Review of longitudinal dynamics and requirements along the Drive-Beam complex

Raul Costa

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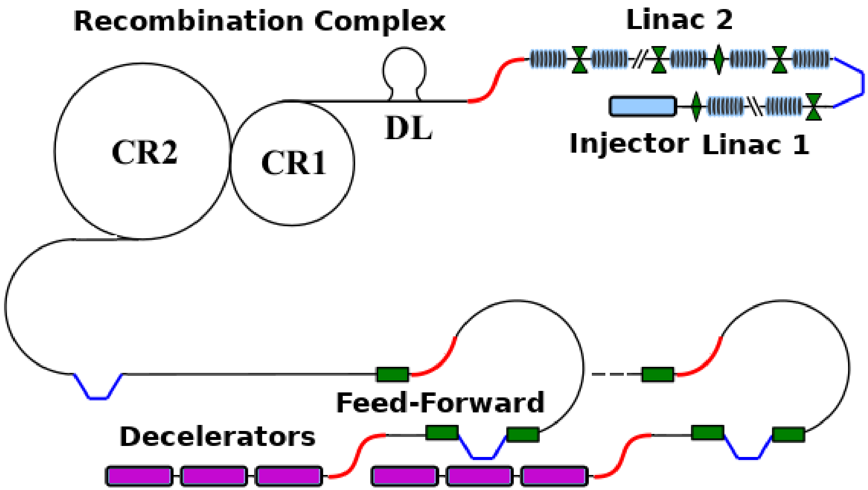
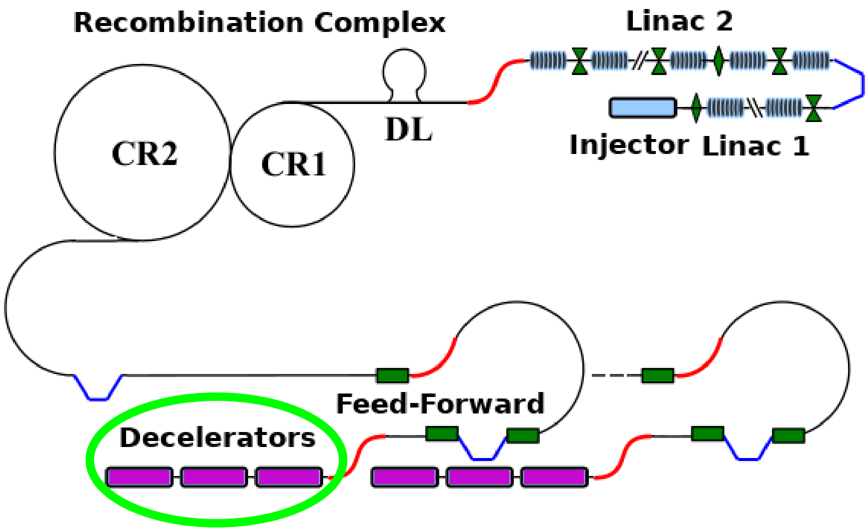
UPPSALA UNIVERSITET

Outline

Motivation



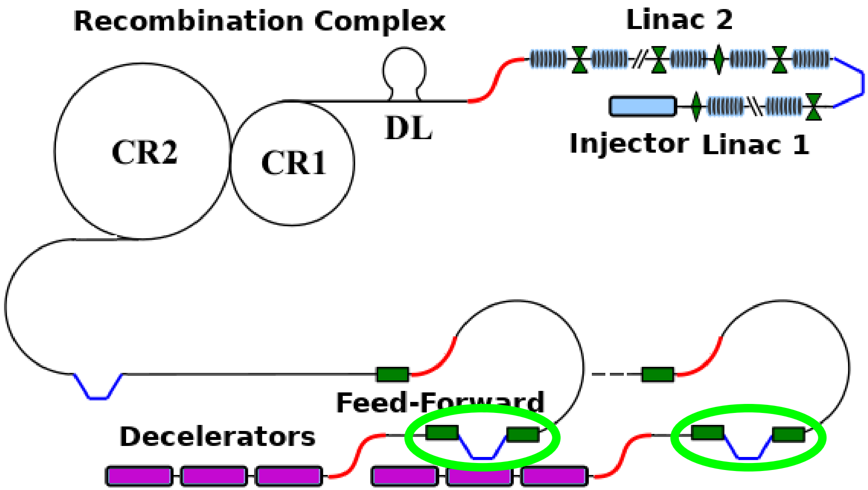
- Establish a full set of longitudinal parameters
- Design the magnetic compressor/decompressor elements
- Reduce the required energy spread



Decelerator requirements:

- 1 mm bunch length
- 1% bunch length stability
- 0.2°phase stability at 12 GHz

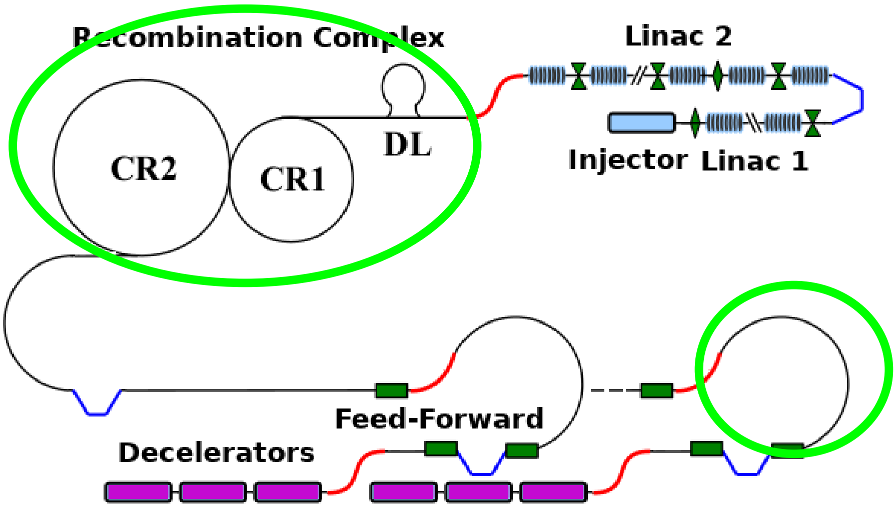
The Drive-Beam complex - step by step



Feed-forward System requirements:

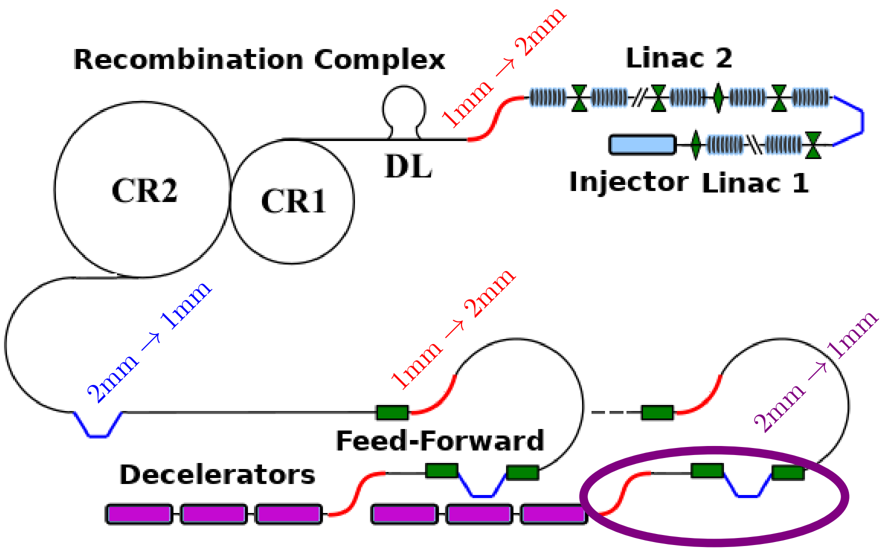
- $2.5° @ 1\,\text{GHz} \rightarrow 0.2° @ 12\,\text{GHz}$
- Correction precision: $46\,\text{fs}$ ($\Delta_z = \pm\,14\,\mu\text{m}$)
- Correction range: $6.9\,\text{ps}$ ($\Delta_z = \pm\,2.1\,\text{mm}$)

The Drive-Beam complex - step by step



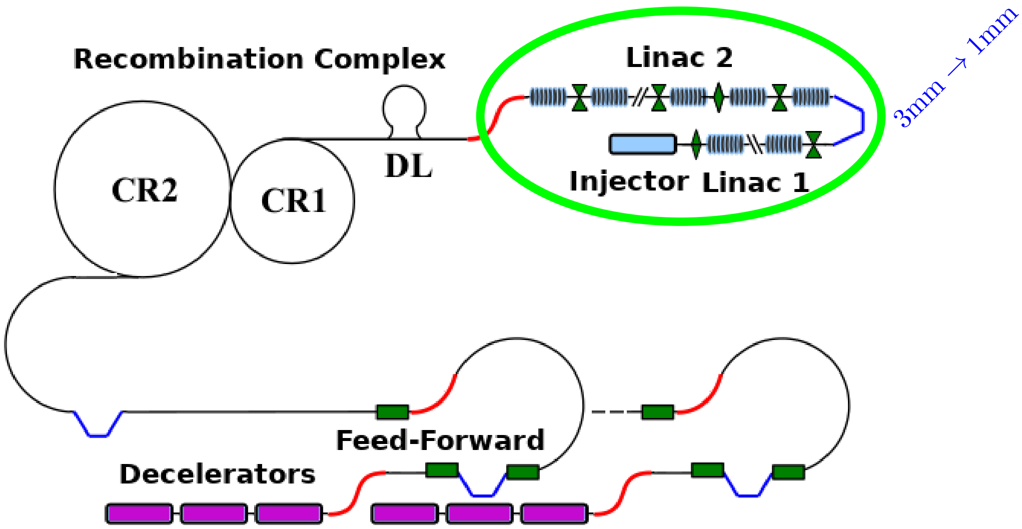
To mitigate coherent synchrotron, $\sigma_z = 2\,\mathrm{mm}$ in the recombination complex,transfer turnaround and turnaround loops

