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Run 25 in the Injectors

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Keith Zeno
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Introduction

This was not only the last RHIC run but was also one of the longest. Data taking began in RHIC using 9.8 GeV/n Gold (BU1/AU1) on June 10th and it ended on December 8th. Polarized proton (BU4/AU6, Gγ=44.5) data taking began on December 11th and it ended on January 20th, and Oxygen (BU3/AU3) data taking took place from February 1st to February 6th. The collision energy was 200 GeV/n for all these cases. There were also short, fixed target experiments using Gold at 8.65 GeV/n (BU1/AU7), 9.8 GeV/n (BU1/AU1), and 13.5 GeV/n (BU1/AU1) during the period from January 21st to 28th.

The notes I write each run are useful to me as a reference and given the length and complexity of this run it is hard to get a good picture of what was going on so I am trying something new: The chart at the end of this note is a record of the dates, from the beginning to the end of 'the run', when beam was in the Booster and/or AGS and the PPM users it was on. This chart is also intended to make finding information in the elogs easier. It also shows which days beam was injected into RHIC and which AGS user(s) provided it. The start and end of the run here are just the first and last day there was beam in the Booster. The chart is divided into these 3 parts so it fits on regular pages: March 3rd to June 30th, July 1st to October 31st, and November 1st to February 7th. The colors are close to the ones the control system uses for each PPM user.

There were often multiple users active on any given day so there are 2 columns of Booster and AGS users for each day. Each setup usually has both a Booster and AGS user. For example, the configuration that was used for the Gold 200 GeV/n run was Booster user 1 and AGS user 1. In some cases, there was beam in the Booster but not in the AGS so only a Booster user is shown. In rare cases there were 3 sets of users on a single day. In those cases, there is an extra row below for that date which contains them (2-Oct, 22-Jan, and 31-Jan). There were a few instances where 2 setups were used to inject into RHIC in one day so there is a second RHIC column where a second AGS user is shown (19-Nov, 25-Jan, 26-Jan, and 31-Jan). Just below Tables I and II contain brief summaries of the setups in the Booster and AGS users, respectively.

The Tandem Gold Setup

This setup is largely unchanged from previous years. Last year's program consisted mainly of a PP run, but there was also a 3-week Gold run. Before this year only the 12-6 merge had been used to provide 9.8 GeV/n Tandem Gold to RHIC. But a 12-6-3 merge was developed near the end of last year's run.[1] It provides two final bunches per AGS cycle instead of 4 but they have twice the intensity. When more intensity than the 12-6 merge could easily provide was desired the merge was switched to 12-6-3. The first fill with the 12-6-3 merge was on June 16th.

[1] See K. Zeno, "The 2024 Run in the Injectors" C-A/AP/715, February 2025, pgs. 33-34

BU1	Tandem Au^{31+} with 6-3-1 merge.
BU2	Linac protons for NSRL
BU3	O^{6+} from Tandem, with 4-2-1 EBIS-type merge
BU4	Normal PP user, dual harmonic, no merge. Used with AU6 for RHIC.
BU5	• Split-merge cycle for PP ending Jan. 28 • H^{2+} starting Jan 29
BU6	EBIS ions for NSRL
BU7	• Set up to look at protons in BtA at injection energy, April 11 only • Tandem Au^{31+} with 9 Tandem pulses per supercycle and lower extraction field starting Sept. 26.
BU8	BU8: EBIS ions for NSRL

Table I: Booster PPM Users in Run 25. The users supplying beam to NSRL are not included in the chart.

AU1	Tandem Au^{77+} with 8 transfers and a 2-1 (12-6) or 4-2-1 (12-6-3) type merge. 4 or 2 final bunches on 9.8 GeV/n flattop for RHIC 200 GeV/n Au run.
AU2	3.85 GeV/n Au^{77+} for APEX experiment in RHIC
AU3	Split-merge PP cycle ending July 1 and O^{8+} starting Jan 22
AU4	• Clone of AU1 Gold cycle for AGS studies. • Except on Feb 2 and Feb 6 where it was used as bare proton machine (no snakes) derived from AU6 setup.
AU5	• PP with $G\gamma=7$ flattop ending July 8. No snakes. • EBIS H^{2+} cycle from February 3 to 7.
AU6	PP cycle for RHIC with skew quads used for horizontal resonance correction. Used with BU4 for RHIC.
AU7	• Tandem Au^{77+} with 6 higher intensity Booster transfers for 3 final bunches using 12-6 merge. Used on August 25th • Tandem Au^{77+} with 9 Booster transfers for 3 final bunches with 3-1 (12-8-4) type merge ending Nov. 10. • Tandem Au^{77+} cycle but with 8.65 GeV/n flattop starting January 25 (used for fixed target experiment).
AU8	• PP split-merge cycle but with no snakes. May 5-May 8 • From May 22 to June 27, it had a $G\gamma=7$ flattop with no merge and the snakes on. Used with BU5 so, 2 bunches in the AGS from 1 Booster cycle.

Table II: AGS PPM users in Run 25

When RHIC started using the 12-6-3 merge the L10 cavity voltage, which is used for the h=3 part of that merge, was lowered from its merge value during the ramp up of the h=12 RF just afterwards. This provides smaller longitudinal emittance (ε_{Long}) at the expense of making larger baby bunches. The L10 remained in this 'relaxed' state until July 18th when it was raised to full voltage (4.5 kV) during the h=12 ramp up since there was no obvious drawback seen in RHIC by doing so.

Then on July 28th a "KL squeeze", which uses the KL (h=6) voltage during the ramp up of h=12, was also used to further reduce the amount of baby bunches. It was kept this way when filling from this point on in the run. Both the KL squeeze and the maximum L10 voltage during the h=12 ramp up are used to make the bunches narrower, so they fit better into the h=12 buckets. Surprisingly, ε_{Long} with the KL squeeze, and L10 at maximum voltage, looked a little smaller than without the squeeze, 0.42 vs. 0.48 eVs.

Table III shows ε_{Long} flattop measurements on BU1/AU1 made throughout the run. The first 2 rows are with the 12-6 merge. The amount of beam in the baby bunches when using this merge is negligible. RHIC was filled with the L10 voltage (after the merge) lowered from its maximum value from June 16th to July 18th. ε_{Long} was about 0.33 eVs in this state and about 20% of the beam was in the baby bunches (rows 4-6 and 8). From July 18 to 28th the L10 was at full voltage there (4.5 kV). ε_{Long} was about 0.5 eVs in this state with about 3% baby bunches. From July 18th to Dec. 8th the KL squeeze was also on. ε_{Long} in that state was about 0.42 eVs and the baby bunches were negligible (row 9).

	Time	**Merge**	**Bunch length (ns)**	**N**	**f_{synch} (Hz)**	**ε_{Long} (eVs)**	**Bunch Intensity**	**L10 (kV)**	**Baby bunch**
1	4/30 1757	12-6	14.38	10	89.68	0.18	1.1e9	-	-
2	6/3 1825	12-6	17.7	6	83.79	0.26	1.6e9	-	-
3	6/11 1539	12-6-3	24.72	6	88.2	0.54	3.0e9	4.5	
4	6/16 1559	12-6-3	19.54	5	86.1	0.33	2.4e9	0.8	20%
5	6/20 1411	12-6-3	19.68	5	86.4	0.33	2.6e9	1	18%
6	7/3 1716	12-6-3	20.2	6	85.6	0.35	2.6e9	1	18%
7	7/12 1641	12-6-3	24.29	8	91.2	0.53	2.8e9	4.5	
8	7/17 1722	12-6-3	19.2	10	95.1	0.35	2.4e9	0.7	24.7%
9	7/28 1456	12-6-3	21.56	10	91.36	0.42	2.3e9	4.5*	<1%
10	9/19 1450	12-6-3	22.34	10	95.92	0.48	2.4e9	4.5	2.8%**

Table III: Au^{77+} Longitudinal emittance (ε_{Long}) measurements on AU1 flattop (9.8 GeV/n). N is the number of length measurements, L10 is the L10 voltage when h=12 ramps up. *-indicates that a KL squeeze was also used. **- Baby bunch measurement in similar state from July 14th (17:16 elog entry). Data is from Booster-AGS-EBIS elog from the indicated times.

Booster 6-3-1 merge without the E6 Cavity

In previous runs, the 6-3-1 merge in the Booster used all 4 RF cavities but the E6 RF cavity was unavailable this year.[2] In past years, E6 was used for the h=2 voltage, but this year the B3 cavity performed this part of the merge in addition to being used for h=6 and 1. This year, when using the 12-6 merge, the flattop ε_{Long} was about 0.22 eVs (see Table III, rows 1 and 2). A measured value last year, using all 4 cavities was also 0.22 eVs which suggests there was not an

[2] See K. Zeno, "Run 16 Tandem Gold Performance in the Injectors and Possible Improvement with AGS Type 6:3:1 Bunch Merge in the Booster" C-A/AP/576, October 2016. Pages 8-10 give an overview of this merge.

obvious degradation without E6.[3] Measurements of the flattop ε_{Long} for the 12-6-3 merge were also made in 2024 with L10 at maximum voltage and no KL squeeze. They varied from 0.44 to 0.54 eVs.[4] These are like the values measured this year with L10 at full voltage and no KL squeeze (rows 3, 7, and 10 in Table III).

Shortening the Supercycle with the 12-6-3 Merge

On May 31st, when RHIC started taking Gold, the supercycle length was 6.6 sec. On June 2nd that was changed to 6.0 sec and remained there until June 19th when it was changed to 5.4 sec. On June 16th, in preparation for the 5.4 sec length, the flattop was shortened since it can be shorter with the 12-6-3 than with the 12-6 merge as there are only 2 bunches extracted instead of 4.

On June 26th the supercycle length was further reduced to 4.8 sec. However, there was not enough time in the 4.8 sec supercycle to fit EBIS timing for NSRL. So, when not filling RHIC the number of Tandem requests was typically kept at 4 instead of 8 to provide room for the NSRL EBIS request, and if 8 were desired the length was switched to 5.4 sec.[5] The length can only be changed in steps of 600 ms because it has to be a multiple of both 150 ms and 200 ms to satisfy both EBIS and Linac timing requirements.

Other Changes to the AGS Magnet Cycle for the 12-6-3 Merge

To reduce the supercycle length from 5.4 to 4.8 sec the AGS main magnet down ramp had to be shortened. Also, the ramp just after the merge was slowed down because there was a loss there, especially when using the 12-6-3 merge. This change caused the F-to-P transfer to happen at a higher field (0.97 vs. 1.25 kG). The loss happened near where the transfer occurs and after this change it no longer happened.[6]

The loss was small with the 12-6 merge bunches but was significant with the larger 12-6-3 bunches. More accelerating voltage is required to deal with the P bank's higher voltage ripple and the transient at the switch from the F to the P bank. Because of this change the beginning of the flattop had to be moved 50 ms later.[7] These changes to the magnet cycle were made on May 29th. Afterwards a large loss might appear near transition if a cavity were to trip off, instead of early in the ramp where it normally would be.[8]

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[3] See Booster-AGS-EBIS elog entries on Oct. 10 2024 from 1758 to 1814. This is also about the same value measured in previous years. For example, see Table I on page 5 of K Zeno, "The 2023 Gold Run in the Injectors", C-A/AP/706. Note the G5 WCM was used for the measurements in Table III to measure the bunch lengths.
[4] See K. Zeno, "The 2024 Run in the Injectors" C-A/AP/715, February 2025, pg. 34.
[5] See Booster-AGS-EBIS June 26 2025 elog
[6] See in K. Zeno, "The 2024 Run in the Injectors" C-A/AP/715, February 2025, pgs. 34-35.
[7] See E. Herbert, Booster-AGS-EBIS May 29, 2025 elog 1742 entry
[8] See Booster-AGS-EBIS July 3, 2025 elog entries from 1601 to 1630.

Administrative Intensity Limits

The administrative Booster Late intensity limit for 5.4 sec was 16e9 Au ions, but was initially lowered to 14.3e9 ions when running the 4.8 sec cycle. On Oct. 10th it was raised back to 16e9. This limit is in place to protect the BtA stripping foil from overheating. Its presence did not affect the intensity delivered to RHIC. There was no obvious deterioration of the BtA foil's performance during the run. Only foil 5 was used and its position was set to the integer value for the entire Gold run, meaning it remained centered in the beampipe.

The administrative AGS Late intensity limit, which exists to protect the plunging stripping foil and the J10 dump, was 8.0e9 Au ions which is the same as it was in the last two 9.8 GeV/n Au runs. Although there is some flexibility in the Booster Late limit this limit cannot be raised.

When the 12-6 merge is used, since there are 4 final bunches, there can only be at most an average of 2.0e9 ions/bunch. But there is cycle-to-cycle intensity variation, mainly due to variations in the Tandem beam, which makes it very difficult, or impossible, to average 2.0e9/bunch over the course of a fill. Perhaps the best-case scenario would be 1.9e9/bunch. Then if I estimate 10% loss between AGS and RHIC this is reduced to about 1.7e9/bunch.

The average AGS Late during filling from August through November using the 12-6-3 merge was about 4.6e9, or 2.3e9/bunch. But in this case the AGS limit of 8.0e9 corresponds to 4.0e9/bunch, which is far more than RHIC requires. However, for the same supercycle length, it takes twice as long to fill than it does with the 12-6 merge. This is a problem because the longer the filling time is the more debunched beam there will be (caused by intra-beam scattering) and the longer the beam sits at injection energy the more its transverse emittance increases.

If there were only 6 Tandem requests and the 12-6 merge was used there could be 3 final bunches and the AGS Late limit would correspond to a maximum average bunch intensity of 2.67e9 per cycle. Instead of twice as long, it would only take 1.33 times as long to fill assuming the supercycle length remains unchanged. Since there are 2 less transfers the injection porch could be 533 ms shorter but the flattop would have to be 225 ms longer for the third extraction. So, the AGS cycle could be about 300 ms shorter, by itself not enough to reduce the supercycle length by 0.6 sec. The shortest cycle used this year with the 12-6 merge was 6.0 sec but it likely could have been shortened to 5.4 sec if there were only 3 final bunches.

The cycle-to-cycle intensity variation would be worse though so, in the best case the average on the flattop for a fill would maybe be 2.5e9/bunch. These bunches will be larger transversely and so I would expect the transfer efficiency to be worse, maybe 85 instead of 90%. This leads to an average bunch intensity in RHIC for a fill of 2.1e9.

The run used the 12-6-3 scheme from June 16th until Dec. 18th, when the Au run ended. From late June until the end of the run the average filling bunch intensity was about 2.2e9 in yellow and 2.1e9 in blue. This is just slightly more than what ideally could have been achieved using the 3 final bunch scheme, but filling with that would have been 33% faster than with the 4.8 sec long 12-6-3 merge cycle.

Attempts to Provide 3 Bunches per AGS Cycle

Using 6 Booster Transfers and the 12-6 merge in the AGS

There were several schemes that were tried to make a viable setup for 3 final bunches. The first one, mentioned above, is simply to use 6 Tandem pulses instead of 8 to reduce the constraint that the AGS Late limit of 8e9 puts on the maximum bunch intensity.

In the early days of RHIC only 4 Booster transfers were used and each transfer resulted in a bunch for RHIC. The supercycle was also shorter, typically around 4.1 sec. The late intensity, for one Booster cycle, was as high as 3.5e9 and Booster Late (with 4 cycles) was as high as 13.7e9.[9] If the same per cycle intensity were available now that would correspond to a Booster Late of 20.6e9 for 6 transfers, well over the amount needed to reach 8.0e9 in the AGS.

To get to a Booster Late of 13.7e9 there was a lot of tuning involved, and it took a long time (weeks to months) to get there. Even so, an AGS late intensity higher than 8.0e9 should be obtainable. Despite that, in the time that was devoted this run to increasing the Booster intensity the highest per Booster cycle obtained was about 3.0e9. Even so, this is well above 2.67e9.

In one case, for each of 2 Booster transfers in an AGS cycle Booster Late intensities of 2.6e9 were obtained and the AGS Late was 2.5e9.[10] Later on in the run, there were 2 pulses with Booster Late intensities of 2.96e9 and 2.76e9 but still with an AGS late of 2.47e9. The beam was on the first 2 transfers which may be why the AGS late/Booster Late efficiency is less than 50% as there is a slow loss on the injection porch that is often bunch intensity dependent.[11]

In Run 21, during 3.85 GeV/n Tandem Au running the AGS bunch intensity on the flattop regularly reached 2.4e9. Since there were 4 final bunches (8 transfers) this corresponded to the AGS administrative limit of 9.6e9 that was in place at the time. Once AGS Late (inadvertently) reached 11.0e9 corresponding to 2.74e9/bunch. This was with 8 transfers, which should be harder to reach than with 6. The 3.85 GeV/n setup was like the one used this year except for the lower flattop and the fact that the beam doesn't go through transition, both of which shouldn't matter.[12]

On Aug. 25th 6 transfers were used and the AGS Late was as high as 7.0e9 corresponding to a bunch intensity of 2.33e9. This appears to be the highest AGS late bunch intensity obtained this run for 6 pulses, although it seems likely that this could have been improved but it would

[9] See Booster-AGS-Au_2011 elog May 24 17:12 entry
[10] See Booster-AGS-EBIS Aug 18 2025 elog 1711 and 1804 entries.
[11] See Booster-AGS-EBIS Aug 19 2025 elog 1715-1851 entries.
[12] See K. Zeno, "Run 21 in the Injectors", September 2021, C-A/AP/653, Figure 1 on pg. 5. The cycle in question was at 01:24 on April 17th 2021.

take time. This work was done on AU7. The injection porch length was not shortened but the flattop was extended to allow for a third extraction and the supercycle was 5.4 sec long.[13] This setup was not used in RHIC.

