Machine performance & challenges in Run24

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Major Installations

1. 56 MHz cavity reinstalled for Run23
   - used to provide more narrow Au bunches at collisions, not used for protons
   - has a fundamental mode damper and two fundamental power couplers to damp higher order modes
2. sPHENIX detector installed starting Run23
   - Commissioning during Run23+Run24
   - Fully operation in Run24.
   - beampipe reinstalled with large misalignment required horizontal bump at injection
3. Repaired 9 o'clock blue helical dipole reinstalled following Run22 failure
   - two of four coils failed in Run22 forced it to be used as a partial snake
4. Sector 4 DX magnet reinstalled following failure that ended Run23
   - the normal conducting to super conducting transition for RHIC PSs arced, resulting in damage to the DX and to the transition housing (valve box)
   - the DX magnet was replaced with a spare during the shutdown period
   - caused by thermal fluctuations that weakened mechanical joints and led to development of new cooling algorithm of the 12x150 A leads.

12x150A lead protection

From F. Micolon

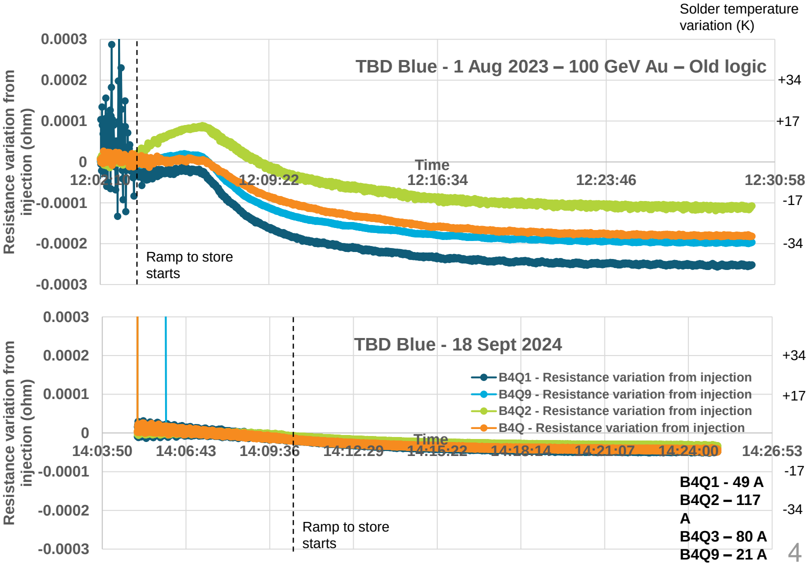
Following the run23 lead failure investigation, a new helium flow logic has been implemented to minimize the solder joint temperature variation.

More details here

With the new helium flow, the resistance (=temperature) variation is reduced significantly. This will help preserve the leads.

At 100 GeV Au, some leads operate closer to their QLI limit (250 mV) - potential QLIs if the service building temperature gets hot next summer.

A QLI was seen Oct 10th because of a control system data transfer issue.



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Shutdown 23 Major Works

Polarized protons at RHIC

- Run24 Summary
  - Running Modes
  - sPHENIX operations with a crossing angle
  - Both Experiments with head-on collisions
- Run24 Shortcomings and Issues
  - RHIC Performance
  - Intensity Limitations, Injectors and RHIC
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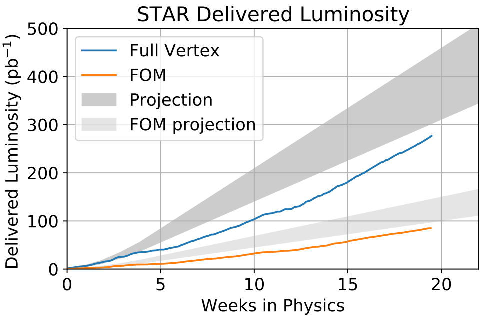
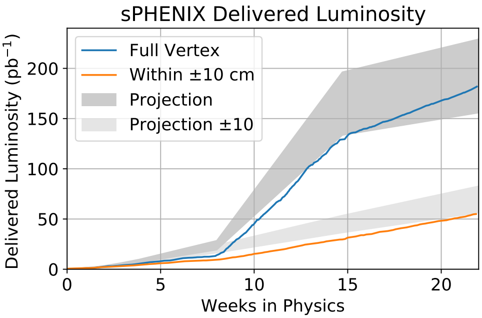
Au at RHIC, 3 week run

