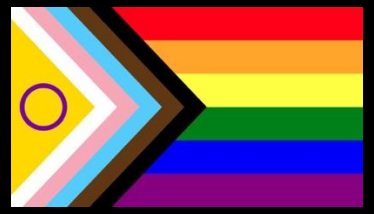


sPHENIX Run Report

2025 RHIC/AGS Annual Users' Meeting

May 22nd, 2025

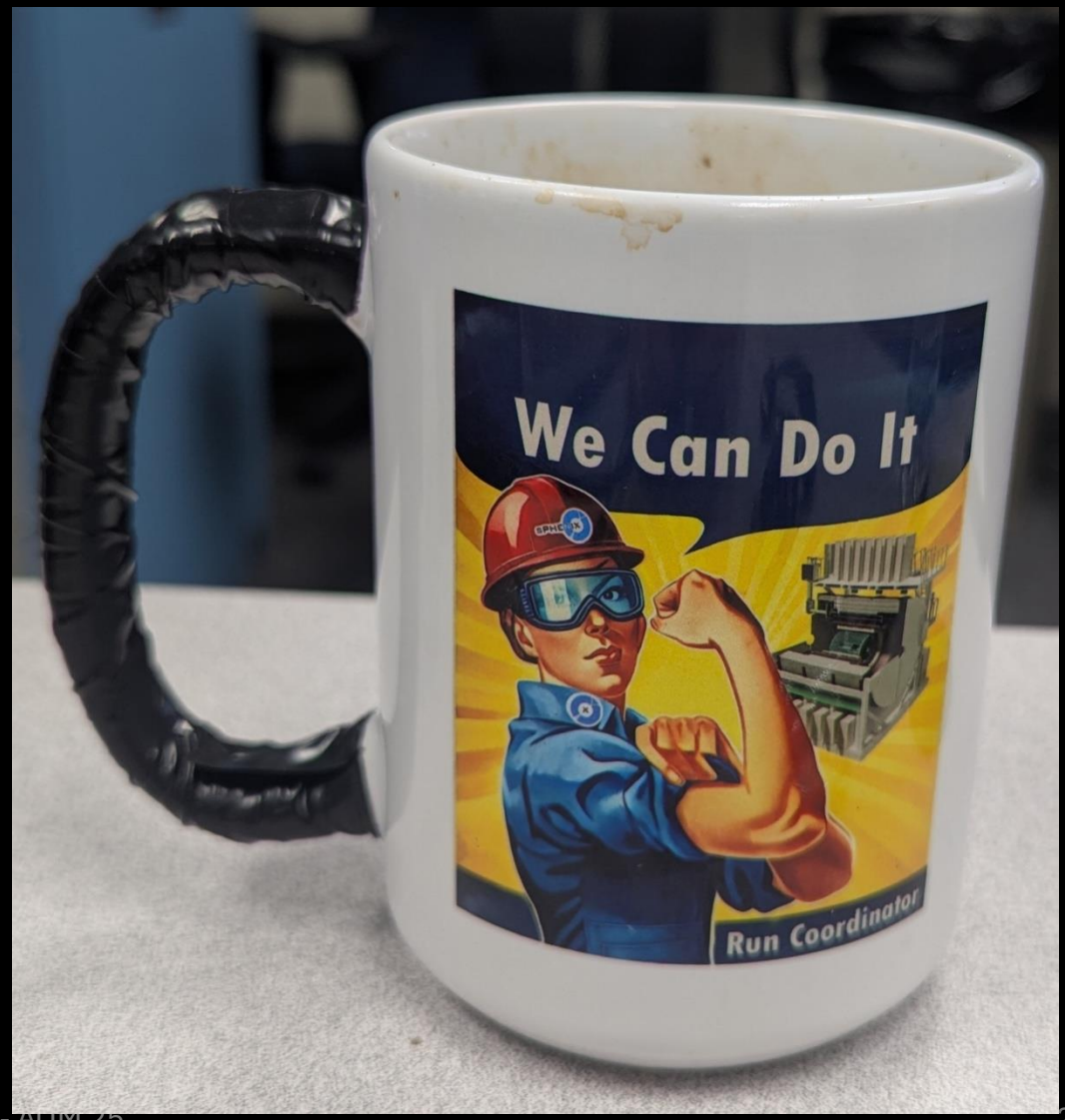
Rosi Reed

Lehigh University

sPHENIX Run 25 Coordinator

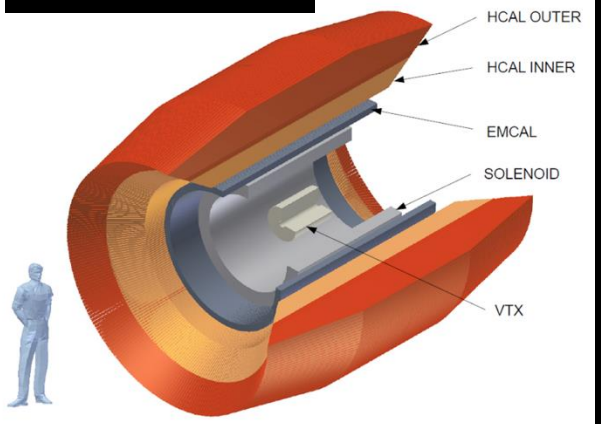
How it started

How it’s going



Look how far we have come!

2012

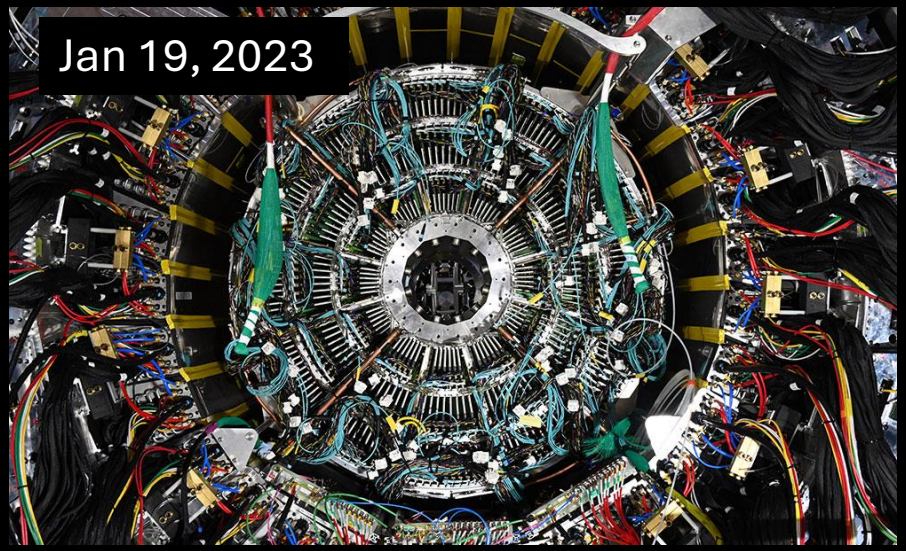


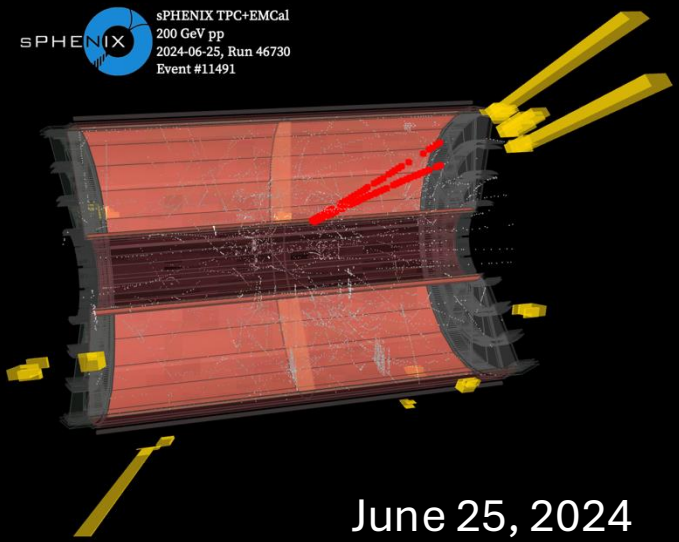
Dec 19, 2015

May 27, 2021

June 8, 2022

Jan 19, 2023



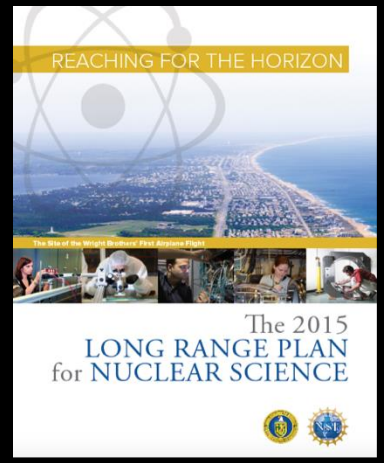


June 25, 2024

RHIC Science Mission

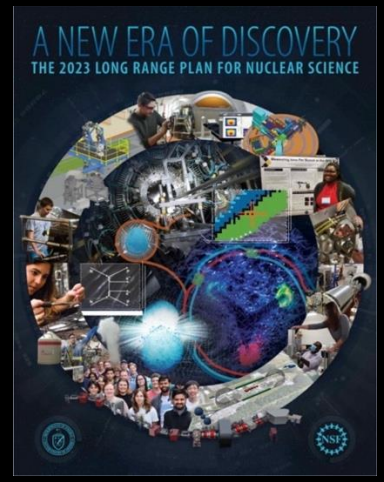
2015 Nuclear Physics Long Range Plan

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**.



2023 Nuclear Physics Long Range Plan: Recommendation 1

The highest priority of the nuclear science community is to capitalize on the extraordinary opportunities for scientific discovery made possible by the substantial and sustained investments of the United States. We must draw on the talents of all in the nation to achieve this goal. Here we emphasized that this recommendation requires (1) … (2) continuing effective operations of the national user facilities and **completing the Relativistic Heavy Ion Collider science program**



2023 Nuclear Physics Long Range Plan: Future of hot QCD facilities

To successfully conclude the RHIC science mission, it is essential to (1) complete the sPHENIX science program as highlighted in the 2015 Long Range Plan, (2) complete the concurrent STAR data collection with the forward upgrade, and (3) analyze the data from all RHIC experiments.

J.Nagle: AUM 2024

The Goal and the Plan and Reality

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 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}

The Real 2023:

10.5 weeks of sPHENIX commissioning

and then…

PAC strongly endorsed 28 weeks in 2024.

The Real 2024:

19 cryo weeks [2 setup, 6 commission, 11 physics] + 6 carry over

How to still achieve the pp minimum of 45 pb^{-1} in that time frame?

*Note that corresponds to 75 pb^{-1} delivered within |z| < 10 cm.

J.Nagle: AUM 2024

The Goal and the Plan and Reality

Year	Species					
2023	Au+Au					
2024	$p^{\uparrow}p^{\uparrow}$					
2024	p Au					
2025	Au+Au	200	24 (28)	20.5 (24.5)	13 (15) nb^{-1}	21 (25) nb^{-1}

Run 23 commissioning was cut short → Continued in Run 24, reduced time for physics weeks

PAC strongly endorsed 28 weeks in 2024.

The Real 2024:

19 cryo weeks [2 setup, 6 commission, 11 physics] + 6 carry over

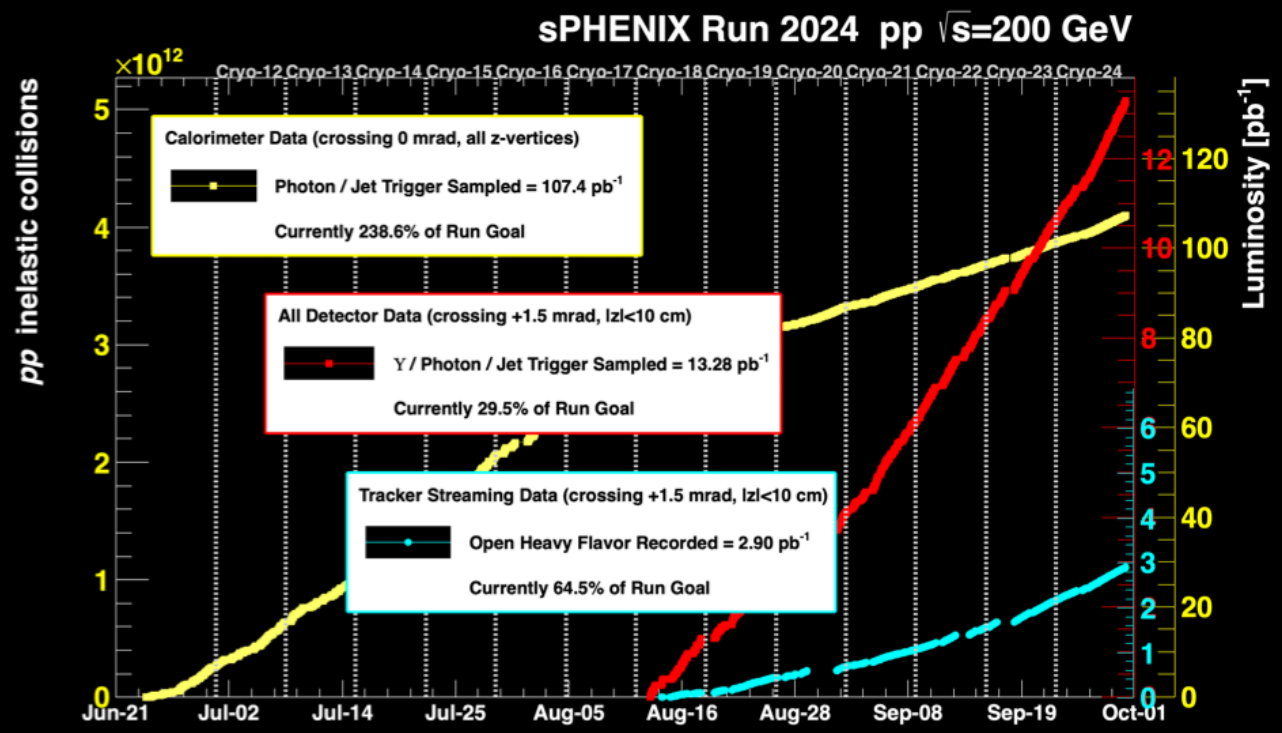
How to still achieve the pp minimum of 45 pb^{-1} in that time frame?

