Progress on Linacs and RLAs for the IDS Baseline

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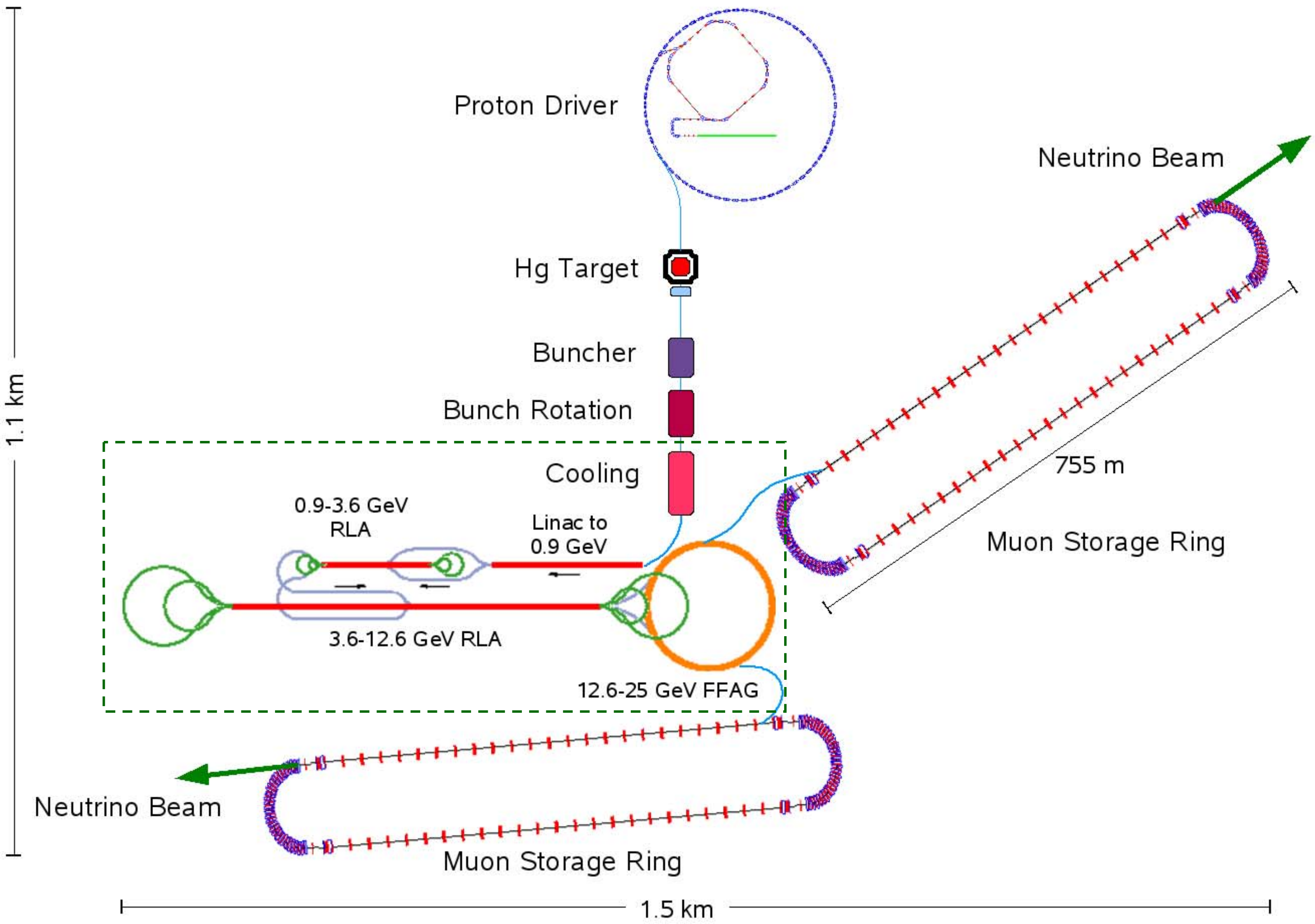
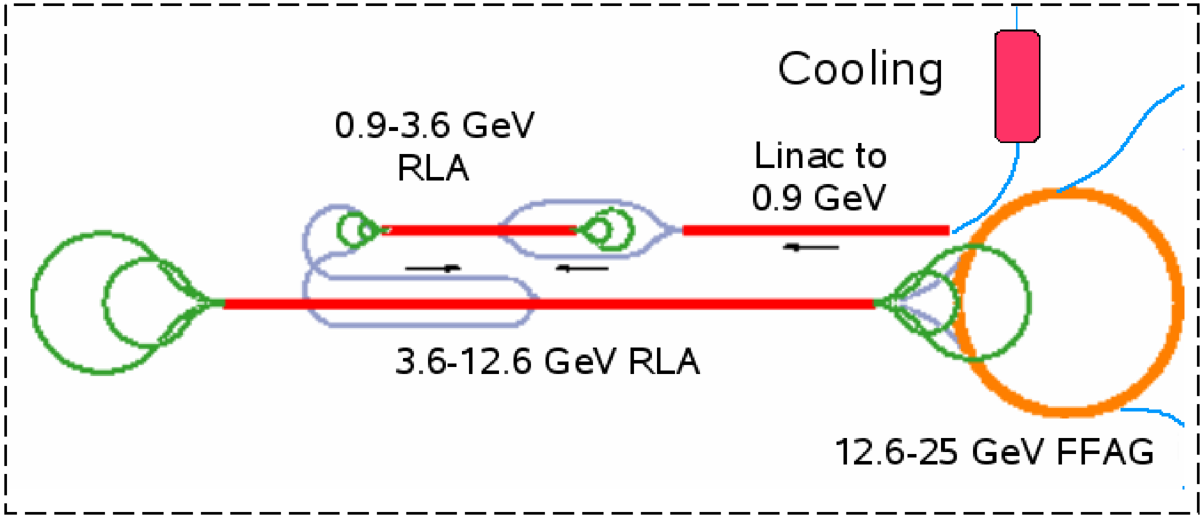
Neutrino Factory – ISS/IDS Baseline

