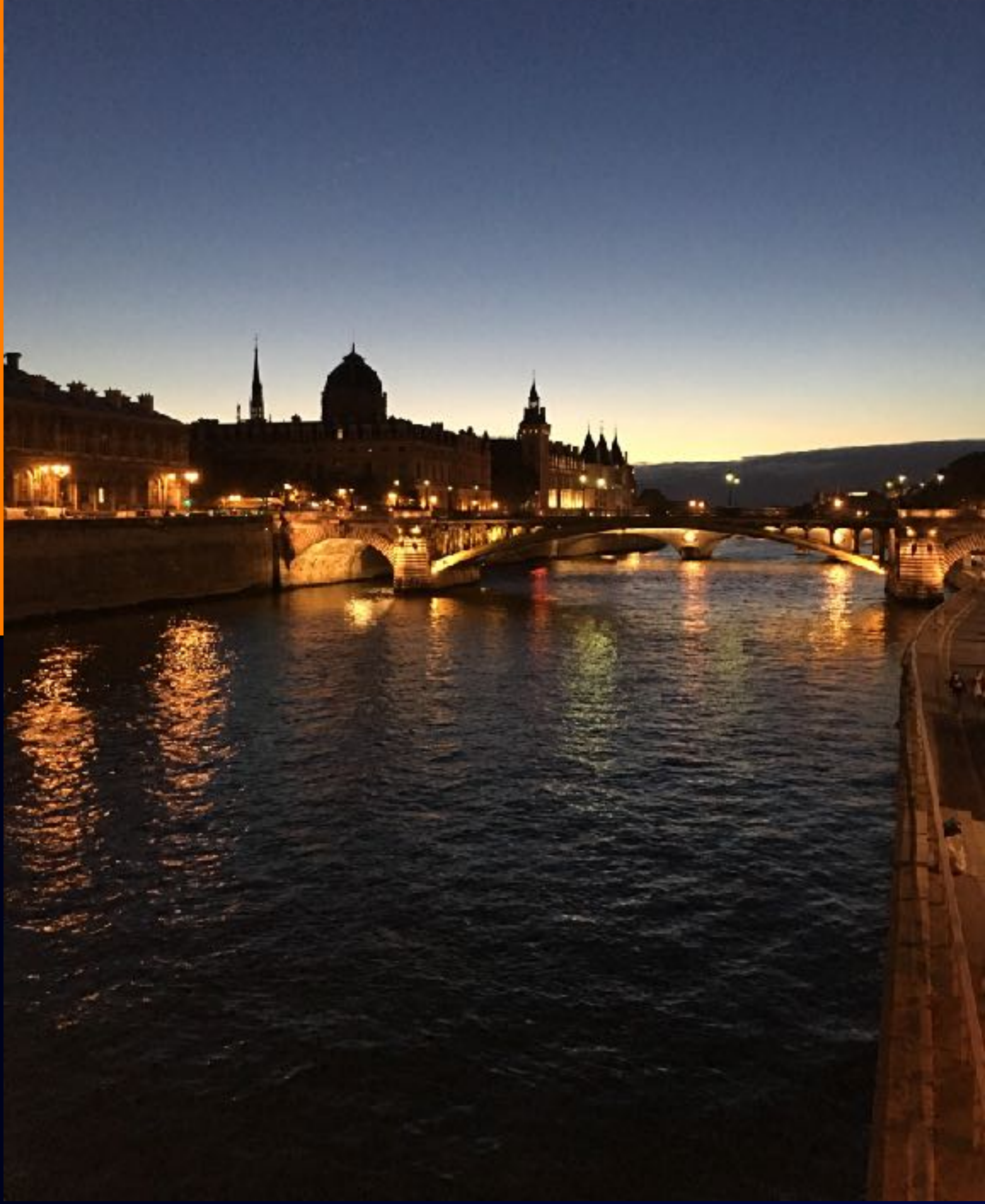
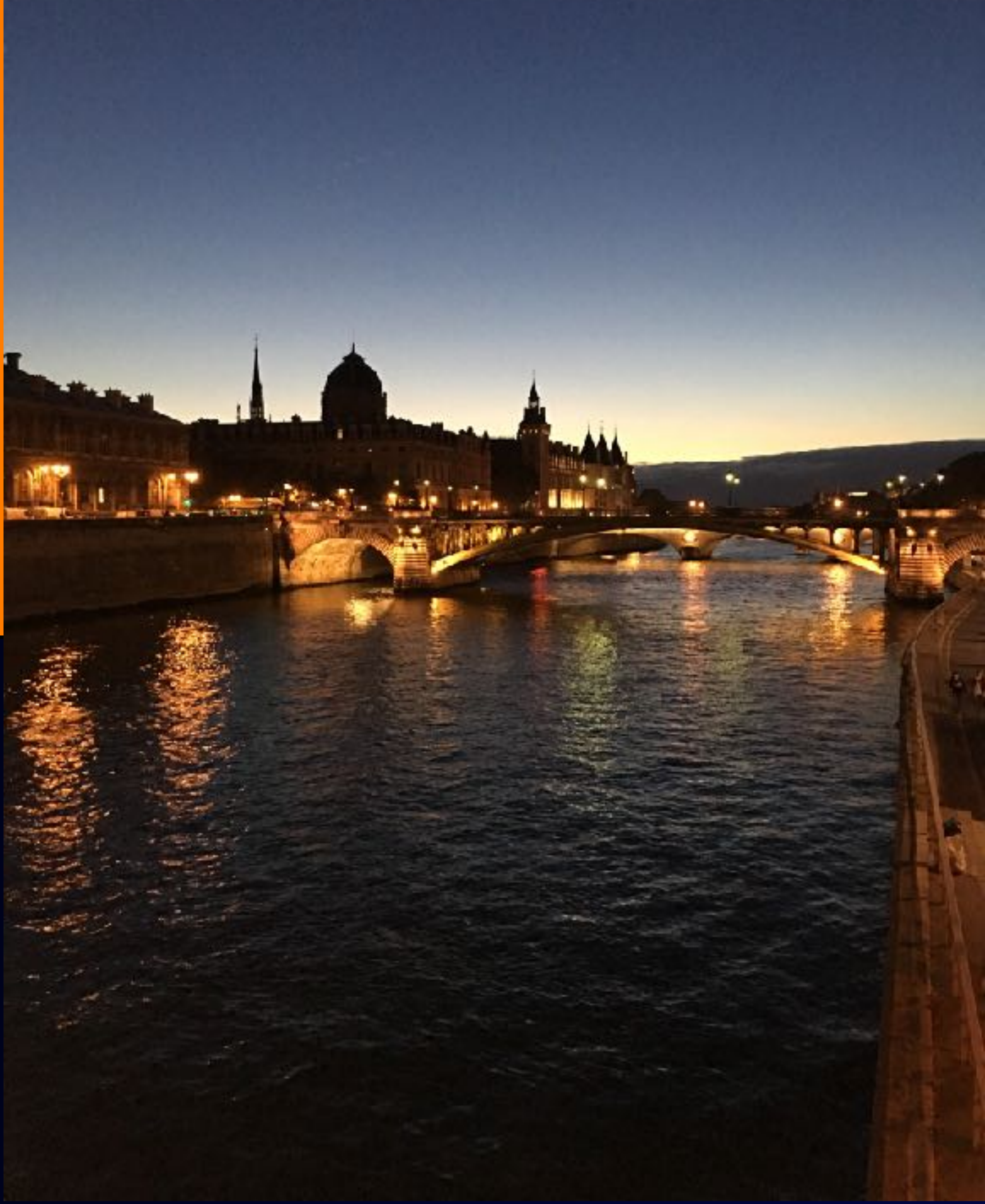
Overview of Muon LFV Experiments



Overview of Muon LFV Experiments

Yoshitaka Kuno
Department of Physics,
Osaka University

LFV/LFUV Workshop
November 9th, 2016
Paris



Outline

- Why Charged Lepton Flavor Violation (CLFV)?
- CLFV Processes with Muons
  - μ→eγ
    - MEG
  - μ→eee
    - Mu3e
  - μ-e conversion
    - Mu2e
    - COMET
    - COMET Phase-I
- Future Prospects
- Summary

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single-purpose experiments

Why CLFV ?

COMET μ e

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Why Rare Decays ?

Effective Lagrangian with New Physics

Effective Lagrangian with New Physics

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \frac{C_{\rm NP}}{\Lambda^2} O_{ij}^{(6)}$$

dimension 6

Λ is the energy scale of new physics （～m_{NP}）

C_{NP} is the coupling constant.

Effective Lagrangian with New Physics

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dimension 6

Λ is the energy scale of new physics （$\sim m_{NP}$)

C_{NP} is the coupling constant.

New Physics could be….

very high energy scale Λ with $C_{NP} \sim 1$

or

very small C_{NP} with not-high energy Λ

Effective Lagrangian with New Physics

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ex: Charged lepton flavor violation (CLFV), μ→eγ ($B<4.2 \times 10^{-13}$ from MEG(2016))

$$\frac{C_{\rm NP}}{\Lambda^2} O_{ij}^{(6)} \to \frac{C_{\mu e}}{\Lambda^2} \overline{e}_L \sigma^{\rho\nu} \mu_R \Phi F_{\rho\nu}$$

$$\Lambda > 2 \times 10^5 \ {\rm TeV} \times (C_{\mu e})^{\frac{1}{2}} \ .$$

Λ > O(10^5) TeV with $C_{\mu e}$~O(1)

or

$C_{\mu e}$~O(10^{-9}) with Λ < O(1) TeV

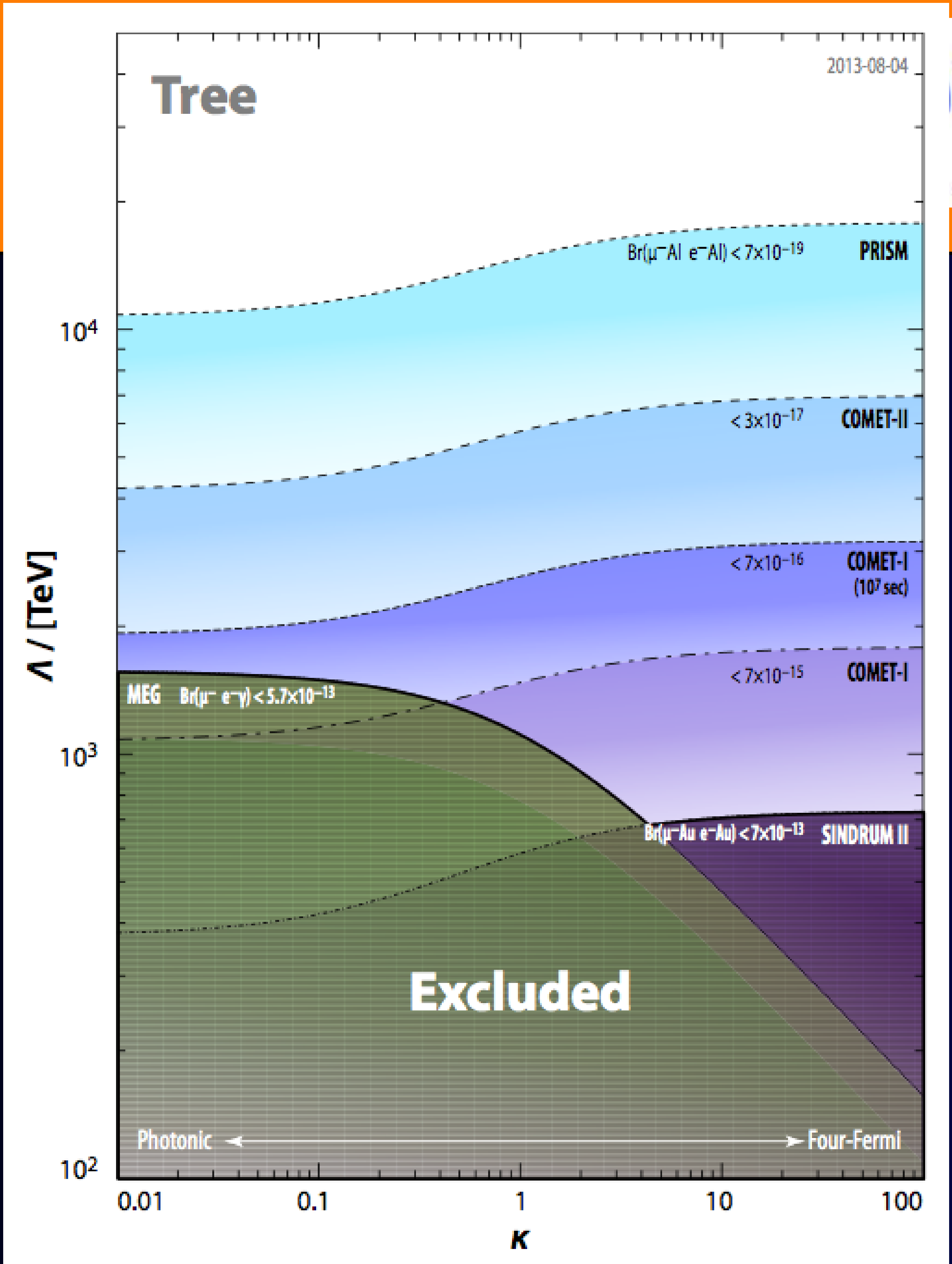
Why Rare Decays ?

Energy reach of New Physics by rare decays such as CLFV

$\Lambda > O(10^5)$TeV

(Indirect search)

It would be strategic to pursue rare decays Before high energy machines (100 TeV).



COMET

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Why Leptons ?

FCNC
(Flavor Changing Neutral Current)

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Quark Sector
(SM suppressed)

SM + NP

Uncertainty of
the SM prediction
Limits the
sensitivity.

SM contribution has to be subtracted.

ex. B→s γ

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(Flavor Changing Neutral Current)

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Lepton Sector
(SM forbidden)

+ NP

Clear signature without any subtractions

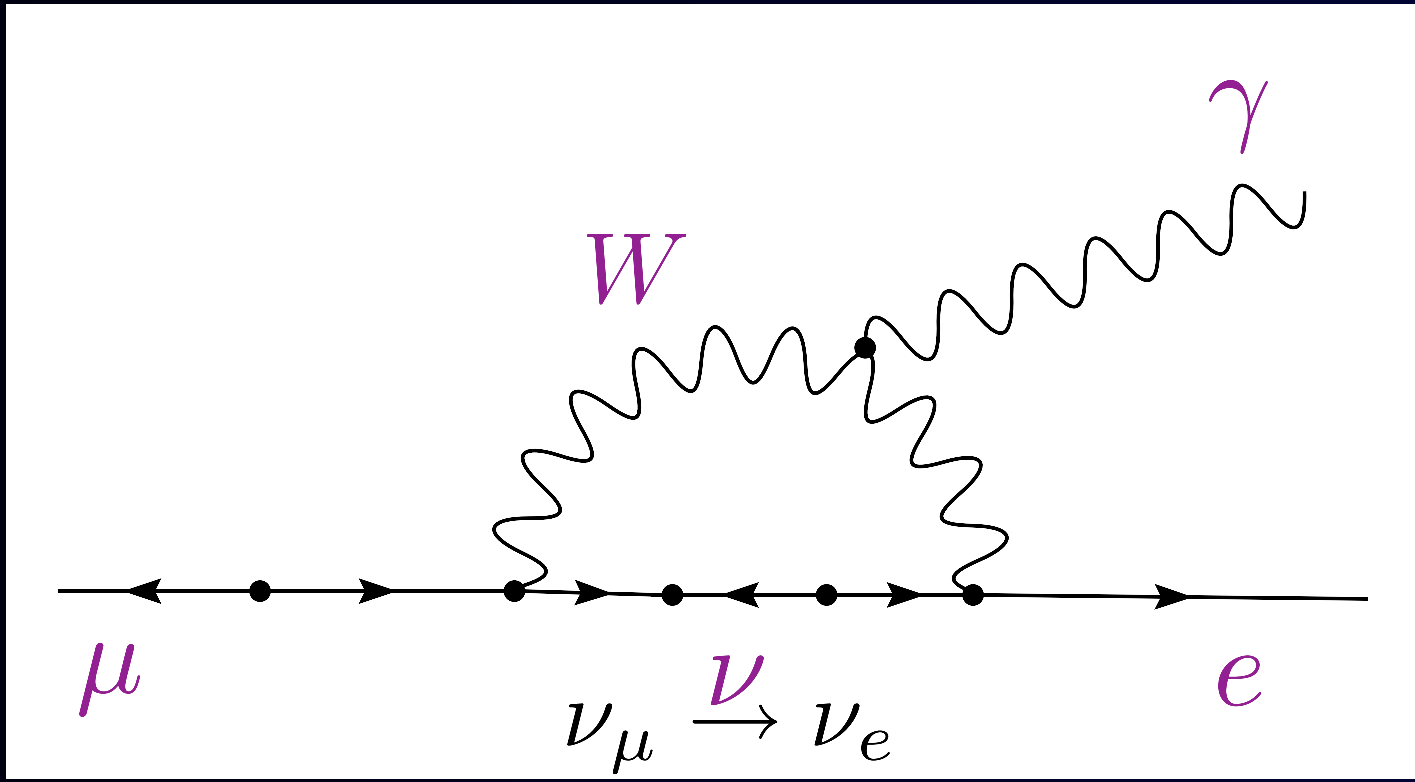
No SM contribution be subtracted.

ex. $\mu \rightarrow e \gamma$

Rare Process
No SM Contribution to CLFV

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

GIM suppression



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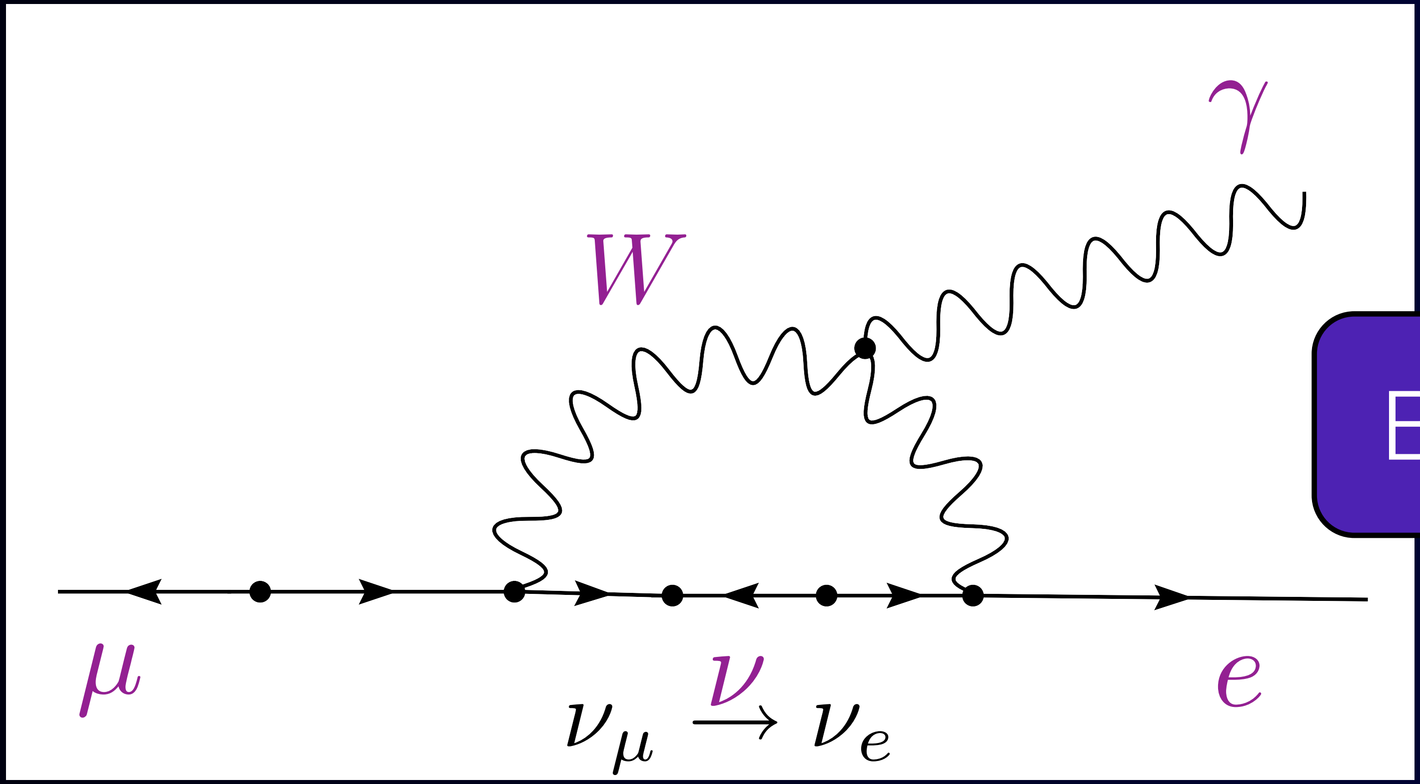

BR~O(10^{-54})

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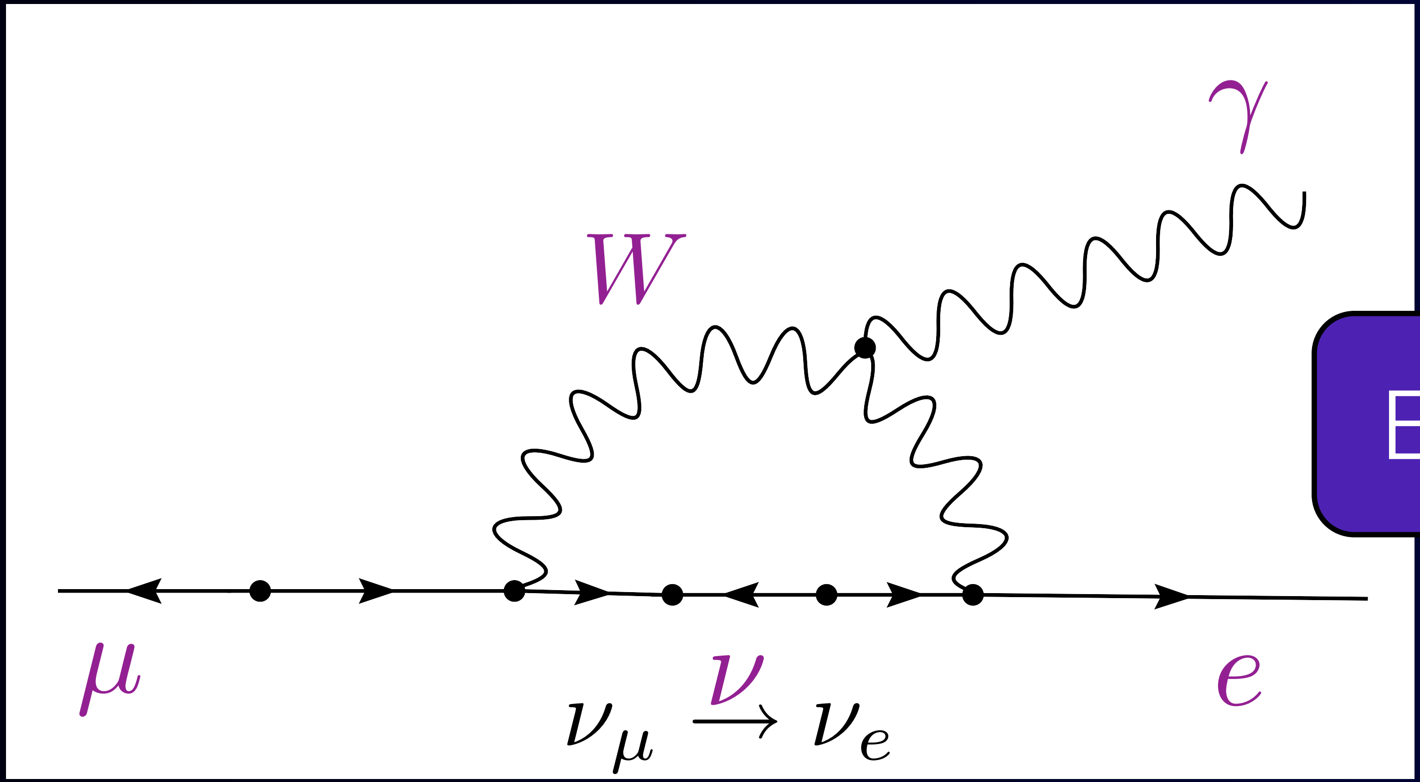

BR~O(10^{-54})

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

Quarks (SM-suppressed) and Leptons (SM-forbidden)

Quarks (SM-suppressed) and Leptons (SM-forbidden)

$$|A_{SM}|^2 \pm \Delta(|A_{SM}|^2)$$

Quark (SM suppressed)

amplitude

$$|A_{\rm SM} + \varepsilon_{\rm NP}|^2 \sim |A_{\rm SM}|^2 + \underline{2Re(A_{\rm SM}\varepsilon_{\rm NP})} + |\varepsilon_{\rm N}|^2$$

subject to uncertainty of SM prediction

NP contribution ~ O(ε)

rate

Lepton (SM forbidden)

$$|A_{\rm SM} + \varepsilon_{\rm NP}|^2 \sim \cancel{|A_{\rm SM}|^2} + 2Re(\cancel{A_{\rm SM}}\varepsilon_{\rm NP}) + \underline{|\varepsilon_{\rm N}|^2}$$

could go higher energy scale

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could go higher energy scale

NP contribution ~ $O(\varepsilon^2)$

$$R \propto \frac{1}{\Lambda^4}$$

$\Lambda \geqq$ x10 —> $R \leqq 10^{-4}$

Various Models Predict CLFV......

