Overview of Failure Mode Studies for ILC and CLIC

A. Latina (CERN)

Workshop on Machine Protection – 6th - 8th June 2012, CERN

Some publications

- Failure modes in CLIC. D. Schulte, F. Zimmermann. PAC 2001
- A study of failure modes in the CLIC decelerator. E. Adli, D. Schulte, I. Syratchev. EPAC08
- Performance evaluation of the CLIC baseline collimation system. J. Resta Lopez. PAC09
- Design of momentum spoilers for the compact linear collider. J. L. Fernadez-Hernando, J. Resta Lopez. PAC09
- Study of selected failure modes in the ILC and CLIC linear colliders. EUROTeV-2008-075
- Implications of a curved tunnel for the main linac of CLIC. A. Latina, P. Eliasson, D. Schulte.
- A study of failure modes in the ILC main linac. P. Eliasson, E. Elsen, K. Kruecker, A. Latina, F. Poirier, D. Schulte, N. Walker, G. Xia. EUROTeV 2006-040
- Halo estimates and simulations for linear colliders. H. Burkhardt et al.

Some more publications

- Tracking studies of the Compact Linear collimation system, I. Agapov, H. Burkhardt, D. Schulte, A. Latina, G.A. Blair, S. Malton, J.Resta-Lopez, PRST-AB 12 (2009)
- Thermal and Mechanical Effects of a CLIC Bunch Train Hitting a Beryllium Collimator, J. L. Fernandez-Hernando, J. Resta-Lopez, IPAC10
- THERMO-MECHANICAL ANALYSIS OF THE CLIC POST-LINAC ENERGY COLLIMATORS, IPAC12: J. Resta-Lopez, J. L. Fernandez-Hernando, A. Latina
- Failure Studies at the Compact Linear Collider: Main Linac and Beam Delivery System, IPAC12: C.O. Maidana, M. Jonker, A. Latina

Collimation System Design

- Collimation system removes halo
  - Low background in the detector
- It also protects the detector from errant beam
  - Important additional function
- Energy errors happen frequently
  - Energy collimation needs to survive impact of beam
- Betatron errors can hopefully be detected between pulses
  - Betatron collimation system can be sacrificial
- Place betatron collimation system after energy collimation
- Energy collimators are close to survival limit
  - J. Resta Lopez

Main Linac Failure Mode Study

Studied different mechanisms to induce losses

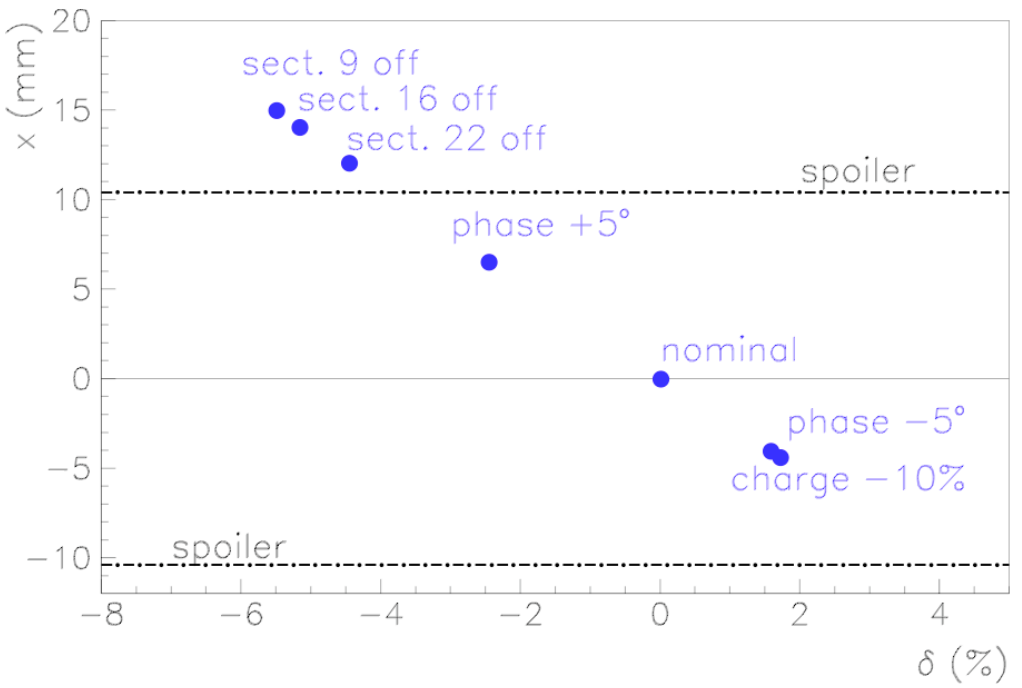
- decelerator failure (no losses in ML except for failure of sector 1 or 2)

