Optimization of Drive Beam parameters w/ PLACET

- Outlook -

E. Adli, AB/ABP / UiO, 21. March 2007

Presentation outline

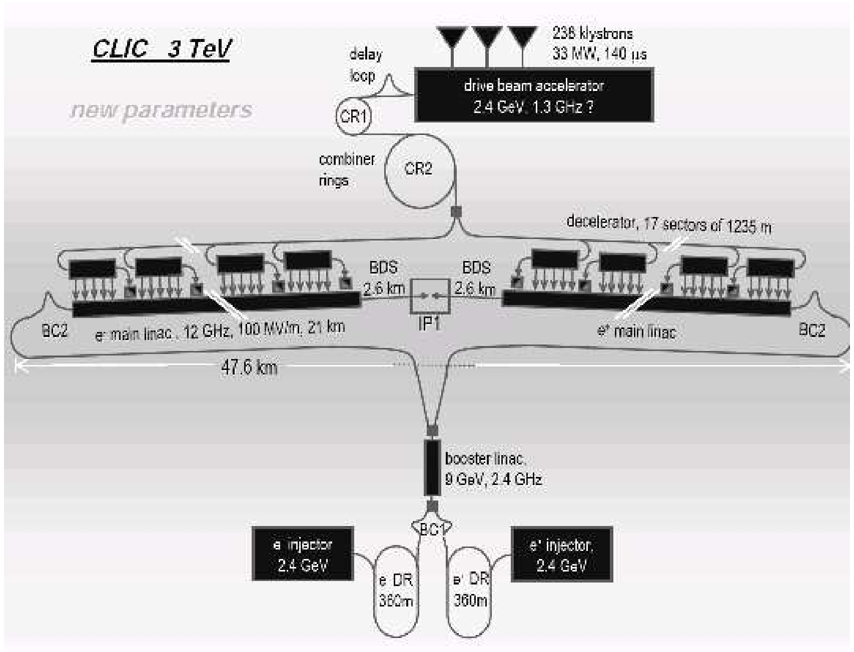
- Case: CLIC PETS power production

- PETS simulations versus PLACET models

- Power extraction and long. dynamics with PLACET

- Transverse dynamics with PLACET

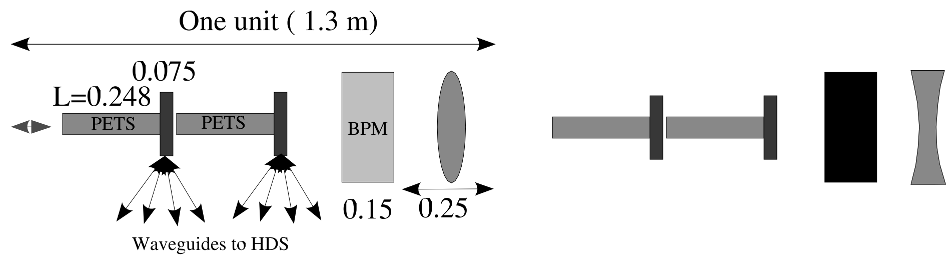
CASE: Drive beam deceleration



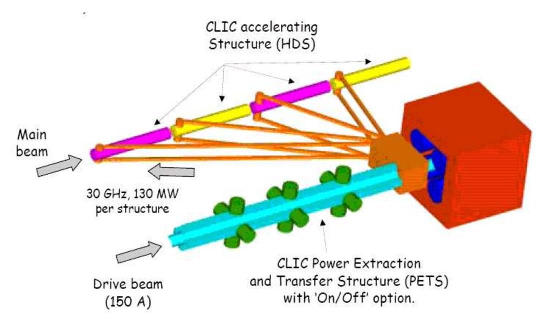
(H. Braun, 2/2/07)

- CLIC 12 GHz
- Each linac: 17 drive beam sectors
- Each sector 780 m long: 600 units containing two PETS and one quad

Schematic view of one unit:

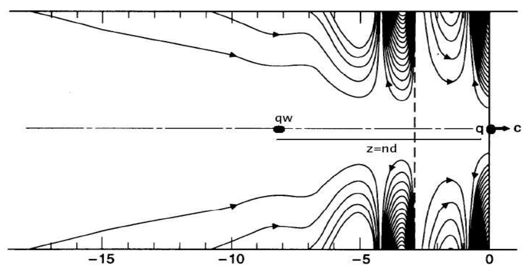


3D views (I. Syratchev, S. Heikkinen):



Power production

- A source particle q_s generates wake fields in the PETS



- A witness particle q_w, following at a distance z, is decelerated by its own field + fields from leading particles

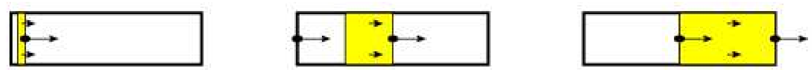
- The total deceleration of q_S is given by

$$\int_0^{l_{cav}} F_L(z) ds \approx -q_s q_w w_L(z)$$

where $w_L(z)$ is the longitudinal monopole wake function (normalized) - the "δ-wake" (h.o.ms ignored here)

Effect of group velocity

- PETS: field is travelling with a group velocity $\beta_L c$



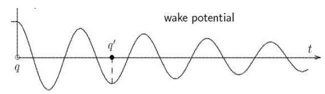
- This leads to
  - factor $\frac{1}{1-\beta_L}$ (concentration of wake field)
  - catch-up distance for the trailing bunch

- Catch up distance: $z\frac{\beta_L}{1-\beta_L}$, the effective distance is reduced by a factor $(L - z\frac{\beta_L}{1-\beta_L})/L$

PETS modelling and PLACET input: W_L

- PETS modelled with GdfidL (I. Syratchev)

- A single mode monopole wake is simulated



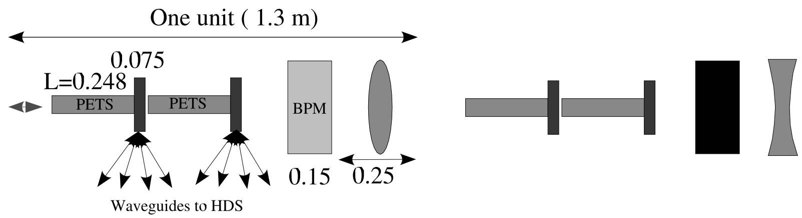
- For a given PETS structure R'/Q, β_L and λ_L are calculated, and taken as input for PLACET simulations

