Proton driver for muon collider and FFAs

J.B. Lagrange
ISIS, RAL, STFC

Power of proton driver for muon collider

- High beam power (>1 MW) with high peak brightness and low repetition rate (5 Hz)
- Cyclotrons would need an accumulator ring with a very challenging injection scheme
- RCS limited by space charge at injection energy
- Full energy linac with challenging accumulator ring possible but expensive

Short pulse proton driver for muon collider

- Short pulse (a few ns)
- Large momentum spread requiring chromaticity correction
- High orders of momentum compaction factor distorts bunch shape

Advantages of FFAs

- **Flexibility**: beam pulse only controlled by RF, allowing fast and sophisticated patterns
- **Sustainability**: energy efficient operation, enhanced with SC or permanent magnets, reduced operating cost
- **Reliability**: DC power supply simple and cheap, low failure rate and higher redundancy
- **Large 6D acceptance**: handling of big beams

Disadvantages of FFAs

- Reverse bend:
  - Pros: Orbit oscillations could reduce problem of neutrino radiation for muon beams
  - Cons: Big circumference of the machine

Mitigation: ➡SC magnets

➡Minimisation of reverse bend, addition of edge focusing

- Orbit excursion too large for high gradient cavities

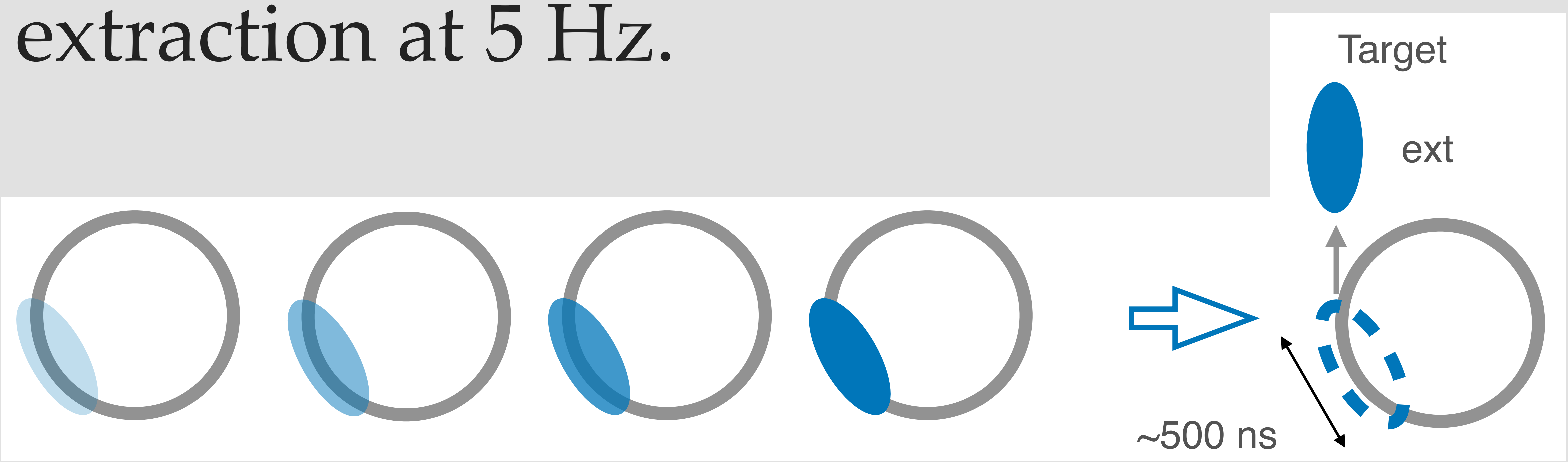
Mitigation: ➡Maximisation of field gradient

