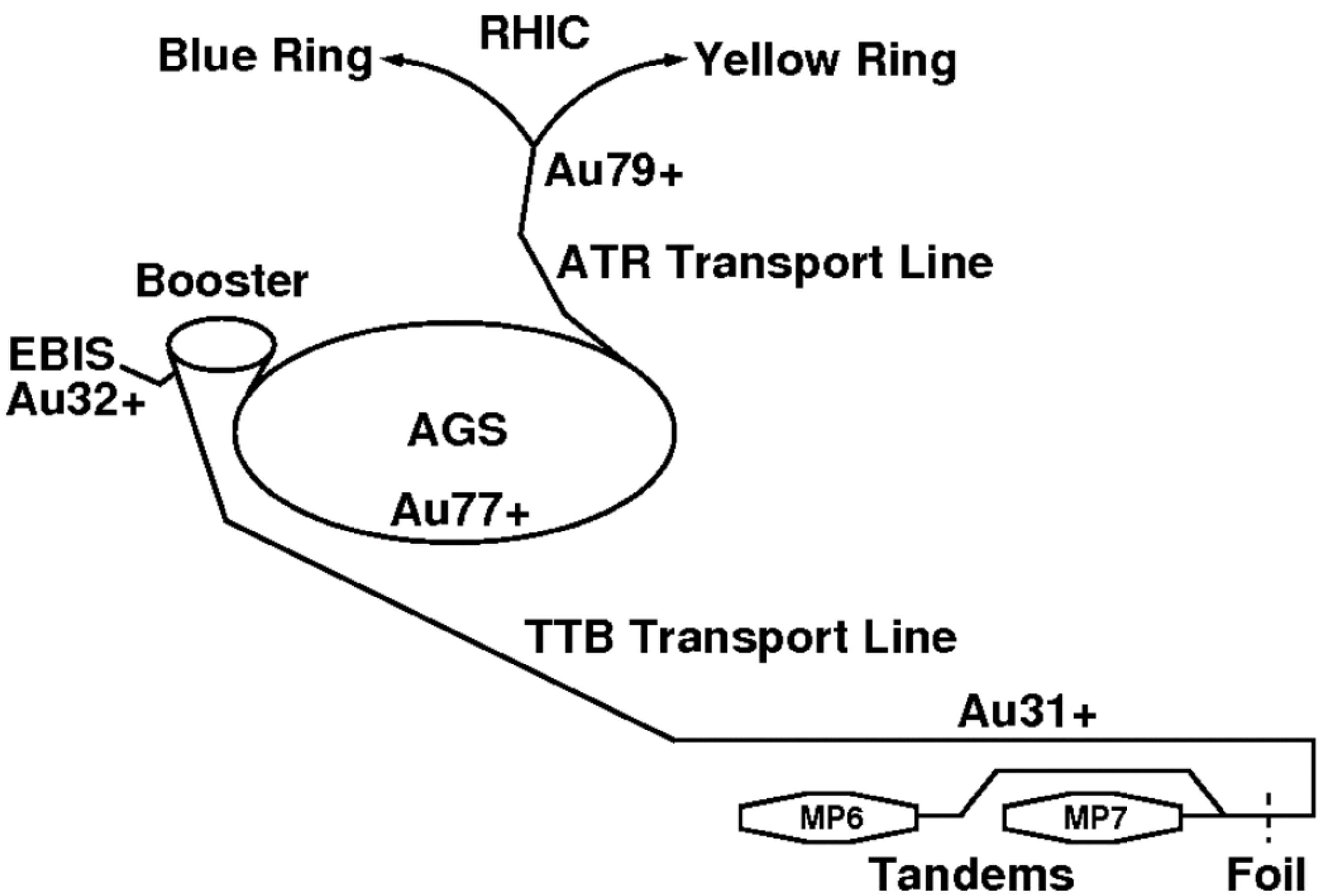
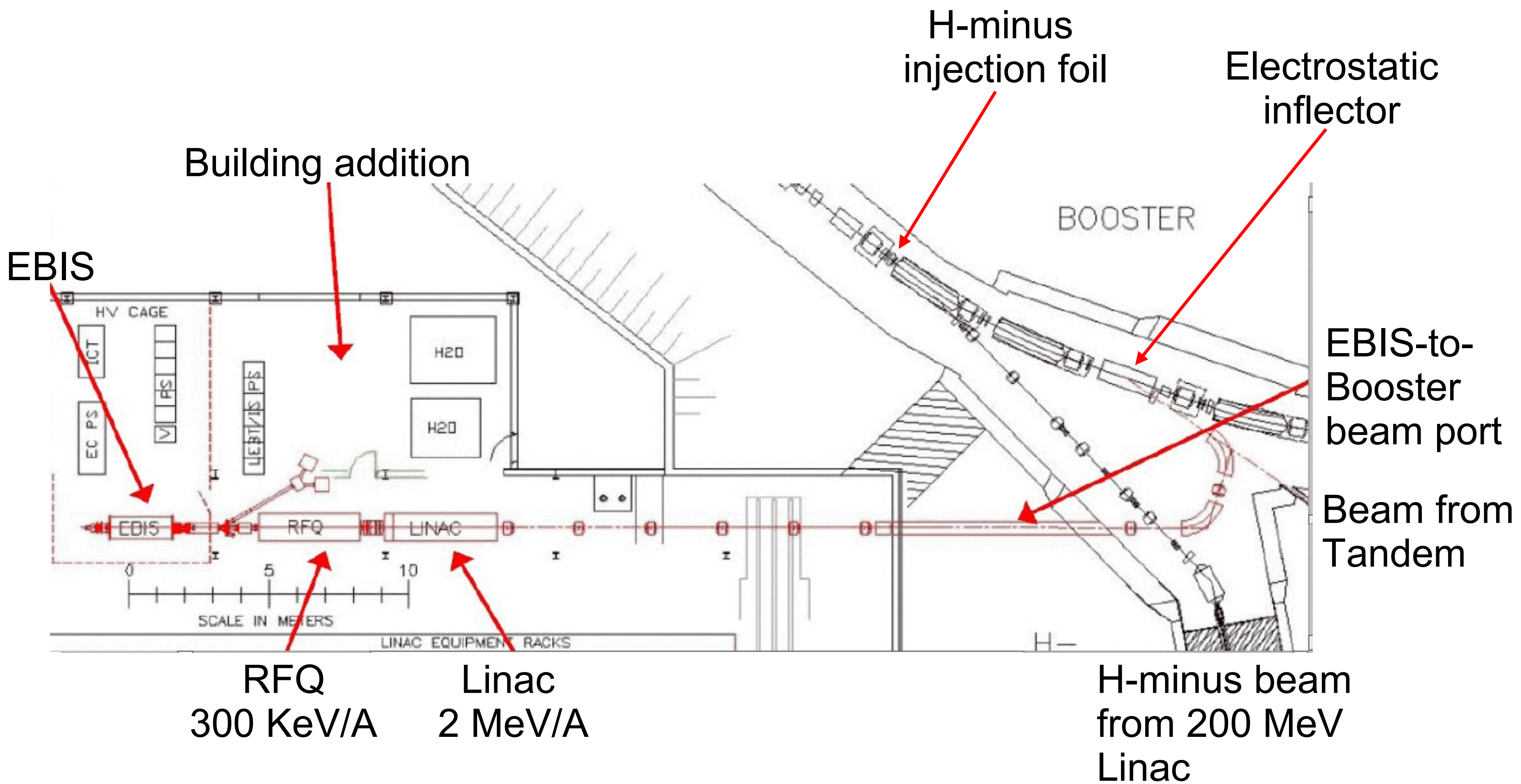
Gold ion intensities in the RHIC injector chain

RHIC retreat 2015

C. Gardner

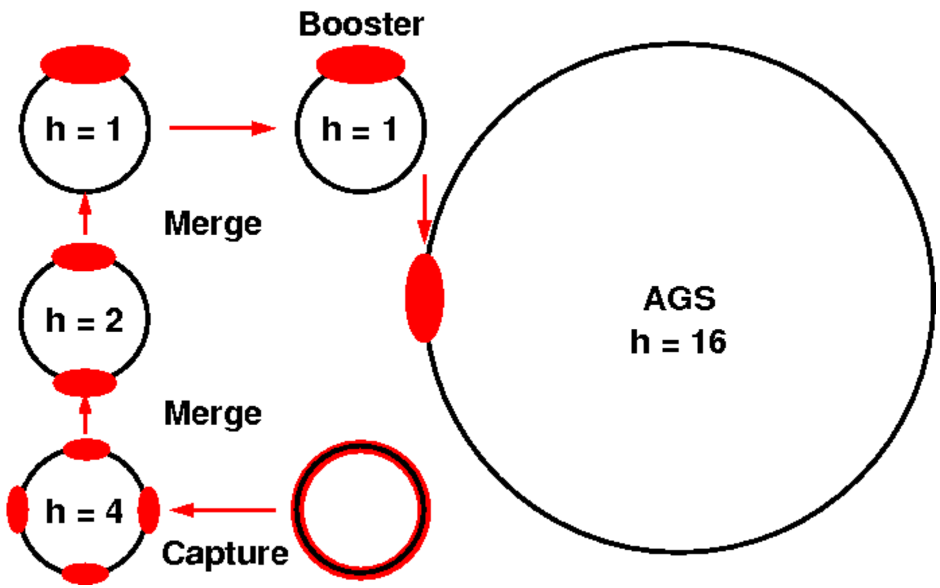


The TTB appendage will likely be pressed into service next year if we have a deuteron-on-gold run.


H-minus injection foil
Electrostatic inflector
Building addition
BOOSTER
EBIS
HV CAGE
ICT
RS
EC PS
LEBT/IS PS
H2O
H2O
EBIS
RFQ
LINAC
EBIS-to-Booster beam port
Beam from Tandem
0
5
10
SCALE IN METERS
LINAC EQUIPMENT RACKS
H-
RFQ 300 KeV/A
Linac 2 MeV/A
H-minus beam from 200 MeV Linac

