AGS Intensity and Polarization Upgrade Plan for RHIC

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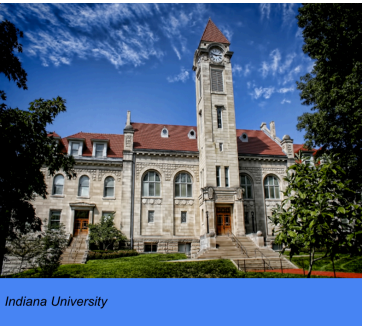


Depolarizing Resonances in the AGS

Imperfection Resonances

$\nu_s = n$ (integer) $G\gamma = 5, 6, \ldots 45$ partial snake(s)

Vertical Intrinsic Resonances

$\nu_s = kP \pm \nu_y$

Strong ones: $G\gamma = 0+\nu_y, 12+\nu_y, 36\pm\nu_y$ strong partial snakes

Note: with two partial snakes in the AGS, P=1. There are a lot weak intrinsic resonances as the result.

Horizontal Intrinsic Resonances

1. non-vertical stable spin direction due to strong partial snake.

2. betatron motion coupled to the vertical betatron motion by coupling elements: solenoid, helical magnet.

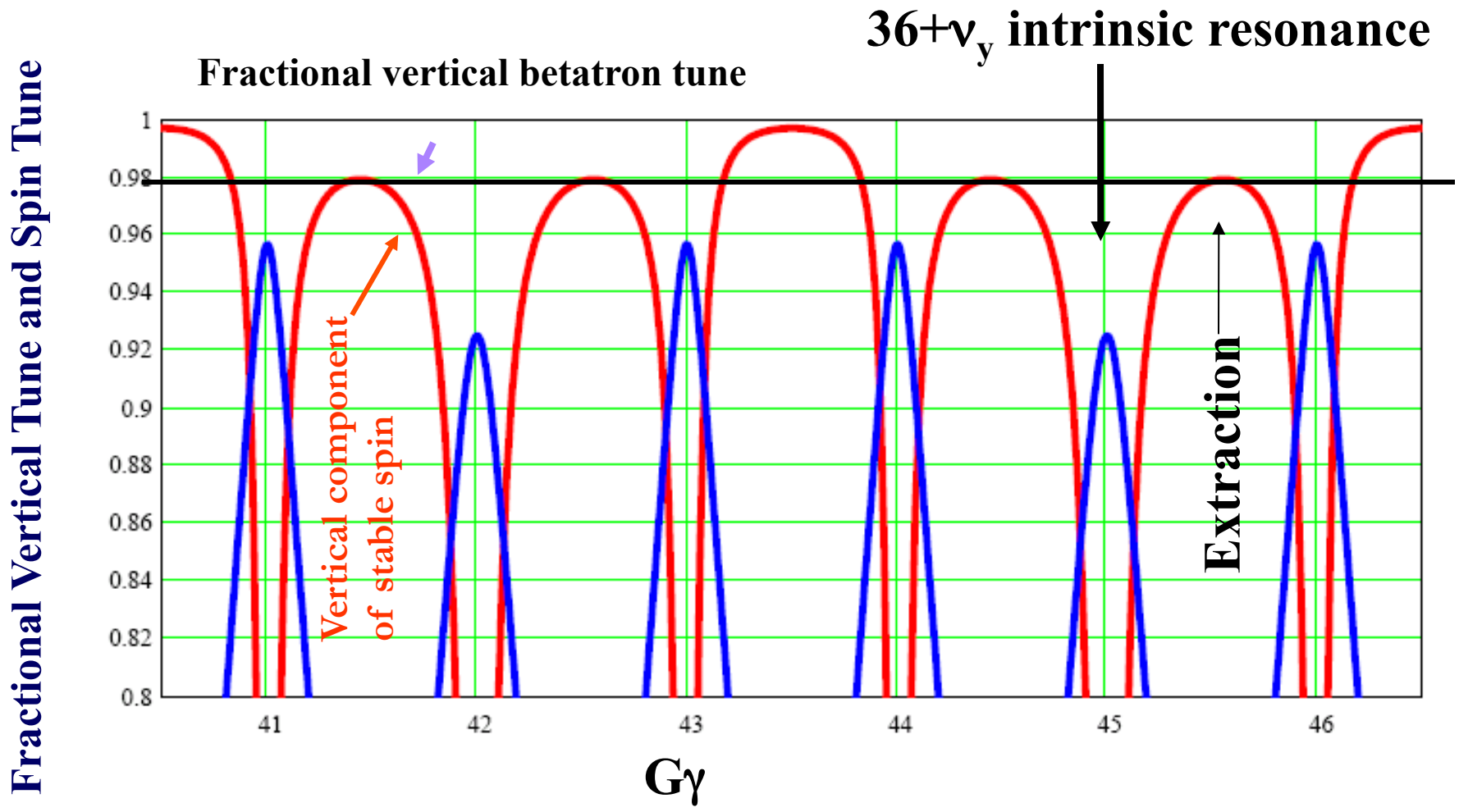
$\nu_s = k \pm \nu_x$ fast crossing speed(tune jump), strong partial snakes

Partial Snake Resonances

strength proportional to nearby intrinsic resonance strength.

