Symmetric ‘Dogbone’ RLA - Lattices

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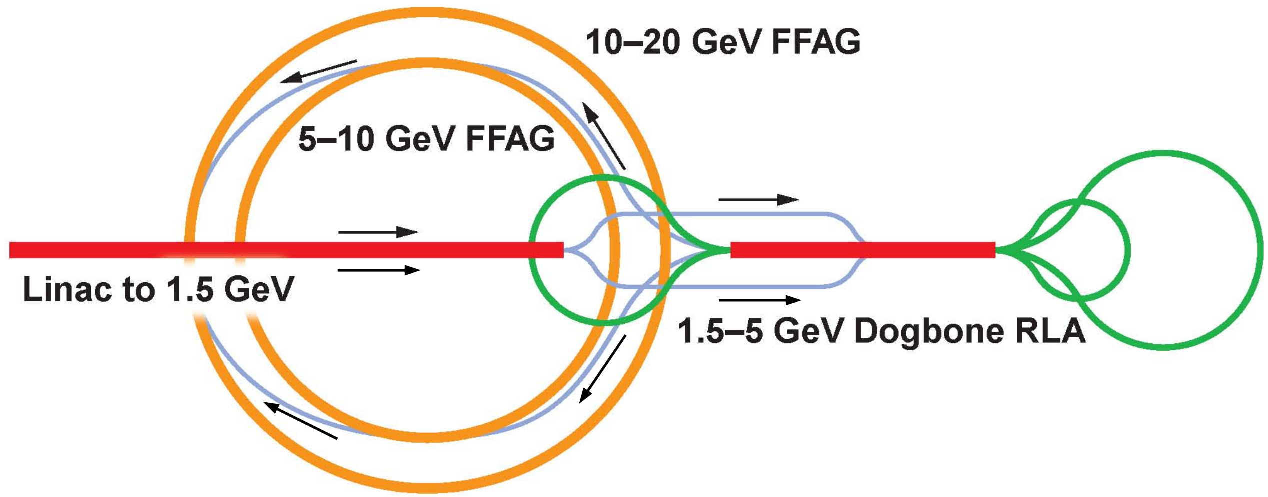
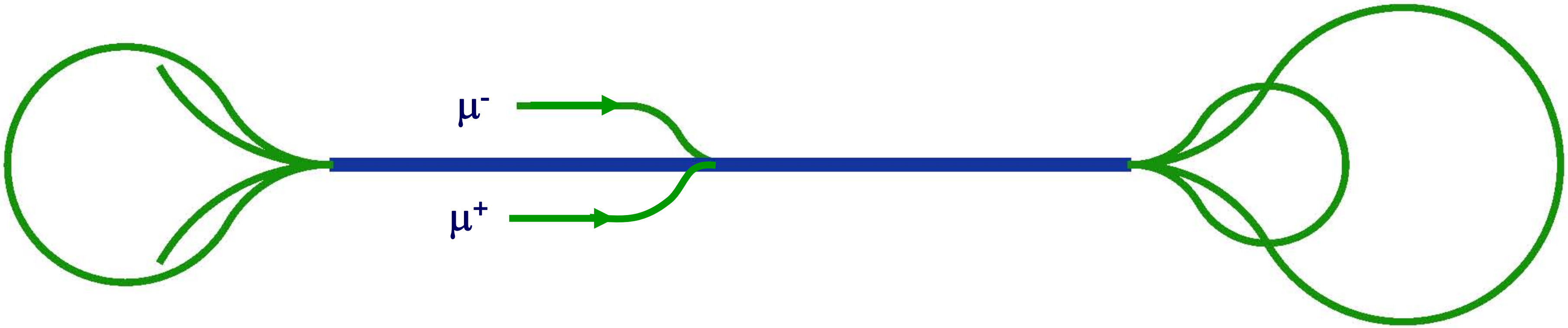
Jefferson Lab

Symmetric Muon Acceleration Complex



- Linear pre-accelerator (273 MeV/c – 1.5 GeV)
- Symmetric 'Dogbone' RLA (allowing to accelerate both μ^+ and μ^- species), 3.5-pass (1.5 – 5 GeV)
- 5 – 10 GeV FFAG
- 10 – 20 GeV FFAG

