Design of the Turnaround Loops for the Drive Beam Decelerators

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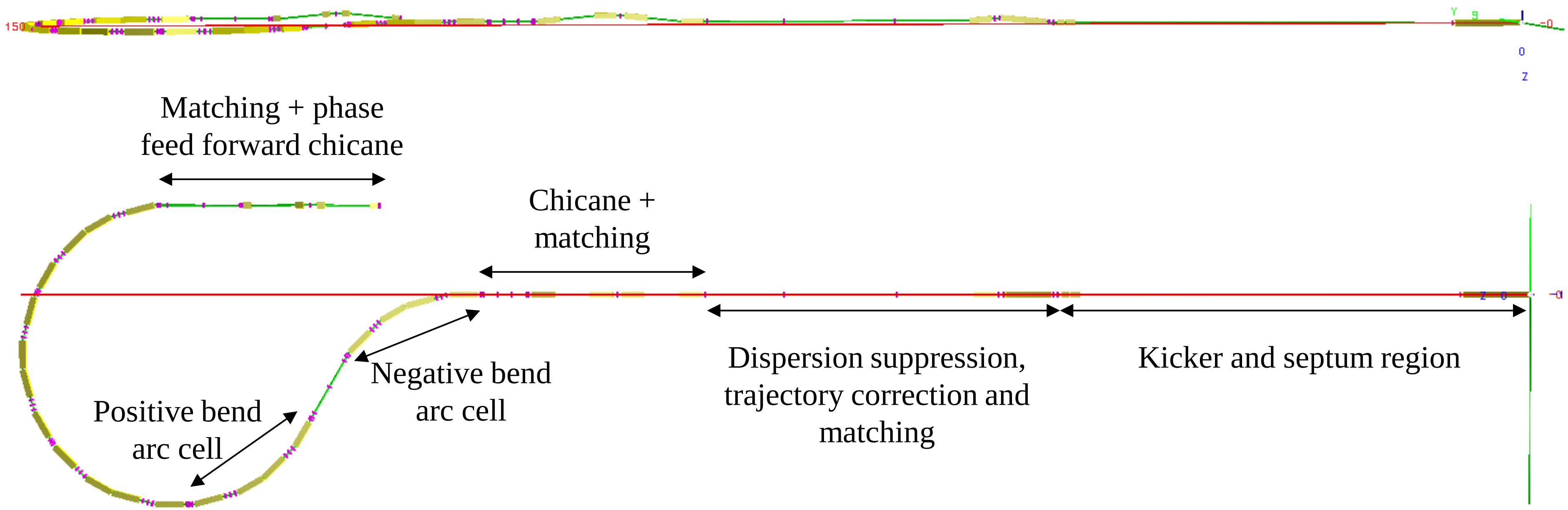
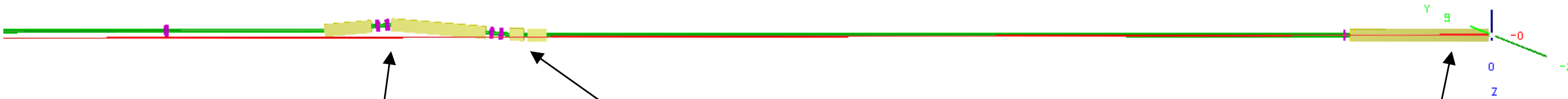
Layout of turnaround loops



Kicker, septa and chicanes all vertical deflections:

- Reduce emittance growth in horizontal plane
- Convenient for spatial constraints in tunnel
- Vertical injection needed to avoid main transfer line colliding with TAL

Zoom in of Injection Region



Dispersion suppressor / trajectory corrector: Ensures beam lines are parallel and dispersion-free beam

Thin and thick septum magnets

Injection kicker: ferrite-loaded or wound-core

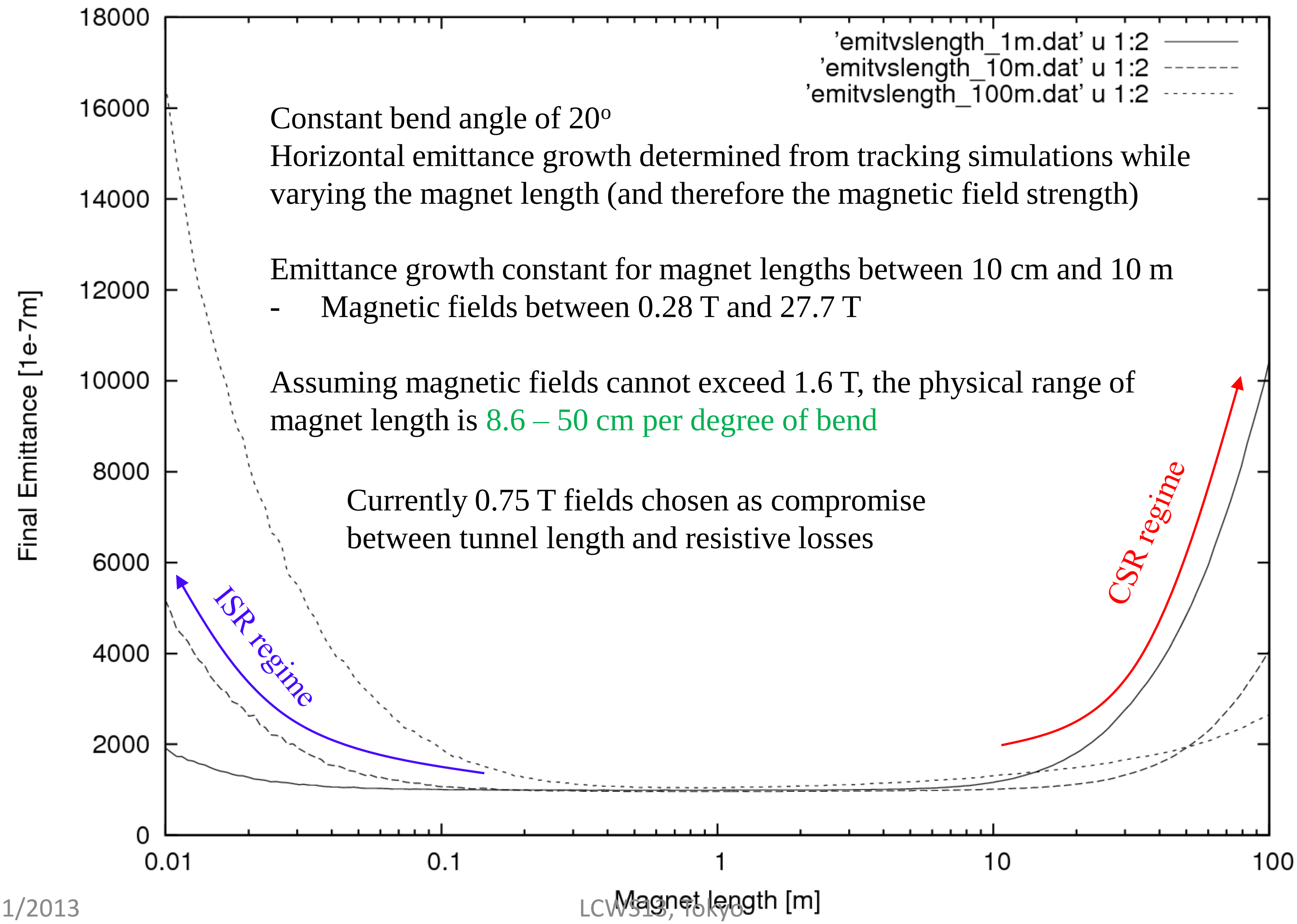
Optimisation constraints

- Optical constraints
  - Transverse and longitudinal emittance growth must be minimised
  - System must be globally isochronous ($R_{56} = 0$)
  - Each subsystem should be modular and dispersion free at each end (except extraction system)

