Matching of Multiple Energy Beamlines for the CEBAF Energy Upgrade

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Abstract

It is currently planned to increase the energy of the CEBAF recirculating linear accelerator to 22GeV by adding two new recirculating arcs that contain multiple new energy passes. These new passes at six different energies must be matched to the existing linac simultaneously, as the beam is continuous (CW), so magnets cannot be ramped. This paper studies propagating several energies in the same beam pipe with a line of quadrupoles acting on all of them simultaneously, with the goal that the combined effect produces a match for each energy. Computer optimisation of the performance this system under various constraints (beamline length, number of magnets) is studied.

Matching Constraints

These beamlines match from the optical functions at the exit of the **CEBAF linacs**, given in Table 1, to the optical functions at the beginning of the **fixed field accelerator (FFA) arc** in Table 2.

Table 1: Matching Conditions Before the Beamline

Beam E_k (GeV)	β_x (m)	β_y (m)	α_x	α_y
10.55	16.63	19.75	0.14	0.03
12.75	58.31	64.75	0.51	-0.2
14.95	61.5	64.53	-0.29	-0.91
17.15	40.81	39.37	-0.65	-0.88
19.35	21.74	25.17	-0.01	-0.07
21.55	26.72	33.88	0.47	0.36

Table 2: Matching Conditions After the Beamline

Beam E_k (GeV)	β_x (m)	β_y (m)	α_x	α_y
10.55	4.157	6.515	3.049	-3.19
12.75	2.951	6.477	1.822	-3.037
14.95	2.718	6.995	1.539	-3.206
17.15	2.602	8.035	1.399	-3.636
19.35	2.521	10.132	1.311	-4.549
21.55	2.455	16.84	1.247	-7.524

The FFA arc has high gradient magnets and small beta functions to preserve the low dispersion, whereas the linac has high beta functions as its focusing scheme is shared with the lowest energy pass.

Optimisation Methods

Levenberg-Marquardt (LM) optimisation was used to find the 30-magnet beamline. There are many local minima in the sum-of-squares error, so multiple random restarts (**basin hopping**) also had to be used until finding an exact solution.

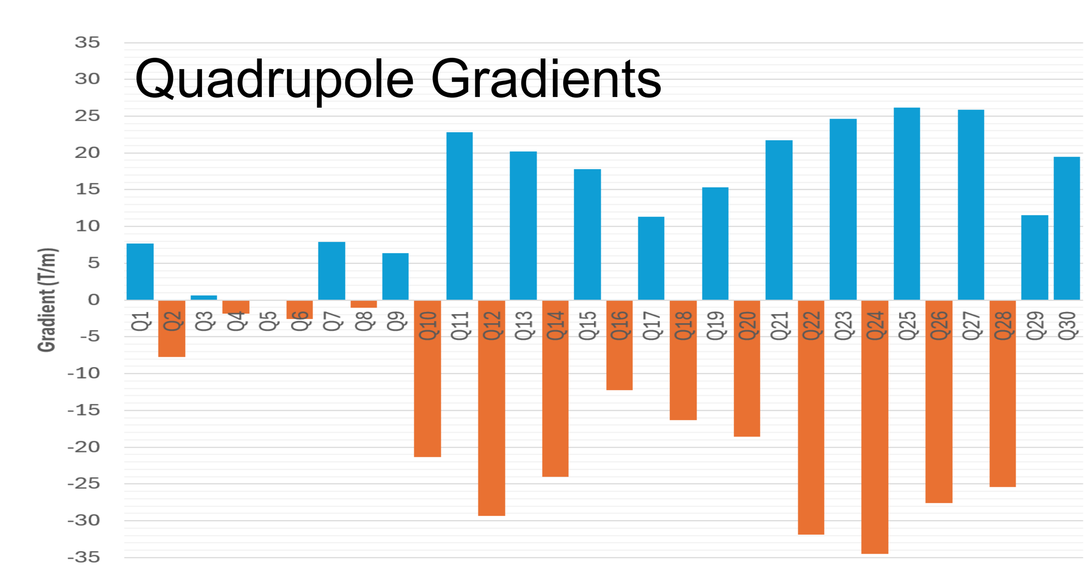
The 40-magnet beamline was found by **simulated annealing** with 10^{-4} per step 'temperature' reduction and adaptive-length random steps in the problem output space.

