A Search for a Muon-to-Electron Conversion Process with a Highly Intense Muon Facility, PRISM

PRISM

Yoshitaka Kuno
Osaka University

October 30th, 2006
Joint Meeting of Pacific Region Particle Physics Communities
Sheraton Waikiki Hotel, Honolulu, Hawaii

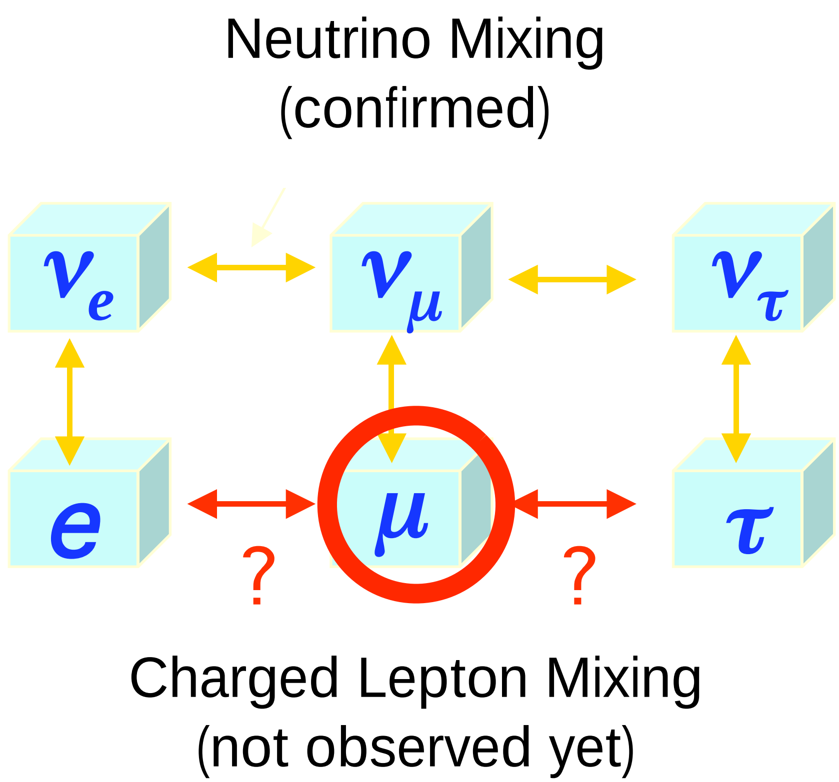
Outline

- Physics Motivation of Charged Lepton Mixing
- muon-to-electron conversion in a muonic atom
- Past Experiments
- What is PRISM/PRIME ?
- R&D status of PRISM/PRIME
- at J-PARC
- Summary

charged Lepton mixing

Physics Motivation of Charged Lepton Mixing

Charged Lepton Mixing



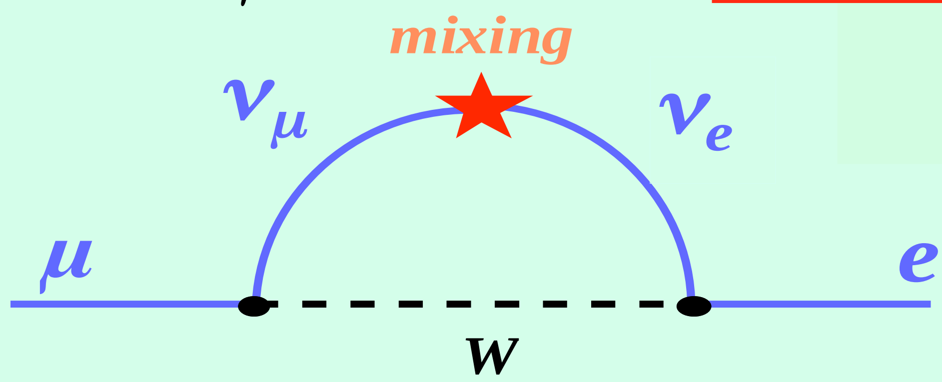
- Why is the muon ?
  - A number of muons available now is the highest (10^8/sec at PSI).
  - High power (M Watt) proton drivers (for neutrino physics) will be available.
  - In future, due to muon collider R&D, a number of muons of 10^{12}-10^{14}/sec will be possible. (4-6 orders of magnitude).
  - The future prospect for muons is better than taus at super-B factory.

From Neutrino Mixing
to Charged Lepton Mixing ....

How does the neutrino mixing contribute to charged LFV ?

