FETS-FFA Longitudinal Dynamics

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CSNS Collaboration Meeting

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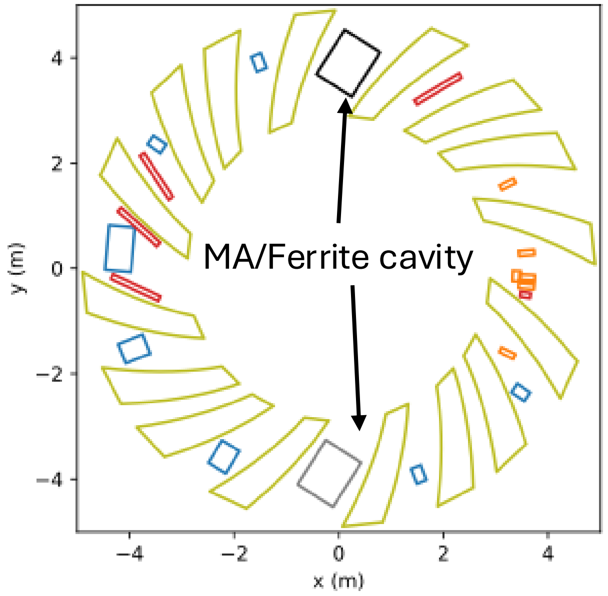
Overview

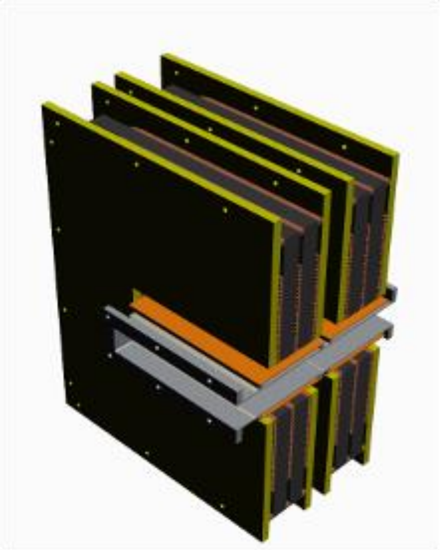
- Achieve lossless acceleration from injection to extraction.
- 100 Hz equivalent cycle (accelerate in 8ms).
- Demonstrate beam stacking and capture.

Parameter	Specification
Energy range	3 –12 MeV
Harmonic	2
RF frequency	2 – 3.7 MHz
Peak RF Voltage / Turn	6kV
Re-bunching Voltage	20kV h=1 (1.85MHz)
Acceleration Time	8ms

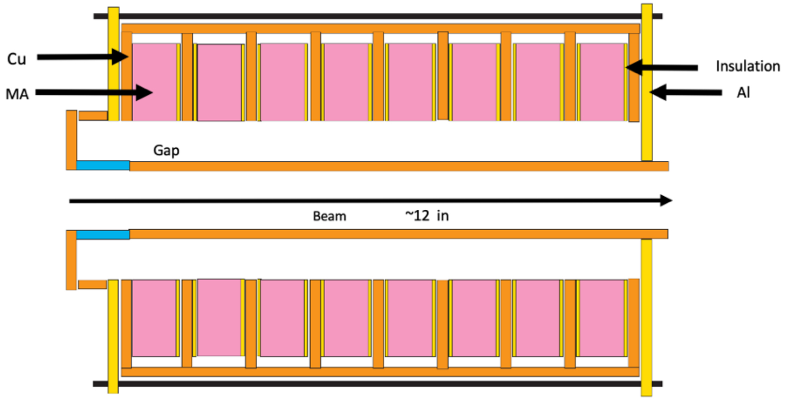
RF Cavity options

- Two cavity technology options are under study
  - 2 x **Magnetic Alloy** cavity, 3kV per gap.
  - 2 x two-gap biased 4M2 **Ferrite-loaded** cavity, 1.5kV per gap.
- In both cases each cavity is run at 10kV in burst mode to rebunch stacked beam.
- The cavities are arranged symmetrically around the ring to mitigate RF knockout during stacking.