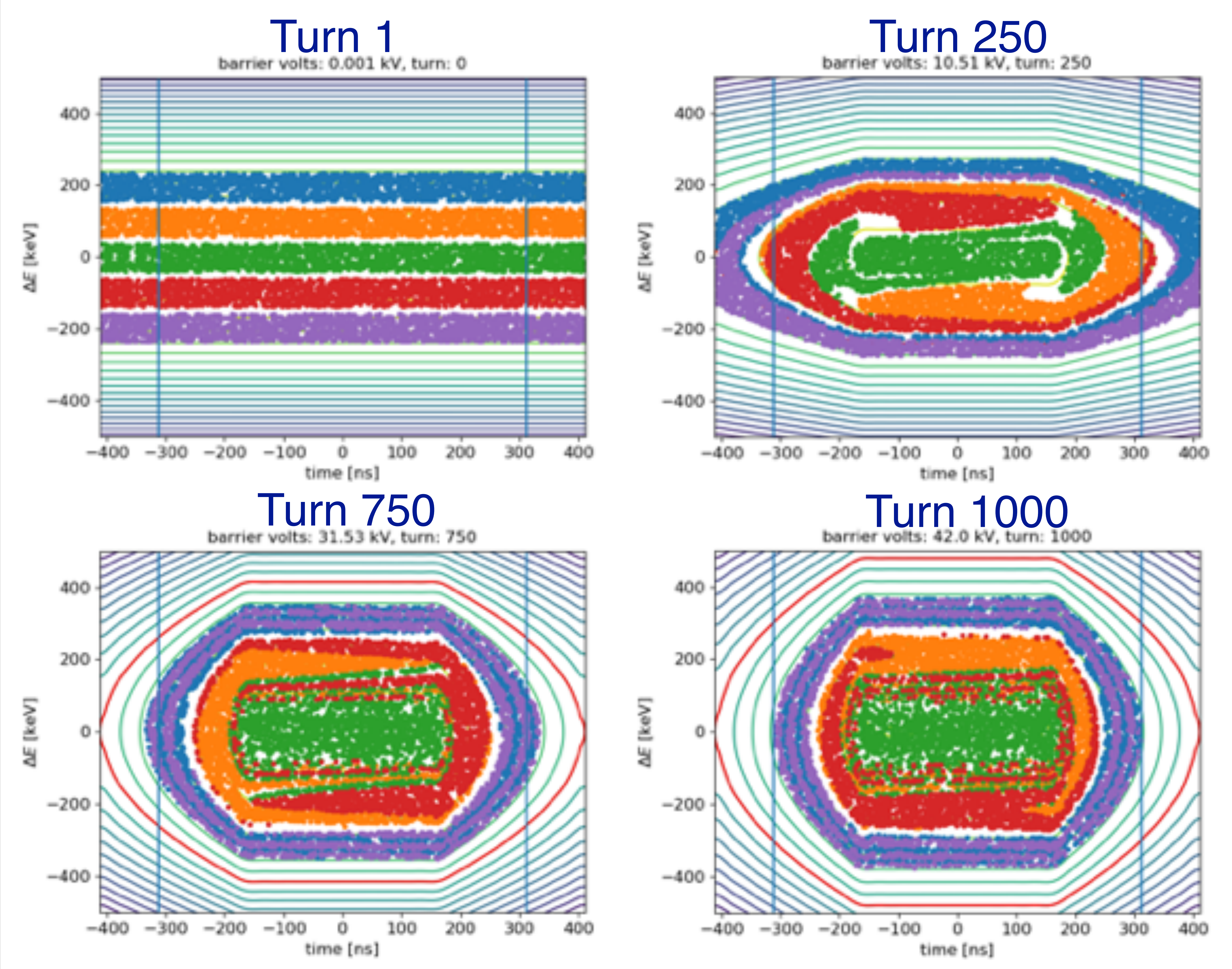
➡Insertion of dispersion suppressor

➡Reduction of momentum range

FFA proton driver

- Beam stacking: Acceleration at higher frequency (e.g. 50 Hz) to reduce bunch intensity at injection energy, then stack beams several times (e.g. 10) at extraction energy, and capture by a barrier bucket for extraction at 5 Hz.