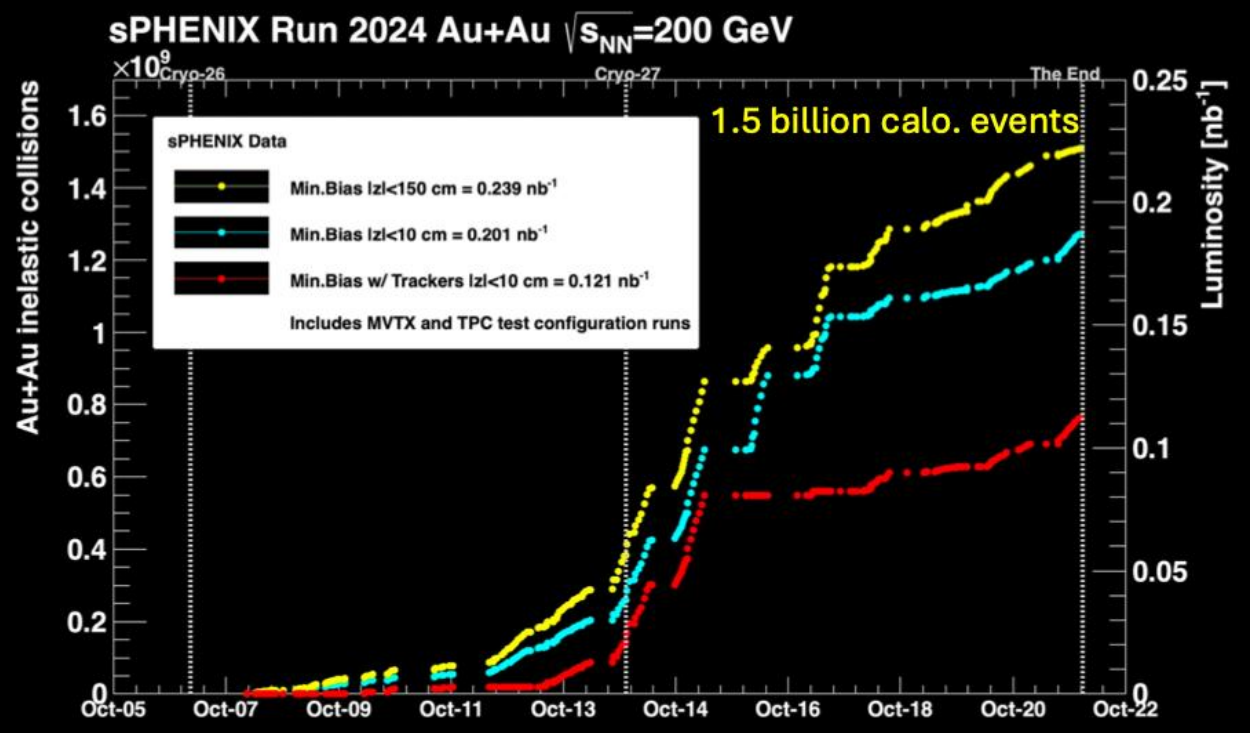
*Note that corresponds to 75 pb^{-1} delivered within |z| < 10 cm.

We ran very efficiently post-commissioning!

Run 24 Luminosity

J.Nagle PAC 2024





Run 2024 pp data set

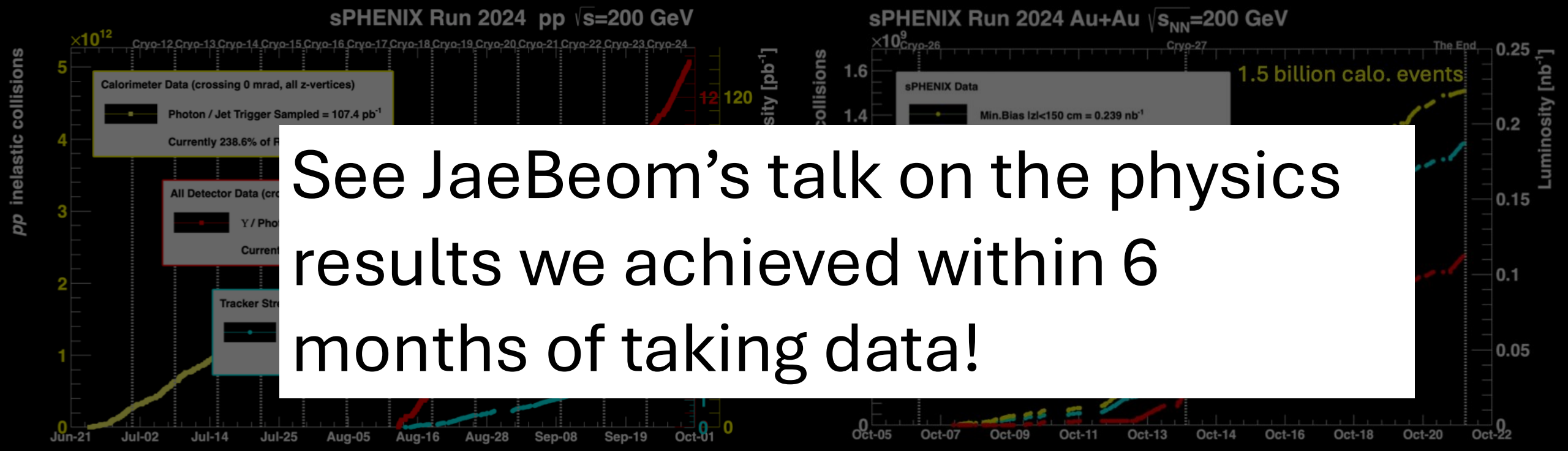
- 230% BUP jets/photons
- 65% BUP open heavy flavor
- 30% BUP Upsilon/full program

Run 24 Au+Au was extremely informative

We ran very efficiently post-commissioning!

Run 24 Luminosity

J.Nagle PAC 2024



See JaeBeom's talk on the physics results we achieved within 6 months of taking data!

Run 2024 pp data set

- 230% BUP jets/photons
- 65% BUP open heavy flavor
- 30% BUP Upsilon/full program

Run 24 Au+Au was extremely informative

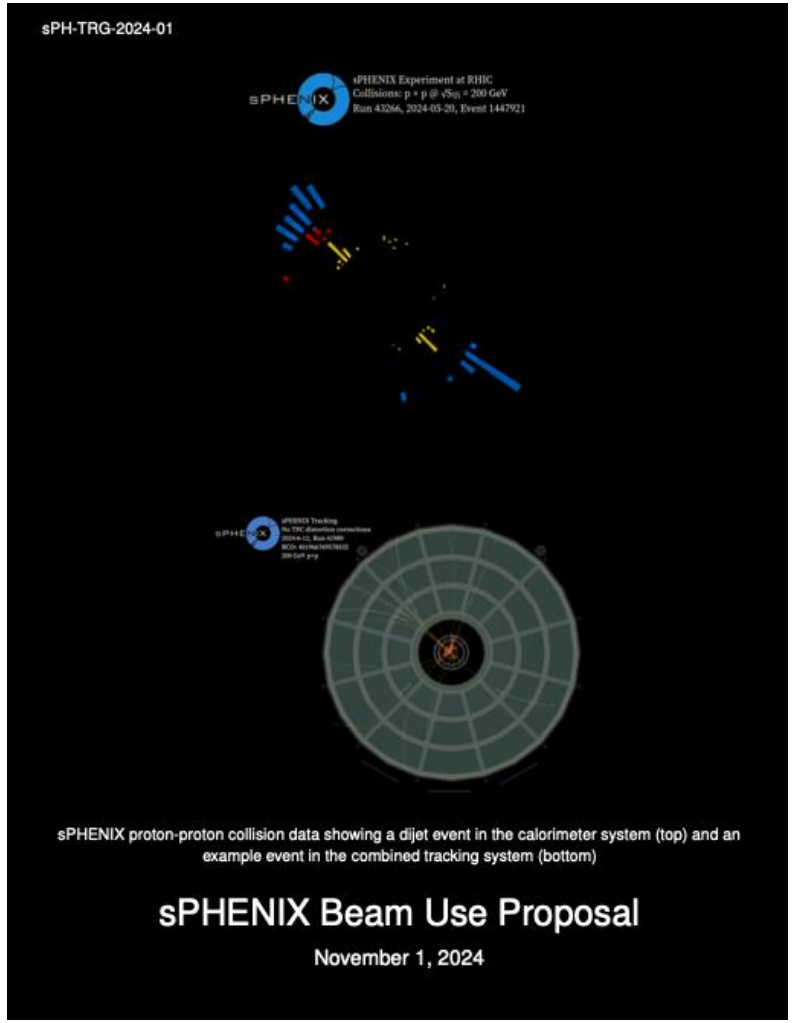
3 Talks and 8 Posters at AUM

- **Daniel Lis “High-pT physics in sPHENIX”**
- **Alexander Patton “sPHENIX Heavy Flavor Overview”**
- **Virgile Mahaut " The Cold QCD Program at sPHENIX “**
- Yuko Sekiguchi ”sPHENIX measurement of long-range two-particle correlations in high-multiplicity p+p collisions”
- Tanner Mengel (University of Colorado) “Underlying event fluctuations and jet background in 200 GeV Au+Au collisions with the sPHENIX detector”
- Mariia Mitrankova (Stony Brook University): "sPHENIX Alignment of the TPC Tracking Detector ”
- Chenxi Ma (Stony Brook University): "sPHENIX Armenteros-Podolanski plot”
- Itsuka Omae “The study of v2 vs. multiplicity with ZDC categorization at 200GeV in AuAu at RHIC”*
- Ryotaro Koike (Kyoto University) “Sub-bunch-crossing Time Resolution of the sPHENIX Intermediate Silicon Tracker”
- Jaein Hwang (Korea University) “sPHENIX Performance of the Intermediate Si Tracker”
- Shuhang Li (Columbia University) "Measurement of isolated prompt photons in $\boldsymbol{p} + \boldsymbol{p}$ collisions at 200GeV with the sPHENIX detector"

* General RHIC Talk

RHIC Science Mission

- "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."
- "The PAC has received beam use requests for running **pp, p+Au, and O+O** collision systems. The PAC sees all three of these **proposed runs as fully aligned with RHIC's core scientific mission**, and in fact as key elements of completing that mission. Each of these three proposed runs is necessary to address central open RHIC Science questions in a decisive way."
- Assuming RHIC start at end of May; latest RHIC (max – min) luminosity projection in BUP24 to complete 7 nb^{-1} Au+Au program requires running until Nov 2025 (max lumi) - April 2026 (min lumi)



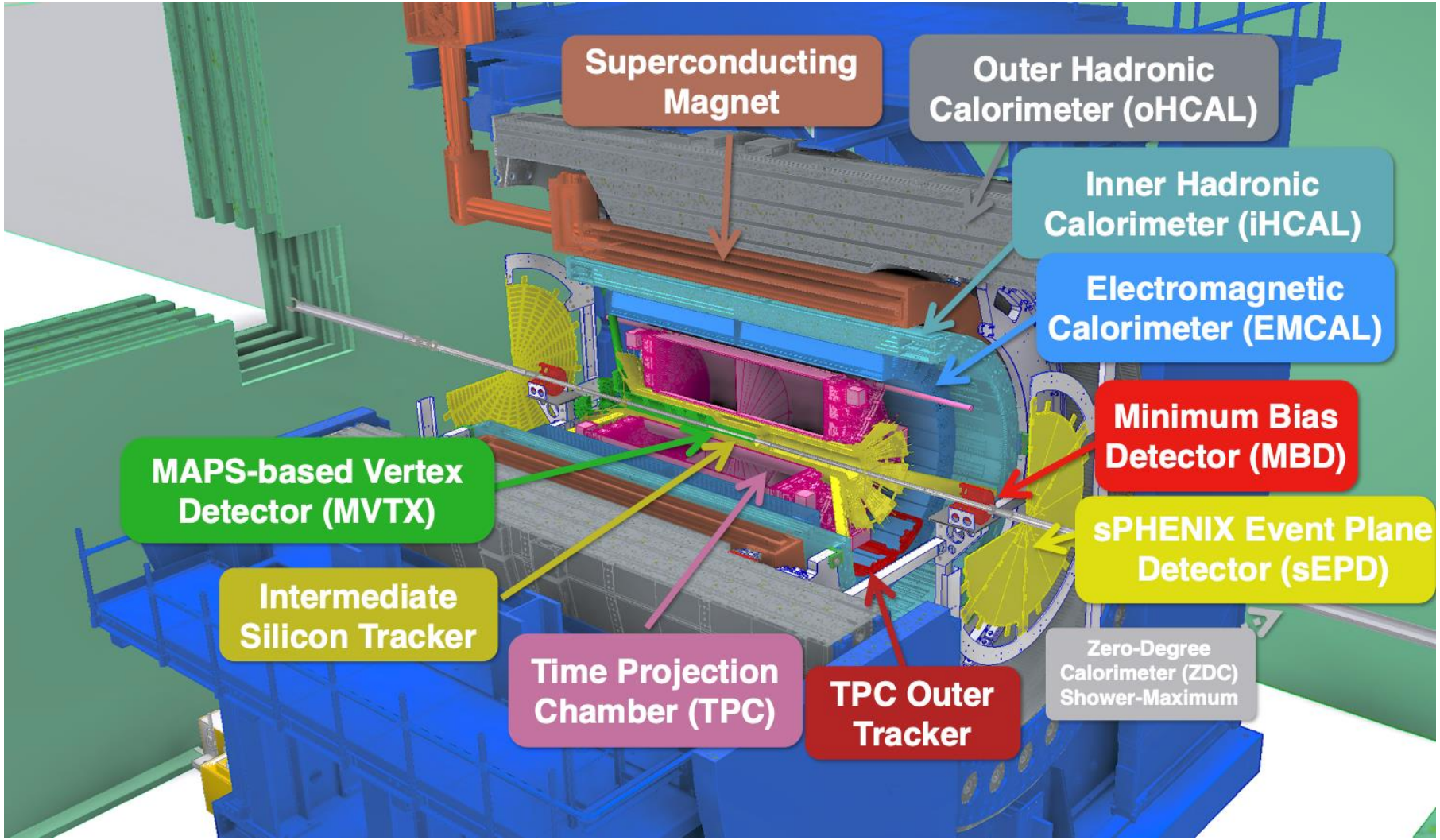
Run 25 sPHENIX BUP

Translate weeks → recorded luminosity

Run-25 Projection, sPHENIX Physics Target: **7 nb^{-1} (50B events)**		
Collision Species	Cryoweeks	Projected luminosity, $\|z\| < 10$ cm
Au+Au 200 GeV	20	2.8 – 5.4 nb^{-1} recorded
Au+Au 200 GeV	28	4.2 – 8.1 nb^{-1} recorded