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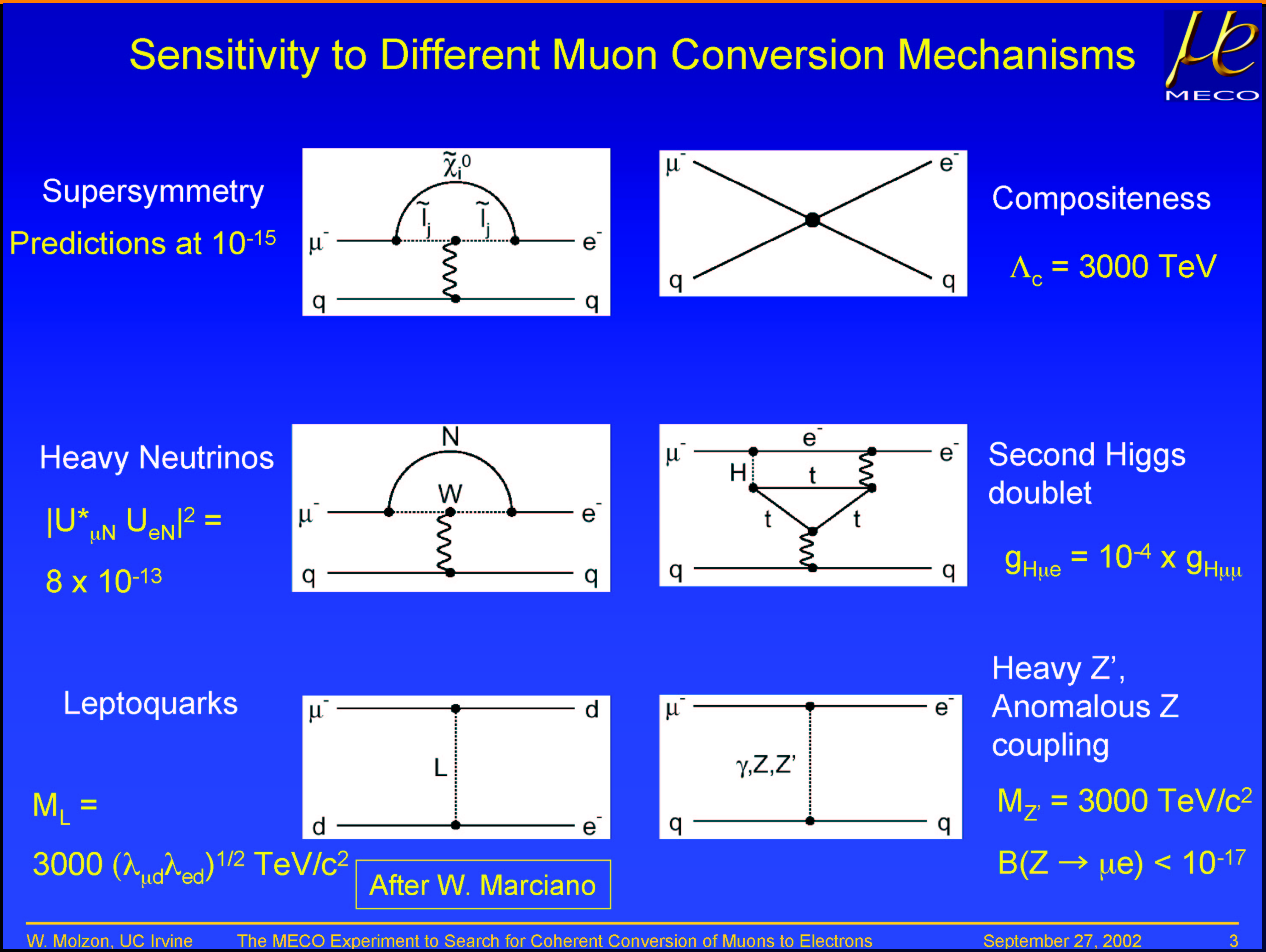

Example of Sensitivity to NP in High Energy Scale : SUSY models

- For loop diagrams,

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

$$y = \frac{g^2}{16\pi^2}\theta_{\mu e}$$

> sensitive to TeV energy scale with reasonable mixing

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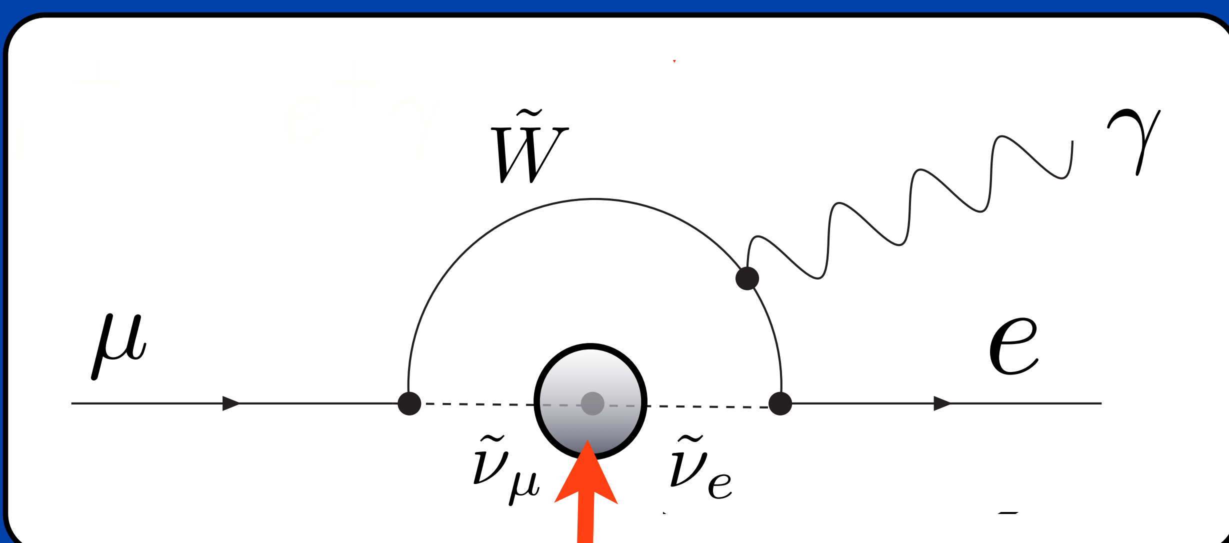

example diagram for SUSY (~TeV)

Physics at about 10^{16} GeV

slepton mixing (from RGE)

$$(m^2_{\tilde{L}})_{21} \sim \frac{3m_0^2 + A_0^2}{8\pi^2} h_t^2 V_{td} V_{ts} \ln \frac{M_{GUT}}{M_{R_s}}$$

SUSY-GUT model

$$(m^2_{\tilde{L}})_{21} \sim \frac{3m_0^2 + A_0^2}{8\pi^2} h_\tau^2 U_{31} U_{32} \ln \frac{M_{GUT}}{M_R}$$

SUSY neutrino seesaw model

COMET

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Why Muons ?

Why muons, not taus ?

of taus
~ $O(10^9)$/year

super KEKB

# of muons
~ $O(10^{15})$/year

PSI

Why muons, not taus ?

of taus
~ O(10^9)/year

super KEKB

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~ O(10^{15})/year

PSI

# of muons
~ O(10^{18})/year

Muon CLFV Experiments

Experimental Limits at Present and in the Future

process	present limit	future	
$\mu \rightarrow e\gamma$	$<4.2 \times 10^{-13}$	$<10^{-14}$	MEG at PSI
$\mu \rightarrow eee$	$<1.0 \times 10^{-12}$	$<10^{-16}$	Mu3e at PSI
$\mu N \rightarrow eN$ (in Al)	none	$<10^{-16}$	Mu2e / COMET
$\mu N \rightarrow eN$ (in Ti)	$<4.3 \times 10^{-12}$	$<10^{-18}$	PRISM
$\tau \rightarrow e\gamma$	$<1.1 \times 10^{-7}$	$<10^{-9} - 10^{-10}$	superKEKB
$\tau \rightarrow eee$	$<3.6 \times 10^{-8}$	$<10^{-9} - 10^{-10}$	superKEKB
$\tau \rightarrow \mu\gamma$	$<4.5 \times 10^{-8}$	$<10^{-9} - 10^{-10}$	superKEKB
$\tau \rightarrow \mu\mu\mu$	$<3.2 \times 10^{-8}$	$<10^{-9} - 10^{-10}$	superKEKB/LHCb

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$X10^{-4}$

List of cLFV Processes with Muons

ΔL=1

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

ΔL=2

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

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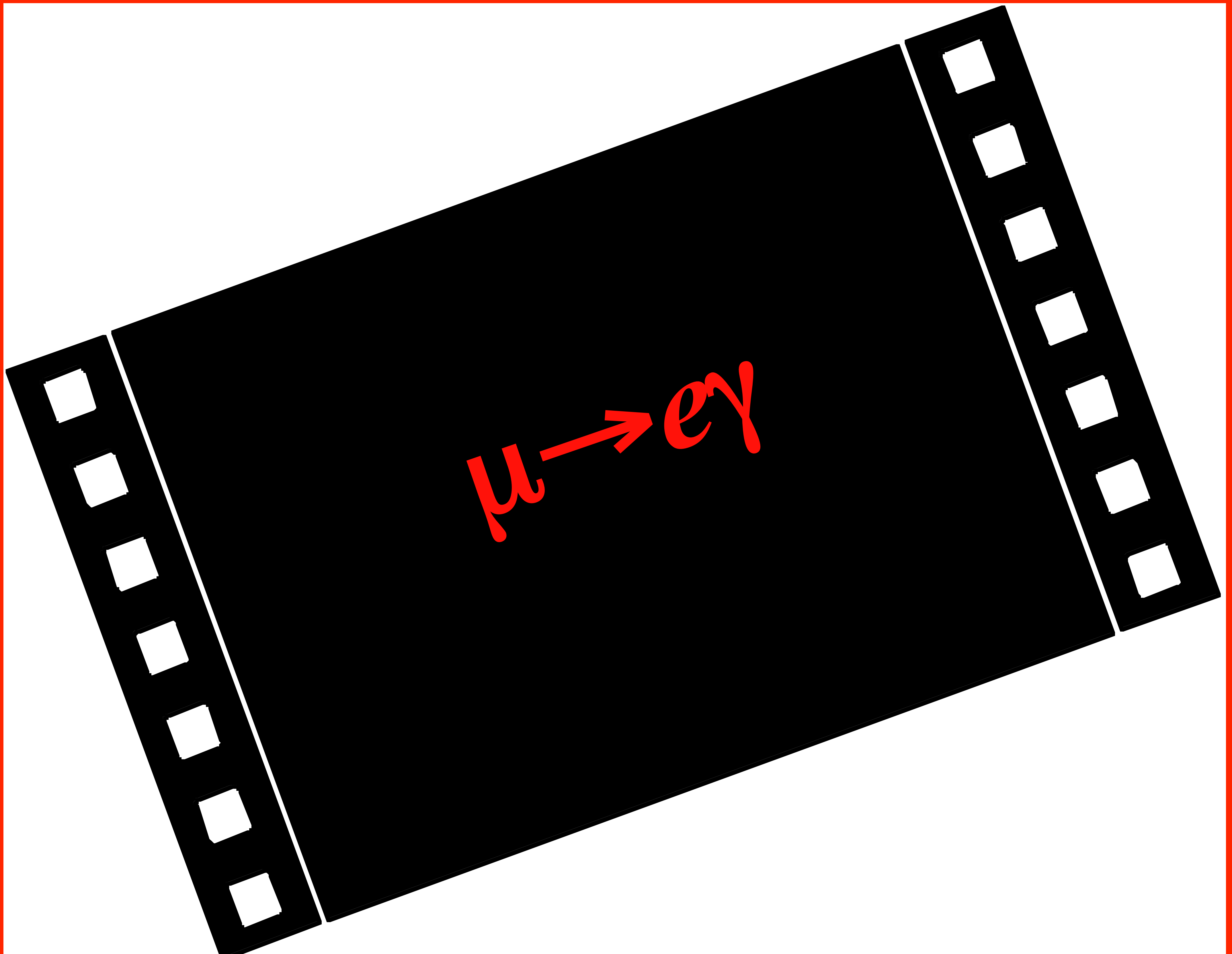
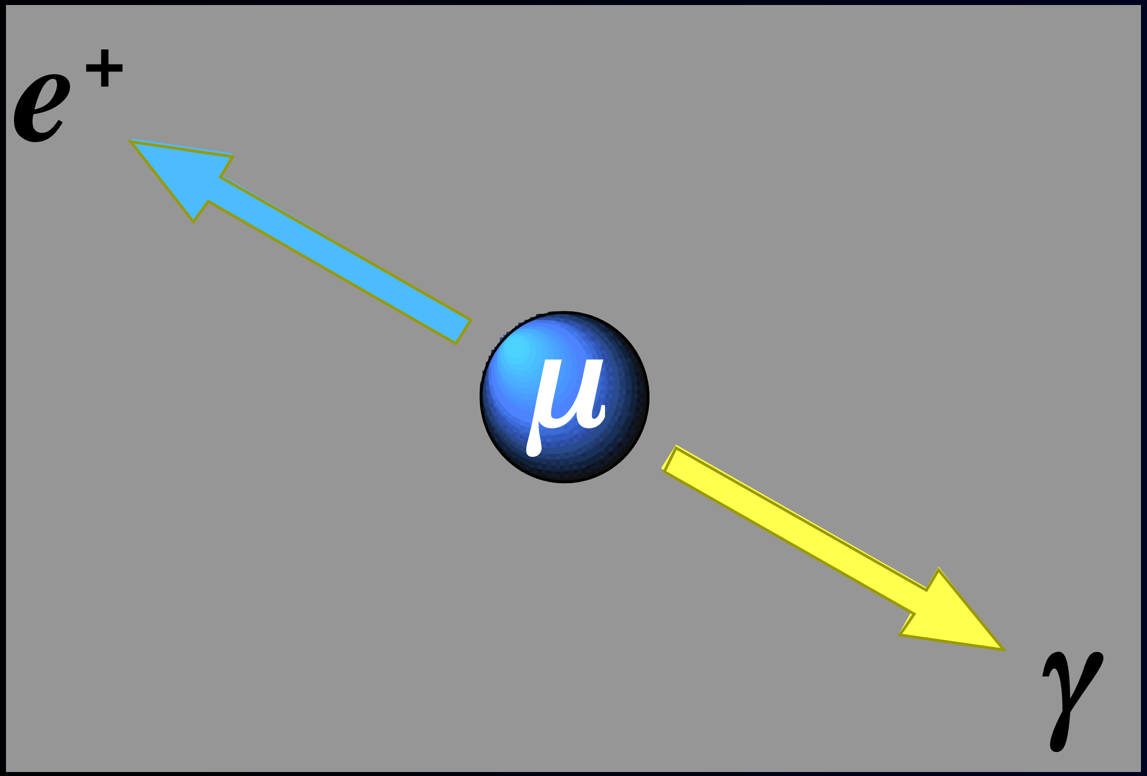

μ→eγ

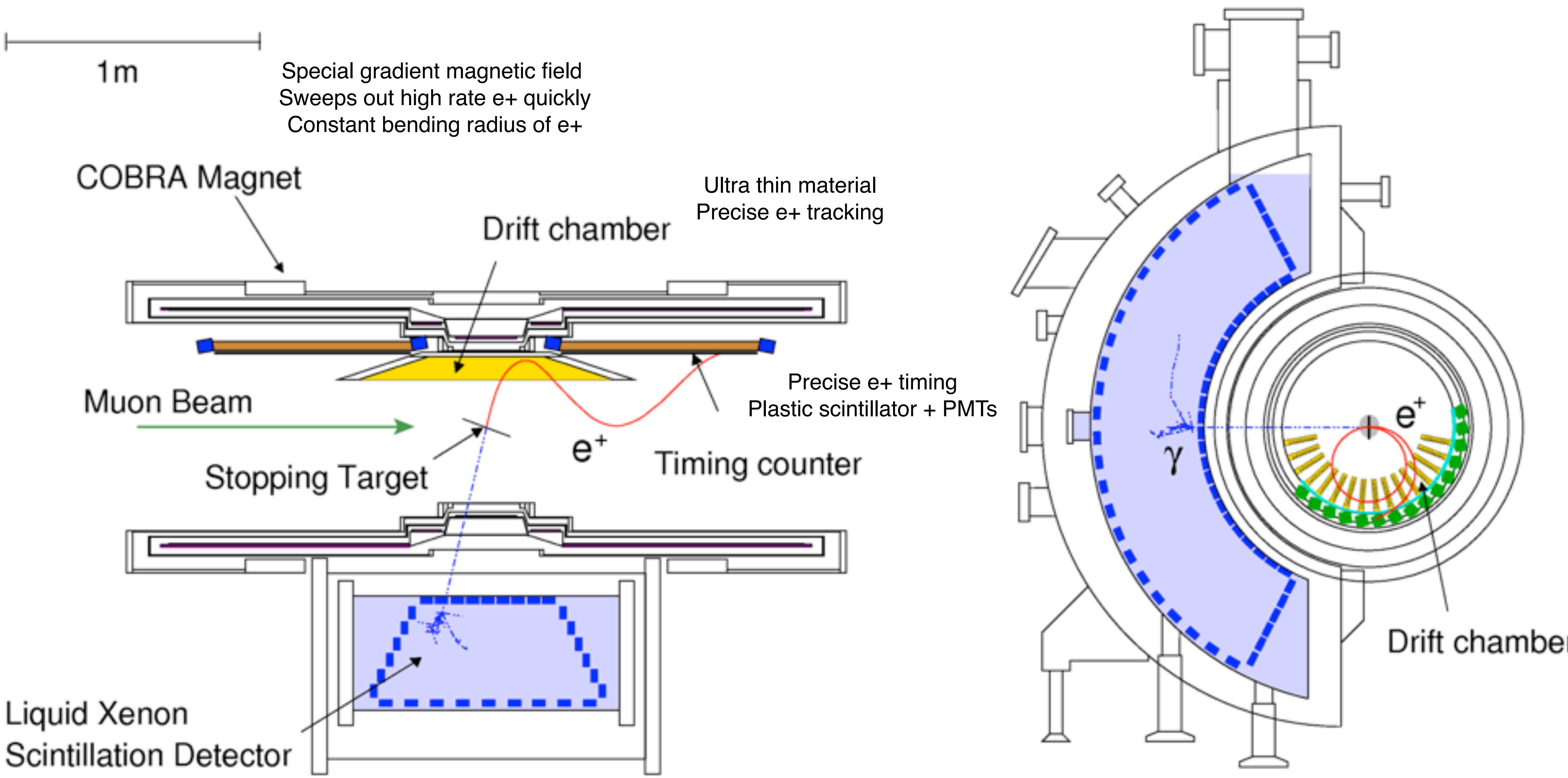
What is $\mu \rightarrow e\gamma$?

- 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 $\mu \rightarrow e\nu\nu\gamma$ when two neutrinos carry very small energies.
  - accidental backgrounds
    - positron in $\mu \rightarrow e\nu\nu$
    - photon in $\mu \rightarrow e\nu\nu\gamma$ or photon from e^+e^- annihilation in flight.

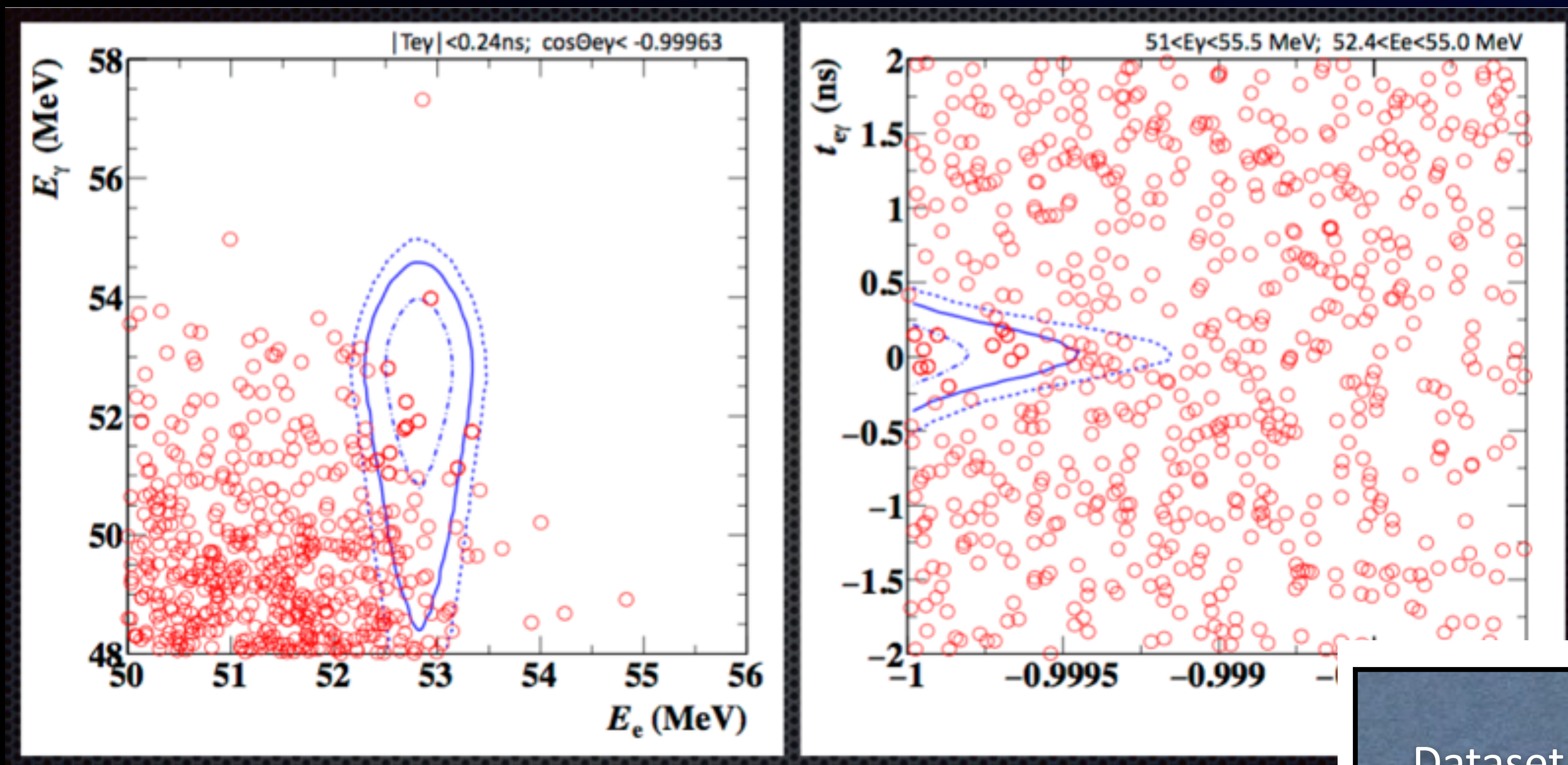
MEG Detector at PSI



2.7 ton of liquid xenon
Homogeneous detector
Good time, position, energy resolution

Waveform digitizer for all detectors

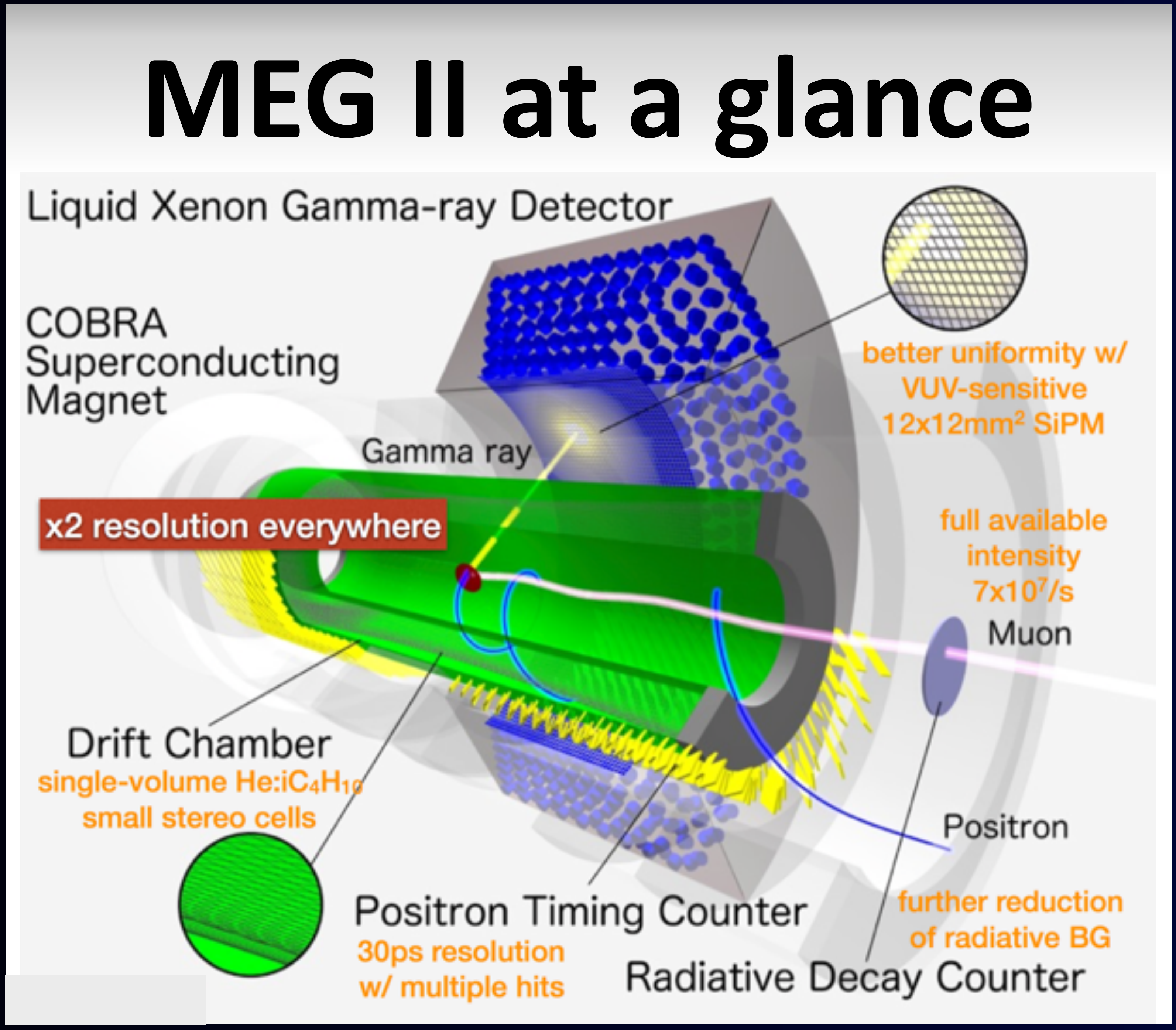
MEG Final Result



$$B(\mu^+ \to e^+\gamma) < 4.2 \times 10^{-13}$$

Dataset	2009-2011	2012-2013	All
Best Fit	-1.3	-5.5	-2.2
90% CL Upper Limit	6.1 10^-13	7.9 10^-13	**4.2 10^-13**
Sensitivity	8.0 10^-13	8.2 10^-13	5.3 10^-13

