Resistive-wall wakes in the BDS

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Acknowledgements:
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Motivation

- Understand the limitations of beam pipe apertures in the Beam Delivery System
- Find or delevelop a tool to estimate the effect of resistive wall wakefields
- Propose an aperture model for CLIC BDS for further use, e.g. in synchrotron radiation reflections study

Resistive wall wake field

- Resistive wall effect is a result of finite vacuum chamber conductivity
- The surface current is delayed with respect to the source and can interact with the following charged particles on the short- and long range

Classical treatment of resisitive wall wake[1]:

$$W(z) = -L\frac{c}{\pi b^3}\sqrt{\frac{Z_0}{\pi \sigma_r z}}, \tag{1}$$

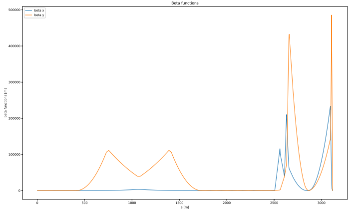
where: Z_0 - impedance of the vacuum, z - longitudinal distance between the source and the impacted particle, σ_r - conductivity of the wall, b - aperture radius, L - length of the considered wake element

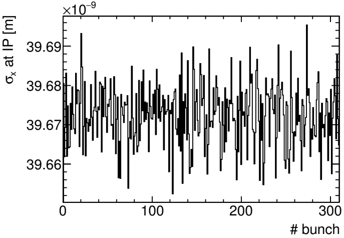
- Assumed are thick walls, ultra-relativistic particles
- Only fundamental transverse mode is considered

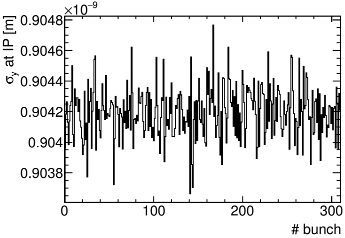
[1] As used in CLIC-Note-818

PyHEADTAIL for CLIC

- Macroparticle simulation code library for modeling collective effects beam dynamics in **circular** accelerators
- Modular software allowing to prepare custom simulation scripts
- Special approach needed to simulate a linear machine:
  - Focus on element-by-element beam parameters instead of turn-by-turn
  - Lattice read from MAD-X Twiss table
  - Use of pre-calculated wakes
- Source code and examples available at: PyHEADTAIL repository and PyHEADTAIL wiki







Analysis workflow

- The most recent designs of BDS at 380 GeV and 3 TeV with L* $=$ 6 m have been used
- Bunch trains have been created at the beginning of the BDS with a uniform offset of $+0.5\ \sigma_{x,y}$ for all bunches
- PyHEADTAIL's linear tracking with multibunch effects but no energy spread at the moment
- PLACET simulations used to establish beam envelopes along the lattice, with synchrotron radiation and non-linearities included
- Sensitivity to the effect was checked by calculating two-beam luminosity in Guinea-Pig, where the beam is duplicated and one of the bunch trains is centered at (0,0) while the other is fully impacted by the resistive wall wake

Assumptions

- Resistive wall wake fields have been calculated assuming round beam pipes made of copper with conductivity of $5.96 \cdot 10^7$ S/m
- Assumed maximal magnetic field at a pole of warm magnets: ~ 1.5 T
- Collimation depth for 380 GeV machine assumed to be the same as for 500 GeV and 3 TeV designs: 15 σ_x and 55 σ_y[1]
- Baseline aperture calculations follow the formula[2]:

$$R = max\{r_{min}, 1.1 + max\{15\sigma_x, 55\sigma_y\}\}, \tag{2}$$

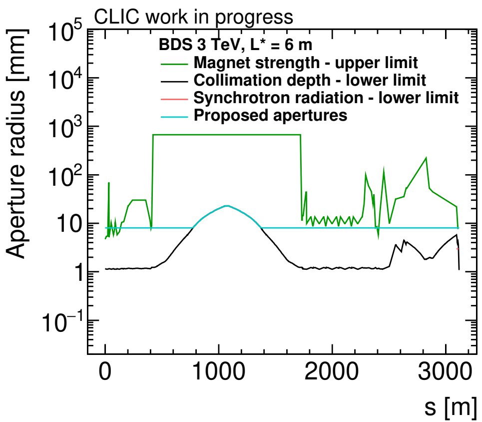
where:

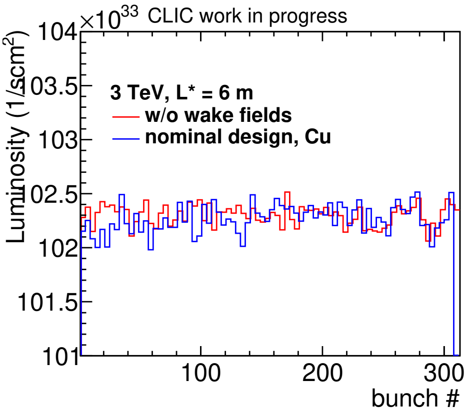
$$\sigma_{x,y} = \sqrt{\varepsilon_{x,y}\beta_{x,y} + (D_{x,y}\delta)^2} \tag{3}$$