Symmetric 'Dogbone' RLA (3.5-pass) scheme



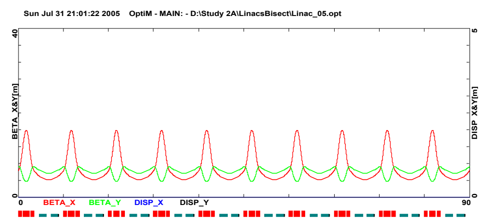
- Main Linac (1 GeV/pass) - triplet focusing
- 3 Arcs based on the same number of cells (90^0 betatron phase advance per cell)

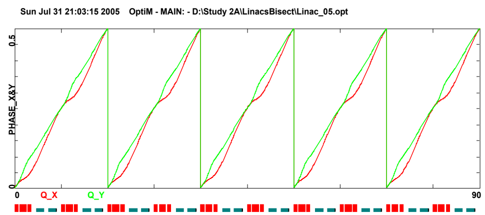
Main Linac - Multi-pass Optics (lower passes)

symmetric optics ($\beta_{out}^{n} = \beta_{in}^{n+1}$, and $\alpha_{out}^{n} = -\alpha_{in}^{n+1}$, n = 0,1,2 pass index)

‘half pass’ (n = 0), 1.5-2GeV

“Bisected” linac



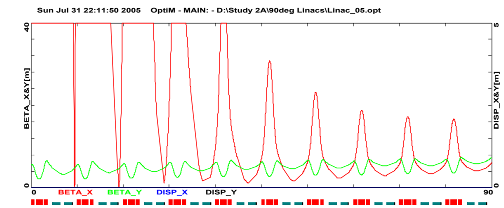


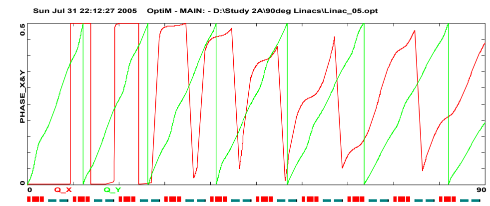
last cell phase adv. ($\Delta\nu_x$=0.25, $\Delta\nu_y$=0.25)

“Uniform” linac

$BetaX=3246m,

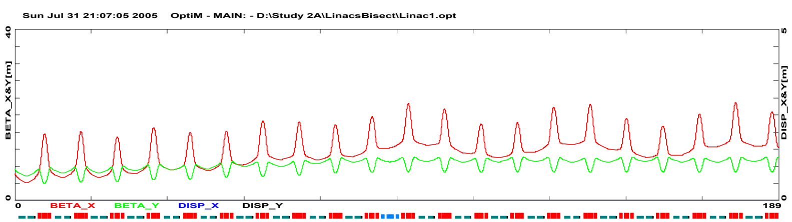
$AlfaX= -11555

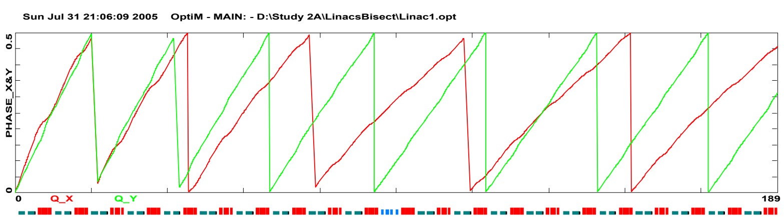




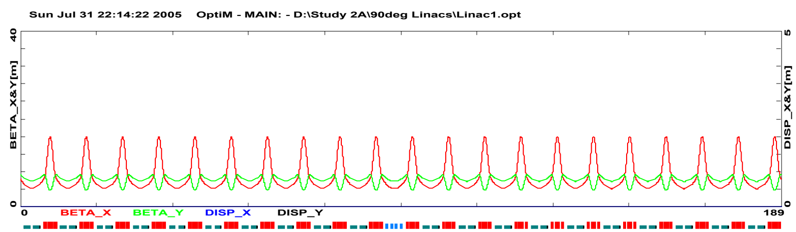
last cell phase adv. ($\Delta\nu_x$=0.25, $\Delta\nu_y$=0.25)