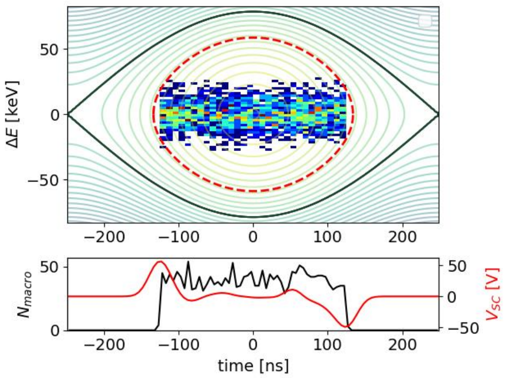
Ferrite cavity design



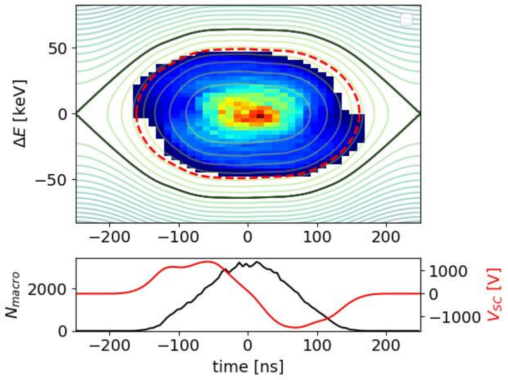
MA cavity schematic

Direct injection into waiting bucket

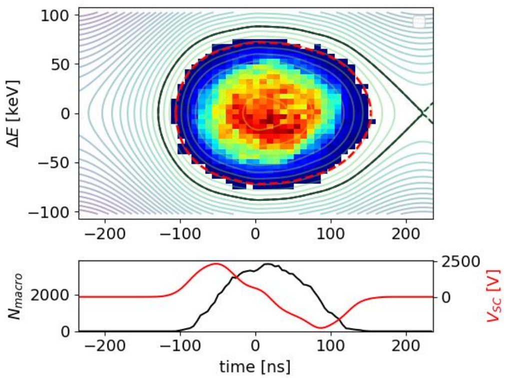
- A beam with chopped duration 250ns with momentum spread +/- 0.004 is injected over 50 turns. Synchrotron period 87 turns.



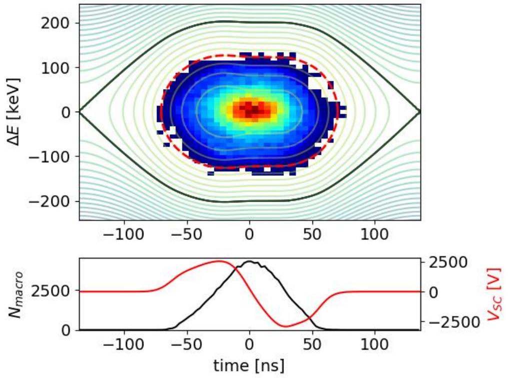
Turn 1



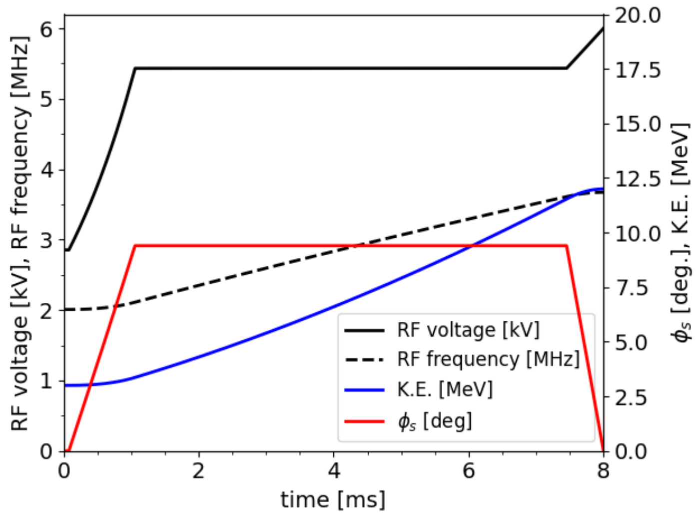
Turn 50 – end injection



During acceleration



Final turn



Maximum intensity case (3e11)
Initial RF voltage: 2.9kV
Max ϕ_s: 9.4 deg
RF voltage@Max ϕ_s : 5.4 kV

- Current injector chopper minimum bunch duration is 450ns. Can be reduced by upgrading power supply.
- Losses from RF bucket during foil crossing not included here. Average energy loss per foil hit is 2.1 keV (from Bethe Bloch).

