Performance Optimisation of the CLIC Drive Beam Recombination Complex

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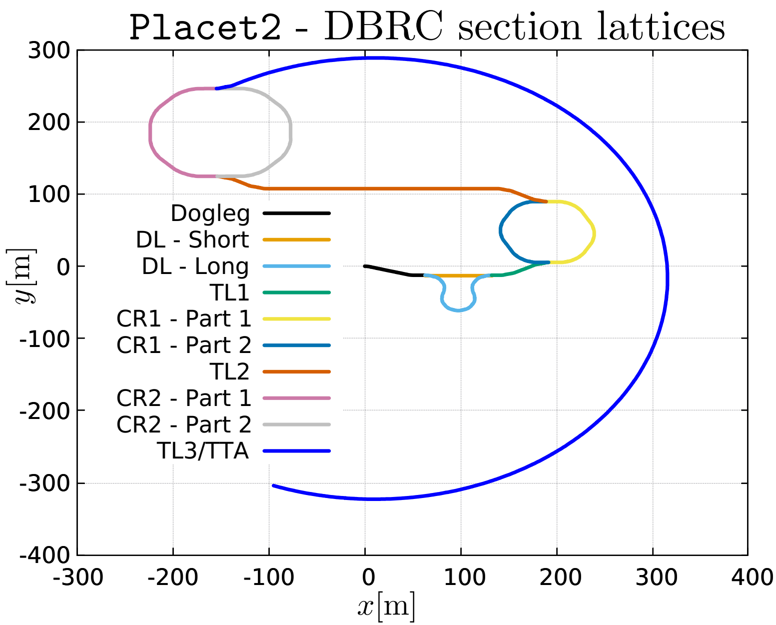
Outline

DBRC review

The Drive Beam Recombination Complex

The DBRC is located between the drive beam linac and the deceleration sectors

It's role is to combine the drive beam by a factor 24× into high frequency pulses



122 bunches	4.2 A	2928 bunches	100 A
0.49975 GHz	2ns ≡ 60cm	11.994 GHz	83ps ≡ 2.5cm
244 ns	between bunches	244 ns	between bunches

70760 bunches (≡ 142μs) train

5.9 μs

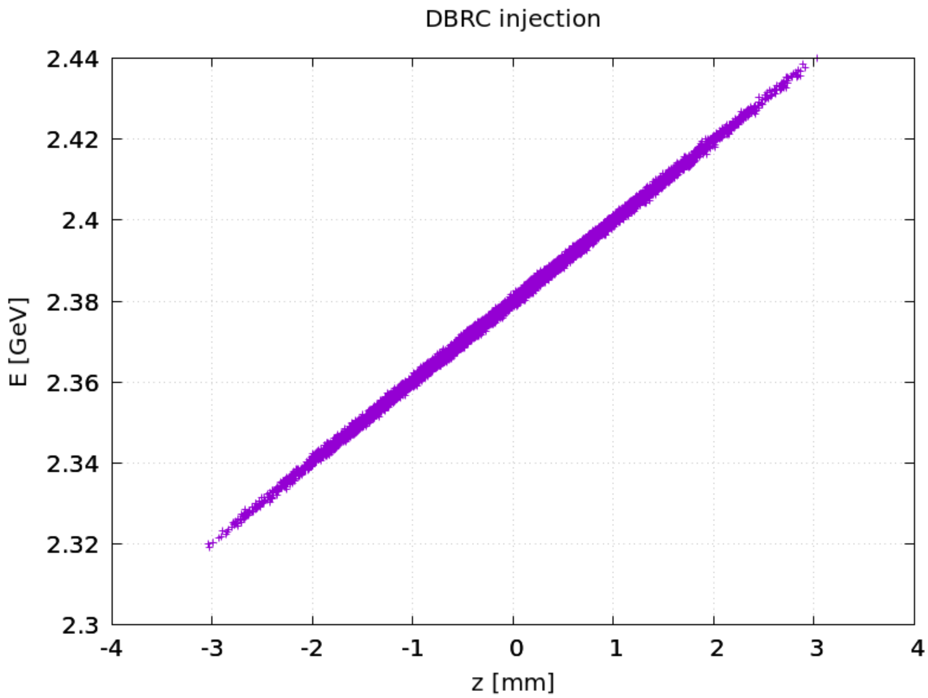
Beam parameters

Injection Parameters:

$$E = 1.9/2.38\,\text{GeV}^*$$
$$\delta = 0.85\,\%$$
$$\sigma_z = 1\,\text{mm}$$
$$\varepsilon_x = 50\,\mu\text{m}$$
$$\varepsilon_y = 50\,\mu\text{m}$$

Extraction Parameters:

$$\sigma_z = 1\,\text{mm}$$
$$\varepsilon_x < 150\,\mu\text{m}$$
$$\varepsilon_y < 150\,\mu\text{m}$$



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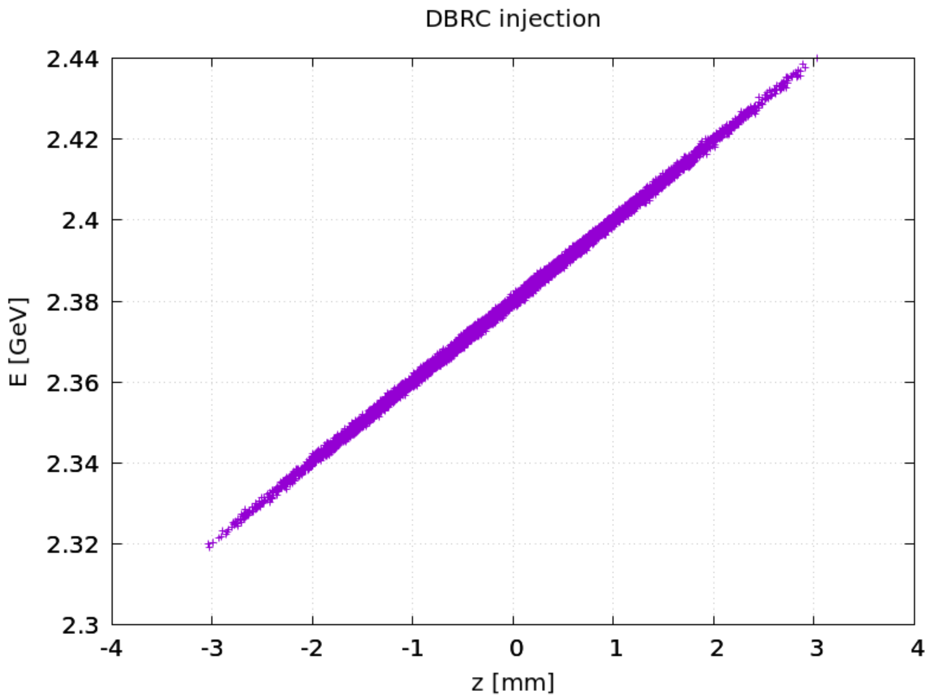
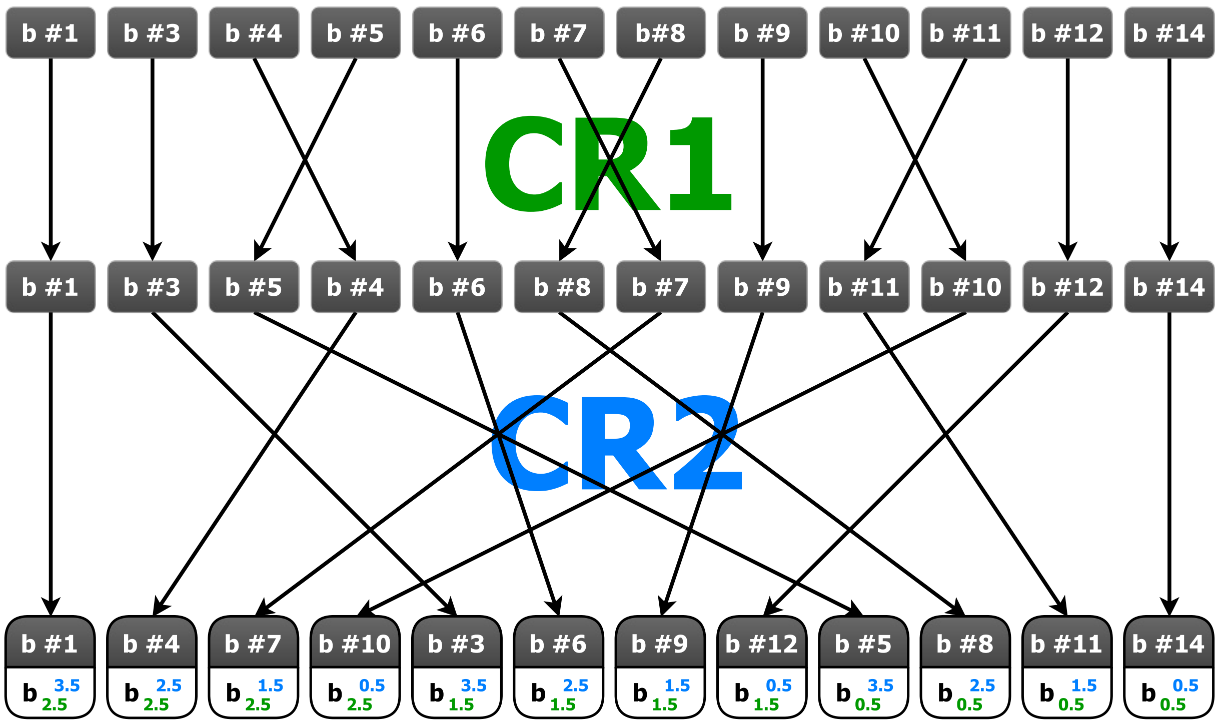
\end{aligned}
$$



* The DB energy is 1.9 GeV for CLIC's 1st stage and 2.38 GeV for stages 2 and 3. Most optical properties of the lattice are similar.

