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Towards nuSTORM facility - overview of accelerator designs

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,

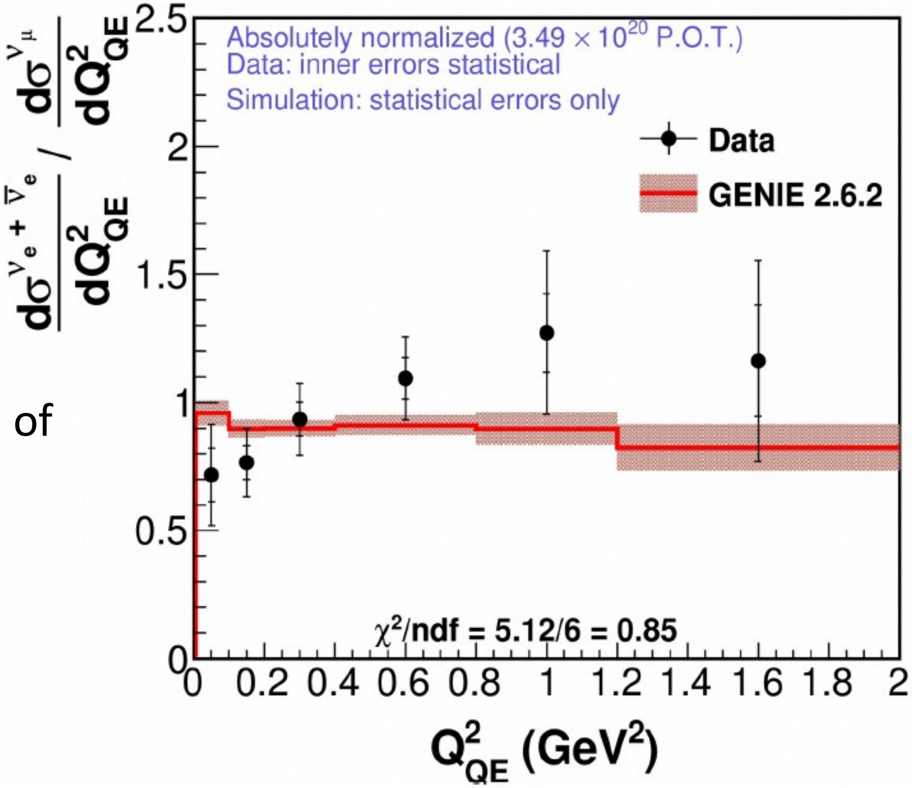
nufact’17, Uppsala, 27/09/17

Outline

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

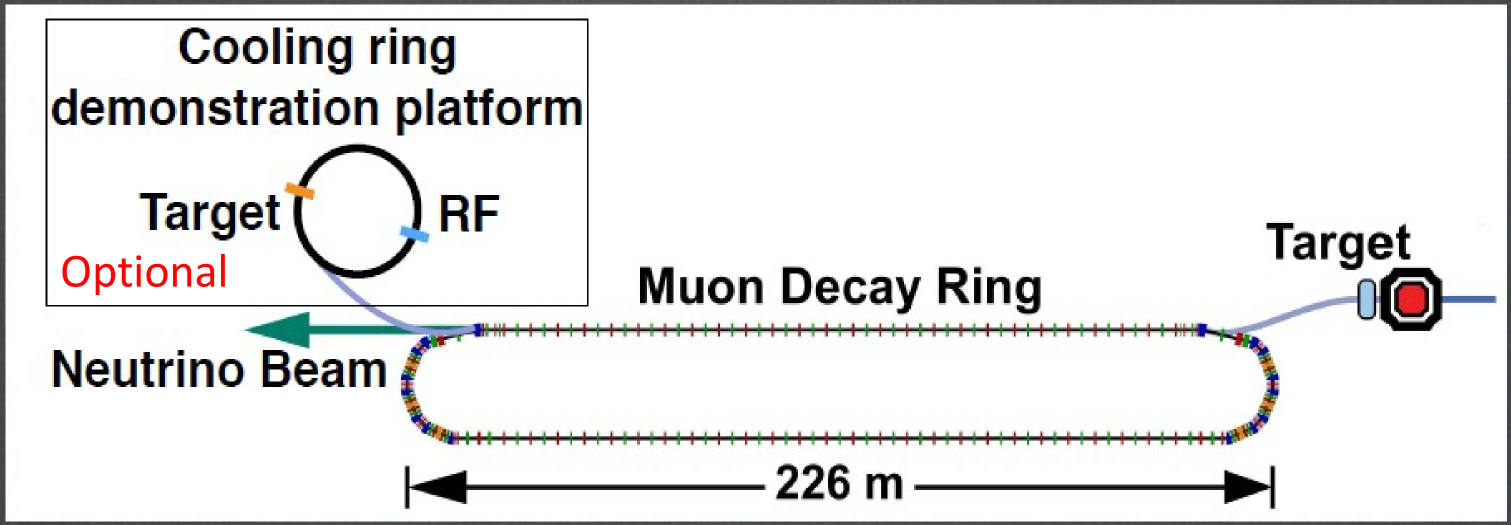
Uncertainty on ratio of $\nu_e - \nu_\mu$ cross sections

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 .

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

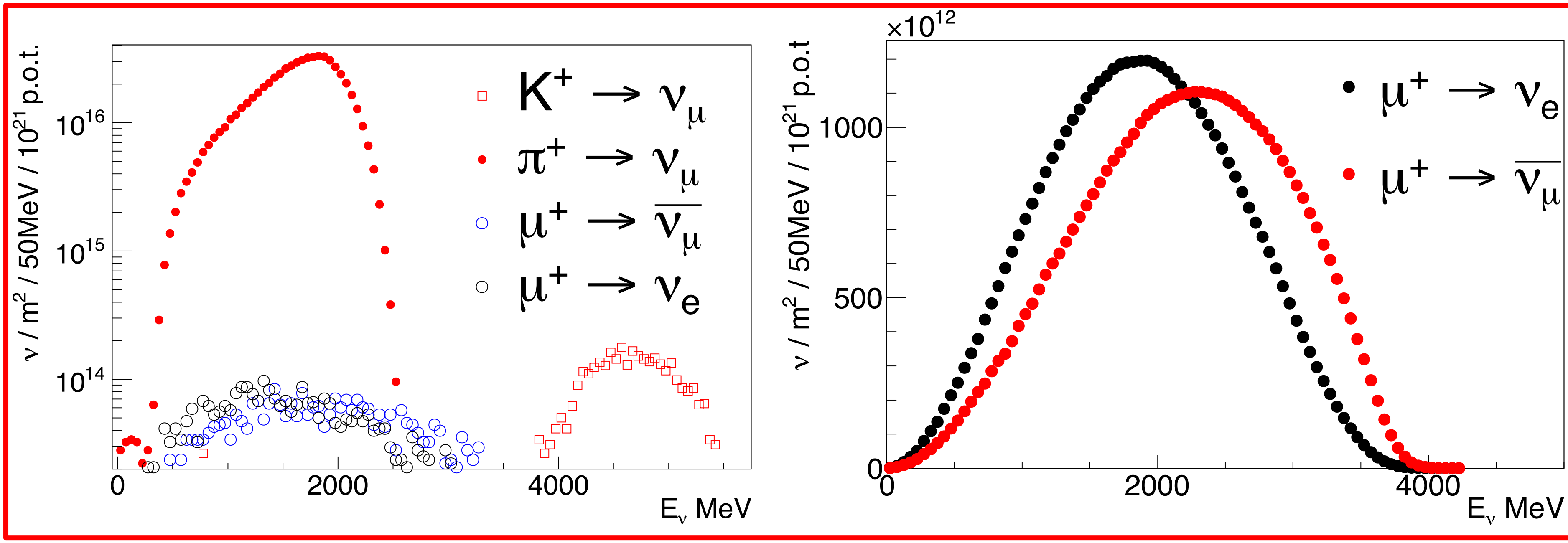
$$\mu^- \longrightarrow e^- + \bar{\nu}_e + \nu_\mu$$

