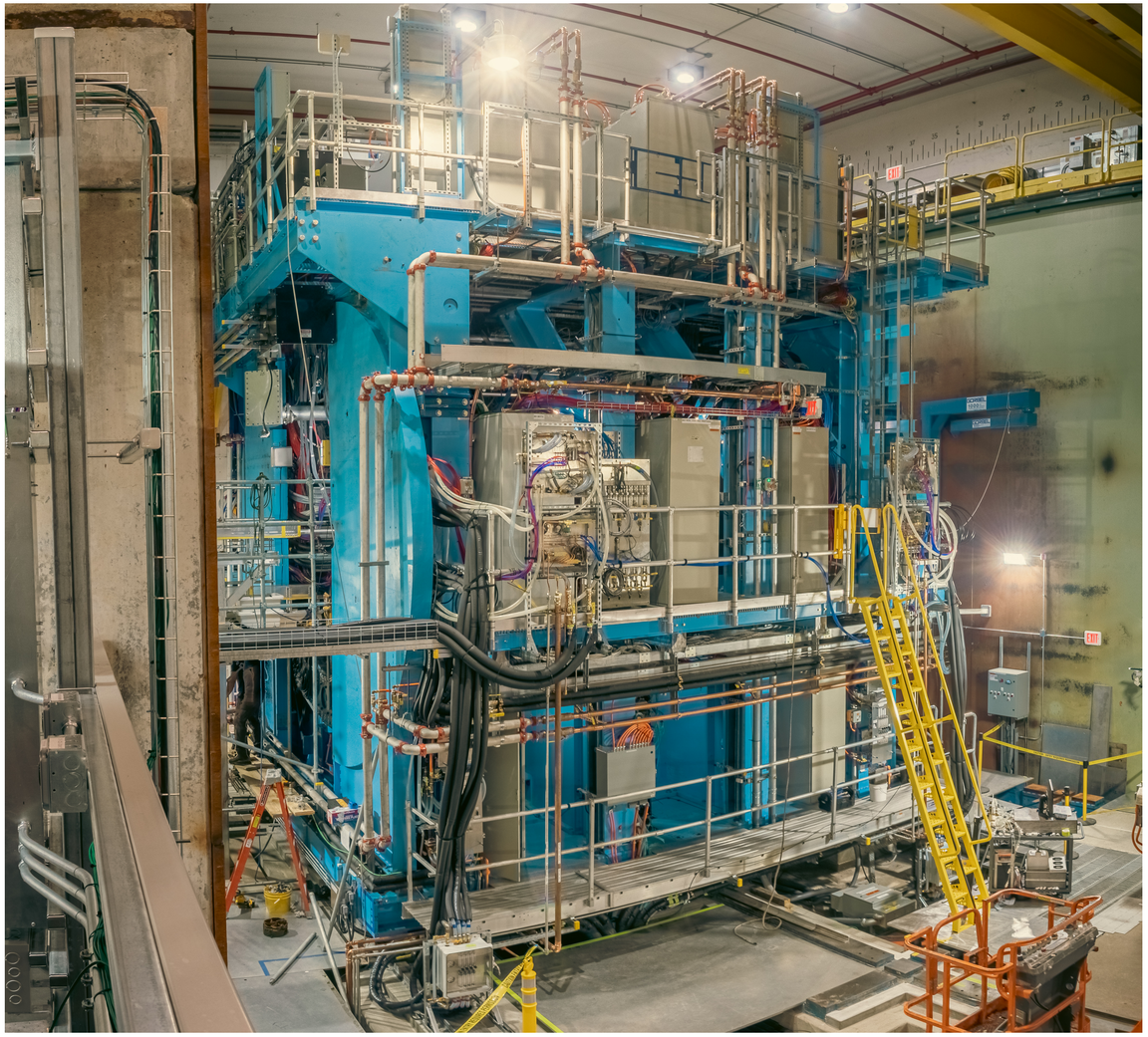
sPHENIX

Beam Use Request for Runs 25-26



BNL NPP Physics Advisory Committee (PAC) Meeting

7 November 2024

Dennis V. Perepelitsa (University of Colorado Boulder)

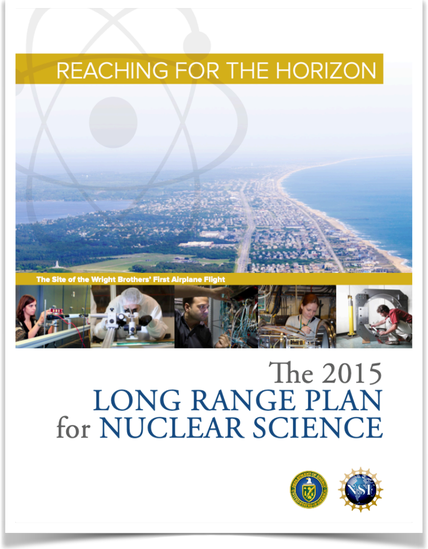
sPHENIX science drivers

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

- Continuing effective operation of the national user facilities ATLAS, CEBAF, and FRIB, and completing the RHIC science program, pushing the frontiers of human knowledge.

2023 US NP LRP



sPHENIX is recognized by the U.S. Nuclear Physics community as the *essential* tool for completing the mission of QGP microscopy at RHIC, based on:

➡ Multi-scale probes (jets over a wide kinematic range, heavy flavor, quarkonia)

➡ Complementarity with the LHC

Collected Run-24 *p+p* datasets

- sPHENIX is grateful to BNL, NPP, and C-AD for enabling an outstanding Run-24, in which we concluded commissioning in *p+p* and took high-quality physics data!
- Run-24 was a significant, but qualified, success in partially reaching the PAC-recommended luminosity targets for our *p+p* reference dataset from BUP'23

Physics program	Luminosity	% BUP23 Goal	Detector and Beam Conditions
Photons, jets, neutral mesons (HCal unique at RHIC)	107 pb^{-1} Sampled	240%	Calo+Global, Triggered, 0mrad + 1.5mrad, wide vertex
Jet+track structure, quarkonia, *b*-jets	13 pb^{-1} Sampled	30%	All sub-systems, Triggered, 1.5mrad, $\lvert z \rvert < 10$ cm
Open heavy flavor (RHIC-unique dataset)	2.9 pb^{-1} Recorded	65%	Trackers, Streaming, 1.5mrad, $\lvert z \rvert < 10$ cm

Evolution of projected Au+Au luminosity

- The scientific case for sPHENIX relies on successfully accumulating a very large Au+Au dataset in Run-25

  ➡ Particularly important for unique, flagship measurements of photon-tagged jet quenching, open beauty, Upsilon excited states

  ➡ For many measurements, expect a key RHIC-LHC complementarity from the overlap of sPHENIX and LHC measurements

- In BUP exercises 2020-22, the projected Au+Au luminosities in Run-25 were as high (*) as 25 nb^{-1} — corresponding to 0.17 Trillion minimum bias events

  ➡ The lower end of the projections was 13 nb^{-1} in any scenario

  ➡ Since then, the Run-23 Au+Au experience has resulted in significant downward revision of expected luminosity production in Run-25

(*) in a 28-cryoweek scenario, sampled luminosity with rare probes triggers

Current Au+Au luminosity projections

	C-AD min	C-AD max
20 cryoweeks Au+Au	**2.4 nb^{-1}**	**4.2 nb^{-1}**
28 cryoweeks Au+Au	**3.6 nb^{-1}**	**6.4 nb^{-1}**

C-AD Projections 28 October 2024

- The ALD request is to consider 20 and 28 cryoweek scenarios in Run-25
- Official C-AD guidance for Au+Au with $\theta = 1$ mrad (confirmed sPHENIX capability)
  - ➡ Folded with standard assumptions on ramp-up time, sPHENIX operational efficiency
  - ➡ Notes: (1) no assumption of 56 MHz cavity operation, (2) assume lower than usual RHIC operating efficiency ($0.6 \rightarrow 0.5$) due to running Au+Au in the summer months
- sPHENIX has a major concern that the lower bound in a 20-week Run-25 scenario of 2.4 nb^{-1} would significantly limit the physics program

Au+Au luminosity target

- The sPHENIX Au+Au luminosity target in Run-25 is 7 nb^{-1}, corresponding to just under 50 Billion minimum-bias events

  ➡ sPHENIX considers this to be the **minimum viable dataset** to carry out **every element of the envisioned physics program**

