RLA with FFAG focusing

FFAG beam transport

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http://www.astec.ac.uk/intbeams/users/machida/doc/ffag/machida20080905.pdf & ppt

Background (1)
focusing in RLA

- RLA uses fixed field magnet.
- Large momentum acceptance is required.

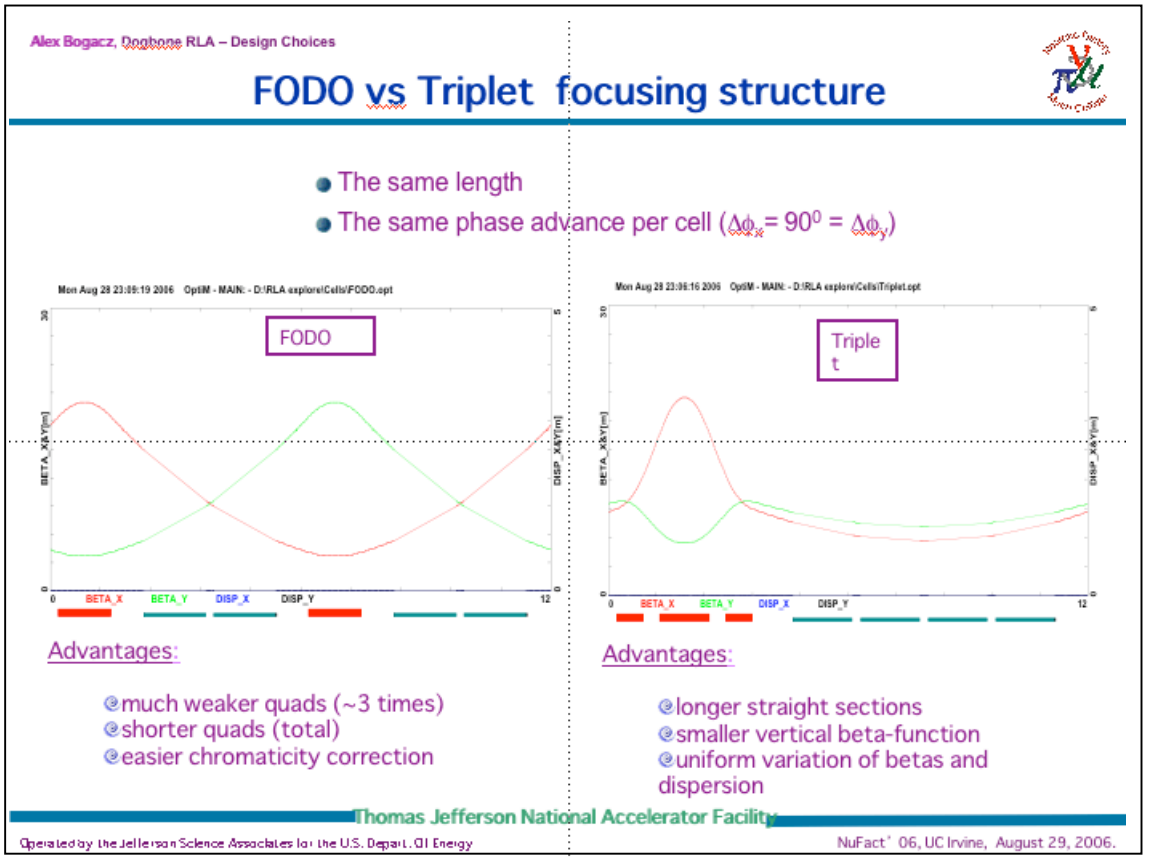
- In both ends of a linac, different momentum beams go into difference arcs.
  - It is possible to optimize the arc optics for each momentum.
  - Make a single arc for all the momenta is a challenge, but that is not the subject of this talk.

- Trouble is the focusing in a linac and in switch yard, where they should give sufficient focusing for all the momentum range.

Background (2)
present solutions

- For muon RLA, possible solutions for focusing in a linac are,
  - FODO quadrupole lattice instead of triplet focusing.
  - Pulsed quadrupole focusing.