One problem observed with this setup is that the late intensity on the 6 Booster cycles tends to drop from one cycle to the next even when the Tandem and early booster intensity do not. This is likely because the vacuum deteriorates over the 6 cycles from beam loss which causes more beam loss (see Figure 1). It is not as noticeable on the typical 12-6-3 cycle because the intensity is not being pushed.

There are also a few notable differences between the Tandem Au setup from the early days of RHIC and this setup. The Booster cycle was 200 ms long but now it is 267 ms long. It is longer because it has a merge porch and this provides more time for these vacuum-related losses to occur. There are also 6 cycles instead of 4 and cycles 5 and 6 will be more affected by the deteriorated vacuum than the first 4. These vacuum-related losses were also a problem during the early days but perhaps not as pronounced because of these differences.[14] They can typically be reduced by reducing the other sources of beam loss since they deteriorate the vacuum.

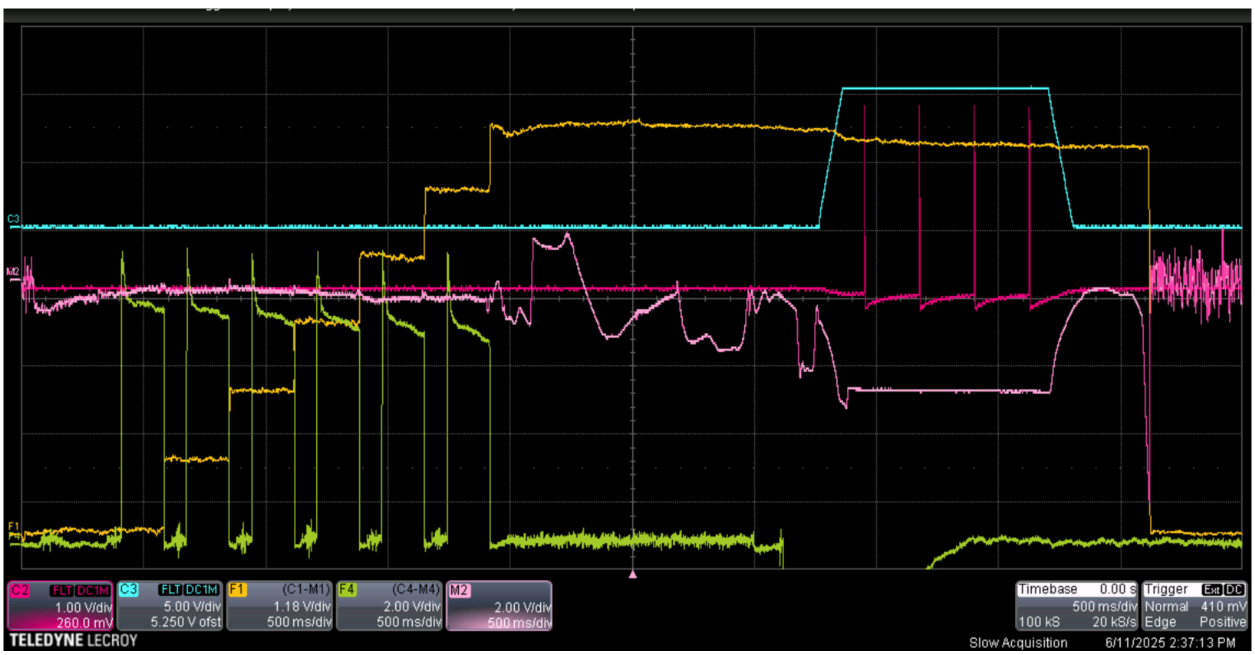

Figure 1: The 6 Booster cycles (green) showing the increasing loss from one cycle to the next. Note that the early intensity across the 6 cycles is about the same. Also shown is the AGS normalized current transformer (orange), the H10 extraction septum current pulses (red), the G09 extraction bump current (blue) and a horizontal BPM (pink). The trigger is at 2500 ms and the sweep speed is 500 ms/div.[15]

[13] See Booster-AGS-EBIS Aug 25 2025 elog 1312-1644 entries. The supercycle could have been shortened to 4.8 sec if the injection porch were shortened, but we didn't get that far.
[14] See Booster-AGS-Au_2011 May 24, 2011 elog 17:15 entry
[15] Taken from the Booster-AGS-EBIS June 11 2025 elog 14:31 entry. The Booster Late intensities for the 6 pulses are 2.418, 2.345, 2.287, 2.247, 2.162, and 2.125e9.

A Hybrid Merge Using 2 Tandem Users

The 12-6-3 merge with 8 Booster transfers can be used to merge 2 sets of 3 bunches into 2 final bunches and the 2 remaining bunches into 1 bunch by changing the BtA cogging pattern. This results in 3 final bunches. The final bunch made from only 2 bunches would normally have only 2 thirds the intensity of the other 2. However, the Tandem pulse width for those 2 cycles can be controlled independently from the other 6 by using a different Tandem user for them.

Figure 2 shows a mountain range of the merge in this configuration. It might have been better, in the case where only 2 bunches are merged, if the incoming bunches were shifted to the right by one bucket but it turns out this does not quite leave enough room for the A5 kicker pulse.

Unfortunately, the Tandem current is known to wander so adjusting the pulse widths and whatever else while filling can be difficult. In the case where the 2.3e9/bunch is desired on the flattop the 3-1 bunches coming into the merge should be 2.3e9/3=0.77e9 and the 2-1 bunches should be 2.3e9/2=1.15e9. If AGS Late/Booster Late were 55% (a typical value) then those bunches at Booster late should have intensities of 0.77e9/0.55=1.4e9 and 1.15e9/0.55=2.1e9, respectively. The total Booster Late intensity would be 12.6e9 and AGS Late would be 6.9e9. There is a GPM that can be used to monitor Booster Late on the individual cycles.[16] Ideally, this setup seems possible but trying to control the intensities of 2 sets of bunches may not be practical.

The bunch lengths on the flattop were measured. For the 3-1 bunches an average of 5 measurements was 23.72 ns and for the 2-1 merge they were 27.2 ns and there is more variation for the latter. If the bunches coming into the 2-1 merge are shifted to the right one bucket to make the merge more symmetric the bunches average 23.0 ns.[17] The normal 12-6-3 bunches are about 21.6 ns (see row 9 in Table III).

RHIC had a store using this hybrid merge. The average bunch intensity in RHIC was about 2.0e9, lower than for a normal fill (2.15e9). Judging from the logged RHIC WCM data the 3-1 bunches at RHIC injection in yellow were about 2.25e9 and the 2-1 bunches were about 1.8e9, only about 80% of the 3-1 bunches.[18] AGS Late did average about 6.9e9 and Booster Late was about 13.8e9.

[16] See Booster-AGS-EBIS July 29 2025 elog entry at 17:26
[17] See Booster-AGS-EBIS July 29 2025 elog entries from 17:29 to 18:05. As mentioned, the A5 pulse precludes using this cogging pattern.
[18] See also Booster-AGS-EBIS Aug. 4, 2025 18:64 entry where I show that the 2-1 bunch intensity in RHIC is about 84% of a 3-1 bunch. Analysis of the logged AGS current transformer data indicates the 2-1 bunch was about 82% of the 3-1 bunch intensity, see Test_Keith elog July 15, 2026 13:28 entry.

Although the intensity was lower in RHIC for the hybrid merge fill, the initial collision rates were the same as for a normal store and the transverse emittances were much smaller.[19]

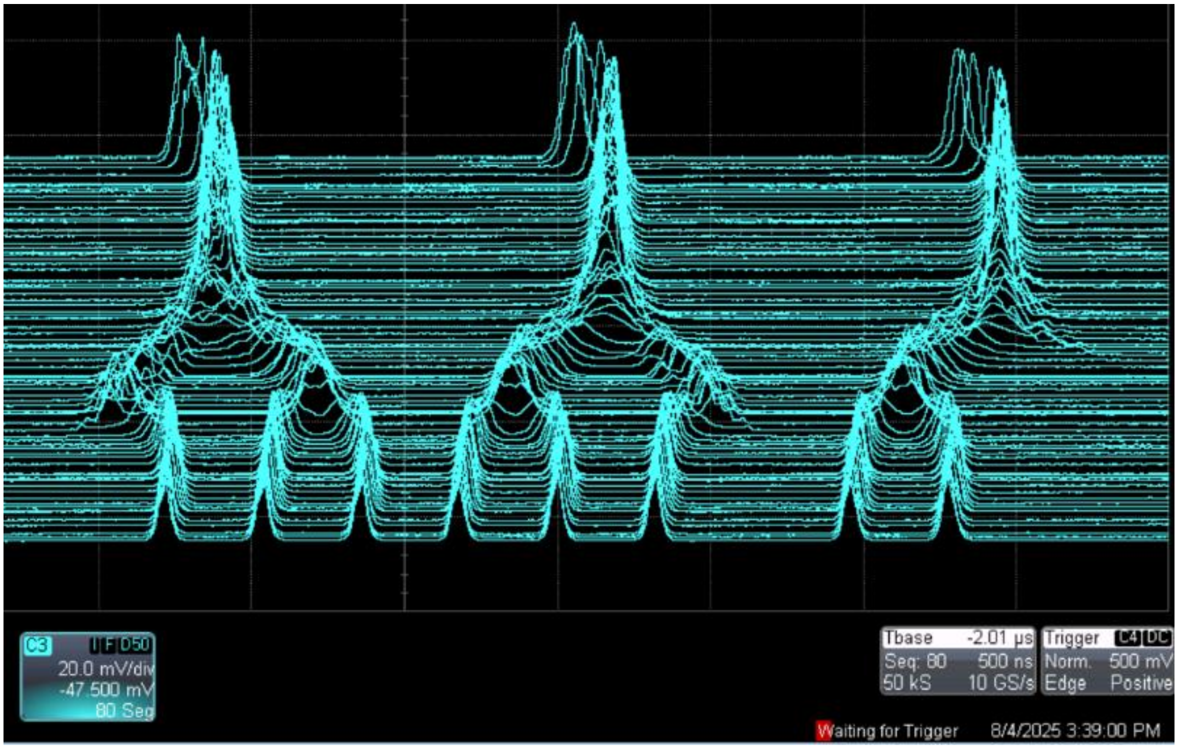

Figure 2: Mountain range display of the AGS 12-6-3 merge where the 2 final bunches on the left are made of 3 incoming bunches and the bunch on the right is only made of 2.[20] Looking from At0+2200 ms to 2400 ms.

9 Booster Cycles with Beam and a 12-8-4 Merge in the AGS

A problem developed with the Booster main magnet power supply (BMMPS) on Sept. 9th. The power supply group did not expect to fix it quickly. However, the BMMPS would work if the peak current on the magnet cycle were lowered. It was decided to modify the magnet function, reducing its peak field to 94% of what it normally is, and adjusting BtA and the AGS to compensate, so that RHIC could continue running. This setup was established that evening and the normal setup was restored the next day.

To do a more traditional 3-1 type merge in the AGS 9 transfers from the Booster are required. This requires 10 Booster cycles and 10 of the normal cycles are over the alarm PPMR limit. But it turns out that 10 of the cycles with the lower peak field remain below the alarm limit for the PPMR.[21] It was set up on BU7 and AU7. The supercycle length could be as short as 5.4

[19] See T. Shrey RHIC elog entry on Aug. 4, 2025 at 21:48.
[20] Taken from Booster-AGS-EBIS August 4 2025 elog entry at 15:38.
[21] This was not only verified with the PPMR calculation in Superman but 10 of the 6.4 kG peak field cycles was also checked locally by Ed Bajon (see Booster-AGS-EBIS Sept. 24th 2025 14:53 entry).

sec but was often 5.8 sec to accommodate NSRL.[22] It needs to be longer than the 4.8 sec AU1 does because the injection porch needs to have room for 9 cycles and the flattop must be longer for the 3rd extraction to fit. Figure 3 shows the normal AGS magnet function and the one for the 9 transfer AU7 cycle and Figure 4 shows a mountain range of the 12-8-4 (3-1 type) merge.

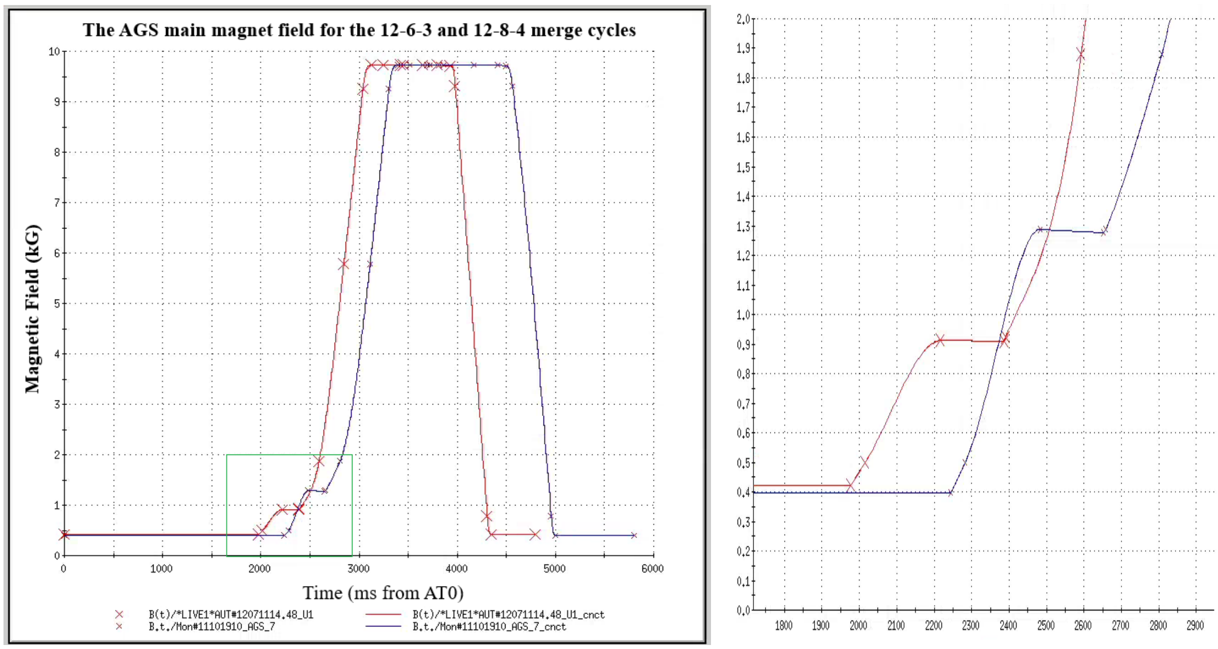

Figure 3: Comparison of the standard AU1 Gold magnet cycle (red) and the AU7 12-8-4 merge magnet cycle (black). The y-axis is the magnetic field in Kilogauss and the x-axis is time from AT0 in milliseconds. The plot on the right highlights the early ramp.

The beam was extracted to the W dump on October 17th. AGS Late was as high as 7.8e9 corresponding to 2.6e9/bunch.[23] The extraction efficiency (uxf1/AGS Late) was about 90% whereas it is normally about 95% on AU1. Booster Late was as high as 1.55e9 during this period, which is close to the administrative limit of 16e9. It would not be hard to reach the AGS Late limit although the Booster Late required would be about 16e9. As mentioned earlier, the Booster Late limit is not set in stone and could probably be raised if it became necessary.

The efficiency (AGS Late/Booster Late) on AU1 is typically about 55% and on AU7 (with 9 transfers) it was about 51% with this AGS Late intensity.[24] So for the same AGS Late, Booster Late is closer to the limit on AU7. The BtA stripping efficiency to Au^{77+} is expected to go down with lower Booster extraction energy, this may be a reason why the efficiency is lower with this setup. The transverse emittance at transfer should also go up a little with lower transfer energy which doesn't help.

[22] BLIP and OPPIS must've been off to allow for a 5.8 sec supercycle.
[23] See Booster-AGS-EBIS Oct. 17, 2025 elog 16:35 entry.
[24] See Booster-AGS-EBIS Oct. 17, 2025 elog 16:35 entry.