$\nu_s = kP \pm m\nu_y$, $m > 1$ avoid the resonance tunes

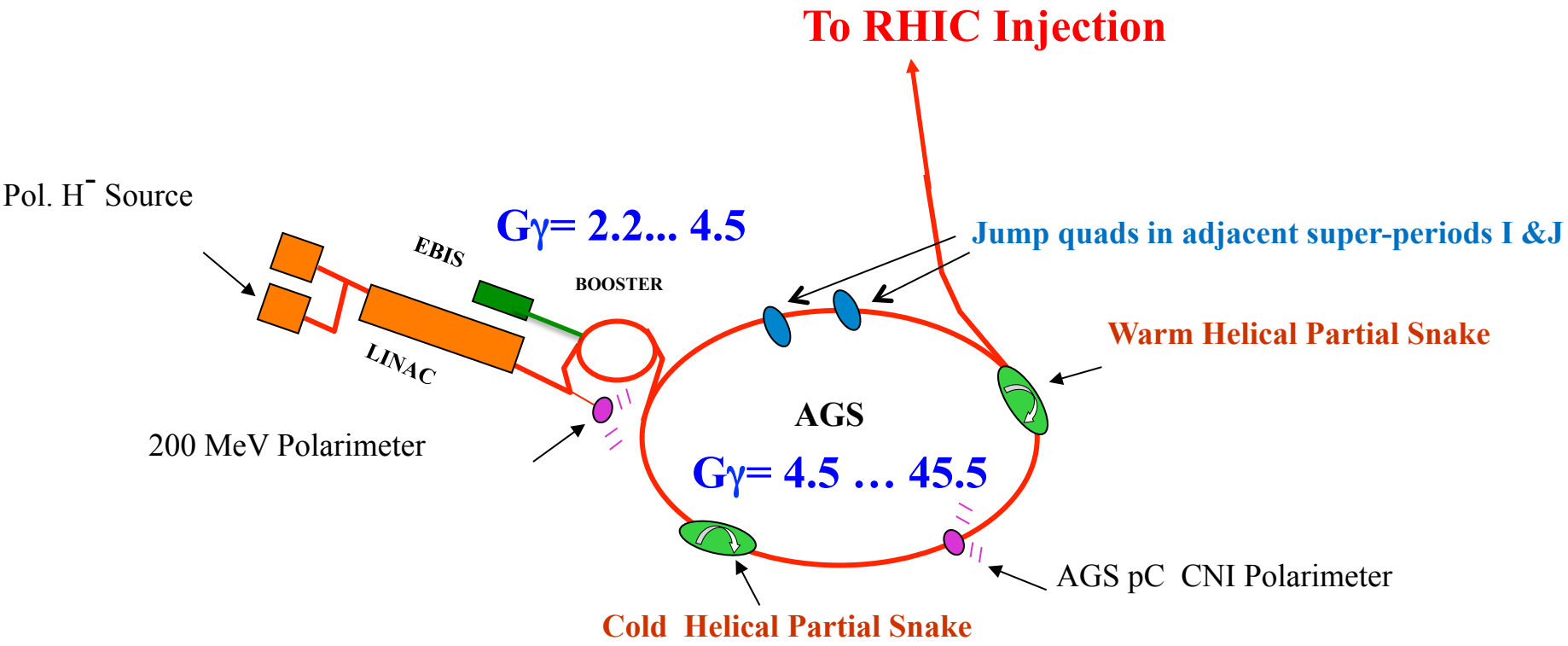
Spin tune with two partial snakes



Spin tune gap modulation of the period of 3 units of Gγ:

$$\cos\pi\nu_s = \cos G\gamma\pi\cos\frac{\theta_w}{2}\cos\frac{\theta_c}{2} - \cos G\gamma\frac{\pi}{3}\sin\frac{\theta_w}{2}\sin\frac{\theta_c}{2}$$

RHIC Injector Chain



AGS has been running as RHIC polarized proton injector with dual partial snakes and two horizontal tune jump quads. It has delivered 65-70% polarization with $2*10^{11}$/bunch intensity and 80% as input polarization.

Polarized Proton in the Injectors

- AGS has been running as RHIC polarized proton injector with dual partial snakes and two horizontal tune jump quads since 2011.
- The dual partial snakes overcome the vertical intrinsic and imperfection resonance in the AGS.
- The introduction of partial snakes generates horizontal intrinsic resonances. They are generally weak but could cause accumulated polarization loss if left uncorrected. A modest horizontal tune jump system has been used to overcome these weak but numerous resonances while maintaining the transverse emittances. A relative gain of 10-15% polarization has been achieved with the tune jump system.
- The upgrade of source has provided more intensity for the injectors. We can get more intensity through injectors. The depolarizing resonance strength is proportional to the square root of emittance. The Further gain in polarization while raising intensity will come from the control of emittance growth.

Booster Bunch with Different Harmonics

- With Booster input current increased by a factor 2, space charge force becomes important.
- The solution is to use dual RF harmonics (H=1 and 2) in the Booster.
- The reduction of peak current is about 25-30%.