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

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

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

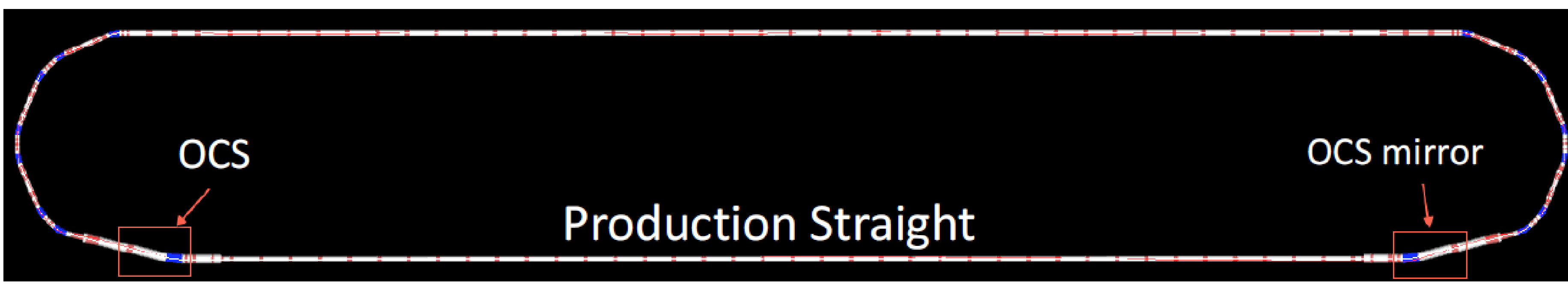
Neutrino Flux



- Multiple channels available
- Good time separation
- Good source of electron neutrinos!

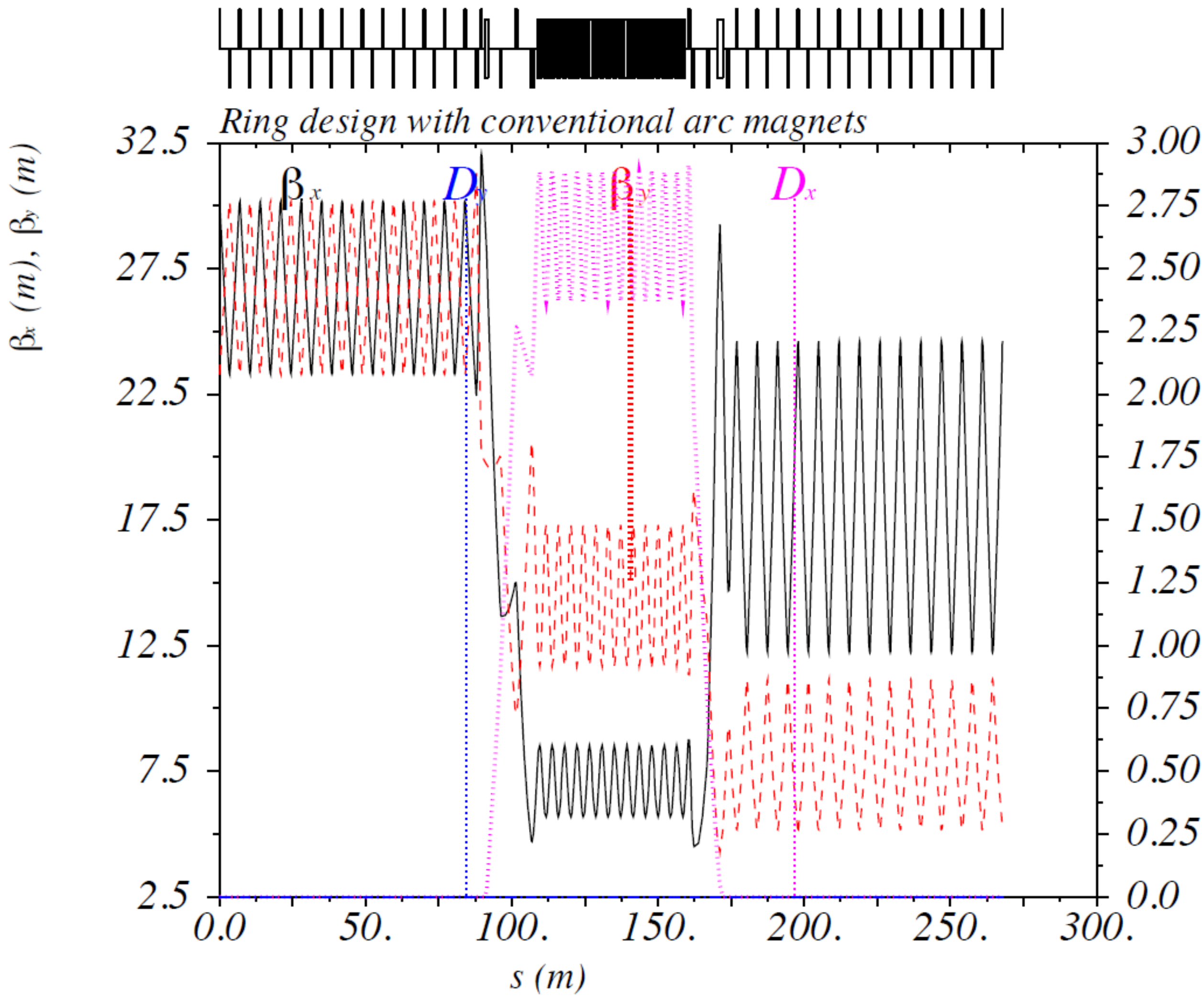
FODO design, A. Liu

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)