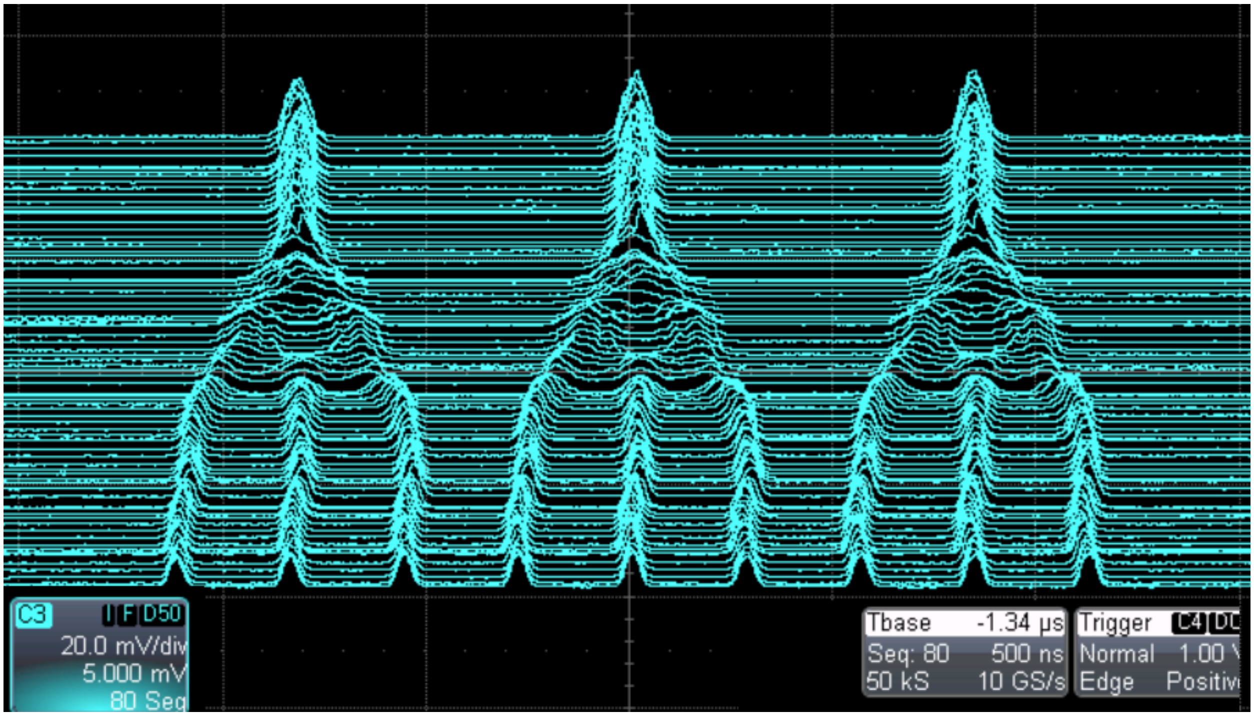

Figure 4: A mountain range display of the AU7 12-8-4 merge used to produce 3 final Gold bunches. Looking from AT0+2450 to 2650 ms.[25]

Ideally, the flattop longitudinal emittance would be 50% higher than the 12-6 merge value of 0.22 eVs (Table III rows 1 and 2) but it was much higher than that, 0.55 vs. 0.33 eVs, for some reason.[26]

This setup is different from the AU1 cycle in that the merge porch happens at a higher energy and the AMMPS switches from the F bank to the P bank on the ramp to the merge porch. The magnet function was changed so that it remained on the F bank during the ramp. The bunch lengths on the flattop were measured in this state and with it switching to the P bank on the ramp. Without the switch to the P bank on the ramp to the porch the bunch length was 23.9 ns and with it they were 24.1 ns, essentially the same.[27] The magnet was left with the transfer from the F to P bank on the ramp to the merge porch taking place.

Table IV contains ε_{Long} measurements made at different points in the cycle. They indicate significant growth between the injection porch and the end of the ramp to the merge porch (0.318 to 0.465 eVs)[28] and growth from the merge (0.465 to 0.63 eVs)[29]. The measurements indicated there was no growth from just after the merge to the flattop. In fact, the flattop ε_{Long} value is smaller than it is just after the merge.

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25 Taken from Booster-AGS-EBIS Oct. 17, 2025 elog 15:05 entry.
26 See Booster_AGS-EBIS Oct. 2, 2025 elog entries 14:26 and 14:31.
27 See Booster-AGS-EBIS Oct. 16, 2025 elog entries from 14:17 to 14:56.
28 See Booster-AGS-EBIS Oct. 24, 2025 elog 17:00 to 18:54 entries
29 See Booster-AGS-EBIS Oct. 30, 2025 elog 15:21 and 15:25 entries.

Date	Time from AT0	Part of the Cycle	Bunch length (ns)	N	f_{synch} (kHz)	Bunch ε_{Long} (eVs)	Total ε_{Long} (eVs)
10/30/25	1000 ms	Injection porch	347	4	1.085	0.106	0.318
10/30/25	2480 ms	Just before merge	89.04	6	1.394	0.155	0.465
10/30/25	2640 ms	Just after merge	153.4	5	2.015	0.63	0.63
10/2/25	3700 ms	Flattop	24.08	5	95.76	0.55	0.55

Table IV: Summary of ε_{Long} measurements made on the 12-8-4 merge cycle with 3 final bunches (AU7). N is the number of length measurements made.

Figure 5 shows the BU7/AU7 setup.[30] Unfortunately, it was not used in RHIC as there was a lot going on and RHIC was satisfied with the 12-6-3 beam. The 12-8-4 merge uses stations K for h=8 and KL for h=4. The L10 cavity is not used, so if we were running AU1 and L10 broke this setup could be used instead.

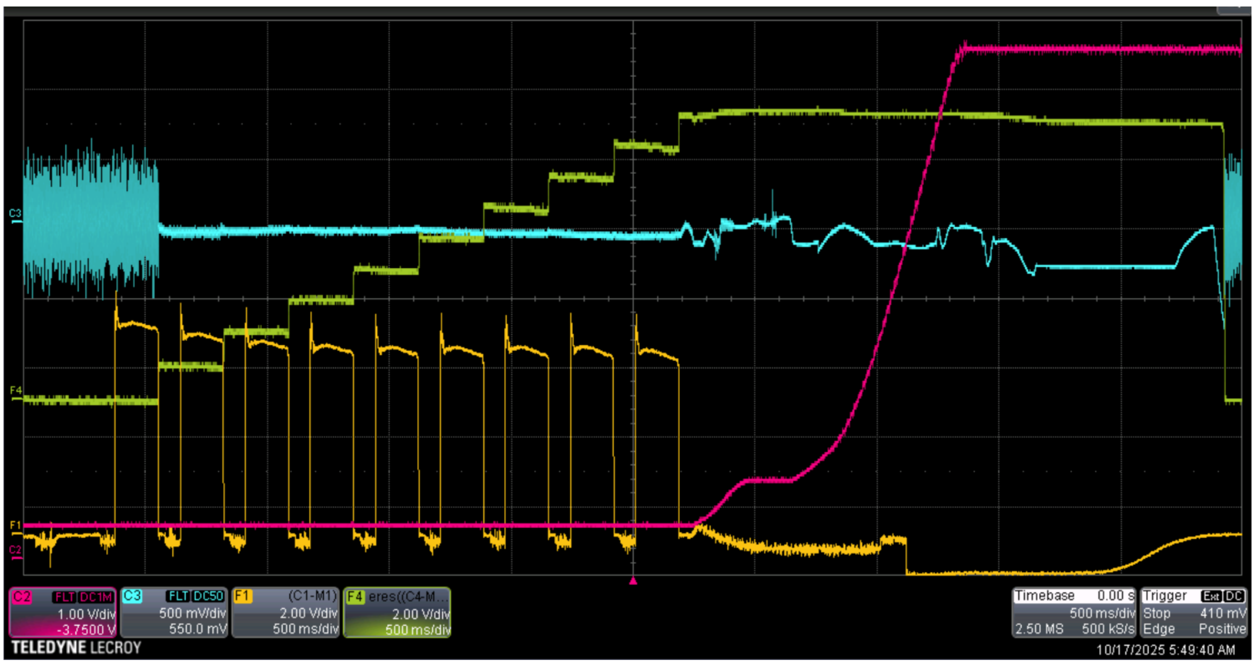

Figure 5: The AU7 Gold cycle which has a 3-1 merge and 9 Booster Transfers at 94% of the AU1 injection rigidity. AGS Late is 7.6e9 ions. F4 (green) is the AGS normalized current transformer, F1 is the Booster normalized circulating transformer, C2 is the AGS main magnet current, and C3 is the J12 horizontal BPM. 500ms/div. Trigger is AT0+2000 ms.

Studies with AU1 Gold Beam

For the same final bunch intensity a bunch on the injection porch and ramp to the merge porch with the 12-6-3 merge only has to be half the intensity it is when a 12-6 merge is used. Consequently, the injectors don't have to be pushed as much to reach the required RHIC bunch intensity. When the injectors are not pushed the final transverse emittance is smaller.

[30] Taken from Booster-AGS-EBIS October 16, 2025 elog 17:45 entry,

For Gold there are 2 mechanisms which affect the transverse emittance. First, because of the nature of multi-turn injection, the longer the Tandem pulse width the more the aperture will be filled during injection resulting in larger transverse emittance. The other mechanism is space charge, both in the Booster and the AGS. Space charge effects early in the Booster cycle and in the AGS on the injection porch and early acceleration ramp can cause emittance growth.

A study was done last year looking at the dependence of flattop emittance on bunch intensity for the 2 merges where the intensity was varied with the Tandem pulse width.[31] The data shows the different intensity dependence of the flattop emittance for the 2 merges. For a bunch intensity of 2.5e9 (typical filling intensity) the data shows the 95% normalized transverse emittance (ε_x, ε_y) from the IPM is expected to be (13.5, 10.2) mm mr for the 12-6 merge and (11.0, 6.3) mm mr for the 12-6-3 merge.[32] An IPM measurement of (ε_x, ε_y) =(10, 8.5) mm mr was made this year on June 20th with the 12-6-3 merge with RF off at 3500 ms and 2.2e9/bunch.[33] A measurement with the RF on and 3.0e9/bunch was (12, 12.8).[34]

A study was performed on Nov. 3rd to see the effect of different pulse widths (315 and 600 μs) on the transverse emittance in BTA before (MW006) and after (MW060) the stripping foil.[35] Table V shows the results. The emittance growth at MW006 between the 2 pulse widths is a factor of 1.68 in the horizontal and 1.89 in the vertical. At MW060 it is less, about 1.30 in both planes. The effect is expected to be less downstream of the foil, and it seems to be, but it is still significant.

	MW006 FWHM x	MW006 FWHM y	MW060 FWHM x	MW060 FWHM y
315 μs	2.69 mm	6.72 mm	8.27 mm	13.76 mm
600 μs	3.49 mm	9.23 mm	9.48 mm	15.44 mm
ε growth	$(3.49/2.69)^2$=1.68	$(9.23/6.71)^2$=1.89	$(9.48/8.27)^2$=1.31	$(15.44/13.76)^2$=1.26

Table V: Growth between Tandem pulse widths of 315 and 600 μs in transverse profile FWHMs in BtA before (MW006) and after (MW060) the stripping foil. The final bunch intensity for the 315 μs case was 1.8e9 and it was 3.5e9 for the 600 μs case. This is foil 5.

Table VI also shows the emittances on the injection porch for the 2 pulse widths using the IPM. The MW006 emittance in the 300 μs case is about the same as the IPM injection porch value but it should be smaller because of the foil. In the 600 μs case the MW006 measurement is much larger than the IPM indicates. The emittance also grows while on the porch, perhaps more so in the 600 μs case.

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[31] See K. Zeno, "The 2024 Run in the Injectors" C-A/AP/715, February 2025, pgs. 34-37.

[32] Last year's measurement was made with logged data of the 'fit by manager' emittances because I could not find logged data for the 'refit' option in the AGSIPM program. The 'fit by manager' value is usually smaller than the 'refit' value but the different intensity dependence in each case is still apparent. The RF was also shutting off at 3500 ms.

[33] See Booster-AGS-EBIS June 20, 2025 elog 18:59 entry. This was using the refit option with RF off.

[34] June 20th 19:05:41 2025 logged data using AGSIPM program. Note that when the RF is on the measured emittance may read high.

[35] See Booster-AGS-EBIS Nov. 3, 2025 elog entries from 16:07 to 16:15

Pulse width	MW006 (ε_x, ε_y) (mm mr)	On Inj. porch@500 ms (ε_x, ε_y) (mm mr)	End of Inj. porch@2000 ms (ε_x, ε_y) (mm mr)
315/300 μs	(5.93, 7.00)	(5.0, 7.5)	(6.0, 7.5)
600 μs	(9.99, 13.2)	(6.5, 9.0)	(8.0, 10)

Table VI: 95% Normalized Transverse emittances at MW006 (calculated using FWHMs in Table V) and on the AGS injection porch using the IPM. The IPM data used a 300 μs not 315 μs pulse width. The difference is small. This is using the 12-6-3 merge and the 'refit' option in the AGSIPM program. The final bunch intensities were 2.6e9 (300 μs) and 3.7e9 (600 μs). The 300 μs case is from Nov. 3 at 16:54:17 2025 and the 600 μs case is from 16:55:05 the same day.[36] The RF was on.

Oxygen from Tandem

Work began on establishing Oxygen in the Booster (BU3) on January 18th. O^{6+} from EBIS had been used in RHIC in 2021 but this year O^{6+} would come from Tandem (MP7).[37] The basic setup from 2021 was used but it was modified for a different injection rigidity. The injection rigidity was kept the same as it was for Tandem Au^{31+}, which allowed for easier switching between the two.[38] Fortunately, this rigidity allows for an RF frequency within the acceptable range for h=4 RF at Booster injection, 4∗157.209Hz=628.8 kHz. Since the Oxygen has the same charge state as it did in 2021, the 4-2-1 merge porch and the merge itself from 2021 can be used. The Booster cycle from 2021 also has the correct extraction field.

O^{8+} was set up in the AGS on AU3 using a modified Tandem Au setup from AU1 with the 12-6-3 merge (in 2021 an 18-9-3 merge was used). The injection field for O^{8+} is significantly higher than for Au^{77+}, 598 vs. 422 G on the magnet function[39]. f_{rev} at AGS injection is 240,350 Hz which corresponds to an h=12 frequency of 2.8842 MHz. The L10 cavity, used for the h=3 part of the merge, has a very small frequency range, and normally runs at 783 kHz. With the Au merge porch the L10 frequency would have been 876 kHz so it was lowered about 200 G. After this change the merge porch was only about 100G higher than the injection porch.

The maximum AGS Late intensity reached during this weeklong run was about 5e10 with about a 200 μs Tandem pulse and 8 Booster transfers for 2 final bunches.[40] During this time Booster input was about 8.4e10 and Booster Late was about 5.4e10. The amount of beam in the baby bunches was about 2-3% which gives a final bunch intensity of 0.975*5e10/2=2.4e10. A typical bunch intensity on the AGS flattop when filling was about 1.5-1.6e10.

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[36] See Booster-AGS-EBIS elog Nov. 3, 2025 elog entries at 16:54 and 16:55. Also, there was some TTB tuning done between the BtA and IPM measurements. That is why the 315 μs intensity is lower for the BtA case than for the IPM one.
[37] K. Zeno, "Run 21 in the Injectors", September 2021, C-A/AP/653, pgs. 18-23
[38] The Booster injection field using the hall probe was 593 G. See Booster-AGS-EBIS Feb. 3rd, 2026 elog 1443 entry.
[39] The AGS injection field for O^{8+} was 647 G according to the hall probe.
[40] See Booster-AGS-EBIS Feb. 1, 2026 elog 16:13 entry. Using EBIS, in 2021, the highest AGS Late was 2.35e10 and it was with a Booster Input of 3.30e10. There were 2 final bunches in 2021.

Foil 4 in BtA was used to strip from O^{6+} to O^{8+}. It is a 4.56 mg/cm^2 Aluminum foil. The BtA efficiency was typically over 90%. The stripping efficiency of the foil was not investigated while Oxygen was running. Figure 6 shows the Oxygen setup.[41] The bunch length on the 12.3 GeV/n flattop was 27.25 ns which corresponds to an ε_{Long} of 0.68 eVs/n. In 2021, with a 12-6-2 merge in the AGS ε_{Long} was about 1.1 eVs/n. Although Au and O are injected into RHIC at the same rigidity, Au is extracted from the AGS at a slightly higher rigidity and then stripped from 77+ to 79+.

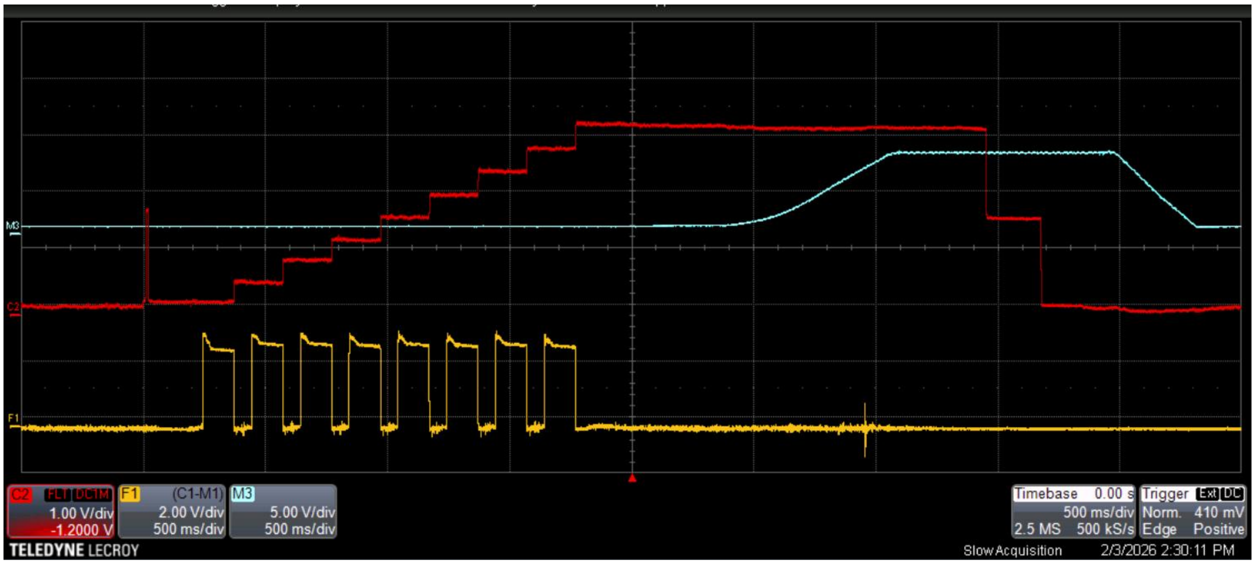

Figure 6: The Tandem Oxygen setup in the Booster and AGS (BU3/AU3) while filling. The AGS Late intensity is about 3e10. The red trace is the AGS normalized current transformer, the orange trace is the Booster normalized current transformer, and the blue trace is the AGS main magnet current. Note there is very little beam remaining in the AGS after the last extraction. The trigger is at AT0+2000 ms. 500 ms/div.

