µCATALYST 07/27/2026 Updates

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Bunching Methods

Project focuses on modeling longitudinal beam dynamics in the AGS to study how RF systems compress a proton bunch to a target of 2ns RMS before extraction

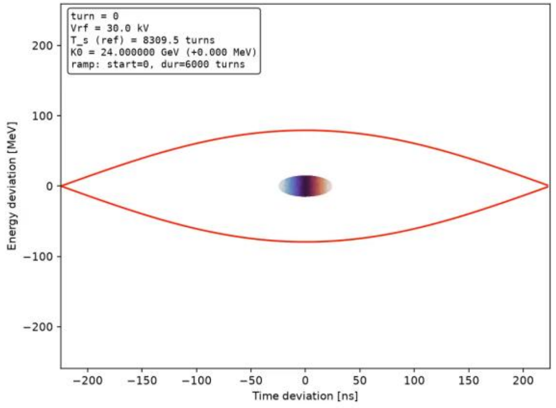
Git: https://github.com/rbeckwith1/bnl-beam-simulation

AGS parameters:

- Momentum Compaction: ~ 0.014
- Harmonic number: h = 6
- Maximum Voltage: 320 kV
- Emittance: 0.95 eV*ns (possibly higher)

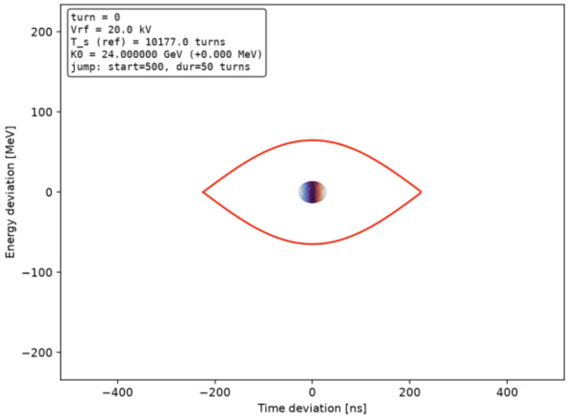
Simulations using general reference values:

Min Bunch Length: 5.952 ns



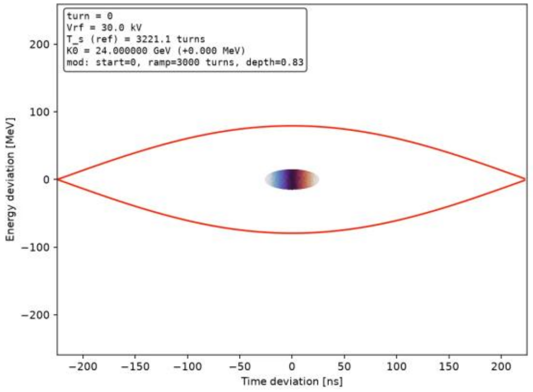
Adiabatic

Min Bunch Length: 3.593 ns



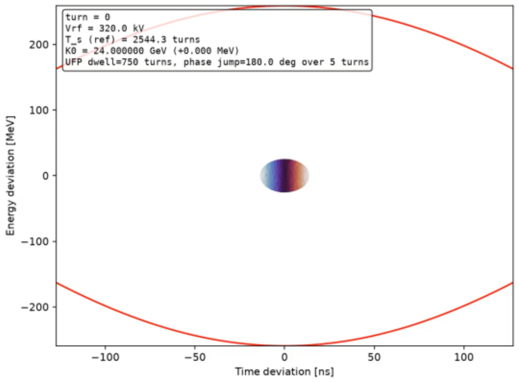
Non-Adiabatic

Min Bunch Length: 2.140 ns



Quad Pumping

Min Bunch Length: 3.052 ns

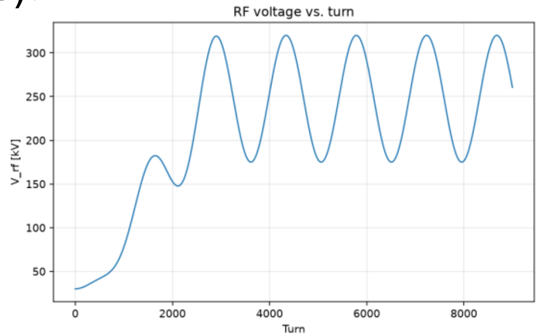


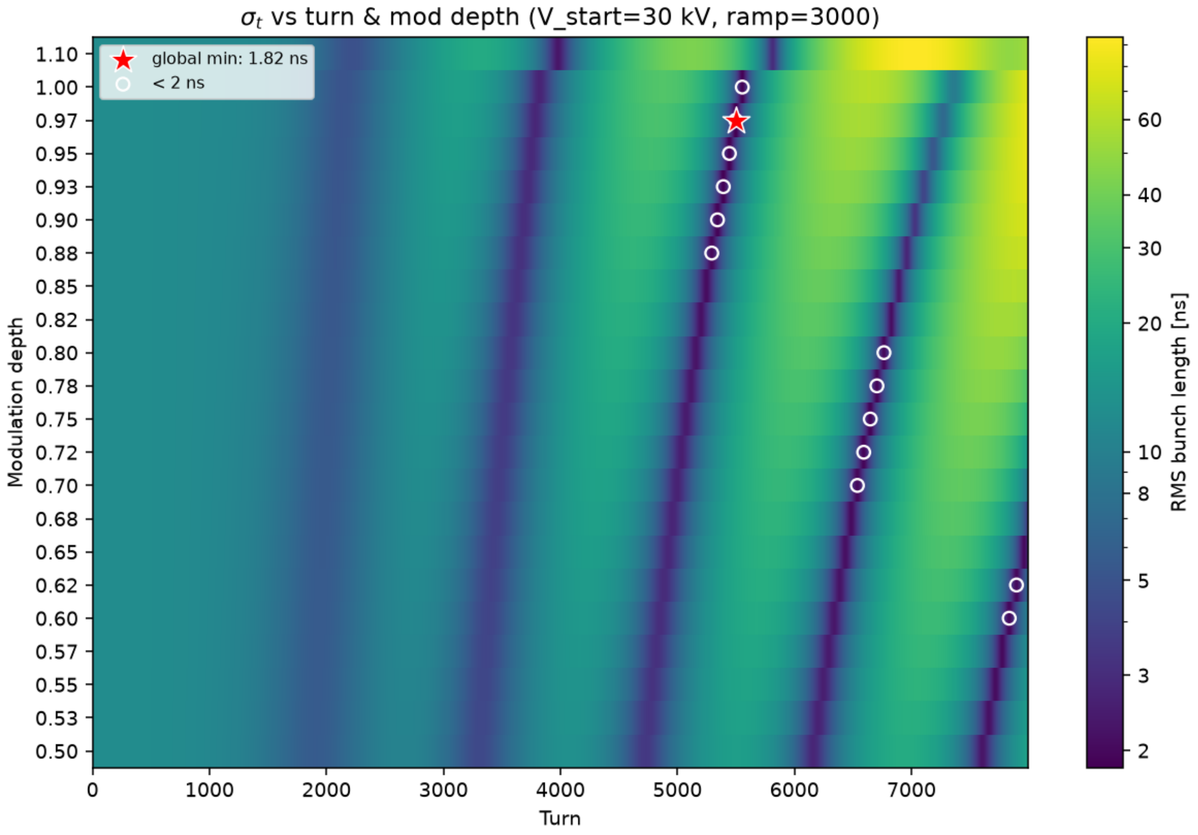
Unstable Fixed-Point

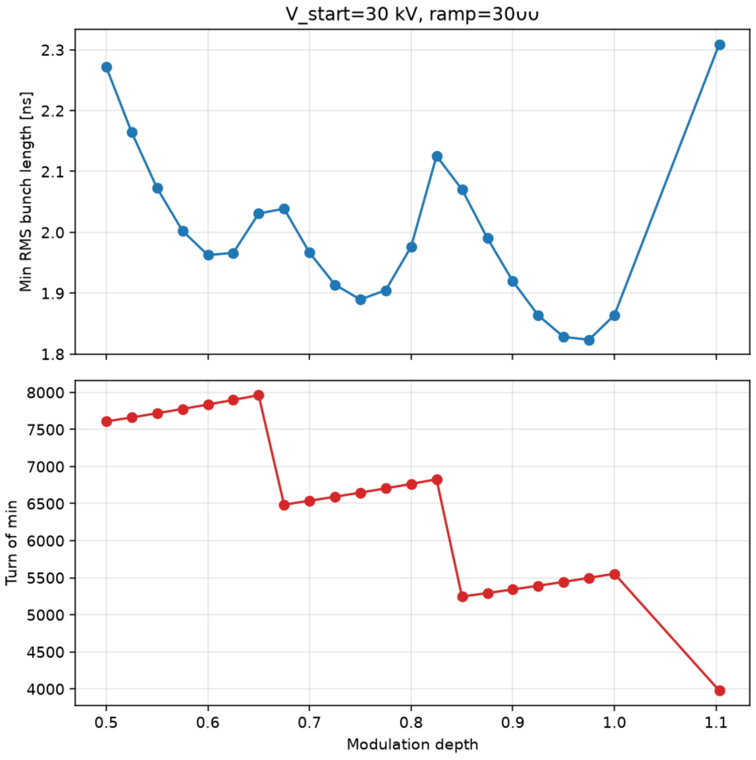
Optimization- Quad Pumping

- Optimization of the quad pumping bunch compression method
- Parameter scan of modulation depth with a fixed starting voltage of 30kV and 3000 ramp turns
- Results shows several configurations below 2ns RMS compression

Modulation depth: Ratio of the minimum RF voltage to the initial voltage (0 = no modulation; 1 = minimum voltage equals the initial voltage).