MEG II upgrade



$$B(\mu^+ \to e^+\gamma) < 4 \times 10^{-14}$$ 2017-2019

MEG-II Improvements

MEG II principal improvements

μ

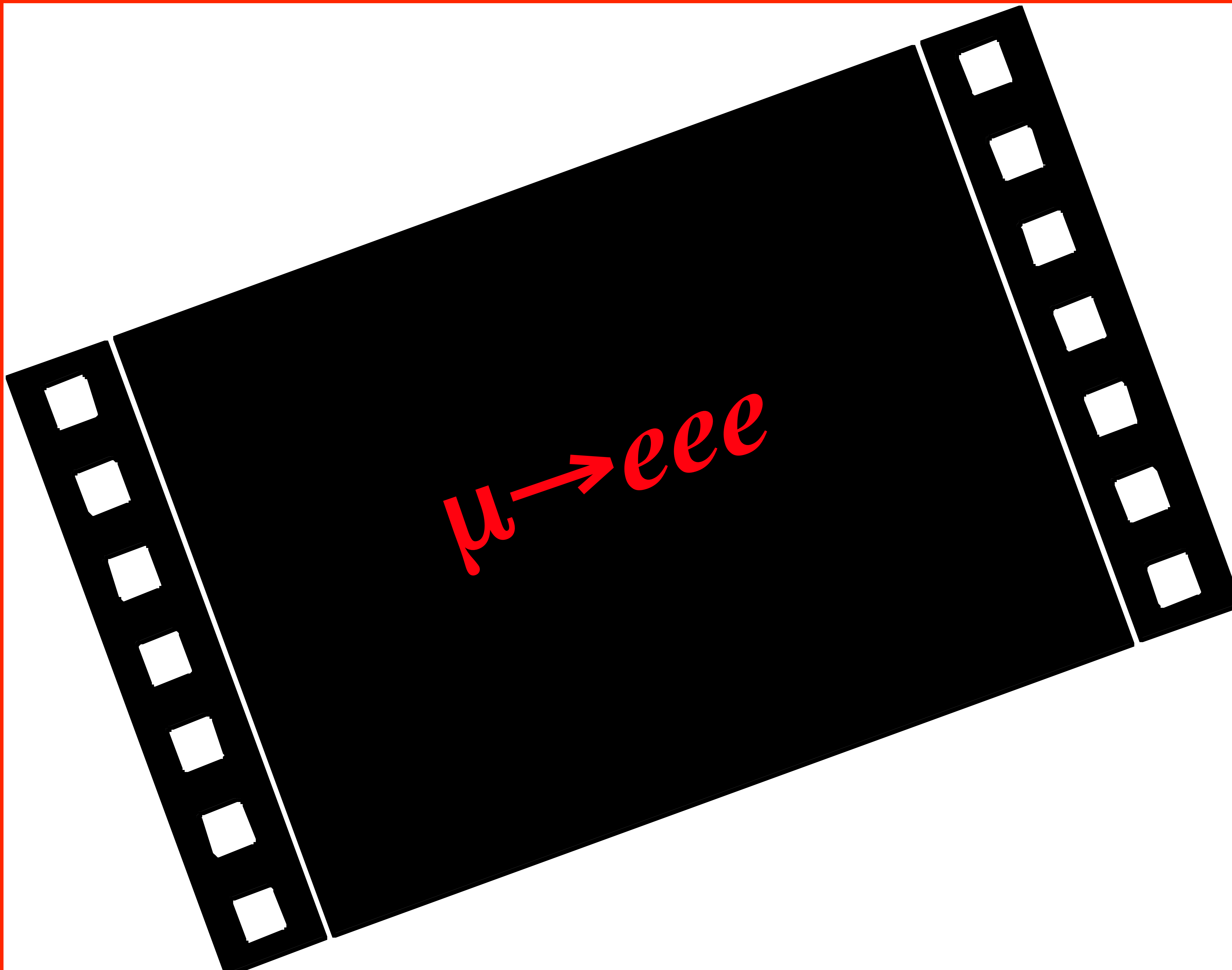
1. **Increasing μ-stop** on target
2. **Reducing** target **thickness** to minimise e+ MS & bremsstrahlung and use a more **robust** one

e

3. **Replacing** the **e+ tracker** reducing its radiation length and **improving** its **granularity** and **resolution**
4. **Improving** the **timing counter granularity** for **better timing** and **reconstruction**
5. **Improving** the **e+ tracking-timing integration** by measuring the e+ trajectory up to the TC interface

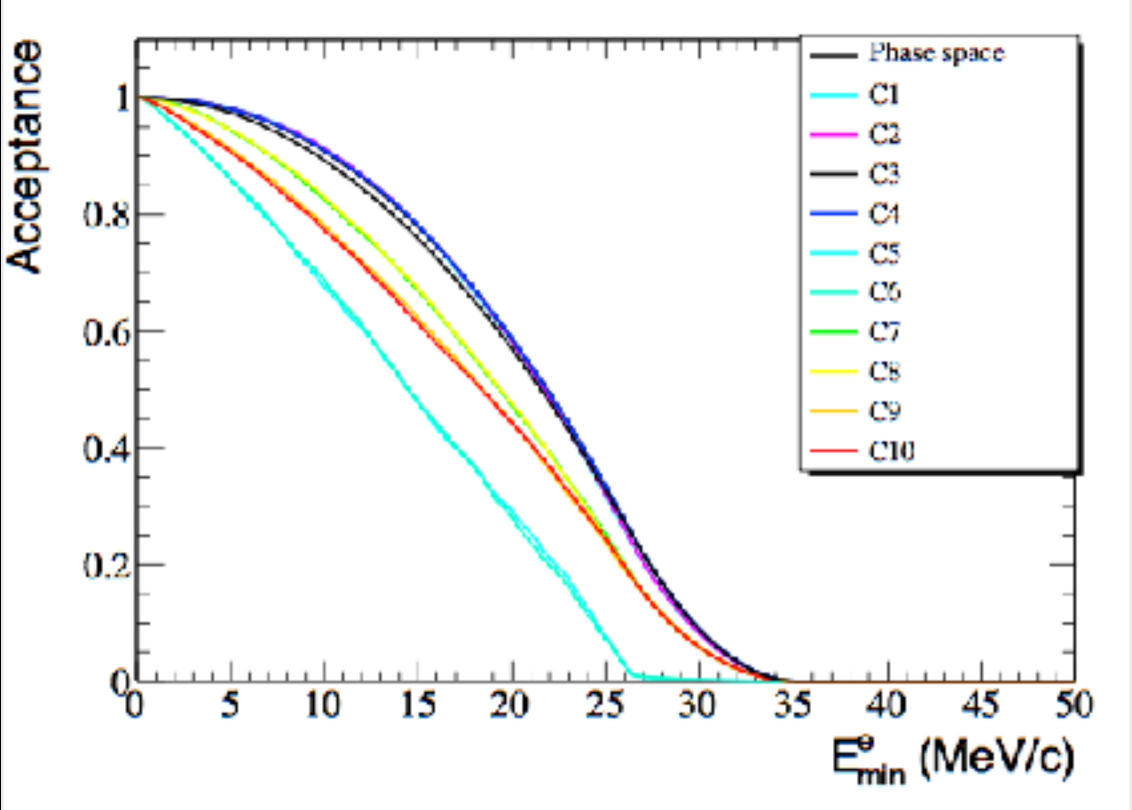
γ

6. **Extending γ-ray** detector **acceptance**
7. **Improving** the **γ-ray energy** and **position resolution** for **shallow** events
8. **Integrating splitter, trigger and DAQ** maintaining high bandwidth


μ→eee

What is μ→eee ?

- Event Signature
  - $\Sigma E_e = m_\mu$
  - $\Sigma P_e = 0$ (vector sum)
  - common vertex
  - time coincidence



acceptance of lowest $e^{\pm}$ vs. its minimum p

- Backgrounds
  - physics backgrounds
    - μ→eννee decay ($B=3.4\times10^{-5}$) when two neutrinos carry very small energies.
  - accidental backgrounds
    - positrons in μ→eνν
    - electrons in μ→eeeνν or μ→eννγ ($B=1.2\times10^{-2}$) with photon conversion or charge mis-id or Bhabha scattering.

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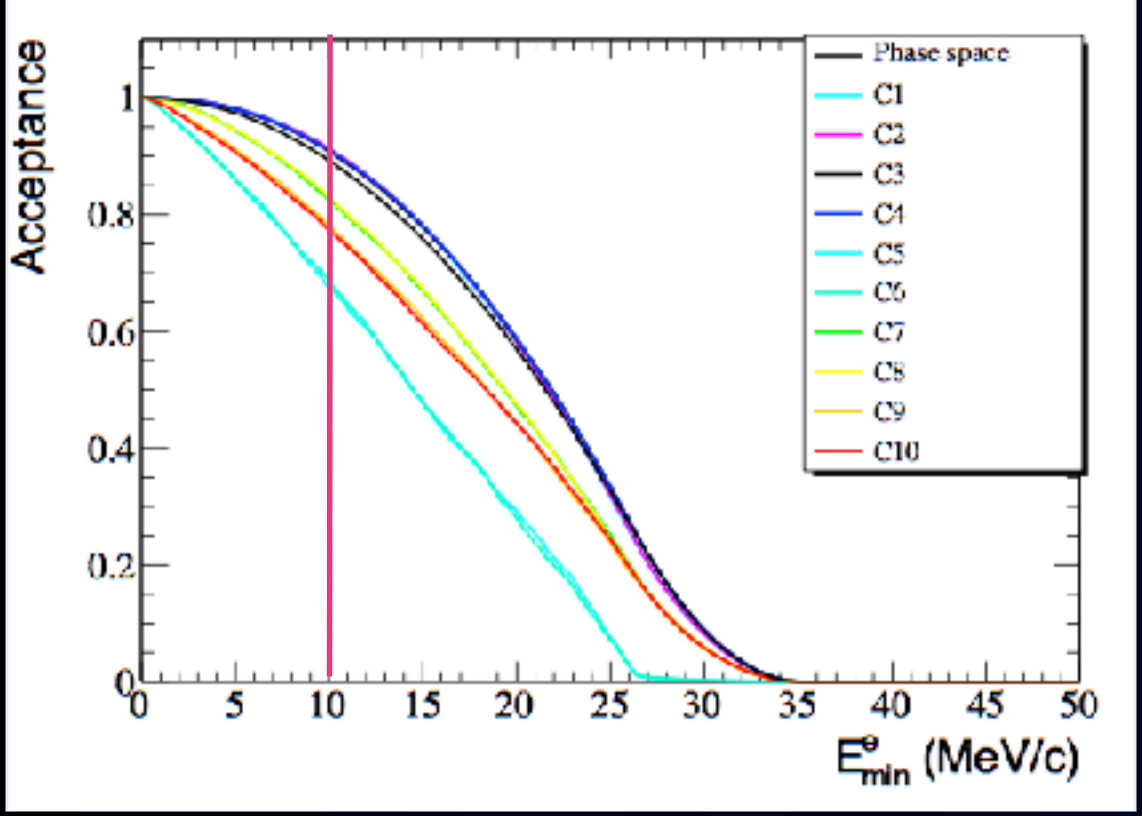

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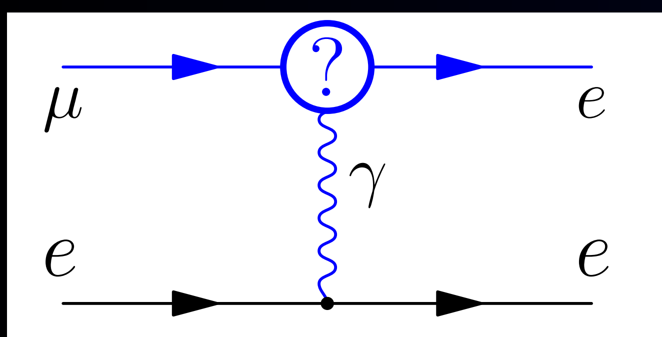
Physics Sensitivity: μ→eγ vs. μ→eee

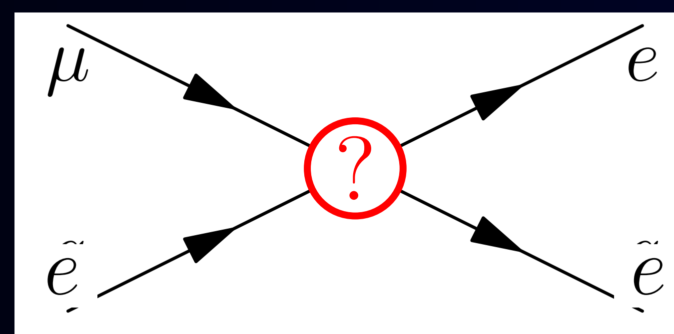
constructive

$$L_{\rm CLFV} = \frac{1}{1+\kappa}\frac{m_\mu}{\Lambda^2}\bar{\mu}_{\rm R}\sigma^{\mu\nu}e_{\rm L}F_{\mu\nu} + \frac{\kappa}{1+\kappa}\frac{1}{\Lambda^2}(\bar{\mu}_{\rm L}\gamma^\mu e_{\rm L})(\bar{e}_{\rm L}\gamma_\mu e_{\rm L})$$

Photonic (dipole) interaction

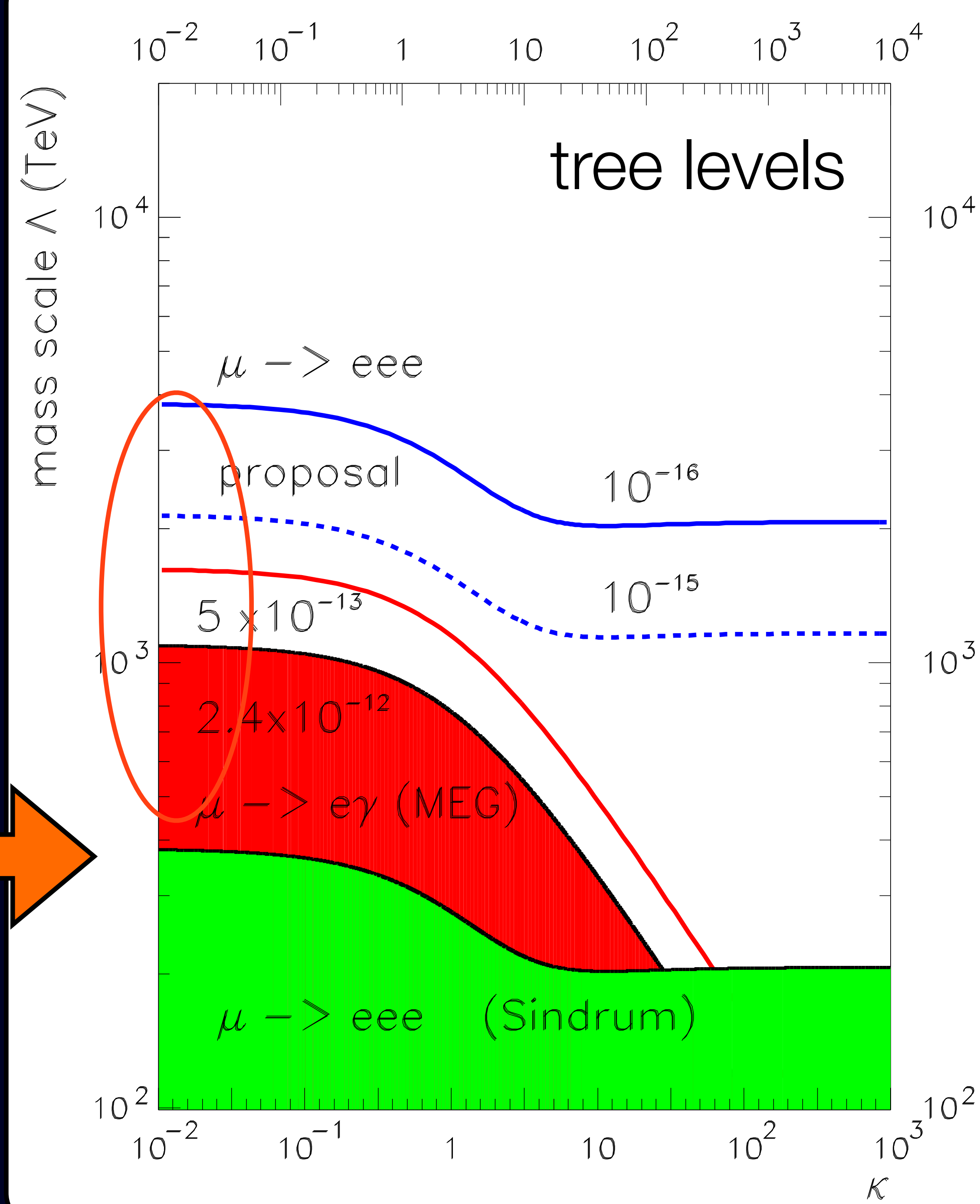


Contact interaction

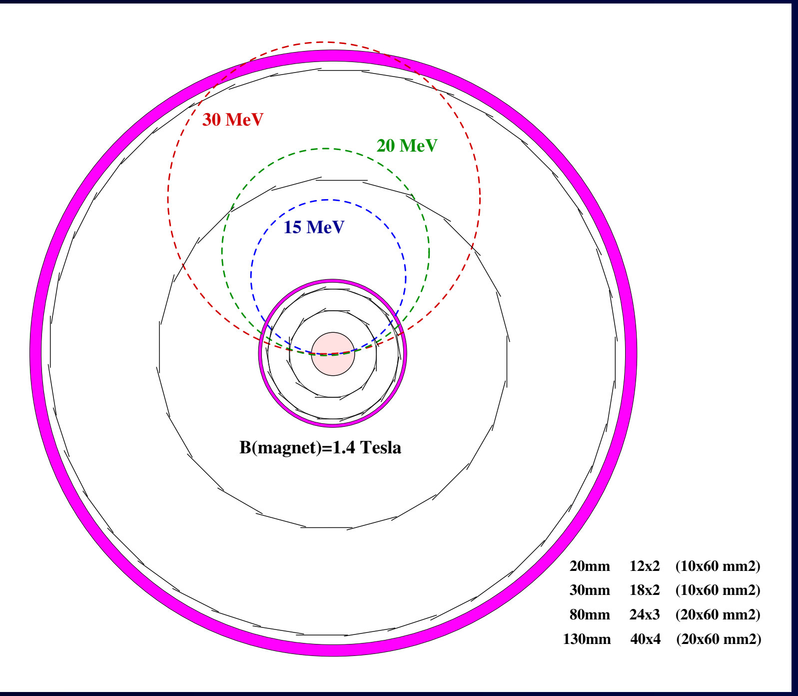


if photonic contribution dominates,

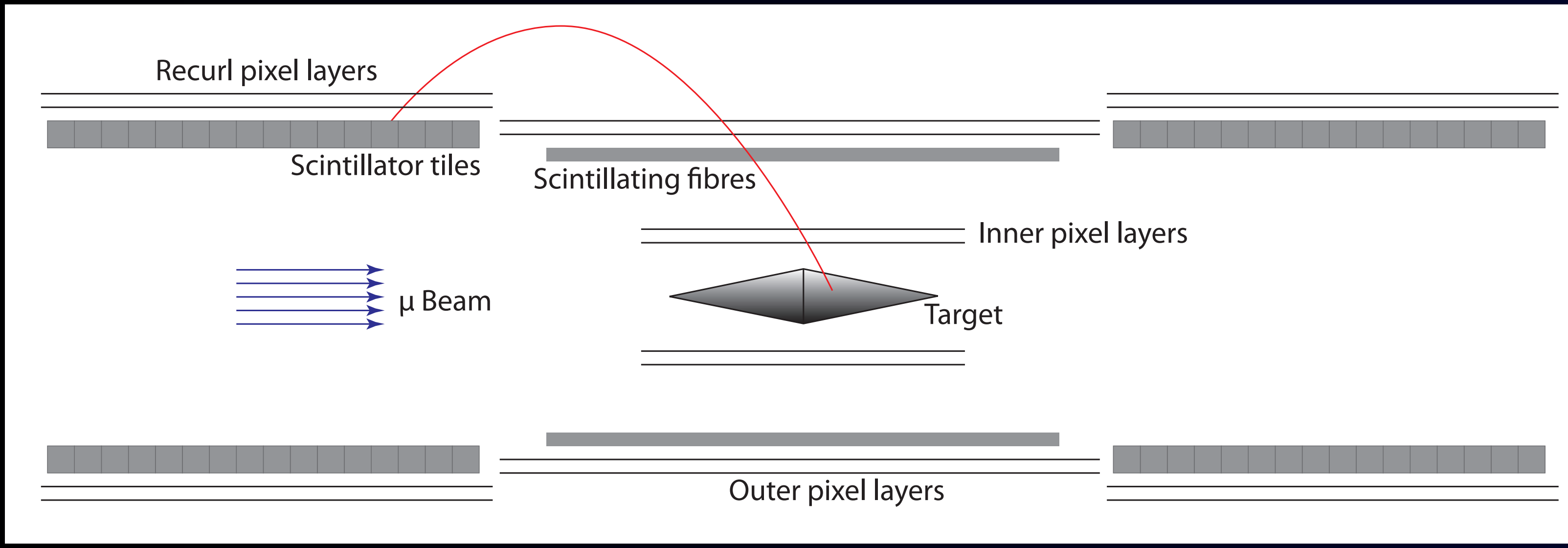
$$\frac{\mathrm{B}(\mu\to eee)}{\mathrm{B}(\mu\to e\gamma)} \approx 0.006$$



Mu3e at PSI (under preparation)

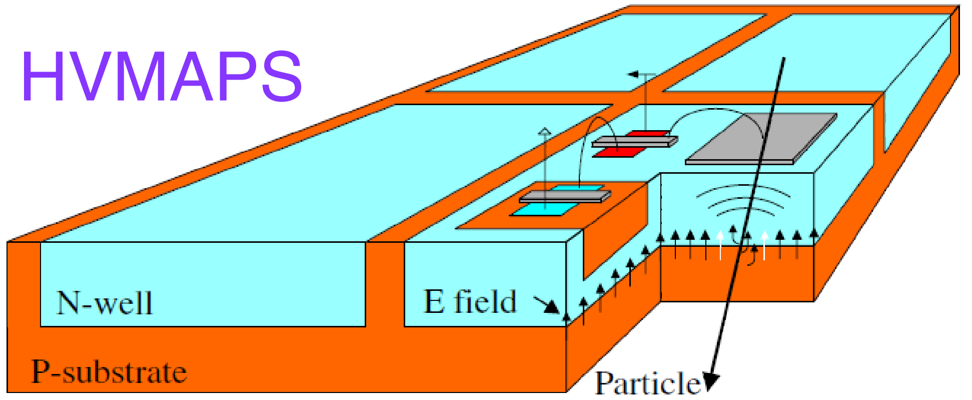


- thin silicon pixel detectors (<50μm thick) with high position resolution
  - high voltage monolithic active pixel (HVMAPS)
  - three (two) cylinders with double layers
- SciFi hodoscopes with high timing resolution.
- Stage-I (2018-)
  - $B \sim 10^{-15}$ with 10^{8} μ/s at πE5
- Stage-2
  - $B < 10^{-16}$ with 10^{9} μ/s at new muon source



80μmx80μm pixel

HVMAPS



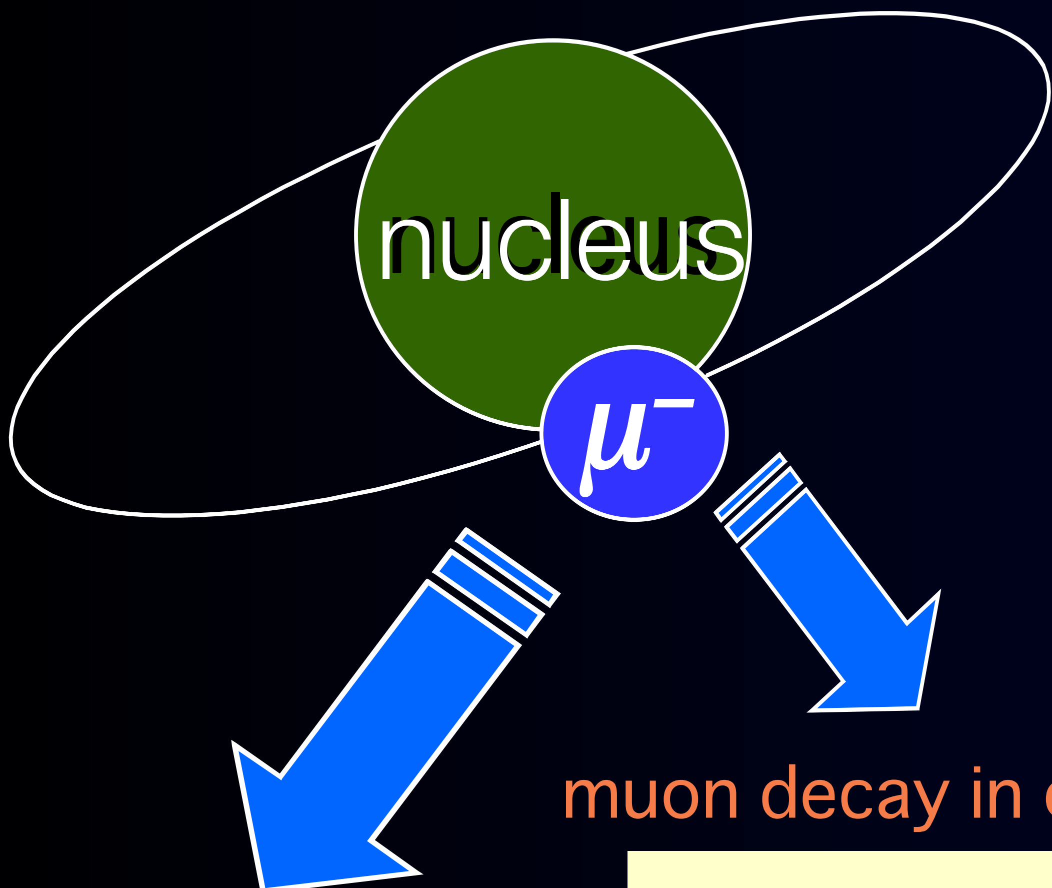
$\mu \rightarrow e$ conversion

in

a muonic atom

What is Muon to Electron Conversion?