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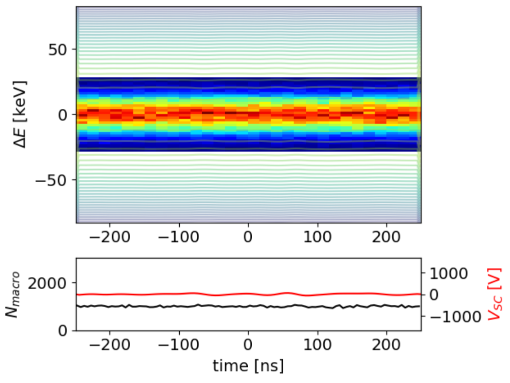
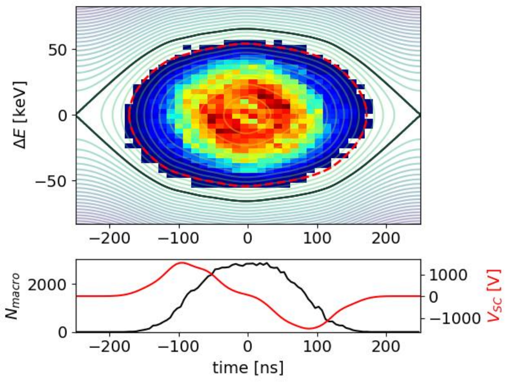
Adiabatic capture at injection

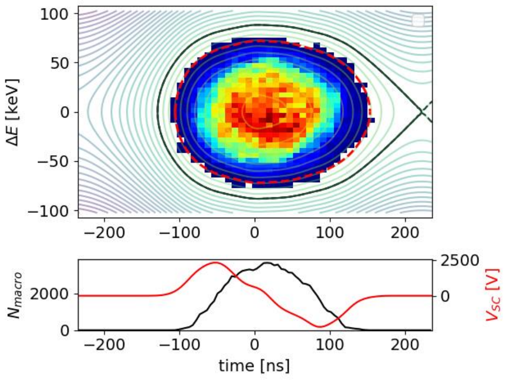
- A beam with momentum spread +/- 0.004 is injected over 50 turns with RF voltage set to zero. Then linearly increase voltage to 2.8kV in 1000 turns before accelerating.



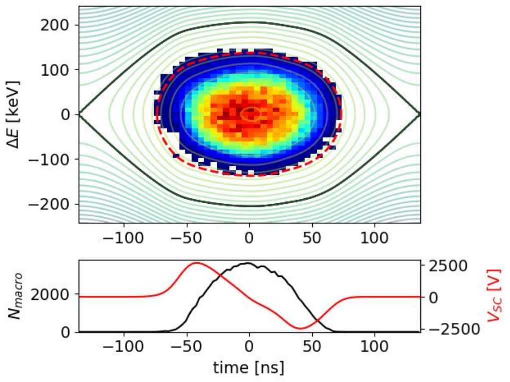
Turn 1 (injection complete)



