2025 RHIC/AGS ANNUAL USERS' MEETING

RHIC 25:
A quarter century of discovery

May 20–23, 2025

STAR Run 25 Report

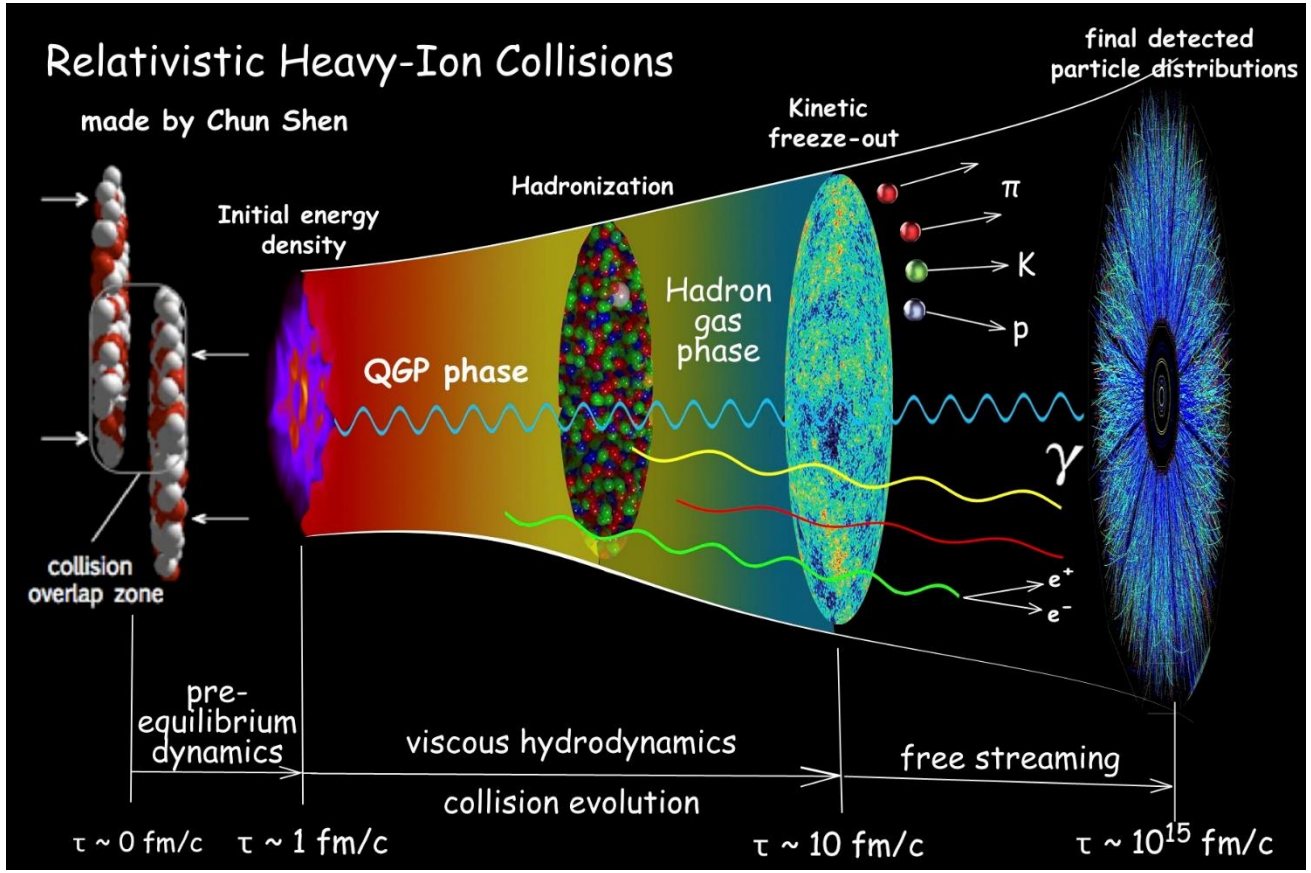
Yu Hu for the STAR Collaboration

May 22, 2025

Lawrence Berkeley National Laboratory

Supported in part by U.S. DEPARTMENT OF ENERGY

The “Little Bang” @ RHIC



Essential questions to be addressed:

1. How do the fundamental interactions between quarks and gluons lead to the perfect fluid behavior of the quark-gluon plasma?
2. What are the limits on the fluid behavior of matter?
3. What are the properties of QCD matter?
4. What is the correct phase diagram of nuclear matter?

Physics Opportunities for 2023+2024+2025

To address important questions about the inner workings of the QGP:

- **What is the nature of the 3-dimensional initial state at RHIC energies?** r_n over a wide rapidit, J/Ψ v_1, photon Wigner distributions
- **What is the precise temperature dependence of shear and bulk viscosity?** v_n as a function of η
- **What can be learned about confinement from charmonium measurements?** J/Ψ v_2
- **What is the temperature of the medium?** Different ϒ states, Ψ(2S), thermal dileptons
- **What are the electrical, magnetic, and chiral properties of the medium?** Λ, Ξ, Ω P_H and K*, ϕ, J/Ψ ρ_{00}, thermal dileptons, CME observables
- **What are the underlying mechanisms of jet quenching at RHIC energies? What do jet probes tell us about the microscopic structure of the QGP as a function of resolution scale?** γ_{dir}+jet I_{AA}, γ_{dir}+jet acoplanarity, jet substructure
- **What is the precise nature of the transition near μ_B=0?** Net-proton C_6/C_2
- **What can we learn about the strong interaction? Correlation functions** Correlation functions

To inform EIC physics with photon induced processes:

- **Probe gluon distribution inside the nucleus:** vector mesons (J/Ψ), dijets (?)
- **Search for collectivity and signatures of baryon junction** inclusive charge particles and cross sections, v_n, identified particle spectra

STAR Beam Use Request for Run 23~25

Assuming 28 cryo-weeks/year of running (~24 physics weeks/year)

$\sqrt{s_{NN}}$ (GeV)	Species	Number Events/Sampled Luminosity	Year
200	*p+p*	142 pb^{-1} (12w)	2024
200	*p+Au*	0.69 pb^{-1} (10.5w)	2024
200	*Au+Au*	18B / 32.7 nb^{-1} (40w)	2023+2025

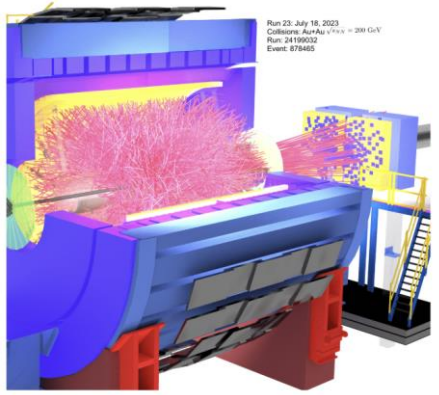
Revised goal:

$\sqrt{s_{NN}}$ (GeV)	Species	Number Events/Sampled Luminosity	Year
200	*p+p*	**170 pb^{-1} (14.5w)**	2024
200	*p+Au*	**0.22 pb^{-1} (5w)**	2025
200	*Au+Au*	8+**9 B** / 1.2 +**28.6 nb^{-1} (+28w)**	23+24+25

"The PAC recommends that the top priority for Run 24 is to complete the commissioning of sPHENIX and to collect the high statistics pp dataset necessary as a reference for all the sPHENIX hard probes Au+Au measurements in Run 25, and simultaneously allow STAR to make landmark polarized proton measurements using its new forward instrumentation."

PAC report

FoM* = 55 pb^{-1} assuming 14.5 weeks



Full detector capability with forward upgrades and excellent PID over an extended η coverage

**FoM: figure of merit*

STAR Beam Use Request for Run 23~25

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PAC report

Let's first recap the Run 24

Run24 - timeline

- 8/1/23 : End of Run23 beam operation (Valve box in 1004B failure)
- 4/2/24 : Shift (2 person) start, flammable gas flow (shift total ~~27~~ 29 weeks) 2 weeks before cooldown
- 4/6: Cosmic data taking with magnet on
- **4/15 : RHIC 4k Cooldown start (~~25~~ 27 cryo weeks)**
- 4/16 : Full Shift (4 person) start + period coordinator
- 4/27 : First collisions for trigger/timing setup
- 4/30 : Start physics with p+p (low-luminosity)
- 5/17 : Start STAR high-luminosity/spin physics
- 5/20 : Rotator on for radial polarization
- ~~8/26 : 19 weeks cooldown mark. switching to Au+Au for 6 weeks~~
- 9/30 : 24 weeks cooldown mark. switching to Au+Au for 3 weeks
- ~~10/7 : End of run~~
- **10/21/24: End of run**

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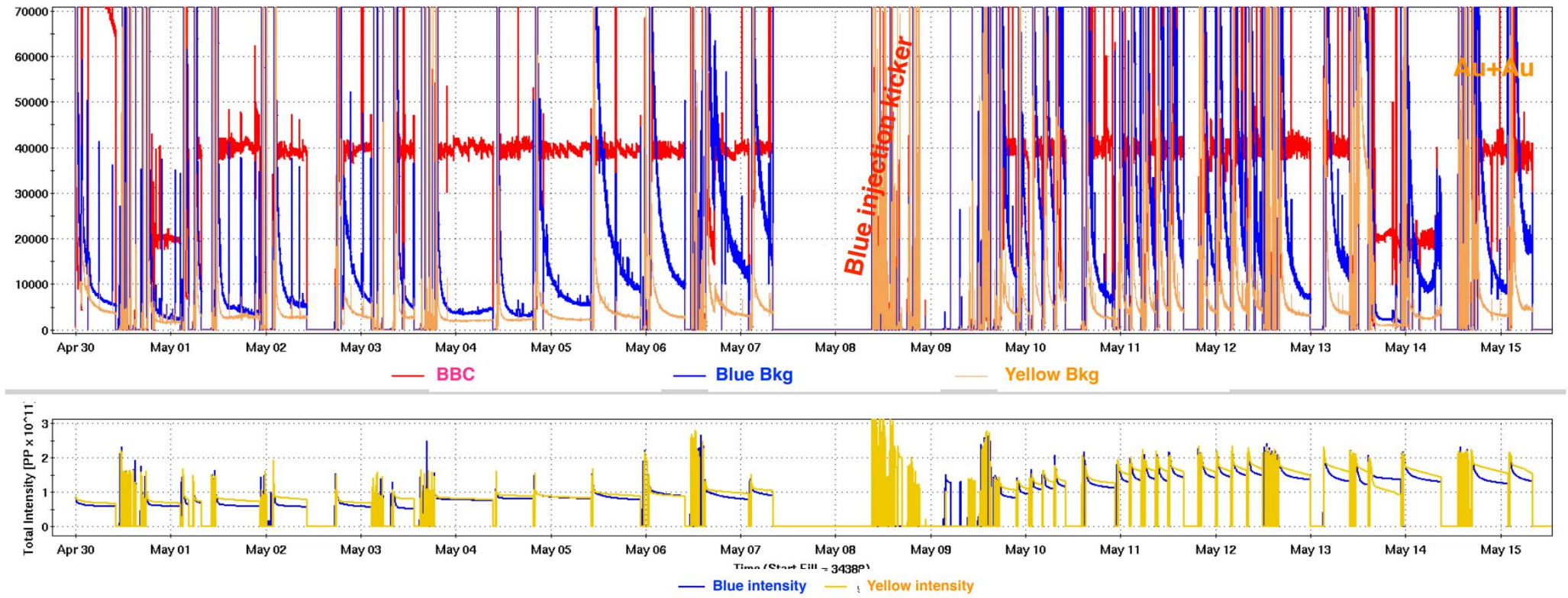
- 4/27 : First collisions for trigger/timing setup
- 4/30 : Start physics with p+p (low-luminosity) — ***Part-1***
- 5/17 : Start STAR high-luminosity/spin physics — ***Part-2***
- 5/20 : Rotator on for radial polarization
- ~~8/26 : 19 weeks cooldown mark. switching to Au+Au for 6 weeks~~
- 9/30 : 24 weeks cooldown mark. switching to Au+Au for 3 weeks — ***Part-3***
- ~~10/7 : End of run~~
- **10/21/24: End of run**