$$\mu \longrightarrow e\gamma$$

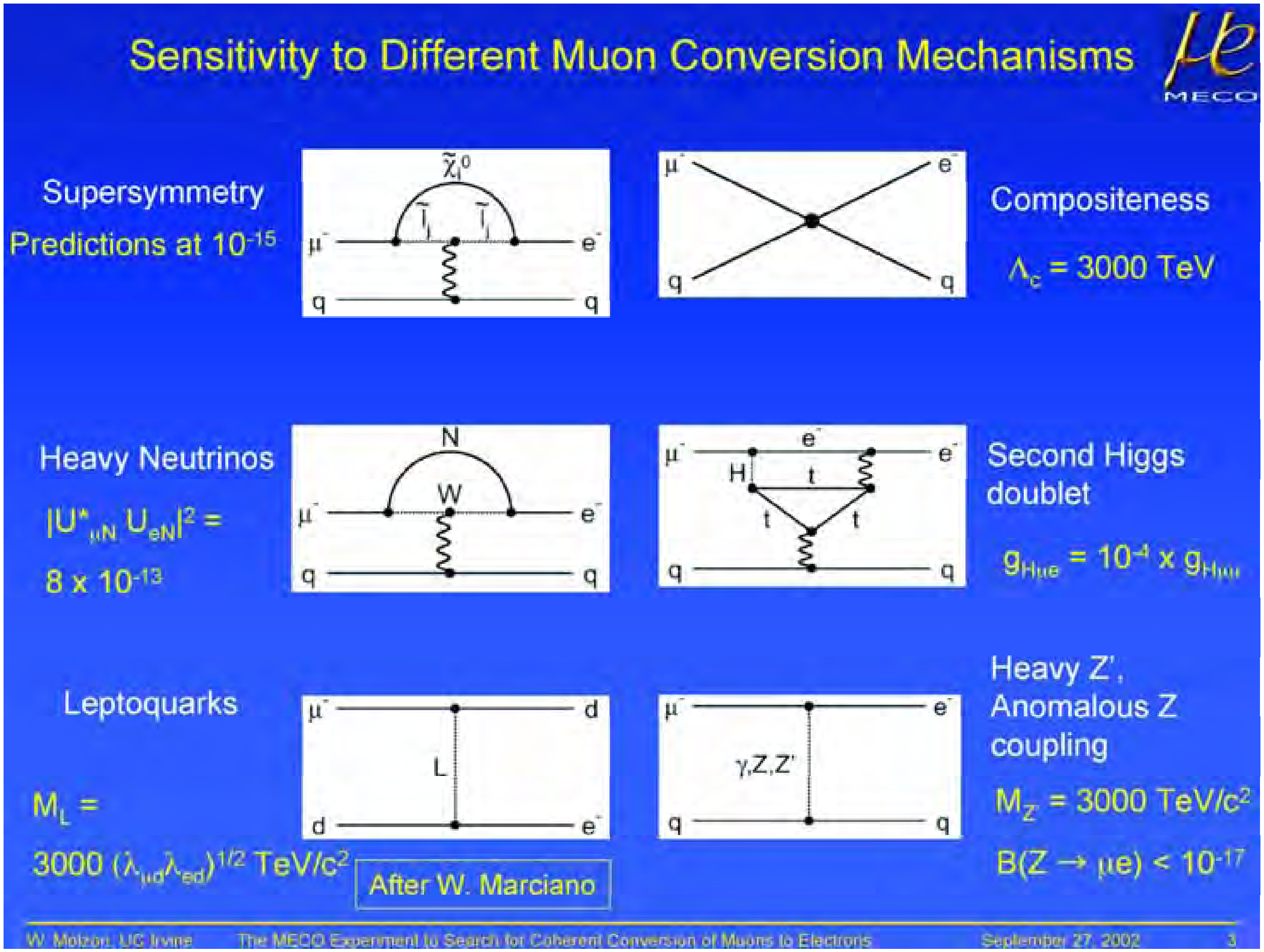
$$\propto (m_\nu / m_W)^4$$



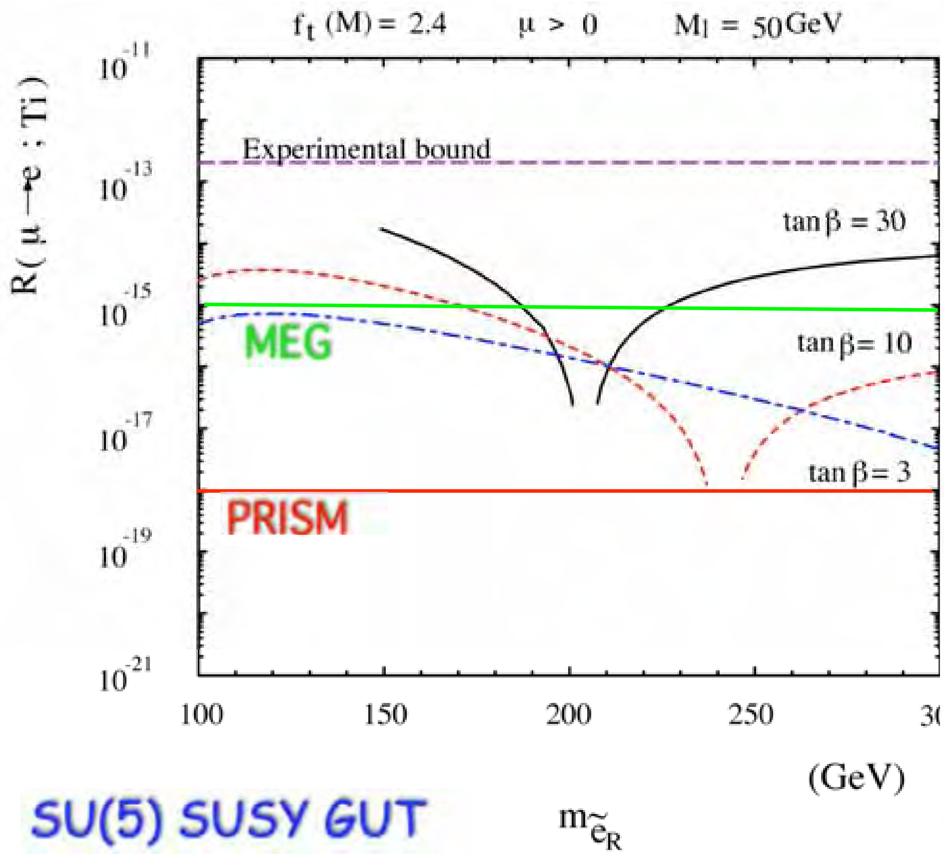
Very Small (10^{-52})

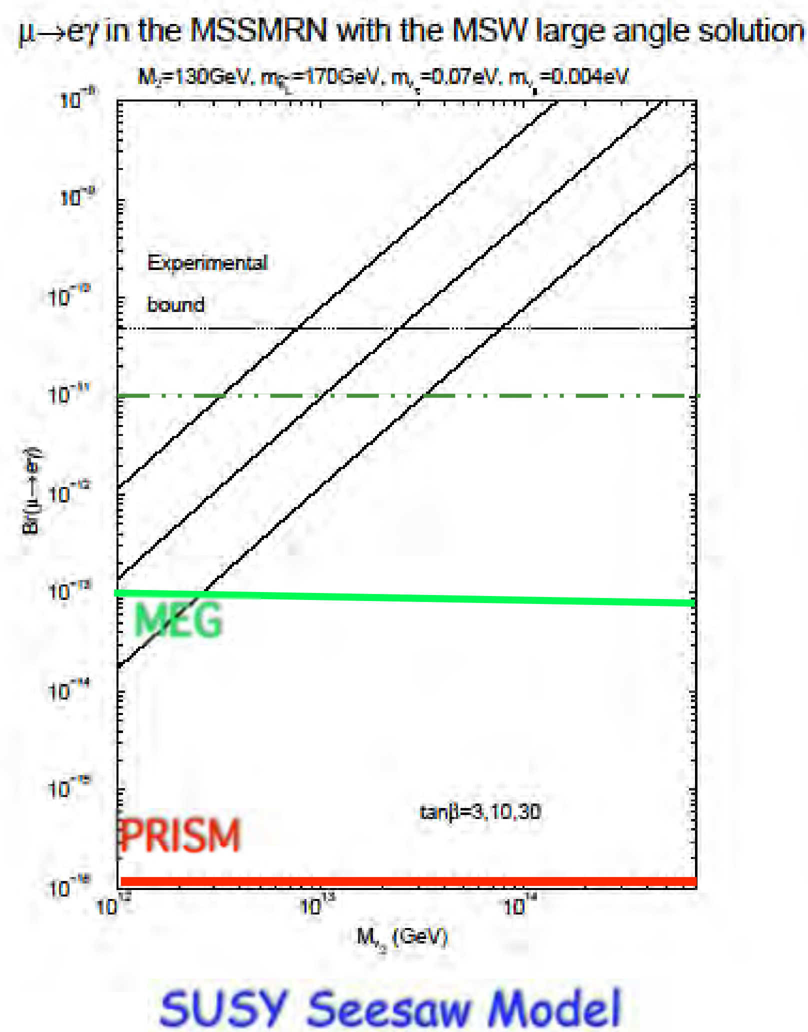
Sensitive to new Physics beyond Neutrino Mixing

Various Models Predict Charged Lepton Mixing.



