FFAG Gantries and Adiabatic Transitions

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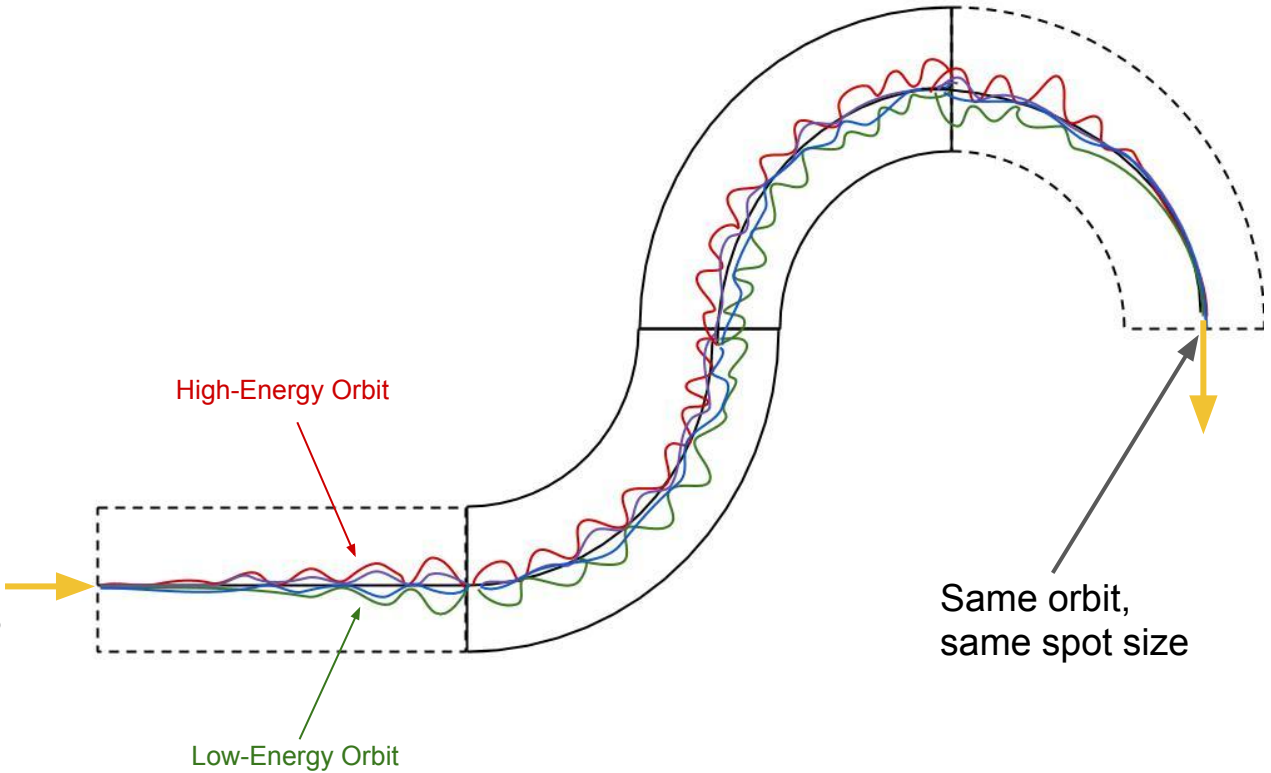
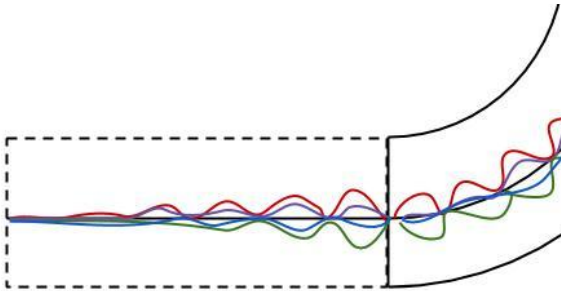
Methodology

Motivation

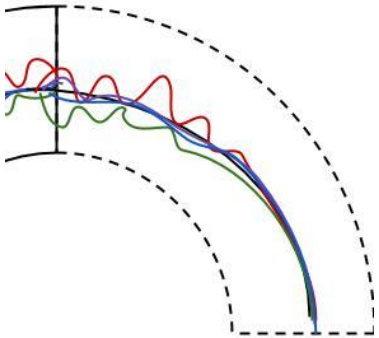
- High Energy Acceptance
  - Decrease size / treatment time
- Permanent Magnets
  - Reduce overall weight
- Uniform Spot Size
  - Easier operation
  - Reproducible spots for scanning



