Beam Physics in Drive Beam Accelerator

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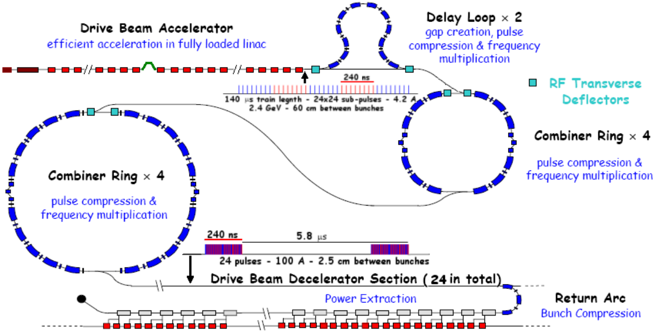
Outline

CLIC RF power production layout



- Beam with 140 μs pulse length and 4.2 A current is accelerated up to 2.4 GeVin 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

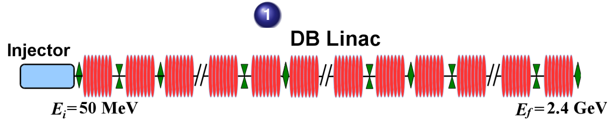
The study aims finding solutions for beam transport through Drive Beam Linac in required tolerances...

- the transverse parameters...
  - small emittance growth
  - small transverse jitter amplification
  - easy correctable lattice
- the longitudinal parameters...
  - stable beam phase
  - stable bunch length
  - small energy spread
- stable bunch charge

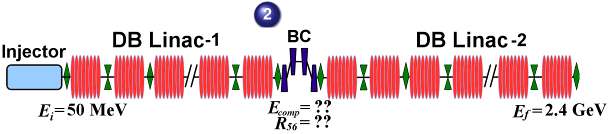
DB Linac Beam Parameters

Initial Beam Energy(MeV)	50
Final Beam Energy(GeV)	2.4
Initial Energy Spread(%)	1
Final Energy Spread(%)	<0.35
Pulse Current(A)	4.2
Bunch Charge(nC)	8.4
Initial Bunch Length(mm)	3
Final Bunch Lenght(mm)	1
Initial Emittance (mm.mrad)	50
Emittance Growth(%)	<10
Pulse Length(μ s)	140
Bunch separation(cm)	60
No of Bunch/Pulse	70128
Bunch length variatiton(%)	<1
Bunch Phase variation(deg)	<0.2

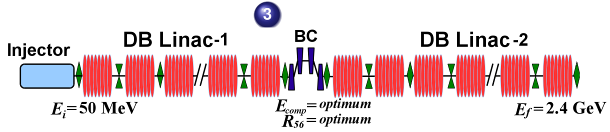
Work flow



- optimising lattice
- optimising structure

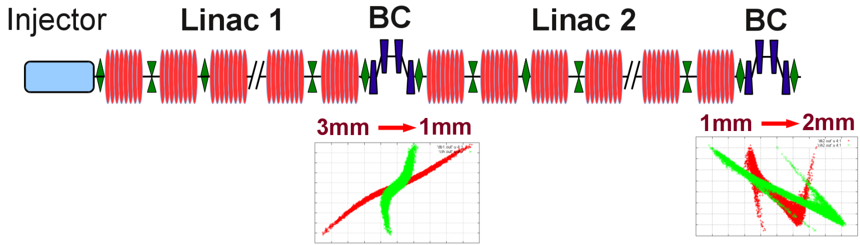


- Finding compression energy
- optimising compressor



- optimising lattice again
- . . .

