Preliminary Design of an FFAG to 25 GeV for the IDS

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Requirements for Muon Acceleration

- Decays: high average gradient ($>$1 MV/m)
  - No time to ramp magnets
- Large longitudinal and transverse emittances
  - 200 MHz SCRF: expensive!
    - Minimize RF in system
    - Multiple passes through RF
  - Large magnet and cavity apertures

Recirculating Linear Accelerator

- Recirculating linear accelerator (RLA)
  - Linac(s) connected by arcs
  - Different arc for each energy
  - Multiple passes through linac
- Satisfies muon acceleration requirement, but
- Number of passes limited
  - Switch yard complexity
  - Aggravated by large beam emittances

Linear Non-Scaling FFAGs
Motivation and Advantages

- Allow many passes through RF
  - No switchyard: single beam line
  - Limited by RF synchronization
    - Time depends on energy
    - Fixed-frequency RF
- Large dynamic aperture
  - Linear magnets
  - High degree of symmetry
  - Rapid acceleration

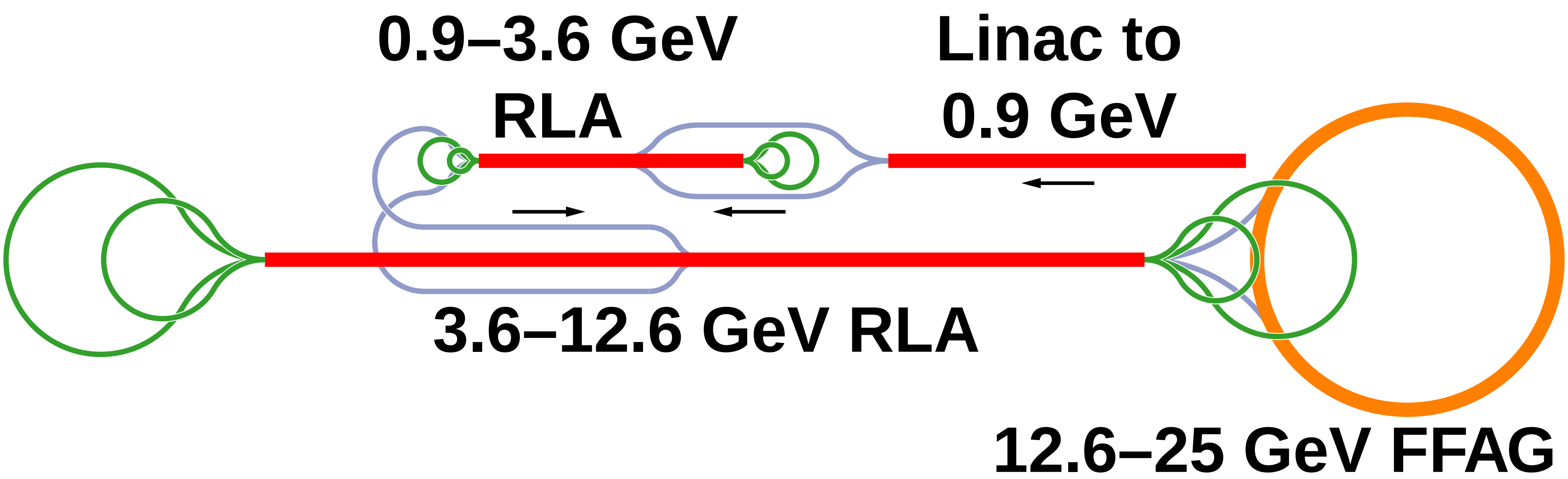
Linear Non-Scaling FFAGs Comparison with Scaling FFAG

- Smaller magnet aperture
- Easily handles bunches in 200 MHz train
  - Maybe "harmonic number jump" for scaling
- Difficulty: nonzero chromaticity
  - Sensitive to lattice errors
    - Is scaling also—random walk?
  - Time depends on transverse amplitude