Section 1



Section 2

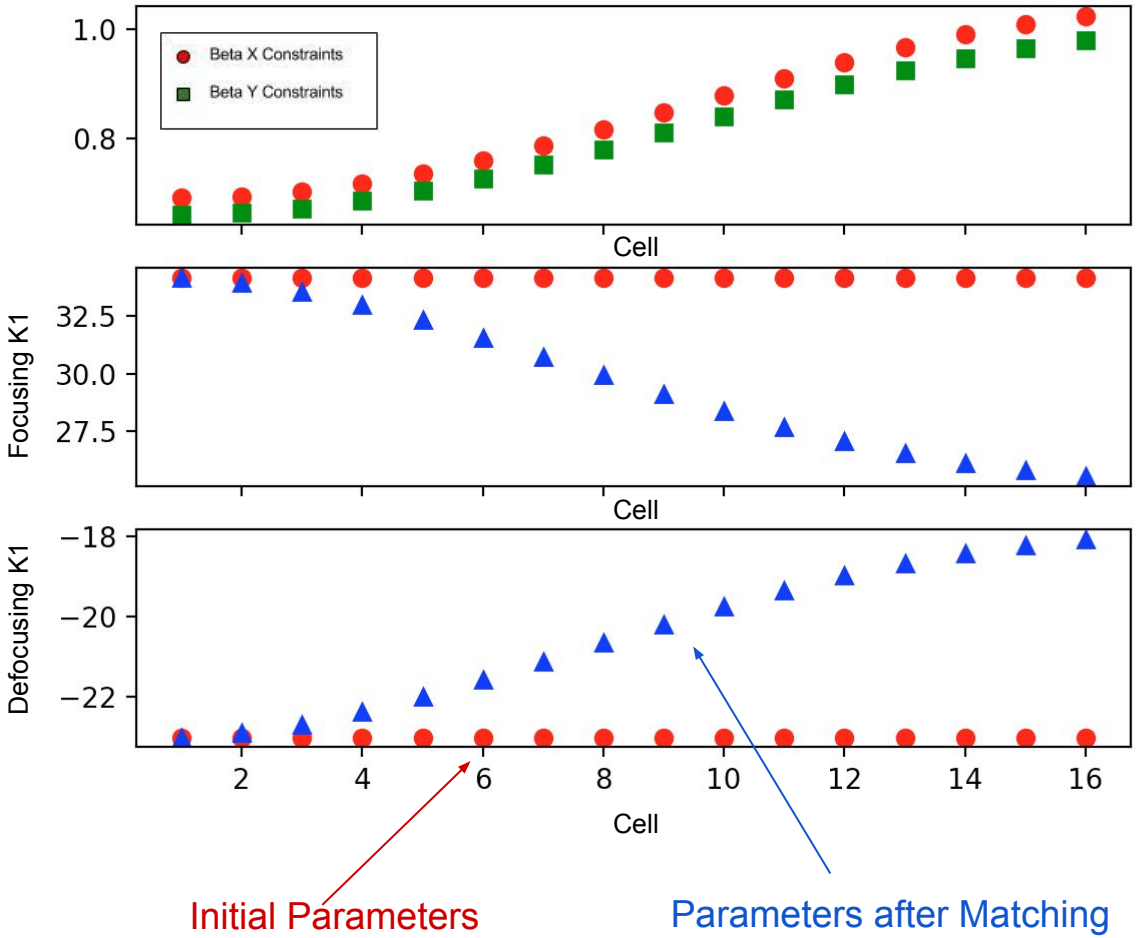


Some Parameters to Consider

- Magnets
  - Varied with optical constraints
- High Energy Acceptance
  - $-0.5 \leq \partial p/p \leq 0.35$
  - P_0=551.345 MeV/c
    - ➢ E = 150 MeV
- Uniform Spot Size
  - $\varepsilon_x \beta_x = \varepsilon_y \beta_y$
  - D_x=0.0 m

Execution

- Identify the constraints
- Create a Unit Cell
  - Ensure stability
  - Find the periodic conditions
- Vary the constraints
  - Based on the transition from CBETA
- Match the transition
  - (Try to) Ensure Stability

