Imperial College London

Science & Technology Facilities Council
ISIS

The Decay Ring, FFAG Racetrack

J-B. Lagrange[1], Y. Mori[1],
J. Pasternak[2] (presenter),
A. Sato[3]

[1]Kyoto University
[2]Imperial College London/RAL-STFC
[3]Osaka University

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Outline

- Introduction
- Racetrack FFAG design
- Beam dynamics in the Racetrack FFAG
- Decay channel and injection design
- Summary and future plans

Introduction

nuSTORM is a very interesting project:

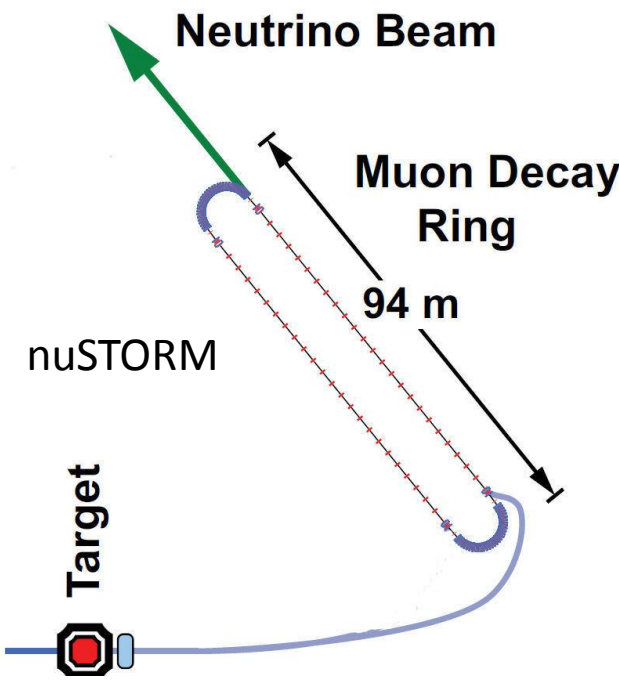
- It has a very strong physics case (sterile neutrino search, precise cross section measurements especially for ν_es and more...)

- It may serve as a demonstration for the Neutrino Factory (muon storage ring based neutrino experiment), but also for a generic future muon accelerator.

- It may become an ideal test for accelerator and detector techniques needed in a future.

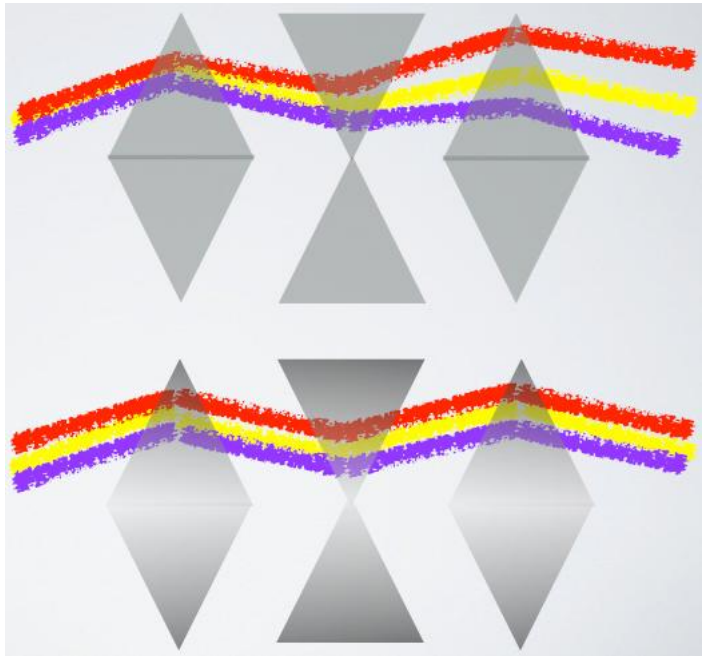
- NuStorm may become the first muon FFAG

- ... Even more it may have other potential uses (beam formation for an advanced muon cooling demonstration).



Why FFAG decay ring?

•FFAGs are very attractive for muons as:
-They have a huge transverse and longitudinal acceptance
-Can perform very rapid acceleration
-Can be constructed with the present-day technology.
-Scaling FFAGs allows to fix the working
point (to avoid resonance crossing for the large momentum spread).
-Can offer higher performance!



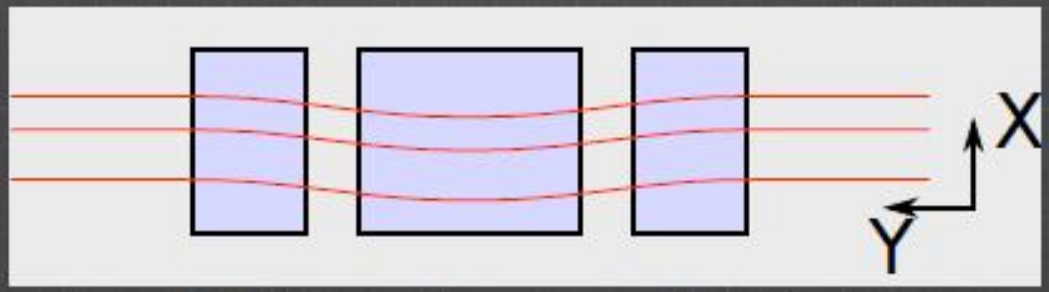
Non-zero chromaticity
(optics non- invariant
with respect to
momentum)

Zero chromaticity
(optics invariant
with respect to
momentum)

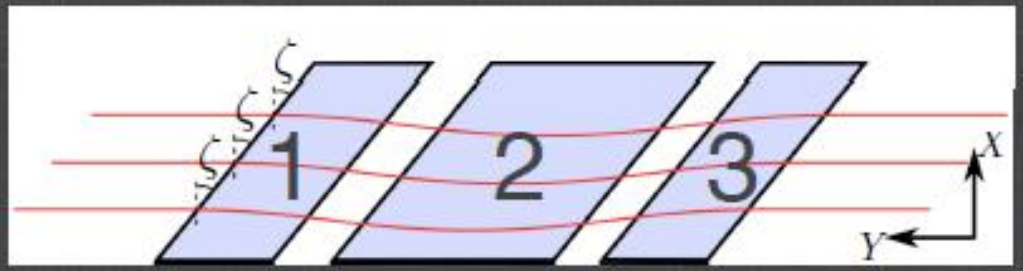
New straight scaling FFAG solution (with zero chromaticity)

