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Towards nuSTORM facility - overview of accelerator designs

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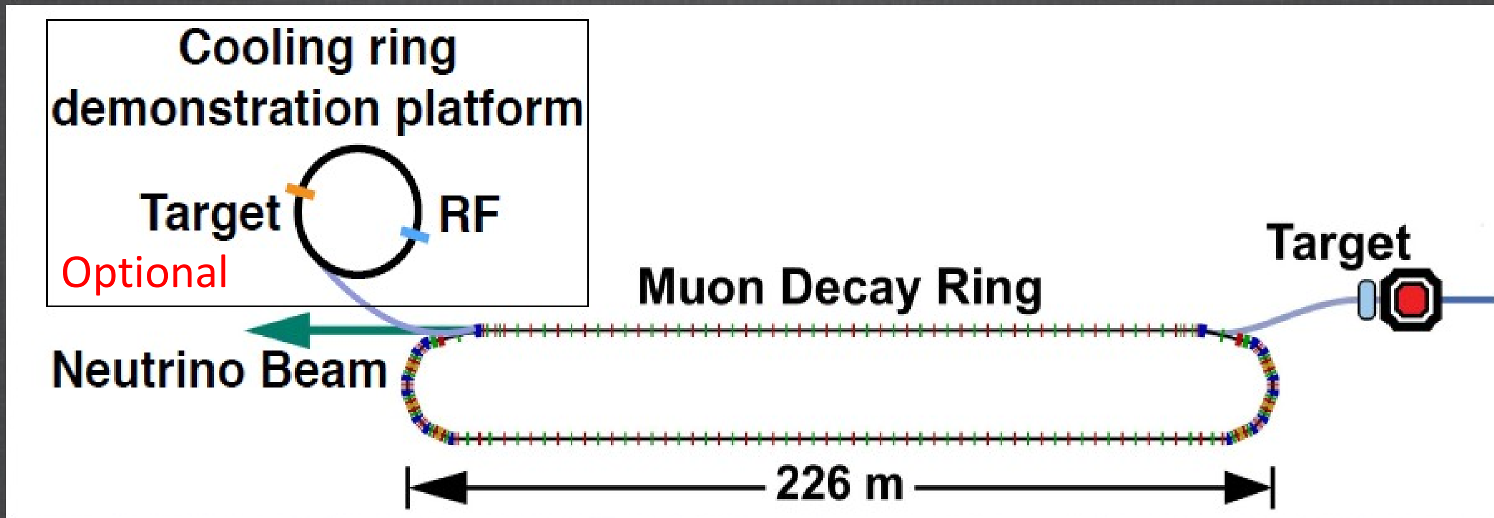
,

FFAG'17, Cornell, 11/09/17

Outline

- Motivation
- FODO design for nuSTORM
- Advanced FFAG concept
- Triplet FFAG design for nuSTORM
- Quadruplet FFAG design for nuSTORM
- Code comparison
- Issues with FFAG design
- Recent developments
- Summary and future plans

nuSTORM Overview



1. Facility to provide a muon beam for precision neutrino interaction physics
2. Study of sterile neutrinos
3. Accelerator & Detector technology test bed
   - Potential for intense low energy muon beam
   - Enables μ decay ring R&D (instrumentation) & technology demonstration platform
   - Provides a neutrino Detector Test Facility
   - Test bed for a new type of conventional neutrino beam

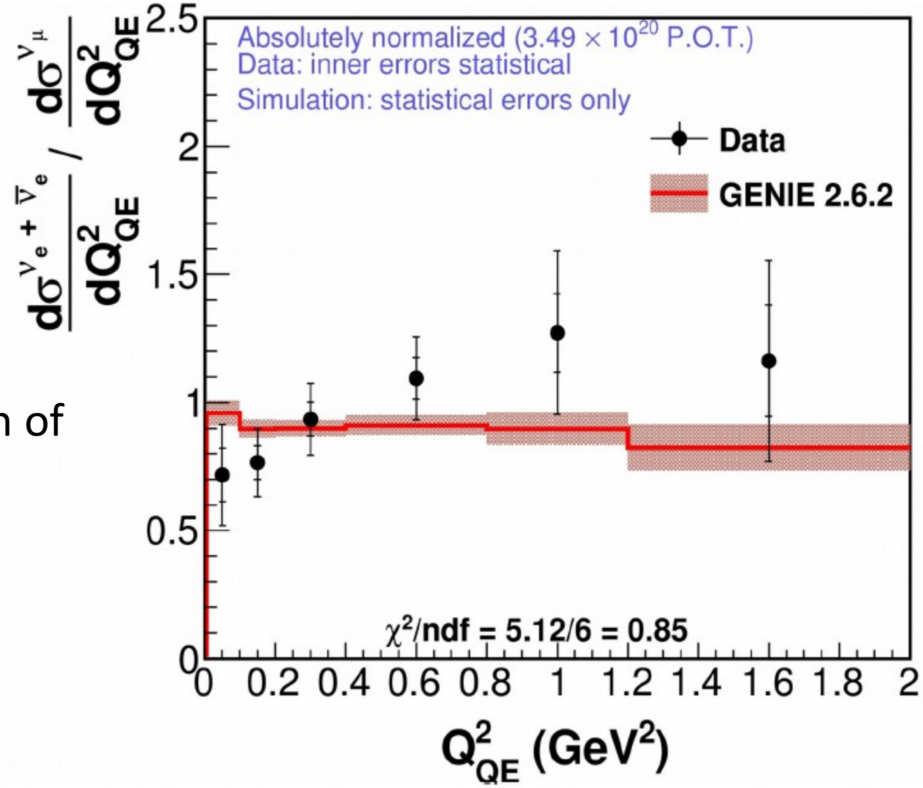
$$\mu^- \longrightarrow e^- + \bar{\nu}_e + \nu_\mu$$