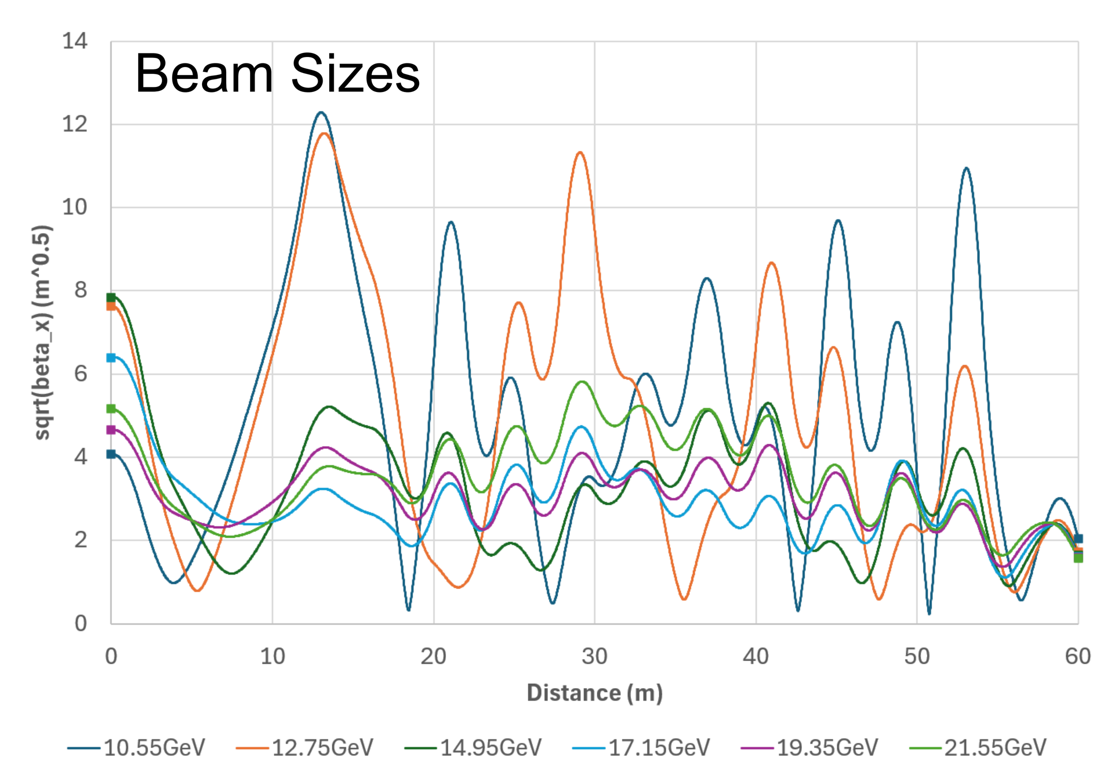
Beamline Solutions

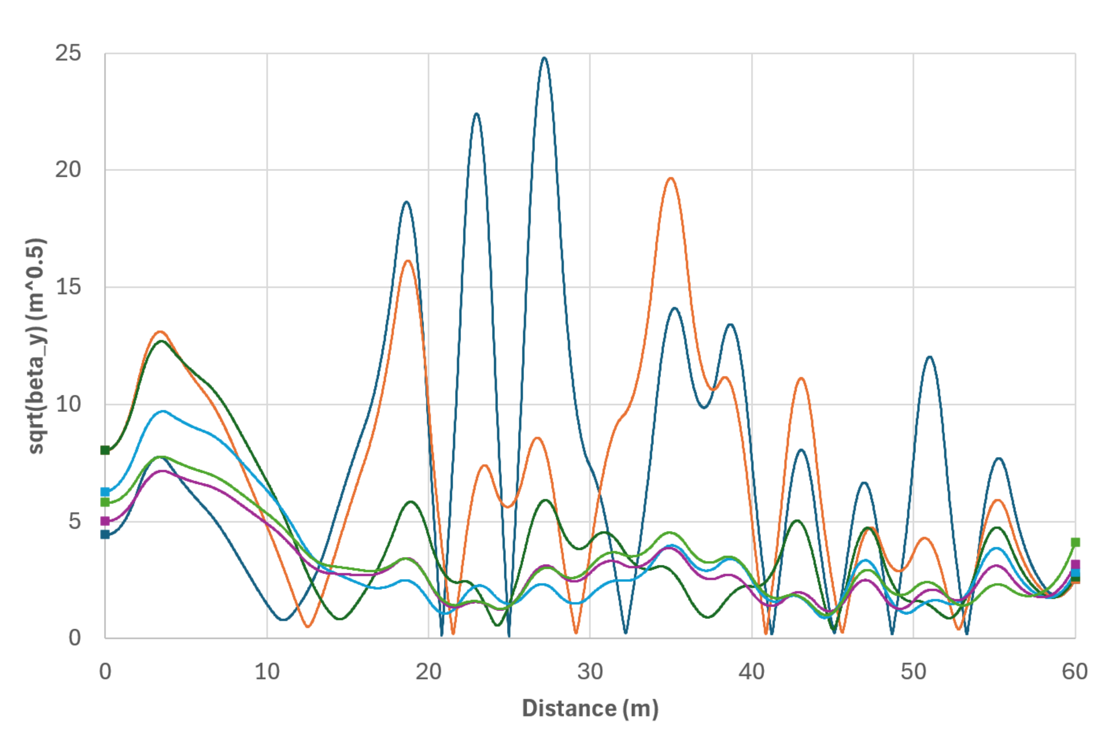
Table 3: Comparison of Matched Beamline Solutions

