CLIC Drive Beam Linac re-baselining (preliminary)

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Ankara University

CLIC Beam Physics Meeting
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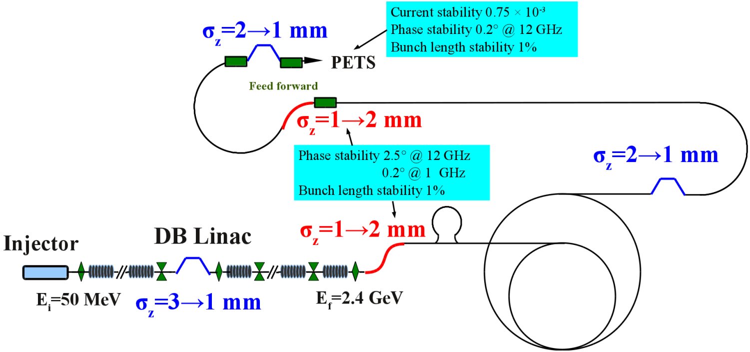
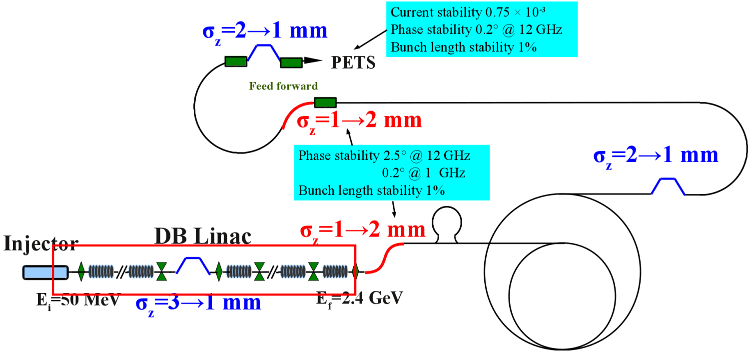
Contents

CLIC RF power production layout



- The beam pulse with 140 μs pulse length and 4.2 A current which consists of 24 $\times$ 24 sub-trains of about 120 bunches each is accelerated up to 2.4 GeV in Drive Beam Linac (DBL).
- After DBL, 24 sub-trains will be merged into a signle sub-train using delay loop (DL), combiner ring one (CR1) and combiner ring two (CR2). (Each sub train will have 100 A pulse current and 240 ns pulse length)
- CLIC requires very thight tolerances at the entrance of PETS. If the full bunch compression is performed in front of PETS one needs large R_{56} required and large R_{56} requires too small energy jitter.
- In order to avoid the strong coupling between energy jitter and beam phase jitter, we propose to make full comression on Linac

CLIC RF power production layout



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Parameters

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
  - > acceptance of large energy errors
- the longitudinal parameters...
  - > stable beam phase
  - > stable bunch length
  - > relatively 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

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- the longitudinal parameters...
  - > stable beam phase
  - > stable bunch length
  - > relatively small energy spread
- stable bunch charge
- The cost
  - > reduction of total length
  - > less number of accelerating structres
  - > less number of magnets small building ...

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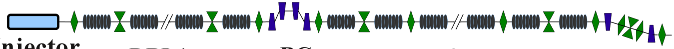
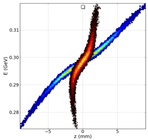
Sketch of Drive Beam Linac (CDR version)



Injector

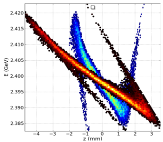
DBL1
85 Acc. Struc.
E_i=50 MeV
E_f=300 MeV

BC
σ_z=3→1 mm



DBL2
665 Acc. Struc.
E_i=300 MeV
E_f=2.4 GeV

BC
σ_z=1→2 mm



DBL-1

- Beam Energy 50-300 MeV
- No of Structure ~ 85
- Rf Phase 20-27.5 deg
- total length ~ 270 m

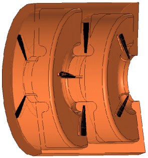
DBL-2

- Beam Energy 0.3-2.4 GeV
- No of Structure ~ 665
- Rf Phase 18 deg
- total length ~ 2100 m