$$\mu^+ \longrightarrow e^+ + \nu_e + \bar{\nu}_\mu$$

$$\pi^- \longrightarrow \mu^- + \bar{\nu}_\mu$$

$$\pi^+ \longrightarrow \mu^+ + \nu_\mu$$

Uncertainty on ratio of $\nu_e - \nu_\mu$ cross sections



J. Morfin, First discussion of nuSTORM in the context of the Physics Beyond Colliders workshop, IC, 16/02/17

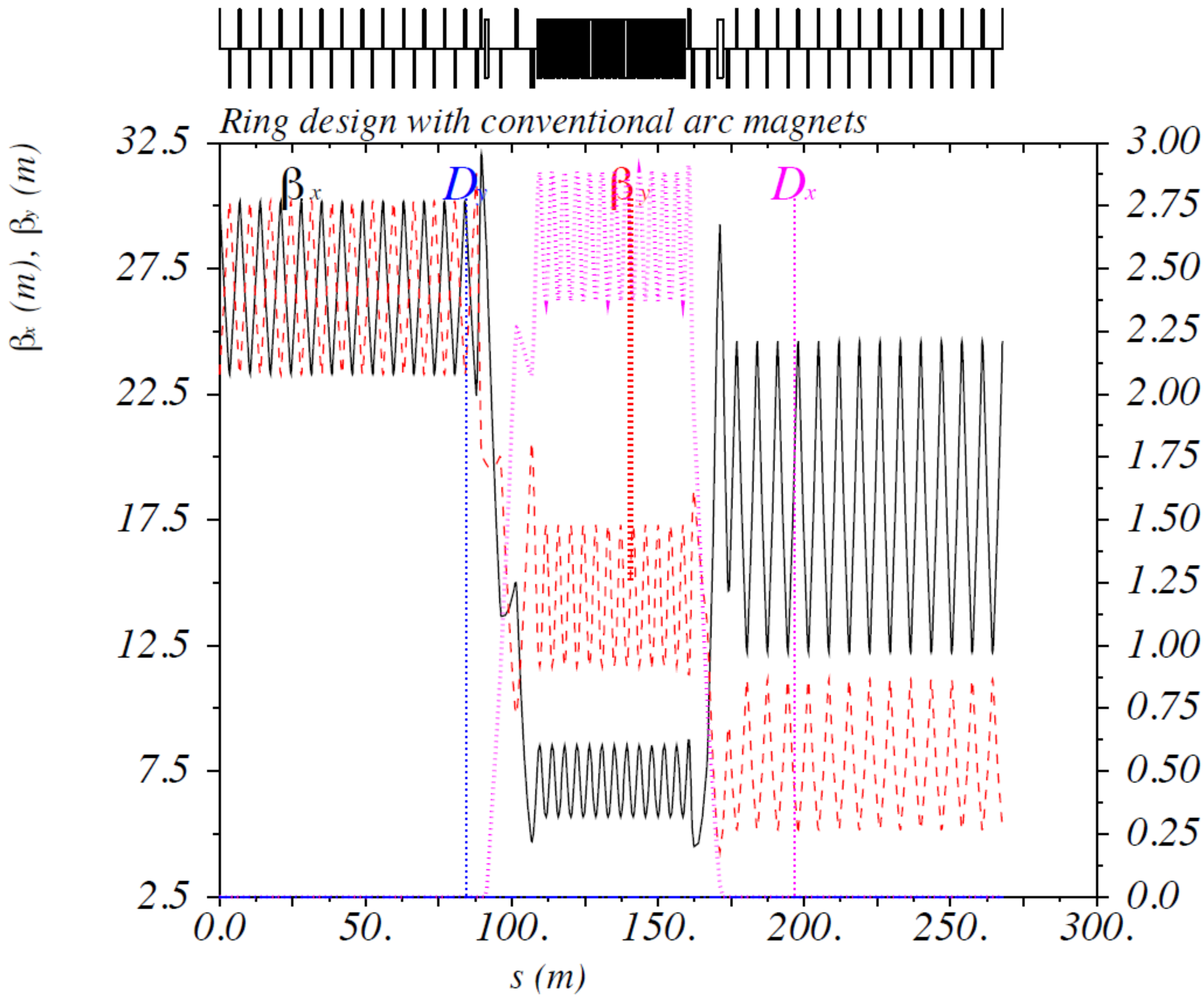
This directly translates into the precision of neutrino oscillation experiments and in particular affects future CP violation searches .

FODO design, A. Liu

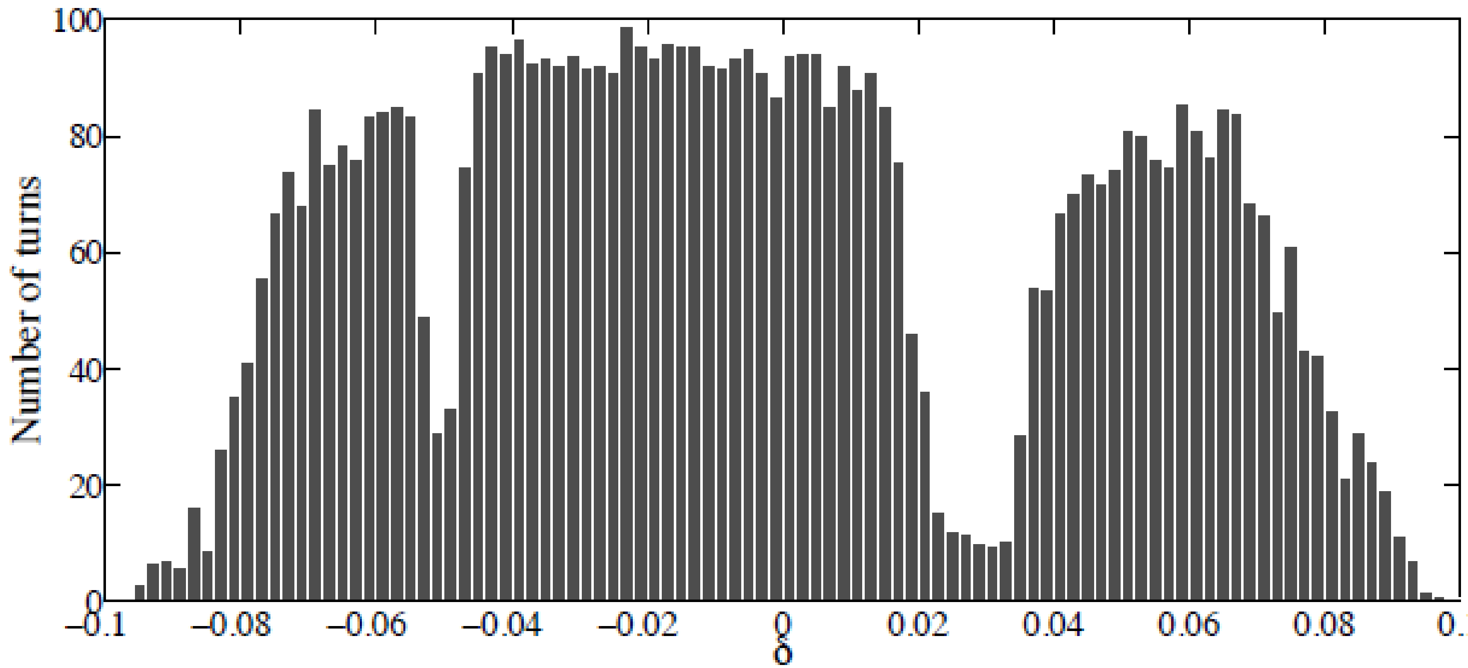
Parameters	Values (units)
Central momentum $P_{0,\mu}$	3800 (MeV/c)
Circumference	535.9 (m)
Arc length	86.39 (m)
Straight length	181.56 (m)
(ν_x, ν_y)	(6.23, 7.21)
$(d\nu_x/d\delta, d\nu_y/d\delta)$	(-3.11,-12.73)

- Based on separated function AG lattice
- Partial chromaticity correction with sextupoles was studied

