EMMA Lattice

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EMMA Design Review
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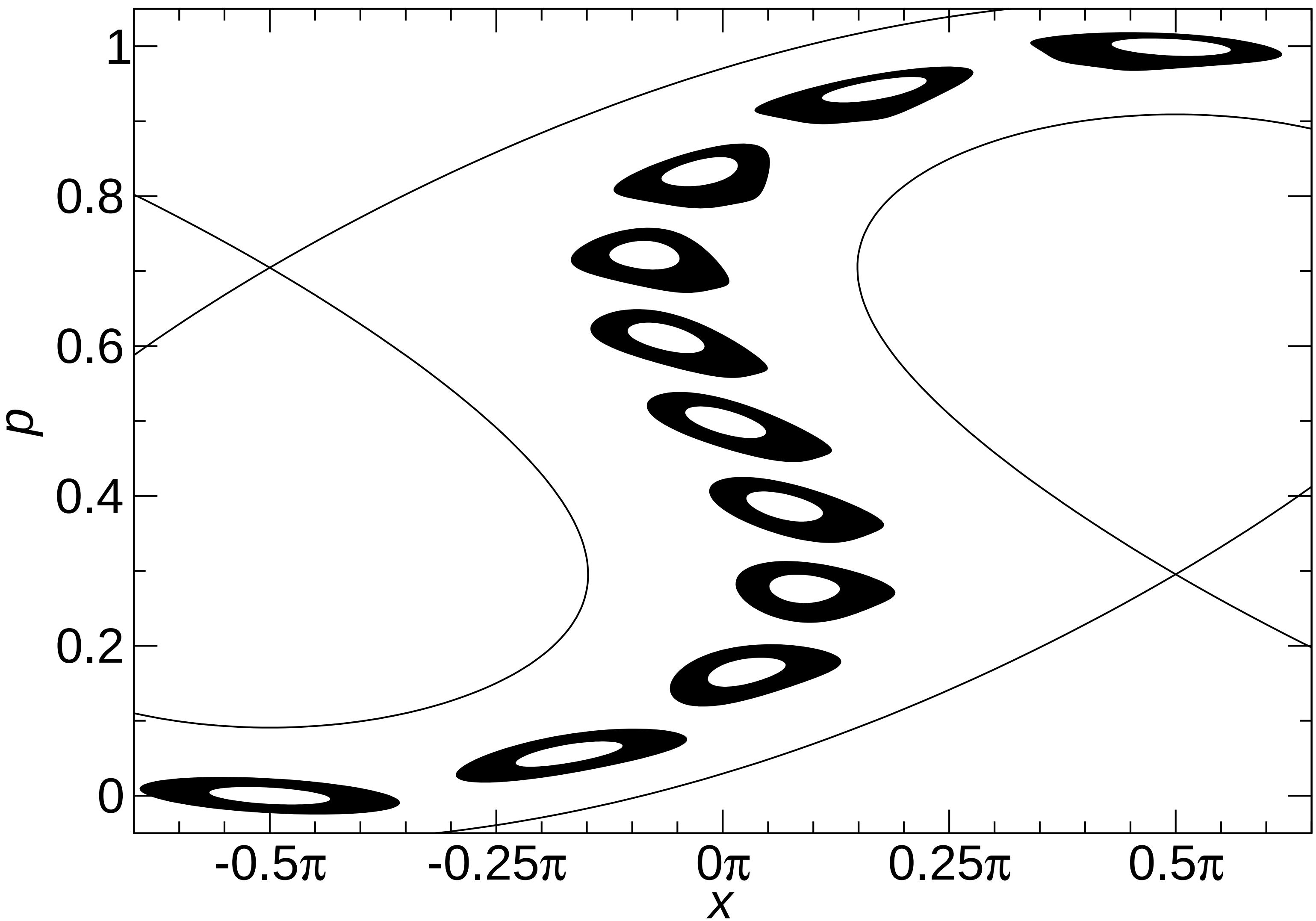
Goals of EMMA