SUSY Predictions for μ-e Conversion





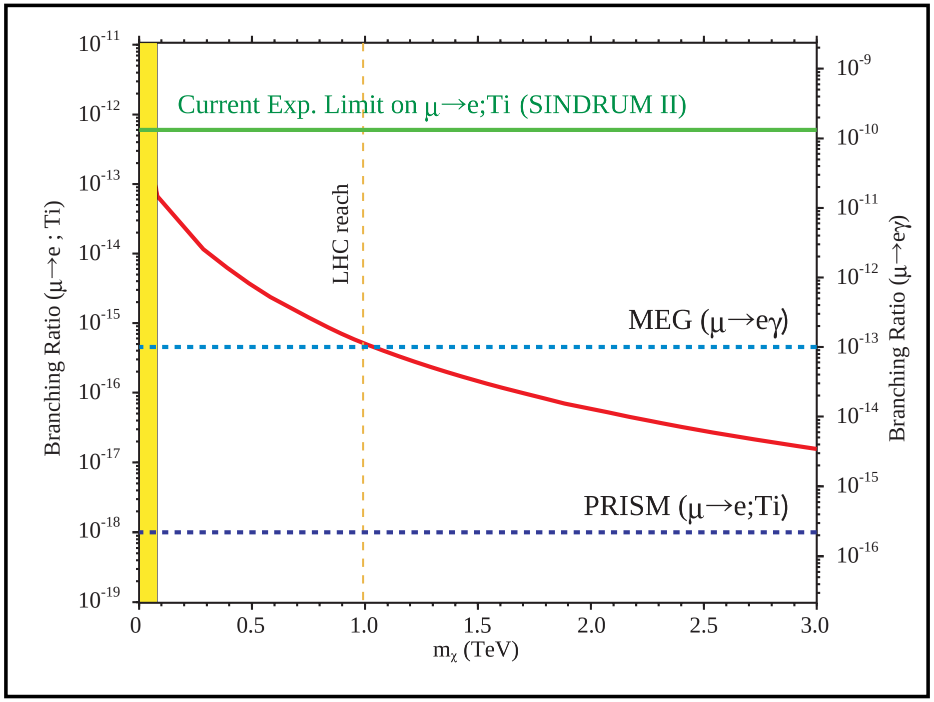
LHC, SUSY and Charged Lepton Mixing

If LHC finds SUSY

LFV search would become important, since the slepton mixing matrix should be studied.
- SUSY-GUT
- SUSY Seesaw models.

If LHC not find SUSY

LFV search would become more important, since



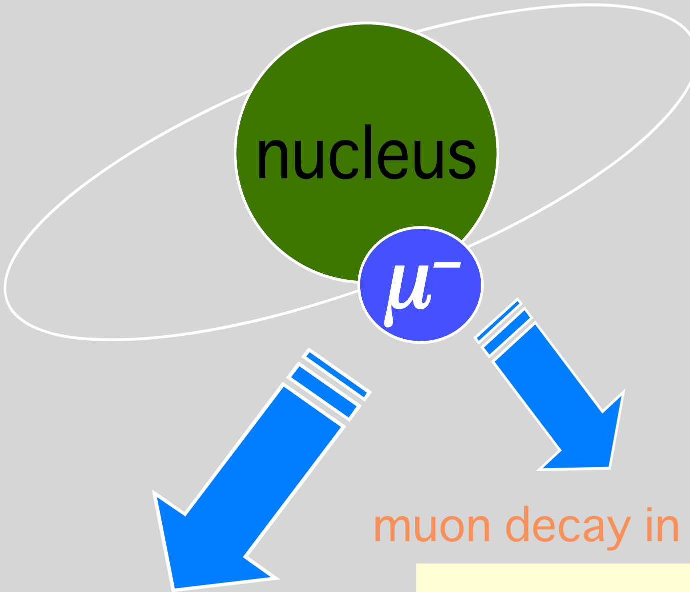
from A.Masiero et al.

What is a
Muon-to-electron
Conversion ?

Present Upper Limits for Charged Lepton Mixing

Process	Current	Future
$\mu^+ \to e^+\gamma$	1.2×10^{-11}	$<10^{-13}$(MEG)
$\mu^+ \to e^+e^+e^-$	1.0×10^{-12}	
$\mu^- A \to e^- A$ (Ti)	6.1×10^{-13}	$<10^{-18}$(PRISM)
~~$\mu^- A \to e^- A$ (Al)~~		~~$<10^{-16}$(MECO)~~
$\tau \to \mu\gamma$	3.2×10^{-7}	
$\tau \to lll$	$1.4 - 3.1 \times 10^{-7}$	
$G_{Mu\overline{Mu}}/G_F$	3×10^{-3} ←	$\Delta L_f = 2$

1s state in a muonic atom



muon decay in orbit

$$\mu^- \rightarrow e^- \nu \bar{\nu}$$

nuclear muon capture

$$\mu^- + (A, Z) \rightarrow \nu_\mu + (A, Z-1)$$

Neutrino-less muon nuclear capture (=μ-e conversion)

$$\mu^- + (A, Z) \rightarrow e^- + (A, Z)$$

lepton flavors changes by one unit.

$$B(\mu^- N \rightarrow e^- N) = \frac{\Gamma(\mu^- N \rightarrow e^- N)}{\Gamma(\mu^- N \rightarrow \nu N')}$$

Muon-to-Electron (μ-e) Conversion

PRISM

μ-e Conversion
Signal and Backgrounds

PRISM

$$\mu^- + (A,Z) \rightarrow e^- + (A,Z)$$

- Signal
  - single mono-energetic electron

$$m_\mu - B_\mu \sim 105 MeV$$

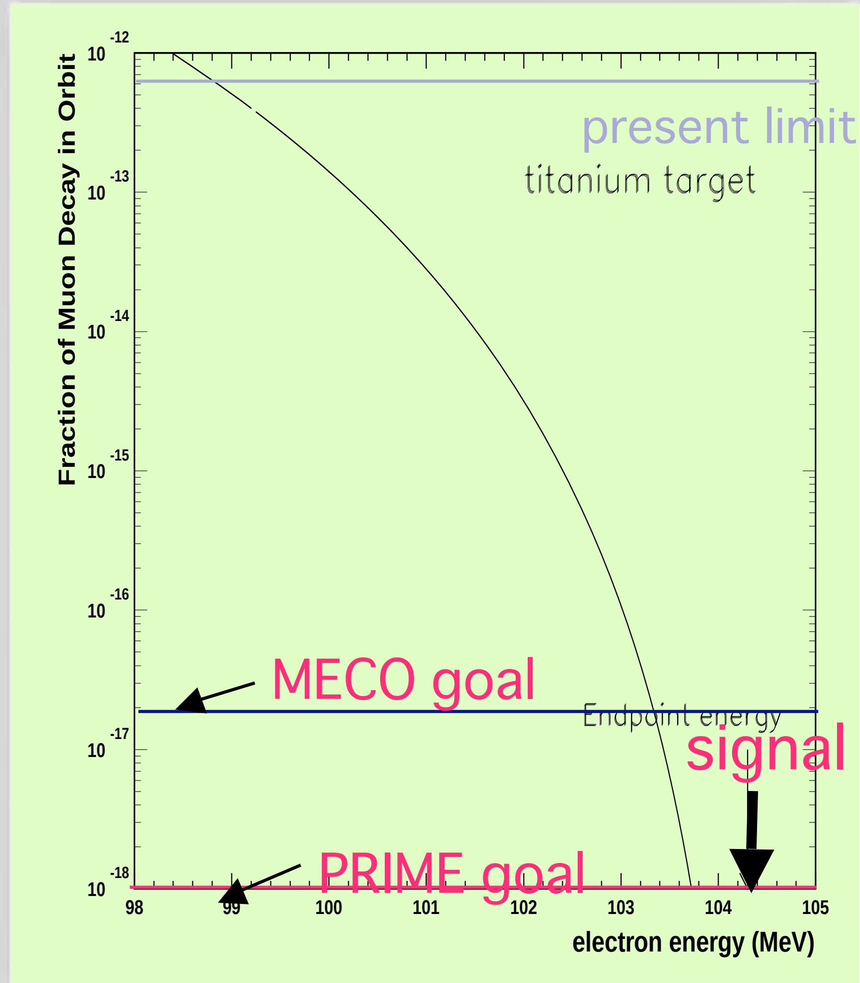
  - coherent process (the same initial and final nucleus)

$$\propto Z^5$$

- Backgrounds
  - Muon decay in orbit
    - Endpoint comes to the signal region $\propto (\Delta E)^5$
  - Radiative muon capture
  - Radiative pion capture
    - pulsed beam required
    - wait until pions decay.
  - Electrons from muon decays in flight
  - Cosmic rays
  - and many others

Muon Decay in Orbit in a Muonic Atom

- Normal muon decay has an endpoint of 52.8 MeV, whereas the end point of muon decay in orbit comes to the signal region.
- good resolution of electron energy (momentum) is needed.

