Drive Beam Linac Stability Issues

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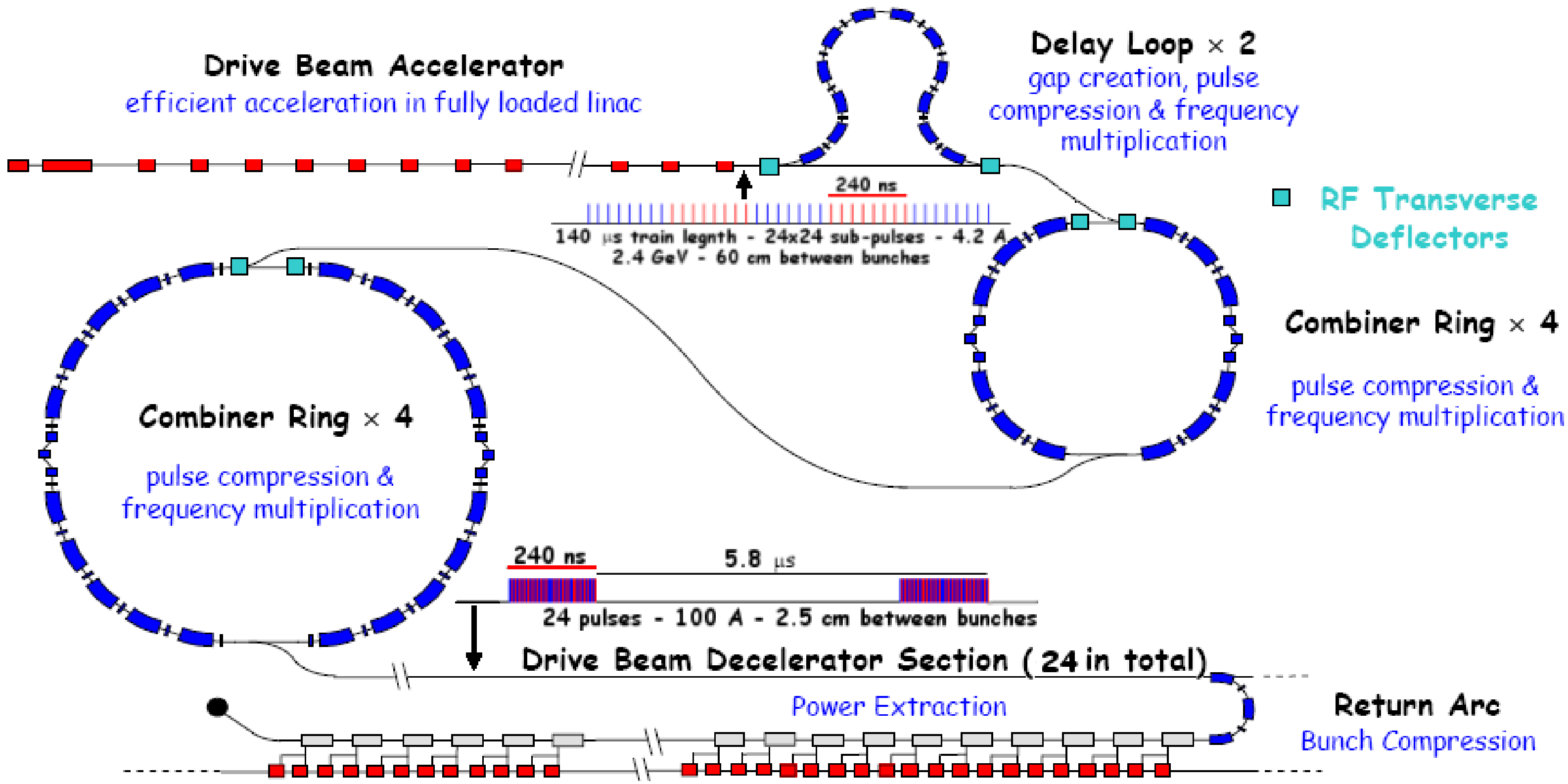
Introduction

- The aim of the study is finding best linac optics in order to transport the beam through linac in required tolerances.
- Currently transverse instabilities have been studied only (which is one of the major task of instabilities in linacs). Multibunch effects have been focused mostly .
- New designing (which is not fully designed) accelerator structure dimensions have been used for building up lattice layouts.
- Since we don’t have fully designed structure CTF3 SICA structure have been used in some points
- PLACET and analytical calculations have been used for calculations

Motivation

Current CLIC RF power production layout

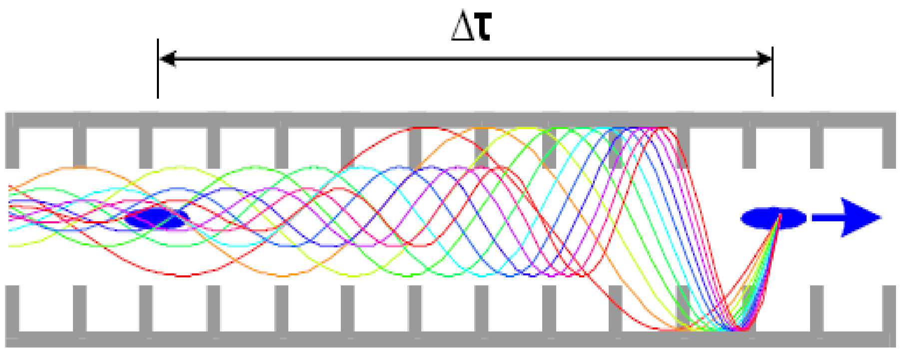


- Beam with 140 µs pulse length and 4.2 A current is accelerated up to 2.4 GeV in drive beam accelerator .
- After delay loop and combiner rings initial pulse is divided 24 sub-pulses with 100 A pulse current and 240 ns pulse length.

Motivation

- One of the major problems with accelerating intense bunches in linac is the instability driven by wakefields.
- This instability, generated by off-axis beam trajectories, can develop within a single-bunch or along a train of bunches and always leads to a dilution of the emittance.
- As it can be seen on table the intensity of drive beam is very high due to fully loaded operation which means strong wake field effect…

	CTF3	CLIC DB
Energy (MeV)	150	2400
Pulse current (A)	3.5	4.2
Bunch charge (nC)	2.33	8.4
Pulse Length (μs)	1.4	140
Bunch separation (cm)	20	60
No of bunches per pulse	2100	70128

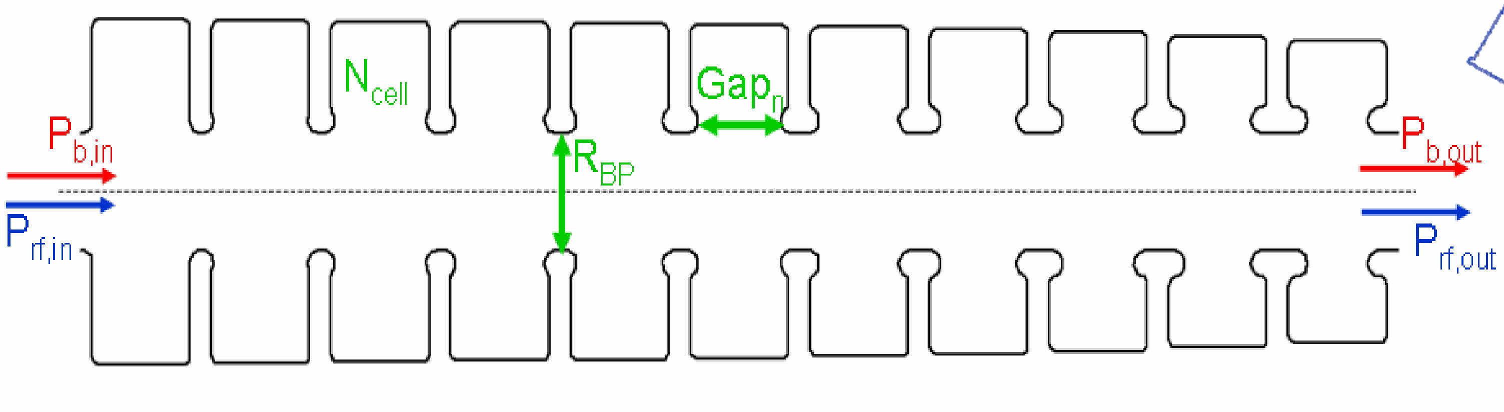


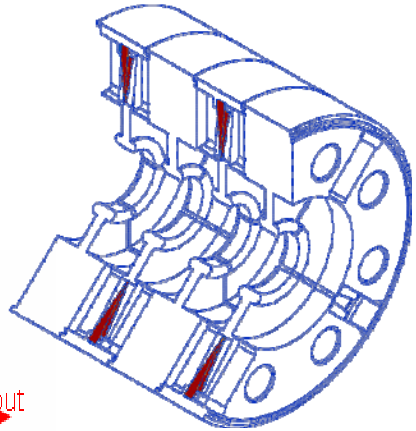
$$F_{wake} \propto Q\, \mathbf{W}(\Delta\tau)$$