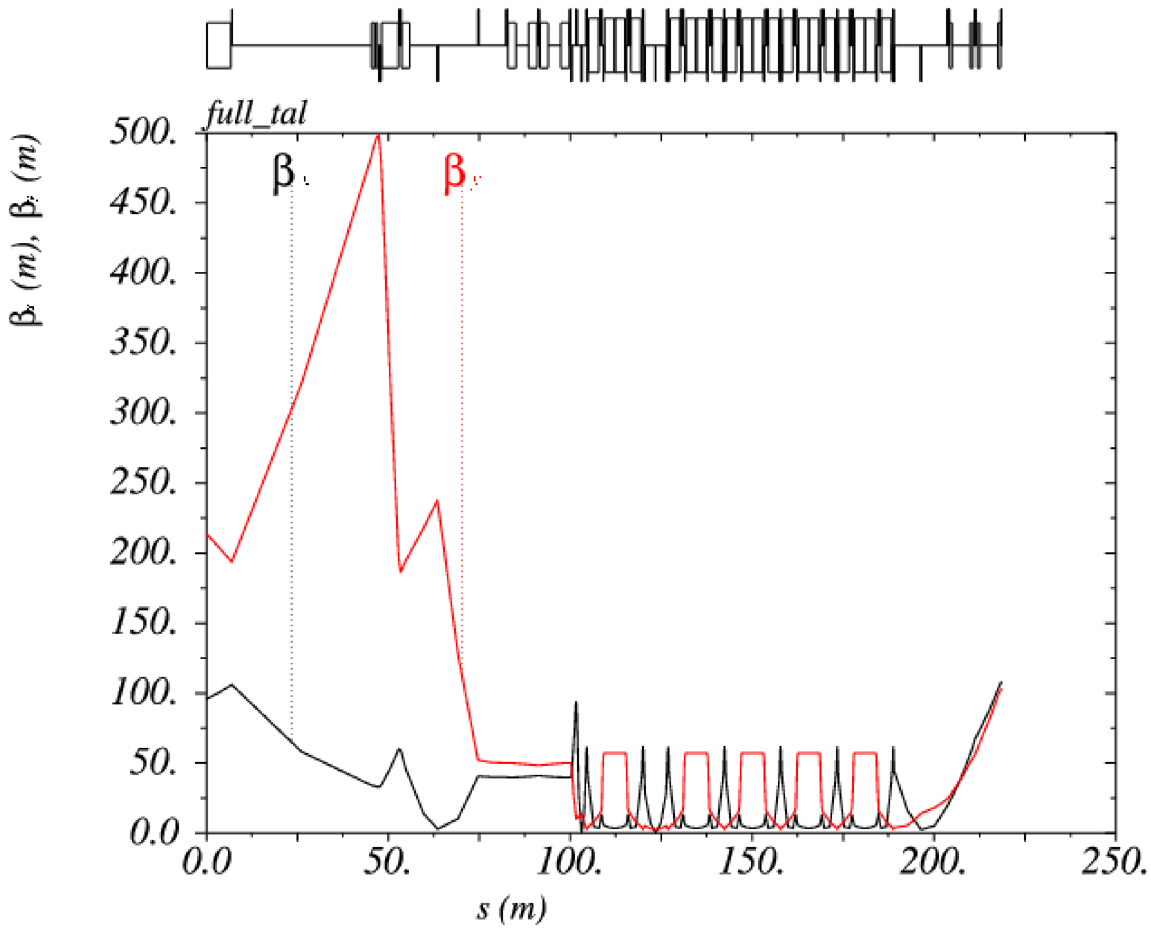
- Geometric constraints
  - Vertical offset needed to avoid beam lines colliding (vertical extraction is easiest solution)
  - Horizontal offset to align beam with decelerator entrance
  - TAL line must be parallel with main transfer line in vertical plane
  - Must provide 180^{o} deflection of beam

- Cost minimisation
  - Minimise total number of magnets and power supplies used (48 TALs in total)
  - Civil engineering costs of tunneling needs to be determined.
    - Currently parameterised in terms of TAL design parameters