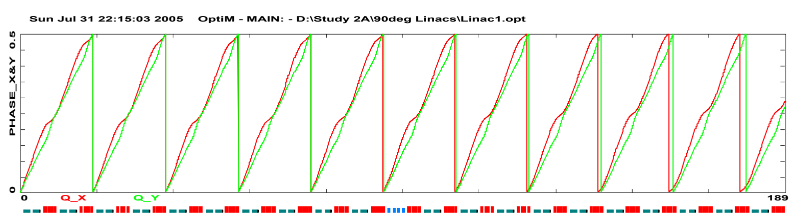
1-pass (n = 1), 2-3GeV





last cell phase adv. ($\Delta\nu_x$=0.11, $\Delta\nu_y$=0.16)





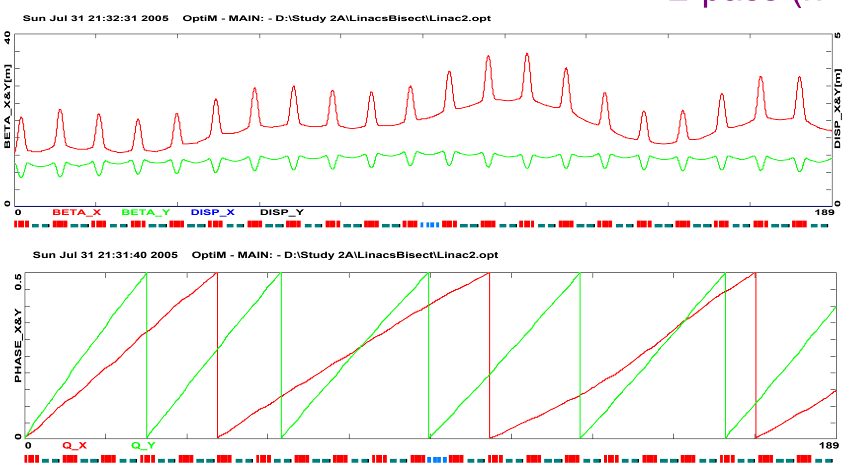
last cell phase adv. ($\Delta\nu_x$=0.25, $\Delta\nu_y$=0.25)

Main Linac - Multi-pass Optics (higher passes)

symmetric optics ($\beta_{out}^{n} = \beta_{in}^{n+1}$,and $\alpha_{out}^{n} = -\alpha_{in}^{n+1}$, n = 0,1,2 pass index)

