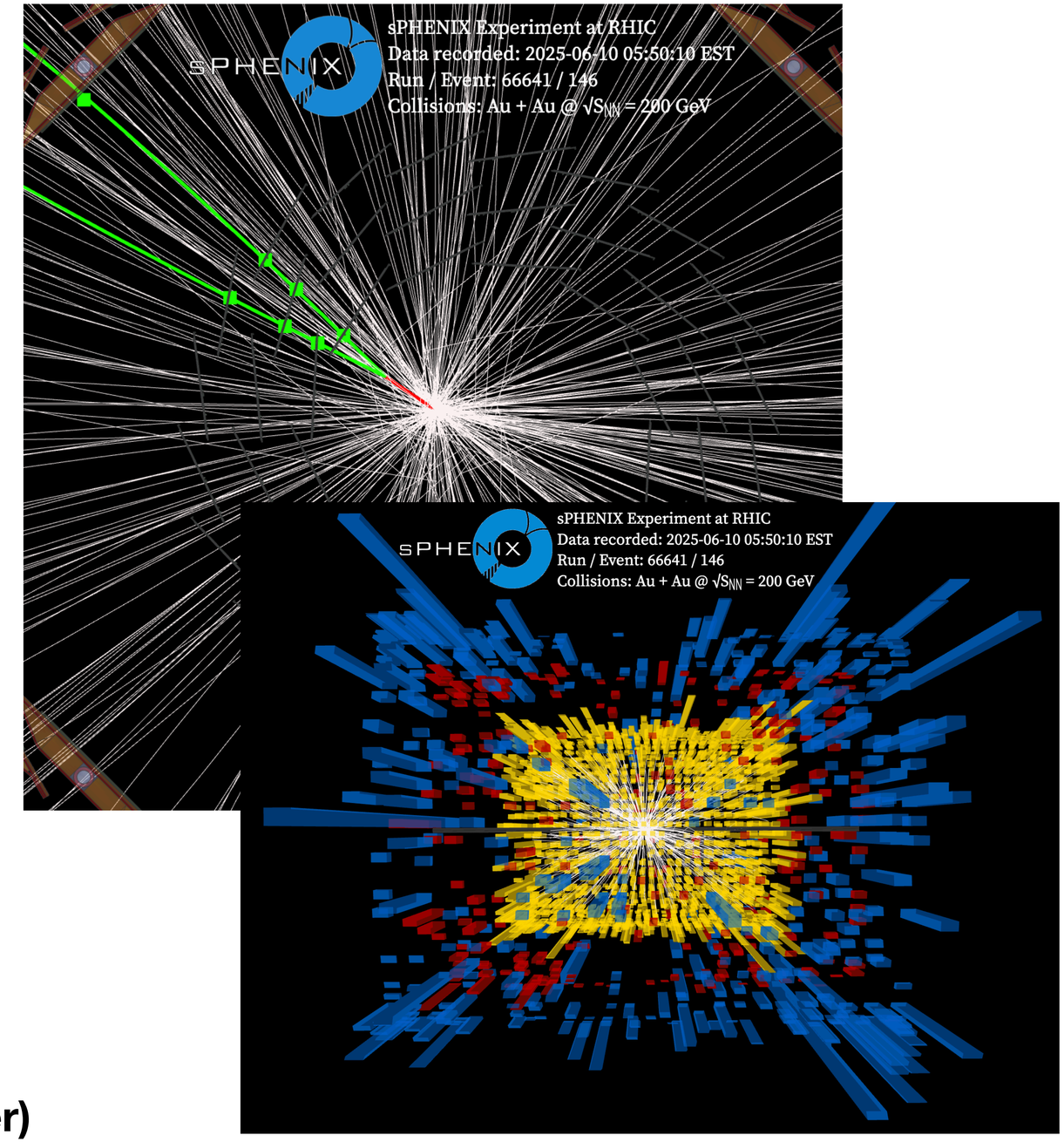
sPHENIX Beam Use Proposal



BNL NPP Physics Advisory Committee (PAC) Meeting

16 October 2025

Dennis V. Perepelitsa (University of Colorado Boulder)

Context: consistent sPHENIX scientific priorities

sPHENIX MIE Proposal, 2015

> With the high luminosity available at RHIC and the high sPHENIX data acquisition bandwidth, sPHENIX will record 100 billion and sample over 2/3 of a trillion Au+Au collisions at $\sqrt{s_{NN}} = 200\,\text{GeV}$ in a 22 week physics run period. The high rate capability of sPHENIX will enable the recording of over 10 million dijet events with $E_T > 20\,\text{GeV}$, along with a correspondingly large γ+jet sample. We envision a run plan for 2021–2022 consisting of two 30 week physics runs allowing a period for final commissioning, 22 weeks of Au+Au running, and extended periods of p+p and $p(d)$+Au running.

- The sPHENIX science case has always required **large integrated luminosities of Au+Au data, and a supporting *p+p* reference**, for precision probes of QGP which are unique at RHIC and overlap with LHC measurements.
- Despite lowered projections, we believe Run-25 will achieve a sufficient Au+Au dataset for the physics program.
- Securing the large *p+p* dataset is the other critical half of the program.

Context: PAC recommended data targets

BNL NPP PAC Report, Sep 2023

"We urge C-AD, BNL and DOE to pursue every possible opportunity to provide RHIC the luminosity and cryo-weeks necessary for sPHENIX to collect **45 pb^{-1} of *p+p*** data in Run 24."

[note: this included 10% of this, or 4.5 pb^{-1}, as tracker-only streaming data]

BNL NPP PAC Report, Nov 2024

"The PAC recommends a Au+Au run in which sPHENIX collects at least **7 nb^{-1}** of data as the highest priority for Run 25."

- We are very grateful to the NPP PAC for a consistent, strong endorsement of the sPHENIX physics goals & large luminosity targets

