RTML Performance at 380 GeV Stage

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CLIC RTML

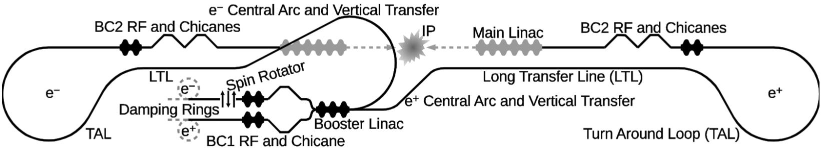


Figure: Sketch of RTML

- Transport beam from damping rings to main linacs
- Match beam properties, like bunch length and energy

Table: RTML Beam properties comparison between 3 TeV and 380 GeV

Properties [unites]		3 TeV		380 GeV	
		Start	End	Start	End
Energy [GeV]	E_0	2.86	9	2.86	9
Charge [nC]		0.65	0.6	0.85	0.85
Bunch length [μm]	σ_s	1800	44	1800	70
Energy spread [%]	σ_E	0.12	1.7	0.12	1.7
Emittance [nm]	$\epsilon_{n,x}$	500	600	700	850
	$\epsilon_{n,y}$	5	10	5	10

We focus on the electron part.

New Bunch Compressor

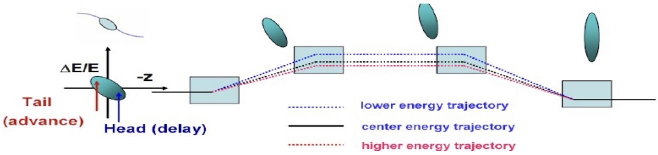


Figure: Sketch of bunch compressor

For the 380 GeV stage, the beam bunch length is changed from 1800 to 70 μm.

According to the bunch compression equation:

$$\sigma_{z_f} = \sqrt{(1 + R_{65} R_{56})^2 \sigma_{z_i}^2 + (E_i/E_f)^2 R_{56}^2 \sigma_{\delta_i}^2} \qquad (1)$$

Assuming that BC1 unchanged and full compression at BC2:

- R_{56} for BC2 will be larger → larger ISR and CSR → large emittance
- RF gradient for BC2 will be smaller

We need to re-optimise the bunch compressors.

- The full compression at the end BC2
- CSR in BC1 and BC2

The Effects of Static Errors

Table: The effect of mis-alignment on different magnets

	Position (x, y)	Angle (x', y')	Roll	Strength
Dipole	No effect	Dispersion	Dispersion	Orbit error
Quad.	Dispersion	Dispersion	Coupling	β erro
Sext.	β error, Coupling	Coupling ...	Coupling ...	Chromatic

The effect of BPM:

- Position offset: Wrong position measurement
- Resolution

The magnets center shift:

- Make DFS less effective.

Emittance measurements errors:

- Make the final emittance optimizer less effective.

Sextupole mover step size:

- Can not tune the final emittance continuously

Static Error Correction - Beam-based Alignment

One to One (1:1) — Steer the beam to the centre of BPMs

- *BPM measurements:* $\mathbf{u}$. ($\mathbf{u}_0$*: results on perfect machine)*
- *Correctors strength:* θ.
- *Response Matrix:* $\mathbf{R}$
- $\theta = min\ \{\ ||\Delta\mathbf{u} - \mathbf{R}\theta||_2^2 + \beta_0^2||\theta||_2^2\ \}$, *here* $\Delta\mathbf{u} = \mathbf{u} - \mathbf{u}_0$, β_0 *is a parameter.*