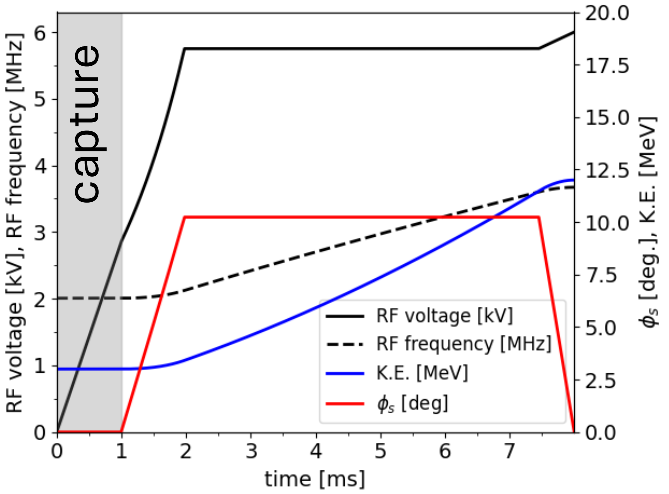
Turn 1000



During acceleration



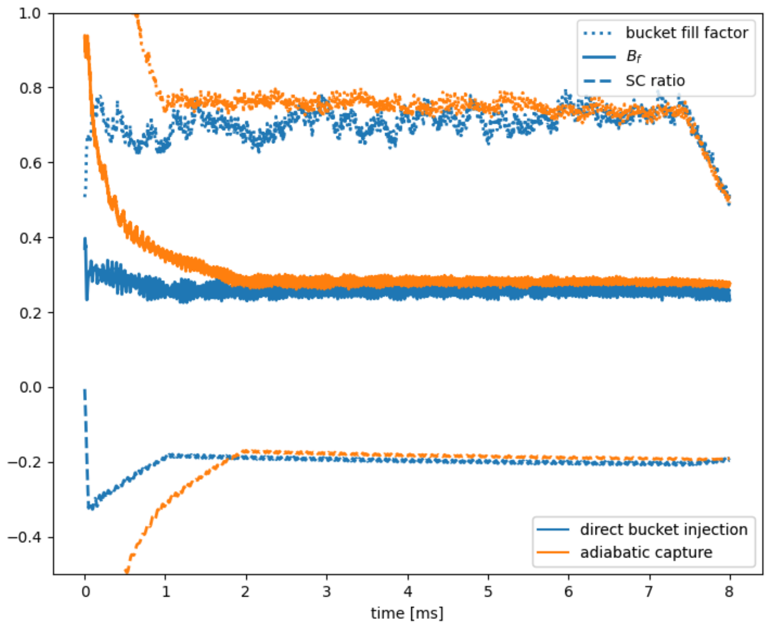
Final turn



Maximum intensity case (3e11).
RF voltage at end of capture: 2.9kV
Max ϕ_s: 10.2 deg
RF voltage@Max ϕ_s : 5.8 kV

- Eases the requirement on the chopped beam duration.
- Losses from RF bucket during foil crossing minimised (see C. Rogers presentation).
- The beam loading voltage is modest.

Key parameters during acceleration cycle



- Less than 80% of the bucket is filled during acceleration. Zero longitudinal losses
- The bunching factor is slightly lower in the direct capture case – line density is more peaked.
- SC ratio > -0.4, i.e. below the microwave instability threshold.

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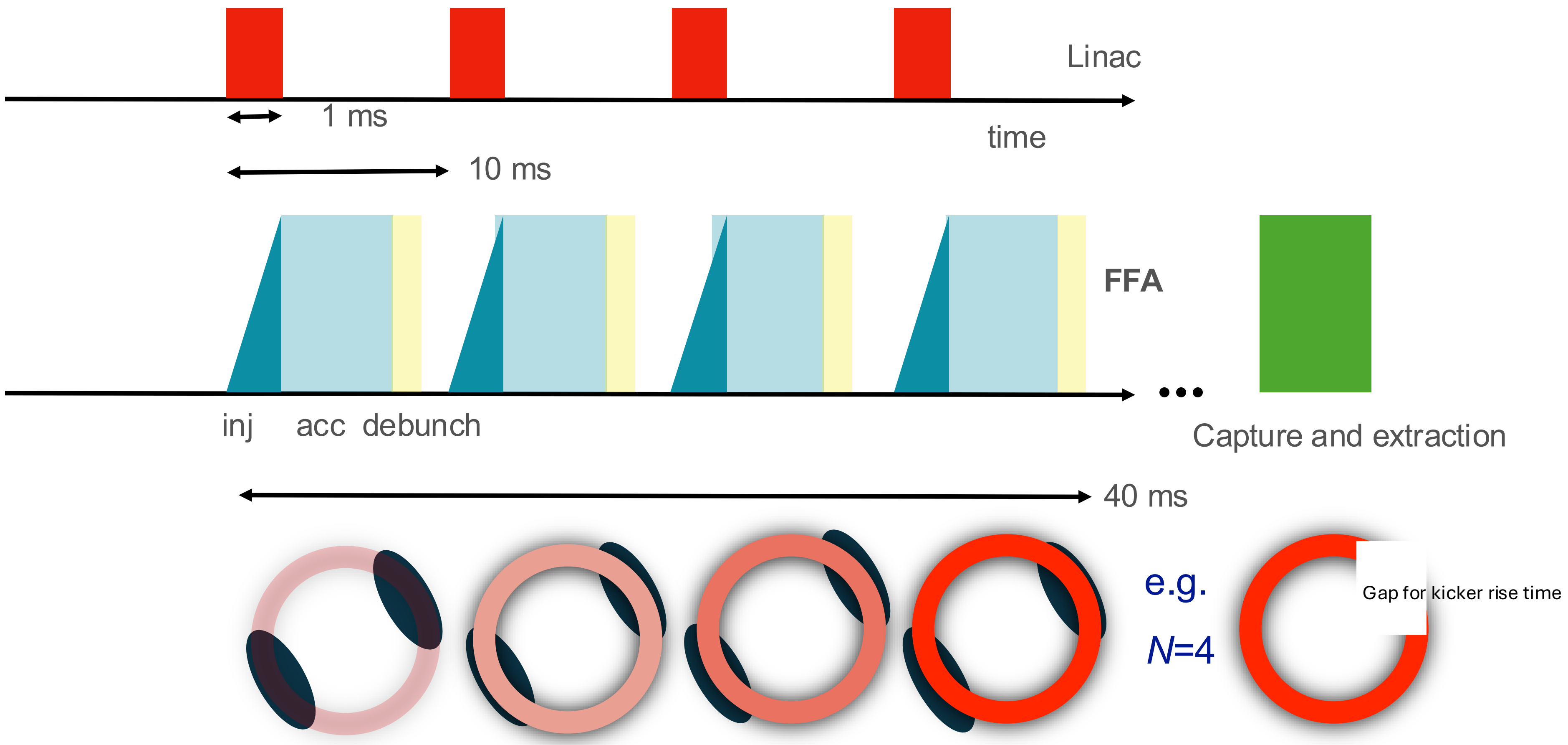
Beam Stacking Scheme