1GHz DBA Structure

- SICA (Slotted Iris –Constant Aperture) principle like in CTF3
- PRF~ 10 to 15 MW power is taken into account

  In other words optimizing klystron cost



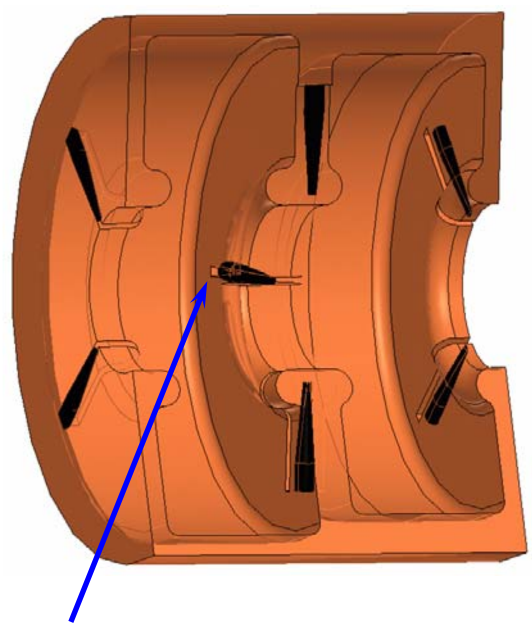


Optimizations still being continued (by Rolf Wegner)
for optimum efficiency (which requires > %95)
for filling time (which requires 245 ns)

$$\eta = \Delta P_b / P_{rf,in}$$

$$t_{fill}$$

1GHz DBA Structure



HOM dampers

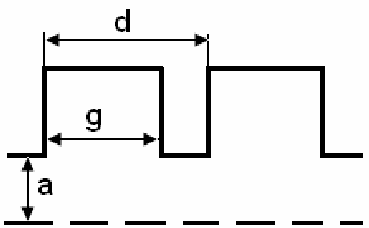
HOM's have not been simulated yet

- **Although it is not finalized we have taken into account**
  - **11 Cell**
  - **R_{BP}= 41 mm**
  - **Varying gap**
  - **Cell length= 99.979 mm**
  - **Gradient 2.4 MV/ per structure (10 MW RF power)**
- **Which are convenient for**
  - $\eta > 95$ %
  - $t_{fil} \approx 245$ ns

From Rolf Wegner

Short range wakes

Both ABCI code and Karl Bane's formulas were used to calculate short range wakes;



$$s_l = 0.41\frac{a^{1.8}g^{1.6}}{d^{2.4}}, \quad Z_0 = 120\pi\Omega$$

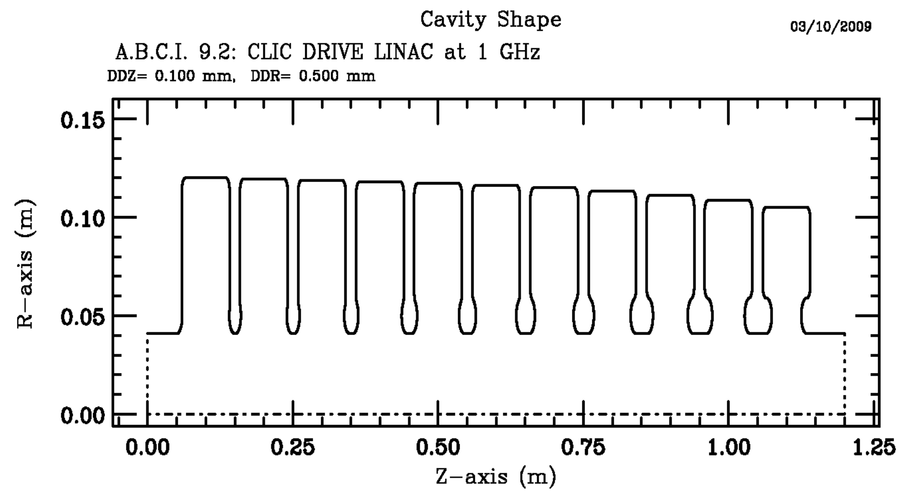
$$W_{||}(s) = \frac{4Z_0 c}{\pi a^2}\exp\left[-\sqrt{\frac{s}{s_l}}\right]$$

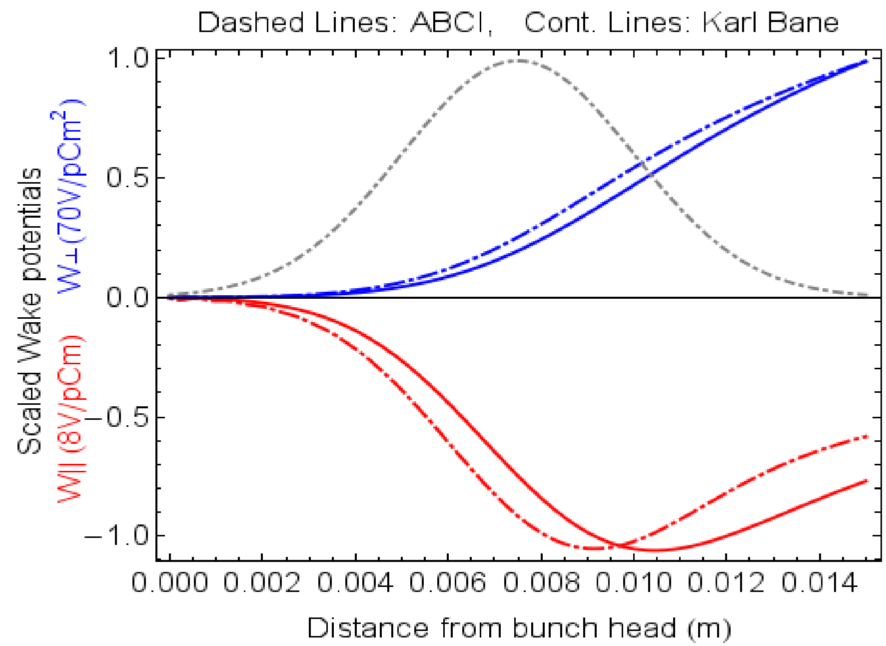
$$s_t = 1.69\frac{a^{1.79}g^{0.38}}{d^{1.17}},$$

$$W_\perp(s) = \frac{4Z_0.c.s_t}{\pi a^4}\left[1-\left(1+\sqrt{\frac{s}{s_t}}\right)\exp\left(-\sqrt{\frac{s}{s_t}}\right)\right]$$

Since the structure does not have constant gap

$$W = \frac{1}{n}\sum_{i=1}^{n} W(g_i)$$





Long range wakes

- Since the HOM's of new structure we were not simulated yet
- Since one of the goal of this study is determine the damping requirements

CTF3 SICA structure transverse modes were scaled and superposition of these modes have been used…

3 GHz SICA (CTF3)		
f [GHz]	**Q**	**K [V/pCm²]**
4.12	8.74	460
4.34	8.11	660
5.20	71.55	170
5.49	3.24	40
4.12	7.25	760
4.35	10.20	420
….	….	…..

$$f' = f\left(\frac{1\ [\text{GHz}]}{3\ [\text{GHz}]}\right)$$

$$Q' = Q$$

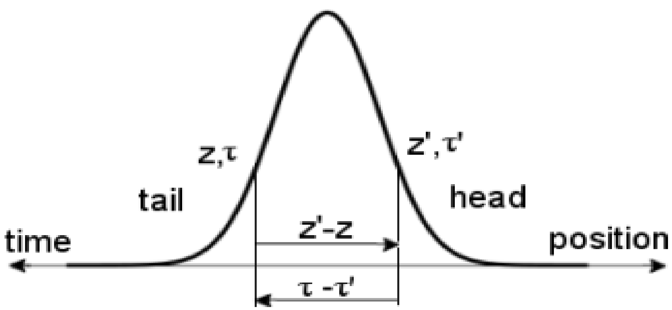
$$K' = K\left(\frac{1\ [\text{GHz}]}{3\ [\text{GHz}]}\right)^3$$

f : Frequency of mode
K: Kick factor of mode
Q: damping fact. of mod

1 GHz SCALED		
f [GHz]	**Q**	**K [V/pCm²]**
1.37	8.74	16.86
1.45	8.11	24.49
1.73	71.55	6.31
1.83	3.24	1.33
1.37	7.25	27.85
1.45	10.20	15.31
….	…..	….