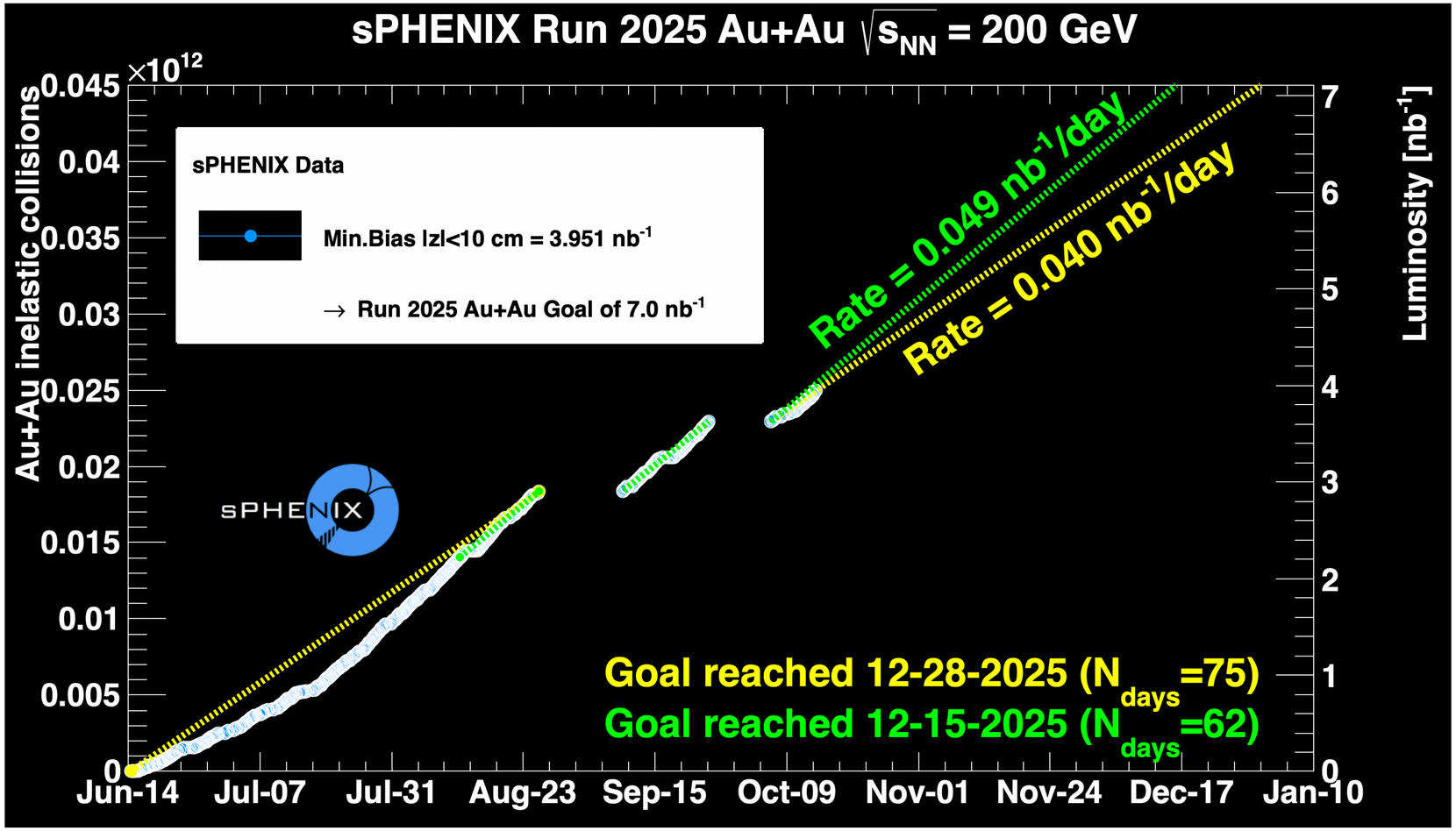
Context: collected Run-24 *p+p* data

- Run-24 *p+p* was a significant, but qualified, success in partially reaching the PAC-recommended luminosity targets for our *p+p* reference dataset

  ➡ Particular deficiencies in the *p+p* baseline for sPHENIX flagship measurements of jet+track structure, Υ, b-jets, open heavy flavor

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

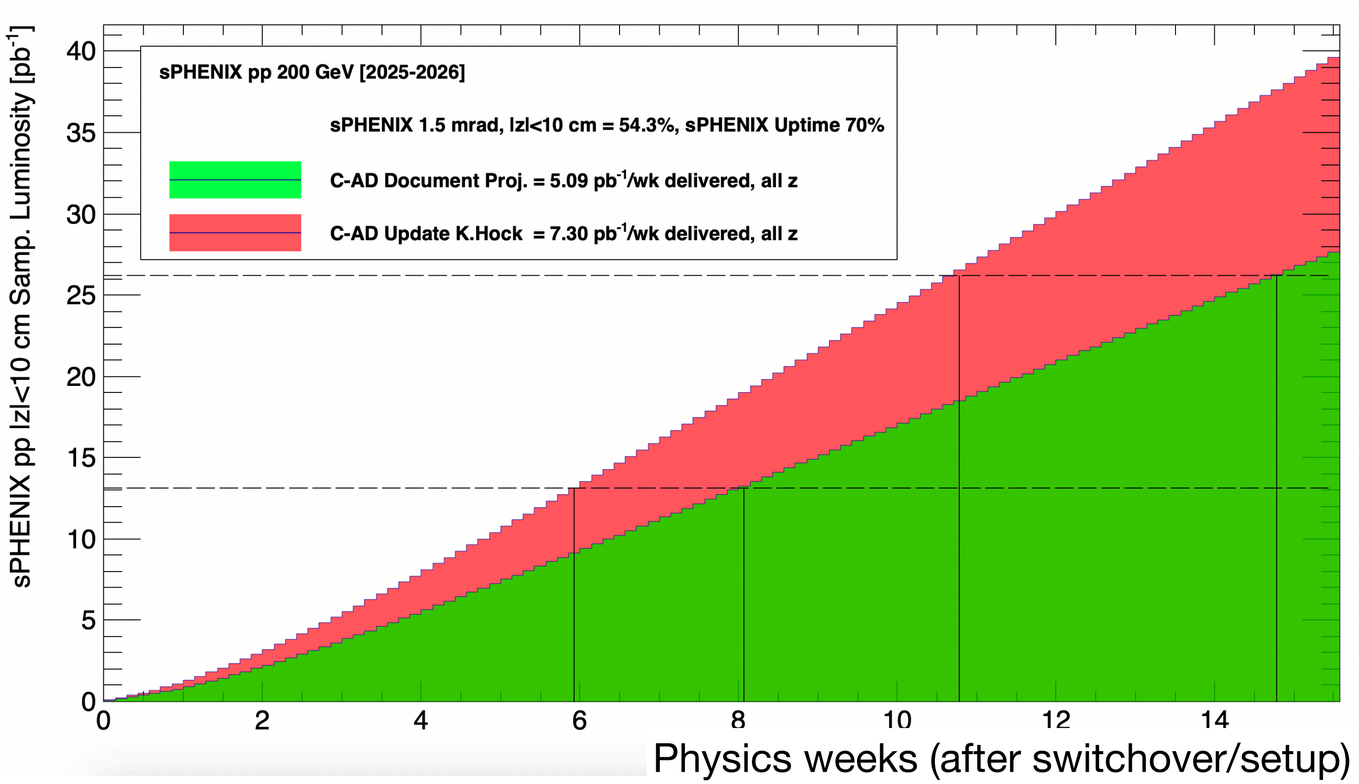
Context: Run-25 Au+Au progress



- sPHENIX taking Au+Au data with high operational efficiency — projected date to reach 7 nb^{-1} target is **15 December 2025**

Context: current projections from C-AD

- Latest projections from C-AD
  - ➡ all sPHENIX requested weeks are “cryoweeks”
    - ➡ i.e. they include the needed switchover+setup time and luminosity development in the first weeks
- All projections include sPHENIX uptime, considering collisions only within $|z| < 10$cm for the tracker acceptance, etc.