[1] From Optimization of CLIC Baseline Collimation System

[2] A. Pastushenko's LCWS2018 talk

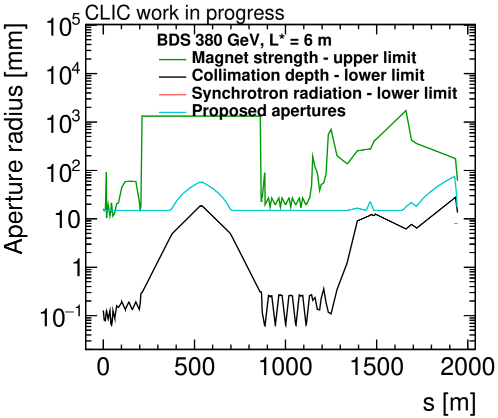
CLIC 3 TeV luminosity impact

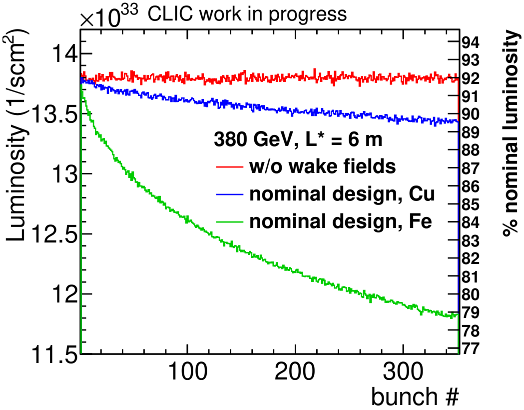




- 3 TeV beam not very sensitive to the resistive wall effect
- The nominal aperture design, with minimal aperture of 8 mm, as stable as the no wake field hypothesis

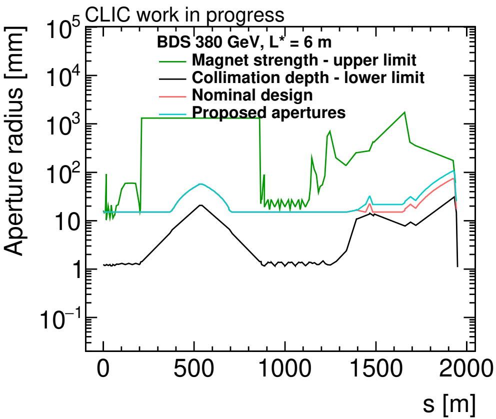
CLIC 380 GeV luminosity impact

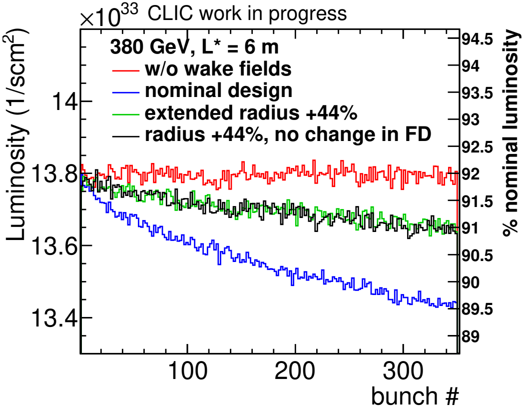




- Using steel leads to high sensitivity to the effect; luminosity decays rapidly along the bunch train
- Copper beam pipe provides more stable beam behaviour

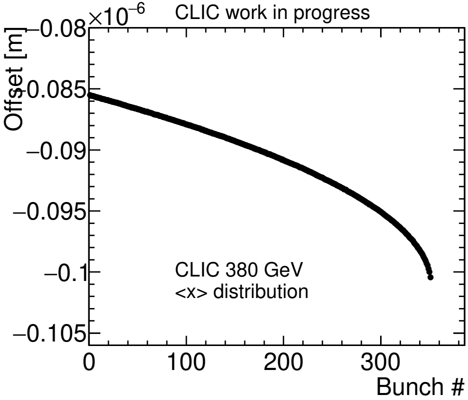
CLIC 380 GeV possible mitigation

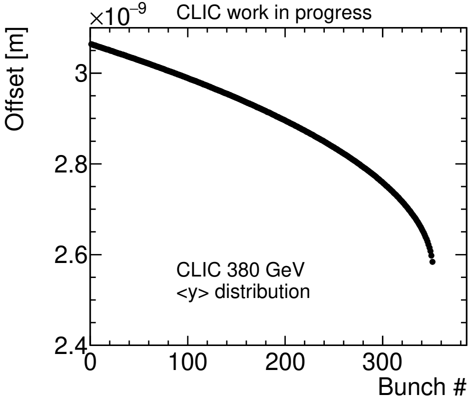




- Extending apertures by 44% reduces sensitivity to resistive wall effect by a factor of 3
- The reduced senstivity remains even if the apertures of the final doublet magnets stay unchanged
- Most of the luminosity loss comes from the offset

CLIC 380 GeV average offsets at IP - example





- Exemplary distribution to show general trend in all designs
- Non linear offset distribution, more rapidly decaying at the end of the bunch train
- Slope stable for most of the train - possible to mitigate with the intra-train feedback(?)

Summary and outlook

- CLIC at 3 TeV stage is not very sensitive to the resistive wall effect, 380 GeV demands more attention
- Steel is not a safe material to use for the beam pipe in the FFS, copper coating is a neccessity
- The nominal design at 380 GeV is slightly sensitive, which can be addressed by an extension of the aperture in the FFS
- Most of the luminosity loss comes from the offset, which can be alternatively cured with intra-train feedback, but the impact on the beam is non-linear
- The aperture models derived from this work are currently used in the synchrotron radiation reflections study

Additional material