1s state in a muonic atom



muon decay in orbit

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

nuclear muon capture

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

Neutrino-less muon nuclear capture

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

Event Signature :
a single mono-energetic electron of 100 MeV

Backgrounds:

(1) physics backgrounds
  ex. muon decay in orbit (DIO)

(2) beam-related backgrounds
  ex. radiative pion capture, muon decay in flight,

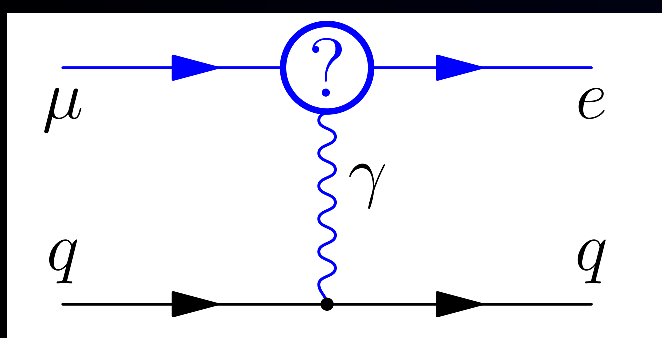
(3) cosmic rays, false tracking

Physics Sensitivity: μ→eγ vs. μ-e conversion

constructive

$$L_{\rm CLFV} = \frac{1}{1+\kappa}\frac{m_\mu}{\Lambda^2}\bar{\mu}_{\rm R}\sigma^{\mu\nu}e_{\rm L}F_{\mu\nu} + \frac{\kappa}{1+\kappa}\frac{1}{\Lambda^2}(\bar{\mu}_{\rm L}\gamma^{\mu}e_{\rm L})(\bar{q}_{\rm L}\gamma_{\mu}q_{\rm L})$$

Photonic (dipole) interaction



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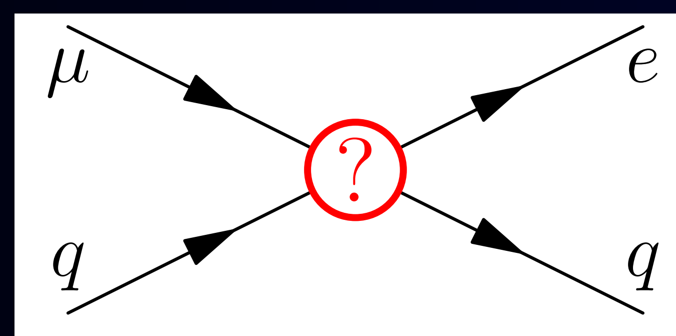
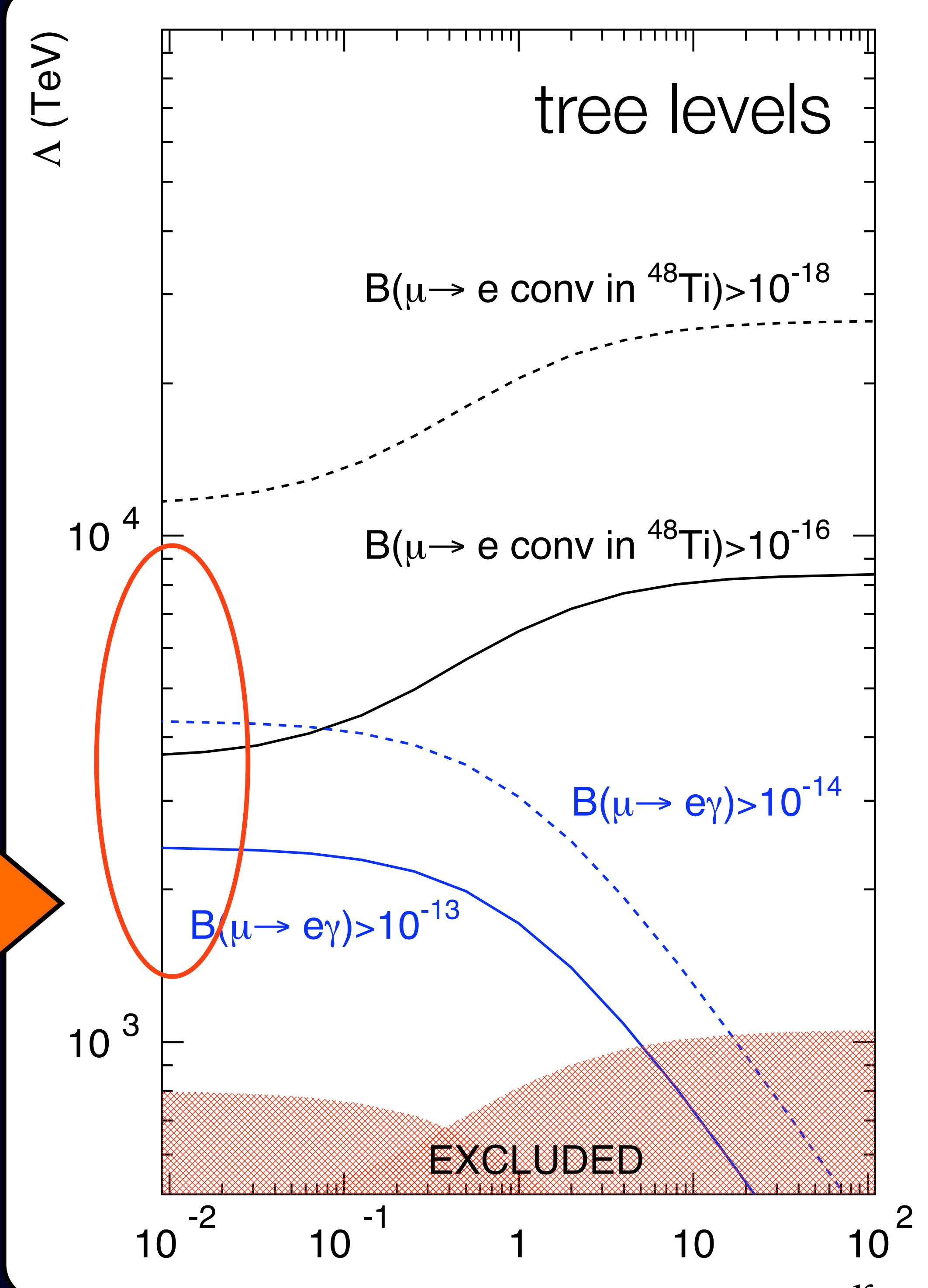


if photonic contribution dominates,

$$\frac{B(\mu N \to eN)}{B(\mu \to e\gamma)} = \frac{G_F^2 m_\mu^4}{96\pi^3\alpha} \times 3 \times 10^{12} B(A,Z)$$

$$\sim \frac{B(A,Z)}{428}$$

- for aluminum, about 1/390~0.003
- for titanium, about 1/230

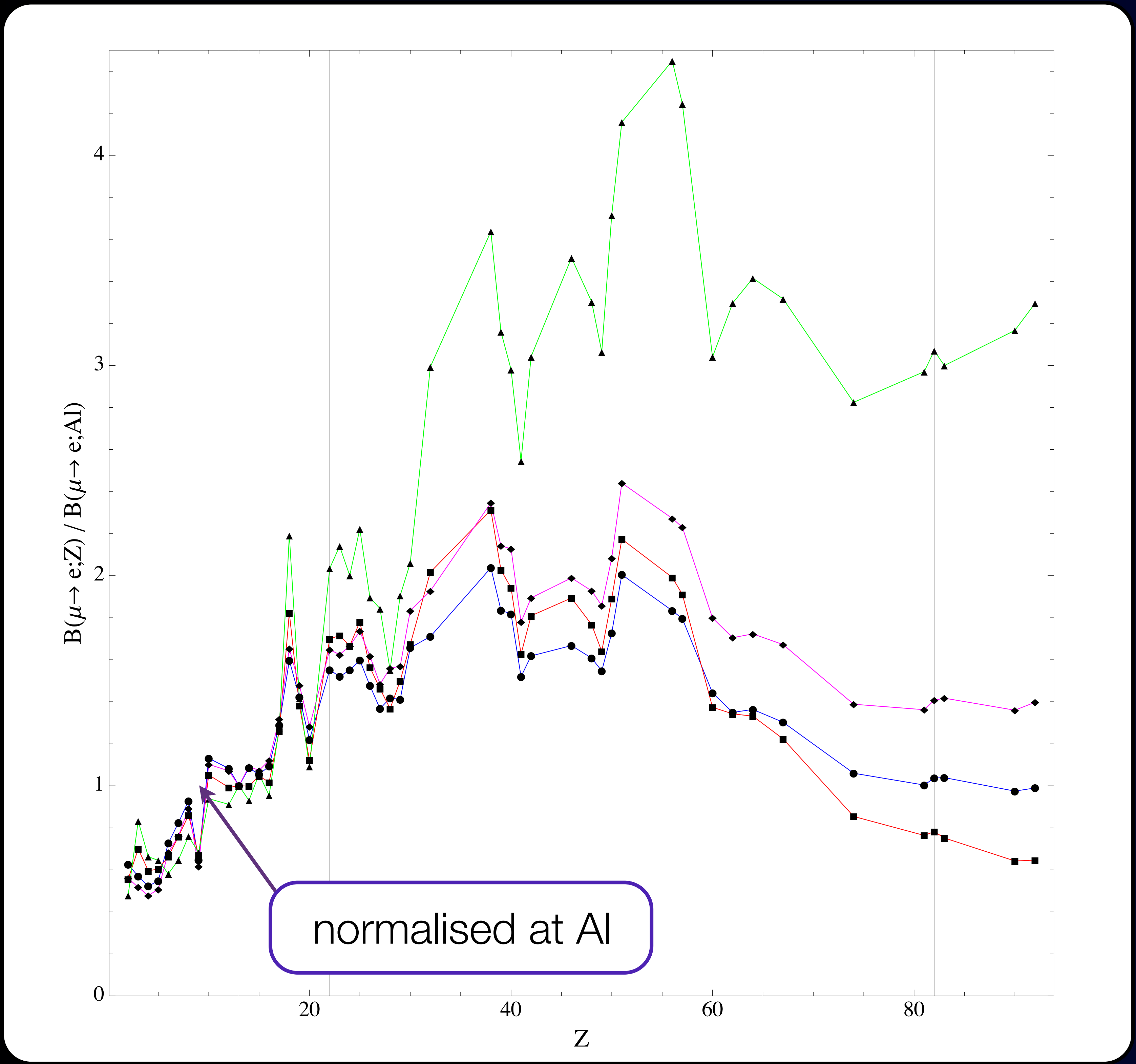


Experimental Comparison : $\mu \to e\gamma$ and μ-e Conversion

Experimental Comparison : μ→eγ and μ-e Conversion

	Beam	background	challenge	beam intensity
μ→eγ	continuous beam	accidentals	detector resolution	limited
μ→eee	continuos beam	accidentals	detector resolution	limited
μ-e conversion	pulsed beam	beam-related	beam background	no limitation

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



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

vector interaction (with z boson)

vector interaction (with photon)

dipole interaction

scalar interaction

Gerco's talk

μ-e conversion vs. Meson→μe

Gerco's talk

μ-e conversion vs. Meson→μe

μ-e conversion

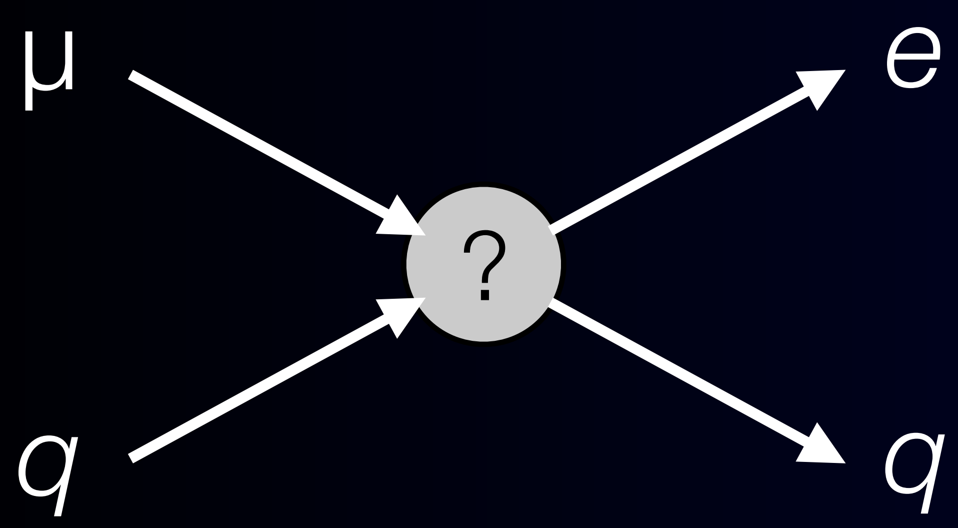
μ-e conversion vs. Meson→μe

μ-e conversion

Meson→μe

μ-e conversion vs. Meson→μe

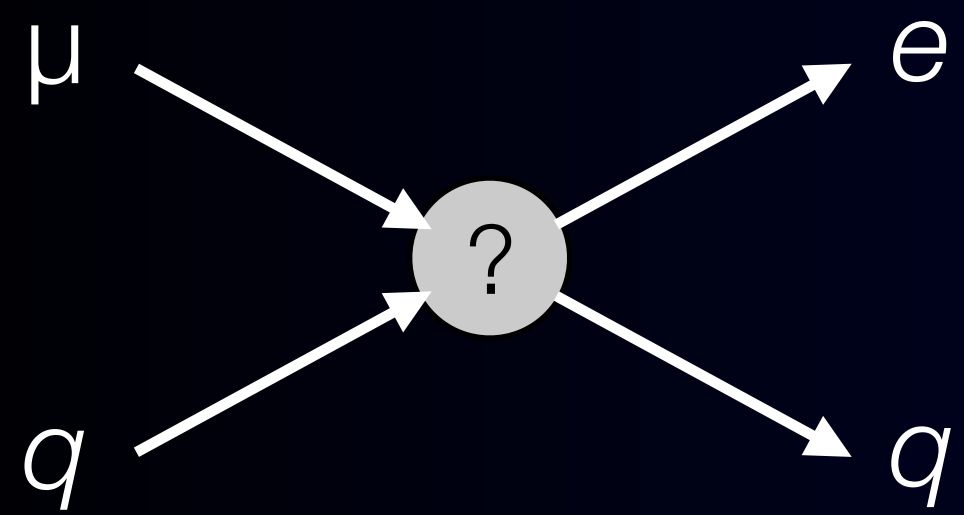
μ-e conversion



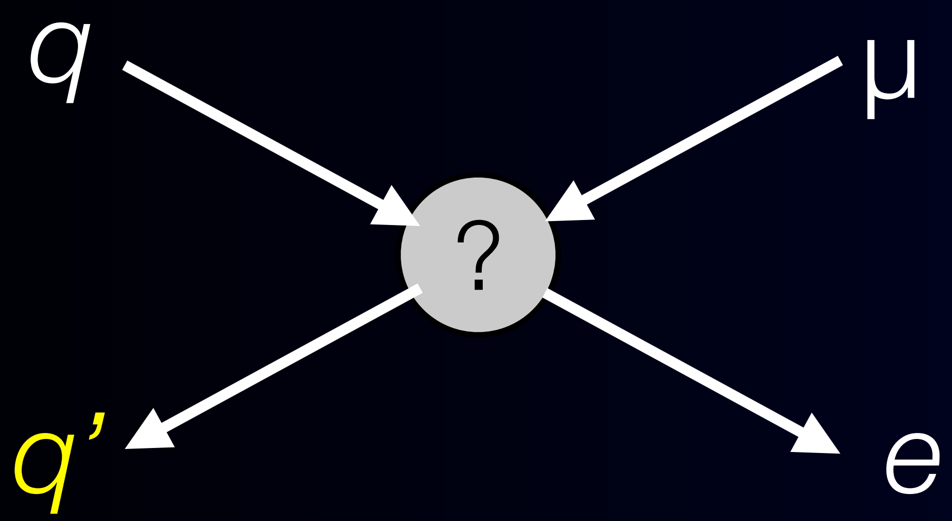
Meson→μe

μ-e conversion vs. Meson→μe

μ-e conversion

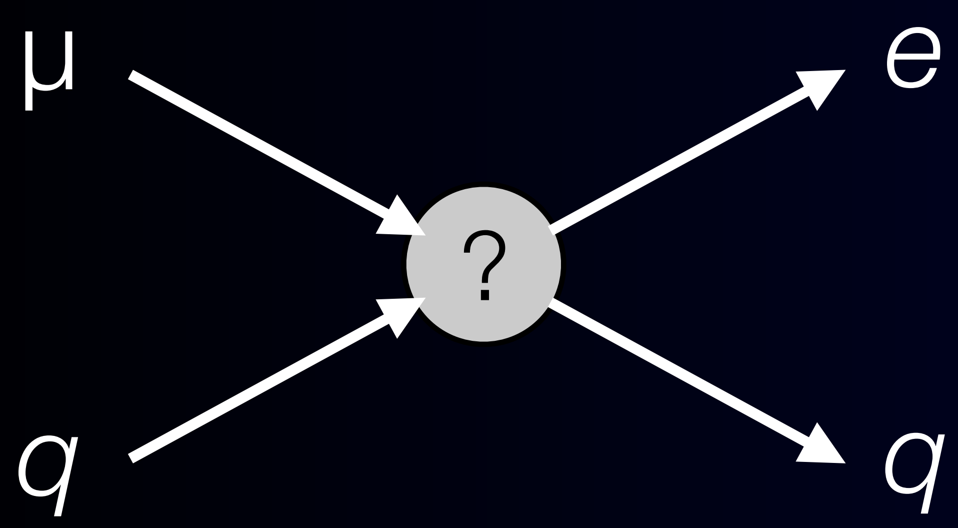


Meson→μe



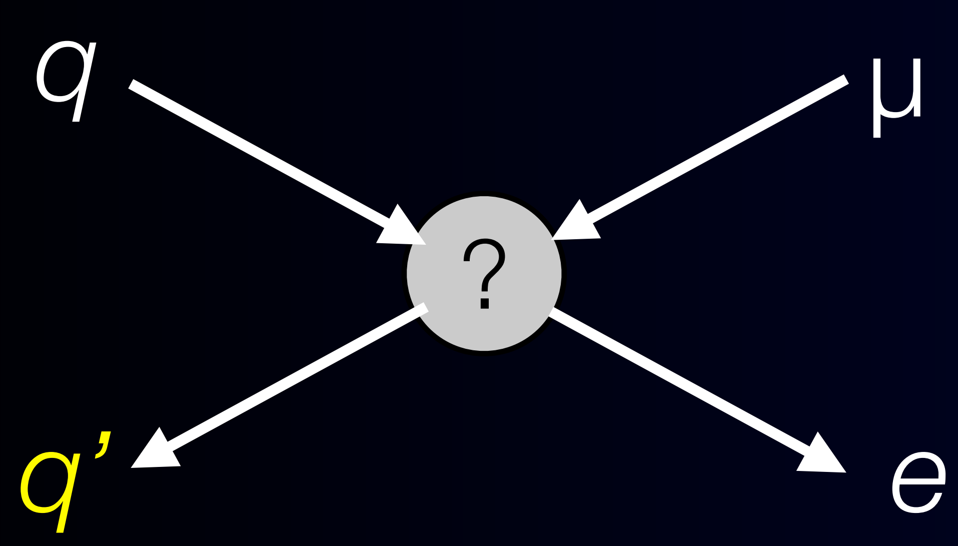
μ-e conversion vs. Meson→μe

μ-e conversion



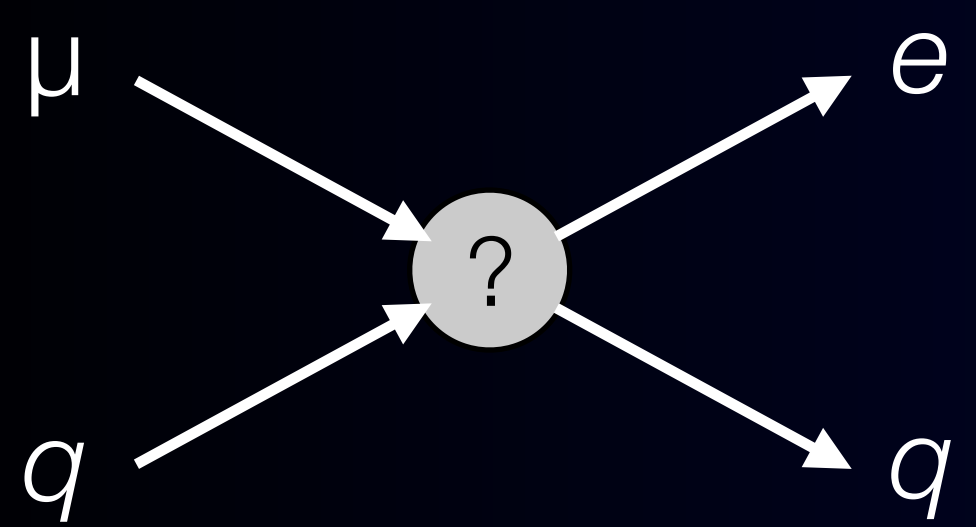
initial and final quark flavors the same

Meson→μe



μ-e conversion vs. Meson→μe

μ-e conversion



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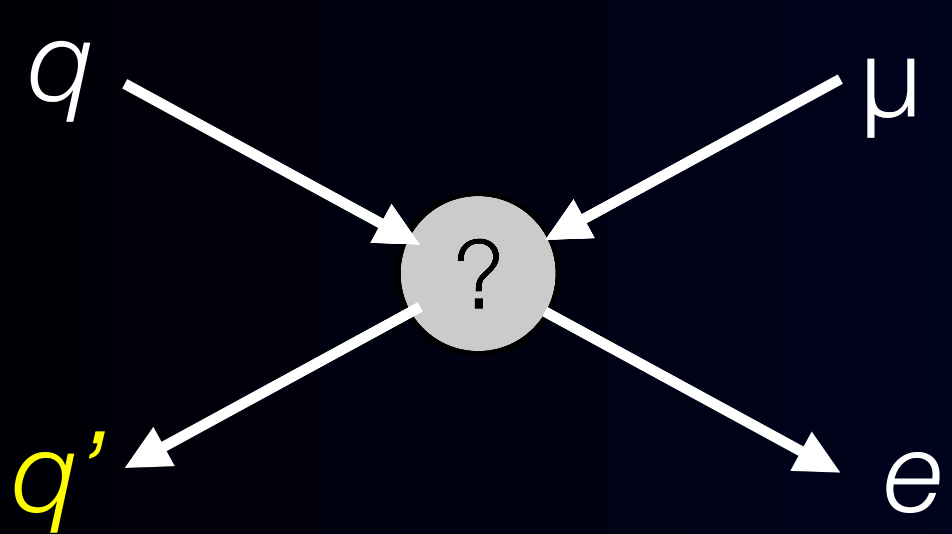


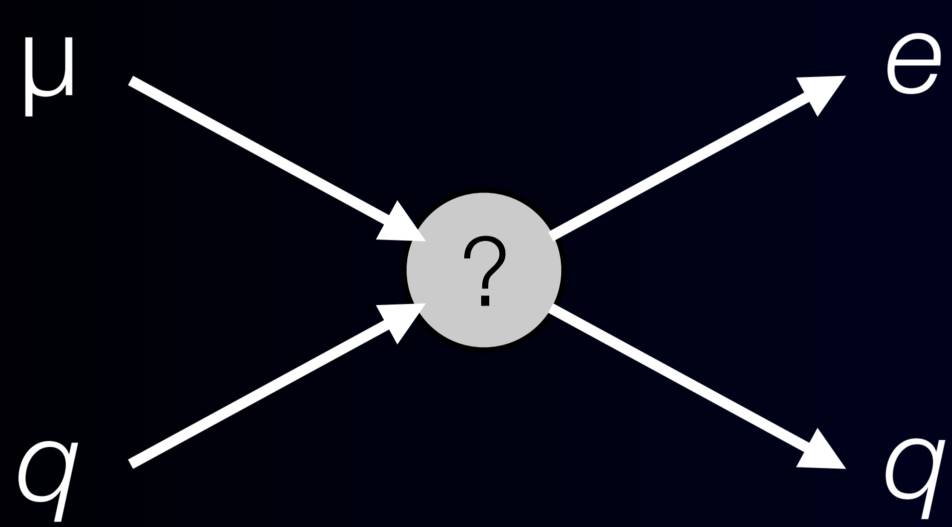
initial and final quark flavors different

(CKM suppressed)

Gerco's talk

μ-e conversion vs. Meson→μe

μ-e conversion



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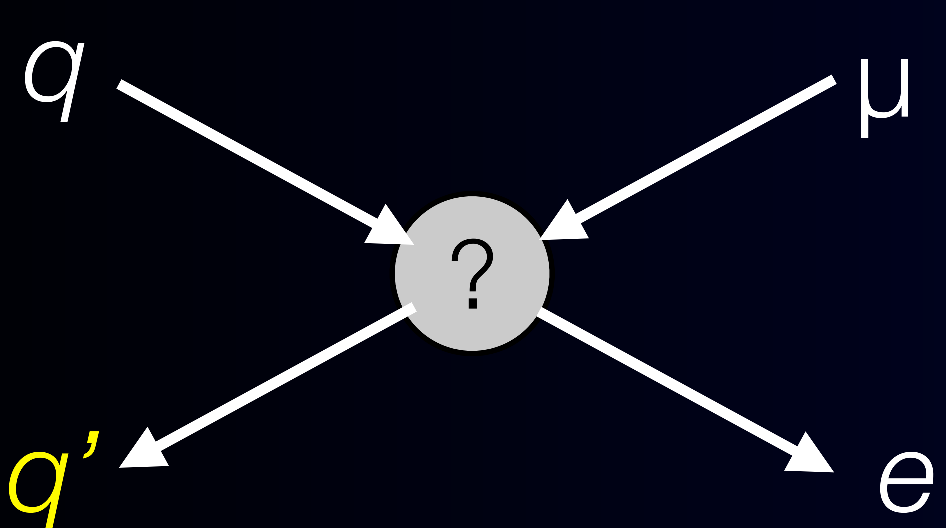


