PRISM

Beam Requirements for μ-e conversion

Beam is critical element for μ-e conversion

MECO

- Higher muon intensity
  - more than 10^{12} μ^-/sec
- pulsed beam
  - rejection of background from proton beam

- Less beam contamination
  - no pion contamination
    - ⇛ long flight path
  - beam extinction between pulses
    - ⇛ kicker magnet

- Narrow energy spread
  - allow a thinner muon-stopping target
    - ⇛ better e^- resolution and acceptance

- Point Source
  - allow a beam blocker behind the target
    - ⇛ isolate the target and detector
    - ⇛ tracking close to a beam axis

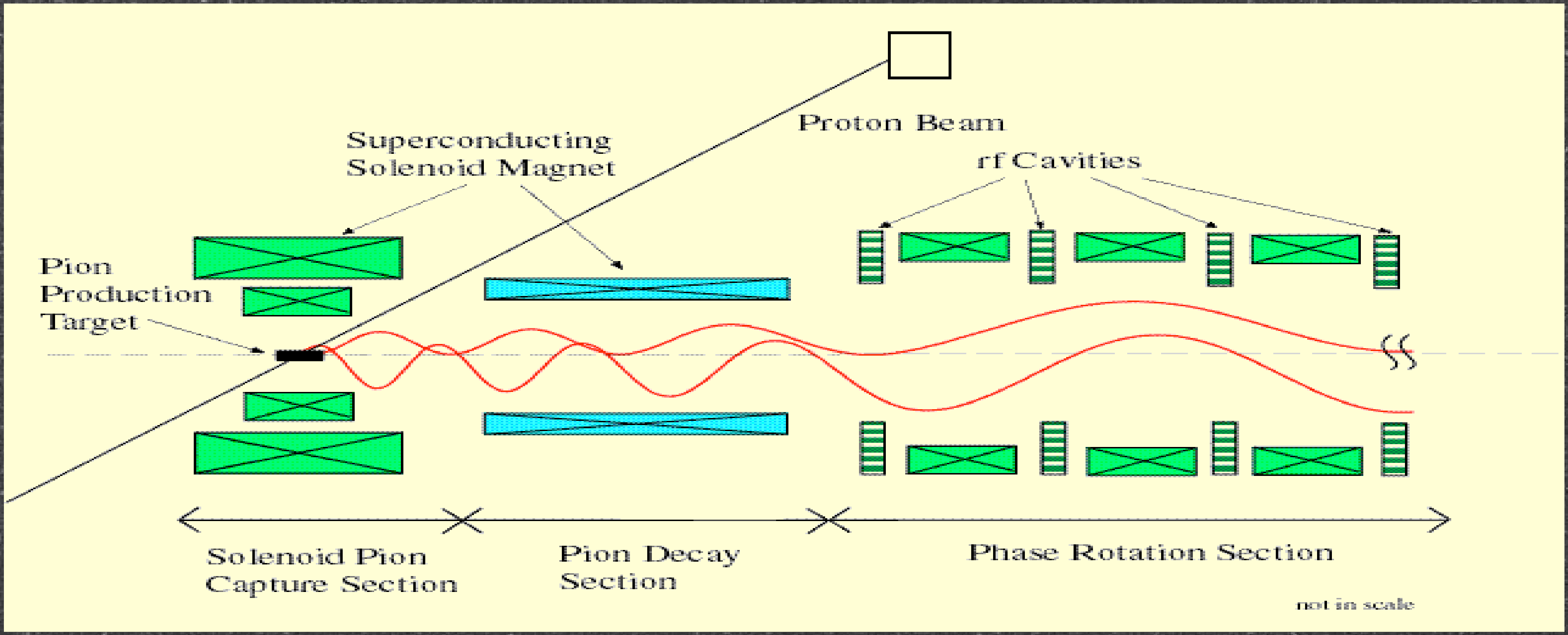
PRISM

PRISM

PRISM=Phase Rotated Intense Slow Muon source

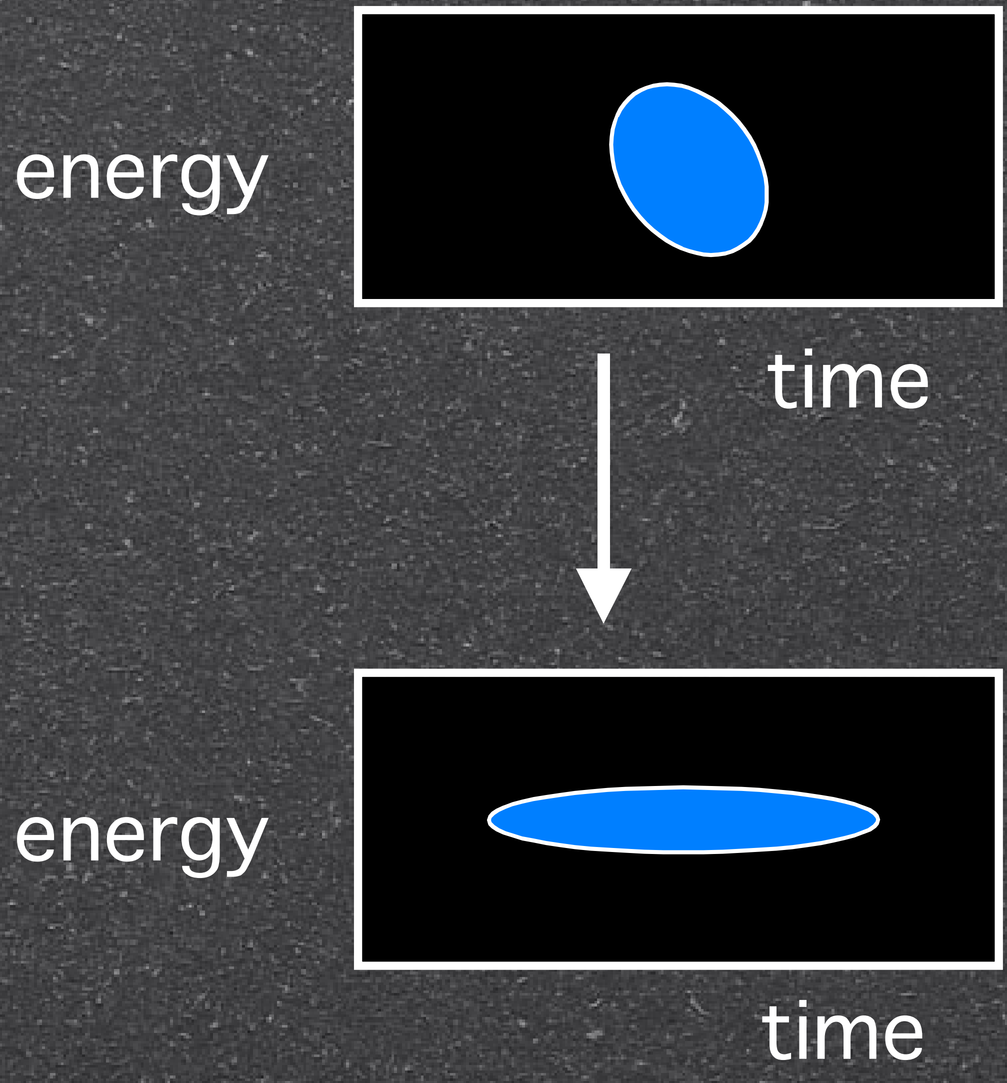
PRISM is a high intensity muon source
with narrow energy spread and high purity.