FODO design, A. Liu

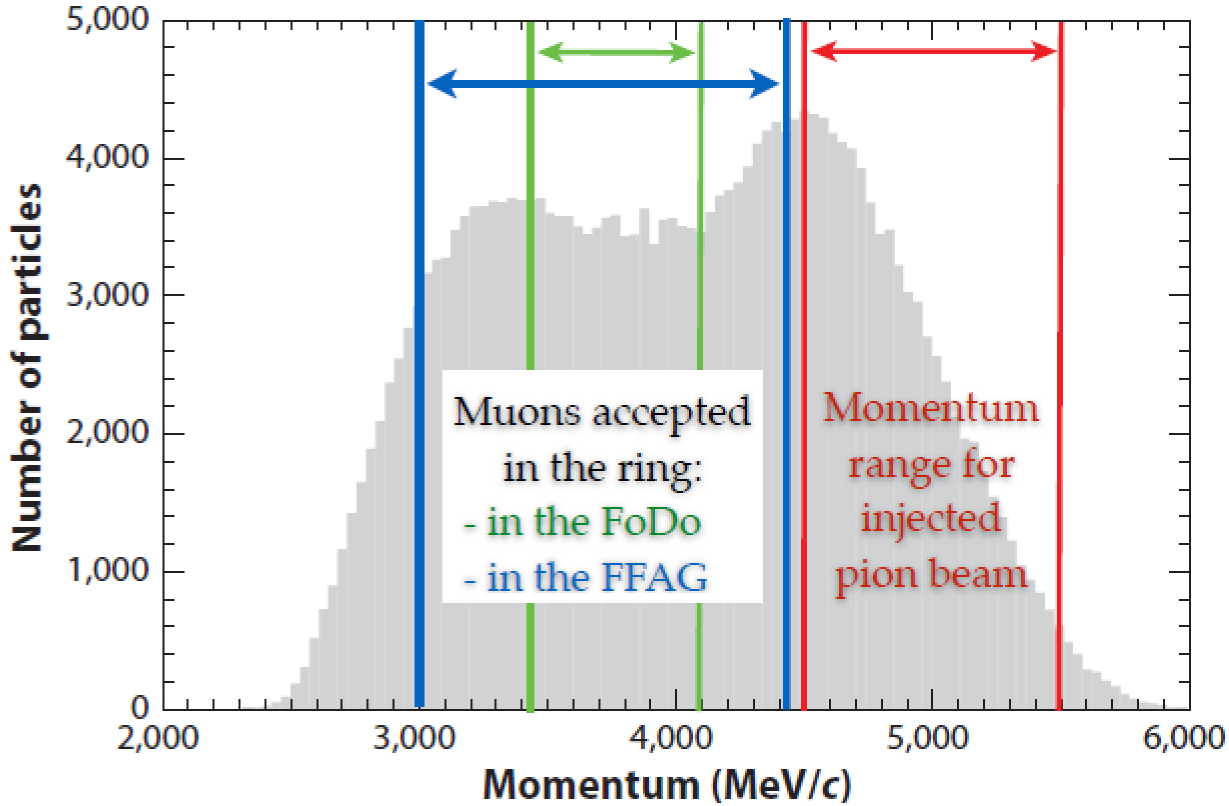


Losses in the FODO (w/o sextupoles)



- Natural chromaticity leads to losses as a function of momentum
- Lattice errors not included

Advantage of FFAG: large momentum acceptance



•FFAG can accept ±16% (triplet) or ±19% total momentum spread.
•FODO - ±9% with 58% efficiency (67% with sextupoles)

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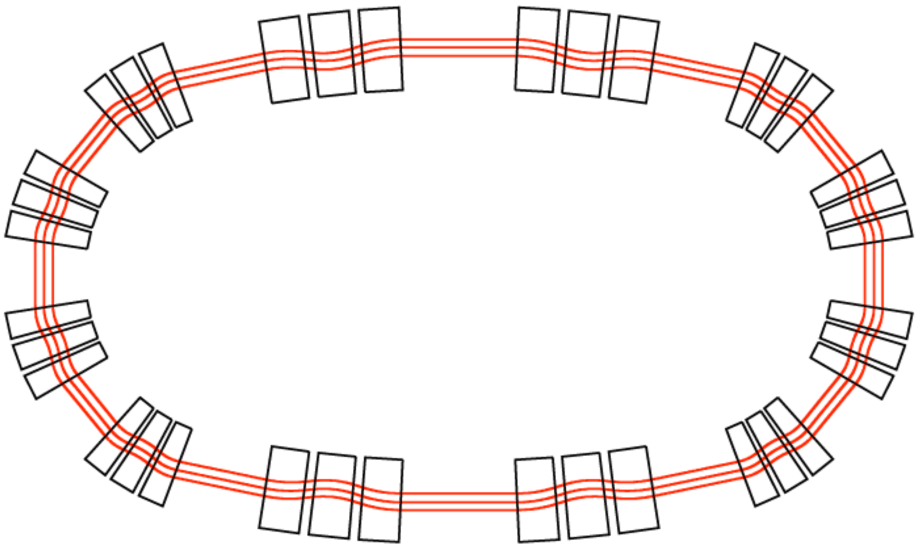
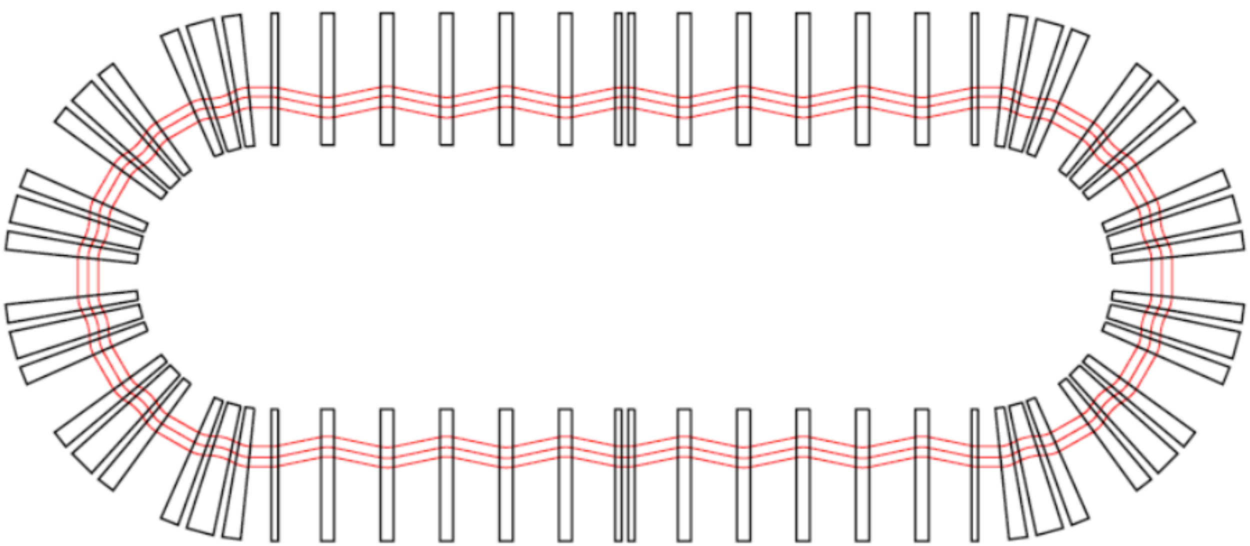
Advanced FFAG



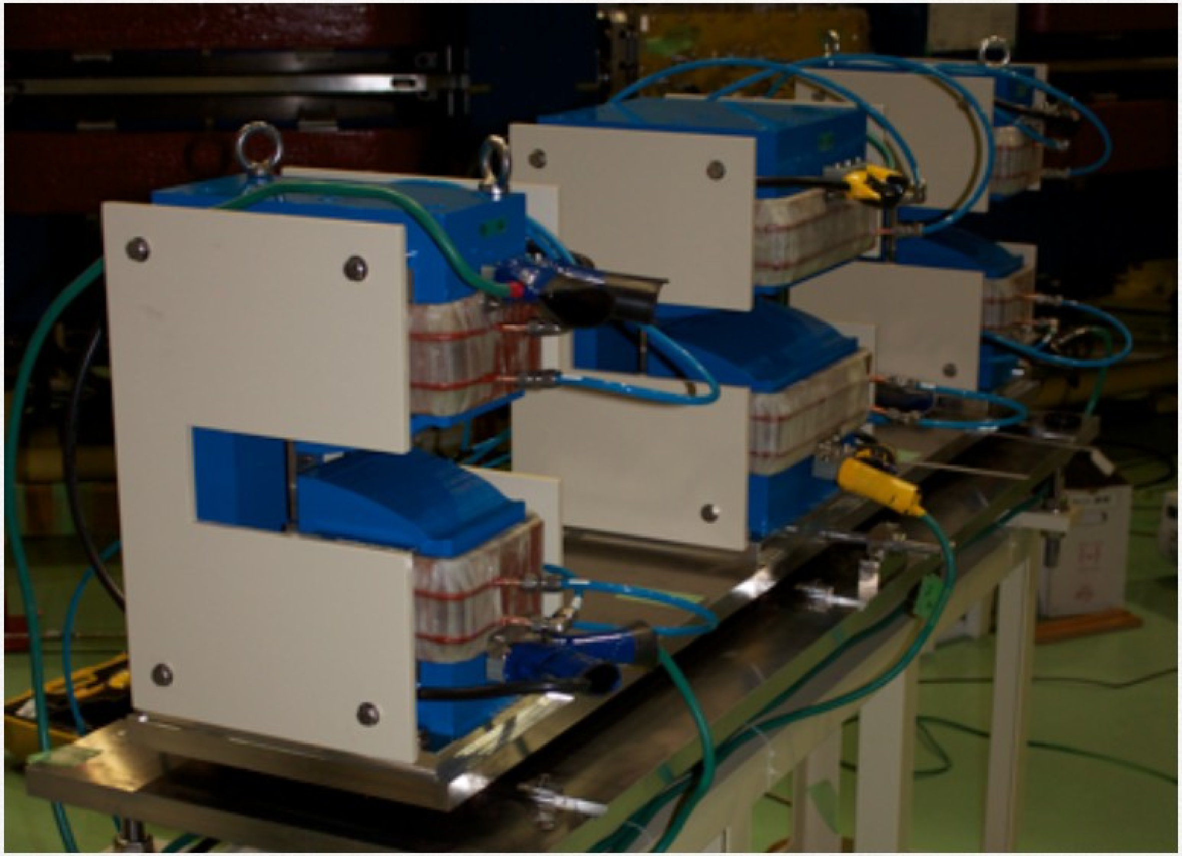
By combining cells with different radius
or arcs with straight cells, long straight sections can be created and neutrino beam can be formed along them.