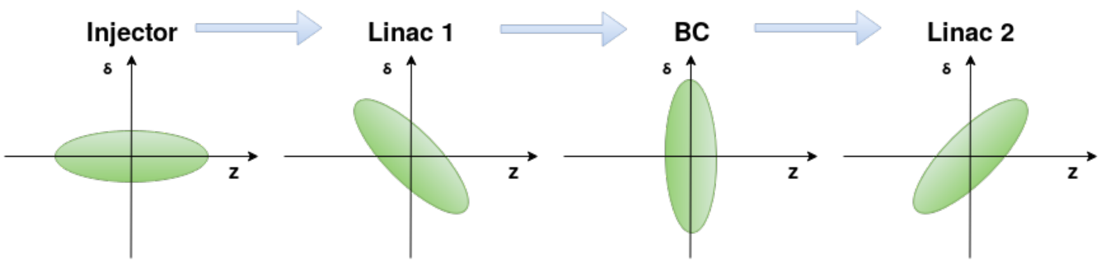
The Drive-Beam complex - step by step



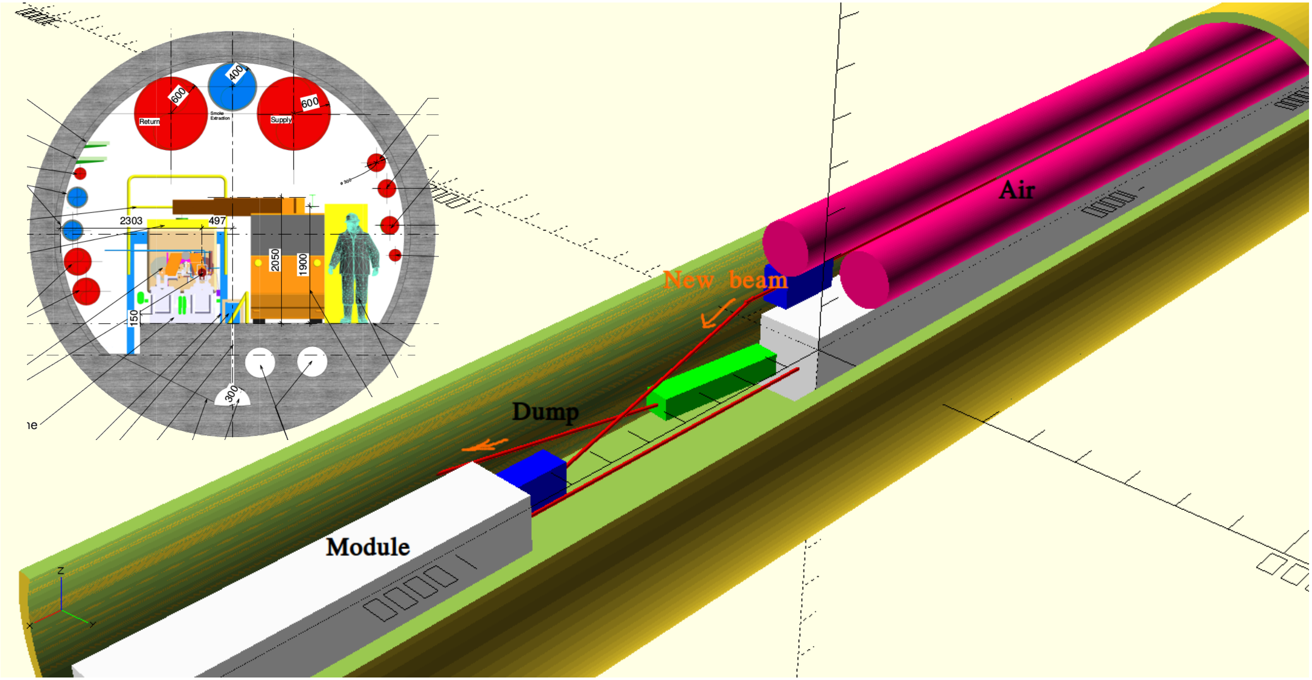
Note: This represents the feed-forward chicane + vertical dogleg

