FFAG lattice with insertions

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http://www.astec.ac.uk/intbeams/users
/machida/doc/nufact/ffag/machida20090701.pdf

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Overview (1)

circular accelerators and insertions

- All the circular accelerator did not have insertions when it was first designed.
  - one (super) period = one unit cell
- Betatron and cyclotron consist of only unit cells.
  - no need to make (super) period because of small number of unit cells.

- Modern synchrotron has all kinds of insertions.
  - dispersion suppressor
  - low beta
  - wiggler
  - etc.

Overview (2)

FFAG optics

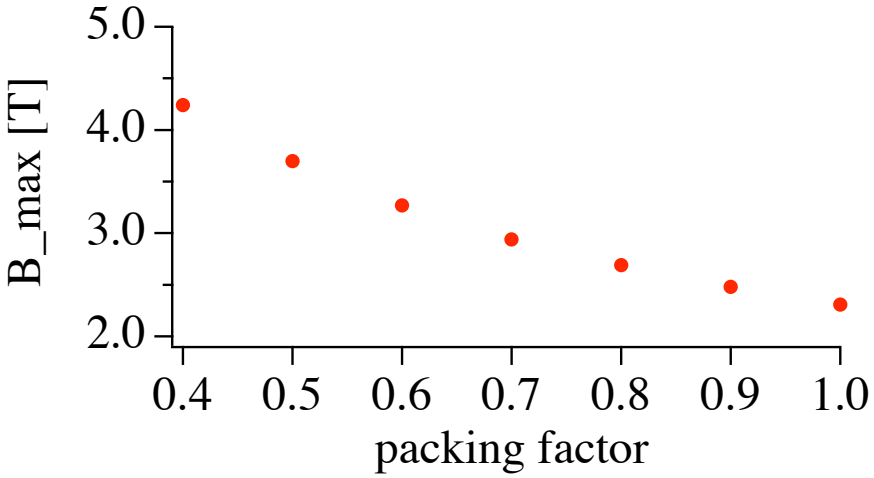
- FFAG optics is still on the primitive stage although the number of unit cells are comparable with synchrotron.
  - one (super) period = one unit cell

- Idea of insertions is nice but FFAG has additional difficulties.
  - orbit moves.
  - beta and alpha functions change.
  - difficult to split into some independent modules.

Overview (3)

advantages

- Injection and extraction become easier if long straight sections are available.
- Circumference factor (average radius/bending radius) will be smaller because magnet packing factor in an arc can increase.

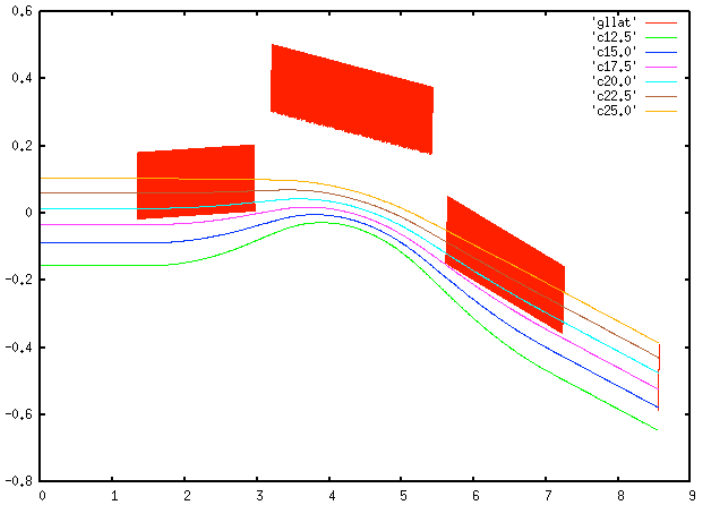


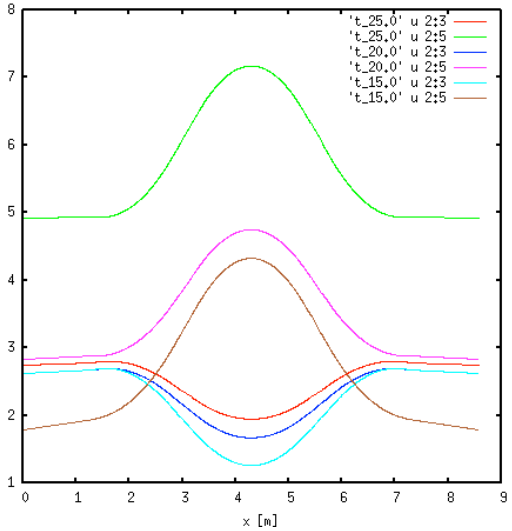
Maximum B fields as a function of magnet packing factor. Average radius and cell tune are fixed at 6.251 m and (0.27, 0.27), respectively. FDF triplet for 0.729 GeV/c beam.

