Rare Muon Decay Experiments

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Osaka University

October 19th, 2009
Workshop on Applications of High Intense Proton Accelerators
Fermi National Laboratory

Outline

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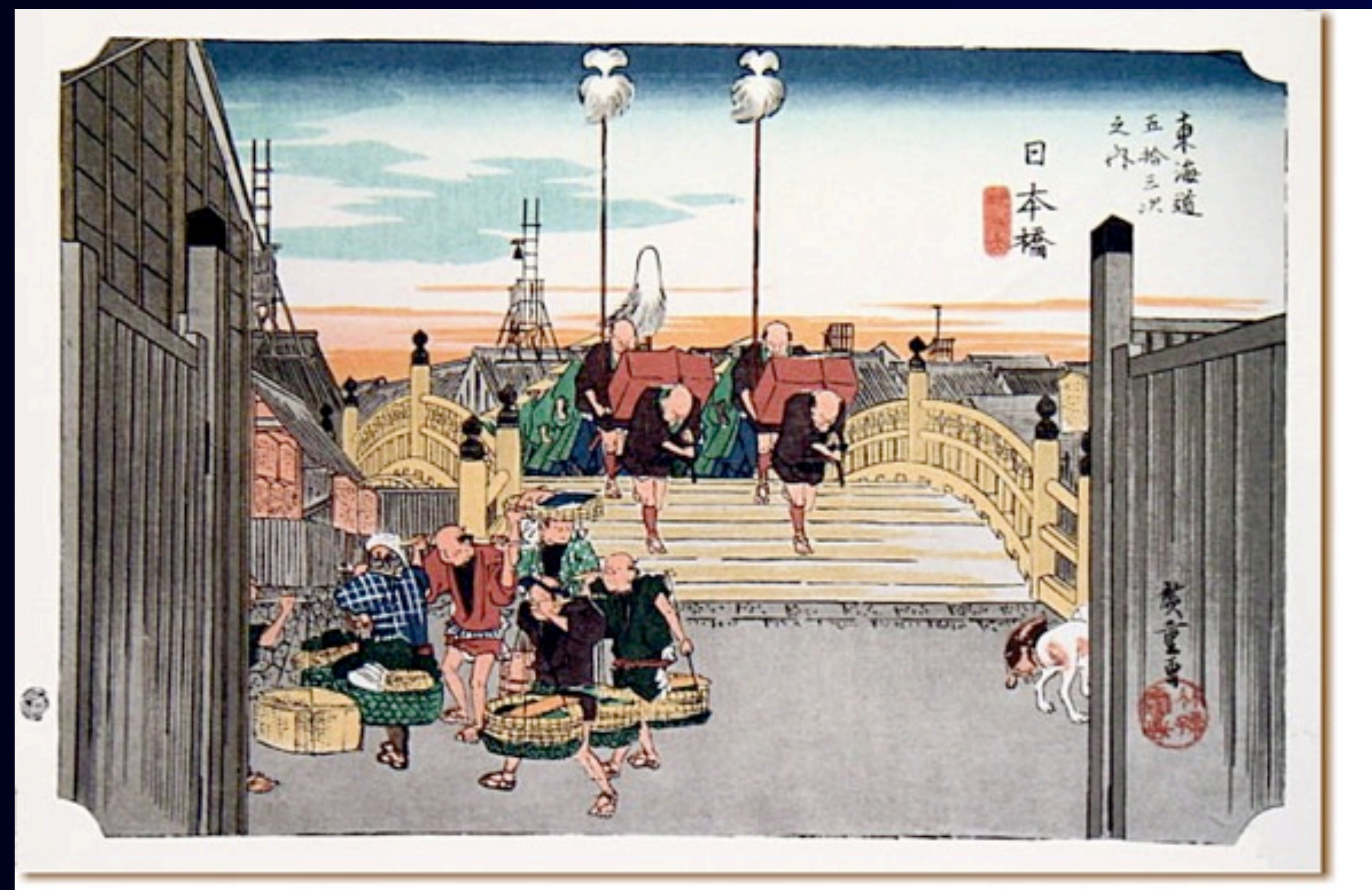
- Intensity Frontier and Charged Lepton Flavor Violation (cLFV)
- cLFV Physics Motivation
- Overview of cLFV Experiments with Muons
    - $\mu \rightarrow e\gamma$
    - μ-e conversion
- Experimental searches for μ-e conversion
- Summary

with block prints of “the fifty-three stations of the Tokaido” (from Tokyo to Osaka) by Hiroshige Utagawa (1797-1858)

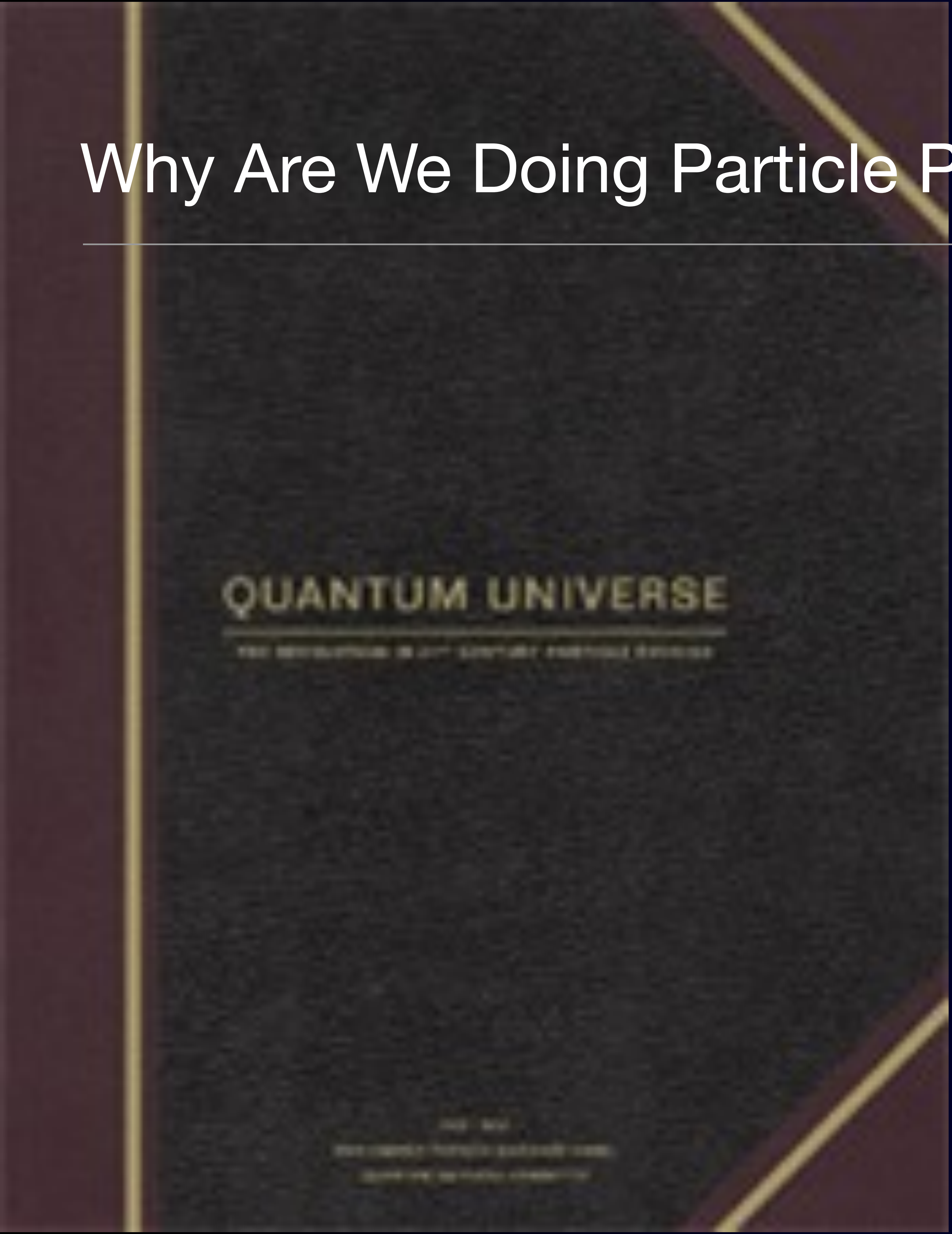
Intensity Frontier & Charged Lepton Flavor Violation

Intensity Frontier & Charged Lepton Flavor Violation



starting from Nihonbashi, Tokyo

Why Are We Doing Particle Physics ?



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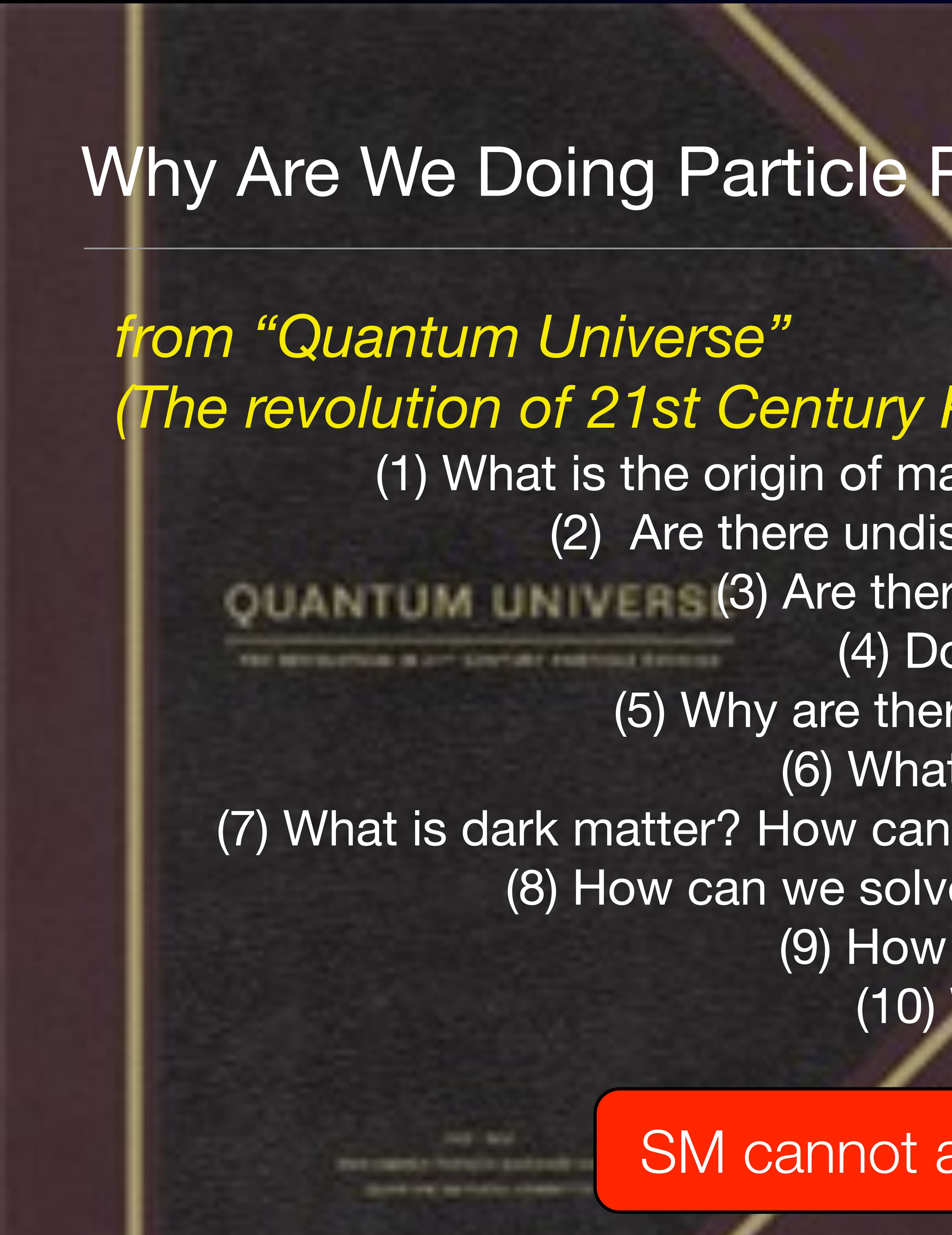

from "Quantum Universe"
(The revolution of 21st Century Particle Physics)

(1) What is the origin of mass for fundamental particles?
(2) Are there undiscovered principles of nature?
(3) Are there extra dimensions of space?
(4) Do all the forces becomes one?
(5) Why are there so many kinds of particles?
(6) What happened to the antimatter?
(7) What is dark matter? How can we make it in the laboratory?
(8) How can we solve the mystery of dark energy?
(9) How did the universe come to be?
(10) What are neutrinos telling us?

SM cannot answer those questions.

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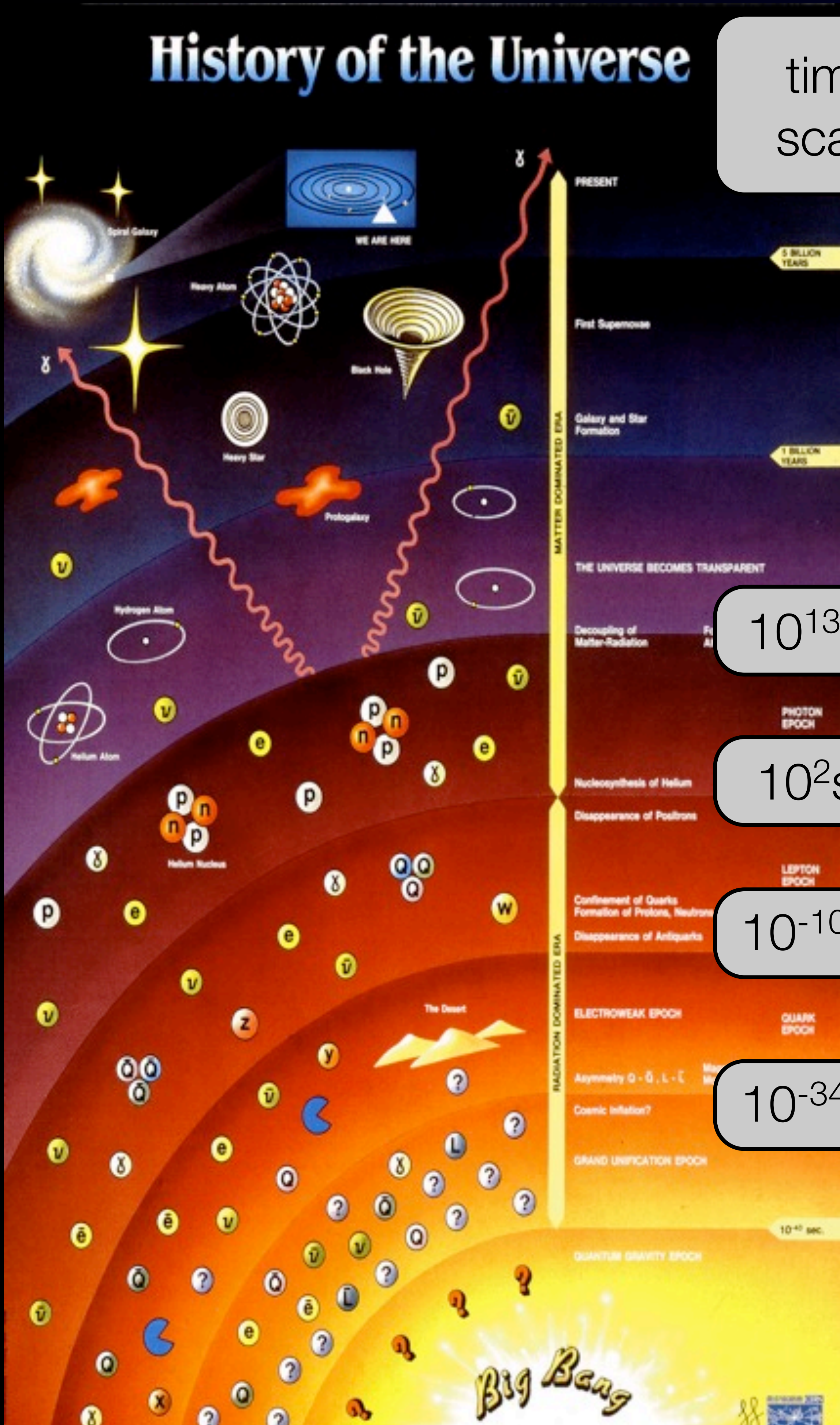


time scale	energy scale
10^{13}sec	10^{-9}GeV
10^{2}sec	10^{-3}GeV
10^{-10}sec	10^{2}GeV
10^{-34}sec	10^{16}GeV
	10^{19}GeV

Electroweak Epoch

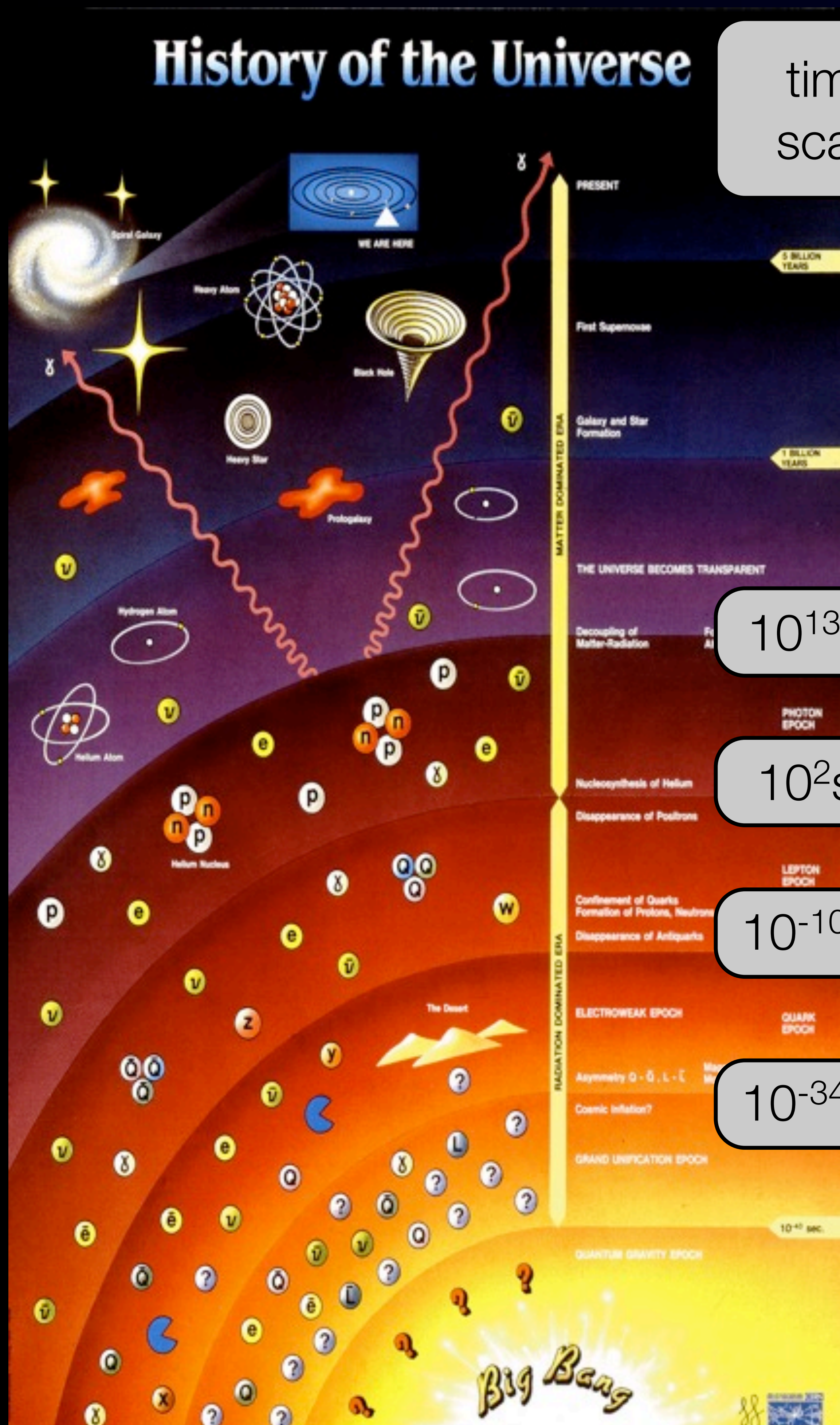
- Higgs particles
- Supersymmetry

Unification Epoch

- Grand unification of fundamental forces
- Origin of Neutrino mass (RH neutrino)
- Leptogenesis (baryogenesis)

Quantum Gravity Epoch

- Superstrings



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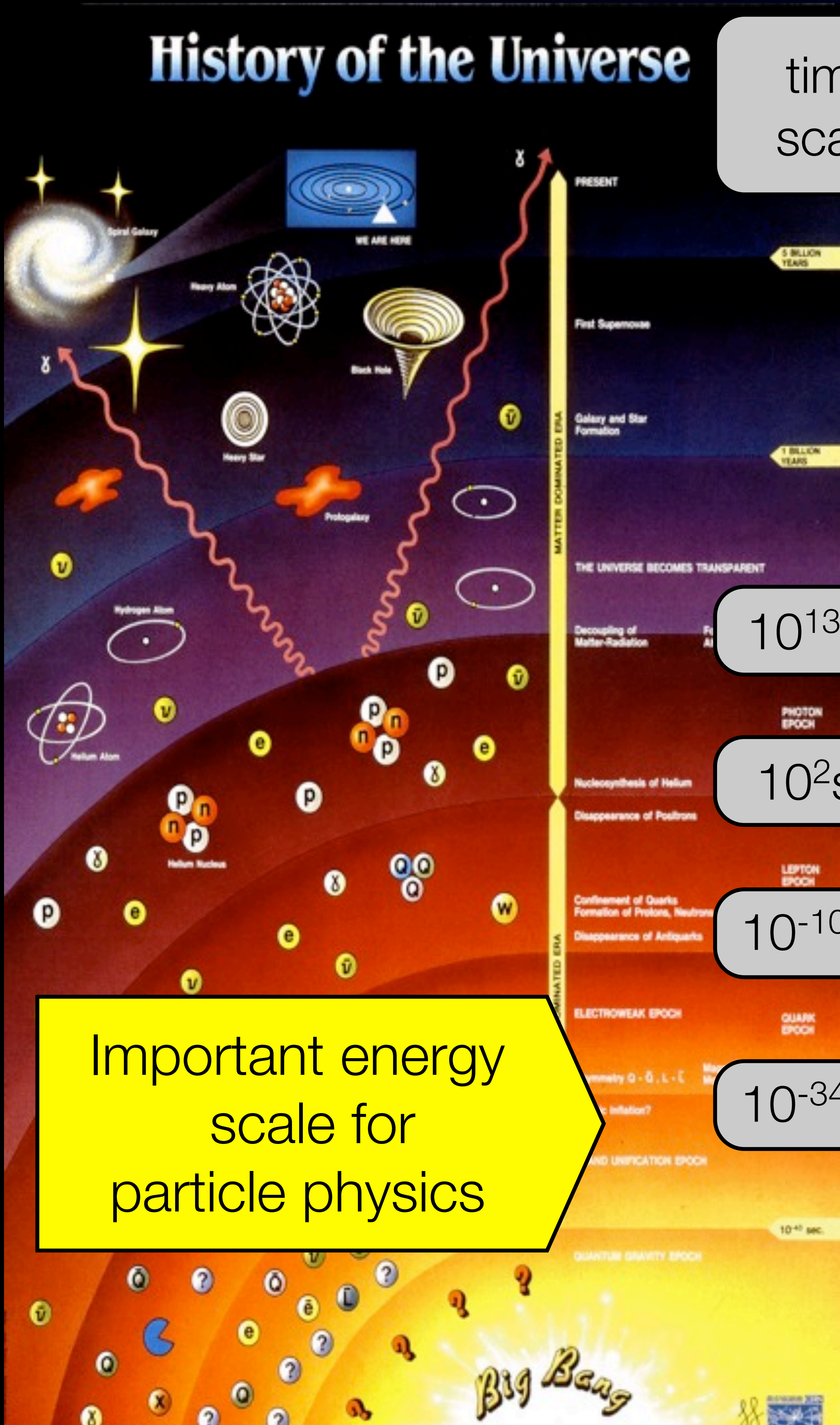

Important energy scale for particle physics

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Electroweak Epoch (10^{2}GeV)

- Higgs particles
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Quantum Gravity Epoch

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Tools :
The Three Frontiers of Particle Physics

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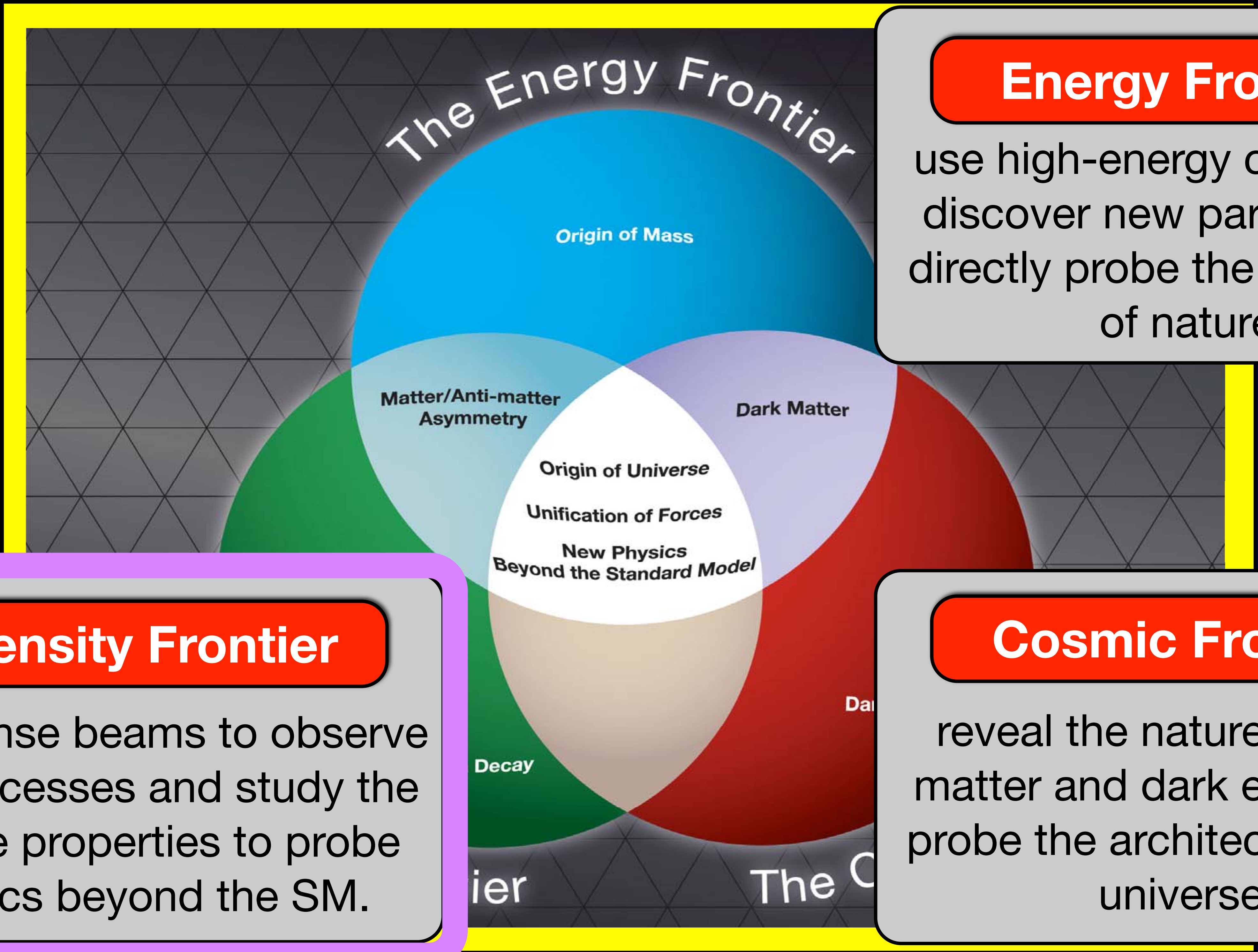


Energy Frontier

use high-energy colliders to discover new particles and directly probe the properties of nature

Intensity Frontier

use intense beams to observe rare processes and study the particle properties to probe physics beyond the SM.

Cosmic Frontier

reveal the natures of dark matter and dark energy and probe the architecture of the universe.