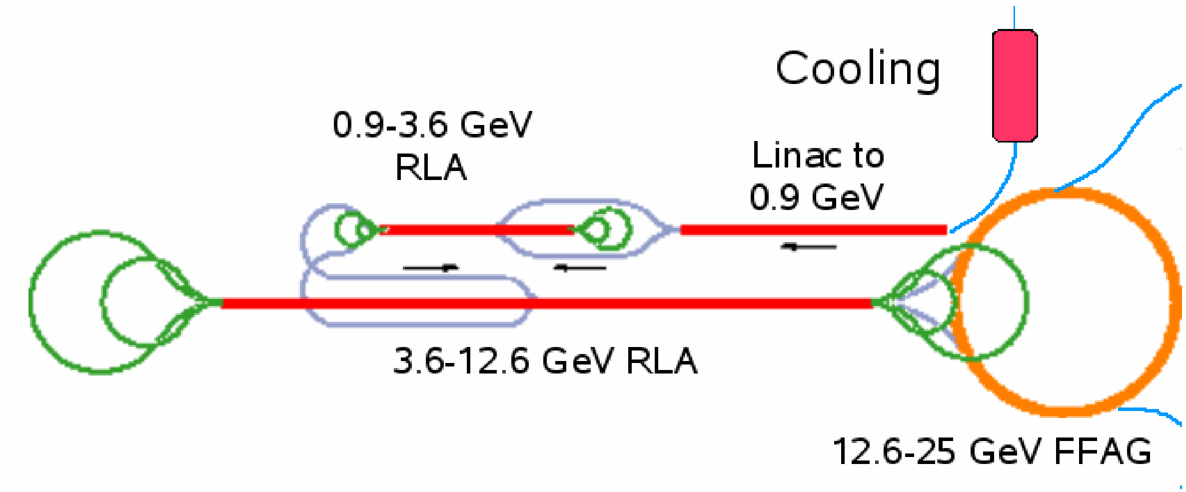


Acceleration Scenario – ISS/IDS Baseline



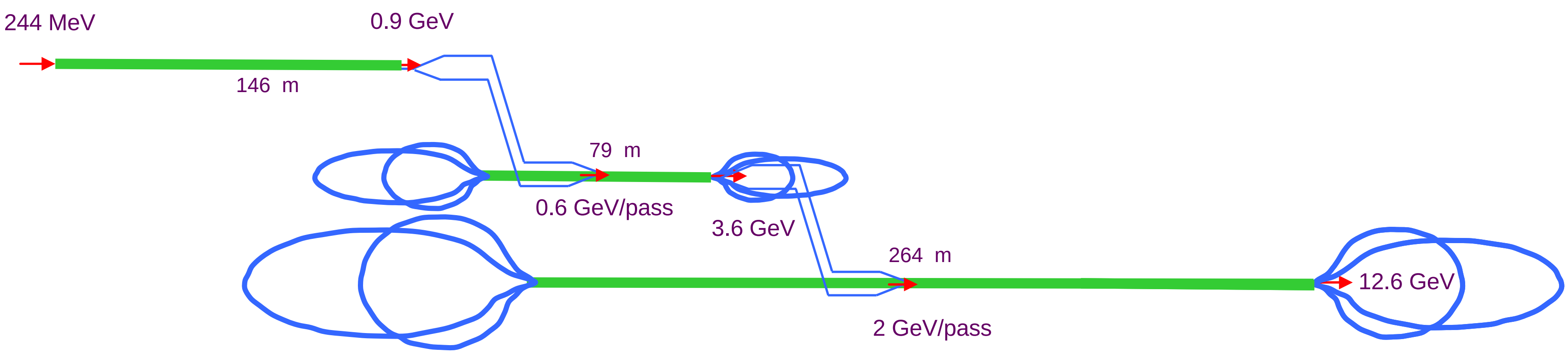
- Linear Pre-accelerator (244 MeV to 900 MeV)
- RLA I – 4.5 pass, **0.6 GeV/pass**, (0.9 GeV to 3.6 GeV)
- RLA II – 4.5 pass, **2 GeV/pass** (3.6 GeV to 12.6 GeV)
- Non scaling FFAG (12.6 GeV to 25 GeV)

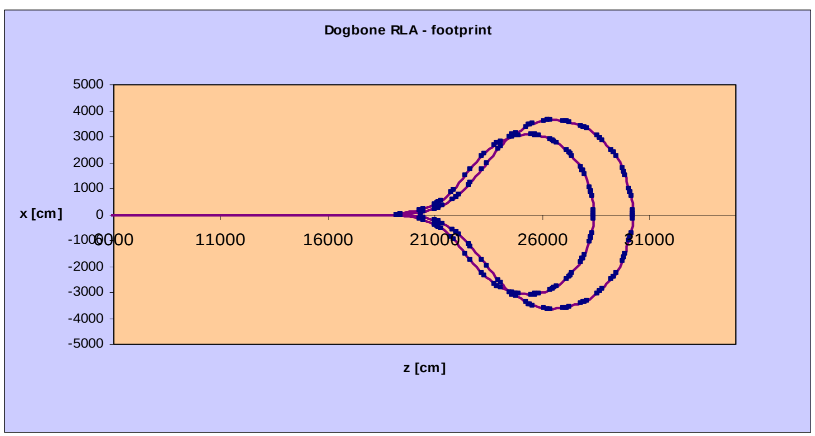
Acceleration Scheme – IDS Goals

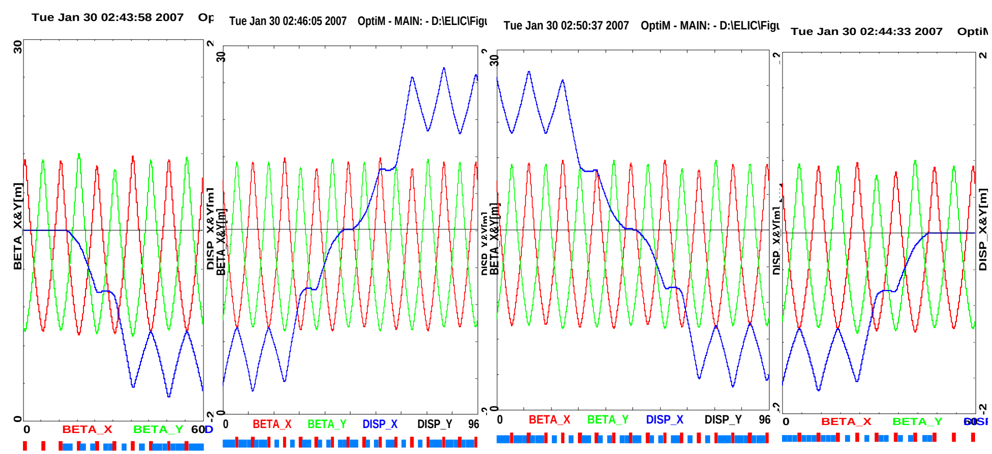


- **Engineering design foundation**
  - Define beamlines/lattices for all components
  - Design lattices for transfer lines between the components
  - Resolve physical interferences, beamline crossings etc ⇒ **Floor Coordinates**
- Carry out end-to-end tracking study ⇒ **Machine Acceptance**
- Engineer individual active elements (magnets and RF cryo modules)

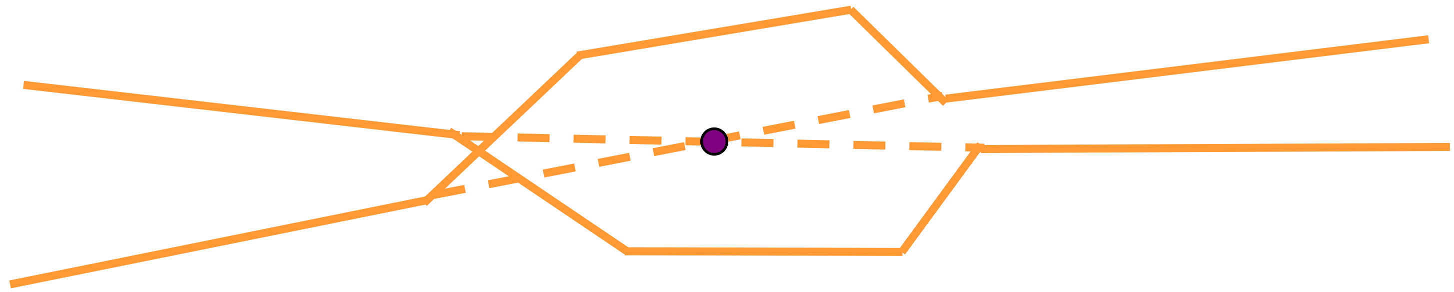
Towards Engineering Design Foundation

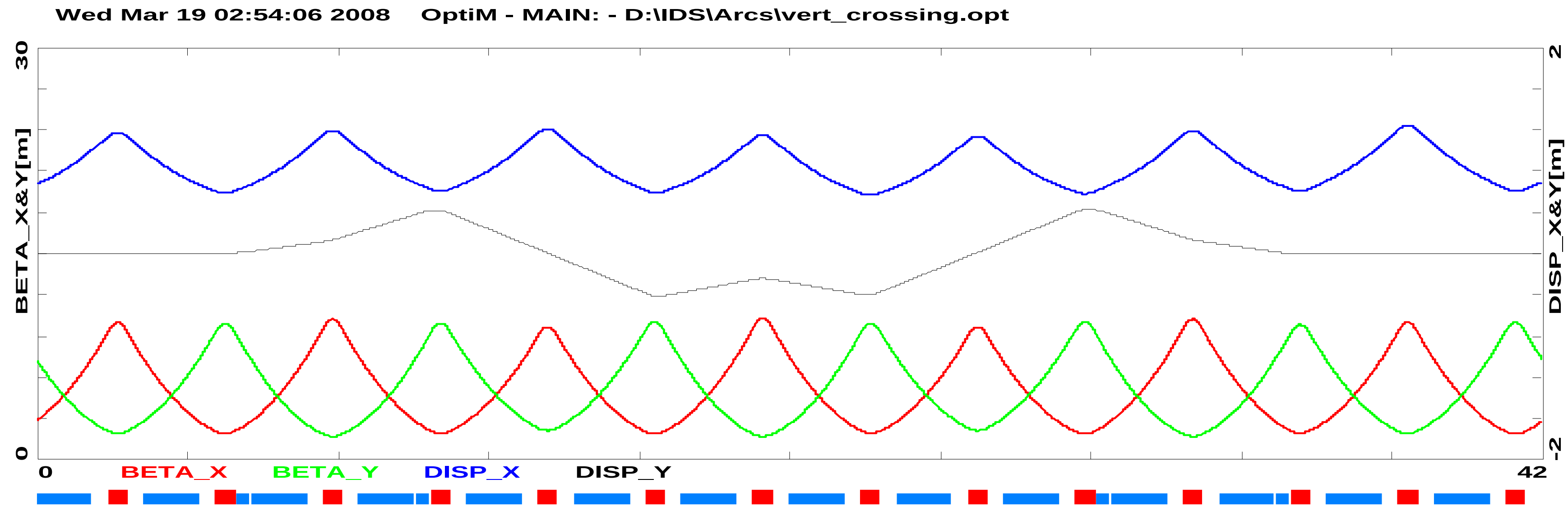






Arcs ‘Crossing’ - Vertical Bypass



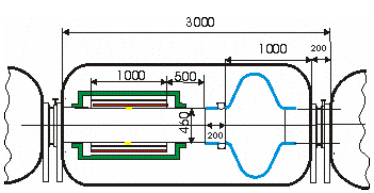


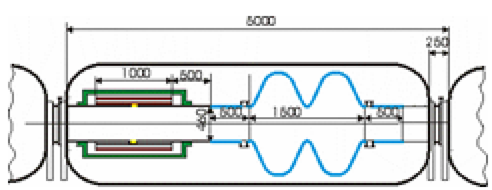
Initial beam emittance after the cooling at 220 MeV/c