Modular approach (1)

what we did for muon FFAG

- Orbit and optics of a normal cell.





- Introduce insertion triplet cell with 2 m longer drift at the both ends.
- The same bend angle over the cell as normal cell.

Modular approach (2)

fitting with multipoles

- Adjust multipoles (dipole, quad. sext.) in a insertion cell to match 1) orbit, 2) beta_h and 3) beta_v at the end.

$$r = \Sigma[(x_h - x_{h,normal})^2 + (b_h - b_{h,normal})^2 + (b_v - b_{v,normal})^2]$$

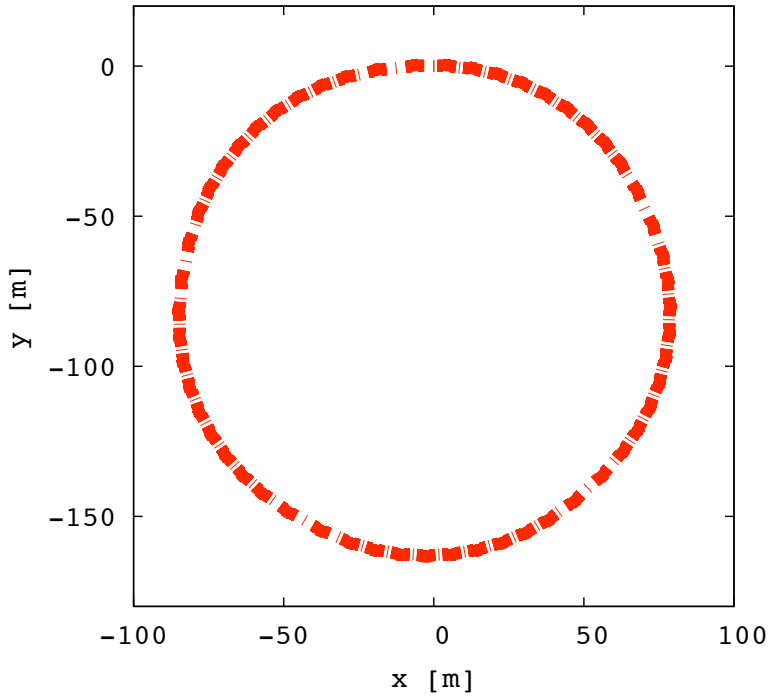
- Summation from 12.5 to 25.0 GeV with 2.5 GeV step.

- More precise matching of orbit than optics.

Modular approach (3)

ring footprint

- 55 total cells are divided into 5 superperiod with 11 cell.
- Within 1 superperiod, 9 normal cells and 2 insertion cells.
  - 7 m drift space between 2 insertion cells
  - 5 m drift space both side of 2 insertion cells.

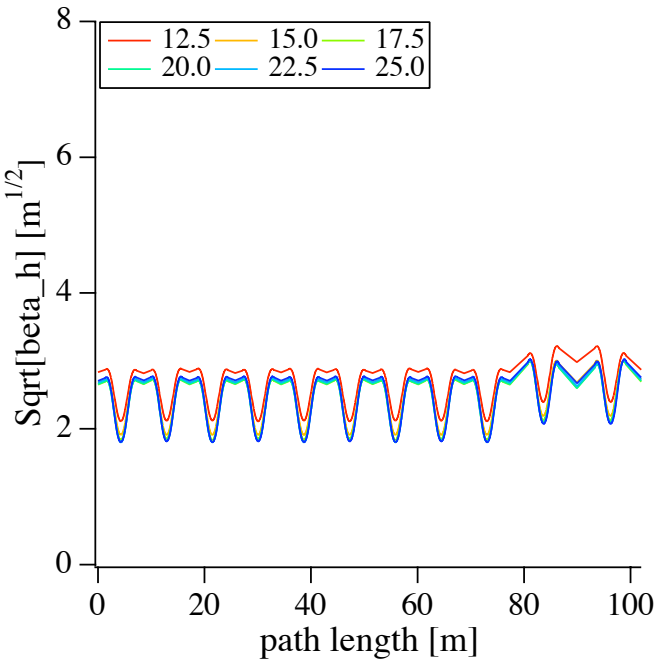


Modular approach (4)