- 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

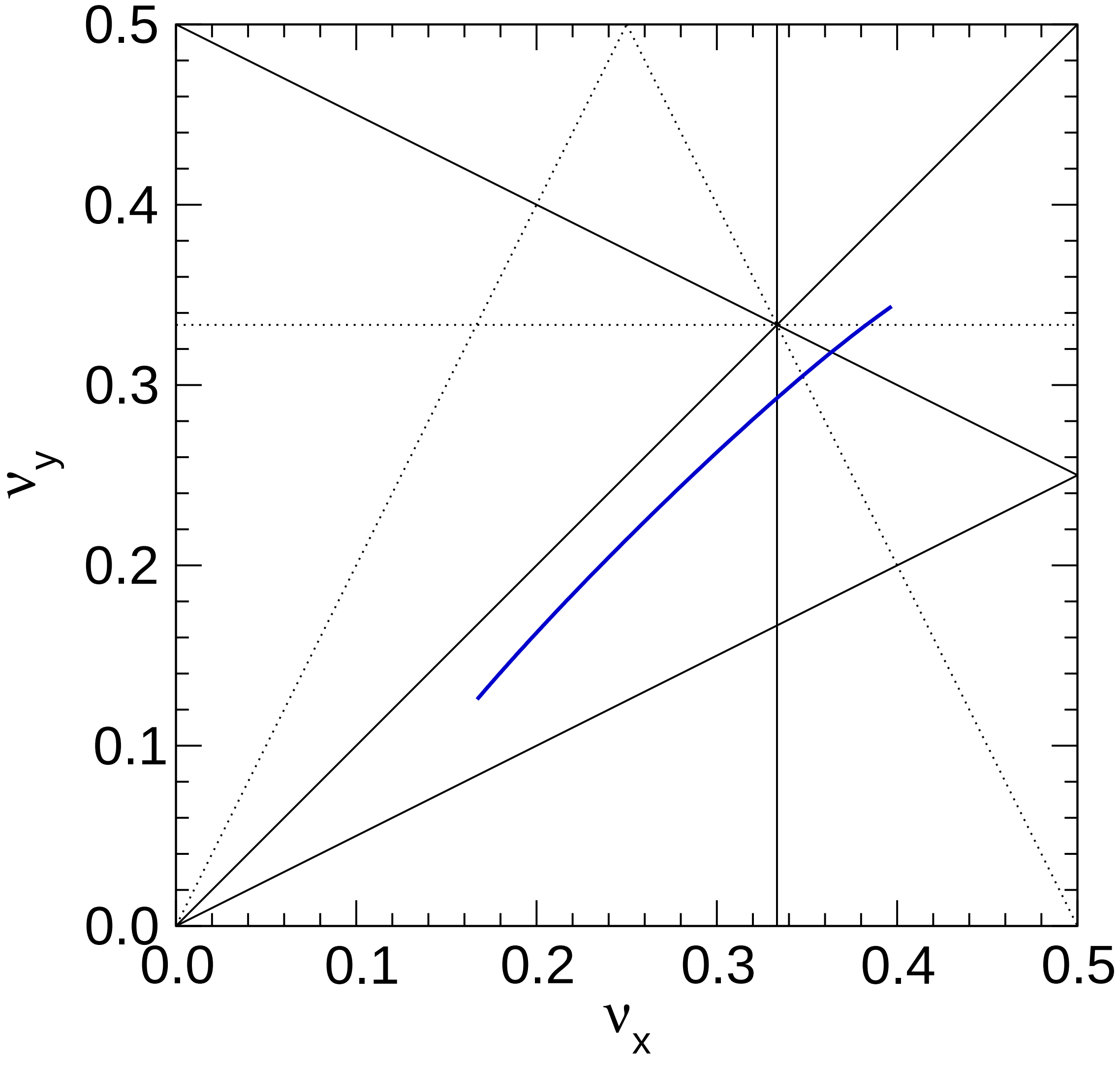
Basic Lattice Parameters

- 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