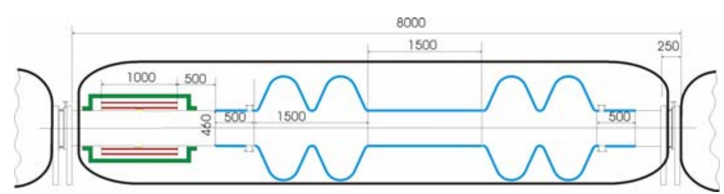
ISS/IDS		ε_{rms}	$A = (2.5)^2\ \varepsilon$
normalized emittance: $\varepsilon_x/\varepsilon_y$	mm·rad	**4.8**	**30**
longitudinal emittance: ε_ℓ $(\varepsilon_\ell = \sigma_{\Delta p}\ \sigma_z/m_\mu c)$ momentum spread: $\sigma_{\Delta p/p}$ bunch length: σ_z	mm mm	**27** **0.07** **176**	**150** **±0.17** **±442**

Pre-accelerator – different style cryo-modules

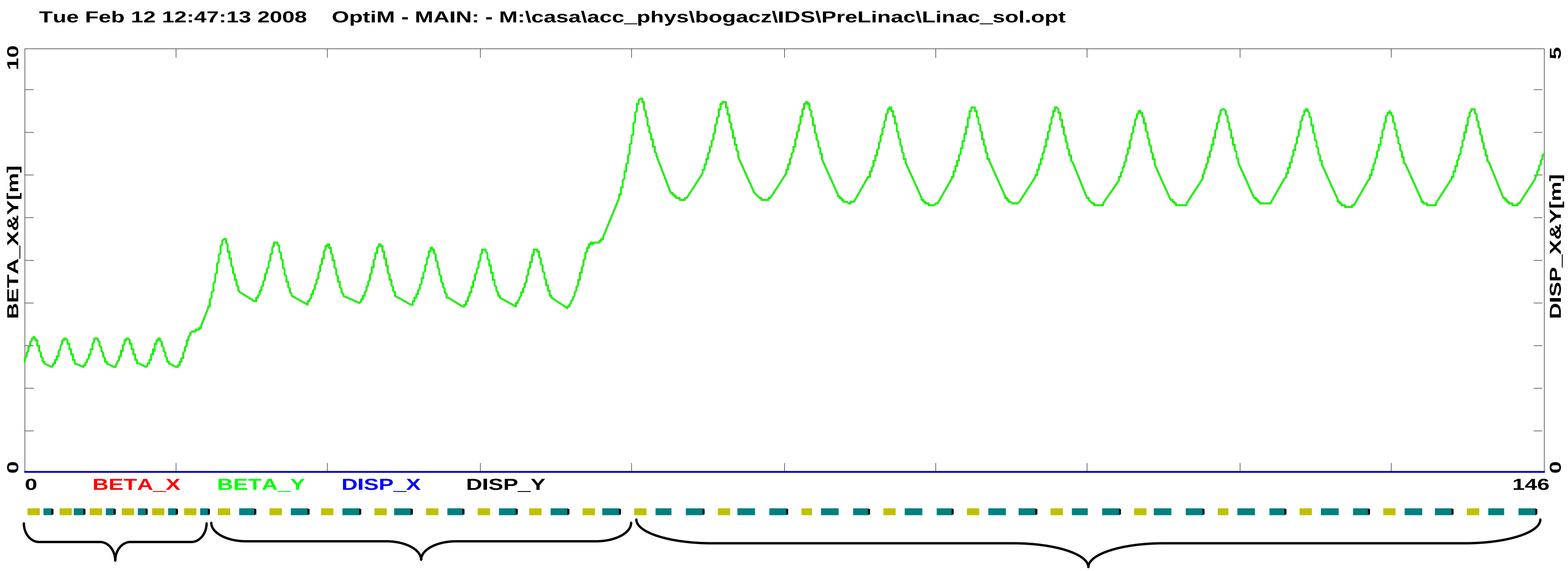
	Short	Medium	Long
Number of periods	6	8	11
Total length of one period	3 m	5 m	8 m
Number of cavities per period	1	1	2
Number of cells per cavity	1	2	2
Cavity accelerating gradient	15 MV/m	17 MV/m	17 MV/m
Real-estate gradient	3.72 MV/m	5.06 MV/m	6.33 MV/m
Aperture in cavities (2*a*)	460 mm	460 mm	460 mm
Aperture in solenoids (2*a*)	460 mm	460 mm	460 mm
Solenoid length	1 m	1 m	1 m
Solenoid maximum field	1.1 T	1.4 T	2.5 T







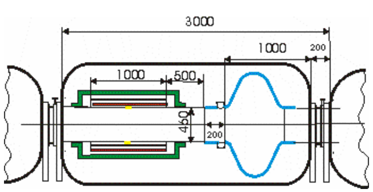
Linear Pre-accelerator – 244 MeV to 909 MeV

