Multibunch wakefield effects

Dario Pellegrini (CERN, EPFL)

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Objective:

Give an overview of long-range wakefields in the LHeC

- Why is difficult to compute them in recirculating machines;
- Strategy adopted;
- State of the simulations;
- Impact of many parameters (recombination pattern, detuning, beam-beam) on beam stability;

Long-Range Wakefields and Higher Order Modes

- 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.
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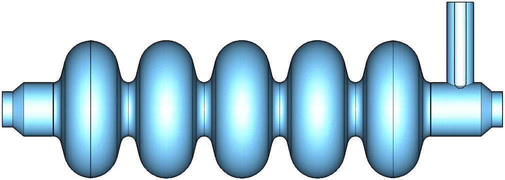
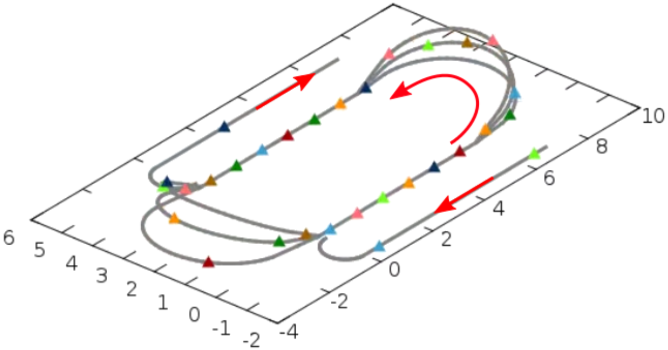


- SPL cavities: 5 cells design at 720 MHz.
- List of HOMs from M. Schuh, all Q-values at TESLA worst.
- Amplitudes are scaled to 802 MHz $\propto f^3$

#	f [GHz]	A [V/C/m^2]	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

The LHeC electron facility



- The current in the linacs is 6 times the one in the injector, arcs, dump;
- Because of recombination, the train structure differs from the injection one;
- Can not perform a straightforward global computation of wakefields effect.

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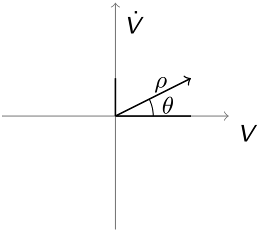

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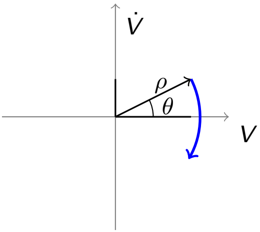

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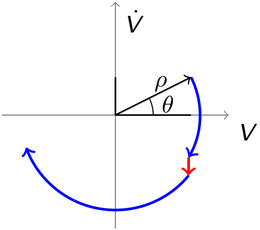
  $\Im(z) = \Im(z_0) + Ne\, A\, L_{cav}\, \delta x$



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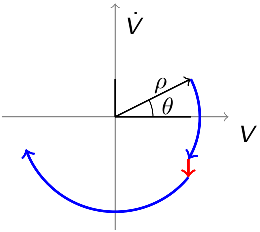
  $\Im(z) = \Im(z_0) + Ne\, A\, L_{cav}\, \delta x$
- Mode → bunch interaction:

  $x' = x'_0 + \frac{e\,\Re(z)}{\gamma\, m_e\, c^2}$

Iterated over all the HOMs of the cavity.



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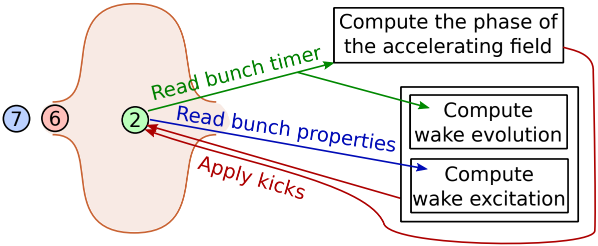

What is currently there in the simulation?

1008.25 m Main Linacs:

- 37 quadrupoles, 25 cm thick, arranged in a FODO lattice;
- gradients scale linearly from 0.21 T/m to 7.88 T/m;
- 16 cavities between each quad, total 576 cavities per linac.