Bogacz



Background (3)
focusing using scaling FFAG principle

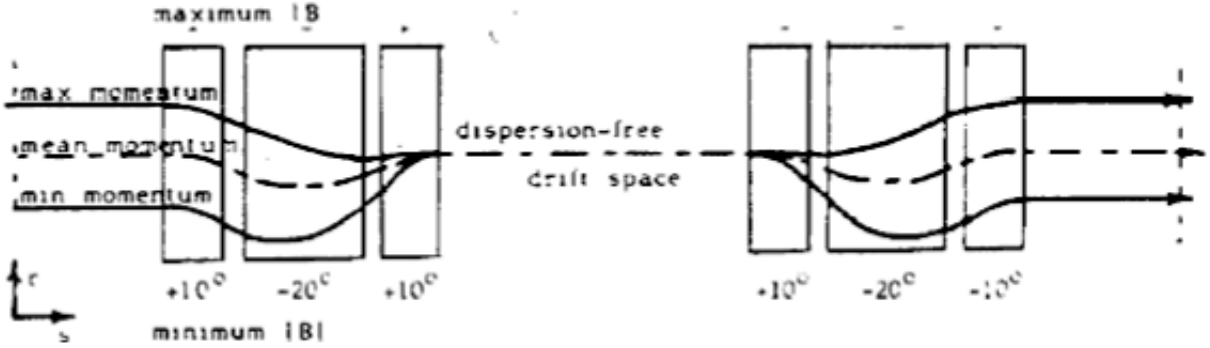
- Is it possible to use scaling FFAG magnet?
  - Keep the same lattice functions for all the momentum range.

- Straight FFAG beam transport in general.
  - Beam transport line for medical facility (from accelerator to gantry).
  - Long straight insertion in a scaling FFAG.

People always said it is possible to make FFAG BT, but no design have seen before.

Background (4)
previous work?

- Meads Jr. proposed “a dispersion free long straight section” (PAC83).



- Not clear if his matrix methods accurately describes scaling optics.
  - “*This [scaling] property simplifies the design in that a design good for one energy is automatically good at all energy.*”

- It is true *only* when every equilibrium orbit is photographic enlargement of every other equilibrium orbit.

Tool development (1)
rectangular scaling magnet

- Added another type of magnet into S-code.
  - Equal field line is straight along longitudinal direction.
  - Field profile is

$$\frac{B_z(y, z=0)}{B_0} = \left(\frac{y}{y_0}\right)^k$$

  - Expand the equation to obtain off plane fields.
  - Necessary to estimate vertical focusing.

$$B_z(x,y,z) = B_0\left(\frac{y}{y_0}\right)^k G(x) - \frac{1}{2}\frac{B_0}{{y_0}^2}\left(\frac{y}{y_0}\right)^{k-2} z^2 + \cdots$$

y: horizontal, z: vertical, x: longitudinal

Tool development (2)
remarks

- There is no machine centre.
  - *y* is measured perpendicularly to longitudinal direction.

$$\frac{B_z(y, z=0)}{B_0} = \left(\frac{y}{y_0}\right)^k$$

- y_0 is arbitrary, but constant.
  - k/y_0 is a measure.

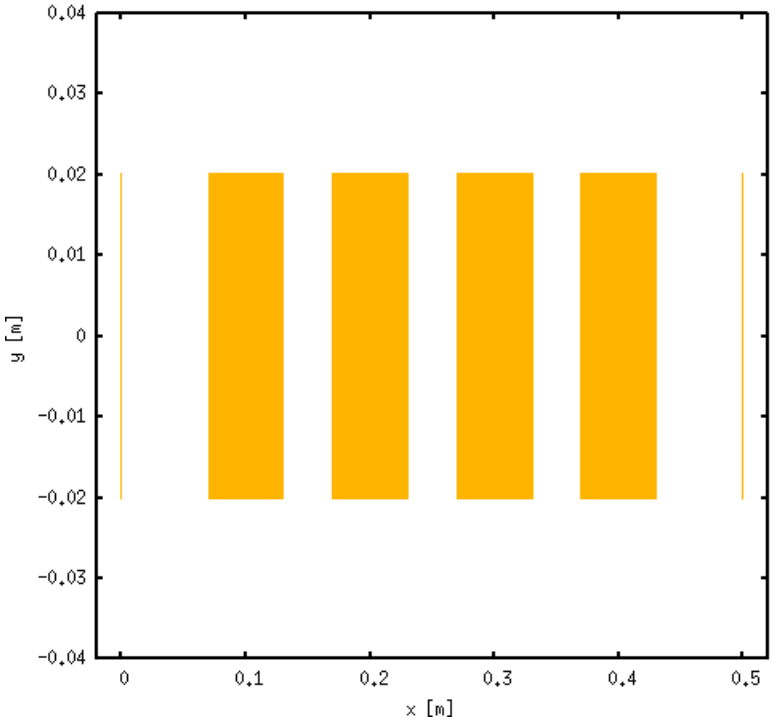
$$\frac{B_z}{B_0} = \left(1 + \frac{\Delta y}{y_0}\right)^k \cong 1 + \frac{k}{y_0}\Delta y$$