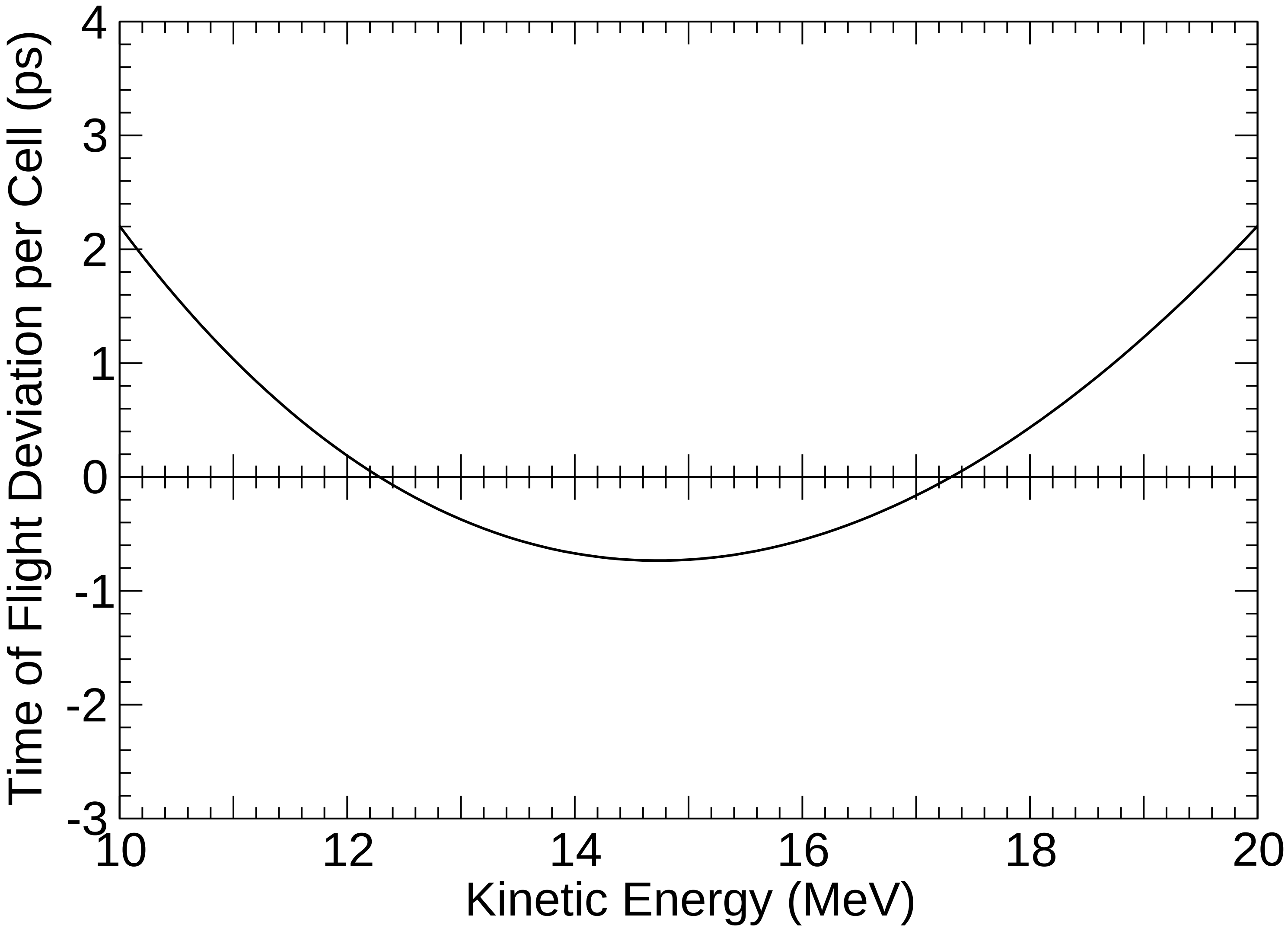
Baseline Lattice Design

- 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)
- This lattice determines the geometry

