Introduction to simulations of recirculating machines such as the CLIC Drive Beam Complex and CTF3

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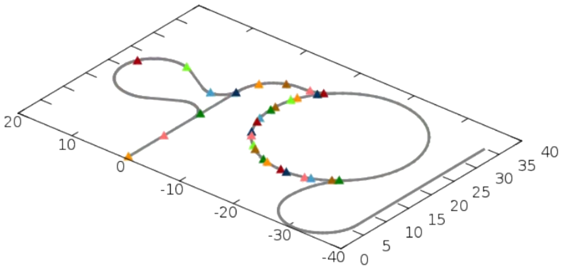
Recirculation:

A wide spectrum of beam manipulations leads to unprecedented performances

- Reach huge currents (100 A in the CLIC drive beam)



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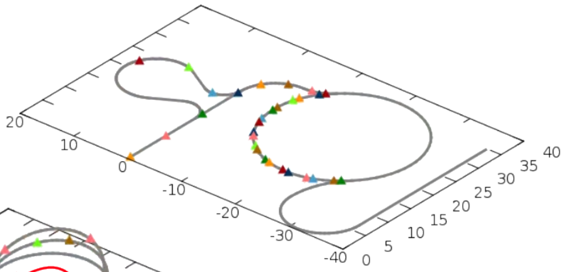

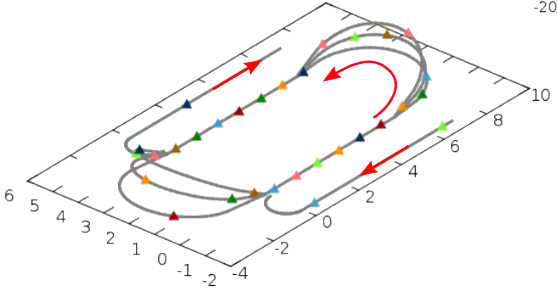

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- Extract the energy from a spent beam.

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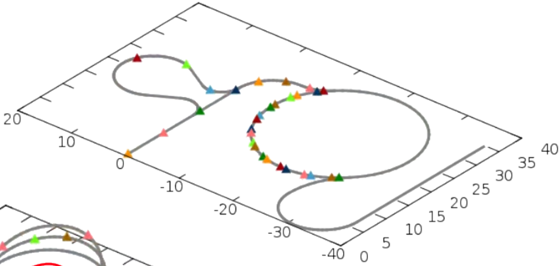

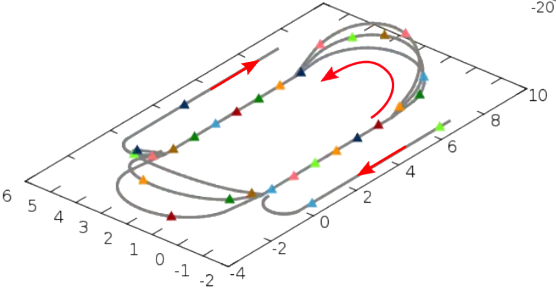

- Multiply the accelerating voltage of a linac,
- Extract the energy from a spent beam.

- Many beamlines in complicate topologies!
  - The bunch train changes its structure!

Recirculation:

A challenge for a tracking code

- How to *describe* a machine:
    - Fast and simply $\rightarrow$ first approach simulation;
    - Accurate and detailed $\rightarrow$ full machine modelling.

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- How to *describe* a machine:
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    - Accurate and detailed → full machine modelling.
- How to simultaneously *track* many bunches in such a lattice:
    - Take the right path;
    - Preserve the order of bunches;
    - Manage time dependent elements.

Recirculation:

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  - Accurate and detailed → full machine modelling.
- How to simultaneously *track* many bunches in such a lattice:
  - Take the right path;
  - Preserve the order of bunches;
  - Manage time dependent elements.
- How to be *fast*:
  - Take advantage of modern-multi-core CPUs with parallel computation;
  - Easily access the element algorithms for improvements.

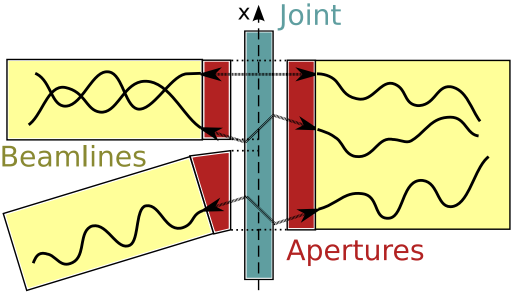
A tracking code for recirculating machines

- A direct extension of PLACET appeared hard.
- New code written from scratch to:
  - implement and test new ideas to handle recirculation;
  - work without structural constraints.
- Plans for a modularisation of PLACET are ongoing;
- Integration of the recirculating tracker into PLACET will follow.

