Beam stacking in the FETS-FFA/ISIS-II

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Beam Stacking

- Beam stacking involves storing successive bunches in the ring. The bunches are allowed to coast and are stacked in terms of energy.
- First proposed by Symon and Sessler during the MURA years. Also known a “longitudinal phase space stacking”, “rf stacking” or “momentum stacking”.

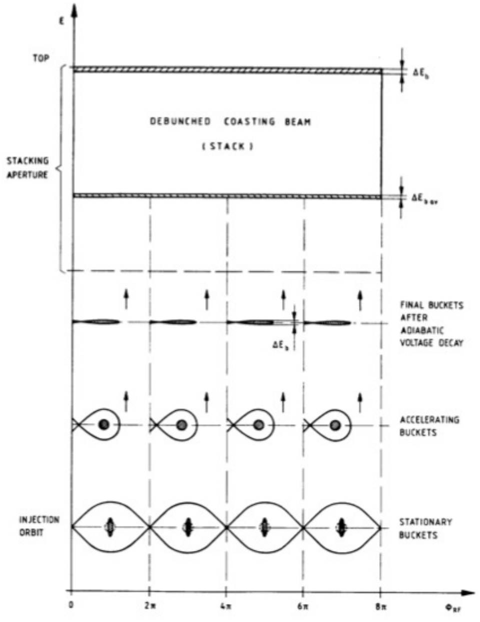


Fig. 3.1 Representation of stacking in phase space

Why stack?
- To increase the circulating current (e.g. ISR).
- To circumvent the intensity limit coming from space charge at injection (~$\beta\gamma^2$).
- To change the extraction rep rate without changing the machine rep rate (ISIS2 FFA option).

E. Ciapala, CAS pp195-225 (1984) DOI: 10.5170/CERN-1985-019-V-1.195

Intersecting Storage Rings (ISR)

- Hundreds of bunches stacked to reach sufficient luminosity (up to 57A circulating current!).
- Phase displacement acceleration used to increase momentum of stack from 26.6 GeV/c to 31.4 GeV/c.
- Large momentum spread of stack resulted in a “working line” instead of working point (non-zero chromaticity).

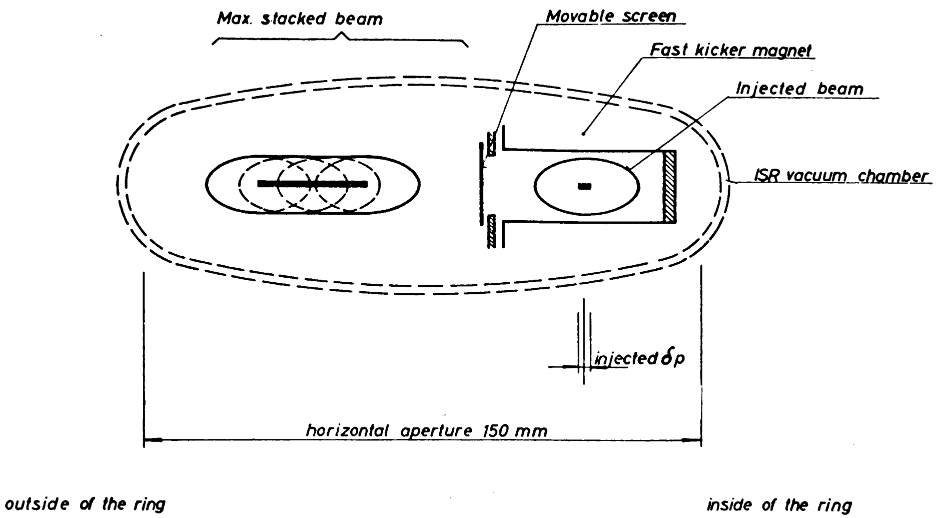


FIG. 2. Cross-section of the vacuum chamber at the position of the beam inflector, with indication of the stacking process.

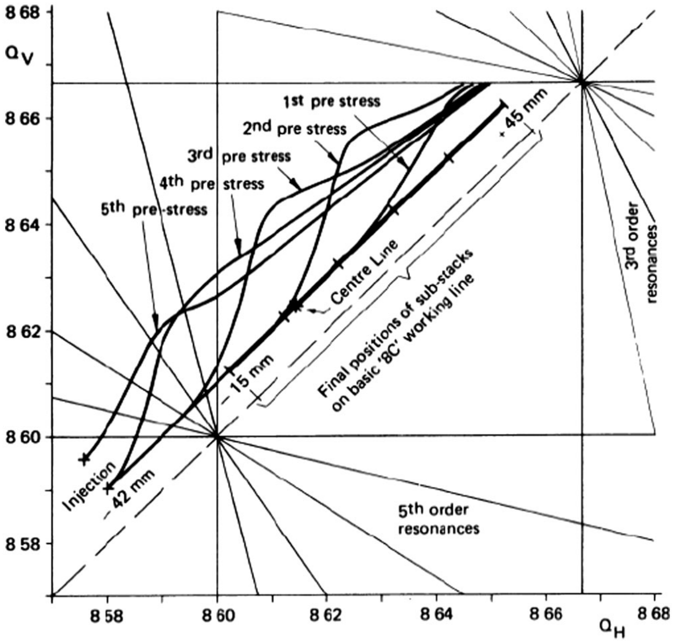


FIG. 8. Working line and space charge compensation.

