EMMA: Injection and Extraction

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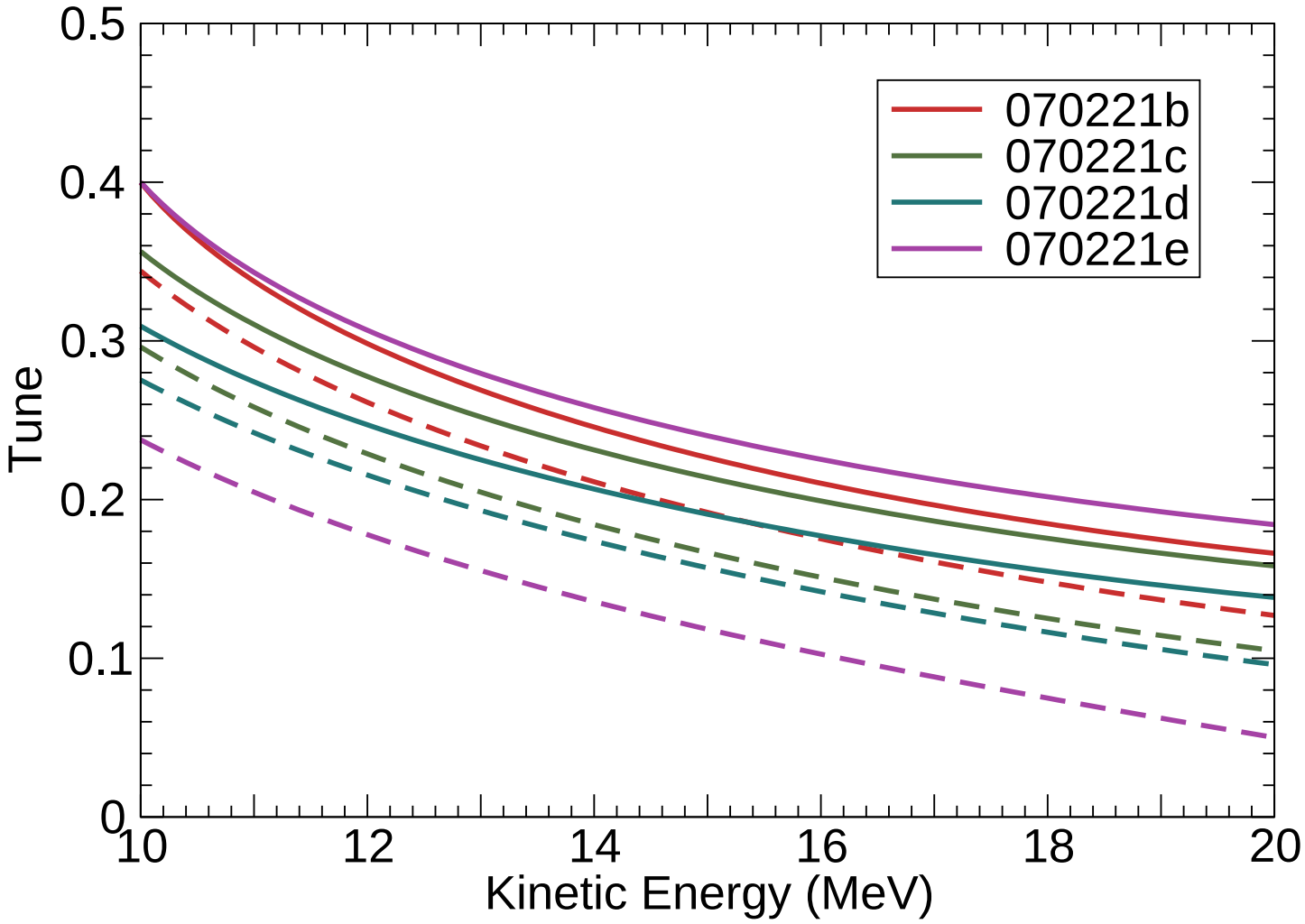
Outline

- Injection/extraction requirements
- Initial injection/extraction scenarios
- Kicker field problems

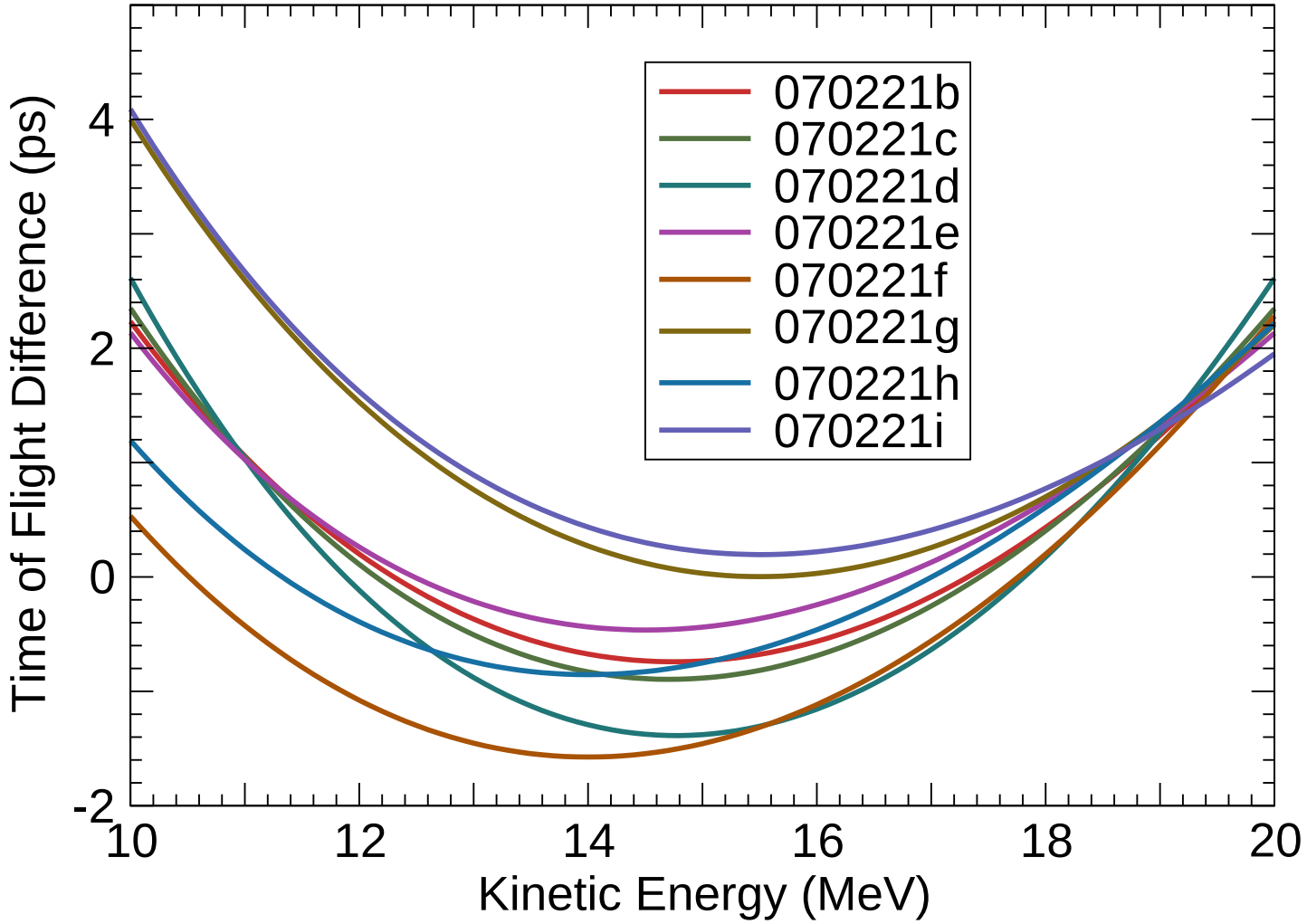
EMMA Tasks Requiring Injection and Extraction

- Determine tunes, time vs. energy
  - Determine if we have the right lattice
  - Find true parameters for that lattice
- Inject/extract at different points in acceleration
- Help scanning horizontal phase space
  - Small beam probes large emittance
  - Small acceptance in injection/extraction lines