Summary

Delivered Luminosity and FOM





	STAR	sPHENIX
Total delivered luminosity (pb^{-1})	271.1	181.9
Misc delivery (pb^{-1})	83.3 (FOM)	55.0 (within $\pm$10 cm)

Poor performance early in the run coupled with two extended periods of reduced availability resulted in luminosity delivery below projections.

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Running Modes

To mitigate beam-beam effects, sPHENIX operation with a crossing angle was sufficient for not using the electron lenses.

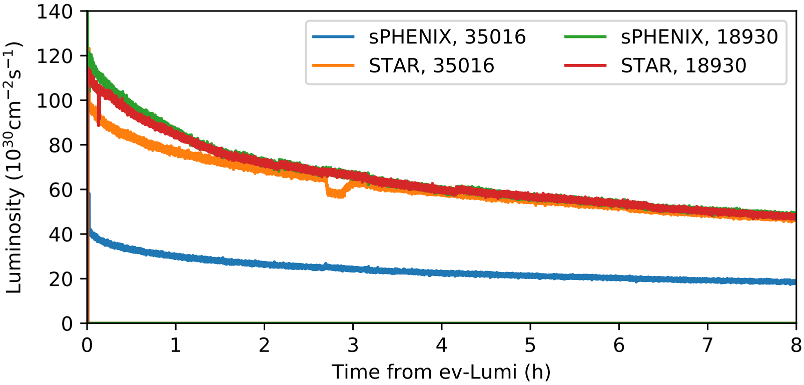
1. sPHENIX with (-) crossing angle, STAR at 0 mrad
   - 2-6 hour store lengths
   - STAR low luminosity run for first two weeks and spin vertical at IP6.
   - STAR full luminosity after first two weeks with spin radial at IP6.
2. sPHENIX with 0 mrad, STAR at 0 mrad
   - sPHENIX brought into collisions first
   - STAR brought into collisions after Beam-beam parameter from sPHENIX below 10×10^{-3}
   - Store length after bringing STAR into collisions was 6 hours.
3. sPHENIX with +1.5 mrad, STAR at 0 mrad
   - 8 hour store lengths

A total of 18 machine development blocks were required to establish, maintain, and improve the above setups.

sPHENIX operations with a crossing angle

With sPHENIX operating with a crossing angle, both experiments could be brought into collisions at the start of store.

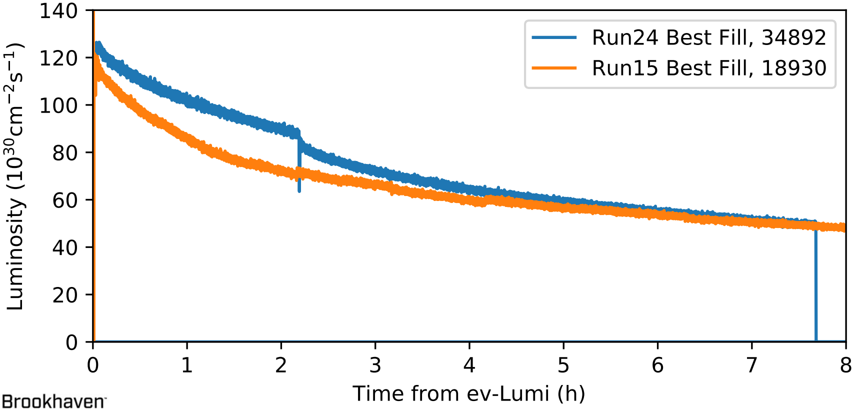
1. sPHENIX operated with a -2 and +1.5 mrad crossing angle (1.5 mrad shown).
2. Unable to exceed best store of Run15.