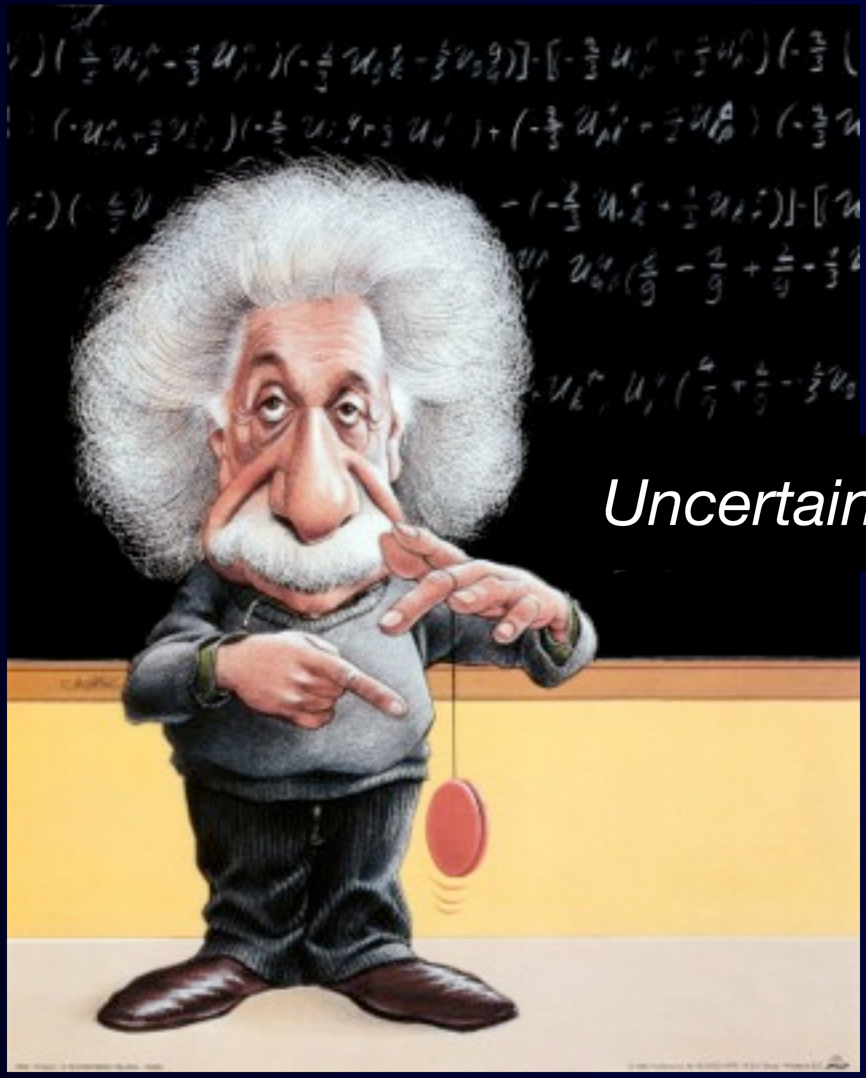
from C. Baltay's talk at the P5 meeting, 29 May 2008

The Intensity Frontier is.....

The Intensity Frontier is.....

- an indirect search
- the energy scale reached by the intensity frontier would be much higher than that of accelerators of O(1 TeV)
- through quantum radiative corrections (renormalization equation group).

Quantum Corrections



Uncertainty principle

- Effects are small.
  - Rare process searches
  - High precision measurements

Why Muons ?

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Guidelines for Rare Process Searches

(1) Many particles are needed. More is better.

The muon is the lightest unstable particle and therefore given energy more muons can be produced.

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Guidelines for Rare Process Searches

(1) Many particles are needed. More is better.

The muon is the lightest unstable particle and
therefore given energy more muons can be produced.

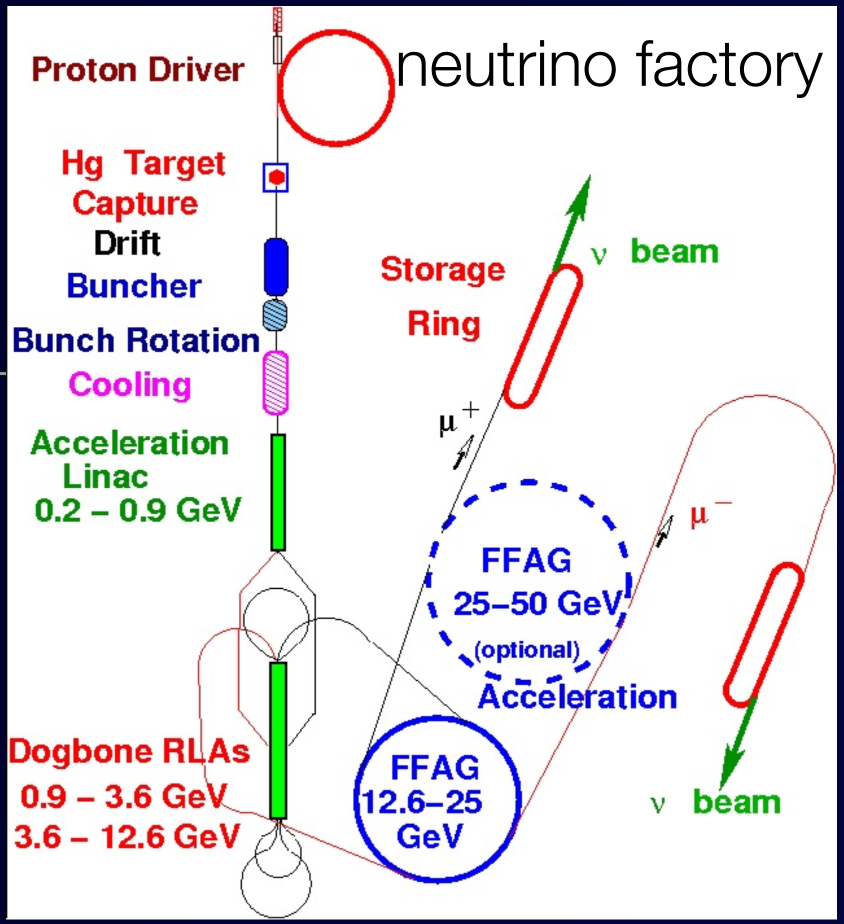
(2) Backgrounds in theoretical & experimental should be less.

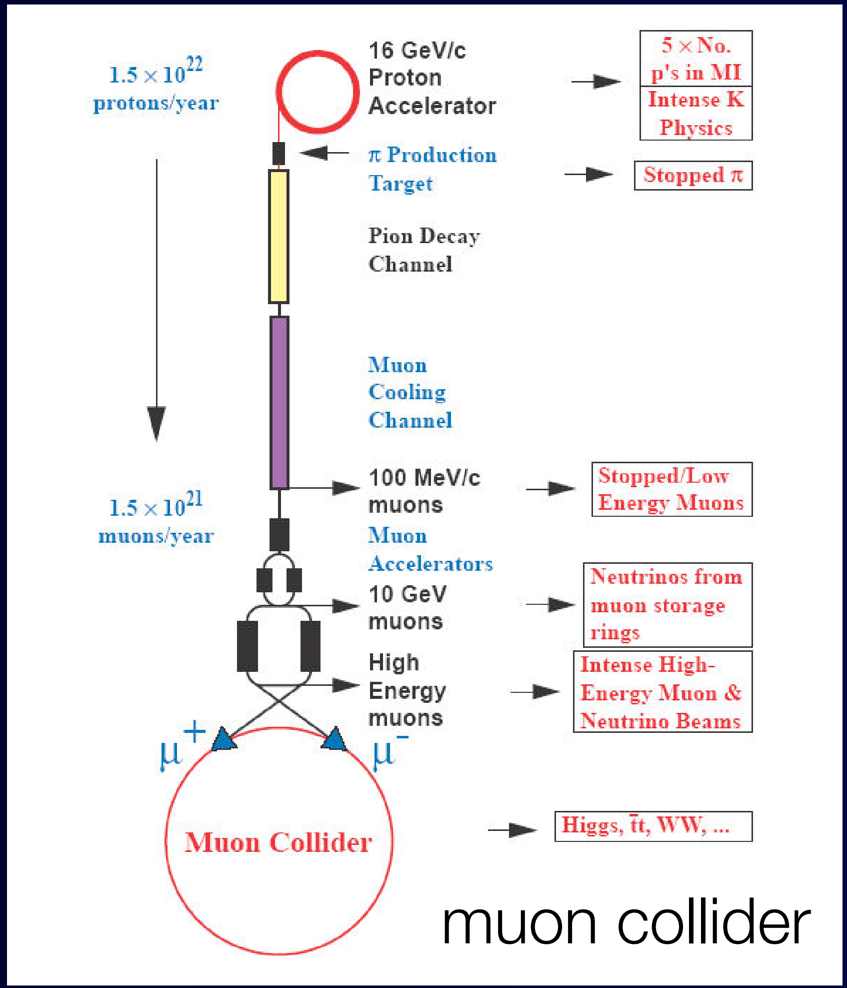
The muon does not have strong interaction, and
therefore the processes with muons are theoretically clean.

How to make more muons ?

How to make more muons ?

- Muons at PSI (PSI cyclotron of >1 MW) is about 10^8 /sec.
- Beam intensity can increase to 10^{11}-10^{14} / sec, with the technology developed for the front end R&D of muon colliders and/or neutrino factories, where intensity improvement factor of up to about O(1,000,000).
- Technical ideas, which can be used for low-energy muon physics, are
  - pion solenoid capture
  - phase rotation
  - cooling





new technology + high power protons

Physics Motivation of cLFV

Physics Motivation of cLFV

at Tenryu river, Shizuoka

What is Lepton Flavor Violation of Charged Leptons (cLFV) ?

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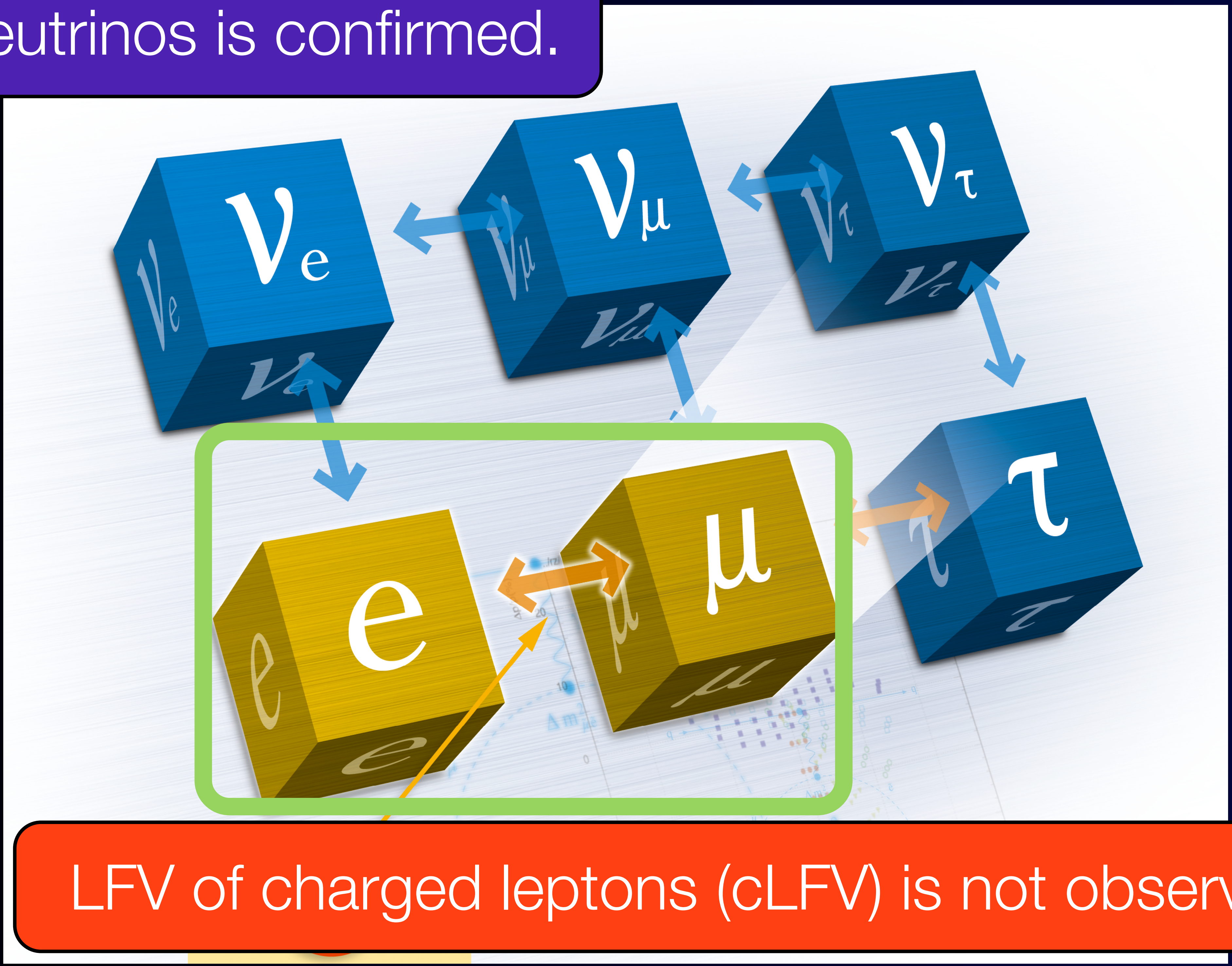
LFV of neutrinos is confirmed.

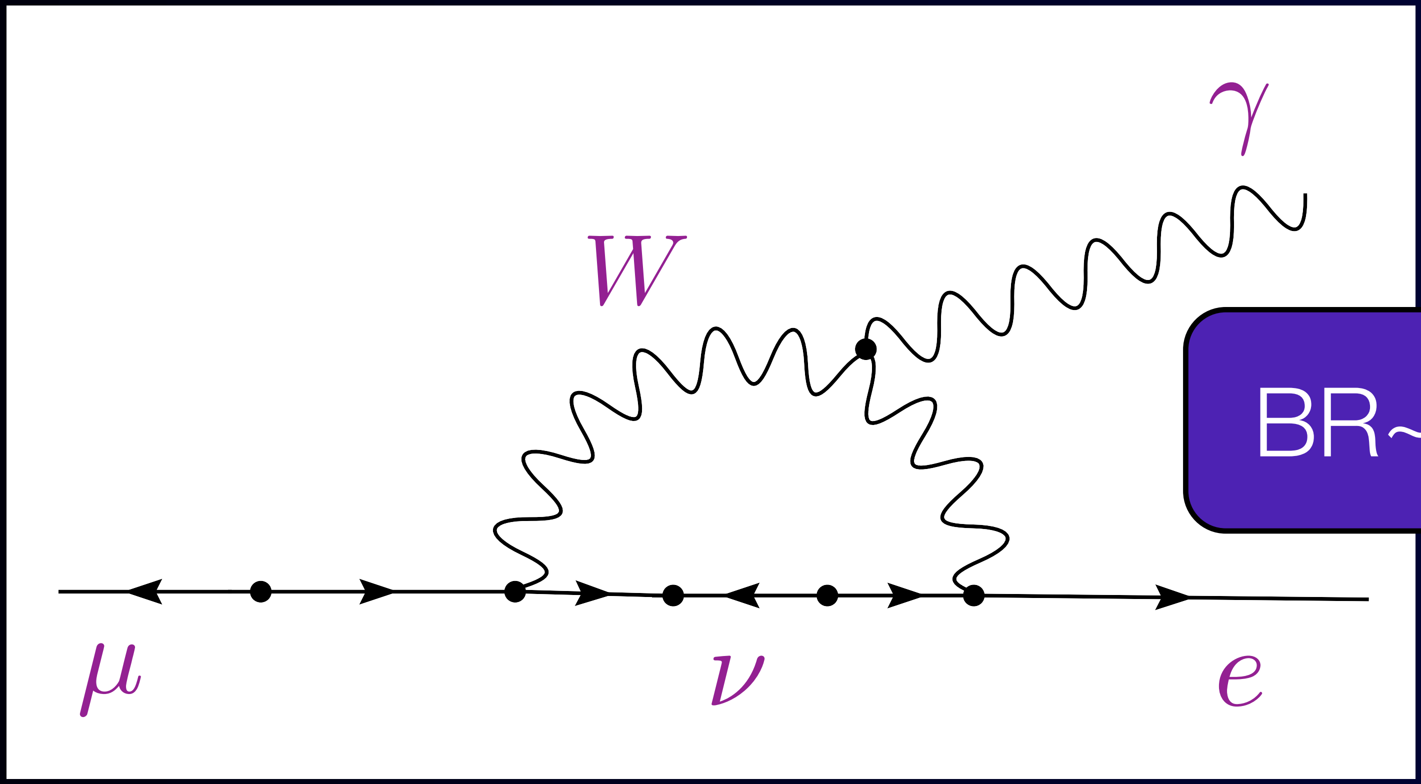


LFV of charged leptons (cLFV) is not observed.

cLFV in the SM with massive neutrinos

cLFV in the SM with massive neutrinos

$$B(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_l (V_{MNS})^*_{\mu_l}(V_{MNS})_{el}\frac{m^2_{\nu_l}}{M^2_W}\right|^2$$



BR~O(10^{-54})

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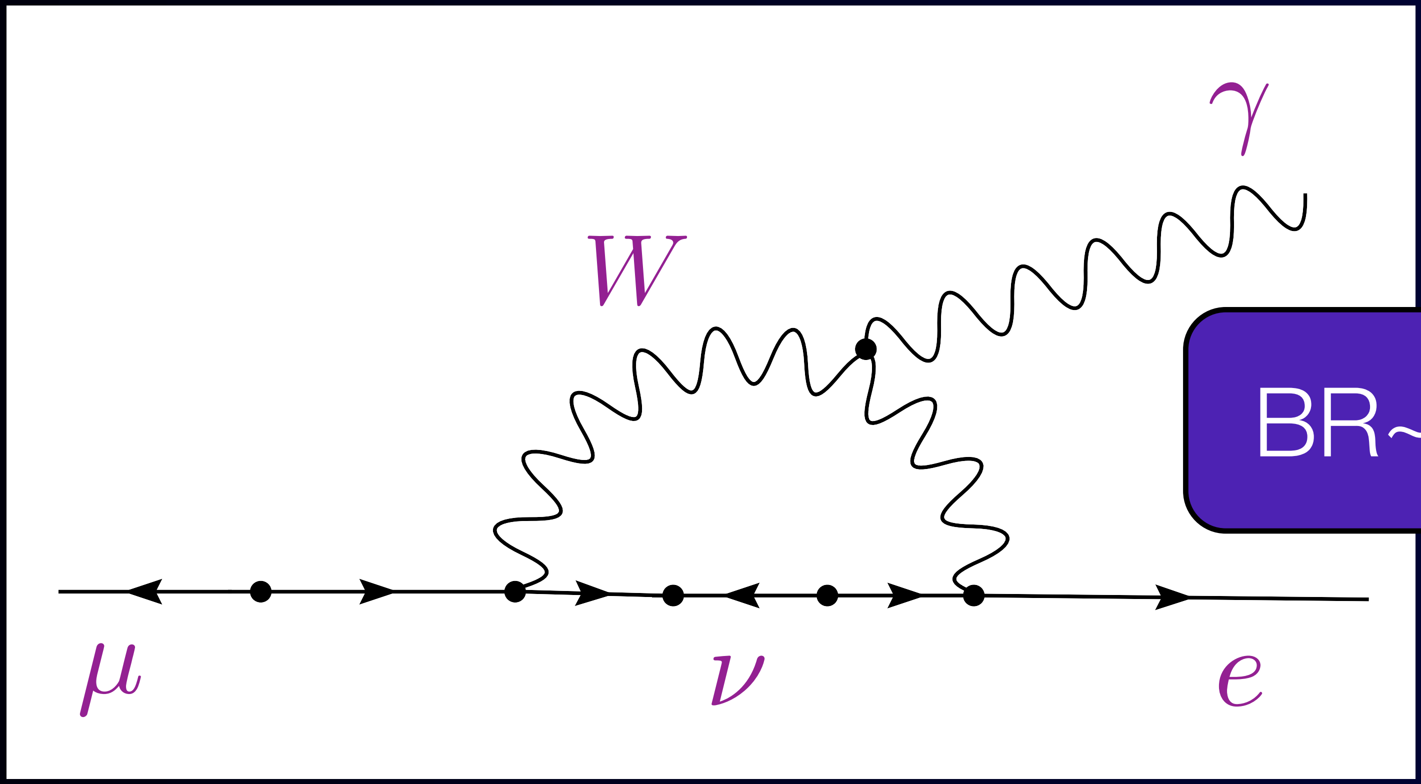

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Observation of cLFV would indicate a clear signal of physics beyond the SM with massive neutrinos.

Relation of cLFV and muon anomalous g-2

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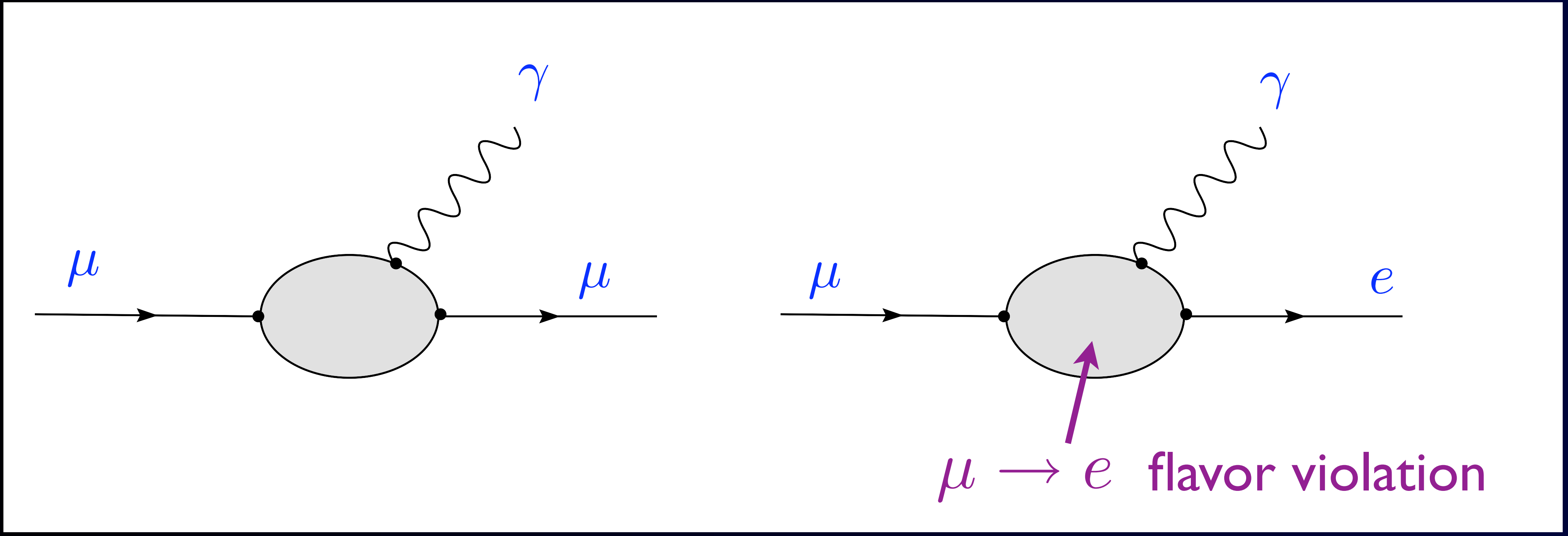
$$\delta a_\mu = a_\mu^{\rm exp} - a_\mu^{\rm SM} = (27.6 \pm 8.1) \times 10^{-10} \quad 3.4\sigma$$

$$\delta a_\mu^{\rm EW} = (15.4 \pm 0.2) \times 10^{-10}$$



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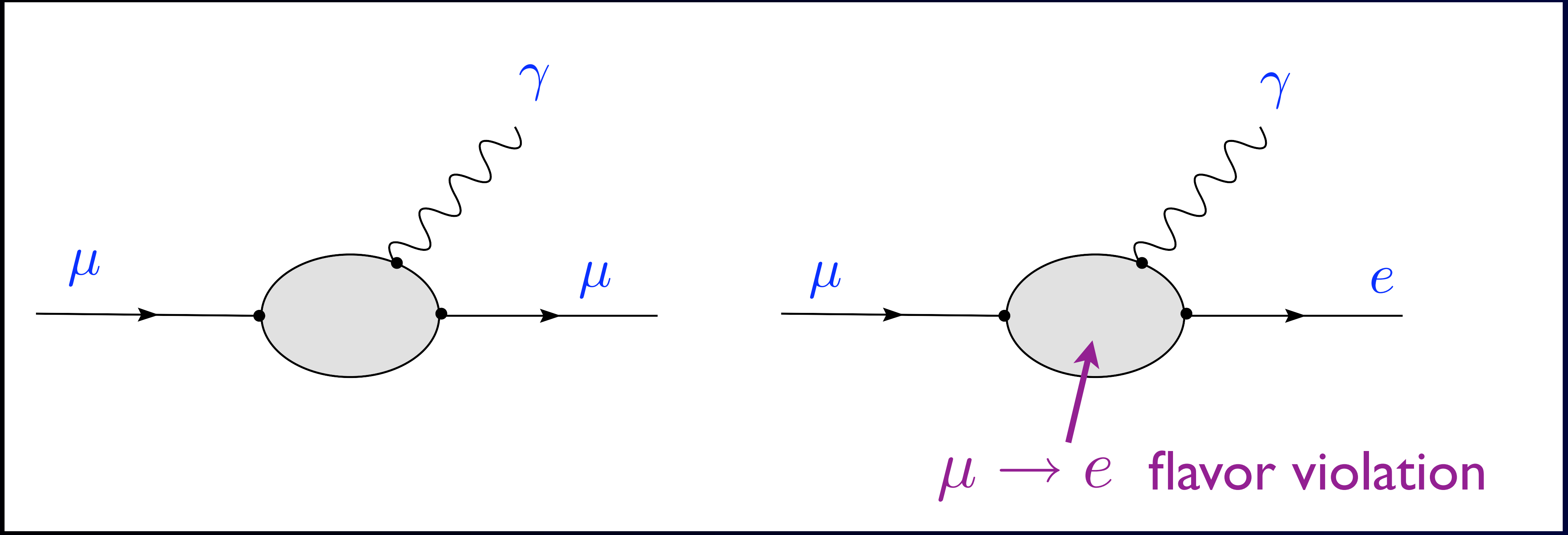

2

New physics contributing to muon g-2 would also contributes to cLFV.

General Consideration on cLFV
- Effective Lagrangian

General Consideration on cLFV - Effective Lagrangian

$$\mathcal{L}_{\mathrm{LFV}} = y\frac{em_\mu}{\Lambda^2}\bar{\mu}_R\sigma^{\mu\nu}e_L F_{\mu\nu} + \mathrm{h.c.} + \cdots$$

$$\mathrm{BR}(\mu\to e\gamma) = y^2\frac{3(4\pi)^3\alpha}{G_F^2\Lambda^4}$$

Λ :new physics scale

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- For tree diagrams,

$$\text{BR}(\mu \to e\gamma) = 1 \times 10^{-11} \times \left(\frac{400\text{TeV}}{\Lambda}\right)^4 \left(\frac{y}{1}\right)^2$$

> sensitive to high energy scale

General Consideration on cLFV - Effective Lagrangian

$$\mathcal{L}_{\mathrm{LFV}} = y \frac{e m_\mu}{\Lambda^2} \bar{\mu}_R \sigma^{\mu\nu} e_L F_{\mu\nu} + \mathrm{h.c.} + \cdots$$

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- For loop diagrams,

$$\mathrm{BR}(\mu \to e\gamma) = 1 \times 10^{-11} \times \left(\frac{2\mathrm{TeV}}{\Lambda}\right)^4 \left(\frac{\theta_{\mu e}}{10^{-2}}\right)^2 \qquad y = \frac{g^2}{16\pi^2}\theta_{\mu e}$$

> sensitive to TeV energy scale with reasonable mixing

Relation to High Energy Frontier

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cLFV = TeV energy scale physics + Flavor mixing

TeV energy scale physics ↑ to be studied by LHC

Flavor mixing ↑ suggested by neutrino

Relation to High Energy Frontier

cLFV = TeV energy scale physics + Flavor mixing

TeV energy scale physics ← to be studied by LHC

Flavor mixing ← suggested by neutrino

3 The physics of cLFV is very complementary to that of LHC.

Various Models Predict Charged Lepton Mixing.