Ordered priority list for additional running in FY26		
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
(*) If sufficient running time is available.		

sPHENIX Detector



Start of Run 25

- sPHENIX Shift sign-up opened January 6
  - 13 weeks of “gas shifts” (Feb 18 – May 20)
  - ?? Weeks of full shifts (May 20 – ??)
  - 2 weeks of end-of-run ”gas shifts” (??)
- Started Isobutane flow Feb 19th
  - Required to prevent sparking in the TPC
  - 24 hour shifts required

- Record cosmics needed to align sPHENIX trackers
- Commission new TPC Power Supply
- TPC line laser commissioning

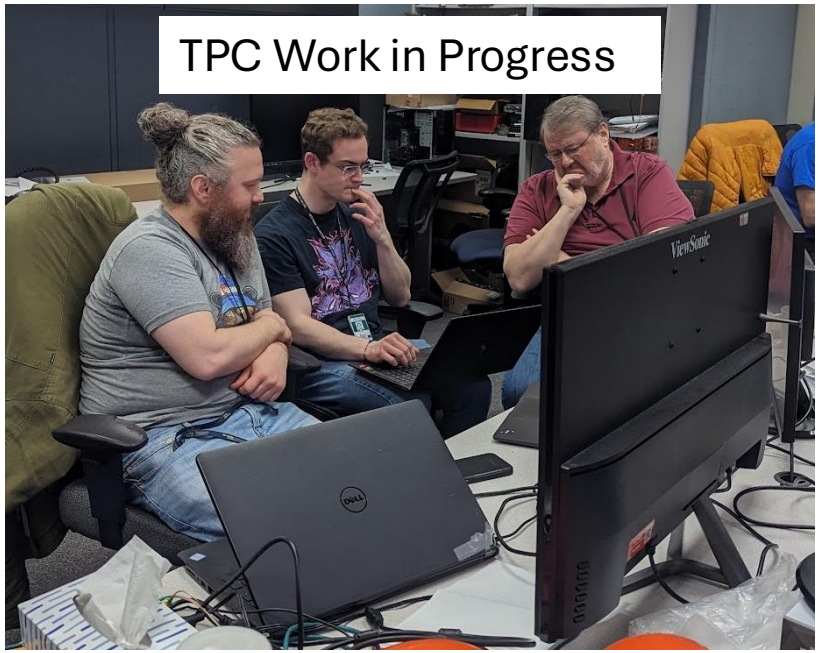
Run 25 sPHENIX Shifters So Far

75 unique shifters for 102 shifts!

sPHENIX Schedule

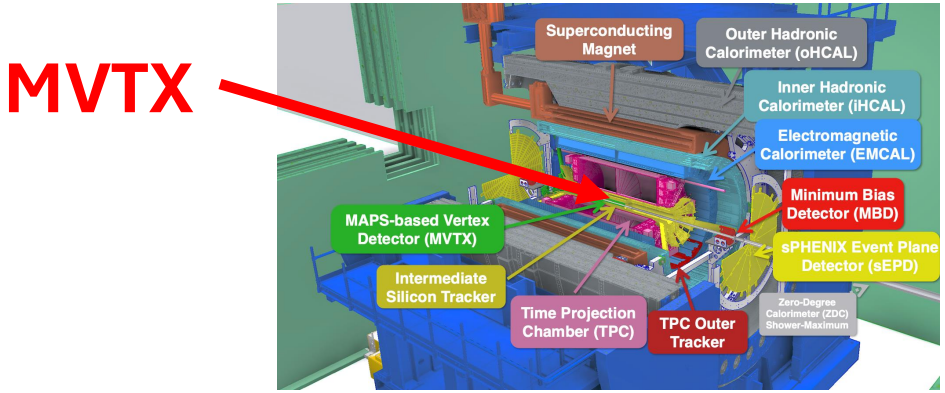
- Feb 14 – Readiness Review
- Feb 18 – Start of Shifts
- Feb 19 – Start of Isobutane
- Feb 27 – Calo DAQfest
- March 10 – Donut and Collar Review
- March 28 – Begin Run Taco Party
- April 21 – 22 - DAQfest
- May 9 – 12 – Dry Run
- May 20 – Start of 4 person shifts

We have been very productive while waiting for beam!

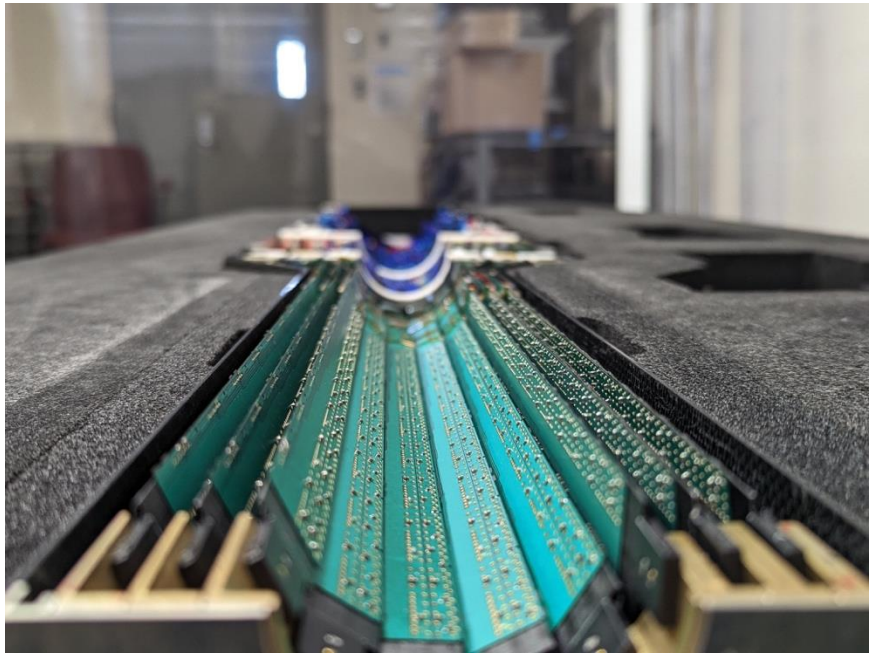


MAPS-based Vertex Detector (MVTX)

- Composed of 3 layers of MAPS using the ALICE ALPIDE
- The front-end readout uses the ALICE Readout Unit
- The back-end uses the ATLAS FELIX
- Records from 2.5 cm to 4.5 cm, radially



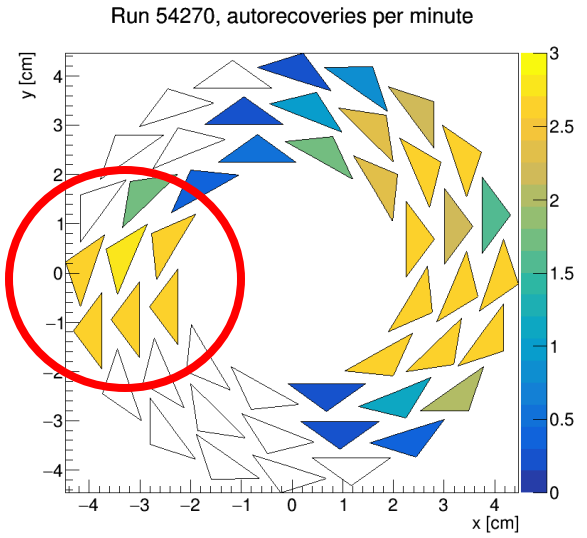
Sensor thickness [μm]	50
Pixel size [μm] / matrix	29 x 27 / 1024 x 512
Technology	180nm CMOS
Power Consumption [mW/cm^2]	40
Stave Material Budget	0.3% X_0
Timing resolution [μs]	~5 – 6
Hit resolution [μm]	< 6
Channels	226M



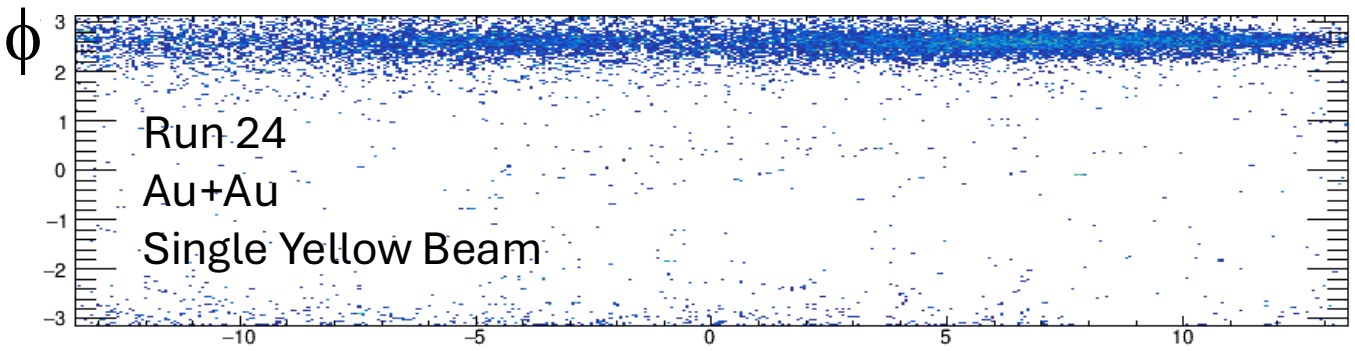
MVTX in Run 25

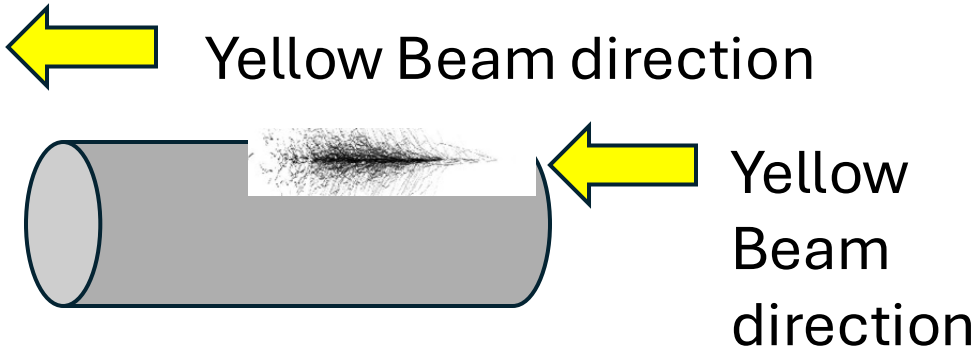
- MVTX Slow Control System updated
- Successful cosmic data taking with other tracking detectors
- Fast offline analysis tool developed for cluster shape and tracking efficiency study
- Issues and challenges
  - Beam halo background in Au+Au
    - Causes detector staves readout to be overwhelmed (10k+ hits instead of 100) and lock up to recover → Auto-recovery
    - Auto-recovery/Reset process takes ~15s
  - Requires continuous onsite presence of MVTX experts