The Drive-Beam complex - step by step





Decelerators injection



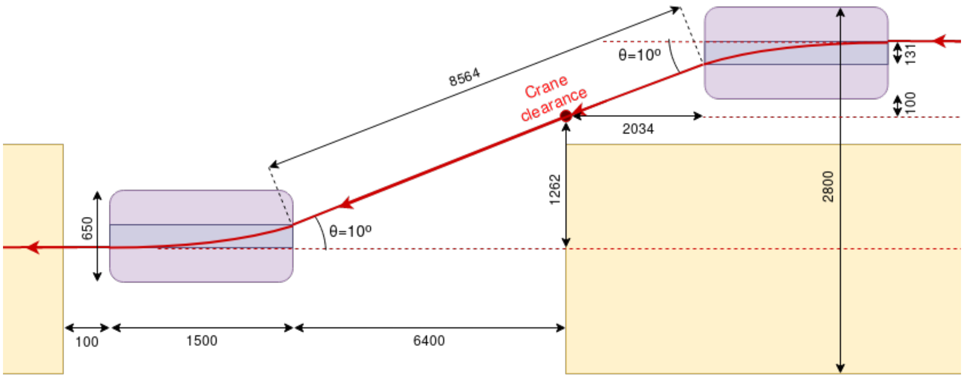
Vertical dogleg

A two-bend achromatic dogleg, has geometry-fixed R_{56}

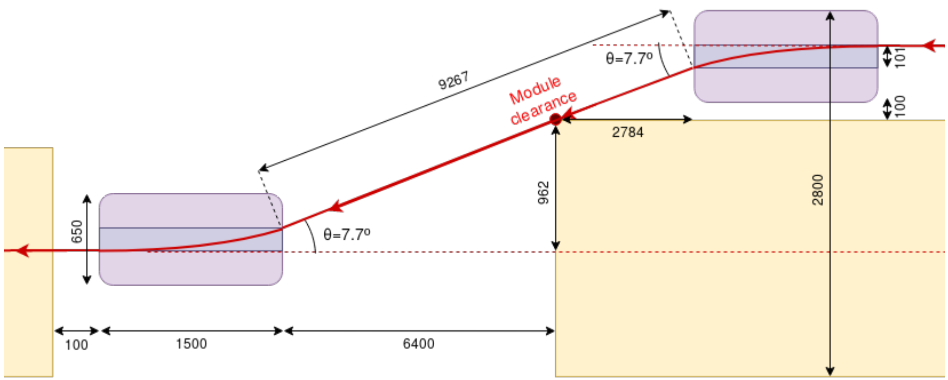
$$R^{\mathrm{dg}} = \begin{bmatrix} R_{33} & (R_{33}+1)\,\dfrac{L_b}{\theta}\tan\dfrac{\theta}{2} & 0 & 0 \\ (R_{33}-1)\,\dfrac{\theta}{L_b}\cot\dfrac{\theta}{2} & R_{33} & 0 & 0 \\ 0 & 0 & 1 & 2L_b\left(1-\dfrac{\sin\theta}{\theta}\right) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$R_{56} > 0$$

Vertical Dogleg

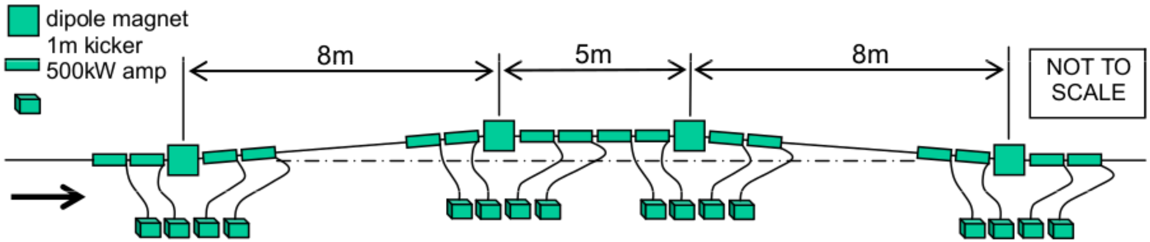


$$\theta = 10.02^\circ$$
$$R_{56} = 15.3\,\mathrm{mm}$$
$$B = 0.928\,\mathrm{T}$$



$$\theta = 7.666^\circ$$
$$R_{56} = 8.97\,\mathrm{mm}$$
$$B = 0.712\,\mathrm{T}$$