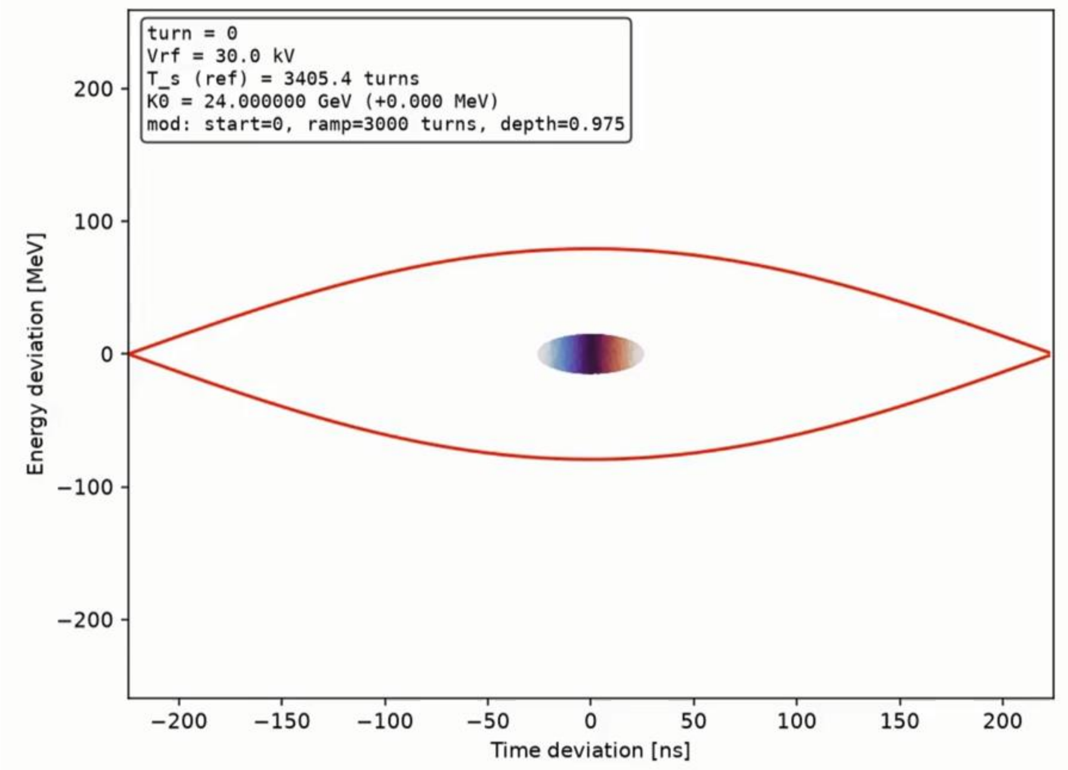


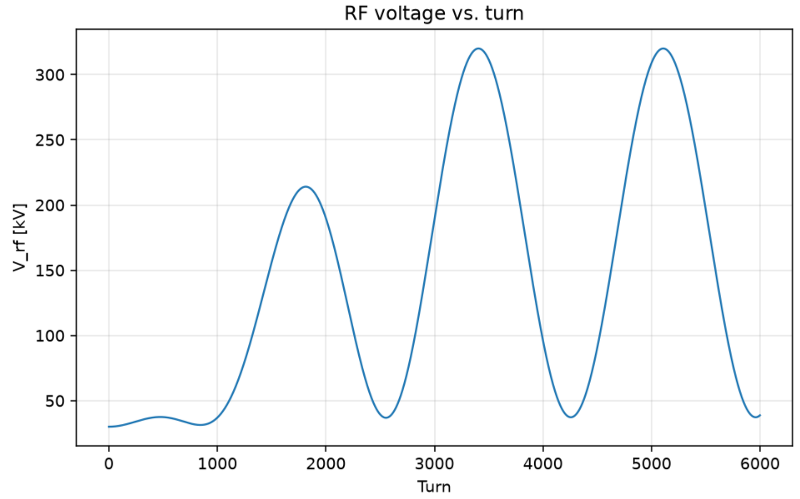


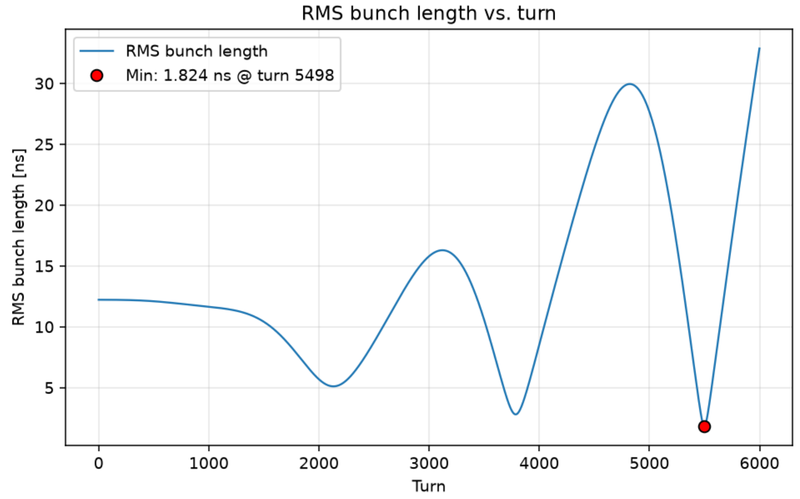


Best Result- Quad Pumping

For starting voltage 30kV and max voltage 320kV
Absolute minimum bunch length: 1.824 ns RMS
Modulation depth = 0.975