How to make straight cell?

Straight scaling FFAG:

FFAG cell with no overall bend.

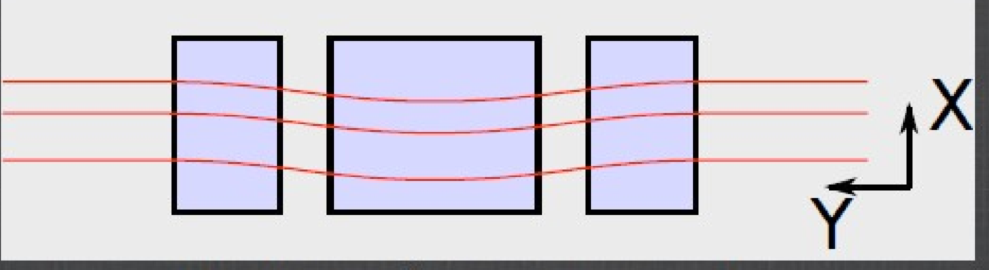


J-B. Lagrange's thesis

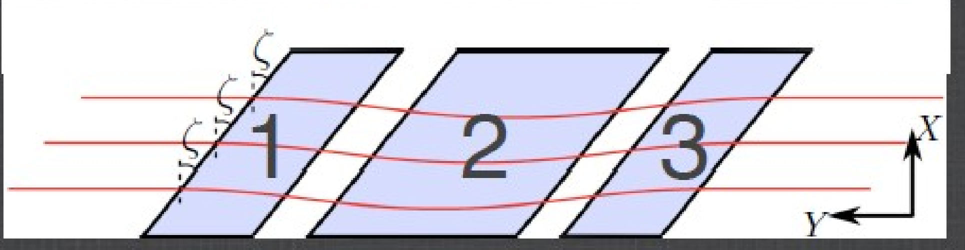
Straight FFAG (principles)

Constant normalized field gradient: $m = \frac{1}{B_y}\frac{dB_y}{dx}$

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



Rectangular case: $\zeta = 0$



Tilted straight case: $\zeta = const.$

...however orbit scallop angle is present!

νSTORM Racetrack FFAG

Constraints:

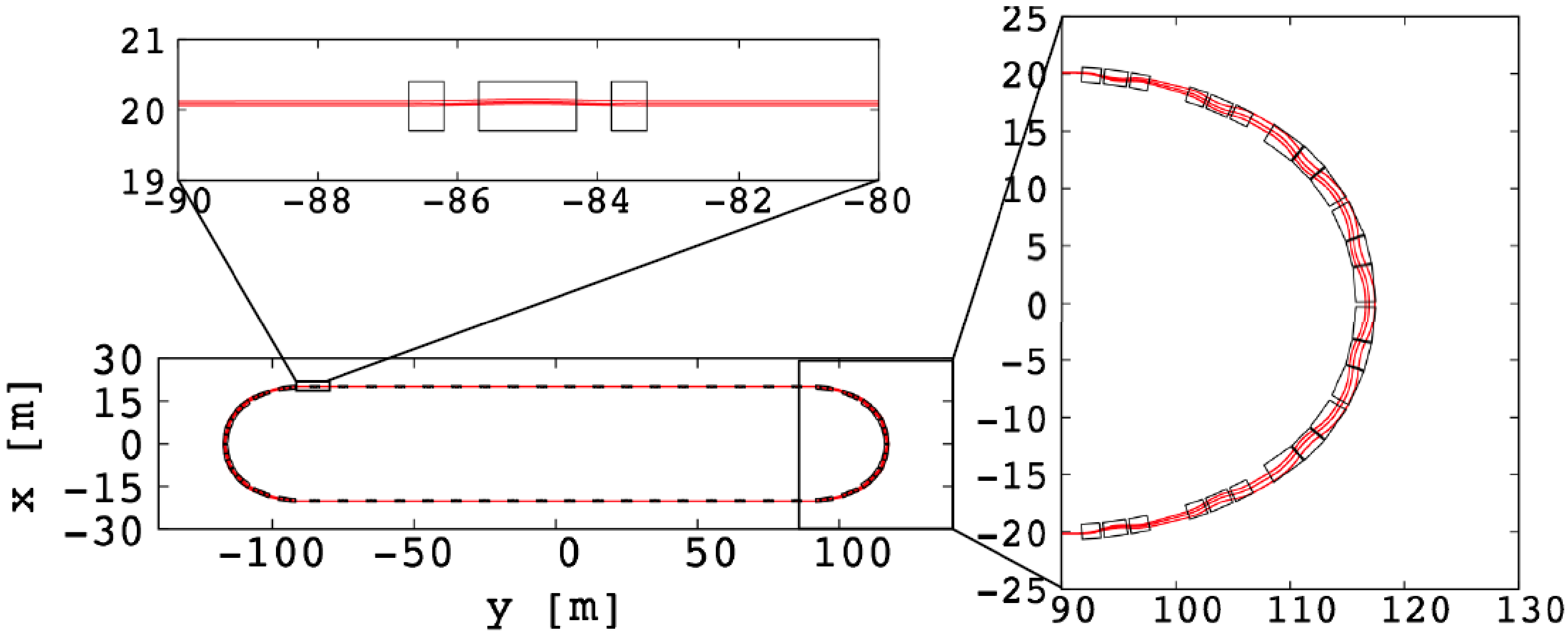
- in the straight part, the **scallop effect** must be as small as possible to collect the maximum number of neutrinos at the far detector.

- **Stochastic injection**: in the dispersion matching section, a drift length of 2.6 m is necessary to install a septum.

- to keep the ring as small as possible, **SC magnets in the arcs** are considered. **Normal conducting magnets in the straight part** are used.

- **large transverse acceptance** is needed in both planes: 1 (2) π mm.rad.

