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International MUON Collider Collaboration

Magnets for vFFA and collider arc with skew Q

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1st Muon Community Meeting

Two exotic options not discussed in MAP

Collider arc with skew quadrupoles

Vertical excursion FFA for muon acceleration

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Collider arc with skew quadrupoles

Vertical excursion FFA for muon acceleration

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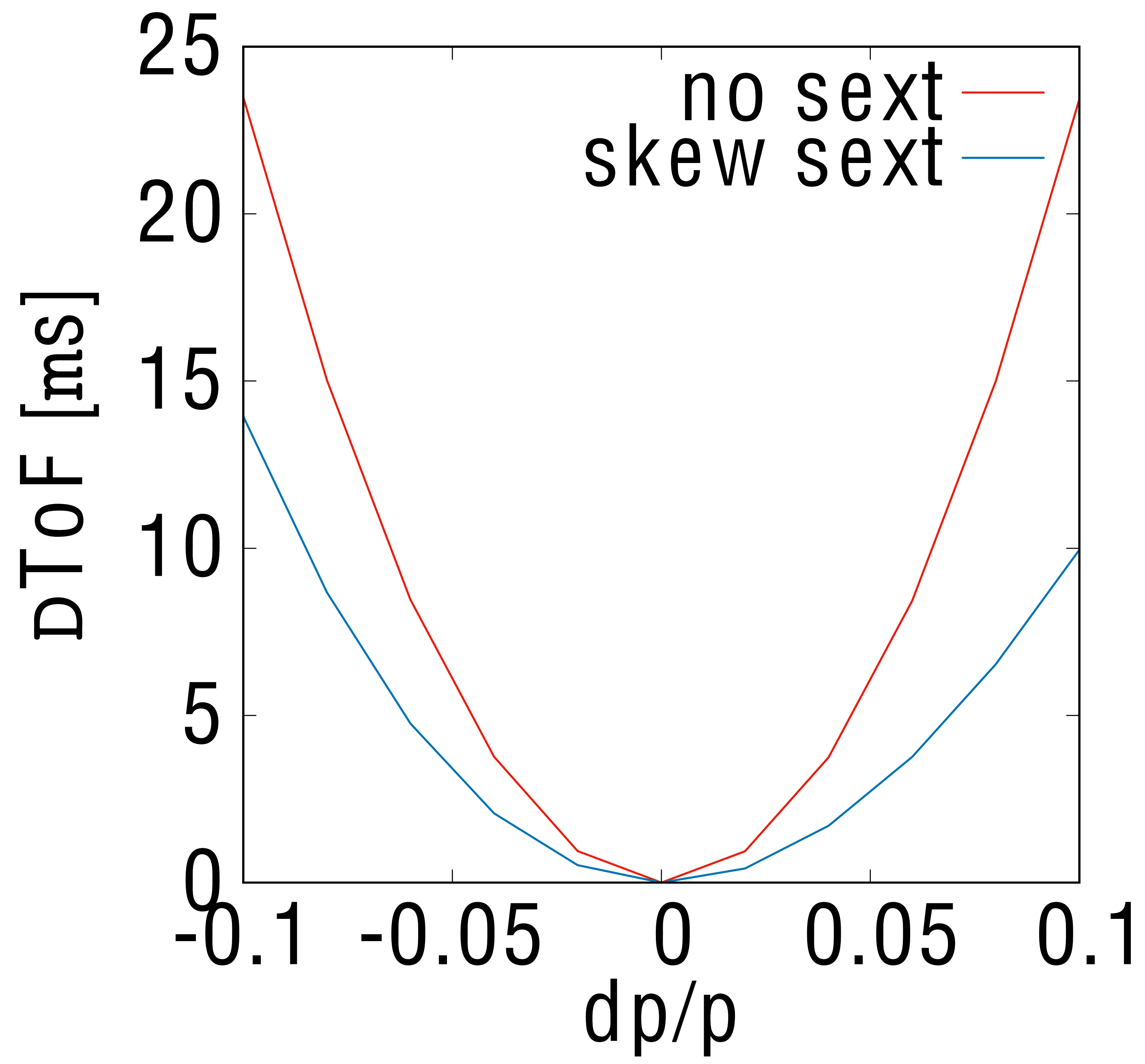
Reasons for skew quadrupole lattice

- Flexible **momentum compaction factor**
  - Without exciting non-zero harmonic of the dispersion function.
  - Without reverse bending.



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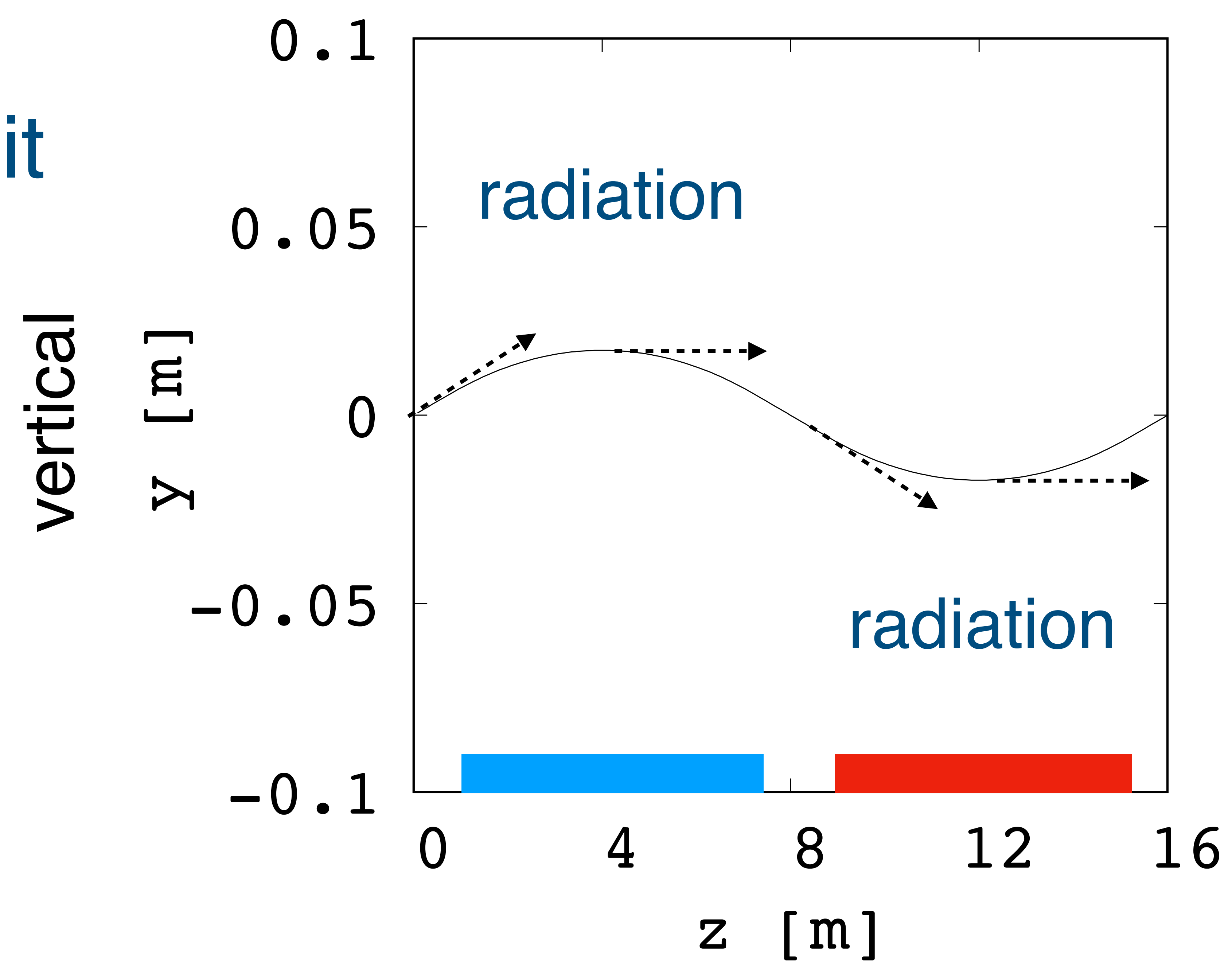
- **Spreading out radiation** by wiggling (wobbling) orbit in vertical as well in horizontal.
  - Angle of wiggling orbit is a function of optics, i.e. easy to adjust different configurations.



