Fixed-Field Gantries and Adiabatic Transitions

Julian Gascoyne with Dr. Suzie Sheehy
julian.mv.gascoyne@gmail.com

Methodology

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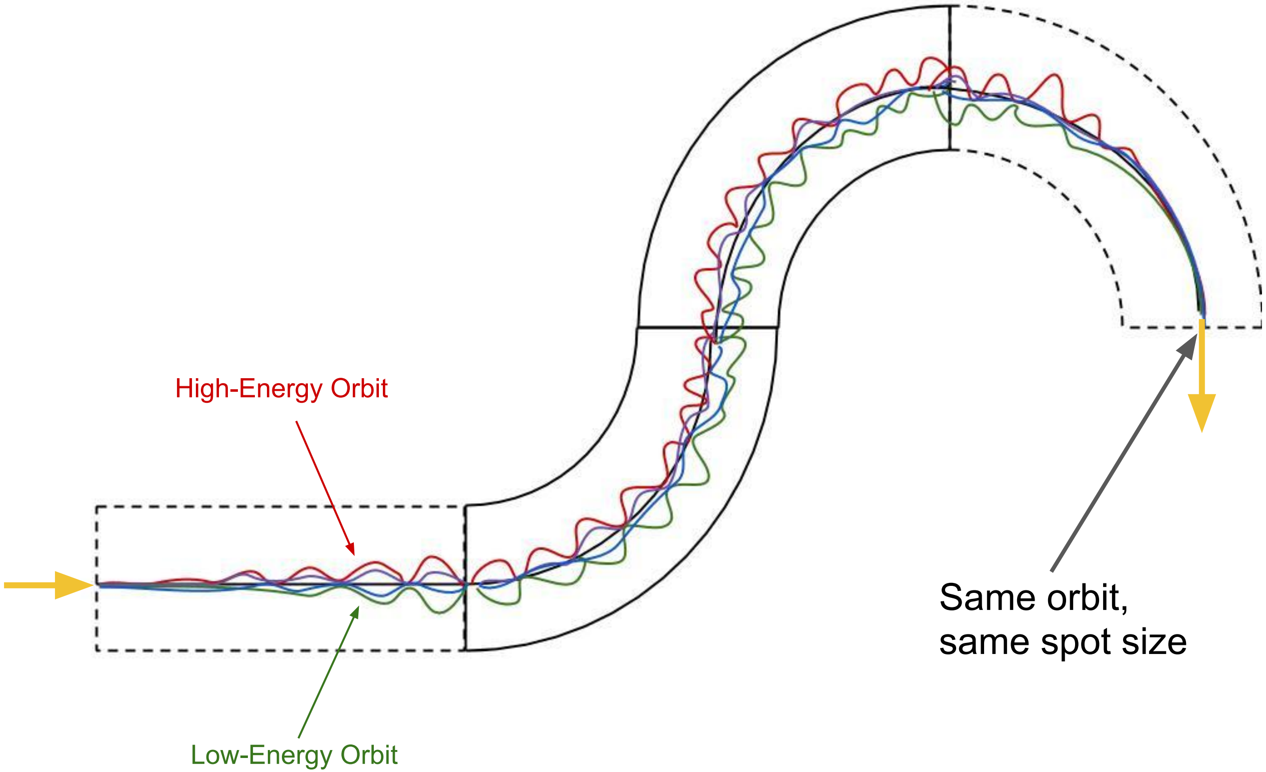
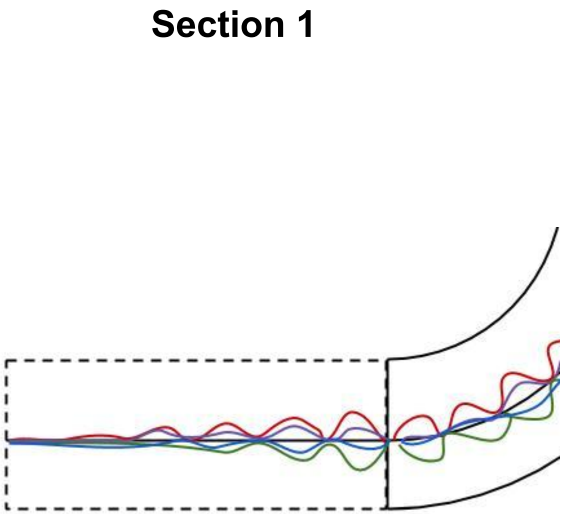
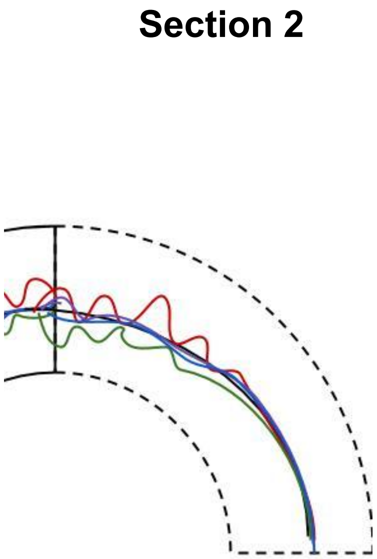
Motivation

