Imperial College London

Science & Technology Facilities Council ISIS

Progress in FFAG design

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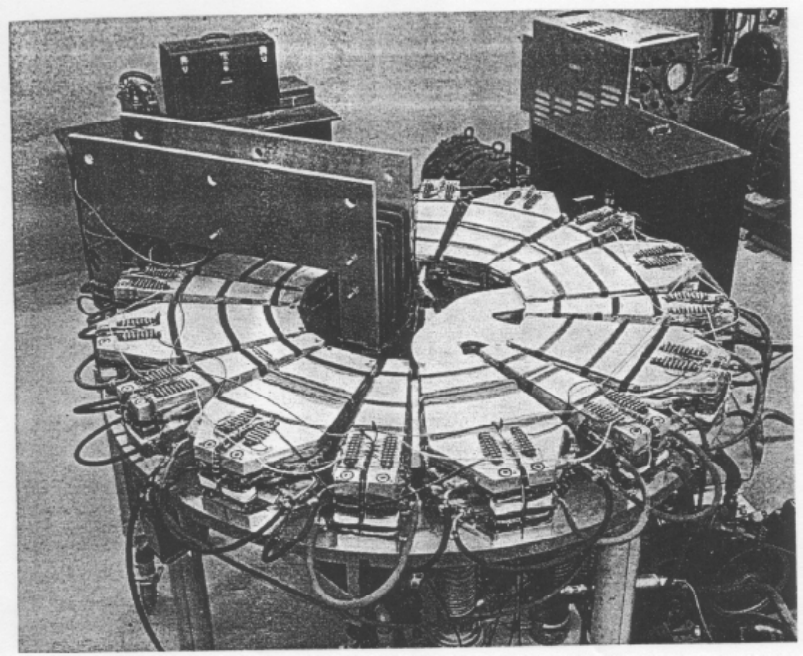
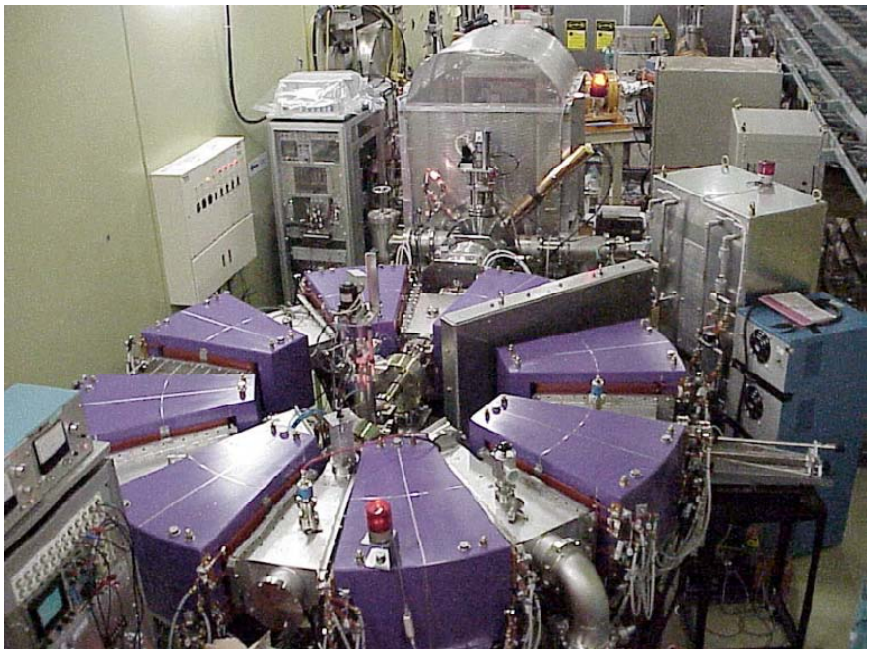
Introduction

FFAG – Fixed Field Alternating Gradient accelerator is a ring with a strong focusing lattice, very large momentum acceptance and small dispersion.
It operates with constant magnetic field, which is compatible with the very fast acceleration needed for muons in the Neutrino Factory

First proposed by Okhawa and Symon et al. in 1953



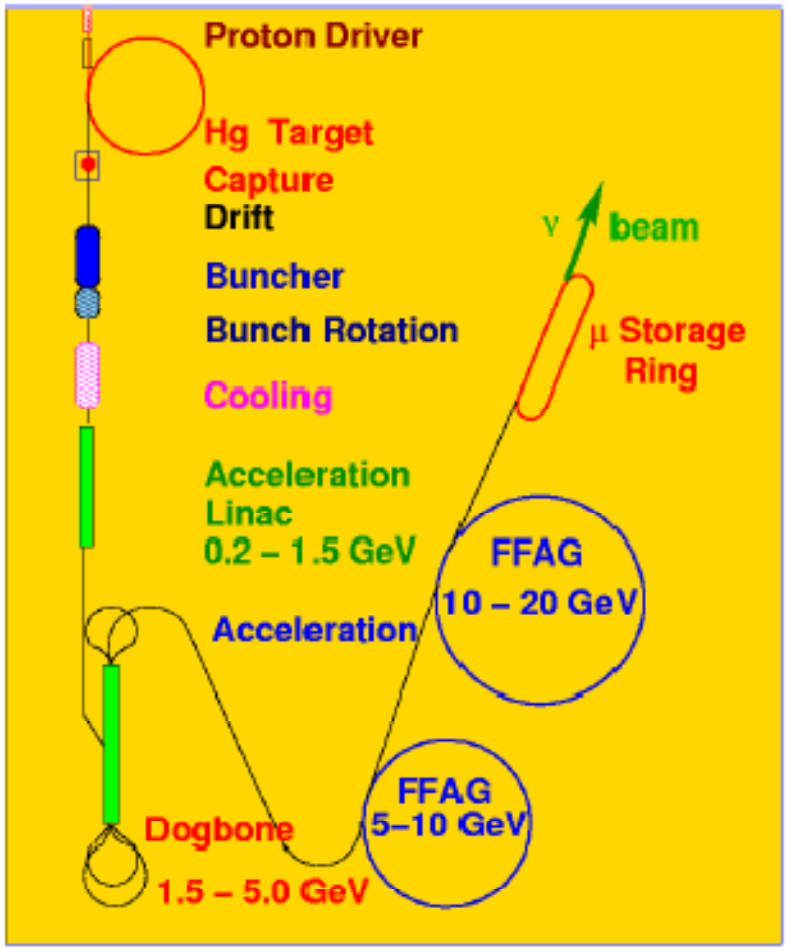
Electron model from 50ties (MURA)