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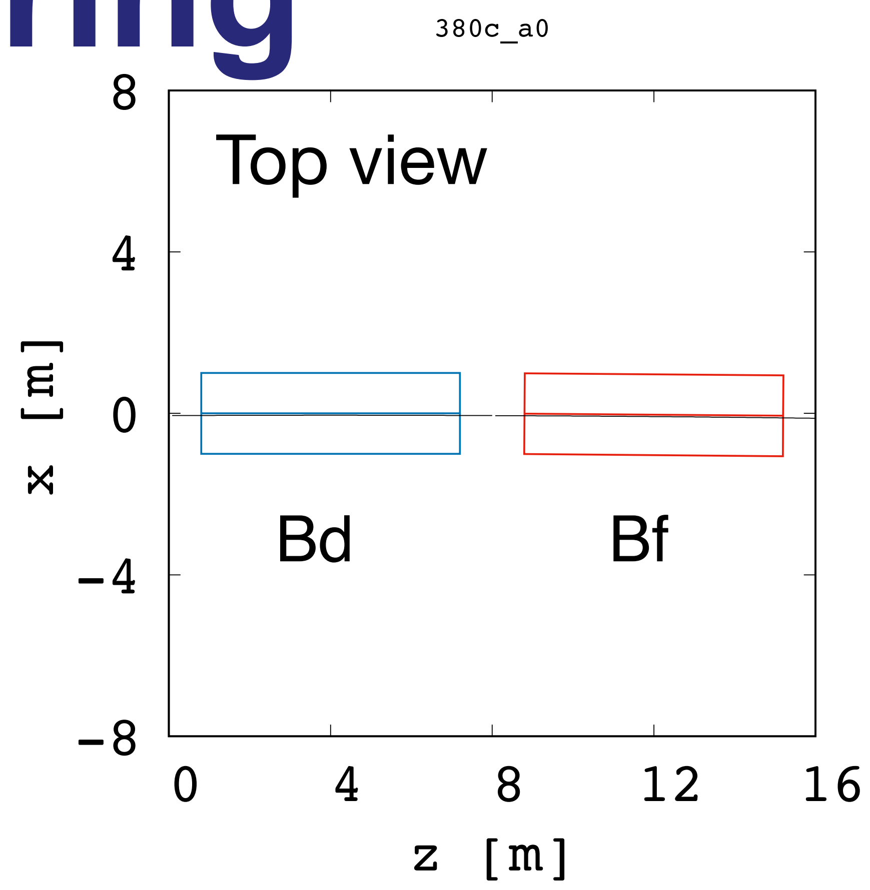
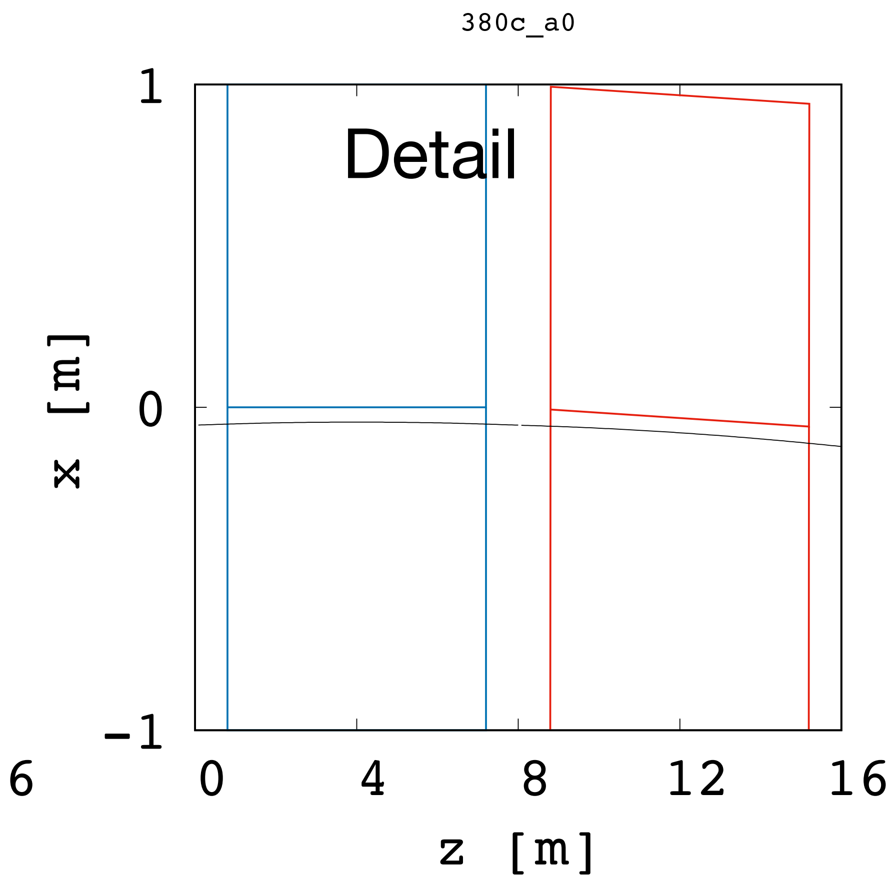
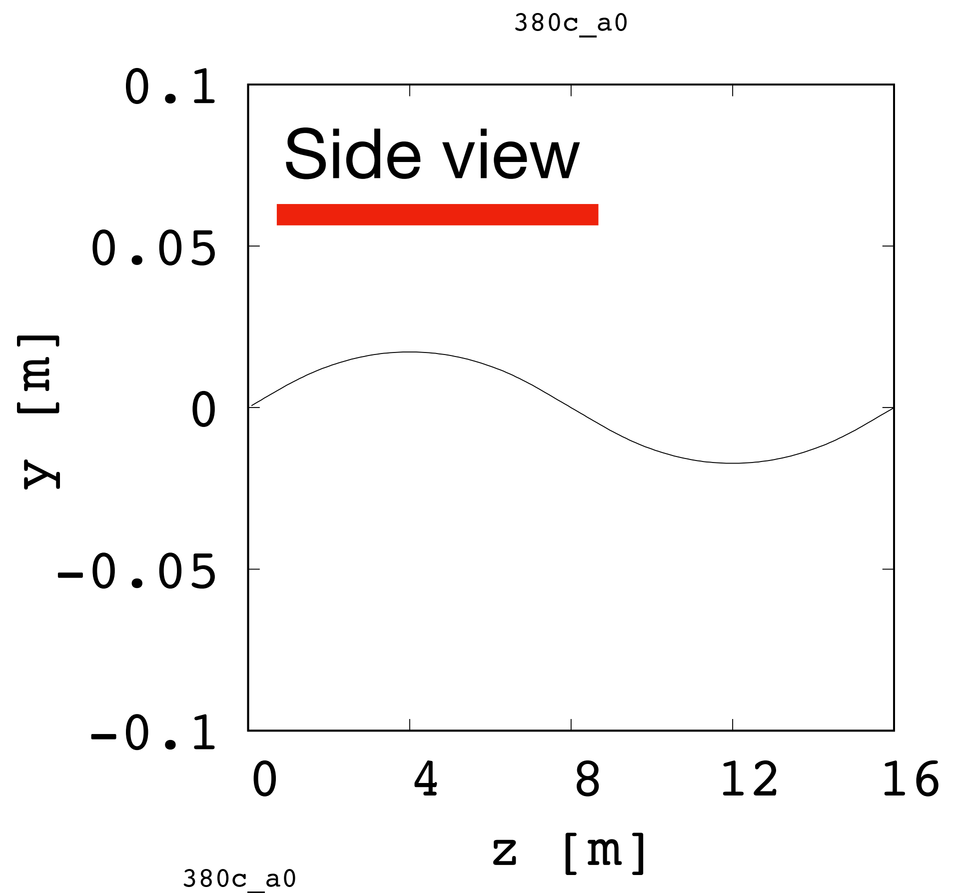
Example: 1.5 TeV collider ring

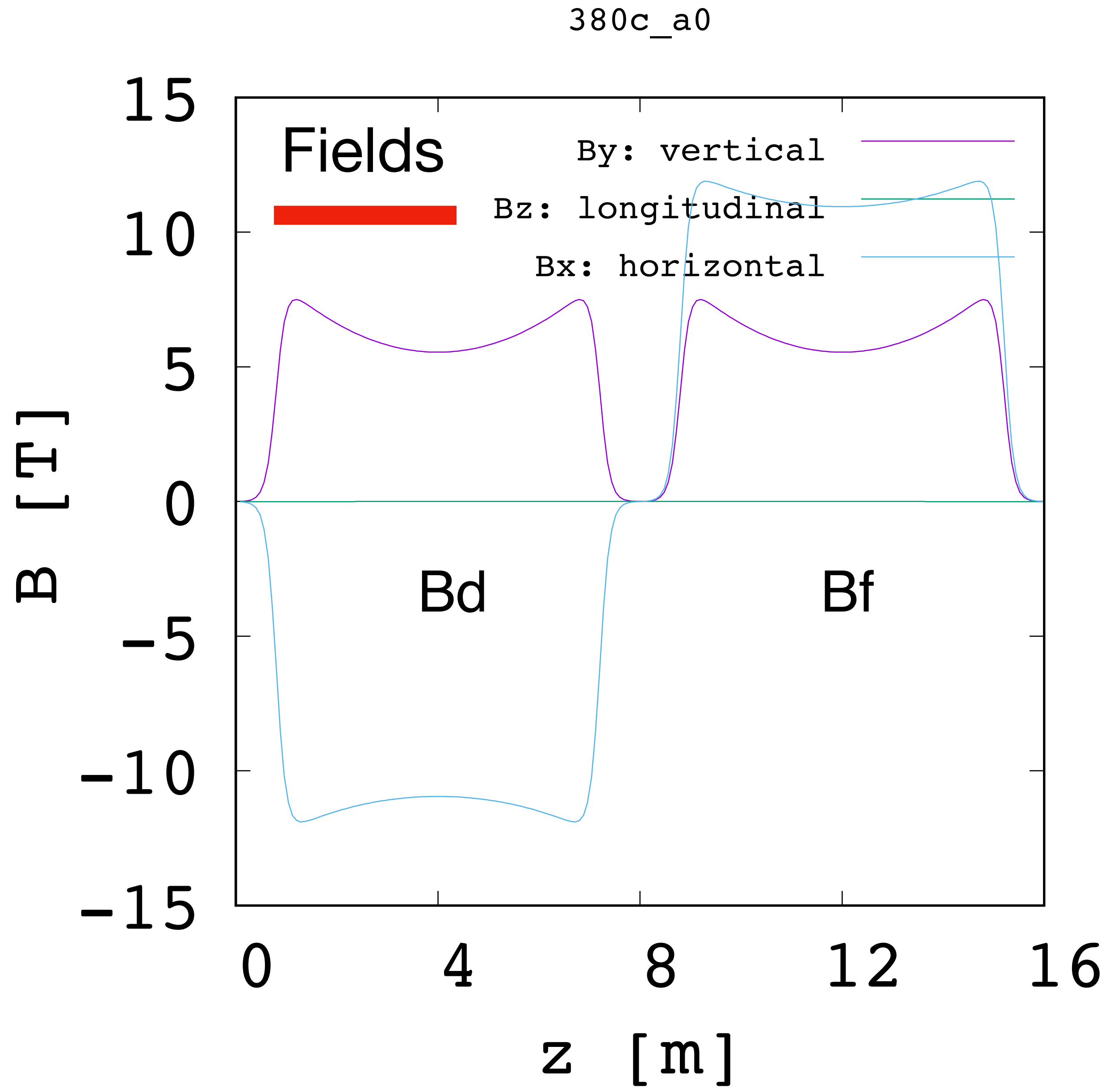
momentum comp=0, arc only

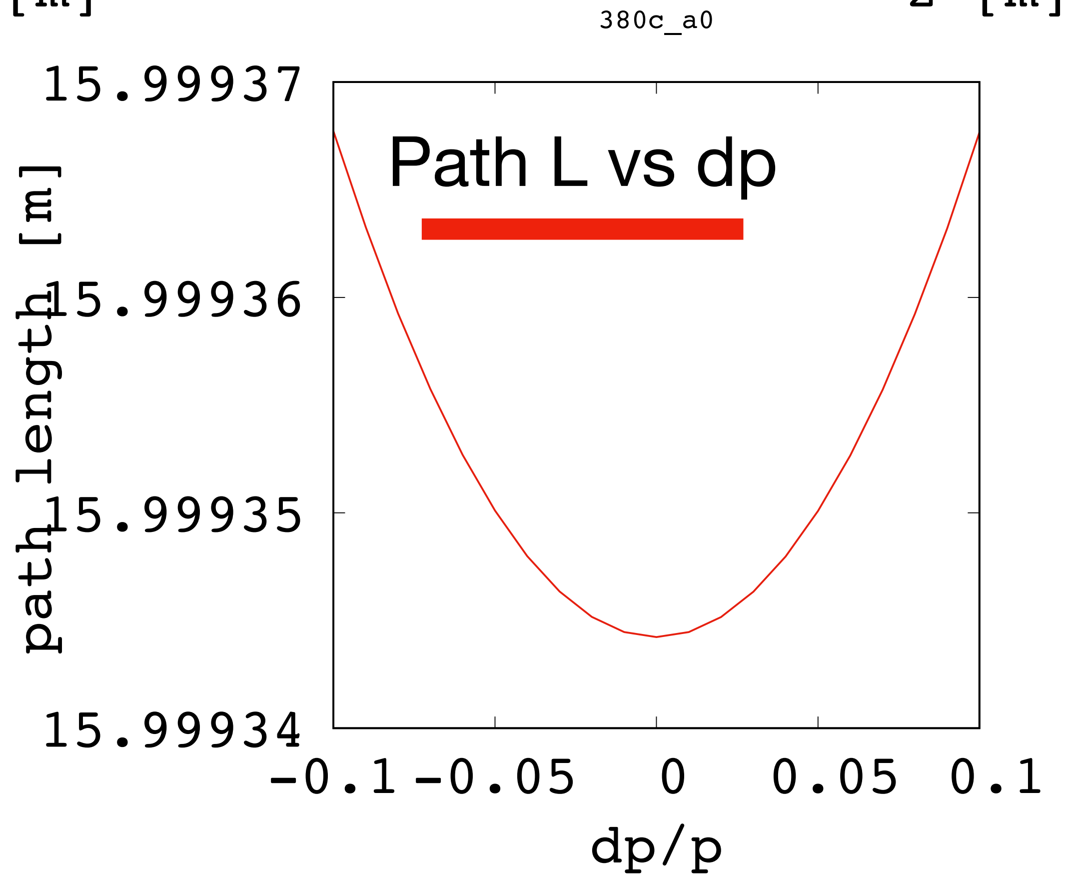
	Skew FODO
Energy	1.5 TeV
Momentum compaction	0
Circumference	6080 m
Cell length	16 m
Magnet length	2 x 6.4 m
# of cell	380
Maximum field	14 T
Field gradient	240 T/m
Cell tune	0.3131 / 0.3131