Dispersion Free Steering (DFS)—Correct the errors from BPM positions

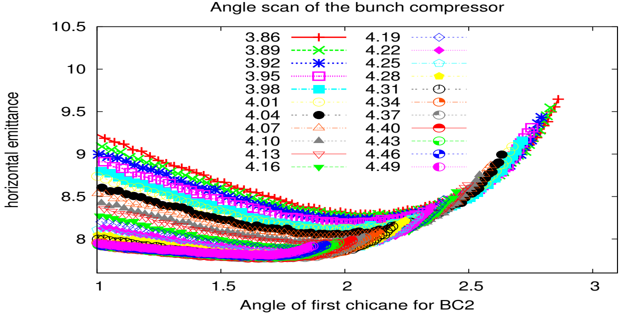
- *Two kind of beam are used: Nominal beam (1) and test beam (2)*
- *Dispersion matrix* $D = R_2 - R_1$, *Dispersion* $\eta = (\ \mathbf{u}_2 - \mathbf{u}_{02}\ ) - (\mathbf{u}_1 - \mathbf{u}_{01})$
- $\theta = min\ \{\ ||\Delta\mathbf{u} - R_1\theta||_2^2 + \omega^2||\eta - D\theta||_2^2 + \beta_1^2||\theta||_2^2\ \}$;

Sextupole Correction Section (SCS) — Correct the coupling and β-beating

- *Sextupole offset can introduce additional quadrupole or skew quadrupoles.*
  - $\frac{e}{p}B_x = mxy$, $\frac{e}{p}B_y = \frac{1}{2}m(x^2 - y^2)$
- *The first five sextupoles in CA or TAL are used for the coupling correction.*

Scan of the BC1

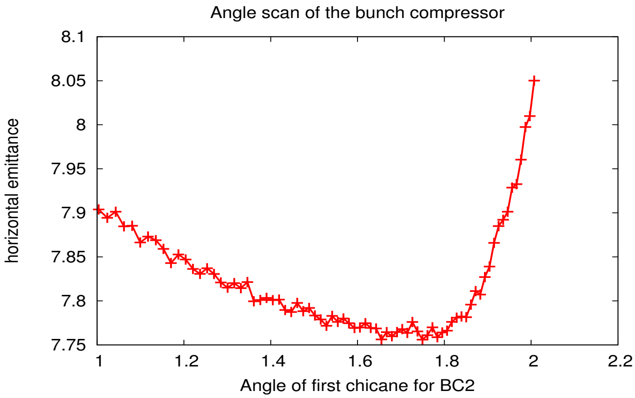
Firstly, we keep the RF in BC1 unchanged and scan the angle of the BC1 chicane in the region [3.86, 4.5] degree.
Then the angle of the first chicane in BC2 is also scanned.



It shows the optimal angle for BC1 chicane is around 4.40 degree. We keep the BC1 chicane angle the same as the 3 TeV stage.

Scan of the BC2

We set the angle of BC1 chicane to 4.418 degree and then scan the BC2



Finally, the angles of the two chicane are set to:

- $\theta_1 = 1.75$ degree
- $\theta_2 = 0.98$ degree

RF gradient for BC2 become 58 MV/m.

Emittance Growth Budget for Static Errors

The total emittance budget for RTML is: $\epsilon_x < 850$ and $\epsilon_y < 10\ \mathrm{nm} \cdot \mathrm{rad}$.

For static errors, we set the budget like: $\epsilon_x < 820$ and $\epsilon_y < 8\ \mathrm{nm} \cdot \mathrm{rad}$

- 700 and 5 $\mathrm{nm} \cdot \mathrm{rad}$ - the initial emittance
- 80 and 1 $\mathrm{nm} \cdot \mathrm{rad}$ - lattice design emittance growth
- 40 and 2 $\mathrm{nm} \cdot \mathrm{rad}$ - static alignment emittance growth

It is required that at least 90% machines can be well corrected.

Simulation Setup

We prepare 100 randomly mis-aligned machines.

- All dipoles, quadrupoles, sextupoles and BPMs are mis-aligned
  - $\sigma_{\text{pos}} = 30\ \mu\text{m}$
  - $\sigma_{\text{roll}} = 100\ \mu\text{rad}$
- BPMs have resolution $\sigma_{\text{res}} = 1\ \mu\text{m}$
- Magnets strength errors are considered
  - Quadrupoles in CA and TAL: 0.01%
  - All other magnets: 0.1%
- magnet centre movement effect is considered.
  - 5% magnets strength will induce 0.35 μm shift

In coupling correction:

- sextuple moves with step size 1 μm
- 1% emittance measurement errors are considered

The dipoles are selected to be the correctors. Each quadrupole will be followed by a dipole corrector.