$\zeta = const. \quad \Longleftrightarrow \quad m = const.$

$$B(X,Y) = B_0 e^{m(X-X_0)} \mathcal{F}\left(Y - (X - X_0)\tan\zeta\right)$$



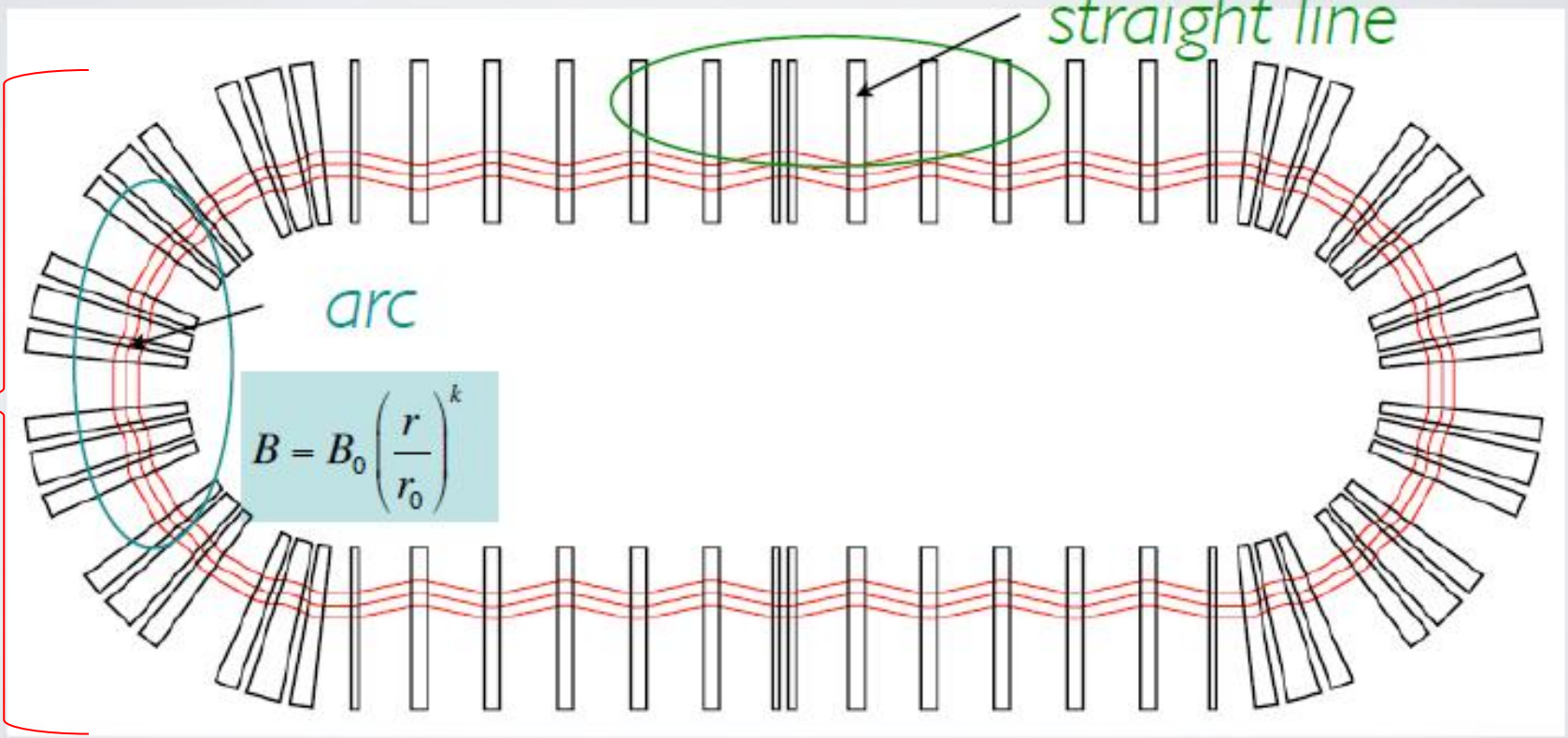
Rectangular case: $\zeta = 0$



Tilted straight case: $\zeta = const.$

RACE TRACK FFAG RING

$$B_z = B_0 \exp\left[\frac{n}{\rho}x\right]$$



Multiple of π phase advance in the arc

Small scallop will have a negligible effect on the neutrino flux

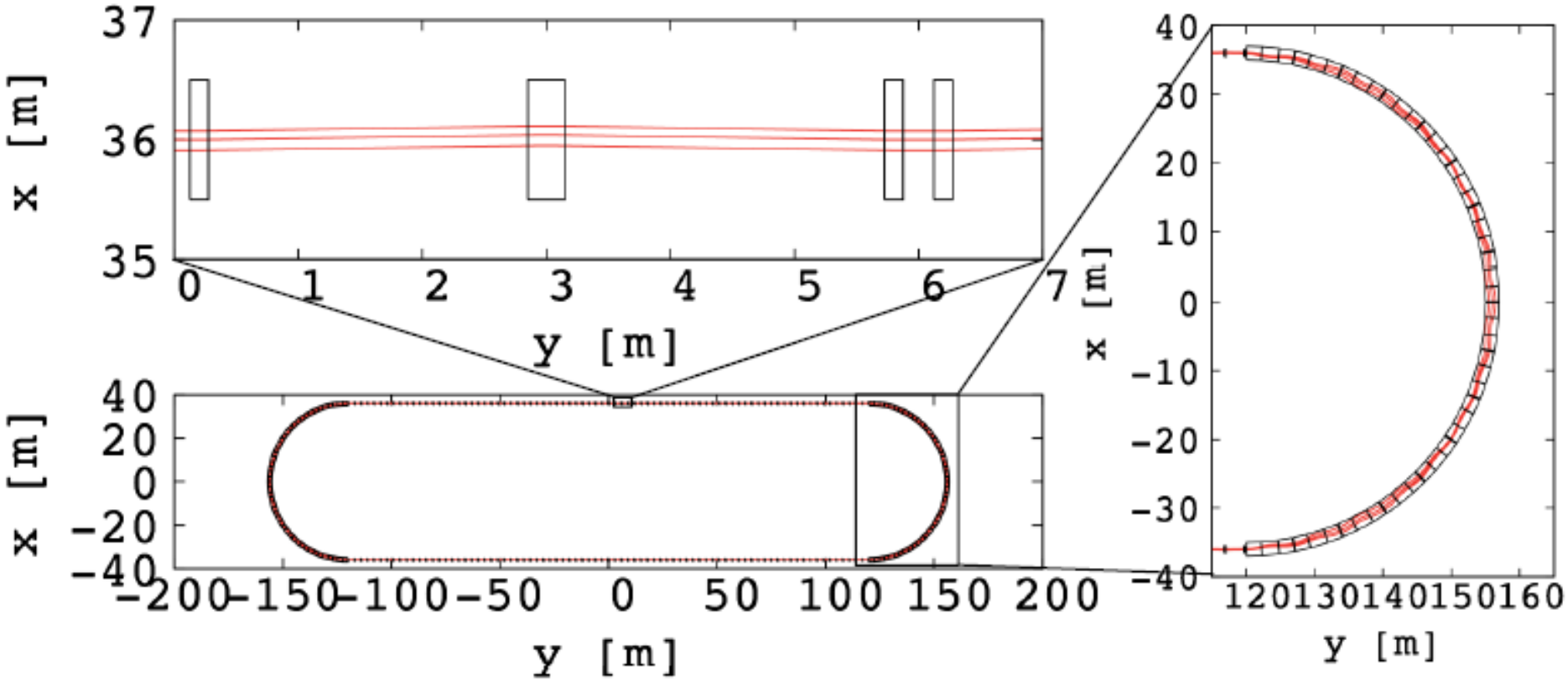
Racetrack FFAG for νSTORM

Constraint: in the straight part, the scallop must be as small as possible.

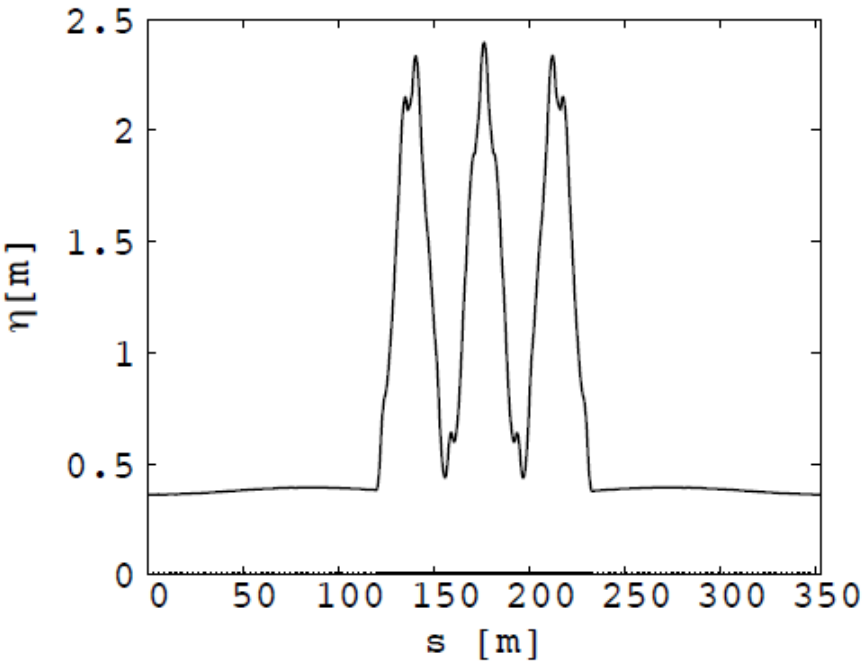
15 mrad has been chosen as the maximum angle.

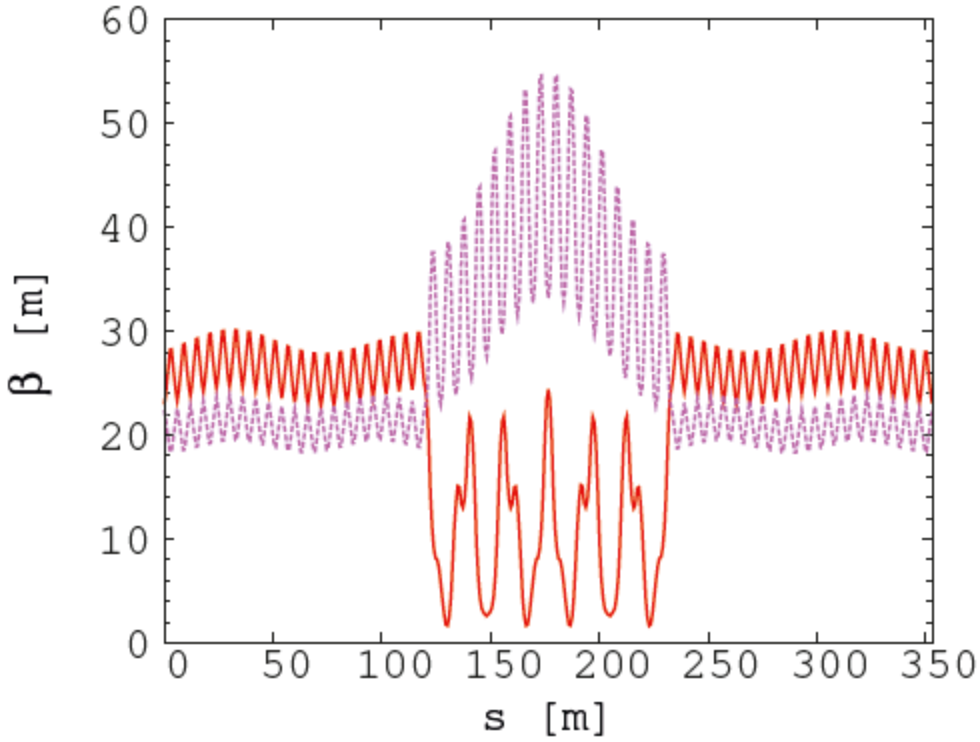
	Circular Section	Straight Section
Type	FDF	DFD
Cell radius [m]/opening angle [deg] or Length [m]	36/11.25	6
k-value or m-value	24.95	2.65 m^{-1}
Packing factor	0.96	0.10
Horizontal phase advance /cell [deg]	67.5	13.1
Vertical phase advance /cell [deg]	11.25	16.7
Average dispersion /cell [m]	1.39	0.38
Number of cells /ring	16 × 2	40 × 2