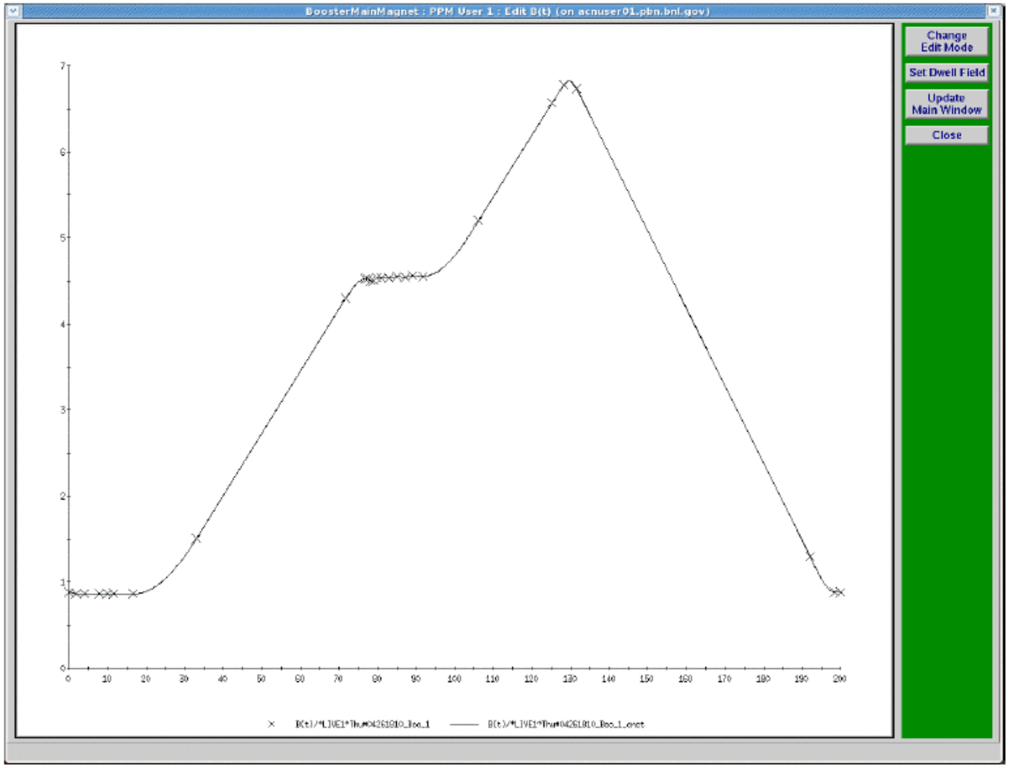
Review of standard setup (our standard since 2012)

Booster Setup



1) Inject 2-turn pulse from EBIS
2) Capture into h=4 buckets
3) Accelerate to merging porch
(49 MeV/A for Au32+ ions)
4) Merge 4 bunches to 2; then
2 bunches to 1
5) Accelerate Au32+ ions to 108
MeV/A
6) Extract and transport to AGS

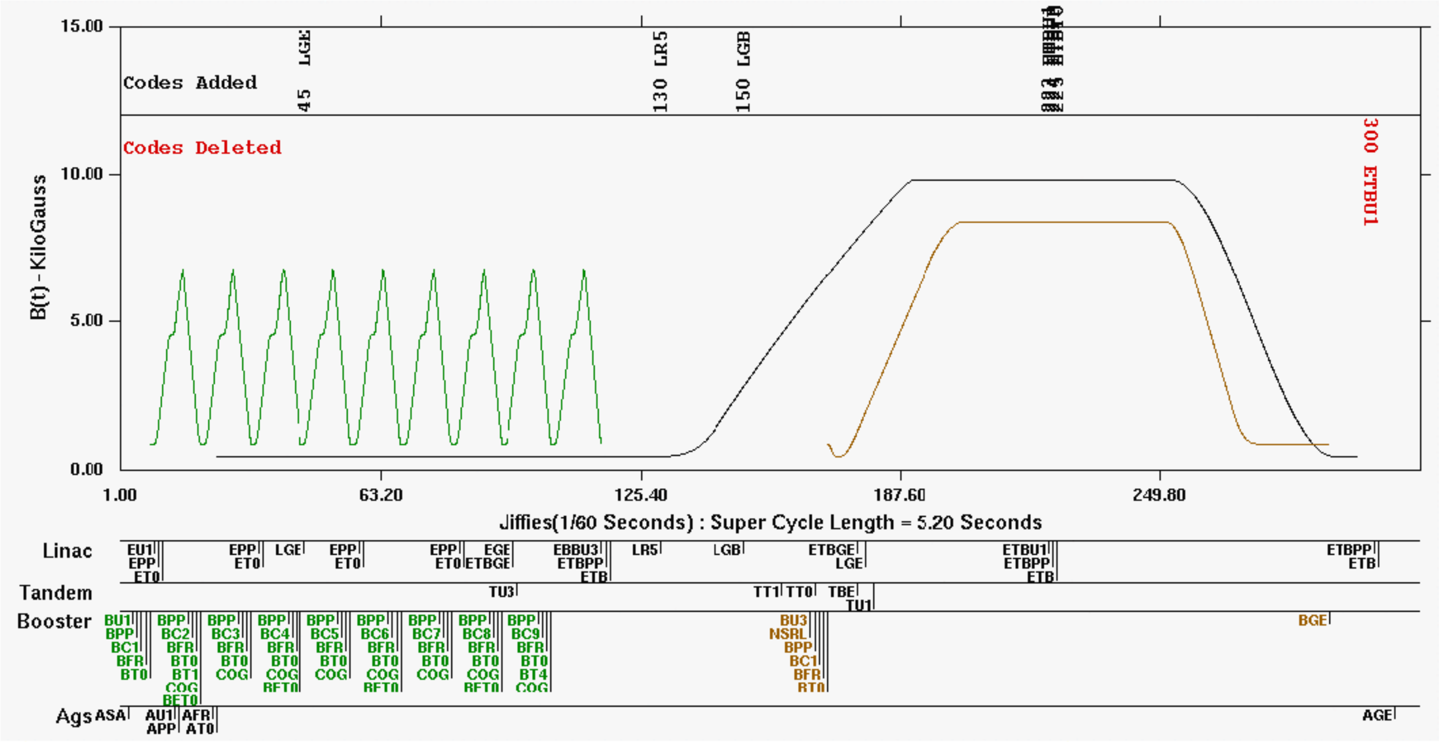
Booster magnetic cycle



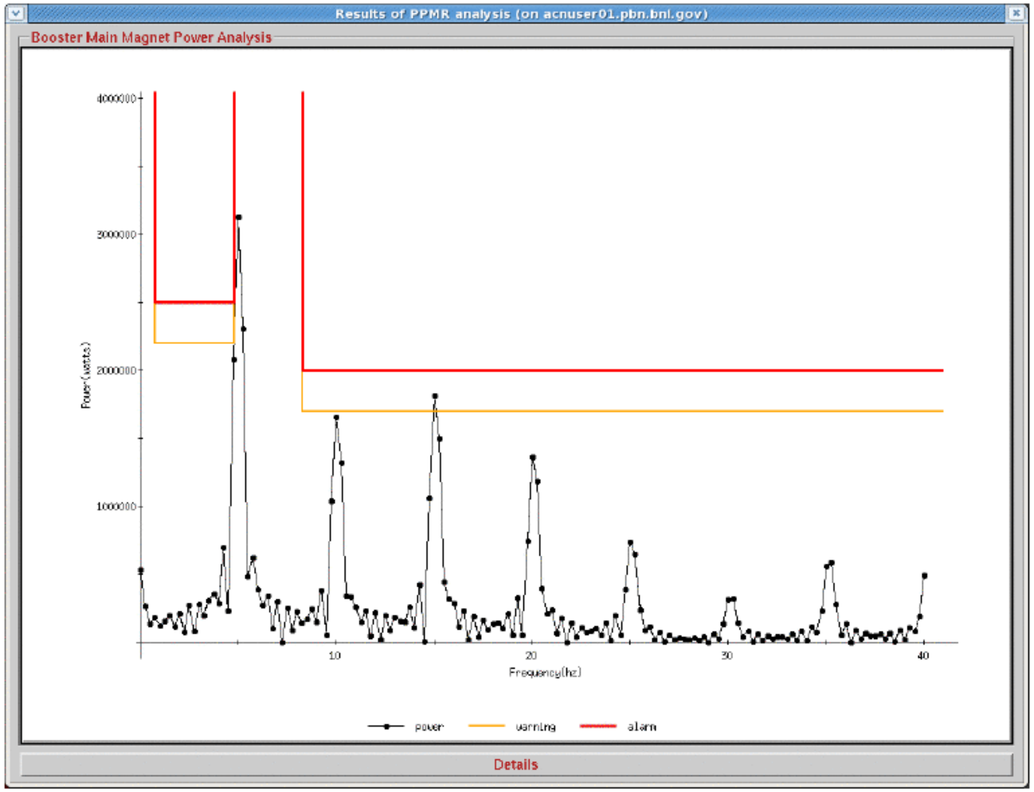
Merges of 4-to-2 and then 2-to-1 take place on the porch.

Cycle length must be 200 ms or less in order to avoid harmful perturb-ations of the local power grid.

9 such per supercycle



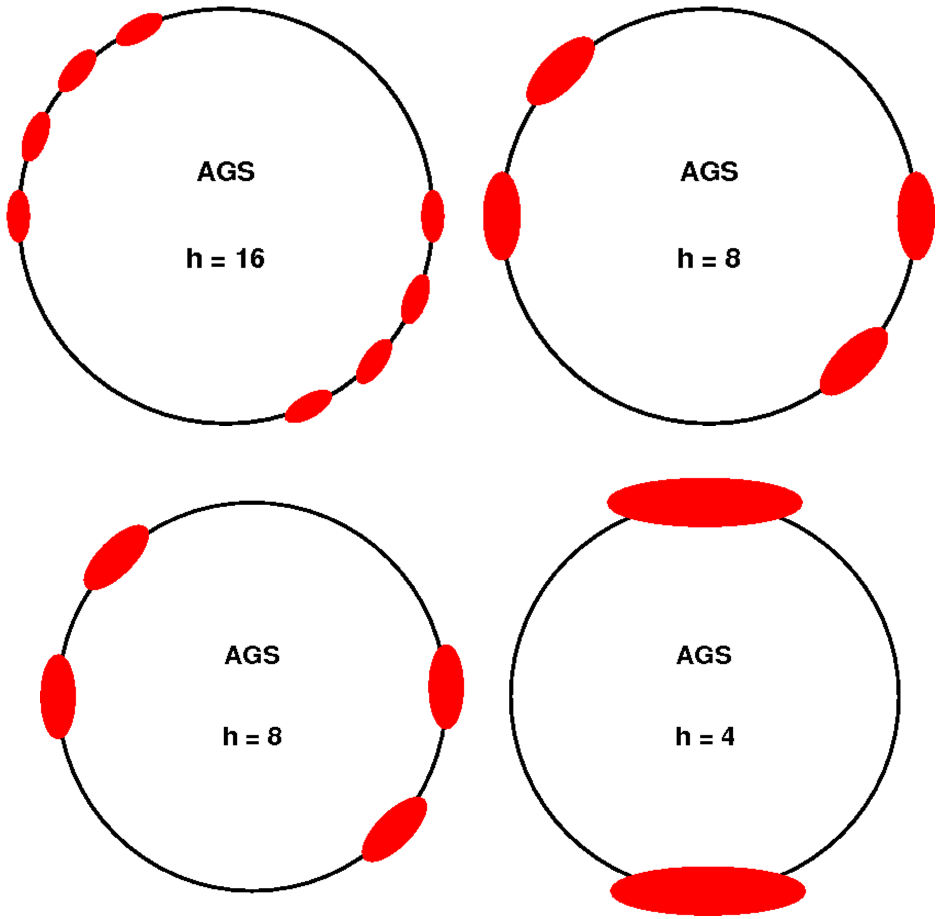
Perturbation of local power grid



We had to work hard to get a cycle with perturbations of the grid that stay below the red line limit.

The peak at 5 Hz just misses the red line.