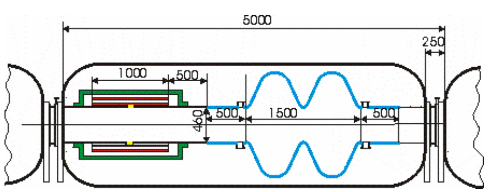


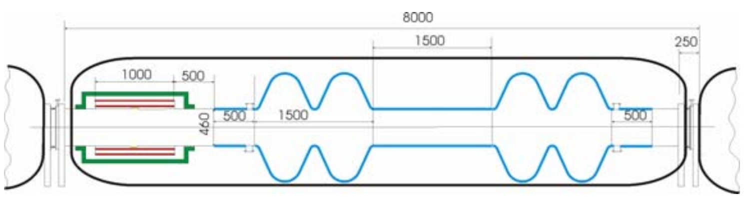
6 short cryos

8 medium cryos

11 long cryos

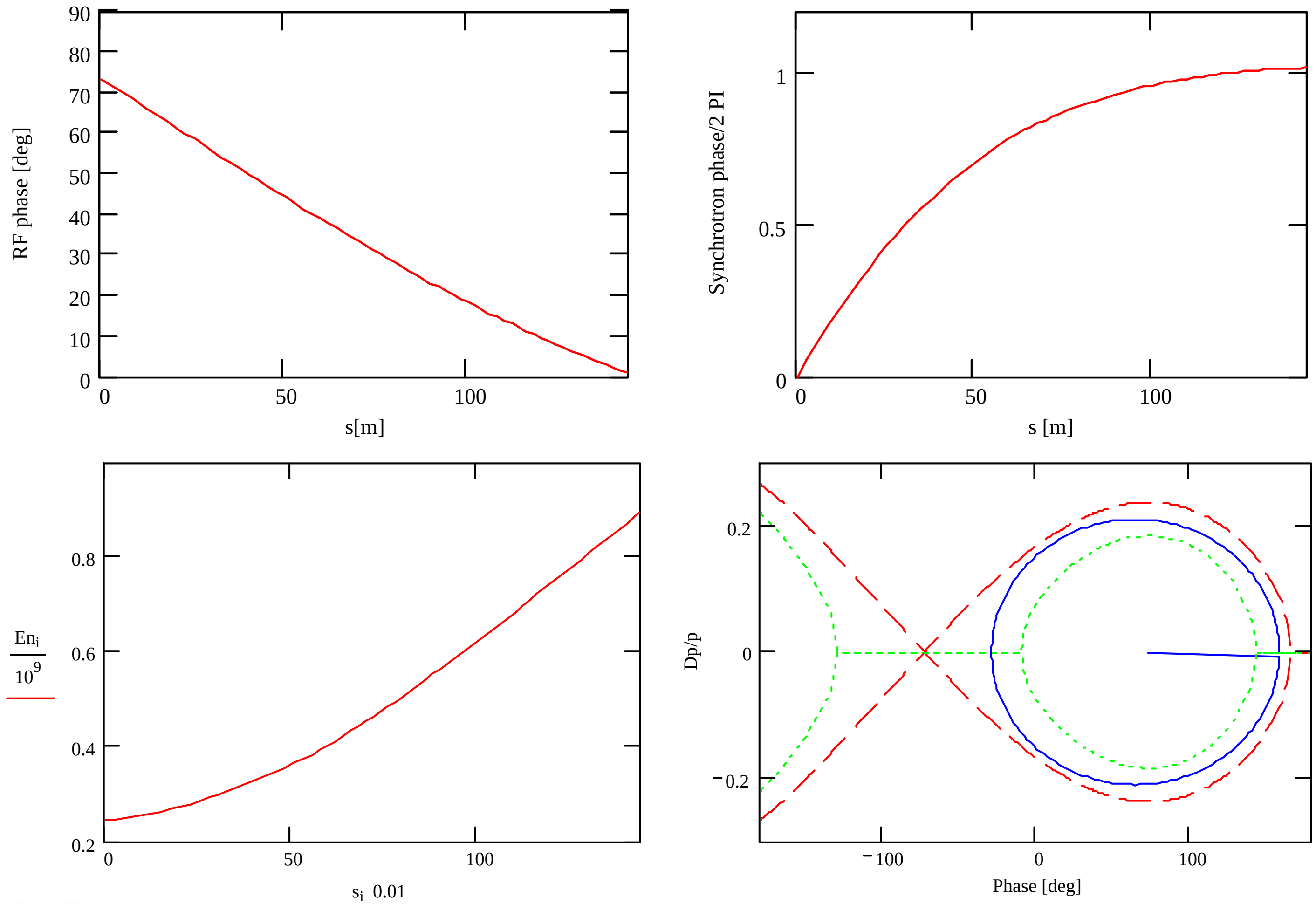




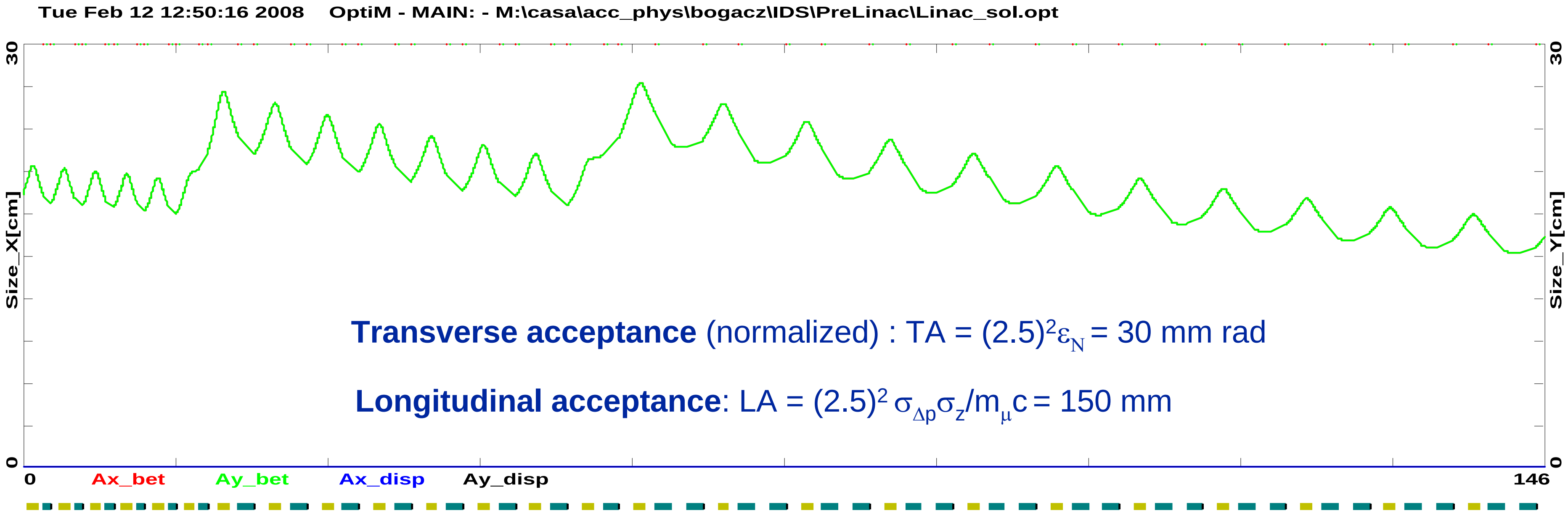


Introduction of synchrotron motion in the linac

Longitudinal acceptance: Δp/p=±0.17 or Δϕ =±93 (200MHz)

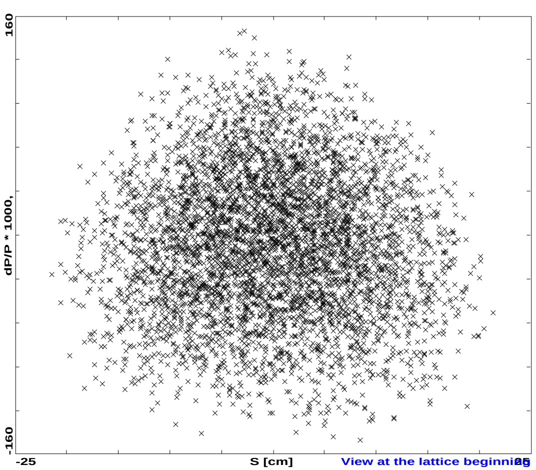


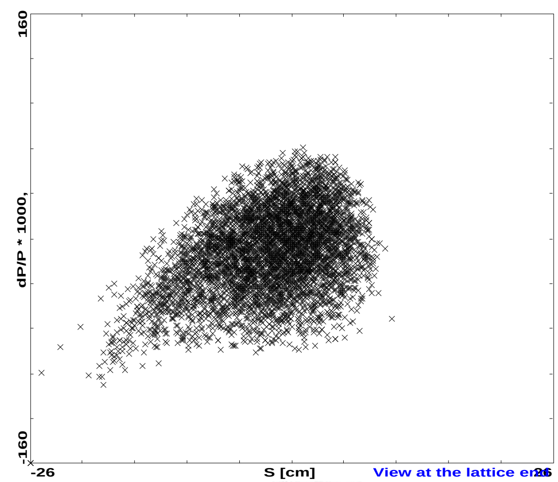
Linear Pre-accelerator – Longitudinal dynamics



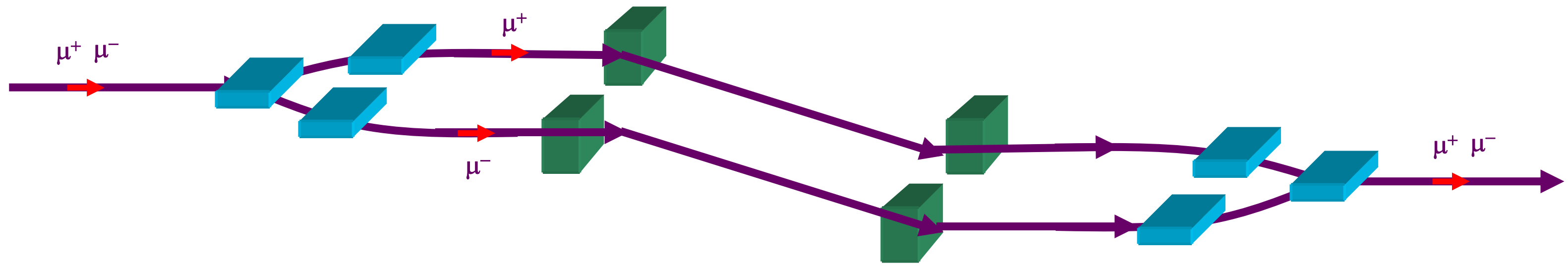
Transverse acceptance (normalized) : TA = $(2.5)^2\varepsilon_N$ = 30 mm rad