Use in Muon Acceleration

- Inefficient at low energies
  - Magnet apertures get large (larger beam)
  - Optimization increases circumference
  - Many cells, many cavities, few turns
- Time depends on transverse amplitude
  - No synchrotron oscillations to fix
  - Builds up with more stages
- Thus only at last stage(s)

IDS Acceleration Scenario



Design Goals

- Accelerate from 12.6 GeV to 25 GeV
- 200 MHz SCRF cavities
- 30 mm normalized transverse acceptance
- Six empty drifts for injection/extraction
- Drift lengths: 2 m single cavity, 3 m for double
  - Two cavities per cell less efficient
  - Time vs. transverse amplitude
- Optimize for cost including decays

Parameters

	FCDC	FDCC	FDFCC	FDC	FDFC
Cells	62	62	55	77	70
D radius (cm)	9.5	10.2	12.5	7.7	9.2
D field (T)	7.6	8.3	7.3	8.1	7.7
F radius (cm)	20.7	20.3	16.7	14.0	12.2
F field (T)	3.4	3.1	3.9	4.0	4.2
Circ. (m)	462	467	445	426	422
RF Volt. (MV)	1526	1424	1246	903	814
Decay (%)	3.5	3.8	4.1	5.4	5.9

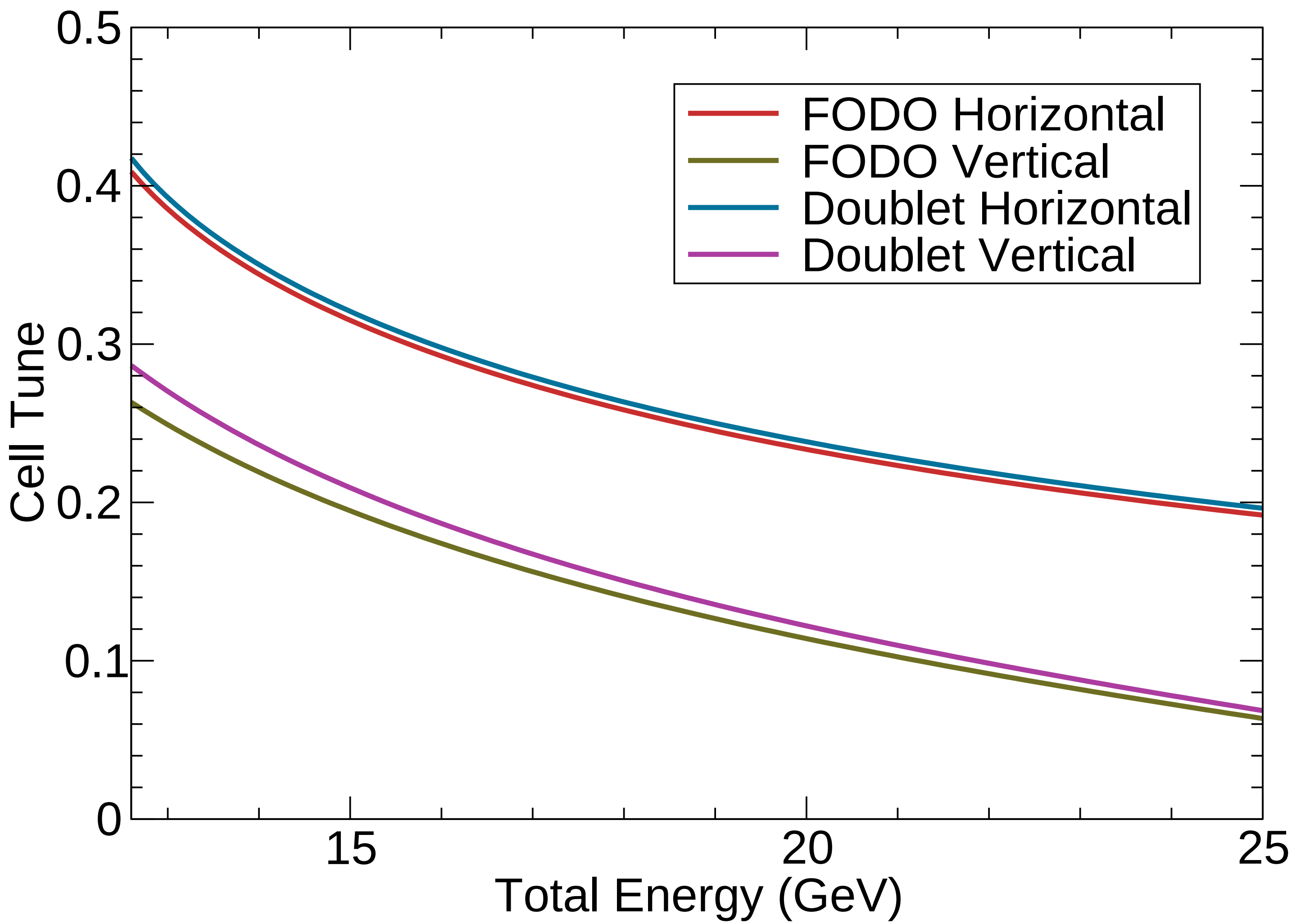
Lattice Design Discussion

- 1 cavity per cell less expensive than 2
  - Less RF
  - Magnets: smaller aperture, lower field
- Two cavities per cell: FODO and doublet lattices very similar
- Triplets more expensive
  - Many more magnets, size/field trade off
  - Doesn’t make up for less voltage

Injection

- Septum followed by kicker in subsequent drift
- 2 cm separation between circulating beam and injected beam at septum
- Ideal tune septum to kicker: 0.25
- Horizontal injection
- Prefer septum just before defocusing magnet
  - Defocusing magnet pushes beam out
  - Beam smaller near defocusing magnet

Lattice Tune



Injection Parameters

	Doublet D First	Doublet F First	FODO First	FODO Second
Kicker Field (T)	0.62	0.62	0.88	1.19
D Radius (cm)	11.0	16.1	9.2	9.9
F Radius (cm)	20.9	33.5	13.2	18.7