y: horizontal, z: vertical, x: longitudinal

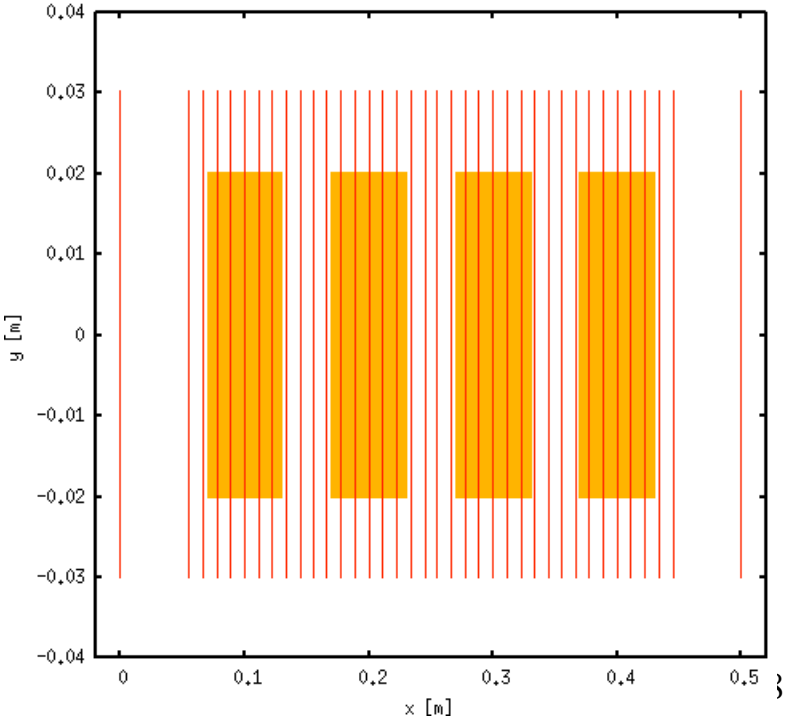
FFAG beam transport (1)
unit cell

- Consider FDDF as a unit cell.
  - There may be other ways.

Place lattice components and attach coordinate system to each component.



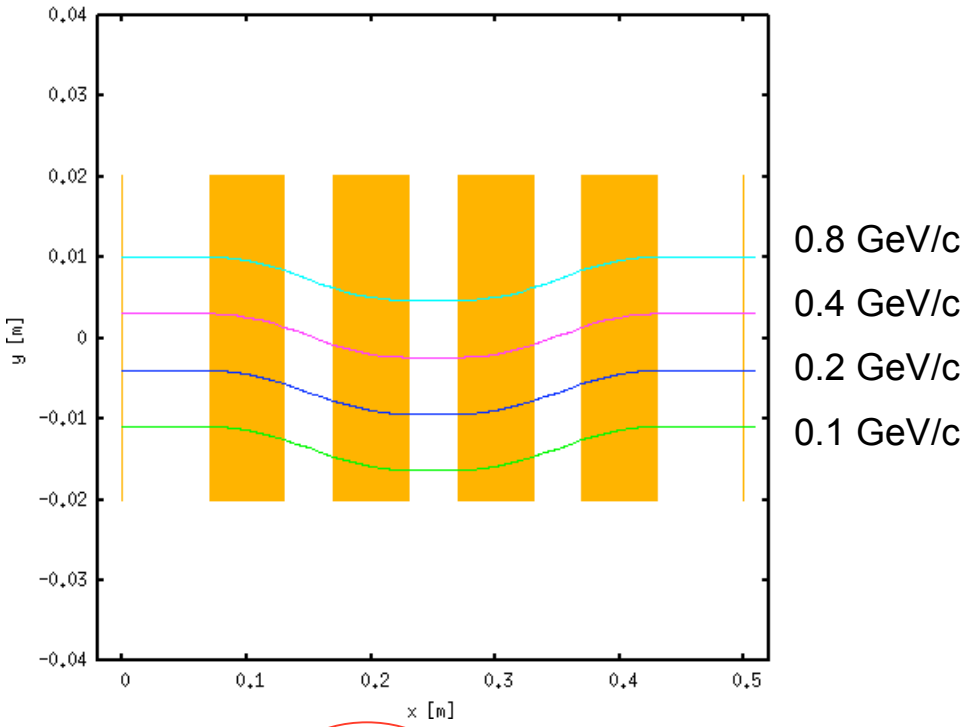
Define magnetic and/or electric fields at thin slices in the coordinate system.