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





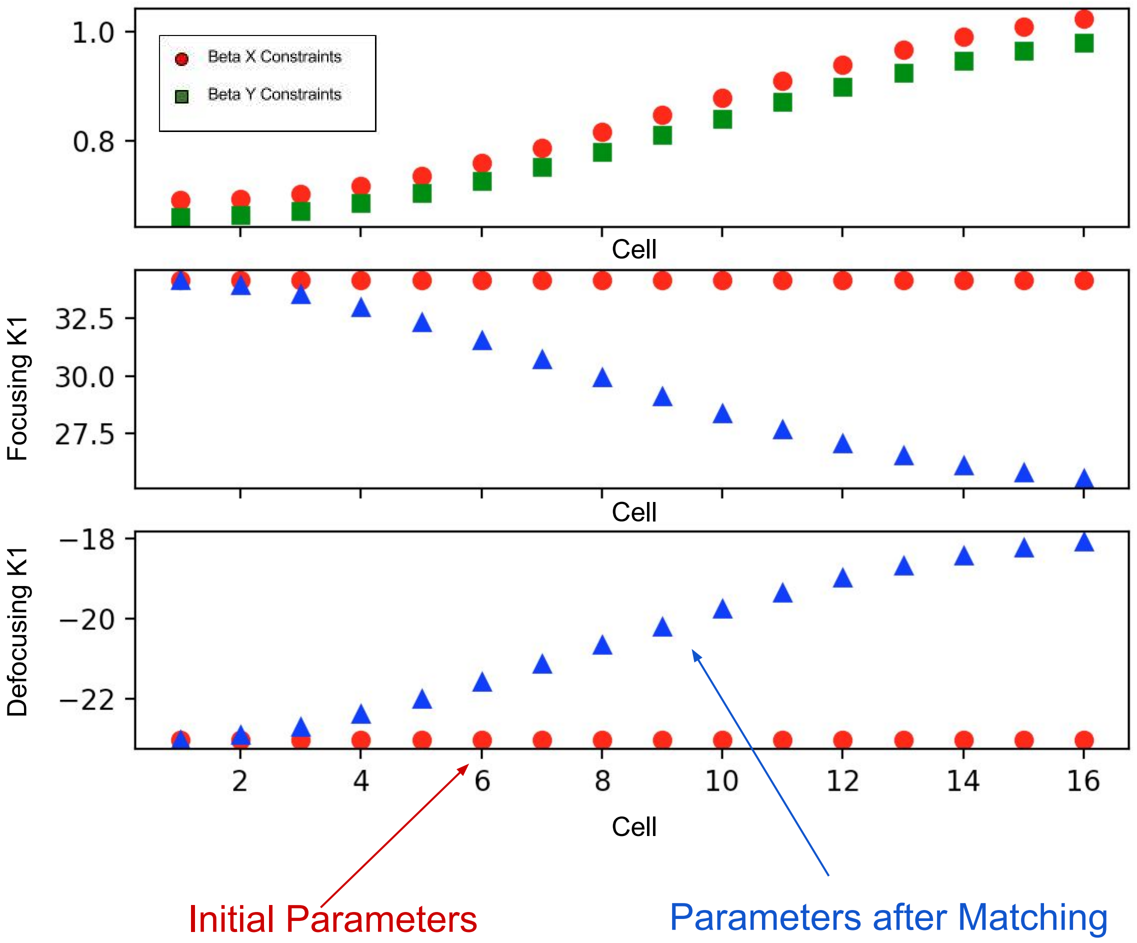


Some Parameters to Consider

- 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

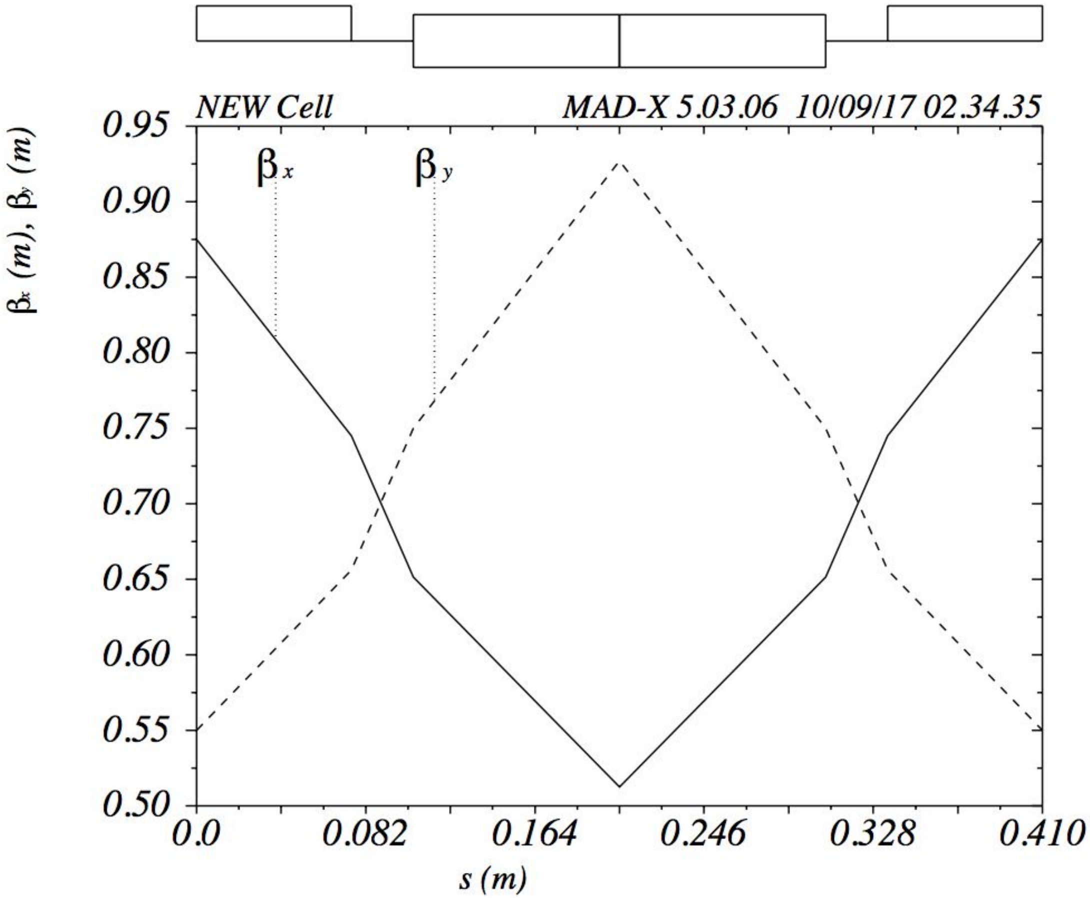
- Identify the constraints
- Create a Unit Cell
    - Ensure stability
    - Find the periodic conditions
- Vary the constraints
    - Based on the transition from CBETA
- Match the transition
    - (Try to) Ensure Stability