Racetrack FFAG Decay Ring Layout

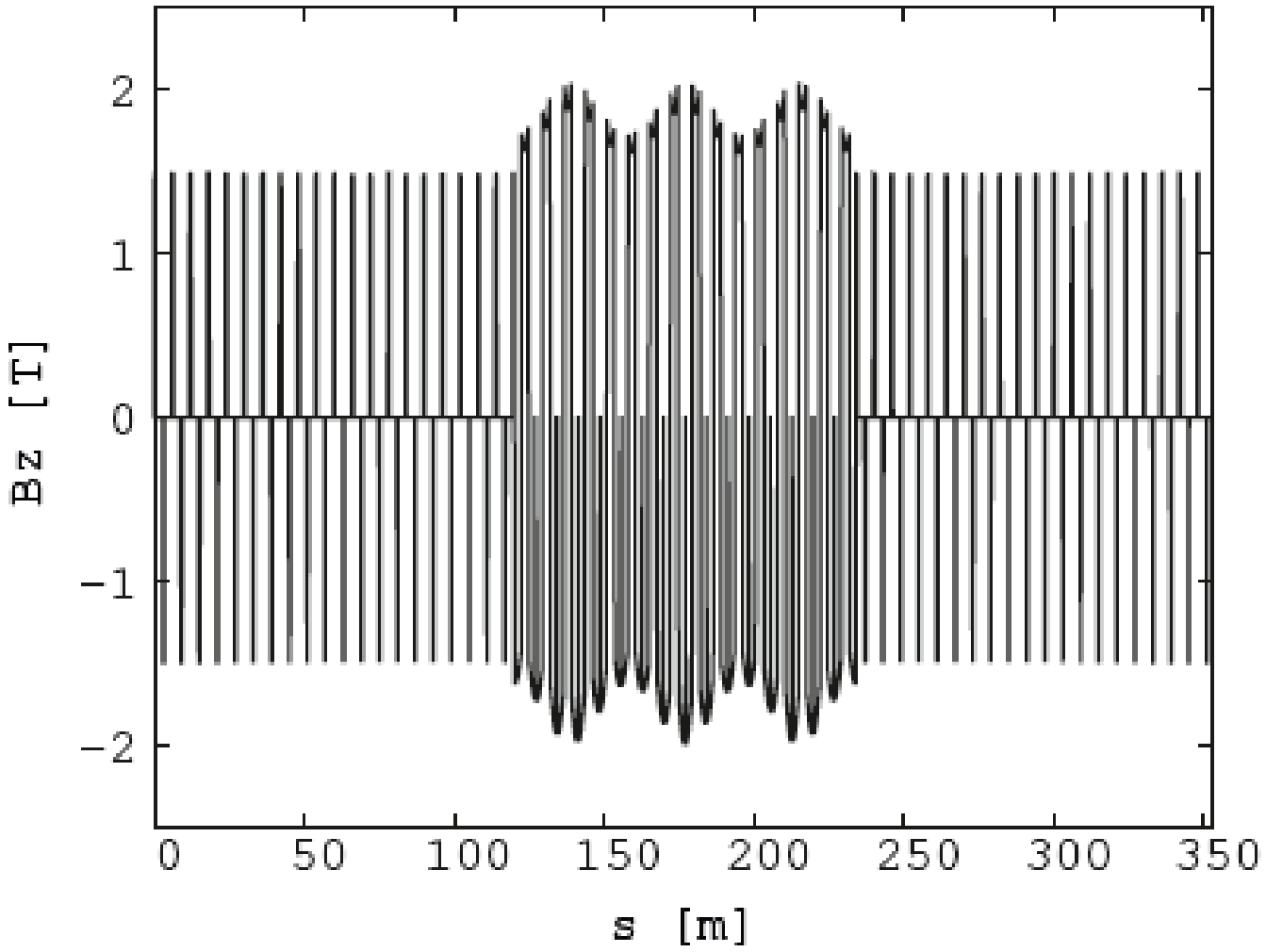


Optics in the Racetrack FFAG Decay Ring

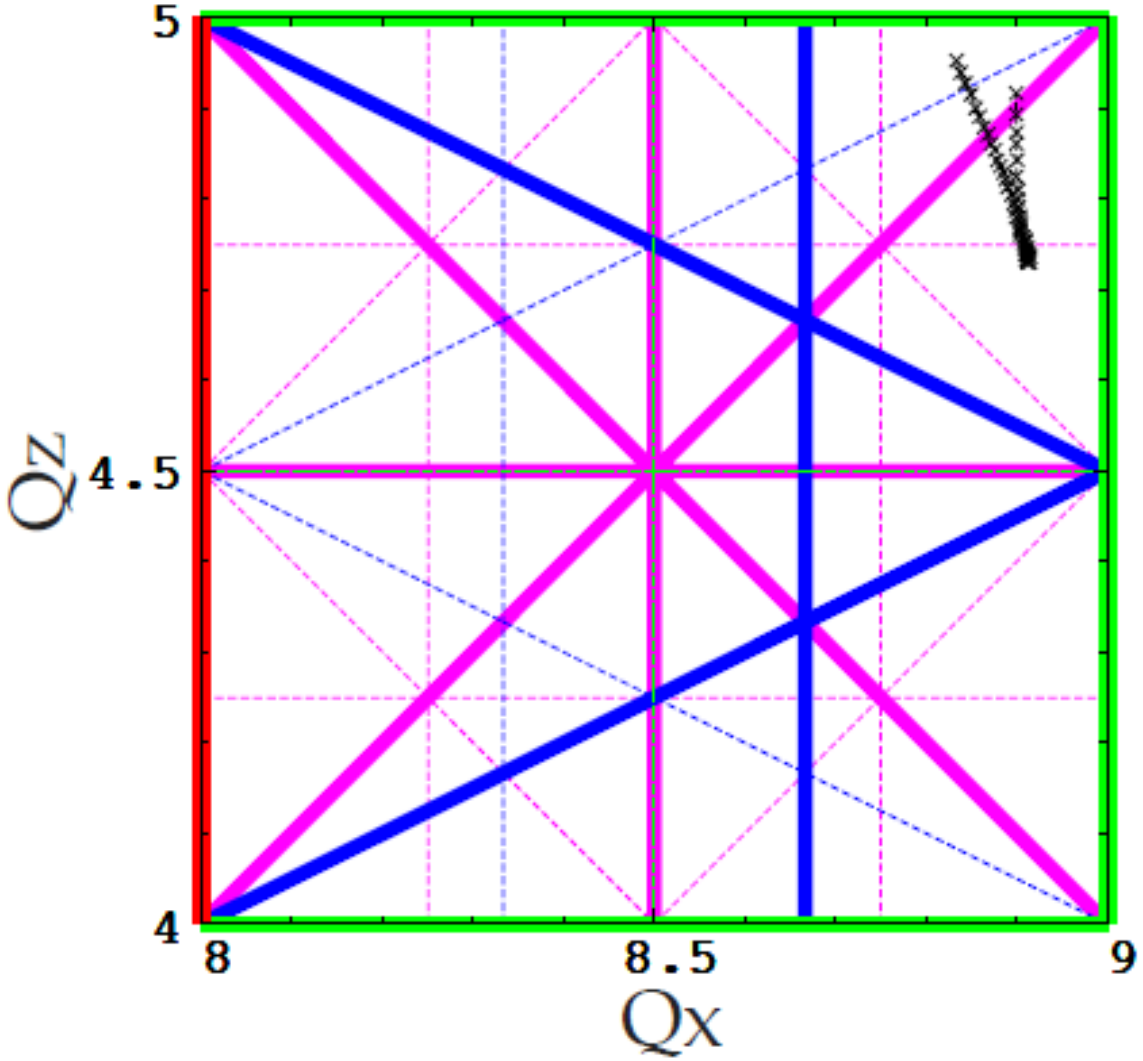




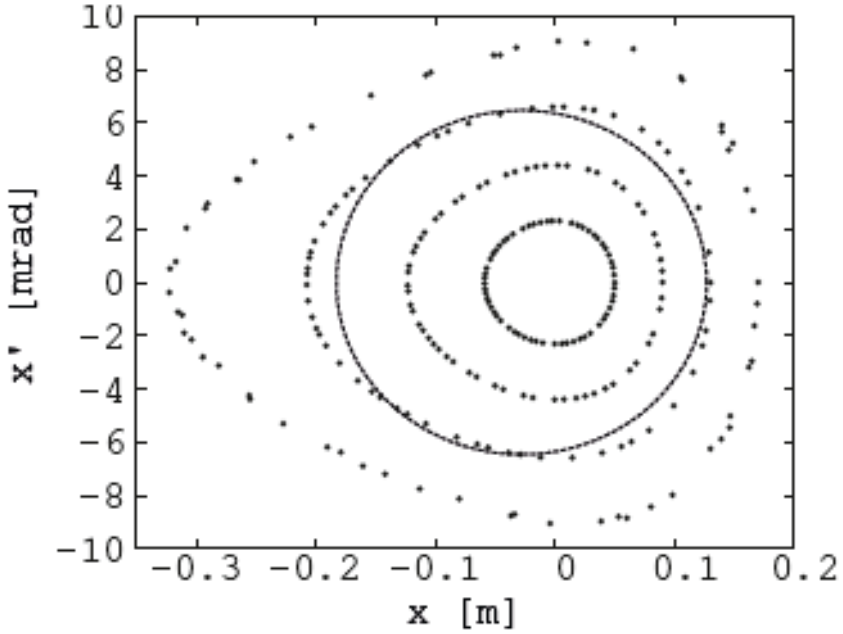
Summary of the maximum vertical magnetic fields in the magnets