Part-I: p+p low luminosity

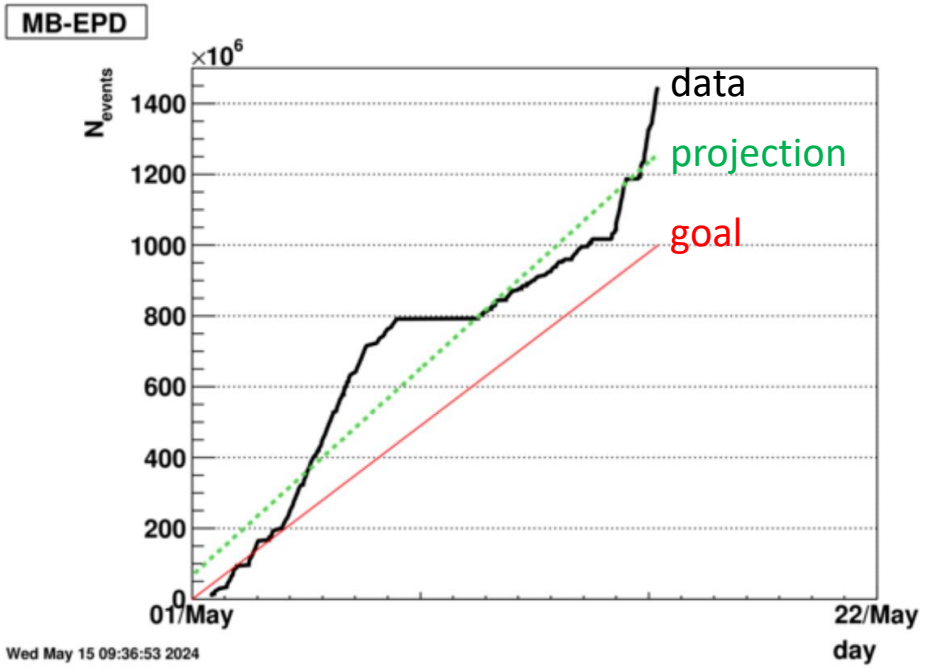
Opportunistic running (2 weeks) during sPHENIX's commissioning



To study collectivity & fluctuation in pp with high-multiplicity and minimal event pile-up

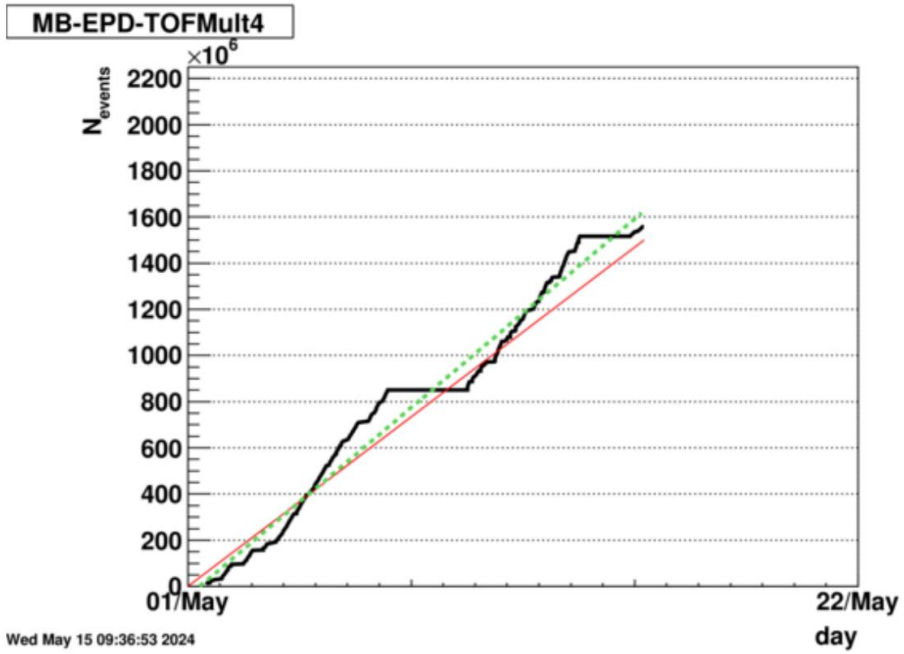
Min-bias with pp low-luminosity

MB trigger:
EPDE+EPDW+(TOFmult>0)



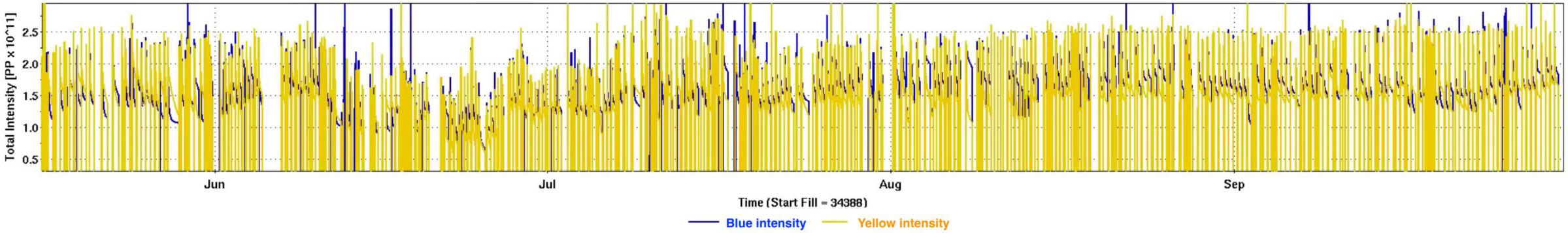
High-multiplicity MB trigger:
EPDE+EPDW+(TOFmult>N)

e.g N=12



Successful ~1.5B each Min-bias and Min-bias high-multiplicity events!

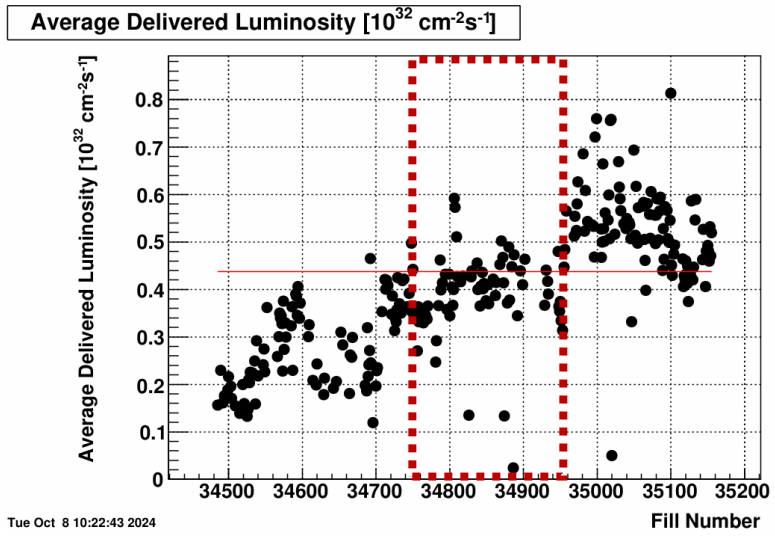
Part-II: p+p high luminosity

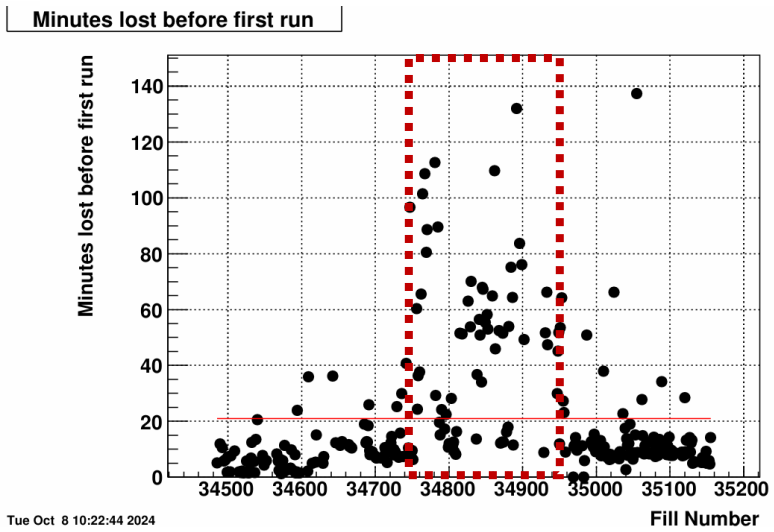


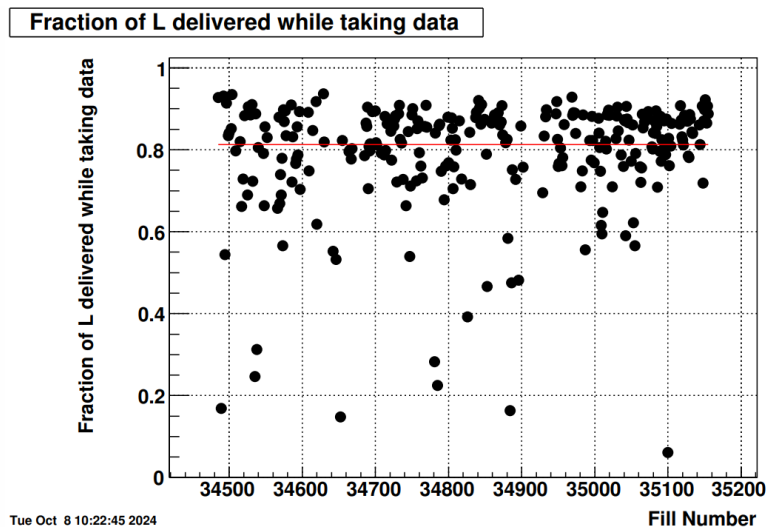
- 19.5 weeks: Machine uptime 57%, STAR uptime 79% during the period
- Some beam-beam effects (background) were found compare with Run 15, due to different machine setups (e-Lens, 56 MHz not fully damped...)
- Machine development on July 16, fixing chromaticity, greatly improved instability and emittance

