

EMMA Lattice

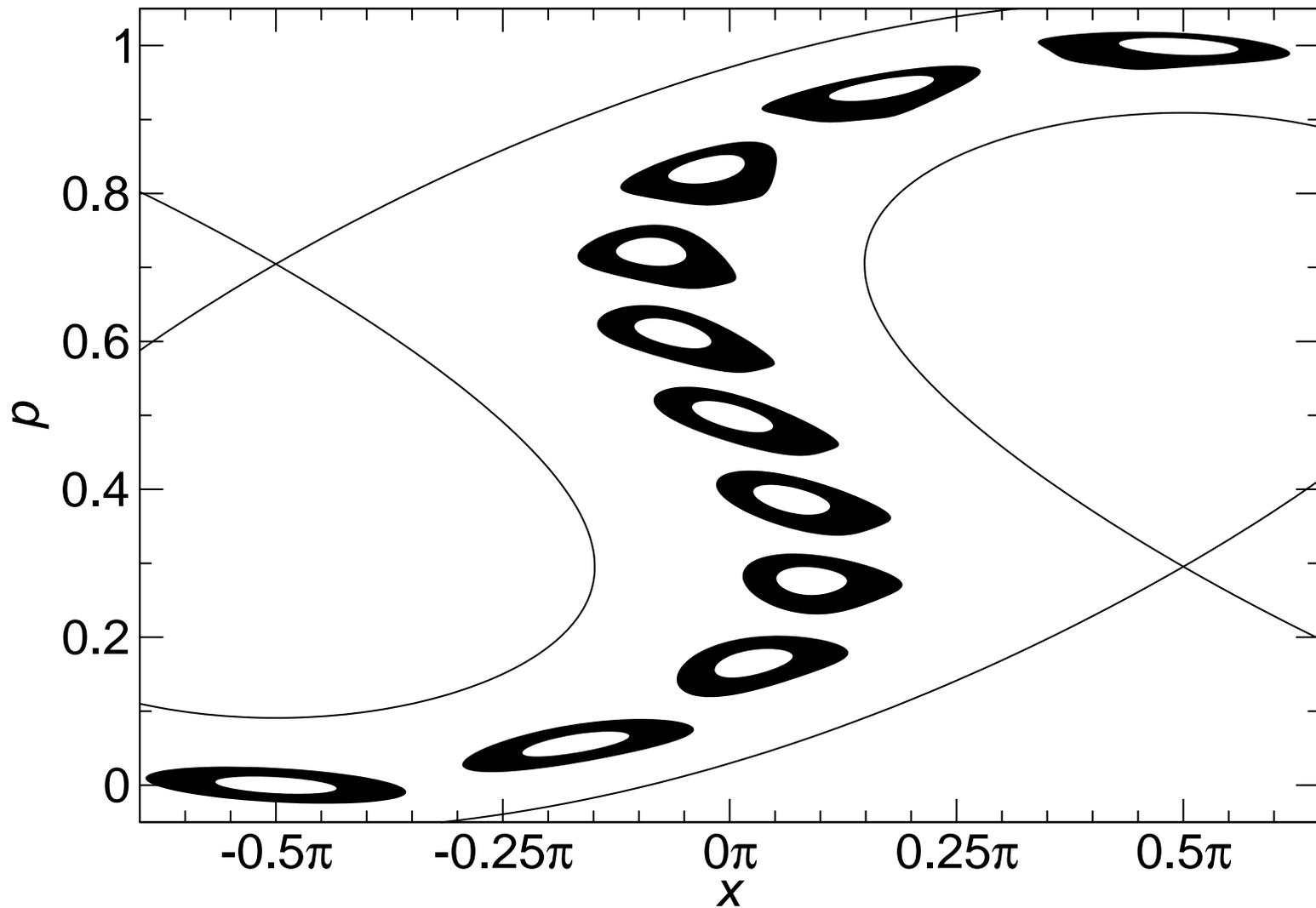
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Brookhaven National Laboratory
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Goals of EMMA

- Must understand goals to understand lattice design
- Study linear non-scaling FFAGs under particular circumstances
 - ◆ Rapid acceleration
 - ◆ Relativistic energies
 - ◆ Main application currently: muon acceleration
- Two important characteristics of non-scaling FFAG lattices
 - ◆ Rapid acceleration through many resonances
 - ◆ Unique longitudinal dynamics: “serpentine acceleration”

Goals of EMMA

Serpentine Acceleration



Goals of EMMA

- EMMA is not simply a demonstration machine
- We want to test our understanding of the underlying dynamics
 - ◆ How does emittance growth depend on which resonances we cross?
 - ◆ How does longitudinal behavior change with machine parameters
 - ★ RF frequency
 - ★ Energy where machine is isochronous
 - ◆ Coupling of transverse and longitudinal motion
 - ◆ What effect do errors have on performance
 - ★ Magnet position
 - ★ Field strength
 - ★ RF phase errors

