

Space Charge Effects in the Alternating Gradient Synchrotron at Injection Energies

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October 2, 2026

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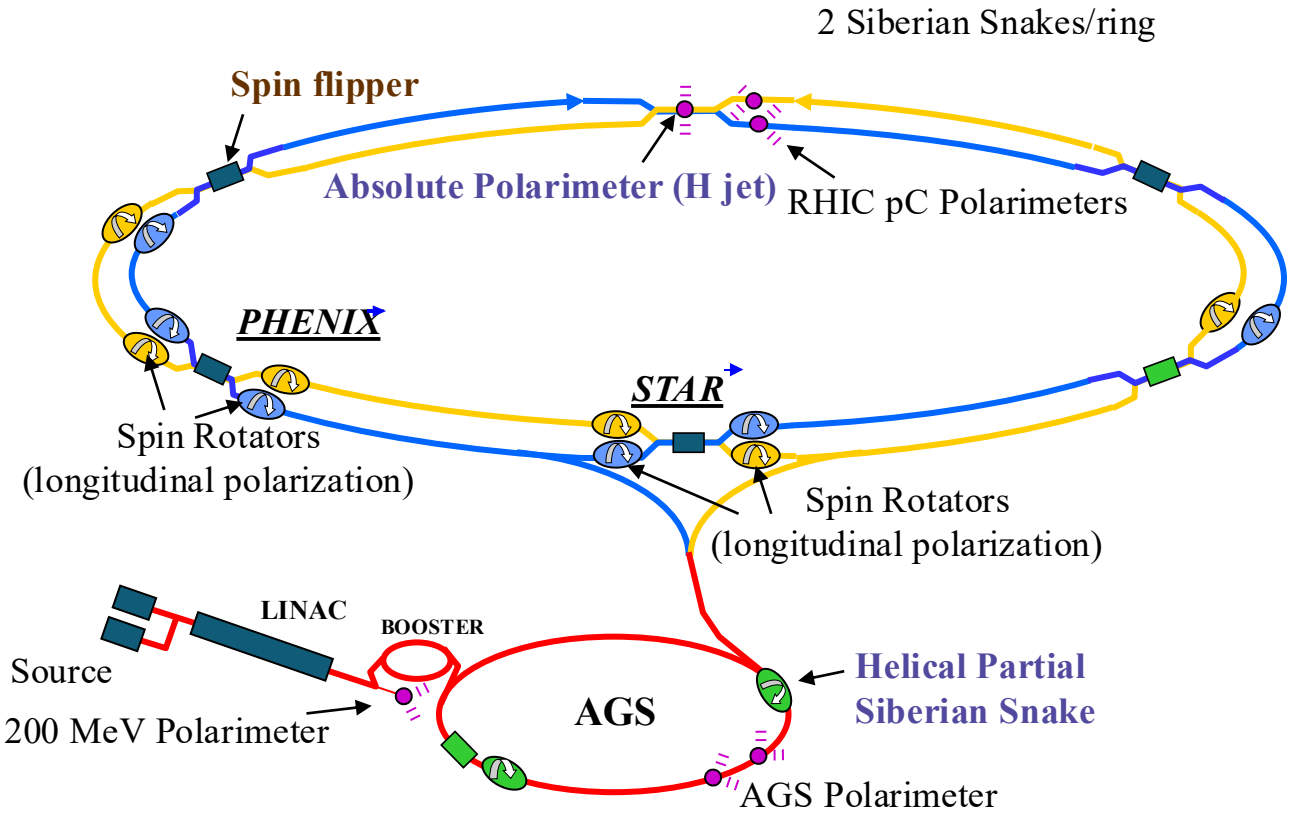
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Motivation: Understand effects of space-charge on proton beam quality in AGS

Why this matters

- Polarized protons are accelerated in AGS before injection in collider rings.
- At AGS injection energy, high intensity increases incoherent space-charge tune spread and affects transverse emittance growth.
- Smaller emittance growth would benifit higher luminosity and minimize polarization loss during acceleration.