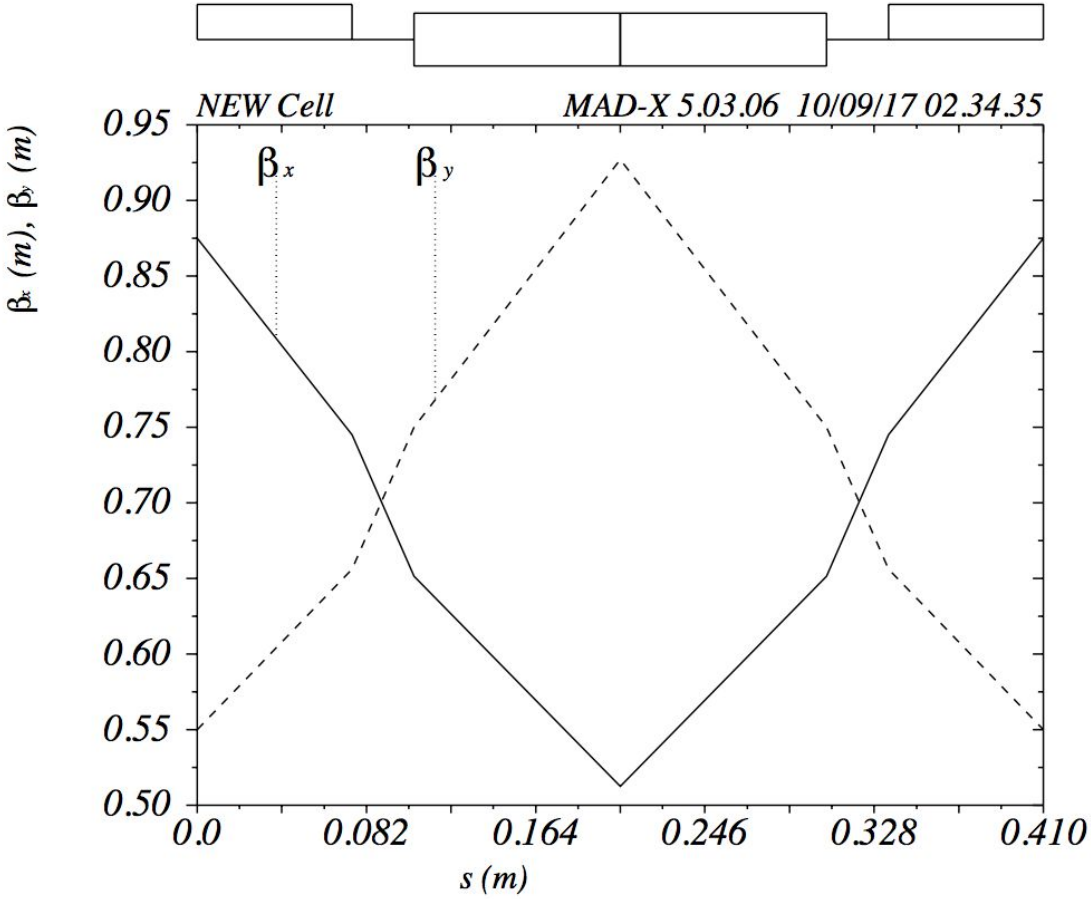


Unit Cells

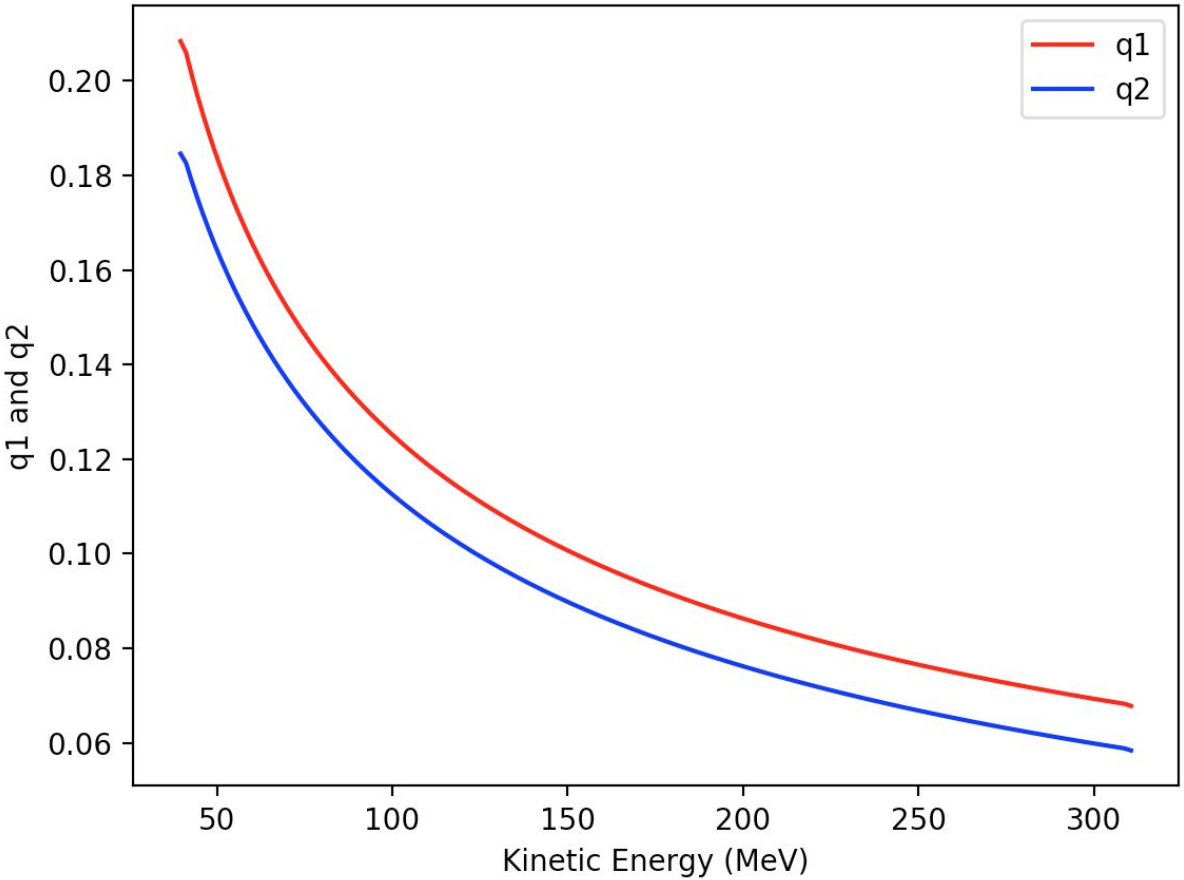
1. Methodology
   a. Motivation
   b. Parameters to Consider
   c. Execution
2. Unit Cells
   a. Parameters
   b. Stability
3. Transition
   a. Accelerator to Gantry
   b. Final 90 degree Arc
4. Conclusions
   a. Conclusions
   b. Future Work

Parameters

- Unit doublet (split in qf)
  - Test Case: Dr. Dejan Trbojevic's triplet*
- Quadrupole (at P_0)
  - K_1 = 29.1753 m^-2
  - Bρ = 1.839 Tm
  - $\partial B_y/\partial x$ = 53.6534 T/m
- Combined-function Dipole
  - Angle = 2.8125º
  - K_1 = -21.6854 m^-2
    - Defocusing
  - Bρ = 1.839 Tm
  - $\partial B_y/\partial x$ = 39.8795 T/m