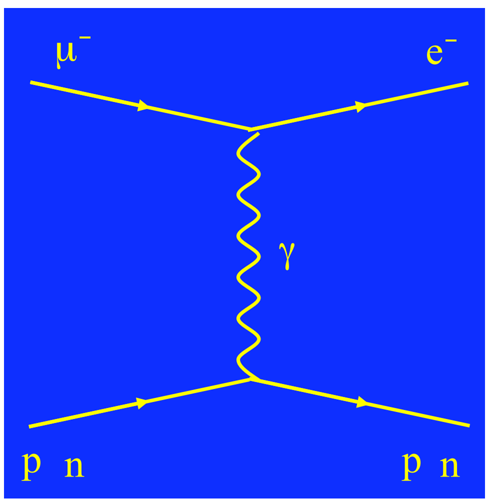


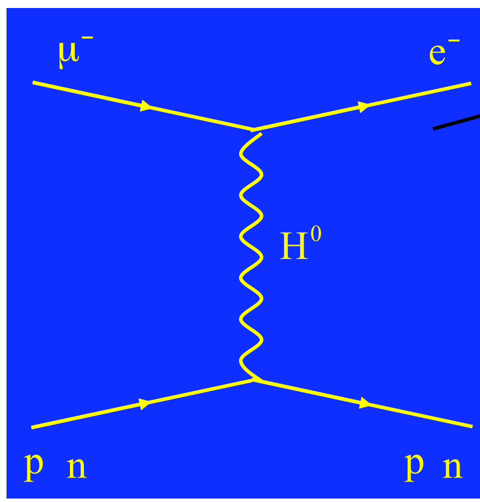
PRISM

Comparison between μ→eγ and μ-e Conversion (Physics sensitivity)

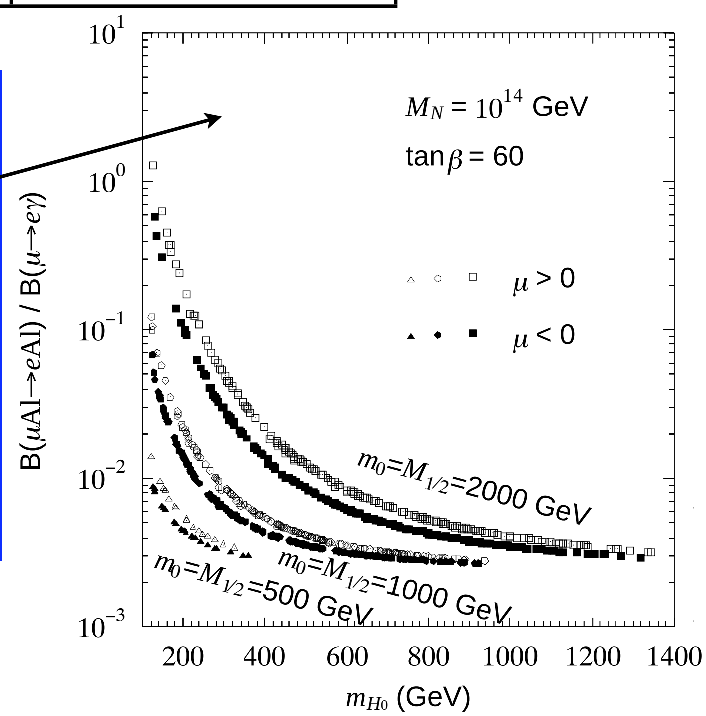
Photonic and non-photonic (SUSY) diagrams

	photonic	non-photonic
• μ→eγ	yes (on-shell)	no
• μ-e conversion	yes (off-shell)	yes





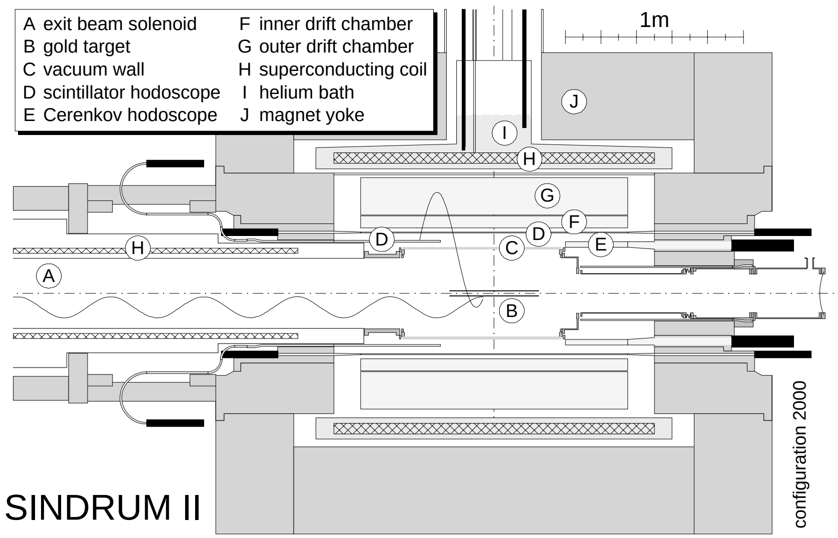
$$\frac{B(\mu N \to eN)}{B(\mu \to e\gamma)} \sim \frac{1}{100}$$



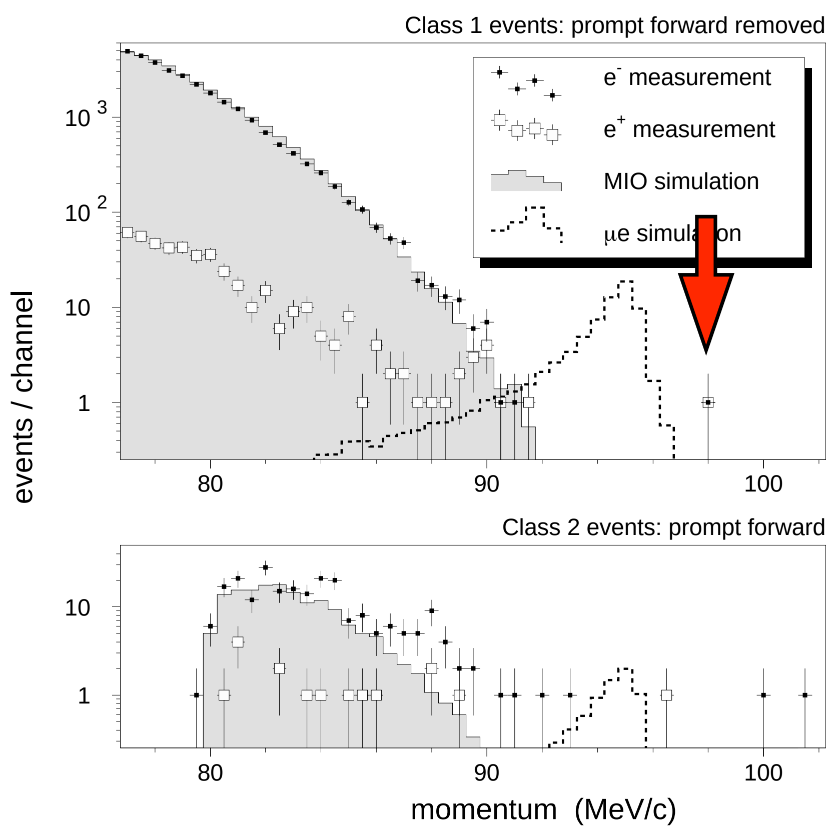
μ-e Conversion Experiments

SINDRUM-II (at PSI)