Triplet solution layout (J-B. Lagrange, JP)

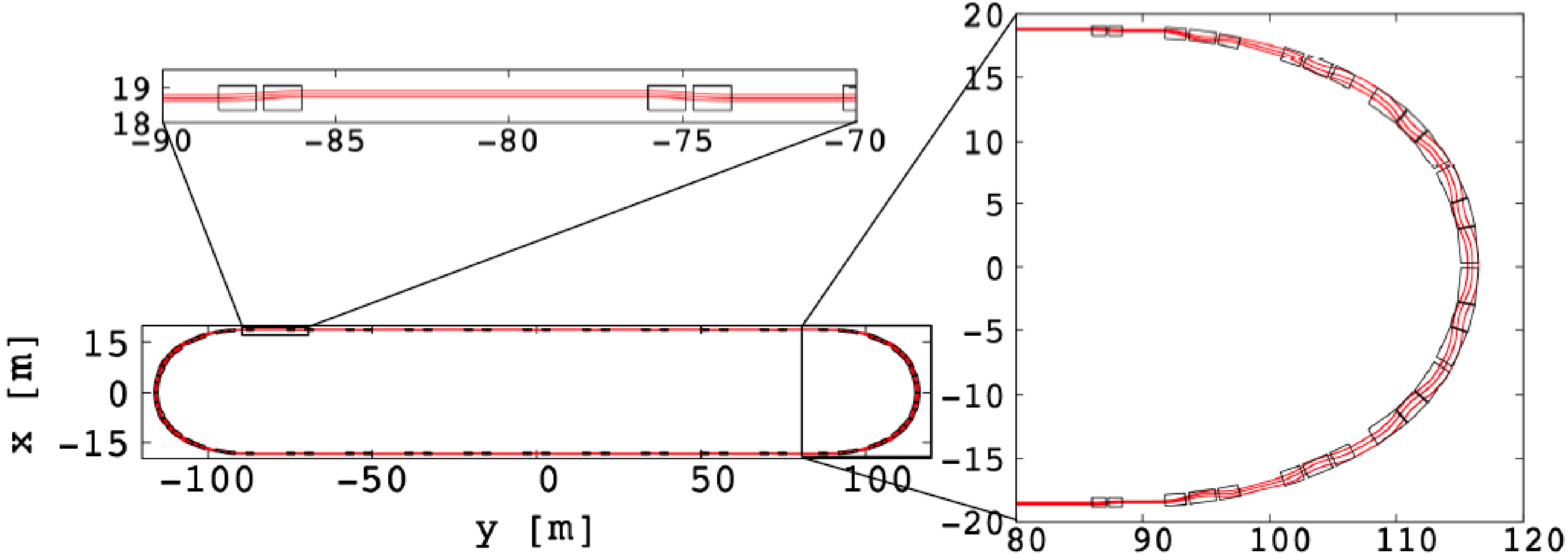


Triplet solution

Cell parameters

	Circular Section	Matching Section	Straight Section
Type	FDF	FDF	DFD
Cell radius/length [m]	17.6	36.2	10
Opening angle [deg]	30	15	
k-value/m-value	6.057	26.	5.5 m^{-1}
Packing factor	0.92	0.58	0.24
Maximum magnetic field [T]	2.5	3.3	1.5
horizontal excursion [m]	1.3	1.1	0.6
Full gap height [m]	0.45	0.45	0.45
Average dispersion /cell [m]	2.5	1.3	0.18
Number of cells /ring	4×2	4×2	36×2

Quadruplet solution (J-B. Lagrange, JP)



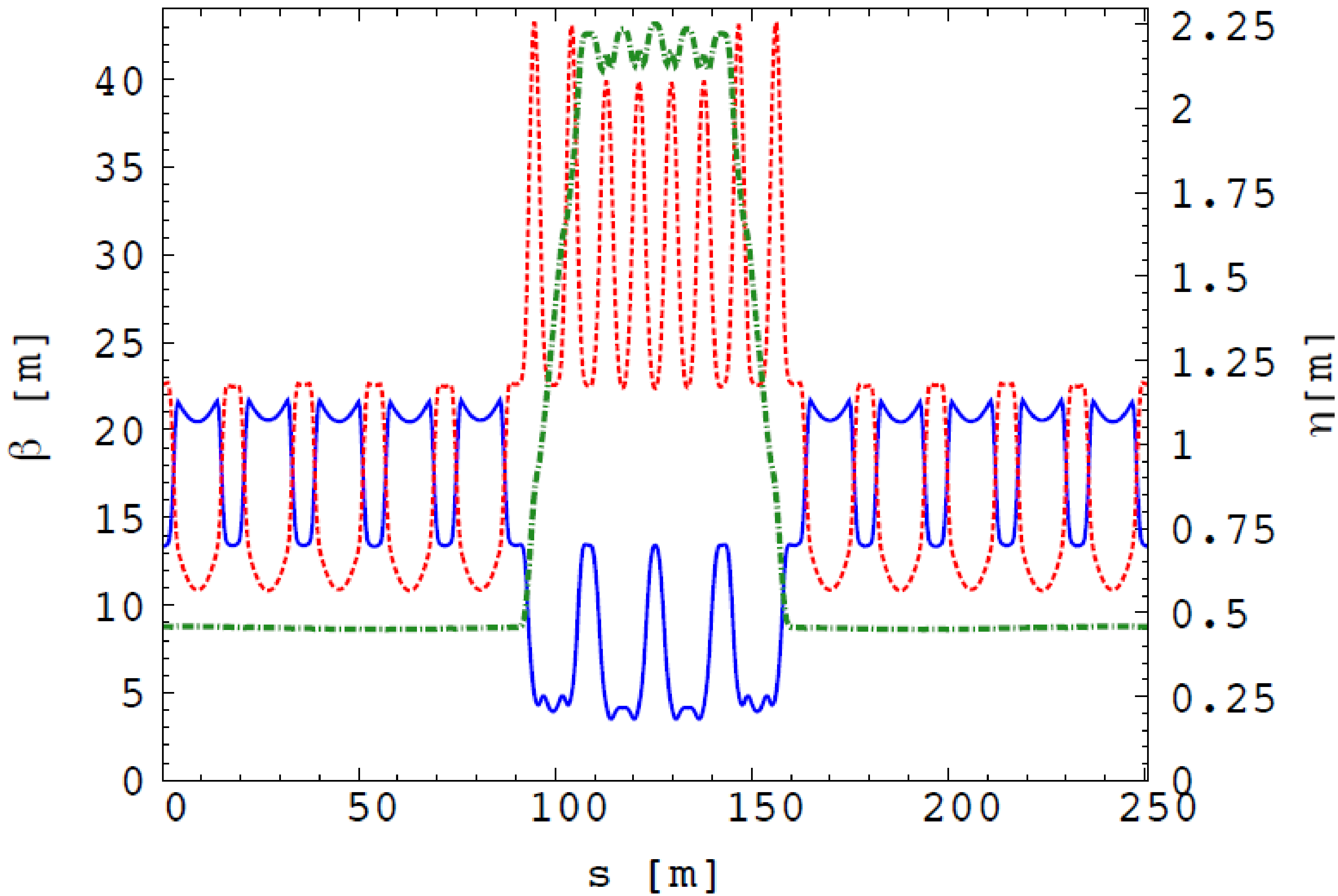
Lattice design includes three cell types (dens arc, matching and straight ones)

Quadruplet Ring FFAG parameters

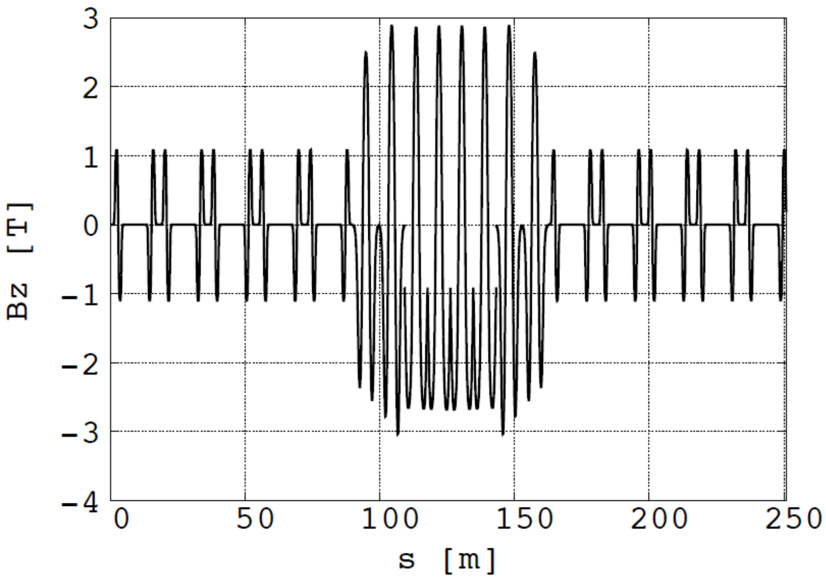
Cell parameters

	Circular Section	Matching Section	Straight Section
Type	FDF	FDF	DFFD
Cell radius/length [m]	15.8	36.1	18
Opening angle [deg]	30	15	
k-value/m-value	6.056	26.	$2.2\ \mathrm{m}^{-1}$
Packing factor	0.92	0.58	0.24
Maximum magnetic field [T]	2.9	3.3	1.7
horizontal excursion [m]	1.4	0.9/1.3	0.7
Full gap height [m]	0.5	0.5	0.25
Average dispersion /cell [m]	2.23	1.34	0.45
Number of cells /ring	4×2	4×2	10×2

