Low Energy Stages - ‘Dogbone’ Muon RLA

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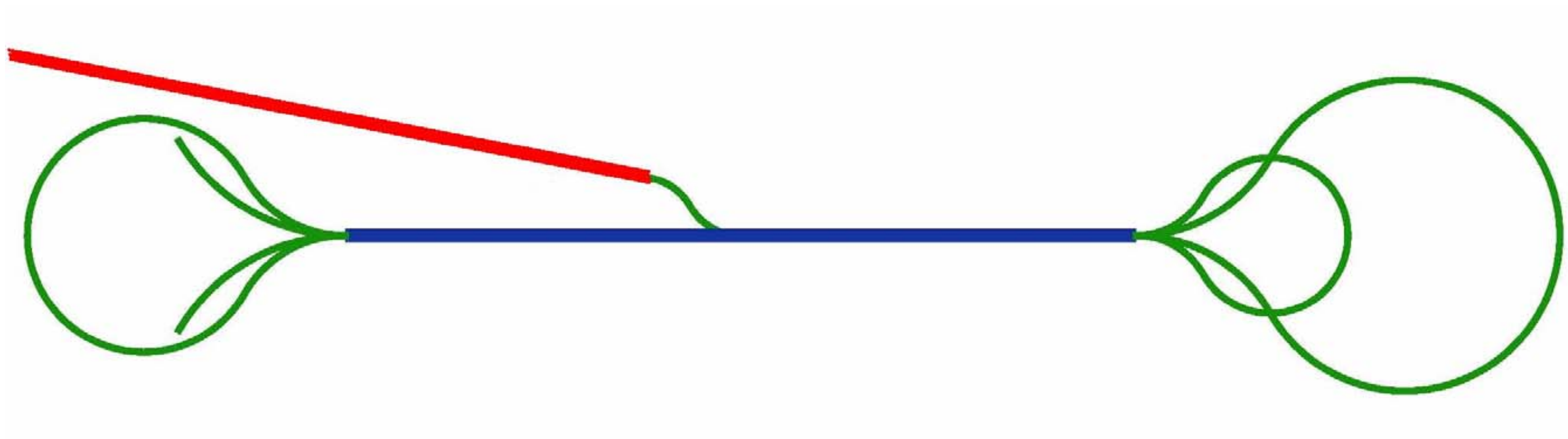
- FFAG acceleration below 5GeV not feasible (cost effective)
- ‘Dogbone’ RLA (3.5-pass) scheme based on 200MHz SRF
  - Pre-accelerator (273 MeV/c – 1.5 GeV) based on solenoid focusing
  - Main Linac (1 GeV/pass) based on triplet focusing
  - Three Arcs with horizontal multi-pass separation
- Initial beam parameters for Study IIa – after cooling at 273 MeV/c
- Lattices – linear optics, tracking studies

'Dogbone' RLA (3.5-pass) scheme



- Pre-accelerator (273 MeV/c – 1.5 GeV) – solenoid focusing
- Main Linac (1 GeV/pass) – triplet focusing
- Single magnet horizontal multi-pass separation
- 3 Arcs based on the same strength of bending magnets (~ 1 Tesla)

Initial beam emittance/acceptance after cooling at 273 MeV/c

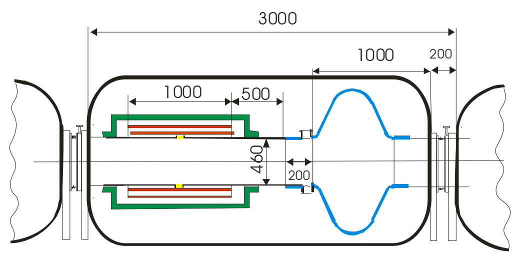
Study IIa		ε_{rms}	$A = (2.5)^2\ \varepsilon$
normalized emittance: $\varepsilon_x/\varepsilon_y$	mm·rad	4.8	30
longitudinal emittance: ε_ℓ $(\varepsilon_\ell = \sigma_{\Delta p}\ \sigma_z/m_\mu c)$ momentum spread: $\sigma_{\Delta p/p}$ bunch length: σ_z	mm mm	27 0.07 176	150 $\pm$0.17 $\pm$442

Machine Parameters

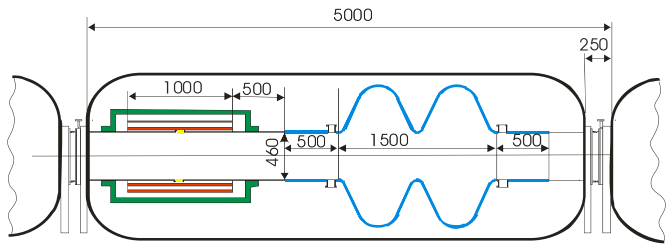
Study IIa		
Final energy	GeV	**5**
Number of bunches per pulse		**89**
Number of particles per per pulse		**$3 \cdot 10^{12}$**
Bunch/accelerating frequency	MHz	**200/200**
Average repetition rate	Hz	**15**
Average beam power	kW	**144**

Pre-accelerator – 3 styles of cryo-modules, solenoid focusing

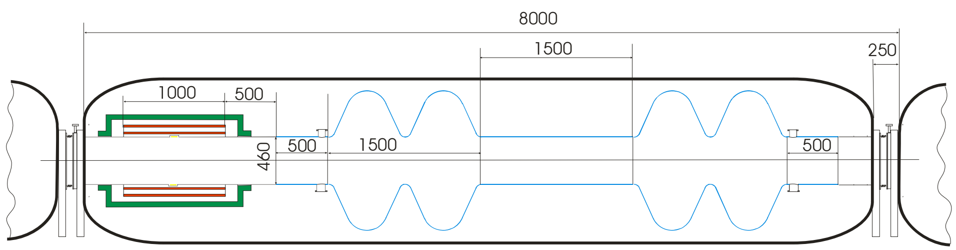
- short (3 m)



- medium (5 m)



- long (8 m)



Blue – SC walls of cavities. Red – solenoid coils. Green – magnetic shielding.