Basic Lattice Parameters

Motivation

- Performance parameters driving basic design
 - ◆ Would like 500 cell-turns for reasonable longitudinal parameters ($a = 1/12$)
 - ★ More cell-turns means more cells, shorter cells
 - ◆ Want achievable fields in magnets (target was 0.2 T)
 - ◆ Want magnets with a “reasonable” length-to-width ratio
 - ◆ Cost and available space

Basic Lattice Parameters

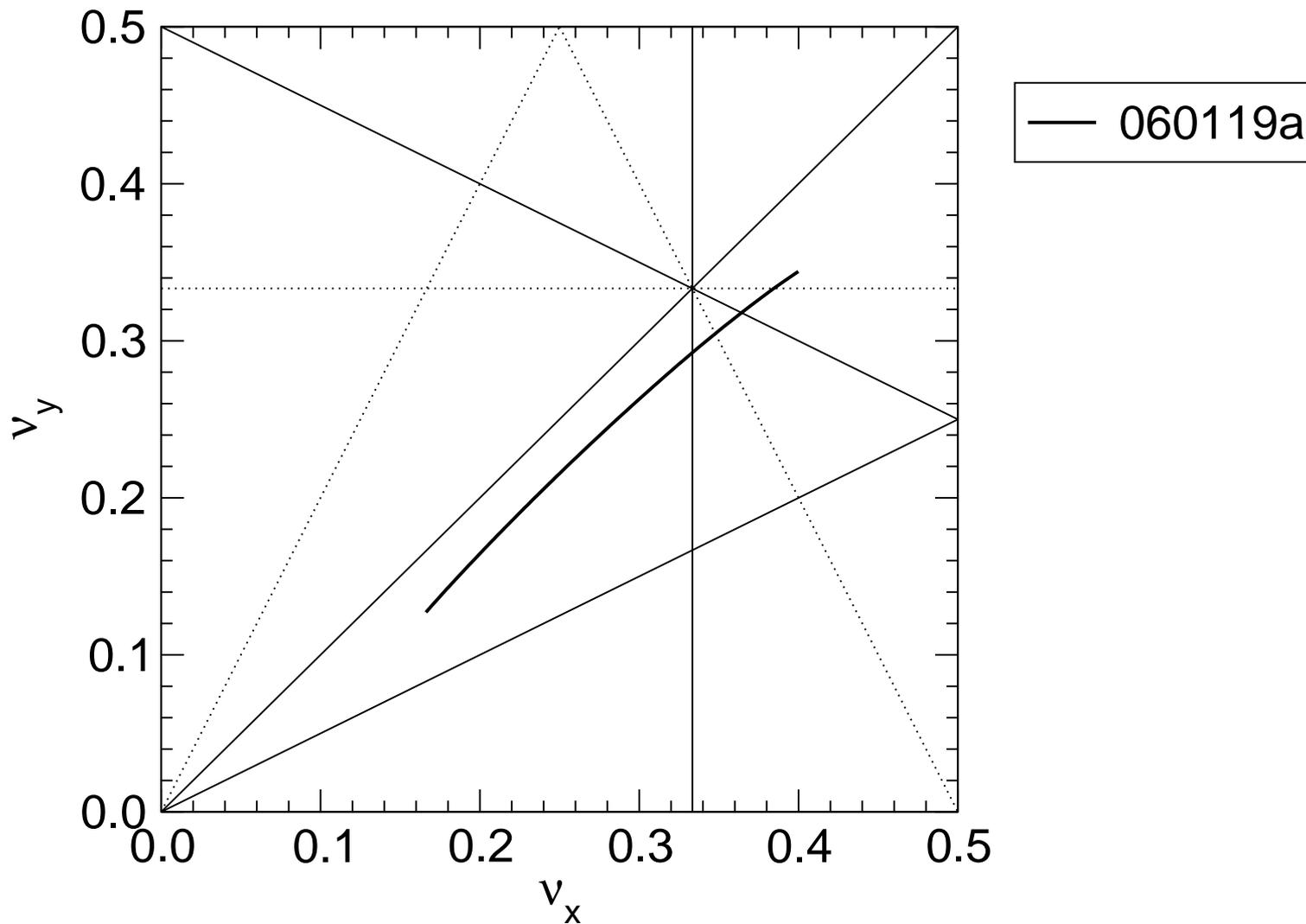
- Energy range: 10–20 MeV kinetic energy
 - ◆ Machine size, magnet fields prevent going higher
- Combined-function doublet cells
 - ◆ Generally give most cell-turns
- 42 cells
 - ◆ Fewer cells would require
 - ★ Fields that are probably too high
 - ★ Magnets which are very short compared to their aperture
 - ◆ More cells increase cost, circumference
- RF Frequency: 1.3 GHz
 - ◆ Higher frequency gives fewer cell-turns for given number of lattice cells
 - ◆ Lower frequency too large