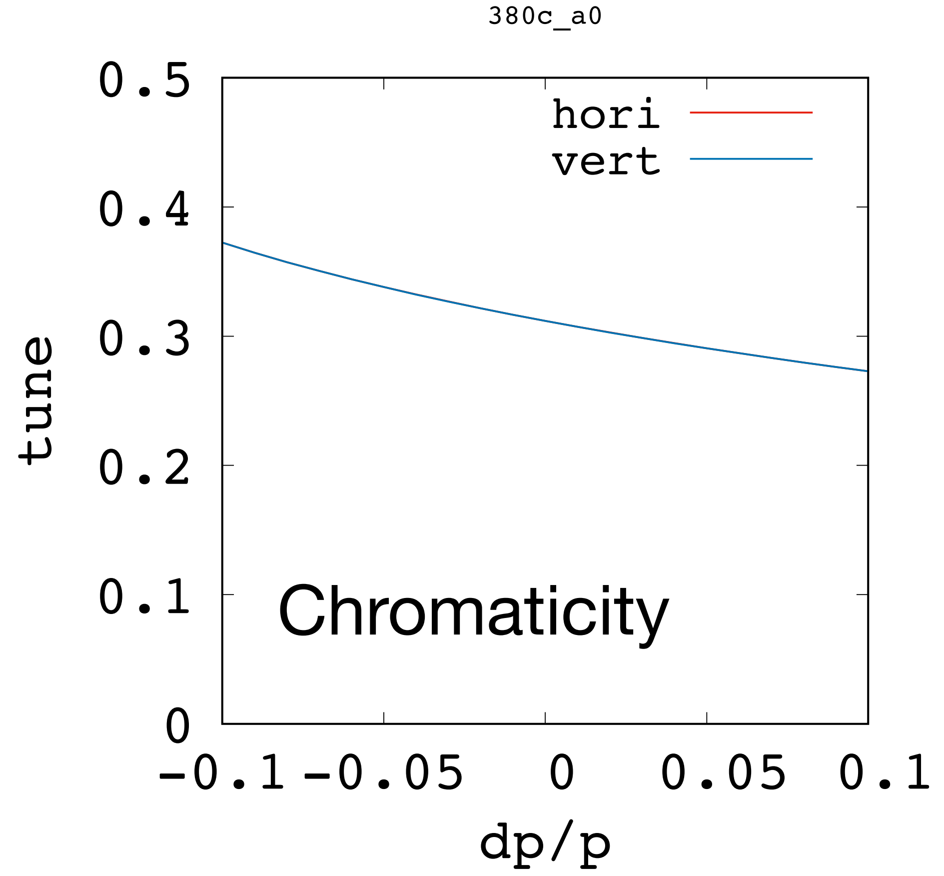












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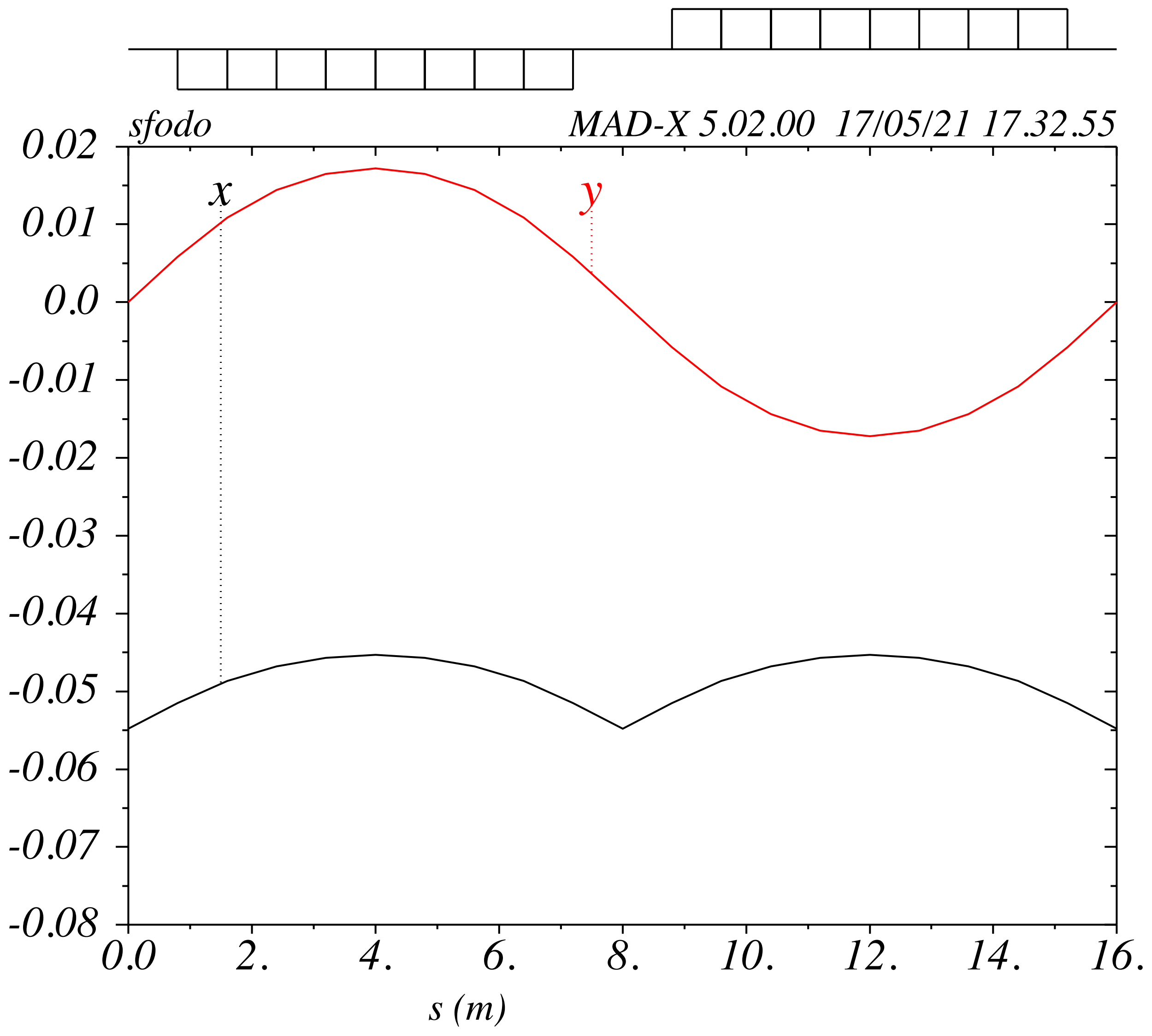
Critical issues

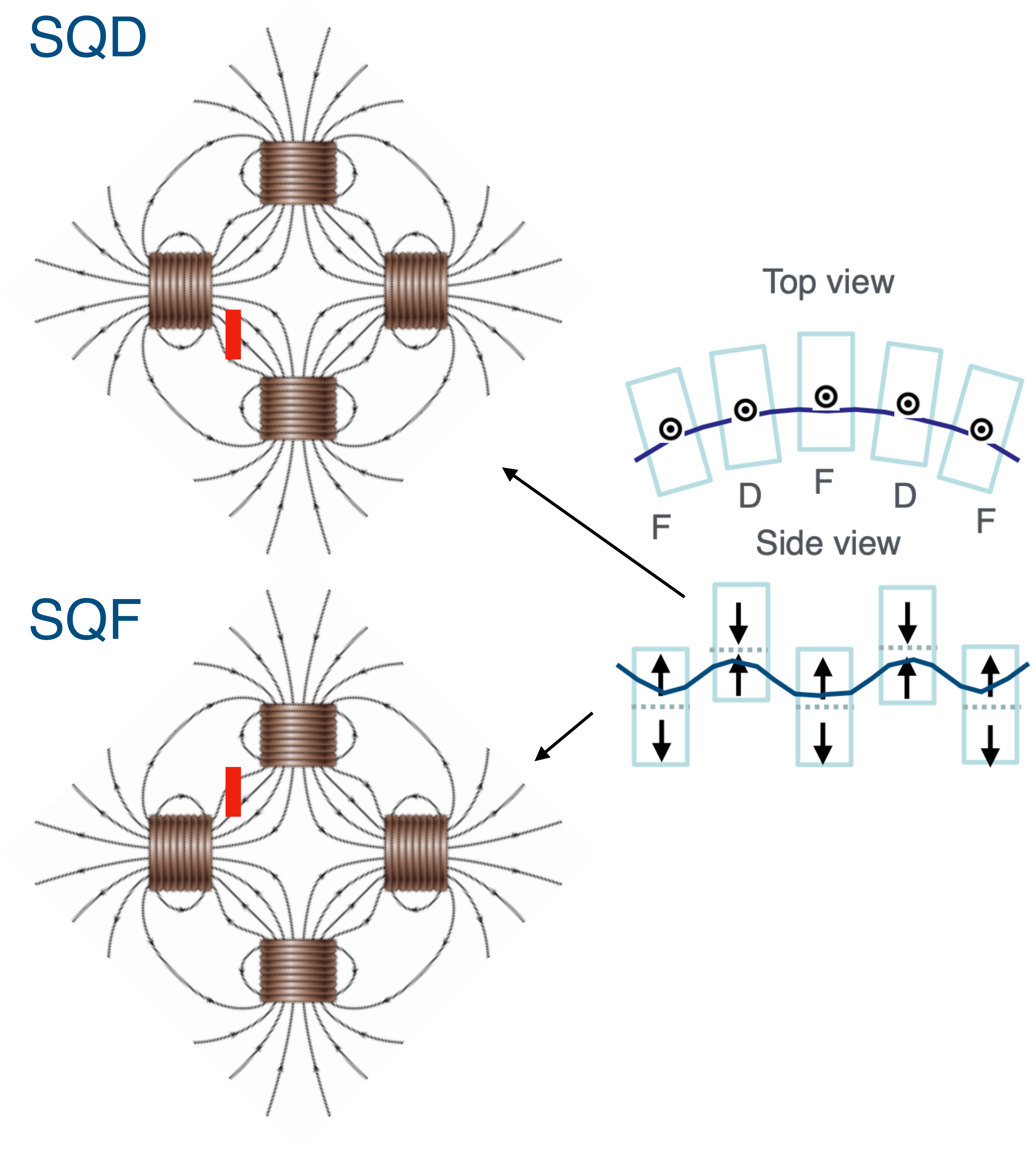
magnet

- The beams go off-centre of skew quadrupoles.

