PRISM system – status and challenges

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on behalf of

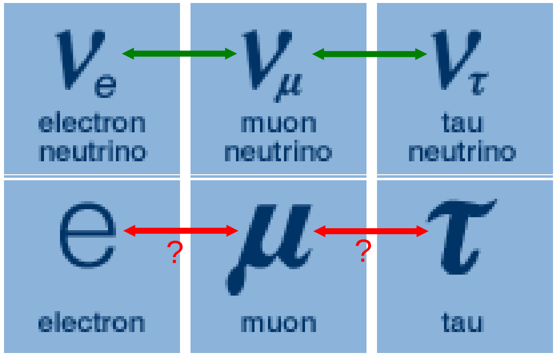
the PRISM Task Force

Outline

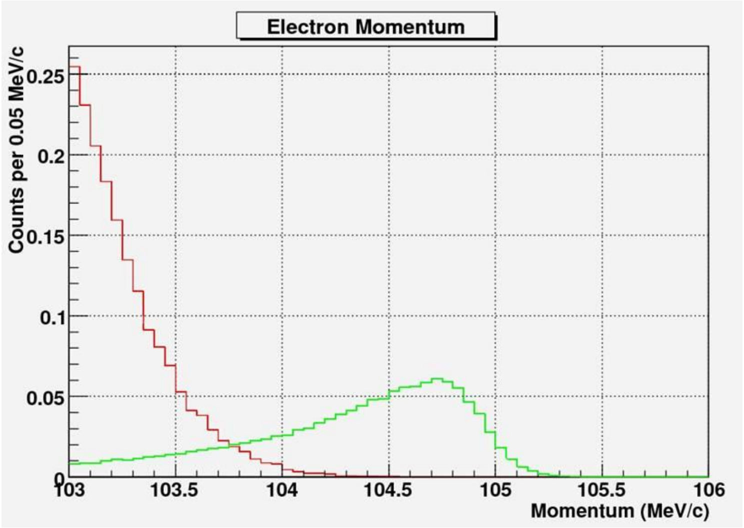
- Introduction
- PRISM concept
- Main challenges
- Status of the achievements
- Summary and future plans.

Introduction

- Charge lepton flavor violation (cLFV) is strongly suppressed in the Standard Model, its detection would be a clear signal for new physics!
- Search for cLFV is complementary to LHC.
- The μ^- + N(A,Z)$\rightarrow$e- + N(A,Z) seems to be the best laboratory for cLFV.
- The background is dominated by beam, which can be improved.
- The COMET and Mu2e were proposed and PRISM/PRIME is the next generation experiment.



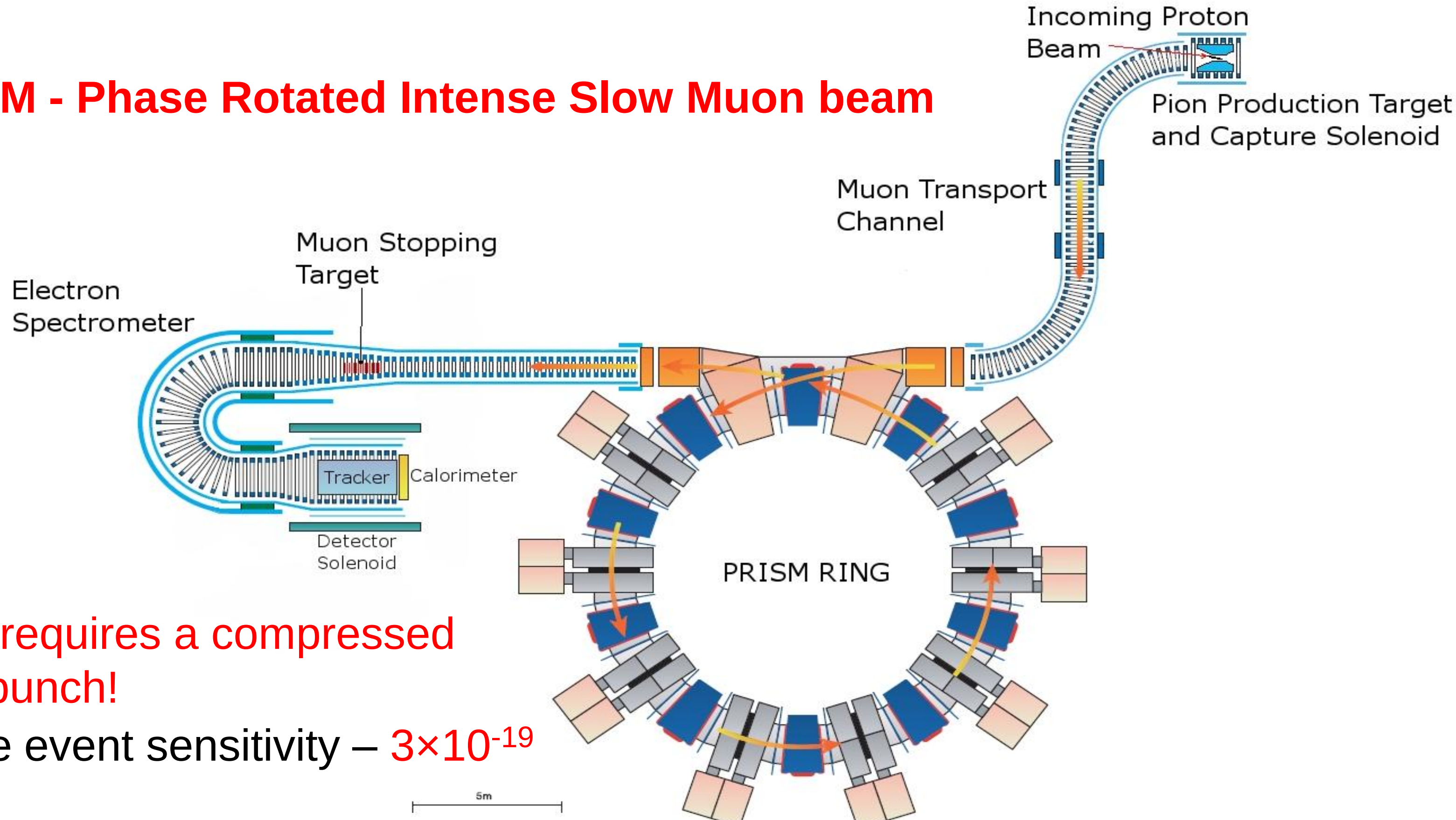
Does cLFV exists?



Simulations of the expected electron signal (green).

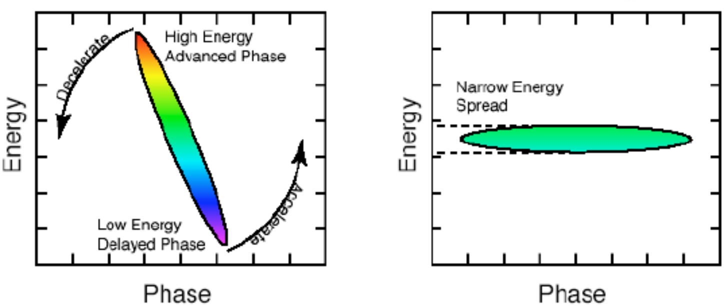
Layout of the PRISM/PRIME

PRISM - Phase Rotated Intense Slow Muon beam



PRISM requires a compressed proton bunch!

Single event sensitivity – 3×10^{-19}



The PRISM/PRIME experiment based on FFAG ring was proposed (Y. Kuno, Y. Mori) for a next generation cLFV searches in order to:

- reduce the muon beam energy spread by phase rotation,
- purify the muon beam in the storage ring.