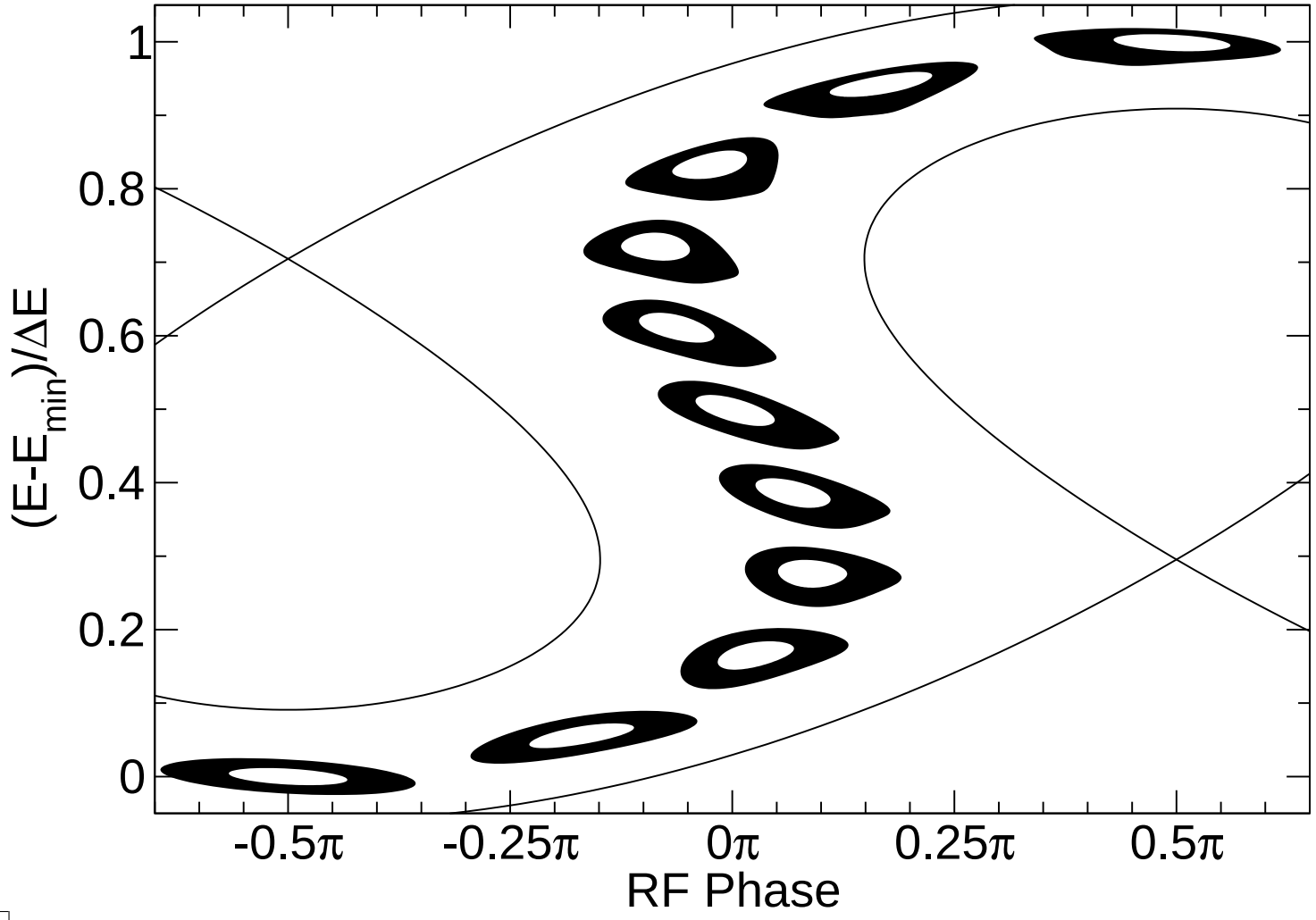
Tune per Cell



Time of Flight per Cell



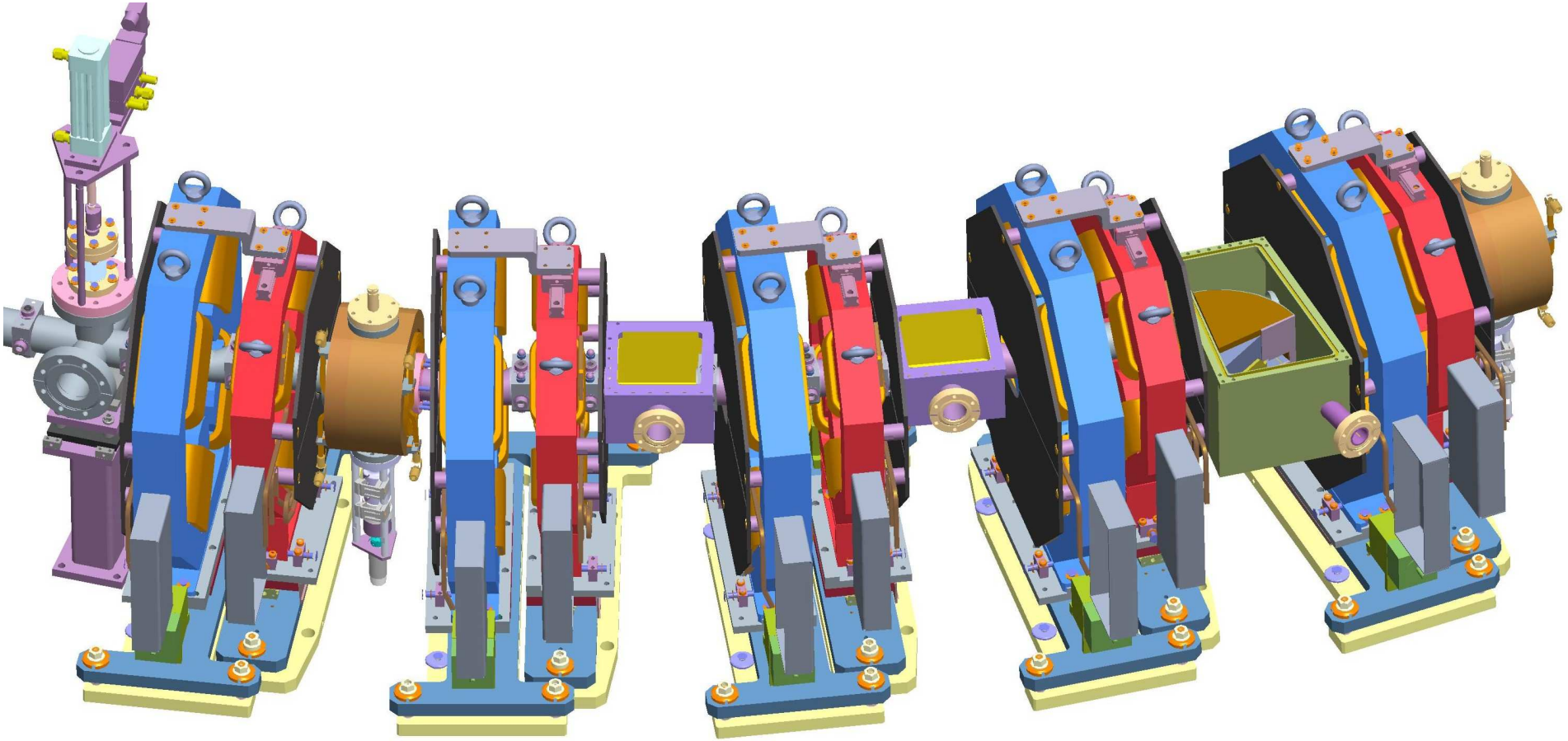
Serpentine Acceleration Longitudinal Phase Space



Available Injection/Extraction Hardware

- One septum, two kickers
- Successive cells
- Separate sets for injection and extraction
- Maximum kicker strength 7 mT m.
- Inject/extraction from/to outside

Injection Layout

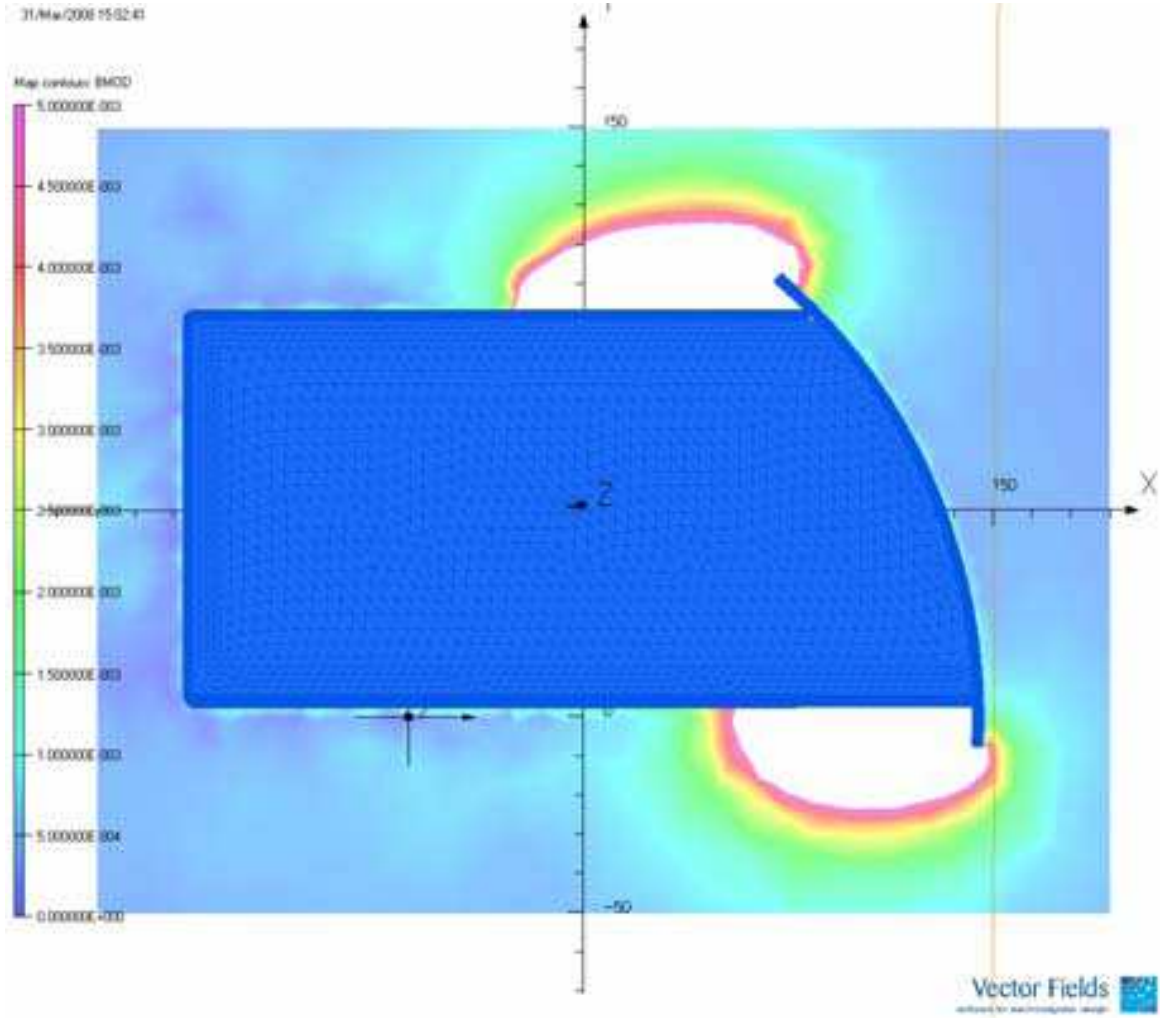


Spatial Limitations

- Vacuum pipe aperture
  - Larger oscillations septum to kicker
  - Pipe widened in injection/extraction regions
- Separation from septum
  - Septum stray fields large
  - Septum stray fields give field perturbations
  - Break symmetry: beam oscillations
  - Try to stay $>$10 mm from circulating beam