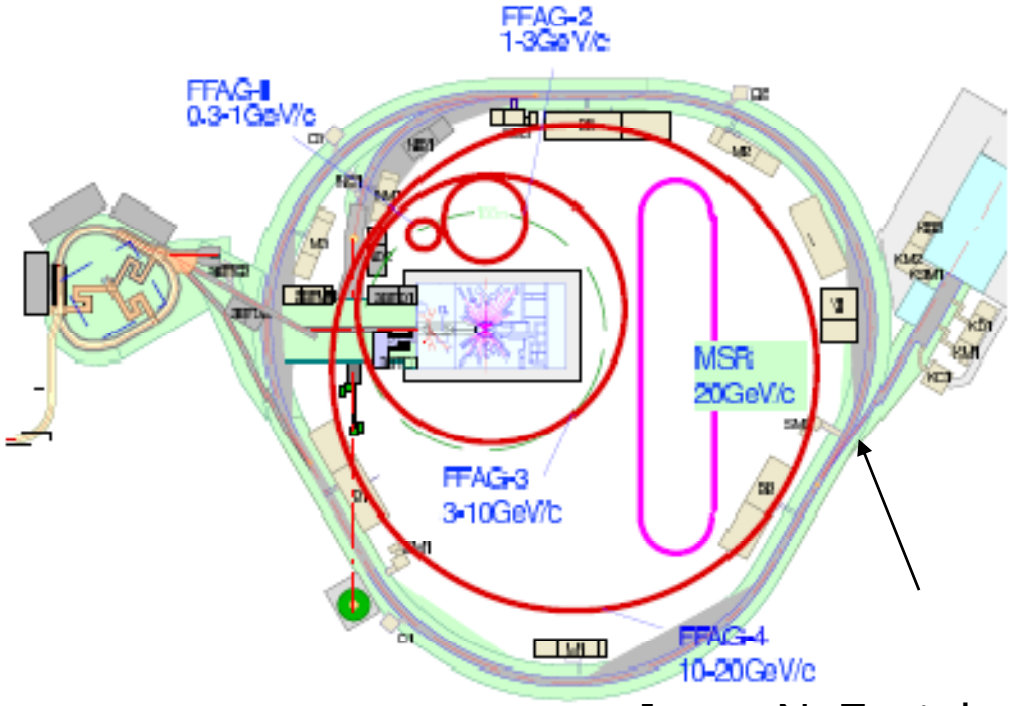


POP-world first proton FFAG
(Mori et al.- 2000)

Several FFAG schemes for NuFact

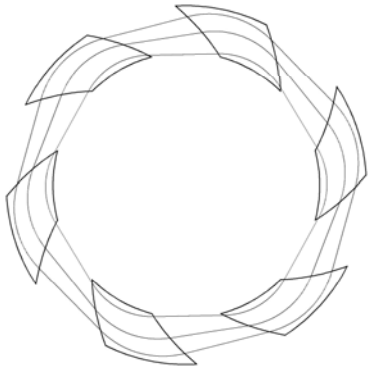
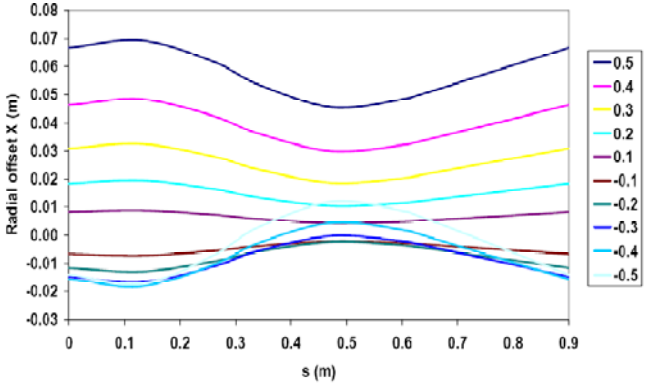
American NuFact design (Study2)



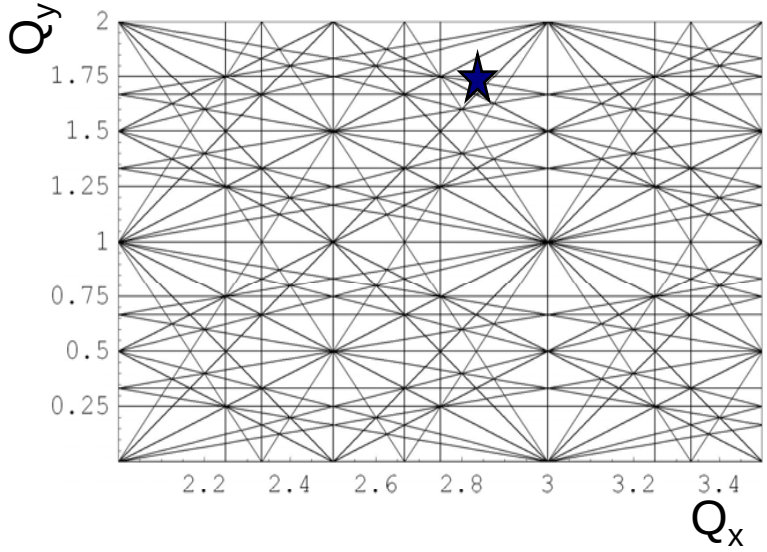


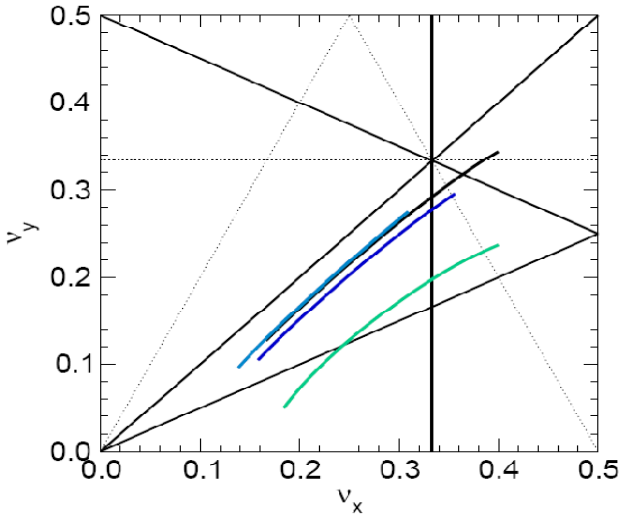
Japan NuFact design

Scaling versus Non-Scaling FFAG

FFAG type	**Scaling**	**Non-scaling**
Magnetic field	$B = B_0 \left(\frac{R}{R_0} \right)^k$	linear
Orbits	scale	non-scale
		