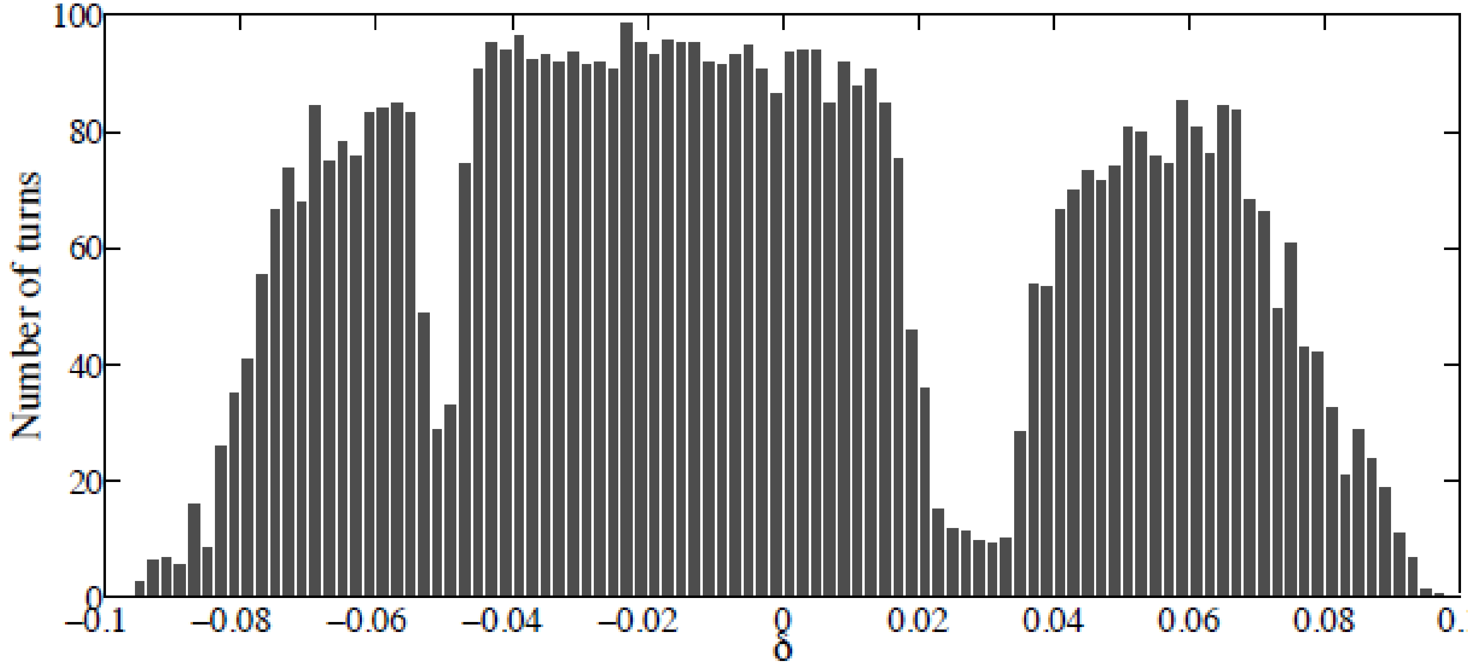


- Based on separated function AG lattice, well known technology
- Partial chromaticity correction with sextupoles was studied

FODO design, A. Liu

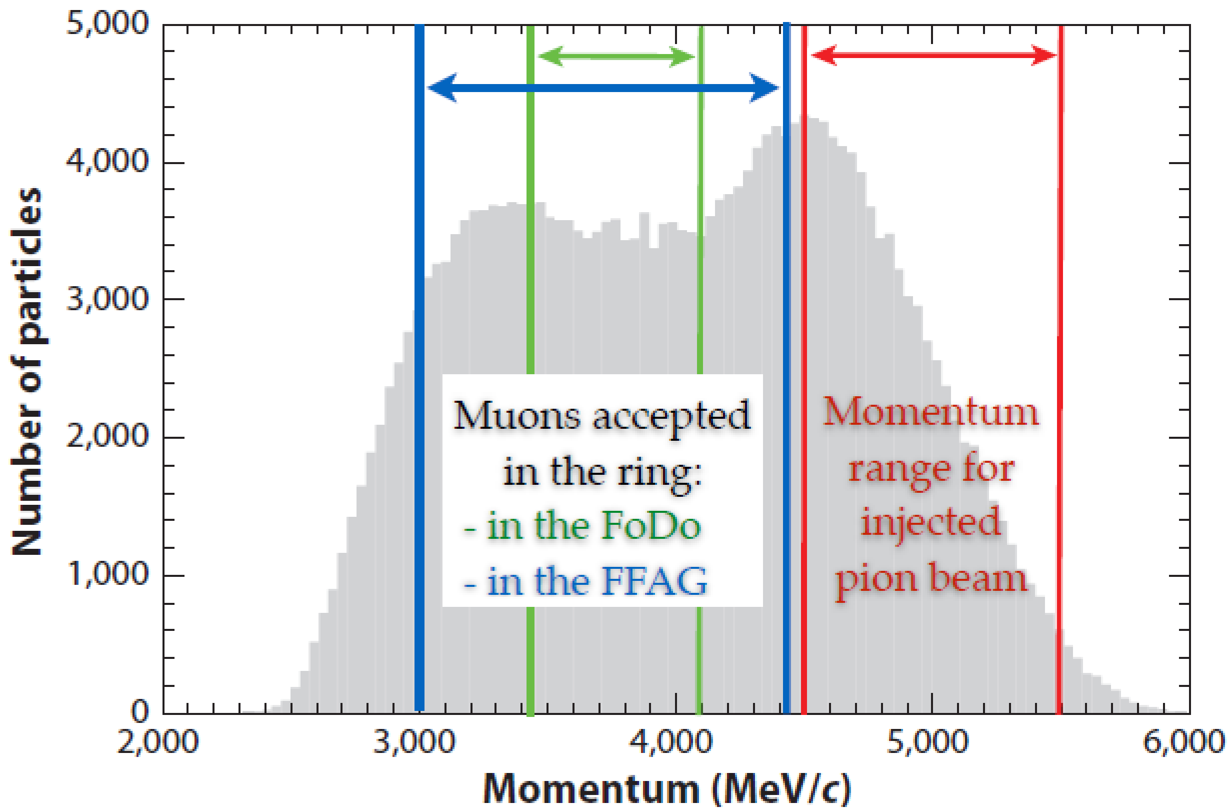


Losses in the FODO (w/o sextupoles)



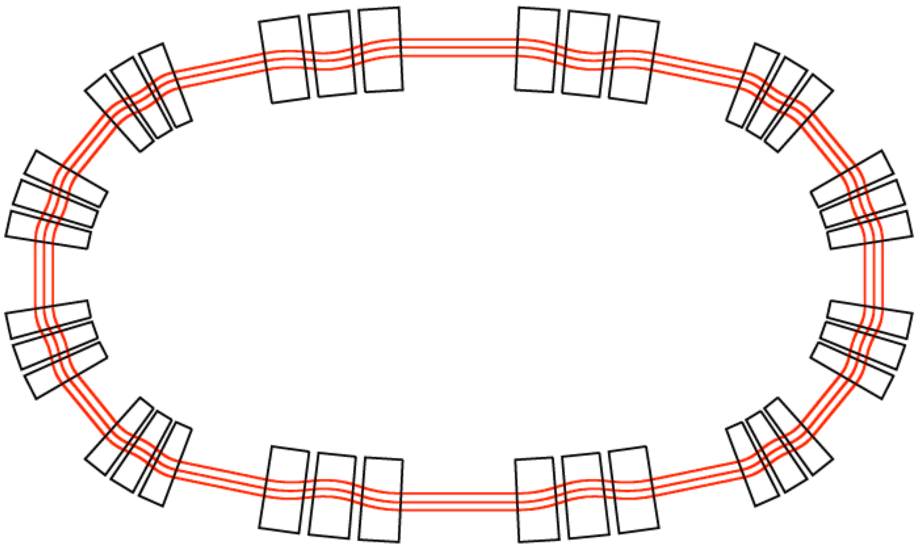
- Natural chromaticity leads to losses as a function of momentum
- Lattice errors not included