Septum Stray Fields

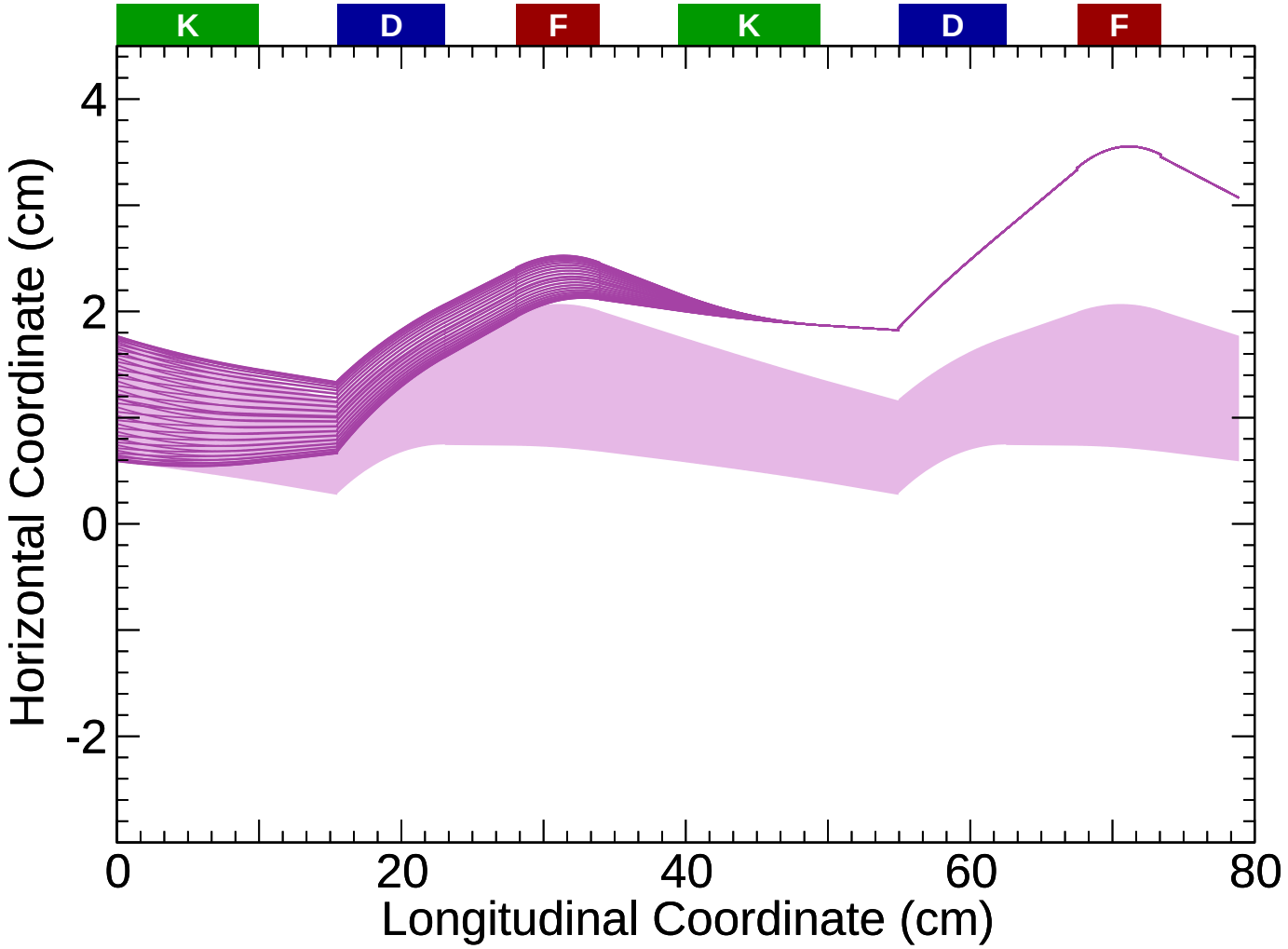
White:
>5 mT



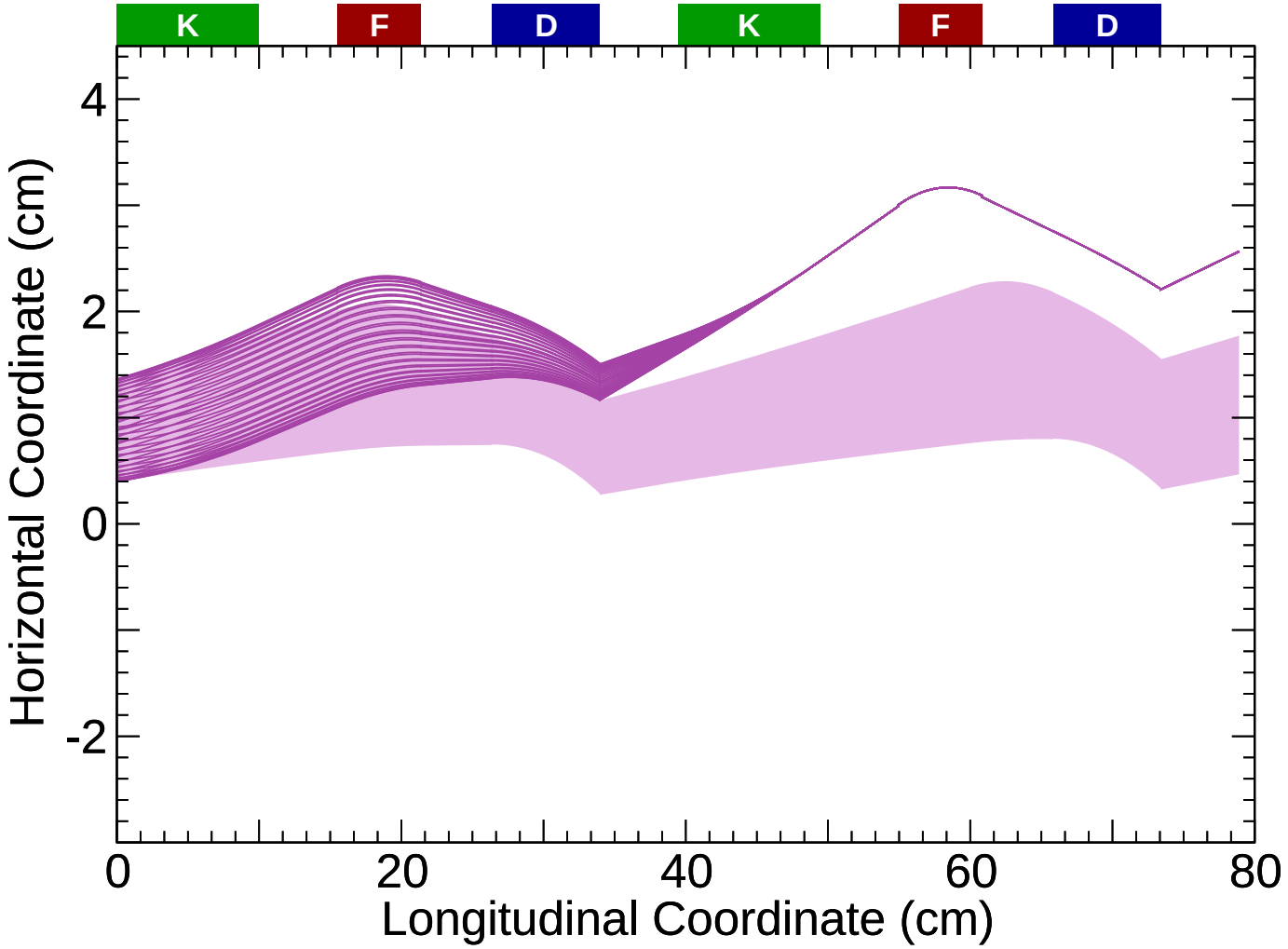
Lattice Orientation
Doublet Lattice

- Doublet not reflection symmetric
- Prefer D next to septum
  - Beam smaller at D
  - D pushes the beam out
  - Smaller excursions in magnets
  - Cannot have for both injection and extraction

