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CERN

Barrier buckets with the Finemet cavity in the PS

Part of the PhD project: Beam Loss Reduction by Barrier Buckets in the CERN Accelerator Complex

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Acknowledgements: A. Alomainy, H. Damerau, S. Gilardoni, M. Giovannozzi, A. Huschauer, K. Mehran

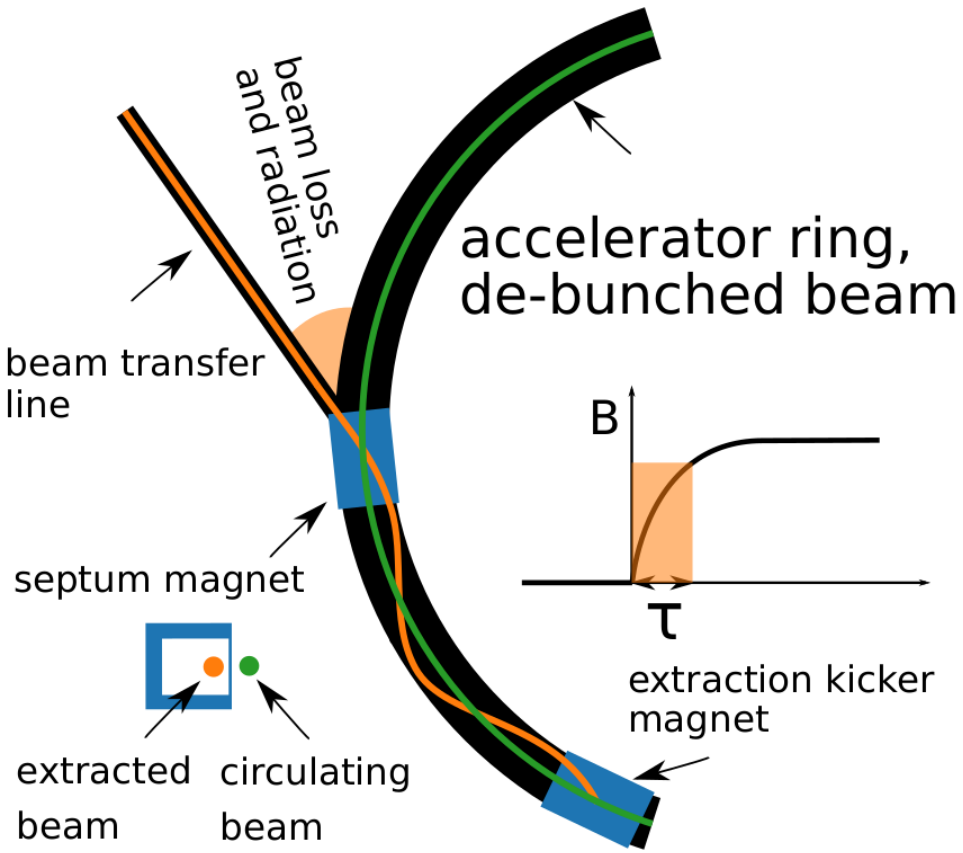
Introduction

Implementation

Low energy and low intensity

High energy and varying intensity tests

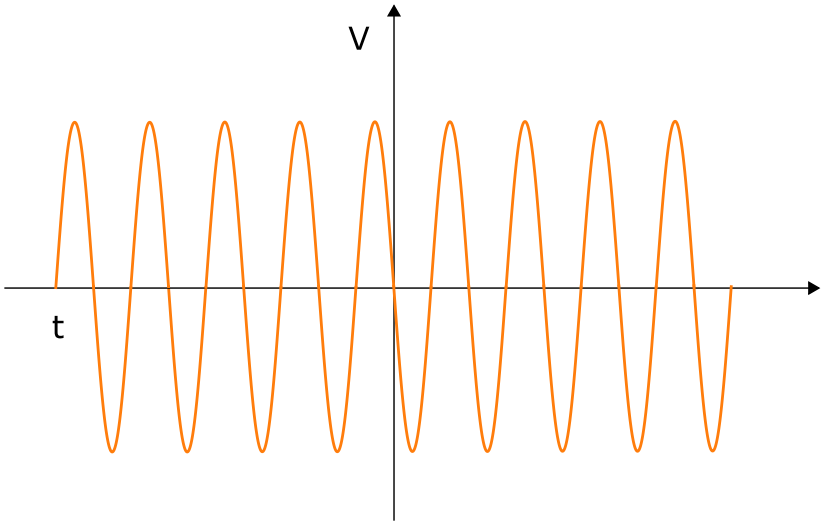
Losses at extraction and motivation



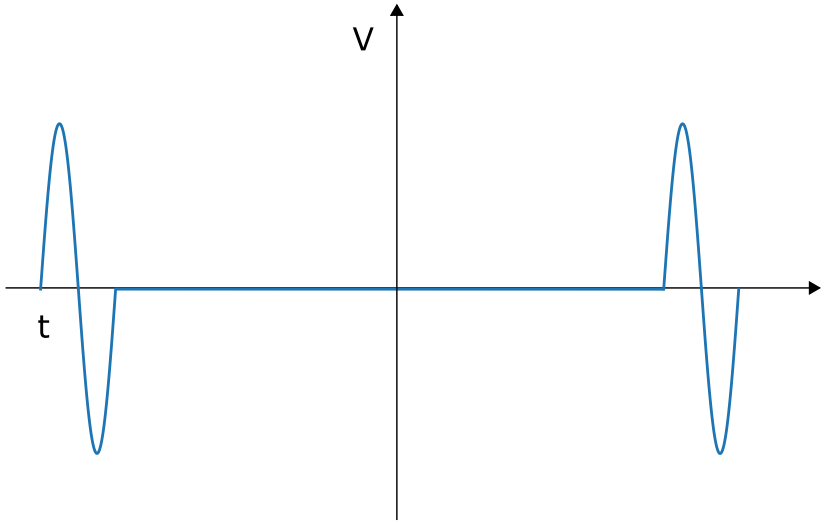
- Further reduce beam losses from badly kicked particles by creating a gap in the beam for the rise time of the extraction kicker.
- Further applications of barrier buckets
  - Reducing the space charge effects (beam instabilities) by reducing the local line density.
  - RF bucket for a multiple injection scheme to accumulate debunched beam.