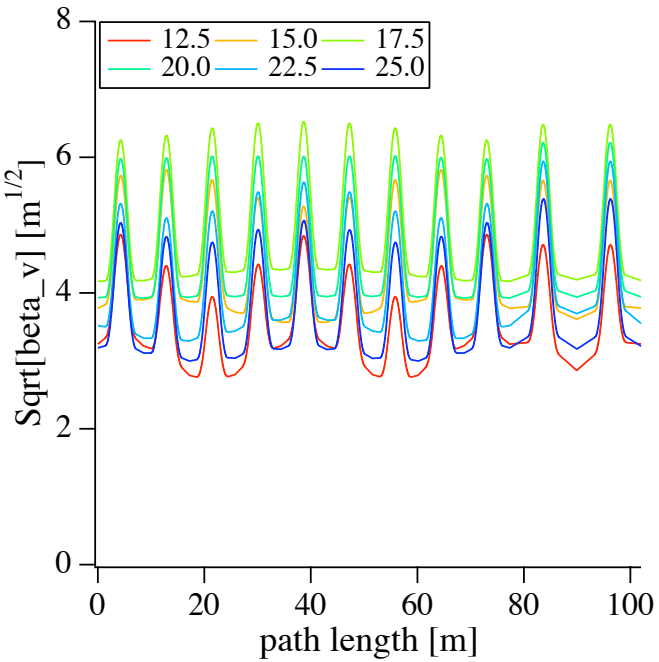
beta function in triplet

- Modulation of beta function with different energy for 1 superperiod (11 cells).

horizontal



vertical



Modular approach (5)

summary

- It works, but matching between an arc and an insertion is not perfect.
  - some beta modulations are excited.

Global approach (1)

idea

- As long as magnetic fields have the shape of

$$B_z = B_{z,0}(\frac{r}{r_0})^k F(\theta)$$

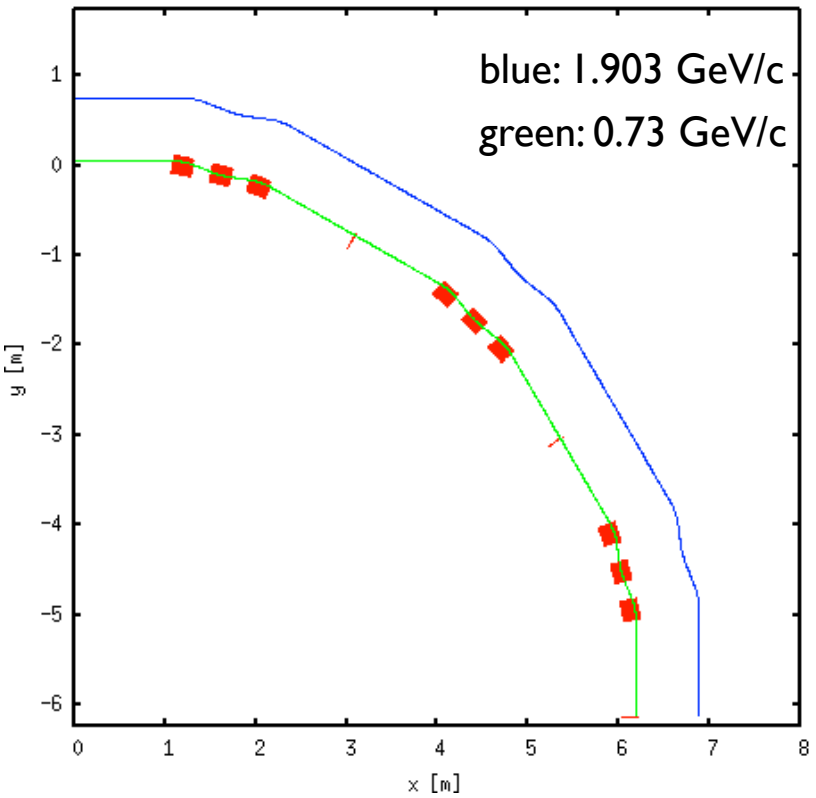
$F(\theta)$ can be arbitrary.