Advantage of FFAG: large momentum acceptance

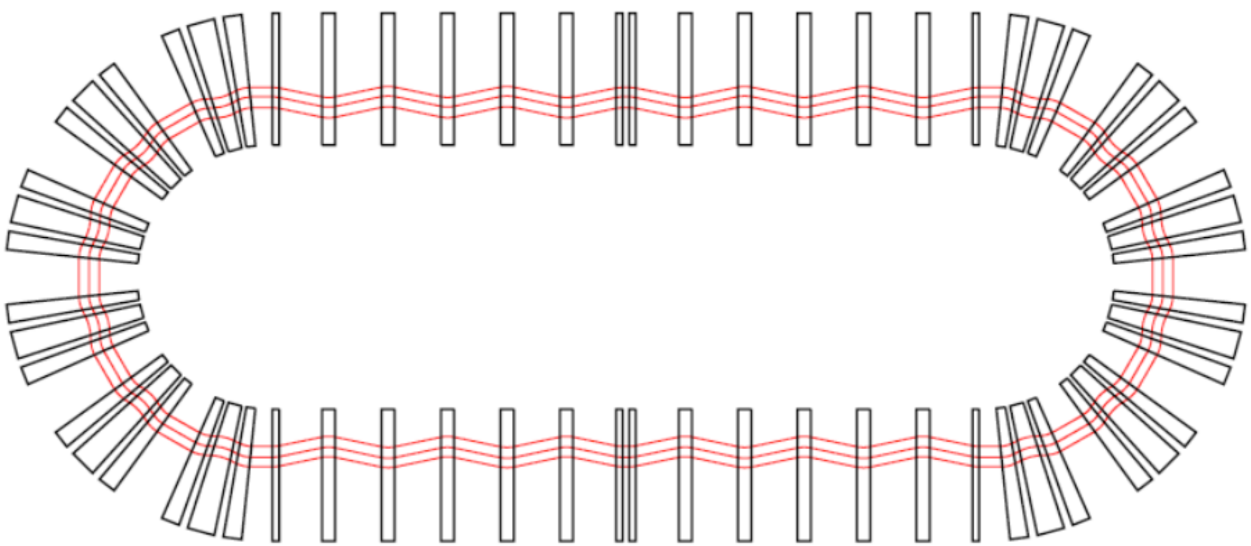


- FFAG can accept ±16% (triplet) or ±19% total momentum spread.
- FODO - ±9% with 58% efficiency (67% with sextupoles)

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.



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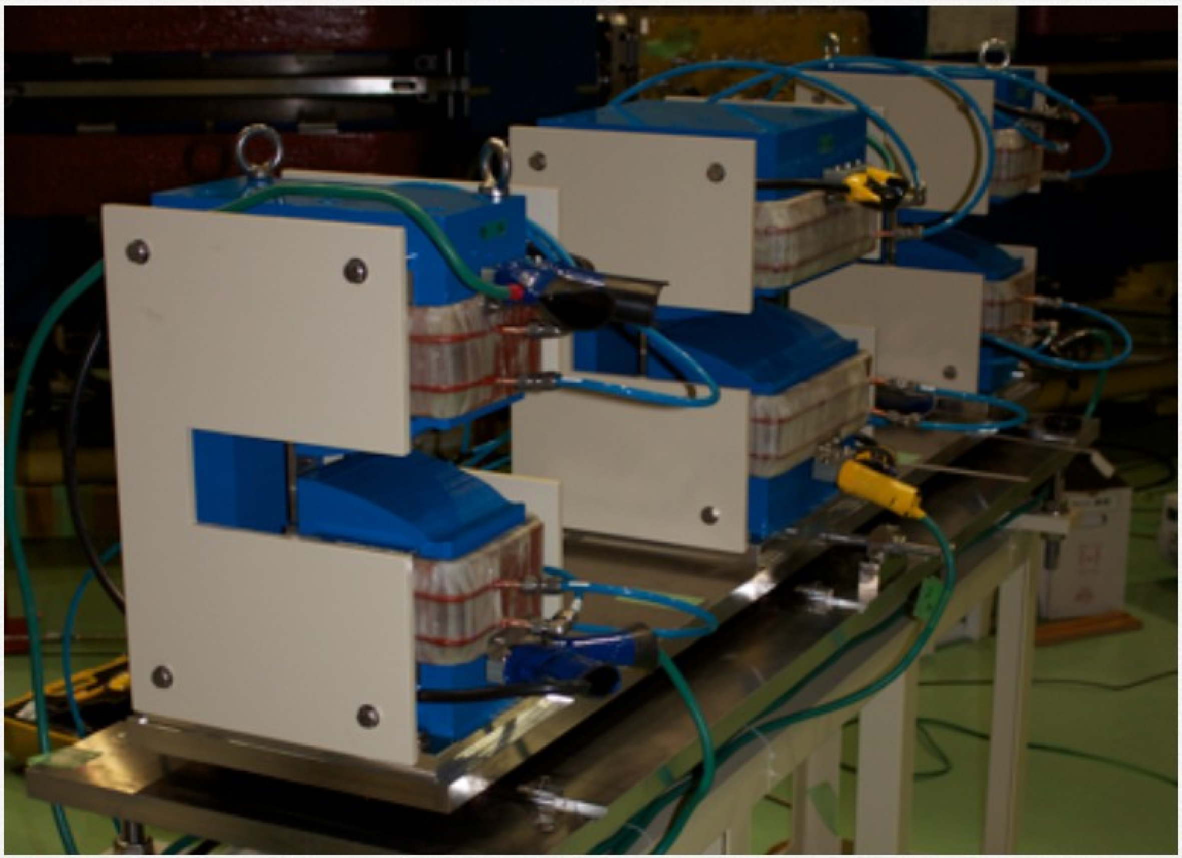
How to make straight cell?

Straight scaling FFAG:

FFAG cell with no overall bend.



J-B. Lagrange's thesis

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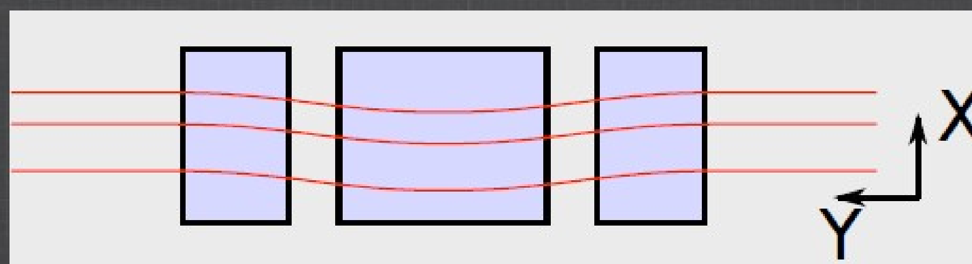
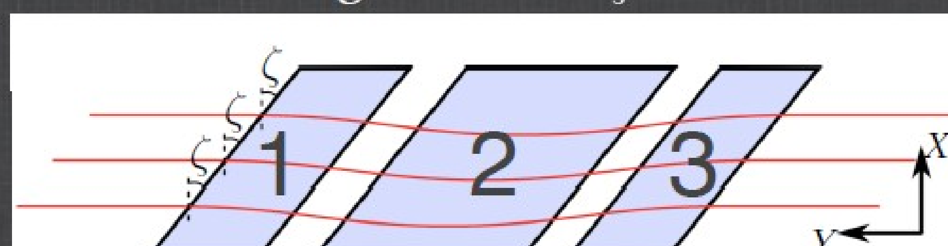
Straight FFAG (principles)