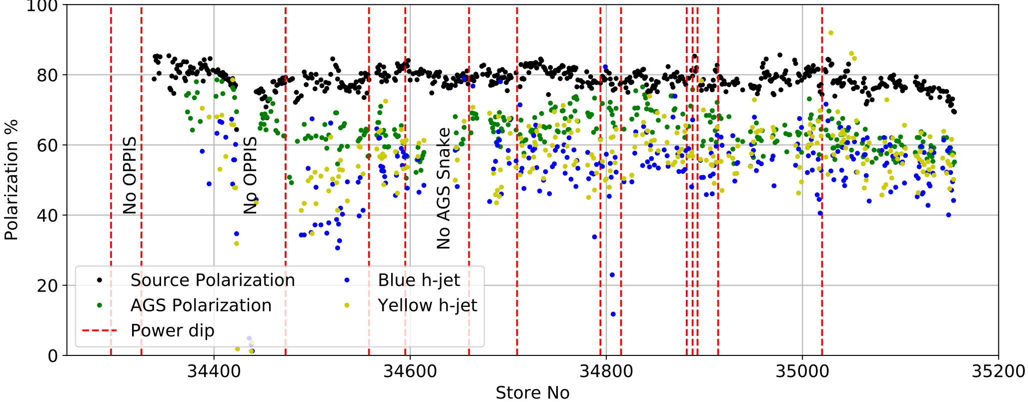
Both Experiments Head on

Due to the large beam-beam parameter of protons, both experiments could not be brought into collisions at maximum intensity

1. sPHENIX was brought into collisions first
2. when the beam-beam parameter reached 10×10^{-3}, STAR was brought into collisions with an additional 6 hours store length.
3. Exceeded the performance of best store from Run15 for a single IP.

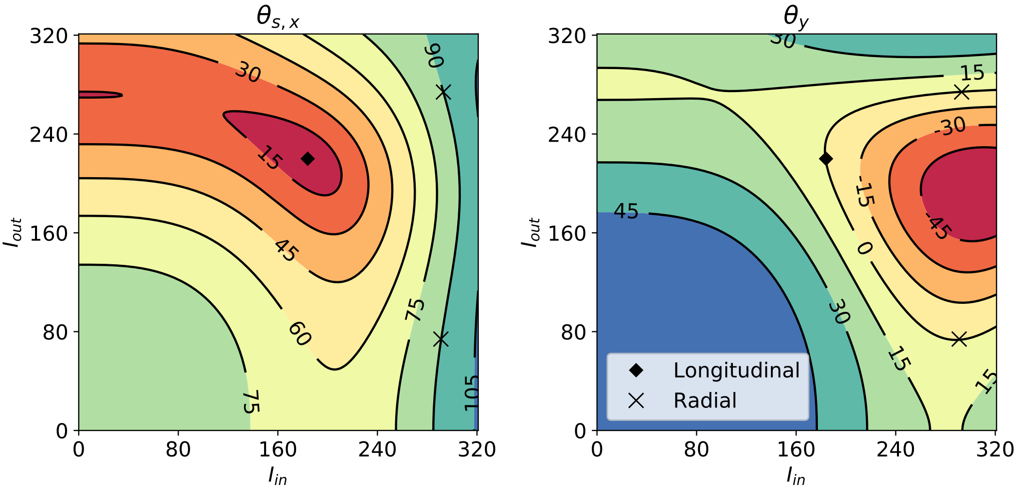


Polarization Performance



- Full run (pending final analysis): $P_{\mathrm{blue,h-jet}}$=54.7%, $P_{\mathrm{yellow,h-jet}}$=57.8%
- Run15: $P_{\mathrm{blue,h-jet}}$=53.0%, $P_{\mathrm{yellow,h-jet}}$=57.4%
- Large emittance dependent polarization transmission due to emittance growth from undamped 56 MHz.
- Power dips (especially early in the run) affected availability of OPPIS and the AGS Cold Snake.

Radial Polarization at STAR



- Initial rotator currents had I_{out}, I_{in} near limits which resulted in numerous quenches.
- Switched to lower current setting with the inner coils still at very high current.