Feed-forward chicane



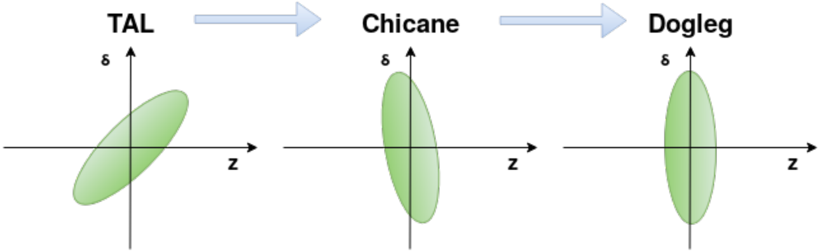
* With equal and parallel R-bends, chicanes are achromatic "for free"

$$R^{\text{chicane}} = \begin{bmatrix} 1 & L_2 + 2L_1 \sec^2\theta + \frac{4L_\text{b}}{\theta}\tan\theta & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & \frac{4L_\text{b}}{\theta}(\theta - \tan\theta) - 2L_1 \tan^2\theta \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$R_{56} < 0$$

Chicane + dogleg

$$R^{\text{chicane+dogleg}} = R^{\text{dg}} R^{\text{chicane}} \qquad R_{56} = R_{56}^{\text{dg}} + R_{56}^{\text{chicane}}$$



CDR chicane specifications:

- $\theta = 0.09\,\text{rad}$
- $L_b = 1.001\,\text{m}$
- $L_1 = 7.03\,\text{m}$
- $R_{56} = -12.5\,\text{cm}$

$$\delta_{\text{corr}} = \frac{z - z_0}{R_{56}}$$

Crane clearance: $\delta_{\text{corr}} = 0.91\%$
Module clearance: $\delta_{\text{corr}} = 0.86\%$

Feed-forward dynamics

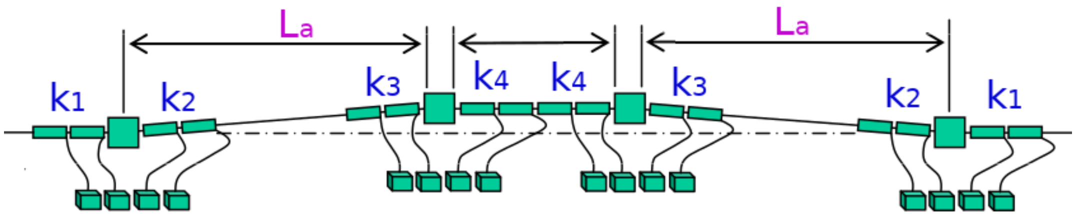
To compute the offsets of through the feed-forward system we can add another dimension to our transport matrix:

$$\begin{bmatrix} x \\ x' \\ z \\ \delta \\ 1 \end{bmatrix} = \begin{bmatrix} R_{11} & R_{12} & 0 & R_{16} & \Delta_x \\ R_{21} & R_{22} & 0 & R_{26} & \Delta_{x'} \\ R_{51} & R_{52} & 1 & R_{56} & \Delta_z \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_0 \\ x'_0 \\ z_0 \\ \delta_0 \\ 1 \end{bmatrix}$$

And define an horizontal deflector as

$$R^{\text{kick}} = \begin{bmatrix} 1 & L_k & 0 & 0 & \frac{L_k}{2} k_1 \\ 0 & 1 & 0 & 0 & k_1 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Feed-forward dynamics

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In[•]:= MatrixForm[chicane8kGeneral = FullSimplify[(kick8.bend1.polerot1.kick7.drift1.kick6.polerot2.bend2.kick5.drift2.ki
Out[•]//MatrixForm=
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$$\begin{pmatrix} 1 & L2 + 2\,Lk + 2\,L1\,\mathrm{Sec}[\theta]^2 + \frac{4\,Sb\,\mathrm{Tan}[\theta]}{\theta} & 0 & 0 & \cdots \\ 0 & 1 & 0 & 0 & \\ 0 & 0 & 1 & 4\,Sb - \frac{4\,Sb\,\mathrm{Tan}[\theta]}{\theta} - 2\,L1\,\mathrm{Tan}[\theta]^2 & \\ 0 & 0 & 0 & 1 & \\ 0 & 0 & 0 & 0 & \end{pmatrix}$$

