Investigation of Tail-Dominated Instability in the Fermilab Recycler Ring

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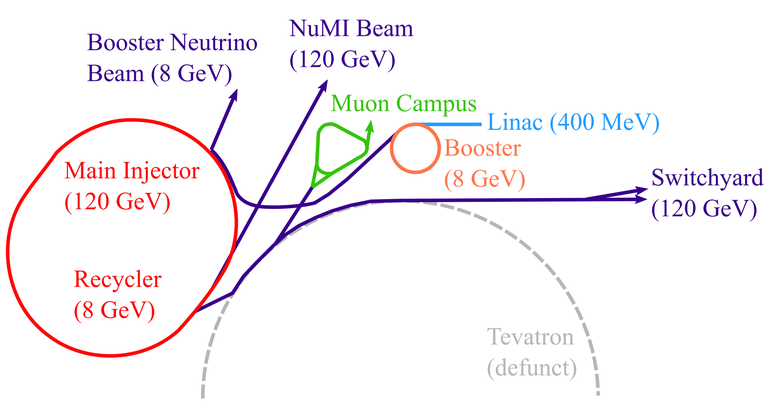
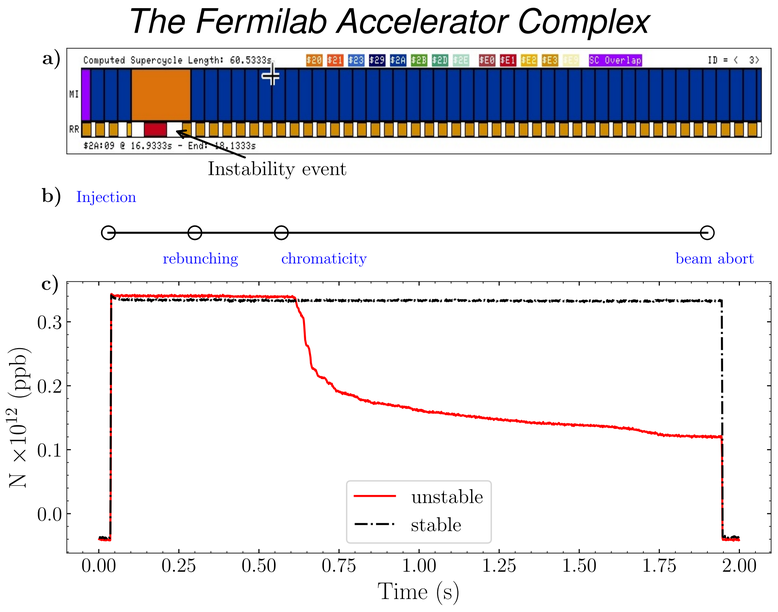
Introduction

In the latest operational run at the Fermilab accelerator complex (22-23), a single bunch, tail-dominated instability was observed in the Recycler Ring (RR). This instability exclusively occurs in the vertical plane when the chromaticity is close to zero. In this work, we conduct a detailed analysis of this instability under different operational parameters. We investigate the impact of space-charge on the head-tail motion and propose potential interpretations of the underlying mechanism of the instability. Moreover, we explore methods to mitigate this instability in the future.

FermiLab Recycler



The Fermilab Accelerator Complex



Timeline and beam intensity with and without the tune change

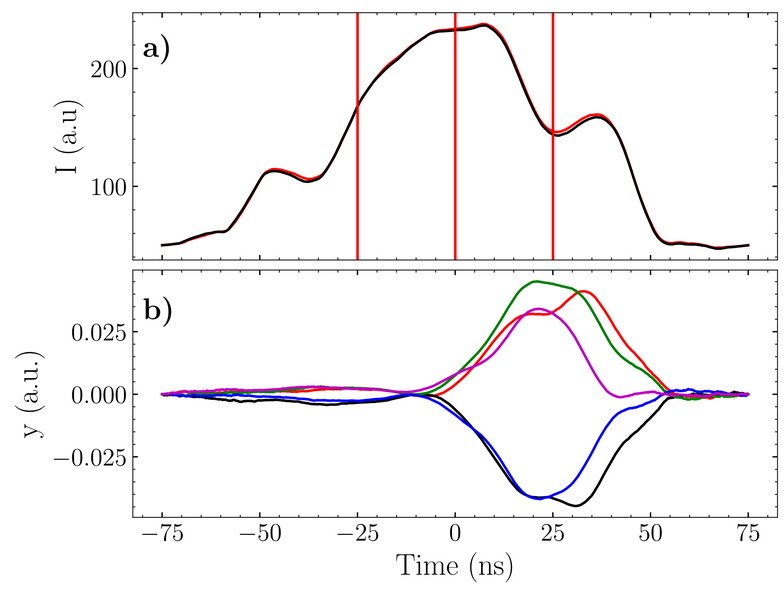
- Ability to study single bunch instability under different operational conditions.
- Different diagonstics tools like IPM, stripline BPMs and wall current monitors.