H=1 vs. H=1 and 2

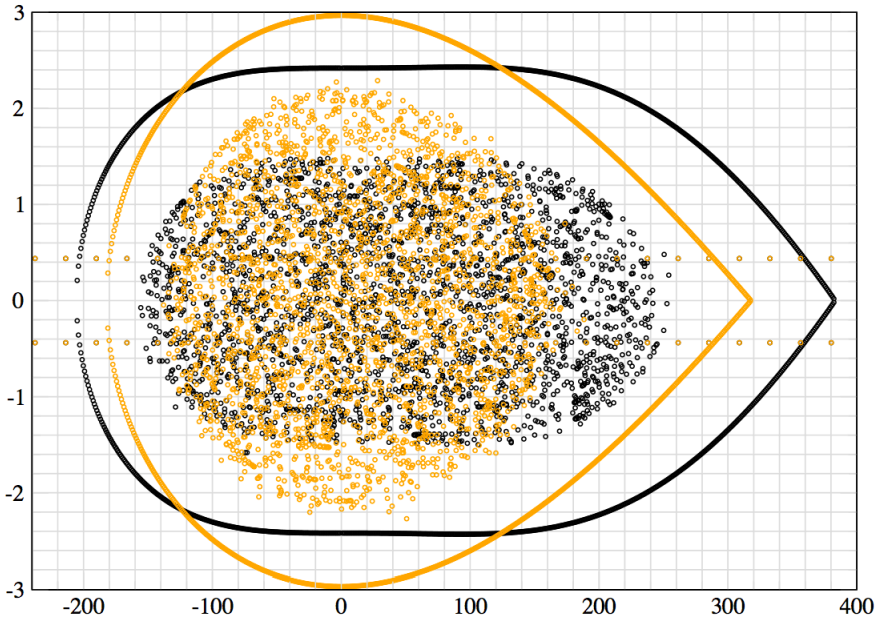


Figure 20: Comparison of single and double harmonic acceleration of PP.

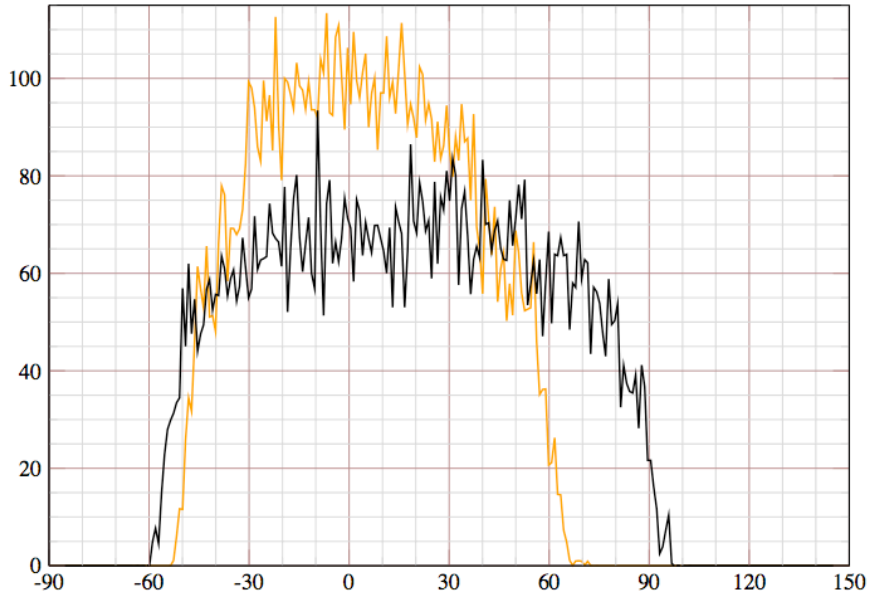
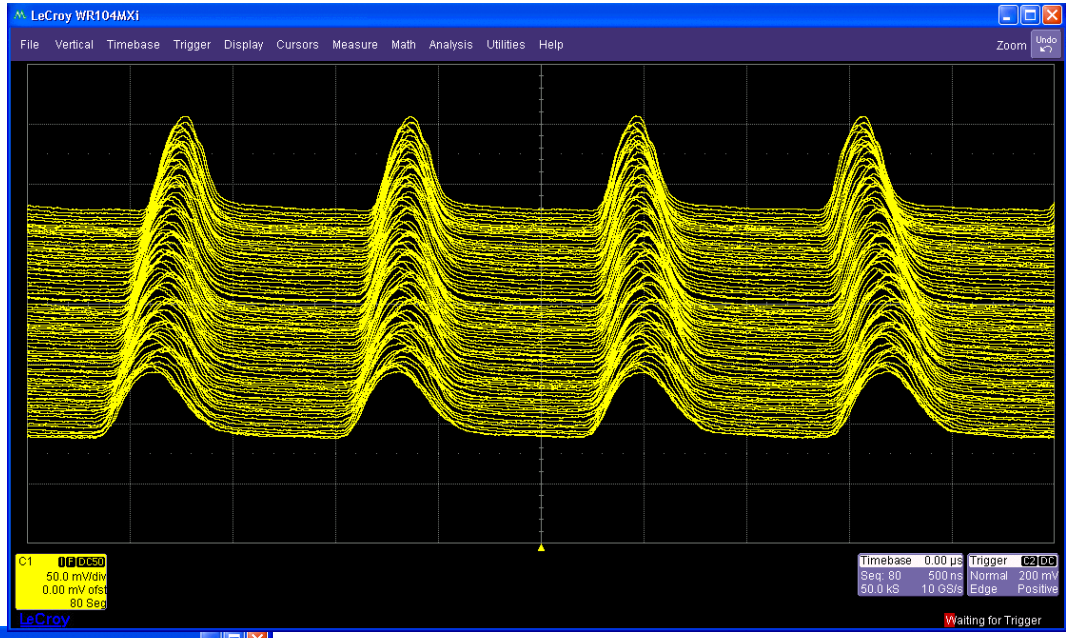


Figure 22: Comparison of single and double harmonic acceleration of PP.

