Application of FFAs to the Muon Collider

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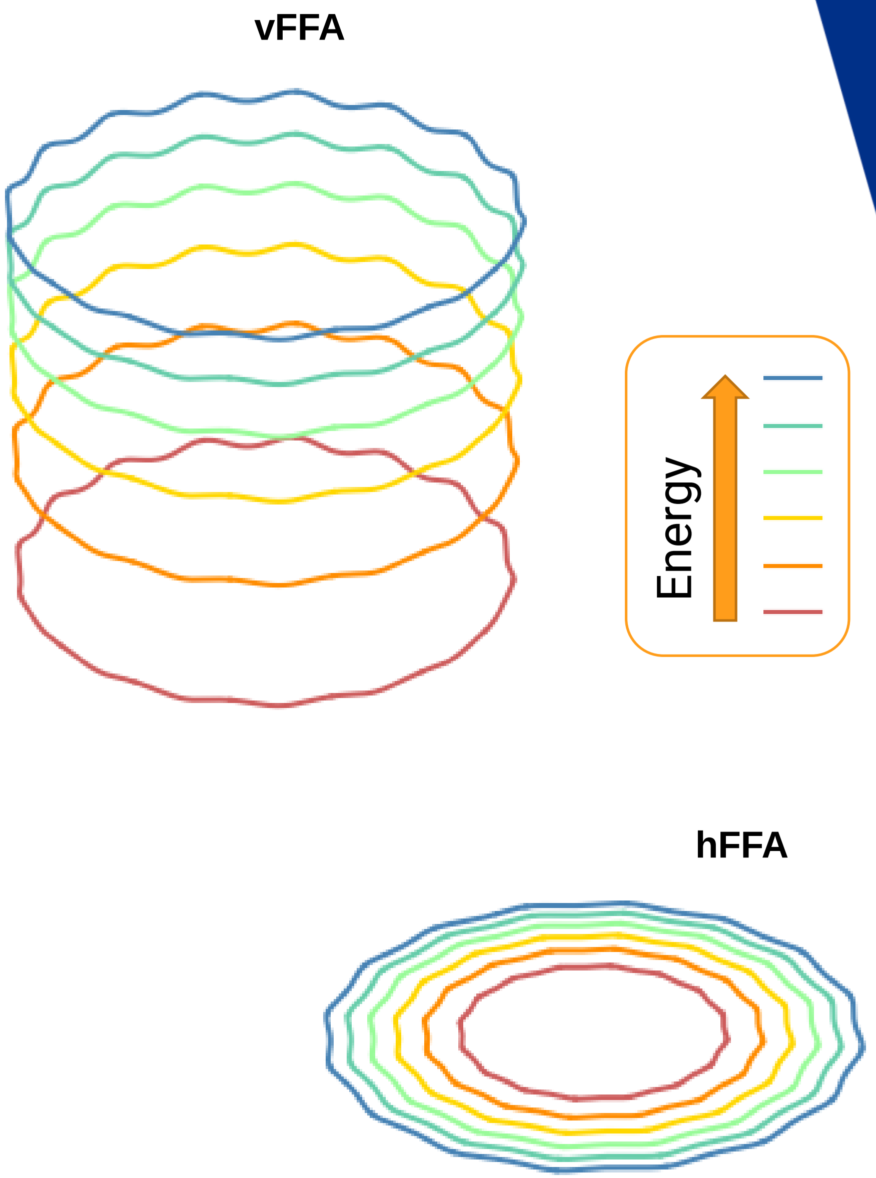
Contents

- Fixed field (alternating gradient) Accelerators (FFAs).
- FFAs as proton drivers.
- Muon acceleration chain overview.
- Challenges with the accelerator.
- vFFA design for muon collider.

What are scaling FFAs?

- Lattice composed of periodic cells of Fixed Field magnets.
- Beam changes position with energy
  - Moves horizontally for the hFFA and vertically for the vFFA.
- The field increases with height/radius according to a scaling law.



