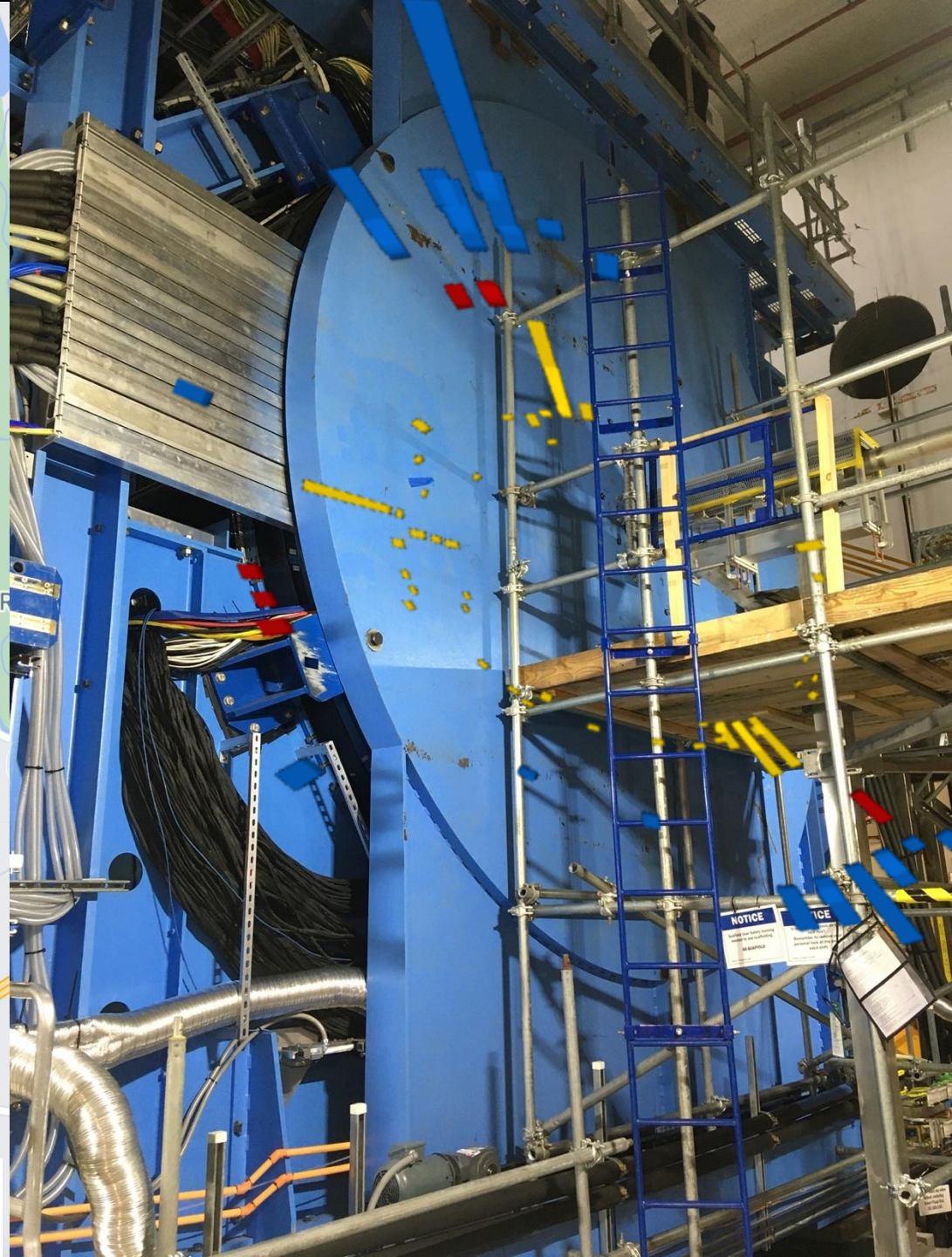
sPHENIX Run 2024 performance, goals achievements and challenges

November 07, 2024

Jamie Nagle
University of Colorado Boulder
sPHENIX 2024 Run Coordinator



sPHENIX plan going into Run 2024:

BUP proton-proton goals

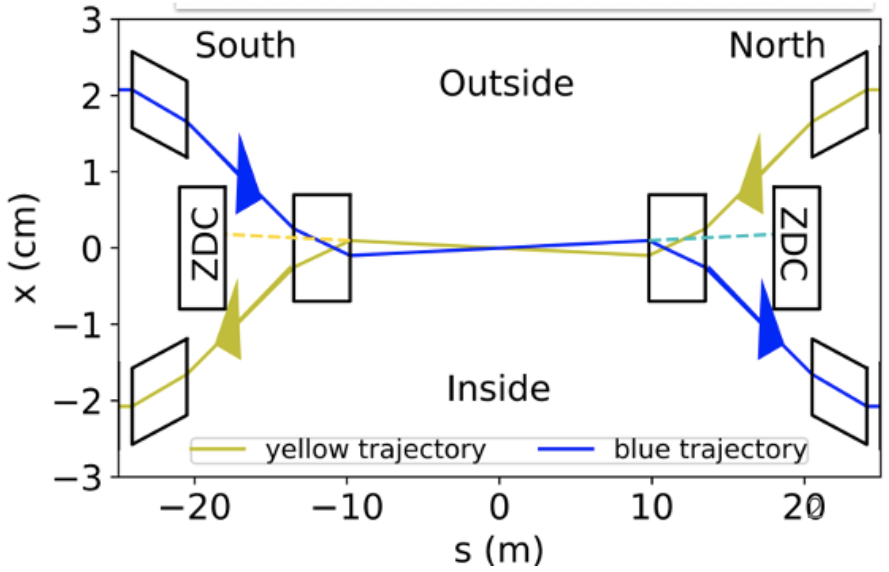
- 45.0 pb^{-1} within |z|<10 cm sampled with photon, jet, Upsilon triggers
- 4.5 pb^{-1} within |z|<10 cm recorded (10% streaming) for open heavy flavor physics

BUP gold-gold goals

- Commission sPHENIX for high occupancy collisions
- Understand beam backgrounds in MVTX and mitigate them

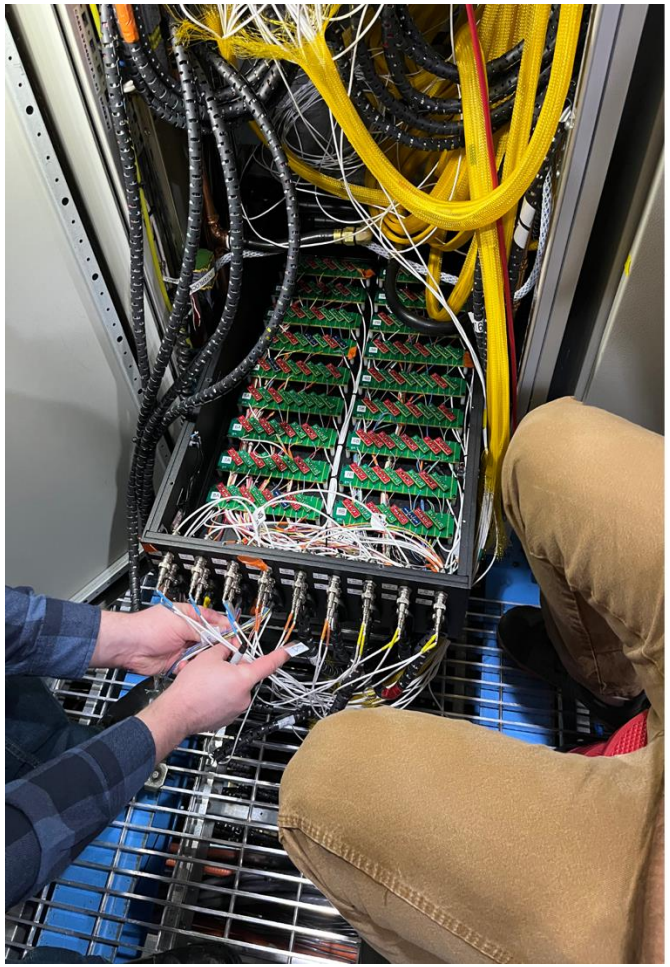
Available:

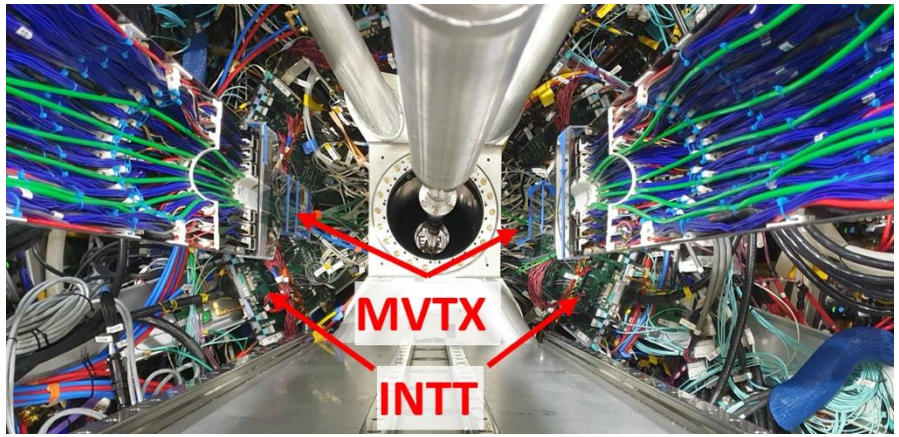
- 19 (FY24)+ 6 (carryover FY23) = 25 cryo-weeks
- Planned -2.0 mrad crossing angle to get needed luminosity and $\sigma_{z\text{-vertex}}$ ~ 10 cm

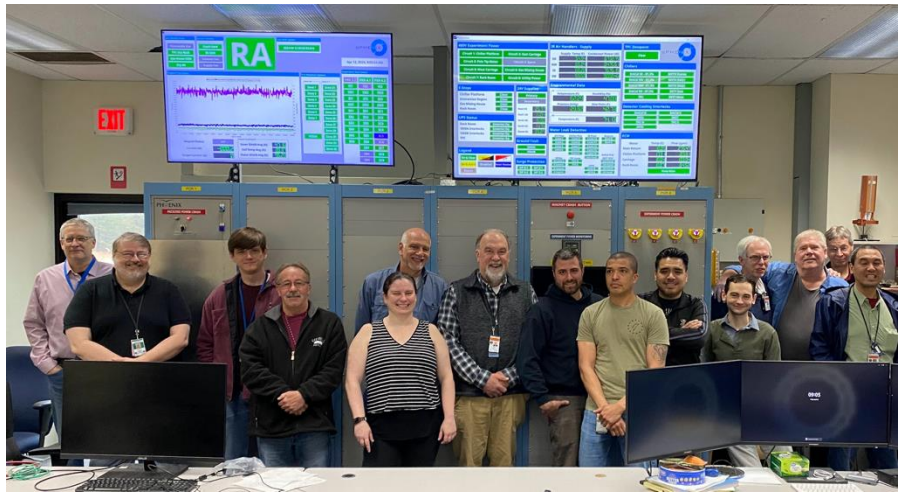


sPHENIX Shutdown Complete

sPHENIX requested delayed cooldown to complete
TPC High Voltage mitigation, reinstall silicon detectors and beam pipe, and check everything out with cosmic rays.





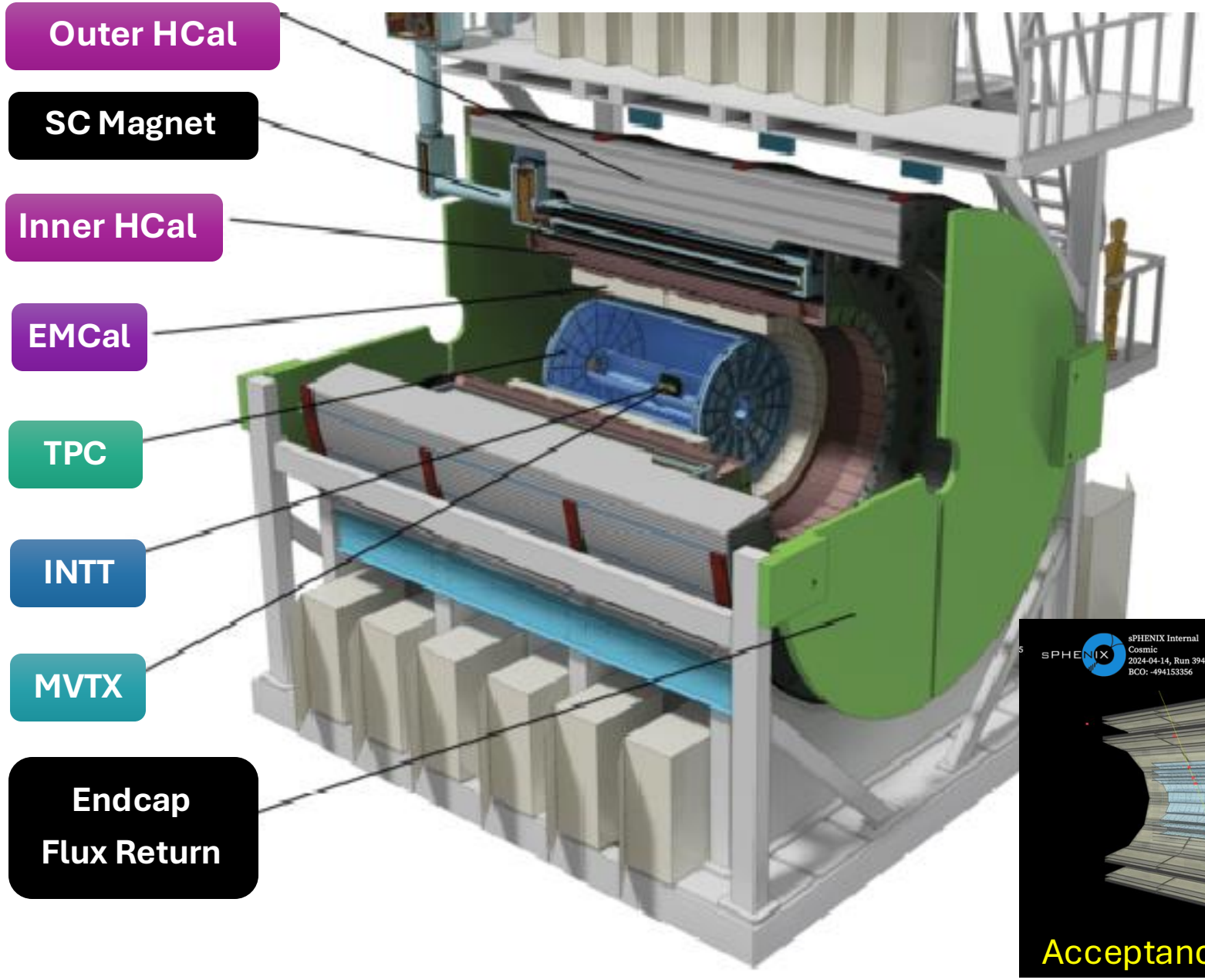


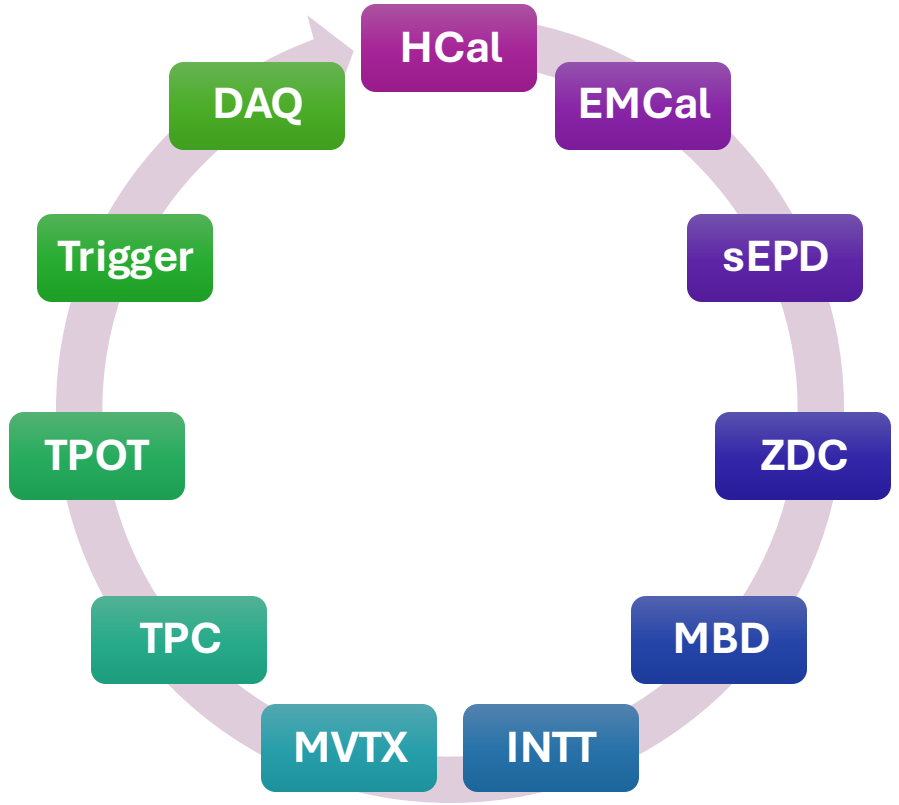
Huge multi-month effort by sPHENIX technical crew, detector experts, and many C-AD personnel.

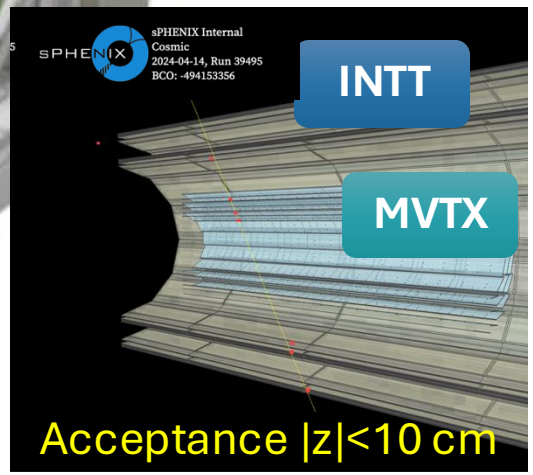
John Haggerty
Kin Yip
Jimmy Labounty
Tom Hemmick,
Evgeny Shulga
Frank Toldo
Jim Mills
Jeff Hoogsteden
Aaron Allen
Joel Vasquez
Dan Cacace
Mike Rau
Mike Lenz
Sean Stoll

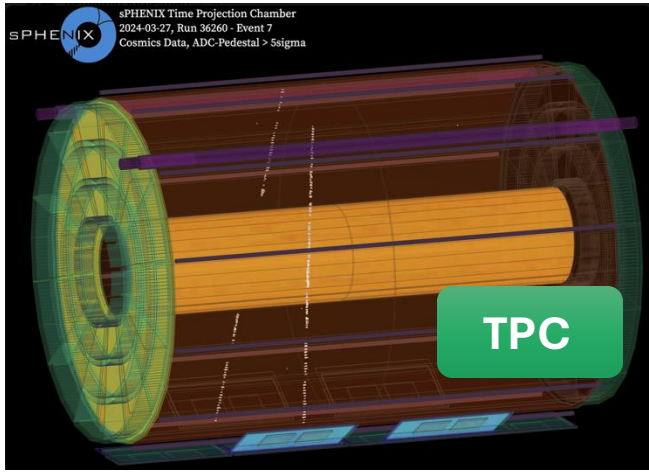
(Not in the picture)
Sal Polizzo
Bill Lenz
Damon Miraglia
Kevin Mandracchia
Marianna Albanese
Rob Pisani
Bob Azmoun
Many more…

sPHENIX Detector Guide

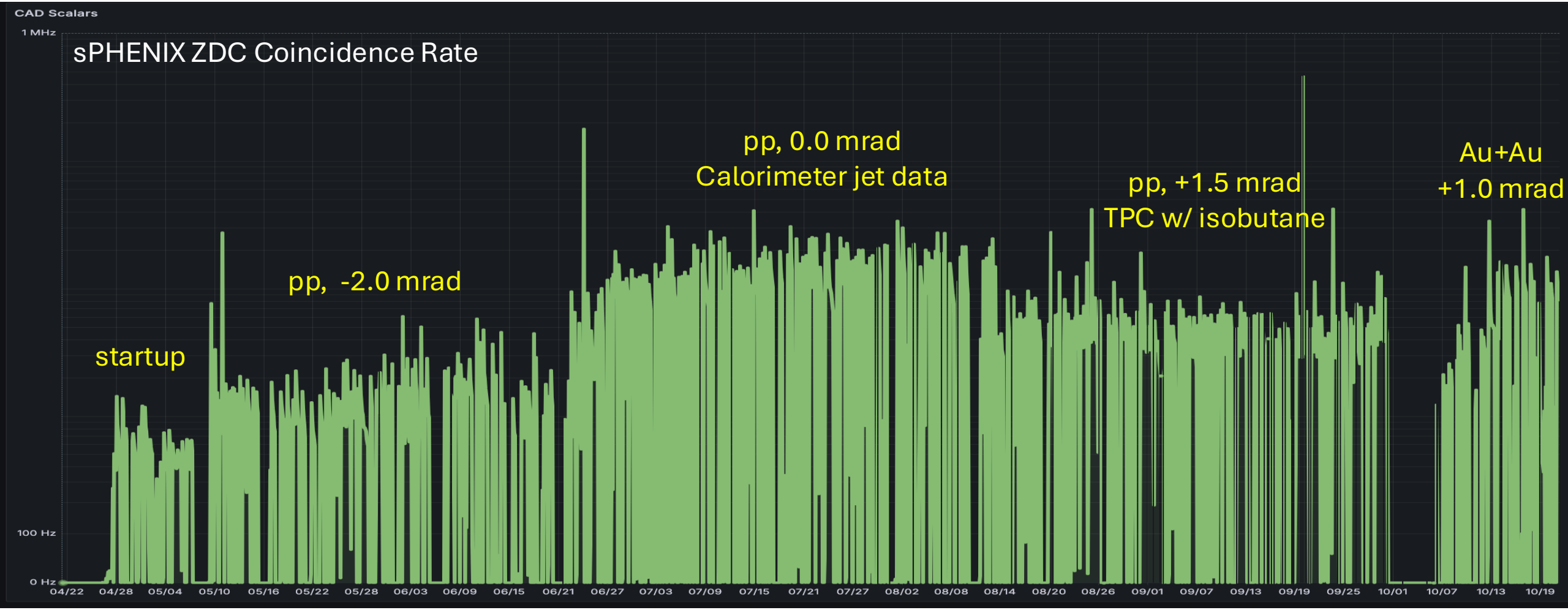






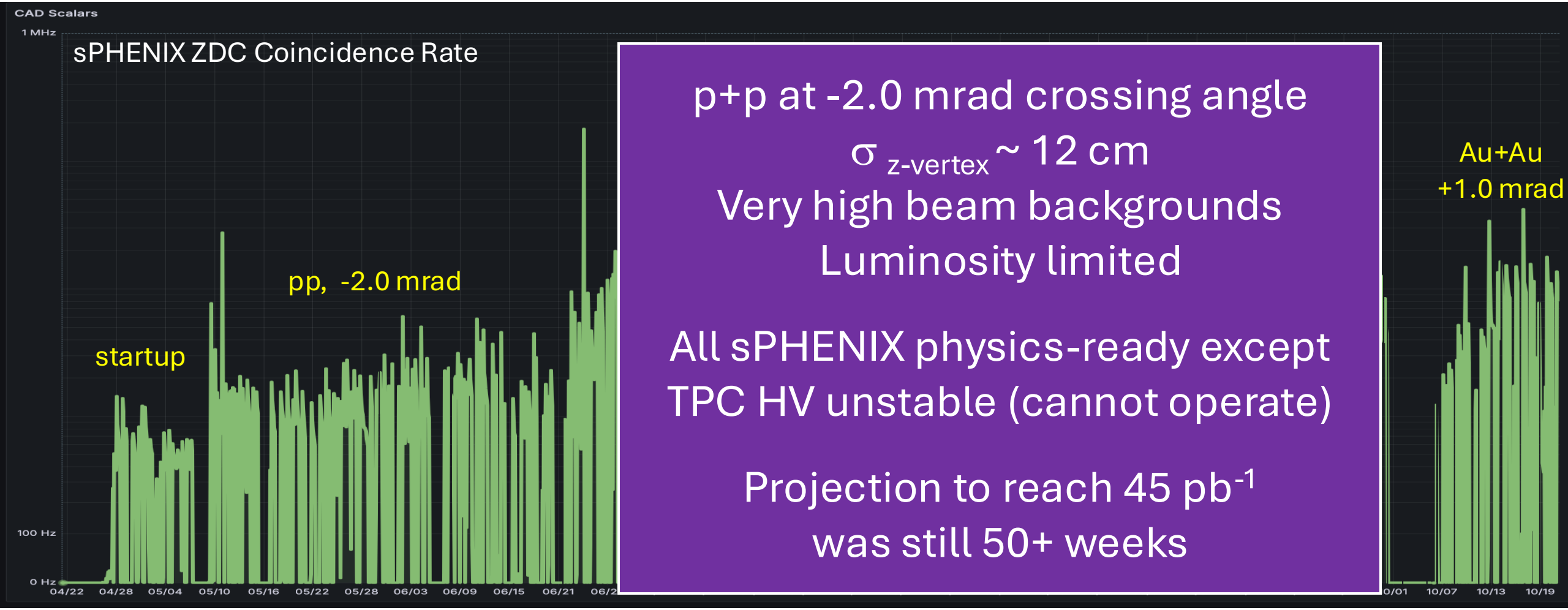


A long and challenging and fun sPHENIX Run 2024



April 28 May 10 June 21 August 14 October 7 October 21

A long and challenging and fun sPHENIX Run 2024



p+p at -2.0 mrad crossing angle

$\sigma_{\text{z-vertex}} \sim 12$ cm

Very high beam backgrounds

Luminosity limited

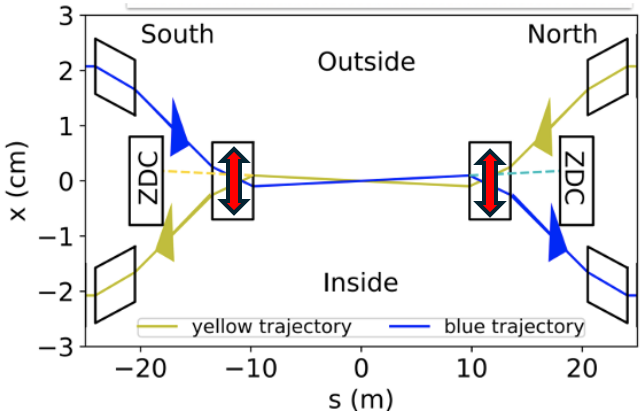
All sPHENIX physics-ready except TPC HV unstable (cannot operate)