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: $\zeta = const.$

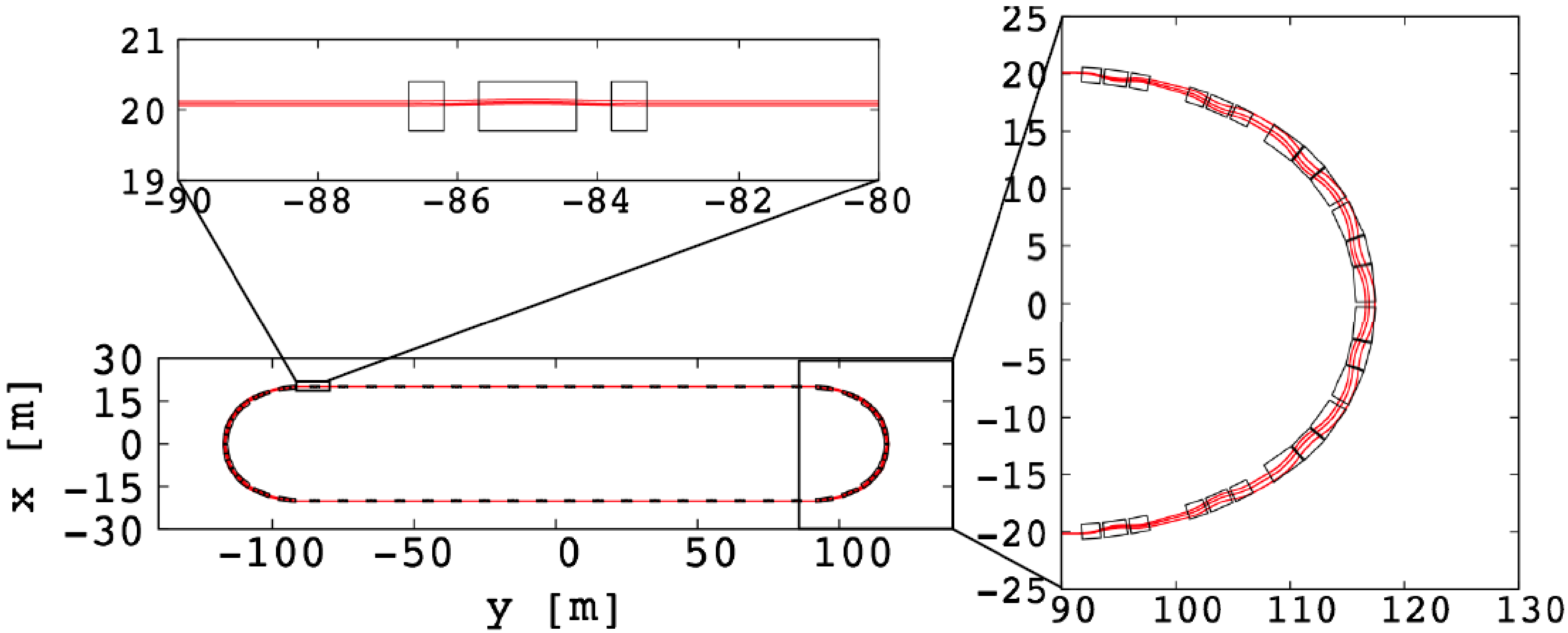
...however orbit scallop angle is present!

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)

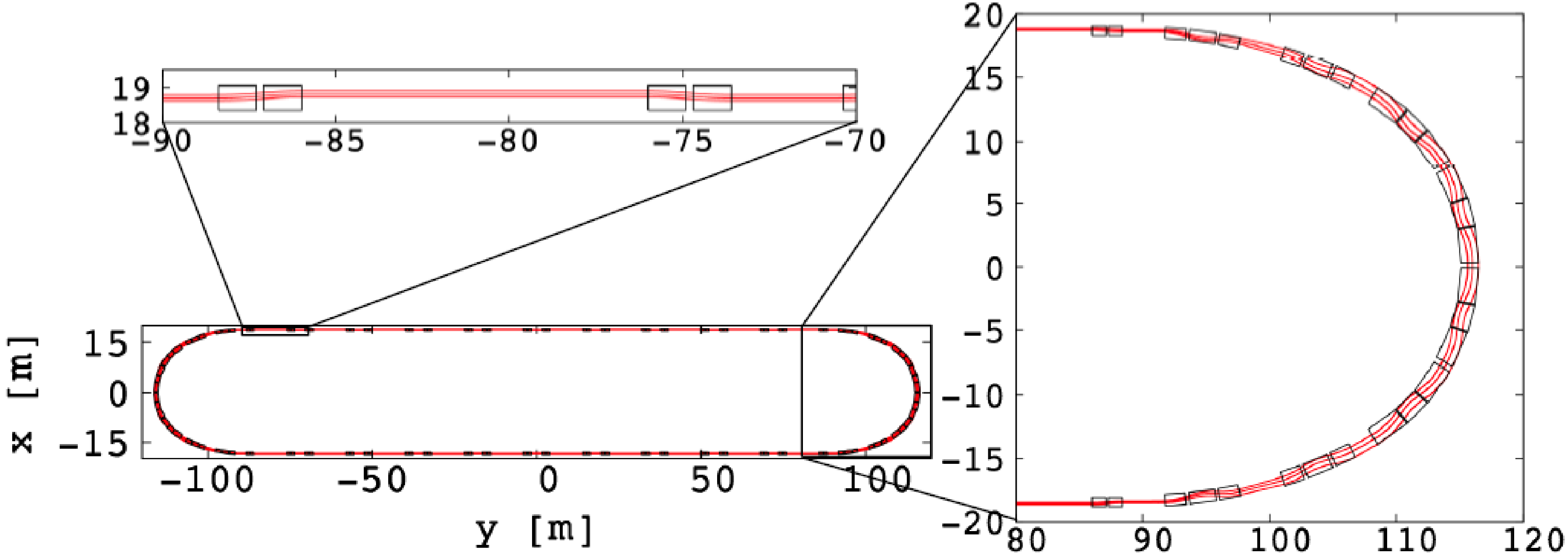


Triplet solution

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 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