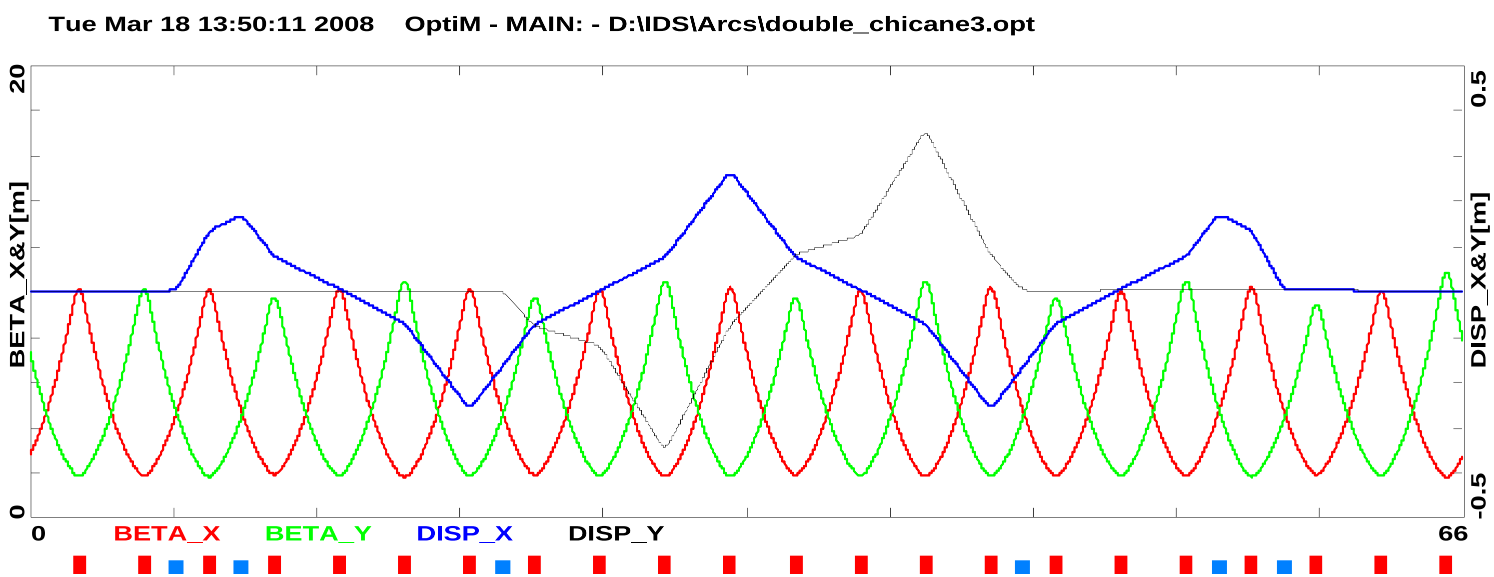
Longitudinal acceptance: LA = $(2.5)^2\,\sigma_{\Delta p}\sigma_z/m_\mu c$ = 150 mm