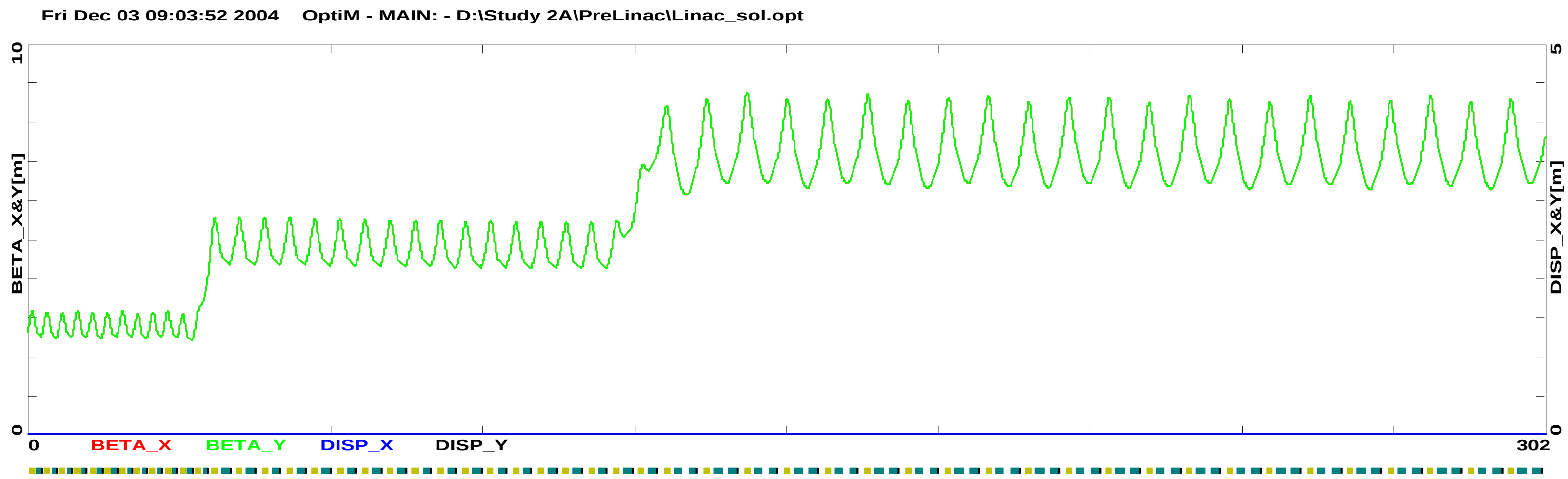
❖Pre-accelerator – parameters of different style cryo-modules

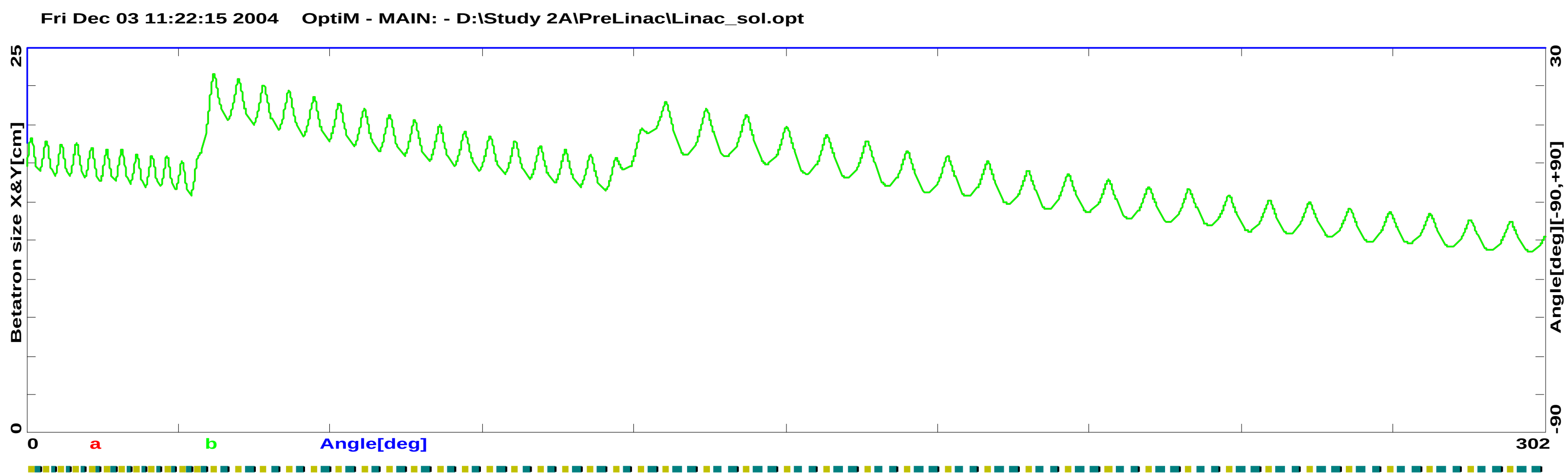
	Short	**Medium**	**Long**
Number of periods	**12**	**18**	**22**
Total length of one period	**3 m**	**5 m**	**8 m**
Number of cavities per period	**1**	**1**	**2**
Number of cells per cavity	**1**	**2**	**2**
Cavity accelerating gradient	**15 MV/m**	**15 MV/m**	**15 MV/m**
Real-estate gradient	**3.72 MV/m**	**4.47 MV/m**	**5.59 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	**1.5 T**	**1.9 T**	**3.9 T**

Total length: 302 m

Total gradient: 2.07 GV

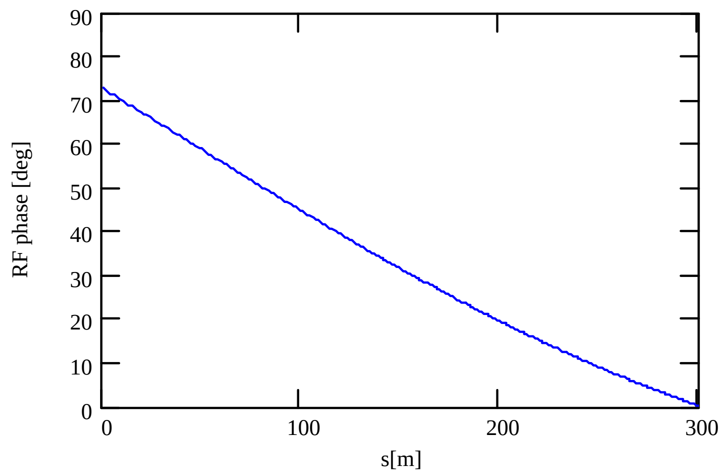
❖Linear Pre-accelerator – Twiss functions and beam envelope (2.5 σ)