- RF to beam phase error
(no losses in ML for error of less than 36°)

- current error

Energy collimators are only hit for sector failures

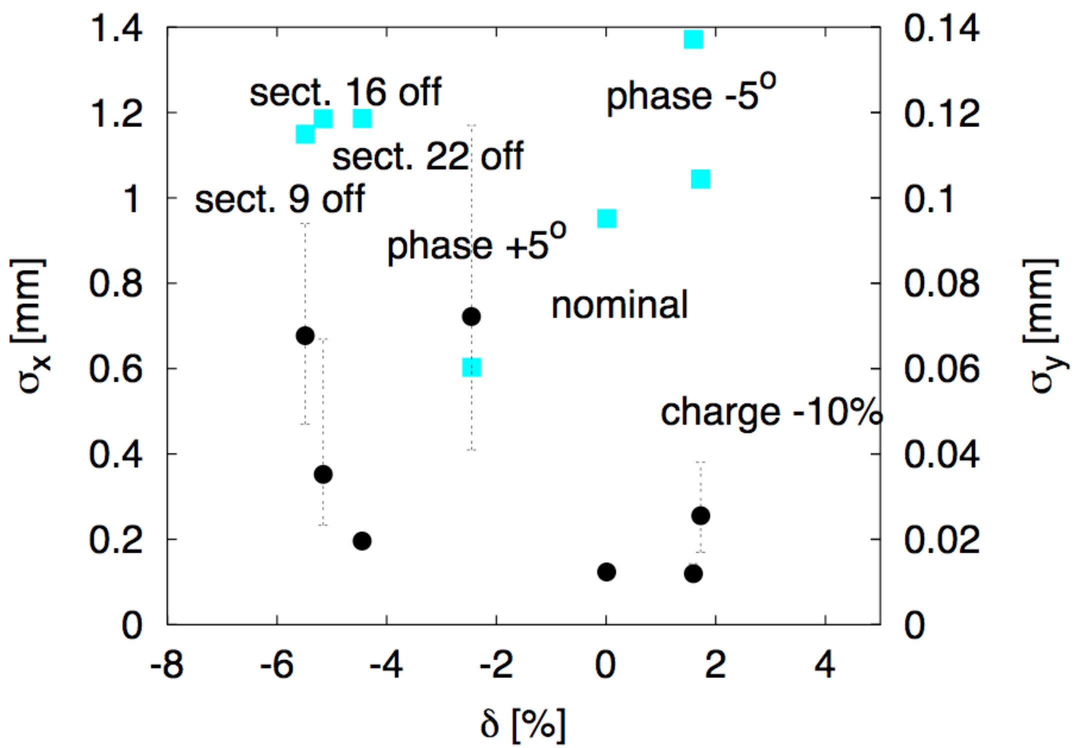
D. Schulte, F. Zimmermann
Old parameters and systems