Auto-recovery rate per minute from BUP



MVTX Background Issues

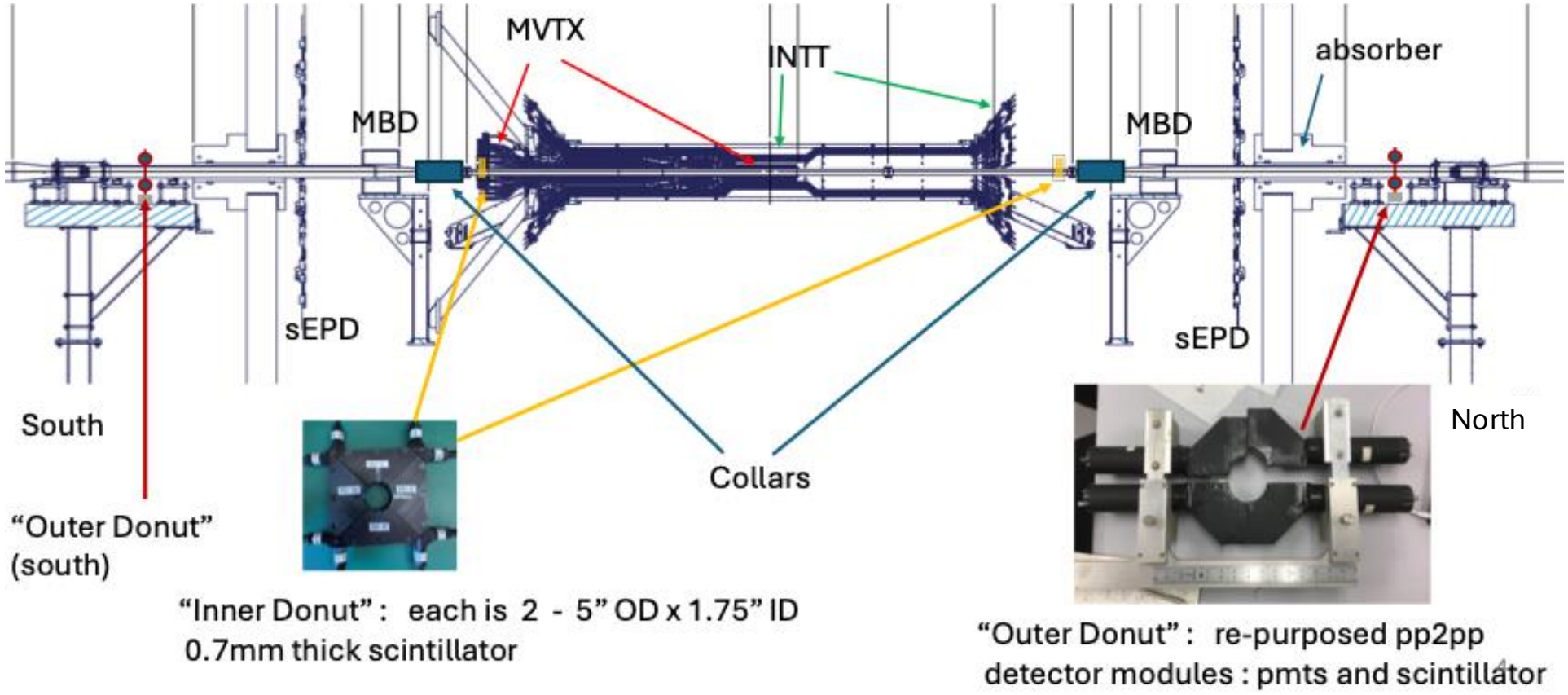


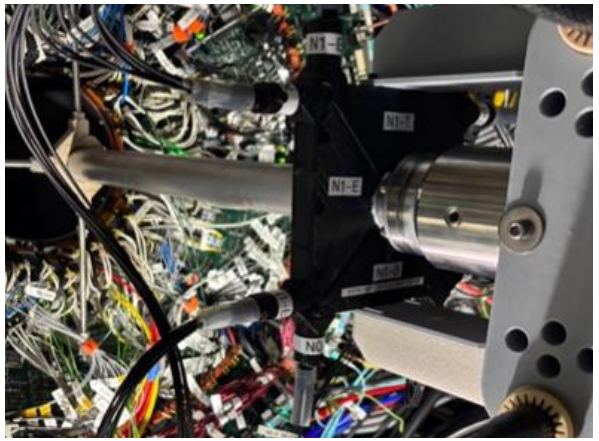


- Hundreds of tests during Run 24 Au+Au running with the help of CAD
  - No ideal configuration removes the background
- Move from **streaming to triggered** mode!
  - Streaming mode susceptible to all "splash" events
  - **We verified we can run in this mode!**
- Many joint sPHENIX-CAD background meetings after Run 24 conclusion
- **MVTX is ready for beam!**
- Post-beam commissioning required

- No problems in pp
- Large background in Au+Au
  - Even with a single bunch in the yellow ring → No collisions
  - Causes auto-recoveries
- Addition of scintillator (donuts) and steel collar (scatterer) for Run 25 background studies

Donut Detectors

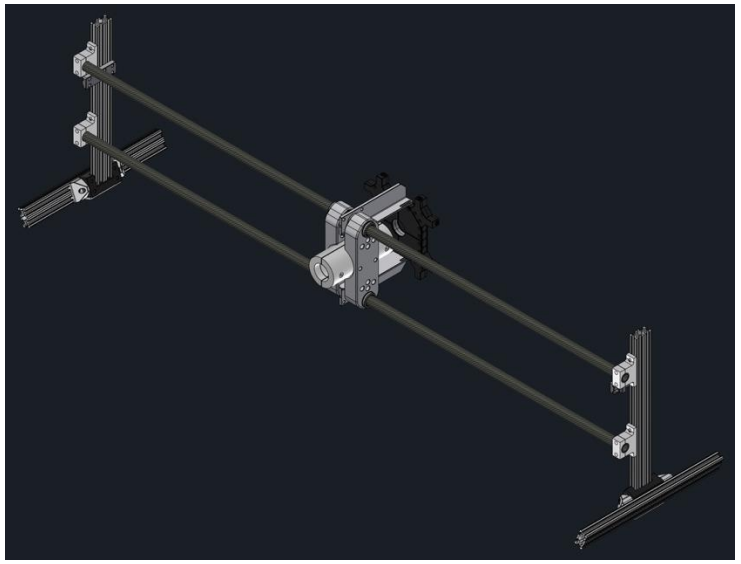


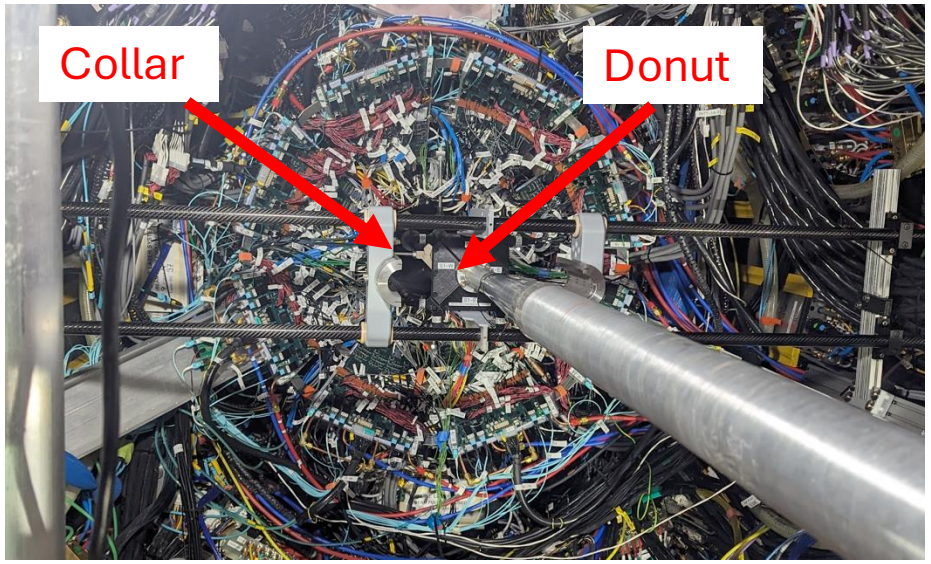


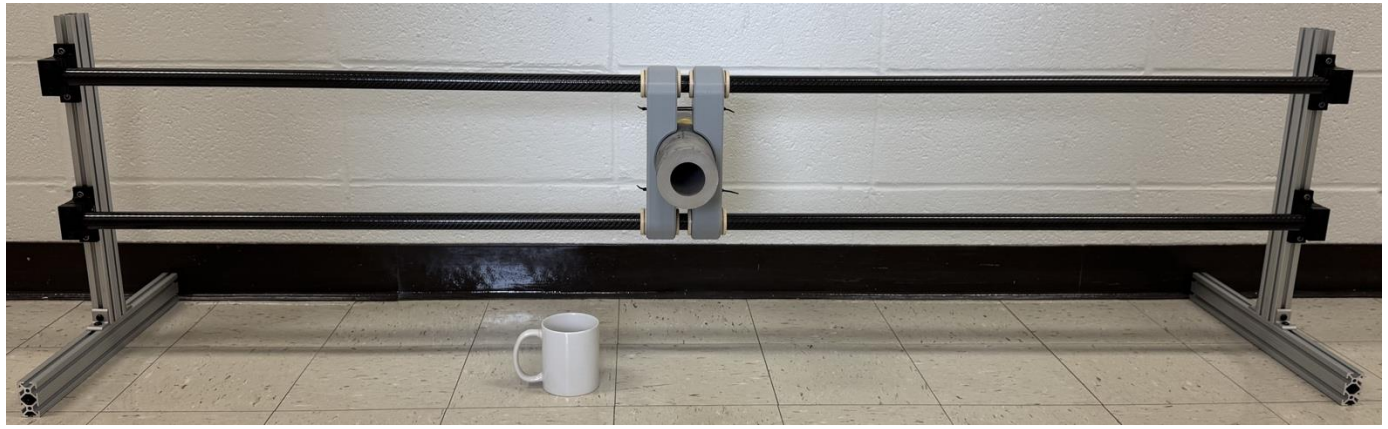
North-side inner donut after installation

The donut detectors are scintillator detectors created to give CAD scalars that directly correspond to background rate (MVTX Autorecovery time takes ~15 s)

Collar





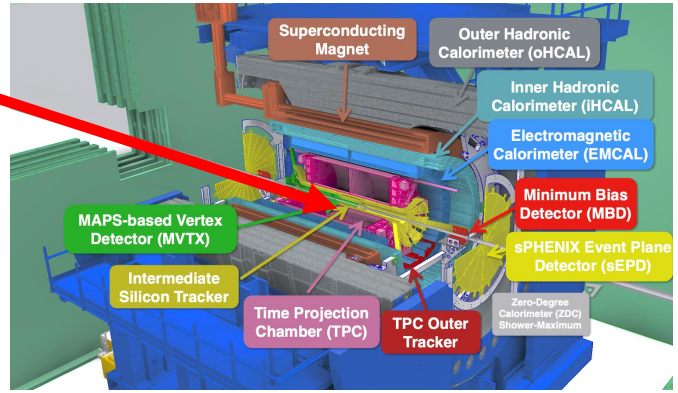


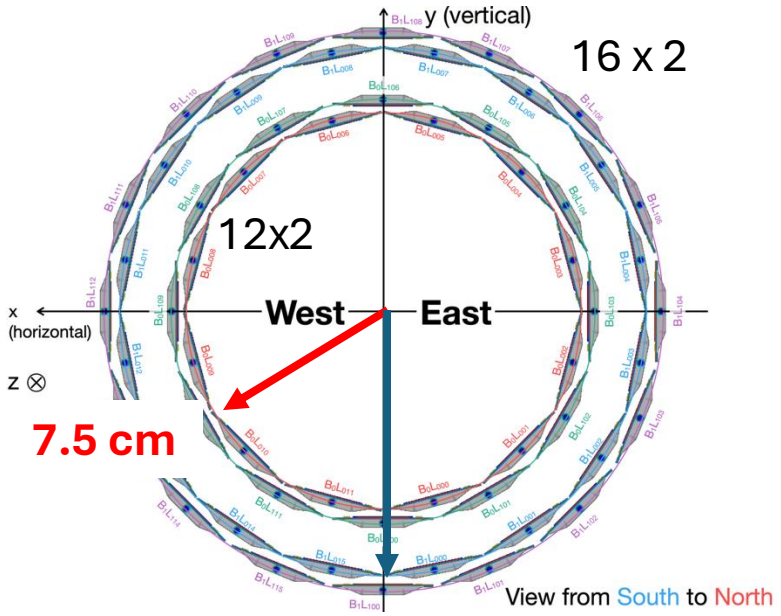
GEANT studies showed that a steel collar could deflect the particles running parallel and through the MVTX

- We will start <u>with the donuts</u> but with the collar open

Intermediate Silicon Tracker (INTT)

- Two layers of Silicon barrel
  - Bridge between the MVTX and the TPC
- Capable of resolving beam crossing
  - Great timing resolution
- Can run in both triggered and streaming mode
- Critical for one of the first two sPHENIX papers (arxiv:2504.02240)

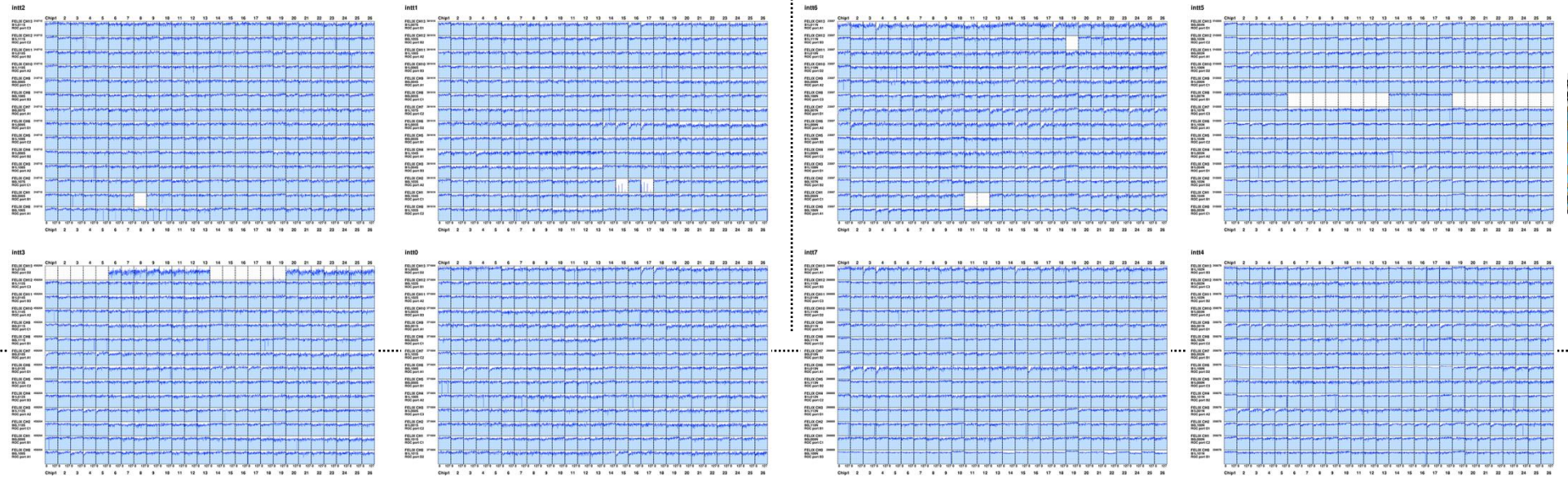


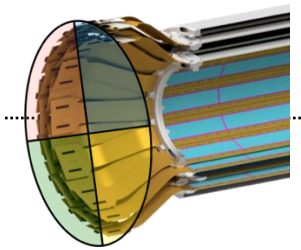


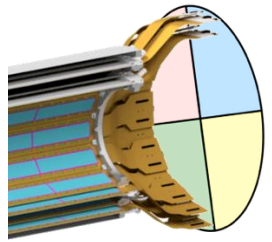
INTT

Pedestal measurements confirmed the detector condition same as 2024

South



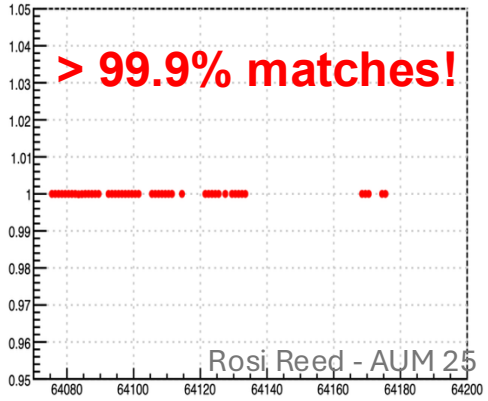




99% alive!