Single Bunch analysis

If only the particles inside a single bunch are taken into account equation of motion of each particle



$$\frac{1}{\gamma(s)}\frac{d}{ds}\left[\gamma(s)\frac{d}{ds}x(\tau,s)\right]+K(s)x(\tau,s)=\frac{F_{\perp}(\tau,s)}{E(s)}$$

$$F_{\perp}(\tau,s)=e\int_{-\infty}^{\tau}d\tau'\ W_{\perp}(\tau-\tau')\,\rho(\tau')\,x(\tau',s)$$

$W_{\perp}$: point like dipole wake per unit length

ρ : charge distribution

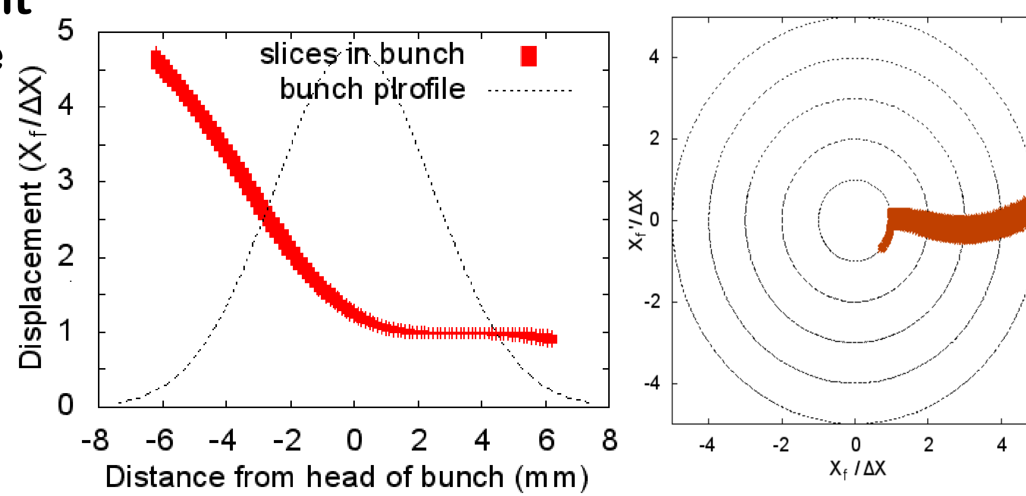
For constant offset the displacement of the trailing slices in bunch will be proportional of

$$\Delta x_i \propto Q\ F_{\perp,i}\int_0^L ds'\ \frac{\beta(s')}{E(s')}$$

L: Linac length

E: energy

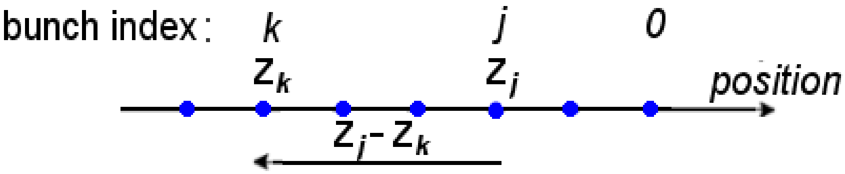
β: betatron functions inside structure



Plots for spoiled beam due to short range wake effect with large betatron

Multi bunch analysis

For multi bunch case point-like bunches with distance in a train are considered. Similarly the equation of motion of each bunch



$$\frac{1}{\gamma(s)}\frac{d}{ds}\left[\gamma(s)\frac{d}{ds}x(z_k,s)\right]+K(s)\,x(z_k,s)=\frac{F_\perp(z_k,s)}{E(s)}$$

$$F_\perp(z_k,s)=Ne\sum_{i=0}^{k-1}W_\perp(z_i-z_k)\,x(z_i,s)$$

Here wake function is sum of modes of structure

$$W_\perp(z)=\sum_m 2K_m\,\sin\left(\omega_m\frac{z}{c}\right)\exp\left(\frac{-\omega_m}{2Q_m}\frac{z}{c}\right)$$

$\boldsymbol{\omega_m}$**:** frequency of mode
$\mathbf{K_m}$**:** kick factor of mode
$\mathbf{Q_m}$: damping factor of mode

The displacement of each bunch in train is given with matrix *A*

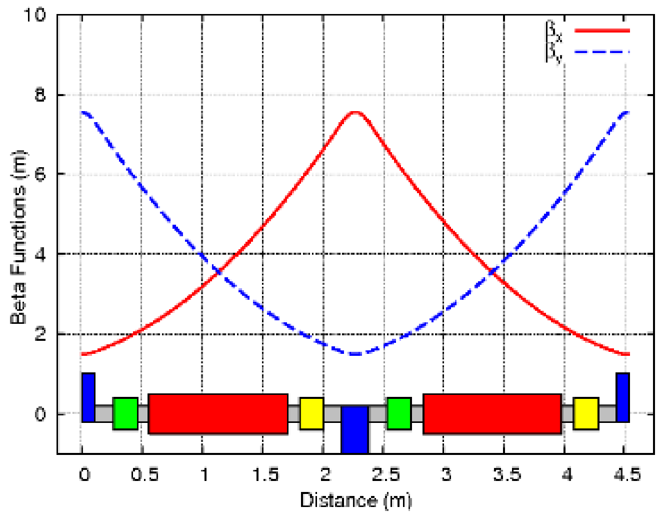
$x_k = A\ x_0$ where $A=\exp(a)$ and
$$a_{j,k}=\begin{cases} iNeW_\perp(z_j\text{-}z_k)\int_0^L ds'\,\dfrac{\beta(s')}{2E(s')} & ;\ j>k \\ 0 & ;j\le k\end{cases}$$

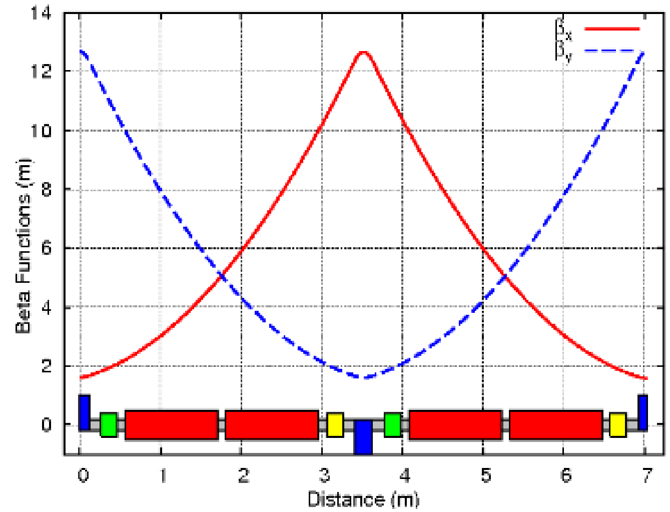
D.Schulte, “Multi-bunch Calculations In The CLIC Main Linac”, PAC09