Single harmonic and barrier buckets

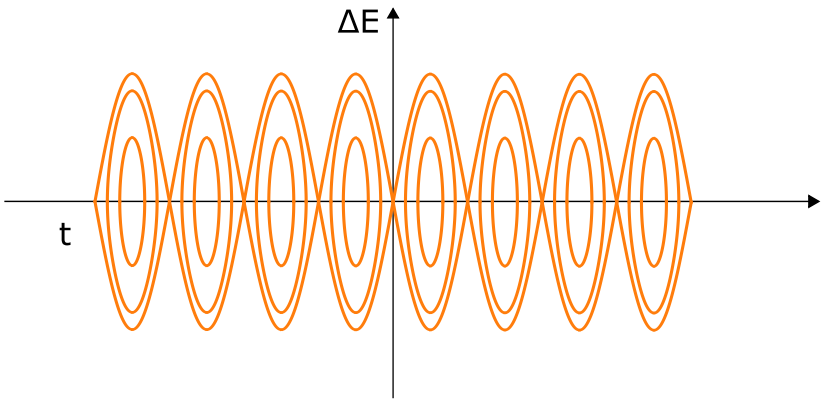
Output of a single harmonic RF system



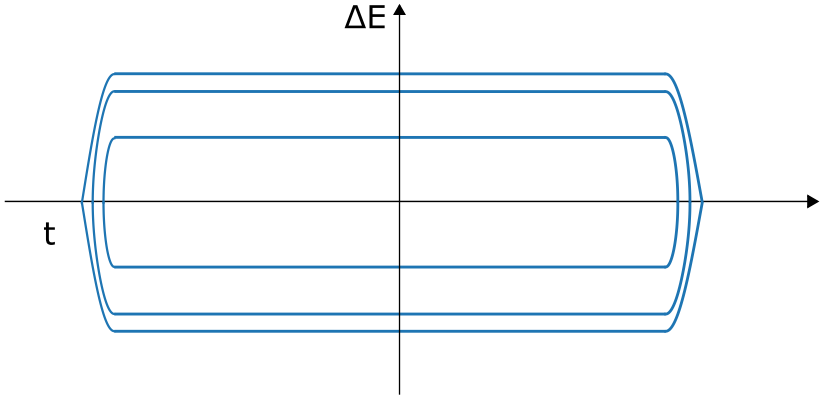
Output of a barrier bucket RF system



Single harmonic buckets



Barrier bucket



Barrier bucket pulse requirements

Particle motion in a barrier bucket generated by a $V_0(t)$ voltage pulse is described by (energy unit: eV):

$$H(\Delta E, \Delta t) = \frac{\eta}{2\beta^2 E_0}(\Delta E)^2 - \frac{\int_0^{\Delta t} V_0(\tau)d\tau}{T} \tag{1}$$

- Since T, η, E_0 and β are given: particle dynamics essentially depends only on the integral of the RF voltage.
- Acceptable performance depends on zero voltage in the flat part, such that ΔE remains constant in this region for a given trajectory.
- The value of the time integral has to be the same on both sides, but this does not mean that $V_0(t)$ has to be a specific function (e.g. sine) or even symmetric.

Main implementation tasks

Use the existing Finemet cavity to generate barrier buckets.

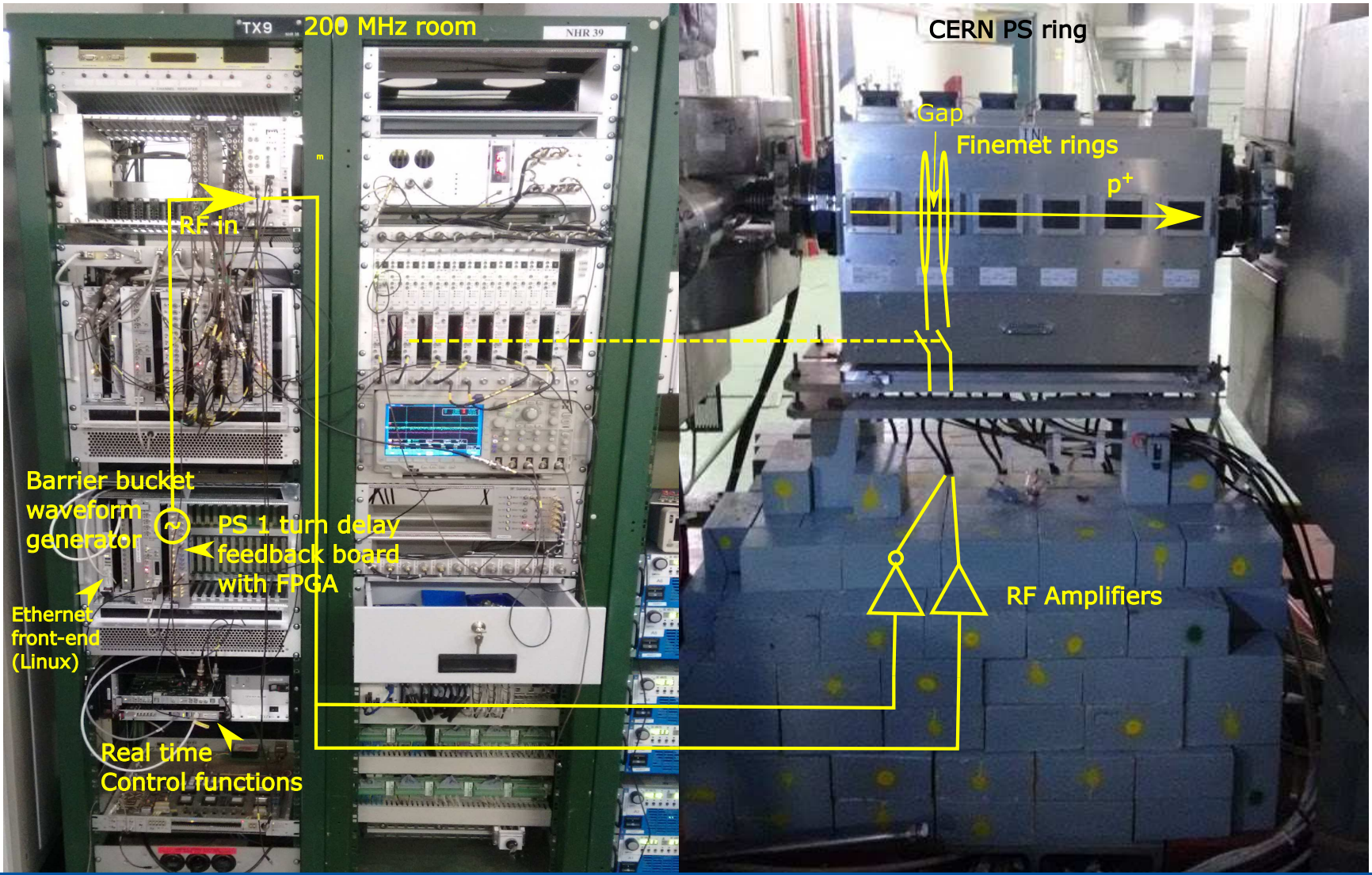
Use parts of existing beam synchronous sine / cosine generator firmware (PS Multi-harmonic Source - MHS).

