Brainstorm on a weaker version of DB lattice

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8 February, 2012

Thanks for all the past and future inputs of the CBPM

The question: can we relax the HW of the DB decelerator?

The DB lattice for the CDR is ready

The baseline lattice of the DB is finalized for the CDR: 2.01 m long cell FODO lattice with $\approx 90^\circ$ phase advance.
It is a dense/strong lattice: a quadrupole each meter, i.e. 40K quads for the 2×24 CLIC decerators.

For "post-CDR" brainstorm

We would like to compare this optics with a weaker one. To do that we need to define a proper framework: proper assumptions and figure of merits. A weaker optics will be WORSE for the DB quality, but could be still acceptable and perhaps a better trade-off.

Put it into perspective...

From the CTF3 exps...

From the experimental work done by the CTF3 team is clear that operating an accelerator with a jittering RF source (short/long term) is very difficult.

From the MB simulation...

For a collider the request on the RF stability (read DB) is even tighter. The decelerator has to provide enough acceptance to garantee the required level of stability (7.5e-4 in the gradient).

What does that mean for the decelerator?

Educated guess+assumptions → With a deceleration of 90%, the 3-sigma beam-envelope radius (99.8% of the beam) has to stay below 6 mm all along the longest decelerator (r_{PETS}=11.5 mm) .

How can we reduce the total beam envelope?

In our linear approach:

$$\text{Total Beam Envelope} = \underbrace{\text{Beam Envelope}}_{(\textit{quads})} + \underbrace{\text{beam centroid}}_{(\text{parasitic dipoles})}$$

Due to linearity we use sliced beam in PLACET. All these quantity are function of the decelerator position, of the bunch position in the train and of the slice position in the bunch.

We have to:

1. Make a smart use of the quads (low $< \beta >$)
2. Try to reduce the parasitic dipoles or their effect:
   - good alignement of the machine (pre-align+BBA)
   - reduce the dipole wake effect: RF design + strong optics.
3. (good quality at the entrance: emittance, jitter in position, energy and beam current).

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We have to:

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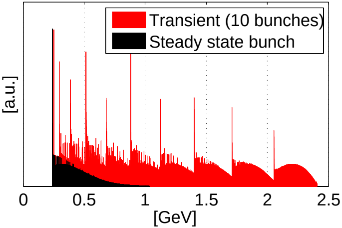
2. Try to reduce the parasitic dipoles or their effect:
   - good alignement of the machine (pre-align+BBA)
   - reduce the dipole wake effect: RF design + strong optics.
3. good quality at the entrance: $\beta\gamma\epsilon = 150\ \mu$m rad, reduced jitter in position, energy and beam current.

We need to transport a beam in a large energy range.
(Fortunately) the beam is dumped after 1 km and we do not need to preserve emittance.

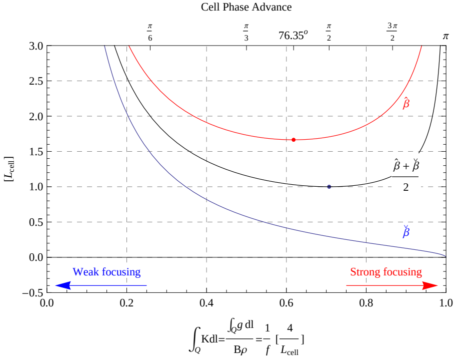


It is known that the off-momentum beta-beating of the FODO cell is relative low so a FODO transport seems natural.

Dimensioning the FODO cell

Rationale for phase advance

- The min envelope (thin lens) is with $\Delta\mu \approx 76^\circ$
- Since $\hat{\beta}$ is very flat around that point, for the dipole wake would be better to reduce the min $\overline{\beta}$ chosing $\Delta\mu = \pi/2$.
- Erik proposed 92.5° to avoid resonance with errors with 4 modules periodicity.