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PRISM parameters

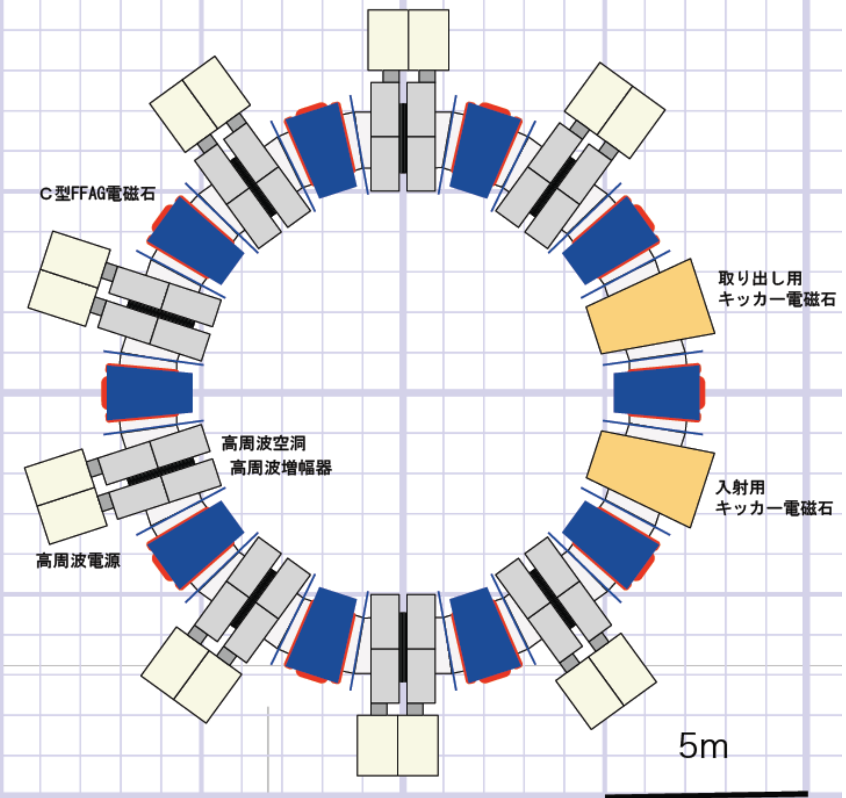
Parameter	Value
Target type	solid
Proton beam power	1-4 MW
Proton beam energy	multi-GeV
Proton bunch duration	~10 ns total (in synergy with the NF)
Pion capture field	4-10 T
Momentum acceptance	±20 %
Reference μ^- momentum	40-68 MeV/c
Harmonic number	1
Minimal acceptance (H/V)	3.8/0.5 π cm rad
RF voltage per turn	3-5.5 MV
RF frequency	3-6 MHz
Final momentum spread	±2%
Repetition rate	100 Hz-1 kHz

Reference Design Parameters, A. Sato

PRISM-FFAG

Phase Rotator

- N=10
- k=4.6
- F/D(BL)=6.2
- r0=6.5m for 68MeV/c
- half gap = 17cm
- mag. size 110cm @ F center
- Radial sector DFD Triplet
- $\theta_F/2$=2.2deg
- θ_D=1.1deg
- Max. field
- F : 0.4T
- D : 0.065T
- tune
- h : 2.73
- v : 1.58



V per turn ~2-3 MV

$\Delta p/p$ at injection = ± 20%

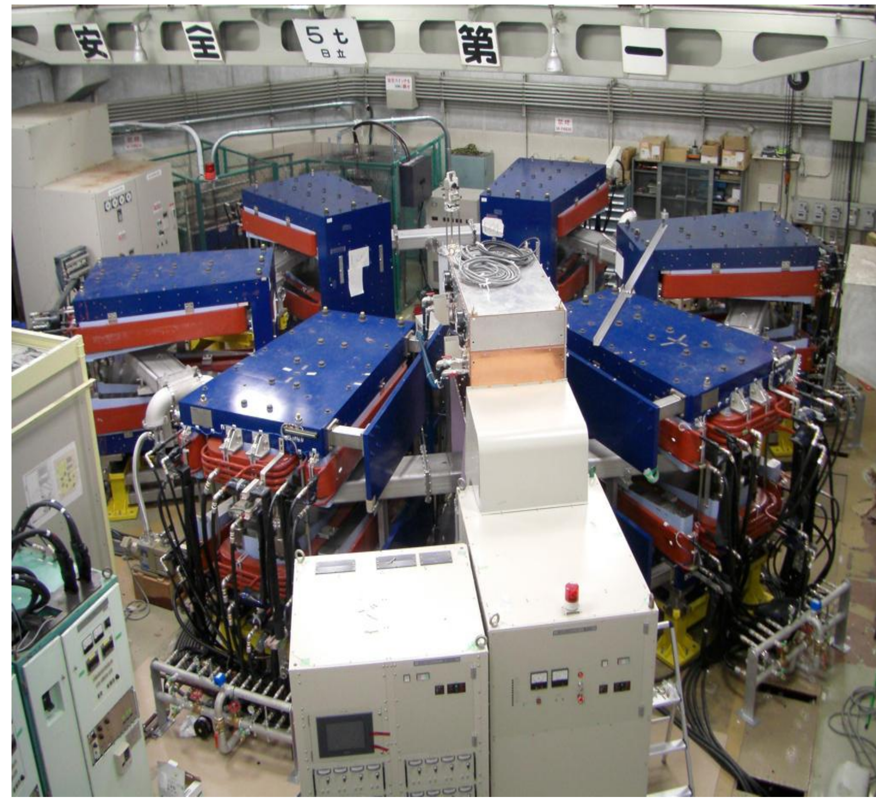
$\Delta p/p$ at extraction = ± 2% (after 6 turns ~ 1.5 us)

h=1

Demonstration Experiment at Osaka

- Original design uses 10 cells. Demonstration experiment used 6 cells.
- Use ^{241}Am alpha source (200 MeV/c degraded to 100 MeV/c with Al foil).
- Can locate position and angle of source.
- Study closed orbits, dynamic aperture and tune.

	10-cell Ring	6-cell Ring
Particle	muon	alpha
Momentum (MeV/c)	68	100
Radius (m)	6.5	3.5
Number of cavities	8	1
Number of field clamps	20	2



PRISM Task Force

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The aim of the PRISM Task Force:

• Address the technological challenges in realising an FFAG based muon-to-electron conversion experiment,

• Strengthen the R&D for muon accelerators in the context of the Neutrino Factory and future muon physics experiments.

The Task Force areas of activity:

- the physics of muon to electron conversion,
- proton source,
- pion capture,
- muon beam transport,
- injection and extraction for PRISM-FFAG ring,
- FFAG ring design including the search for a new improved version,
- FFAG hardware systems R&D.

Members:

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M. Lancaster, UCL, London, UK

You are welcome to join us!

PRISM Task Force Design Strategy

Option 1:
Adopt current design and
work out injection/extraction,
and hardware

Option 2:
Find a new design

They should be evaluated in parallel and
finaly confronted with the figure of merit (FOM)
(number of muons delivered to target/cost).

Requirements for a new design:

- High transverse acceptance (at least 38h/5.7v [Pi mm] or more).
- High momentum acceptance (at least ± 20% or more).
- Small orbit excursion.
- Compact ring size (this needs to be discussed).
- Relaxed or at least conserved the level of technical difficulties.
  for hardware (kickers, RF) with respect to the current design.

Challenges for the PRISM accelerator system

• The need for the compressed proton bunch:
- is in full synergy with the Neutrino Factory and a Muon Collider.
- puts PRISM in a position to be one of the incremental steps of the muon programme.