The 95% normalized transverse emittances at MW006 in BtA, $(\varepsilon_x, \varepsilon_y)$, were (5.5, 4.6) mm mr with a 150 µs pulse (Figure 7). The Booster Late intensity was about 5e9 for 1 cycle (the equivalent of about 2.8e10 at AGS late with 8 transfers). In 2021, using EBIS, $(\varepsilon_x, \varepsilon_y)$, was (4.1, 2.0) mm mr when AGS Late for 12 transfers was about 1.1e10.[42]

The AGS IPM indicates an $(\varepsilon_x, \varepsilon_y)$ of (7, 8) mm mr on the injection porch with 4 transfers of 5.5e9 each which corresponds to a flattop bunch intensity of 2.0e10.[43] There is data for the flattop for 2e10/bunch too, $(\varepsilon_x, \varepsilon_y)$=(18, 18) mm mr, but the RF was on so those values are probably too high. The flattop $(\varepsilon_x, \varepsilon_y)$ from the IPM in 2021 was (10.1, 8.4) mm mr. AGS Late

[41] Taken from Booster-AGS-EBIS Feb. 3, 2026 elog 14:36 entry.
[42] See K. Zeno, "Run 21 in the Injectors", September 2021, C-A/AP/653, pg. 23.
[43] See Booster-AGS-EBIS Jan. 27 2026 elog 16:52 entry. AGS Early was 2.2e10 for 4 transfers to the AGS. So, the bunch intensity on the injection porch (before the merge) was 2.2e10/4=5.5e9.

for 2 final bunches was about 2.3e10 and the RF was on for it as well.[44] The bunch intensity is about half what it is in the measurement described just above (1.15 vs. 2.0e10).

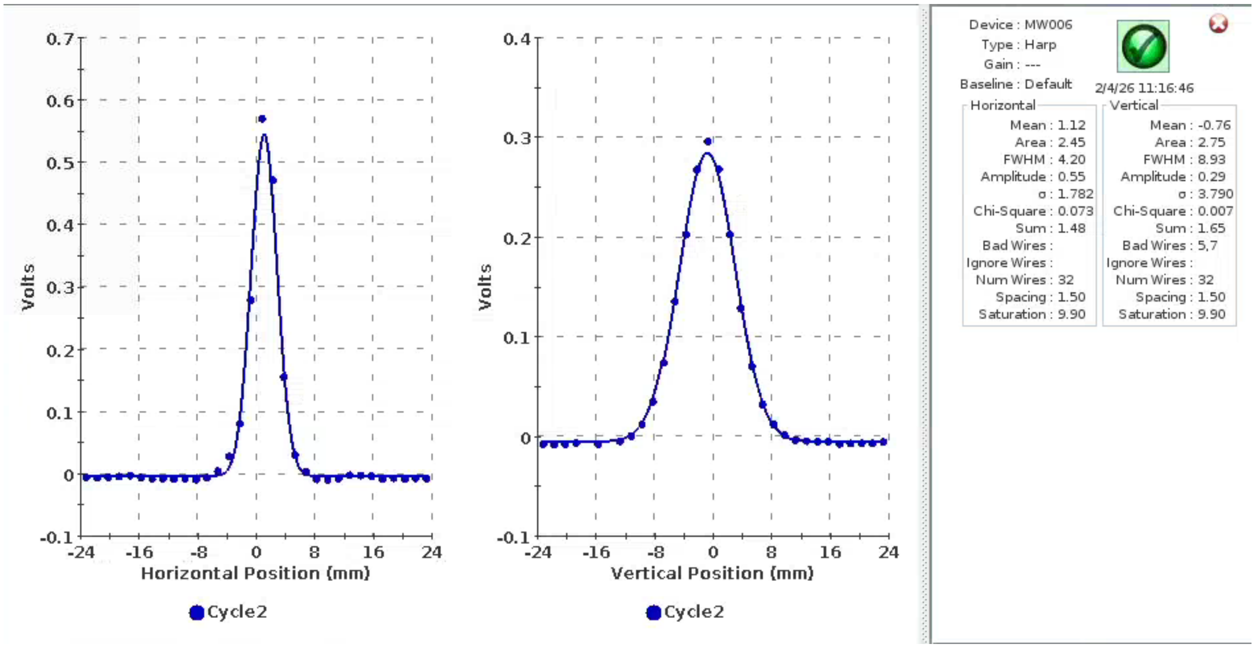

Figure 7: BtA MW006 multiwire O^{6+} profiles from Feb. 4th. The FWHMs for the horizontal and vertical are 4.20 and 8.93 mm, respectively. These correspond to an ε_x of 5.5 mm mr and an ε_y of 4.6 mm mr.[45]

The C3 inflector was a problem during most of the Oxygen run. Although it may not have had a significant impact on Oxygen running in RHIC, it did in the injectors. The required setpoint was quite high, about 69 kV, and it would often trip when switching back and forth between Oxygen and NSRL when NSRL had a much lower setting (both the RHIC and NSRL Booster user coexist on the same supercycle). So, when filling, NSRL had to stop taking beam so it wouldn't trip.

In addition, Tandem had problems with voltage regulation which caused the Booster intensity to become unstable. The inflector's performance continued to deteriorate. Eventually its setpoint had to be varied by large amounts to keep the beam injecting into the Booster. These amounts were so large that it was very unlikely the required changes could have been compensating for some other problem. Having this and the regulation problem happening around the same time made it very difficult to provide stable beam. The regulation problem was fixed on Feb. 3rd. Attempts were made to stabilize C3, and finally the power supply was replaced on Feb. 4th, which fixed the problem. The run ended on Feb. 6th.

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[44] See K. Zeno, "Run 21 in the Injectors", September 2021, C-A/AP/653, Footnote 56 on bottom of pg. 23.

[45] See Booster-AGS-EBIS Feb. 4, 2026 elog comment below 11:16 entry. The equations used to calculate 95% normalized emittances from FWHM at MW006 are $\varepsilon_x=0.31*(\text{fwhm\_x})^2$ and $\varepsilon_y=0.0574*(\text{fwhm\_y})^2$ using β_x=3.0m and β_y=16m at MW006. and $\beta\gamma$=0.849.

Polarized Proton Intensity Scans in BtA with Fixed Scraping

In Run 24 there were intensity scans which used the Linac pulse width and a fixed amount of scraping in Booster. These were done for what was the normal PP setup (BU4/AU4) and the split-merge setup (BU3/AU3). Both used the tune jump quads in the AGS which were replaced this year by the skew quads.[46]

The focus of the scans was the flattop transverse emittance. During those scans it was noticed that the transverse emittance at BtA MW006 depended on the pulse width even though the scraping remained fixed.[47] This effect was more pronounced for BU4 than for BU3. This type of scan was repeated this year, looking at BtA, for the standard split-merge Booster setup (BU5 this year) and BU4 setup.

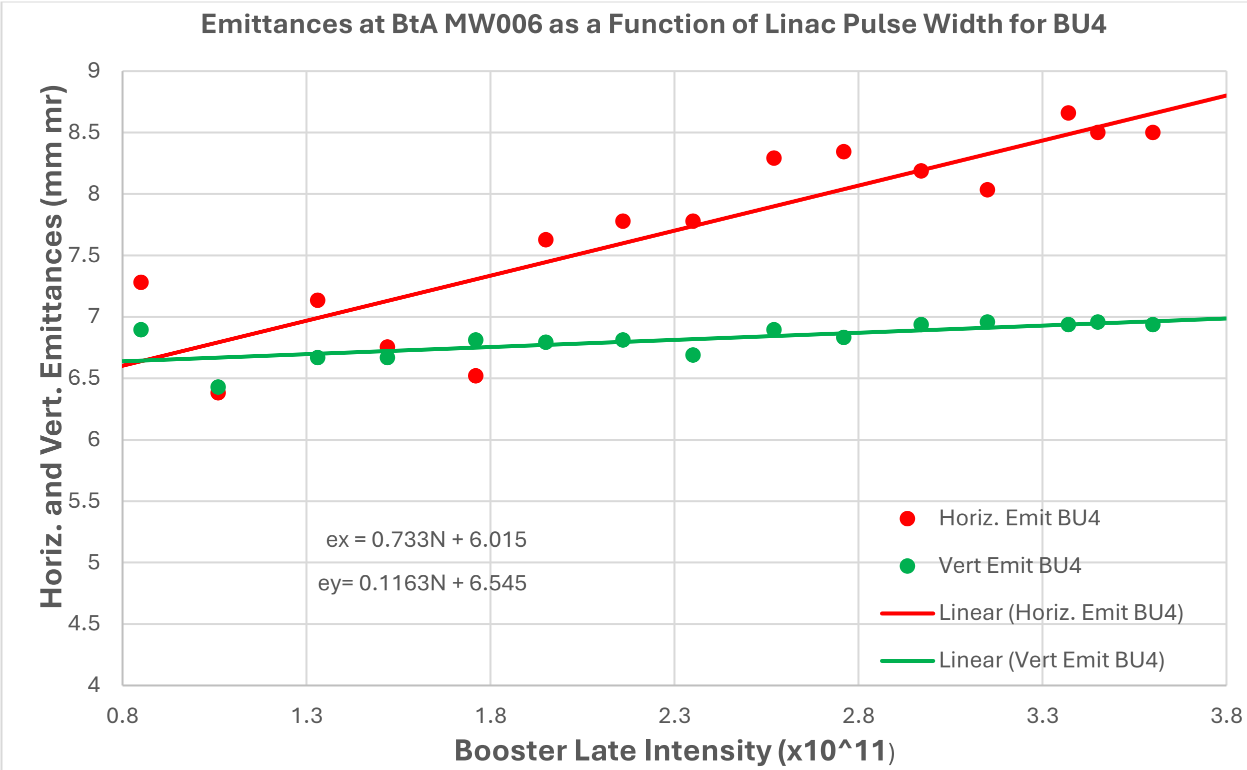
The pulse width scan on BU4 was done on April 21st. The scraping was adjusted such that a 300 μs pulse provided about 3.65e11 at Booster Late. In Run 24 the AGS Late intensity with a 300 μs pulse was about 3.0e11 for the scan but when the scan was done this year the AGS was not available. So, a Booster Late of 3.65e11 was used which during Run 24's scan corresponded to about 3.0e11 at AGS Late. Figure 8 shows the results. The same scan was done with BU5 on April 25.

The higher the input the more the beam can be scraped. The Booster Input for the BU4 scan was about 5.9e11 and it was 6.55e11 for BU5. In Run 24 the input was about 6.0e11 for the BU4 scan and 6.7e11 for the BU3 scan. The fact that they are not all the same complicates the interpretation of the results. In Run 24, for the BU4 case, the fit for ε_x grew by a factor of (9.19/6.80)=1.35 and for ε_y it grew by (4.55/3.60)=1.28 going from the shortest pulse to the longest. This year, for BU4, the fit for ε_x grew by a factor of (8.80/6.60)=1.33, and for ε_y it grew by (6.99/6.64)=1.05. So, although the ε_x behavior is similar the growth in the vertical is much less. This year, for BU4, the vertical (with the shortest pulse width) is much larger than it was last year, 6.7 vs. 3.7 mm mr.

The vertical was also much smaller for BU3 last year than it was for BU5 this year, 3 vs. 5 mm mr respectively. BU5 this year shows virtually no growth in the vertical and only about 14% in the horizontal. So, there's not much problem with growth on BU5, the problem is with the vertical size. These measurements were taken early in the run and perhaps the setups were not optimized. The initial horizontal emittances are quite similar to last year, around 6-6.5 mm mr.

On December 15th MW006 profiles on BU4 were taken with 50, 150, and 300 μs long pulses though the 300 μs case only corresponded to a Booster late of 2.2e11 (Booster Input was

[46] See V. Schoefer et al., "Accelerating Through Partial Snake Resonances with Betatron Coupling Spin Resonance Compensation", IPAC'26-the 17th International Particle Accelerator Conference.
[47] See K. Zeno, "The 2024 Run in the Injectors", February 2025, C-A/AP/715, Figure 16 on pg. 18.



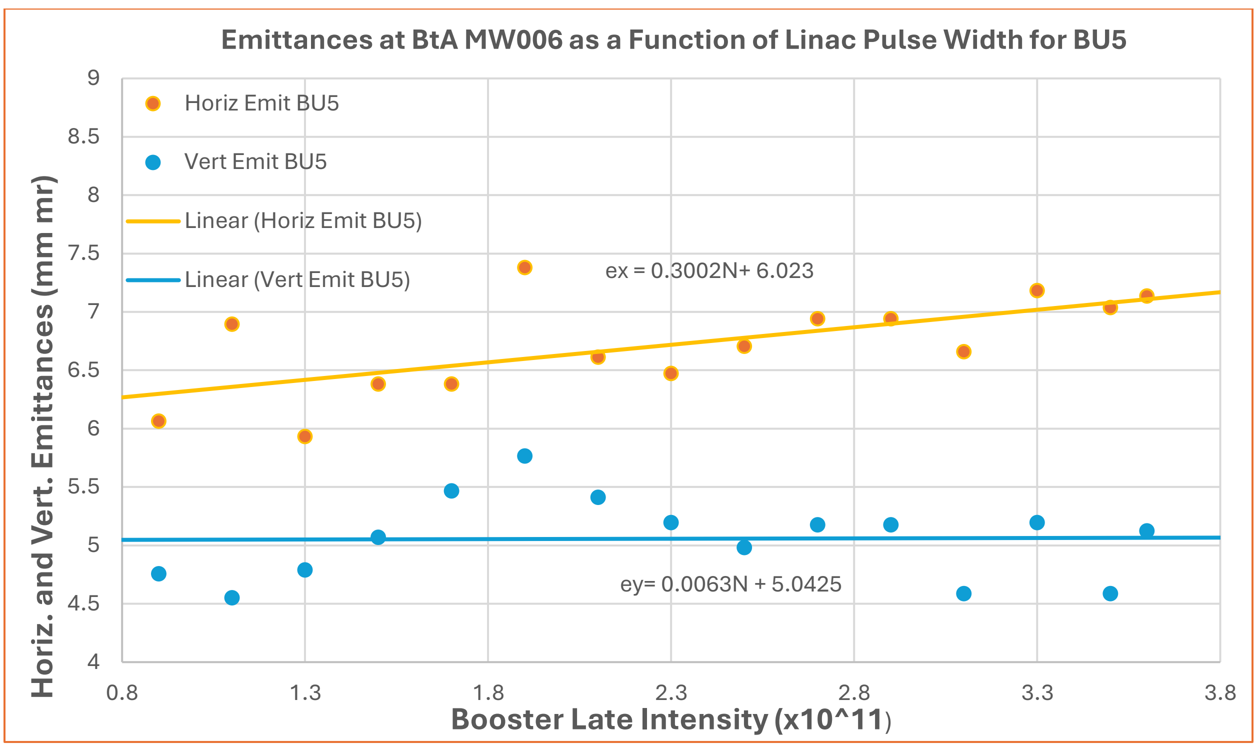


Figure 8: BtA MW006 multiwire horizontal and vertical 95% normalized emittances as a function of Booster Late for BU4 (normal PP, top) and BU5 (split-merge, bottom). Where ε_x=0.82(fwhm_x)^2 mm mr and ε_y=0.155(fwhm_y)^2. Linear fits to the data are also shown. The BU4 data is from April 21 and the BU5 data is from April 25.

about 7e11). There was not much intensity dependence apparent between the 50, 150, and 300 µs cases. (ε_x,ε_y) for the 50, 150, and 300 µs cases was (5.6, 2.4), (5.2, 2.4), and (6.1, 2.5) mm mr. respectively.[48] Another pulse width scan with fixed scraping was made on April 18 which did not show much, if any, intensity dependence (see Figure 9).

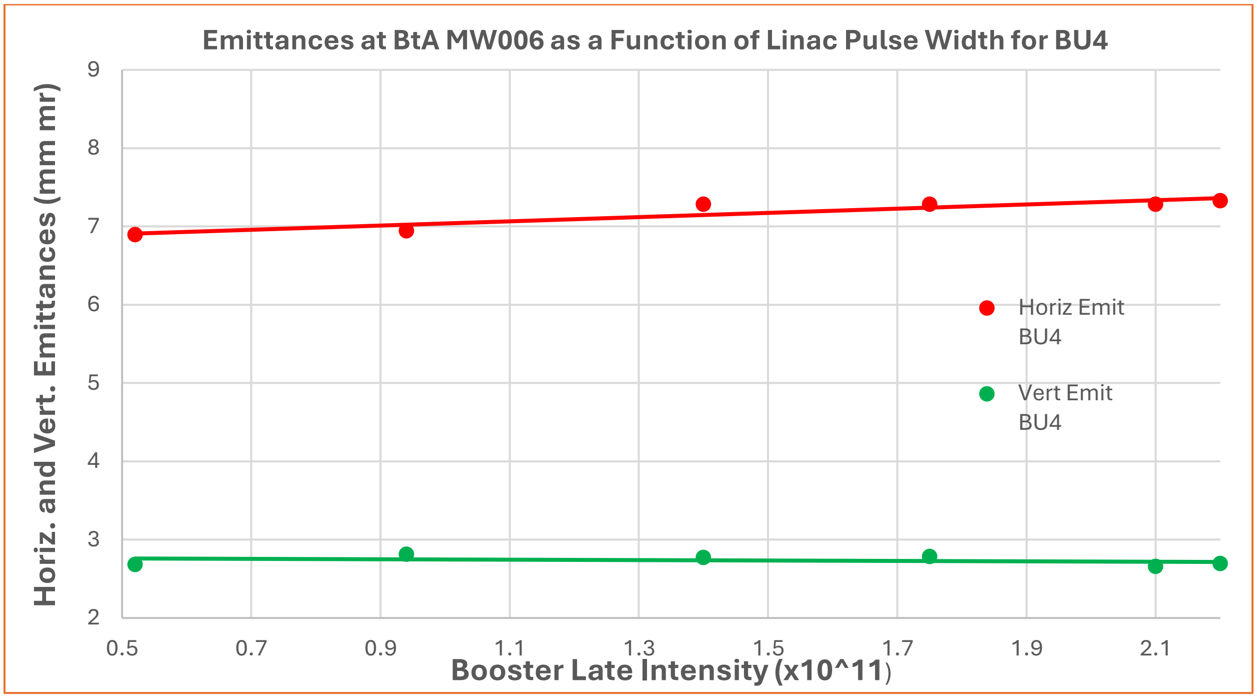


Figure 9: BtA MW006 multiwire horizontal and vertical 95% normalized emittances as a function of Booster Late for the BU4 (normal PP) setup with a fixed amount of scraping. Linear fits to the data are also shown. The data is from April 18.