- The longitudinal wake function is then:

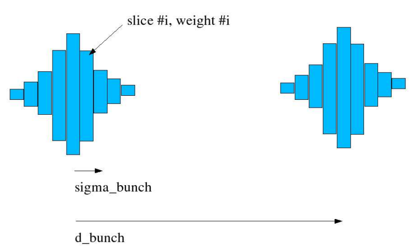
$$W_{\delta L}(z) = \omega_L \frac{R'}{Q} \frac{1}{1-\beta_L} \cos(\omega_L \frac{z}{c})(L - z\frac{\beta_L}{1-\beta_L})[V/C]$$

PLACET simulations

One CLIC Drive Beam sector deceleration simulation has been modelled



- 1 sector - 600 units with 2 PETS and one quadrupole in each unit
- PETS with long. monopole wake and transverse dipole wake
- A sliced drive beam is defined

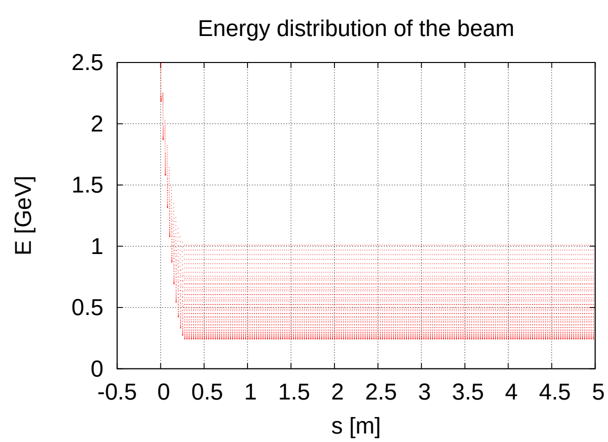


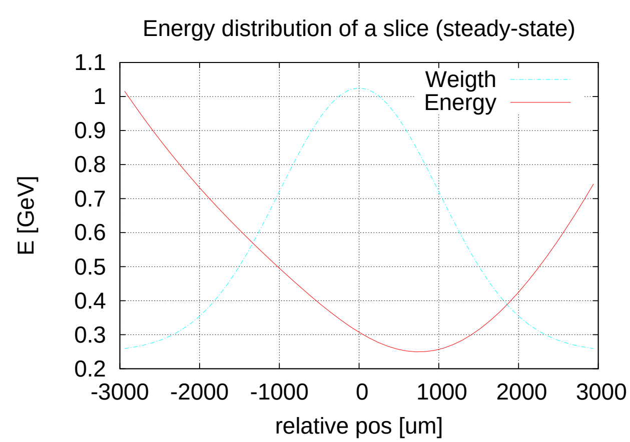
Beam deceleration and power calculations

- Long. wake parameters: $\frac{R}{Q} = 1130\Omega/m$,$\beta_L = 0.453$, $f_L = 11.99GHz$

- Initial beam: bunched beam with $n_b = 200$,$\sigma = 1000\mu m$, $I = 99.9A$, $E_0 = 2.5GeV$ (flat initial energy profile - 90% final spread)

- Distance between bunch centres: $z = nd$, $d = \frac{c}{11.99GHz} = 25mm$





Beam after sector - 90% energy spread	Bunch (steady-state) after sector

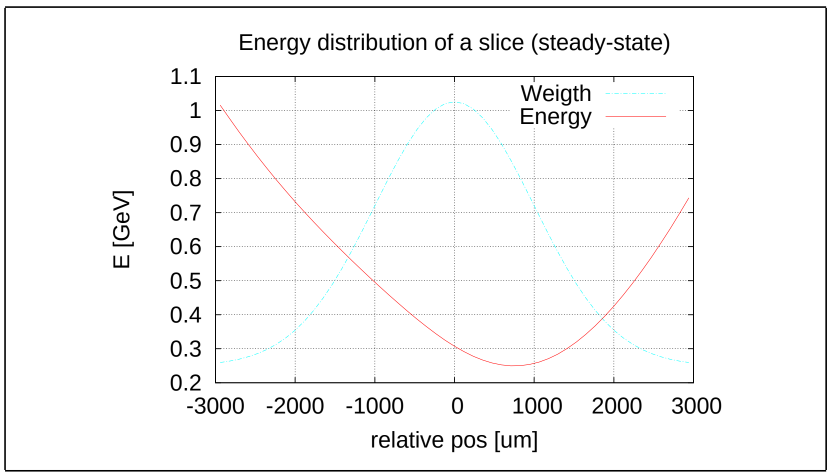
Power extraction efficiency

- For the nominal situation with $\lambda_L = \lambda_{ext} = \frac{c}{11.99GHz}$:

$$P = U_f \overline{I_f} = (\frac{\pi}{2\lambda_L})\frac{R'}{Q} l_{cav}^2 I^2 F^2(\sigma)\frac{1}{\beta_g}$$

- long. parameters as above: $l_{cav} = 0.25mm$ gives power production of $P = 174MW$ (as required by HDS)

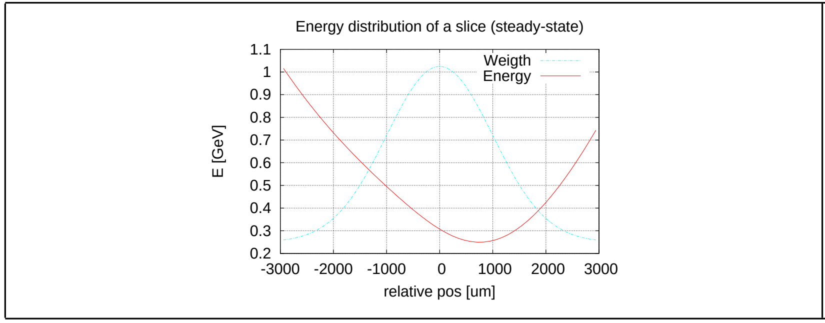
- power extraction efficiency $\varepsilon = \frac{P_{out}}{P_{in}} = \frac{P[W]\times N_{cav}}{E_e[eV]\times I[A]} = S\times\frac{P[W]}{\Delta E_{cav}[eV]\times I_{train}[A]}$