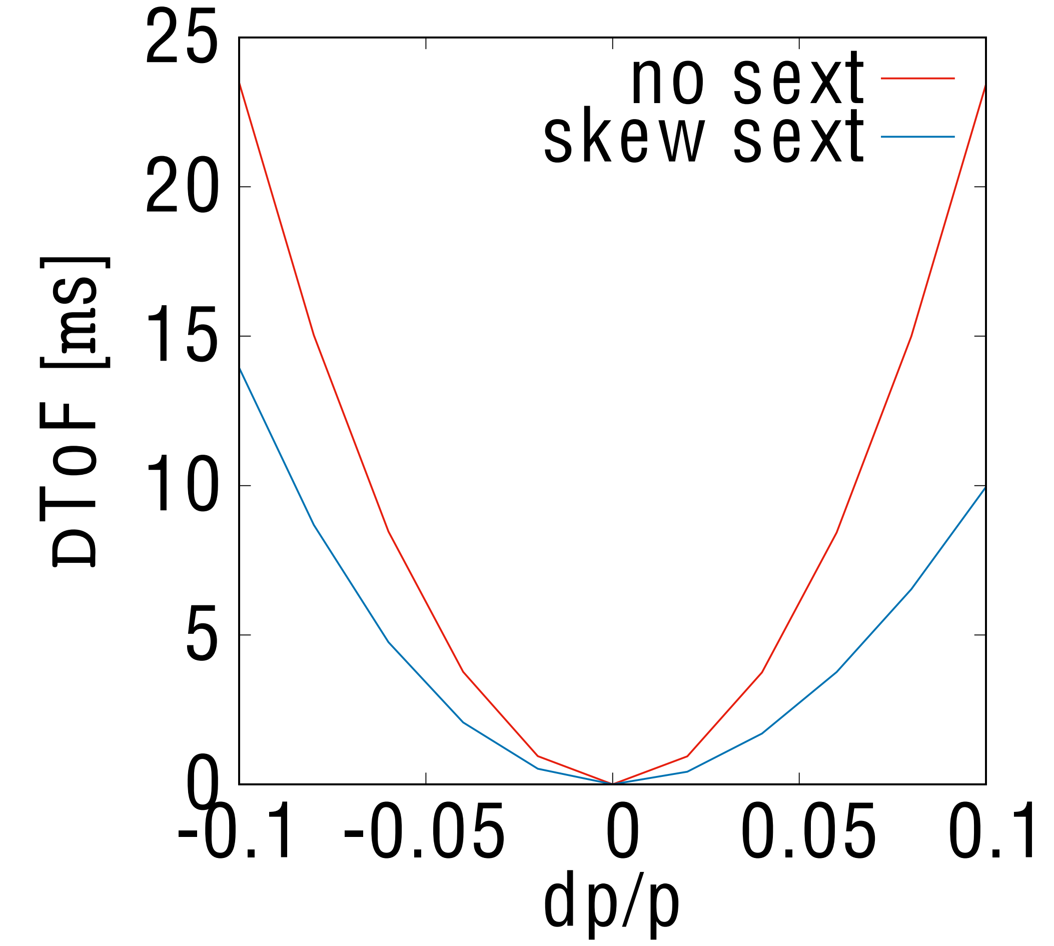


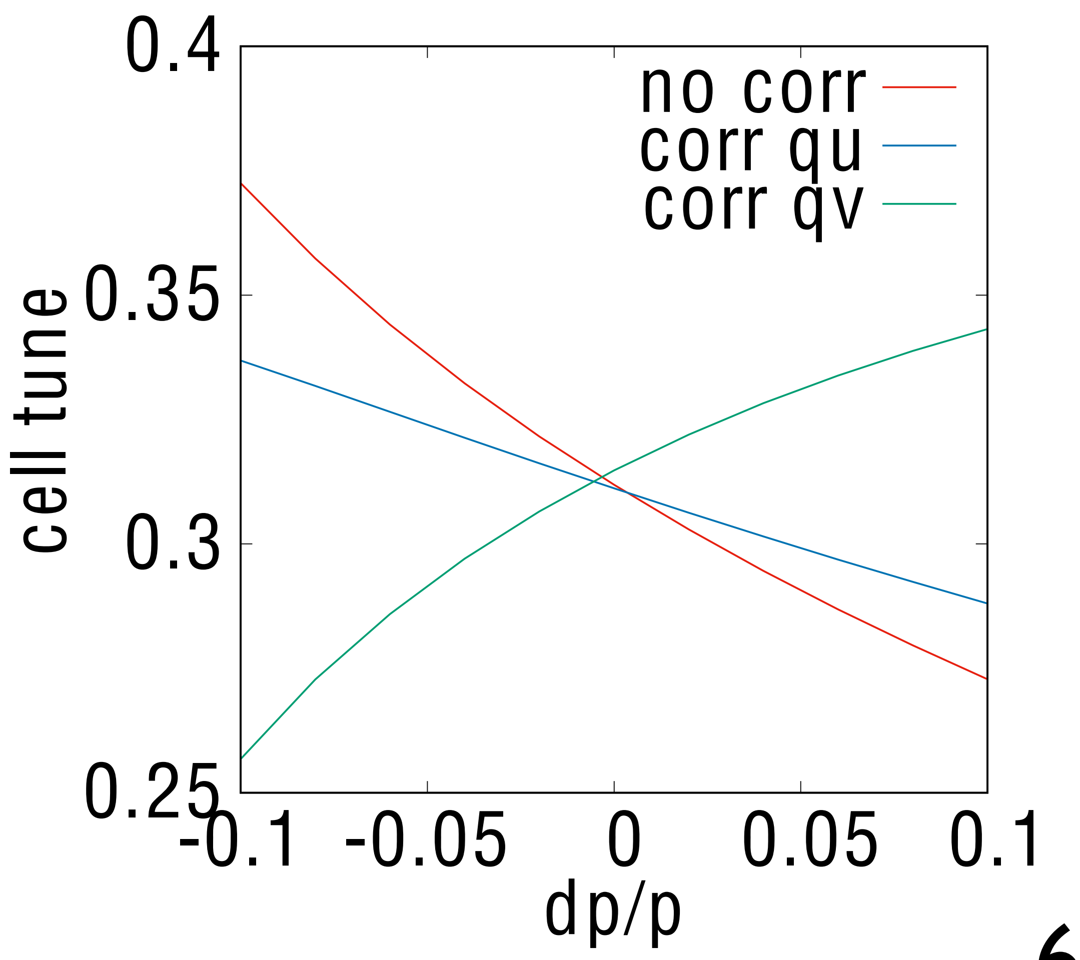
Orbit is off-centre

- - 50 mm in horizontal
- +/- 25 mm in vertical



- Nonlinear components (sext, octu) for both chromaticity correction and flexible momentum compaction factor in the main magnet.





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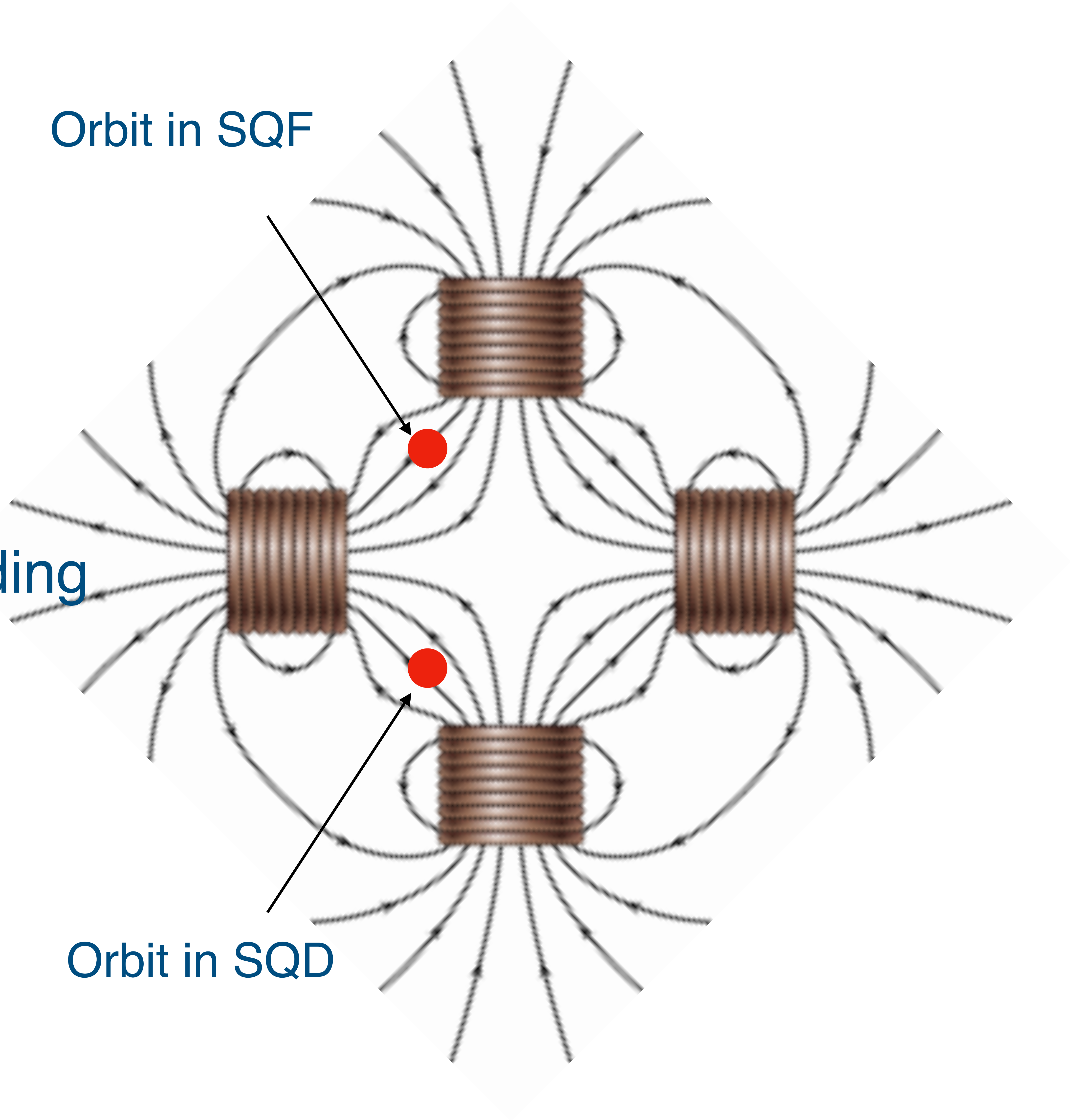
Magnet R&D for collider arc with skew Q

Combined function magnet including
- Skew quadrupole
- Horizontal and vertical dipole
- Skew sextupole
- (Other nonlinearity)

Combined function wide aperture magnet including
- Skew quadrupole
- Horizontal and vertical dipole
- Skew sextupole
- (Other nonlinearity)



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R&D proposal

- **Combined skew quadrupole magnet for collider arc**
  - Control of the momentum compaction factor and mitigation of radiation due to neutrinos decaying from muons can be achieved by a lattice whose main elements are skew quadrupoles with vertical displacement.
  - To make the collider arc compact and increase magnet packing factor, combined function magnet is a solution which combines skew quadrupole, skew sextupole, horizontal and vertical dipole and other nonlinear components.
  - As an alternative, horizontal and vertical dipole components could be eliminated if there is enough aperture (+0.05 m).
  - Depending on the outcome from feasibility of a combined function magnet, optics design will be adjusted, e.g. location of a nonlinear element in a cell if it is physically separated.