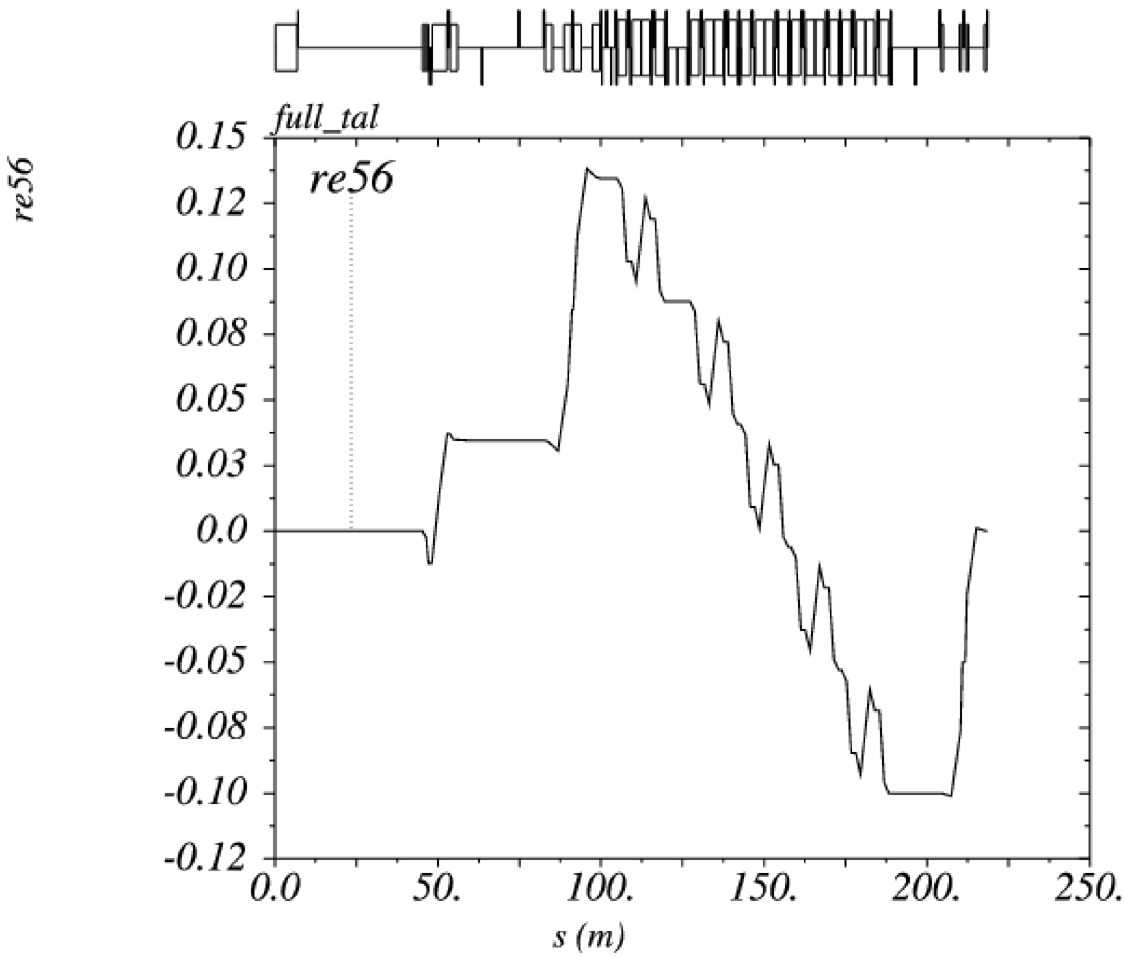
Emittance growth optimisation



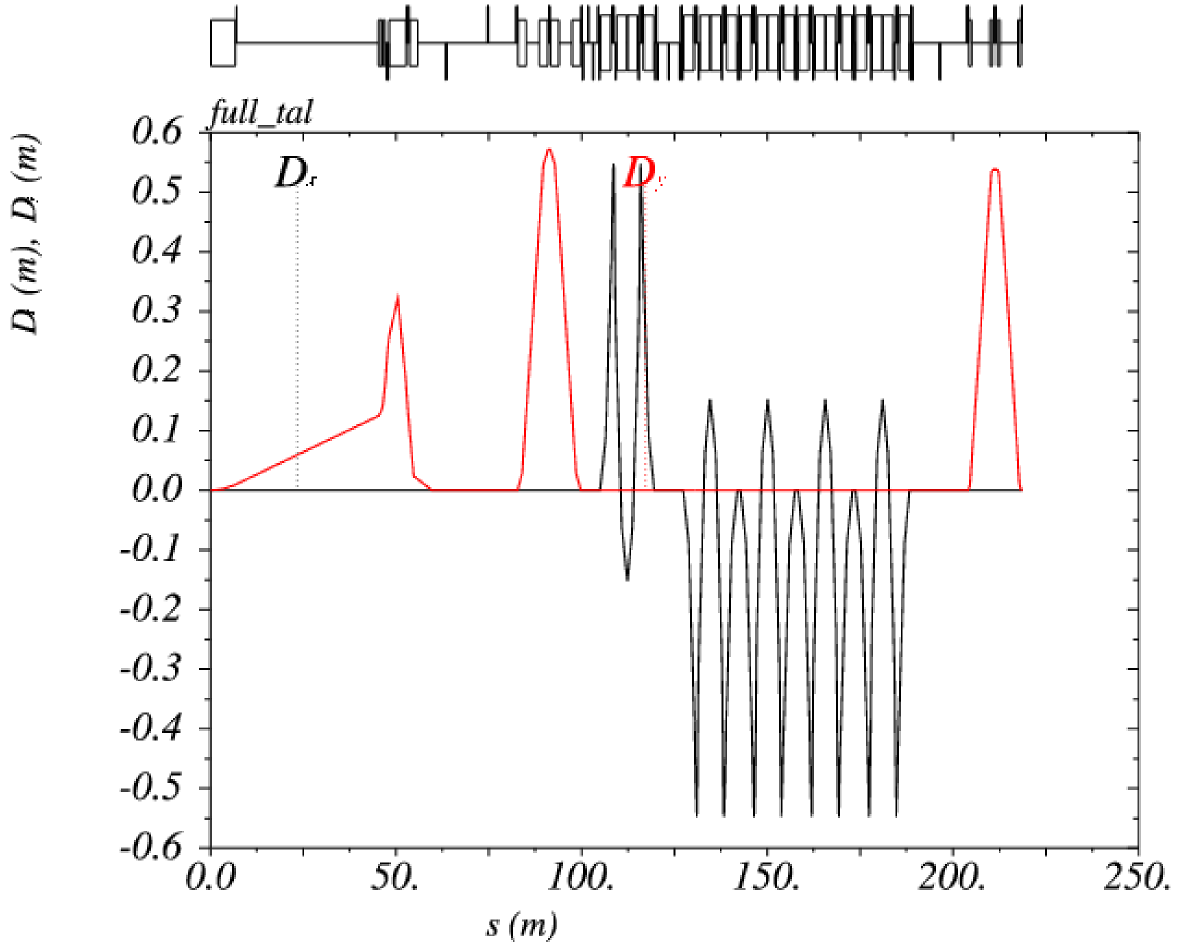
β functions: monochromatic beam



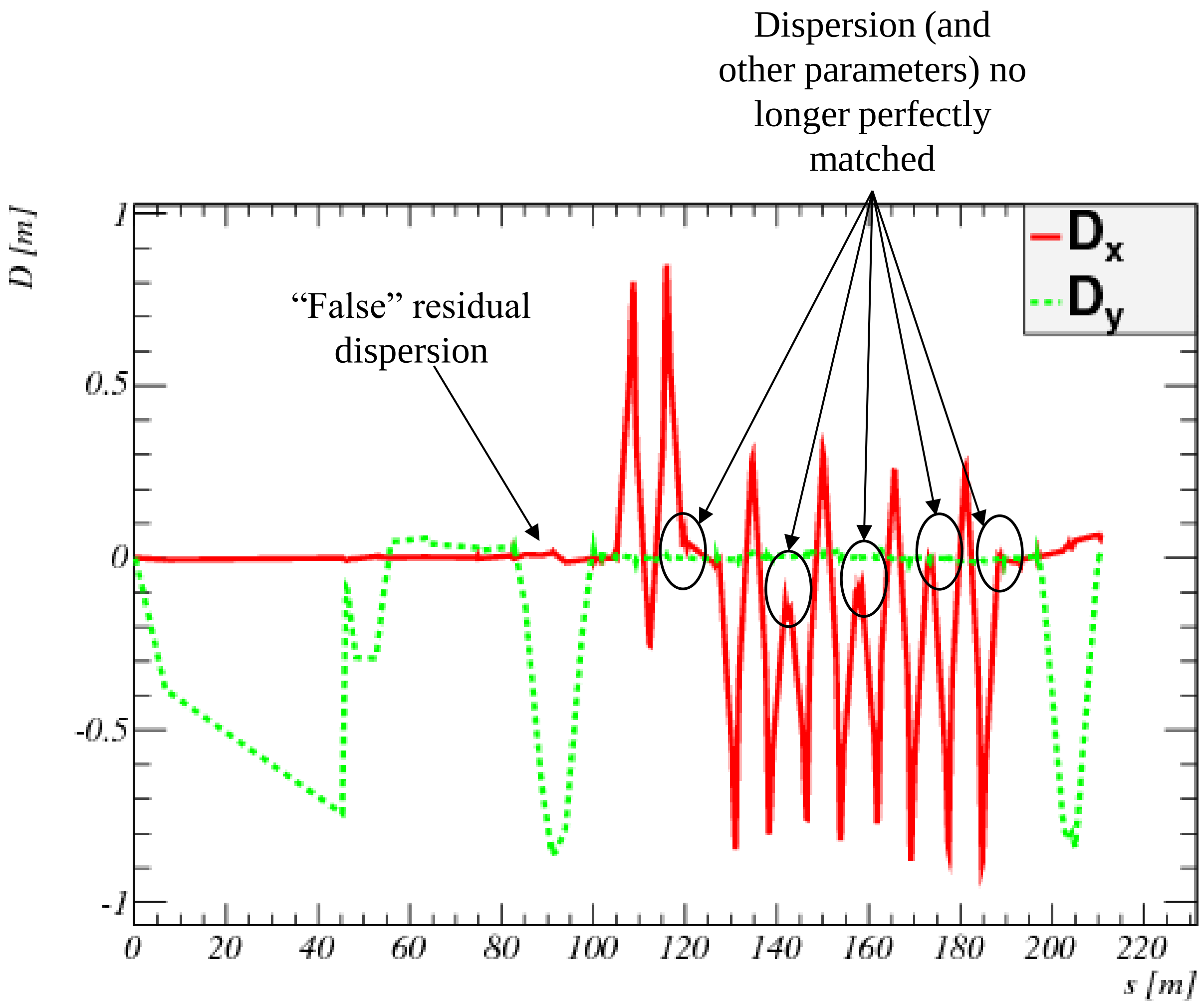
R_{56} element: monochromatic beam



Dispersion: monochromatic beam



Dispersion: simulated 6D phase space



Off-momentum beam dynamics

Off-momentum particles are not matched through the TALs:

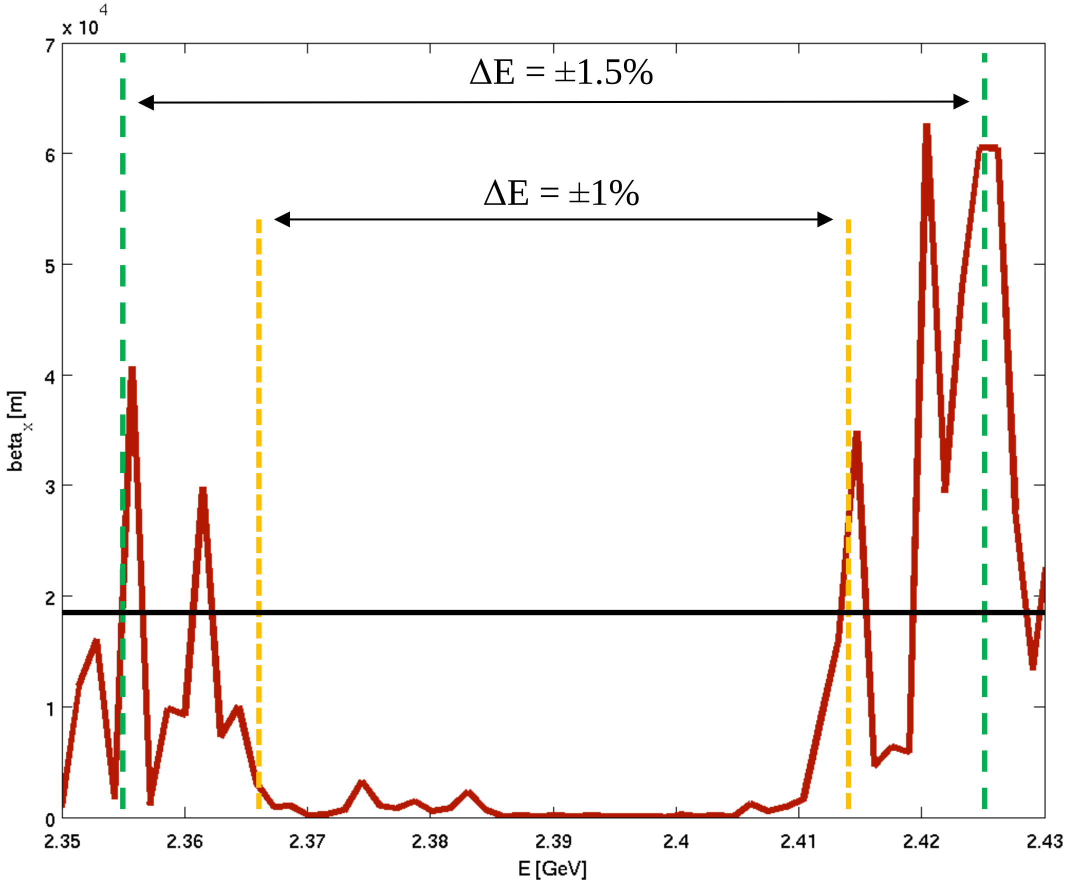
- Optics are well matched in MADX for monochromatic beam (penalty function ~10^{-20})
  - Optics no longer matched for simulated longitudinal phase space

