RLA Muon Acceleration – Low Emittance Option

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- Lower initial 6D emittance (momentum spread/beam sizes) promised by the 'Next Generation Cooling Devices', eg, the Helical Cooling Channel
- 5-pass, 20 GeV RLA based on 400MHz SRF - linear optics
  - Simplified front-end linear Pre-accelerator (400 MHz SRF)
  - Compact Spr/Rec – 'smooth' transition of optics between linacs and Arcs
  - Optimized multi-pass linacs optics
- Transverse emittance preservation scheme
  - Chromatic corrections with sextupole families

Estimated final parameters of a helical 6D cooling channel♣

Parameter	Unit	equilibrium rms value
Beam momentum, p	MeV/c	250
Synchrotron emittance, ε_s	mm	0.3
Relative momentum spread	%	2
Beam width due to $\Delta p / p$	mm	1.5
Bunch length	mm	21
Transverse emittances, $\varepsilon_+ / \varepsilon_-$	mm-mr	100/300
Beam widths, σ_1 / σ_2	mm	4.5/2.8

♣Helical cooling channel – J-Lab/Muons Inc. SBIR proposal

Initial beam emittance after cooling at 250 MeV/c

rms values		Study II Cooler*	Helical Cooler♣
normalized emittance: $\varepsilon_x/\varepsilon_y$	mm·rad	2.4	0.1/0.3
longitudinal emittance: ε_ℓ ($\varepsilon_\ell = \sigma_{\Delta p}\, \sigma_z/m_\mu c$)	mm	27	0.3
momentum spread: $\sigma_{\Delta p/p}$		0.08	0.02
bunch length: σ_z	mm	163	21

*straight ionization cooling channel

♣Derbenev/Johnson helical cooling channel

Pre-accelarator acceptance at 250 MeV/c

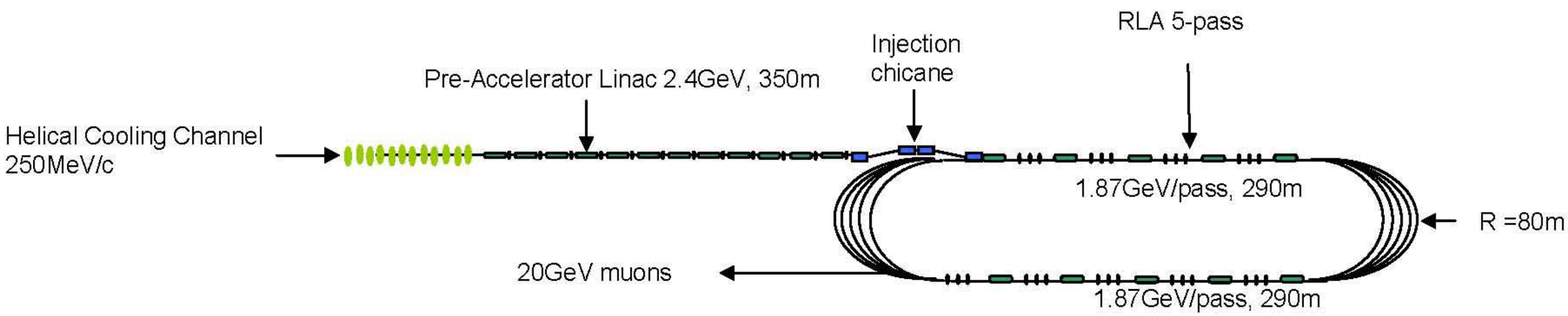
$A = (2.5)^2\ \varepsilon$		Study II Cooler*	Helical Cooler♣
normalized transv. acceptance	mm·rad	15	0.25/0.75
longitudinal emittance: A_ℓ $(A_\ell = \Delta p\ L/m_\mu c)$ momentum spread: $\Delta p/p$ bunch length: L	mm mm	170 ±0.20 408	0.75 ±0.05 52

*straight ionization cooling channel

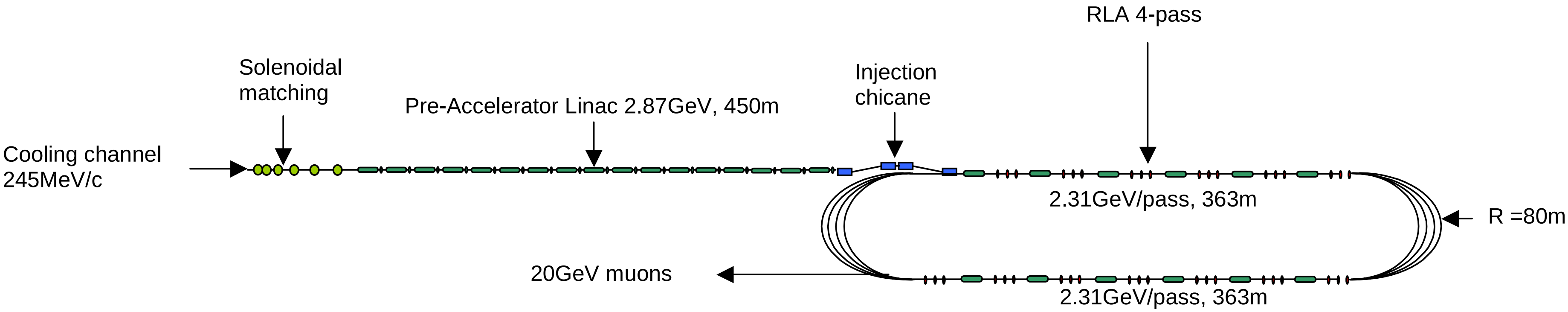
♣Derbenev/Johnson helical cooling channel

