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# Run 16, eIPM Summary

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August 2016

Collider Accelerator Department

**Brookhaven National Laboratory**

**U.S. Department of Energy**

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# eIPM Summary

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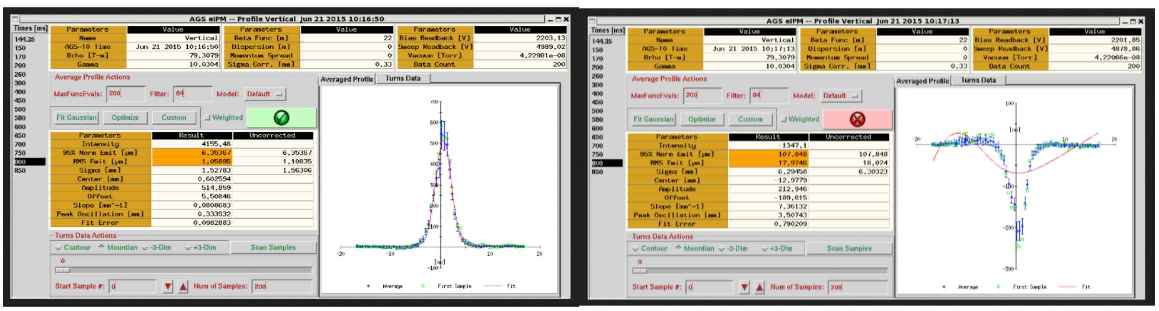
## 2015 Shutdown

We corrected three problems with the eIPMs during the summer shutdown.

### AC coupling and "negative profiles"

We installed new amplifiers for Run 15. These were charge-sensitive amps designed to integrate over the 200ns-long injected bunches and decay to baseline in one full revolution period, ~2.7us. The input stage was built on a small circuit board which replaced the fast pulse amplifiers used originally in RHIC. We used the existing output drivers on the carrier board which were transformer-coupled to the twisted-pair signal lines leaving the tunnel. With AC coupling, there could be no DC component in the output signal. When the digitizers were triggered on the beam pulse we got good profiles, left. When we moved the trigger point we got 'inverted profiles' from the undershoot, right. In these two examples the trigger signal timing is different by 70° at harmonic number 1.



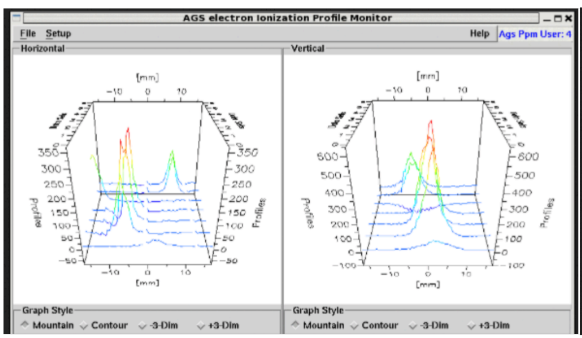
The "negative profiles" where not a problem during proton fills when only one bunch was injected in each AGS cycle. However when several bunches were injected the individual bunch profiles interfered which each other and dramatically reduced the average profile. During the shutdown we removed the output transformers to dc couple the amplifiers to the digitizers. This eliminated the "negative" profiles and provided good profile measurements with heavy-ion operation.

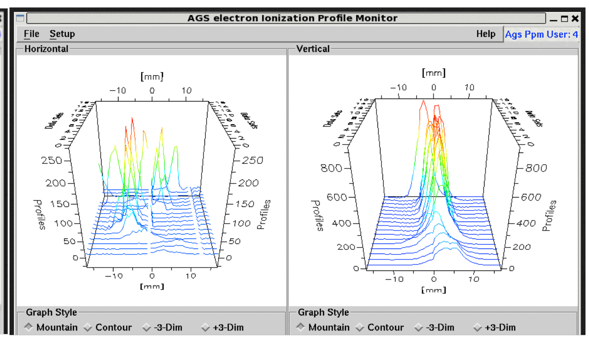
### Detector "dead zone"

The biasing of the detector creates a "dead zone" with a width of about 1/3 of the beam aperture next to the MCP. Free electrons created in this zone will not pick up enough energy from the sweep field to enter the MCP channels. In RHIC, with smaller beams and better orbit control, this has not been a problem, but in AGS the beam-position movement in the detector caused measurement artifacts.

The measurement aperture issue with the vertical eIPM was discovered during beam studies. When beam is extracted from AGS a steering bump is introduced which moves the beam to the outside of the ring. Normally the beam leaves the AGS so the disappearance of vertical profiles was expected. During the beam studies the steering bump was being introduced but the beam was not extracted. The left plot below shows the horizontal and vertical profiles records from the beginning of the machine cycle (front) to the end (back) taken at seven different times. At the fifth measurement the beam moves out of the horizontal eIPM aperture to the left and the vertical profile disappears, which is the behavior we had been observing. However the bump is removed for the last two measurements and both horizontal and vertical profiles are back. The vertical eIPM was installed with the MCP on the outside of the ring. The extraction bump was moving the beam into the dead zone of the detector.

To correct this measurement artifact, we rotated the detector head by 180° moving the dead zone to the inside of the ring. The right figure shows that in this configuration we get good vertical profiles during the full machine cycle with large horizontal movements of the beam.