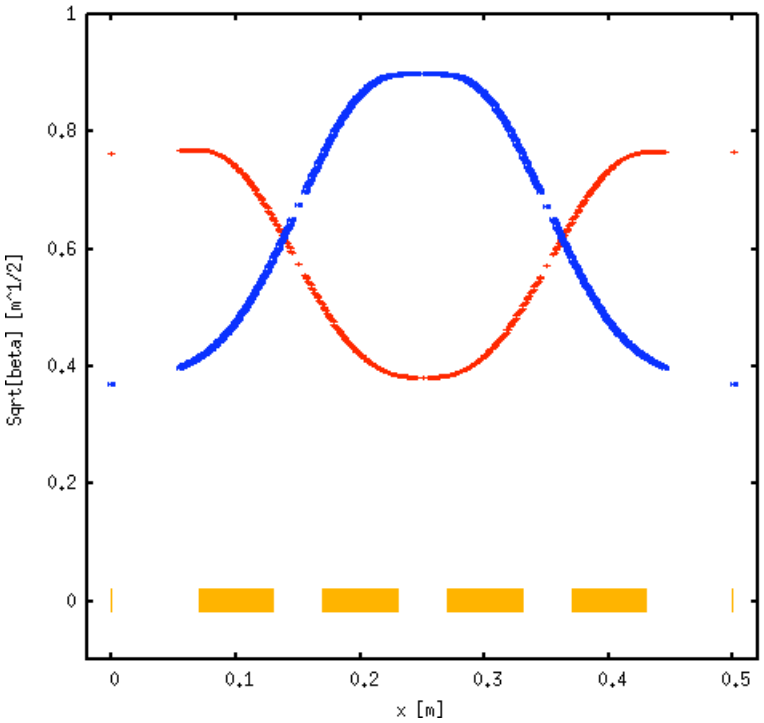
FFAG beam transport (2)

orbit and optics with boundary condition

Orbit for different momentum.



Beta function is identical for all the momenta.



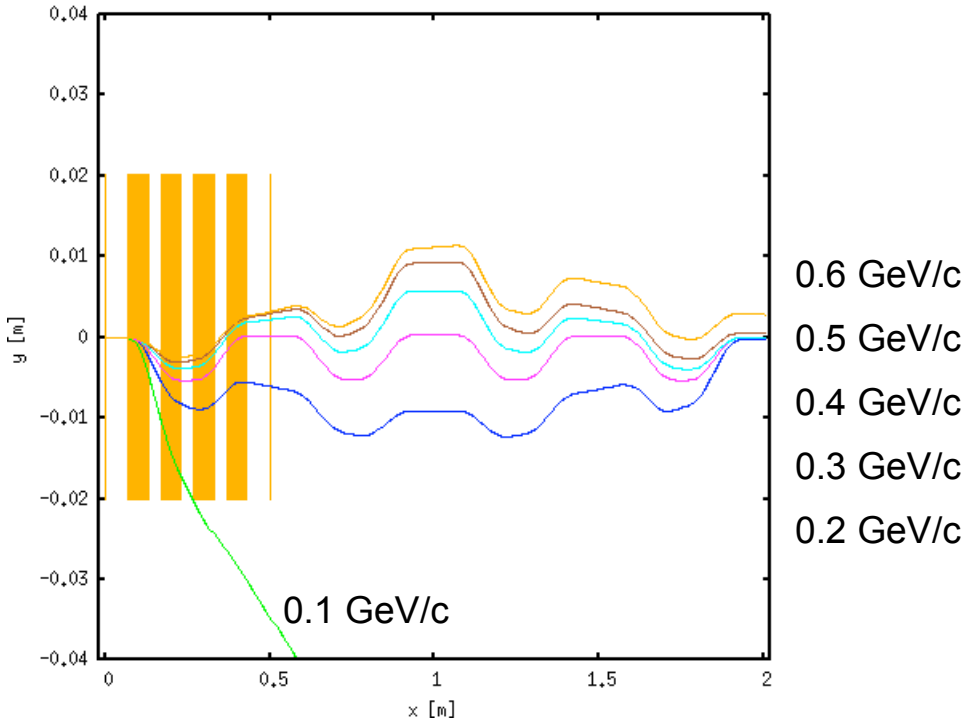
$$\frac{p}{p_0} = \left(\frac{y}{y_0}\right)^{k \text{ or } k+1}$$