Baseline Configuration
Tune Footprint



Baseline Configuration
Time of Flight

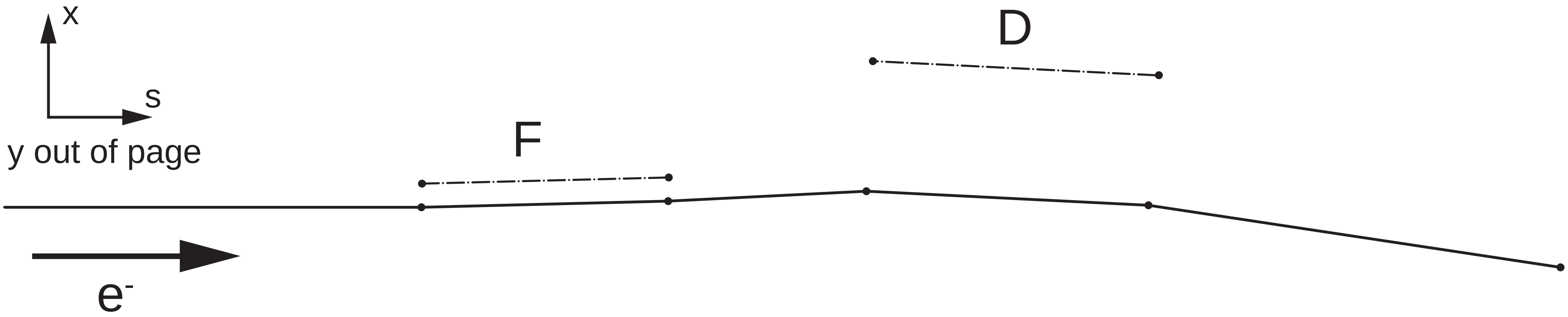


Baseline Configuration
Lattice Parameters

- Assuming a longitudinally rectangular field profile
- Hard-edge end fields, assuming a multipole end field profile
- Layout is a sequence of connected line segments
  - Bend by half magnet angle at entrance and exit
- Displacement is distance of quad center from line

Long drift	210.000 mm
Short drift	55.452 mm
D length	70.921 mm
D angle	215.333 mrad
D displacement	33.306 mm
D gradient	-4.892 T/m
F length	58.221 mm
F angle	-65.733 mrad
F displacement	8.459 mm
F gradient	6.650 T/m