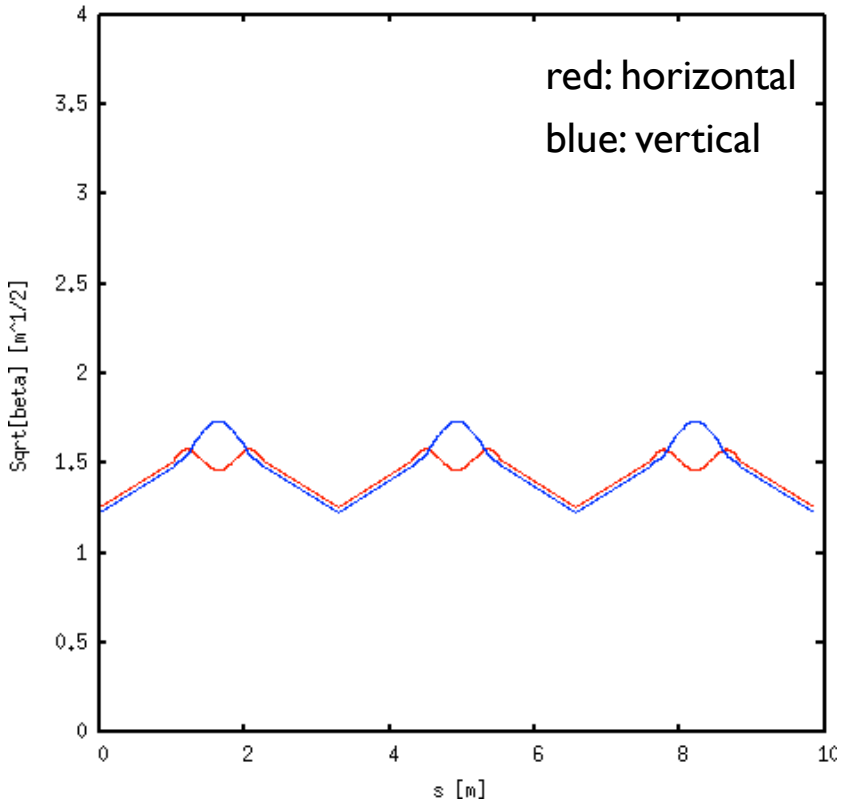
- FFAG with insertions can be designed with more complex function of $F(\theta)$.
  - FD, FDF, etc are the simplest case.

Global approach (2)

PAMELA

- Start from FDF
  - similar to PAMELA but with low k.