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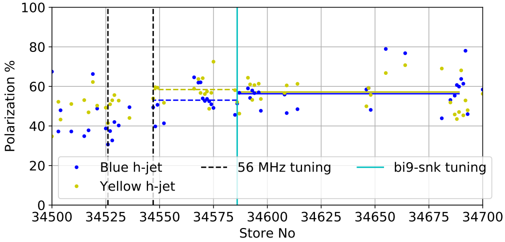
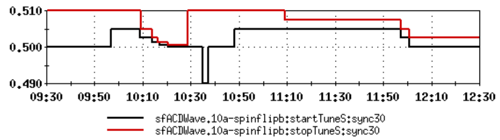
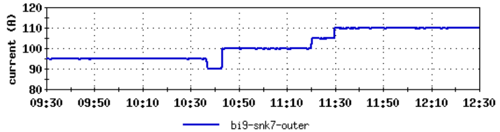
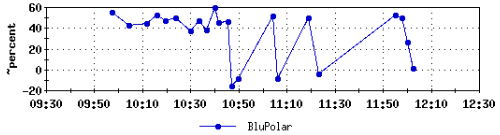
Spin tune measurement at Injection

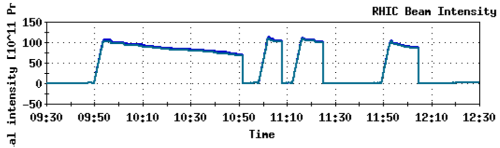
- Following the improved emittances with a fully damped 56 MHz, P_{blue}/P_{yellow}=90.8%.
- Spin tune was measured and the outer coil of the new snake was adjusted to achieve the desired spin-tune.
- Outer coil increased 15 A to move ν_s from: $\nu_s > 0.51 \Rightarrow 0.5025 > \nu_s > 0.5$
- First time measuring ν_s at injection using a single AC dipole from the spin-flipper











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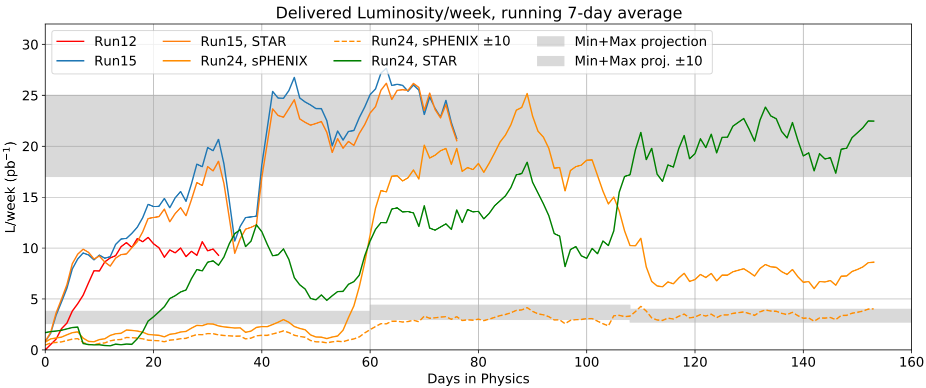
Au at RHIC, 3 week run

Summary

Machine Performance



- sPHENIX delivered luminosity briefly exceeded the maximum projected luminosity.
- Following return to sPHENIX operation with a crossing angle (+1.5 mrad) at day 106, STAR and sPHENIX remained in their projection windows.
- Two distinct periods of low availability reflected in delivered luminosity (at ∼day #50, and #100).