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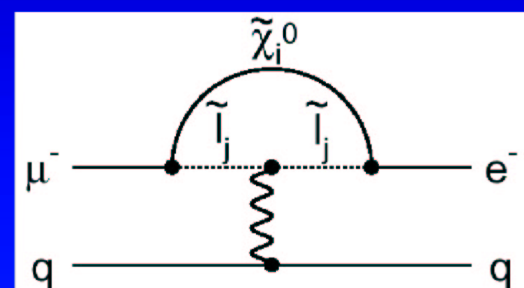
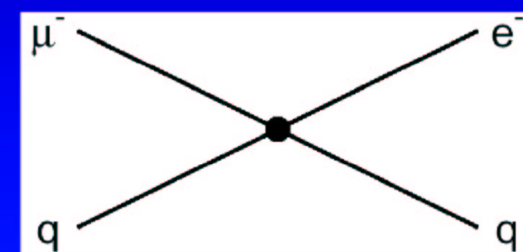
Sensitivity to Different Muon Conversion Mechanisms

MECO

Supersymmetry

Predictions at 10^{-15}





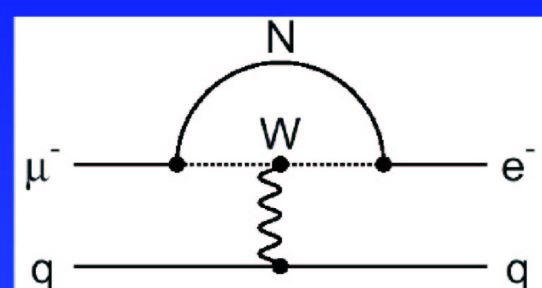
Compositeness

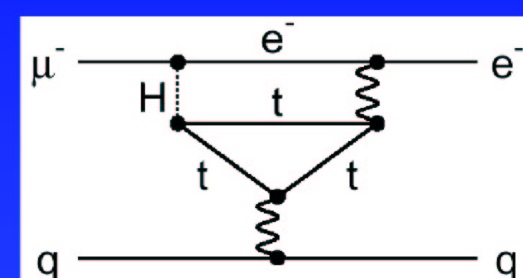
Λ_c = 3000 TeV

Heavy Neutrinos

$|U^*_{\mu N} U_{eN}|^2 =$

8×10^{-13}





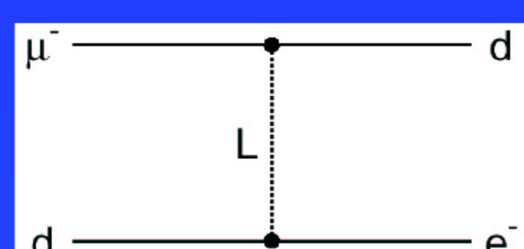
Second Higgs doublet

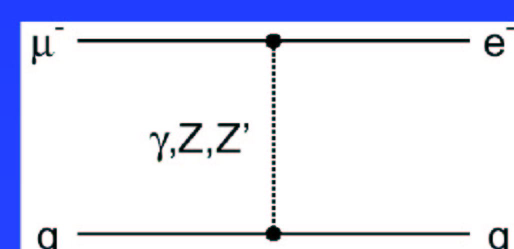
$g_{H\mu e} = 10^{-4} \times g_{H\mu\mu}$

Leptoquarks

$M_L =$

$3000 \, (\lambda_{\mu d}\lambda_{ed})^{1/2}$ TeV/c^2





Heavy Z', Anomalous Z coupling

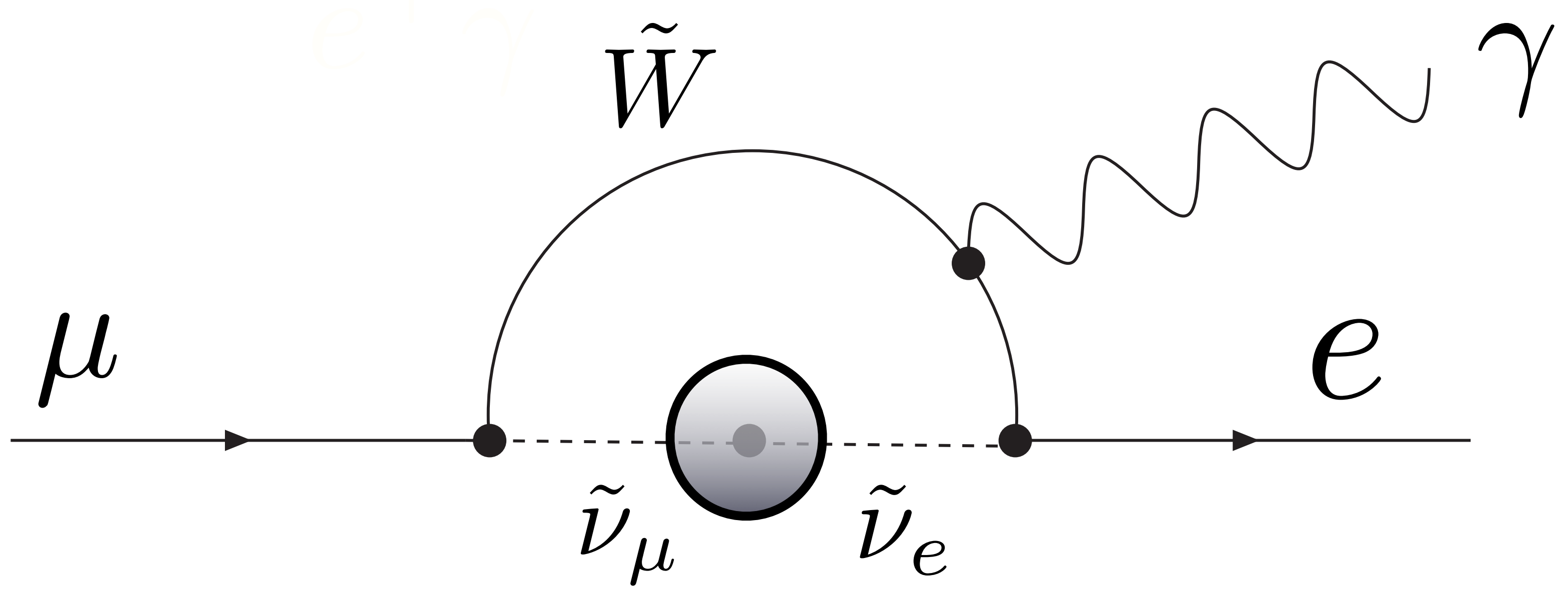
$M_{Z'}$ = 3000 TeV/c^2

$B(Z \to \mu e) < 10^{-17}$

After W. Marciano

LFV in SUSY Models

an example diagram



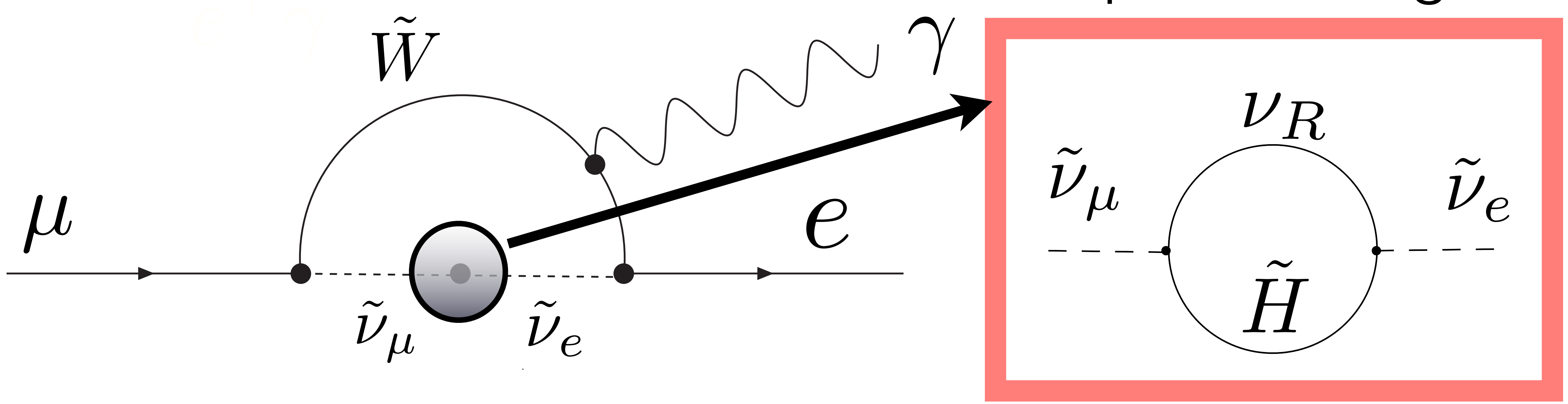
Since neutrinos are mixed & LFC is violated, sleptons can mix.

$$\mathrm{BR}(\mu \to e\gamma) \simeq 1 \times 10^{-11} \left(\frac{150\ \mathrm{GeV}}{m_{\mathrm{SUSY}}}\right)^4 \left(\frac{\tan\beta}{20}\right)^2 \left(\frac{\Delta_{21}}{3 \times 10^{-4}}\right)^2$$

LFV in SUSY Models

an example diagram

Slepton Mixing



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Minimal SUSY Scenario

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slepton mass matrix

$$m_{\tilde{l}}^2 = \begin{pmatrix} m_{11}^2 & m_{12}^2 & m_{13}^2 \\ m_{21}^2 & m_{22}^2 & m_{23}^2 \\ m_{31}^2 & m_{32}^2 & m_{33}^2 \end{pmatrix}$$

$\Delta m_{ij}^2 = 0$ @ Planck energy scale

New physics at high energy scale would introduce off-diagonal mass matrix elements, resulting in slepton mixing.

neutrino seesaw mechanism (~10^{15}GeV)

grand unification (GUT) (~10^{16}GeV)

$\Delta m_{ij}^2 \neq 0$ @ Weak energy scale (100 GeV)

4 cLFV have potential to study physics at very high energy scale.

SUSY Prediction for muon to electron conversion

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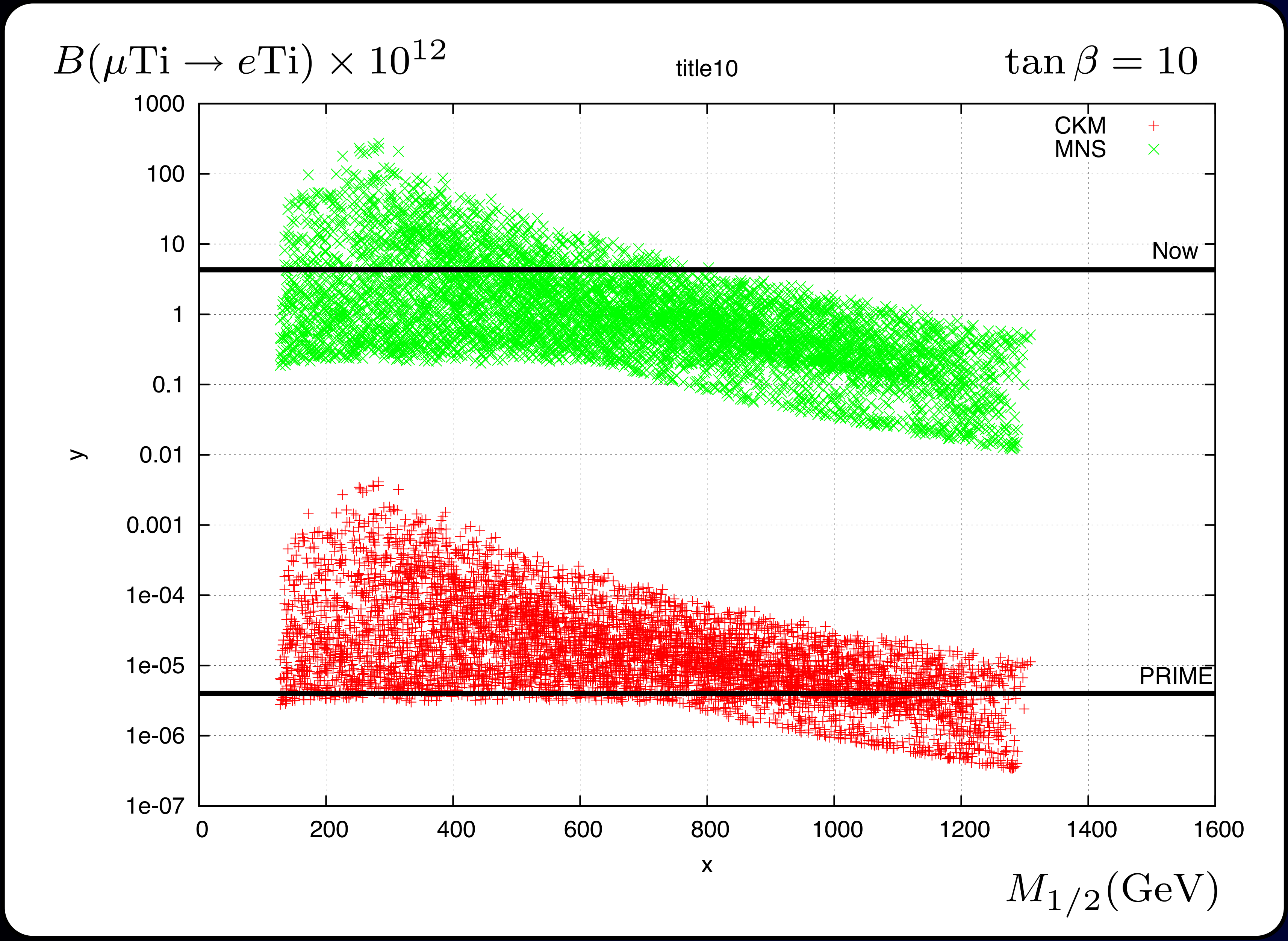

Calibbi, Faccia, Masiero, Vempati, hep-ph/0605139

BR~10^{-18}

5

Theoretical predictions are just below the present experimental bound.

Physics Motivation Summary

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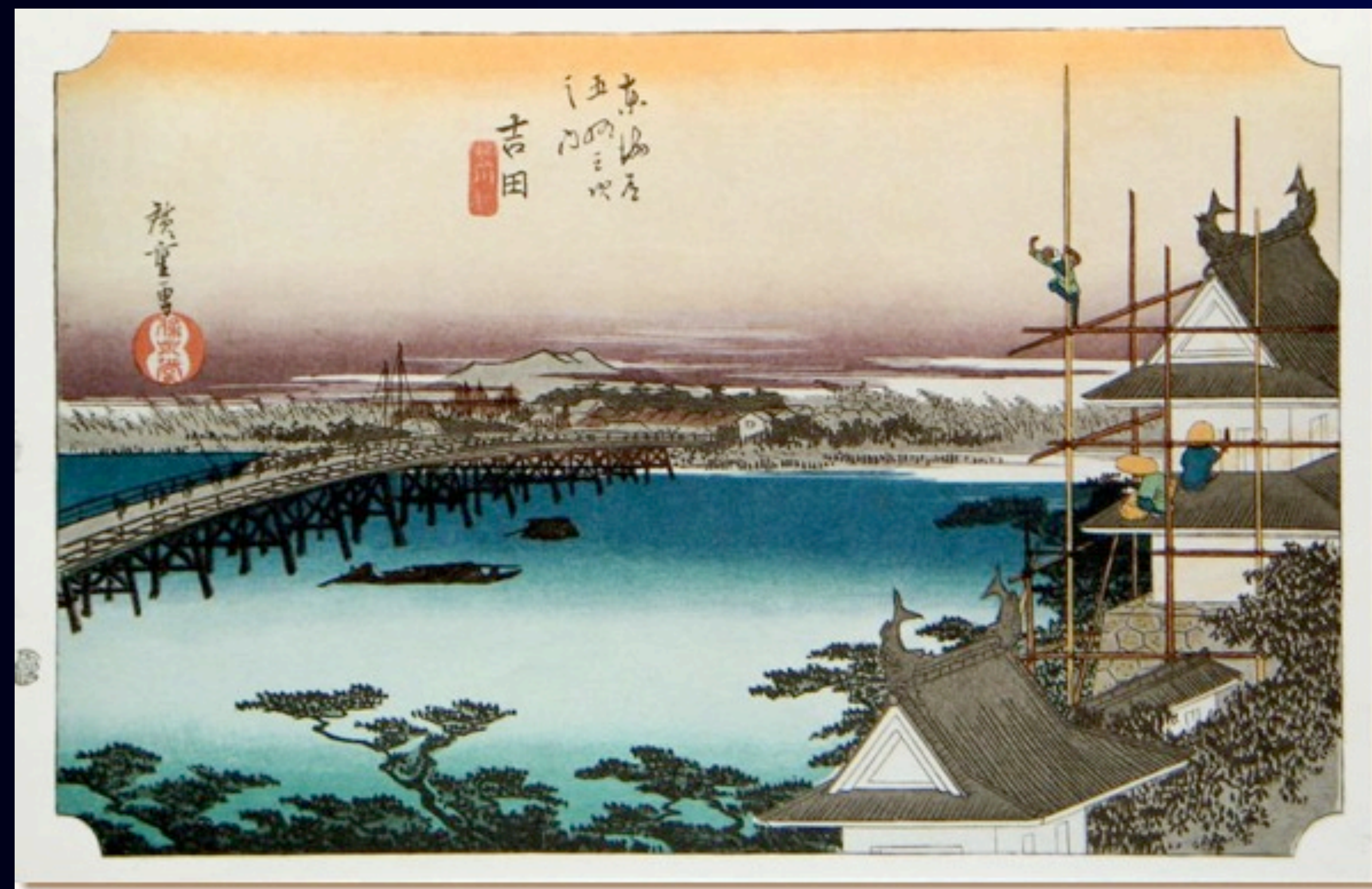
1. Observation of cLFV would indicate a clear signal of physics beyond the SM with massive neutrinos.
2. New physics contributing to muon g-2 would also contributes to cLFV.
3. The physics of cLFV is very complementary to that of LHC.
4. cLFV have potential to study physics at very high energy scale.
5. Theoretical predictions are just below the present experimental bound.

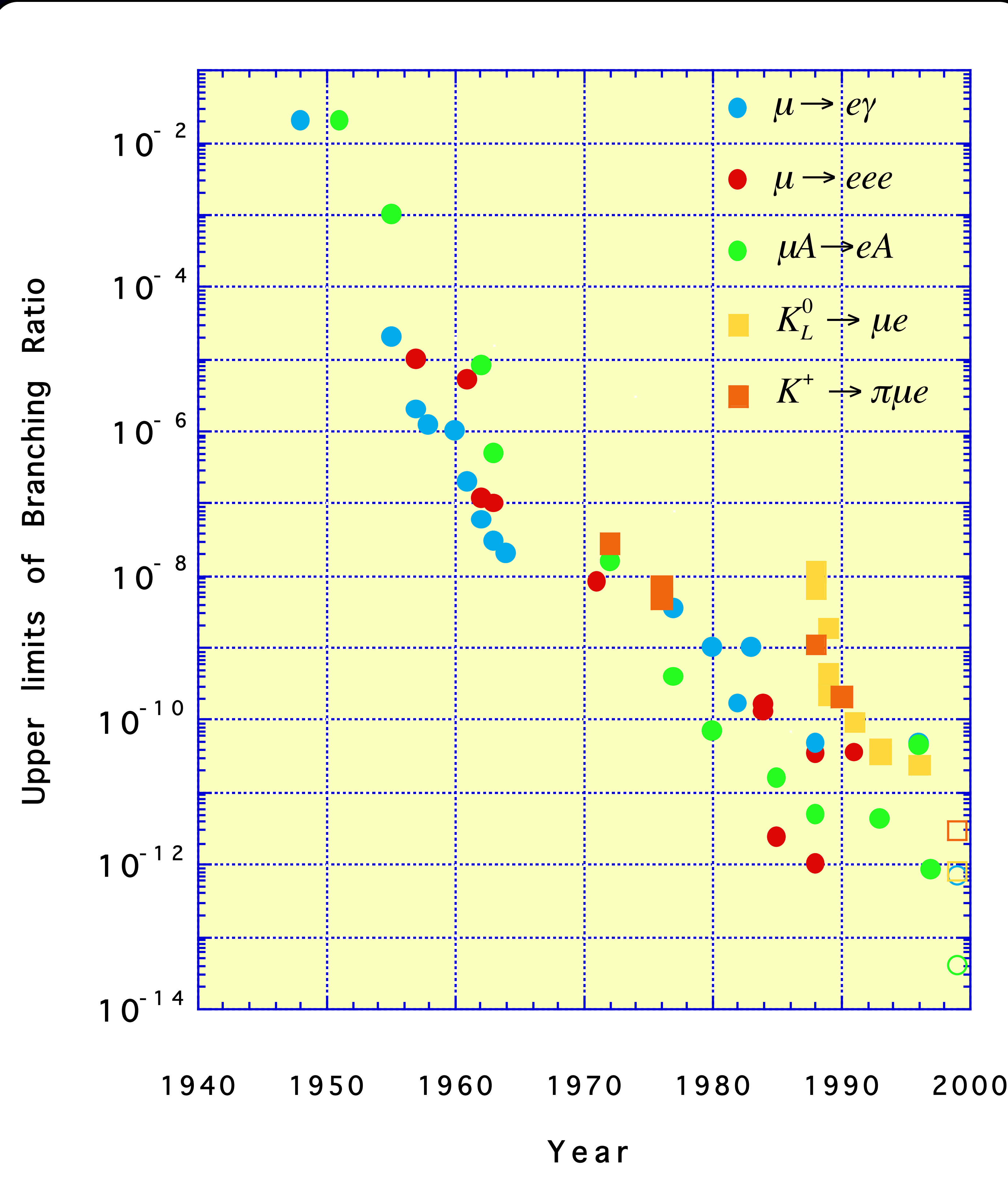
LFV Experiments

LFV Experiments



at Yoshida (Toyohashi), Aichi

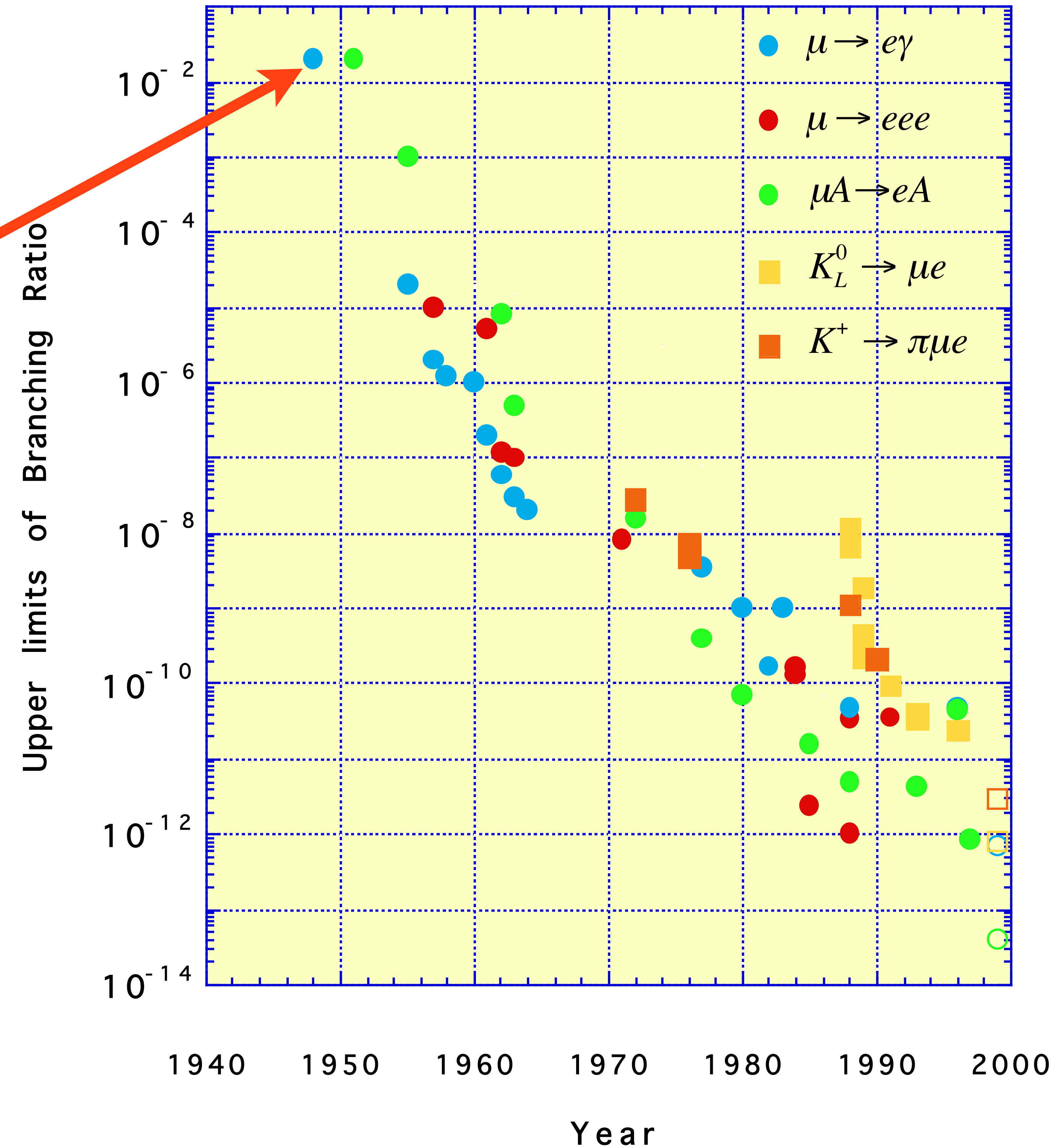
cLFV History



cLFV History

First cLFV search

Pontecorvo in 1947



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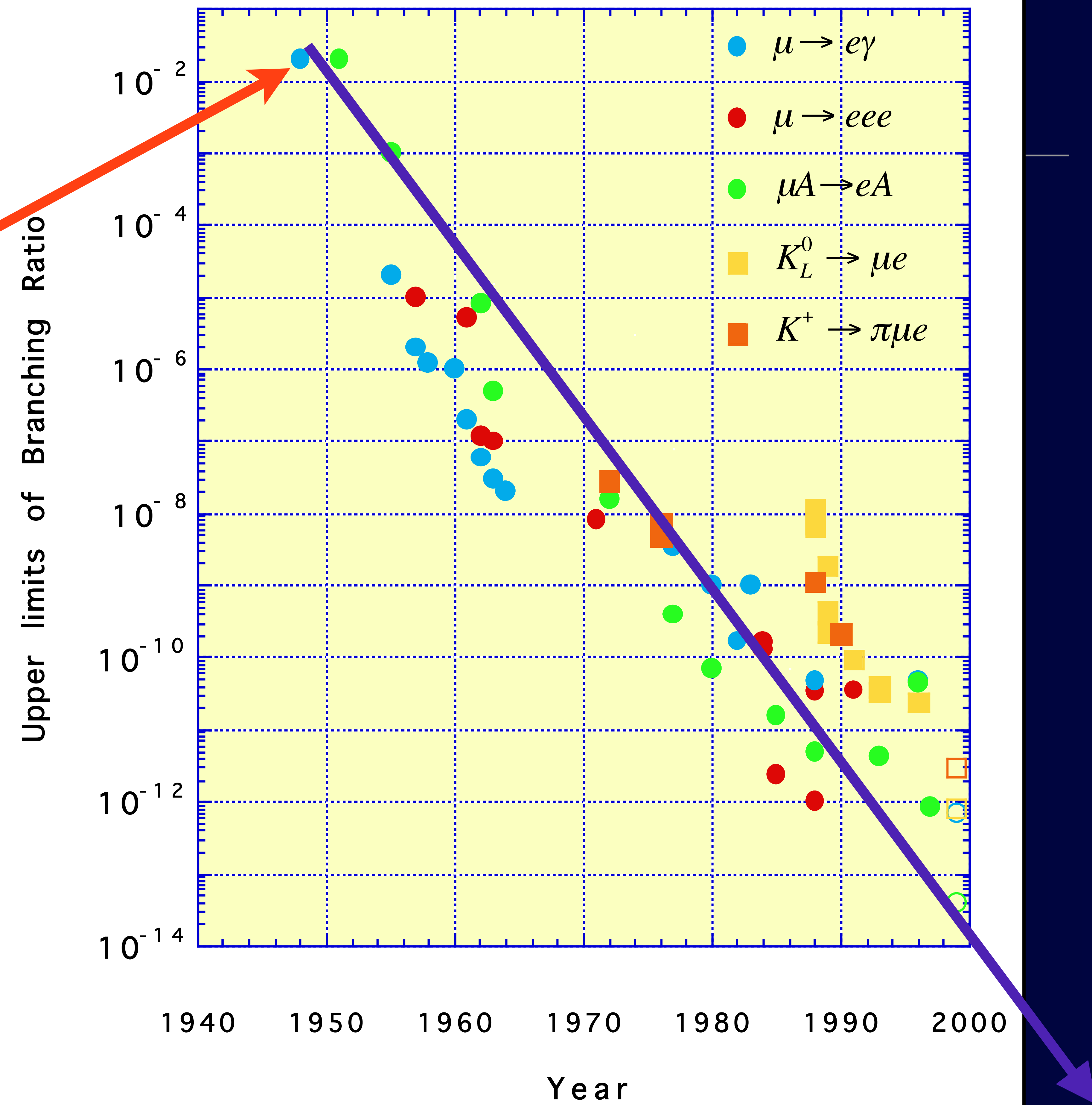

Present Limits and Expectations in Future

process	present limit	future	
$\mu \to e\gamma$	$<1.2 \times 10^{-11}$	$<10^{-13}$	MEG at PSI
$\mu \to eee$	$<1.0 \times 10^{-12}$	$<10^{-13} - 10^{-14}$	?
$\mu N \to eN$ (in Al)	none	$<10^{-16}$	Mu2e / COMET
$\mu N \to eN$ (in Ti)	$<4.3 \times 10^{-12}$	$<10^{-18}$	PRISM
$\tau \to e\gamma$	$<1.1 \times 10^{-7}$	$<10^{-9} - 10^{-10}$	super B factory
$\tau \to eee$	$<3.6 \times 10^{-8}$	$<10^{-9} - 10^{-10}$	super B factory
$\tau \to \mu\gamma$	$<4.5 \times 10^{-8}$	$<10^{-9} - 10^{-10}$	super B factory
$\tau \to \mu\mu\mu$	$<3.2 \times 10^{-8}$	$<10^{-9} - 10^{-10}$	super B factory