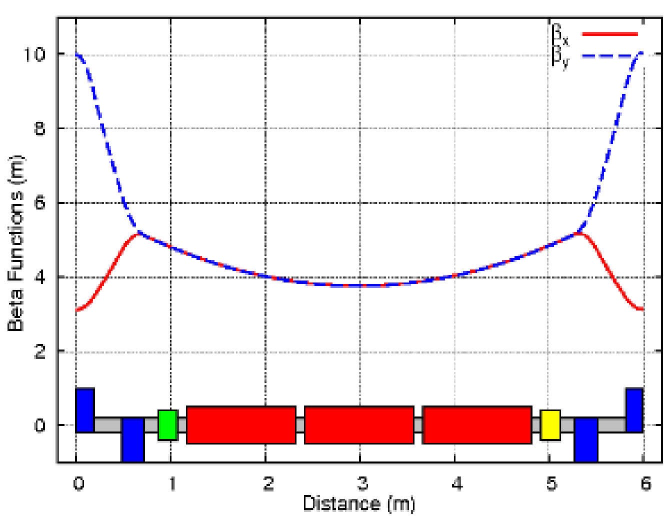
Lattices

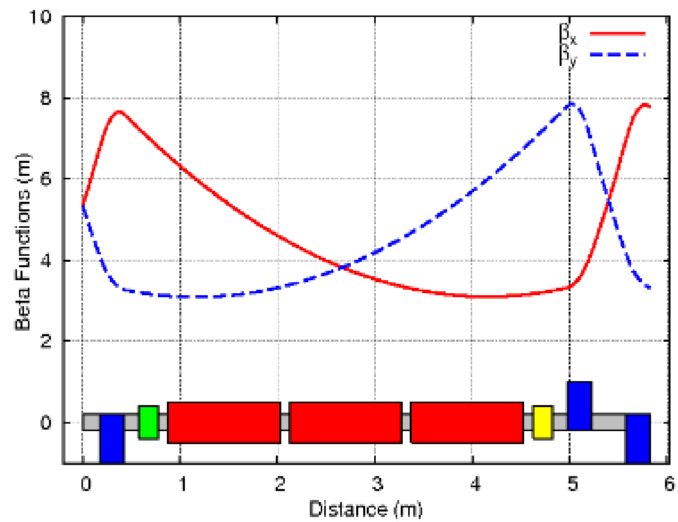
$$\Delta x \propto \int \frac{\beta(s')}{E(s')} ds'$$

Minimum deflection of particles from their ideal path requires small betatron oscillation which means strong lattice







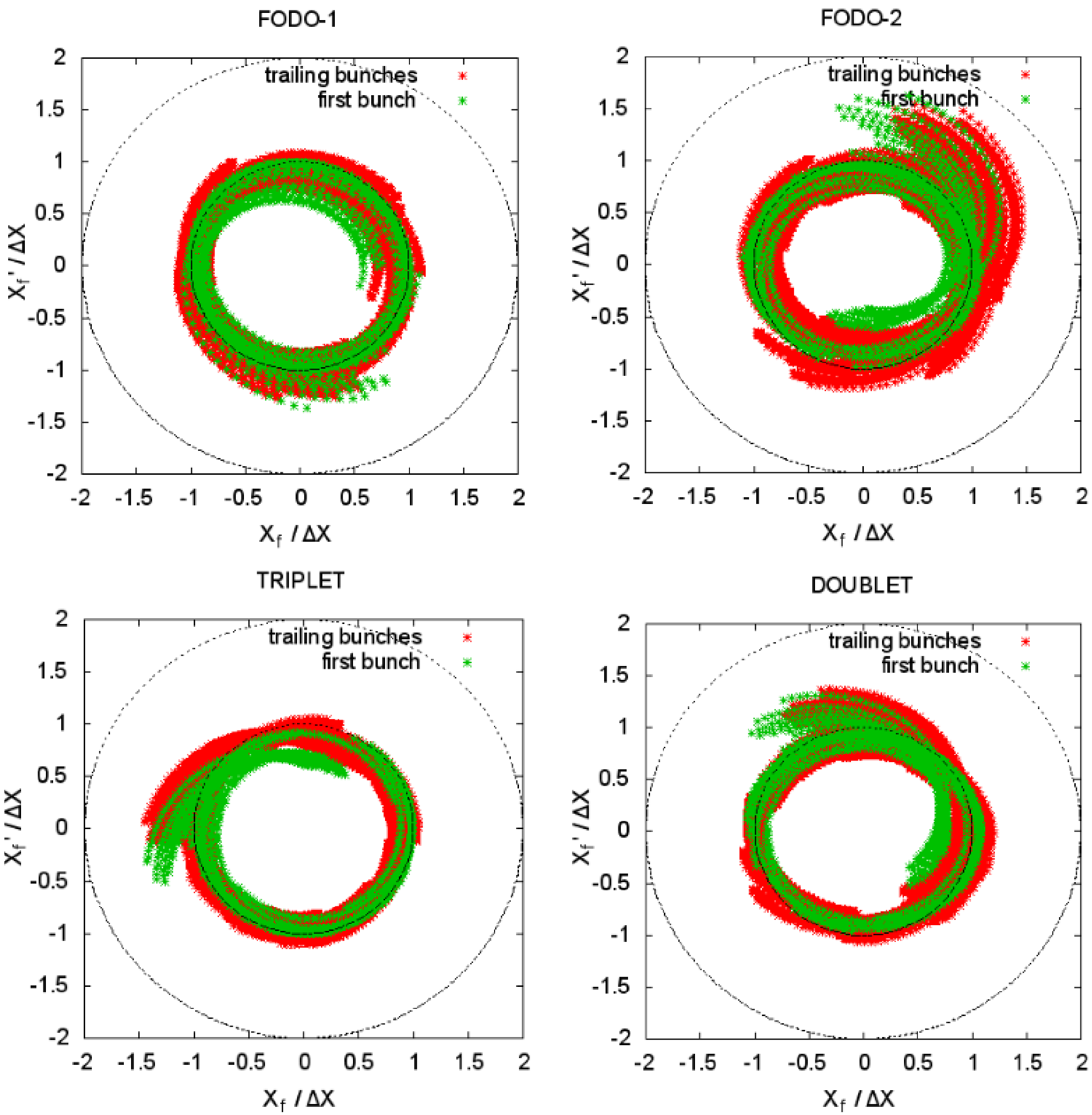


Four different lattice types were taken into account

Quadrupoles were considered to has length between 22 cm to 35 cm

Maximum quad field is considered to be 1 T for 40 mm quad aperture at 2.4 GeV

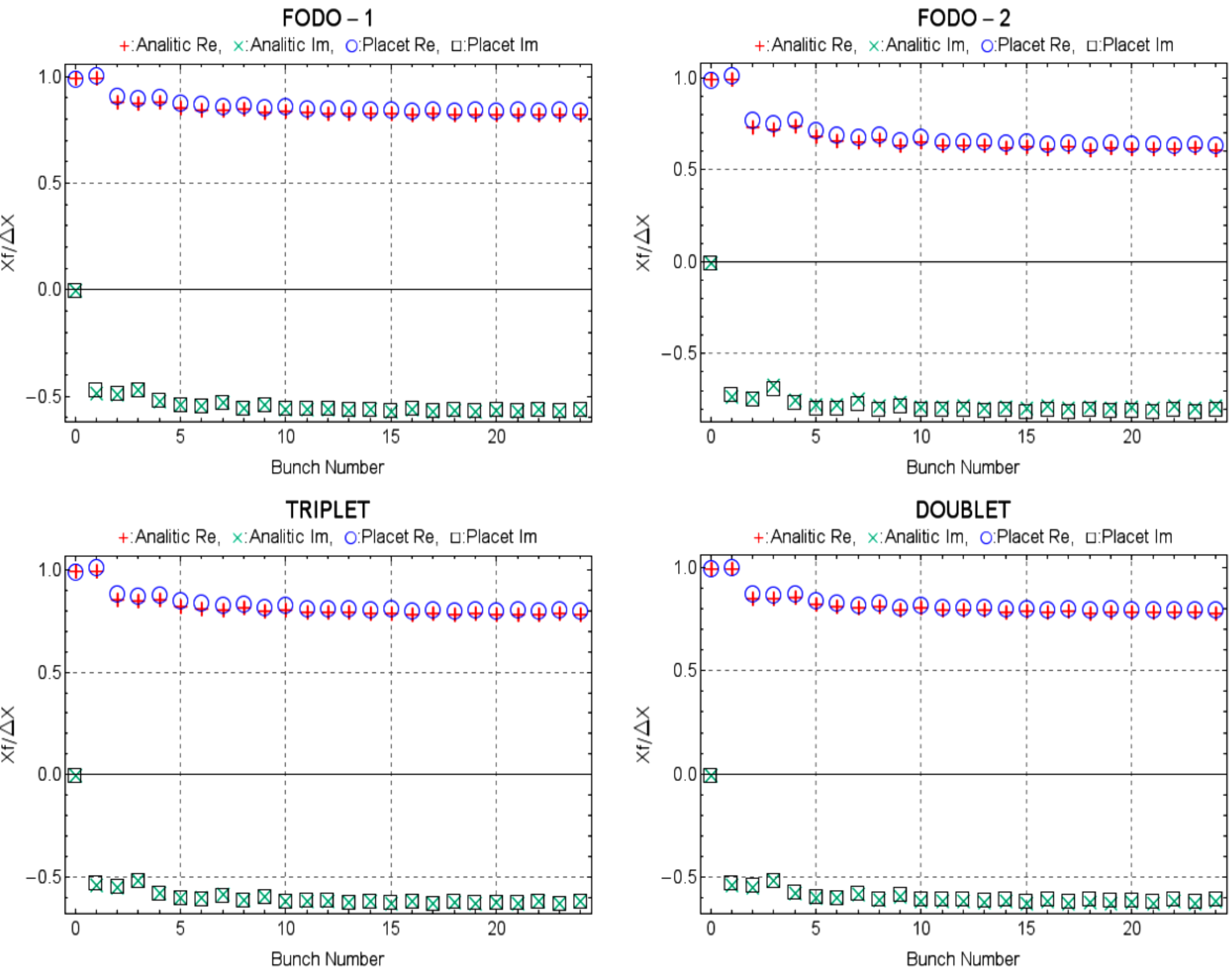
Short range wake effects



Plots shows normalized final phase space of the sliced bunches injected with an offset (PLACET)