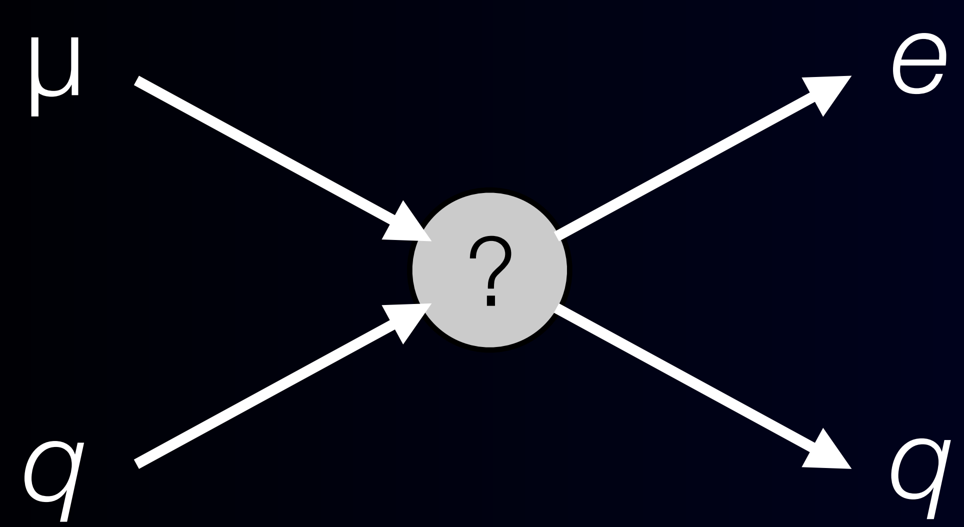
initial and final quark flavors different

(CKM suppressed)

only one hadron

μ-e conversion vs. Meson→μe

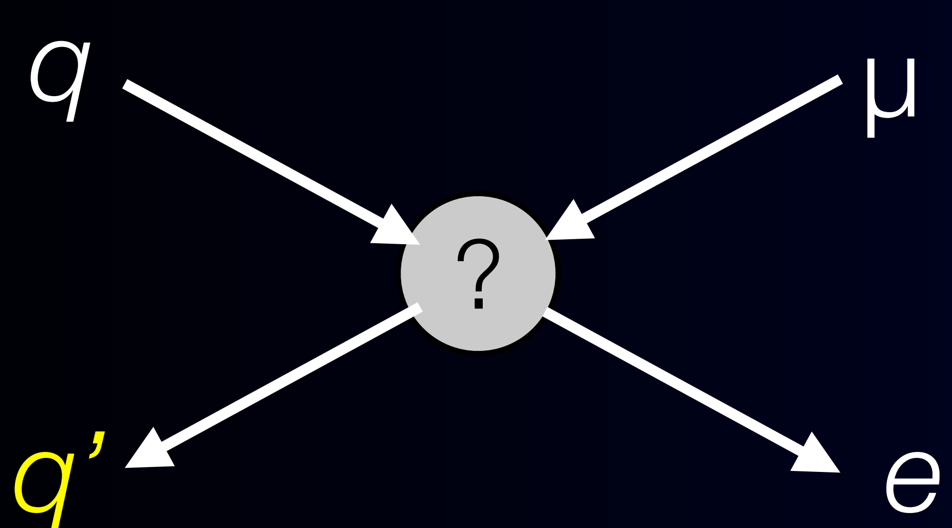
μ-e conversion



initial and final quark flavors the same

many hadron (nucleons) in nucleus

Meson→μe



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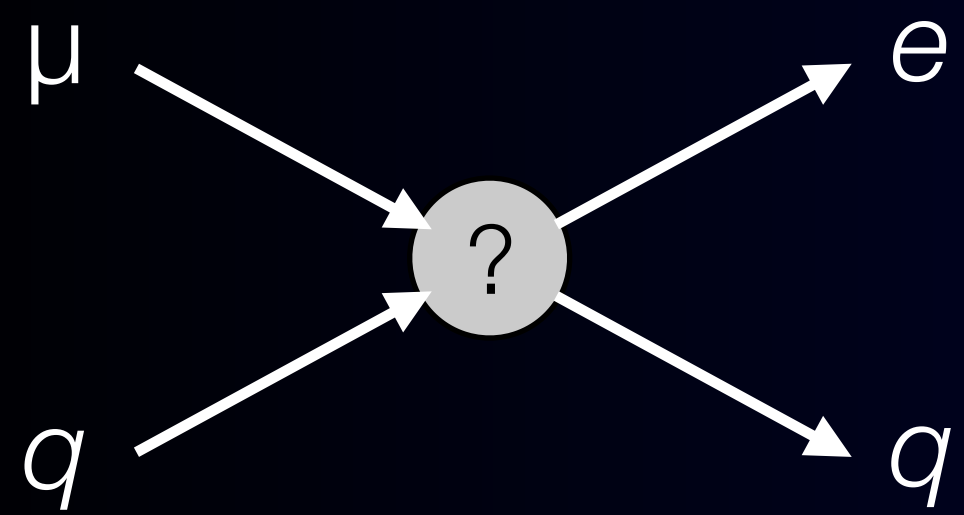

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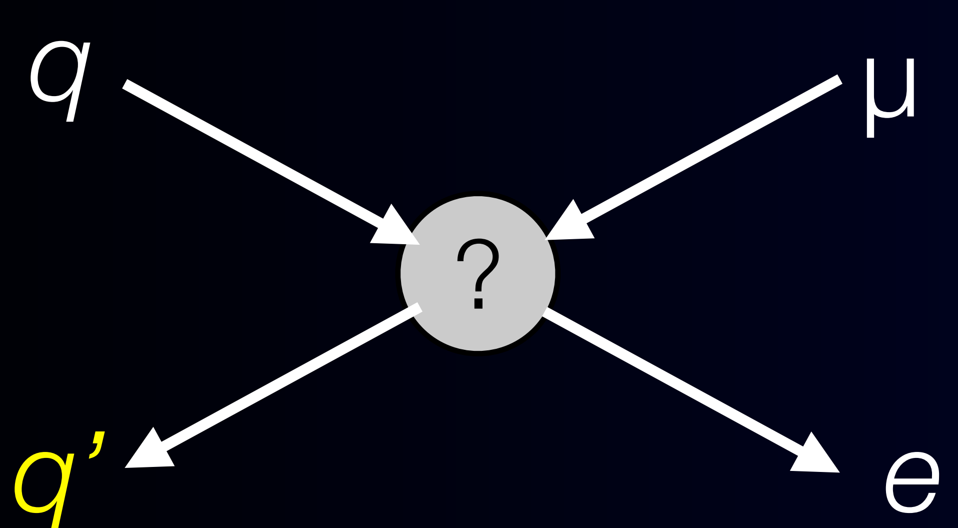
many hadron (nucleons) in nucleus

coherency $|\sum_{1}^{N} M|^2$

Meson→μe



initial and final quark flavors different

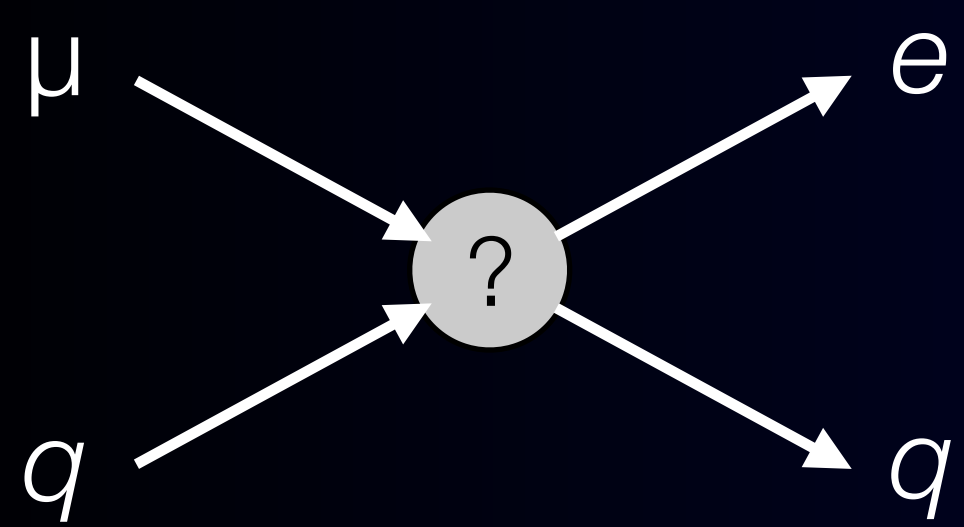
(CKM suppressed)

only one hadron

Gerco's talk

μ-e conversion vs. Meson→μe

μ-e conversion $O(10^{-12}) \rightarrow O(10^{-16})$



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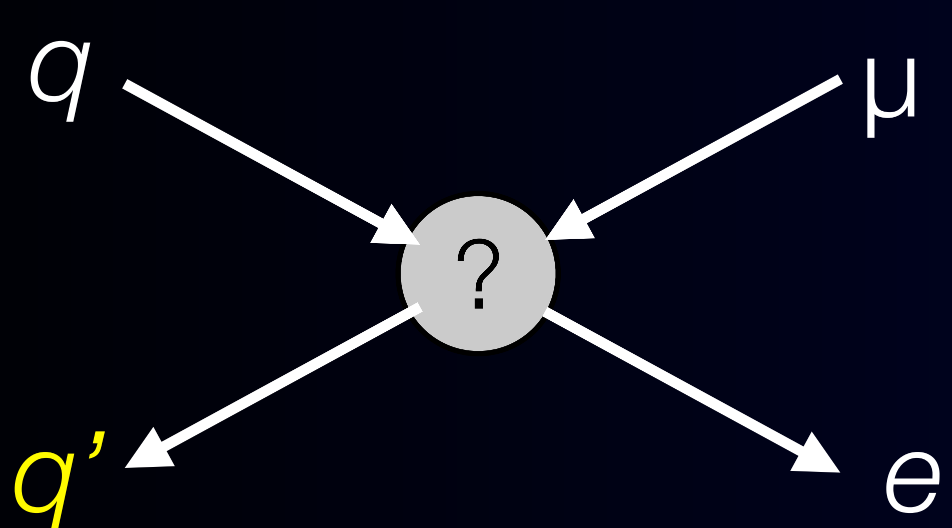

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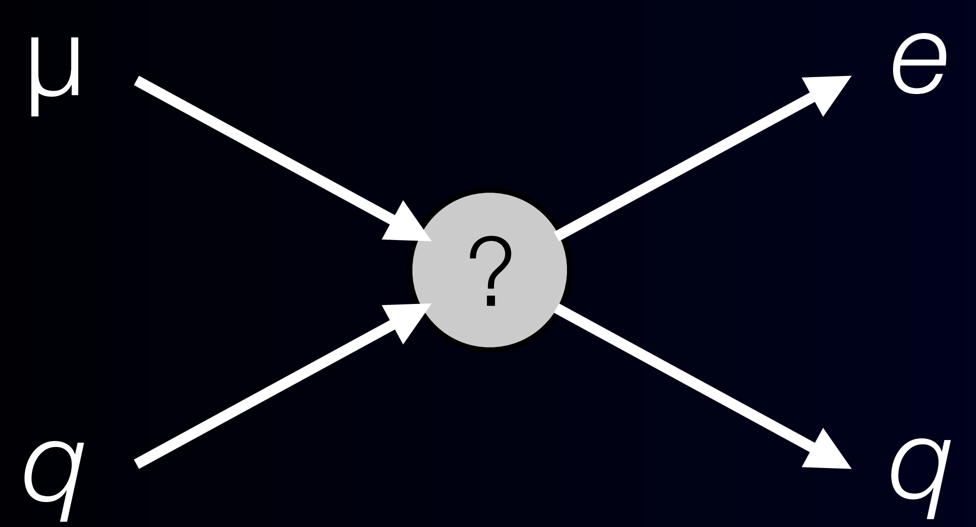
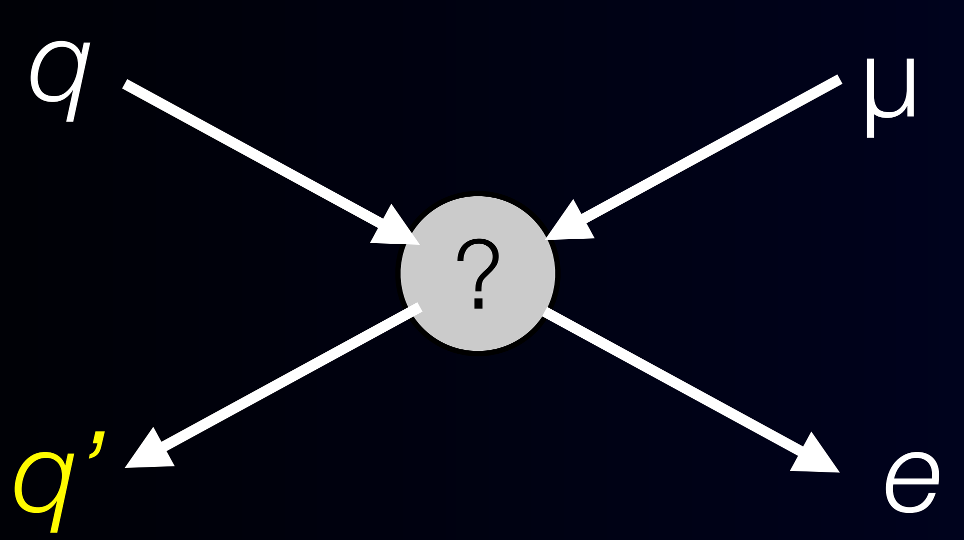


initial and final quark flavors the same

many hadron (nucleons) in nucleus

coherency $|\sum_{1}^{N} M|^2$

Meson→μe O(10^{-9})



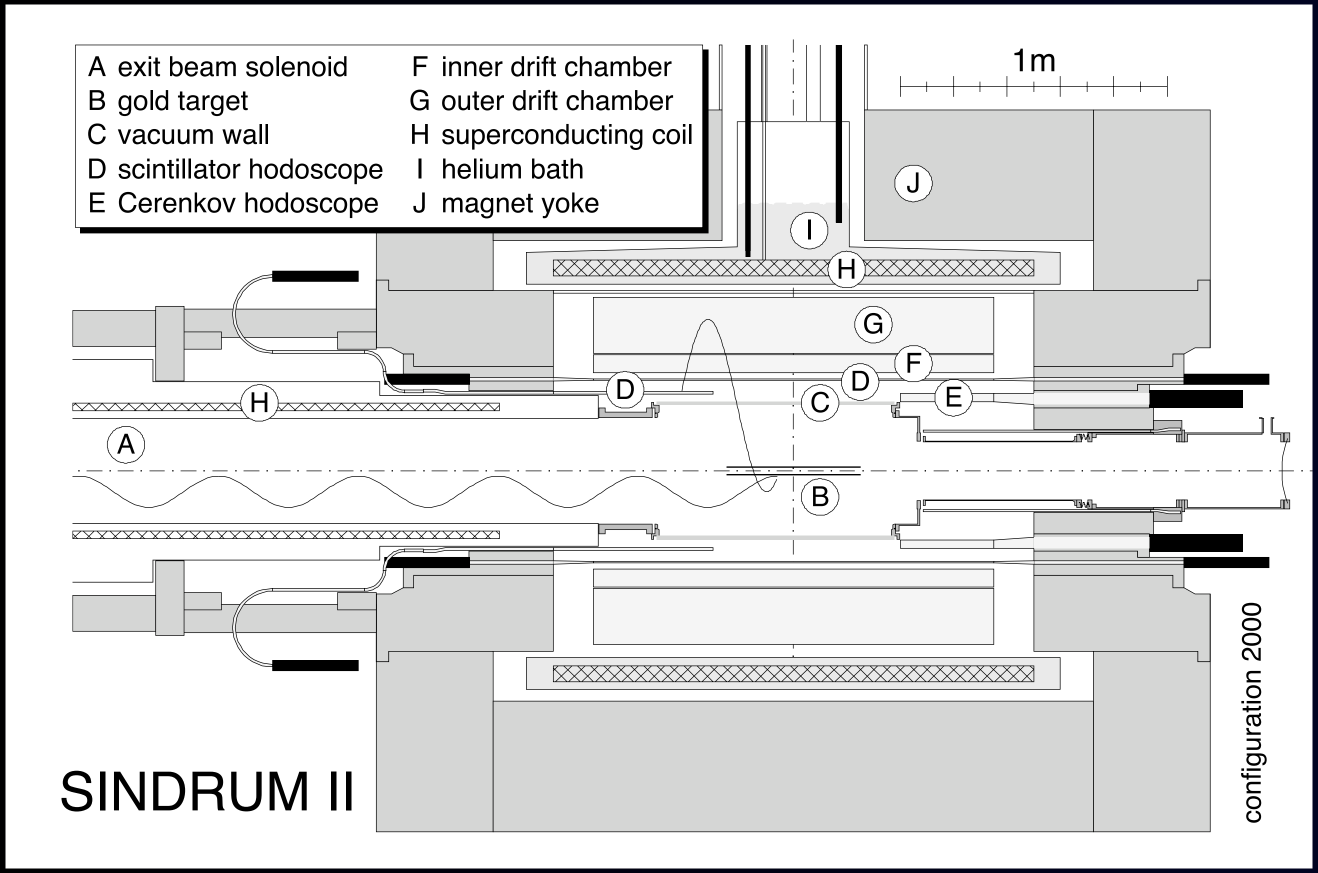
initial and final quark flavors different

(CKM suppressed)

only one hadron

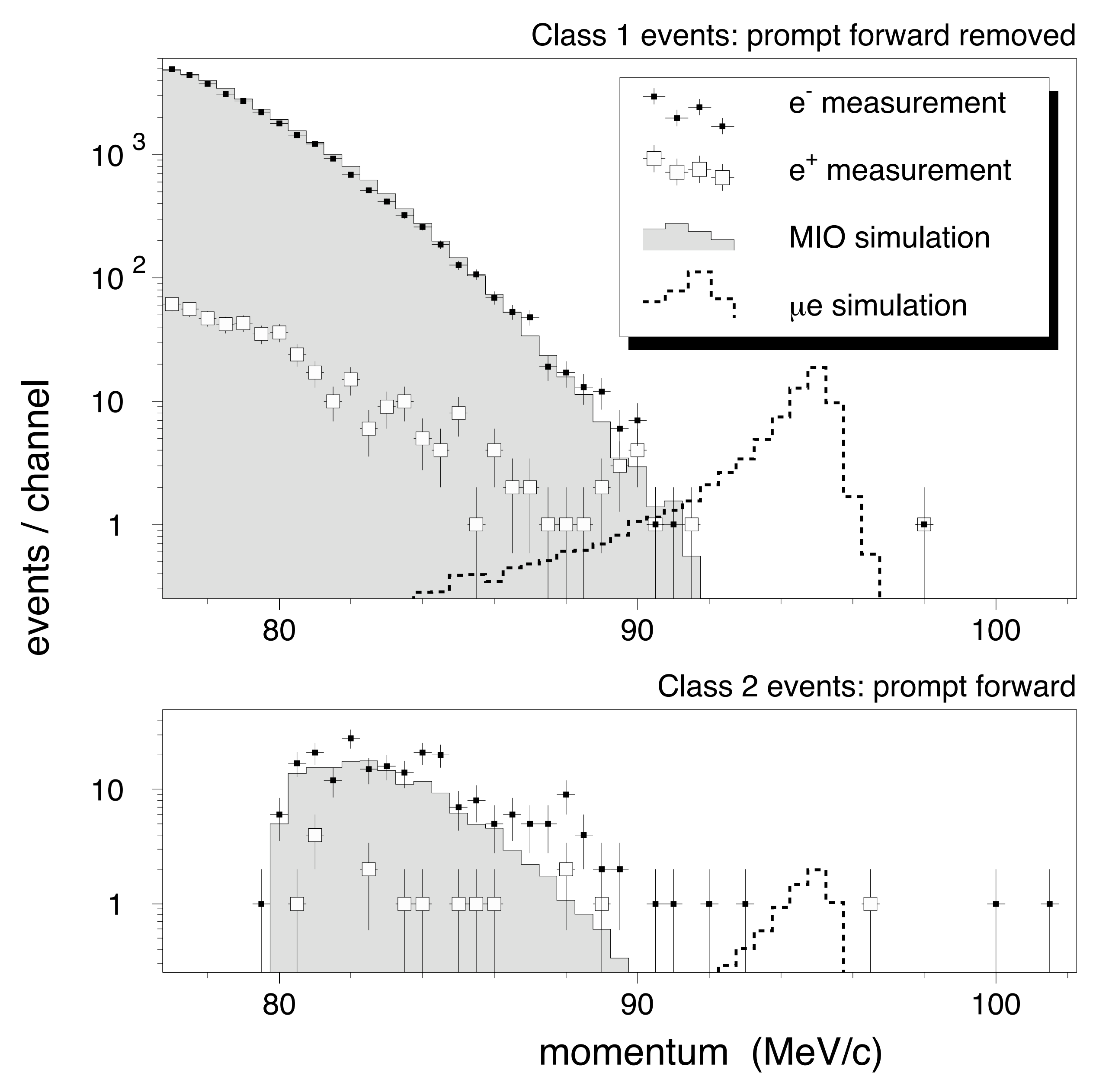
Previous Measurements

SINDRUM-II (PSI)



Published Results (2004)

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



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.

μ
OMET
e

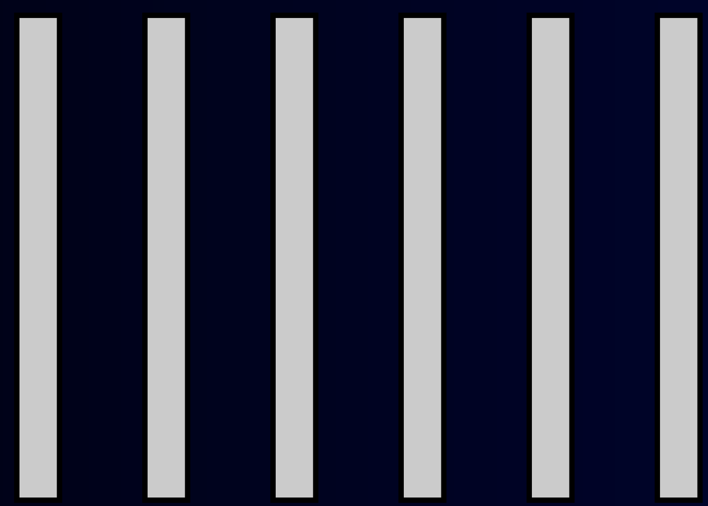
Osaka University

In order to make a new-generation experiment to search for μ-e conversion …

In order to make a new-generation experiment to search for μ-e conversion …

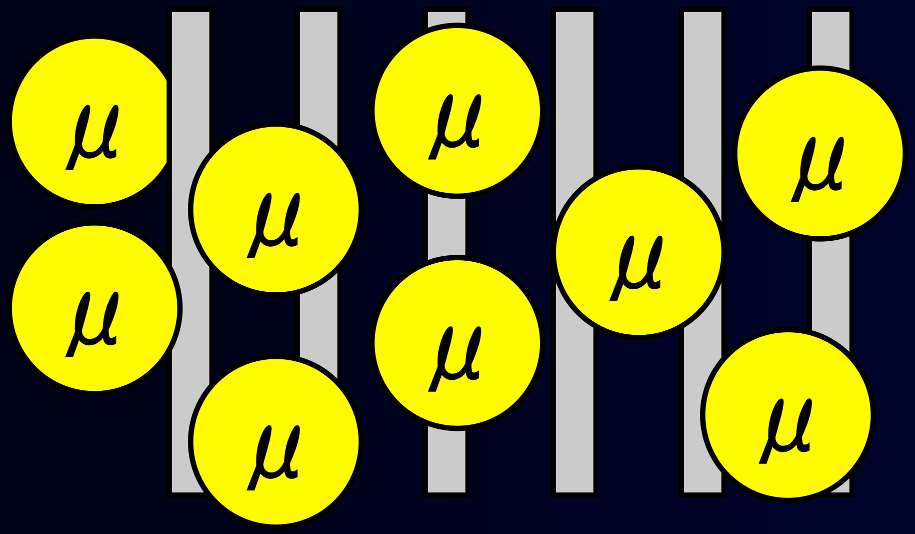
$$B(\mu N \to eN) \leq 10^{-16}$$

Principle of Measurement of μ-e Conversion



muon stopping target

Principle of Measurement of μ-e Conversion



muon stopping target

A total number of muons is the key for success.

COMET : 10^{18} **muons** (past exp. 10^{14} muons)

(note: 10^{10} sec=1000 years needed at PSI.)

Long-Term Project ?