$$\frac{\Delta y}{y_0} \approx \frac{p/p_0}{k}$$

FFAG beam transport (3)

insertion with 2 π phase advance

- A section with 2 π phase advance transports zero dispersion from one end to the other.
  - As an example, 4 unit FDDF cells with π/2 horizontal phase advance.

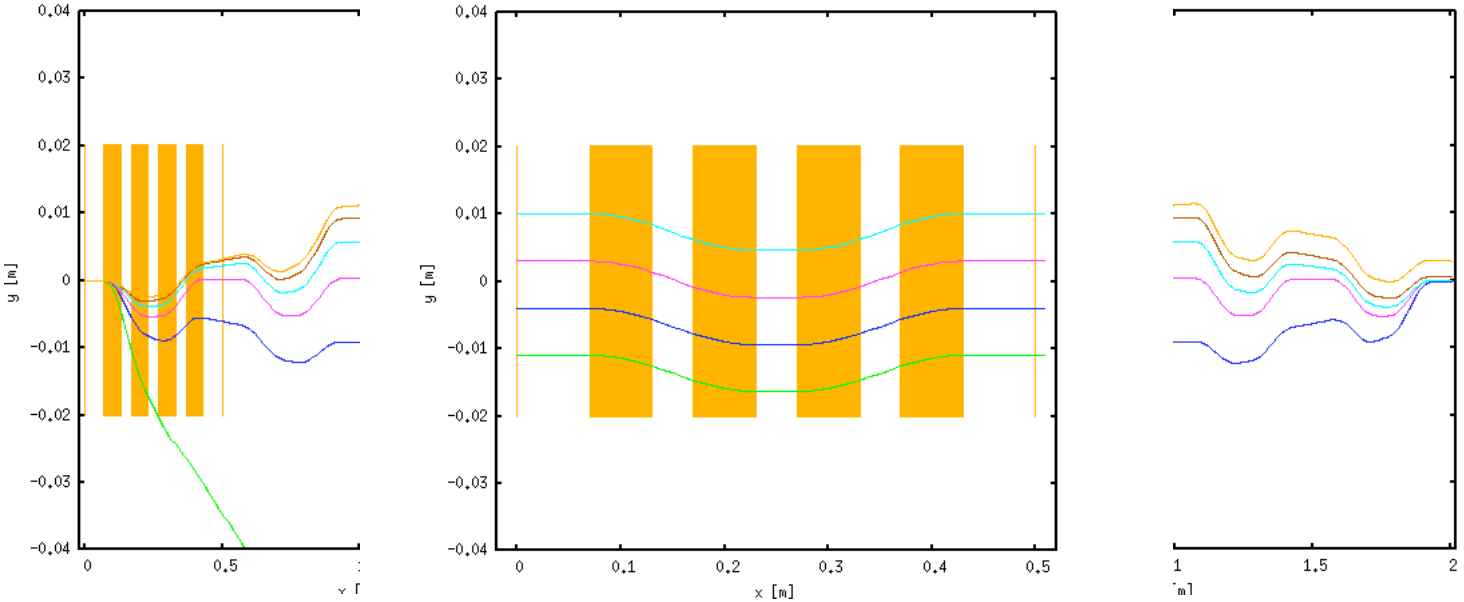


  - Works in momentum range between 0.2 and 0.5 GeV/c.

FFAG beam transport (4)

dispersion suppressor

- Use a half section with π phase advance as a dispersion suppressor.