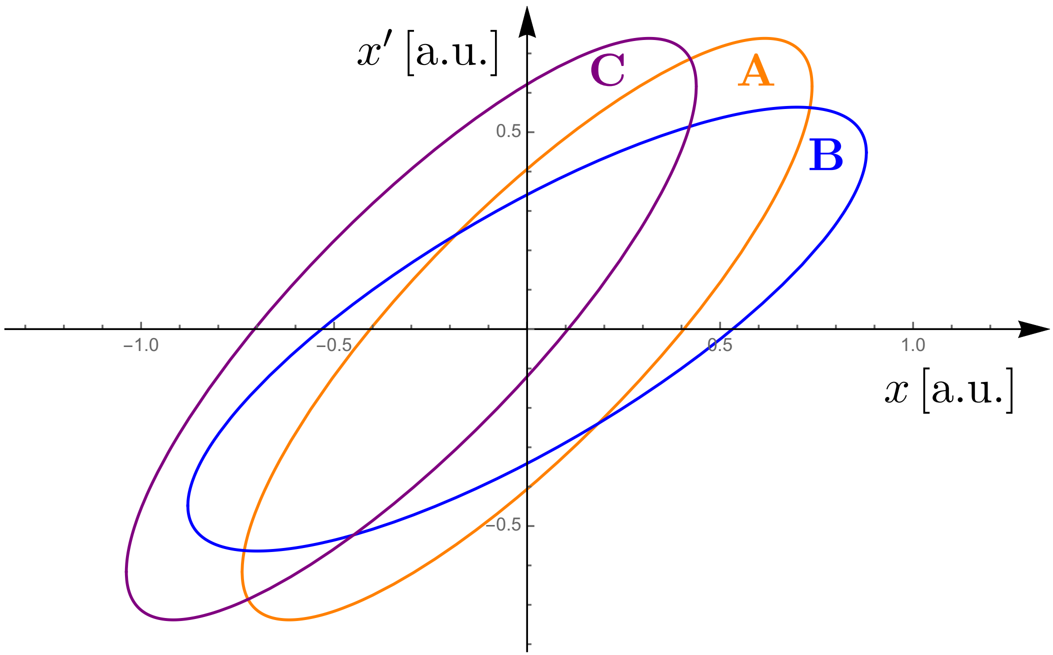
Notation

We are tracking 12 bunch "families" differentiated by the number of turns they take in CR1 and CR2: $\mathbf{b}_{\text{CR1}}^{\text{CR2}}$



Design challenges

Transverse pulse emittance



Targeting $\langle\varepsilon\rangle$ does not ensure twiss and centre-orbit match
We project all distributions on top of one-another and compute $\tilde{\varepsilon}$

$$\tilde{\varepsilon} \geq \langle\varepsilon\rangle$$

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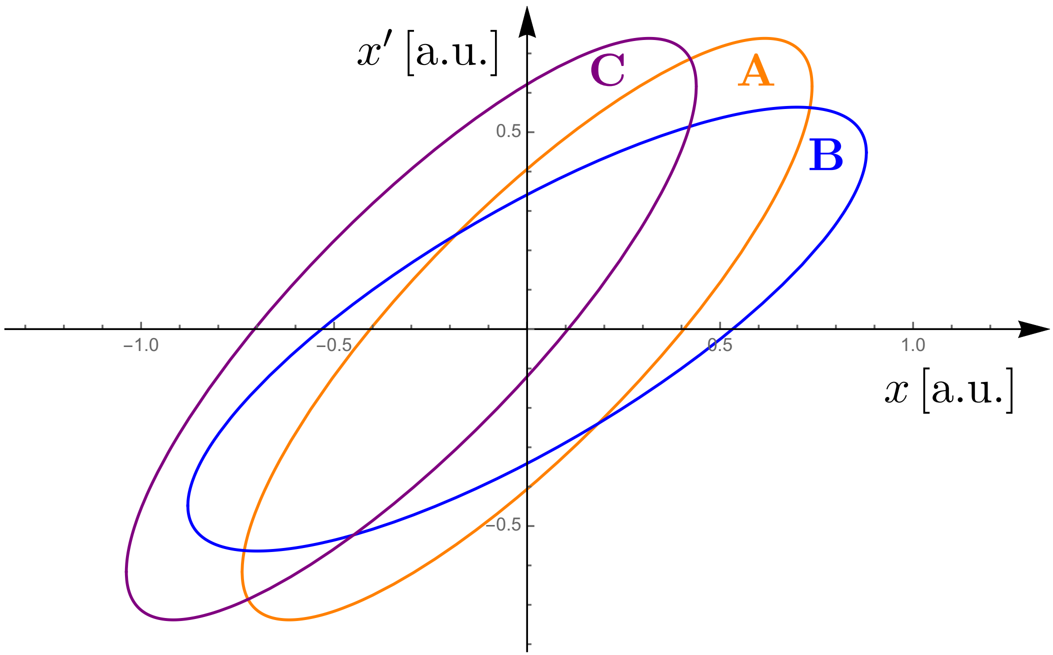

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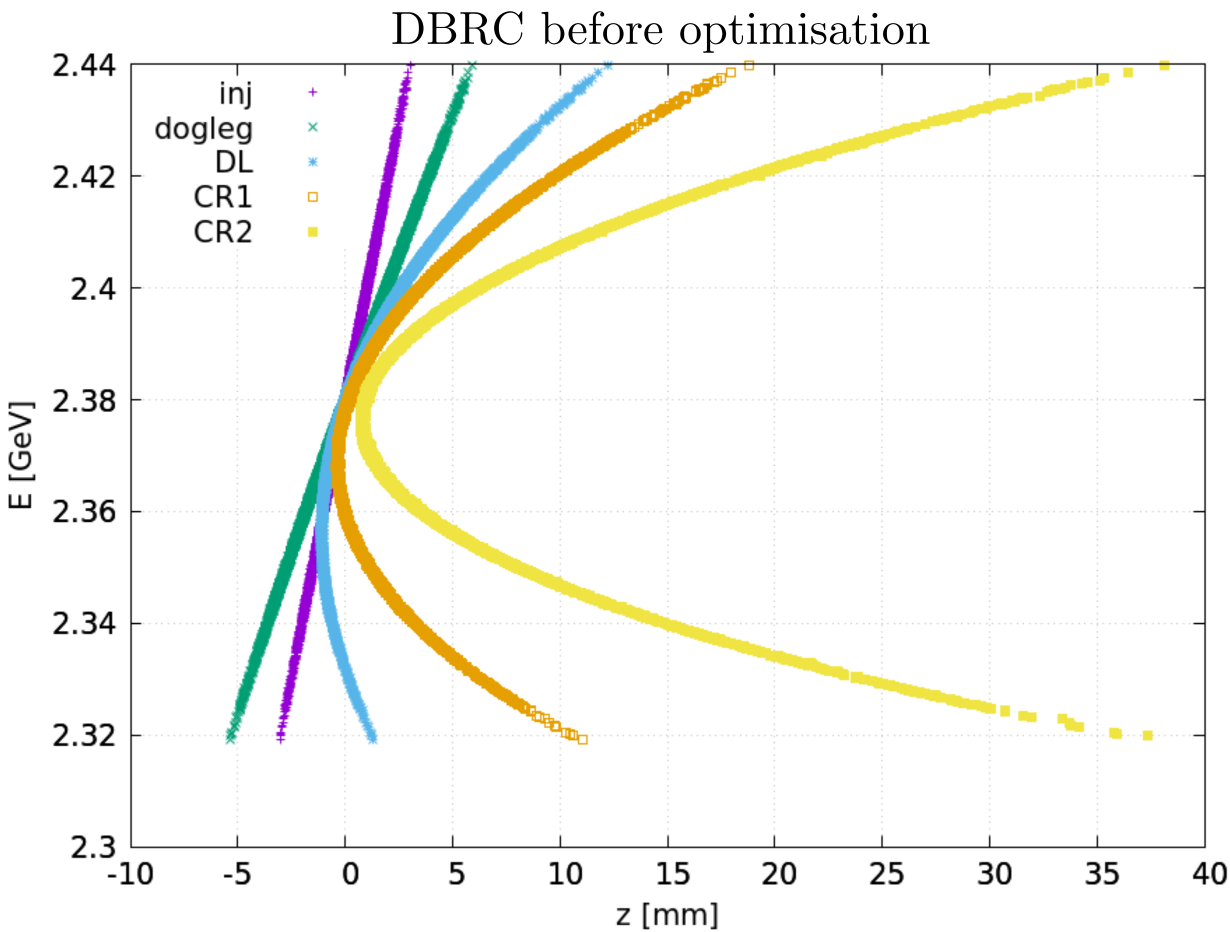
$$\tilde{\varepsilon} \geq \langle\varepsilon\rangle$$