unpublished



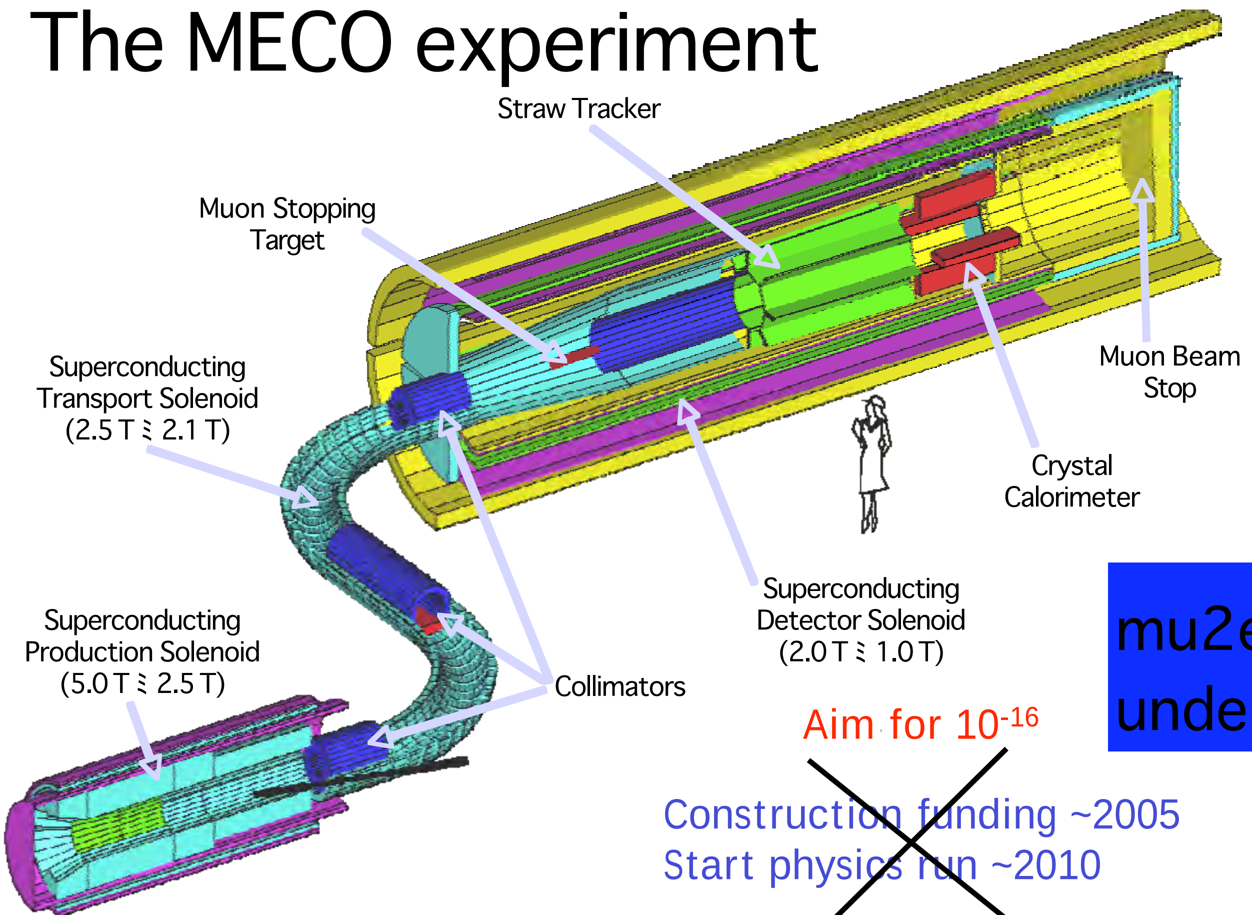
$$B(\mu^- + Au \rightarrow e^- + Au) < 7 \times 10^{-13}$$



There is one background event above the signal region, and it is speculated that it might come from pion contamination in a beam.

MECO Experiment (at BNL)

The MECO experiment



Aim for 10^{-16}

~~Construction funding ~2005~~
~~Start physics run ~2010~~

CANCELLED

mu2e @ Fermilab is under discussion.

Beam Requirements for μ-e conversion

Beam is a critical element for μ-e conversion.

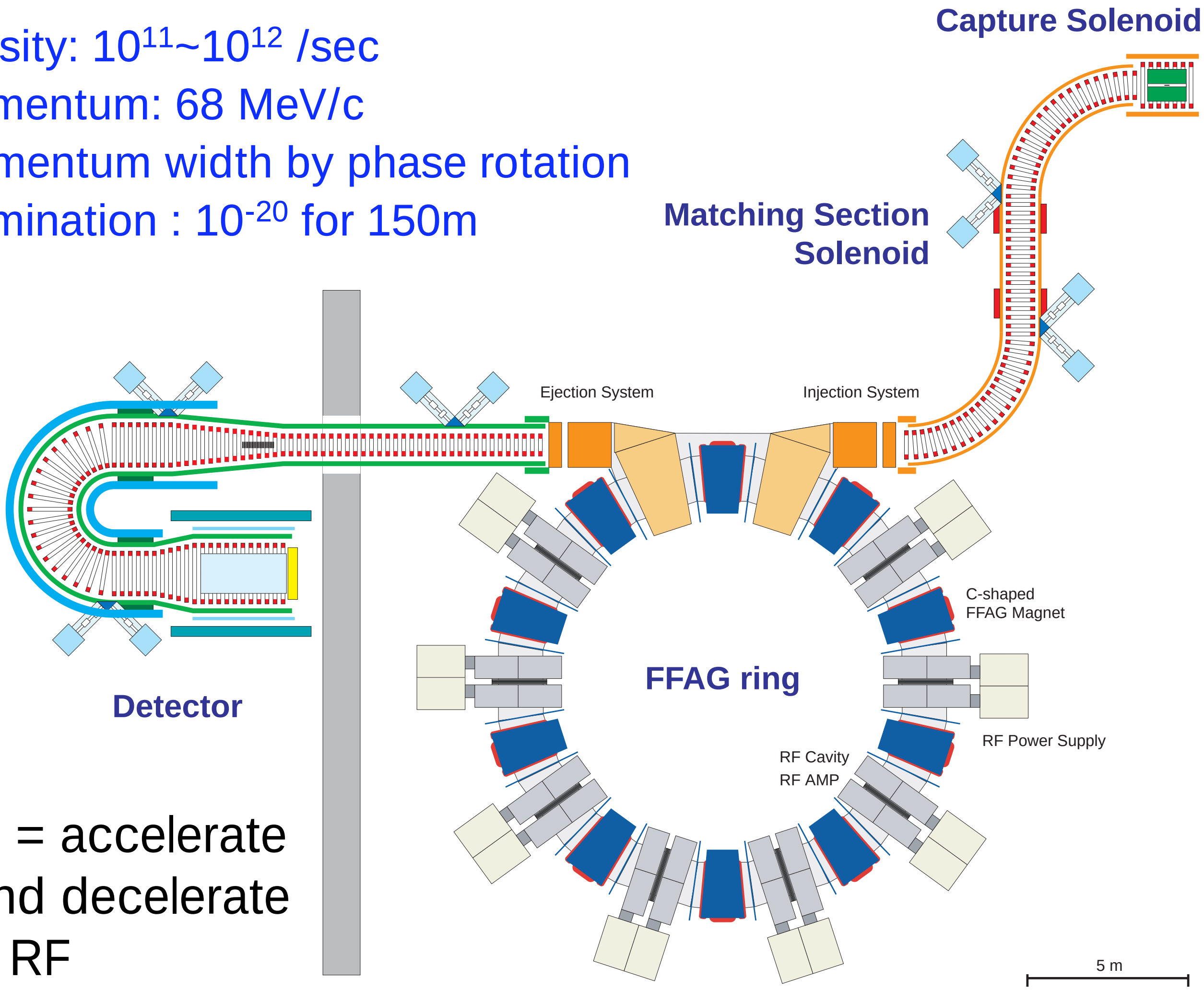
Objectives	Beam Requirements	How in PRISM
• High sensitivity	• high muon beam intensity	• Pion capture SC solenoid (10^{12}/s)
• Reduction of pion background in a beam	• a long beam channel (about 150m results in 10^{-20} survival.)	• muon storage ring (FFAG) (about 10 m dia. & 5 turns)
• Reduction of background of muon decay in orbit (good e^- energy resolution)	• narrow beam spread (a thin muon stopping target)	• Phase Rotation (at FFAG) (x1/10)