• Target and capture system:
-is in full synergy with the Neutrino Factory and a Muon Collider studies.
-requires a detailed study of the effect of the energy deposition induced by the beam

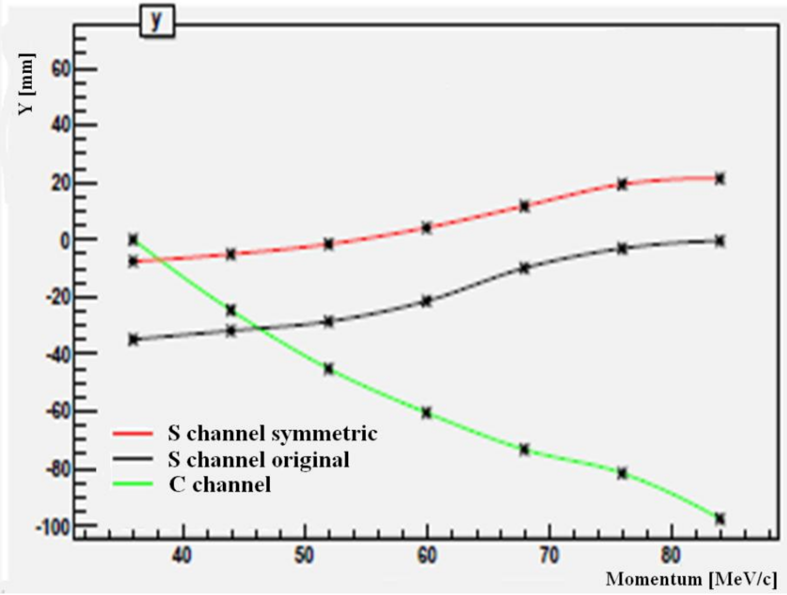
• Design of the muon beam matching from the solenoidal capture to the PRISM FFAG ring.
-very different beam dynamics conditions.
-very large beam emittances and the momentum spread.

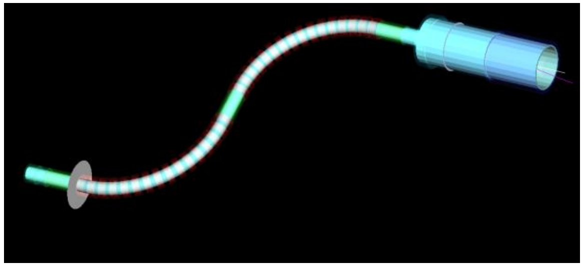
• Muon beam injection/extraction into/from the FFAG ring.
-very large beam emittances and the momentum spread.
-affects the ring design in order to provide the space and the aperture.

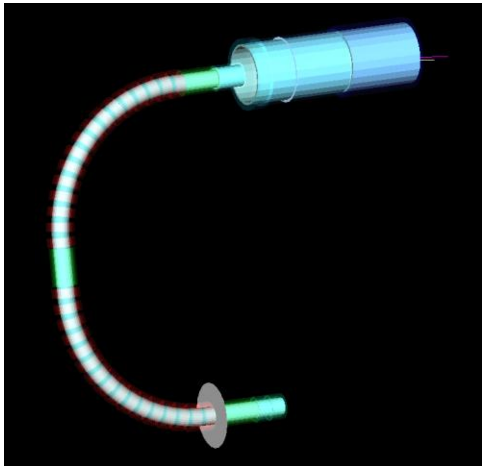
• RF system
-large gradient at the relatively low frequency and multiple harmonics (the “sawtooth” in shape).

Matching to the FFAG I

- Muon beam must be transported from the pion production solenoid to the Alternating Gradient channel.
- Two scenarios considered, S-shaped and C-shaped.
  - S-shaped with correcting dipole field has the best transmission and the smallest dispersion.

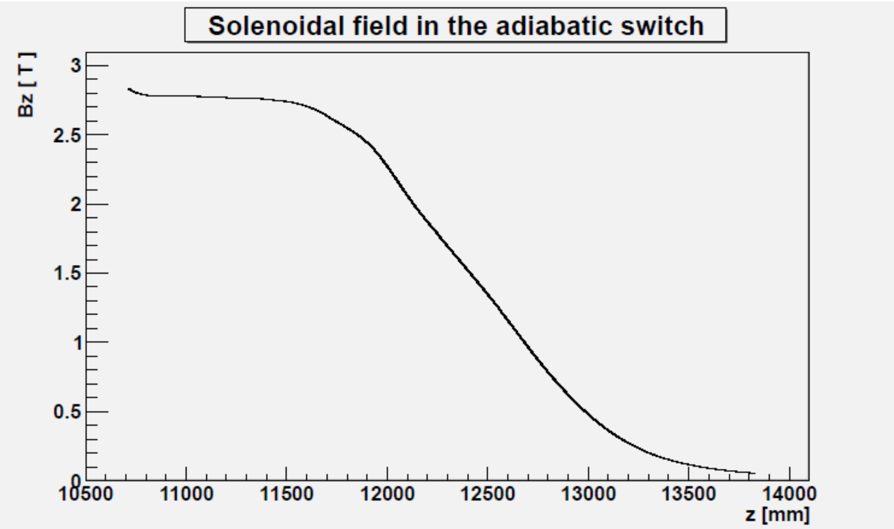


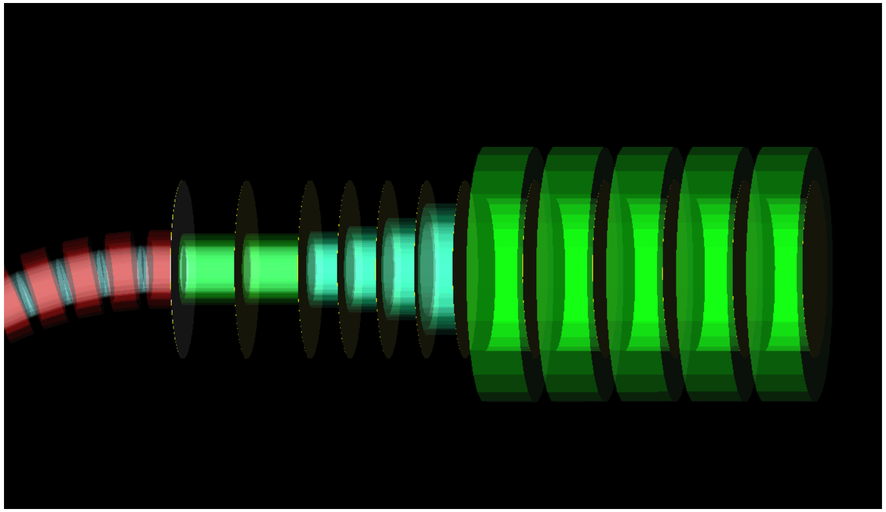




The mean vertical beam position versus momentum at the end of bend solenoid channel for various configurations.

Matching to the FFAG II





Initial version of the adiabatic switch

Preliminary geometry: the end of the S-channel together with matching solenoids, adiabatic switch and 5 quad lenses.

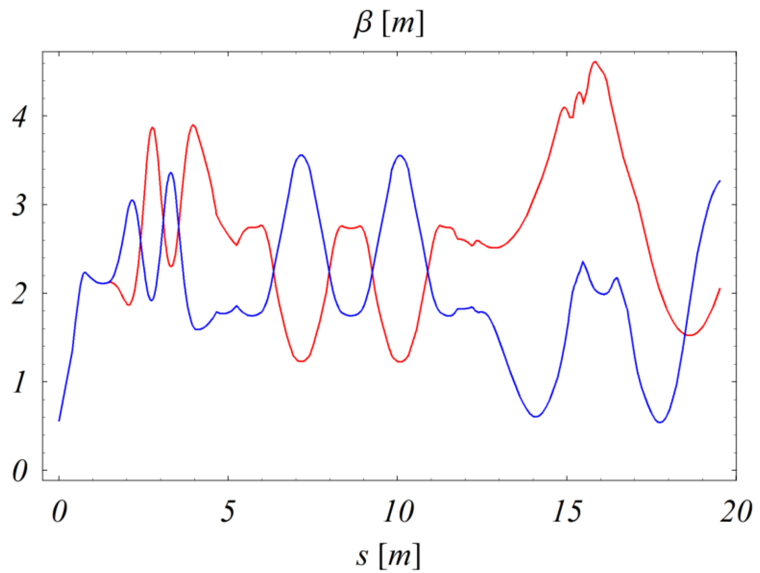
Current best version includes:

- adiabatic switch from 2.8 to 0.5 T (to increase the beam size),
- additional solenoidal lense to match α=0 (not shown in the pictures above),
- 5 quad lenses,