Two exotic options not discussed in MAP

Collider arc with skew quadrupoles

Vertical excursion FFA for muon acceleration

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Reasons for vertical excursion FFA (vFFA)

- **DC magnet**: no need to ramp according to the beam momentum.

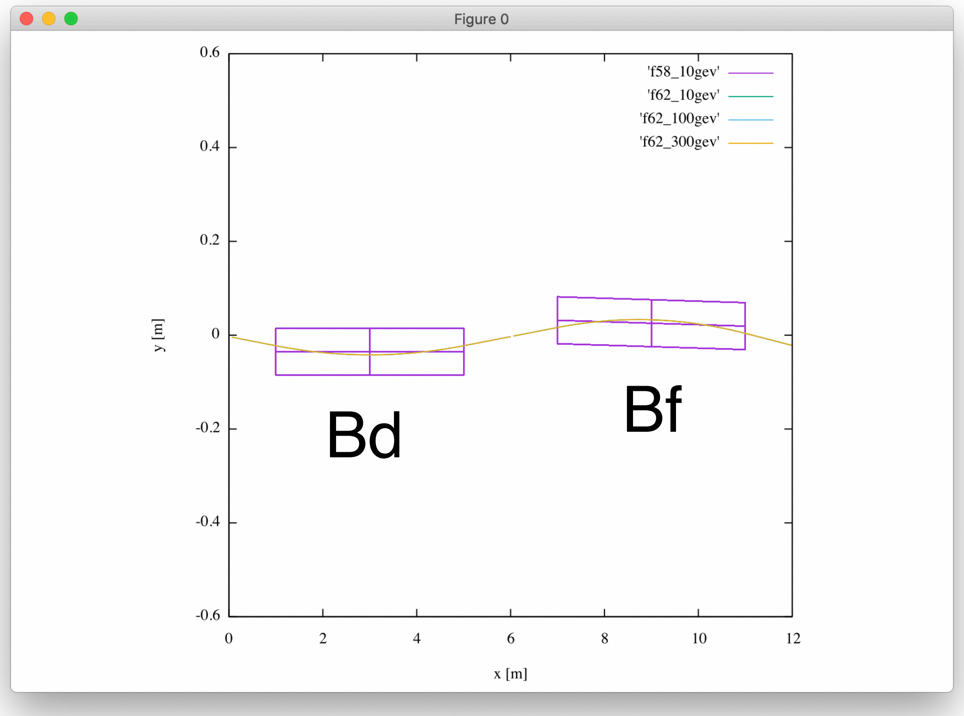
- **Isochronous operation**: no need to modulate RF frequency according to the beam momentum.

- The beam orbit moves up when the beams are accelerated.

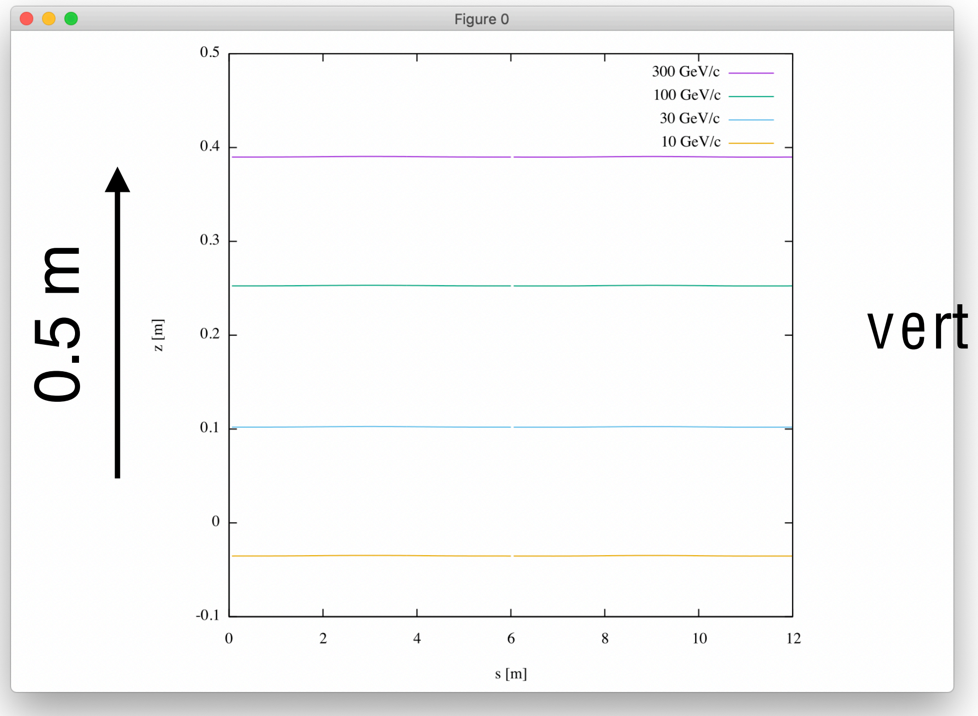
$$B = B_0 \exp\left(my\right)$$

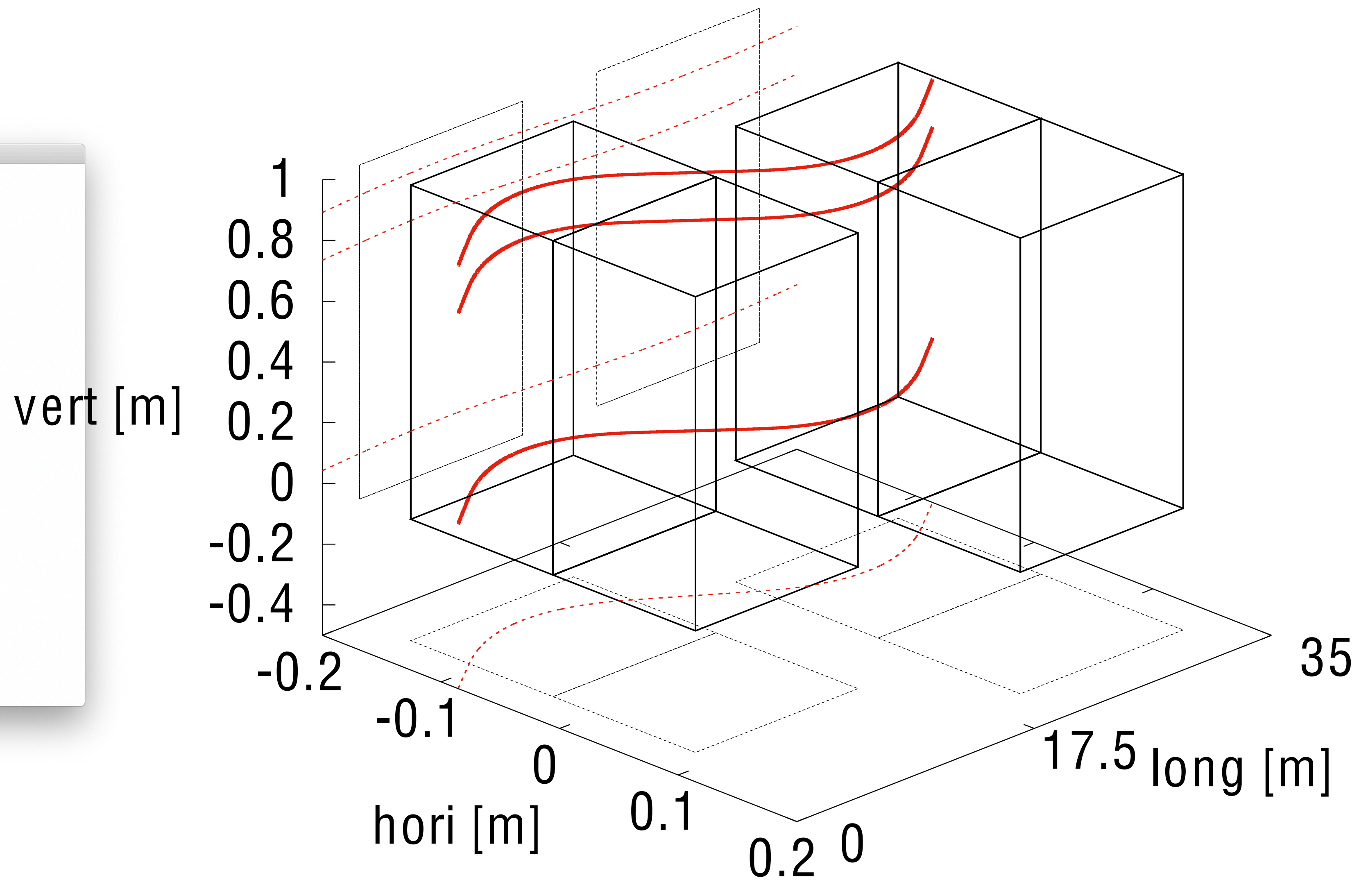
m : field index
y : vertical

Top view



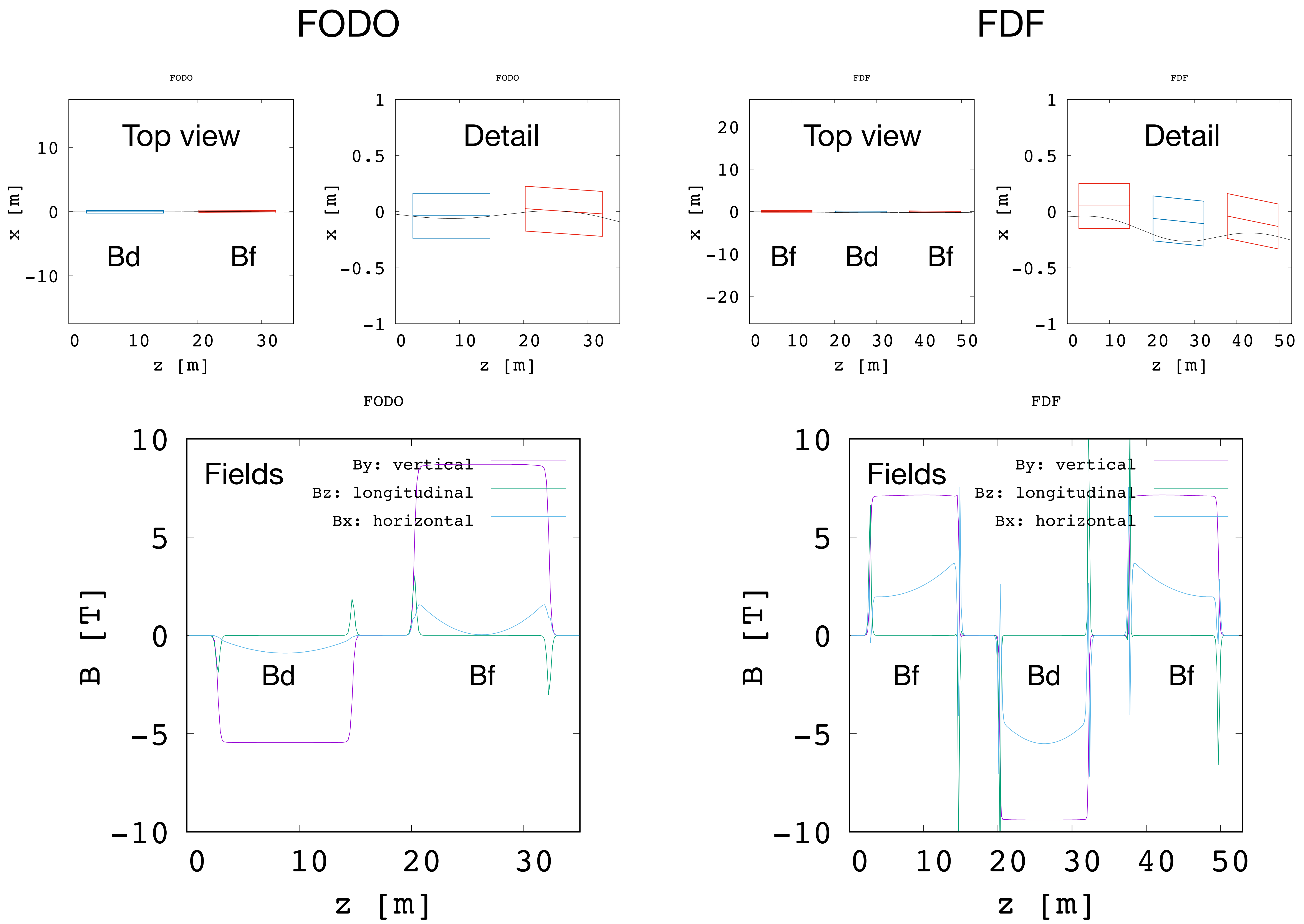
Side view





Example: 1.5 TeV accelerator in similar size of LHC tunnel

	FODO	FDF
Energy	50 GeV to 1.5 TeV	50 GeV to 1.5 TeV
Cell length	35 m	52.5 m
Magnet length	2 x 15 m	3 x 15 m
# of cell	810	540
Maximum field	8.7 T	10.6 T
Field index m	6.8	3.0
Orbit excursion	0.50 m	1.13 m
Cell tune	0.3957 / 0.0861	0.3510 / 0.1515