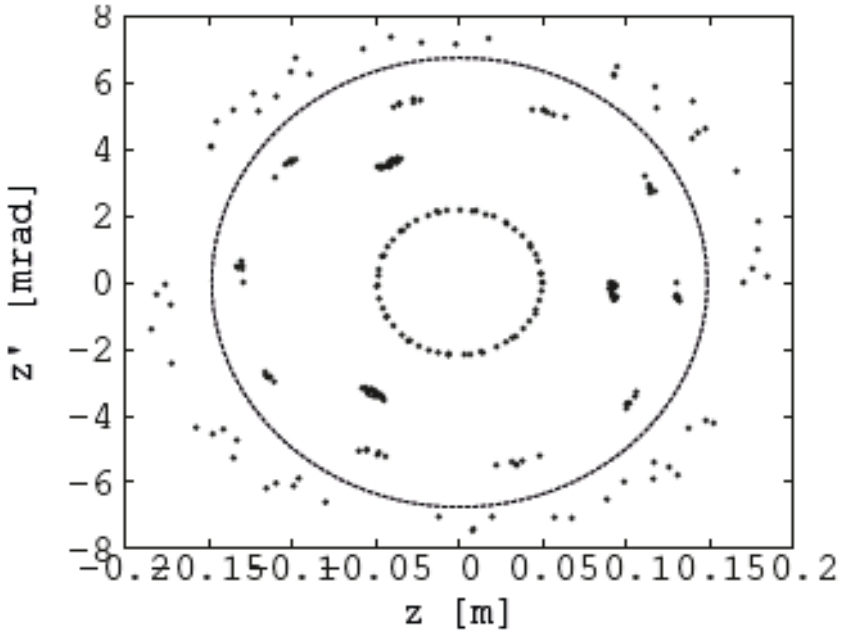


Tune diagram for ±26% momentum spread



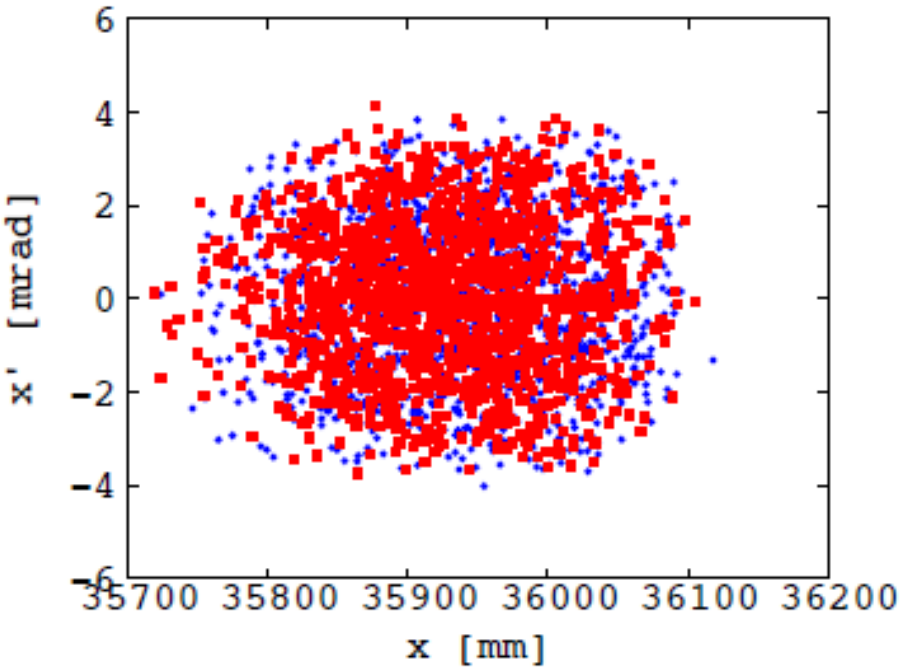
Acceptance studies

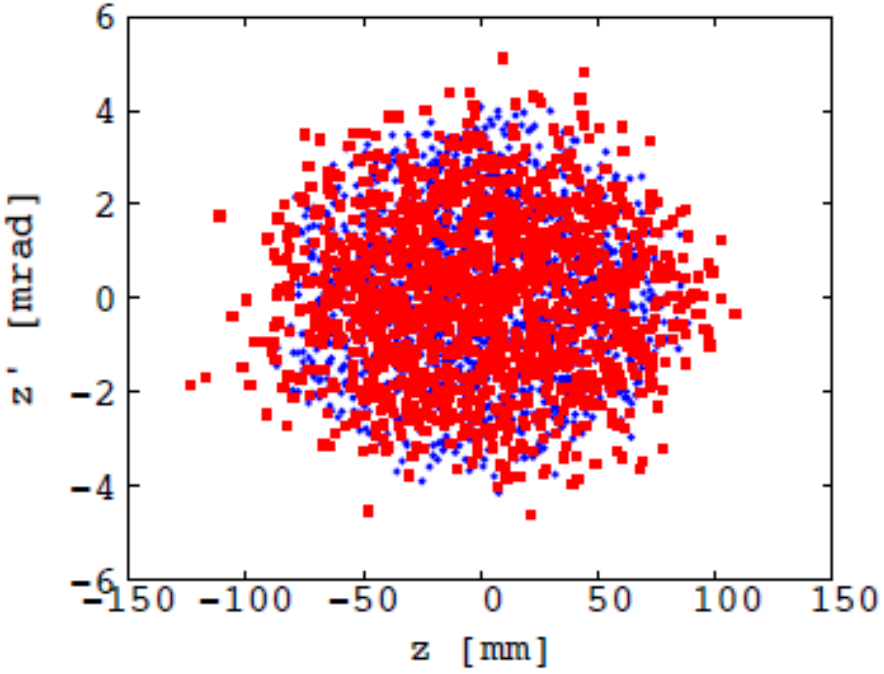




Elipse corresponds to 1 Pi mm rad unnormalized emittance.

Tracking studies



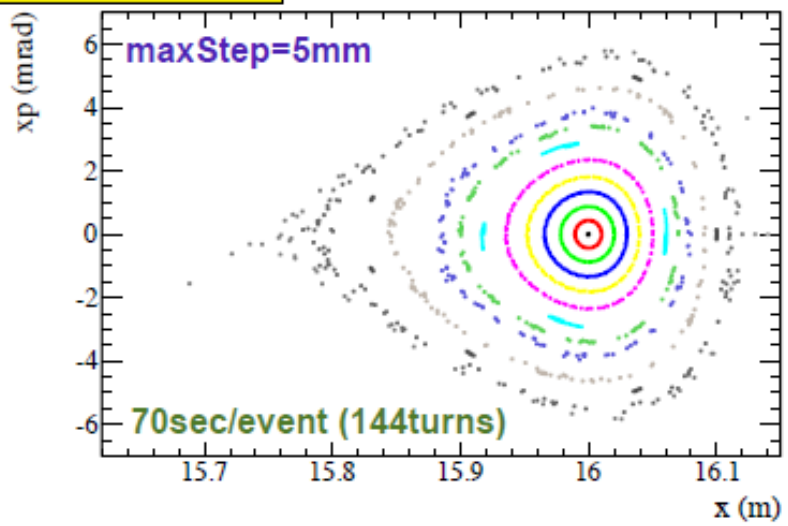


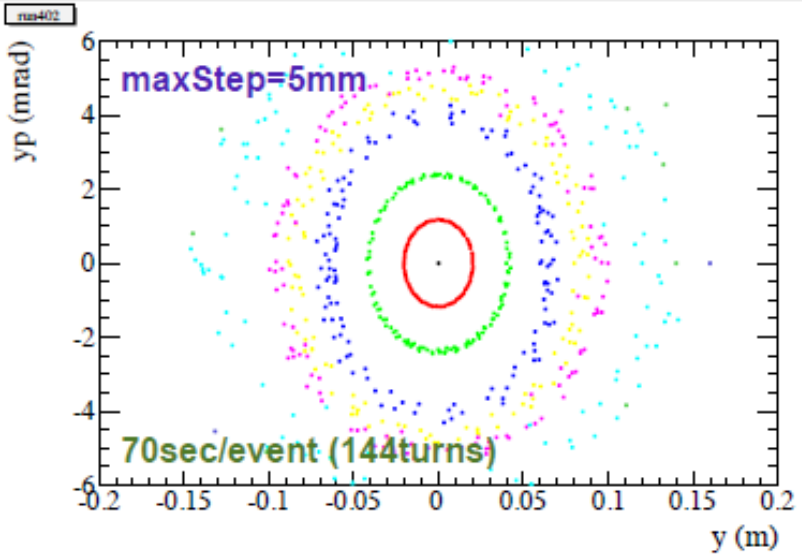
extraction
injection

- 60 turns
- Initial Waterbag distribution
- ±26% momentum spread
- Only 0.7 % beam loss!

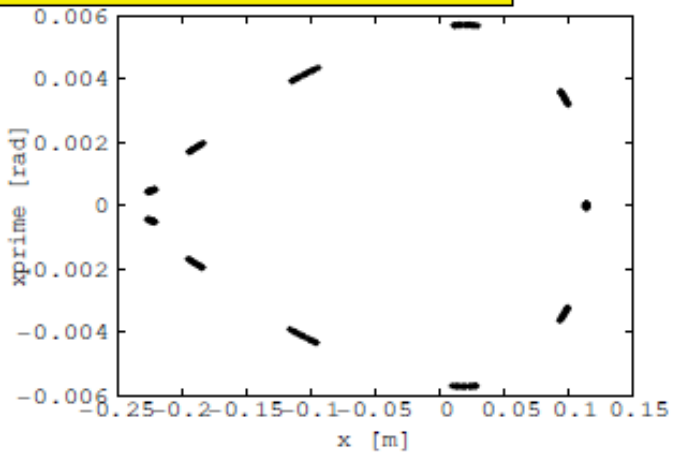
Code comparison for the 2 GeV/c FFAG ring version