Main Linac Failure Modes 2

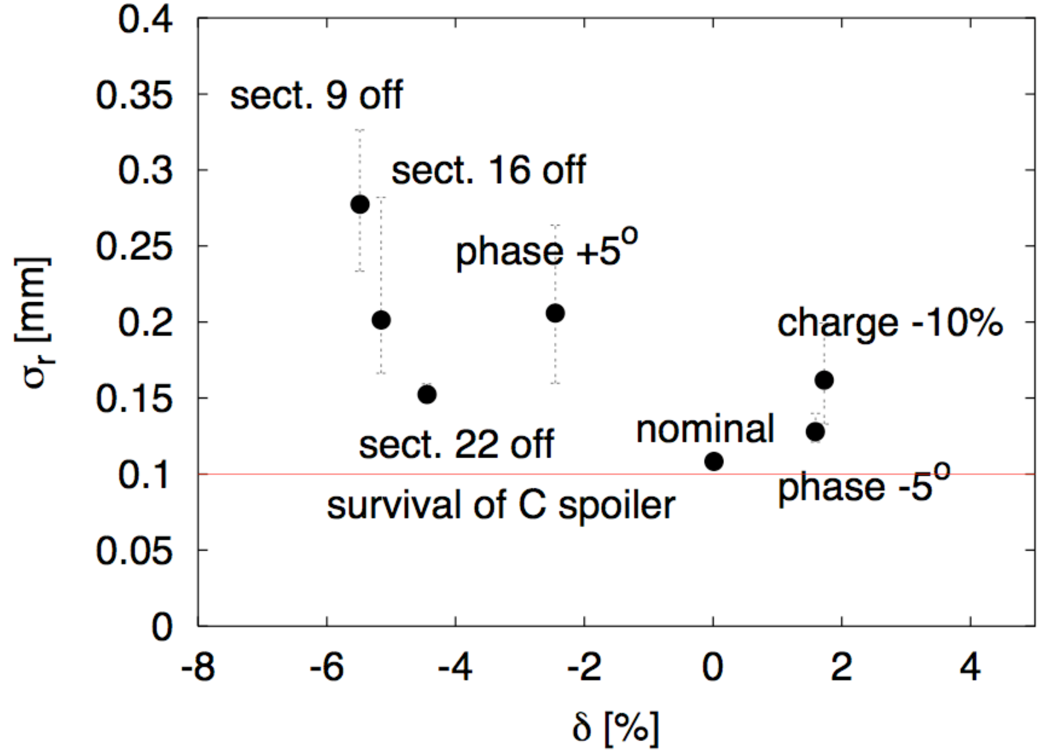
Integrated Study of main linac with realistic imperfections and beam delivery system (PLACET+MAD)

Failure leads to an energy error and a spot size blow-up at collimators



Main Linac Failure Modes 3

Noticeable increase of beam spot size

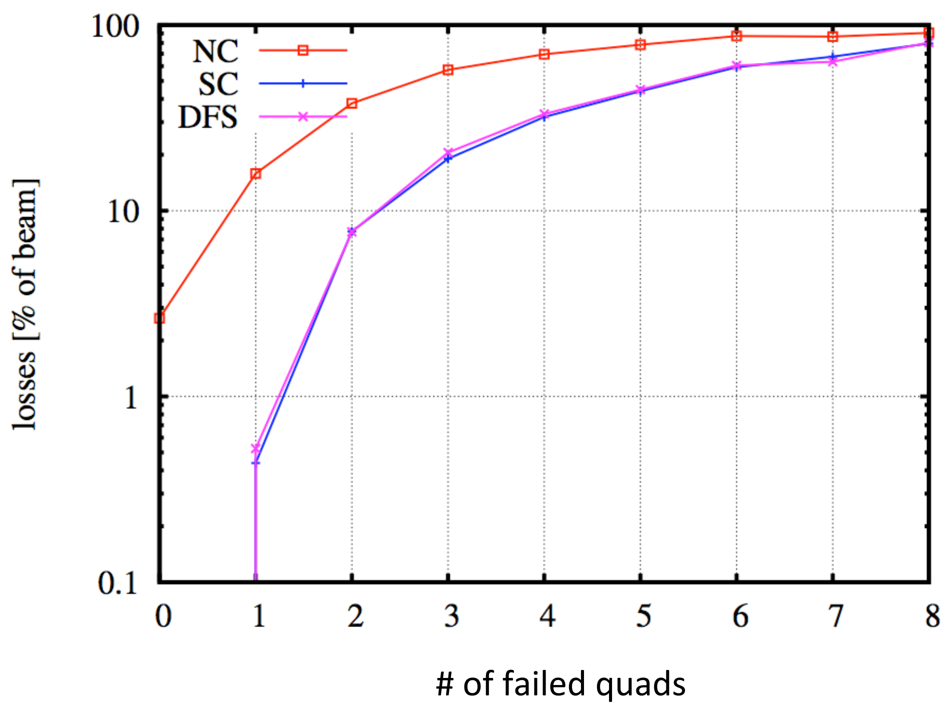


Failure Modes in the CLIC Decelerator

E. Adli, D. Schulte

Decelerator simulated with realistic imperfections and beam-based correction (PLACET)