Prototype solution:

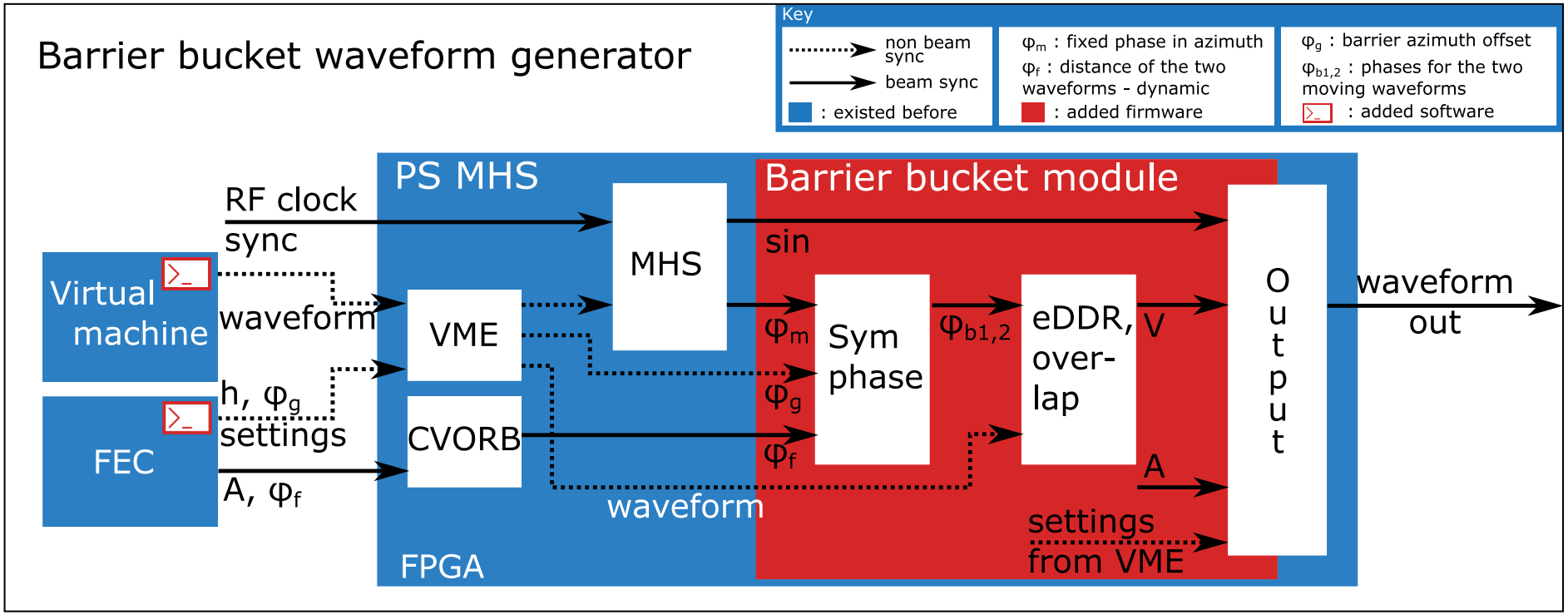
1. Adding arbitrary waveform generator firmware to the PS MHS and using the phase outputs of the MHS module and CVORB functions to drive it.
2. Real-time moving barrier module developed.