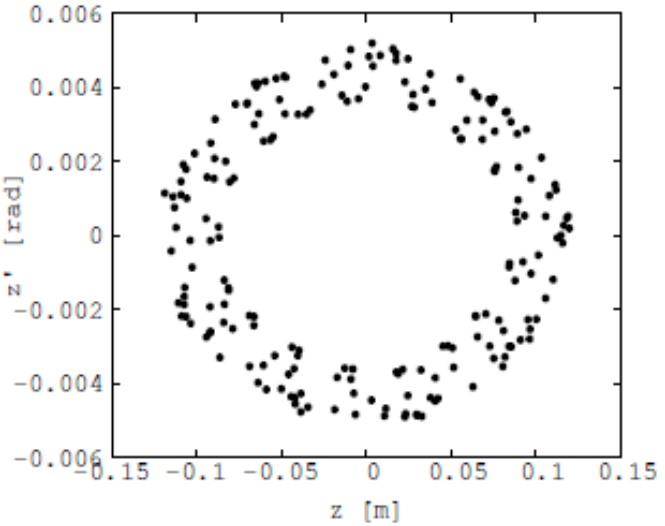
g4beamline





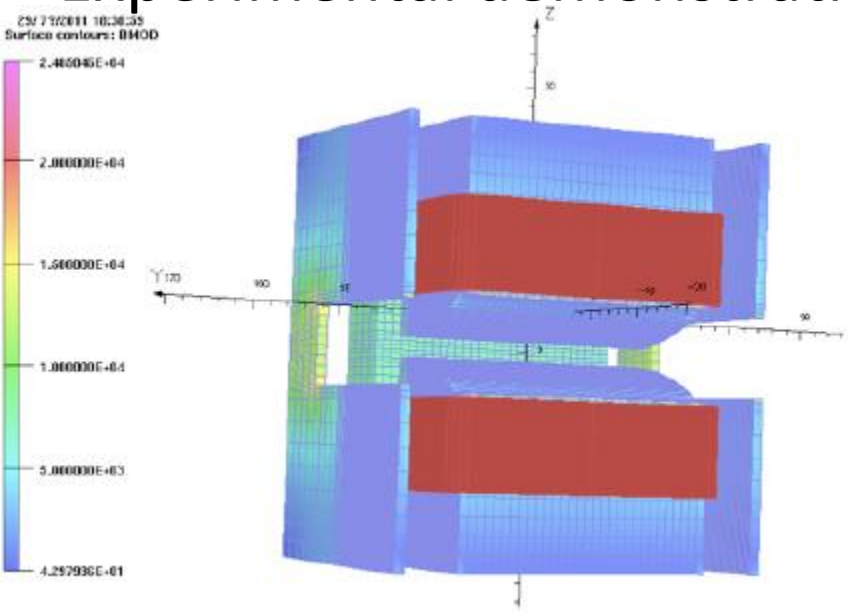
JB's original tracking code



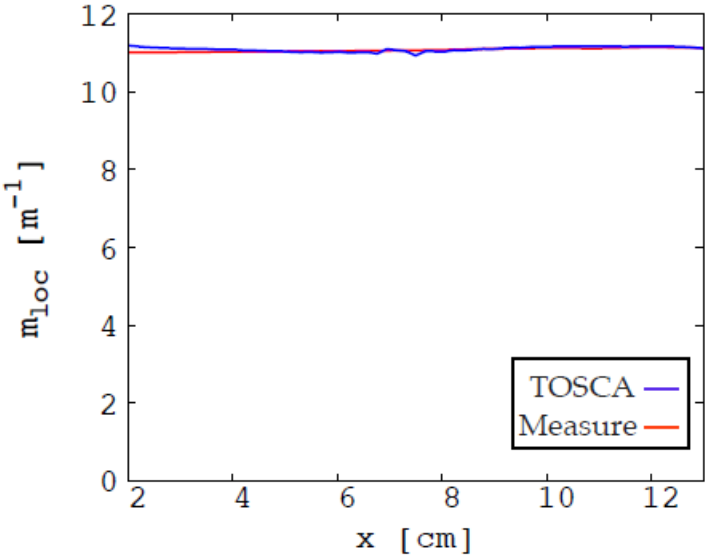


Studies for 3.8 GeV/c case -> work in progress...

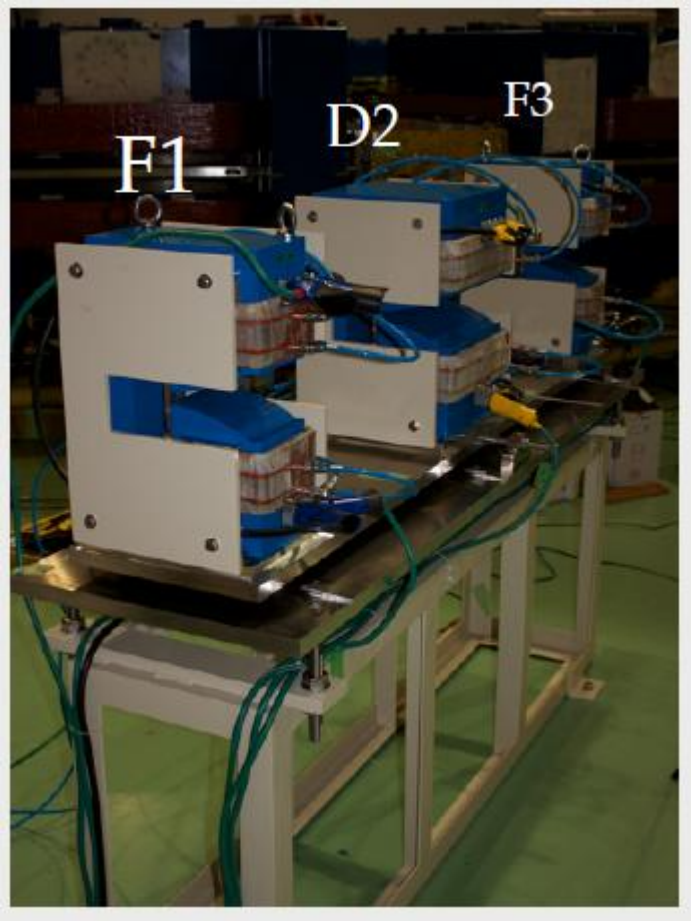
Experimental demonstration of the straight FFAG at KURRI



Straight FFAG magnet were design in TOSCA



Measured effective m value for different horizontal positions



Straight FFAG triplet section was constructed, measured and tested with beam .
The principle is proven experimentally!

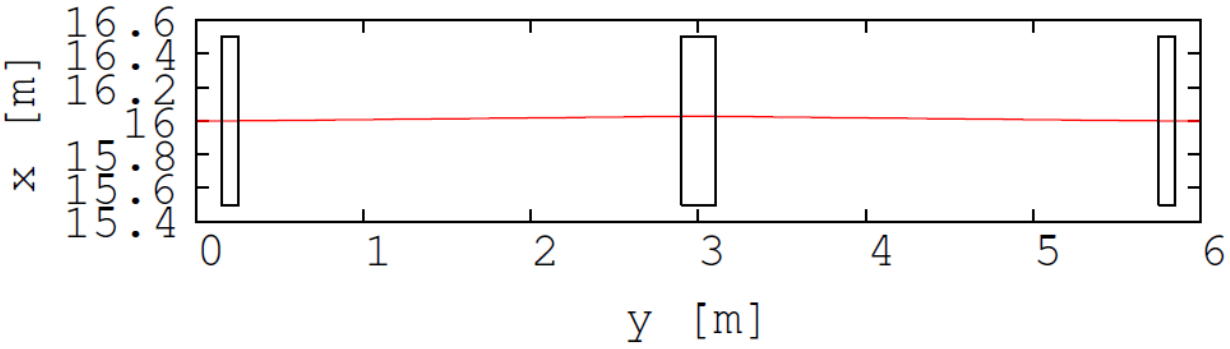
Results are very promising!

Assumptions and observations

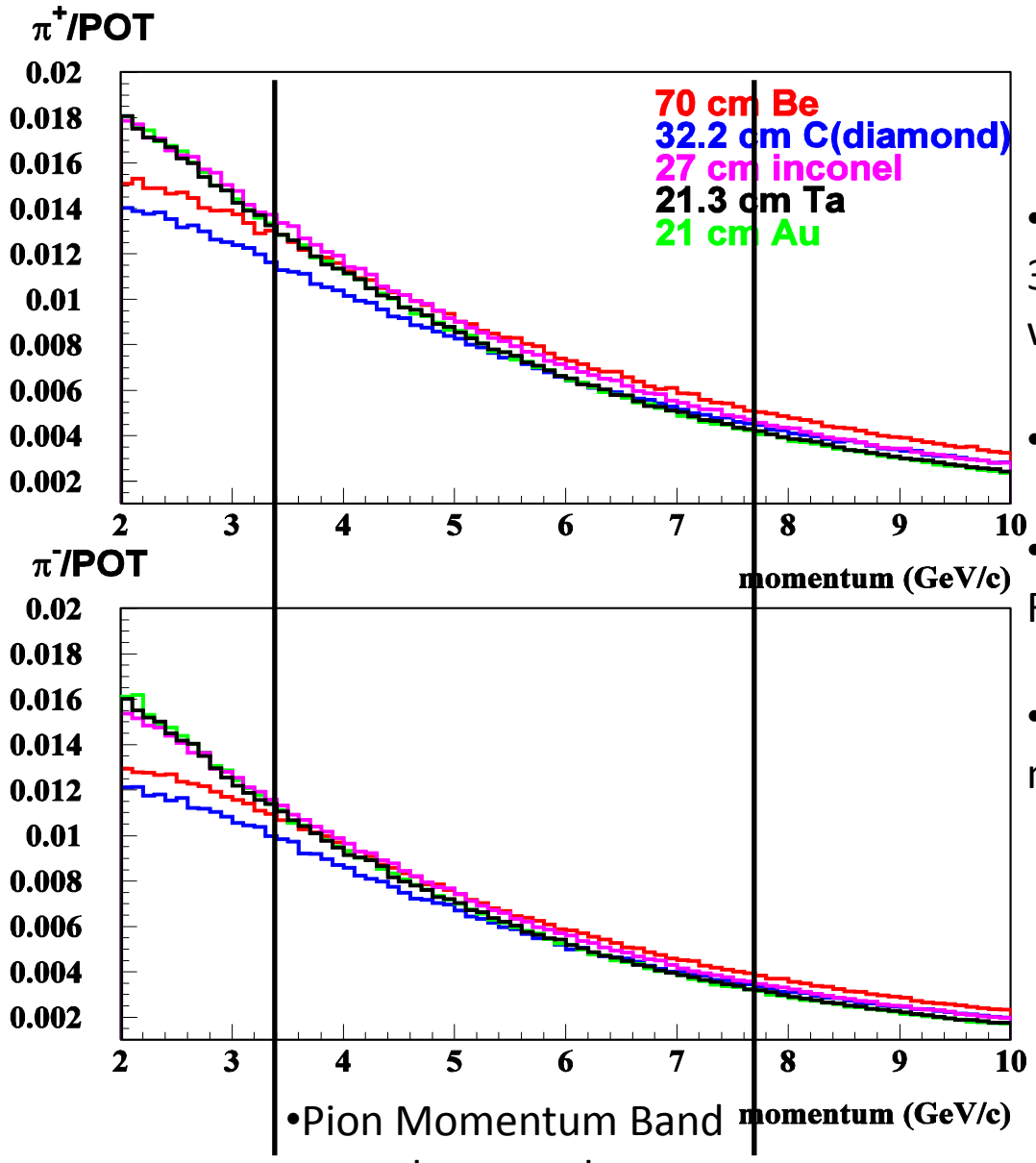
- The drift length in the straights are long (about 2.6 m) in the Racetrack FFAG decay ring.
- They are ideal places to put kickers and septum.