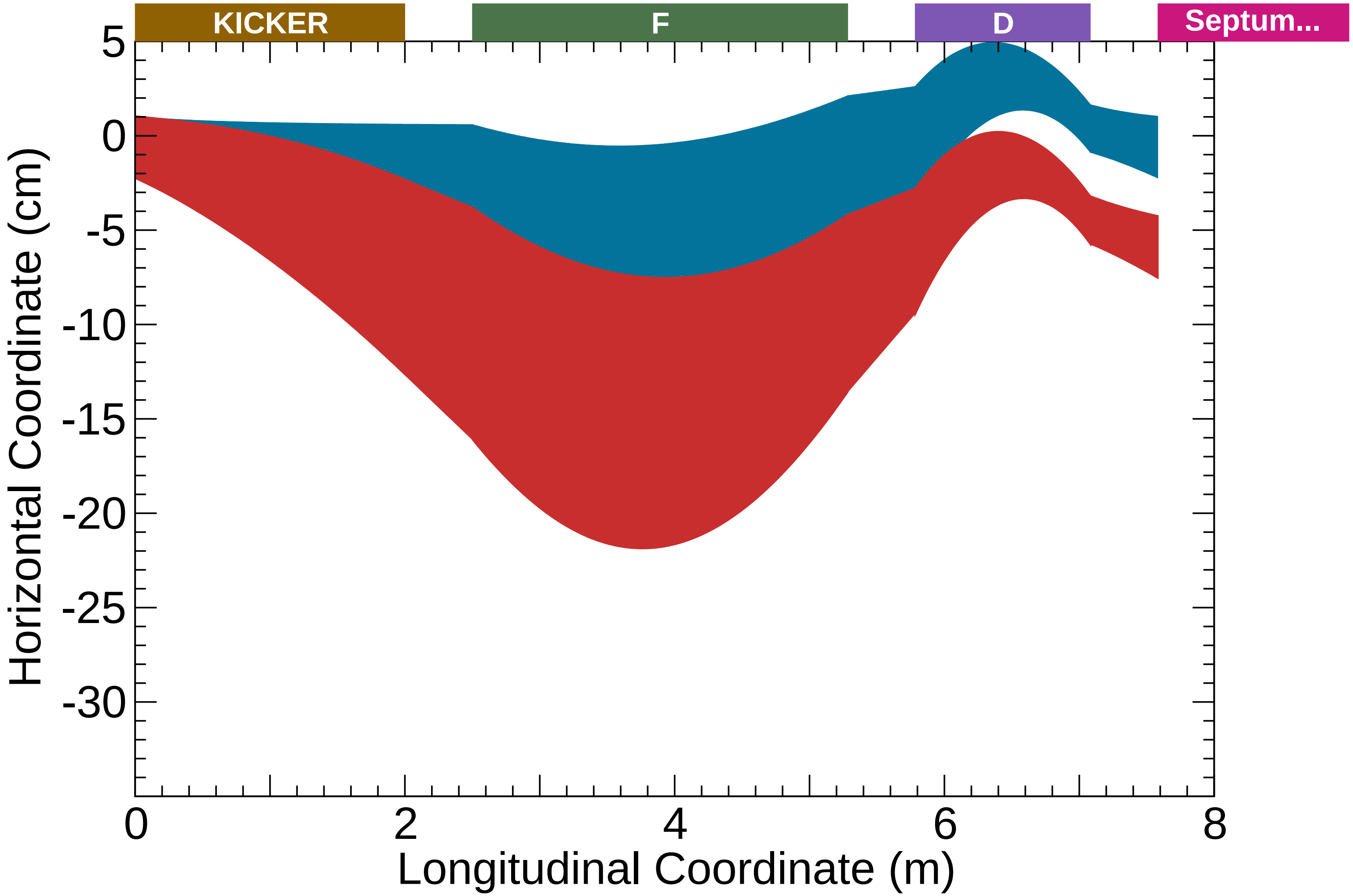
Injection: Commentary

- Only studied 2 cavities per cell, doublet and FODO
- Kicker fields too high (0.5 T goal)
  - Better in doublet: longer drift
  - Use second kicker
- Magnet aperture needed close to design
  - Except when F near septum
  - Outside “good field region,” but not for long
  - FODO slightly better than doublet

Injection Doublet Commentary

- F near septum requires too much aperture
  - Want to avoid special magnets
  - Symmetry breaking bad for FFAGs
- Doublet must either inject or extract wrong way
  - Could inject vertically, extract horizontally
  - Other sign is opposite direction!
    - Injection horizontal, extract vertical
    - Signs asymmetric