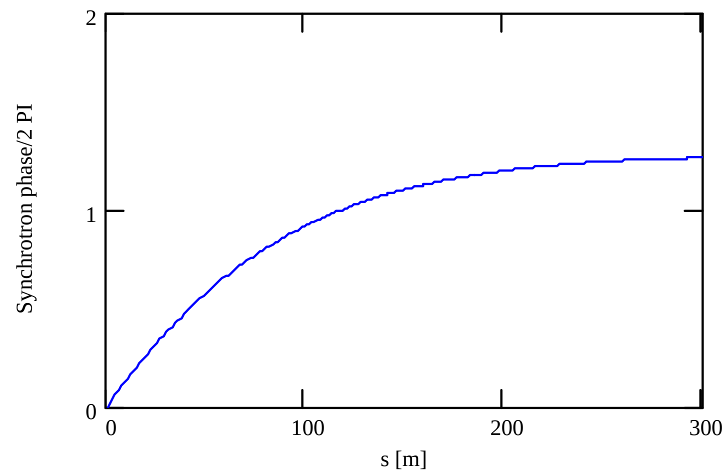


❖ Introduction of synchrotron motion in the initial part of the linac

- allows to perform adiabatic bunching/compression of the beam
- prevents head-to-tail 'sag' in acceleration
- reduction of effective accelerating gradient (1.3GV out of 2 GV)

