PRISM

Progress on R&D studies

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on behalf of

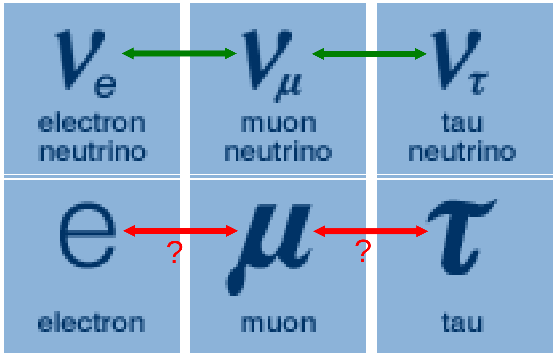
the PRISM Task Force

Outline

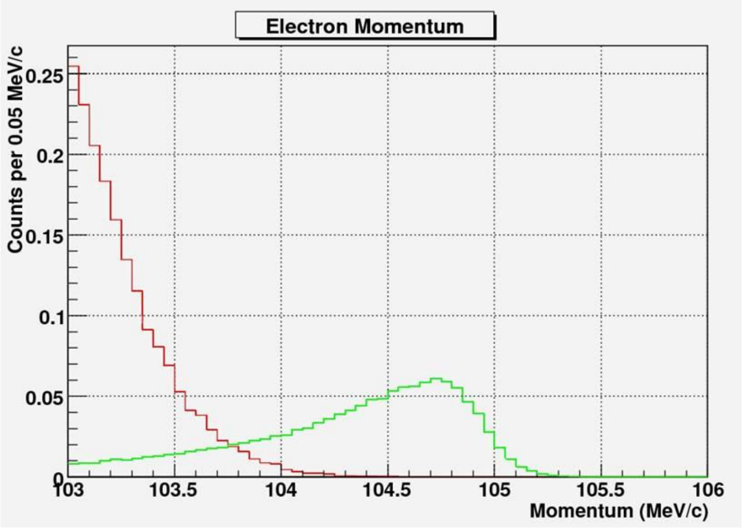
- Introduction.
- PRISM/PRIME experiment.
- Proton beam
- PRISM Task Force initiative.
- Muon beam matching into FFAG ring.
- Injection/extraction hardware.
- RF development.
- Reference PRISM FFAG ring modifications.
- Alternative ring designs.
- Conclusions

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)→e^- + N(A,Z) seems to be the best laboratory for cLFV.
- The background is dominated by beam, which can be improved.
- PRISM/PRIME is the next generation experiment (possible upgrade path to COMET).



Does cLFV exists?



Simulations of the expected electron signal (green).

PRISM System Concept

PRISM - Phase Rotated Intense Slow Muon beam

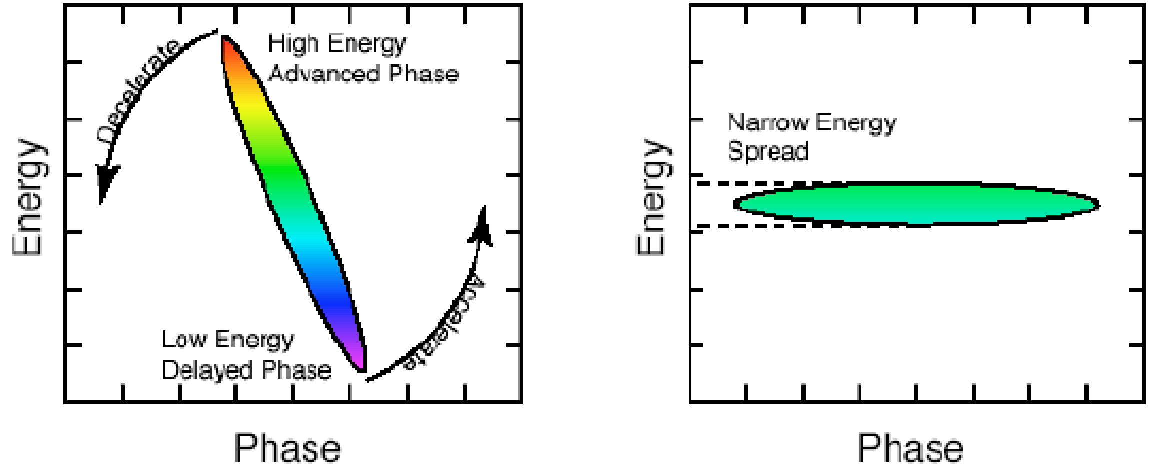
•The PRISM/PRIME experiment based on FFAG ring was proposed (Y. Kuno, Y. Mori) for a next generation cLFV searches in order to:

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

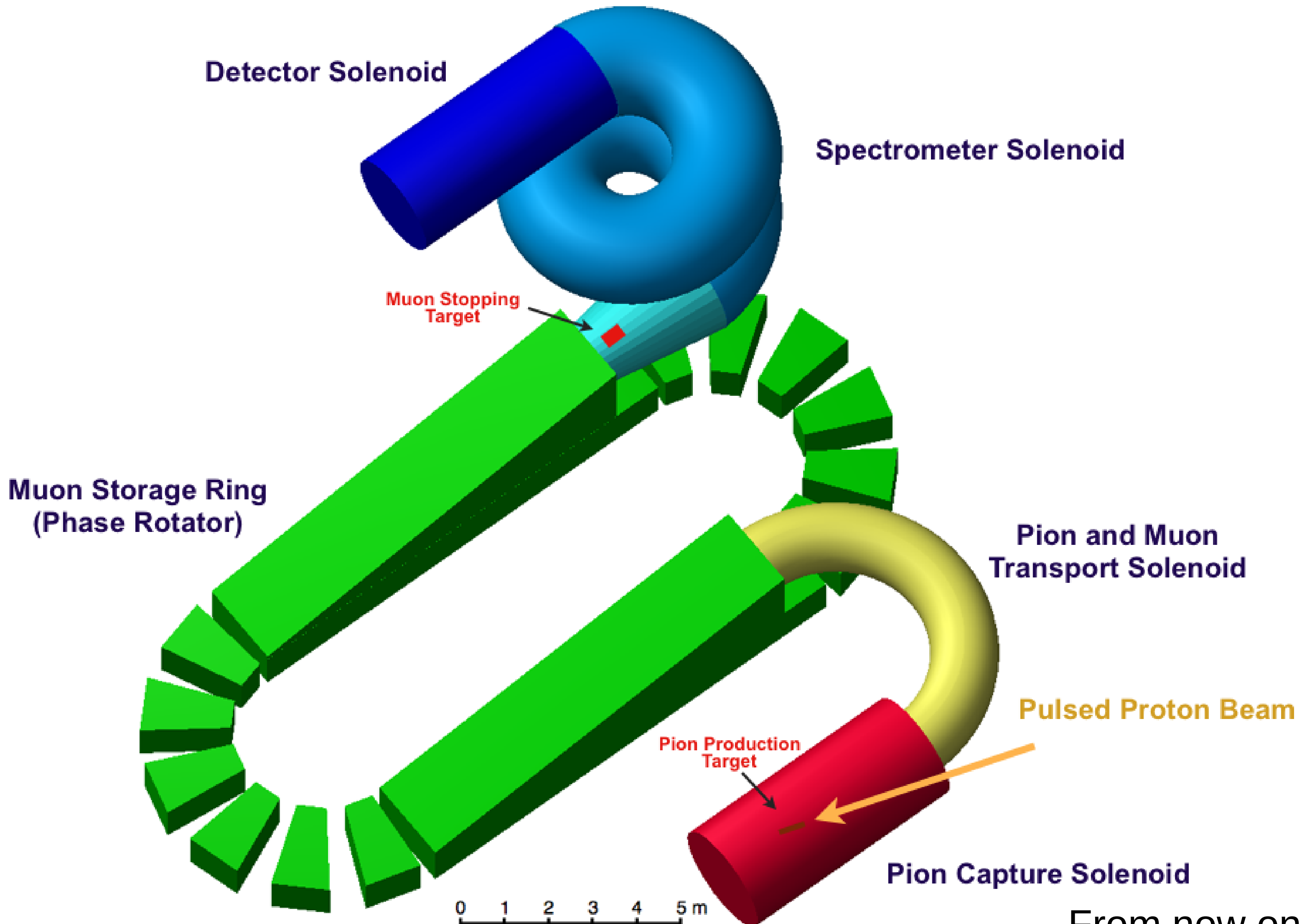
• PRISM requires a compressed proton bunch and high power proton beam

- It needs a new proton driver!