Dispersion	small	very small

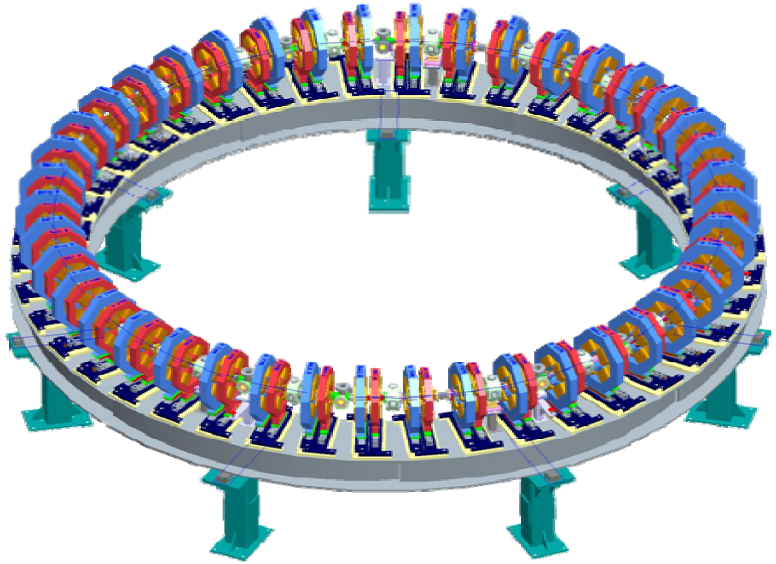
FFAG type	**Scaling**	**Non-scaling**
Tune	constant	changing (not always)
Acceleration	stationary bucket harmonic number jump – HNJ	quasi-isochronous HNJ

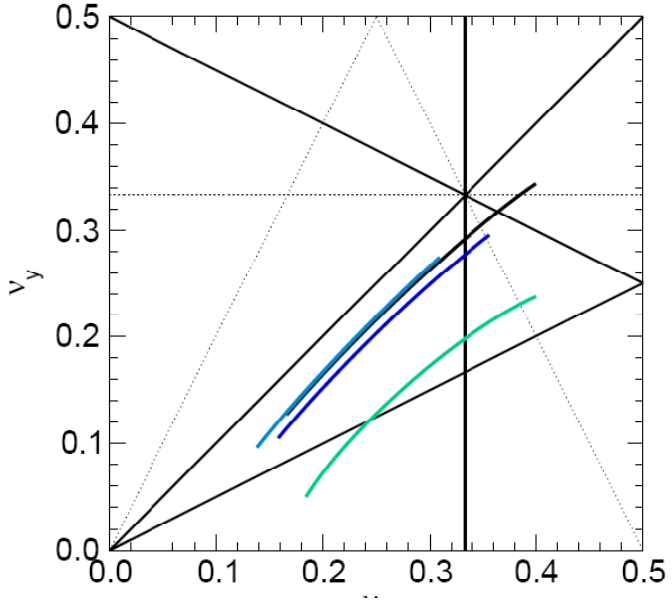




Experimental work on Non Scaling FFAG

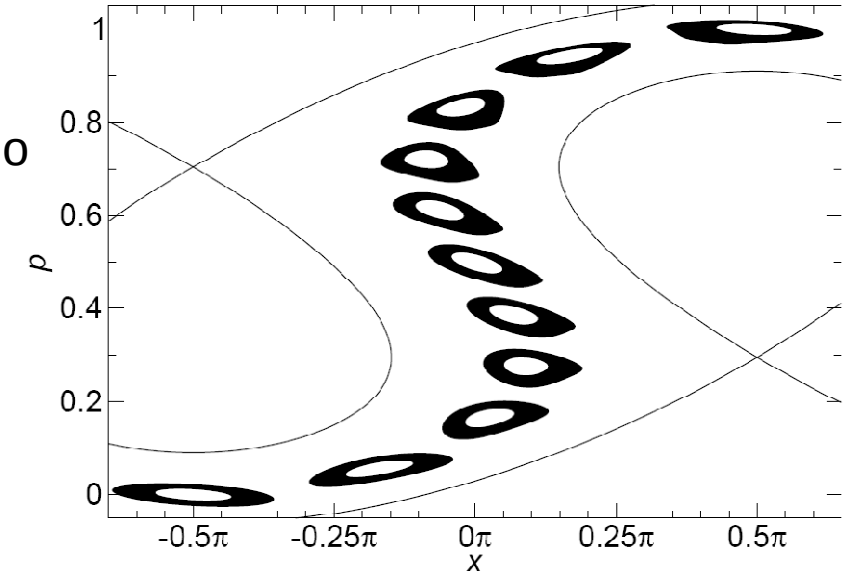
EMMA (Electron Model for Many Applications)





EMMA – first non-scaling FFAG:

- Model for muon accelerator at the Neutrino Factory
- Demonstration of the novel „serpentine" acceleration principle (10 –20 MeV)
- Experiments for fast resonance crossing
- Under construction in DL (UK).

