Front-End-Simulation Aspects of Beam Dynamics

LHeC Workshop 2017, CERN

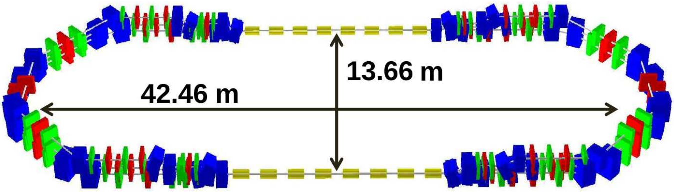
Dario Pellegrini (CERN)
for the LHeC Machine Study Group

Sept 12th, 2017

Scope of the Talk

- Review the *tracking* studies (CDR lattice),
- Stress various *beam dynamics aspects*,
- *Projections* to the new compact lattice.

CDR Lattice



PERLE

Powerful Energy Recovery Linac for Experiments

Conceptual Design Report

to be published in J.Phys.G

CELIA Bordeaux, MIT Boston, CERN, Cockcroft and ASTeC Daresbury, TU Darmstadt, U Liverpool, Jefferson Lab Newport News, BINP Novosibirsk, IPN and LAL Orsay

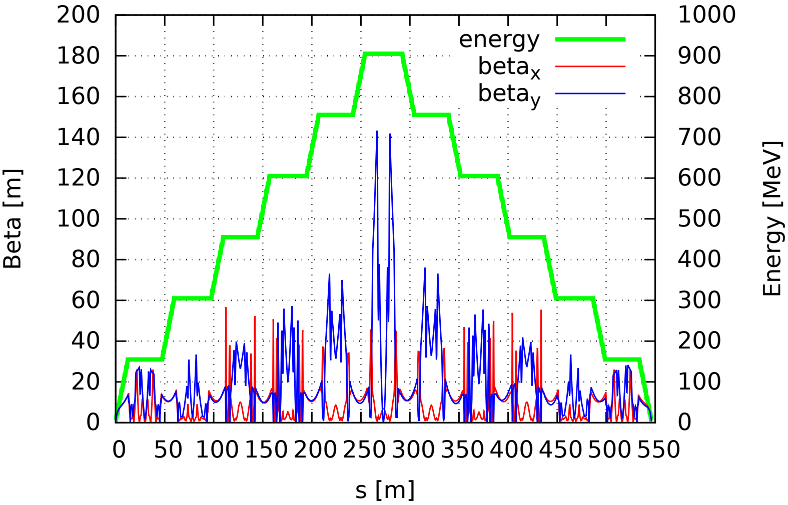
May 13^{th}, 2017

PERLE → PERLE@Orsay:

- Only one cryomodule per linac (16 → 8 cavities).
- Review of the low energy arcs for higher filling factor after dropping the highest energy ones.
- Footprint reduction by a factor ≈ 2

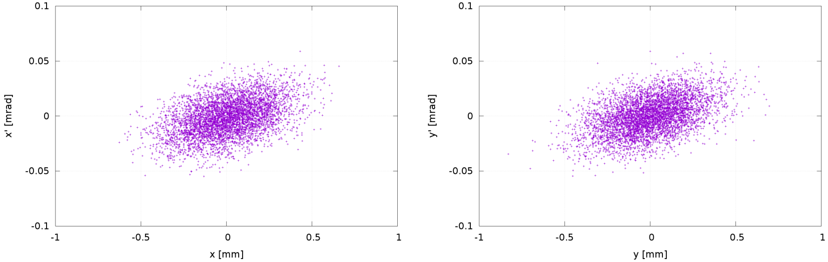
More details in A. Bogacz's talk.

End-to-End Optics from Tracking



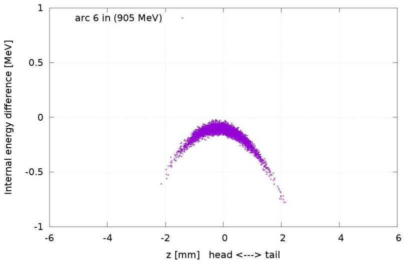
- Optics extracted from tracking simulation
- Well matched optics from injector to dump
- RF focussing from standing waves cavities plays an important role

Transverse Phase Space at Dump



- Very linear Phase Space.
- Need to include perturbations: especially CSR and lattice imperfections.
- Need to study the impact of the beam application (eg laser scattering) on the deceleration.