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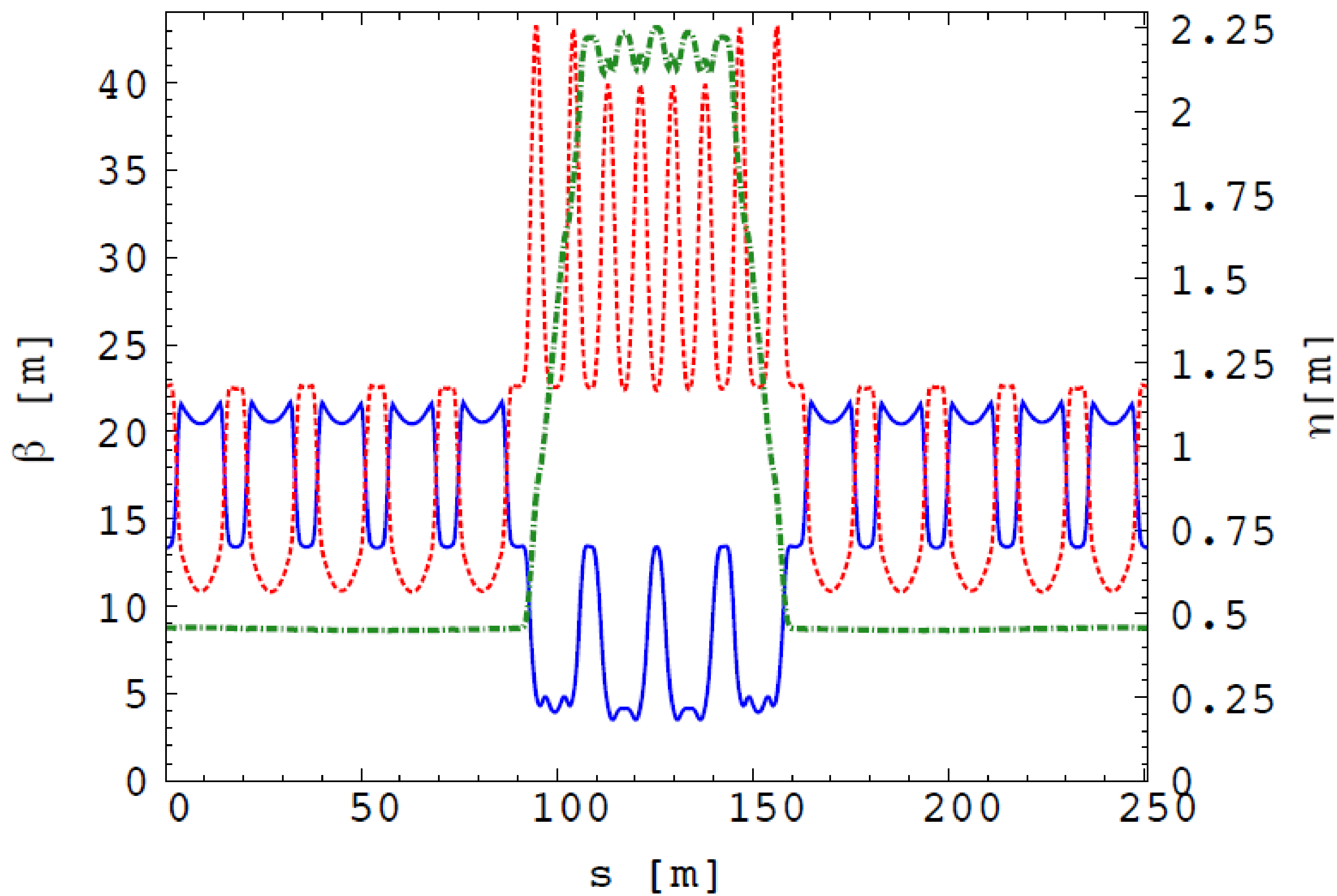
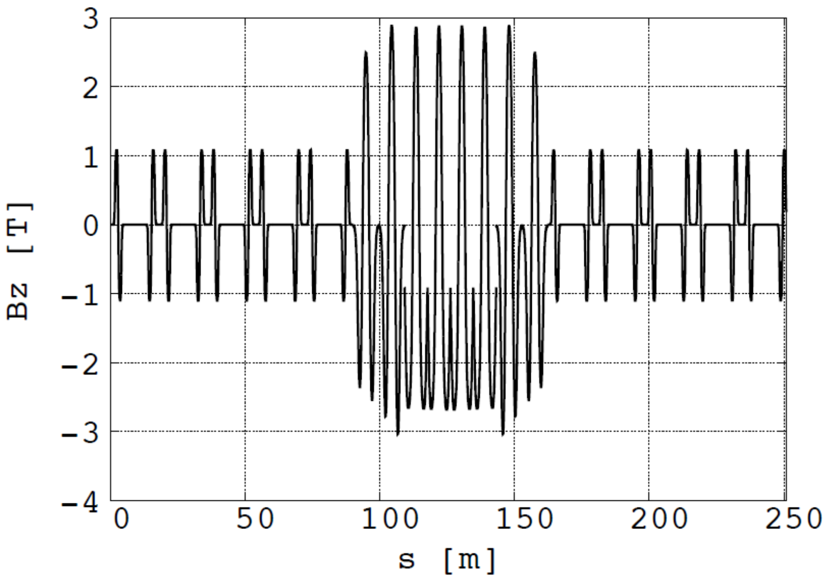
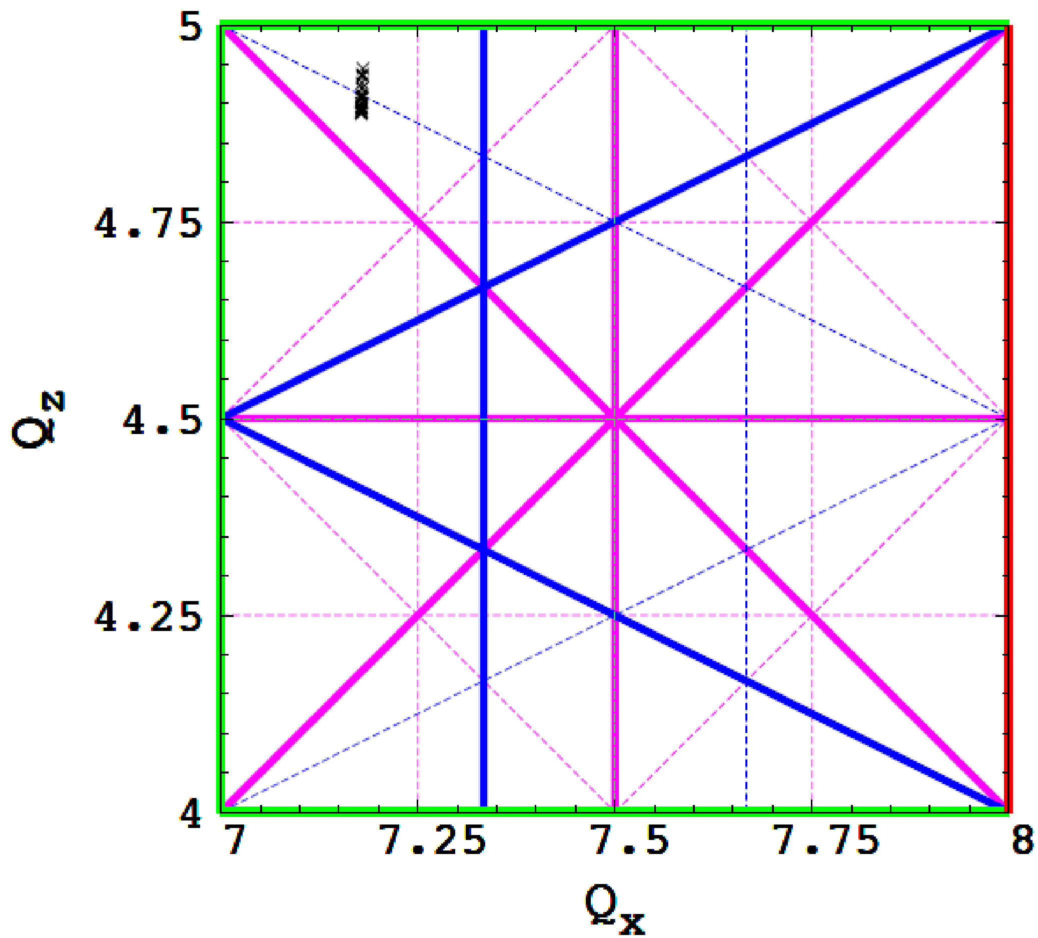
Quadruplet FFAG, lattice functions