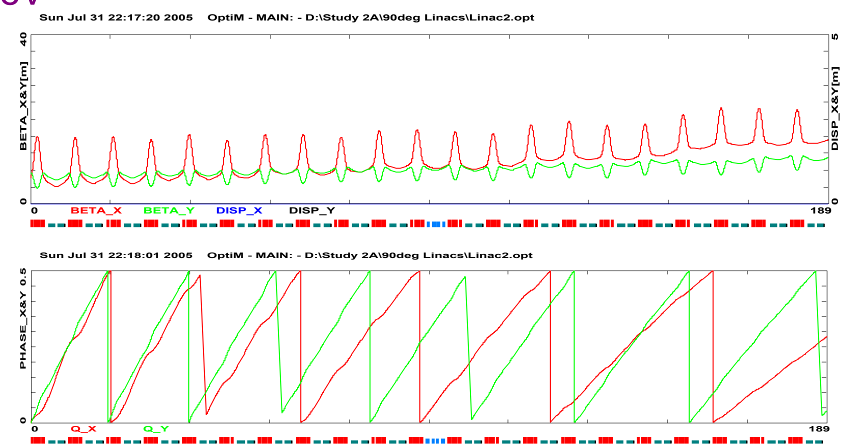
2-pass (n = 2), 3-4GeV

"Bisected" linac



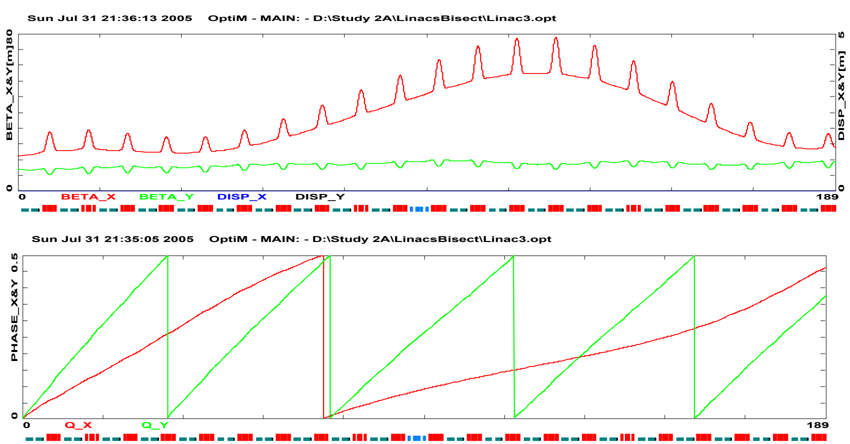
last cell phase adv. ($\Delta\nu_x$=0.07, $\Delta\nu_y$=0.14)

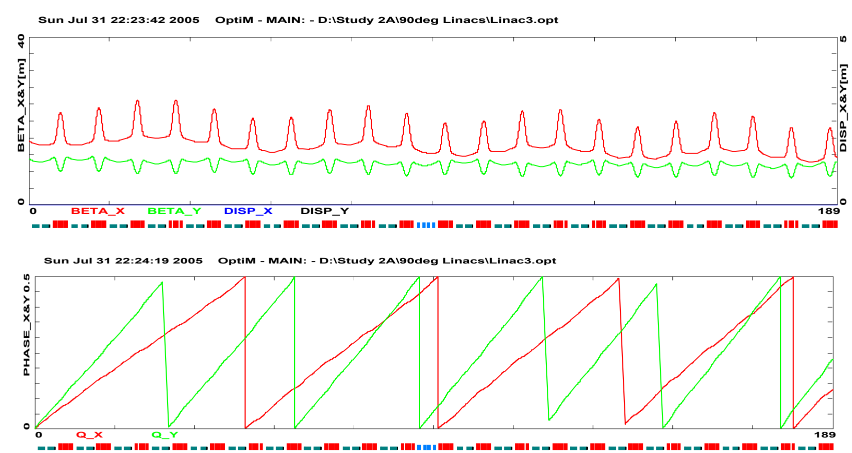
"Uniform" linac



last cell phase adv. ($\Delta\nu_x$=0.09, $\Delta\nu_y$=0.14)

3-pass (n = 3), 4-5GeV





Linac Optics - beam transport choices

- Multi-pass linac focusing imposes (by design) mirror symmetry of the droplet arcs by requiring exit/entrance to/from the next linac betas to be equal and alphas to be of the opposite sign.
- Two possible 'symmetric' linac scenarios were examined:
  - 'uniform' linac focusing - 90^0 phase advance/cell set for 1-pass linac (2-3GeV). It minimizes phase slippage on higher passes and overall 'beta beating', but the over focusing on the 'half pass' (quads too strong by the ratio of 2.5/1.5 = 1.67) makes the initial match at injection impossible (3.5 km beta).
  - 'bisected' linac - 90^0 phase advance/cell set for the 'half pass' linac (1.5-2GeV). As a consequence linac phase advance/cell in the first part of 1-pass drops to about 45^0. Forcing 90^0 phase advance/cell in the second half of the linac is not desirable and it would cause large 'beta beating' (Bob Palmer). Instead, one choses to keep 45^0 phase advance/cell throughout the second part of the linac. The 'beta beating' is rather small including higher passes; the phase advance at the end of 2-pass linac drops by another factor of two (22.5^0).
- 'bisected' linac is a clear winner