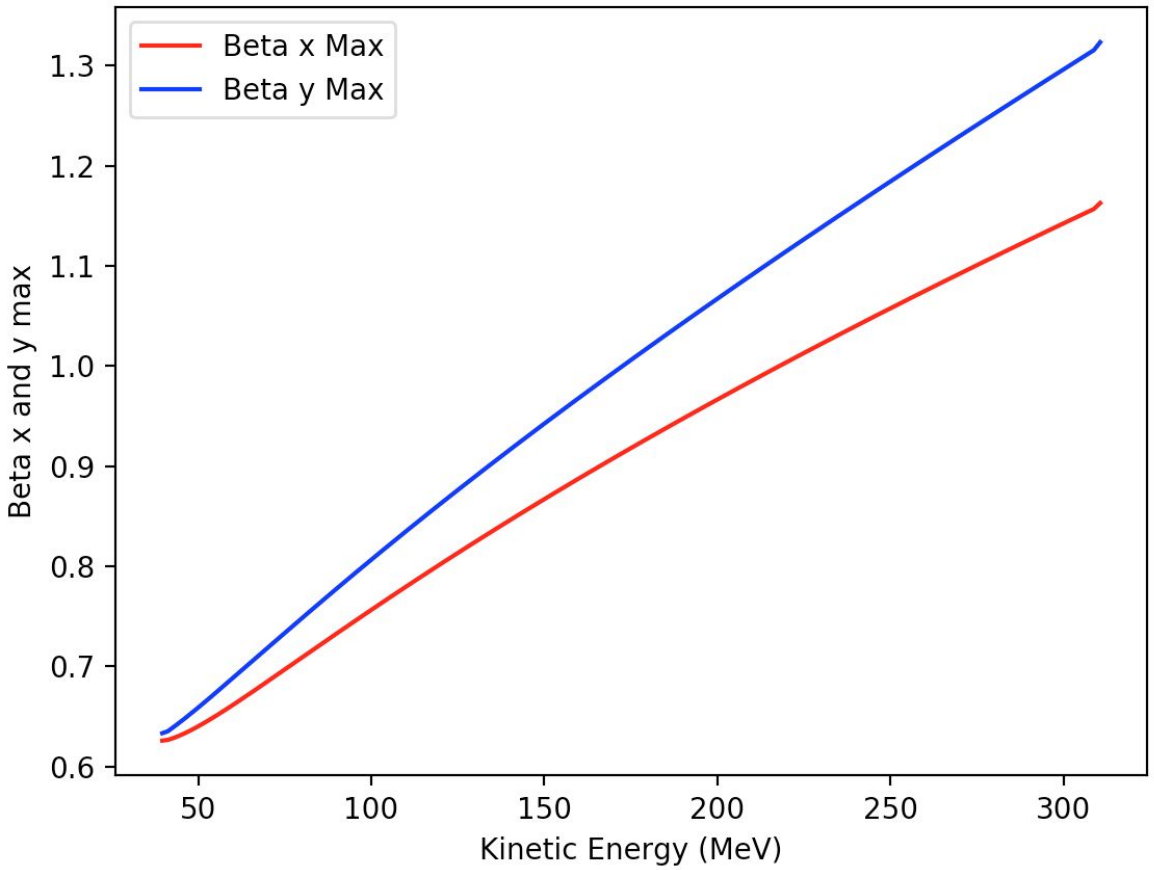


* D. Trbojevic, Patent: US 2012/0313003 A1, 2012



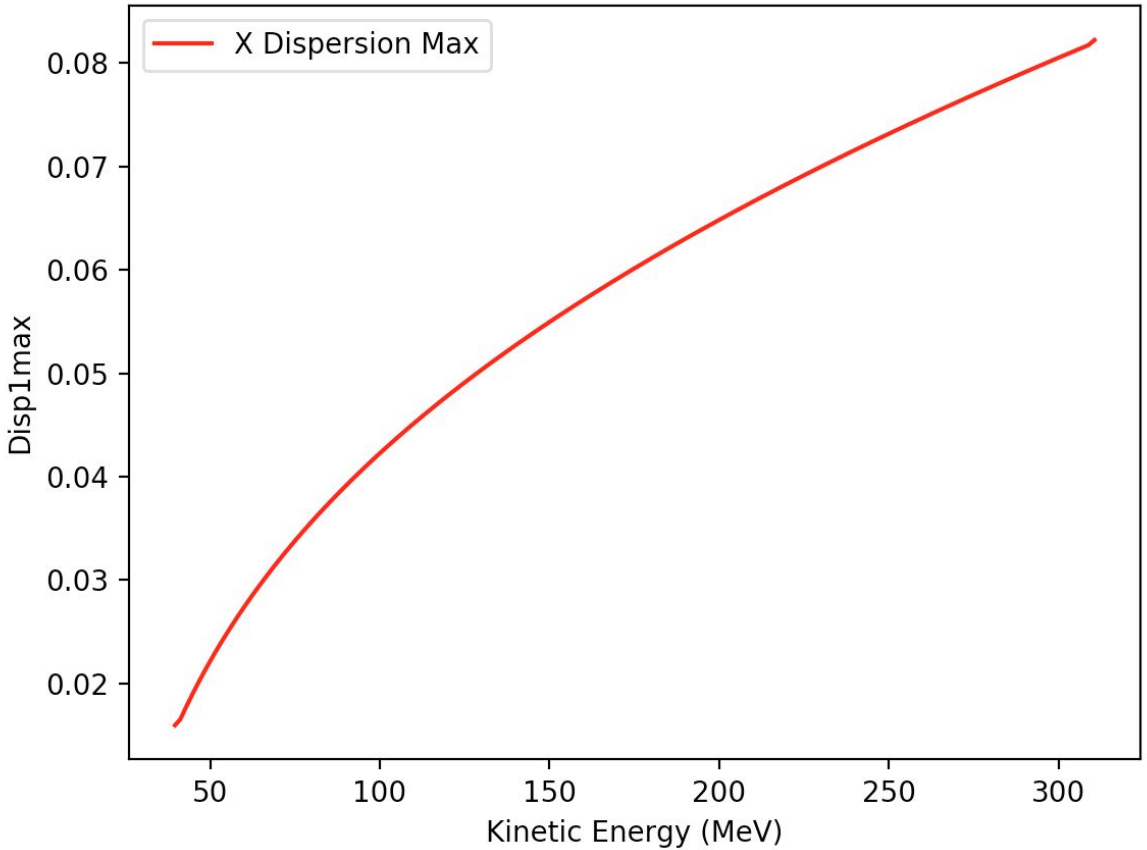
Stability

- Tunes decrease with energy
  - Stable over range
-



Stability

- Tunes decrease with energy
  - Stable over range
- β_x and β_y increase with energy
  - Close together
-



Stability

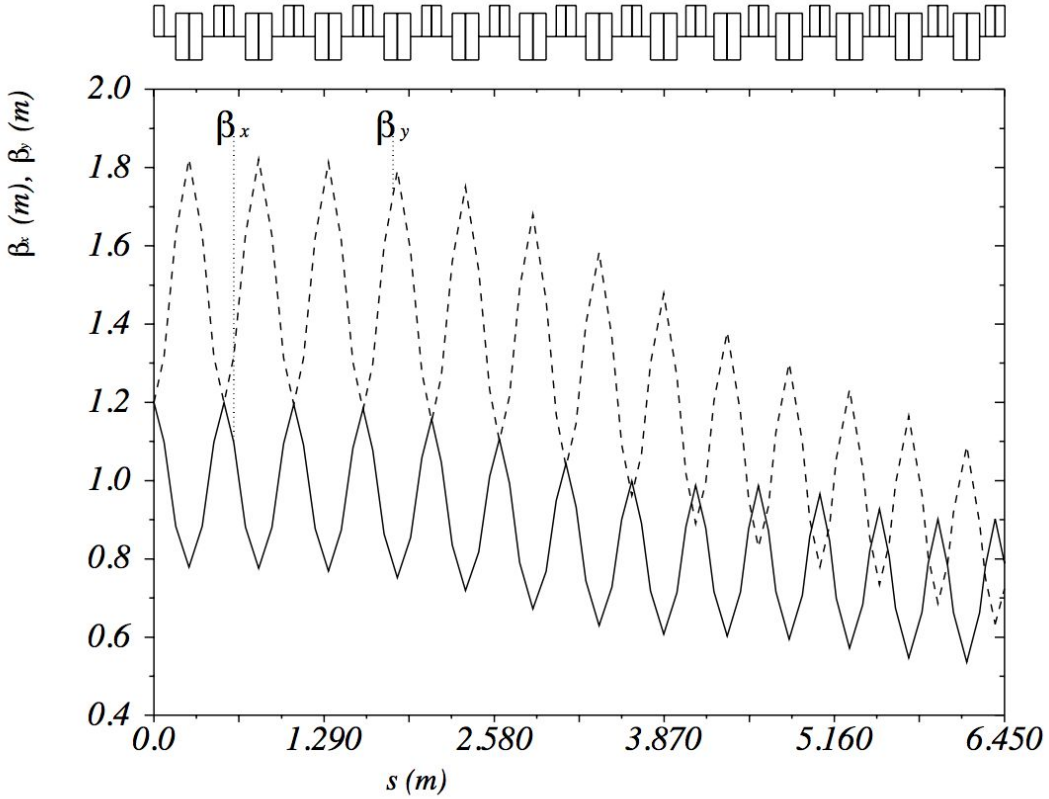
- Tunes decrease with energy
  - Stable over range
- β_x and β_y increase with energy
  - Close together
- Small Dispersion also gets larger with energy