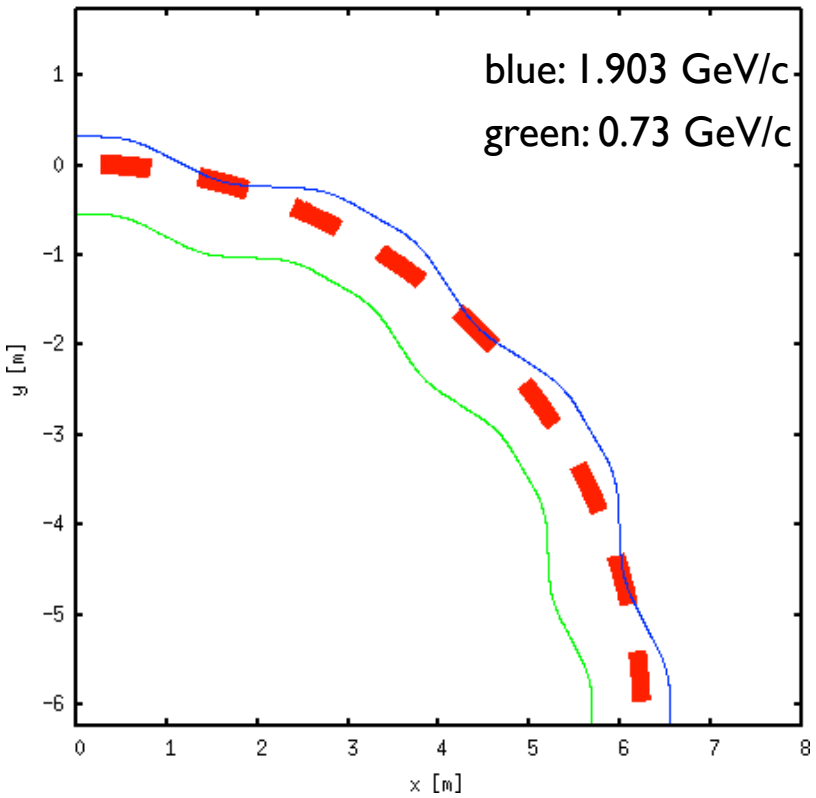


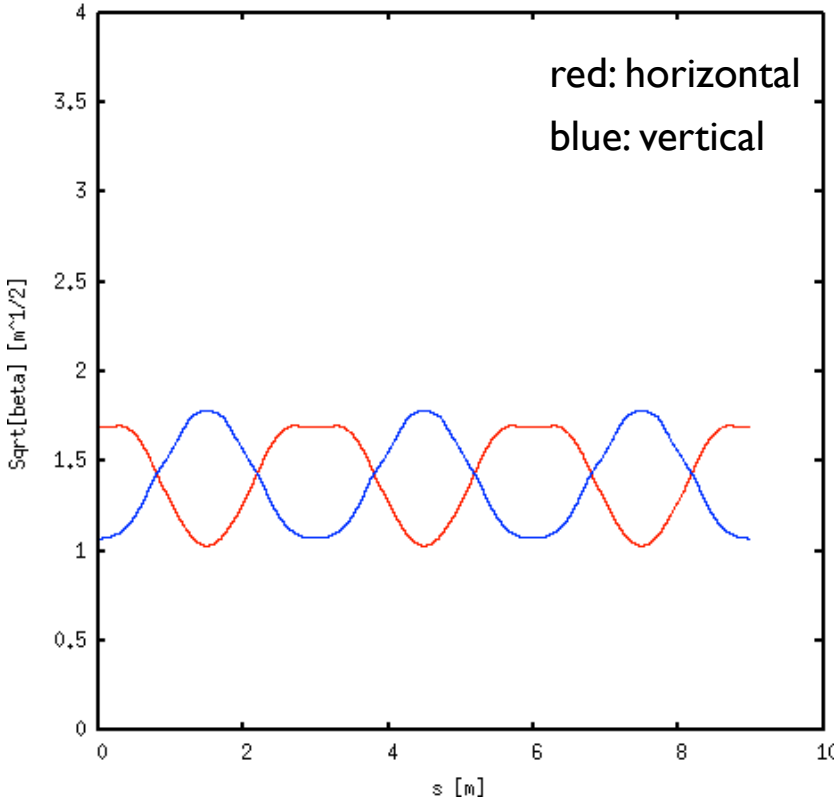


Global approach (3)

high packing factor

- Start from FDF
  - increase packing factor to lower the fields.