The short range wake effect seems acceptable for all lattices.

Long range wake effects



Calculations were done using PLACET and analytical equations for

$2\times Q_m$ of CTF3

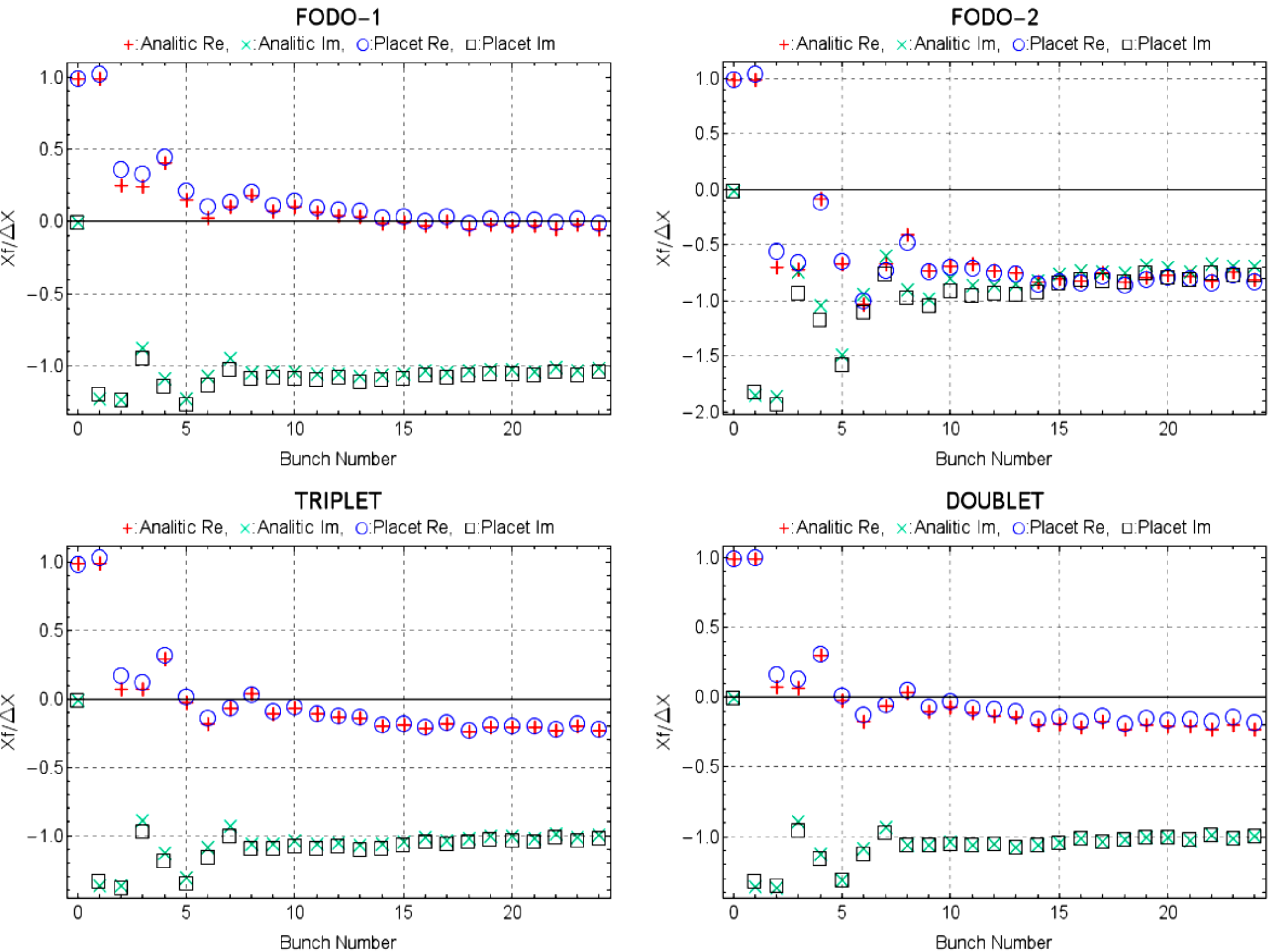
$1\times K_m$ of CTF3

Plots shows normalized amplitudes of the bunches at the end of the linac for an offset of incoming train.

