Post-Linac Collimation System for the European XFEL

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DESY

The collimation system should simultaneously fulfil several different requirements:

- In first place, during routine operations, it should remove with high efficiency off-momentum and large amplitude halo particles, which could be lost inside undulator modules and become source of radiation-induced demagnetization of the undulator permanent magnets.

- The system also must protect undulator modules and other downstream equipment against mis-steered and off-energy beams in the case of machine failure without being destroyed in the process.

- From beam dynamics point of view, the collimation section should be able to accept bunches with different energies (up to ±1.5% from nominal energy) and transport them without noticeable deterioration of beam parameters.

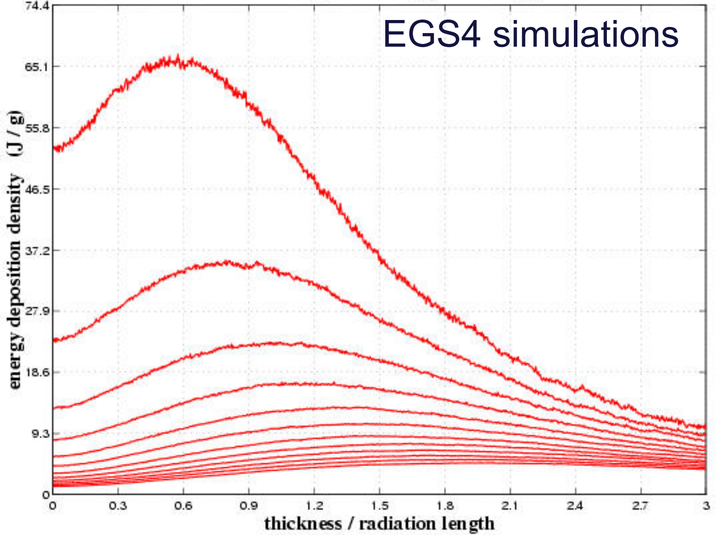
Emergency Scenario:

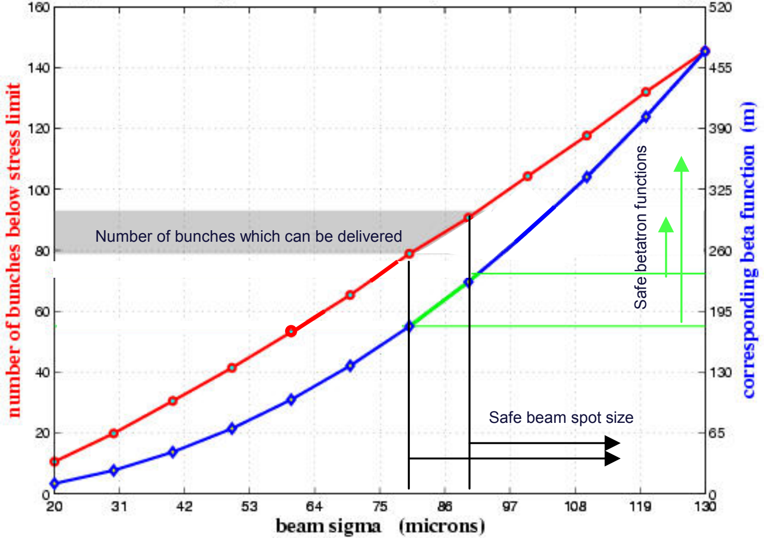
detect a failure and switch the beam production off as quickly as possible

Candidate for Collimator Material: Titanium Alloy

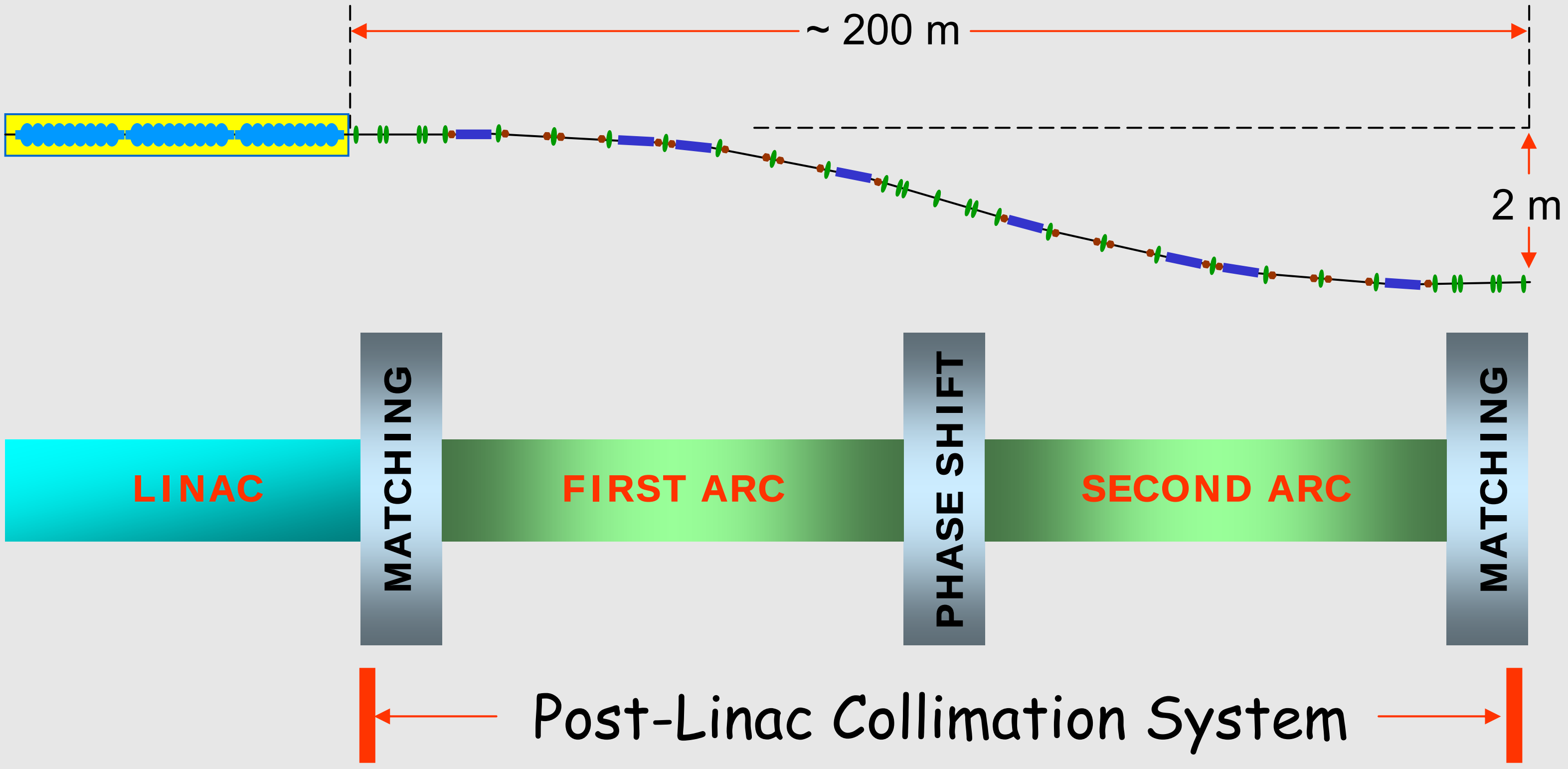
Rough stress analysis shows that to withstand a direct impact of such number of bunches (~100) which can be delivered to collimator location until failure will be detected and the beam production will be switched off, the beam spot size should be not smaller than 80-90 microns