Projection to reach 45 pb^{-1} was still 50+ weeks

April 28 — May 10 — June 21 — August 14 — October 7 — October 21

Chapter 1

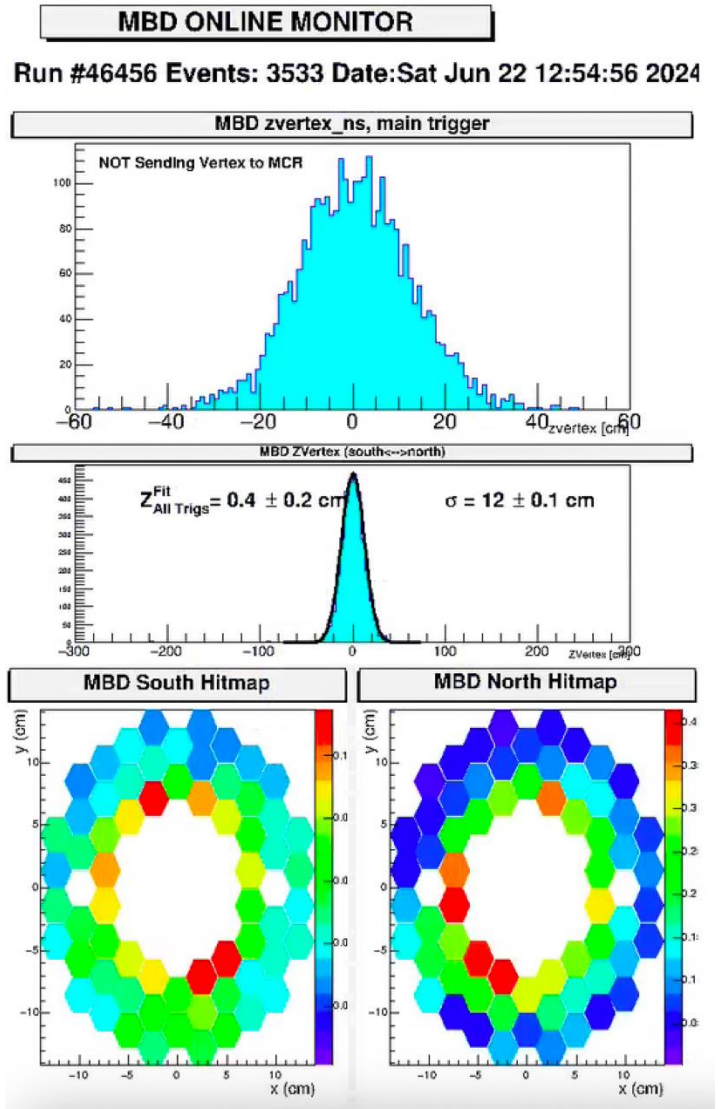
C-AD changed
D0 magnet polarity



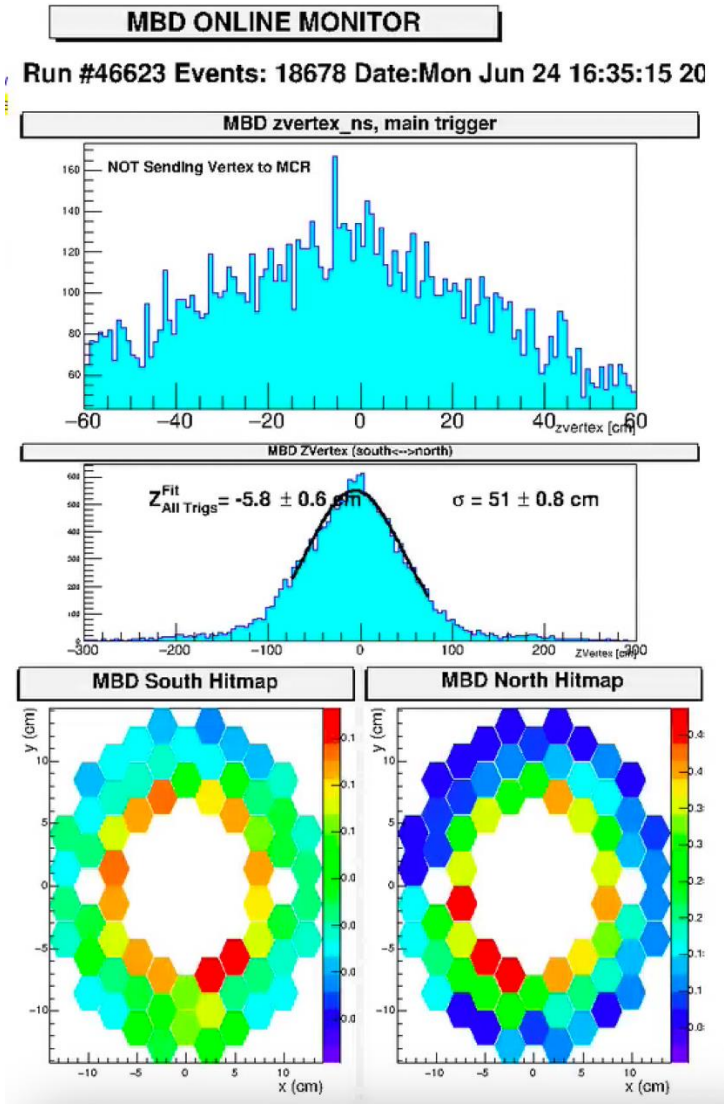
+2 mrad crossing,
instead of earlier
-2 mrad crossing.

June 24, 2024,
started running
sPHENIX at
0 mrad crossing.

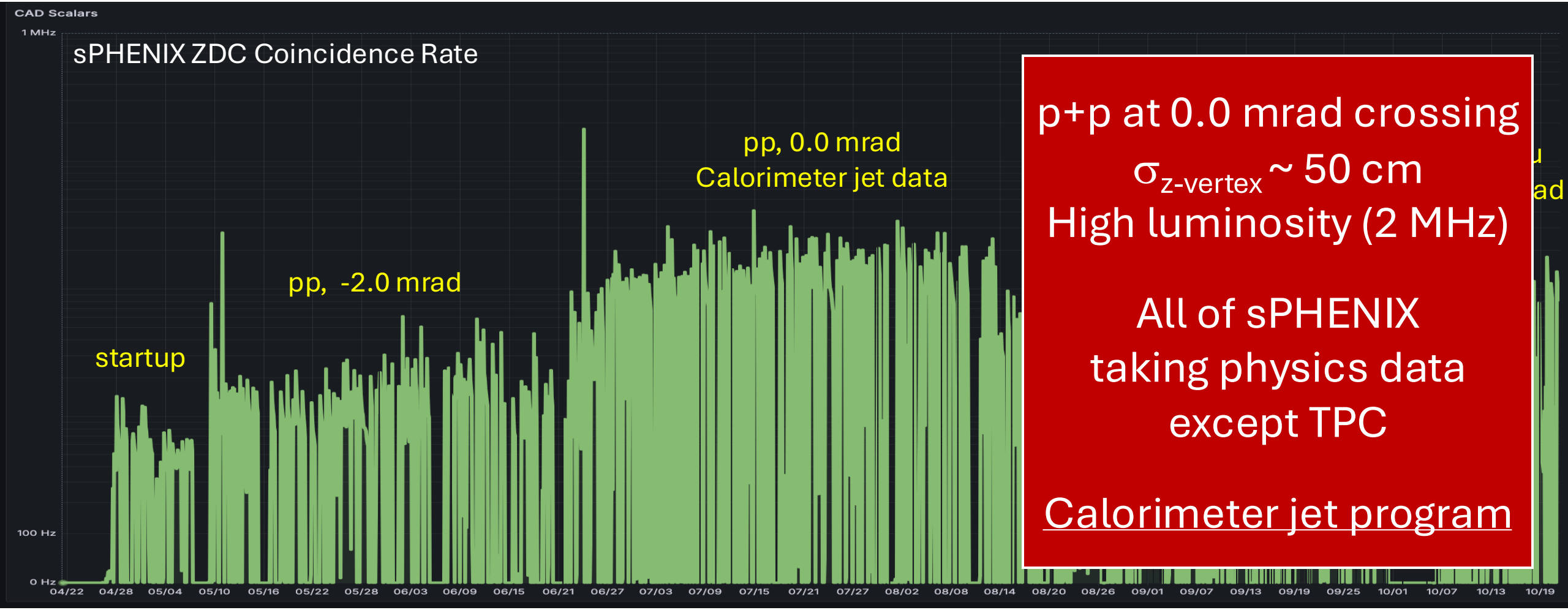
+ 2 mrad has the same
z-vertex width as -2 mrad
σ ~ 12 cm



+ 0 mrad has a wide
z-vertex distribution
σ ~ 50-60 cm



A long and challenging and fun sPHENIX Run 2024



p+p at 0.0 mrad crossing

$\sigma_{z\text{-vertex}} \sim 50$ cm

High luminosity (2 MHz)

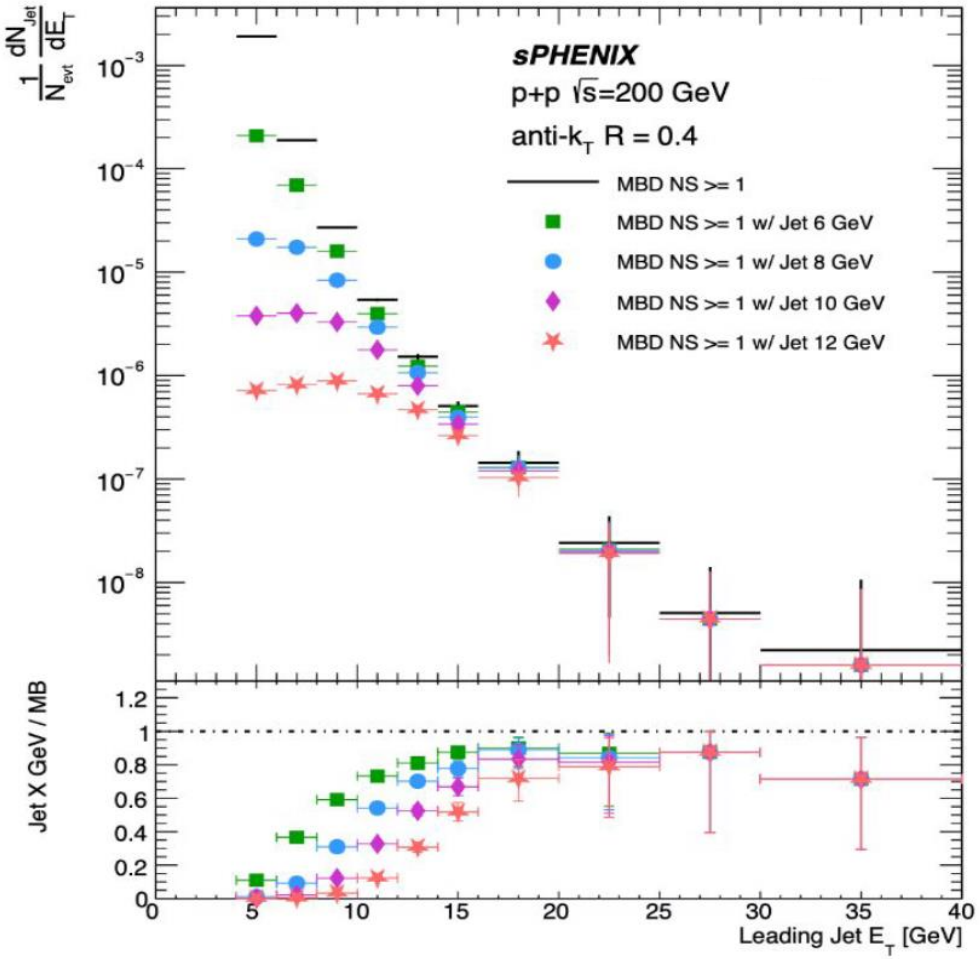
All of sPHENIX taking physics data except TPC

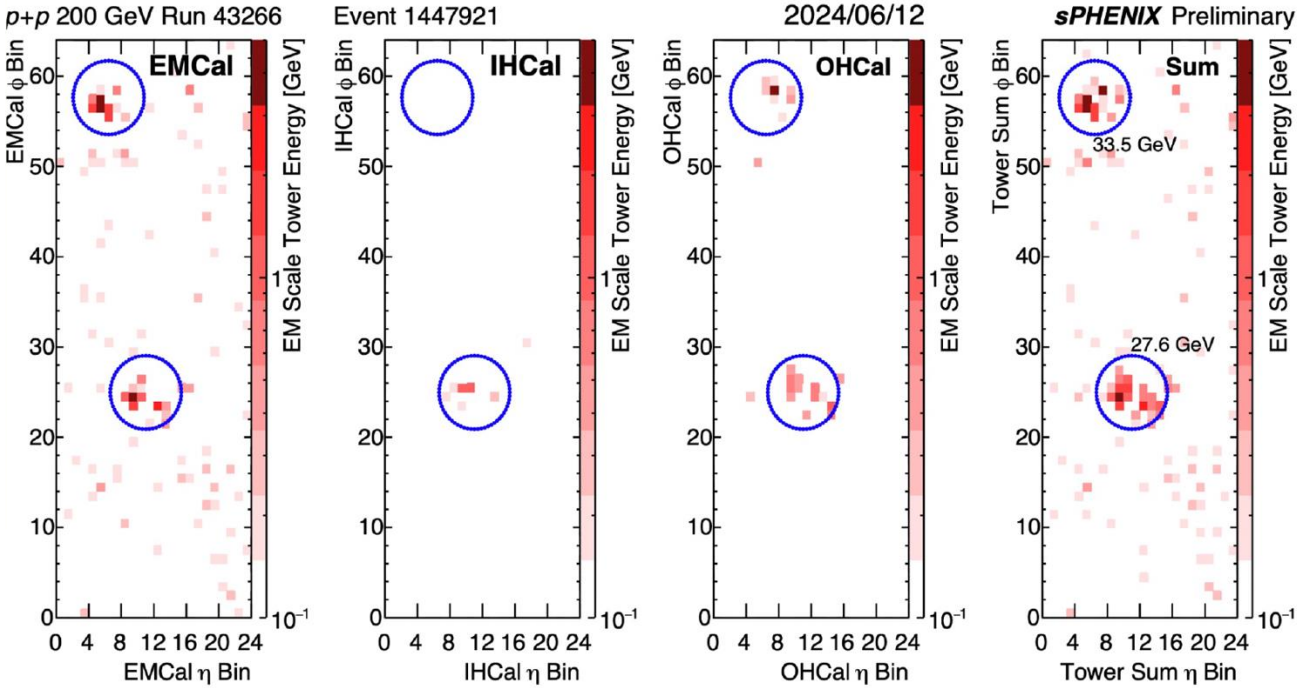
Calorimeter jet program

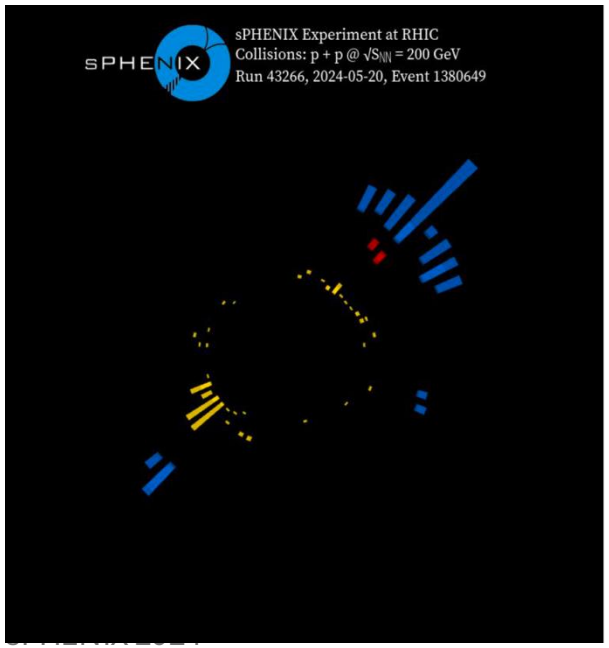
April 28 May 10 June 21 August 14 October 7 October 21

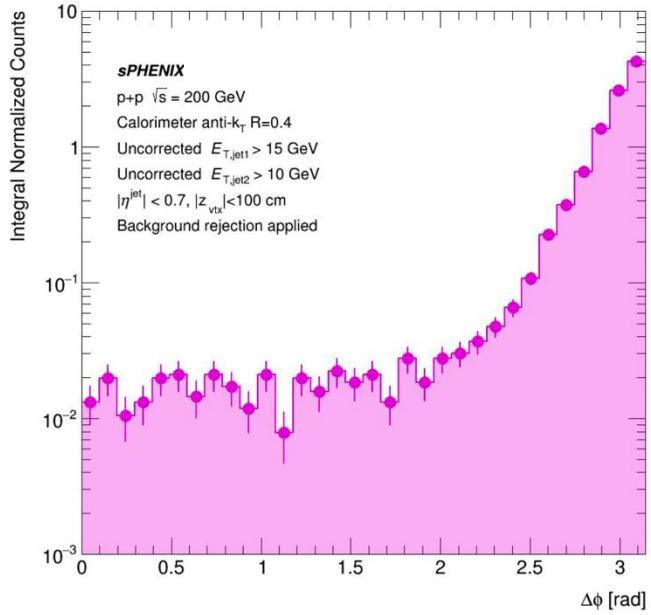
Chapter 2

sPHENIX Triggers sampling full luminosity with DAQ livetime > 98% and exceeding BUP spec. 60% uptime



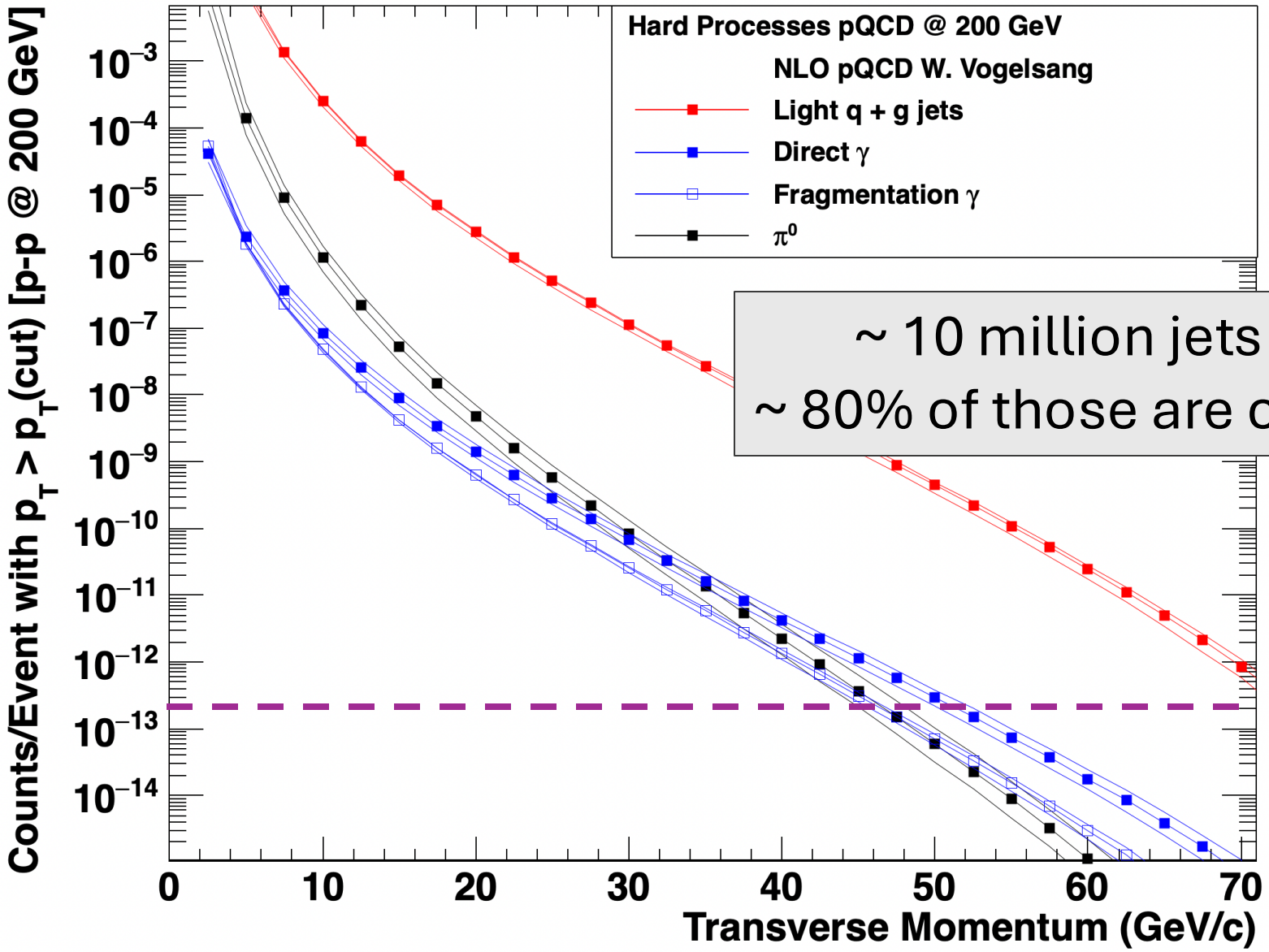






Fast offline analysis in SDCC

Excellent jet/photon data set



~ 10 million jets $p_T > 20$ GeV

~ 80% of those are contained dijets

Plot made by
Jamie Nagle in 2010 ☺

TPC Status

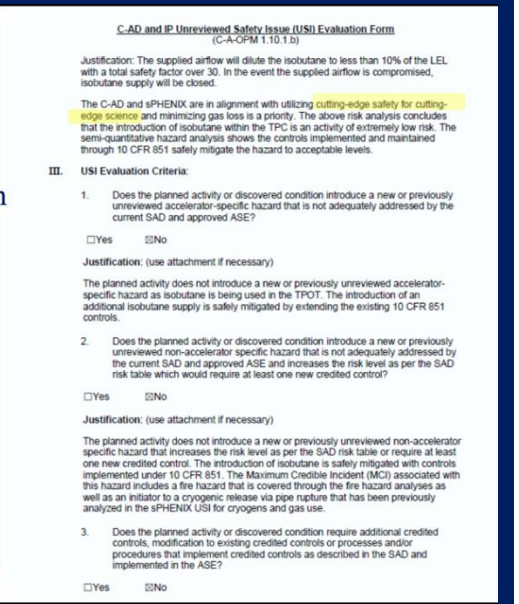
Heavy lift by many people to safety approve isobutane in the TPC.

(Kin) An “all negative” USI (Unresolved Safety Issue) — concerning our usage of isobutane in TPC — has been signed by C-AD this morning, after the AESRC (Accel. & Expt. Safety Review Com.) review on July 17, 2024. This is good news.

- A walkthrough has been scheduled on Tuesday, July 23, 2024, at 11 am.
- We also need isobutane delivery, finish testing and procedure revision etc.

Flowing isobutane in TPC of sPHENIX

- Agreement to implement the July 12 version of the USI.
- There will be an AESRC review tomorrow and after that, the USI would be ready for signatures.
- We are also updating procedures, alarm instructions and necessary training.
- Walkthrough will be scheduled in consultation with AESRC.
- Target date for operation: earlier next week.



C-AD and IP Unreviewed Safety Issue (USI) Evaluation Form
(C-A-OPM 1.10.1.b)

Justification: The supplied airflow will dilute the isobutane to less than 10% of the LEL with a total safety factor over 30. In the event the supplied airflow is compromised, isobutane supply will be closed.

The C-AD and sPHENIX are in alignment with utilizing cutting-edge safety for cutting-edge science and minimizing gas loss is a priority. The above risk analysis concludes that the introduction of isobutane within the TPC is an activity of extremely low risk. The semi-quantitative hazard analysis shows the controls implemented and maintained through 10 CFR 851 safely mitigate the hazard to acceptable levels.

III. USI Evaluation Criteria:

1. Does the planned activity or discovered condition introduce a new or previously unreviewed accelerator-specific hazard that is not adequately addressed by the current SAD and approved ASE?

☐Yes ☒No

Justification: (use attachment if necessary)

The planned activity does not introduce a new or previously unreviewed accelerator-specific hazard as isobutane is being used in the TPOT. The introduction of an additional isobutane supply is safely mitigated by extending the existing 10 CFR 851 controls.

2. Does the planned activity or discovered condition introduce a new or previously unreviewed non-accelerator specific hazard that is not adequately addressed by the current SAD and approved ASE and increases the risk level as per the SAD risk table which would require at least one new credited control?

☐Yes ☒No

Justification: (use attachment if necessary)

The planned activity does not introduce a new or previously unreviewed non-accelerator specific hazard that increases the risk level as per the SAD risk table or require at least one new credited control. The introduction of isobutane is safely mitigated with controls implemented under 10 CFR 851. The Maximum Credible Incident (MCI) associated with this hazard includes a fire hazard that is covered through the fire hazard analyses as well as an initiator to a cryogenic release via pipe rupture that has been previously analyzed in the sPHENIX USI for cryogens and gas use.

3. Does the planned activity or discovered condition require additional credited controls, modification to existing credited controls or processes and/or procedures that implement credited controls as described in the SAD and implemented in the ASE?