List of cLFV Processes with Muons

ΔL=1

- $\mu^+ \rightarrow e^+\gamma$
- $\mu^+ \rightarrow e^+e^+e^-$
- $\mu^- + N(A,Z) \rightarrow e^- + N(A,Z)$
- $\mu^- + N(A,Z) \rightarrow e^+ + N(A,Z-2)$

ΔL=2

- $\mu^+e^- \rightarrow \mu^-e^+$
- $\mu^- + N(A,Z) \rightarrow \mu^+ + N(A,Z-2)$
- $\nu_\mu + N(A,Z) \rightarrow \mu^+ + N(A,Z-1)$
- $\nu_\mu + N(A,Z) \rightarrow \mu^+\mu^+\mu^- + N(A,Z-1)$

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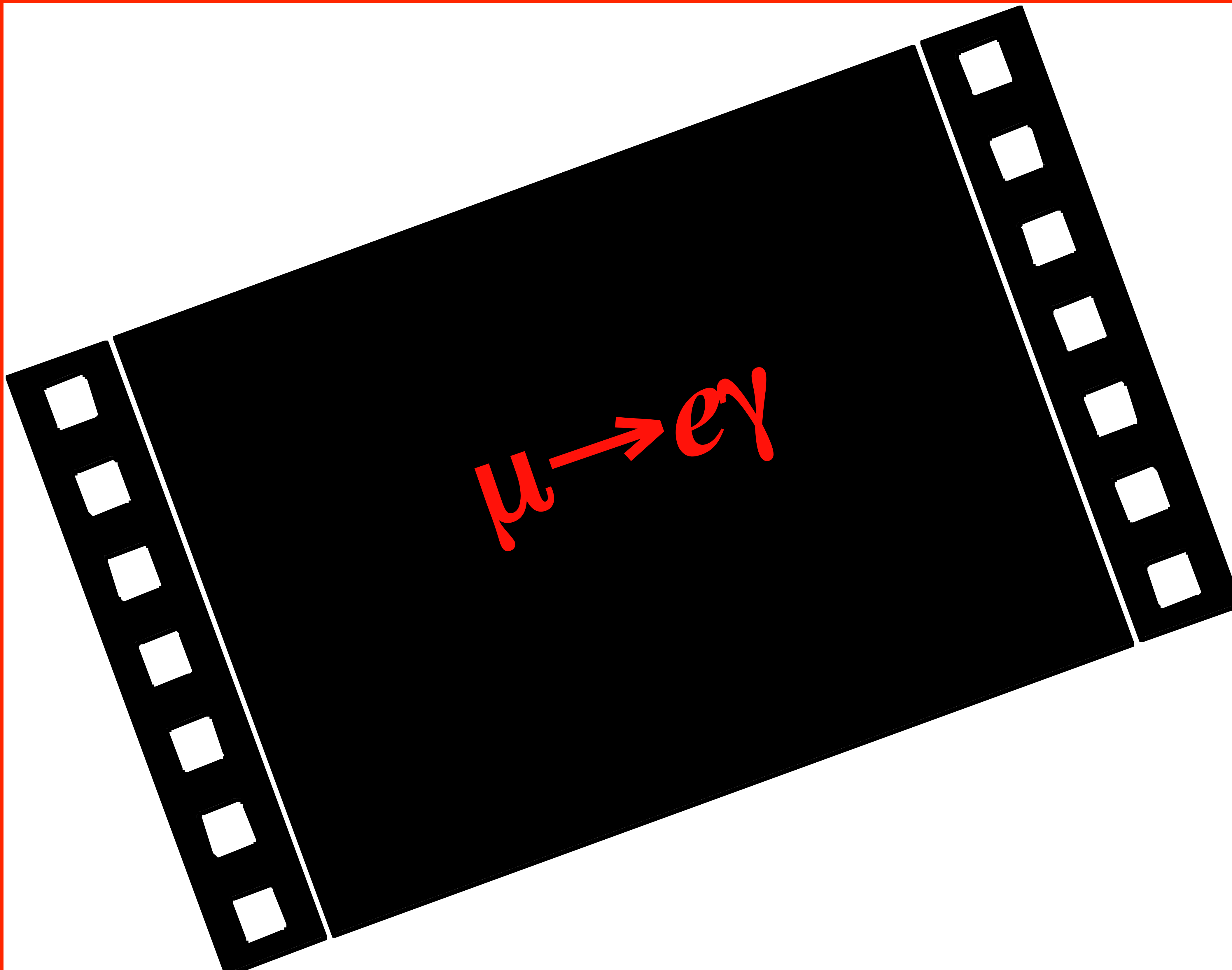
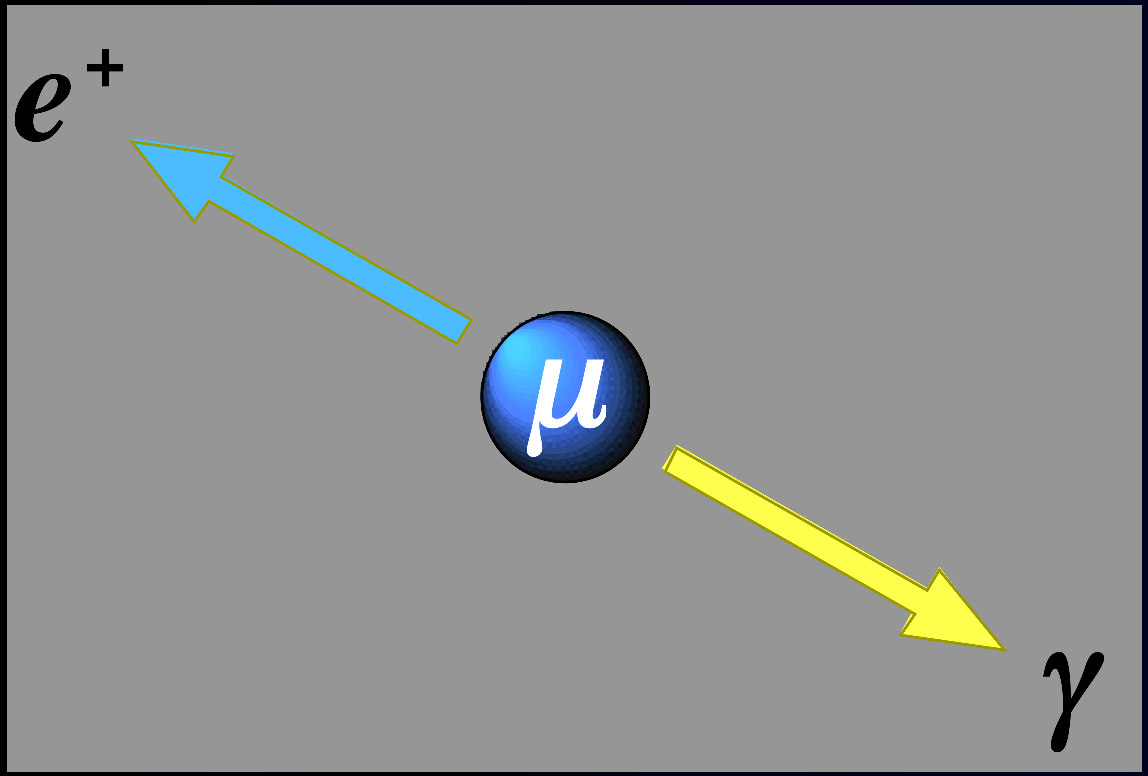

μ→eγ

What is $\mu \to e\gamma$?

- Event Signature
  - $E_e = m_\mu/2$, $E_\gamma = m_\mu/2$ (=52.8 MeV)
  - angle $\theta_{\mu e}$=180 degrees (back-to-back)
  - time coincidence



- Backgrounds
  - prompt physics backgrounds
    - radiative muon decay $\mu \to e\nu\nu\gamma$ when two neutrinos carry very small energies.
  - accidental backgrounds
    - positron in $\mu \to e\nu\nu$
    - photon in $\mu \to e\nu\nu\gamma$ or photon from e^+e^- annihilation in flight.

MEG at PSI

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- DC beam 10^7 muons/sec.
- Goal : $B < 2 \times 10^{-13}$
- COBRA : spectrometer for e^+ detection.
- Liquid Xenon detector for photon detection.

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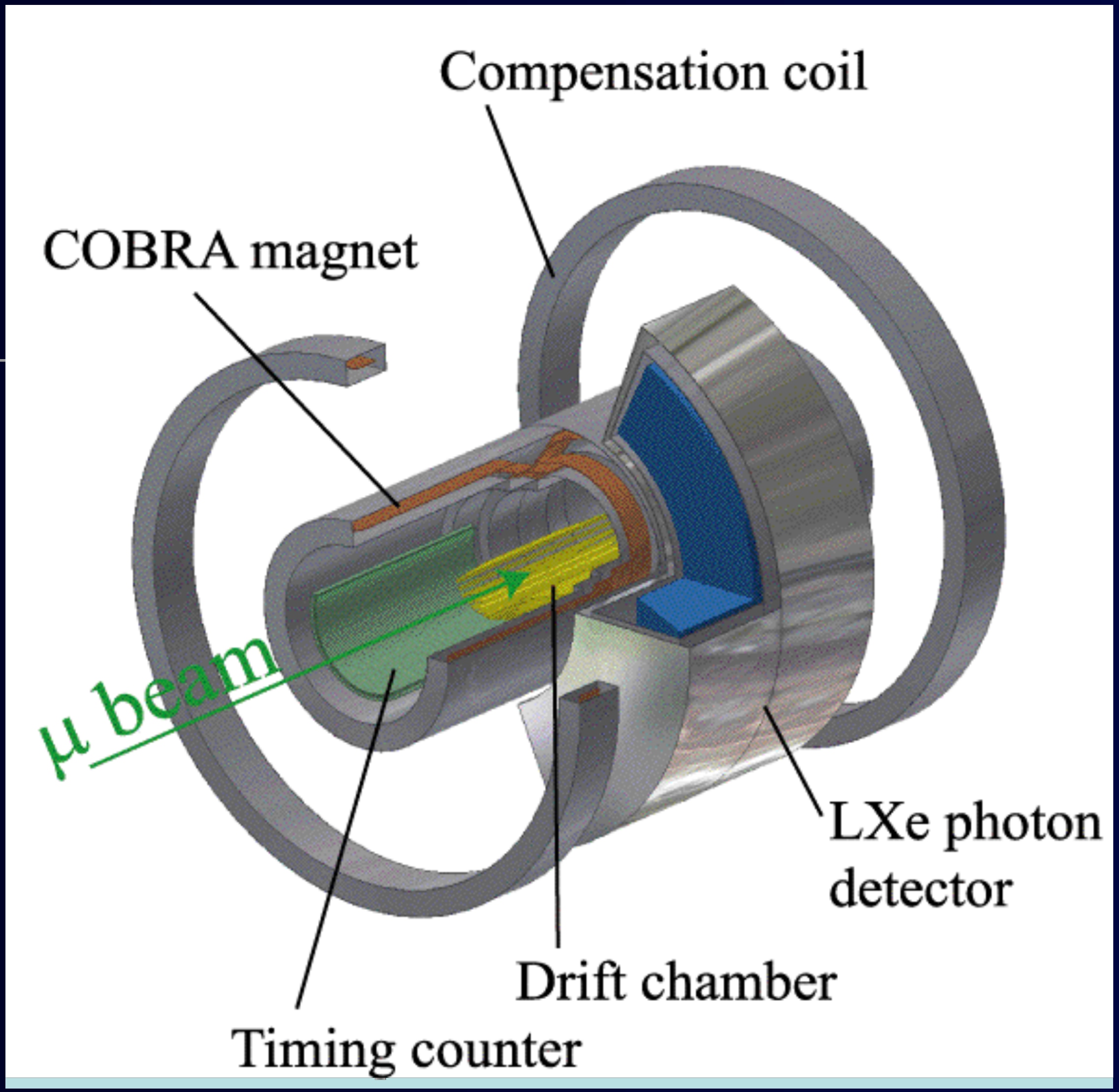
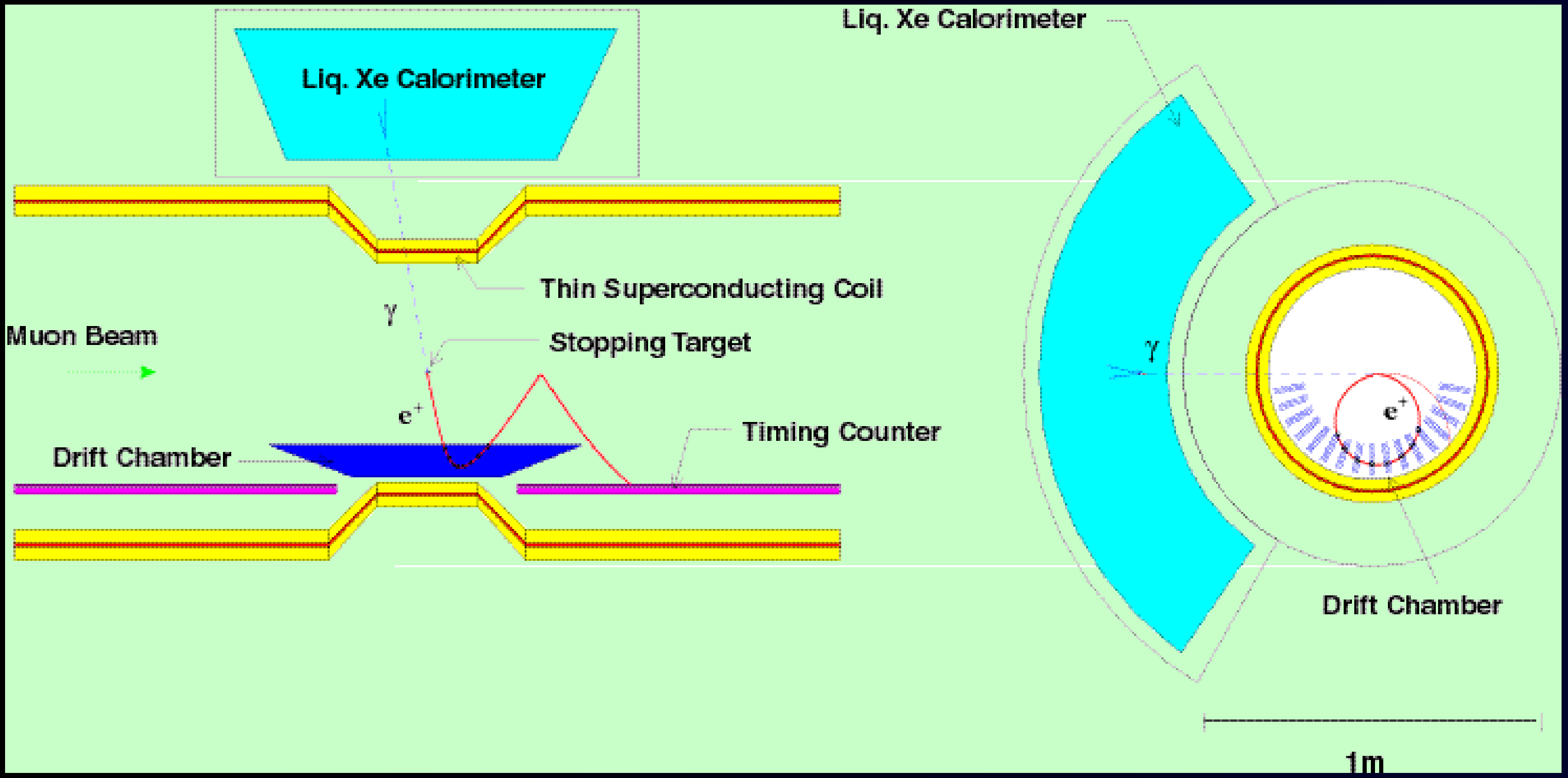
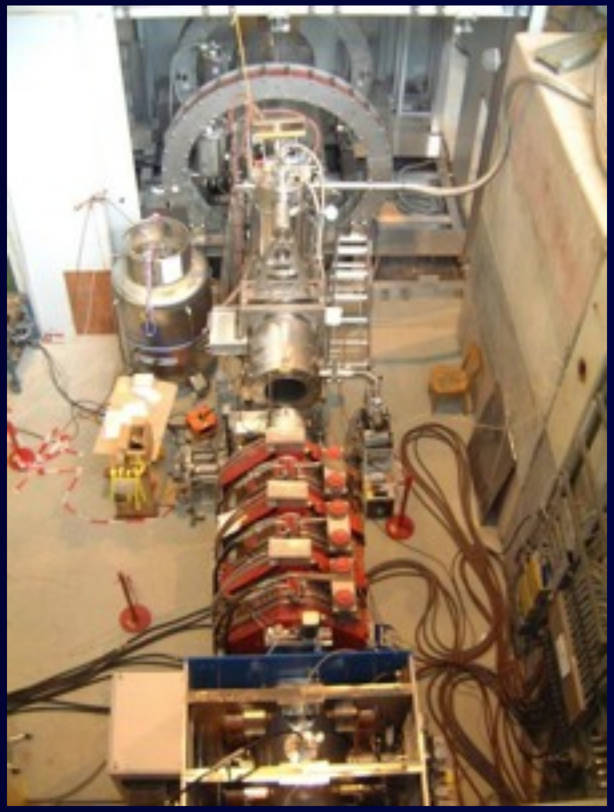




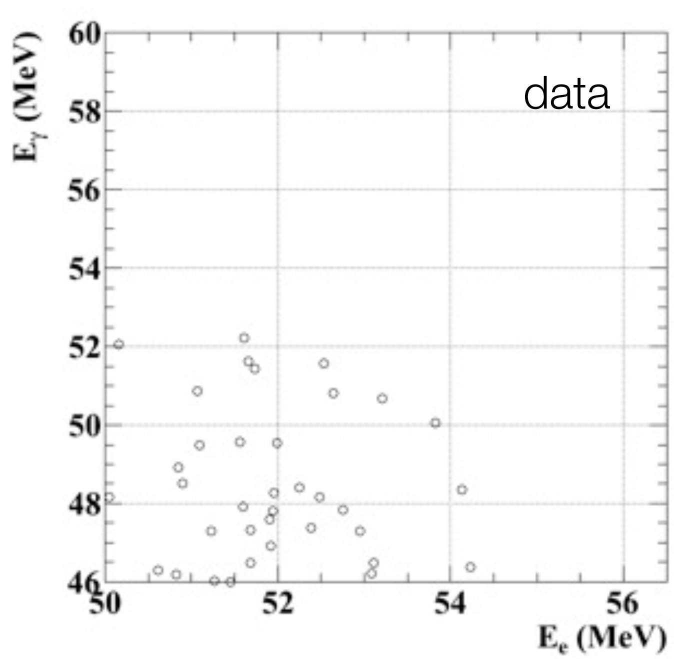


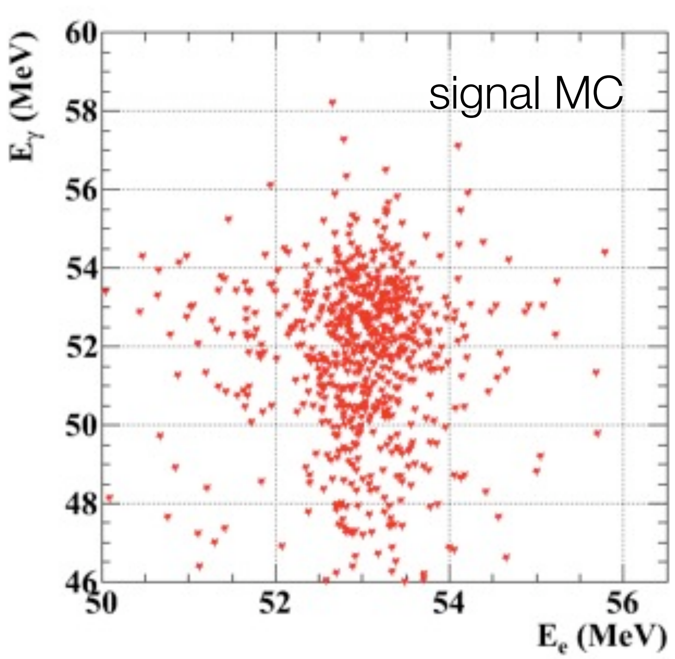
MEG Preliminary 2008 Data Result

The Preliminary 2008 Data Result

$$\mathrm{BR}(\mu^+ \to \mathrm{e}^+\gamma) < 3.0 \times 10^{-11}$$

MEGA result: $\mathrm{BR}(\mu^+ \to e^+\gamma) < 1.2 \times 10^{-11}$





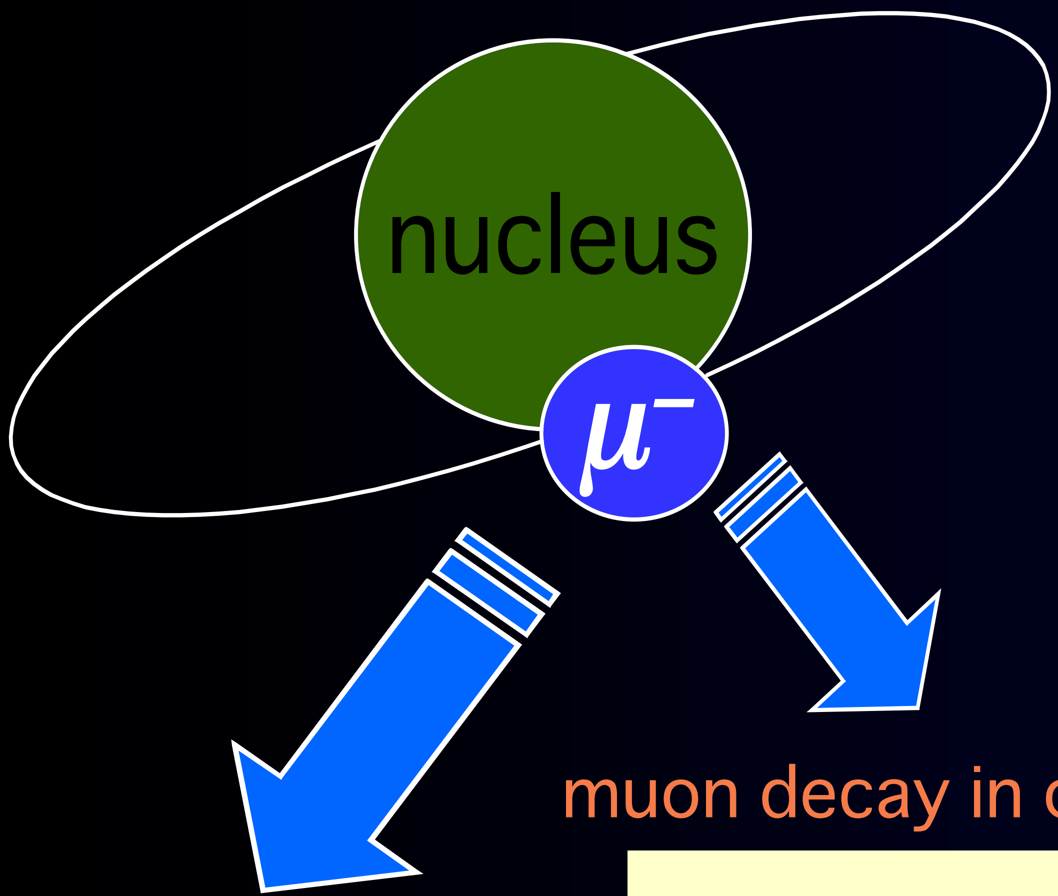
Note: all the other parameters are cut to select ~90% of signal events in these plots

$\mu \rightarrow e$ conversion in a muonic atom

What is a Muon to Electron Conversion ?

What is a Muon to Electron Conversion ?

1s state in a muonic atom



muon decay in orbit

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

nuclear muon capture

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

What is a Muon to Electron Conversion ?

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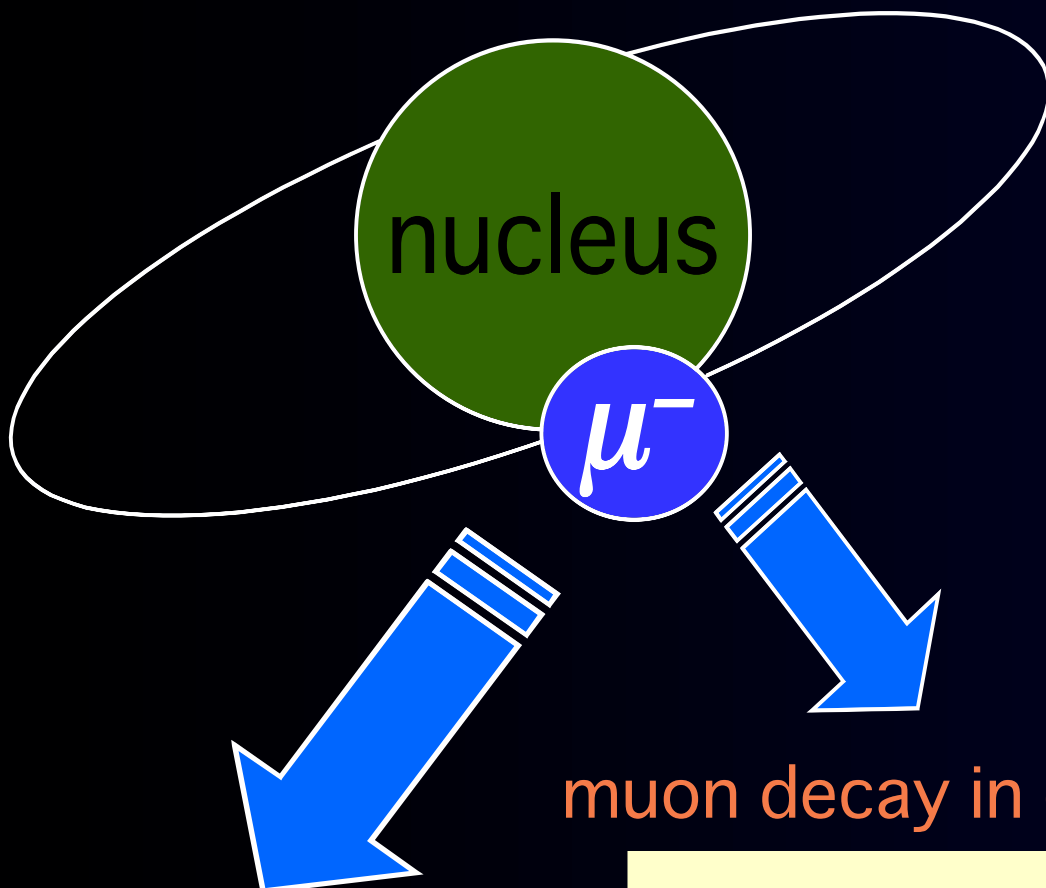


muon decay in orbit

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

nuclear muon capture

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

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

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

lepton flavors changes by one unit.

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

μ-e Conversion
Signal and Backgrounds

μ-e Conversion
Signal and Backgrounds

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

- Signal
  - single mono-energetic electron

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

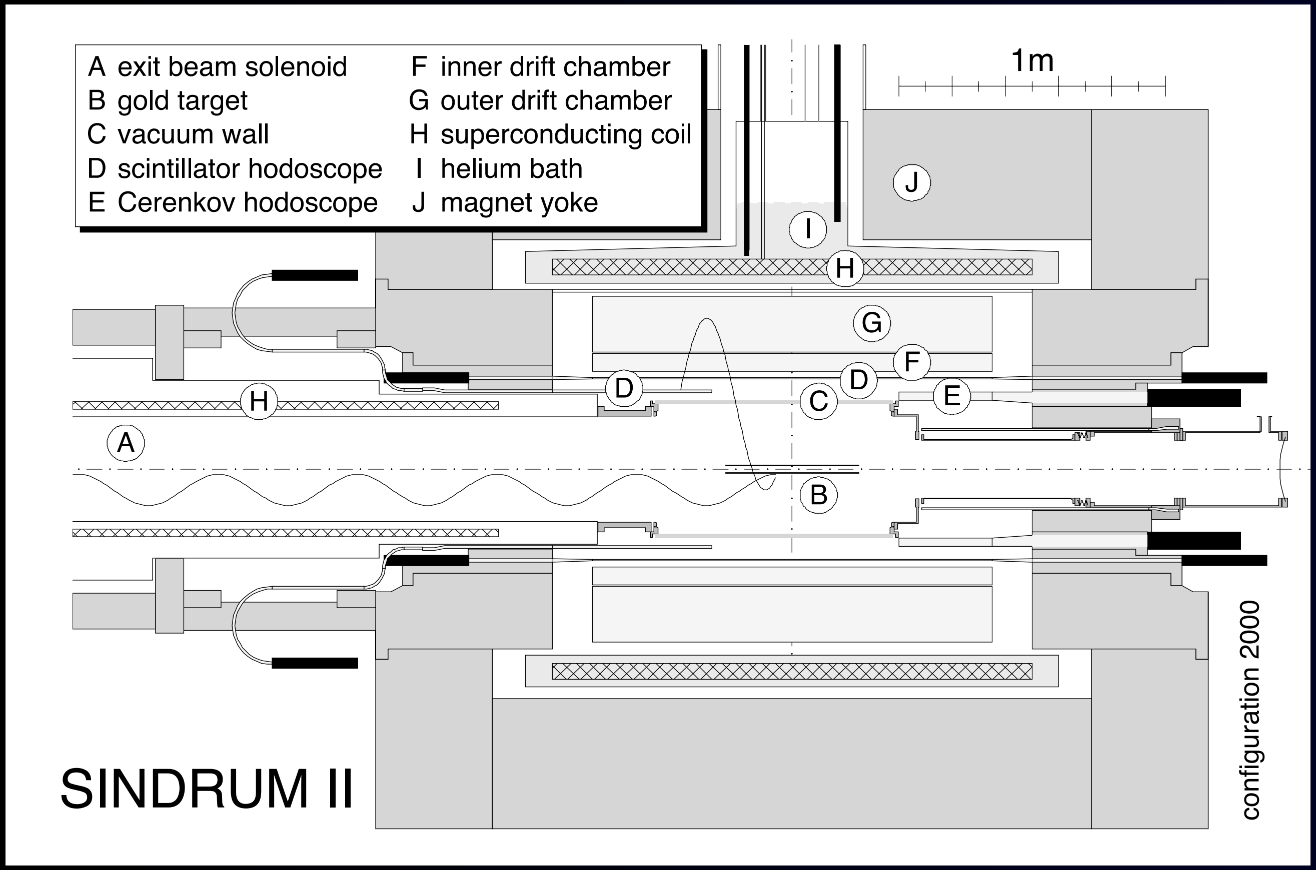
- The transition to the ground state is a coherent process, and enhanced by a number of nucleus.

$$\propto Z^5$$

- Backgrounds
  - Intrinsic physics background
    - muon decay in orbit (DIO)
  - beam-related background
    - radiative pion capture
    - muon decay in flight (DIF)
  - cosmic-ray background
  - tracking failure
  - etc....