Baseline Lattice Design

- This is our demo lattice: it tries to model the real machine
 - ◆ Avoid $\nu_x - 2\nu_y = 0$ resonance, which we tend to cross slowly
 - ◆ Avoid $\nu_x - \nu_y = 0$ resonance to avoid linear coupling
 - ◆ Get horizontal tune high to achieve performance (500 cell-turns at $a = 1/12$, 20 kV per lattice cell)
 - ◆ Initial pole-tip estimates are comparable for both magnets
 - ◆ Time of flight same at low and high energy
 - ◆ Synchronized to 1.3 GHz RF
 - ◆ Long drift has space for cavity
- Use displaced quadrupoles to get combined function (engineering considerations)

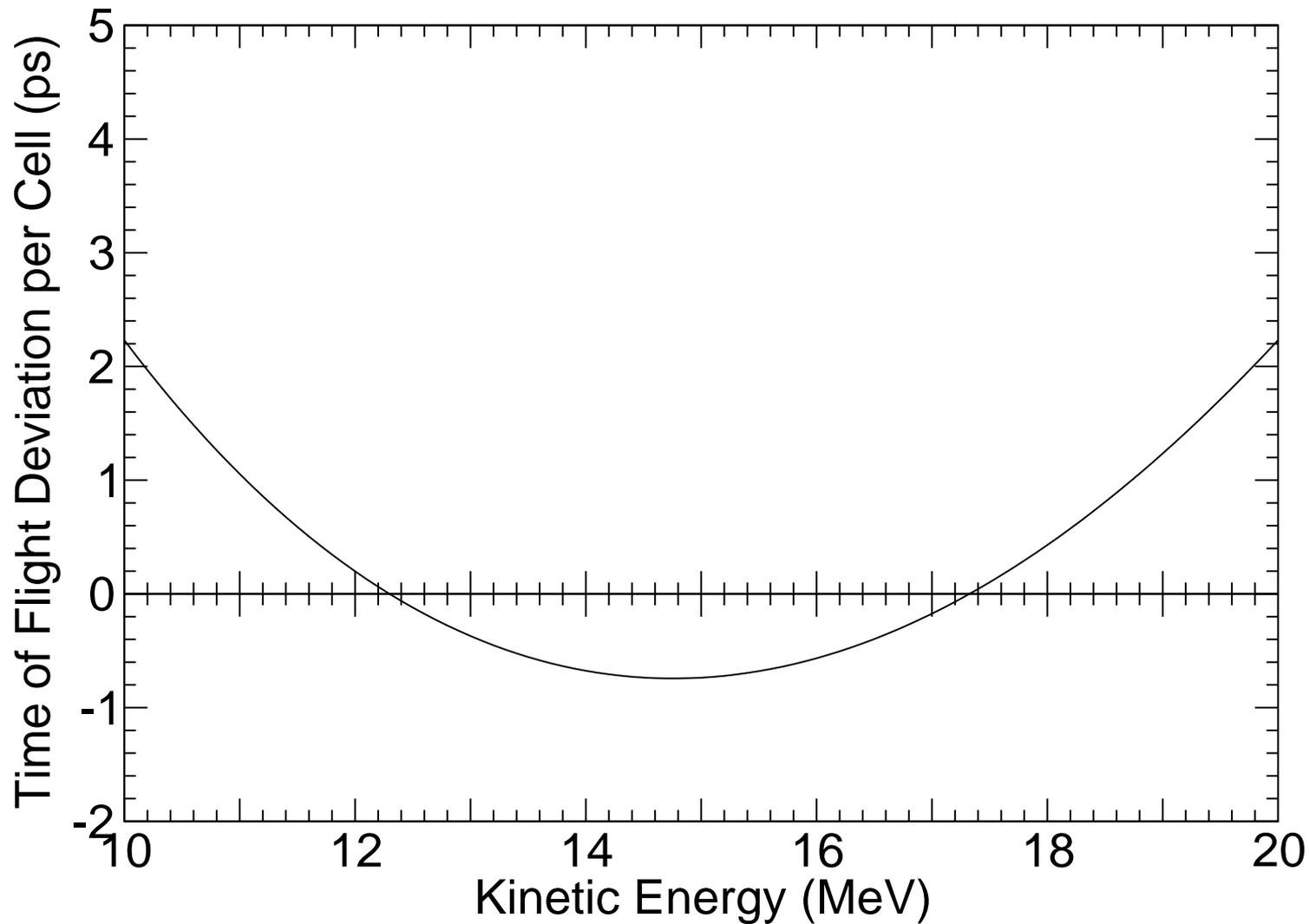
Baseline Configuration

Tune Footprint



Baseline Configuration

Time of Flight



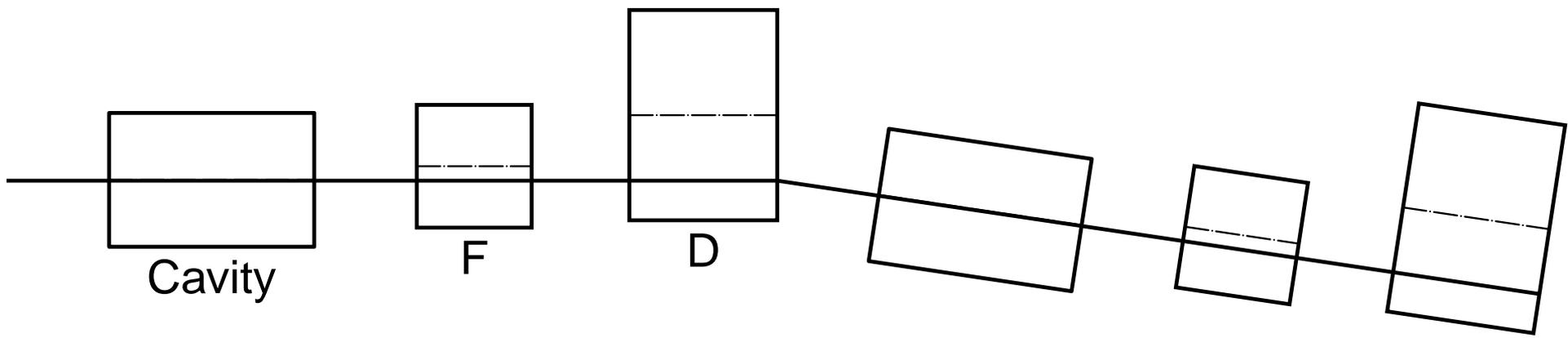
Baseline Configuration

Lattice Parameters

- Assuming a longitudinally rectangular field profile