  ➡ 7 nb^{-1} of Au+Au results in a matched *NN*-luminosity between 107 pb^{-1} of calorimeter-only *p*+*p* data and 0-10% Au+Au events (*) — thus, calo-only observables would be co-limited by *p*+*p* and Au+Au

  ➡ 7 nb^{-1} represents >50% of the low end of previous projections (13 nb^{-1})

  ➡ 7 nb^{-1} is close to the upper end of C-AD projections in an aggressive 28-cryoweek running scenario

(*) $(107\ \text{pb}^{-1})(\sigma_{\text{NN}} = 42\ \text{mb}) \approx (7\ \text{nb}^{-1})(\sigma_{\text{AA}} = 6.8\ \text{b})(f_{0-10\%} = 0.1)(N_{\text{coll}} = 960)$

Beam Use Proposal

The sPHENIX request is sufficient Au+Au running to reach the integrated luminosity target of 7 nb^{-1}

Priority-ordered list of physics-driven additional running, given sufficient available physics weeks for each item

sPHENIX Physics Target in Run-25: **7 nb^{-1} (50B events)**		
Collision Species	Cryoweeks	Projected luminosity, $\lvert z\rvert < 10$ cm
Au+Au 200 GeV	20	2.4 – 4.2 nb^{-1} recorded
Au+Au 200 GeV	28	3.6 – 6.4 nb^{-1} recorded

If Au+Au luminosity target is met, ordered priority list for additional running:		
Collision Species	Physics weeks	Projected luminosity, $\lvert z\rvert < 10$ cm
1. p+p 200 GeV	8	13 pb^{-1} sampled + 3.9 pb^{-1} streaming
2. p+Au 200 GeV	5	80 nb^{-1} sampled + 24 nb^{-1} streaming
3. O+O 200 GeV	2	13 nb^{-1} sampled + 3.9 nb^{-1} streaming

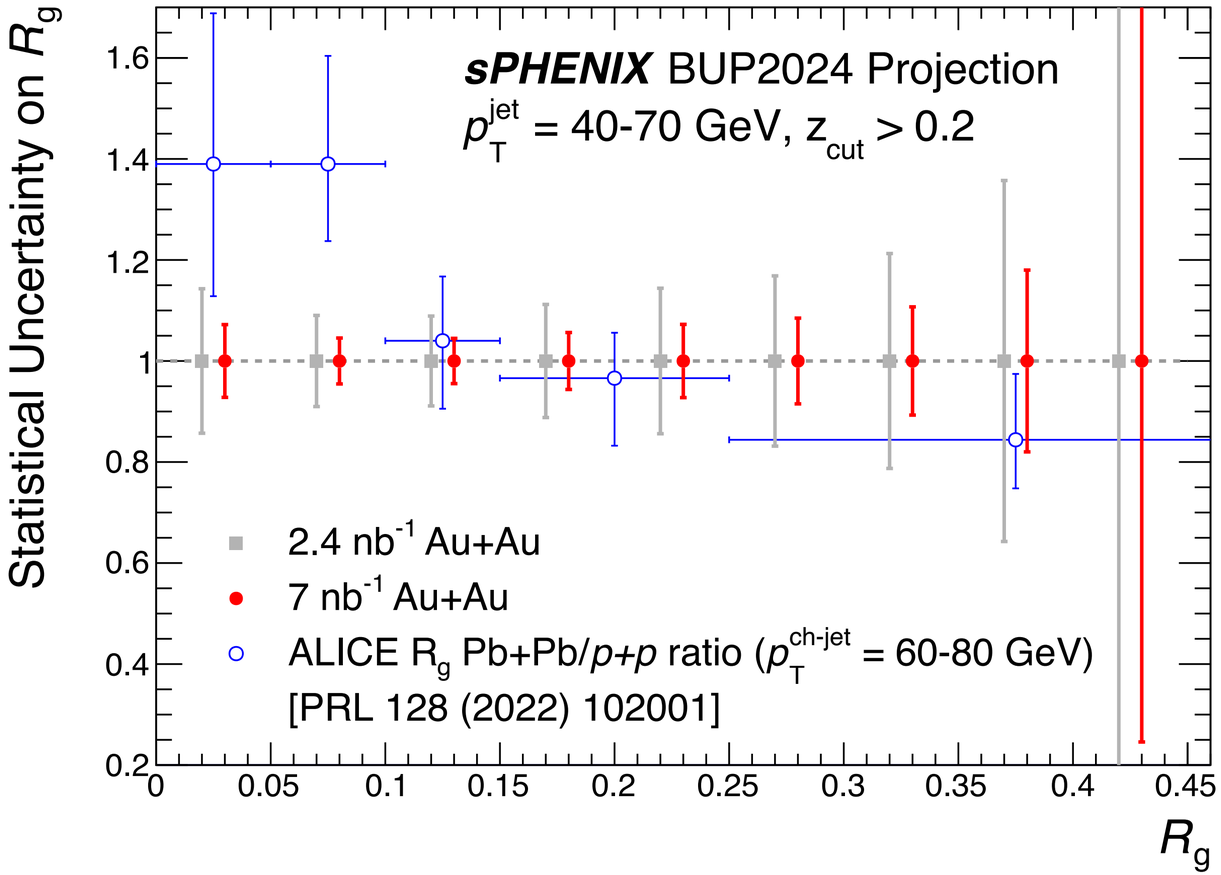
Au+Au flagship physics: jet structure

Example: groomed jet radius R_g for jets, in overlapping kinematic range w/ **ALICE**

Under the **minimal Run-25 luminosity scenario**, difficult to distinguish similar magnitude of modifications at RHIC

With the **target Au+Au luminosity**, sPHENIX can measure the modifications in detail

Similar impact for other jet (sub-)structure observables!



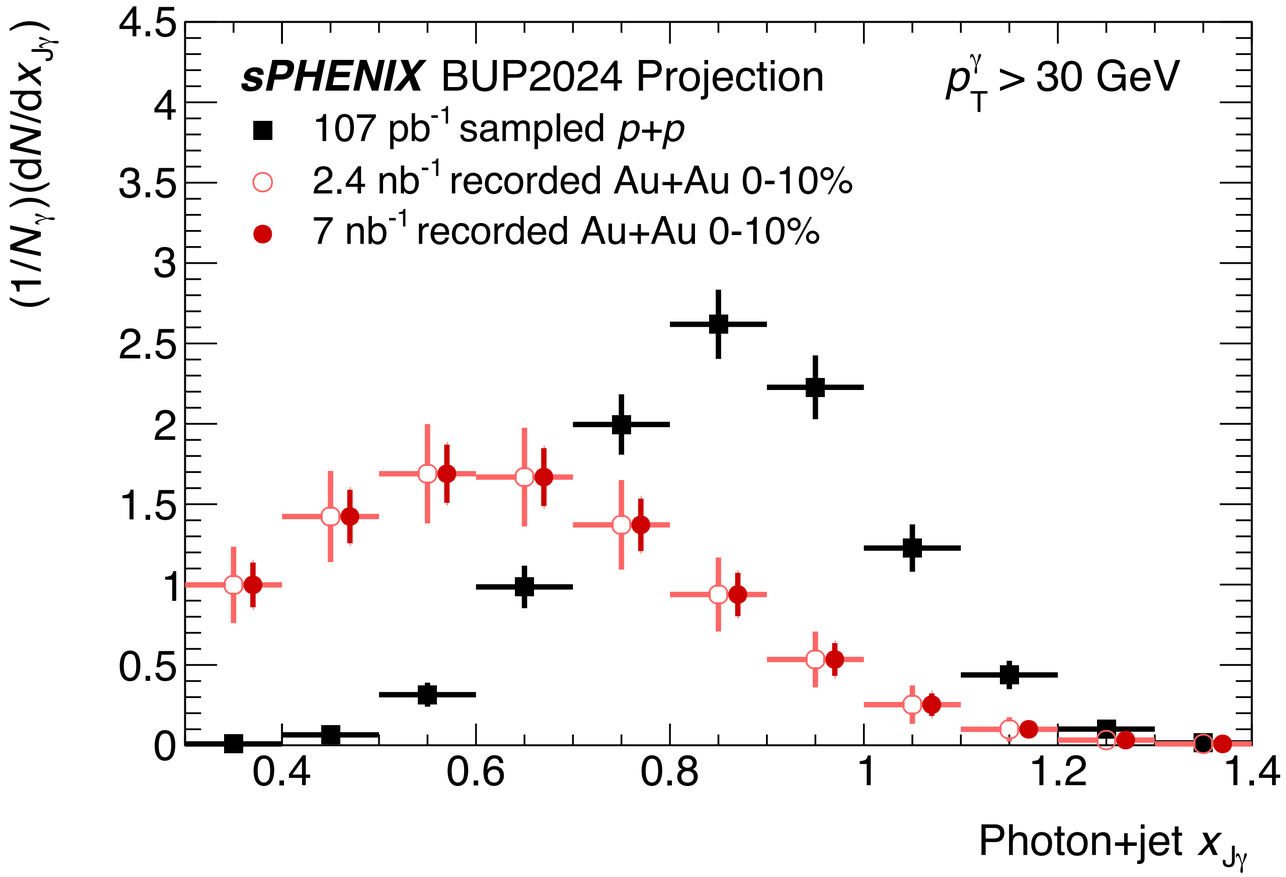
Au+Au flagship physics: photon+jet

Projected distribution of photon+jet $x_{J\gamma}$, including in recorded **Run-24 *p+p* calorimeter data**

Under the **minimal Run-25 luminosity scenario**, can do photon+jet physics in Au+Au, but with modest precision

With the **target Au+Au luminosity**, sPHENIX can perform a detailed study of photon+jet events

Similar impact for photon-tagged jet properties & event correlations!