Previous Measurements

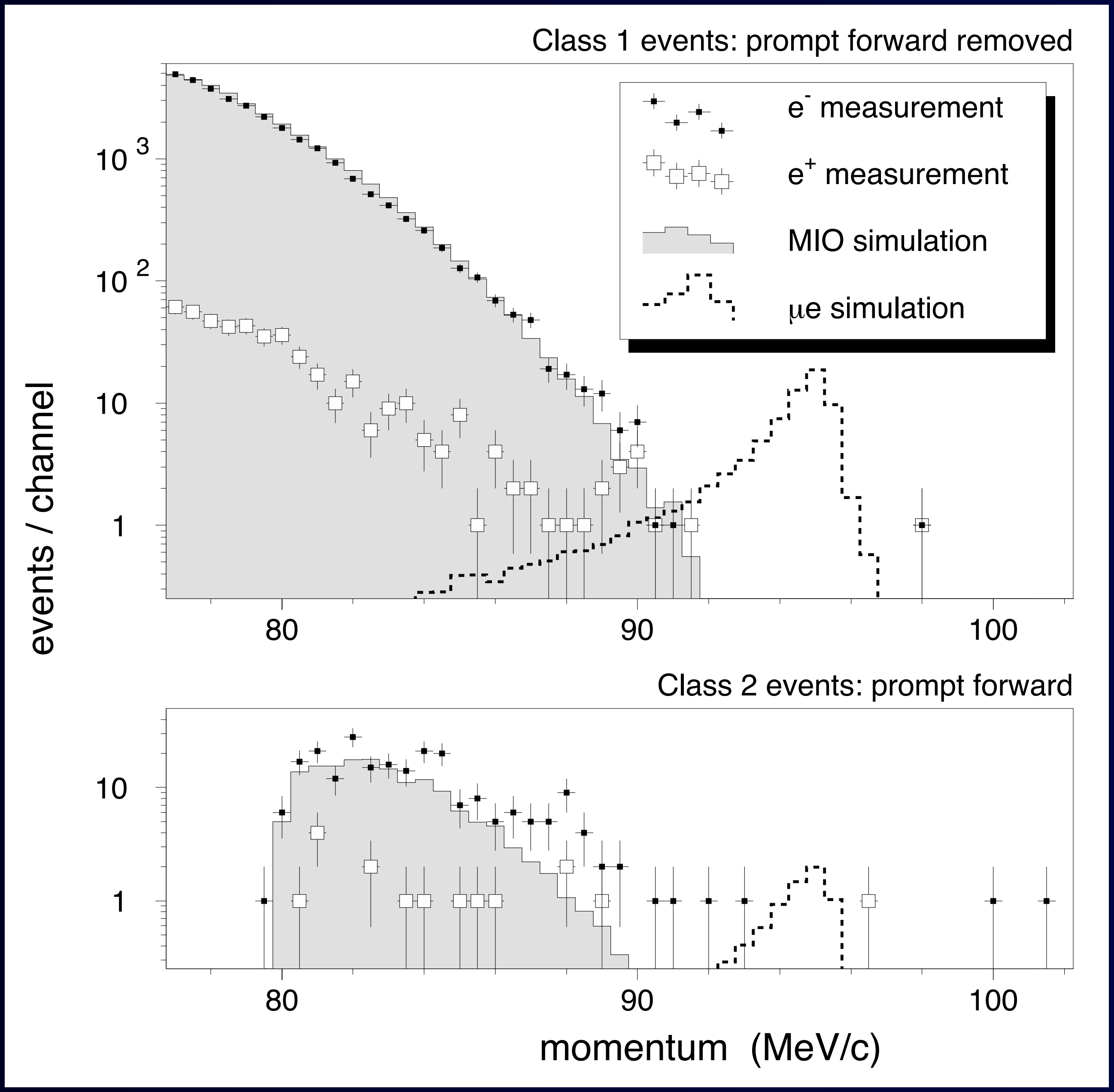
SINDRUM-II (PSI)



PSI muon beam intensity ~ $10^{7\text{-}8}$/sec beam from the PSI cyclotron. To eliminate beam related background from a beam, a beam veto counter was placed. But, it could not work at a high rate.

Published Results (2004)

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



Experimental Design for Muon to Electron Conversion

Experimental Design for Muon to Electron Conversion

at Okazaki, Aichi

Experimental Comparison between $\mu \to e\gamma$ and μ-e Conversion

	background	challenge	beam intensity
• $\mu \to e\gamma$	accidentals	detector resolution	limited
• μ-e conversion	beam	beam background	no limitation

- $\mu \to e\gamma$: Accidental background is given by (rate)^2. The detector resolutions have to be improved, but they (in particular, photon) would be hard to go beyond MEG from present technology. The ultimate sensitivity would be about 10^{-14} (with about 10^8/sec) unless the detector resolution is radically improved.
- μ-e conversion : Improvement of a muon beam can be possible, both in purity (no pions) and in intensity (thanks to muon collider R&D). A higher beam intensity can be taken because of no accidentals.

Experimental Comparison between $\mu \to e\gamma$ and μ-e Conversion

	background	challenge	beam intensity
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- μ-e conversion : Improvement of a muon beam can be possible, both in purity (no pions) and in intensity (thanks to muon collider R&D). A higher beam intensity can be taken because of no accidentals.

μ-e conversion might be a next step.

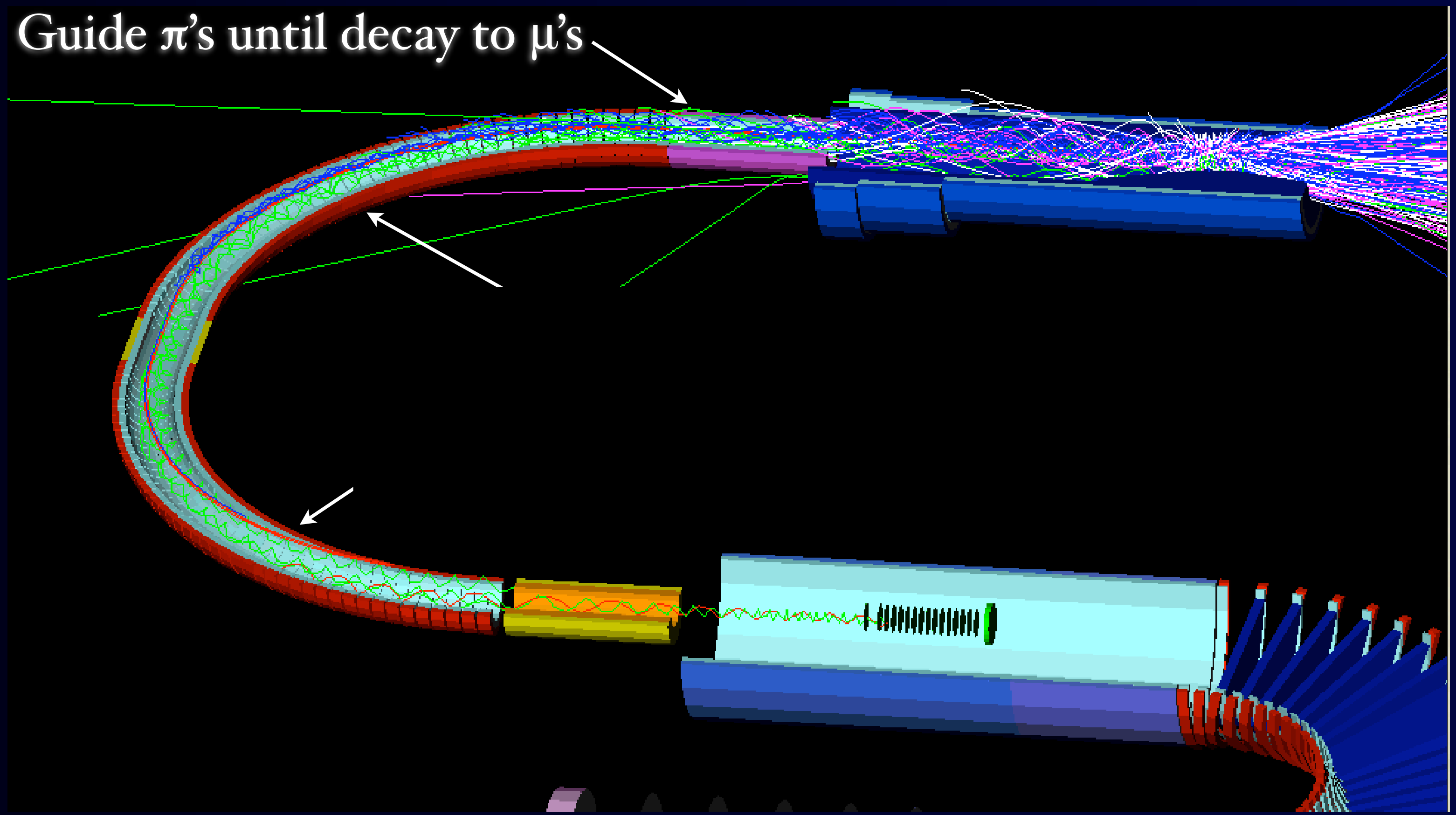
Improvements for Signal Sensitivity

To achieve a single sensitivity of 10^{-16}, we need

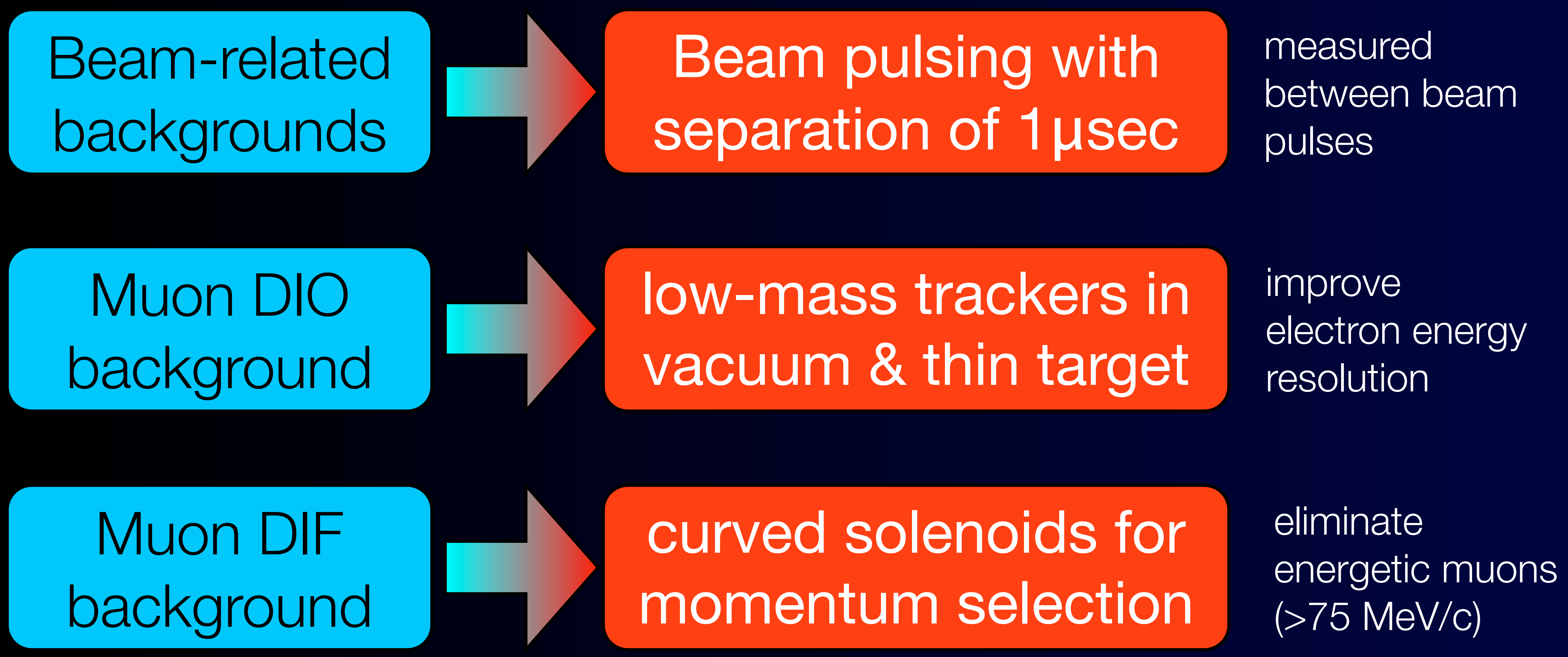
10^{11} muons/sec (with 10^{7} sec running)

whereas the current highest intensity is 10^{8}/sec at PSI.

Pion Capture and Muon Transport by Superconducting Solenoid System

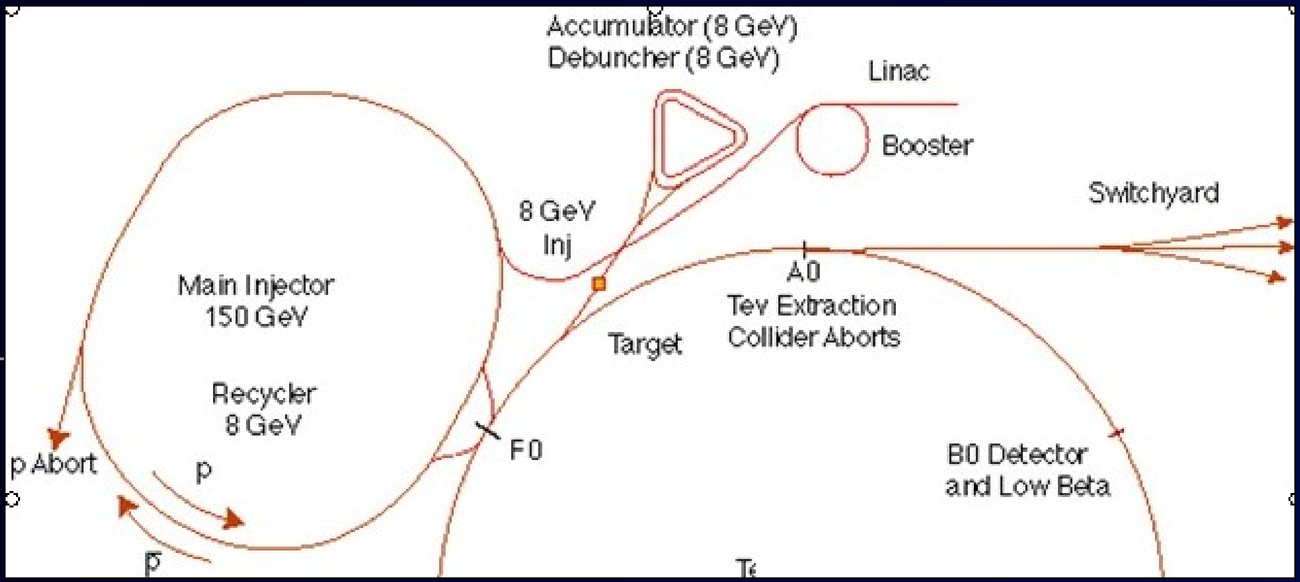


Improvements for Background Rejection

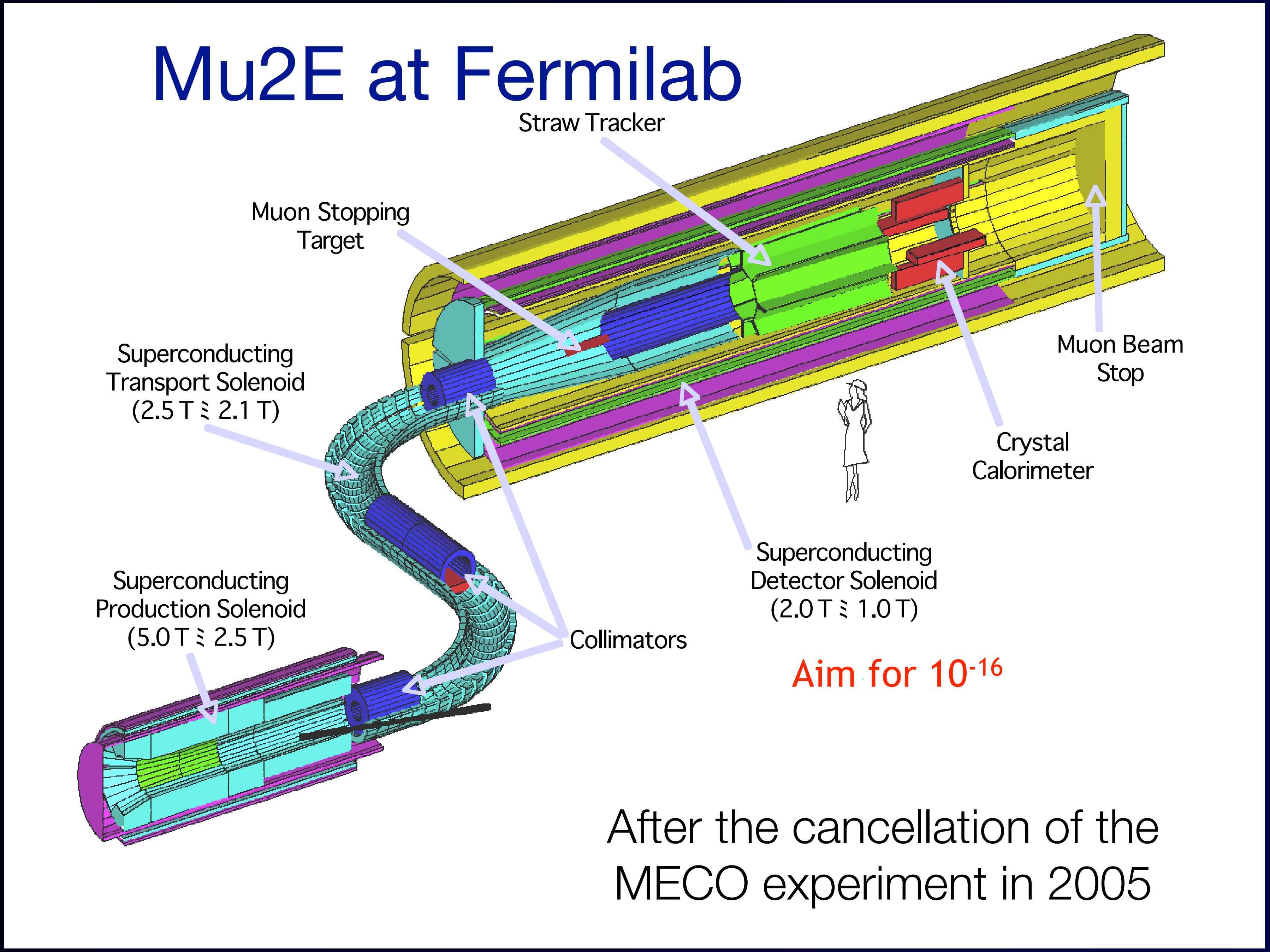


base on the MELC proposal at Moscow Meson Factory

Mu2E at Fermilab

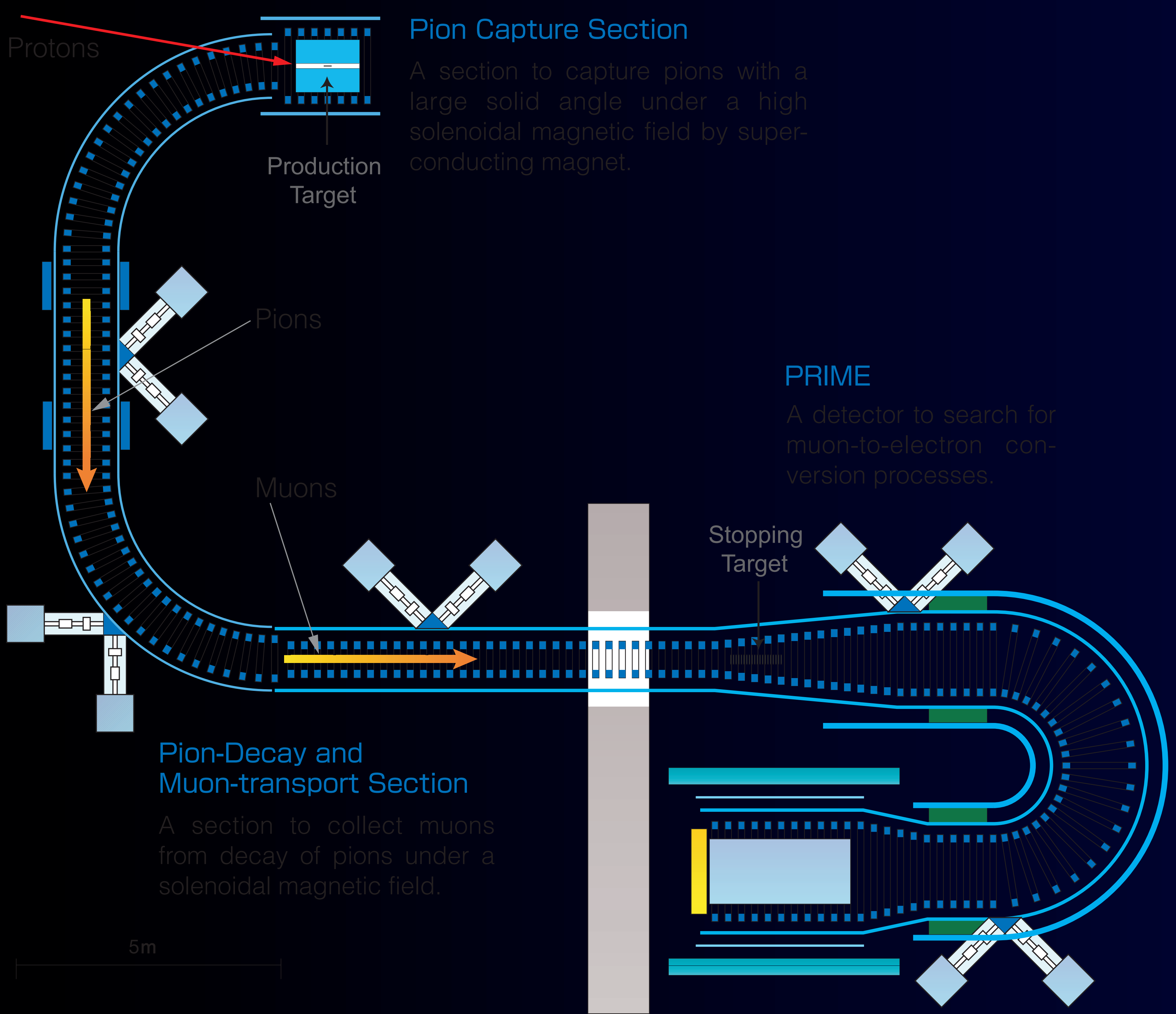


- After Tevatron shutdown, use the antiproton accumulator ring and debuncher ring for beam pulsing.
- Proton beam power is 20 kW and >200 kW for pre and post Project-X, respectively.



COMET (COherent Muon to Electron Transition) in Japan

$$B(\mu^- + Al \to e^- + Al) < 10^{-16}$$



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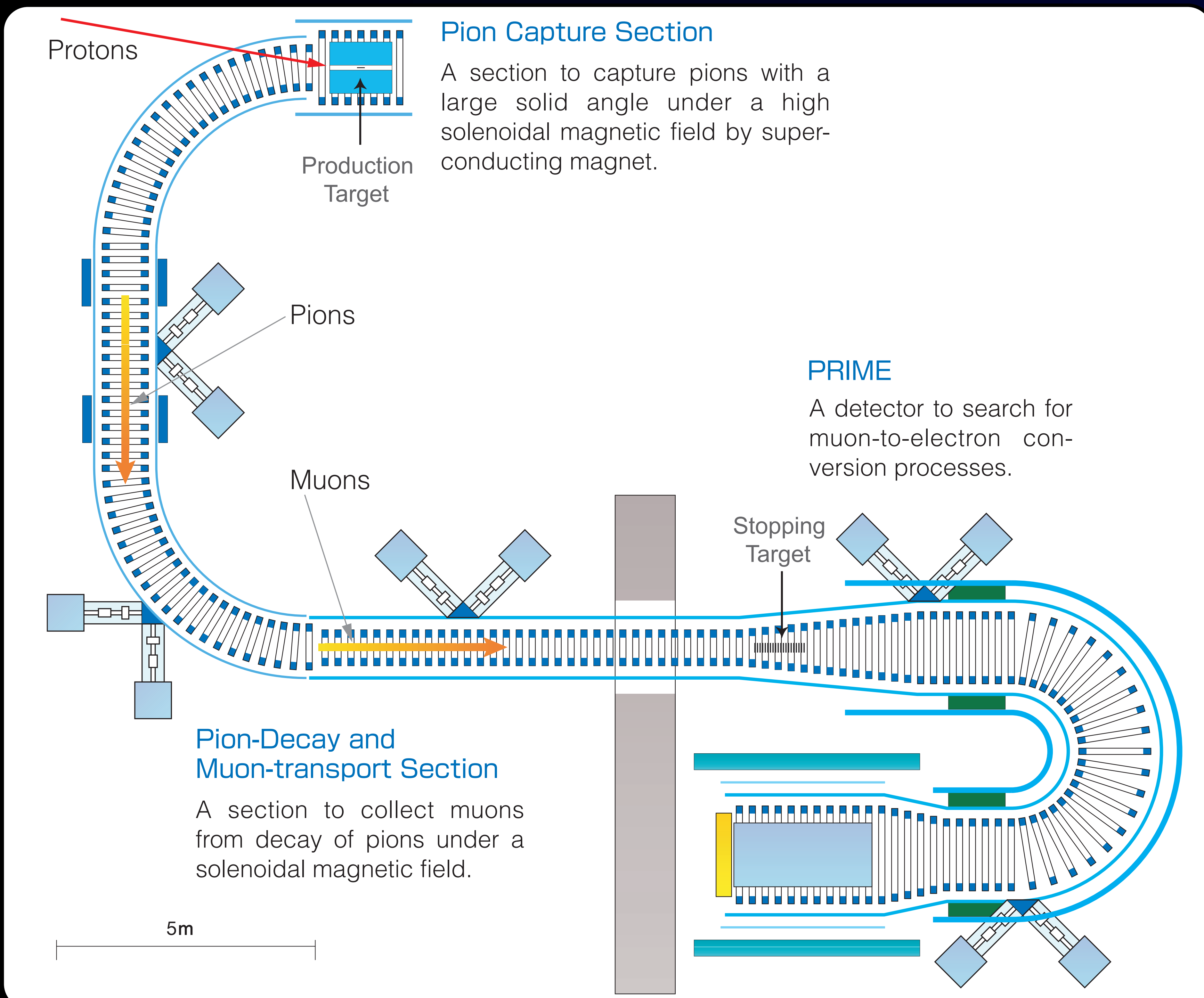