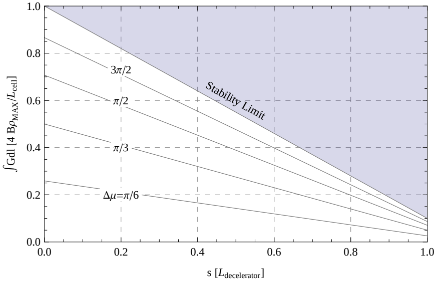


NB: $\overline{\beta} \propto L_{cell}$ and $g \propto 1/L_{cell}$

Dimensioning the FODO lattice

Costant $\Delta\mu$ along the lattice?

- If $\Delta\mu$ constant the gradient has to be reduced during the deceleration. High g at the start of the decelerator.



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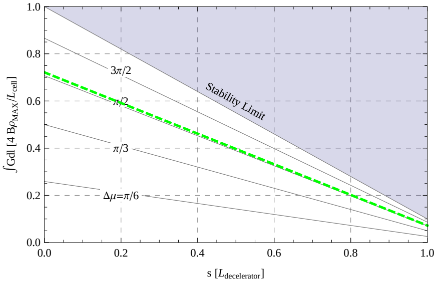

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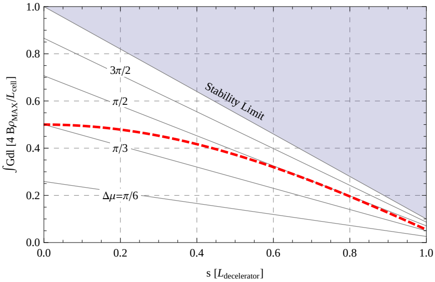
Costant $\Delta\mu$ along the lattice?

- If $\Delta\mu$ constant the gradient has to be reduced during the deceleration. High g at the start of the decelerator.
- We can explore alternative loading curve to relax HW spec (gradient) but reducing the focusing when there is not sufficient decoherence (reduced to ΔE) could produce instabilities.



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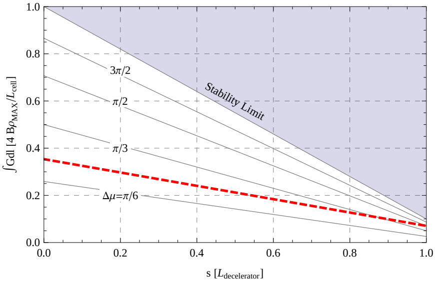

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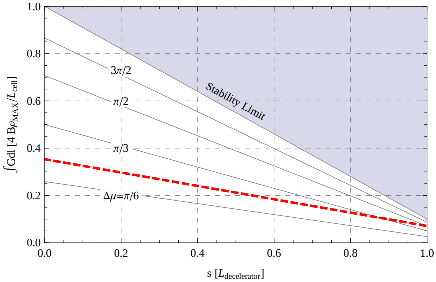
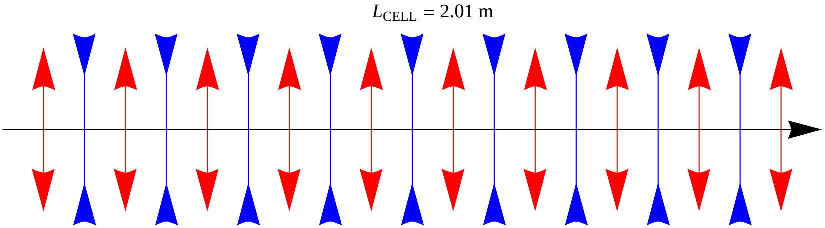


NB: dipole wake studies has to be done even for commissioning scenario (?): a 12 GHz beam with 80% the bunch current could be more prone to unstability due to the reduced ΔE. On the other hand the E is higher in average...

Length of the FODO cell

The key point: the length of the FODO cell.



