TAPERING AND ENERGY COMPENSATION

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Tapering and energy compensation

- Synchrotron radiation energy losses over one turn is significant, even at the z-pole energy (45.6 GeV) and becomes critical at the ttbar energy

→ Rf phase (energy compensation) and magnet relative strengths (tapering) must be **self-consistently** adjusted

  - Energy loss and energy compensation (gain from cavities) impacts tapering and vice-versa
  - Need to find a fixed-point in an extended parameter space

- Tapering schemes must be devised to accomadate
  - Practical considerations: powering scheme, cabling, cost
  - Beam dynamics considerations: orbit shift, beta-beating, chromatic correction, dynamical and momentum apertures

→

  - Ideal tapering: each element is adjusted to match exactly the beam momentum at that location
  - Realistic tapering: magnets are adjusted in groups (mean rigidity) within magnet families

Outline

- Powering schemes and considered tapering schemes
- Self-consistent algorithm to find a fixed-point in the rf phase / tapering / closed-orbit correction space
  - Present implementation in xsuite
  - Required extensions
  - Implementation
- Results for multiple tapering schemes
  - ttbar
  - Z

Powering schemes for the arc magnets

Arc dipole

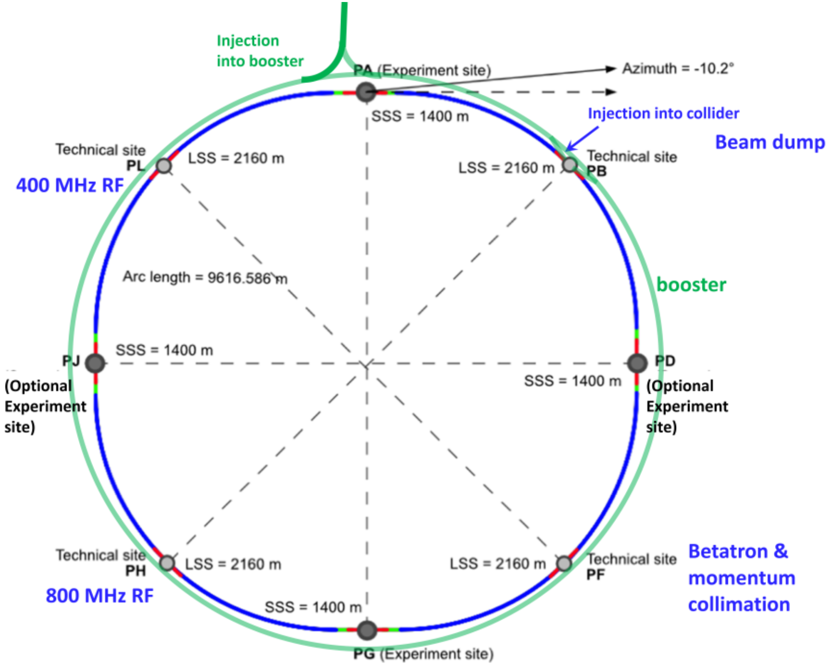
- Twin aperture
- 2840 magnets
- 2 circuits per arc
- **16 circuits** in total

Arc quadrupole

- Twin aperture
- 2840 magnets
- Half-arc powering
- **32 circuits** (16 FQ + 16 DQ)

Arc sextupole

- Single aperture
- 600 magnets at Z
- 2336 magnets at $t\bar{t}$
- Family powering
- **584 circuits** (292 FS + 292 DS) (GHC lattice)



All other magnets considered individually powered in this study.

Tapering schemes

Tapering scheme	Dipoles	Quadrupoles	Sextupoles
D#_Q#_S#_M#	Individual	Individual	Individual
D8_Q0_SC_M#	Arc | 8	No tapering	Circuit | 2 x 292
D8_Q8_SC_M#		Arc | 2 x 8	
D8_Q16_SC_M#		Half arc | 2 x 16	
D16_Q0_SC_M#	Half arc | 16	No tapering	
D16_Q8_SC_M#		Arc | 2 x 8	
D16_Q16_SC_M#		Half arc | 2 x 16	
D32_Q0_SC_M#	Quarter arc | 32	No tapering	
D32_Q8_SC_M#		Arc | 2 x 8	
D32_Q16_SC_M#		Half arc | 2 x 16	
D64_Q0_SC_M#	Eigth arc | 64	No tapering	
D64_Q8_SC_M#		Arc | 2 x 8	
D64_Q16_SC_M#		Half arc | 2 x 16	

Naming convention:

DX_QY_SZ_MW

X: number of dipole tapering families

Y: number of quadrupole tapering families

Z: number of sextupole tapering families

W: number of tapering families for other magnets

#: individually tapered

0: no tapering applied

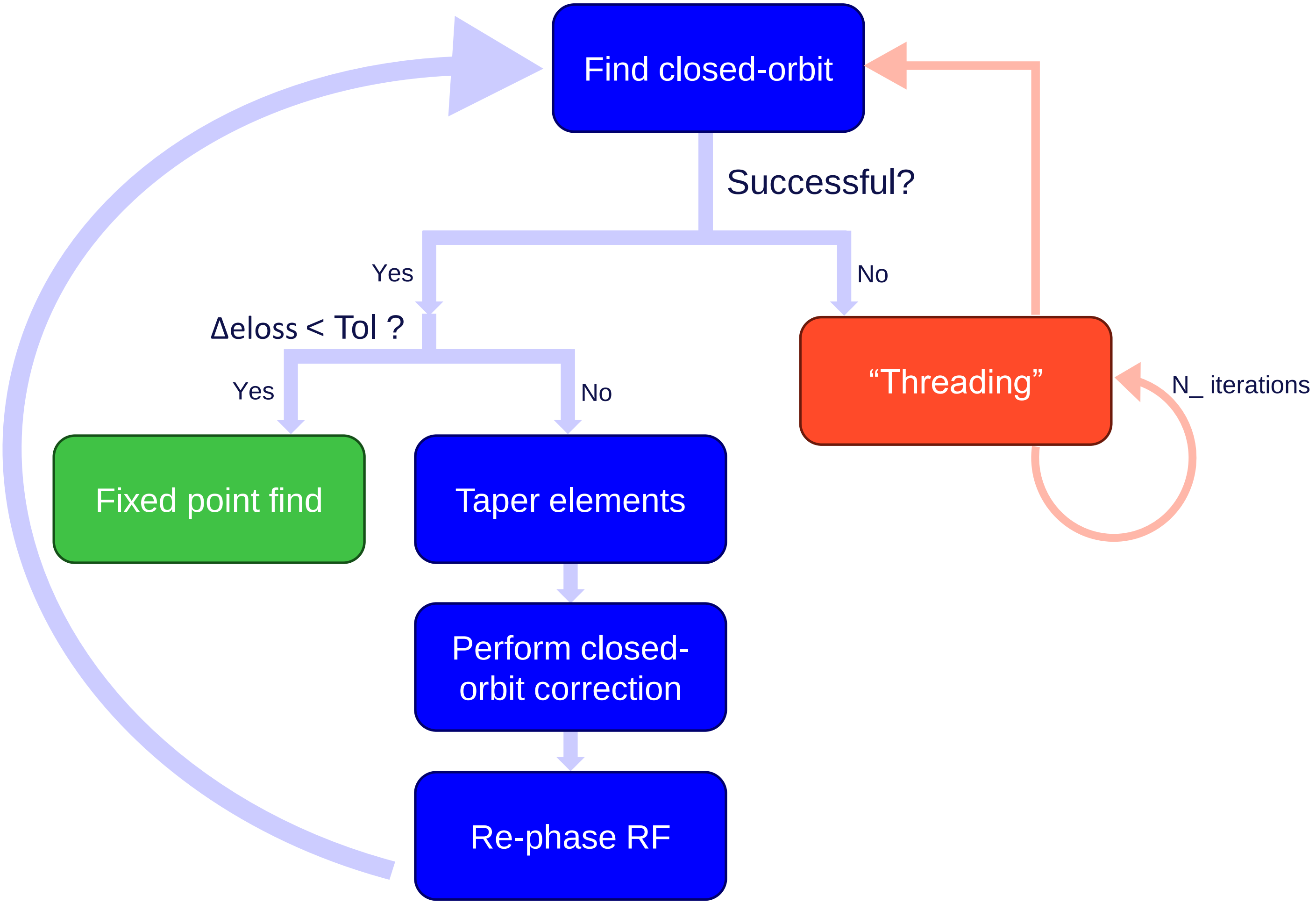
Self-consistent tapering algorithm

- Current implementation
  - Limited to ideal tapering
  - Assumes that an initial closed-orbit can be found
  - Self-consistency implied by the ideal tapering, no closed-orbit search (initial guess without synchrotron radiation is used and tracked throughout)

- Improvements for self-consistent grouped tapering
  - Must rely on closed-orbit search
    - If closed-orbit not available at the start, ”SR threading” is needed
  - Takes tapering groups as input
    - Indicates what to do with the groups: no tapering, ideal tapering, mean rigidity tapering, etc.
  - Perform closed-orbit correction at the groups boundaries (crucial for the straight sections, also crucial at boundaries in the arcs – see later)