	Measured polarization (Run 17, full run avg)
Exit of Booster	80 – 84 %
Exit of AGS	67 – 70 %

* Polarization loss mainly comes from ramp loss

Injector complex context

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Context adapted from the provided AGS introduction deck

Main observables: IPM emittance • bunch length • energy ramp

Simulation strategy: benchmark first, then perform optimization for operations

Machine input
optics, RF, energy, intensity

→

Xsuite model
Footprint, ramp/fixed energy

→

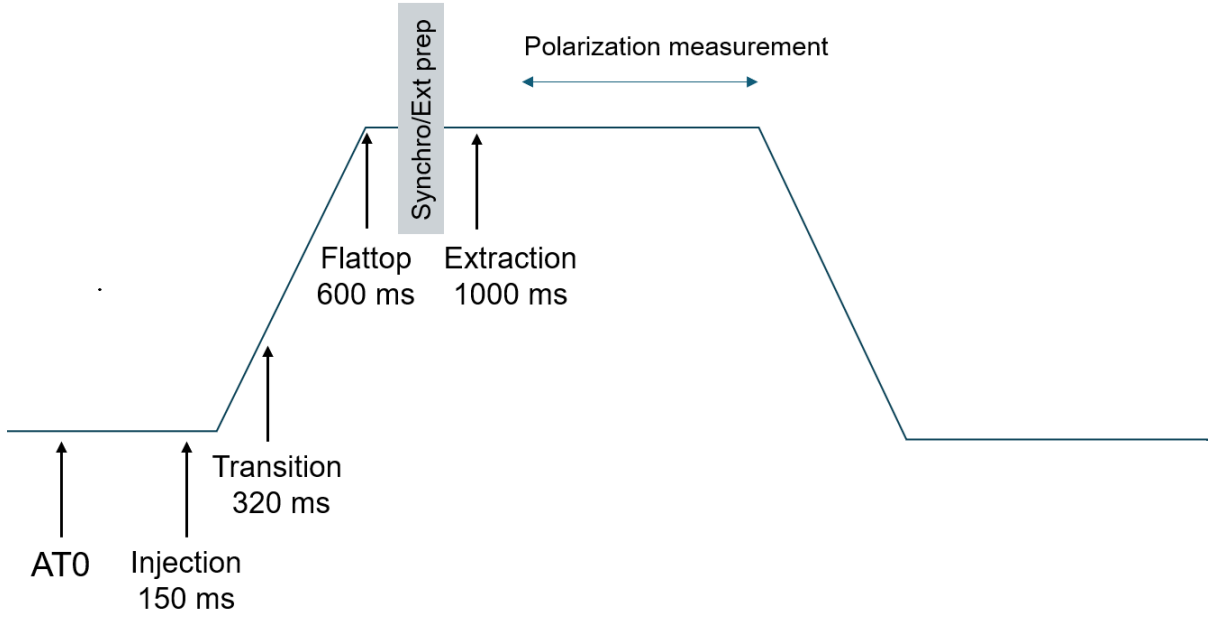
Benchmark
IPM emittance, bunch length

→

Predict
Injection-energy scans

Questions to address

- Footprint: use simulation to identify tune-spread.
- Ramp benchmark: does the model reproduce the observed evolution and scales?
- No-ramp fixed energy: isolate injection-energy space-charge dynamics.



Final Goal: develop a model to help make final machine decision for future high-intensity setup.

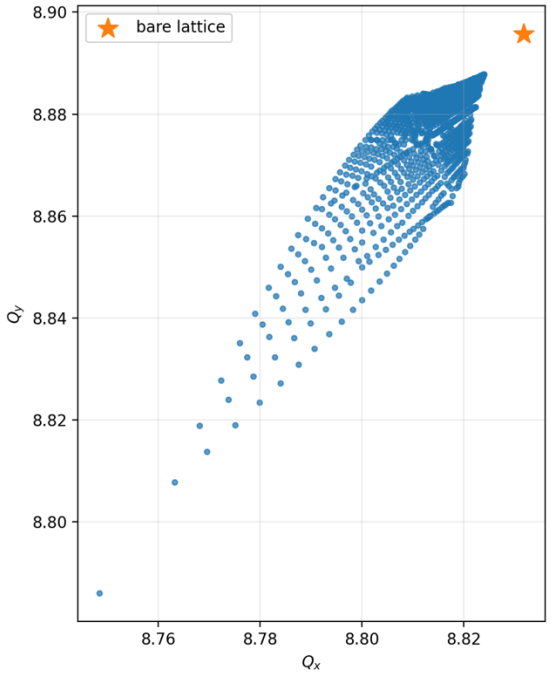
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AGS space-charge tune footprint

