FD cell optics versus FFDD and FFFDDD in the NLC Linac

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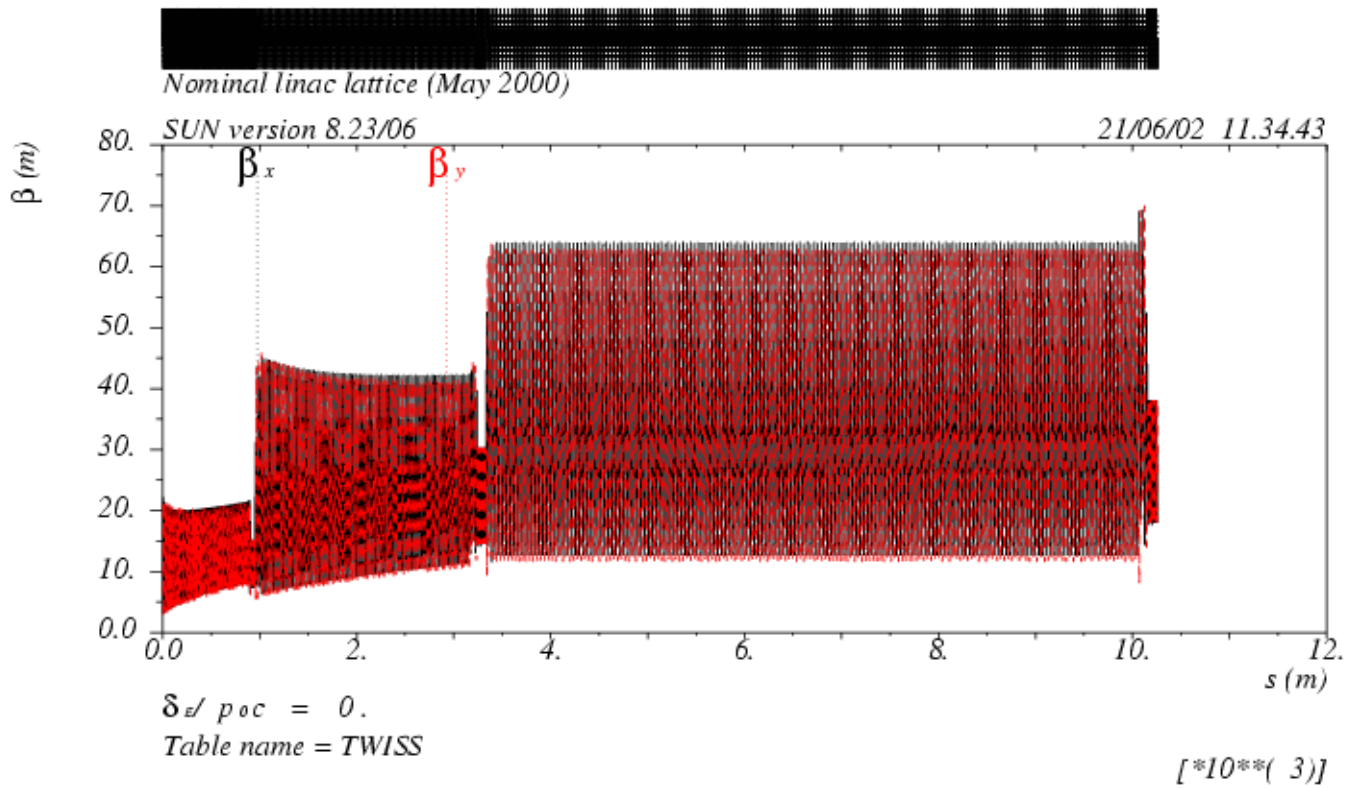
The nominal NLC linac has 3 sectors consisting of FD cells with RF-structures:

- 1st sector: F - 3RF - D - 3RF -
- 2nd sector: F - 3RF - 3RF - D - 3RF - 3RF -
- 3rd sector: F - 3RF - 3RF - 3RF - D - 3RF - 3RF - 3RF -