(energy: 20GeV, normalized emittance: 1.4 mm·mrad, bunch charge: 1 nC, bunch spacing: 200 ns).





Layout and Structure



~ 200 m

2 m

LINAC

MATCHING

FIRST ARC

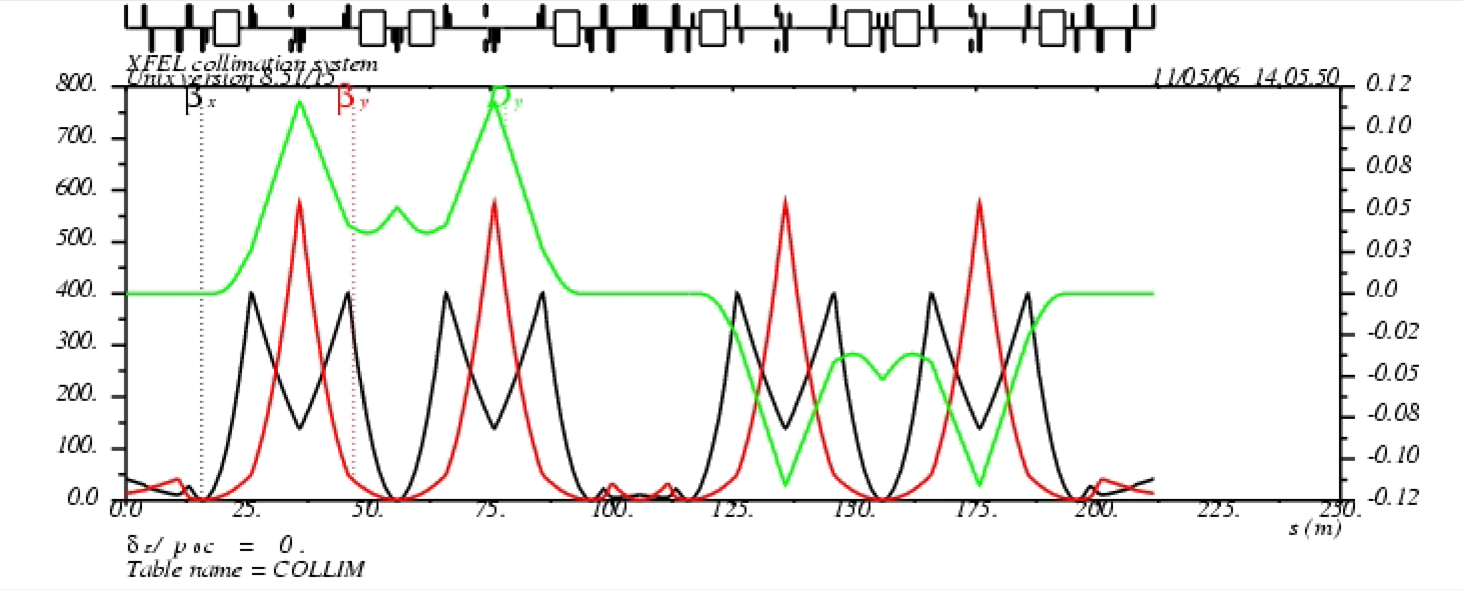
PHASE SHIFT

SECOND ARC

MATCHING

Post-Linac Collimation System

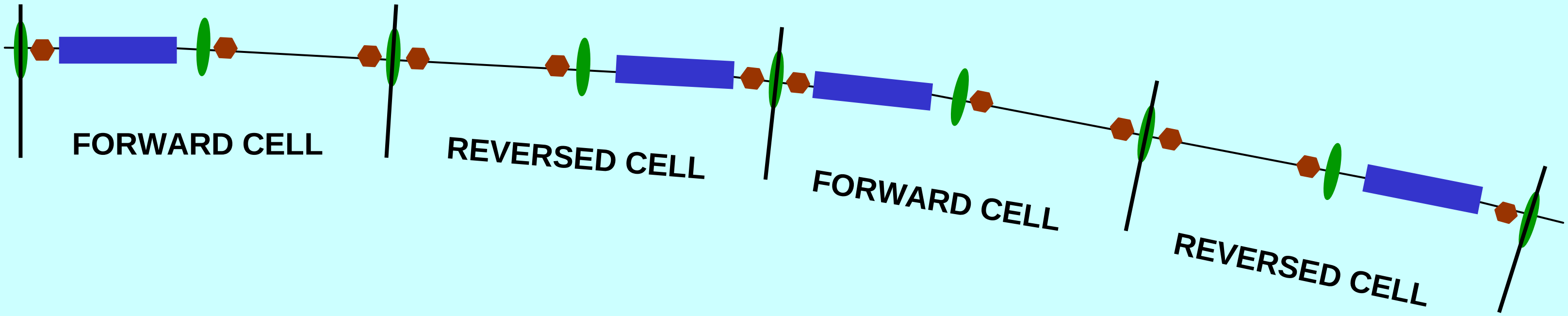
Linear Optics Functions



The energy and the vertical plane collimation will be done simultaneously at the same positions, and therefore the ratio of dispersion to vertical betatron function at spoiler locations is properly adjusted.