On January 16th, using BU4, with a Booster input of 7.2e11 and a 300 µs pulse AGS Late was 2.5e11 and at MW006 (ε_x,ε_y) was (7.1, 2.8) mm mr and for an AGS Late of 3.2e11 they were (7.5, 4.6) mm mr. Booster Late was adjusted by changing the vertical scraping.[49] During Run 24, the BU4 pulse scan data, with fixed scraping, indicate (ε_x,ε_y) for 2.5e11 AGS Late was (8.2, 4.2) mm mr and for 3.0e11 it was (9.2, 4.5) mm mr which seem somewhat larger than this years' Jan. 16th data. 2.5e11 was a typical filling intensity this run. In Run 17, which is perhaps regarded as the best run transverse emittance-wise, a typical filling intensity was about 2.25e11 and (ε_x,ε_y) was about (6.5, 3) mm mr, which is not far from the January 16th 2.5e11 (ε_x,ε_y).[50]

Figures 10 and 11 show MW006 profiles for BU4 and BU5 respectively with no scraping from late April. Booster Late on BU4 was higher than on BU5, 4.7 vs. 4.1e11. For BU4 (ε_x,ε_y)

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[48] See Booster-AGS-PP Dec. 15, 2025 elog entries from 17:47 to 17:54.
[49] See Booster-AGS-PP Jan. 16, 2026 elog 15:21 and 18:31 entries.
[50] See K. Zeno, "An Overview of Booster and AGS Polarized Proton Operations During Run 17", October 2017, C-A/AP/594, Figure 24 on pg. 31.

was (10.9, 6.4) mm mr and for BU5 (ε_x,ε_y) was (9.8, 7.6) mm mr. The horizontal is a little bigger on BU4 than on BU5 and the vertical is a little bigger on BU5 than on BU4. Their "average" emittances are nearly the same, 8.9 mm mr for BU4 and 8.8 mm mr for BU5.[51] In both cases the vertical profile has large tails. When the beam is scraped vertically these tails disappear.[52]

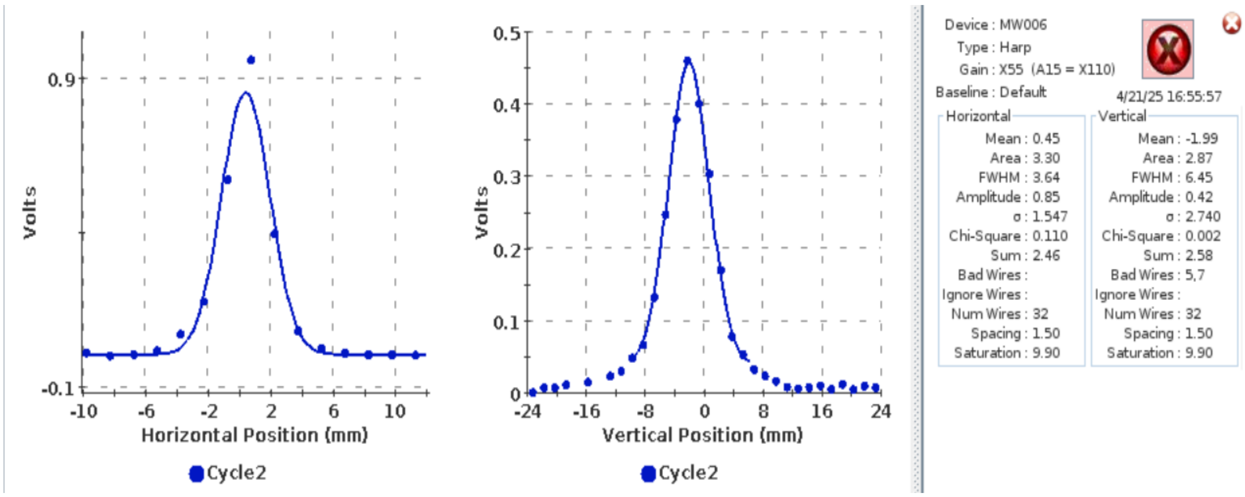

Figure 10: BtA MW006 profiles for polarized protons on the standard BU4 cycle with no scraping and a 300 μs pulse. The Booster Late intensity was 4.7e11 and Booster Input was about 6.0e11. Note that there are significant tails on the vertical distribution.[53]

AGS IPM Flattop Emittance vs. Intensity Controlled by Vertical Scraping for Polarized Protons

On January 16th AGS Late intensity vs. IPM Flattop emittance measurements were taken. The intensity was varied by adjusting the vertical scraping.[54] The AGS IPM profiles are noisier than they have been in previous years, especially in the vertical. Also, as has been the case for many years, when the RF is shut off on the flattop using early turn off the beam induces voltage on the cavities which causes it to rebunch.[55] This affects the momentum spread which in turn affects the horizontal profiles. This effect gets stronger as the intensity is raised and I think it has become more pronounced through the years. After the RF is turned off the (measured) horizontal emittance drops and when the beam rebunches it starts to increase. Ideally, for a good measurement, the beam should completely debunch and remain debunched. It is not clear to me

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[51] The average emittance (E_{avg}) I use is $\sqrt{(\epsilon_x^2 + \epsilon_y^2)/2}$

[52] See Booster-AGS—PP April 21, 2025 elog entries from 16:57 to 17:06.

[53] See Booster-AGS-PP April 21, 2025 elog 16:55 and 16:57 entries

[54] See Booster-AGS-PP Jan. 16, 2026 elog entries from 17:51 to 18:34. The data that was used was logged data viewed in the AGS IPM program and the AGS Late scaler from this time.

[55] For example, see Booster-AGS-PP Jan. 5, 2026 elog entries from 17:41 to 17:47. This shows what the WCM looks like when the RF is shut off and how the IPM profiles look. There is also more about this problem in K. Zeno, "The 2024 Run in the Injectors", February 2025, C-A/AP/715, pgs. 14-15.

whether the indicated horizontal emittance starts to increase before it ever reaches the "debunched" value but I try to pick the time where ε_x is a minimum. For this scan the integration period was doubled in an attempt to reduce the noise.

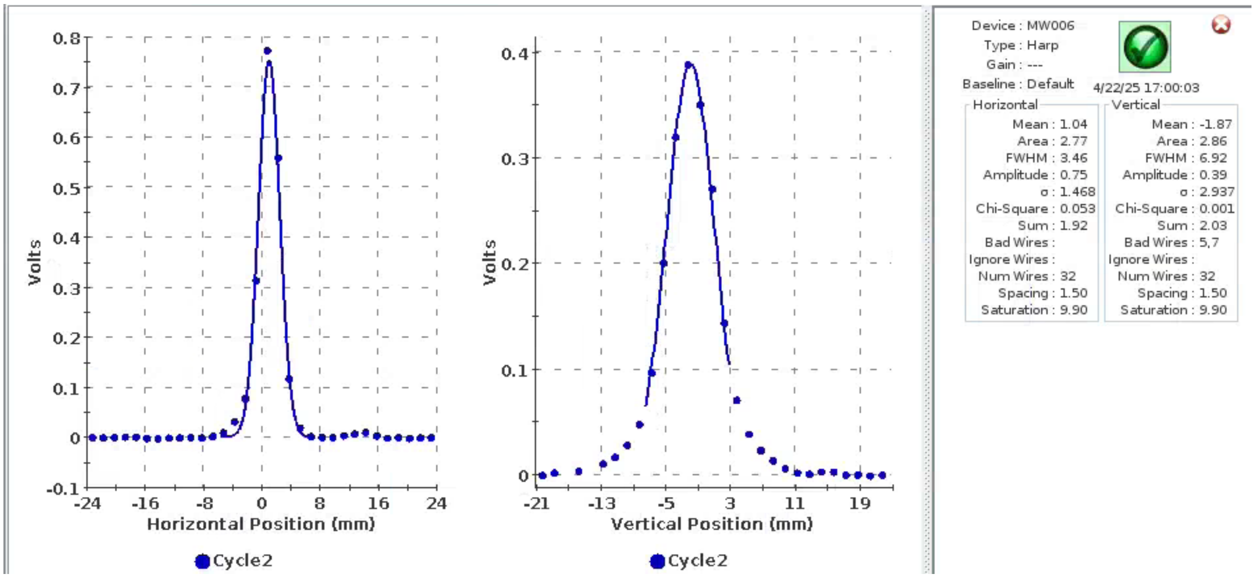

Figure 11: BtA MW006 profiles for polarized protons on the split-merge (BU5) cycle with no scraping and a 300 μs pulse. The Booster Late intensity was 4.1e11 and Booster Input was about 6.2e11. Note that there are significant tails on the vertical distribution.[56]

The RF off time was set to At0+950 ms and the data used for this was the value at At0+990 ms for both the horizontal and vertical emittance. Ten cycles of data were taken for each vertical scrape setting. The 95% normalized emittance was used together with the Refit option. Figure 12 shows the results.

As mentioned above, intensity scans were performed in Run 24 as well but the intensity was varied using the pulse width and the scraping was held fixed. In Run 24 the horizontal and vertical both seem to grow at a similar rate but in Figure 12 ε_y increases with intensity more than ε_x.[57] Perhaps this is because the ε_y coming out of the Booster is increased to increase AGS Late not the pulse width.

There were 2 MW006 profiles taken during this year's scan, one at an AGS Late of 2.5e11 and one at 3.2e11. (ε_x,ε_y) was (7.1, 2.8) mm mr for 2.5e11 and (7.5, 4.6) for 3.2e11. ε_x in BtA did not change much between the intensities (~4%) but it changed by about 20% on the flattop. ε_y changed by 64% in BtA, but only 25% on the flattop. The intensity dependence also looks more linear in this year's data. It also seems like the variation, especially in the vertical, gets larger at higher intensities but in Run 24 that did not seem to be the case.

[56] See Booster-AGS-PP April 22, 2025 elog 16:56 to 17:01 entry
[57] See K. Zeno, "The 2024 Run in the Injectors", February 2025, C-A/AP/715, Figure 14 on pg. 17.

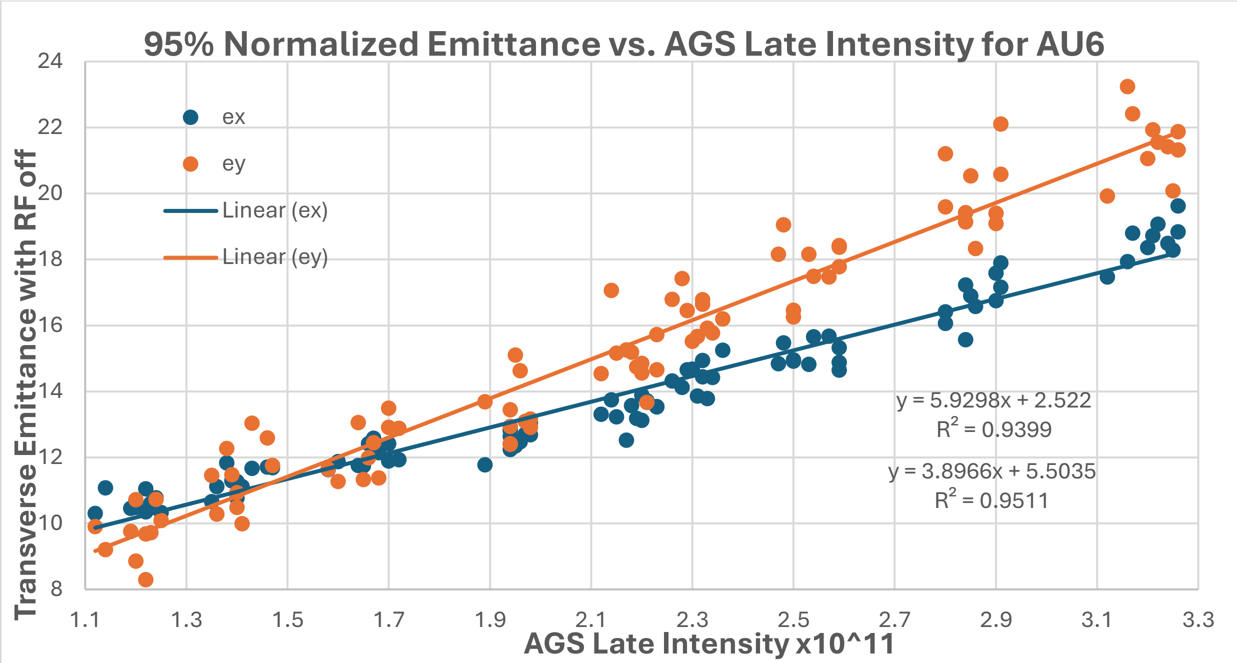

Figure 12: AGS IPM transverse 95% normalized flattop emittances as a function of AGS Late for the standard BU4/AU6 setup (snakes on, skew quads on) in mm mr. The solid lines are linear fits to the data, ε_x=3.8966N+5.5035 and ε_y=5.9298N+2.522, where N is AGS Late/10^{11}. The intensity was varied by adjusting the vertical scraping in the Booster. Orange is the vertical data and blue is the horizontal data. The data was taken on January 16, 2026.

On Jan. 13th eleven IPM flattop emittance measurements were made with an AGS Late of 2.6e11, close to the filling intensity.[58] The average AGS Late for these was 2.60e11, the average (ε_x,ε_y) was (13.46, 15.11) mm mr, and the standard deviations were (σ_x,σ_y)=(0.52, 1.02) mm mr. This was done with a 300 μs pulse. These emittances are significantly smaller than what is shown in Figure 12 for 2.6e11, about (15.5, 18.0) mm mr. One reason why is that in Figure 12 the scraping was set to be able to provide an AGS Late of 3.2e11 with a 300 μs pulse, but here it is set to provide only 2.6e11 with a 300 μs pulse. So, this comparison suggests that scraping works.

AGS IPM Flattop Emittance Versus Pulse Width with No Snakes and Fixed Scraping

In this study only 100, 200, and 300 μs pulse widths were used and the AGS was set up without snakes. BtA MW006 profiles for the 3 cases were taken and (ε_x,ε_y) were (7.2, 2.9), (7.1,2.6), and (8.0, 2.9) mm mr, respectively. There was roughly a 10% increase in ε_x and no change in ε_y going from a 100 to 300 μs pulse. The AGS IPM flattop emittance was measured at At0+1047 ms. Ten measurements were made for each pulse width. The RF early turn off was set

[58] See Booster-AGS-PP Jan. 13, 2026 elog entries at 1715 and 1758. The RF early turnoff occurs at 900 ms and the measurements were made at 948 ms.

to At0+1000 ms and the Refit option was used. Figure 13 shows the results including the BtA MW006 data.[59]

The IPM fits have nearly the same slope in both planes. In BtA ε_x increases by about 10% going from a 100 to 300 µs pulse but the flattop ε_x increases by about 40% and there is no obvious change in ε_y in BtA with pulse width.[60] So, the IPM intensity dependence can't be attributed to increases in the BtA emittances. I could imagine that the positive slopes on the IPM data might be related to the rebunching problem since I measure the horizontal and vertical when the horizontal reaches a minimum.[61]

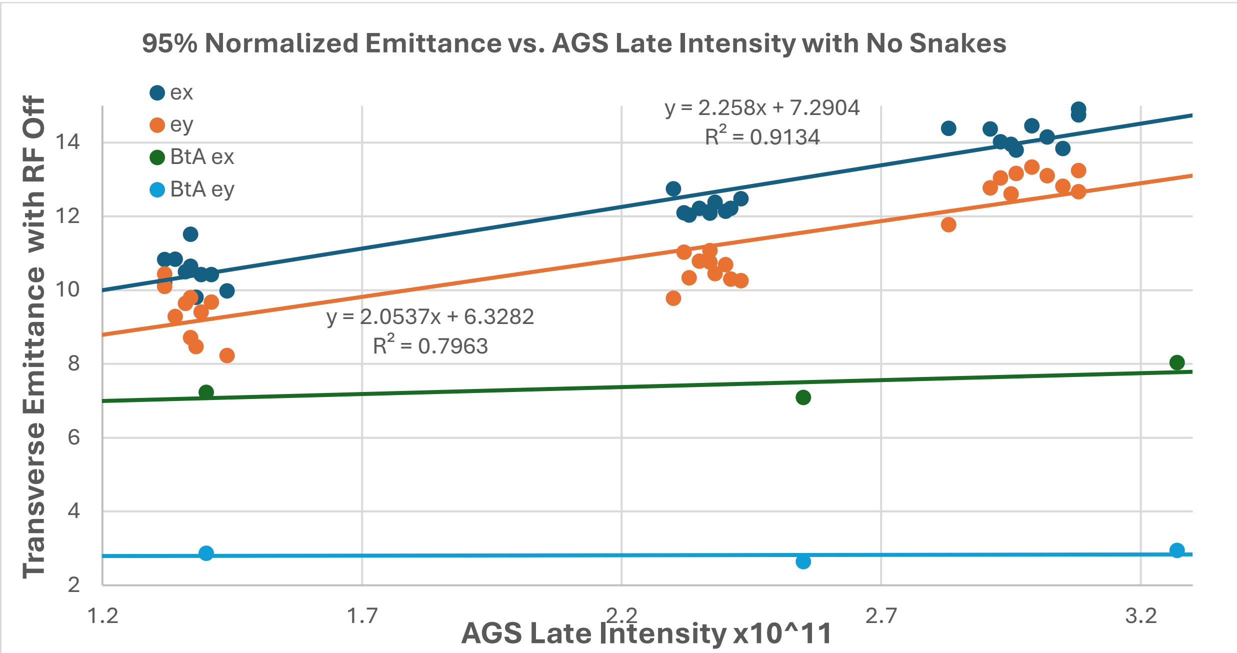

Figure 13: AGS IPM transverse 95% normalized emittances as a function of AGS Late for a No snake setup (AU4) with a fixed amount of scraping. Data was taken with pulse widths of 100, 200, and 300 µs. The solid dark blue and orange lines are linear fits to the IPM data. Orange is the vertical IPM data and dark blue is the horizontal IPM data. The green and lighter blue are ε_x and ε_y at the BtA MW006 multiwire.