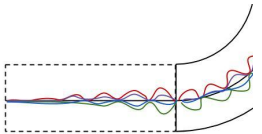
Transition

Accelerator to Gantry

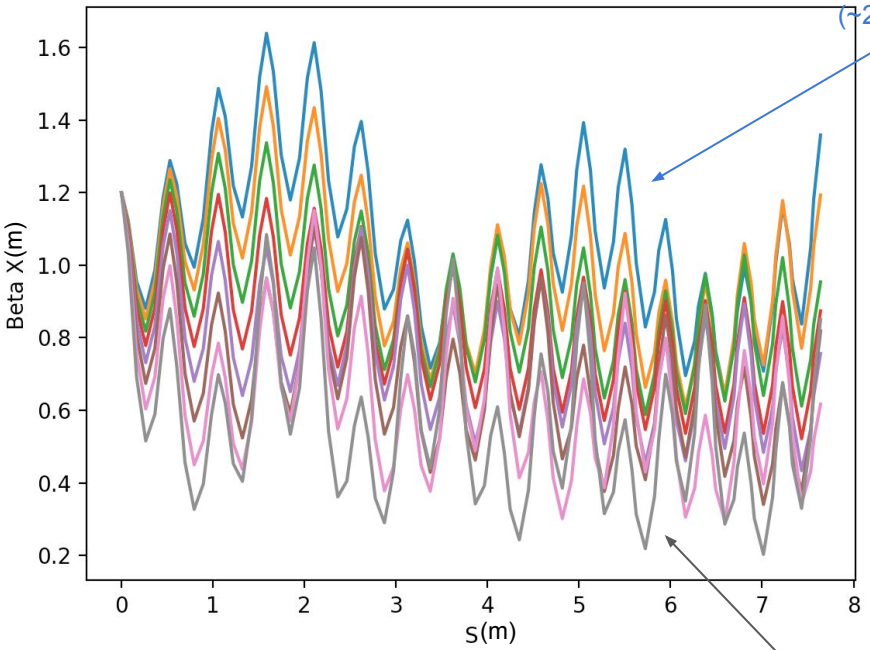
Accelerator to Gantry Constraints

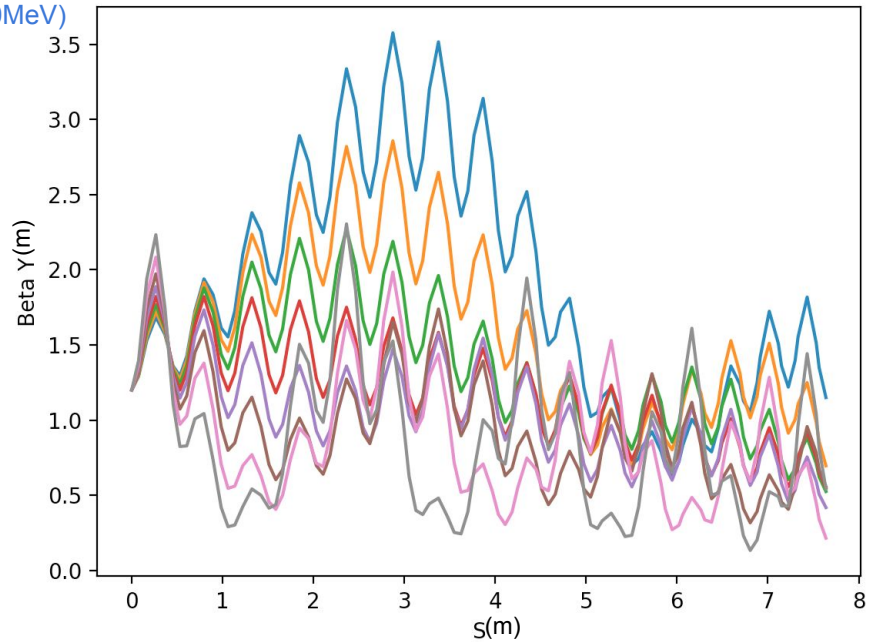
- Initially
  - Rotationally symmetric
    - $\varepsilon_x\beta_x=\varepsilon_y\beta_y$
    - $D_x=0.0$ m
    - $D_x' = 0.0$
  - Match accelerator's β functions
    - $\beta_x = \beta_y = \sim 1.2$m
- By the end
  - Must match periodic conditions of cells