• This will allow for a single event sensitivity of 3×10^{-19}



Conceptual Layout of PRISM/PRIME



From now on
the talk is focused on
accelerator physics

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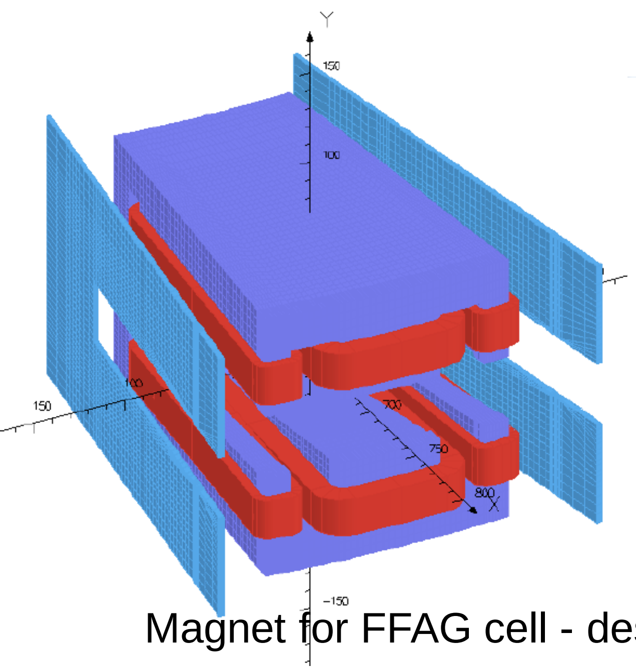
PRISM parameters

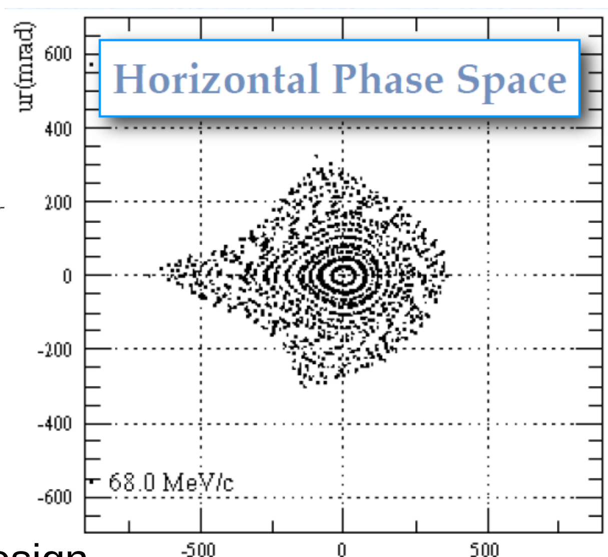
Parameter	Value
Target type	solid
Proton beam power	1-4 MW
Proton beam energy	multi-GeV
Proton bunch duration	~10 ns total (in synergy with the NF)
Pion capture field	4-10 T
Momentum acceptance	±20 %
Reference μ^- momentum	40-68 MeV/c
Harmonic number	1
Minimal acceptance (H/V)	3.8/0.5 π cm rad
RF voltage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

R&D work in Osaka

- 10 cell DFD ring has been designed
- FFAG magnet-cell has been designed, constructed and verified.
- RF system has been designed, tested and assembled.
- 6 cell ring was assembled and its optics was verified using α particles.
- Phase rotation was demonstrated for α particles.



Magnet for FFAG cell - design



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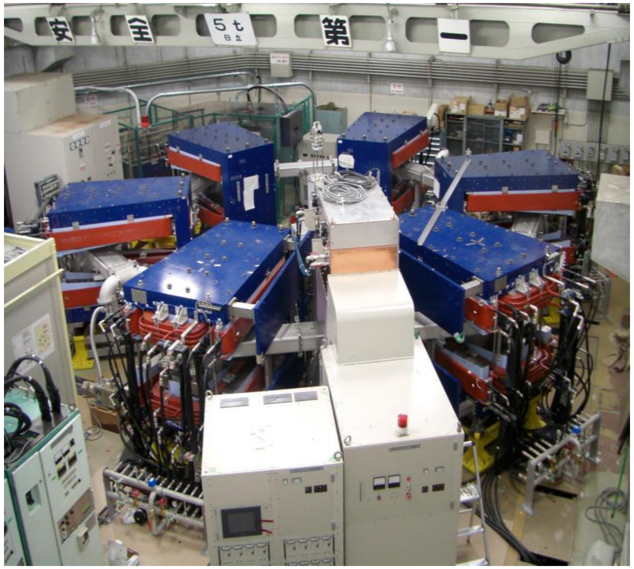
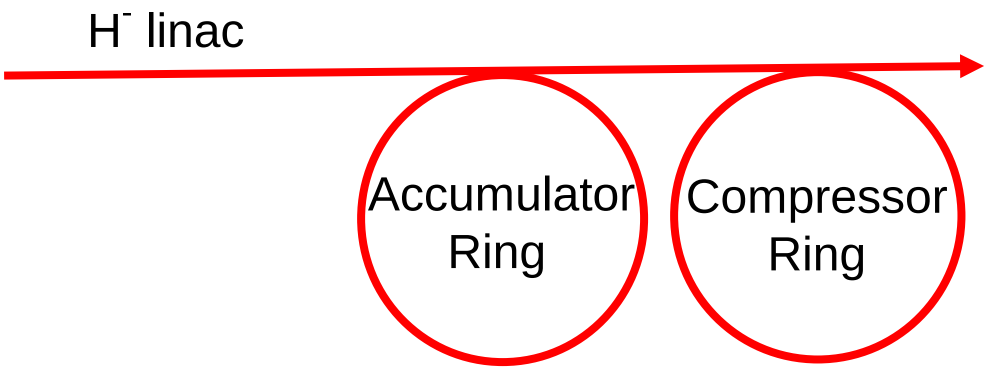
6 cell FFAG ring at RCNP

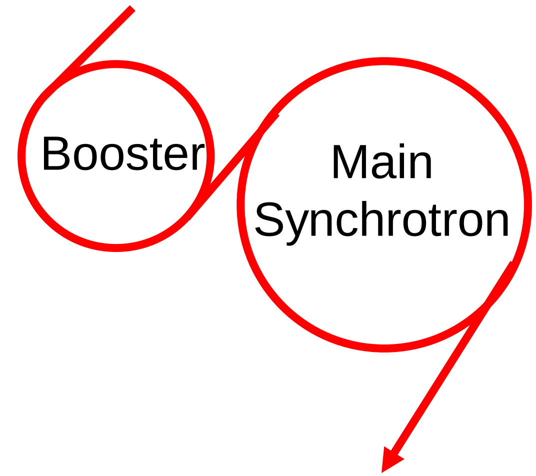


Proton Beam for PRISM/PRIME

Two methods established – BASED on LINAC or SYNCHROTRON acceleration.



H^- linac followed by the accumulator and compressor



High power synchrotrons produce many bunches and extract one by one (proposed at J-PARC).

PRISM/PRIME needs a short bunch (~10 ns)!
Where could it be done ?:

- at Fermilab
- at J-PARC,
- at CERN (using SPL or SPS),
- at RAL (MW ISIS upgrade could be adopted).
- at ESS

In general any Neutrino Factory Proton Driver would work for PRISM!

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).