Note: I'll talk more about emittance evaluation emittance later

Longitudinal profile



Source of the longitudinal issues

$$z\left(s\right) = z + R_{56}\delta + T_{566}\delta^{2}$$

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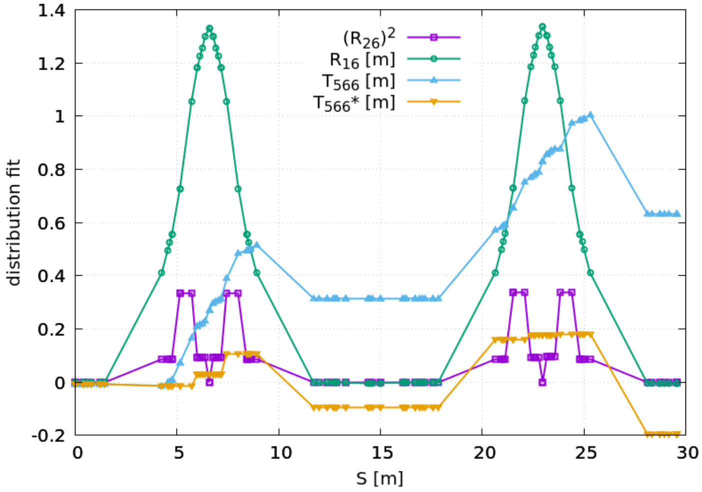
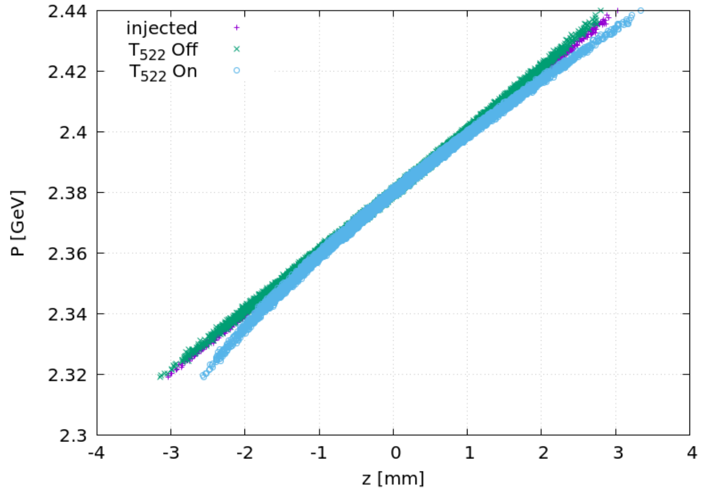
$$T_{566_{[n]}} \sim T_{566_{[n-1]}} + \left(R_{26_{[n-1]}}\right)^2 T_{522_{[n]}}$$

$$T_{522_{[\mathrm{Drift}]}} = \frac{L}{2}$$

T_{566} tracking - single arc (CR2)