Injection
Doublet, D Near Septum



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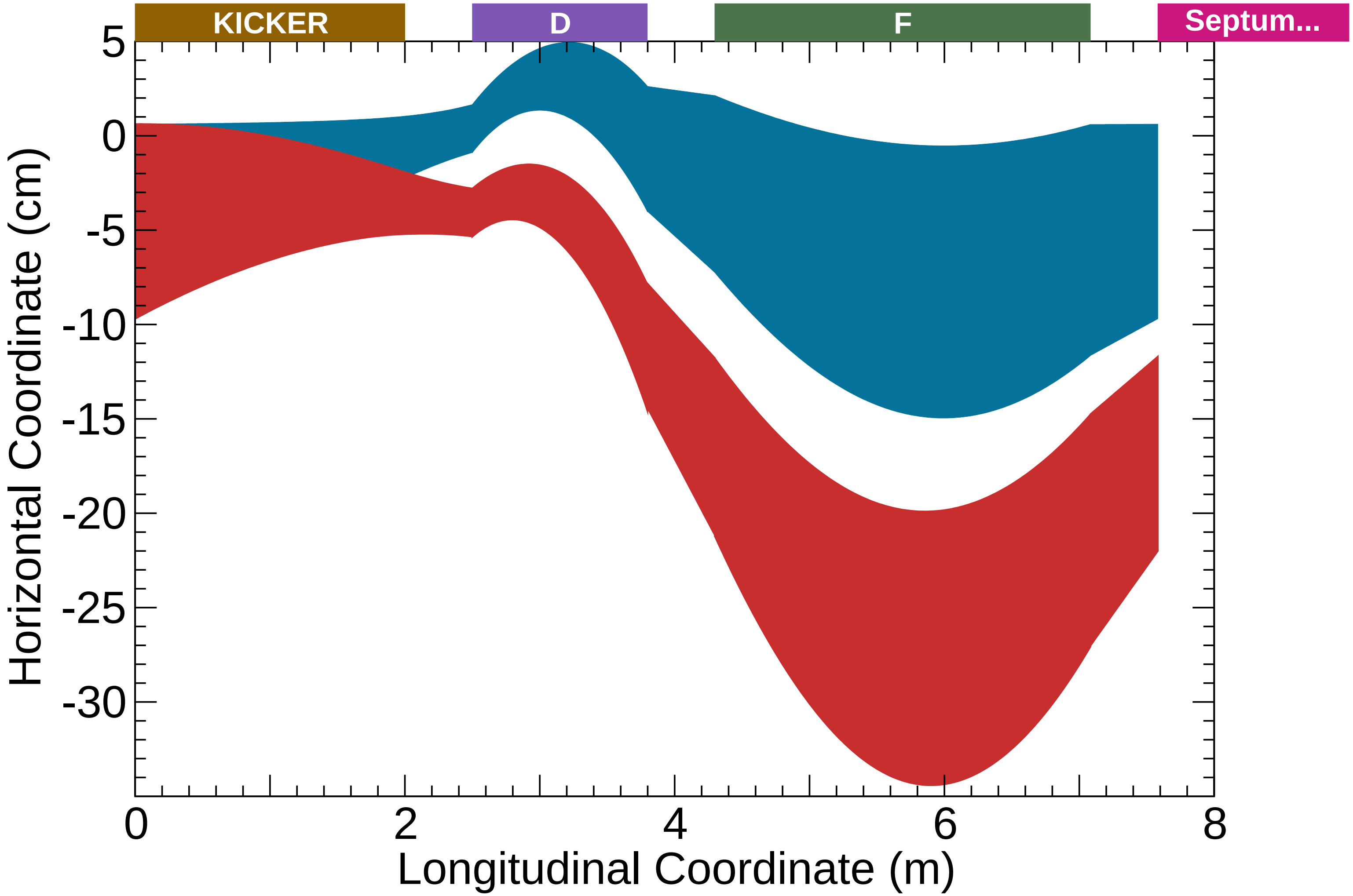
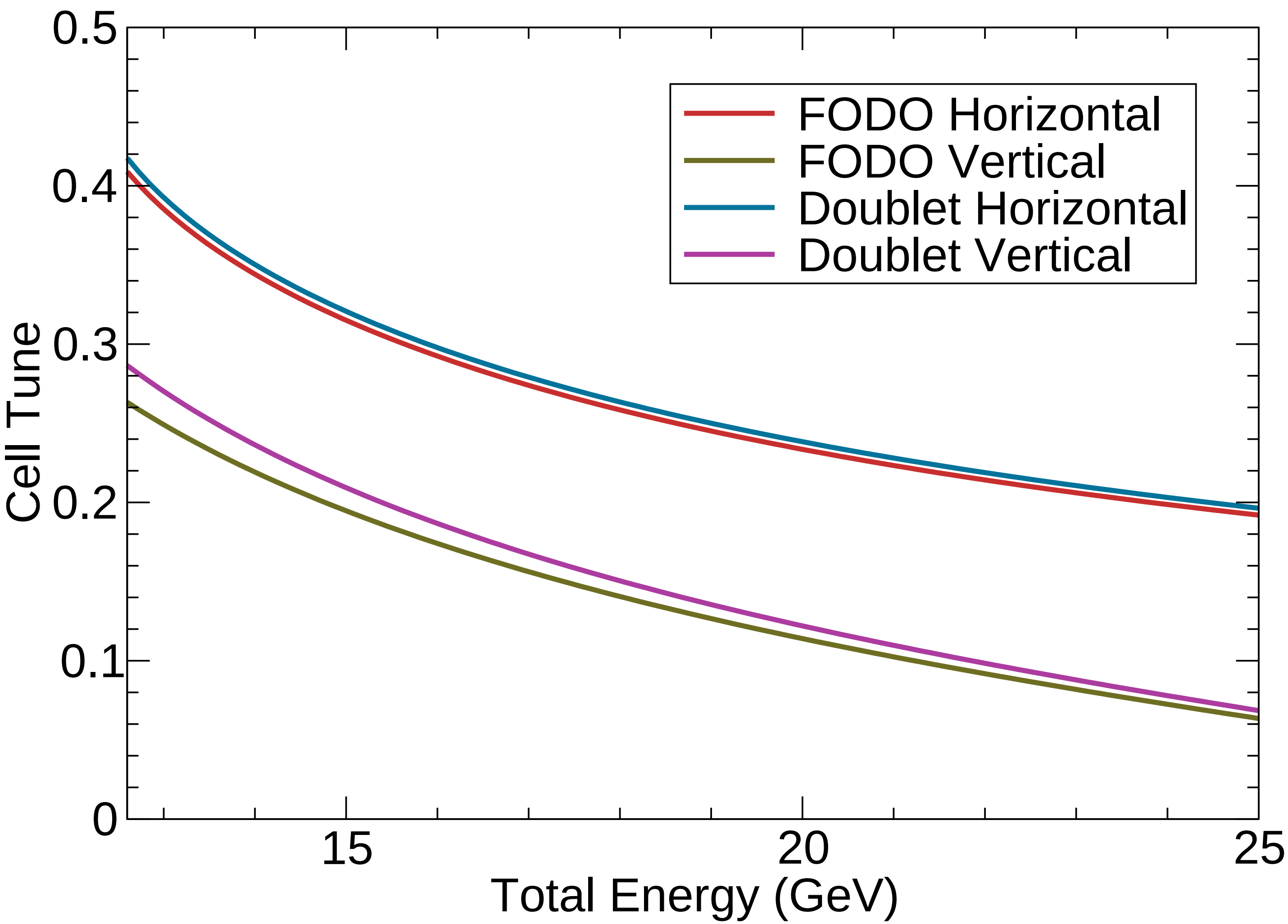
Injection
Doublet, F Near Septum