Will keep watching the background during Run25

pp luminosity and efficiency



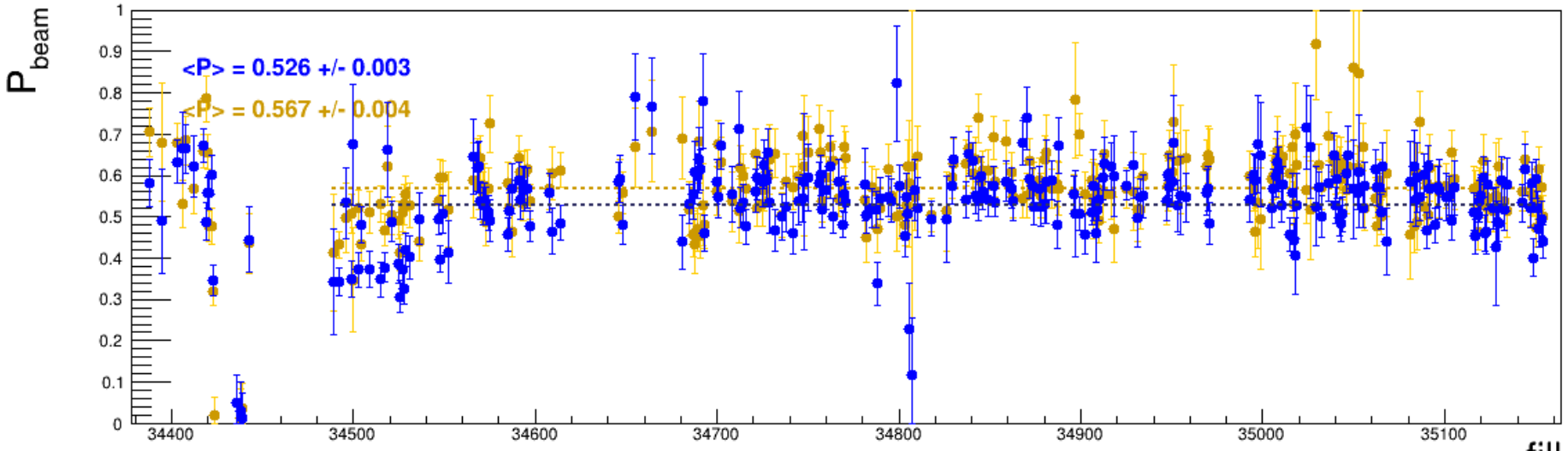




- Raising trend is observed for the averaged delivered Luminosity
- STAR is running efficiently

**Red-rectangle: Collision at STAR when beam-beam parameter is < 10^{-3} with a minimum wait time of 40 mins if the beam-beam parameter is above that threshold at the beginning of store*

Polarization

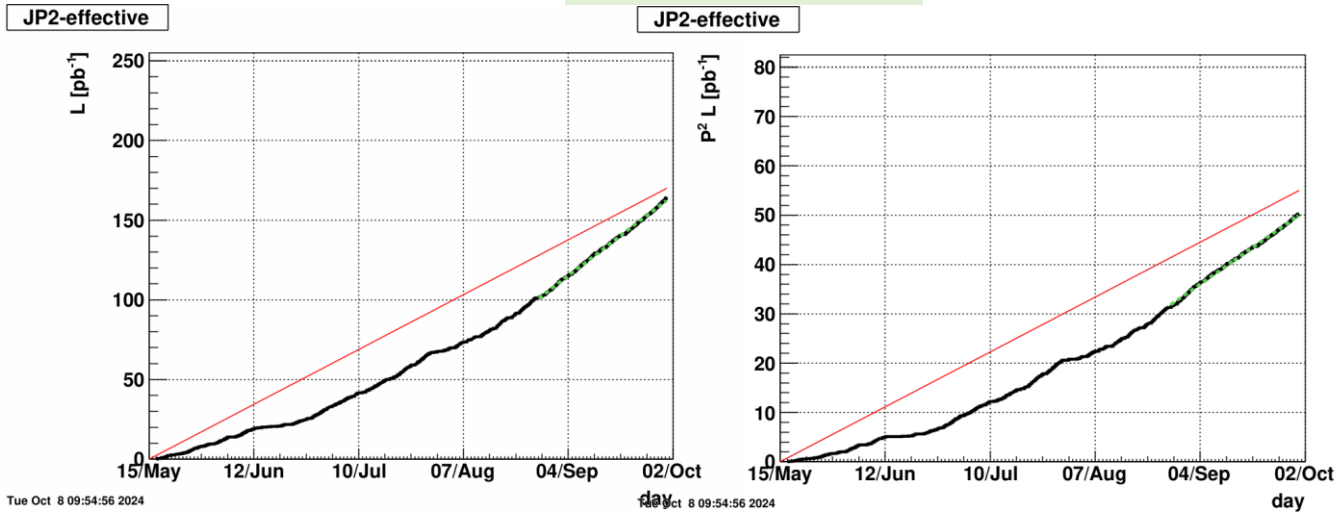


https://wiki.bnl.gov/rhicspin/Polarimetry/H-jet/Run24pp

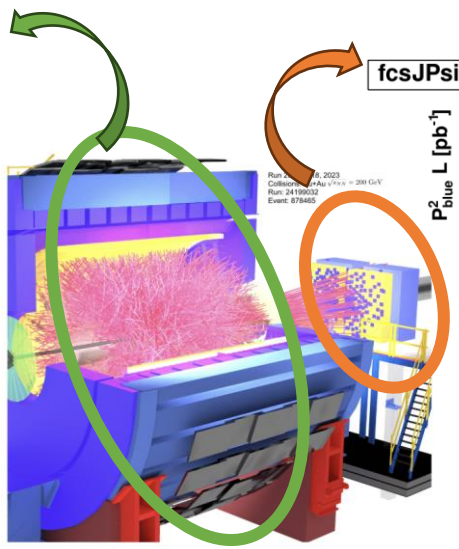
- Goal assume 57% for Yellow and Blue polarization
- Polarization **~53% Blue**, **~57% Yellow** (H-Jet measurement)

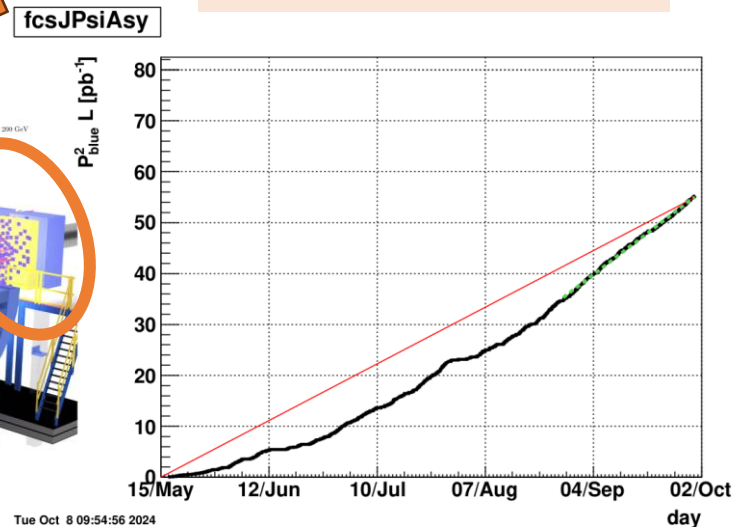
pp sampled luminosity and FoM

Mid rapidity



Forward rapidity

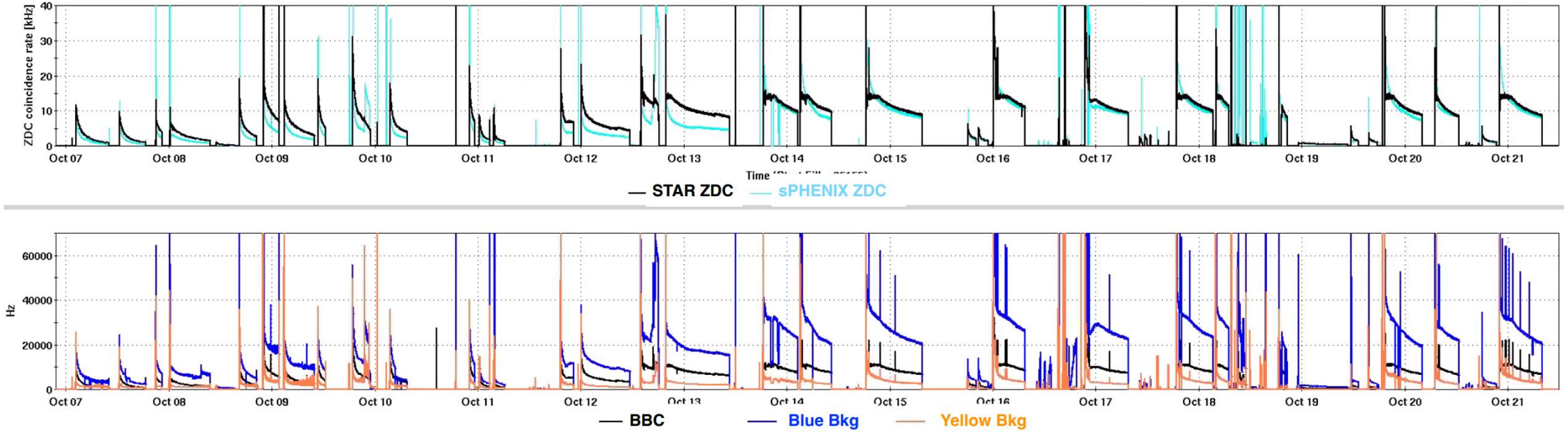




Trigure	Sampled Luminosity (pb^{-1})	Fraction of goal
JP2	164.2	97%
JP2 FoM	50.3	91%
fcsJPsi FoM	58.5	106%

Achieved our goals for pp!