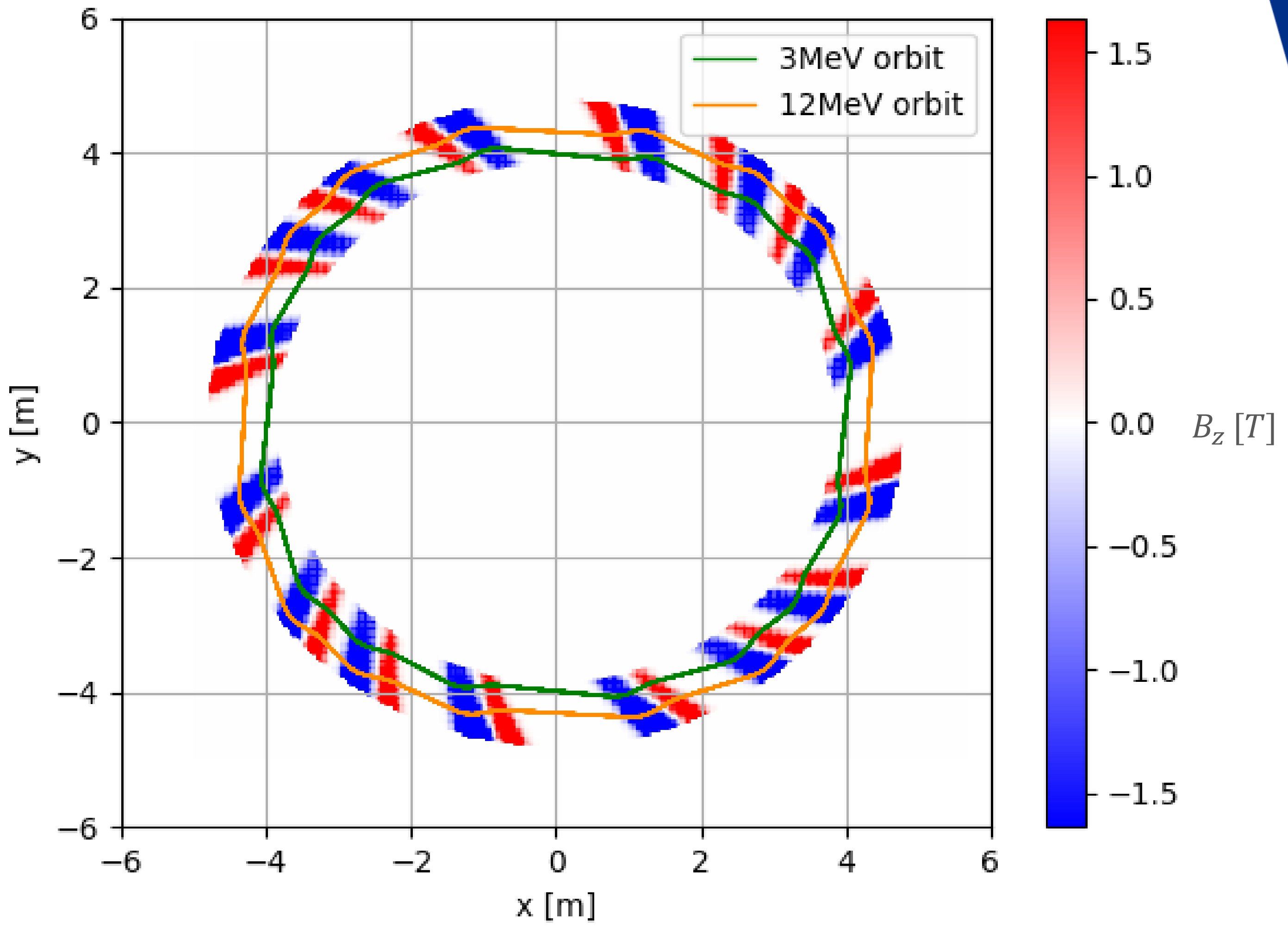
FFAs for megawatt class proton accelerators

- FFAs have several characteristics that lend themselves well to high power proton accelerators:
  - Large dynamic aperture → intense beams.
  - Freedom with the RF program → Beam stacking!
  - Fixed field magnets → potentially lower electricity costs.