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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,Y. Mori, Kyoto University, KURRI, Osaka, Japan
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D. Kelliher, S. Machida, C. Prior, STFC-RAL-ASTeC, Harwell, UK
M. Lancaster, UCL, London, UK

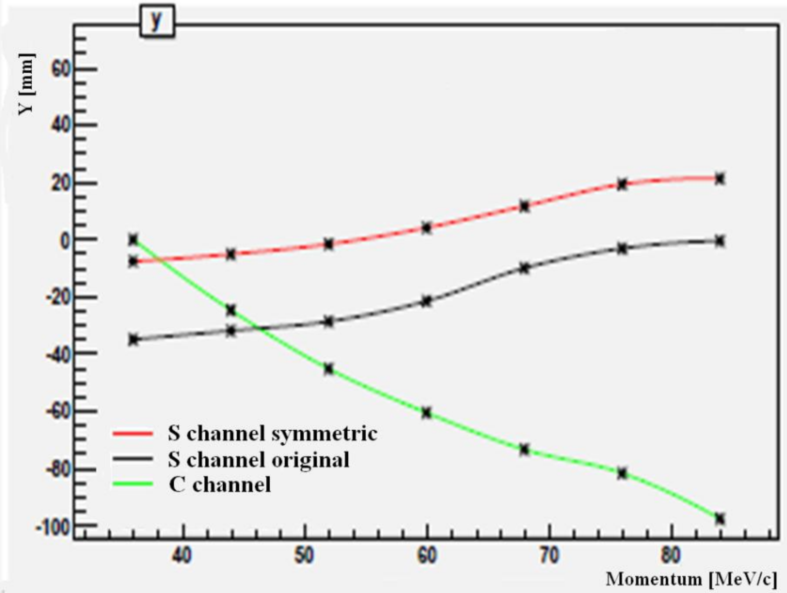
You are welcome to join us!

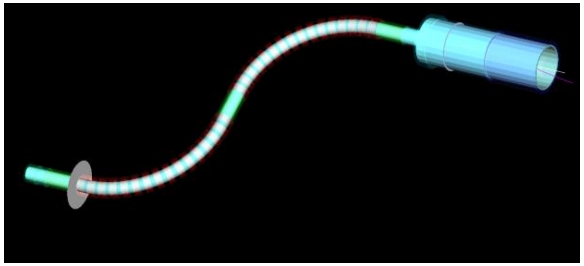
Main challenges before TF started working:

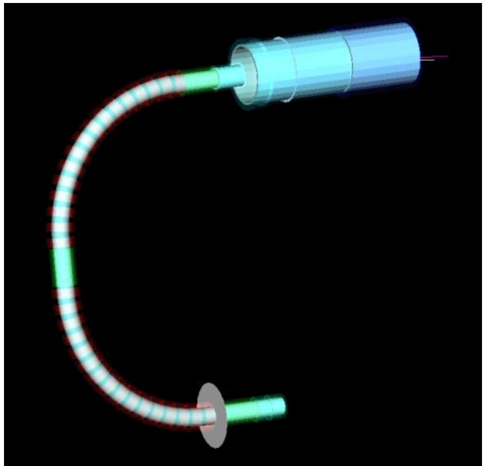
- Matching from the solenoid into FFAG
- Injection/Extraction geometries
- Kicker hardware
- Septum magnet
- RF system
- Beam dynamics in FFAG

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.

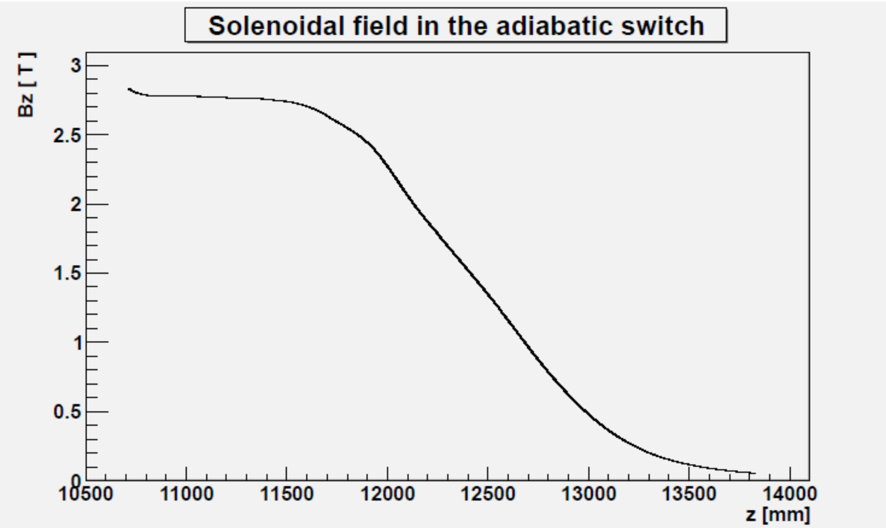


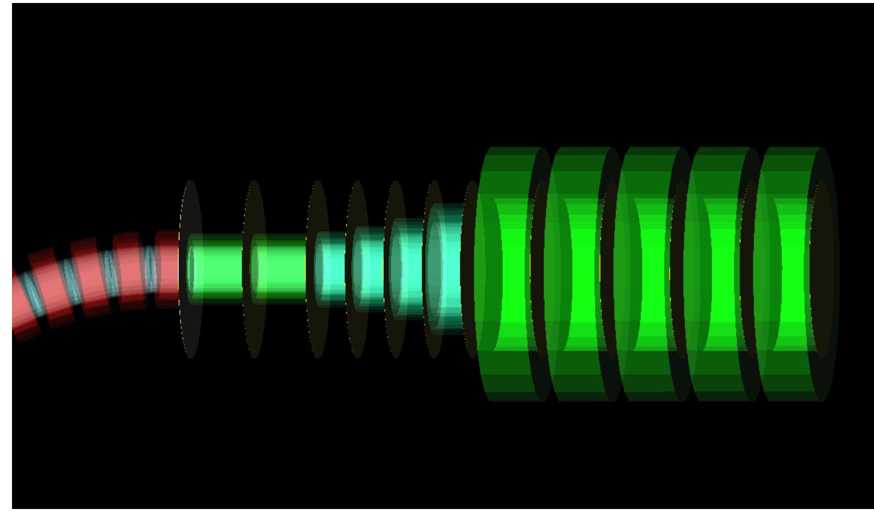




The mean vertical beam position versus momentum at the end of bend solenoid channel for various configurations.

Matching to the FFAG II





Initial version of the adiabatic switch

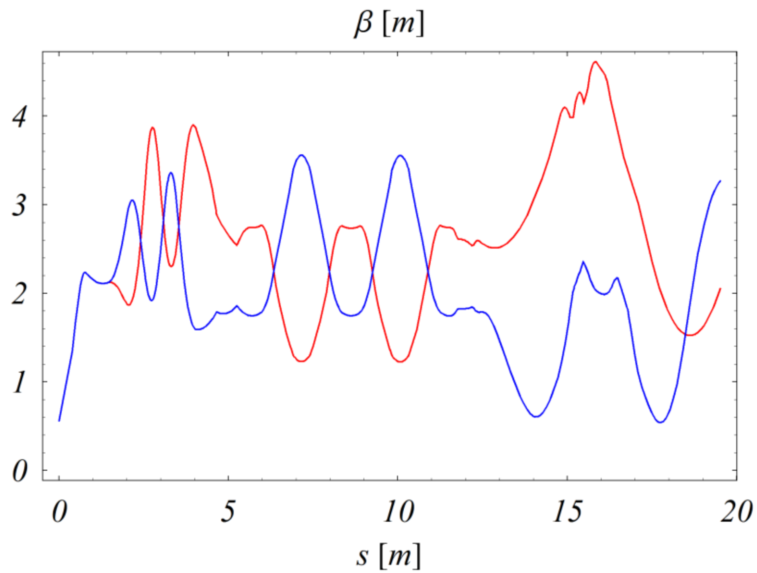
Preliminary geometry: the end of the S-channel together with matching solenoids, adiabatic switch and 5 quad lenses.