AGS Setup



1) Inject 8 Booster loads of 1 bunch into harmonic 16 buckets
2) Merge 8 to 4; then 4 to 2
3) Gives 4 Booster loads per bunch
4) Squeeze each bunch into a h=12 bucket
5) Accelerate Au77+ ions to 8.86 GeV/A
6) Extract and transport to RHIC

Intensities, losses, and loss reduction measures (K. Zeno)

Gold Intensities

1) 1.2e9 Au32+ ions per EBIS pulse at end of ETB line
2) 0.95 injection efficiency
3) Booster Output/Input = 0.85
4) Gives 1.0e9 Au32+ ions per bunch at Booster extraction
5) 0.65 BTA stripping efficiency
6) AGS Input / Booster Output = 0.56 to 0.58
7) Gives 4.46e9 Au77+ on AGS injection porch after 8 transfers (8 x 1.2e9 = 9.6e9)
8) 2.23e9 Au77+ ions per bunch after merges on AGS injection porch
9) Some 2 to 3% ends up in satellite bunches during squeeze into harmonic 12
10) Most other loss occurs during h=12 capture and early acceleration
11) One ends up with 2.1e9 Au77+ ions per bunch at AGS extraction

Booster losses

1) Booster Output / Input = 0.85; Injection efficiency = 0.95

2) Most loss occurs during capture and early acceleration:
Fraction lost = (0.15 – 0.05)/0.95 = 0.11

3) Possible causes?

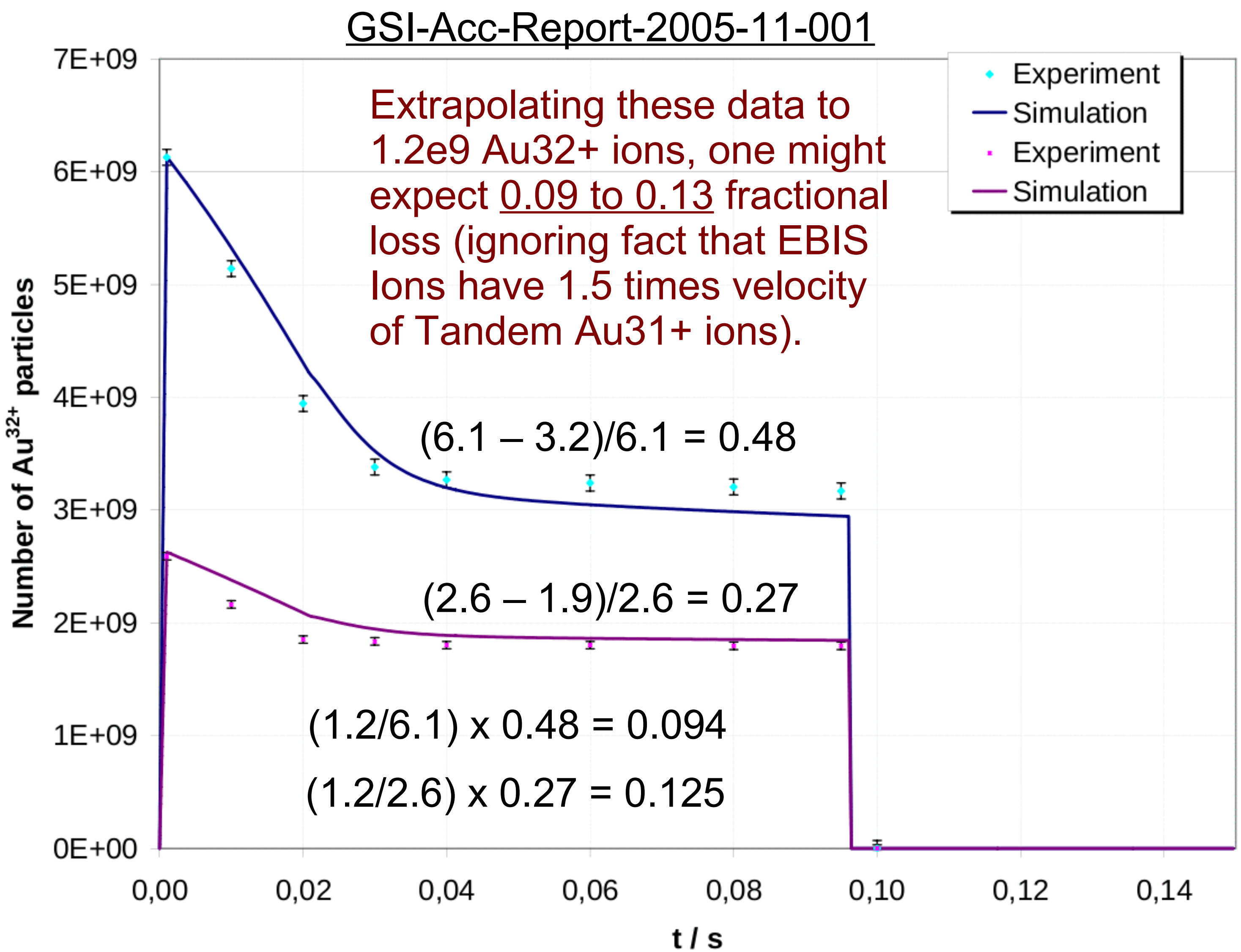
a) Loss-induced vacuum degradation

b) dp/p in regions of nonzero dispersion

c) Transverse space charge

(dQ = 0.28e-10 per Au32+ ion at injection,
so not an issue for 1.2e9 ions)

a) Loss due to vacuum degradation

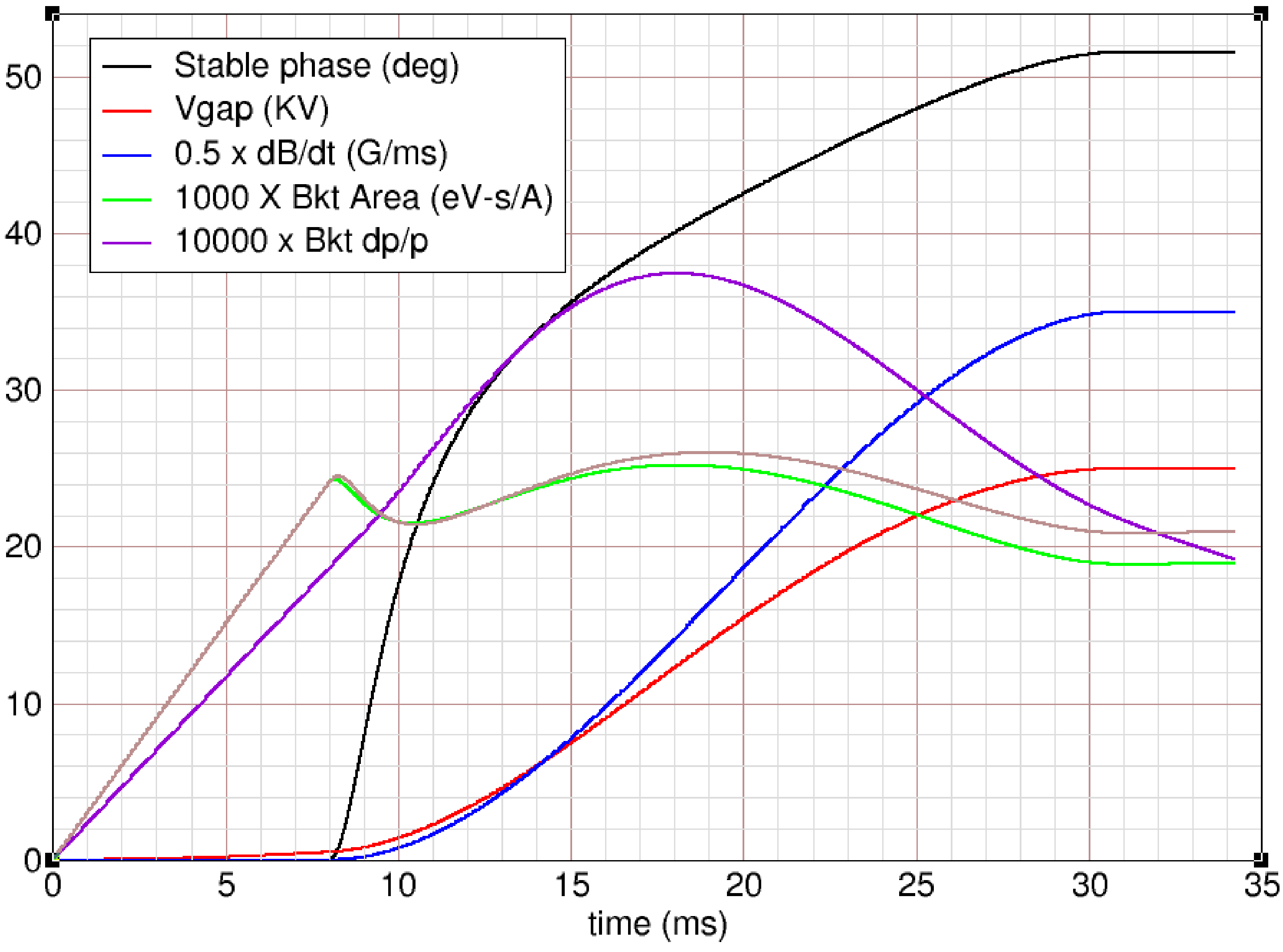


Extrapolation is consistent with observed fractional loss of 0.11.

2014 MAC recommended increasing pumping speed in injection region.

b) Loss due to dp/p with nonzero dispersion

dp/p x d = 0.0037 x 2.9m = 11mm (not insignificant)



If RF voltage rises too quickly, bucket and beam dp/p can can become too large and beam is lost in regions of large dispersion. (4 and 6 quads)

With new Booster RF system we have much better control of voltage, so loss has likely been minimized by K. Zeno's careful tuning.

(AGS input / Booster output) Loss

1) Although measured efficiency of Au32+ to Au77+ stripping is 0.65, one finds AGS input / Booster output is at most 0.58.

2) There is no evidence that the stripping efficiency has degraded; K. Zeno has moved the beam spot to presumably virgin areas on the stripper and found no increase in efficiency.

3) Partial explanation may be slow loss due to transverse resonance excitation during the 200 ms time periods between transfers from Booster to AGS.

4) During current shutdown we will make operational the system that "corrects" the 3Qh = 26 and Qh + 2Qv = 26 resonances.

Ags Losses:

1) Most (if not all) beam loss in Ags occurs during h=12 capture and early acceleration.

2) The fraction of injected beam in the 2 main bunches at extraction is 2 x 2.06/4.46 = 0.92.

3) Some 2 to 3% of the injected beam ends up as satellite bunches on either side of the main bunch.

4) There is evidence that "correction" of the 3Qh = 26 and Qh + 2Qv = 26 resonances will improve the capture and early acceleration efficiency.

Loss reduction measures:

1) 2014 MAC: “In order to minimize beam loss from charge-exchange, modifications of the AGS Booster vacuum system, preferably around the injection and extraction systems should be considered.”

2) The 3Qh = 26 and Qh + 2Qv = 26 resonance correction system in AGS is being made operational.