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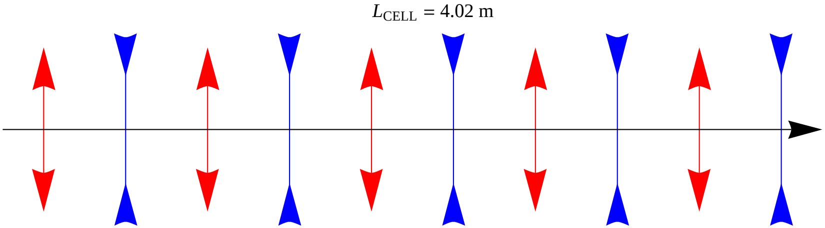

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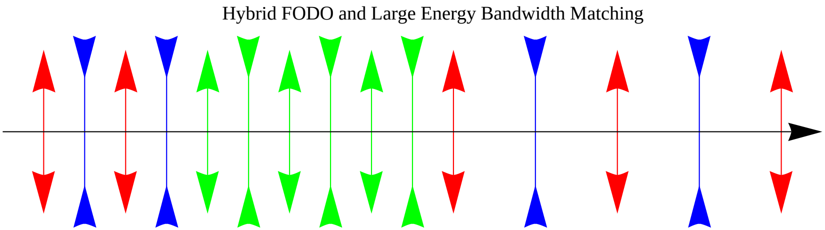

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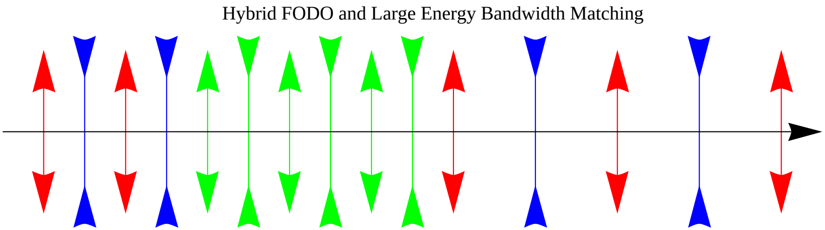


In this presentation we will try to compare the 2 m vs the 4 m lattice (neglecting for the moment the hybrid solution) assuming $\Delta\mu = 92.5^\circ$ (2 m), $\Delta\mu = 95.8^\circ$ (4 m) and costant phase advance along the lattice for the most decelerated particle. We will focus on the methods, the assumptions, the observables and the FoM.

Dipole Wake

We are considering 8 modes of transverse dipole wake field.

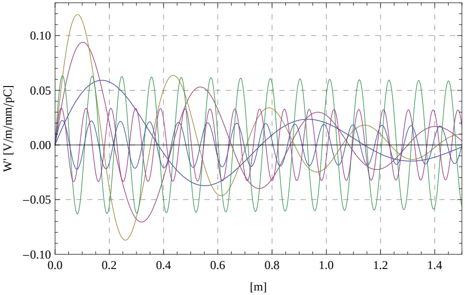
f [GHz]	$\beta_t[-]$	A [V/(m^{2}pC)]	Q [-]
3.95	0.43	73.73	3.40
6.93	0.67	107.83	5.50
8.5	0.7	138.85	5.00
12.01	0.67	3985.5	6.82
16.40	0.56	3369.3	6.30
27.41	0.18	63.4	527.00
28.00	0.03	22.56	156.0
32.82	0.02	33.68	943.00

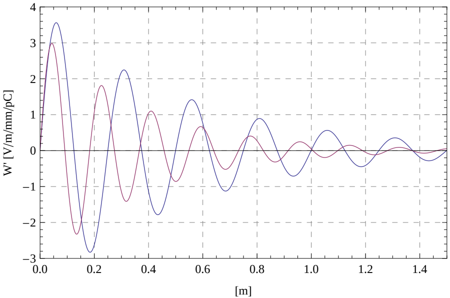
Equivalent magnetic field

$$\int_{s_1}^{s_2} \frac{y_1 q_1 q_2 W'_T}{E_2} ds = \int_{s_1}^{s_2} \frac{q_1 c B_{eq}}{E_2} ds$$