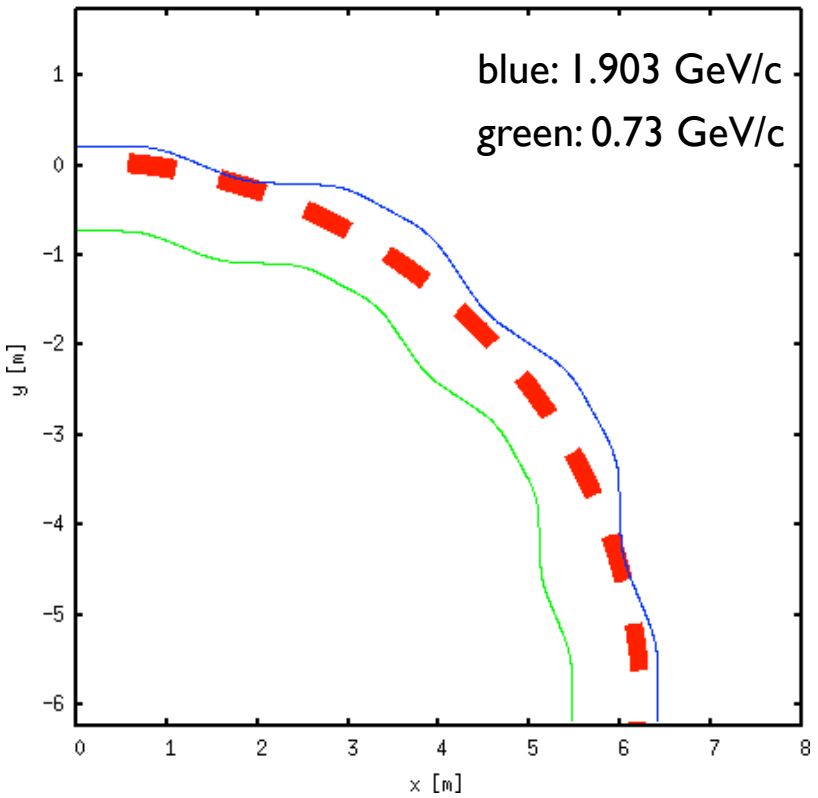


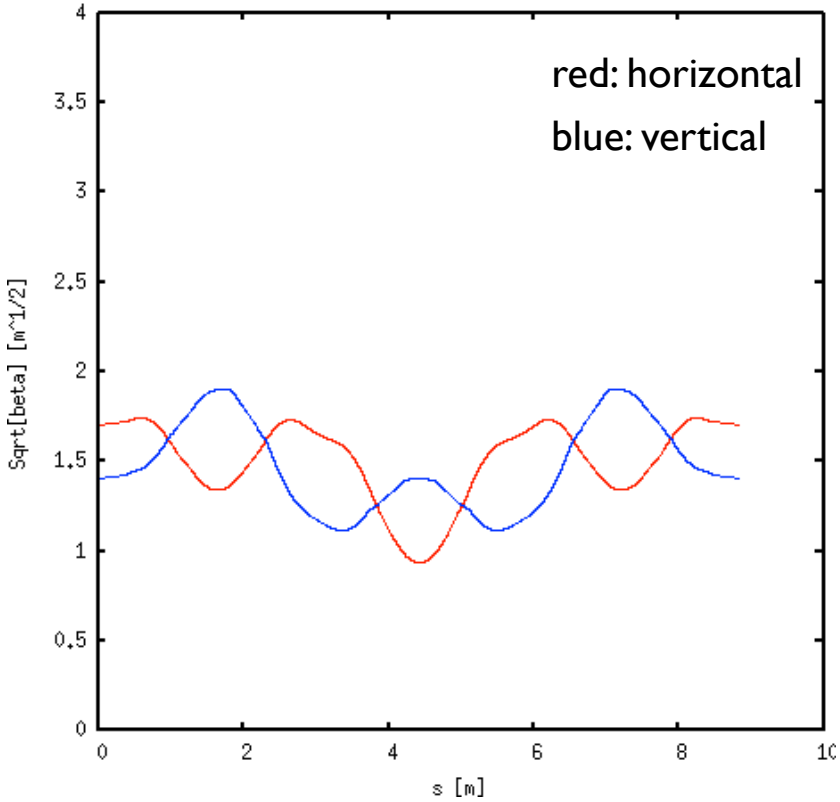


Global approach (4)

space at the both end of 3(FDF)

- O(FDF)(FDF)(FDF)O
  - insert straight space (O) every 3 FDF so the lattice now has 4 fold symmetry.