Implementation

Hardware installation



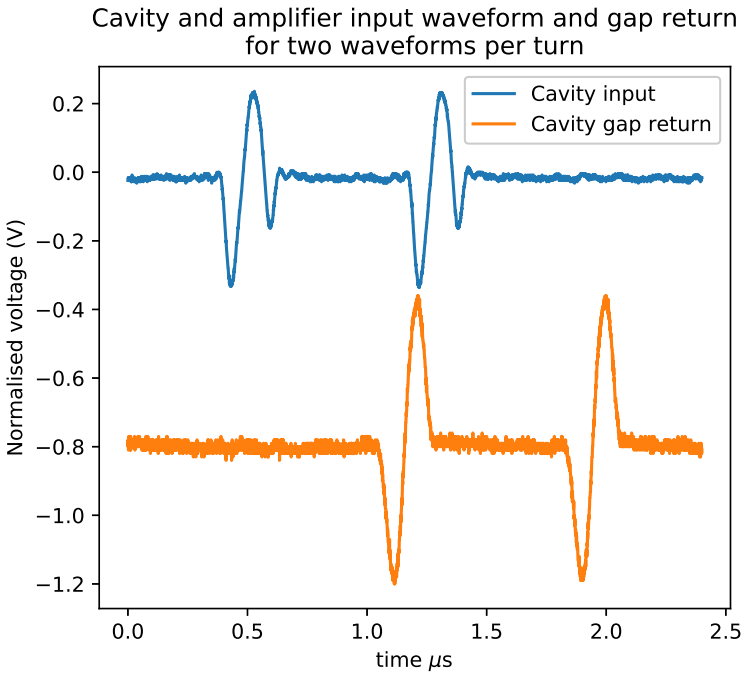
Prototype firmware and software

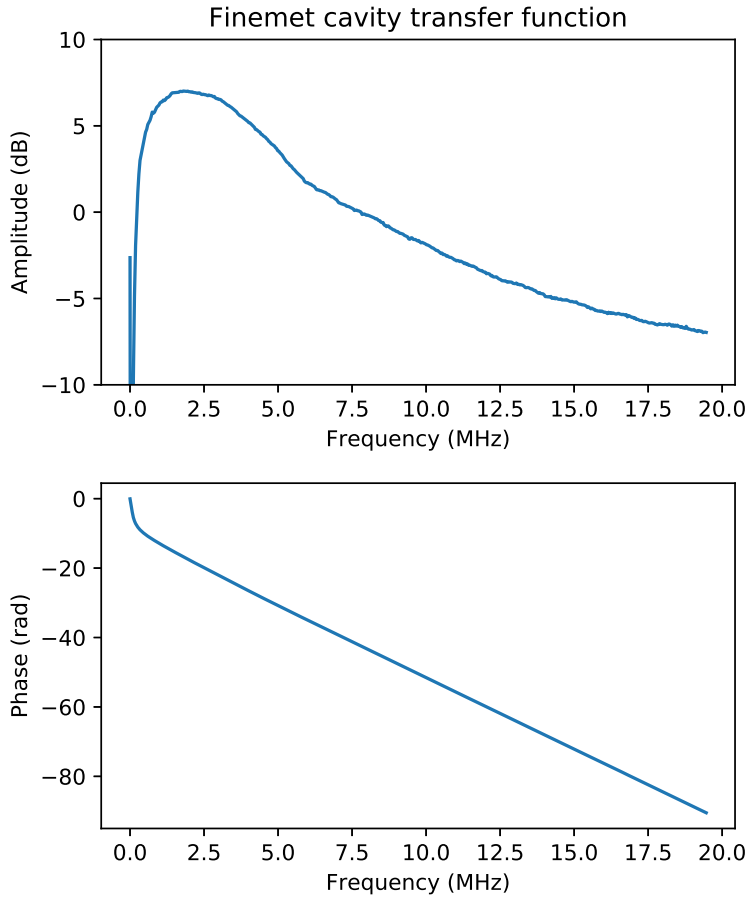


Beam synchronous, arbitrary waveform generator.

Model: waveform distortion based on inverse transfer function

Based on cavity transfer function measurement.