Calculations and checks by Jamie Nagle (sPHENIX Run-24 Coordinator) and Kiel Hock (C-AD Run-24 Run Coordinator)

Top priority after Au+Au: *p+p* running

- sPHENIX requests that the PAC endorses **12 additional cryoweeks of *p+p* running** with "**must do**" priority
  - ➡ this is the optimal amount to meet the original *p+p* luminosity target in all channels and provide a crucial calibration of the Run-25 detector configuration
  - ➡ with **7 additional cryoweeks as a "minimum" request**

Dataset	Existing Run-24 *p+p* dataset	Total dataset with a "few weeks" of Run-25 *p+p*	Total dataset with 7 weeks of Run-25 *p+p*	Total dataset with 12 weeks of Run-25 *p+p*
All-subsystem triggered	13 pb^{-1}	18 pb^{-1}	26 pb^{-1} **Double the dataset!**	39 pb^{-1} **~90% of original target!**
Streaming tracker-only	2.9 pb^{-1}	4.5 pb^{-1} **Meet the target!**	11 pb^{-1} **>2x target!**	19 pb^{-1} **New opportunities!**

* *The triggered, calo-only dataset would also increase. For example, in 12 weeks of running, by approximately +50% from all-vertex events.*

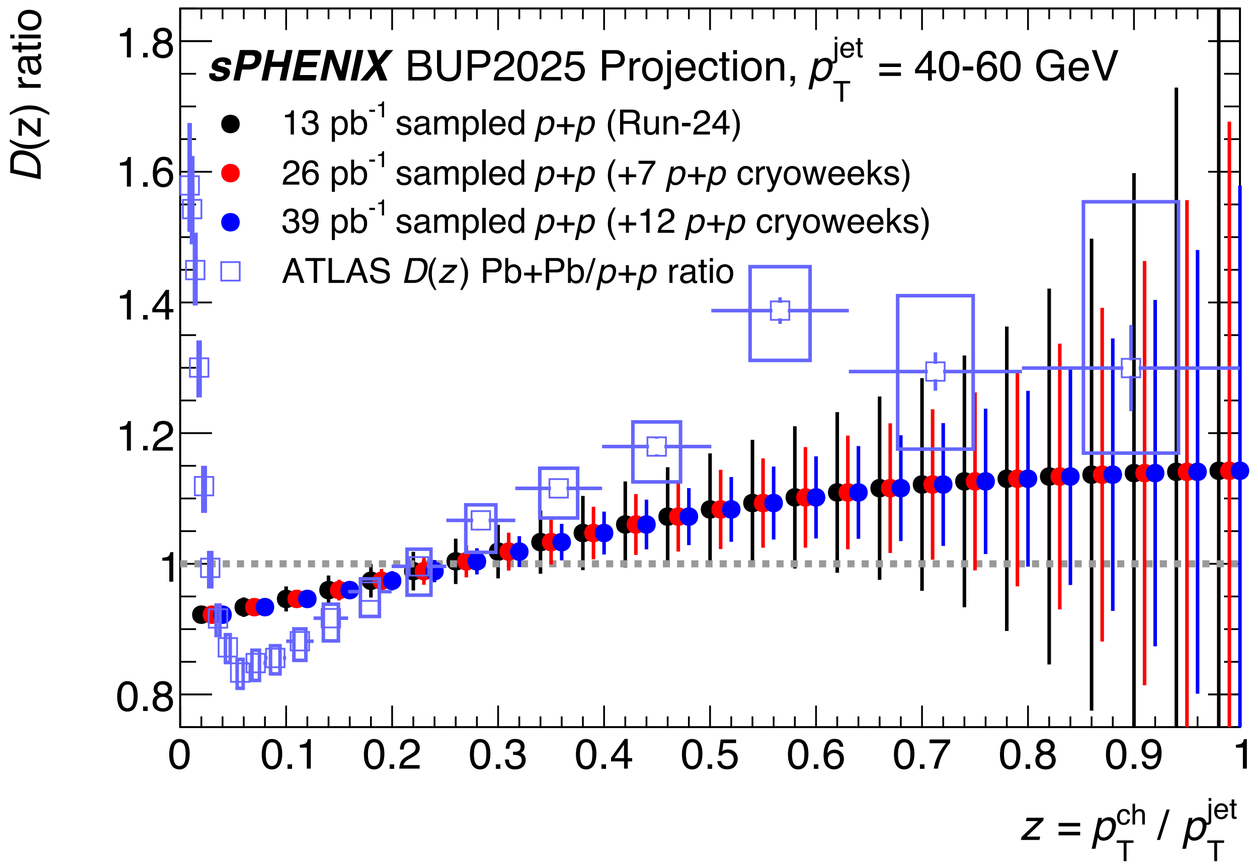
p+p running — triggered, all-subsystem data

Most jet (sub-)structure measurements need full-tracking information

p+p will be the dominant uncertainty in comparison to 0-10% Au+Au

Example: uncertainty on the jet fragmentation function $D(z)$ from *p+p* collisions, compared to the modifications seen at the **LHC**

Meeting the *p+p* luminosity target **greatly improves sPHENIX precision**, to a level needed to observe LHC-like modifications