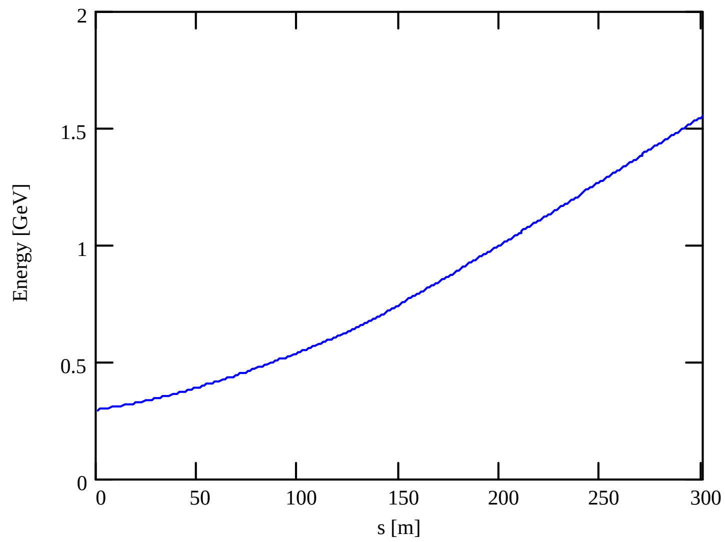


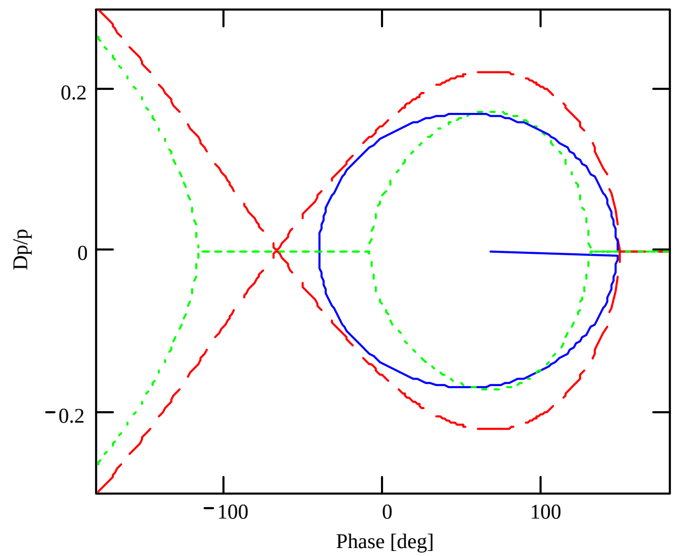
Cavity phase along the linac



Synchrotron phase along the linac

❖Pre-accelerator (273 MeV/c – 1.5 GeV) – Longitudinal dynamics



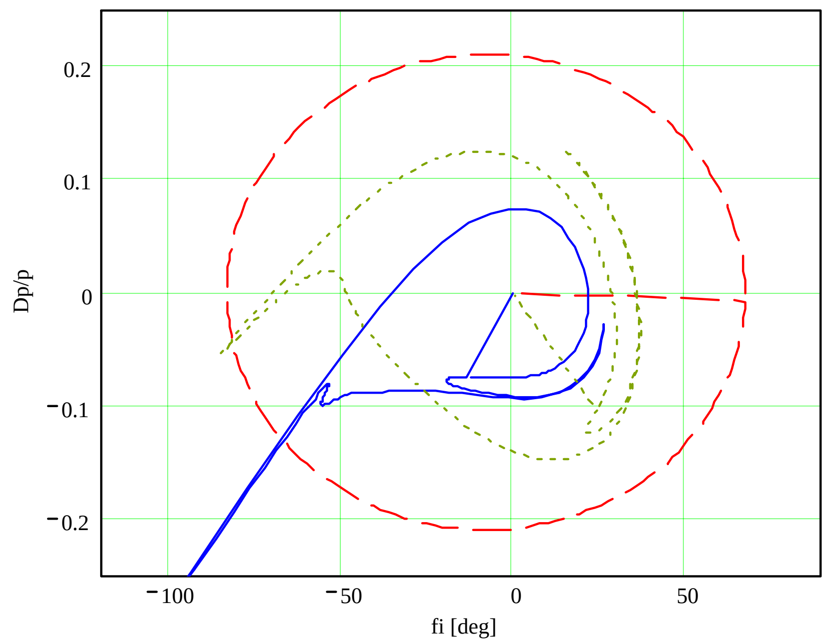


energy profile along the linac

longitudinal acceptance, bucket height

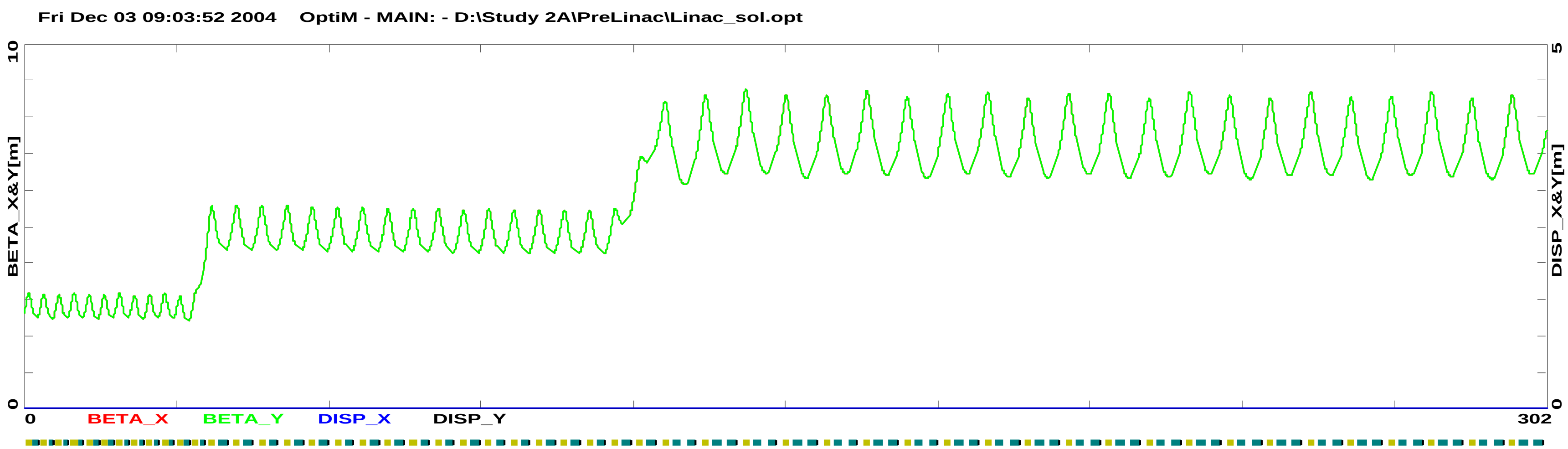
$\Delta p/p=\pm 0.17$or $\Delta\phi = \pm 93$ (200MHz)

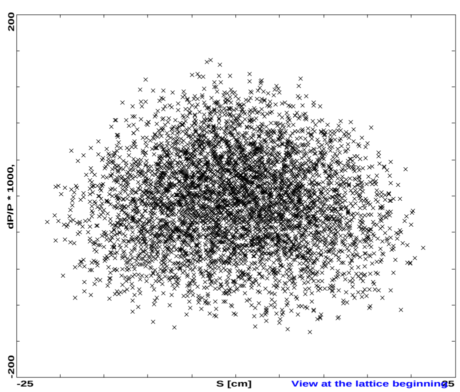
❖Pre-accelerator (273 MeV/c – 1.5 GeV) – Longitudinal acceptance

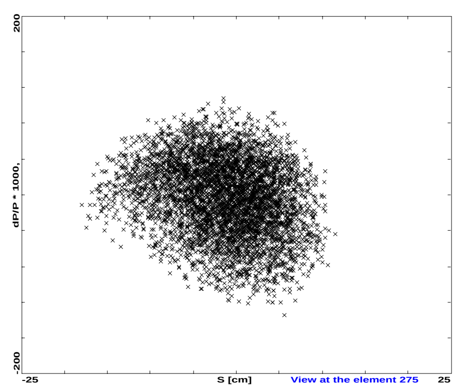


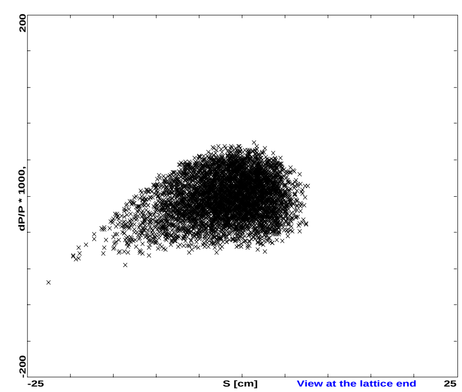
Phase space contours before, half-way through and at the end of acceleration – contours defined for particles at 2.5σ (95% of particles contained inside)