❖RLA based muon accelerator complex (250MeV/c – 20GeV)

Helical Cooler scenario

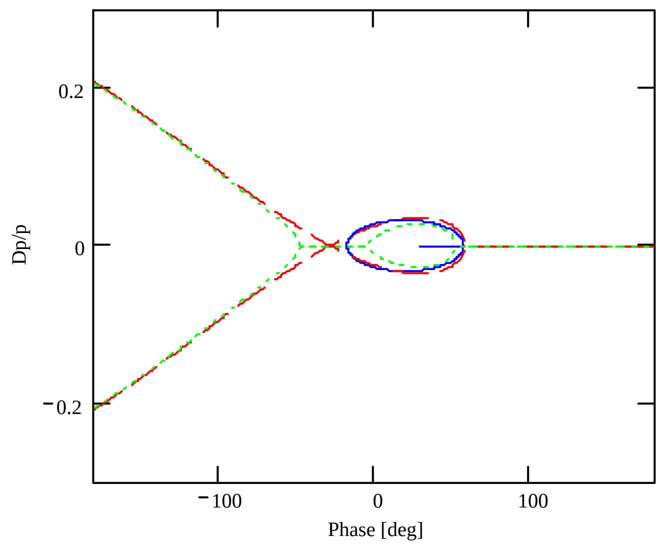


Study II scenario



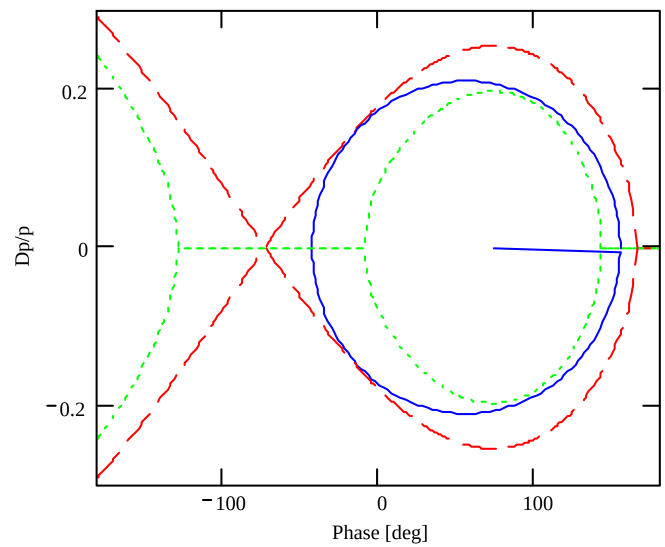
❖ Linear Pre-accelerator – Longitudinal dynamics

$\Delta p/p = \pm 0.05$ or $\Delta\phi = \pm 52$ (400MHz)



'Helical Cooler' scenario

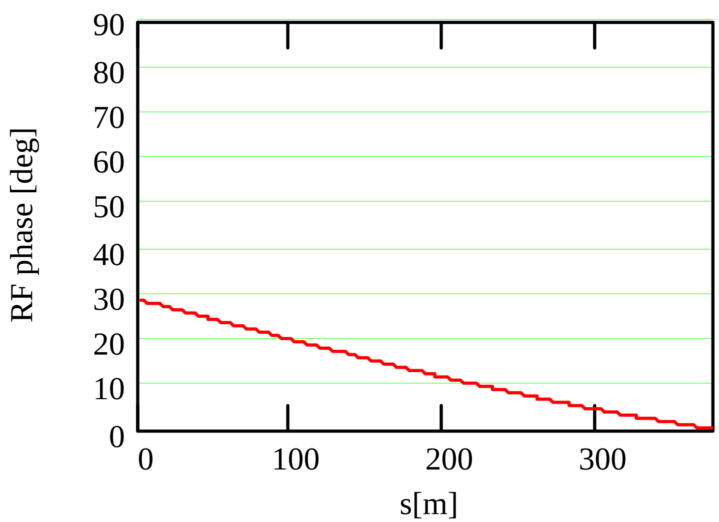
$\Delta p/p = \pm 0.21$ or $\Delta\phi = \pm 89$ (200MHz)



