Muon Beam and FFAG Storage Ring for PRISM

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on behalf of the PRISM Task Force

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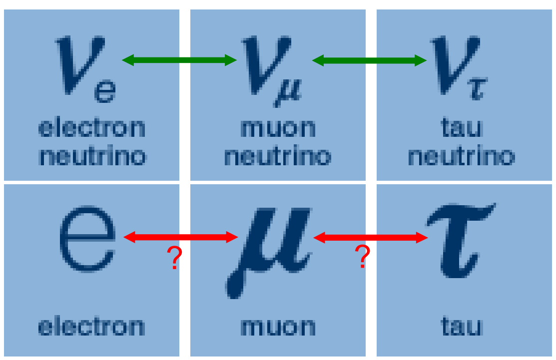
Outline

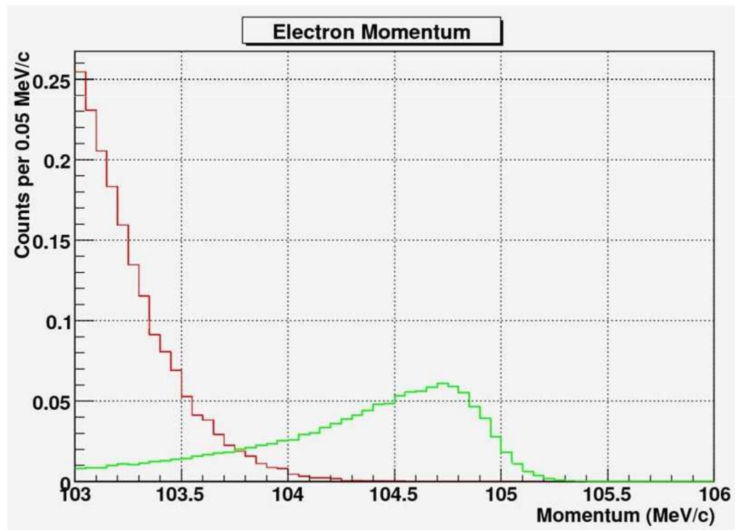
- Introduction.
- PRISM/PRIME experiment.
- Pion production and capture.
- Muon transport.
- Reference PRISM FFAG ring design.
- Injection/extraction and kicker studies.
- Accelerator R&D at RCNP.
- PRISM Task Force initiative.
- Alternative ring designs.
- Conclusions and future plans.

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)→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.



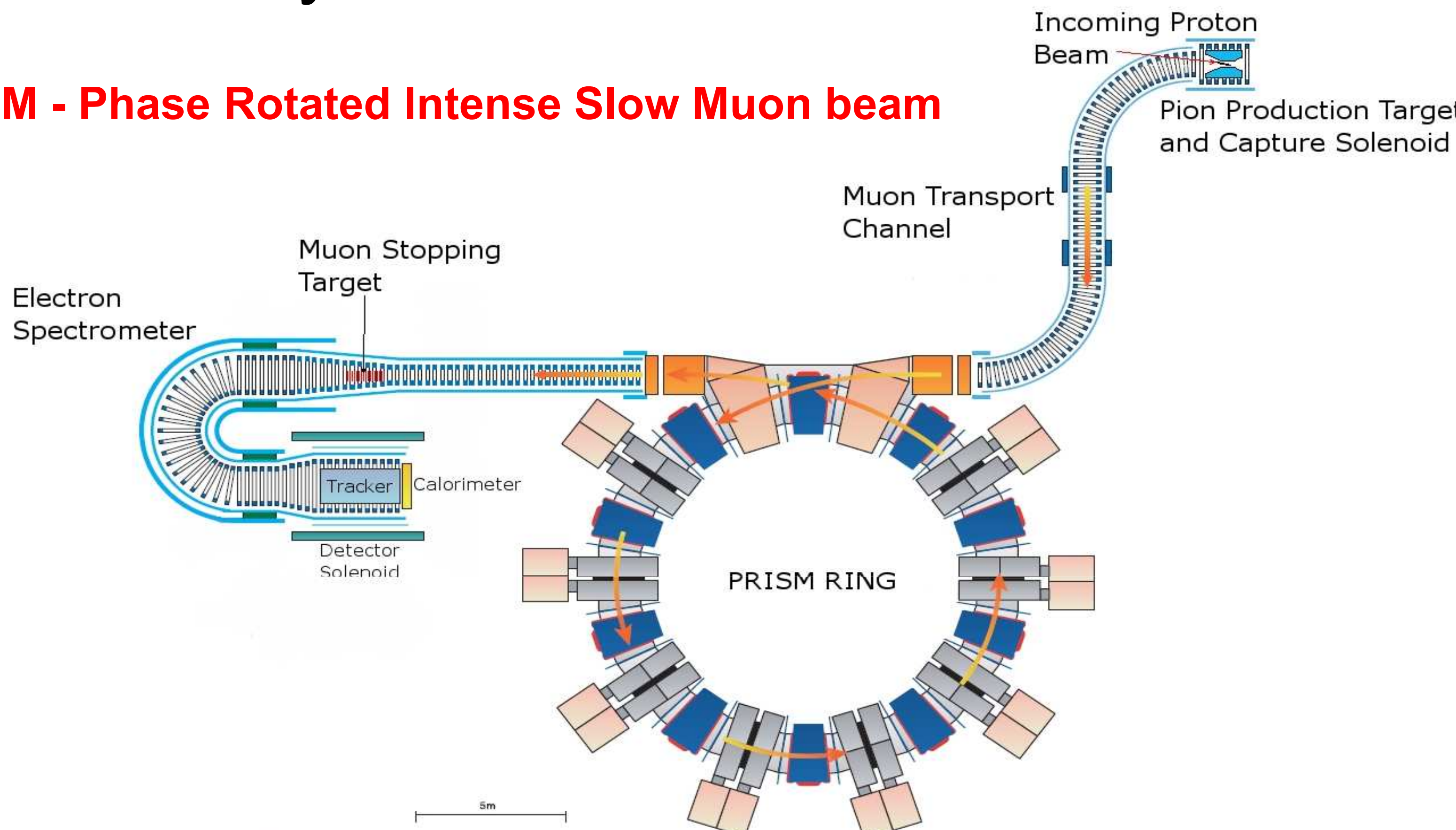
Does cLFV exists?

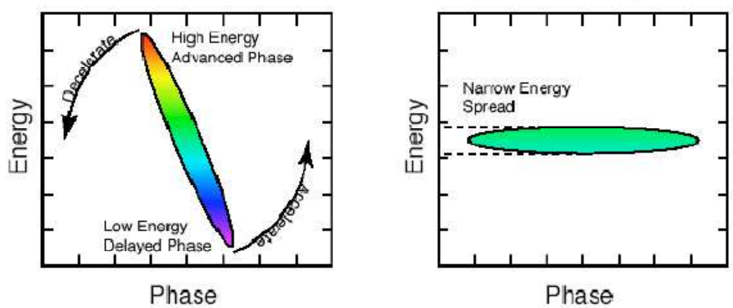


Simulations of the expected electron signal (green).