What is PRISM ?
What is PRIME ?

PRISM Muon Beam

PRISM=Phase Rotated Intense Slow Muon source

- muon intensity: 10^{11}~10^{12} /sec
- central momentum: 68 MeV/c
- narrow momentum width by phase rotation
- pion contamination : 10^{-20} for 150m



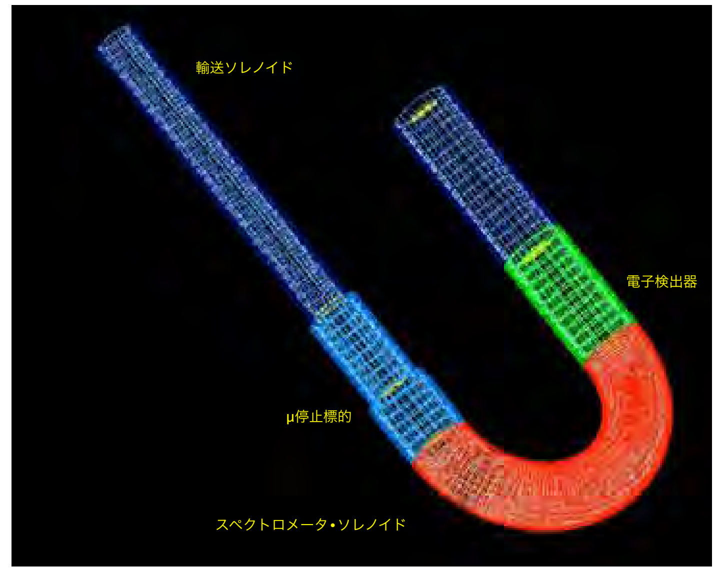
Phase rotation = accelerate slow muons and decelerate fast muons by RF

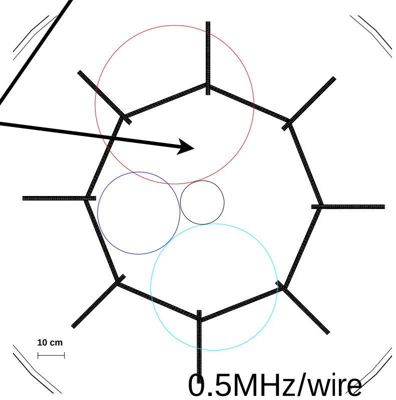
PRIME Detector

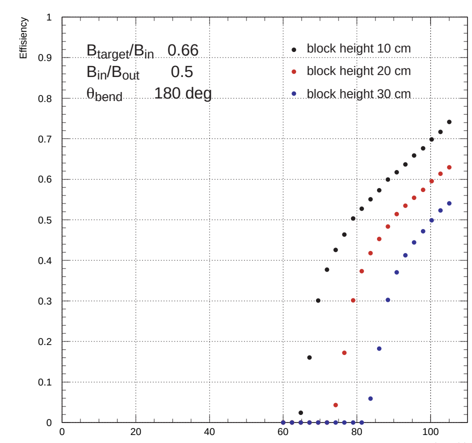
PRIME=PRISM Mu E conversion detector

$$D = \frac{p}{qB}\theta_{bend}\frac{1}{2}\left(\cos\theta + \frac{1}{\cos\theta}\right)$$

- Detector rates
  - normal muon decays
  - muon decays in orbits
  - causing false tracking...
- MECO : a straight solenoid and P_T cut only
  - high single rates for tracking wire chambers ~ 500 kHz/wire
- PRIME : Curved Solenoid
  - vertical drift is used for momentum selection.







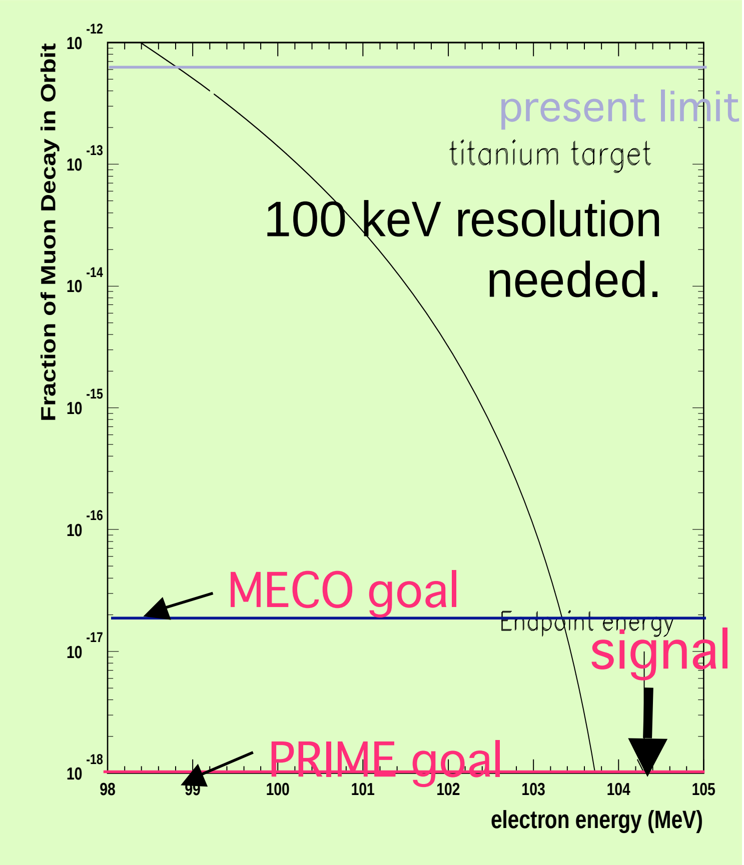
PRISM/PRIME Sensitivity for μ-e conversion

$$B(\mu^- + Ti \rightarrow e^- + N) > 10^{-18}$$

preliminary

	PRIME
proton beam power	0.6 MW
muon intensity	2×10^{11}/sec
acceptance	0.22
time window	100%
running period	5 year
Single Event Sensitivity	6×10^{-19}