Part-III: 3 weeks of Au+Au 200 GeV



(9/30 - 10/21)

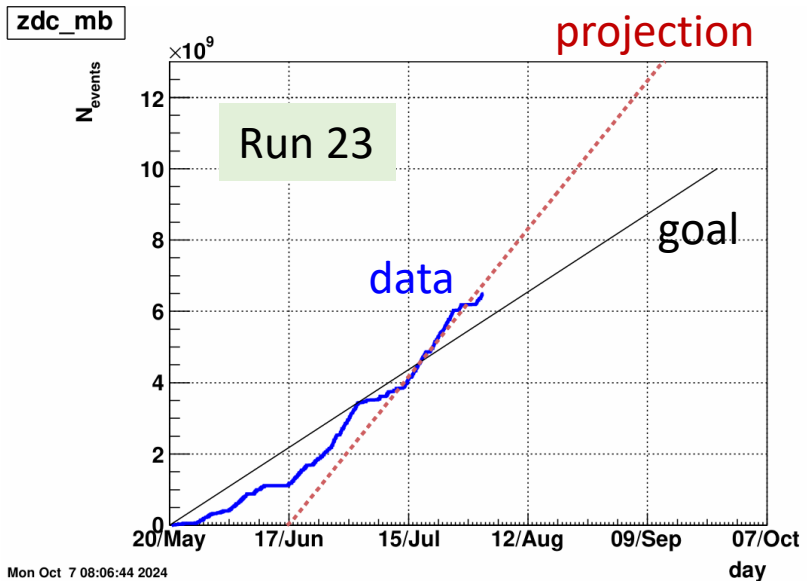
Machine:

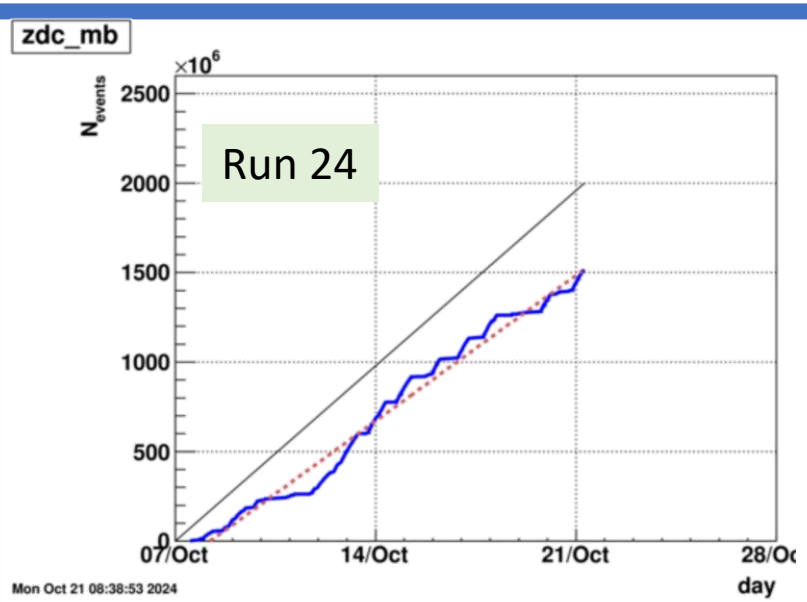
- To understand & reduce background in sPHENIX mVTX
- 56 MHz cavity commissioning

STAR:

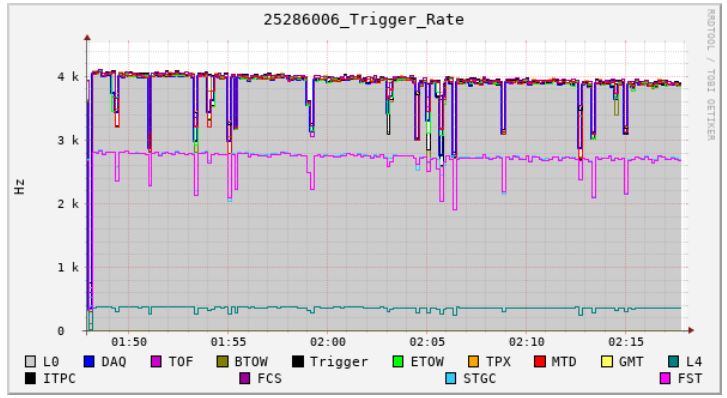
- Taking physics for Au+Au 200 GeV program

Min-bias in Au+Au 200 GeV





An example of STAR DAQ rate:



Min-bias:

- 6.5B (Run23) + 1.52B (Run24) = Total 8B / Goal 18B

Min-bias maximum DAQ > 4k Hz:

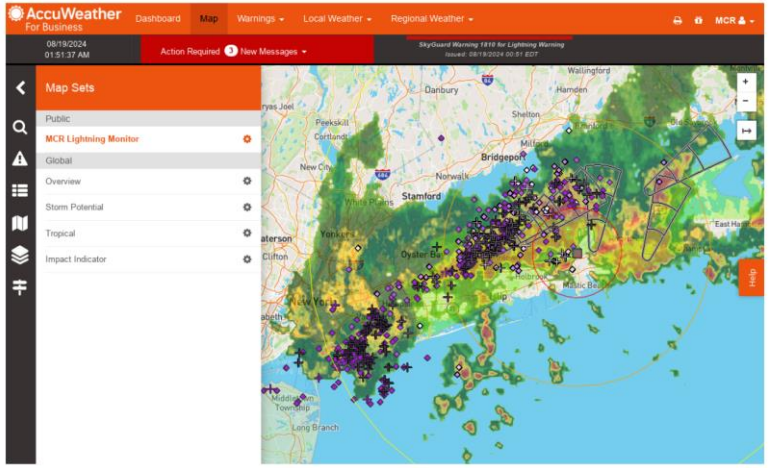
- An impressive upgrade on the STAR TPC DAQ rate – since June 2023

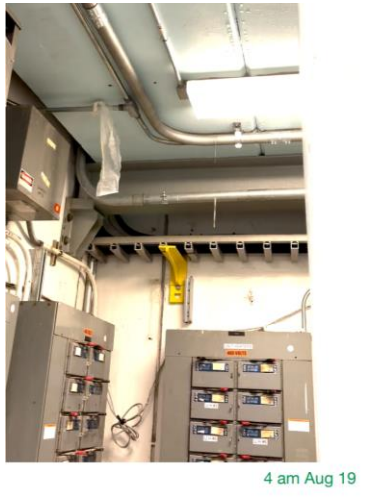
To be continued in Run25 with high-luminosity and MB

- Balance the MB and High-luminosity program, for example:
  - Focus more on MB trigger at the beginning of Run25
  - Focus more on High-luminosity trigger once the luminosity is higher/at the beginning of the fill

Operation challenges - weather

- No major impact from temperature issues on operation (Magnet cooling, AC,..)
- Unusually large number of power dips
  - ex: Recovery of ZDC TCIM (8 days no, incorrect ZDC signals to CAD Aug. 6-14)
- Multiple weather-related stand-downs
  - Shutdown due to flood at STAR (Aug 19)
- …





Thanks to the tireless efforts of the STAR shift crews, the STAR operation team, and the strong support from the RHIC/CAD/site supporting team!

Run25 will also go through summer. We are prepared.

STAR Beam Use Request for Run 23~25

Assuming 28 cryo-weeks/year of running (~24 physics weeks/year)

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A short (a couple hours) mini-PAC meeting scheduled on June 17th

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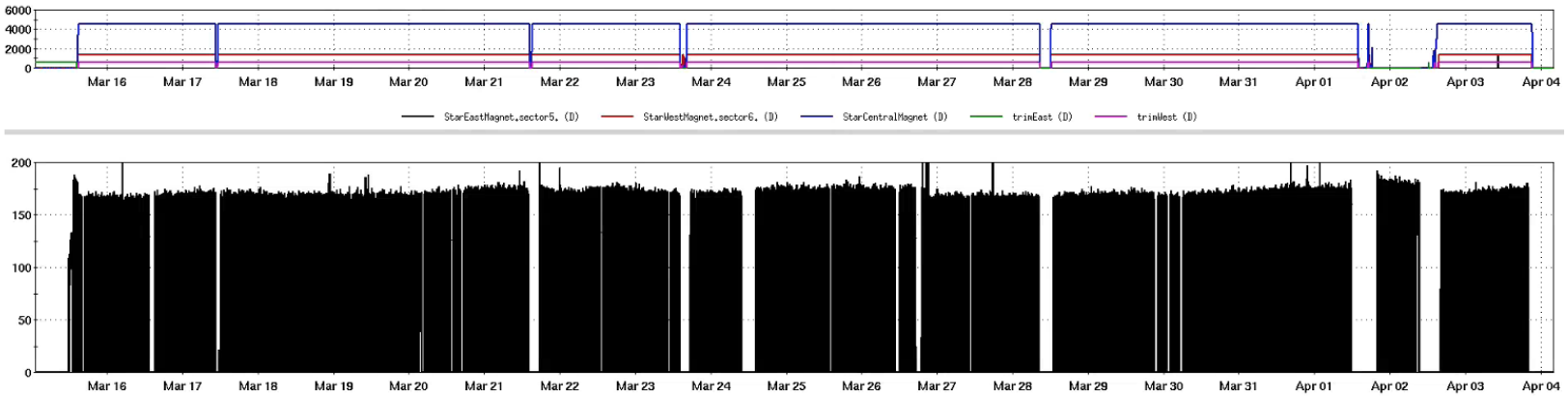
PAC report

Here goes to run 25!