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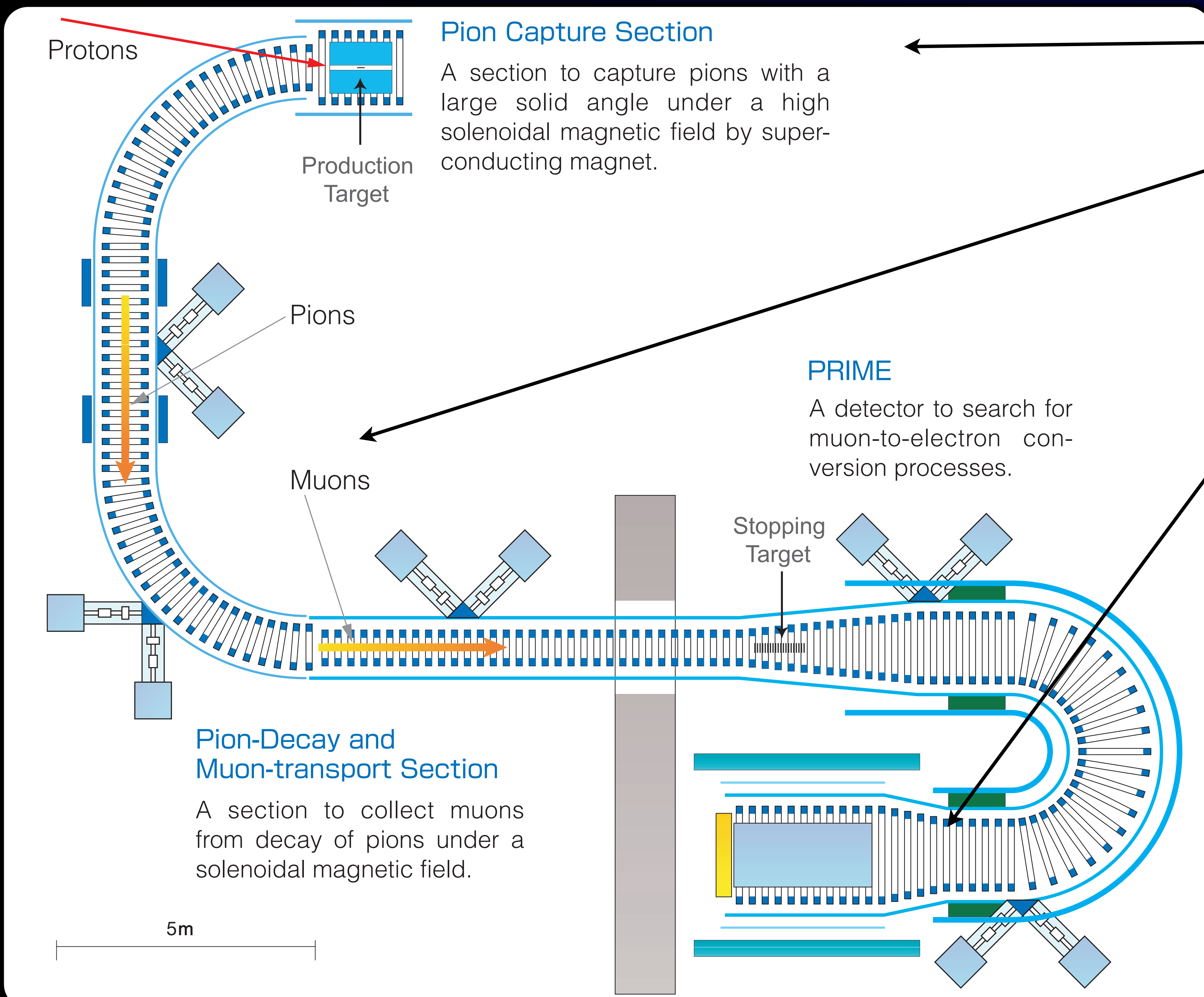

Proton Beam

The Muon Source
- Proton Target
- Pion Capture
- Muon Transport

The Detector
- Muon Stopping Target
- Electron Transport
- Electron Detection

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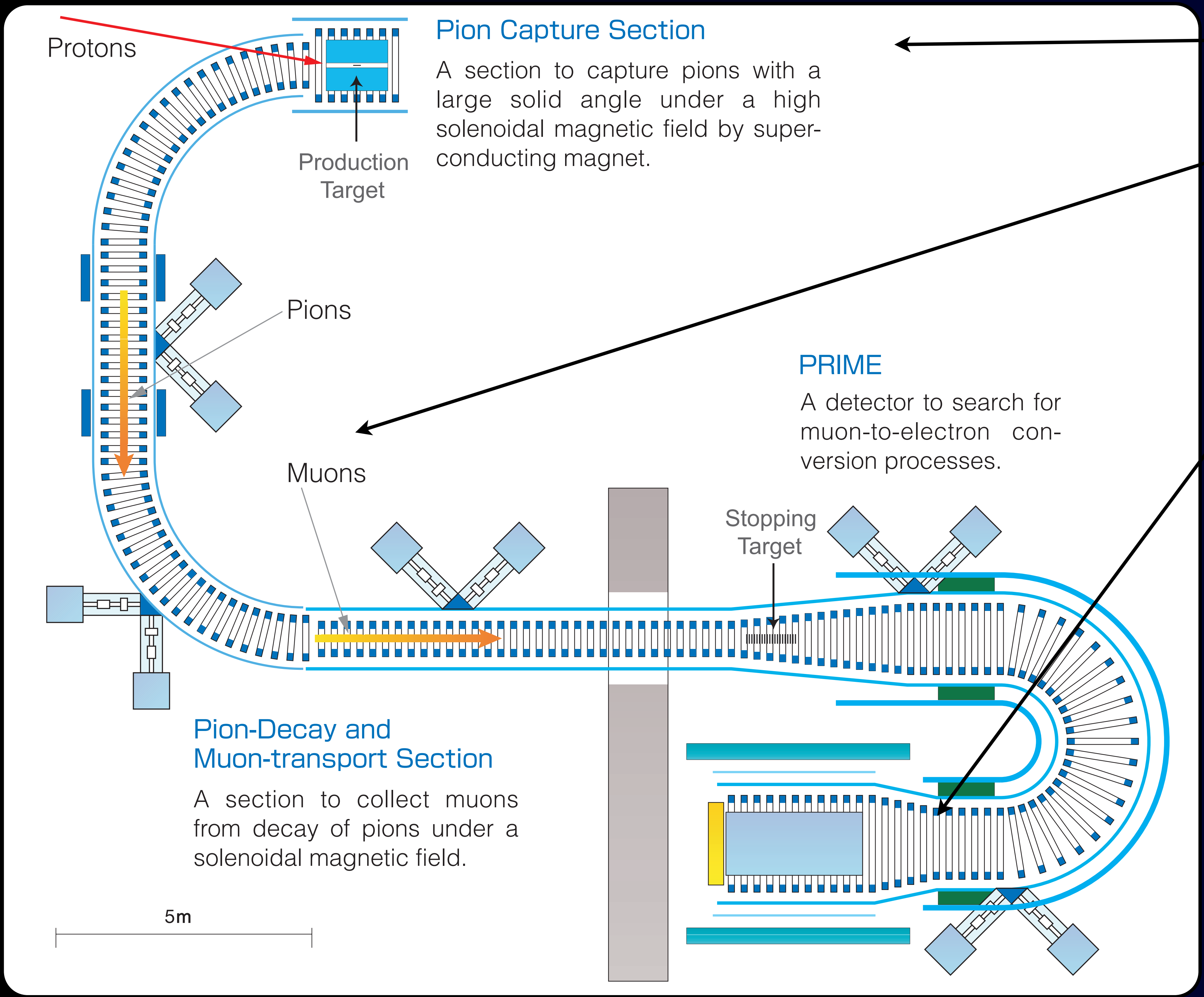

Proton Beam

The Muon Source
- Proton Target
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The Detector
- Muon Stopping Target
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proposed to J-PARC

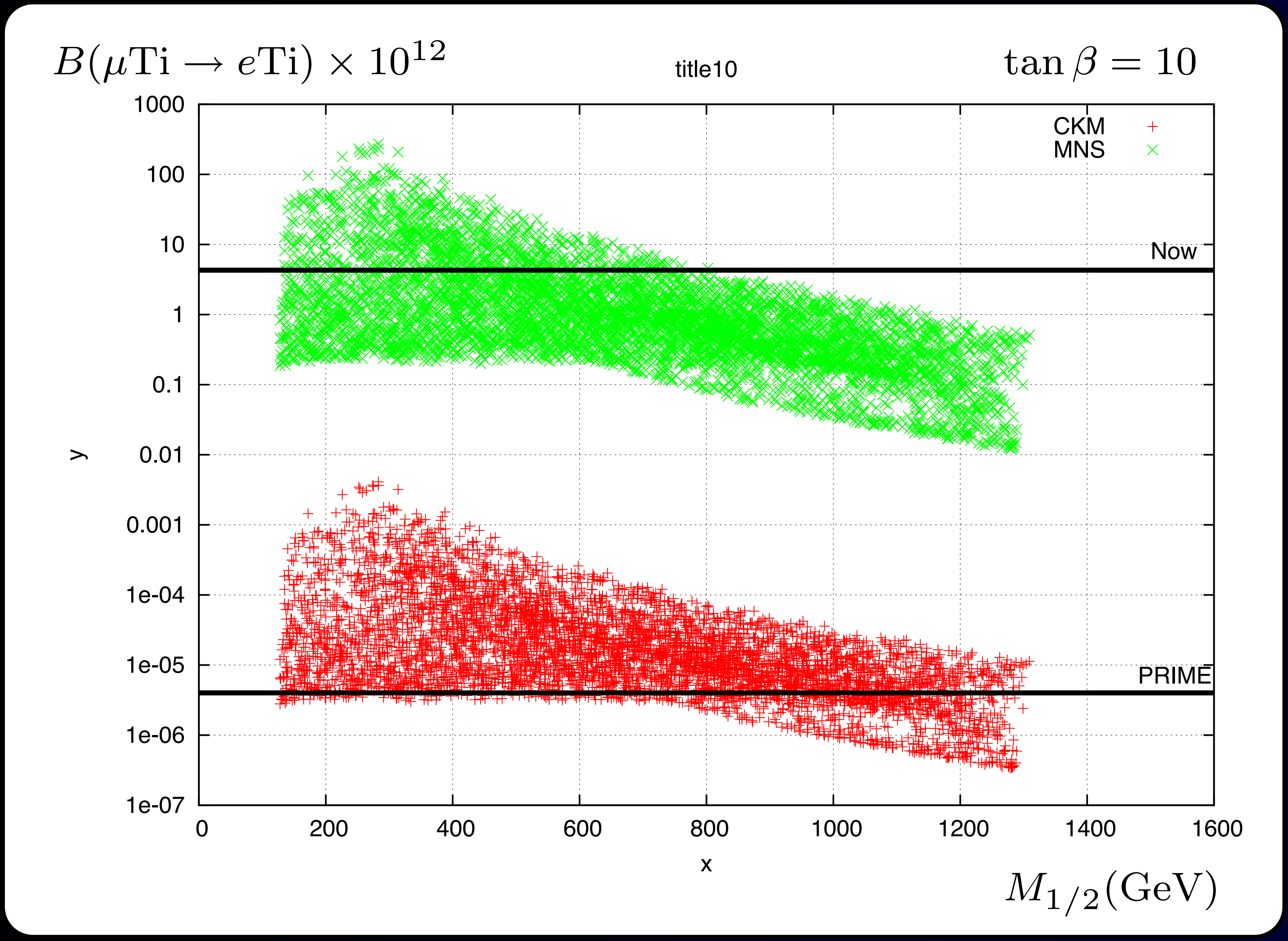
10^{-18} Sensitivity with PRISM

10^{-18} Sensitivity with PRISM

at kyogo, Aichi

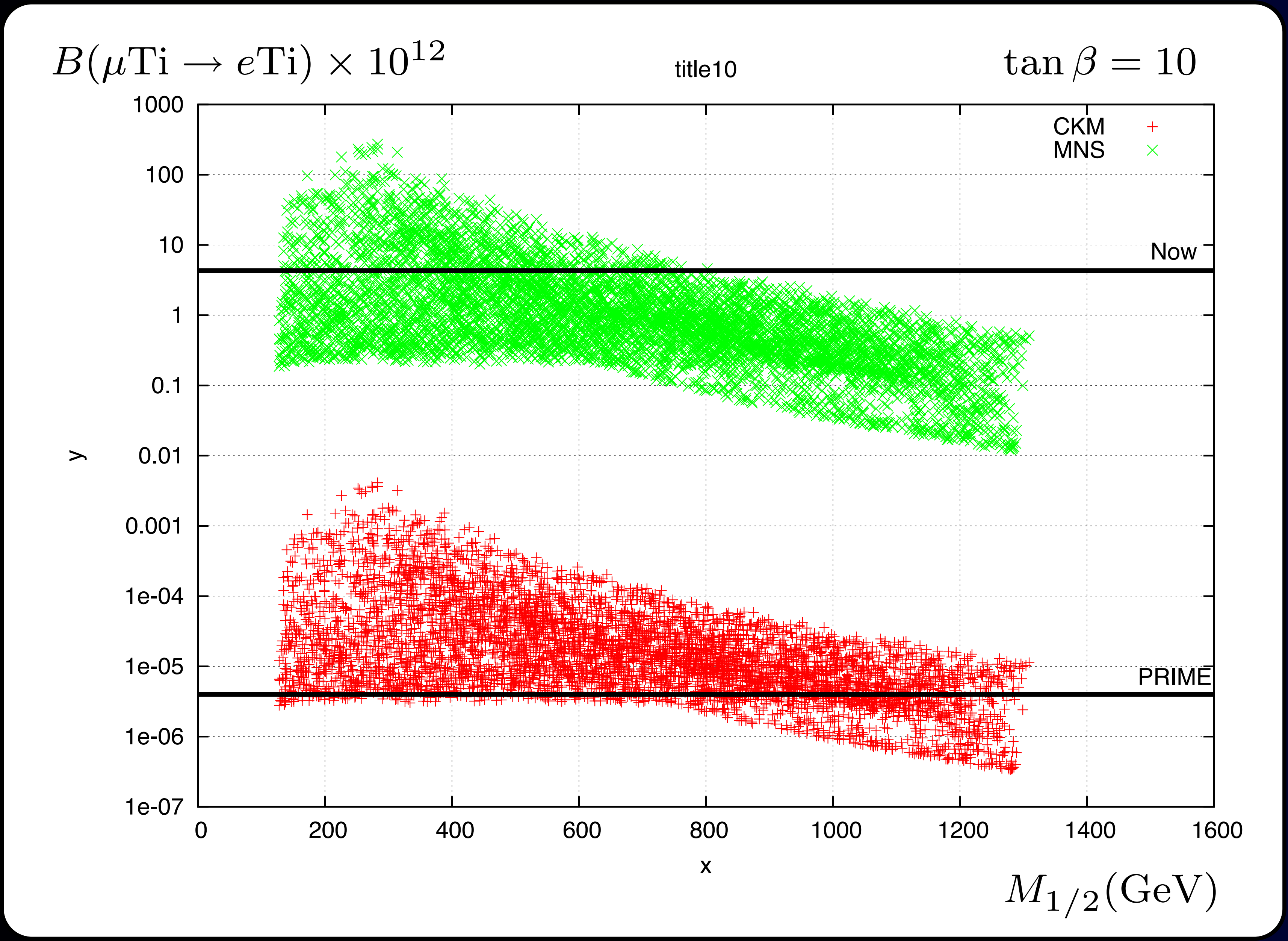
Why Sensitivity of $<10^{-18}$?

Why Sensitivity of <10^{-18} ?



BR~10^{-18}

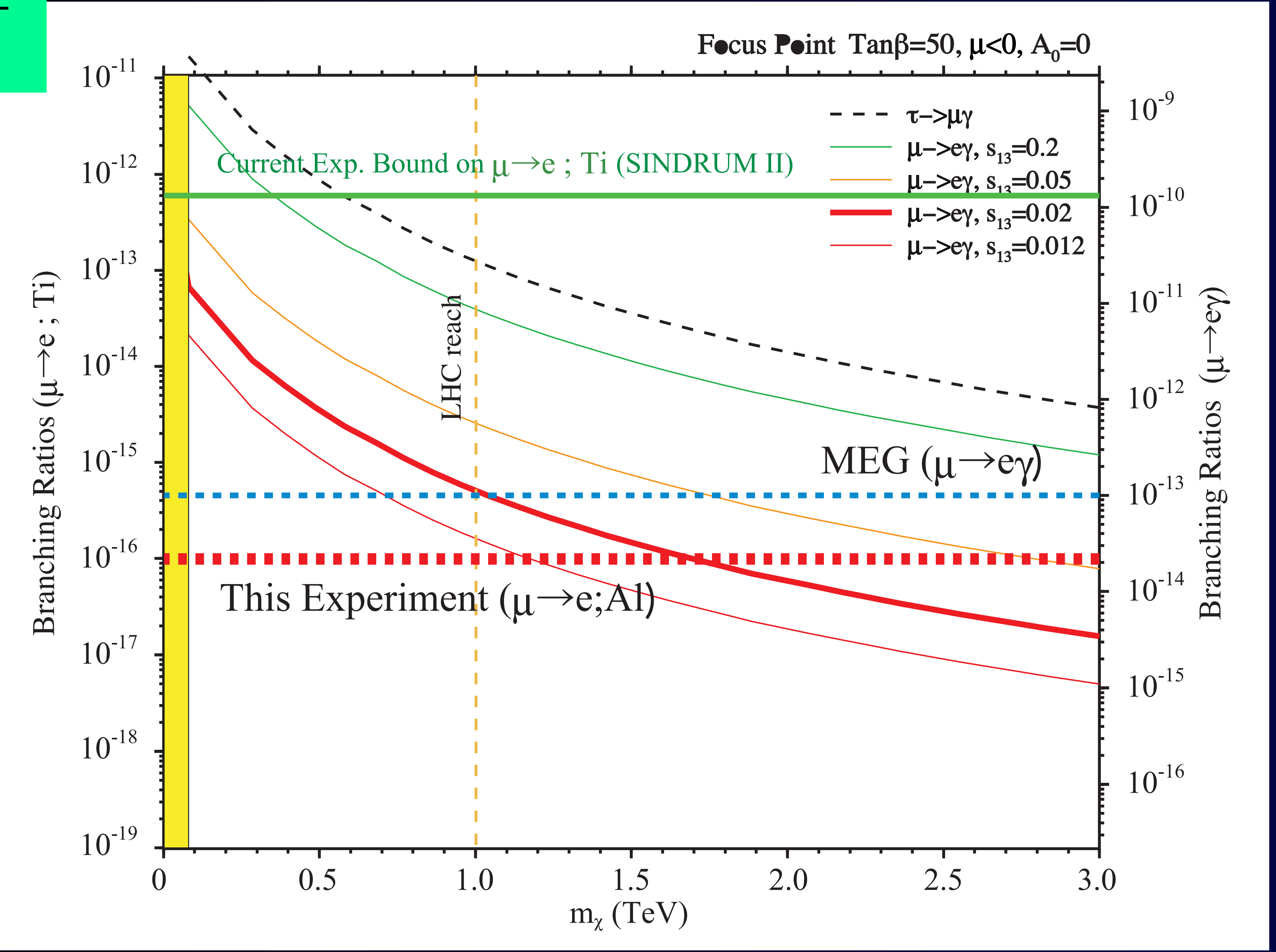
Why Sensitivity of <10^{-18} ?



BR~10^{-18}

Full coverage of SUSY parameter space can be made.

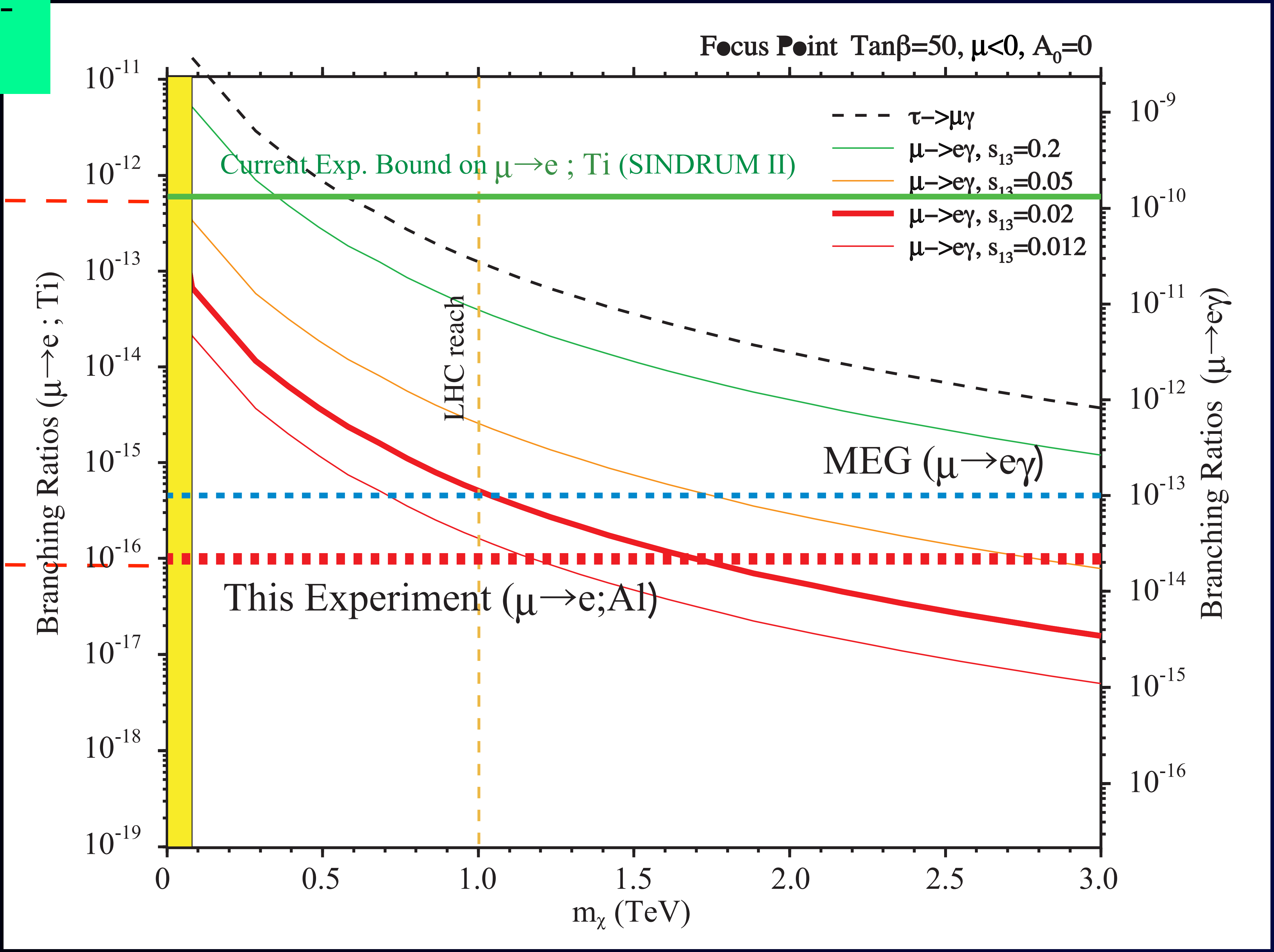
mSUGRA with right-handed neutrinos



Sensitivity Goals

mSUGRA with right-handed neutrinos

will be improved by a factor of 10,000.



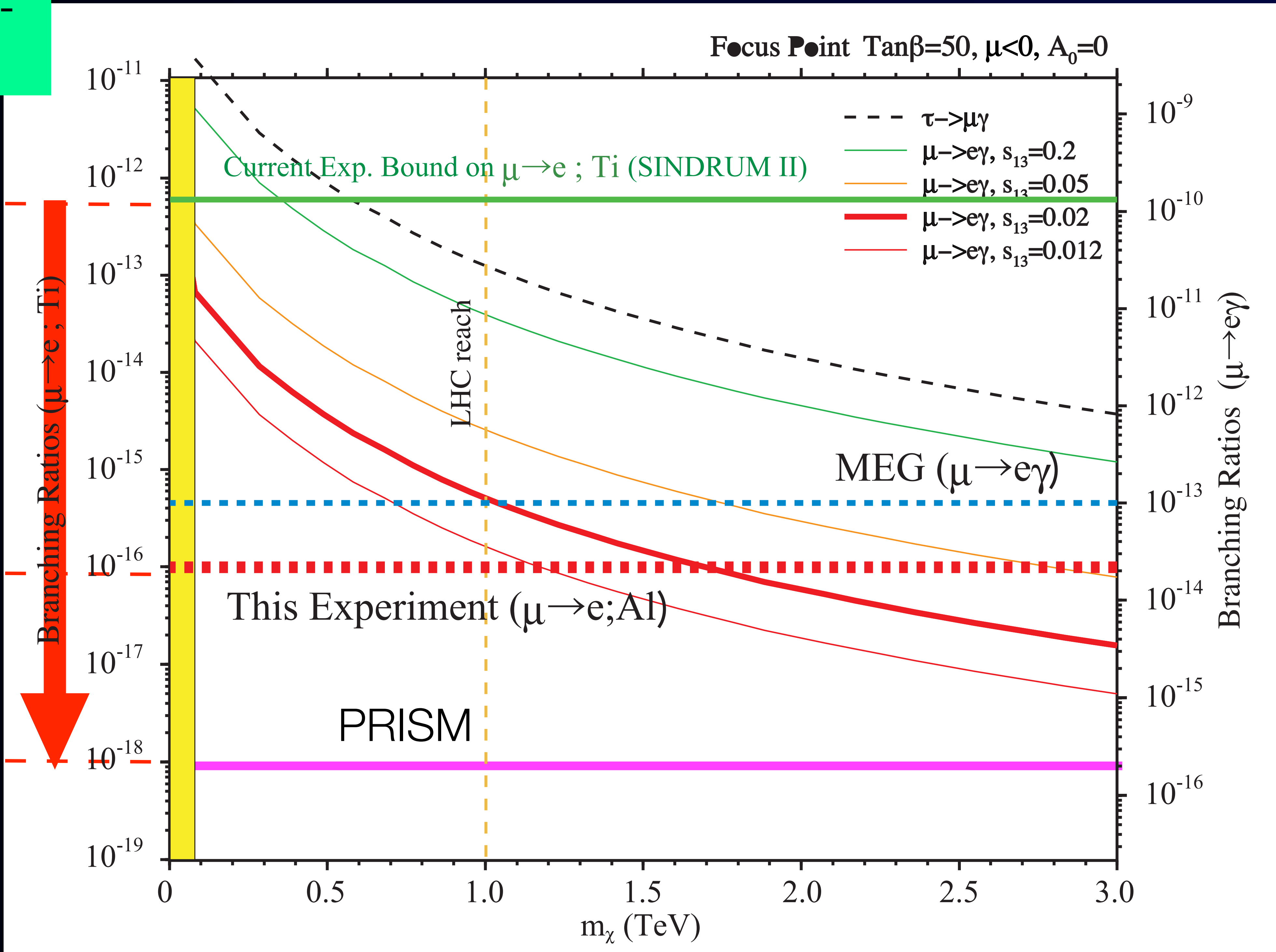
$$B(\mu^- + Al \to e^- + Al) < 10^{-16}$$

Sensitivity Goals

mSUGRA with right-handed neutrinos

will be improved by a factor of 10,000.

will be improved by a factor of 1000,000.



Sensitivity Goals

$$B(\mu^- + Al \to e^- + Al) < 10^{-16}$$

$$B(\mu^- + Ti \to e^- + Ti) < 10^{-18}$$

Signal Sensitivity of $< 10^{-18}$

Signal Sensitivity of < 10^{-18}

To achieve a signal sensitivity of 10^{-18}, MW beam power is essential.

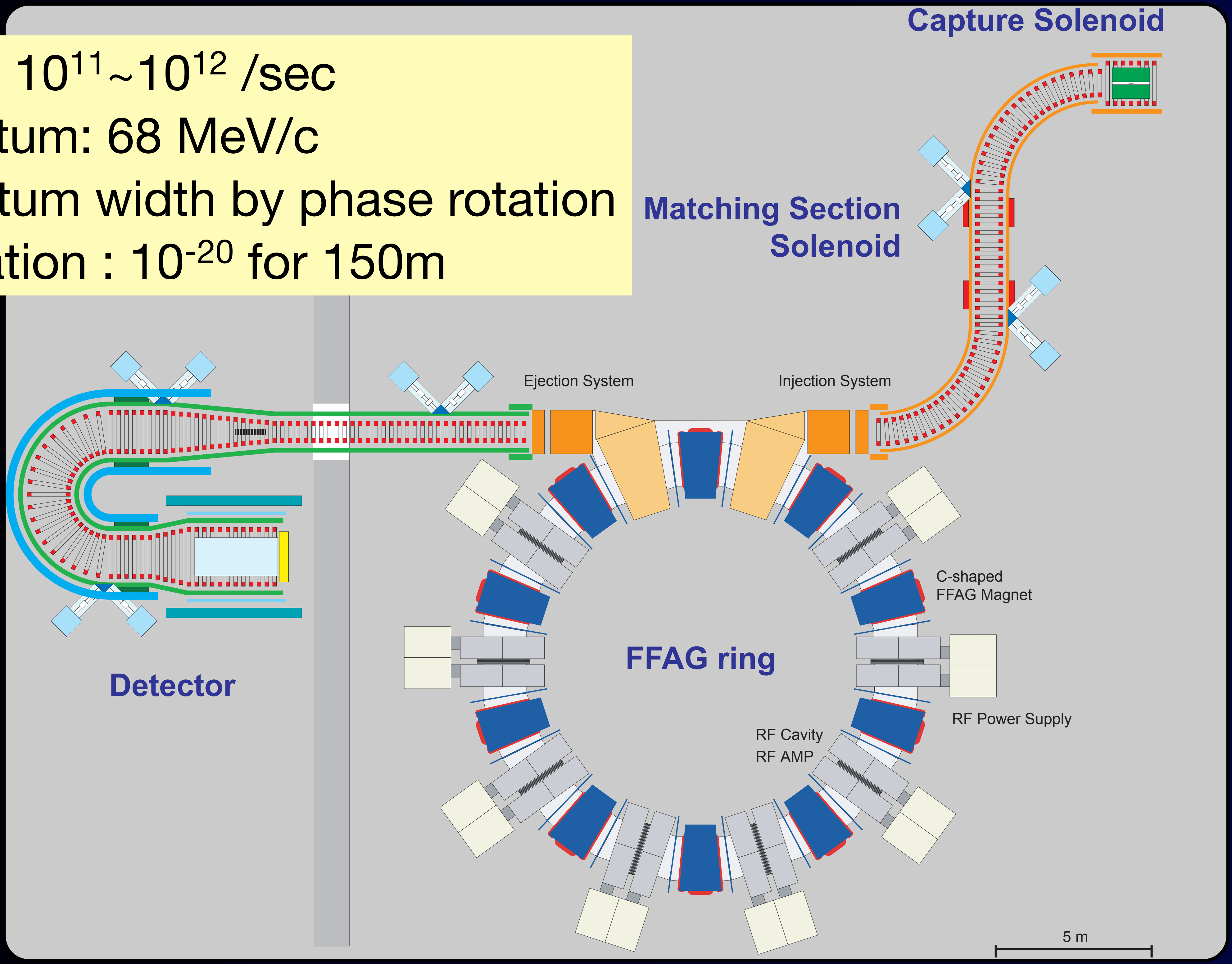
+

Time structure of a beam is very important to consider searches for other various rare processes.
(Discussions will be held tomorrow.)