Work in Progress



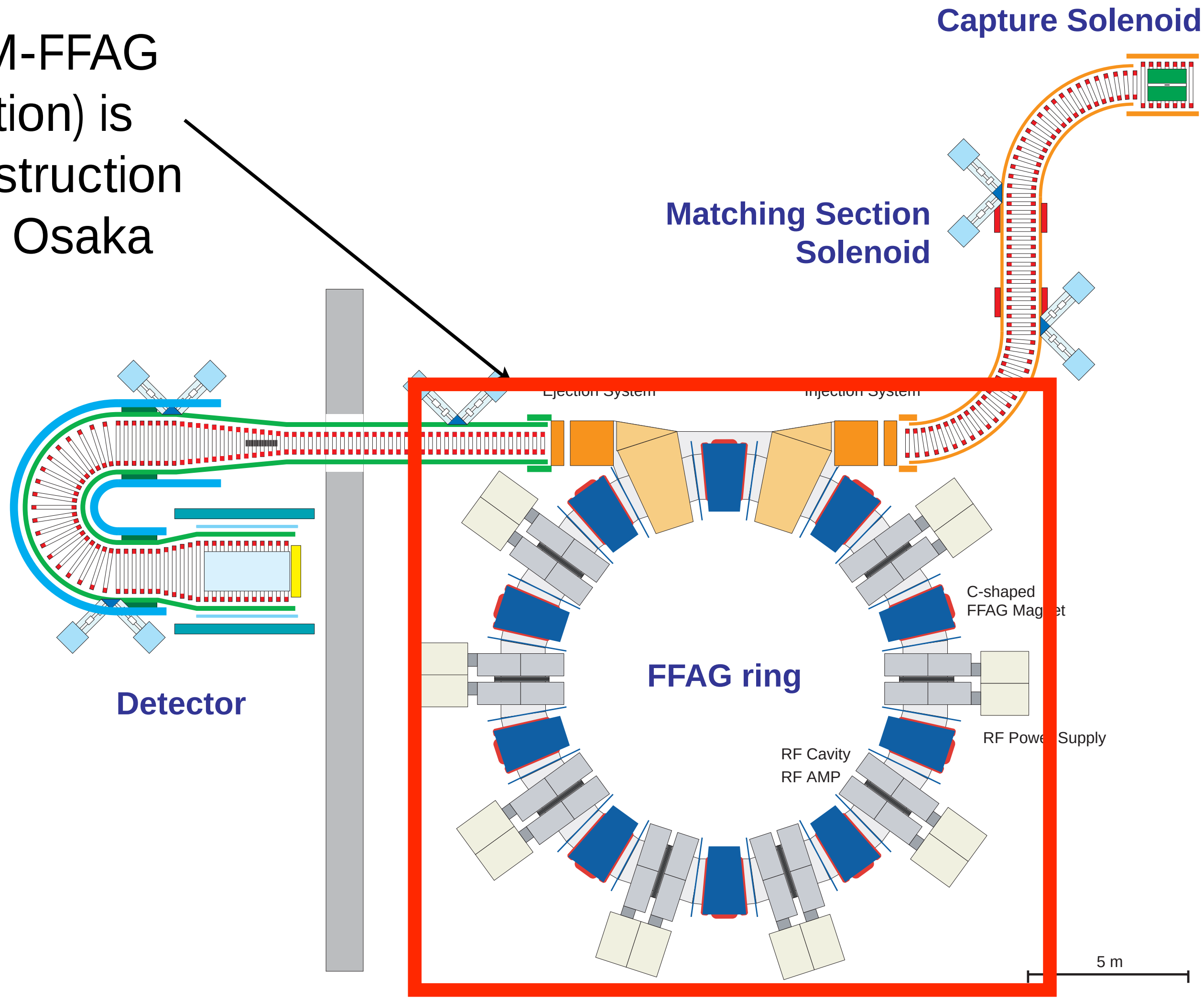
from the PRISM/PRIME LOI (2006)

PRISM Features to Reject Backgrounds

- (1) Long muon flight length
  - about 40 m circumference x 5-6 turns at the muon storage ring (PRISM-FFAG)
  - pion survival rate of <10^{-20}
- (2) Narrow muon beam energy spread
  - goal : +- 3 %
  - by phase rotation at the PRISM-FFAG ring
- (3) Muon beam energy selection before the detector
  - momentum slit after the PRISM-FFAG ring
  - 68 MeV/c +- 3% (not 104 MeV)
- (4) Beam extinction at muons
  - Kicker magnets of the PRISM-FFAG ring
  - no proton extinction needed
- (5) Small duty factor of detection
  - ~ 10^{-4} for a detection of 1 μs with 100 Hz repetition

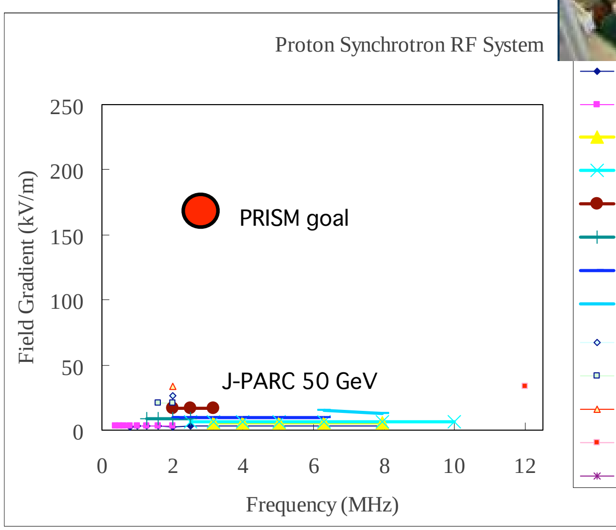
PRISM FFAG Ring R&D

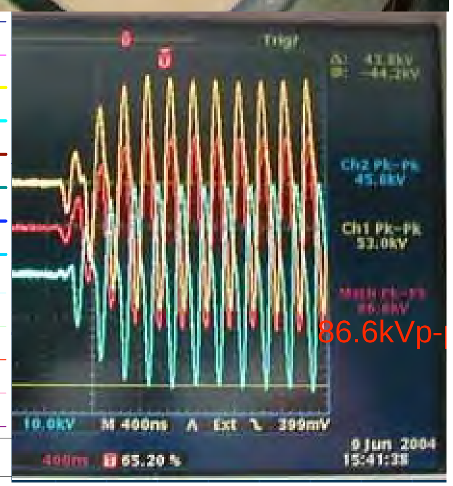
The PRISM-FFAG ring (a portion) is under construction for R&D at Osaka University.



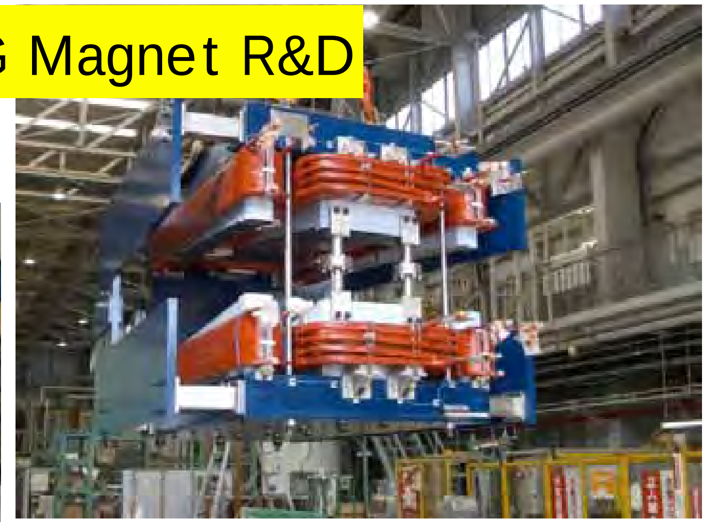
PRISM FFAG R&D is Going...