Effect of RF on the stacked beam

- **Phase displacement** – Following Liouville, an accelerating bucket (with area A) will cause a downward shift of the average energy of the coasting beam once it passes through.

$$\langle \Delta E \rangle = \frac{A}{T_{stack}}$$

- **Scattering** – The energy spread of the coasting beam is increased by the moving bucket passage. This tends to increase with Γ=sin ϕ_s. Defining

$$\delta p_{\rm rms} = \sqrt{\sigma_f^2 - \sigma_{in}^2}$$

where σ_{in}, σ_f are the rms momentum spreads before and after bucket passage, Messerschmid numerically found the following approximate relation holds for Γ<~0.8.

$$\delta p_{\rm rms} \approx \Gamma \Delta p_s$$

where Δp_s is the bucket height of the equivalent stationary bucket.

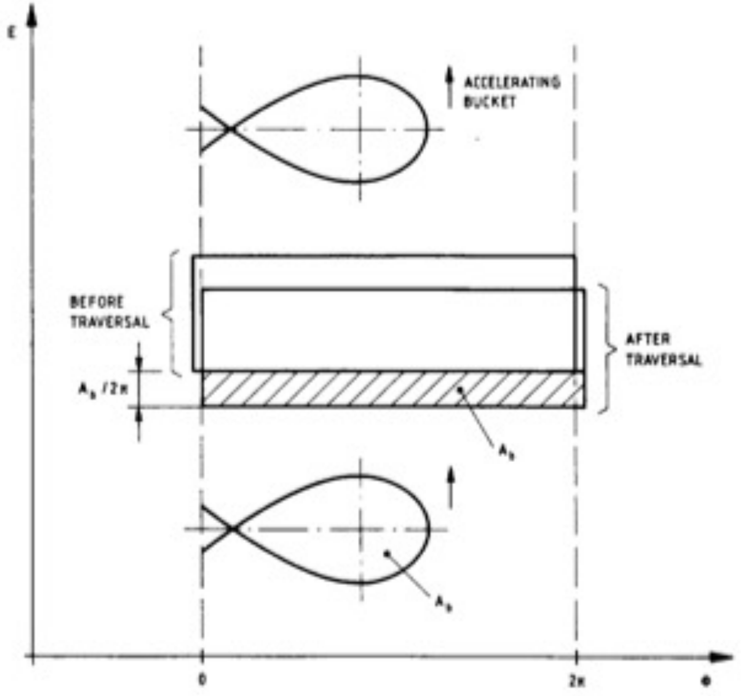
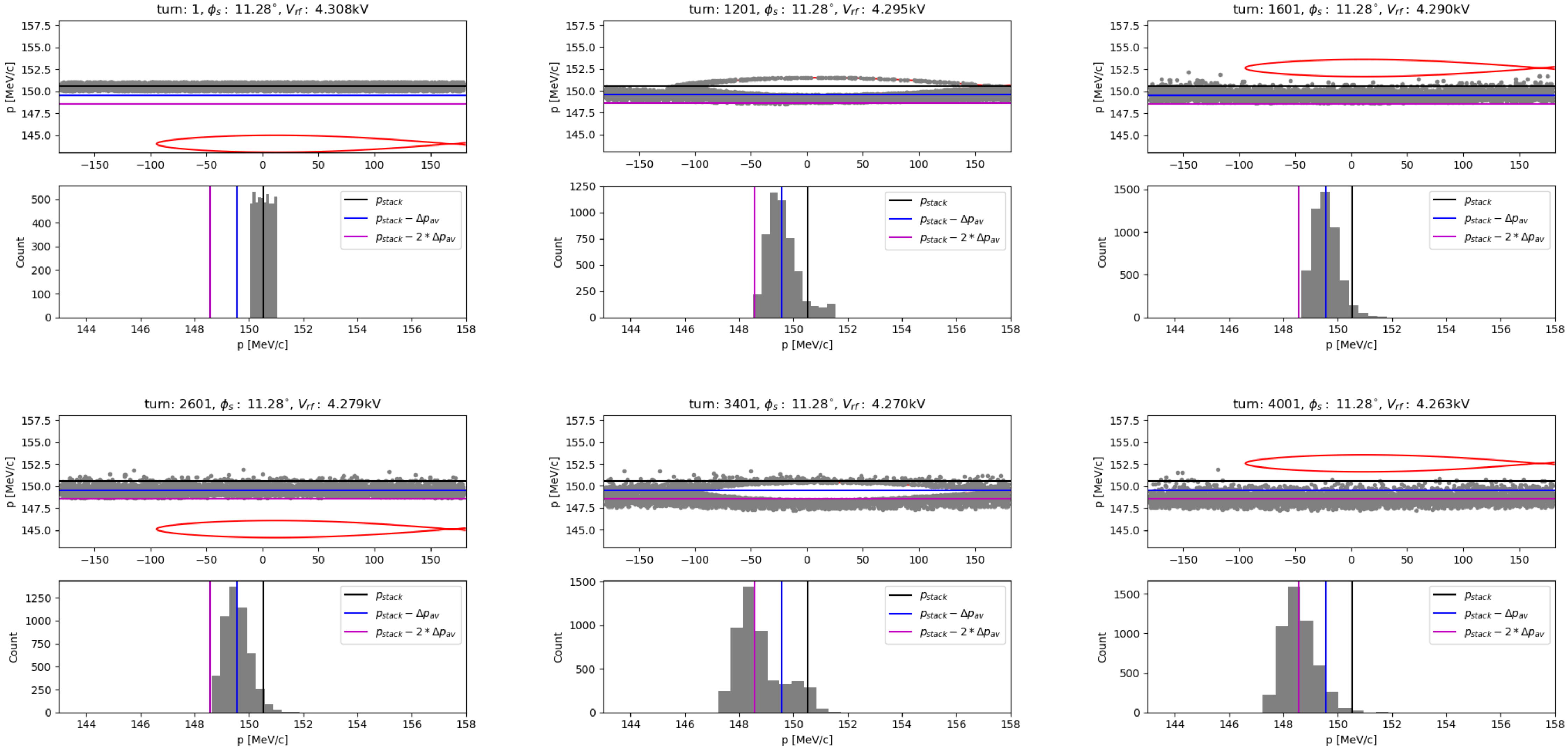