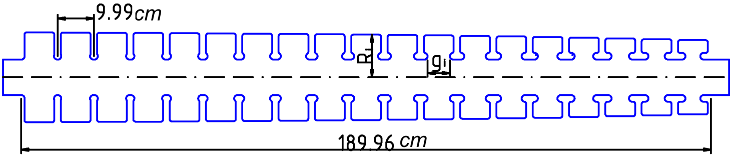
With higher gradient the baseline would be shorter

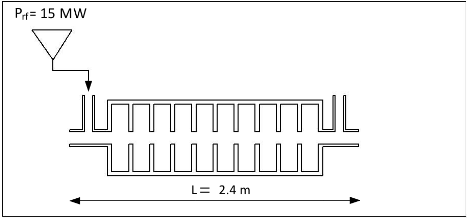
CLIC Drive Beam Accelerating Structure

SICA (Slotted Iris-Constant Aperture) principle



Rolf Wegler





$$E_{acc} \approx \frac{P_{rf}}{L_{struc}}$$

Structure parameters

- P_{RF} = 15 MW
- Cell number = 19 Cell
- Total length = 2.4 m
- Cell length = 99.979 mm
- RBP = 49 mm
- Gap length = 40-80 mm
- Gradient = 1.8 MV/ m
- Efficiency = > 95 %

CLIC Drive Beam Accelerating Structure

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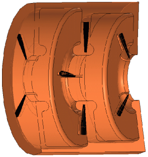

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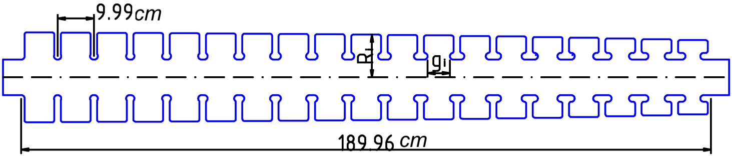
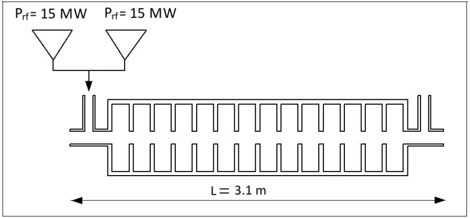




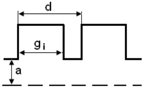
$$E_{acc} \approx \frac{P_{rf}}{L_{struc}}$$

Structure parameters

- P_{RF} = 30 MW
- Cell number = 26 Cell
- Total length = 3.1 m
- Cell length = 99.979 mm
- RBP = 49 mm ??
- Gap length = 40-80 mm ??
- Gradient = 2.6 MV/ m
- Efficiency = > 95 % ??

Wakes of the Structure

Short range wake fields (Karl Bane)



$$Z_0 = 120\pi\Omega$$

$$s_{\|0,i} = 0.41\frac{a^{0.18}g_i^{1.6}}{d^{2.5}}$$

$$s_{\perp 0,i} = 1.69\frac{a^{1.79}g_i^{0.38}}{d^{1.17}}$$

$$s_{\|0,av} = \frac{1}{n}\sum_{i=1}^{n} s_{\|0,i}, \quad s_{\perp 0,av} = \frac{1}{n}\sum_{i=1}^{n} s_{\perp 0,i}$$

$$W_{\|}(s) = \frac{4Z_0c}{\pi a^2}\exp\left(-\sqrt{\frac{s}{s_{\|0,av}}}\right)$$

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

Long range wake fields

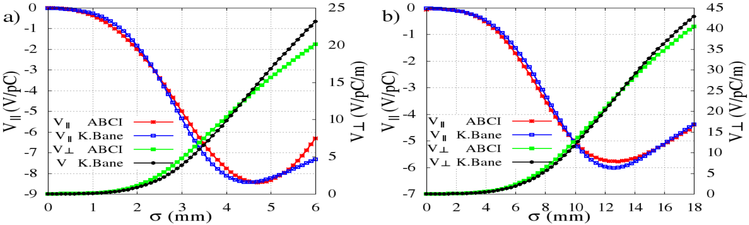
HOM's of CTF3 given in design report are scaled for 1 GHz structure

- **f:** frequency of mode
- **K:** kick factor of mode
- **Q:** Damping term of mode