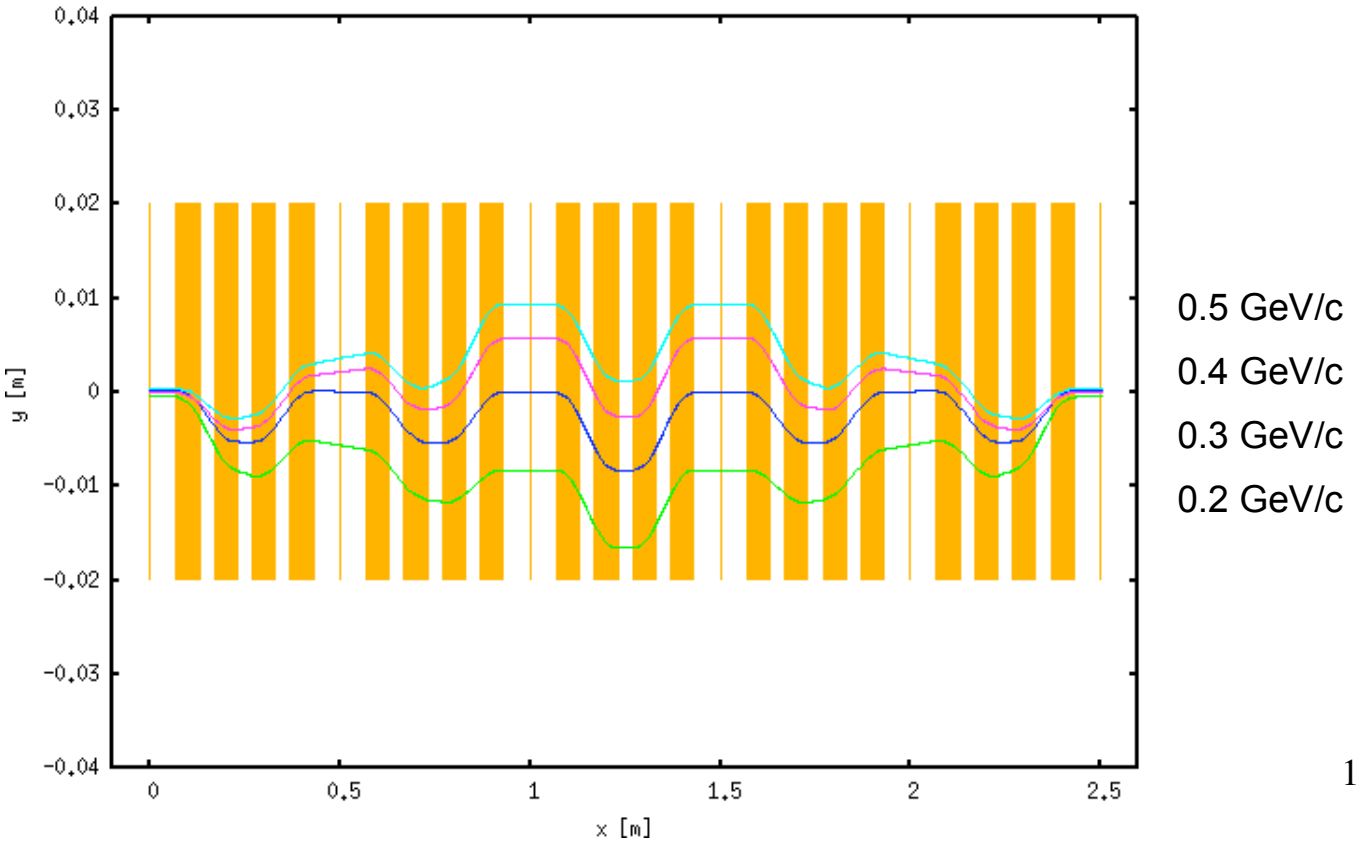
k=100 ~50 100

In order to match orbit excursion between the centre and suppressor, field index *k* has to be about a half of suppressor.

FFAG beam transport (5)