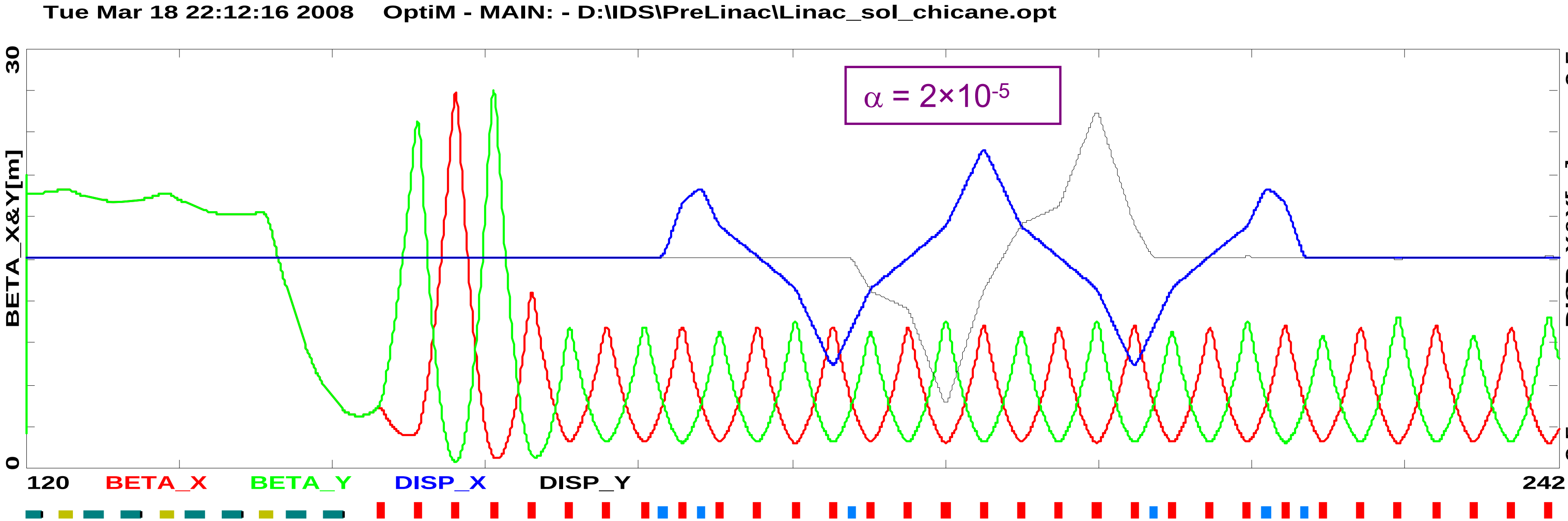


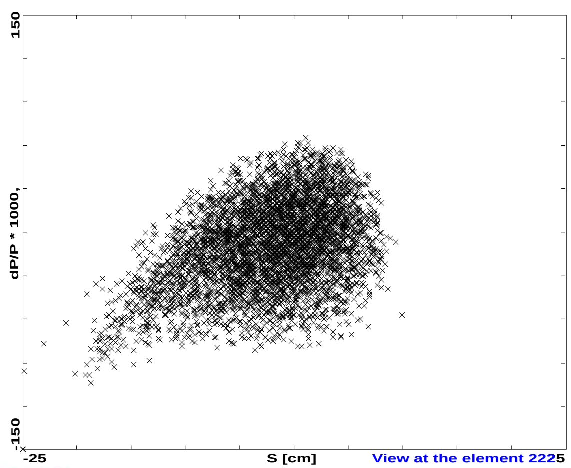
Injection double-chicane

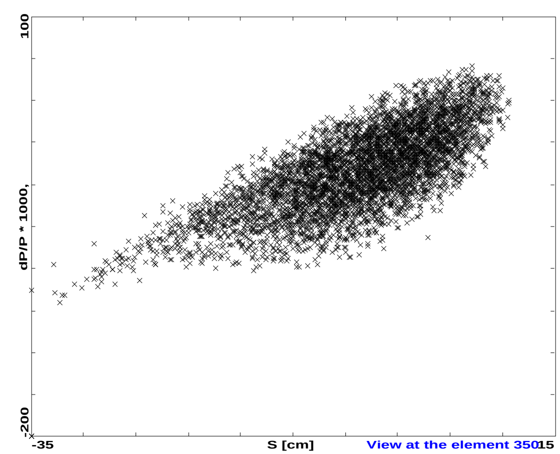




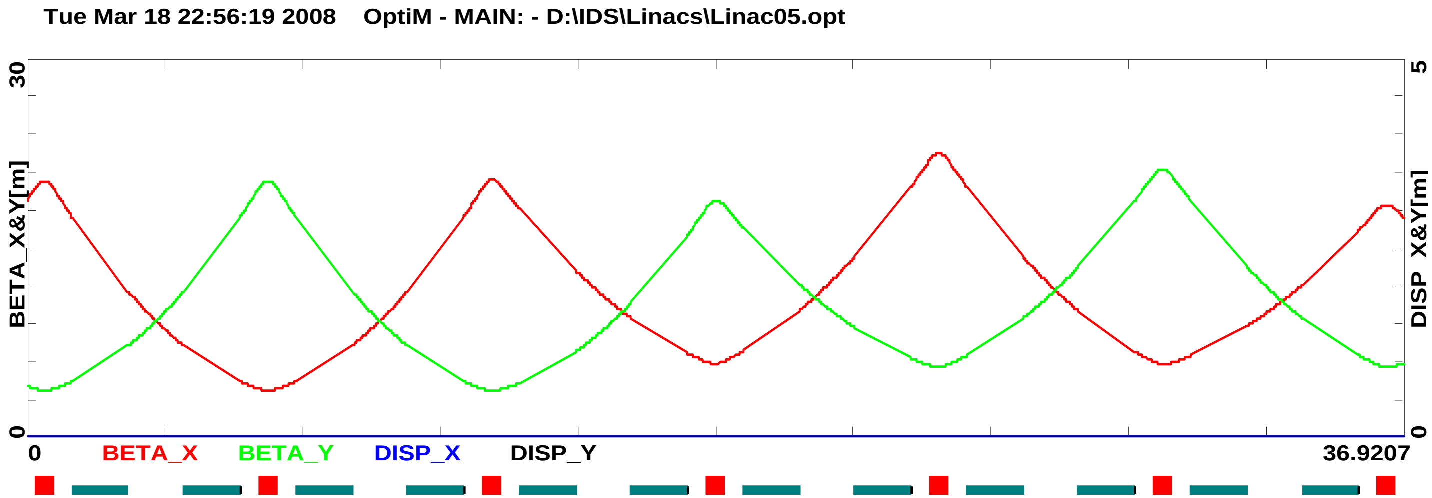
Pre-accelerator–Chicane–Linac Matching

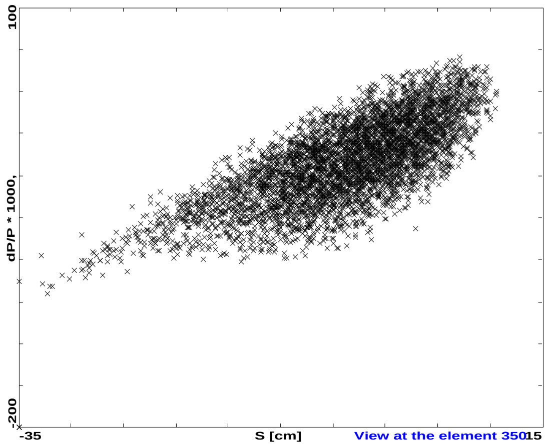


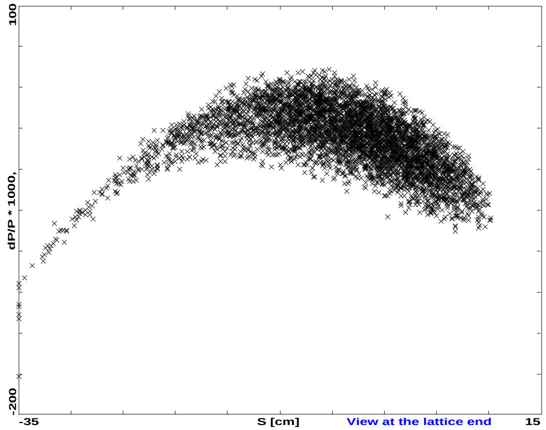




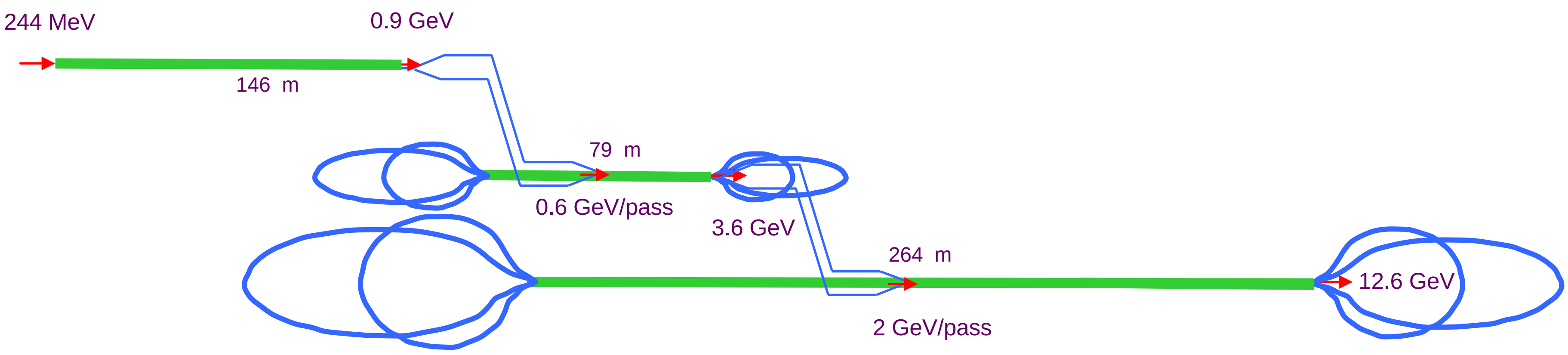
RLA I Linac – Longitudinal Dynamics







Linear Pre-accelerator + RLA complex



'Dogbone' RLA with FODO Focusing

- RLA requirements
  - Simultaneous acceleration of both μ^+ μ^- species
  - Manageable orbit separation at recirculation arcs
- Beam dynamics challenges – RLA Optics solutions
  - Phase slippage in the linacs
  - Multi-pass linac optics
  - Orbit separation – linac ends
  - Droplet return arc – compact lattice design

RLAs for Muon Acceleration

- **'Dogbone'** (Single Linac) RLA has advantages over the Double-Linac RLA 'Racetrack'
  - better orbit separation at linac's end ~ energy difference between consecutive passes ($2\Delta E$)
  - allows both charges to traverse the Linac in the same direction (more uniform focusing profile
  - the droplets can be reduced in size according to the required energy
- **FODO** Optics is superior to Triplet focusing – more passes are possible with the FODO scheme

Phase slippage in the linac

- Phase slippage of a semi-relativistic muon beam injected with the initial energy E_0 and accelerated by ΔE in a linac of length, L – assuming uniformly spaced RF cavities phased for a speed-of-light particle

$$b_{k\ i\ 1} \qquad b_{k\ i} \quad \frac{h}{\ } \, 360 \ \frac{1}{2} \ \frac{m}{Eb_{k\ i}}^{\ 2}$$

$$Eb_{k\ i\ 1} \qquad Eb_{k\ i} \quad h \quad E_k$$

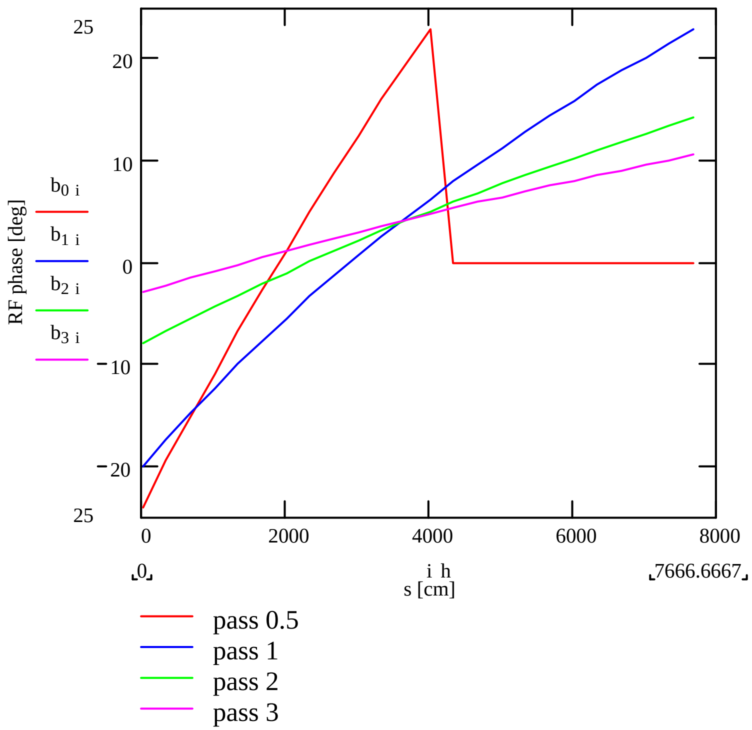
where

$$h \quad \frac{L_{linac}}{N_{cav}} \qquad \frac{c}{f_0} \qquad k \quad 0 \ \ 4 \qquad i \quad 0 \ \ 1N_{cav} \quad 1$$

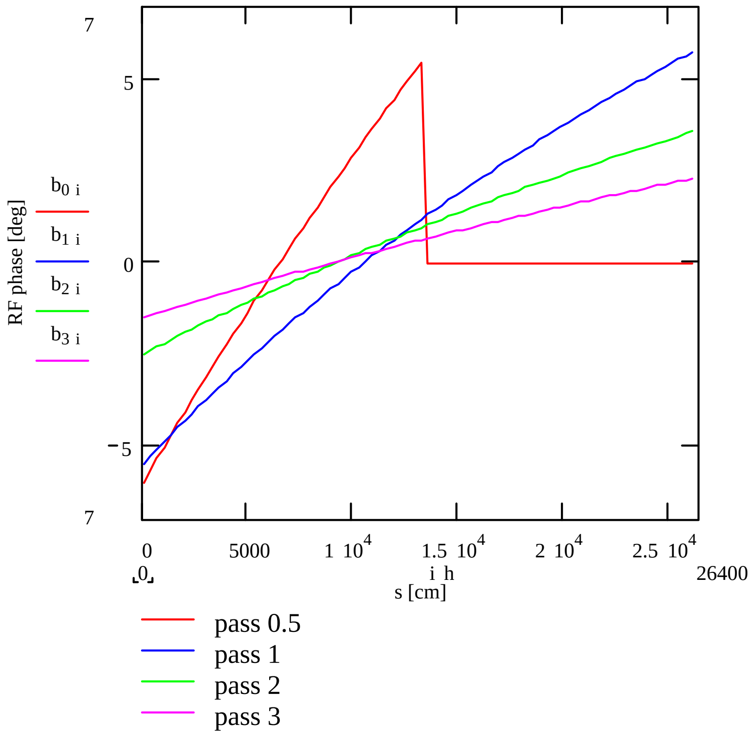
- The injection energy, E_0 , needs to be chosen, so that a tolerable level of the RF phases slippage along the main linac can be maintained (~40 deg).

