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Beam Stacking in a Vertical FFA

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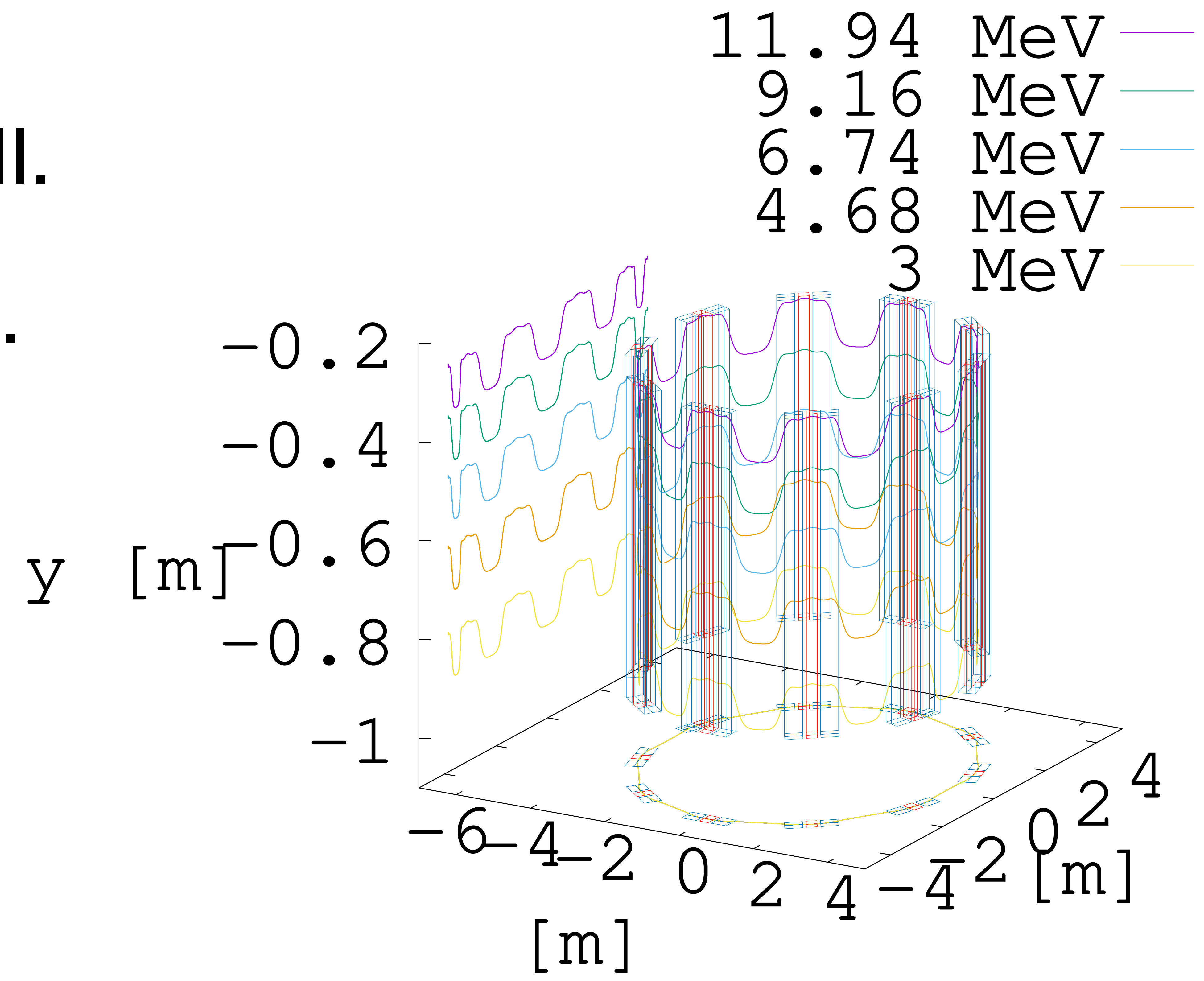
FFA'20 Workshop, TRIUMF (Nov 30th - Dec 4th, 2020)

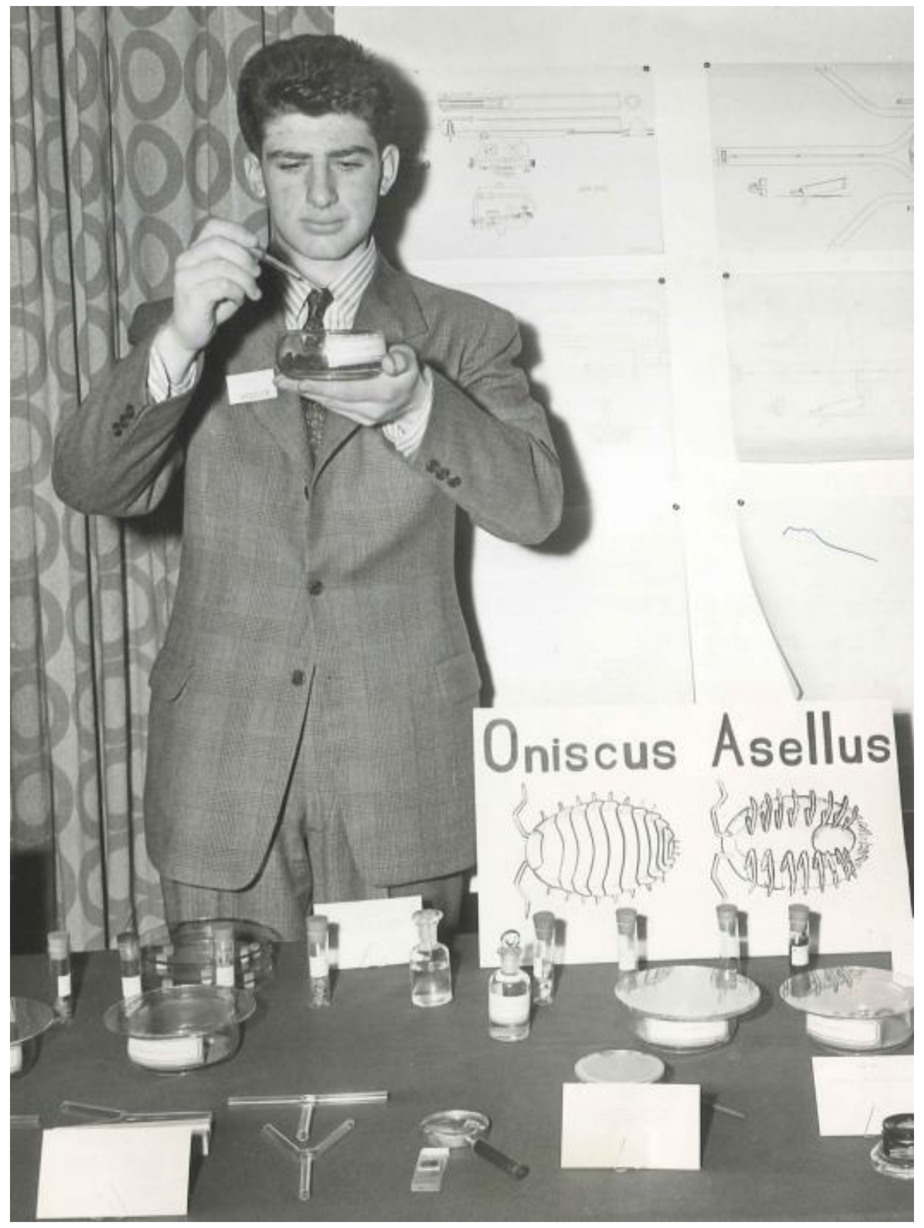
Introduction

- The FETS-FFA is a prototype ring for ISIS-II.
- Demonstrating beam stacking is a key aim.
  - Allows flexibility in the delivery of beam to target stations.
  - Allows lower repetition rates at high peak output.



Beam stacking

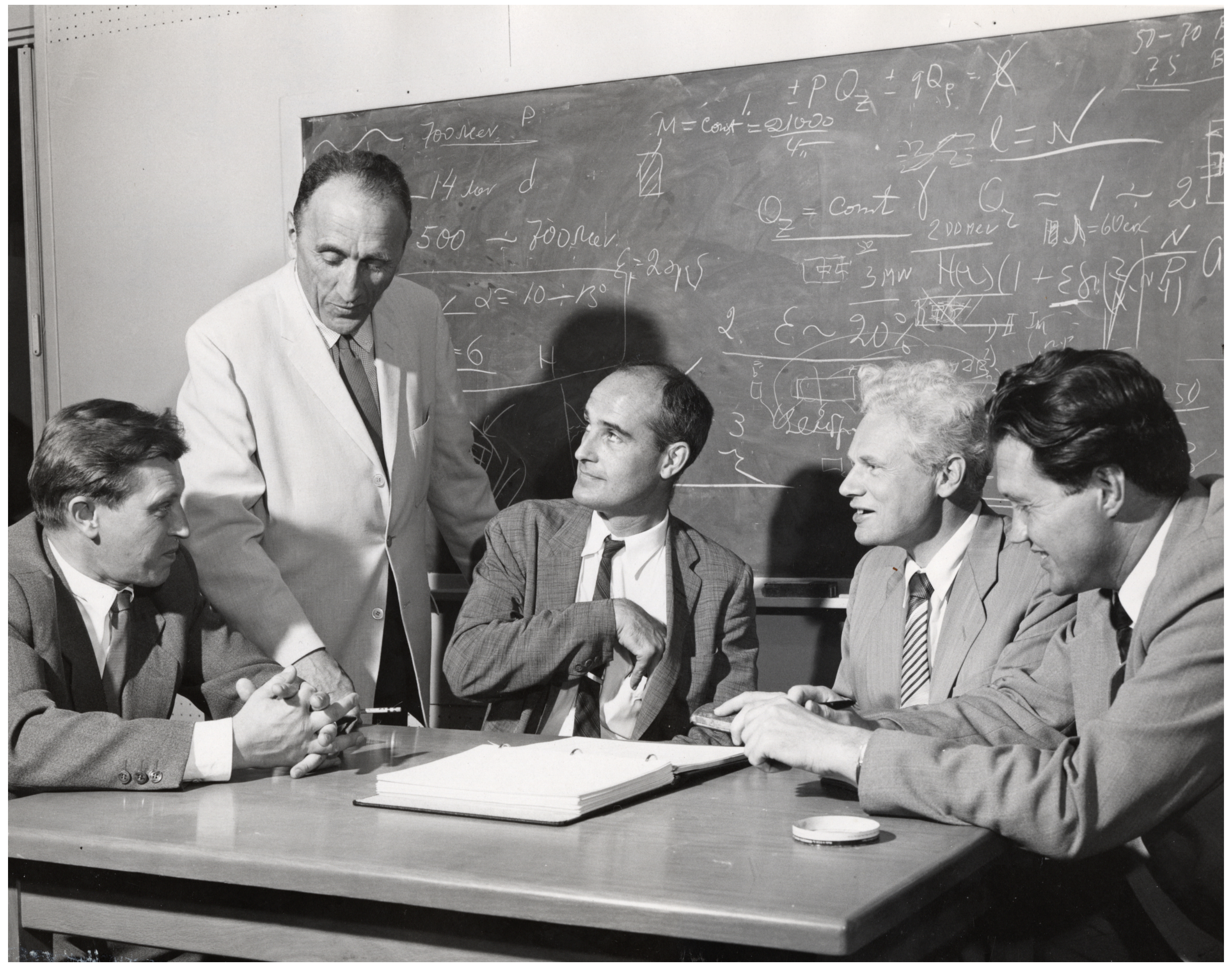
- Successive beam pulses are stored in the ring. Coasting beams are stacked in terms of energy (in a VFFA they are also stacked vertically!).
- What is the effect of the accelerating RF on the stacked beam? The topic was first addressed by K. Symon and A. Sessler.



Phase Displacement

Scattering

Subharmonic effects



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Effect of RF on the stacked beam

Phase Displacement

- Accelerating bucket will cause a downward shift in the energy of the coasting beam it moves through (a consequence of Liouville theorem)^.

$$\left\langle E_{shift} \right\rangle = \frac{\omega_0 A}{2\pi}$$

Scattering

- The energy spread of the beam is increased by a bucket passing through. The effect is proportional to $\Gamma = \sin\phi_s$.

$$\sigma = \frac{16}{(2\pi)^{3/2}}\Gamma(\phi_s)\sqrt{\frac{eVE}{h|\eta|}}$$

Subharmonics

- If $f_{stack}/f_{rf} = m/n$ then the RF may affect the stacked beam. In the case of "bucket lift" some of the stacked beam is trapped and accelerated in a subharmonic bucket.