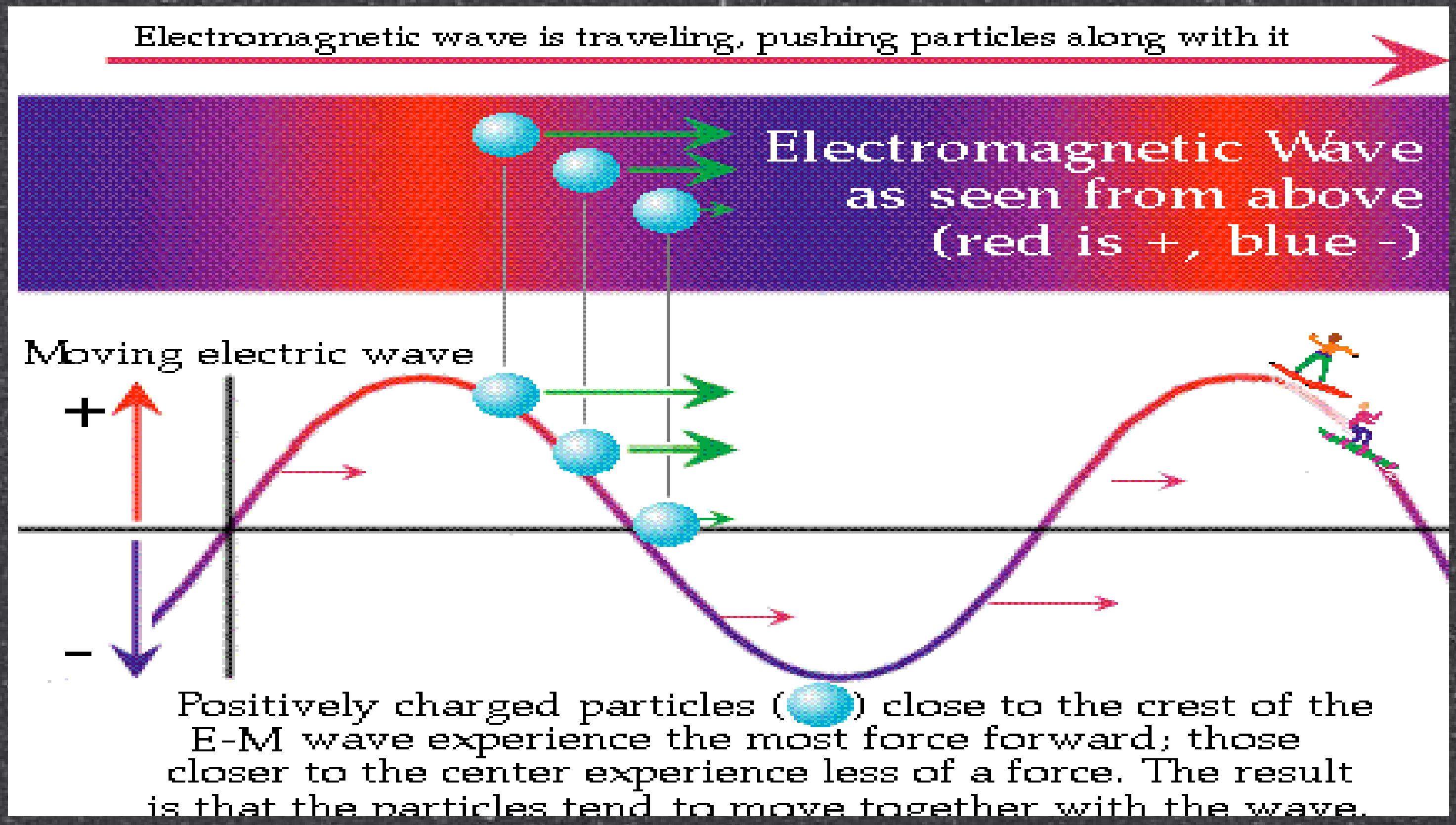
- high intensity: (Solenoid Pion Capture)
- narrow momentum width: (Phase rotation)
- small emittance (in future): (Cooling)



What is Phase Rotation ?

- Phase Rotation = decelerate particles with high energy and accelerate particle with low energy by high-field RF
- A narrow pulse structure (<1 nsec) of proton beam is needed to ensure that high-energy particles come early and low-energy one come late.





FFAG for Phase Rotation

- a ring instead of linear systems
  - reduction of # of rf cavities
  - reduction of rf power consumption
  - compact

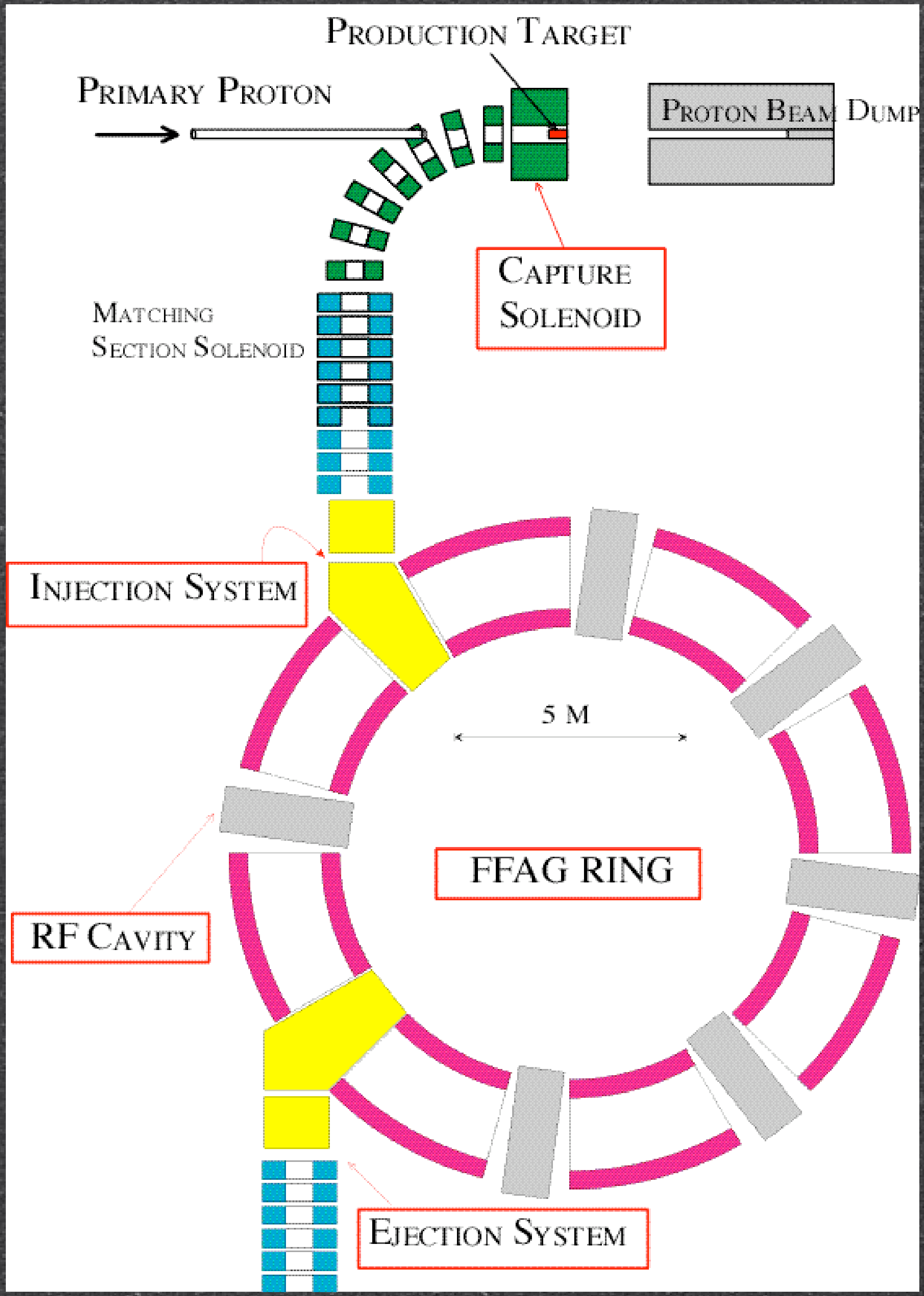
- synchrotron oscillation for phase rotation
  - not cyclotron (isochronous)
- large momentum acceptance
  - larger than synchrotron
  - ± several 10 % is aimed
- large transverse acceptance
  - strong focusing
  - large horizontal emittance
  - reasonable vertical emittance at low energy

FFAG = Fixed Field Alternating Gradient Synchrotron

PRISM

PRISM=Phase Rotated Intense Slow Muon source

- Specifications
  - muon intensity: 10^{11}~10^{12} /sec
  - central momentum: 68 MeV/c
  - momentum width: 3 % (<--- 30 %)
    - by phase rotation (5turns)
  - Repetition : 100 Hz
  - pion contamination : 10^{-18} for 150m