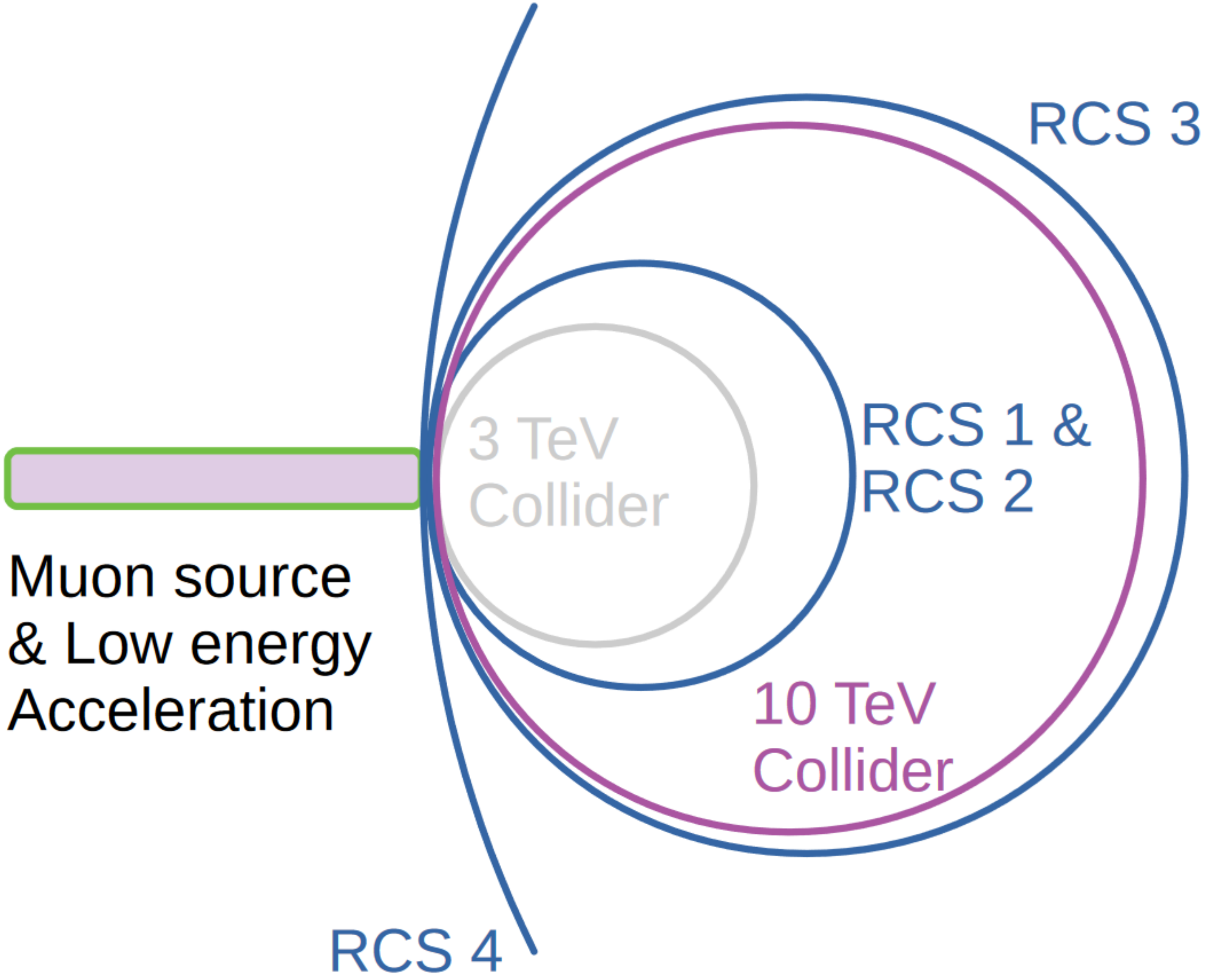
FETS-FFA project

- FETS-FFA is the proposed ISIS-II FFA prototype machine.
- Although FFAs have been built and operated successfully, high intensity beams with low losses are yet to be demonstrated.