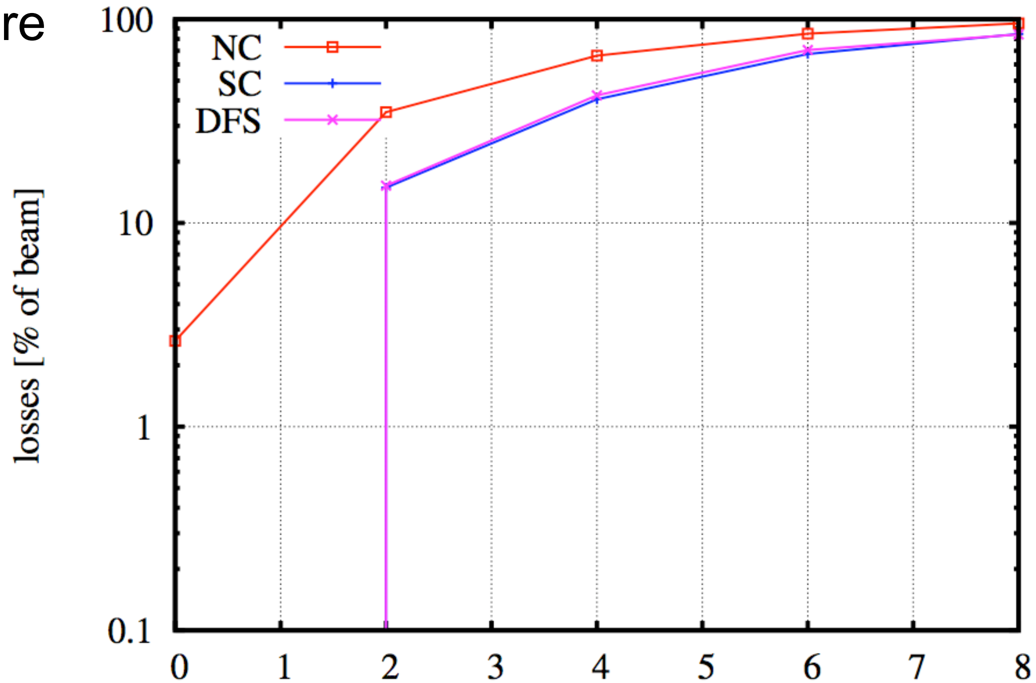
Failure of individual quadrupoles studied



Simulation of Failure modes for uncorrected machines (NC), 1:1 steered machines (SC), and DFS steered machines (DFS)

Decelerator Failure Modes 2

If a consecutive pair of quadrupoles fails, the losses are significantly more severe



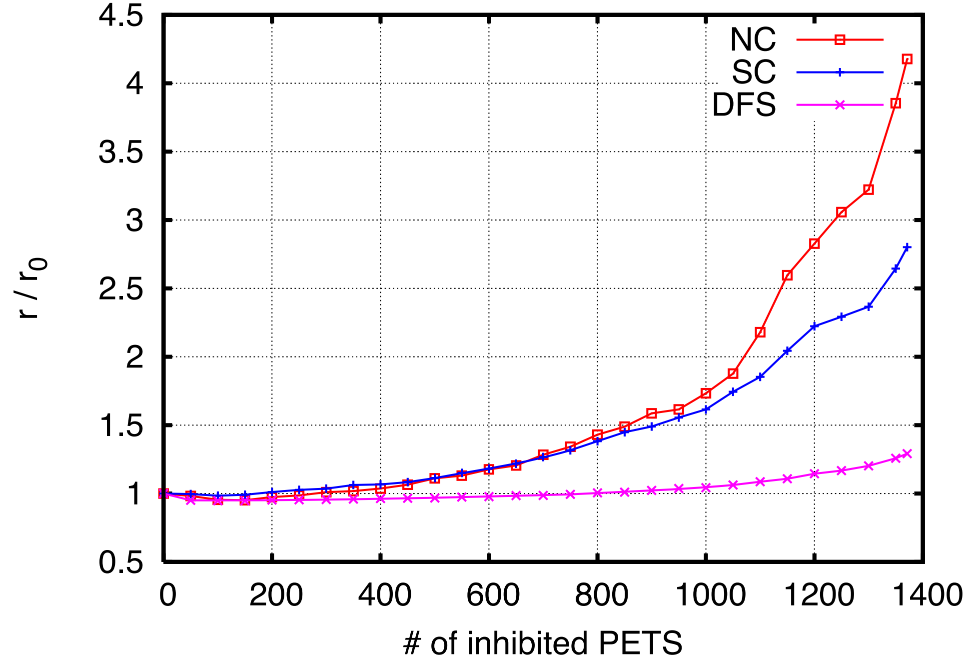
Decelerator Failure Modes 3

- The decelerator lattice contains up to two PETS between each quadrupole, where each PETS extracts ~ 0.1% of the beam energy.