OTO and DFS setup

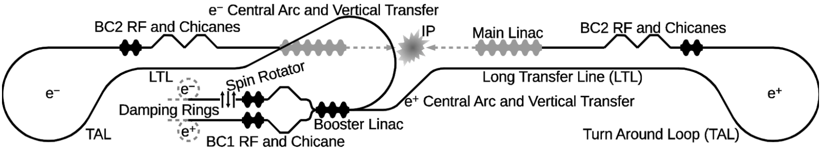


Figure: Sketch of RTML

RTML is divided to 7 sections: SR, BC1, BOO, CA & VT, LTL, TAL and BC2.

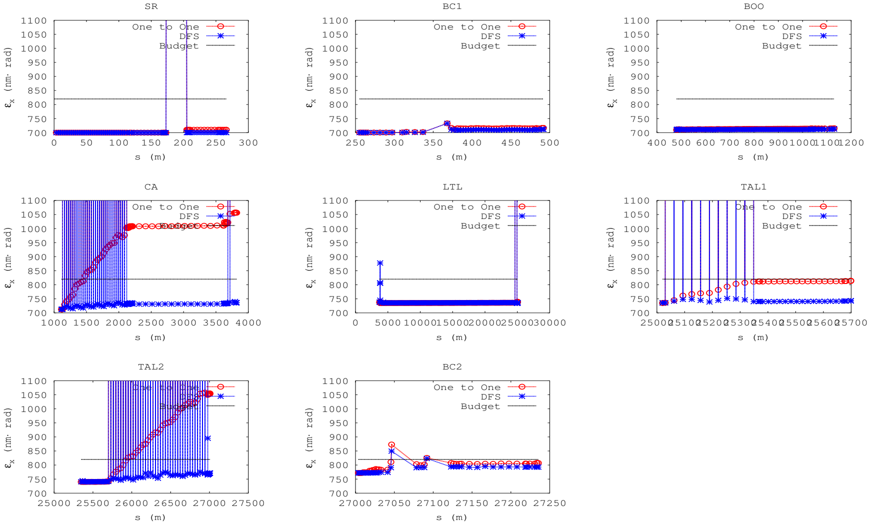
For each section, we get a response matrix **R** and dispersion response matrix **D**.

To get the **D**, we need the test beam:

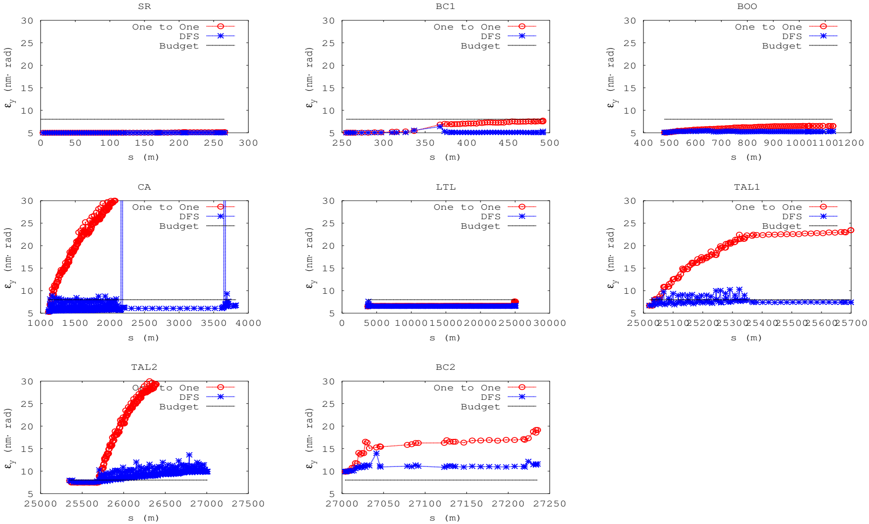
- BC1 & BC2 - change the RF cavity phase
- BOO - change the RF gradient
- CA & VT - use the test beam from BOO (BOO lattice is scaled)
- SR & LTL & TAL - scale the lattice (magnet centre shift is introduced)

The parameters β_0 and β_1 for OTO and DFS are scanned in the $[1:7] \times [1:7]$ space for each section. The weight parameter ω is set to 30.