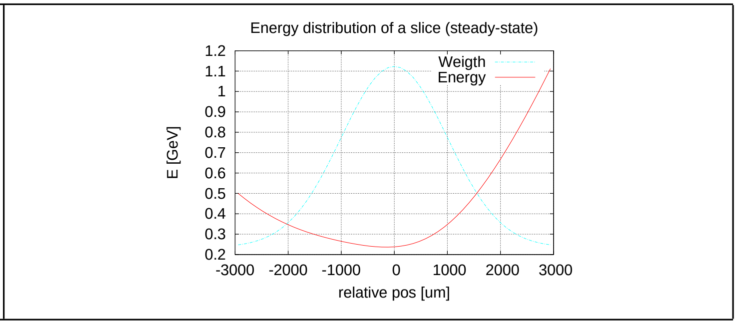
Bunch (steady-state) : $\varepsilon = 84.8\%$

Introducting detuning

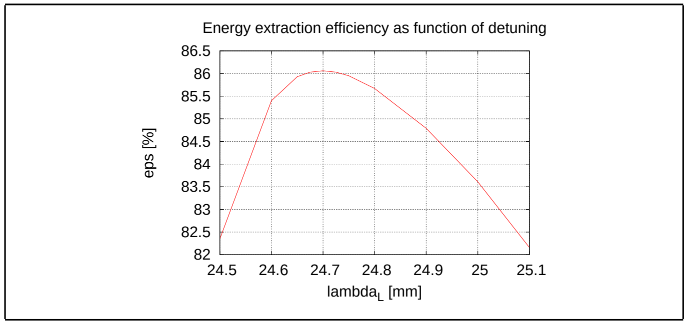
- E_{min} is shifted towards end of bunch due to single-bunch wake
- compensate by shifting bunch forward in time wrt. wake -> $\lambda_T < d$
  - adjusting λ_T one can find a maximum for ε



Bunch (steady-state) no detuning



Bunch (steady-state) $\varepsilon = \varepsilon_{max}$



Energy extraction efficiency

Parameter optimization: longitudinal

Parameters

Parameters of interest for power production (nom)

P	174.0 MW	Cavity steady state power output
E_0	2.5 GeV	Initial beam energy
S	90.0 %	Max final energy spread
I	99.9 A	Current
l_{cav}	0.25 m	Cavity length
λ_L	25.0 mm	Longitudinal mode wavelength (11.99GHz)
ε	84.8 %	Power Extraction Efficiency coefficient

Relations:

$$P = P(\lambda_L, I, l_{cav}) \propto I^2, \propto l_{cav}^2$$

$$E_0 = E_0(\lambda_L, S, I, l_{cav}) \propto I, \propto l_{cav}^2, \propto (1/S)$$

and

$$\varepsilon(P, E_0, I) = \frac{P[W] \times N_{cav}}{E_0[eV] \times I[A]} = S \times \frac{P[W]}{\Delta E_{cav}[eV] \times I_{train}[A]}$$

Fixed parameters

- We fix:
  - $P = 174MW$ (requirement from main linac)
  - S=90% (wanted for beam stability)

- Still two degrees of freedom, shared between l_{cav},I, E_0 and λ_L. We also fix:

- $E_0 = 2.5GeV$ (compromise SR effects and beam rigidity)

leaving one degree of freedom

Working points

With one further constraint we find two working points:

- **Config A) Without detuning:**

INPUT: $P = 174MW$,$S = 90\%$,$E_0 = 2.5GeV$, $\lambda_L = 25.0mm$

OUTPUT: $l_{cav} = 24.82cm$, $I = 98.1A$, $\varepsilon = 84.8\%$

- **Config B) Optimal detuning:**

INPUT: $P = 174MW$,$S = 90\%$,$E_0 = 2.5Gev$, $\varepsilon = \varepsilon_{max}(= 87.6\%)$

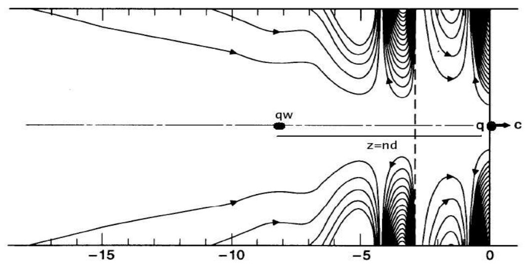
OUTPUT: $l_{cav} = 25.86cm$, $I = 95.9A$, $\lambda_L = 24.75mm$

(To be used for the transverse studies)

Transverse dynamics

Transverse instabilities

- A source particle q_s induces wake fields in PETS cavity



- A witness particle q_w, following at a distance z, is kicked by the fields from leading particles

- The total transverse force on q_w is given by (1D)

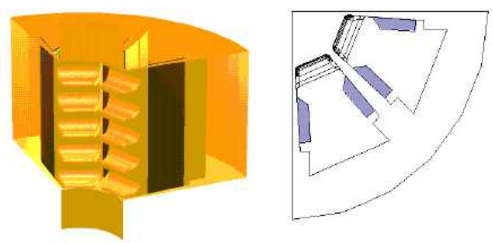
$$\int_0^{l_{cav}} F_y(z)ds \approx -\Delta y q_s q_w w_T(z)$$

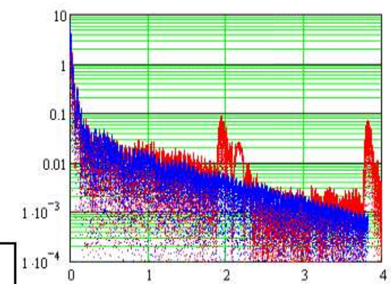
where $w_T(z)$ is the transverse dipole wake function - the "δ-wake" (h.o.ms ignored here)

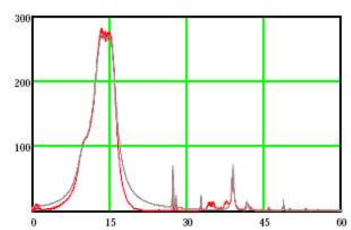
PETS modelling and PLACET input: W_T

- PETS are modelled with GdfidL (I. Syratchev)