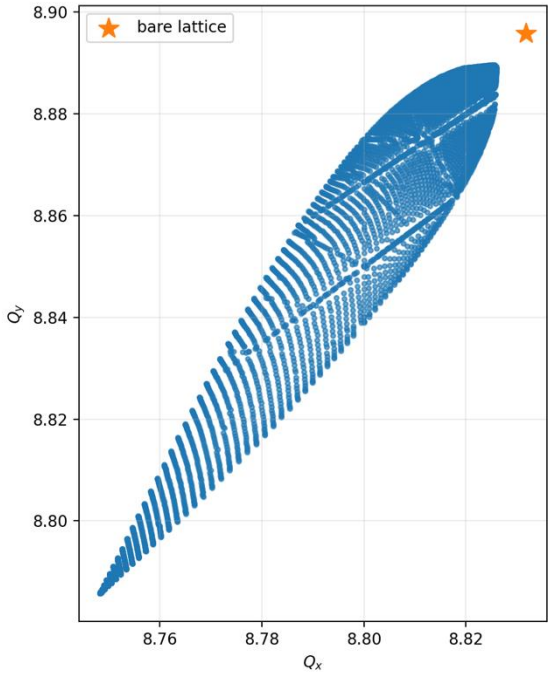
Frozen space-charge potential for the prescribed bunch; tune extraction from tracked probe particles

N = 1×10¹¹

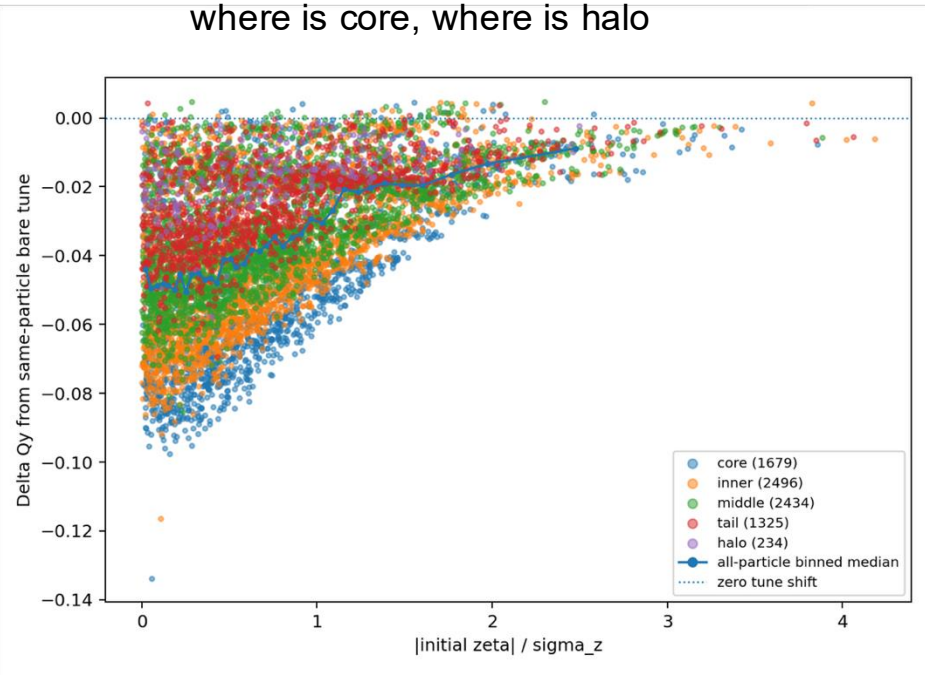
Probe particles using (Jx, Jy)



Probe particles using polar (r, theta)



Tracking with entire bunch to see where is core, where is halo



Polar sampling resolves the beam core better

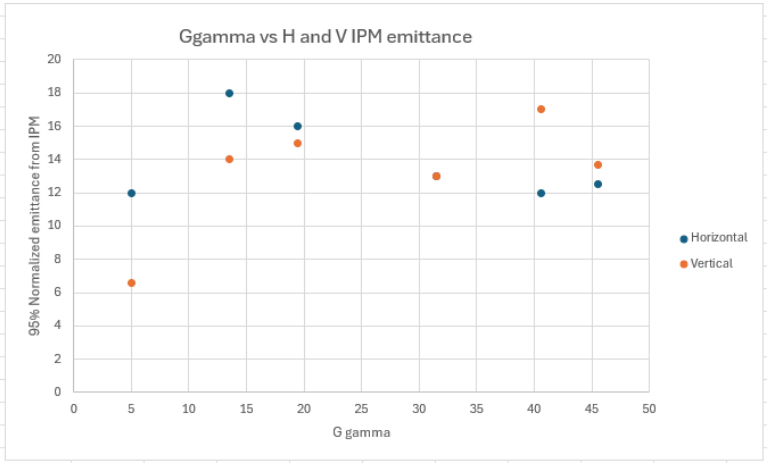
The footprint and particle-tracking conclusions are consistent.
Maximum changes in (Qx, Qy) ~ (-0.07, -0.1), in reasonably good agreement with (-0.17, -0.25) reported in EIC PDR (2.5e11 intensity) and in RHIC Run 17 ~ -0.2 for 2e11 intensity (IPAC 17)

