Studies of decelerator tolerances.

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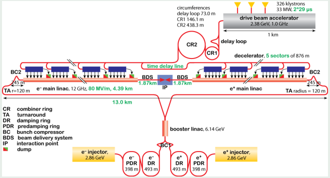
Introduction

Motivation

- Determine tolerances of the drive beam with respect to delivered beam from the DB complex.
- Try and inject interesting types of beams.
- Investigate “worst case” - first decelerator section.

- Main goals:
  - Keep 3σ envelope (“the envelope”) below 3mm.
  - Preserve machine efficiency.

Layout



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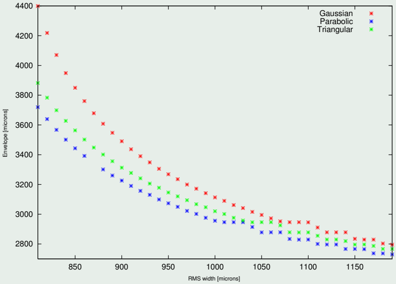
1. Introduction
2. Beam shape and width
3. Phase jitter
4. Studies of the “worst case”
5. Brainstorming/Outlook

Beam shaping

- Inject bunches of various longitudinal shapes (form factors) - vary RMS width.
- Gaussian, parabolic, triangular bunches injected. For each the charge is set to zero outside 3σ, $\sqrt{5}\sigma$ and $\sqrt{6}\sigma$, respectively.



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- The efficiency drops slightly with other bunch shapes.

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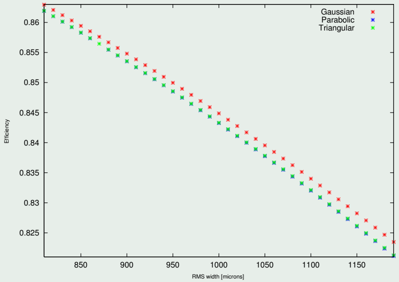

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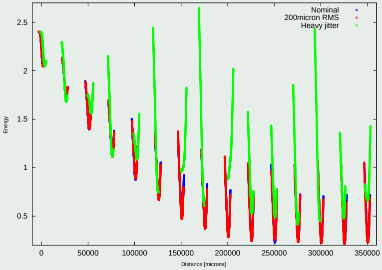
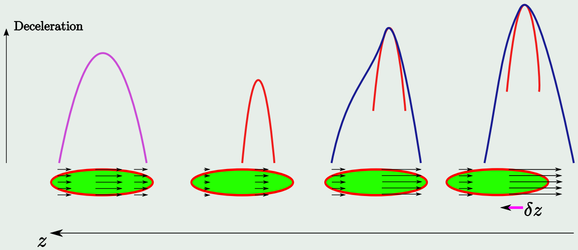
Starting point

Phase jitters

- Observation:
  - With even relatively small longitudinal jitters ($\sim 200\mu m$ RMS $\approx 2.9 degree$), some parts of bunches become more decelerated than nominally.
  - With very large jitters, some particles recive accelerating kicks instead of deceleration.
  - Current Phase tolerance = 0.2degree=13.9μm.
  - Source of more deceleration?

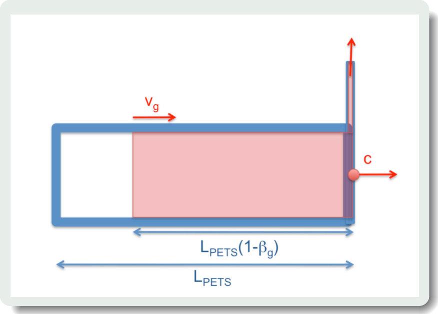


Longitudinal wakefield



- The decelerating wake is the sum of single- and multi-bunch effects.
- The multi-bunch wake peaks at the center of a bunch.
- The single-bunch wake peaks towards the rear of the bunch.

Longitudinal wakefield

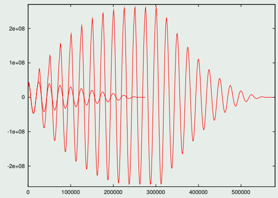


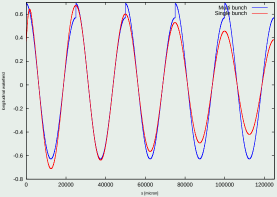
- Three players in the wakefield:
  1.) Emitting slice,
  2.) Field, (velocity $c\beta_g$)
  3.) Pickup slice - distance d away
- $$z_1(t) = ct$$ $$z_2(t) = \beta_g ct$$ $$z_3(t) = ct - d$$
- $$z_2 = z_3 \Rightarrow ct_{catch-up} = d/(1-\beta_g)$$
- $$z_3 = \beta_g d/(1-\beta_g)$$
- The trailing charge only feels the field during a distance

$$L_{eff} = L_{pets} - \beta_g d/(1-\beta_g)$$

Longitudinal wakefield

- Longitudinal wakefield for a (longitudinal delta function) charge.
- $$W_l(d) \propto \begin{cases} \left(L_{pets} - \frac{\beta d}{1-\beta}\right) \cos\left(\frac{2\pi d}{\lambda}\right) & , \quad \text{for } [d > 0] \bigcap [L_{pets} - \frac{\beta d}{1-\beta}] > 0 \\ 0 & , \quad \text{otherwise} \end{cases}$$
- Fill time of $\sim$10 bunches.
- Effect of bunch n on bunch $n + k$ decreases linearly in k.
- Distance from maximum of multi bunch wakefield to maximum of single bunch is 1637μm.
- Expect 7% extra deceleration from a bunch displaced by that amount from field calculation.