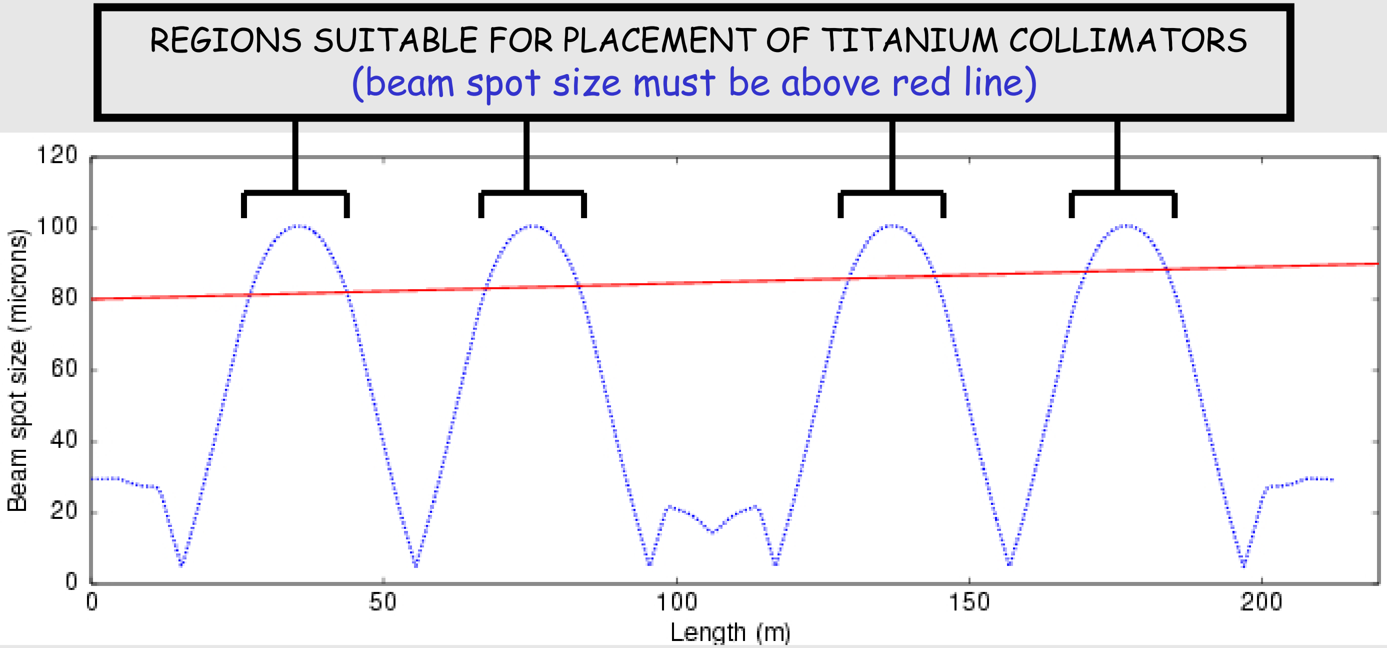
Arc: a Second-Order Achromat

The arc consists of four 90°cells and $M_{arc} = M_f \circ M_r \circ M_f \circ M_r$

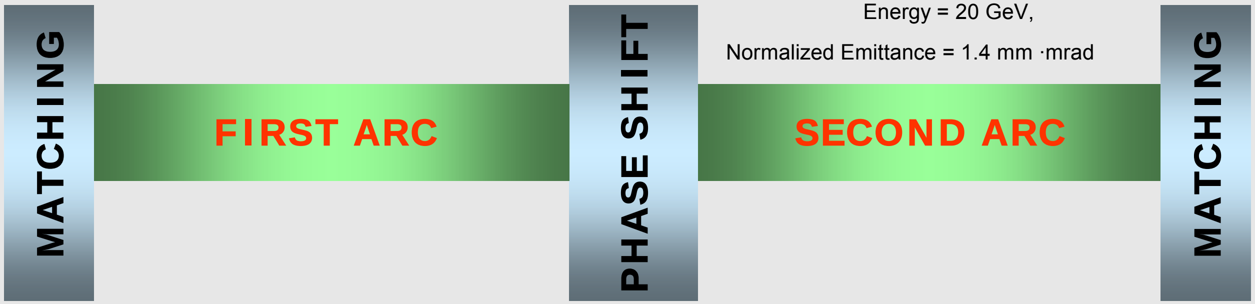


The linear matrix of the forward cell has diagonal elements practically equal to zero. This guarantees that all 2nd order geometric aberrations of the map M_{arc} vanish automatically. According to theory, four independent sextupoles per cell are required to obtain a second-order achromat. However, because of the inner cell symmetries, the number of independent sextupoles can be reduced to three.

Beam Spot Size: $\sqrt{\sigma_x \sigma_y}$



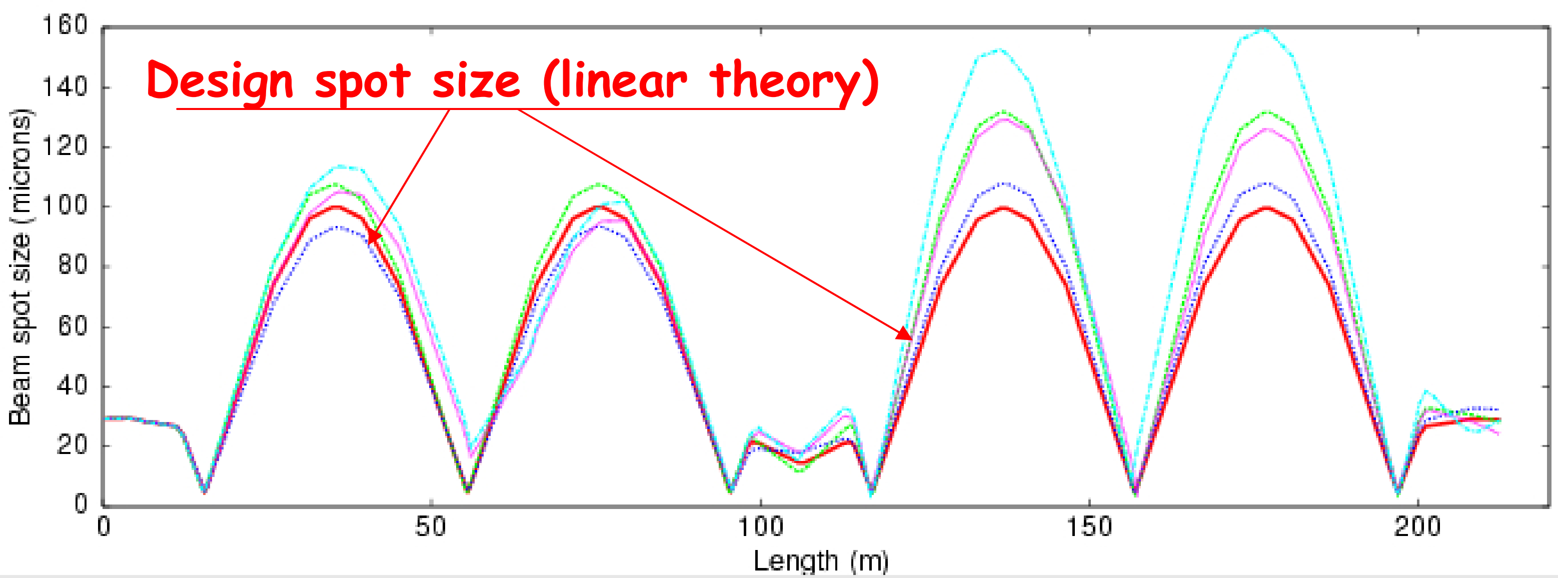
REGIONS SUITABLE FOR PLACEMENT OF TITANIUM COLLIMATORS
(beam spot size must be above red line)