- Current design has large chromaticity due to strong quads needed in arc cells
  - Tried using sextupoles but this leads to other instabilities
    - Significantly reduces energy acceptance

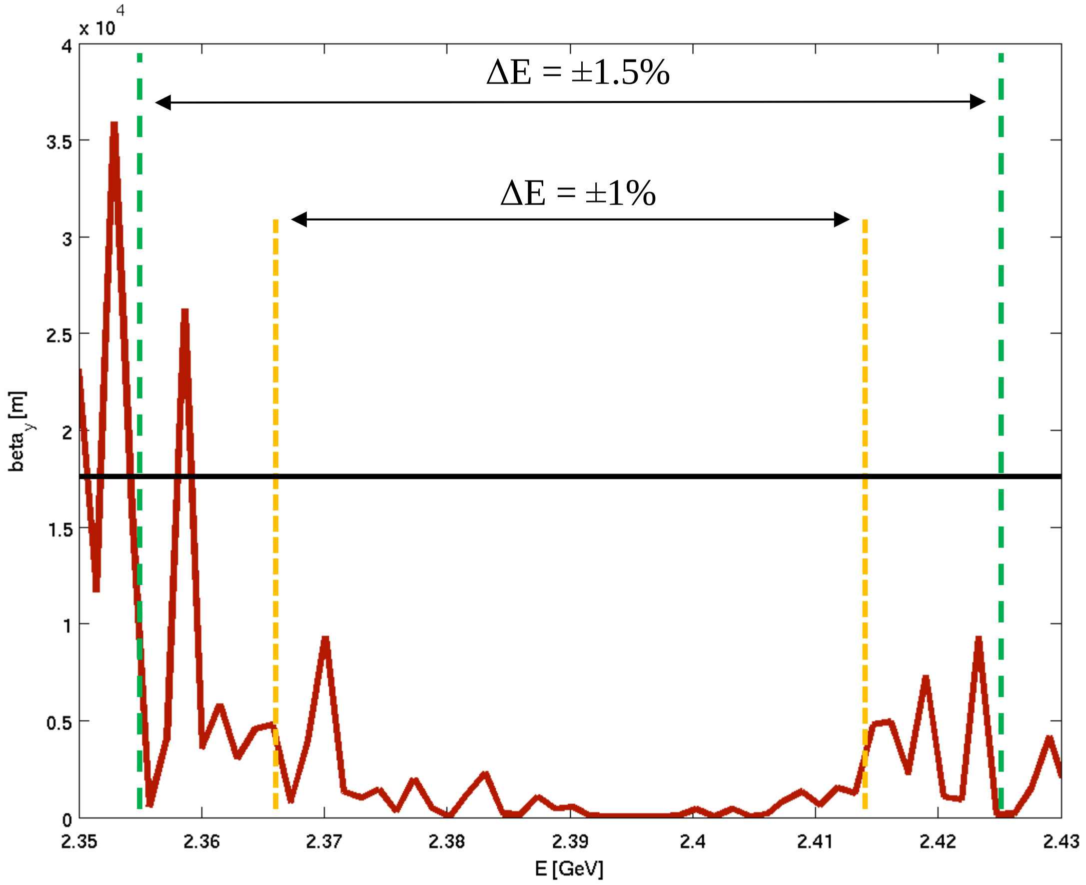
- Ran series of tracking simulations with test bunches of different energy to scan energy dependence

- Currently altering nominal energy of TAL to minimise nominal dispersion; then rematch R56 in 2nd chicane
  - Start re-optimising optics globally to minimise emittance growth and maximise energy acceptance