N	Rep rate
1	100 Hz
2	50 Hz
5	20 Hz
10	10 Hz

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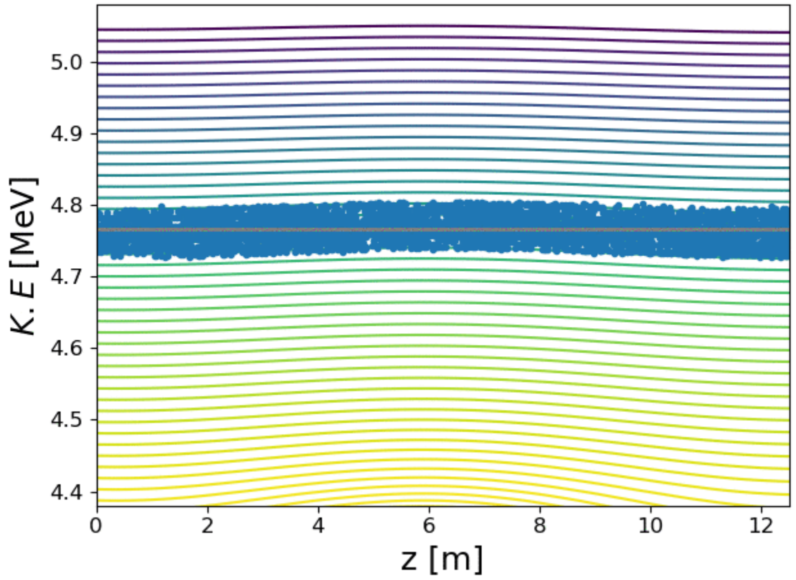
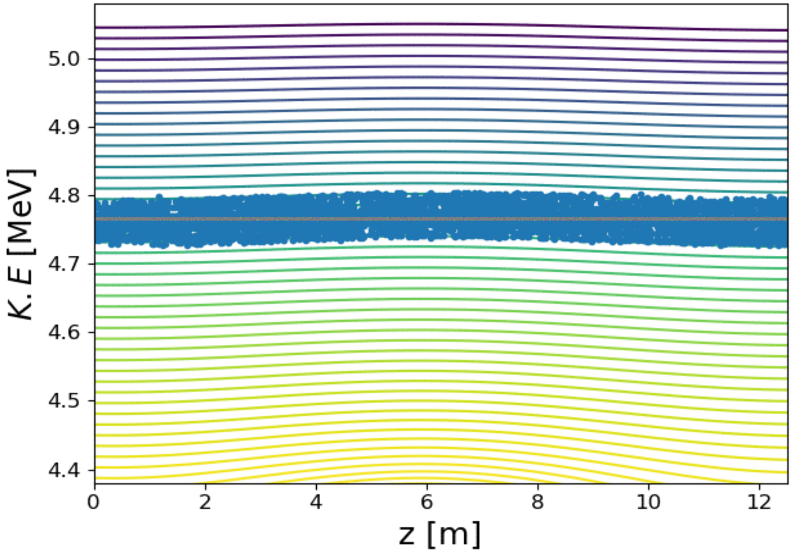
- Stack N beams to reduce the beam seen by users by a factor N.

Phase displacment

- When an RF bucket with area A passes through coasting beam
  - Mean energy of coasting beam is displaced $\langle \Delta E \rangle = \frac{\omega_0 A}{2\pi}$
  - Energy spread of coasting beam is increased by phase scattering. Scattering increases with synchronous phase.