Implementation in xsuite

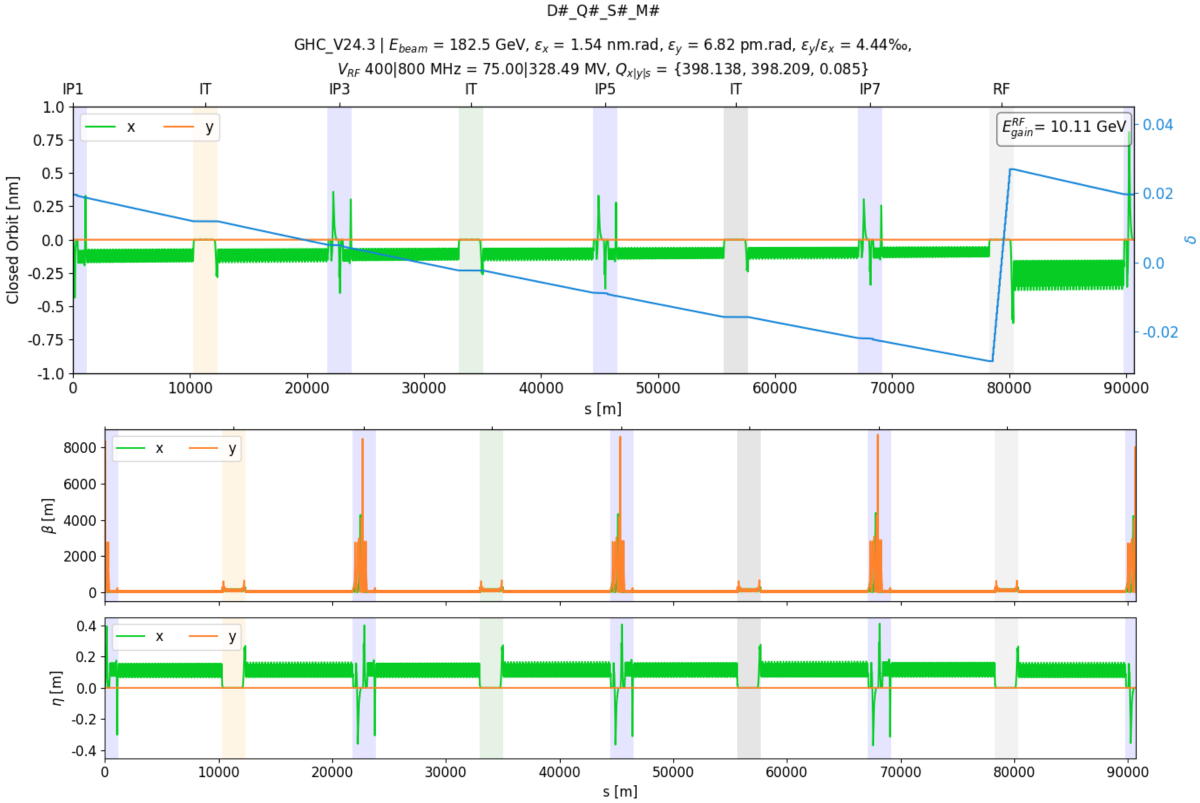
- Relies on usual 6D closed-orbit search
- If no closed-orbit can be found without tapering
  - Perform “**threading**”: track through single element, obtain energy loss, taper the element, re-start tracking (leap-frog), after a full turn re-phase the cavities to compensate for energy loop; iterate as required
- Tapering
  - Find closed-orbit
  - Taper elements
  - Perform closed-orbit correction
  - Re-phase rf
  - Iterate until fixed-point found


Find closed-orbit
Successful?
Yes
No
Δeloss < Tol ?
Yes
No
"Threading"
N_ iterations
Fixed point find
Taper elements
Perform closed-orbit correction
Re-phase RF

Results – ttbar energy

Reference with individual tapering

- Closed orbit ~ $10^{-9}\ m$
- ~ 5.5% of energy loss via SR
- Reference value for dispersion: **0.1 m**