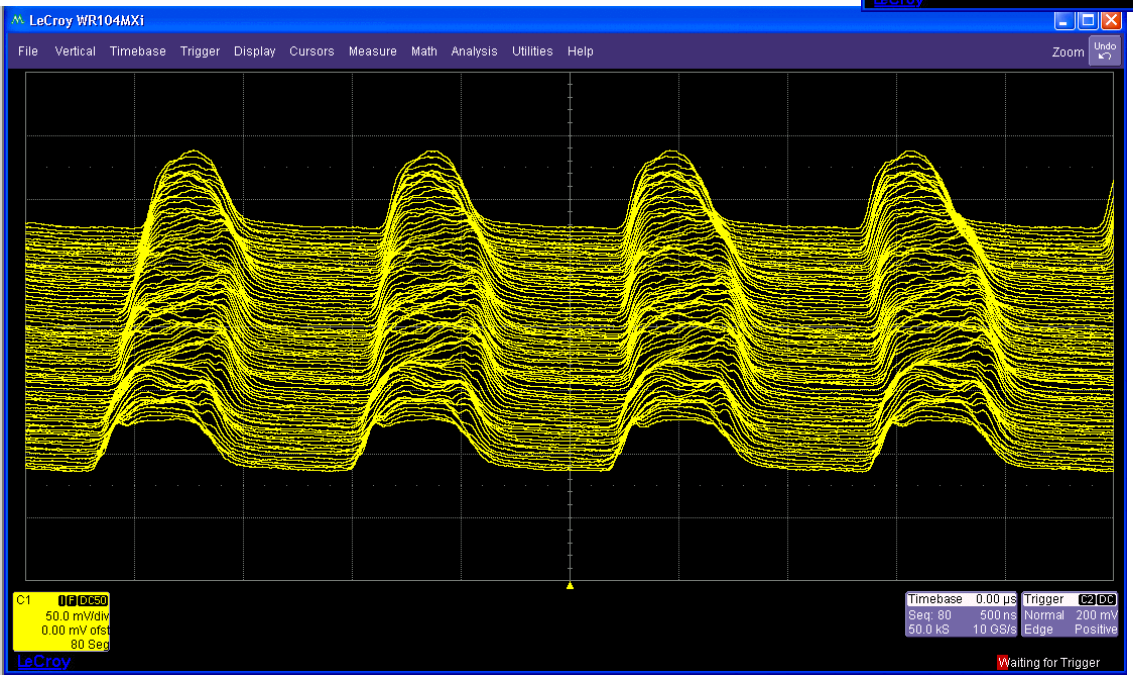
Booster Dual Harmonics RF Cavities

H=1 only

With dual harmonics, the peak current is reduced, so the space charge effect on emittance blowup (growth) is mitigated.