$\phi_s = 5°$



$\phi_s = 10°$

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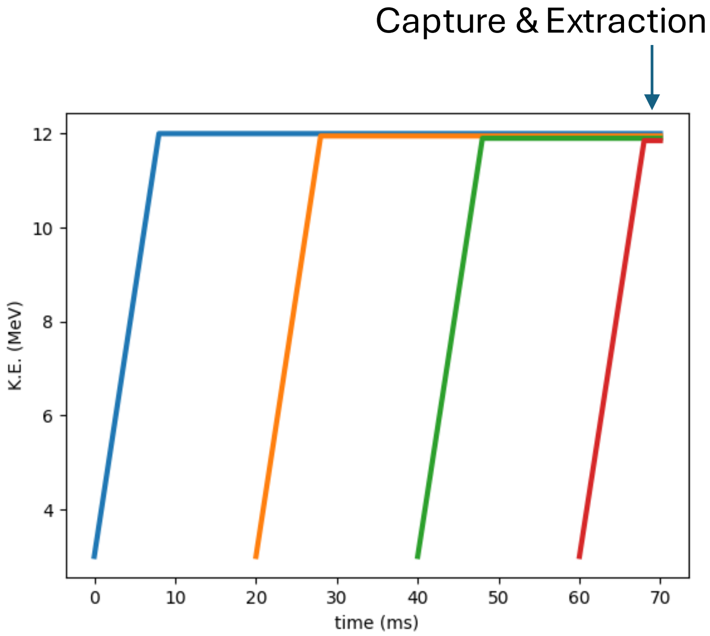
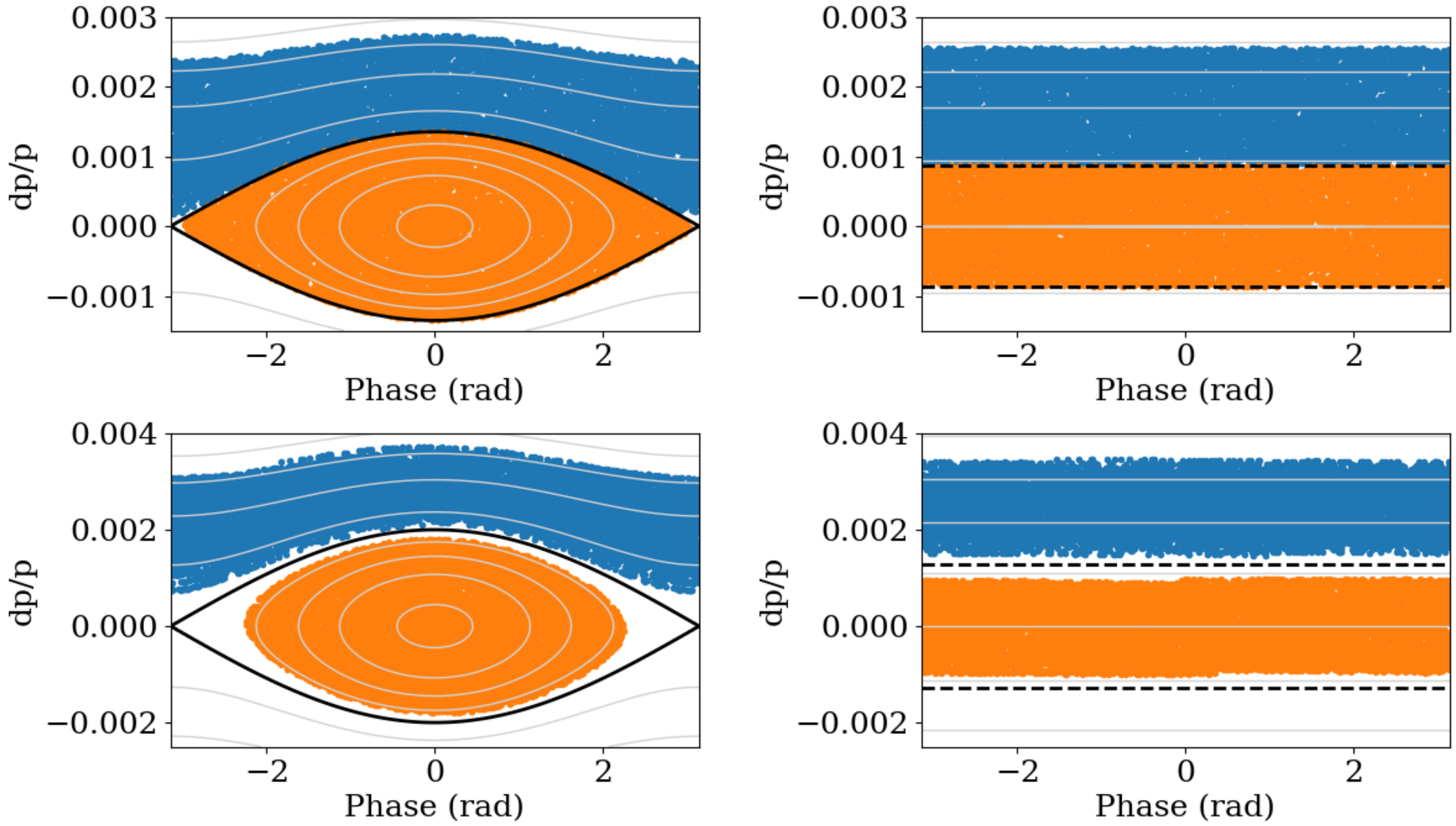
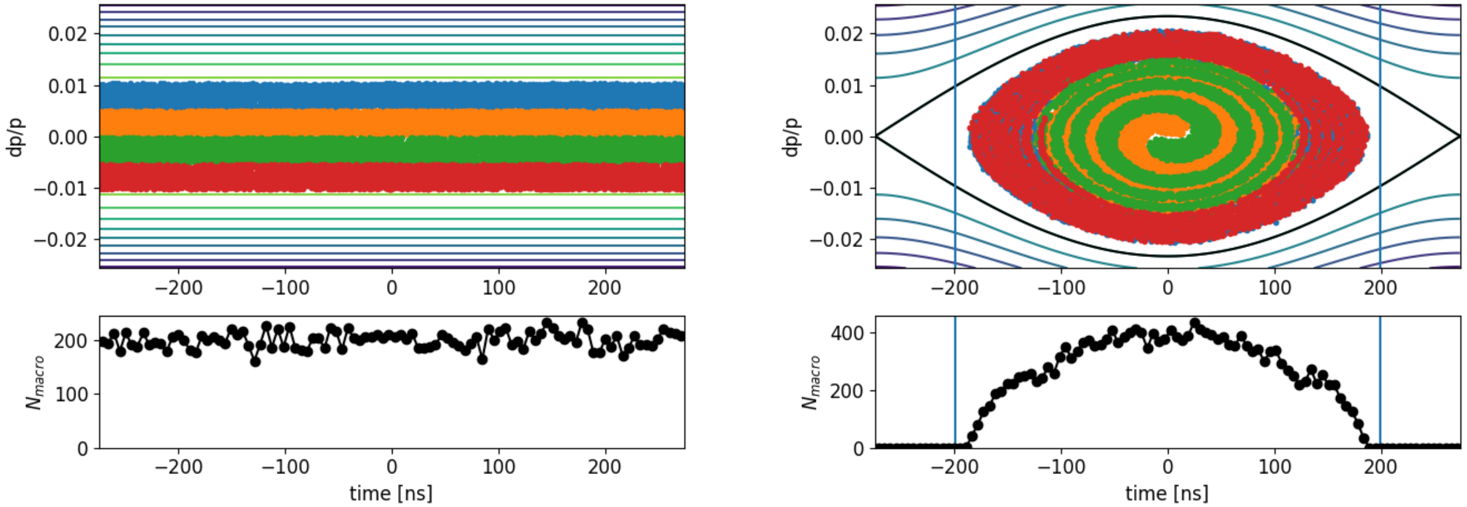
Beam Stacking