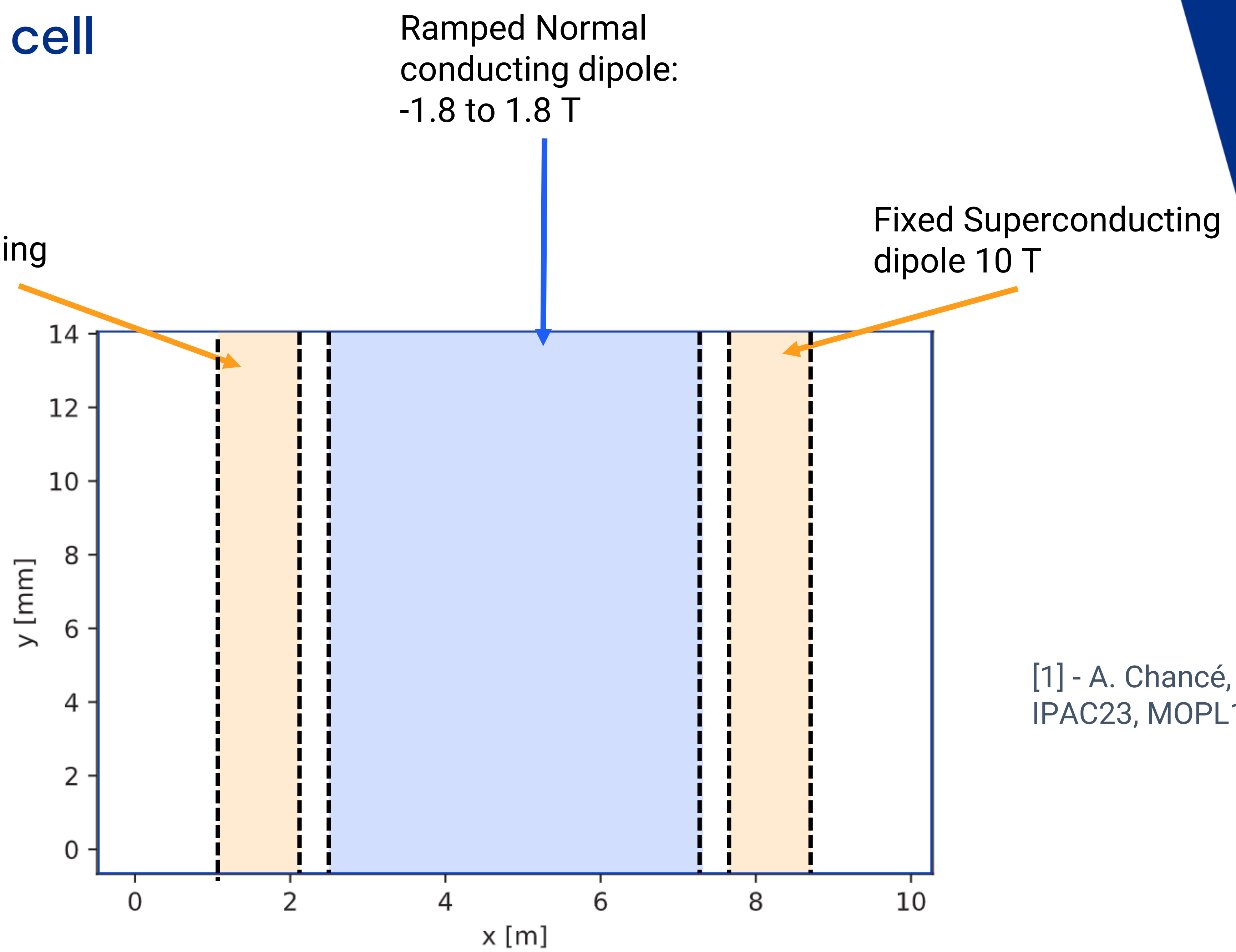
hFFA lattice



Rapid Cycling Synchrotron accelerator chain



Hybrid RCS2 cell



[1] - A. Chancé, IPAC23, MOPL162

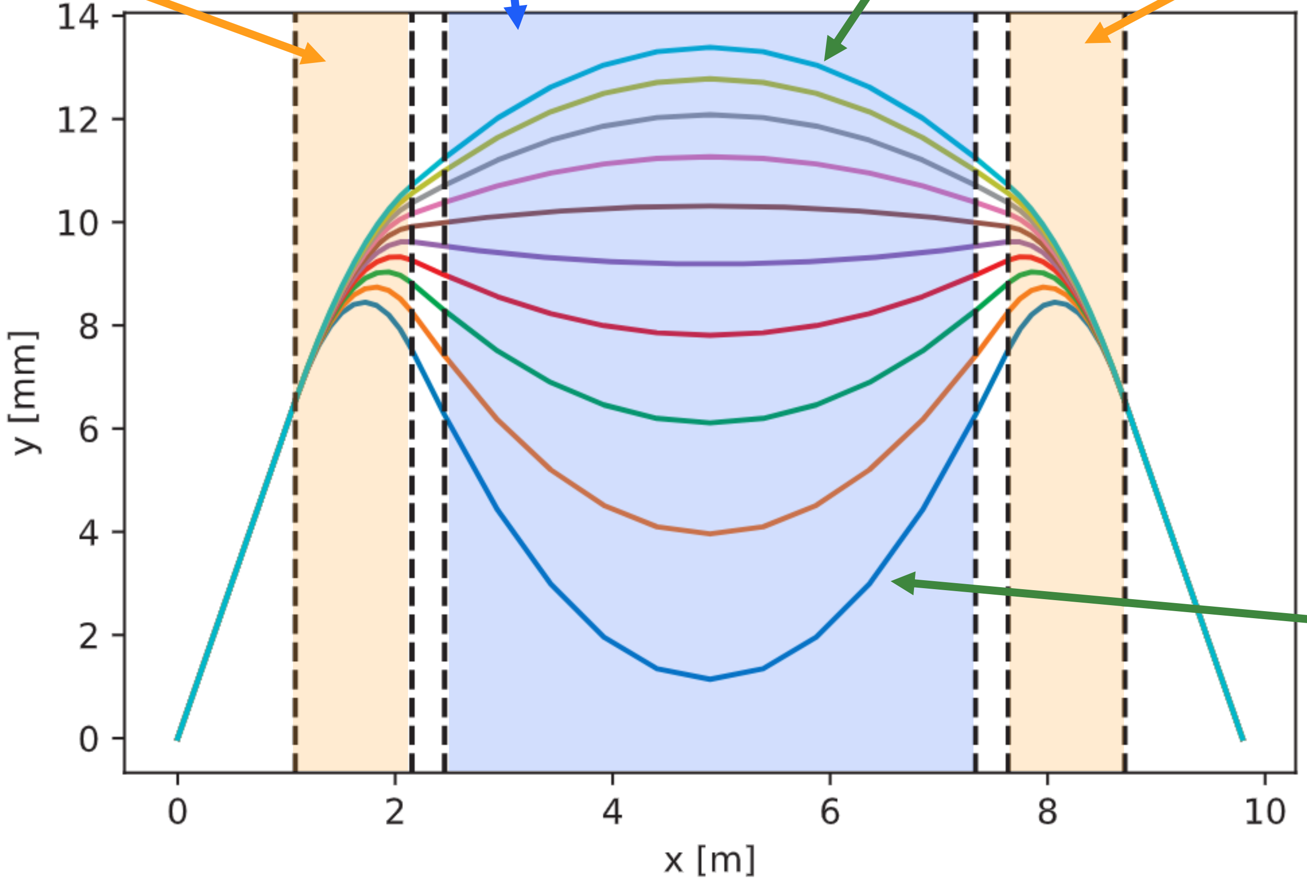
Hybrid RCS2 cell

Ramped Normal conducting dipole: -1.8 to 1.8 T

Fixed Superconducting dipole 10 T

Extraction energy orbit

Fixed Superconducting dipole 10 T



Injection energy orbit

[1] - A. Chancé, IPAC23, MOPL162

Challenges with the RCS design

- The acceleration time scale must be comparable to the muon lifetime. → Require ramped magnets but cannot ramp superconducting magnets with current technology.