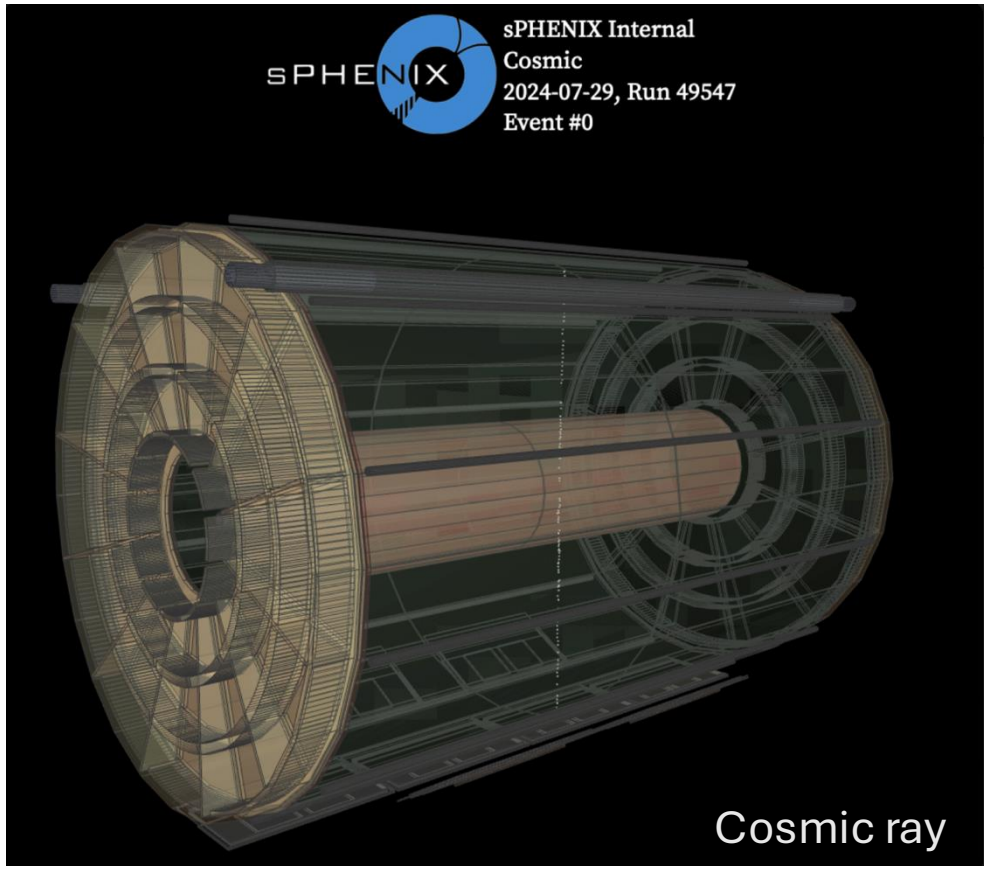
☐Yes ☒No

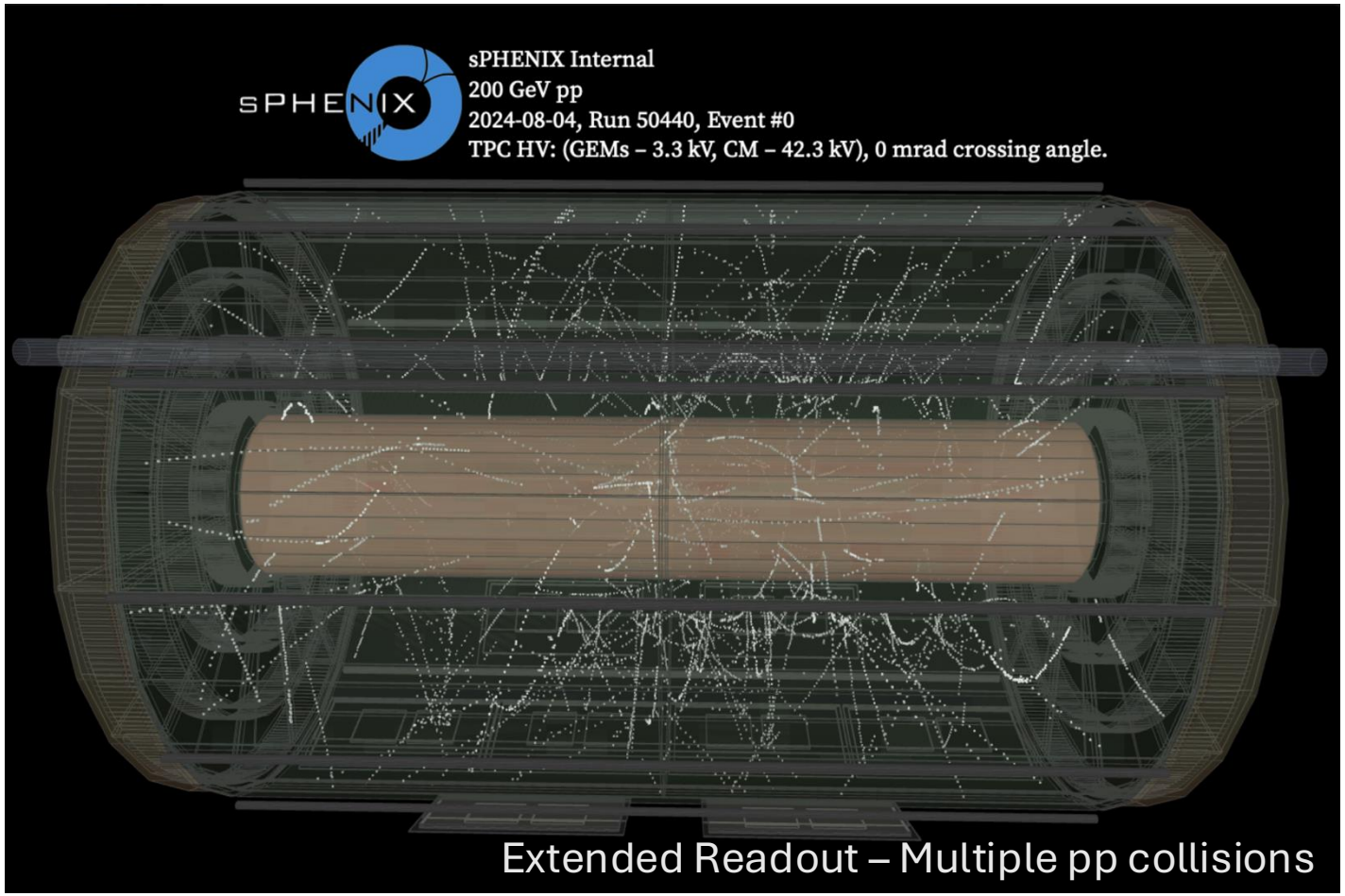
Table 1: Scenarios Requiring Isobutane Valve Isolation

Location	Scenario	Engineered Control/Response	Administrative Control/Response
IR8 (sPHENIX Detector Hall)	Bore Dehimidifiers ∑N > 100 cfm and ∑S > 100 cfm	Turn off Isobutane Supply (KGT) and alarm sPHENIX Control Room	No Change
IR8 (sPHENIX Detector Hall)	Ceiling VESDA HSSD Smoke Detected		No Change
IR8 (sPHENIX Detector Hall)	Bore VESDA HSSD Smoke Detected		No Change
IR8 (sPHENIX Detector Hall)	Bore isobutane detected		Alarm MCR; Resume after handheld flammable gas survey
Gas Mixing House	GMH Vent Fan Fail		No Change
Gas Mixing House	Isobutane Shed Vent Fan Fail		No Change
Gas Mixing House	GMH Isobutane Detected		Alarm MCR; Resume after handheld flammable gas survey
Gas Mixing House	>6% Isobutane Mixture		No Change
Gas Mixing House	Emergency Stop Button		No Change

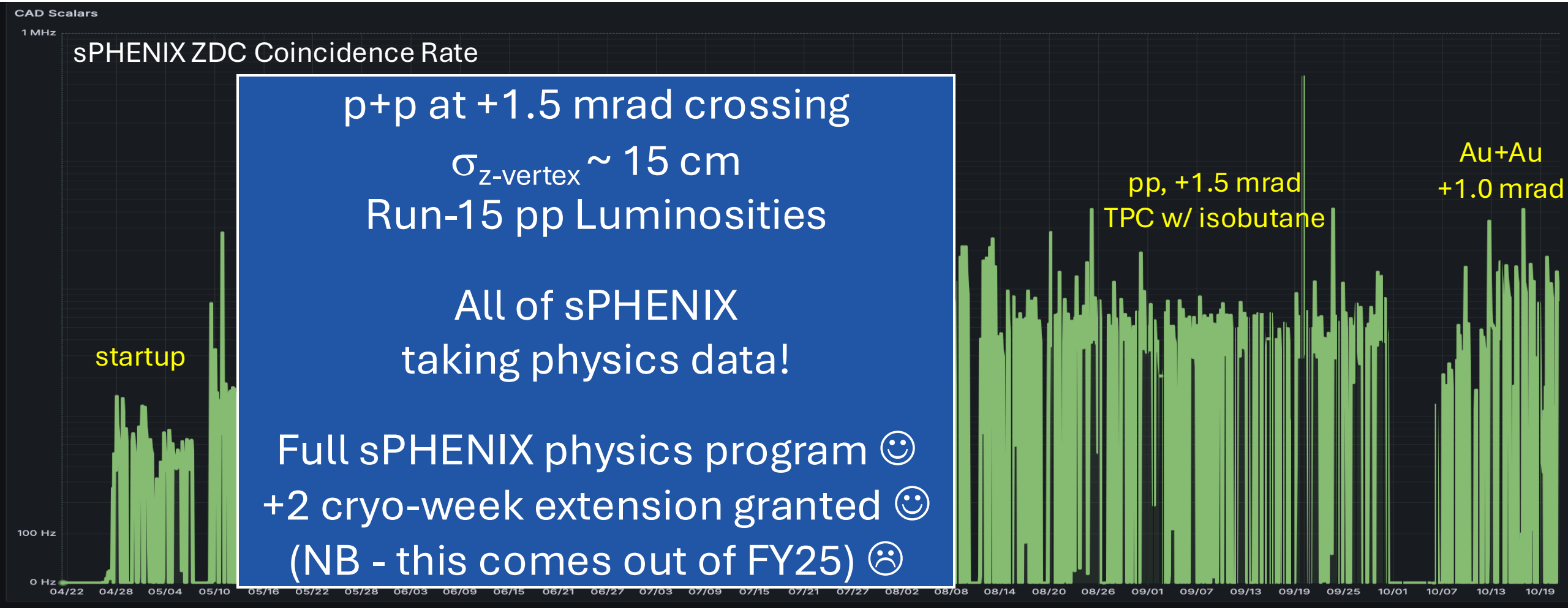
- We are implementing the above controls necessary for sPHENIX to flow isobutane from the Gas Mixing House to the IR.
  - The firmware and software implementation/changes are done by an outside company as well as a BNL software engineer.
- Fans in the isobutane shed and the Gas Mixing House are being restored.
- Ventilation in the IR bore (~ inside Magnet doors) needs to be maintained continuously.

Got Isobutane? Yes!





A long and challenging and fun sPHENIX Run 2024



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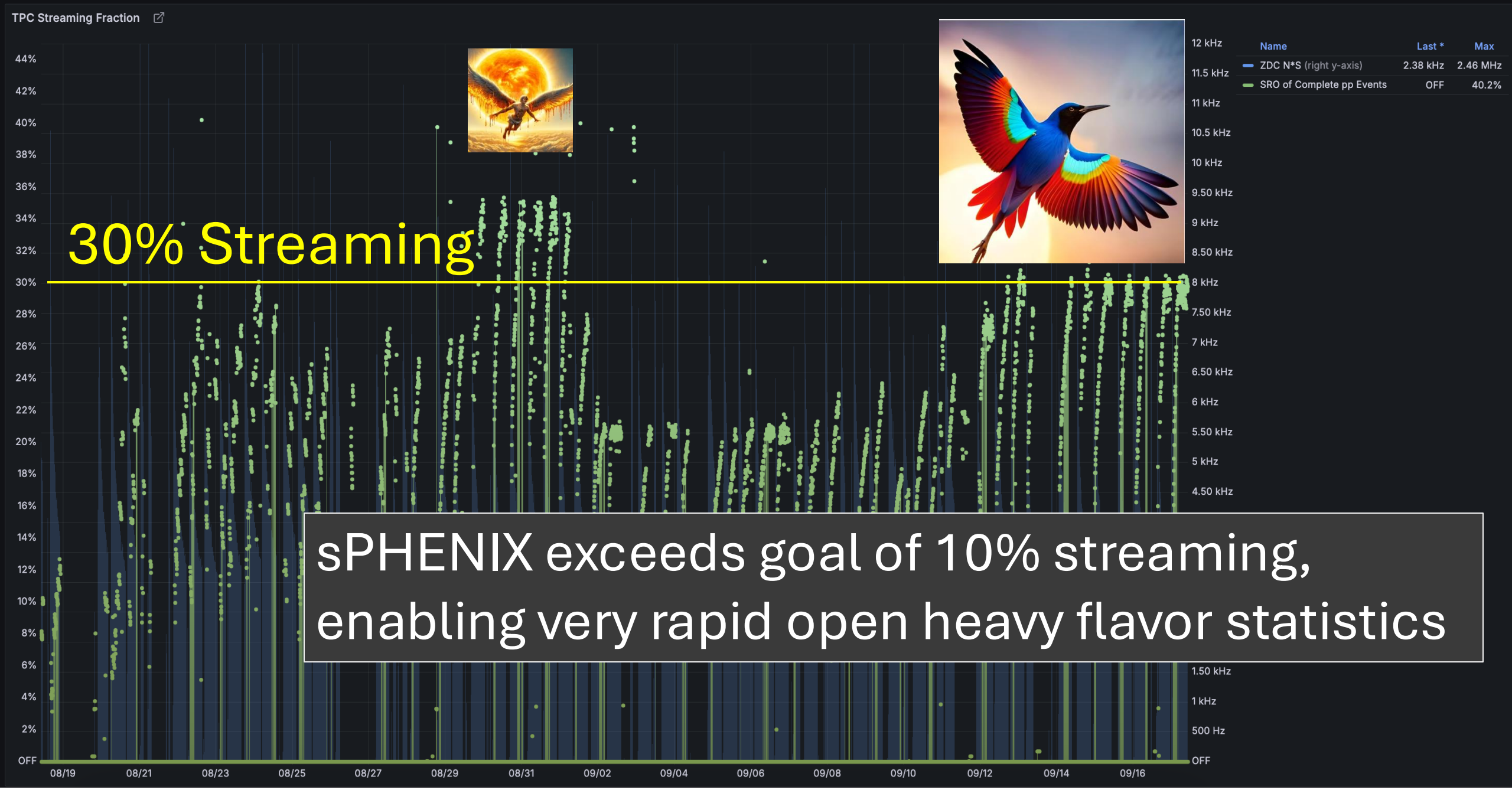
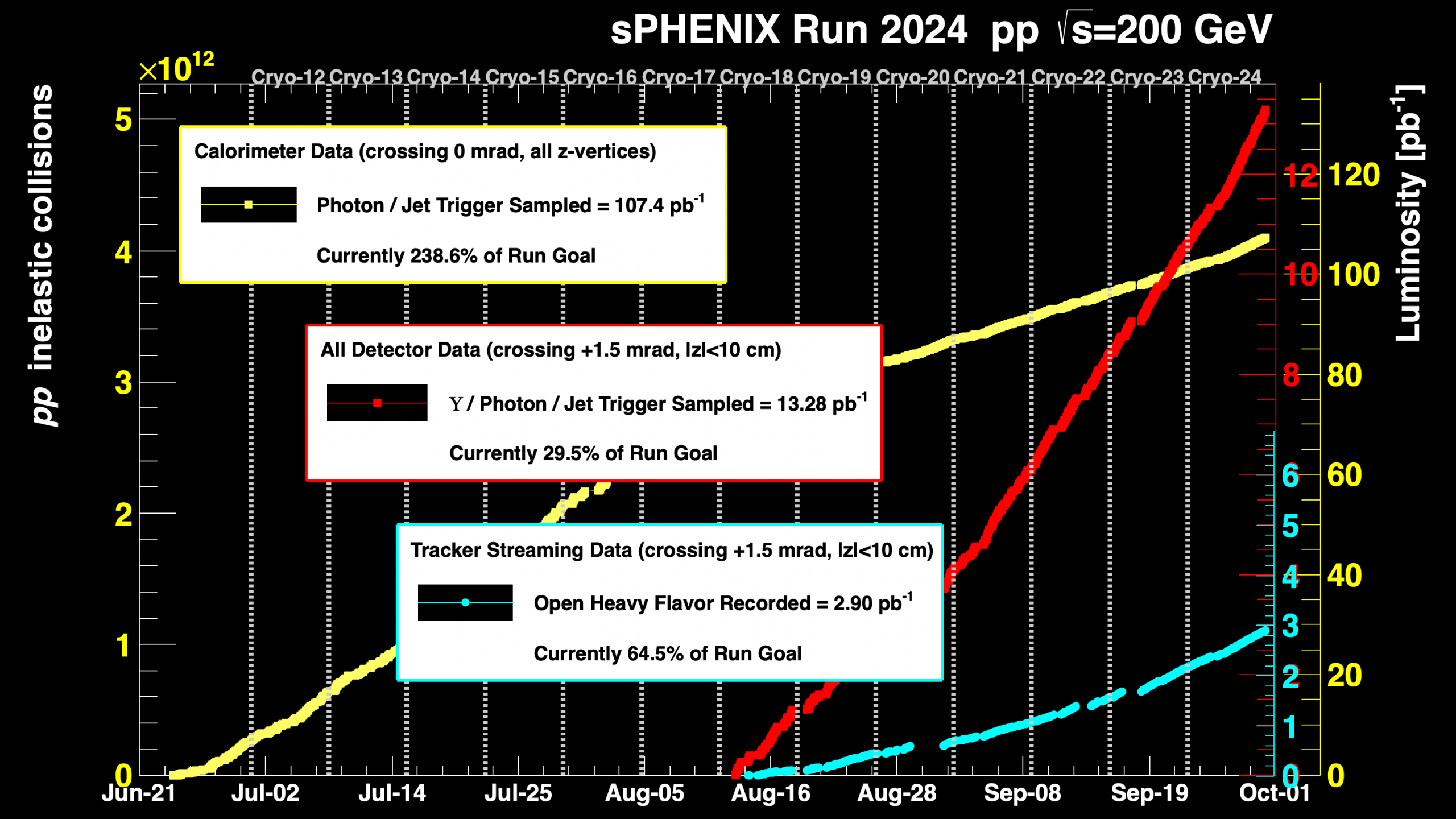
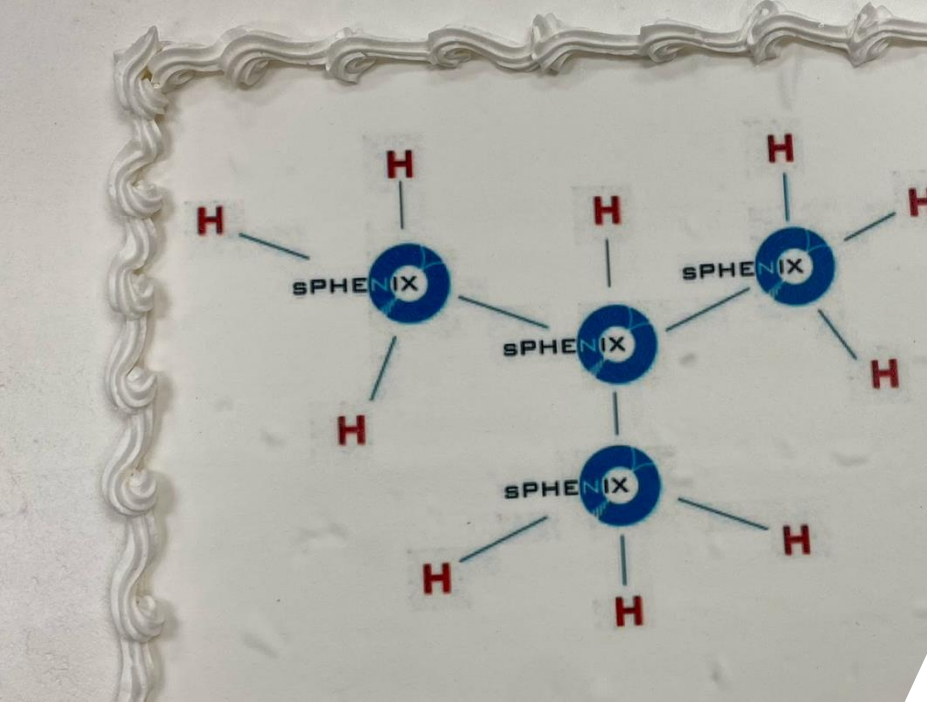
Chapter 3



sPHENIX exceeds goal of 10% streaming, enabling very rapid open heavy flavor statistics


sPHENIX Run 2024 pp √s=200 GeV
×10^12
pp inelastic collisions
Luminosity [pb^-1]
Cryo-12 Cryo-13 Cryo-14 Cryo-15 Cryo-16 Cryo-17 Cryo-18 Cryo-19 Cryo-20 Cryo-21 Cryo-22 Cryo-23 Cryo-24
Calorimeter Data (crossing 0 mrad, all z-vertices)
Photon / Jet Trigger Sampled = 107.4 pb^-1
Currently 238.6% of Run Goal
All Detector Data (crossing +1.5 mrad, |z|<10 cm)
Υ / Photon / Jet Trigger Sampled = 13.28 pb^-1
Currently 29.5% of Run Goal
Tracker Streaming Data (crossing +1.5 mrad, |z|<10 cm)
Open Heavy Flavor Recorded = 2.90 pb^-1
Currently 64.5% of Run Goal
0
1
2
3
4
5
0
20
40
60
80
100
120
0
1
2
3
4
5
6
8
10
12
Jun-21
Jul-02
Jul-14
Jul-25
Aug-05
Aug-16
Aug-28
Sep-08
Sep-19
Oct-01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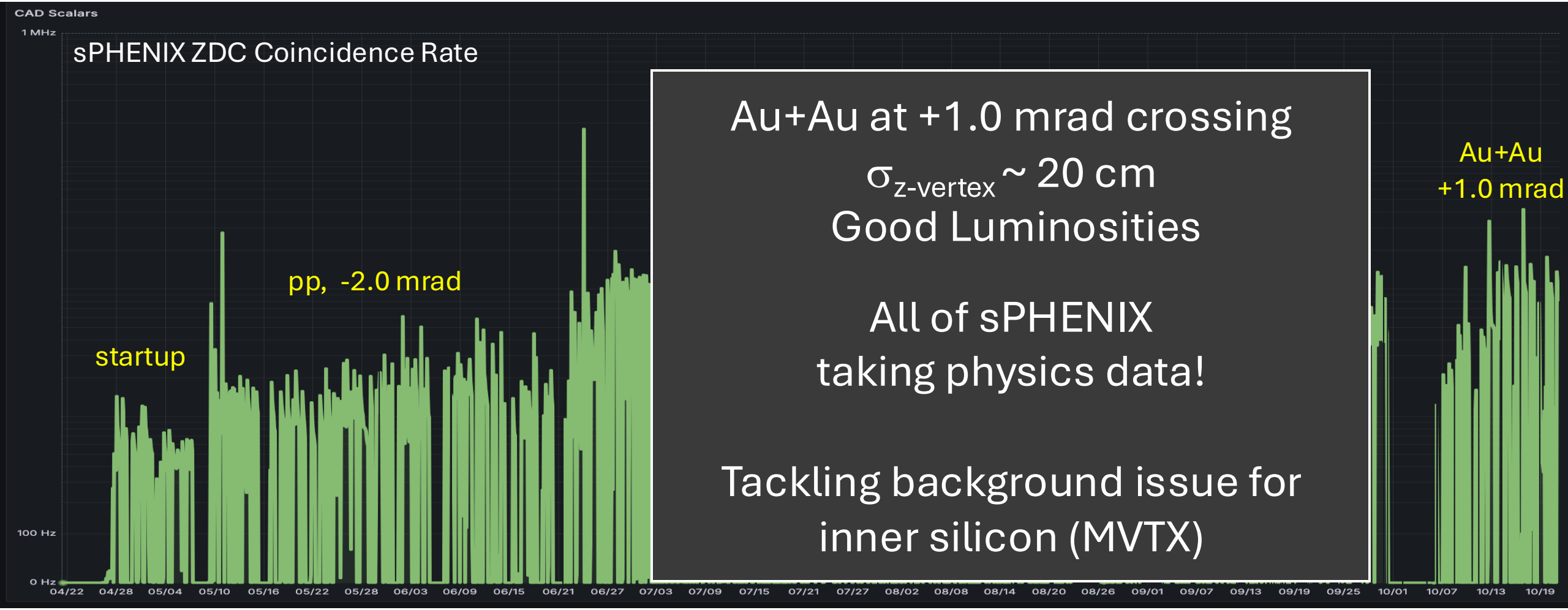
A long and challenging and fun sPHENIX Run 2024



Au+Au at +1.0 mrad crossing

$\sigma_{z\text{-vertex}} \sim 20$ cm

Good Luminosities

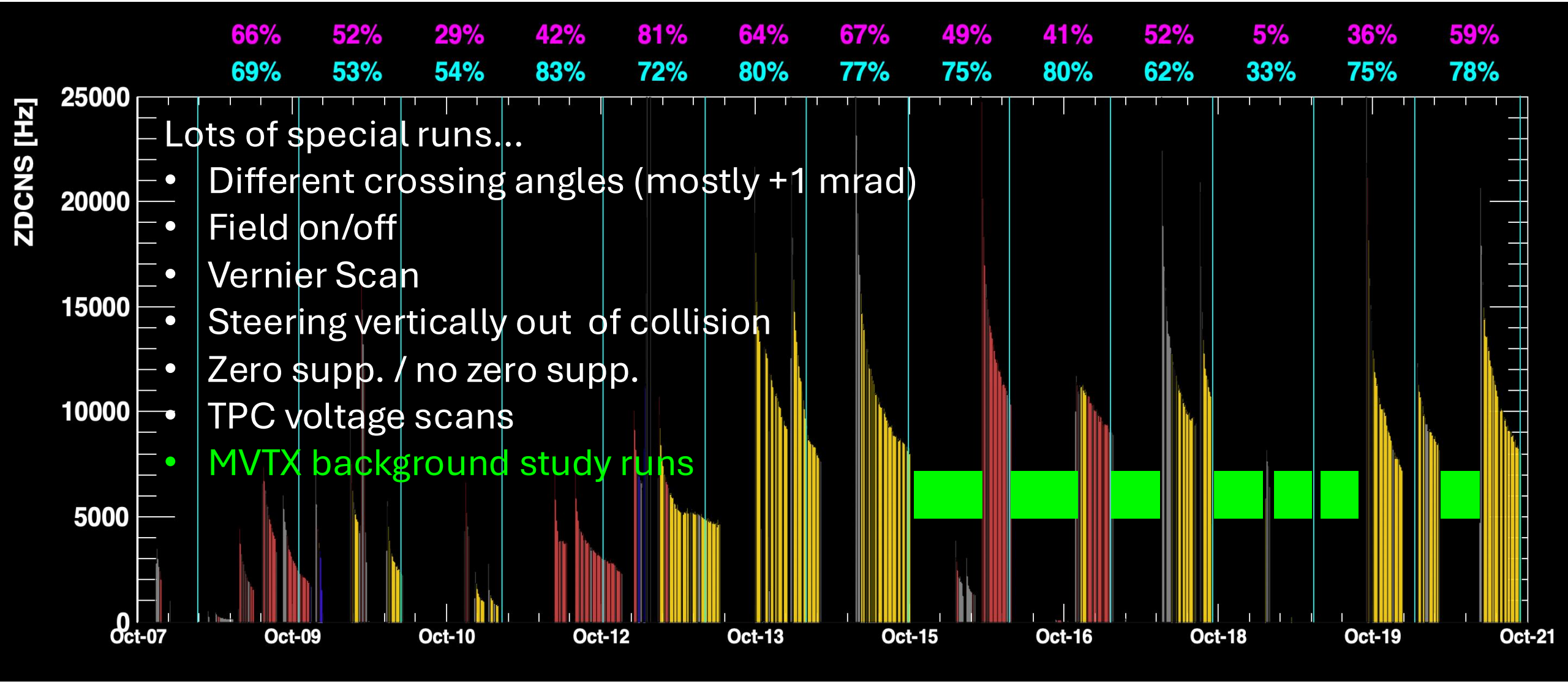
All of sPHENIX taking physics data!