- Stack N beams to reduce the repetition rate seen by target by a factor N.
- Stack successive beams at lower energies to avoid phase displacement.
- Need to allow space between beams to avoid longitudinal loss / phase displacement.

Capturing the stacked beam (1)



- Capture by linearly increasing voltage to 20kV (h=1) in 2000 turns.
- Vertical lines show 150ns target abort gap for extraction kicker.
- Captured beam dp/p: +/-0.021 – determines acceptance of extraction septum
- This is the low intensity case where longitudinal space charge is negligible.

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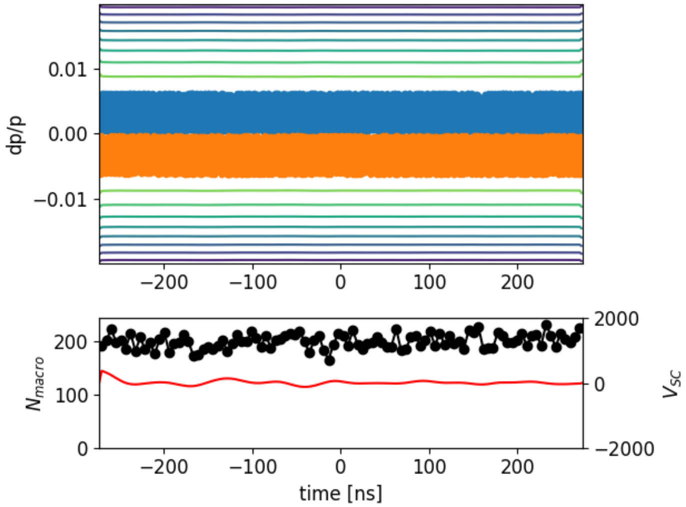
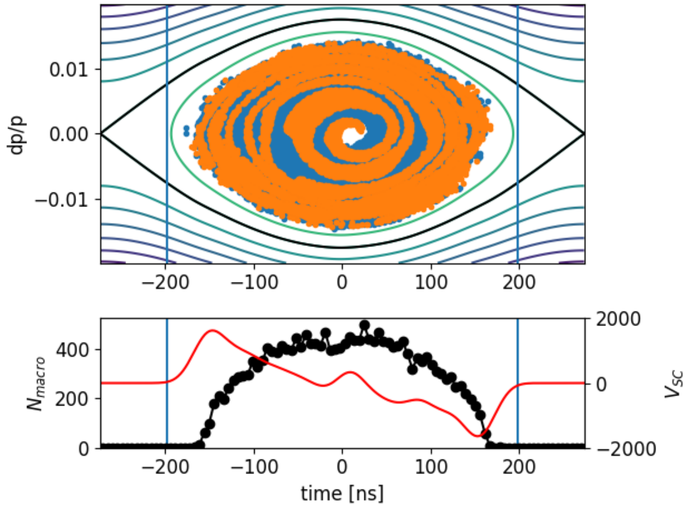
Capturing the stacked beam (2)