Layout of the PRISM/PRIME

PRISM - Phase Rotated Intense Slow Muon beam

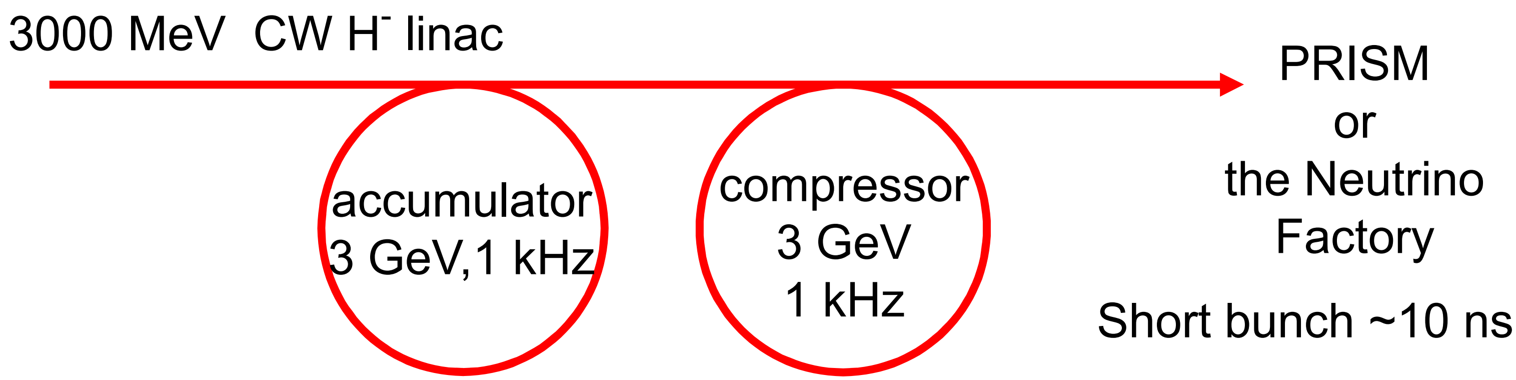




The PRISM/PRIME experiment based on FFAG ring was proposed (Y. Kuno, Y. Mori) for a next generation cLFV searches in order to:

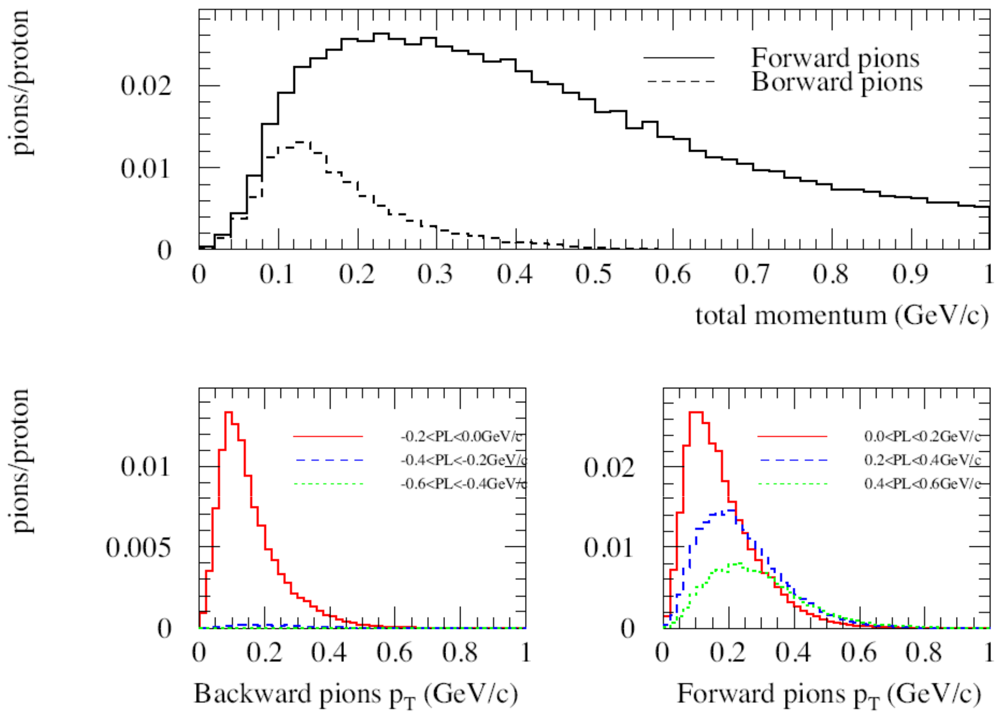
- reduce the muon beam energy spread by phase rotation,
- purify the muon beam in the storage ring.

Short bunch structure with CW H^- linac for PRISM at the Project-X

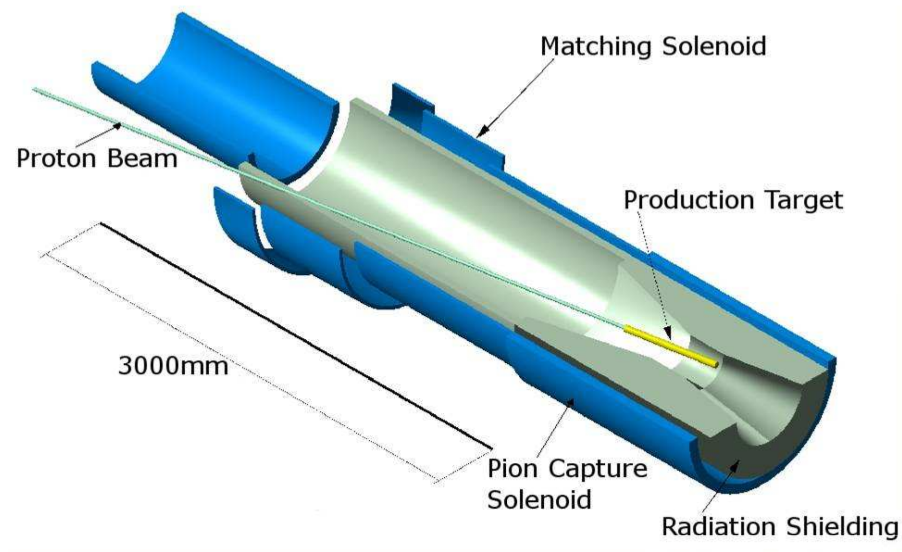


- For efficient muon phase rotation, pulsed beam with a short bunch length is required (~10 ns).
- In order to achieve the required power level (~2 MW) a quasi-continuous injection from the CW H^- linac is necessary.
- The gap for extraction kicker needs to be prepared (low energy chopper would be an option).
- In order to perform the final bunch compression another ring (compressor) seems to be needed.
- Higher power level could be achieved by further acceleration (in RCS or FFAG ring).
- Beam for the Neutrino Factory (3 compressed bunches at 50 Hz) would be also suitable for PRISM (with 150 Hz effective rate).