Energy = 20 GeV,

Normalized Emittance = 1.4 mm ·mrad

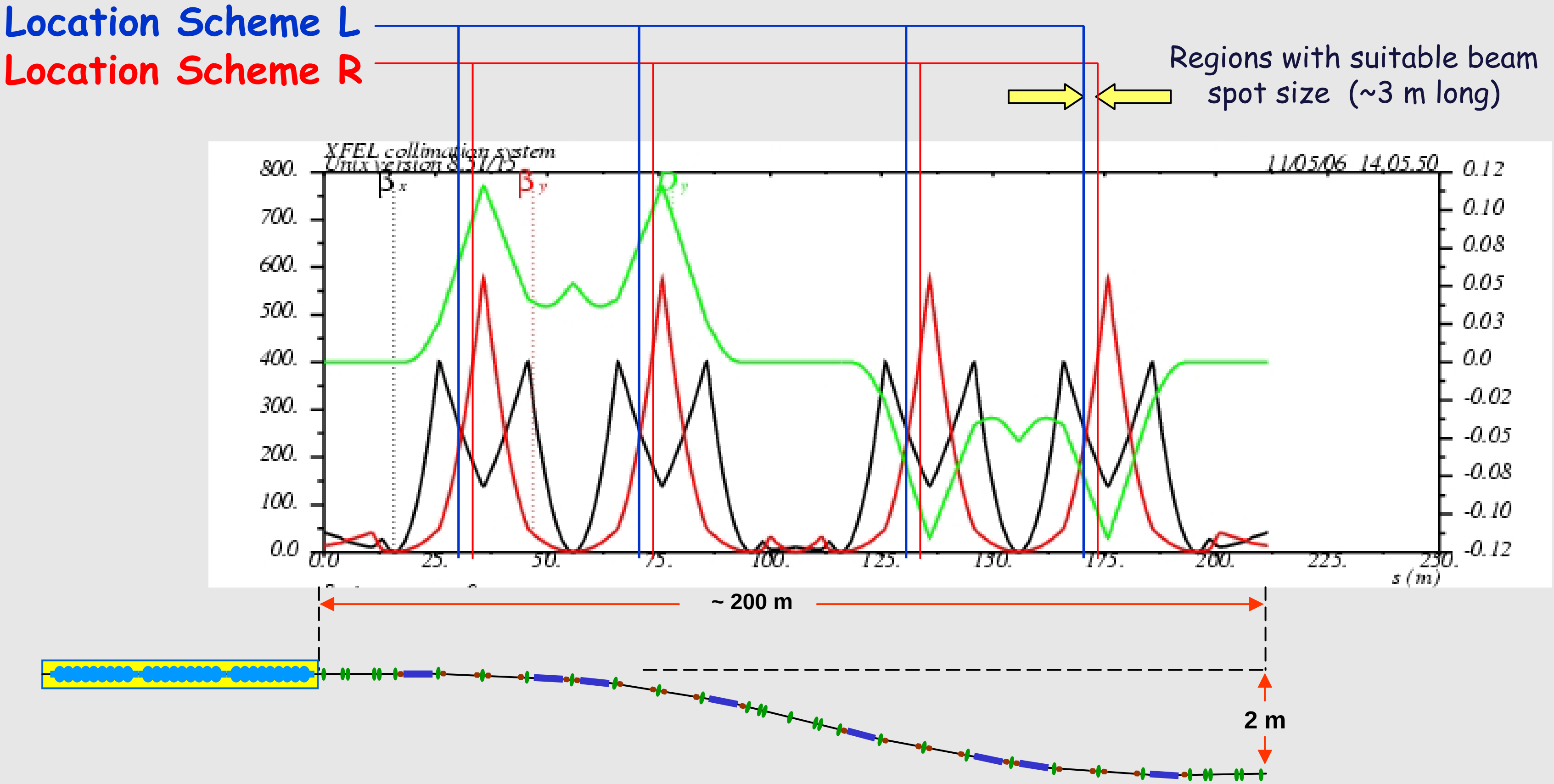
Effect of Energy Offset and Nonlinearities on Evolution of Beam Spot Size Along Collimation Section



Beam spot size (rms) extracted from accurate tracking simulations:

matched Gaussian beam at the entrance with energy offset -3% (green) , with energy offset +3% (blue), with y-offset 40σ (magenta), with both energy offset -3% and y-offset 40σ (sky-blue) .