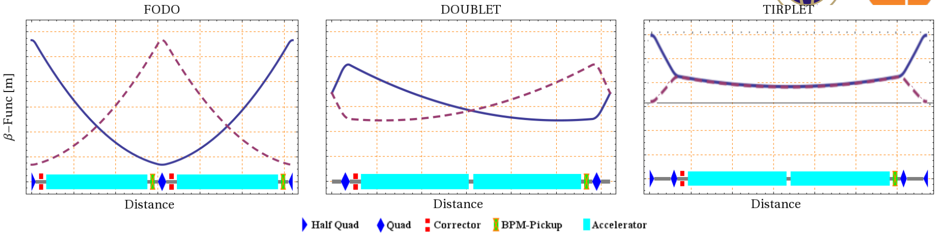
$$\mathbf{f'} = \mathbf{f}\tfrac{1}{3}, \quad \mathbf{K'} = \mathbf{K}\left(\tfrac{1}{3}\right)^3, \quad \mathbf{Q'} = \mathbf{Q}$$

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
...	...	...

No long range longitudinal wake field (perfect beam loading)



Lattices



CDR version

FODO

Total length $L = 6.2m$
Quad length $L_q = 0.2m$
Quad strength $K_q = 2.6m^{-2}$
Phase advance $\mu_{x,y} = 103^\circ$

DOUBLET

Total length $L = 6.2m$
Quad length $L_q = 0.2m$
Quad strength $K_q = 2.86m^{-2}$
Phase advance $\mu_{x,y} = 58^\circ$

TRIPLET

Total length $L = 6.74m$
Quad length $L_q = 0.22; 0.16m$
Quad strength $K_q = 2.86; -2.0m^{-2}$
Phase advance $\mu_{x;y} = 46^\circ; 49^\circ$

Updated version

FODO

Total length $L = 7.56m$
Quad length $L_q = 0.18m$
Quad strength $K_q = 2.2m^{-2}$
Phase advance $\mu_{x,y} = 95^\circ$

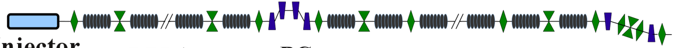
DOUBLET

Total length $L = 7.64m$
Quad length $L_q = 0.22m$
Quad strength $K_q = 2.86m^{-2}$
Phase advance $\mu_{x,y} = 58^\circ$

TRIPLET

Total length $L = 8.11m$
Quad length $L_q = 0.25; 0.18m$
Quad strength $K_q = 2.88; -2.07m^{-2}$
Phase advance $\mu_{x;y} = 56^\circ; 59^\circ$

Sketch of Drive Beam Linac (CDR version)



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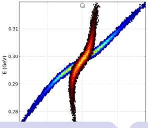
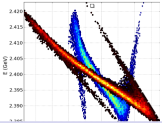


DBL2
665 Acc. Struc.
E_i=300 MeV
E_f=2.4 GeV

BC
σ_z=1→2 mm



CDR version

DBL-1

- Beam Energy 50-300 MeV
- No of Structure ∼ 85
- Rf Phase 20-27.5 deg
- total length ∼ 270 m

DBL-2

- Beam Energy 0.3-2.4 GeV
- No of Structure ∼ 665
- Rf Phase 18 deg
- total length ∼ 2100 m

Updated version

DBL-1

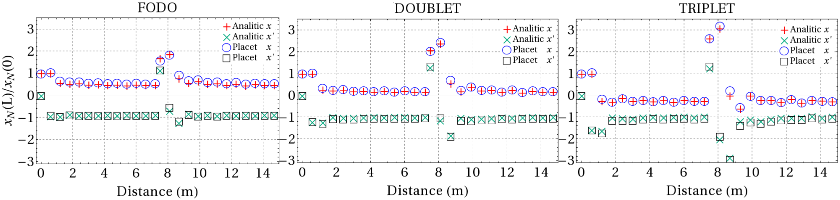
- Beam Energy 50-300 MeV
- No of Structure ∼ 45
- Rf Phase ∼ 25 deg
- total length ∼ 170 m

DBL-2

- Beam Energy 0.3-2.4 GeV
- No of Structure ∼ 320
- Rf Phase ∼ 15 deg
- total length ∼ 1350 m