- During machine operation it will be necessary to inhibit PETS power production in case of structure breakdown

- To avoid breakdowns in the main linac PETS will have to be switched off

- The relative change of the beam envelope is shown for randomly chosen PETS

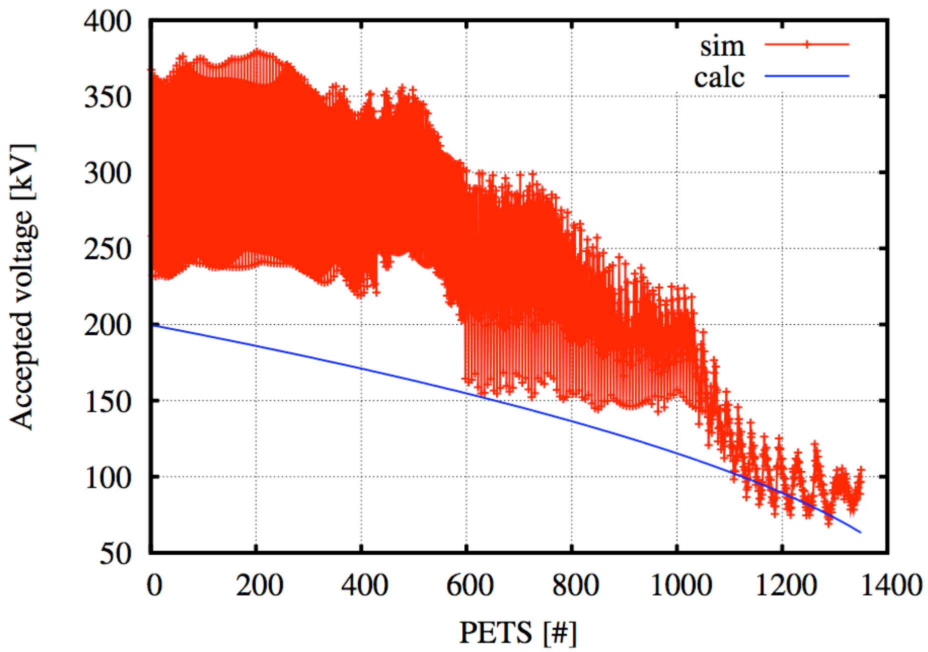


Decelerator Failure Modes 4

RF breakdown in the PETS can result in transverse kicks
The maximum voltage leading to a maximum centroid motion of 1mm is shown

A properly steered machine behaves better than an uncorrected one also wrt. failure modes. For a steered machine we conclude: more than two simultaneous quadrupole failures leads to unacceptable loss levels.

Quadrupole power supply jitter is acceptable up to 10−3. Inhibiting up to 1/3 of the PETS is not severe for beam stability (up to 2/3 for a dispersion-free steered machine). PETS break down voltage up to 50-200 kV is acceptable for beam stability, depending on PETS position.