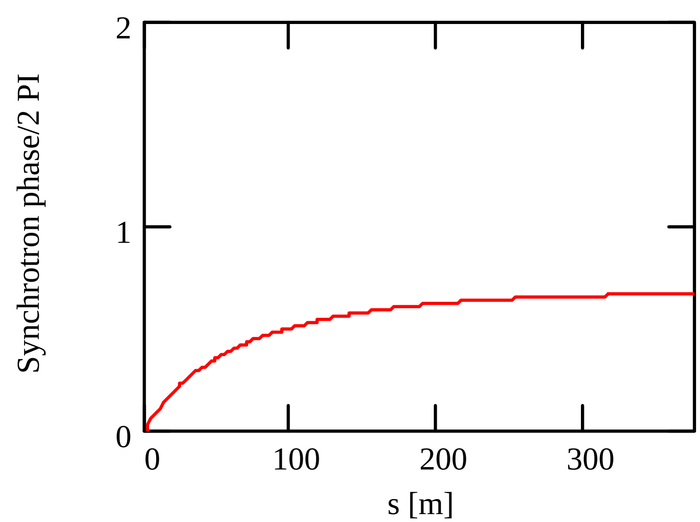
'Study II' scenario

❖ Introduction of 'modest' 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
- 'small' reduction of effective accelerating gradient (2.1 GV out of 2.4 GV)