Current best version includes:

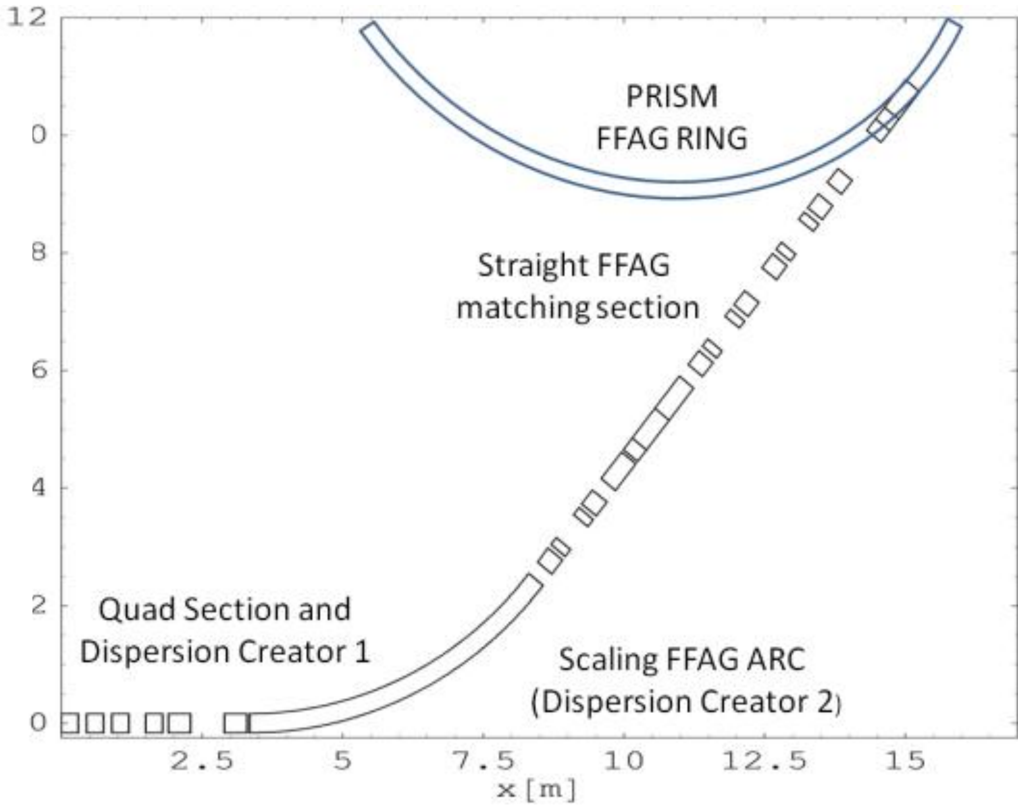
- adiabatic switch from 2.8 to 0.5 T (to increase the beam size),
- additional solenoidal lens to match α=0 (not shown in the pictures above),
- 5 quad lenses,

Matching to the FFAG III

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



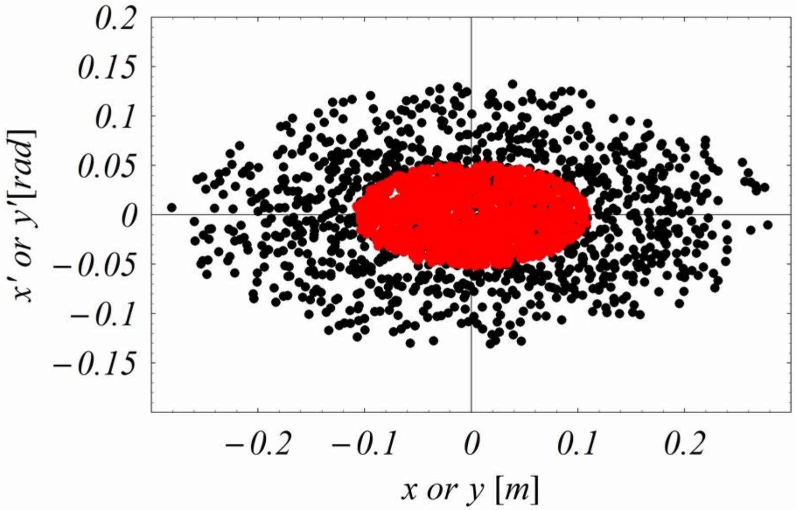
Horizontal (red) and vertical (blue) betatron functions in the PRISM front end.



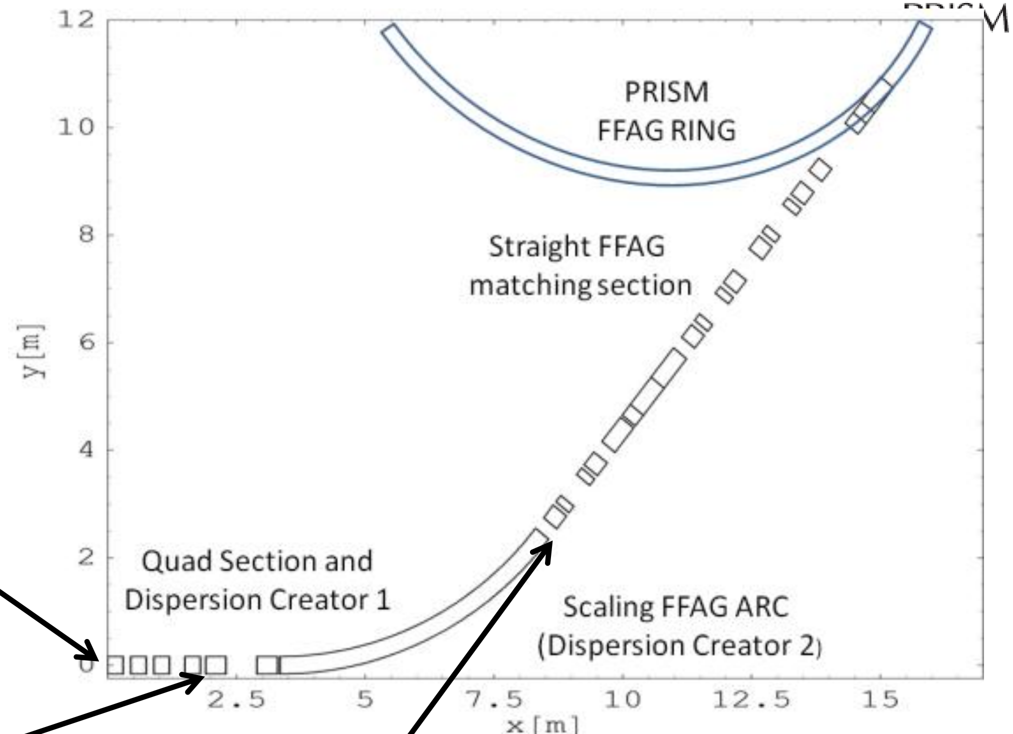
Layout of the matching section seen from the above.

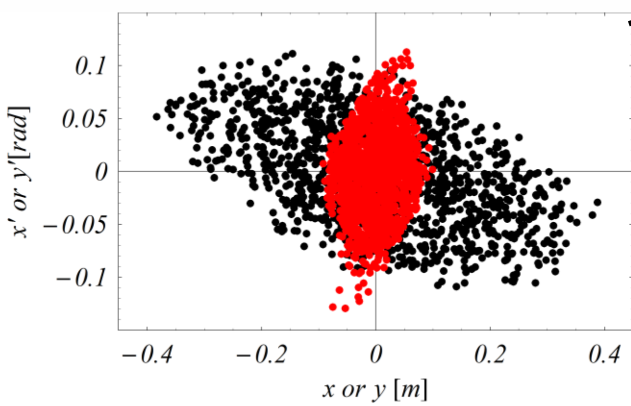
Matching to the FFAG IV

- Tracking status (work in progress)

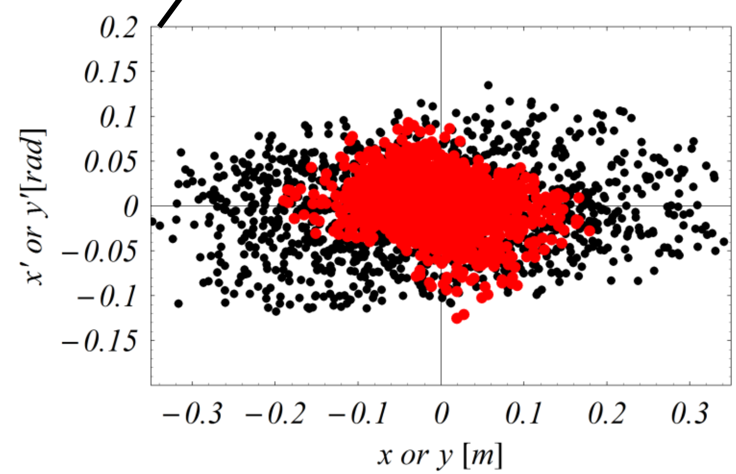


Horizontal (black) and vertical (red) phase spaces at the input to the AG part of the PRISM muon front end.