Longitudinal Emittance
(K. Zeno)

Emittance (eV-s/A) evolution

0.024 unbunched beam at Booster injection

0.080 total bunched at Booster injection

0.089 merged bunch at Booster extraction

0.10 bunch in h=16 bucket on Ags injection porch

0.43 per bunch after merges (on injection porch)

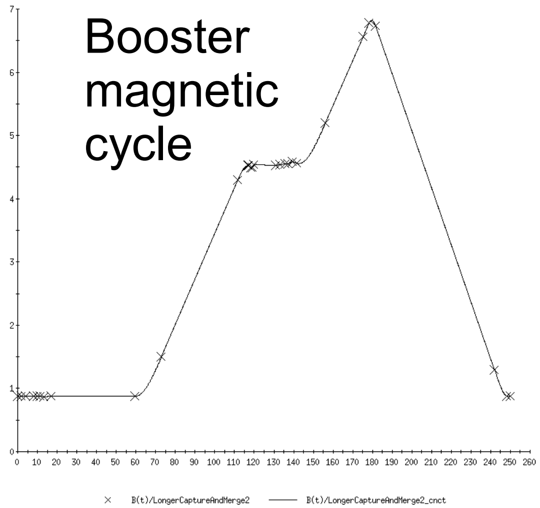
0.7 at Ags extraction (growth not understood)

Aside from reducing losses, how can we increase the bunch intensity and keep the longitudinal emittance sufficiently small?

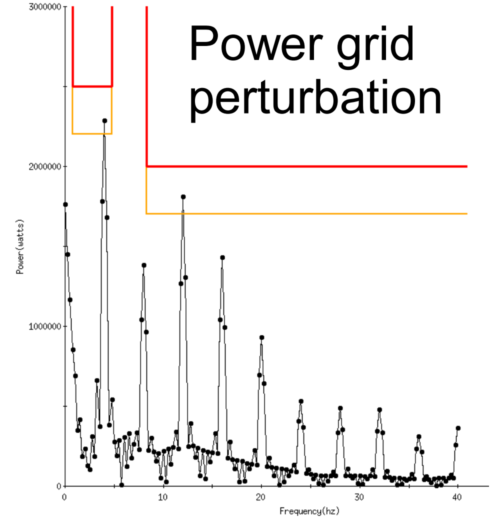
6 to 3 to 1 merging scheme:

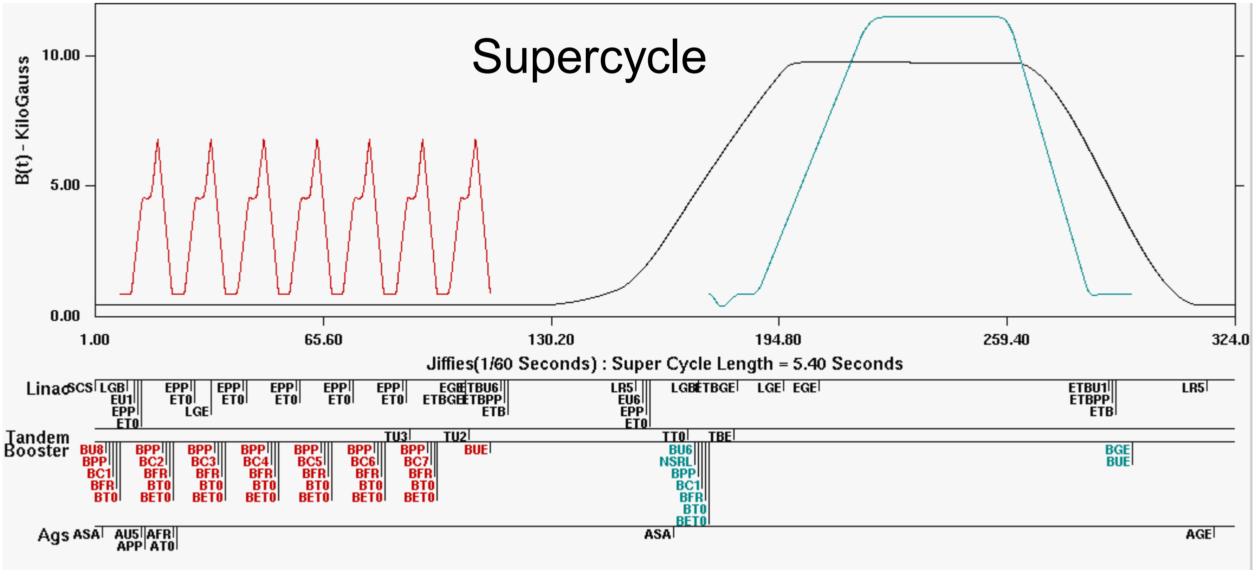
1) Put 6 Booster loads into one bunch instead of just 4.
2) In principle we then should be able to get 3.0e9 Au77+ ions per bunch at Ags extraction. Factor of 1.5 increase.
3) Longitudinal emittance also increases by factor of 1.5.
4) During the relatively short development time in May 2015 we were able to merge 6 Bunches into 1 on the Ags injection porch and achieved 2.4e9 Au77+ ions per bunch at Ags extraction.
5) Loss during capture and early acceleration on Ags injection porch was substantial; the next few slides show setup and results.

Setup for 6 transfers to Ags

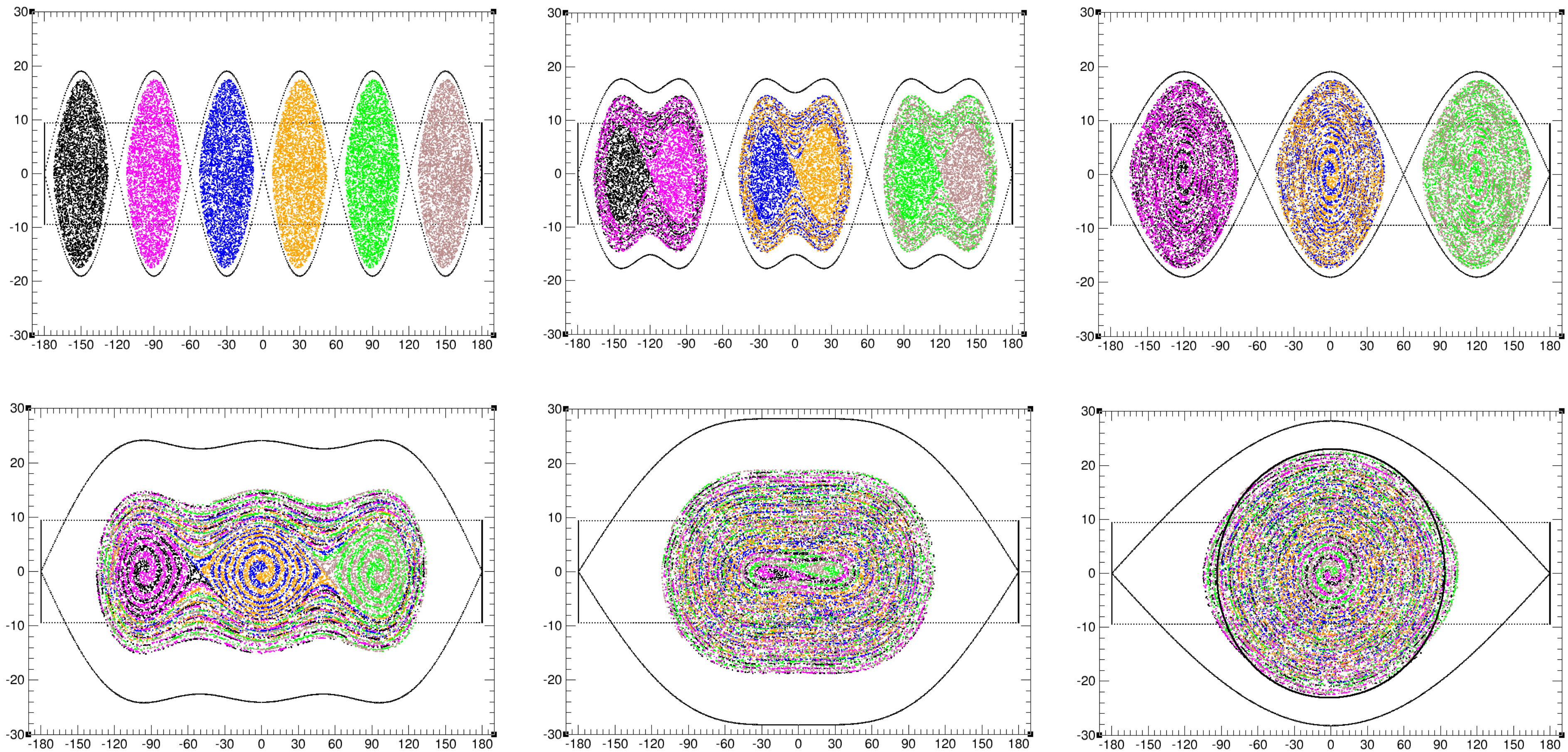


K. Zeno was able to extend Booster injection and merging porches by 40 and 10 ms, respectively, without exceeding grid perturbation limits. Hope is that we will be able to reduce longitudinal emittance.