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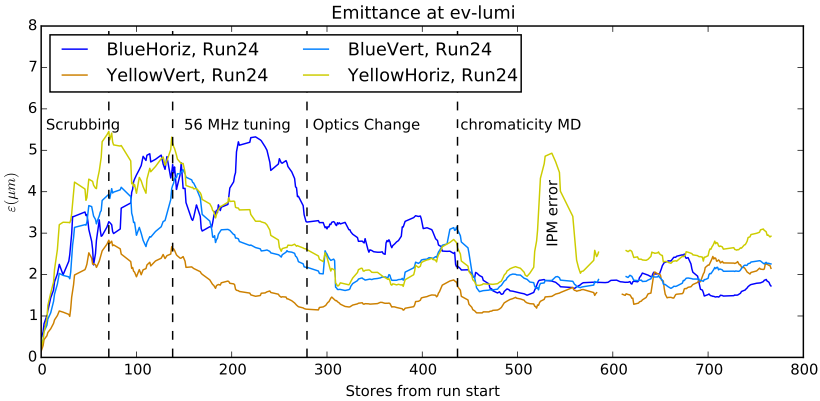
Machine Performance



- Emittance increase followed the intensity ramp, found to be caused by insufficiently damped 56 MHz SRF cavity.
- Vacuum response at newly installed components (mainly sector 4 DX) drove several dedicated scrubbing sessions and two hour stores.
- Updating optics and appropriate chromaticity changes led to nominal emittance.

Injector Configurations to Increase Intensity

Ahead of the run, simulations and planning for the injectors to support 3×10^{11} in RHIC were performed. The injector configurations and outcomes were:

1. Nominal jump quad user
   - Maximum RHIC intensity supported $\sim 2.5 \times 10^{11}$/bunch injected.
2. Booster bunch split+AGS merge
   - No clear benefit over standard jump quad user.
3. Two LINAC pulses+AGS merge
   - Stability issues with second LINAC pulse when injecting into Booster, needed more development time.
4. Combination of 2+3 with the skew quads
   - Standard skew quad user supported intensity $> 2.5 \times 10^{11}$/bunch injected.

Original start date for AGS development February 5, 2024. Cold wave started 4/15.

- Cold snake not available until March 29, 2024.
- OPPIS not available until April 24, 2024.

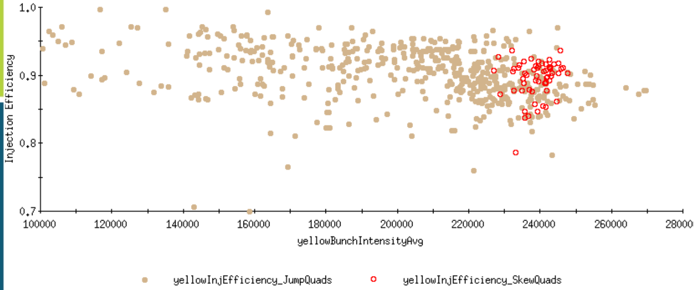
Polarized proton development did not begin until after Blue and Yellow were ready for injection on hysteresis.

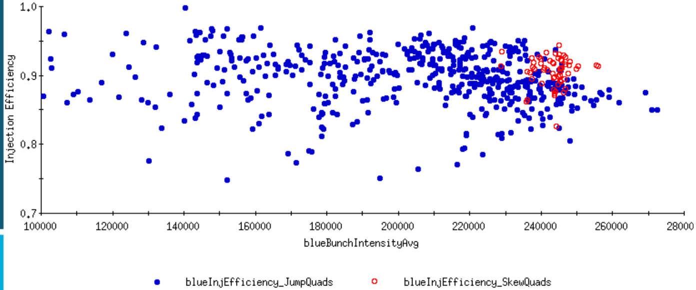
RHIC Intensity Limitations

Several factors prevented increasing the intensity beyond 2.5×10^{11}, including:

1. Bunch intensity from injectors
   - Eventually resolved after making the AGS skew quad user primary $\rightarrow$ better emittances.
   - Skew quad user became primary for store 35072
2. Intensity limit for Blue accelerating RF
   - RHIC ring temperature affected the performance of the power amplifiers in ring,
   - Was resolved as temperatures cooled toward end of the polarized proton run,
   - Improved cooling for proton running in summer months would raise potential intensity limits.
3. Losses at rebucketing
   - adjustments of the store frequency and radius at rebucketing optimized.
4. Dynamic aperture
   - Unable to squeeze IP8 further with 1.5×10^{11}
   - Determined operating intensity near limit.

