Wake field limitations in a low gradient main linac of CLIC

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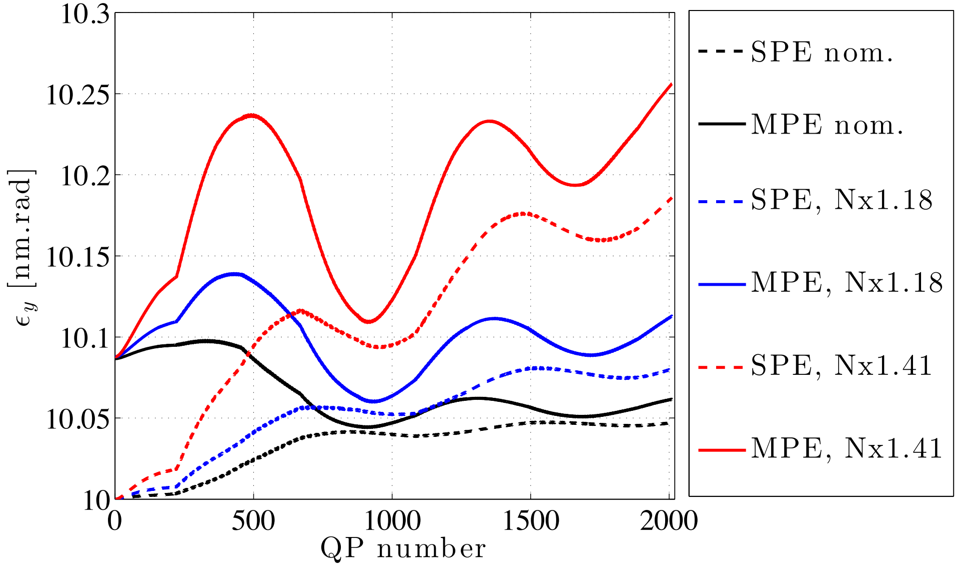
Content



1. Wake field effects in a gradient-scaled main linac
2. Main linac scaling and beam parameters
3. Wake field limitations for initial jitter
4. Wake field limitations for misalignments
5. Conclusions

1. Wake field effects in a gradient-scaled main linac

Purpose of the study

• Optimisation of the acceleration gradient in the main linac of CLIC for the re-baselining

• A change of the gradient also changes linac length, induced energy spread due to RF

• The beam parameters (as charge) have to be adjusted.

• Charge is an especially important beam parameter

Luminosity   RF efficiency   other important parameters

How does the maximal charge scale with the acceleration gradient?

Why is the beam charge so important?

$$\mathcal{L} = H_D \frac{N^2 f_{rep} n_b}{4\pi\sigma_x\sigma_y} = \frac{H_D}{4\pi}\frac{N}{\sigma_x}\frac{1}{\sigma_y}P_{beam} = \frac{H_D}{4\pi}\frac{N}{\sigma_x}\frac{1}{\sigma_y}\eta_{RF}P_{RF}$$

Luminosity spectrum, constant

RF efficiency

RF power

$$\frac{P_{beam}}{P_{wall}} = \frac{R_S I}{G} \quad \rightarrow \quad \eta_{RF} \approx\propto N$$

<u>**What can one do with high charge:**</u>

•When N $\uparrow$ then

1. L $\uparrow$ or
2. if L = const. then $P_{RF}\downarrow$ since $\eta_{RF}\uparrow$

•At the same time, when N $\uparrow$ then $\sigma_x\uparrow$ and therefore

1. $\beta_x^*\uparrow$ (relaxed final focus design) or
2. $\varepsilon_x\uparrow$(relaxed damping ring specifications)

Possible limitations and test cases

Possible limitations:

1. Local wake field kick

- If local wake field kick becomes too large, the BNS damping does not work anymore. At a certain charge N an instability starts to occur.
- K_{loc} prop. $W(2\sigma_z)N$ … local kick
- For $k_{loc1} = k_{loc2}$ => $N_2 \approx N_1(L_1/L_2)$, e.g. for half the gradient $N_2 \approx N_1/2$

2. Integrated wake field kick

- BNS damping does not work perfectly, due to several reasons.
- $k_{int} \propto \int_0^L k_{loc}(s)\mathrm{d}s$ … integrated kick
- For $k_{int1} = k_{int2}$ => $N_2 \approx N_1\sqrt{(L_1/L_2)}$, e.g. for half the gradient $N_2 \approx N_1/\sqrt{2}$