Concepts of a tracking code for recirculating machines

Lattice Description

- A *Machine* consists of a set of interconnected beamlines;
- *Beamlines* are standard sequences of elements;
- *Apertures* and *Joints*:
  - Allow for beamlines connection;
  - Route the bunches through the correct path (based on their offset);
  - Synchronise the machine preserving bunch order.



Machine operation and Synchronisation

- The machine owns *global timer* used for synchronisation $\rightarrow$ increases at small steps;
- Each bunch owns an *internal timer* $\rightarrow$ increases as bunch travels through thick elements;
- Bunches travel straight down beamlines, their timer can be greatly increased,
- but are forced to wait at the subsequent joints until the global timer exceeds their internal one.

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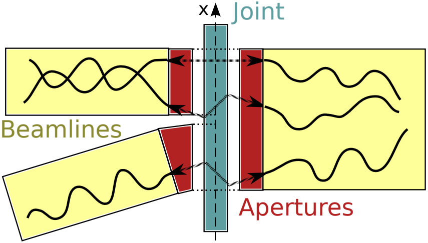
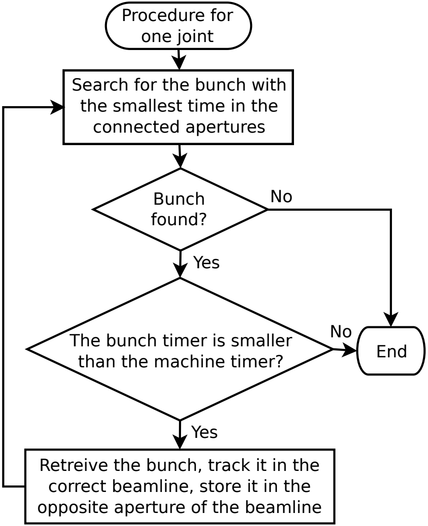
- Global timer steps smaller than shortest beamline ⇒ bunch order is preserved;
- Elements always see bunches in the correct time sequence ⇒ element time is the being-tracked bunch time.

Tracking Operation

Advance Procedure

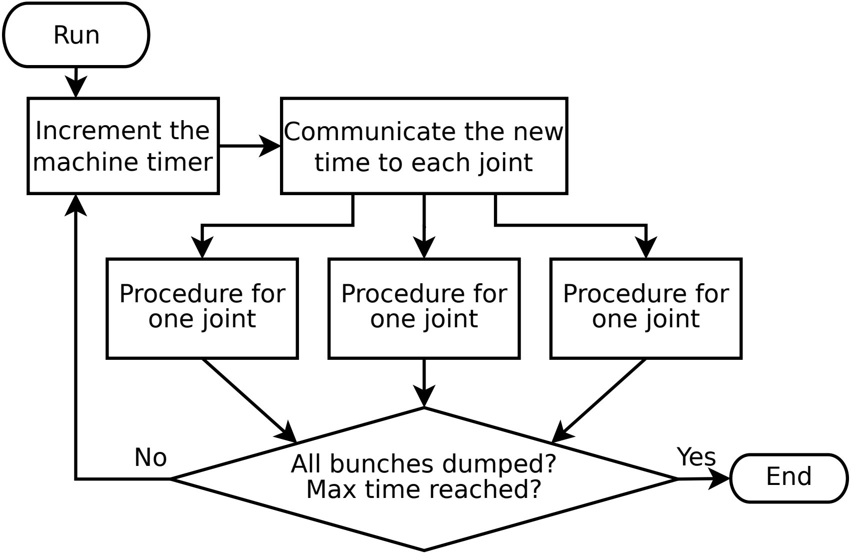
- Transmit the *machine time* to each joint.
- Each joint applies the advancing algorithm.





Tracking operation

Run Procedure



A Physic Study: Long-Range Wakefields

Higher Order Modes and Long-Range Wakefields

- The field in a cavity has many Higher Order Modes (*HOMs*) of oscillation.
- HOMs are excited by bunches passing through the cavity and affect the followings $\Rightarrow$ long-range wakefields.
- Dipolar modes are particularly bad as they are strong and easily excited by orbit displacements.