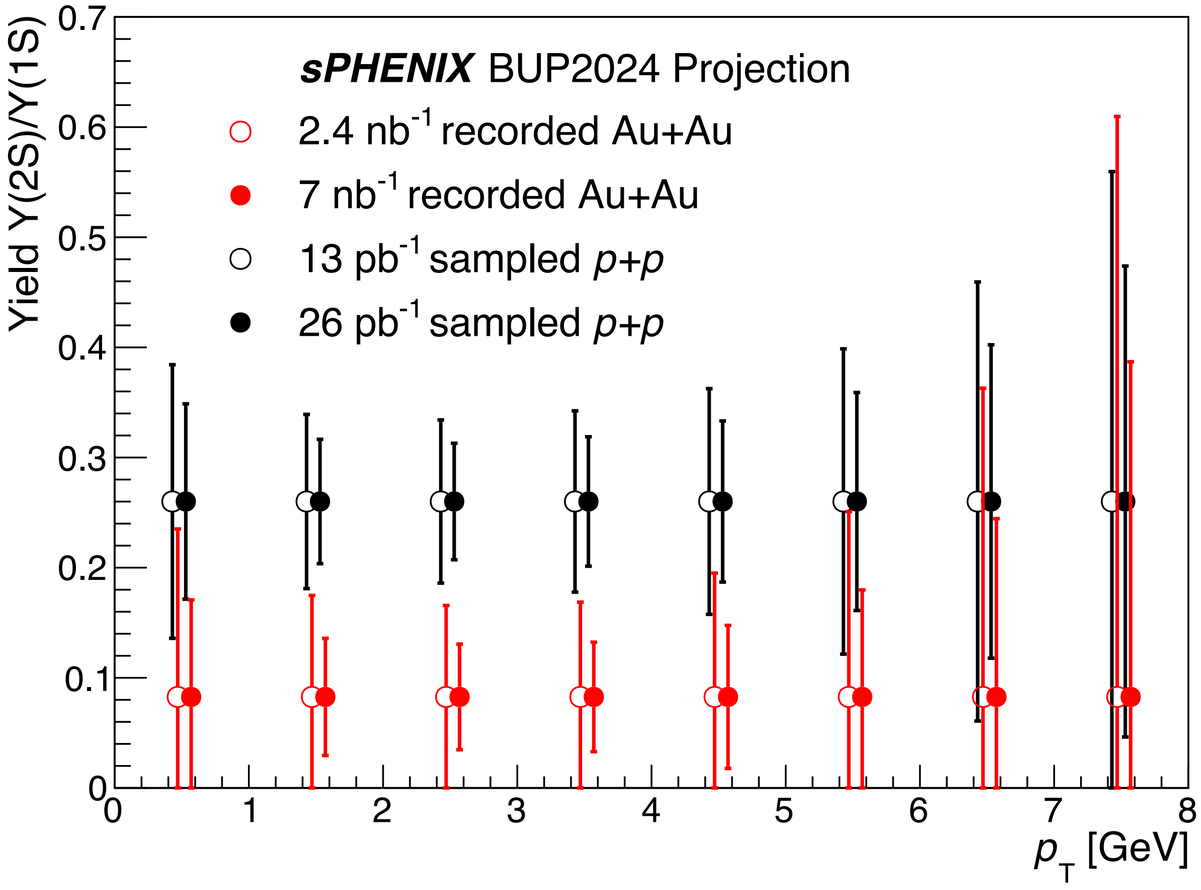
Au+Au flagship physics: Upsilons

Projected Upsilon 2S/1S ratio in different ***p+p*** and Au+Au scenarios

Under the **minimal Run-25 luminosity scenario (open)**, difficult to measure $\Upsilon(2S)$ at all, less distinguishable from ***p+p*** 2S/1S baseline

The **target Au+Au luminosity (filled)**, has a major impact on the Upsilon program

(This part of the program also benefits from supplemental ***p+p*** running …)



Physics-driven additional running

- The highest priority for sPHENIX in Run-25 is collecting a large Au+Au dataset to carry out the QGP physics program

- If the luminosity target of 7 nb^{-1} is expected to be met, sPHENIX requests a priority-ordered list of additional running, given sufficient time for each item

  ➡ sPHENIX is flexible(*) about the particular scheduling within a Run, a long extension of Run-25 into FY26, or split with a Run-26, as long as the Au+Au luminosity target is met

- We note that all the additional running requests could also fit comfortably inside, e.g., a 20 cryoweek Run-26

If Au+Au luminosity target is met, ordered priority list for additional running:		
Collision Species	Physics weeks	Projected luminosity, $\|z\| < 10$ cm
1. p+p 200 GeV	8	13 pb^{-1} sampled + 3.9 pb^{-1} streaming
2. p+Au 200 GeV	5	80 nb^{-1} sampled + 24 nb^{-1} streaming
3. O+O 200 GeV	2	13 nb^{-1} sampled + 3.9 nb^{-1} streaming

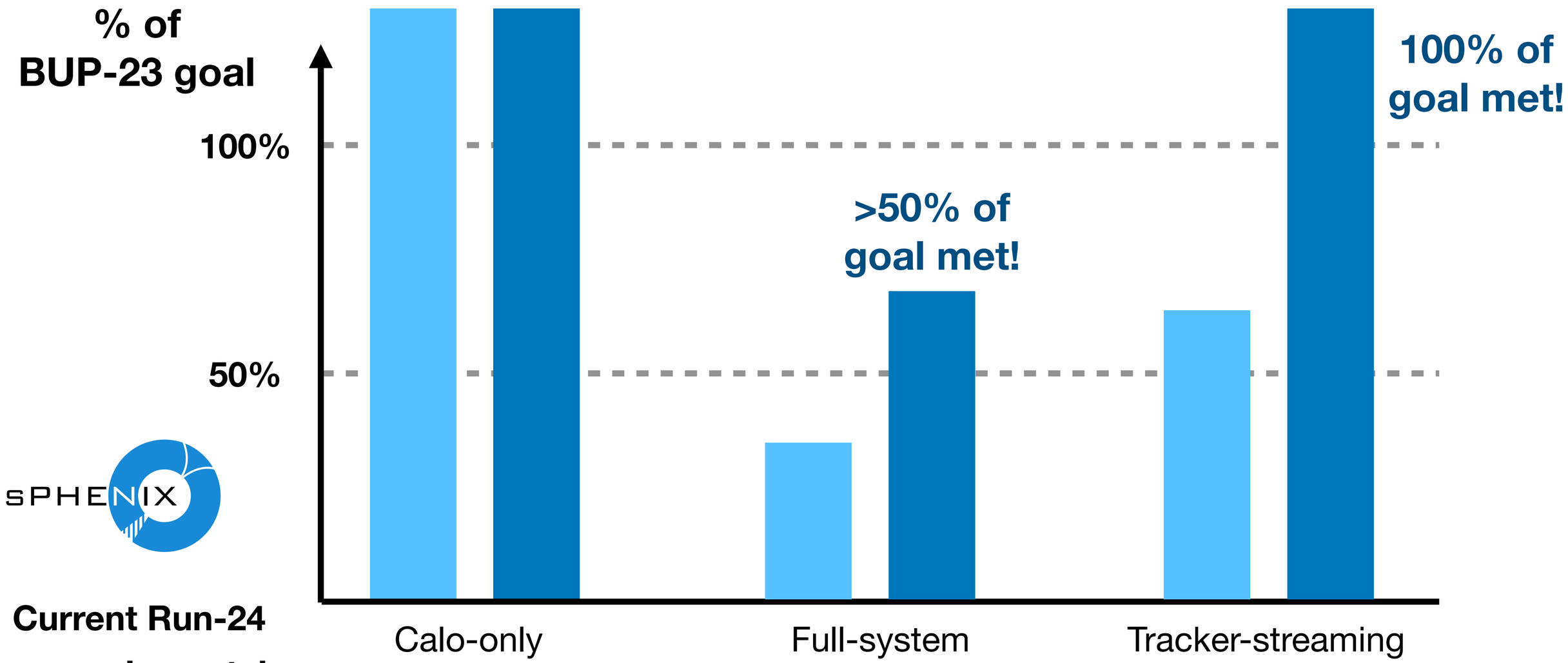
(*) not ready to start Run-25 with p+Au as the first species