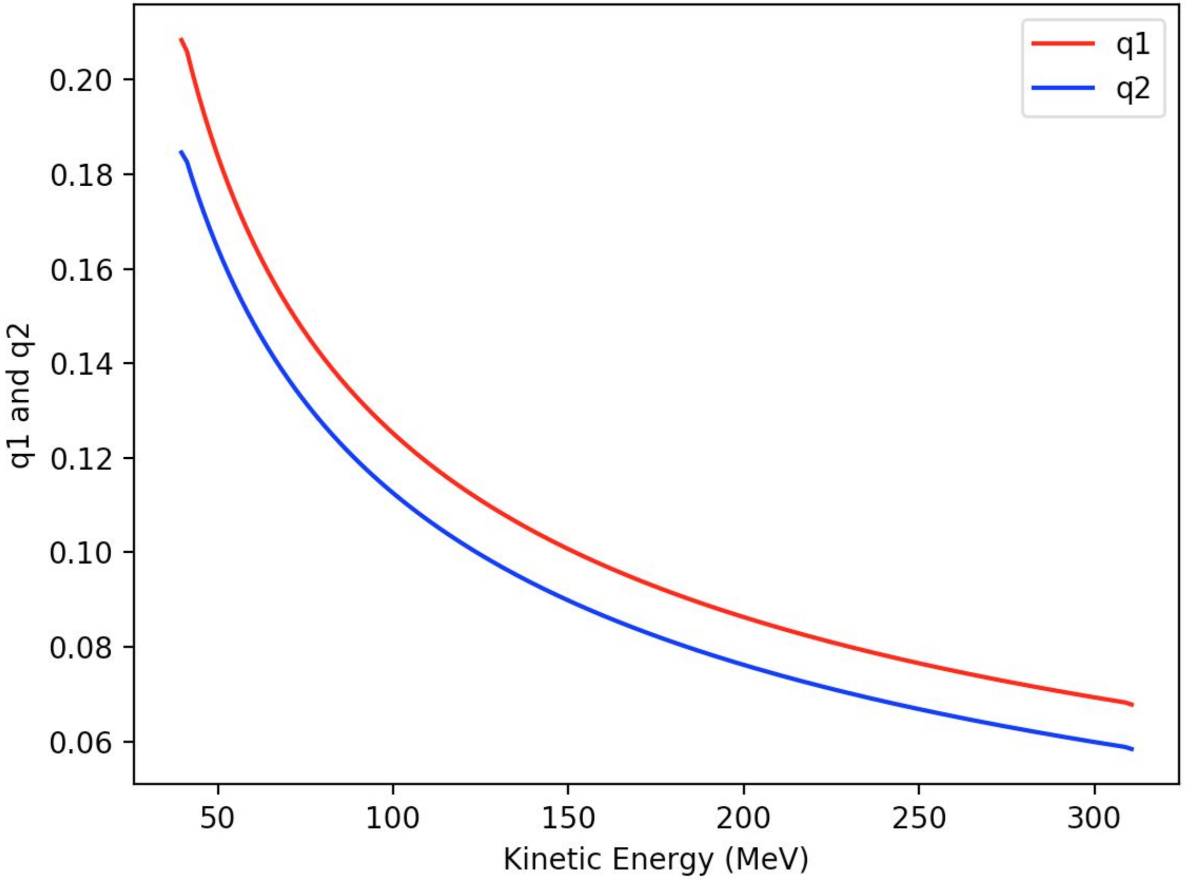
Unit Cells

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

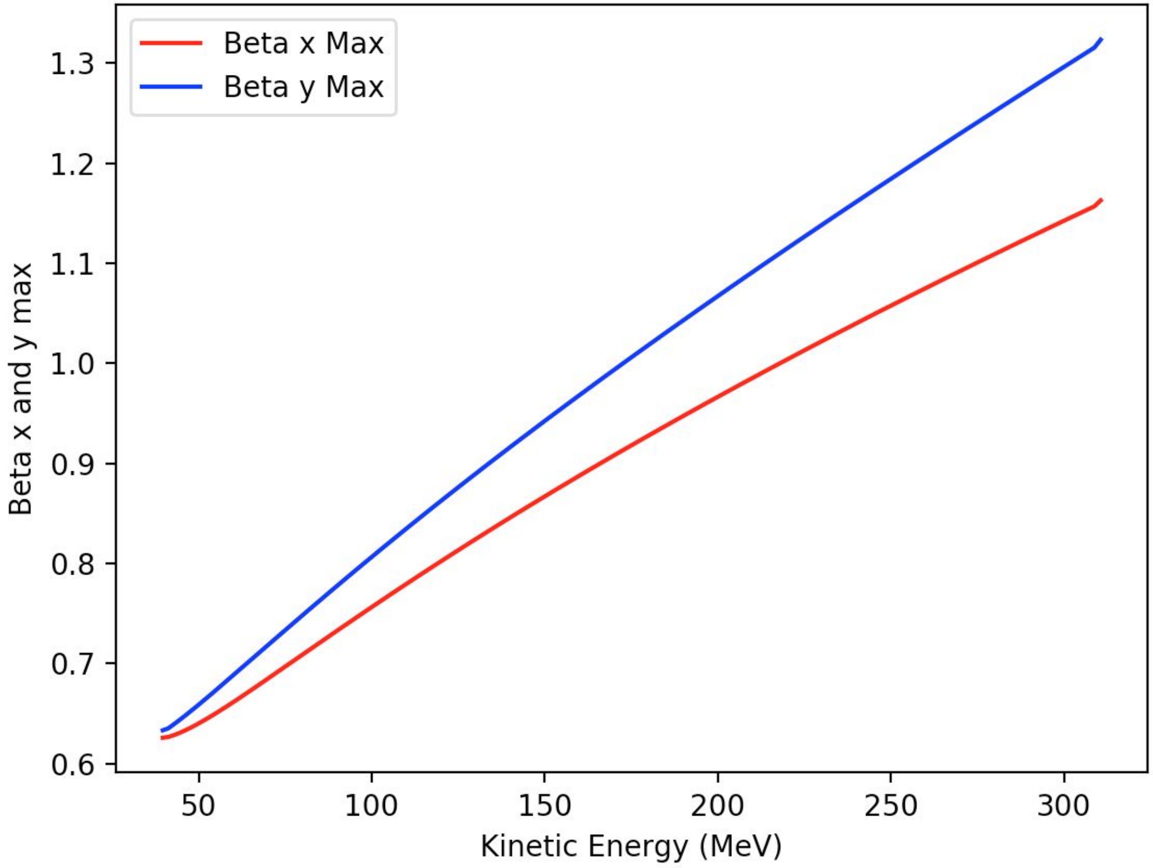


* D. Trbojevic, Patent: US 2012/0313003 A1, 2012



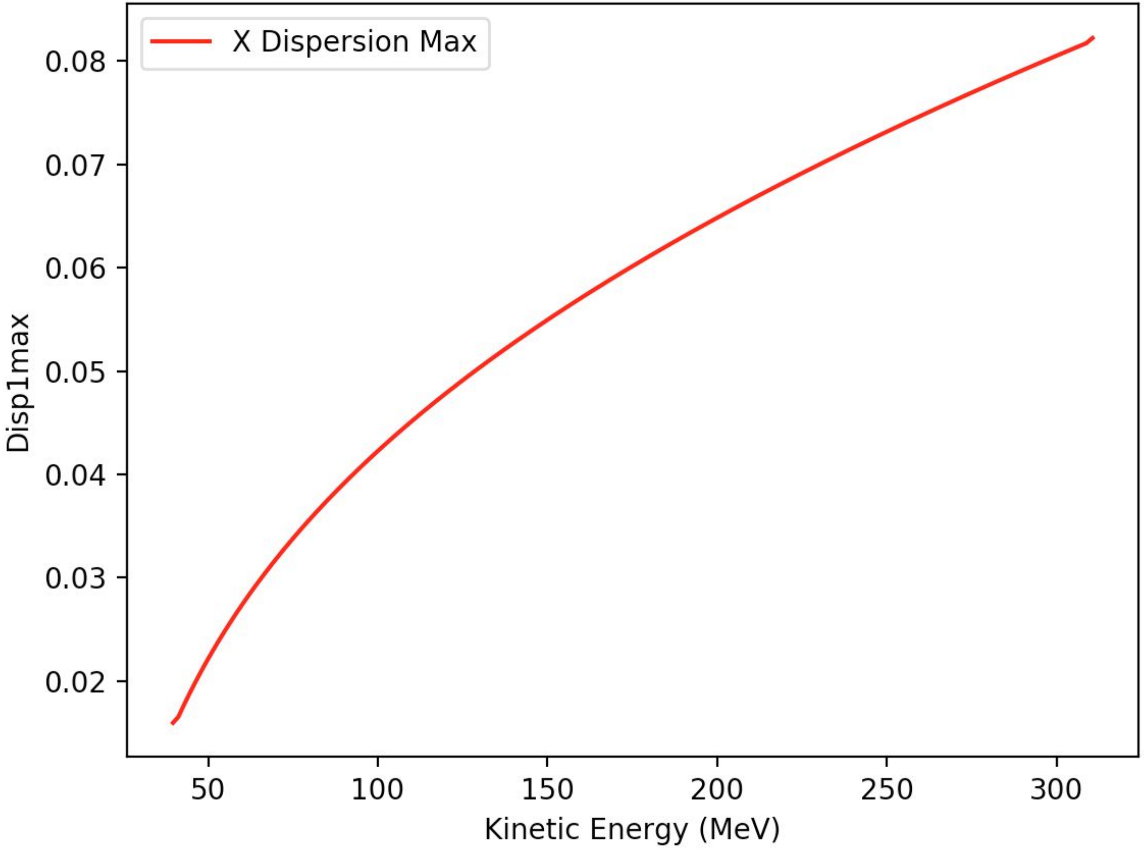
Stability