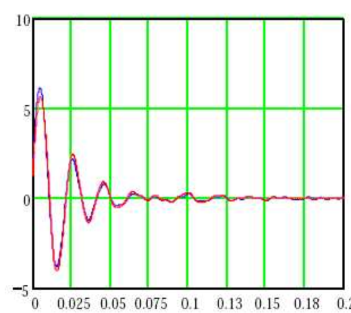
- For a given PETS structure, the transverse δ-wake / impedance is calculated

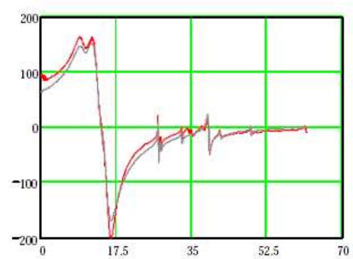






W_T	Q	F
0.045	300	27.44
0.019	180	28.05
0.017	290	32.912
0.2	85	39.12
0.03	120	41.83
0.015	380	48.91
0.85	3.7	10.0
4.82	3.8	13.4
2.63	6.2	15.46





I. Syratchev, 09.02.07, CERN

PETS modelling and PLACET input: W_T

- Multiple modes identified from GdfidL calc

- For each mode, w_{T_i},Q_i,f_{T_i}, β_{T_i} are identified

- The total wake function for each mode thus:

$$W_{T_i}(z) = w_{T_i} \sin(\omega \frac{z}{c})(L - z_{ij} \frac{\beta_T}{1-\beta_T}) e^{-z\omega/2cQ(1-\beta_T)} [V/Cm]$$

- Transverse kick of q_w :

$$\Delta y'_w = \sum_{modes} \frac{\Delta p_{y,w}}{m_w c} = \sum_{modes} y_s \frac{q_s q_w}{E_w} W_{\delta T}(z) [rad]$$

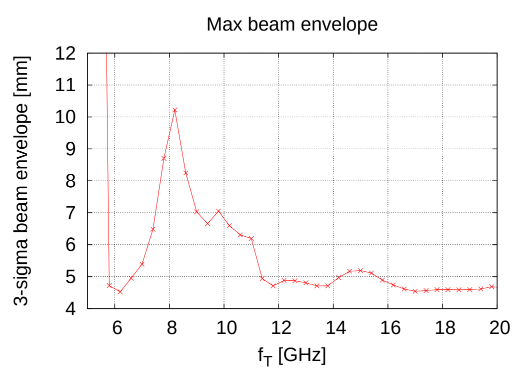
Beam blow-up

- Metric used: $3 - sigma$ beam envelope at end of lattice

- Initial conditions: beam with initial static offset + jitter at the transverse resonance frequency

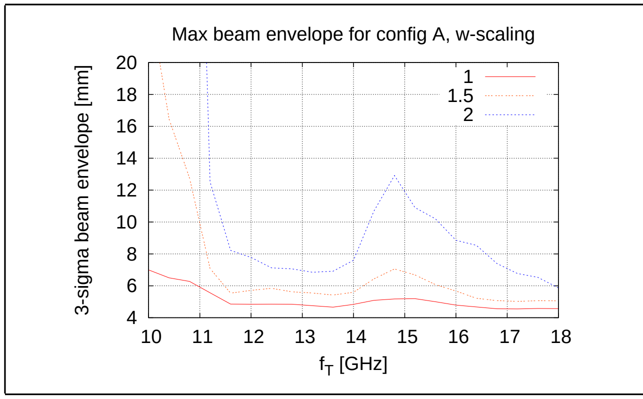
- Beam blow-up depends on z/λ_{T_i}: $\sin(\frac{2\pi}{\lambda_{T_i}}z) = 0 \Rightarrow z = \frac{n}{2}\lambda_T \Rightarrow f_T = \frac{n}{2}12GHz$ (zeros)

- Dominant transverse mode simulated: $w_T = 7V/pCm/mm$,$Q = 8.2$,$\beta_T = 0.475$

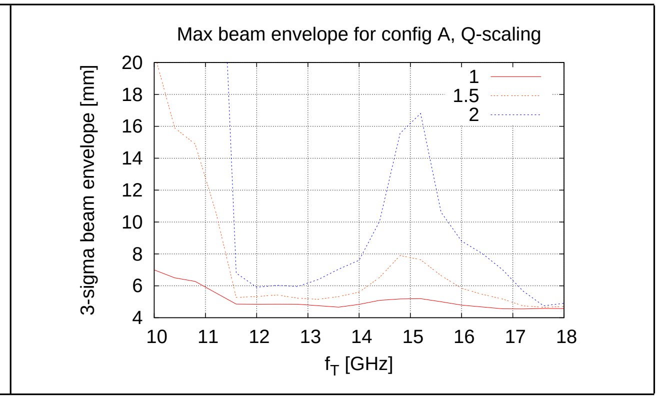


Config$A$), One transverse mode (freq. f_T, Q fixed)