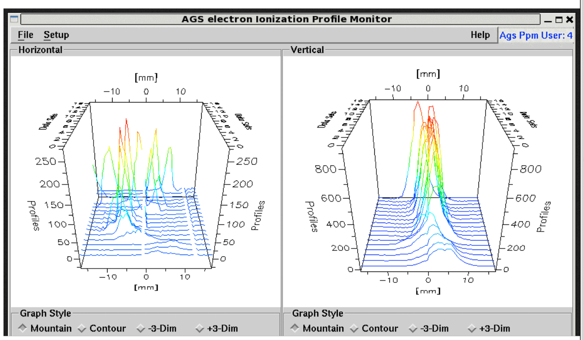



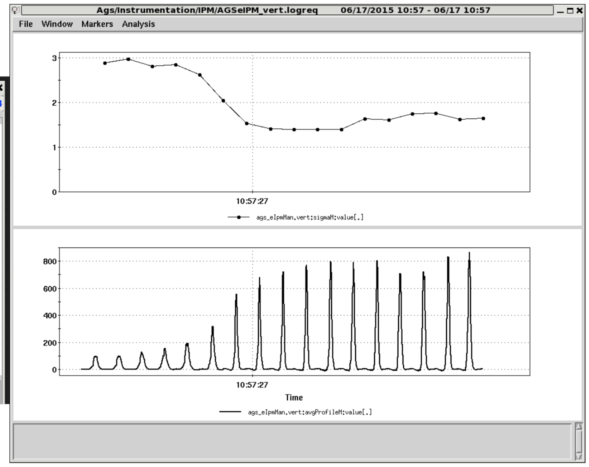

Once we were aware of the measurement artifacts arising when the beam was near the dead zone boundary we were able to understand that this was the cause of strange behavior of the horizontal eIPM. Dedicated measurements showed that the AGS orbit in the horizontal IPM was consistently below beam line center, in the direction of the MCP. During the Run 15-16 shutdown we flipped over the horizontal eIPM detector to place the 'dead zone' at the top of the chamber.

### Gain control on ramp

Gain feedback on the RHIC IPMs is done between measurements. We set a target profile amplitude which is in the linear range of the instrument. After each measurement the profile amplitude is compared to the target amplitude and the MCP bias voltage is adjusted appropriately for the next measurement. This works on RHIC because the profile changes between measurements are very small.

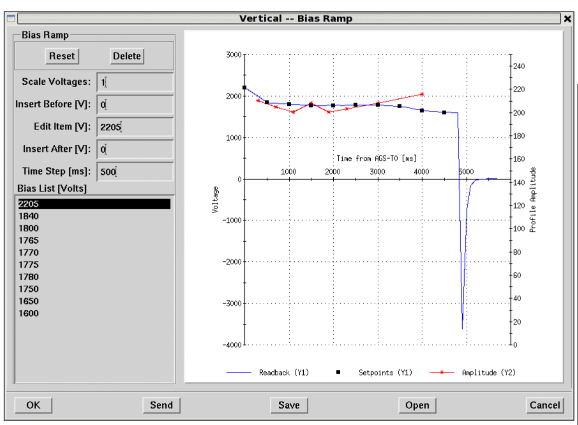
In the AGS we want to make several profile measurements during a single machine cycle. As the beam is accelerated, the profile width decreases and the amplitude increases. This is shown in the two figures below. We would like the amplitudes of the measured profiles to remain about the same during the machine cycle. To do this we added the capability to program a MCP voltage ramp during the machine cycle. The control is via the analog input to the Beltran power supply which has a response bandwidth of ~0.6Hz which is adequate to correct this dataset.