PRIME

PRIME = PRIME Mu E experiment

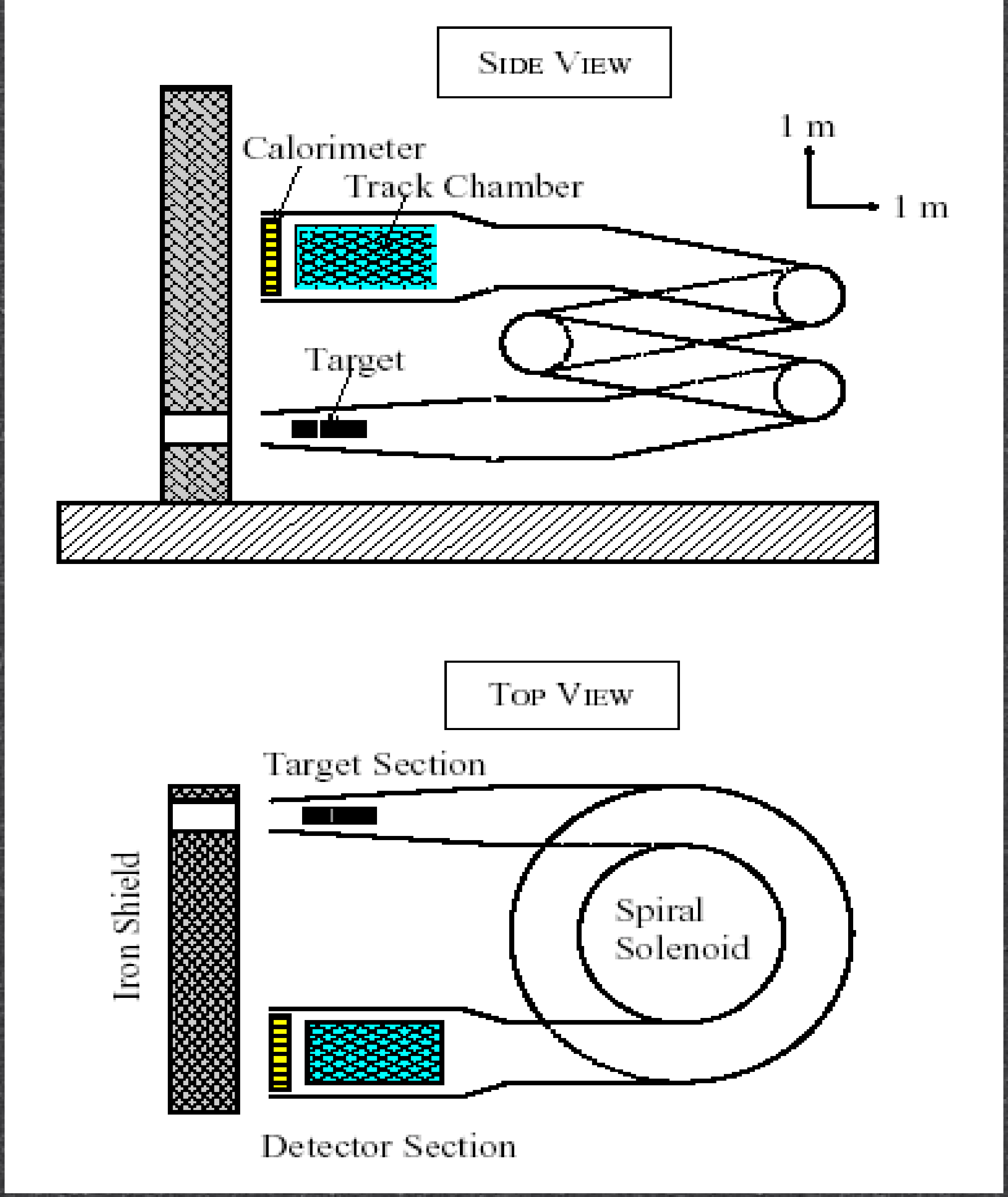
using PRISM

Aim at 10^{-18}

Detector Option:
Spiral solenoid spectrometer

eliminate low energy particles by a toroidal magnetic field

$$D = \frac{1}{0.3B}\frac{s}{R}\frac{(p_s^2 + \frac{1}{2}p_t^2)}{p_s}$$



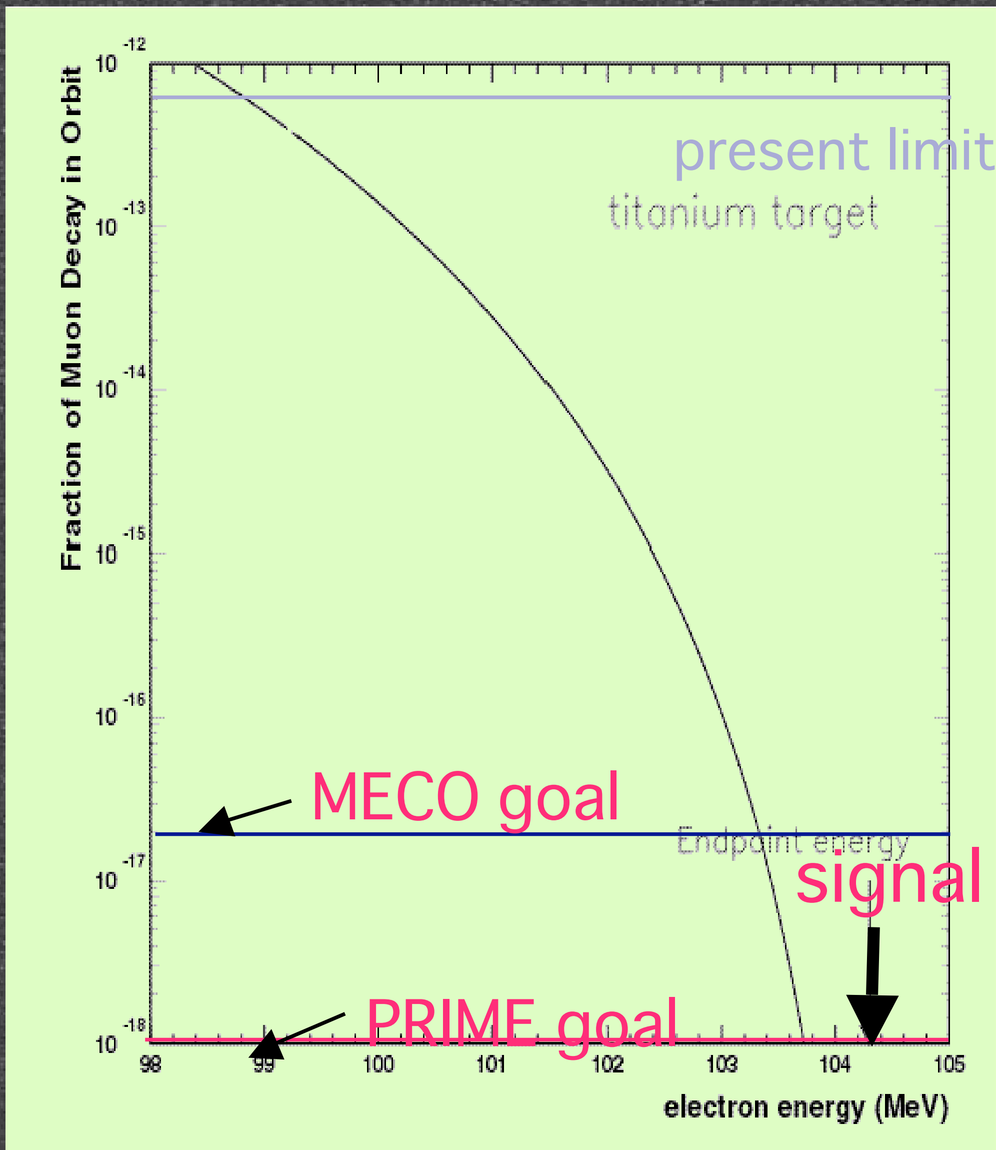
PRIME Sensitivity

At the best muon intensity from PRISM,

$$B(\mu^- N \to e^- N) \sim 6 \times 10^{-19}$$

	PRIME	MECO	improvement factor
muon intensity	$1.3\text{x}10^{11}$/sec	$2\text{x}10^{11}$/sec	0.65
stopping efficiency	80 %	40%	2
detector acceptance	35%	20%	1.8
time window	100%	40%	2.5
running period	can run for 5 years	1 year	5
a total			30

PRIME Background Rates



Muon Decay in Orbit ($\propto (E_{\mu e} - E_e)^5$)

Detector Resolution $\Delta E_e = 235$ keV

Preliminary !

at the sensitivity of 10^{-18}

Background	Rate	comment
Muon decay in orbit	0.05	energy reso 350keV(FWHM)
Radiative muon capture	0.01	end point energy for Ti=89.7MeV
Radiative pion capture	0.03	long flight length in FFAG, 2 kicker
Pion decay in flight	0.008	long flight length in FFAG, 2 kicker
Beam electron	negligible	kinematically not allowed
Muon decay in flight	negligible	kinematically not allowed
Antiproton	negligible	absorber at FFAG entrance
Cosmic-ray	< 10^-7 events	low duty factor
Total	0.10	