Sketch of Drive Beam Linac



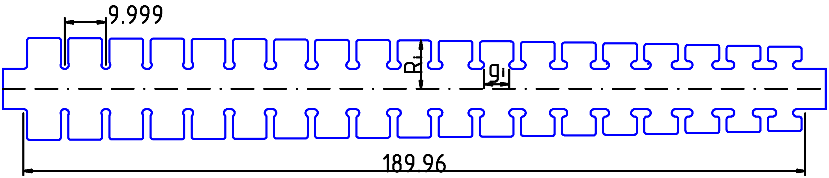
DBL-1

- Beam Energy 50-300 MeV
- No of Structure $\sim$ 85
- Rf Phase 20-27.5 deg

DBL-2

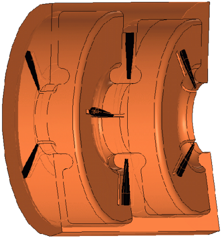
- Beam Energy 0.3-2.4 GeV
- No of Structure 665
- Rf Phase 18 deg

CLIC Drive Beam Accelerating Structure



SICA (Slotted Iris-Constant Aperture) principle like CTF3

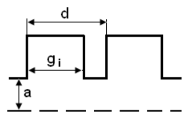
- P_{RF} = 15 MW
- Cell number = 19 Cell
- Total length = 2.4 m (including coupler & connectors)
- RBP = 49 mm
- Cell length = 99.979 mm
- Gap length = 40-80 mm
- Gradient = 3.4 MV/ per structure
- Efficiency = > 95 %



R. Wegler

Wakes of the Structure

Short Range wakes (Karl Bane)



$Z_0 = 120\pi\Omega$

$$s_{\|0,i} = 0.41\,\frac{a^{0.18} g_i^{1.6}}{d^{2.5}},\; s_{\perp 0,i} = 1.69\,\frac{a^{1.79} g_i^{0.38}}{d^{1.17}}$$

$$W_{\|}(s) = \frac{1}{n}\sum_{i=1}^{n} \frac{4 Z_0 c}{\pi a^2} \exp\left(-\sqrt{\frac{s}{s_{\|0,i}}}\right)$$

$$W_{\perp}(s) =$$

$$\frac{1}{n}\sum_{i=1}^{n} \frac{4 Z_0 c s_{\perp 0,i}}{\pi a^4}\left[1 - \left(1 + \sqrt{\frac{s}{s_{\perp 0,i}}}\right) e^{-\sqrt{\frac{s}{s_{\perp 0,i}}}}\right]$$

Long Range wakes

HOM's of CTF3 given in design report are scaled for 1 GHz structure

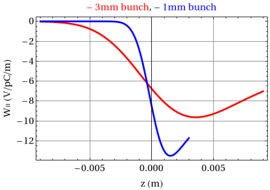
f:frequency of mode

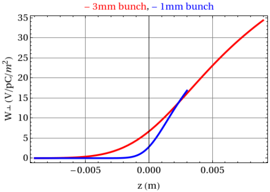
K:kick factor of mode

Q:Damping term of mode

$f' = f\frac{1}{3}$, $K' = K(\frac{1}{3})^3$, $Q' = Q$

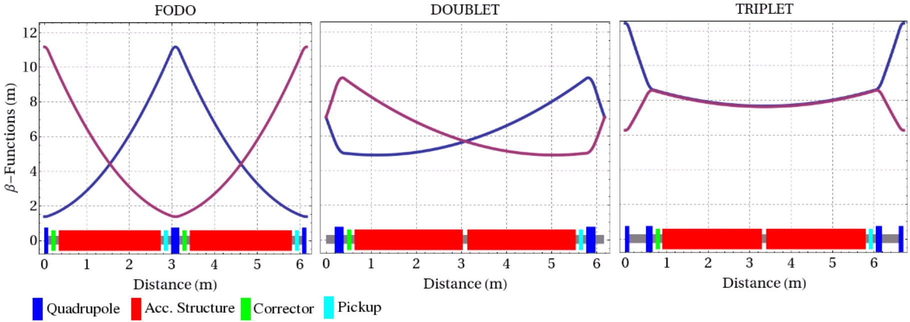
f [GHz]	Q	K [V/pC/m$_2$]
1.37	8.74	16.86
1.45	8.11	24.48
1.73	71.55	6.31
...	...	...