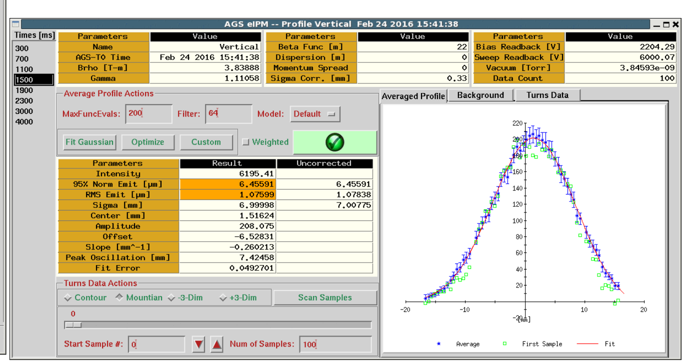


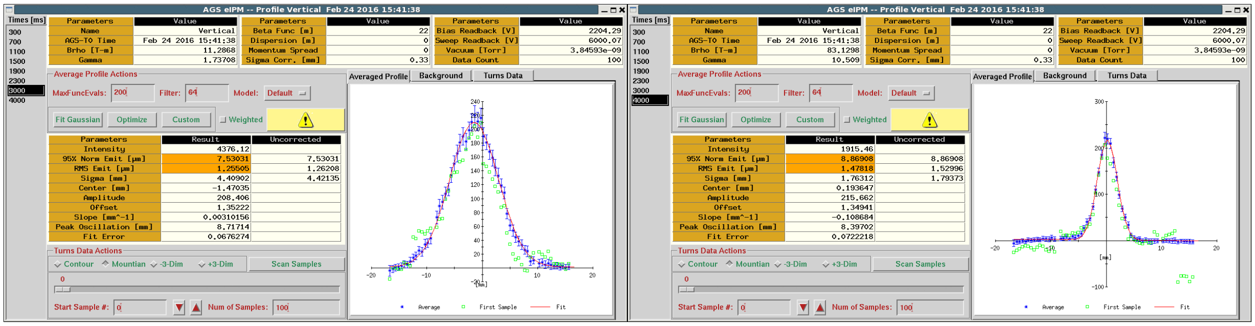



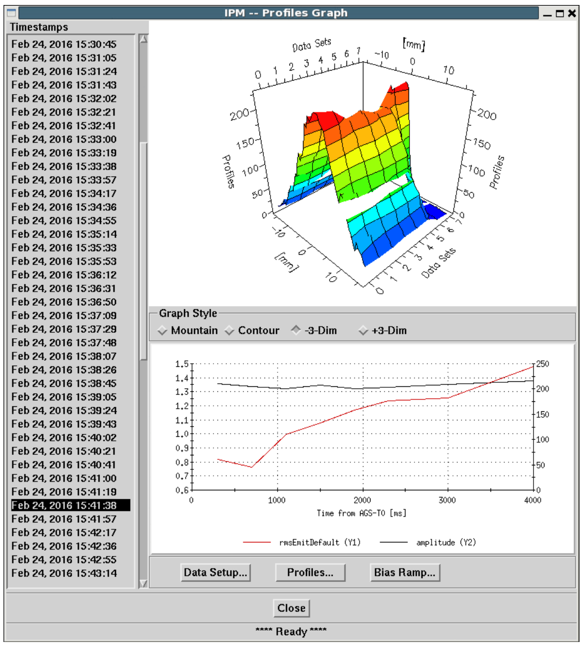

*Top of right plot shows the beam sigmas and the bottom shows profile amplitudes during the full AGS acceleration cycle.*

The plots below show the gain control results. The first plot shows the Bias Ramp editing page. The blue data shows the set voltage points and the read back of the MCP bias voltage. Here we have ten points at 0.5s intervals. The red points show the measured profile amplitudes. The next three plots show the measured beam profiles before, during and after the acceleration ramp. The last plot is a mountain range plot of the ten-profile record with a plot of the profile amplitudes and the measured emittances.





