CLIC RTML Emittance Measurement

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Outline

1. Generalities
2. RTML section
3. 2D Emittance measurement section
4. Beam and measurement simulations
5. Simulations with beam and measurement errors included
    - Beam size error
    - Non-physical results
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    - Discussion of the results
8. Future work

Description

- Problem: Measure the Emittance at the end of RTML.
- Possible solution: We propose a 2D Measurement section based on a 4-FODO lattice.
- Unsolved issues: General specifications of the laser wire (LW) beam profile monitor

Emittance definition

4 × 4 Beam matrix

$$\sigma = \begin{pmatrix} \langle x^2\rangle & \langle xx'\rangle & \langle xy\rangle & \langle xy'\rangle \\ \langle xx'\rangle & \langle x'^2\rangle & \langle x'y\rangle & \langle x'y'\rangle \\ \langle xy\rangle & \langle x'y\rangle & \langle y^2\rangle & \langle yy'\rangle \\ \langle xy'\rangle & \langle x'y'\rangle & \langle yy'\rangle & \langle y'^2\rangle \end{pmatrix} = \begin{pmatrix} \Sigma_{xx} & \Sigma_{xy} \\ \Sigma_{xy}^T & \Sigma_{yy} \end{pmatrix}$$

Projected emittance

$$\varepsilon_x = \sqrt{\det \Sigma_{xx}} = \sqrt{\sigma_{11}\sigma_{22} - \sigma_{12}^2} = \sqrt{\langle x^2\rangle\langle x'^2\rangle - \langle xx'\rangle^2}$$

$$\varepsilon_y = \sqrt{\det \Sigma_{yy}} = \sqrt{\sigma_{33}\sigma_{44} - \sigma_{34}^2} = \sqrt{\langle y^2\rangle\langle y'^2\rangle - \langle yy'\rangle^2}$$

It will coincide with the intrinsic emittance if the beam is uncoupled, but always $\varepsilon_{\text{proj}} > \varepsilon_{\text{intr}}$.

Beam matrix transformation

Beam matrix transformation

$$\sigma_i = R_i \sigma_0 R_i^T, \quad i = 1, \dots, N$$

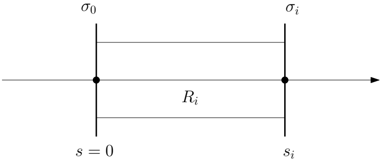

Figure: Line scheme

Transformation $\sigma_i = R_i \sigma_0 R_i^T$

$$(\sigma_i)_{11} = {(R_i)_{11}}^2 (\sigma_0)_{11} - 2 (R_i)_{11} (R_i)_{12} (\sigma_0)_{12} + {(R_i)_{12}}^2 (\sigma_0)_{22}$$

$$(\sigma_i)_{33} = {(R_i)_{33}}^2 (\sigma_0)_{33} - 2 (R_i)_{33} (R_i)_{34} (\sigma_0)_{34} + {(R_i)_{34}}^2 (\sigma_0)_{44}$$

Phase advance per cell

Optimal phase advance per cell

The number of unphysical solutions of the system is minimal if[a]:

$$\Delta\mu = 180^\circ/N$$

where N is the number of equations of the set (number of scanners)

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[a] I.Agapov, G.Blair, M.Woodley (2007)

RTML general layout

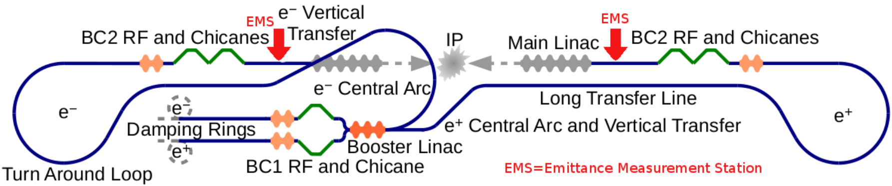


Figure: Ring to Main Linac layout (Courtesy of F.Stulle)

RTML section parameters

Table: Beam parameters at the end of RTML

Property	Symbol	Value	Unit
Energy	E_0	9	GeV
Bunch length	σ_s	44	μm
Total energy spread	σ_{E}	< 1.7	%
Normalized emittance	$\varepsilon_{n,x}$	< 600	nm rad
	$\varepsilon_{n,y}$	< 10	nm rad
Emittance error	$\delta\varepsilon_x/\varepsilon_x$	< 10	%
	$\delta\varepsilon_y/\varepsilon_y$	< 10	%