STAR requests an extension of Run-25 beyond 28 cryo-weeks, allowing 5 weeks of p+Au physics data collection to achieve a sampled luminosity of 0.22 pb^{-1}

https://indico.bnl.gov/event/25236/contributions/98279/attachments/58396/100284/BUR25_Ruan.pdf

Run25 - timeline

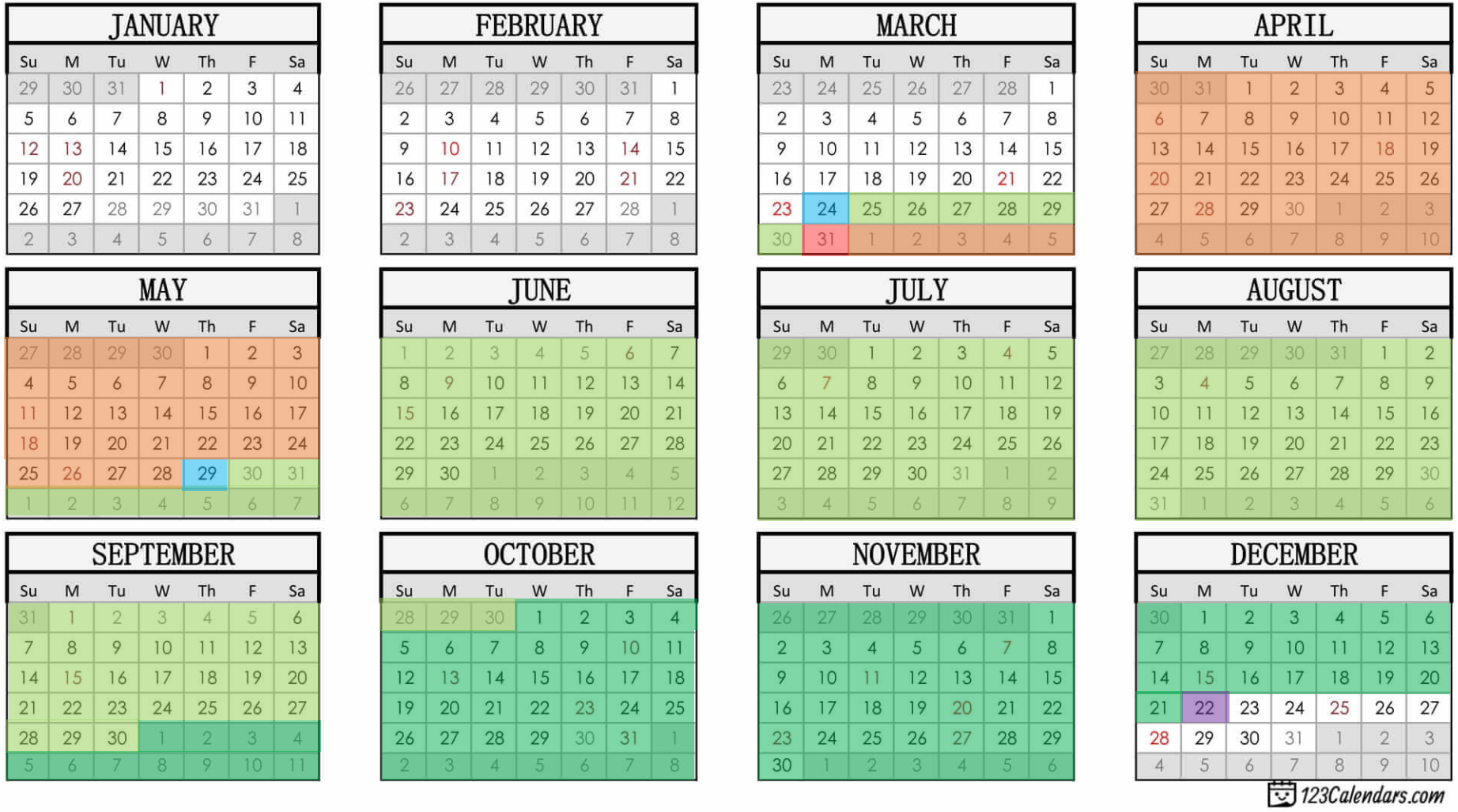


RHIC&AGS AUM 2025 May 19-23

- 3/11/25 : Shift (2 person) start, flammable gas flow (TPC)
- **3/15/25 : Cosmic data taking w. full field**
- 3/31/25 : Flip STAR magnet polarity and continue running cosmic data
- 4/3/25 : Operation paused
- **5/20/25 : Operation restarted (4-person shift), flammable gas flow (TPC)**
- 5/21/25 : Full field, bring each subsystem and prepare for cosmic data
- …

To be continued…

Current plans on run 25

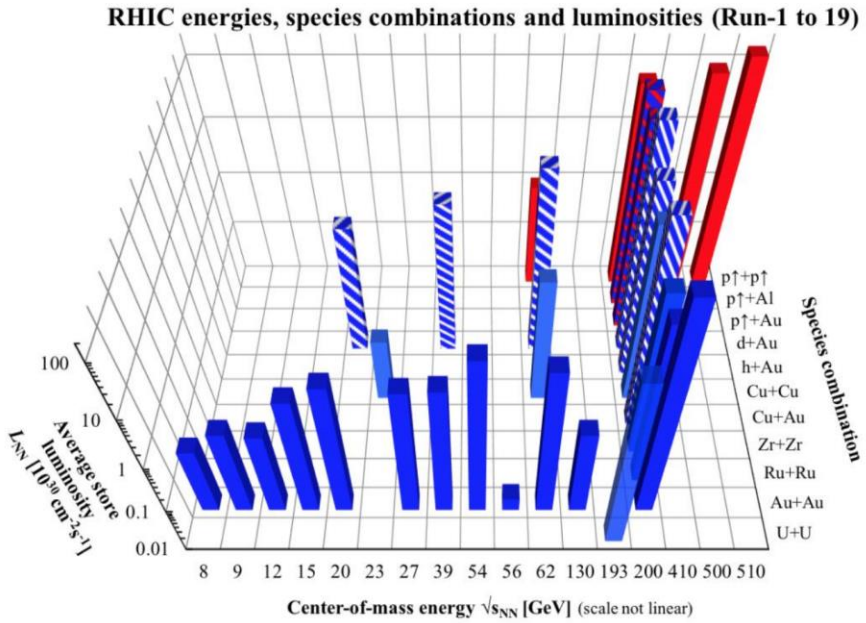


- Start 4K wave
- A short to ground in the Blue ring dipole return bus was found
- Pause to diagnostics and repair the short
- FY 25 Operation (18)
- FY 26 Operation* (12)
- End of Run-25

* based on FY26 guideline

Amazing journey w. STAR

major upgrades over the last twenty years to improve particle identification and vertex reconstruction, and is still evolving with an extension to forward rapidity as of today. pioneered in using new technologies: MRPC, MAPS, GEM and siPM.
Estimate 35M(initial) +75M(upgrades)$.



Detector	primary functions	DOE+(in-kind)	year
TPC+Trigger	$\|\eta\|$ <1 Tracking		1999-
Barrel EMC	$\|\eta\|$ <1 jets/γ/π^0/e		2004-
FTPC	forward tracking	(Germany)	2002-2012
L3	Online Display	(Germany)	2000-2012
SVT/SSD	V0/charm	(France)	2004-2007
PMD	forward photons	(India)	2003-2011
EEMC	1< η <2 jets/π^0/e	(NSF)	2005-
Roman Pots	diffractive		2009-
TOF	PID	(China)	2009-
FMS/Preshower	2.5< η <4.2	(Russia)	2008-2017
DAQ1000	x10 DAQ rate		2008-
HLT	Online Tracking	(China/Germany)	2012-
FGT	1< η <2 $W^{\pm}$		2012-2013
GMT	TPC calibration		2012-
HFT/SSD	open charm	(France/UIC)	2014-2016
MTD	muon ID	(China/India)	2014-
EPD	event plane	(China)	2018-
RHICf	η >5 π^0	(Japan)	2017
iTPC	$\|\eta\|$ <1.5 Tracking	(China)	2019-
eTOF	-2< η <-1 PID	(Germany/China)	2019-
FCS	2.5< η <4 calorimeter	(NSF)	2021-
FTS	2.5< η <4 Tracking	(NCKU/SDU)	2021-

2

- 24 years of operation, major successful upgrades, vibrant physics programs
- 330 published papers, 321 PhD and 22 MS theses

Summay

Run24

- Many challenges we had - dynamic schedule, beam configurations, weather… however
  - No major issues with detectors
  - Achieved original goals for pp
  - Studied the collectivity & fluctuation w. low-luminosity pp run
  - Collected 1.52B MB events for AuAu 200 GeV

It was a successful Run24!

Run25

- **Run25 has started**, STAR is looking forward to getting more physics!

Thank you!

2025 RHIC/AGS ANNUAL USERS' MEETING

RHIC 25:

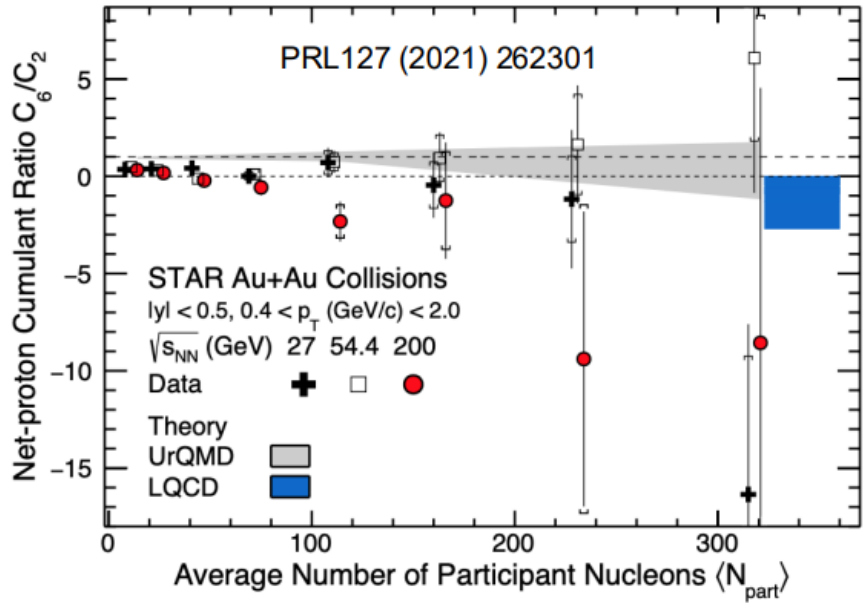
A quarter century of discovery

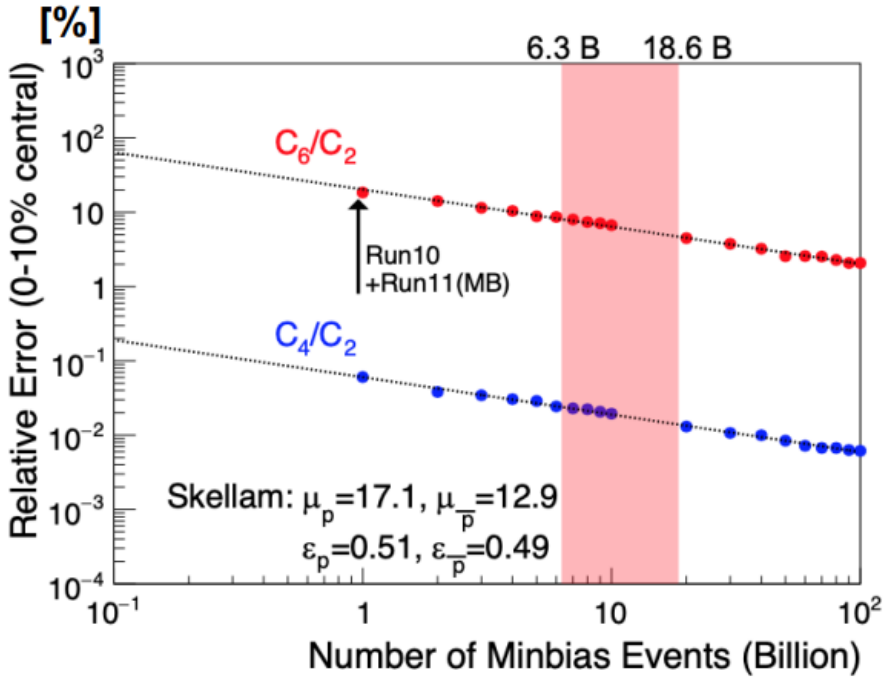
May 20–23, 2025

Backups

Chiral cross-over transition

Improved PID, extended η coverage by iTPC





Lattice QCD predicts a sign change of susceptibility ratio χ_6^B/χ_2^B at T_C
The cumulants of net-proton distribution sensitive to chiral cross over transition at μ_B=0