There have been a lot of different scans presented here and Table VII can be used as a guide to these.

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[59] See Booster-AGS-PP Feb. 6, 2026 elog entries from 1545 to 18:06. An intensity scan of the no snakes or "bare" machine was also done in Run 16. See K. Zeno, "An Overview of Booster and AGS Polarized Proton Operations During Run 17", October 2017, C-A/AP/594, Pages 21-23.
[60] In the data from 2017 the BtA (ε_x,ε_y) data have slopes but those slopes are similar to the slopes on the no snakes IPM data. Since there was no scraping in this case and the Rb temperature was used to change the intensity some positive slope is expected (ibid. Figure 18).
[61] See for example the 16:24 entry in the Booster-AGS-PP Feb. 6, 2026 elog where the vertical continues to drop after the horizontal has reached a minimum at 1047 ms.

Date	Pulse width	Vert. Scraping	MW006 data?	Flattop IPM data?	User	Figure
4/21	Varied	Fixed	Yes	No	BU4	8 (top)
4/25	Varied	Fixed	Yes	No	BU5	8 (bottom)
12/15	Varied	Fixed	Yes	No	BU4	-
4/18	Varied	Fixed	Yes	No	BU4	9
1/16	Fixed	Varied	No	Yes	BU4/AU6	12
2/6	Varied	Fixed	Yes	Yes	BU4/AU4	13

Table VII: A summary of the different PP intensity scans described above listed in the order that they are encountered in the text above.[62]

Rebunching Revisited

It was mentioned above that the beam starts to rebunch after the RF is turned off and the beam has largely debunched on the flattop and that this rebunching may start too soon to allow for a good IPM measurement. Figure 14 is a comparison of a horizontal measurement from 2016 where the beam did not rebunch and one from last run when it did. The RF shuts off at 1000 ms in both cases. Note that in the 2016 case the value continues to decrease while the 2026 case it starts to go up after having reached a minimum. At 1047 ms, about when the 2026 value starts to go up, the 2016 ε_x is 15.1 mm mr and it ultimately drops to 13.6 mm mr. This suggests there's not enough time before the beam starts to rebunch to make a valid measurement.

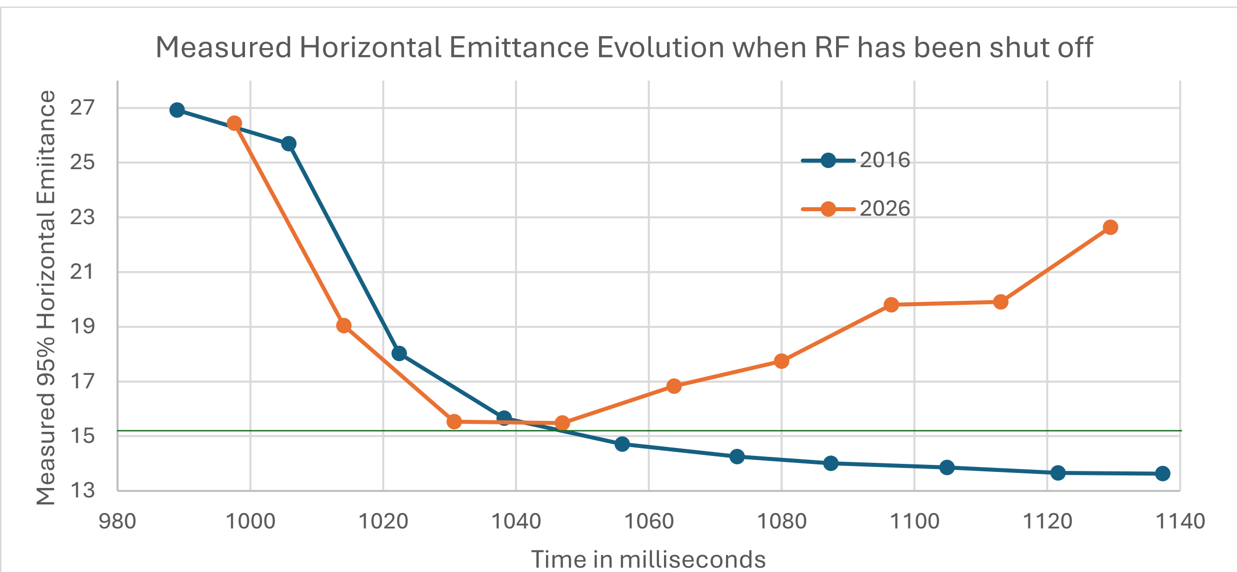

Figure 14: Measured horizontal IPM emittance after the RF shuts off at 1000 ms for a measurement on June 27, 2016 at 17:31:29 (blue) and one made on Feb, 6, 2026 at 16:21:02 (orange). AGS Late was 3.1e11 for the 2026 measurement and 2.6e11 for the 2016 one.[63]

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[62] There is another pulse width vs. MW006 scan in the Booster-AGS-pp Jan. 5, 2026 elog 18:05 entry.

[63] In the 2016 case the RF was actually shut off at 1500 ms. In the plot, all the 2016 points have been shifted 500 ms earlier to account for this in this figure and Figure 15. See also Booster-AGS-PP_2016 June 27, 2016 17:28 and 17:32 entry and Booster-AGS-PP Feb. 6, 2026 elog 16:22 entry.

Figure 15 shows the vertical for the 2 cases. When I measure the vertical emittance I use its value at the time the horizontal measurement was made, which is 1047 ms in the 2026 case. In the 2016 case the vertical is about 12.4 mm mr at 1047 ms and it eventually drops to 11.2 mm mr. So, the vertical still drops considerably after the measurement time suggesting that there is not enough time to make a vertical measurement either. The 2026 value also continues to decrease after 1046 ms so a later measurement time in the vertical could be justified.

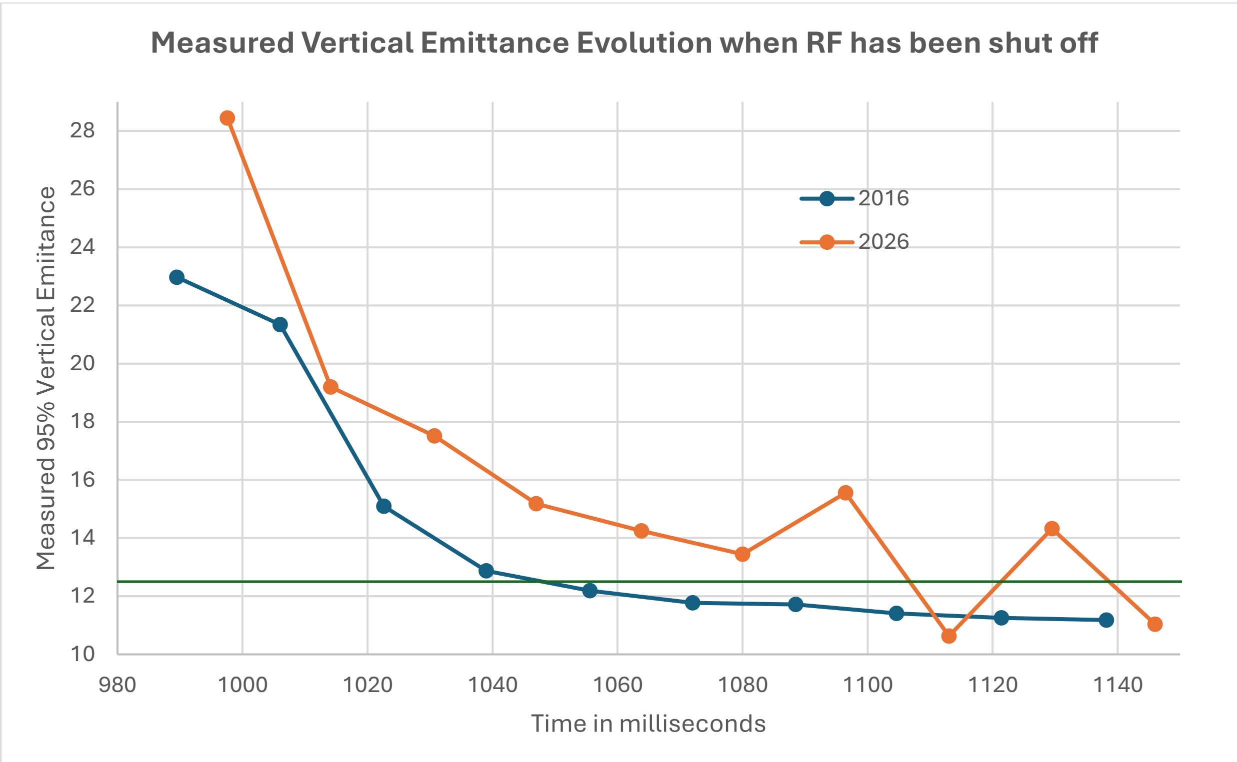

Figure 15: Measured vertical IPM emittance after the RF shuts off at 1000 ms for a measurement on June 27, 2016 at 17:31:29 (blue) and one made on Feb, 6, 2026 at 16:21:02 (orange). AGS Late was 3.1e11 for the 2026 measurement and 2.6e11 for the 2016 one. The horizontal line has the 2016 emittance value at 1047 ms.

In the Jan. 13th case discussed above (ε_x, ε_y) was (13.46, 15.11) mm mr for 2.6e11 (pg. 22). If I try to compensate for this rebunching effect by subtracting how much ε_x and ε_y would decrease after the measurement time, I get (13.46-1.5, 15.11-1.2) mm mr, or (11.96, 13.91) mm mr.[64] Those emittances would be comparable with some measurements from 2017.[65]

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[64] For the Jan 13th data the RF was shut off at 900 ms and the measurement was at 948 ms. The Jan. 13th data was then shifted 100 ms later so it lines up with the Feb. 6, 2026 data. That is, the measurement time is 1047 ms once shifted and RF off time becomes 1000 ms. Note also that the data from 2016 is for 2.6e11.

[65] See K. Zeno, "An Overview of Booster and AGS Polarized Proton Operations during Run 17", October 2017, C-A/AP/594;BNL-114742-2017-IR Figure 18 on page 21. In the figure (ε_x,ε_y) is (13.5, 14.5) mm mr at 2,6e9 for the dual harmonic case. This is with scraping that allows for as much as 3.1e11.

Polarized Proton Longitudinal Emittance Measurements

Several flattop longitudinal emittance measurements were made with protons in May on the split-merge (AU3) cycle. They are shown in Table VIII. In past runs $\varepsilon_{\mathrm{Long}}$ can usually be reduced to about 1.2 eVs as was the case here.[66] Table IX contains a few measurements on the standard AU6 cycle. These values are like last run's, which were a little smaller than in the run before that.[67]

Date	Avg. of…	Length (ns)	f_{synch} (Hz)	$\varepsilon_{\mathrm{Long}}$ (eVs)	AGS Late
May 1	5	37.46	122	1.63	2.3e11
May 5	6	34.3	135.1	1.44	2.6e11
May 8	13	30.48	145	1.22	1.9e11
May 9	10	32.05	141	1.31	1.6e11
May 9	10	31.88	141	1.30	2.7e11
May 12	4	35.48	134	1.53	2.7e11
May 13	10	31.46	134.1	1.20	2.7e11
May 22	10	29.97	132.4	1.08	2.0e11
May 27	10	32.03	133.5	1.24	2.0e11

Table VIII: Longitudinal emittance (ε_{Long}) measurements this run made on the split-merge cycle after the merge. The RF harmonic is 12. For each measurement several bunch length measurements were taken. The number of those is indicated in the "Avg. of…" column. The average bunch length of those measurements is in the 3rd column. The synchrotron frequency (f_{synch}) was measured for each measurement, The Bbrat program was used to calculate ε_{Long}.

Date	Avg. of…	Length (ns)	f_{synch} (Hz)	$\varepsilon_{\mathrm{Long}}$ (eVs)	AGS Late
April 18	1	30.2	127.6	1.09	1.8e11
April 29	12	26.74	127.4	0.86	1.5e11
Dec. 11	5	27.84	129.4	0.94	2.1e11
Dec. 12	5	29.48	129.1	1.05	2.2e11
Jan. 5	12	27.83	122.1	0.89	2.5e11

Table IX: Longitudinal emittance ($\varepsilon_{\mathrm{Long}}$) measurements this run made on the standard AU6 cycle (no flattop merge). The RF harmonic is 6. For each measurement several bunch length measurements were taken. The number of those is indicated in the "Avg. of…" column. The average bunch length of those measurements is in the 3rd column. The synchrotron frequency (f_{synch}) was measured for each measurement, The Bbrat program was used to calculate $\varepsilon_{\mathrm{Long}}$. The Dec. 11th measurement is with the γ transition jump off.

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[66] See K. Zeno, "The 2022 Polarized Proton Run in the Injectors", October 2022, C-A/AP/685. Table I on page 24 contains $\varepsilon_{\mathrm{Long}}$ measurements on the split-merge cycle.

[67] See K. Zeno, "The 2022 Polarized Proton Run in the Injectors", October 2022, C-A/AP/685. Table II on page 25 contains $\varepsilon_{\mathrm{Long}}$ measurements on the standard cycle.

Longitudinal Emittance Measurement at AGS Injection on the Split-Merge Cycle

On May 2nd the ε_{long} of the 2 bunches at AGS injection on the split-merge cycle was measured.[68] ***f**$_{synch}$* near Booster extraction could not be measured. Normally, the ***f**$_{synch}$* is measured and ε_{long} is calculated using that, but if f_{synch} is not available 0.8 times the RF reference voltage is used instead.[69] The bunch lengths at AGS injection were 196 and 210 ns. The RF reference voltage was 680 V. Using these lengths and an Rf voltage of 0.8 times 680V yields 0.37 and 0.40 eVs, respectively.

Note that with the split-merge setup the initial bunch is split into 2. By adjusting the RF phasing during the split you can easily put more beam into one bunch than the other and the 2 bunches will have different emittances.

Accelerating Molecular Hydrogen Ions (H_2^+) in the AGS,

During the run EBIS developed a molecular Hydrogen (H_2^+) beam. NSRL used it and there was interest in accelerating it to a typical flattop energy in the AGS. Nick Kling championed this effort. I did a lot of setting up the Booster and AGS without beam, some of which I will document here. I also did some beam work in the AGS.

One potential problem with accelerating H_2^+ in the AGS is that the vacuum is not as high there as it is in the Booster so just because it survives in the Booster doesn't mean that it will in the AGS.[70]

The Booster setup used to provide H_2^+ to the AGS was a modified version of the $^3He^{2+}$ setup used in 2024. The AGS setup was a modified version of the Au^{77+} setup used this run on AU1.

A few comments on how to modify the $^3He^{2+}$ Booster setup loaded into BU5 for H_2^+:

- Set charge state and atomic mass to H_2^+ values, 1 and 1.87585 GeV/c^2, respectively (which are the same as deuteron values).
- For the same Booster extraction field as $^3He^{2+}$ (5331 kG on the function) h=1 at extraction should be 1.134 MHz for deuterons or H_2^+. Extraction happens at the peak.
- For the 4-2-1 merge in Booster h=2 is 0.85 MHz (ok for the A6 cavity) and 0.425 MHz for h=1 (OK for A3 and B3 cavities).

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[68] See Booster-AGS-PP May 2, 2026 elog entries from 17:13 to 17:55.
[69] See K. Zeno, "Longitudinal Emittance Measurements in the Booster and AGS during the 2014 Gold Run", August 2014, C-A/AP/523, page 7.
[70] H_2^+ has a one-electron covalent bond. This bond is weaker than the H_2 molecule's two-electron covalent bond. Also, the protons in H_2^+ are further away from each other than they are in H_2 because there is only one electron holding them together. See Wikipedia article on Dihydrogen cation.