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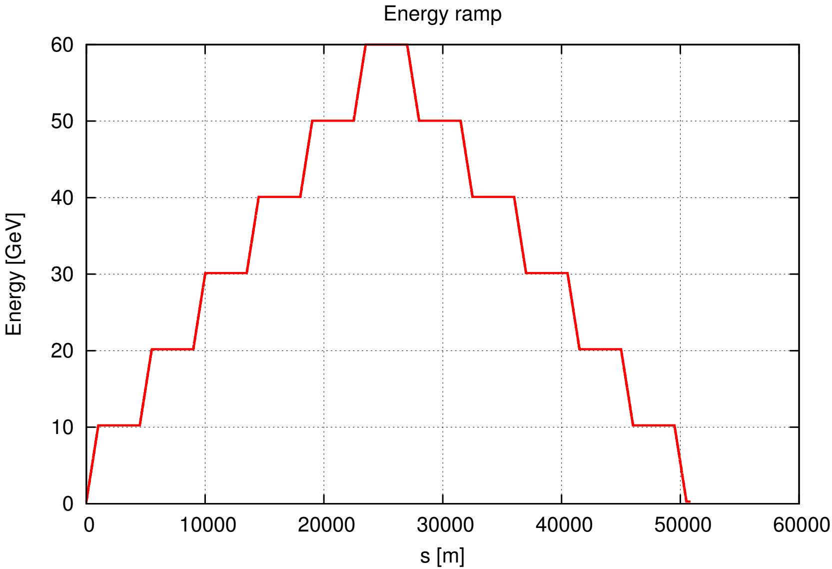
1200 periods at 25 ns = 8994 m in total.

Beam Parameters used in the simulation

	Proton collision	Ion collision
Injection Energy	300 MeV	
Bunch Spacing	25 ns	100 ns
Particles per bunch	2e9	4e9
Normalised RMS Emittance	50 μm	
IP β function	0.12 m	
Injection β_x	11.5 m	
Injection β_y	99.0 m	
Injection α_x	0.43	
Injection α_y	-2.71	
Injection size (σ_x)	1.0 mm	
Injection size (σ_y)	2.9 mm	

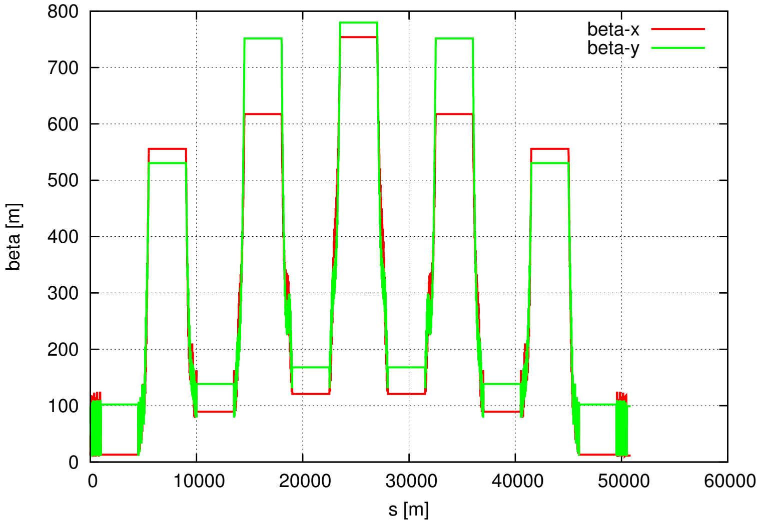
- Injection Twiss Functions are specified at the entrance of the first quadrupole

Energy ramp


Energy ramp
Energy [GeV]
60
50
40
30
20
10
0
0
10000
20000
30000
40000
50000
60000
s [m]

Betatron functions

Achieved through minimisation of β/E



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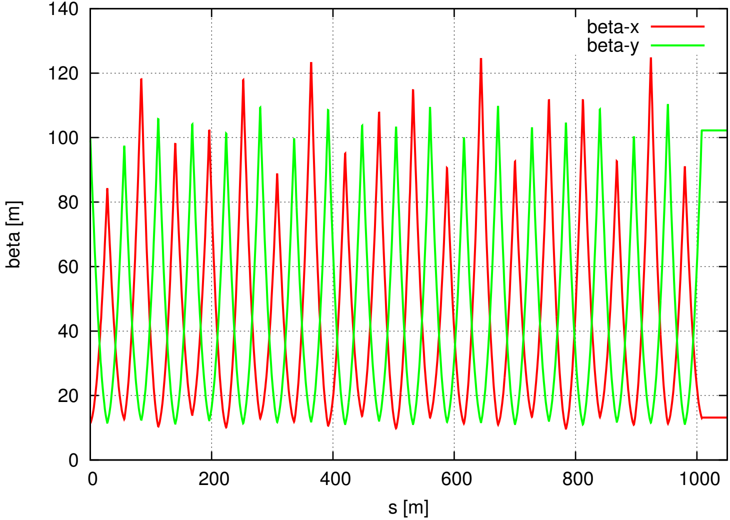
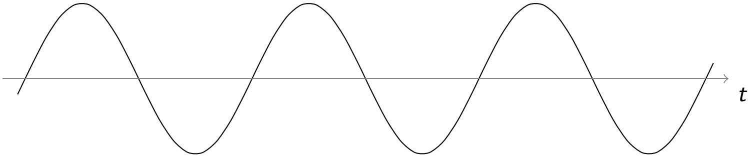