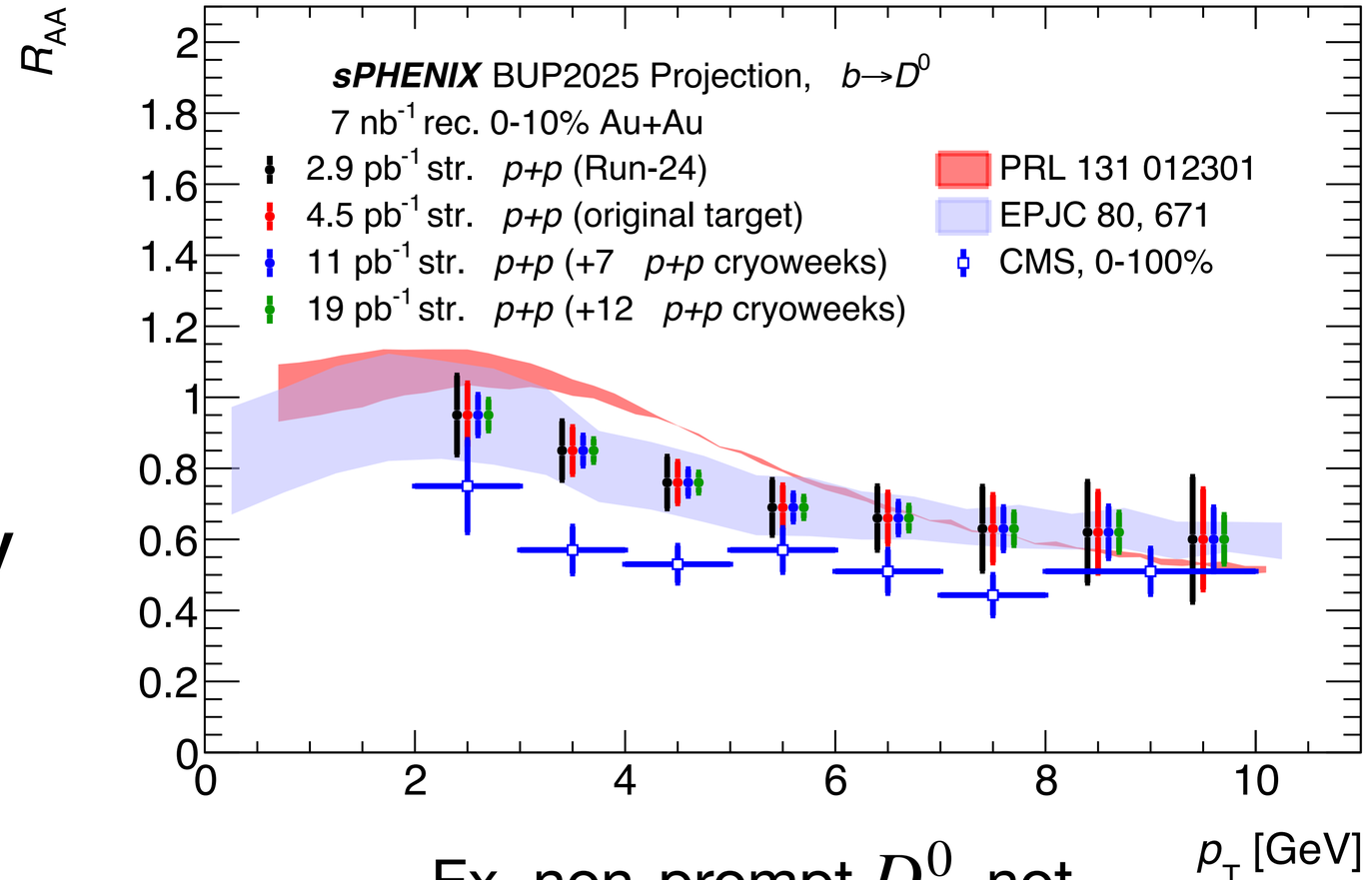
p+p running — tracker-only streaming data

For **open heavy flavor**, *p+p* data is the limiting factor compared to Au+Au

sPHENIX buffer box upgrade will raise the streaming fraction to $\geq$ 60% (10% in original proposal)

Meeting the *p+p* luminosity target **greatly improves sPHENIX precision** for:

1. Distinguishing between models
2. Data comparisons with **LHC**



Ex. non-prompt D^0, not measured before at RHIC

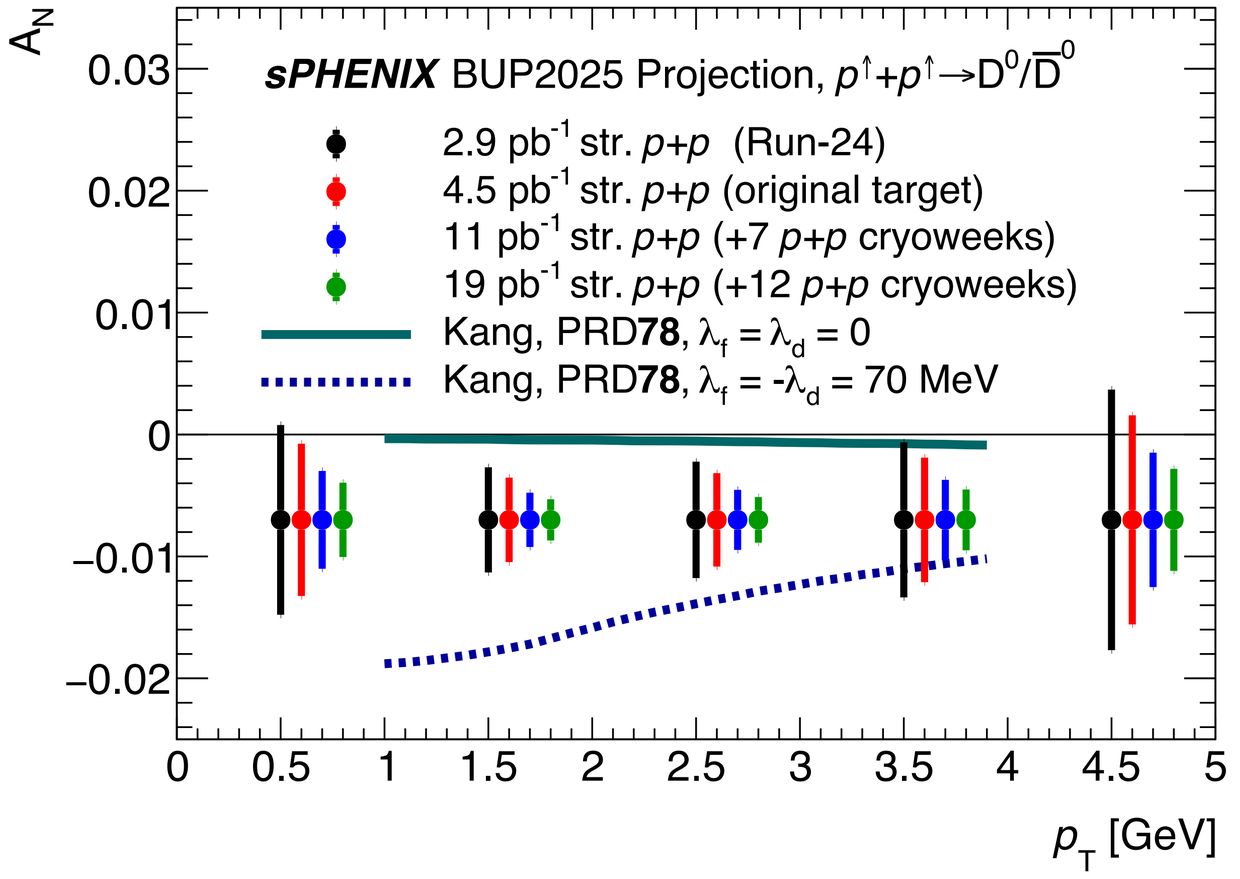
p+p running — tracker-only streaming data

The much increased streaming % results in **very fast accumulation — many RHIC-unique measurements** in *p+p* collisions

Example: $D^0\,A_{\mathrm{N}}$ in polarized *p+p* collisions

⇒ precisely constrain gluon Sivers TMD function & directly **connect with EIC science**

Another example: detailed probe of heavy flavor hadronization universality in *p+p*