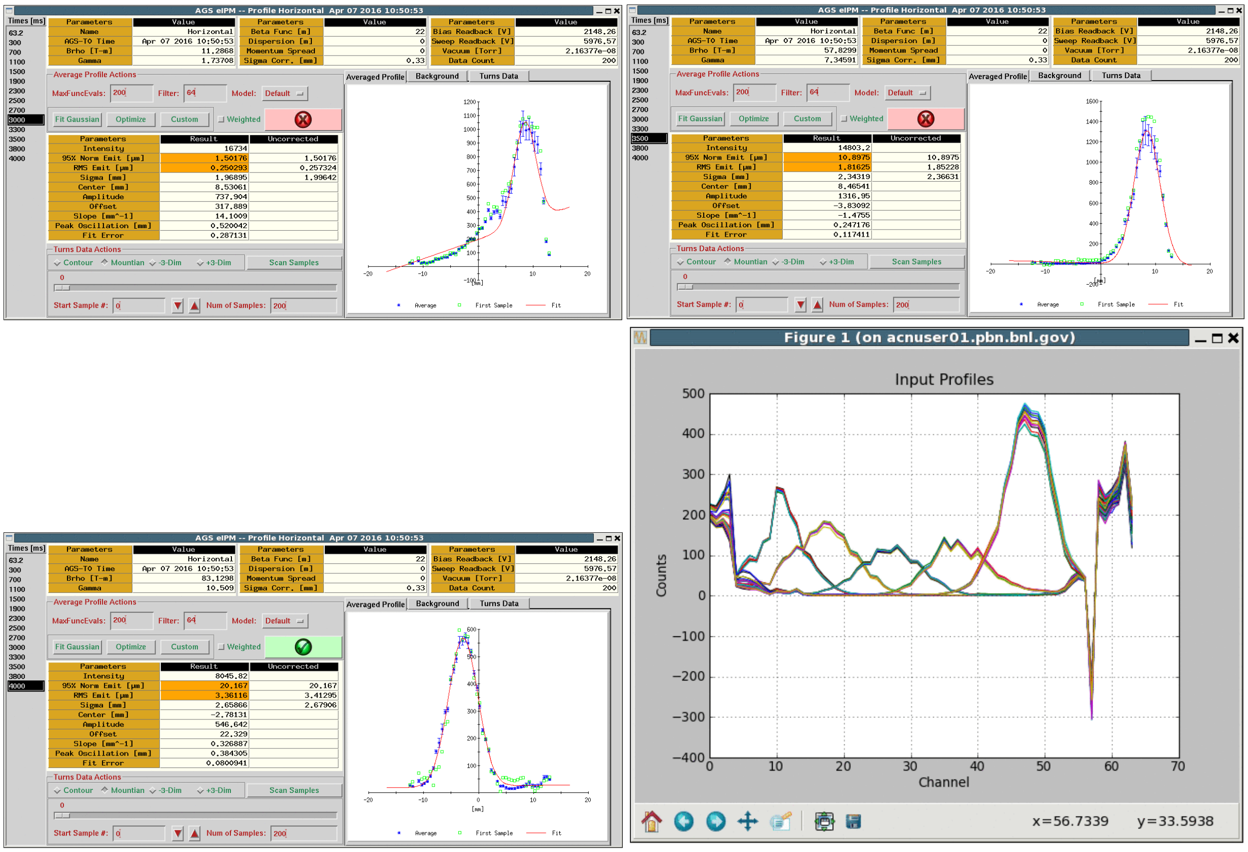




# Run 16

## Gain depletion on horizontal MCP

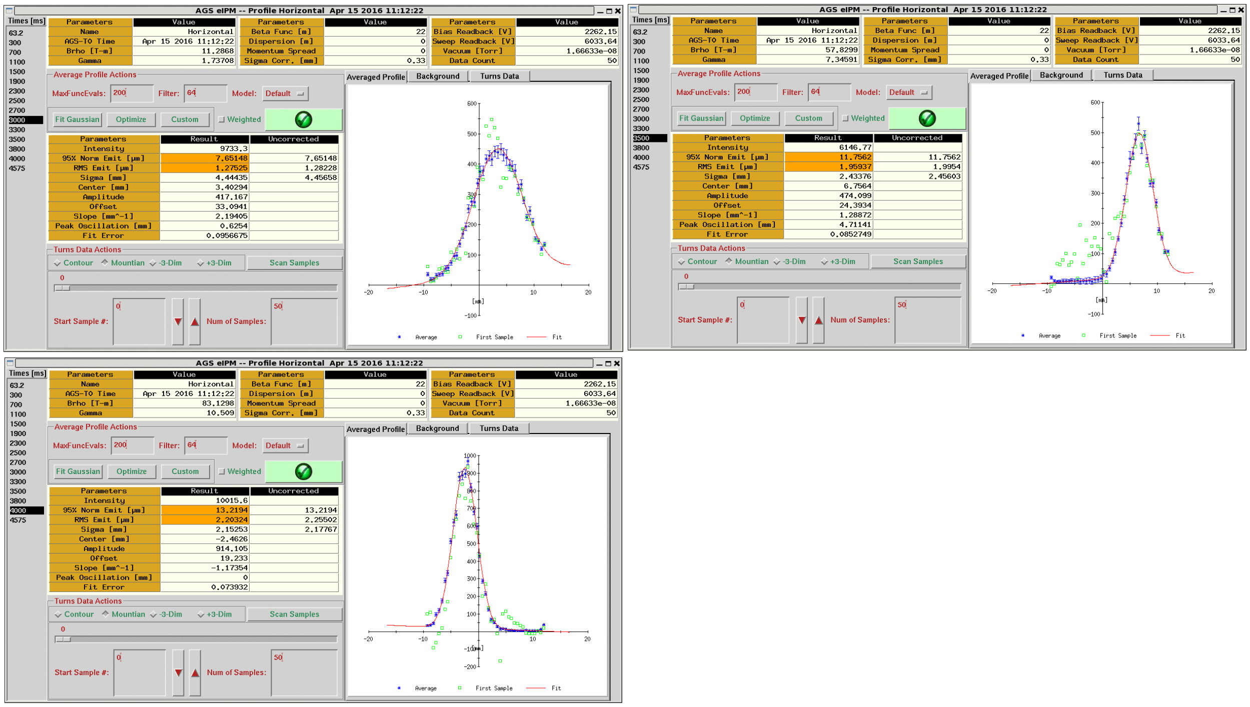
At the start of Run 16 the vertical eIPM gave good profiles, but the horizontal gave mixed results. The beam moves horizontally continuously during the AGS beam cycle. This movement is large enough that the beam is frequently out of the measurement aperture of the eIPM. If there is a position-dependent error in the eIPM, the beam movement can result in a measured beam emittance that appears to get larger and smaller as the beam cycle progresses. As we studied these measurement we found that when the beam was left of center or far to the right in the detector the profiles were very clean but they became distorted when the beam moved to the right of center.

The top three figures show this effect. These are measurements taken at 3.0s, before acceleration, and at 3.5s and 4.0s after acceleration. The profile before acceleration has a long tail and the Gaussian fit shows the beam to be smaller before acceleration than after. Figure 4 is a crude calibration scan showing five profiles taken at different horizontal positions. This shows that MCP is severely damaged over the center and left parts of the aperture, but maintains good gain on the far right. The first profile actually is a broad beam peaked at about 4mm with the right tail amplified by a factor of three higher that the center and left of the profile.



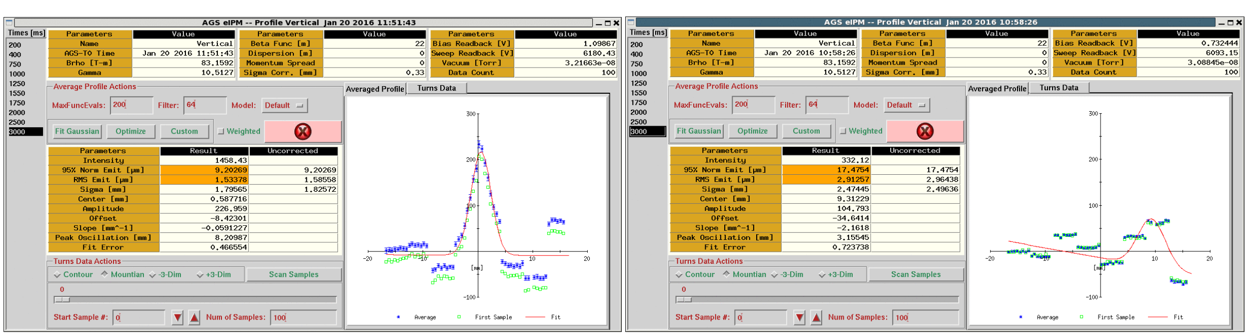

We constructed approximate gain correction values for channels 10-48 from the scan. Below is a calibration scan after these first corrections were applied. Also are profiles after corrections at the same times as those above. The profile at 3.0s is Gaussian and the beam sigmas decrease as the beam is accelerated.