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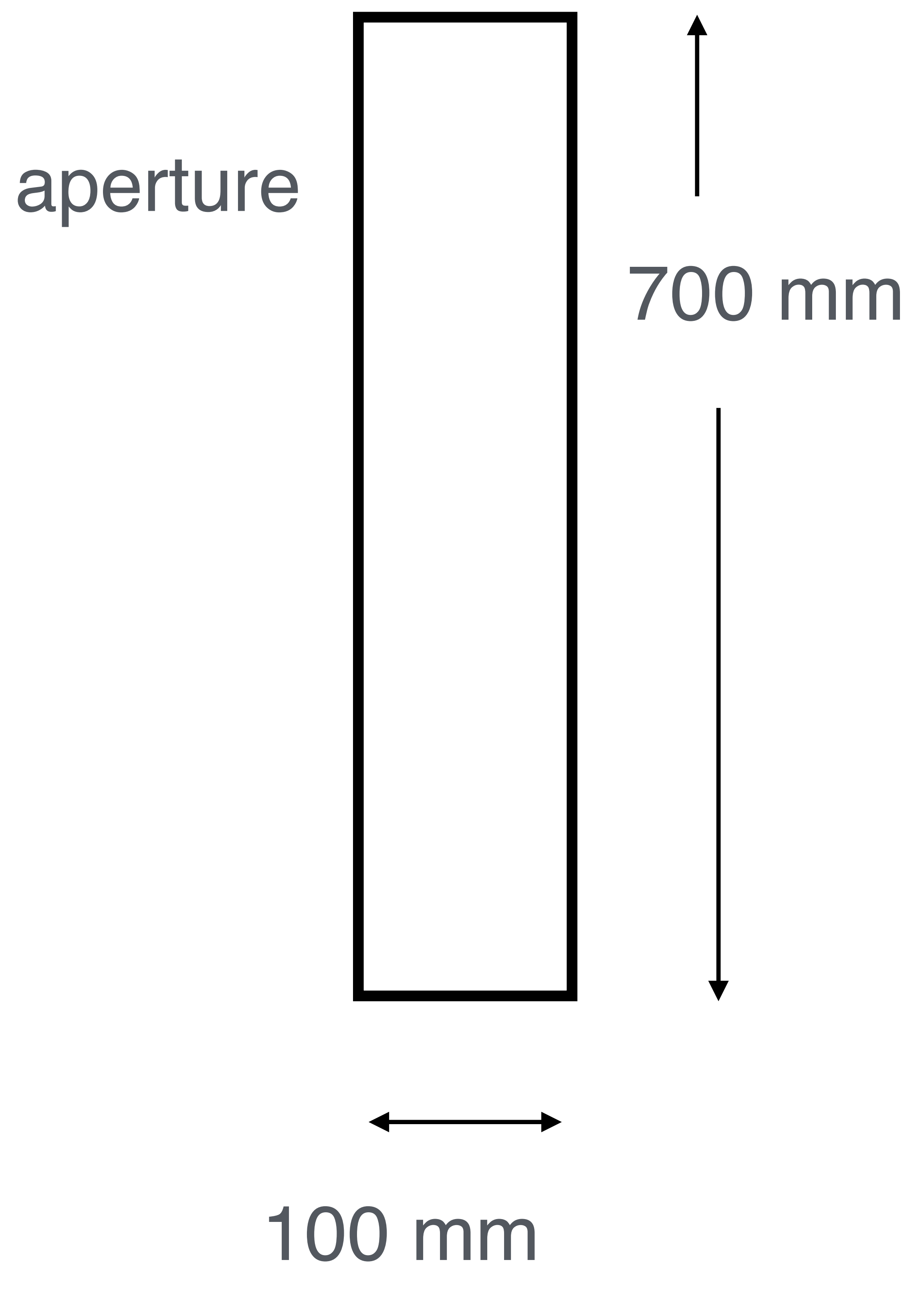
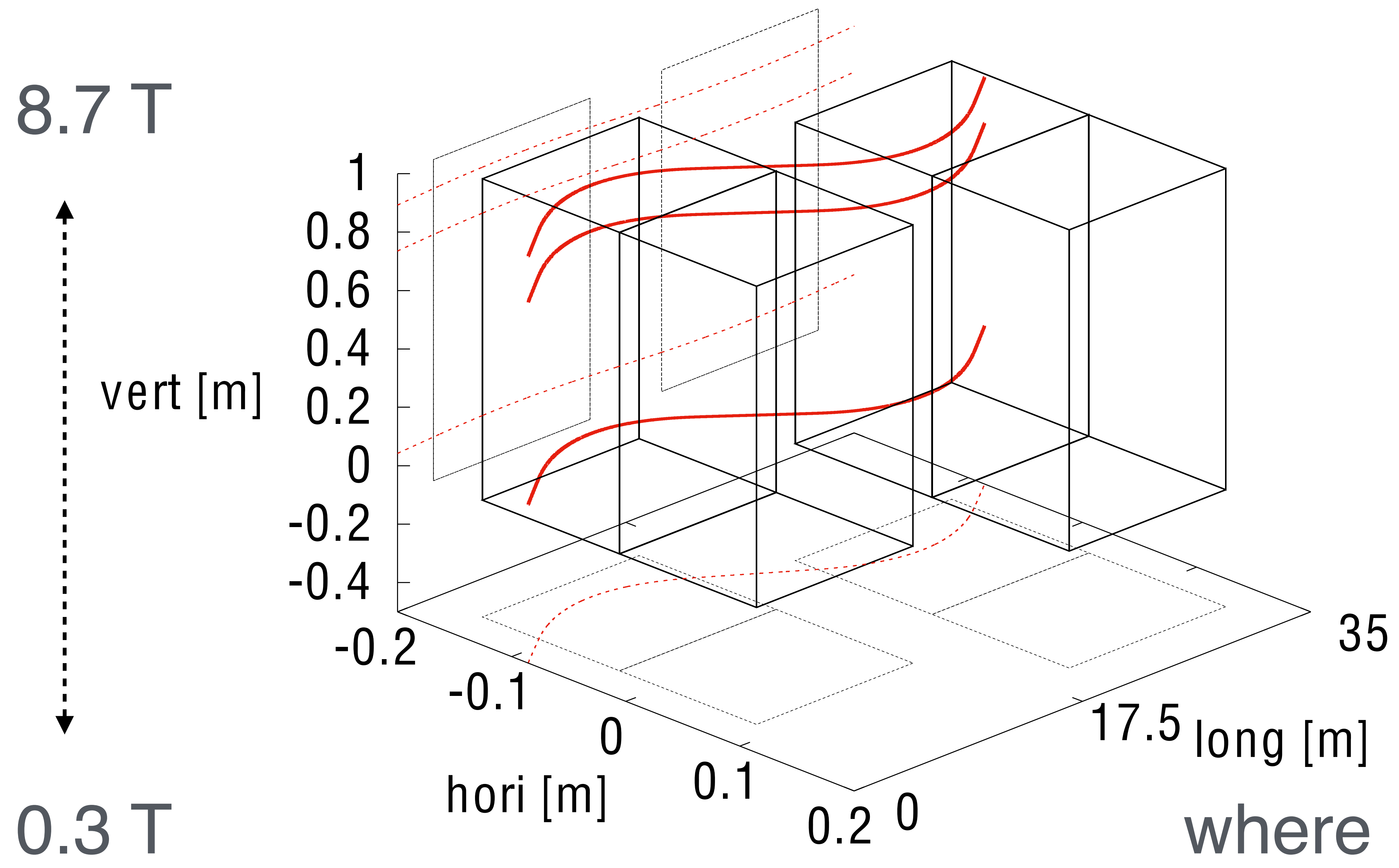
- Reduction of reverse bending is one of optimisation targets.

Critical issues

magnet

- DC but large aperture (in vertical) magnet.





- 3D magnetic field increase exponentially.