Good agreement with analytical calculations and PLACET

The amplitudes (for 2xQm and 1xKm of CTF3) seems agreeable for all lattices

Long range wake effects



Calculations were done for

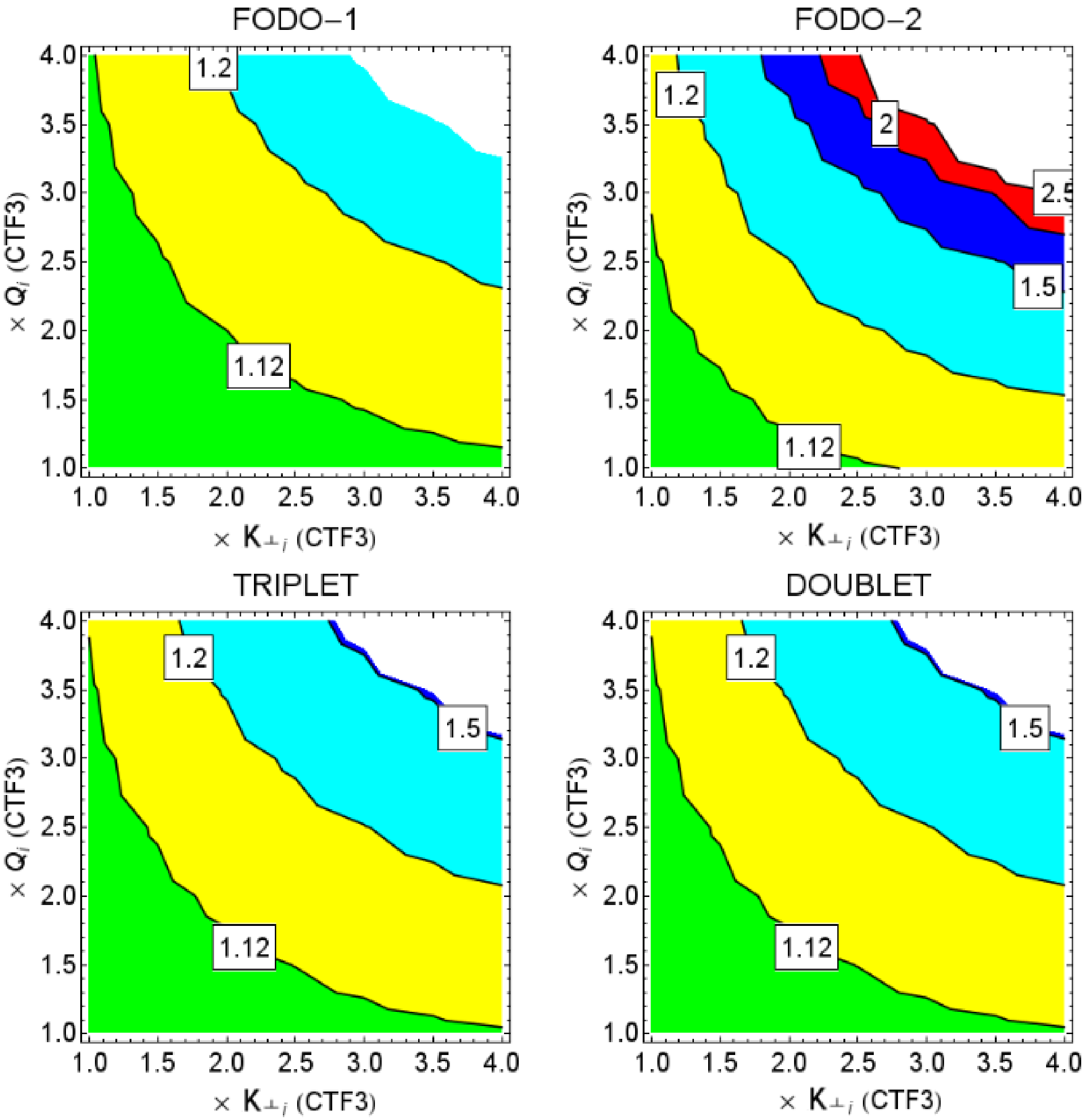
$3 \times Q_m$ of CTF3

$2 \times K_m$ of CTF3

Again good agreement with analytical calculations and PLACET

For FODO-1 TRIPLET and DOUBLET amplitudes seems acceptable

Coherent jitter



Coherent jitter of all bunches of the incoming beam causes scattering of the trailing bunches.

Coherent jitter is given with

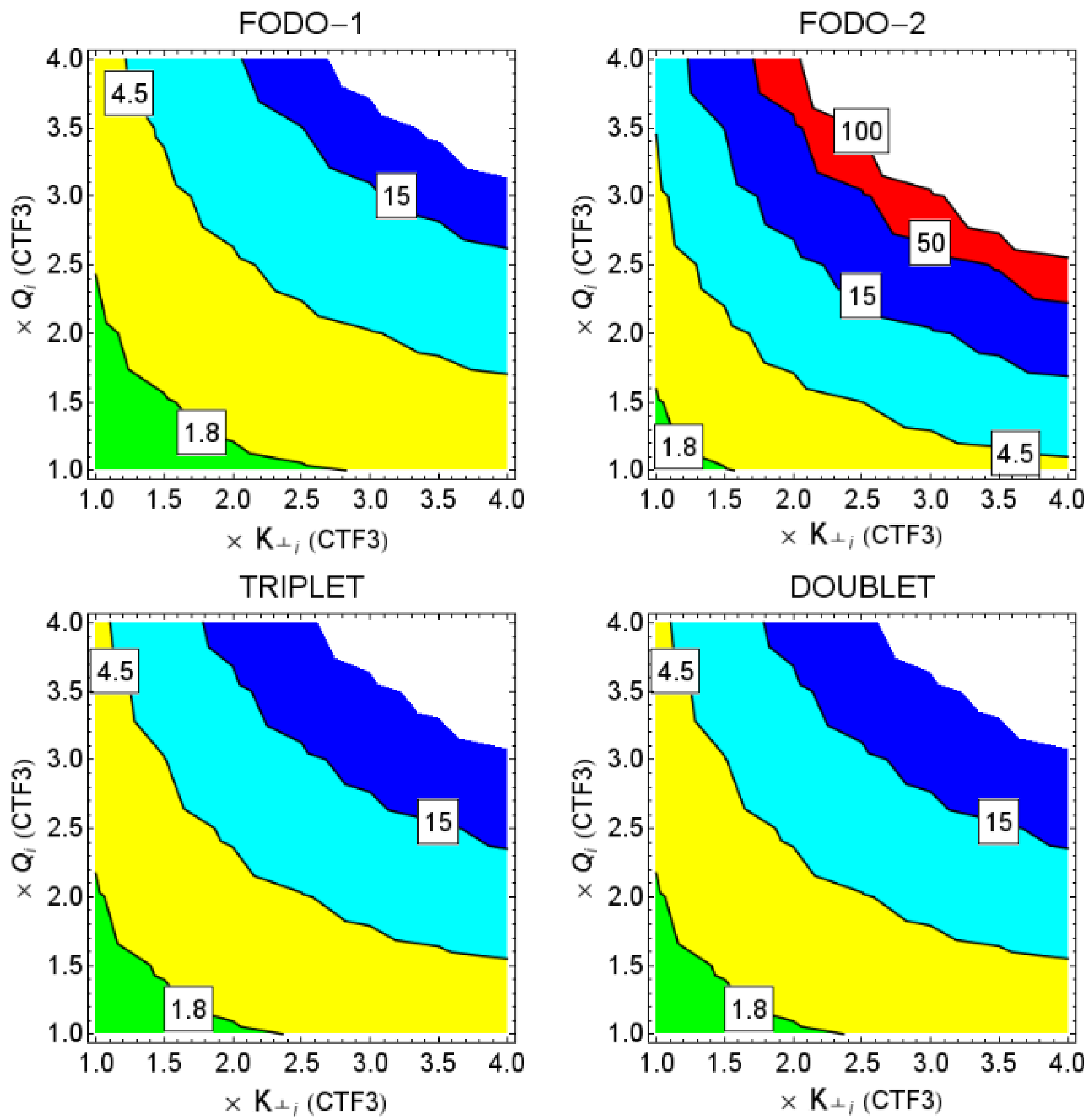
$$F_c = \frac{1}{n}\sum_j \left|\sum_k A_{j,k}\right|^2$$

Calculations was done analytically with scaling damping factor and kick factor of CTF3 structure

For all lattices coherent jitter is acceptable in green and yellow areas.

FODO-1 lattice allows larger Q and K

Bunch to bunch jitter



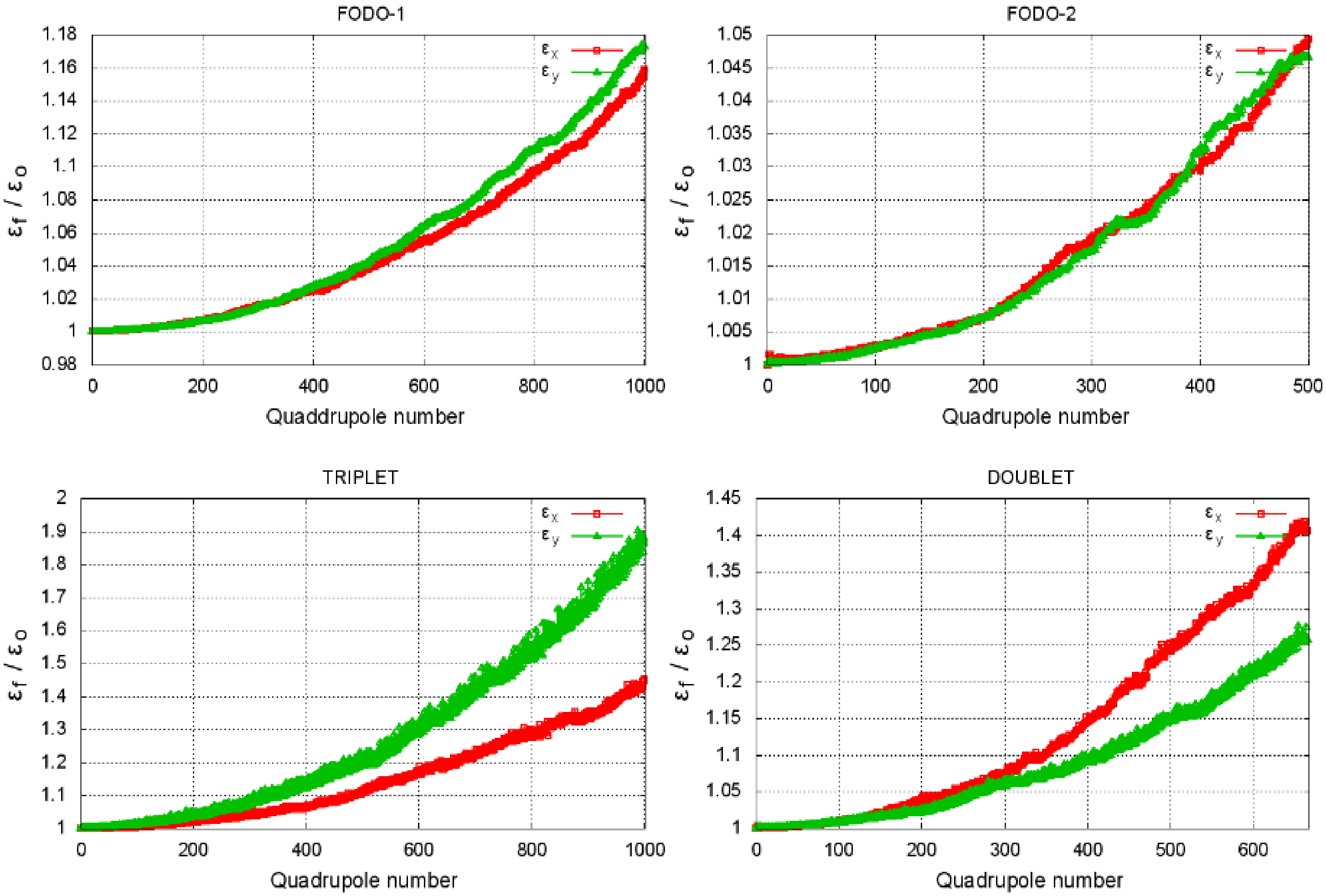
Random bunch-to-bunch jitter of the incoming beam also leads to scattering of the final bunches and it is given with