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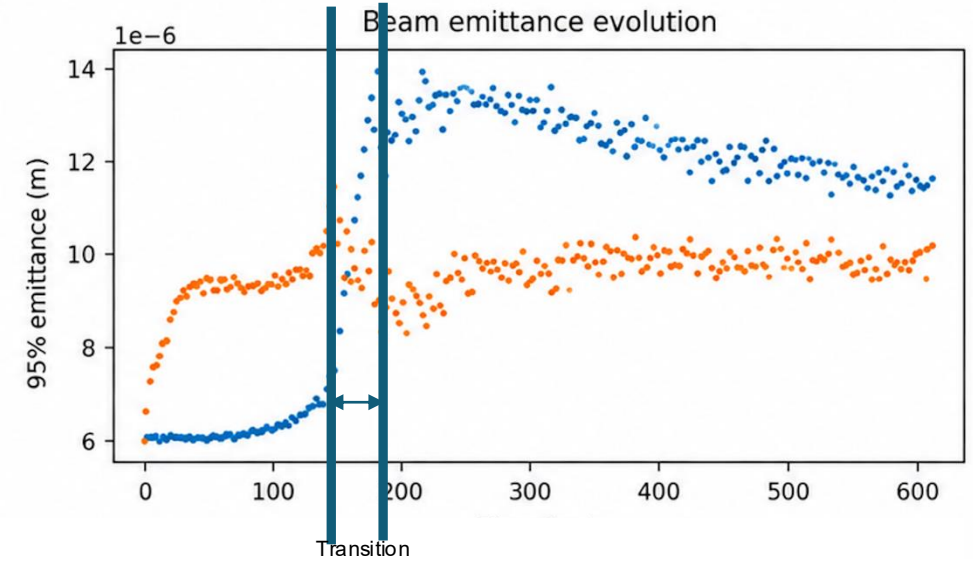
Ramp benchmark: AGS cycle – the coupled beam evolution

Simulated ramp results are compared with measured IPM emittance trends.

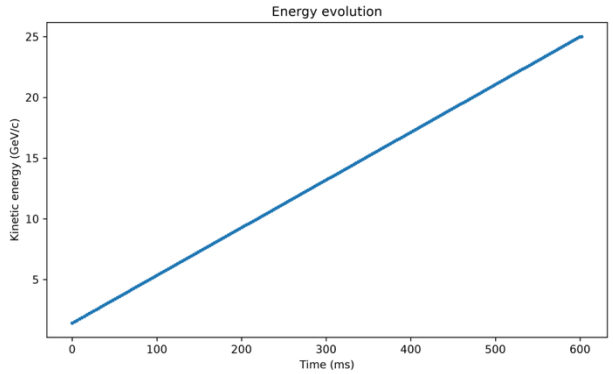
Measured emittance scan (vs Gγ)



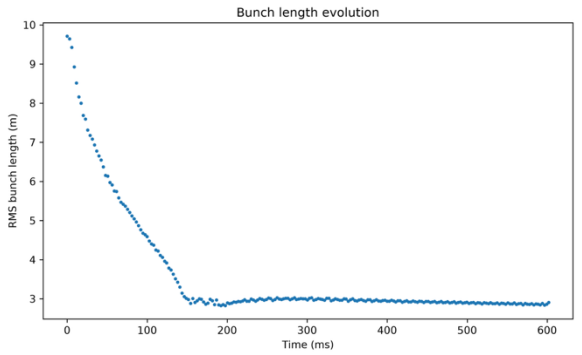
Simulated emittance evolution during ramp



Energy evolution



Bunch length evolution



Qualitative agreements:

1. Horizontal emittance starts higher than vertical. No obvious emittances growth after transition.
2. Vertical emittance blowup during transition.
3. Final numbers are within 20% difference: 95% emittances (x y) (12.5 13.7) um measured / (9.8 11.6) um simulated.