Fig. 2.5 Phase displacement

Messerschimid, CERN-ISR-RF/72-28 (1972)

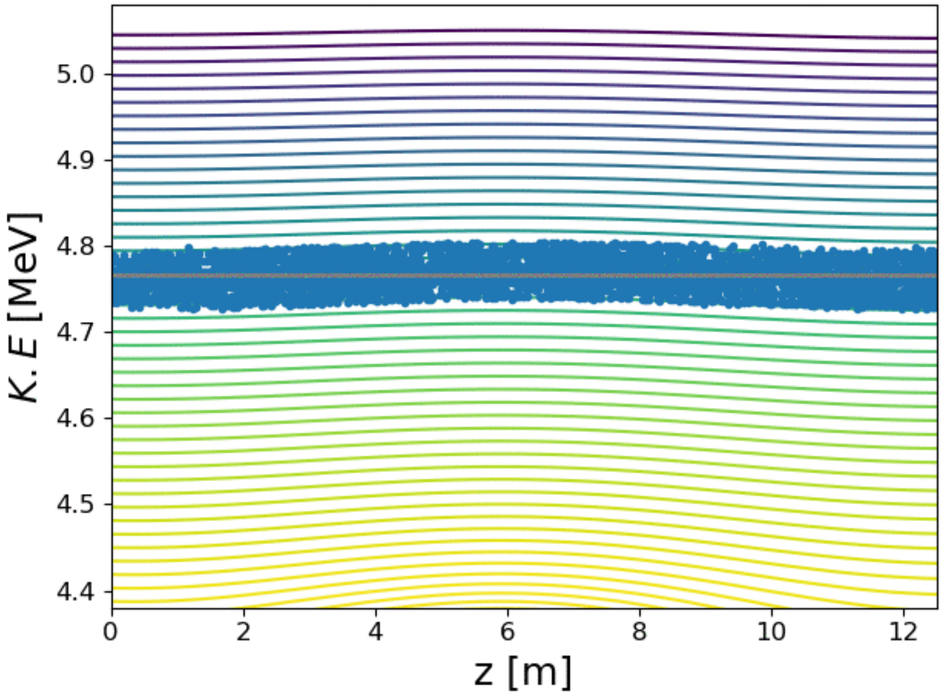
Phase displacement



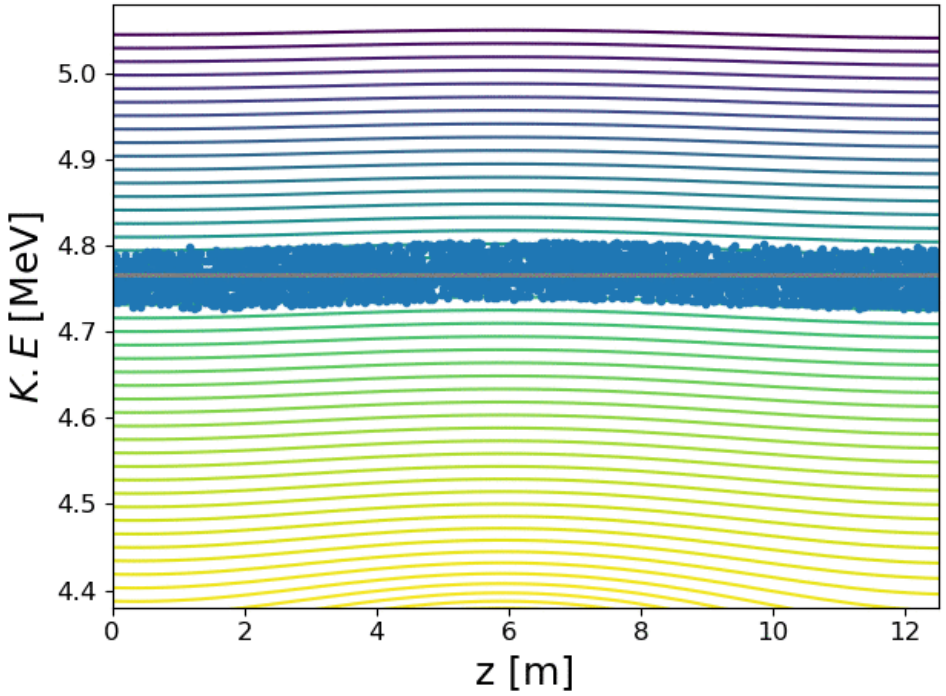
1st crossing

2nd crossing

Empty bucket traversal



Φ_s=5°



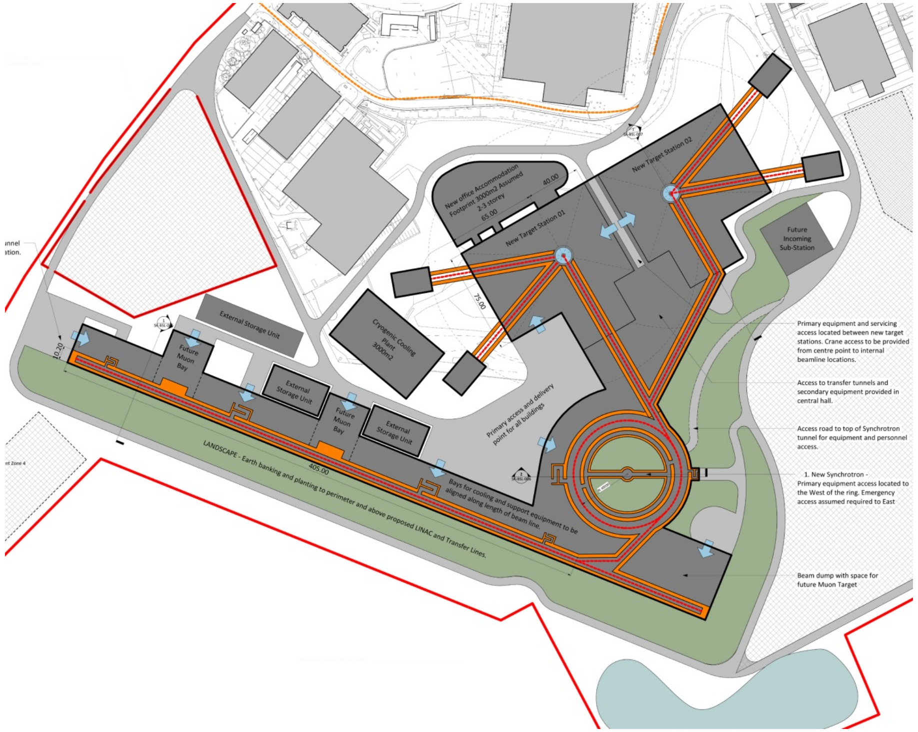
Φ_s=10°

Adjust voltage so that the bucket area A is the the same in both cases.

Distance between horizontal lines is $\langle \Delta E \rangle = \dfrac{A}{T_{stack}}$