$$B_x(x,y,z) = B_0 \exp(my) \sum_{i=0}^{N} b_{xi}(z)\, x^i,$$

$$B_y(x,y,z) = B_0 \exp(my) \sum_{i=0}^{N} b_{yi}(z)\, x^i,$$

$$B_z(x,y,z) = B_0 \exp(my) \sum_{i=0}^{N} b_{zi}(z)\, x^i.$$

where

$$m = (1/B)\,(\partial B/\partial y)$$

$$b_{x0}(z) = 0,$$

$$b_{y0}(z) = g(z),$$

$$b_{z0}(z) = \frac{1}{m}\frac{dg}{dz},$$

$$b_{x,i+1}(z) = -\frac{1}{i+1}\left(m b_{yi} + \frac{db_{zi}}{dz}\right),$$

$$b_{y,i+2}(z) = \frac{m}{i+2} b_{x,i+1},$$

$$b_{z,i+2}(z) = \frac{1}{i+2}\frac{db_{x,i+1}}{dz}.$$

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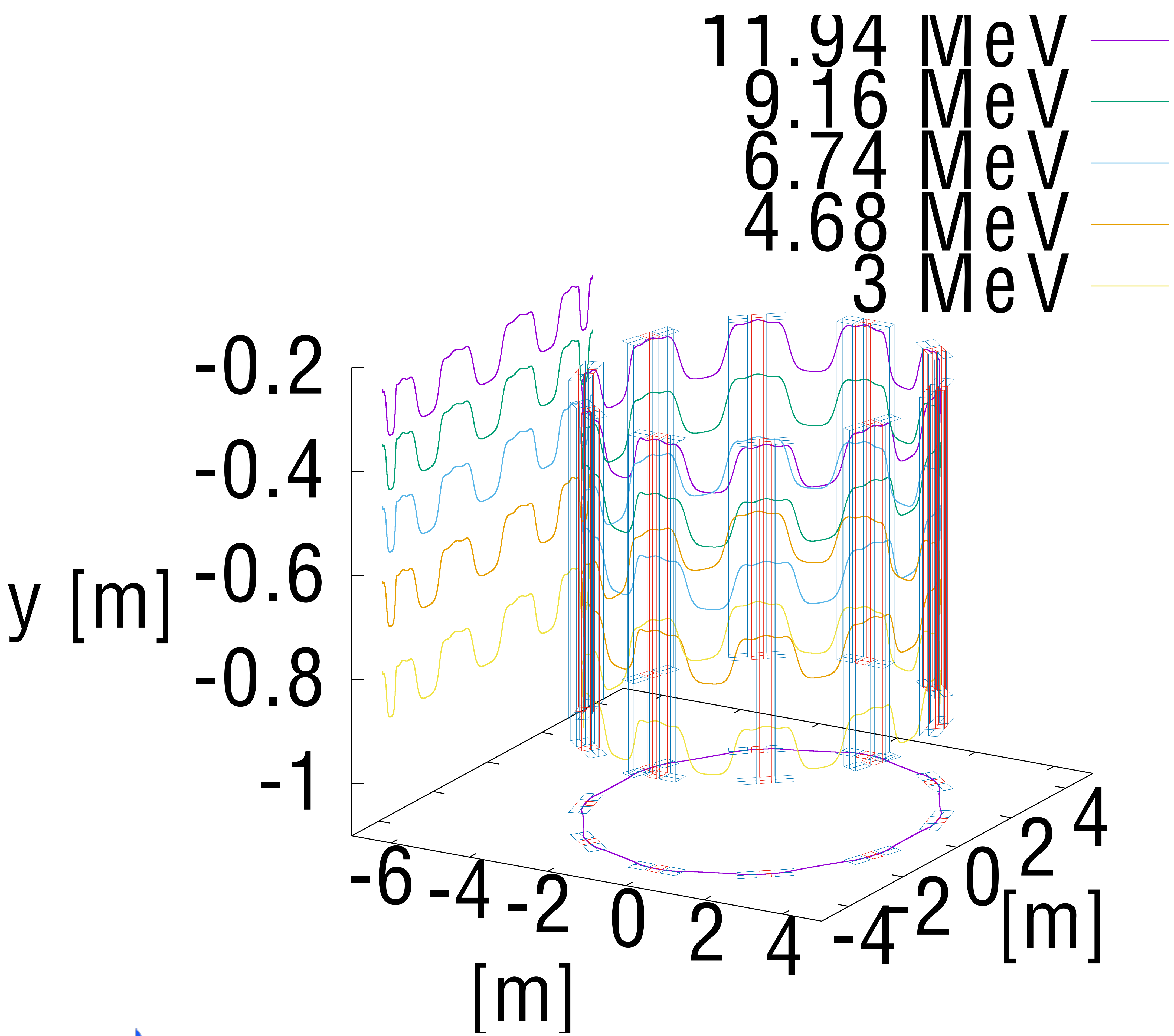
Magnet R&D for small vFFA

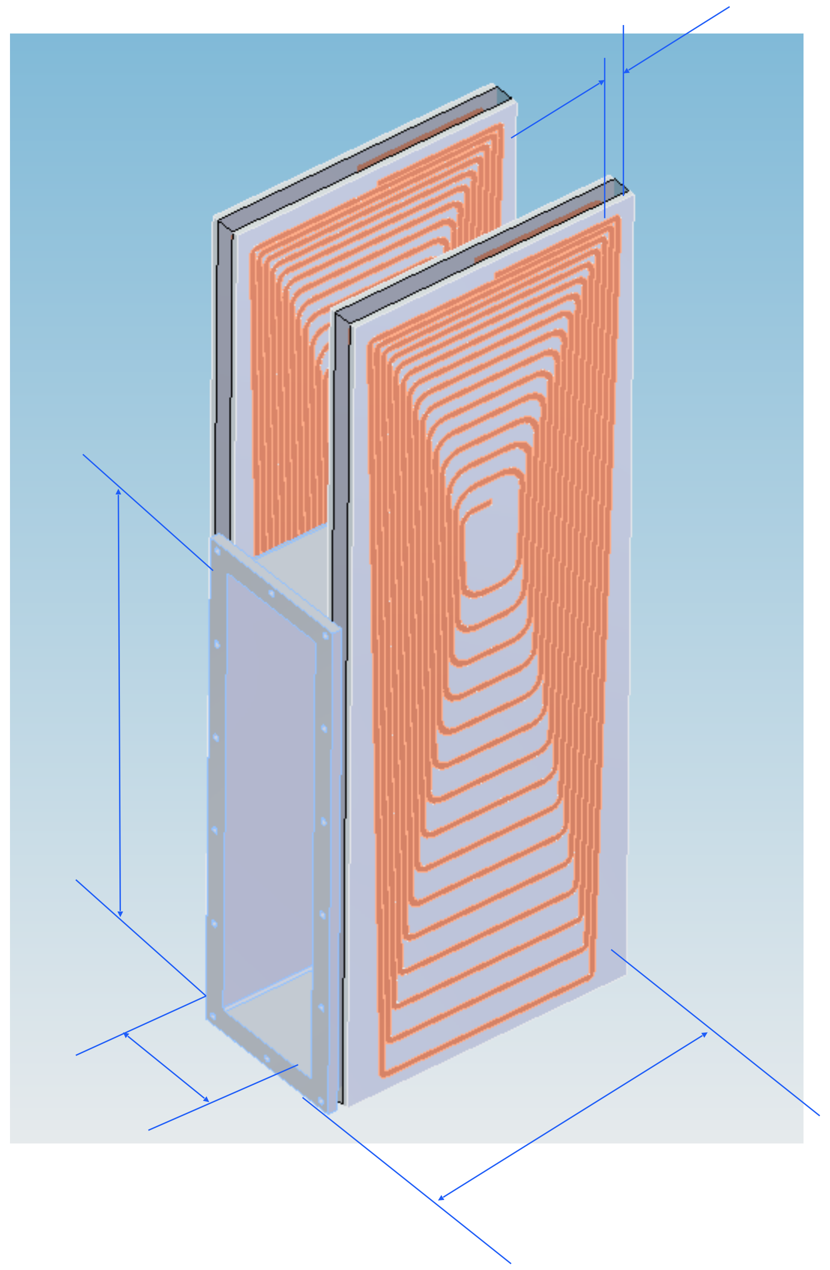
at STFC/RAL



Magnet specifications for test ring

Energy	3 - 12 MeV
Aperture	700 mm (H) x 300 mm (D)
Field	1.5 ~ 3 T
Gradient	1.6 /m

- First prototype magnet will be normal conducting.
- Plan to construct a superconducting magnet later.



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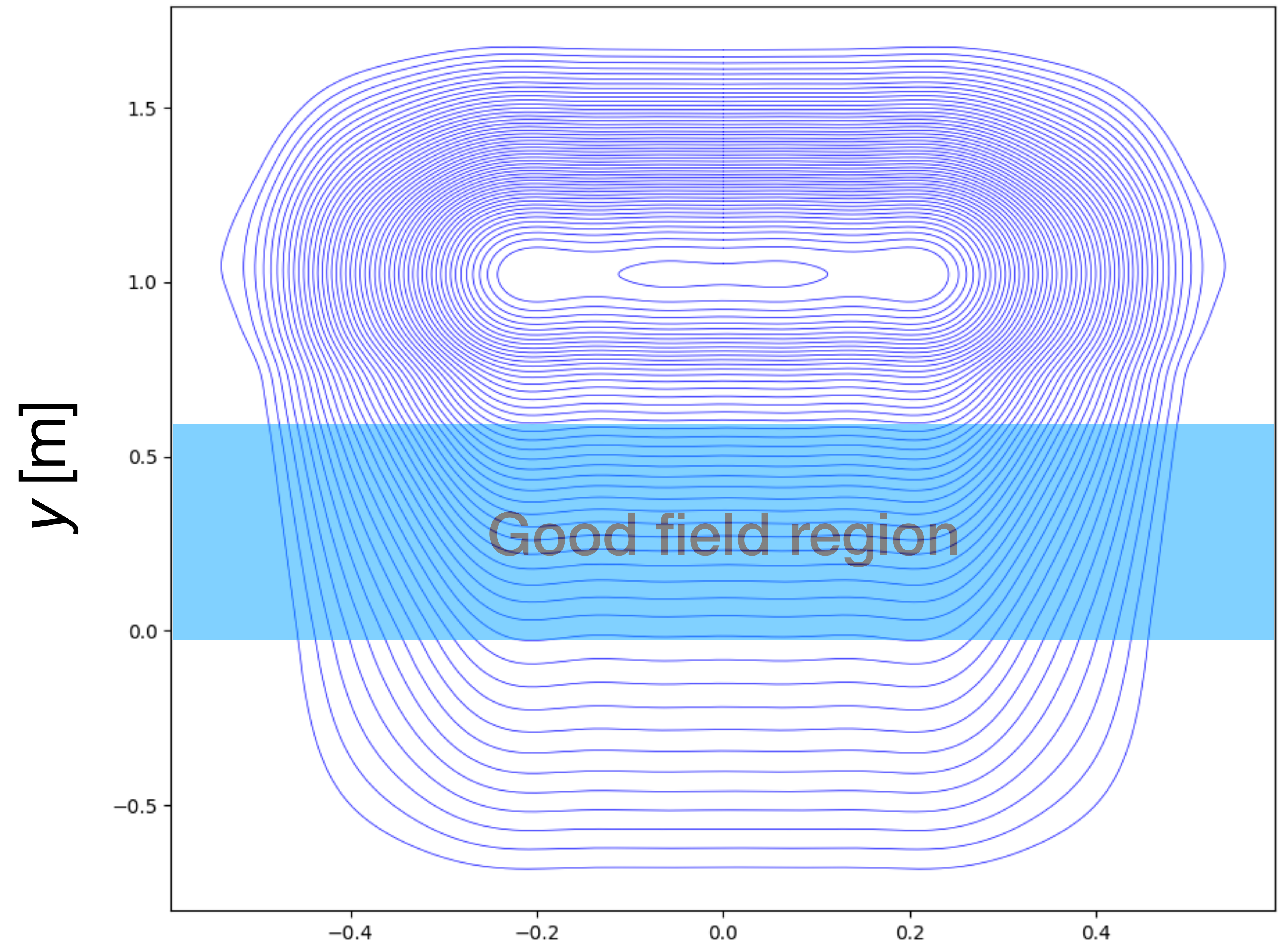
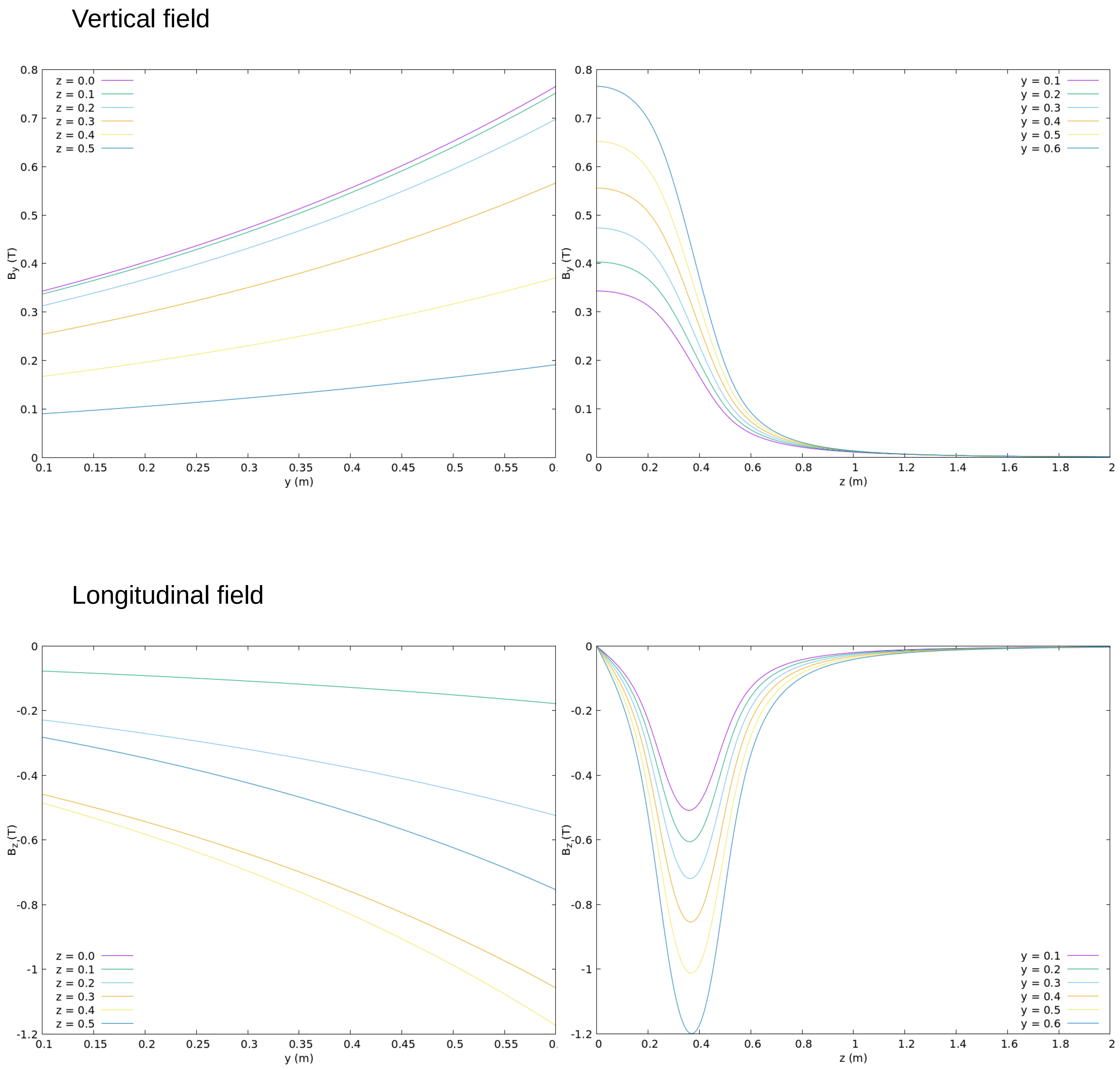
Normal conducting magnet design