Config A, w and Q scaling

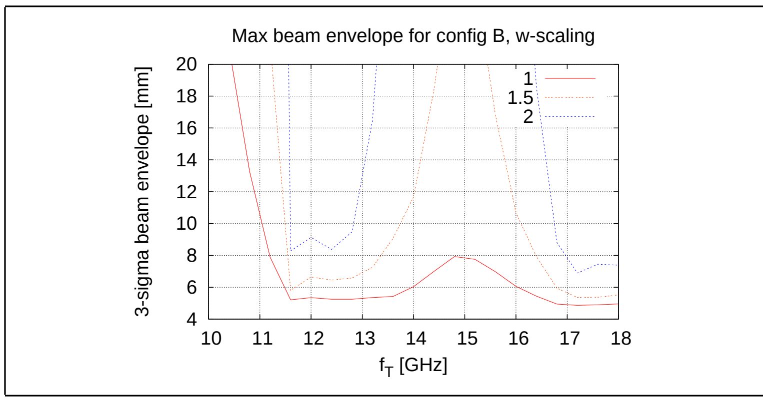


No detuning, $d = 25mm$

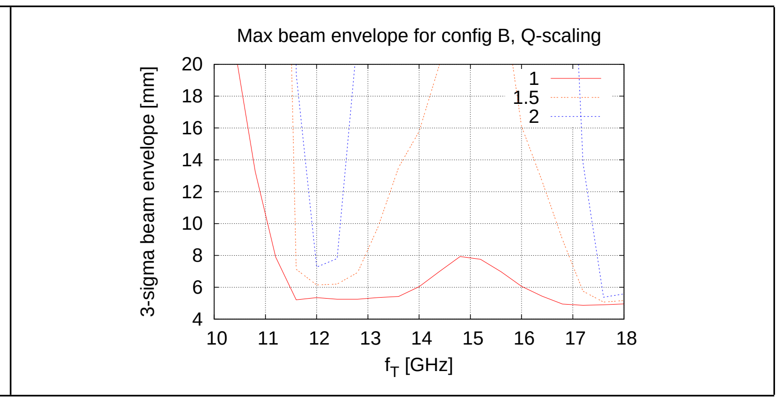


No detuning, $d = 25mm$

Config B, w and Q scaling

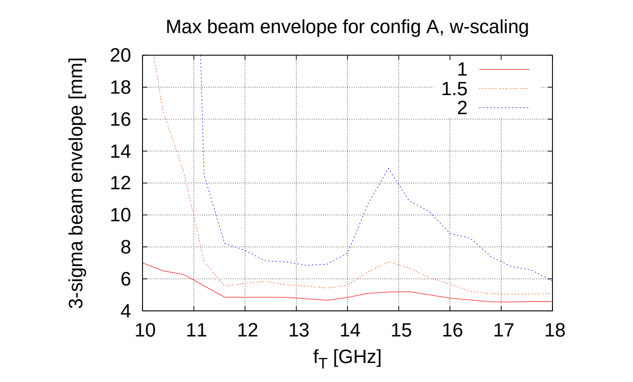


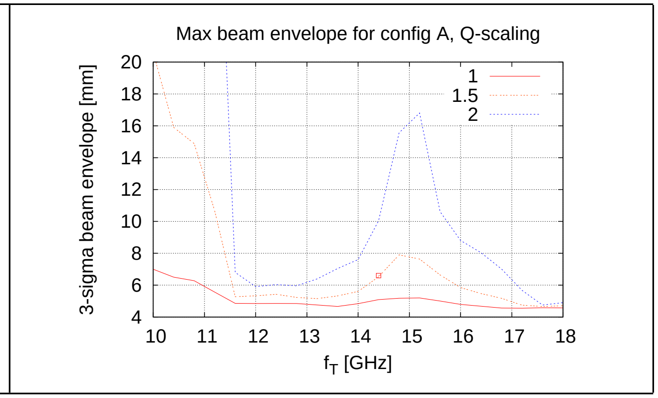
Optimal detuning, $d = 25mm$



Optimal detuning, $d = 25mm$

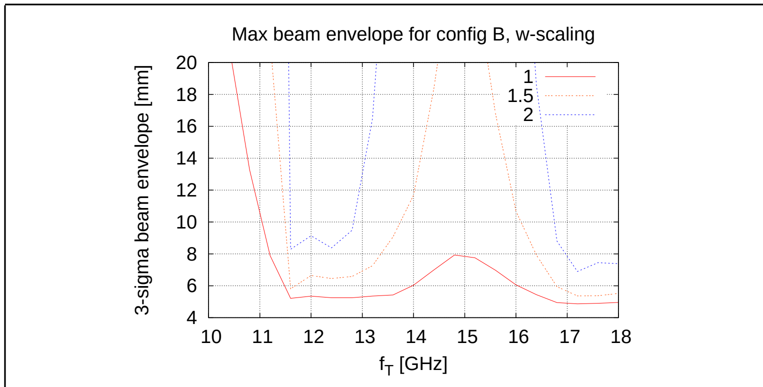
Config A, w and Q scaling

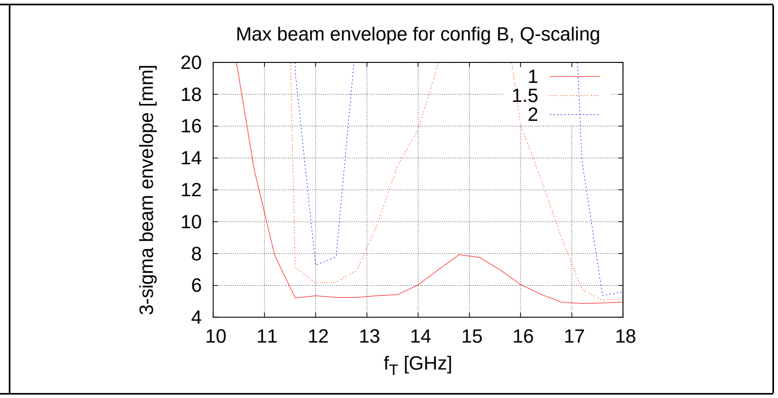




No detuning, $d = 25mm$	No detuning, $d = 25mm$

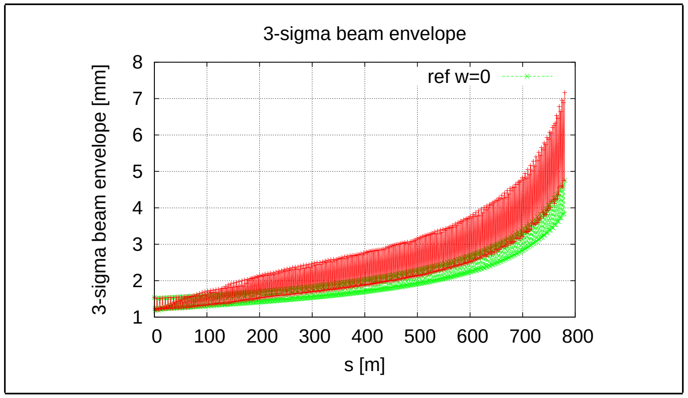
Config B, w and Q scaling





Optimal detuning, $d = 25mm$	Optimal detuning, $d = 25mm$

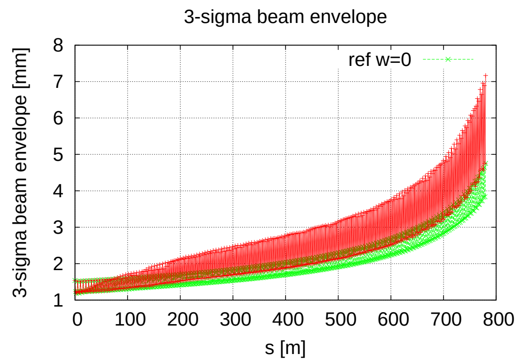