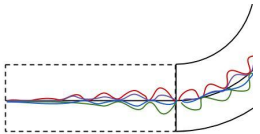


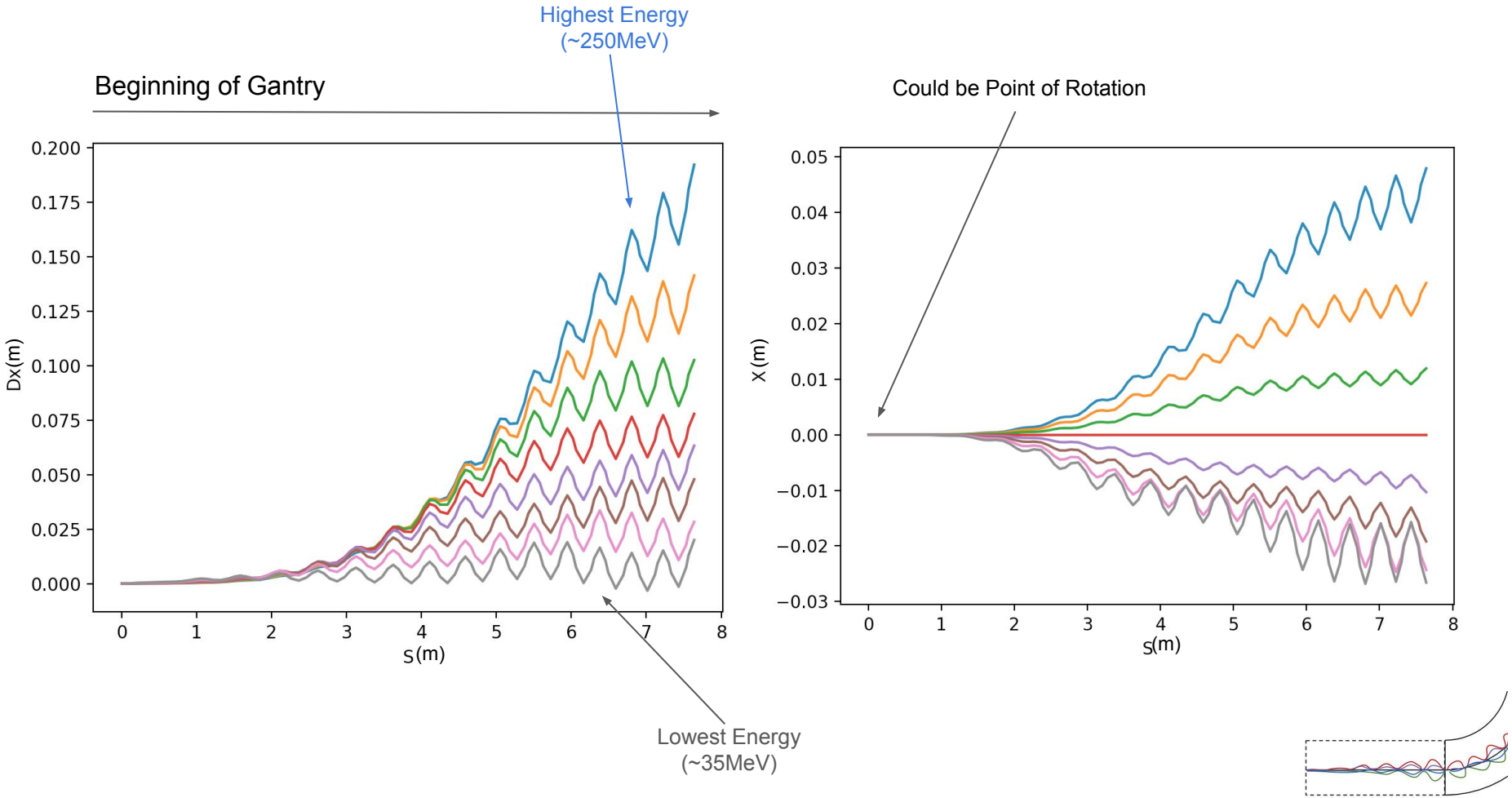


Beginning of Gantry







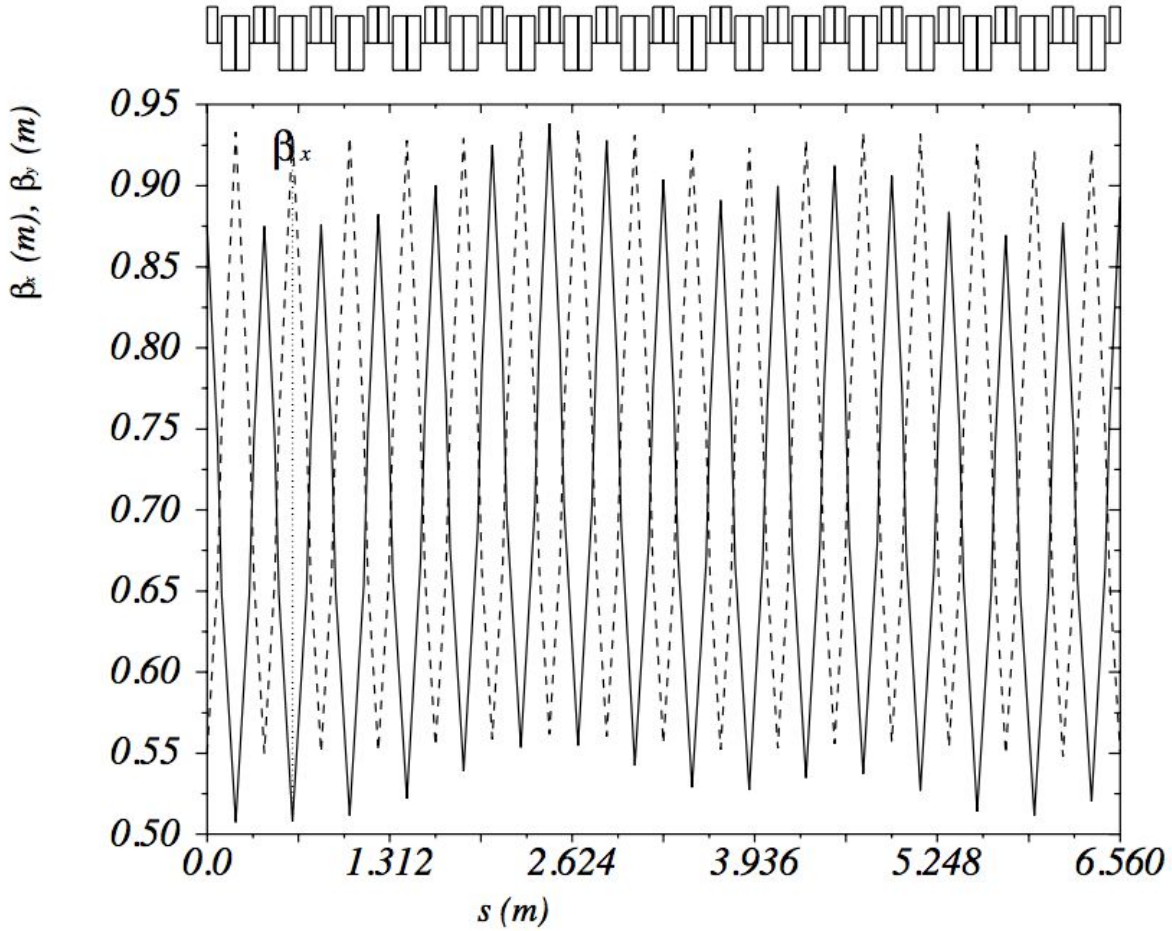

Highest Energy
(~250MeV)
Beginning of Gantry
Could be Point of Rotation
Dx(m)
S(m)
X(m)
S(m)
Lowest Energy
(~35MeV)