Lattice Cell Layout



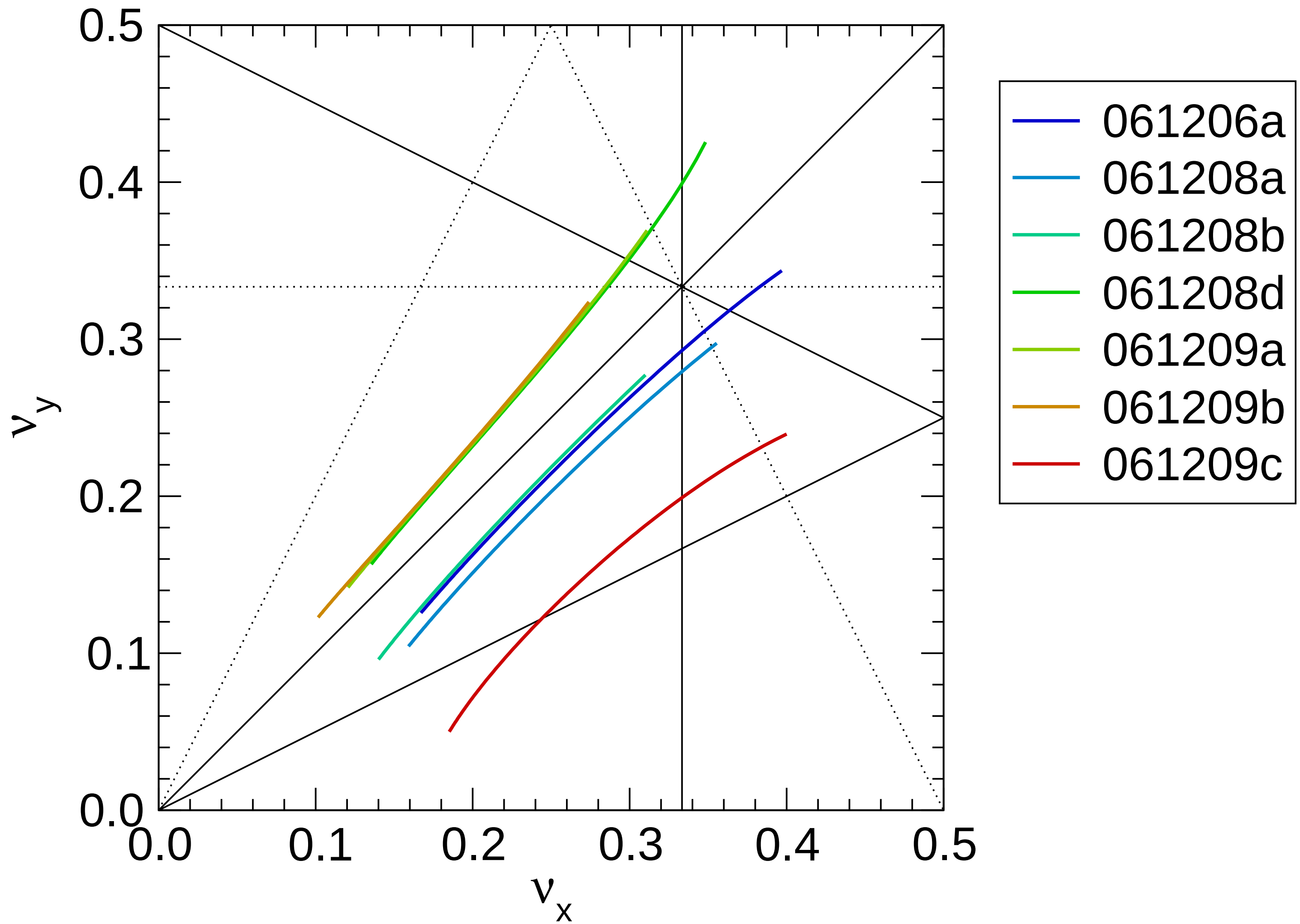
Alternate Configurations

- 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 $\nu_x + 2\nu_y = 1$
  - Go above $\nu_x - \nu_y = 0$
  - Make ν_x as high as practical, ν_y as low as practical