Inspection of beam stability

- Fill the machine with perfectly aligned bunches;
- Enter a misaligned bunch (typically horizontally: $1\sigma_x$);
- Keep injecting aligned bunches;
- Monitor the amplitude of bunches at dump;
- Verify the damping of the excitation introduced by the misaligned bunch.

Pattern dependency (I)

According to the lengths of the arcs, bunches at different turns can be placed into different RF buckets.



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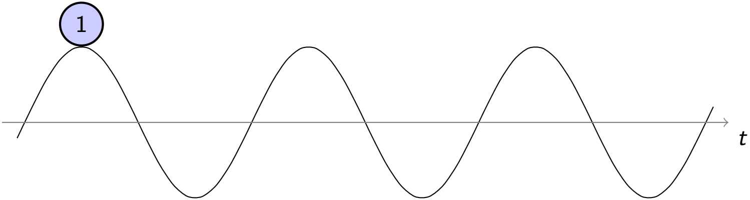

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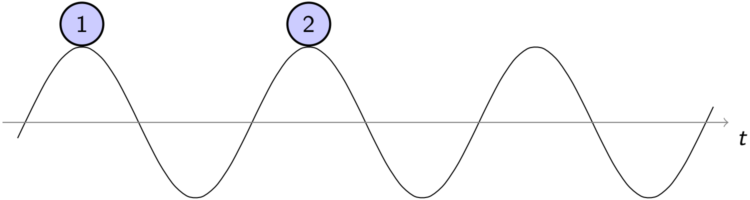

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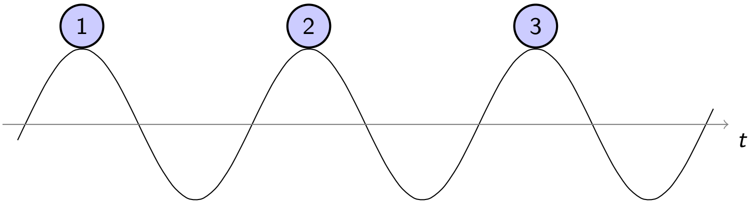

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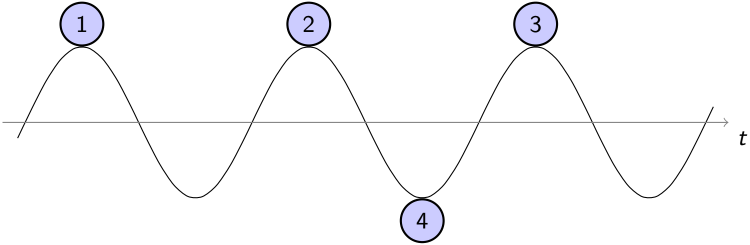

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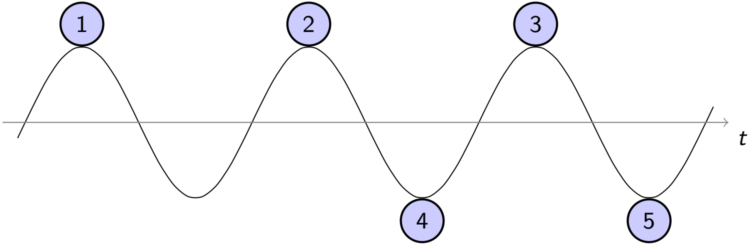