Design of the station lattice: MAD-X

- The most commmonly used lattice in a straight diagnostics section is a FODO lattice
- In the proposed lattice the measurement is done by means of four laser wire scanners with 2 LWs each. Therefore four FODO cells compose the whole lattice.
- Contraints to be imposed:
    - on the quadrupole strength to reduce chromaticity effects
    - on the cell length to avoid having too small or too large beam sizes
- MAD-X has a matching option to perform the adjustment of the parameters (k and L)

Design of the station lattice

- We develop 2D measurement line.
- Assuming that there is a Skew Correction Section upstream, the beam matrix is uncoupled:

$$\sigma = \begin{pmatrix} \Sigma_{xx} & 0 \\ 0 & \Sigma_{yy} \end{pmatrix}$$

Steps to follow

- Set initial conditions for the Twiss functions
- Set phase advance per FODO cell ($\Delta\mu = 180^\circ/N$)
- Set contraints on the field strength k and cell length L

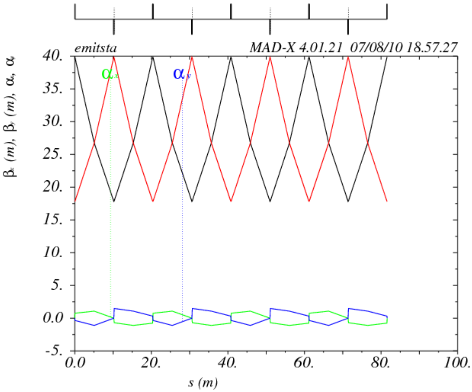
Design of the lattice of the emittance measurement line

Table: Key parameters of the lattice design

$L_{1/2}$ [m]	10
L_T [m]	81.6
l_q [m]	0.20
k [m^{-2}]	0.37765
B [T]	0.7558

$$\beta_{\max} = 39.84\text{m}$$

$$\beta_{\min} = 17.83\text{m}$$



Initial beam

Twiss functions

$$\beta_x = 39.84\text{m} \quad \beta_y = 17.83\text{m}$$

$$\alpha_x = \alpha_y = 0$$

$$\varepsilon_{x,N} = 600\text{nm rad} \quad \varepsilon_{y,N} = 10\text{nm rad}$$

Beam parameters

$$\langle x \rangle = \langle x' \rangle = 0$$

$$\langle y \rangle = \langle y' \rangle = 0$$

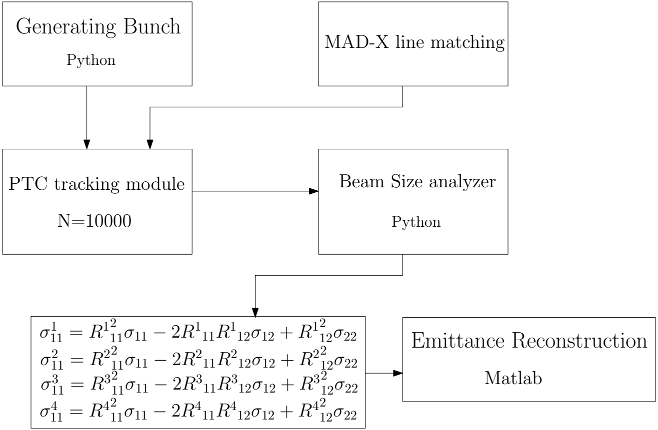
$$\sqrt{\langle x^2 \rangle} = \sqrt{\varepsilon_{x,N}\beta_x/\gamma} = \sqrt{\sigma 0^x_{11}} = 36.88\mu\text{m}$$

$$\sqrt{\langle x'^2 \rangle} = \sqrt{\varepsilon_{x,N}/(\beta_x\gamma)} = \sqrt{\sigma 0^x_{22}} = 9.26 \cdot 10^{-7}$$

$$\sqrt{\langle y^2 \rangle} = \sqrt{\varepsilon_{y,N}\beta_y/\gamma} = \sqrt{\sigma 0^y_{11}} = 3.18\mu\text{m}$$

$$\sqrt{\langle y'^2 \rangle} = \sqrt{\varepsilon_{y,N}/(\beta_y\gamma)} = \sqrt{\sigma 0^y_{22}} = 1.78 \cdot 10^{-7}$$

Simulation scheme



Generating Bunch

Python

MAD-X line matching

PTC tracking module

N=10000

Beam Size analyzer

Python

$$\begin{aligned}
\sigma^1_{11} &= {R^1}^2_{11}\sigma_{11} - 2{R^1}_{11}{R^1}_{12}\sigma_{12} + {R^1}^2_{12}\sigma_{22}\\
\sigma^2_{11} &= {R^2}^2_{11}\sigma_{11} - 2{R^2}_{11}{R^2}_{12}\sigma_{12} + {R^2}^2_{12}\sigma_{22}\\
\sigma^3_{11} &= {R^3}^2_{11}\sigma_{11} - 2{R^3}_{11}{R^3}_{12}\sigma_{12} + {R^3}^2_{12}\sigma_{22}\\
\sigma^4_{11} &= {R^4}^2_{11}\sigma_{11} - 2{R^4}_{11}{R^4}_{12}\sigma_{12} + {R^4}^2_{12}\sigma_{22}
\end{aligned}$$