Studied Lattices

$\Delta x \propto \int \frac{\beta(s)}{E(s)} ds \Rightarrow$ Minimum deflection of particles from their ideal path requires small betatron oscillations



FODO

Total length 6.2 m
Quad length 0.2 m
Quad strength 2.6 m^{-2}

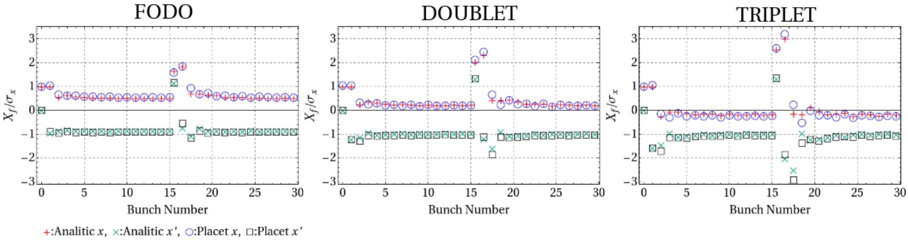
DOUBLET

Total length 6.2 m
Quad length 0.2 m
Quad strength 2.86 m^{-2}

TRIPLET

Total length 6.74 m
Quad length 0.22;0.16 m
Quad strength 2.86;-2.0m^{-2}

Long range wake effecs



$$a_x = \frac{\sigma_{x,0}}{\Delta x} \frac{x_f}{\sigma_{x,f}}$$

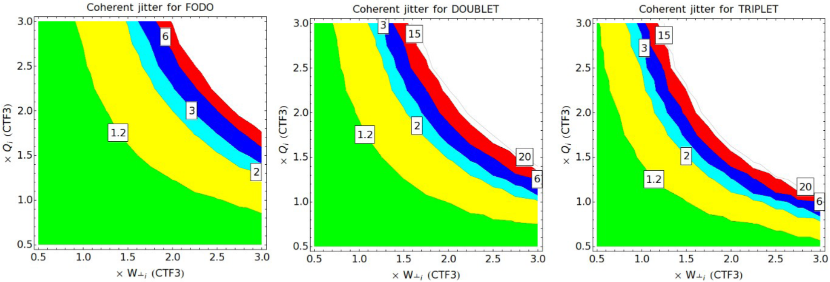
$$a_{x'} = \frac{\sigma_{x,0}}{\Delta x} \frac{x'_f}{\sigma_{x',f}}$$

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

At overlapping point on train triplet lattice is worst one.. FODO lattice is agreeable

Coherent Jitter

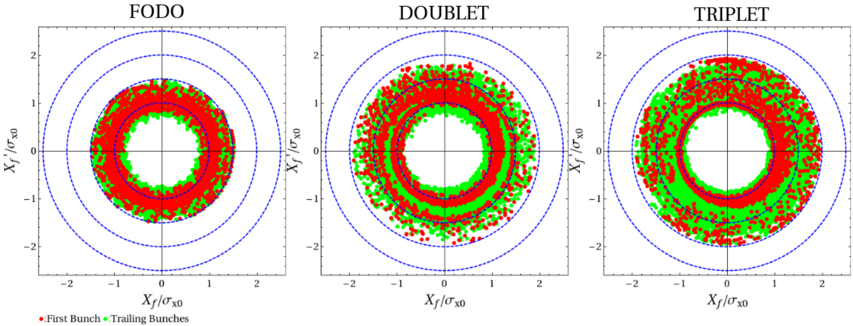
Coherent offset of all bunches of the incoming beam causes scattering of the trailing bunches. It can be found with summing amplifications of all bunches in train.



$$F_c = \frac{1}{n}\sum_i |a_i|^2$$

Computation was performed for point like bunches with constant charge and constant distance (train of 100 bunch) with scaling kick factor and damping factor of HOMs of CTF3 structure.