Quadruplet, lattice design

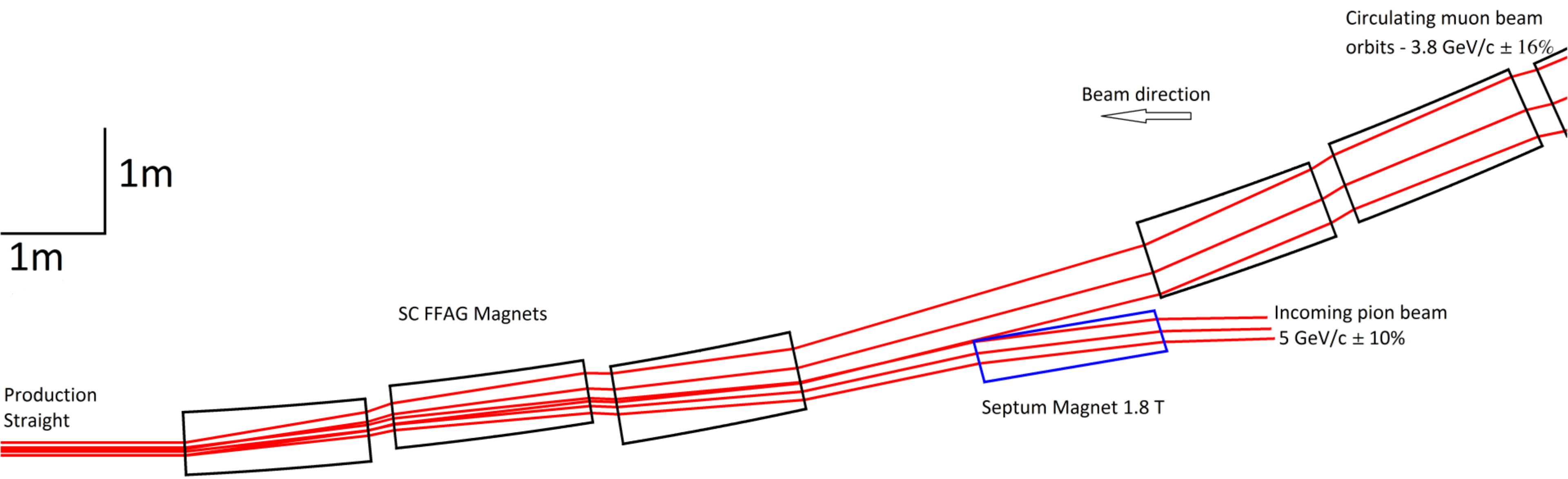


Magnetic field at the top momentum particle



Chromatic tune spread for 19% momentum spread

Injection section

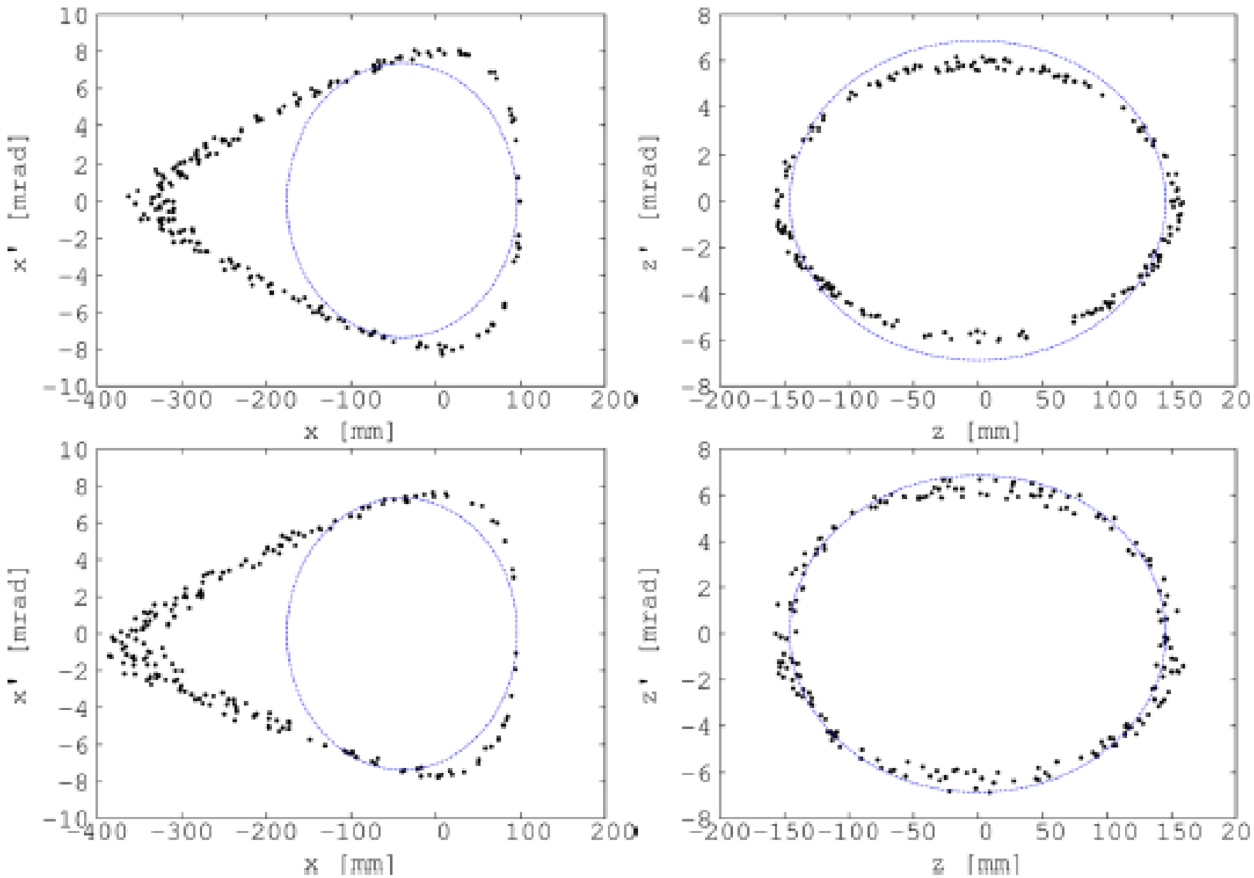


- Injection system will use septum magnet and NO kicker (stochastic injection)
- Special optics allows to introduce a sufficient straight section length