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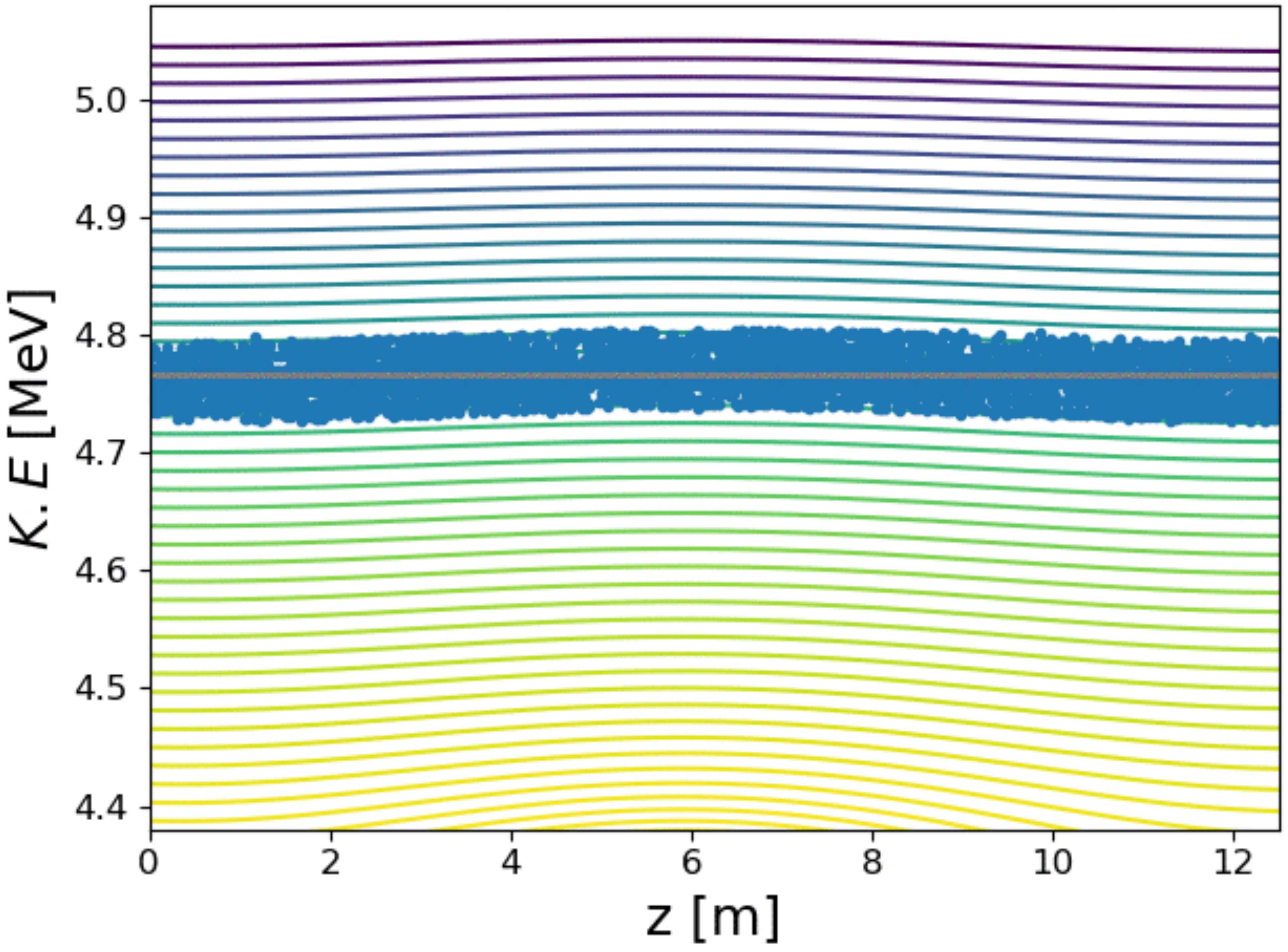
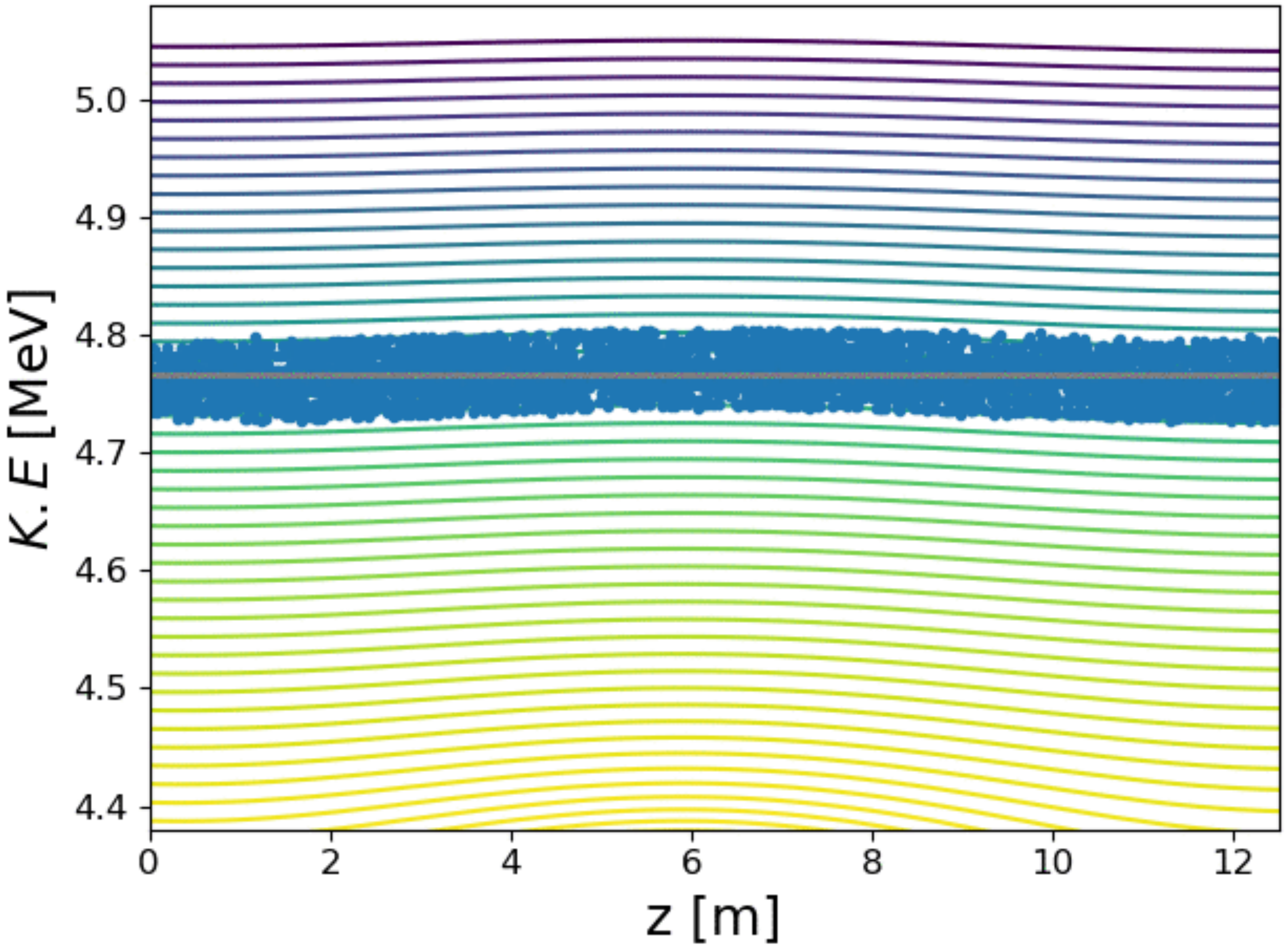
^K. R. Symon and A.M. Sessler, Proc. CERN Symposium on High-Energy Accelerators (Geneva) 1, p44 (1956), MURA Report 106 (1956)

Movies

Empty bucket passing through a coasting beam



$\phi_s = 5^\circ$



$\phi_s = 10^\circ$

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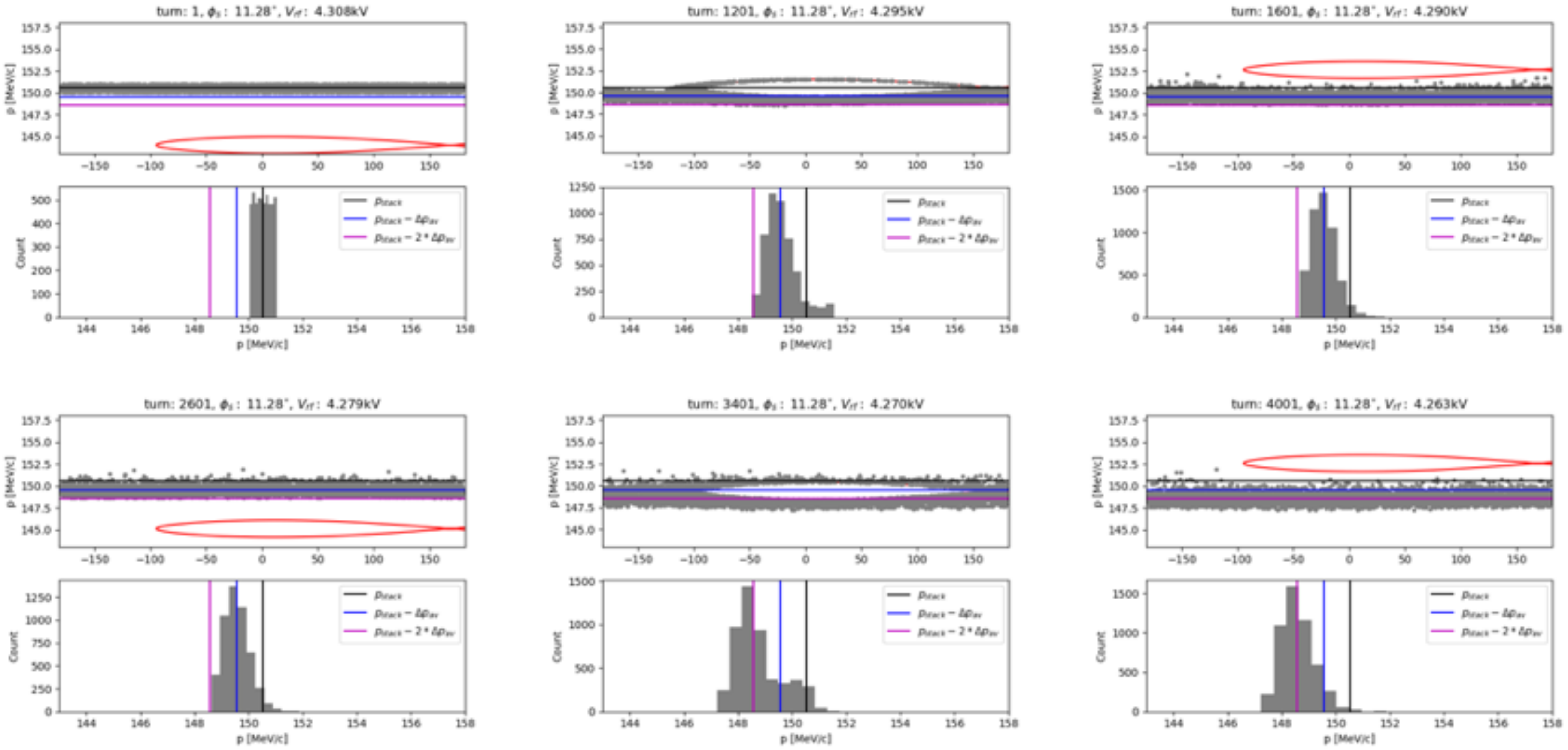
Multiple bucket passes