Nominal linac lattice with FD cells

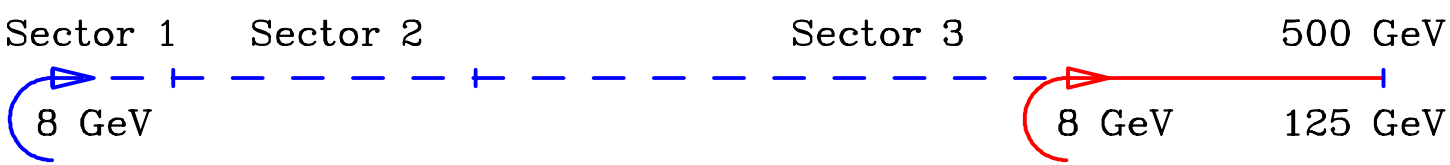


• The linac cell length is increased as ~$E^{1/2}$ to take into account the reduced wakefield effect on emittance dilution.

• **Nominal FD optics:**
Length of the FD cells is increased step-wise from sector to sector to minimize the number of quadrupoles.

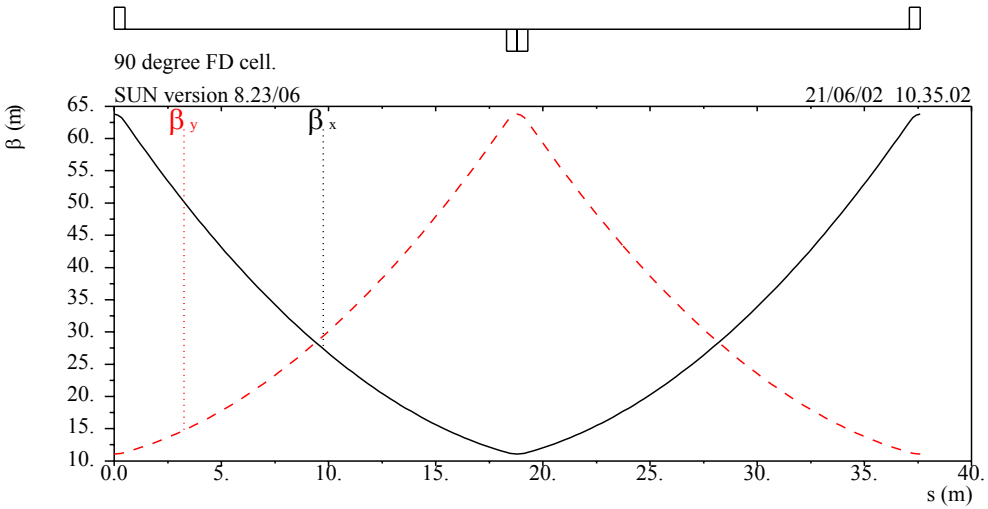
• **FFDD, FFFDDD optics:**
In this option, the distance between quadrupoles is not changed from sector to sector. This increases the number of quadrupoles, but makes the optics more flexible. The cell length is increased with energy as ~$E^{1/2}$ by using FFDD and FFFDDD cells in the 2nd and 3rd sectors.

• **Example of FFDD, FFFDDD optics for a low energy scenario:**
Assume that only the last part of the full linac is installed for the low energy beam, and injection is provided at the beginning of low energy linac. The nominal long FD cell in the 3rd sector
[F - 3RF - 3RF - 3RF - D - 3RF - 3RF - 3RF -] is replaced by 3 short FD cells for the low energy beam
[F - 3RF - D - 3RF - F - 3RF - D - 3RF - F - 3RF - D - 3RF -]. This short cell structure is upgradable to the long cell optics for the nominal beam energy by changing the quadrupole polarities from FDFDFD to FFFDDD.