Pion Production

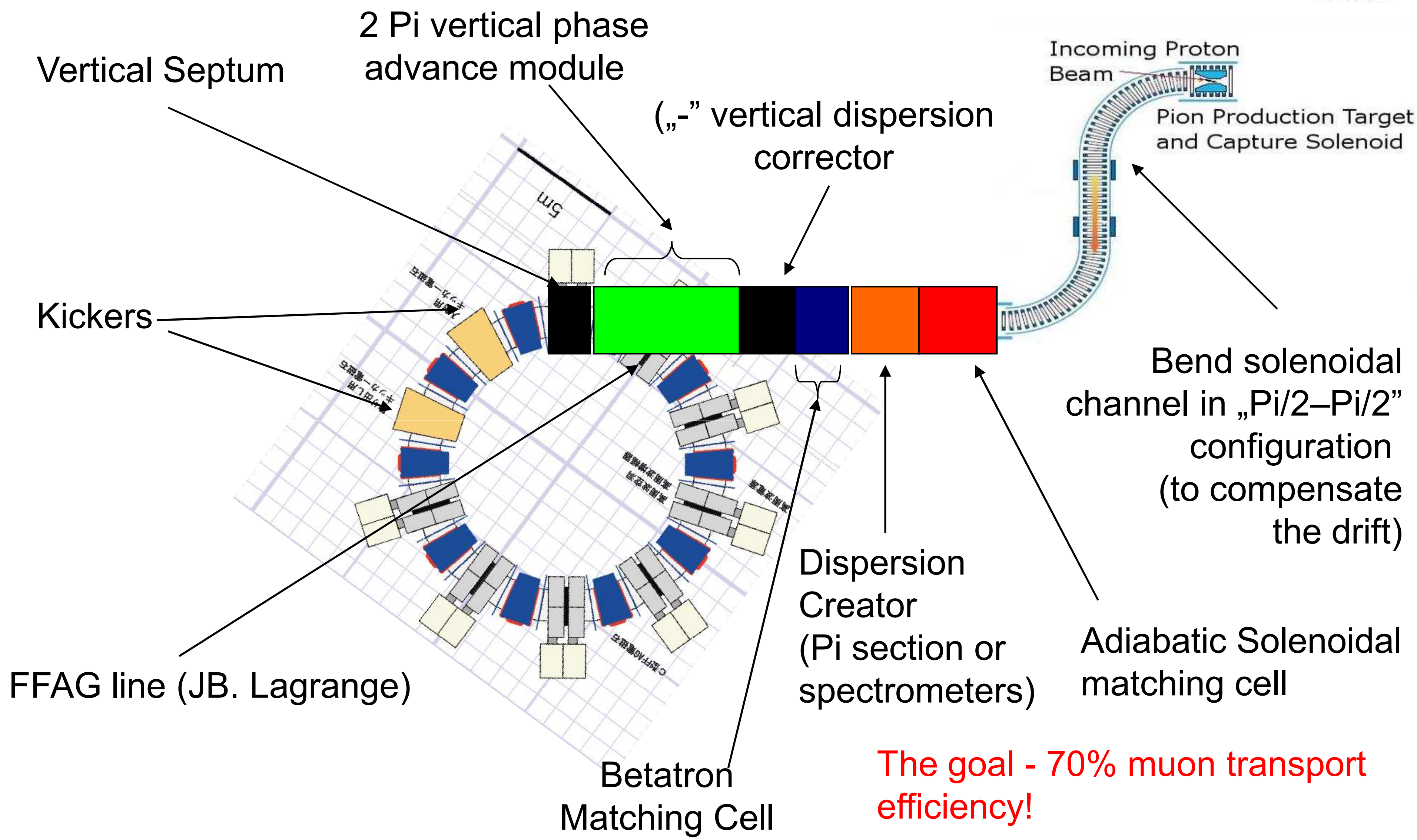


Au target simulations using MARS



- 2 (4) MW proton beam power.
- Beam energy 3-8 GeV.
- Proton bunch length at the target ~10 ns.
- Heavy metal (W, Au, Pt, Hg) target.
- 12 (20) T SC pion capture solenoid.
- Backward pion collection.

Pion/Muon Transport



The goal - 70% muon transport efficiency!

Pion/Muon Transport (2)

- Bend solenoids create drift of charged particles in the vertical plane.

$$drift = \frac{1}{qB}\left(\frac{s}{R}\right)\frac{p_L^2 + \frac{1}{2}p_T^2}{p_L}$$

- In order to compensate for this effect, the dipole field needs to be introduced.

- Similar muon transport system is under construction for Muon Science Innovative Commission (MUSIC) at RCNP,Osaka University.
- Combined function – SC solenoid and dipole magnet design was done in collaboration with Toshiba.