Emittance Reconstruction

Matlab

Error simulation

- Beam size error ⇒ Error in σ_0^i
- Jitter error ⇒ Error in centroid position

$$\sigma_{\text{scan}}^2 = \sigma_e^2 + \sigma_{\text{jit}}^2$$

$$\left(\frac{\delta\sigma_e}{\sigma_e}\right)^2 = E_{\text{scan}}^2 + E_{\text{jit}}^2$$

Beam size error

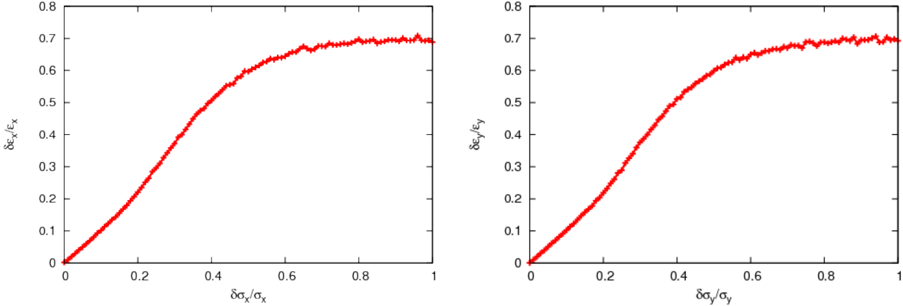


Figure: Horizontal and vertical emittance errors as a function of the beam size measurement

Beam size error: 10% Relative error

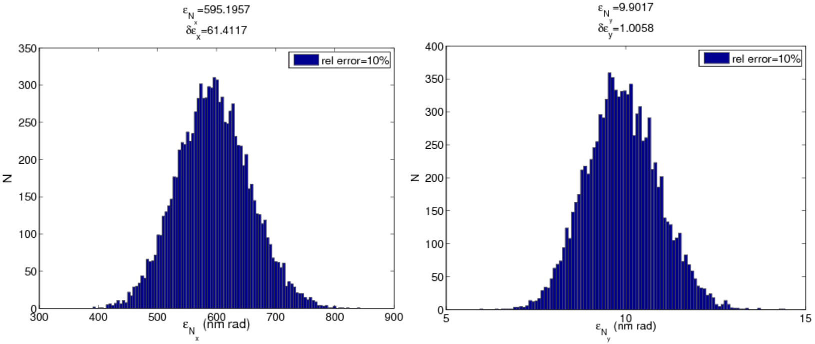


Figure: Distribution of reconstructed horizontal emittance for 10% random errors of the beam size measurements

Beam size error: 35% Relative error

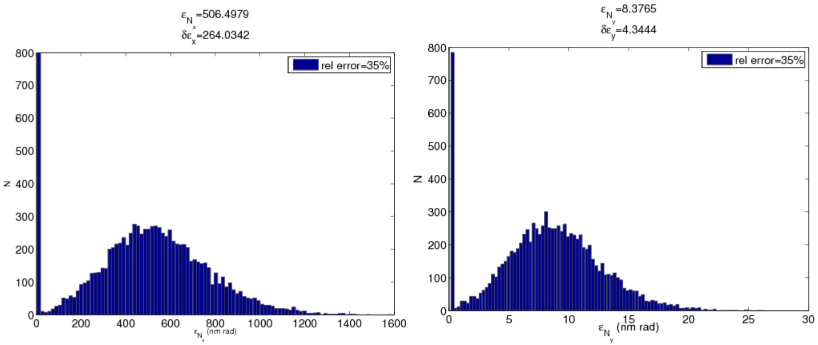


Figure: Distribution of reconstructed horizontal and vertical emittance for 35% random errors of the beam size measurements

Non physical results

- There are for which the emittance becomes complex i.e $\varepsilon^2 = \sigma_{11}\sigma_{22} - \sigma_{12}^2 < 0$.
- The number of cases increases as we increase the beam size error.