H=1 and H=2 on



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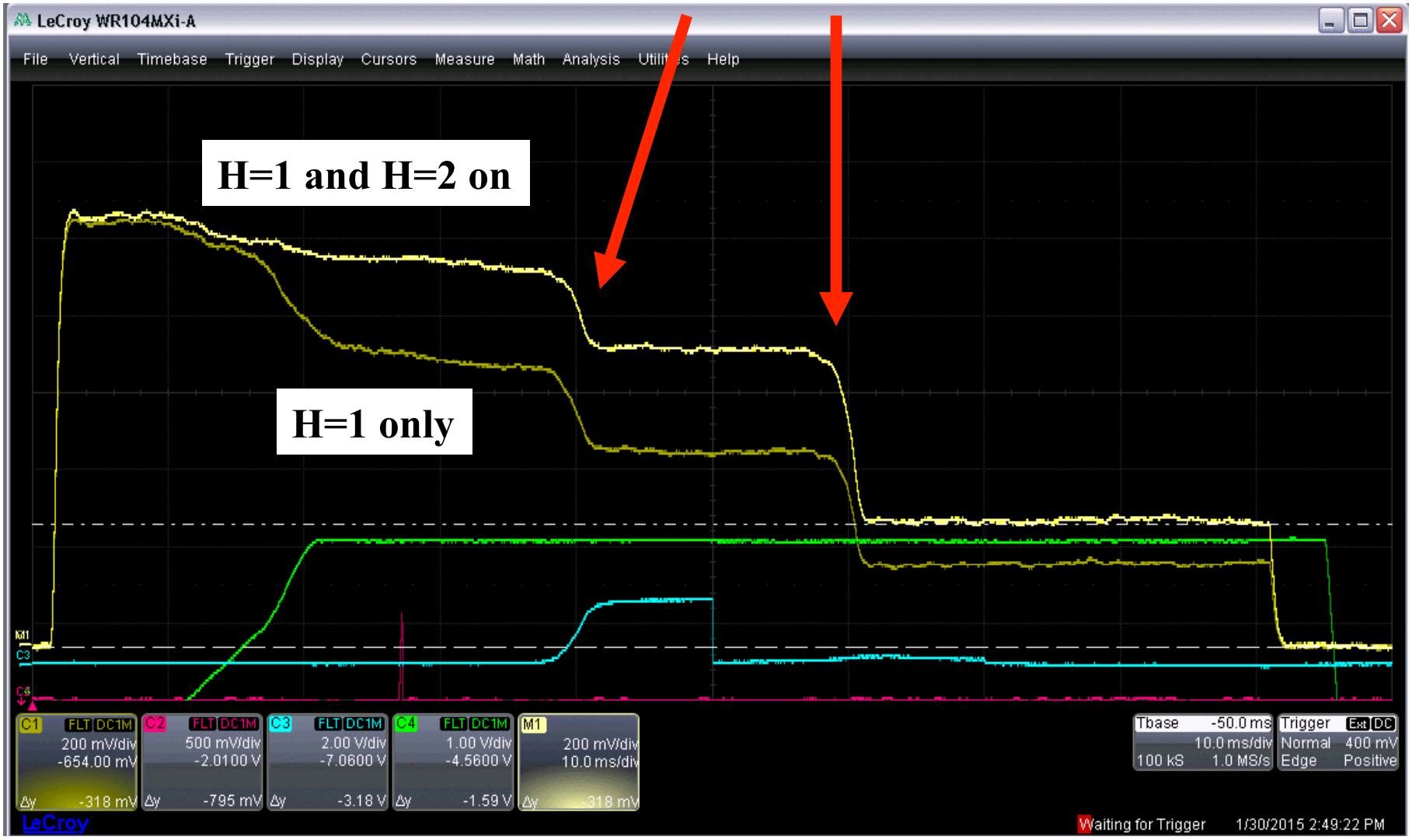
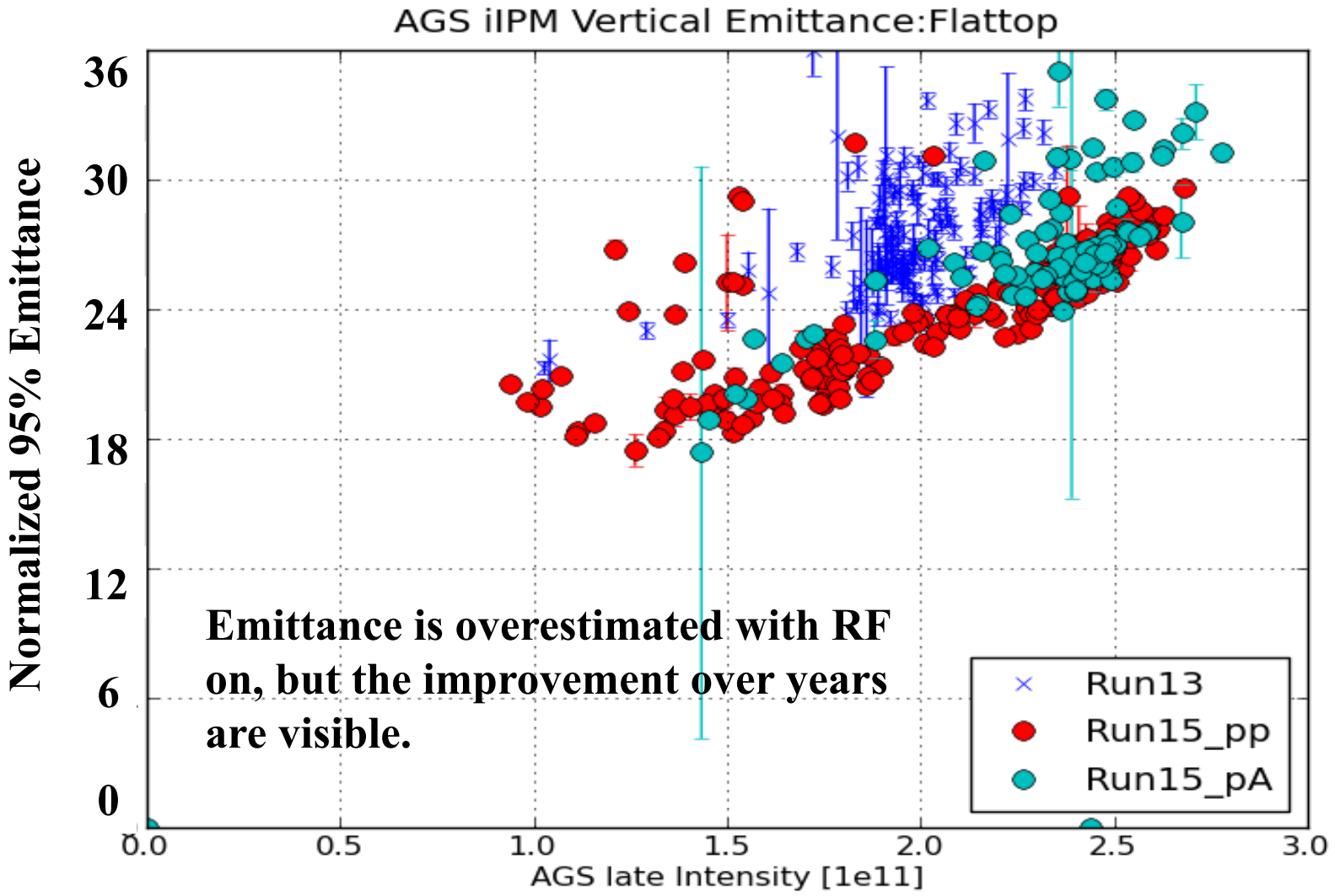
Booster Intensity vs. Time