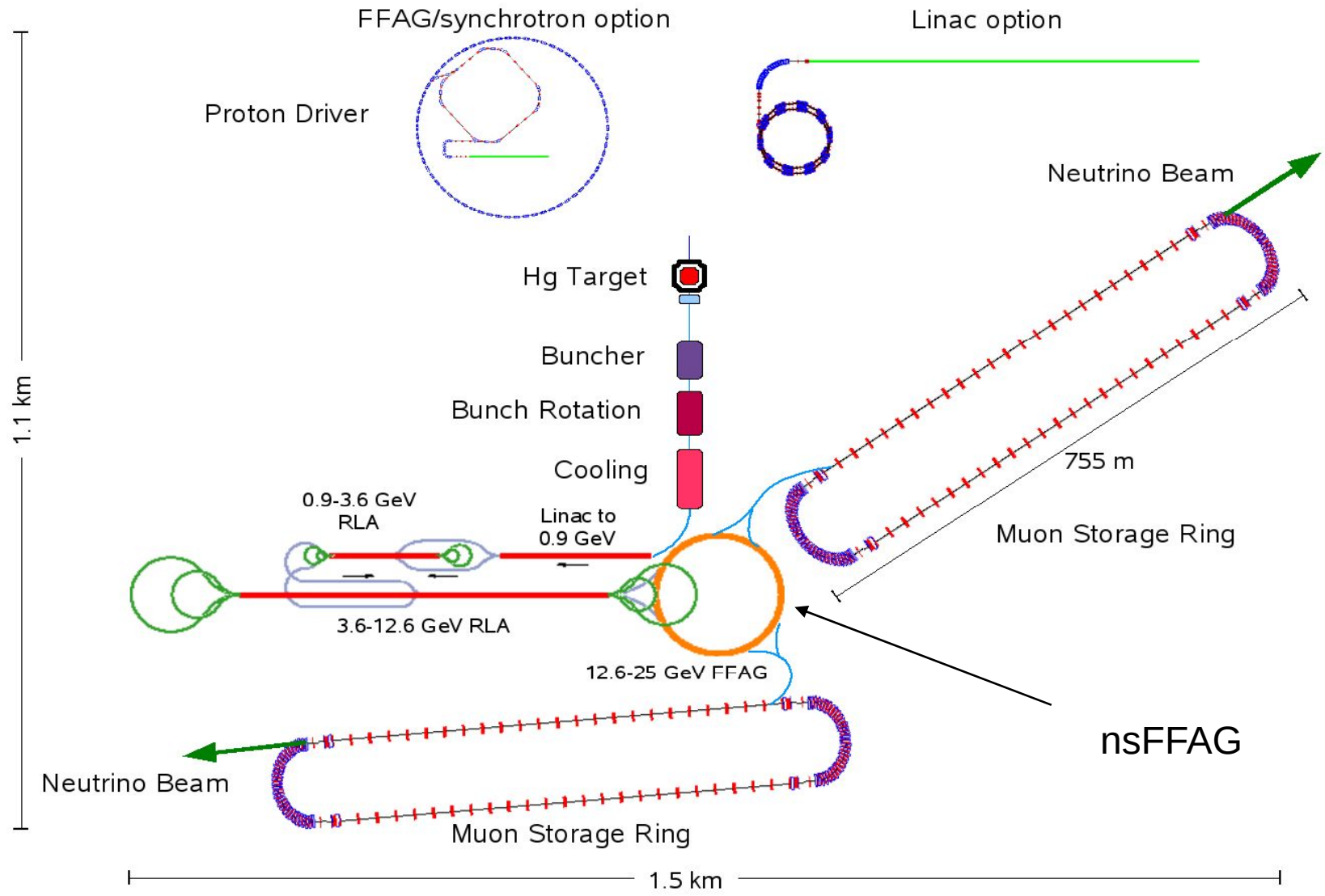


Motivations

Motivations for Non Scaling FFAGs as muon accelerators:

- quasi-isochronous design enables high frequency RF
- linear fields gives huge DA and allows for simple magnets
- small orbit excursion should allow for cost effective design
- Muons pass 8-12 turns in the RF cavities in the same lattice, which should be cheaper with respect to RLA

Reference IDS Neutrino Factory Design

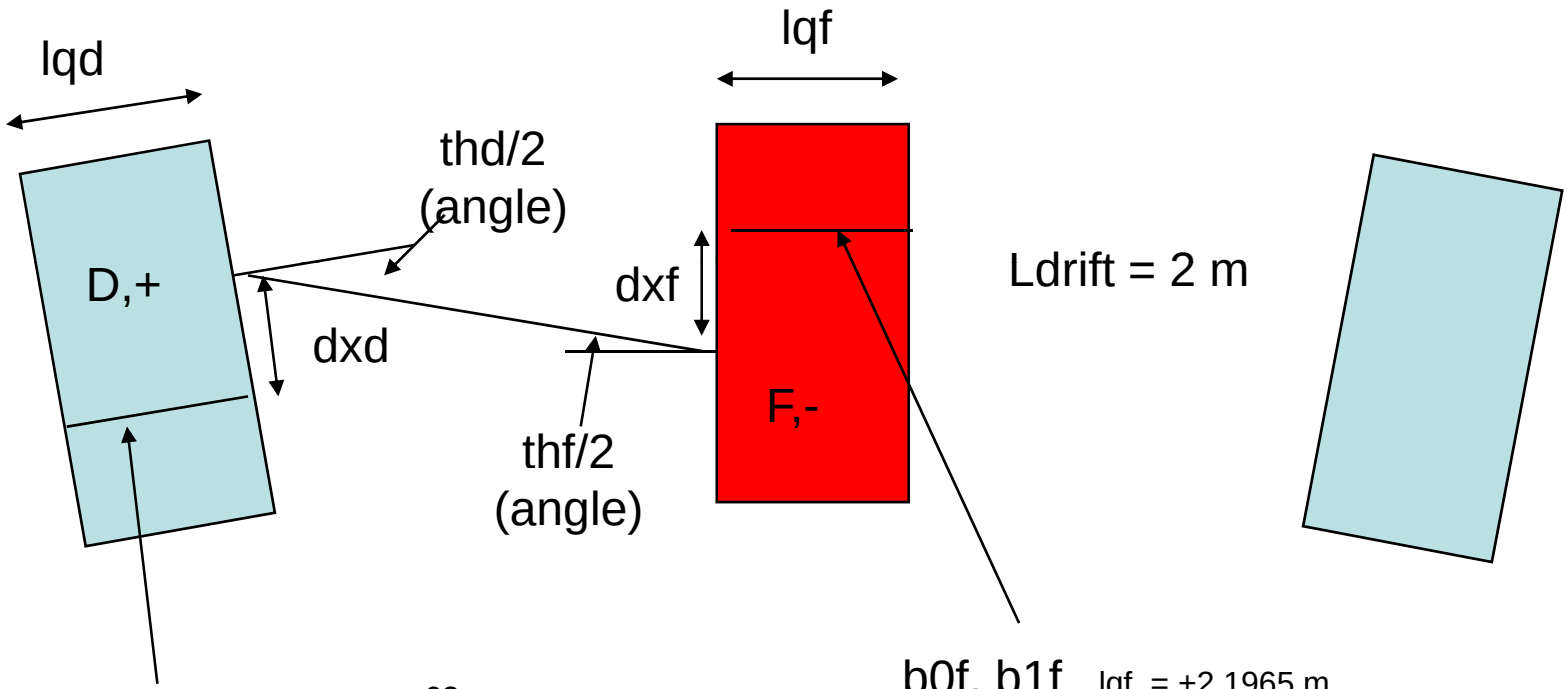


IDS designs by J. Scott Berg

Parameters

	FCDC	FDCC	FDFCC	FDC	FDFC
Cells	62	62	55	77	70
D radius (cm)	9.5	10.2	12.5	7.7	9.2
D field (T)	7.6	8.3	7.3	8.1	7.7
F radius (cm)	20.7	20.3	16.7	14.0	12.2
F field (T)	3.4	3.1	3.9	4.0	4.2
Circ. (m)	462	467	445	426	422
RF Volt. (MV)	1526	1424	1246	903	814
Decay (%)	3.5	3.8	4.1	5.4	5.9