Empty buckets passing through coasting beam



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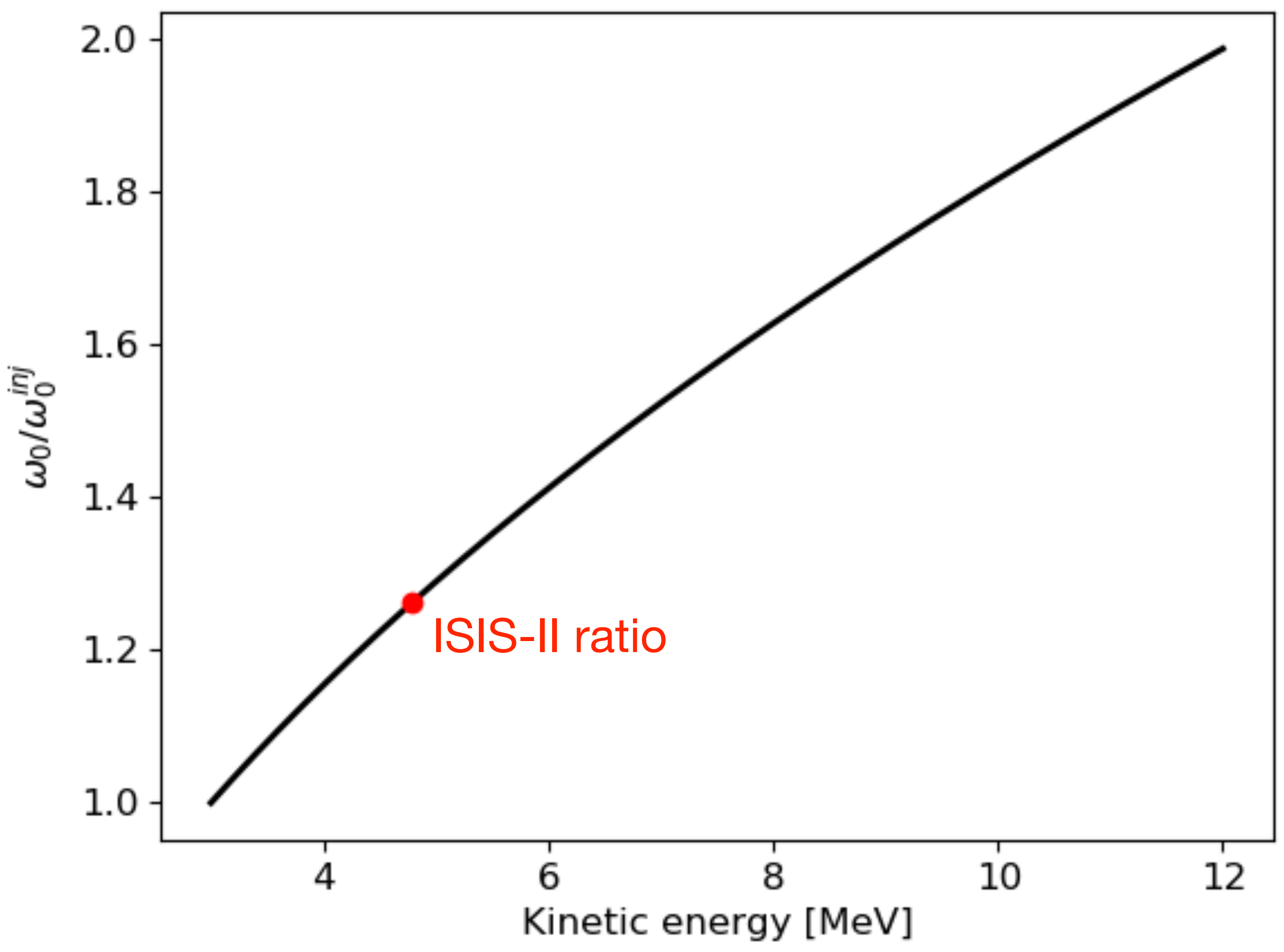
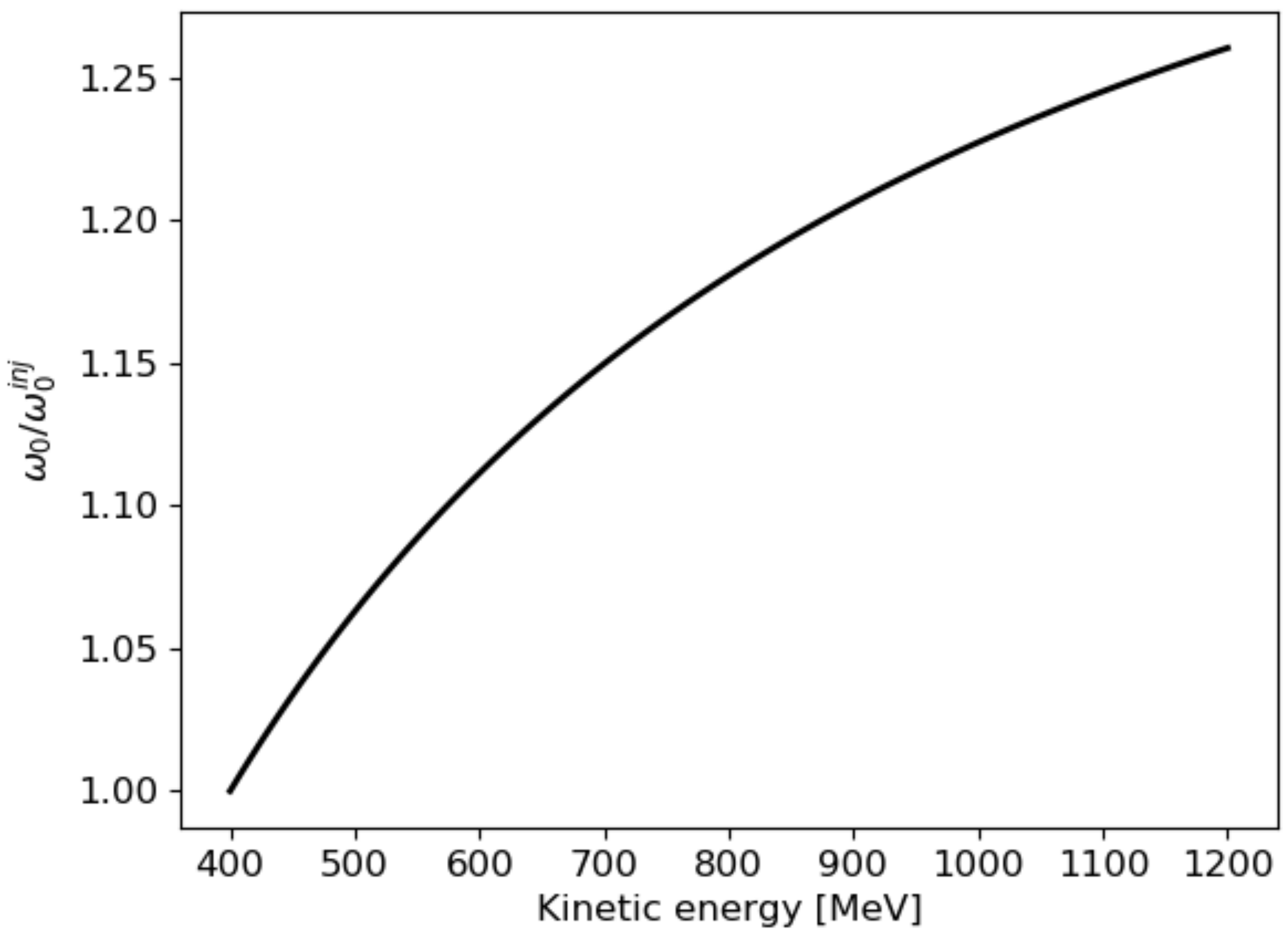
Stacking energy choice



FETS-FFA



ISIS-II

- Avoid the stacked beam seeing harmonics of the RF during acceleration.
- A natural choice is 4.8MeV where the frequency ratio corresponds to ISIS-II.

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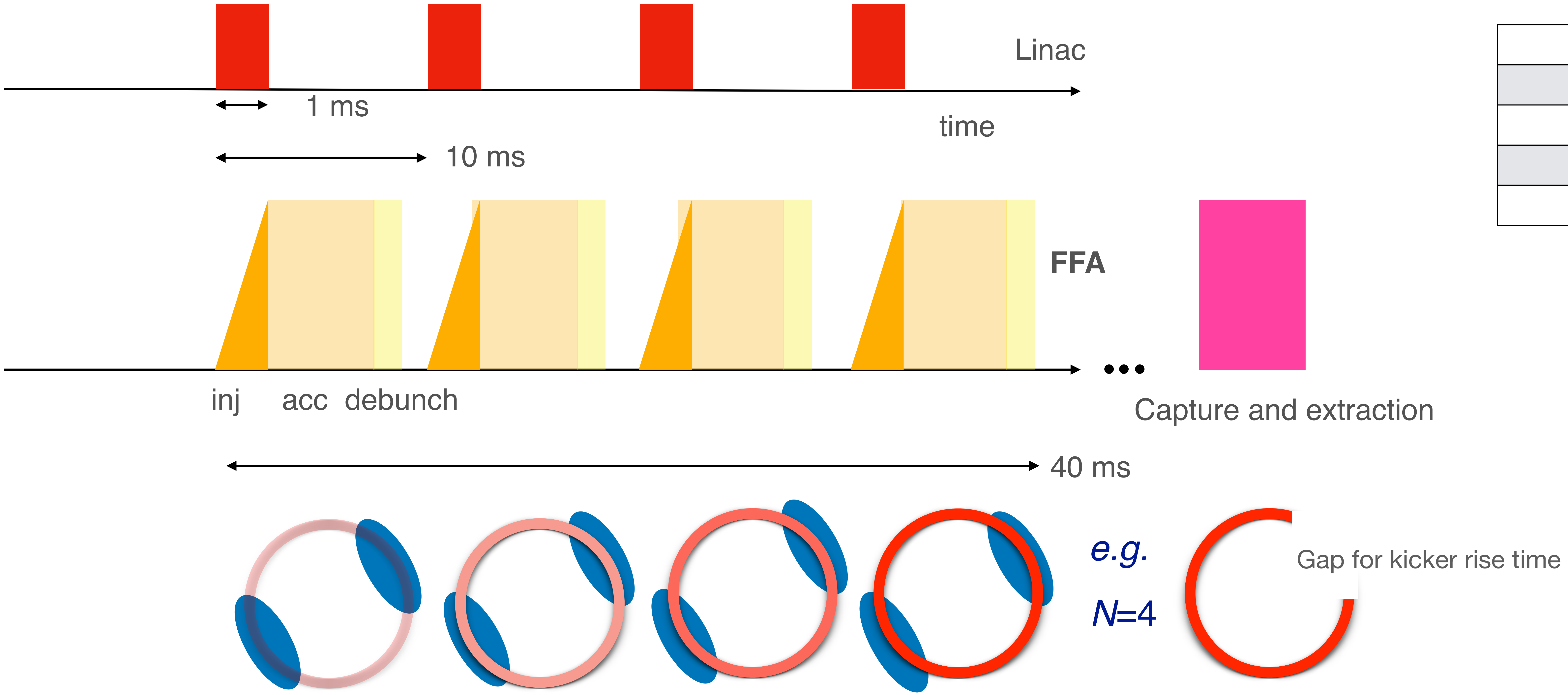
Beam Stacking Scheme