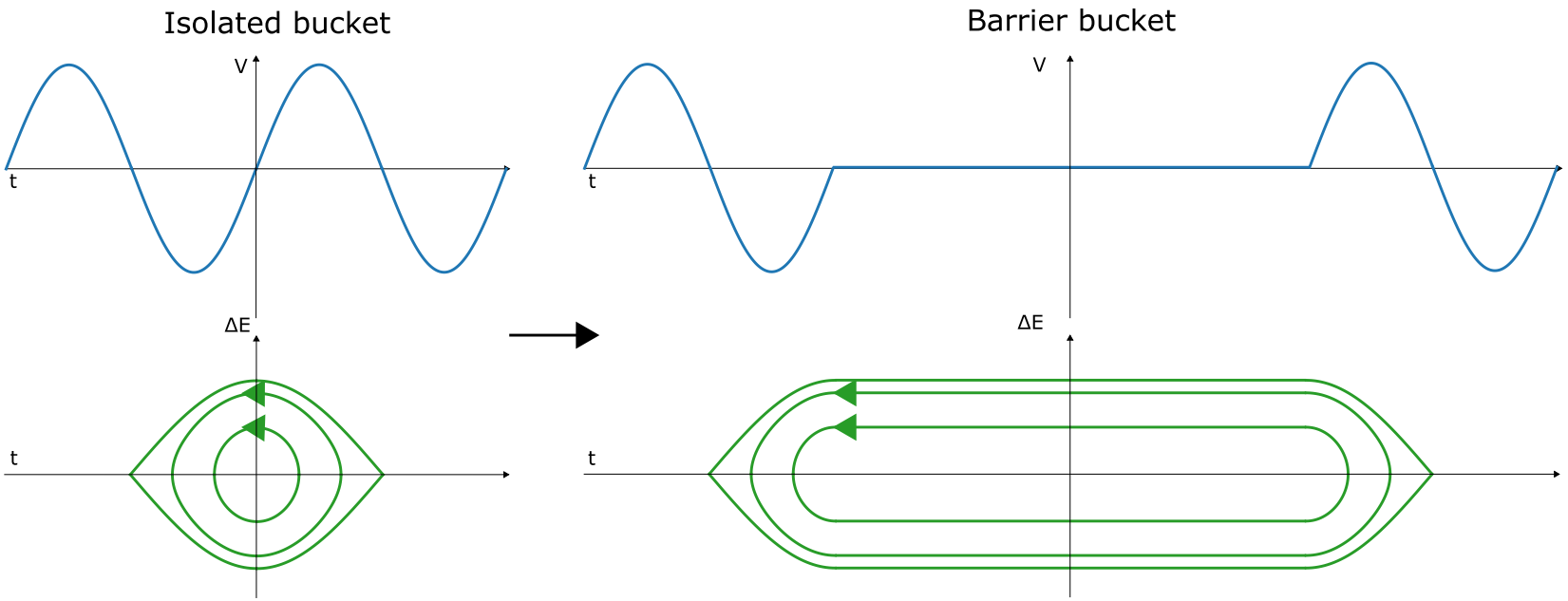




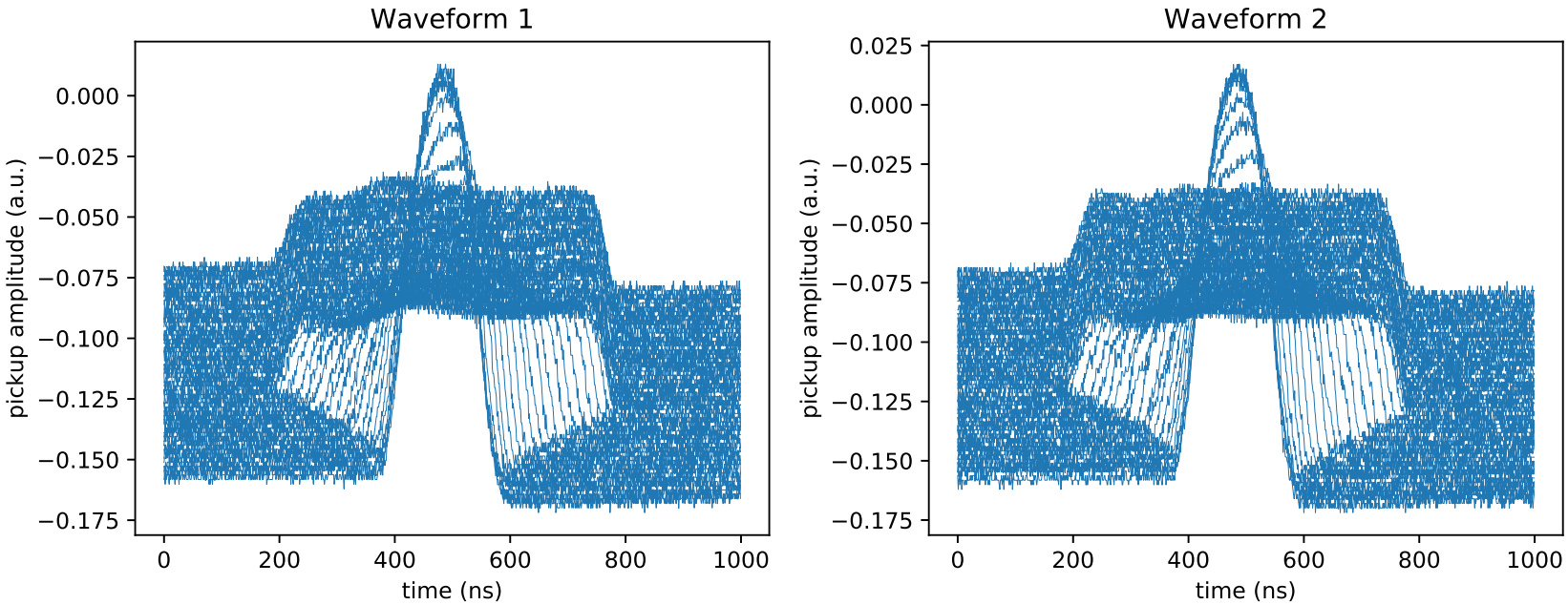
Low energy and low intensity

Strategy: sine bucket to barrier bucket

System in an early stage: no amplitude control, only phase.
Impossible to make matched injection due to low voltage.
Creating controlled initial conditions by removing uncaptured beam.
From an isolated bucket, the distance between the barriers is increased to create a barrier bucket.

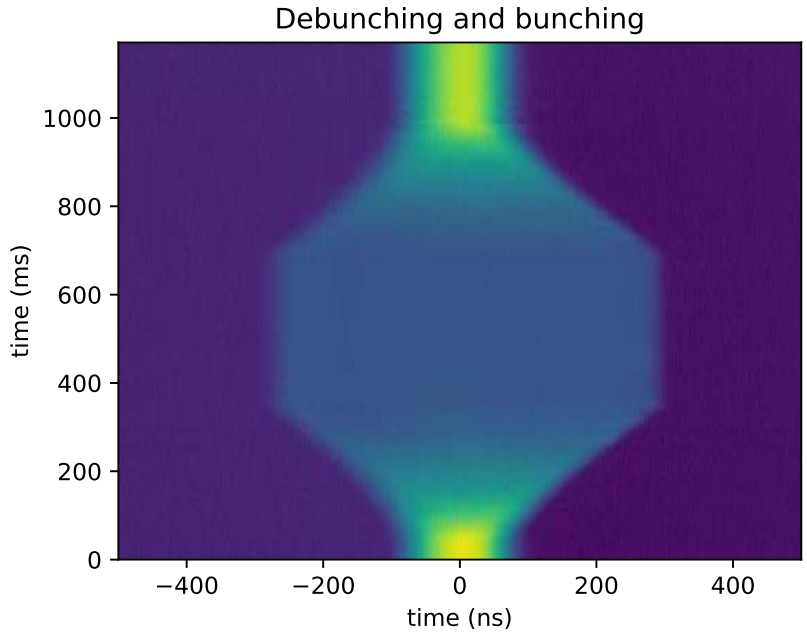


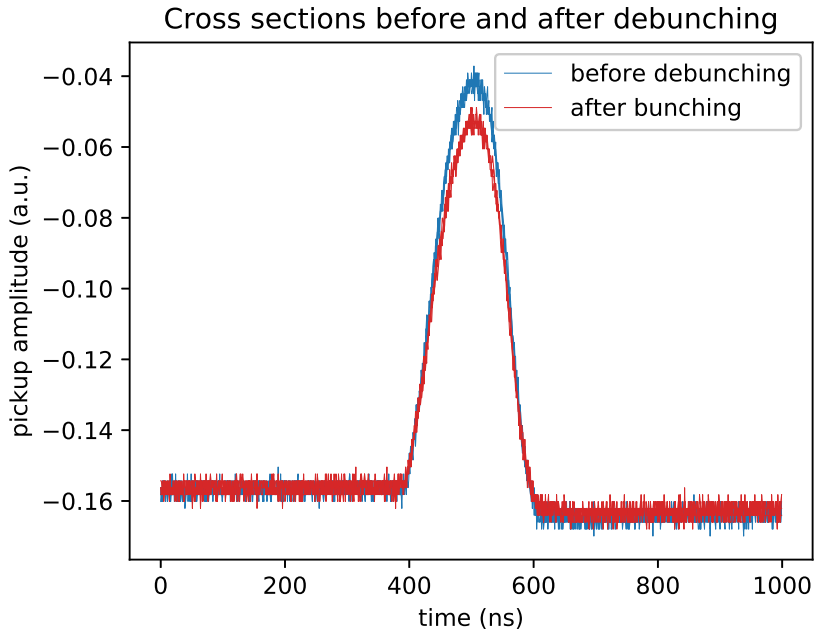
Stretching barriers - sensitivity around zero volts