3. Incoherent kicks due to misalignments

- For incoherent kick and therefore oscillations BNS damping does not work very well.
- $k_{incoh} = \sqrt{(k_1^2+k_2^2+ \dots k_n^2)}$ … incoherent kick
- $k_{incoh1}/k_{incoh2} = \sqrt{(L_1/L_2)}$ => $N_1(L_1/L_2) < N_2 < N_1\sqrt{(L_1/L_2)}$, e.g. for half the gradient $N_1/2 < N_2 < N_1/\sqrt{(2)}$

Test machine:

- Machine that has half the gradient and is twice as long as the standard main linac

Test imperfections:

1. Initial jitter: tests local and integrated WF limits: 1% emittance growth (10% σ_y and σ_{yp} jitter)
2. Misalignments: tests local and incoherent WF limits, simulated via 20 time steps of ground motion D with QP stabilisation V1 (approximation of the action of orbit feedback).

2. Main linac scaling and beam parameters

Lattice scaling

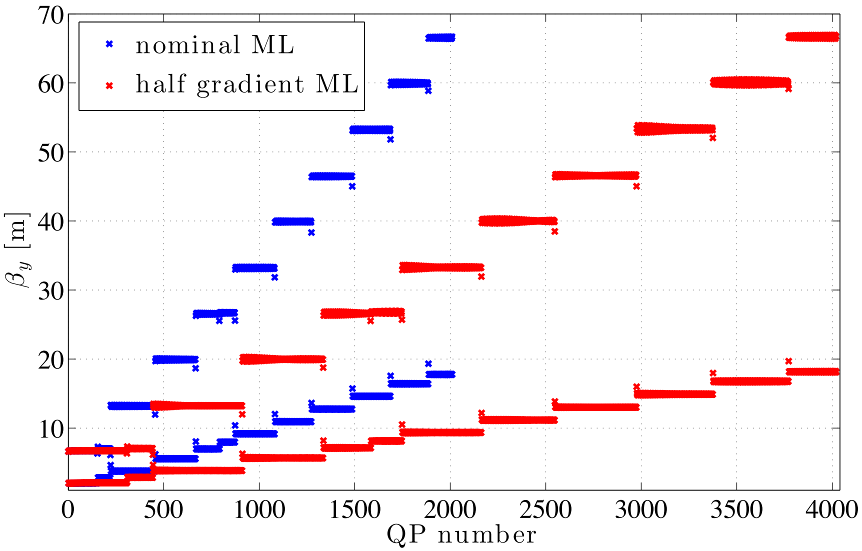
- The 12 sectors have been prolonged by a factor, by putting more original FODO cells

- Also the number of cavities per decelerator and the number of cavities running at the specified phase have been scaled.

- The scaling is available in the Framework of Jochem and me:

```
set use_linac_scaling 1
set linac_scaling_factor $factor
```

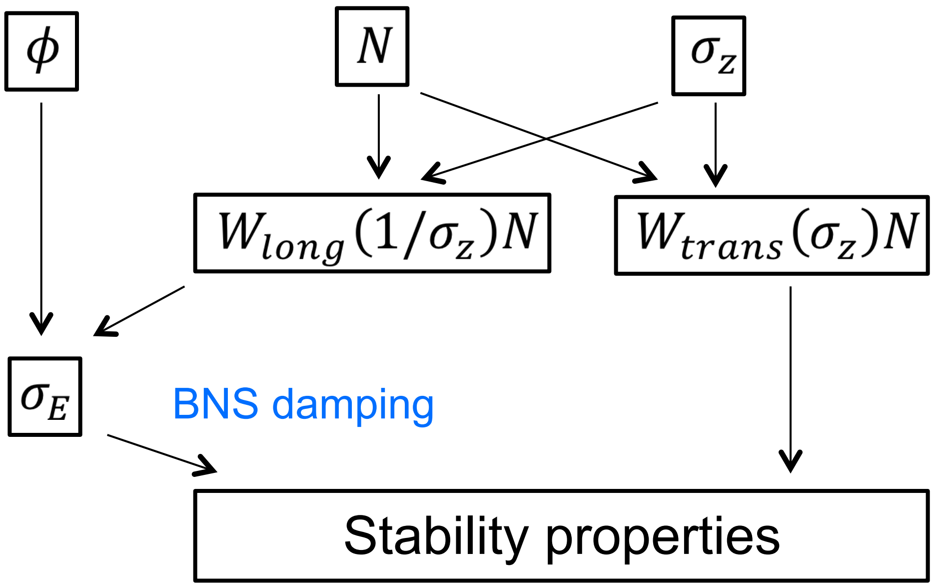
The rest is done automatically, (e.g. change of gradient