Cavity phase along the linac

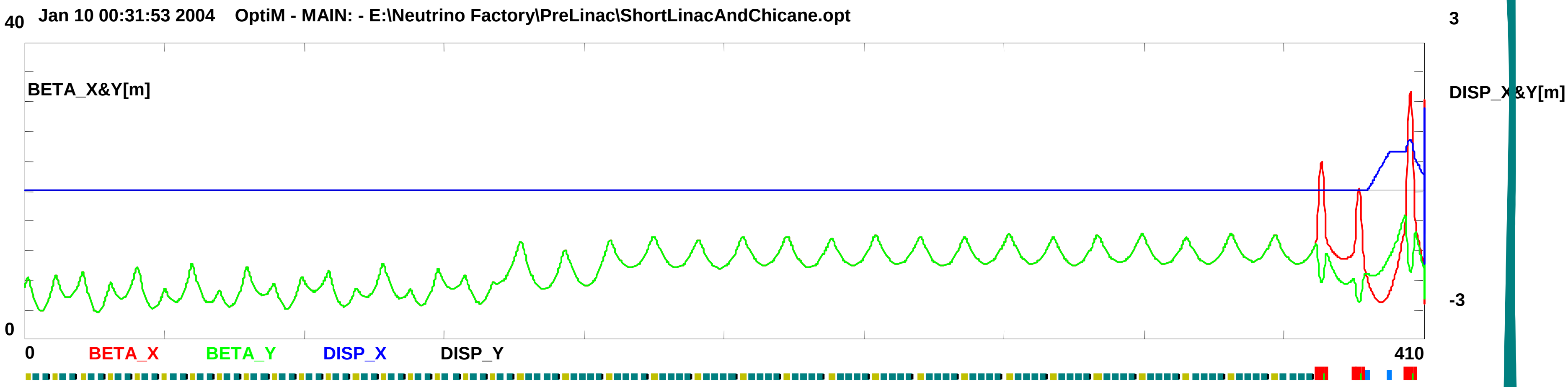


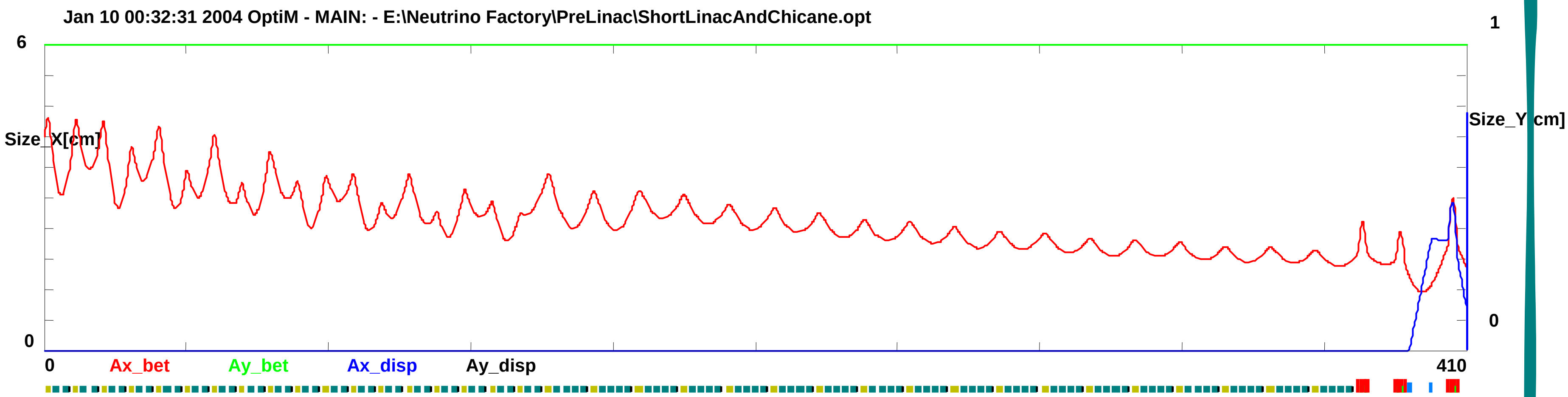
Synchrotron phase along the linac

- Short Pre-accelerator - only two flavors of cryo-modules (short and long)
  - Short cruo-module – 1 SC solenoid + 2 cavities (two-cell 400MHz cavities)
  - Long cruo-module – 1 solenoid + 4 cavities (two-cell 400MHz cavities)
  - Cryo-module design driven by limiting power of the fundamental couplers (~1 MW) – 1 coupler per cell required
- Pre-accelerator – cryo-module parameters

	Short cryo-module	Long cryo-module
Number of periods	12	18
Total length of one period	8 m	13 m
Cavity accelerating gradient	15 MV/m	17 MV/m
Real-estate gradient	5.59 MV/m	7.79 MV/m
Aperture in cavities (2*a*)	56 mm	40 mm
Aperture in solenoids (2*a*)	56 mm	42 mm
Solenoid length	1 m	1.5 m
Solenoid maximum field	2.1 T	4.2 T