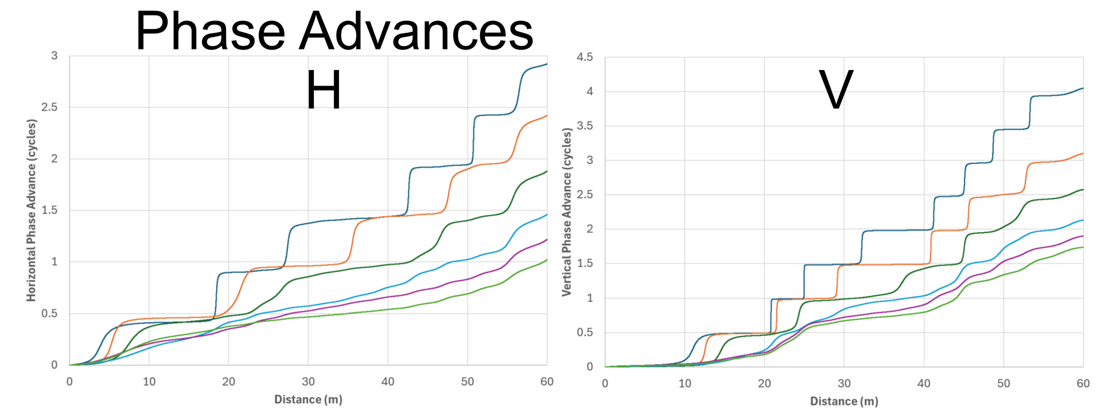
Design Constraints		
Total length	60 m	48 m
Quadrupoles	30	40
Quadrupole length	1.8 m	1.0 m
Drift length	0.2 m	
Maximum gradient	±50 T/m	
Optimised Results		
Maximum β_x	150.9 m	2416 m
Maximum β_y	614.9 m	1101 m
Maximum $\sigma_x/\sigma_{x,in}$	3.013	12.05
Maximum $\sigma_y/\sigma_{y,in}$	5.580	7.466
Largest gradient	34.54 T/m	50.00 T/m
Maximum $\lvert\beta-\beta_{goal}\rvert$	1.75 μm	9.42 μm
Maximum $\lvert\alpha-\alpha_{goal}\rvert$	8.70×10^{-7}	3.85×10^{-6}