svn co svn+ssh://[username]@svn.cern.ch/reps/clicsim/trunk/CLIC/

Overview of the beam parameter choice

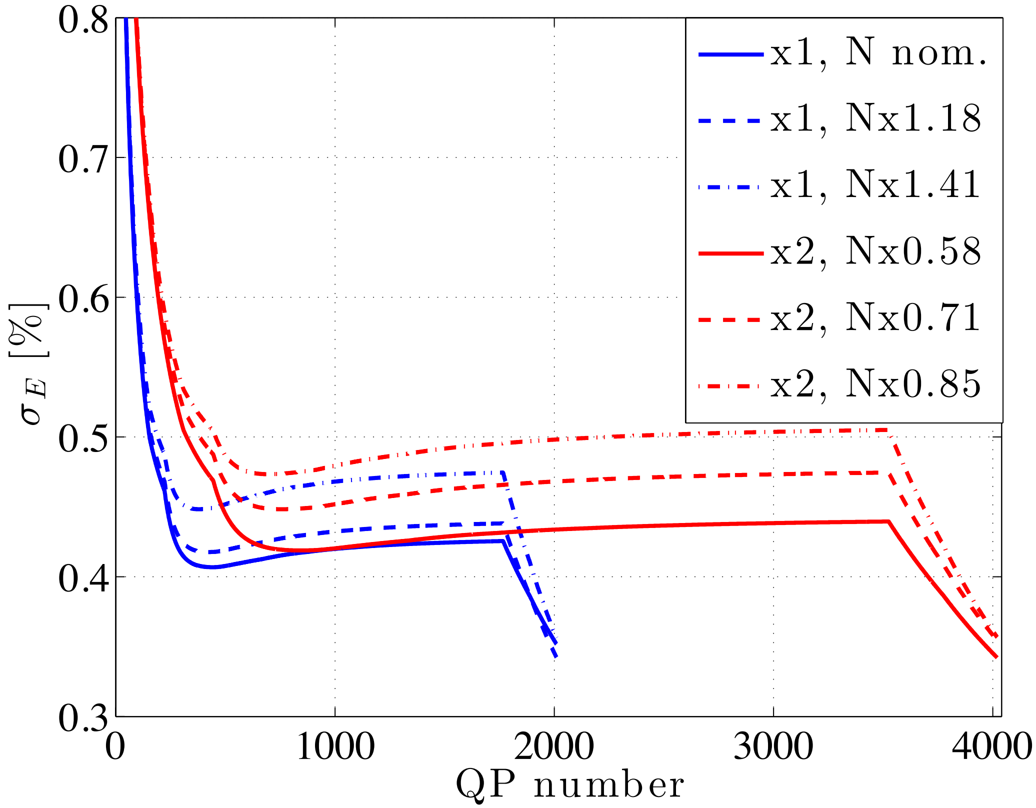
- Charge cannot just be increased!
- To create a proper energy spread along and especially at the end of the linac also the bunch length has to be changed



Recipe to find *N* and σ_z:

1. σ_E has to be kept small for a the BDS (0.35%)
2. ϕ is limited by not increasing the linac length too much (8 degree)
3. Combinations of N and σ_z can be found to fulfill create this σ_E. These combinations can be found with an iterative approach (script from Daniel)
4. Which combination can be used (N_{max}) has to be determined via simulations (my task)