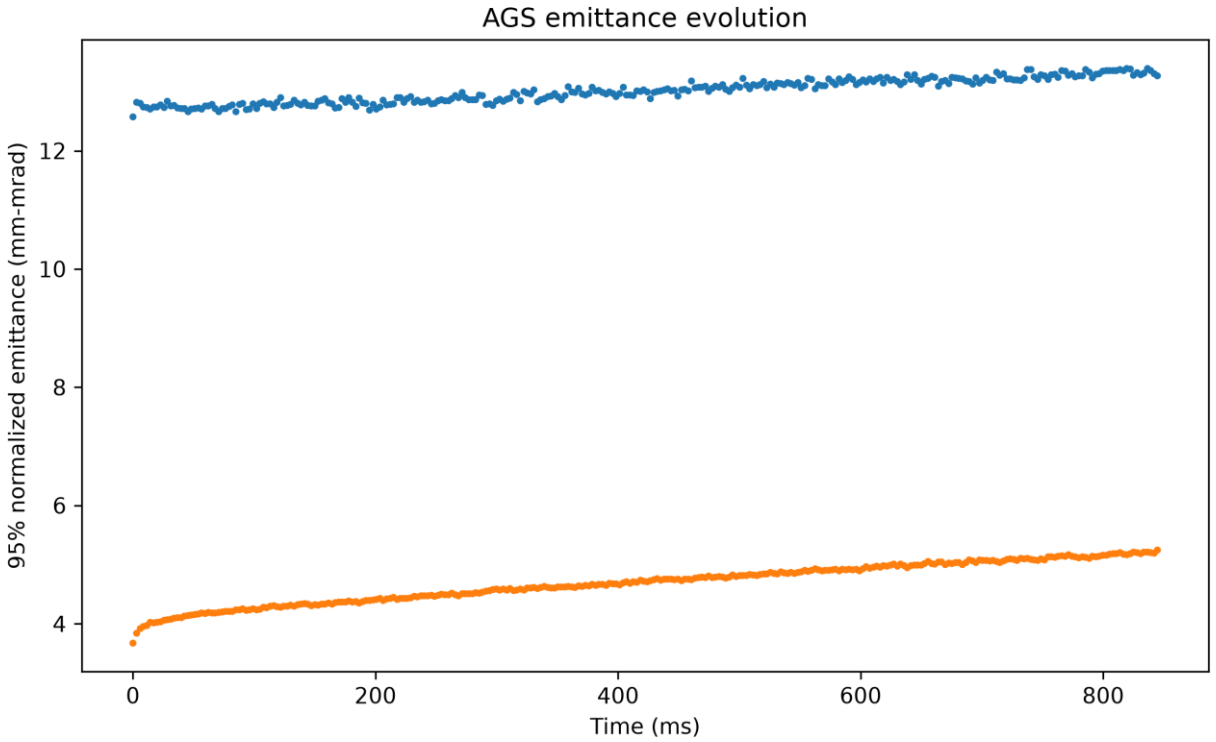
Need to take a deeper look (work in progress):

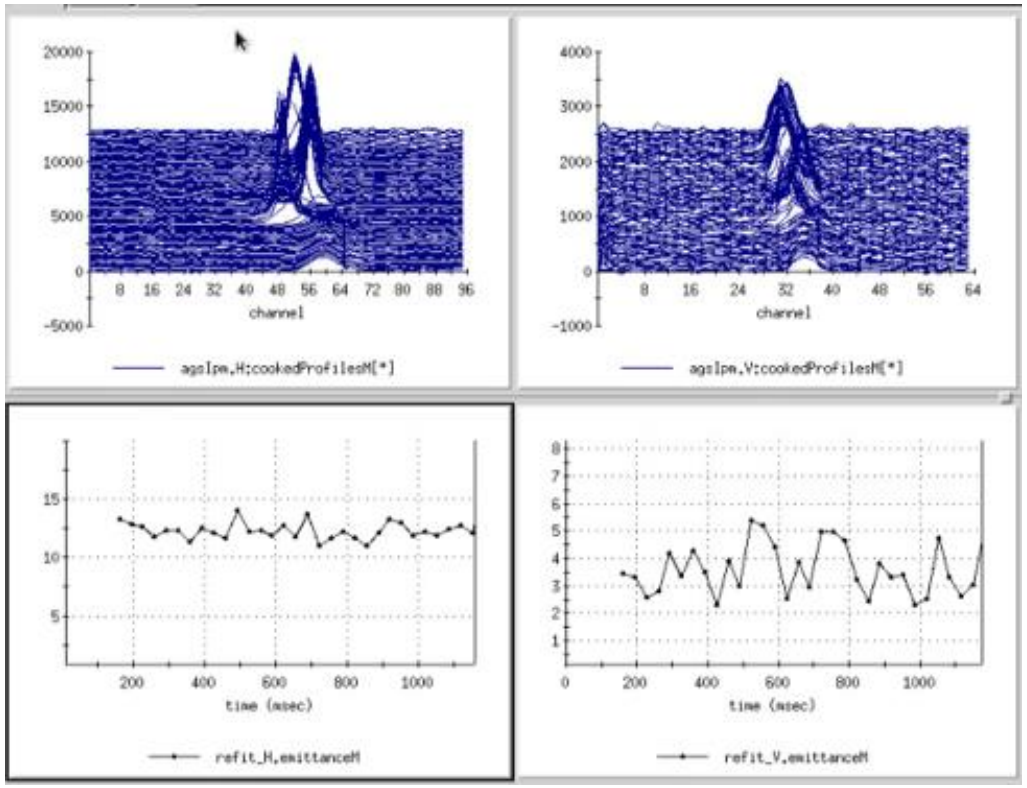
1. Initial stages at low energies.
2. Transition energy dynamics