❖Linear Pre-accelerator – Longitudinal dynamics, particle tracking

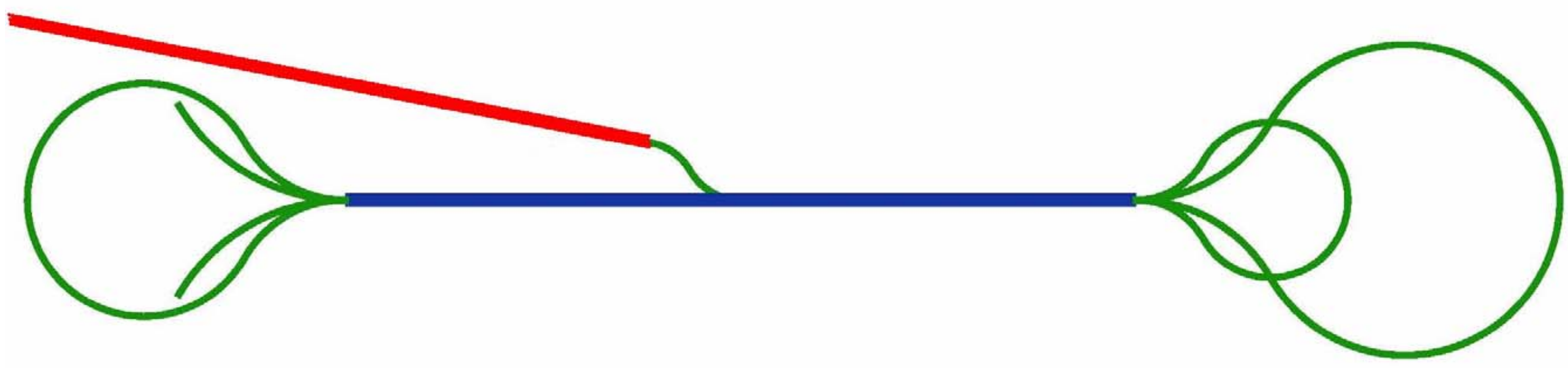






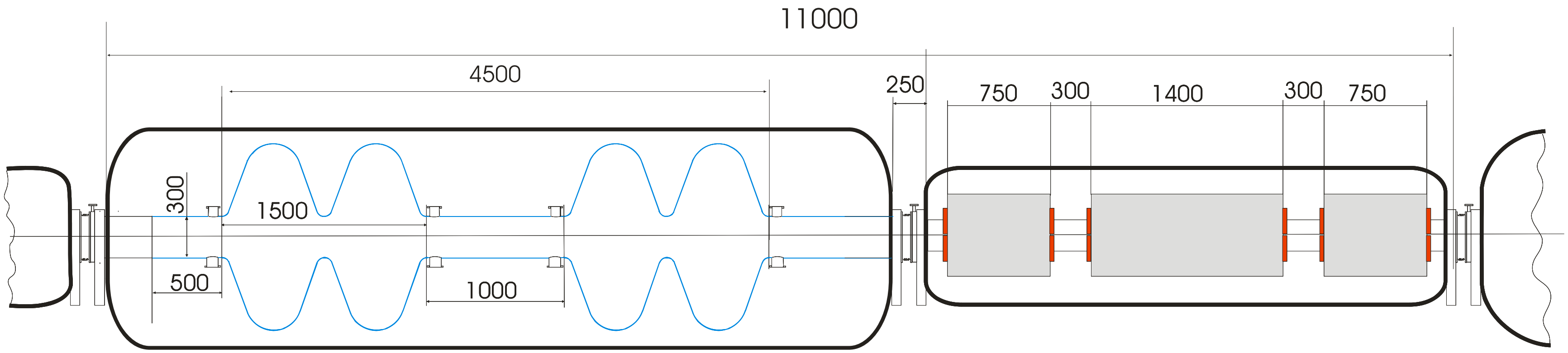


'Dogbone' RLA (3.5-pass) scheme



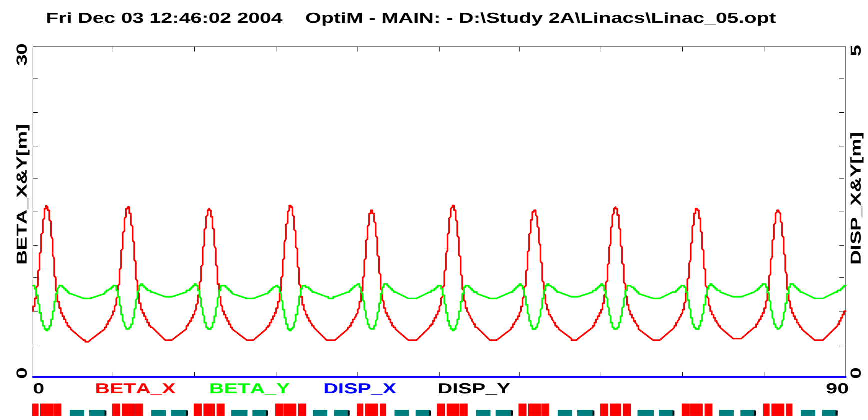
- Multi-pass linac optics
- Focusing compromise strategy
  - Focusing optimized for the half-pass (1.5-2 GeV) – 90^0 phase advance per cell
  - Uniform focusing restored in the second half of the first full-pass (2.5-3 GeV)

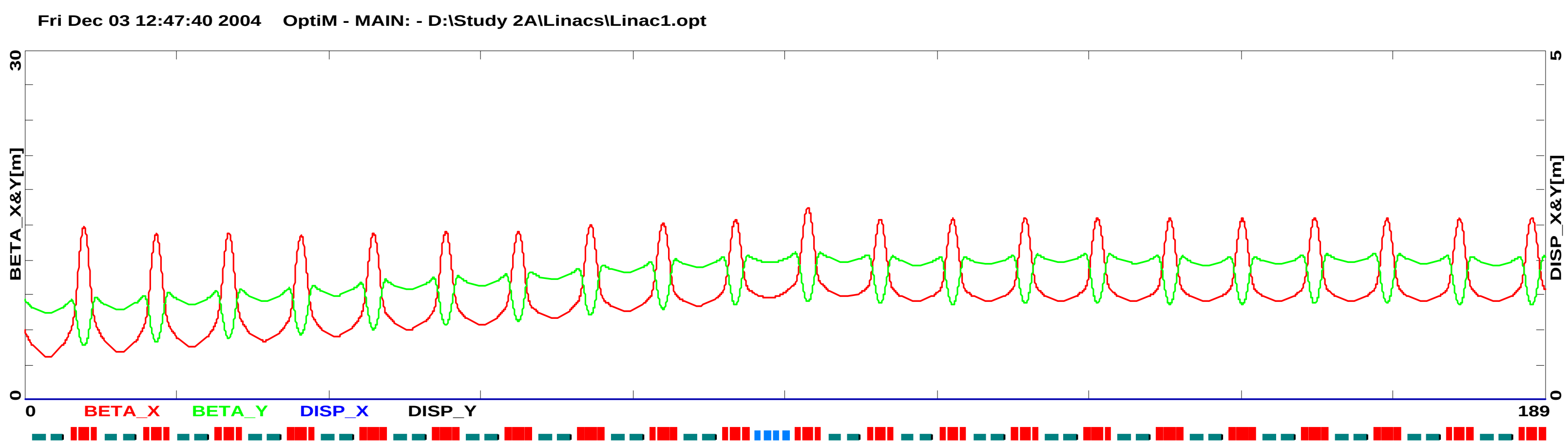
Main linac cell – long cryo-module & triplet



❖Main Linac – multi-pass Optics (lower passes)