Alternate Configurations
Tune Footprints



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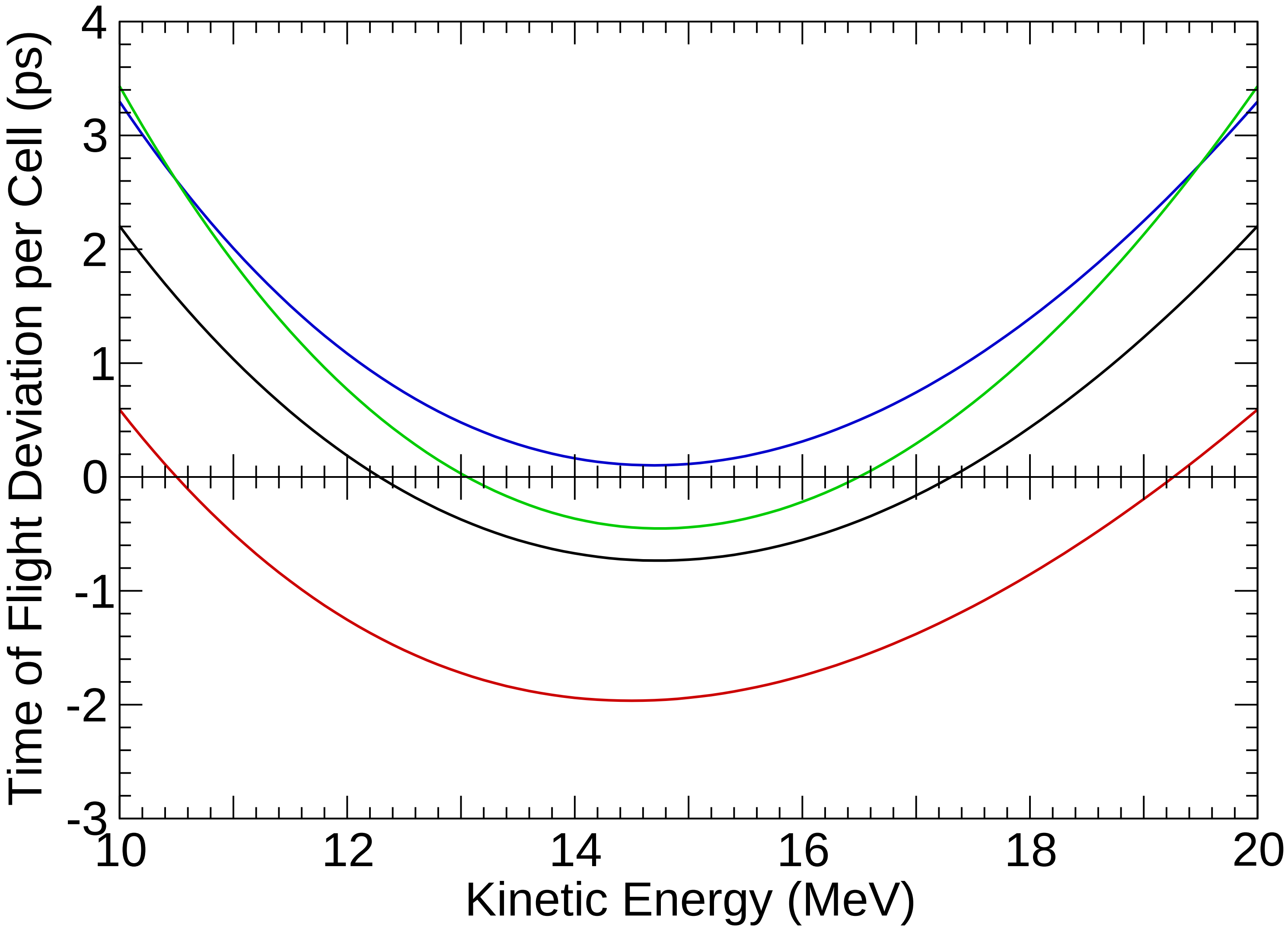
Alternate Configurations
Passing Through Different Resonances

- Configurations above $\nu_x - \nu_y = 0$
  - Require significant aperture increases
    - Low tunes increase horizontal aperture
    - High tunes increase vertical aperture
  - Less interesting in the situations EMMA is studying
    - They tend to have larger horizontal apertures
    - It is difficult to make them isochronous
  - I suggest that we ignore these when determining apertures
- Configuration between $\nu_x - \nu_y = 0$ and $\nu_x - 2\nu_y = 0$ and below $3\nu_x = 1$ then determines aperture
  - Avoids all resonances driven to lowest order by sextupole
  - Thus important to keep