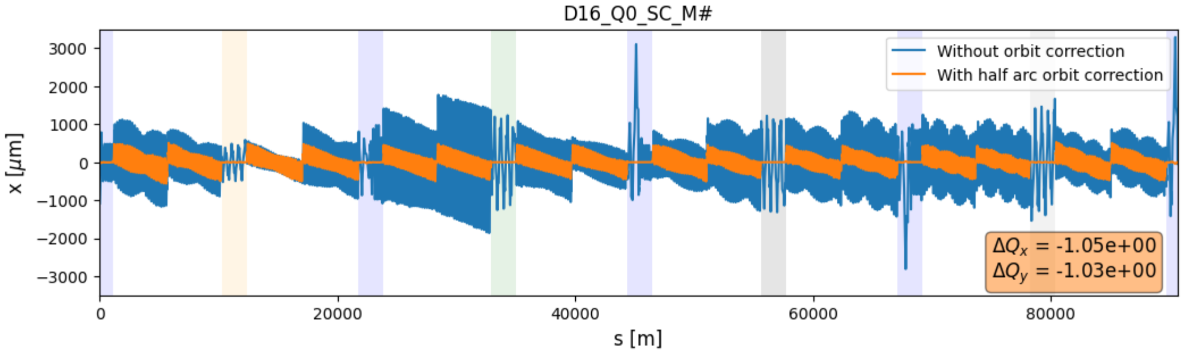
Results – ttbar energy

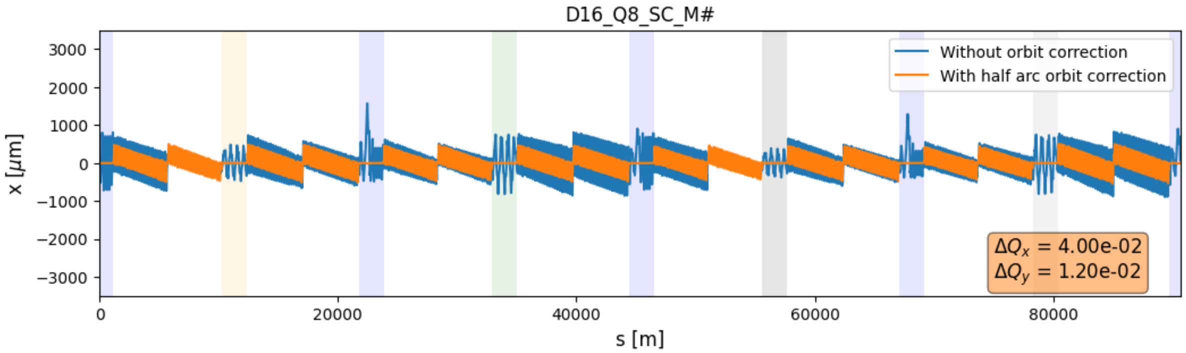
Impact of the orbit correction

- Reduction of the orbit oscillations
  - Cancelled at the IP
- Better symmetry along the machine