1.5-2 GeV

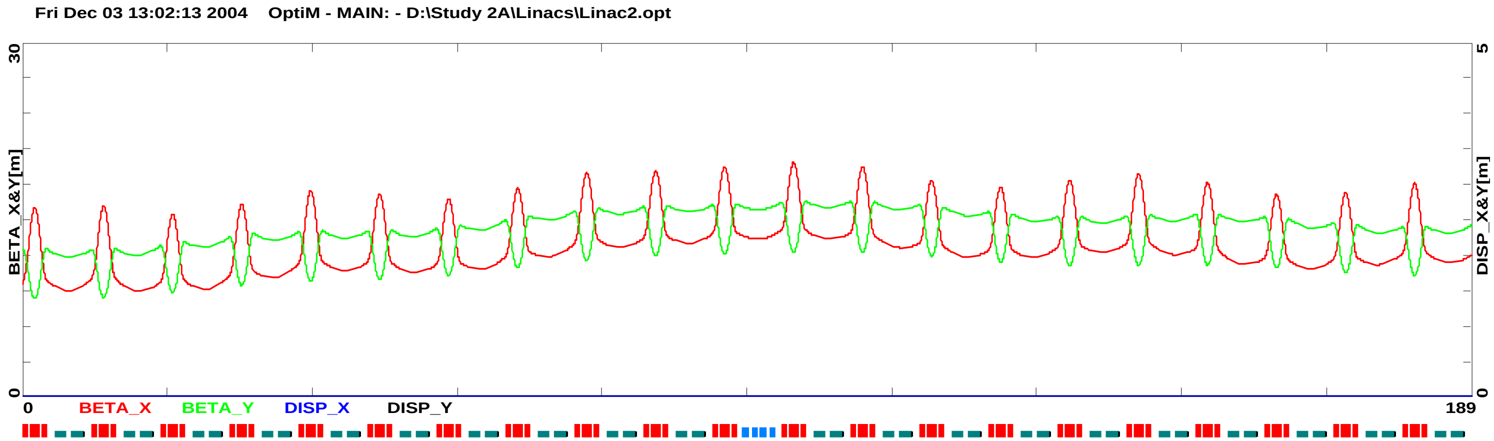




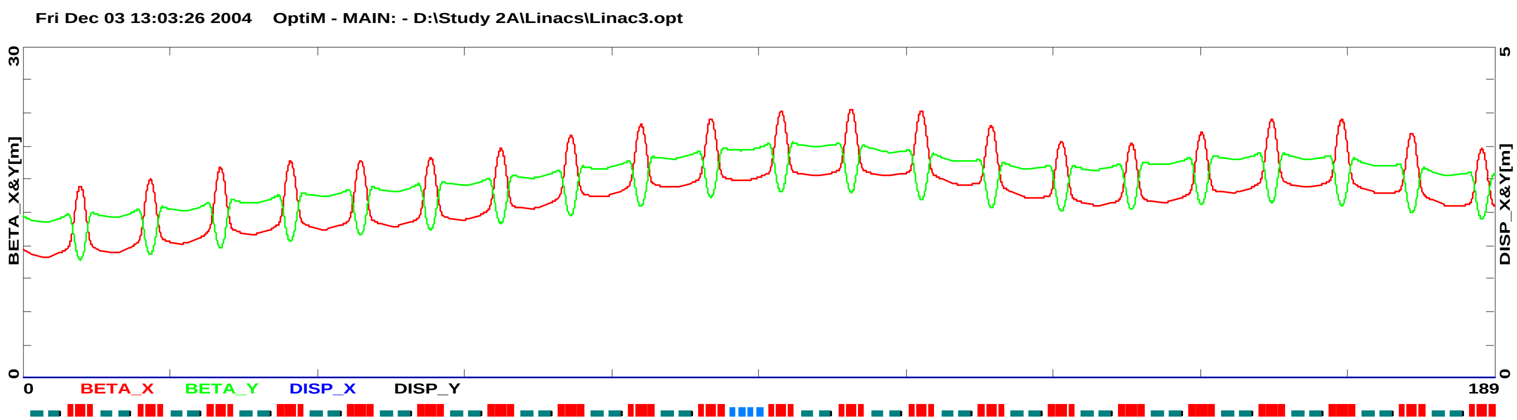
2-3 GeV

❖Main Linac – multi-pass Optics (higher passes)