Alternate Configurations
Passing Through Different Resonances

- 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

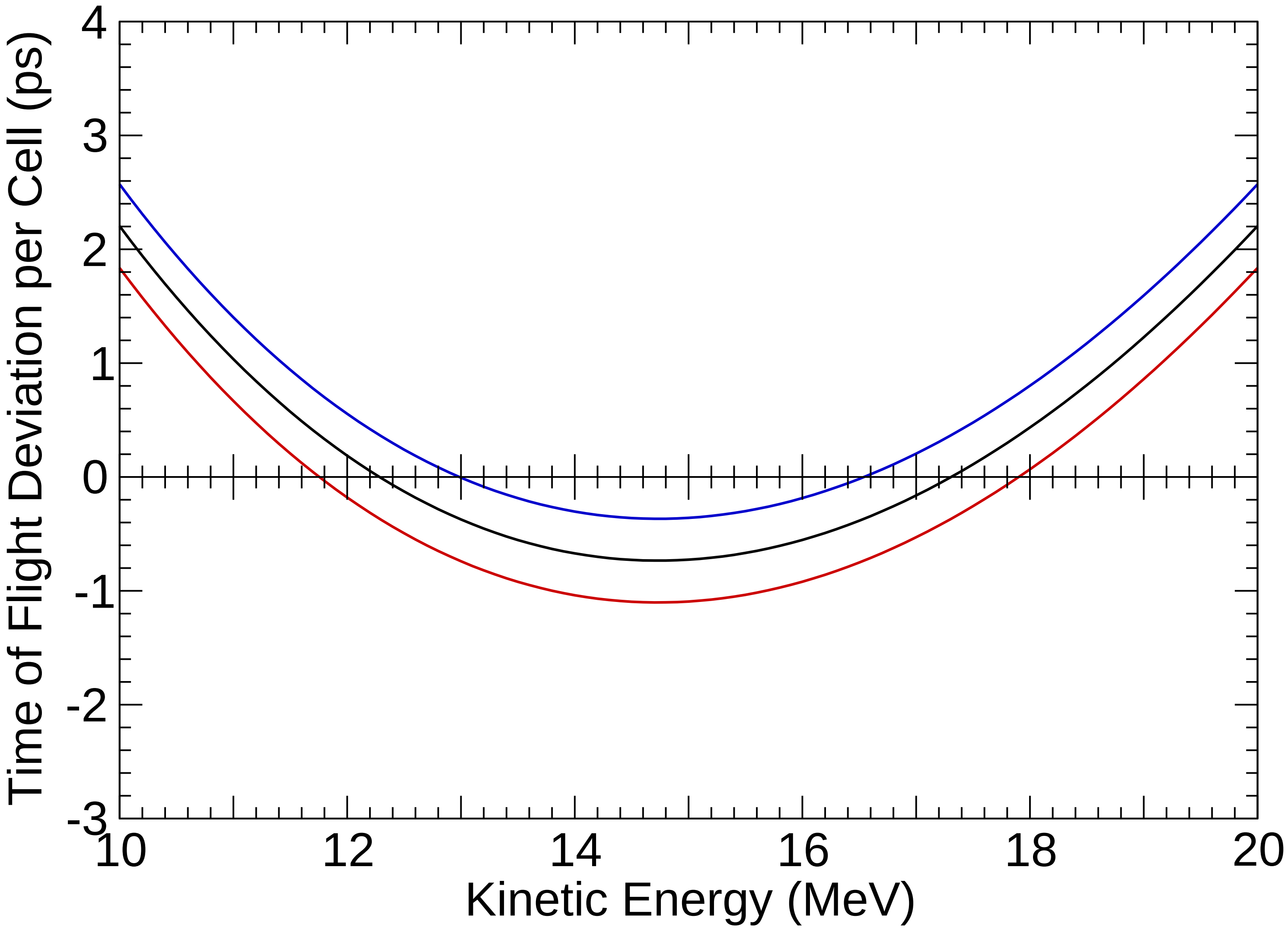
Passing Through Different Resonances
Time of Flight