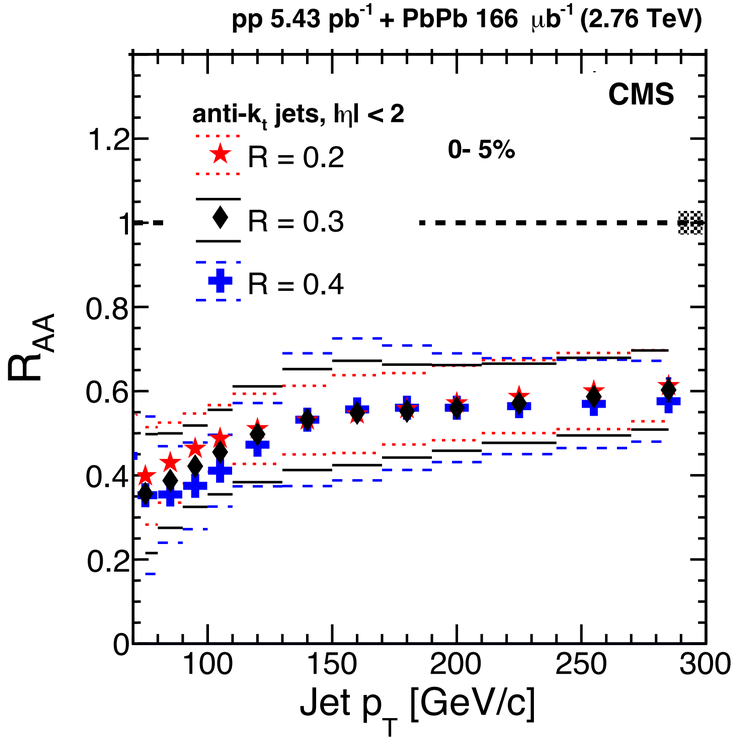


p+p running — data quality

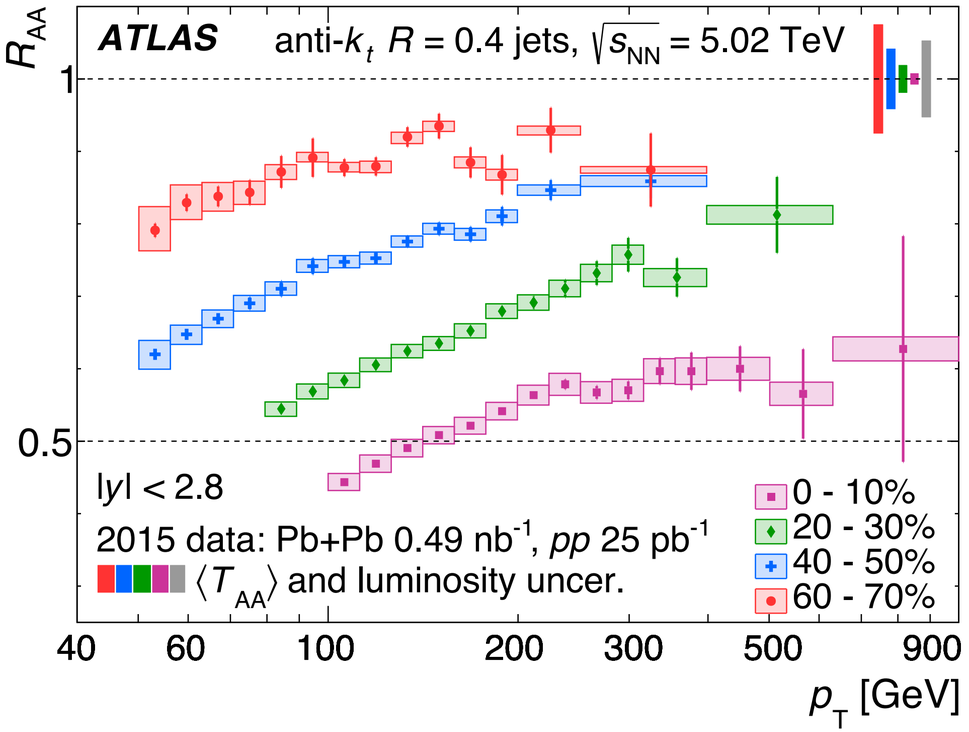
- The Run-25 detector configuration has significant improvements compared to Run-24, including:
  - ➡ improved gain balancing and stability from the upgraded TPC high voltage system
  - ➡ deployment of the TPC line laser
  - ➡ implementation of TPC digital current monitoring
  - ➡ optimized dynamic range of EMCal tower gain
- sPHENIX subsystem experts expect that *p+p* data in Run-25 will have **major qualitative improvements** over the existing Run-24 *p+p* data
  - ➡ these improvements are **above and beyond the statistical gain alone**

p+p running — detector calibration

- LHC experience: highly beneficial to have *p+p* & Au+Au data within the same running period, for detector calibration & cancellation of uncertainties



LHC Run 1 example: Pb+Pb data from 2011 and *p+p* data from 2013



LHC Run 2 example: **both datasets from 2015**

“What if only a few weeks were available?”

- If the Au+Au luminosity target was met, and there were only a few cryoweeks available (i.e. significantly fewer than 7 cryoweeks), sPHENIX would still request to **spend any remaining time running *p+p***

  ➡ Even a few weeks of *p+p* running could meet the original luminosity target for the tracker-only streaming dataset (e.g. open heavy flavor, slides 9-10)

  ➡ This data would still provide a critical calibration point for the Run-25 detector configuration

  ➡ C-AD guidance is that the switchover from Au+Au to polarized *p+p* is very fast, on the order of a week

Dataset	**Existing Run-24 *p+p* dataset**	**Total dataset with a “few weeks” of Run-25 *p+p***
Streaming tracker-only	2.9 pb^{-1}	**4.5 pb^{-1} Meet the target!** 🎯