North

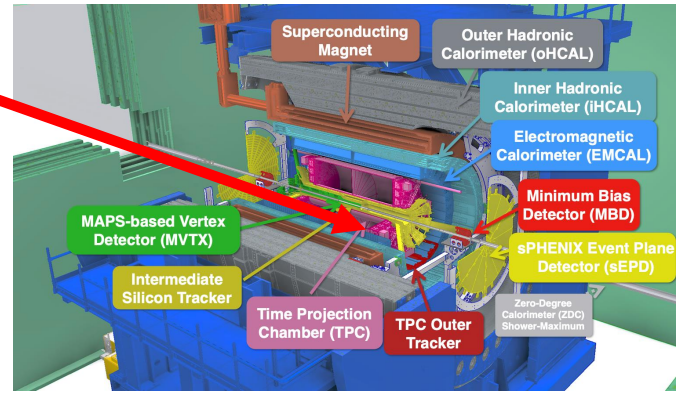
Low-level study reproduced 2024 matching to the trigger data

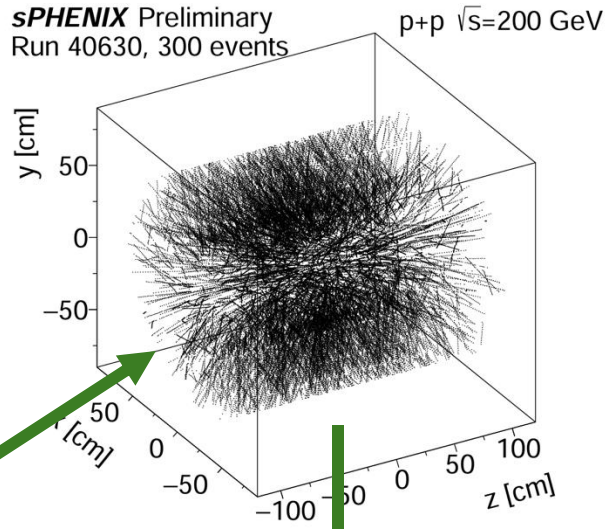


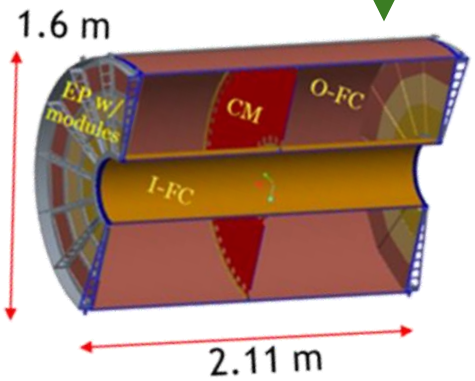
Lots of effort by the onsite crew!

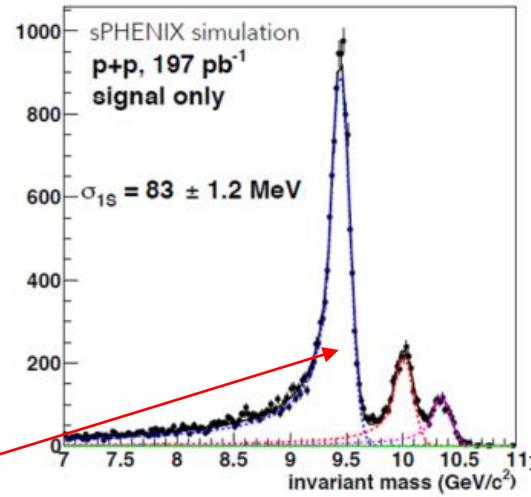
INTT is ready for Run25!

Time Projection Chamber (TPC)









- A next-generation TPC operated in continuous readout mode using Gas-Electron Multiplier (GEM) avalanche w/ Low Ion Back Flow (IBF)
- Front End Electronics (FEE) uses SAMPA chip (developed by ALICE)
- Data Aggregation Module (DAM) uses the FELIX board (ATLAS)

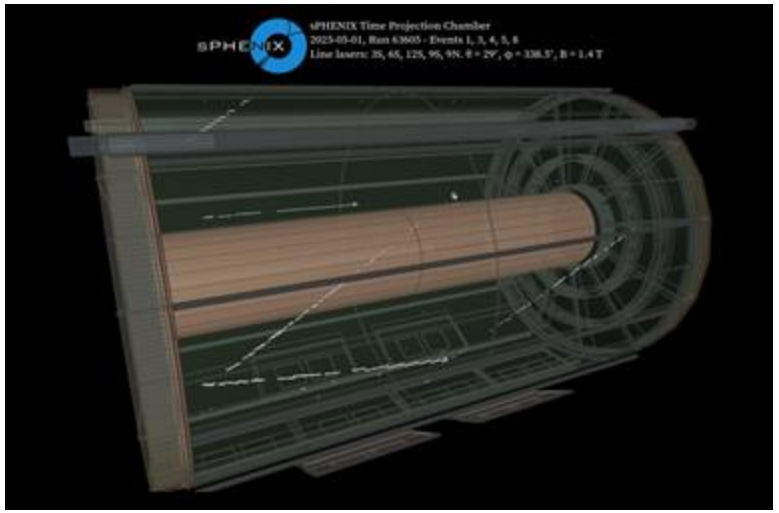
High Momentum Resolution:
- Large Lever Arm (Maximize Active Area)
- High Precision (Good Single Point Resolution)
- High Accuracy (Low Distortion)

Charged Tracking in sPHENIX:
- TPC provides p-resolution

Time Projection Chamber (TPC)

Line Laser Commissioning

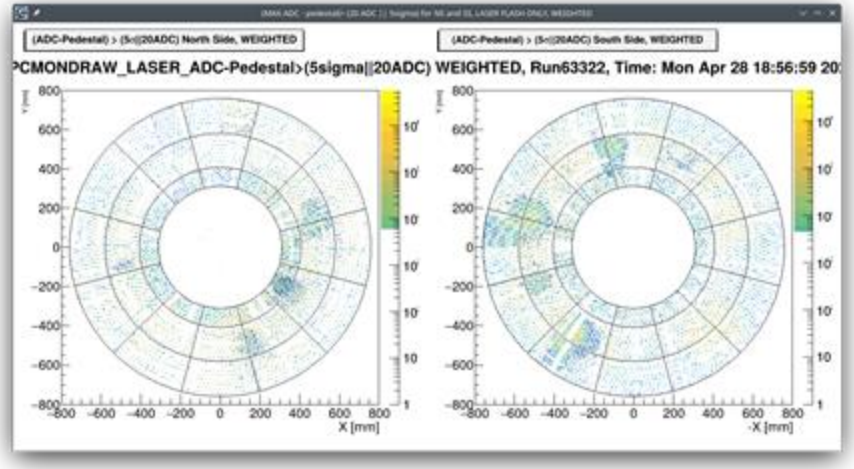
- Fully deployed



- Laser scan the TPC volume for static distortion correction
  - Run during “down” times

Diffuse Laser Commissioning

- 5/6 diffuse lasers successfully illuminate TPC central membranes



- Resulting photoelectron clusters collected across the readout

HV System Upgrade

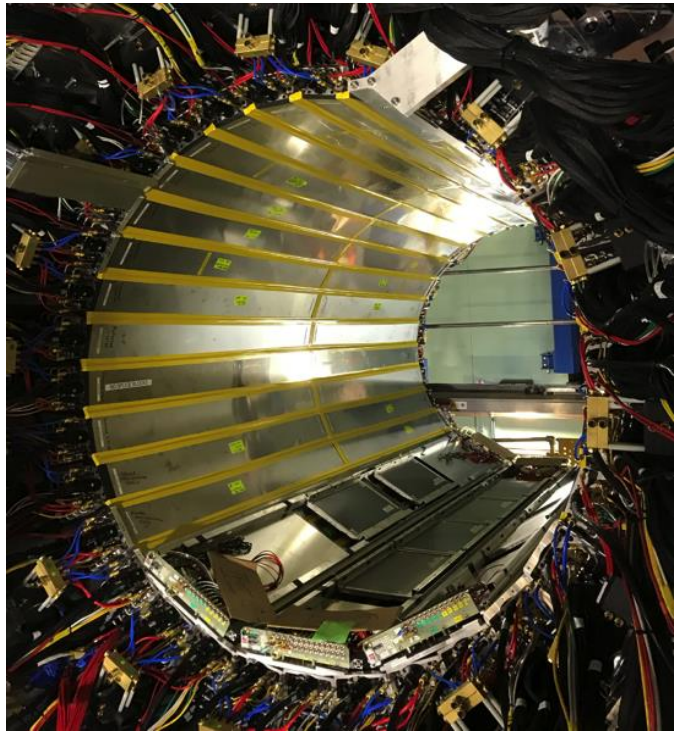
- New CAEN HV system installed, commissioned, and in daily use
  - Gain balancing done

TPC is ready for beam!

Time Projection Chamber Outer Tracker (TPOT)

Late addition (design 2021, construction 2022)

- 8 MicroMesh Gaseous detectors (Micromegas) to provide one space point (σ < 500μm) outside of the TPC with limited acceptance



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Full Length Article

The sPHENIX Micromegas Outer Tracker

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ABSTRACT

The sPHENIX Time Projection Chamber Outer Tracker (TPOT) is a Micromegas based detector. It is a part of the sPHENIX experiment that aims to facilitate the calibration of the Time Projection Chamber, in particular the correction of the time-averaged and beam-induced distortions of the electron drift. This paper describes the detector mission, setup, construction, installation, commissioning and performance during the first year of sPHENIX data taking.

1. Introduction

The sPHENIX detector [1,2] is an experiment located at the Relativistic Heavy Ion Collider (RHIC) [3] in Brookhaven National Laboratory (BNL). It focuses on measuring jets as well as open and hidden heavy flavor production in heavy ion collisions and to study the properties of the Quark Gluon Plasma created in gold on gold (Au + Au) collisions at a center of mass energy per nucleon–nucleon collision $\sqrt{s_{NN}} = 200$ GeV. It will also collect data using proton–proton ($p+p$) and possibly proton-gold ($p+Au$) collisions to serve as a reference to the Au + Au data and to study the cold nuclear matter that constitutes the initial state of such collisions.

Fig. 1 presents a schematic view of the sPHENIX detector. The two beams provided by RHIC collide at the center of the experiment. The products of the collisions are measured in the various subsystems that constitute the detector. Going outwards starting from the beam line, sPHENIX is comprised of the following subsystems: the MAPS-Based Vertex Detector (MVTX); the INTermediate Tracker (INTT); the Time Projection Chamber (TPC); the Time Projection Chamber Outer Tracker (TPOT), which is the topic of this paper; the Electromagnetic Calorimeter (EMCAL); the Inner Hadronic Calorimeter (IHCAL); the solenoid superconducting magnet that delivers a longitudinal magnetic field of intensity 1.4 T and the Outer Hadronic Calorimeter (OHCAL). The tracking subsystems are the MVTX, INTT, TPC and TPOT. The calorimetry subsystems are the EMCAL, IHCAL and OHCAL. sPHENIX also contains a number of forward detectors, namely the Minimum Bias Detectors (MBD), the sPHENIX Event Plane detectors (sEPD), the Zero Degree Calorimeters (ZDC) and the Shower Maximum Detector (SMD), which is part of the ZDC.

TPOT is a late addition to the sPHENIX apparatus. It is installed on the outside of the TPC and greatly facilitates the calibration of the

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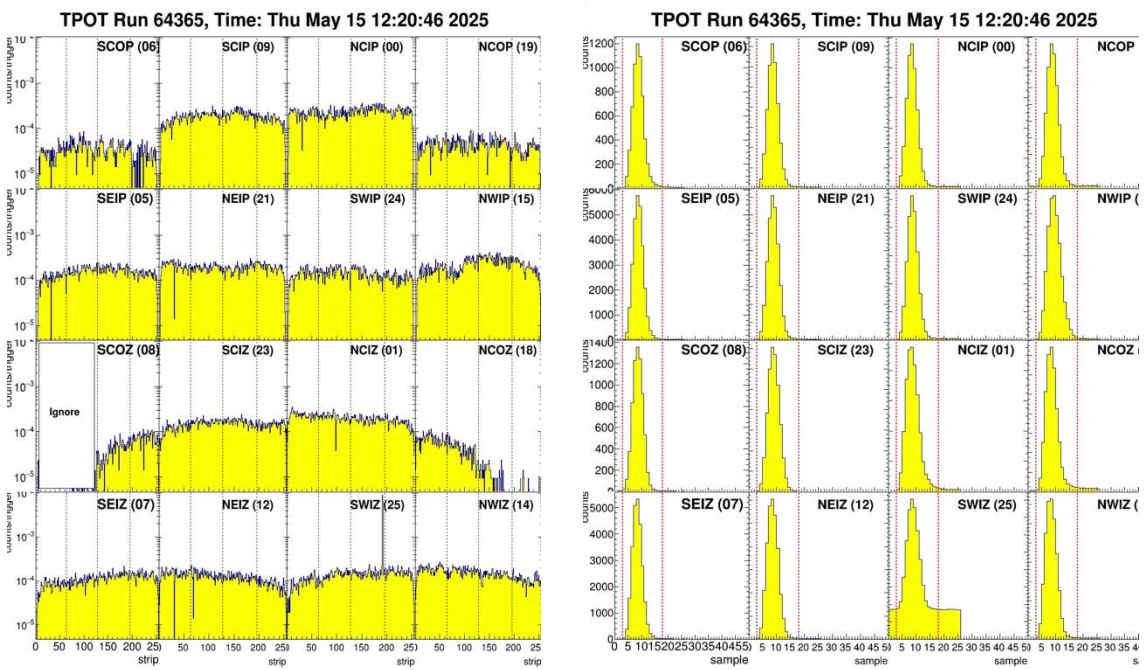
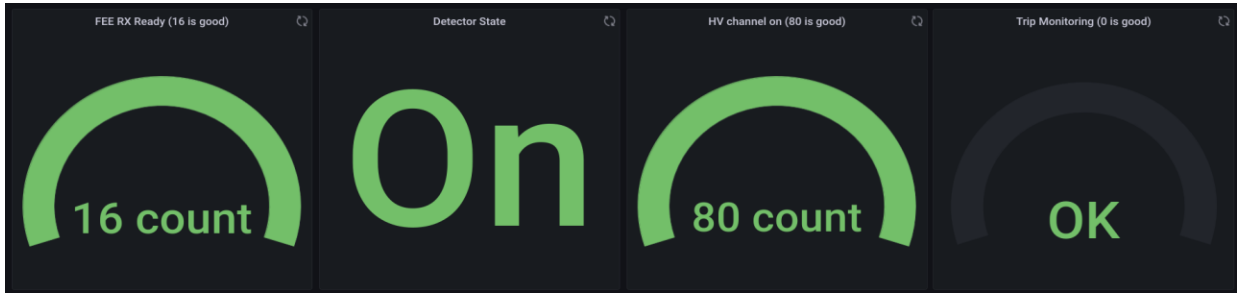
Time Projection Chamber Outer Tracker (TPOT)