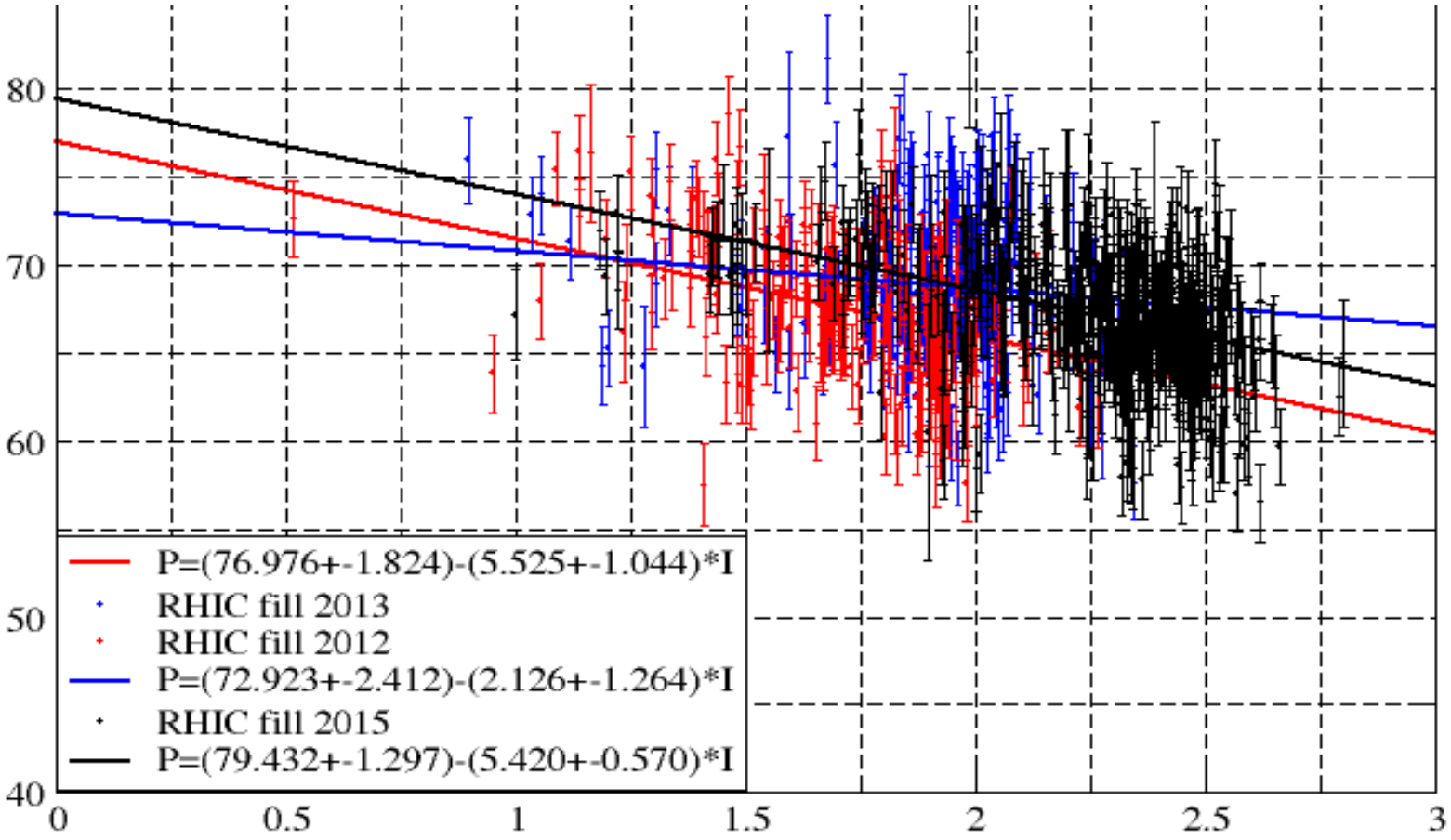
More beam survived through the same aperture(scraping): same emittance but more intensity, a brighter beam.