- Hard-edge end fields, assuming a multipole end field profile
- Magnet and cavity axes are parallel in a given cell
- Displacement is distance of quad center from line

Long drift	210.000 mm
Short drift	50.000 mm
D length	75.699 mm
D displacement	34.025 mm
D gradient	-4.707 T/m
F length	58.782 mm
F displacement	7.507 mm
F gradient	6.697 T/m

Lattice Cell Layout



Alternate Configurations

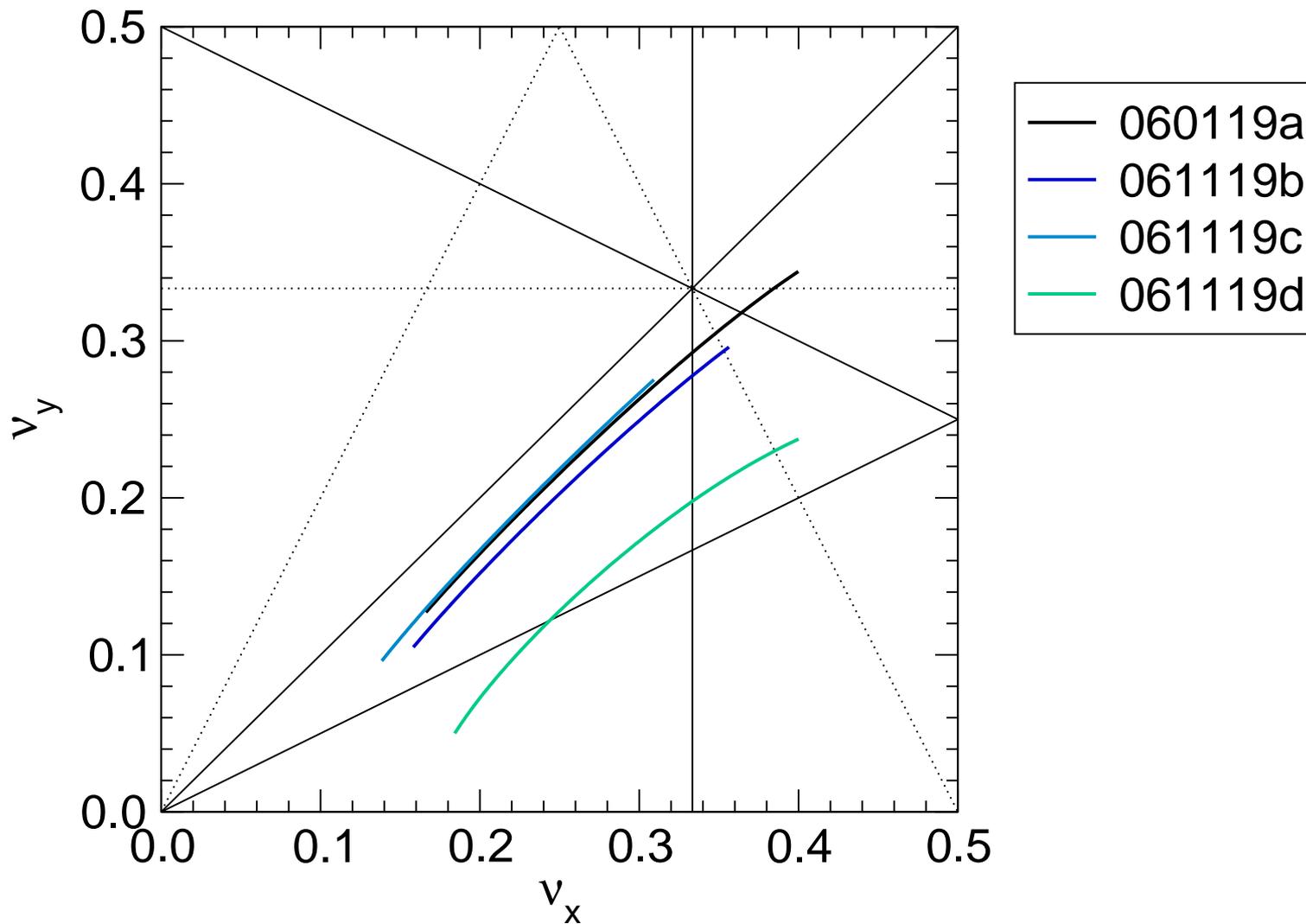
- Try to accomplish study goals
 - ◆ Pass through different sets of resonances
 - ◆ Study range of longitudinal dynamics parameters
- Vacuum chamber remains in place
- Only allowed lattice changes
 - ◆ Horizontal displacement of magnets
 - ◆ Change in magnet gradients
 - ◆ Change in RF frequency
- Different configurations will determine vacuum chamber size, magnet and cavity apertures