ISIS-II requirements

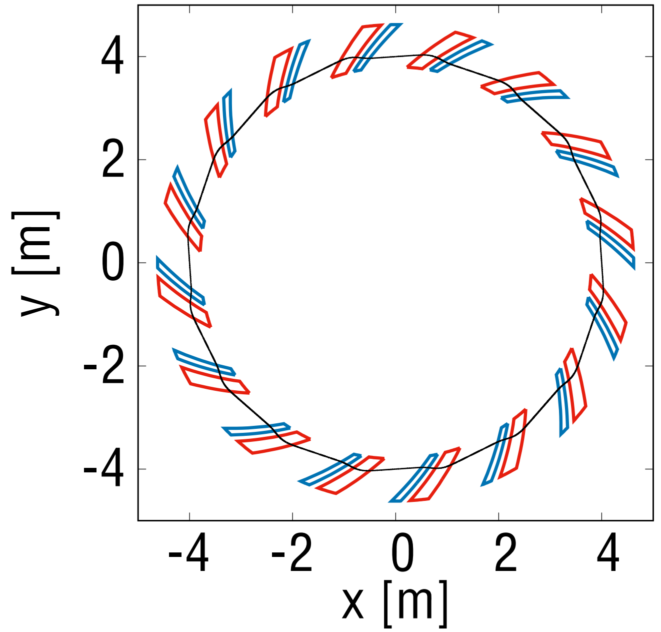
- Beam power 1.25-2.5 MW, beam energy 1.2 GeV.
- RCS, Accumulator Ring and FFA options being studied in parallel.
- Beam stacking would allow flexibility to choose between operation at high peak current with low repetition rate or at low peak current with high repetition.
- For example, with the ring operating at 100Hz, stacking 4 beams would deliver 25 Hz at high current to the target.