60m Length, 30 Magnets

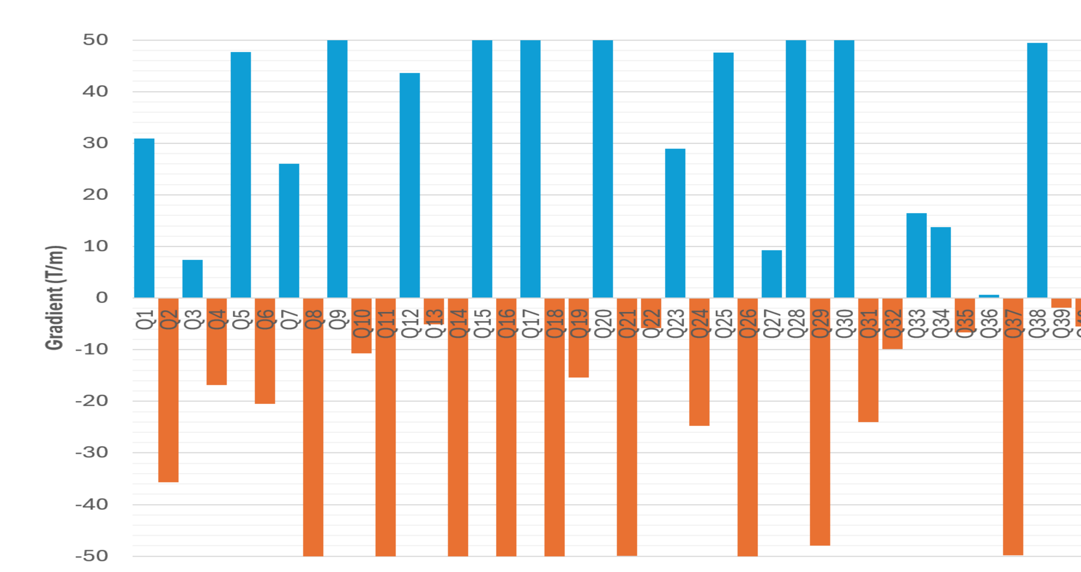


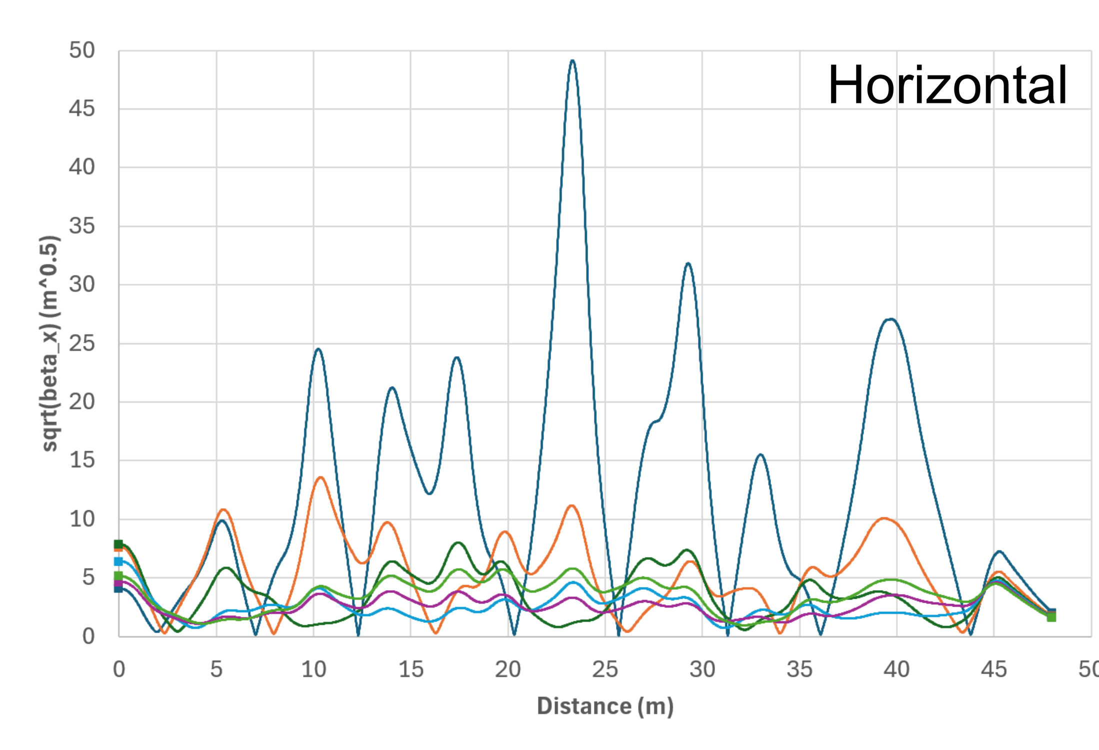


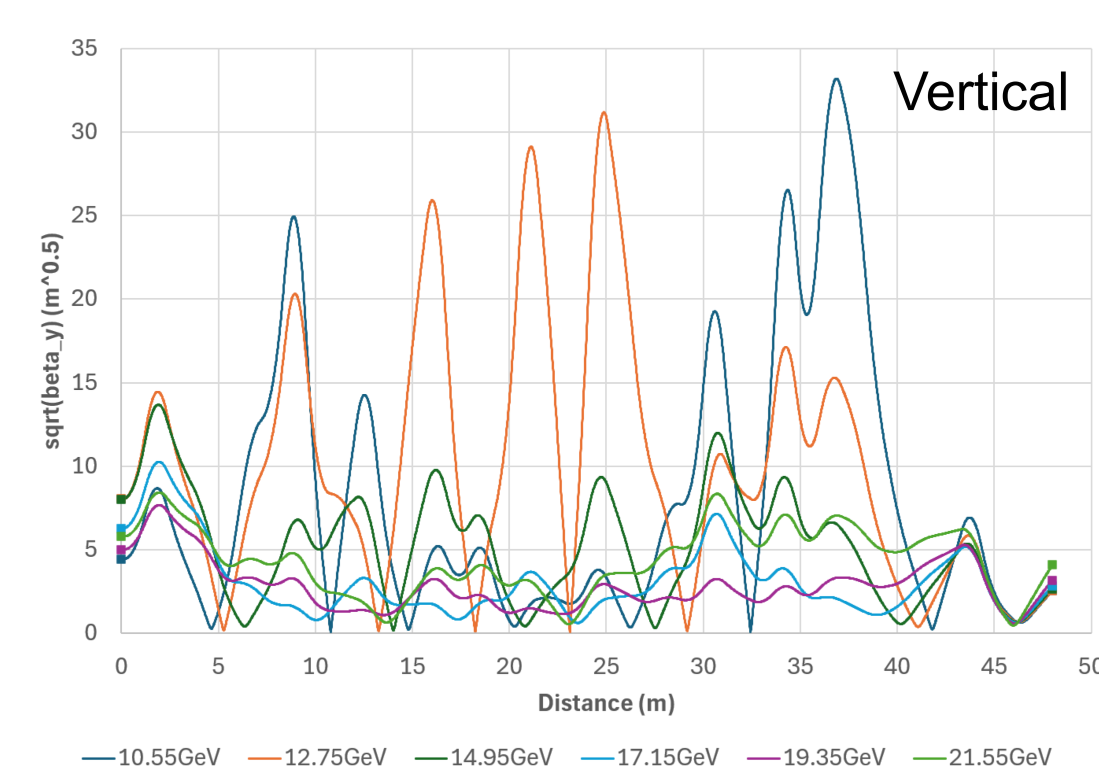


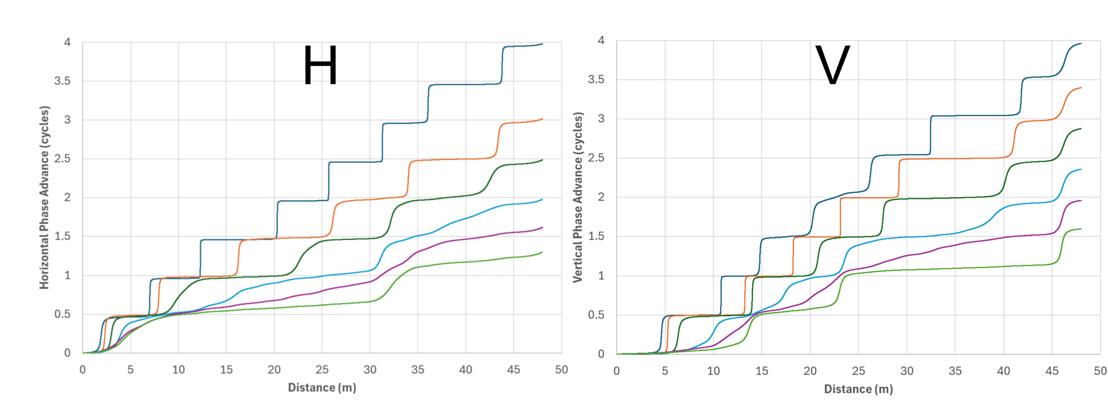


48m Length, 40 Magnets









Comparision

- Both beamlines are exact matches for all six energies simultaneously.
- The 40-magnet beamline is shorter.
- The 30-magnet beamline requires a lower quadrupole gradient.
- The 30-magnet beamline is likely less sensitive to errors because its beta functions vary less.
- The 30-magnet beamline has a smaller beam expansion factor relative to the linac, so fewer problems with aperture or field aberrations.

Overall, the 30-magnet beamline looks more practical unless length is highly constrained.