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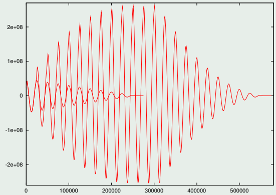

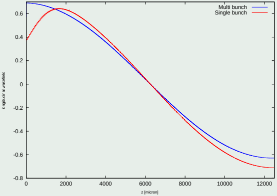

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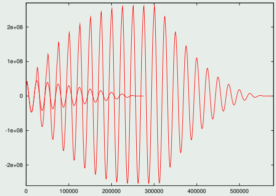
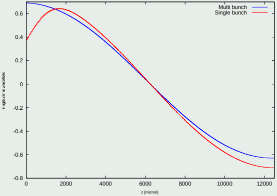
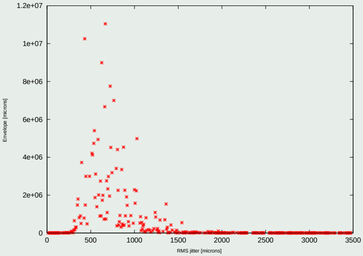




- The envelope of the beam blows up for phase-jittered beams - up to unphysical “meter-scales”.
- The envelope remains relatively small beneath the current 0.2degree tolerance.
- It is confirmed that the excess deceleration is constant throughout the machine - and in the range 0-3.5%
- Some jitters are worse than others - 400-1000μm. above that magnitude of jitter, decoherence of the wake occurs.
- How about “freak” bunches - bunches that have got very large displacements?



Increasing RMS jitter:
Nominal → Enhanced single bunch effects → decoherence.

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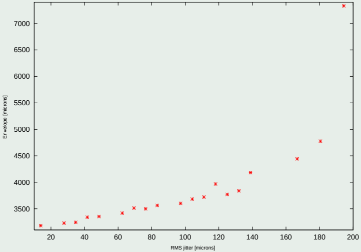

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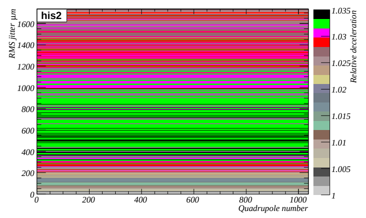

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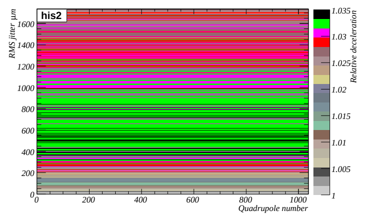

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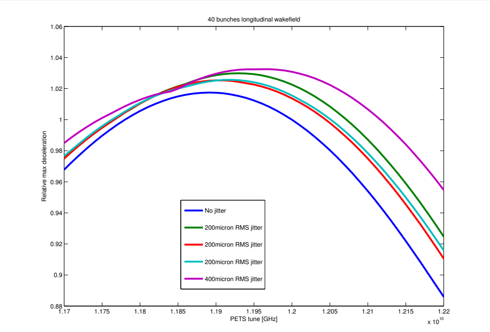
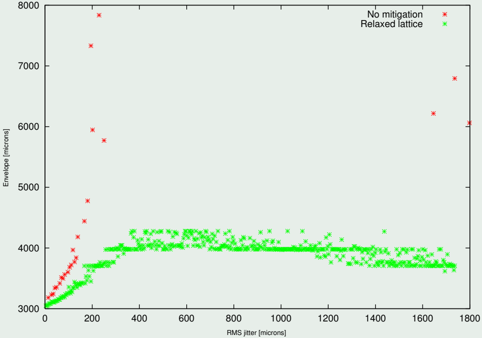
Detuning the cavities?

- Try to detune the cavities away from (towards?) the wakefield enhancement.
- Observe the maximum field.
- Detuning does not decrease sensitivity to jitter (possibly even worse).
- The effect of detuning on machine efficiency has not been studied.



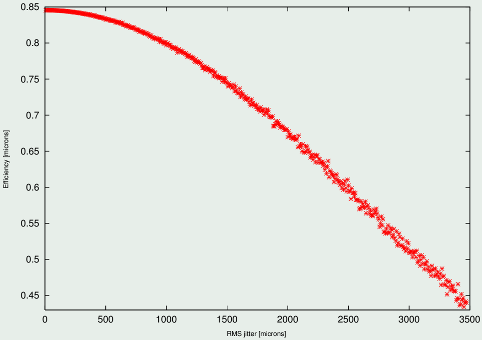
Tapering the lattice

- Relaxing the quadrupole gradient towards the end of the lattice helps.
- This is very preliminary, and can certainly be optimized further.