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



PRISM=Phase Rotated
Intense Slow Muon source

PRISM Muon Beam

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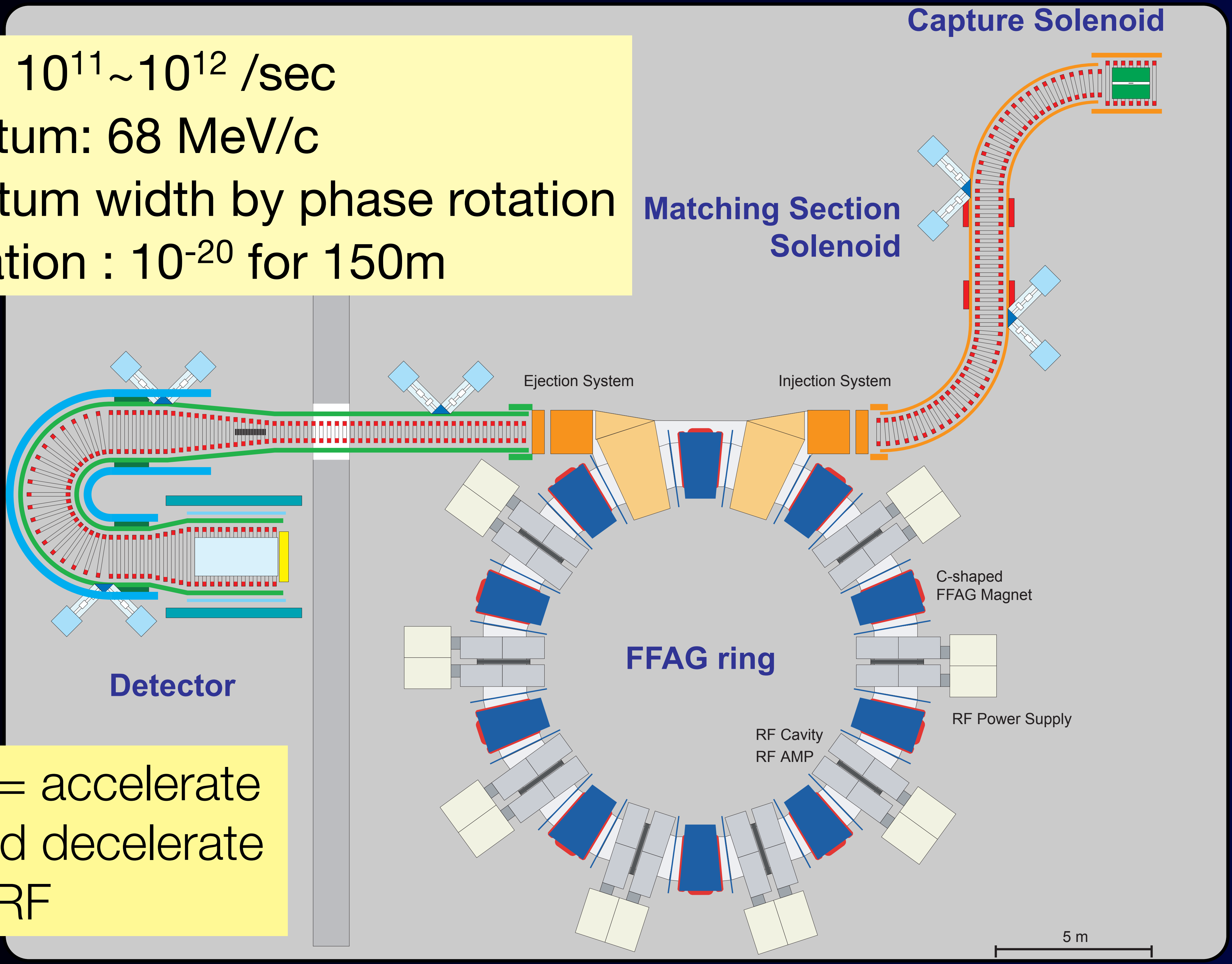


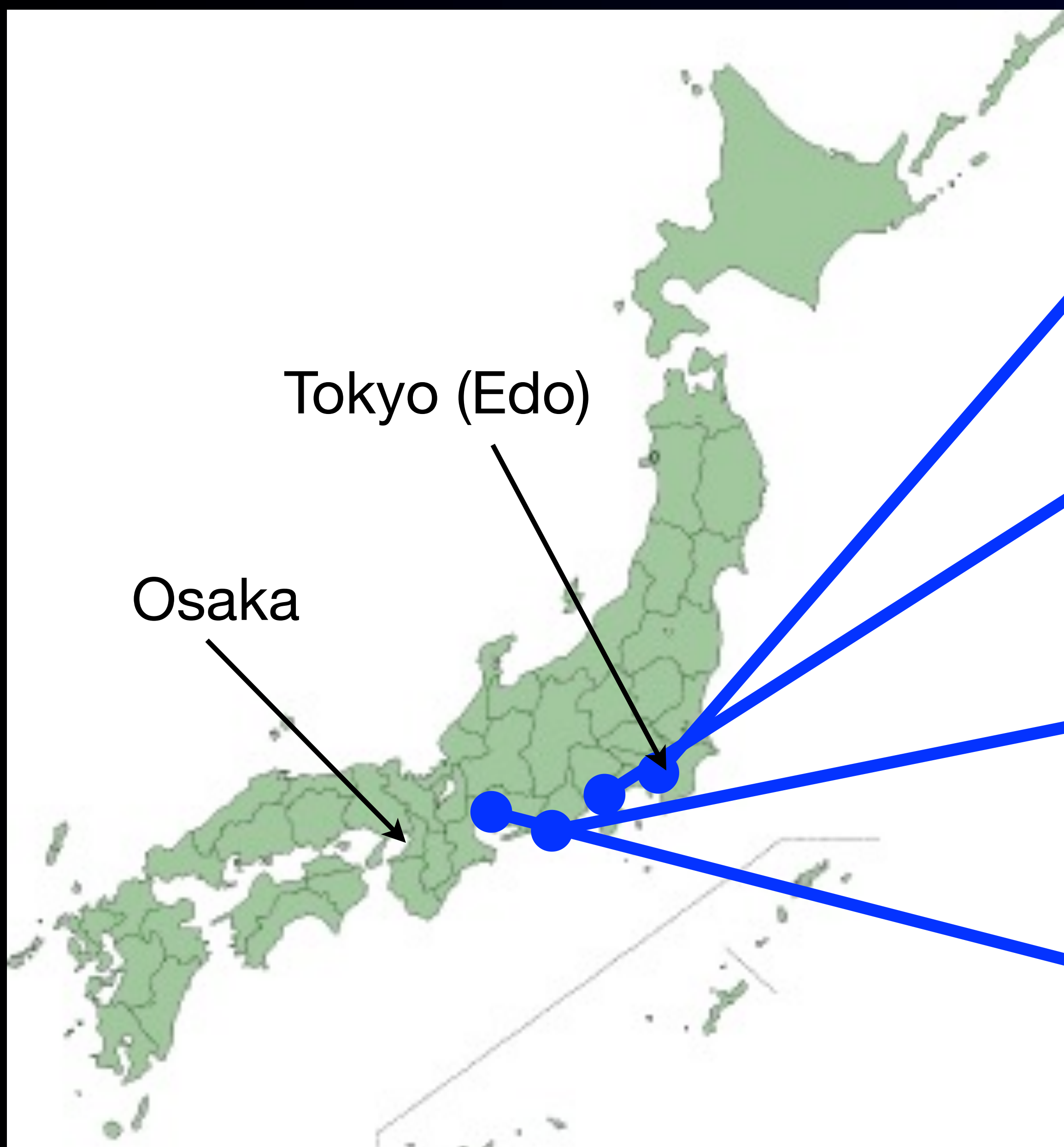
Phase rotation = accelerate slow muons and decelerate fast muons by RF

R&D on the PRISM Muon Storage (FFAG) Ring at Osaka University

Summary

- Physics motivation of cLFV processes is significant and robust in the LHC era.
- The cLFV processes with muons are, for example, $\mu \rightarrow e\gamma$ and μ-e conversion.
- The MEG experiment to search for $\mu \rightarrow e\gamma$ with sensitivity of 10^{-13} is running.
- The next step would be μ-e conversion, where Mu2E (for 10^{-16} sensitivity) in Fermilab and COMET (for 10^{-16} sensitivity) in Japan are being planned.
- For further development, aiming at 10^{-18} sensitivity needs a proton beam of MW power.

The fifty-three stations of the Tokaido (from Tokyo to Osaka) block prints by Hiroshige Utagawa (1797-1858)



A journey has not been complete...

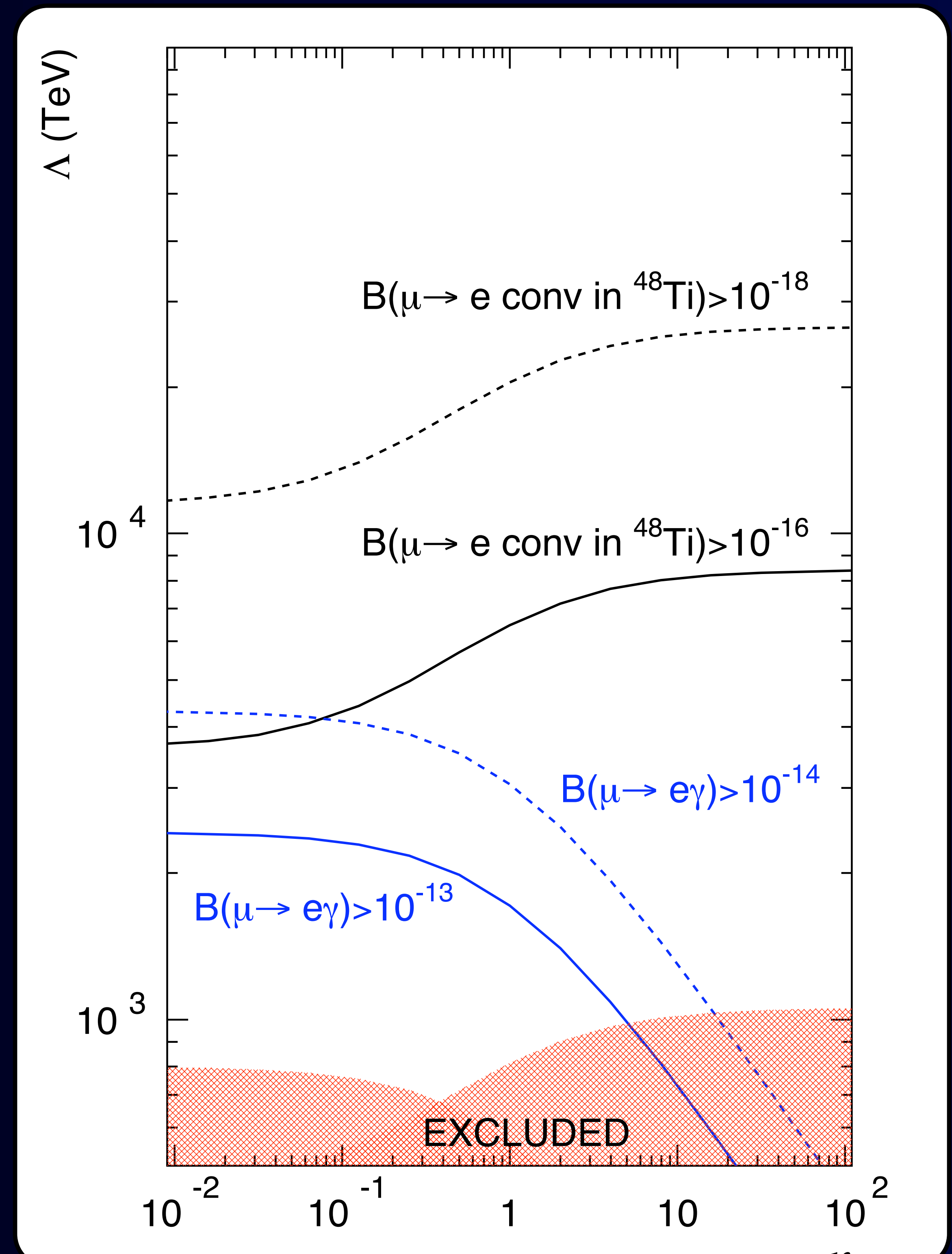
Backups

Physics Sensitivity Comparison between μ→eγ and μ-e Conversion

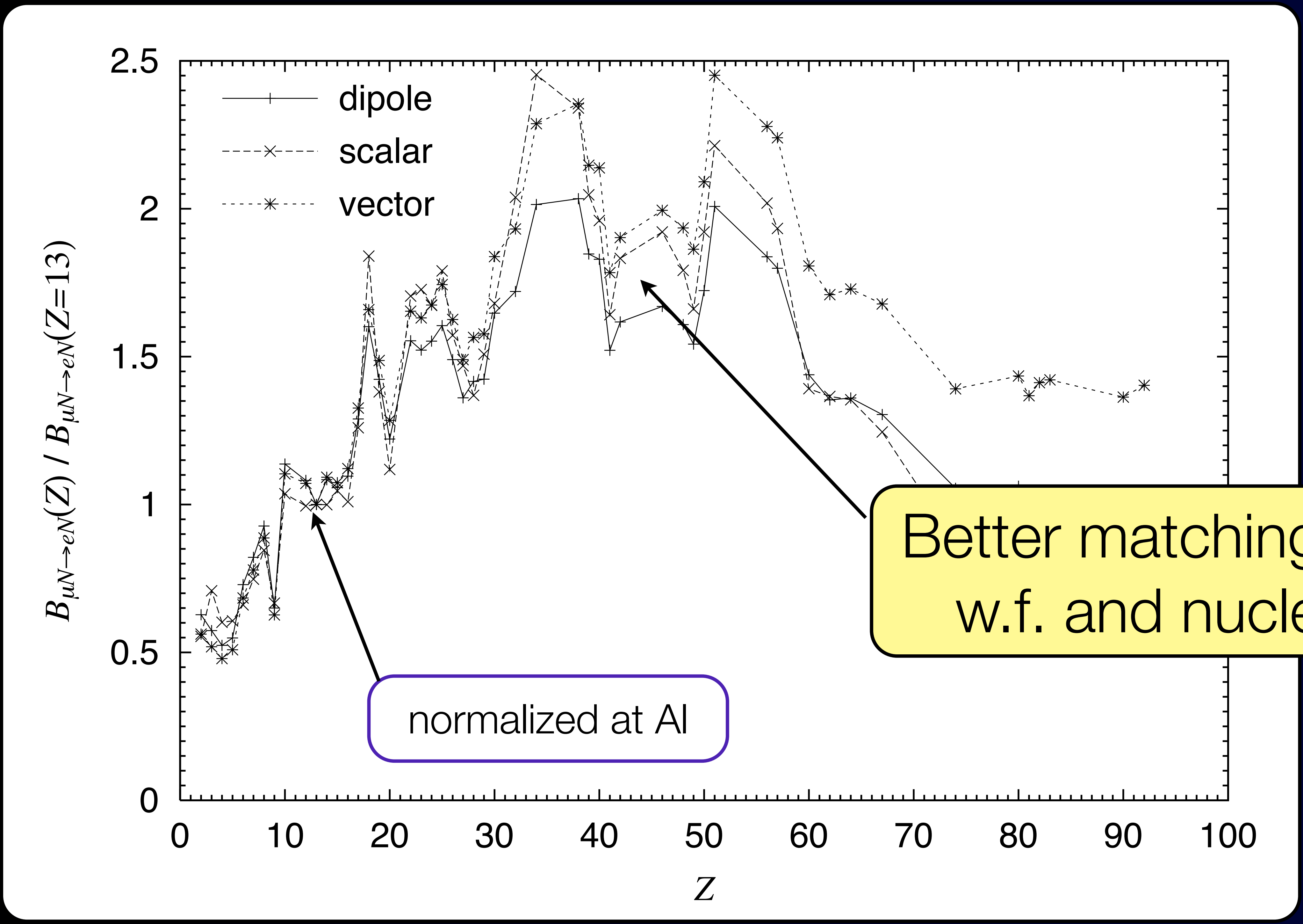
Photonic (dipole) and non-photonic contributions

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

more sensitive to new physics

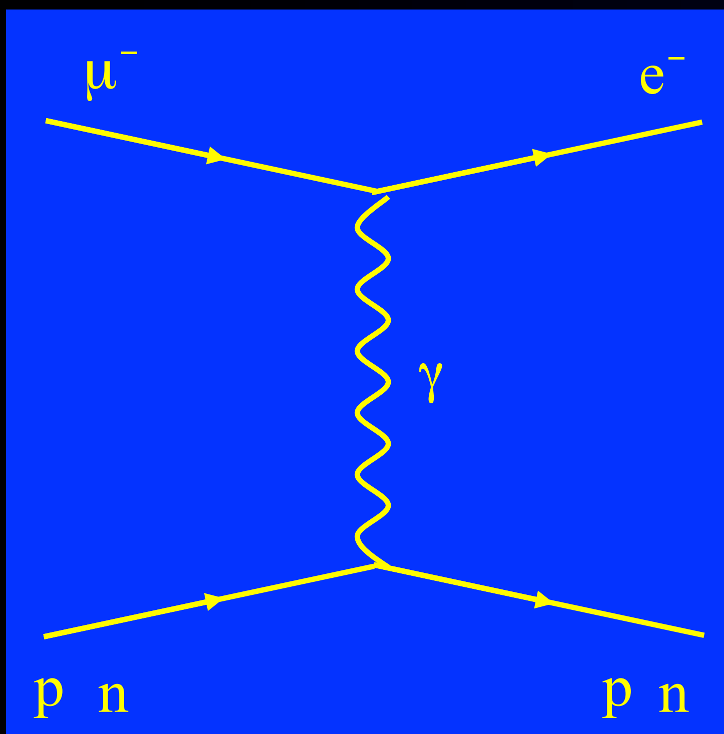


μ-e Conversion : Target dependence (discriminating effective interaction)

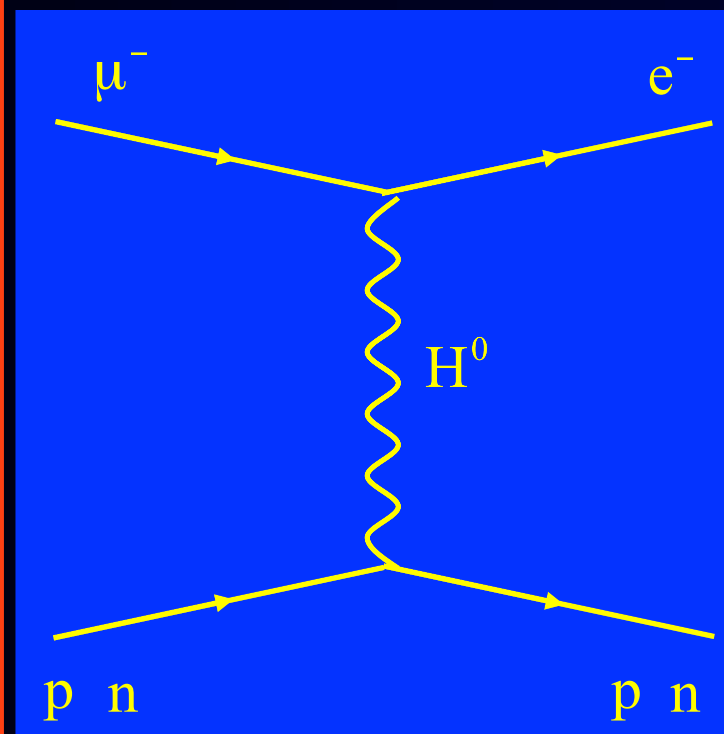


R. Kitano, M. Koike and Y. Okada, Phys. Rev. D66, 096002 (2002)

SUSY Higgs Mediated Contribution (large tanβ)

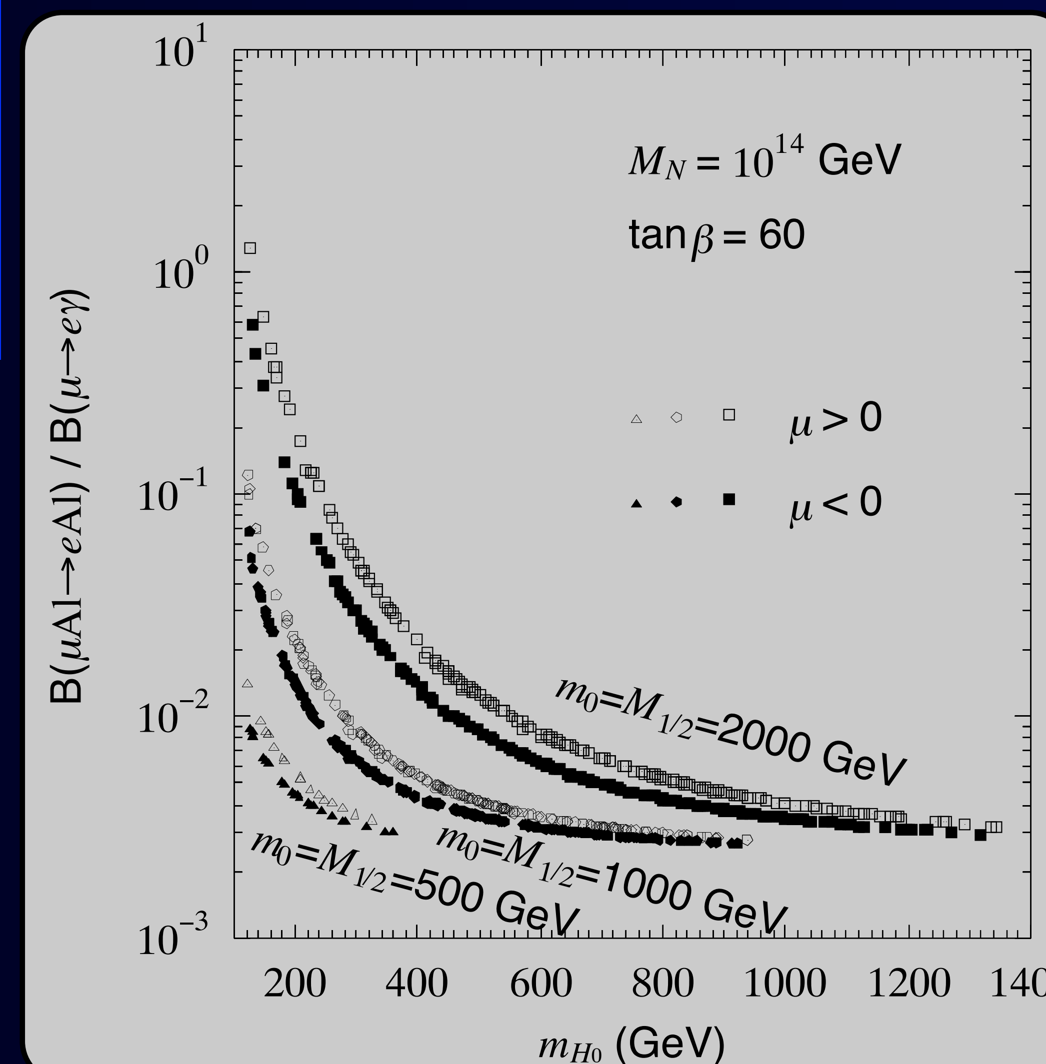


$$\frac{B(\mu N \to e N)}{B(\mu \to e\gamma)} \sim \frac{1}{100}$$



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

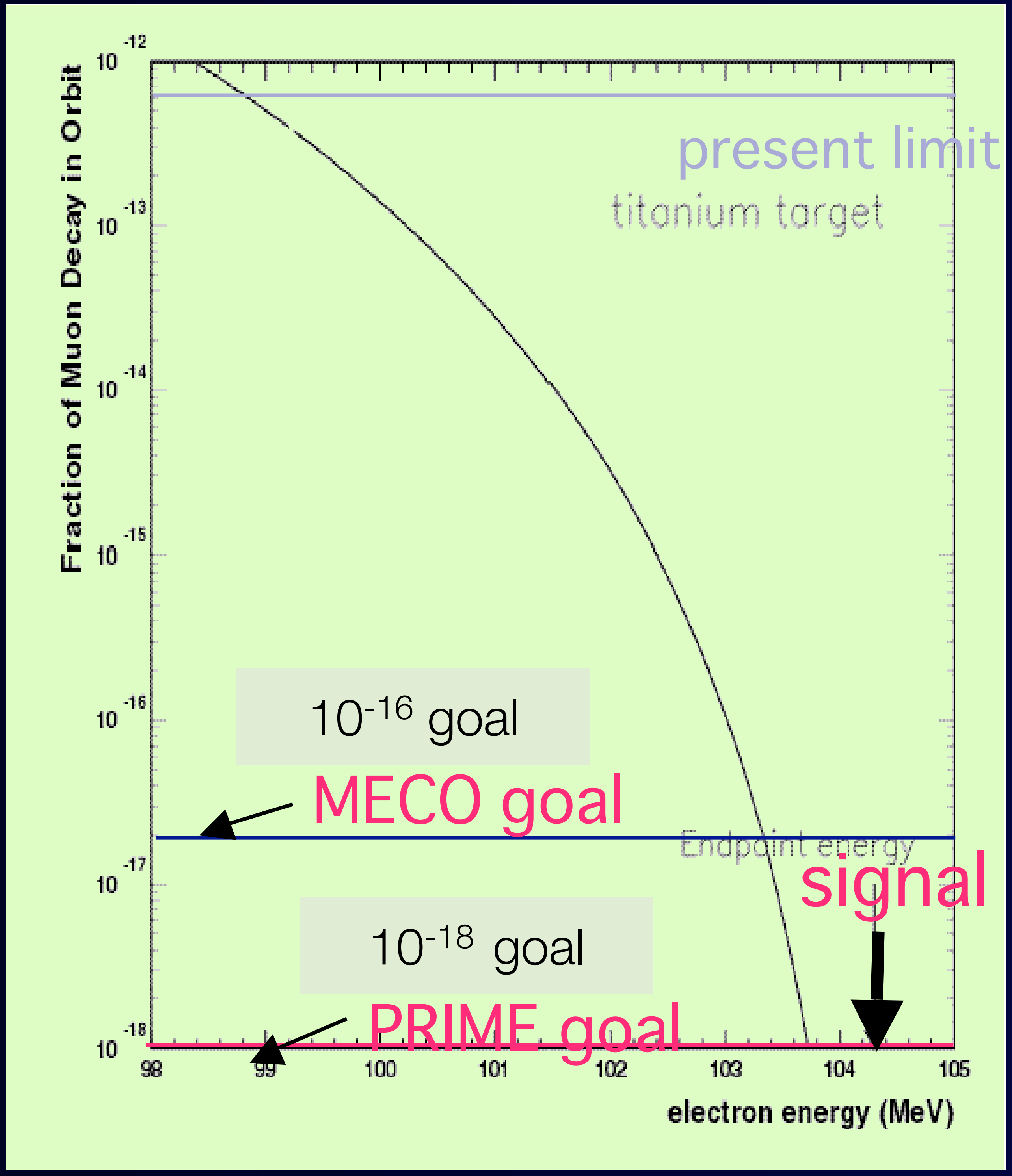
R. Kitano, M. Koike, S. Komine and Y. Okada, Phys. Lett. B575, 300 (2003)



Muon Decay In Orbit (DIO) 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.

$$\propto (\Delta E)^5$$



Design Difference Between Mu2e and COMET

	Mu2e	COMET
Muon Beam-line	S-shape	C-shape
Electron Spectrometer	Straight solenoid	Curved solenoid

Charged Particle Trajectory in Curved Solenoids

- A center of helical trajectory of charged particles in a curved solenoidal field is drifted by

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

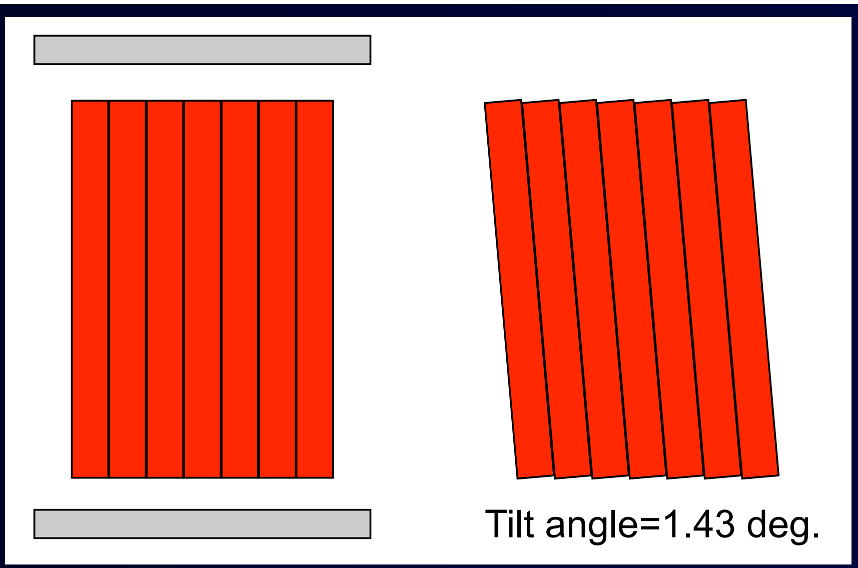
D : drift distance
B : Solenoid field
θ_{bend} *: Bending angle of the solenoid channel*
p : Momentum of the particle
q : Charge of the particle
θ *: atan(*P_T/P_L*)*

  - This can be used for charge and momentum selection.