Bunch intensity from injectors





- With the standard jump quad user, increasing intensity beyond 2.5×10^{11} saw diminishing returns
- The improved emittance from the skew quad user provided $\sim$2% increase in injection efficiency and facilitated higher intensity.
- Plots show injection efficiency vs injected intensity in RHIC with jump quad as solid circles, and skew quad as open circles.

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Polarized Proton availability

OPPIS availability

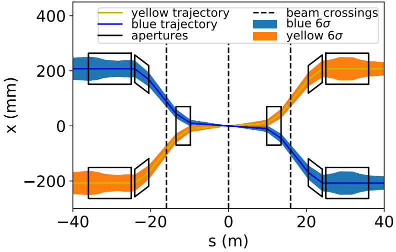
- OPPIS had high spark rate which was prompted it to be taken offling on April 14.
- Contaminants found in Rb cell, replaced with spare.
- Power dip on April 17 caused significantly higher spark rate.
- Cooling line for ionizer burst on May 8, recovered May 10.
- End of run polarization degraded due to Rb cell issues.

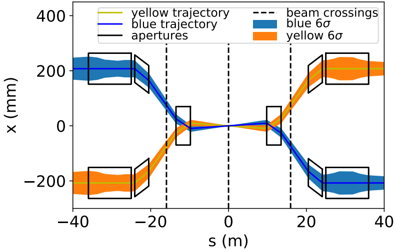
AGS Cold Snake availability

- Cold snake failed its cold hi-pot several times.
- Several warm-ups and cooldowns eventually cleared.
- Power dip from water intrusion in a 13.8 kV transformer on May 27 caused the cold snake to vent helium and a clog to form, reducing cooling capacity of cold head 5. Partial warmup to clear clog unsuccessful.
- Cold snake ramped down in between fills to conserve helium. Prevent development of even the standard AGS user.
- Full warm up to clear clog and full cooldown from June 10-14.

Operation of IP8 with -2 mrad crossing angle and switch to +1.5

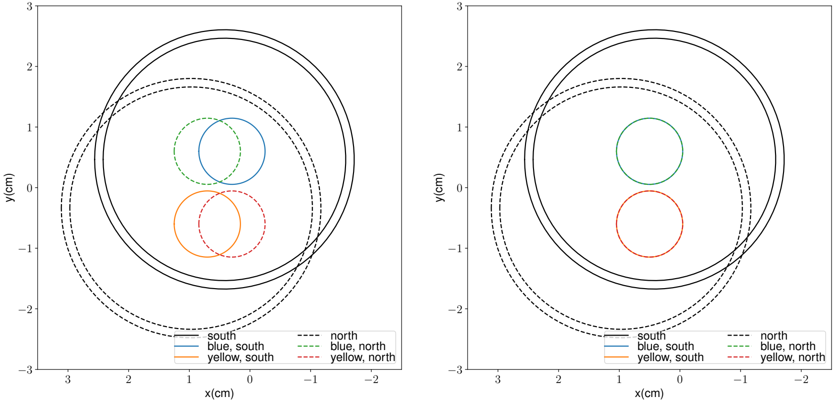
- To maximize delivered luminosity it sPHENIX, there was intent to reduce the IP8 β^* to 60 cm.
- To maximize clearance through the entrance face of the DX magnets, a negative crossing angle can be used.
- Supporting a (-) crossing angle no longer supports 0 mrad crossing.
  - The negative crossing angle at injection had correlated radiation damage on the EMCAL from injected blue beam.
- With a (+) crossing angle, the maximum supported crossing angle is +1.5 mrad.
- Time period of (-) crossing angle coincided with 56 MHz and Optics issues, leading to degraded performance.
- Later determined there was insufficient dynamic aperture to squeeze IP8 below 85 cm.





sPHENIX Beampipe with a negative crossing angle

- With a negative crossing angle, the minimum supported angle is -0.8 mrad (left)
- This was the operating mode for the first 60 days before changing the D0 polarity for (+) crossing angle.
- Positive crossing angle configuration allowed for 0 mrad at IP8 (right).