Efficiencies

- Efficiency: $\eta = \frac{E_0 - \frac{\sum_i E_i N_i}{\sum_i N_i}}{E_0}$ - E_i, N_i measured at the end of decelerator.
- With relatively small changes in efficiency, very large changes in envelope (with nominal lattice) can occur.



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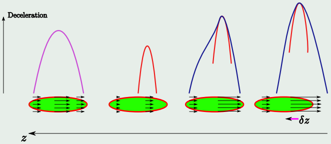
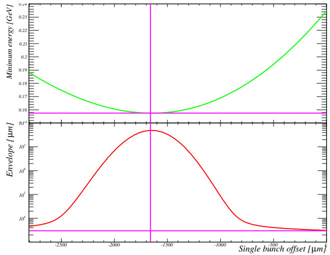
Displacing one bunch in the steady state





- Displace one bunch (in the steady state) to highest max deceleration.
- Chose the 30th bunch out of 32.
- Observe minumum energy after passing decelerator.
- Maximum envelope strongly correlated with offset and minimum energy.
- Maximum deceleration (10μm granularity) observed at an offset of 1660μm.
- Factor 2 growth at ~700 μm offset.

Lattice tapering strategy

- Relax the lattice towards the end to accomodate lower energies.
- The nominal and required quadrupole field strengths are:

$$\begin{aligned} k_0(n) &= (-1)^n A\,(1 - f(n)) \\ k_1(n) &= (-1)^n A\,(1 - Cf(n))\,, \quad C \geq 1 \\ \Rightarrow k_1(n) &= (-1)^n A \left[1 - C(1 - (-1)^n k_0(n)/A)\right] \end{aligned}$$

- The gradient approximately decreases linearly

$$f(n) \approx 0.9 \cdot \frac{n-1}{N}$$

- Due to relaxation of the β-function, the best possible envelope becomes $\sim$4 mm.

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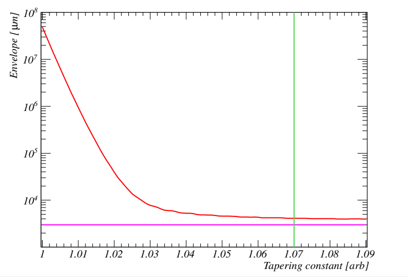

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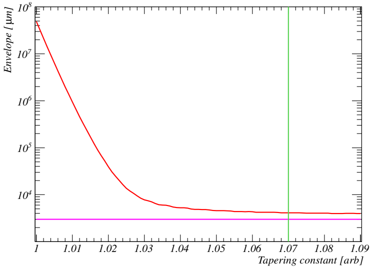
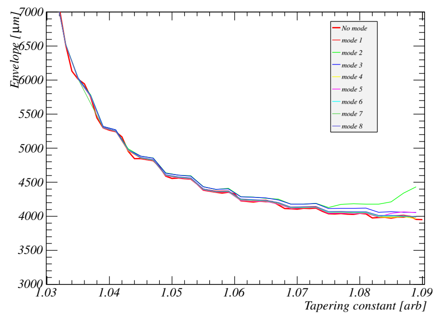


Effects of transverse wakes with lattice tapering

- Drive bunches transversely (in this case, in x) at cavity transverse dipole freqencies.
- Driving transversely at amplitude of 300μm
- Inject only 50 bunches (201 slices) - displace the 30th - maybe more bunches are needed. Preliminary study.
-

Mode number	frequency [GHz]
1	3.95
2	6.92
3	8.50
4	12.01
5	16.40
6	27.41
7	28.00
8	32.82

- Some growth - especially due to mode 2 and 3, but not terrible with 7% tapering.



Increase the energy of the DBA?

- One rather extreme possibility is to increase the DB energy.
- Estimate of needed increased energy to account for extra deceleration (worst case).
- Strategy: Fix gradient at the end of the lattice to nominal value.
- $k_0(N) = k_1(N) + (-1)^N \delta$
- $\Rightarrow \delta = A\left[f(N)(C-1)\right]$
- $\approx A \cdot 0.9 \cdot 0.07 = A \cdot 0.063$.
- Mitigation for worst case requires a 6.3% increase in initial energy.
- Similar decrease in efficiency.
- Studies ongoing - other options are maybe more viable.

Content

Further studies

- Extract info from CTF3 on phase jitter/bunch shape?
- More work on optimizing the lattice to cope with jitter and longitudinal displacement.
- Need to optimize parameters with a constraint on the machine efficiency.
- Additional understanding of the interplay between detuning and phase jitter.
- Can “worst case” occur?
- What are the consequences of the recombination/beam loading compensation?