- The injection field needs to be set to the H_2^+ value, 274G on the function. Since there is not enough time for the field to change much going from dwell to injection, the dwell field needs to be set to the same value as the injection field.
- The Calibrate setting should be changed from 2130 to 2890 GCC so that extraction will happen at the correct field. This change is needed because the dwell field for the $^3He^{2+}$ magnet cycle is different than it is for H_2^+ and the extraction triggers (*brf.synch.strt.gt* and *brf.xtrcn_strt.gt*) are gauss events.
- The BtA settings should be the same as they were for $^3He^{2+}$.

The Au^{77+} AGS setup loaded into AU5 needed to be modified as well for H_2^+. It was set up using only a 12-6 merge. The injection and merge porches were set to occur at the same field, 839 kG on the function.

The H_2^+ beam was injected onto the AGS injection porch but only lasted for several 100 milliseconds. It was noticed on Feb. 7th that the vertical IPM leak was on but it seems that it does not affect the loss rate because the loss rate was about the same a few nights before when the leak was off.[71] This is puzzling because the main suspect for the loss mechanism is inadequate vacuum.

The profiles on MW006 and MW060 are negative. This is not particularly surprising as there is a loosely bound electron involved. At one point a stripping foil was inserted and the DH2-3 setting was halved. This state is shown in Figure 16. H_2^+ becomes 2 protons after passing through the foil and so it is a positive signal.[72] Figure 17 shows MW060 without the foil inserted and DH2-3 set to the nominal setting for transfer to the AGS of H_2^+.

Figure 18 shows the MW006 profiles with Gaussian fits from which ε_x and ε_y were measured to be 1.54 and 1.34 mm mr, respectively. These emittances are quite small which makes me wonder if the indicated profile widths depend on whether the profiles are from electrons or positive ions.

Figure 19 shows the beam in the Booster and AGS. Most of the beam in the AGS is gone in 300 ms or so but judging from the noise level on the BPM it looks like there is still bunched beam present up to at least 550 ms after injection. Also, since there is very little beam left after 300 ms but there is still a sign of it after 550 ms the beam that is circulating during that time is only being lost at a very slow rate.

At one point, the injection time was moved to 2400 ms, just after the time the merge would occur, and the beam accelerated up the early part of the ramp for about 110 ms.[73] It also

[71] See N. Kling, Booster-AGS-EBIS Feb. 7, 2026 elog 17:01 entry.
[72] See N. Kling, Booster-AGS-EBIS Feb. 7, 2026 elog 13:03 entry. From Device Set History it appears that foil 4 (an Aluminum foil) was inserted.
[73] See Booster-AGS-EBIS Feb. 7, 2026 elog 18:36 entry.

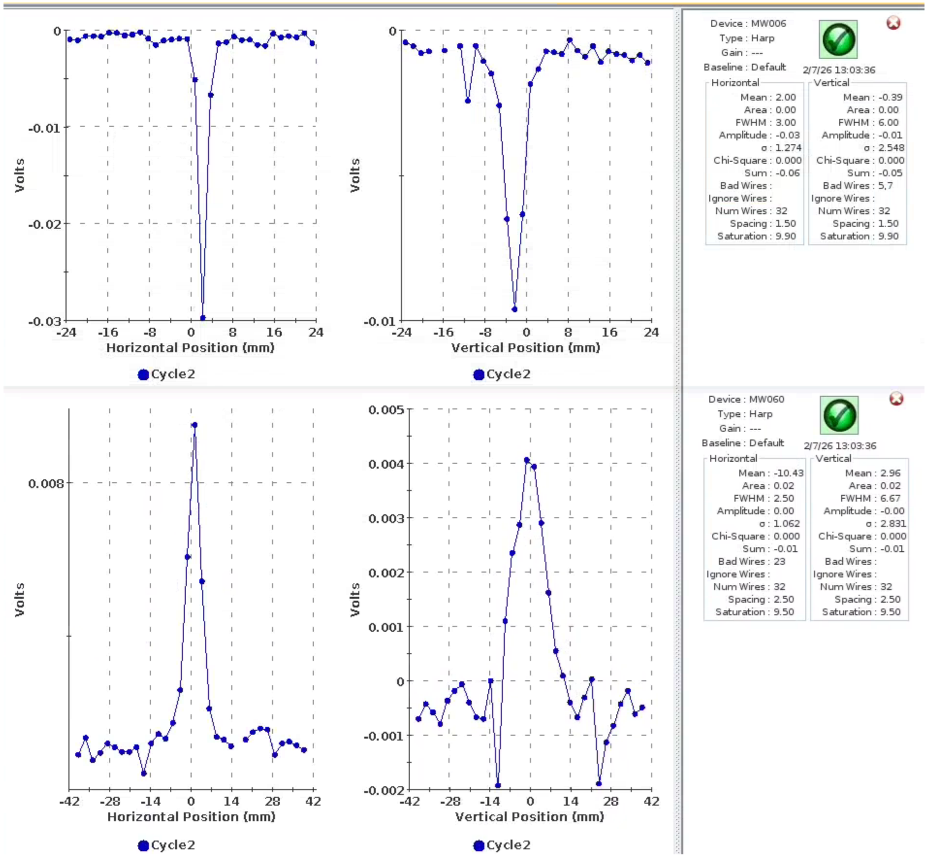

Figure 16: BtA MW006 (top) and MW060 (bottom) with H_2^+ extracted from the Booster. The profiles on MW006 are negative but the MW060 profiles are positive. A BtA foil is inserted and DH2-3 is set to about half the value required for H_2^+ so MW060 is looking at protons. Booster cycle 1, which has no beam on it, is used as the baseline.

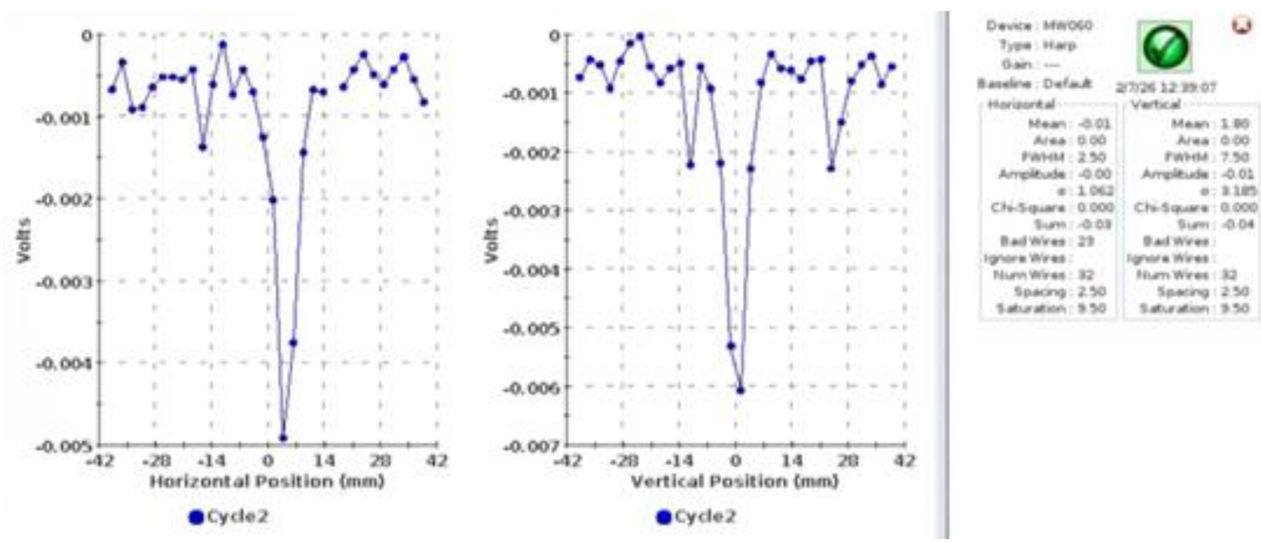

Figure 17: Looking at H_2^+ on BtA multiwire MW060 with no BtA foil inserted. Booster cycle 1, which has no beam on it, is used as the baseline.

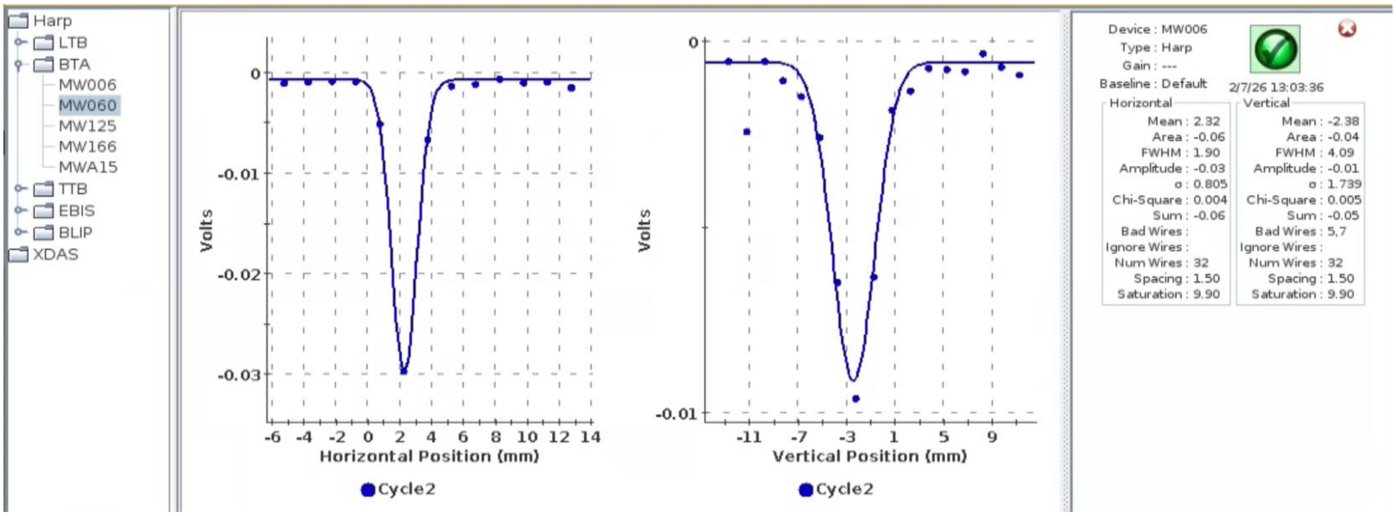

Figure 18: H_2^+ profiles on BtA multiwire MW006 together with Gaussian fits. The 95% normalized horizontal emittance is 1.54 mm mr and the vertical one is 1.34 mm mr. $\beta\gamma$=1.181 and the equations used to calculate 95% normalized emittances from FWHM at MW006 are $\varepsilon_x=0.43*(\text{fwhm\_x})^2$ and $\varepsilon_y=0.080*(\text{fwhm\_y})^2$ using β_x=3.0m and β_y=16m. The profile for Booster cycle 1, which has no beam on it, is used as the baseline.

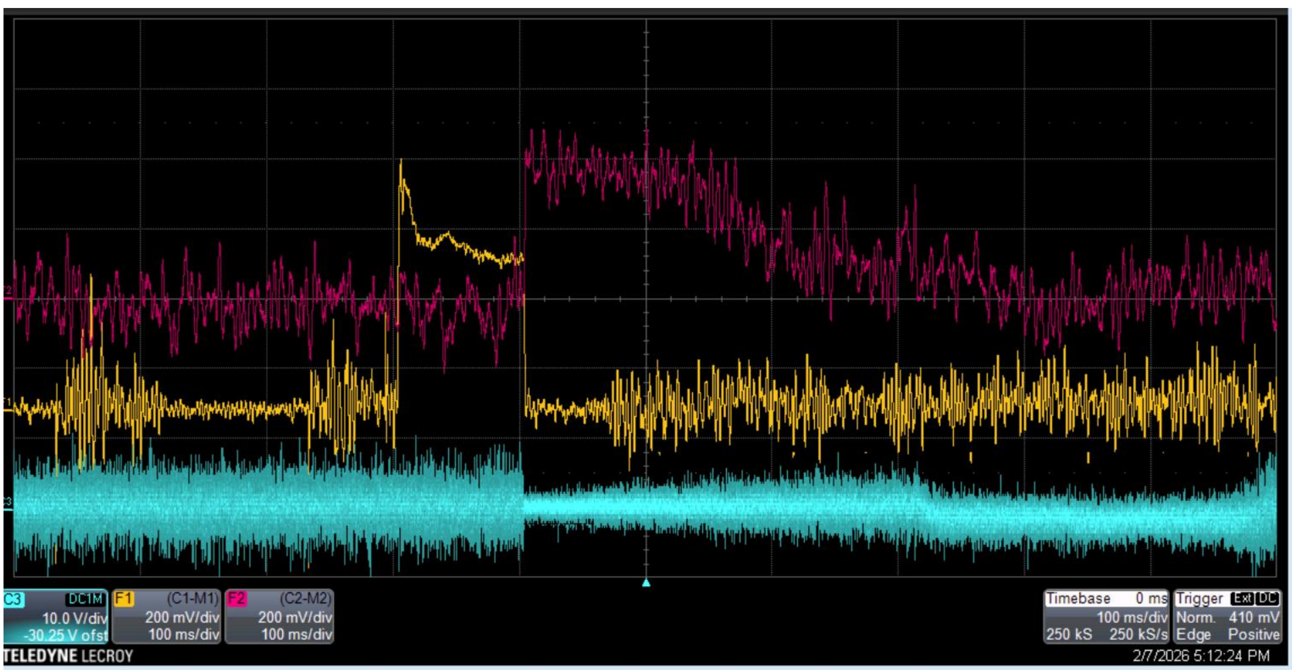

Figure 19: H_2^+ beam in the Booster and AGS. F1 is the Booster normalized transformer, F2 is the AGS normalized current transformer, and C3 is the J12 horizontal BPM which is sensitive to bunched beam. The trigger is at 1750 ms and the sweep is 100ms/div.[74]

[74] See Booster-AGS-EBIS Feb. 7, 2026 elog entry at 17:18.

survived the F-to-P bank transfer without any problem. Without RF it only survives for 10-20 ms. It accelerates with the beam control loops on or off but the B2B Phase trails off around 2500 ms. It is suspected that it trails off because the intensity is too low for the phase loop to work. Adding amplification to the wall current monitor signal should help if that is the problem.[75]

The H_2^+ kinetic energy at AGS injection is about 516 MeV/n and acceleration to 2510 ms, where the beam was lost, corresponds to a kinetic energy of 885 MeV/n. Rough estimates of the intensity at different points in the cycle are: Booster injection 9e9, Booster near extraction 7e9, and AGS at injection 3.1e9 H_2^+ ions.[76]

Summary

The RHIC run consisted of about 6 months of Gold using Tandem (BU1/AU1), a month of Polarized Protons using skew quads instead of tune jump quads to preserve polarization through partial snake resonances (BU4/AU6), 6 days of Oxygen (BU3/AU3), and about a week of Au fixed Target experiments. All the fixed target experiments used BU1/AU1 except 8.65 GeV/n which used BU1/AU7.

The Gold setup used for RHIC (BU1/AU1) has been used in previous years. Except this year a 12-6-3 merge was used to merge the bunches from 4 Booster transfers into 1 instead of a 12-6 merge which merges 2 transfers into 1 bunch. The setup was first used in Run 24 though not for the RHIC run itself.

Another thing that was different this year was that the E6 Booster RF cavity was not available so the 6-3-1 Booster merge had to be reconfigured to work without it. ε_{long} on the flattop was about the same as in previous years when E6 was used, 0.22 eVs using the 12-6 merge (see Table III). There were some modifications to the AGS cycle used with the 12-6-3 merge (still AU1). The flattop was shortened which allowed for a shorter supercycle, 4.8 vs. 5.4 sec. The early ramp after the merge was also slowed down to eliminate a loss there due to a lack of bucket area associated with the transfer from the Flat to Pulsed rectifier bank of the AGS main magnet power supply.

The 12-6-3 merge can provide more than enough bunch intensity and the bunches have smaller transverse emittance than the 12-6 merge bunches for a similar intensity. However, there are only 2 bunches per AGS cycle available to RHIC when filling with a 12-6-3 merge and 4 with the 12-6 merge. The faster the fill is the less time there is for transverse emittance growth and intra-beam scattering. So, 3 bunches per AGS cycle might be preferable to 2 providing the supercycle remains reasonably short and the bunch intensity is sufficient.

[75] F. Severino, private communication.
[76] See Booster-AGS-EBIS Feb. 9, 2026 elog entries from 14:02 to 17:44

Three ways to get 3 bunches on the flattop were investigated during the run but none of them were used for filling on a consistent basis. They are:

1) Using only 6 Booster Transfers and the 12-6 merge in the AGS. Found on pages 6-7.
2) A hybrid merge using 2 Tandem users in the same supercycle that have different pulse lengths. Found on pages 8-9.
3) 9 Booster cycles with beam and a 12-8-4 merge in the AGS. Found on pages 9-12.

There were a couple of studies with Au looking at beam with different Tandem pulse widths in BtA and on the injection porch. The results are documented in Tables V and VI and are relevant since they show the pulse width's effect on transverse emittance. They also show the BtA foil's effect on it.

The Oxygen setup in the AGS was described on pgs. 14 to 16. A typical bunch intensity on the flattop when filling was 1.5-1.6e10 although AGS Late bunch intensity did reach 2.4e10 using a 12-6-3 merge. ε_{Long} on the flattop was 0.68 eVs/n and in run 21 it was 1.1 eVs. The Oxygen ε_{Long} was significantly larger than for the 12-6-3 Au merge (0.42 eVs, Row 9 in Table III). The RF setups for Oxygen and Gold are similar in the AGS but they are different in the Booster. A 4-2-1 merge was used for Oxygen with an EBIS-like merge porch that is much shorter than the one used for Tandem Au, about 16 ms vs. 63 ms.