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

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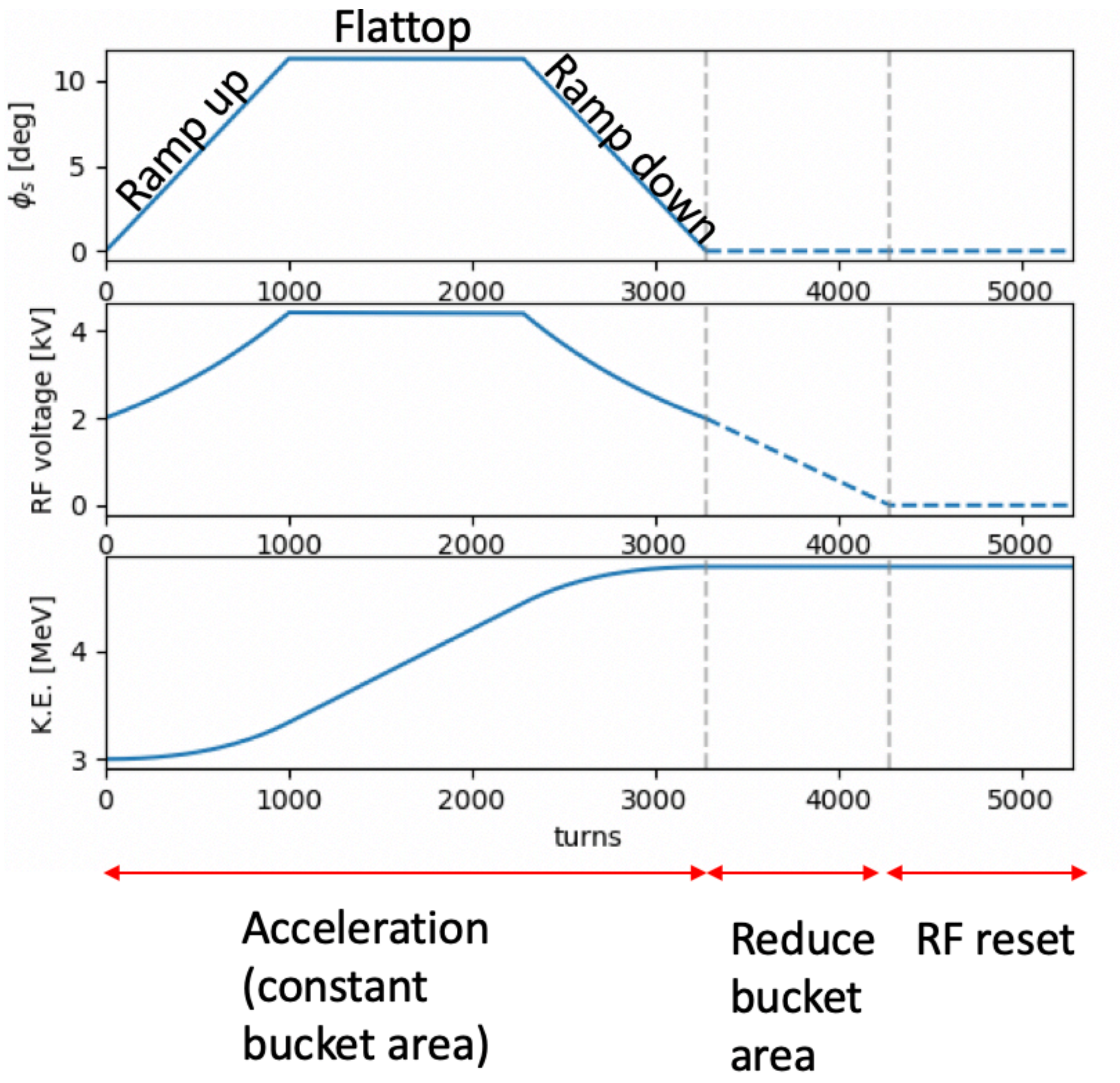
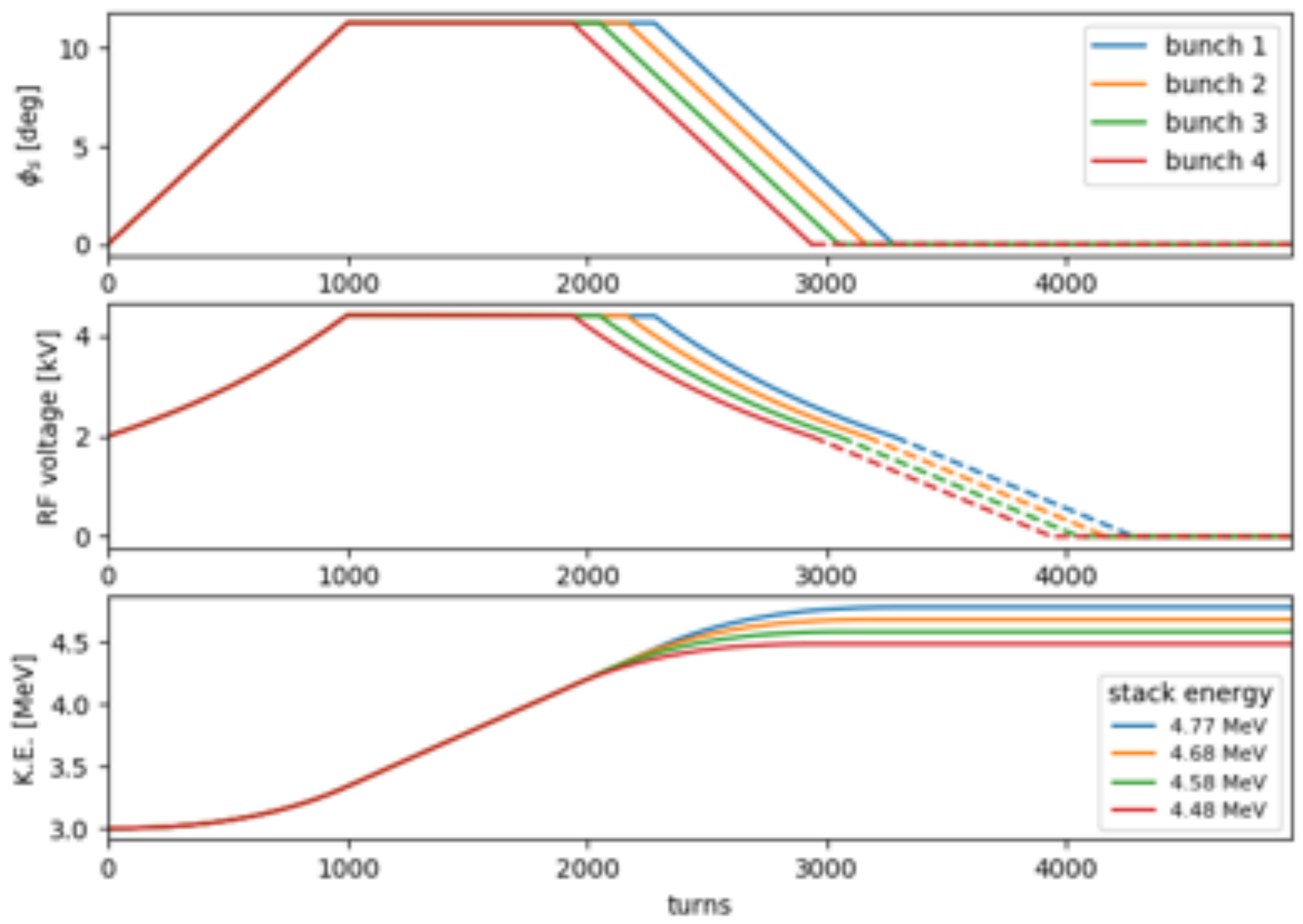
- Stack N beams to reduce the beam seen by users by a factor N.

FETS-FFA: Stacking at the bottom

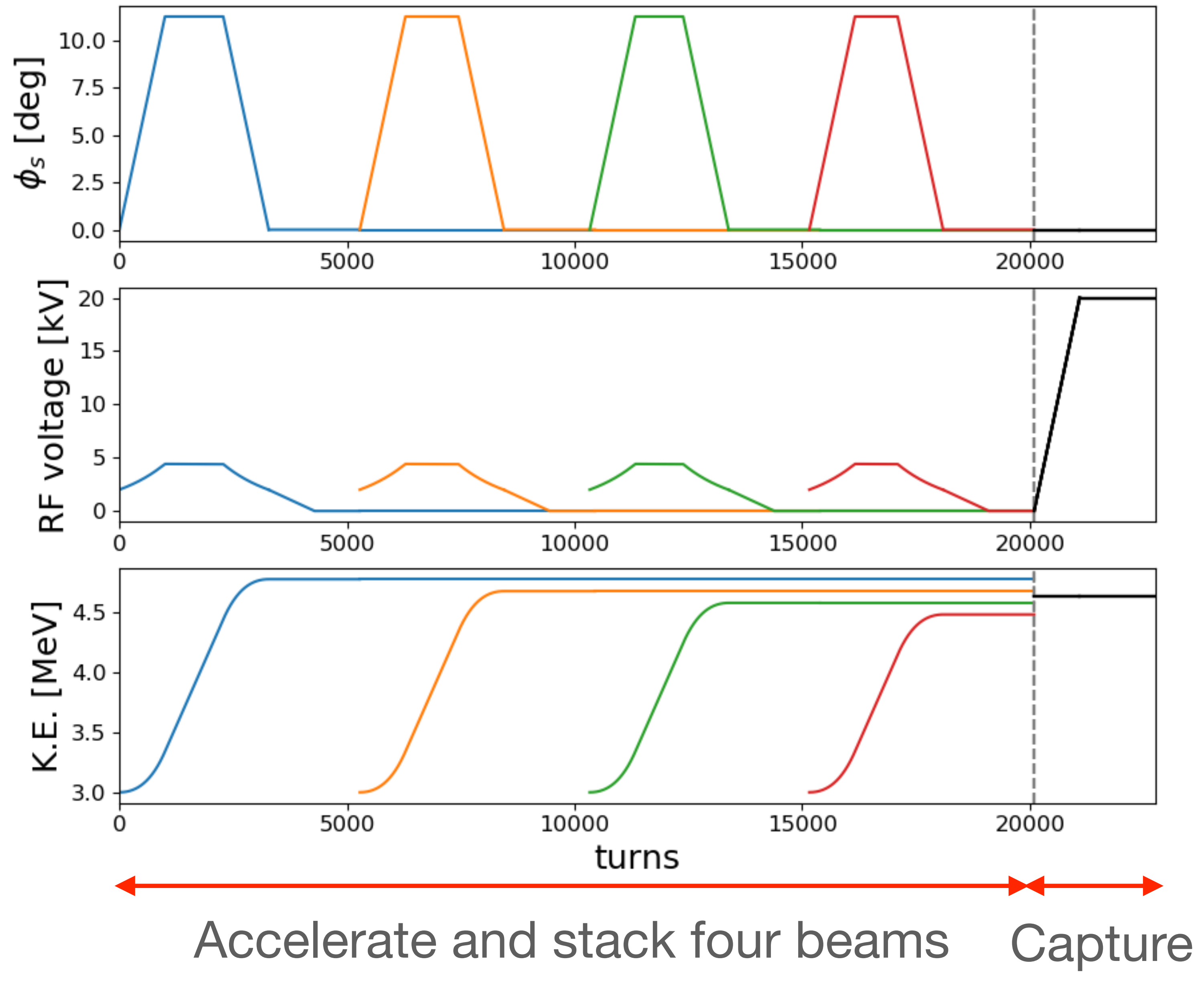


Stacking a single beam



- 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)

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FETS-FFA: Acceleration stage

Injection ($\phi_s = 0$) | End of ϕ_s flattop | ϕ_s ramped down to zero

- Bucket area and longitudinal emittance (75% of BA) remain constant.