Injection/Extraction
F Near Septum



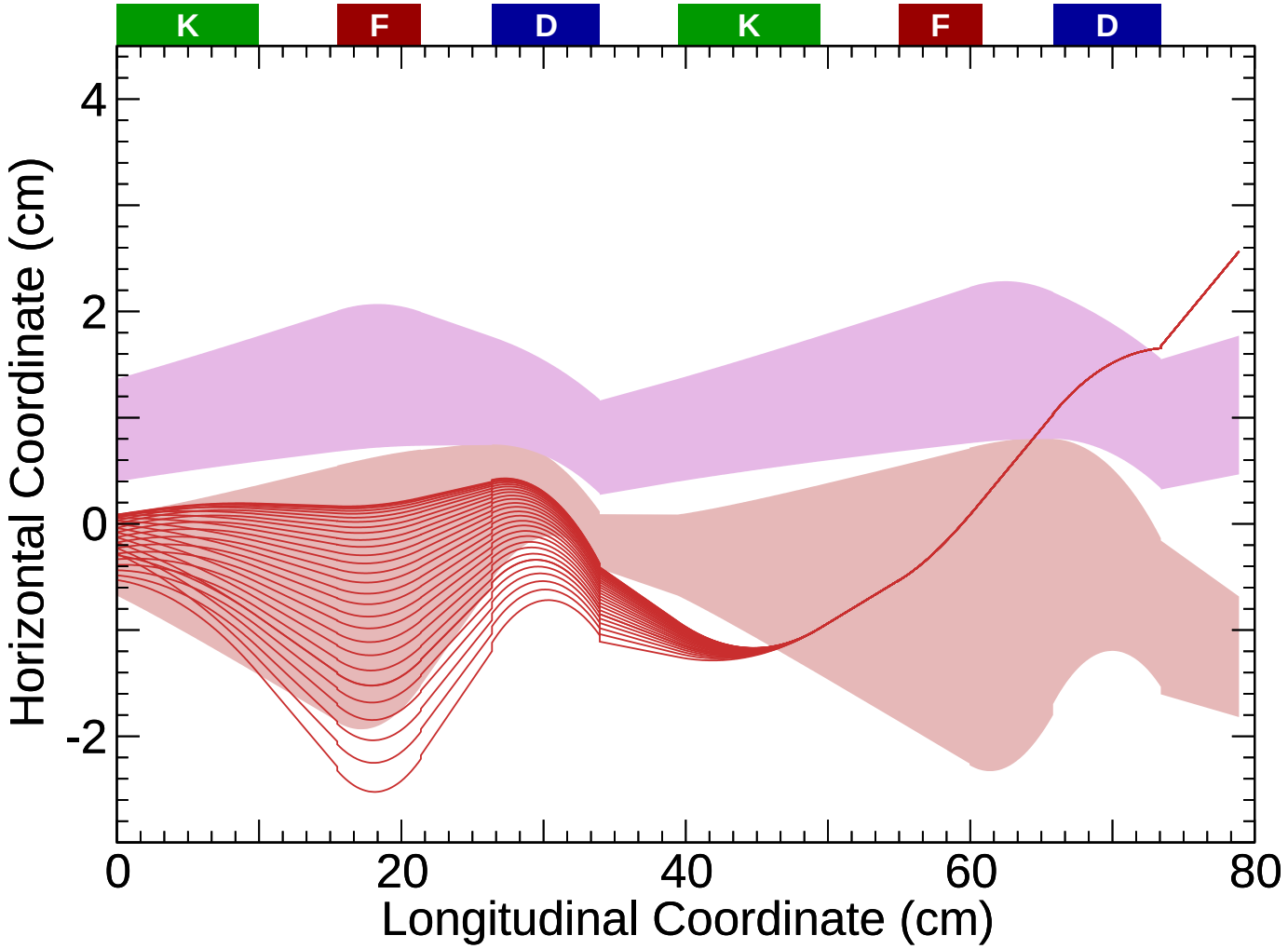
Injection/Extraction
D Near Septum



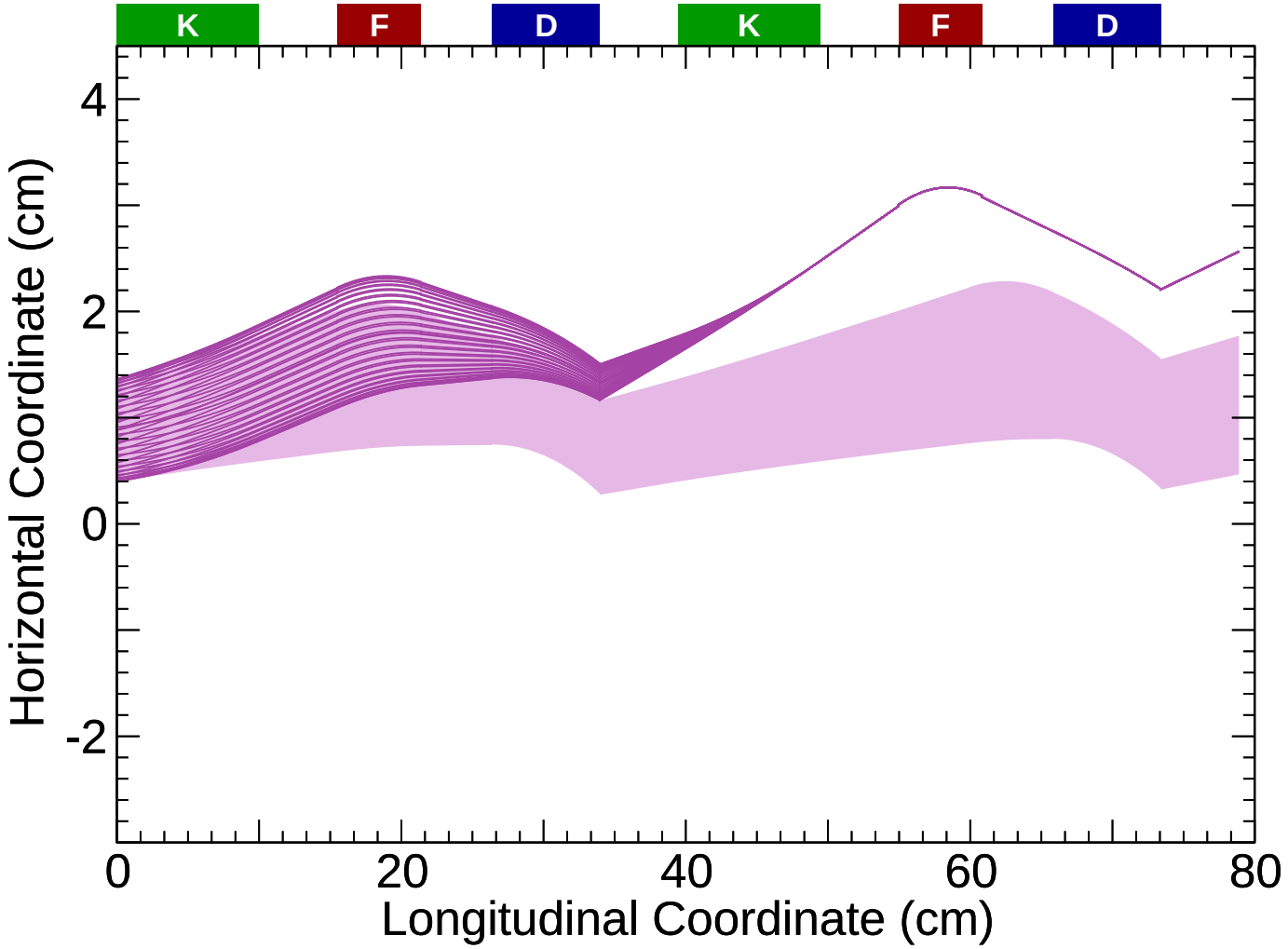
Lattice Orientation
Choosing Orientation

- Acceleration: beam moves inside to outside
- Injection/extraction easier if septum closer
- Injection septum outside all circulating energies
- Extraction septum just outside extracted orbit
  - Move septum for each extraction energy
- Put D near injection septum
  - Injection more important
  - Injection septum further from orbit