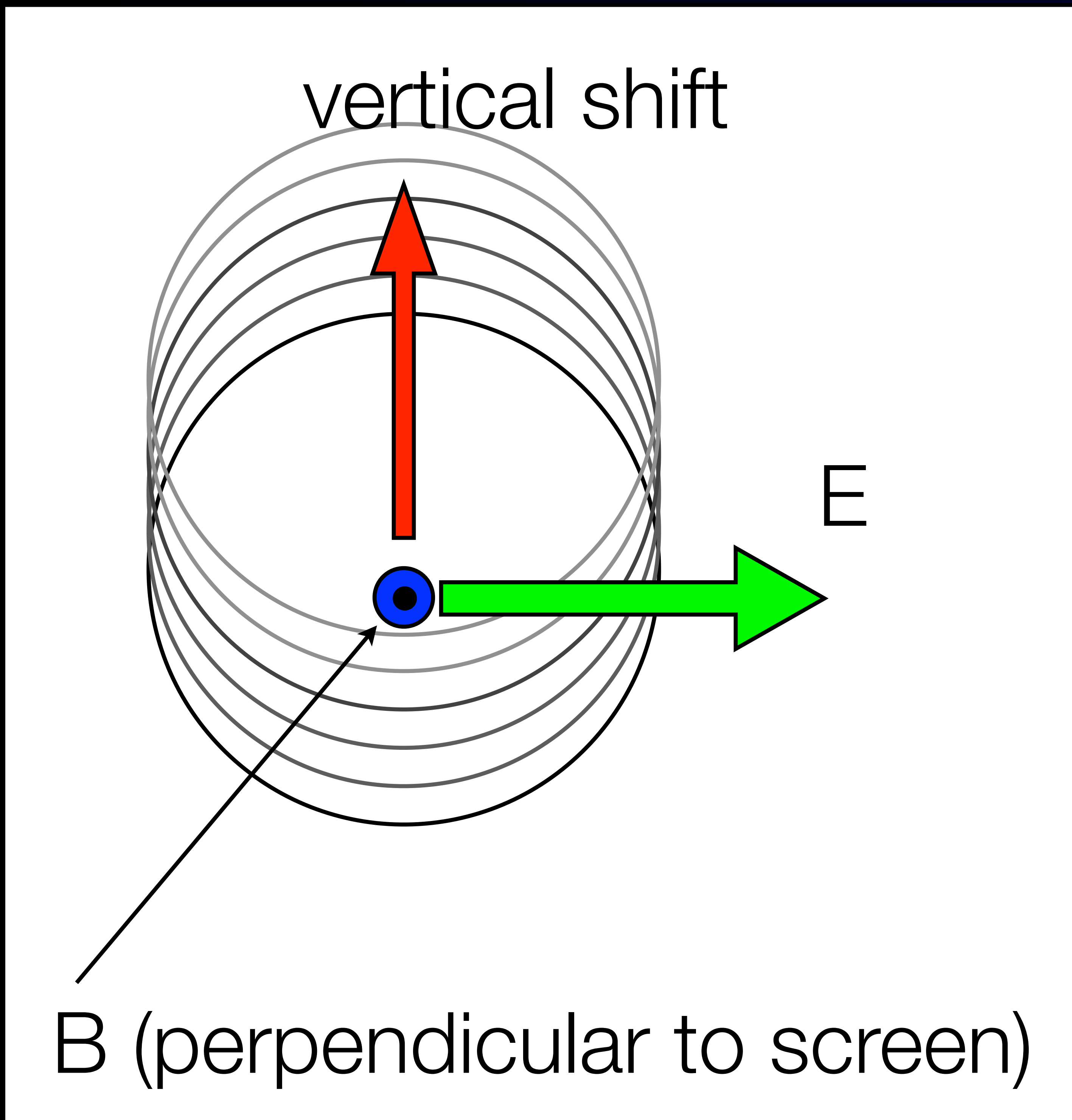
- This drift can be compensated by an auxiliary field parallel to the drift direction given by

$$B_{comp} = \frac{p}{qr}\frac{1}{2}\left(\cos\theta + \frac{1}{\cos\theta}\right)$$

p : Momentum of the particle
q : Charge of the particle
r : Major radius of the solenoid
θ *: atan(*P_T/P_L*)*



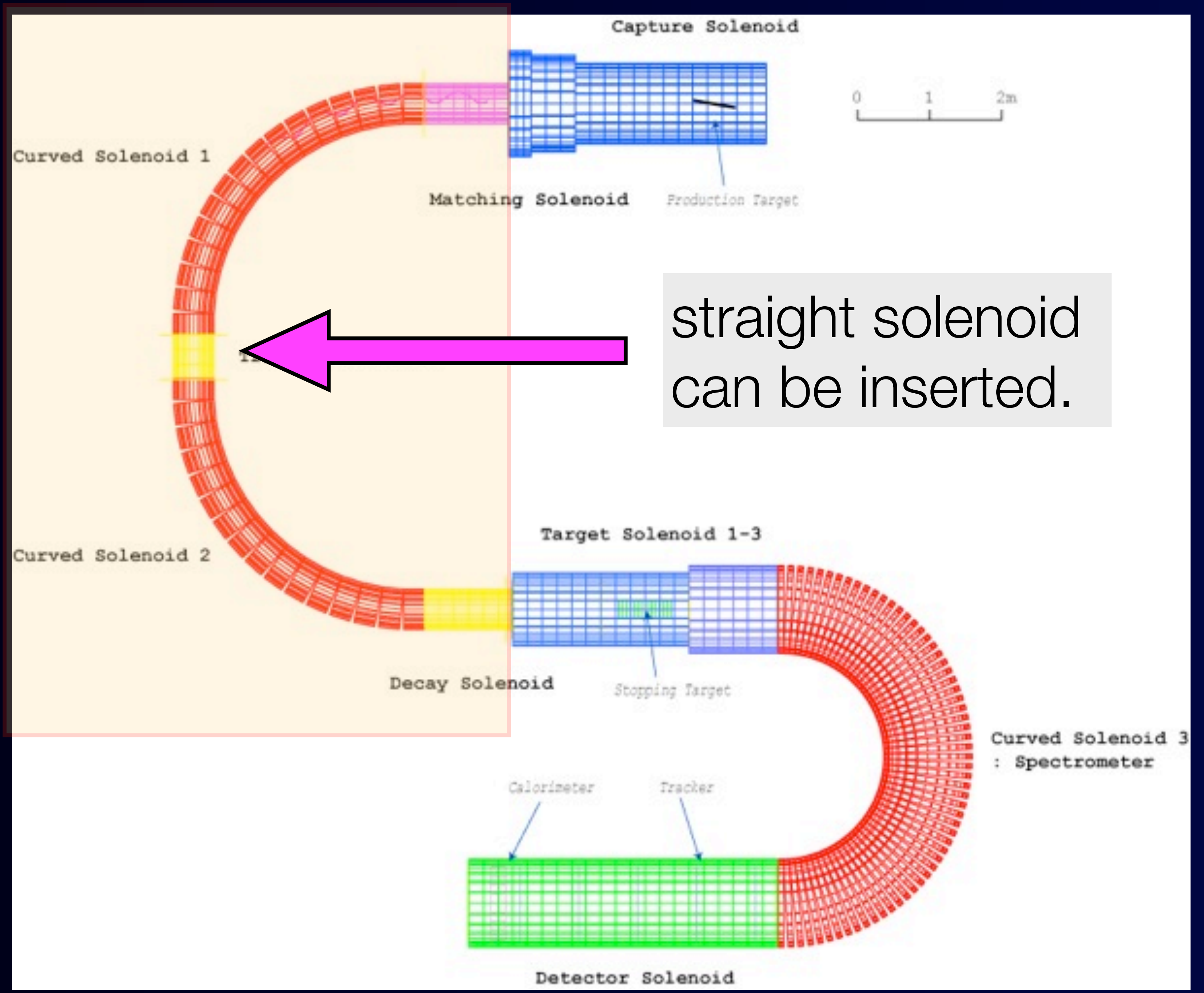
EM Physics for Particle Trajectories in Toroidal Magnetic Field



- For helical trajectory in a curved mag. field, a centrifugal force gives E in the radial direction.
- To compensate a vertical shift, an electric field in the opposite direction shall be applied, or a vertical mag. field that produces the desired electric field by v x B, can be applied.

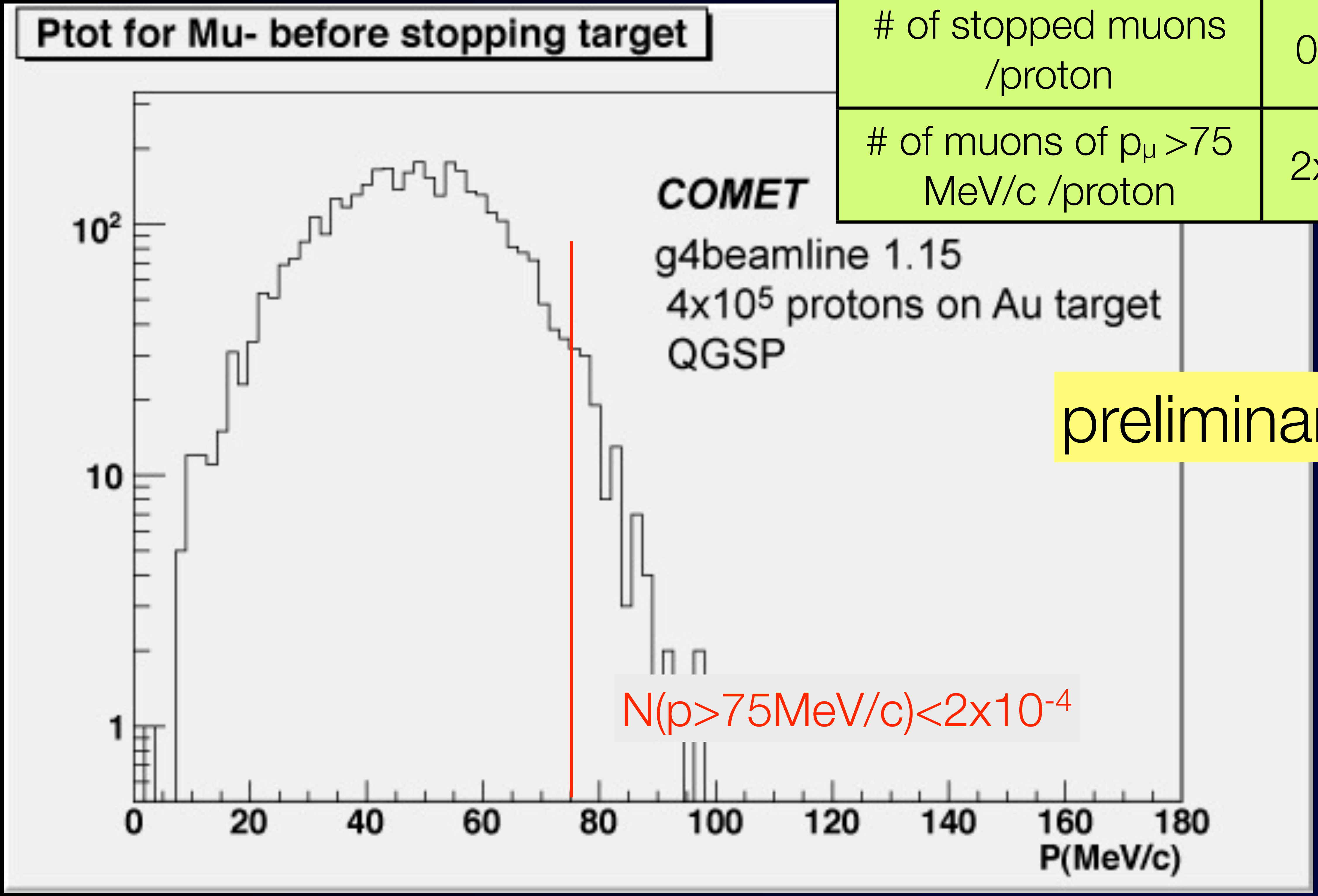
Muon Transport Solenoid Beam-line for COMET

- C-shape beam line :
  - better beam momentum separation
  - collimators can be placed anywhere.
- Radius of curvature is about 3 meters.
- A straight solenoid section can be inserted between the two toroids.
- Reference momentum is 35 MeV/c for 1st bend and 47 MeV/c for 2nd bend.



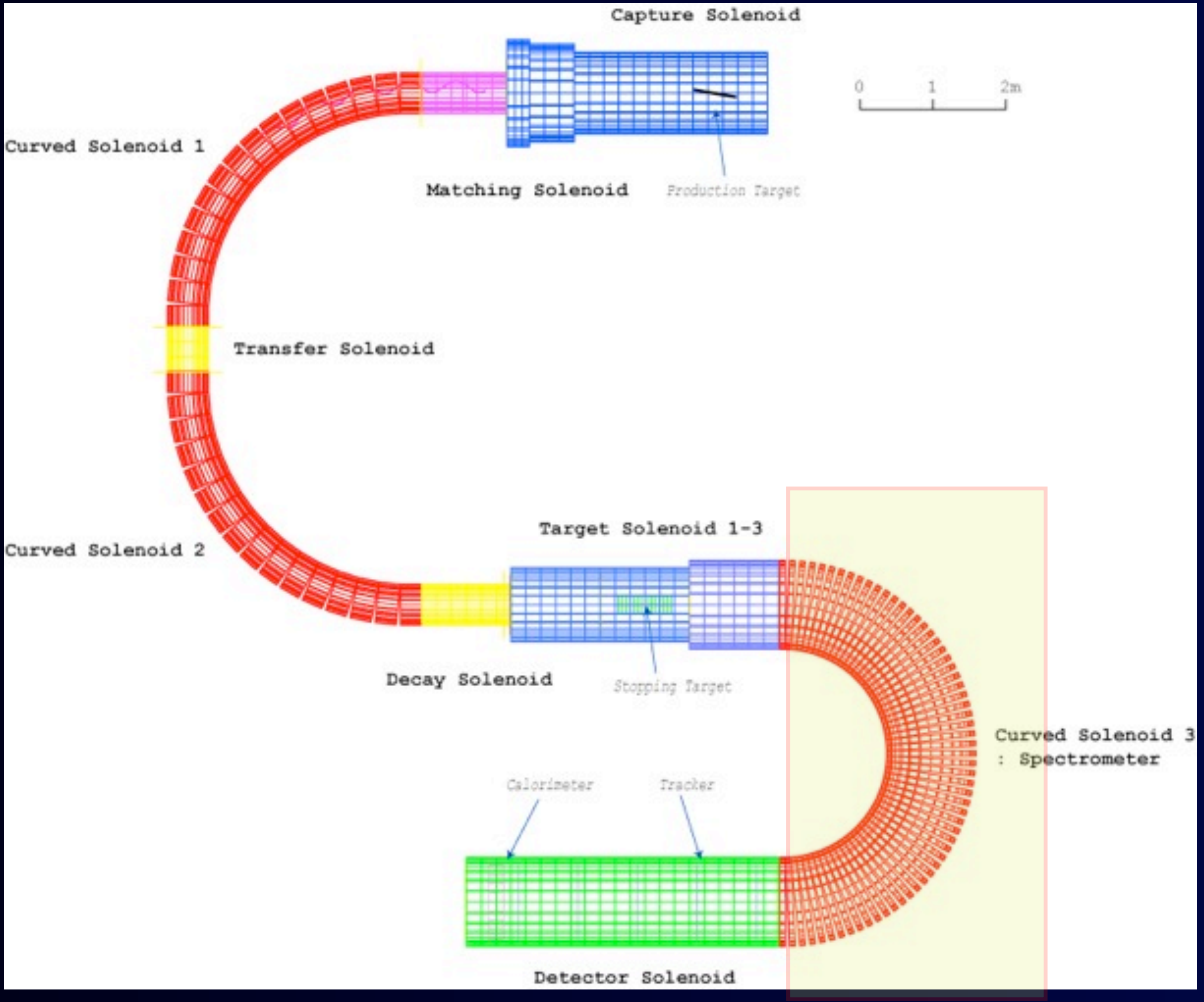
Muon Momentum Spectrum at the End of the Transport Beam Line

# of muons /proton	0.009
# of stopped muons /proton	0.003
# of muons of p_μ >75 MeV/c /proton	$2x10^{-4}$



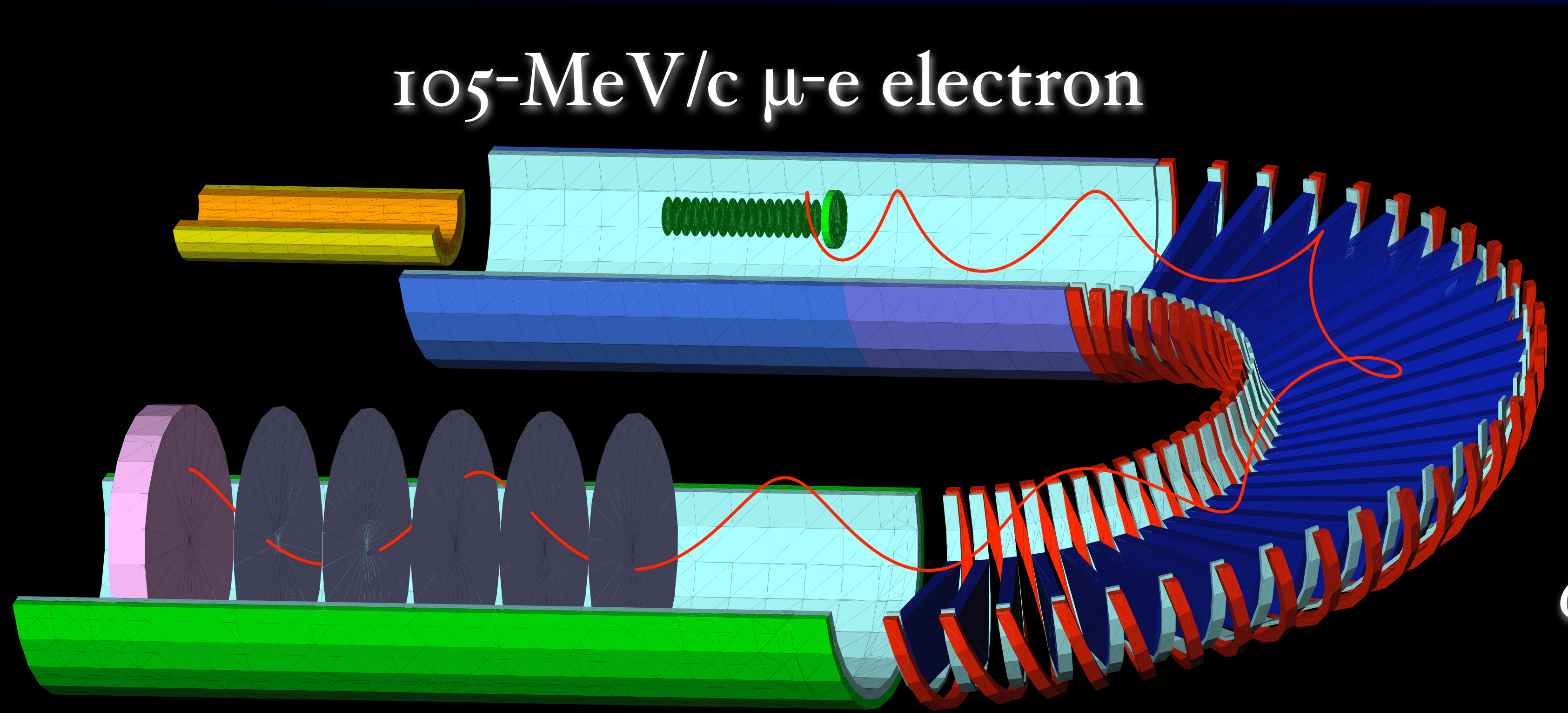
Curved Solenoid Spectrometer for COMET

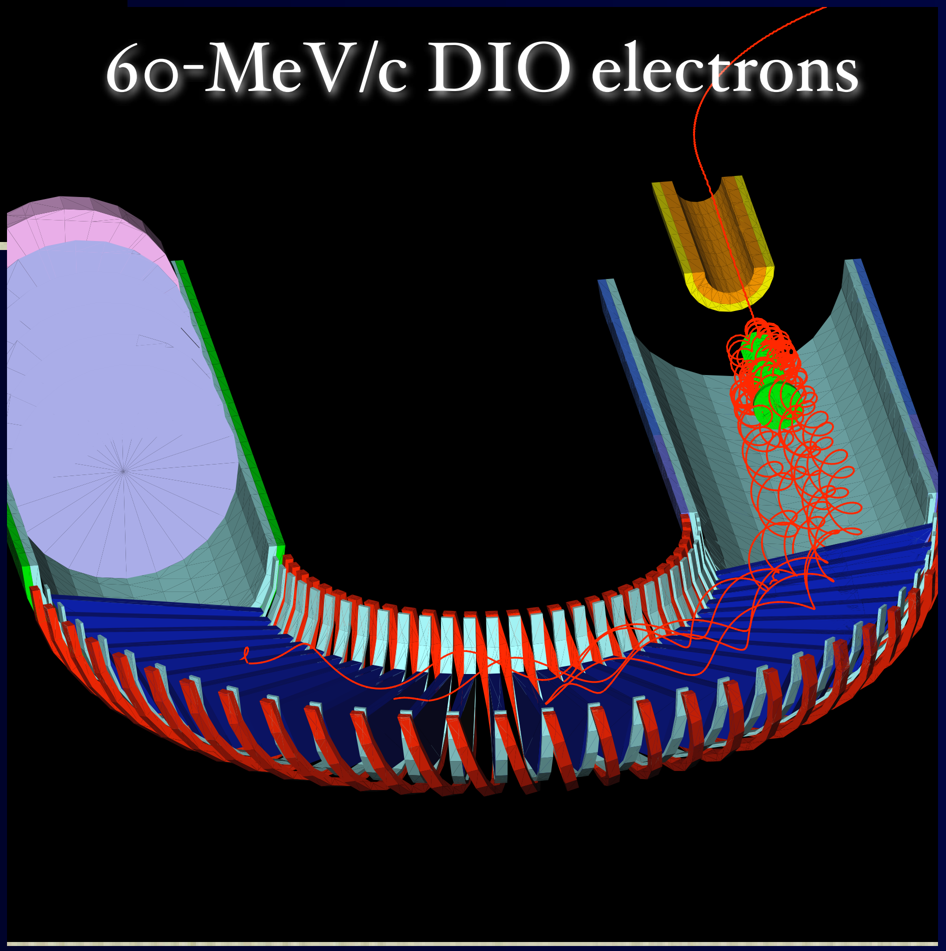
- 180 degree curved
  - Bore radius : 50 cm
  - Magnetic field : 1T
  - Bending angle : 180 degrees
- reference momentum ~ 104 MeV/c
- elimination of particles less than 80 MeV/c for rate issues
- a straight solenoid where detectors are placed follows the curved spectrometer.



schematic

Event Displays for Curved Solenoid Spectrometer



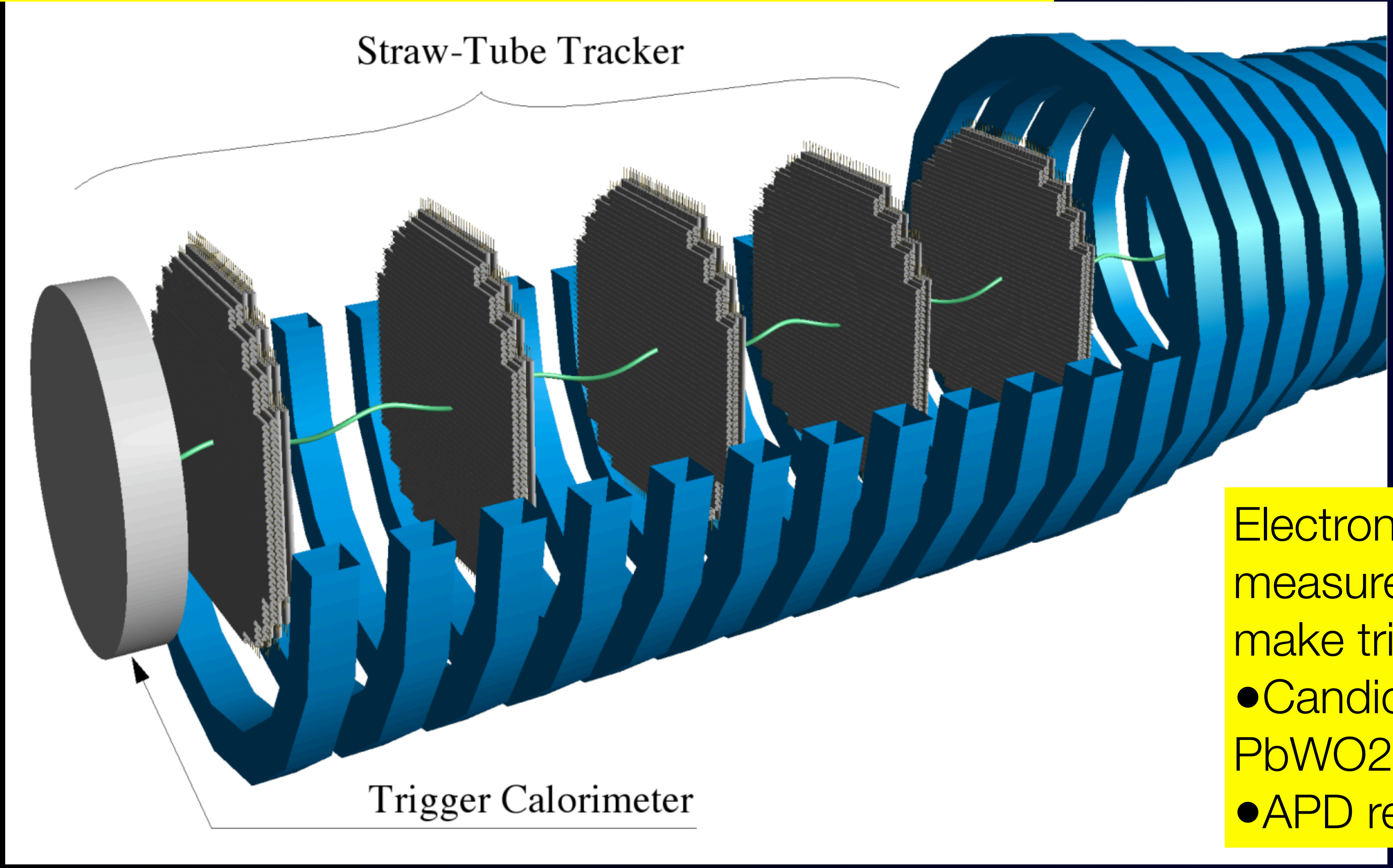


Electron Detection (preliminary)

Straw-tube Trackers to measure electron momentum.
- should work in vacuum and under a magnetic field.
- A straw tube has 25μm thick, 5 mm diameter.
- One plane has 2 views (x and y) with 2 layers per view.
- Five planes are placed with 48 cm distance.
- 250μm position resolution.

Under a solenoidal magnetic field of 1 Tesla.

In vacuum to reduce multiple scattering.



Electron calorimeter to measure electron energy and make triggers.
- Candidate are GSO or PbWO2.
- APD readout (no PMT).