$$B_{eq} = \frac{y_1 q_2 W'_T}{c}$$

$$(q_1 = 8.4 \text{ nC}, \ y_1 = 1 \text{ mm})$$





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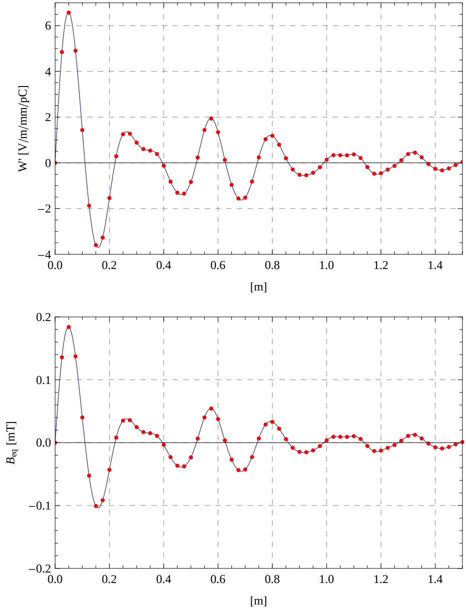
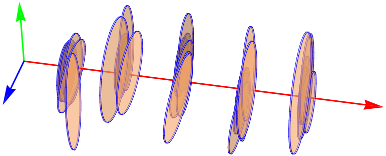
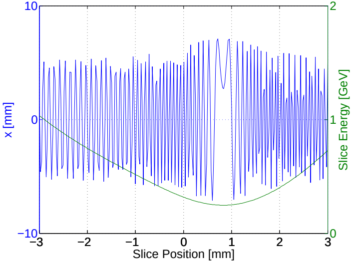


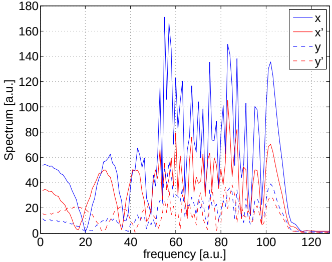
The model of the beam

The sliced beam:



How many slices per bunch? More than 200!





The model of the beam II

At the moment, to explore the formalism, we consider "only" 20 bunches. The linear system can be represented as

$$\begin{aligned} X_{end} &= A \times X_{start} + B \times XP_{start} \\ A(,B) &= D_{A(,B)} + T_{A(,B)} \end{aligned} \quad (1)$$

- X is a (n_{slices} $n_{bunches}$)$\times$1
- D is diagonal (betatron oscillations)
- T is strictly triangular (induced wake, coupling btw slices)

Similarly for the vertical plane.

Together with the information about the intitial β-functions and the slices' energy at the end of the decelerator the Eq. 1 allow us to compute the β-functions at the end (for each slices) and the motion of the centroids. We assume x,y planes decouple. For the moment we are considering only the envelope at end of the decelerator.

The method

Different steps...

1. Once we computed, with PLACET, the matrices A, B, the final energy of the slices (that does not depend on the optics) and the starting β's we have a complete description of the decelerator. But, do we know the spectrum of X, XP?
2. We guess the initial spectrum of X, XP (to be discuss later)
3. We compute the simple envelope and using a MonteCarlo the max 3σ centroid motion.
4. the total beam envelope for each slices is our FoM.

We could even define transfer functions and use them as FoM, or for particular initial distribution we could avoid the MonteCarlo and solve the problem in a semi-analyitical form.

The initial beam spectrum

We do not know the power spectrum of the beam at the entrance. For the slice i we have

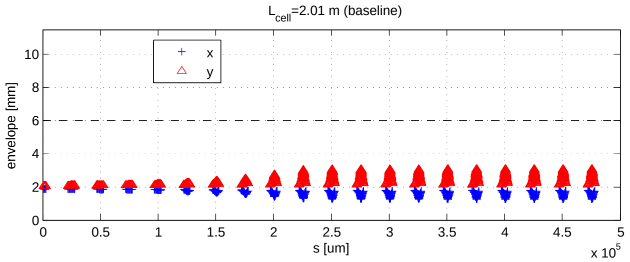
$$x_i = \sqrt{\epsilon_i \beta} \cos(\phi_i), \quad xp_i = \sqrt{\frac{\epsilon_i}{\beta}} \sin(\phi_i) \qquad (2)$$