Beam blow up: illustration of coherence

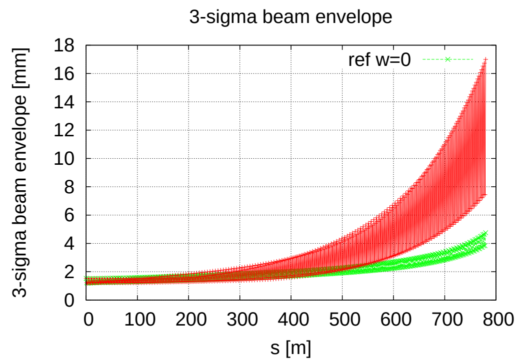


A (low E, decoh.) : 7.2mm

(green reference graph: beam envelope w/o transverse wakefields)

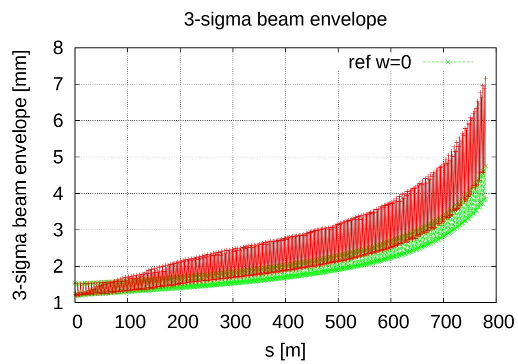
Beam blow up: illustration of coherence

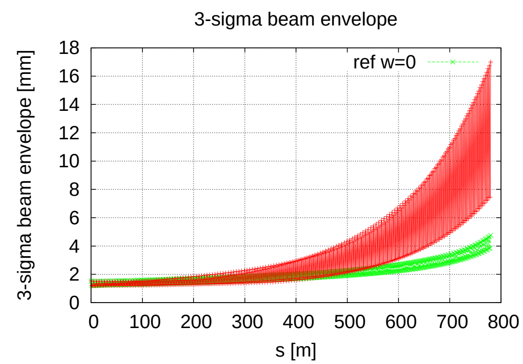




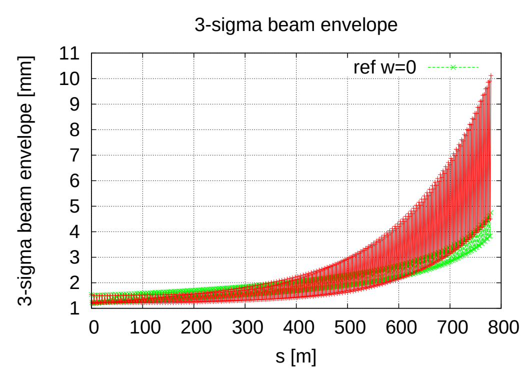
A (low E, decoh.) : 7.2mm	A, R/Q=0 (high E, coh.) : 17.0mm

Beam blow up: illustration of coherence



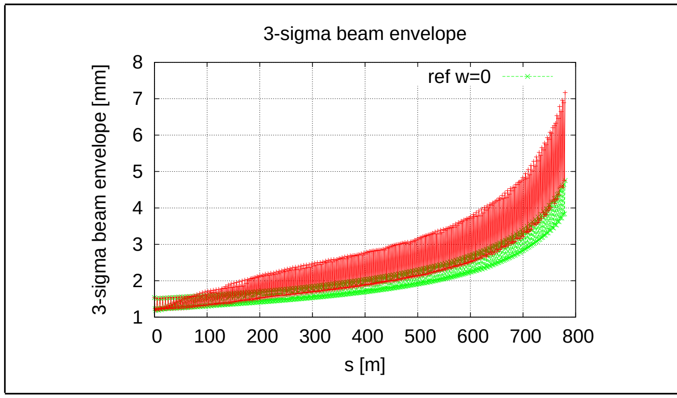


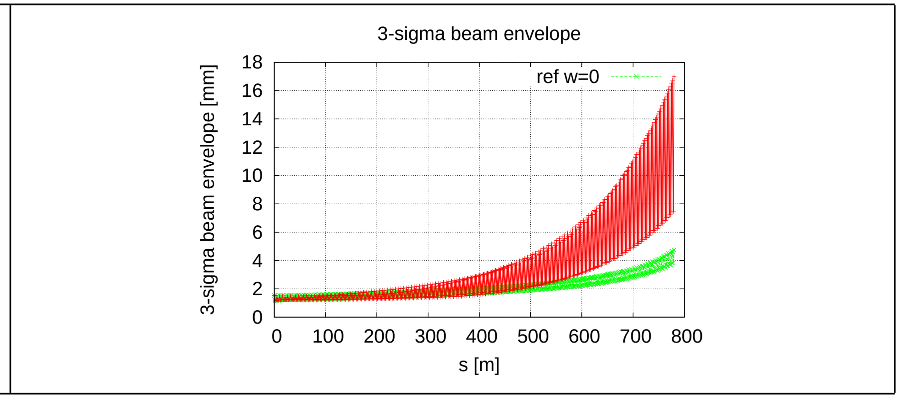
A (low E, decoh.) : 7.2mm	A, R/Q=0 (high E, coh.) : 17.0mm



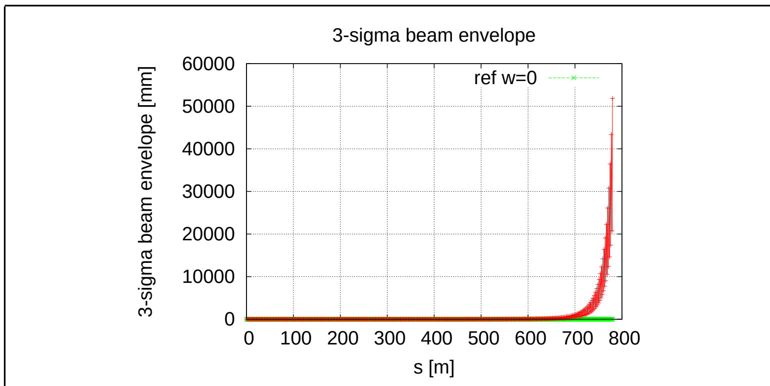
———————————————————	A, R/Q=0, PLB (high E, coh.) : 10.1mm