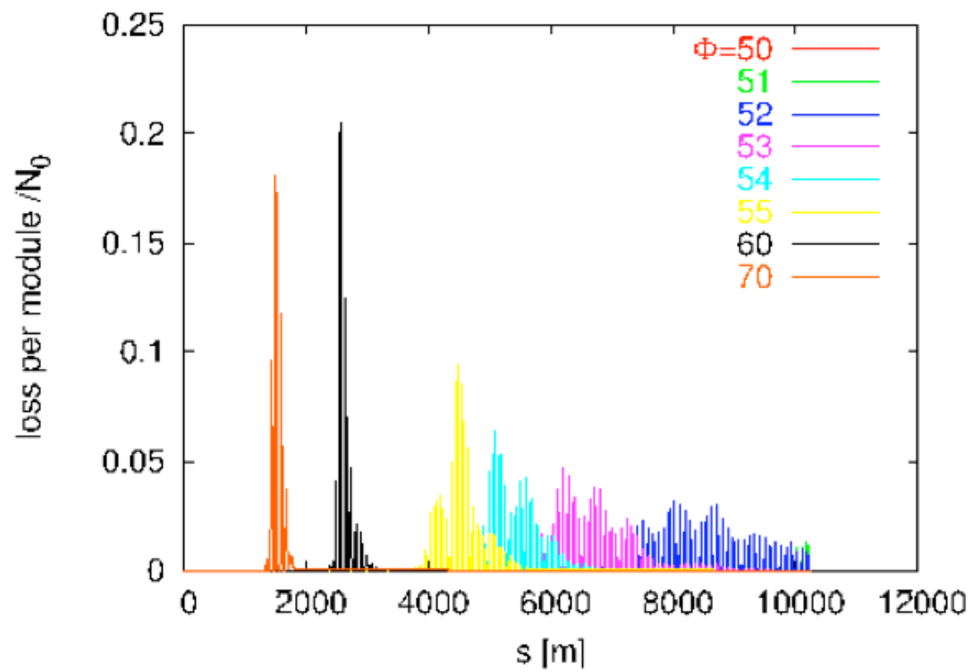
Loss Distribution in the ILC Main Linac

EUROTeV 2006-040

PLACET simulations of losses for different phase errors

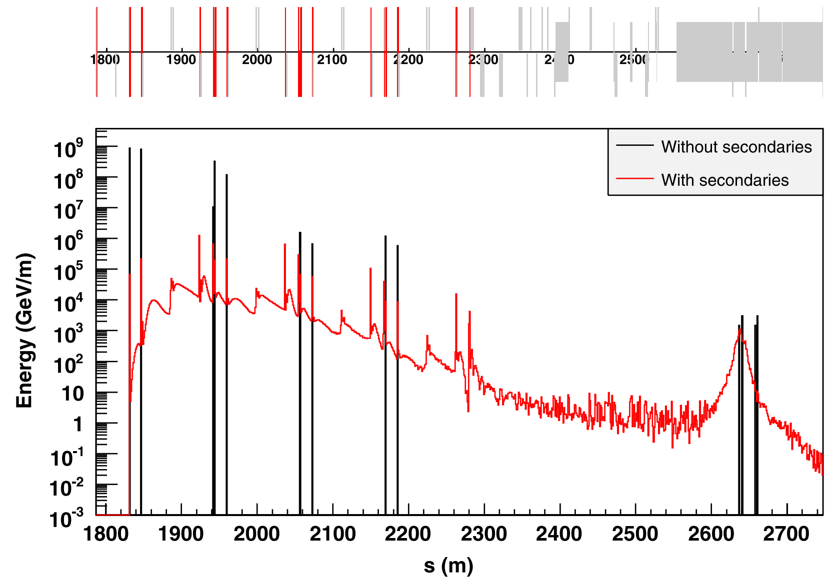
- Collaboration DESY / CERN published at EPAC 2006
- Studies of quadrupole failures and errors
- Studies of klystron phase errors, and their impact on the machine protection

failing quads	% lost particles	failing quads	% lost particles
2	2 %	10	80 %
6	37 %	12	95 %
8	73 %	14	100 %

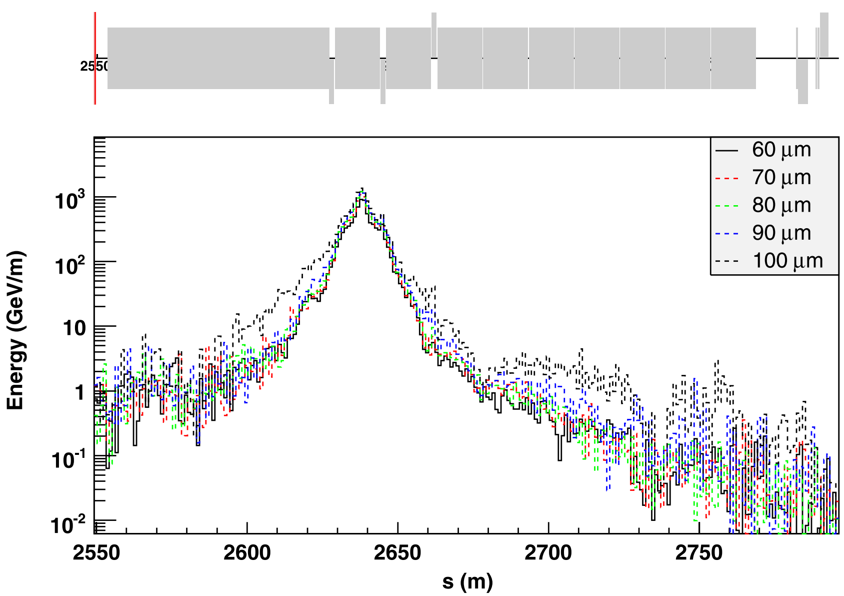


Tracking studies of the Compact Linear collimation system (PRST-AB)

- Review of methods and results of integrated studies with MADX, PLACET, HTGEN, GEANT4 and FLUKA



Energy deposition along the beam line from halo particles, with (red) and without (black) secondary particle production and scattering. Losses from synchrotron radiation have not been included.