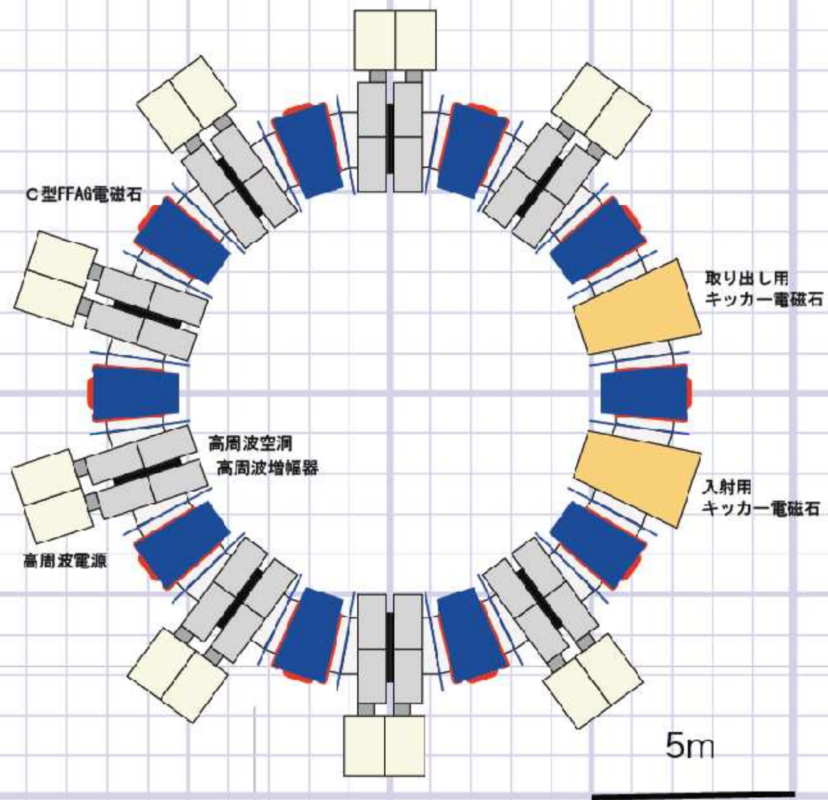
MUSIC bend solenoid under construction

Reference Design Parameters – A. Sato

PRISM-FFAG

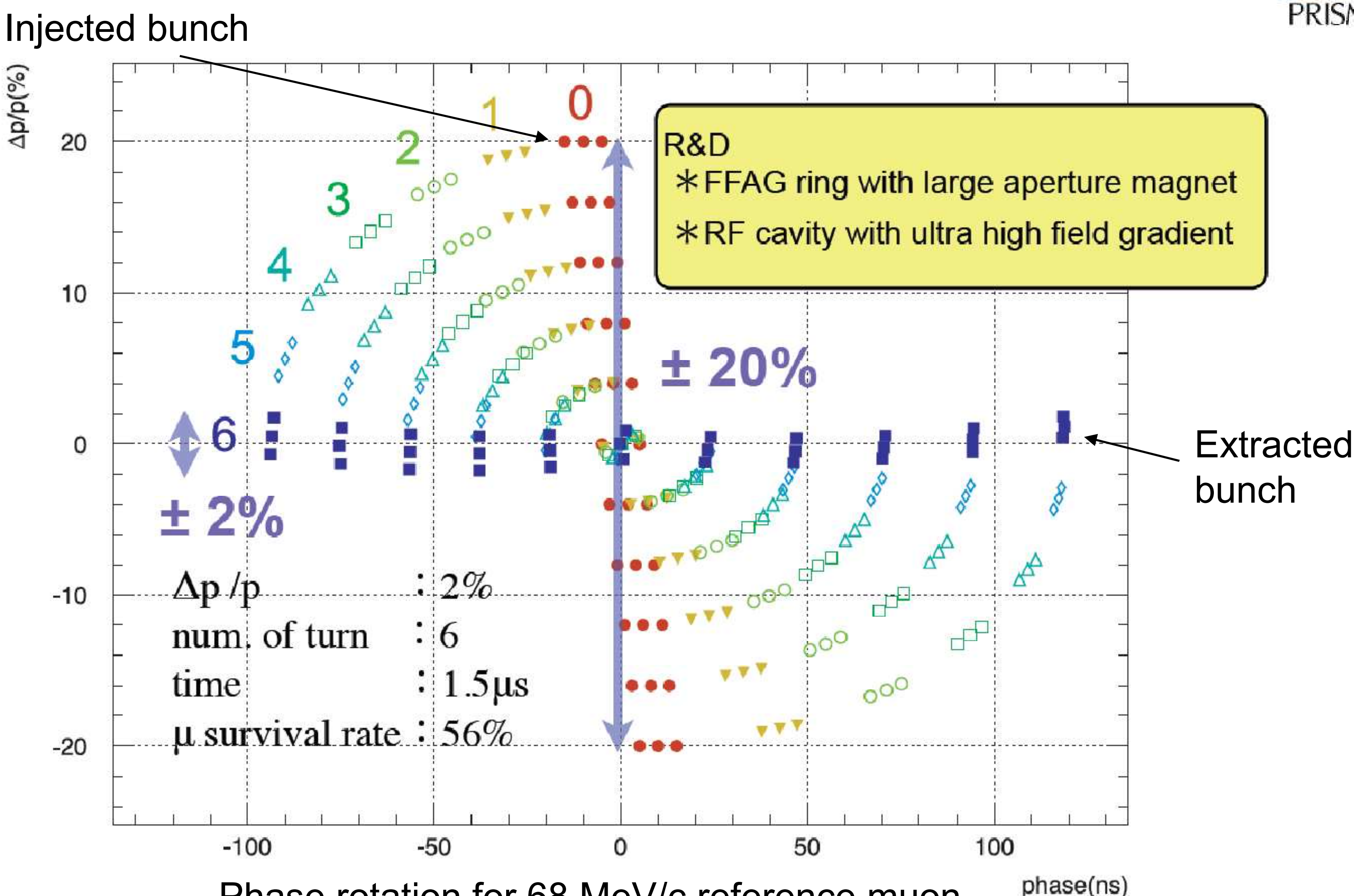
- N=10
- k=4.6
- F/D(BL)=6.2
- r0=6.5m for 68MeV/c
- half gap = 17cm
- mag. size 110cm @ F center
- Radial sector DFD Triplet
- $\theta_F/2$=2.2deg
- θ_D=1.1deg
- Max. field
- F : 0.4T
- D : 0.065T
- tune
- h : 2.73
- v : 1.58

Phase Rotator



V per turn ~2-3 MV
Δp/p at injection = ± 20%
Δp/p at extraction = ± 2% (after 6 turns ~ 1.5 us)
h=1

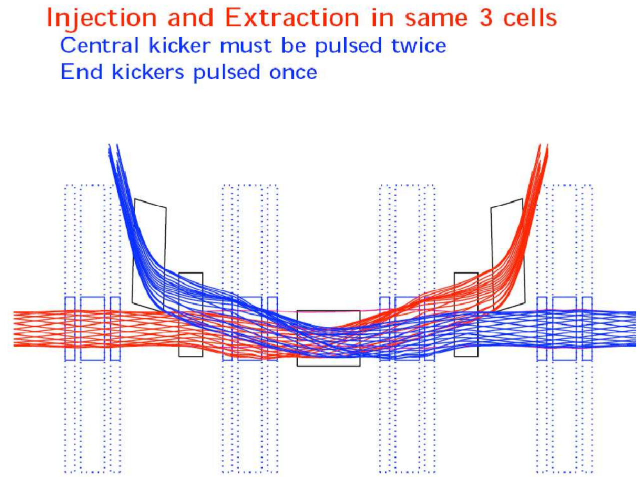
Phase rotation calculations in PRISM ring

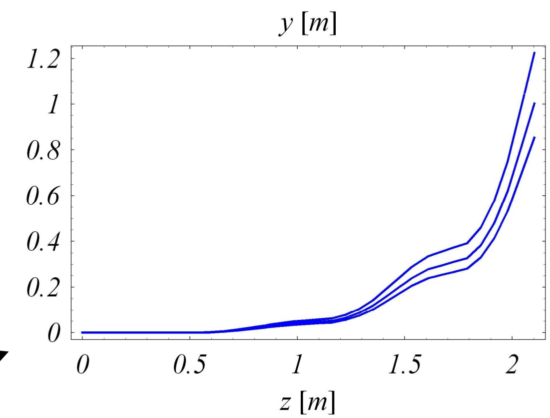


Phase rotation for 68 MeV/c reference muon

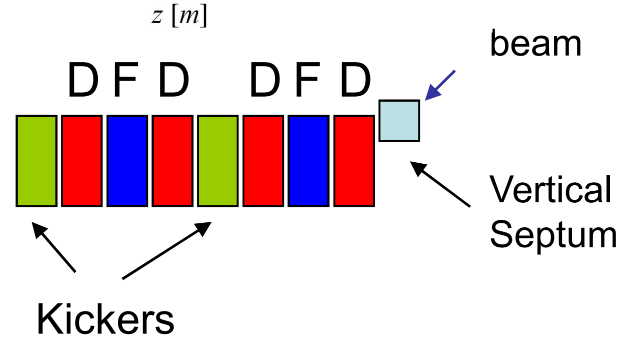
Injection/extraction studies

- The reference design injection/ extraction uses 2 short kickers, 1 long one and a short septum (septum and kicker are placed in the same drift). It works for both injection and extraction.
- In order to facilitate the hardware and increase the purity of the beam, it is proposed to have separate injection and extraction.
- It will use 2 long kickers and 1 long septum. This allows to reduce the max B field in the magnets and helps to reduce the aberrations.