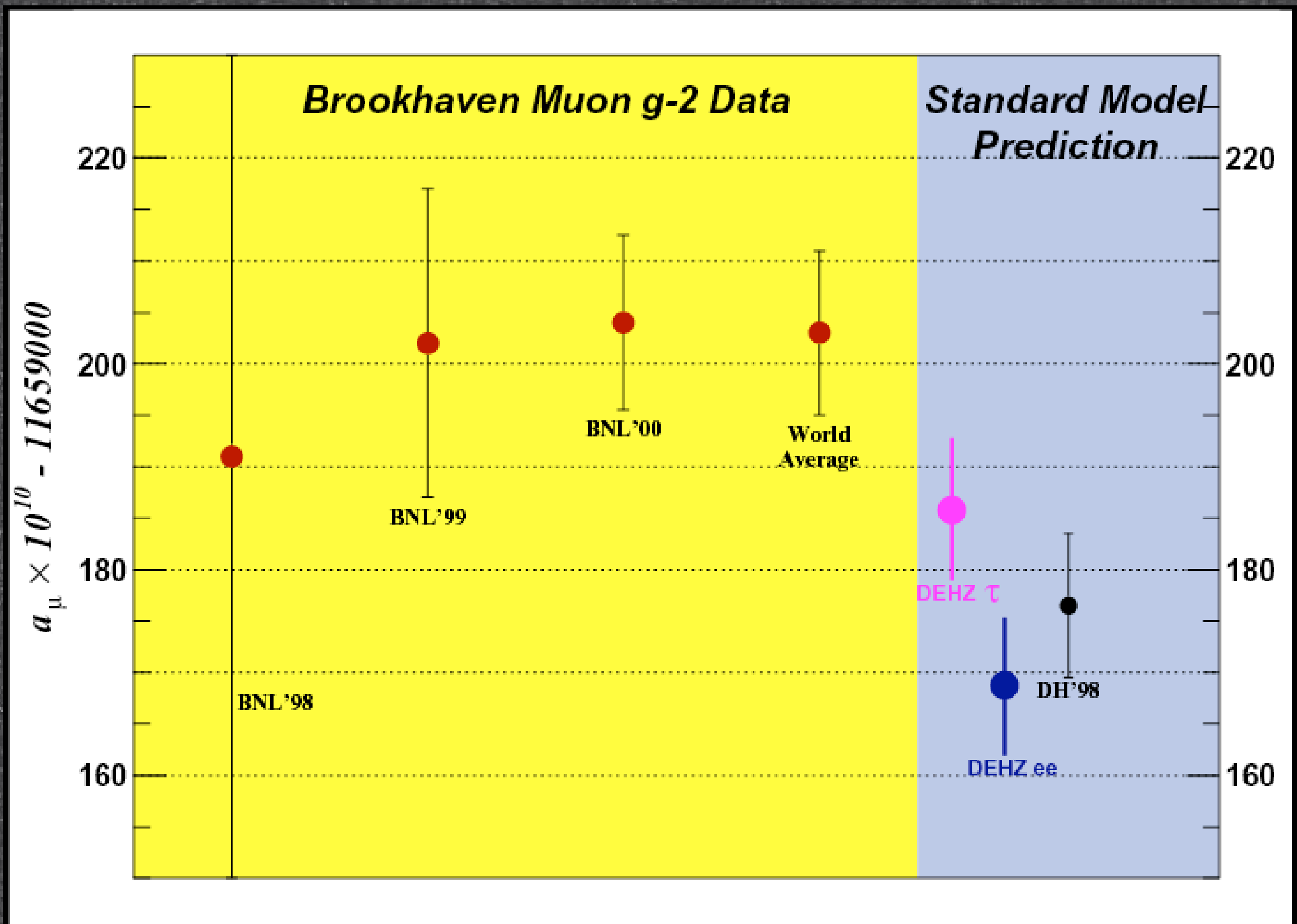
Muon Electric Dipole Moment

Electric Dipole Moments

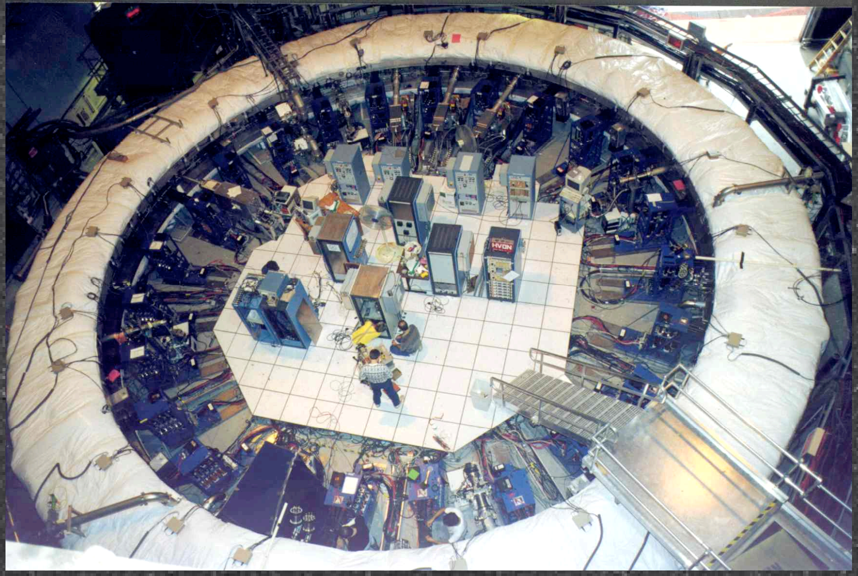
- EDM is T-odd and P-odd, and CP-violating if CPT is held.
- New CP violation mechanism is needed for baryogenesis.
- Search for EDM would give a wide window for new physics since EDM in SM is very small.

	upper limits	SM values
Neutron	$< 6.3 \times 10^{-25} e \cdot cm$	$< 10^{-31} e \cdot cm$
Proton	$(3.7 \pm 6.3) \times 10^{-31} e \cdot cm$	
^{199}Hg	$< 2.1 \times 10^{-28} e \cdot cm$	$< 10^{-28} e \cdot cm$
Electron	$< 1.6 \times 10^{-27} e \cdot cm$	$< 10^{-38} e \cdot cm$
Muon	$< 1.1 \times 10^{-18} e \cdot cm$	$< 10^{-35} e \cdot cm$