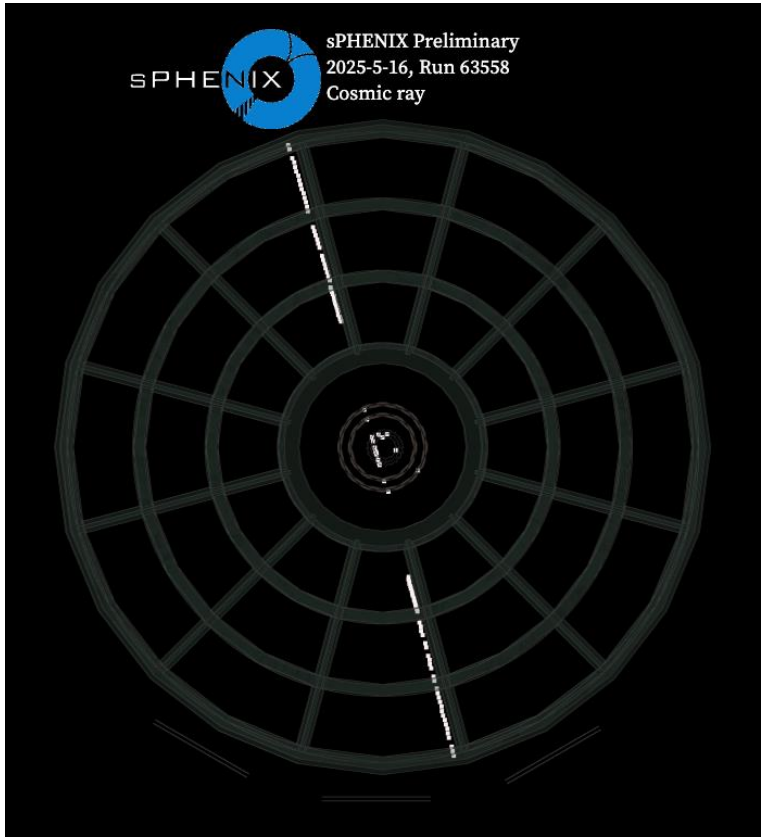
- Left: hit profile consistent with trigger. Acceptance is identical to run 2024
- Right: hit time distributions
  - One noisy channel in SWIZ, being investigated
  - Online QA, Offline QA, standing orders and expert wiki page updated
- **TPOT is ready for beam!**

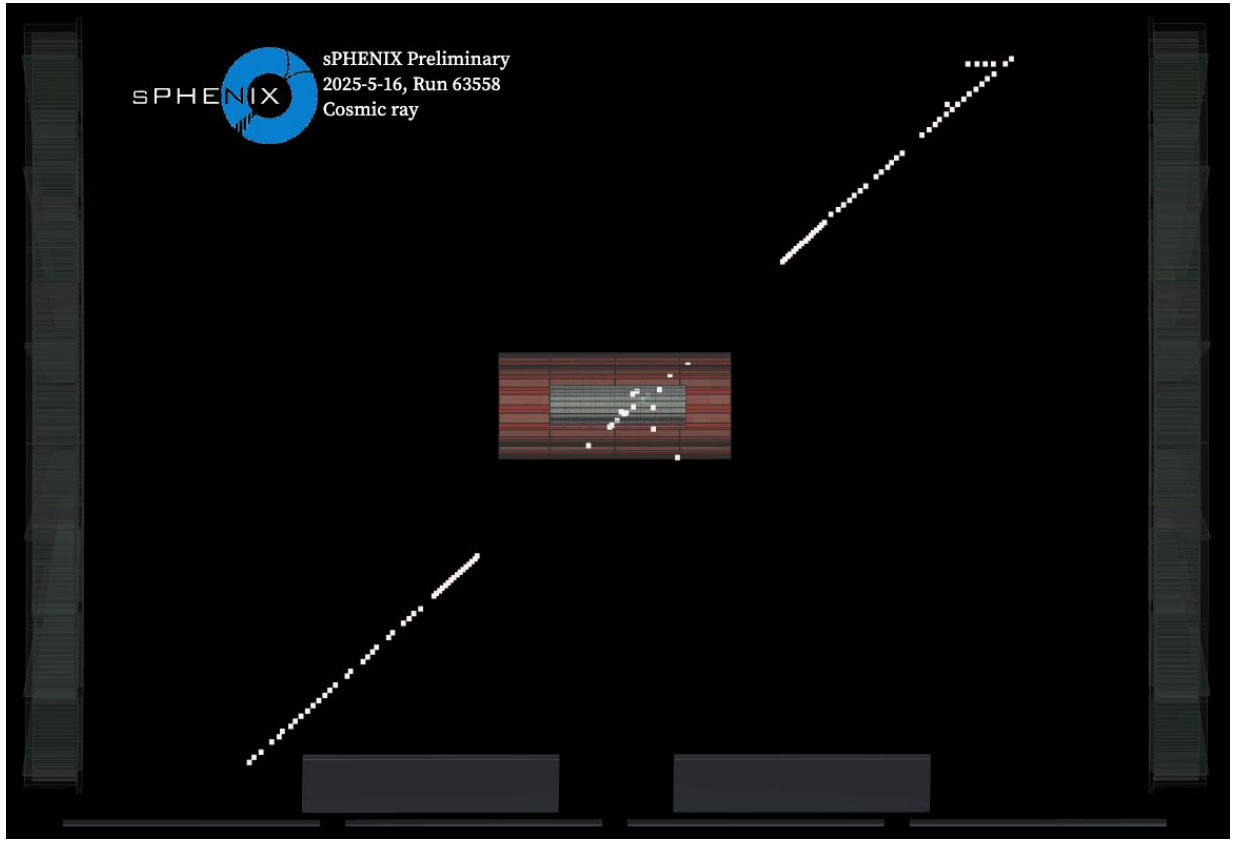
- Detector is ON (HV and FEE) since March 2
- New firmware for FEE, EBDC and GTM clock synchronization in place since April 1st and works flawlessly
- Timing and noise levels are reasonable
- No difference with respect to 2024

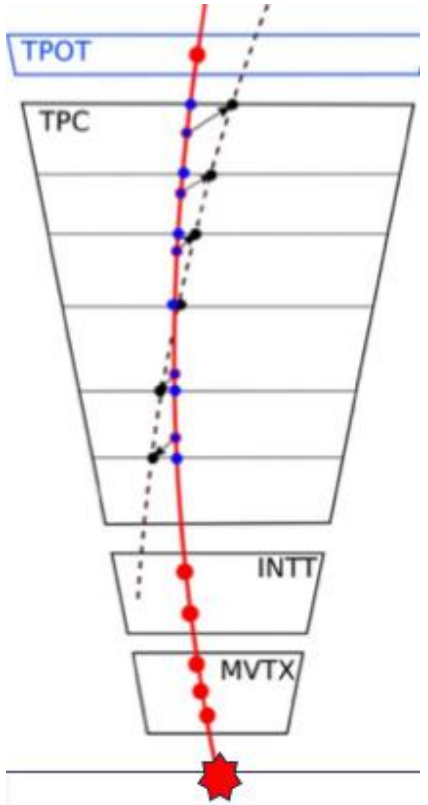


Combining Tracking Detectors

Run 25 Cosmics





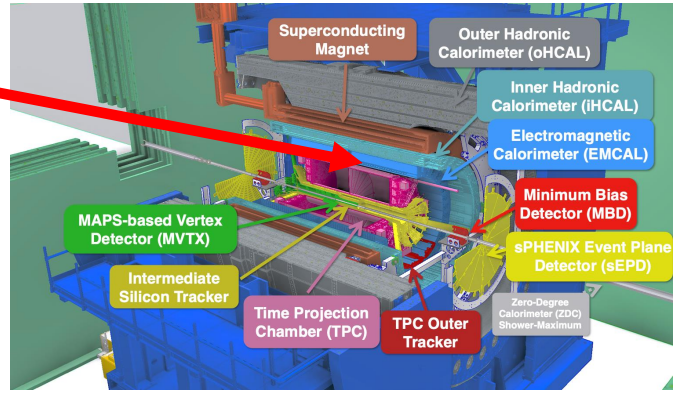


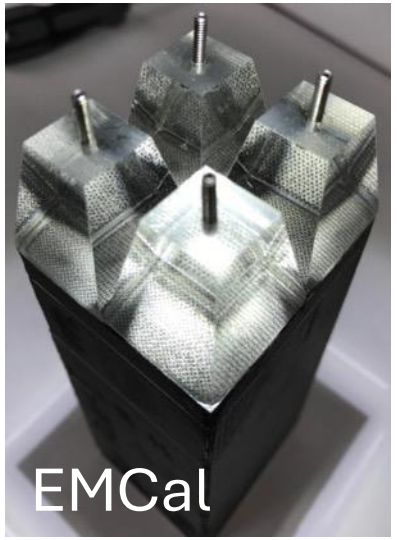
Combining information from all 4 tracking detectors shows that we are well-aligned and ready to analyze Run 25 data

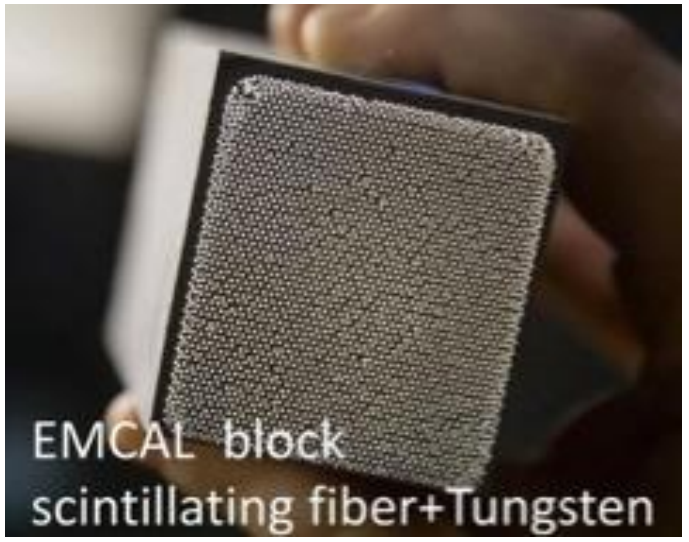
Electromagnetic Calorimeter
(EMCal)

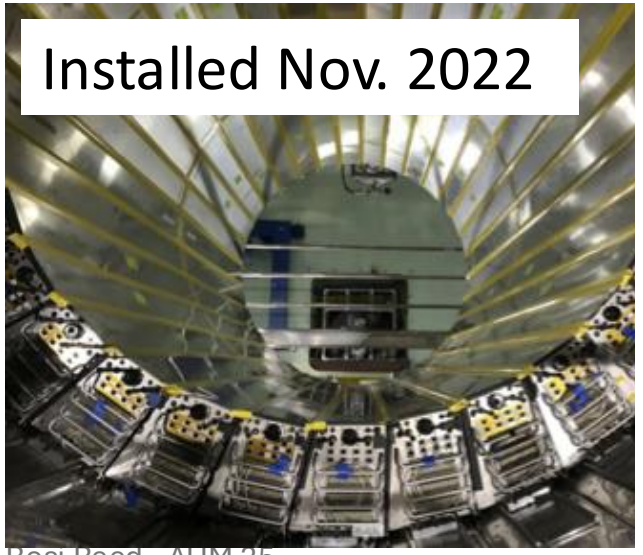
- EMCal: Scintillating fibers embedded in W powder
  - $\Delta\eta \times \Delta\phi = 0.024 \times 0.024$ → 24,576 2D projective towers
- $\sigma_E/E < 15\%/\sqrt{E} \oplus 5\%$