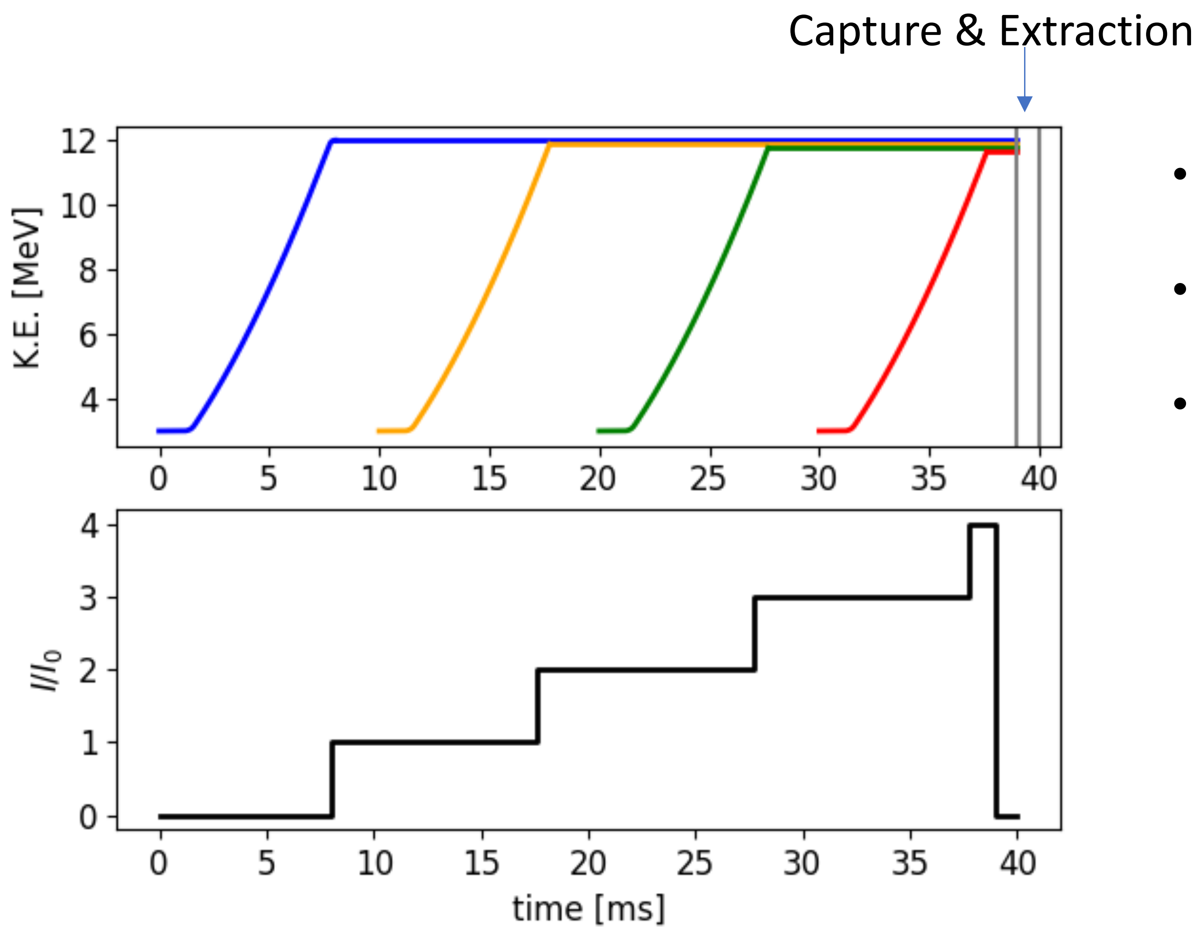
FETS-FFA

- Since high intensity operation of FFA is unproven, a prototype ring, the 3-12MeV FETS-FFA, will be built.
- A FD-Spiral hFFA lattice is chosen both for ISIS-II and the prototype ring.
- Ferrite and MA-based cavities under development.

Parameter	Value
Cavity for Acceleration	
RF frequency range (h=2, broadband)	1.8 – 3.42 MHz
RF peak voltage	6 kV
Cavity for Stacking	
RF frequency range (h=1, fixed)	1.7 MHz (extraction frequency)
RF peak voltage	20 kV (stack 4 beams)