Priority #1: supplemental *p+p* running

- Top sPHENIX request is 8 weeks of additional *p+p* running
- The available *p+p* reference from Run-24 is expected to be a major limiter for jet+track, *b* measurements, and Upsilon physics
- The expected RHIC performance is well known from Run-24 *p+p* experience

  ➡ sPHENIX calculates that we would need at least 8 weeks of running to have a significant impact over the available Run-24 statistics

Supplemental *p+p* running & BUP'23 luminosity goals



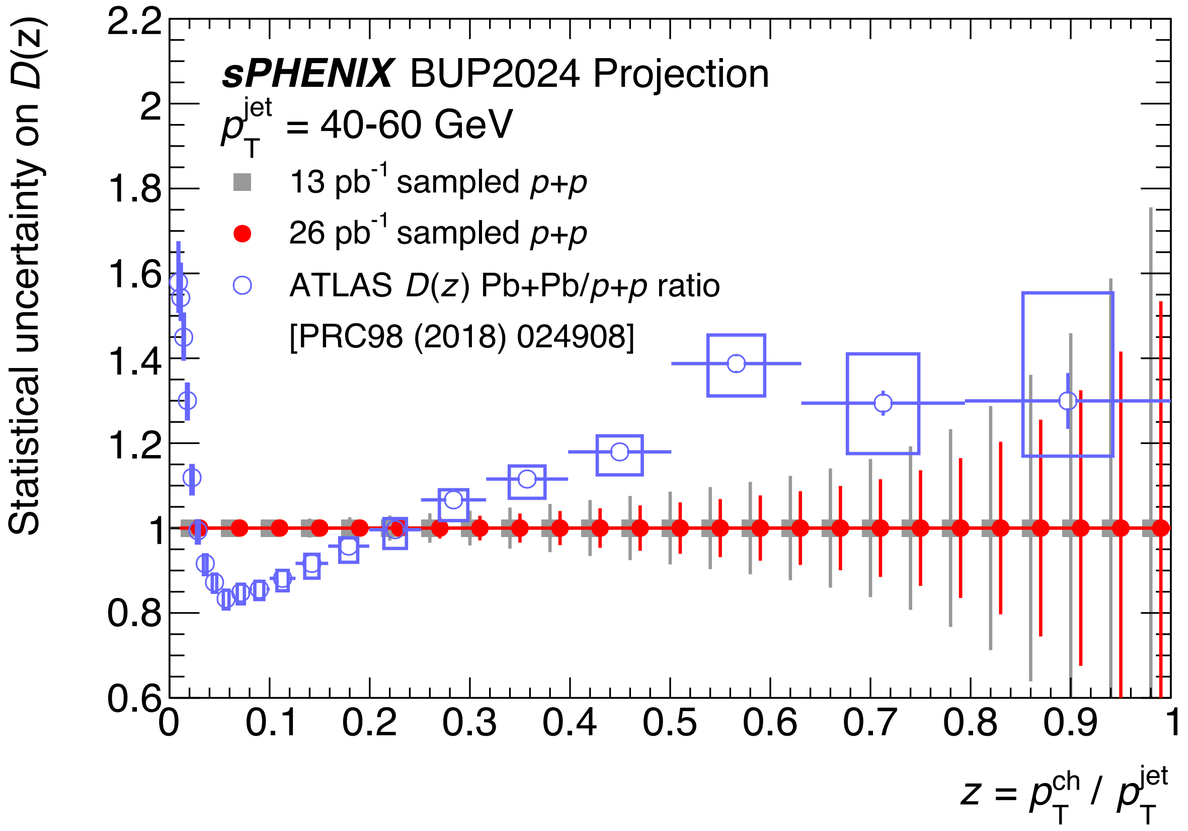
p+p baseline: jet+track

Some jet (sub-)structure measurements can be made in calorimeter data, but for many, need full-tracking information

p+p is the dominant uncertainty compared to 0-10% Au+Au

Example: fragmentation function $D(z)$ for jets, compared to **ATLAS**

Increasing the **recorded *p+p* dataset** with **supplementary *p+p* data** improves sPHENIX ability for precise, differential measurements at high-z



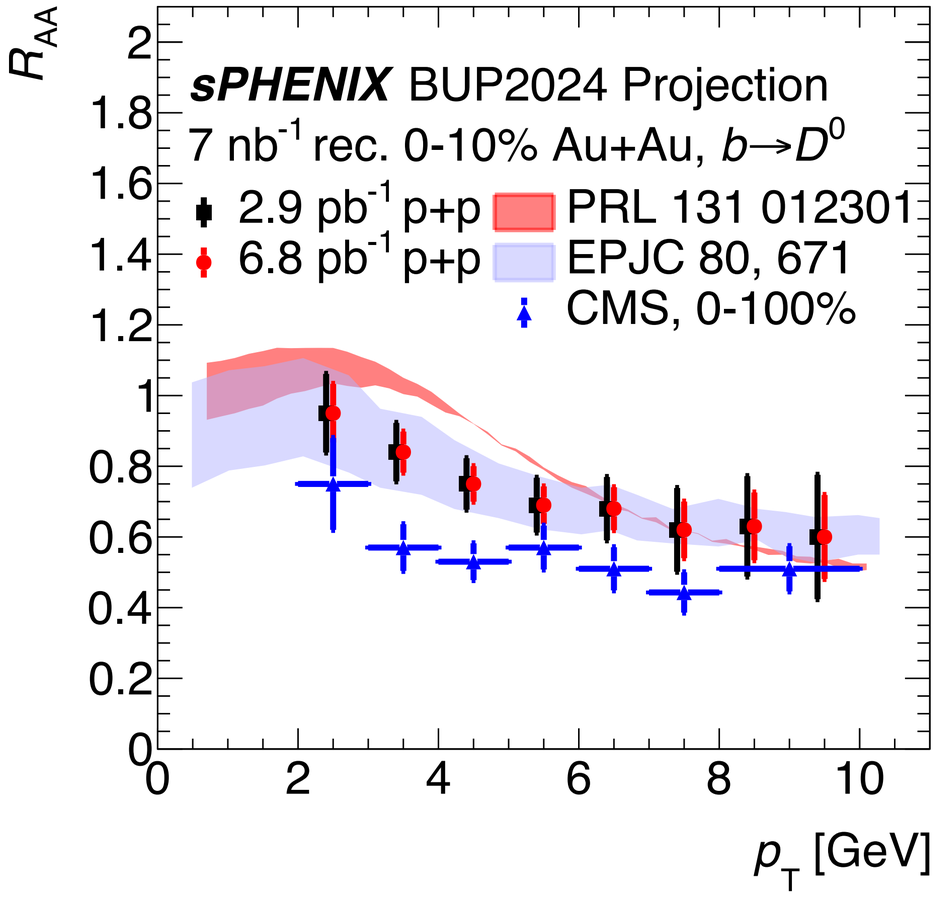
p+p baseline: open heavy flavor

For un-triggerable observables like open heavy flavor, *p+p* data is the strongly limiting factor compared to Au+Au

Example: non-prompt D^0 (not measured before at RHIC), where *p+p* baseline is from streaming readout

Increasing the **recorded *p+p* dataset** with **supplementary *p+p* data** directly improves sPHENIX precision for:

1. Distinguishing between models
2. Comparisons with LHC (**CMS**)



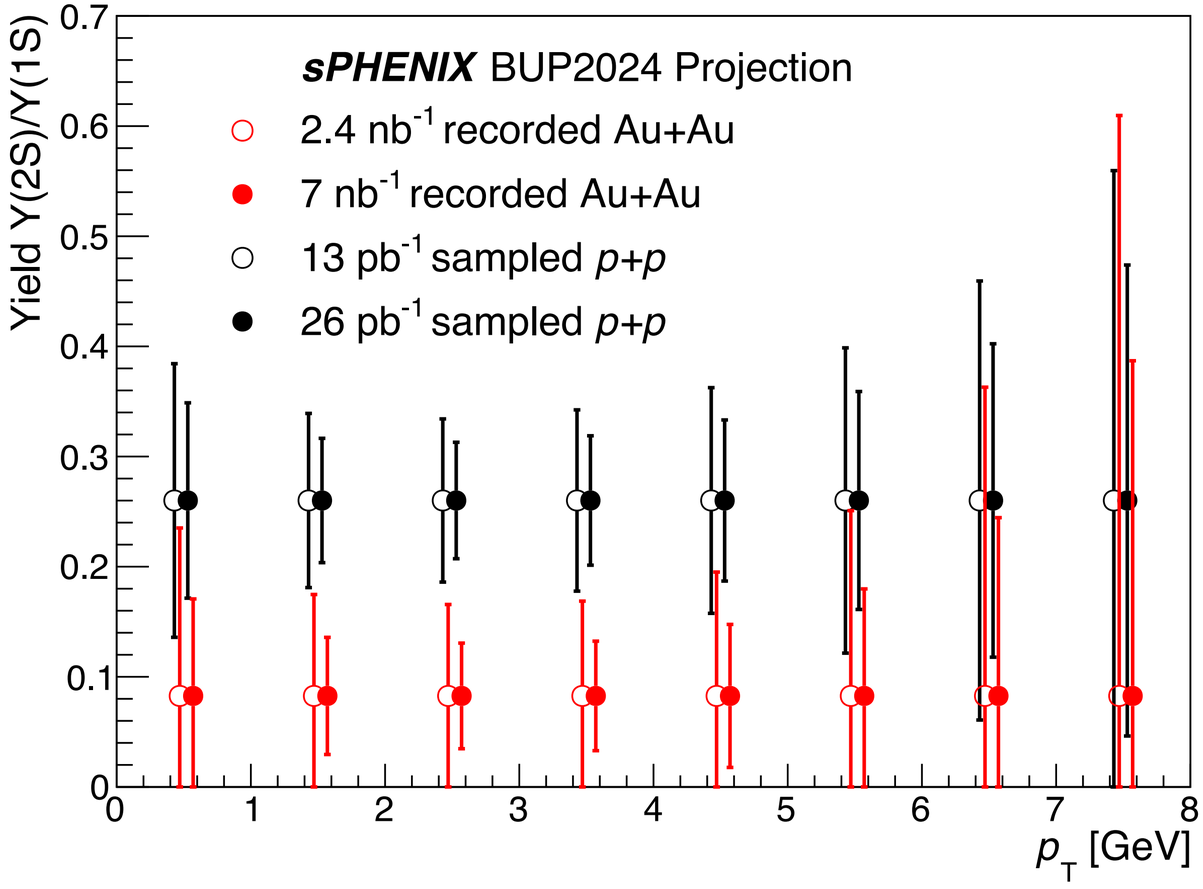
p+p baseline: Upsilons

(repeated projection from Au+Au section)

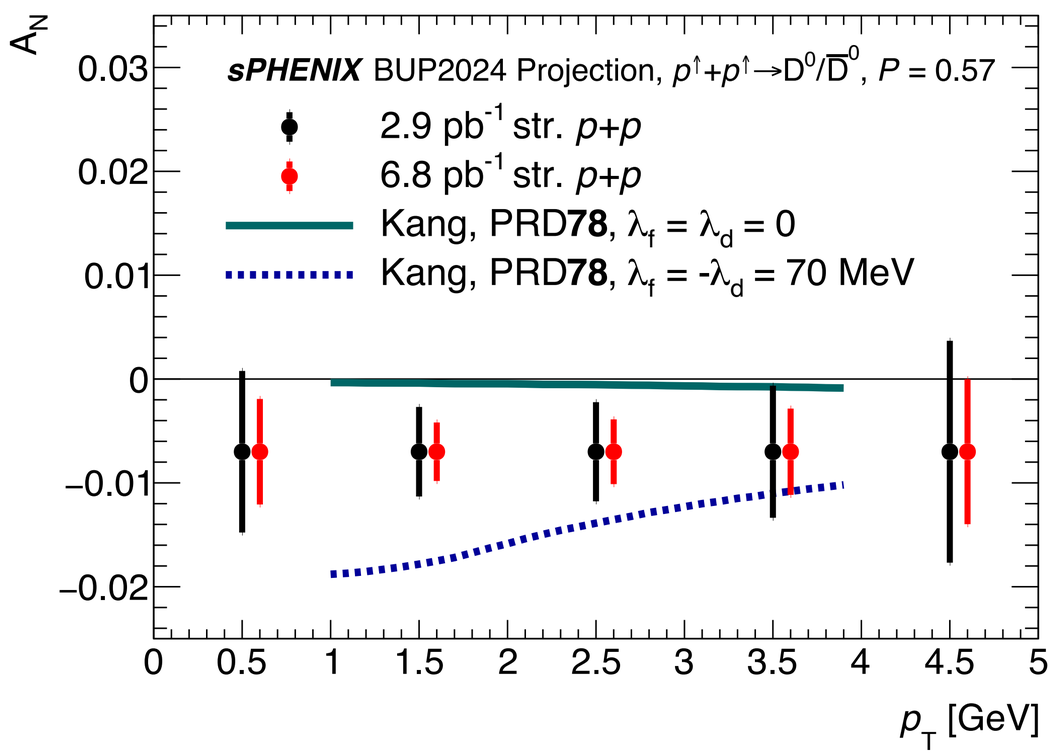
Projected Upsilon 2S/1S ratio in different ***p+p*** and **Au+Au** scenarios

Open vs. **closed** black points show the impact of supplementary *p+p* running

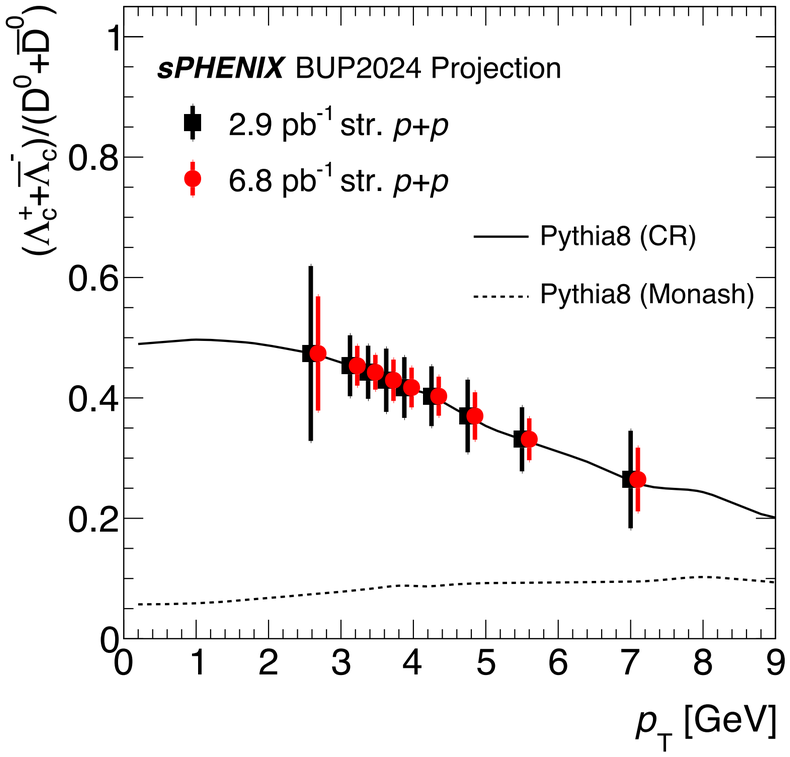
Upsilon 2S and 3S measurement prospects benefit from both additional *p+p* and Au+Au luminosity



Impact for *p+p*-only measurements



D^0 A_N in polarized *p+p* collisions - precisely constrain gluon Sivers TMD function