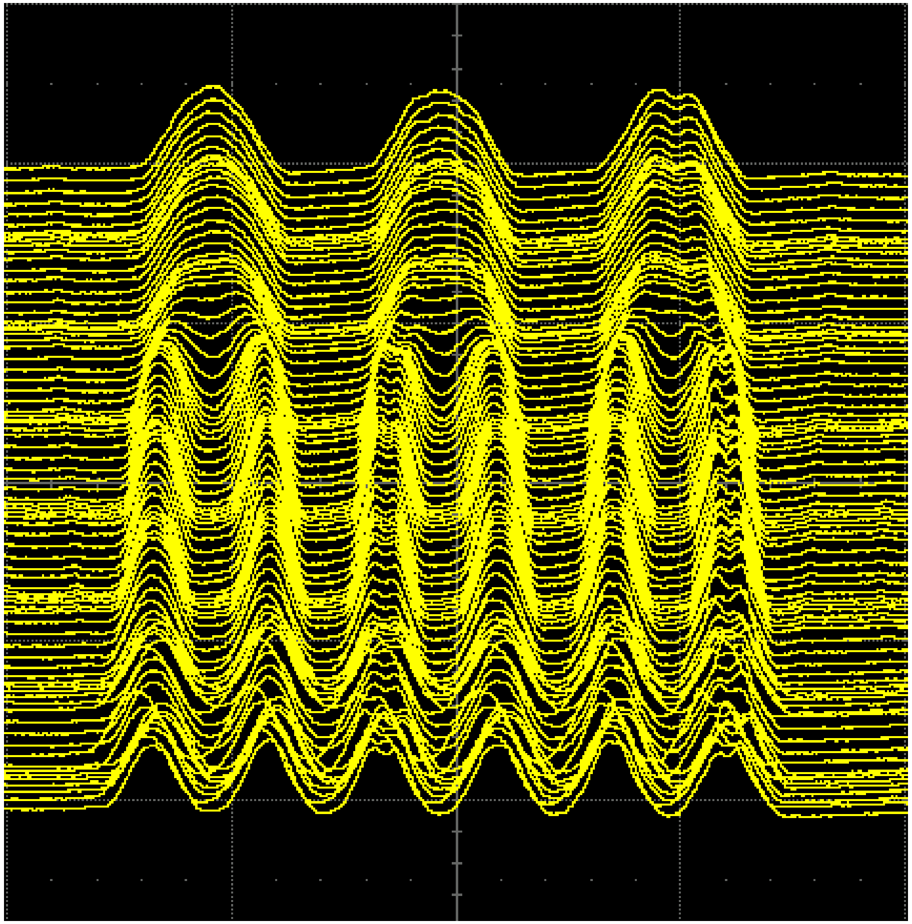


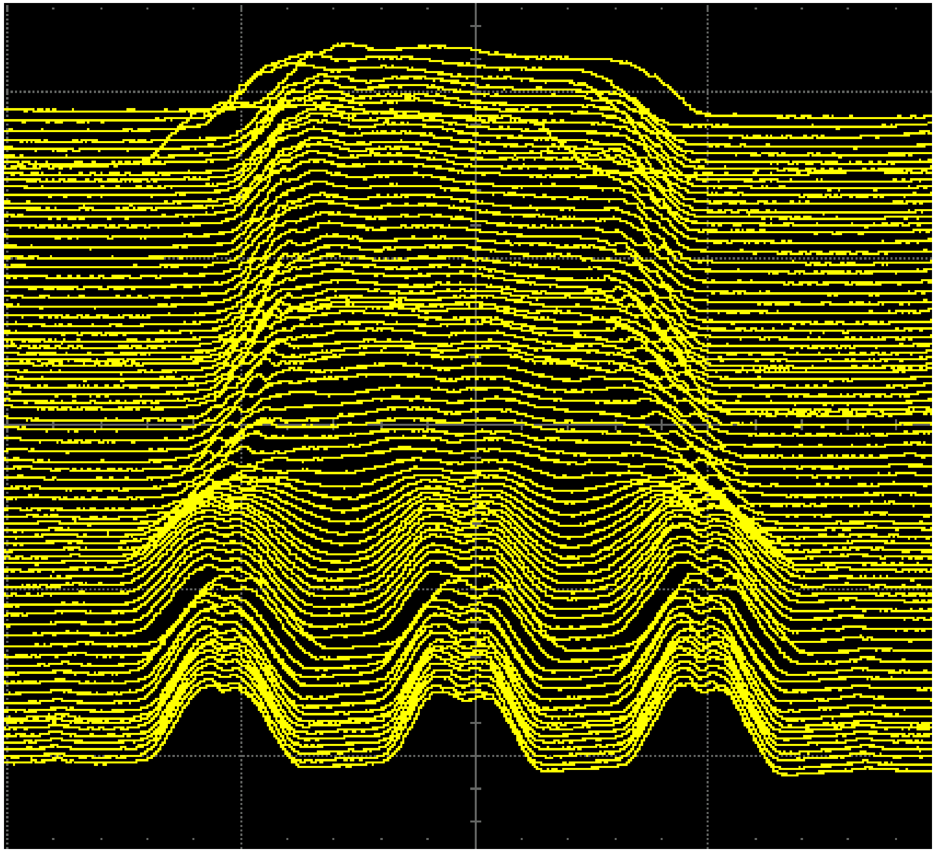
6 to 3 to 1 merge on Ags injection porch:



This simulation shows that it is possible to do the merge in a way that (nearly) conserves the gross longitudinal emittance.

<u>Observed 6 to 3 to 1 mountain range</u> (K. Zeno):

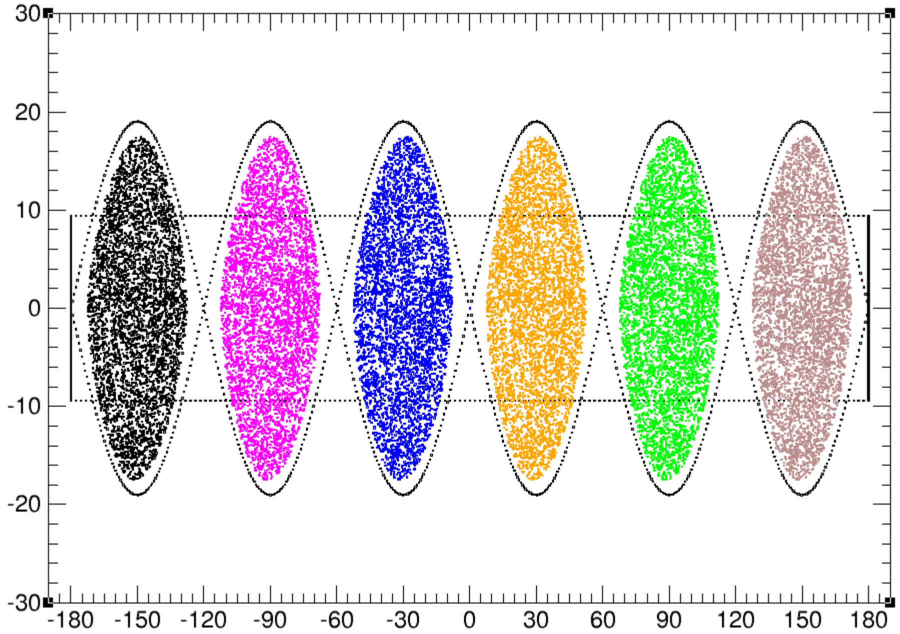




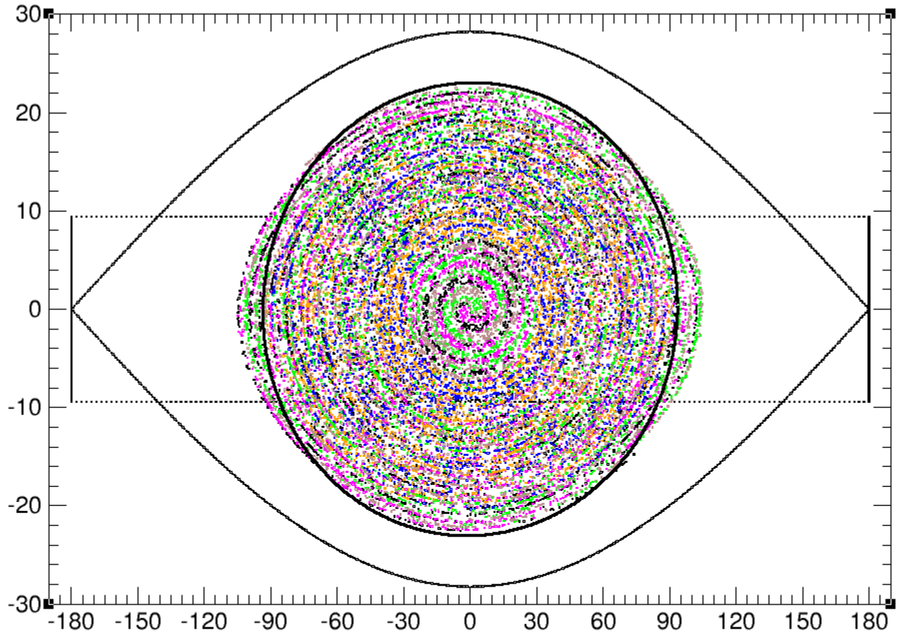
Based on previous measurements, we know that total emittance of the 6 bunches before merge can be as small as <u>0.60 eV-s/A</u>.

Start simulation with 6 bunches each having an emittance of 0.10 eV-s/A

6 x 0.10 = <u>0.60</u> eV-s/A total



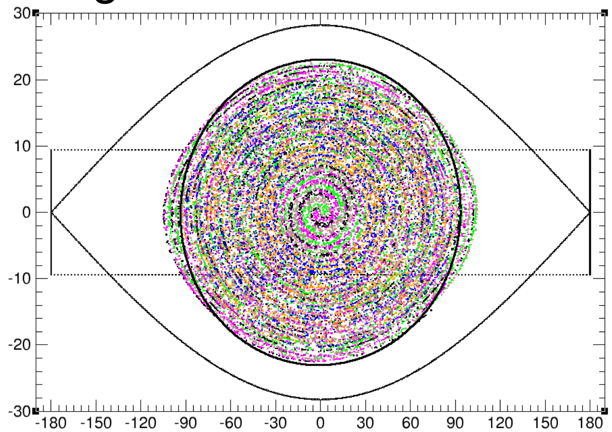
Black ellipse is <u>0.60</u> eV-s/A



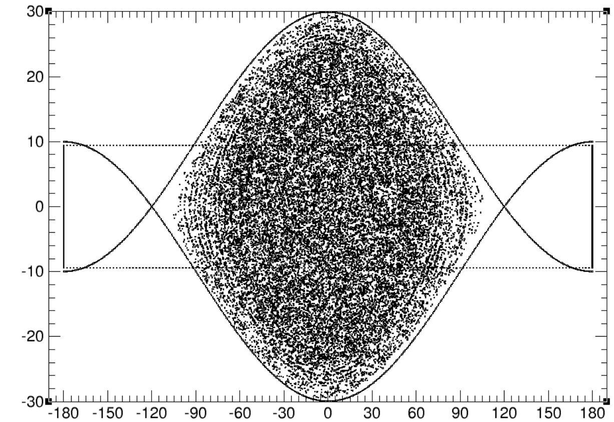
Final merged bunch is only slightly larger than 0.60 eV-s/A.

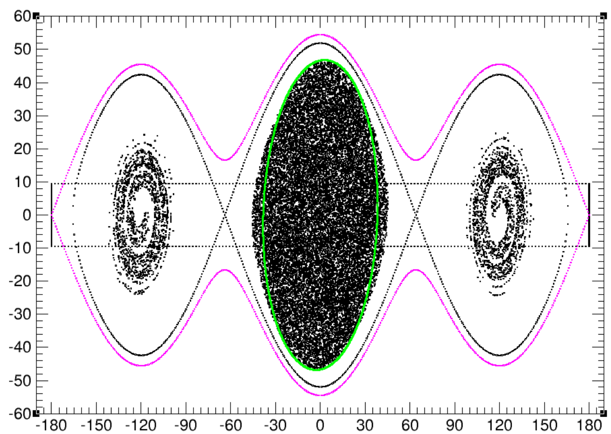
Simulation of squeeze into h=12 bucket:

Merged bunch in h=4 bucket

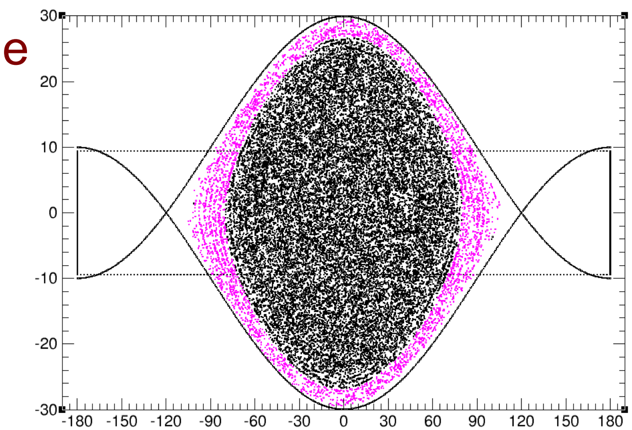


h=8 voltage near max available





As h=12 voltage is brought up, some particles escape into buckets on either side of main bunch.