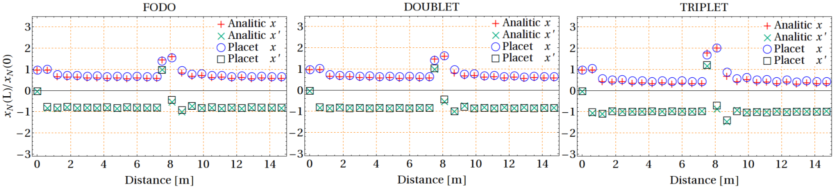
Long range transverse wake effects

CDR version



$$\begin{pmatrix} x_N(s) \\ x'_N(s) \end{pmatrix} = \sqrt{\frac{\gamma(s)}{\beta_x(s)}} \begin{pmatrix} 1 & 0 \\ \alpha_x(s) & \beta_x(s) \end{pmatrix} \begin{pmatrix} x(s) \\ x'(s) \end{pmatrix}$$

Update version



Plots shows normalized amplitudes of point like bunches of two sub-trains of 15 bunches each at the end of the linac.

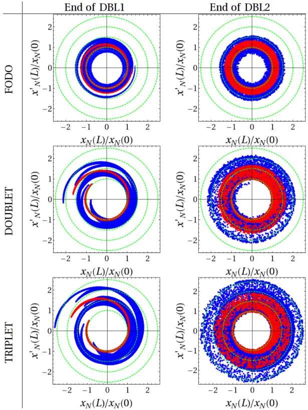
All bunches has same initial offset. The amplification reaches steady state rapidly within sub-train length.

The amplification is slightly high due to strong kick caused by closer bunches at sub-train switching point.

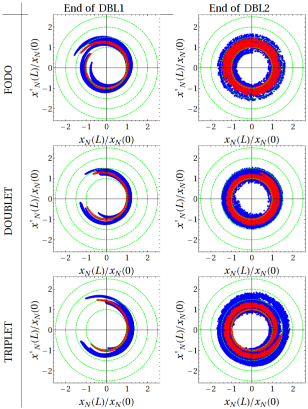
All lattices gives better results for new-baseline. Much improvement for doublet ant triplet lattice.

Transverse short & long range wake effects

CDR version



Update version



Plots show normalized amplifications of bunches of two sub-train at the end of DBL1 and DBL2. Each train consist of 15 bunch and each bunch has same initial offset (red points first bunch, blue points trailing bunches)

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

Triplet lattice gives worse results than the others.

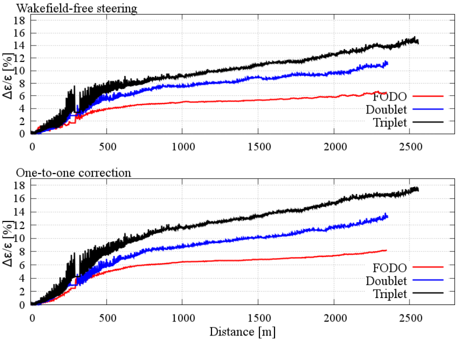
Much improvement for doublet lattice.

Emittance Growth

Error Type	Quads	Structures	BPMs
position errors $\sigma_{x,y}$ (μm)	300	300	300
angle errors $\sigma_{x',y'}$ (μrad)	300	0	300
roll errors σ_{θ} (μrad)	1000	#	0

- the beamline on bunch compression section is perfectly aligned
- the beam is injected without any offset to DBL1 and DBL2
- resolution of BPMs =10 μm
- varying parameters of test beams; energy, charge, gradient

CDR version



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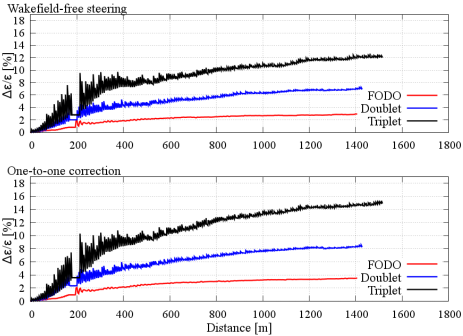
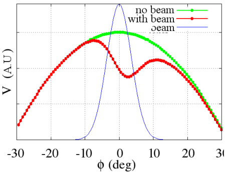
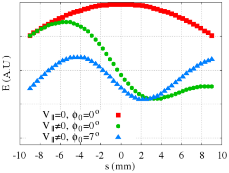
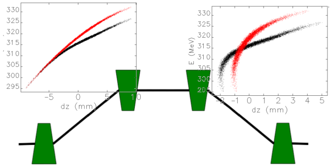


Plot shows the emittance growth along the beamline consisting of DBA1 and DBA2.
For all type of lattices the growth is smaller than CDR version due to shorter accelerating structures ($N_{acc} \times L_{acc}$) and less number of magnets..