Impact of the quadrupoles tapering

- Relatively limited on the closed orbit
- Larger impact on the **tune shift**

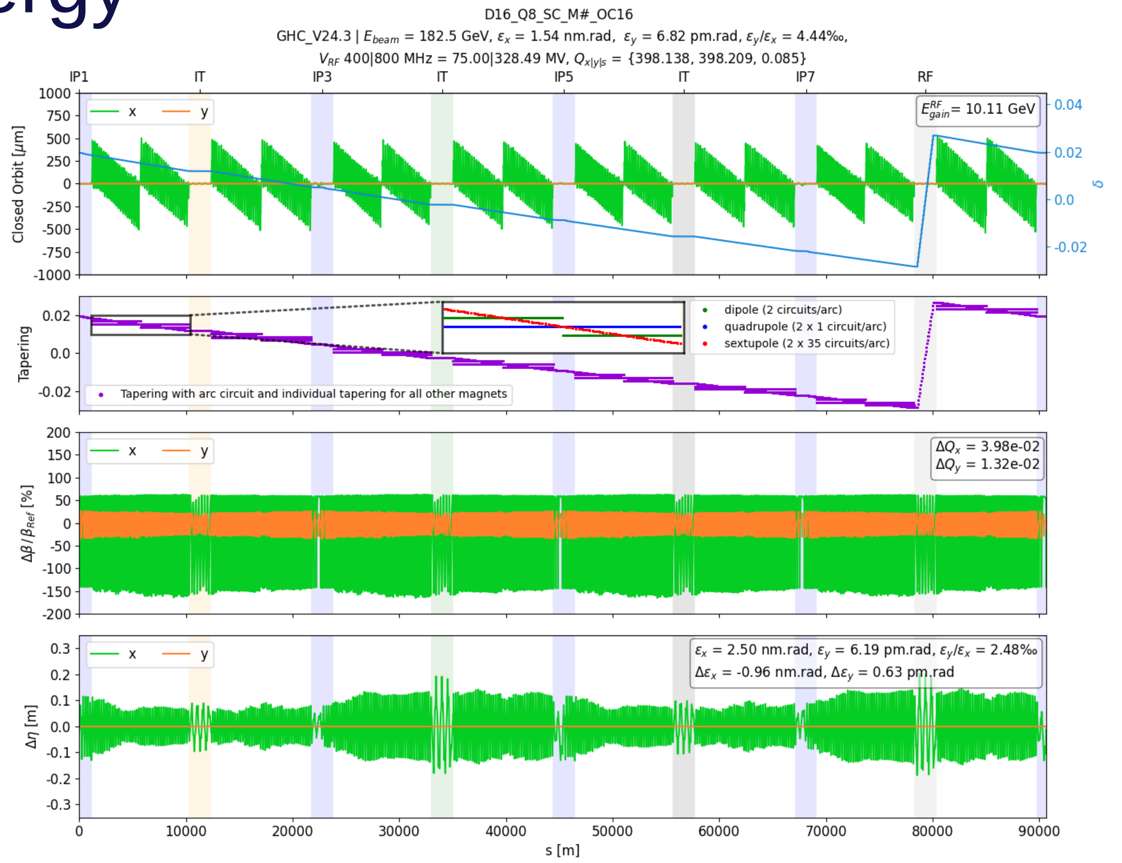




Results – ttbar energy

D16_Q8_SC_M#_OC16

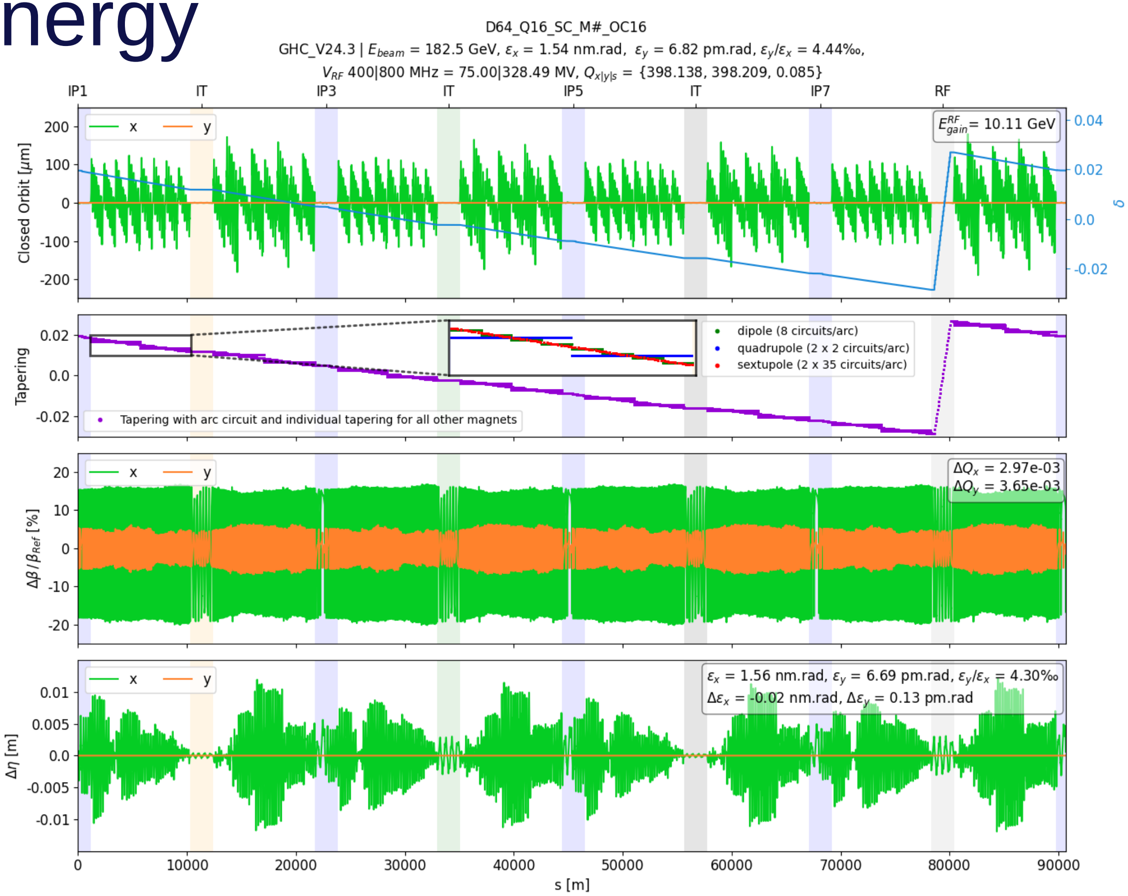
- Closed orbit ~ $500\ \mu m$
- Very large beta beating up to 150%
- Tune shift 10^{-2}
- Large dispersion shift



Results – ttbar energy

D64_Q16_SC_M#_OC16

- Closed orbit ~ $100\ \mu m$
- Acceptable beta beating <20%
- Tune shift 10^{-3}
- Small dispersion beating