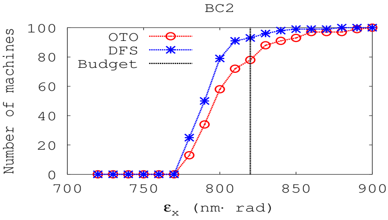
Average horizontal emittance after OTO and DFS

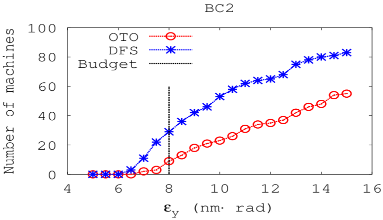


Average vertical emittance after OTO and DFS



Emittance distribution at the end of RTML





- There are 8 bad machines in the horizontal plane.
- But in the horizontal plane, there are 71 bad machines
- Totally, there are 73 bad machines.

We need coupling correction to improve this.

Coupling Correction Setup

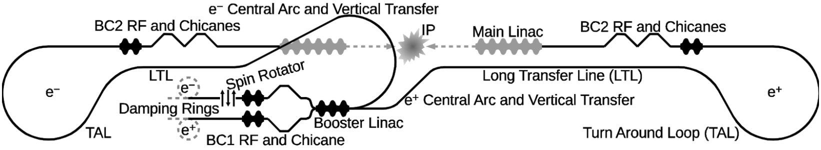


Figure: Sketch of RTML

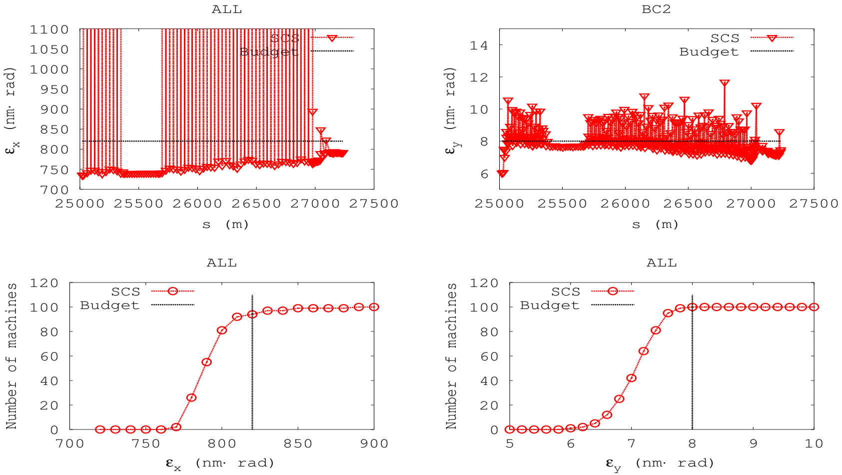
Two correction sections are used

- The first five sexupoles in CA are used to optimise the emittance after LTL
- The first five sextupoles in TAL are used to optimise the final emittance.

The SIMPLEX algorithm is used

- It is difficult to use the multi-knobs technique due to large lattice
- $f = \omega \times \frac{\epsilon_x}{700} + \frac{\epsilon_y}{5}$
- The weight between the horizontal and vertical plane can be adjusted.

Coupling Correction Results



- There are 7 bad machines in the horizontal plane.
- In the horizontal plane, all machines are well corrected.

Conclusion

The bunch compressors are re-optimised for the 380 GeV stage.

The Static BBA is successfully applied for the 380 GeV stage.

- All dipoles, quadrupoles, sextupoles and BPMs are mis-aligned
  - $\sigma_{\text{pos}} = 30\ \mu\text{m}$
  - $\sigma_{\text{roll}} = 100\ \mu\text{rad}$
- BPMs have resolution $\sigma_{\text{res}} = 1\ \mu\text{m}$
- Magnets strength errors are considered
- magnet centre movement effect is considered.
- Sextupoles moves with step size 1 μm
- 1% emittance measurement errors are considered.

Thank you!