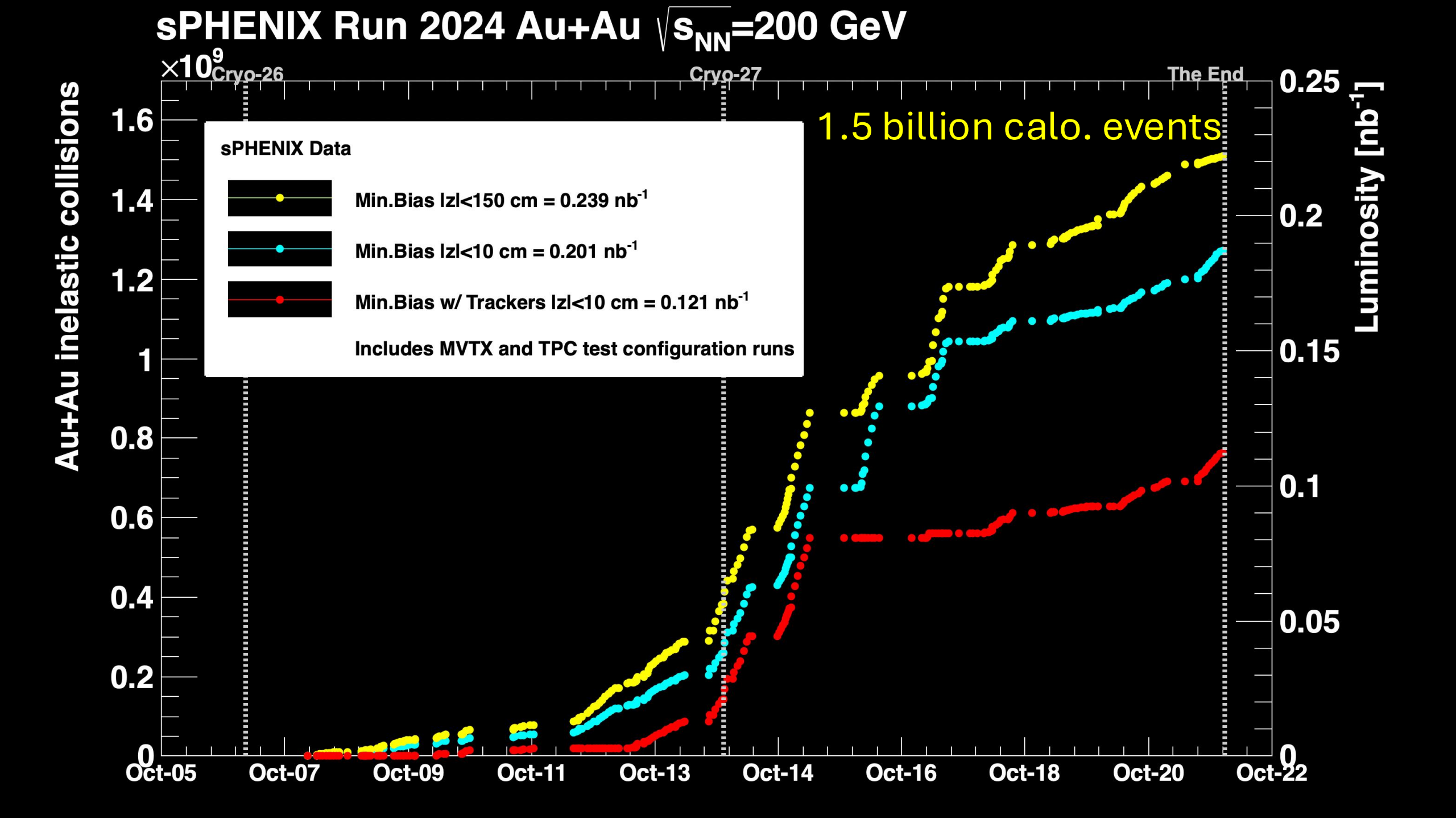
Tackling background issue for inner silicon (MVTX)

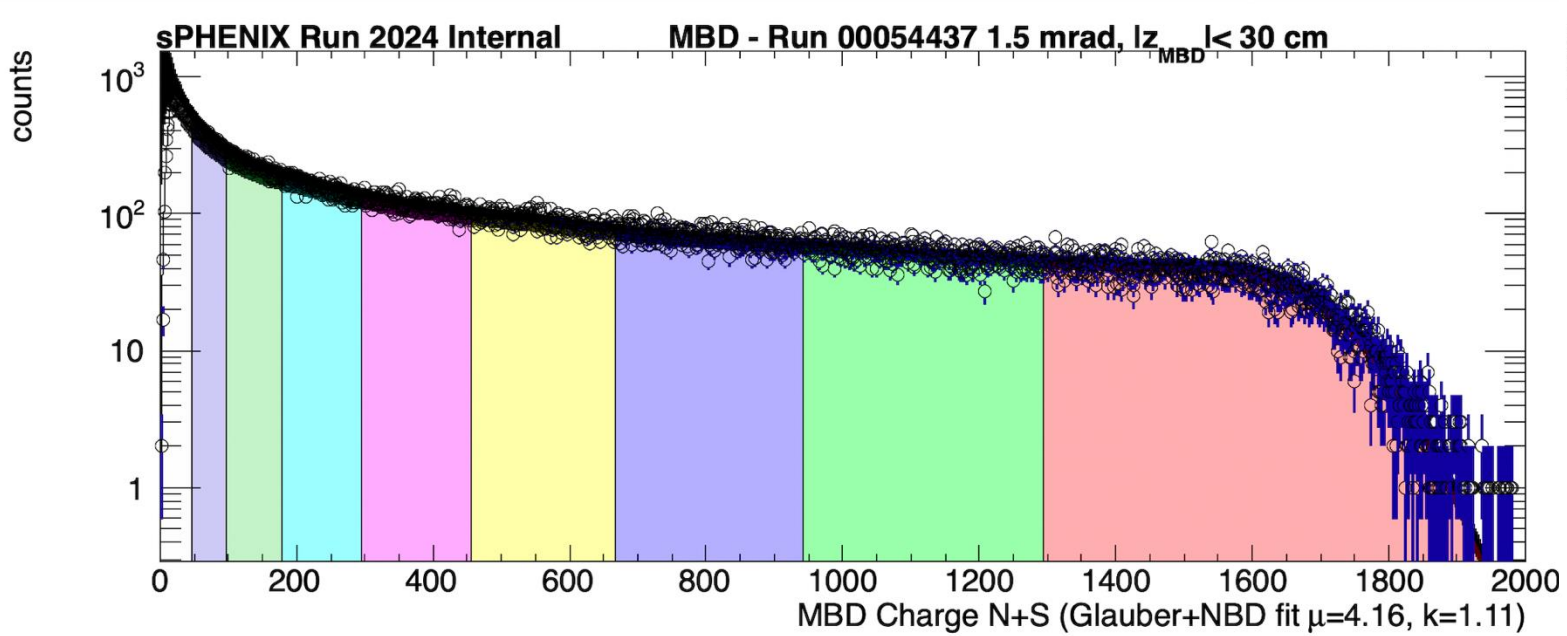
April 28 May 10 June 21 August 14 October 7 October 21

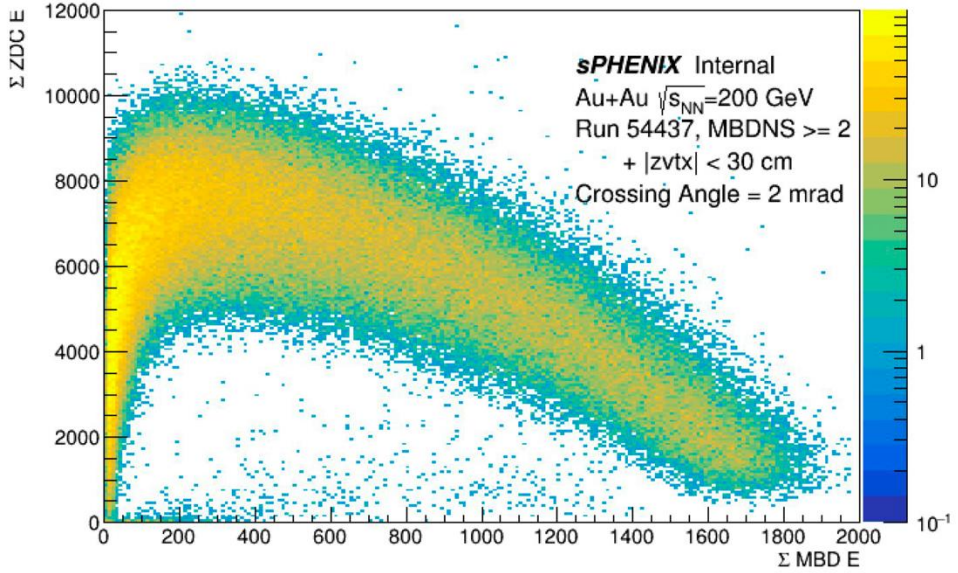
Chapter 4

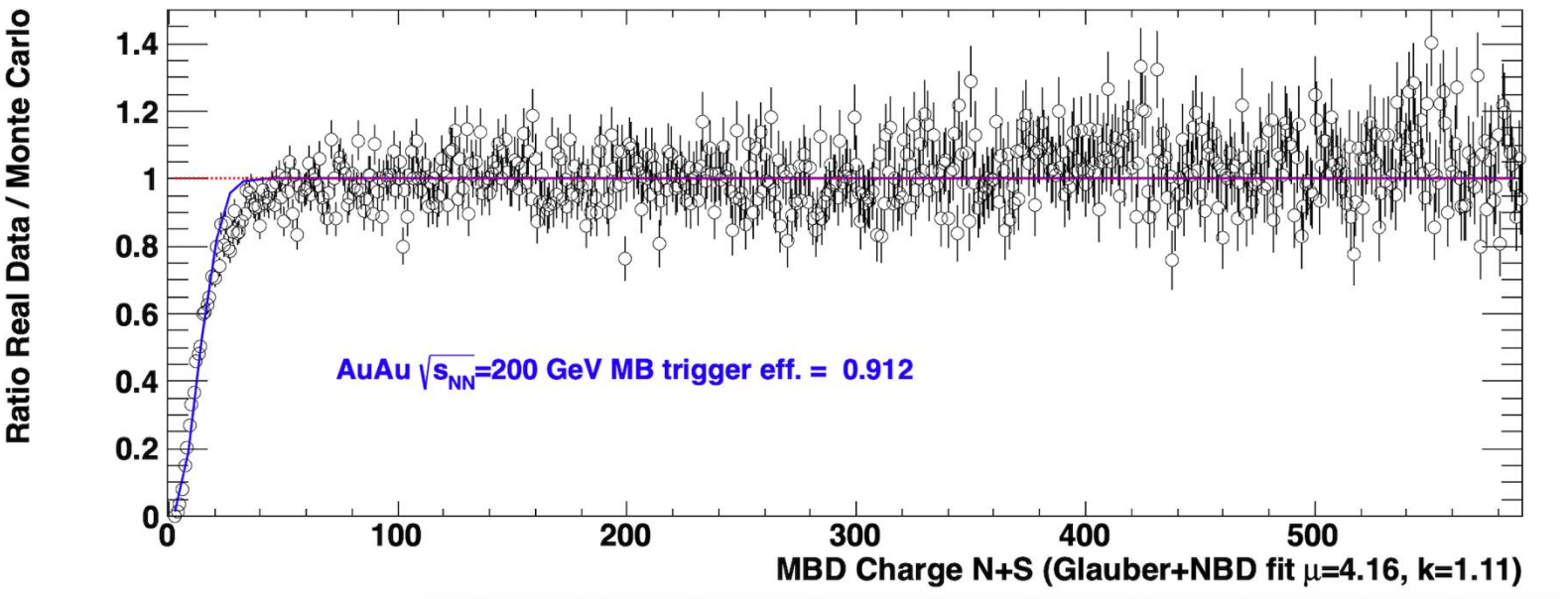
Au+Au 3 weeks in a nutshell

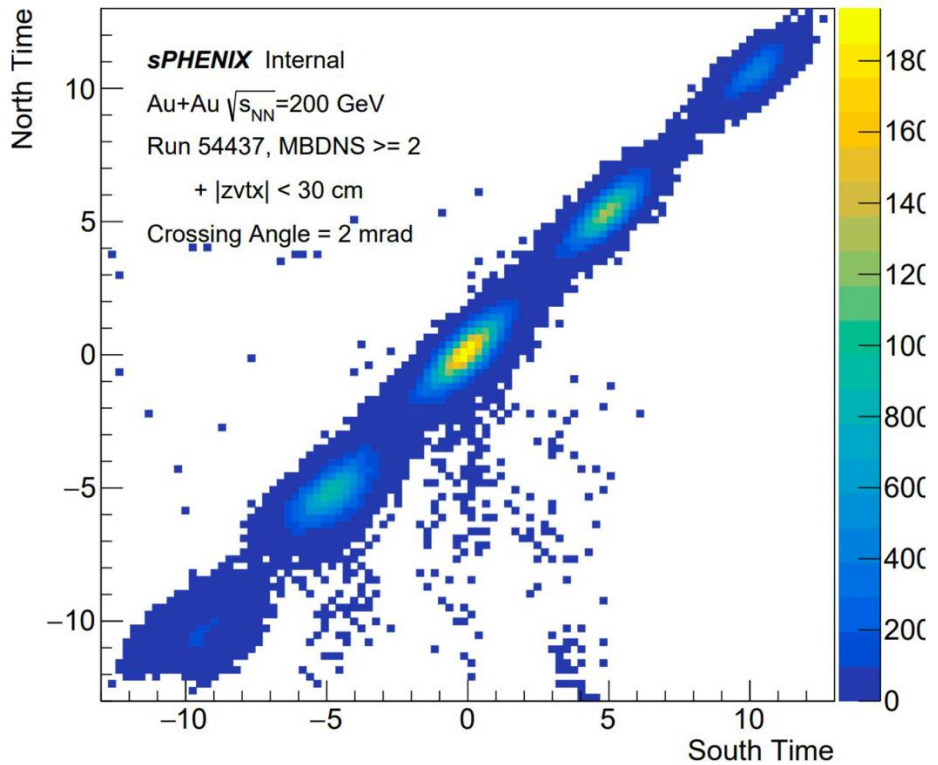



sPHENIX Run 2024 Au+Au $\sqrt{s_{NN}}$=200 GeV
$\times 10^9$
Au+Au inelastic collisions
Luminosity [nb^{-1}]
Cryo-26
Cryo-27
The End
1.5 billion calo. events
sPHENIX Data
Min.Bias |z|<150 cm = 0.239 nb^{-1}
Min.Bias |z|<10 cm = 0.201 nb^{-1}
Min.Bias w/ Trackers |z|<10 cm = 0.121 nb^{-1}
Includes MVTX and TPC test configuration runs
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
0.05
0.1
0.15
0.2
0.25
Oct-05
Oct-07
Oct-09
Oct-11
Oct-13
Oct-14
Oct-16
Oct-18
Oct-20
Oct-22

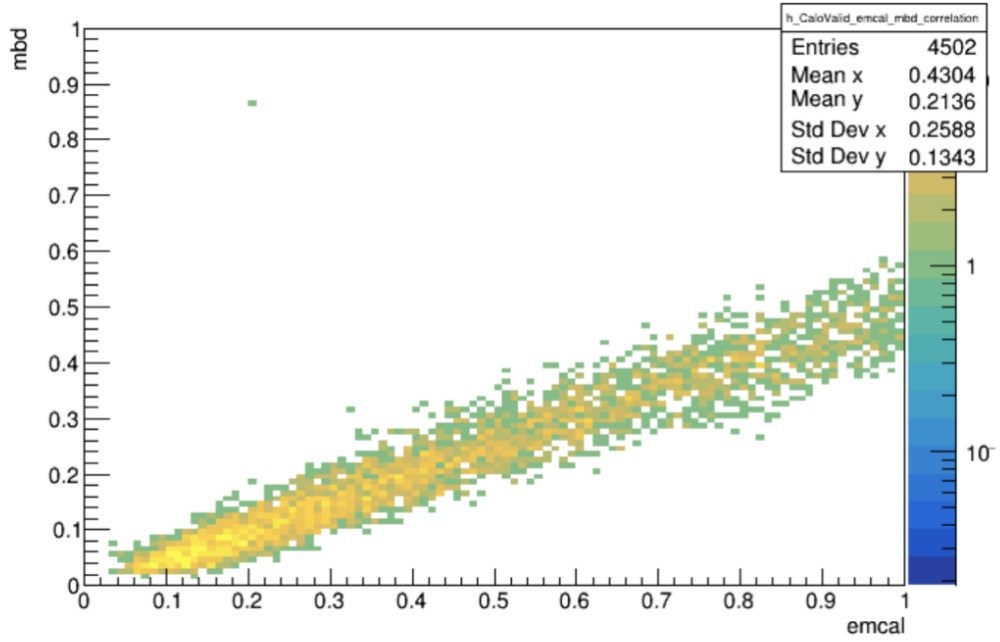

sPHENIX Run 2024 Internal
MBD - Run 00054437 1.5 mrad, |z_MBD|< 30 cm
counts
MBD Charge N+S (Glauber+NBD fit μ=4.16, k=1.11)


sPHENIX Internal
Au+Au √s_NN=200 GeV
Run 54437, MBDNS >= 2
+ |zvtx| < 30 cm
Crossing Angle = 2 mrad
Σ ZDC E
Σ MBD E

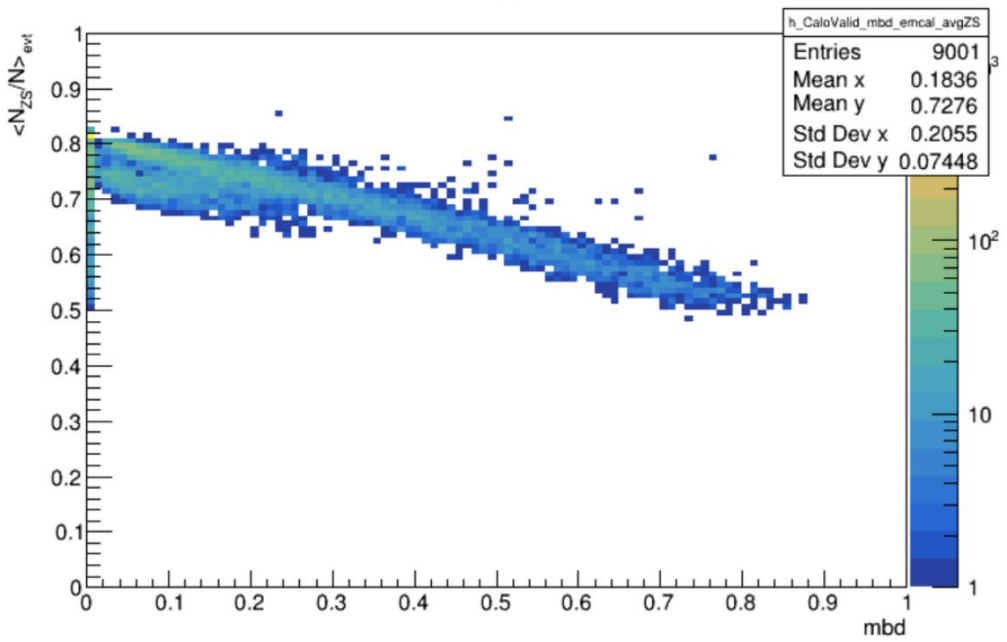

Ratio Real Data / Monte Carlo
AuAu √s_NN=200 GeV MB trigger eff. = 0.912
MBD Charge N+S (Glauber+NBD fit μ=4.16, k=1.11)

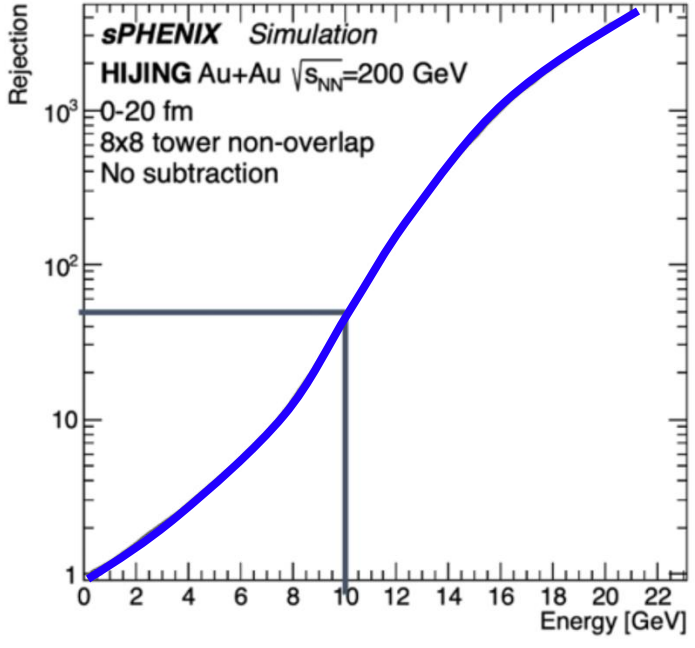

sPHENIX Internal
Au+Au √s_NN=200 GeV
Run 54437, MBDNS >= 2
+ |zvtx| < 30 cm
Crossing Angle = 2 mrad
North Time
South Time

MBD vs EMCal



EMCal Zero Suppression vs MBD

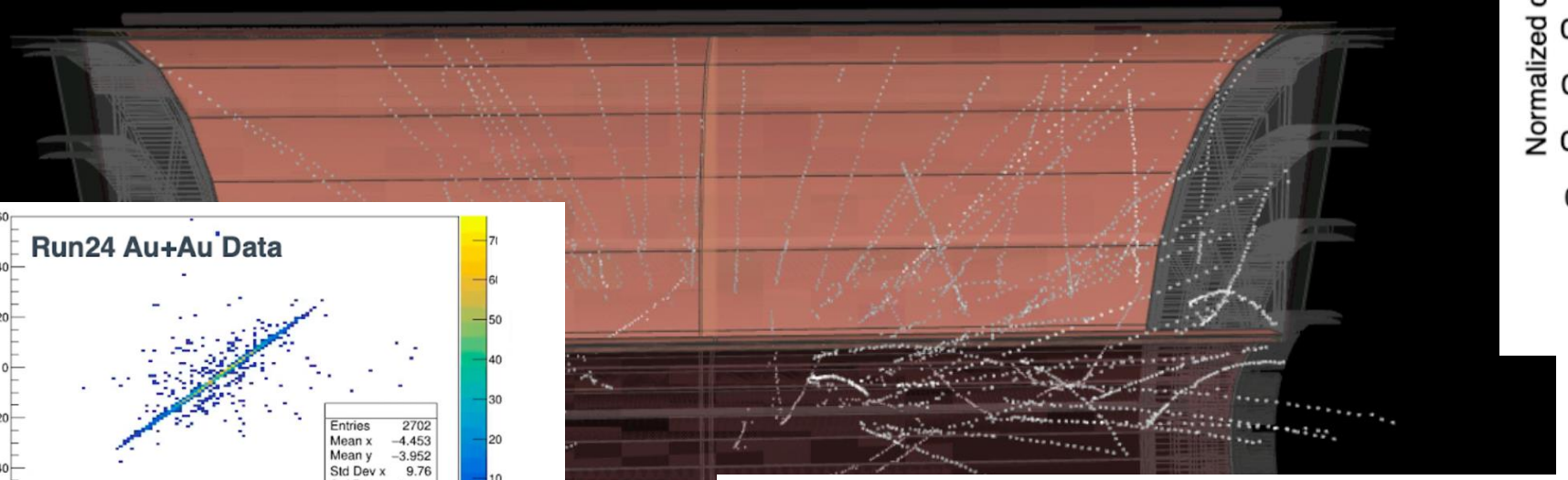


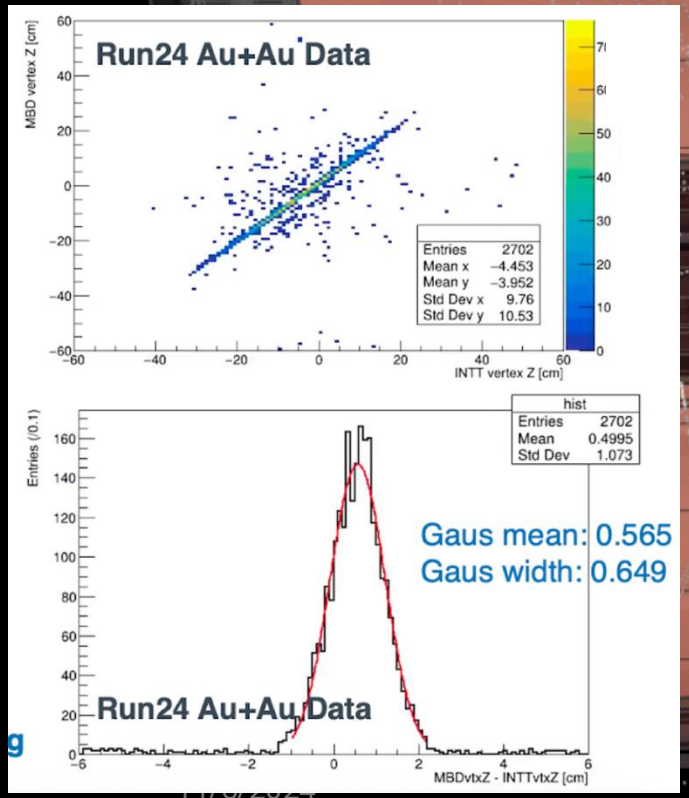


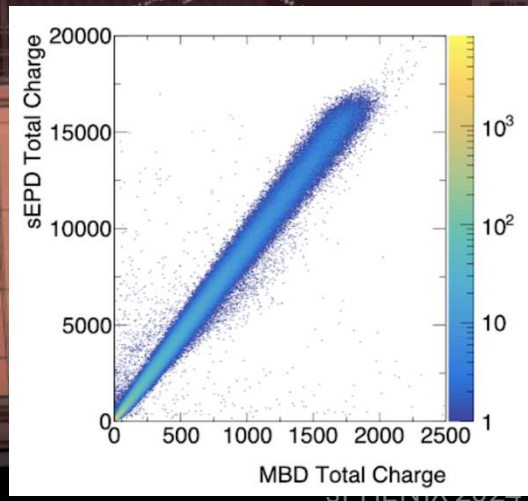
Minimum Bias Triggers working.
MBD/ZDC ratio as expected.
Vernier scan complete.

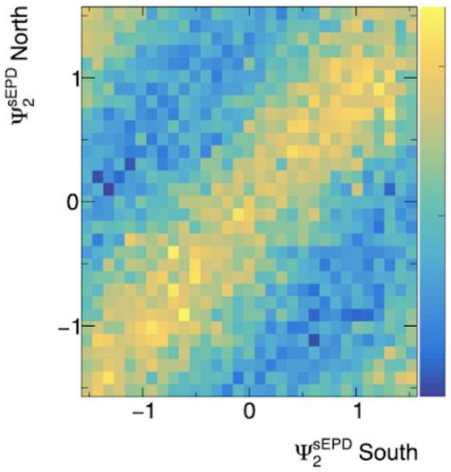
Tested photon trigger rejections
10, 14, 18, 20 GeV thresholds

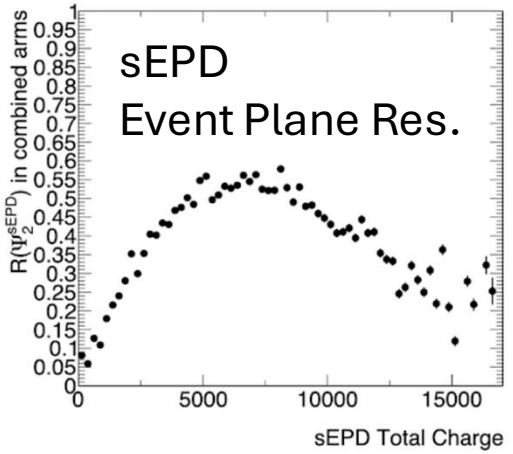
sPHENIX Internal
200 GeV AuAu
2024-10-12, Run 54469, Event #48
TPC HV: (GEMs – 3.31 kV, CM – 43.3 kV), 2 mrad crossing angle.