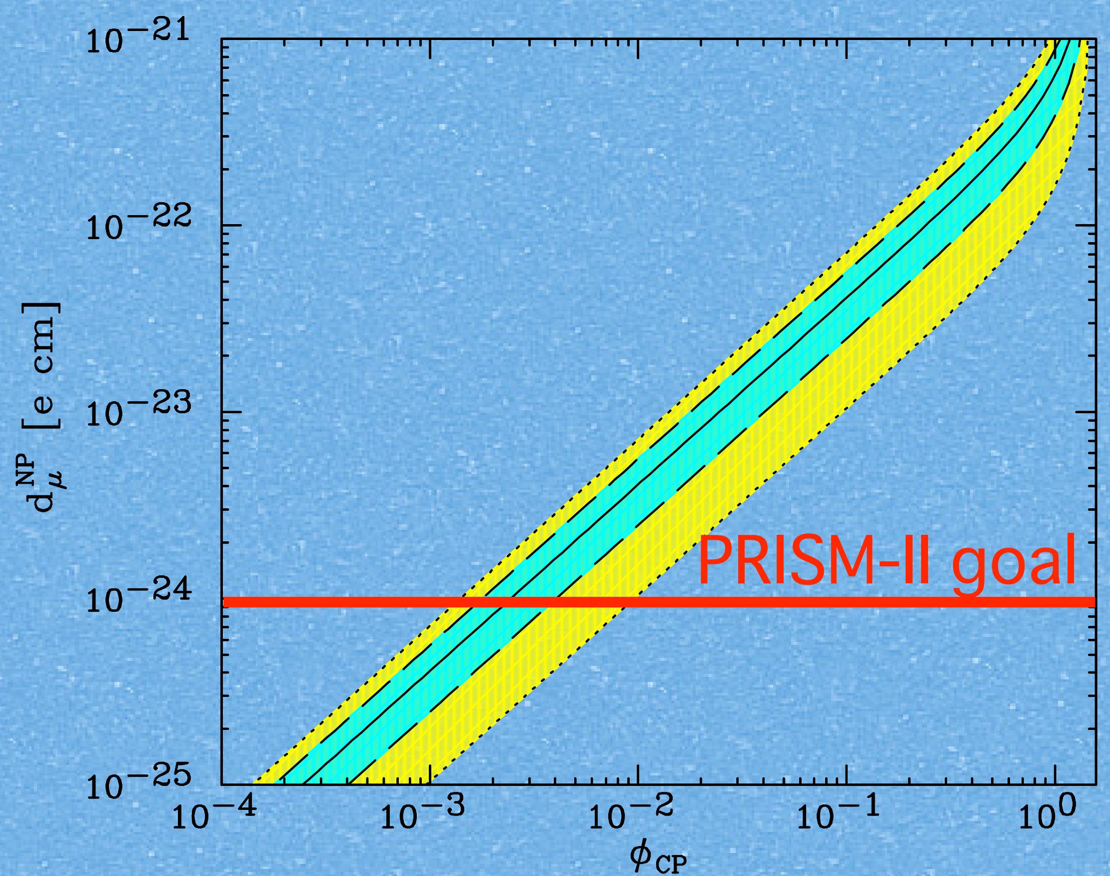
Muon (g-2) vs. muon EDM



$$a_\mu = 11659204(7)(5) \times 10^{-10} \ (0.7ppm)$$



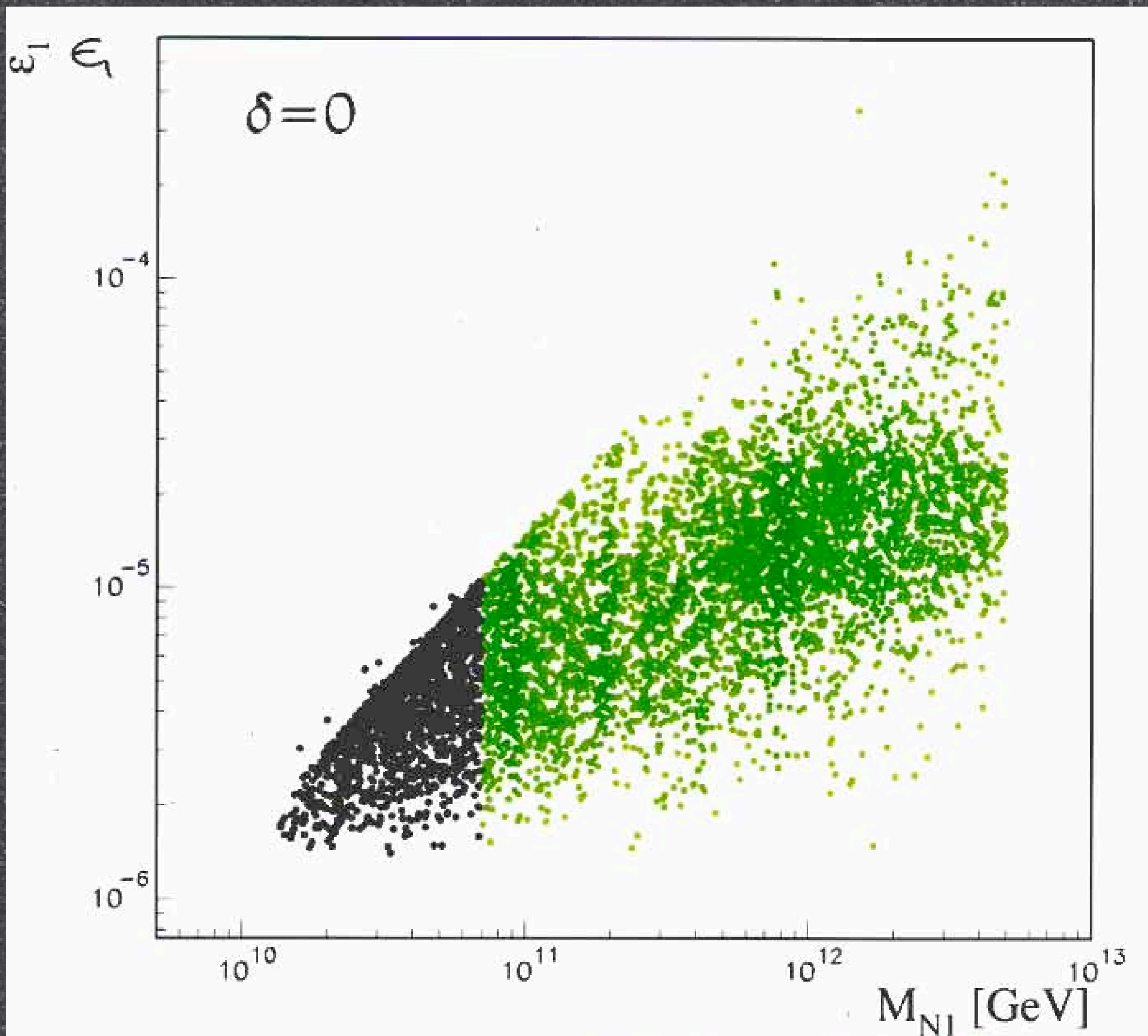
Muon (g-2) and EDM might be related.

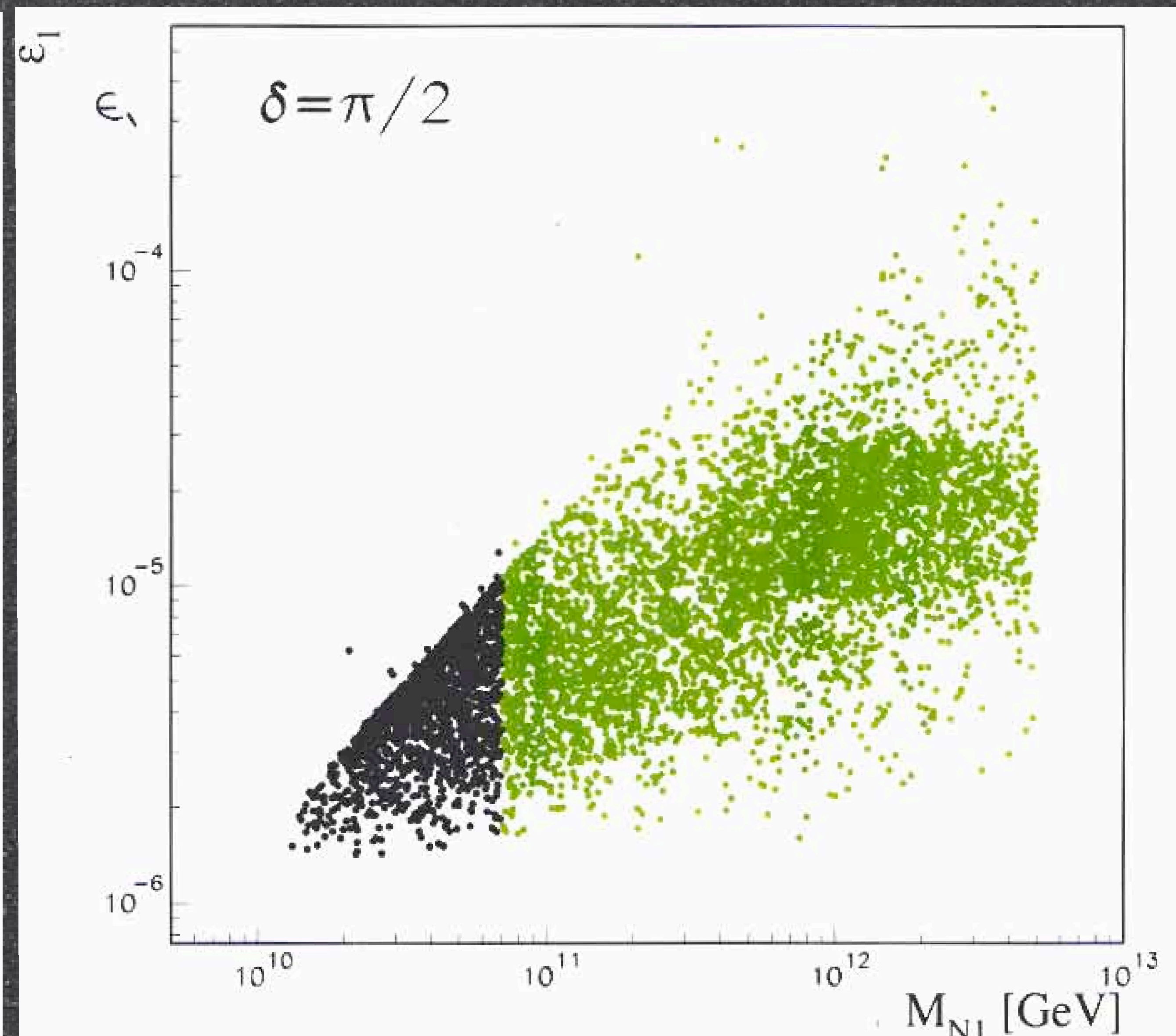


$d_\mu^{NP} \approx 3\times 10^{-22}(\frac{a_\mu^{NP}}{3\times 10^{-9}}) \tan\phi_{CP}\ e\cdot cm$, $a_{NP} = a_\mu^{exp} - a_\mu^{SM} \approx 3(1)\times 10^{-9}$

Feng, Matchev, Shadmi, NP B613, 366(2001)

Leptogenesis and MSSM





Leptogenesis is almost independent on dirac phase of neutrino mixing (a la J. Ellis et al.)