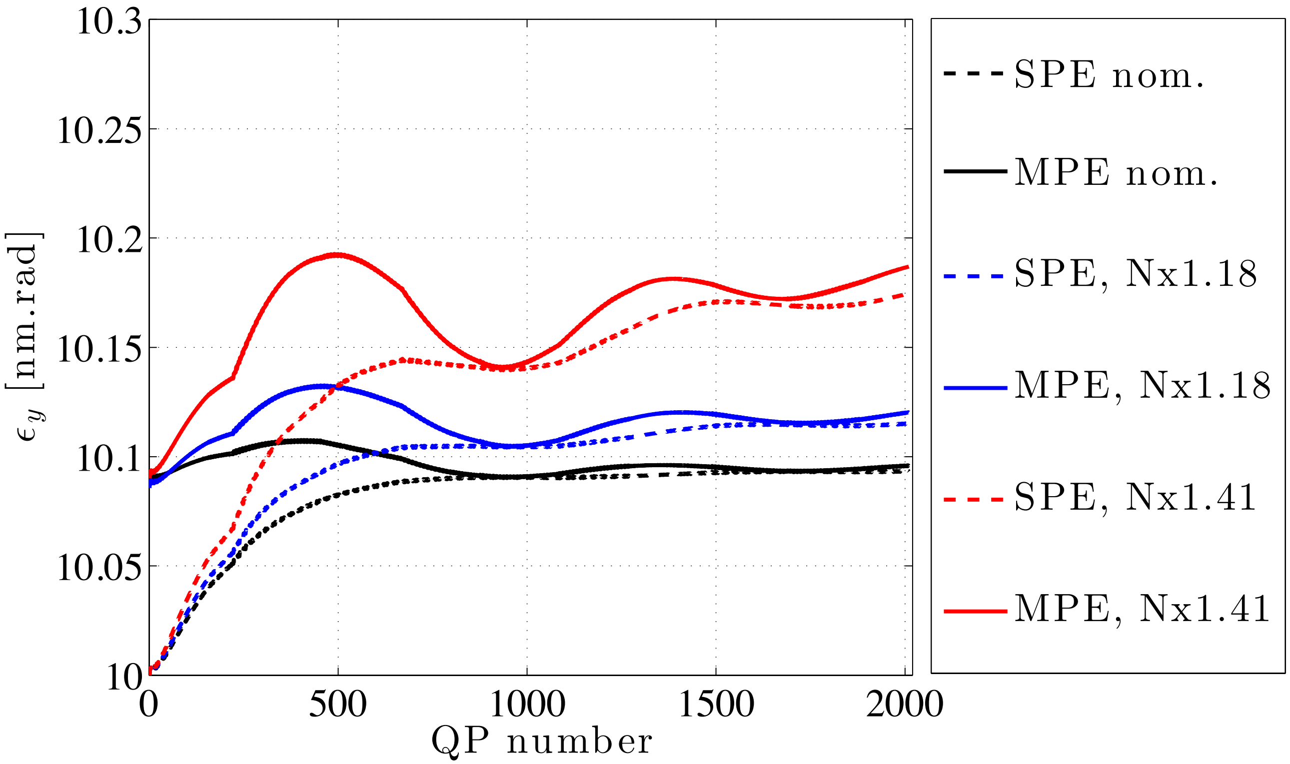
Comments to the created energy spread



- Due to the change of the bunch length with a change of the charge, the RF acts differently in the beam.
- The energy spread is not the same for the different charges, to reach the same final energy spread.
- Higher average energy spread for higher charges will help for the BNS damping.

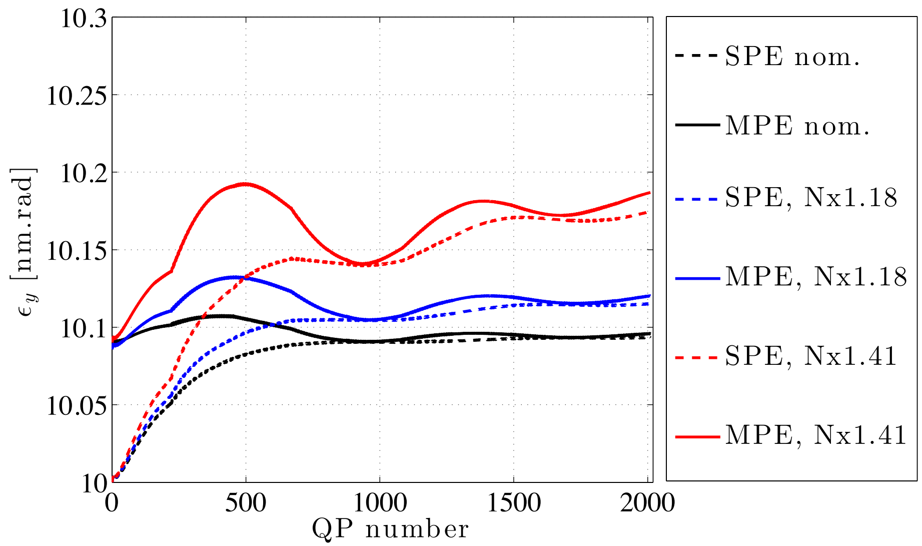
3. Wake field limitations for initial jitter