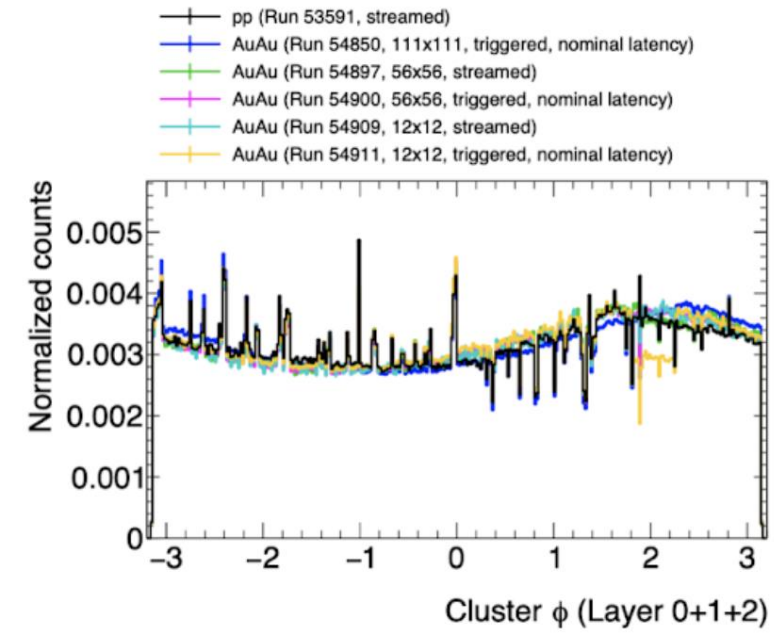




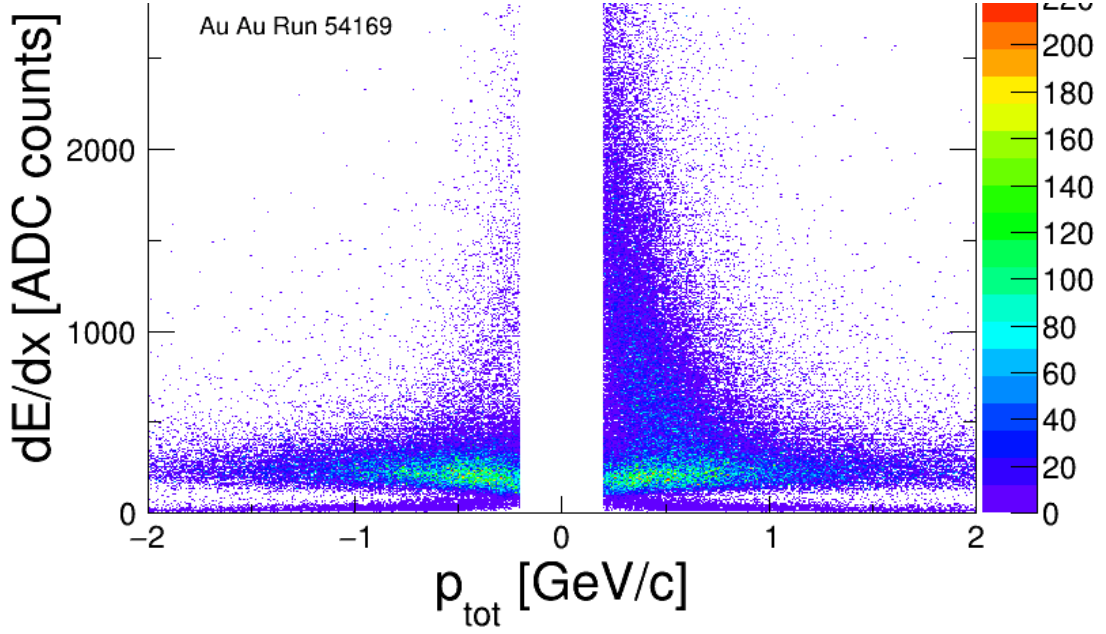


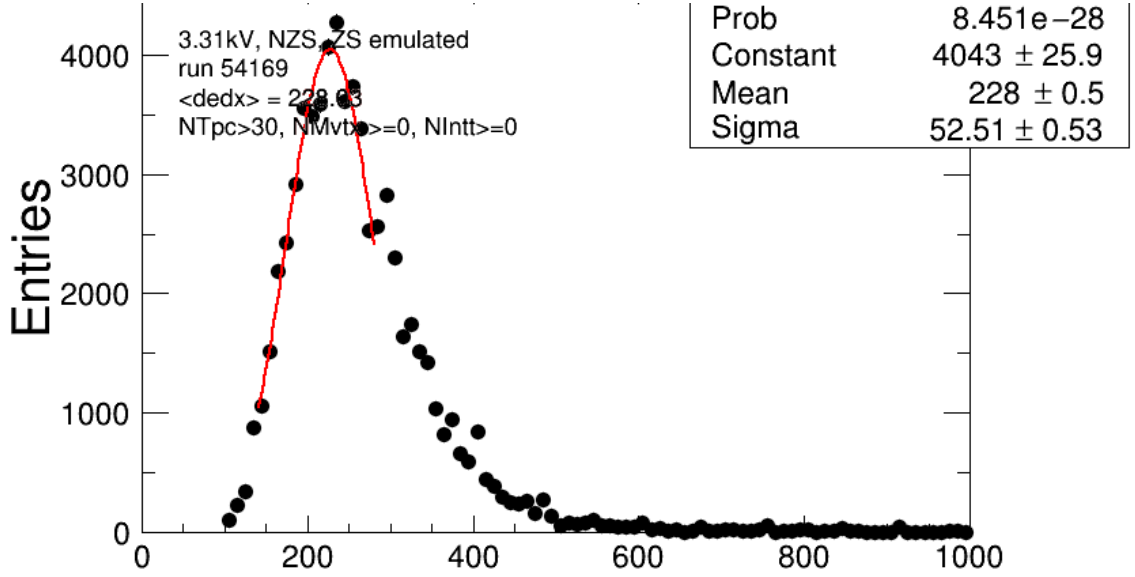


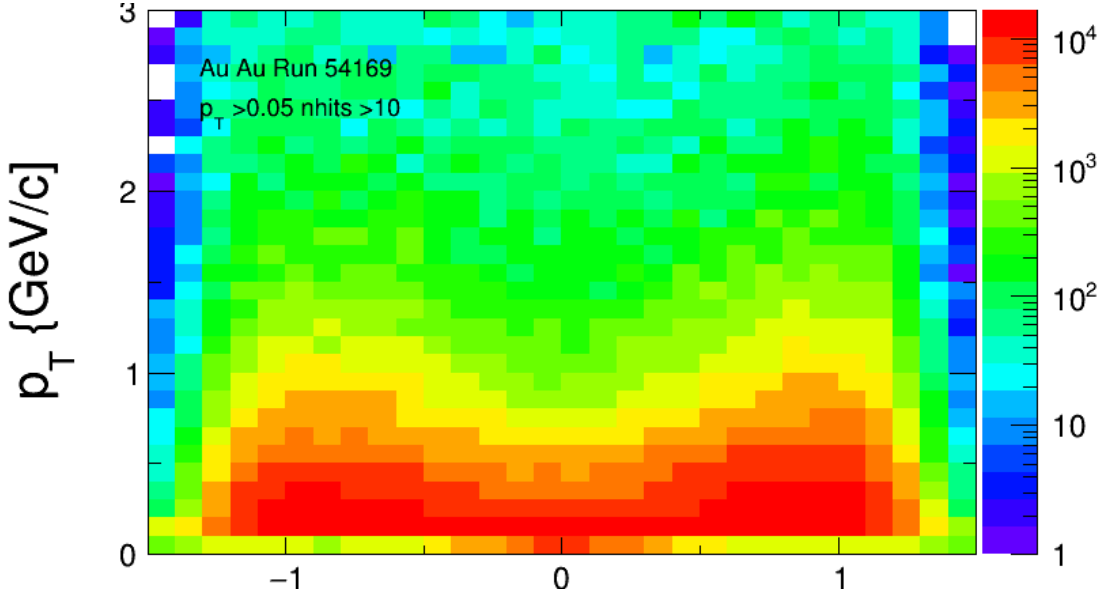




TPC w/ isobutane looks very good







TPC Summary

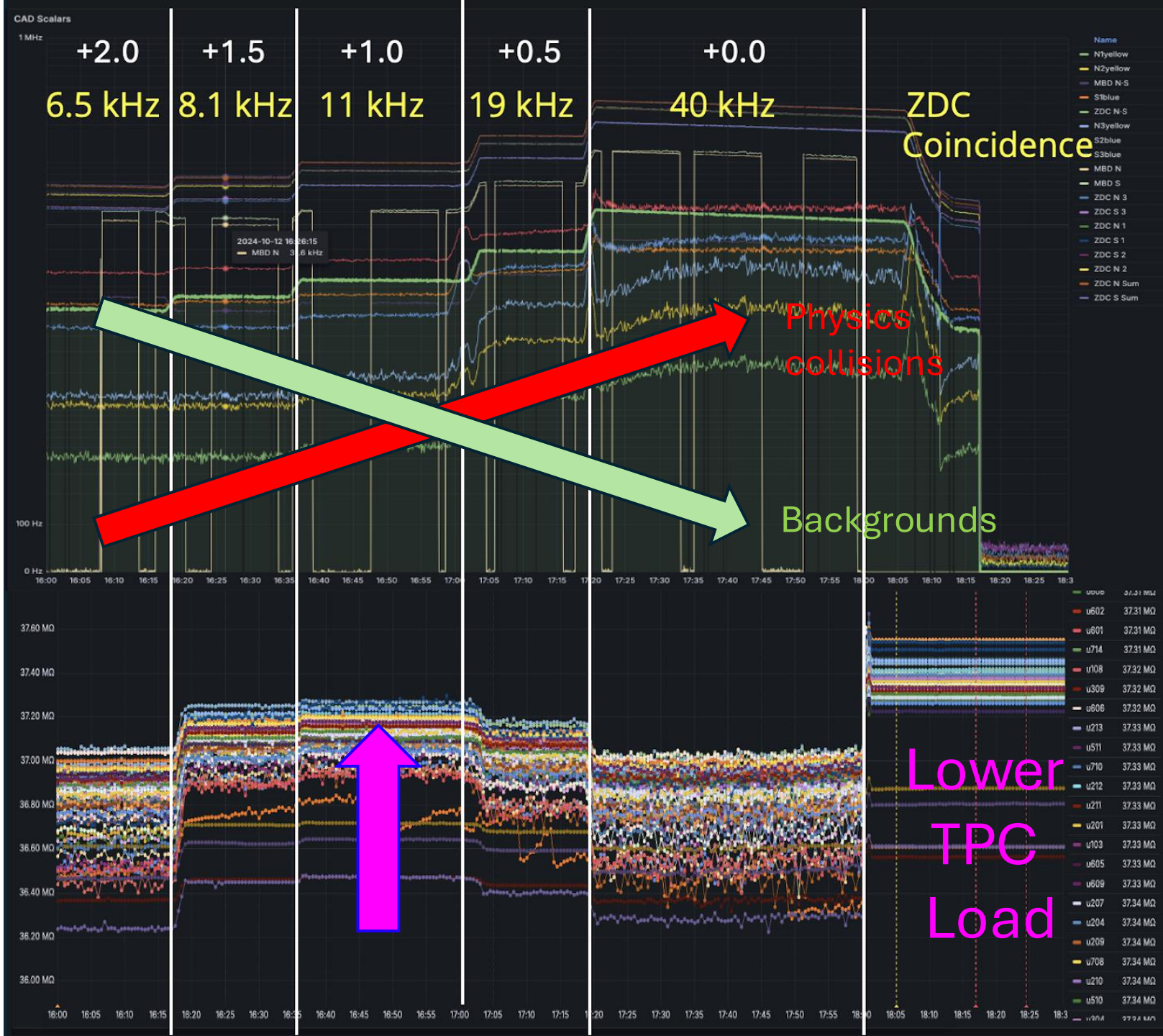
The TPC charge load appears to be dominated by beam background (not collisions)

Charge load is directly related to TPC distortions.

Implications for Run 2025, default is now +1.0 mrad to start.

Tested 2 sectors w/ new CAEN HV system.

Potential gas contamination issue in last 10 days. Under study.

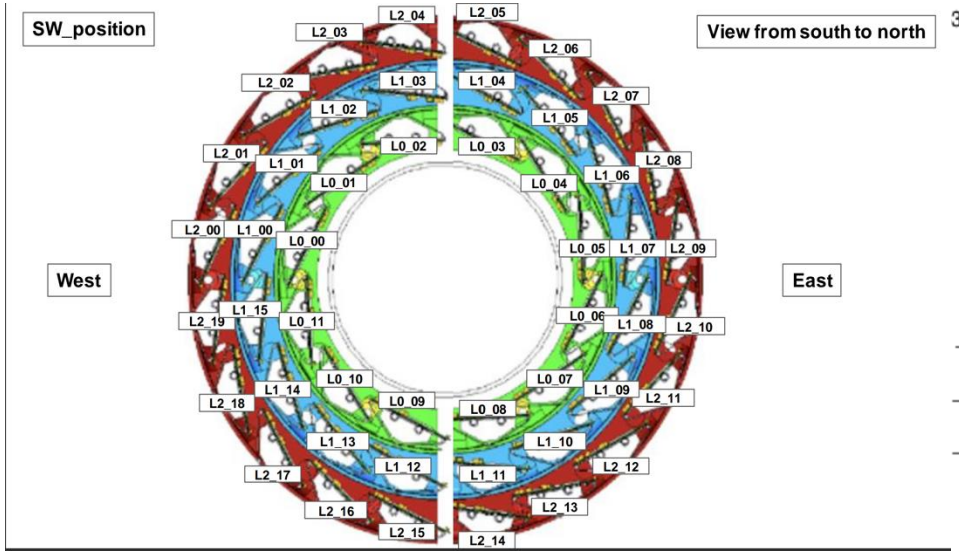


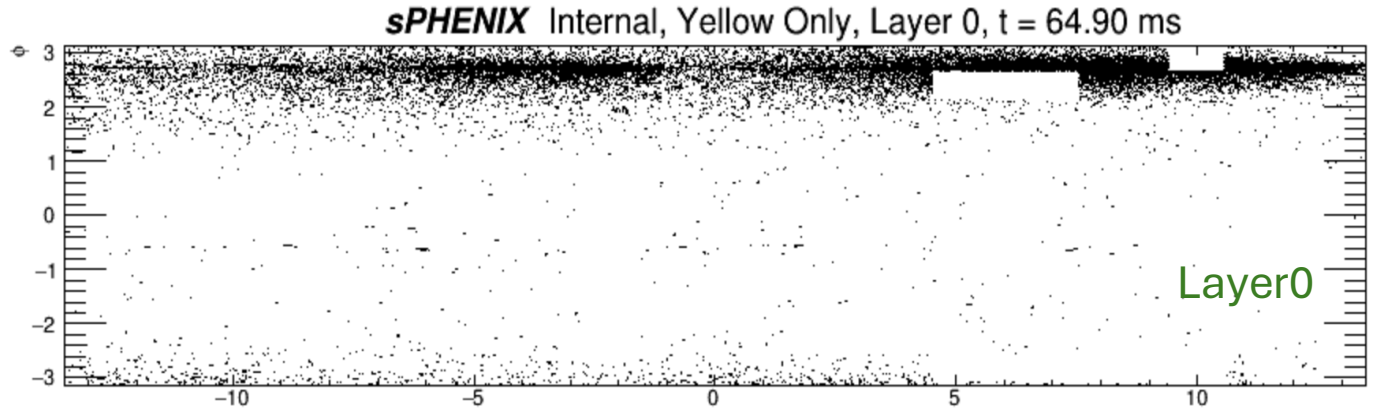
MVTX Backgrounds

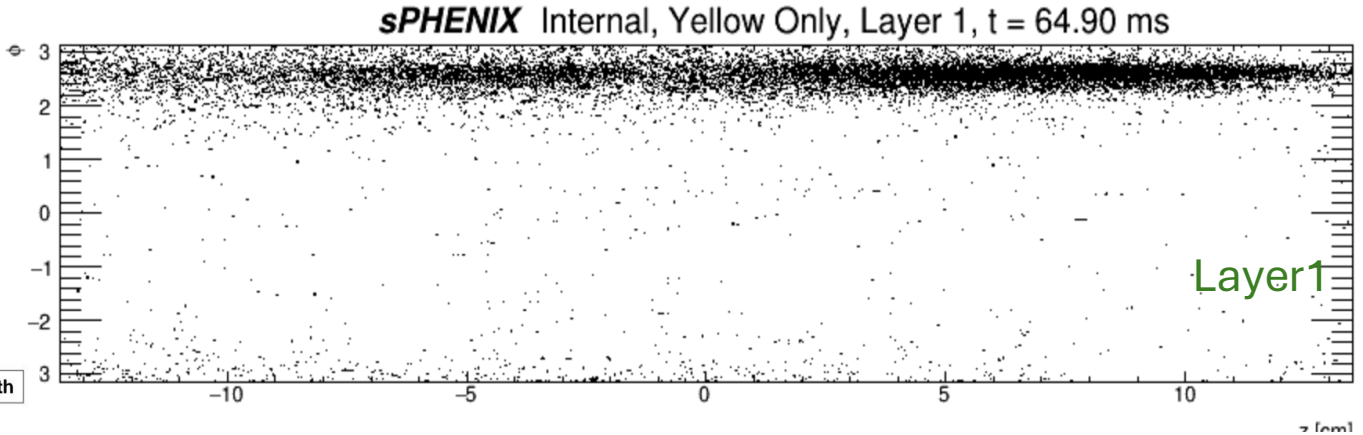
No problems in proton-proton

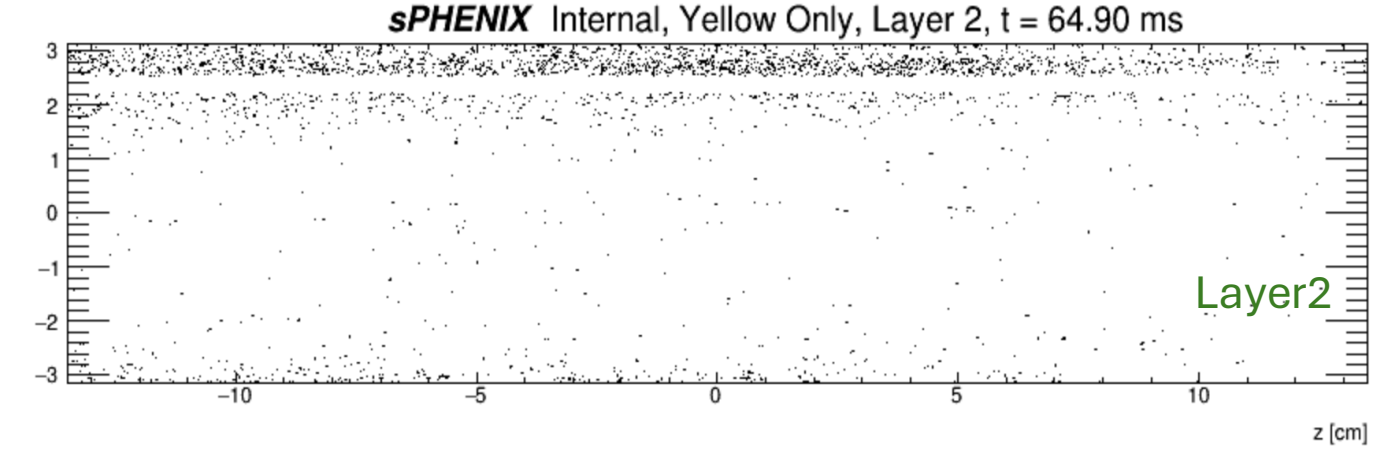
Major background in Au+Au, even with just one bunch in the yellow ring
(i.e., no collisions)

Beam backgrounds… induces auto-recoveries in MVTX



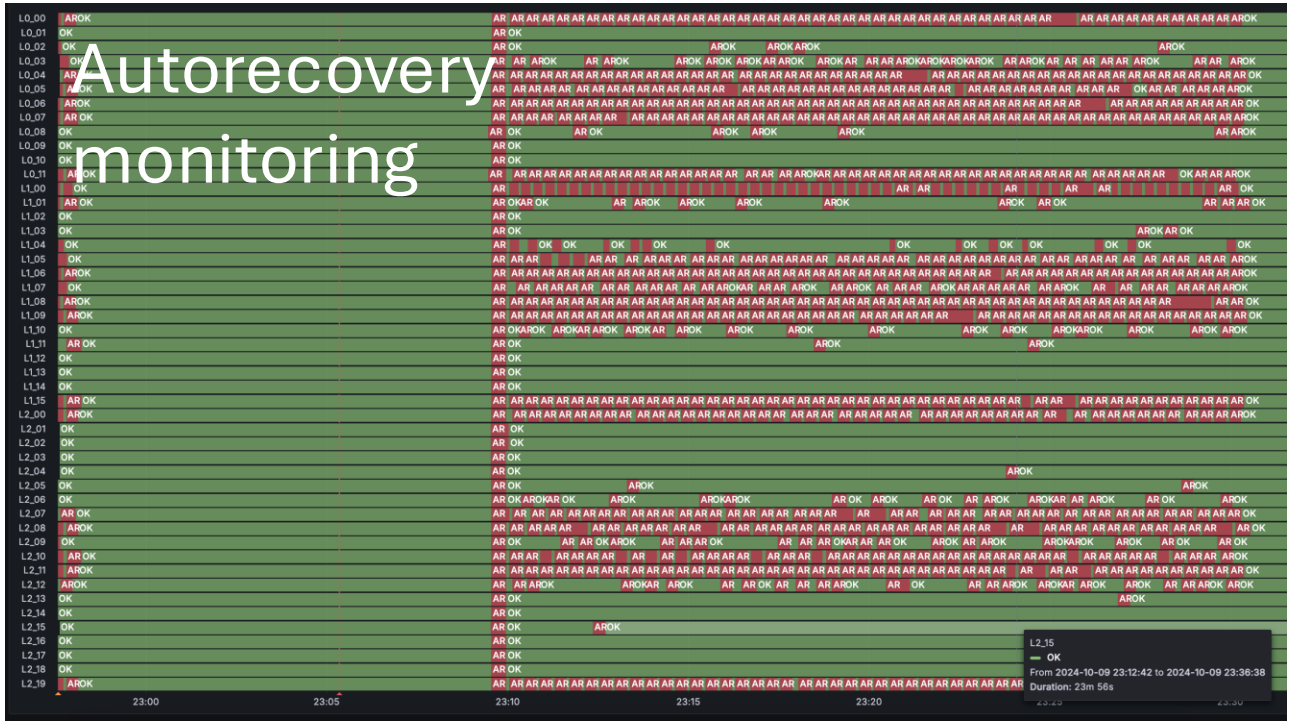


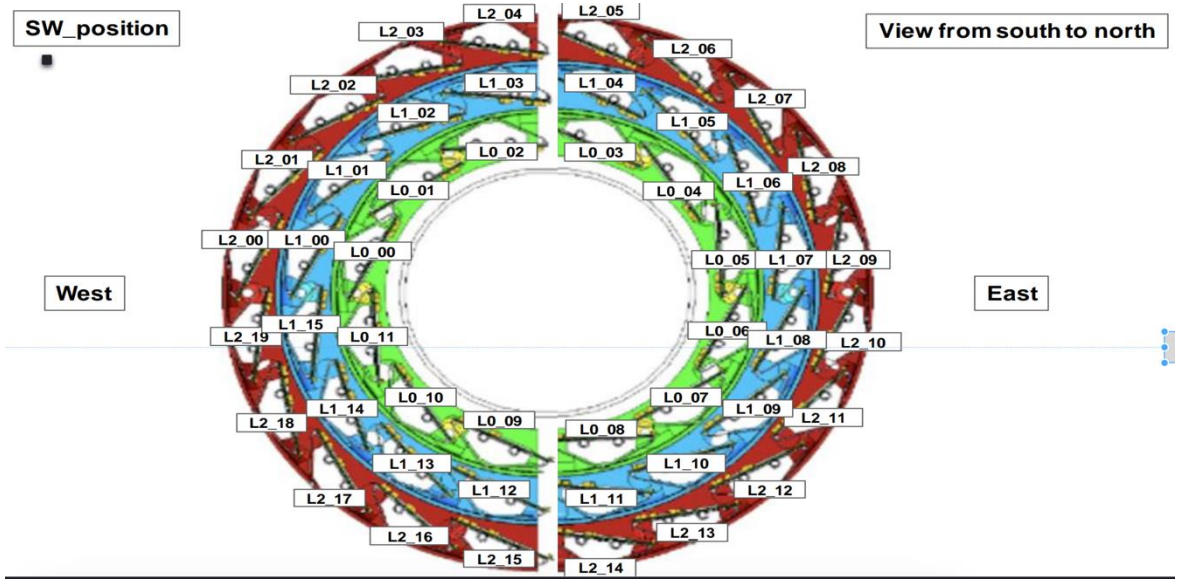




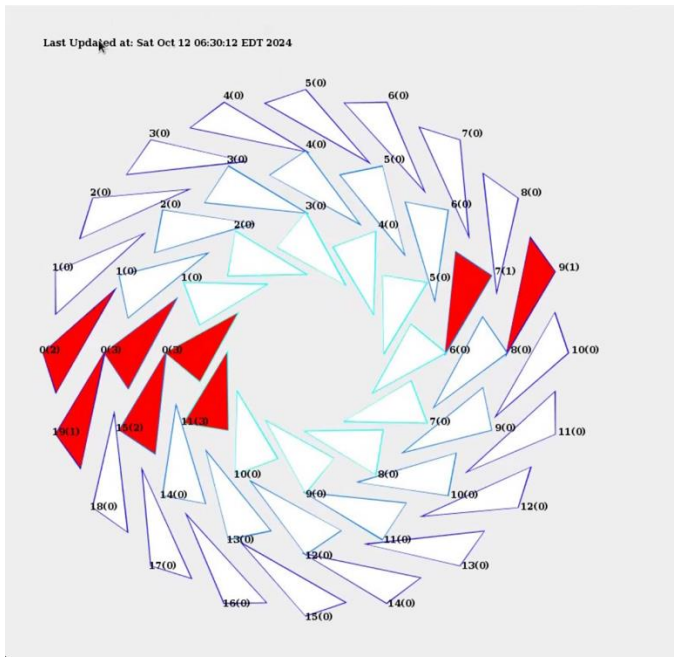
Yellow Beam Direction

Autorecovery monitoring

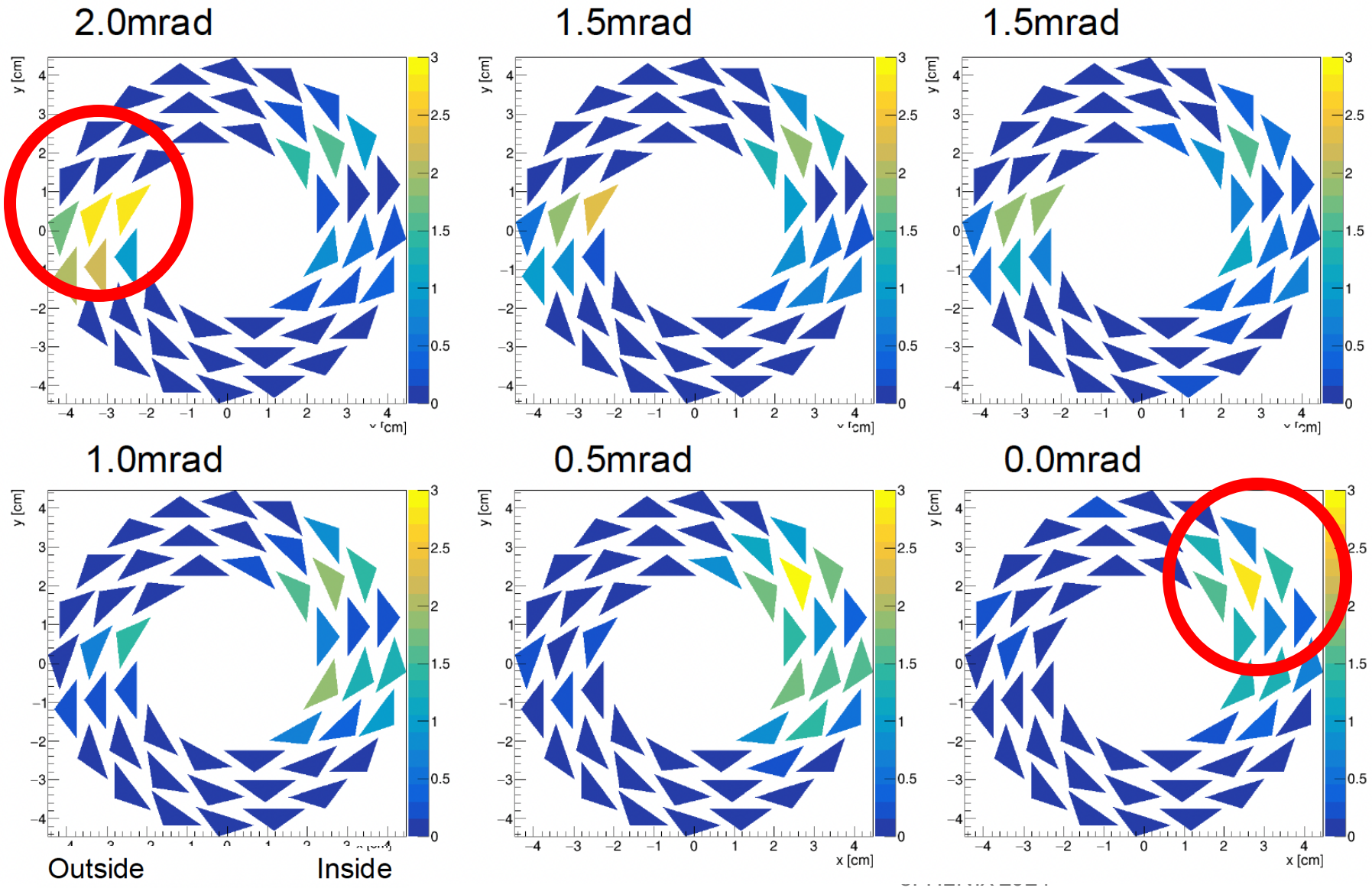




Working together!
sPHENIX and C-AD working together.
Hundreds of careful tests.