Longitudinal Phase Space



- The isochronous arcs preserve the longitudinal phase space.
- Small chirp at the dump: need careful matching of the arc length.
- 0.6 mm bunch length, 3 mm also achievable with <1% RF-induced energy spread.
- Possibility to tune R_{56} and RF phase (by arc length adjustments) to perform longitudinal gymnastics.

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1	150	0.0428	0.0000189
2	300	0.685	0.0001077
3	450	3.468	0.000304
4	600	10.961	0.000648
5	750	26.762	0.001180
6	900	55.494	0.001939
7	750	26.762	0.002557
8	600	10.961	0.003254
9	450	3.468	0.004381
10	300	0.685	0.006600
11	150	0.0428	0.013214
dump	5	0	0.40729 **< 1%**

Bending radius $\rho = 0.523$ m

A. Valloni

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≈150 KeV lost = 1‰ energy difference in the arc at 150 MeV: not really an issue, will be smaller for PERLE@Orsay.

Coherent Synchrotron Radiation

$$P = x\frac{e^2 c}{\varepsilon_0} N^2 R^{-2/3} \sigma_z^{-4/3}; \quad x \approx 0.0279$$

$$\Delta E = P\frac{L/c}{eN}$$

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Energy loss per particle per arc (ignoring drifts):

N	R [m]	σ_z [mm]	ΔE [KeV]
2×10^9	1	1	23.0
2×10^9	1	3	5.3
2×10^9	0.6	1	19.4
2×10^9	0.6	3	4.5

- σ_z =3 mm causes a total loss of 60 KeV, quite negligible,
- σ_z =1 mm causes a total loss of 250 KeV, probably still ok,
- A smaller radius causes less total energy loss, but the process is more violent (energy redistribution, microbunching).

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Some tracking studies performed by A. Valloni (*indico*) to be validated on the compact lattice, no big issues expected.

Modelling the steady state operation

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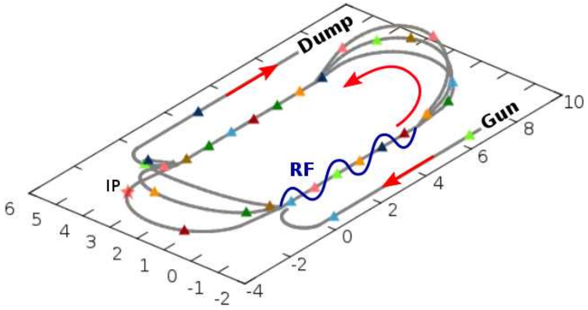

- Continuous bunch injection and extraction,
- Different energy bunches interleaved,
- Placet2 to perform simultaneous synchronised tracking in presence of HOMs.

Beam Recombination Pattern

- Multi-bunch effects $\propto \int_{\text{linacs}} \frac{\beta}{E} \mathrm{d}s$ $\rightarrow$ low energy bunches are more susceptible.
- Arc length tuning $\rightarrow$ control of the RF buckets filling.
- Maximise the distance in the linacs between bunches at turn 1 and 6!

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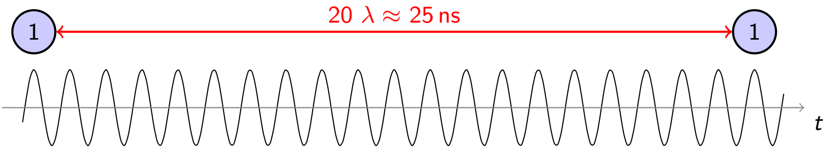

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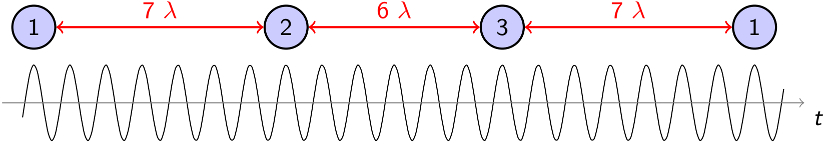