❖Linear Pre-accelerator – Lattice layout, Beam envelope



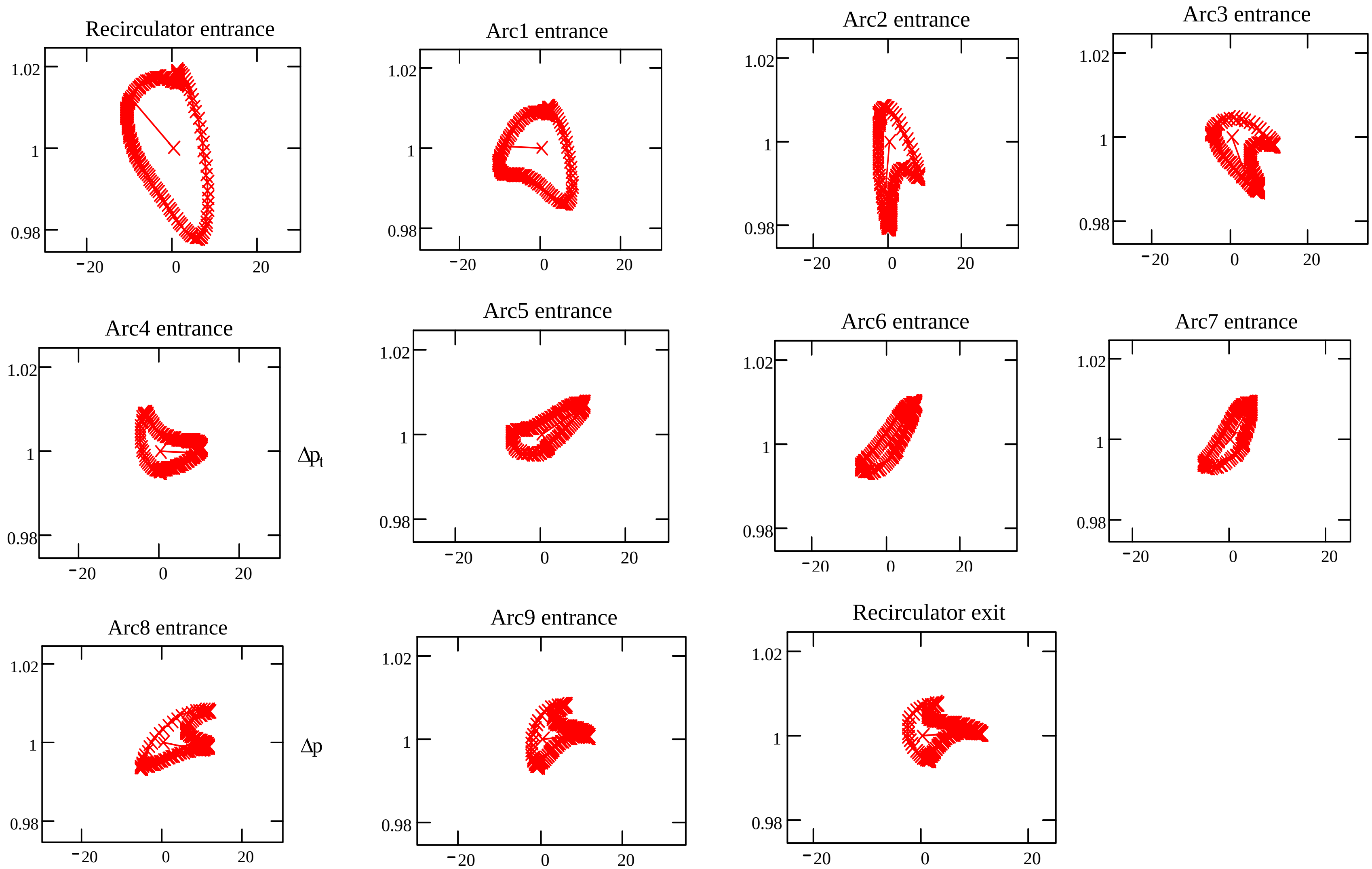


Beta-functions & beam envelopes (2.5σ) (from 250MeV/c to 2392MeV)

Main parameters for the RLA

Initial energy	2.39 GeV
Final energy	20 GeV
Number of passes	5
Total initial energy acceptance	±0.02
Total final energy acceptance	±0.006
Initial transverse acceptance	60 mm·mrad
Final transverse acceptance, $\varepsilon_x / \varepsilon_y$	15/10 mm·mrad
Total voltage per linac	1.86776 GV
Circumference	≈1100 m

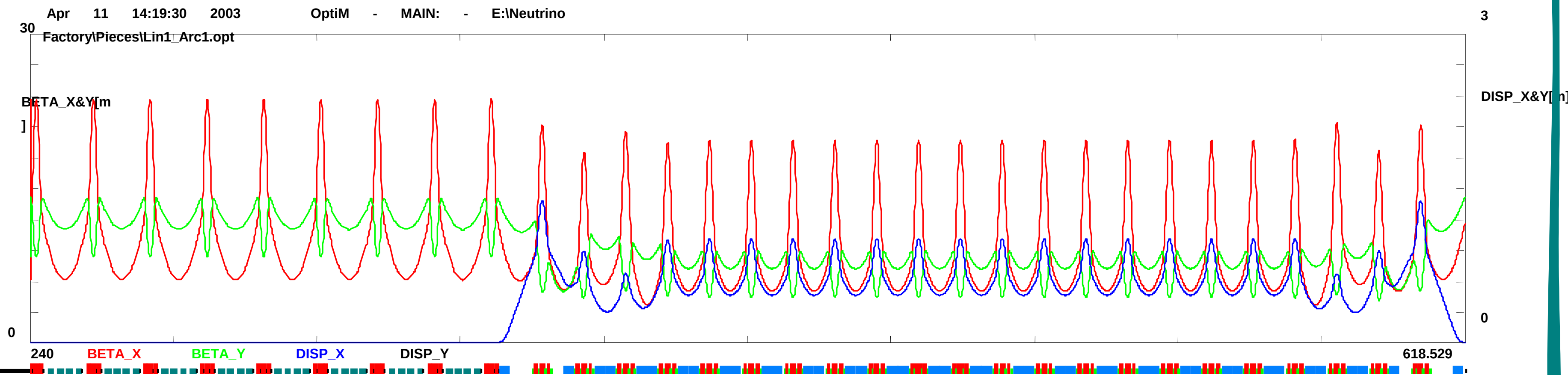
Longitudinal dynamics in the RLA, $M_{56} = 0.7$ m