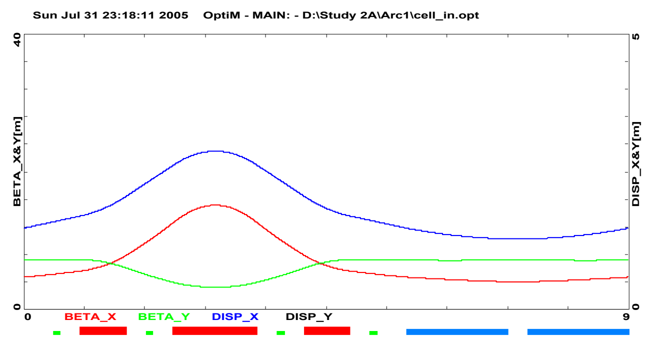
Arc Optics - beam transport choices

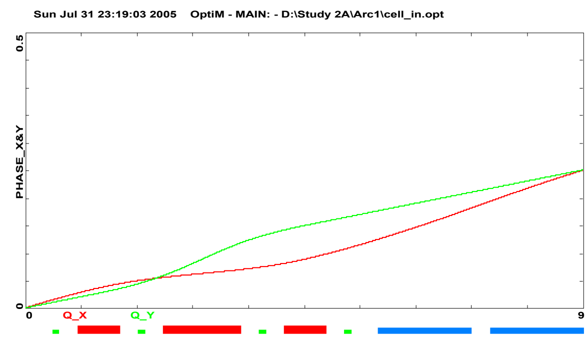
- There is great advantage to have 90^0 phase advance/cell in the arcs – cancellation of chromatic effects.
- Phase advance 'mismatch' from/to the linacs is not detrimental - it induces larger 'beta beating' in Spr/Rec regions, but we match betas in this region anyway
- The 'phase mismatch' is at the similar level as in StudyII scheme for 4-pass racetrack RLA
- Single dipole (horizontal) separation of multi-pass beams in RLA
  - No need to maintain achromatic Spreaders/Recombiners
  - Compact Spreaders/Recombiners – minimized uniform focusing breakdown
- Scalable Arc optics (Arc1-3):
  - Keep the same number of cells in each arc (M_{56} scales as number of cells)
  - Scale Arc1 (bends and quads) by factor of 3/2 to get Arc2 and by 4/2 to get Arc3.
- Variable phase advance/cell Arc optics (Arc1-3):
  - Large dispersion for smaller phase advance/cell
  - Increasing number of cells in each arc (large M_{56})

Mirror-symmetric Arc optics

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

‘outward’ cell’ at 2GeV (T = 1911.64 MeV)





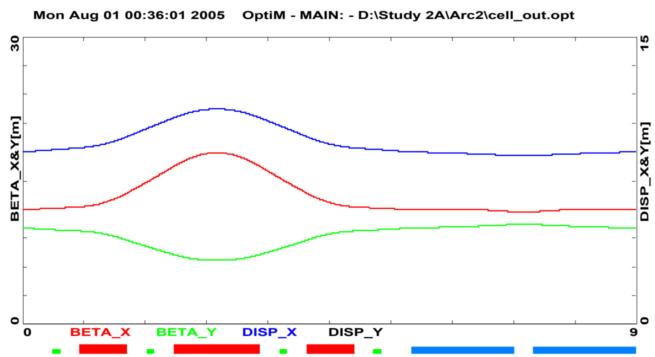
cell phase adv. ($\Delta\nu_x$=0.25, $\Delta\nu_y$=0.25)

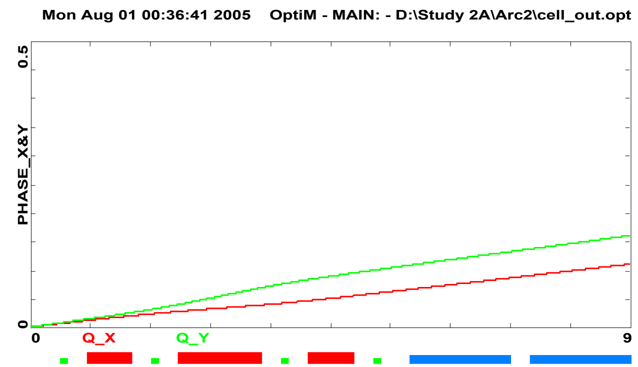
$E=1911.64;
$P= 2014.529
$Hr=$P/$c*1e11; => 6719.745
dipoles (2 per cell)
$Nout=2
$Lb=150; => 150 cm
$ang=60/(2*$Nout); => 15 deg
$B=$PI*$Hr*$ang/(180*$Lb); => 11.728169 kGauss
quadrupoles (triplet):

L[cm]	G[kG/cm]
68	-0.2921
125	0.3118
68	-0.2921

‘Slow’ phase advance/cell Arc Optics

‘outward’ cell’ at 3GeV (T = 2920.75 MeV)