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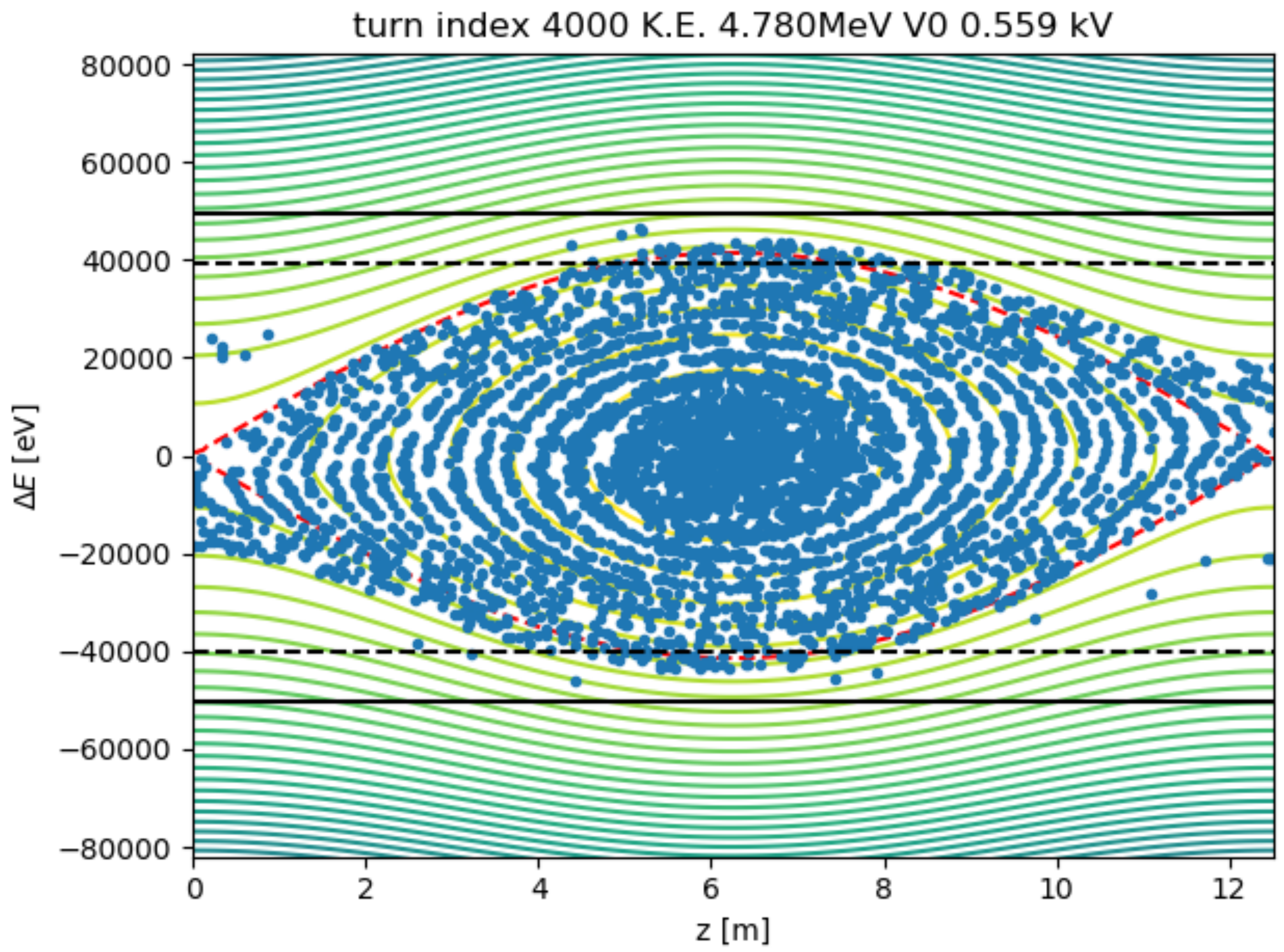
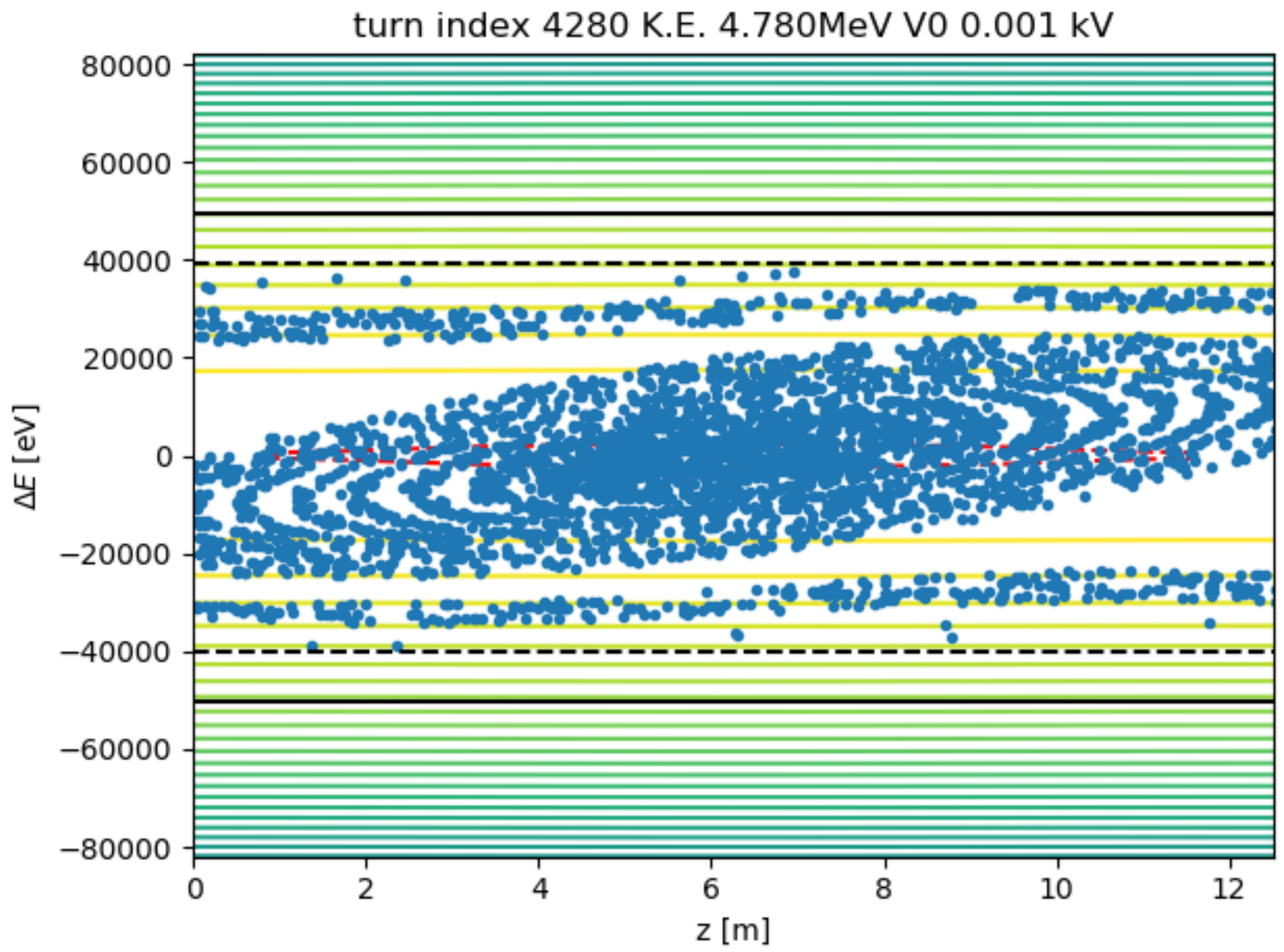
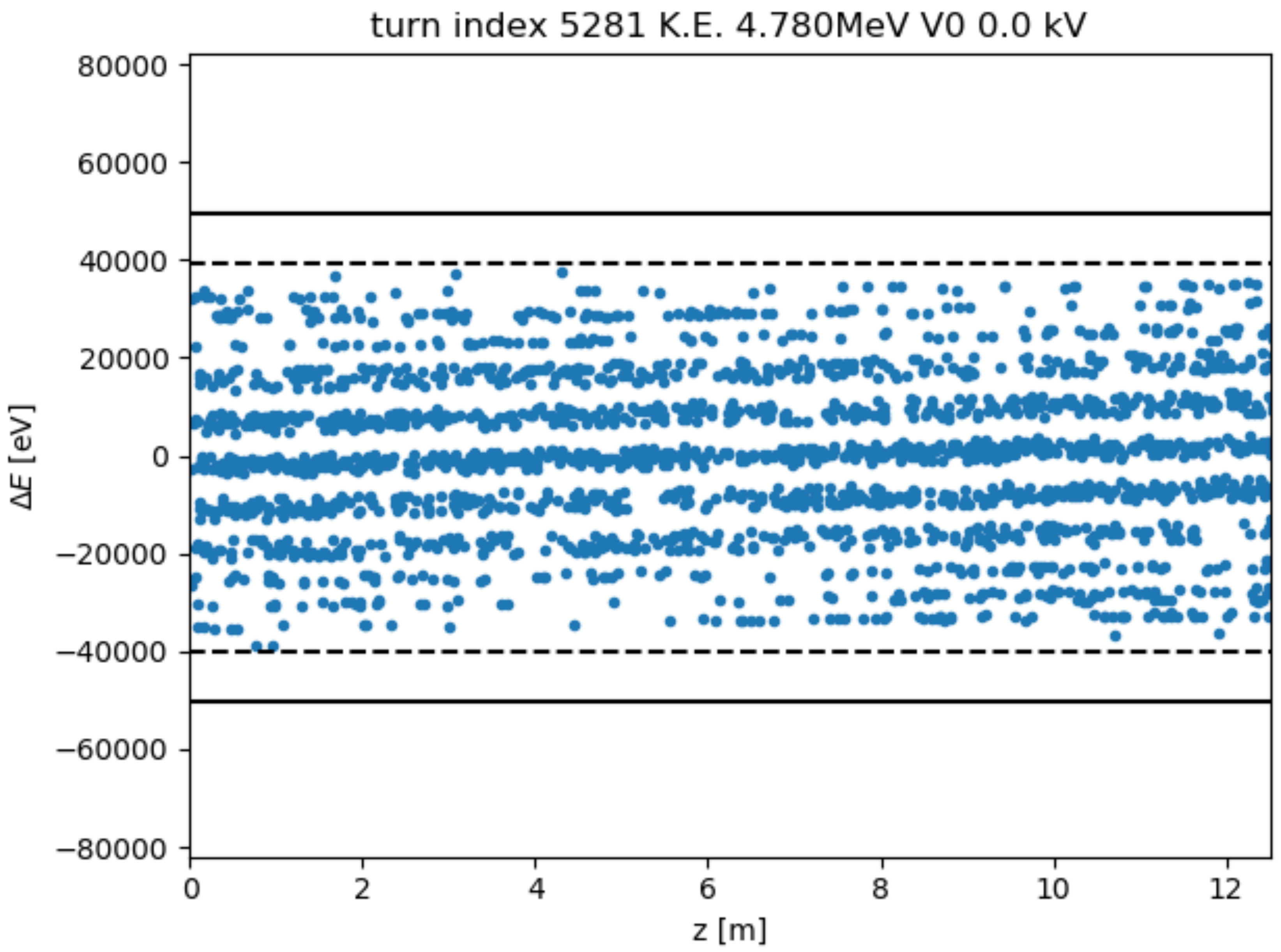
FETS-FFA: Adiabatic Debunching



RF Voltage reduced to 0.6kV



RF voltage reduced to zero



1000 turns later

- RF voltage linearly ramped to zero in 1000 turns. The emittance is preserved.