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Initial growth with no energy ramps: 0.8×10^{11} protons/bunch

By fixing the beam energy, we can isolate early stage emittance growth from transition energy dynamics.

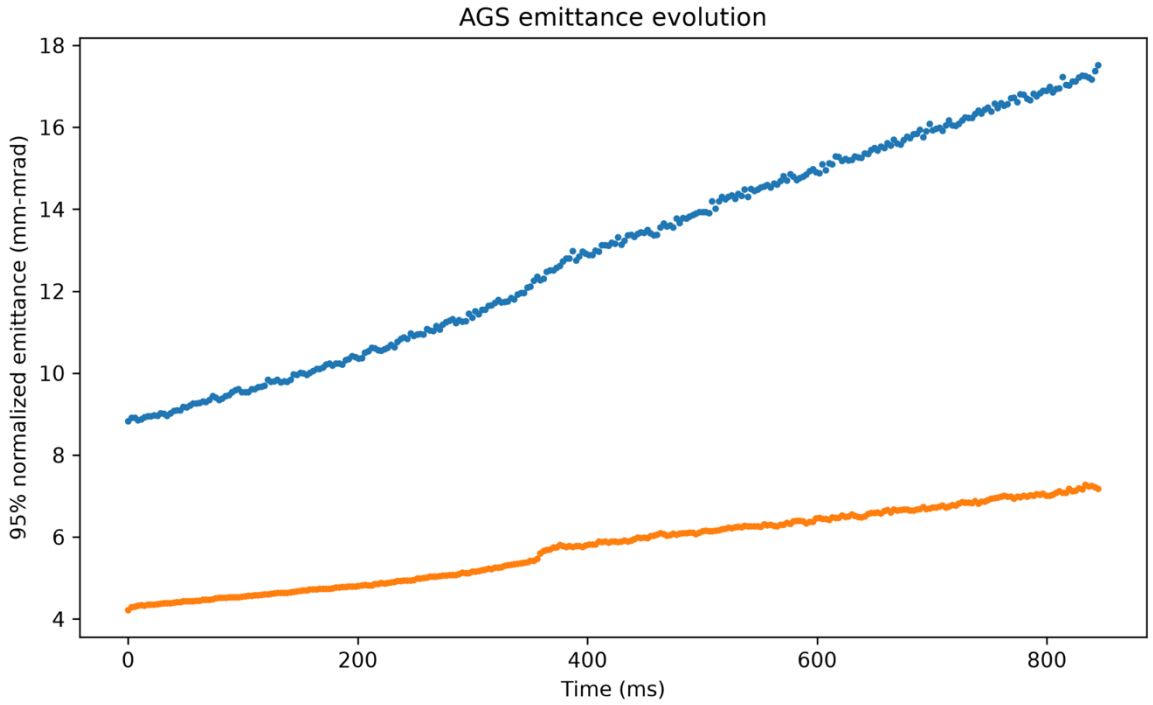


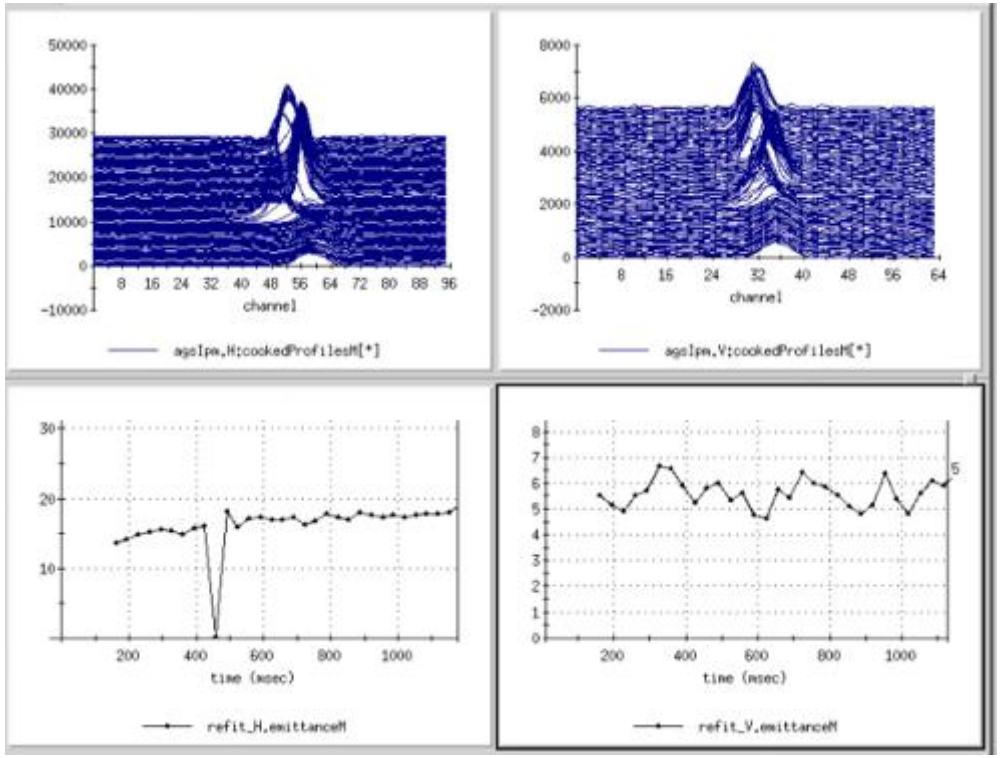


- At low intensity, the emittances from simulation have qualitatively good agreement – low emittance growth.
- The initial quick growth is likely due to lattice mismatch (beam was generated and injected using nominal lattice)

Initial growth with no energy ramps: 2×10^{11} protons/bunch

At high intensity, the simulation has some disagreements with measurements:

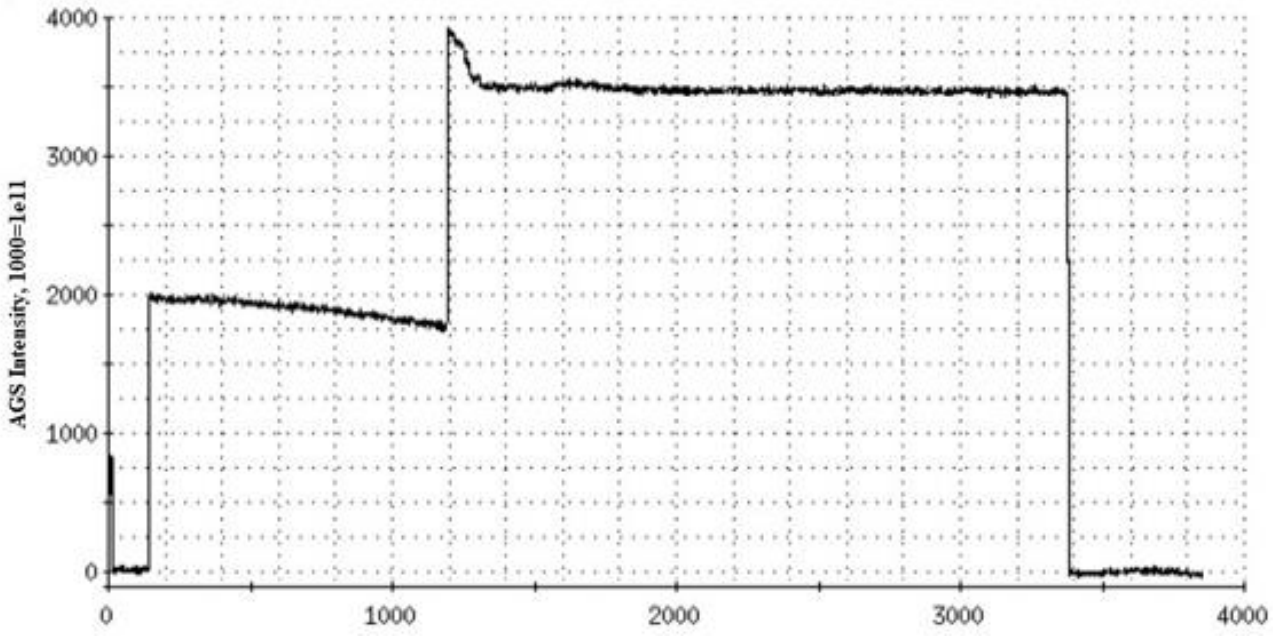




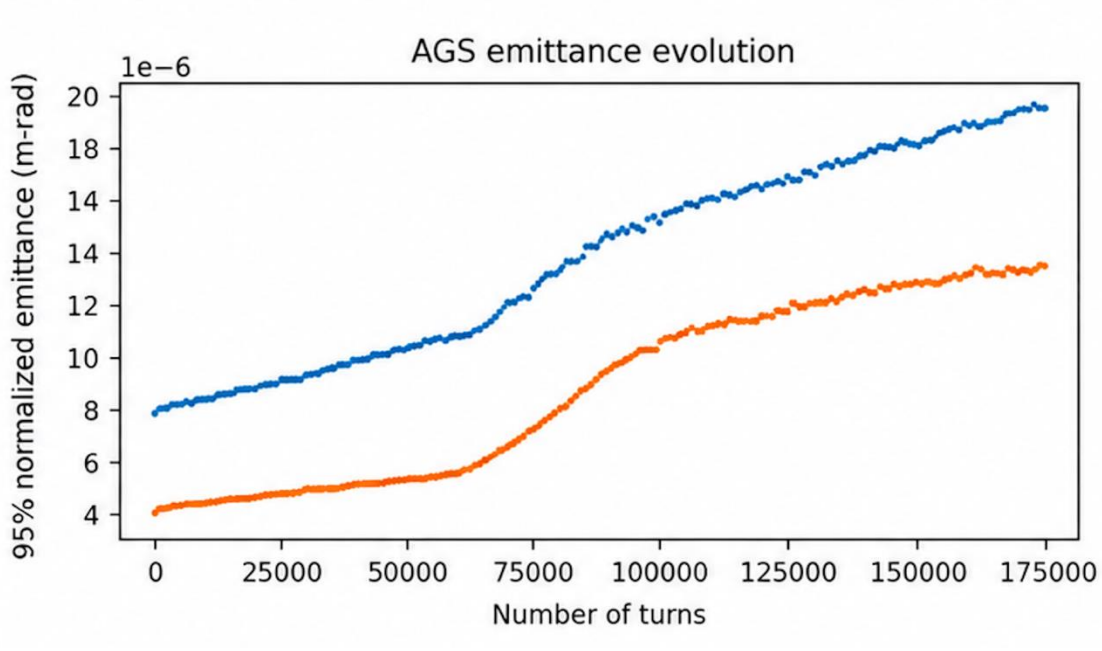
- Growth is more pronounced in the simulation when intensity is increased.
  - In simulation, (x, y) grow from (8.4, 4.2) um to (17.3, 6.4) um at 800 ms.
  - In experiment, (x, y) grow to about (18, 5.8) um at 800 ms but with much lower slope.
- The change of slope at around 400 ms is likely caused by crossing of resonances.

Possible reasons for discrepancies

1. Likely beam loss in real machine (about 10% at 1 s)



2. Beam parameters in real machine are probably different from what was used in simulation



Initial bunch length was changed from 14 m to 9.7 m in this run, much higher growth

- Next step would be to include what are known missing effects in simulation and identify what are possible starting point.

Summary

- We performed preliminary studies of the tune footprint and emittance evolution with space charge effect in Xsuite for AGS's ramp process. The results have qualitative agreement with what was expected and observed in experiment.
- The various sections of the ramp have been separated and preliminary studies for each region are being performed.
- We identified some possible reasons why simulation results have discrepancies for high intensity case and the missing factors will be implemented to see effects.
- The model, when fully benchmarked, will be used to explore different operational scenarios.