Transition

Final 90 Degree Arc

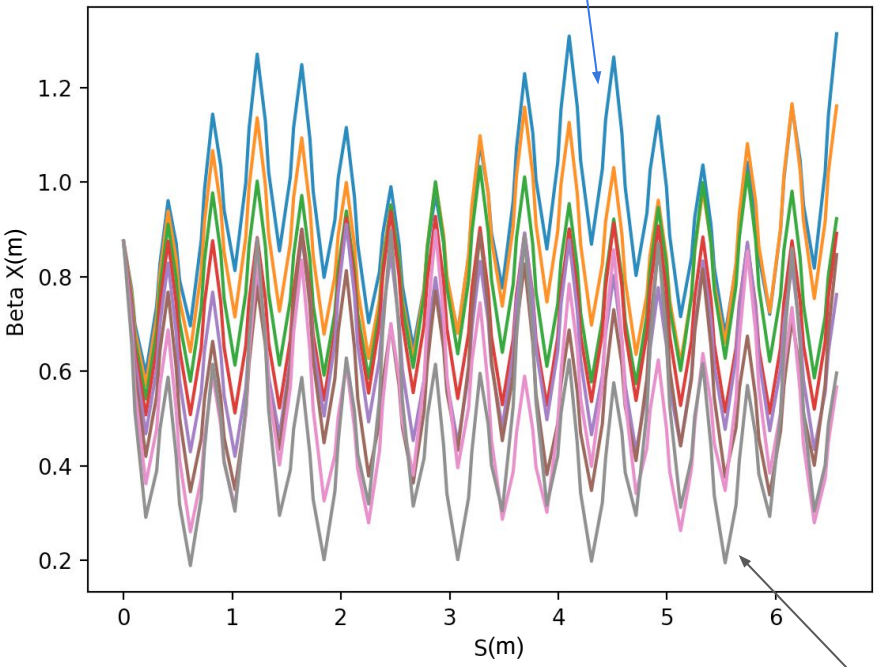
Final 90 Degree Arc Constraints

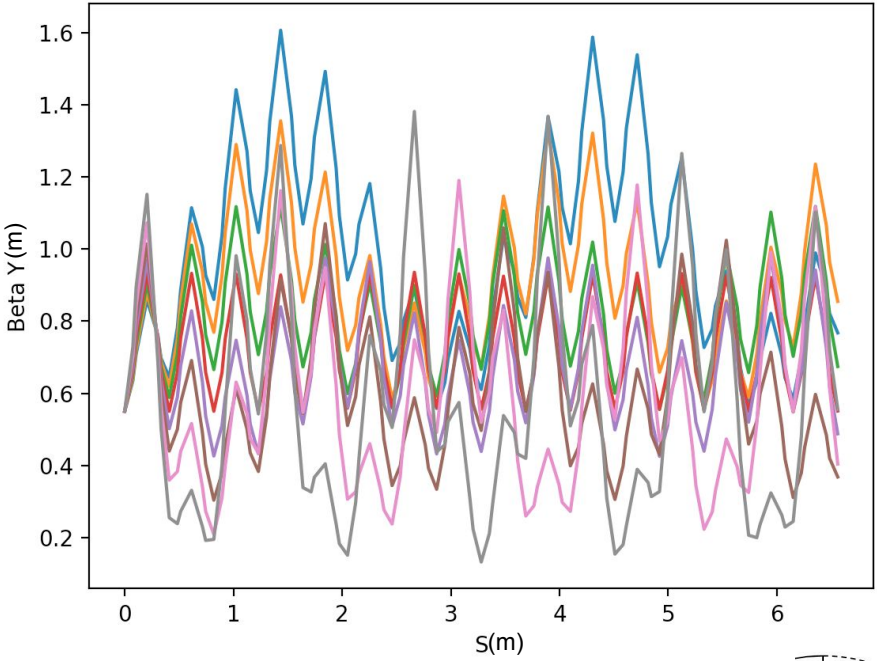
- Uniform Bend Angle
- Constraints of magnets based upon D_x
- Merger of orbits



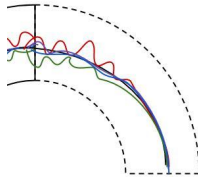
Highest Energy
(~250MeV)

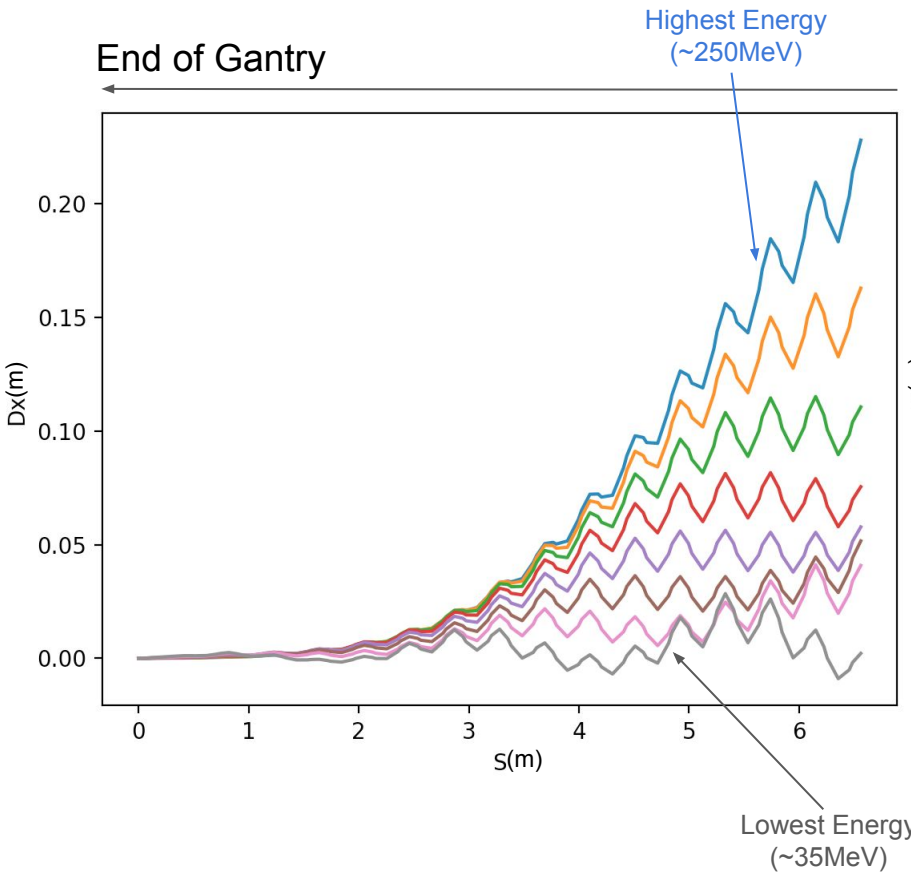
End of Gantry

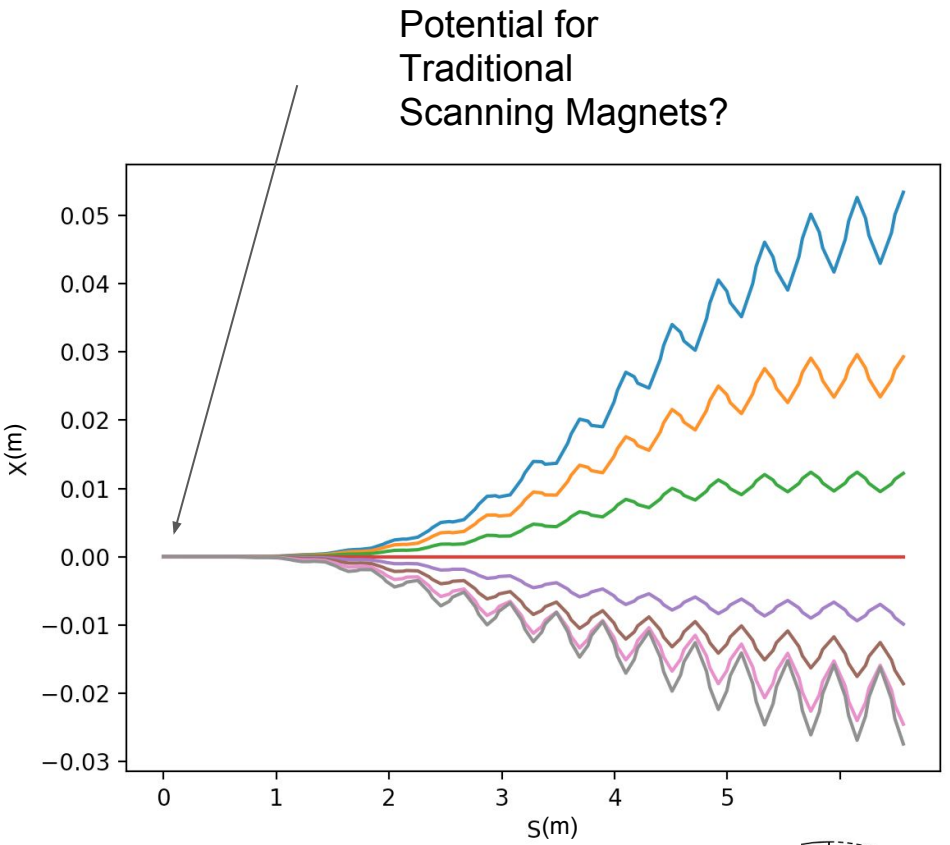


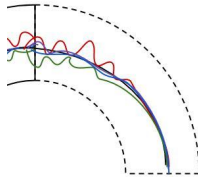


Lowest Energy
(~35MeV)