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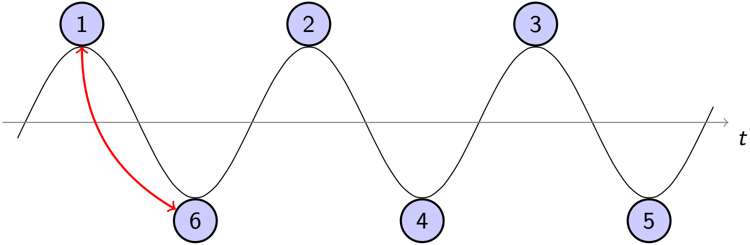

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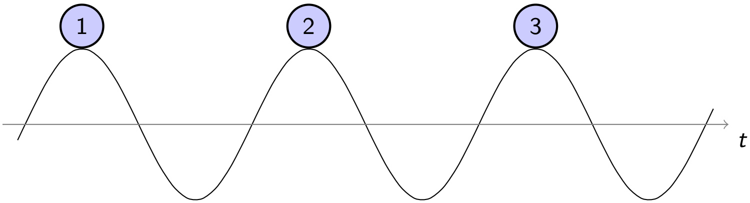

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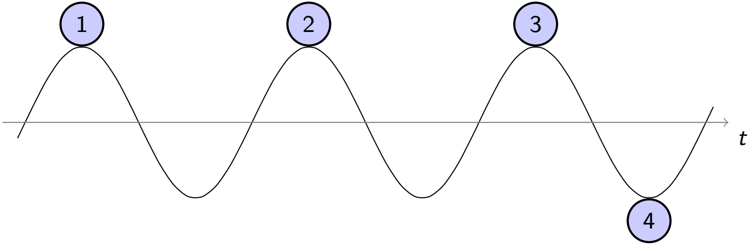

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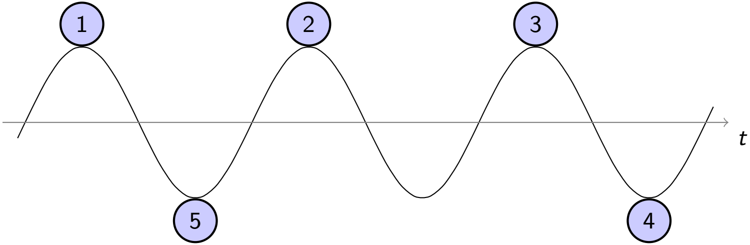

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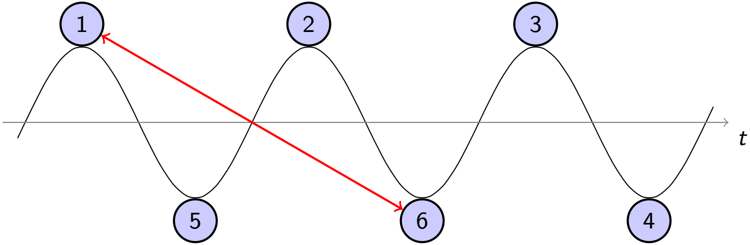

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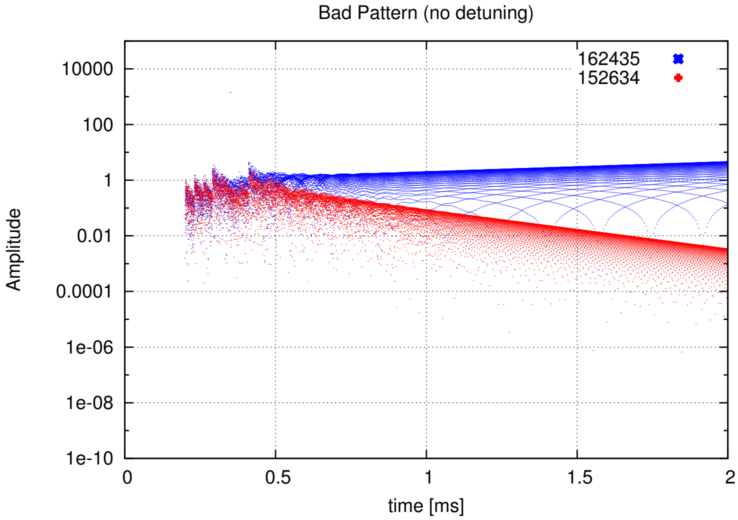
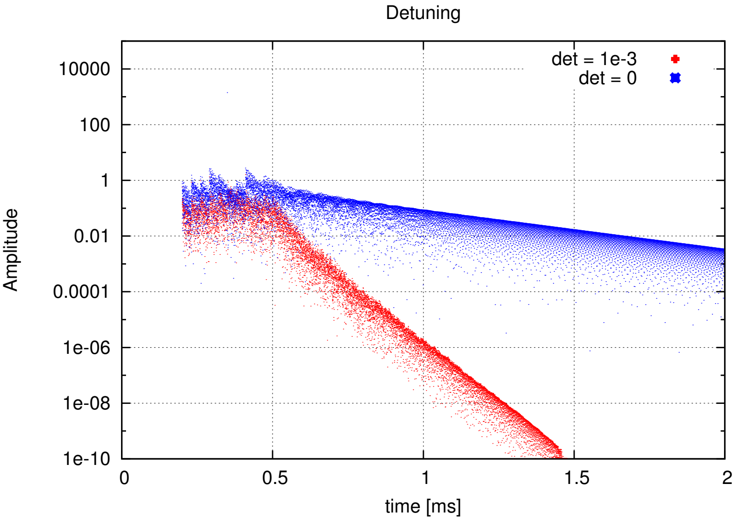
- Pattern 152634 is better!