Phase slippage in the RLA linac

RLA I (0.6 GeV/pass)



RLA II (2 GeV/pass)



RF phase slippage along the multi-pass linacs; initial **'gang phases'** for each pass were chosen for the optimum longitudinal bunch compression in each linac-Arc segment

Multi-pass Linac Optics

- The focusing profile along the linac (quadrupole gradients) need to be set so that one can transport multiple pass beams within a vast energy range (provide adequate transverse focusing for given aperture) .

- The beam is traversing the linac in both directions – one chooses a **'flat focusing profile'** (Bob Palmer) for the entire linac: e.g. the quads in all cells are set to the same gradient, corresponding to 90 deg. phase advance per cell determined for the lowest energy (injection) – no quad scaling with energy

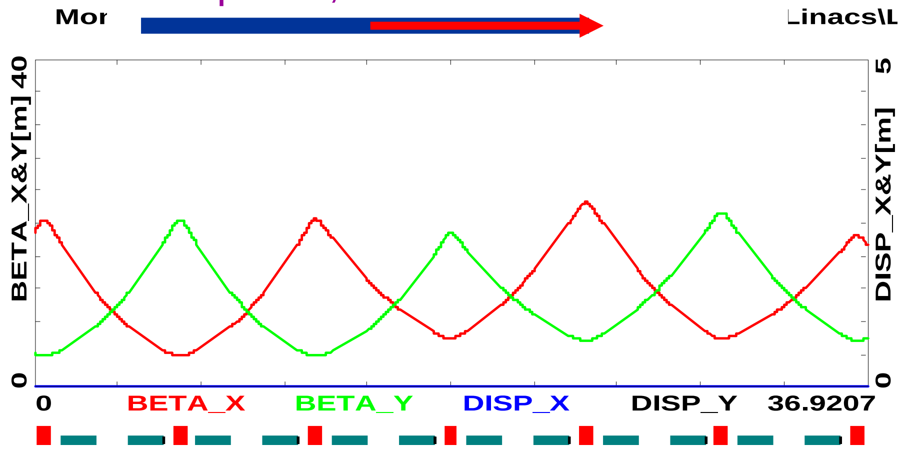
- The requirement of simultaneous acceleration of both $\mu^{\pm}$ species imposes **mirror symmetry** of the 'droplet' Arcs optics (the two species move in the opposite directions through the Arcs). This in turn puts a constraint on the exit/entrance Twiss functions for the two consecutive linac passes:

$$\beta^{out}_{n} = \beta^{in}_{n+1} \text{ and } \alpha^{out}_{n} = -\alpha^{in}_{n+1}$$

where n = 0, 1, 2.. is the pass index

FODO - 'flat focusing' linac profile

'half pass' , 900-1200 MeV

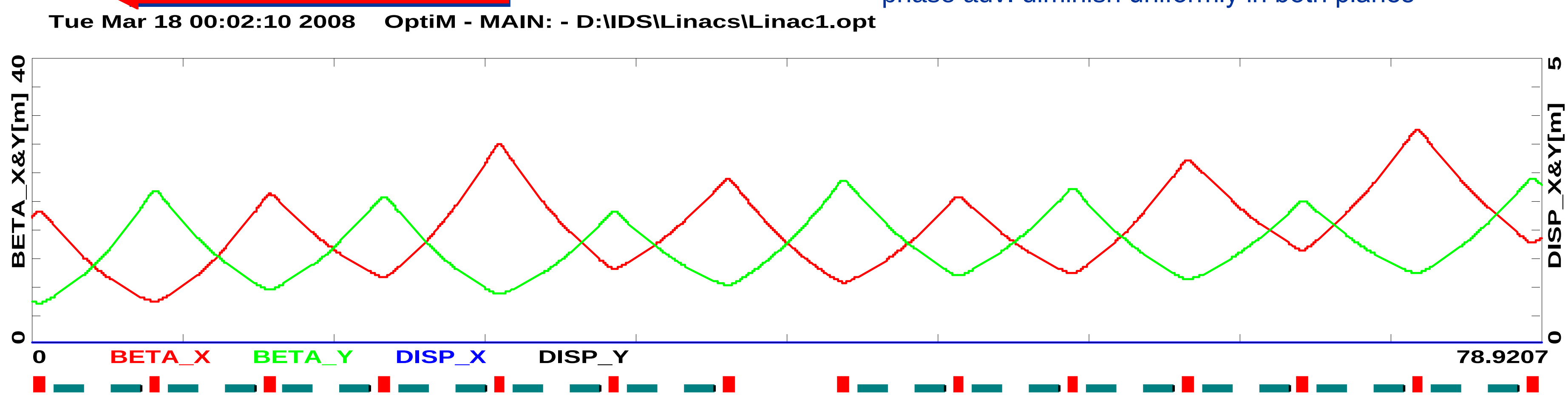


initial phase adv/cell 90 deg – fixed gradient in all cells (no scaling with energy)

Linac cryo-module – solenoid replaced with a quad

1-pass, 1250-1800 MeV

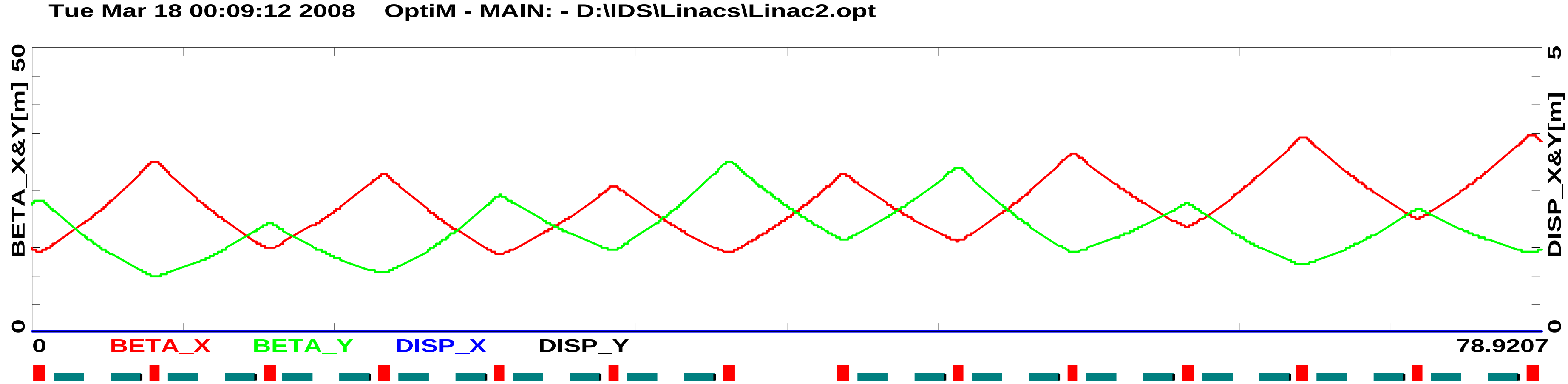
phase adv. diminish uniformly in both planes