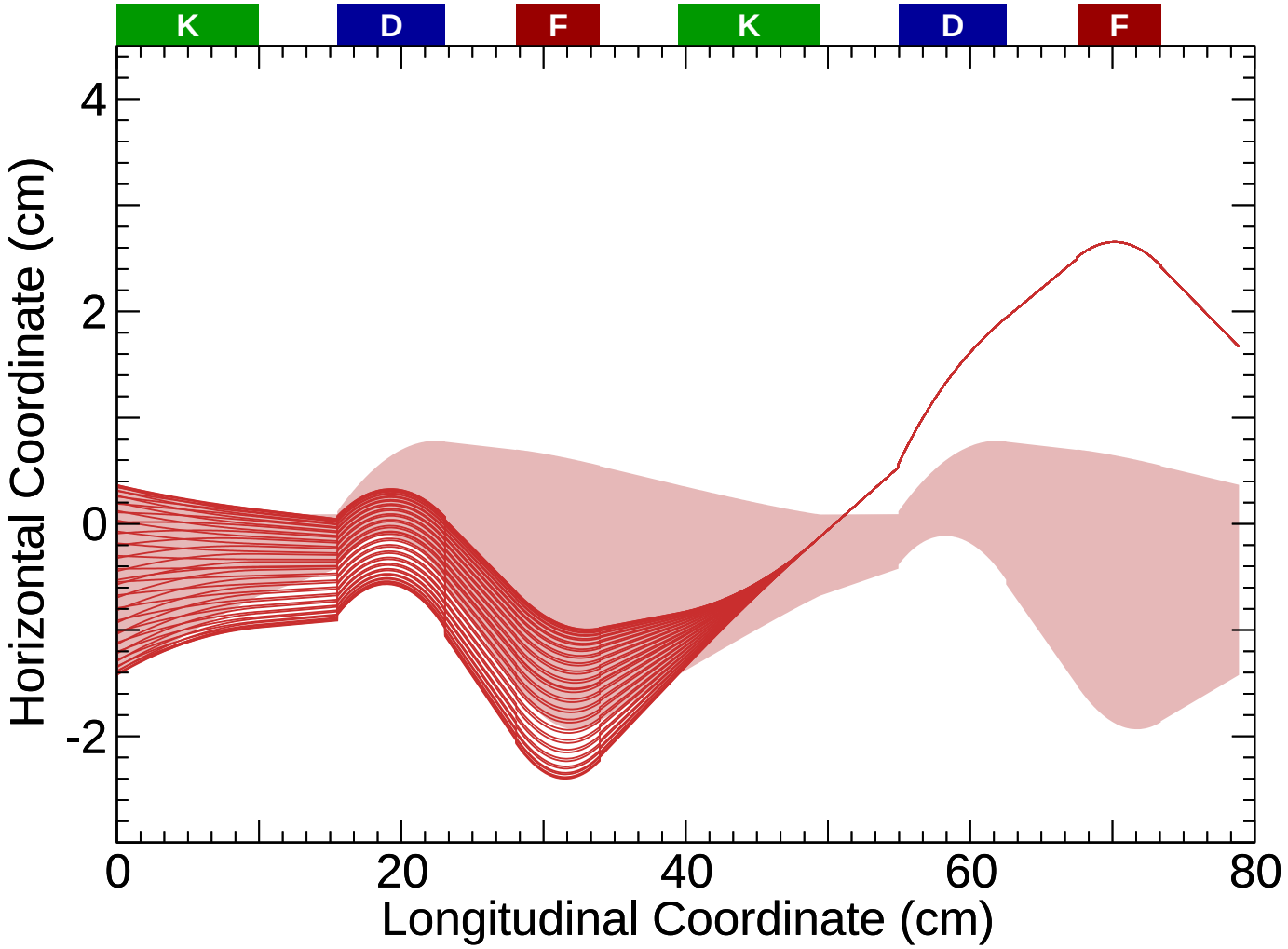
Injection
10 MeV



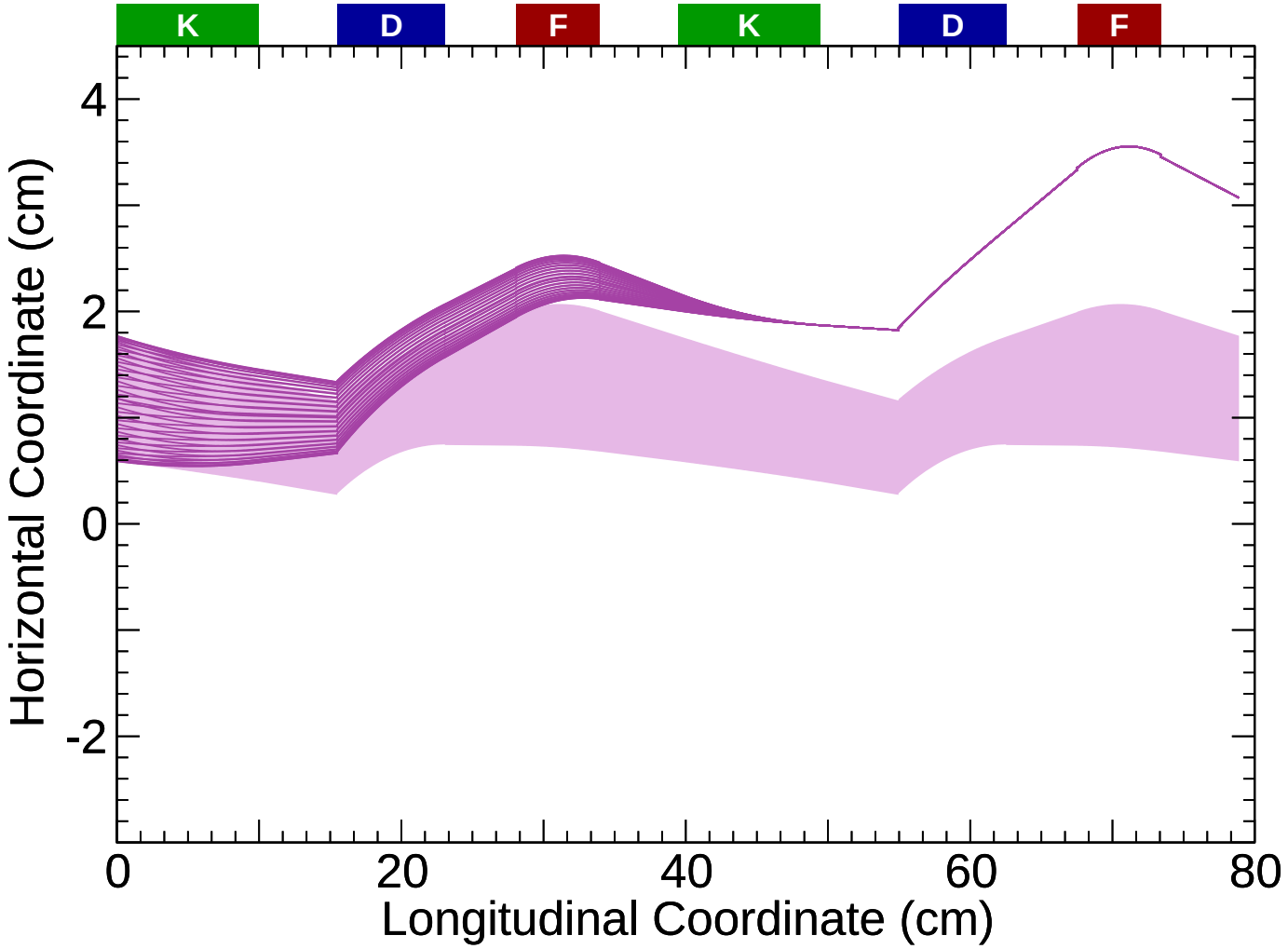
Injection
20 MeV



Extraction
10 MeV



Extraction
20 MeV



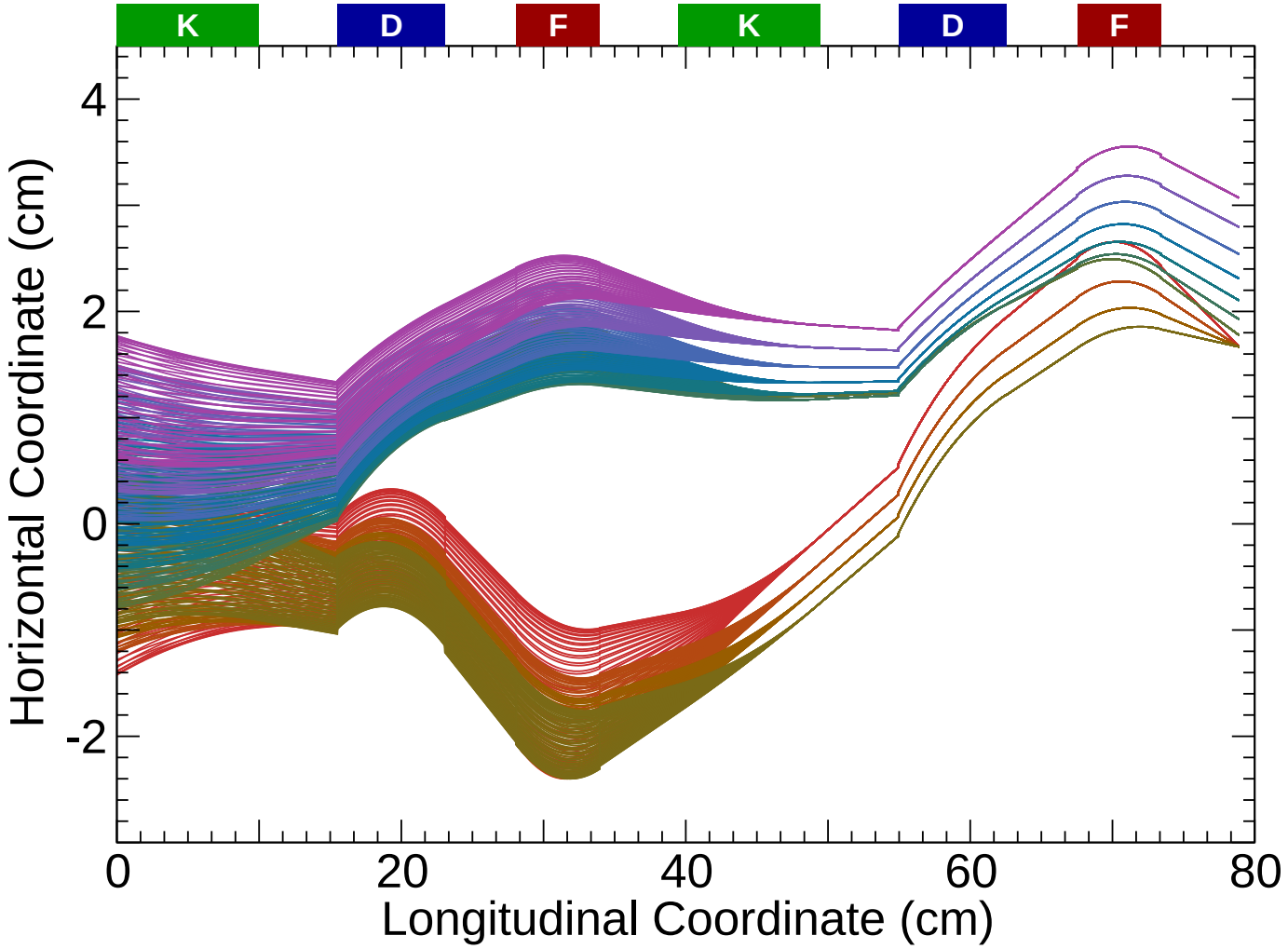
Transverse Phase Space Scanning

- Beam from ALICE: small transverse emittance
- EMMA should transmit large emittance
- Scan transverse phase space with beam
  - Small acceptance in inj/ext lines
  - Horizontal phase space: use 2 kickers
  - Vertical: static magnets in inj/ext lines
- Extraction: must reverse process
  - Challenge: predicting kicker settings!