X-ing angle summary, 1x1 bunches

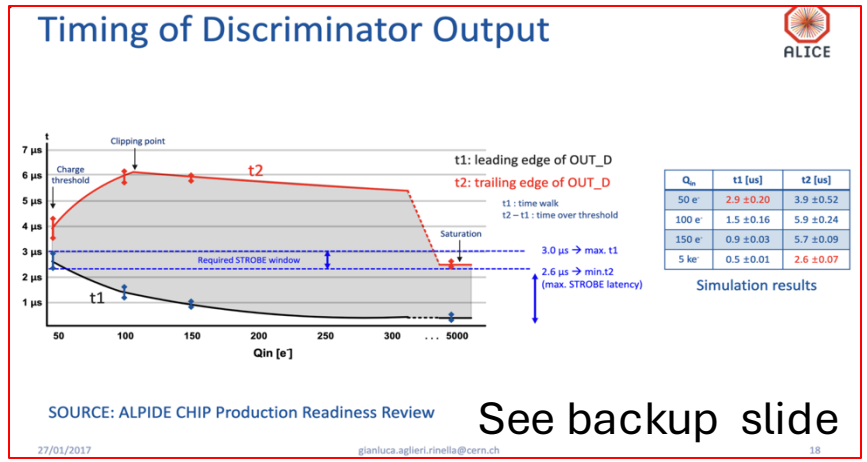


Crossing angle change completely moves where the background hits.

C-AD has many test results to develop a mitigation.

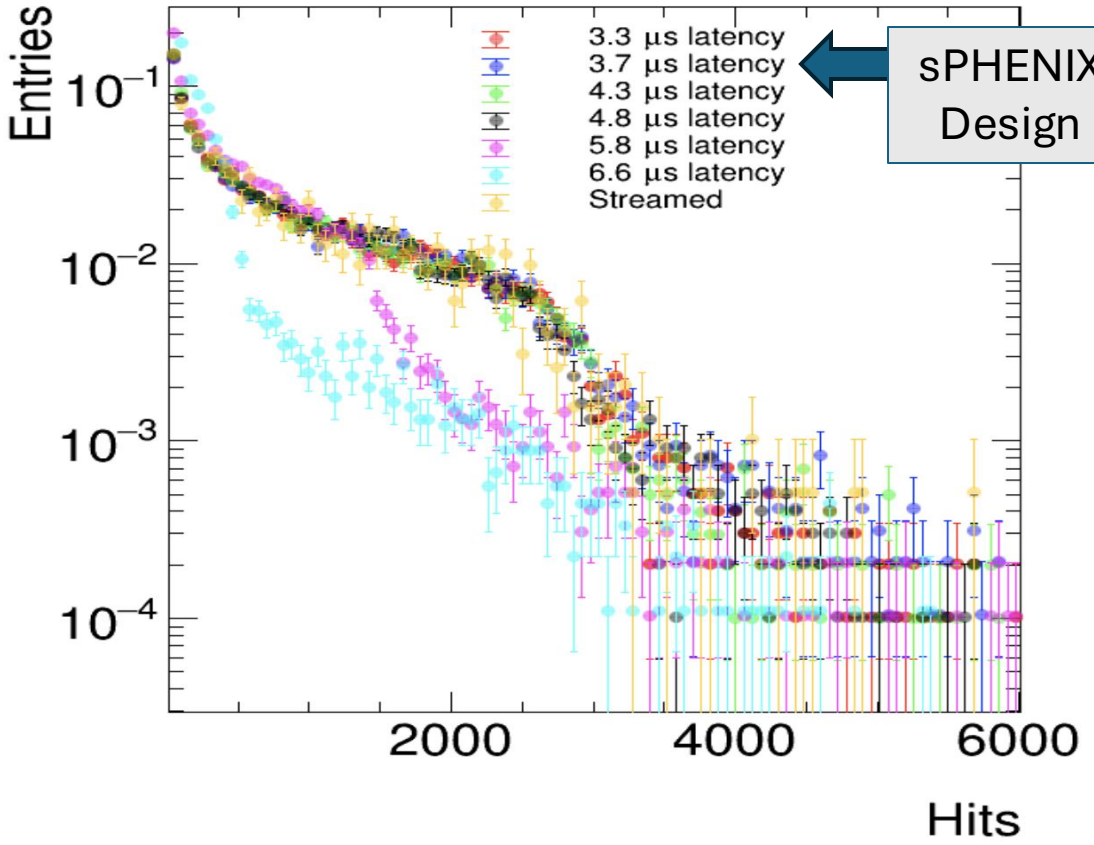
sPHENIX MVTX intended to run in 100% streaming mode. That makes it susceptible to 100% of splash events → autorecovery (AR)

ALICE ALPIDE supports triggered mode with 2.5 microsecond latency. Reduces AR by x10-20.



See backup slide

sPHENIX default is 3.7 ms.
Latency scan yielded encouraging results,
But full analysis needed to understand efficiency for low p_T kaons and protons



Confident that next year running in triggered mode and with C-AD improvements, MVTX will be fully functional.

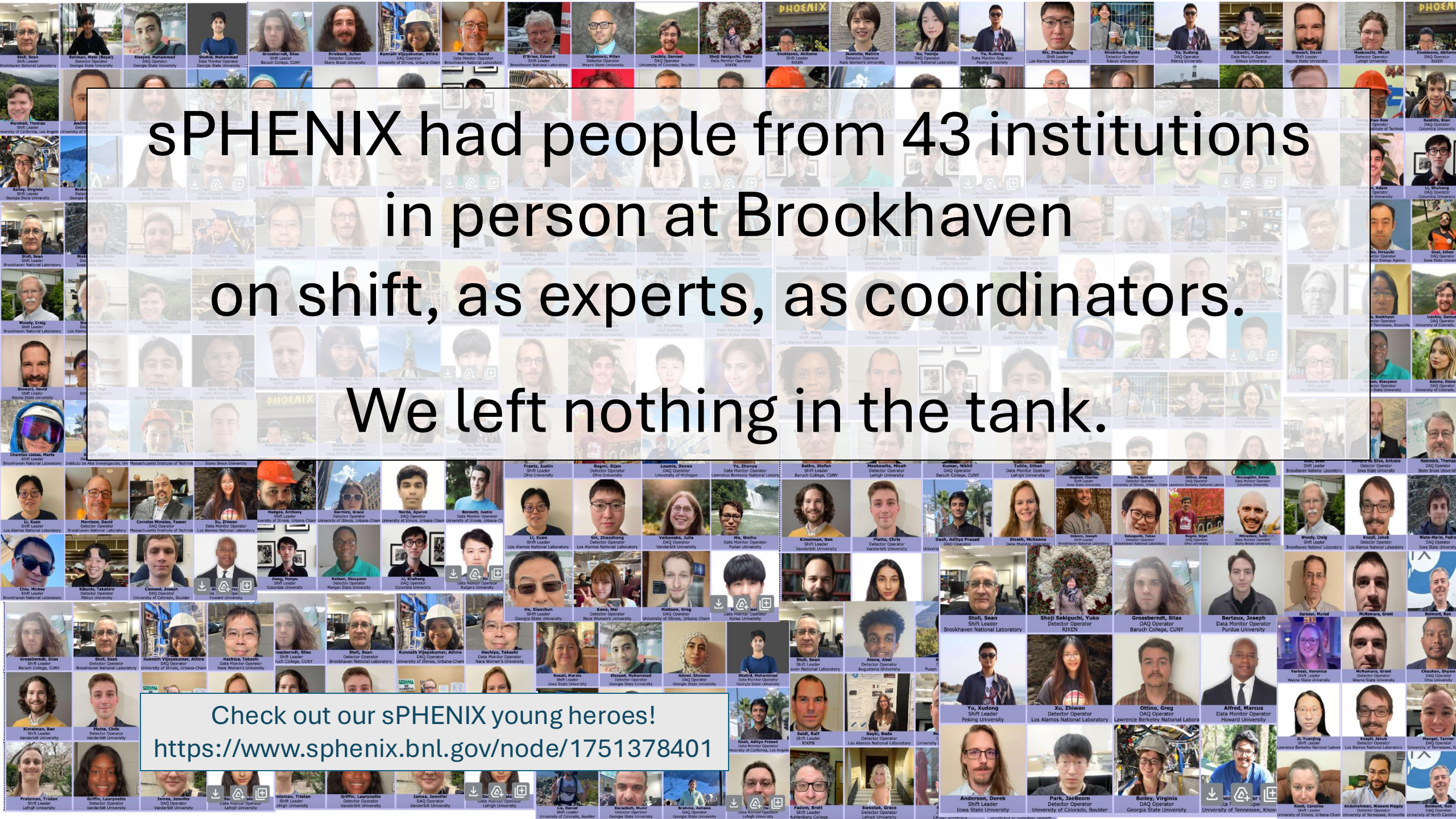
- Note streaming mode for future p+Au running may be an issue.

Given many challenges,
excellent sPHENIX pp data set the result of
sPHENIX and C-AD smarts and true grit.

Run 2024 pp data set

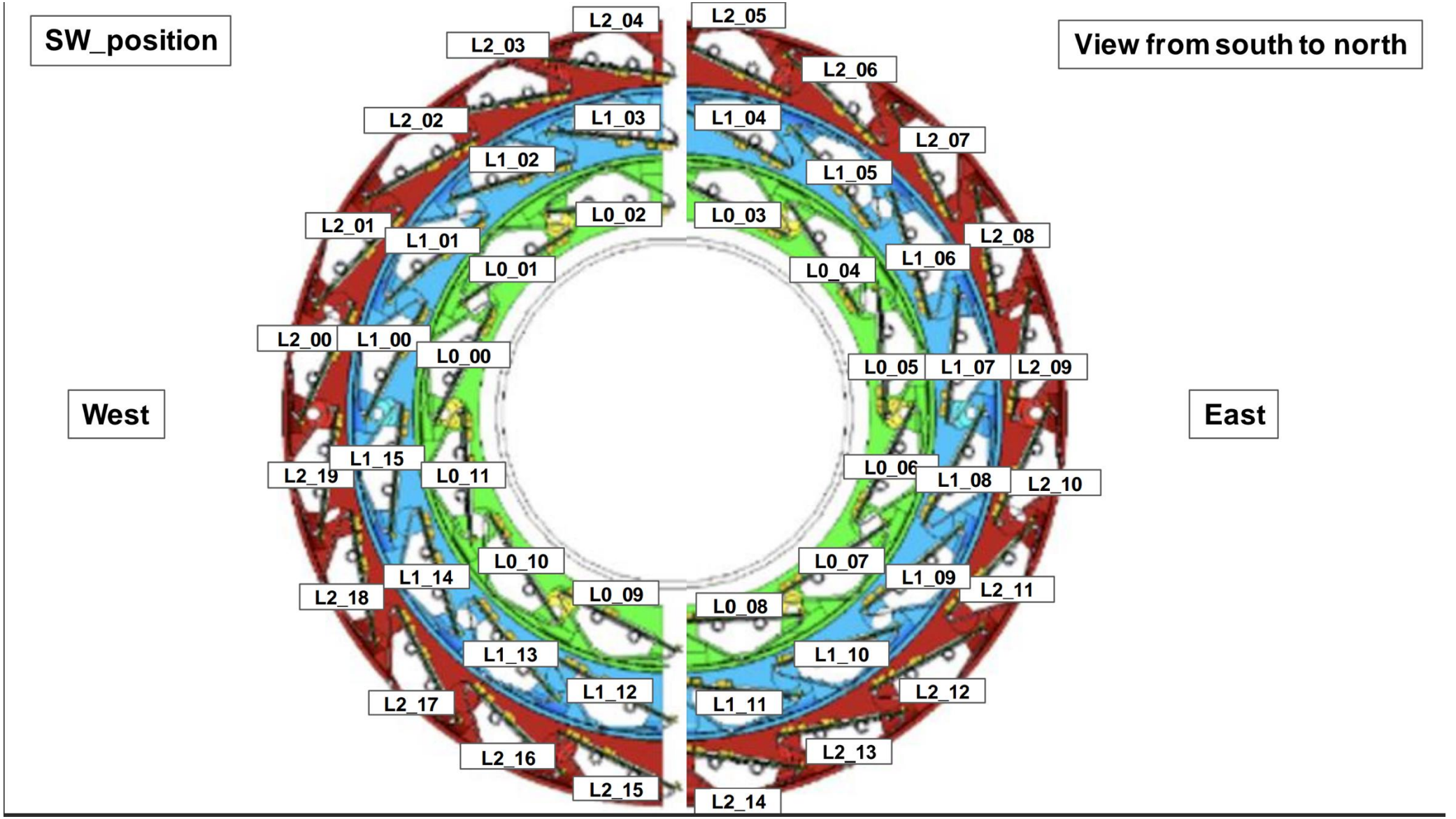
- 230% BUP jets/photons
- 65% BUP open heavy flavor
- 30% BUP Upsilon/full program

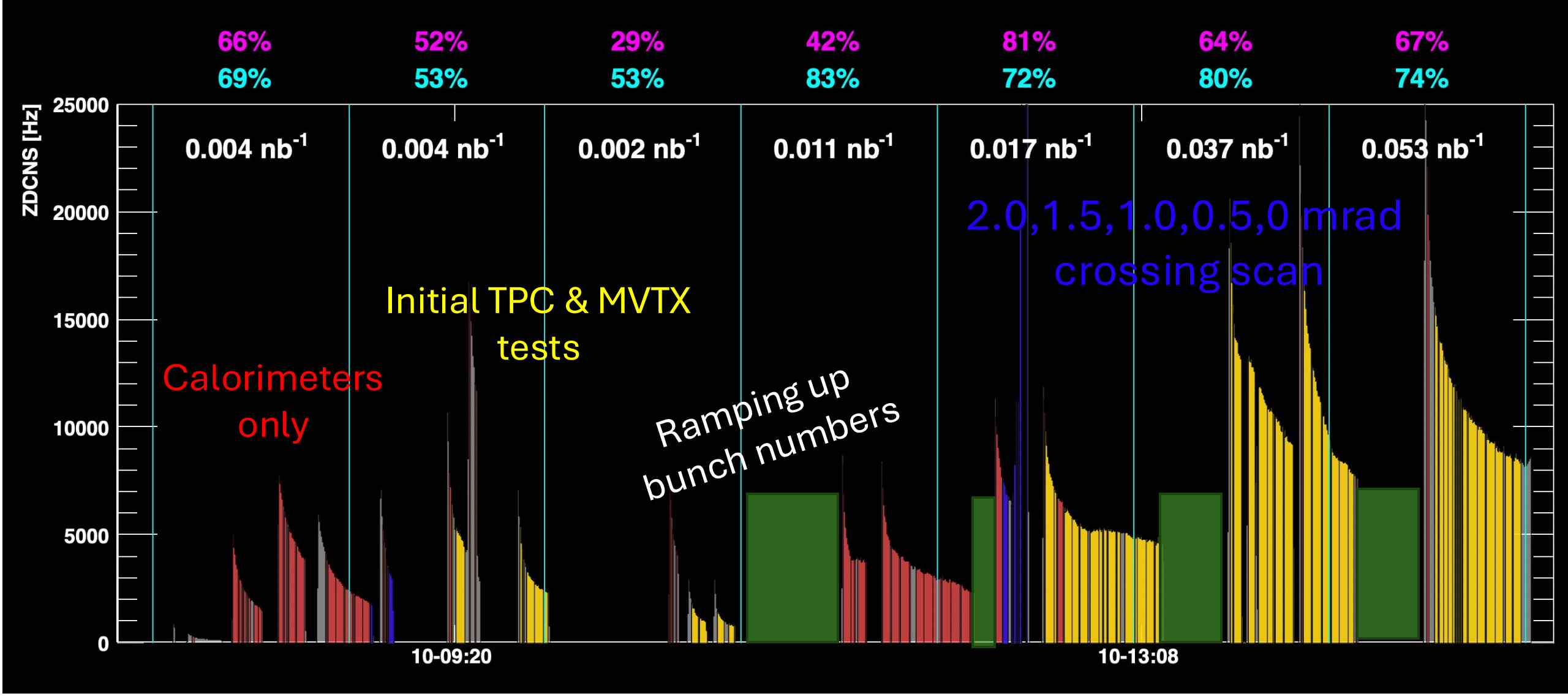
sPHENIX and C-AD have the data needed to solve remaining issues for a very successful Run 2025 Au+Au.


sPHENIX had people from 43 institutions
in person at Brookhaven
on shift, as experts, as coordinators.
We left nothing in the tank.
Check out our sPHENIX young heroes!
https://www.sphenix.bnl.gov/node/1751378401

EXTRAS

sPHENIX MVTX – “We have a problem Houston…”

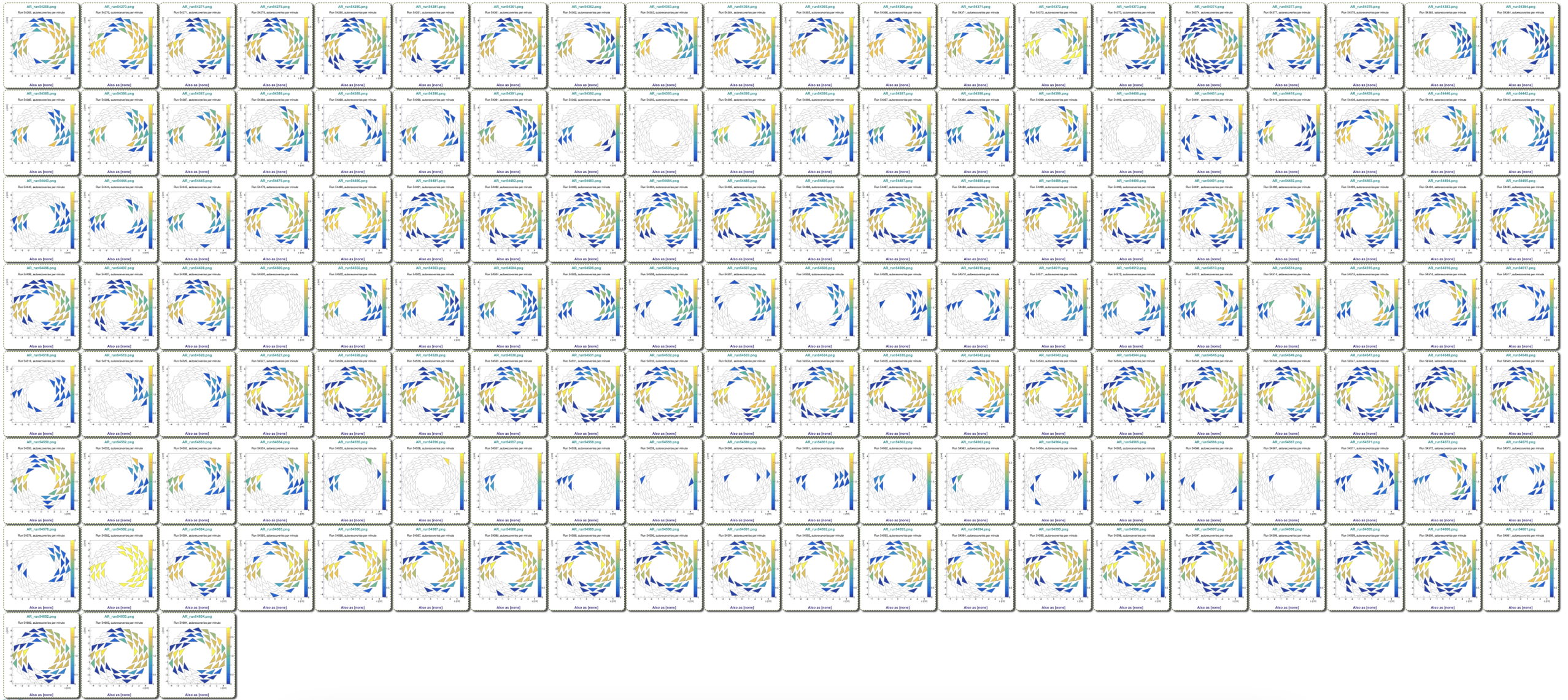



66%
69%
52%
53%
29%
53%
42%
83%
81%
72%
64%
80%
67%
74%
ZDCNS [Hz]
25000
20000
15000
10000
5000
0
0.004 nb-1
0.004 nb-1
0.002 nb-1
0.011 nb-1
0.017 nb-1
0.037 nb-1
0.053 nb-1
Calorimeters only
Initial TPC & MVTX tests
Ramping up bunch numbers
2.0,1.5,1.0,0.5,0 mrad crossing scan
10-09:20
10-13:08
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Monday
Dedicated MVTX background studies

Many detailed studies over the 10 days

with quantification of the backgrounds

many with 1x1 and12x12 bunch to not saturate auto-recoveries...



MVTX – design in sPHENIX to run in streaming mode with 5-10 microsecond strobe. In that case, 100% of "big splash" events will cause an auto-recovery.

If we can run in triggered mode (which is supported), the auto-recoveries will only be if there is a "big splash" event coincident with a triggered event within ~5 microseconds.

Thus, if we run the DAQ rate at 2 kHz, one only sees 2e3 x 5e-6 = 1% of "big splash events", and so auto-recovery rate is expected to be **100x** lower.

The sPHENIX Au+Au plan is for a DAQ rate of 15 kHz, which still should reduce the auto-recovery rate by **13x**.

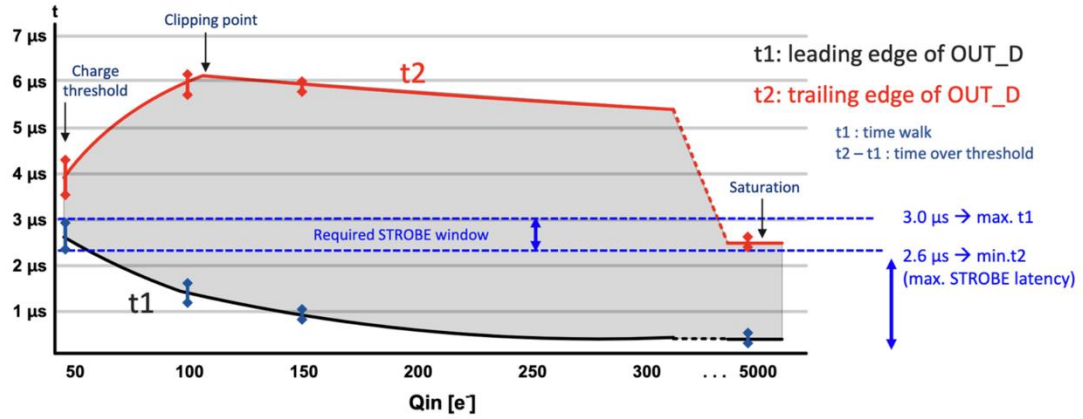
This effort is completely multiplicative in benefit to any reduction in the "big splash" event rate by C-AD.

What is the challenge of running the MVTX in triggered mode?

sPHENIX was designed with 4 microsecond trigger latency spec.
The graph below shows that this is late for the ALPIDE chip and will miss hits,
And this will be charge-deposit dependent.