- We try to design injection system assuming that the muon beam is formed in the decay channel.

- First we need a decay channel.



Considerations for decay channel



•Pion Momentum Band to produce good muons

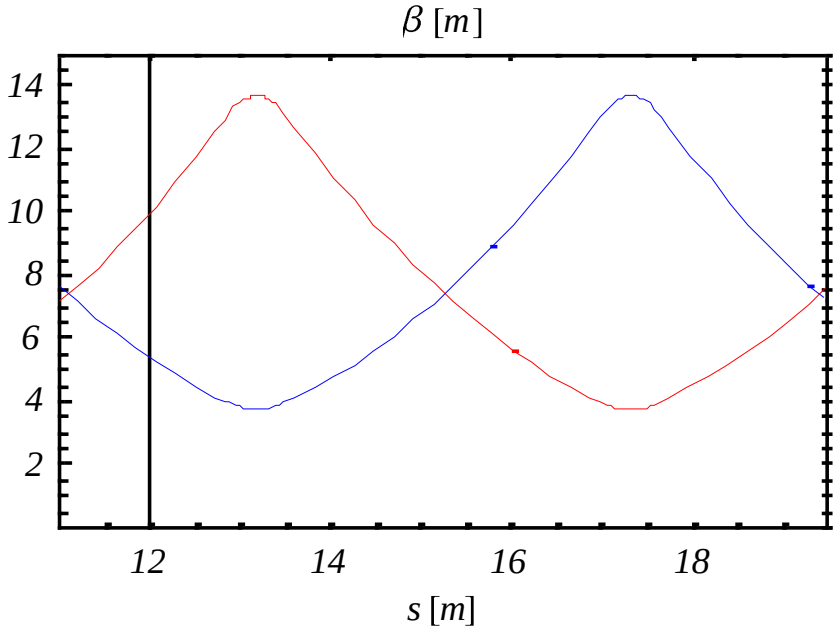
•Pions in the momentum between 3.19 and 7.69 GeV/c can produce muons within 3.8 GeV/c ±16%.

•Mean momentum is ~5440 MeV/c.

•Spill needs to be 50% of the Decay Ring length

• To use those muons, the decay length needs to be about 210 m (~69%/39% of low/high energy pions decays).

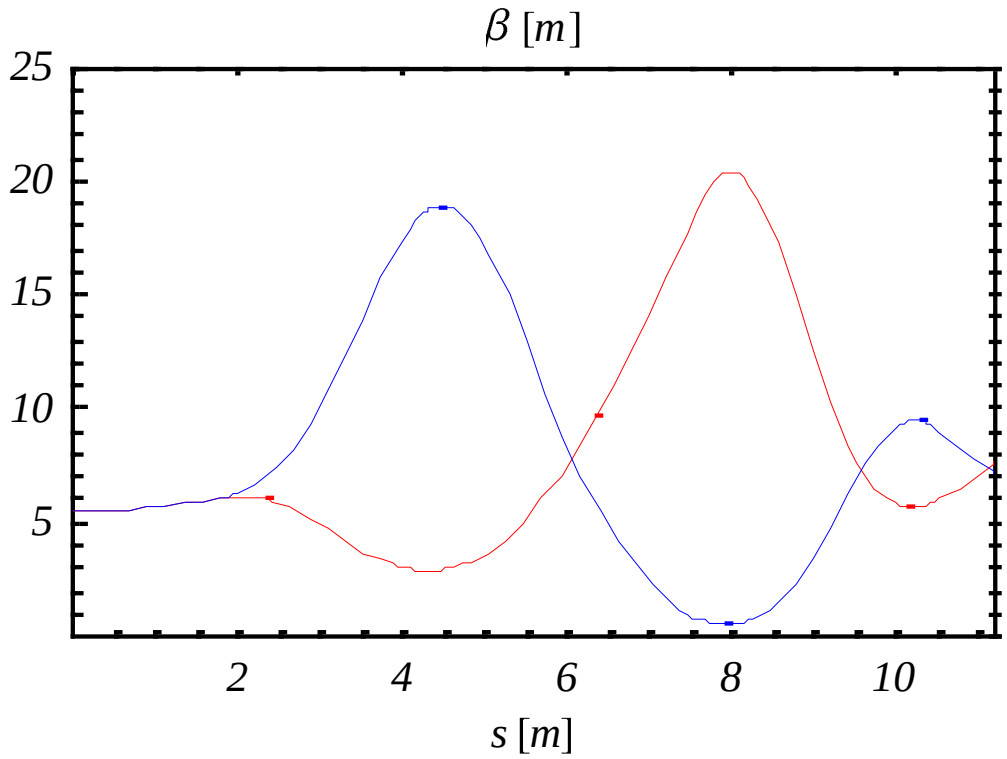
Decay Channel Considerations (2)



- Symmetric FODO type
- Cell length 8.3 m
- Quad length 0.65 m
- B field at the poles 1.4 T
- Half aperture 0.17 m -> Large quads!
- Central momenum 5440 MeV/c
- Momentum acceptance +-42%

  (for all pions contributing to the muons wanted-3.8 GeV/c+-16%, this means both forward and backward decays)
- Physical acceptance ~2 Pi.mm.rad
- Phase advance per cell 70 degrees
- Normal conducting quads

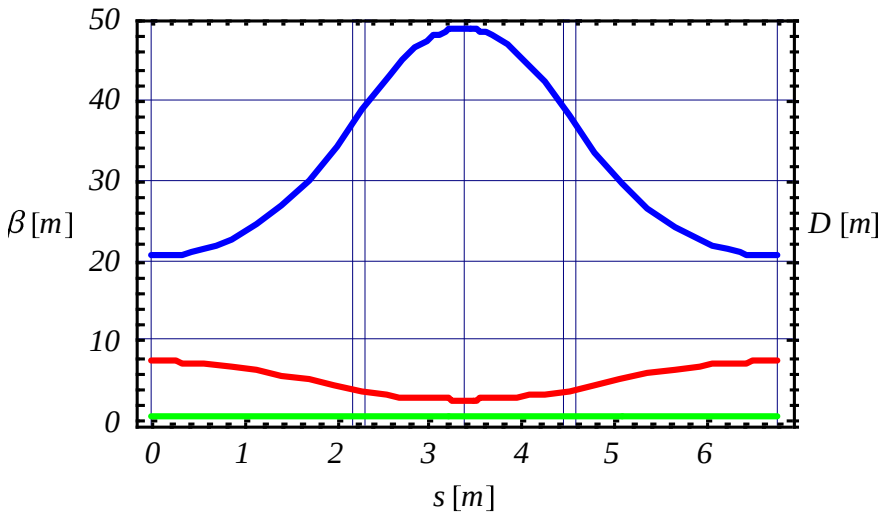
Matching with the horn

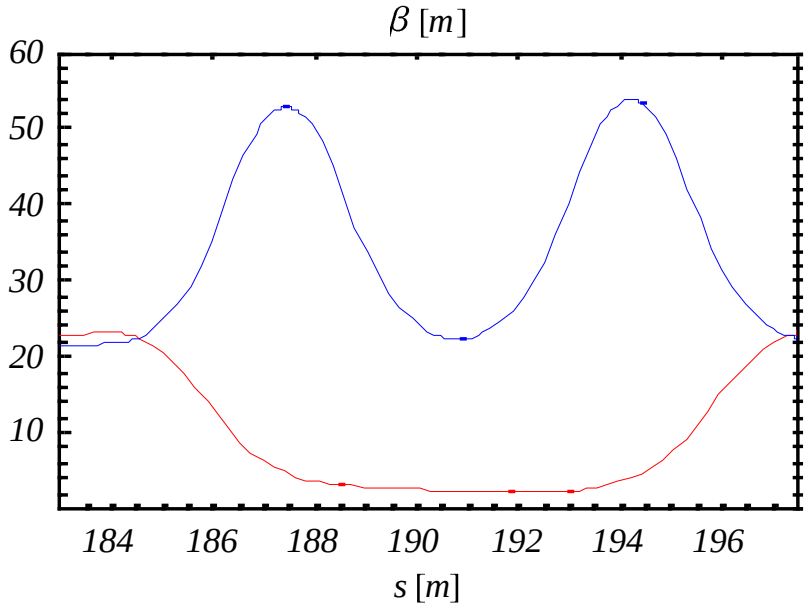


- Starting condition downstream the horn β=5.52 m, α=0.
- Consists of 4 normal conducting quads (max B about 2T).