AGS Flattop IPM Vertical Emittance for RHIC Fills

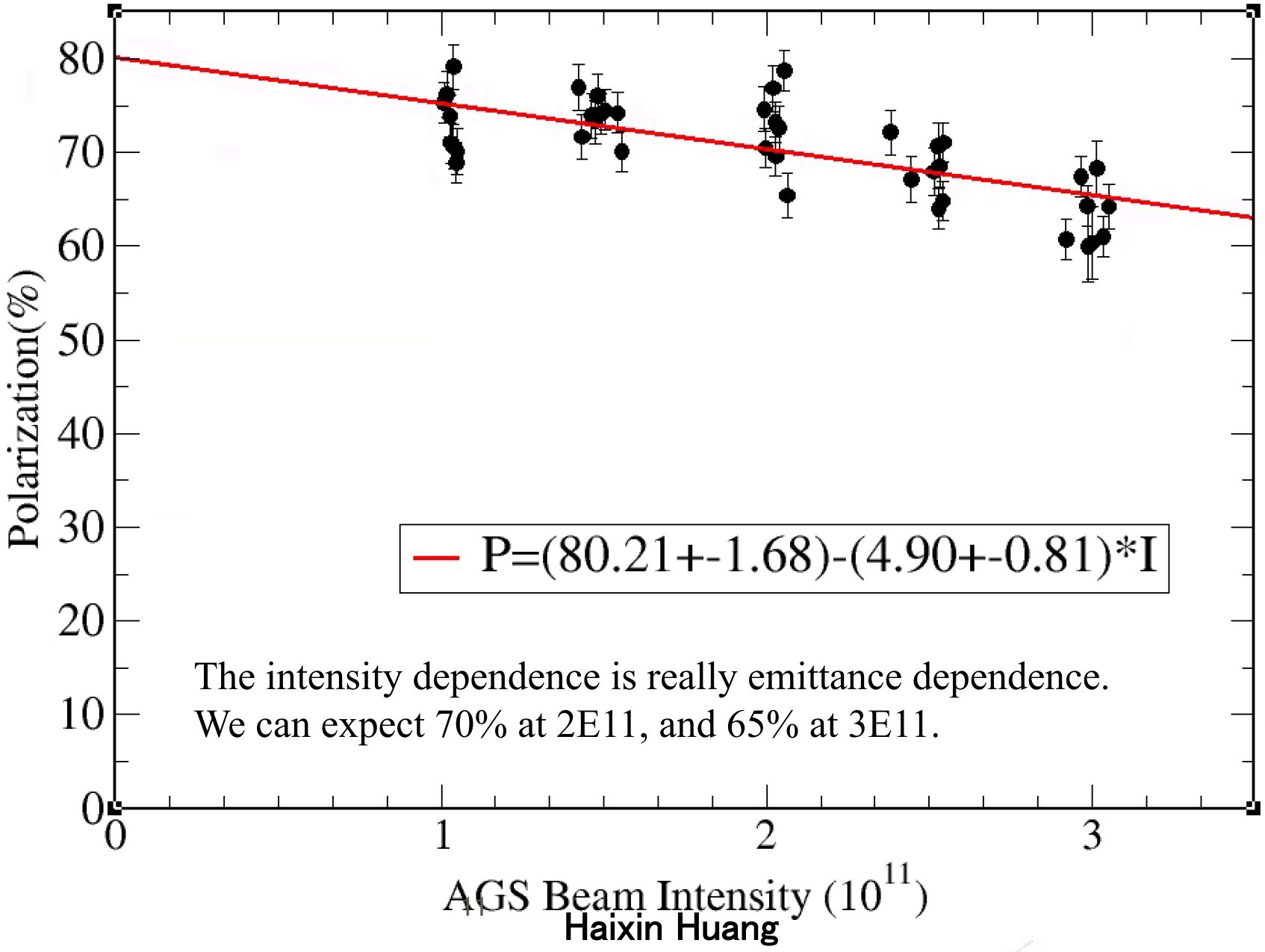


AGS Extraction Polarization for RHIC

In run15, the polarization was maintained at similar level as run13 but at higher intensity. The emittance out of AGS is smaller due to heavier scraping in the Booster. The smaller emittance helped us to maintain polarization with higher intensity.



AGS Polarization vs. Intensity (Dedicated Scan)



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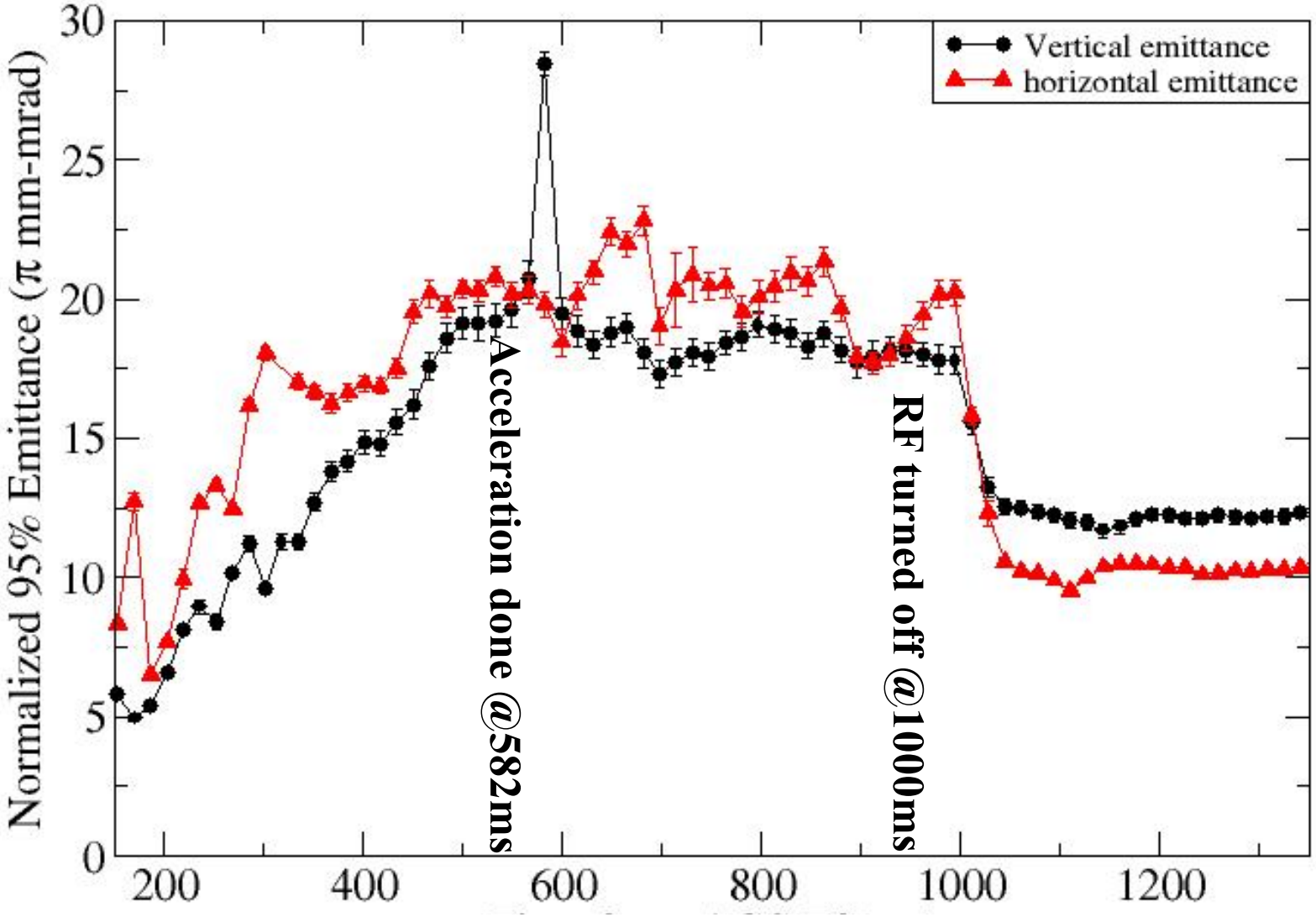
Emittance Evolution along AGS Cycle



The Bottom Line of Emittance

Emittances with,$2*10^{11}$ at AGS extraction.