Collimator Locations



Location Scheme L

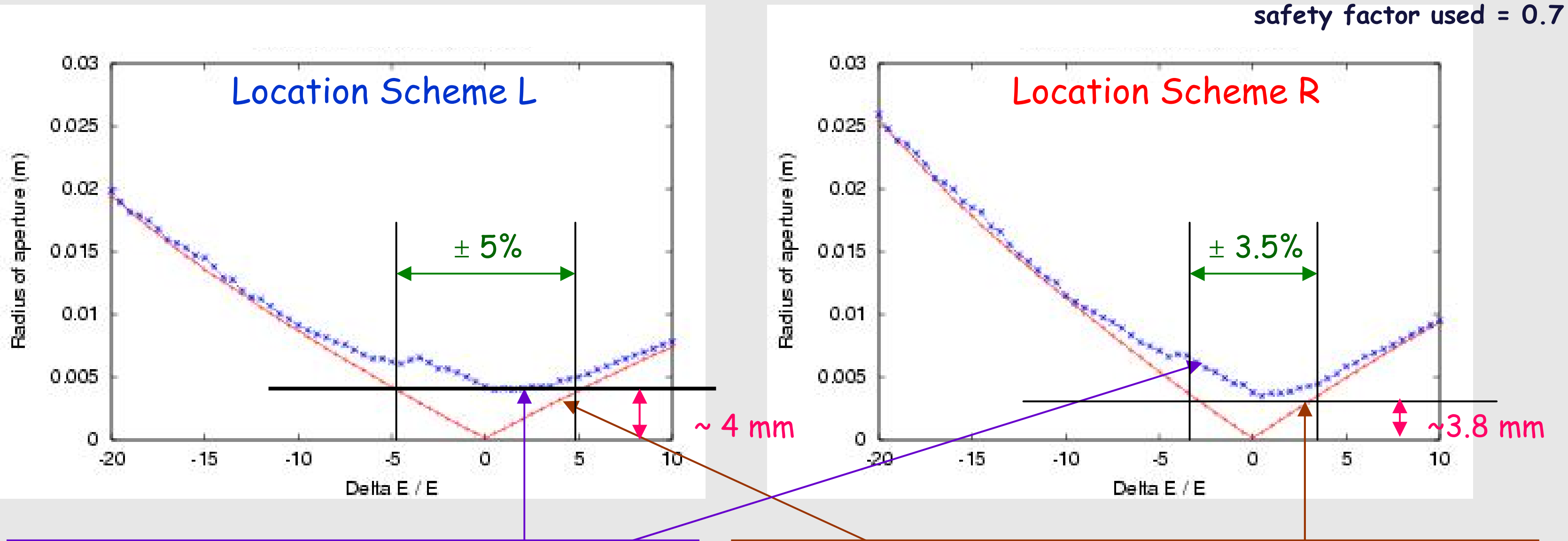
Location Scheme R

Regions with suitable beam spot size (~3 m long)

The main difference between Scheme L and Scheme R is the energy offset which will be collimated

Apertures Required for Cylindrical Spoilers

safety factor used = 0.7



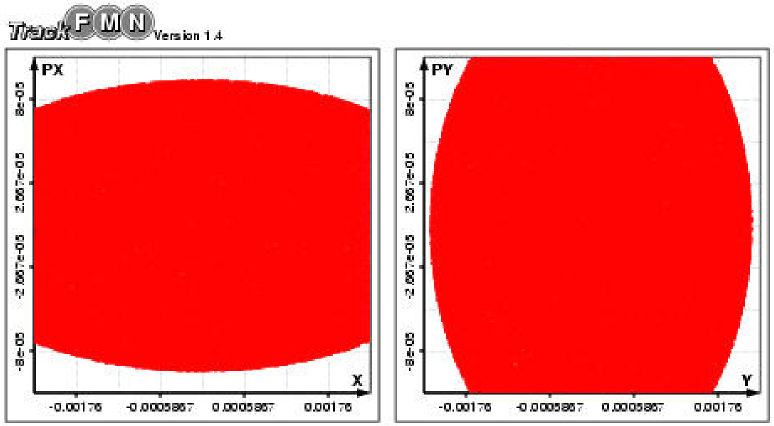
Aperture required for protection of the undulator vacuum chamber

Aperture required to block the corresponding mono-energetic fraction of incoming particles in the collimator section

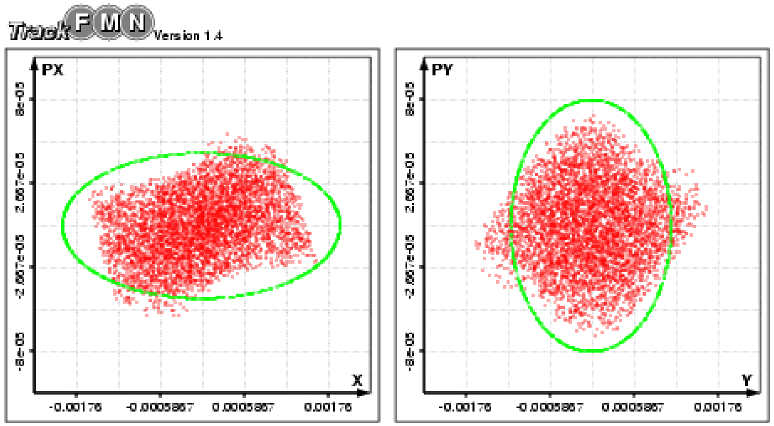
Because the distribution of the incoming particles, which need to be collimated, is difficult to predict the initial distribution was modeled by mono-energetic 4-dimensional slices, with a transverse extend over the radius of the vacuum chamber at the collimator section entrance (the maximum values for transverse momentums were chosen so as fully populate the acceptance of the transport line), and the results are presented as a function of the energy deviation.

Example of Collimation Simulations

Four round collimators (“black absorbers”) with radii equal to 4mm. Location scheme R.



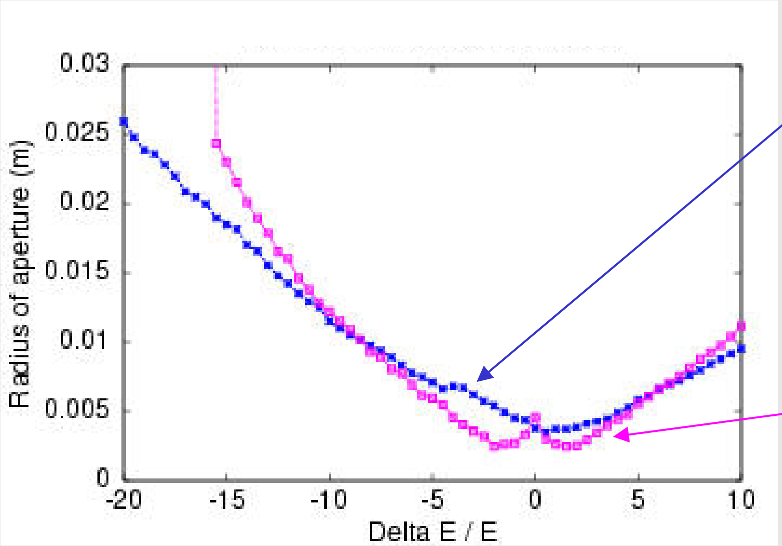
Initial phase space. 100σ ellipses uniformly populated by particles with nominal energy.