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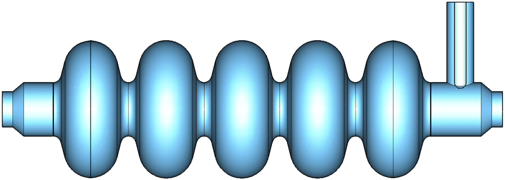

- SPL cavities: 5 cells design at 720 MHz.
- List of HOMs from M. Schuh, all Q-values at TESLA worst.

#	f [GHz]	A [V/C/m²]	Q
1	0.9151	9.323	1e5
2	0.9398	19.095	1e5
3	0.9664	8.201	1e5
4	1.003	5.799	1e5
5	1.014	13.426	1e5
6	1.020	4.659	1e5
7	1.378	1.111	1e5
8	1.393	20.346	1e5
9	1.408	1.477	1e5
10	1.409	23.274	1e5
11	1.607	8.186	1e5
12	1.666	1.393	1e5
13	1.670	1.261	1e5
14	1.675	4.160	1e5
15	2.101	1.447	1e5
16	2.220	1.427	1e5
17	2.267	1.377	1e5
18	2.331	2.212	1e5
19	2.338	11.918	1e5
20	2.345	5.621	1e5
21	2.526	1.886	1e5
22	2.592	1.045	1e5
23	2.592	1.069	1e5
24	2.693	1.256	1e5
25	2.696	1.347	1e5
26	2.838	4.350	1e5

Long-Range Wakefield in Complex Topologies

Goal $\rightarrow$ Reduction to a local problem: interaction bunch-mode in a single cavity

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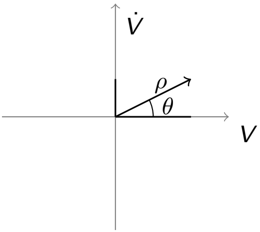

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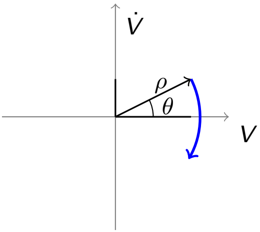

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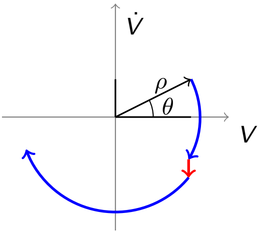
  $\Im(z) = \Im(z_0) + Ne\,A\,L_{cav}\,\delta x$



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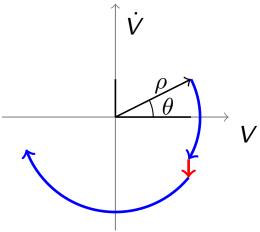
- Mode → bunch interaction:

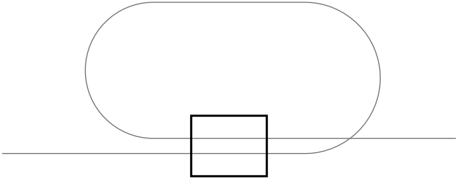
$$x' = x_0' + \frac{e\,\Re(z)}{\gamma\, m_e\, c^2}$$

Iterated over all the HOMs of the cavity.



A Single Cavity Case

A bunch sees an RF deflector a few times in a Combiner Ring.



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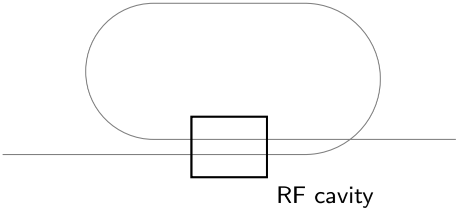

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- Can a *positive feedback* take place?

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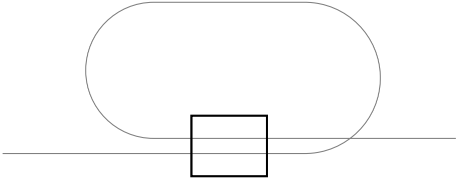