- 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

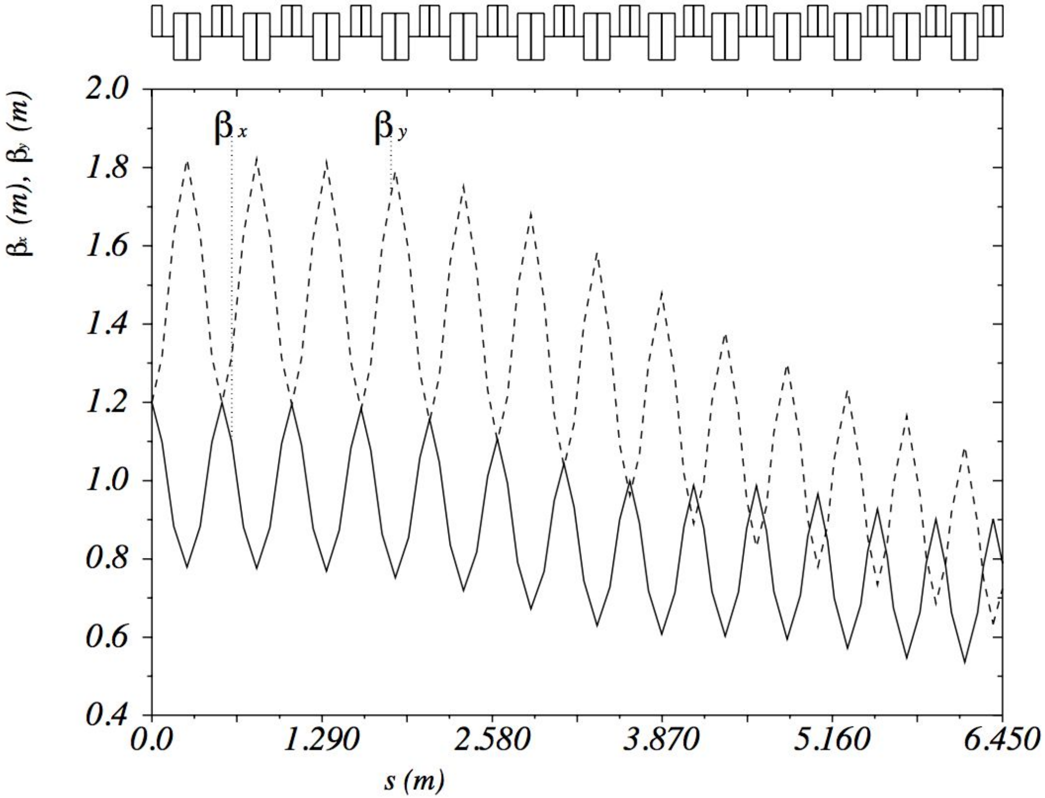
- Tunes decrease with energy
  - Stable over range
- β_x and β_y increase with energy
  - Close together
- Small Dispersion also gets larger with energy