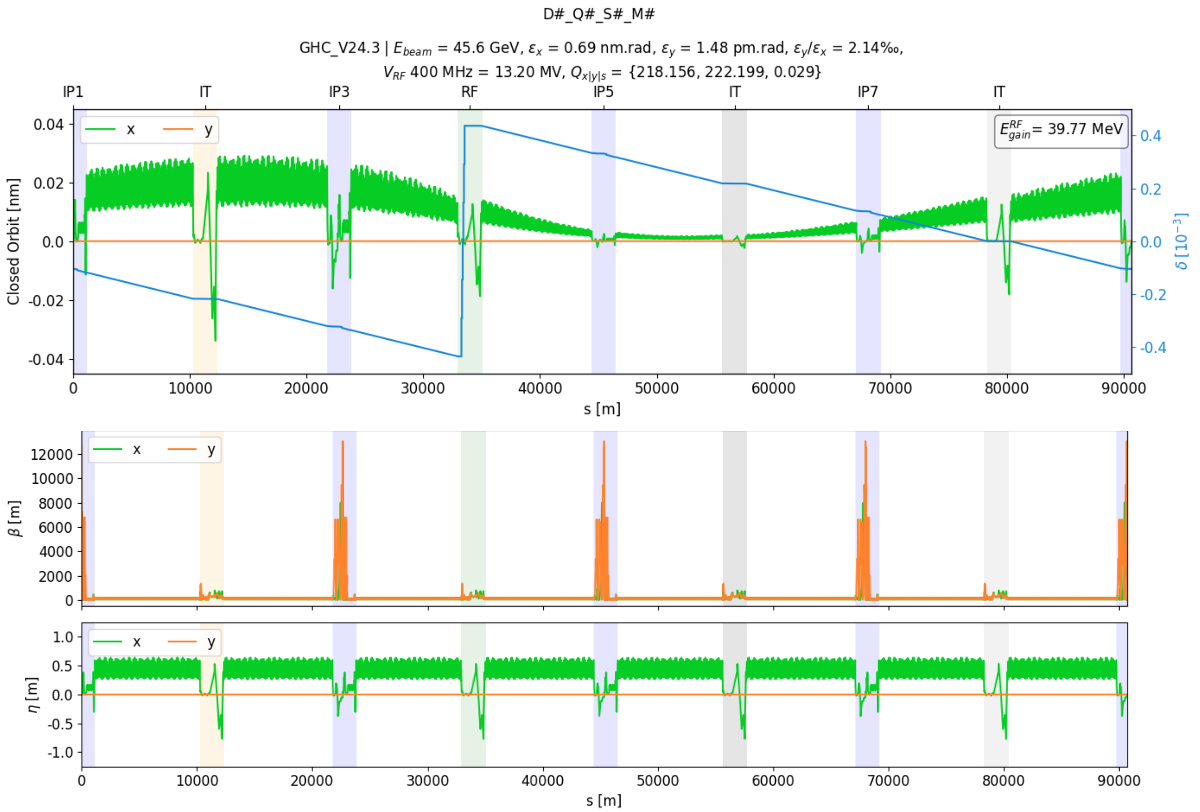


Closed-orbit correction performed self-consistently in the fixed-point search. Do we need more? User-provided function or matching routine to self-consistently rematch tune, optics, etc. ?