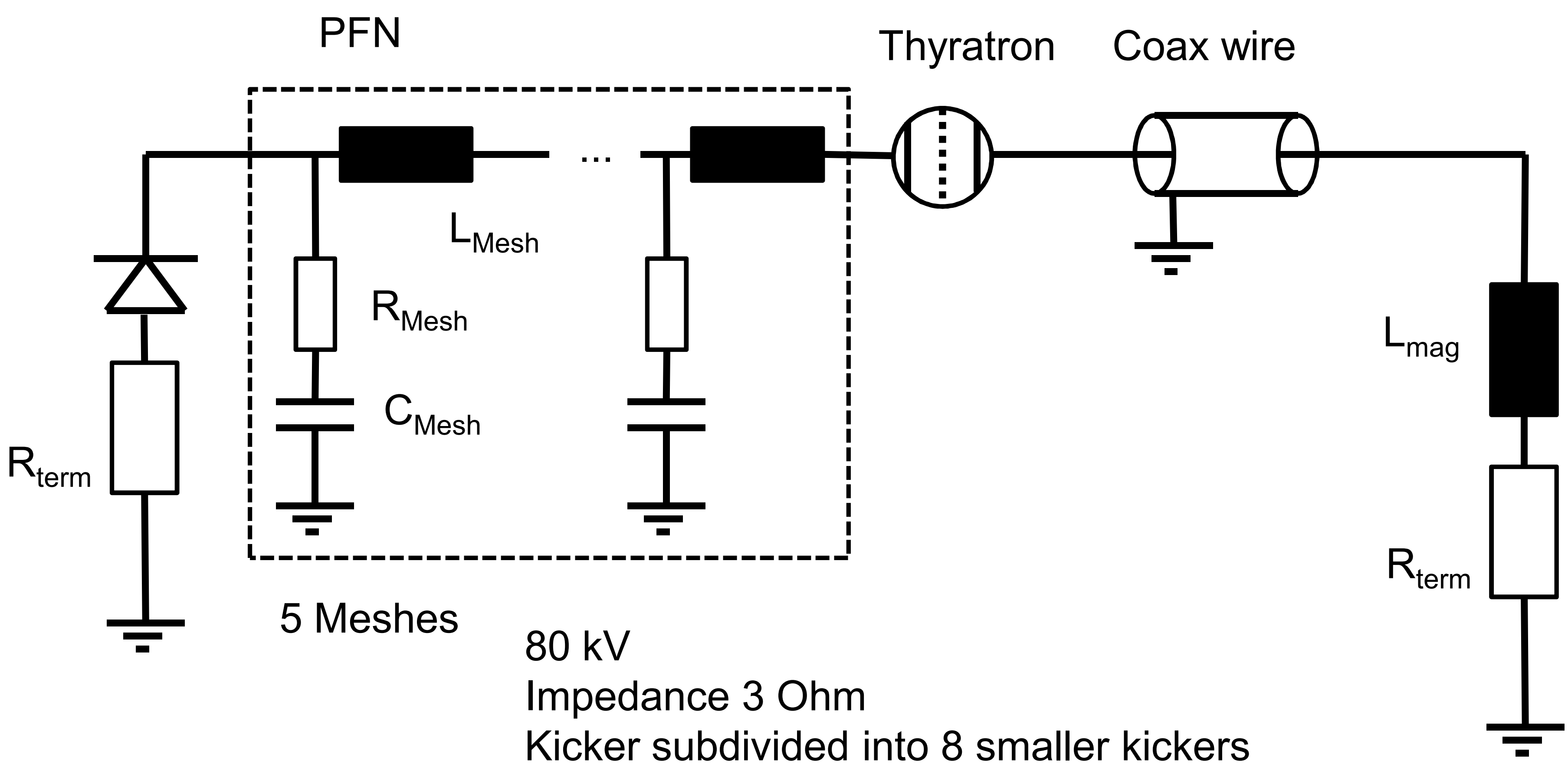




Orbits for central and ±20% momenta



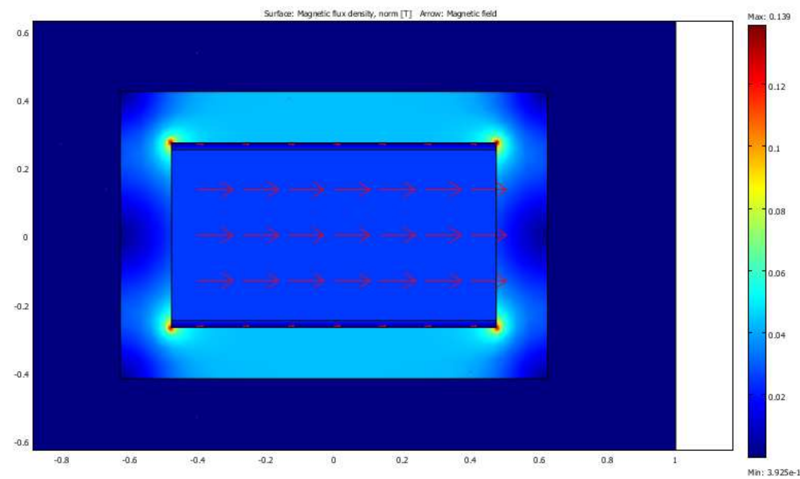
PRISM kicker schematic, H. Witte

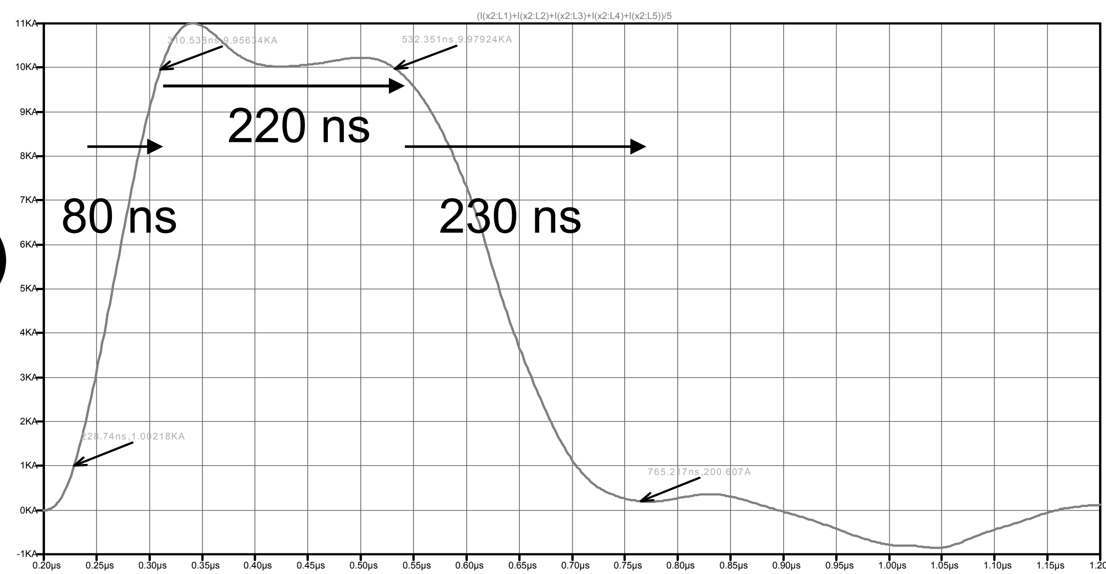


80 kV
Impedance 3 Ohm
Kicker subdivided into 8 smaller kickers
Travelling wave kicker
Each sub-kicker has 5 sections
1 plate capacitor per section