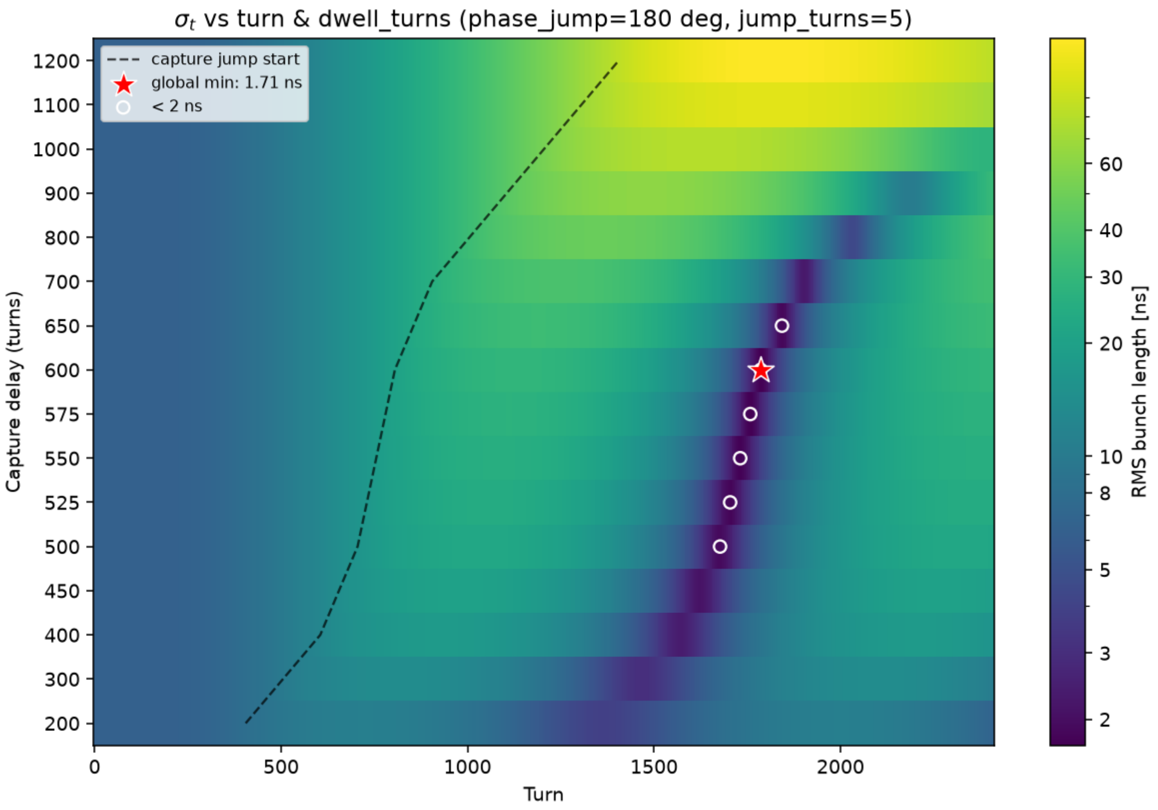


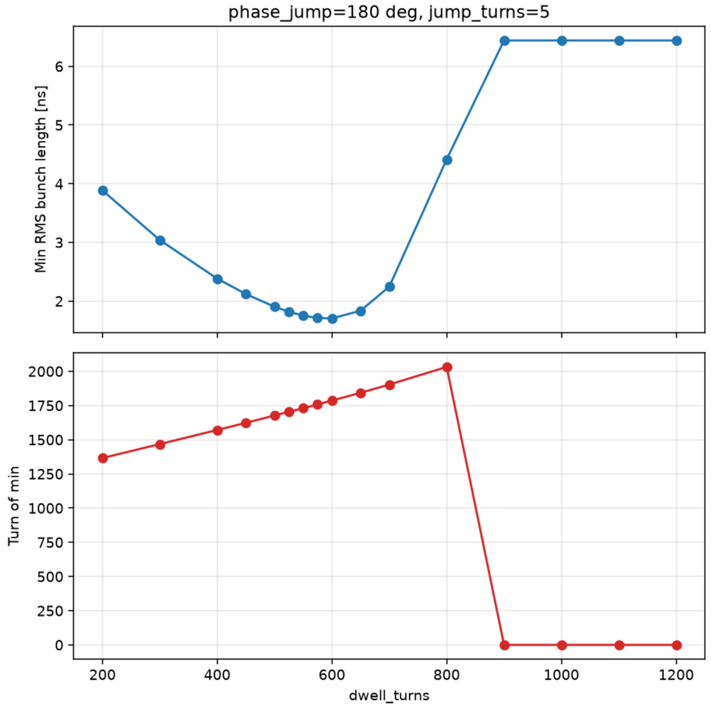


Optimization- Unstable Fixed Point Method

- Optimization of the unstable fixed-point bunch compression method
- Parameter scan of the capture delay with a fixed 180 degree phase jump and 5 jump turns
- Also shows configurations below 2ns RMS target