Observed a hint of a sign change from peripheral to central collisions at 200 GeV
$C_6/C_2 < 0$ at central collisions

High statistics measurements (10% statistical error for C_6/C_2 in central) will pin down the sign change

Impact of STAR science goals without pA data

- Quantitative comparisons of the validity and the limits of factorization and universality in lepton-proton and proton-proton collisions for initial and final state TMDs
  Test of Sivers non-universality: $Sivers_{SIDIS} = -- Sivers_{DY, W+/-,Z0;}$ Full jet and dijet Sivers asymmetry
  Probe final state TMDs: Collins asymmetry for hadrons in jet
  - Requirement:
    - large data sets √s = 200 and 508 GeV $p^{\uparrow}p$
      → low to high x, highest and lowest x with fSTAR
    - A_{UT} for $W^{+/-}$ Z^0, A_{UT} for hadrons in jet

~~First look at gluon GPD → E_g~~
  - Requirement:
    - data sets √s = 508 GeV $p^{\uparrow}p$ and √s = 200 GeV $p^{\uparrow}A$
    - A_{UT} for J/ψ in UPC

- Physics driving the large A_N at forward rapidities and high x_F
  - Requirement:
    - large data sets √s = 200 and 508 GeV $p^{\uparrow}p$
      → low to highest x_F → fSTAR
    - charge hadron A_N at forward rapidities

~~Nuclear dependence of PDFs, FF, and TMDs~~
  - Requirement:
    - large equal data set of √s = 200 $p^{\uparrow}p$ and $p^{\uparrow}Au$
      → low to high x, highest and lowest x with fSTAR
    - R_{pA} direct photons and DY, hadrons in jet A_{UT}

~~Non-linear effects in QCD~~
  - Requirement:
    - large equal data set of √s = 200 $p^{\uparrow}p$ and $p^{\uparrow}Au$
      → lowest-x through fSTAR
    - correlations for $h^{+/-}$, γ-jet, di-jets

Full detector capability with forward upgrades and excellent PID over an extended η coverage

Without pA data, STAR's forward upgrade will not be fully utilized for its discovery potential and RHIC will lose important physics opportunities on the following:

- **First look at gluon GPD → E_g**
- **Probe nuclear dependence of PDFs, FF, and TMDs**
- **Study non-linear effects in QCD**
- **Discover a novel vortical configuration**

https://indico.bnl.gov/event/25236/contributions/98279/attachments/58396/100284/BUR25_Ruan.pdf

Brookhaven National Laboratory

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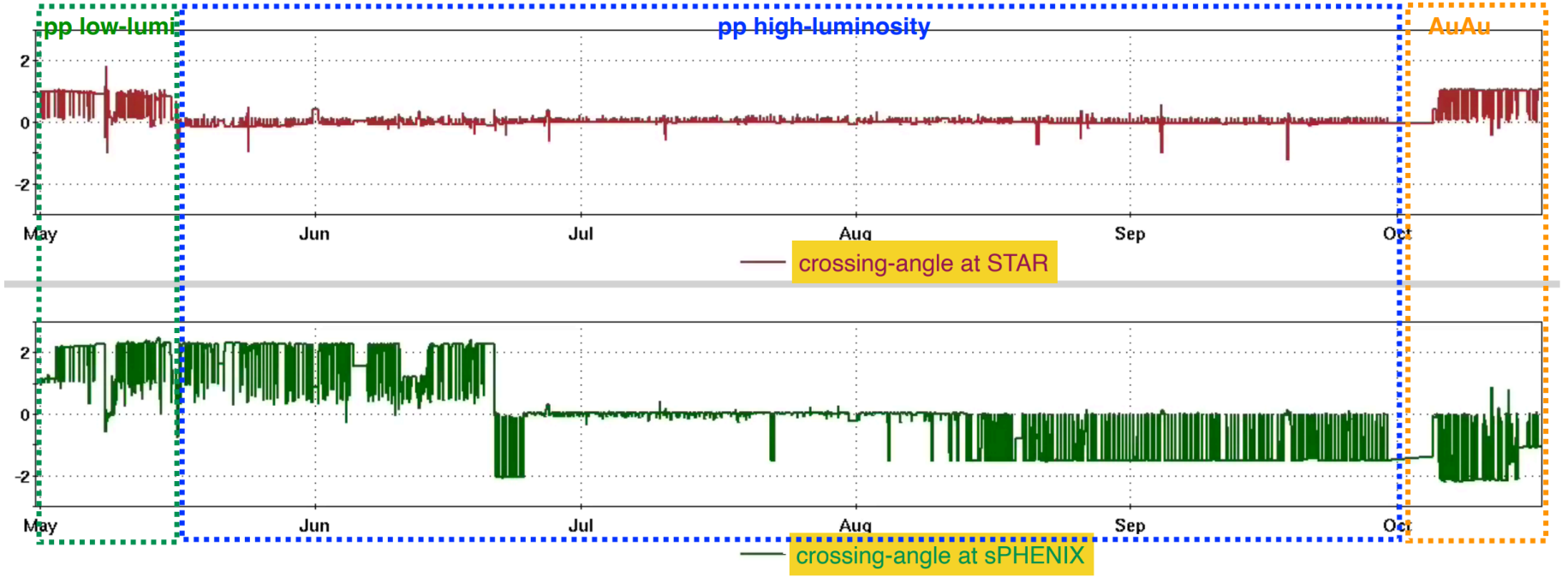
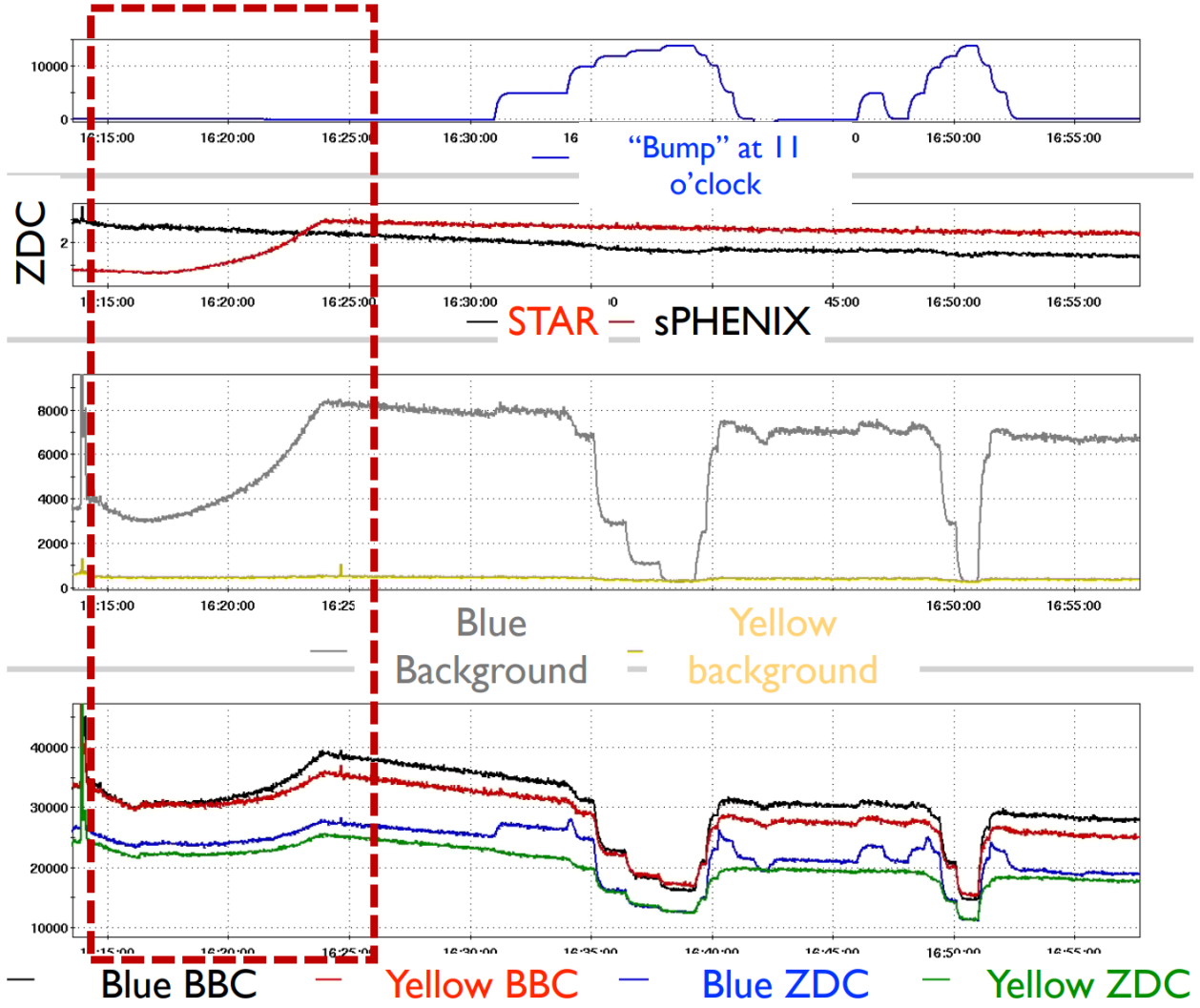
Crossing angle at STAR