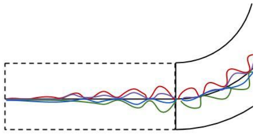
Transition

Accelerator to Gantry

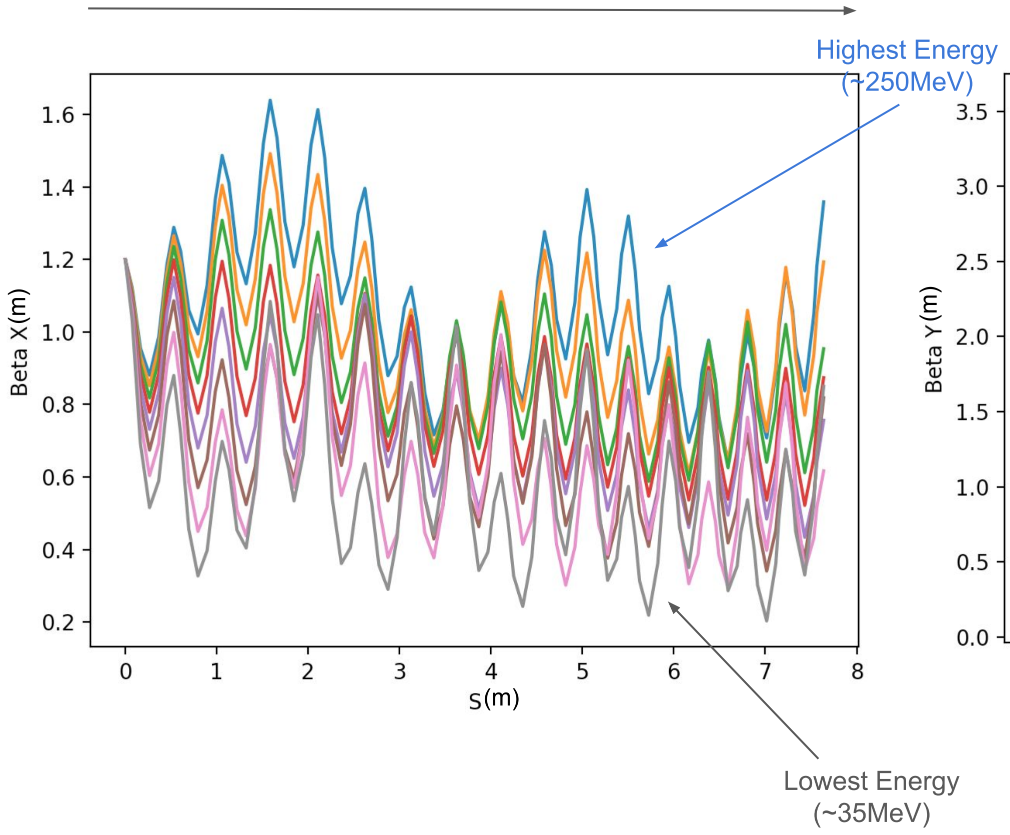
Accelerator to Gantry Constraints

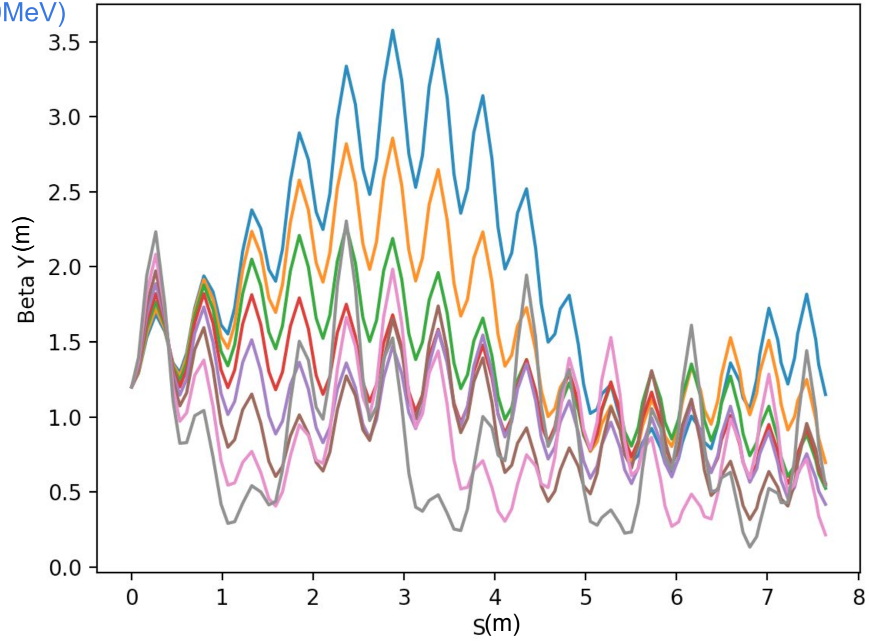
- Initially
  - Rotationally symmetric
    - $\epsilon_x\beta_x=\epsilon_y\beta_y$
    - D_x=0.0 m
    - D_x' = 0.0
  - Match accelerator's β functions
    - β_x = β_y = ~1.2m
- By the end
  - Must match periodic conditions of cells