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Au at RHIC, 3 week run

Summary

Au at RHIC, 3 week run

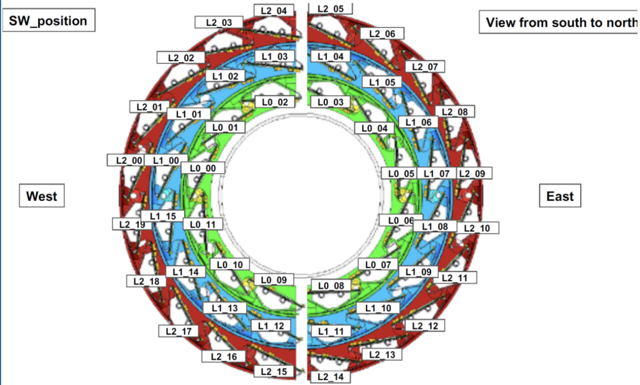
Goals of 3-week Au run

- Increase intensity to 1.8×10^9/bunch, fully commission the 56 MHz RF system.
- Ensure sPHENIX systems are ready for Run25.
- Provide enough physics for STAR to reach 1-2 B events on their minbias trigger.

Notes

- Injection into blue delayed 4.5 days due to g9-blw-ps failure.
- Injection into yellow delayed 5 days due to yellow abort kicker issue.
- 3 days from first injection to physics.
- Max intensity reached 1.5×10^9/bunch
- 2 sessions of successful 56 MHz commissioning. Operated at full voltage with 1.3e9/bunch.
- Backgrounds on sPHENIX MVTX prompted daily studies from 10/11 to 10/21 (discovered on 10/09, absorber install on 10/10 with no observed effect). All other systems, ready to go.
- STAR recorded over 1.5 B minbias events.

The MVTX detector



- 48 staves in three layers, centered at 0 m, and extends $\pm$13.5 cm.
- Simulations by sPHENIX show a single Au ion (or shower from striking the beampipe) with a longitudinal trajectory, striking the MVTX would result single/multiple MVTX staves going into auto-recovery
- Simulations during diagnostics indicated the source of backgrounds was from particles with a large momentum error.
- Auto recovery process is 20s

Beampipe radius	2.14 cm
MVTX Layer 0	2.4 cm
Layer 1	3.1 cm
Layer 2	3.9 cm

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sPHENIX MVTX Backgrounds studies

Studies performed and their implications

Study	Summary
Yellow only studies	High backgrounds even with single bunch → prompted single yellow bunch studies
Blue only studies	Significantly lower backgrounds than with yellow, 56 bunches in blue better than single yellow bunch → primarily sourced by yellow
Unrebucketed beam	Improved auto-recoveries → affected by bucket area
Local steering (position and angle)	Significant reduction in auto-recovery rate → losses can be moved locally and redistributed
Unsqueeze of IP8	No significant change → losses not the result of local scraping in triplet or local dispersion
Squeeze of IP10	weak change in auto-recoveries with a bump at IP10 → particles can be lost at upstream squeezed IR
Adjustment of global octupoles	Little to no effect → not from high betatron amplitude particle
Prefire protection bump	Significant reduction when combined with local steering and 12 bunches (did not scale to 56 bunches)→ off-momentum particle
Bump scan in dispersive region	reduction in auto-recoveries → phase of prefire protection bump may not be optimal

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Summary

Summary

On polarized protons

- This was a long run that required almost constant attention from experts to improve and sustain machine performance .
- Supported a large number of machine configurations to support sPHENIX commissioning.
- Despite these difficulties, high luminosity was delivered to both STAR and sPHENIX.
  - This was the highest total luminosity run for 100 GeV polarized protons.
  - This was the highest luminosity/store except for Run15.

On Au

- Studies to diagnose the MVTX autorecovery backgrounds required low bunches and was not compatible with advancing other goals.
  - A combination of sPHENIX operating the MVTX in triggered mode, and accelerator optimizations to minimize the source of backgrounds, will allow for high quality data taking in Run25.
  - A task force has been assembled to implement the best possible background reduction configuration.
- 1.5 B minbias events were delivered to STAR (goal of 1-2 B events)

Thank you

Thank you and questions.