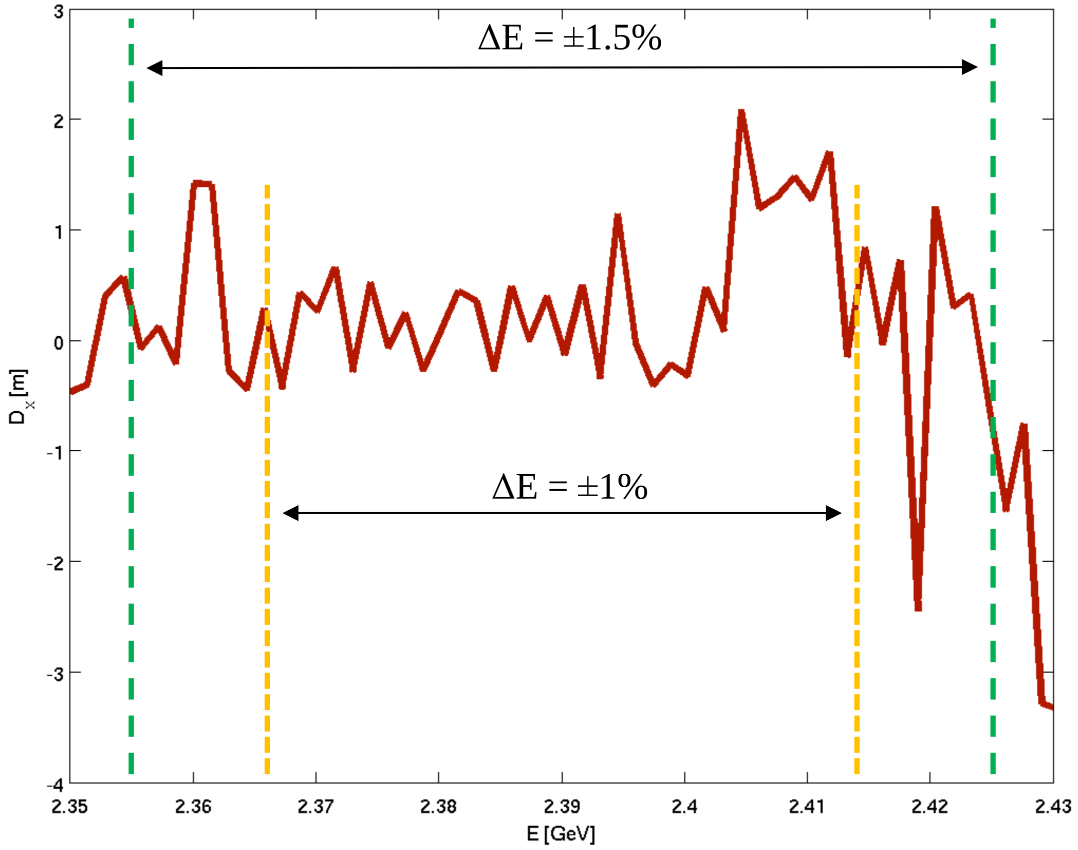
β_x energy scan



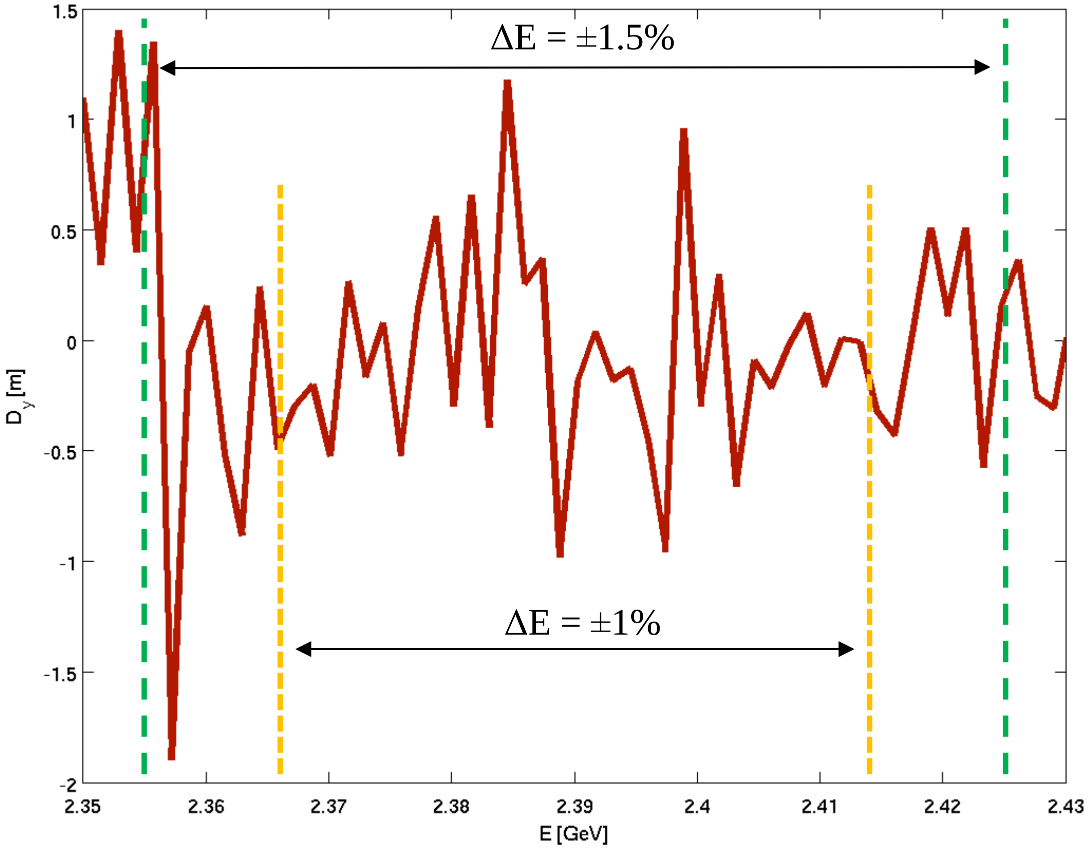
β_y energy scan



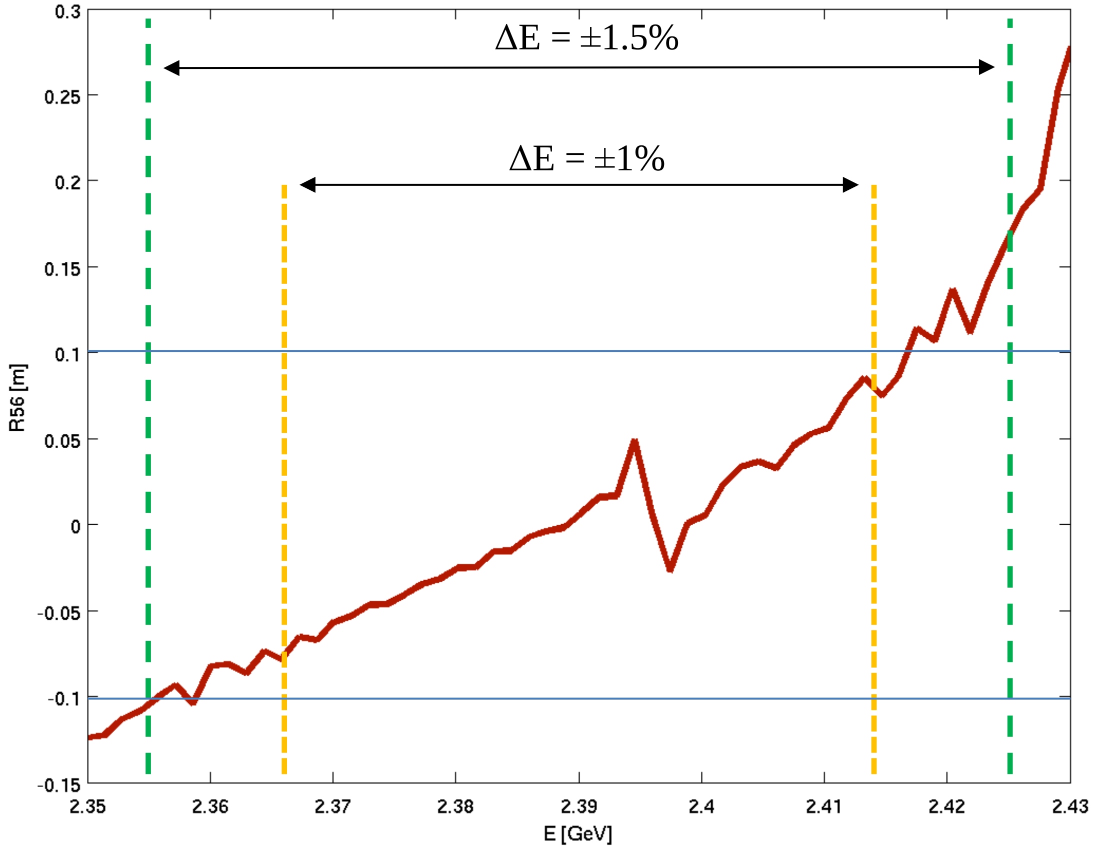
D_x energy scan



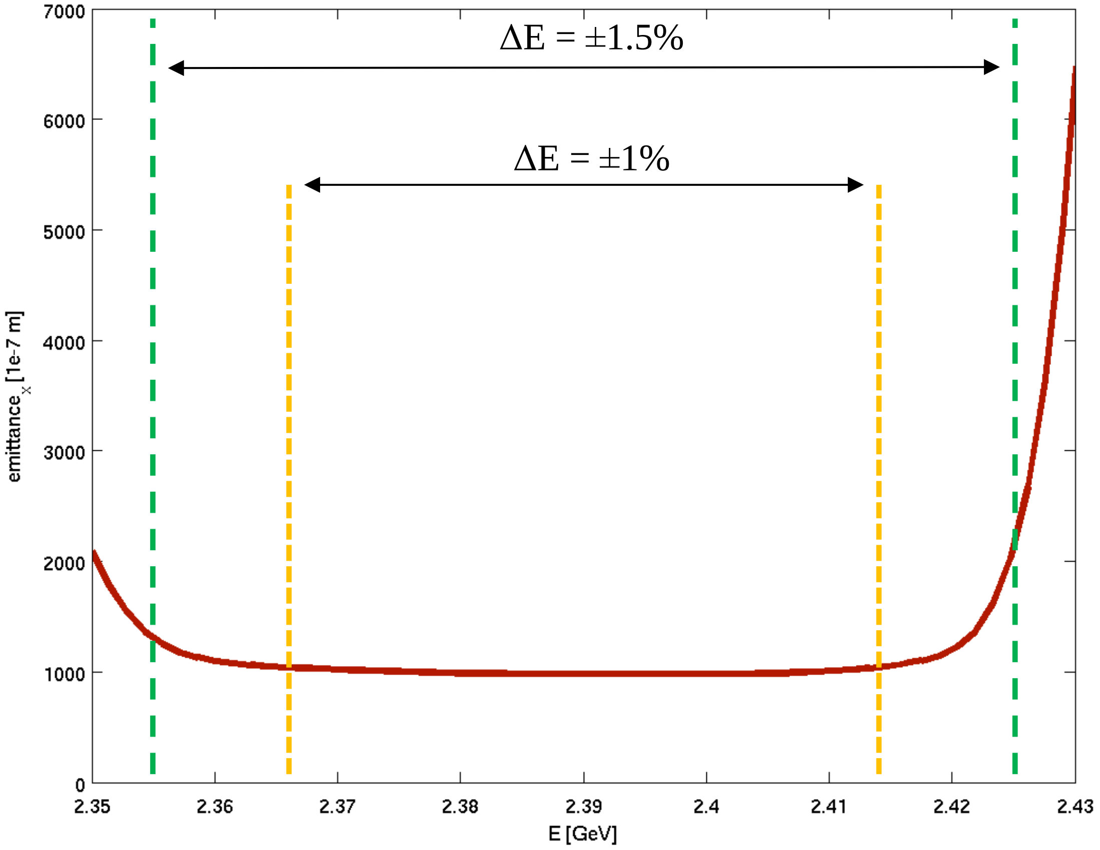
D_y energy scan