Energy deposition along the beam line from halo particles for different collimator gap settings. Both wake- fields and secondary particle production are switched on. A zoomed view of the interaction region. The IP is located at 2796 m.

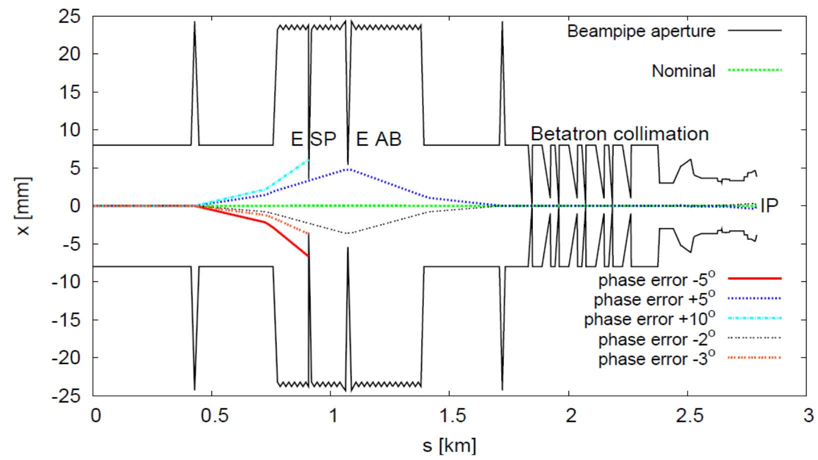
Losses in the CLIC Beam Delivery System

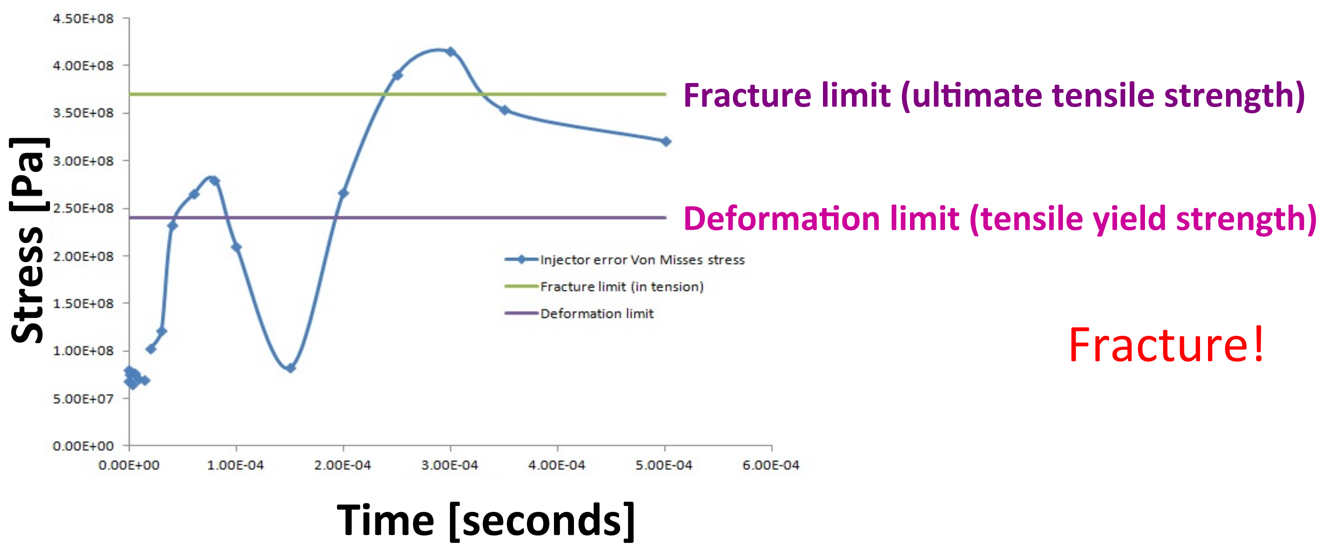
J. Resta-Lopez, J. L. Fernandez-Hernando, A. Latina