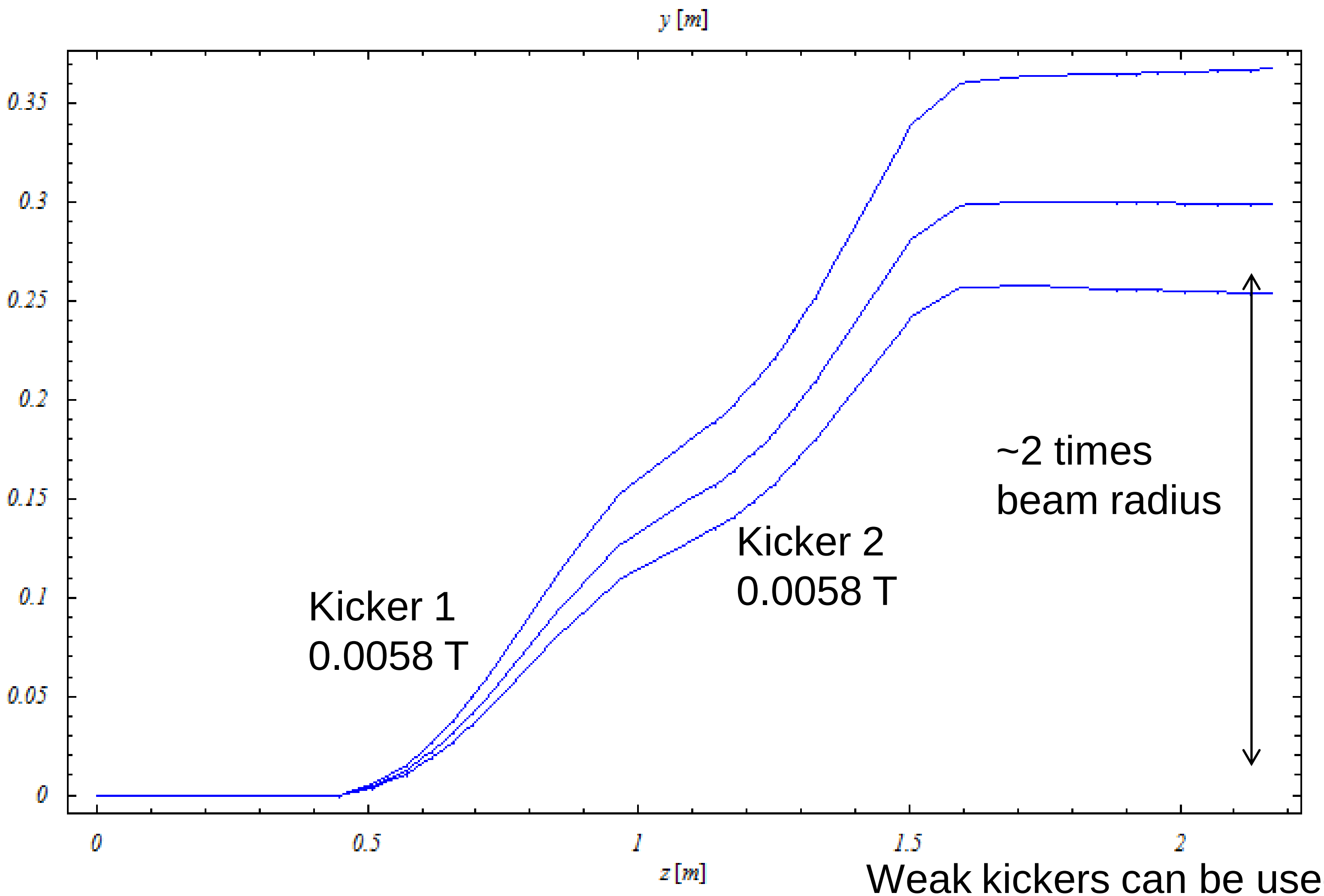
At the end of the quad Channel



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

Vertical injection

Orbit separation with 2 kickers



Weak kickers can be used!

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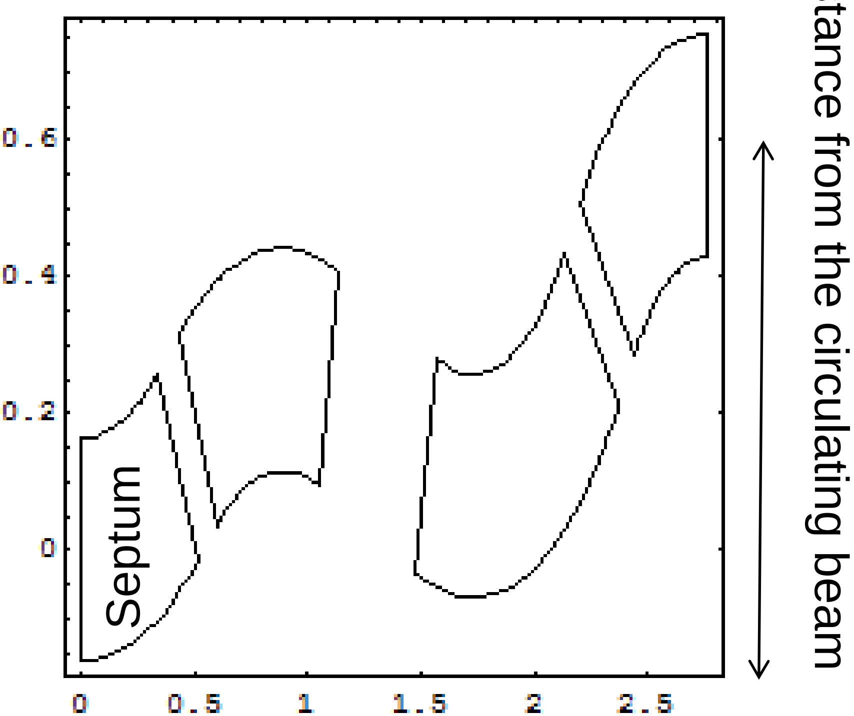
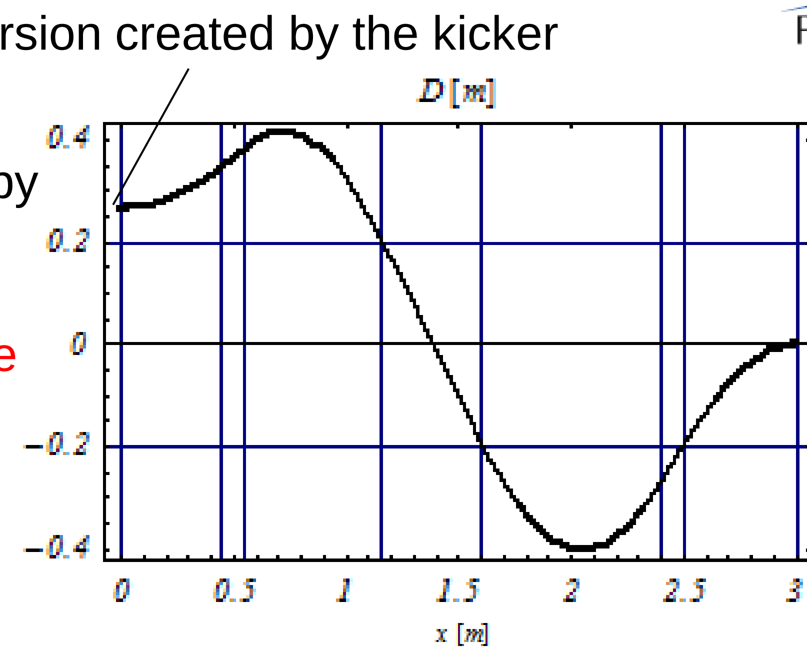
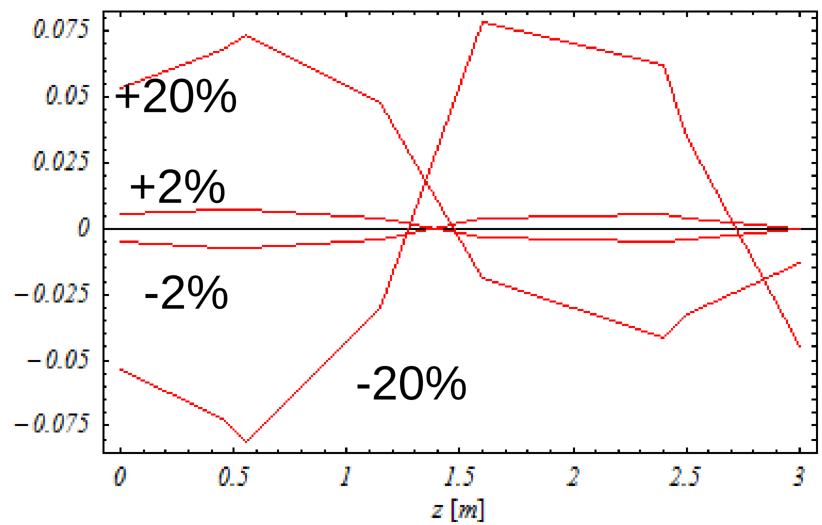
Vertical injection – vertical dispersion suppression

• System of vertical deflectors is proposed to suppress the vertical dispersion produced by the kicker and septum.