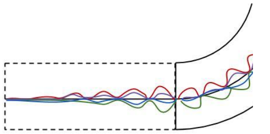


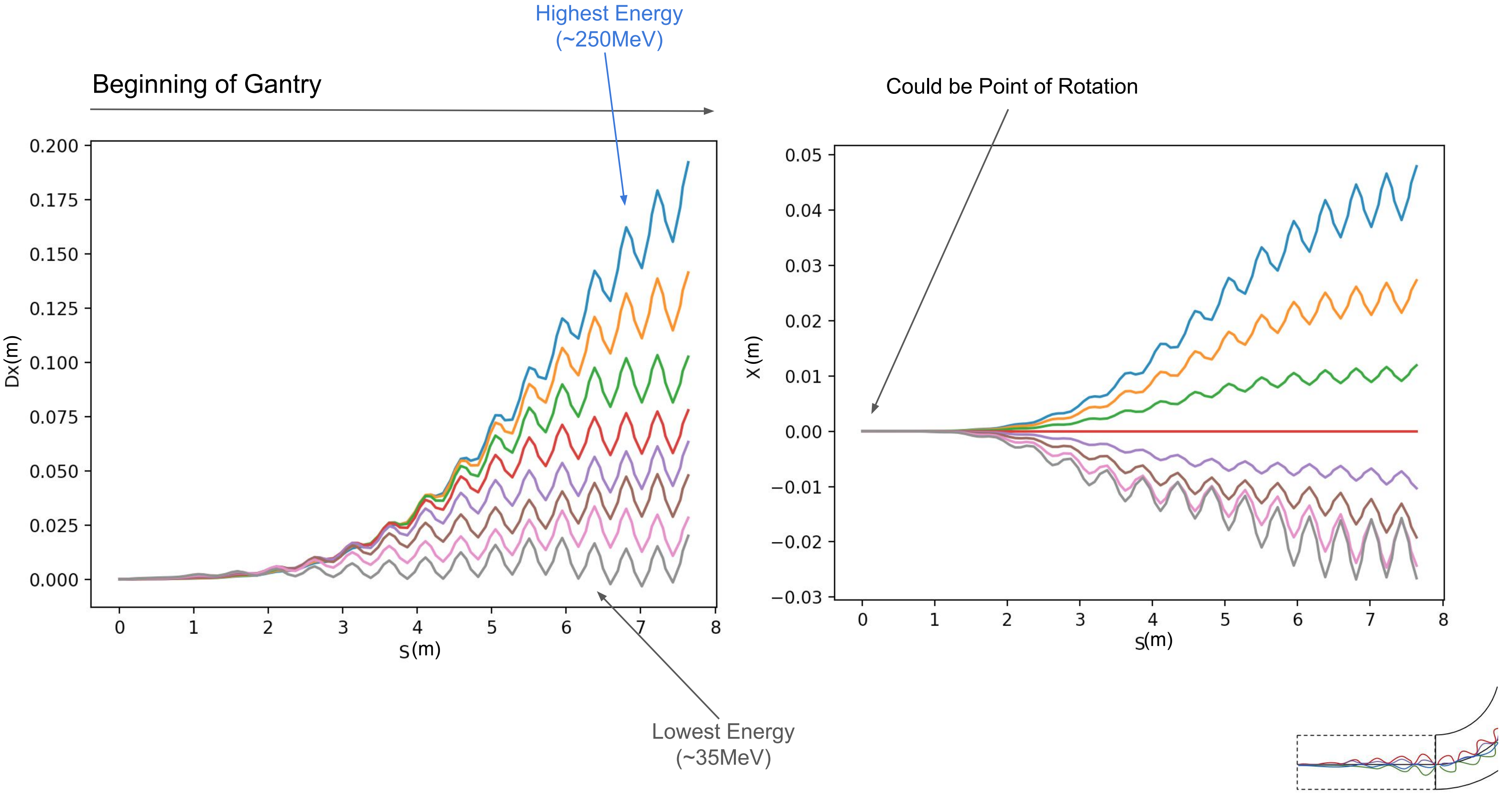


Beginning of Gantry









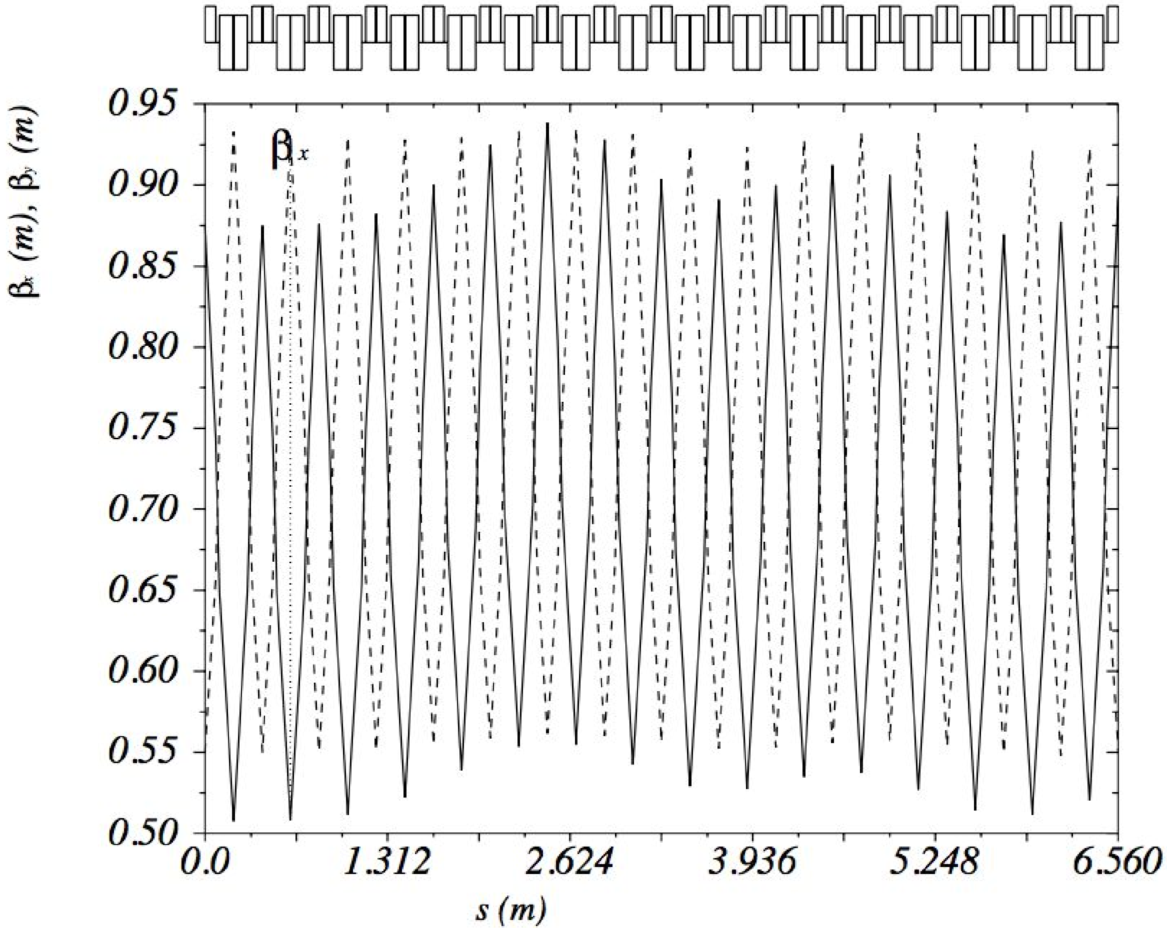
Highest Energy
(~250MeV)
Beginning of Gantry
Could be Point of Rotation
Dx(m)
S(m)
X(m)
S(m)
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
0.05
0.04
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03
0 1 2 3 4 5 6 7 8
Lowest Energy
(~35MeV)