End of Gantry
Highest Energy
(~250MeV)
Lowest Energy
(~35MeV)
Dx(m)
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
5
6
S(m)


Potential for
Traditional
Scanning Magnets?
X(m)
0.05
0.04
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03
0
1
2
3
4
5
S(m)



Conclusions

and Future Work

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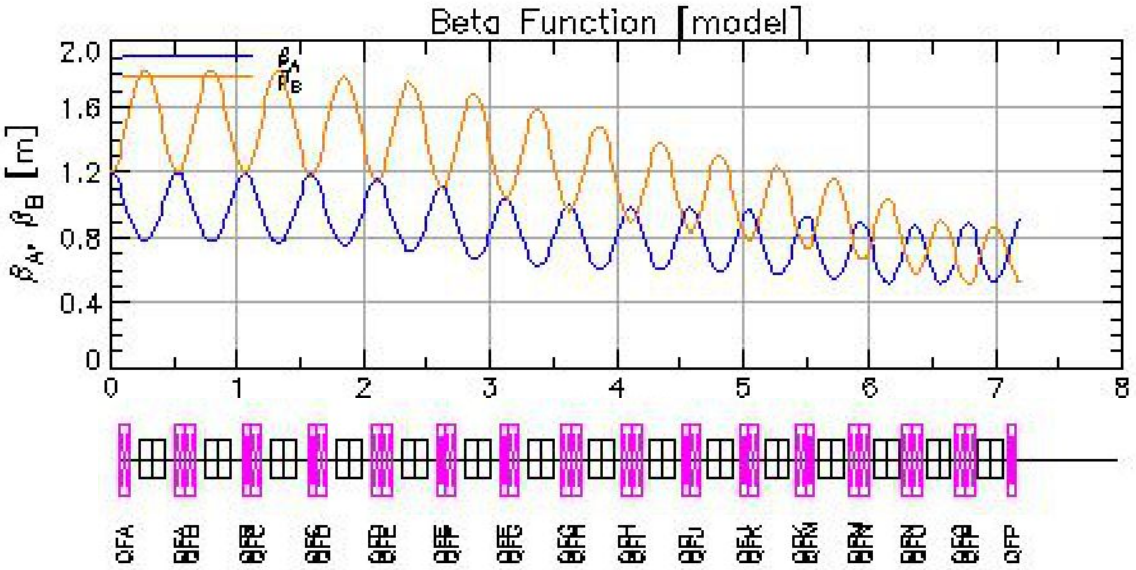

Future Work

- Decrease the size
  - Use of stronger magnets
- Transition over the inflection point
- Use a more suitable code
  - Optimised for Fixed-Field Accelerators

Conclusions

- Developed a unit cell to cover all energies
- Applied method of adiabatic variance to constraints
- Used unit cell to make a transition
  - Matched to constraints
  - Over entire energy range

Thank You!

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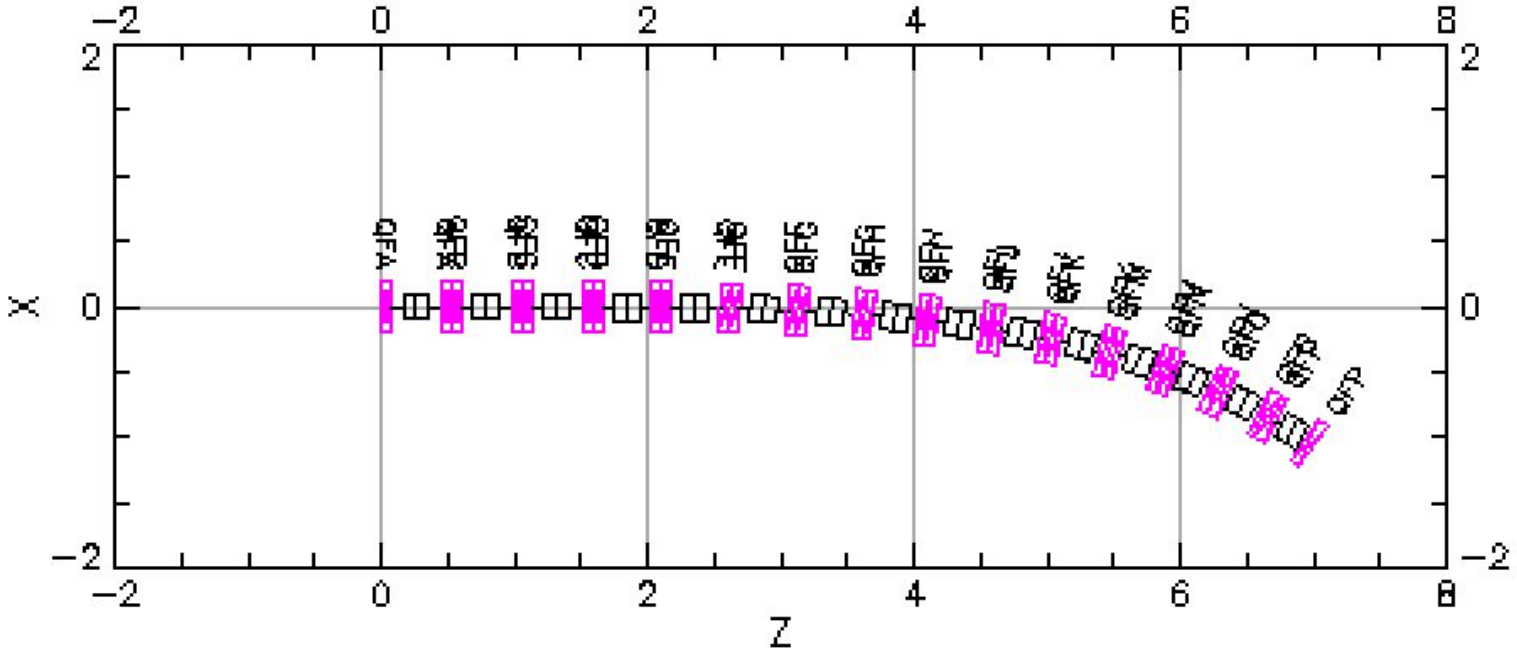
Appendix: A1



Appendix: A2

1. $f(x) = \frac{1}{2} + \left(x - \frac{1}{2}\right) \sum_{n=0}^{3} \frac{(2n)!}{(n!)^2} x^n (1-x)^n$

2. $\frac{d}{dx}\left[f(x)\right]$

3. $g(x) = \sin\left(\frac{\pi}{2}x\right)^2$

4. $\frac{d}{dx}\left[g(x)\right]$