Λ_c/D^0 ratio *p+p* - critical baseline for Au+Au, not measured at RHIC

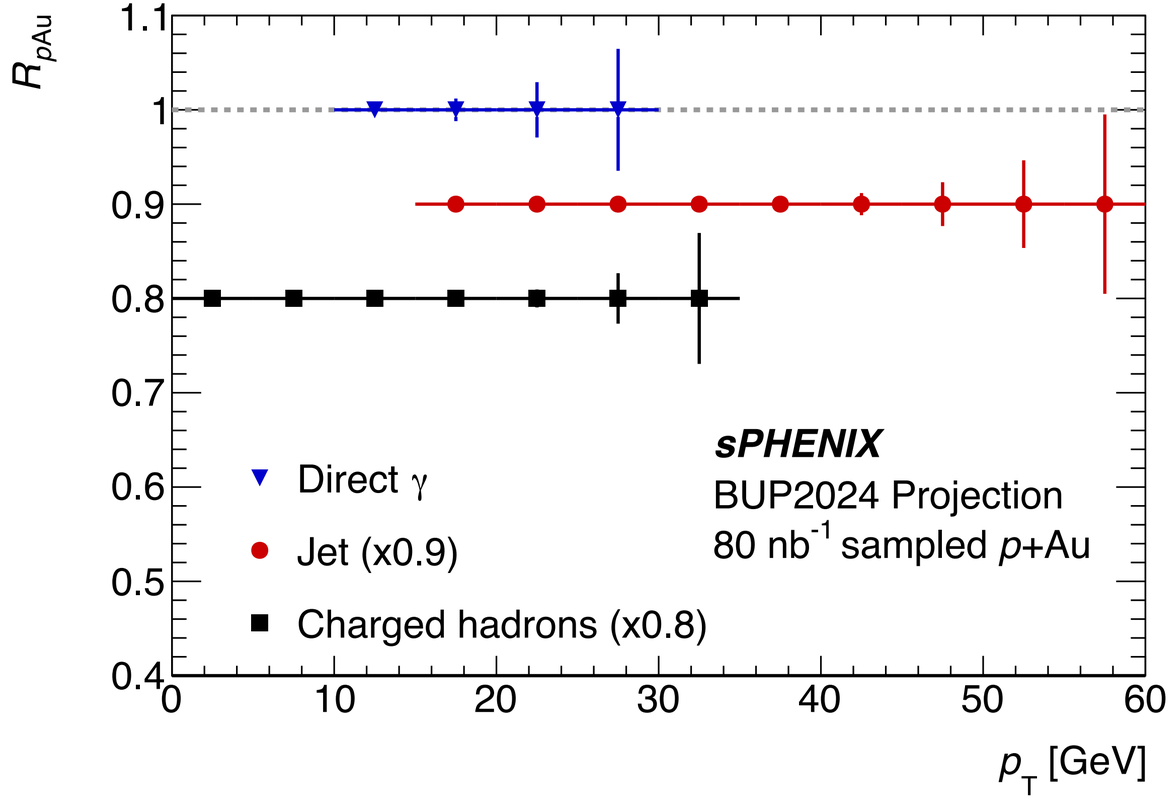
sPHENIX is our one chance to measure these - every pb^{-1} counts!

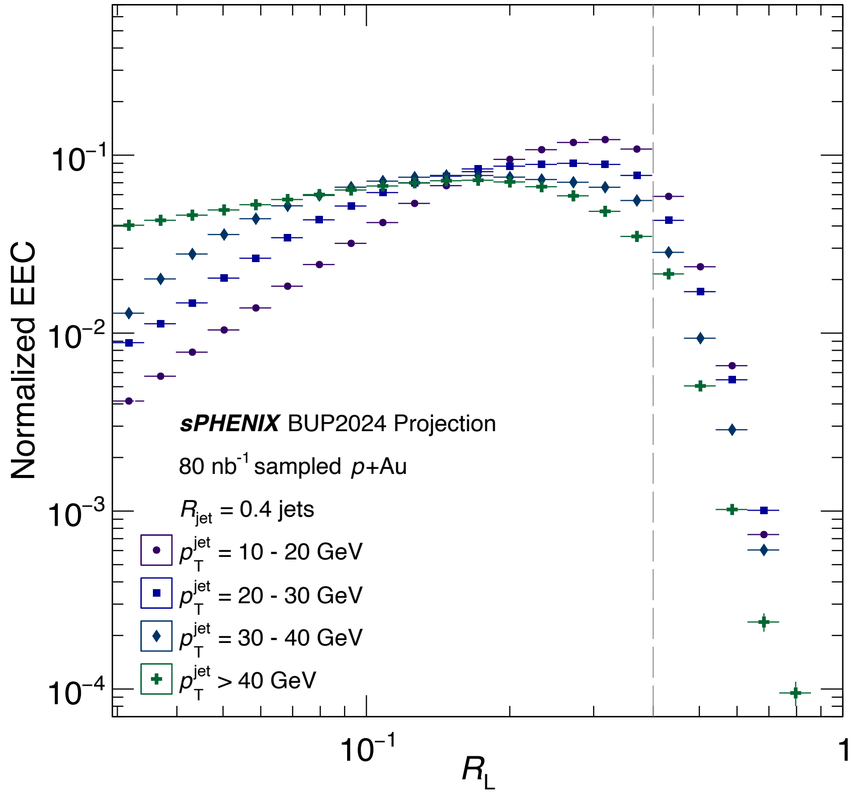
Priority #2: *p*+Au running

- Second sPHENIX request is 5 weeks of *p*+Au running
- *p*+Au has always been part of the envisioned sPHENIX program, but achieving needed Au+Au and *p*+*p* statistics given lowered luminosity projections led us to prioritize those systems above *p*+Au
- Since RHIC has not run *p*+Au in 10 years, the projected luminosity in sPHENIX should be understood to have a large overall uncertainty

  ➡ it is the novelty of the collision system (explored with unique sPHENIX capabilities) that is impactful, rather than any particular luminosity target