List of Machine Developments for Polarized Protons

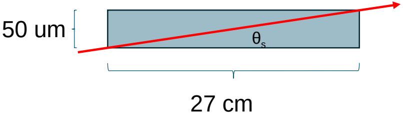
4/30	Revert to design orbit to fix walk toward unstable point
5/03	Clean up ramp, increase octupoles, tested squeeze, vacuum limitations observed
5/07	Scrubbing development and scrubbing session
5/09	Scrubbing session
5/13	Ramp diagnostics
5/14	Emittance growth and electron clouds
5/17	Ramp development and rotator setup
5/20	Ramp development and rotator setup
5/29	56 MHz and ramp development
6/07	Blue spin tune measurement
6/13	Run22 ramp test and ramp development
6/21	IP8 Polarity Swap and updated RHIC optics
6/25	Commission storage ramp 2
7/3	Collapse IP8 then IP6 I
7/5	Collapse IP8 then IP6 II
7/18	Chromaticity MD
8/15	Rebucketing MD
8/29	beta squeeze

Outcome of machine developments also summarized in Status Meeting slides

RHIC/MVTX Local Geometry

MVTX spans +/-13.5 cm around IP
Active layer is 50 um

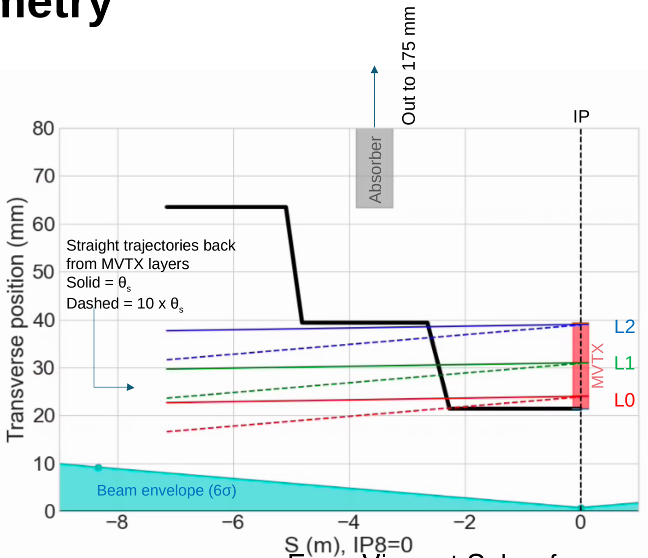
θ_s: "Skimming" angle: max angle of a trajectory that traverses the whole length of one MVTX layer: 50um/26.5cm = 0.19 mrad



Beam envelope = 6σ, no dispersion, ε=2.5 um rms,norm
No dispersion included, no crossing, nominal beam pipe

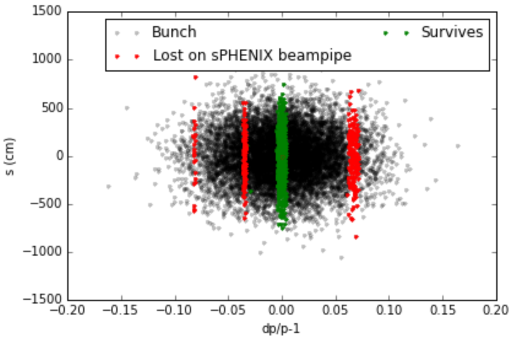
Whatever exits the pipe (doesn't need to be beam Au necessarily), probably exits at the small taper
Geometry does not exclude the larger taper, but would traverse L2->L0

Possible to load the medium pipe with absorber discs? (not *today*, obviously)



From Vincent Schoefer

Passing large bunch from DH20 through IP



A very oversized bunch was generated and tracked through the IP

- Triplet, DX, D0, and sPHENIX apertures put into model.
- Particles with specific momentum values are lost at the sPHENIX beampipe (red). Must be generated through reactions/capture somewhere.
- Used to inform source of losses. Needs more in depth tracking studies to determine possible origination.

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