$$F_{rms} = \frac{1}{n}\sum_{j}\sum_{k} A_{j,k}A^{*}_{j,k}$$

For all lattices the limit of acceptability is the area of green and yellow

Again FODO-1 lattice allows larger Q and K

Emittance growth



Misalignment for all Quads

Err_x,y=0.2 mm

Err_px,y=0.2 m.rad

Misalignment for all BPMs

Err_x,y=0.2 mm

Err_px,y=0.0

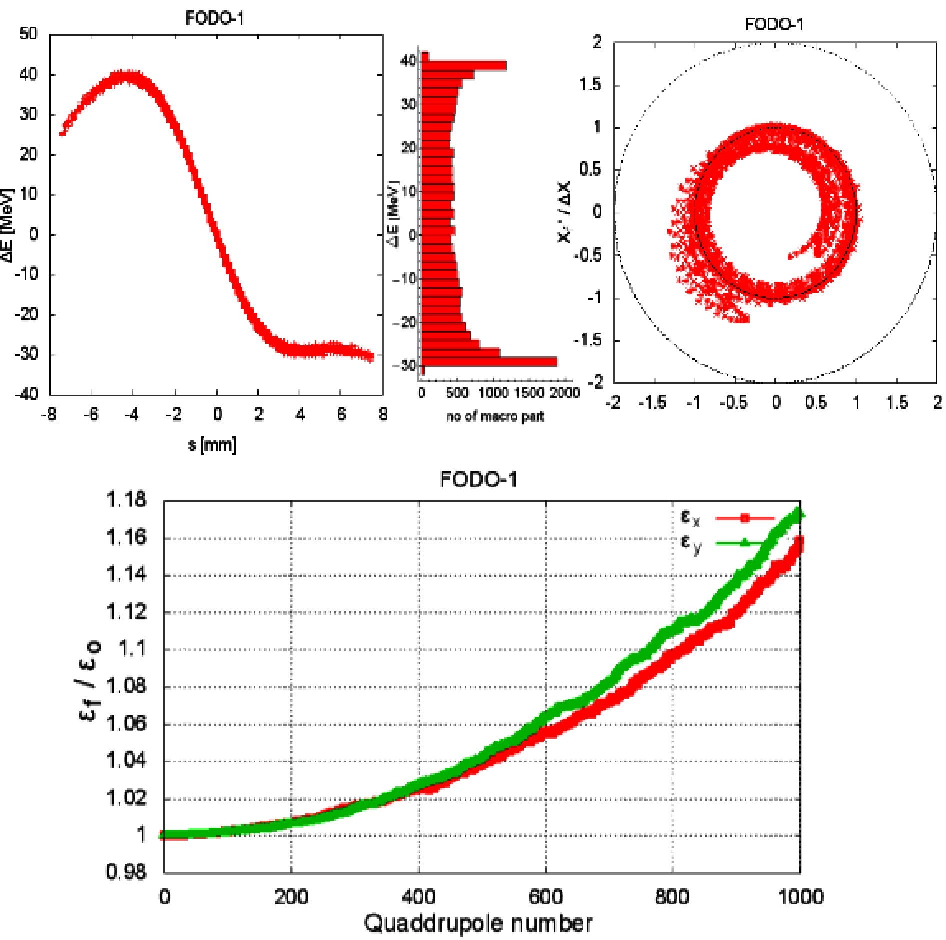
RF structures and other pieces are perfectly aligned

1 to 1 corrections were performed

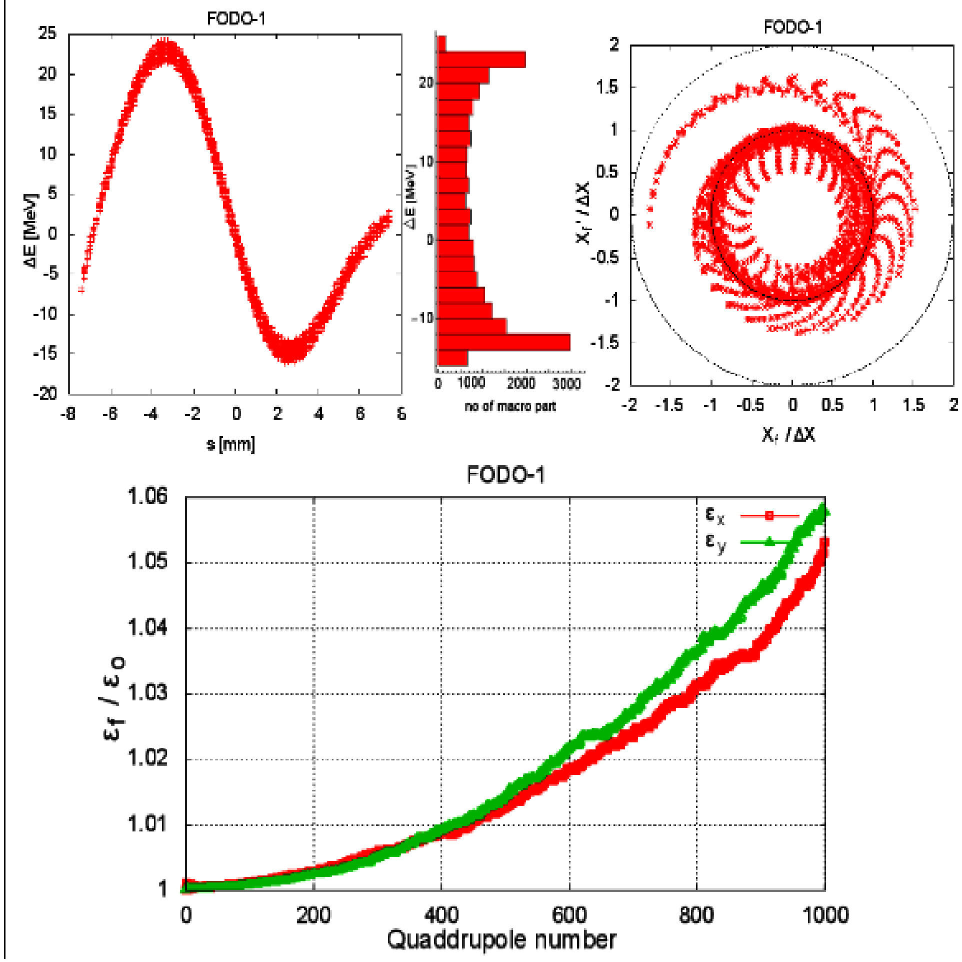
Since quadrupole strengths are weaker in FODO2 alignment is easier than other lattices. Triplet lattice the emittance growth is huge due to strong quadrupoles and alignment difficulty