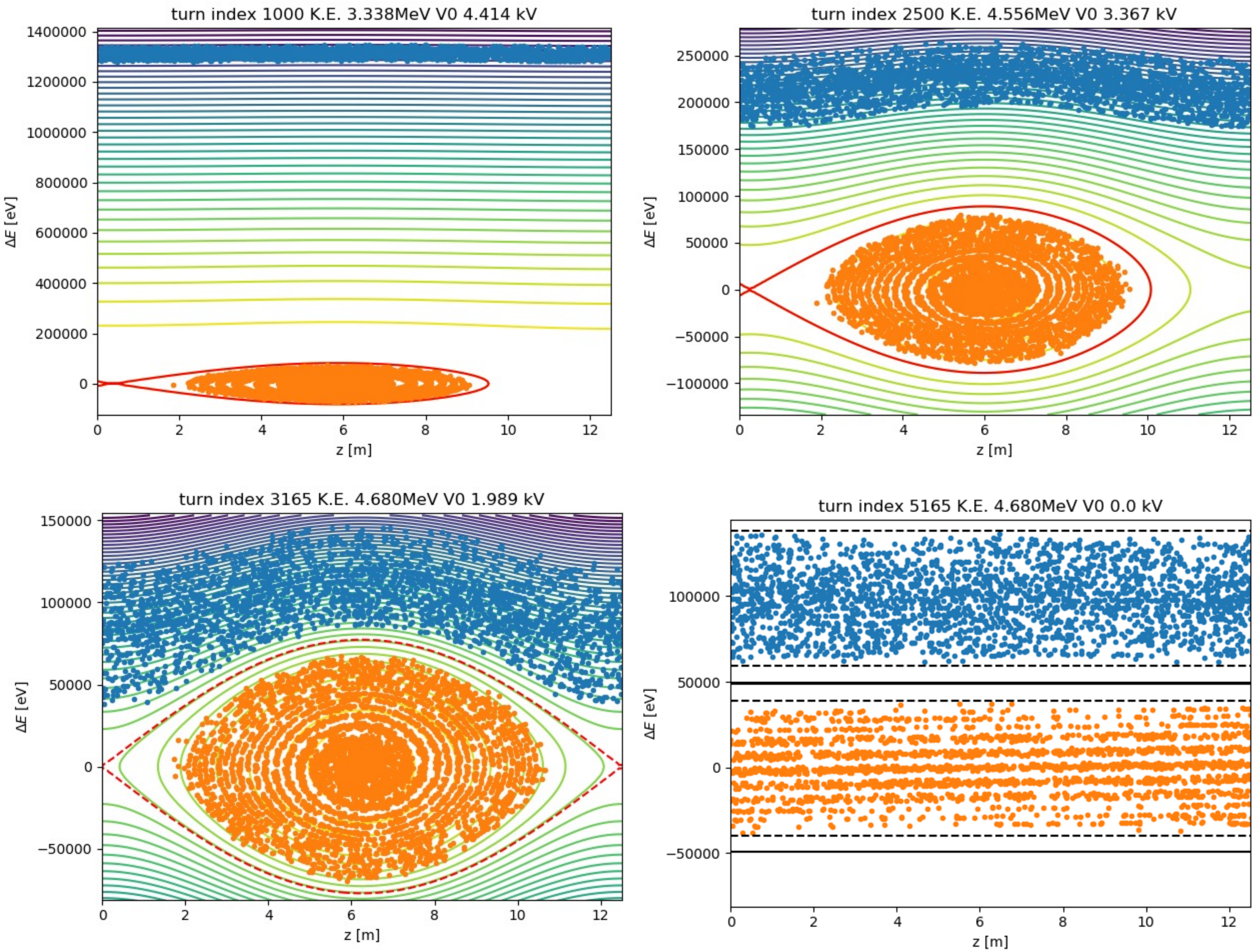


Beam Stacking – FETS-FFA case



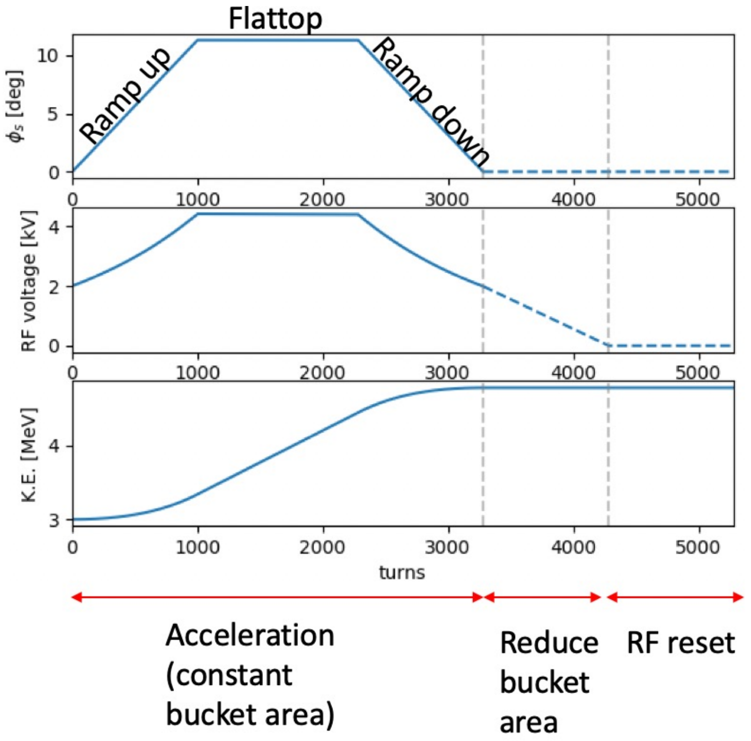
- Stack N beams to reduce the repetition rate seen by target by a factor N.
- Stack successive beams at slightly lower energies to avoid phase displacement.
- Capture to ensure enough beam-free time for the extraction kicker rise time.