	Hori. Emit.	Vert. Emit.	
Linac	5.5+-1.0π	6.0+-1.0 π	They have been improved lately
BtA (Booster exit)	9.2+-0.9π	7.1+-1.0 π	Stripping foil, multi-turn injection
AGS extraction	10+-1.0π	12+-1.0π	Measured by IPM with RF off

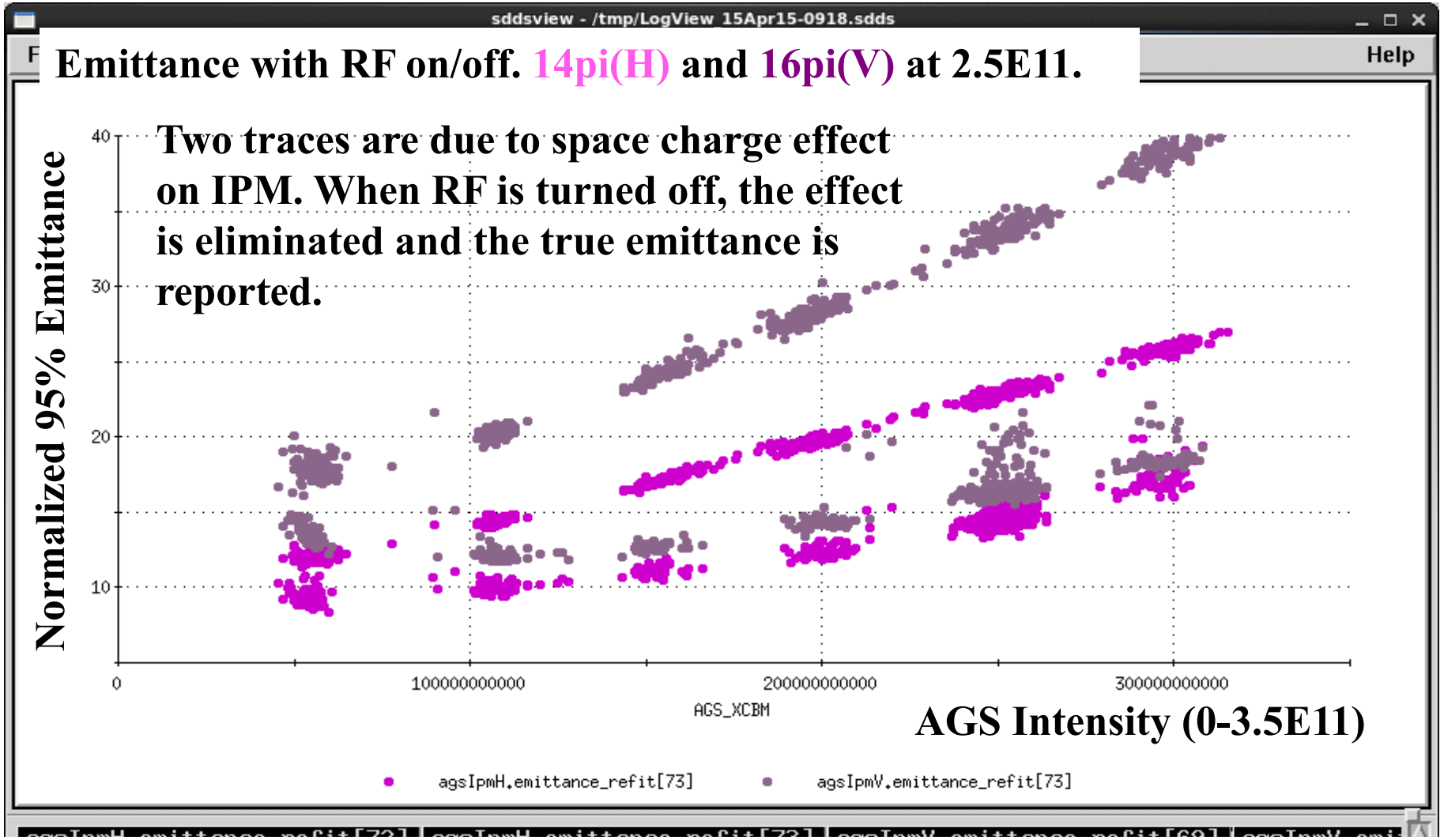
- These emitttances are measured with different devices and each has its own systematic errors.
- BtA measurement was without Booster scraping.
- The IPM measurements suggest vertical emittance growth on the ramp.
- Two possible sources: the vertical emittance growth at AGS injection and along AGS ramp. To confirm the injection one, we need turn-by-turn emittance information at injection. Electron collecting IPM have been installed in AGS and they are under commissioning.

Plan for the Future

- The first priority is to find out possible sources of the jump quad timing drift. AGS main magnet field drift affects JQ timing. Two options: add a field feedback (changing the actual main magnet function); or change the jump quad trigger to Gauss Clock Count(magnet filed) trigger instead of real time trigger.
- There is space charge effect near AGS injection. Longer bunch with less peak current will be helpful. Lower harmonic (H=6 instead of 8) will be used in the future operation. Such an RF setup has been tested for a snake-less AGS. In addition, dual harmonics will also be used for AGS, based on the success in the Booster. The dual harmonic RF cavity is only possible before peak RF voltage is reached (~220ms). H=6 and 12 is the combination to use.
- Adding more instrumentation for quicker and better measurement of emittance(eIPM) and betatron tunes(BBQ).
- The emittance evolution simulation has started for Booster. The realistic magnet settings and beam parameters are used. The plan is to do the emittance evolution simulations for AGS,too.
- In the coming years, the polarization gain is expected to come from emittance preservation and robust jump quad timings.

Backup Slides

IPM Emittance vs. Intensity at AGS Extraction



Emittance is smaller for the same AGS late intensity in run15 thanks to heavier Booster scraping and dual harmonics in the Booster . The heavy Booster scraping is possible due to more Booster input.