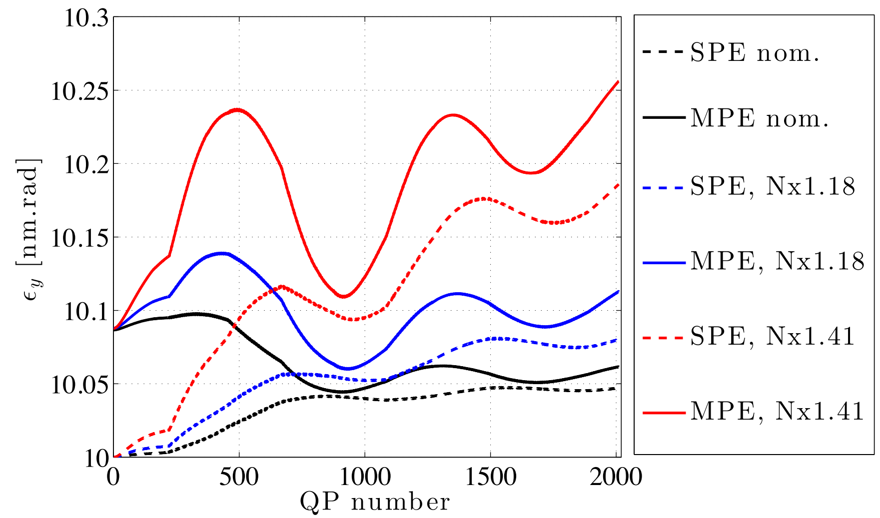
WF effects in the standard ML



- For nominal charge N, no amplification of initial beam jitter
- For 18% more charge already a small amplification visible
- For 41% more charge amplification of jitter effect by a factor 2
- ML design stays in regime were no WF amplification is observable (security)

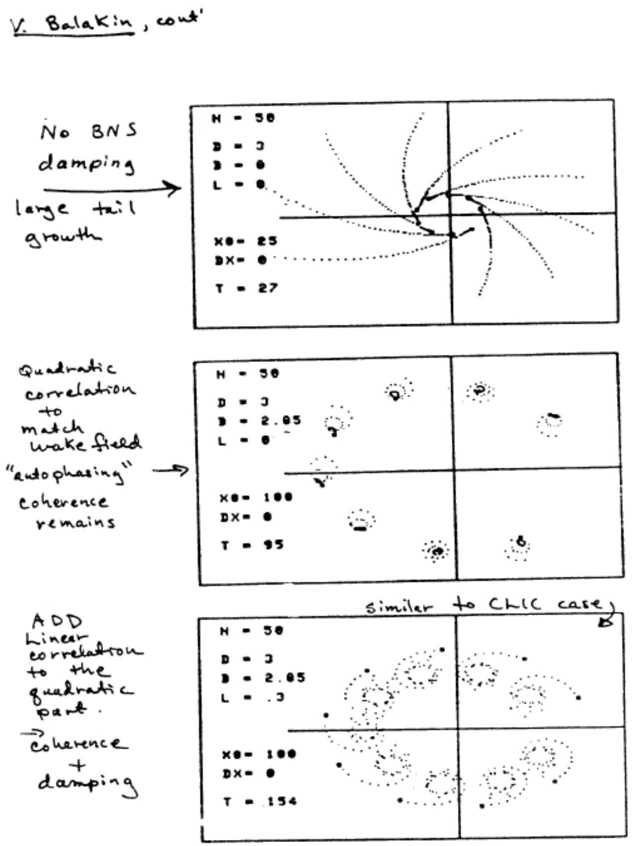
WF effects in the standard ML without initial incoherent energy spread





- Without initial uncorrelated energy spread (right), the initial filamentation does not stop the "natural" wake field influence on the beam propagation.
- In the nominal CLIC case, the initial oscillations would be are actually damped.
- It seems to be possible that oscillations are also damped by wake field effects!

Beam oscillation damping via wake fields



V. Balakin, Proceedings of the International Workshop on the Next-Generation Linear Colliders, SLAC-report-335, page 56, 1988