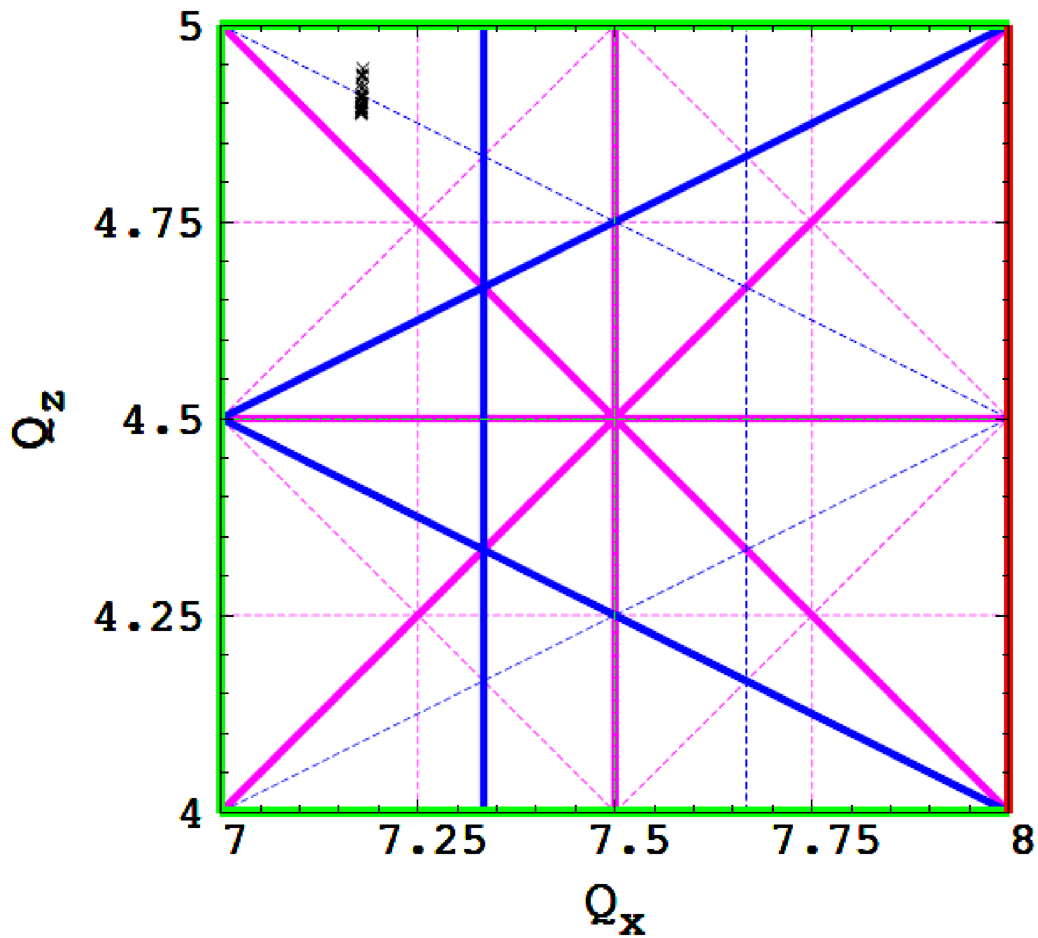
Quadruplet FFAG, lattice functions



Quadruplet, lattice design

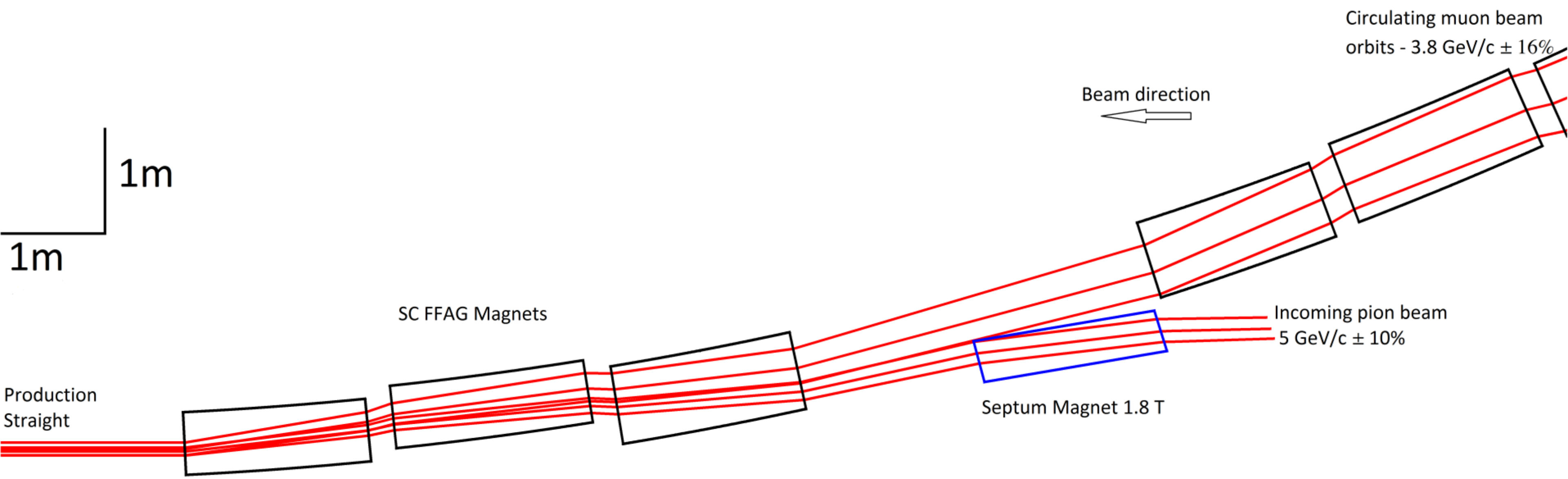


Magnetic field at the top momentum particle



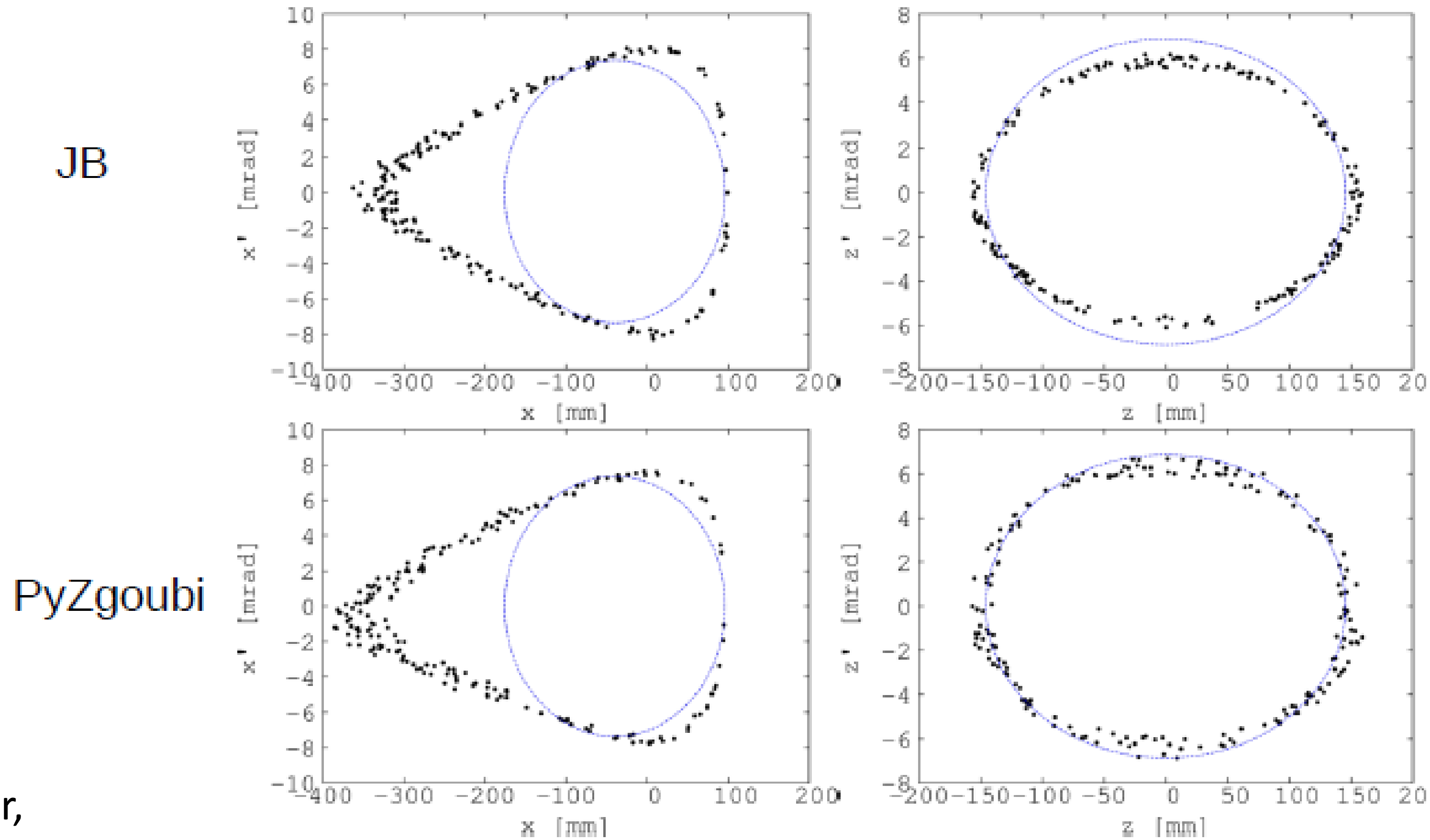
Chromatic tune spread for 19% momentum spread

Injection section