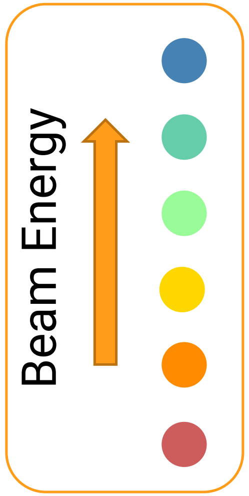
- Ideally, use fixed frequency RF cavities. → Minimal path length difference between the injection and extraction orbits.

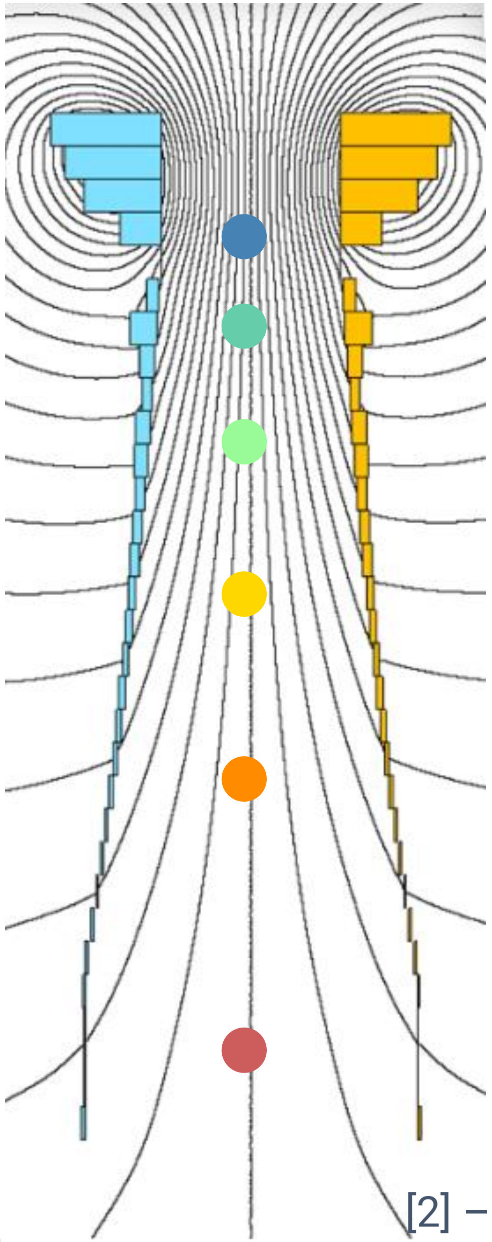
Normal conducting dipole has high ramp rates of 1000s T/s

What kind of machine could solve these issues?

- Requirements:
  - Solving ramping issue. → Fixed Field magnets.
  - Zero path length difference. → All orbits have the same radius.

vFFA origin story





- Originally invented in the 1950s.
- Reinvented and revived by Stephen Brooks in 2013.
- Investigated at ISIS for its potential as a spallation source proton driver but it could be more well suited to muon acceleration.

Beam direction
is into the page.

[2] – S Brooks, Phys. Rev. ST Accel. Beams 2013

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Max's vFFA analytical model

REF:

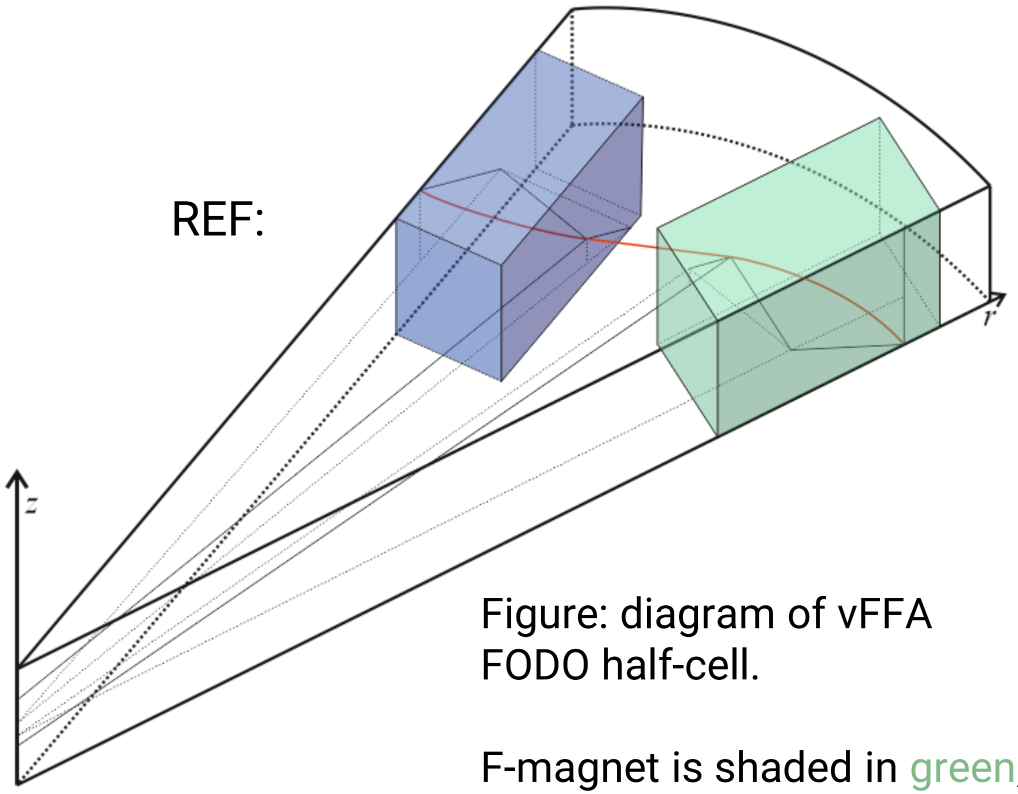


Figure: diagram of vFFA FODO half-cell.

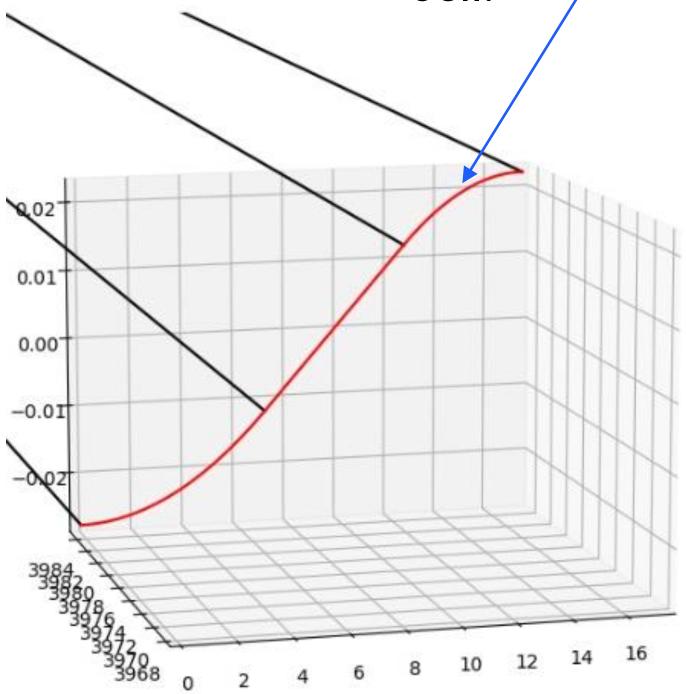
F-magnet is shaded in green;
D-magnet is shaded in blue.

- Horizontal field components in the magnet body give non-planar orbits.
- Skew quadrupole components give rise to strongly coupled optics
  - Use decoupled tunes u and v tunes rather than horizontal and vertical tunes.
- Complicated to simulate, the analytical model allows for a much simpler design process.