p+Au physics: hard process yields

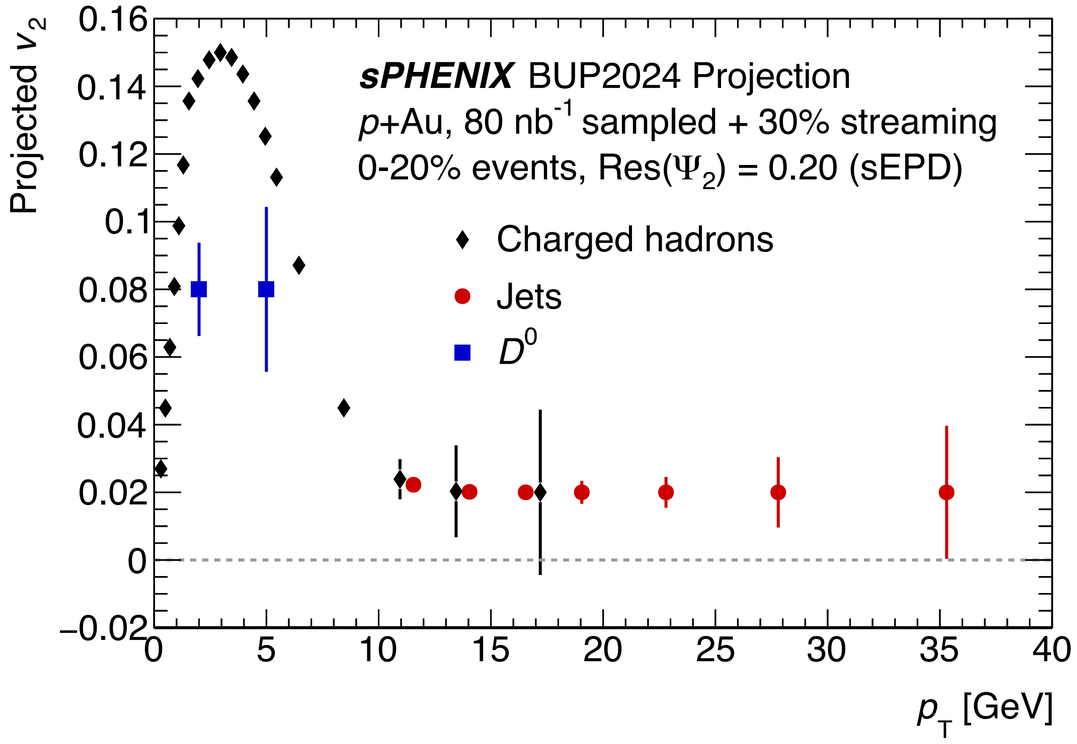




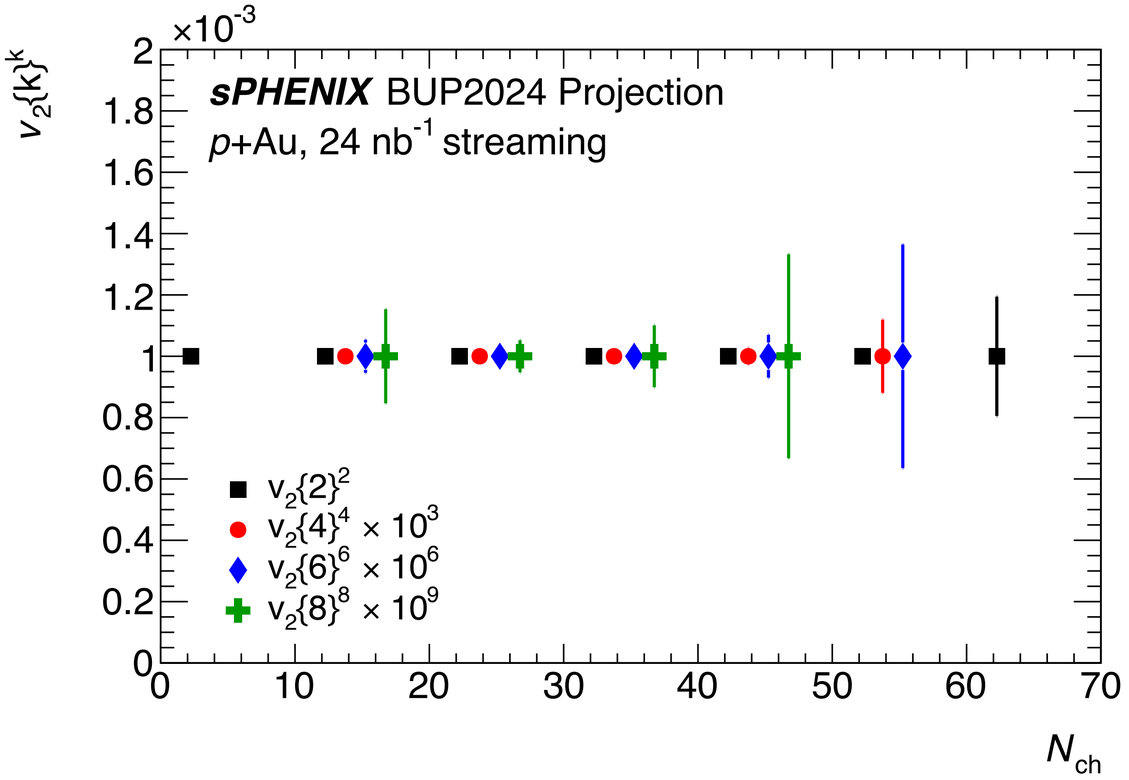
R_{pA} for **photons**, **jets**, and **hadrons** over broad kinematic range - cold nuclear matter effects, large yields for study

Detailed measurements of jet properties (c.f. modification of EECs in *p*+Pb reported by ALICE at HP'24)

p+Au physics: collective behavior



Broad measurements of collective behavior of **hadrons, jets** and even **charm**, from low to high p_T



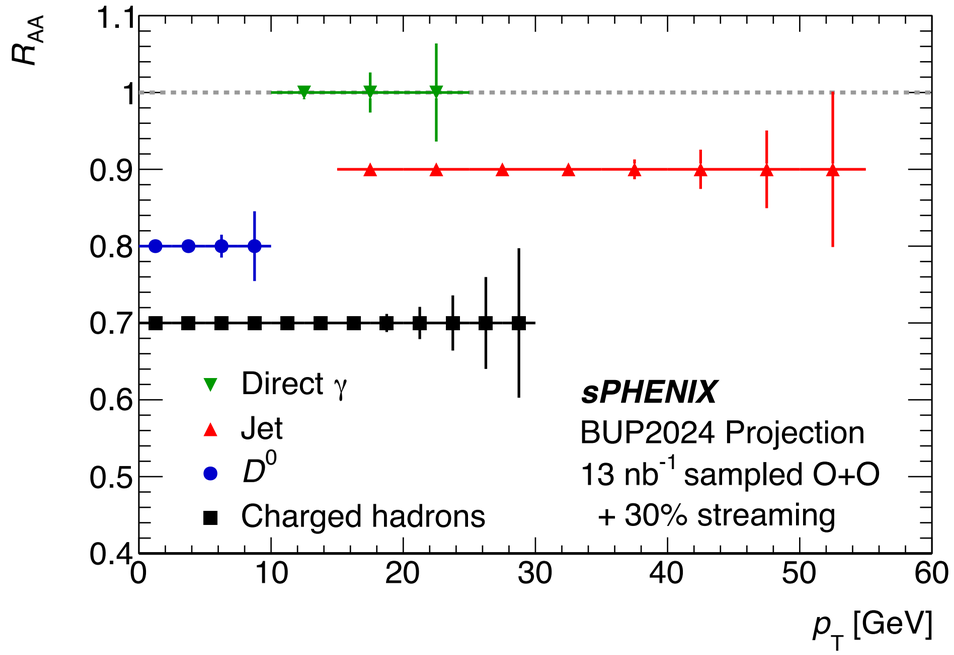
Multi-particle correlations in the large sPHENIX tracker acceptance + streaming readout capability

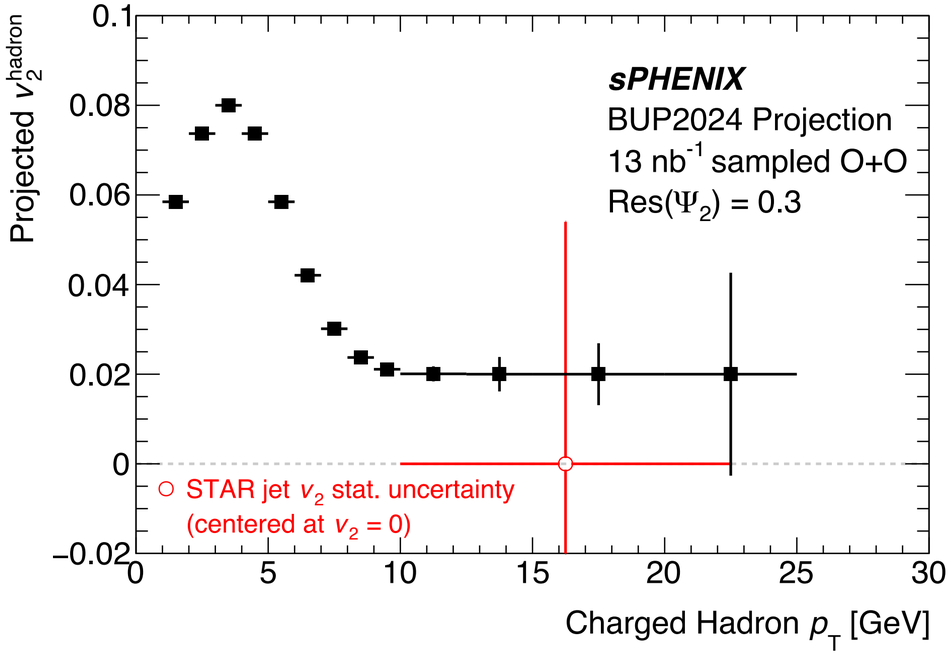
+ measurements in polarized $\vec{p}+A$ not discussed here - unique RHIC capability!