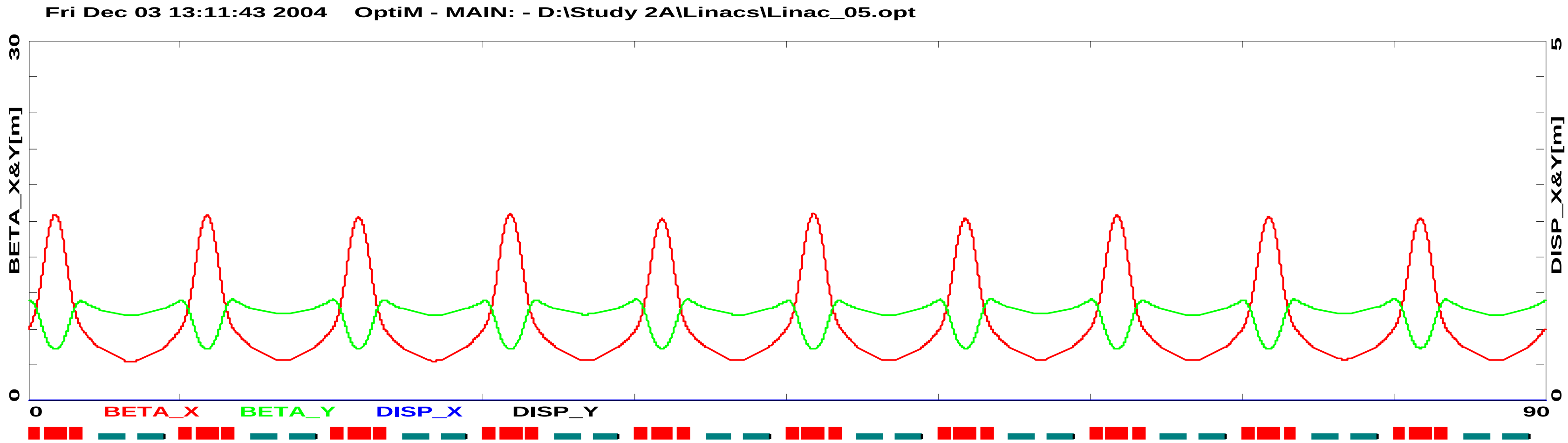
3-4 GeV

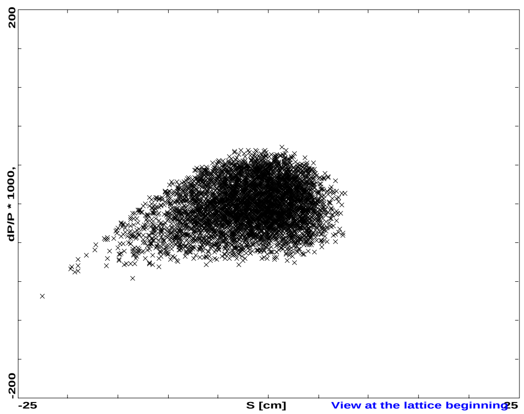


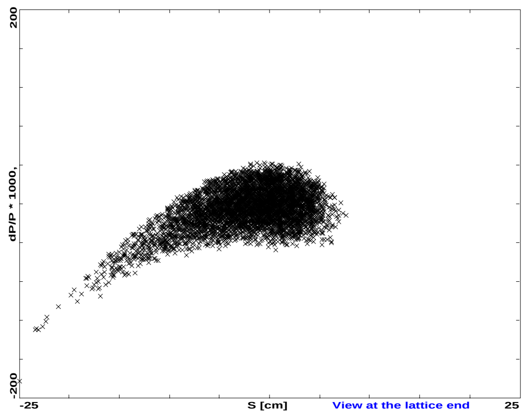
4-5 GeV



❖Main Linac – the half-pass (1.5-2 GeV) longitudinal tracking





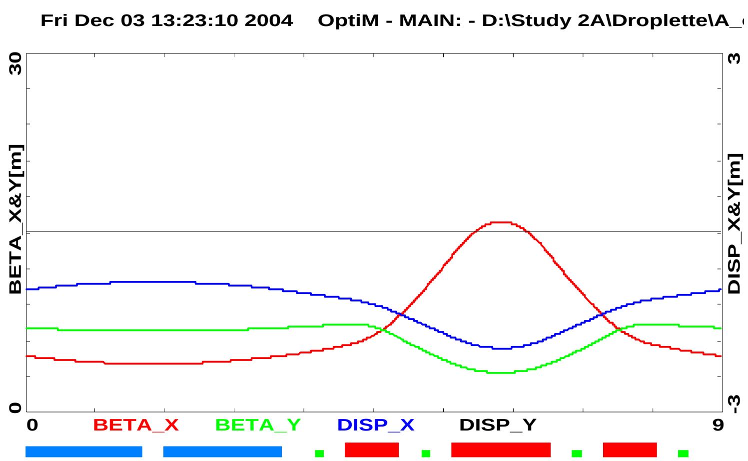


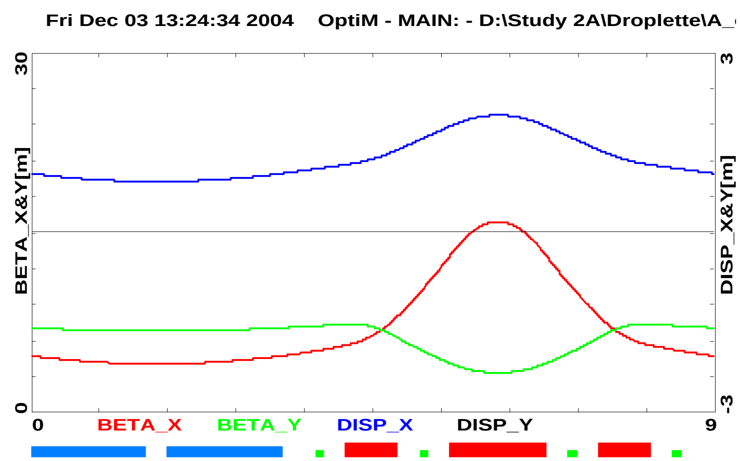
Arc Optics – beam transport choices

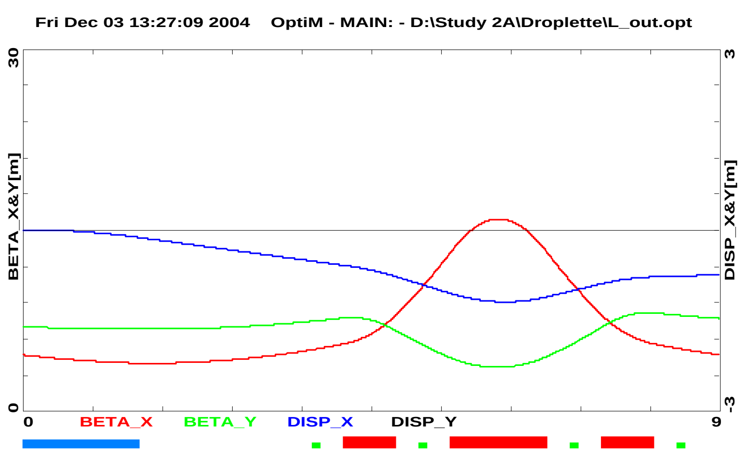
- Principle of uniform focusing periodicity (90^0) – cancellation of chromatic effects
- Single dipole (horizontal) separation of multi-pass beams in RLA
  - No need to maintain achromatic Spreaders/Recombiners
  - Compact Spreaders/Recombiners – minimized emittance dilution
- SC dipoles and quads (triplets) in RLA (1 Tesla dipoles/1 Tesla quads)
- Requirement of high periodicity and ‘smooth’ transition between different kinds of optics, linac-spreader-arc-recombiner-linac

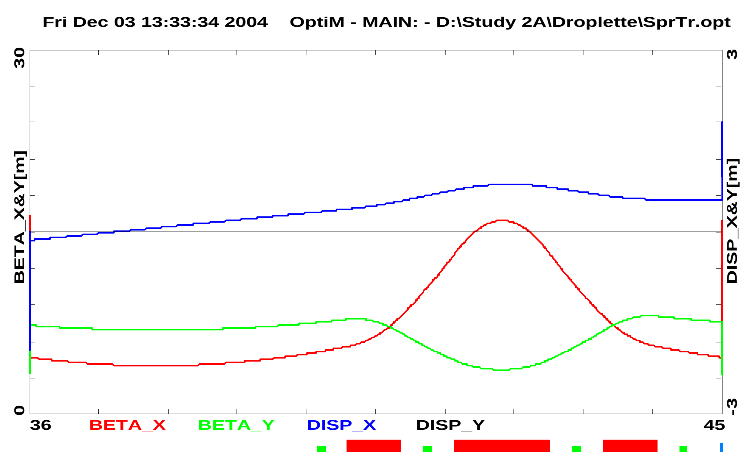
- 'Droplet' return arc footprint (60^0 out – 300^0 in – 60^0 out)