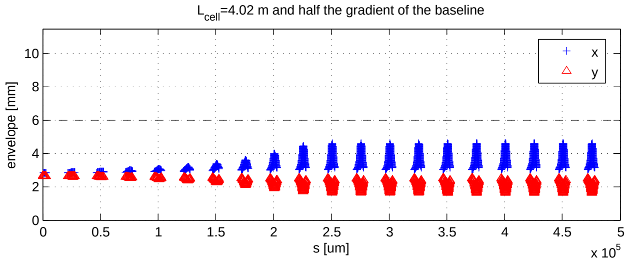
We assume that there are three main mechanisms for producing the initial jitter:

1. misteering of the beam, $\epsilon_i = \epsilon_1$ and coherent phase ($\phi_i = \phi_0$),
2. unclosed orbit in the CRs, $\epsilon_i = \epsilon_2$ and intra-bunch coherent jitter ($\phi_i = \phi_b$, slices belonging to the same bunch have the same phase),
3. intra-bunch white noise, $\epsilon_i = \epsilon_3$ but no particular condition on ϕ_i.

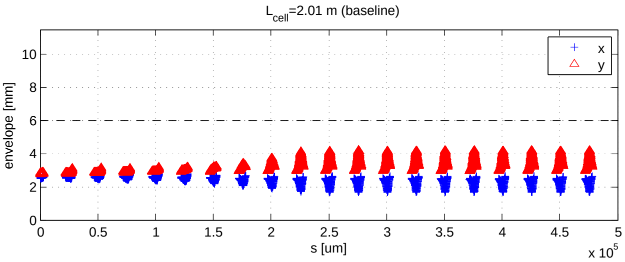
NB: not considering peaks in the input power spectrum that could be produced by wake-fields acting, e.g., in DB linac.

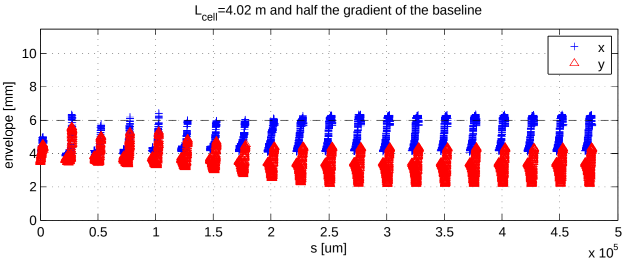
Total envelope ($\epsilon_1 = \epsilon_2 = \epsilon_3 = 0$)



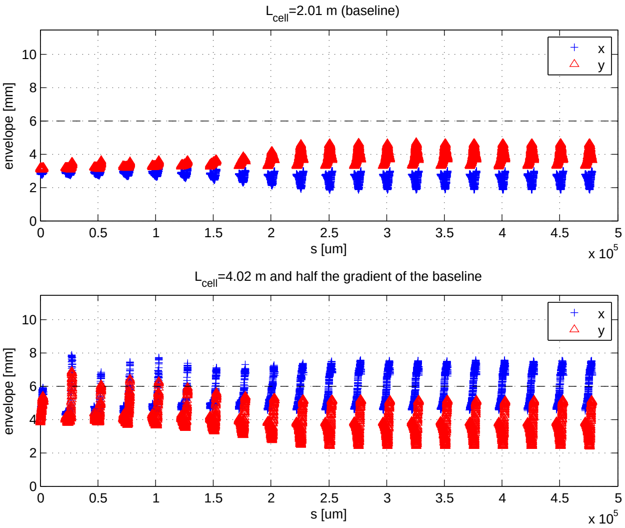


Total envelope ($\epsilon_1 = \epsilon_2 = \epsilon_3 = 15\ \mu$m rad)