Short Range wake effects

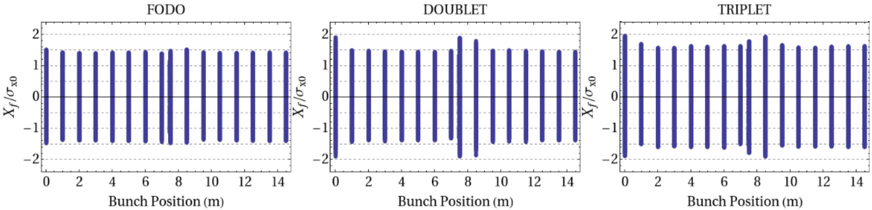


Plots show normalized amplification of a train with 50 bunches with constant initial offset (red points first bunch, blue points trailing bunches)

The long range kicks are dumped due to energy spread within each individual bunches

At FODO lattice amplification is acceptable. Triplet lattice is worse one

Short and long Range wake effects



Plots show normalized amplification of a train with 16 bunches with constant initial offset

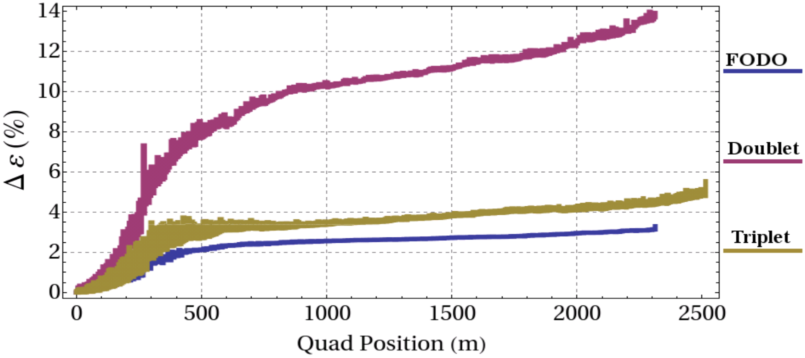
The long range kicks are dumped due to energy spread within each individual bunches

At FODO lattice amplification is acceptable. Triplet lattice is worse one

Emittance Growth

All elements are assumed to be scattered around perfectly aligned line with a normal distribution of $\sigma = 200\mu m$ and $\sigma' = 200\mu rad$

BPMs are placed in frond of each quadrupole for all lattice types.



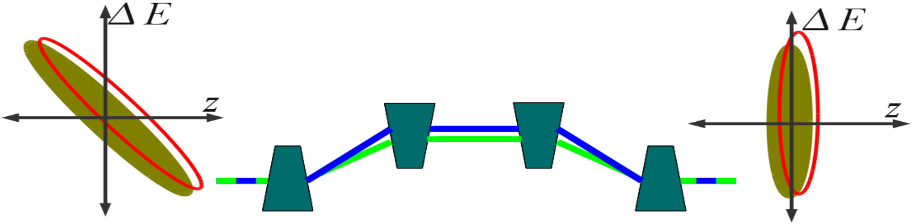
Plot shows the emittance growth along the beamline consisting of DBA1 and DBA2. For bunch compressor section the beamline assumed to be perfect.

FODO and triplet lattice type emittance growth is quite small while for doublet it is above 10

Design of bunch compressor

If there is any variation on desired relative energy spread, the error will be transferred to phase or length of outgoing bunch

$$\delta_z = R_{56}\delta_E$$



What can change relative energy spread ?