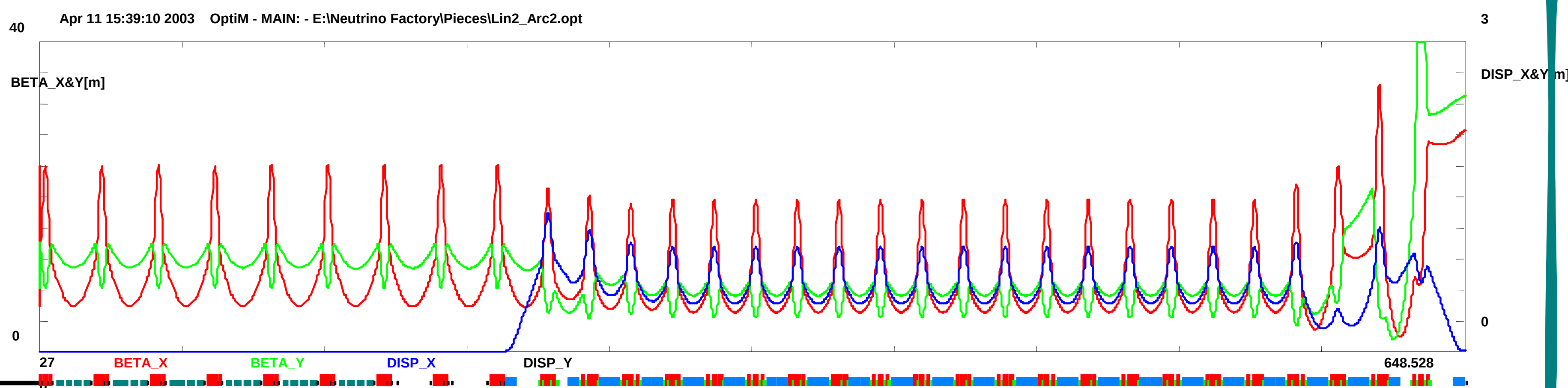


Beam transport choices

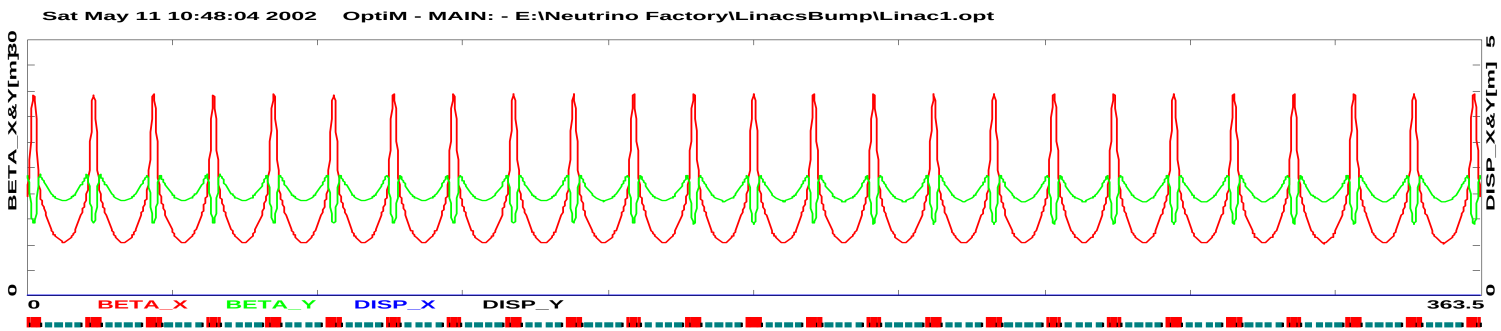
- Principle of uniform focusing periodicity (90^0) – cancellation of chromatic effects
- Single dipole (horizontal) separation of multi-pass beams in RLA
  - No need to maintain achromatic Spreaders/Recombiners
  - Compact Spreaders/Recombiners – minimized emittance dilution
- SC dipoles and quads (triplets) in RLA (2 Tesla dipoles/1 Tesla quads)
- Requirement of high periodicity and 'smooth' transition between different kinds of optics, linac-spreader-arc-recombiner-linac