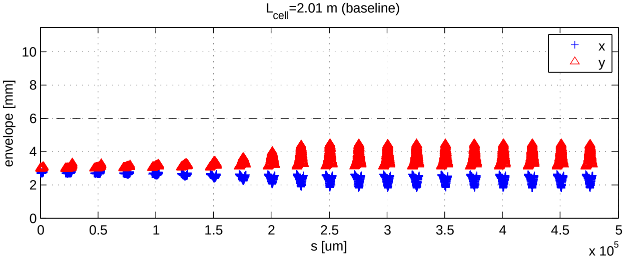


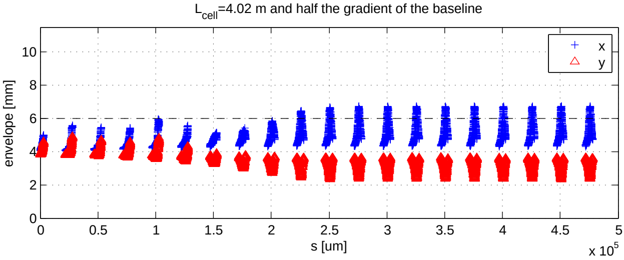


Total envelope ($\epsilon_1 = \epsilon_2 = \epsilon_3 = 30\ \mu$m rad)



Total envelope ($\epsilon_1 = 0, \epsilon_2 = \epsilon_3 = 30\ \mu$m rad)





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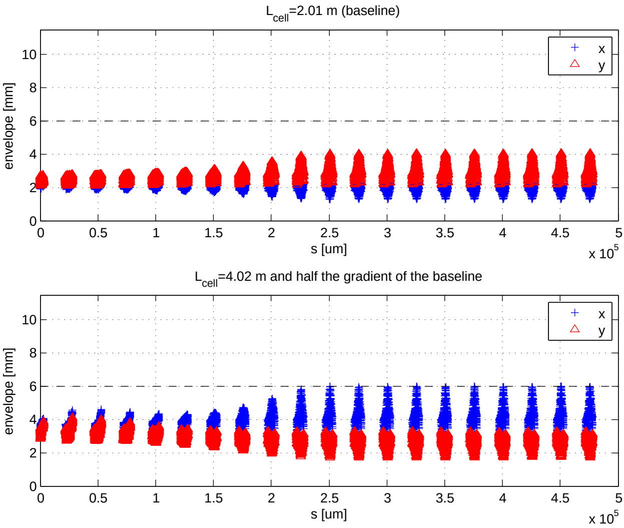
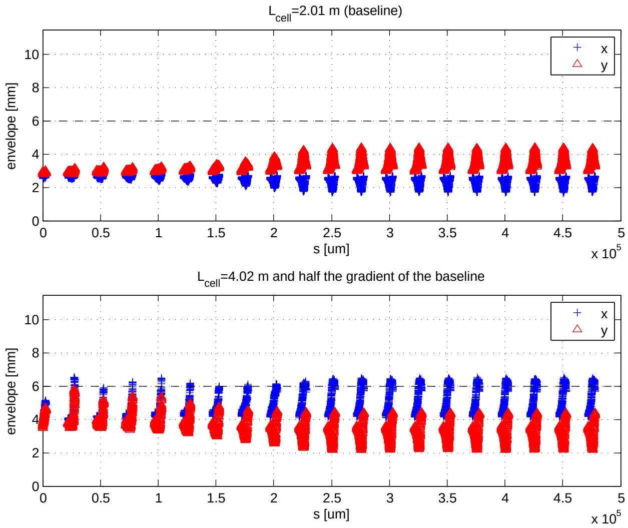
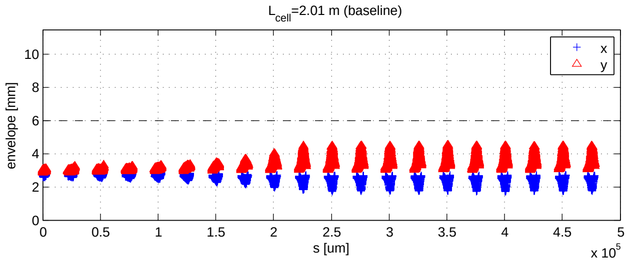
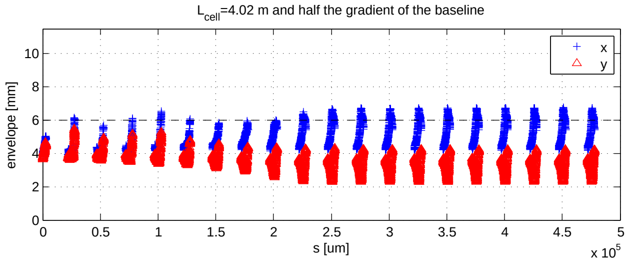