- 'Droplet' return arc (inward and outward cells), missing dipoles



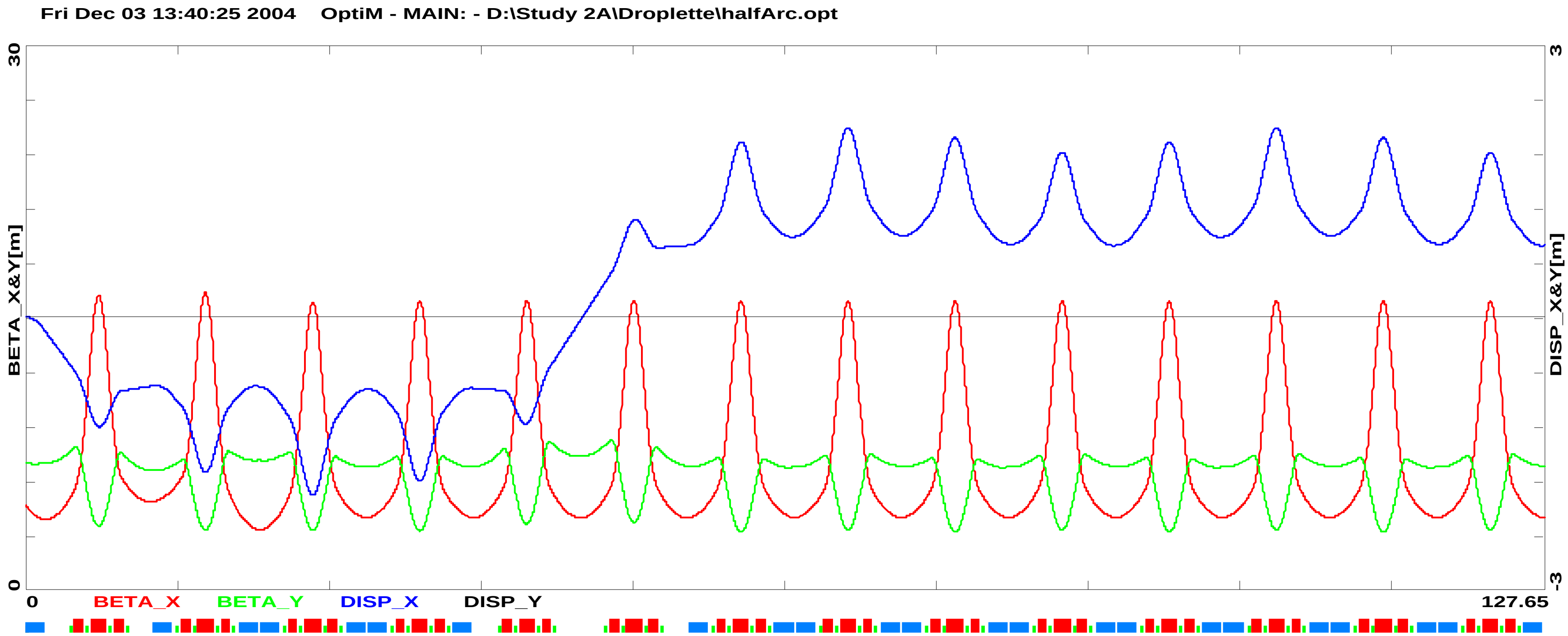






- 'Droplet' return arc footprint (60^0 out – 300^0 in – 60^0 out)

❖'Droplet' return half-Arc (Spreader and Transition)



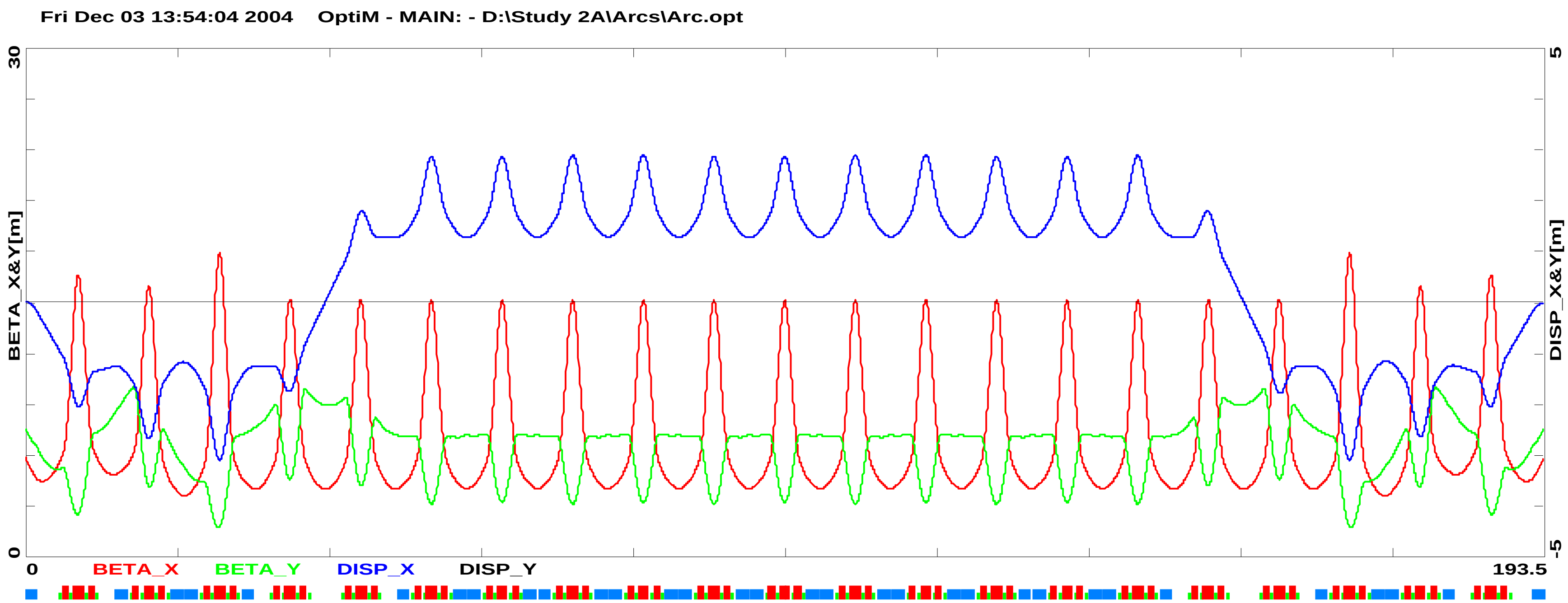
Dipoles:

L[cm]	B[kG]
150	7.8

Quads:

	L[cm]	G[kG/cm]
D	68	-0.32
F	125	0.32

❖'Droplet' return Arc (matched to the linac)



Summary

- Lattice for 3.5-pass, 5 GeV, RLA based on 200MHz SRF – linear optics
  - Pre-accelerator, three styles of cryo-modules
  - Proof-of-principle Arc optics lattice – further longitudinal compression in the Arcs, with M_{56} ~ 3 m
  - multi-pass linac optics
  - compact Spr/Rec - 'smooth' transition of optics between linacs and Arcs
- Still to be demonstrated… Emittance preservation scheme – nonlinear corrections in the Arcs
  - Chromatic corrections in the Arcs to effectively restore longitudinal space linearity (via three families of sextupoles)
  - Emittance preservation checked independently by ICOOL