• It works for small and large positive Δp/p, however there are problems for large negative one.







There are ideas how to improve matching!

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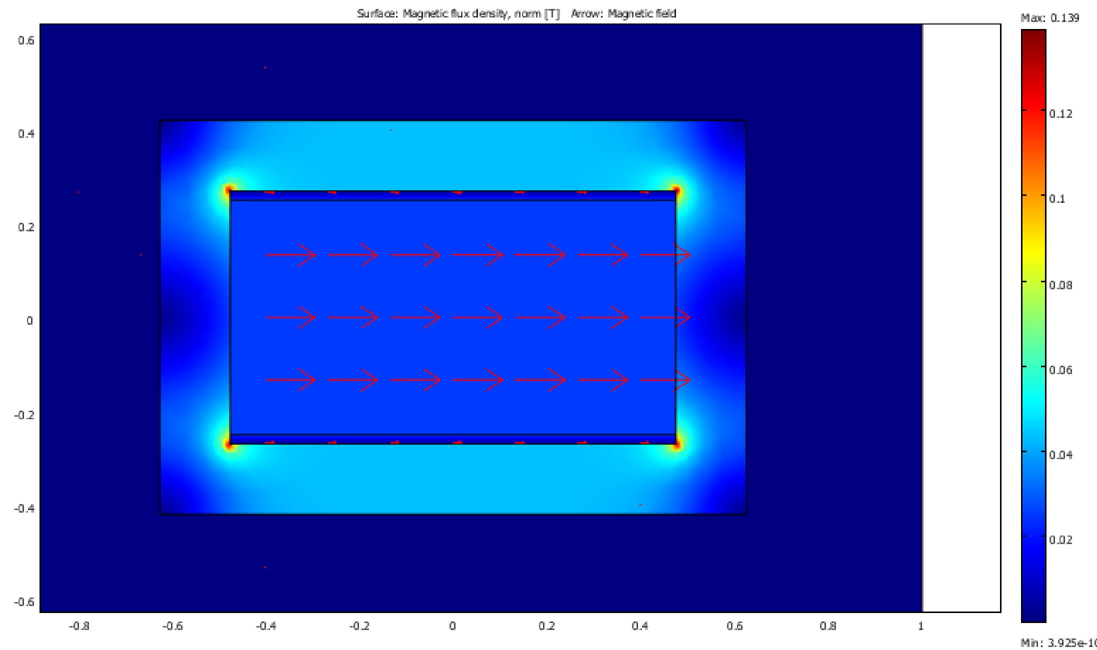
Preliminary PRISM kicker studies

- 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



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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.

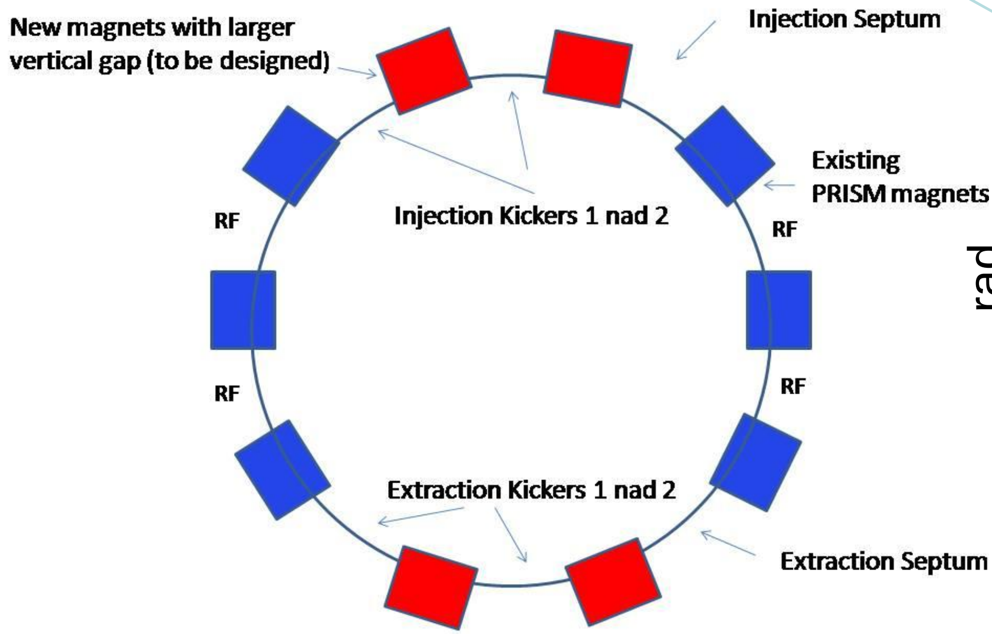
• For the PRISM RF system in order to either reduce the core volume cutting the cost by a factor of 3 or to increase the field gradient.

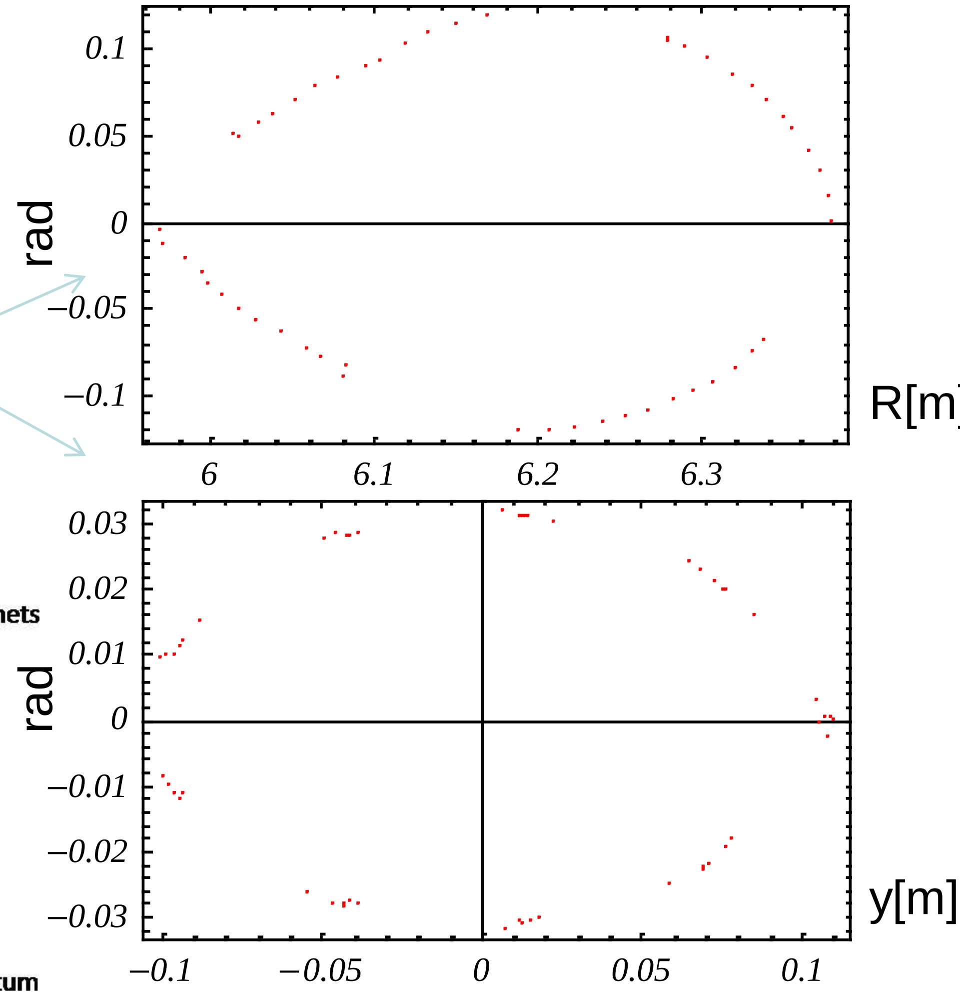
•Both options should be considered.