Final phase space. Green: target ellipses. Collimator apertures 4mm are still too large and need further reduction (answer: ~3.8mm).

Spoiler Location: Scheme R

Sextupole magnets in the collimator section not only improve beam dynamics, but also allow to use spoilers with larger radii.



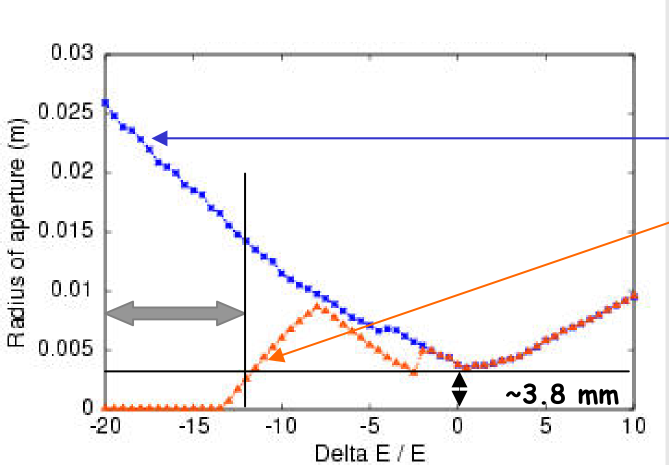
Aperture required for protection of the undulator vacuum chamber. Sextupoles are on.

Aperture required for protection of the undulator vacuum chamber. Sextupoles are off.

Collimation depth obtained by tracking simulations:

Simulations show that all particles with transverse offset larger than ~80 σ (at energy 20 GeV) will be collimated by touching one of the spoilers. All particles with transverse offset smaller than ~23 σ will pass through the collimation section freely. Some particles with offsets in between 23 to 80 σ are absorbed in the vacuum system of the collimation section. Collimators also will stop all particles with an energy offset larger than ±3.5%.

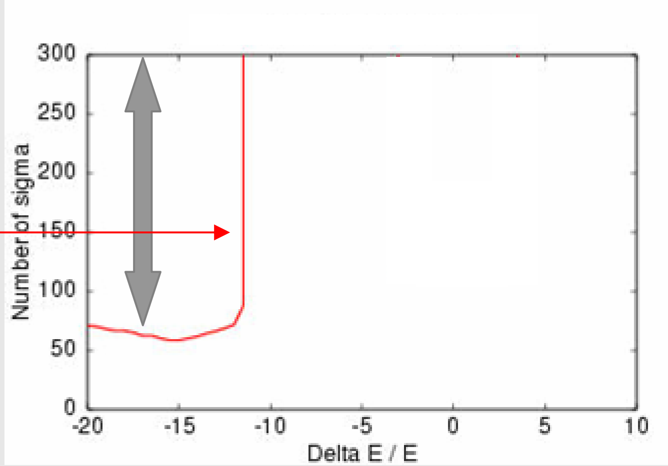
Spoiler Location: Scheme R



Aperture required for protection of the undulator vacuum chamber

With additional requirement to have no uncontrolled losses on the beam pipe downstream of the first collimator

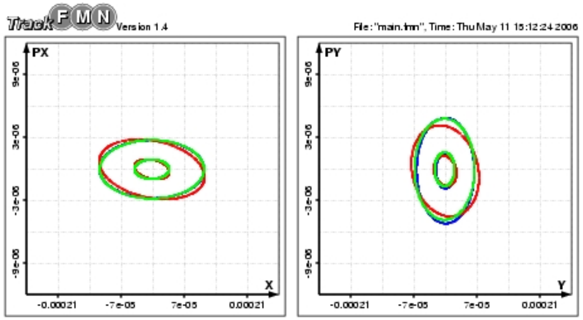
Transverse offset in sigmas (15 GeV) at the collimator section entrance required for particle to be able to hit the vacuum pipe downstream of the first collimator (apertures are fixed and equal to 3.8 mm)



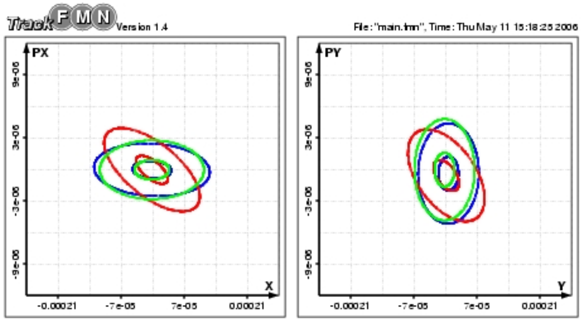
Particles which have simultaneously large negative energy offset (more than 10%) and large transverse offset (more than 50 sigma at the collimator section entrance) could be able to hit the vacuum pipe downstream of the first collimator in uncontrolled way (without touching spoilers). This problem could be relaxed by introducing additional (large aperture) spoilers or by appropriate placement of absorbers (not decided yet).

Beam Dynamics: Energy Offset and Nonlinearities

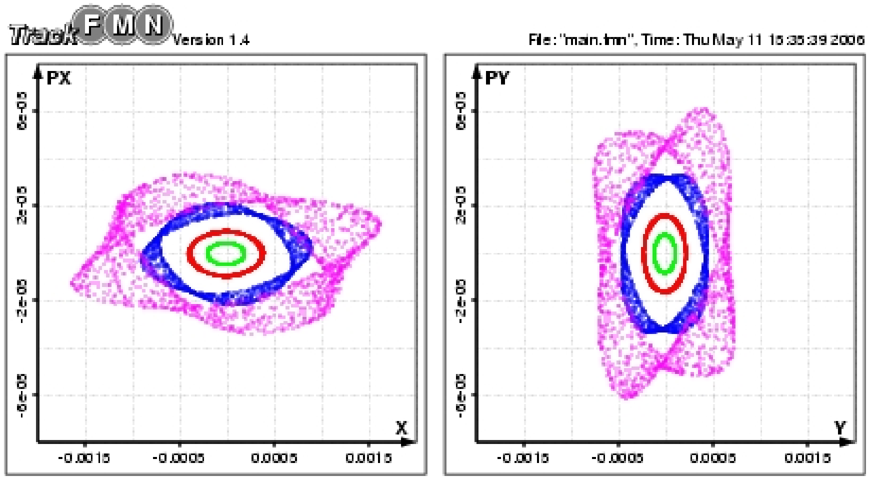
Beam transfer properties of the entire collimation section.