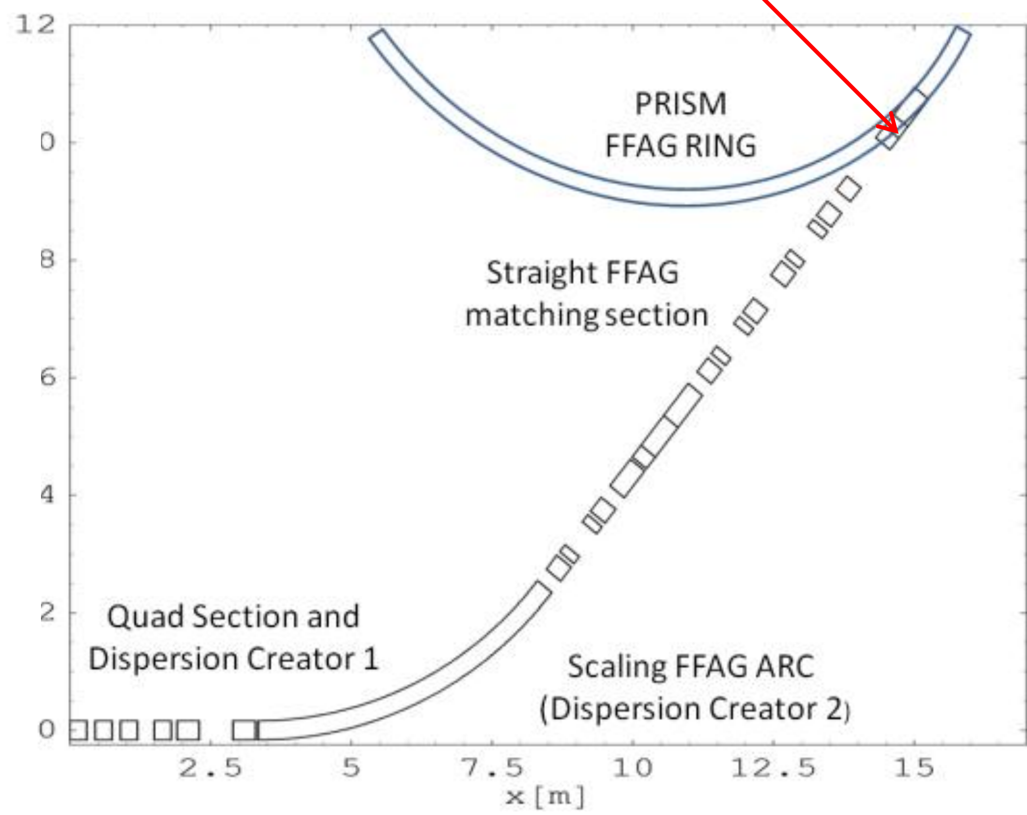
Matching to the FFAG III

- A dedicated transport channel has been designed to match dispersions and betatron functions.

The transfer line-ring interface is the most difficult.



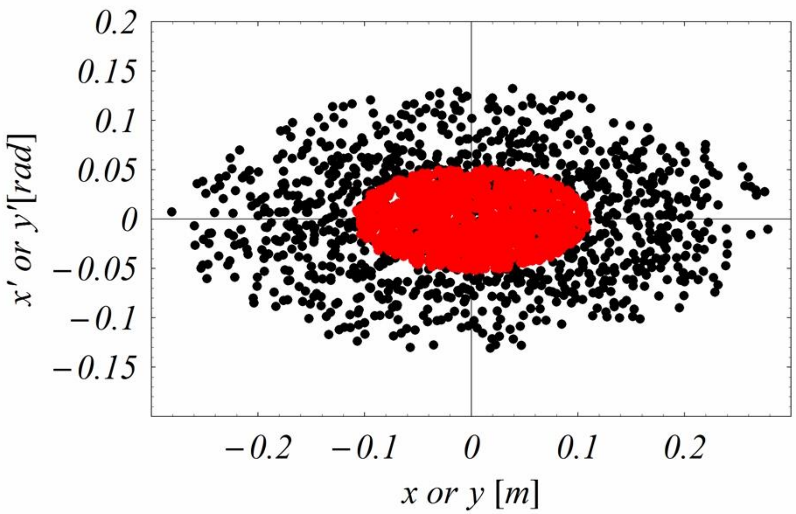
Horizontal (red) and vertical (blue) betatron functions in the PRISM front end.



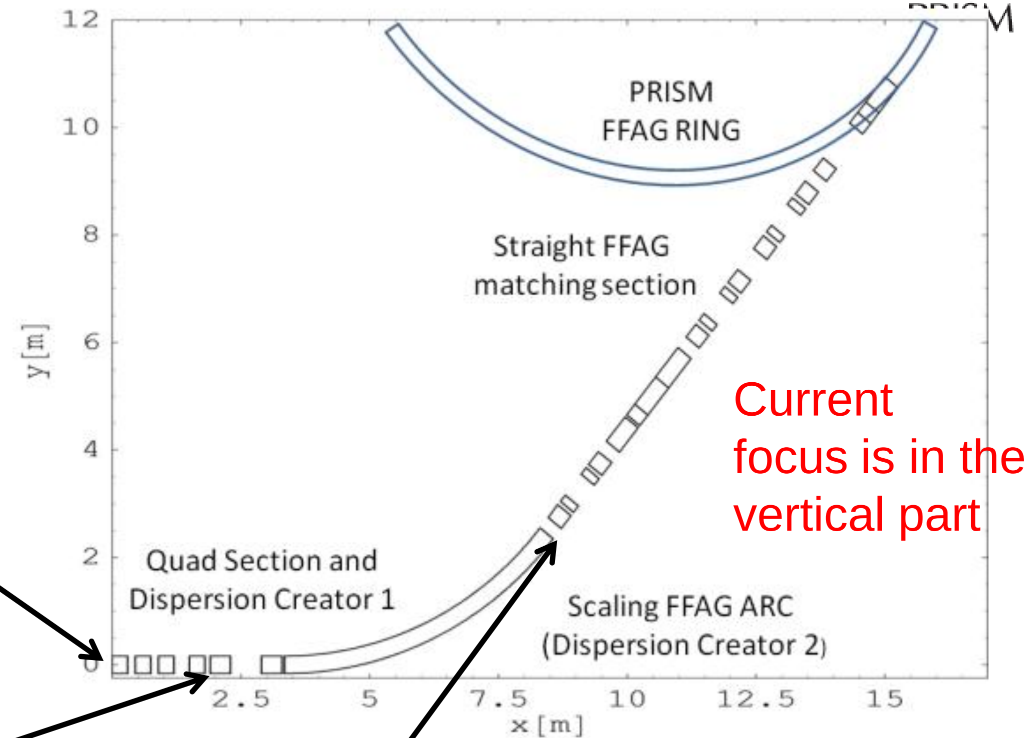
Layout of the matching section seen from the above.