The first high impedance core annealed at J-PARC

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!





We can re-use existing magnets!

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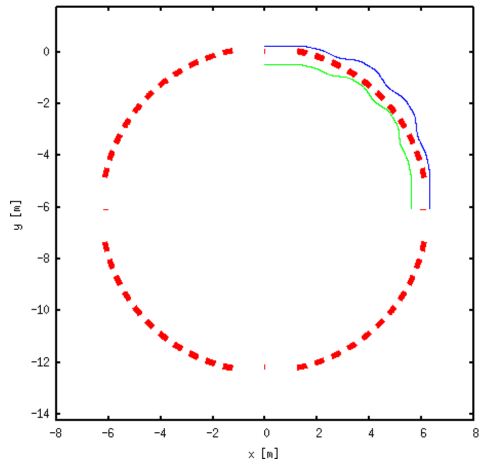
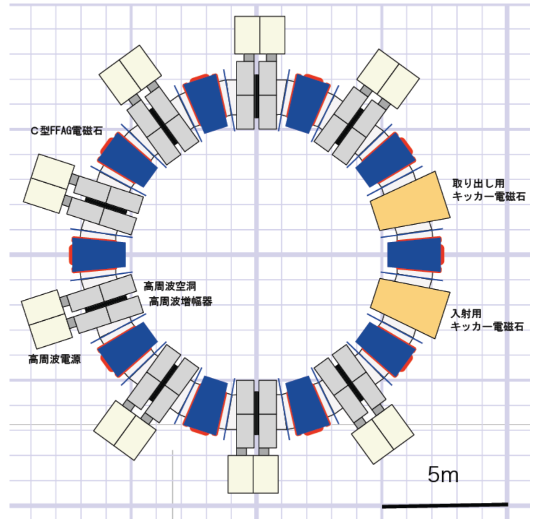
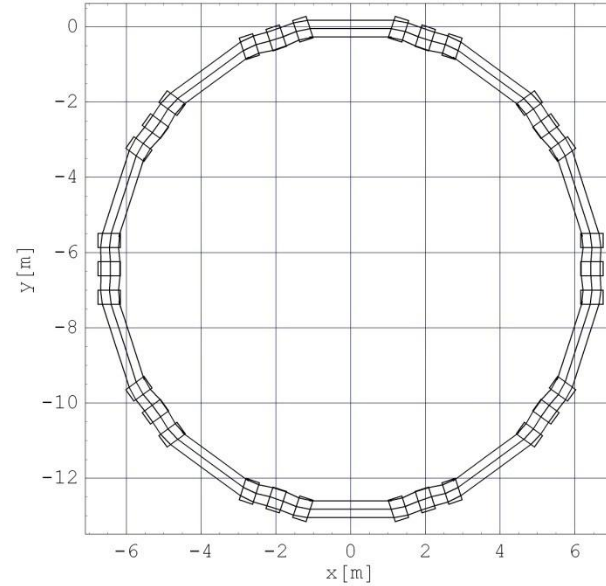
Some of FFAG Ring Choices



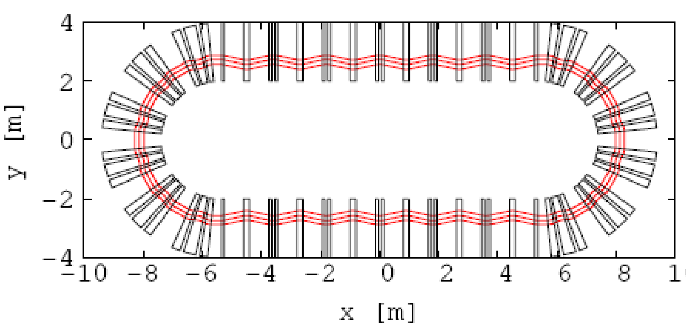
Scaling Superperiodic



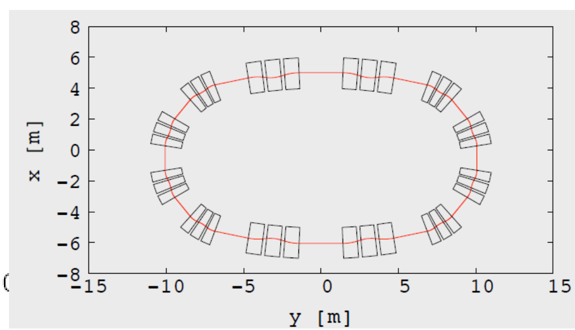
Reference design



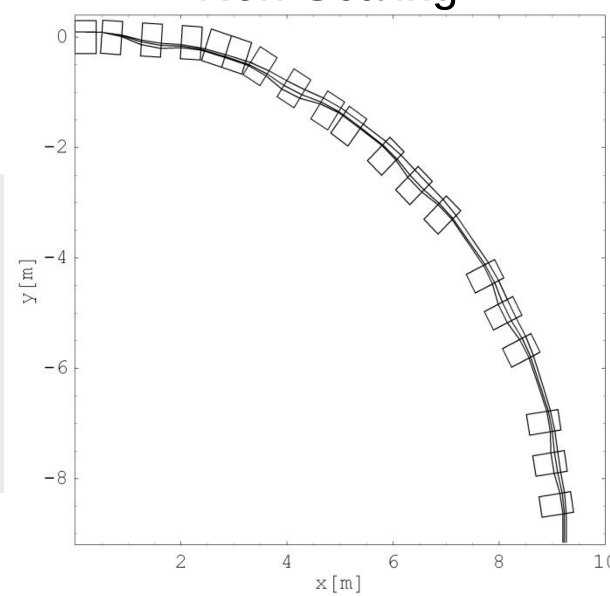
Non-Scaling



Advanced scaling FFAG



“Egg-shaped”