Scott's FODO, 1 out of 62 cells

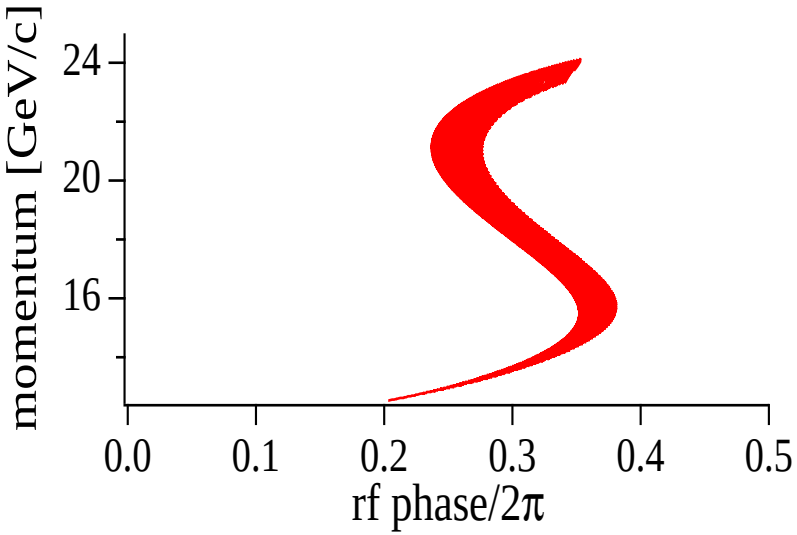


n = 62
lqd = +1.2550e+00 m
thd = +1.3238e-01rad
dxd = +4.3393e-02 m
b0d = +6.1269e+00 T
b1d = -1.5752e+01 T/m

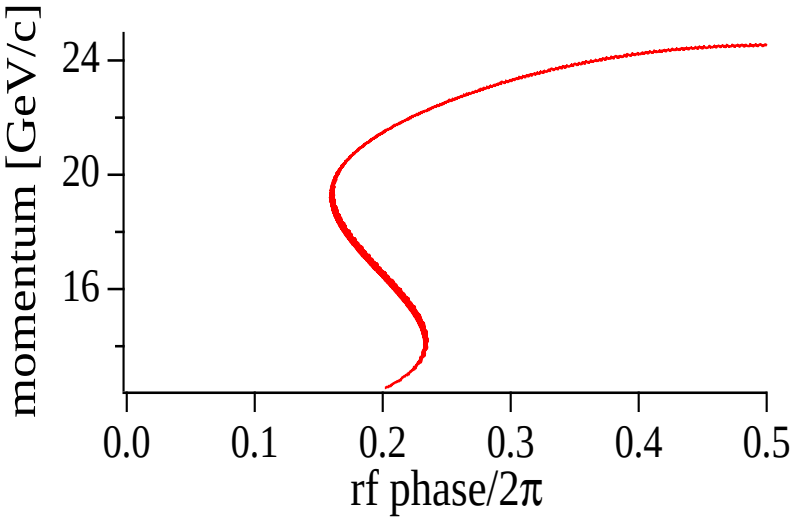
lqf = +2.1965 m
thf = -3.1046e-02 rad
dxf = -1.9979e-03 m
b0f = -8.3898e-01 T
b1f = +1.2202e+01 T/m

Problems of NS-FFAG

- Very compact lattice with short straight sections makes injection/extraction difficult.
- Due to natural chromaticity time of flight depends on amplitude, which introduces longitudinal blow-up and limits acceptance.
- Beam loading.



Natural chromaticity

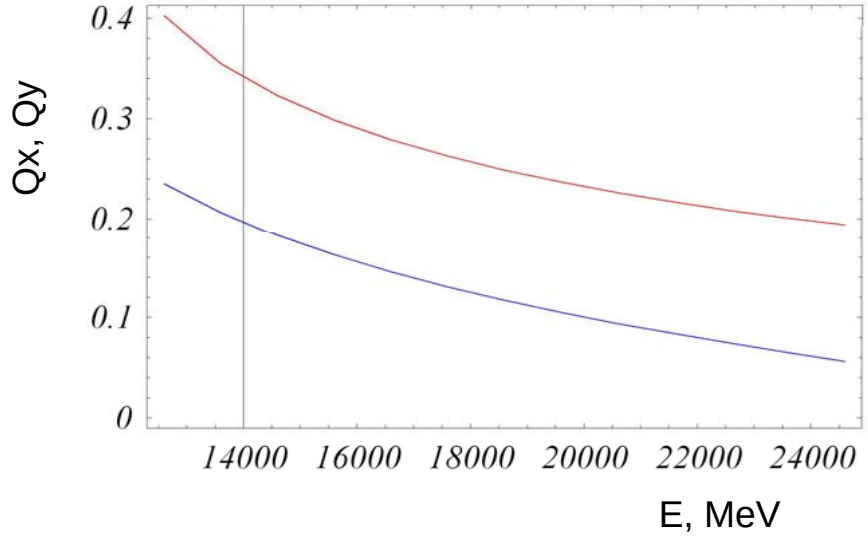


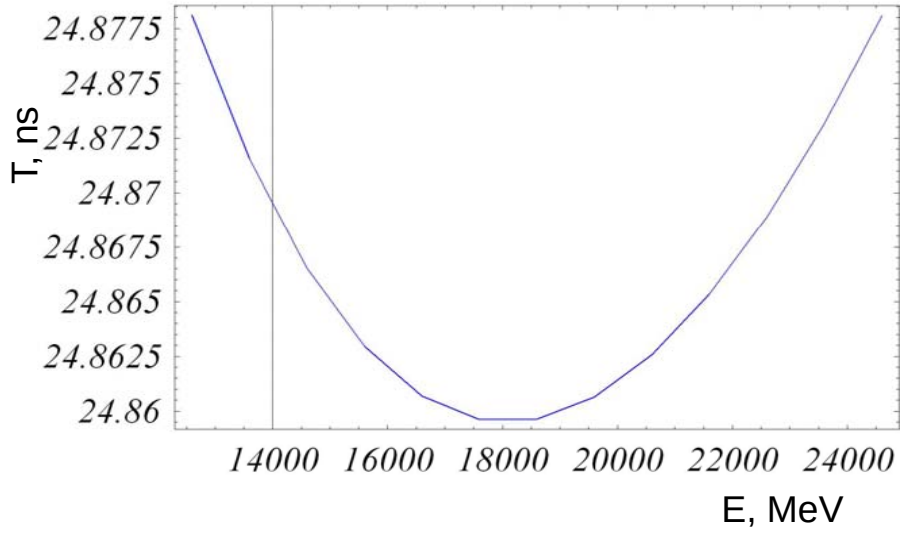
Corrected chromaticity, study by S. Machida