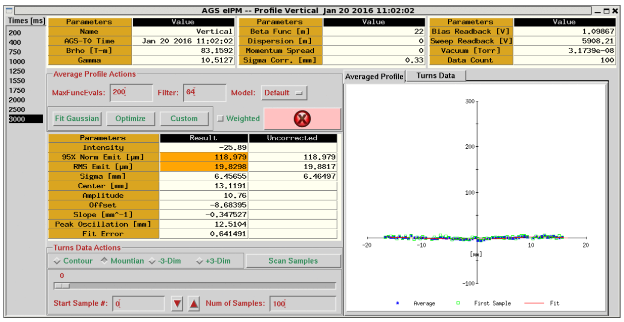
These results show that the distorted profiles are caused by a severely damaged MCP from beam exposure. The damage is most severe in the MCP center. It is least damaged on the right side which is the inside of the AGS ring. The left side which is damaged is the outside of the ring where the beam is kicked for extraction.

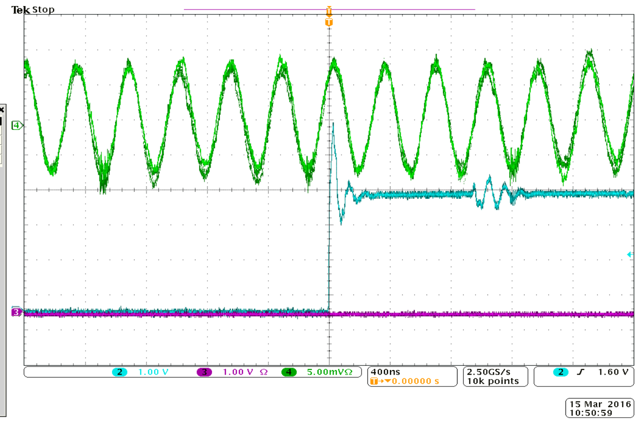


## Rf pickup on profile signals

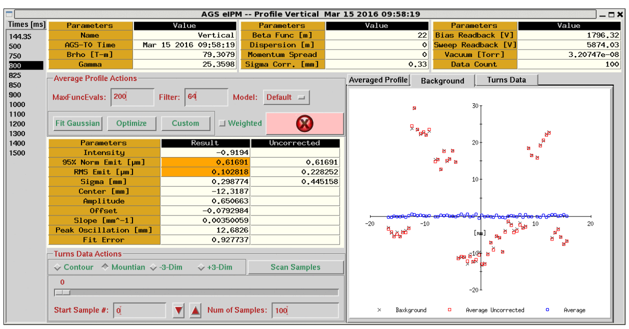
Before Run 16 started the dc offsets on the eIPM amplifiers were measured and corrections were entered into the Manager. When beam operations started we saw large dc offsets. These offsets appeared in groups of 8, corresponding to the 8-channel amplifier boards. For each board the dc offsets were about the same, but the value of the dc offsets were different for the eight amplifier boards. The left figure below shows a beam profile and the right figure shows the baseline with no beam. This 8-channel grouping of dc offsets is due to rf noise being picked up in the tunnel. The left figure in the second row shows the dc offsets with the acceleration rf turned off and the right figure shows the rf signal on one of the signal cables from the amplifiers in the tunnel to the digitizers in E10.

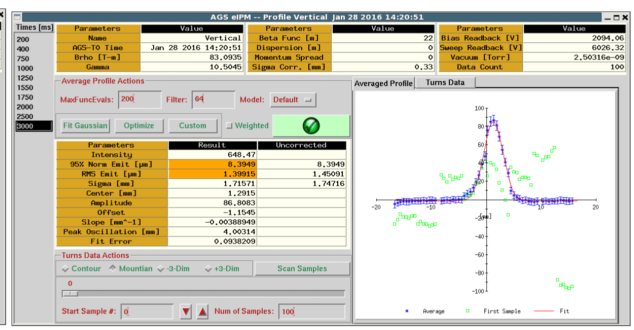





To correct the rf pickup we added active background subtraction in the manager. Each measurement now uses two machine cycles. One is done normally and one is done with the electron gate turned off. The "off" data are subtracted from the "on" data to produce a complete profile data set. An example of this is shown in the two figures below. The left figure shows the baseline with no beam and rf subtraction and the right figure shows a beam profile with background subtraction.