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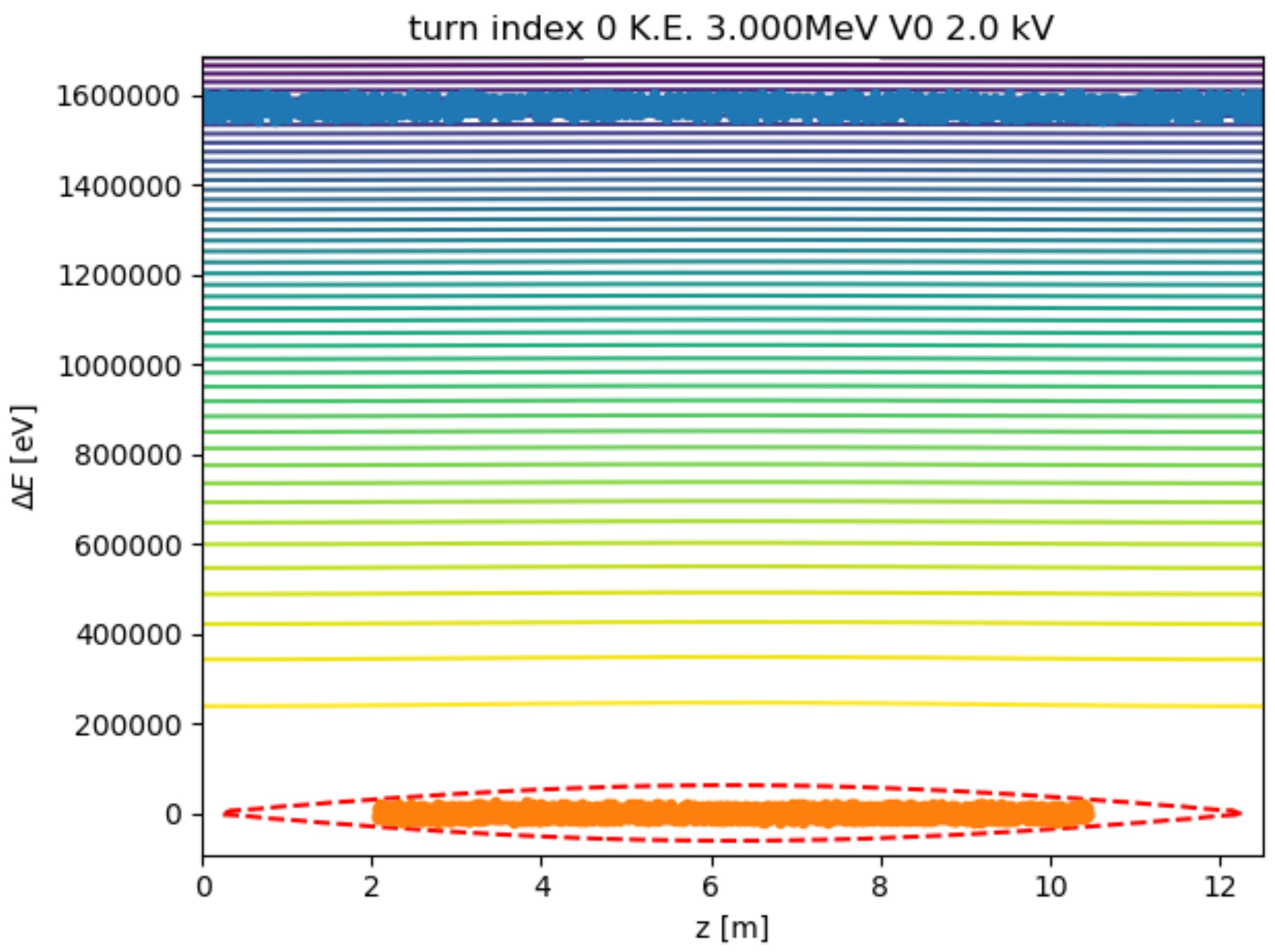
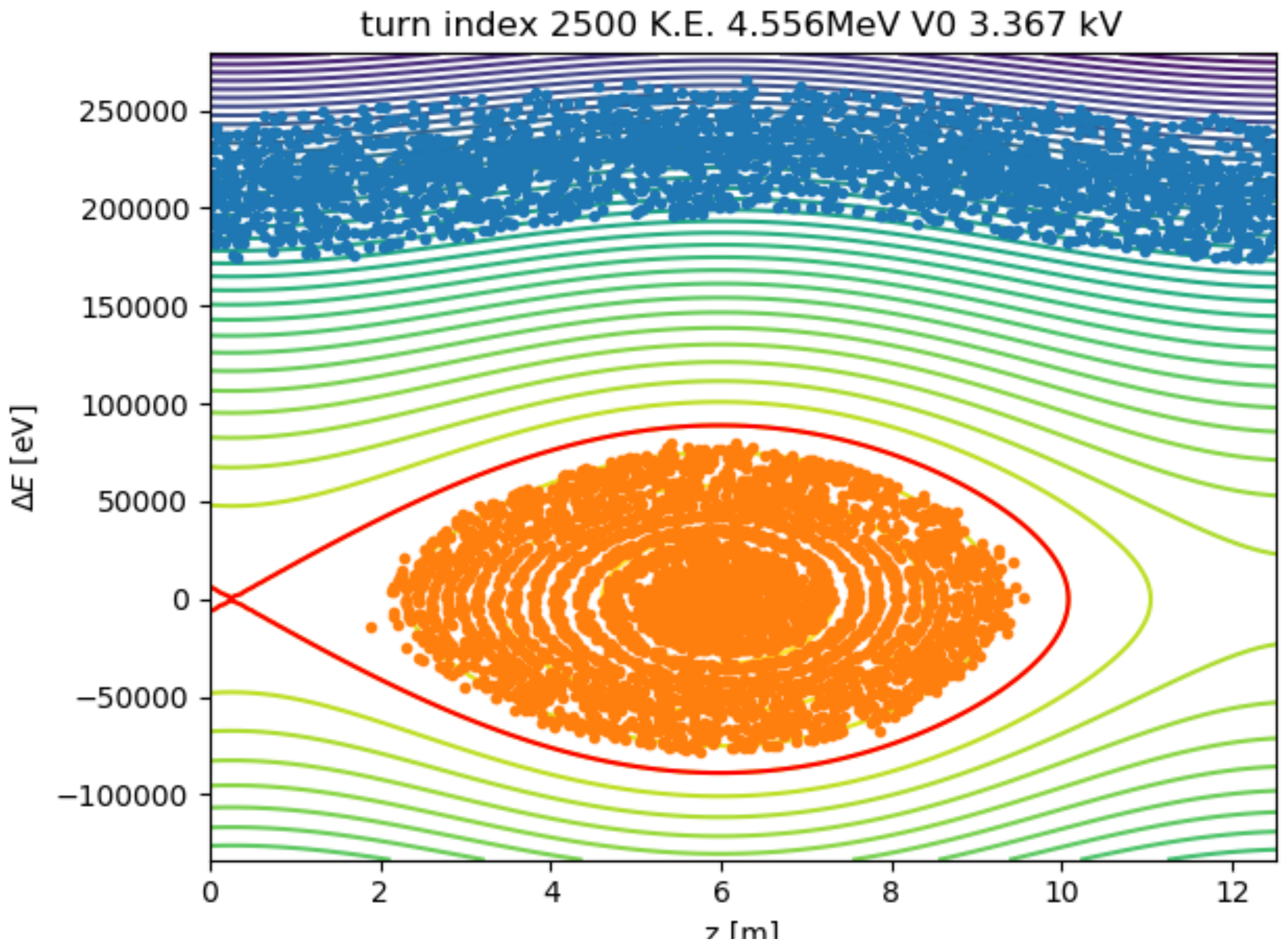
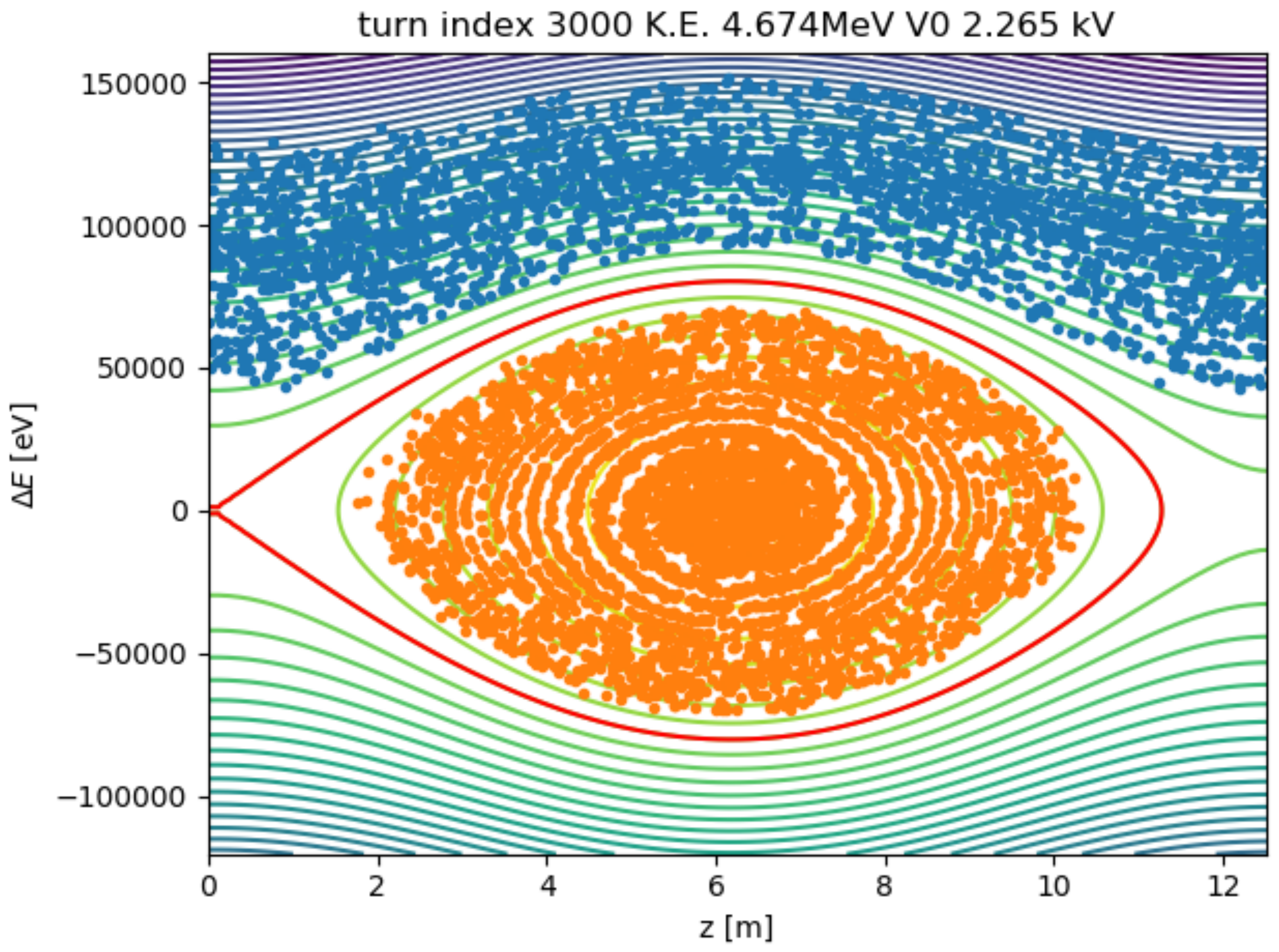
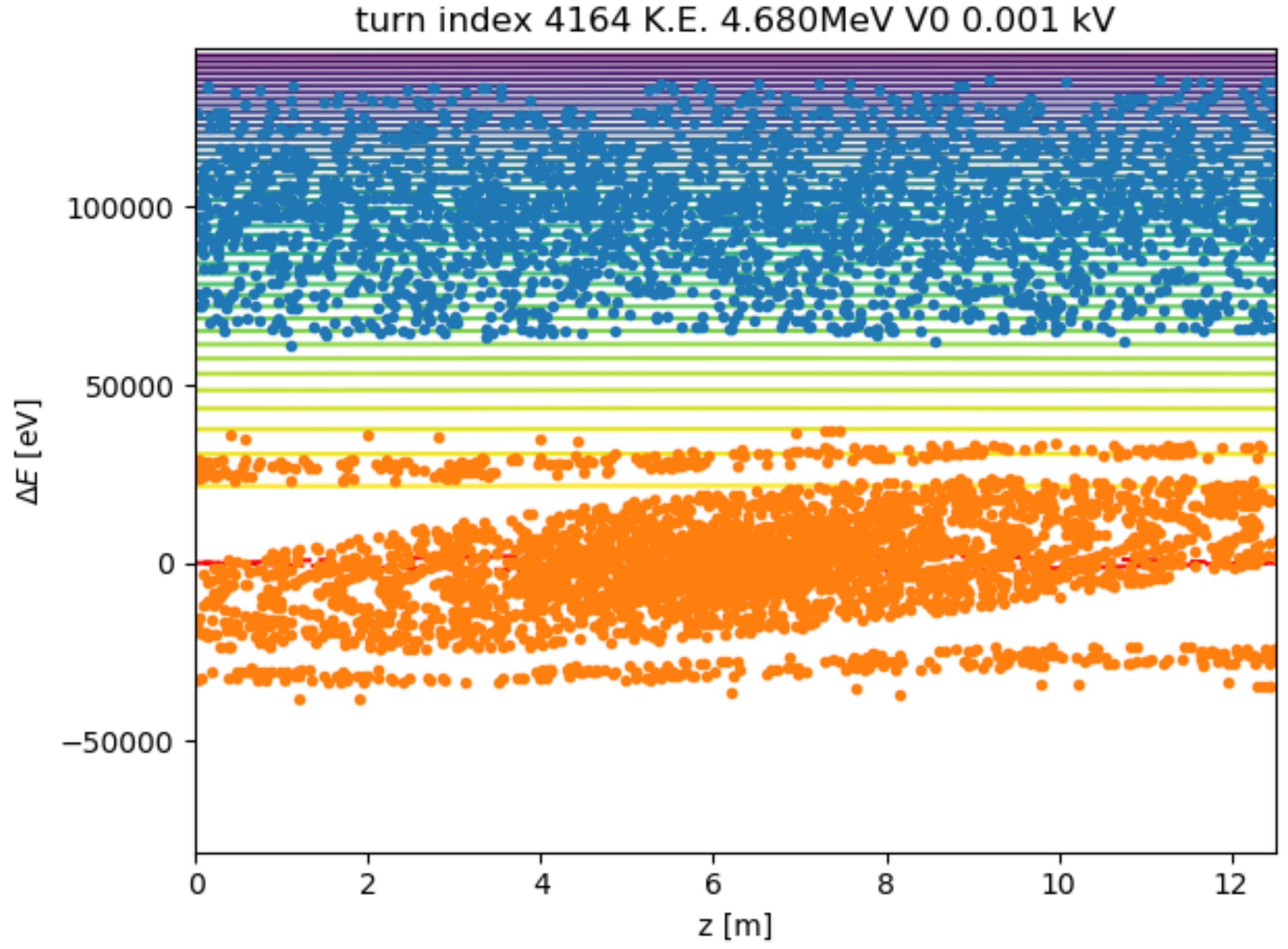
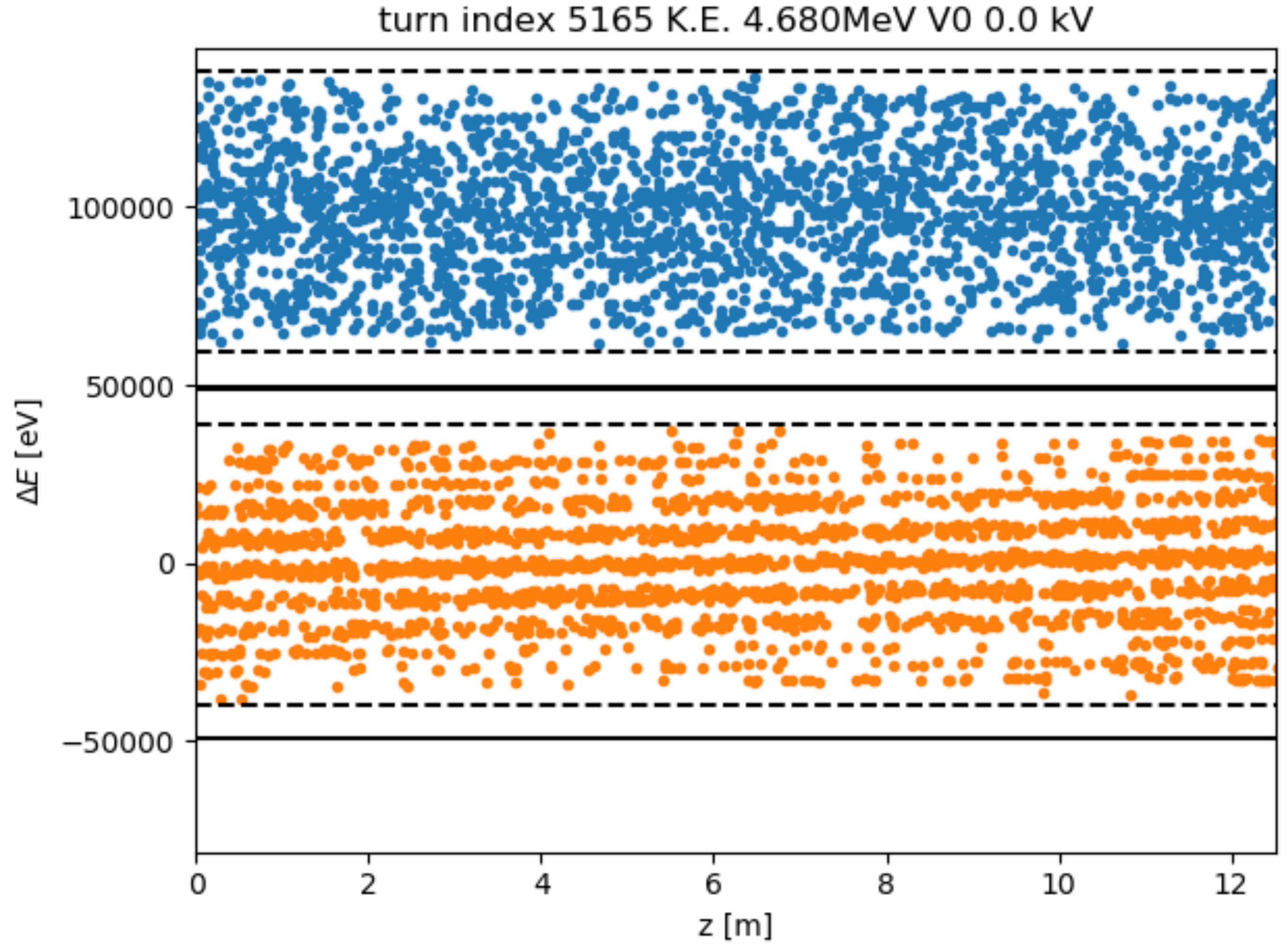
FETS-FFA: Stack Two Beams