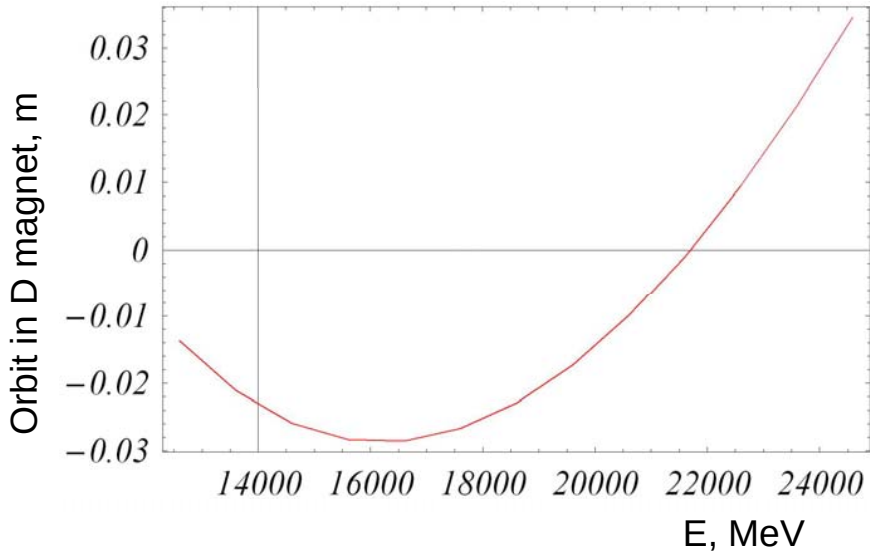
Goals of IDS/EUROnu FFAG study:

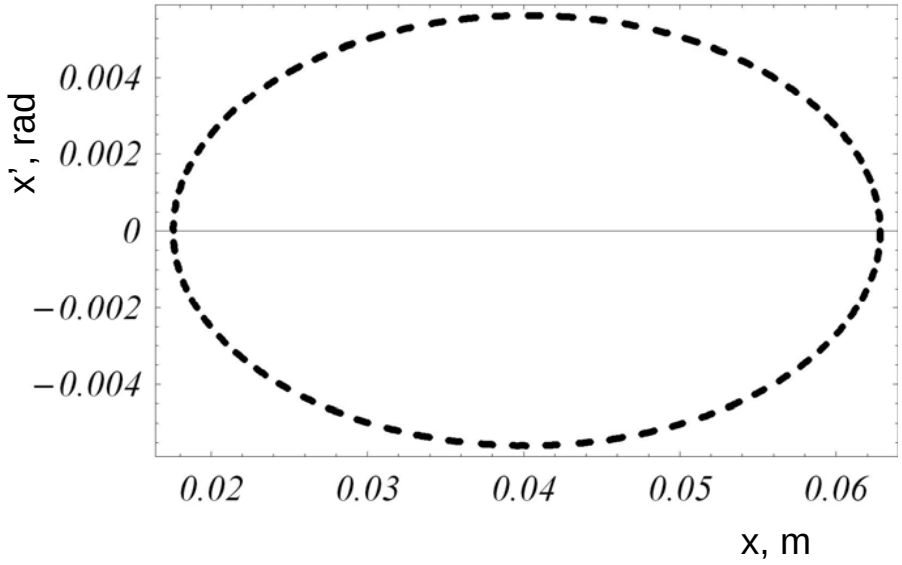
- Make an independent crosscheck of beam dynamics principles
- Design realistic injection/extraction systems
- Obtain the working lattice solution
- Model the essential hardware components
- Make the realistic cost estimate
- Contribute to end-to-end simulations

Beam dynamics in IDS NS-FFAG (BeamOptics)