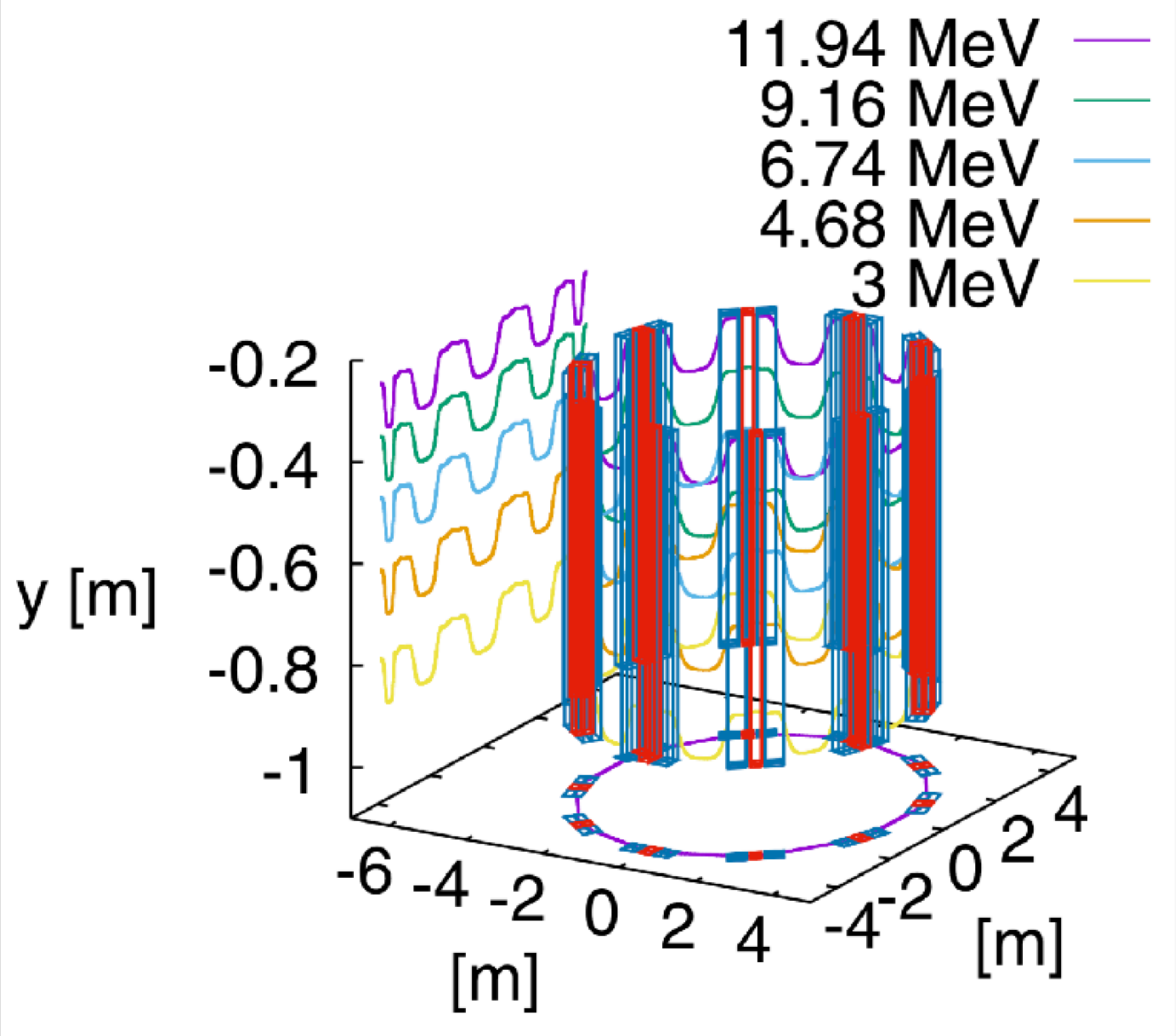




(D. Kelliher, ISIS, RAL)

Vertical excursion FFA (VFFA)

- Invented in 1955, rediscovered in 2013.
- Orbit moves vertically when the beam is accelerated.
- Constant path length over whole momentum range (zero momentum compaction factor for all orders)
- isochronism for ultra-relativistic energies (slippage factor only dependent of Lorentz gamma, like a Linac).