Alternate Configurations

Passing Through Different Resonances

- Focus on resonances to third order
 - ◆ Skew quad driven
 - ◆ Upright sextupole driven
 - ★ We have upright sextupole, since we're off-axis in the magnet
- Vary how we cross these, or on which side we're on
 - ◆ Stay between $\nu_x - \nu_y = 0$ and $\nu_x - 2\nu_y = 0$, vary whether we cross $3\nu_x = 1$ and $\nu_x + 2\nu_y = 1$
 - ◆ Difficult to go above $\nu_x - \nu_y = 0$, don't do it
 - ◆ Make ν_x as high as practical, ν_y as low as practical

Alternate Configurations Tune Footprints



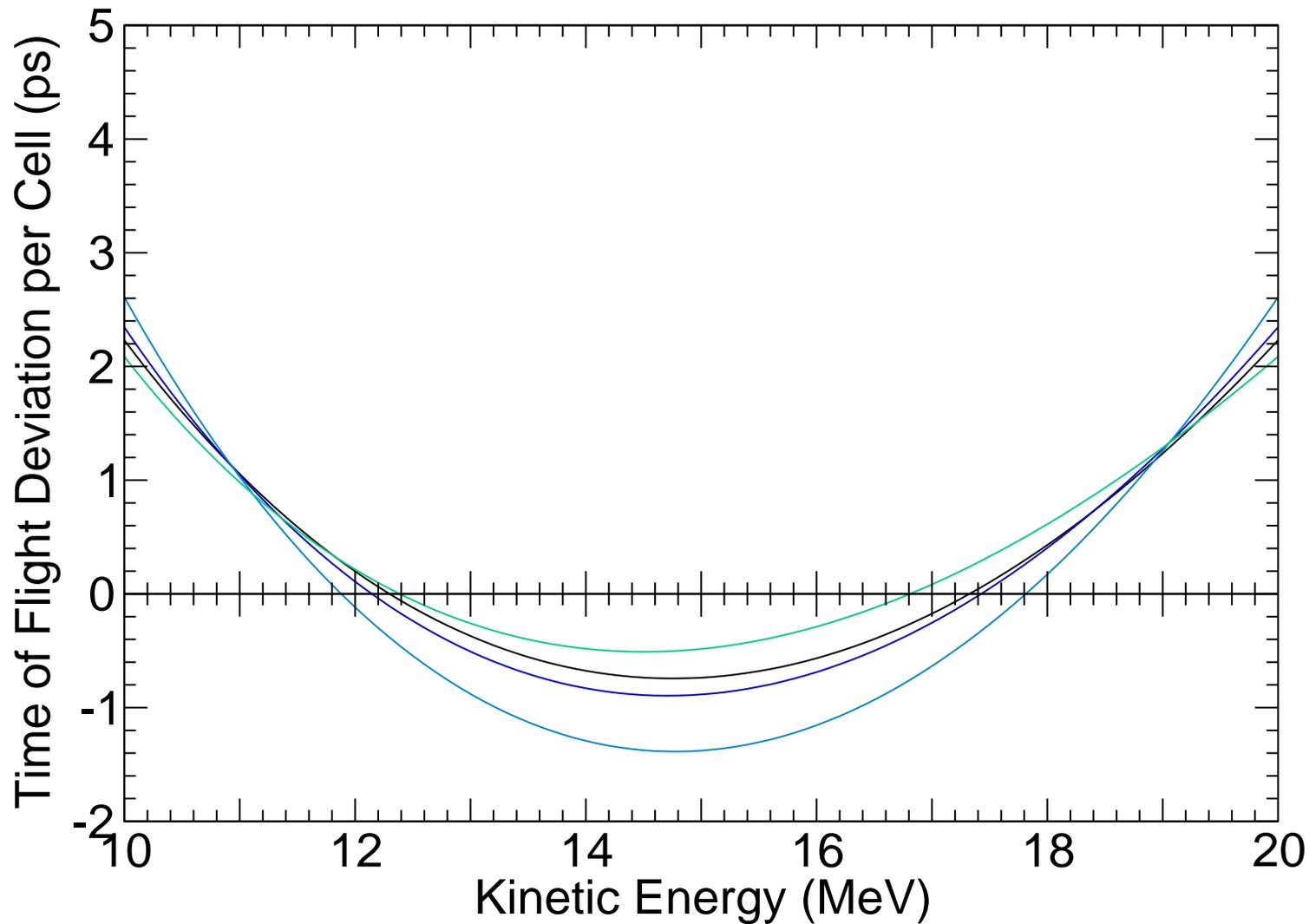
Alternate Configurations

Passing Through Different Resonances

- Configuration between $\nu_x - \nu_y = 0$ and $\nu_x - 2\nu_y = 0$ and below $3\nu_x = 1$ determines aperture
 - ◆ Avoids all resonances driven to lowest order by sextupole