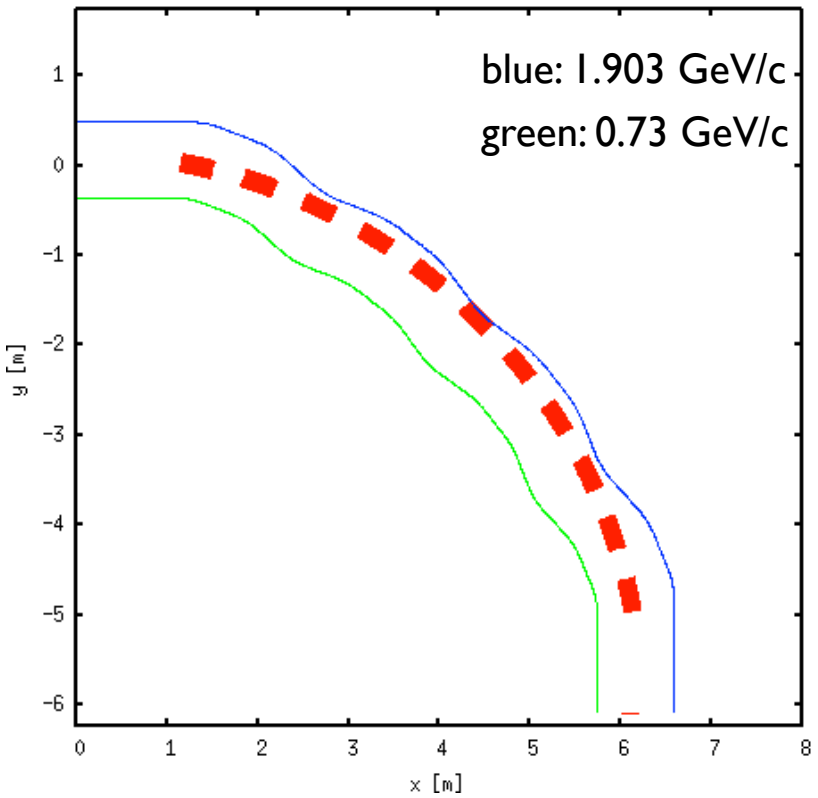


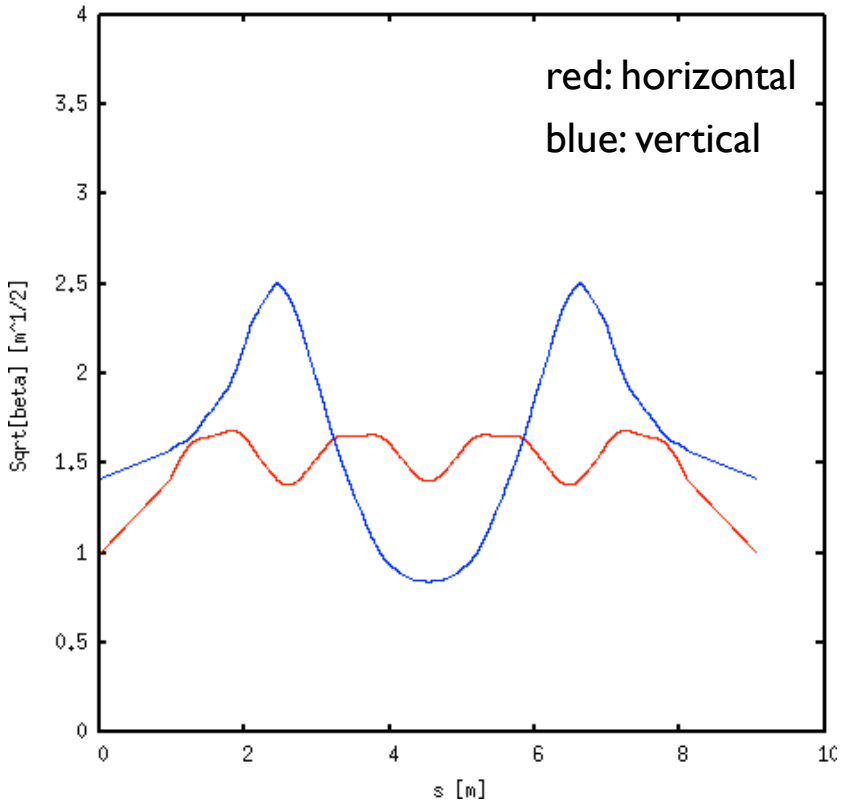


Global approach (5)

break FDF sequence

- OF(FDF)(FDF)(FDF)FO
  - Insert straight space (O) and F every 3 FDF.