Placet2 can now track individual tensor elements

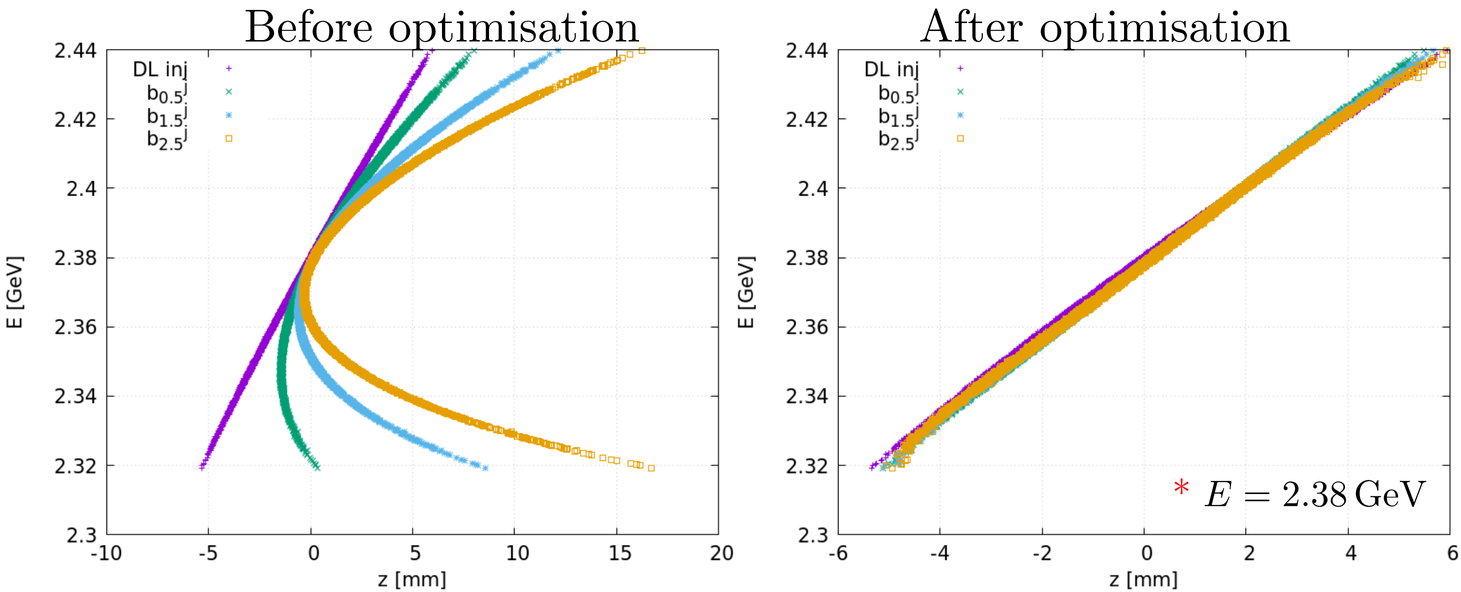




* If $T_{522} = T_{544} = 0$

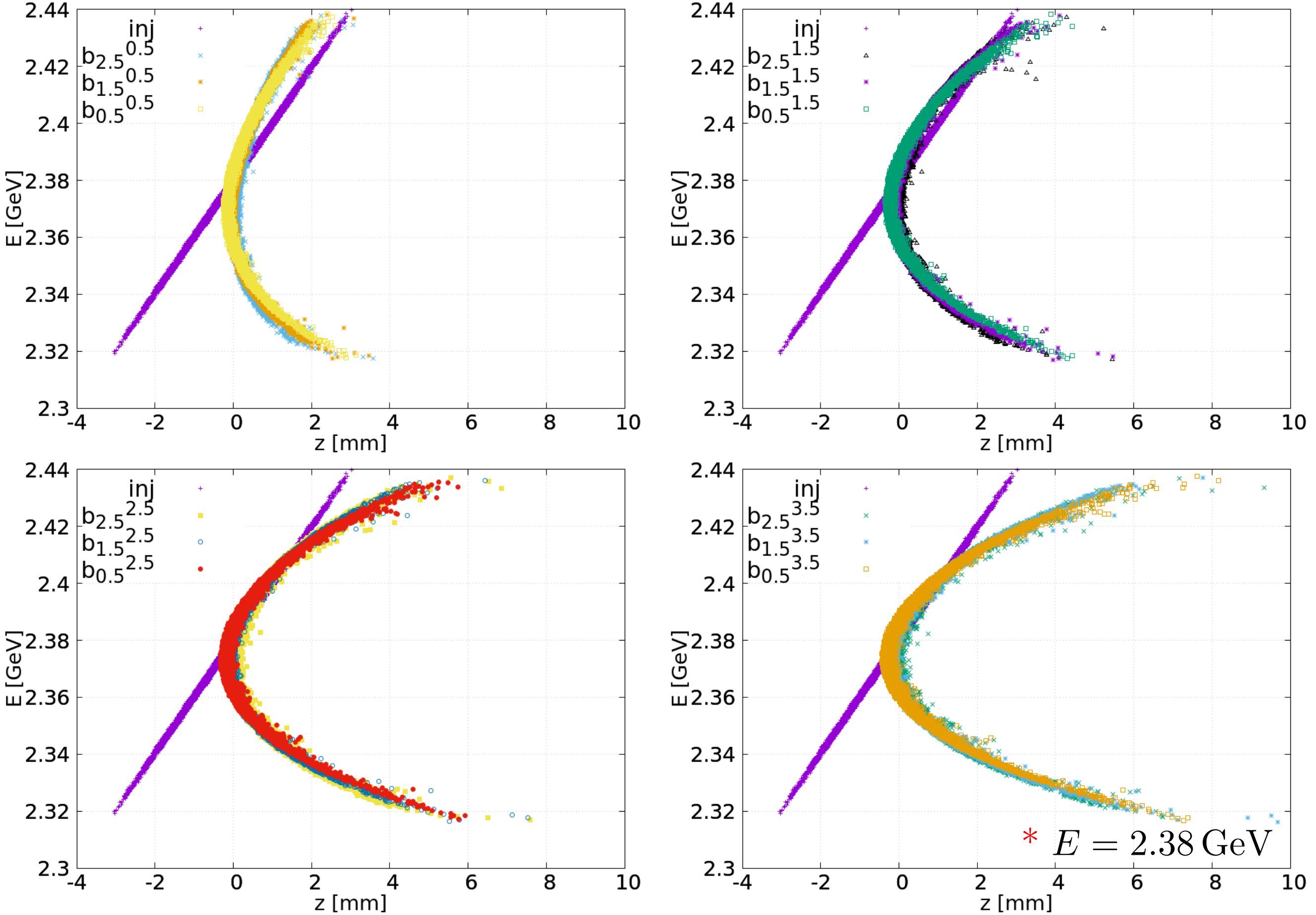
Results

Combiner Ring 1 optimisation



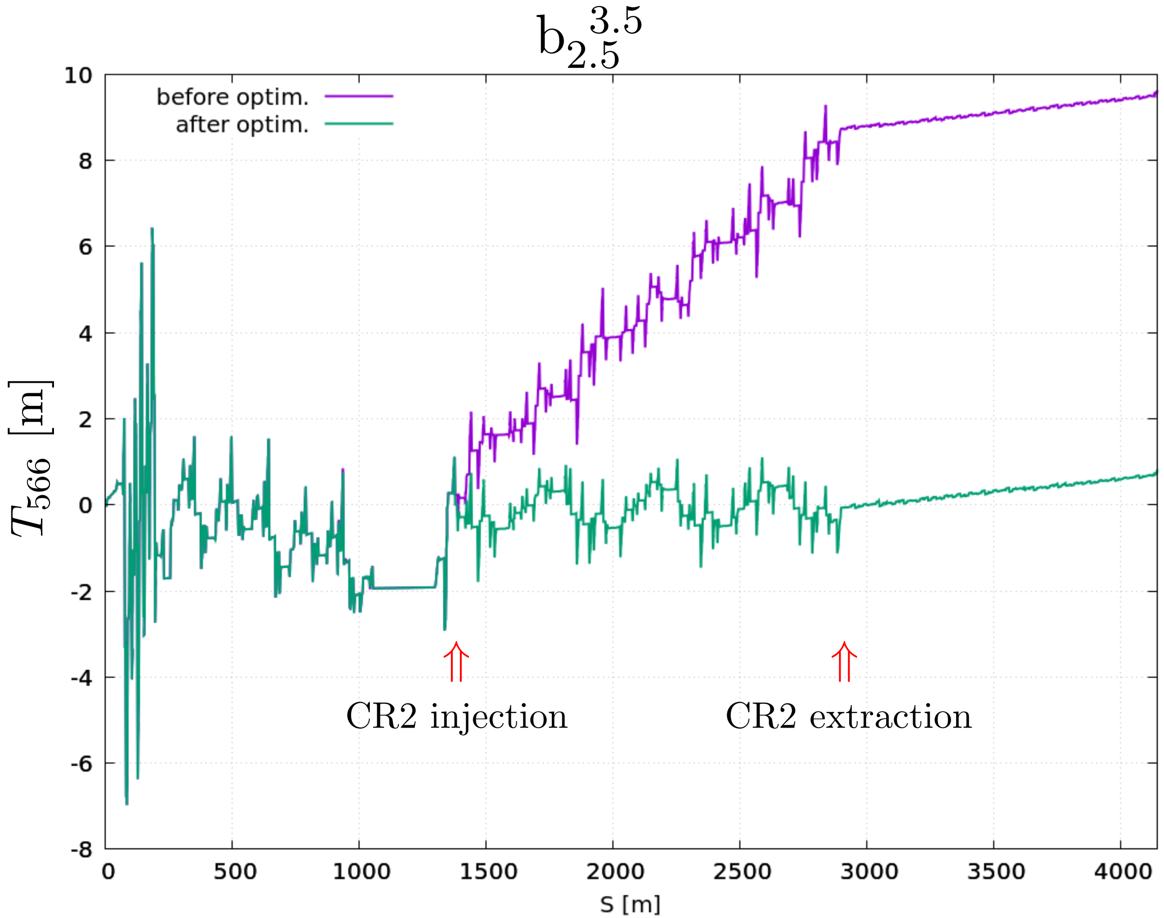
Emittance [μm]	$b_{0.5}^j$	$b_{1.5}^j$	$b_{2.5}^j$	$\langle\varepsilon_i\rangle$	$\tilde{\varepsilon}_i$
Horizontal	79	72	90	80	88
Vertical	56	56	64	59	59

Longitudinal profile before CR2 optimisation



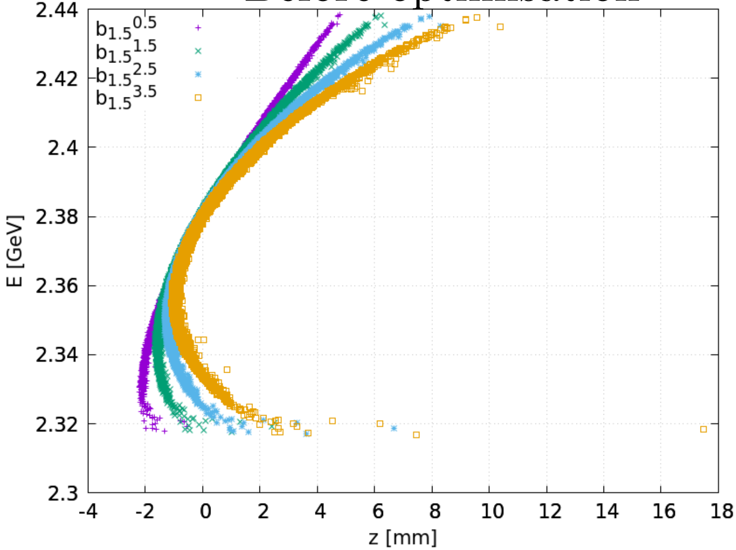
* $E = 2.38\,\mathrm{GeV}$

80 μm results - T_{566} correction

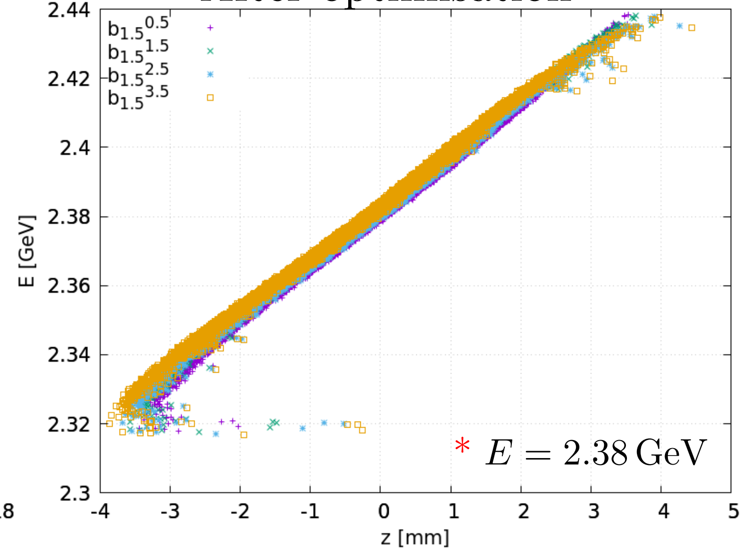


Combiner Ring 2 optimisation

Before optimisation

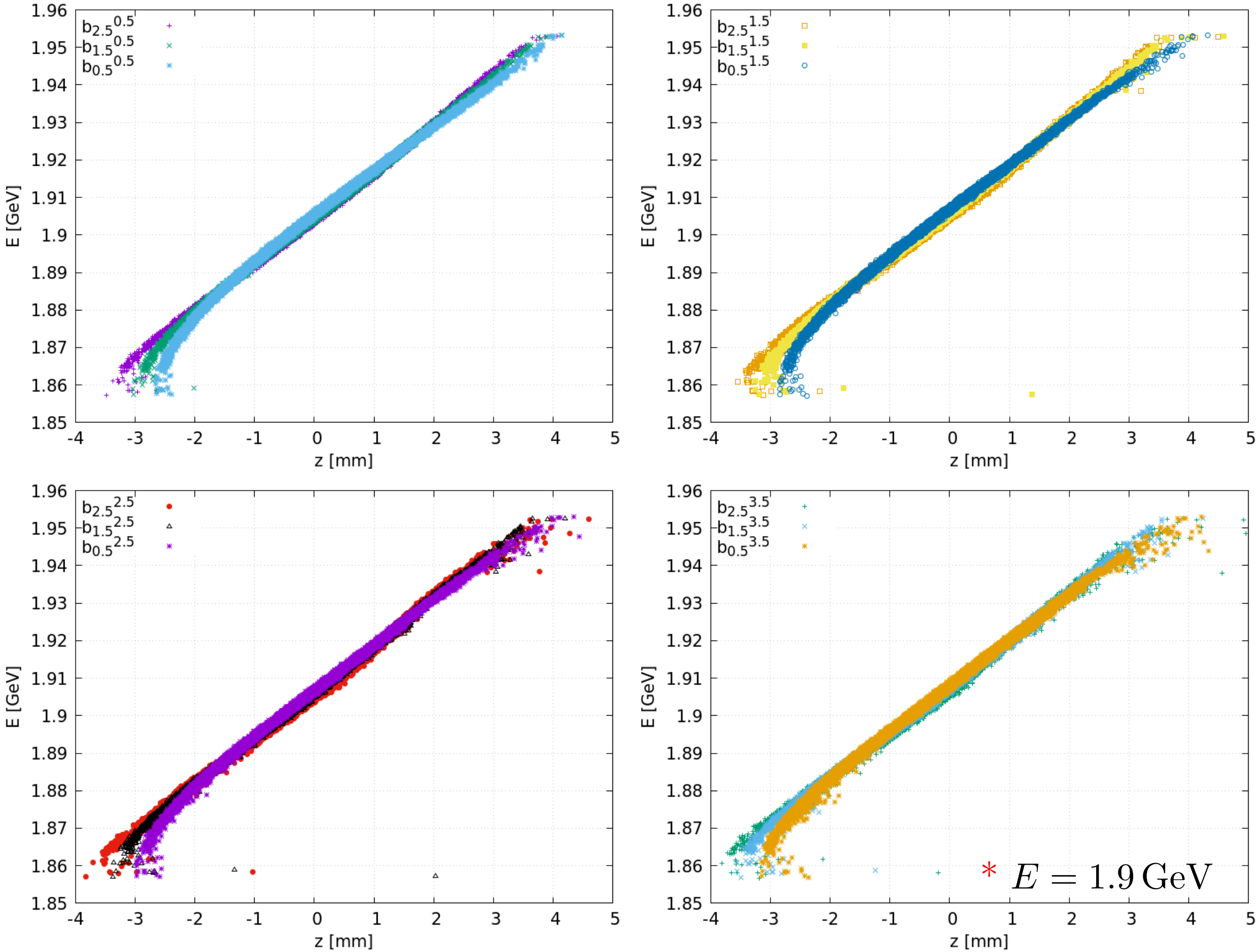


After optimisation



Emittance [μm]	$\mathrm{b}_{1.5}^{0.5}$	$\mathrm{b}_{1.5}^{1.5}$	$\mathrm{b}_{1.5}^{2.5}$	$\mathrm{b}_{1.5}^{3.5}$	$\langle \varepsilon_i \rangle$	$\tilde{\varepsilon}_i$	$\tilde{\varepsilon}_i\left(\mathrm{b}_i{}^j\right)$
Horizontal	75	77	89	96	84	87	120
Vertical	65	70	70	76	70	70	71