Additional running

If the Au+Au and *p*+*p* luminosity targets are achieved…

Next-highest priority: O+O collisions

SCIENTIFIC MEETING

APS Division of Nuclear Physics (DNP) 2025

Invited Session Workshop

Workshop: Proton-Oxygen and Oxygen-Oxygen Collisions at RHIC and LHC I

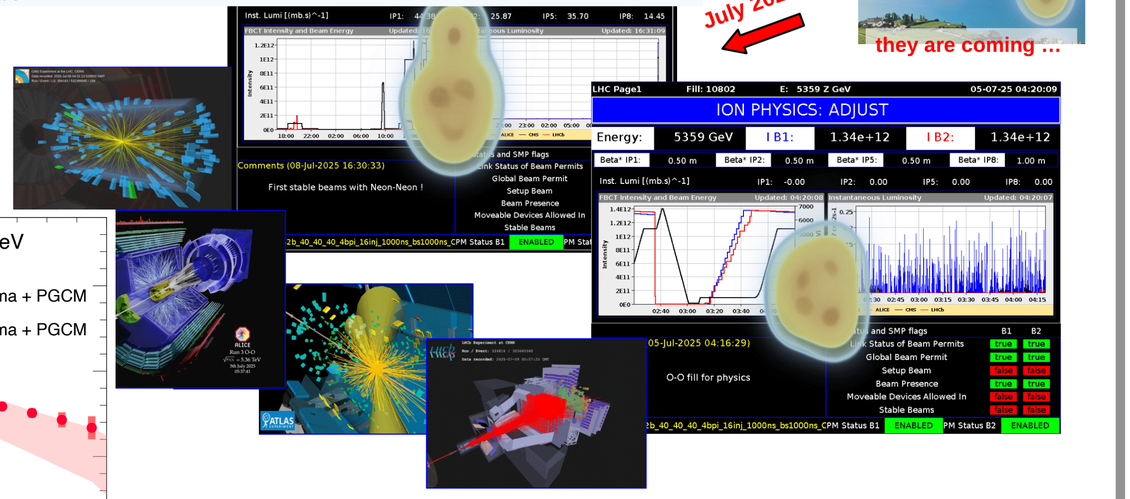
Light ion collisions at the LHC - 2025

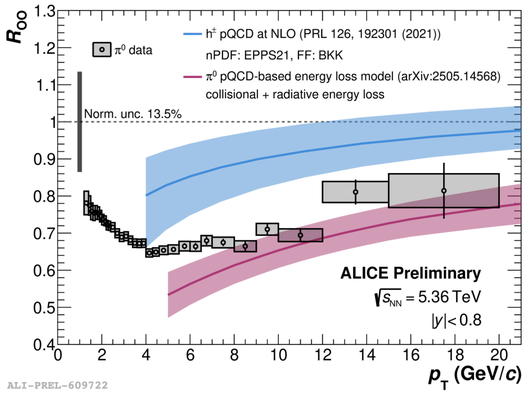
1–3 Dec 2025
CERN

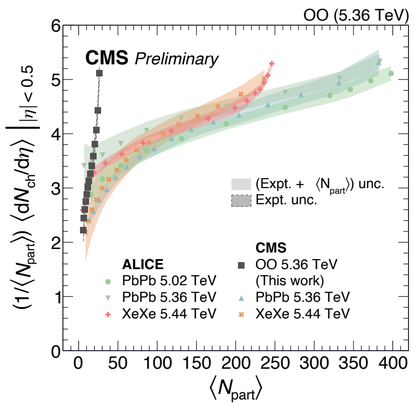
November 2024

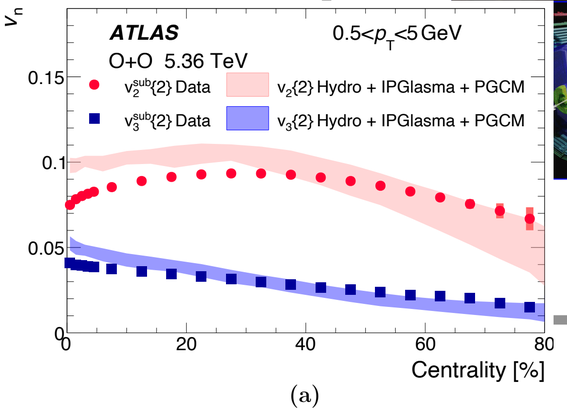
they are coming …

July 2025



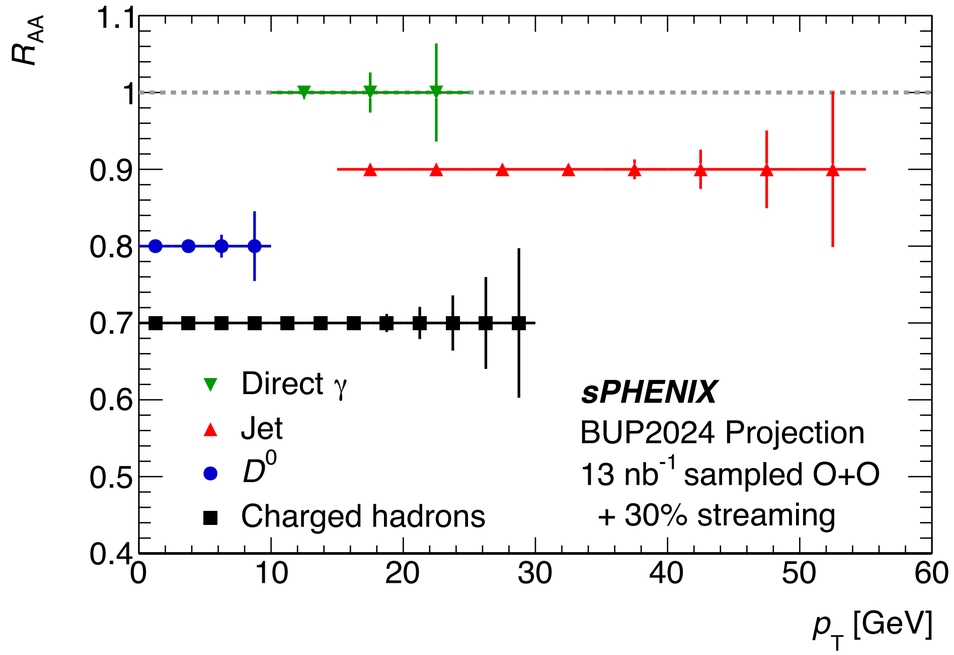


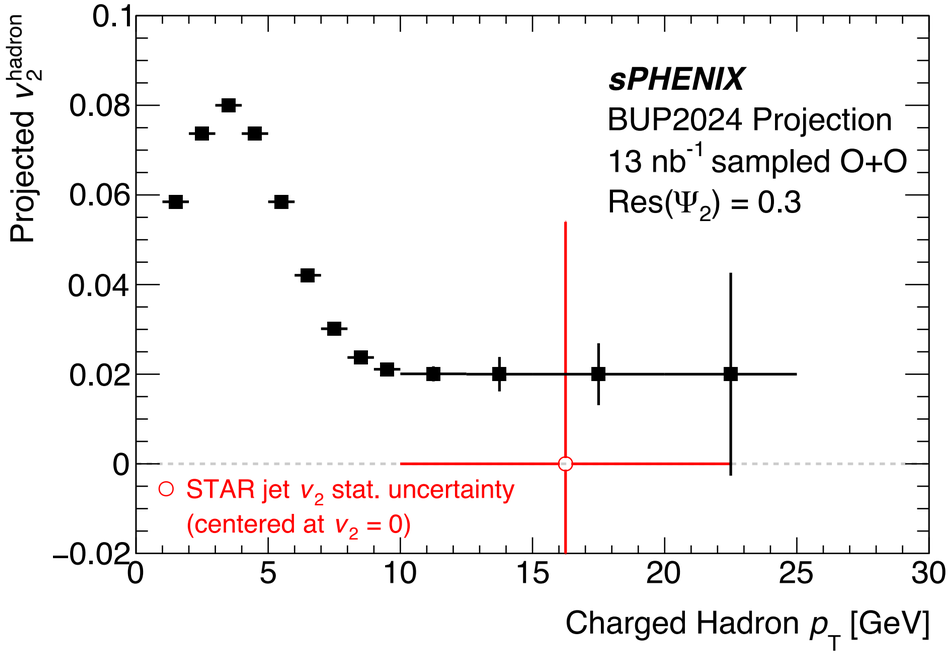




- Major community interest in light ion collisions given the success of the LHC run
- RHIC has proven capability for a **highly impactful two-week O+O program**