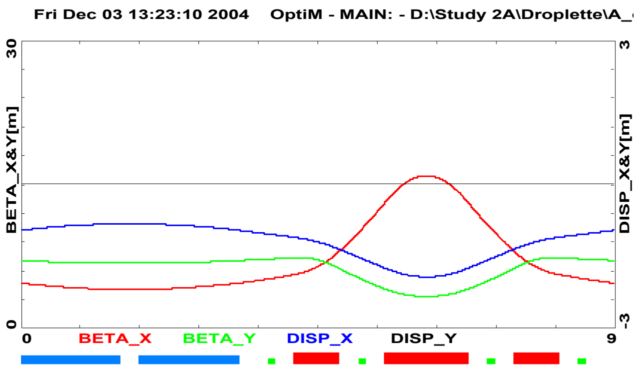
cell phase adv. ($\Delta\nu_x$=0.125, $\Delta\nu_y$=0.16)

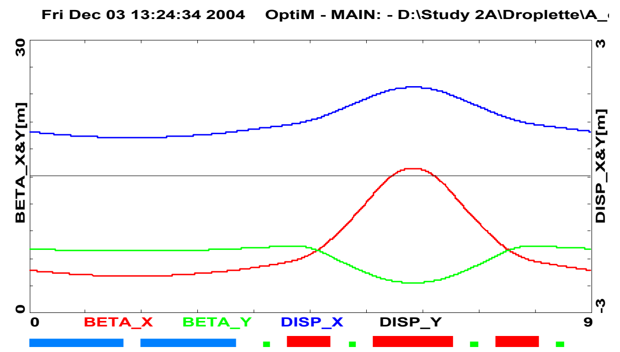
$E=2920.75;
$P= 3024.56307
dipoles (2 per cell)
$Nout=2
 $Lb=150; =>   150 cm
$ang=60/(2*$Nout); =>   15 deg
$B=$PI*$Hr*$ang/(180*$Lb); =>   17.608 kGauss
quadrupoles (triplet):

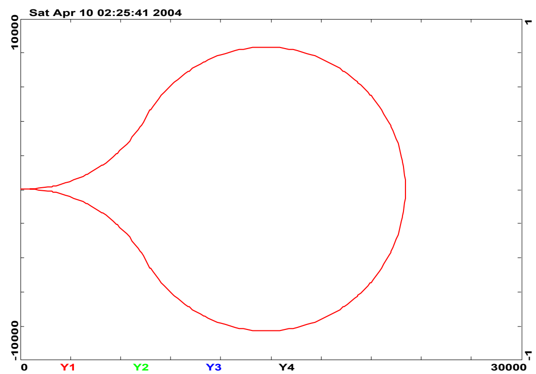
L[cm]	G[kG/cm]
68	-0.1847
125	0.2093
68	-0.1847

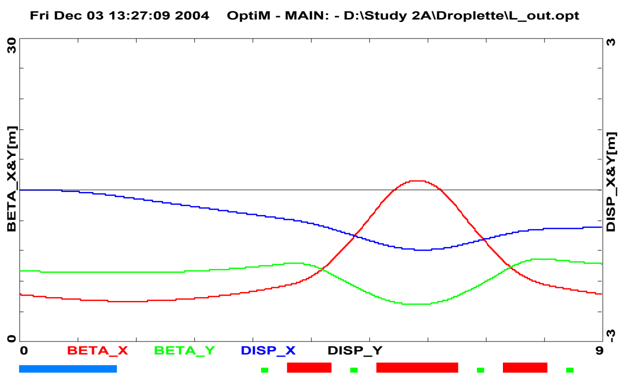
Droplet Arc (60^0 out - 300^0 in - 60^0 out) – Optics building blocks

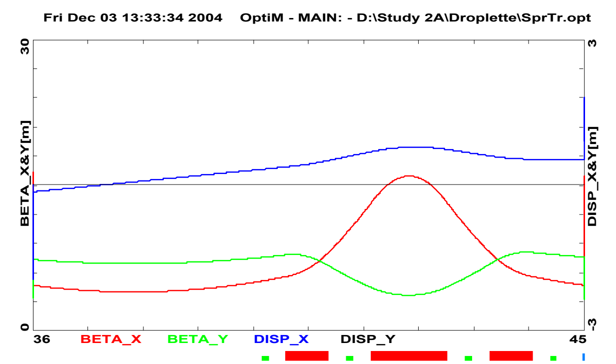
90^0 phase advance/cell: inward and outward cells, missing dipole cells