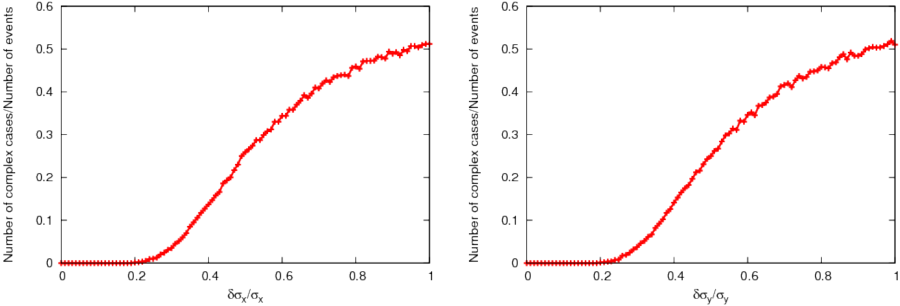


Figure: Fraction of simulations with non-physical beam matrix as a function of the beam measurement error

Jitter error

- We introduce these errors as a shift in the initial distribution i.e. $\langle x \rangle = \langle y \rangle \neq 0$.

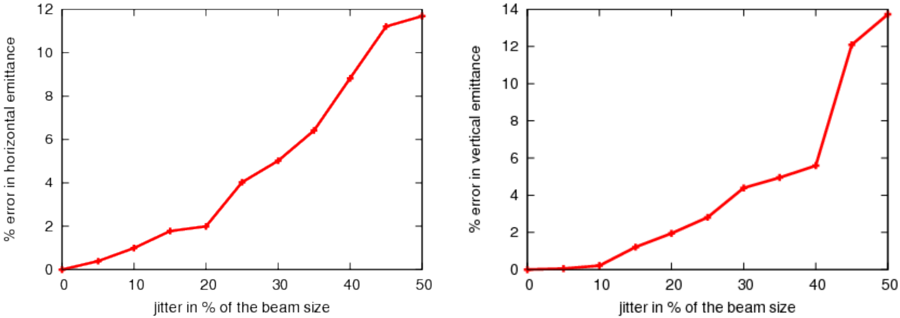
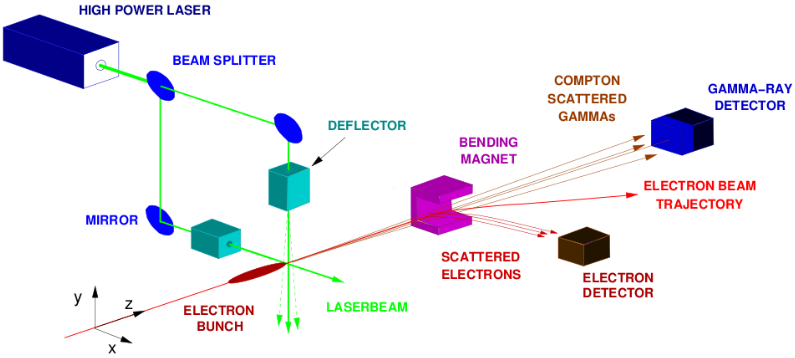


Figure: Horizontal and vertical emittance errors for the case of non-zero beam jitter

Laser Wire scheme



- ATF studies reveal submicron measured beam sizes.

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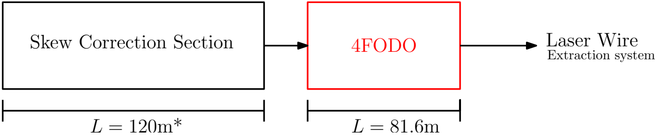
[1] G.A.Blair et al. 2001

Discussion of the results

- Line proposal[2]:



Skew Correction Section

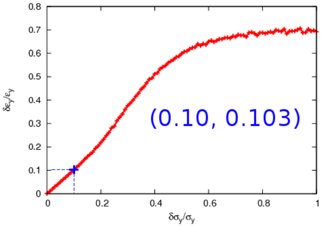
4FODO

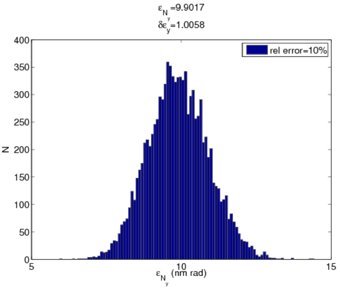
Laser Wire
Extraction system

$L = 120\text{m}^*$

$L = 81.6\text{m}$

- $\delta\varepsilon_x/\varepsilon_x = \delta\varepsilon_y/\varepsilon_y = 10\% \Rightarrow \delta\sigma_y/\sigma_y \approx 10\% \rightarrow \delta\sigma_y \approx 0.5\mu\text{m}$





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[2] The SCS lenght is taken from the ILC project

Future work

- Design of a Skew Correction Section.
- Determine general parameters of the LW beam profile monitors and check its feasibility
- Consider/Design a section for extraction of Compton scattered photons

Thank you!