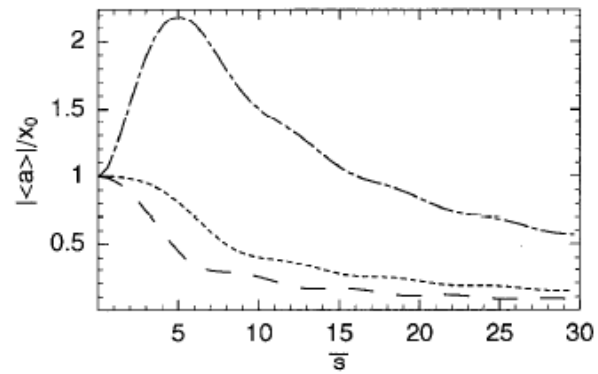
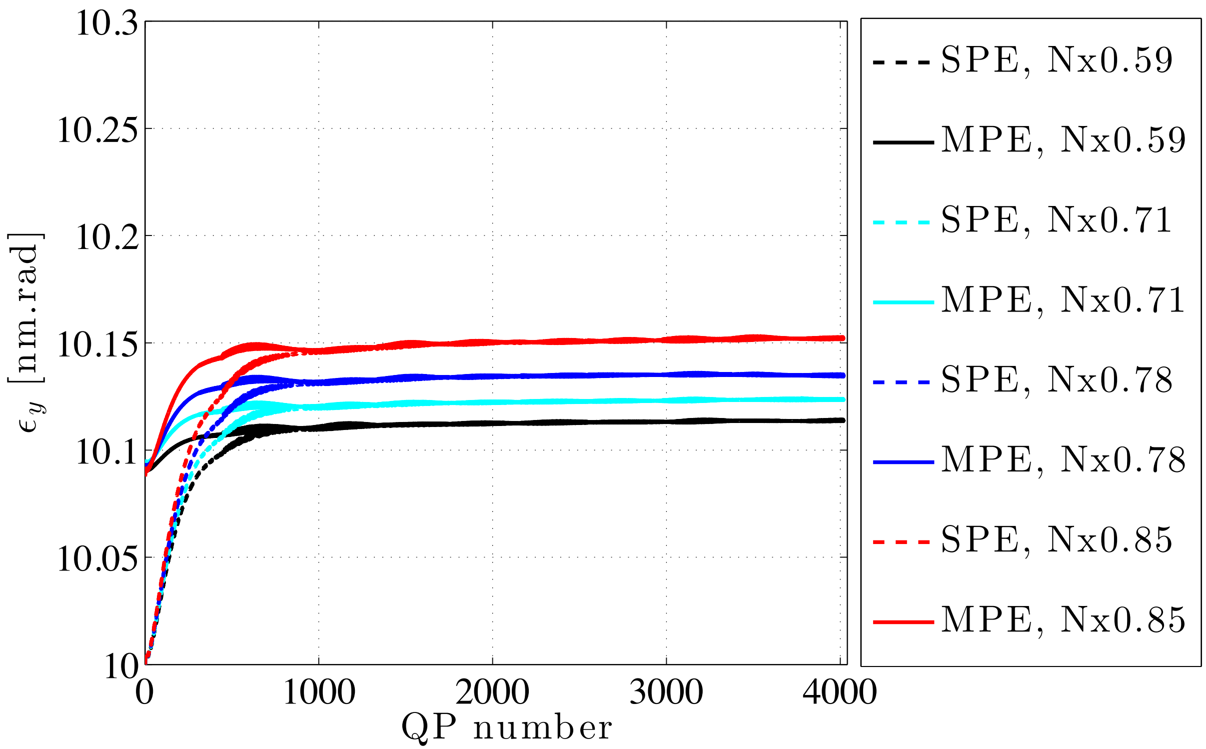


Figure 9: Absolute value of $\langle a(s)\rangle$ for the initial offset $a = x_0$. Dashed line – $f = 1$, dotted line – $f = 2$, dash-dotted line – $f = 5$.

G. V. Stupakov, BNS Damping of Beam Breakup Instability, SLAC-AP-108, 1997

1. What is the limit of this damping process?
2. Could it be used to make the ML more robust and allow for higher charge?