O+O physics: quenching and flow





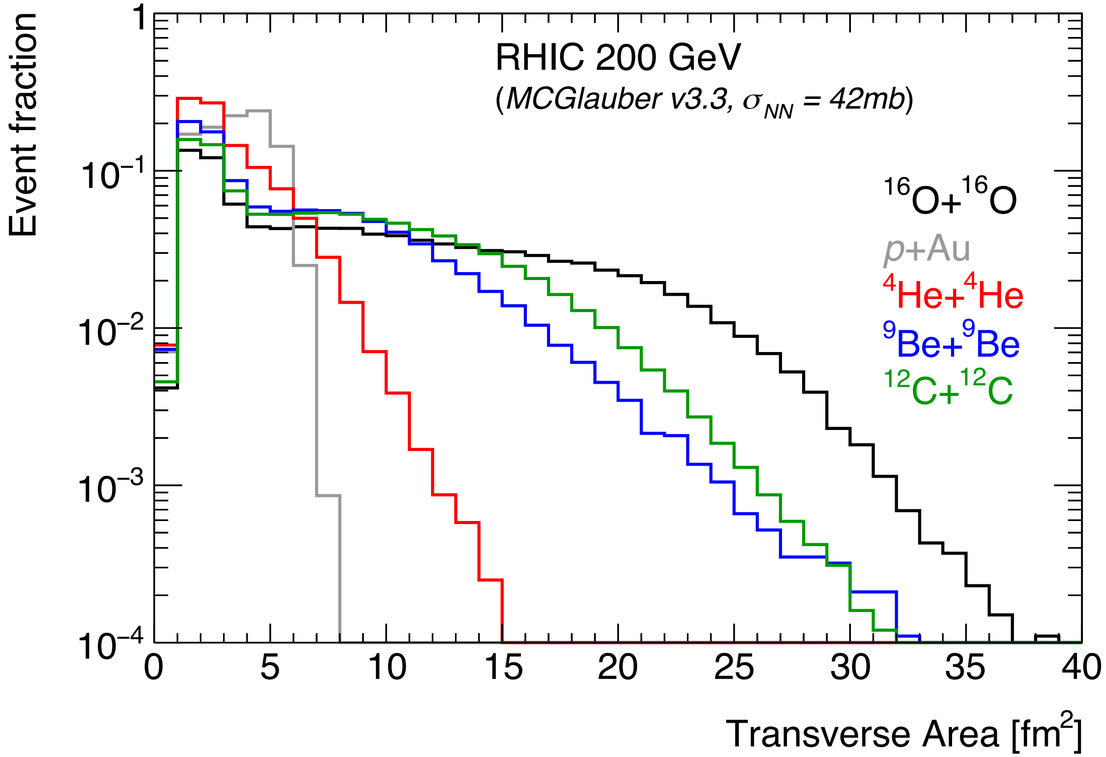
R_{AA} for **photons**, **jets**, **hadrons** and **charm** (from streaming readout) over broad kinematic range

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

RHIC opportunity in light ion running

^{4}He+^{4}He (α+α) collisions have similar transverse area to *p*+Au without extreme asymmetry

Lighter species like **^{9}Be+^{9}Be**, **^{12}C+ ^{12}C** interpolate between *p*+Au and O+O



Significant jet quenching in **O+O collisions**

➡ We note that the unique flexibility of RHIC can provide a variety of nuclei from $A = 4$ to $A = 16$, intermediate ions, etc. — much more readily than can the LHC

➡ RHIC+sPHENIX can address **what is the smallest system which exhibits jet quenching?** Scientific input from the PAC would be very useful.

p+Au running with sPHENIX

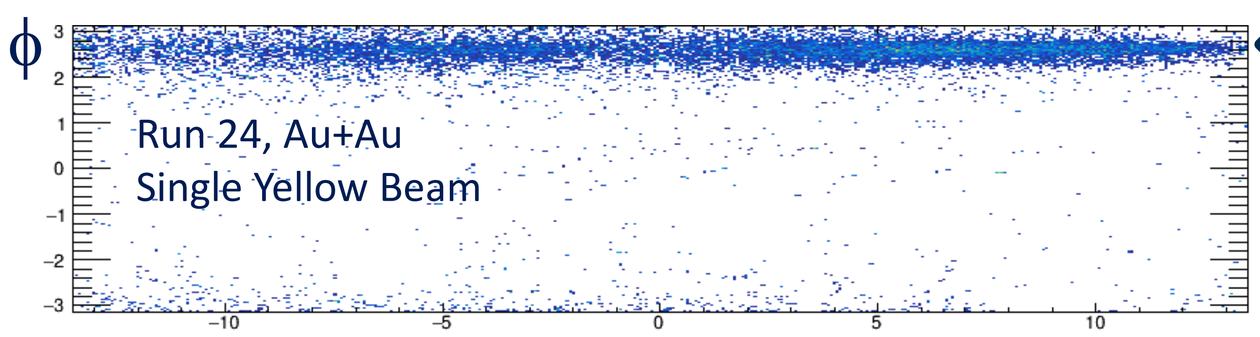
- The sPHENIX Collaboration has maintained a long interest in the physics of *p*+Au collisions

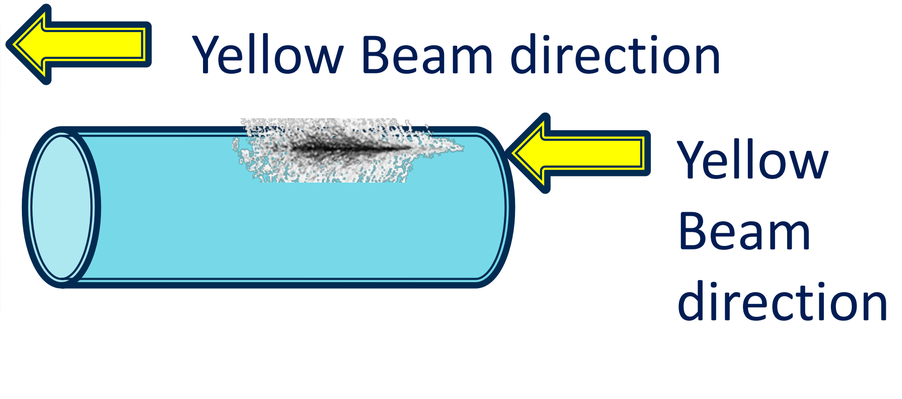
  ➡ in addition to jet and photon probes, a significant part of this interest was collecting an unprecedented, large streaming dataset for heavy flavor and multi-particle collectively measurements

  ➡ Run-25 experience has not provided a solution for running the MVTX in streaming mode when Au beams are present, and thus the sPHENIX physics output from a *p*+Au run is, at this time, significantly degraded

  ➡ there is no request for *p*+Au running from sPHENIX at the end of Run-25

Beam backgrounds in the MVTX





- Any running with Au beams causes a significant acceptance loss in the MVTX from auto-recovery lock up
- We thank C-AD for the long effort to characterize and attempt to mitigate the Au beam background issue
- After a commissioning period in Run-25, sPHENIX found a working point operating the MVTX in **triggered mode** for Run-25 Au+Au

  ➡ in Au+Au, collision rates are low enough to take them all with Minimum Bias triggers — this is not the case in *p*+Au