Muon Spin Precession

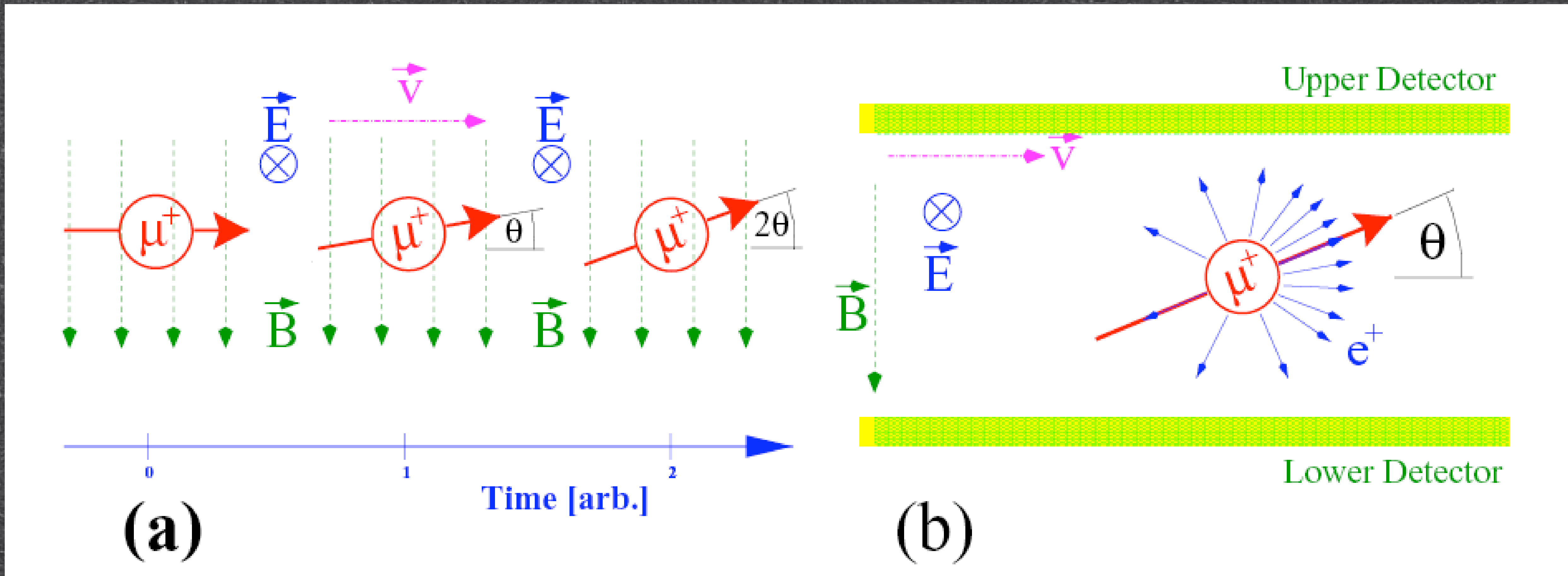
- muon spin precession relative to momentum vector ($\vec{\beta}\cdot\vec{B}=\vec{\beta}\cdot\vec{E}=0$)

$$\vec{\omega}=-\frac{e}{m}\left[a\vec{B}+\left(\frac{1}{\gamma^{2}-1}-a\right)\frac{\vec{\beta}\times\vec{E}}{c}+\frac{\eta}{2}\left(\frac{\vec{E}}{c}+\vec{\beta}\times\vec{B}\right)\right]$$

- g-2 measurement : 2nd term = 0
- EDM measurement: 1st+2nd terms =0

$$a=\frac{g-2}{2};\; EDM=\eta\cdot\frac{e\hbar}{4mc}=\eta\times 4.7\times 10^{-14}\, e\cdot cm$$

Measurement Principle



Cancellation E field

$$E = \frac{aBc(\gamma^2 - 1)}{\beta} \qquad E = 2\ \mathrm{MV/m},\ B = 0.25\ \mathrm{T}$$

E field for EDM rotation

$$E = Bc\beta \qquad B = 0.25\ \mathrm{T} \rightarrow E = 72\ \mathrm{MV/m}$$

Statistical Req. for EDM

@BNL/AGS

- stage 1: $N_\mu P_\mu^2 = 10^{12}$
  - use the existing g-2 ring but with weak magnetic focusing
  - aim at 10^{-22} e cm (400 hours)

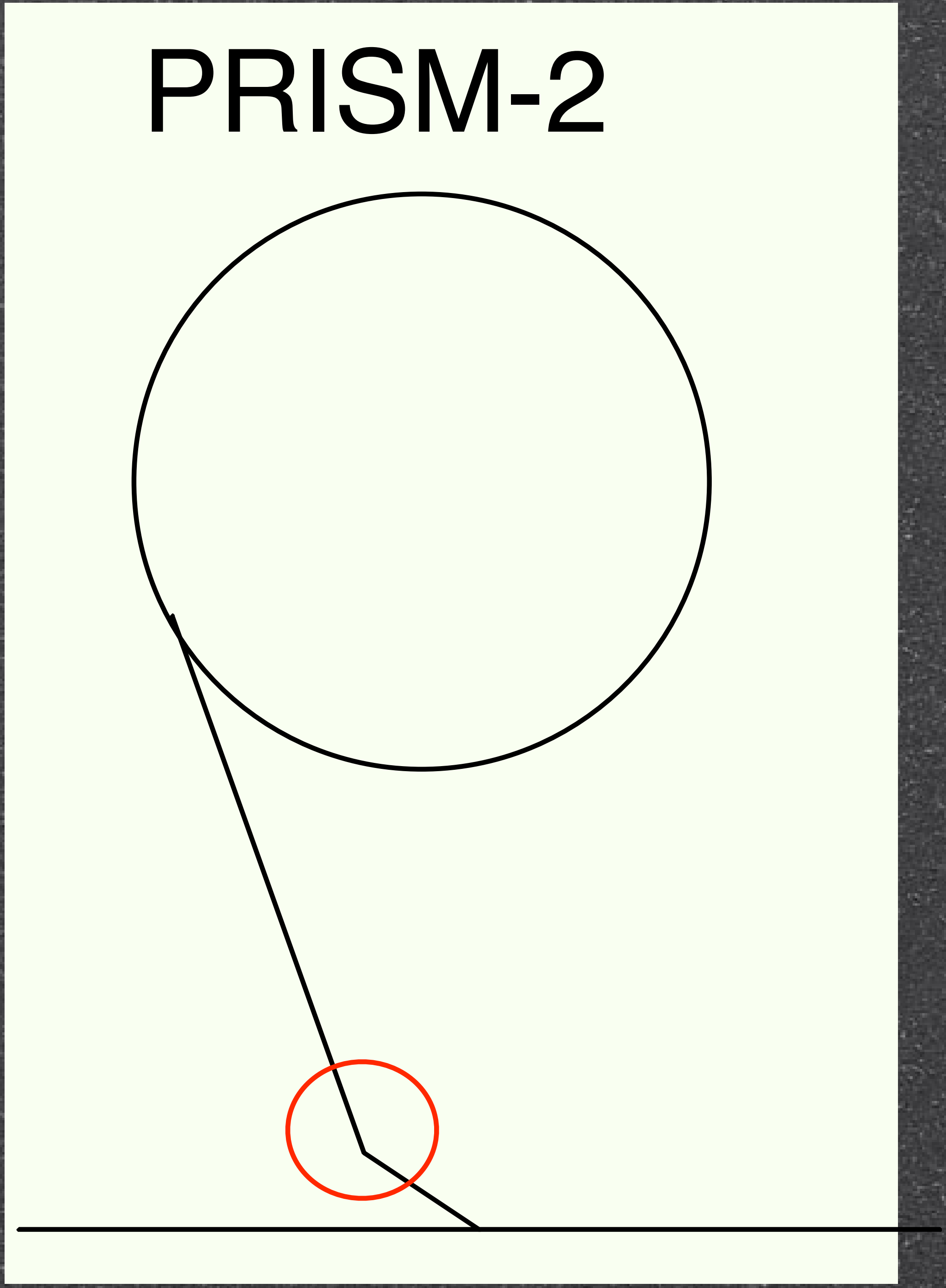
- stage 2: $N_\mu P_\mu^2 = 10^{16}$
  - strong focusing
  - aim at 10^{-24} e cm (4000 hours)

@J-PARC

- stage 3: $N_\mu P_\mu^2 = 10^{20}$
  - use cooled muon beams from the stage II of the front end of NuFact.
    - ⇛momentum : 0.2-0.5 GeV/c
    - ⇛10^{11} muons/sec
  - new storage ring
  - aim at 10^{-26} e cm (for a year)

PRISM-II

PRISM-II = FFAG-based phase rotator for the muon EDM measurement.



Increase N (intensity)