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



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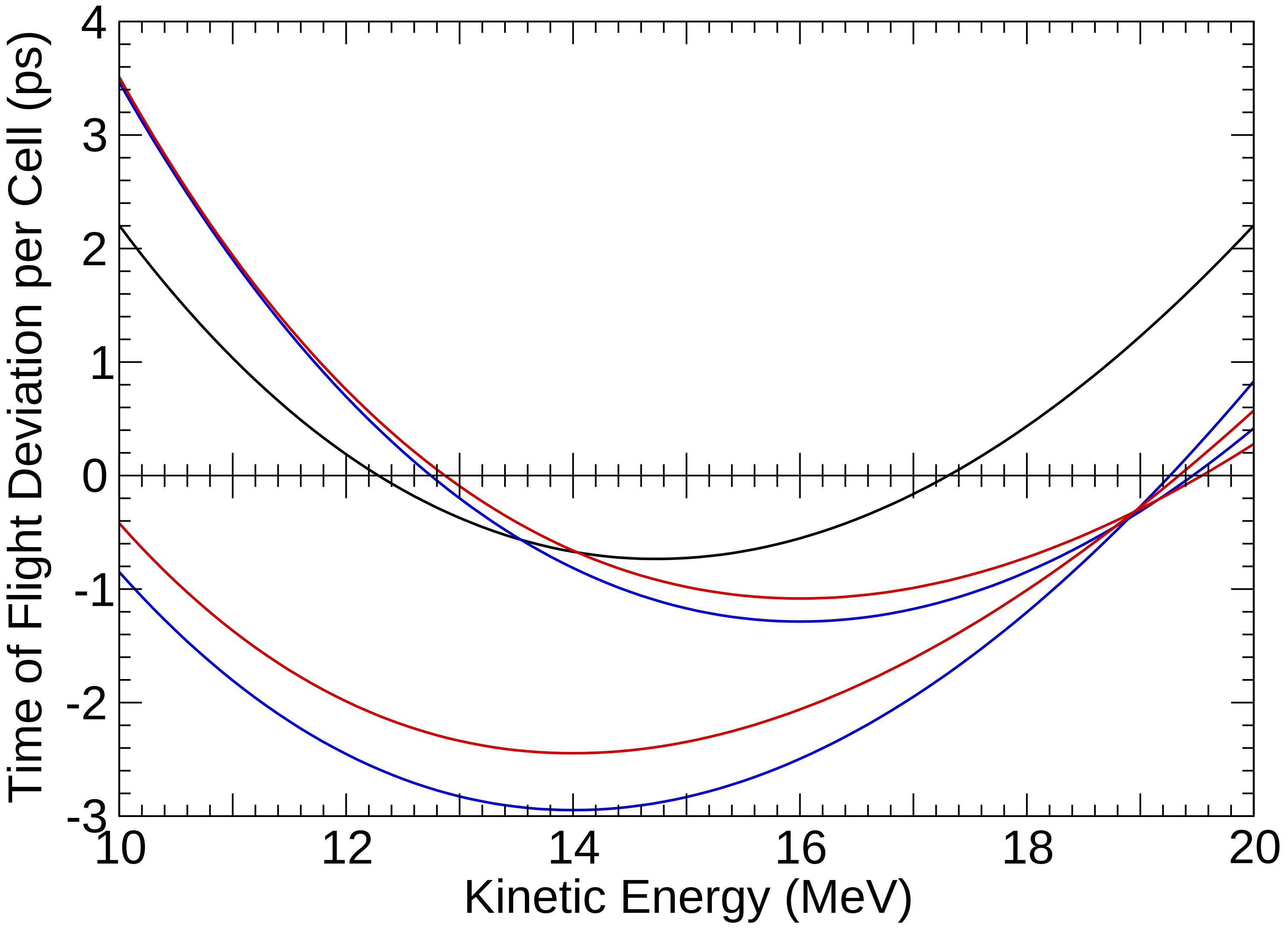
Alternate Configurations

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 16 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



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Required Quad Parameters for Configurations

- D Quad (dimensions in mm)
  - Vacuum chamber: horizontal [-8.297,16.030], half height 11.722
  - Quad center displacement: [28.293,51.823], baseline 33.306
  - Maximum horizontal quad coordinate: -60.120
  - Maximum gradient: -5.041 T/m
- F Quad
  - Vacuum chamber: horizontal [-19.737,22.218], half height 8.874
  - Quad center displacement: [6.172,12.429], baseline 8.459
  - Maximum horizontal quad coordinate: -32.166
  - Maximum gradient: 6.799 T/m

Required RF Parameters for Configurations

- Cavity aperture: horizontal [-17.164,21.265], half height 11.128
- Frequency tunability range: [1.297457,1.301423] GHz
  - Allows running different b in different configurations
  - Allows running at fixed frequency over entire energy range
- RF voltage
  - Assuming one cavity every third cell
  - To achieve $a = 1/6$ in all symmetric configurations: 159 kV/cavity
  - More is desirable, up to 360 kV