Recycler parameters

Parameter		Value
Synchrotron tune	ν_s	0.0005
Chromaticity	ξ_x,ξ_y	-0.75,-0.16
Betatrone tune	ν_x,ν_y	25.40,20.44
Emittance	$\epsilon_{N,rms}$	2.5 π mm mrad
Energy	E	8 GeV
Radius	R	528 m

Observed instability

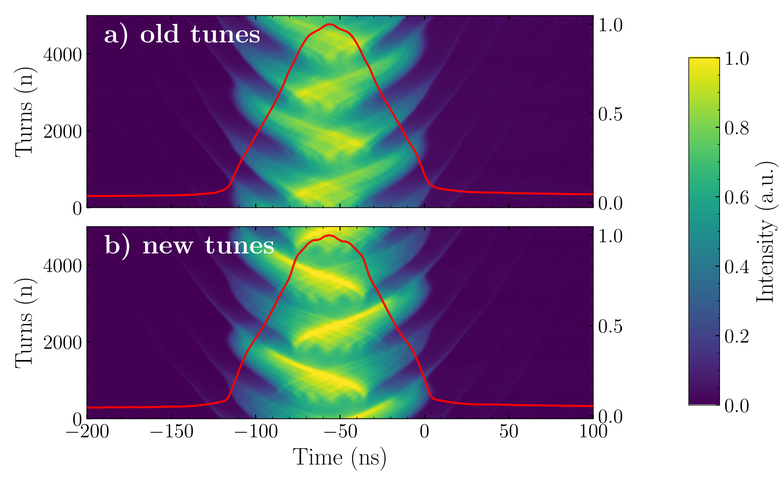
Tail dominated instability was observed close to zero chromaticity at RR.



Beam vertical distribution (a) and vertical motion (b)

- distinct threshold $\sim 0.35 \times 10^{12}$ (pbb)
- Subject to machine day to day variation
- The instability shows a head to tail amplification with some node structure that indicates that modes other than the rigid modes are being excited.

The instability vanished by changing the tune from 0.4, 0.44 to 0.39, 0.46 in the horizontal and vertical planes, respectively.



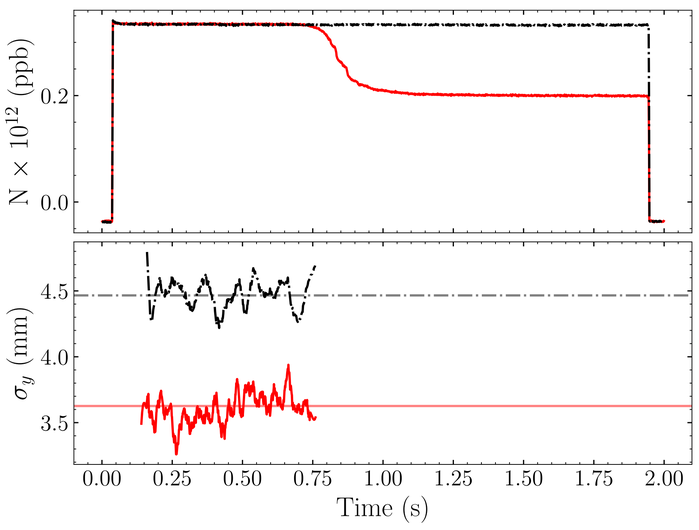
- No changes in the beam size or the profile of the beam was observed in the vertical or the longitudinal planes.

Space-charge effect : We increased the beam size by driving the beam into resonance for a short period of time and then moving it back to its nominal values for the tune.

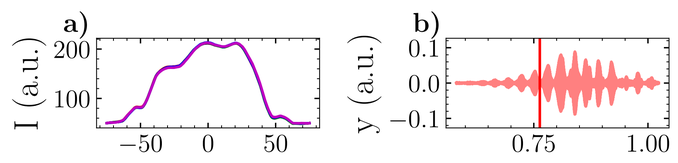
- The beam size changes by 1 mm in both planes (vertical and horizontal).
- After the beam size increased, the instability also vanished.
- No change in the long profile was observed when the beam size increase.

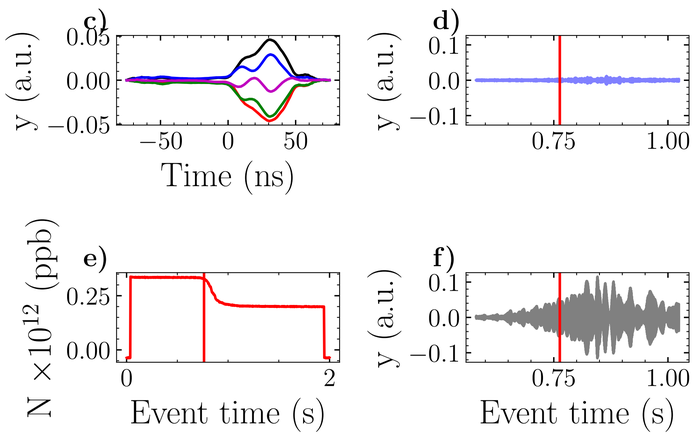
Discussion

- Increasing the beam size change the strength of our space-charge tune shift from 16 to 10.
- Vanishing instabilities with lower space-charge strength could be an indication that it is not TMCI.



IPM data of the vertical beam size





Beam distribution in the vertical plane and vertical motion along the bunch

Summary

- Single bunch tail dominated instability was observed at RR
- Decreasing the space-charge by increasing the beam for the same intensity eliminate the instability
- Tune dependence is still not clear, more investigation will take place

References

[1] R .Ainsworth, *et al*, *A DEDICATED WAKE-BUILDING FEEDBACK SYSTEM TO STUDY SINGLE BUNCH INSTABILITIES IN THE PRESENCE OF STRONG SPACE CHARGE* (HB 2021).

[2] A. Chao, *Physics of collective beam instabilities in high energy accelerators*, (1993).

[3] A. Burov, *Convective instabilities of bunched beams with space charge*, (2019)