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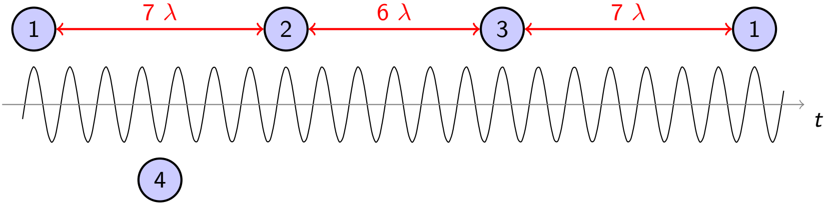

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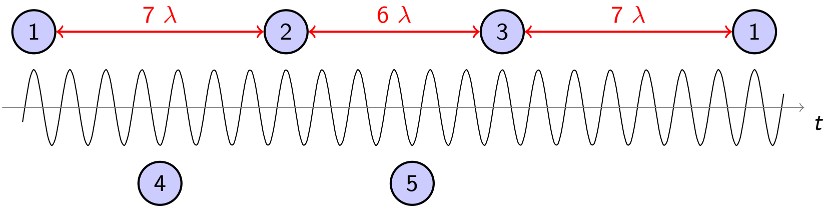

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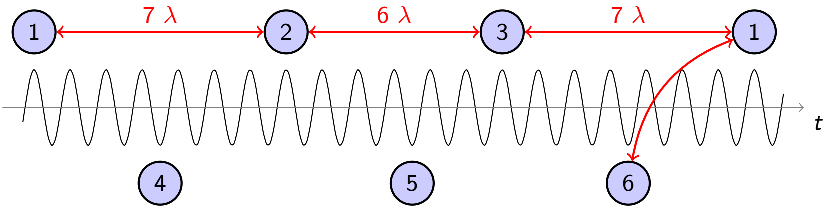

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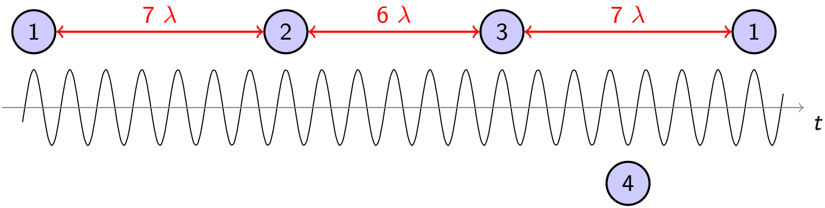

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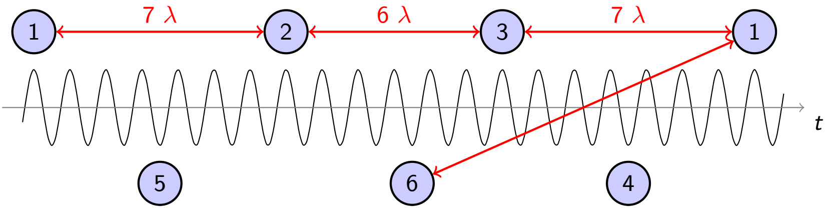

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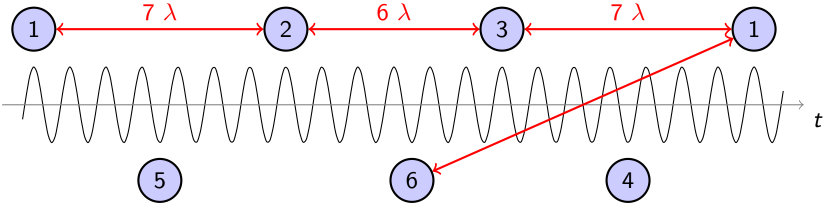

Need flexible arc lengths to test operational schemes for the LHeC:

- Experimental validation of threshold current vs recombination pattern
- Additional tests: eg recombination of all the bunches in the same bucket

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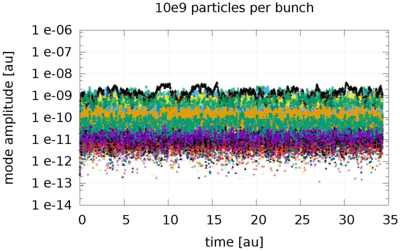