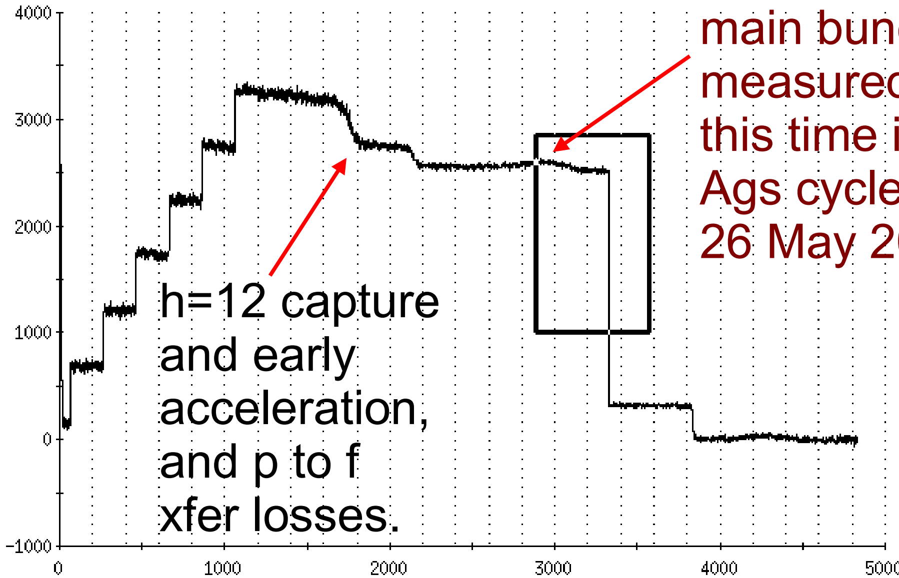


13% of original bunch ends up in satellite bunches. Area of green ellipse superimposed on main bunch is 0.5 eV-s/A. Magenta points in lower right plot are particles that end up in satellite bunches.

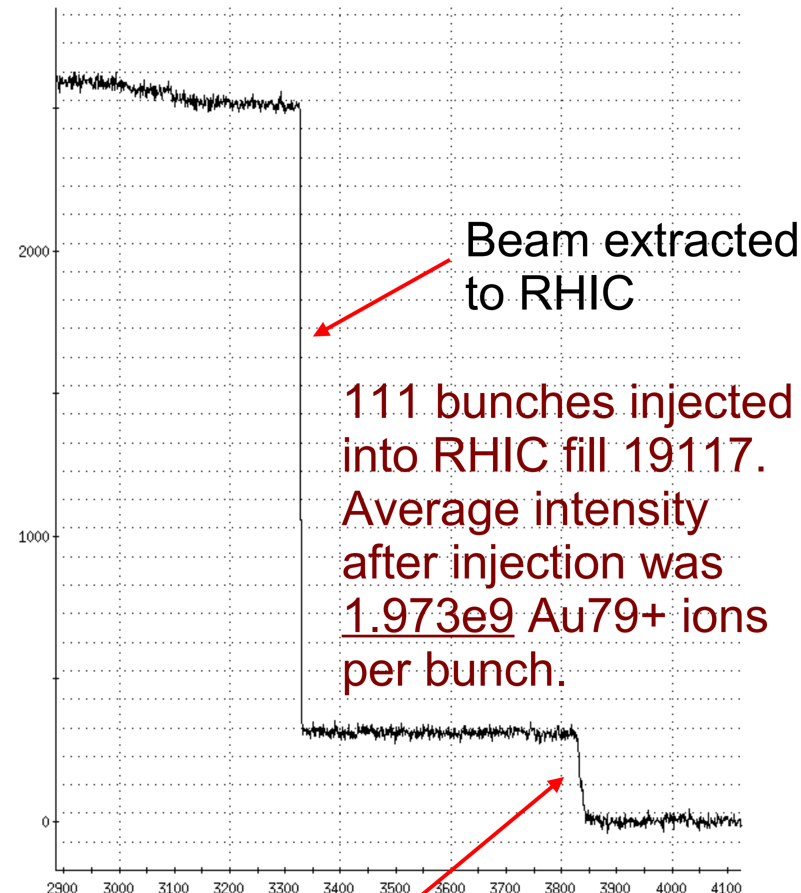
Acceleration of 6 to 3 to 1 merged bunch:

28 May 2015 elog
RHIC fill 19117

Max of 2.4e9 Au77+ ions in main bunch measured at this time in Ags cycle on 26 May 2015.



There is evidence (and hope) that the 3Qh = 26 and Qh + 2Qv = 26 resonance correction will reduce the capture and early acceleration loss.



Beam in satellite bunches

Final Comments

1) It is hoped that the resonance correction will significantly reduce the capture and early acceleration loss.

2) In order to reduce the amount of beam lost to satellite buckets we need to reduce the longitudinal emittance in Booster by a factor of 4/6. We hope that this is possible with further tuning on the longer injection porch.

3) This would give a final merged bunch with the same longitudinal emittance as the one obtained in the standard 4 to 2 to 1 scheme. We know that the 4 to 2 to 1 merged bunch produces only small satellites (2 to 3%) and it accelerates well in Ags and in RHIC.

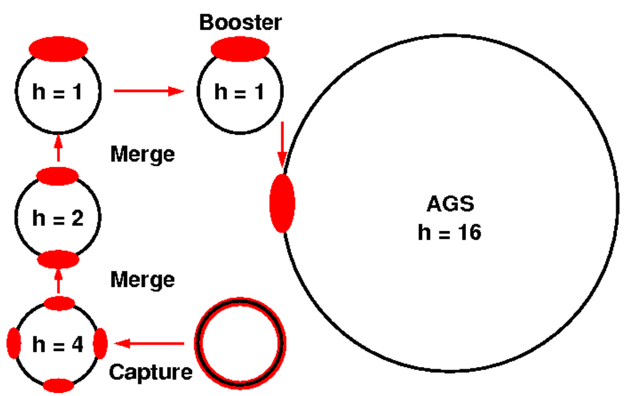
References

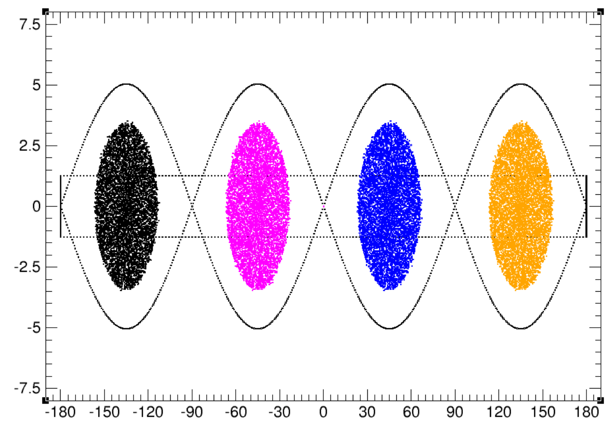
1) Our IPAC15 paper "Operation of the RHIC Injector Chain with Ions from EBIS"

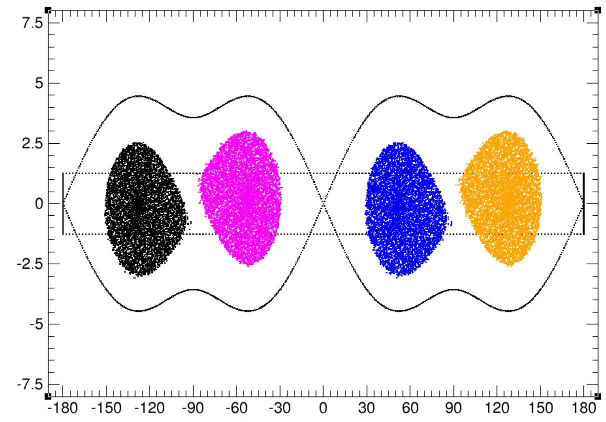
2) K. Zeno's C-A/AP Note 523, "Longitudinal Emittance Measurements in the Booster and AGS during the 2014 RHIC Gold Run"