Pattern dependency (II)

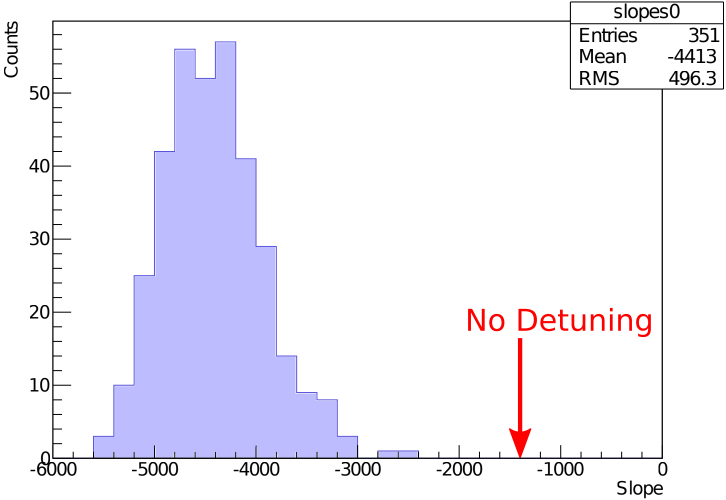


Detuning of the cavities

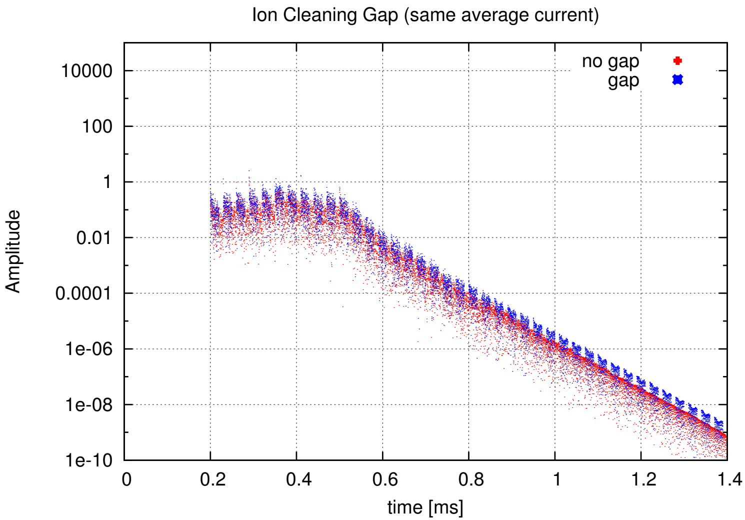


Impact of Detuning

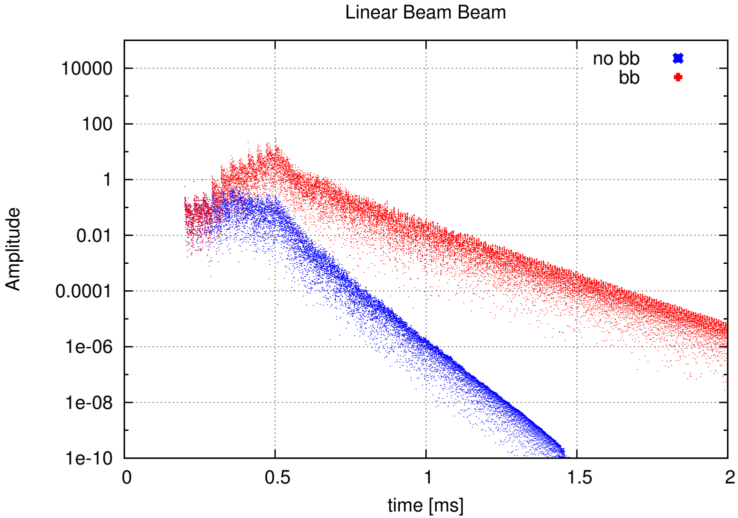
- 351 machines with a detuning factor of $1e-3$ have been simulated.
- The distribution of the slopes of the amplitudes is shown:



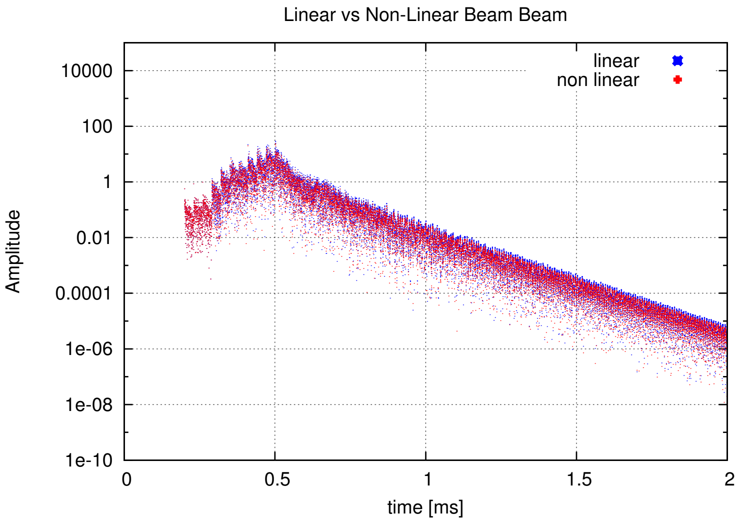
Gaps for Ion Cleaning



Linear Beam-Beam effect



Linear vs Non Linear Beam-Beam effect



Phase advance in the Final Focus

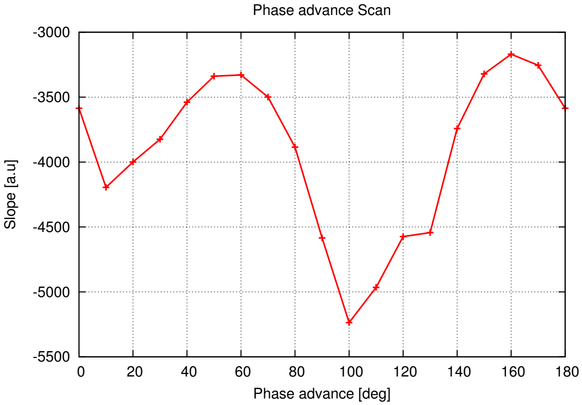
Transport of the beam from the end of Linac 1 to the IP is done with the matrix:

$$\begin{pmatrix} \sqrt{\frac{\beta_{IP}}{\beta_L}}(\cos\psi + \alpha_L \sin\psi) & \sqrt{\beta_{IP}\beta_L}\sin\psi \\ \frac{\alpha_L - \alpha_I P}{\sqrt{\beta_{IP}\beta_L}}\cos\psi - \frac{1+\alpha_{IP}\alpha_L}{\sqrt{\beta_{IP}\beta_L}}\sin\psi & \sqrt{\frac{\beta_L}{\beta_{IP}}}(\cos\psi - \alpha_{IP}\sin\psi) \end{pmatrix}$$

And similar to go back into Linac 2.

- The phase advance ψ does not affect the shape of the beam,
- but it determines how the average offset and angle mix together.
- A scan of this parameter has been done.

Phase advance from Linacs to IP (II)