 - ◆ Thus important to keep
- Longitudinal dynamics gets modified as well
- Path length changes
 - ◆ RF frequency must be adjusted
- Range of time of flight (min to max) changes
 - ◆ Need more or less voltage to get same a
 - ◆ Number of turns to accelerate changes

Passing Through Different Resonances

Time of Flight



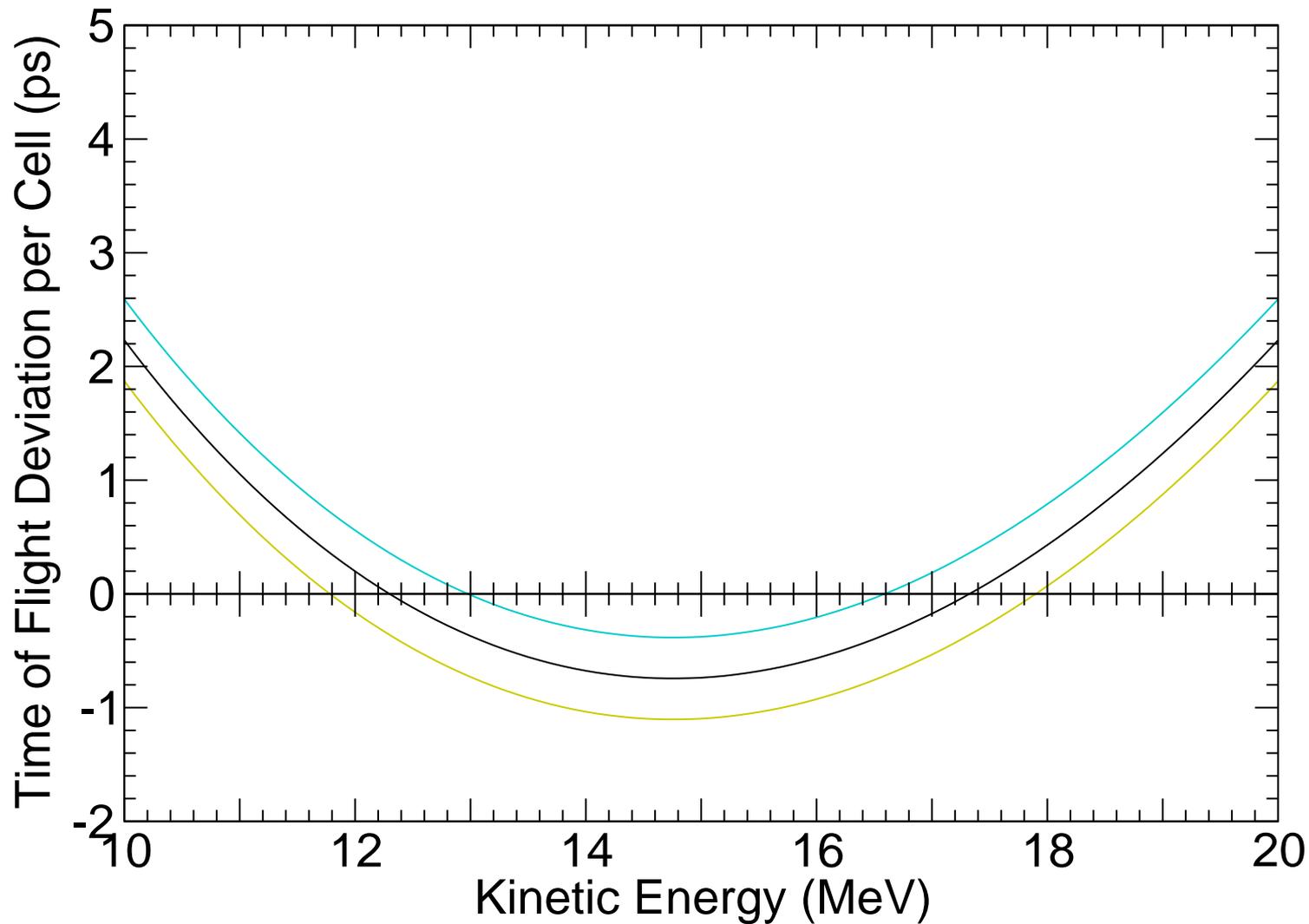
Alternate Configurations

Longitudinal: Vary Synchronized Energy



- Change the energies that are synchronized to the RF
- Changes the longitudinal dynamics (varies b)
 - ◆ More or less longitudinal phase space acceptance
 - ◆ More or less longitudinal phase space distortion
- Useful in commissioning: running at fixed energy
 - ◆ Running with cavities off will give beam loading problems
- Requires that the RF frequency be varied
- No effect on aperture