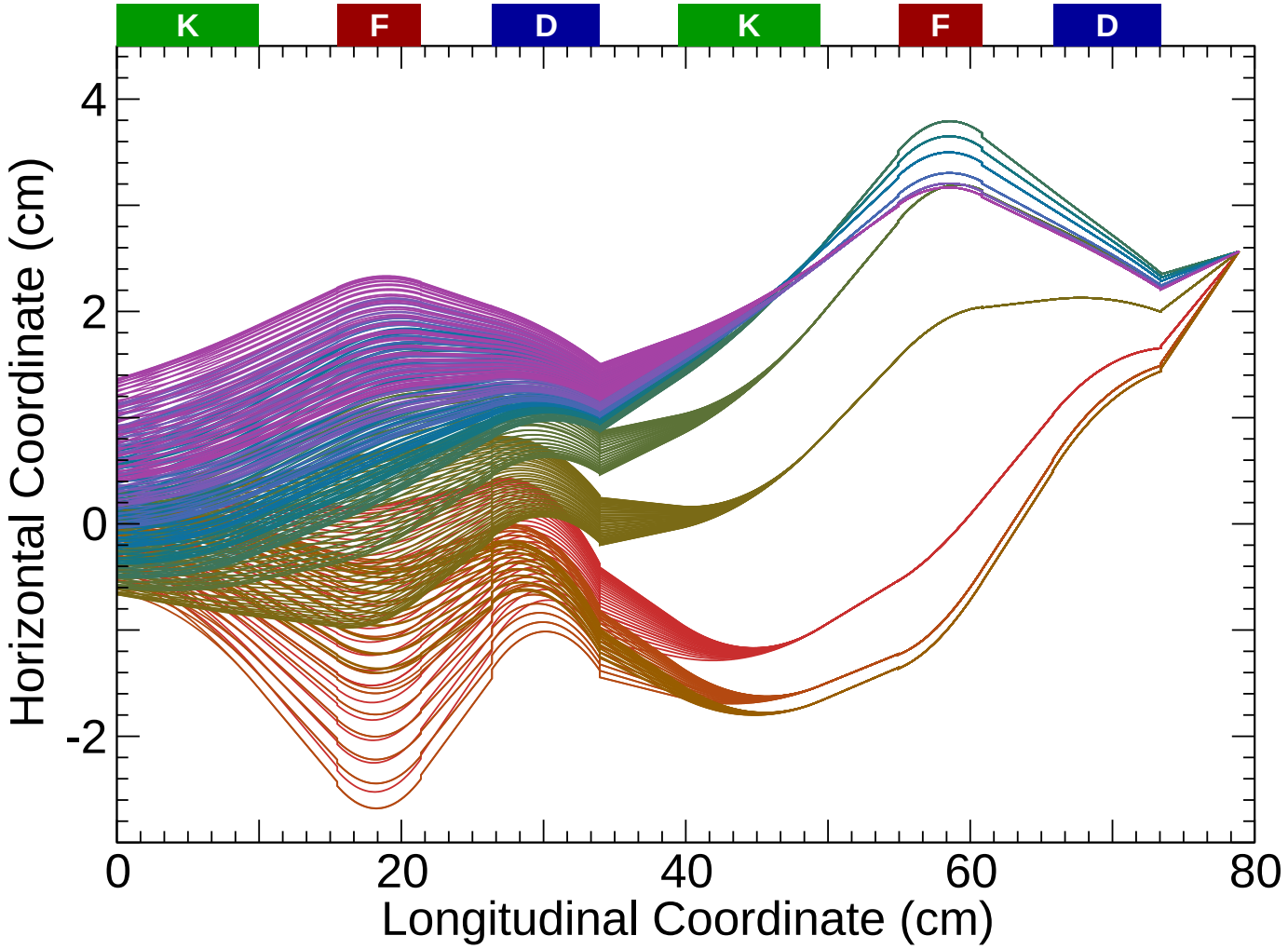
Injection/Extraction Procedure

- For each configuration and energy
  - Place septum
    - Injection septum position same at all energies
  - Determine septum field
- Scan horizontal phase space with kickers
  - Measurement, trial and error at extraction
  - Kicker jitter will make more challenging
  - Chromaticity: extract part of beam (Machida)

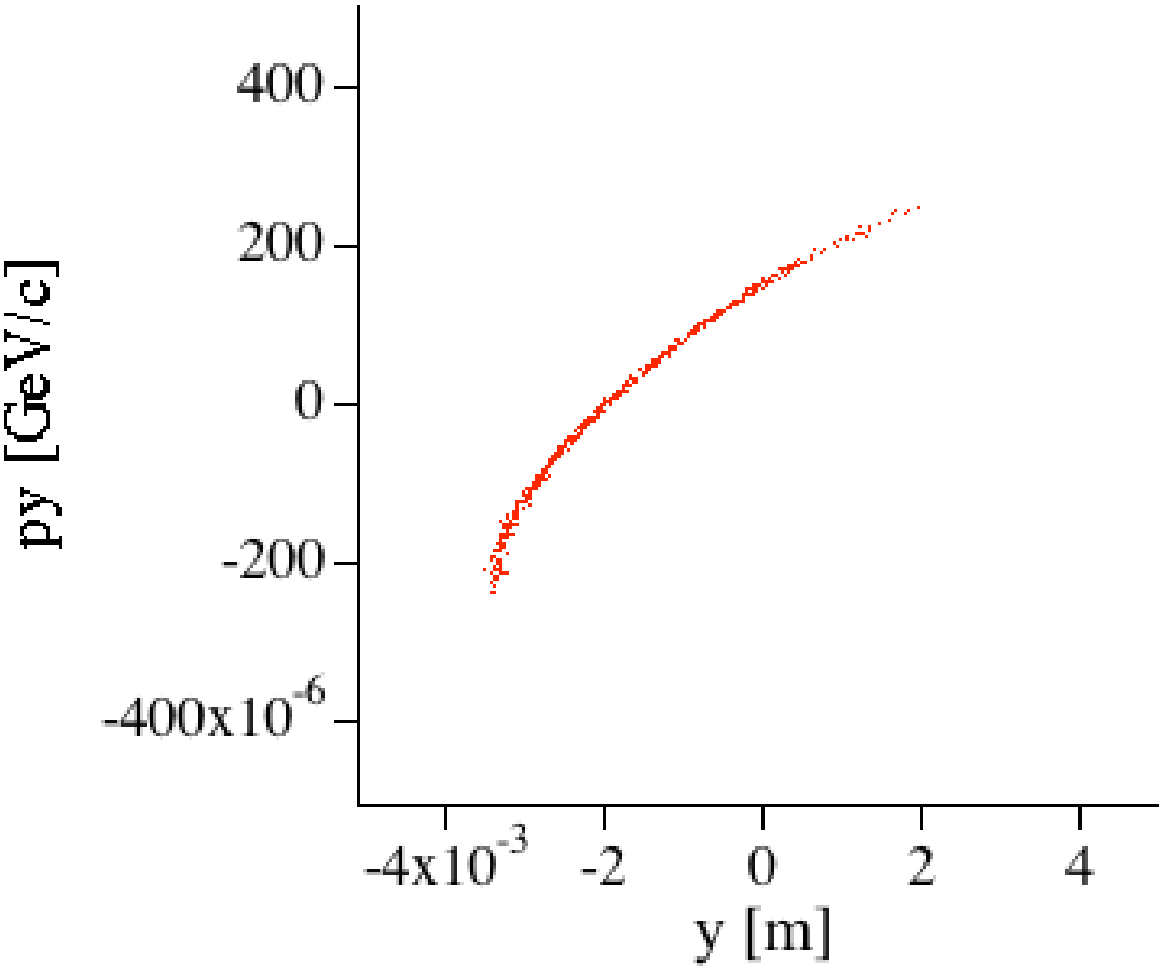
Extraction Orbits



Injection Orbits



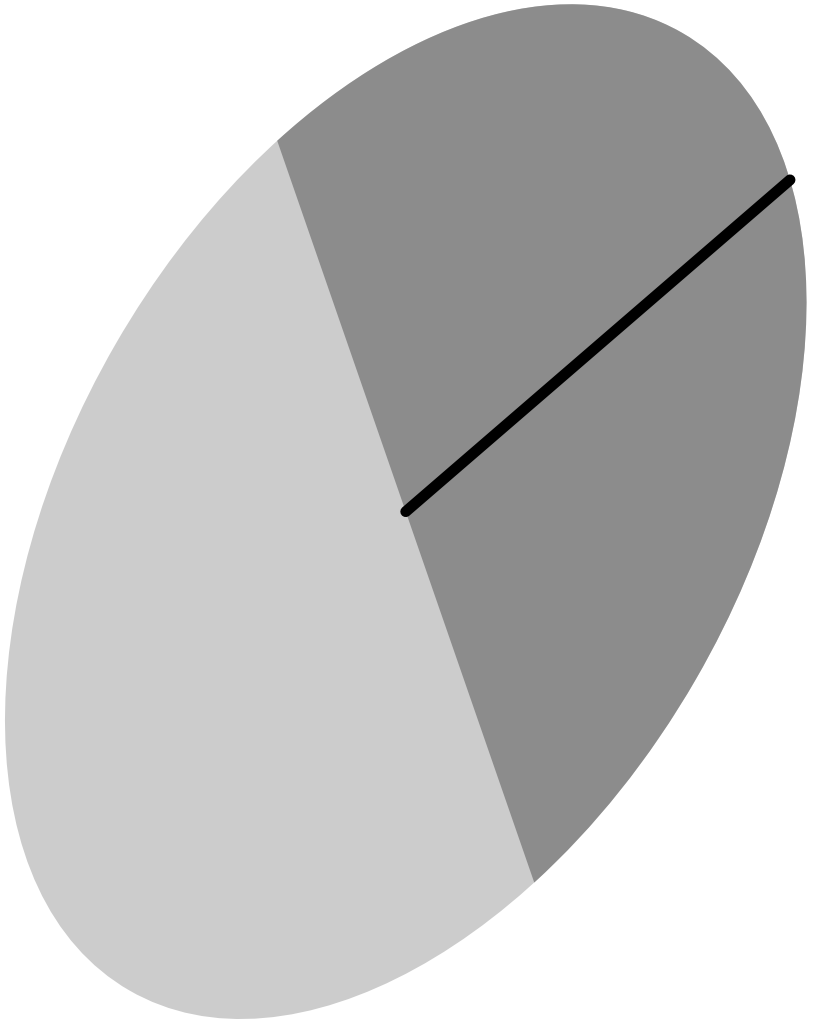
Transverse Spreading from Chromaticity (Machida)