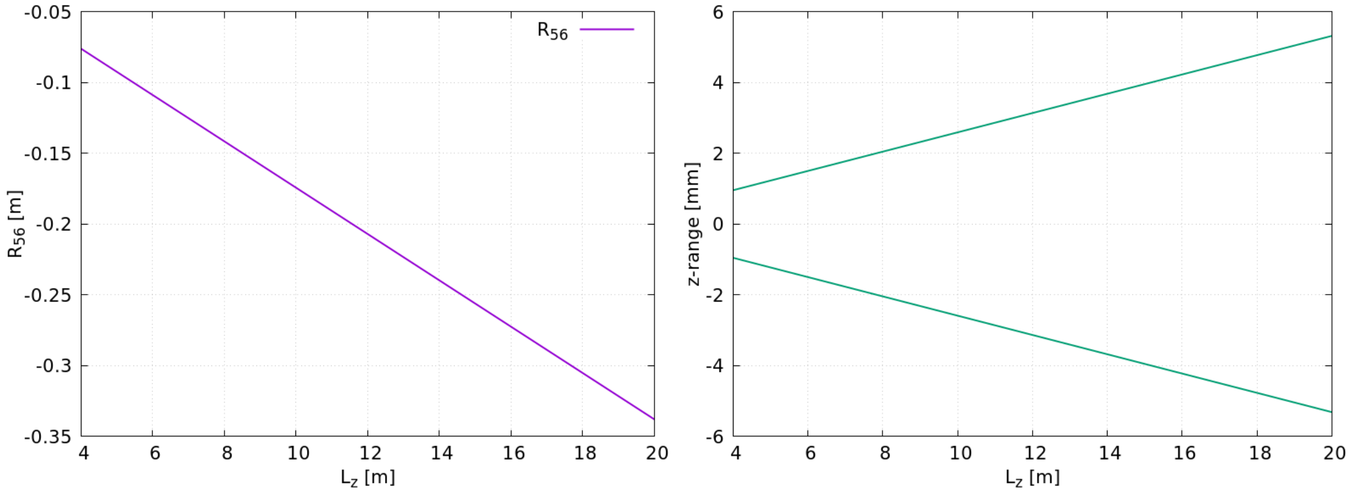
$\mathrm{Sec}[\theta]^2\,((2\,L2\,(tk1+tk4)+4\,L1\,(2\,tk1+tk4+tk5)+Lk\,(3\,tk1+tk4+3\,tk5\ldots$

Imposing $\Delta_x = \Delta_{x'} = 0$ we get

$$\Delta_z = 4L_d \csc\theta\,(\sec\theta - 1)\,k_4 + 2\tan\theta\,\left(L_a \sec^2\theta\,k_4 + (L_a \sec\theta - L_k)\,k_3\right)$$

Feed-forward dynamics

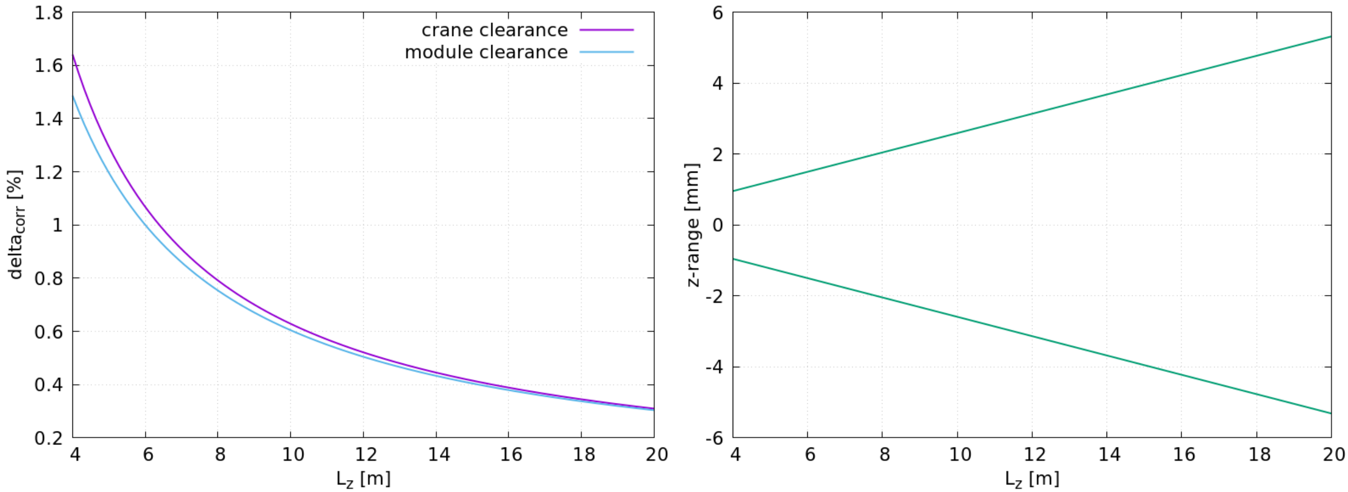
$L_k = 1\,\mathrm{m},\ k_{\max} = 750\,\mu\mathrm{rad}$