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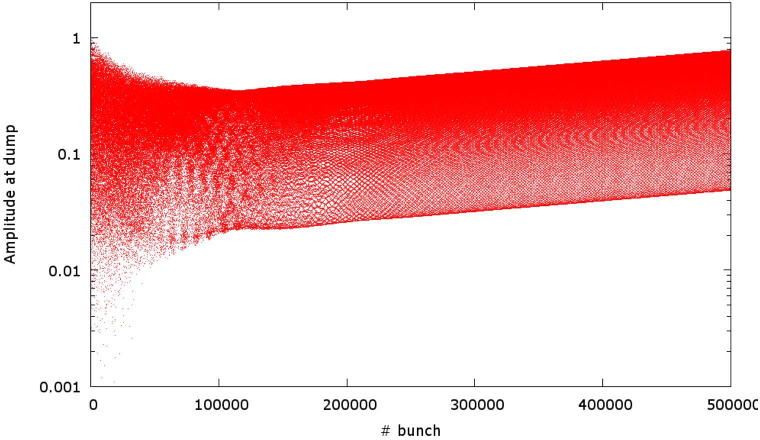
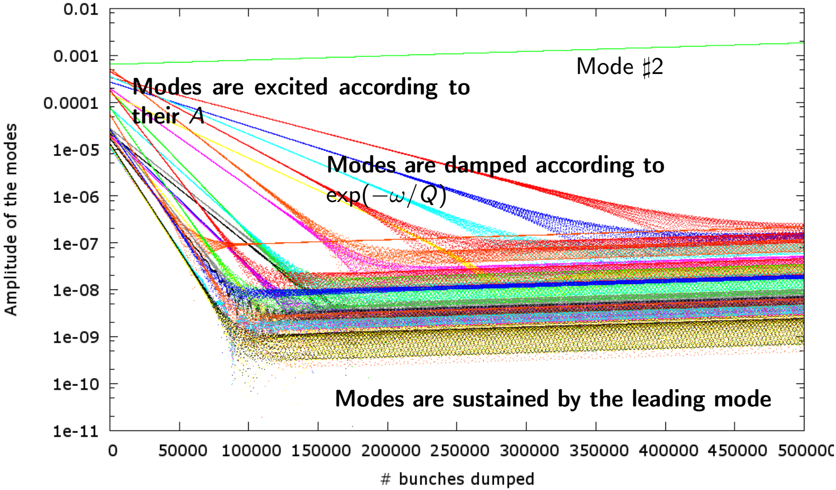
- Simulation technique:
  1. Inject a bunch with some offset → modes excitation.
  2. Inject many centred bunches → look at their orbit excitation (amplitude at dump).

Evolution of the excitation



A look at the modes

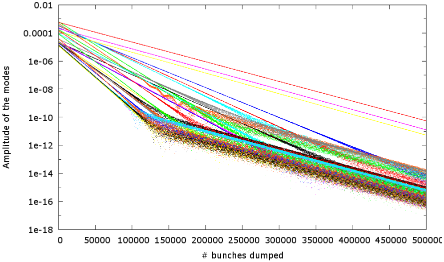
The amplitude of the 26 modes of the cavity is plotted over the same timespan of the previous slide.

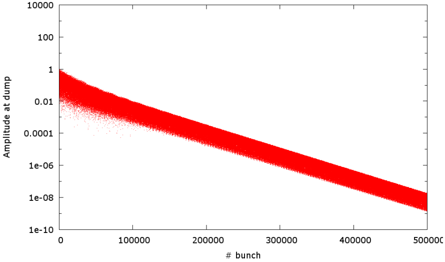


Mitigation of mode ♯2

by matching the return time

$$I_{th} = \frac{2pc^2}{e\omega \frac{R}{Q} Q} \frac{1}{T_{12} \sin(\omega t_r)}$$





- Now the feedback on mode ♯2 is negative!
- The initial excitation is damped;
- Bunches coming later are less effected by it.

First Application to a Real Machine: CTF3[1]

- Techniques for tracking non-linear dispersion and chromaticity are being investigated;
- Detailed simulations of CTF3 Combiner Ring will start soon;
- Achieve the first start-to-end simulation with automatic handling of the recombination process:
  - Reconstruction of the machine model,
  - Measurements of chromatic emittance growth,
  - Machine optimisation,
  - Experimental verification of mode suppression.
- Code will be consolidated;
- Knowledge transfer to the CLIC Drive Beam Complex, and (multipass) Energy Recovery Linacs will follow.

[1] for an introduction to CTF3 please refer to the talks of R. Corsini and F. Tecker

Summary

- New code has been developed to handle the issues related to recirculation:
  - Bunch routing over multiple beamlines,
  - Preservation of the order of bunches,
  - Handling of time-dependent elements,
  - Introduction of a model for Long Range Wakefields;
- Multibunch instability can be investigated even when the bunch train is altered by recirculation;
- Experimental validation is foreseen in the next months at CTF3;
- Applications to CLIC Drive Beam Complex will follow.

Thank You!