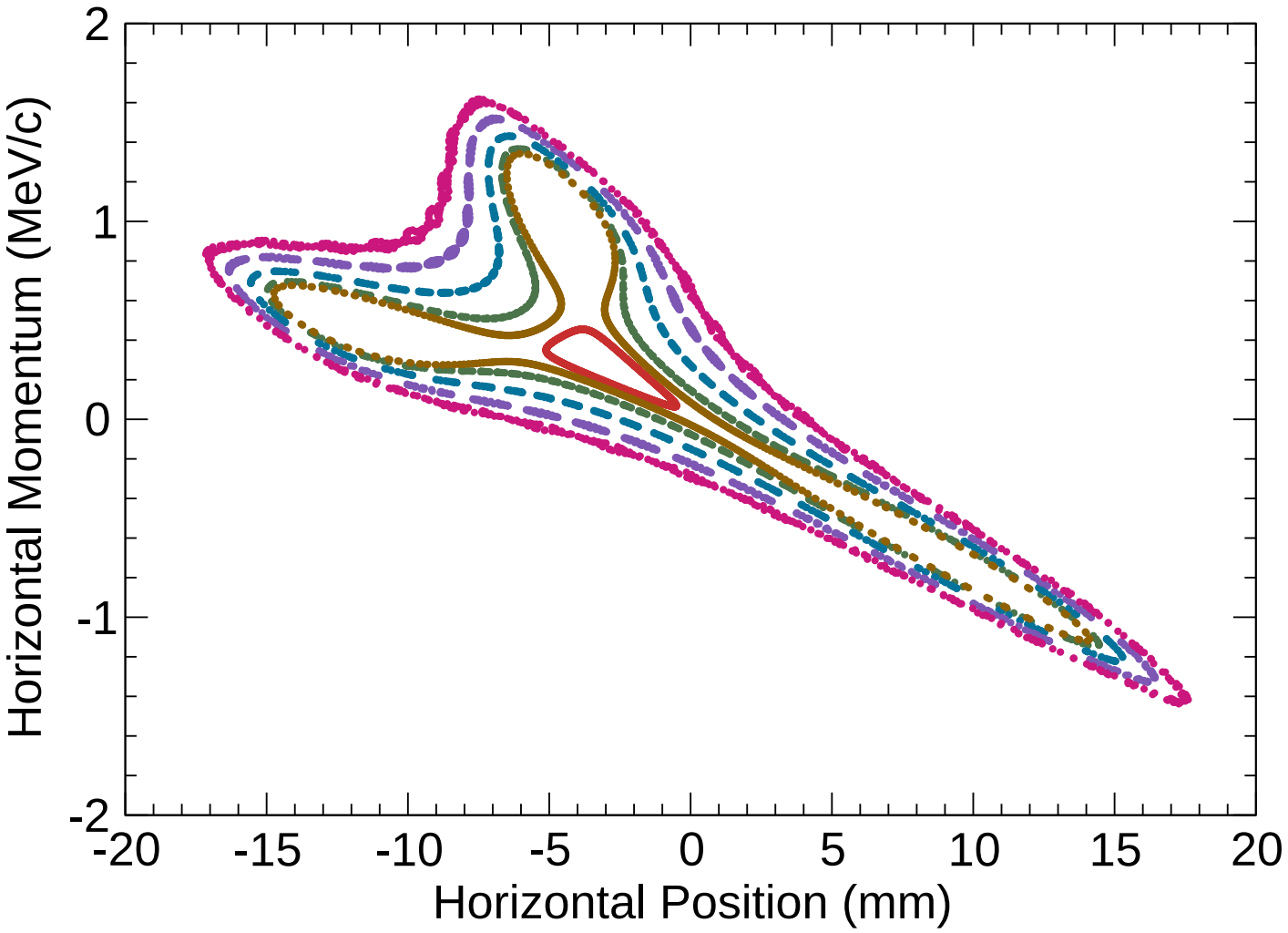
Injection
Scan Partial Ellipse

- Low energy injection: travels across aperture
- Large amplitude injection oscillation
- Closed orbit can be injected
- Some large amplitude particles hit aperture
- Solution: only inject partial ellipse
  - Only really need radial line in phase space
  - Scan half ellipse to see structure
    - Skip out-of-pipe half

Injection
Partial Ellipse



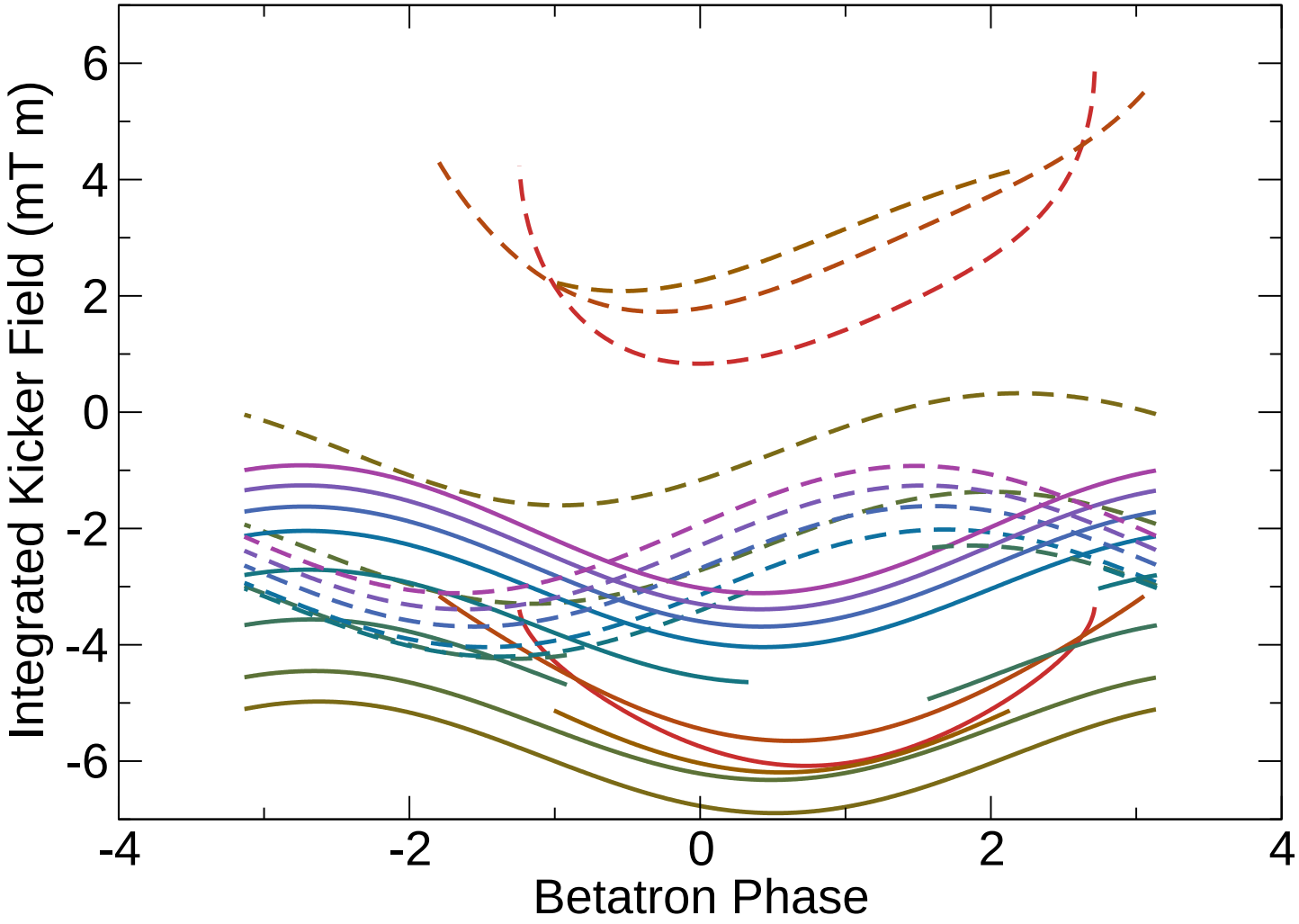
Horizontal Phase Space (11 MeV)



Problem: Minimum Kicker Strength

- Kickers have minimum excitation
  - Factor of 3 or so below maximum
- Working scenario requires wide range of kicker strengths
  - This scenario did try to minimize kicker fields