$\Delta E/E_0$ = -1.5%, 0%, +1.5%



$\Delta E/E_0$ = -3.0%, 0%, +3.0%

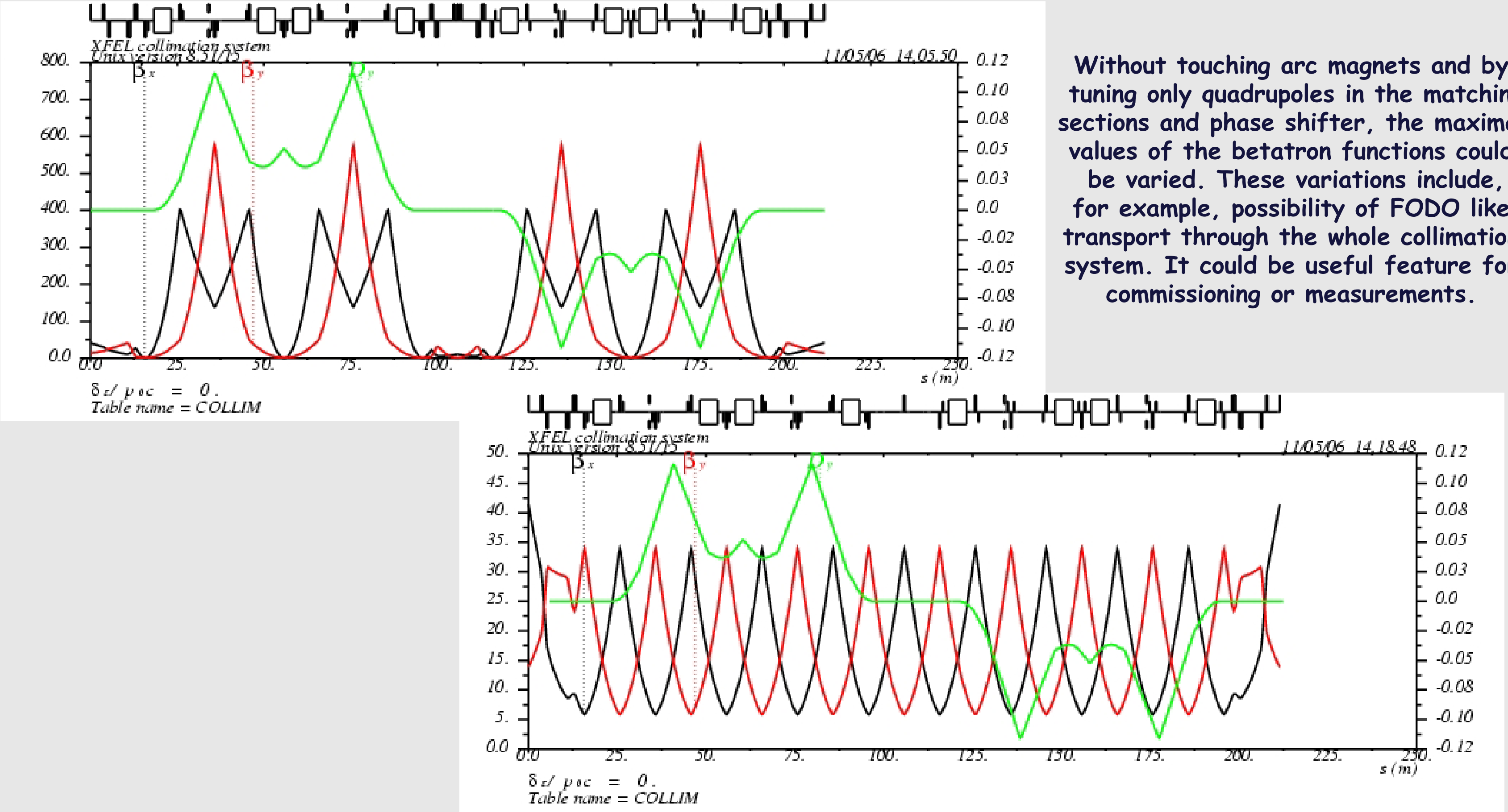


5σ 10σ 20σ 30σ

Longitudinal dynamics with and without sextupoles:

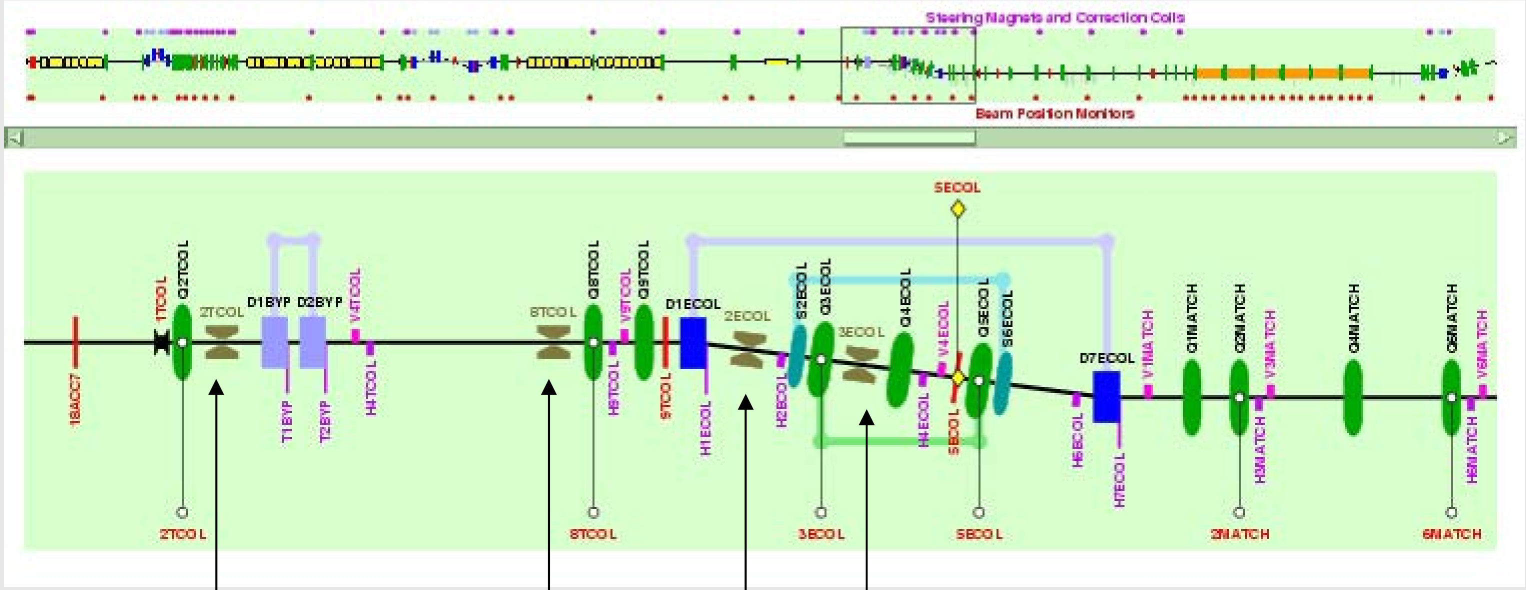
$$Z_f = Z_0 - 0.89 \cdot (\Delta E / E_0) - 5.6 \cdot (\Delta E / E_0)^2 + \dots \quad \text{(mm)}$$
$$Z_f = Z_0 - 0.89 \cdot (\Delta E / E_0) - 9.2 \cdot (\Delta E / E_0)^2 + \dots \quad \text{(mm)}$$
$$Z = \beta_0 C \cdot (t_0 - t)$$