short straight line

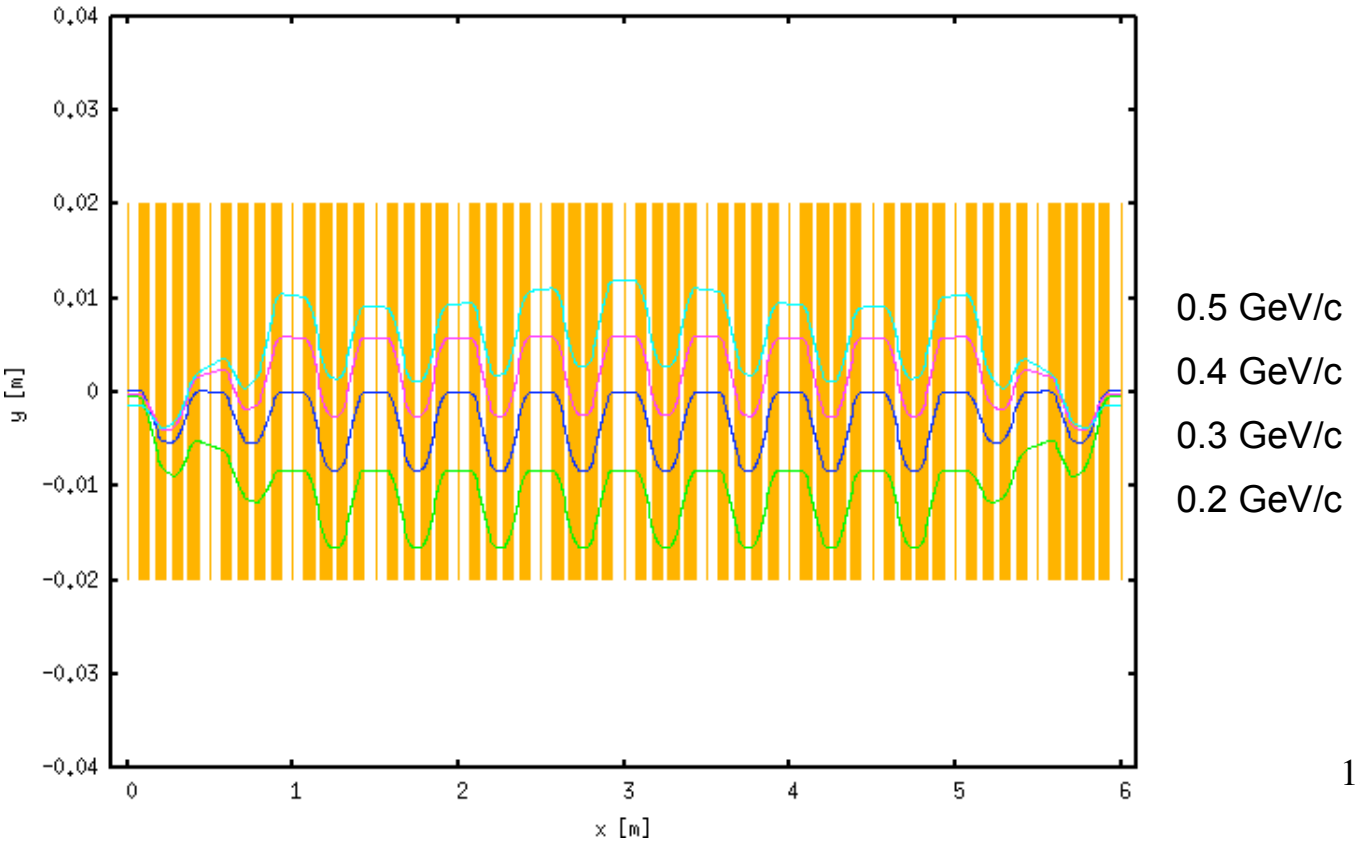
- FDDF unit cell + dispersion suppressors at the both end make a shortest FFAG beam transport.
  - Almost zero dispersion at the both end.



FFAG beam transport (6)