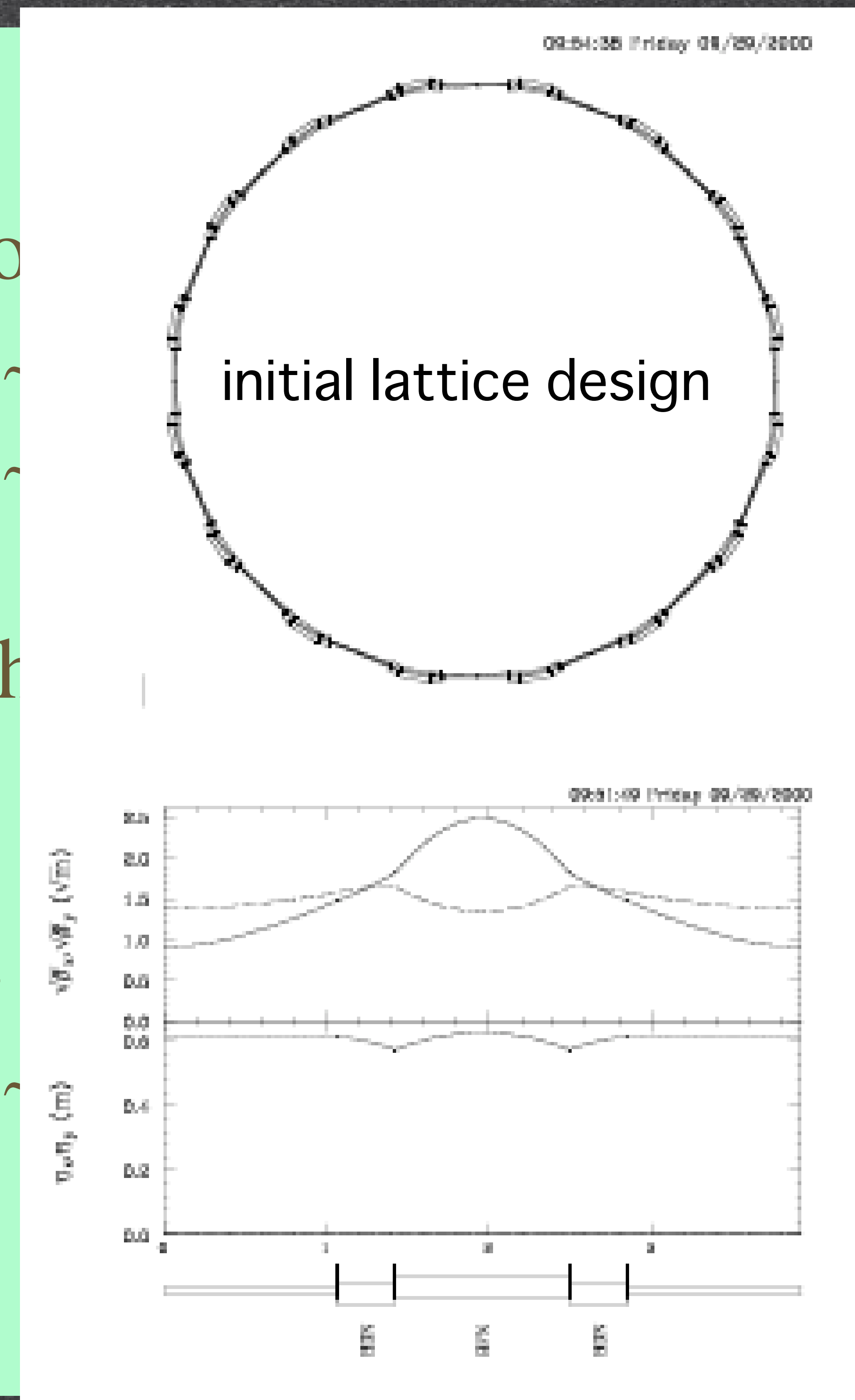
→ phase rotation to increase intensity within the given momentum band

Increase P (polarization)

→ curved solenoid to select (parent) pion momentum to keep reasonable muon polarization.

PRISM-II

- $d_\mu < 10^{-24}$ e.cm → $NP^2 > 10^{16}$ total
- Long decay section with pion mo
  - Initial muon ~
  - Polarization ~
    - Backward decay of pions
- Accept 500 MeV/c muons and ph
  - Transverse 800 π mm.mrad
  - Momentum acceptance ±30%
    - →±1~2% for muon strage ring
  - Decay survivability ~
  - $NP^2 = 10^9 \sim 10^{10}$

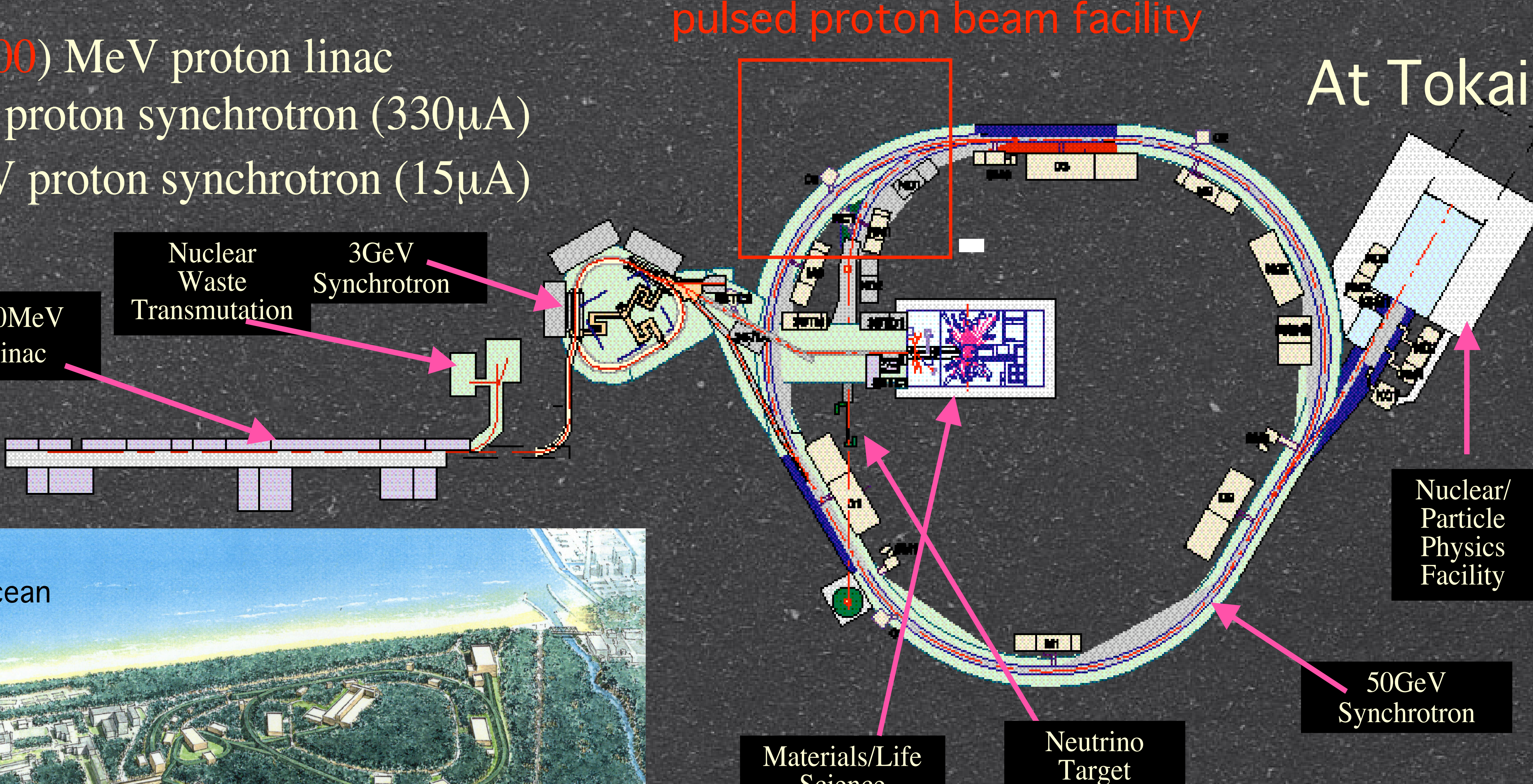


J-PARC case
(Muon Factory)

Proton Machine

J-PARC = Japan Proton Accelerator Research Complex

400 (200) MeV proton linac
3 GeV proton synchrotron (330μA)
50 GeV proton synchrotron (15μA)
(40)



Major Topics at MF

The muon system is one of the best place to search for physics beyond the standard model.

Process	In Standard Model
muon lepton flavor violation	forbidden process
muon EDM	suppressed process
muon g-2	precise measurement