In order to achieve $\Delta_z = \pm 2.1\,\mathrm{mm}$

- $L_z \geq 8.2\,\mathrm{m}$ (not 7m has mentioned before)
- $R_{56} \leq -14.5\,\mathrm{cm}$
- $\delta^{\mathrm{c.c.}}_{\mathrm{corr}} = 0.77\%$
- $\delta^{\mathrm{m.c.}}_{\mathrm{corr}} = 0.73\%$

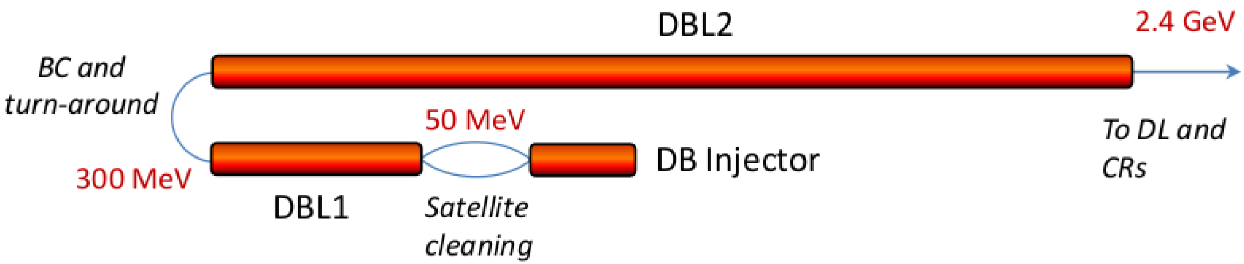
Could we go further?

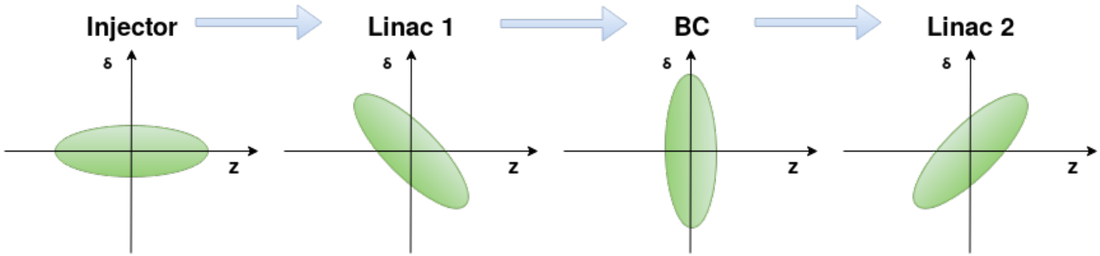


Increasing L_z to 15m would allow us reduce δ_{corr} to 0.4%

- We do not require higher range but could reduce deflector strength
- High δ_{corr} has been "problematic" in other studies
- Reduce horizontal aperture requirements (TAL)
- Horizontal footprint: $0.62\,\text{m} \rightarrow 1.35\,\text{m}$

Linac bunch-compressor





- Linac 1 creates a negative chirp
- Bunch-compressor fully compresses
- Linac 2 creates a negative chirp

Linac bunch-compressor

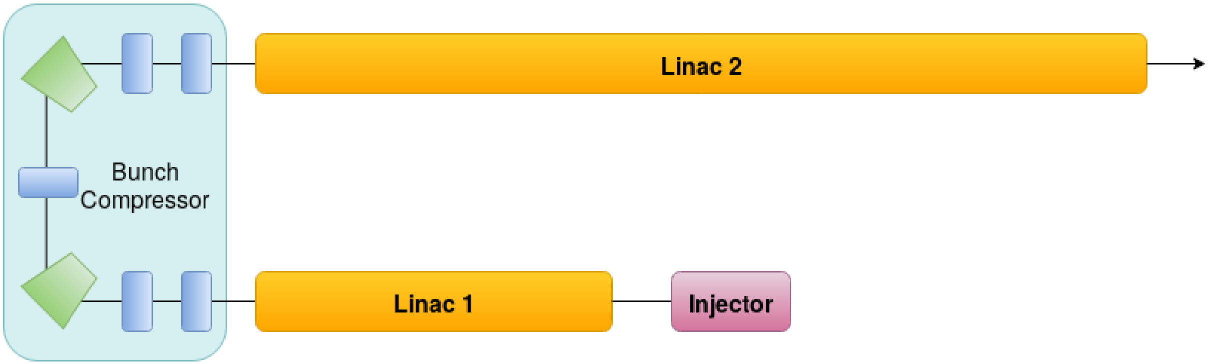
Similarly to doglegs, two-bend achromatic arcs have geometry-fixed R_{56}

$$R^{\text{arc}} = \begin{bmatrix} R_{11} & (R_{11}-1)\dfrac{L_b}{\theta}\tan\dfrac{\theta}{2} & 0 & 0 \\ (R_{11}+1)\dfrac{\theta}{L_b}\cot\dfrac{\theta}{2} & R_{11} & 0 & 0 \\ 0 & 0 & 1 & 2L_b\left(1-\dfrac{\sin\theta}{\theta}\right) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$R_{56} > 0$$