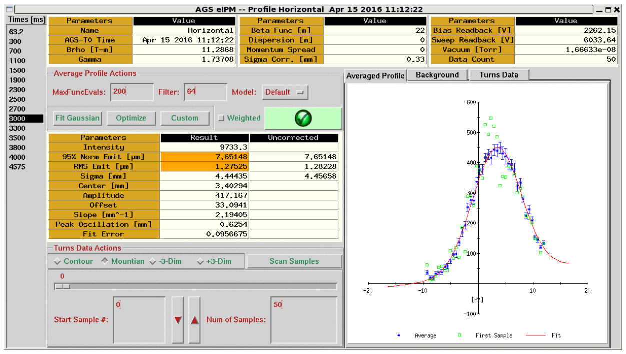


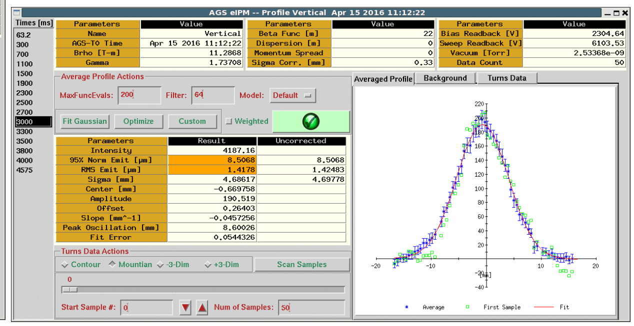




## Some Run 16 results

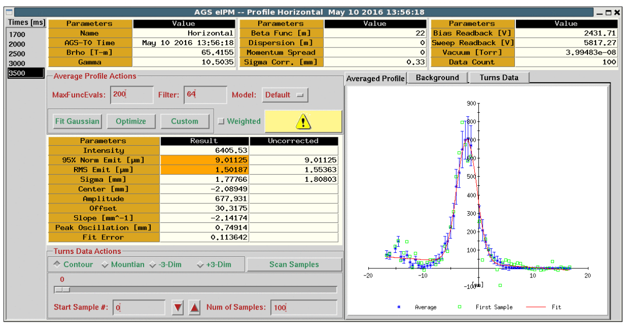
The rf background subtraction was implemented early in the run. After that the vertical eIPM gave good results, but there were still problems with horizontal. The biggest issue was the depleted MCP. The gain corrections implemented on April 12 brought the vertical and horizontal eIPMs into agreement, as shown in the figures below. The top pair are horizontal and vertical profiles of Au beam made just before acceleration on April 15 and the bottom pair are profiles from the deuteron beam at full energy on May 10.

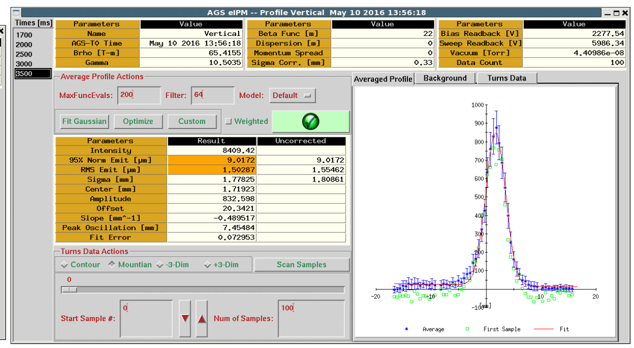
One issue with the horizontal detector can be seen in the two left profiles. On April 15 we had all channels to the left of -10mm and to the right of +10mm removed from the data analysis. On both extremes of the detector we were getting anomalous signals which are not understood. This is seen in the left of the profile from May 10 with all of the channels enabled.