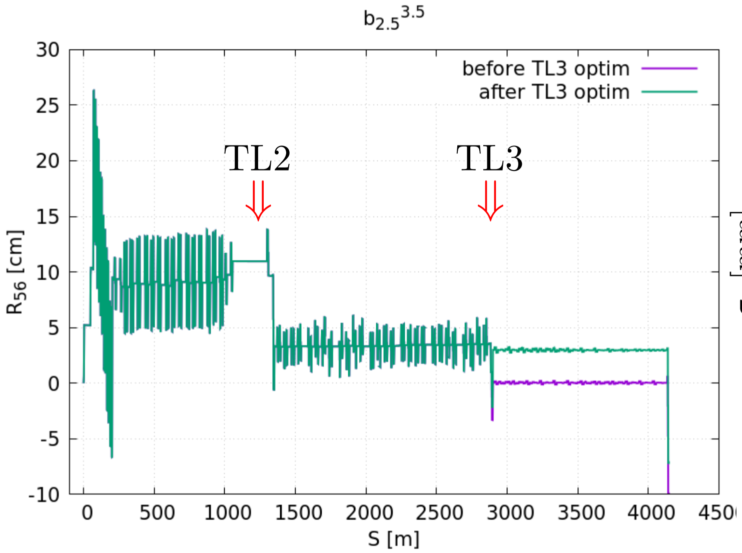
Longitudinal profile after CR2 optimisation

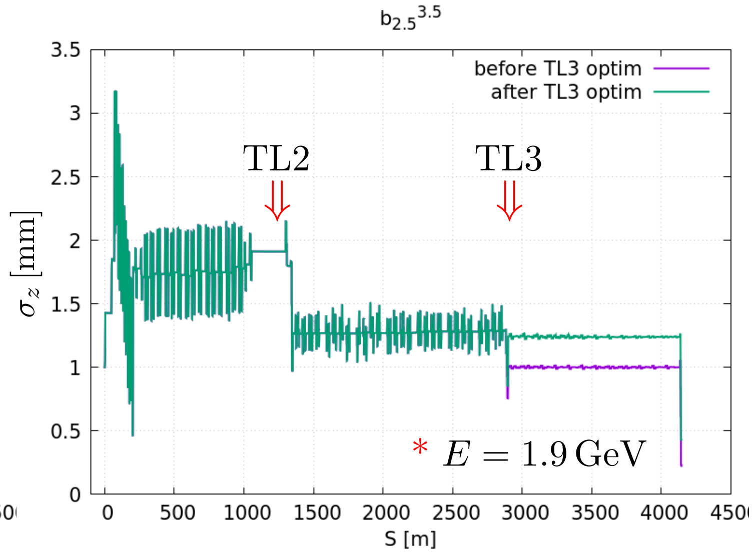


Extraction results (after TTA)

Bunch	S_{total} [m]	ε_x [μm]	ε_y [μm]	T_{566} [m]	σ_z [mm]
$\mathrm{b}_{2.5}^{3.5}$	4145	207	161	0.23	0.43
$\mathrm{b}_{2.5}^{2.5}$	3706	169	137	0.21	0.42
$\mathrm{b}_{2.5}^{1.5}$	3267	166	154	0.21	0.42
$\mathrm{b}_{2.5}^{0.5}$	2828	116	98	0.22	0.41
$\mathrm{b}_{1.5}^{3.5}$	3853	106	142	0.35	0.42
$\mathrm{b}_{1.5}^{2.5}$	3414	84	107	0.36	0.42
$\mathrm{b}_{1.5}^{1.5}$	2975	87	98	0.38	0.42
$\mathrm{b}_{1.5}^{0.5}$	2536	80	85	0.39	0.42
$\mathrm{b}_{0.5}^{3.5}$	3560	107	146	0.54	0.43
$\mathrm{b}_{0.5}^{2.5}$	3121	96	113	0.54	0.43
$\mathrm{b}_{0.5}^{1.5}$	2682	89	101	0.57	0.43
$\mathrm{b}_{0.5}^{0.5}$	2243	108	91	0.59	0.43
b_{i}^{j}	–	117	112	–	–

R_{56} in the transfer lines





The decrease in bunch length originates in non-zero R_{56} (unwanted side-effect of previous optimisation scans)

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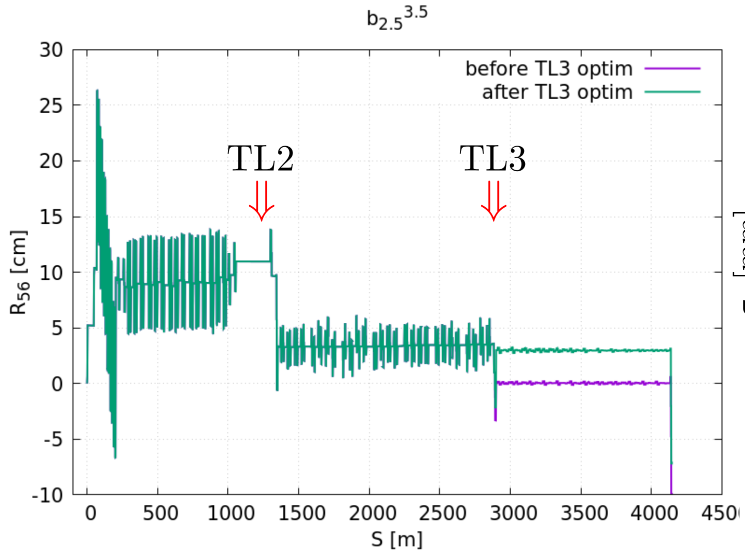

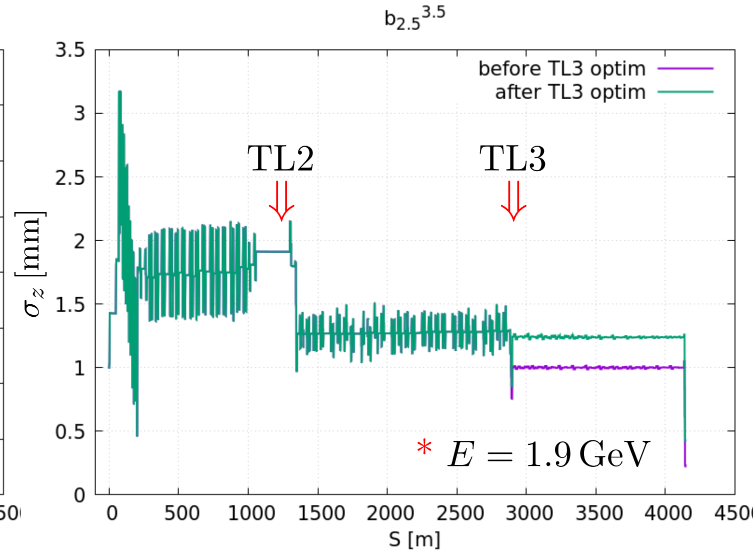

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TL3 has already been optimised to have $R_{56} \sim 0$

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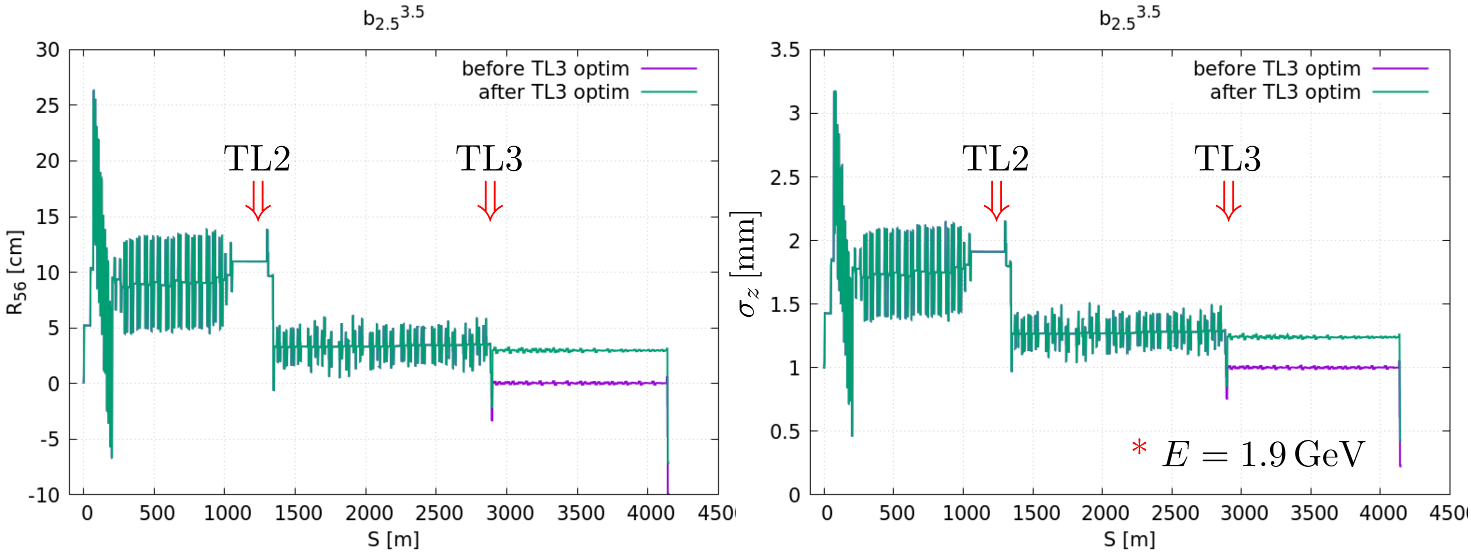

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TL2 is next...