Vary Synchronized Energy Time of Flight



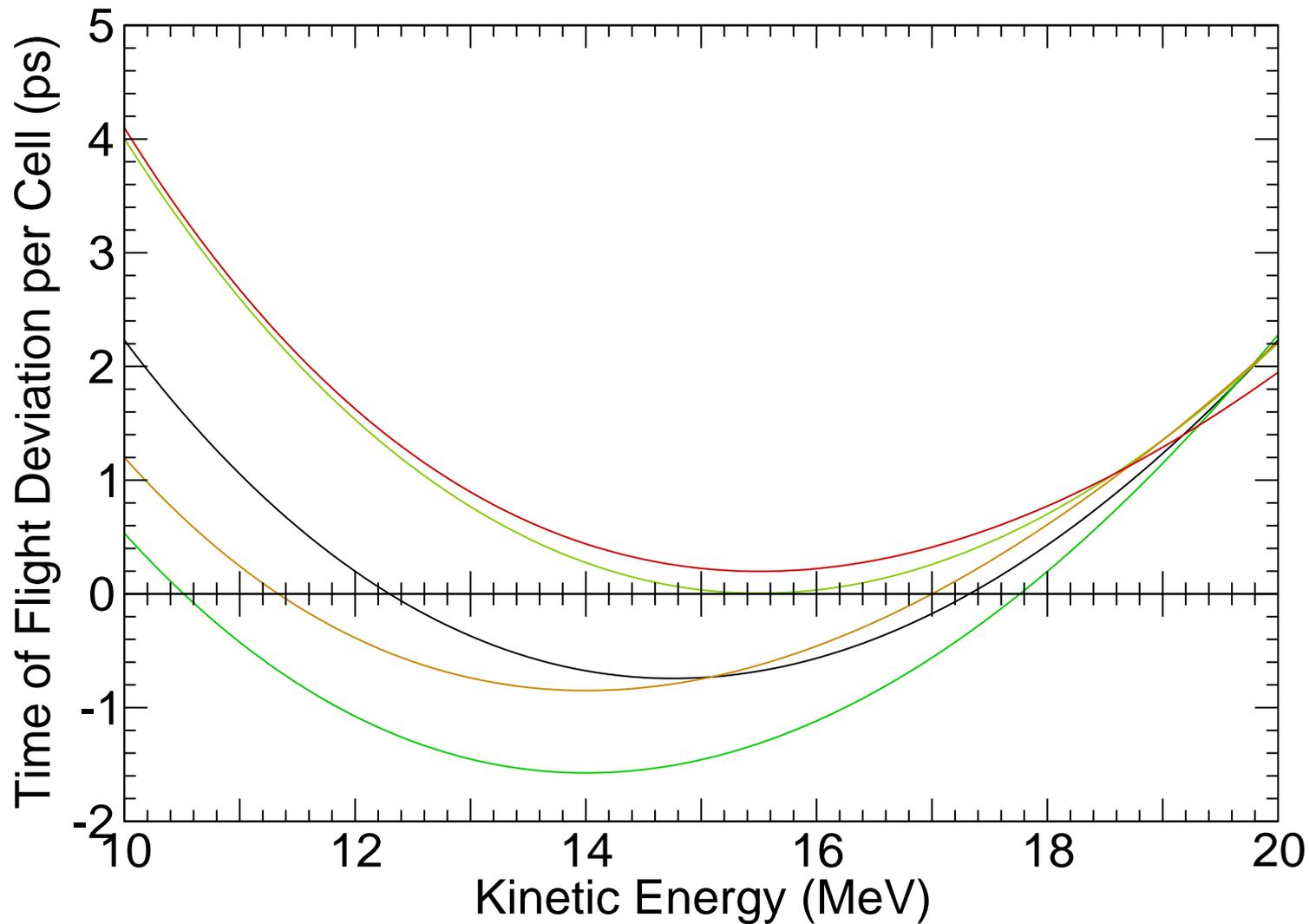
Alternate Configurations

Longitudinal: Vary Centering of ToF Curve

- Move the energy for the minimum of the time of flight curve
- Time at low and high energy will now be different
- Looking at variations in longitudinal phase space behavior
- Extremes: place minimum at 14 MeV and 15.5 MeV
 - ◆ Going further requires increasing apertures significantly
- Considered doing this for different lattices
 - ◆ Lattice below $3\nu_x = 1$
 - ★ Increased aperture significantly
 - ★ Already largest aperture
 - ★ Thus, not proposing to try this
 - ◆ Only considering for high-tune lattices
- As before, must adjust RF frequency and voltage, increase apertures