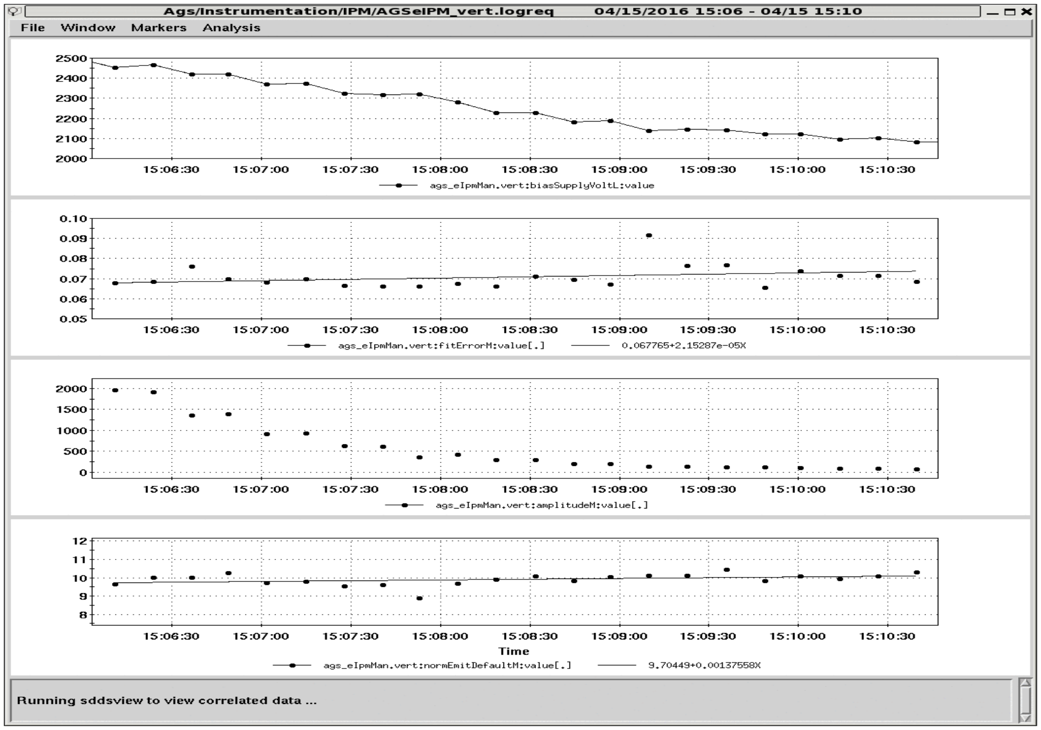

*Profiles of Au beam at injection energy, April 15*






*Profiles of deuteron beam at extraction energy, May 10*

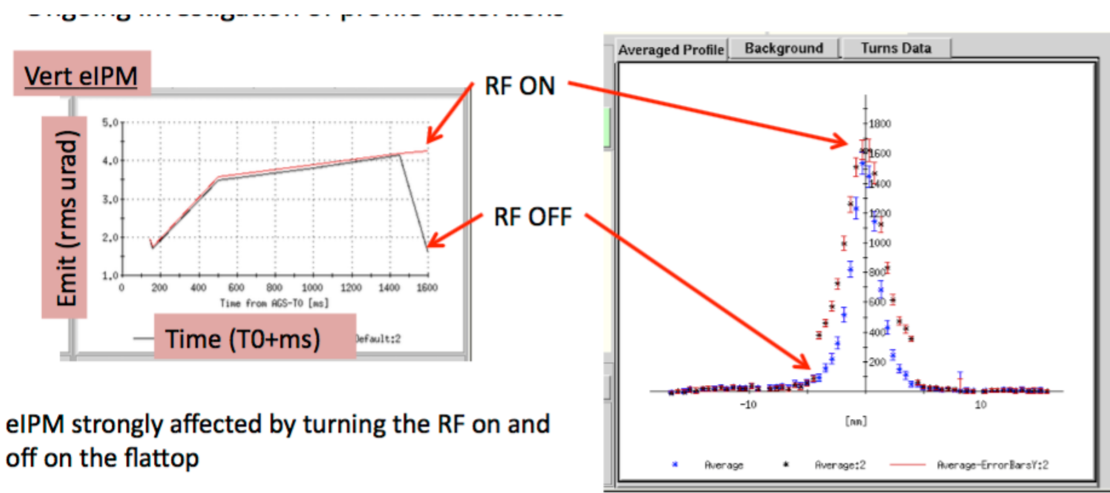
Finally we show a study where the MCP bias voltage was continuously lowered (top plot). This lowers the gain of the MCP resulting in lowering the profile amplitude from 2000 to 83 (third plot). Dropping the gain through the full range of the VME digitizers increases the measured emittance by only 4% (bottom plot) and increases the fit error from 0.068 to 0.074 (second plot).



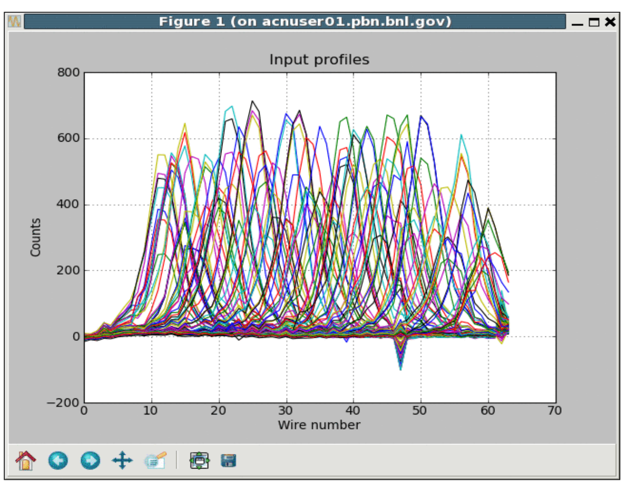

## Polarized proton studies, June 26-28

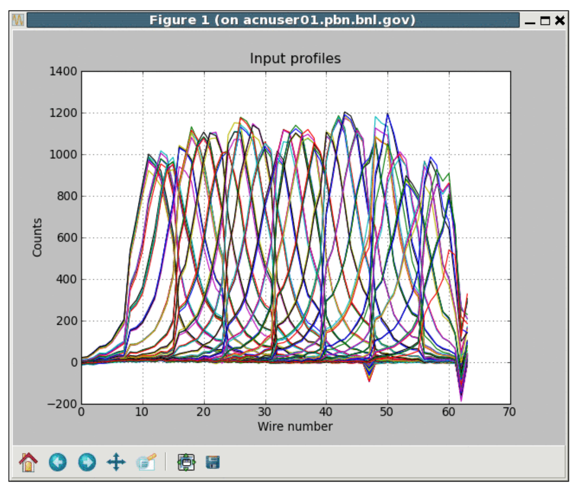
At the end of Run 16 there was a three-day beam run to study polarized proton beams in the AGS. One of many reasons for this run was to do commissioning studies on the eIPMs.

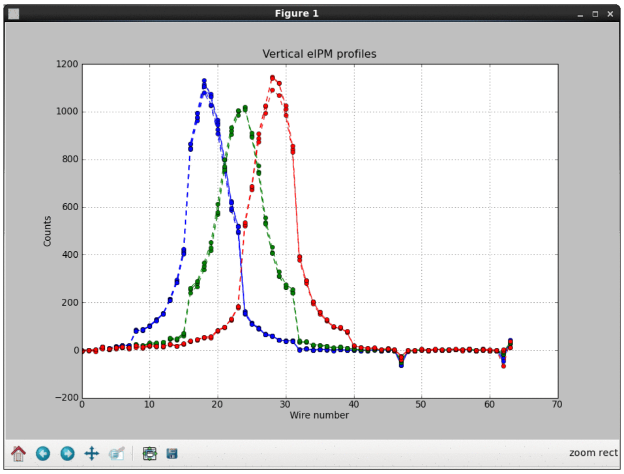
The surprise from this run was that the rf noise pickup had a different effect on the profile measurements than it had for the entire Run 16. For these three days, the rf had very little effect on the baseline but had a strong effect on the beam profile. This is seen in the first figure below. We noticed the measured emittance at full energy was about twice as large with the rf on than with it off (left). When the profiles were compared with beam centered on the vertical eIPM, the rf-on case shows the portion of the profile covered by the center two 8-channel amplifier groupings was raised and broadened compared to the rf-off case but the rest of the 8-channel groupings show no difference with rf on and off (right).