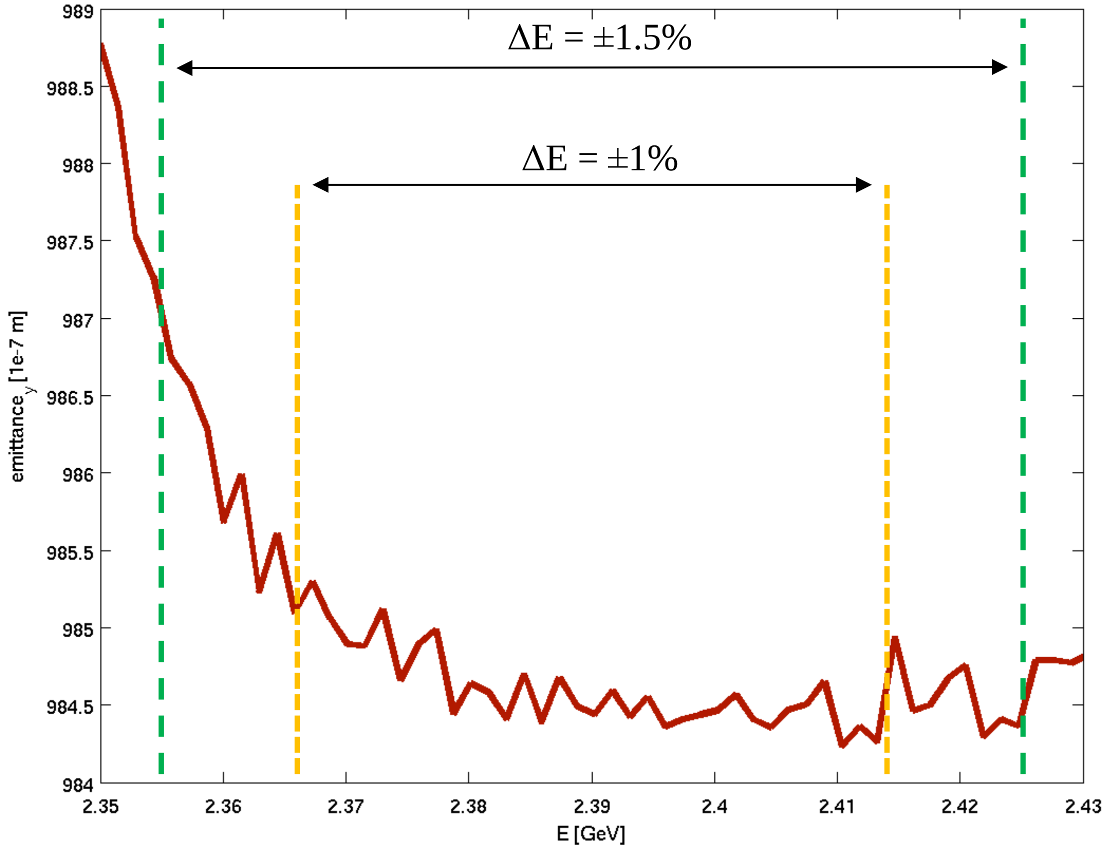
R_{56} energy scan



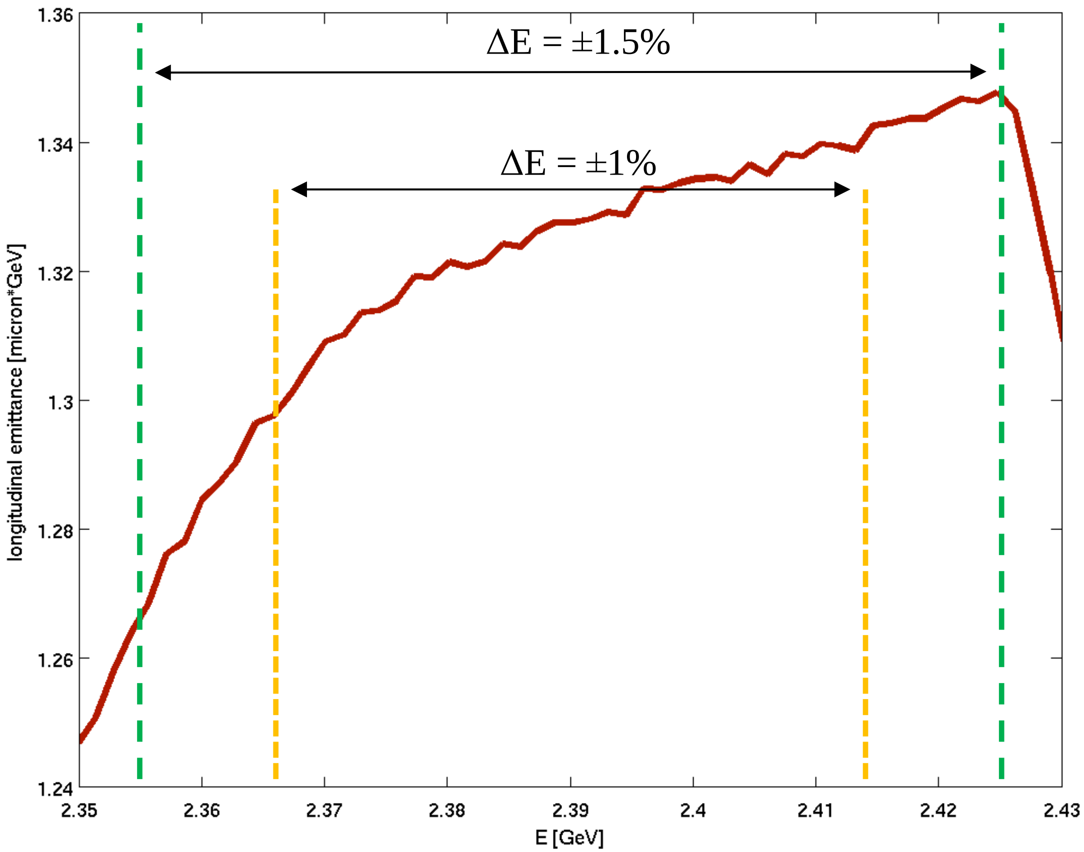
ε_x energy scan



ε_y energy scan

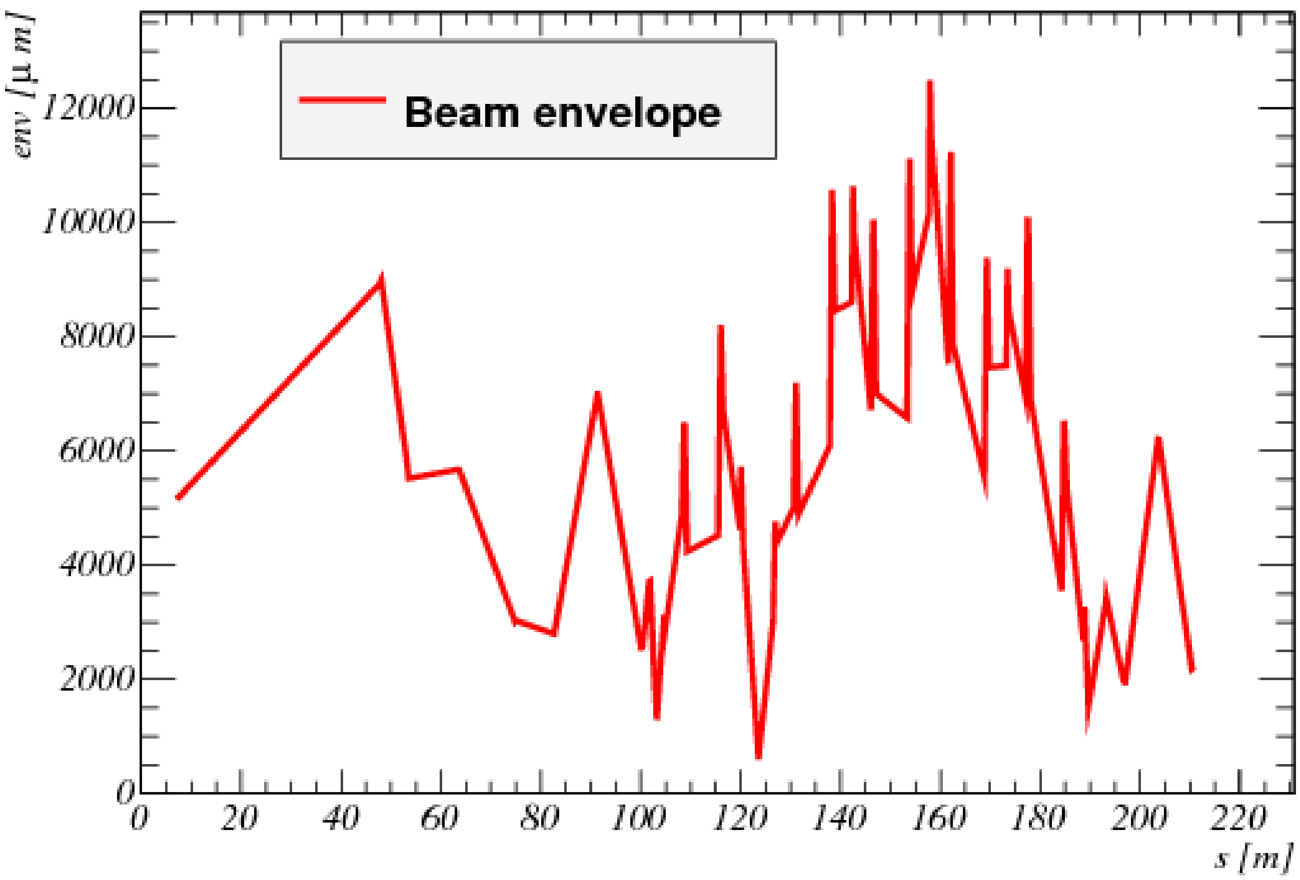


ε_L energy scan

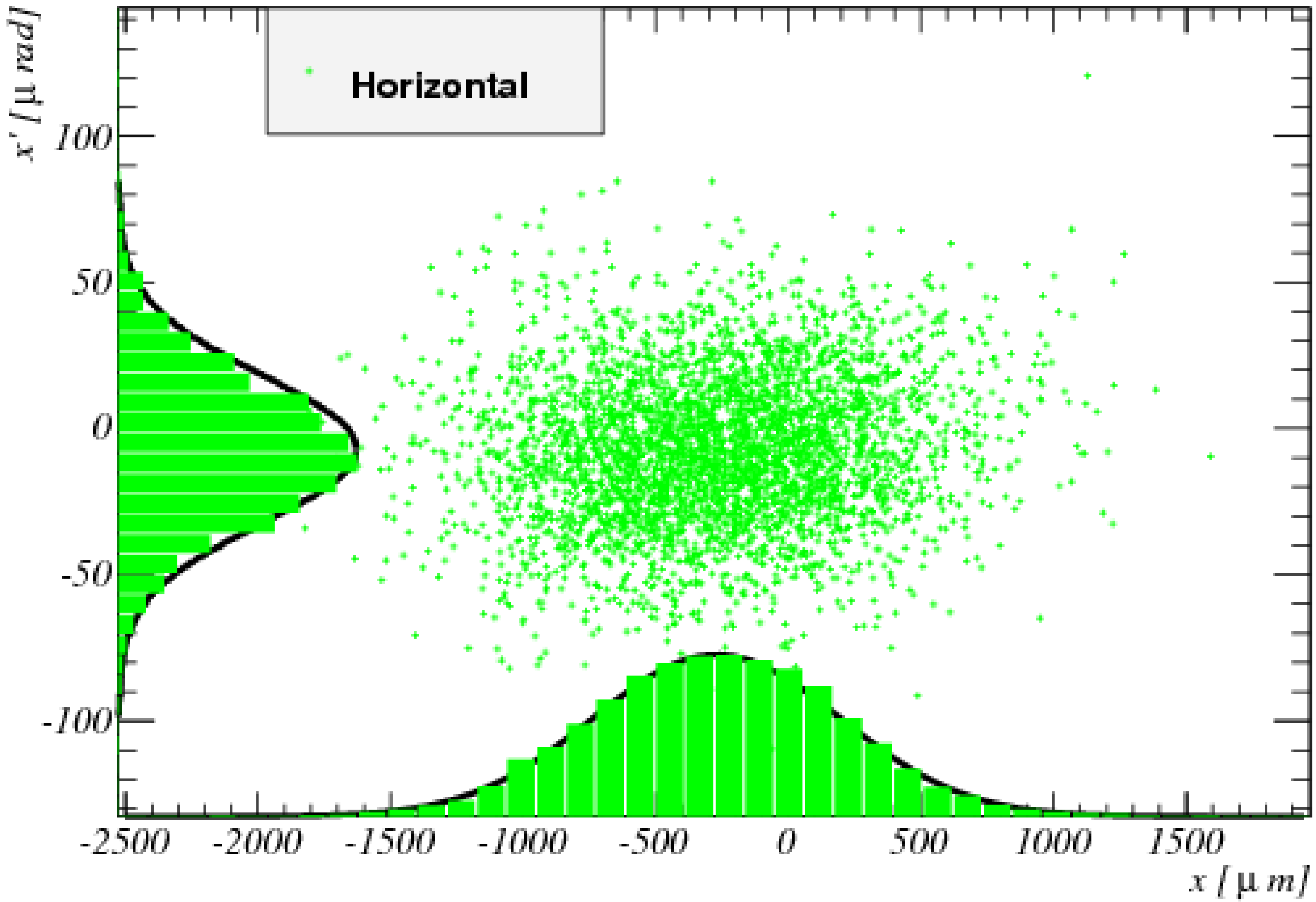


Note: the test bunches used for this scan have nominal bunch length but small energy spread to accurately scan energy. However this means that the initial longitudinal emittance is very small and not representative of the real beam.