Timing of Discriminator Output

ALICE



t1: leading edge of OUT_D

t2: trailing edge of OUT_D

t1 : time walk

t2 – t1 : time over threshold

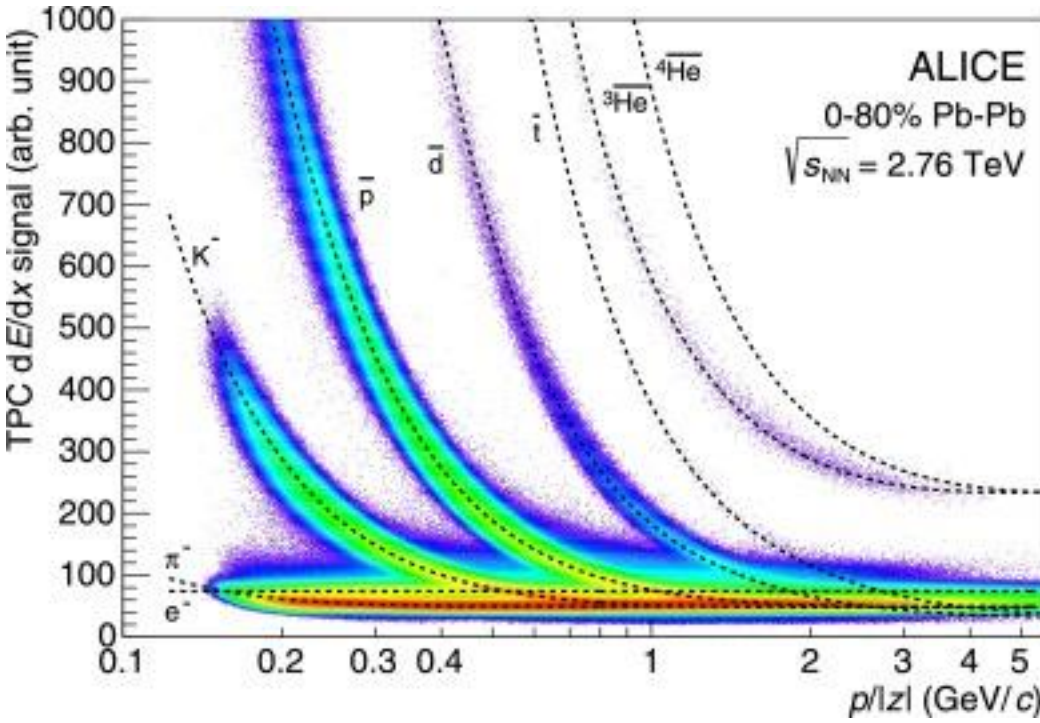
3.0 µs → max. t1

2.6 µs → min.t2 (max. STROBE latency)

Q_{in}	t1 [us]	t2 [us]
50 e⁻	2.9 ±0.20	3.9 ±0.52
100 e⁻	1.5 ±0.16	5.9 ±0.24
150 e⁻	0.9 ±0.03	5.7 ±0.09
5 ke⁻	0.5 ±0.01	2.6 ±0.07

Simulation results

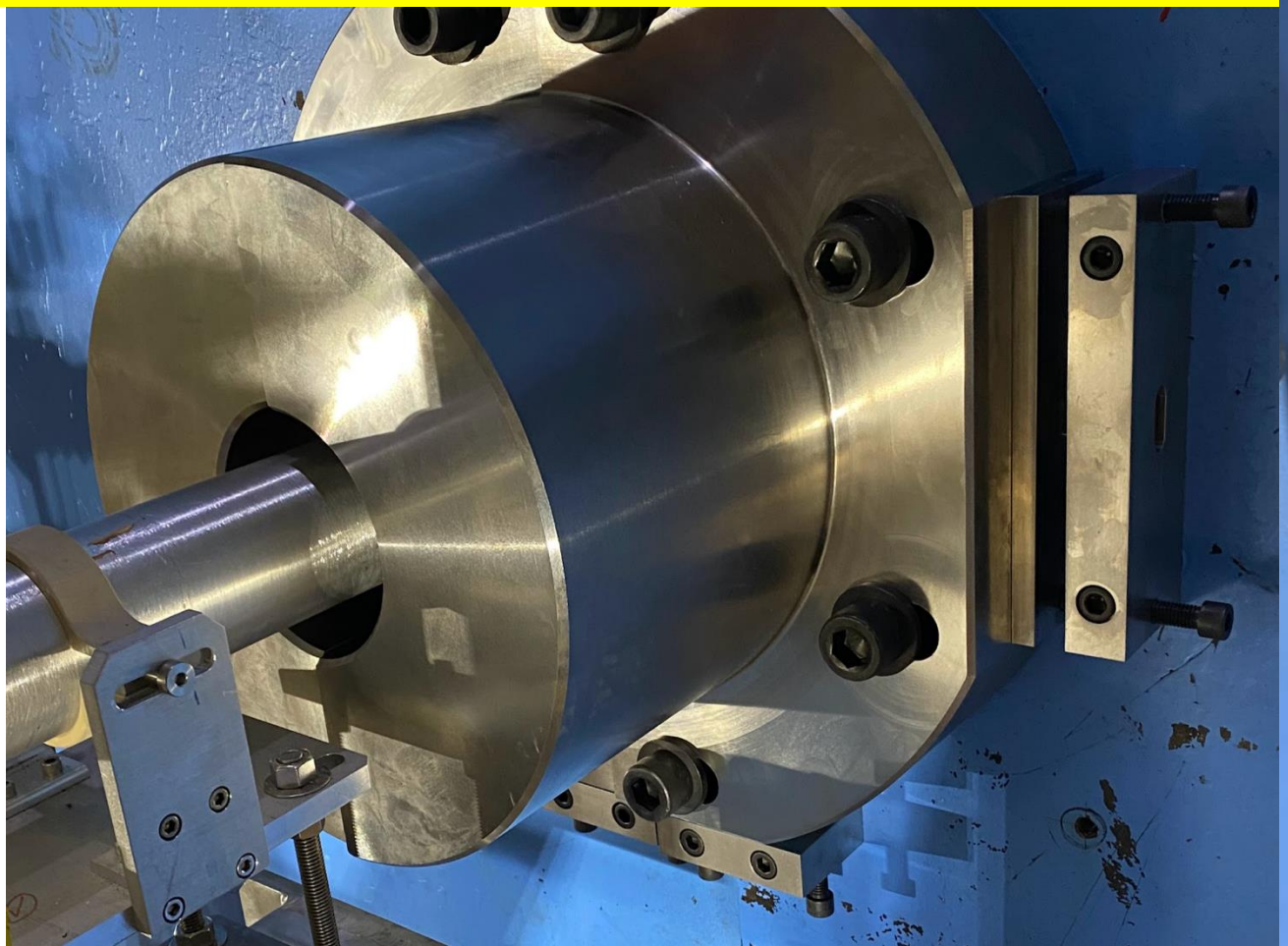
SOURCE: ALPIDE CHIP Production Readiness Review

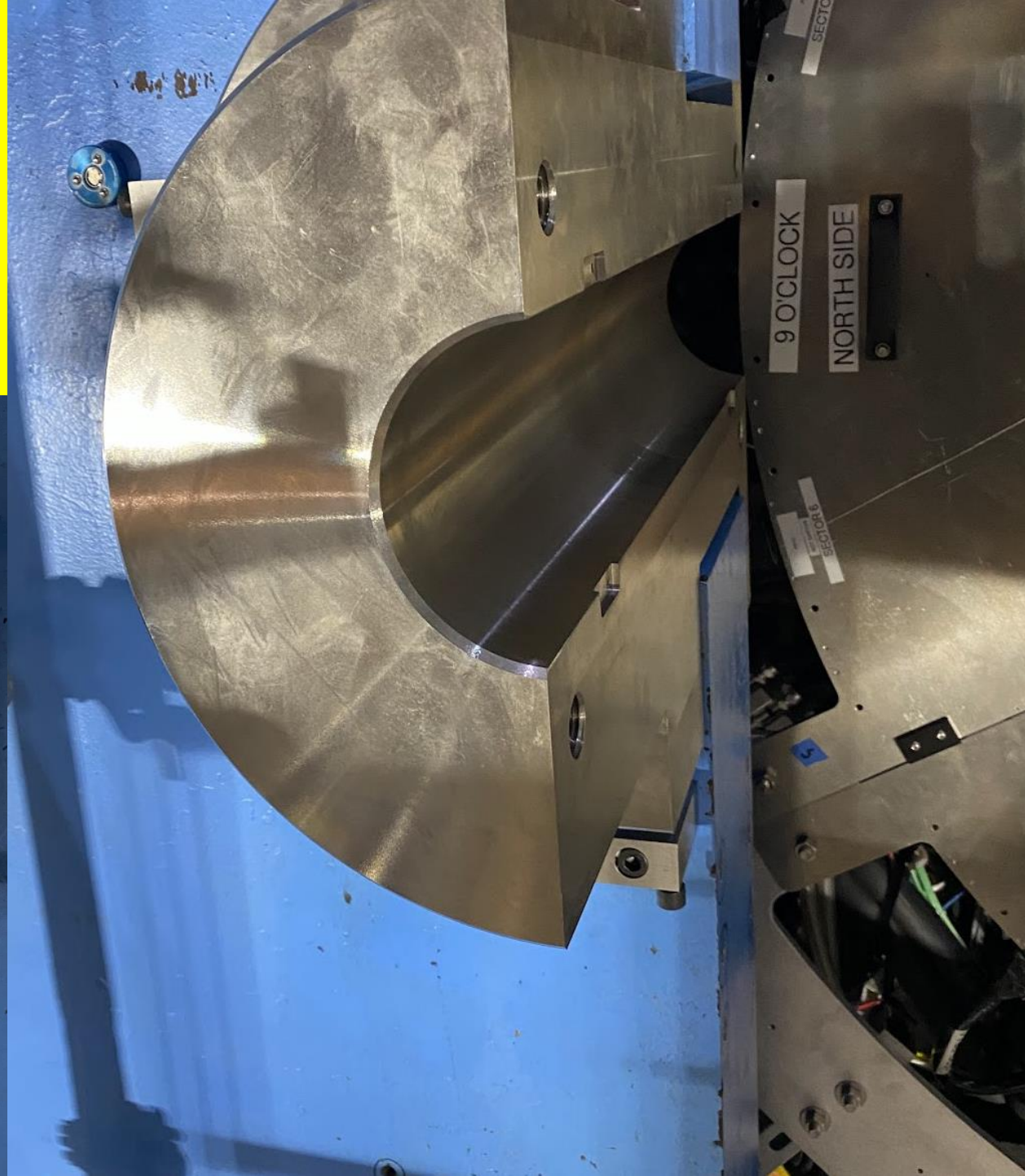


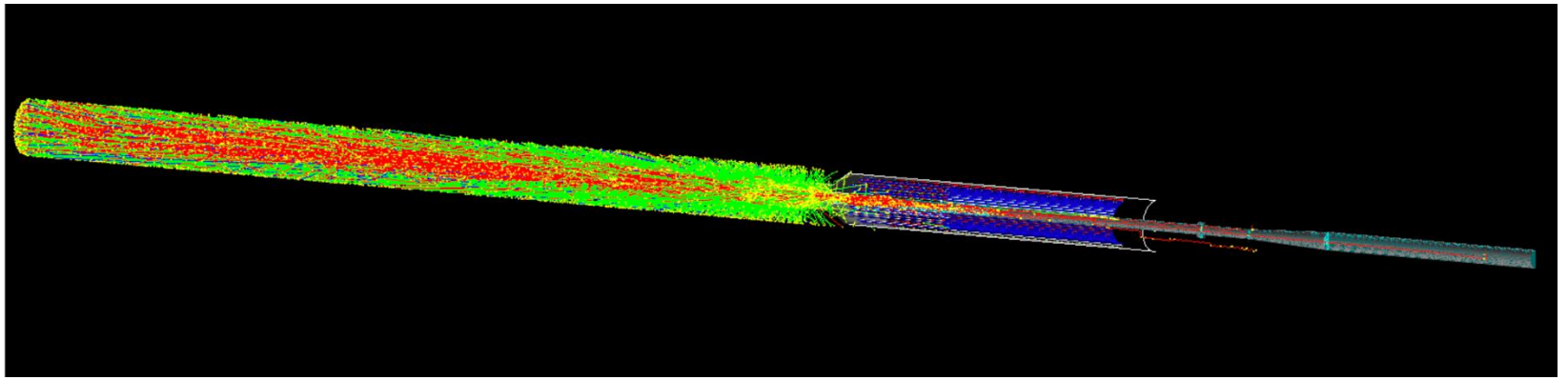
Charge deposit depends on particle momentum and species. Note that heavy flavor decays include kaons and protons.

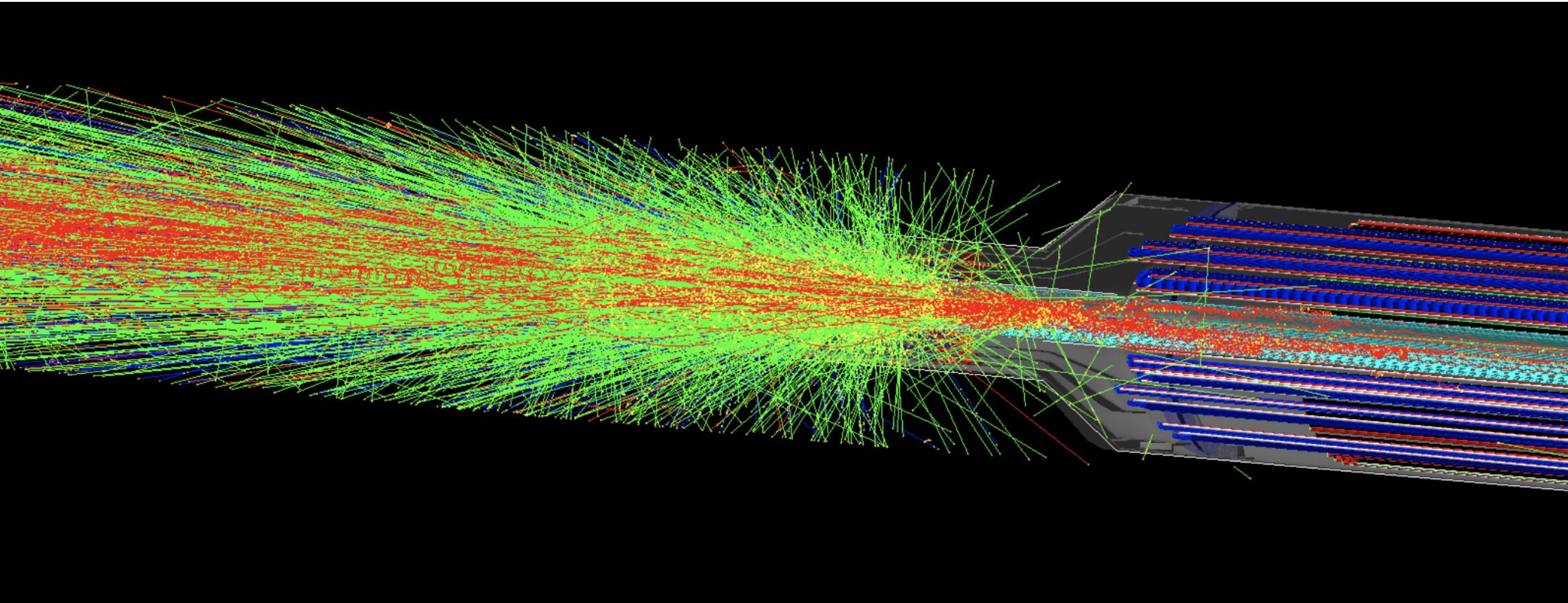
North absorber installed on
Thursday, October 10, 2024
Shielding for Yellow Beam backgrounds

No impact on MVTX auto-recoveries…
Maybe not so surprising…

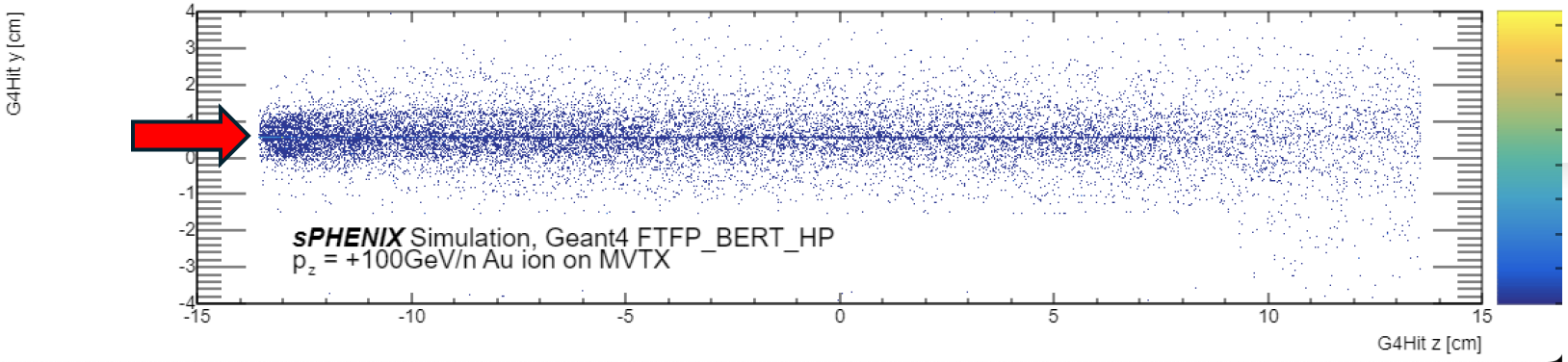




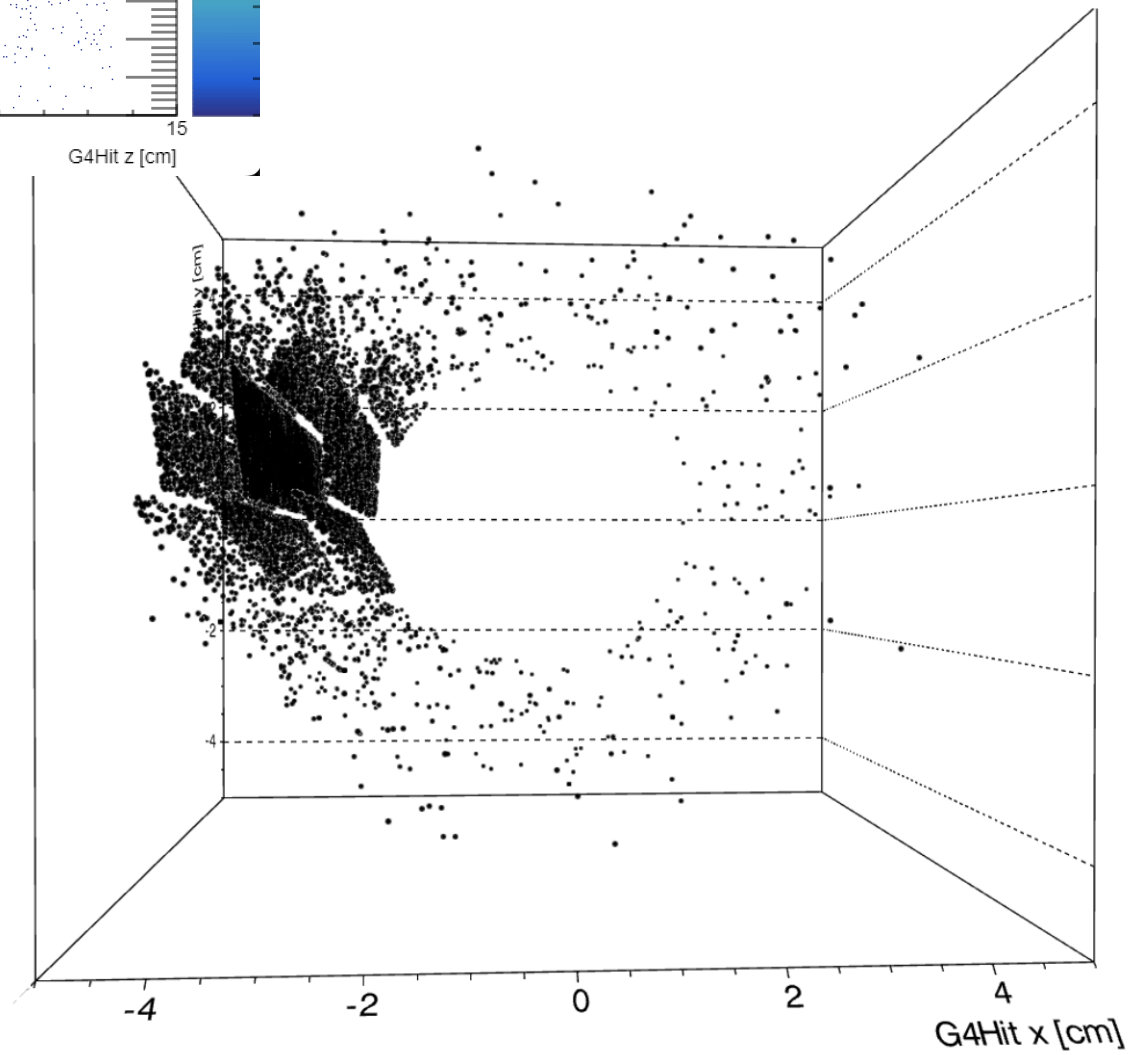




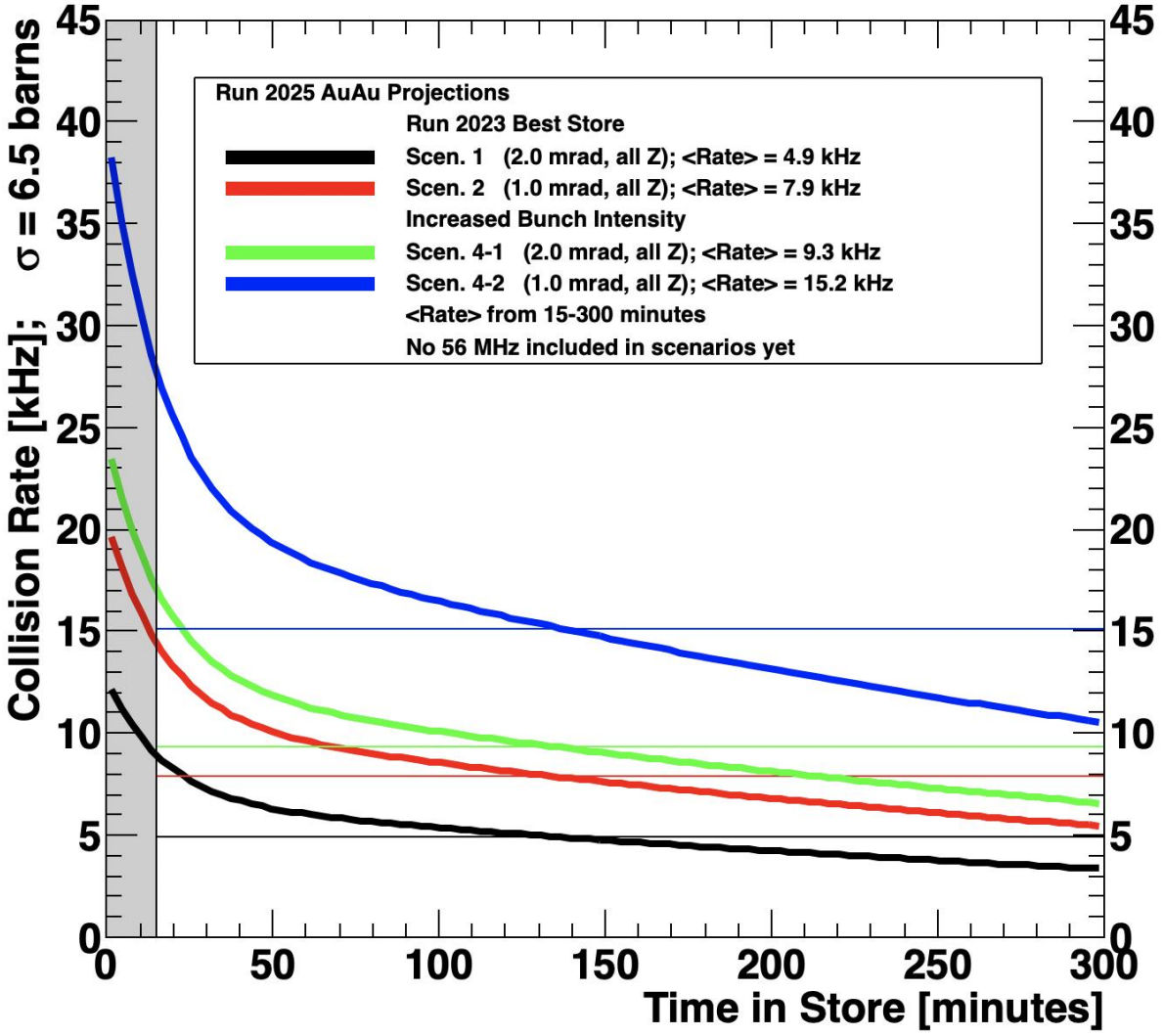
GEANT Simulation [Jin Huang]

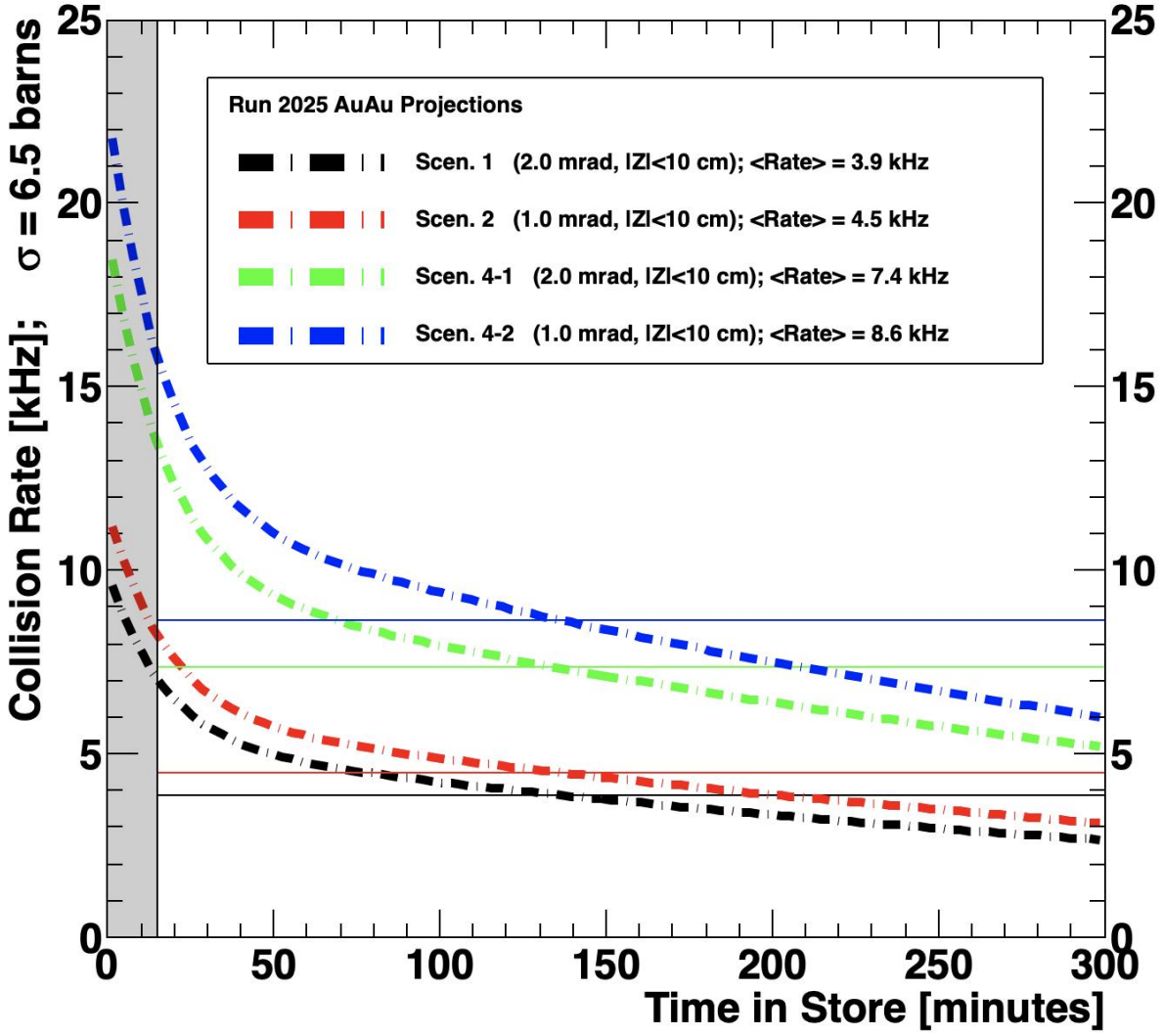


Single 100 GeV Au ion striking the edge of the 50-micron thick silicon material.