Longitudinal short range wake effects







The longitudinal short range wakefield causes decelerating voltage the bunch thus it disturbs the correlated energy spread.

$$V_{\|} = 2Ne^2 \int_0^{\infty} W_{\|}(z' - z)\rho(z')dz' \qquad \delta_z = R_{56}\delta_E$$

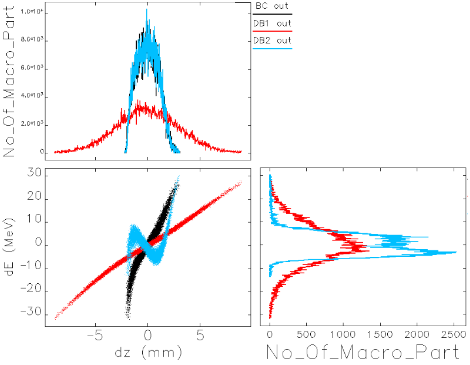
Longitudinal bunch profile plays important role on the shape of decelerating voltage..

Compressing with large energy spread an small R_{56} would improve the bunch profile at the end of DBL2

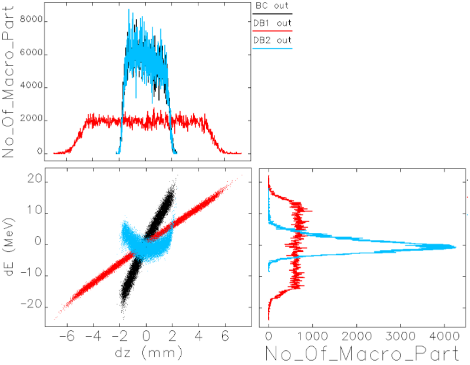
That would also allow large longitudinal errors in drive beam linac

Bunch compressor with $R_{56} = 6\text{cm}$ and different initial bunch distributions

Gaussian initial distribution

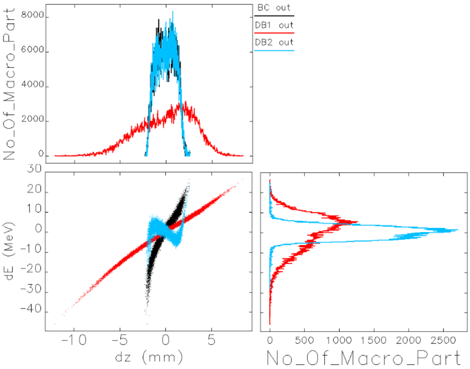


Plateau initial distribution

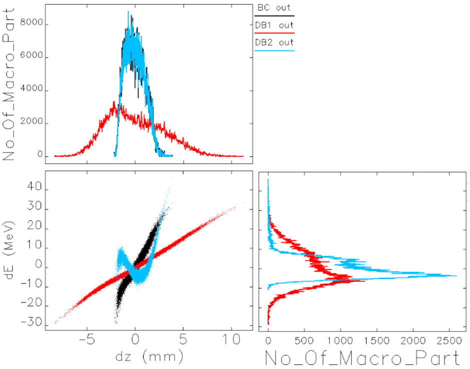


Bunch compressor with $R_{56} = 6$cm and different initial bunch distributions

Hight density on tail of bunch



Hight density on head of bunch



Conclusion

- High gradient accelerating structure brings out new advantages
  - The linac length would be reduced about 1 km.. But one should check if klystrons and their modulators would fit within this length?
  - With high gradient structure both FODO and Doublet lattice gives acceptable results in terms of beam amplification and miss-alignment errors.
  - In order to define better lattice next step will be acceptance of lattices versus gradient energy errors.
- Bunch compressor with small R_{56}
  - Large energy spread would beat the effect of wakefield
  - Small R_{56} would allow larger gradient end energy tolerances..
  - However the distribution of incoming beam from DB injector is required for better design.

Further work

- Checking if Karl-Banes formula is acceptable for new structure.. One should also check the beam pipe radius and gap length(s) of the structure.
- Checking the acceptance of lattices in terms of energy and gradient errors in DBL
- Designing real bunch compressor using initial distribution created by Parmela. Do we need chicane or arc for bunch compressor? feed-forward system?
- Including miss-alignments in bunch compressor section.

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Thank you