Strawman *p*+Au running plan

8 cryoweeks of *p*+Au (5 physics weeks)

RHIC switchover/setup time
sPHENIX MVTX commissioning
physics data-taking

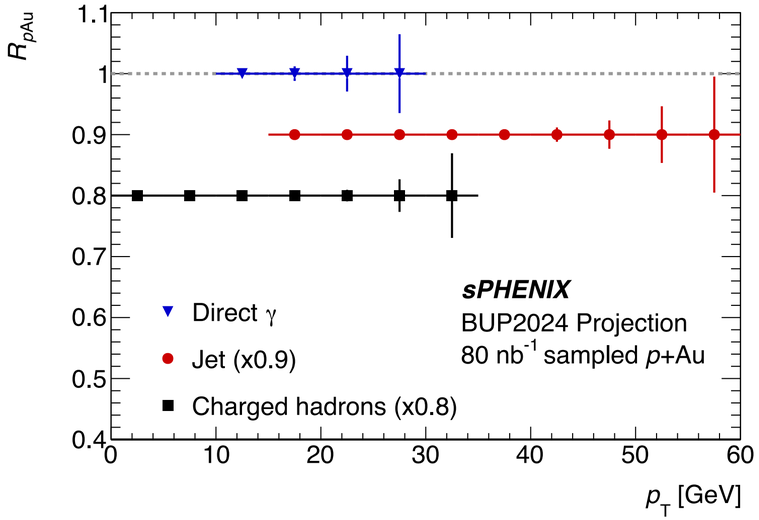
- Per C-AD, any *p*+Au running requires 2 weeks switchover/setup
- sPHENIX could attempt to find an operating point for the MVTX, including for streaming data-taking in Au beam backgrounds

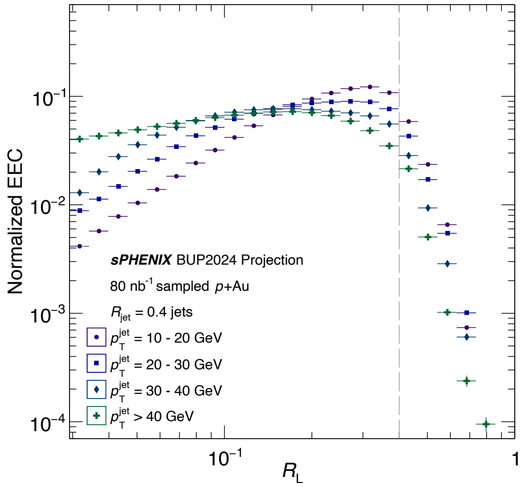
  ➡ at least one week where sPHENIX has control of the beam & access for single-beam, shielding, orbit, etc., tests

  ➡ **no guarantee of a successful solution for streaming readout in *p*+Au running**

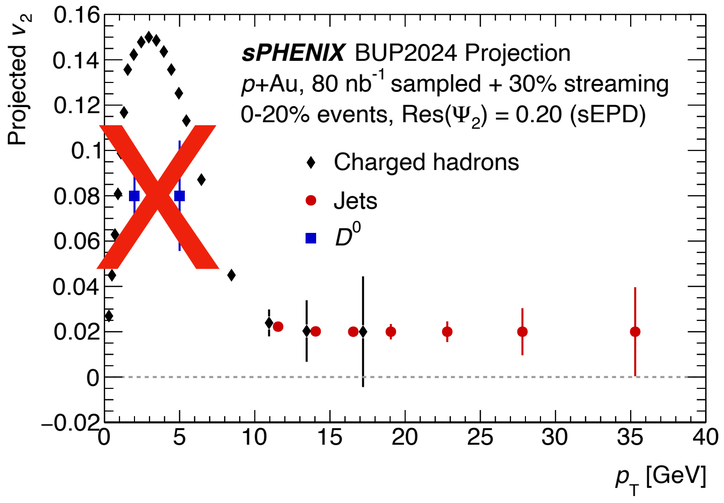
p+Au physics output from sPHENIX

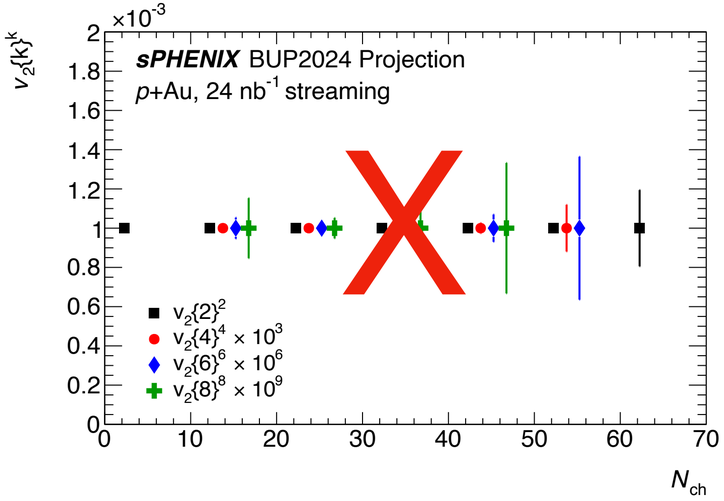
(Projection plots are from previous BUPs for 5 physics weeks)





- Some triggered, all-system measurements (likely) possible — jets, photon, high-p_T hadrons ✅





- No assurance of streaming readout
- Without streaming readout, **no heavy-flavor or collectivity program** ❌

Comparison of *p*+*p* and *p*+Au running

7 cryoweeks of *p*+*p*

- ➡ 2x all-system triggered data ✅
- ➡ >200% of tracker-only streaming data target ✅
- ➡ calibration point after Au+Au data ✅
- ➡ even a smaller, few-week run would be impactful (see slide 13)

8 cryoweeks of *p*+Au (5 physics weeks)

- ➡ no assurance of heavy flavor / collectivity program ❌
- ➡ collect high-statistics triggered dataset (jets, photons) ✅

- RHIC switchover/setup time
- sPHENIX MVTX commissioning
- physics data-taking

Role of the PAC after RHIC Run-25

- The NPP PAC has played a crucial role in the sPHENIX physics program over the last decade
- After data-taking, there are many years of data production, reconstruction, calibration, analysis, and preservation
- Strong, continued support from BNL and DOE will be required in terms of computing personpower, resources, and user support
- We highly recommend the PAC continue to meet annually to discuss and advise the ALD

Summary

- The sPHENIX optimal request is for **12 cryoweeks of *p+p* running** to complete the needed *p+p* reference data that was started in Run-24 and reduce systematic uncertainties on Run-25 Au+Au measurements

  ➡ A minimal dataset of **7 cryoweeks of *p+p* running** would still result in a major improvement, and even **a few weeks of *p+p* running** would have a significant impact on both statistics & data quality

- If there is time remaining, the sPHENIX request is for **two weeks of O+O and/or other light ion running**

- Due to the unsolved technical challenge of RHIC Au beam backgrounds in the sPHENIX MVTX, there is **no request for *p*+Au running at the end of Run-25**