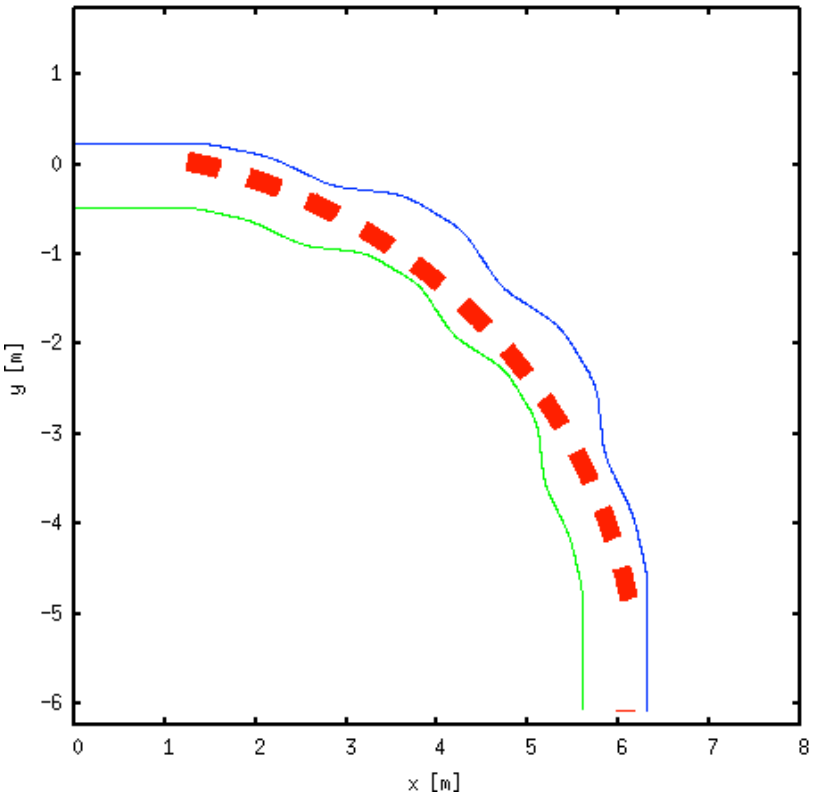


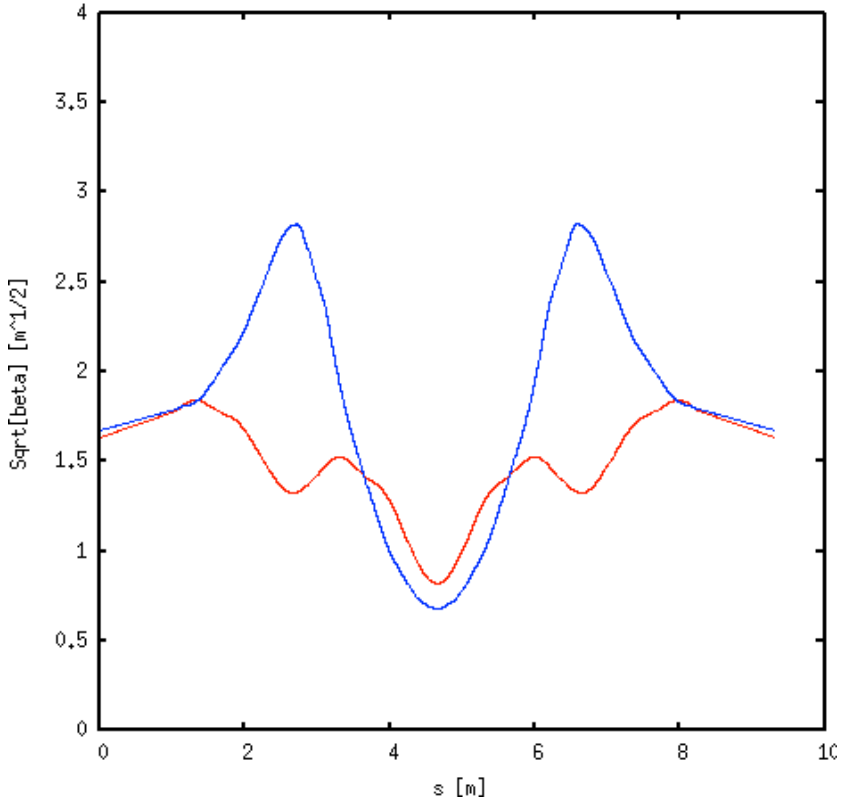


Global approach (6)

2 kinds of F

- $OF_1(F_1DF_2)(F_2DF_2)(F_2DF_1)F_1O$
  - F_1 is 75% of F_2.





Summary

- Superperiod structure with insertions is a natural outcome in FFAG lattice design.
- Modular approach seems OK for a muon (nonscaling) FFAG.

- Global approach work for a scaling FFAG.
  - code is ready to handle many kinds of Fs and Ds.
  - fitting routine is under development.