Optimisation techniques with particle losses

General technique

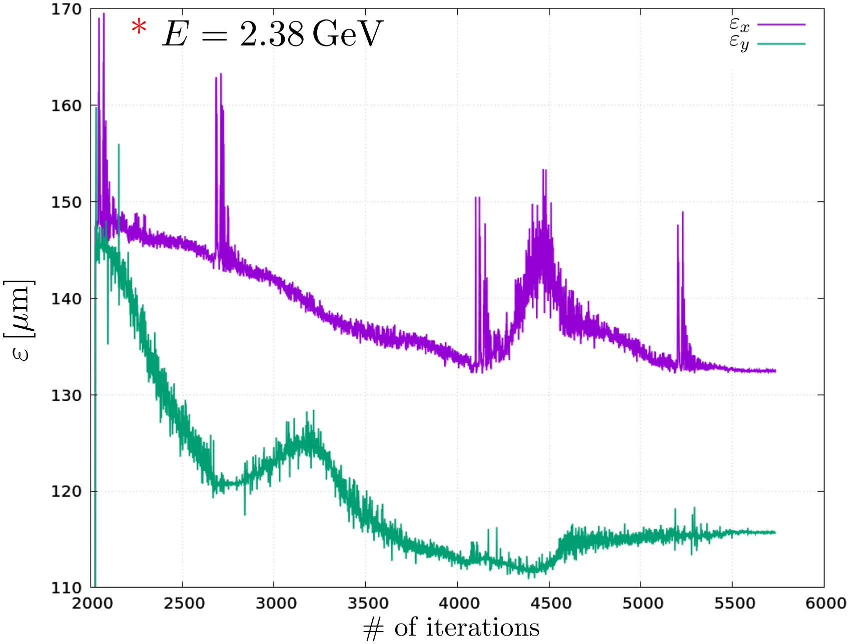
Optimisation is performed by changing optical strengths of some elements

`Placet2`'s API to `Octave` to access Nelder-Mead's downhill simplex algorithm

We Define element families (7-40) and minimize $w_1\varepsilon_x + w_2\varepsilon_y + w_3T_{566}{}^*$

Takes a lot of computing time and fine tuning

Ex: partial CR2 optimisation



* In reality minimizing the error of a linear fit is more efficient

Emittance evaluation from a particle distribution

In multiple particle tracking we evaluate emittance as

$$\varepsilon_q = \sqrt{\det\left(\begin{bmatrix} \operatorname{cov}(q,q) & \operatorname{cov}(q,q') \\ \operatorname{cov}(q',q) & \operatorname{cov}(q',q') \end{bmatrix}\right)}$$

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However, **if particle losses are possible during optimisation**, increasing particle loss will decrease the ε_q evaluation

The optimisation scan will therefore "attempt" to lose more particles!

Emittance evaluation from a particle distribution

When 1st attempting to address this, we added a term to the merit function such that

$$w_1\varepsilon_x + w_2\varepsilon_y + w_3T_{566} + W_4N_{\text{Losses}}\ ; \quad W_4 \gg w_i$$

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Instead of using the full distribution, we compute ε_q using a fixed number of macro particles (99% of the original distribution)

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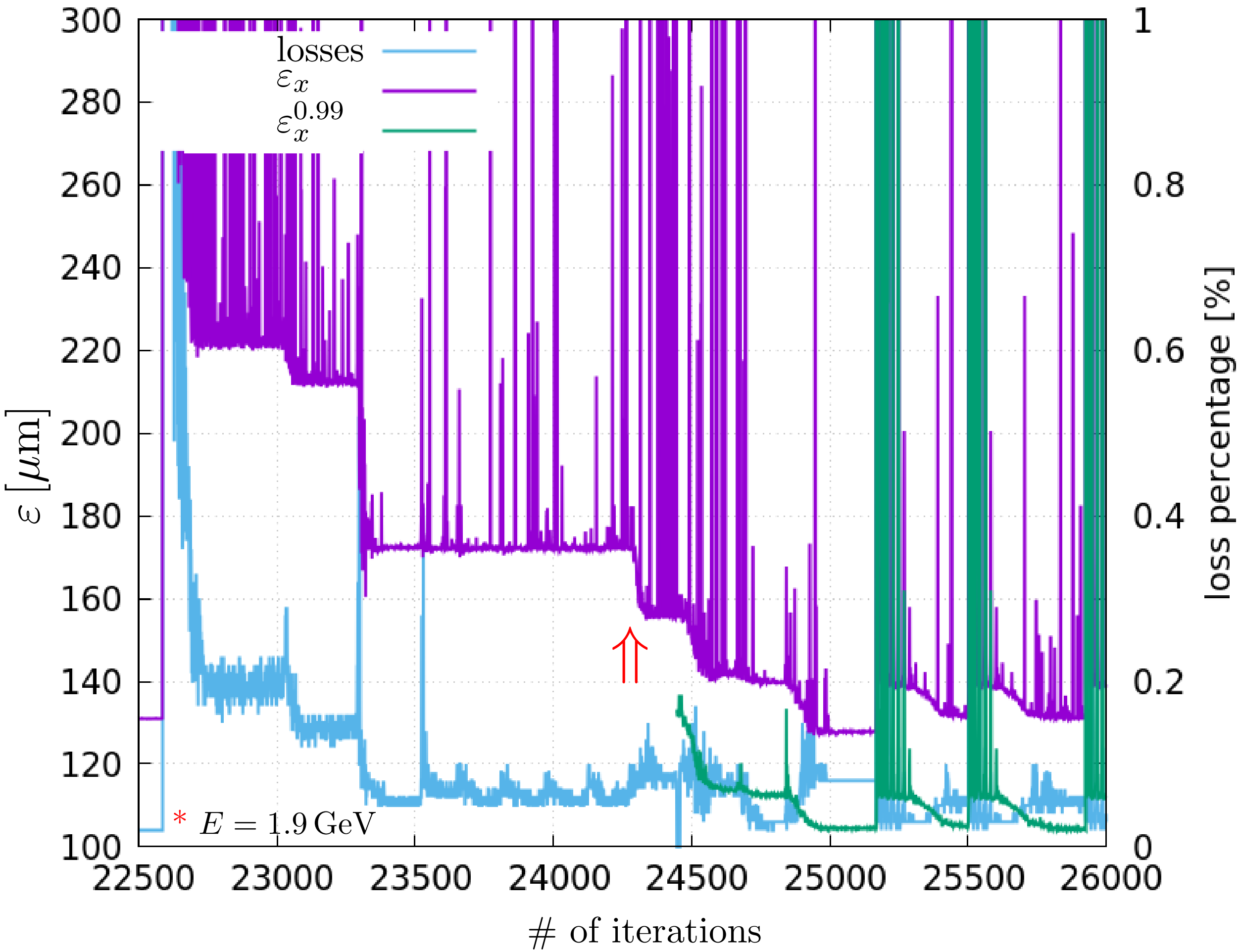
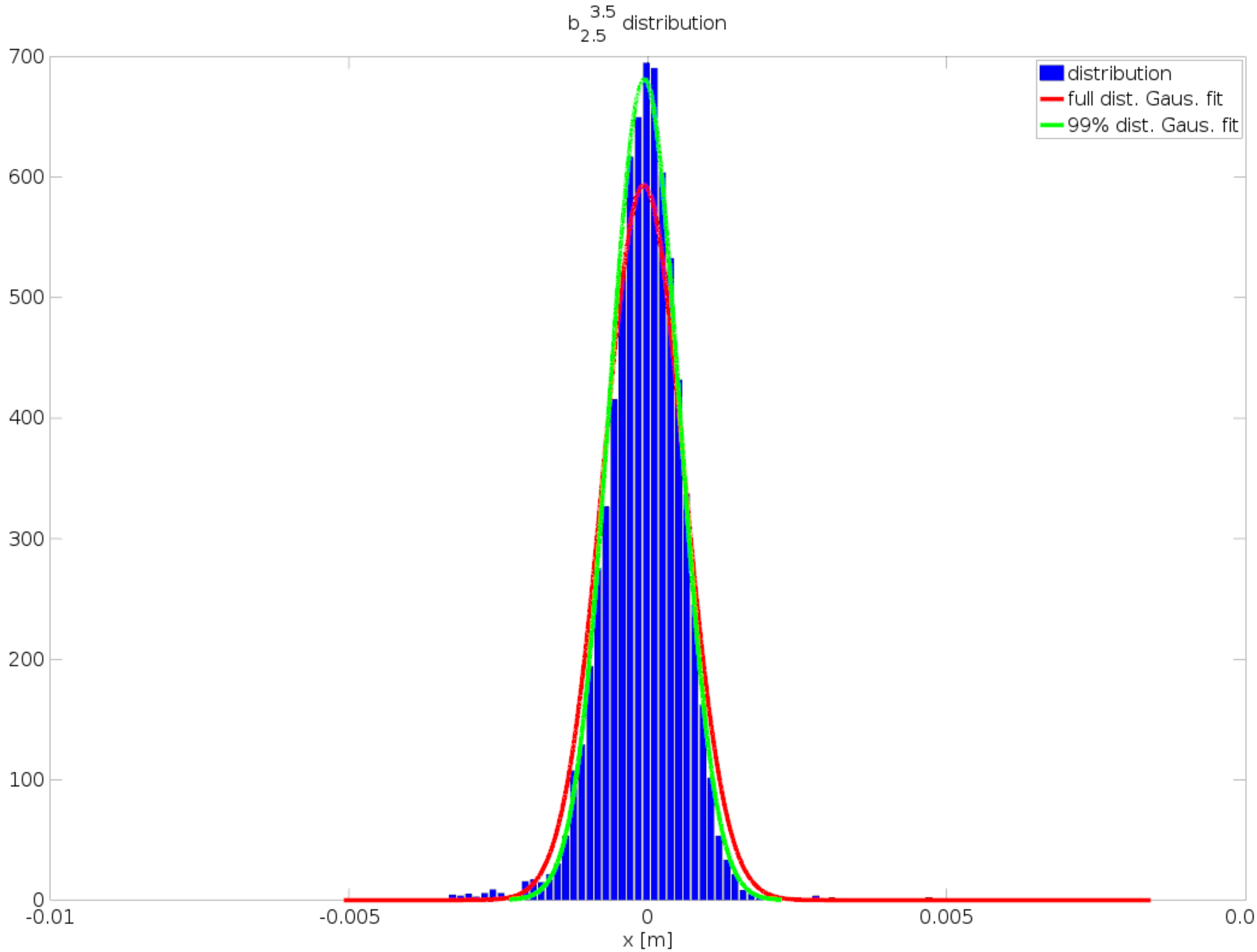
This also provides a better fit to the particle distribution (since the bunch is not actually Gaussian at extraction)