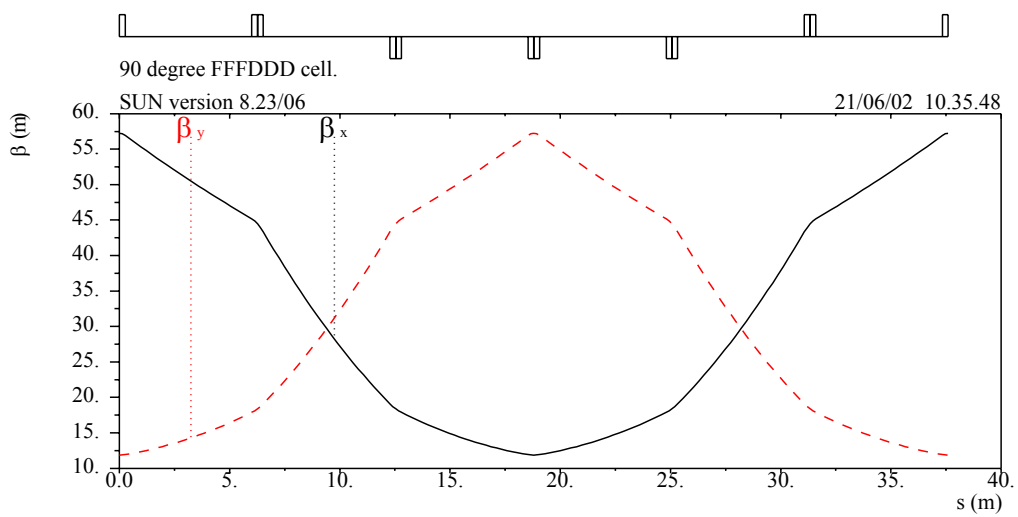


BLUE: 500 GeV nominal linac; RED: 125 GeV low energy linac.

Optics of 90º FD and FFFDDD cells



Question: How do the linac parameters and tolerances compare in the nominal FD and alternative FFDD, FFFDDD optics?



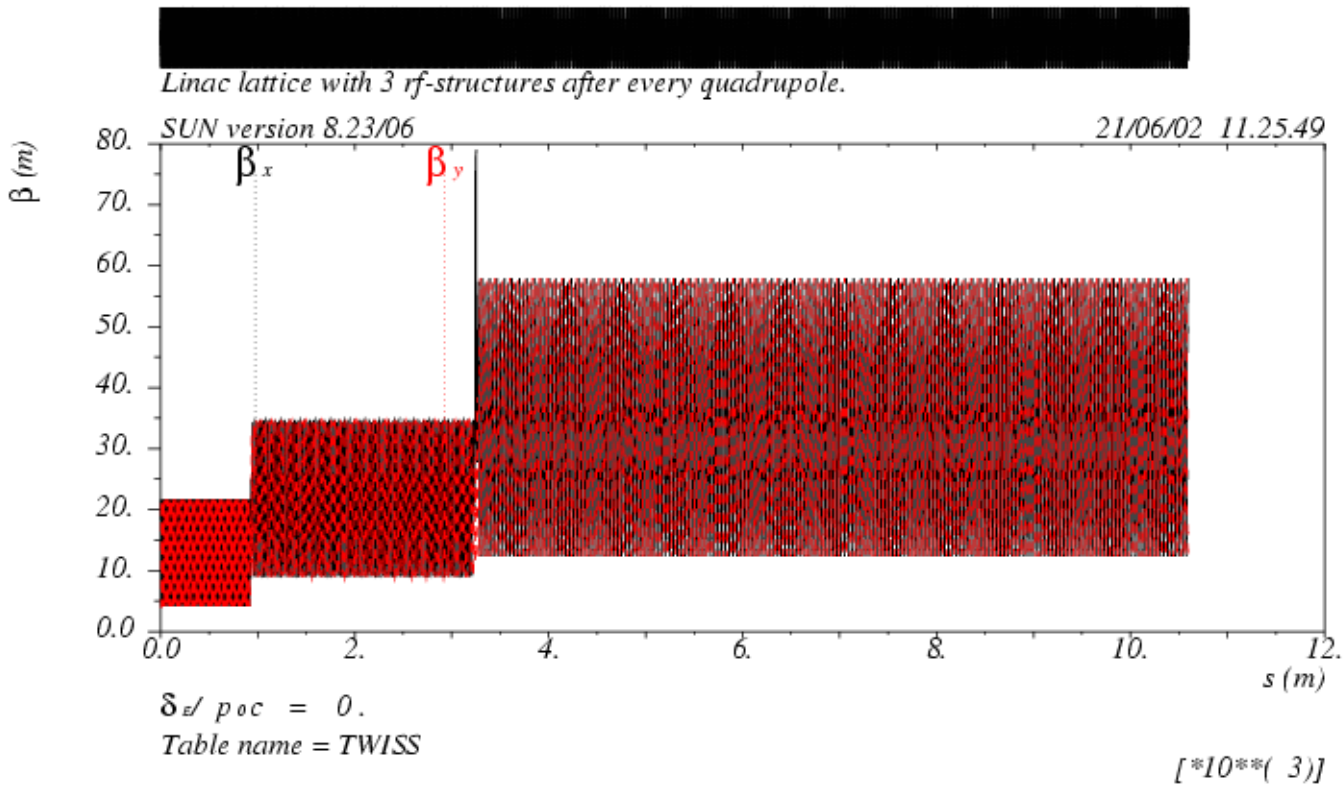
FFFDDD versus FD:

- 3 times more quadrupoles.
- Combined quadrupole strength 60% higher.
- Individual quadrupoles 50% weaker.
- Maximum β function 10% lower.
- Cell linear chromaticity about the same.

Test linac optics with FFDD and FFFDDD cells in the 2nd and 3rd sectors:

- 500 GeV beam.
- Constant 90° phase advance per cell.
- Same length quadrupoles (12.75 inches = 32.385 cm).

Test linac lattice with 90° FD, FFDD and FFFDDD cells



Comparison of linac parameters for 500 GeV beam

Cell optics	FD	FD / FFDD / FFFDDD
Initial / final energy, GeV	8 / 500	8 / 500
Total length, m	10257.924	10591.537
Total RF-structures	4752	4977
Total length of RF-structures, m	8565.480	8975.522
Length of one RF-structure, m	1.8025	1.8034
Accelerator gradient, MV/m	57.440	54.816
Total quadrupoles	724	1660
Total quadrupole length, m	510.029	537.267
Total quadrupole strength, kG	420062	630325
Max. quadrupole gradient, kG/m	1373.8	2021.0
Total x/y phase advance, [2π]	79.68 / 84.12	88.45 / 88.87

Beam parameters:

- Normalized emittance, x/y: $3\ 10^{-6}$ / $3\ 10^{-8}$ m
- Particles per bunch: $1.1\ 10^{10}$
- rms bunch length: 150 μm
- Transverse wakefield slope in RF-structures: $1.29\ 10^{20}$ V/C/m^3

Comparison of ground motion tolerances for 500 GeV beam (analytical calculation)

Cell optics		FD	FD / FFDD / FFFDDD
Quadrupole rms misalignment for 6% emittance dilution, μm	X	80.8	78.2
	Y	8.11	7.79
FR-structure rms misalignment for 6% emittance dilution, μm	X	14.9	15.4
	Y	1.52	1.54
Quadrupole jitter for beam jitter amplitude of 25% of beam size, nm	X	75.0	83.4
	Y	7.45	8.35

Summary

The FFDD, FFFDDD cell optics in the linac provides more optical flexibility and similar ground motion tolerances compared to the nominal FD optics, but it requires more than twice the number of quadrupoles with ~50% increase in total quadrupole strength and ~5% longer linac at the full beam energy.