An example for off-crest acceleration

$\varphi_{RF}=0^{o}$, $\Delta E/E=1\%$

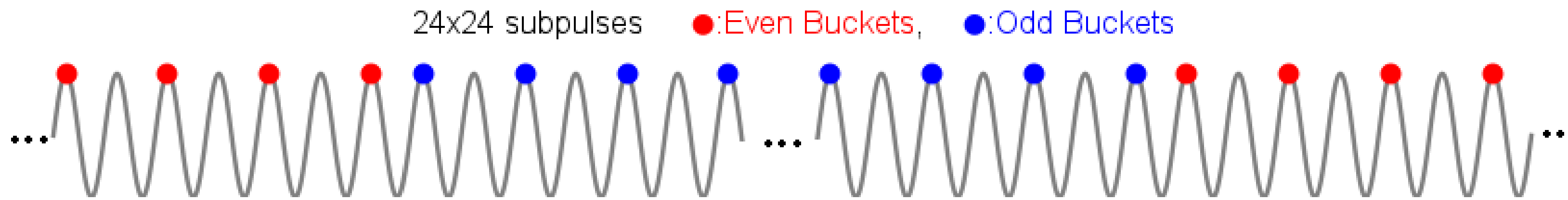


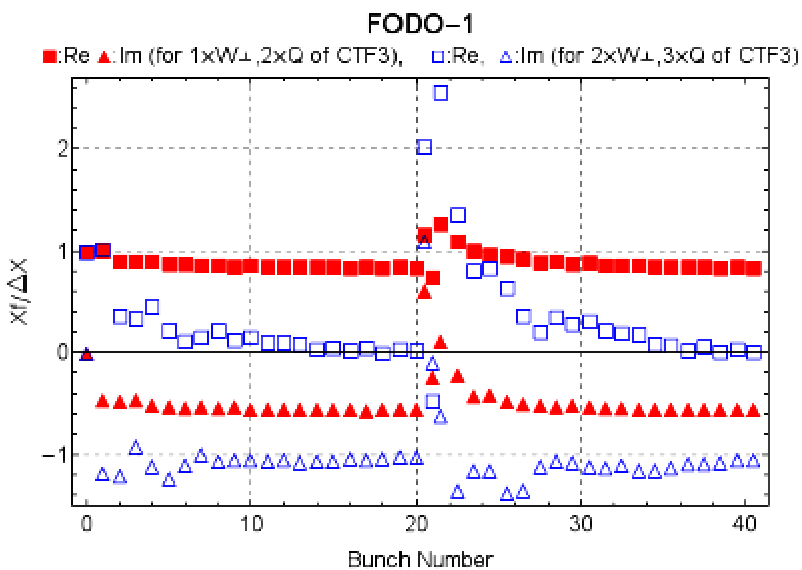
$\varphi_{RF}=5^{0}$, $\Delta E/E=0.6\%$

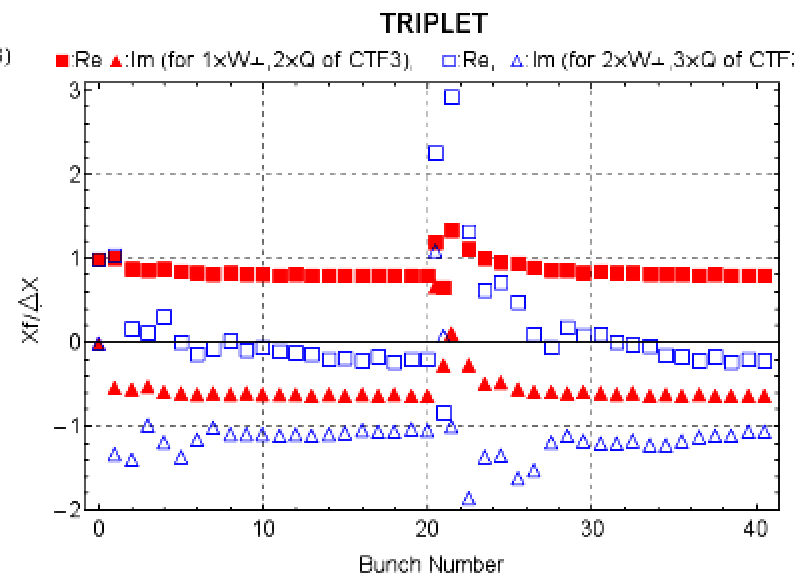


- **Plots shows various results for FODO-1 lattice**
- **Energy spread and emittance growth can be reduced but transverse single bunch instability occurs even in strongest lattice**

CLIC DB time structure





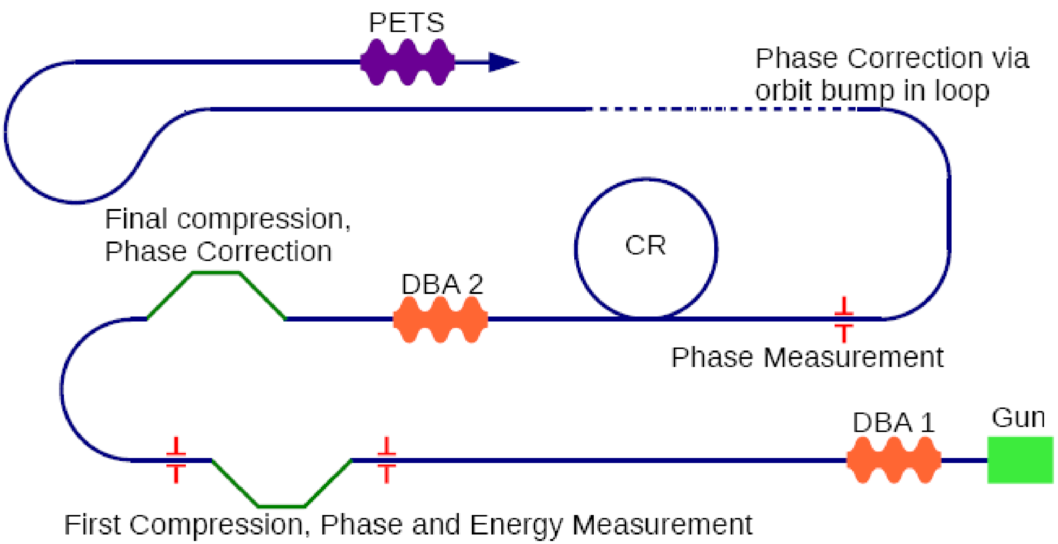


- CLIC DB pulse consist of 24x24 sub pulses which fills even-odd RF buckets
- At an exact time sub pulse switches and starts to fill odd (-even) bucket
- On that point the wake will change due to timing of bunches.
- This chance can cause not only amplitude change but also beam losses..
- This condition was not taken into account this situation in all calculations above

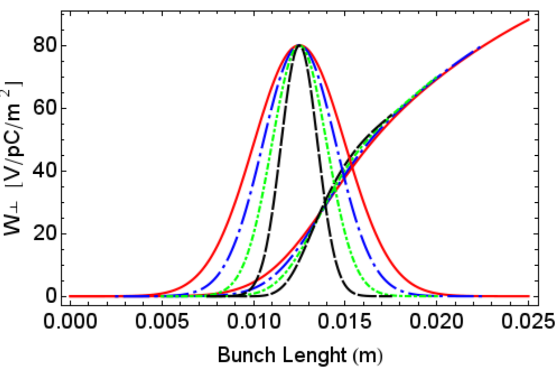
Conclusion

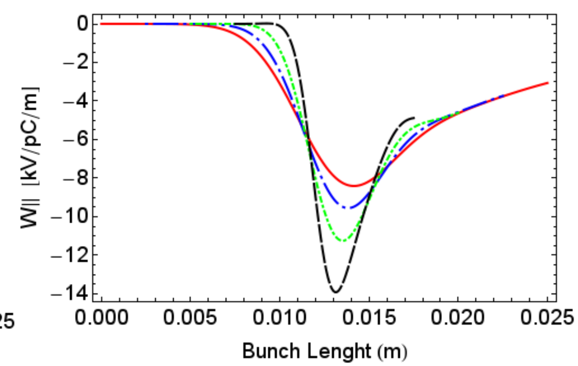
- We have 4 different type lattices to make calculations for DB linac after the structure fully designed
- However the simulations give some ideas about damping requirement for the structure incase the kick factors of new structure are close values to CTF3
- The beam was considered to be without any phase or energy error and we didn't make any calculation about longitudinal stability
- DB pulse time structure was not taken into account for all calculations as well
- …

Further work plan



F.Stulle Last Beam Phy. meeting





Wake potentials for different bunch length for designing structure (ABCI result)

- **Using same lattices with final design of structure and with DB time structure**
- **Checking longitudinal stability with various injection errors**
- **Checking if bunch compressor is necessary on DB linac**
- **Simulating off-crest acceleration in order to reduce energy spread and emittance growth**

thank you for your attention

And Special Thanks to Daniel Schulte