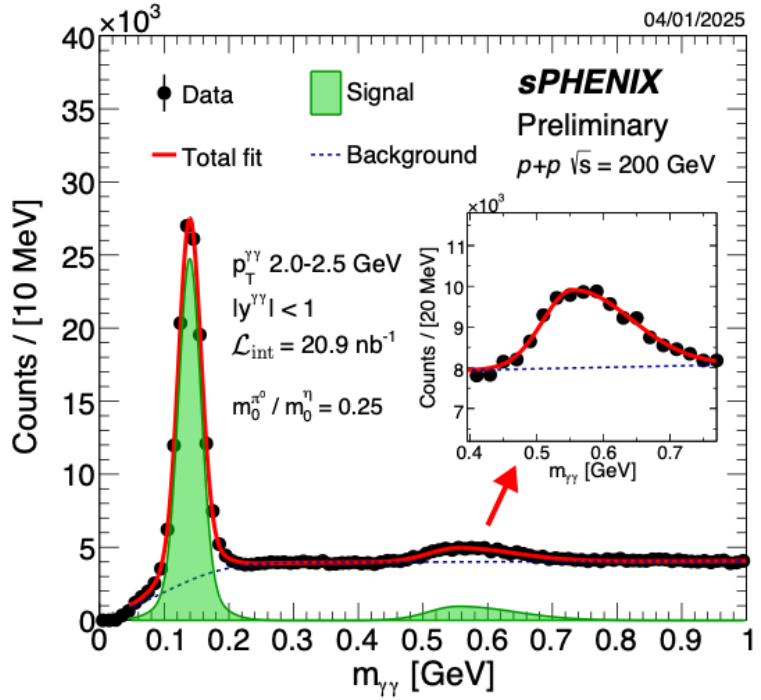
EMCal







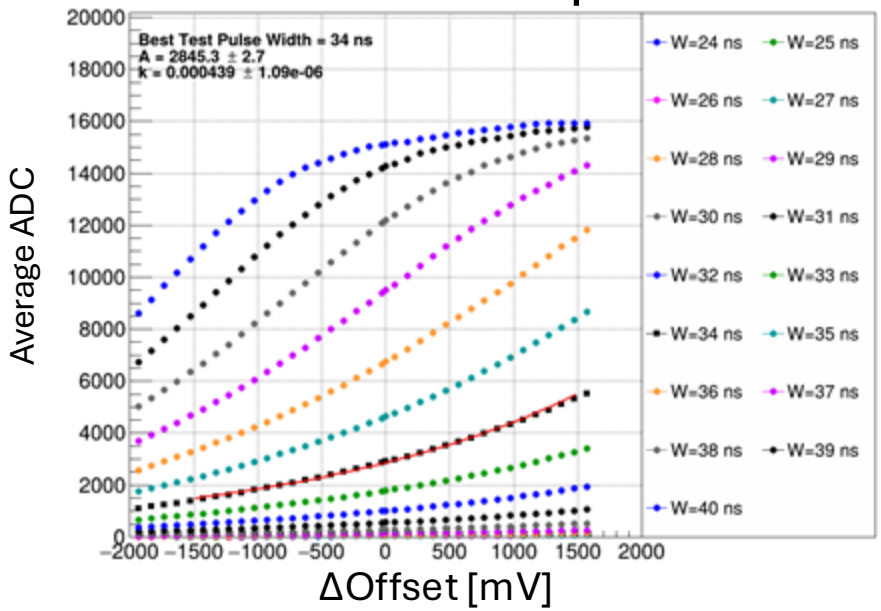


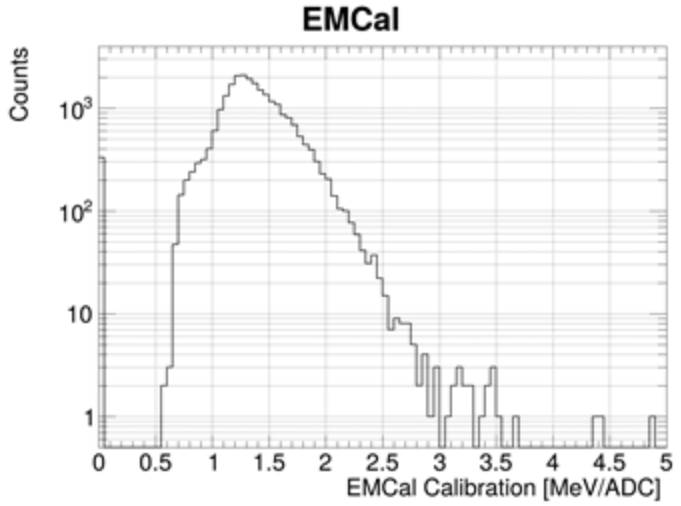


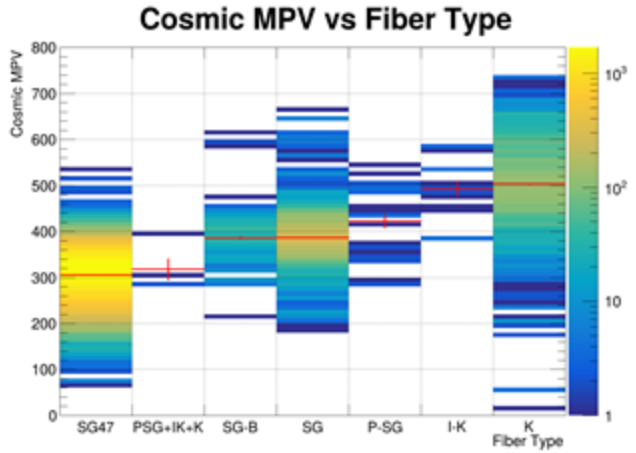
Electromagnetic Calorimeter
(EMCal)

- Gain Optimization Goal:
  - Reduce variation in the calibration constants (ADC→MeV)
  - Increase channel saturation threshold to cover a wider range of E_γ
- Strategy:
  - Use the Cosmic MPV* to derive gain factors with a uniform response
  - Use EMCal LEDs, determine V_{bias} ←→EMCal response
- Use these relationships to derive new V_{bias}
- **EMCal is ready for beam!**

EMCal LED Response







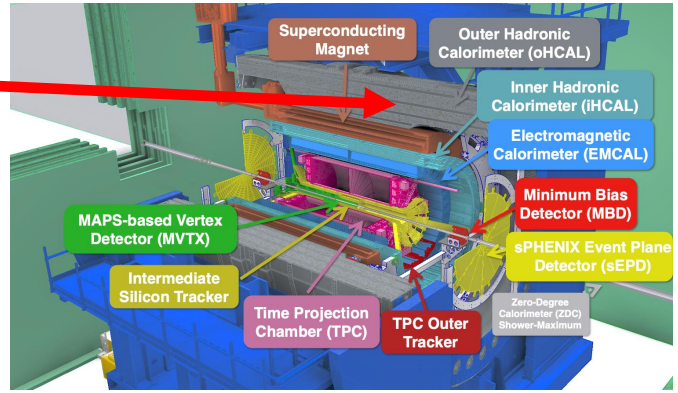
*Cosmics: Recorded during pre-installation of EMCal

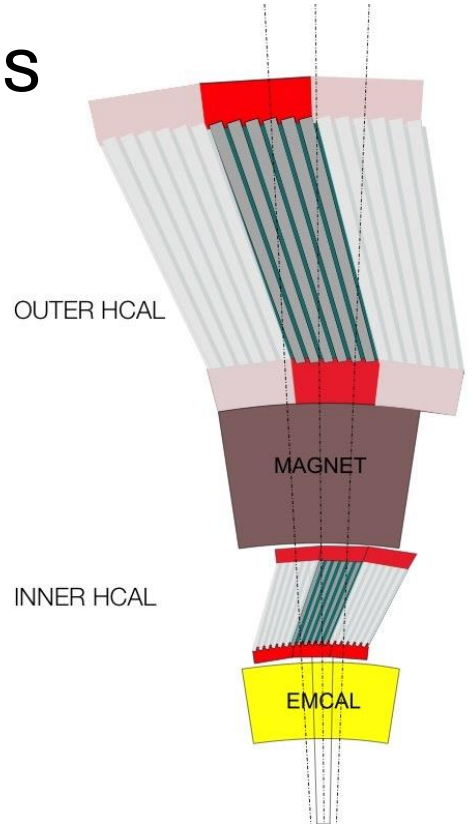
Average Cosmic MPV

Hadronic Calorimeters
(HCal)

- HCal: Plastic scintillating tiles + tilted Steel/Al plates
- $\Delta\eta \times \Delta\phi = 0.1 \times 0.1 \rightarrow$ 1,536 towers
- $\sigma_E/E < 100\%/\sqrt{E}$

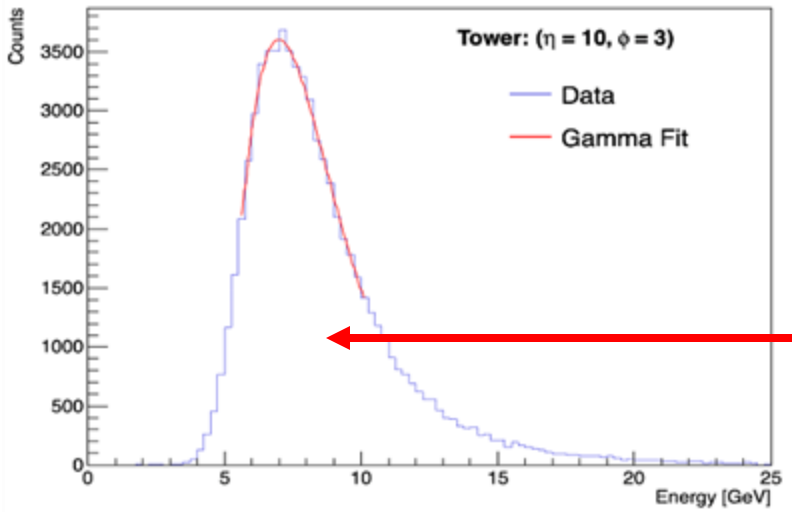
HCal

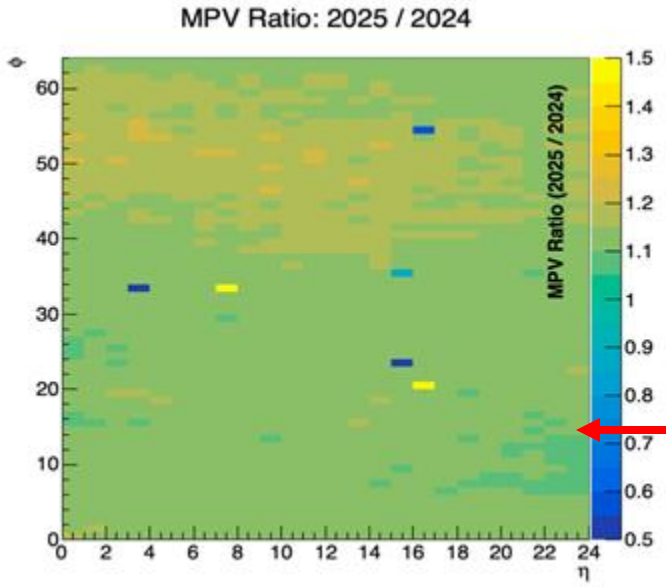


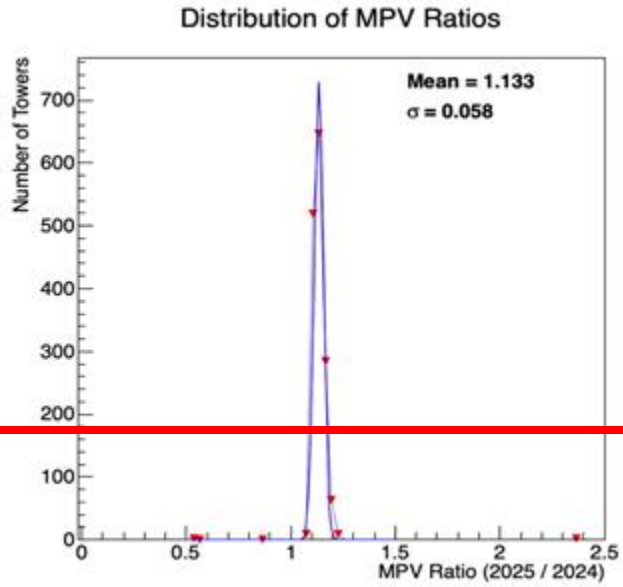


- Outer HCAL $\approx 3.5\lambda_I$
- Magnet $\approx 1.4X_0$
- Inner HCAL $\approx 1\lambda_I$
- EMCAL $\approx 18X_0 \approx 1\lambda_I$

Hadronic Calorimeters
(HCal)

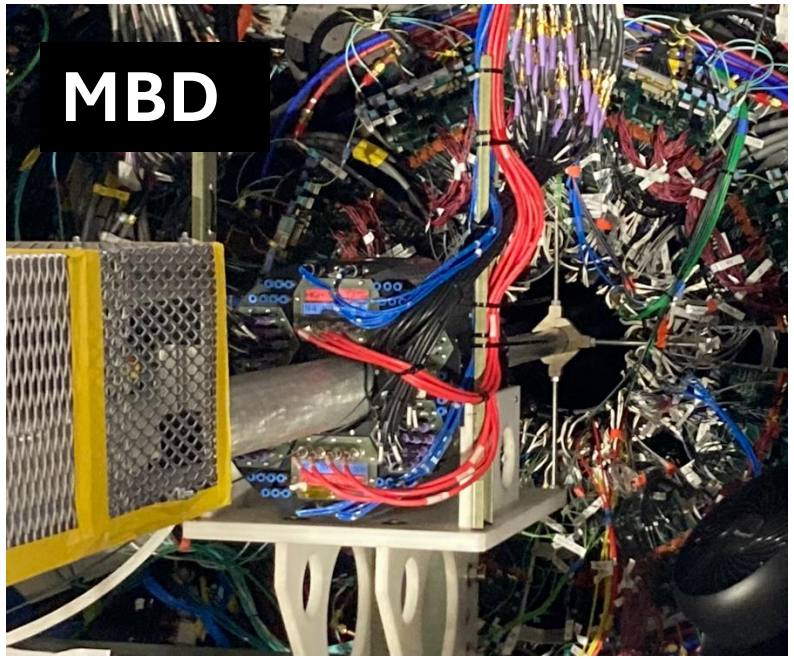


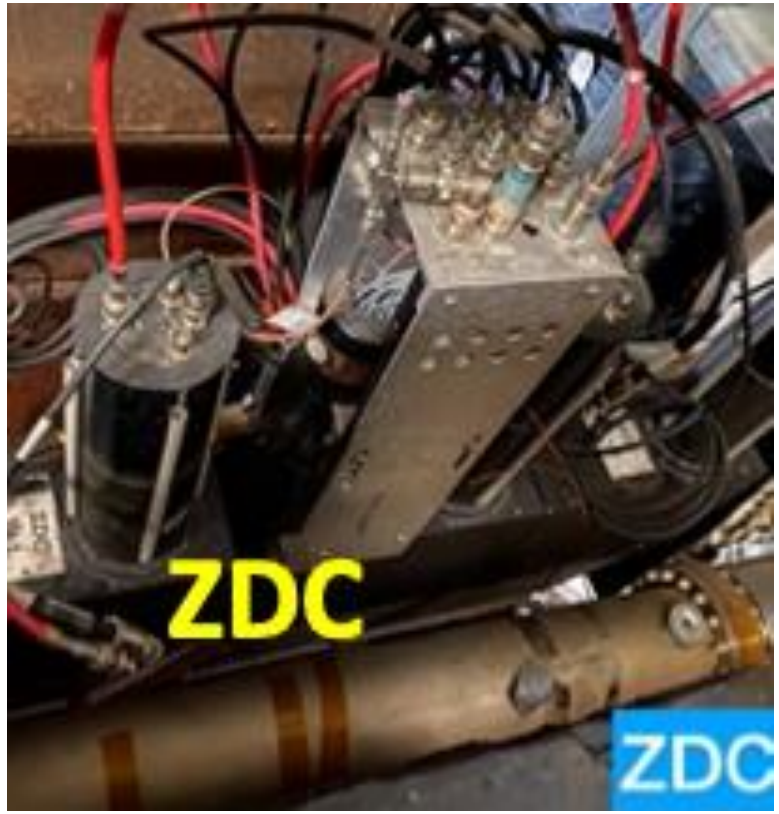




- All HCAL towers are live, and ready to take beam collision data!
- The MPV of the energy distribution from the cosmics is extracted
- 2025 <MPV> show a 13.3% increase from 2024
  - Consistent with the observed 3–4 °C rise in HCal T
- Ratio of 2024/2025 MPV values