Emittance evaluation from a particle distribution



Gaussian fit comparison



Conclusions and Outlook

Conclusions

- `Placet2` has been updated to track individual tensor elements
- The main DBRC design challenges were identified and addressed
- With an injected beam of 50 μm, the latest lattice has minimal T_{566} ($< 60\,\text{cm}$) while meting the emittance budget ($\varepsilon_x = 117\,\mu\text{m}\,;\ \varepsilon_y = 112\,\mu\text{m}$)
- The transfer lines present some unwanted R_{56} ($\sim$ -7 cm)
- Particle loss and long non-Gaussian are detrimental to the performance of our optimisation scans
- When losses are possible, estimating ε using 99% of the particle distribution improves the performance of optimisation scans
- It also provides a better fit for distributions with long tails

Outlook

- DBRC
    - Remove R_{56} from TL2 (or update the final chicane)
    - Implement the delay loop's short path
    - Try to optimise for $\delta = 1\%$
    - Implement misalignments and beam-based alignment techniques

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  - Implement decelerators
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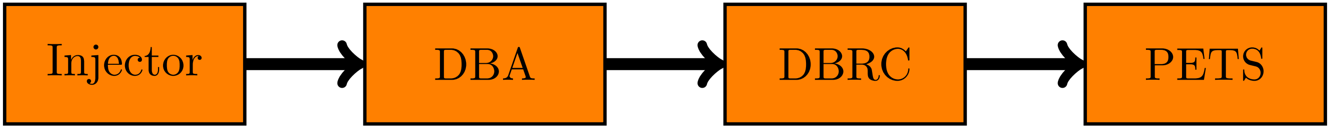
- Full drive beam integration



Full drive beam integration (status)

Output:

$\varepsilon_x \leq 35\,\mu\mathrm{m}$

$\varepsilon_y \leq 35\,\mu\mathrm{m}$

$E = 50\,\mathrm{MeV}$

$\delta = 0.95\%$

Full drive beam integration (status)

Output:

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$\varepsilon_y \leq 35\,\mu\text{m}$

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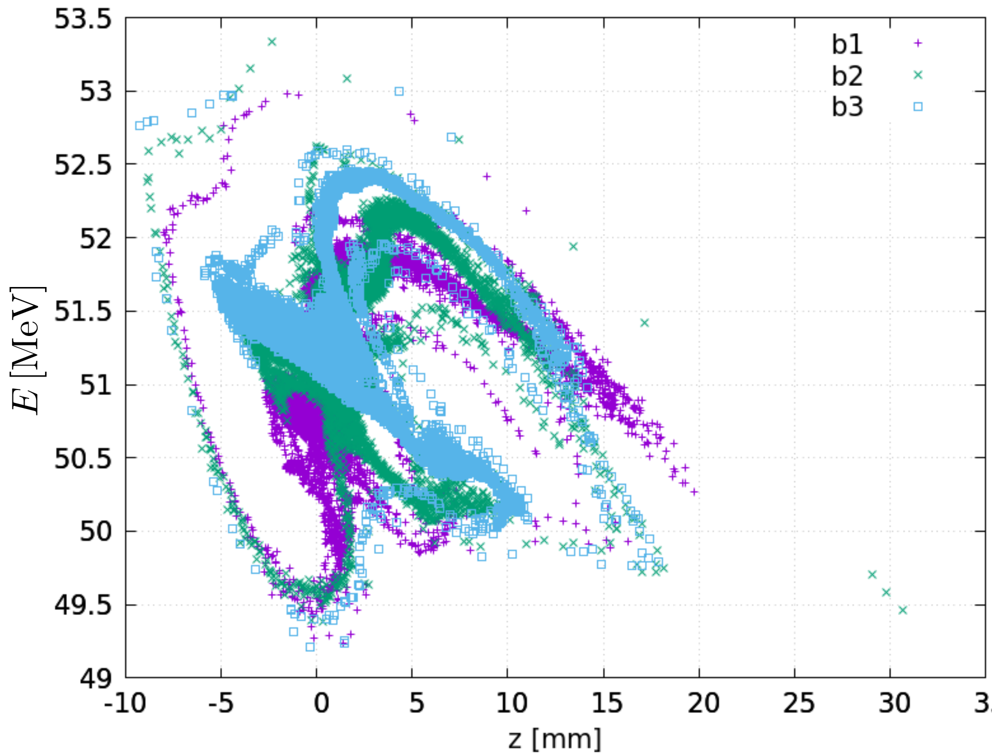
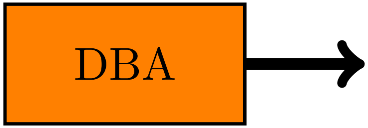


* Thanks to Steffen Doebert and Shahin Hajari for the distributions

Full drive beam integration (status)



Input:

$\varepsilon_q = 30\,\mu\mathrm{m}$

$E = 50\,\mathrm{MeV}$

$\delta = 1\%$

Gaussian

Full drive beam integration (status)

DBA $\longrightarrow$

Input:

$\varepsilon_q = 30\,\mu\mathrm{m}$

$E = 50\,\mathrm{MeV}$

$\delta = 1\%$

Gaussian

Output:

$\varepsilon_q = 31\,\mu\mathrm{m}$

$E = 1.9\,\mathrm{GeV}$

$\delta = 0.84\%$

Full drive beam integration (status)

DBA

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$\delta = 1\%$

Gaussian

Output:

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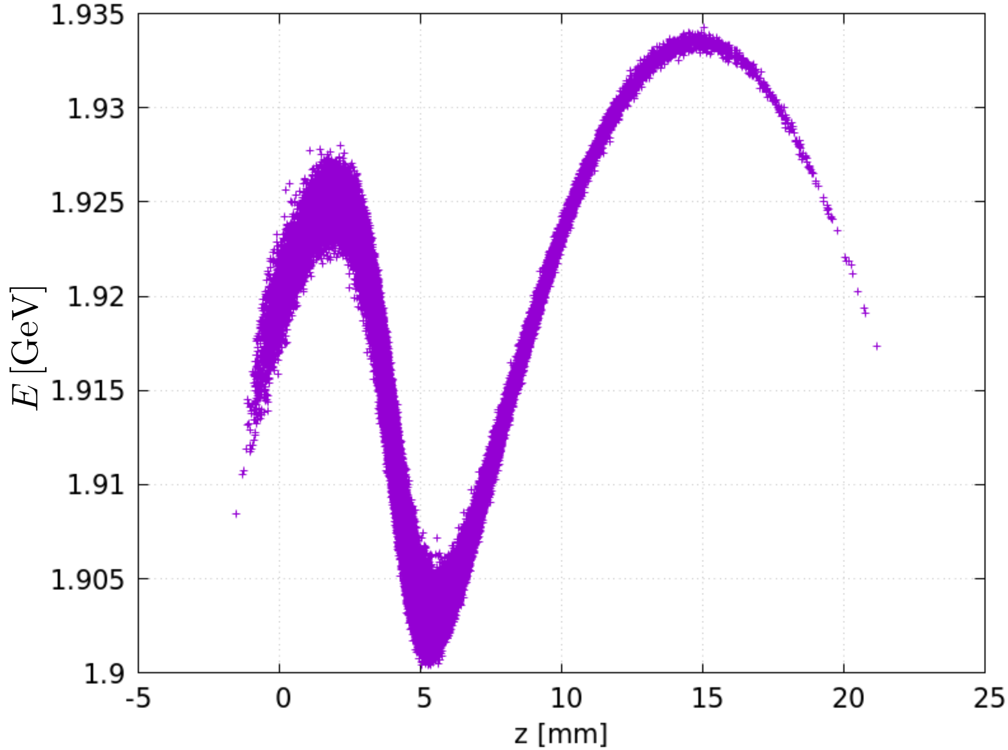


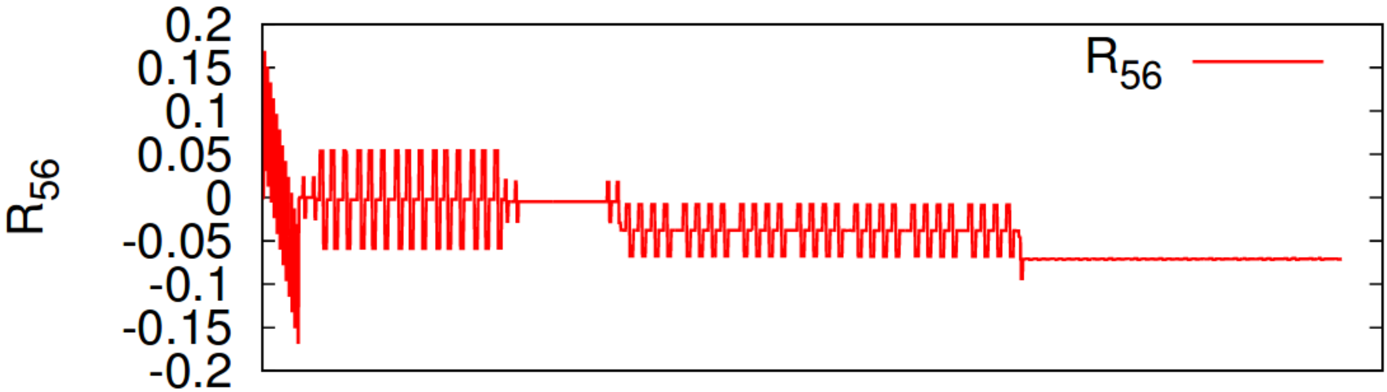
* Thanks to Avni Aksoy and Andrea Latina for the distribution