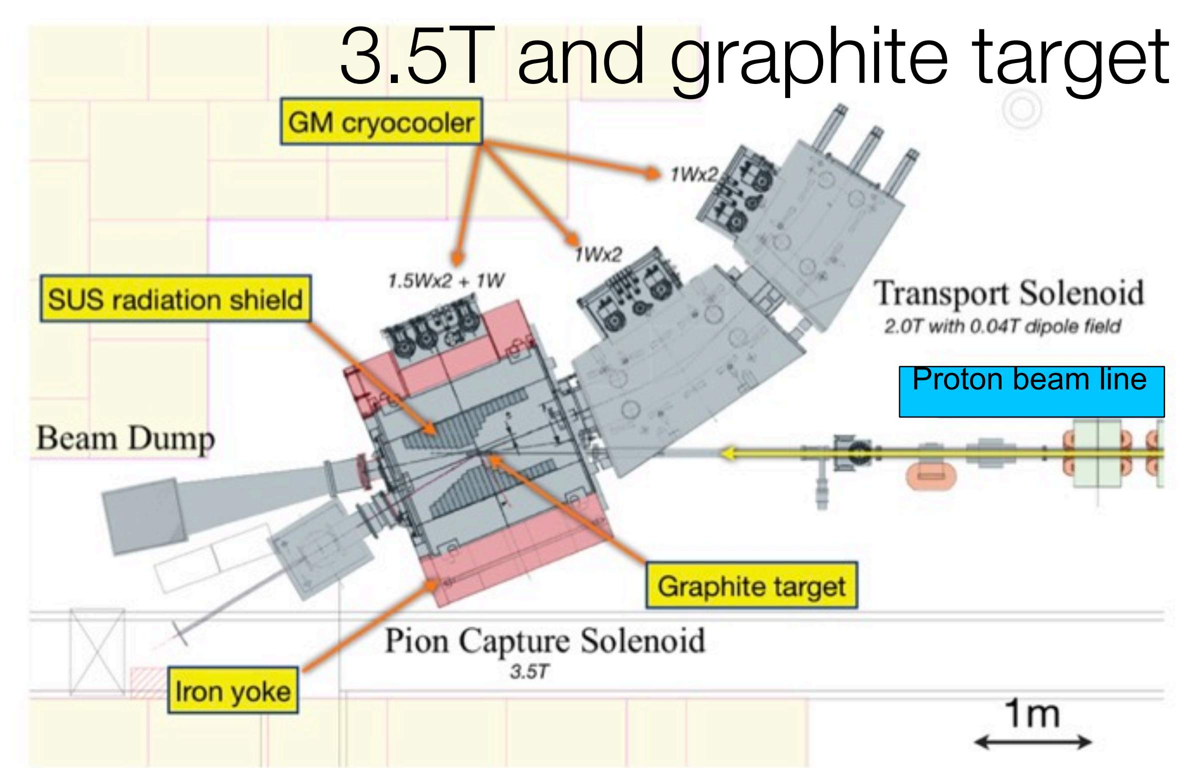
Long-Term Project ?

1000 years ?

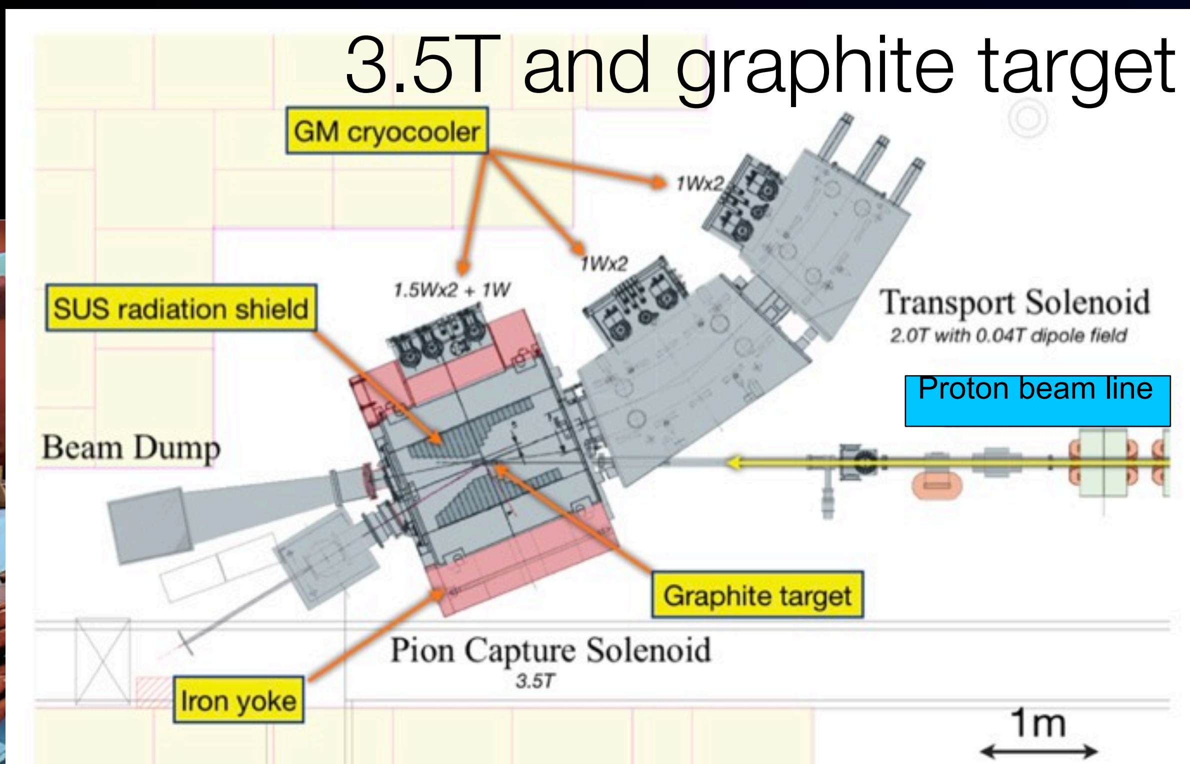
MuSIC at RCNP, Osaka University
- Highly Intense Muon Source -

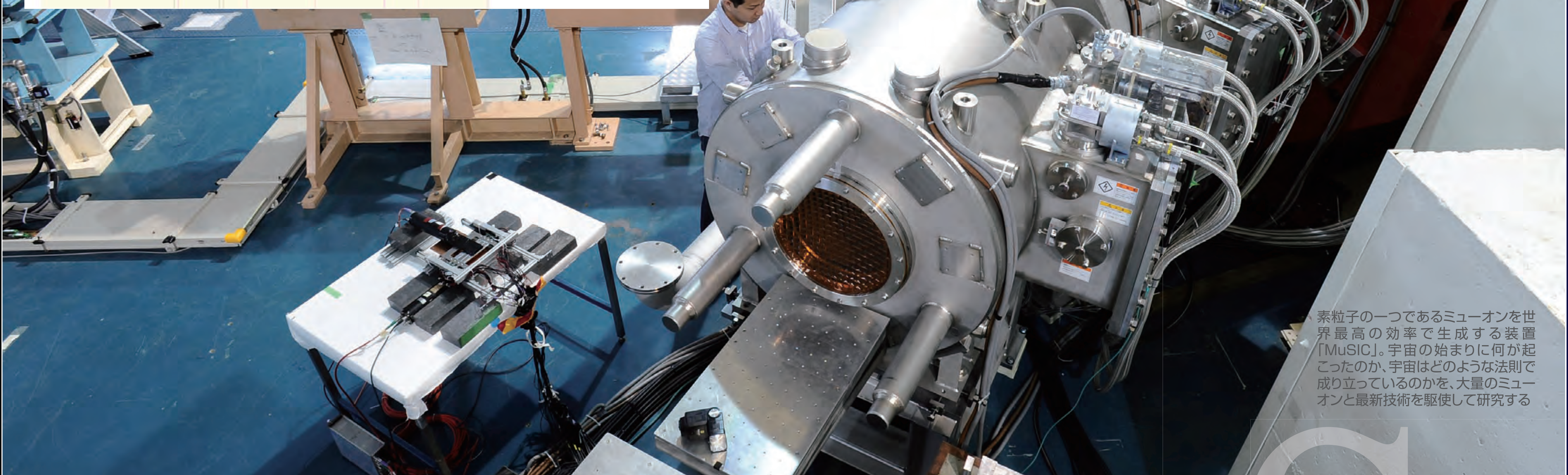
3.5T and graphite target

MuSIC at RCNP, Osaka University
- Highly Intense Muon Source -

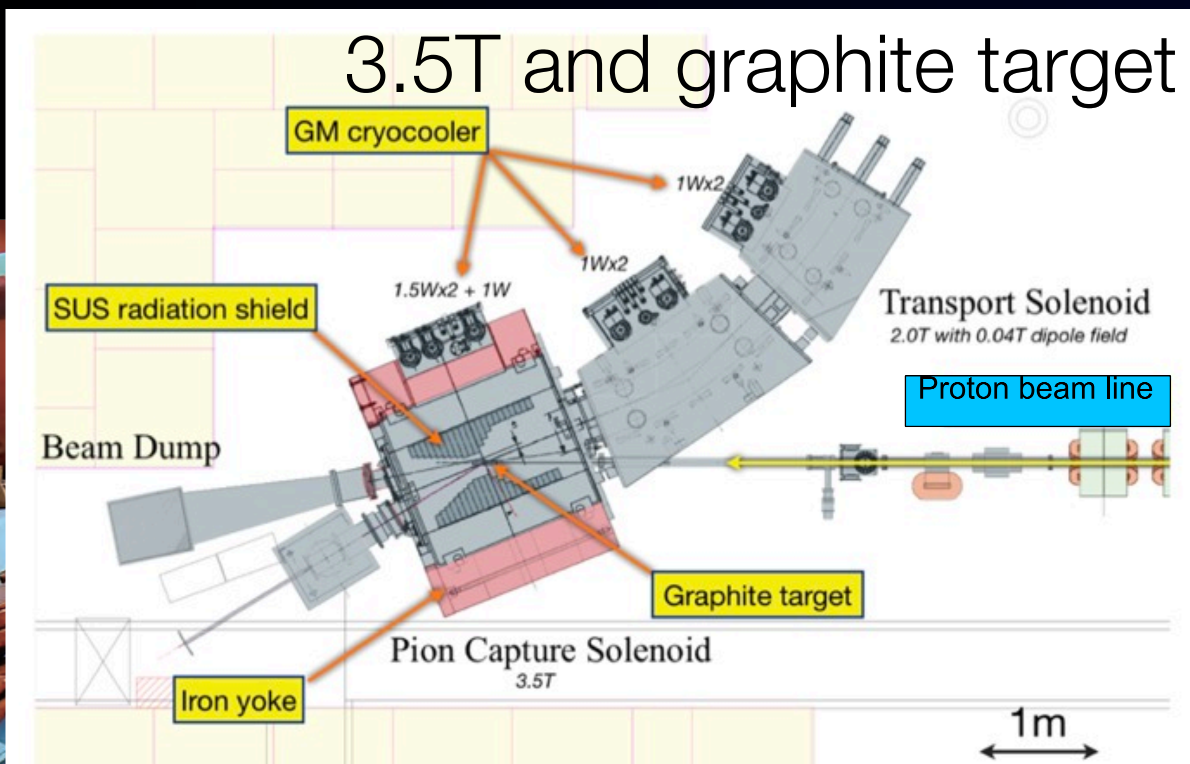


MuSIC at RCNP, Osaka University
- Highly Intense Muon Source -





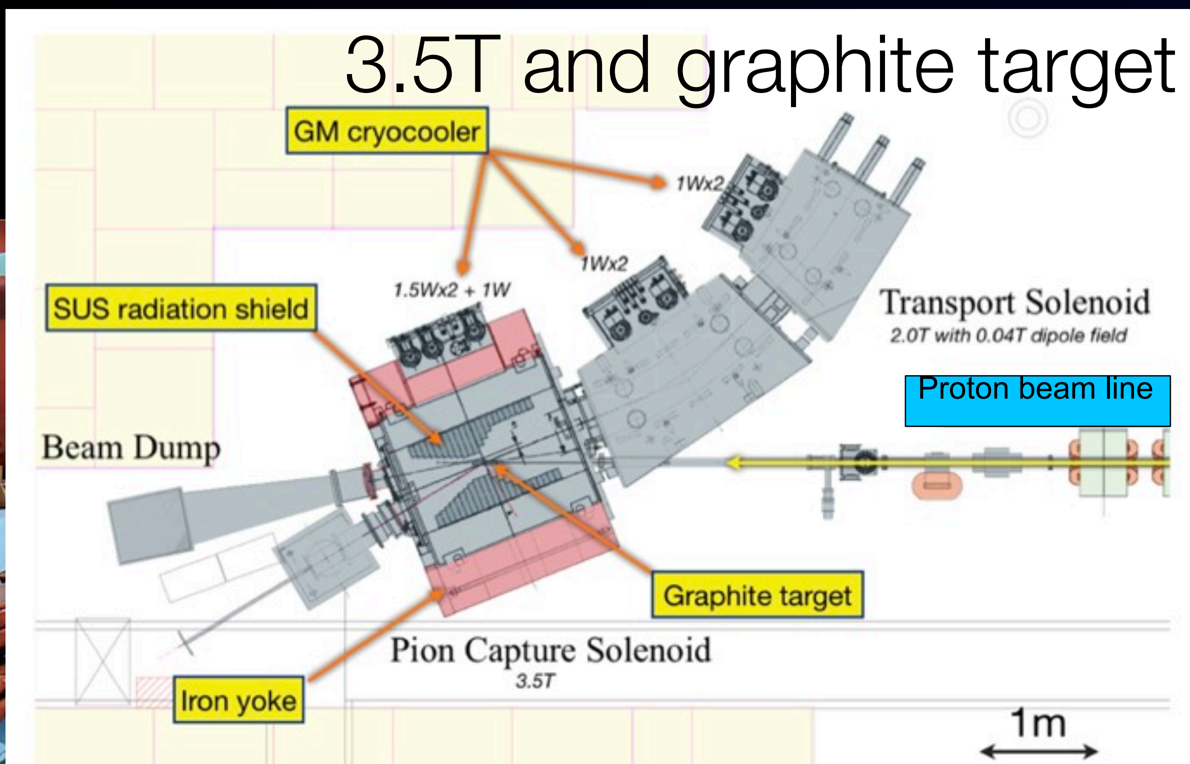
MuSIC at RCNP, Osaka University - Highly Intense Muon Source -

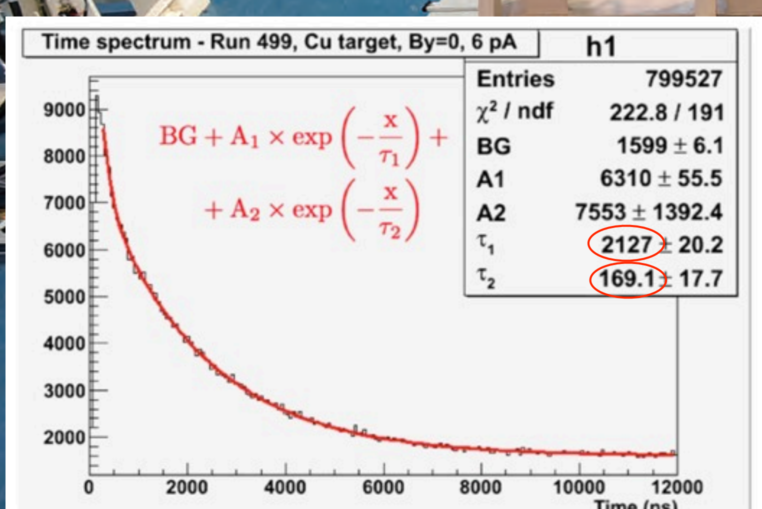


Muon Science Intense Channel (>2011)

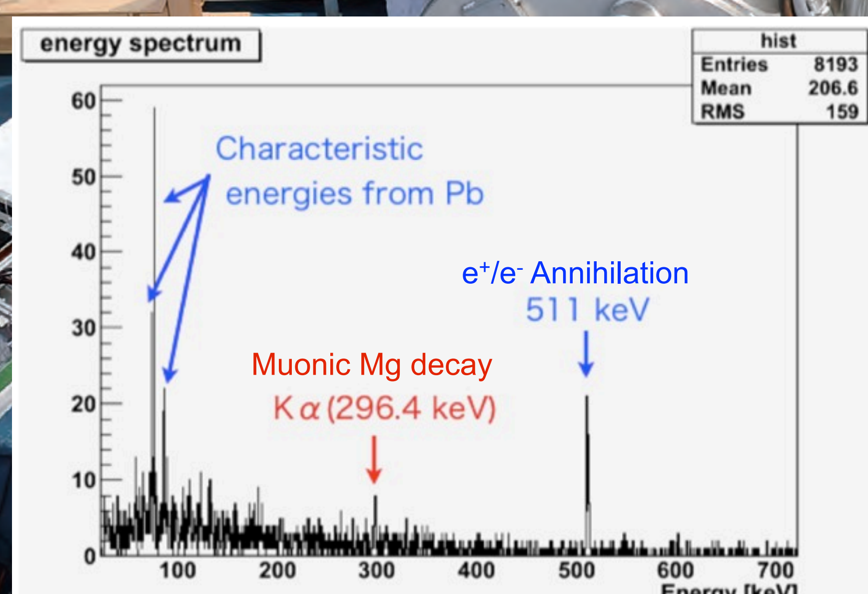
MuSIC at RCNP, Osaka University
- Highly Intense Muon Source -

Muon Science Intense Channel (>2011)





	Free muon*	Cu**	Plastic scint.**
τ (ns)	2197.03 ± 0.04	163.5 ± 1	2026.3 ± 1.5



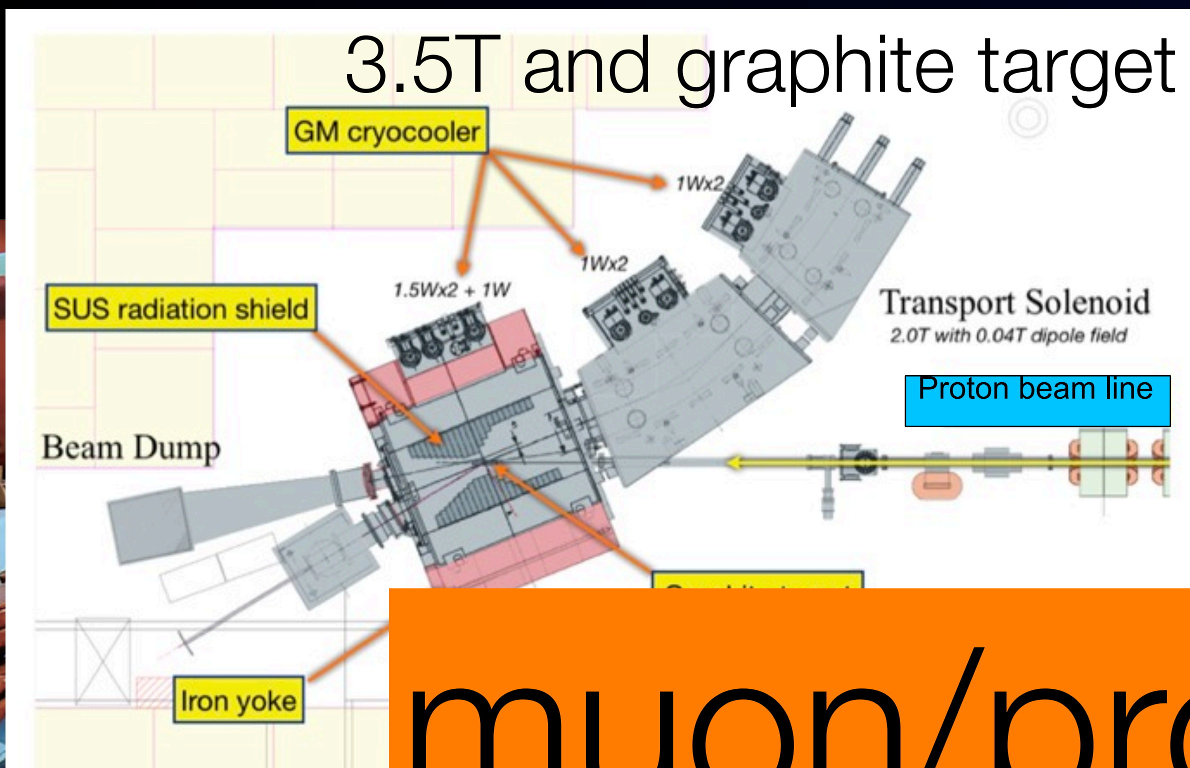
MuSIC muon yields

μ^+ : 3×10^8/s for 400W

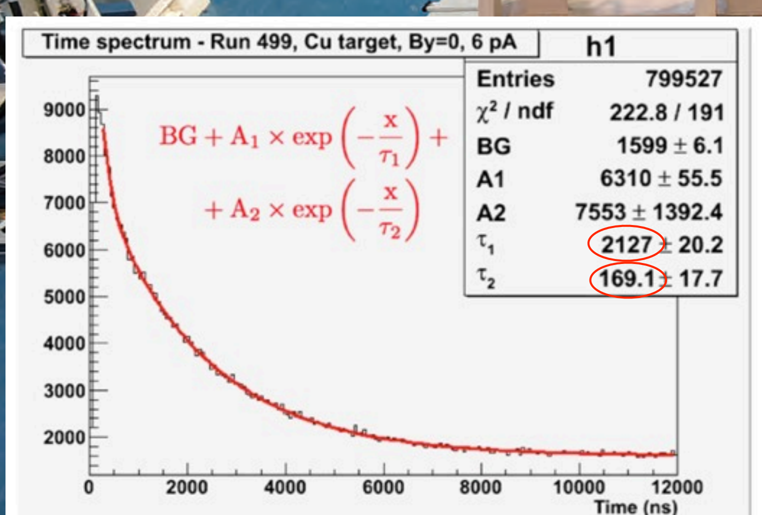
μ^- : 1×10^8/s for 400W

MuSIC at RCNP, Osaka University
- Highly Intense Muon Source -

Muon Science Intense Channel (>2011)



muon/proton~x1000



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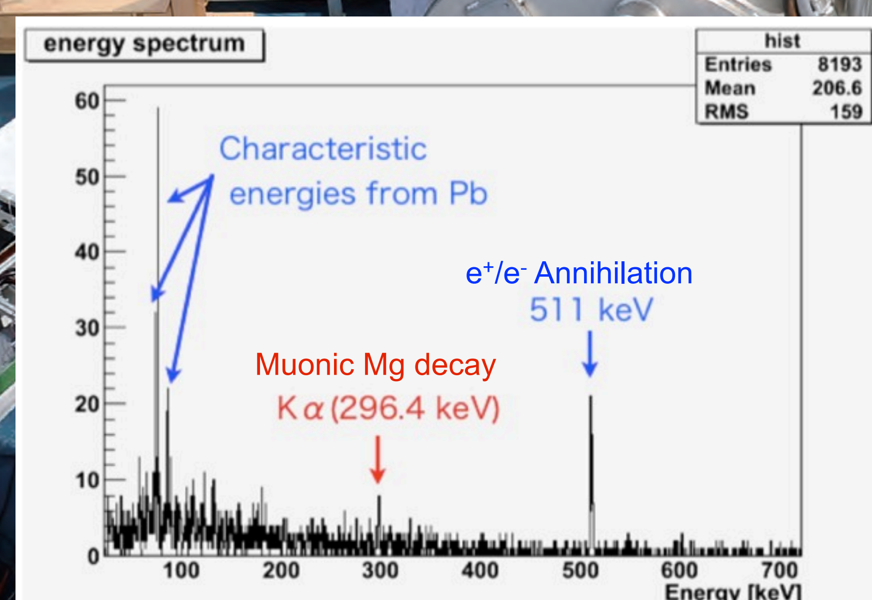

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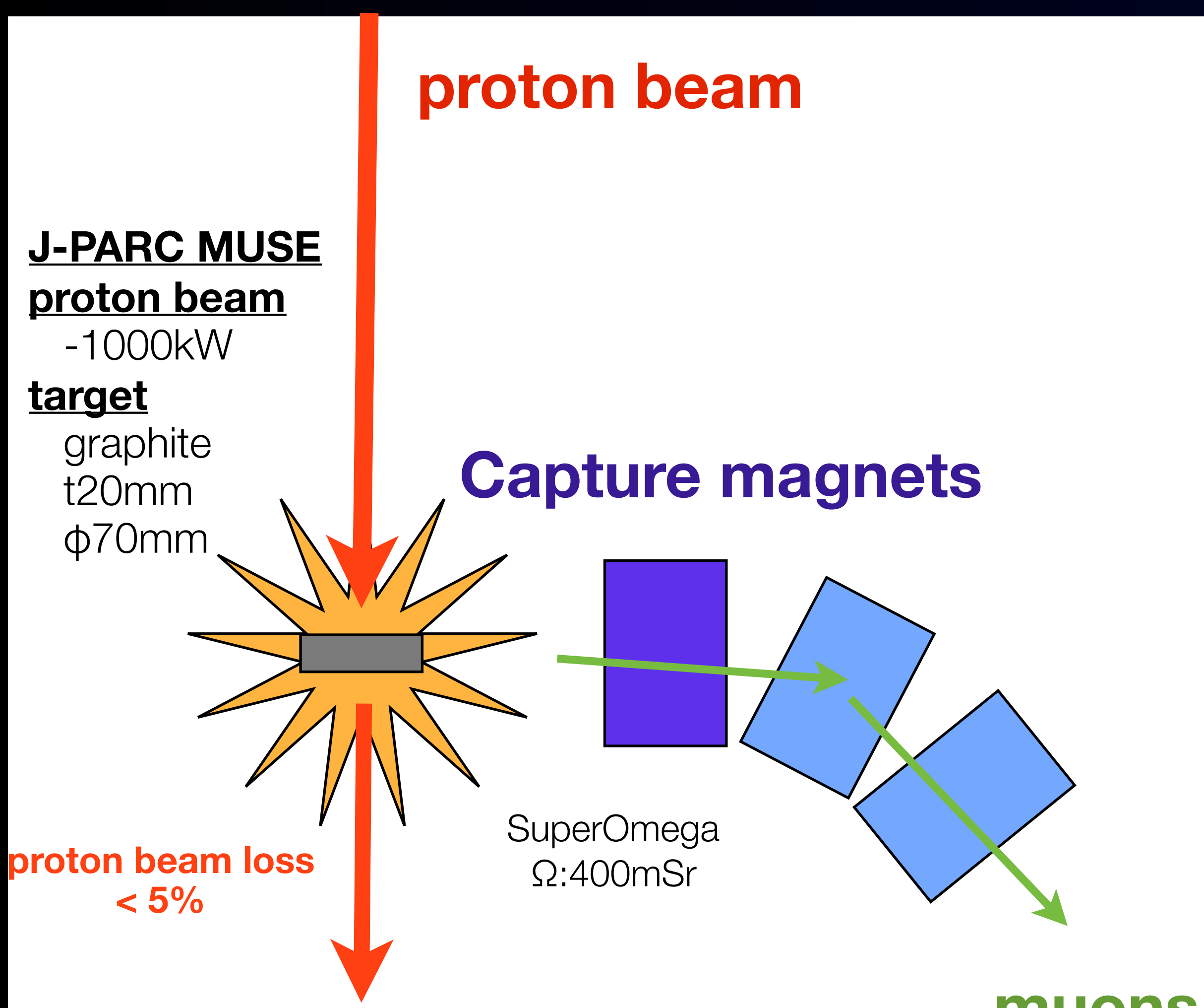
Production and Collection of Pions and Muons