Arc 1 and 2 optics – smooth transition in Spreaders/Recombiners

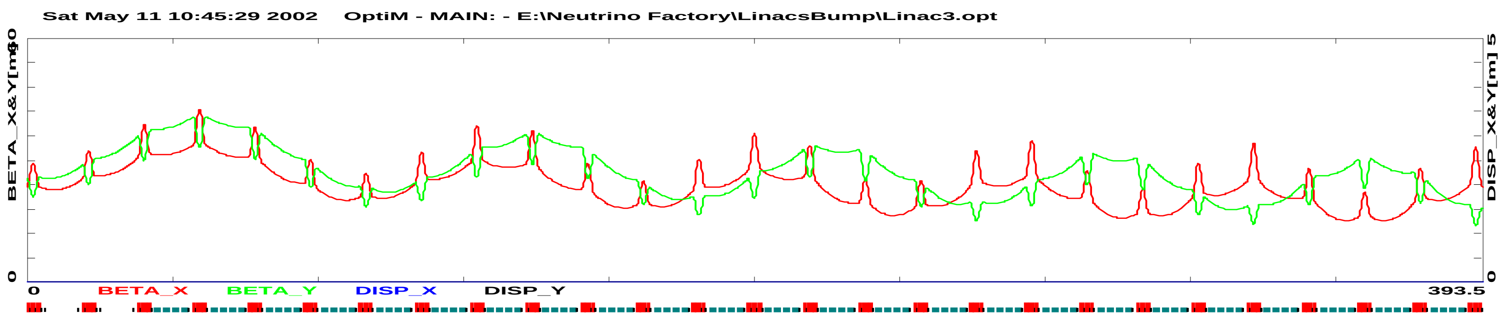




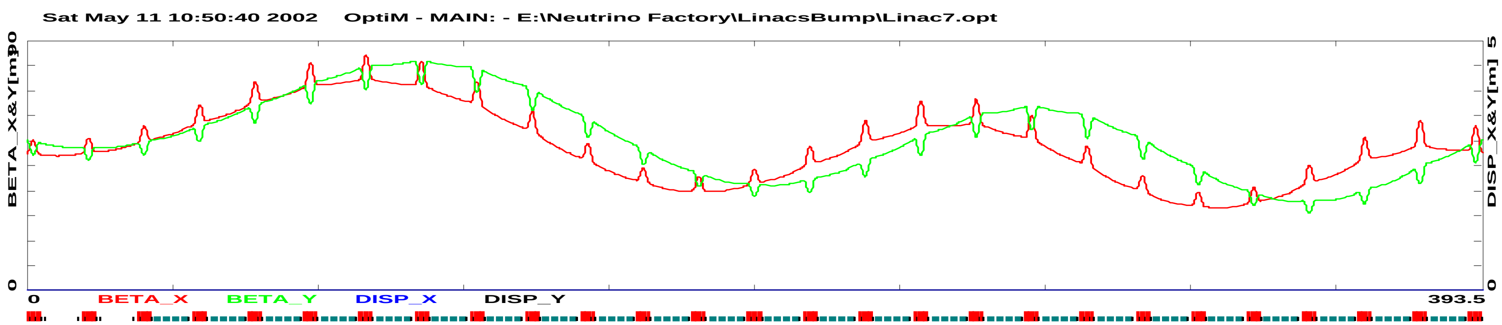
❖Optimized linac optics for multi pass beams – smooth transition Arc-linac