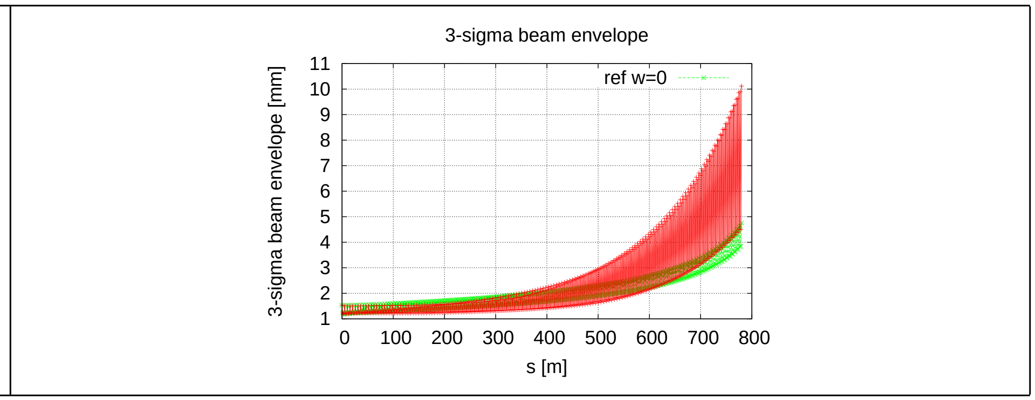
Beam blow up: illustration of coherence





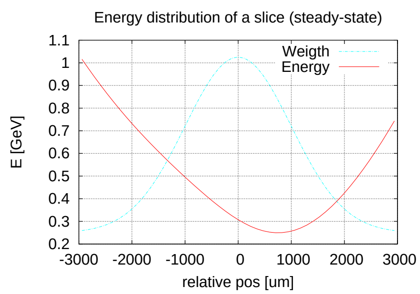
A (low E, decoh.) : 7.2mm	A, R/Q=0 (high E, coh.) : 17.0mm



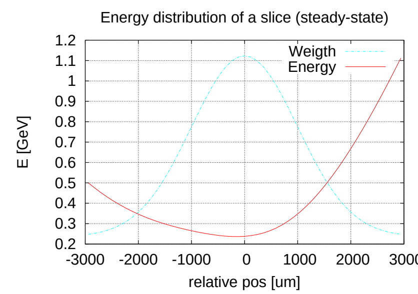


A, PLB (low E, coh.) : 5e4mm	A, R/Q=0, PLB (high E, coh.) : 10.1mm

Beam blow up: detuning versus coherence



Bunch (steady-state) no detuning



Bunch (steady-state) $\varepsilon = \varepsilon_{max}$

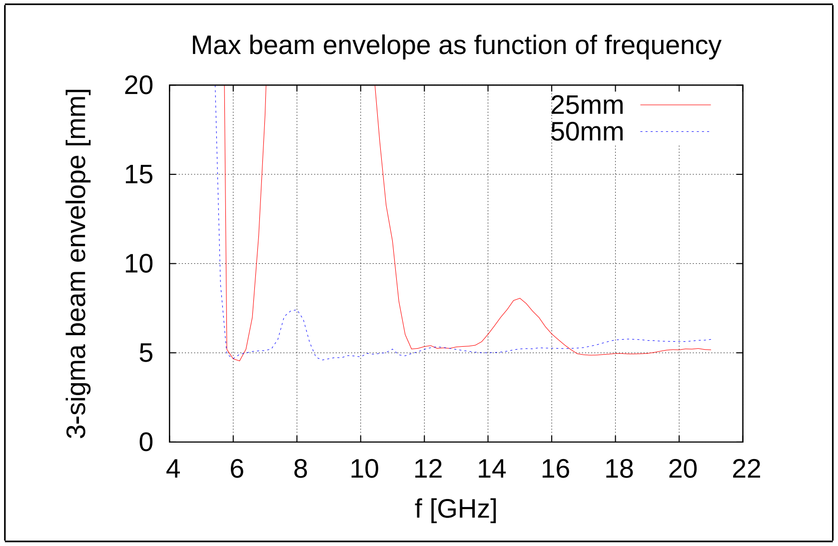
- Detuned working point: less energy spread around centre

- Might need to compromize effeciency and transverse stability

Improvement of transverse envelope: 2nd harmonic

- Bunch spacing increased by filling every second bucket

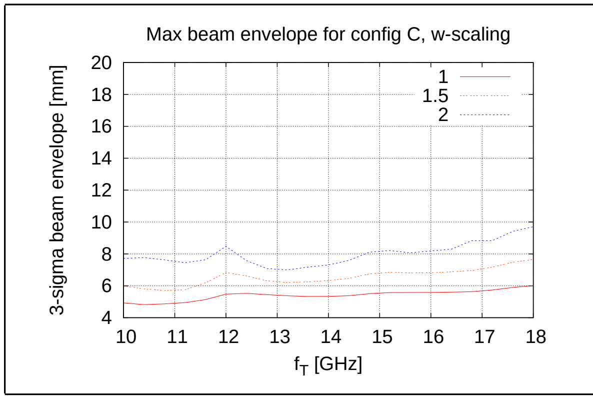
- Now zero-crossings at: $f_T = \frac{n}{2} 6GHz$