Matching to the FFAG IV

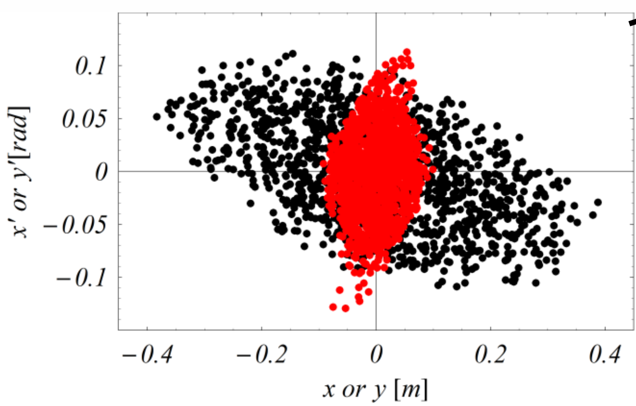
- Tracking status (work in progress)



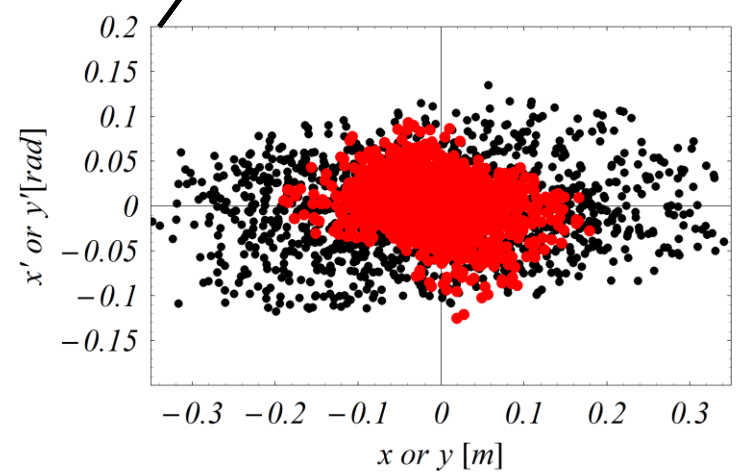
Horizontal (black) and vertical (red) phase spaces at the input to the AG part of the PRISM muon front end.



Current focus is in the vertical part



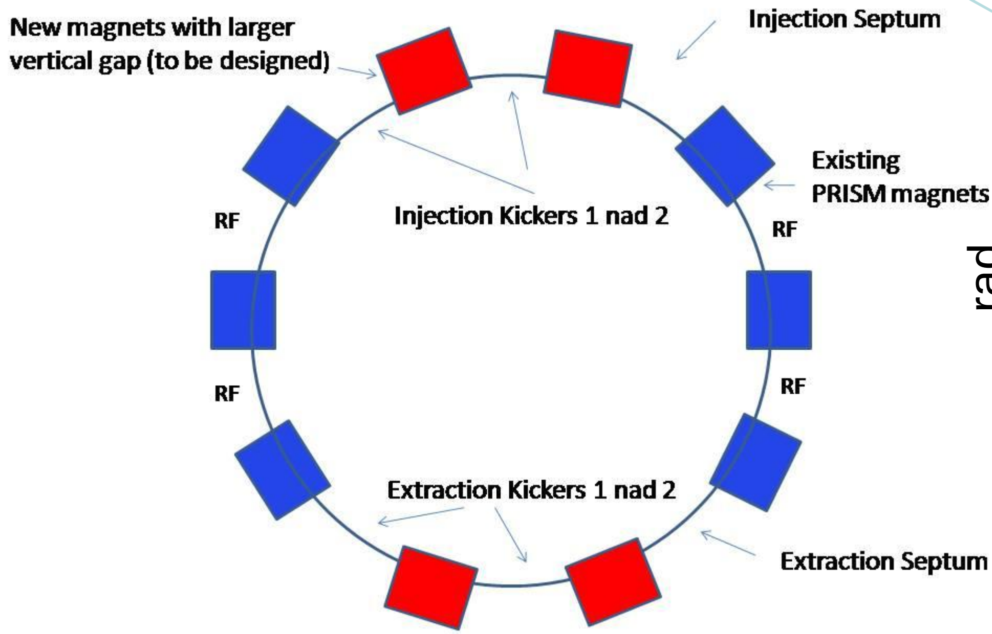
At the end of the quad Channel

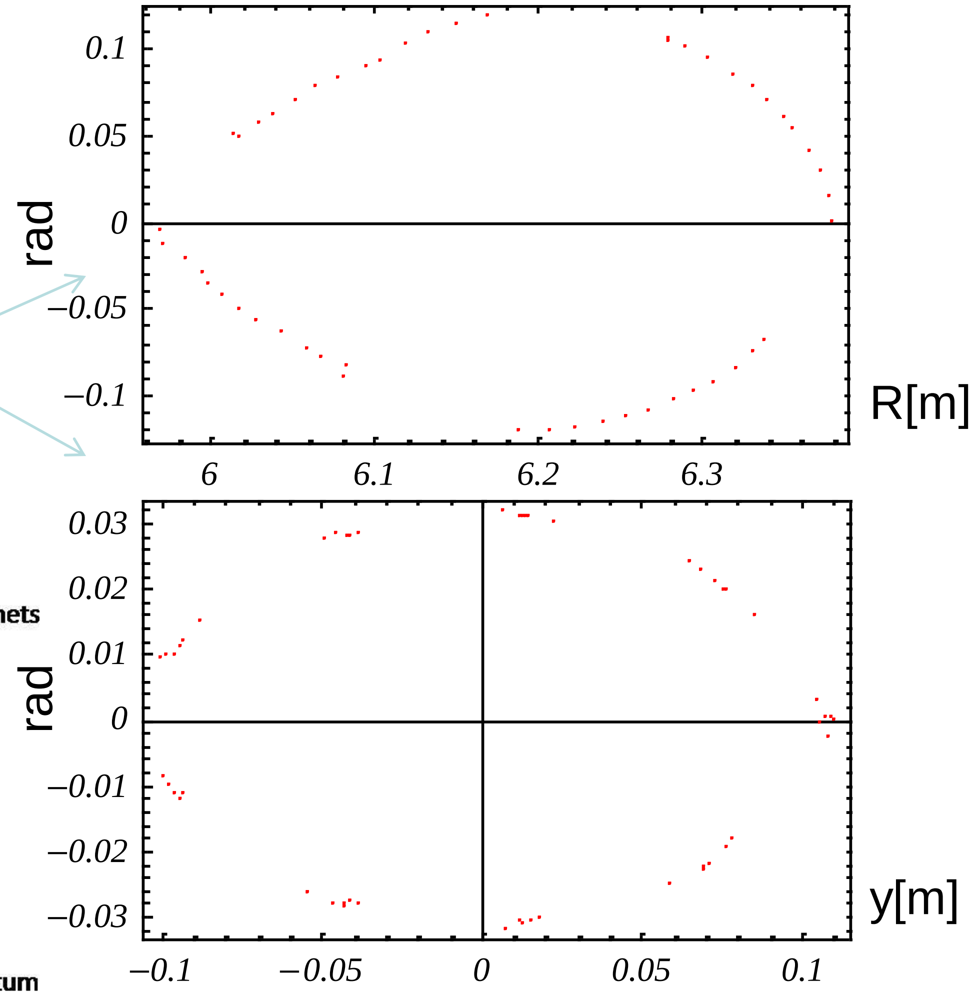


At the end of the horizontal dispersion creator (transmission 97%)

Reference design modifications for Injection/Extraction

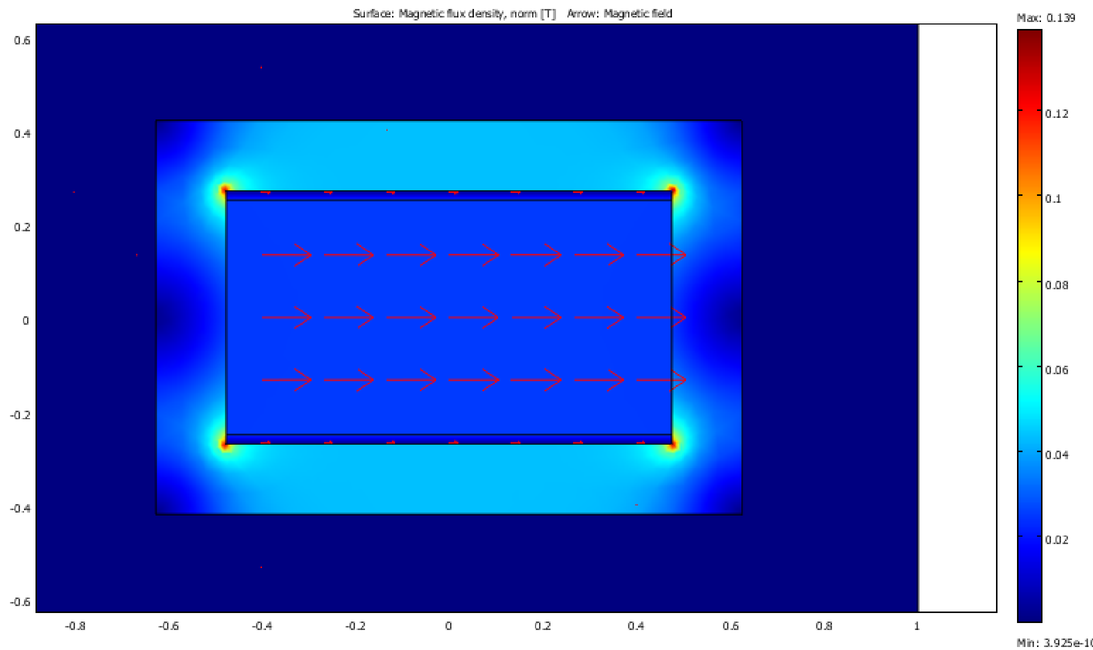
- In order to inject/extract the beam into the reference design, special magnets with larger vertical gap are needed.
- This may be realised as an insertion (shown in red below).
- The introduction of the insertion breaks the symmetry but this does not limits the dynamical acceptance, if properly done!