Stacking process

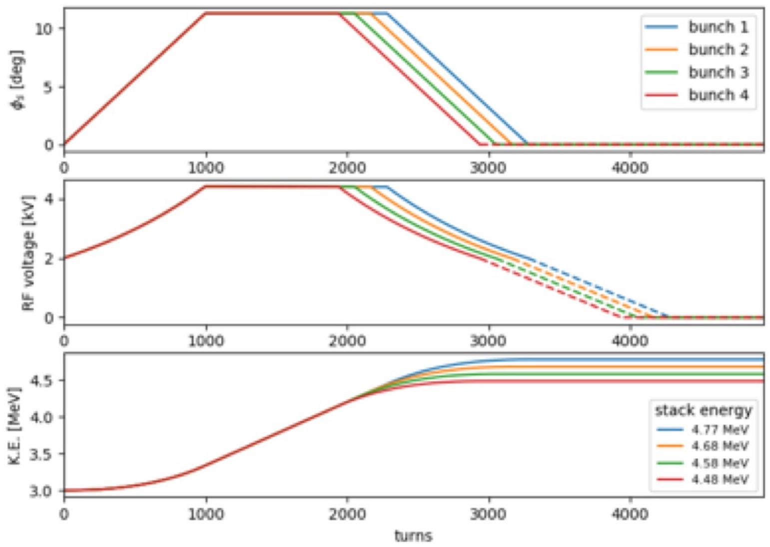


- Assume a beam has already been stacked and is coasting (blue).
- Inject a second bunch (orange) and accelerate to just below the coasting beam.
- Ensure ϕ_s is zero at final energy.
- Debunch adiabatically.

RF Program

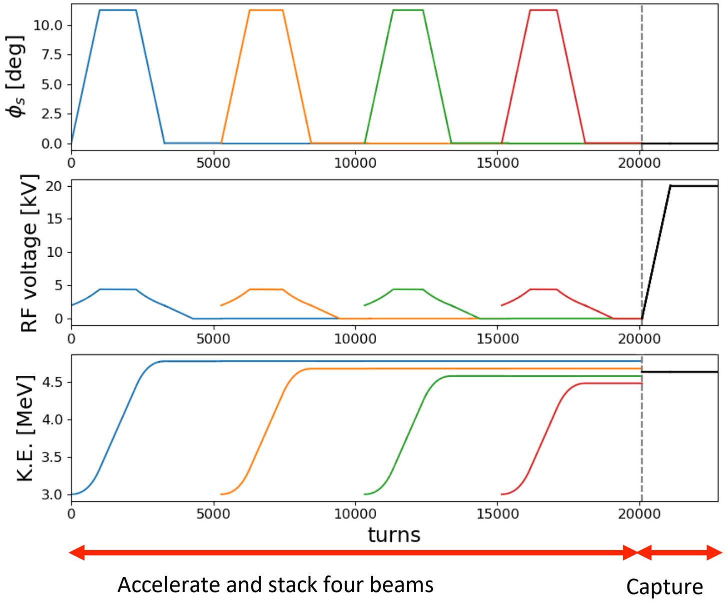


Stacking a single beam



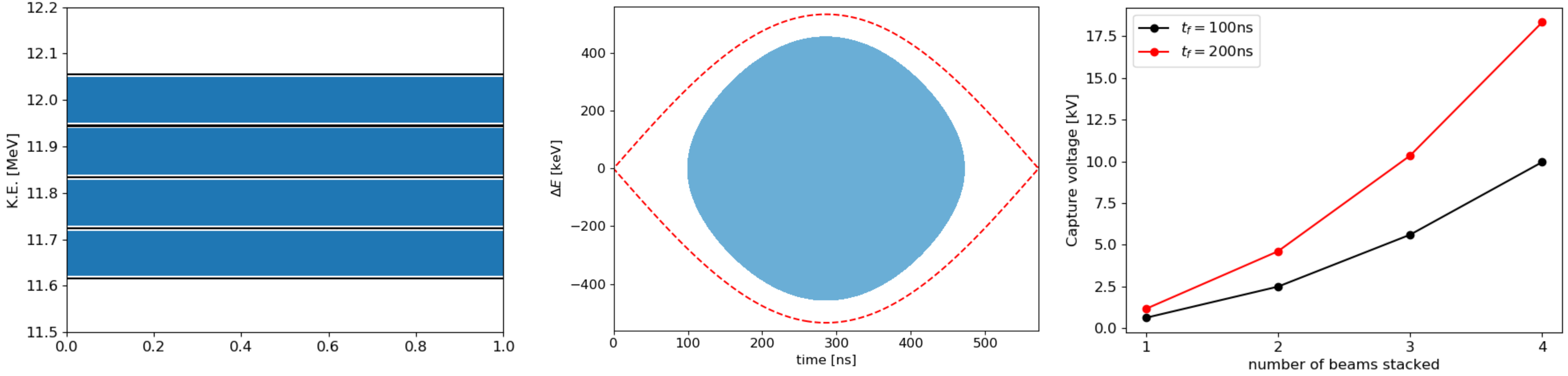
- Stack at the bottom by adjusting number of turns in flattop.
- This ensures the final energy of each consecutive is reduced by the phase displacement shift.