Transition

Final 90 Degree Arc

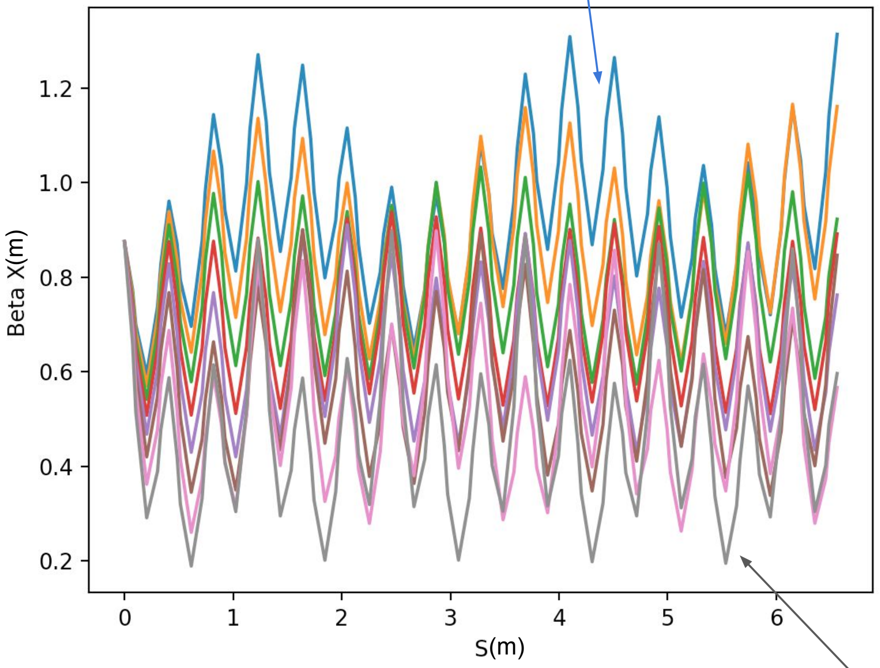
Final 90 Degree Arc Constraints

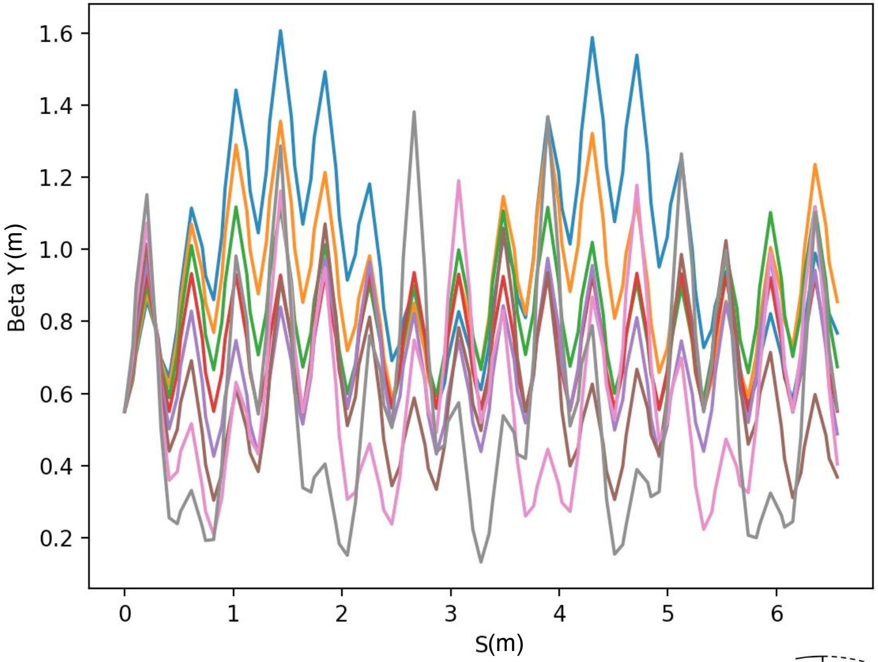
- Uniform Bend Angle
- Constraints of magnets based upon D_x
- Merger of orbits



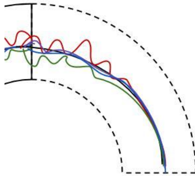
Highest Energy
(~250MeV)

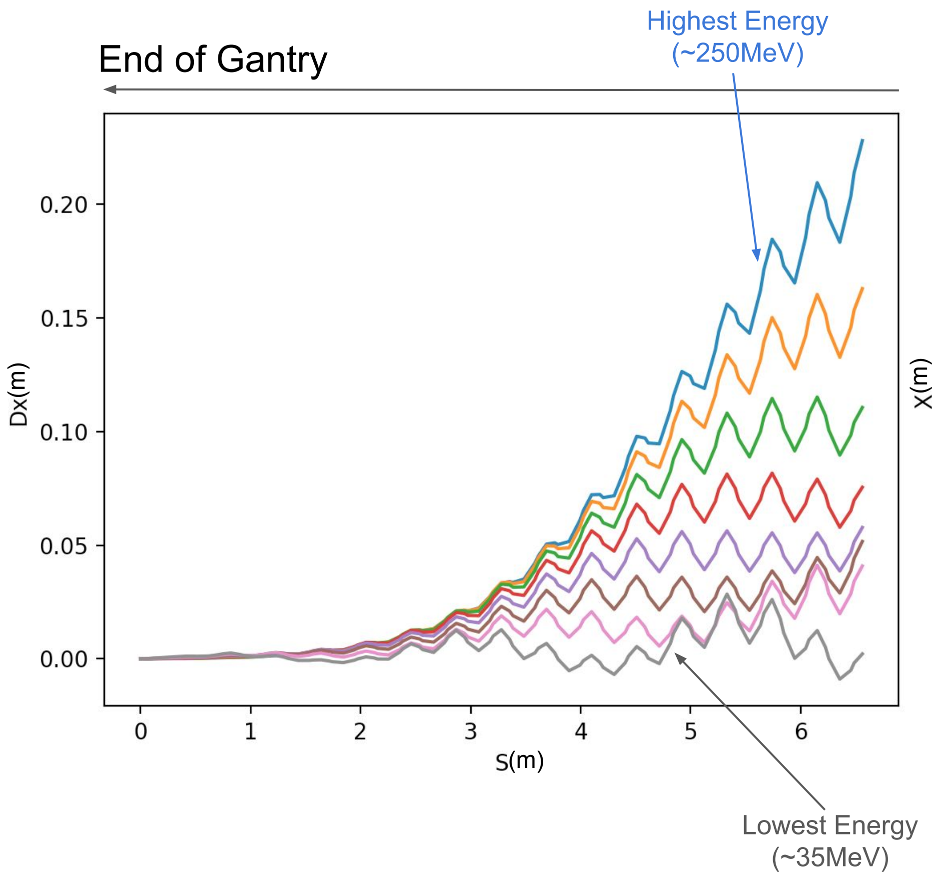
End of Gantry



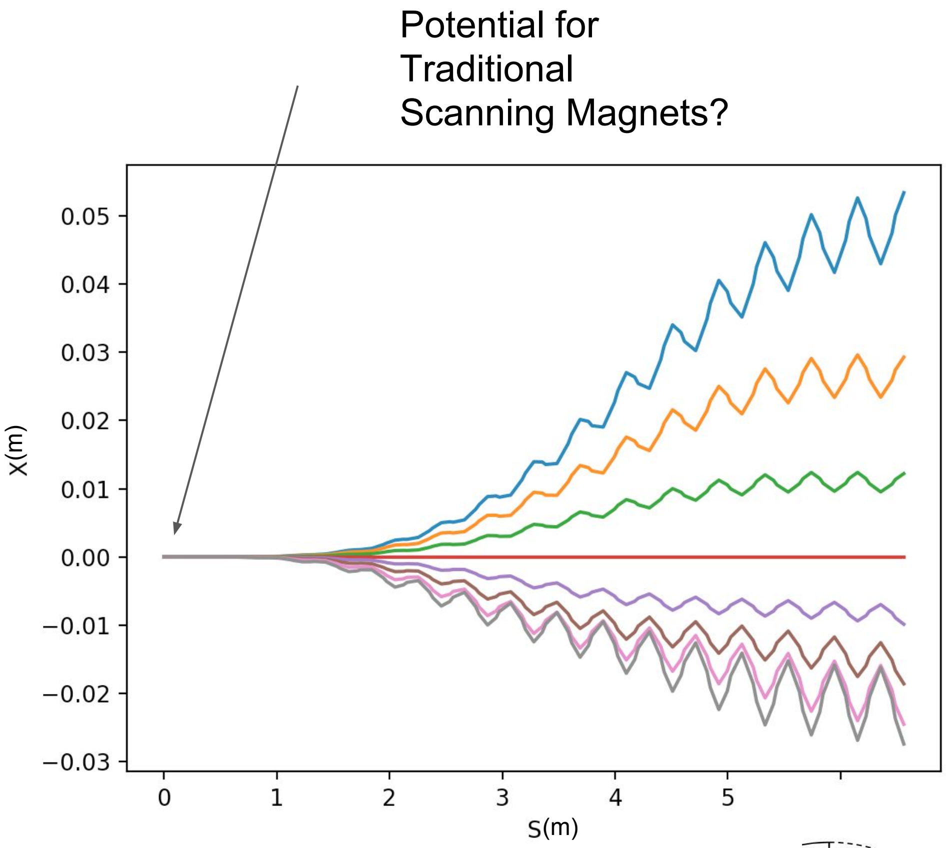


Lowest Energy
(~35MeV)