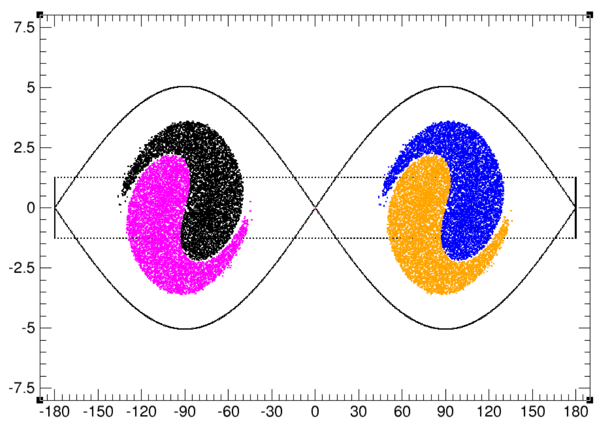
Additional Slides

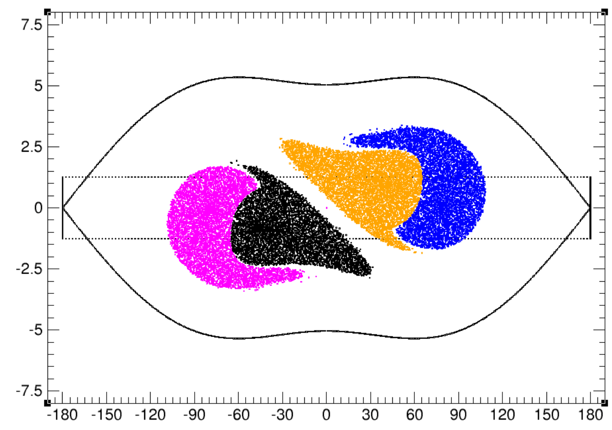
Booster 4 to 2 to 1 merge

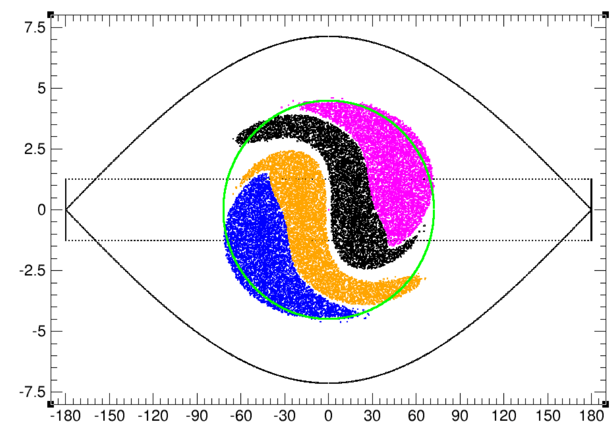










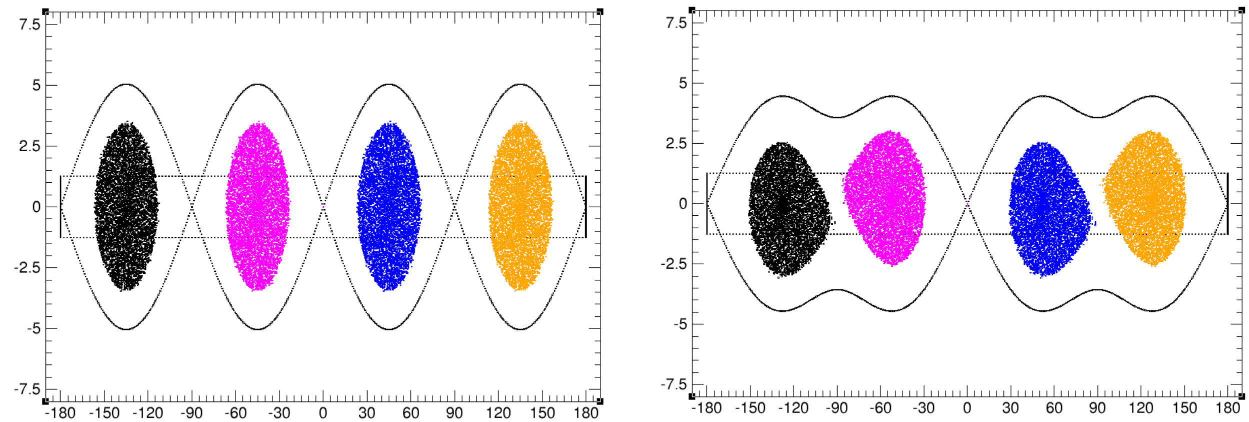


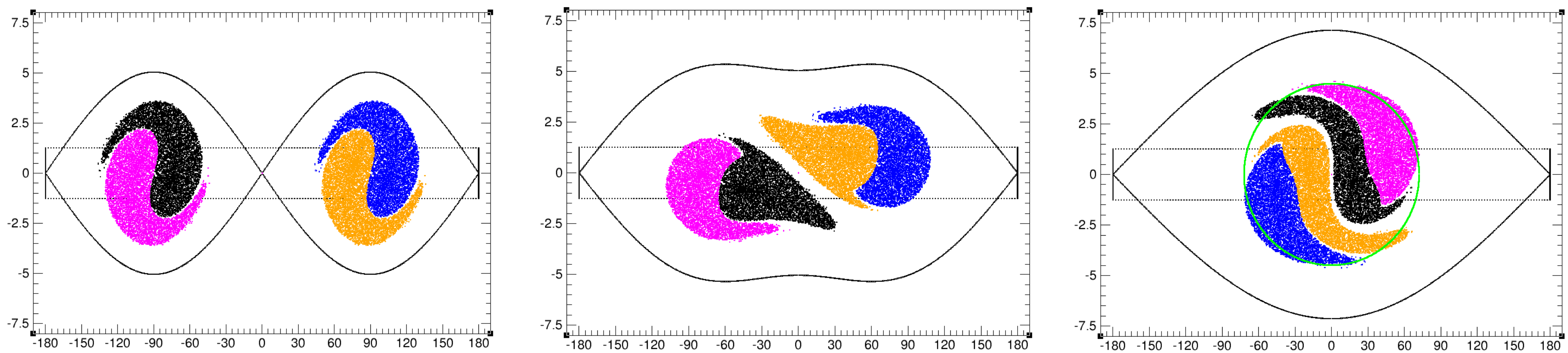
Booster 4 to 2 to 1 merge

1) Total initial emittance is 0.080 eV-s/A (measured)

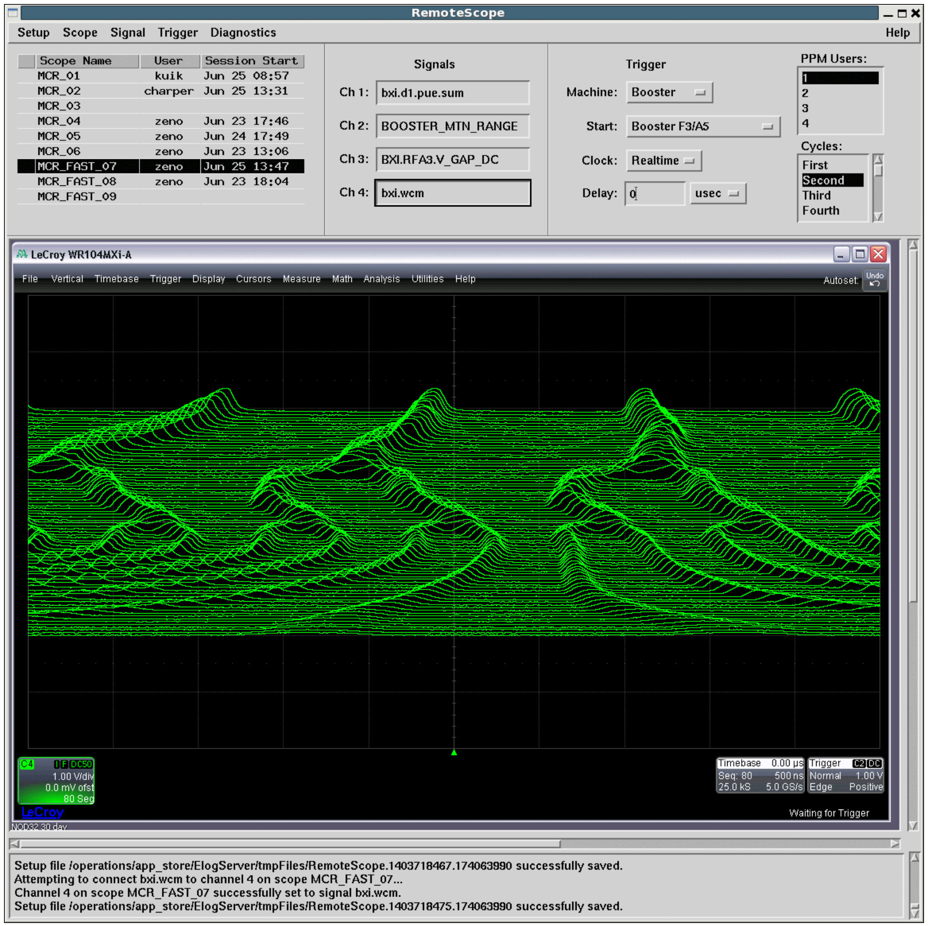
2) Final emittance (green ellipse) is 0.090 eV-s/A (measured)

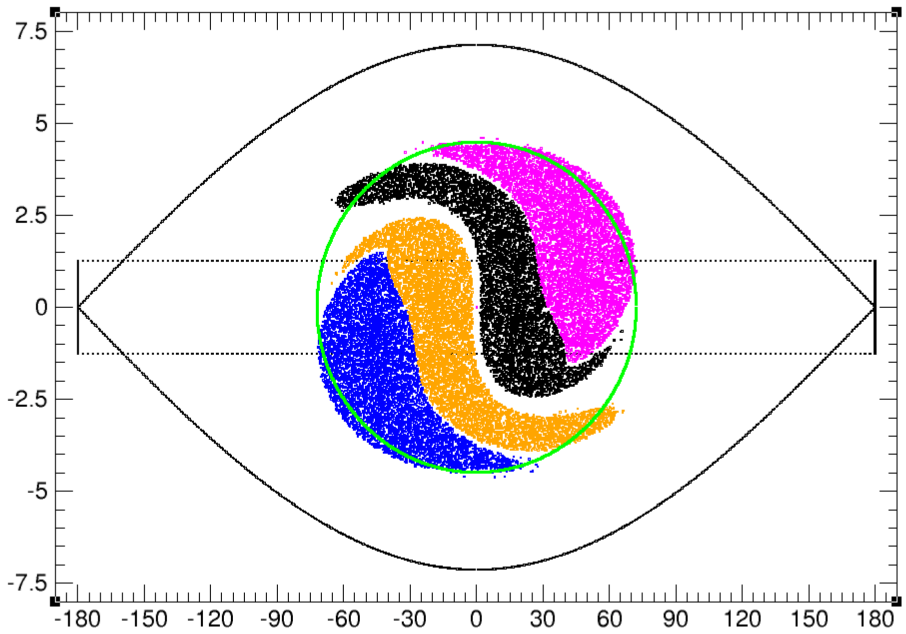
3) Small increase; agrees with simulation





Booster 4 to 2 to 1 merge



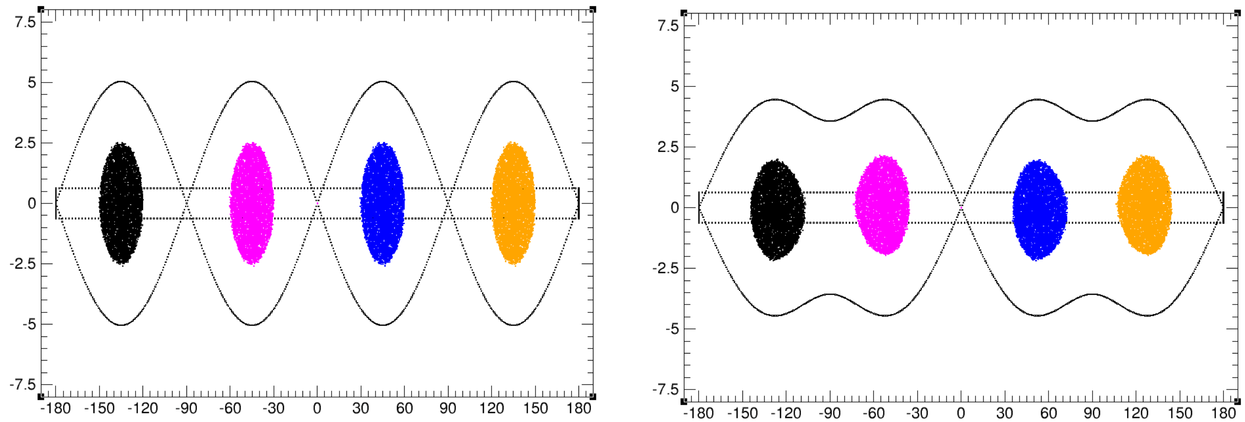


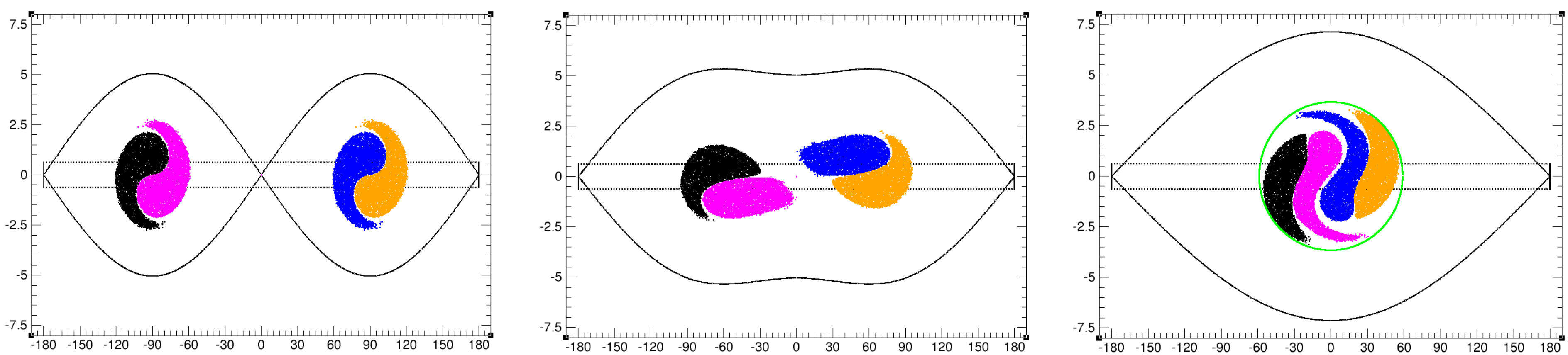
With reduced initial emittance:

1) Try simulation with initial emittance of <u>0.040 eV-s/A</u>

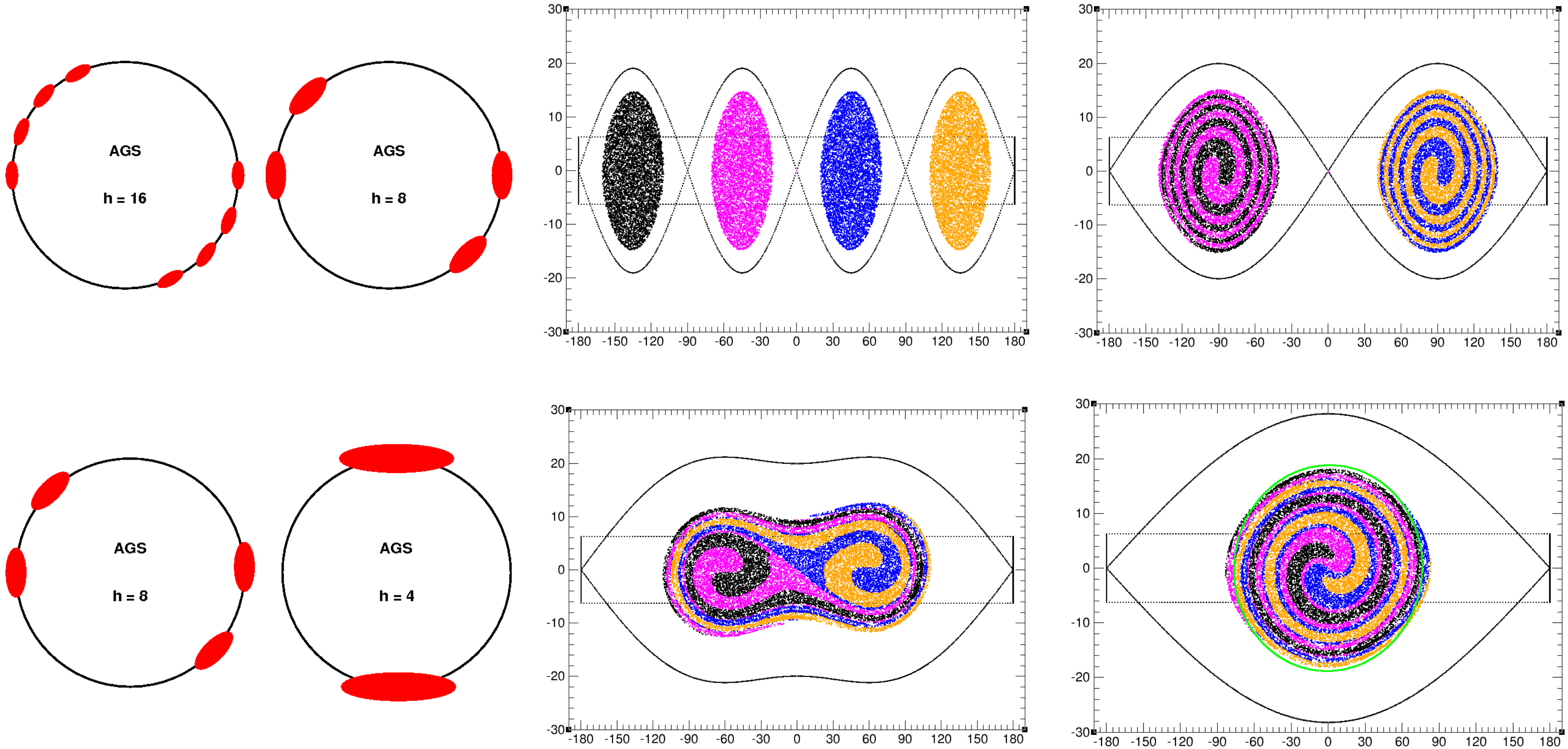
2) Increase merge time from 15 to 30 ms.

3) Gives final emittance (green ellipse) of <u>0.060 eV-s/A</u>





Ags 4 to 2 to 1 merge

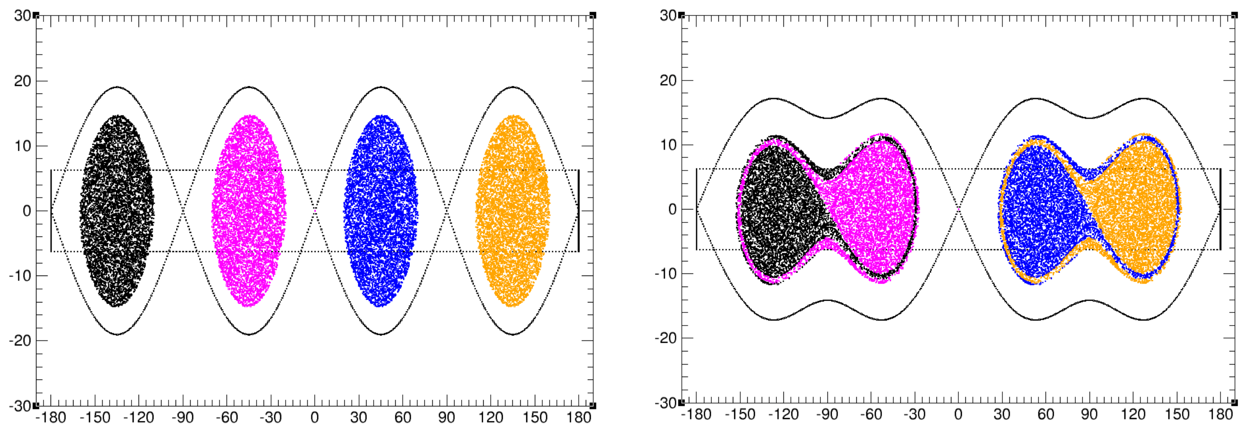


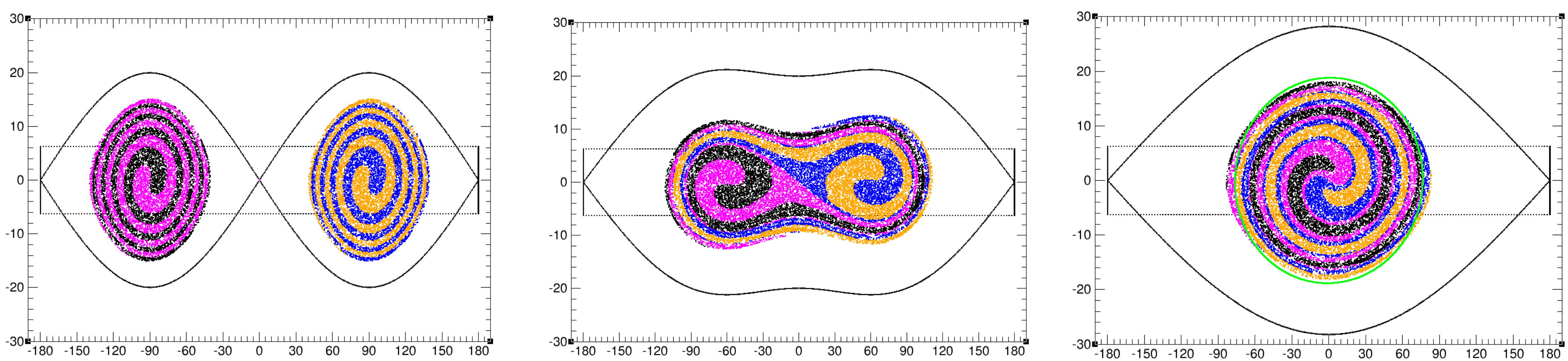
Ags 4 to 2 to 1 merge

1) Total initial emittance is
   0.40 eV-s/A (measured)

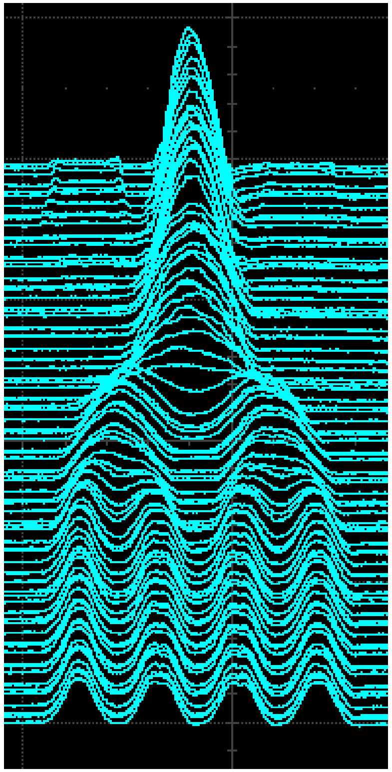
2) Green ellipse surrounding
   merged bunch has same
   emittance

3) Final measured emittance
   of 0.43 eV-s/A agrees
   with simulation





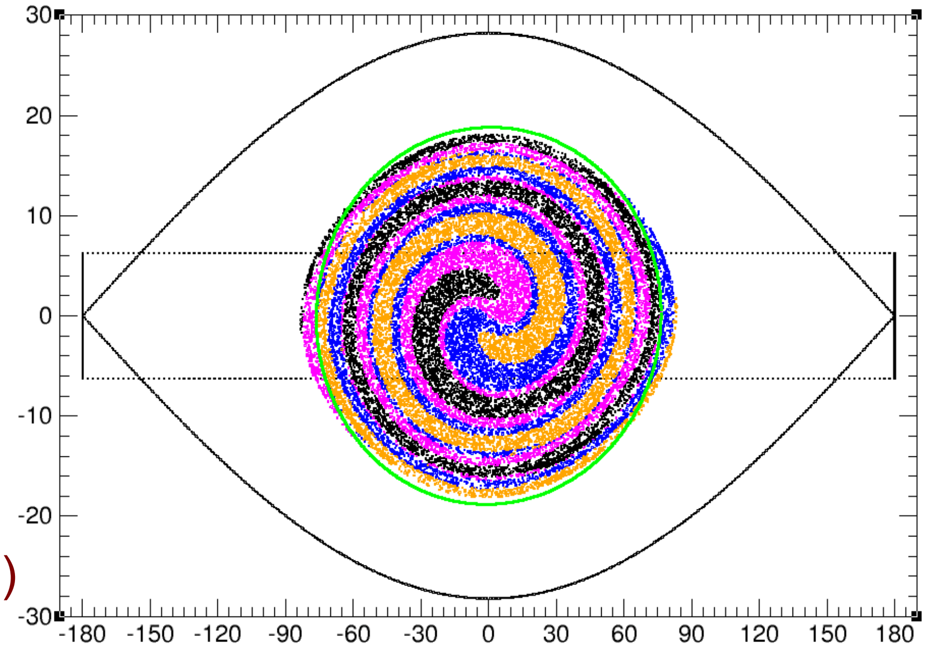
4 to 2 to 1 merge on Ags injection porch:



0.40 eV-s/A is total measured emittance of 4 bunches before merge.

0.43 eV-s/A is total measured emittance after 4 to 2 to 1 merge.

(Zeno measurements)



Area of green ellipse is 0.40 eV-s/A.
Simulation agrees with measurement.