- Current error of beam → changes wake field
- Incoming phase error of bunch or phase error RF
- Gradient error of linac or energy error of incoming beam

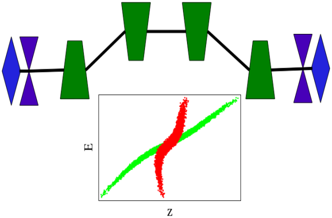
for fully loaded opr.

$$\frac{\delta E}{E_0} \propto \frac{2\delta G}{G_0}$$

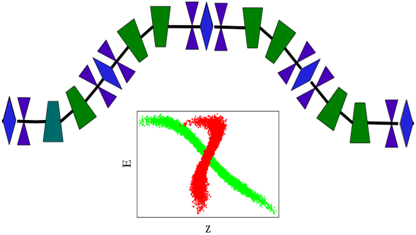
$$\frac{\delta E}{E_0} \propto \frac{\delta N}{N_0}$$

Studied bunch compressors

Four different bunch compressor has been taken into account



$R_{56} = -0.10; -0.12; -0.14$

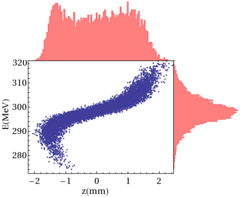


$R_{56} = +0.26$

- Bunch compressor is located at 300 MeV for both type
- For chicane phase of Rf of DBL1 = 23 ; 27.5 degree
- For arc phase of Rf of DBL1 = − 7.5 degree
- For all bunch compressors only single bunch case has been computed

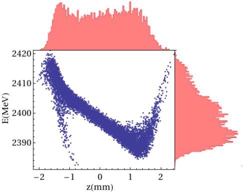
Phase Spaces at the end of compressor and Linac-2

Long Phase space at end of Compressor R56=−0.1



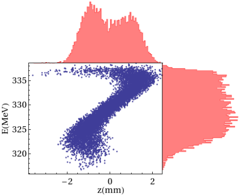
σ_{xrms}	= 0.345	(mm)
σ_{yrms}	= 0.987	(mm)
σ_{zrms}	= 1.00	(mm)
ϵ_{xrms}	= 49.0	(μm.rad)
ϵ_{yrms}	= 50.4	(μm.rad)
ϵ_{zrms}	= 2.59	(MeV.mm)
<E>	= 298.7	(MeV)
ΔE/E	= 2.06	(%)
ΔE	= 45.0	(MeV)
<ΔE>	= 6.16	(MeV)

Long Phase space at end of DBL2 R56=−0.1



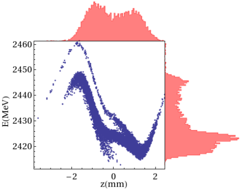
σ_{xrms}	= 0.119	(mm)
σ_{yrms}	= 0.349	(mm)
σ_{zrms}	= 1.00	(mm)
ϵ_{xrms}	= 49.3	(μm.rad)
ϵ_{yrms}	= 50.3	(μm.rad)
ϵ_{zrms}	= 3.78	(MeV.mm)
<E>	= 2399.	(MeV)
ΔE/E	= 0.313	(%)
ΔE	= 38.8	(MeV)
<ΔE>	= 7.50	(MeV)

Long Phase space at end of Compressor R56=+0.26



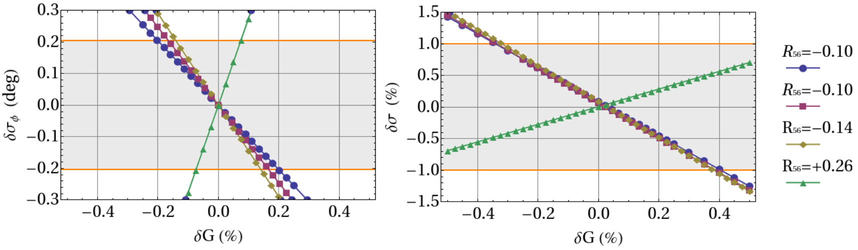
σ_{xrms}	= 0.329	(mm)
σ_{yrms}	= 0.932	(mm)
σ_{zrms}	= 1.00	(mm)
ϵ_{xrms}	= 49.0	(μm.rad)
ϵ_{yrms}	= 50.3	(μm.rad)
ϵ_{zrms}	= 2.68	(MeV.mm)
<E>	= 329.3	(MeV)
ΔE/E	= 1.42	(%)
ΔE	= 21.8	(MeV)
<ΔE>	= 4.67	(MeV)

