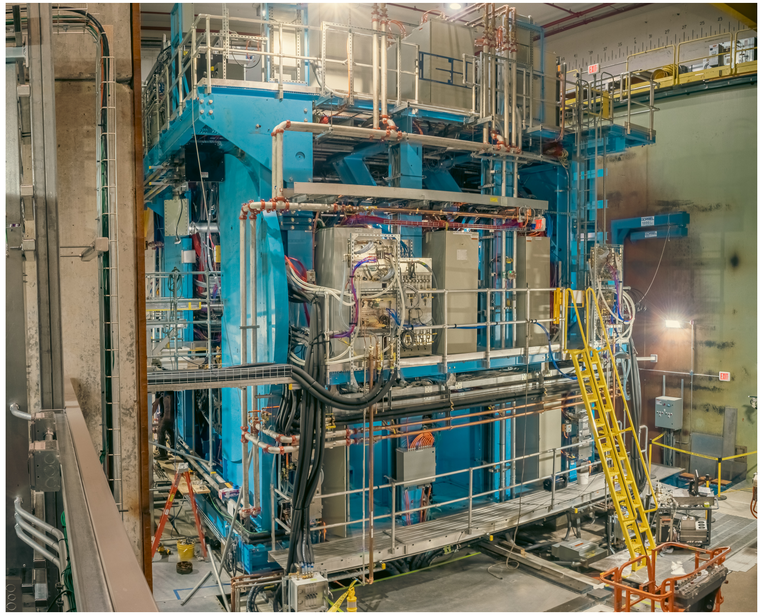
In response to the developments with RHIC, this Beam Use Proposal outlines a specific plan to deliver the impactful physics in 2024-2025, and we continue to work with C-AD to further optimize the available luminosity

sPHENIX will be able to perform a broad range of new jet, HF and Cold QCD measurements

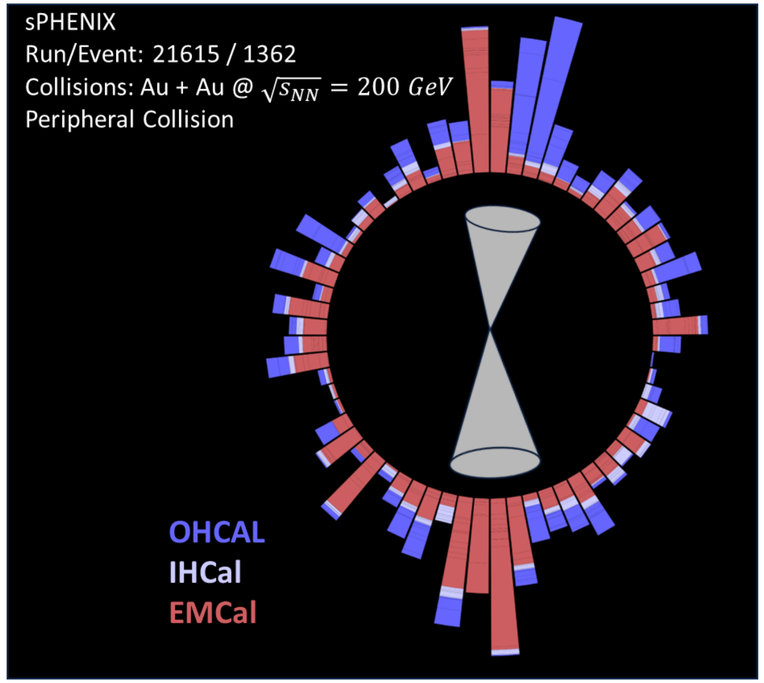
This exciting physics program requires dedicated time to finish detector commissioning

A large *p*+*p* data sample in Run-2024 is critical to success of entire scientific program - no space for *p*+Au running within the current cryo-week allocations





Outlook for PAC (2/2)



The lowered Au+Au and *p*+*p* projections put <u>key elements of the RHIC science mission as defined in the LRP at risk</u>, including the direct overlap of γ+jet and Υ physics with the LHC

We ask the PAC to recommend an aggressive and broad effort by BNL to maximize the available cryo-weeks, ideally beyond the current plans in 2024/2025

…and to ensure sufficient resources for CA-D to improve upon current reduced luminosity expectations