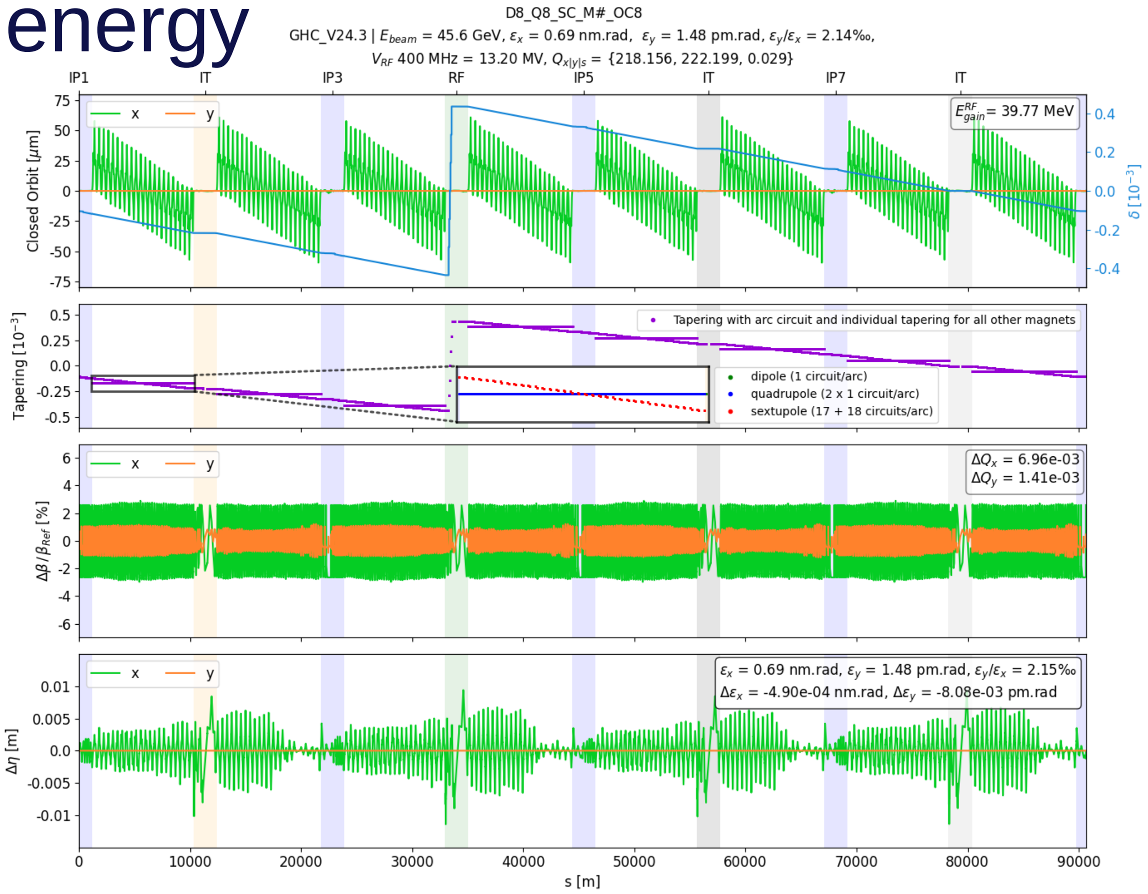
Results – Z-pole energy

Reference with individual tapering

- Closed orbit ~ $10^{-11}\ m$
- ~ 0.1% of energy loss via SR
- Reference value for dispersion: **0.5 m**



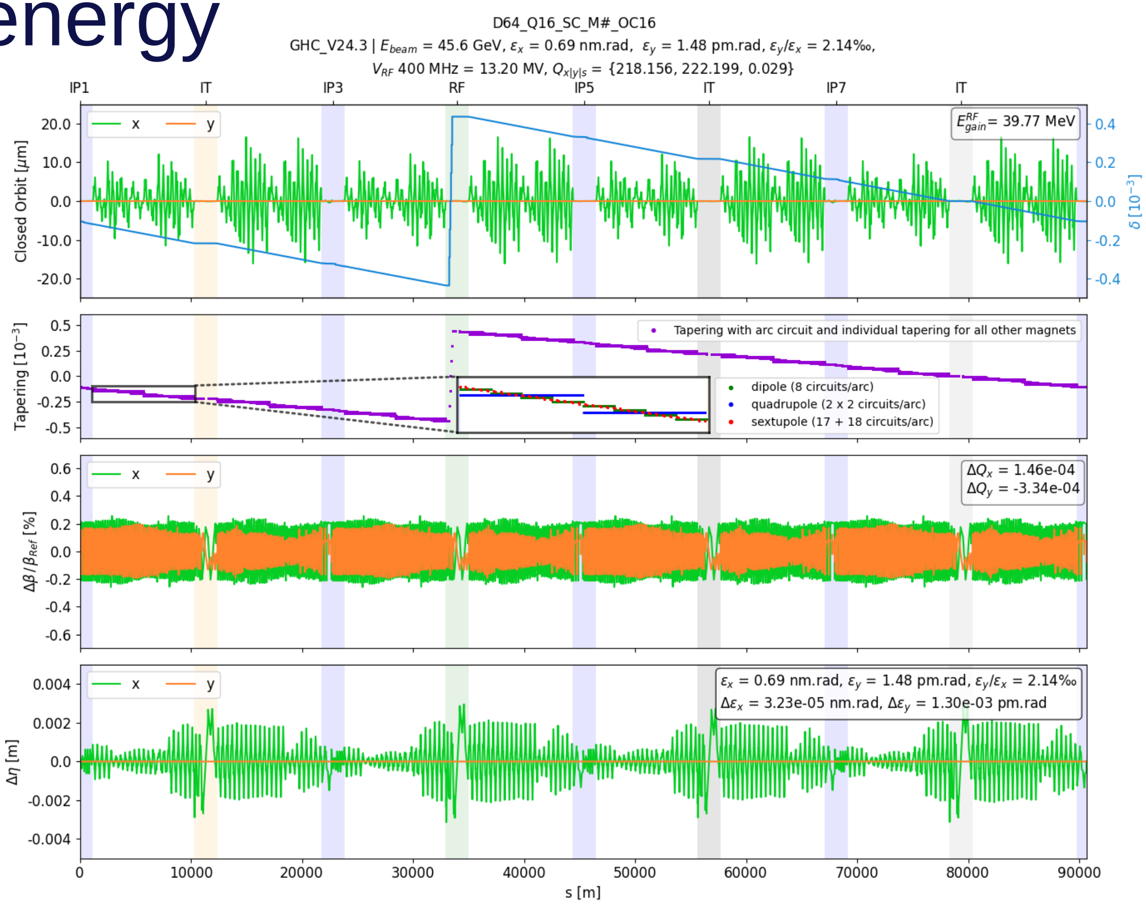
Results – Z-pole energy



D8_Q8_SC_M#_OC8

- Closed orbit ~ $50\ \mu m$
- Beta beating < 3%
- Tune shift 10^{-3}
- Small dispersion shift