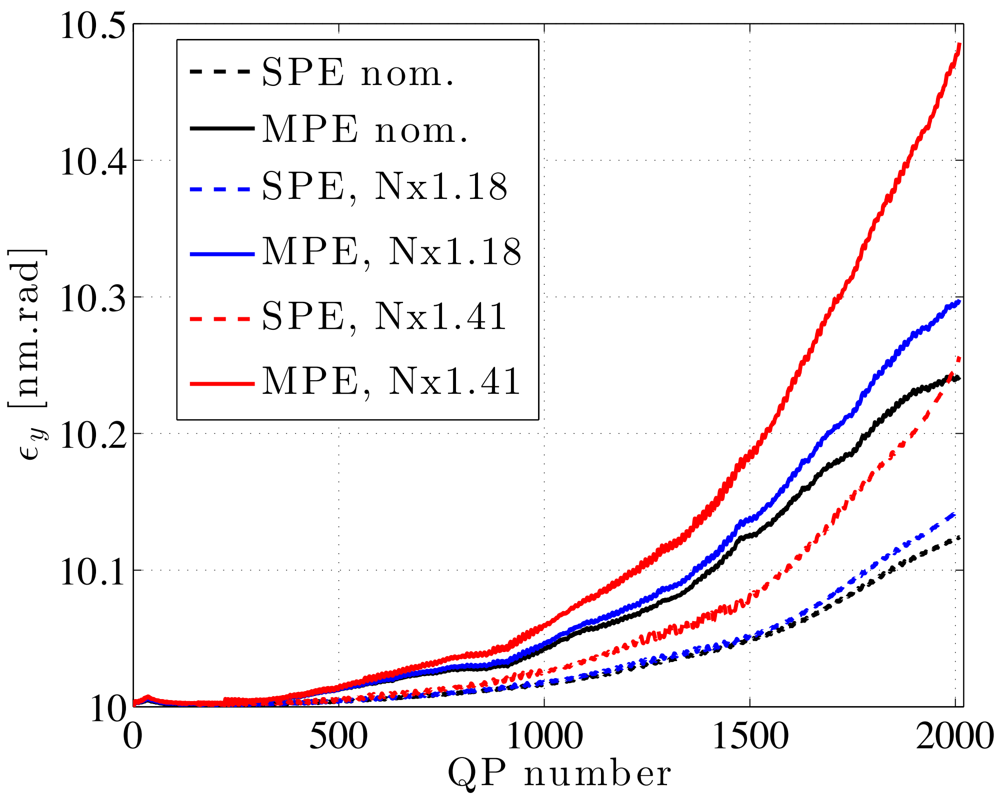
WF effects in the ML with half gradient



- Initial beam jitter is less critical then for the nominal ML.
- Correlated energy spread is build up slower, due to the lower gradient.
- Oscillations can filament fully.
- Remaining growth come from an instability where the coherent energy spread is not build up yet.

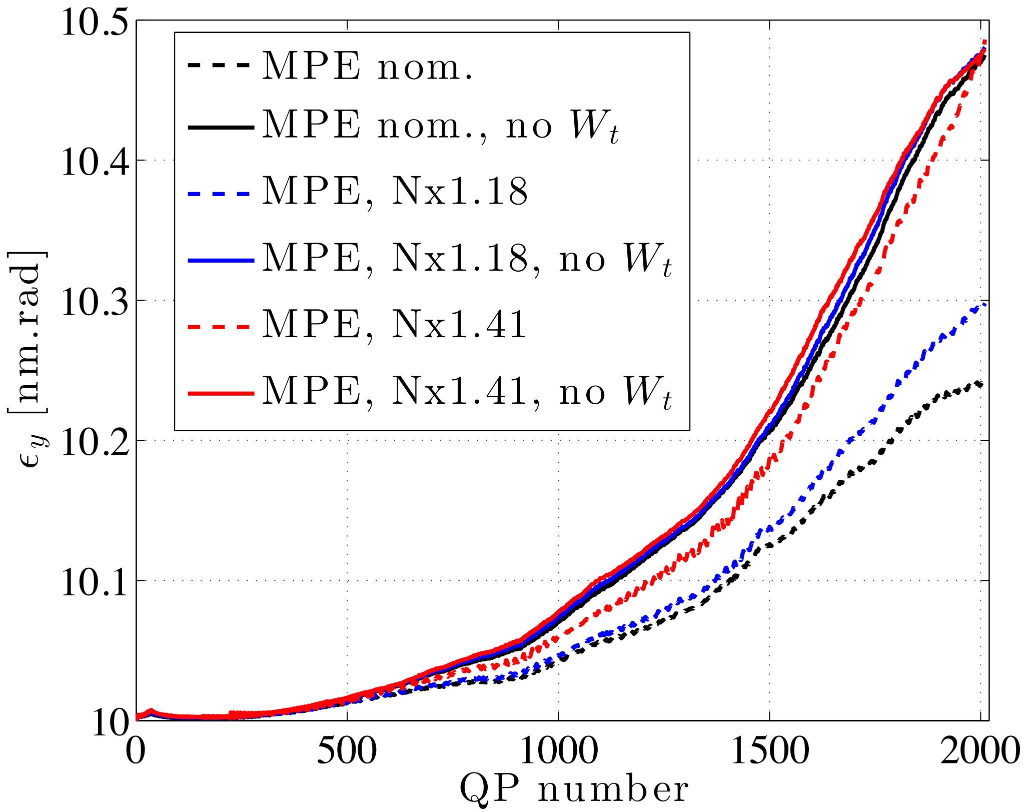
4. Wake field limitations for misalignments