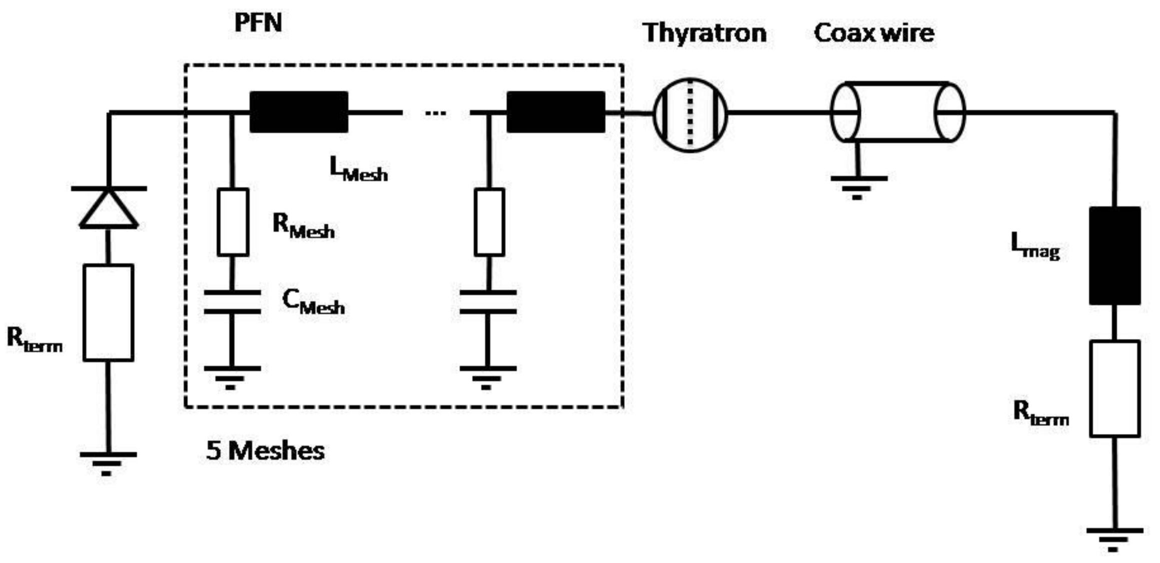


Preliminary PRISM kicker studies

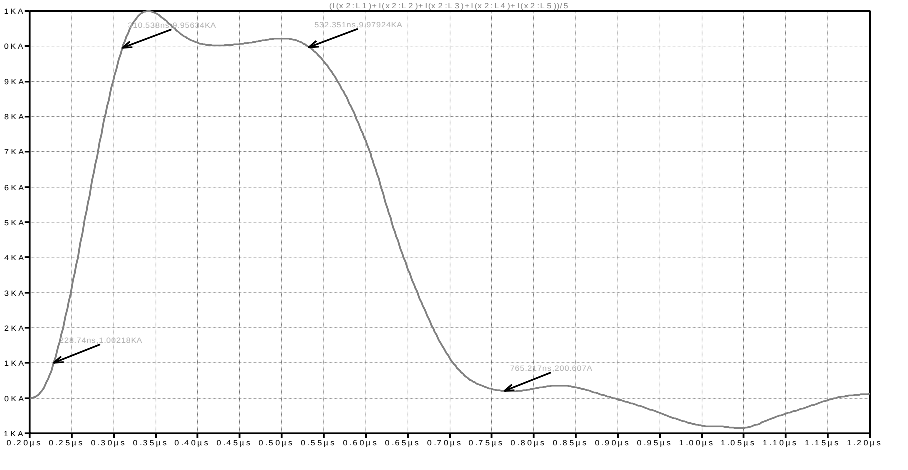
- length 1.6 m
- B 0.02 T
- Aperture: 0.95 m x 0.5
- Flat top 40 /210 ns (injection / extraction)
- rise time 80 ns (for extraction)
- fall time ~200 ns (for injection)
- W_{mag}=186 J
- L = 3 uH (preliminary)
- I_{max}=16 kA



PRISM Pulse Formation



80 kV
Impedance 3 Ohm
Kicker subdivided into 8 smaller kickers
Travelling wave kicker
Each sub-kicker has 5 sections
1 plate capacitor per section



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RF development

•Substantial progress has been achieved in the design of MA cavities using a new FT3L.

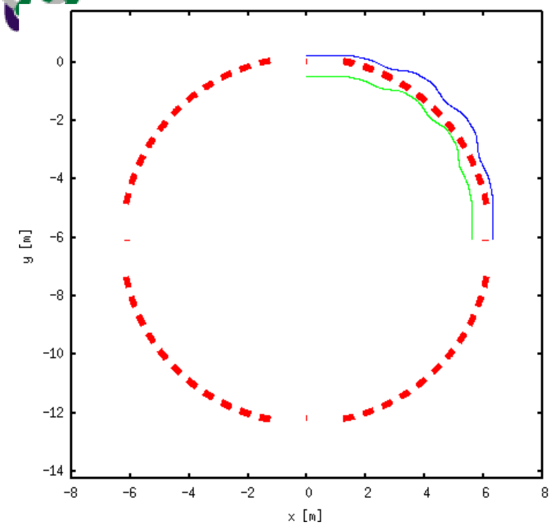
• Large-size MA cores have been successfully fabricated at J-PARC. Those cores have two times higher impedance than ordinary FT3M MA cores.

• For the PRISM RF system in order to either reduce the core volume cutting the cost by a factor of 3 or to increase the field gradient.

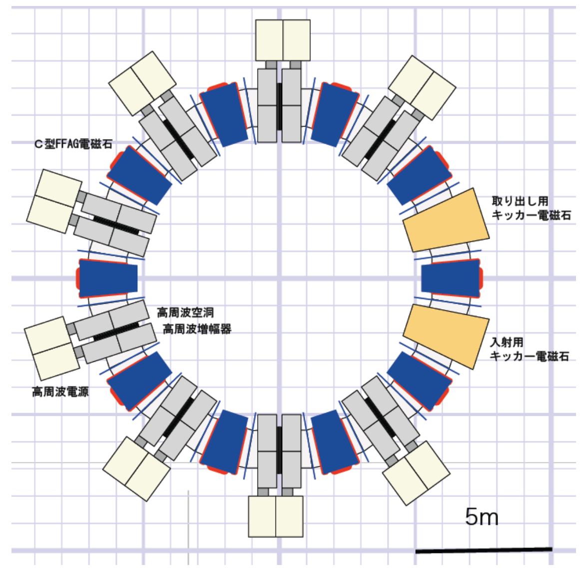
•Both options should be considered.