Lattice Tune



Injection
FODO Commentary

- Injection and extraction with D near septum
- Kicker in first drift more effective
  - Horizontal tune high
  - Most phase advance in D
    - First drift about 0.25 away
- Kickers half of length for doublet

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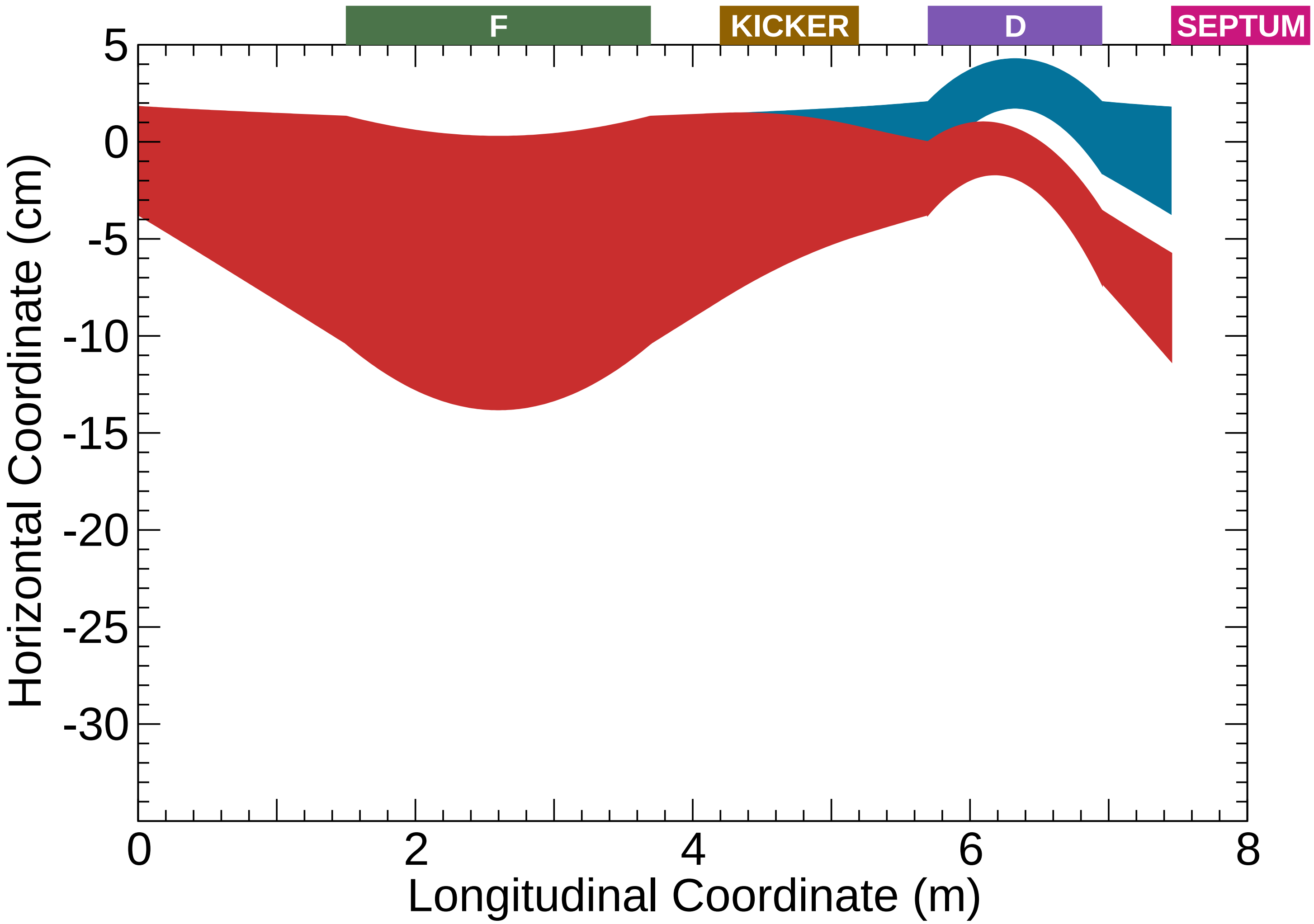
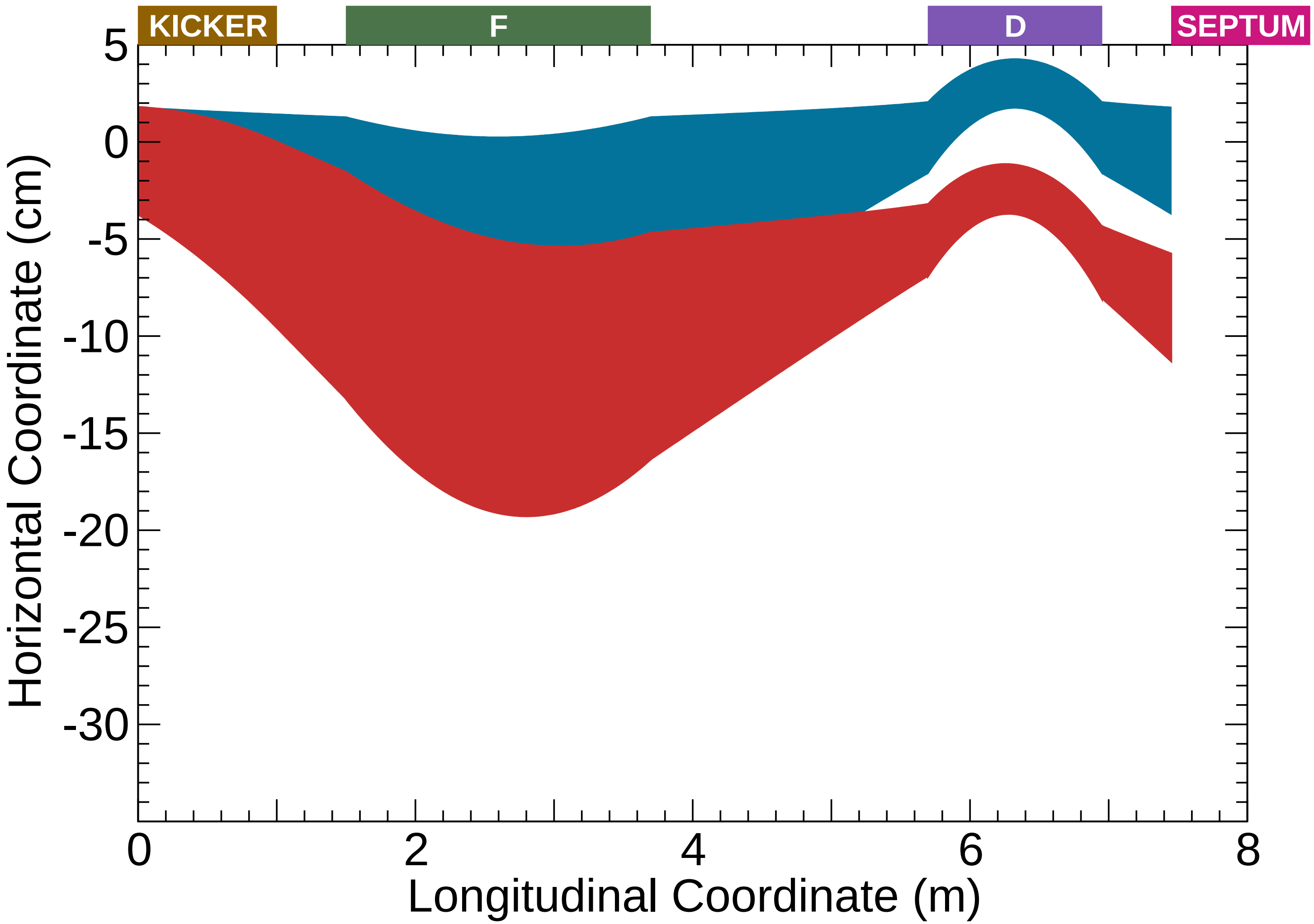
Injection
FODO, Kicker in First Drift



Injection
FODO, Kicker in Second Drift



Injection/Extraction Conclusions

- Doublet lattice problematic due to
  - Requirement to run both signs
  - Lack of directional symmetry
  - Need for both injection and extraction
- Injection/extraction probably force
  - FODO for 2 cavity per cell
    - Triplet also possible
  - Triplet (vertical) for 1 cavity per cell

Tasks

- Design simplistic at this point
  - Careful choice of longitudinal parameters
  - Study performance under tracking
  - Compare 1- and 2-cavity options
- Study with beam loading
  - Develop scheme for handling bunch trains that arrive too rapidly, if necessary
- Complete injection/extraction design