Preliminary PRISM kicker studies

- length 1.6 m
- B 0.02 T
- Aperture: 0.95 m x 0.5 m
- 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





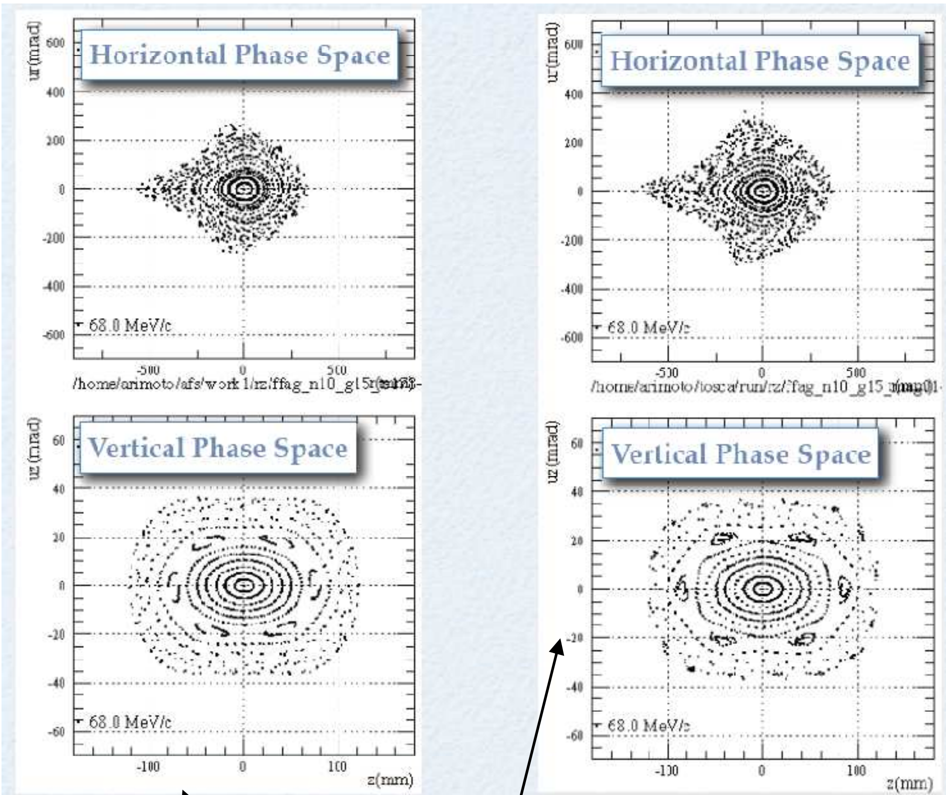
H. Witte, M. Aslaninejad,
J. Pasternak

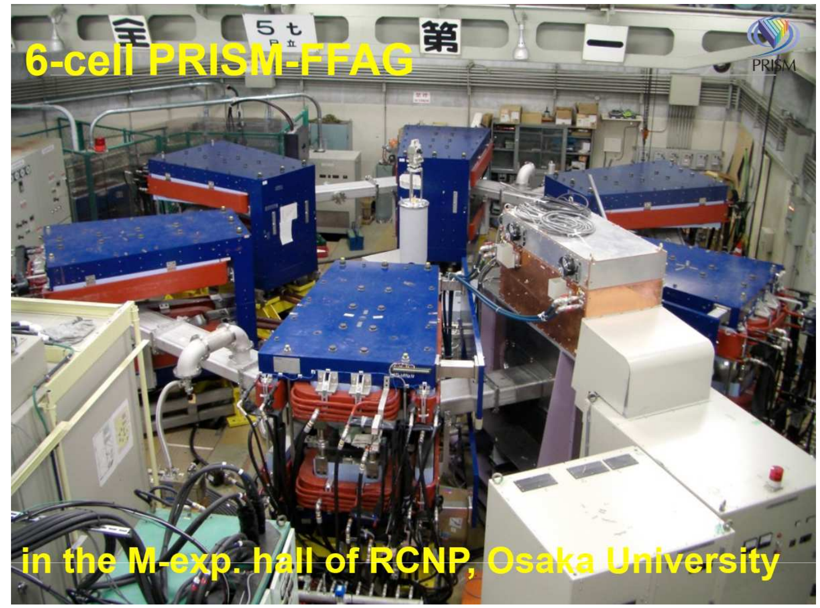
08.11.2010, Fermilab,
The Project-X Muon Workshop

J. Pasternak

Kicker system seems feasible!