Dispersion Creator to Match Ring Orbits

Symmetric optics

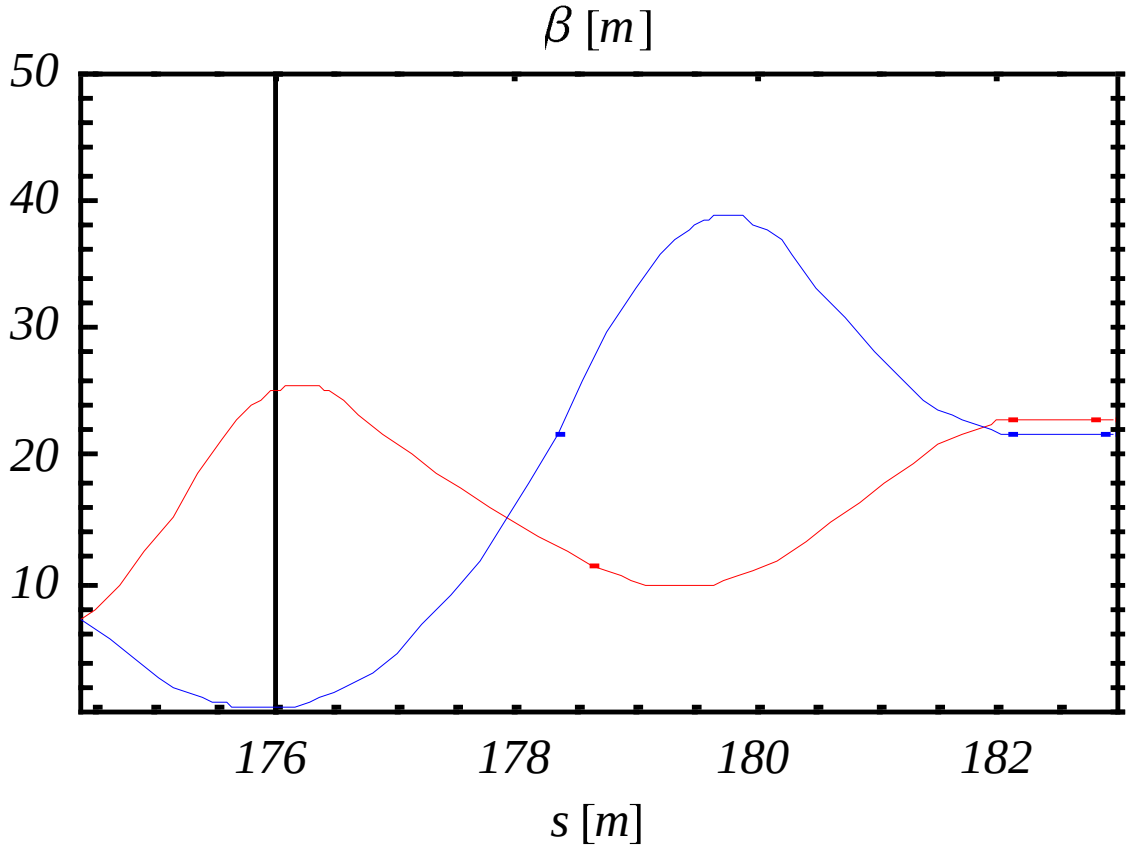




Optics included mismatch

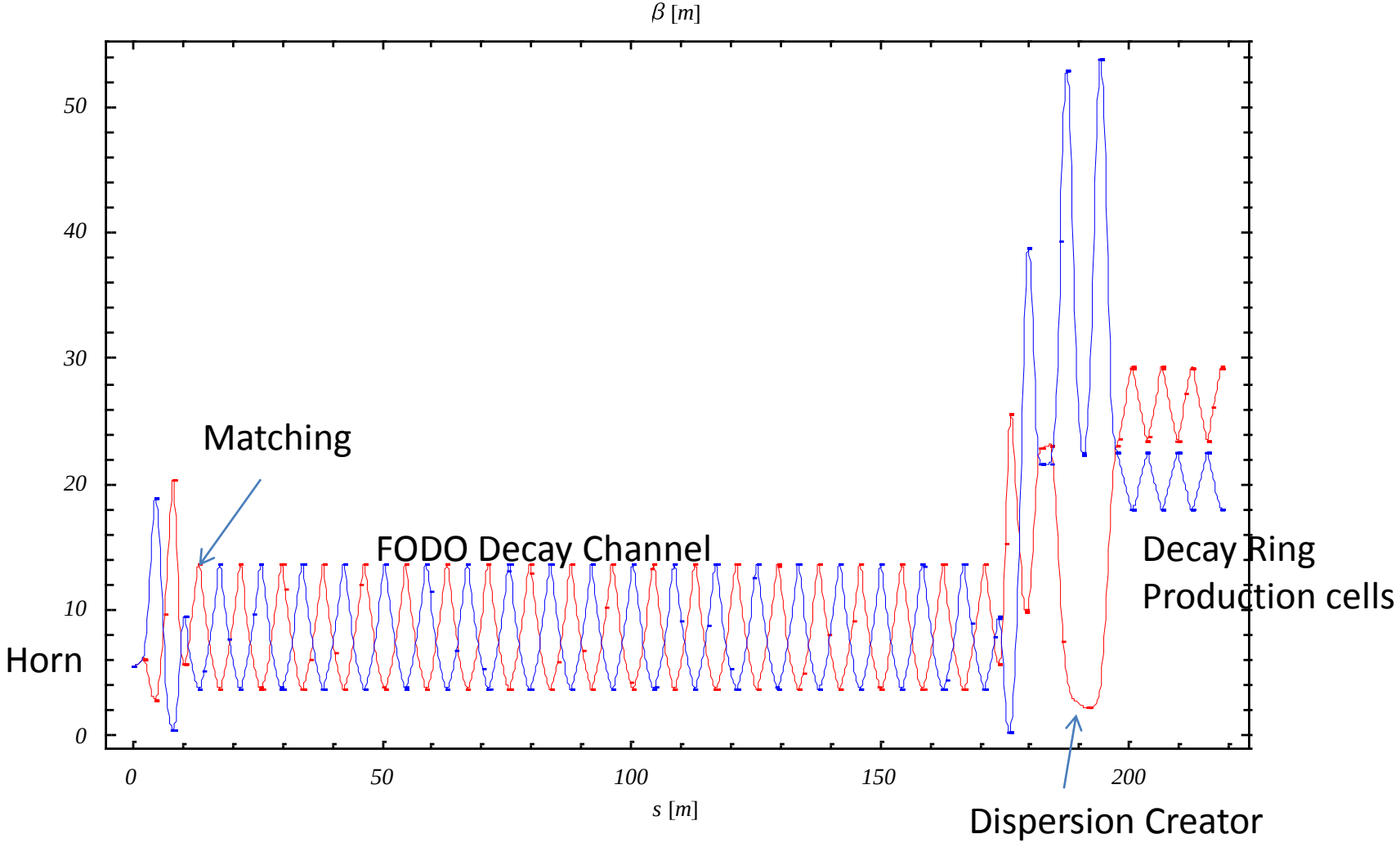
- 2 circular scaling FFAG cells
- 90% horizontal phase advance/cell
- R ~ 55 m
- Max B ~ 2 T (normal conducting)
- k 88
- Based on decay ring cell structure
- Effect of septum in beta matching is included.

Matching from FODO Channel into the Dispersion Creator



- Consists of 4 normal conducting quads (max B about 2T).