Initial C-AD on projections for Run 2025

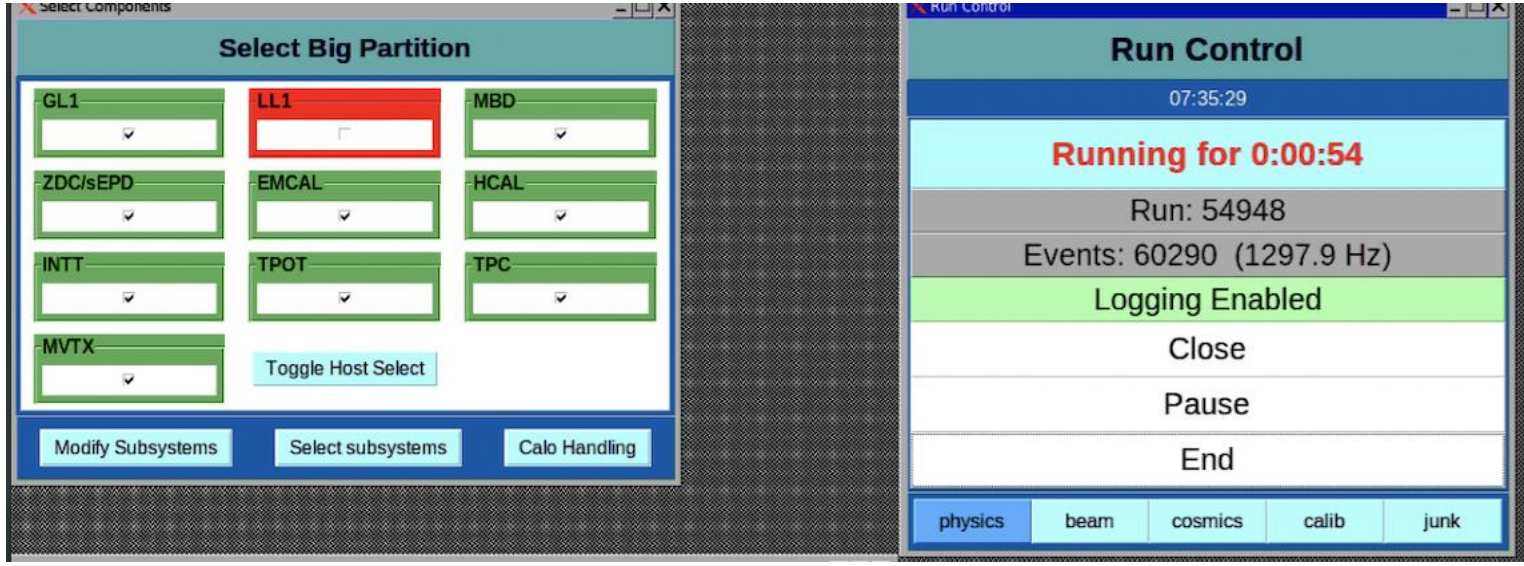




DAQ Rate Tests:

ADC systems at 12 kHz
Some mods for sEPD on ZS, then ~15 kHz (!)

Working on ways to separately throttle different systems,
e.g., TPC may not get to 15 kHz
e.g., MVTX with triggered mode may not get to 15 kHz

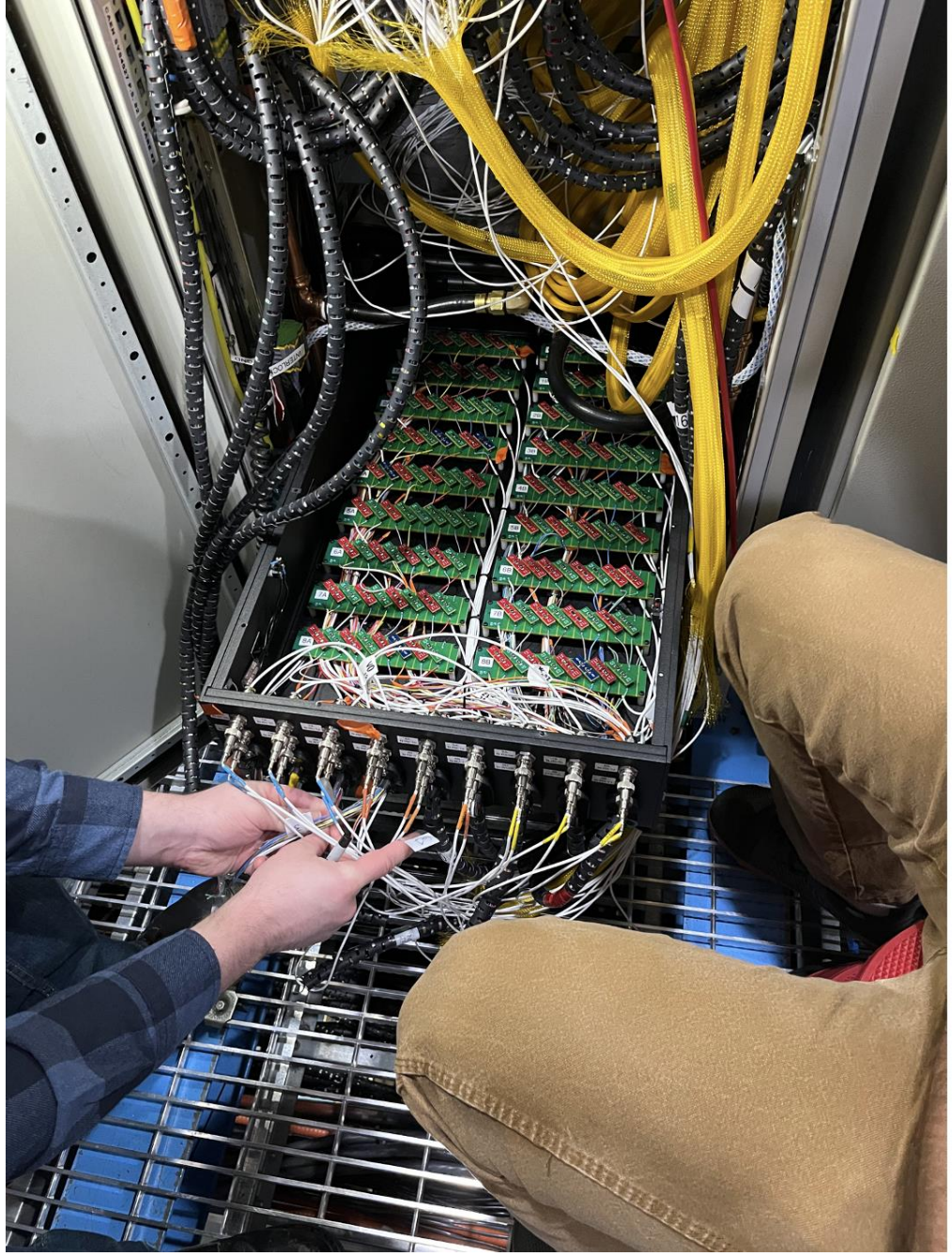


Overall, very stable performance of TPC in AuAu.

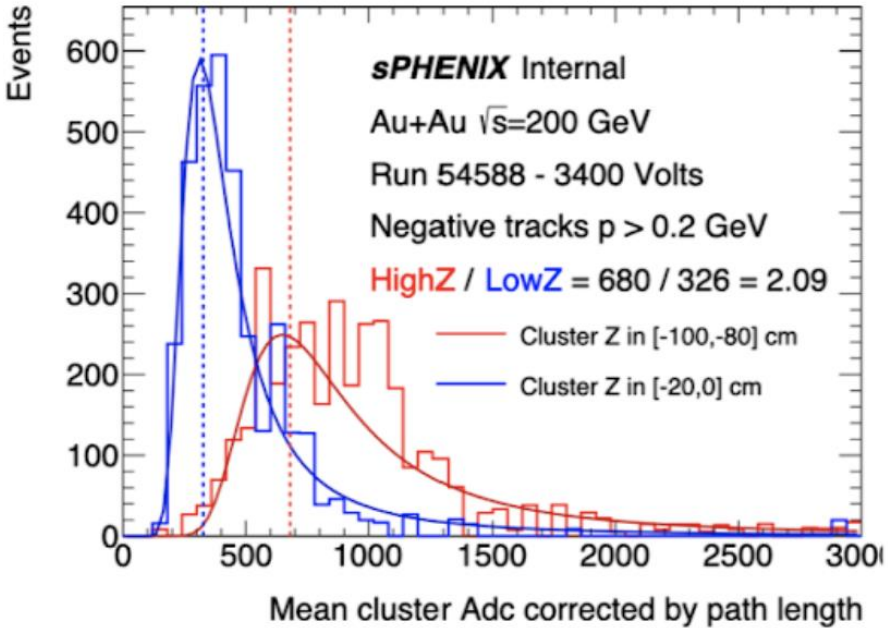
Zero suppression enabled 5.5 kHz running; which with 2x buffer boxes next year and HPSS upgrades get us into the range of 11 kHz (with more knobs to turn).

CAEN HV supplies connected to 2 sectors.
Very important experience gained for full deployment next year.

Still developing offline tools make us very susceptible to issues that are only discovered after weeks.
Online2Offline effort is crucial.



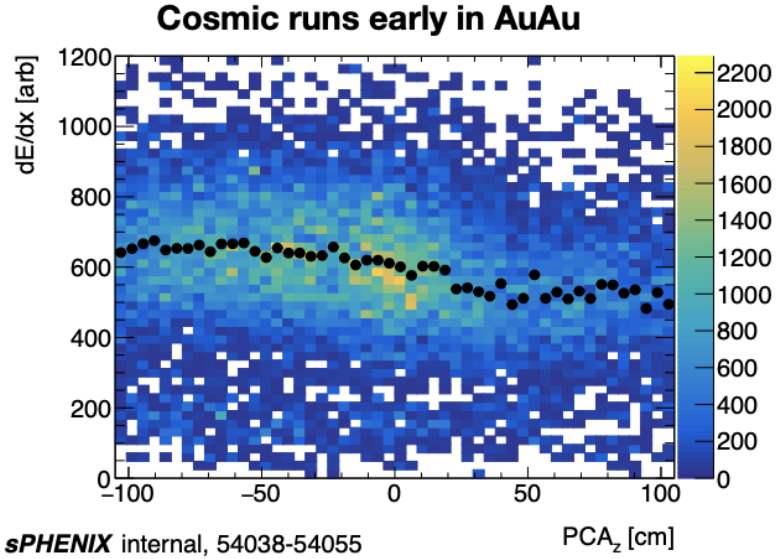

TRIPP LITE
CAEN Mod. A4533
PRIMARY
Power Supply
CAEN SY4527

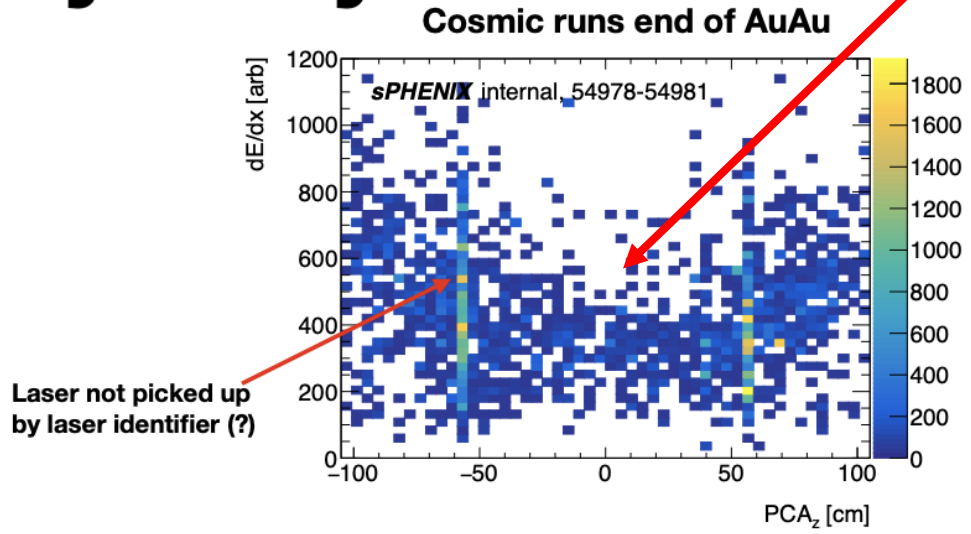


Very low charge collection from tracks near the central membrane.

Many tests to understand the origin. Key tests w/ cosmics after beam dropped.

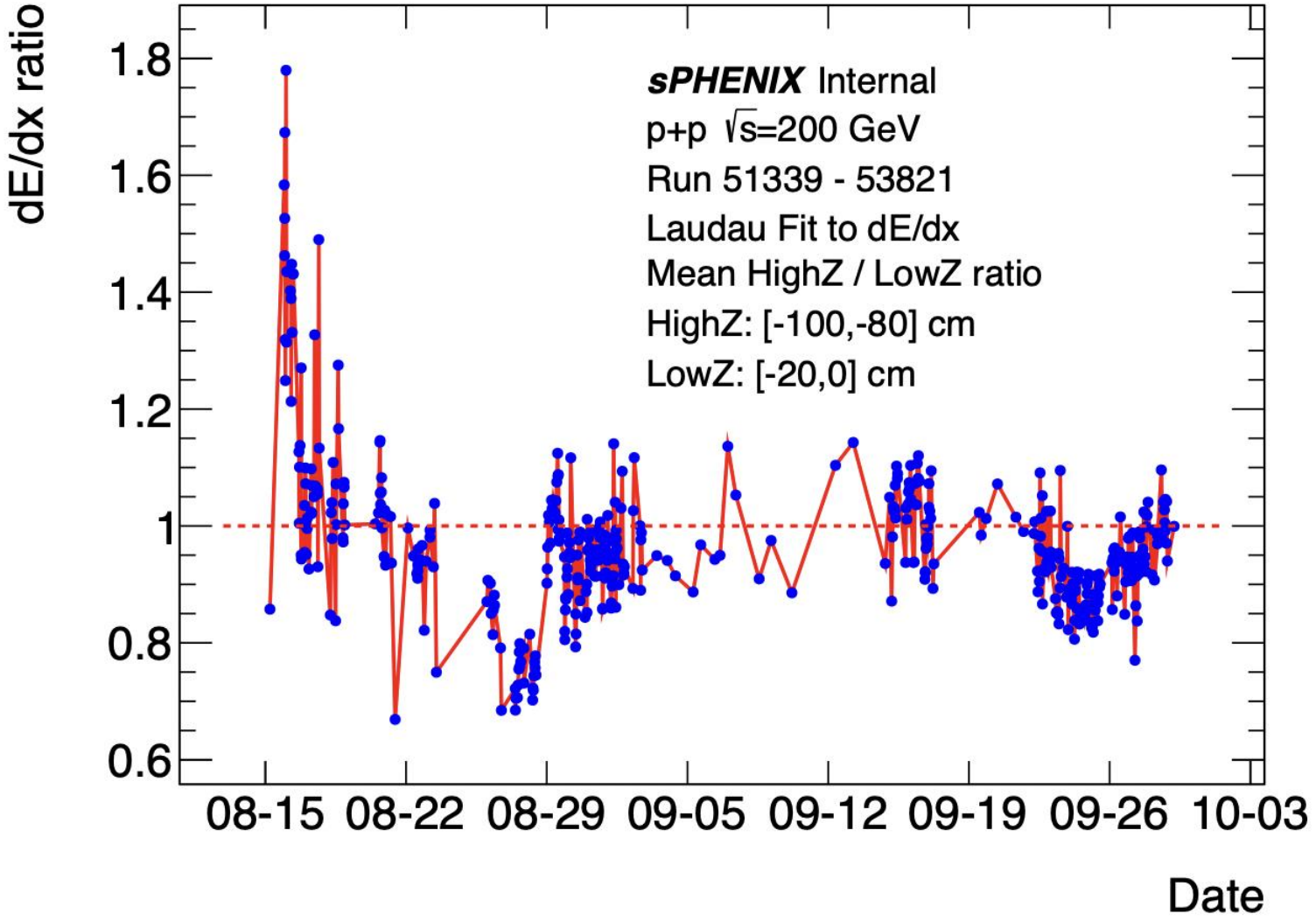
TPC Mystery



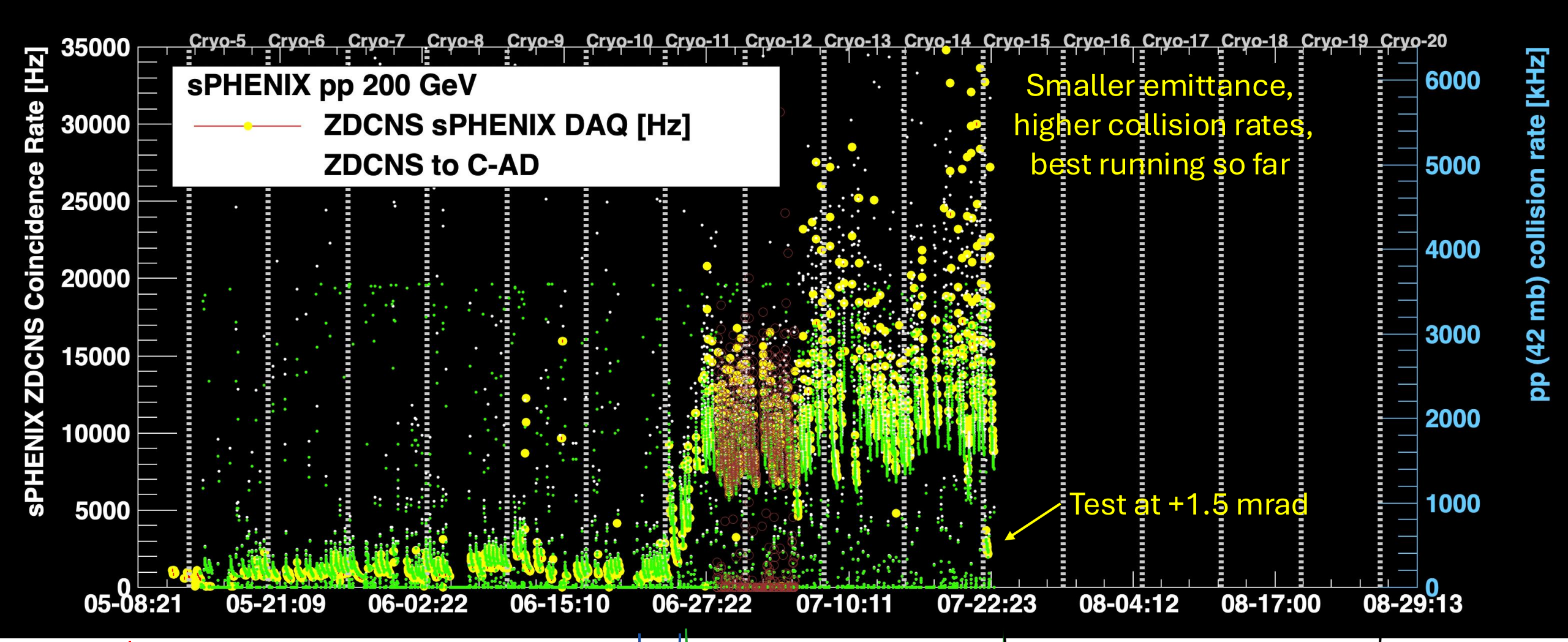


Likely significantly compromised tracking performance in all AuAu data.

Problem appears not to be present for almost entire pp run.



Investigation of the cause is ongoing. Critical to fully explore and test each hypothesis.



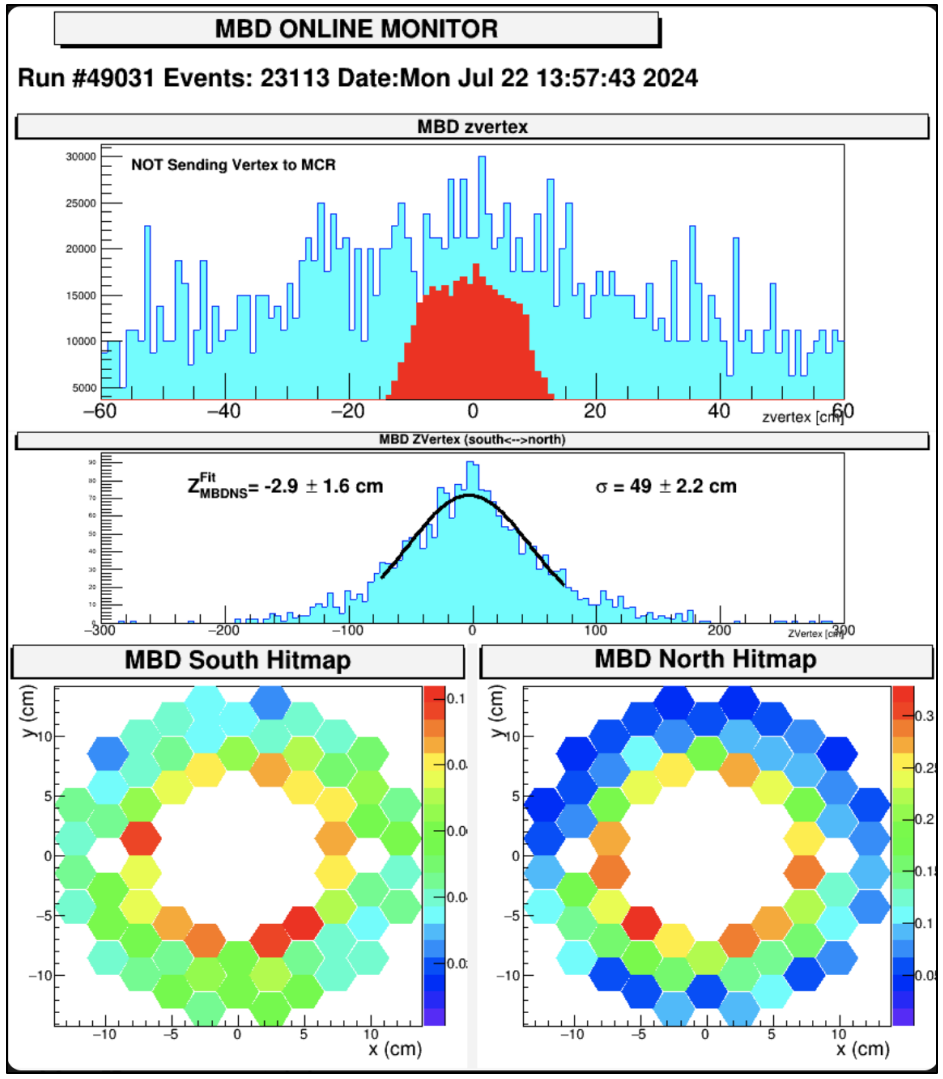
-2 mrad crossing

+2 mrad crossing

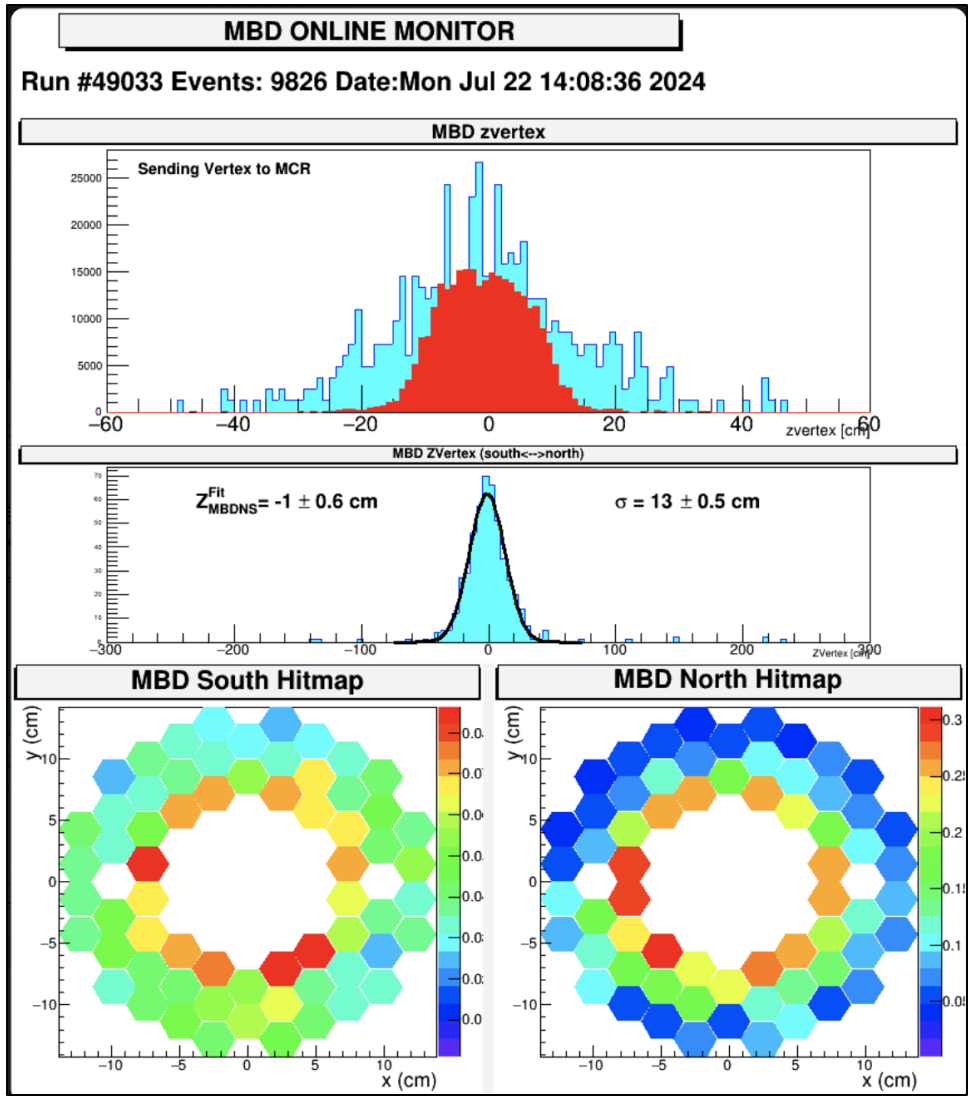
0 mrad crossing

5 weeks left until
19 complete cryo-weeks

0 mrad



+1.5 mrad



ZDCNS rate down by 1/5 and then need to account for double interactions and acceptance change.

Details from the Run really matter…

Radiation damage on the EMCal was correlated with the blue injections: with the negative crossing angle configuration