If both θ and R_{56} are fixed, so is L_b and therefore B

Linac bunch-compressor



σ_z: $3\,\mathrm{mm} \to 1\,\mathrm{mm}$

$\delta^{\text{injector}} = 1\%$

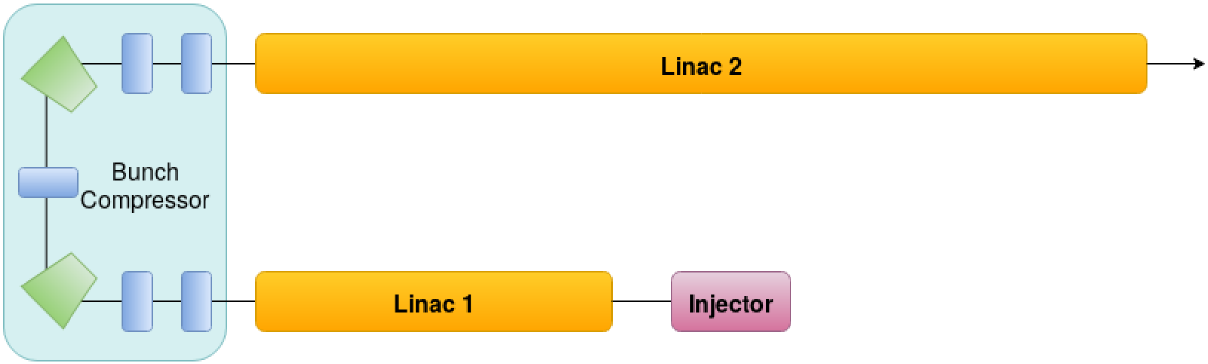
$\phi_{\mathrm{RF}} = -5.45°$

$R_{56} = 0.6\,\mathrm{m}$

$L_b = 0.83\,\mathrm{m}$

$B = 1.9\,\mathrm{T}$

Linac bunch-compressor



σ_z: $3\,\text{mm} \rightarrow 1\,\text{mm}$

$\delta^{\text{injector}} = 1\%$

$\phi_{\text{RF}} = -5.45°$

$R_{56} = 0.6\,\text{m}$

$L_b = 0.83\,\text{m}$

$B = 1.9\,\text{T}$

σ_z: $3\,\text{mm} \rightarrow 2\,\text{mm}$

$\delta^{\text{injector}} = 1\%$

$\phi_{\text{RF}} = -2.73°$

$R_{56} = 1.2\,\text{m}$

$L_b = 1.65\,\text{m}$

$B = 0.95\,\text{T}$

Linac bunch-compressor

The σ_z: $3\,\mathrm{mm} \rightarrow 2\,\mathrm{mm}$ option:

- Reduces ϕ_{RF}
- Keeps beamline separation below 4m
- Eliminates σ_z: $1\,\mathrm{mm} \rightarrow 2\,\mathrm{mm}$ dogleg after Linac 2

Alternatively we can design a four-bend arc:

- Allows for $3\,\mathrm{mm} \rightarrow 1\,\mathrm{mm}$
- Is tunable during operations
- Viable for both 1 mm and 2 mm options

Conclusions

- Review of the Drive-beam complex requirements
- Overview of compression systems (arc, dogleg and chicane)
- Study of the feed-forward dynamics and Δ_z range
- Vertical dogleg design options established ($R_{56} = 15$ or 9 mm)
- CDR chicane study: $R_{56} = -12.5\,\text{cm}$ and max $\Delta_z = 1.77\,\text{mm}$
- Requirement to increase chicane arms to a minimum of 8.2m
- Proposal to increase them further to reduce $\delta_{\text{corr}}{}^*$
- DBL bunch-compressor design options proposed

Outlook

- Design four-bend bunch-compressor (also needed for eSPS)
- Fix δ_{corr} (CLIC note)
- Transverse dynamics of TAL to FF to dogleg to decelerator
- Chromatic effects in the vertical dogleg
- With fixed δ_{corr} previous studies can be resumed

Thank you