Optics in Pion/Muon Front End of FFAG decay ring ring for nuSTORM

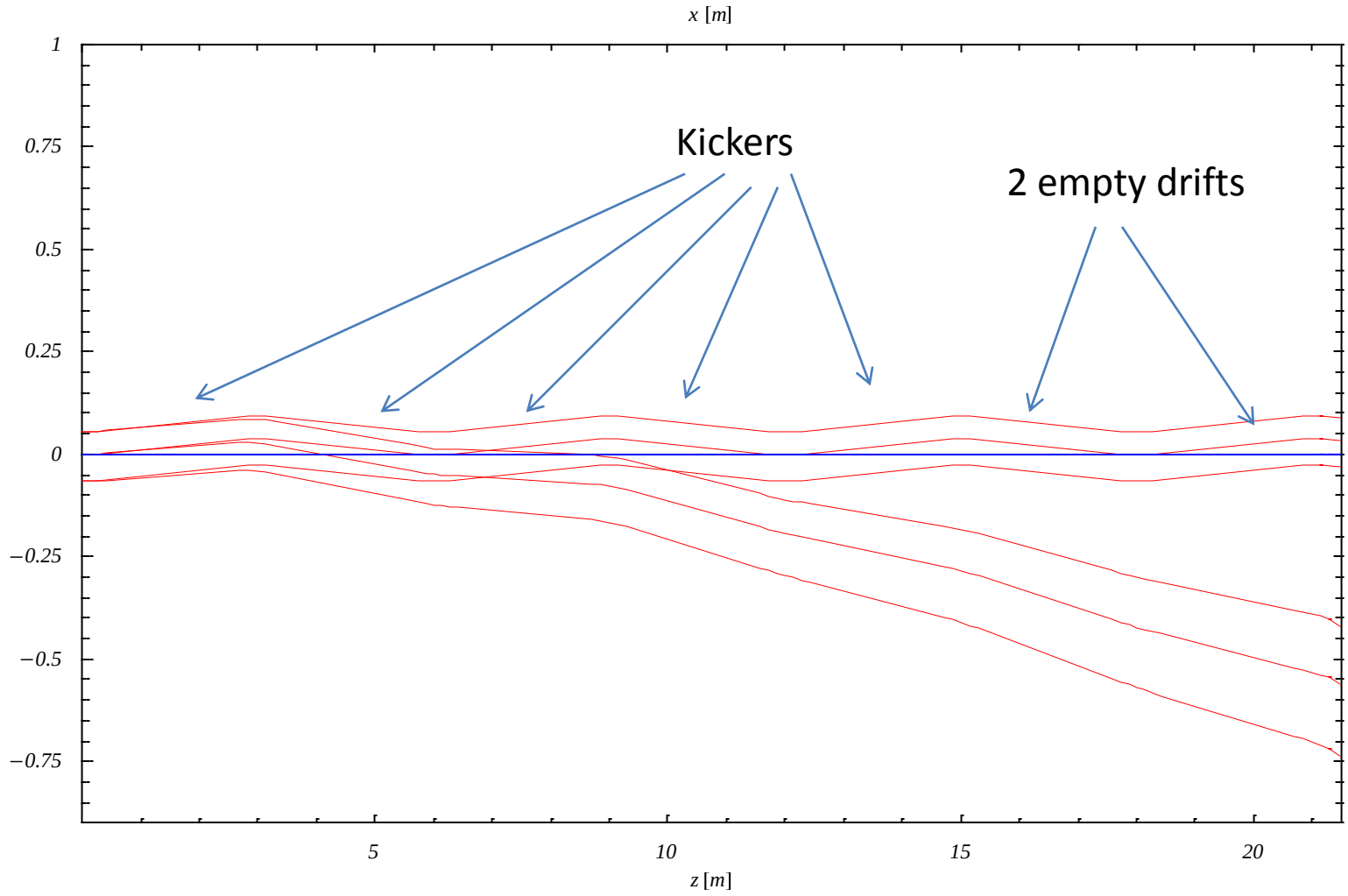


- Consists of only normal conducting magnets (max B about 2T).
- Matching at 5.44 GeV/c (in reality an adiabatic transition to 3.8 GeV/c at the end of FODO is needed.

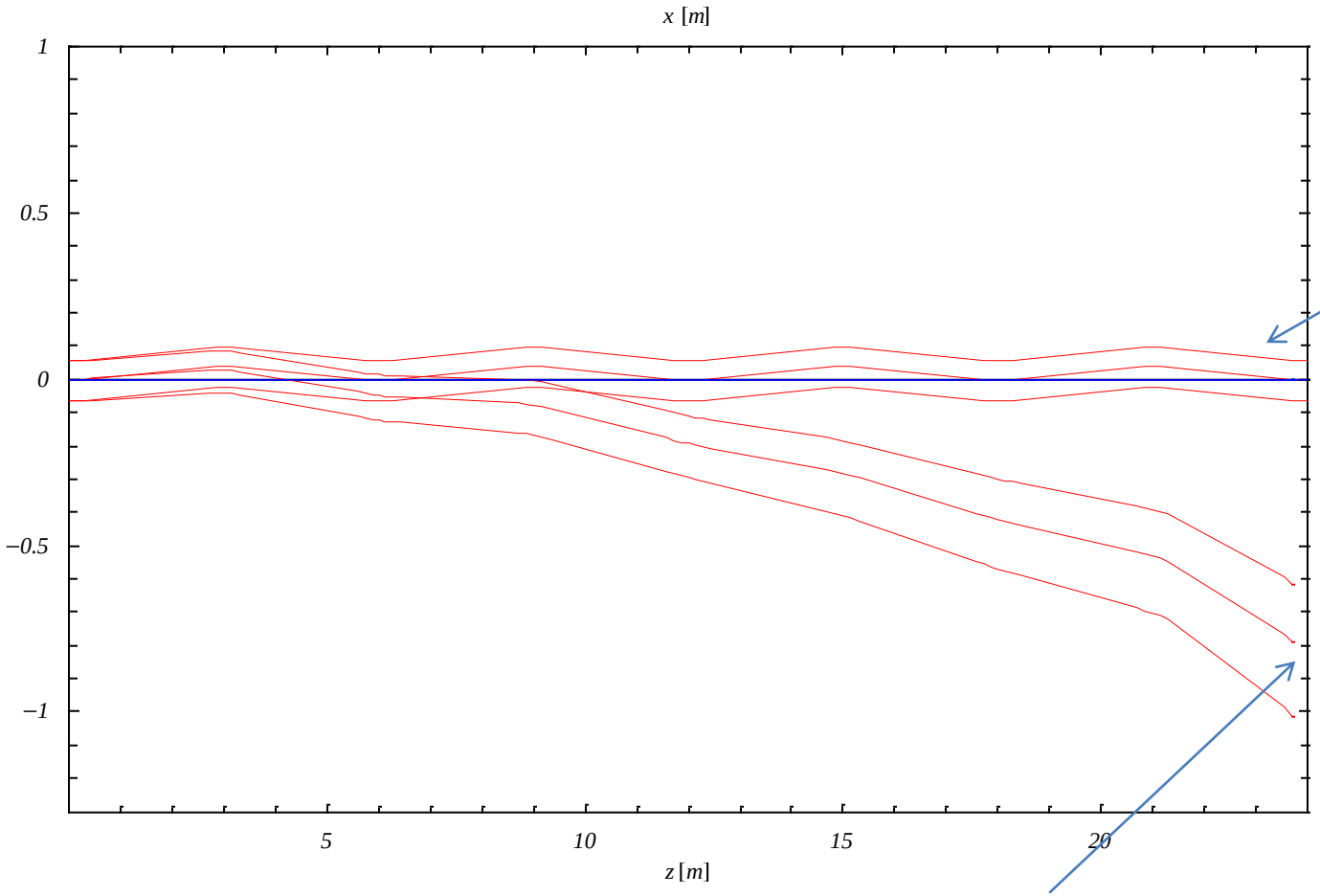
Preliminary injection

- The long drifts are the natural place for septum and kickers.
- Kickers must be distributed (the more the weaker they are), but the matching conditions can be more difficult.
- Optics of the drift has been reproduced and zero chromaticity condition confirmed.
- Closed orbits have been calculated.
- The needed orbit separation was estimated based on the tracking studies and is about 12cm*2+1cm~25 cm.
- The additional separation to clear the magnet was assumed to be about 20 cm.

Injection from the inside of the new ring for 3.8 GeV/c (Orbits for +-16%, effect of 2 kickers without septum)



Injection from the inside of the new ring for 3.8 GeV/c (Orbits for +-16%, effect of 2 kickers with septum included)



Larger dispersion could be reduced with FFAG-like septum
(in this study the septum is a pure dipole)

Parameters for injection from the inside of the ring (3.8 GeV/c)

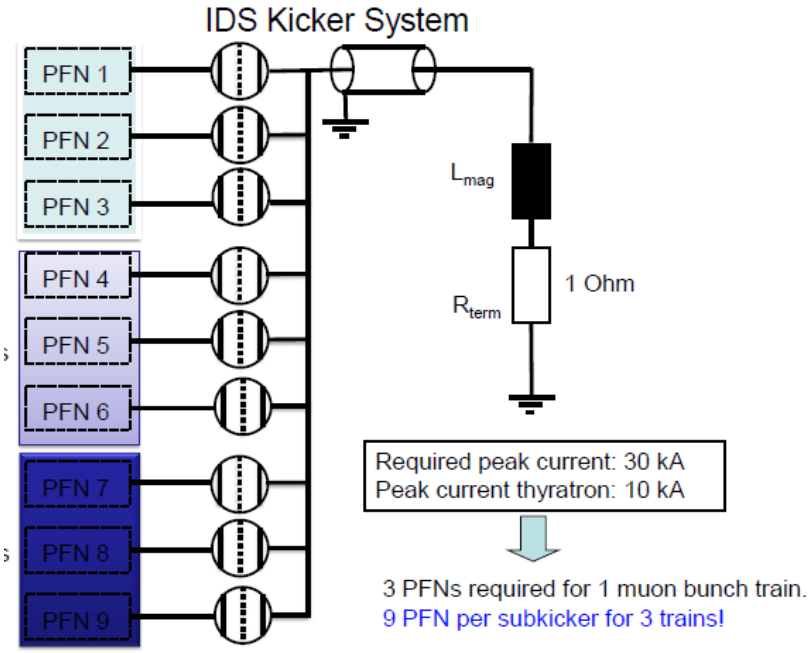
- Number of kickers 5
- Kicker B field 0.047 T
- Kicker length 2.275 m
- Max kicker aperture 75x30 cm
- Septum B field 0.6 T
- Septum length 2.275 m in length and
- Septum aperture 70x30 cm

Kickers for FFAGs

- We have designed the kicker for the FFAG in the IDS-NF baseline (25 GeV).
- We believe it can be constructed and operated (especialy as some main parameters are very similar to the SPS dump kicker.
- It requires large aperture similar to the one required for the current design of the Racetrack FFAG for the nuSTORM.
- More studies are needed for the nuSTORM injection.

Table XXVIII. Parameters of the kicker system

Kicker total aperture (h×v)	0.3×0.3 m
Kicker length	4.4 m
Rise/fall time (5-95%)	1.9 μs
Kicker max field	≈0.1 T
Kicker pulse duration at the top	0.3 μs
Charging voltage	60 kV
Peak current in the magnet	30 kA
Kicker inductance	5.1 μH
Kicker impedance	1 Ω
Peak current at switch	10 kA
Repetition rate	50 Hz
Number of sub-kickers	4-5
Number of PFNs per micro-pulse per sub-kicker	3
Total number of PFNs	36 (for 4 sub-kickers)
Total averaged power per kicker	≈1.25 MW
Total peak power per kicker	≈2.5 MW



Summary and future plans

• Racetrack FFAG Decay Ring has been designed and promising results have been obtained (momentum spread up to ±26%).

• The decay channel of ~ 200 m has been designed based on the FODO channel for both forward and backward decays using only normal conducting magnets.

•Preliminary design for the single turn full aperture muon injection into FFAG Decay Ring has been worked out and seems feasible.

• More tracking studies are needed (including errors) and the evaluation of the cost and the performance.

•We need to work on the direct pion injection option (the stochastic injection).