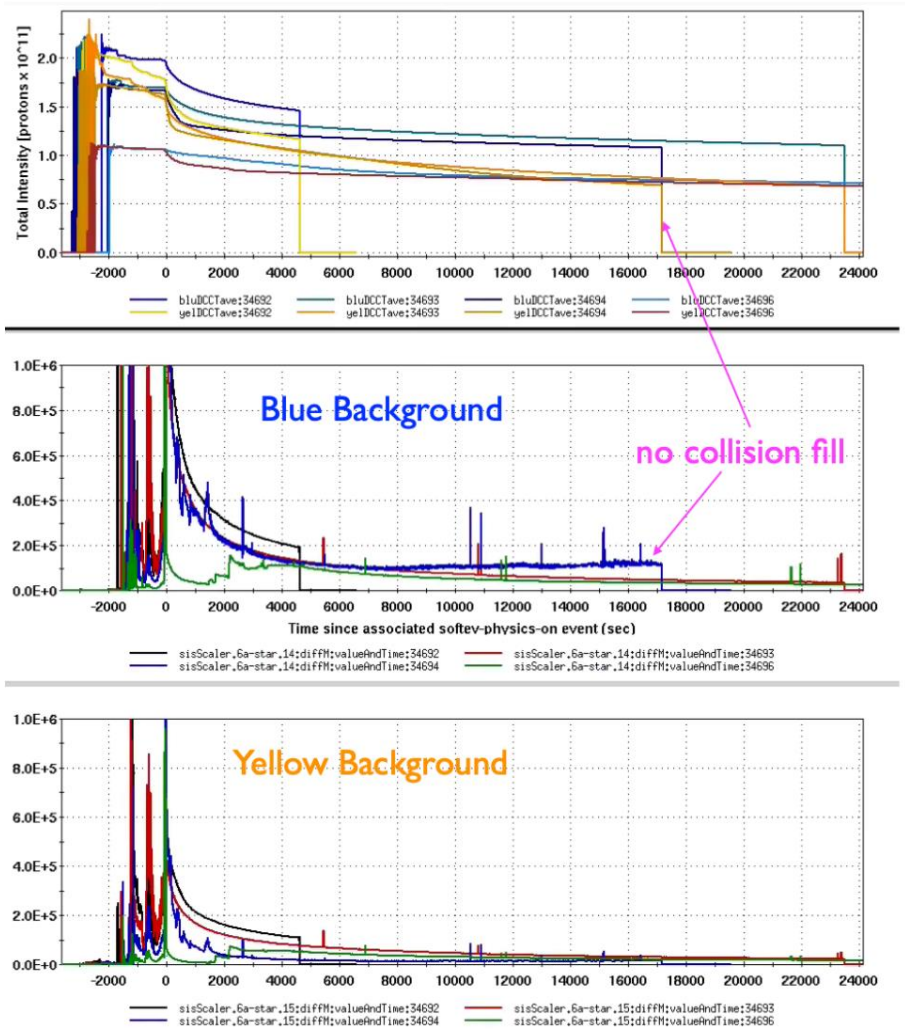
- Crossing angle STAR 0 (or 1) mrad, sPHENIX 2 (or 1.5, 1, 0) mrad
  - Reduce luminosity by x3-4 at 1 mrad; Expect to reduce beam-beam effect
- Beam-beam effect with crossing-angle affects total maximum luminosity available
- Crossing-angle/luminosity at sPHENIX changes background at STAR (found to be correlated with the luminosity at sPHENIX)

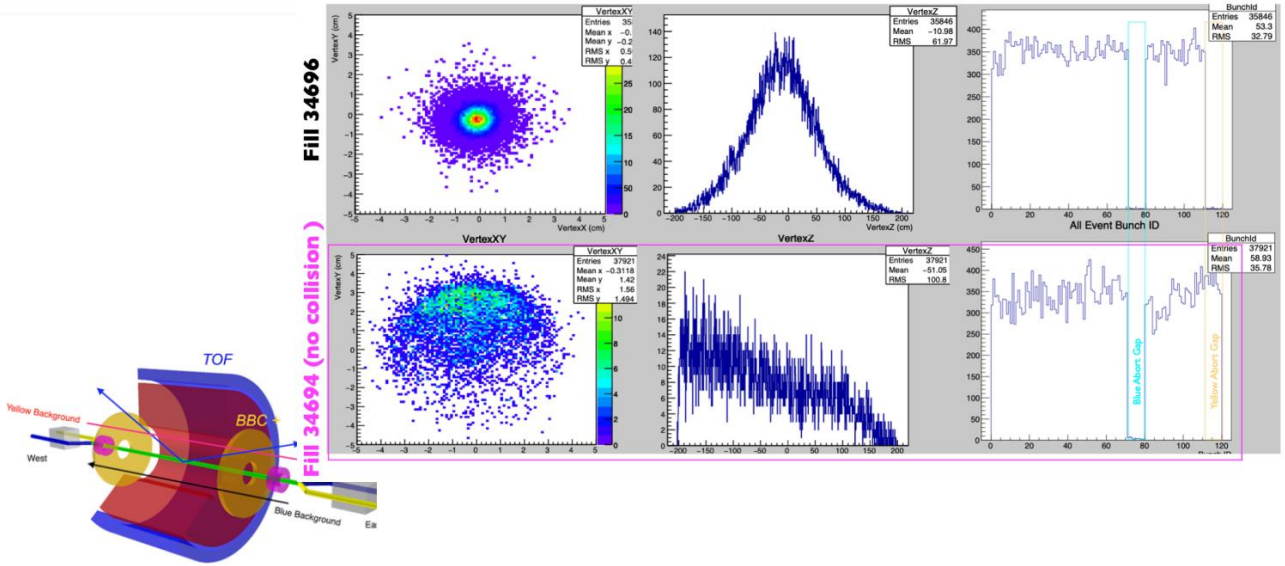
Au78 background



- Blue background understood with "Au78 test" (June 29)
- Correlation are found between the crossing-angle/luminosity at sPHENIX and blue background at STAR

Background in blue

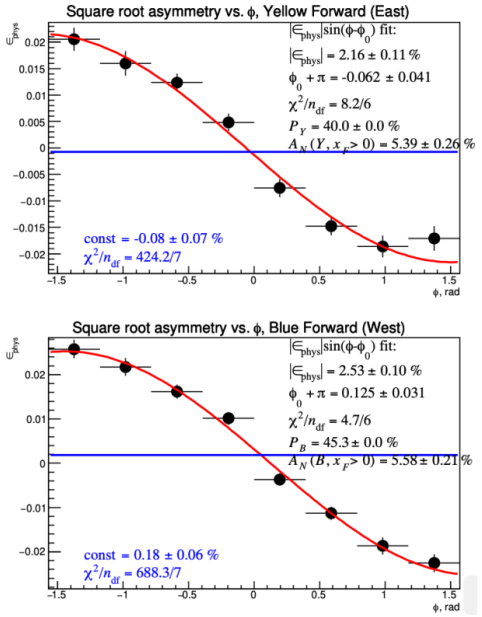




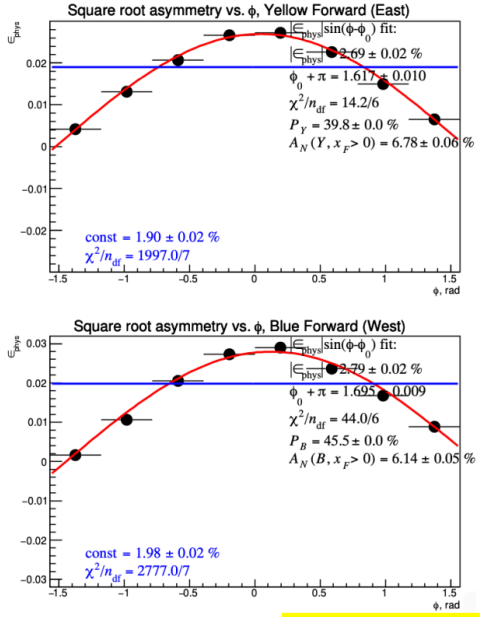
- High background in Blue (significant non-collision related)
- Some reduction/improvement was made by adding “Mask” at 11 o’clock (Jul 12)
- Further reduction required significant beam developments needing new dynamic aperture - not implemented

Radial (horizontal) polarization

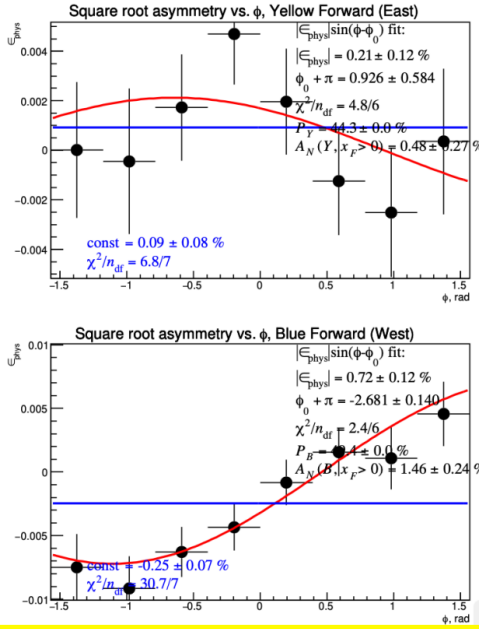
Vertical



Horizontal



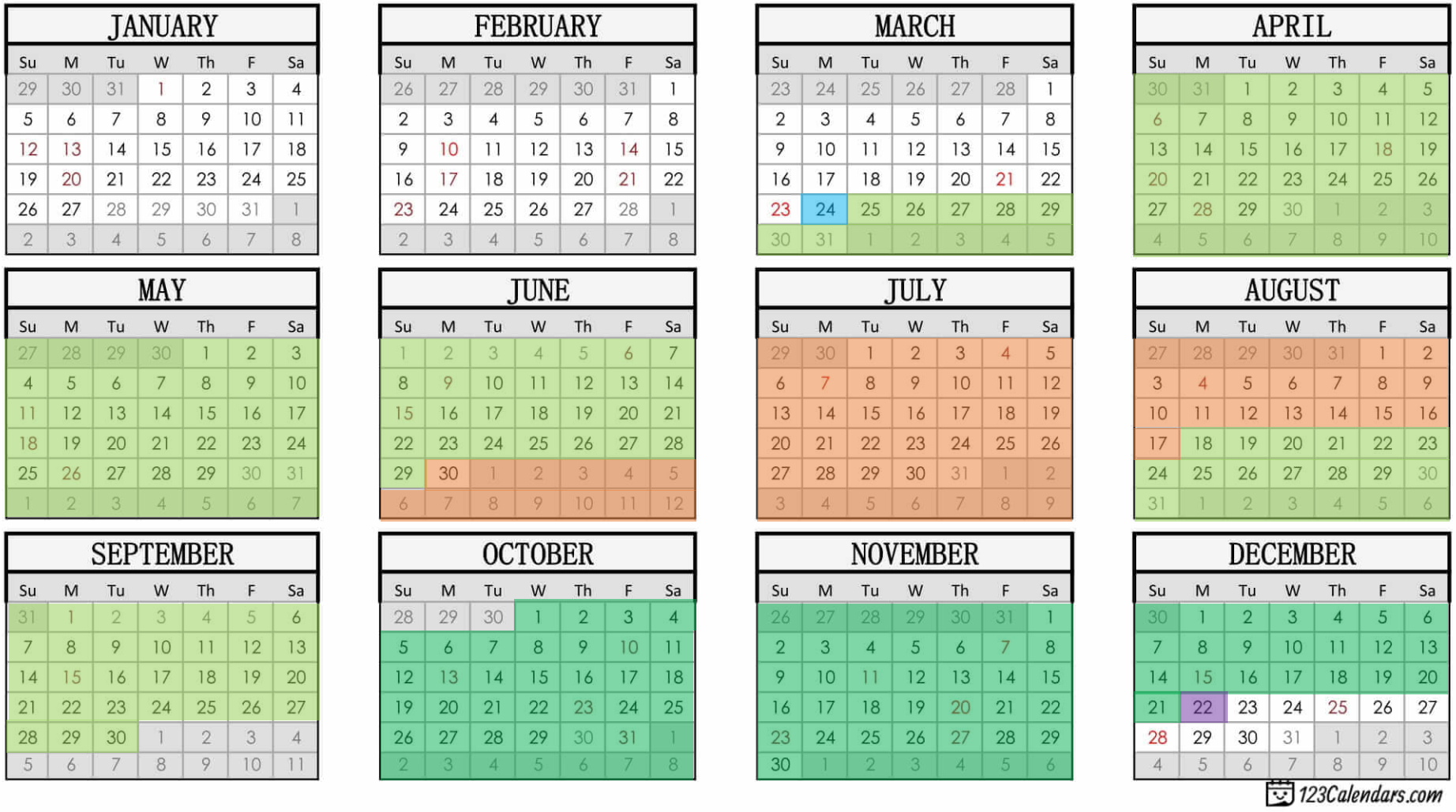
Longitudinal



3d spin direction measurements at STAR (APEX session on Aug. 21)