Production and Collection of Pions and Muons

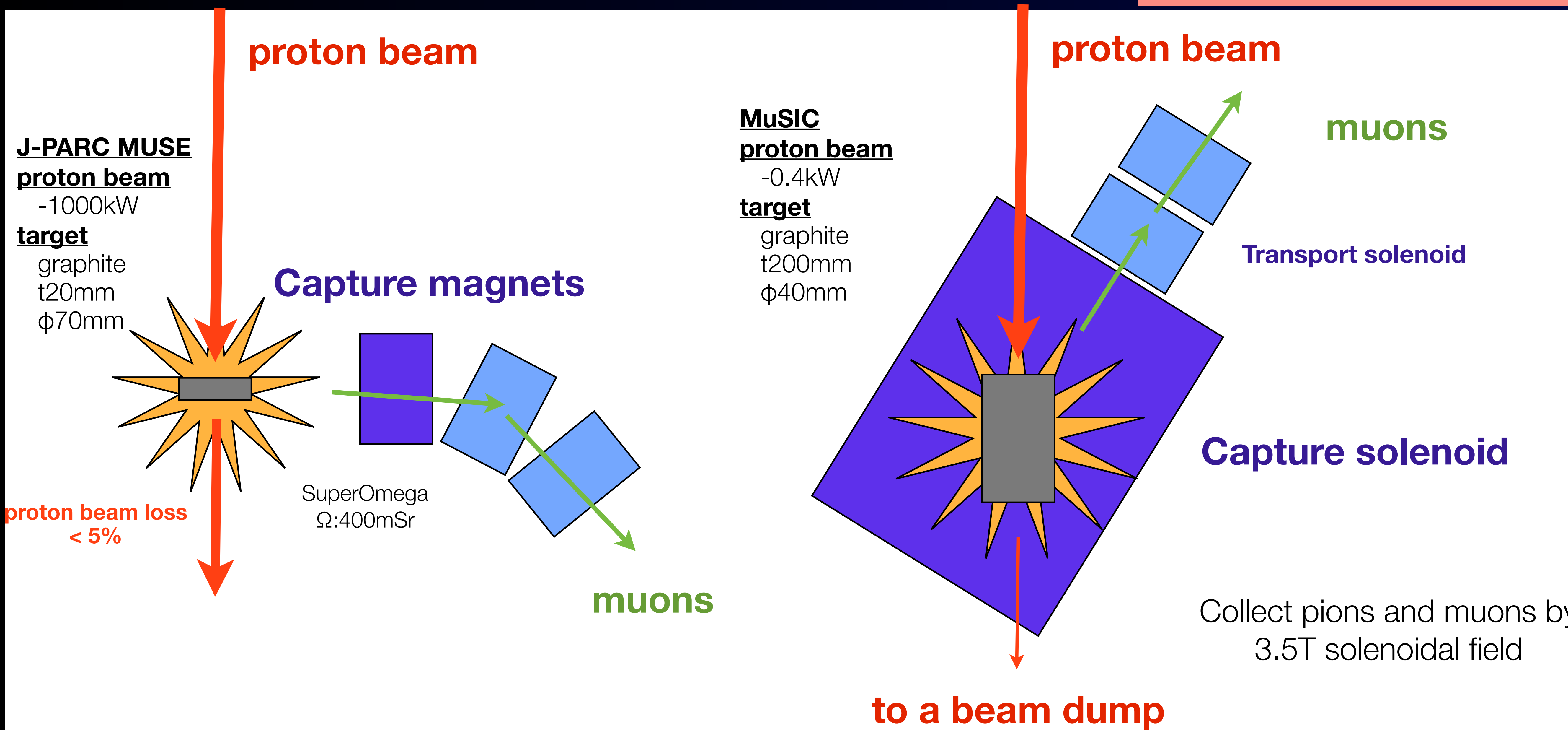
Conventional muon beam line



Production and Collection of Pions and Muons

Conventional muon beam line | **More efficient**

MuSIC,COMET,PRISM,
Neutrino factory,
Muon collider



Large solid angle & thick target

Improvements for Background Rejection

Beam-related backgrounds	→	Beam pulsing with separation of 1μsec	measured between beam pulses

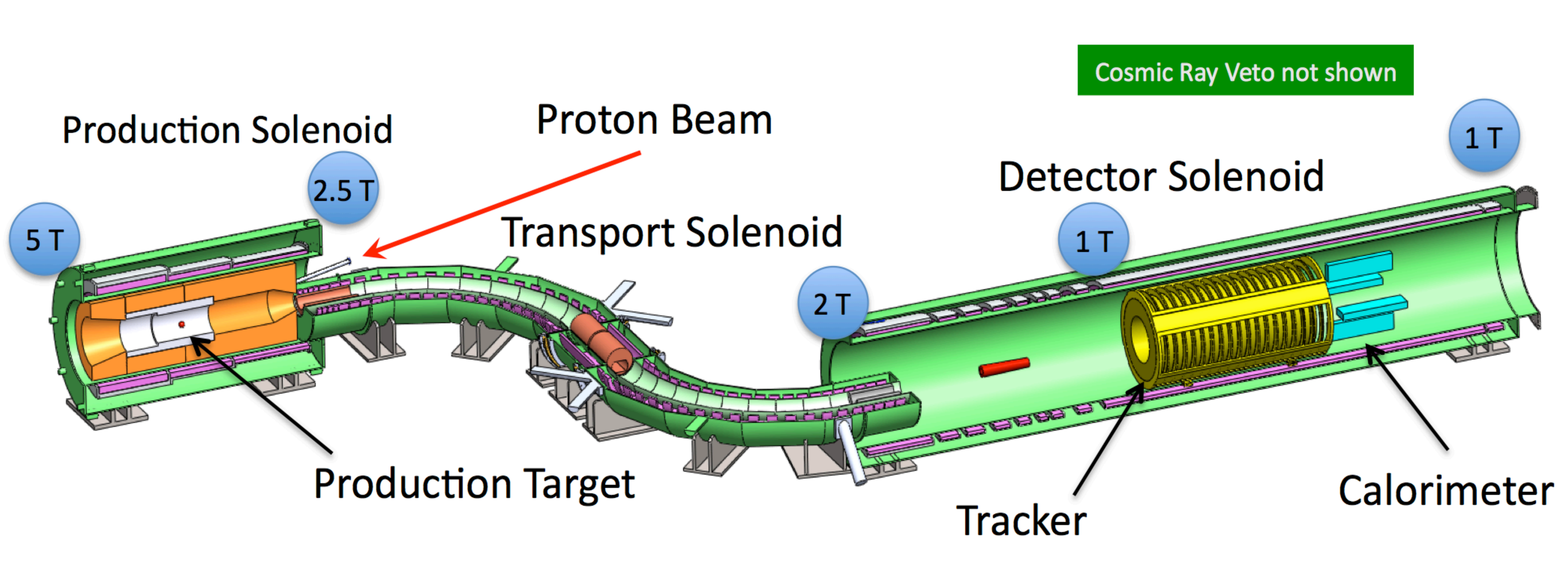
proton extinction = #protons between pulses/#protons in a pulse < 10^{-9}

Muon DIO background	→	low-mass trackers in vacuum & thin target	improve electron energy resolution
Muon DIF background	→	curved solenoids for momentum selection	eliminate energetic muons (>75 MeV/c)

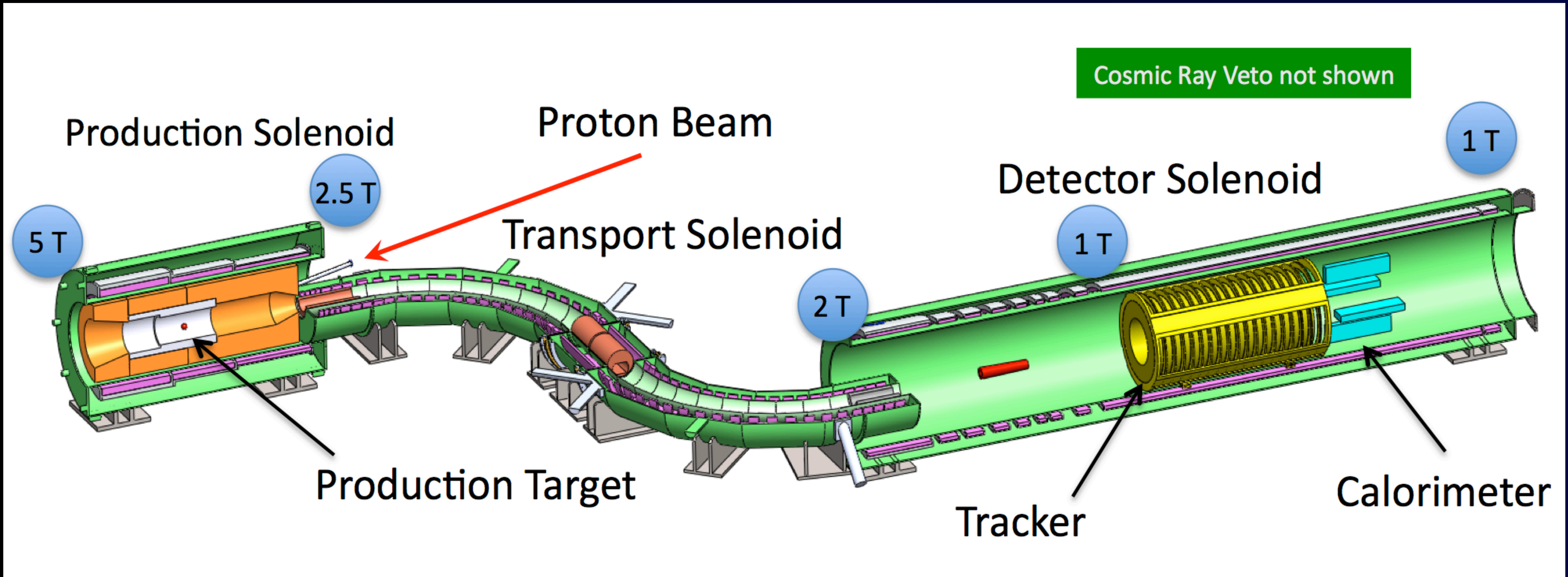
base on the MELC proposal at Moscow Meson Factory

Mu2e at Fermilab

Mu2e at Fermilab



Mu2e at Fermilab



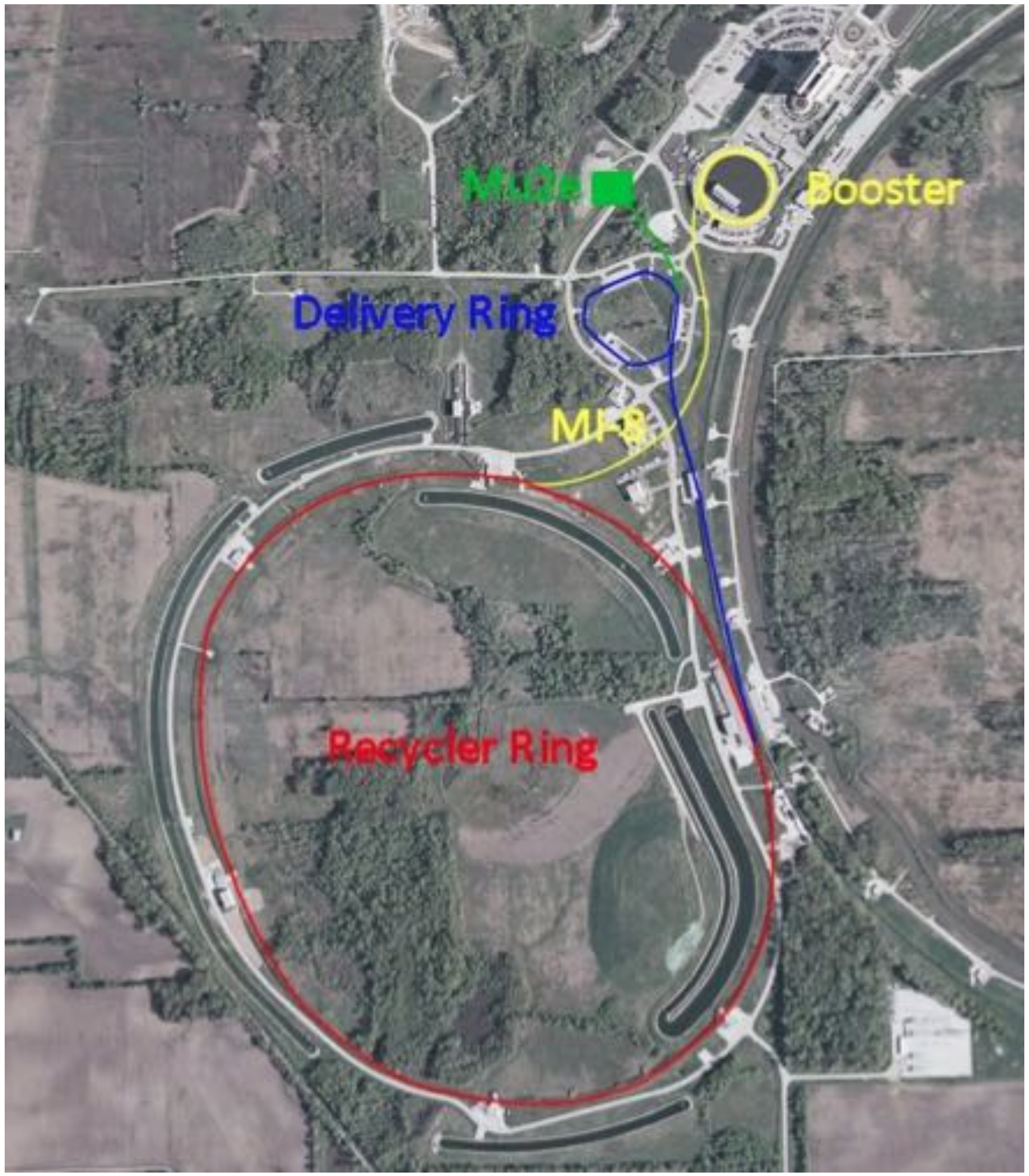
Single-event sensitivity : $(2.5\pm0.3)\times10^{-17}$

Total background : (0.36 ± 0.10) events

Expected limits : $< 6\times10^{-17}$ @90%C.L.

Running time: 3 years (2×10^{7}sec/year)

Mu2e Proton Beam line - Fermilab



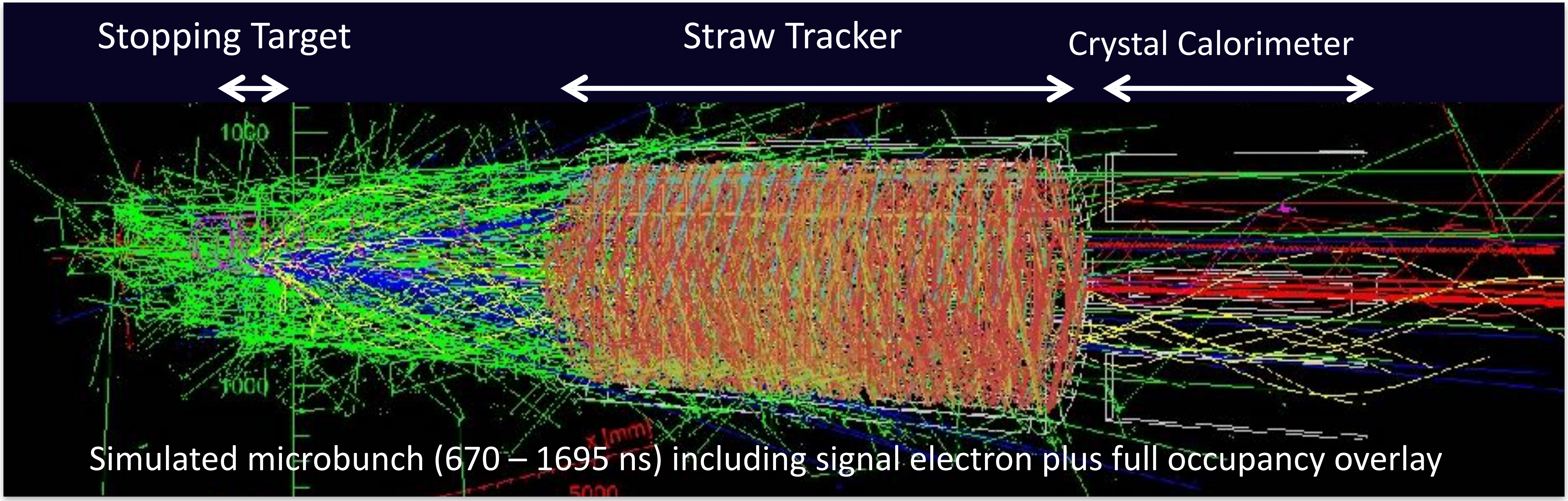
- Mu2e makes use of existing infrastructure at Fermilab
- Mu2e uses 8 kW of protons
  - From the Booster (8 GeV)
  - Re-bunched in the Recycler
  - Slow-spill from Delivery Ring
    - aka Accumulator/Debuncher for Tevatron anti-protons
    - Revolution period 1695 ns
- Mu2e can (and will) run simultaneously with NOvA

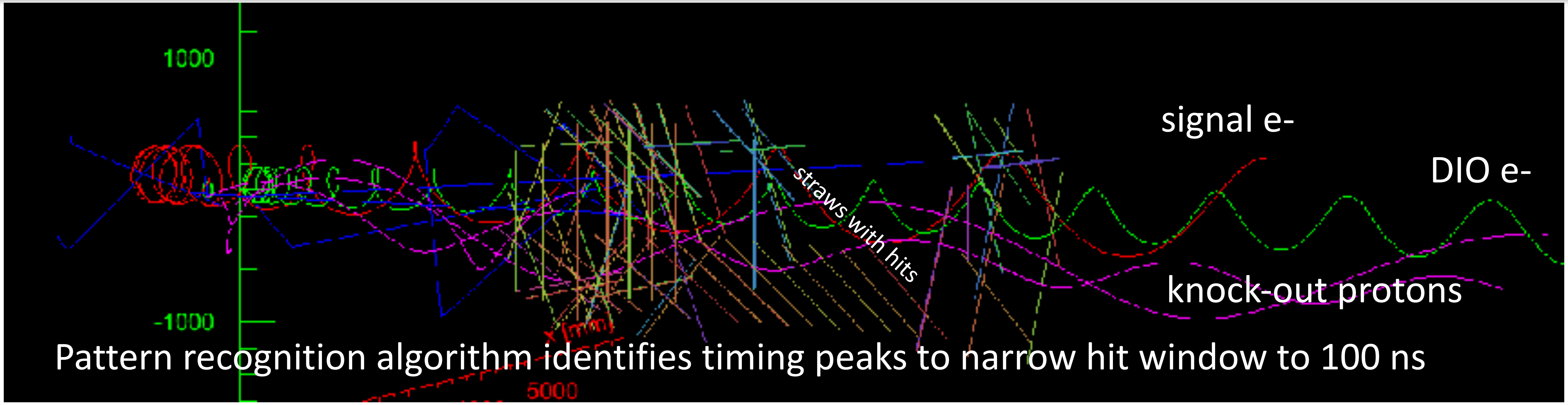
Muon Campus Civil Construction

- Common Muon Campus for Muon (g-2) and Mu2e experiments – common beam line, cryogenics, utilities

Mu2e Simulations

-LBNL, Fermilab, Irvine, Boston, Virginia, NIU, Caltech, Frascati, Pisa, Novosibirsk, Louisville, CUNY, Muons Inc., Yale





- Utilize a detailed, hit-level GEANT4 simulation, realistic occupancy overlays, full reconstruction, pattern recognition, and track fitting. Full systematic error analysis.

Mu2e Sensitivity

- Estimated background yields for 3.6 x 10^{20} POT

Category	Background process	Estimated yield (events)
Intrinsic	Muon decay-in-orbit (DIO)	0.199 ± 0.092
Late Arriving	Muon capture (RMC)	$0.000^{+0.004}_{-0.000}$
	Pion capture (RPC)	0.023 ± 0.006
	Muon decay-in-flight (μ-DIF)	<0.003
	Pion decay-in-flight (π-DIF)	$0.001 \pm <0.001$
	Beam electrons	0.003 ± 0.001
Miscellaneous	Antiproton induced	0.047 ± 0.024
	Cosmic ray induced	0.082 ± 0.018
	Total background:	0.36 +/- 0.10

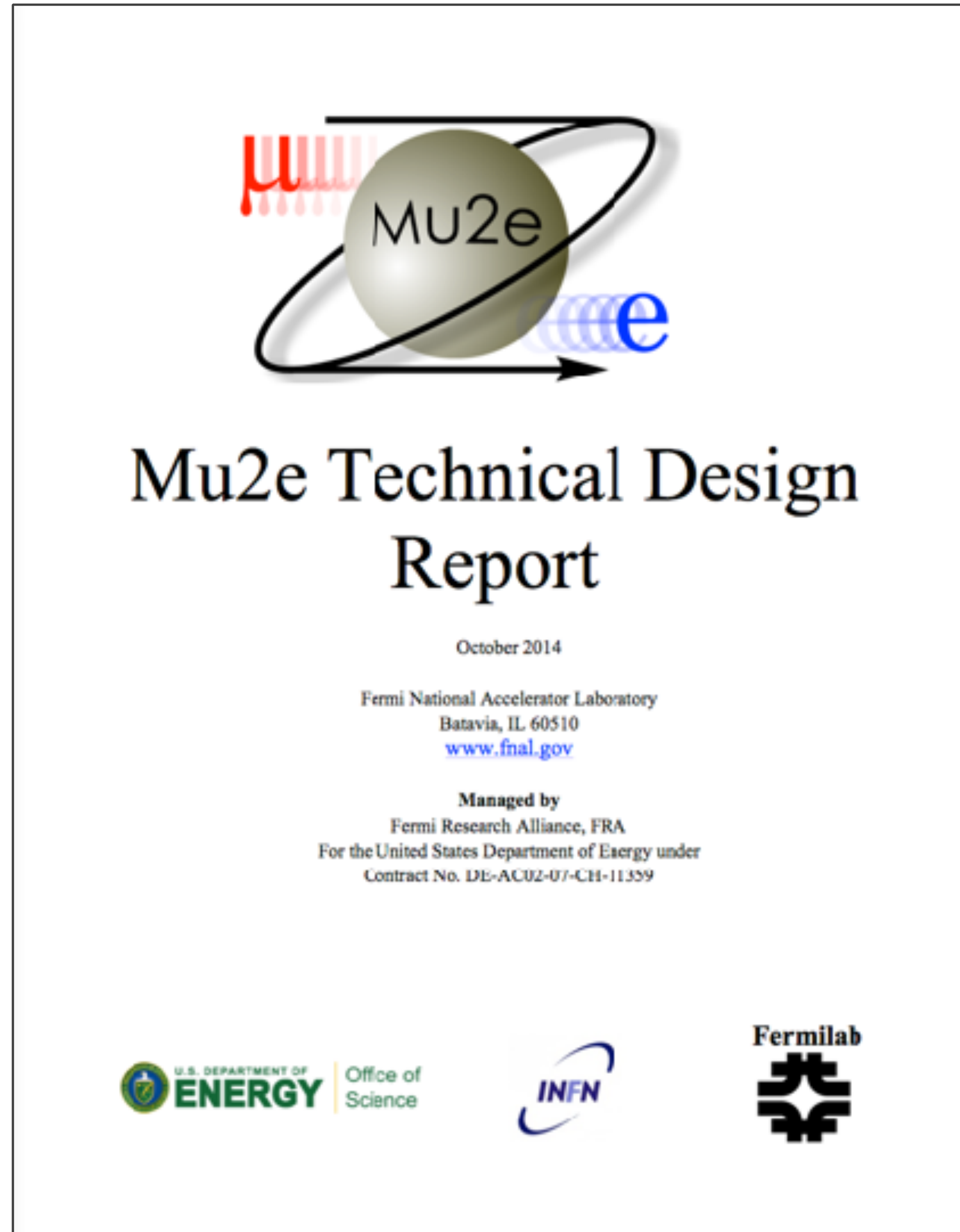
- Estimated signal sensitivity for 3.6 x 10^{20} POT

Parameter	Value
Physics run time @ 2×10^7 s/yr.	3 years
Protons on target per year	1.2×10^{20}
μ^- stops in stopping target per proton on target	0.0019
μ^- capture probability	0.609
Total acceptance x efficiency for the selection criteria of Section 3.5.3	$(8.5 \pm^{1.1}_{0.9})\%$
Single-event sensitivity with Current Algorithms	$(2.87 \pm^{0.32}_{0.27}) \times 10^{-17}$
Goal	2.4×10^{-17}

- Total background yield: (0.36 +/- 0.10) events
- Total signal acceptance x efficiency: (8.5 +/- 1.0) %
- Single-event-sensitivity: (2.9 +/- 0.3) x 10^{-17}
- Total background yield: (0.36 +/- 0.10) events
- Expected Limited: 6 x 10^{-17} @ 90% CL

Mu2e Recent Progress

- Technical Design Report completed arXiv:1501.05241
  - 888 pages, 621 figures
- Awarded CD-3a (June 2014)
  - Authorized purchase of superconductor in production lengths
- Awarded CD-2/3b (March 2015)
  - Project baseline at $273.7M
  - Authorized building start, TS coil fabrication



Mu2e Technical Design Report

October 2014

Fermi National Accelerator Laboratory
Batavia, IL 60510
www.fnal.gov

Managed by
Fermi Research Alliance, FRA
For the United States Department of Energy under
Contract No. DE-AC02-07-CH-11359