The first high impedance core annealed at J-PARC

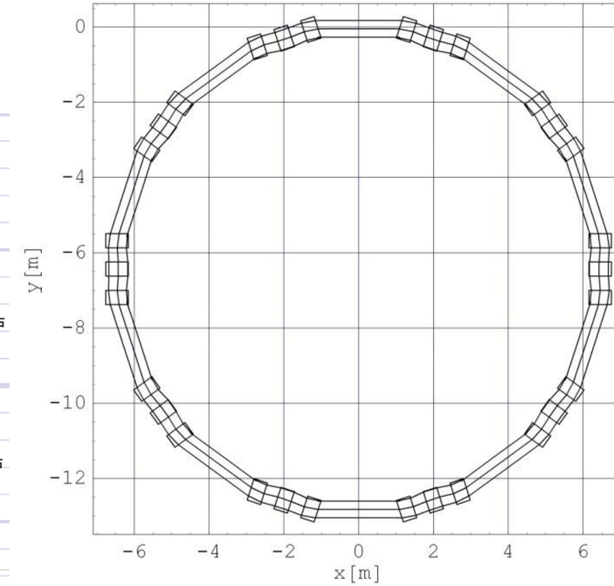
FFAG Ring Choice



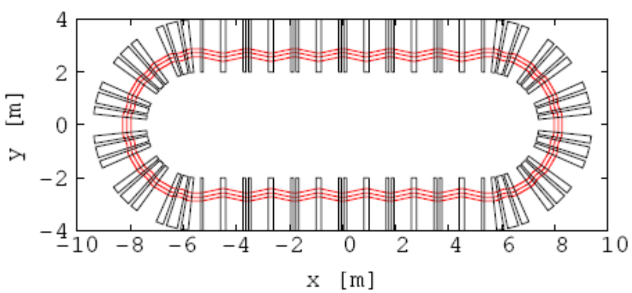
Scaling Superperiodic



Reference design

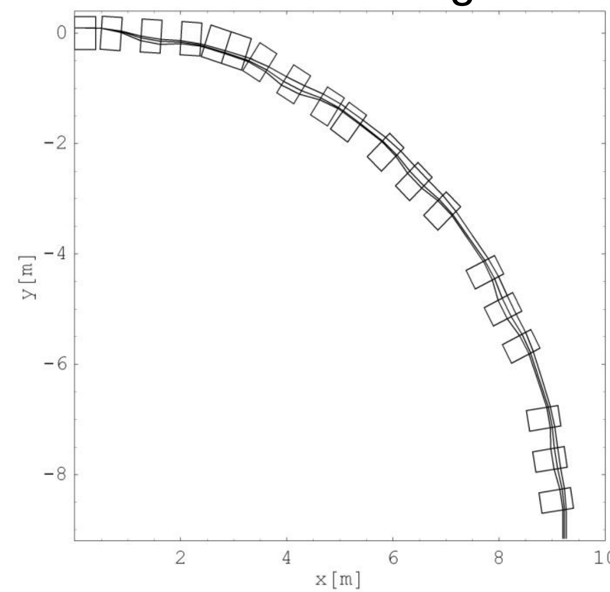


Non-Scaling



Advanced scaling FFAG

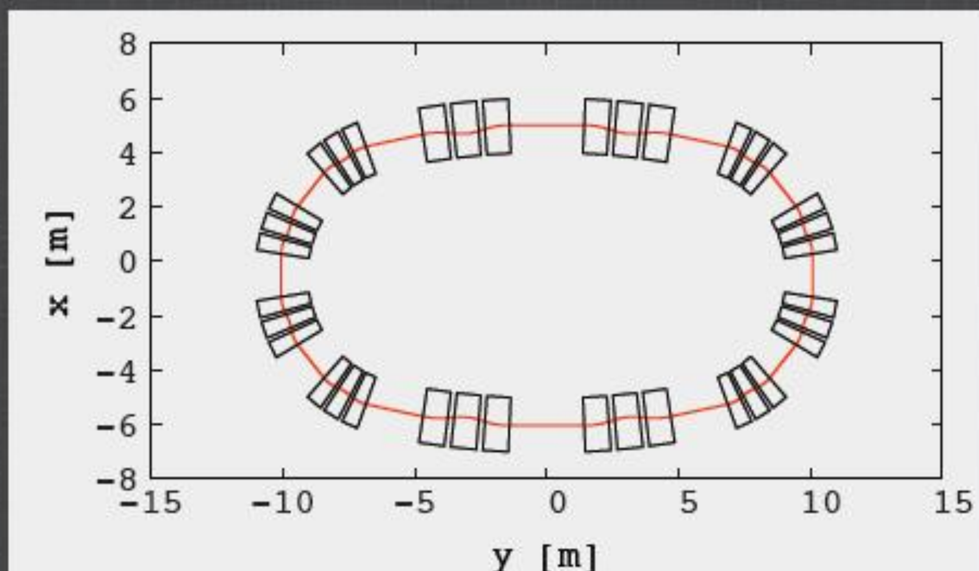
- We need to decide about the possible baseline update very soon.
- The choice is dictated by the performance.



Advanced NS-FFAG

Egg-shape design

Small Bending cell FDF triplet		Large Bending cell FDF triplet	
k-value	3.82	k-value	28.9503
total bending angle	39.15 deg.	total bending angle	11.7 deg.
Average radius	5 m	Average radius	30 m
Phase advances:		Phase advances:	
Horizontal μ_x	90 deg.	Horizontal μ	75 deg.
Vertical μ_z	60 deg.	Vertical μ	81 deg.
Dispersion	1 m	Dispersion	1 m

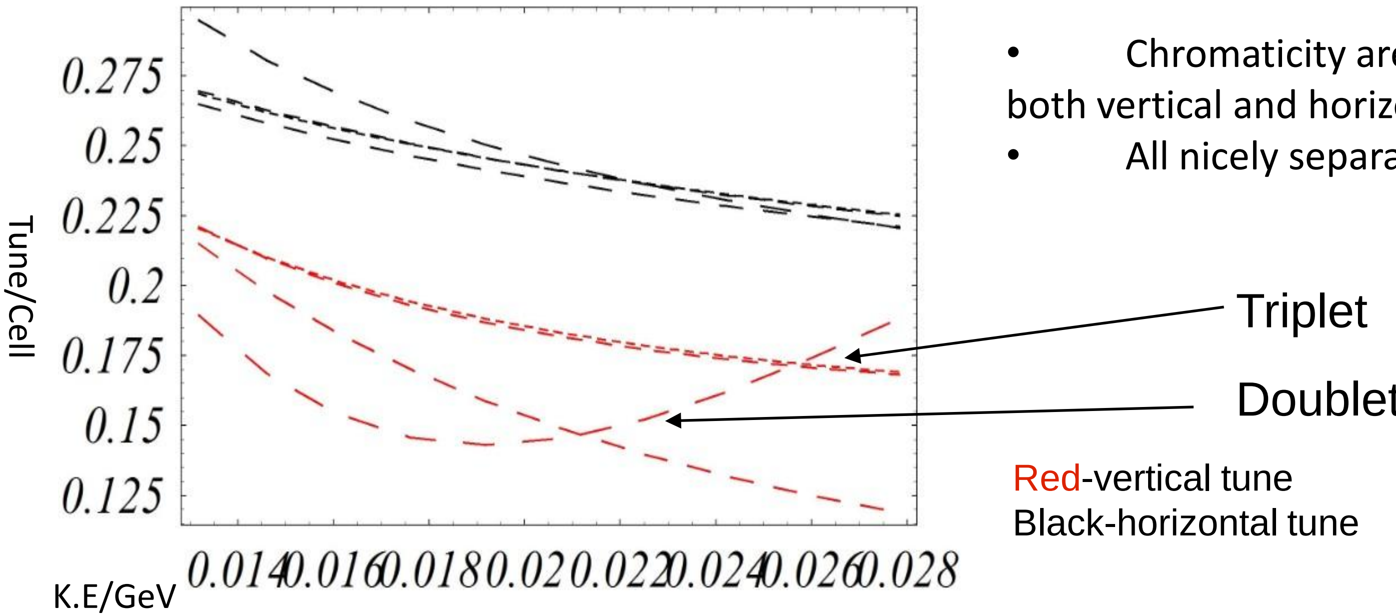


The most promising concept, work in collaboration with JB Lagrange.
This work triggered the progress on the nuSTORM FFAG design.