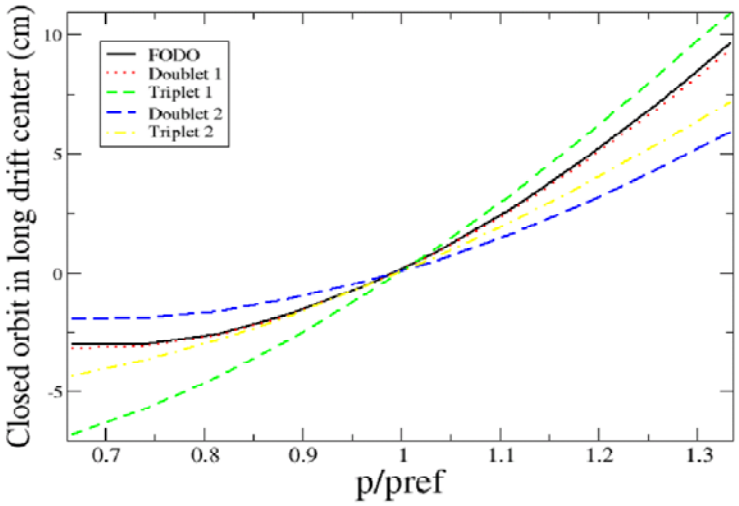


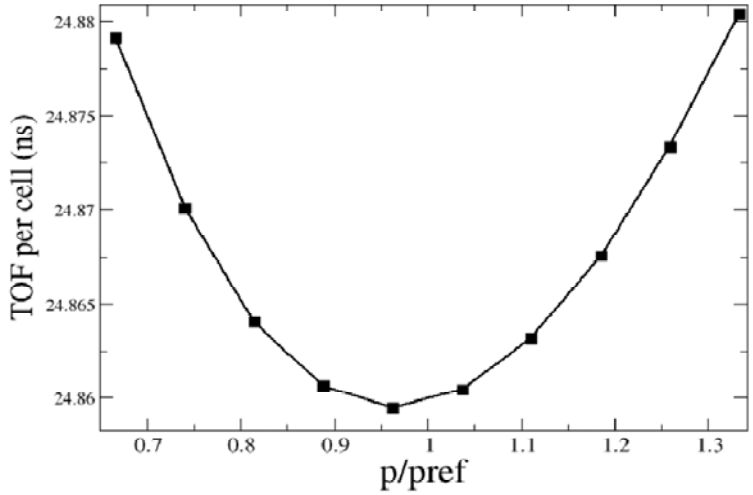


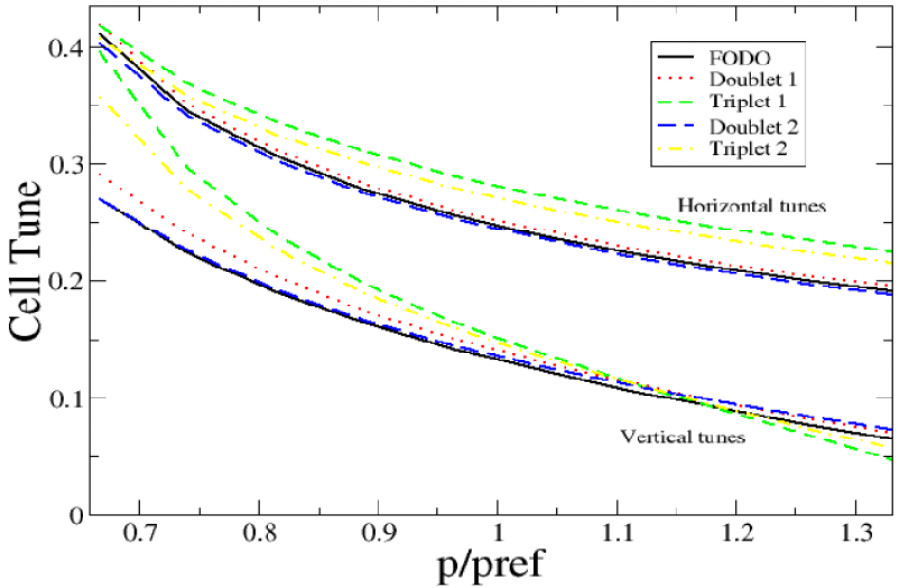




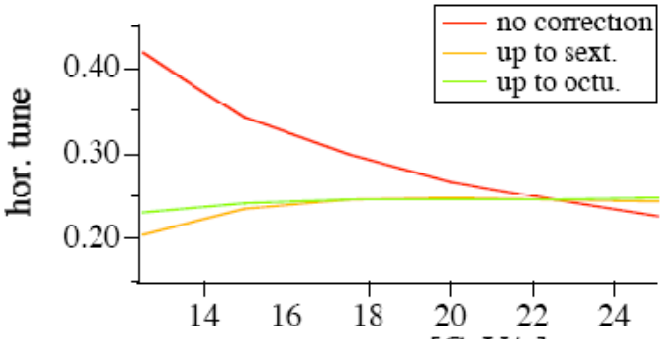
Beam dynamics using Zgoubi – D. Kelliher

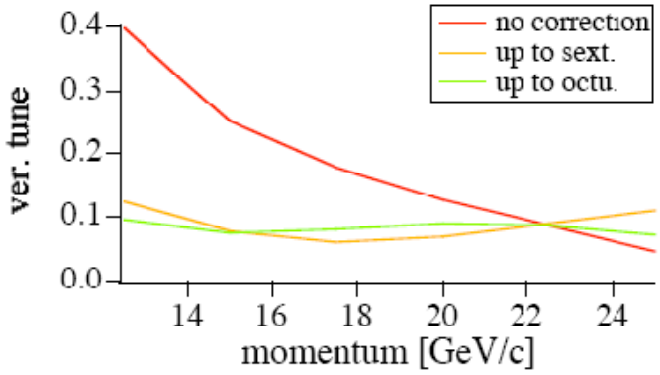




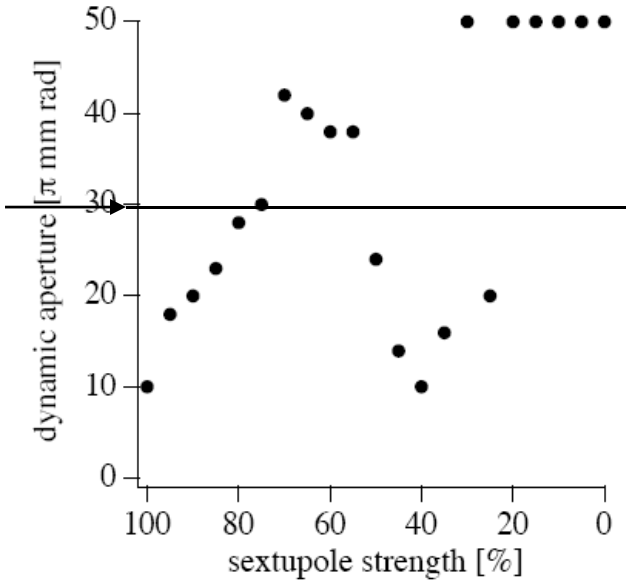


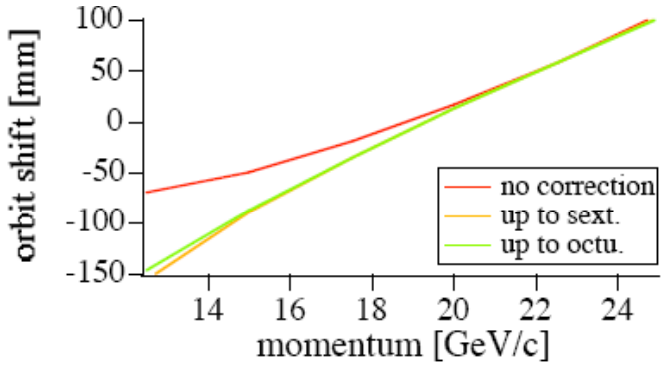
Chromaticity correction (S. Machida)