Results – Z-pole energy

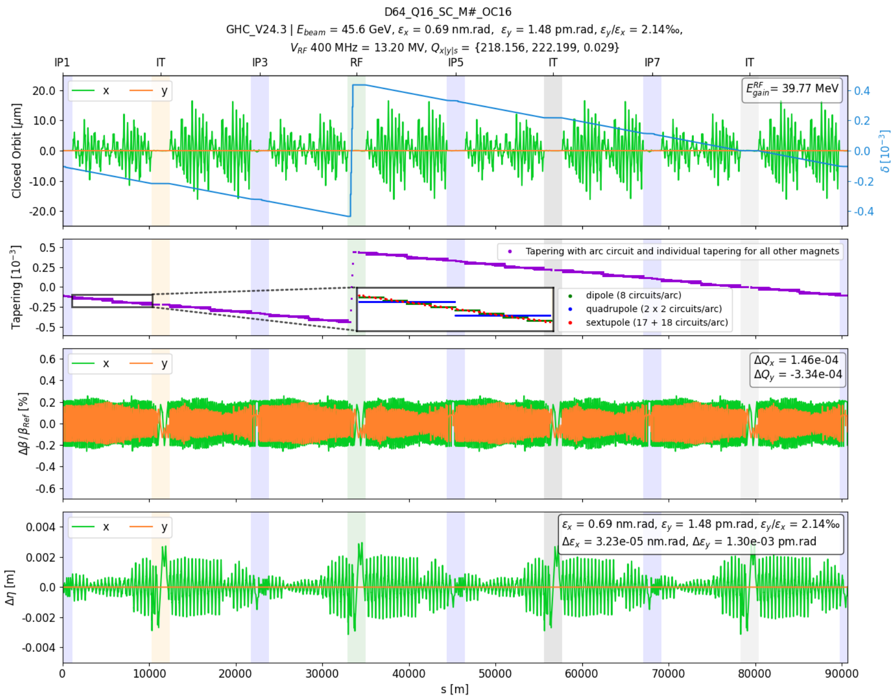


D64_Q16_SC_M#_OC16

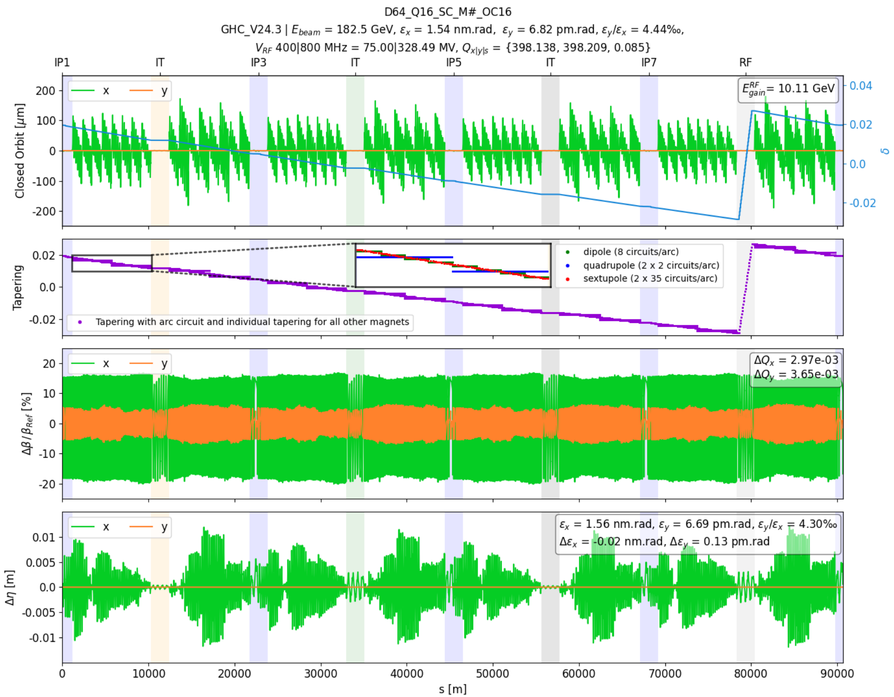
- Closed orbit ~ $10\ \mu m$
- Beta beating < 0.2%
- Tune shift 10^{-4}
- Very small dispersion shift

Results comparison

Z-pole energy



ttbar energy



Thank you for your attention.