Long Phase space at end of DBL2 R56=+0.26



σ_{xrms}	= 0.118	(mm)
σ_{yrms}	= 0.345	(mm)
σ_{zrms}	= 1.00	(mm)
ϵ_{xrms}	= 49.0	(μm.rad)
ϵ_{yrms}	= 50.2	(μm.rad)
ϵ_{zrms}	= 4.83	(MeV.mm)
<E>	= 2428.	(MeV)
ΔE/E	= 0.374	(%)
ΔE	= 48.5	(MeV)
<ΔE>	= 9.09	(MeV)

RF Gradient Tolerance

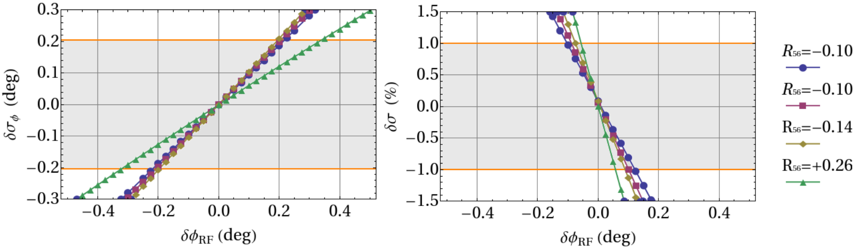


The RF amplitude tolerance is limited by the phase error of the bunches, the length variations are small

The amplitude tolerance of the effective gradient is 0.2%

- for the accelerating power amplitude the tolerance is 0.1% → it will be 0.2% for the klystron power
- for beam current it is 0.2%

RF Phase Tolerance

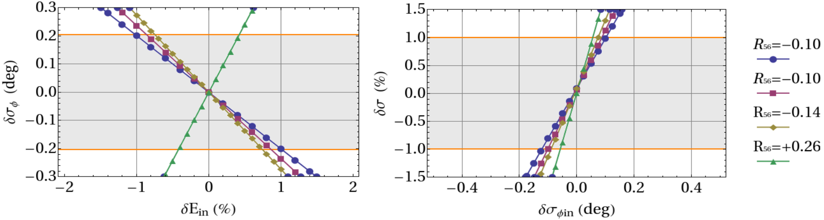


The phase tolerance is limited by the bunch length variation. Largest tolerance is given with $R_{56} = -0.1$

The phase tolerance for the effective gradient is 0.1deg

- for klystron phase it is 0.05deg
- for the beam phase it is 0.1deg

Incoming bunch energy and phase tolerance



incomin energy tolerance is limited by phase error,

incoming phase tolerance is limited by bunch length variation

The incoming energy tolerance is 1%

Incoming energy 50 MeV $\rightarrow$ 0.5MeV $\approx$ 0.2% gradient tolerance over 85 structure

Incoming phase tolerance is 0.1deg

It is identical to the phase tolerance of the effective gradient

Conclusion

- Three type of lattices has been studied and FODO lattice yields best results. Additionally it has
  - low cost
  - easy operation
- In order to have weaker lattice one can use two accelerating structure per half FODO cell after 1.5 GeV. That wouldn't change wakefield effects much since integration along beamline will not change much.
- Computations on compressor sections were performed under linear approximation and missalingments of the elements on this section were not taken into account.
- Although arc compressor is better about saving RF power (about 10 structure), larger tolerances are achieved with chicane that has $R_{56} = -0.1$m.
- Computed longitudinal tolerances can be summarized as

RF power error	(%)	0.2
Beam current error	(%)	0.2
RF phase error	(deg)	0.05
Incoming beam phase error	(deg)	0.1

- Obviously these tolerances can be tighter for multibunch beam loading case since there can exist bunch-to*bunch energy spread and phase shift.

Thank you for your attention . . .