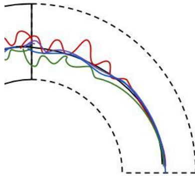




End of Gantry
Highest Energy
(~250MeV)
Lowest Energy
(~35MeV)
0.20
0.15
0.10
0.05
0.00
Dx(m)
0
1
2
3
4
5
6
S(m)

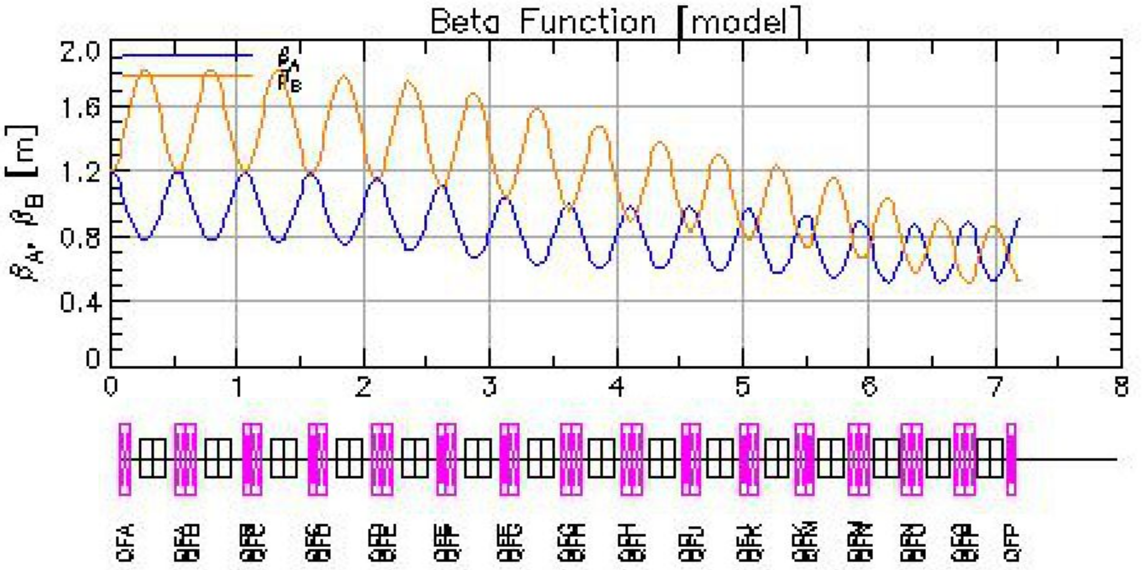


Potential for
Traditional
Scanning Magnets?
0.05
0.04
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03
X(m)
0
1
2
3
4
5
S(m)



Conclusions

and Future Work



Future Work

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

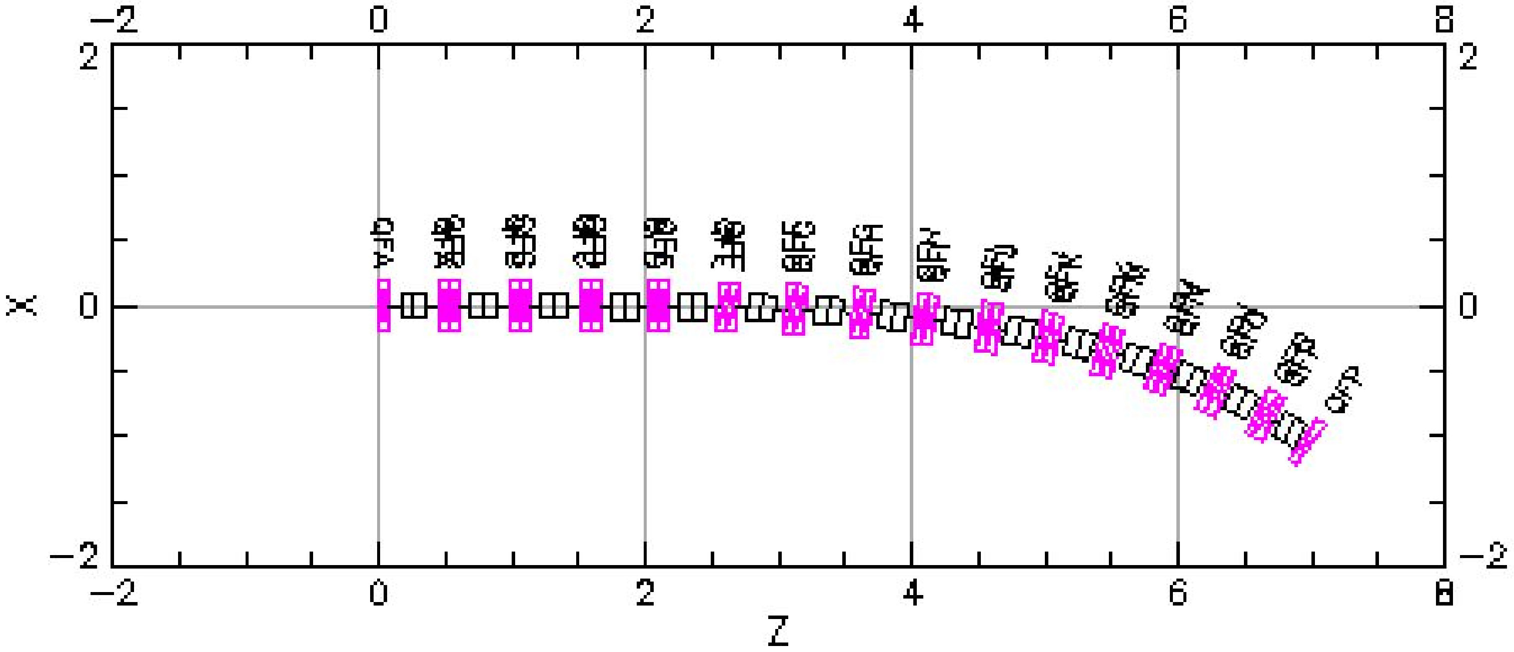
Conclusions

- 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!

julian.mv.gascoyne@gmail.com

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