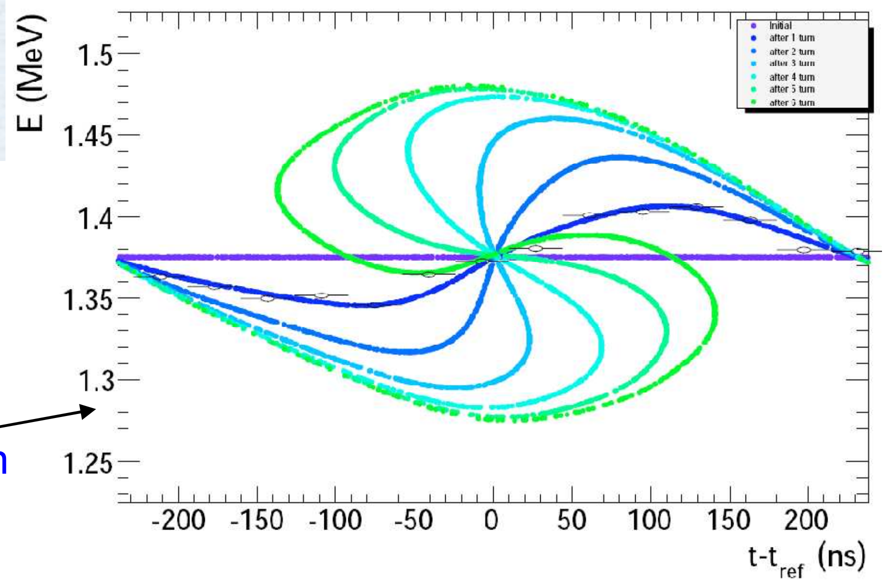
Accelerator R&D at RCNP, A. Sato





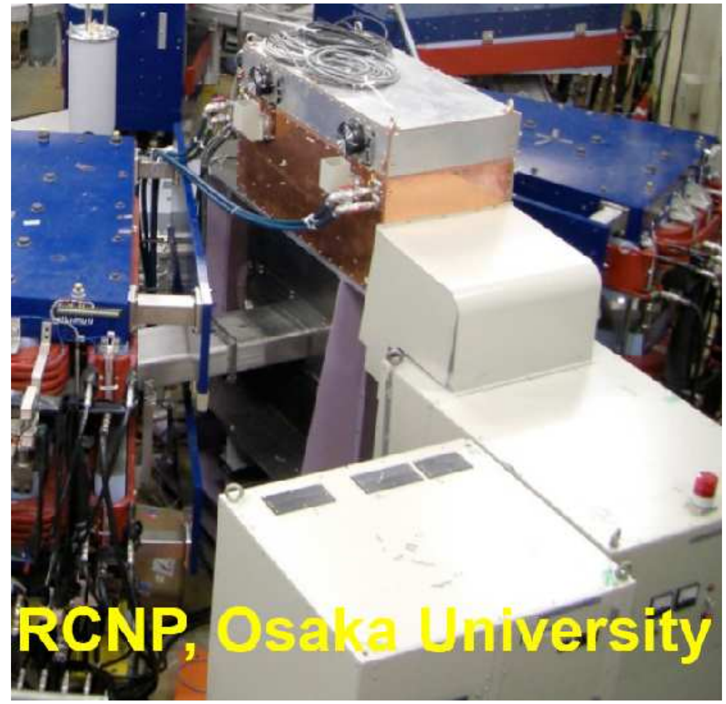
Beam dynamics calculations with simulated and measured B fields.

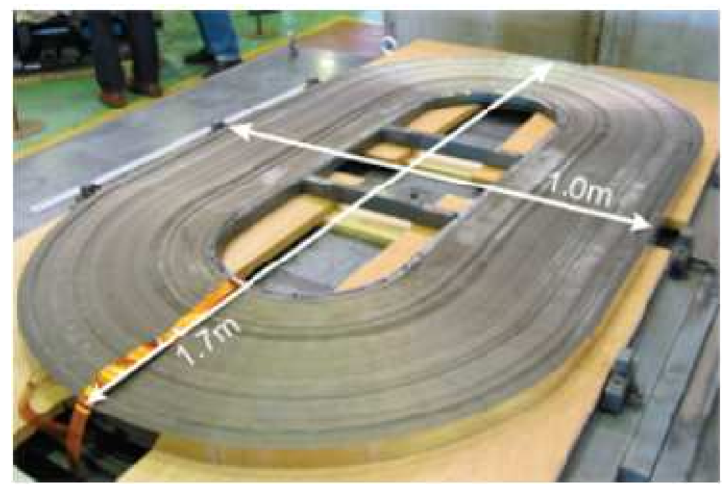
- FFAG magnets were designed and constructed.
- Magnetic fields were measured and confronted with simulations.
- 6 cell FFAG ring was assebled and phase rotation experiment using alpha particles was performed.



Status and progress on RF, C. Ohmori

- An RF system has been constructed and tested.
- Very large (~1.7 m X 1.0 m) magnetic alloy cores were loaded in the cavity.
- To drive the cavity, a compact and high peak power amplifier was developed for very low duty operation.
- Development of a new material, FT3L, is undergoing in order to improve the performance of magnetic alloy and reduce the cost.





PRISM Main Parameters

Proton beam parameters	
Beam power	2-4 MW
Beam kinetic energy	3-8 GeV
Bunch length at the pion production target	~10 ns
Repetition rate	1 kHz
Target and pion/muon beam transport	
Target type	solid
Capture element	solenoid 12-20 T
Transport system	solenoidal channel / FFAG transport line
Beam polarity	negative
PRISM ring parameters	
Machine function	Muon beam phase rotation and purification
Machine type	FFAG
Momentum acceptance	±20 %
Reference muon momentum	40-50 MeV/c
Physical acceptance (H/V)	(3.8-5.0/0.6) π cm rad
Harmonic number	1
RF voltage per turn	5.5 MV
RF frequency	3-6 MHz
Injection/extraction type	single turn
Extraction kicker rise time	50-60 ns
Repetition rate	1 kHz
Initial beam momentum spread	±20 %
Final beam momentum spread	±2 %
Number of turns	~6
Number of synchrotron oscillations	1/4 or 3/4

PRISM Task Force

.

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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C. Ohmori, KEK/JAEA, Ibaraki-ken, Japan
H. Witte, T. Yokoi, JAI, Oxford University , UK
J-B. Lagrange, Y. Mori, Kyoto University, KURRI, Osaka, Japan
Y. Kuno, A. Sato, Osaka University, Osaka, Japan
D. Kelliher, S. Machida, C. Prior, STFC-RAL-ASTeC, Harwell, UK
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

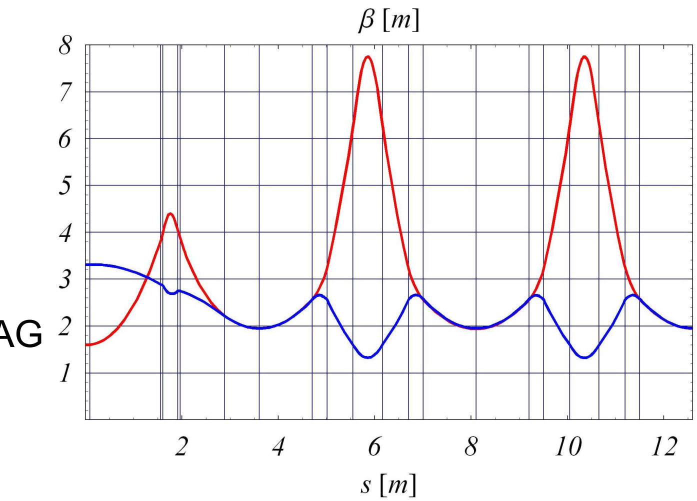
They should be evaluated in parallel and
finaly confronted with the figure of merit (FOM)
(number of muons delivered to target/cost).