- Injection system will use septum magnet and NO kicker (stochastic injection)
- Special optics allows to introduce a sufficient straight section length

PyZgoubi vs JB's code comparison



*Triplet lattice

S. Tygier,
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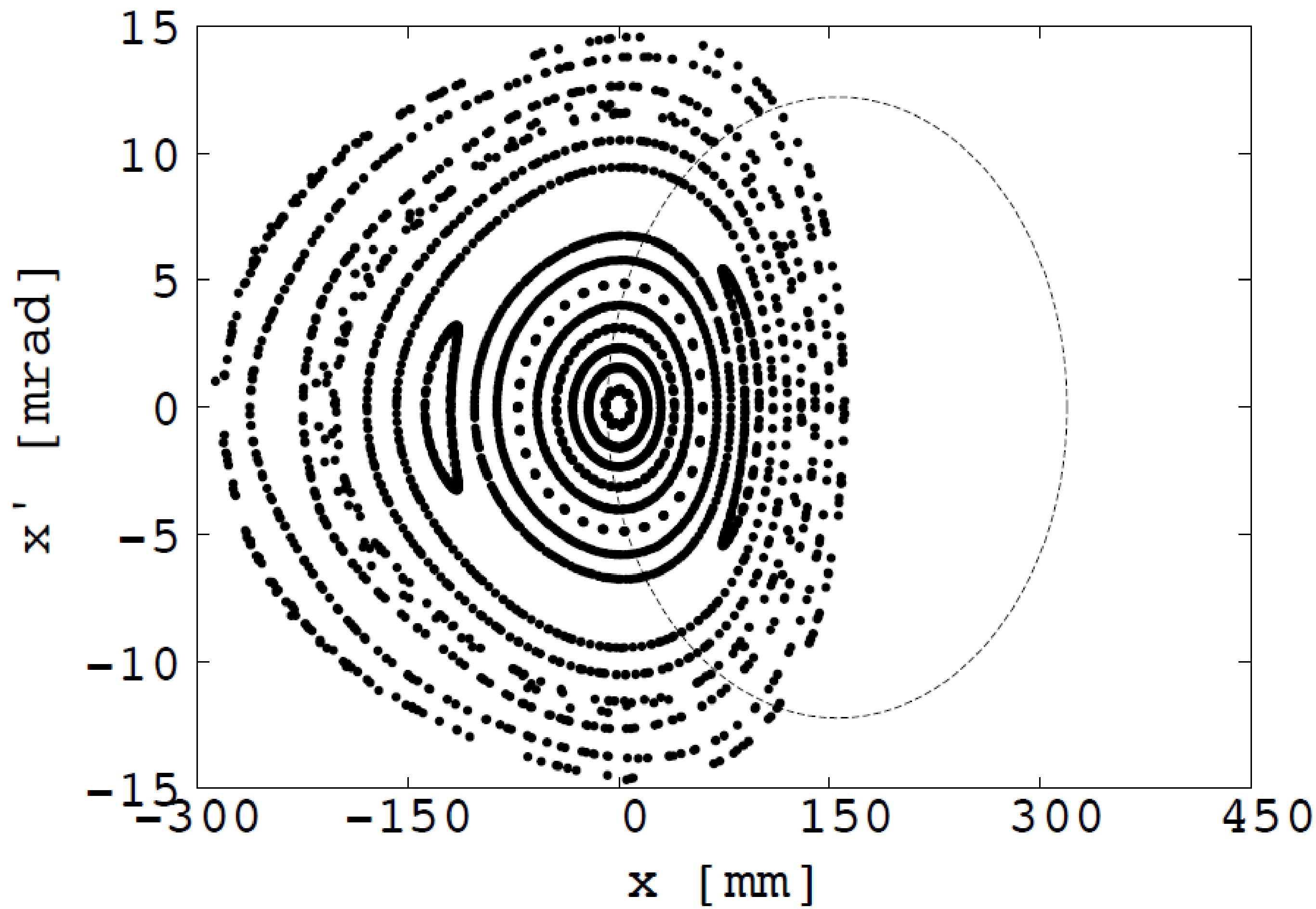
Very good agreement!