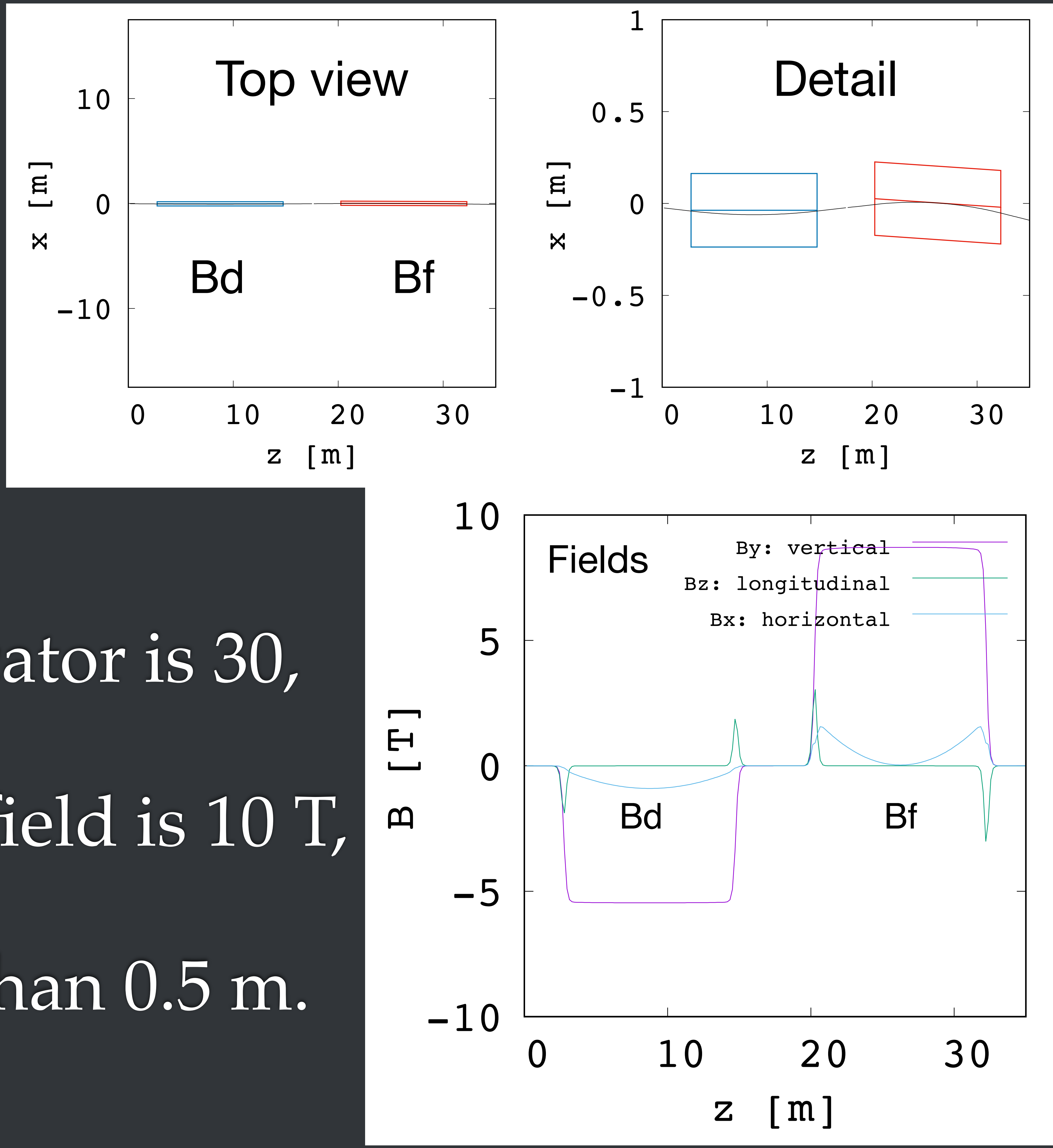
FFA proton driver (2)

- Scaling VFFA has zero chromaticity (all orders) and zero momentum compaction factor (all orders).
- Bunch rotation would be in linear regime with a VFFA used as an accumulator ring.

VFFA lattice for muon acceleration

Design constraints:

- LHC circumference,
- Final energy 1.5 TeV,
- Momentum multiplicator is 30,
- Maximum magnetic field is 10 T,
- Orbit excursion less than 0.5 m.