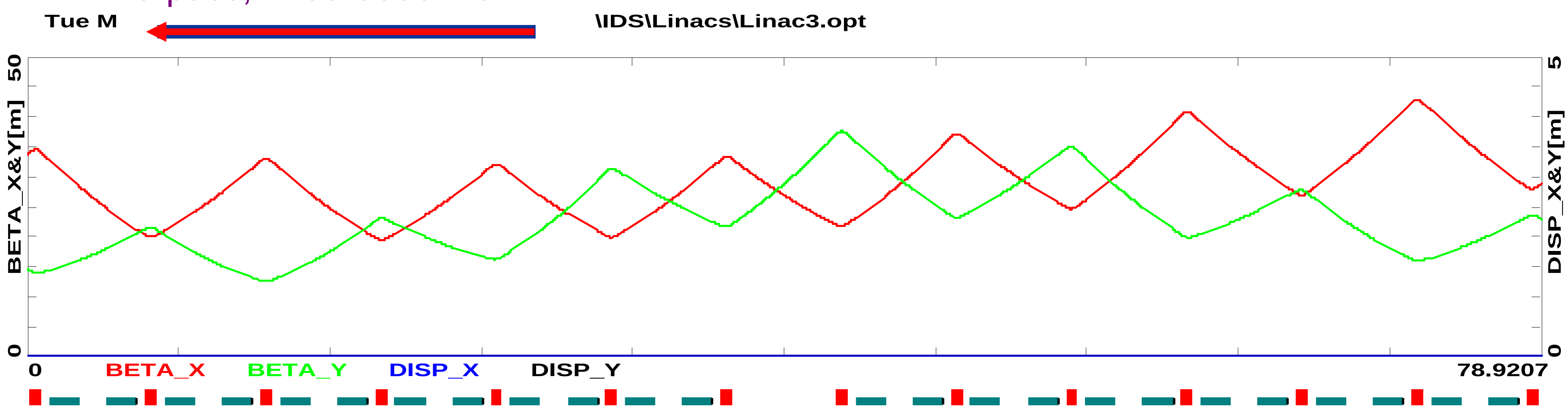
FODO - ‘flat focusing' linac profile

2-pass, 1800-2400 MeV

phase adv. diminish uniformly in both planes



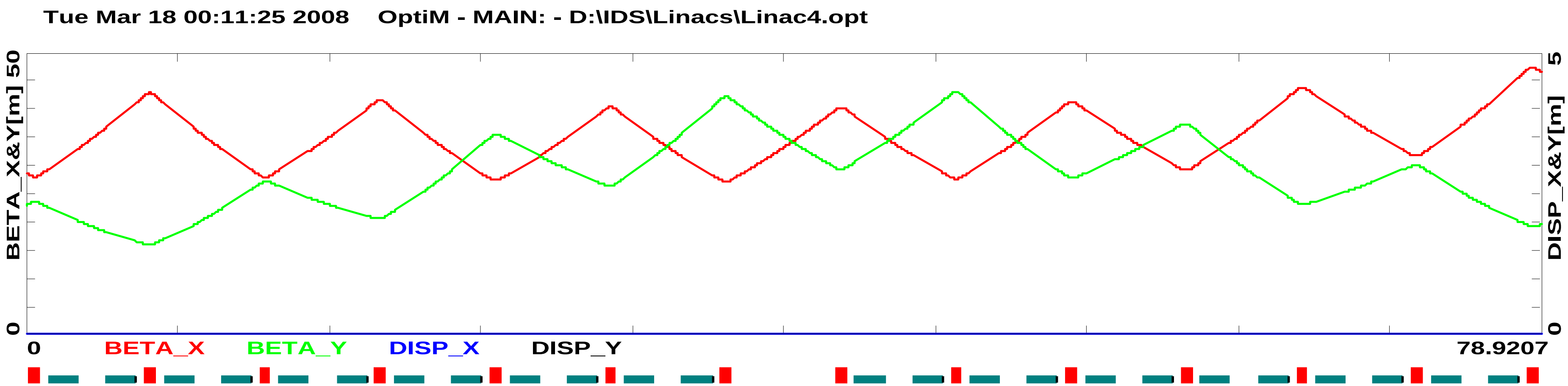
3-pass, 2400-3000 MeV

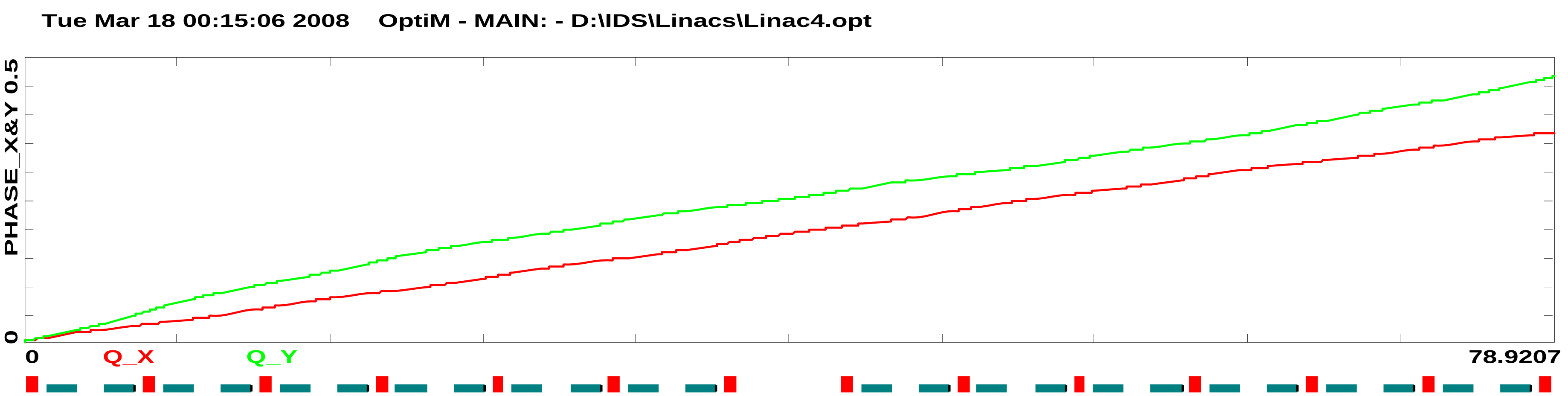


FODO - 'flat focusing' linac profile

4-pass, 3000-3600 MeV

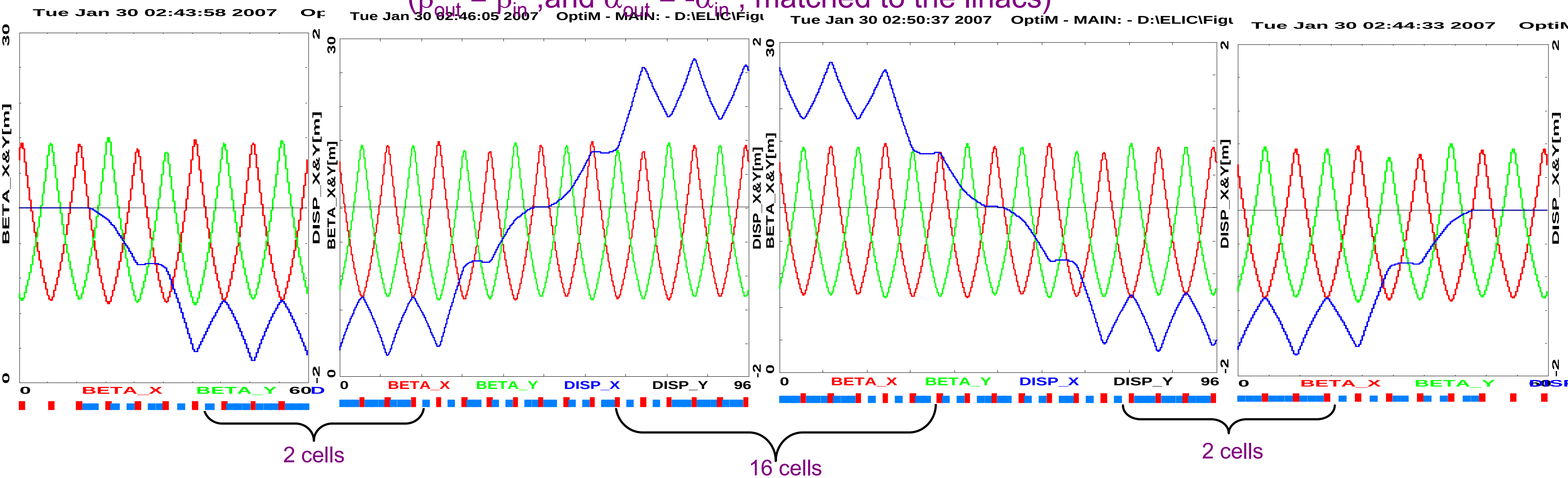
phase adv. still larger then 180 deg. in both planes

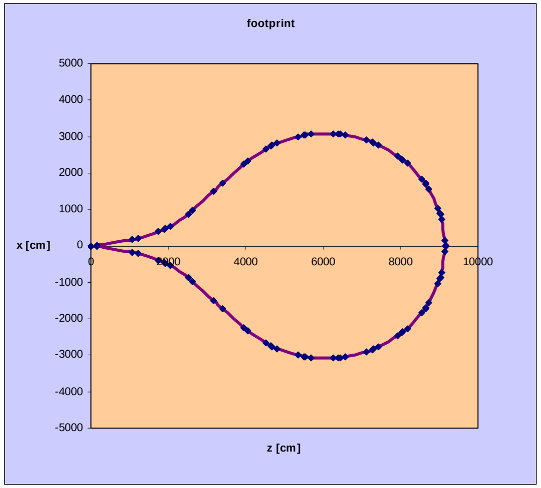




Mirror-symmetric ‘Droplet’ Arc – Optics

($\beta_{out} = \beta_{in}$, and $\alpha_{out} = -\alpha_{in}$, matched to the linacs)





Summary

- IDS Goals – laying **engineering design foundation**
  - Define beamlines/lattices for all components
  - Design lattices for transfer lines between the components
  - Resolve physical interferences, beamline crossings etc $\Rightarrow$ Floor Coordinates
- Carry out end-to-end tracking study $\Rightarrow$ Machine Acceptance
- Implementing chromatic corrections with sextupoles
- Engineer individual active elements (magnets and RF cryo modules)
- Element count and costing