- Investigate possible failure mode scenarios in the main linac that could generate significant energy deviation
- Important to study the degree of damage to the energy spoiler by beam impact

Injection phase error:

- For phase error ~> +5º and <~ -3º the beam hits the energy spoiler (ESP)



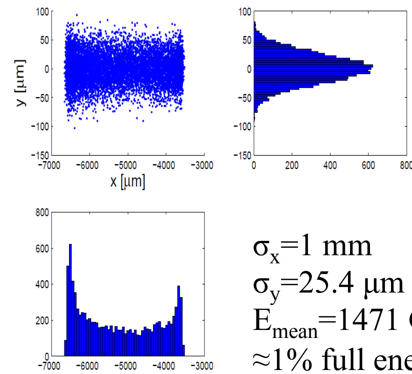


Losses in the CLIC Beam Delivery System

RF cavity fail

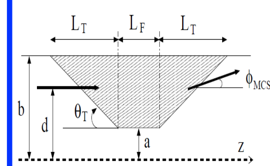
- 1500 cavities switched off in the
- last section of the main linac

Result from FLUKA-ANSYS:



σ_x=1 mm
σ_y=25.4 µm
E_{mean}=1471 GeV
≈1% full energy spread

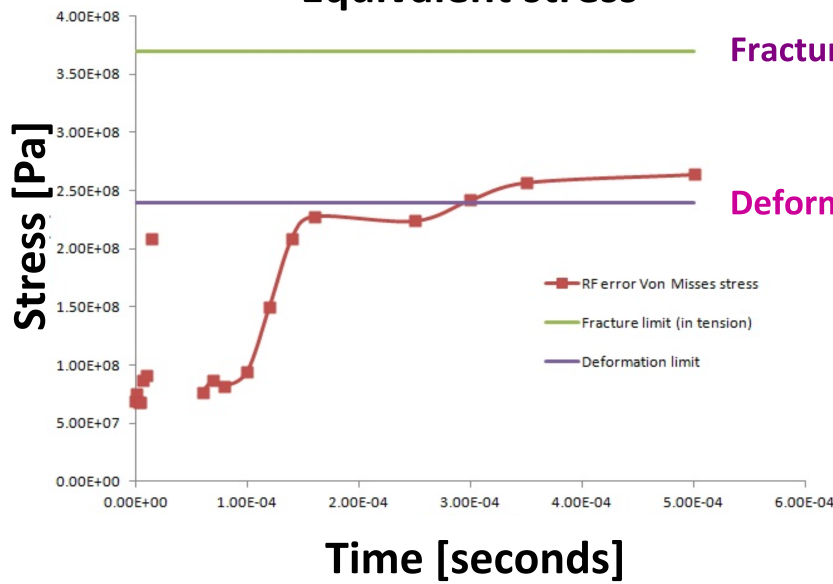
Beryllium spoiler



Run **FLUKA** and **ANSYS**

?

Equivalent stress



Fracture limit (ultimate tensile strength)

Deformation limit (tensile yield strength)

Deformation!

Simulation Tools we developed and use

- PLACET
  - The main tool for our performance studies
  - Has been extensively compared:
    - Single particle:
      - MAD, SAD, Merlin, Lucretia, ELEGANT
    - Single particle with large energy spread:
      - DIMAD, Elegant
    - Wakefield simulation:
      - Merlin, SLEPT, Lucretia, LIAR, ELEGANT
  - Can calculate losses and losses maps
  - HTGEN:
    - Halo and tail generation routines

- BDSIM (RHUL)
  - Extension of Geant-4 for accelerators
  - Interfaced with PLACET for tracking + secondary particle generation and transport studies with misalignment and wakefields

Other Tools used

- FLUKA:
  - energy deposition and temperature rise
- ANSYS:
  - mechanical stress

Summary

- Several studies of failure modes have been performed during the last years for the linacs of CLIC and ILC within the framework of EUROTeV; their results should be reviewed and updated to the latest parameter sets and lattices
- Studies in the CLIC BDS have been carried out more regularly, seeing the successful integration of multiple numerical tools, to allow the simulations of complex scenarios to investigate material survivability
- The community has shrunk over the years, but significant efforts are still on going from the experts
- Powerful tools have been developed and benchmarked and are available to explore various scenarios of failure modes and recovery schemes
- A big thank to all people whose plots and data have been used for preparing this presentation