Vary Centering of ToF Curve

Time of Flight

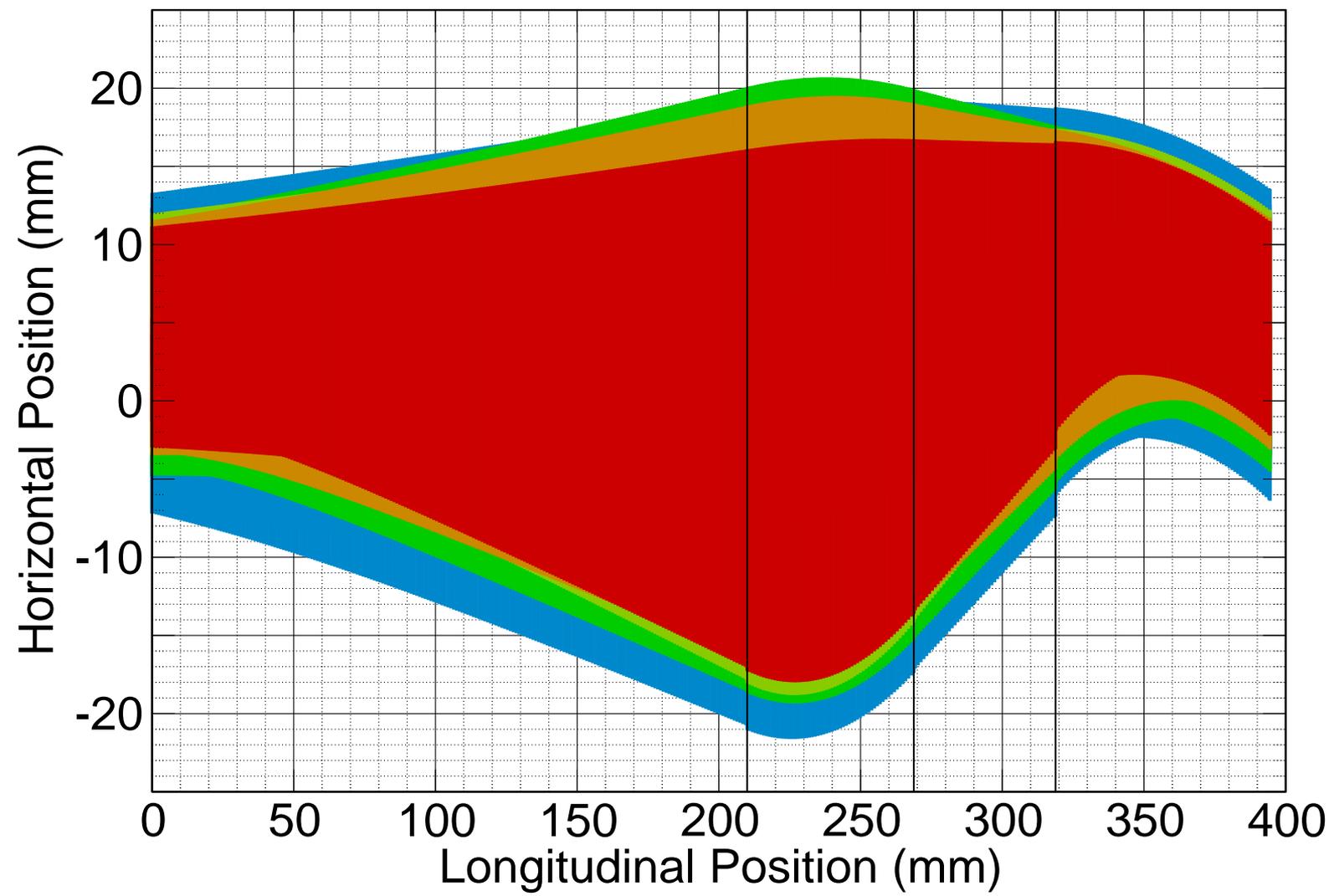


Required Quad Parameters for Configurations

- D Quad (dimensions in mm)
 - ◆ Vacuum chamber: 26.182×11.678
 - ◆ Quad center displacement: $[28.745, 48.560]$, baseline 34.025
 - ◆ Maximum horizontal quad coordinate: -55.960
 - ◆ Maximum gradient: -4.845 T/m

- F Quad
 - ◆ Vacuum chamber: 42.319×8.907
 - ◆ Quad center displacement: $[4.903, 10.218]$, baseline 7.507
 - ◆ Maximum horizontal quad coordinate: -31.843
 - ◆ Maximum gradient: 6.849 T/m

Horizontal Beam Footprint



Required RF Parameters for Configurations

- Cavity aperture: 34.734×10.571
- Frequency tunability range: 5582 kHz
 - ◆ Allows running different b in different configurations
 - ◆ Allows running at fixed frequency over entire energy range
- RF voltage: to achieve $a = 1/6$ in all symmetric configurations
 - ◆ Every other cell: 109 kV/cavity
 - ◆ Ever third cell: 163 kV/cavity
 - ◆ 19 cavities: 120 kV/cavity
 - ★ Current desired configuration: every third cell non-adiabatic, every second cell, no room for injection
 - ◆ Would like higher a (about 1/4): voltage proportional to a