WF effects in the standard ML



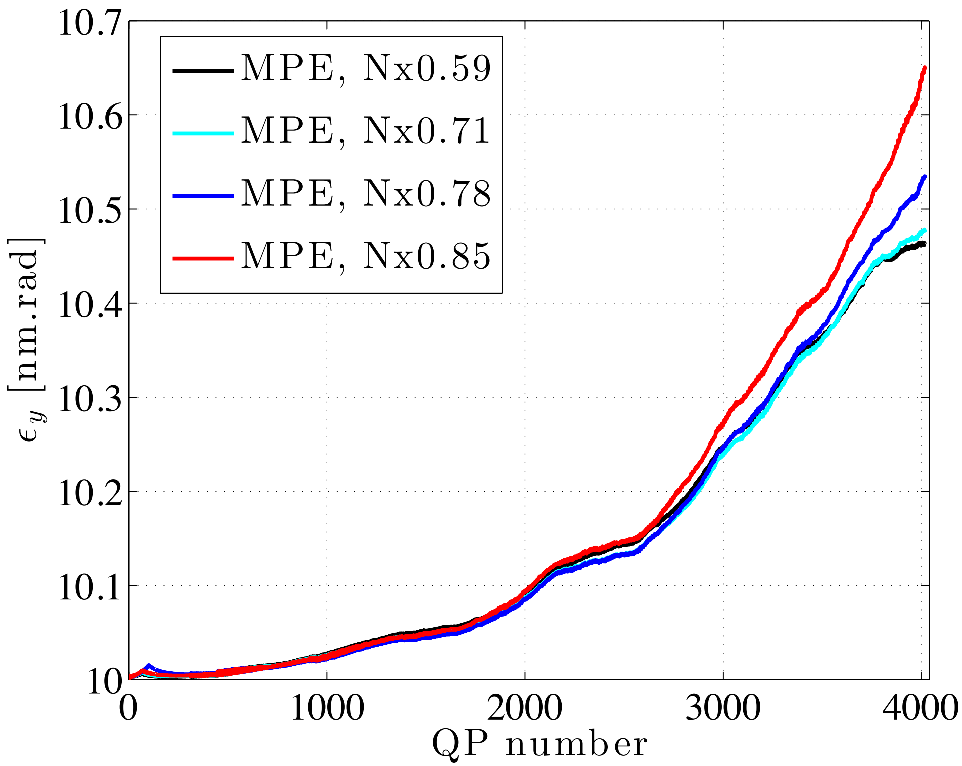
- For the nominal charge, no increase of the emittance due to wake field is observable.
- For 20% more charge, already and effect in the end of the ML can be observed.
- For 40% more charge, the emittance is increase by a factor of 2.
- ML design says in a regime where no wake fields effects are visible (security).
- Misalignment effects seems to be more important then the initial beam jitter.

WF effects in the standard ML without transversal wake fields



- To check how much the the emittance growth is dependent on the transverse wake field, the wake fields have been turned off.
- Without transverse WFs, the emittance is independent of charge and twice as large as for the nominal case.
- WFs actually help against misalignments!
- A factor 2 of emittance reduction seems to be the optimum.

WF effects in the ML with half gradient



- With increasing charge emittance increases mainly in the end of the linac.
- In this area the correlated energy spread is reduced.
- Robustification in this area could be an interesting topic.
- For $N_2=N_1/\sqrt{2}$ the long linac shows the same WF behaviour as the nominal one.
- However, the optimal emittance growth is higher by a factor of 2, but this is independent of the charge!

5. Conclusions

• Misalignments seem to have a higher influence than the initial beam jitter.

• The minimal multi-pulse emittance growth due to misalignments scales linear with the linac length:

$$\varepsilon_{y,mp,mis} \approx 0.24 \mathrm{x} L/L_0 \text{ [nm.rad]}$$

This is independent of the used charge, if the charge is small enough.

• The maximal useable charge scales as:

$$N = N_0\sqrt{(L_0/L)} \qquad \text{e.g. } L = 2\mathrm{x}L_0 \quad \Rightarrow \quad N = N_0/\sqrt{2}$$

This corresponds to the instability case and allows to use high charge in the scaled ML.

• The main linac seems to operate in a regime where beam oscillations are damped due to wake fields. This reduces the multi-pulse emittance growth by a factor of 2 for nominal and the prolonged main linac.

• Optimisation of this damping behaviour seems to be an interesting topic.

• Instabilities due to too high charge occur in certain areas in the linac. Focusing on these areas could improve the behaviour.

• Open point is the change of performance of alignment methods (DFS, RF alignment). To be finished.

Thank you for your attention!