RF R&D



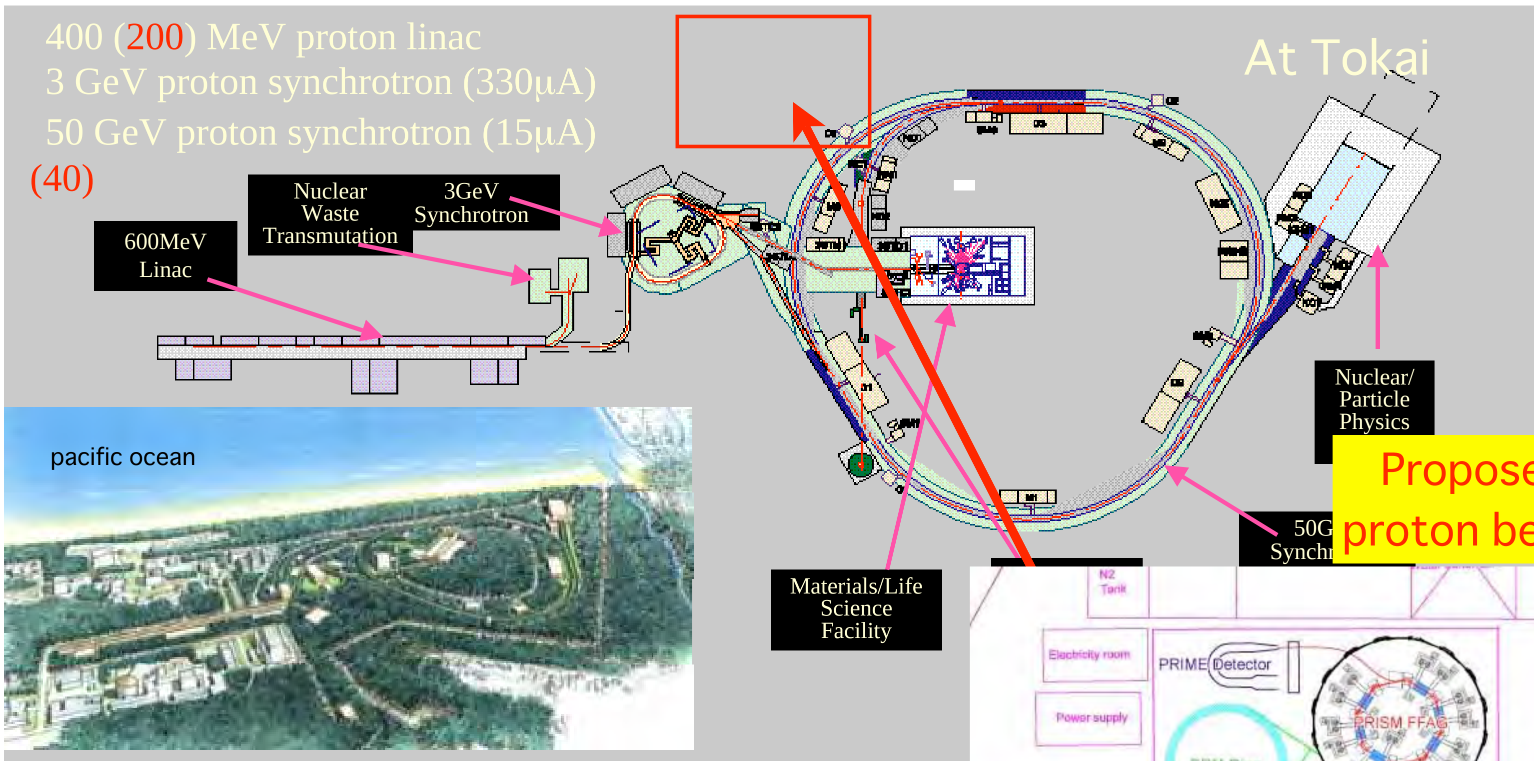


FFAG Magnet R&D

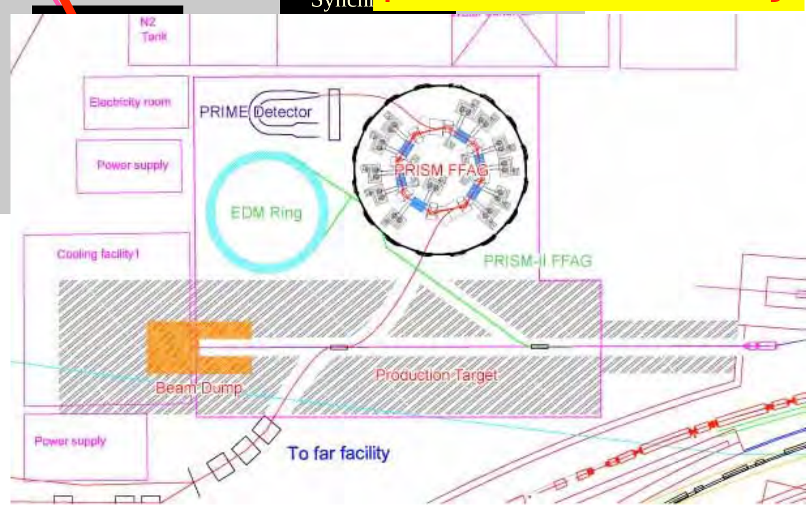


J-PARC = Japan Proton Accelerator Research Complex

PRISM/PRIME at J-PARC



Proposed pulsed proton beam facility



This pulsed proton beam facility has not yet been funded.

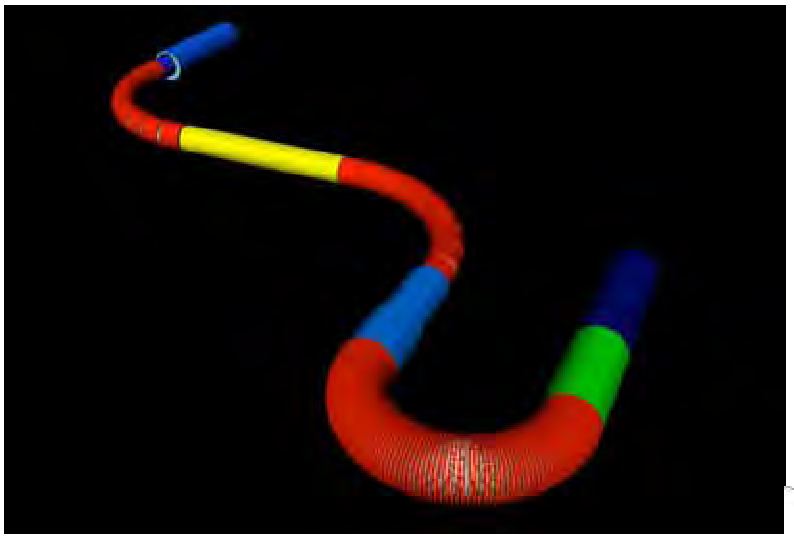
Summary and Outlook

- Charged lepton mixing is sensitive to physics beyond the Standard Model (and neutrino oscillation). It is in particular sensitive to SUSY-GUT and SUSY-Seesaw models, and others.
- The searches for charged lepton mixing with muons are the most promising. The processes are $\mu \to e\gamma$ and μ-e conversion and others. The comparison between $\mu \to e\gamma$ and μ-e conversion is made.
- The PRISM/PRIME is a Japanese project aiming to search for μ-e conversions at sensitivity of 10^{-18}. The R&D programs are going on and the PRISM-FFAG ring is under construction at Osaka University.
- Hope to make discovery soon.

End of My Slides

Backup Slides

Staging Approach for PRISM/PRIME



Stage 1 :
w/o PRISM-FFAG
goal : 10^{-16}

Stage 2 :
w PRISM-FFAG
goal : 10^{-18}