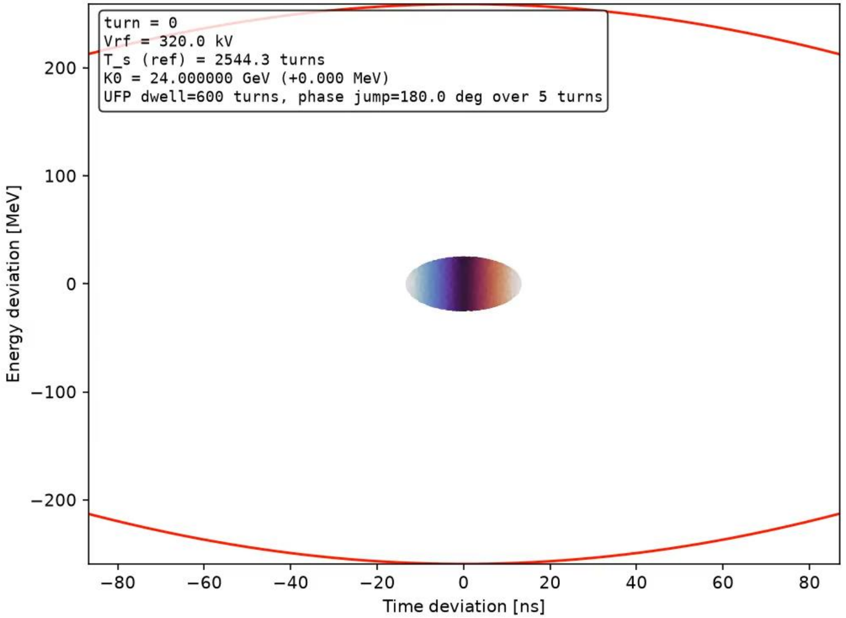
Dwell turns: number of turns at unstable fixed point

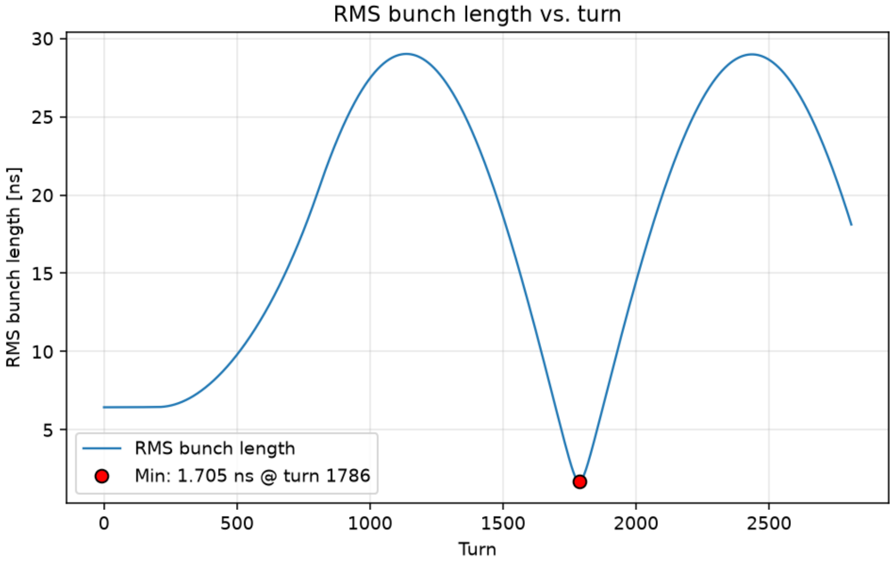




Best Result- Unstable Fixed Point Method

For 5 jump turns and a 180 degree phase jump
Absolute minimum bunch length: 1.705 ns RMS
Dwell turns = 600





Conclusion and Next Steps

Current Model:

- Implements four bunch-compression strategies (non-adiabatic, adiabatic, quad pumping, unstable fixed point) with turn-by-turn phase-space tracking, acceleration, and voltage-ramp control

Currently Working on:

- Implementing Keil-Schnell/Boussard microwave-instability diagnostics and identifying transient instability windows during compression
- Updating initial bunch distribution to match AGS definition, using revised emittance value

Next Steps:

- Re-run optimization studies incorporating machine limits
- Optimizing non-adiabatic method parameters for minimum bunch length
- Benchmarking against CERN's BLonD package to validate tracking accuracy