Injection Kicker Fields



Linear Model

- Far from perfect, but gives idea of behavior

$$B_{K0} = \frac{p}{qL_K}\frac{p_1 x_{\text{sep}} - x_1 p_{\text{sep}}}{p_1 x_0 - x_1 p_0}$$
$$B_{K1} = \frac{p}{qL_K}\frac{p_0 x_{\text{sep}} - x_0 p_{\text{sep}}}{p_0 x_1 - x_0 p_1}.$$

  - x_{sep} and p_{sep} are position and momentum difference from circulating beam to septum

Linear Model

- Minimum $|B_{Ki}|$ when

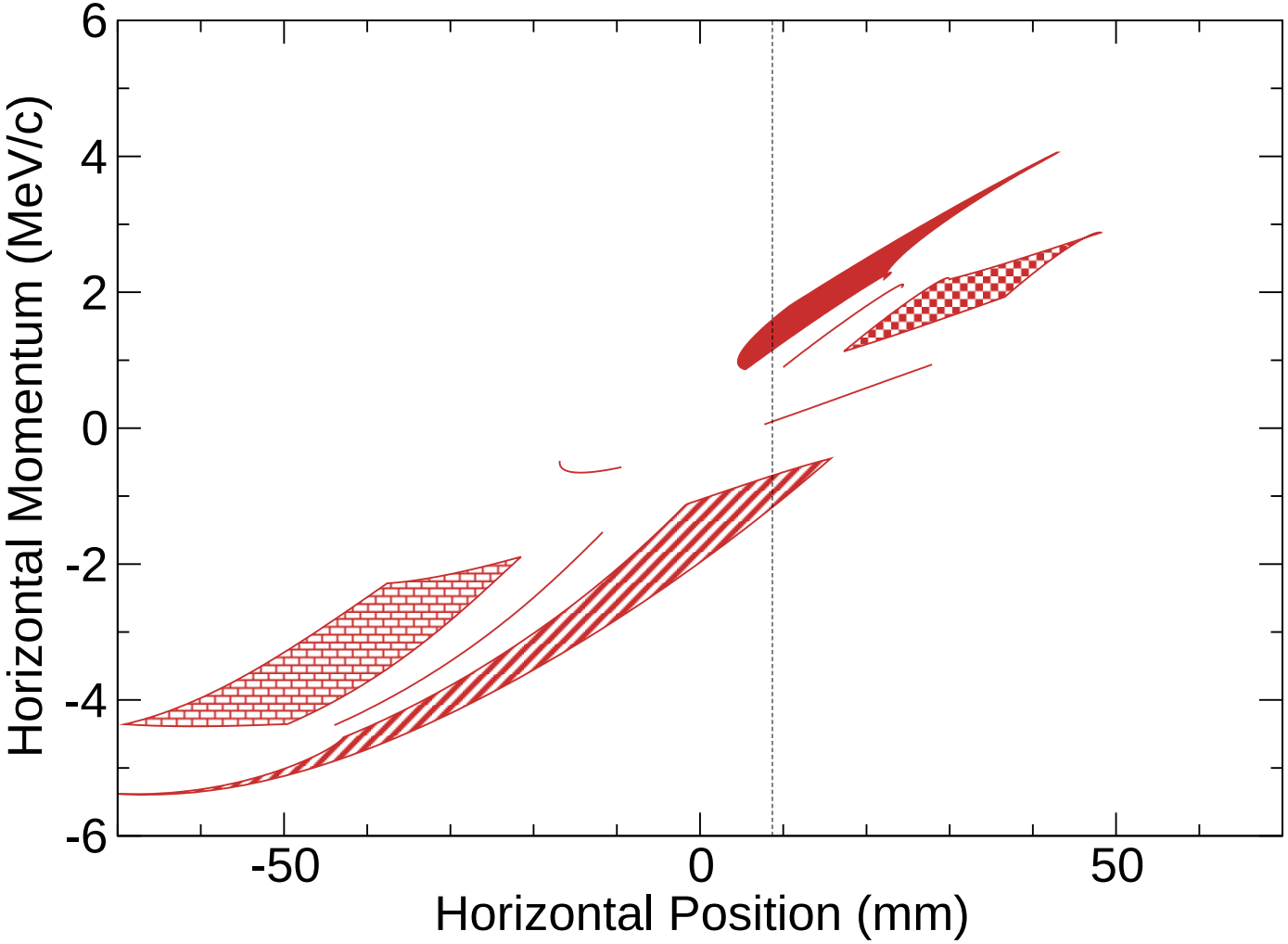
$$B_{K0} = \frac{p}{qL_K} \frac{x_{\text{sep}}}{x_0 \pm x_1}.$$

- Denominator sign from signs of x_0 and x_1
- One B_{Ki} increases, the other decreases
- To increase both B_{Ki}, increase x_{sep}
  - Distance a problem for aperture
  - Alternative: make inefficient choice for kickers (wrong sign in above equation)

Phase Space at Septum

- Scan phase space at septum
  - Varying kicker strengths by factor of 3
  - Maximum 7 mT-m
  - Four sign combinations
  - Also show one kicker off

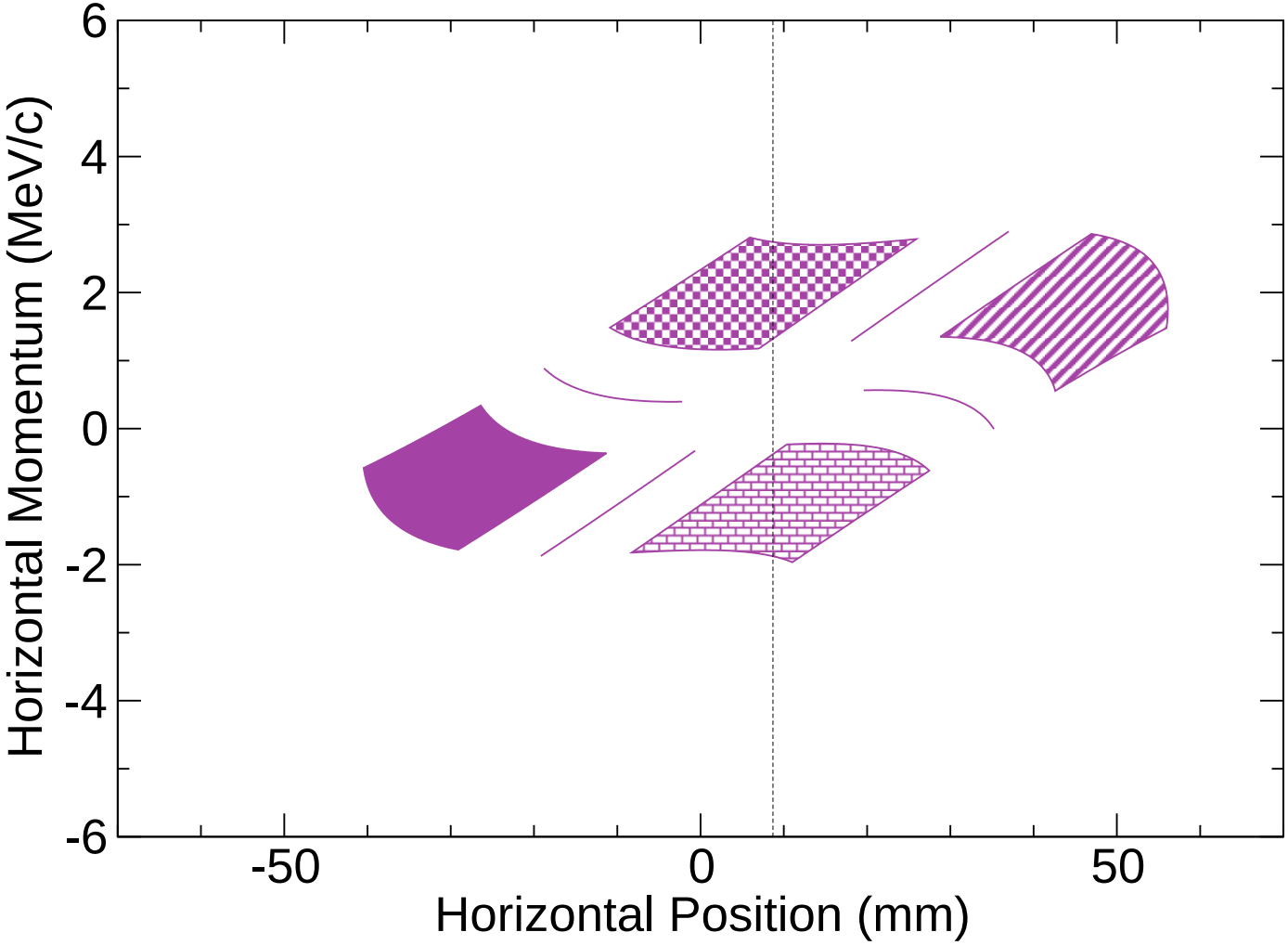
Septum Phase Space
10 MeV Injection



Septum Phase Space
10 MeV Injection

- At 10 MeV, see strong nonlinearity
- Push-pull only workable possibility
- Numbers look good for injection

Septum Phase Space
20 MeV Injection



Septum Phase Space
20 MeV Injection

- More linear at 20 MeV
- Push-push natural, but throws beam very far
  - If use kickers for painting, must use center of region
  - Push-pull or pull-push probably don't throw beam far enough
- Could use septum for painting
  - Push-off or off-push doesn't throw so far
  - May use corner of push-pull or pull-push

Concluding Remarks

- Injection and extraction systems do many things
  - Wide energy range
  - Large transverse phase space
- Have a working scheme, but
  - Kicker strengths too low
  - Still working on system for larger minimum