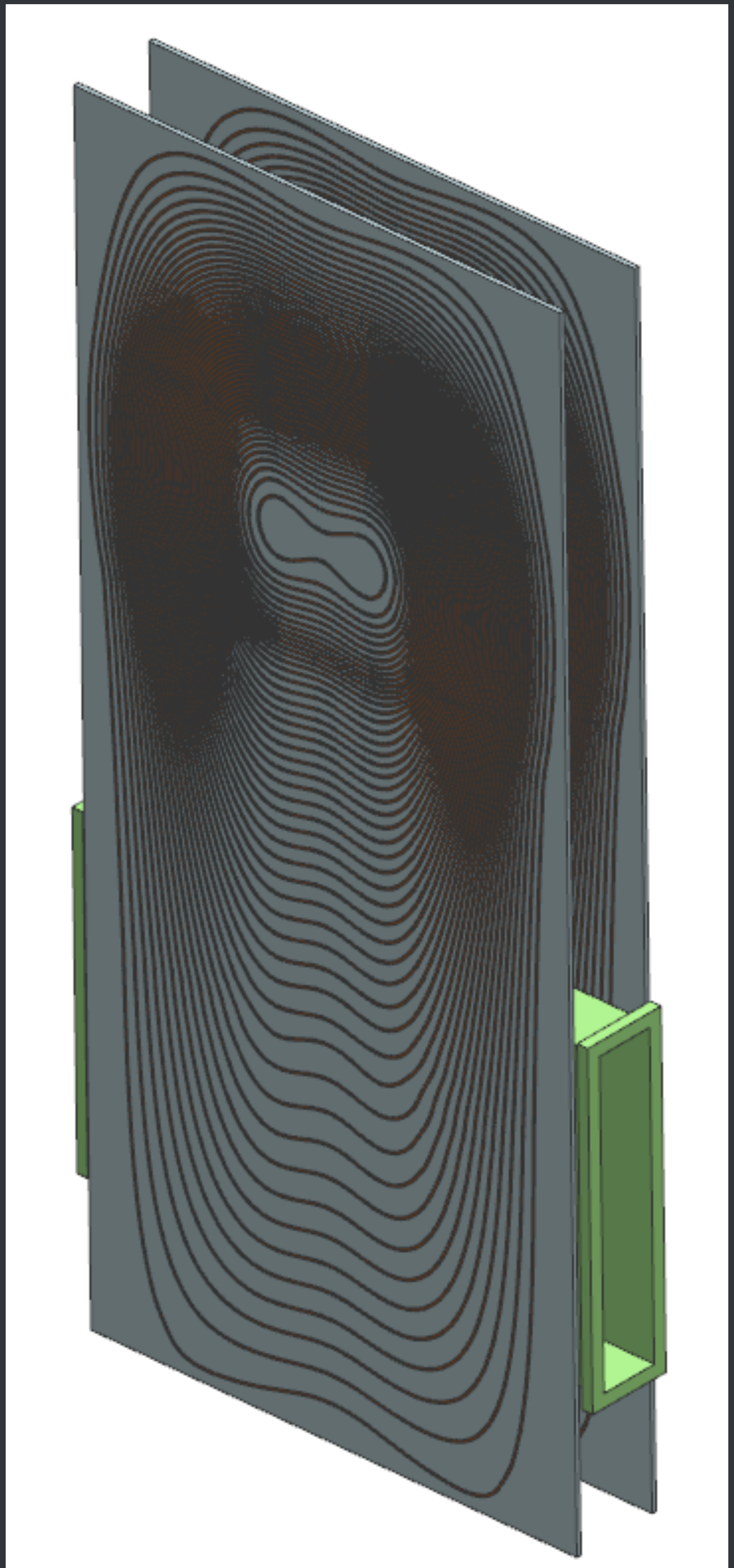
	FODO design
Energy	50 GeV to 1.5 TeV
Cell length	35 m
Number of cells	810
Packing factor	86%
Maximum field	8.7 T
Normalised gradient m^*	6.8 m^{-1}
Orbit excursion	0.50 m
Cell tune	0.3957/0.0861

$* m = \frac{1}{B}\frac{dB}{dy}$ (y: vertical direction)

First VFFA prototype

Prototype parameters:

- Normal conducting with SC winding method
- 1 m-long magnet
- Normalised gradient m=1.3 m^{-1}.
- 0.6 m vertical good field region
- 22 cm full gap size
- Coil made of 50 contours, each contour made of 16 turns
- 6 mm minimum spacing (centre coil to centre coil)



R&D for VFFA magnet

	1st NC prototype	1.2 GeV proton	1.5 TeV muon
Aperture H [mm] x D [mm]	600 x 220	900 x 300	700 x 200
Length [m]	1	2 ~ 3	10 ~ 20
Max Field [T]	0.01	6	9
Normalised gradient m^* [m^{-1}]	1.3	0.9 ± 25 %	6.8
Momentum ratio	2	2	30

$*m = \frac{1}{B}\frac{dB}{dy}$ (y: vertical direction)

(PRELIMINARY NUMBERS)

Science and Technology Facilities Council

Summary

- FFAs good candidates for future muon and high power pulsed proton facilities
- Preliminary design for muon acceleration from 50 GeV to 1.5 TeV
- Development at RAL of FFA as a proton driver for spallation neutron source
- Proof of principle ring (3-12 MeV proton) planned before 2030
- Coil-based prototype VFFA magnet designed

Thank you for your attention