Pass 1

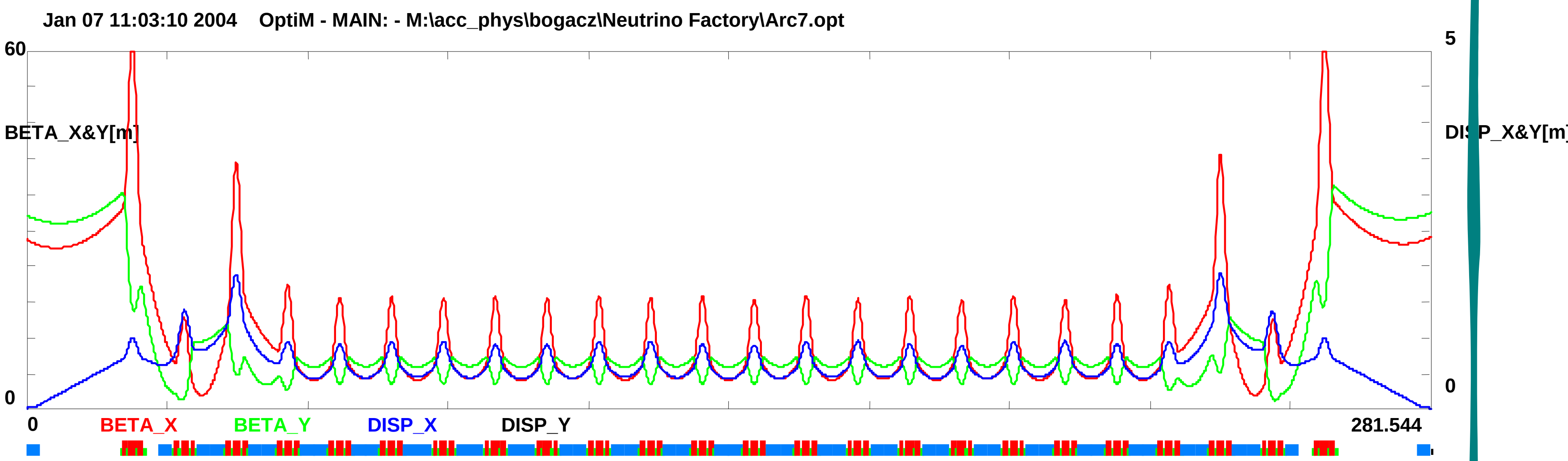


Pass 2

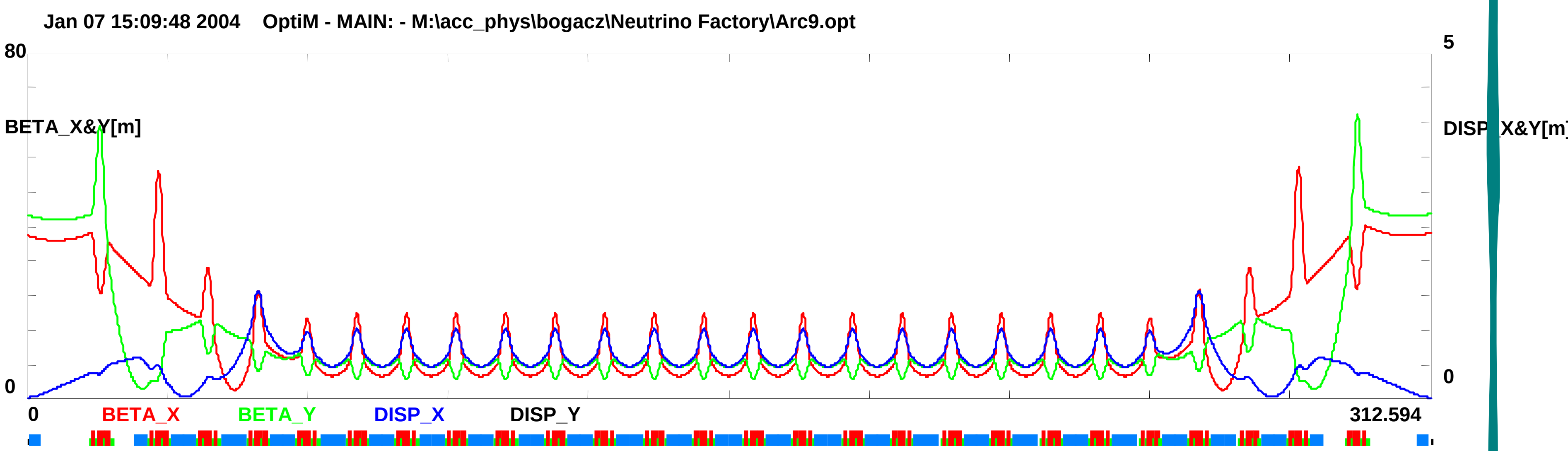


Pass 4

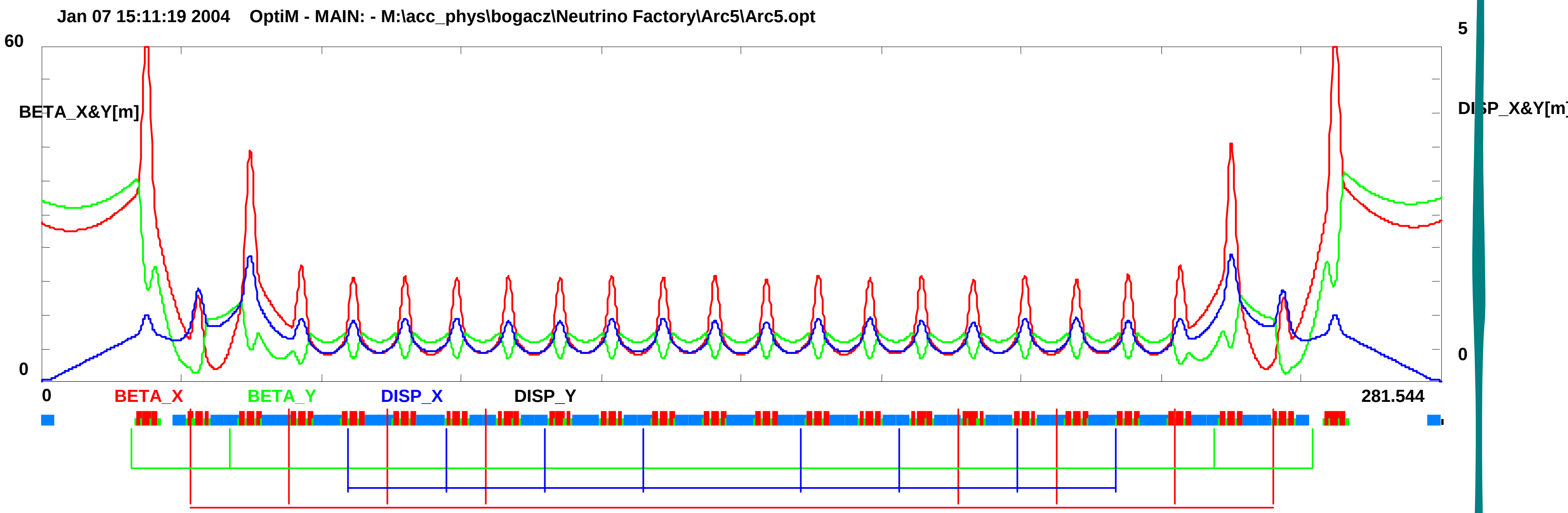
❖ Arc 7 Optics - beta-functions and the horizontal dispersion matched to both adjacent linacs, larger difference of Twiss functions.



❖ Arc 9 Optics - beta-functions and the horizontal dispersion matched to both adjacent linacs, much larger Twiss functions difference (compared to Arc 1, 3, 5 and 7)



❖Chromatic Corrections Scheme in the Arcs – Arc 5 example



Summary

- Lower initial emittance of a Helical Cooling Channel
- Lattice for 5-pass, 20 GeV, RLA based on 400MHz SRF - linear optics
  - Shorter linear Pre-accelerator, momentum compression down to $\Delta p/p=\pm 0.02$
  - Further longitudinal compression in the RLA, small $M_{56}=0.7$m ($\Delta p/p=\pm 0.006$)
  - multi-pass linac optics
  - compact Spr/Rec - 'smooth' transition of optics between linacs and Arcs
- Emittance preservation scheme – nonlinear corrections in the Arcs
  - Chromatic corrections in the Arcs to effectively restore longitudinal space linearity (via three families of sextupoles)