The end

Thank you

Extra slides

R_{56} before optimisation

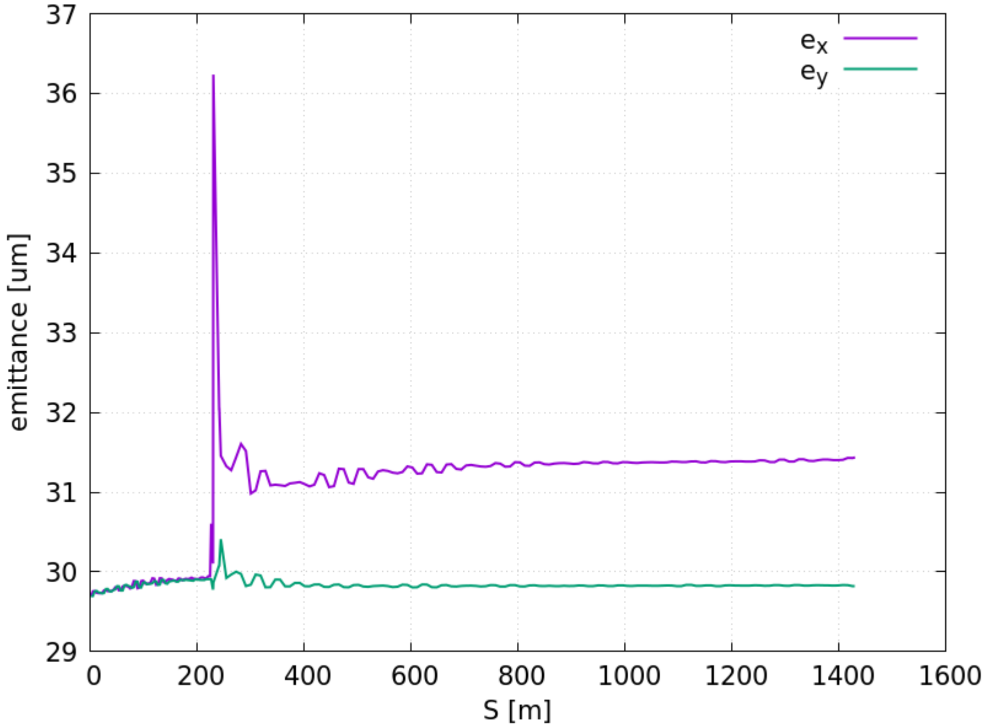


* From Eduardo Marin's CLIC Workshop 2016

DBA simulation parameters

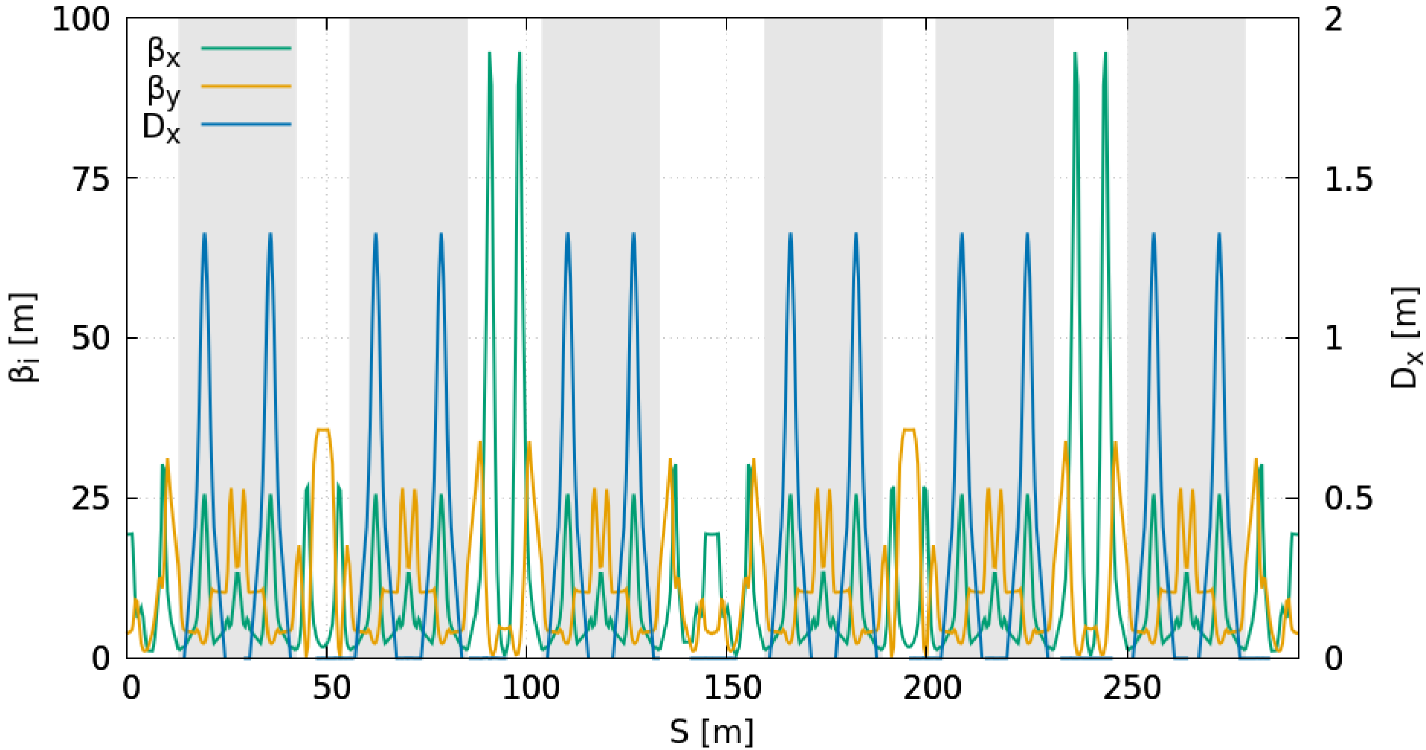
DBA simulation parameters:	
Initial energy (MeV)	50
Final energy (GeV)	1.9
Initial Energy Spread (%)	1.0
Bunch Charge (nC)	8.4
Initial emittance (μm)	30
BPM resolution (μm)	10
Misalignment errors - Quad. and Acc. (μm rms)	200
Pitch errors - Acc. (μrad rms)	200

DBA simulations (WFS)

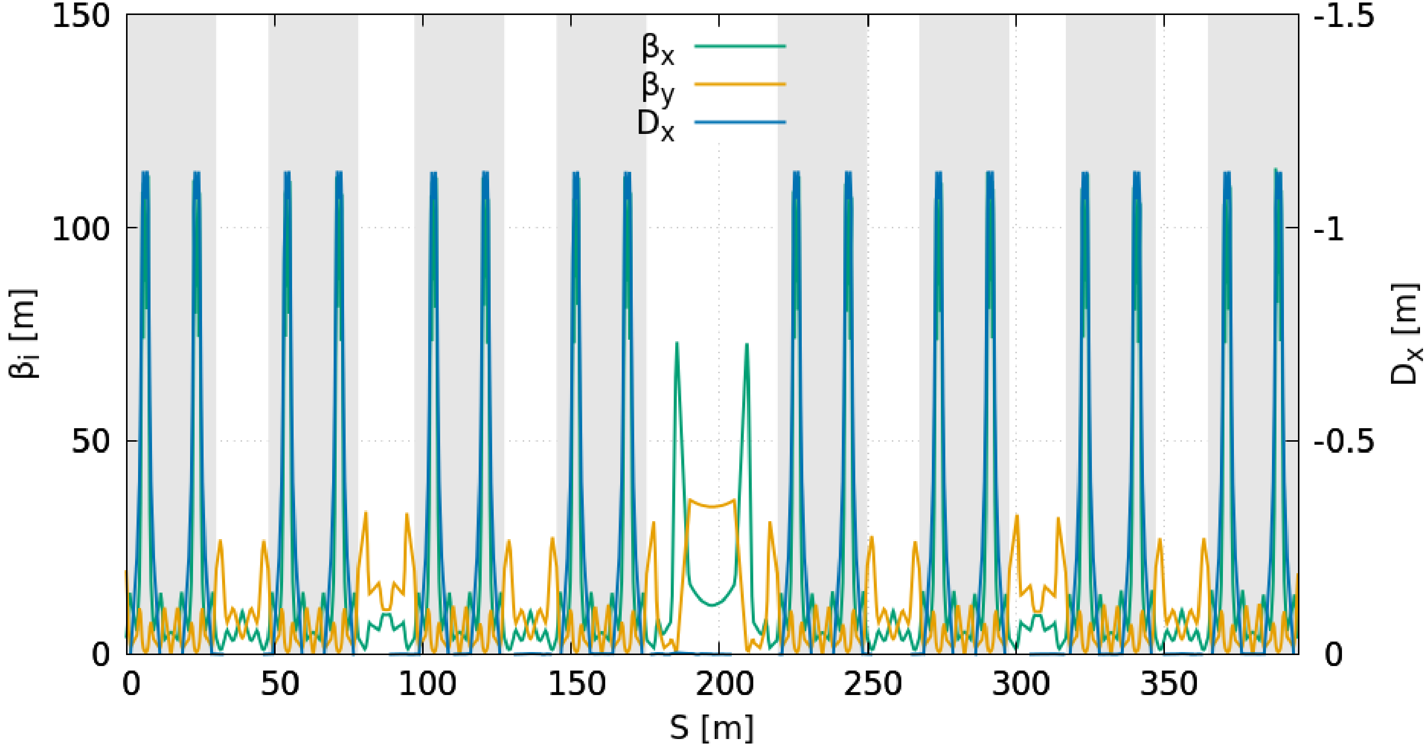


- Average final emittance: $\varepsilon_x = 31\ \mu\text{m}$, $\varepsilon_y = 30\ \mu\text{m}$
- Final energy spread of $0.836\% \pm 0.004\%$

CR1 Lattice



CR2 Lattice



150
100
50
0
-1.5
-1
-0.5
0
βx
βy
Dx
βi [m]
Dx [m]
0
50
100
150
200
250
300
350
S [m]