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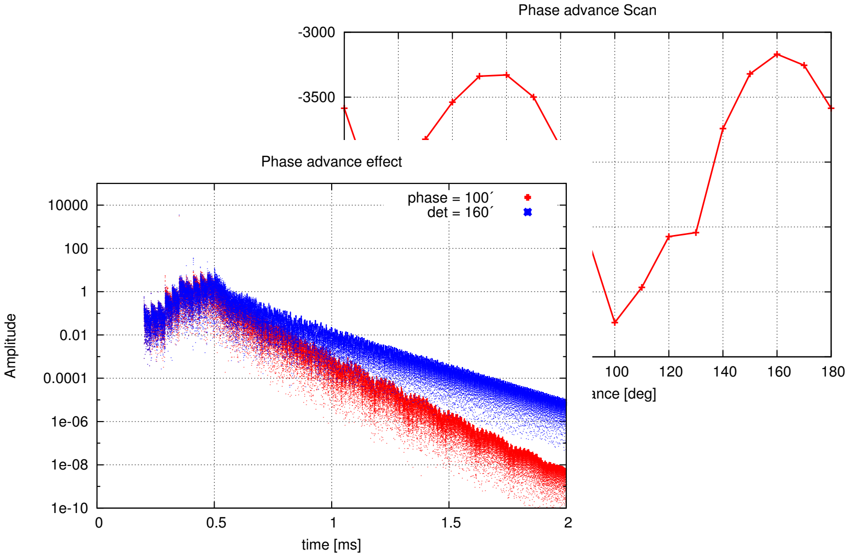
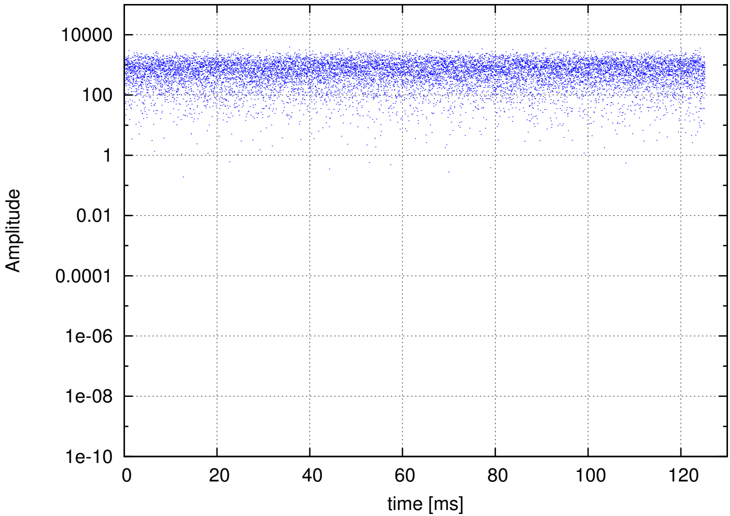
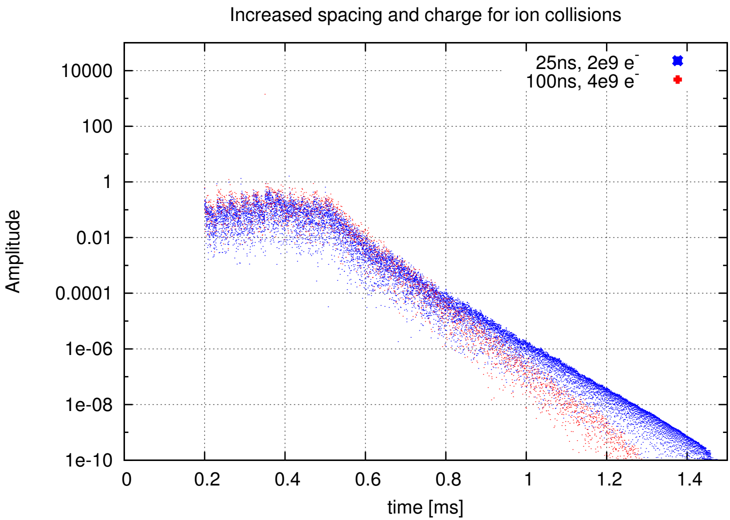


Stability of a Jittering Beam

5 million bunches with incoming offset of 0.1 σ_x (cuts at 0.5 σ_x). The beam does not show any breakup.



Ion collision setup



Summary

- A model for dipolar long-range wakefields has been implemented into a tracking code for recirculating machines.
- The FODO in the linacs has been optimized to reduce the effect of wakefields.
- Many cases have been explored verifying the impact of different bunch trains on the stability, with the cavities scaled at the new frequency of 802 MHz.
- The impact of the beam-beam has been investigated.
- The threshold current that indefinitely sustains an excitation is reached at 25 ns spacing with about $7e9$ particles per bunch, more than tree times bigger the charge foreseen.
- **The currents foreseen for the LHeC are safe within this context.**
- Additional HOM dampers could give a better margin.
- Future works may:
  - add the impact of element misalignments and study a good correction;
  - study the coupling with ions cloud;
  - include longitudinal effects (required arc optic);
  - ...