- Transverse space charge limits intensity of a single beam at injection to 3e11.
- At extraction since βγ is double, two beams at this intensity can be stacked,,
- Capture by linearly increasing voltage to 12kV (h=1) in 2000 turns.

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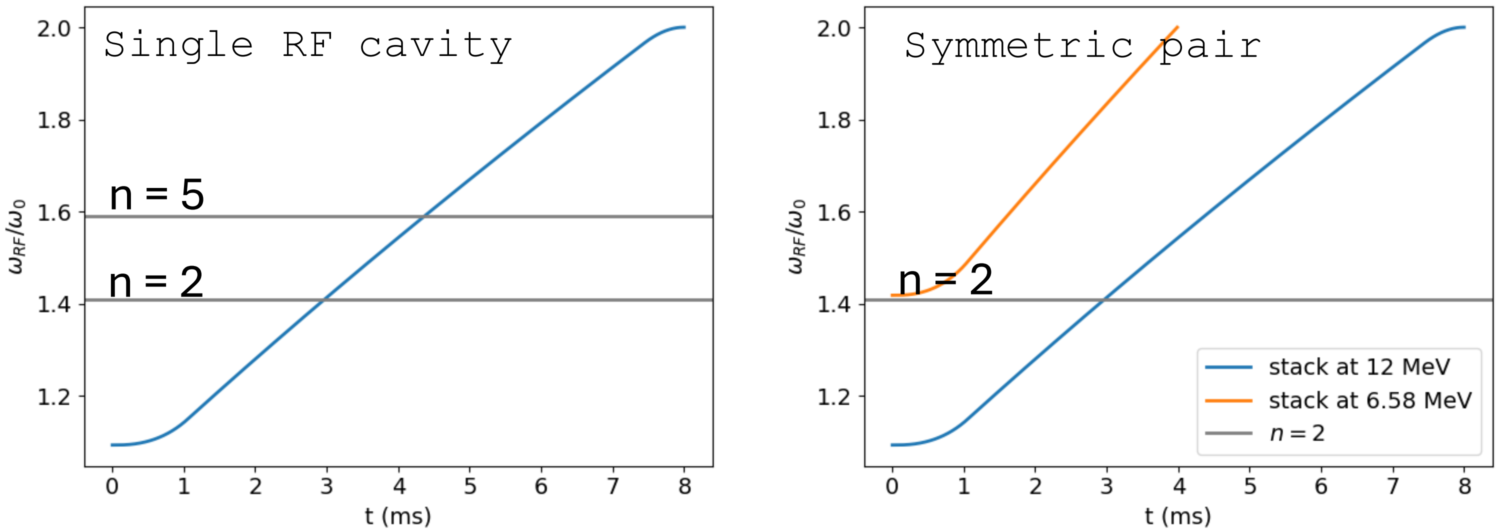
RF Knockout

- The finite dispersion at the RF cavity results in an effective dipole kick.
- When a beam is coasting at fixed frequency ω_0 a resonance can occur with azimuthal mode number n when the RF frequency ω_{rf} and the horizontal tune Q_x satisfy a rational relationship.

$$\pm Q_x = \frac{\omega_{RF}}{\omega_0} + n$$

- Mitigate RF knockout by placing RF cavities symmetrically around the ring. In the case of two symmetrically arranged RF cavities, one knockout resonance is eliminated.



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Summary

- RF requirements for acceleration and rebunching the stacked beam have been established.
- The beam is either directly injected into a waiting bucket or adiabatically captured.
- Up to 4 stacked beams can be captured with 20kV RF voltage.
- A symmetric pair of RF cavities is required to mitigate RF knockout.