PyZgoubi vs JB's code comparison

JB

PyZgoubi



*Triplet lattice

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

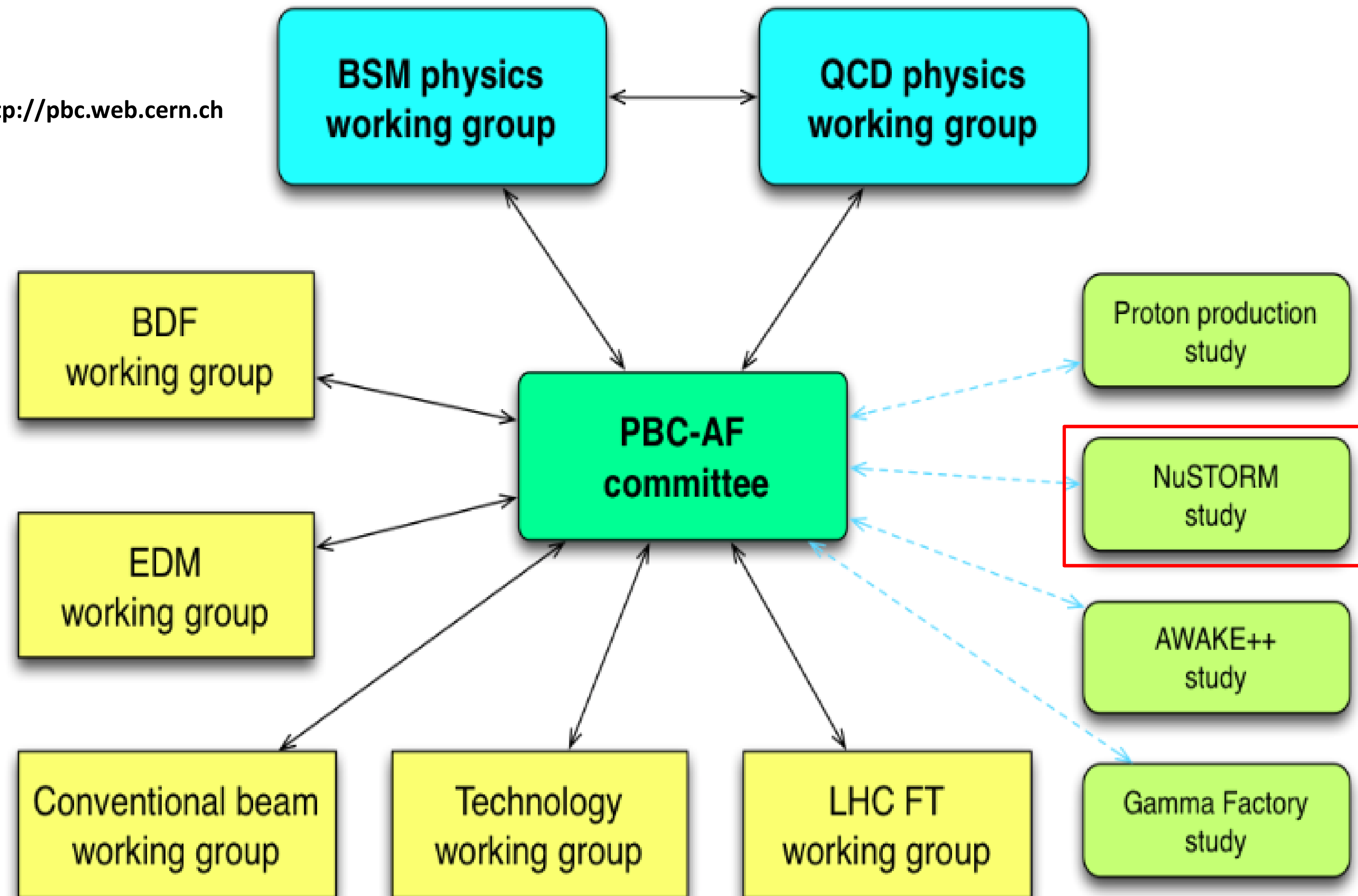
Very good agreement!

nuSTORM plans at FNAL

Funded siting study and delivered Project Definition Report

Physics Beyond Colliders study group

http://pbc.web.cern.ch



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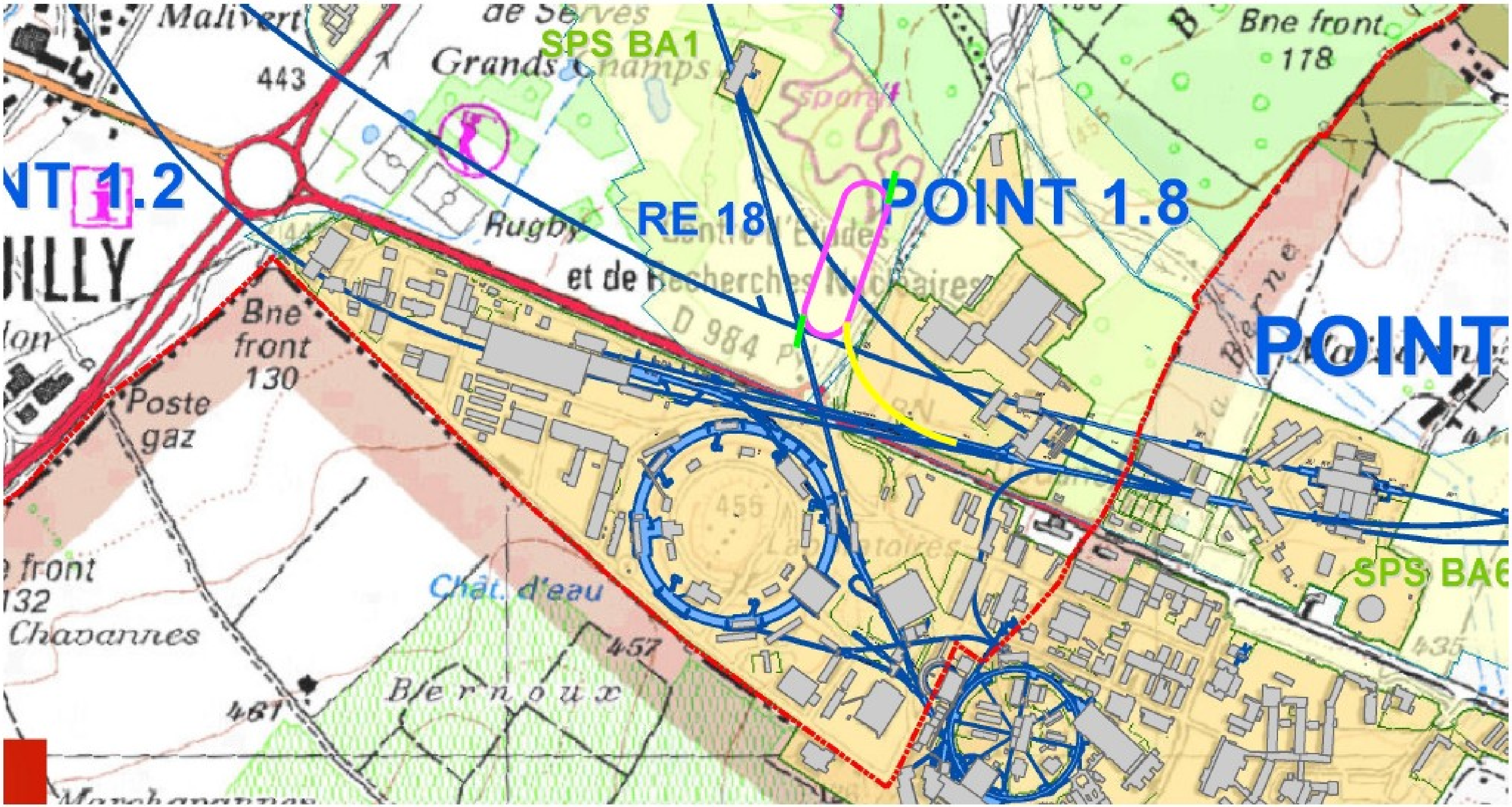
Discussions on a possible implementation of nuSTORM at CERN, I. Efthymiopoulos, PBC meeting at CERN, July 2017



A very promising option was identified!

Conclusions

- nuSTORM is an important as it can measure neutrino interaction precisely, which can reduce systematic errors of neutrino oscillation experiments seeking CP violation signal.
- Solid designs exist and could be implemented straightaway (FODO or FFAG)
- 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.
- Study continues in the framework of Physics Beyond Colliders aiming for a full feasibility of implementation at CERN

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.