long straight line

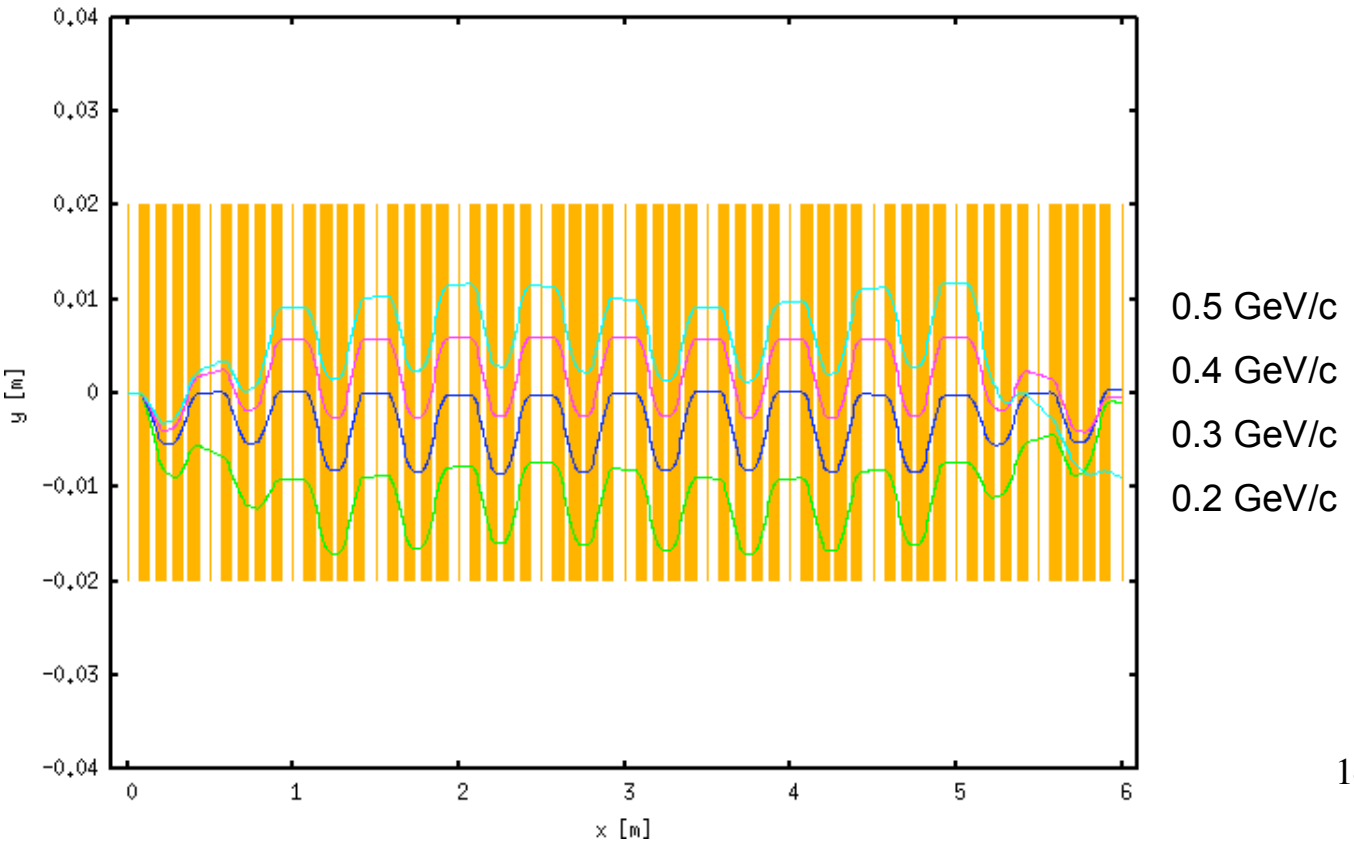
- Several FDDF unit cell + dispersion suppressors at the both end make a long FFAG beam transport.
  - Almost zero dispersion at the both end with periodicity condition.



FFAG beam transport (7)

long straight line

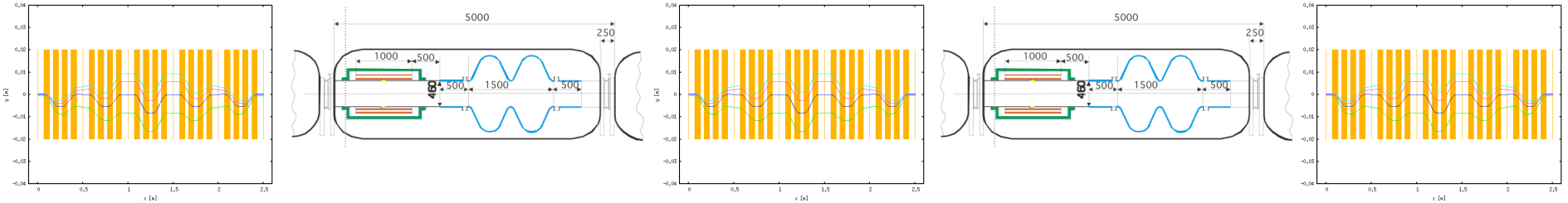
- Several FDDF unit cell + dispersion suppressors at the both end make a long FFAG beam transport.
  - Start (0,0) at the entrance.



FFAG beam transport (8)

as linac focusing of RLA

- Too many focusing magnets at the moment.
- Momentum range of 2~2.5 may not be enough.



Summary

- Rectangular scaling magnet is introduced to model FFAG straight beam transport.
- Dispersion suppressor is made by π phase advance section and twice as much field index.
- FFAG straight beam transport with momentum acceptance of 2~2.5 was realized.
  - Phase advance deviates quickly beyond that range.
- It may be too much complicated as RLA focusing.