There were six polarized proton intensity scans carried out this run and described in the text (see Table VII). The first four in the table looked at the observed growth in BtA with fixed scraping when the pulse width was varied, one used a fixed pulse width and varied vertical scraping and looked at the emittance on the flattop (1/16), and another varied the pulse width while keeping the scraping fixed (2/6). That last scan was done without snakes and there is data for BtA and the AGS flattop.

As regards the BtA scans, at least this year, there can be a lot of growth or it can be minimal and when a lot of growth does occur (as in the top plot in Figure 8) it is in the horizontal. The horizontal scrape happens at a lower energy than the vertical one. I wonder if there is still some space charge effect present after the horizontal scrape but before the vertical which causes the horizontal emittance to grow and that that is not the case for the vertical after the vertical scrape occurs. Also, this assumes the so-called vertical scrape does not scrape in the horizontal too.

Figure 12, which is a scan where the vertical scraping is varied, shows more vertical than horizontal growth as AGS Late increases. This is unlike a pulse width scan in 2024 where the horizontal and vertical increased at about the same rate. This may indicate that for this year's scan at least the emittances have not flipped between when the beam was scraped in the Booster and when the emittances are measured on the flattop.

In the *Rebunching Revisited* section I argued for the idea that there is not enough time before the beam starts to rebunch to make a good IPM measurement in the horizontal. And since the vertical measurement is made at the same time in the cycle there is not enough time for a good measurement in that plane either. The implication is that the emittances I measure are larger than they actually are, perhaps by 10% or so.

Also, the rebunching problem could make it appear as if there is intensity dependent emittance growth when there isn't because the rebunching is less pronounced at lower intensities and so it could be that there is more time for the measured emittance to fall before it starts to rebunch. Something like this might explain the apparent intensity dependence in the No snake case (Figure 13) since it is surprising in the No snake case that intensity dependent growth is present.

Some PP ε_{long} measurements made during the run for the split-merge and normal cycles are shown in Tables VIII and IX.

At the end of the run attempts were made to accelerate H_2^+ to the AGS flattop. These attempts were unsuccessful. The beam survived on the injection porch for 100s of milliseconds but would eventually be lost (see Figure 19). At one point the vertical IPM leak was found to be on and the survival was not any worse than it was when the leak was off. Without the leak the vacuum is in the 10^{-9} Torr range and with it on it is in the 10^{-7} Torr range. It was surprising that whether the leak was on or off had no discernable effect on survival since the AGS vacuum was the prime suspect for the lack of survival.

This note covered material related to polarized protons but not much about the polarization itself and the new skew quads. As I have done in previous Injector notes, I focused more on beam qualities like emittance that are expected to affect polarization because I think that is a more productive approach for me.

Acknowledgements:

Many thanks to Iris Zane, the scope lady, for all her assistance with the scopes, the AGSLossMonitor program, and countless other things.

	Booster	AGS	Booster	AGS		Booster	AGS	Booster	AGS	RHIC
					1-May	BU5	AU3			
					2-May	BU5	AU3			
3-Mar	BU1				3-May					
4-Mar	BU1				4-May					
5-Mar	BU1				5-May	BU5	AU8			
6-Mar	BU1				6-May					
7-Mar	BU1				7-May					
8-Mar					8-May	BU5	AU8	BU5	AU3	
9-Mar					9-May	BU5	AU3			
10-Mar	BU1				10-May					
11-Mar					11-May					
12-Mar	BU1				12-May	BU5	AU3			
13-Mar	BU1	AU1			13-May	BU5	AU3			
14-Mar					14-May	BU5	AU3			
15-Mar					15-May	BU1	AU1			
16-Mar					16-May					
17-Mar	BU1	AU1			17-May					
18-Mar					18-May					
19-Mar					19-May	BU5				
20-Mar	BU1	AU1			20-May	BU5				
21-Mar	BU1	AU1			21-May	BU5	AU3			
22-Mar					22-May	BU5	AU3	BU5	AU8	
23-Mar					23-May	BU5	AU8			
24-Mar					24-May					
25-Mar					25-May					
26-Mar	BU1	AU1			26-May					
27-Mar					27-May	BU5	AU3	BU1	AU1	
28-Mar					28-May	BU1	AU1	BU5	AU8	
29-Mar	BU1	AU1			29-May	BU5	AU8	BU1	AU1	
30-Mar					30-May	BU5	AU8	BU1	AU1	
31-Mar	BU1	AU1			31-May	BU1	AU1			AU1
1-Apr	BU1	AU2			1-Jun	BU1	AU1			AU1
2-Apr	BU1				2-Jun	BU1	AU1	BU5	AU8	AU1
3-Apr					3-Jun	BU1	AU1			AU1
4-Apr					4-Jun	BU1	AU1			AU1
5-Apr					5-Jun	BU1	AU1	BU5	AU8	AU1
6-Apr					6-Jun	BU1	AU1			AU1
7-Apr	BU4				7-Jun	BU1	AU1			AU1
8-Apr	BU4	AU6			8-Jun	BU1	AU1			AU1
9-Apr	BU4				9-Jun	BU1	AU1			AU1
10-Apr	BU4	AU6			10-Jun	BU1	AU1			AU1
11-Apr	BU4		BU7		11-Jun	BU1	AU1			AU1
12-Apr					12-Jun	BU1	AU1			
13-Apr					13-Jun	BU5	AU8	BU5	AU3	
14-Apr	BU4	AU6			14-Jun	BU5	AU8	BU1	AU1	
15-Apr	BU4	AU6			15-Jun	BU1	AU1			AU1
16-Apr	BU4	AU6			16-Jun	BU1	AU1			AU1
17-Apr	BU4	AU6			17-Jun	BU1	AU1	BU1	AU7	AU1
18-Apr	BU4	AU6			18-Jun	BU1	AU1			AU1
19-Apr					19-Jun	BU1	AU1			AU1
20-Apr					20-Jun	BU1	AU1	BU5	AU5	AU1
21-Apr	BU4				21-Jun	BU1	AU1	BU5	AU8	AU1
22-Apr	BU4		BU5		22-Jun	BU1	AU1	BU5	AU8	AU1
23-Apr					23-Jun	BU1	AU1			AU1
24-Apr	BU5				24-Jun	BU1	AU1			AU1
25-Apr	BU5				25-Jun	BU1	AU1			AU1
26-Apr					26-Jun	BU1	AU1			AU1
27-Apr					27-Jun	BU1	AU1	BU5	AU8	AU1
28-Apr	BU4	AU6			28-Jun	BU1	AU1	BU5	AU5	AU1
29-Apr	BU4	AU6	BU5	AU3	29-Jun	BU1	AU1			AU1
30-Apr	BU1	AU1			30-Jun	BU1	AU1	BU5	AU3	AU1

March 3rd to June 30th

	Booster	AGS	Booster	AGS	RHIC
1-Jul	BU1	AU1	BU5	AU3	AU1
2-Jul	BU1	AU1			AU1
3-Jul	BU1	AU1	BU5	AU5	AU1
4-Jul	BU1	AU1			AU1
5-Jul	BU1	AU1			AU1
6-Jul	BU1	AU1	BU5	AU5	AU1
7-Jul	BU1	AU1			AU1
8-Jul	BU1	AU1	BU5	AU5	AU1
9-Jul	BU1	AU1			AU1
10-Jul	BU1	AU1			AU1
11-Jul	BU1	AU1			AU1
12-Jul	BU1	AU1			AU1
13-Jul	BU1	AU1			AU1
14-Jul	BU1	AU1			AU1
15-Jul	BU1	AU1			AU1
16-Jul	BU1	AU1			AU1
17-Jul	BU1	AU1			AU1
18-Jul	BU1	AU1			AU1
19-Jul	BU1	AU1			AU1
20-Jul	BU1	AU1			AU1
21-Jul	BU1	AU1			AU1
22-Jul	BU1	AU1			AU1
23-Jul	BU1	AU1			AU1
24-Jul	BU1	AU1			AU1
25-Jul	BU1	AU1			AU1
26-Jul	BU1	AU1			AU1
27-Jul	BU1	AU1			AU1
28-Jul	BU1	AU1			AU1
29-Jul	BU1	AU1			AU1
30-Jul	BU1	AU1			AU1
31-Jul	BU1	AU1			AU1
1-Aug	BU1	AU1			AU1
2-Aug	BU1	AU1			AU1
3-Aug	BU1	AU1			AU1
4-Aug	BU1	AU1			AU1
5-Aug	BU1	AU1			AU1
6-Aug	BU1	AU1			AU1
7-Aug	BU1	AU1			AU1
8-Aug	BU1	AU1			AU1
9-Aug	BU1	AU1			AU1
10-Aug	BU1	AU1			AU1
11-Aug	BU1	AU1			AU1
12-Aug	BU1	AU1			AU1
13-Aug	BU1	AU1			AU1
14-Aug	BU1	AU1			AU1
15-Aug	BU1	AU1			AU1
16-Aug	BU1	AU1			AU1
17-Aug	BU1	AU1			AU1
18-Aug	BU1	AU1			AU1
19-Aug	BU1	AU1			AU1
20-Aug	BU1	AU1			AU1
21-Aug	BU1	AU1			AU1
22-Aug	BU1	AU1			AU1
23-Aug	BU1	AU1			AU1
24-Aug	BU1	AU1			AU1
25-Aug	BU1	AU1	BU1	AU7	AU1
26-Aug	BU1	AU1			AU1
27-Aug					
28-Aug					
29-Aug					
30-Aug					
31-Aug	BU1	AU1			

	Booster	AGS	Booster	AGS	RHIC
1-Sep					
2-Sep					
3-Sep					
4-Sep	BU1	AU1			
5-Sep	BU1	AU1			AU1
6-Sep					
7-Sep					
8-Sep	BU1	AU1			AU1
9-Sep	BU1	AU1			
10-Sep	BU1	AU1			AU1
11-Sep	BU1	AU1	BU1	AU2	AU1
12-Sep	BU1	AU1	BU1	AU7	AU1
13-Sep	BU1	AU1			AU1
14-Sep	BU1	AU1			AU1
15-Sep	BU1	AU1			AU1
16-Sep	BU1	AU1			AU1
17-Sep	BU1	AU1			AU1
18-Sep	BU1	AU1			AU1
19-Sep	BU1	AU1	BU1	AU7	AU1
20-Sep	BU1	AU1			AU1
21-Sep	BU1	AU1			AU1
22-Sep	BU1	AU1			AU1
23-Sep	BU1	AU1			AU1
24-Sep	BU1	AU1			AU1
25-Sep	BU1	AU1			AU1
26-Sep	BU1	AU7	BU7	AU7	
27-Sep					
28-Sep					
29-Sep					
30-Sep					
1-Oct	BU1	AU1	BU7	AU7	
2-Oct	BU1	AU1	BU1	AU4	
2-Oct			BU7	AU7	
3-Oct	BU1	AU1			
4-Oct					
5-Oct	BU1	AU1			
6-Oct	BU1	AU1	BU7	AU7	AU1
7-Oct	BU1	AU1	BU7	AU7	AU1
8-Oct	BU1	AU1			AU1
9-Oct	BU1	AU1			AU1
10-Oct	BU1	AU1	BU7	AU7	AU1
11-Oct	BU1	AU1			AU1
12-Oct	BU1	AU1			AU1
13-Oct	BU1	AU1	BU1	AU4	AU1
13-Oct			BU7	AU7	
14-Oct	BU1	AU1	BU7	AU7	AU1
15-Oct	BU1	AU1			AU1
16-Oct	BU1	AU1	BU7	AU7	AU1
17-Oct	BU1	AU1	BU7	AU7	AU1
18-Oct	BU1	AU1			AU1
19-Oct	BU1	AU1			AU1
20-Oct	BU1	AU1			AU1
21-Oct	BU1	AU1			AU1
22-Oct	BU1	AU1			AU1
23-Oct	BU1	AU1			AU1
24-Oct	BU1	AU1	BU7	AU7	AU1
25-Oct	BU1	AU1			AU1
26-Oct	BU1	AU1			AU1
27-Oct	BU1	AU1			AU1
28-Oct	BU1	AU1			AU1
29-Oct	BU1	AU1			AU1
30-Oct	BU1	AU1	BU7	AU7	AU1
31-Oct	BU1	AU1			AU1

July 1st to October 31st

	Booster	AGS	Booster	AGS	RHIC	RHIC
1-Nov	BU1	AU1			AU1	
2-Nov	BU1	AU1			AU1	
3-Nov	BU1	AU1			AU1	
4-Nov	BU1	AU1	BU1	AU2	AU1	
5-Nov	BU1	AU1			AU1	
6-Nov	BU1	AU1			AU1	
7-Nov	BU1	AU1	BU1	AU2	AU1	
8-Nov	BU1	AU1	BU1	AU2	AU1	
9-Nov	BU1	AU1			AU1	
10-Nov	BU1	AU1	BU7	AU7	AU1	
11-Nov	BU1	AU1			AU1	
12-Nov	BU1	AU1			AU1	
13-Nov	BU1	AU1			AU1	
14-Nov	BU1	AU1			AU1	
15-Nov	BU1	AU1			AU1	
16-Nov	BU1	AU1			AU1	
17-Nov	BU1	AU1	BU4	AU6	AU1	
18-Nov	BU1	AU1			AU1	
19-Nov	BU1	AU1	BU1	AU2	AU1	AU2
20-Nov	BU1	AU1	BU4	AU6	AU1	
21-Nov	BU1	AU1	BU4	AU6	AU1	
22-Nov	BU1	AU1			AU1	
23-Nov	BU1	AU1			AU1	
24-Nov	BU1	AU1	BU4	AU6	AU1	
25-Nov	BU1	AU1	BU4	AU6	AU1	
26-Nov	BU1	AU1			AU1	
27-Nov	BU1	AU1	BU4	AU6	AU1	
28-Nov	BU1	AU1			AU1	
29-Nov	BU1	AU1			AU1	
30-Nov	BU1	AU1	BU4	AU6	AU1	
1-Dec	BU1	AU1	BU4	AU6	AU1	
2-Dec	BU1	AU1	BU4	AU6	AU1	
3-Dec	BU1	AU1			AU1	
4-Dec	BU1	AU1	BU4	AU6	AU1	
5-Dec	BU1	AU1	BU4	AU6	AU1	
6-Dec	BU1	AU1	BU4	AU6	AU1	
7-Dec	BU1	AU1	BU4	AU6	AU1	
8-Dec	BU1	AU1	BU4	AU6	AU1	
9-Dec	BU4	AU6			AU6	
10-Dec	BU4	AU6			AU6	
11-Dec	BU4	AU6			AU6	
12-Dec	BU4	AU6			AU6	
13-Dec	BU4	AU6			AU6	
14-Dec	BU4	AU6			AU6	
15-Dec	BU4	AU6			AU6	
16-Dec	BU4	AU6	BU1	AU1	AU6	
17-Dec	BU1	AU1			AU1	
18-Dec	BU4	AU6			AU6	
19-Dec	BU4	AU6			AU6	
20-Dec	BU4	AU6			AU6	
21-Dec	BU4	AU6			AU6	
22-Dec	BU4	AU6			AU6	
23-Dec	BU4	AU6			AU6	
24-Dec	BU4	AU6			AU6	
25-Dec	BU4	AU6			AU6	
26-Dec	BU4	AU6			AU6	
27-Dec	BU4	AU6			AU6	
28-Dec	BU4	AU6			AU6	
29-Dec	BU4	AU6			AU6	
30-Dec	BU4	AU6			AU6	
31-Dec	BU4	AU6			AU6	

	Booster	AGS	Booster	AGS	RHIC	RHIC
1-Jan	BU4	AU6			AU6	
2-Jan	BU4	AU6			AU6	
3-Jan	BU4	AU6			AU6	
4-Jan	BU4	AU6			AU6	
5-Jan	BU4	AU6			AU6	
6-Jan	BU4	AU6			AU6	
7-Jan	BU4	AU6			AU6	
8-Jan	BU4	AU6			AU6	
9-Jan	BU4	AU6			AU6	
10-Jan	BU4	AU6			AU6	
11-Jan	BU4	AU6			AU6	
12-Jan	BU4	AU6			AU6	
13-Jan	BU4	AU6			AU6	
14-Jan	BU4	AU6			AU6	
15-Jan	BU4	AU6			AU6	
16-Jan	BU4	AU6			AU6	
17-Jan	BU4	AU6			AU6	
18-Jan	BU4	AU6	BU3		AU6	
19-Jan	BU4	AU6	BU3		AU6	
20-Jan	BU1	AU1			AU1	
21-Jan	BU1	AU1	BU1	AU7	AU1	
22-Jan	BU1	AU1	BU3	AU3	AU1	
22-Jan			BU1	AU7		
23-Jan	BU1	AU1	BU3	AU3	AU1	
24-Jan	BU1	AU1			AU1	
25-Jan	BU1	AU1	BU1	AU7	AU1	AU7
26-Jan	BU1	AU7	BU1	AU1	AU7	AU1
27-Jan	BU1	AU1	BU3	AU3	AU1	
28-Jan	BU1	AU1				
29-Jan	BU1	AU1	BU5		AU1	
30-Jan	BU1	AU1	BU5		AU1	
31-Jan	BU1	AU1	BU3	AU3	AU1	AU3
			BU5			
1-Feb	BU3	AU3			AU3	
2-Feb	BU3	AU3	BU4	AU4	AU3	
3-Feb	BU3	AU3	BU5	AU5	AU3	
4-Feb	BU3	AU3	BU5	AU5	AU3	
5-Feb	BU3	AU3			AU3	
6-Feb	BU3	AU3	BU4	AU4	AU3	
7-Feb	BU5	AU5				

November 1st to February 7th