Priority #3: O+O running

- Last sPHENIX request is 2 weeks of O+O running
- Apply unique sPHENIX capabilities to testing interplay of flow and jet quenching in a novel “symmetric light ion” system
  - ➡ High-luminosity O+O data would have major, timely complementarity with LHC 2025 running
  - ➡ However, physics program also possible with Al+Al, Ar+Ar, etc.
- Luminosity projection is taken from Run-21 O+O RHIC performance
  - ➡ Even a short two-week run would be impactful

O+O physics: quenching and flow





R_{AA} for **photons**, **jets**, **hadrons** and **charm** (from streaming readout) over broad kinematic range

Measure evolution of v_2 from low to high p_T (c.f. uncertainties in **STAR jet v_2** in O+O)

Conclusion

- sPHENIX successfully finished commissioning started in Run-23 and took high-quality *p*+*p* reference data in Run-24, partially meeting the luminosity goals

- The top priotity in Run-25 is to collect a very high luminosity Au+Au dataset for the long-envisioned QGP physics program with unique capabilities at RHIC

  ➡ The target Au+Au luminosity of $7\ \mathrm{nb}^{-1}$ is needed to realize the LRP science mission of multi-scale QGP probes and complementarity with the LHC

- If additional RHIC running time were to become available, sPHENIX stands ready to capitalize on these opportunities with physics-driven proposals for *p*+*p*, *p*+Au, and O+O running

- We ask NPP management to find ways to get as close to the priority goals as possible through a global optimization of the remaining RHIC run time

Questions / discussion

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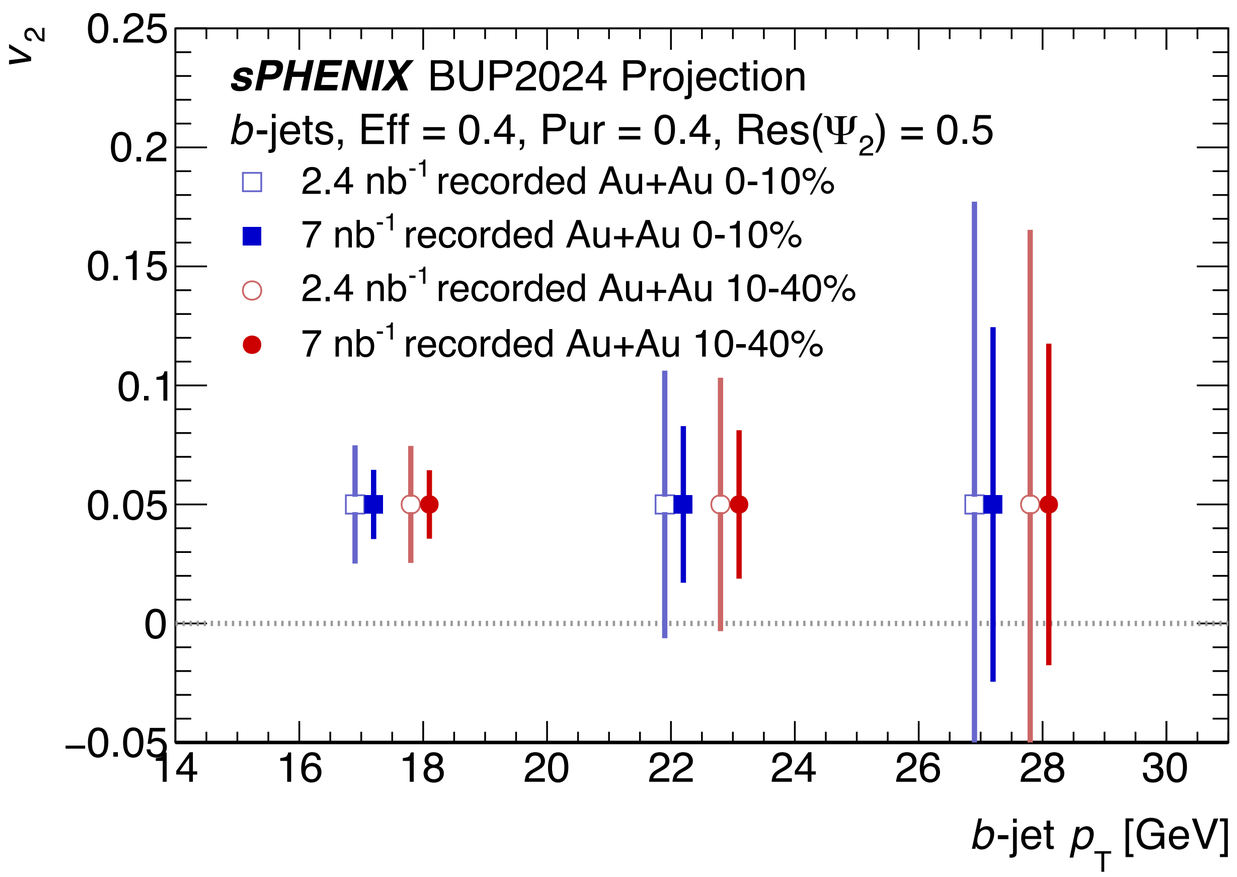
Au+Au flagship physics: *b*-tagged jets

Projected *b*-jet v_2, shown for **central** and **mid-central** events

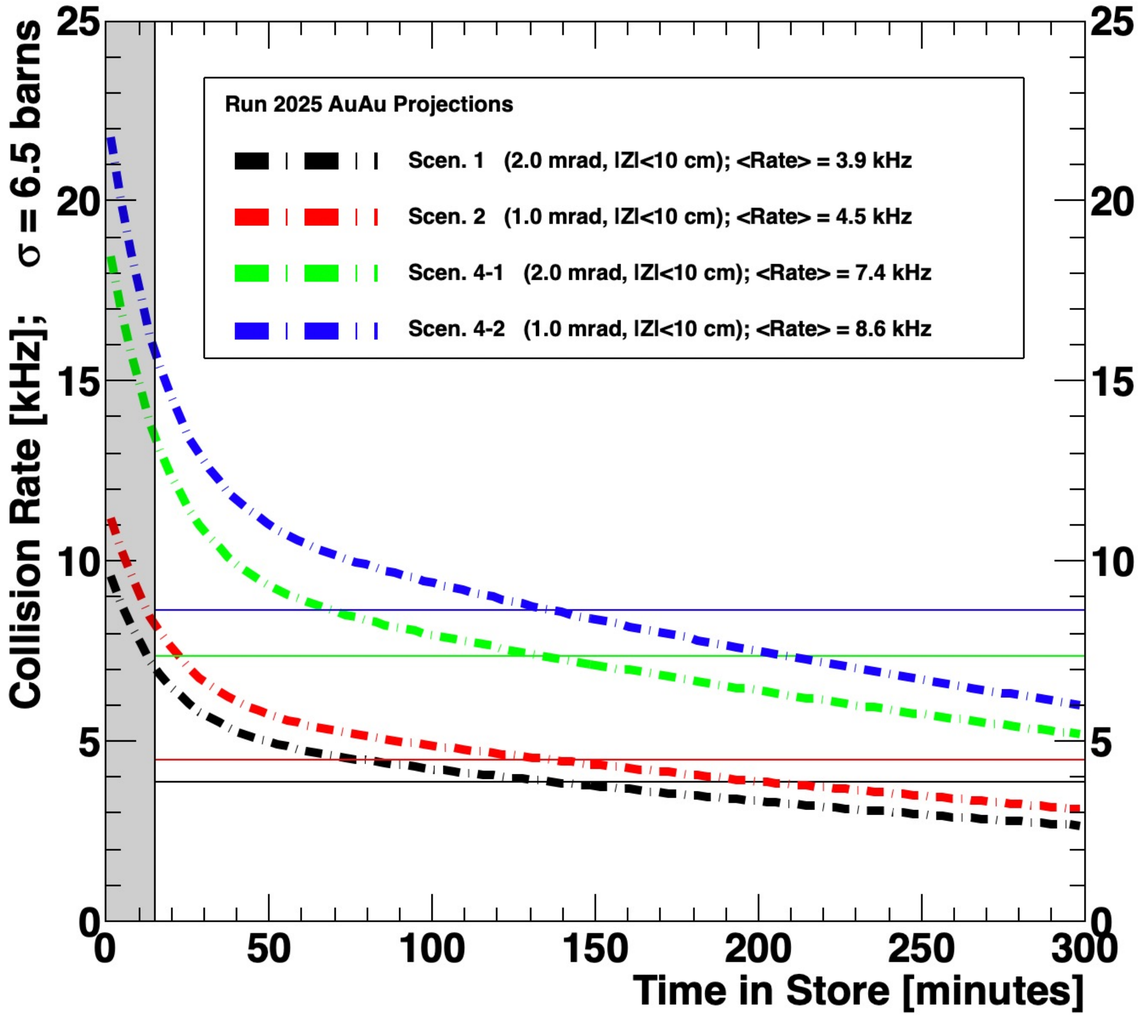
Under the **minimum (open)** scenario, this measurement may not be statistically significant

With the **target luminosity (closed)**, much better opportunity to map out this physics in some detail

Similar impact for, e.g., *b*-jet R_{AA}, correlations, sub-structure, etc.



Alternative Au+Au luminosity projections



sPHENIX BUP'24 luminosity projections are also cross-checked with modeling of the full luminosity time profile in store

Based on demonstrated Run-23/24 RHIC Au+Au performance with additional modeling (thanks to Kiel Hock of C-AD)