Requirements for a new design:

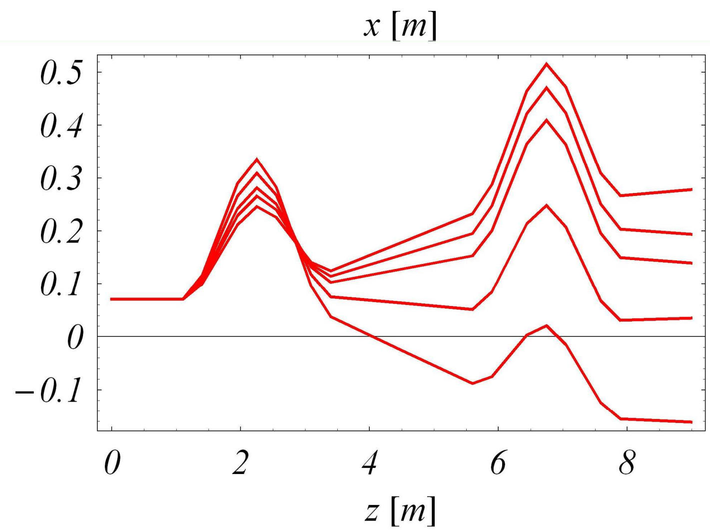
- High transverse acceptance (at least 38h/5.7v [Pi mm] or more).
- High momentum acceptance (at least ± 20% or more).
- Small orbit excursion.
- Compact ring size (this needs to be discussed).
- Relaxed or at least conserved the level of technical difficulties.
  for hardware (kickers, RF) with respect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

Examples of PRISM –TF studies

Matching
to AG FFAG
channel



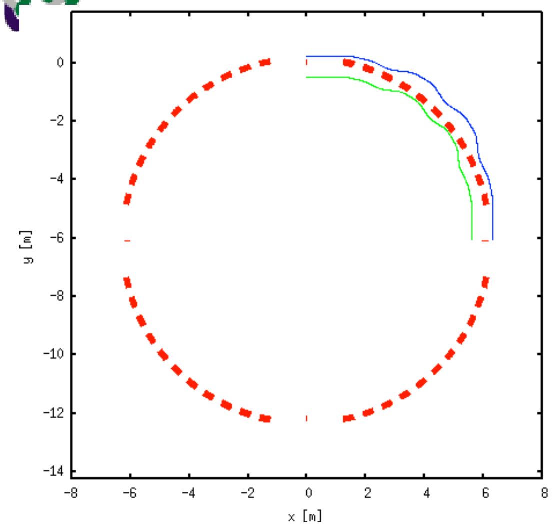
Matching
to solenoidal
channel



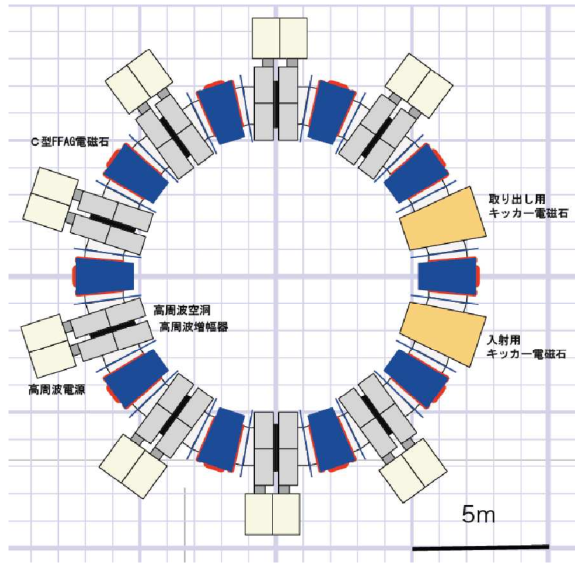
Muon Orbits in dispersion creator

- Design and modeling of the muon transport channel.
- RF development.
- FFAG ring injection/extraction system studies.
- Kicker studies.
- Alternative FFAG ring designs for PRISM.

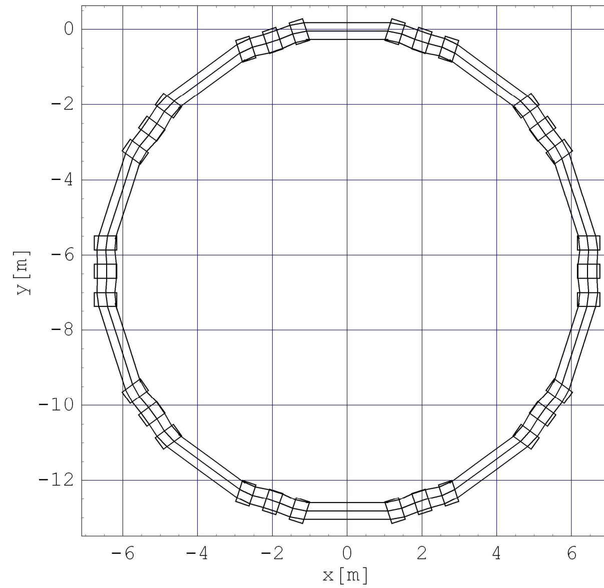
FFAG Ring Choice



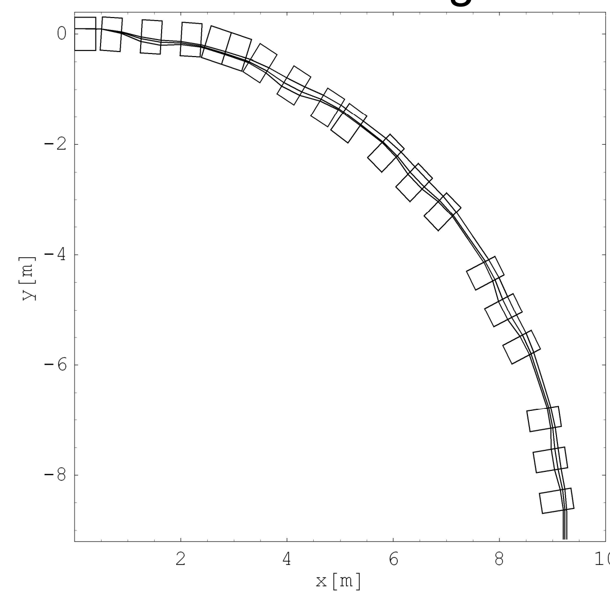
Scaling Superperiodic



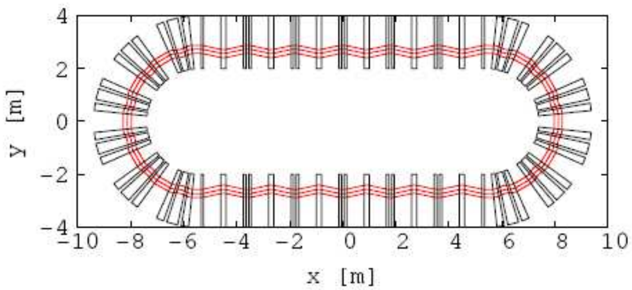
Reference design



Non-Scaling



Advanced NS-FFAG



Advanced scaling FFAG

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

Conclusions and future plans

- PRISM/PRIME aims to probe cLFV with unprecedented precision ($\sim 10^{-18}$).
- 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:
  - injection/extraction and matching to from the solenoidal channel,
  - alternative FFAG designs with new characteristics,
  - FFAG type beamline designs,
  - hardware studies (RF and kicker).
- PRISM-TF aims on CDR at the end of 2011.