NS-FFAG ring parameters

Lattice type	“FDF”	“FDF”	“FDF”	FD
F gradient (T/m)	0.1035	0.0545	0.0446	0.6
D gradient (T/m)	0.0997	0.0989	0.1184	-0.14
F field (T)	0.2307	0.0019	0.1756	0.18
D field (T)	-0.0833	0.2500	-0.0685	0.1756
Long drift length (m)	1.1	1.1	1.1	1.1
Short drift length (m)	0.377	0.3	0.3	0.3
Length of F (m)	0.377	0.5	0.5	0.3
Length of D (m)	0.377	0.5	0.5	0.75
N	10	10	10	10

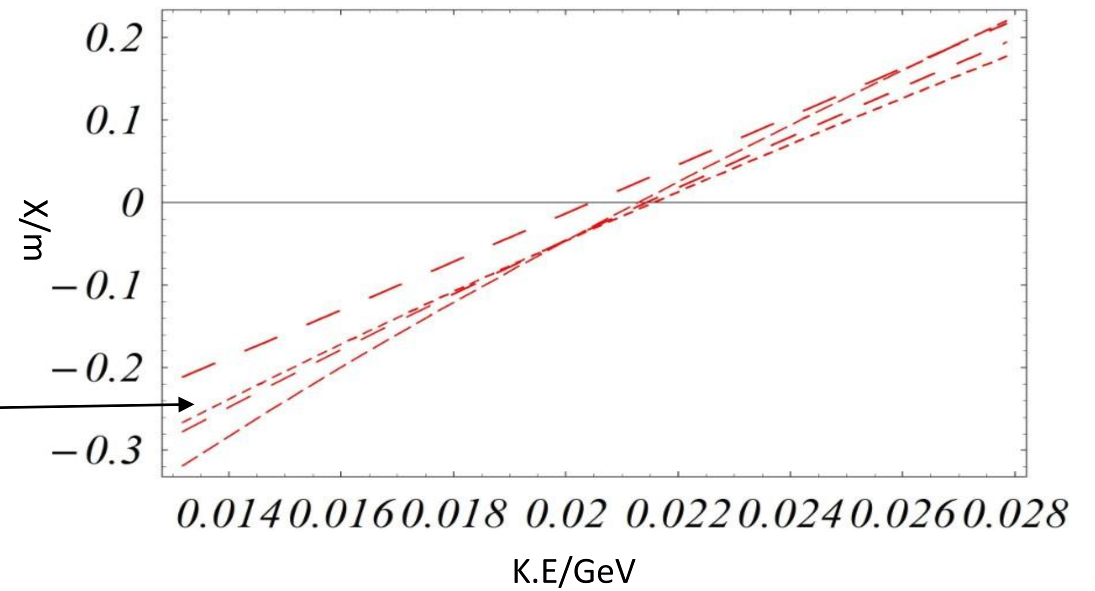
Orbits and tunes



- Chromaticity are relatively flat in both vertical and horizontal planes
- All nicely separated.

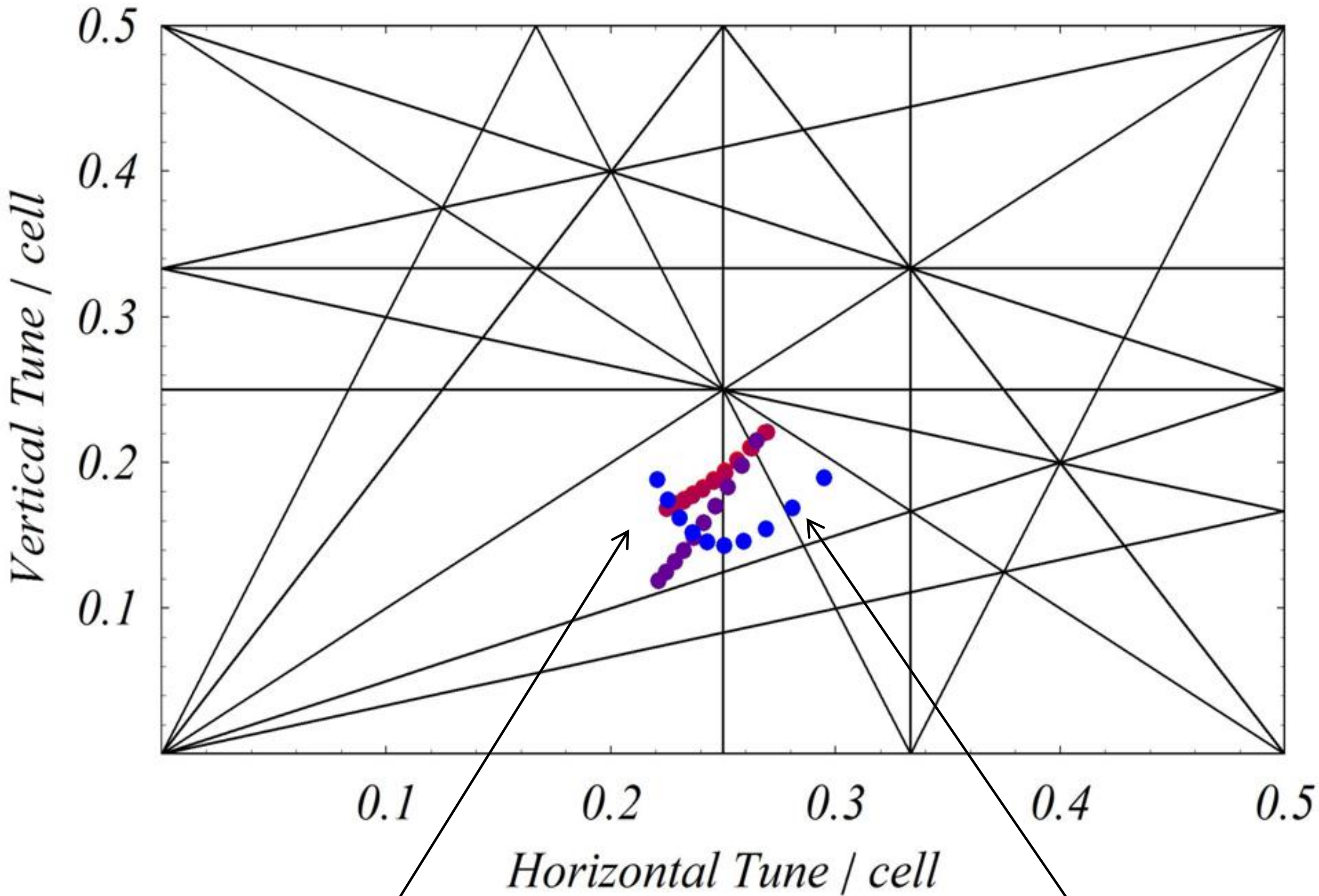
Red-vertical tune
Black-horizontal tune

- Orbit excursion
- Orbits are very linear with momentum



Doublet orbist are the most compact

Resonance diagram



This region gives large dynamical acceptance (DA).

Parabolic *Operation Point* for doublet

Conclusions and future plans

- PRISM/PRIME aims to probe cLFV with unprecedented sensitivity (single event - 3×10^{-19}).
- The reference design was proven in many aspects (phase rotation, magnet design, RF system, etc.) in the accelerator R&D at RCNP, Osaka University.
- PRISM Task Force continues the study addressing the remaining feasibility issues and a substantial progress has been achieved.
- PRISM Task Force aims to demonstrate the feasibility of the PRISM system.
- PRISM/PRIME and nuSTORM FFAG have interesting synergies. It is certainly interesting to explore them further.

Future work

•Further work on the injection/extraction systems.

•Review of the alternative ring designs and evaluation of their performance.

•Optimisation of alternative ring options or more alternatives?

•Baseline design of the PRIME detector system.

•Full G4 physics simulation of the best option.