- Requested to maximize figure of merit and minimize systematics for physics measurements with forward detectors - Rotation 90±5 degree
- Residual polarization to be estimated

Orignal plans on run 25



JANUARY

Su	M	Tu	W	Th	F	Sa
29	30	31	1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	1
2	3	4	5	6	7	8

FEBRUARY

Su	M	Tu	W	Th	F	Sa
26	27	28	29	30	31	1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	1
2	3	4	5	6	7	8

MARCH

Su	M	Tu	W	Th	F	Sa
23	24	25	26	27	28	1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31	1	2	3	4	5

APRIL

Su	M	Tu	W	Th	F	Sa
30	31	1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	1	2	3
4	5	6	7	8	9	10

MAY

Su	M	Tu	W	Th	F	Sa
27	28	29	30	1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31
1	2	3	4	5	6	7

JUNE

Su	M	Tu	W	Th	F	Sa
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	1	2	3	4	5
6	7	8	9	10	11	12

JULY

Su	M	Tu	W	Th	F	Sa
29	30	1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31	1	2
3	4	5	6	7	8	9

AUGUST

Su	M	Tu	W	Th	F	Sa
27	28	29	30	31	1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31	1	2	3	4	5	6

SEPTEMBER

Su	M	Tu	W	Th	F	Sa
31	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	1	2	3	4
5	6	7	8	9	10	11

OCTOBER

Su	M	Tu	W	Th	F	Sa
28	29	30	1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	1
2	3	4	5	6	7	8

NOVEMBER

Su	M	Tu	W	Th	F	Sa
26	27	28	29	30	31	1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	1	2	3	4	5	6

DECEMBER

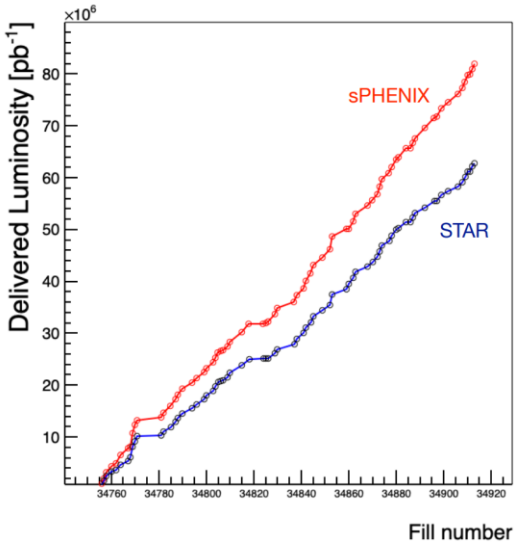
Su	M	Tu	W	Th	F	Sa
30	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31	1	2	3
4	5	6	7	8	9	10

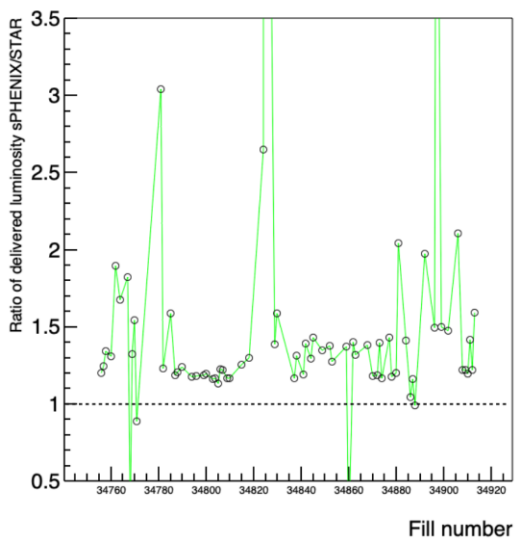
123Calendars.com

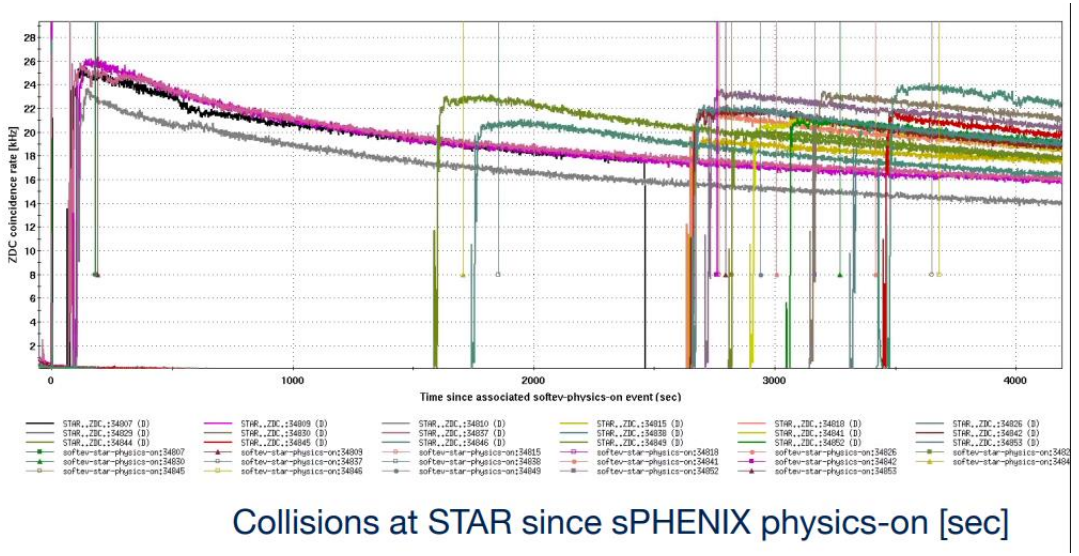
- Start 4K wave
- FY 25 Operation (14+6)
- 7 weeks pause
- FY26 Operation* (12)
- End of Run-25

* based on FY26 guideline

Running with sPHENIX, beam-beam effect

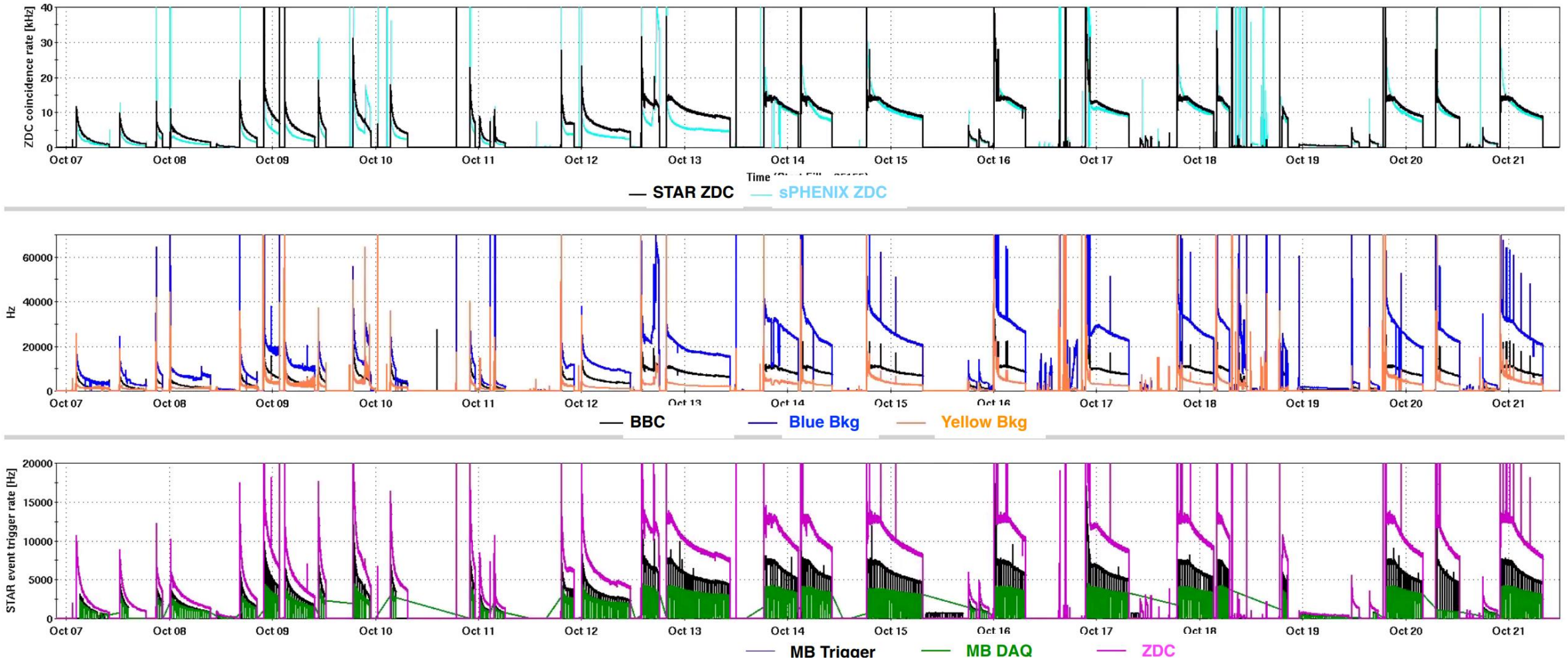






- STAR and sPHENIX collisions at separate times from July 5 to Aug 10 (until sPHENIX adding crossing angle when TPC was operational)
- Collision at STAR when beam-beam parameter is < 10-3 with a minimum wait time of 40 mins if the beam-beam parameter is above that threshold at the beginning of store
- sPHENIX/STAR delivered ~ 1.3 during the period

3 weeks of Au+Au 200 GeV



(9/30 - 10/21)