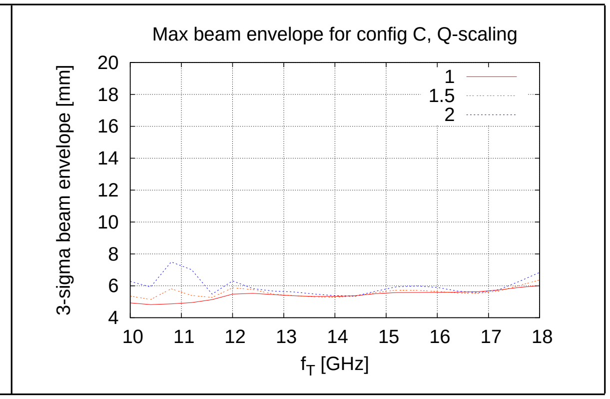
Config B, d=25mm and d=50mm

- Two new working points defined, config C and config D

Config C, w and Q scaling

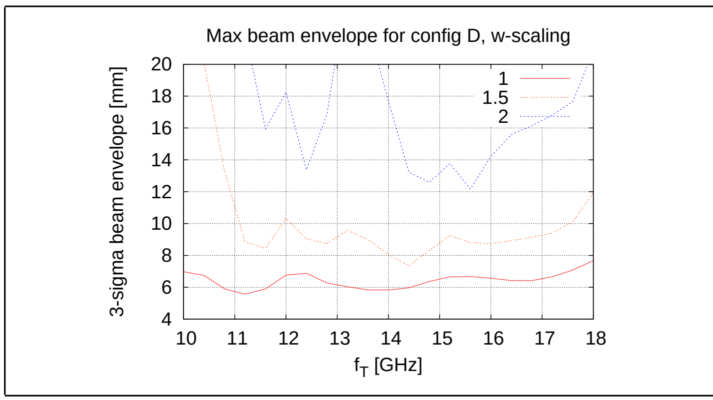


No detuning, $d = 50mm$

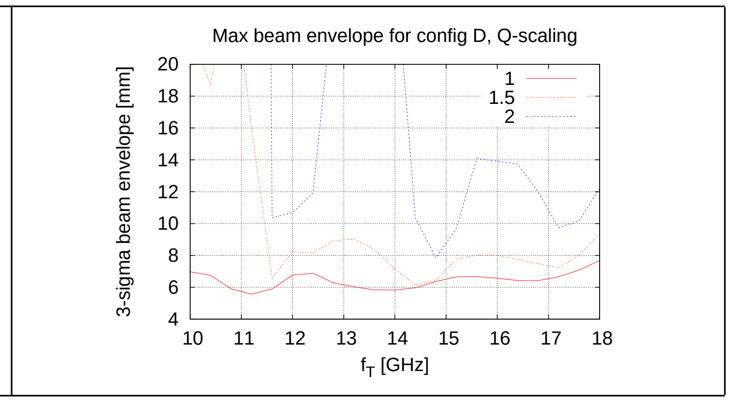


No detuning, $d = 50mm$

Config D, w and Q scaling



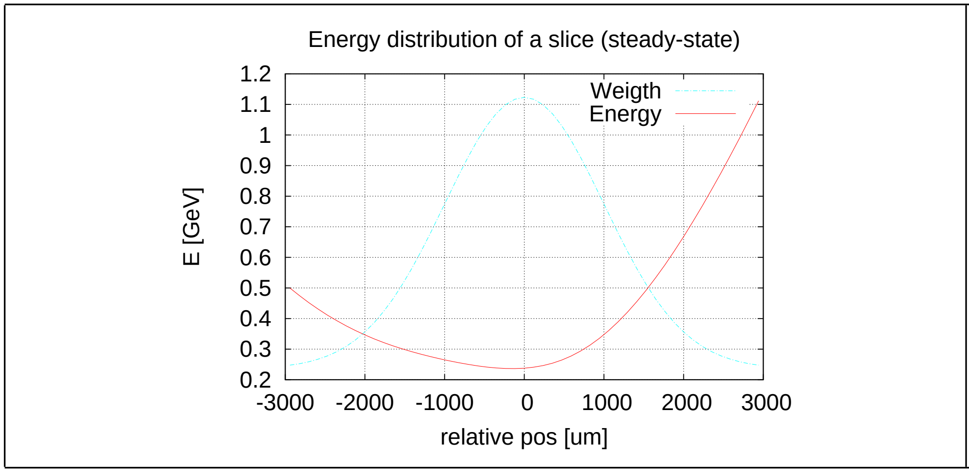
Optimal detuning, $d = 50mm$

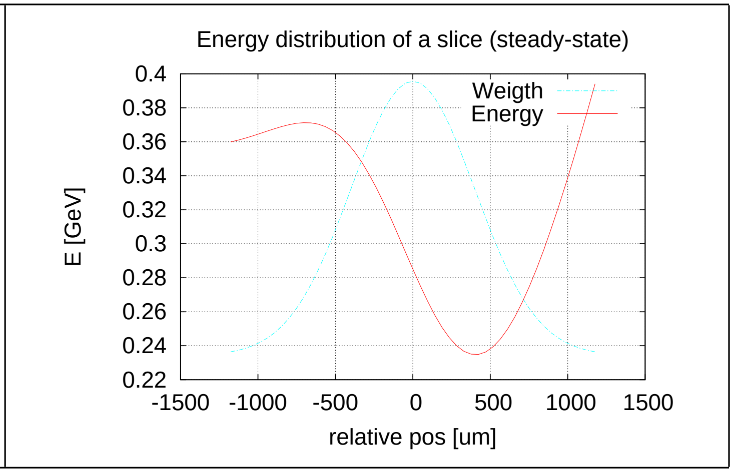


Optimal detuning, $d = 50mm$

Further parameters to optimize...

- Bunch length





Detuned $\sigma = 1000\mu m$ (ss) $\varepsilon_{max} = 87.6\%$	Detuned $\sigma = 400\mu m$ (ss) ε_{max}

Prelim. conclusions of PLACET studies

- can simulate longitudinal profile (improved power extraction)
- can identify dangerous transverse modes and safety margins
- **can help optimize Drive Beam parameters working point**

Future outlooks

- all sims so far for perfect Linac
  - scattered elements
  - beam based alignments

- similar studies for TBL

- better understanding of instability limits (analytic formulae)

References

Background info and some of the figures:

- Figures and lots of other input from I. Syratchev
- Various CLIC notes and CLIC meetings reports
- PLACET manual, D. Schulte, 2000
- Physics of collective beam instabilities..., A. Chao, 1993