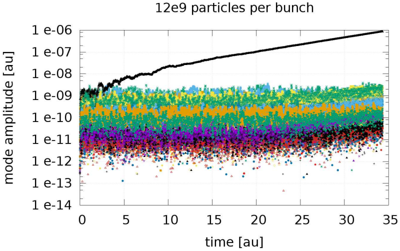

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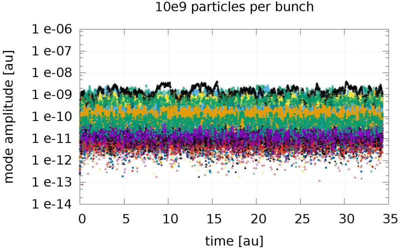

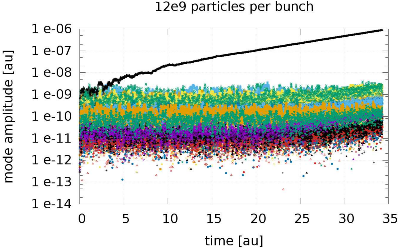

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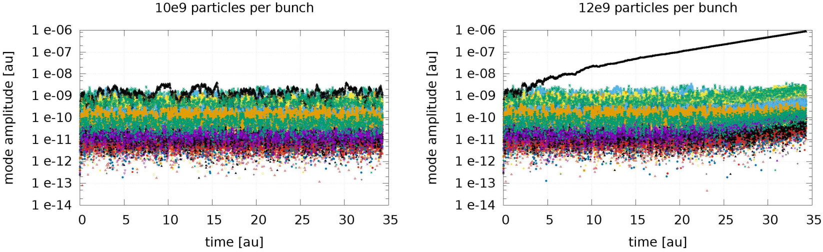

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PERLE@Orsay: less cavities ☺ ; smaller β in the linacs ☺ ; reduced energy ☹ .

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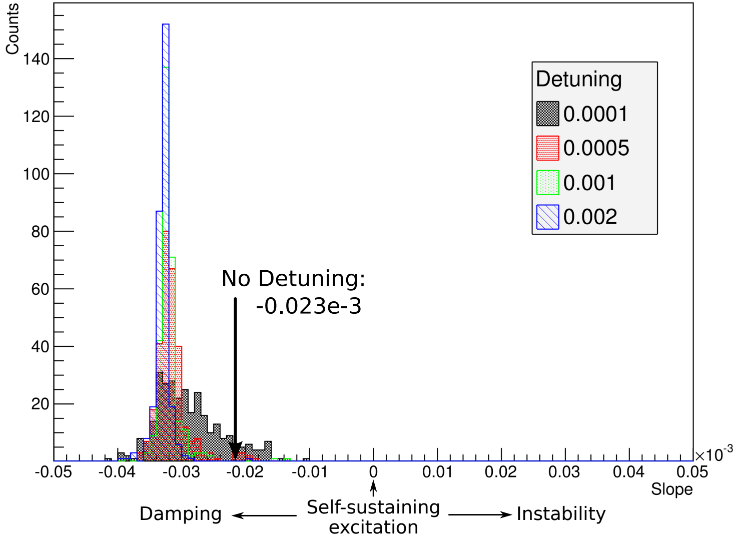

Conclusions and Outlook

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Still a lot of work to be done:

- Enforce the *tracking* studies updating them to the compact version of the lattice (especially HOMs and CSR),
- Check the *momentum* acceptance,
- Establish lattice *tolerances* for beam transport and beam quality preservation,
- Develop an effective way to tune the arc *time-of-flight* (great flexibility required by recombination pattern experiments),
- Study *ion trapping* and fix requirements for ion cleaning,
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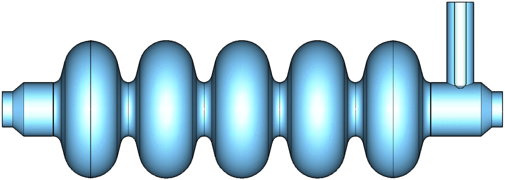
Thank You!

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 ⇒ long-range wakefields.
- Dipole modes are particularly bad as they are strong and easily excited by orbit displacements.



- 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