Forward Detectors



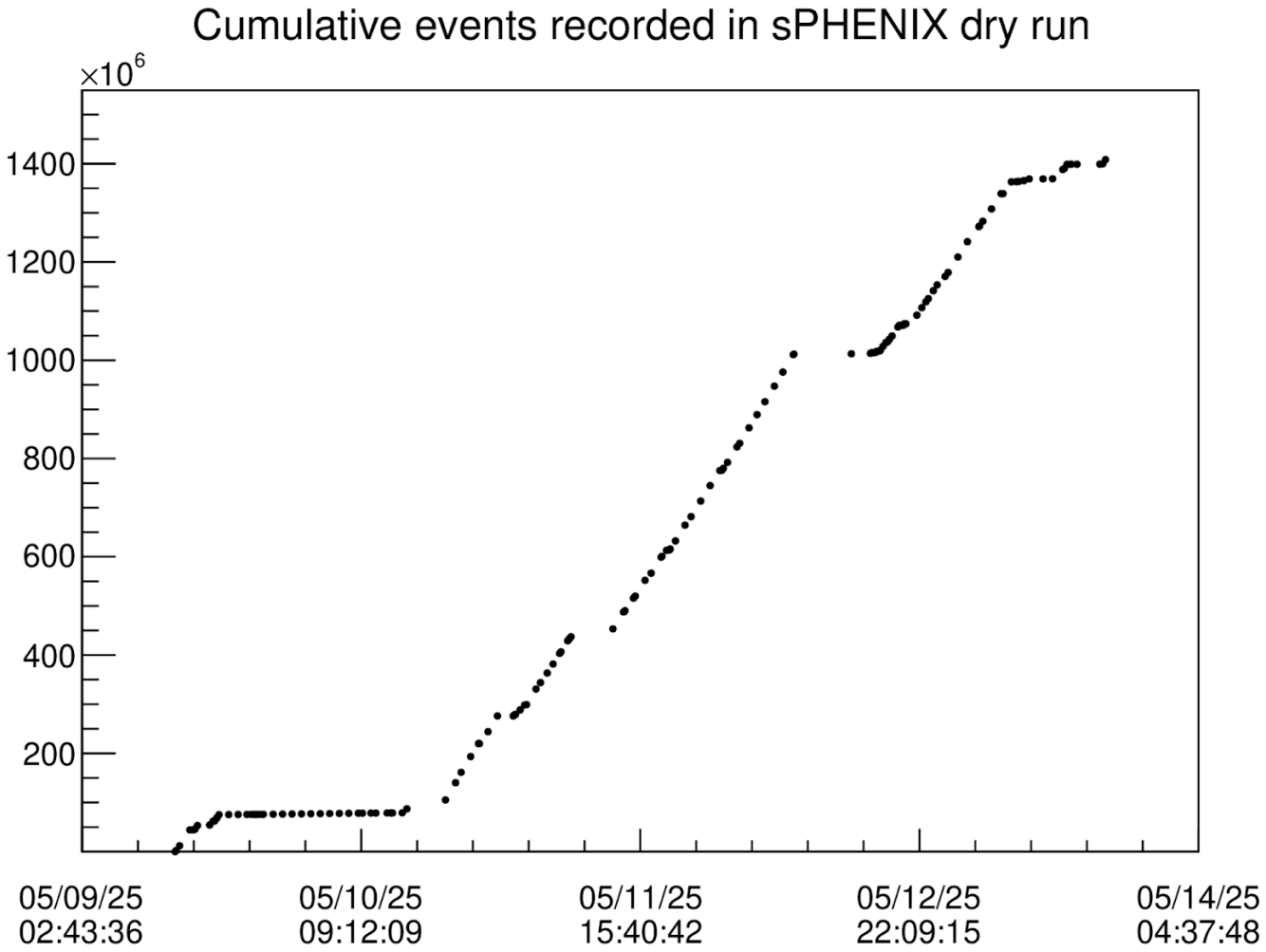


- The MBD and sEPD were successfully reinstalled and running since March
- **All forward detectors are ready for beam!**

sPHENIX Dry Run

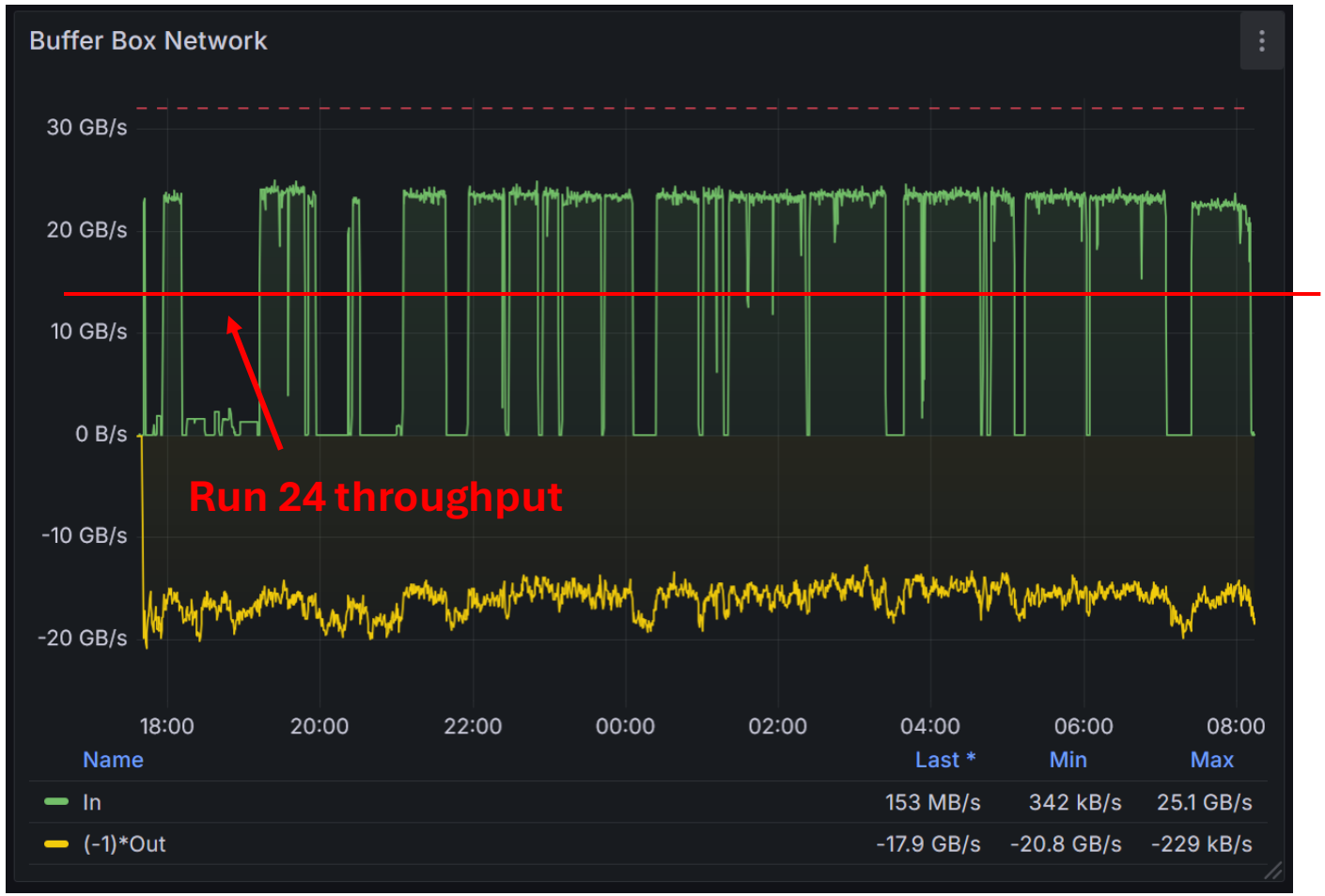
- With most summer tasks completed, we wanted to test sPHENIX to verify that we're ready for data and find any remaining issues
- Campaign 1 – throughput
  - Remove TPC Zero Suppression (ZS) threshold and tune EMCal ZS threshold to mock Au+Au data size
  - Use random triggers to increase rate
- Campaign 2 – tracking
  - Run HCal coincidence trigger to select events with cosmics through tracking detectors
  - Increase rate via random triggers
- Run the electronics and software in planned operation mode
  - Verify monitoring plots
  - Verify offline analysis

sPHENIX Dry Run



- We recorded over 1B events! (With all subsystems!)
- Online monitoring went well, small errors were fixed
- Many improvements to the DAQ improve uptime

sPHENIX Dry Run



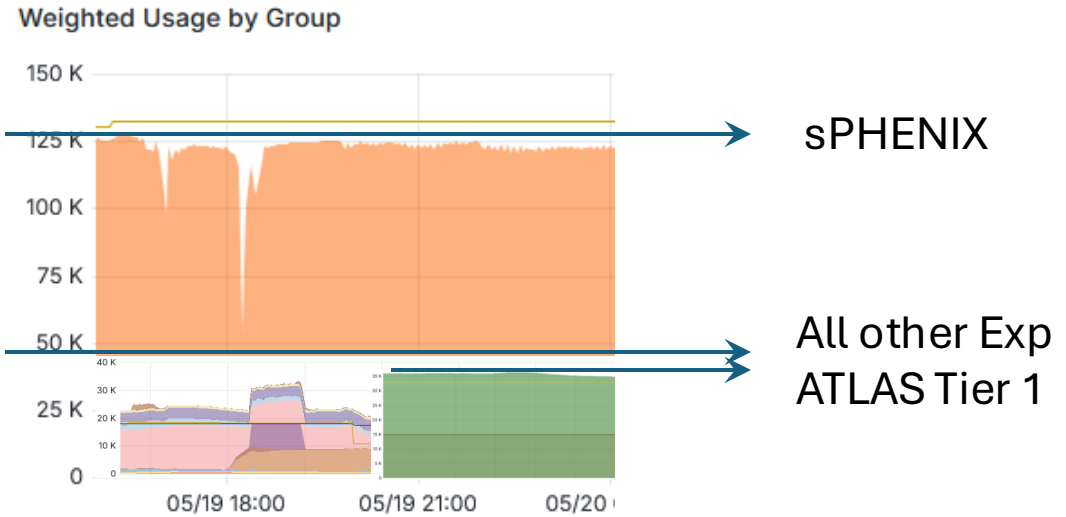
- Green line: sPHENIX Runs emulating 9 kHz Au+Au collisions
  - About twice the throughput of Run24!
- Yellow lines: Bufferbox → SDCC copy throughput
  - In Run24, it had to be stopped during data taking

sPHENIX@SDCC

- 1196 machines (132,576 cores) among largest condor instances in the world
- 4 tape silos, 100 LTO9 tape drives
- Ingest continuous 23GB/sec to HPSS (including archiving to 68 tape drives)
- Total tape capacity ~640PB
- 80PB Lustre storage, > 350GB/sec i/o bandwidth

Sites – 1Q2025		Petabytes	M Files	Since	Country
ECMWF	European Centre for Medium-Range Weather Forecasts	1,275	787	2002	United Kingdom and Italy
Shared Services Canada	Shared Services Canada	966	71	2017	Canada
Met Office	United Kingdom Met Office	781	1,832	2009	United Kingdom
METEO FRANCE	Meteo France – French Weather and Climate	693	1,088	2015	France
NOAA R&D	National Oceanic and Atmospheric Administration Research & Development	392	104	2002	United States
NERSC	Lawrence Berkeley National Laboratory – User	386	257	1998	United States
Brookhaven National Laboratory	Brookhaven National Laboratory	349	262	1998	United States
MAX PLANCK	Max Planck Computing and Data Facility	331	110	2011	Germany

sPHENIX will make HPSS@BNL #1 in the US, 4th worldwide



sPHENIX adds almost x2 cores to the sdcc HTC farm

sPHENIX Dry Run

- DAQ system has been well tested
  - Maximum data transfer to SDCC is ~35 GB/s, exceeding goal by almost a factor of 2
  - Thanks to the SDCC farm upgrade!
- Initial tracking results
  - Low-level GL1 INTT and MVTX matching shows no data dropping issue
  - Clear correlation between TPOT and trigger
  - Updated MVTX hot pixel map to be generated
- Offline results for full tracking analysis in progress

Conclusions

- 2023 Nuclear Physics Long Range Plan: Future of hot QCD facilities → To successfully conclude the RHIC science mission, it is essential to (1) **complete the sPHENIX science program** as highlighted in the 2015 Long Range Plan
  - This requires at least **7 nb^{-1} of Au+Au** data
  - The Upsilon program requires at least an additional **13 pb^{-1} of sampled p+p data**
    - Additional streaming data would improve open heavy flavor program
    - Small systems data would be a unique opportunity to address key questions
      - Connection to EIC physics
- We have spent the calendar year improving our performance and uptime, ready to take high quality data!

Begin of Run
Taco Party

sPHENIX @ 1 Mile DOE Race

Ready to Run!