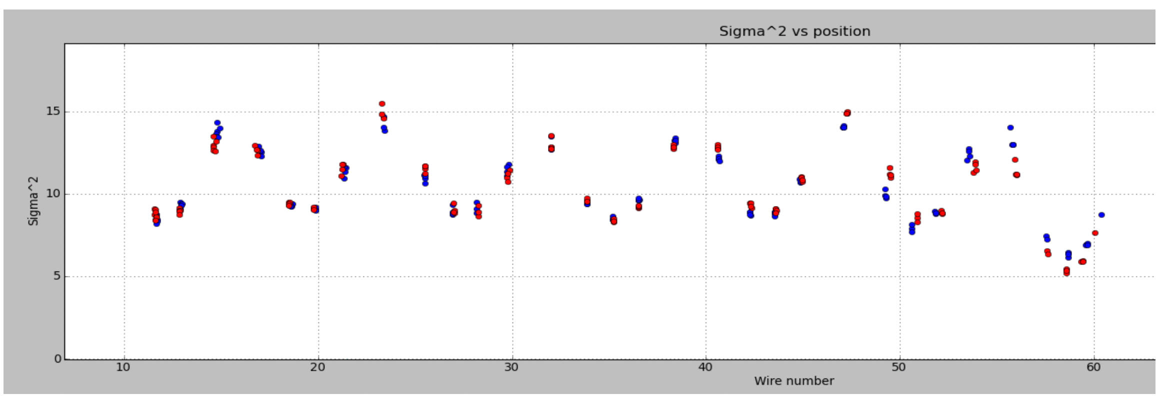

This pattern of profiles discontinuities at the breaks between the 8-channel amplifier groupings with the rf on appeared across the entire eIPM as shown here. The left figure shows a composite of all the profiles taken with rf off and the right figure shows the profiles with the rf on.






The figure above shows profiles of the beam with the beam in three positions in the vertical eIPM. There is a gain step between 8-channel amplifier boards and the size of the step increases as the profile amplitude gets larger. This behavior results in a position-dependent emittance as shown below. Here we plot the measured sigma$^2$ vs. position of the center of the beam. This 8-channel gaps in the profile measurements was not seen in the rest Run 16 and it is not understood.

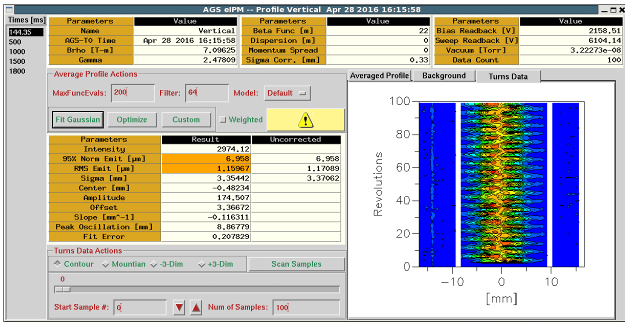


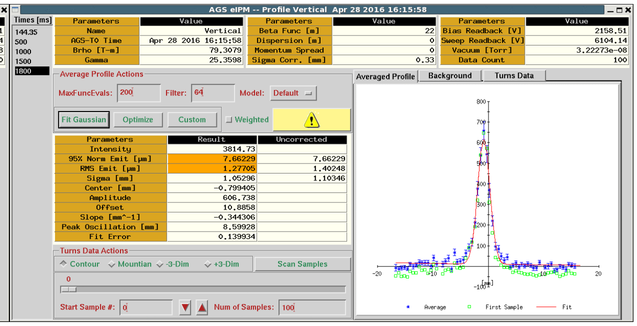

*Measured sigma$^2$ vs. position of the center of the beam*

### Injection matching

One motivation for adapting RHIC IPMs for use in the AGS was to use the turn-by-turn measurement capability at injection to minimize injection errors which increase beam emittance. We can use the eIPMs to measure the contribution of injection mismatch to the AGS output beam emittance.

These two figures are proton-beam measurements made with the vertical eIPM on April 28, 2016. The left plot is a contour plot is of the first 100 turns at injection (144ms past $t_0$) showing dipole oscillations. The right plot is the beam profile at top energy showing the measured beam sigma and the calculated beam emittance.




For a profile measurement, the digitizers are triggered on each turn for a set number of turns. These measurements used 100 turns of data. An emittance measurement is obtained by averaging all of the single-turn measurements. We also fit gaussian curves to each single-turn profile. We plot the measured beam centers vs. turn number (below left) and profile sigmas vs. turn number (below right) at injection, together with the discrete Fourier transforms of these signals. This gives peaks at the dipole and quadrupole frequencies.

We plan to optimize the injection match by changing steering and focusing in the BtA line to minimize the amplitudes of the dipole and quadrupole lines in the DFTs. We planned an experiment at the end of Run 16 to measure the effects of matching on the final emittance, but we ran out of time from beam problems. We will make these measurements in Run17.