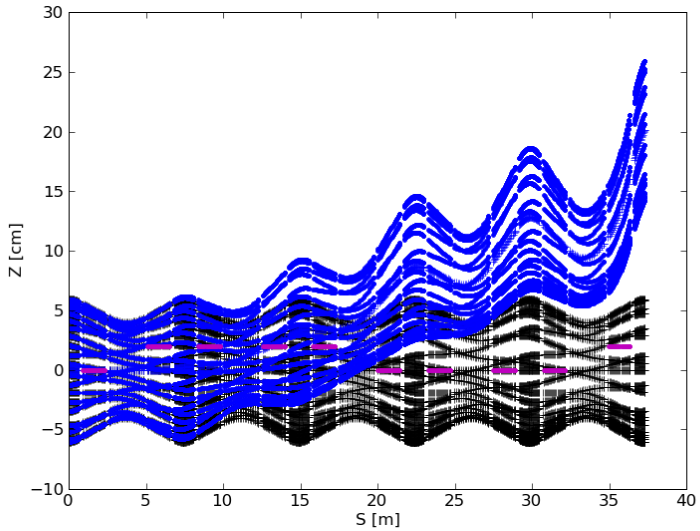


Required DA

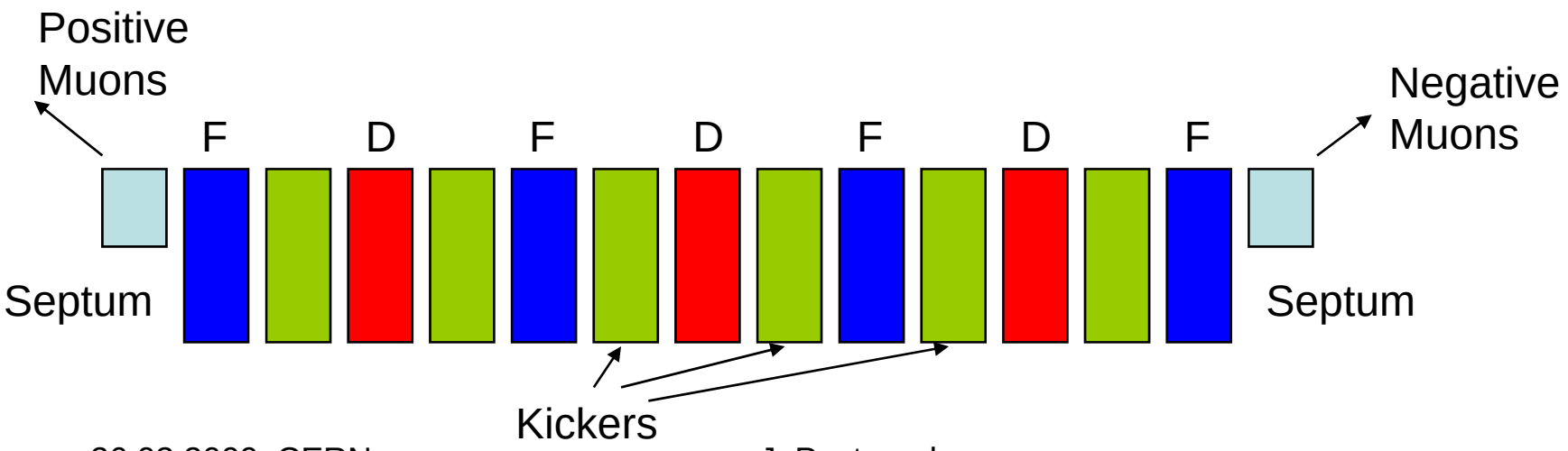




Extraction at 25 GeV (work with D. Kalliher)

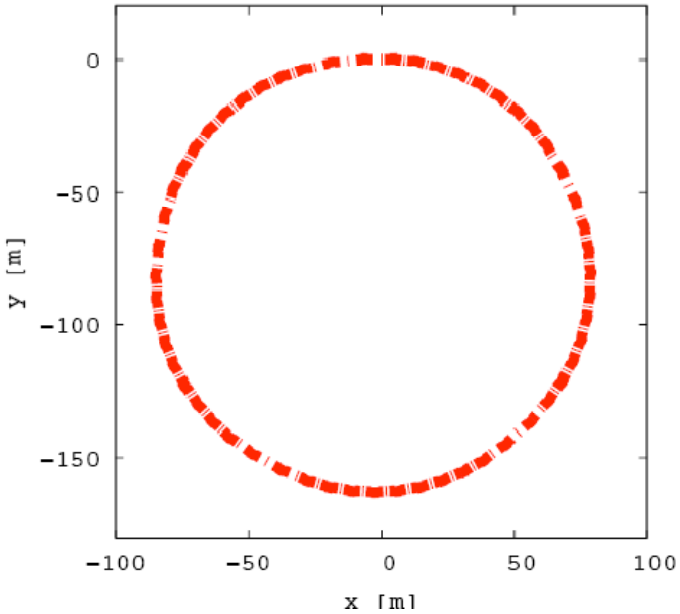


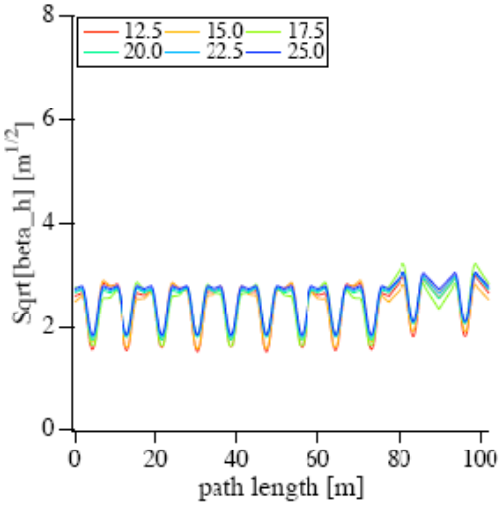
- We try to distribute kickers to reduce strengths (0.07 T).
- Extraction seems to be easier in vertical plane.
- It looks, that we need superconducting septum magnets (4 T).
- We try to use the same kickers for both signs of muons

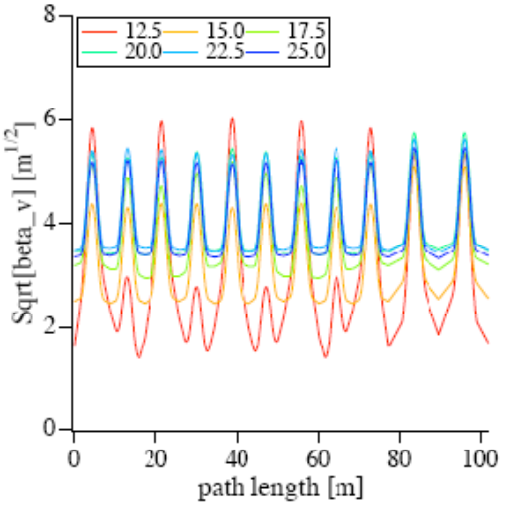


Lattice with insertion (S. Machida)

- Lattice with insertions (superperiodicity 5) proposed in order to increase the drift length (7m).
- Lattice is based on 70% chromaticity correction.
- Results are very promising!







Summary and future plans for muon NS-FFAG

- Reference design for the muon acceleration in the Neutrino Factory exists.
- Beam dynamics has been successfully checked using independent codes.
- First results on beam extraction were obtained.
- New lattice solution with insertions and chromaticity correction was proposed

- Work continues on injection/extraction, towards lattices with insertions and chromaticity correction
- We are on the good path!