The bunch shape is sensitive to asymmetries in the voltage. A small change of the peak voltage ($< 1\%$) on the input causes a distortion of the bunch.

Stretching and squeezing a bunch with the a barrier bucket RF system

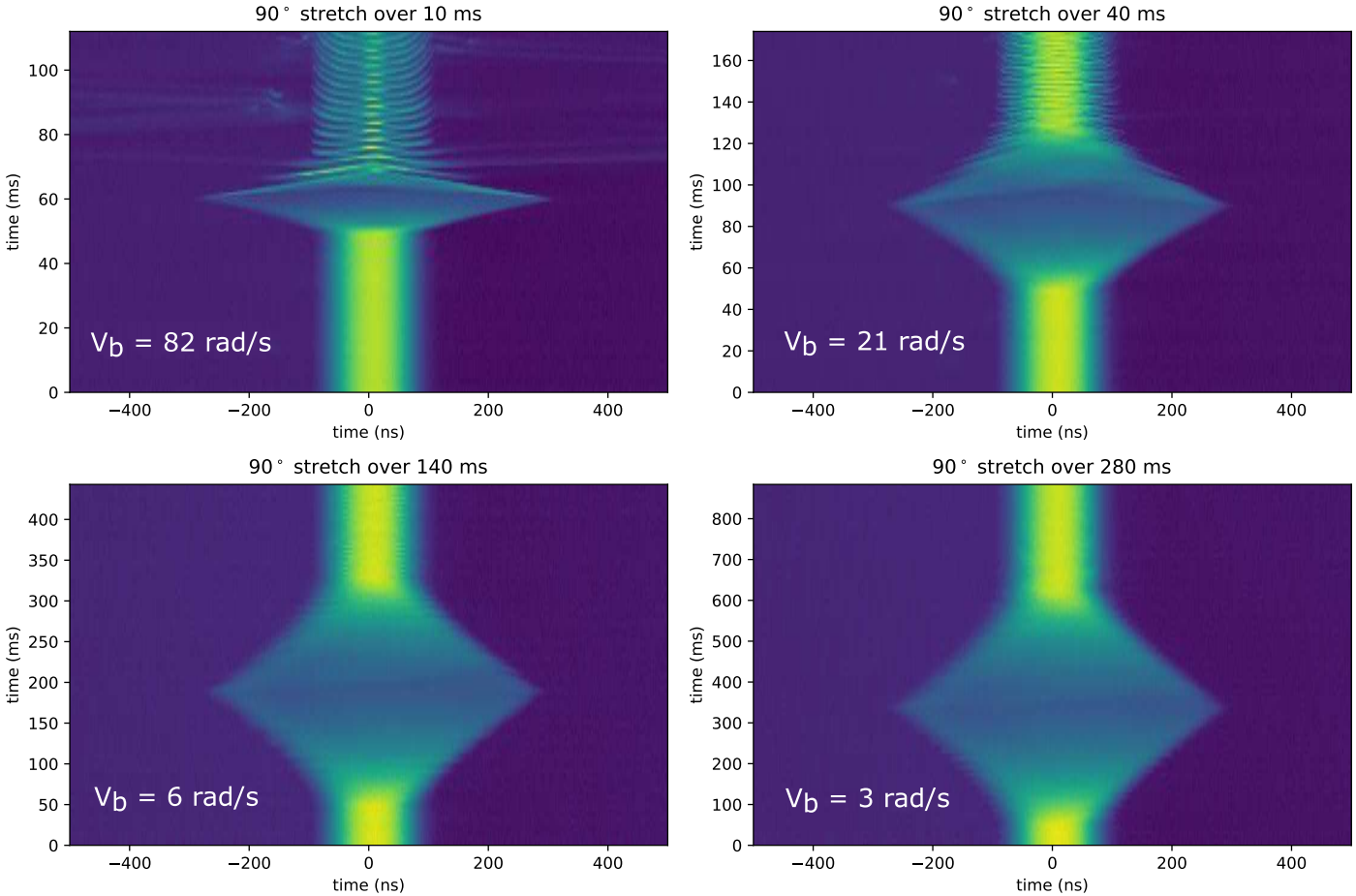




The bunch shape is restored after the manipulation. Losses with reference measurement, too. Slight asymmetries possible explanations: left is fuzzier than right: potential having a different shape on each sides, closer to a rectangle on the right, but having an absolute same height. Left is slightly shorter than right: baseline higher on the left.