Total envelope ($\epsilon_1 = \epsilon_2 = 15, \epsilon_3 = 30$ μm rad)

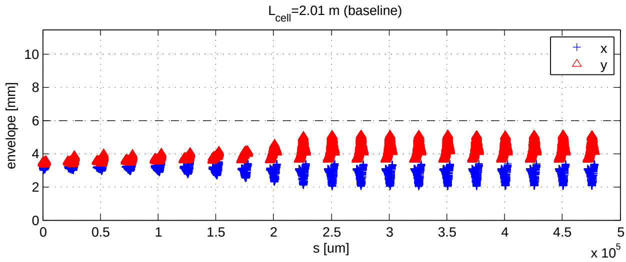


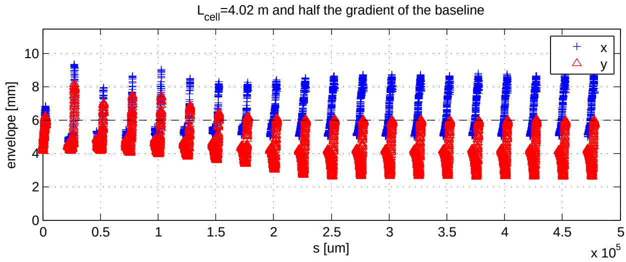
Total envelope ($\epsilon_1 = \epsilon_3 = 10, \epsilon_2 = 30\ \mu$m rad)



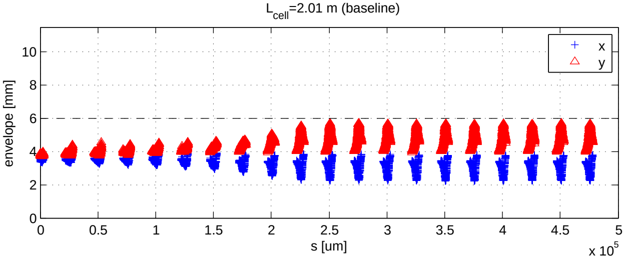


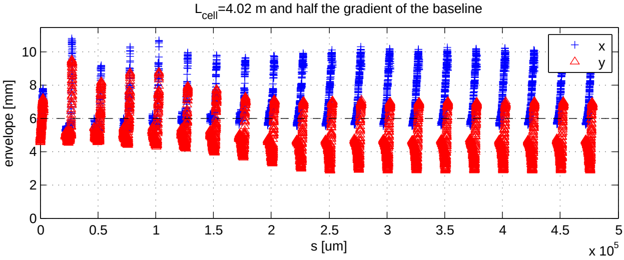
Total envelope ($\epsilon_1 = \epsilon_2 = \epsilon_3 = 50\ \mu$m rad)





Total envelope ($\epsilon_1 = \epsilon_2 = \epsilon_3 = 80\ \mu$m rad)





Summary

- We present “potential” directions to relax the HW the DB lattice requirements.
- To compare the performance of the different lattice we present a possible Figure of Merit and a method for a complete definition of our linear system.
- A critical point is to undestand the “transverse position spectrum” of the incoming beam.
- We present a comparison with a 2 m, 80 T/m lattice with a 4 m, 40 T/m lattice: the strongest lattice can cope with errors 2/3 times larger than its weaker counterpart.

Thank you