first prototype

A. Letchford, STFC/RAL

Size	2.3 m (H) x 1.0 m (W)
Aperture	600 mm (H) x 220 mm (D)
Field	~ 0.01 T
Gradient	1.3 /m
Coils	50 turns
Space	4.7 mm between coils





R&D for muon vFFA

magnet

all numbers are preliminary.

	1st n.c. prototype	12 MeV proton	1.2 GeV proton	1.5 TeV muon
Aperture (H) x (D)	600 mm x 220 mm	700 mm x 300 mm	700 mm x 300 mm	700 mm x 200 mm
Length	1.0 m	0.5 ~ 1.0 m	2 ~ 3 m	10 ~ 20 m
Max field	~ 0.01 T	~ 3 T	~ 6 T	~ 9 T
Gradient, *m*	1.3 /m	1.3 /m +/- 25%	1.3 /m +/- 25%	6.8 /m
High/low field ratio	2	2	2	~ 30

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$$m = (1/B)\,(\partial B/\partial y)$$

R&D proposal

- **Magnet for vFFA accelerator**
  - DC magnet operation together with fixed RF frequency is the main advantage of vFFA as a muon accelerator.
  - Feasibility of magnets for vFFA as well as vFFA concept itself has to be demonstrated. At STFC/RAL, feasibility study on vFFA for a spallation neutron source is going on and normal conducting prototype magnet is being designed.
  - Magnets for vFFA muon accelerator may be realised as an extrapolation of the activity.
  - R&D on vFFA magnets aims for the construction of a scale down model of superconducting vFFA magnet.

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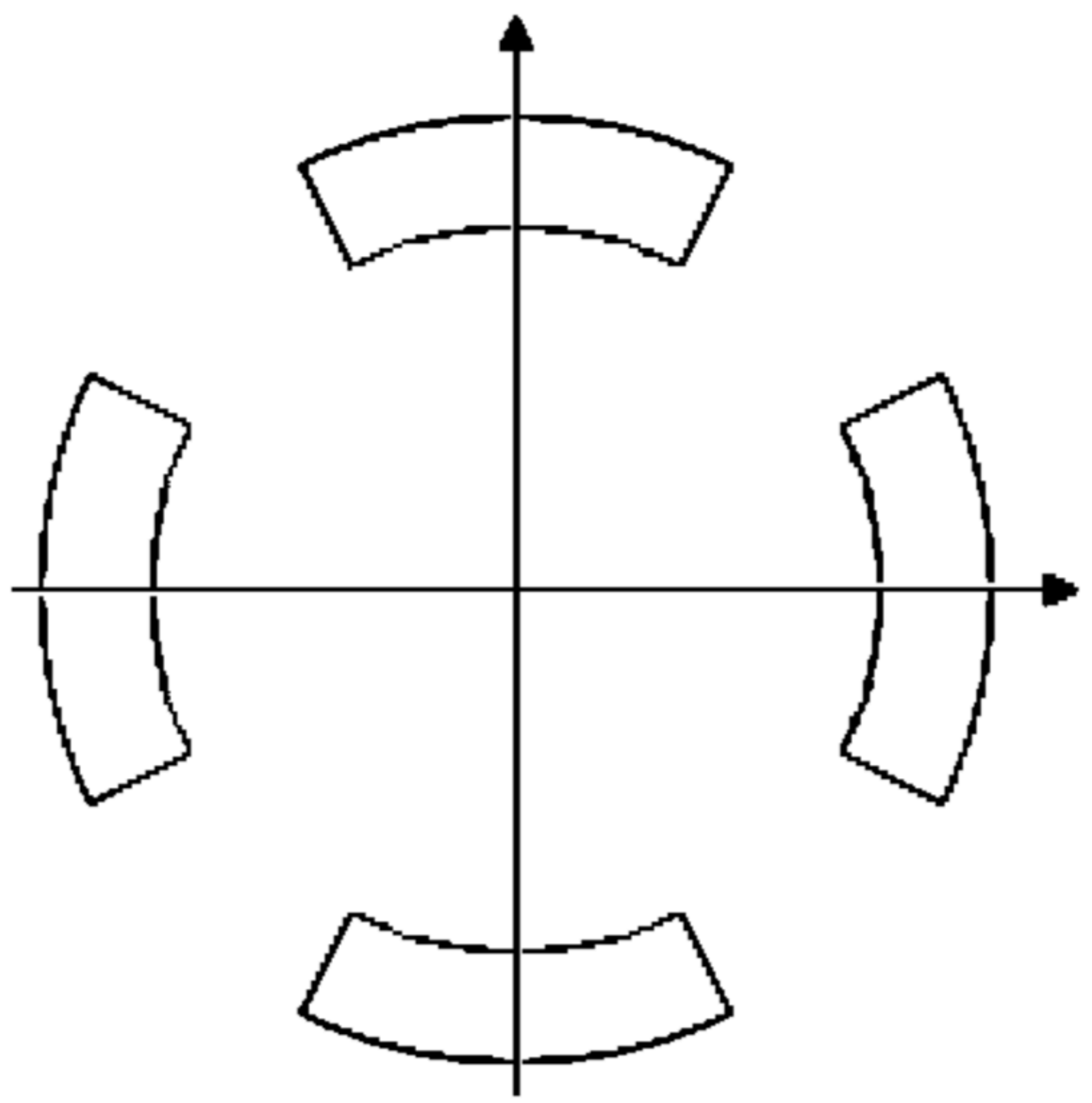
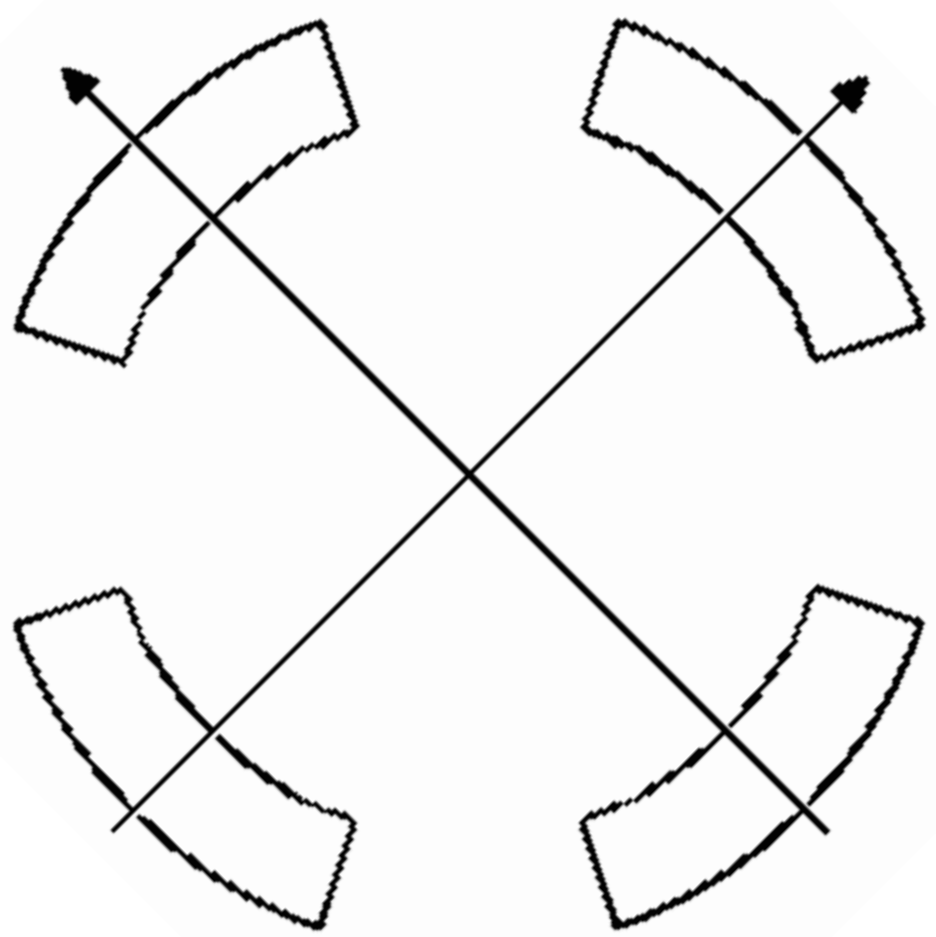
Thank you for your attention

Superconducting coil

Normal quad



Skew quad



Does the gap in horizontal plane help?

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