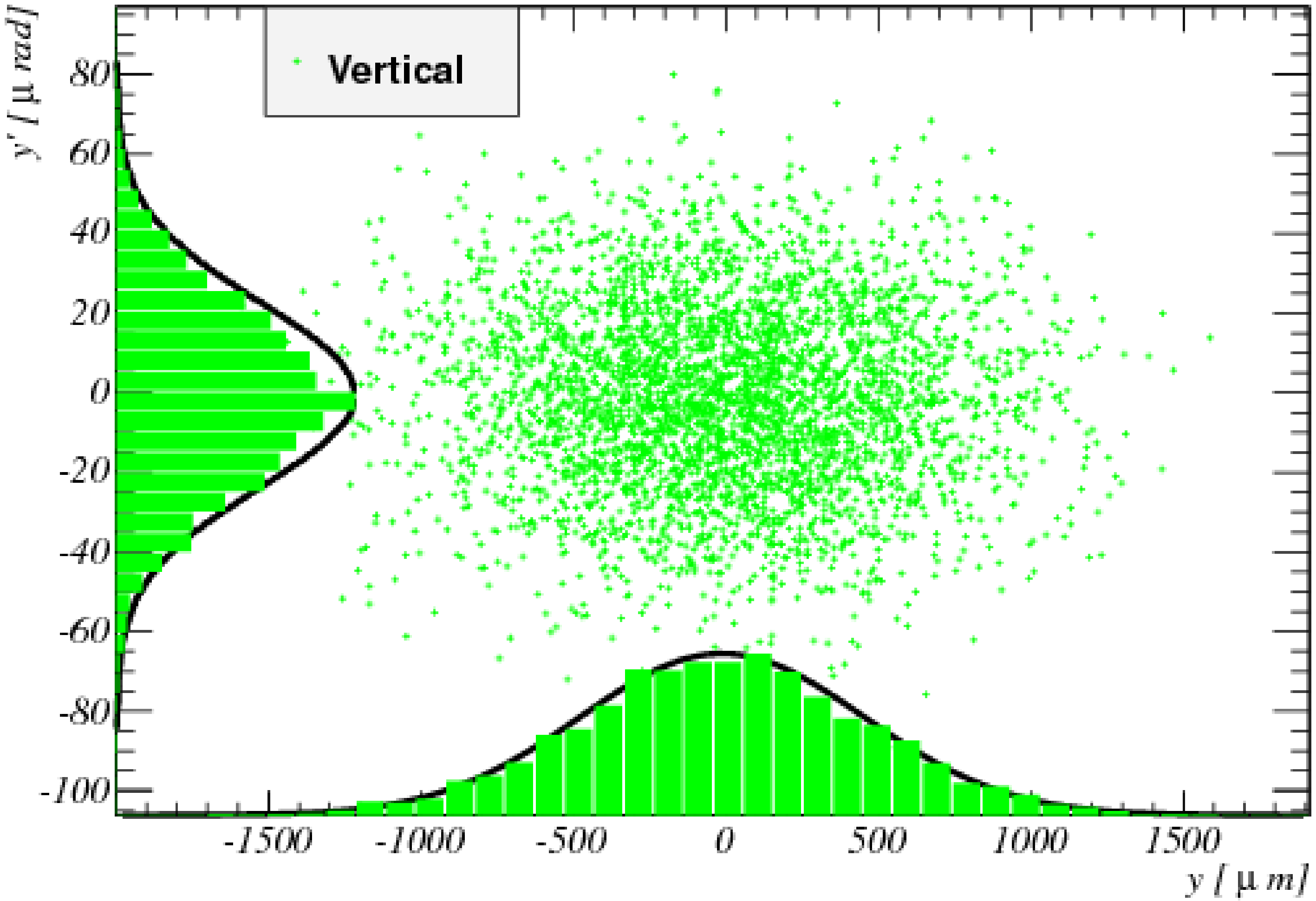
Beam envelope along TAL



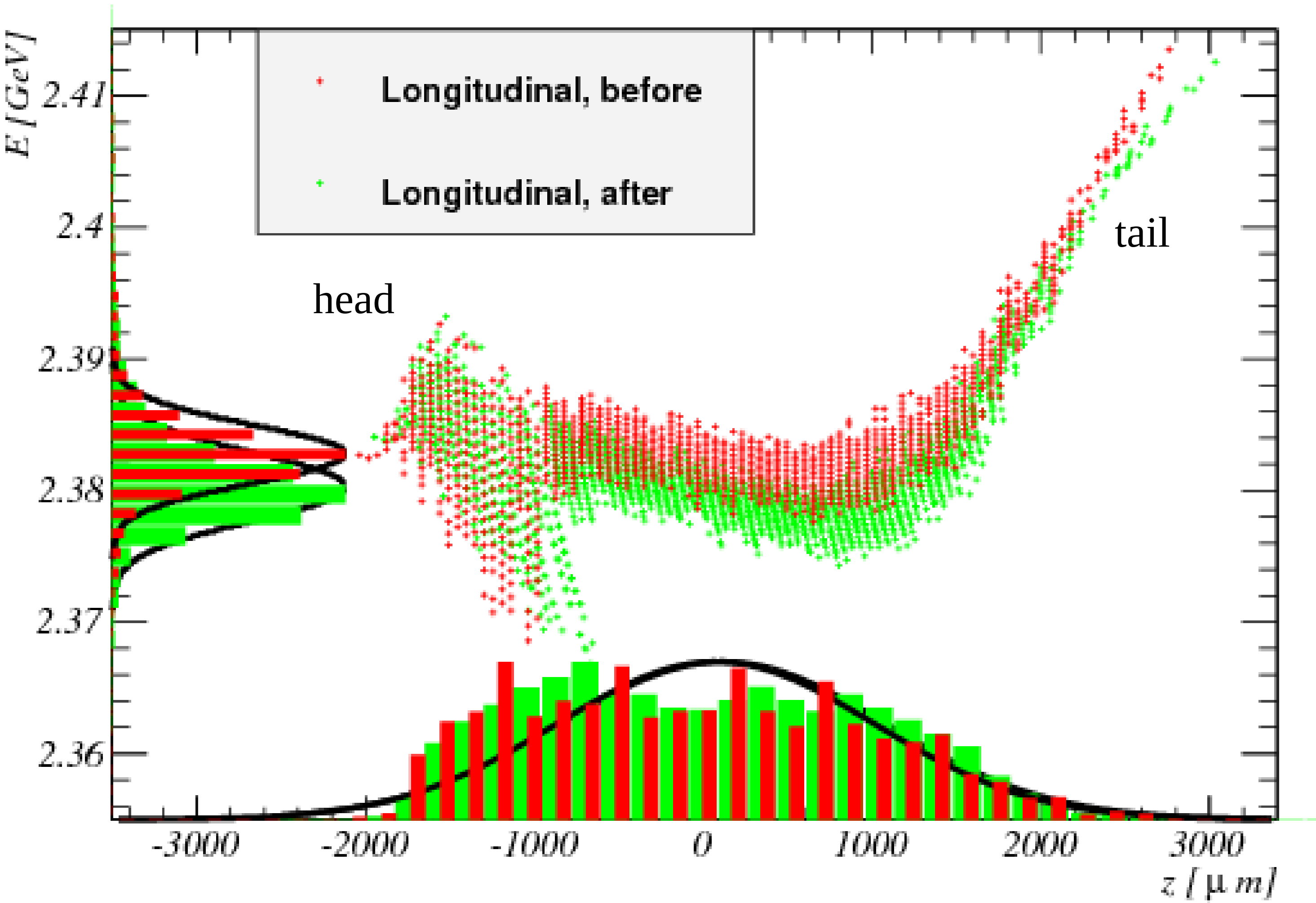
Horizontal phase space



Vertical phase space



Longitudinal phase space



TAL present status

Emittance growth:

- $\Delta\varepsilon_x = 5.9\ \mu m$ ($4.6\ \mu m$ with CSR shielding, discussed in J. Esberg's talk)
- $\Delta\varepsilon_y = 80\ nm$
- $\Delta\varepsilon_L = 0.5\ \mu m$

Modify optics to improve matching for simulated 6D particle distribution

- Fix "false" horizontal residual dispersion in vertical bend regions
  - Possibly due to rounding errors on tilt angle ($\pi/2$)
  - Investigate transverse beam coupling in simulated distribution

- Correct dispersion and derivative in arc cells
  - Might be due to "false" dispersion, but need to see

Tracking simulations suggest CSR emittance growth not as strongly dependent on bunch length as first thought.

- Investigate emittance growth for TAL with 1st chicane removed; is it necessary?

- Working towards full baseline design of drive beam system
  - Once we finish work on final TAL need to look at recombination system as next major challenge

Initial design considerations for combiner rings

Injection system:

- RF deflectors needed and septum magnets
- Creates local orbit bump which is different for each sub-pulse in bunch train in CR
  - This will change the relative phase between sub-pulses (discussed on next slides)

Extraction system:

- Use standard kicker – septum extraction scheme
  - Kickers has high burst rate (>100 kHz) which will be challenging

Arc cells:

- Similar to design for TALs
- Tuneable R56 achromats

Trajectories in injection region

Consider sub-pulses on final pass of injection region before extraction:

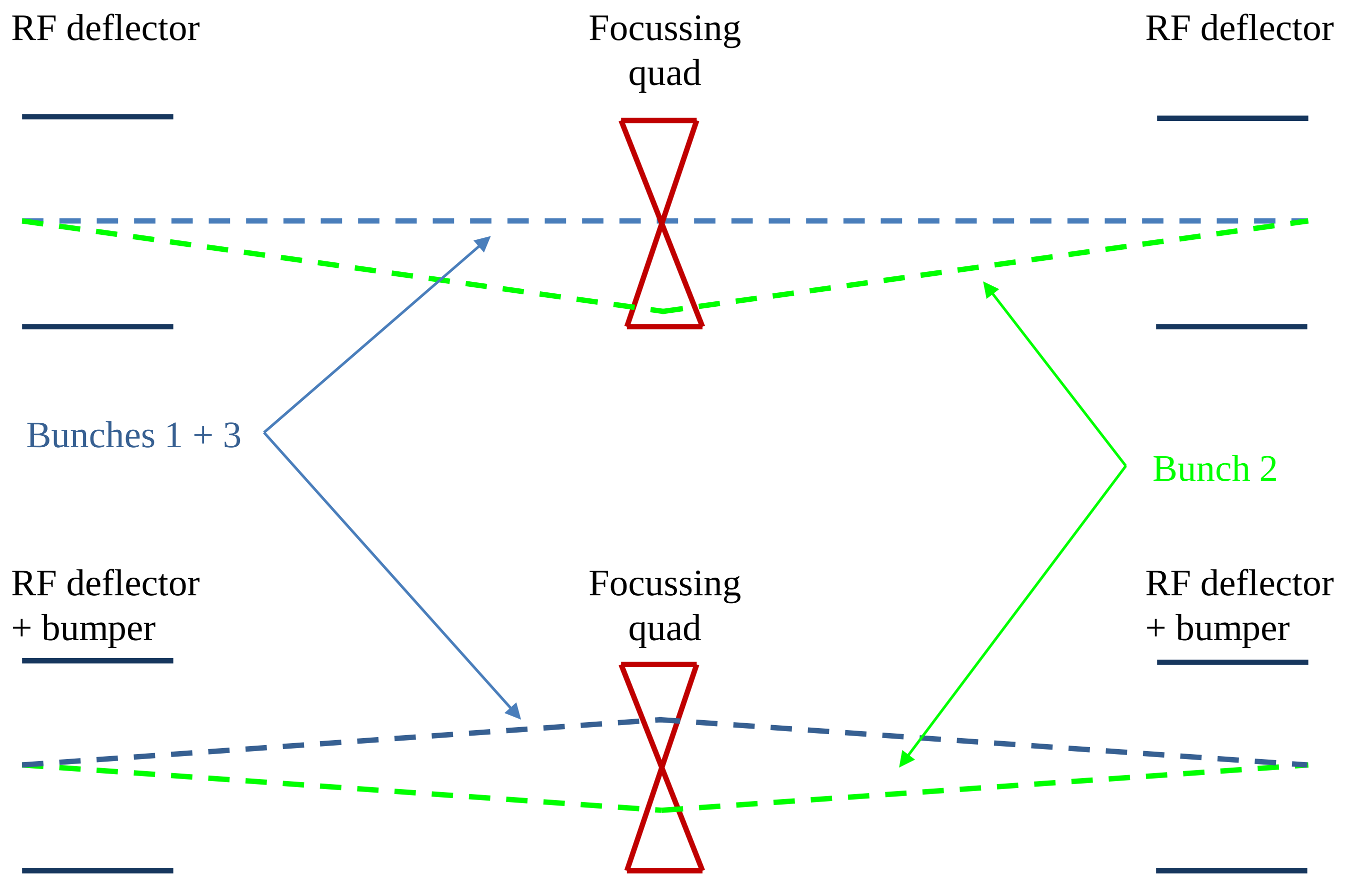
CR1:
Bunch 1: $-\frac{\theta_{max}}{2}$
Bunch 2: $-\frac{\theta_{max}}{2}$
Bunch 3 (injected bunch):θ_{max}

Phase and R56 of injected bunch can be matched in upstream transfer line.
Bunches 1 and 2 have same orbit, so same phase and R56 through injection region.

CR2:
Bunch 1: no deflection
Bunch 2: $-\theta_{max}$
Bunch 3: no deflection
Bunch 4 (injected bunch):θ_{max}

Phase and R56 of injected bunch can be matched in upstream transfer line.
Bunches 1 and 3 have same orbit, but it is different to the bunch 2 orbit.
Over all 4 turns in CR2, bunches 1 and 2 will see a phase delay relative to bunches 3 and 4.

Solution to CR2 phase problem



Key points

All three stored bunches have identical path lengths and R56

Helps with injection:

- 33% reduction in RF deflector strength

Simple optical system:

- Can use 60^{o} FODO cell
- Dispersion suppression cell needed downstream
- But no complicated R56 correction needed as this can be done by the arc cells