Stacking multiple beams (overlaid)



Stacking multiple beams (sequential)

Capture requirements for FETS-FFA



- Left: Ideal stack of four beams assuming 90% bucket fill and emittance 0.062 Vs.
- Centre: Hamiltonian contour than captures the same emittance. The bunched beam after capture has a momentum spread dp/p = +/- 0.02.
- Right: Capture voltage assumes a beam free time of 100ns or 200ns is required. This is to accommodate the extraction kicker rise time.

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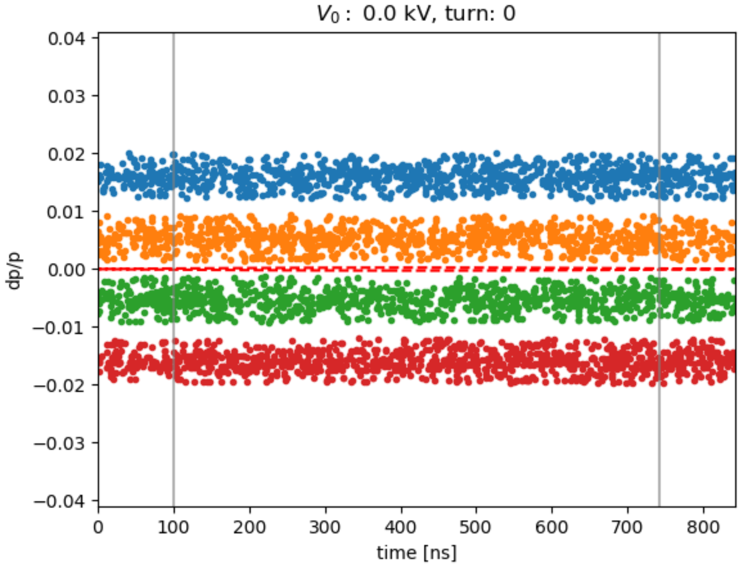
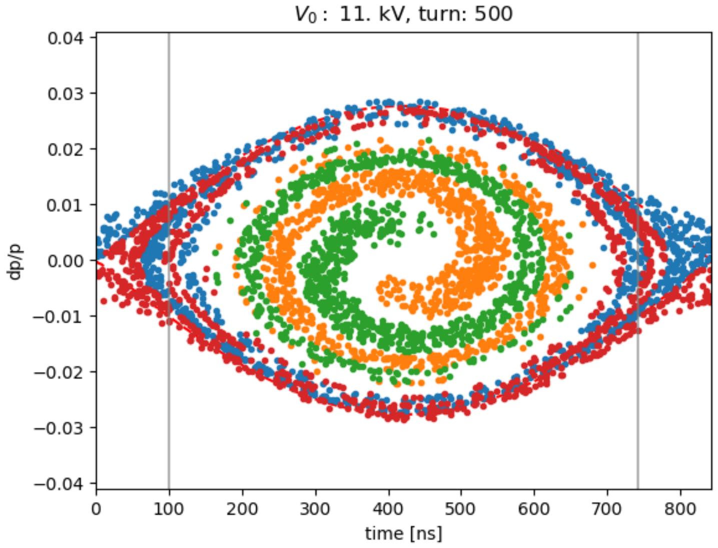
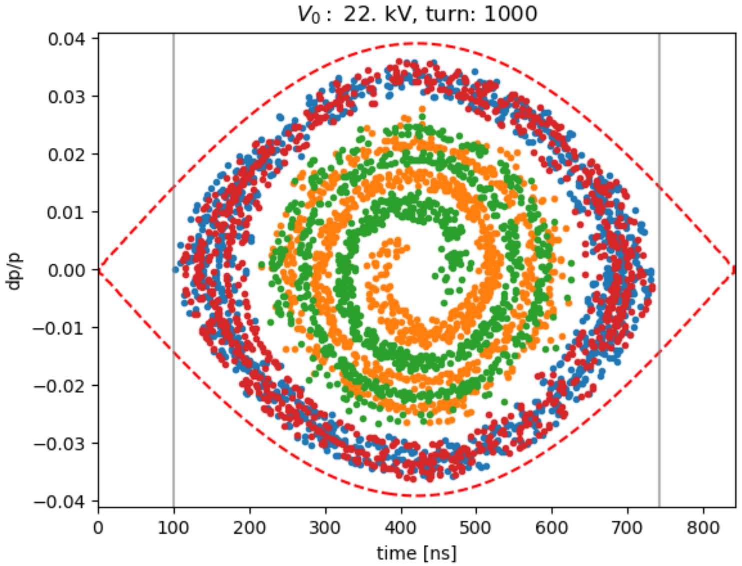
Tracking results







- Track capture process in PyHEADTAIL.
- Capture the beam by linearly increasing the RF voltage from zero to 22kV in 1000 turns.
- 200ns beam free time created for extraction kicker.