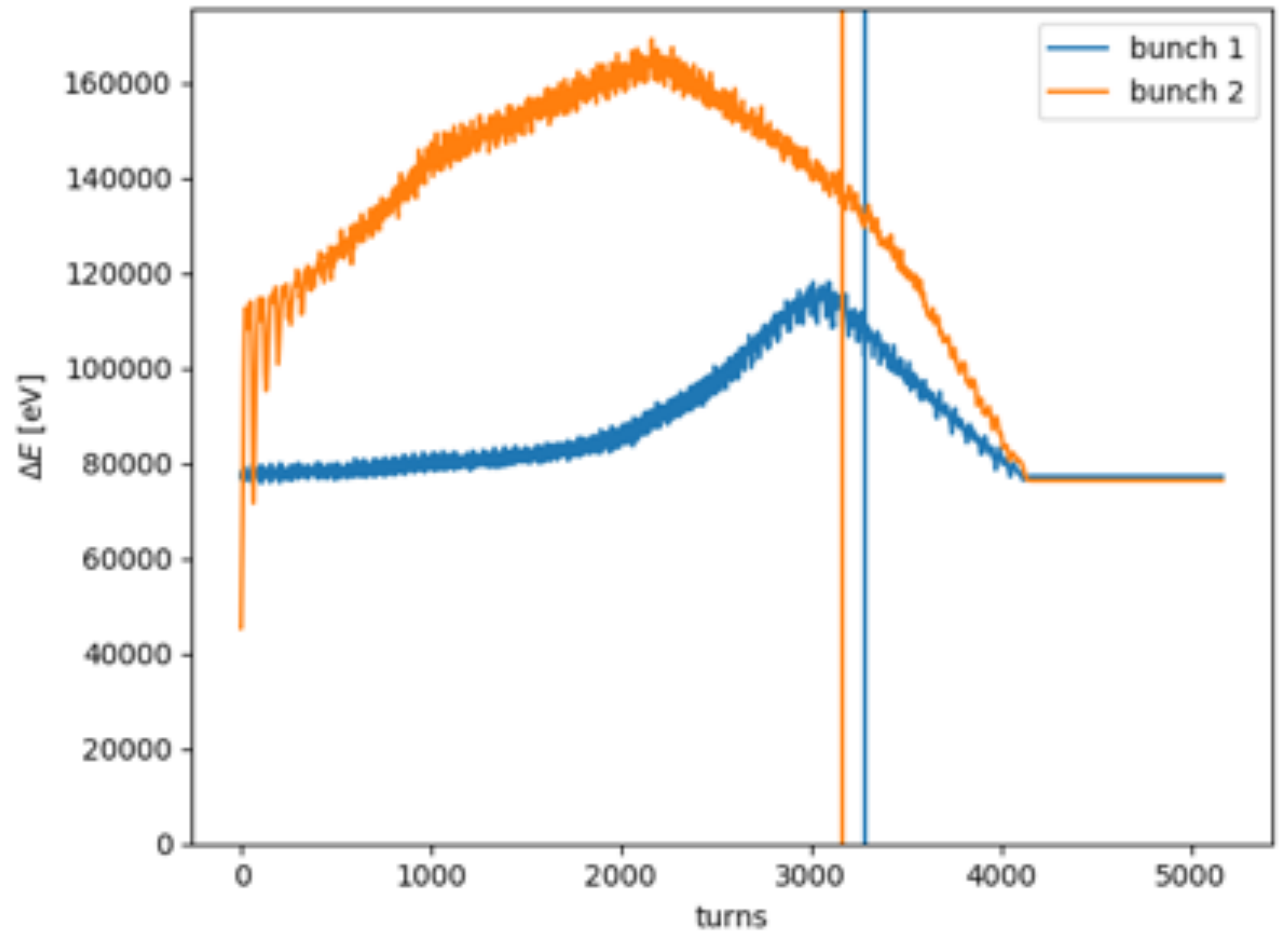












Energy spread during second bunch acceleration

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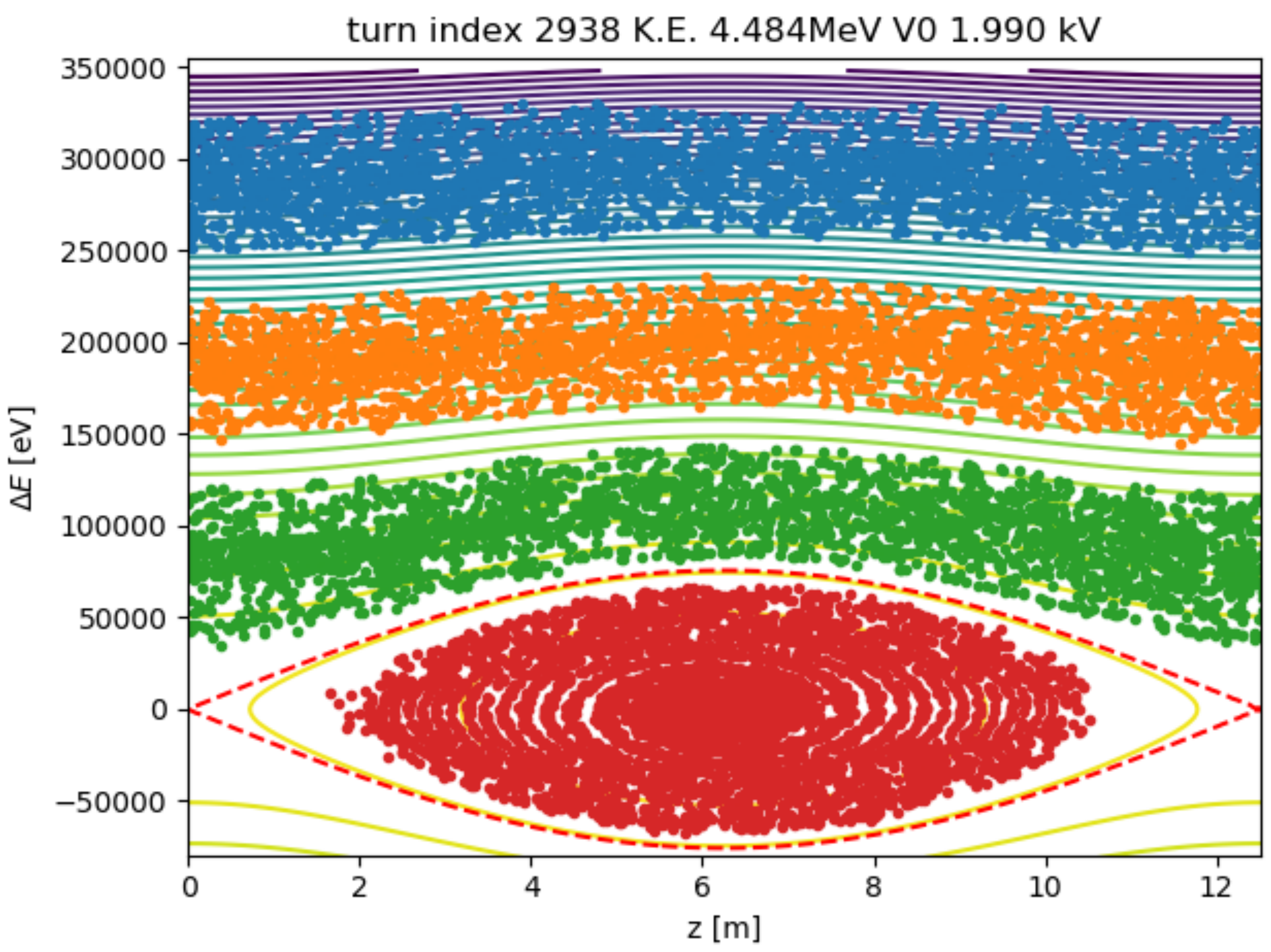
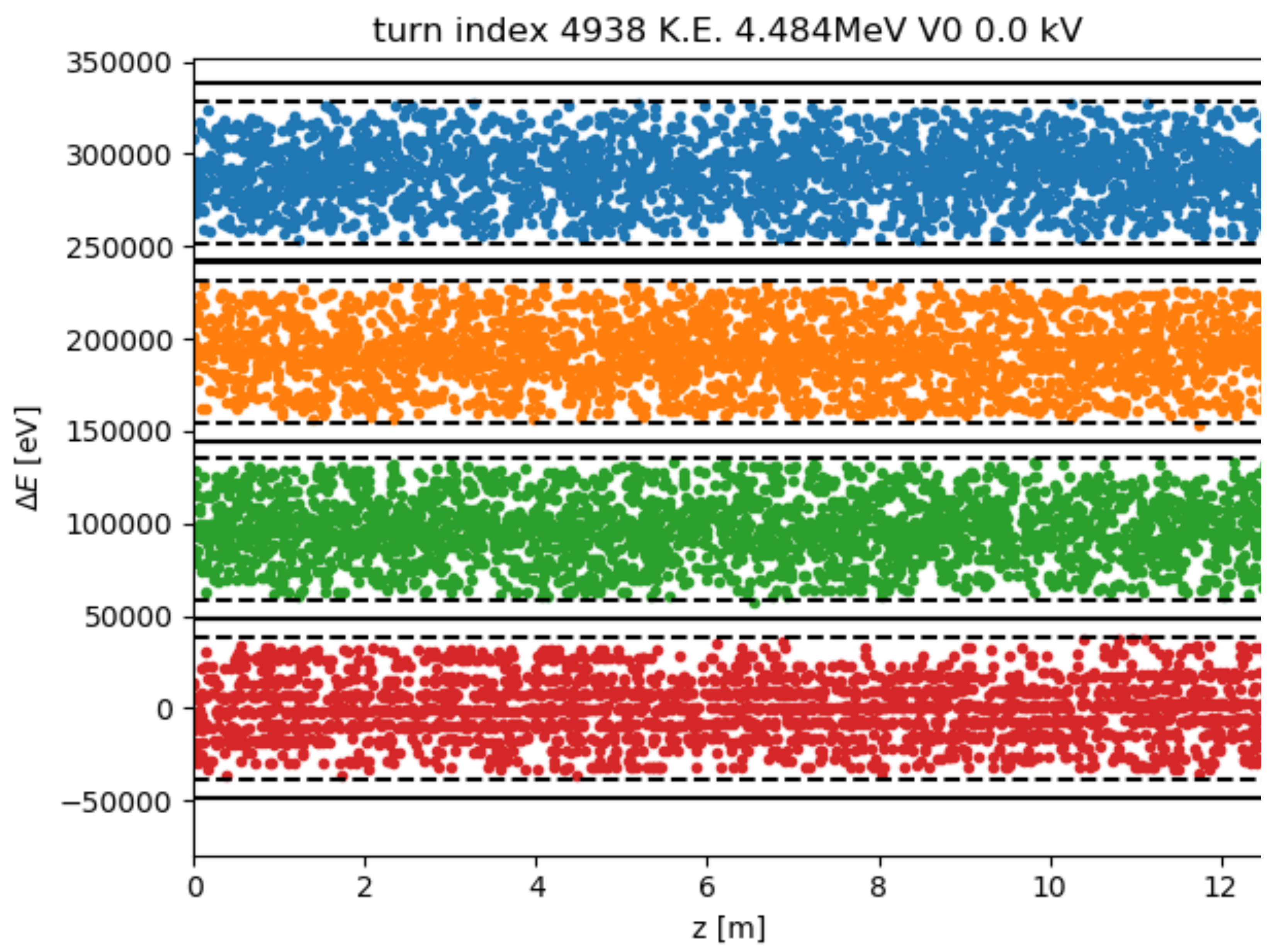
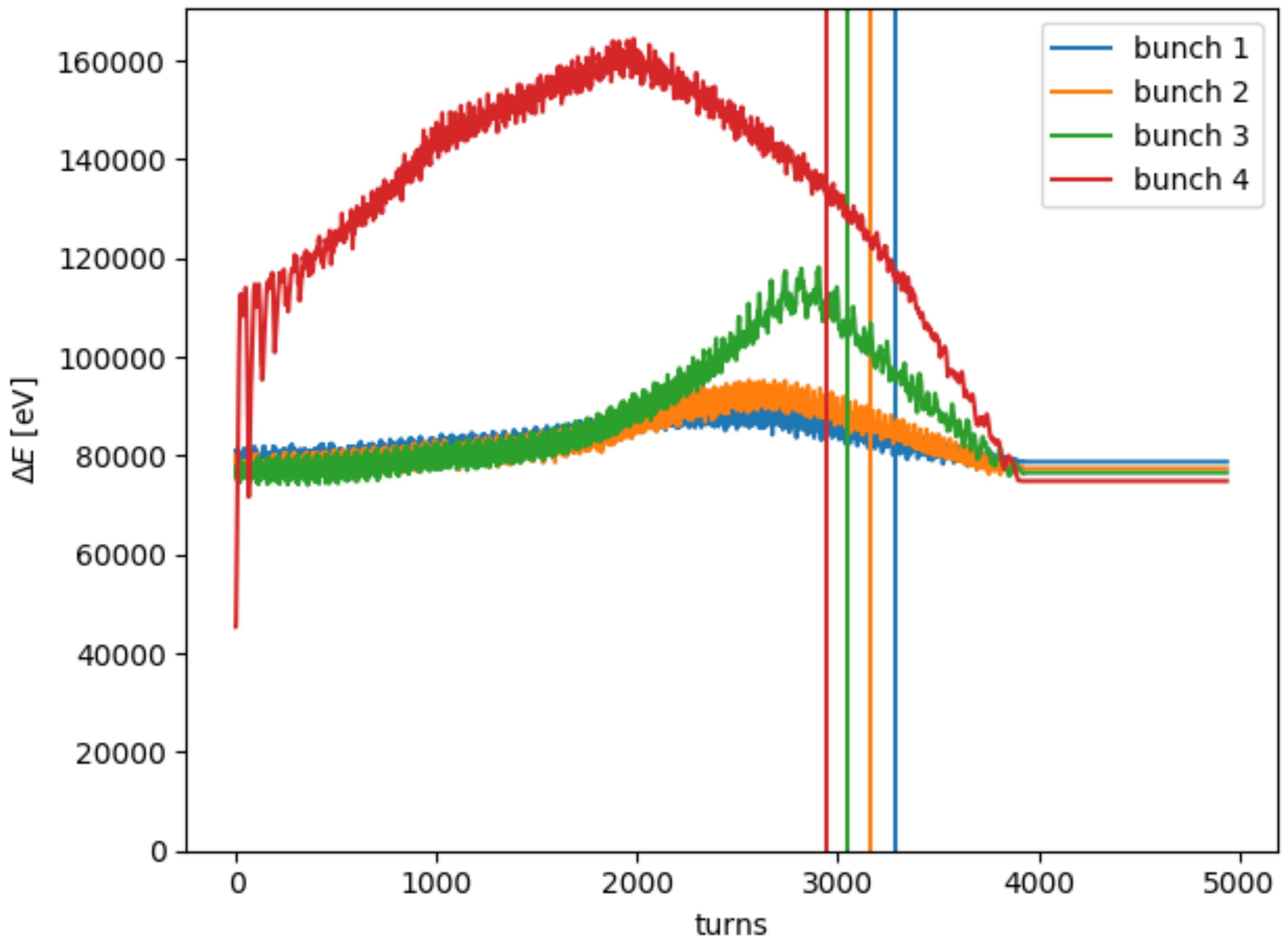
FETS-FFA: Stack Four Beams







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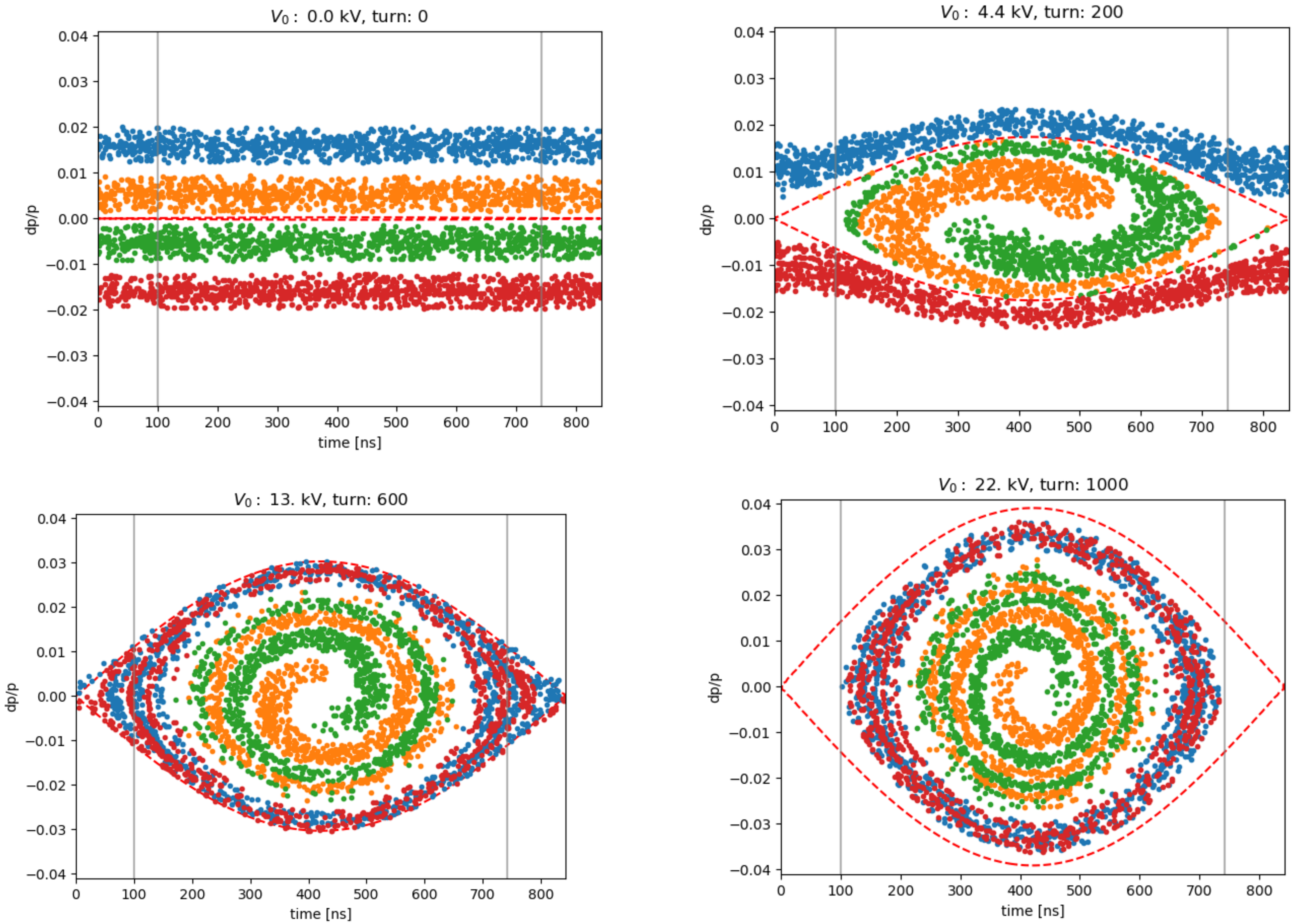
FETS-FFA: Capture

- The stacked beam must be captured before extraction.
- 22kV is enough to ensure 200ns beam-free time for the extraction kicker rise time.
- 1000 turns is sufficient to ensure the capture is adiabatic.



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FETS-FFA RF Specs

3-12 MeV proton VFFA

- Plan to install one variable frequency cavity for acceleration and a separate fixed-frequency cavity for stacking.

Parameter	Value
Acceleration	
RF frequency range (h=2)	1.91 – 3.8 (4.5) MHz
RF peak voltage	4.4 (5.2) kV RF cavity design: 6kV
Stacking	
RF frequency range (h=1)	~ 1 MHz (fixed but adjustable)
RF peak voltage	35 kV (stack 5 beams)

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