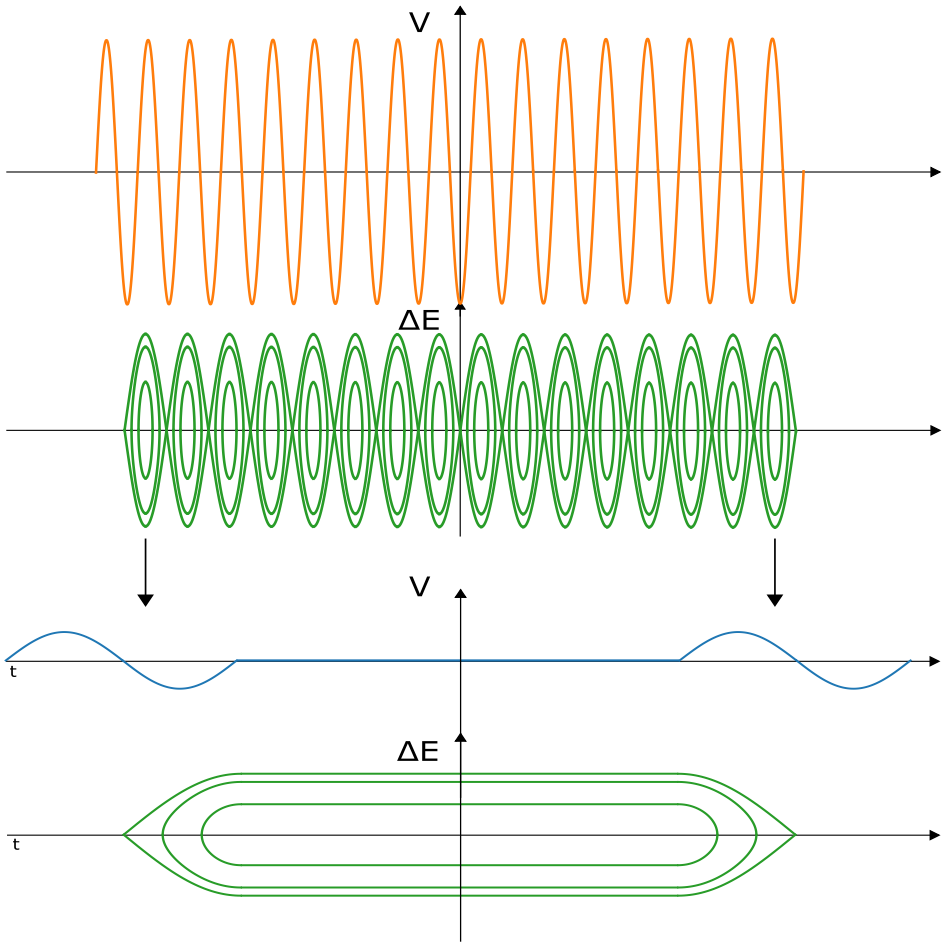
Limits of adiabaticity - preliminary

Speed of particle on outer trajectory of the barrier bucket $\sim 100\,\mathrm{rad/s}$



High energy and varying intensity tests

Strategy: re-bunching multiple bunches to a static barrier bucket



Limited time available compared to low energy tests at flat top.

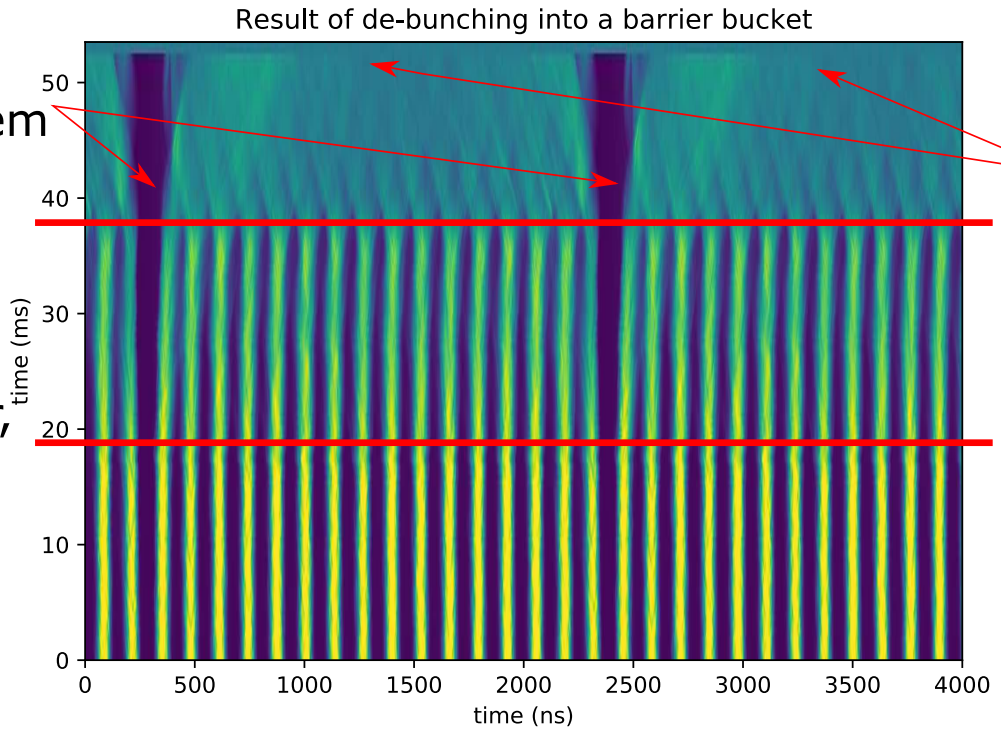
Lowering the amplitude of the harmonic RF system and raising the amplitude of the barrier bucket RF system.