Optics Flexibility



Without touching arc magnets and by tuning only quadrupoles in the matching sections and phase shifter, the maximal values of the betatron functions could be varied. These variations include, for example, possibility of FODO like transport through the whole collimation system. It could be useful feature for commissioning or measurements.

Collimator System of the FLASH Linac

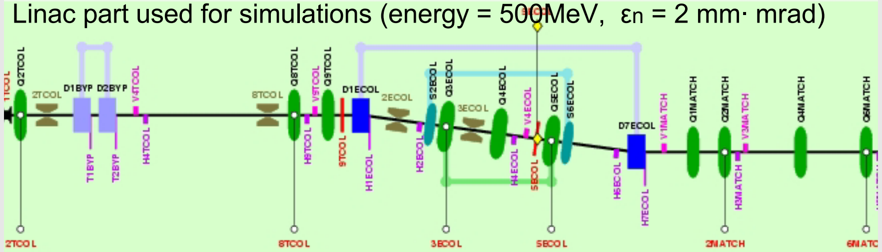


r=2mm **r=2mm** **r=6mm** **r=2mm**

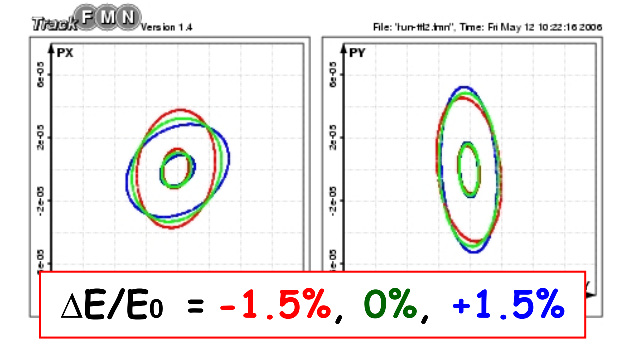
Four conical tapered collimators

Theoretical safety factor used for calculation of collimator apertures: 0.9.
Energy offset collimated is about ±3%.
More details can be found in TESLA report: TESLA 2003-17, May 2003.

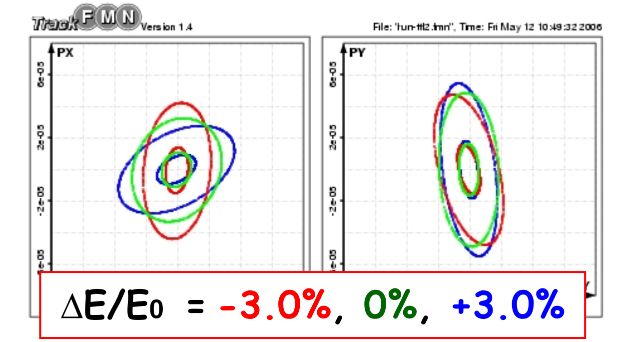
Beam Transfer Properties of the FLASH Collimator Section



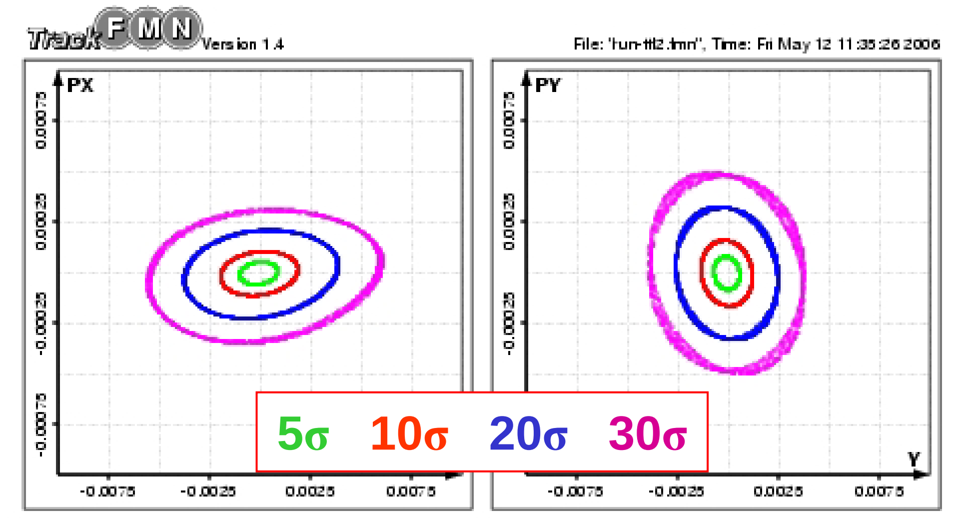
Linac part used for simulations (energy = 500 MeV, εn = 2 mm· mrad)



ΔE/E0 = -1.5%, 0%, +1.5%



ΔE/E0 = -3.0%, 0%, +3.0%



5σ 10σ 20σ 30σ

Longitudinal dynamics with and without sextupoles:

$Z_f = Z_0 - 0.46 \cdot (\Delta E / E_0) - 17.8 \cdot (\Delta E / E_0)^2 + \ldots$ (mm)

$Z_f = Z_0 - 0.46 \cdot (\Delta E / E_0) - 54.8 \cdot (\Delta E / E_0)^2 + \ldots$ (mm)

Theoretical transfer properties of the FLASH collimator section are good, except for the relatively low safety factor (0.9) used for collimator apertures calculations. Current work is to establish better correspondence between the theory and the practice.