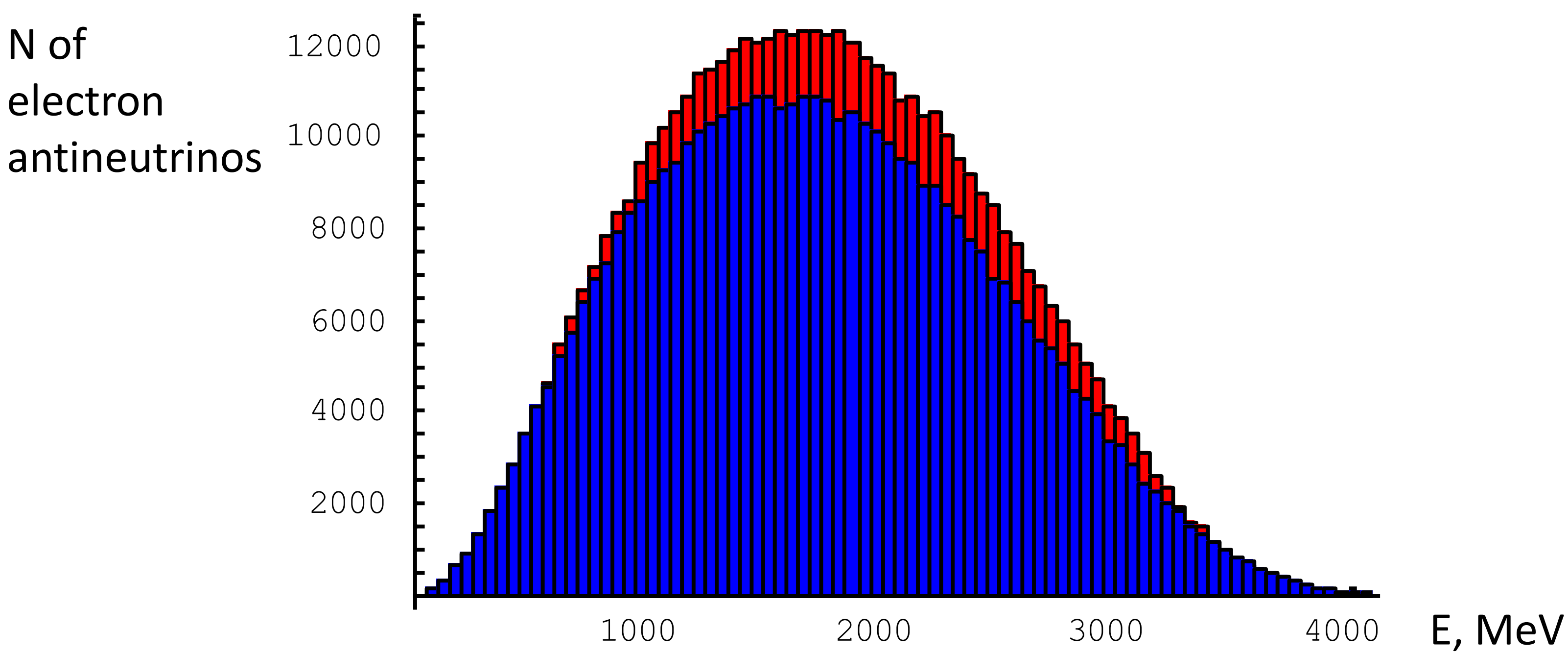
Issues with FFAG design



- Muon beam capture efficiency is reduced due to dispersion present in the decay straight

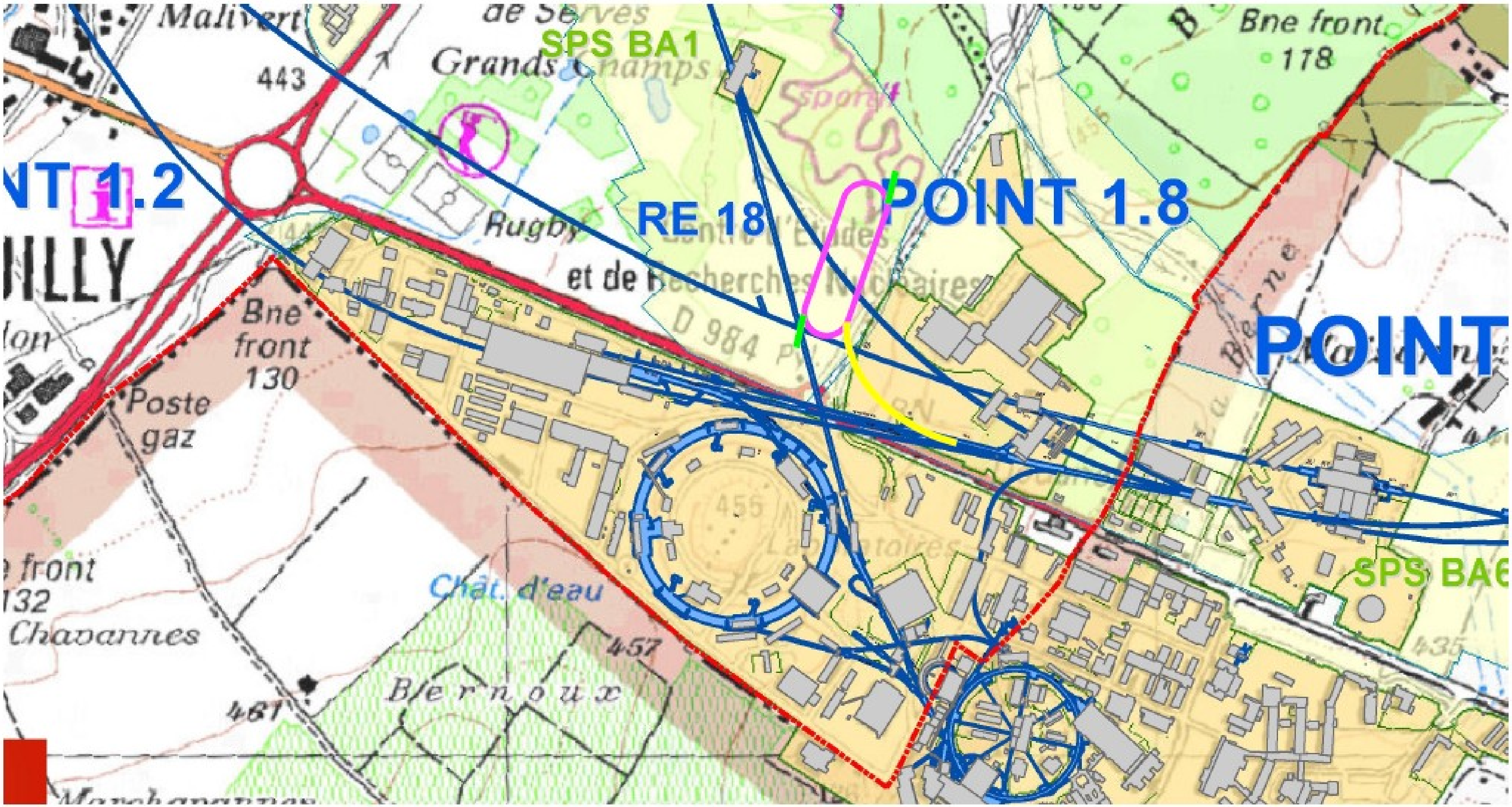
Issues (2): Effect of scallop on the neutrino spectrum

- Near detector distance: 50m, 5m diameter, simulation for 4000000 stored muons



nuSTORM FODO (red) versus triplet FFAG (blue)

Discussions on a possible implementation of nuSTORM at CERN,
I. Efthymiopoulos, PBC meeting at CERN, July 2017



A very promising option was identified!

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Conclusions

- FFAG design allows to substantially increase the ring’s momentum acceptance (and so the neutrino flux), while maintaining a very large transverse acceptance
- Modular FFAG design by combining straight FFAG cells with a very compact circular FFAG arcs has been successfully accomplished allowing for a sufficient space for injection. While doing so the zero-chromaticity can be maintained.
- Matching between different optical modules is possible
  - Automatic design toolkit was created.

Future plans

- The design needs to be revisited focusing on the goals of scattering experiment(s)
  - Energy (range) needs to be redefined
- Further improvement into the design should be investigated:
  - Compact Arc
  - Accommodation of zero dispersion and no scallop section (Hybrid design)
- Further details concerning the injection and magnet systems need to be studied.
- Error study needs to be performed.