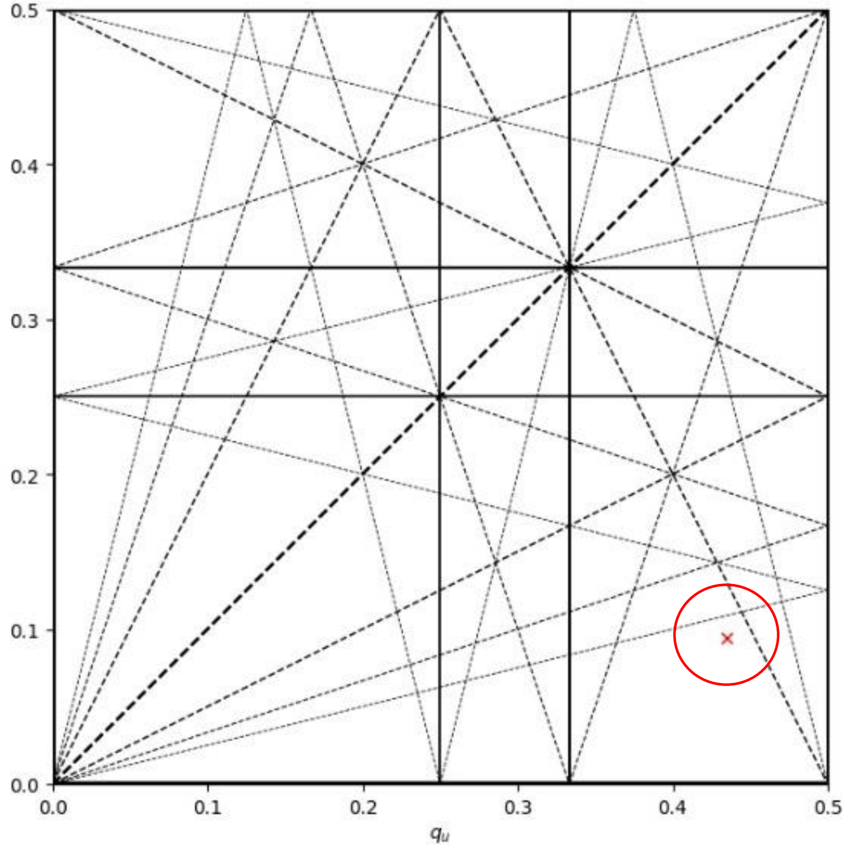
Using the model

Orbit through the cell.

Closed orbit calculation.



Decoupled tune calculation.



v tune

u tune

Designing with the model vs simulation

Parameter	Original (simulation-based)	Analytic optimisation
Circumference [km]	28	25
Number of Cells	810	720
Injection Energy [TeV]	0.75	0.75
Extraction Energy [TeV]	1.5	1.5
F-magnet length [m]	12.0	14.5
D-magnet length [m]	12.0	9.5
Drift length [m]	5.5	5.5
Peak Dipole Field [T]	8.7	7.1
M-value [1/m]	6.8	7.57
Excursion [m]	0.10	0.092
Tune	(0.40,0.086)	(0.44, 0.098)

Muon collider vFFA design

Parameter	RCS4	VFFA4 (Preliminary)
Circumference [km]	35	35
Injection energy [TeV]	1.5	1.5
Extraction energy [TeV]	5	5
Max. SC dipole field [T]	16	16
Size of field ramp [T]	3.6	0
Ramp rate [T/s]	565	0
Path length difference [mm]	9.4	0
Excursion [cm]	1.3	10

Pros of the vFFA

- Fixed magnets – no need for ramping.
- Zero path length difference.
- On crest acceleration.
- Zero momentum compaction factor.

Cons of the vFFA

- Vertical excursion increases the demands on magnet and cavity design.
- Highly non-linear field.
- New and untested magnets/technology.

Summary

- Fixed field accelerators and how they could offer a better solution for high power proton drivers.
- The challenges with the current hybrid RCS design.
- vFFA alternative to the hybrid RCS.
- Optimising a vFFA with Max’s analytical model.

References

[1] - A. Chancé, IPAC23, MOPL162, Parameter ranges for a chain of rapid cycling synchrotrons for a muon collider complex

[2] – S. Brooks, Phys. Rev. ST Accel. Beams, Vertical orbit excursion fixed field alternating gradient accelerators