Result of de-bunching at flat top

Gap kept with the barrier system

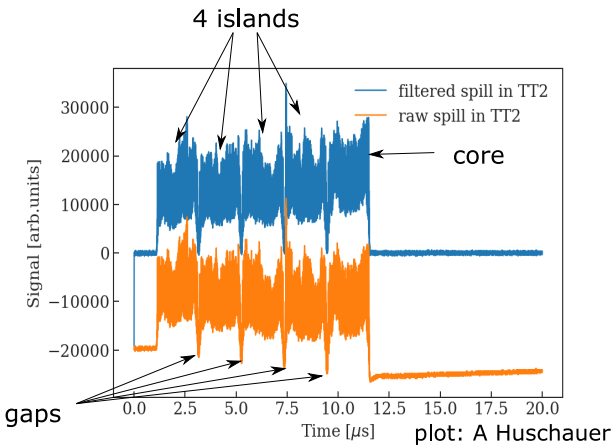
Normal RF OFF

Normal RF lower, Barrier ON

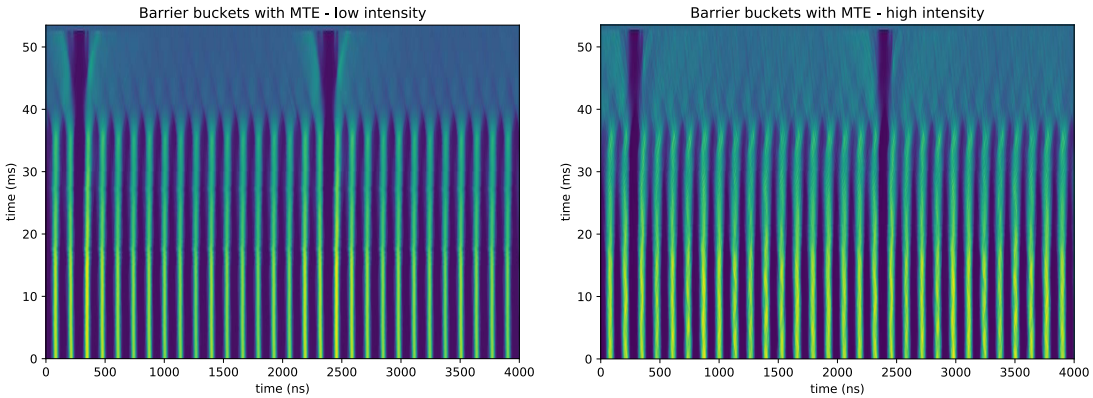


Quasi constant longitudinal line density

Intensity scan with MTE



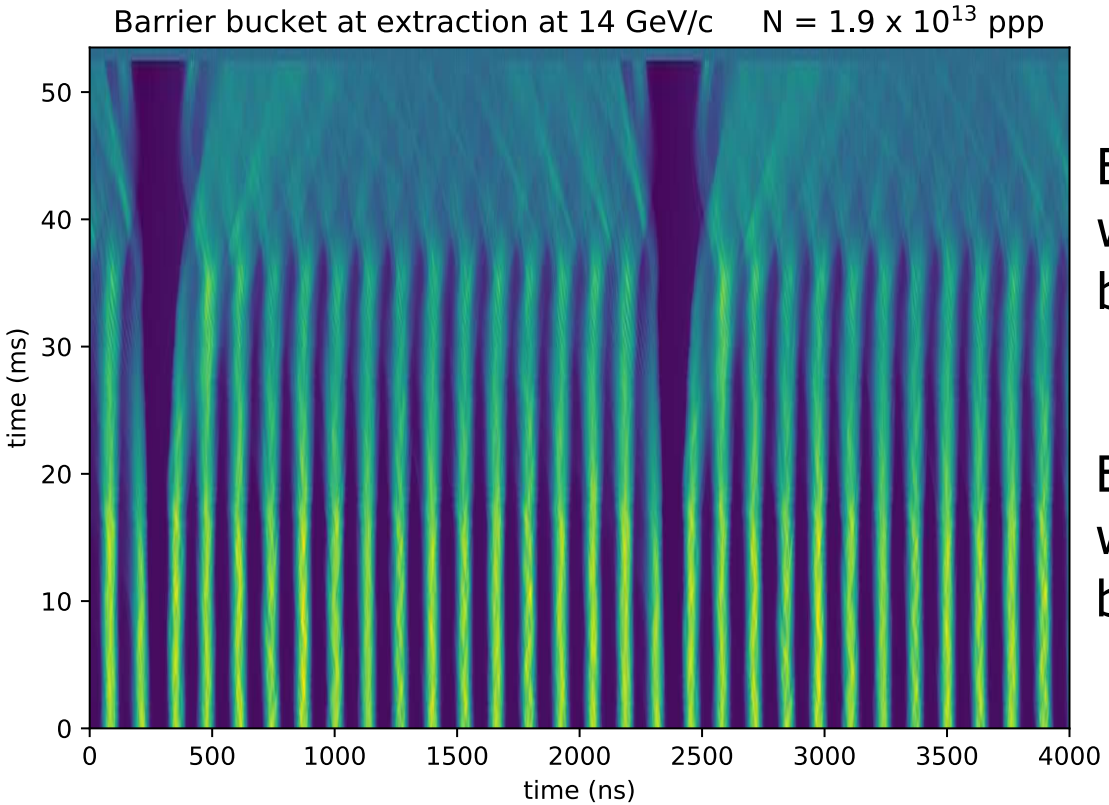
Barrier buckets at low and high inentisites with MTE



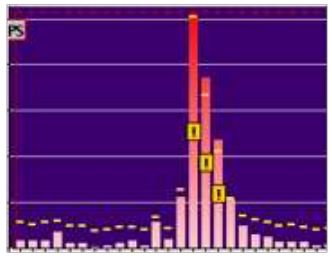
Multi-turn Exctraction (MTE) combined with barrier buckets.

Gap preserved throughout the $\sim 0.4 \cdot 10^{13}$ ppp - $\sim 2.2 \cdot 10^{13}$ ppp range - perhaps even more constant line density at higher intensities. To be analysed.

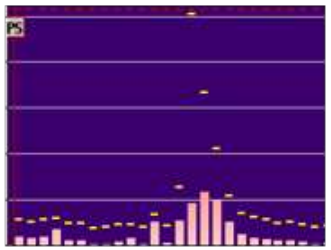
Beam loss reduction



Extraction loss without barrier bucket



Extraction loss with barrier bucket



Summary

- Prototype barrier firmware and software developed.
- Successful validation at low energy and low intensity. (Original min. aim.)
- Quick progress at high energy and varying intensities. (Original max. aim.)
- Successful combination with MTE achieved with varying gap size.
- Significant beam loss reduction in the PS proven.

Outlook

- Not synchronised extraction to SPS was possible.
- Main limitation: only works with PS internal RF signals, there is no synchronisation with the SPS due to low voltage.
- Further integration into controls environment / modifications for operational firmware can be done the standard way.