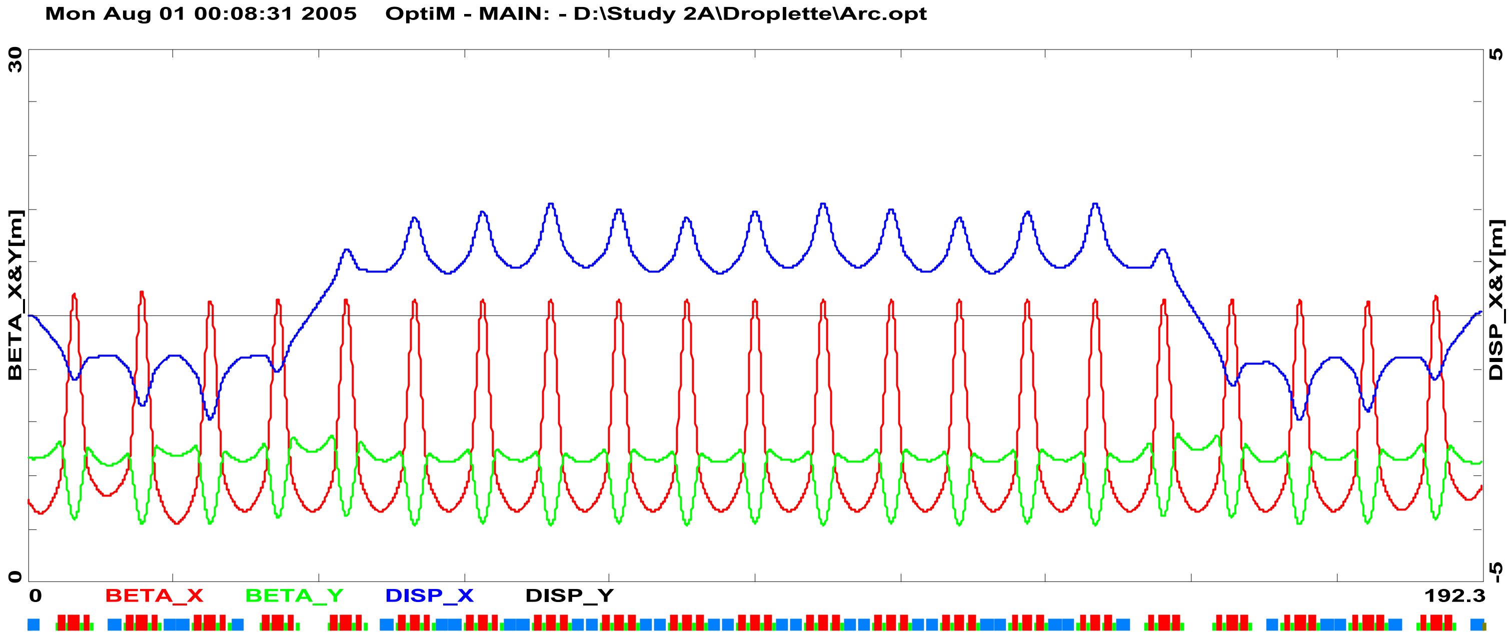






Arc 1 Optics - minimum number of cells

$Nout=2, need minimum of 3 triplets to match 6 Twiss parameters



cell count: 2 out + 10 in + 2 out, no net bending in 'transitions' – 3 cell (1+1+1) transition)

Summary

- Symmetric 'Dogbone' RLA (allowing to accelerate both μ^+ and μ^- species), 3.5-pass (1.5 – 5 GeV) scheme - Linear Optics
  - multi-pass linac optics – optimized focusing profile
  - tolerable phase 'slippage' in the higher pass linacs
  - mirror-symmetric Arc optics based on constant phase advance/cell (90^0) and equal number of cells in each arc
  - compact lattice architecture for Spr/Rec/Trans