LOI to J-PARC

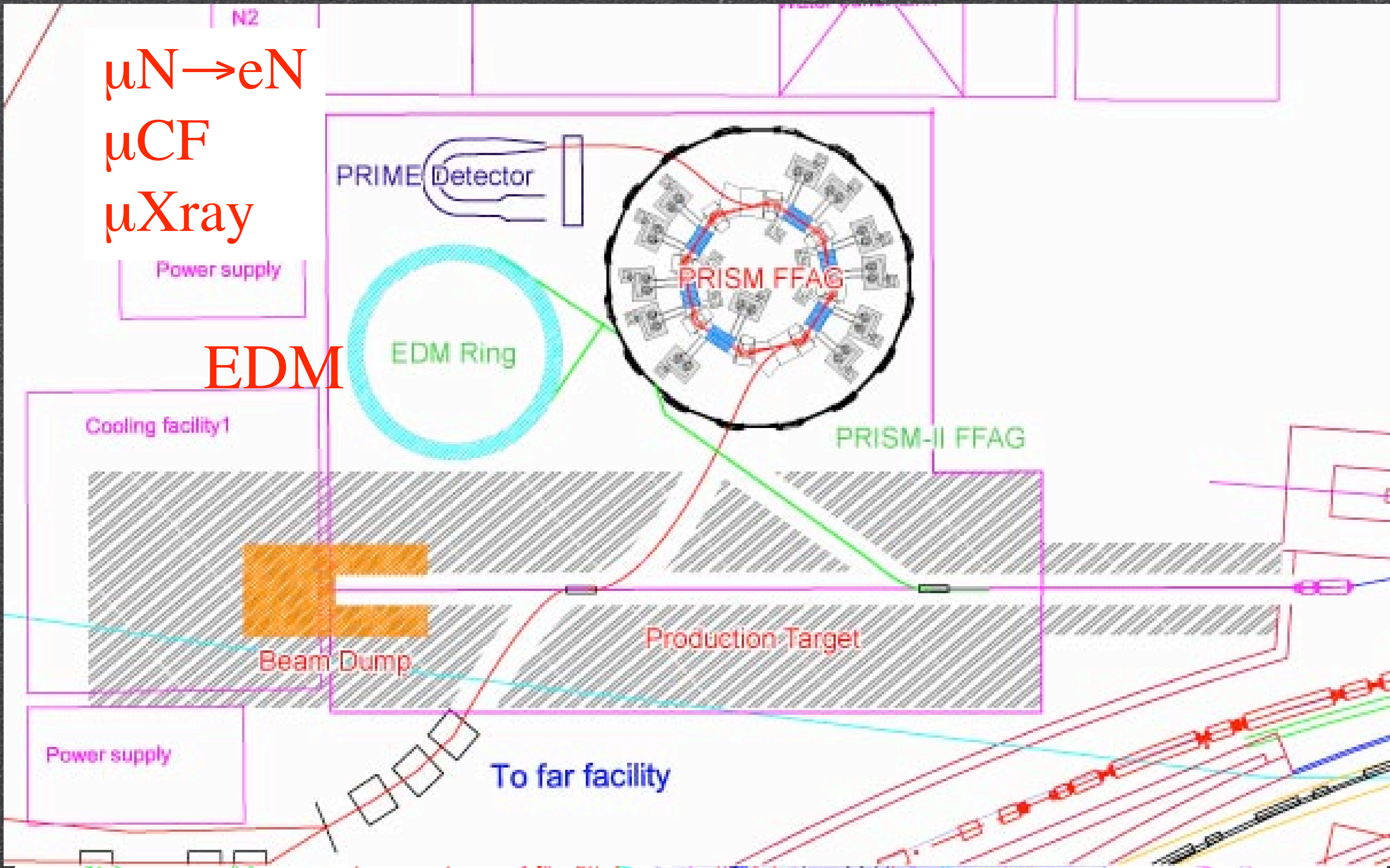
for muon particle physics

	title	contact persons
1	The PRISM Project - A Muon Source of the World-Highest Brightness by Phase Rotation -	Y. Mori, K. Yoshimura, N. Sasao, Y. Kuno
2	An Experimental Search for the μ-e Conversion Process Towards an Ultimate Sensitivity of the Order of 10^{-18}	Y. Mori, K. Yoshimura, N. Sasao, Y. Kuno
3	Request for A Pulsed Proton Beam Facility at J-PARC	R.S. Hayano, Y. Kuno
4	A Study of Neutrino Factory in Japan	Y. Mori, Y. Kuno
5	Search for a Permanent Muon Electric Dipole Moment at 10^{-24} ecm Level	Y. Semertzidis, J. Miller, Y. Kuno
6	An Improved Muon (g-2) Experiment at J-PARC	L. Roberts
7	A Study of a Target System for a 4-MW, 50-GeV Proton Beam	K. McDonald, H. Kirk, Y. Kuno, Y. Yoshimura

A pulsed proton beam is required for all.

Muon Factory@J-PARC

Pulsed Proton Beam Facility is newly requested to J-PARC.

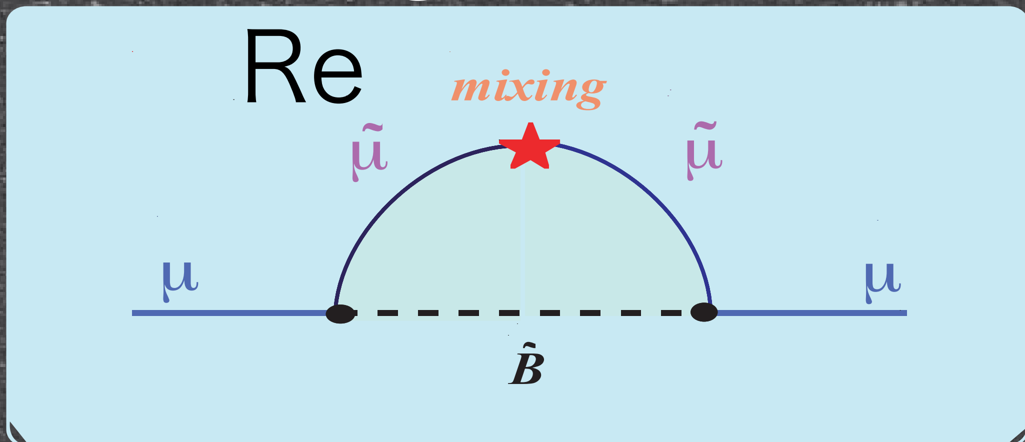


Prospect at MF

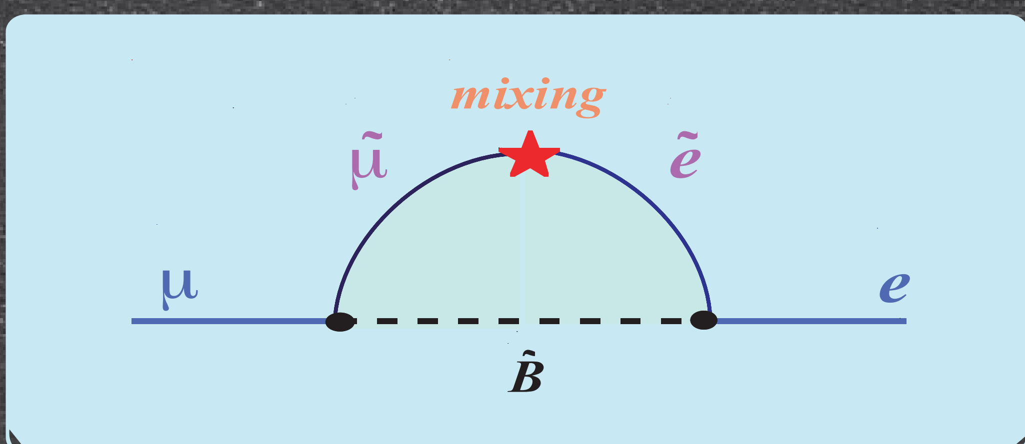
- Muon Lepton Flavor Violation
  - *$BR(\mu N \rightarrow e N) < 10^{-18}$*
- μ-EDM
  - $d_\mu < 10^{-19}$ e.cm $\rightarrow$ *$d_\mu < 10^{-24}$ e.cm*
- g-2
  - 0.7 ppm $\rightarrow$ *0.05 ppm*

The Muon Trio

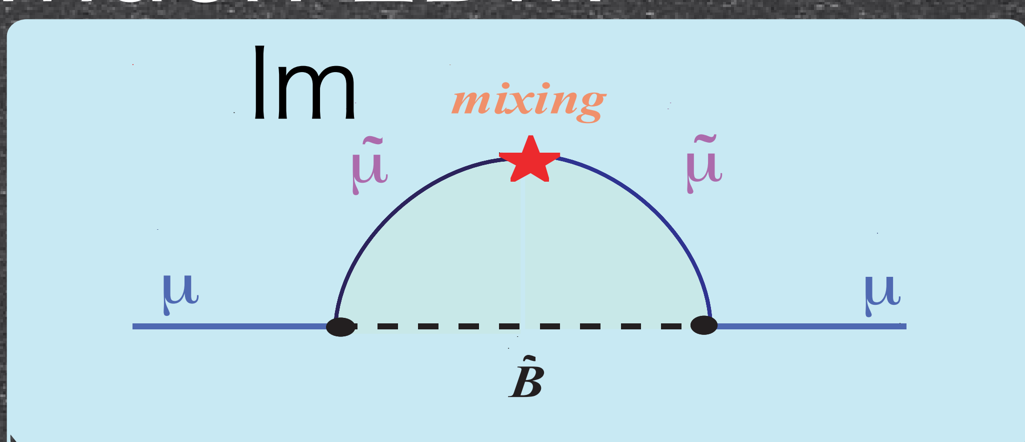
Muon g-2



Muon LFV



Muon EDM



in SUSY case

Slepton mixing matrix

$$\begin{pmatrix} m^2_{\tilde{e}\tilde{e}} & \Delta m^2_{\tilde{e}\tilde{\mu}} & \Delta m^2_{\tilde{e}\tilde{\tau}} \\ \Delta m^2_{\tilde{\mu}\tilde{e}} & m^2_{\tilde{\mu}\tilde{\mu}} & \Delta m^2_{\tilde{\mu}\tilde{\tau}} \\ \Delta m^2_{\tilde{\tau}\tilde{e}} & \Delta m^2_{\tilde{\tau}\tilde{\mu}} & m^2_{\tilde{\tau}\tilde{\tau}} \end{pmatrix}$$

Hints for SUSY breaking