Advanced NS-FFAG

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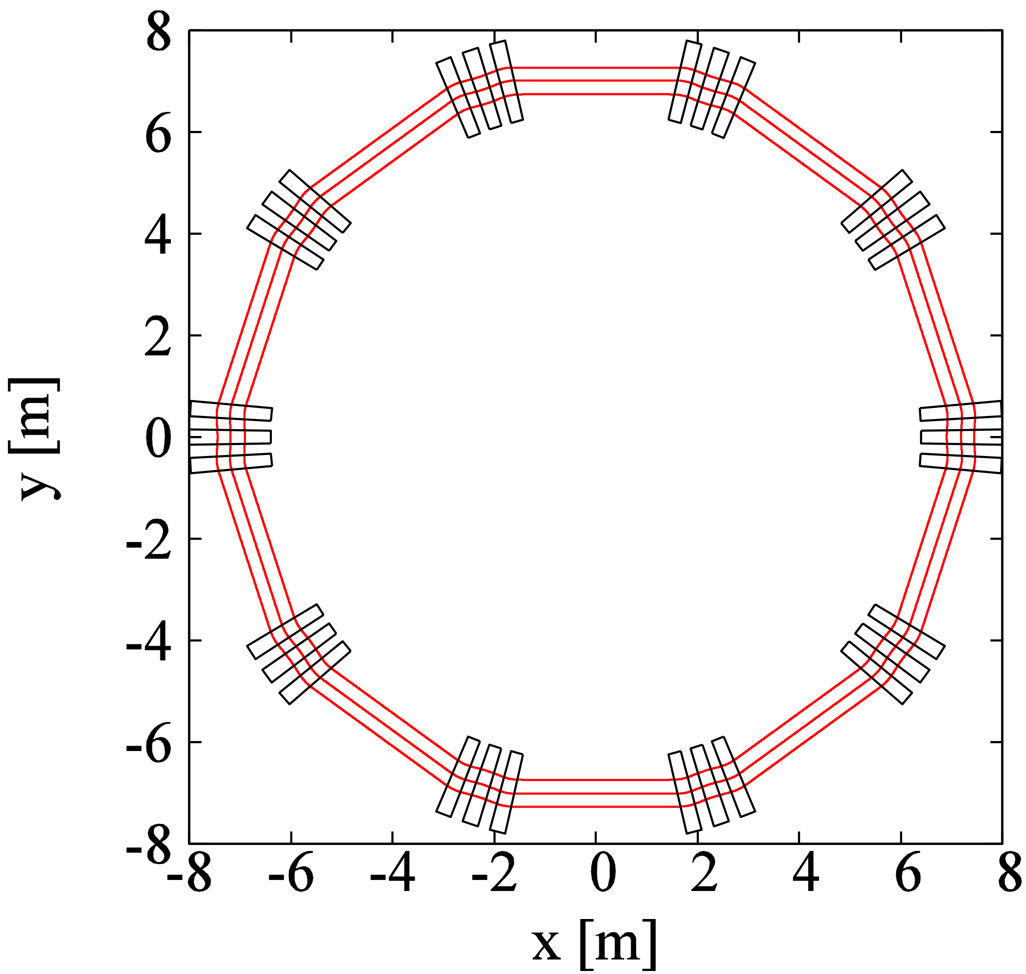
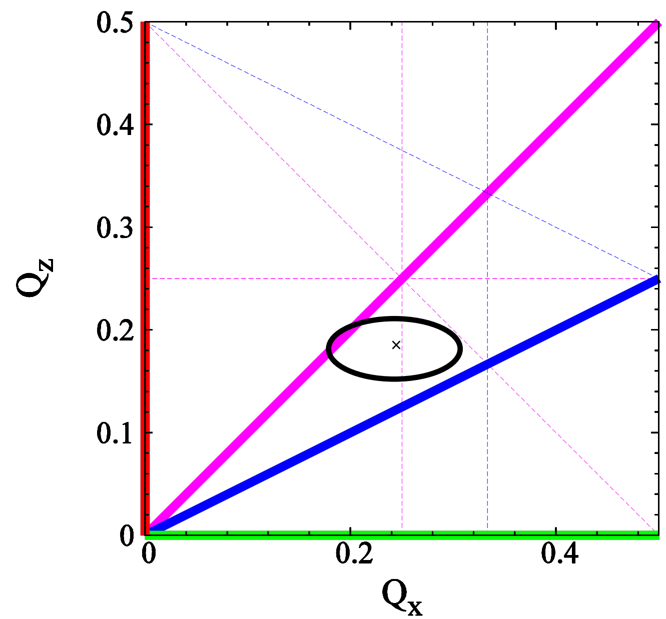
New FDF scaling FFAG design



- FDF symmetry motivated by the success of ERIT at KURRI
- 10 cells
- k 4.3
- R_0 7.3 m
- (Q_H, Q_V) (2.45, 1.85)
- Minimal drift length 3m



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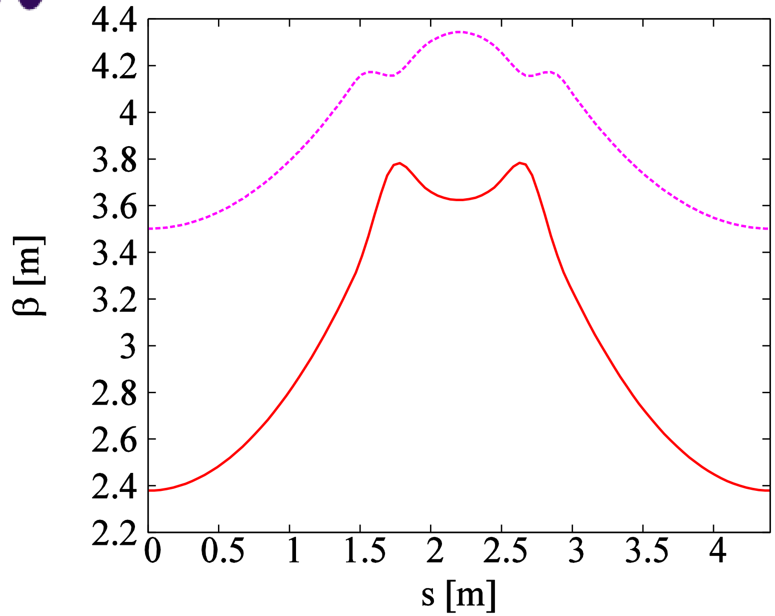
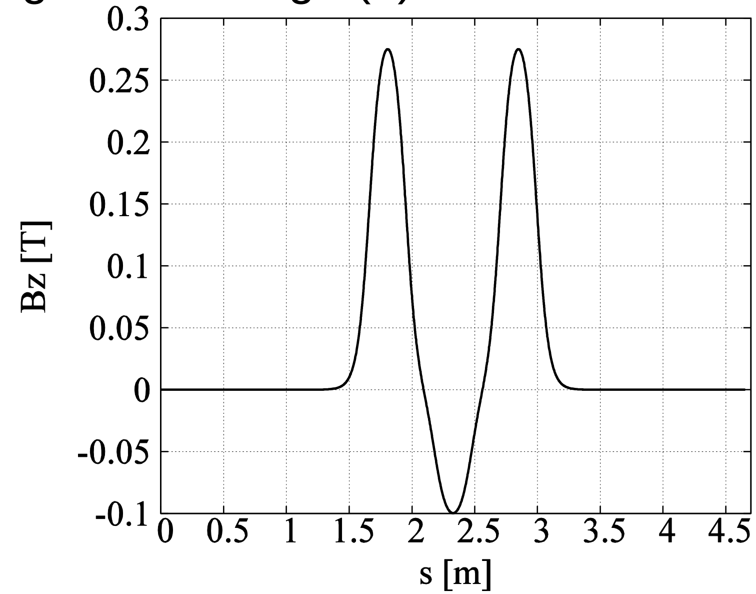
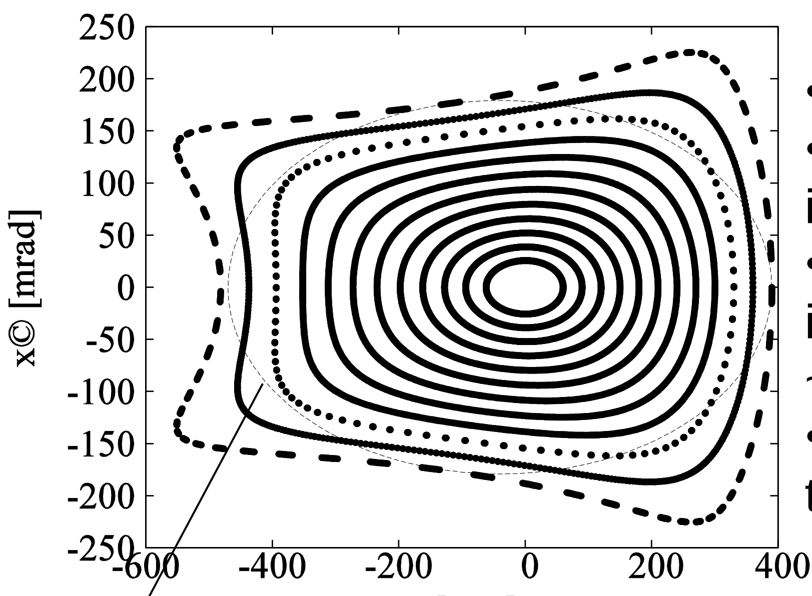
New FDF scaling FFAG design (2)







77000 π.mm.mrad!

- Enge field fall-off used to study fringe fields
- Enormous horizontal acceptance is achieved in simulations
- Vertical long term stability of ~3000 π.mm.mrad is achieved, however with some optimization ~5000 π.mm.mrad should be stable for a few turns.
- 5000 π.mm.mrad is what we currently aim for due to injection limitations.

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Main challenges at present:

- Matching from the solenoid into FFAG
- Injection/Extraction geometries
- Kicker hardware
- Septum magnet
- RF system
- Beam dynamics in FFAG -> we believe we have now improved ring design.

Conclusions

- 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 approaching full feasibility.
- PRISM becoming a serious choice for next generation cLFV experiment