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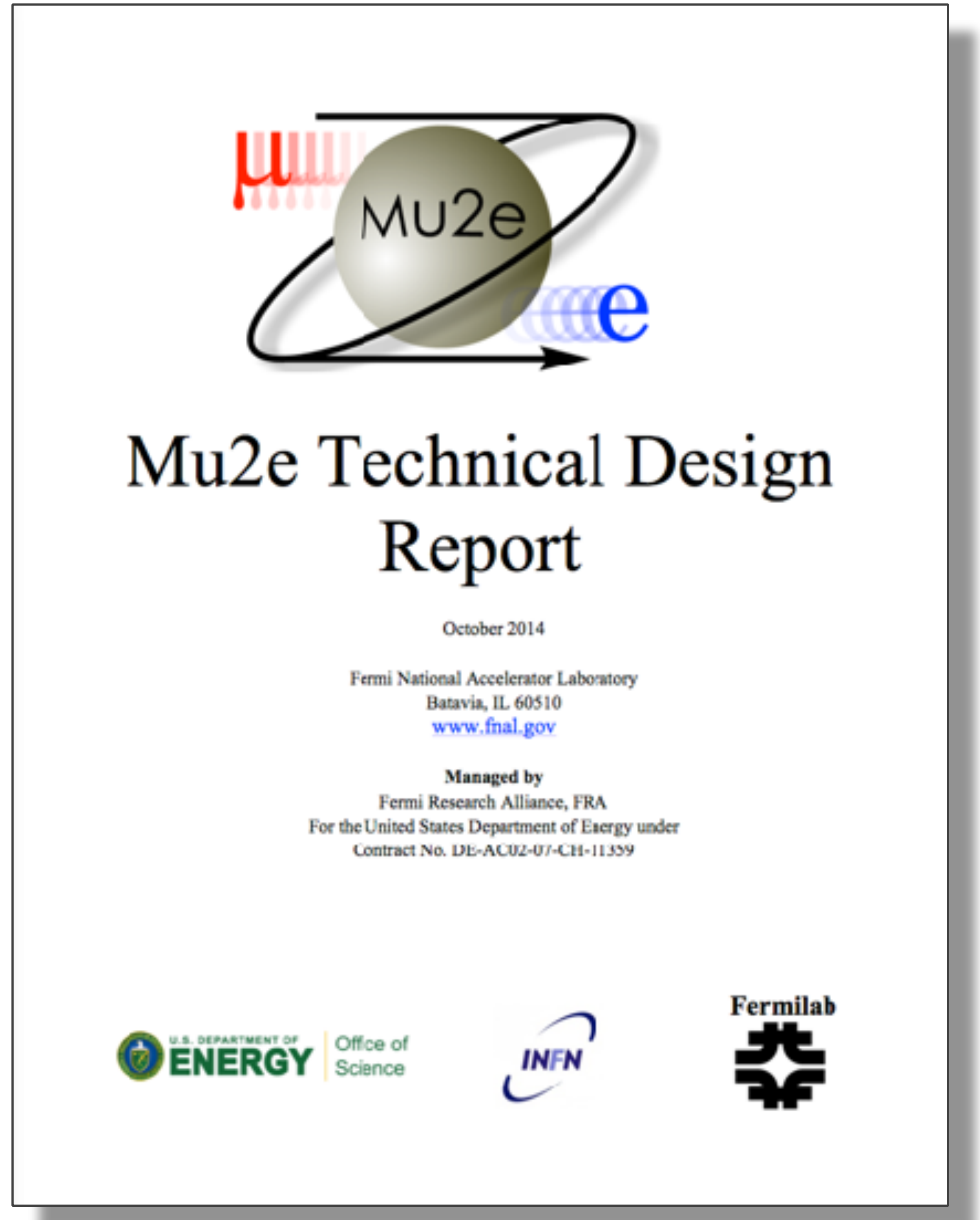
Mu2e

Mu2e Technical Design Report

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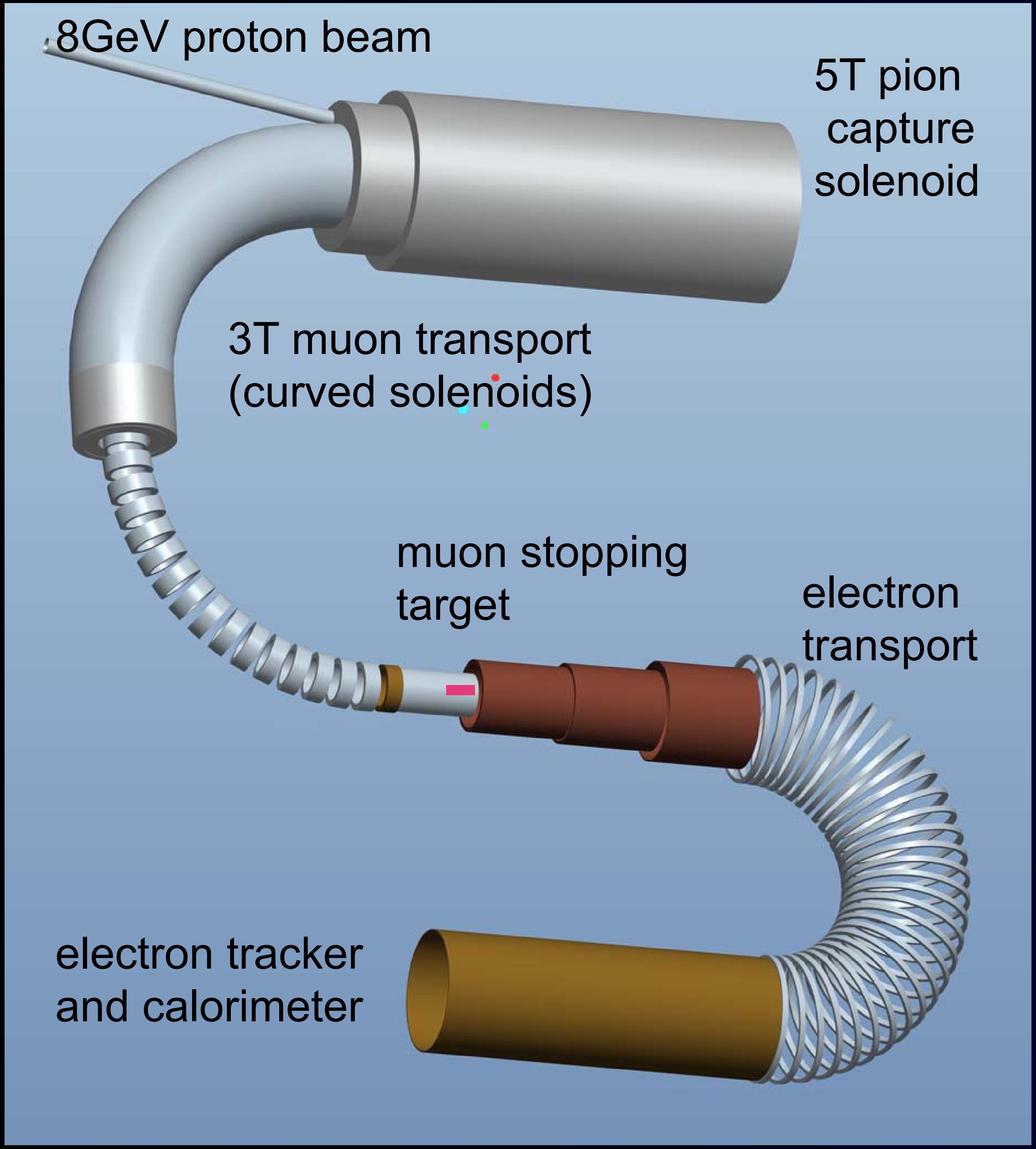
INFN

Fermilab

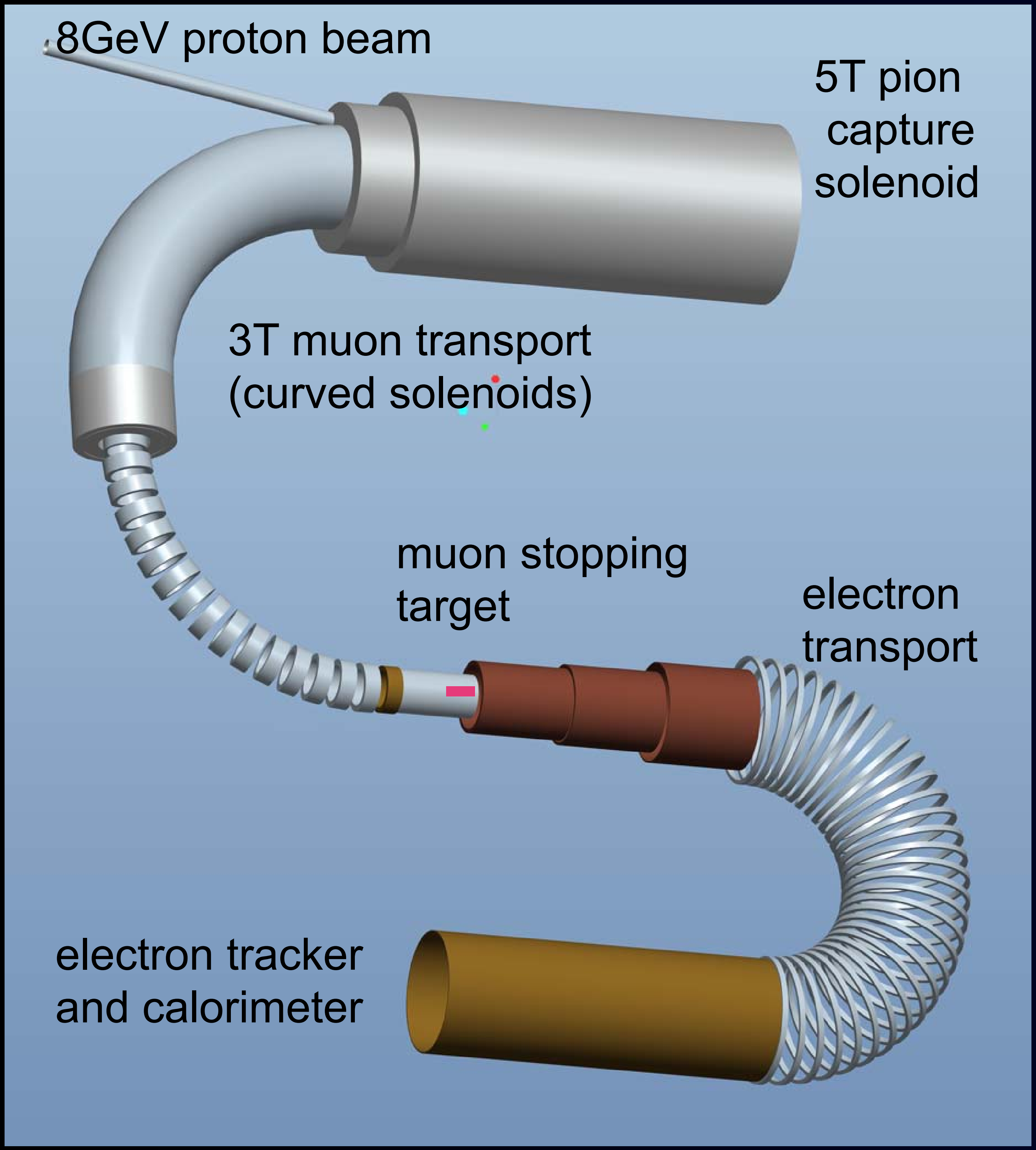
COMET at J-PARC

COMET at J-PARC: E21

COMET at J-PARC: E21



COMET at J-PARC: E21



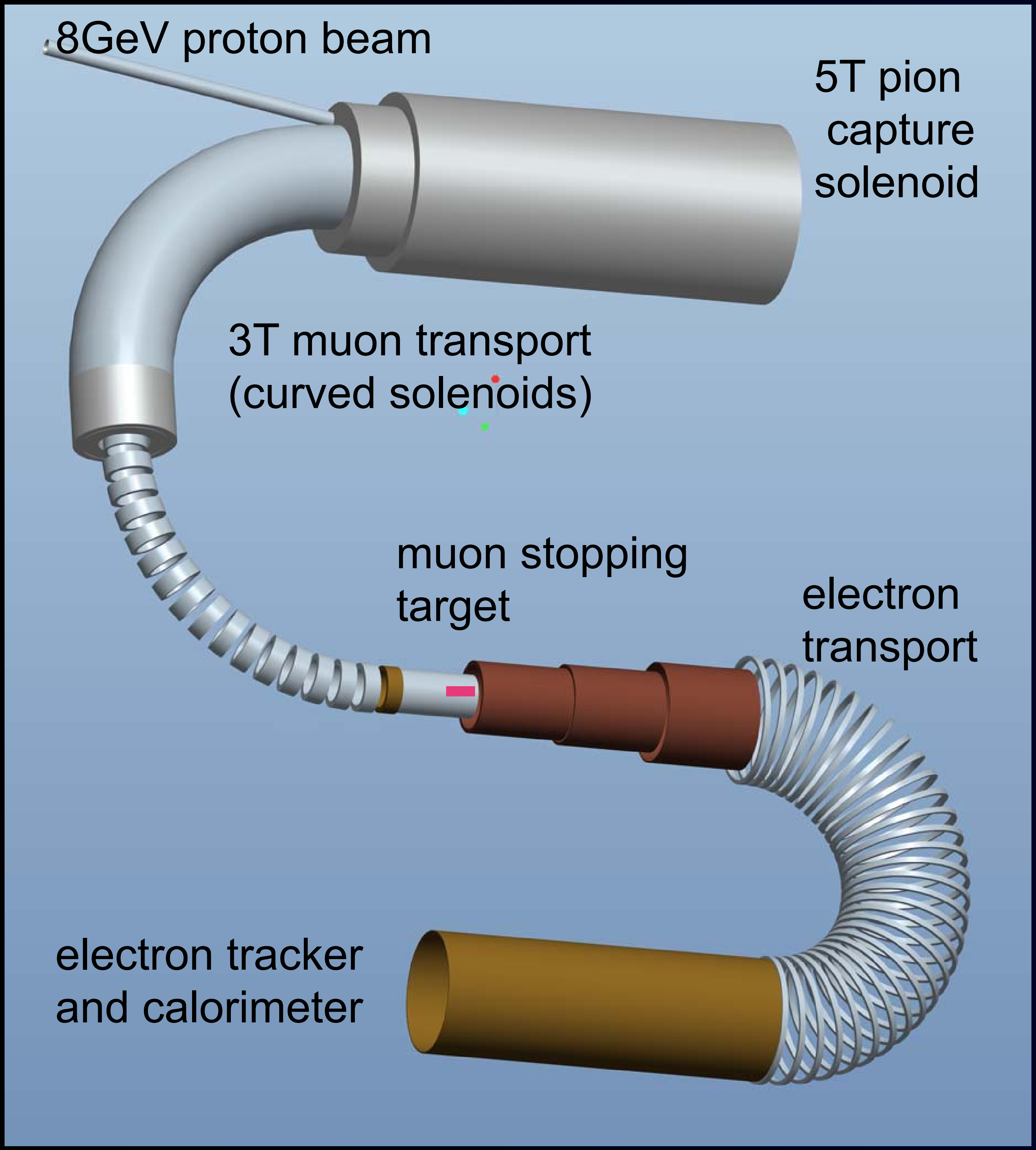
Physics sensitivity : $(1.0\text{-}2.6)\times10^{-17}$

Total background : 0.32 events

Expected limits : $< 6\times10^{-17}$@90%CL

Running time: 1 years (2×10^{7}sec)

COMET at J-PARC: E21



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Why COMET, not Mu2e ?

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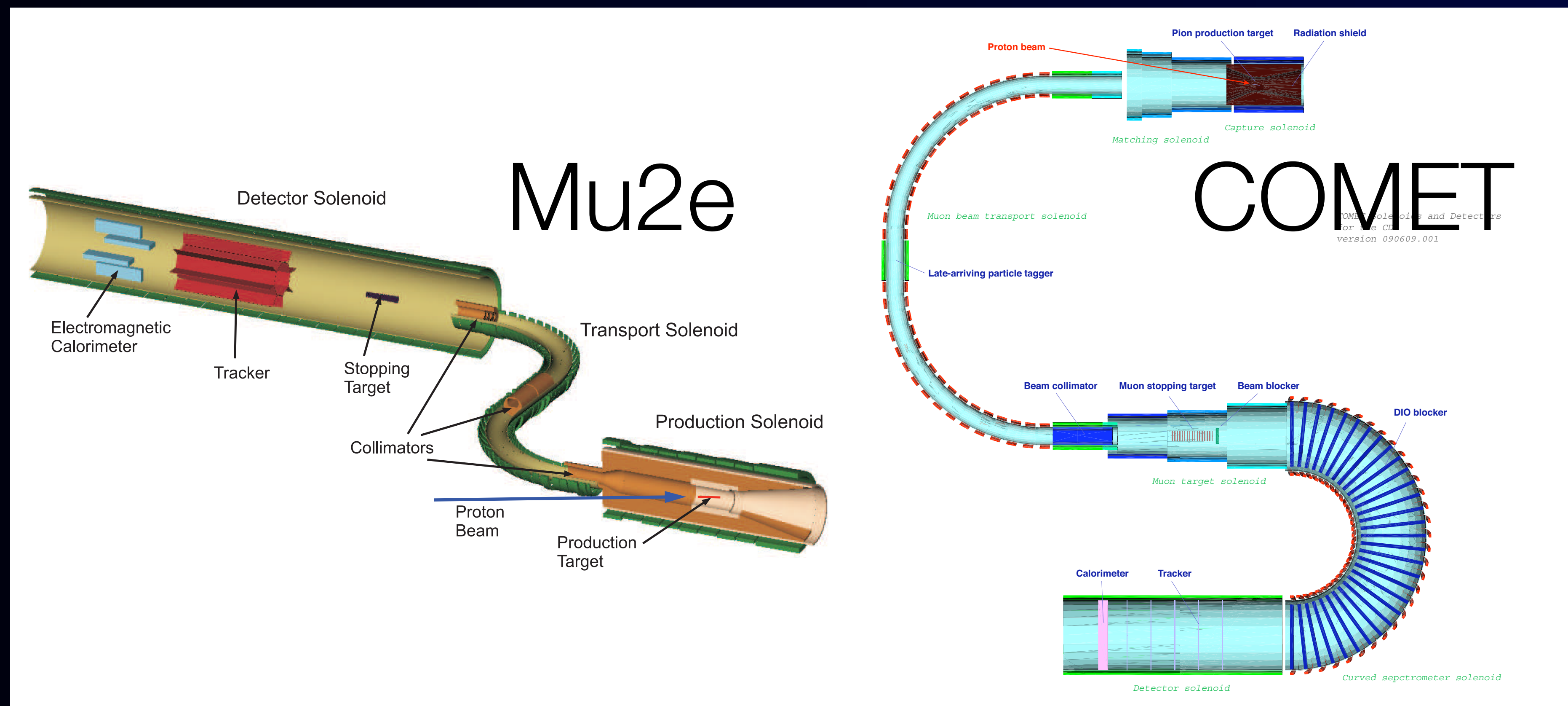
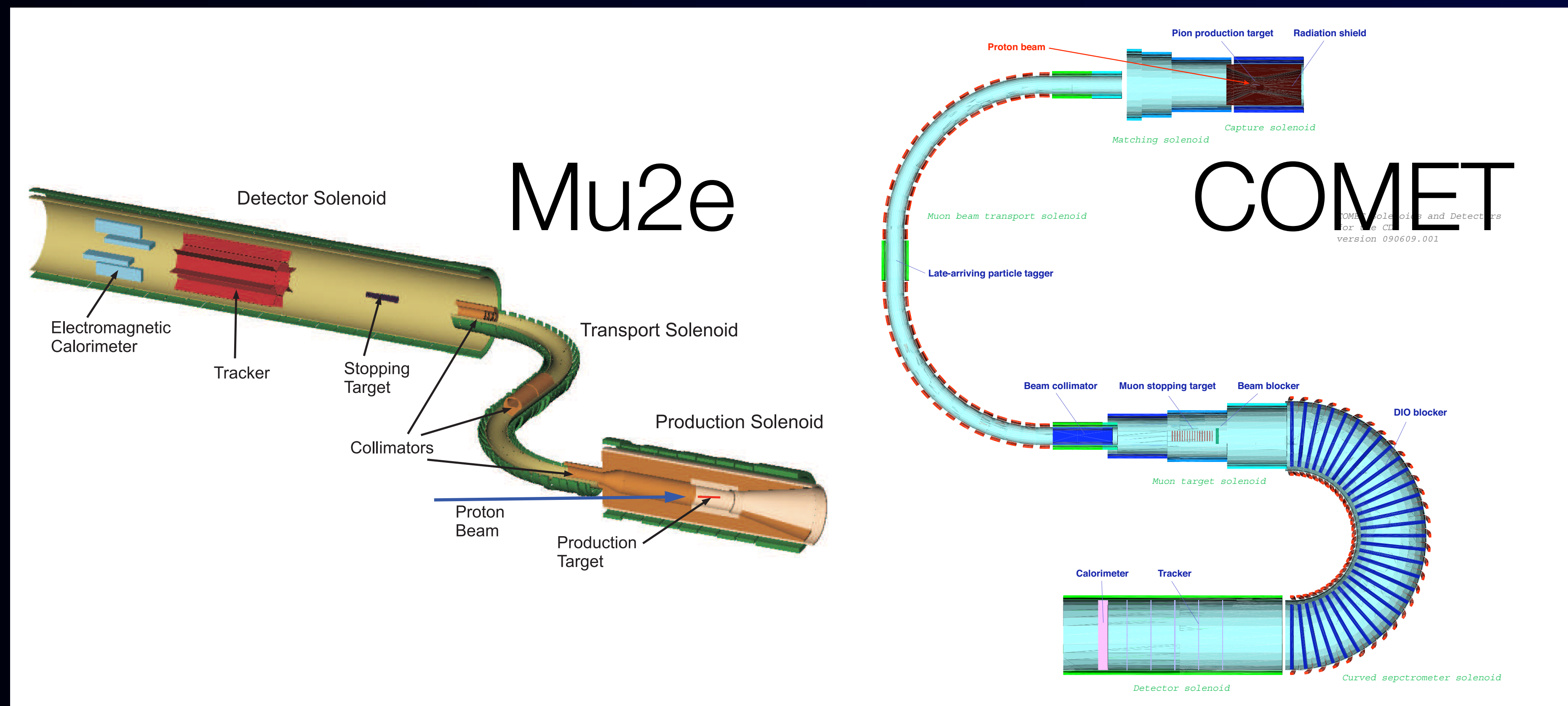


Sensitivity / 2×10^{7} sec
= 7.5×10^{-17}

Sensitivity / 2×10^{7} sec
= 1.0×10^{-17}

Why COMET, not Mu2e ?



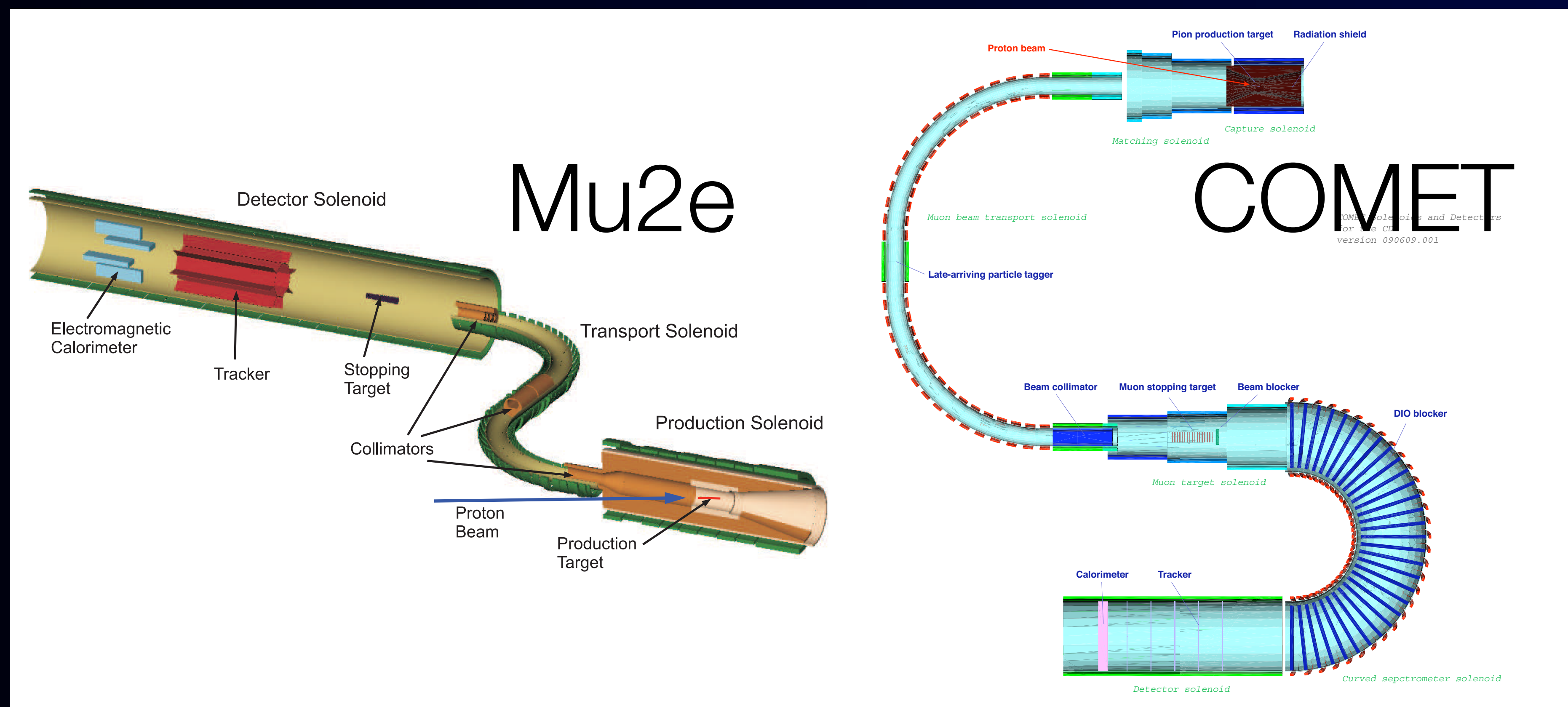
Sensitivity / 2×10^{7} sec
$= 7.5 \times10^{-17}$

Sensitivity / 2×10^{7} sec
$= 1.0 \times10^{-17}$

proton beam ~ 8kW

proton beam ~ 56kW

Why COMET, not Mu2e ?



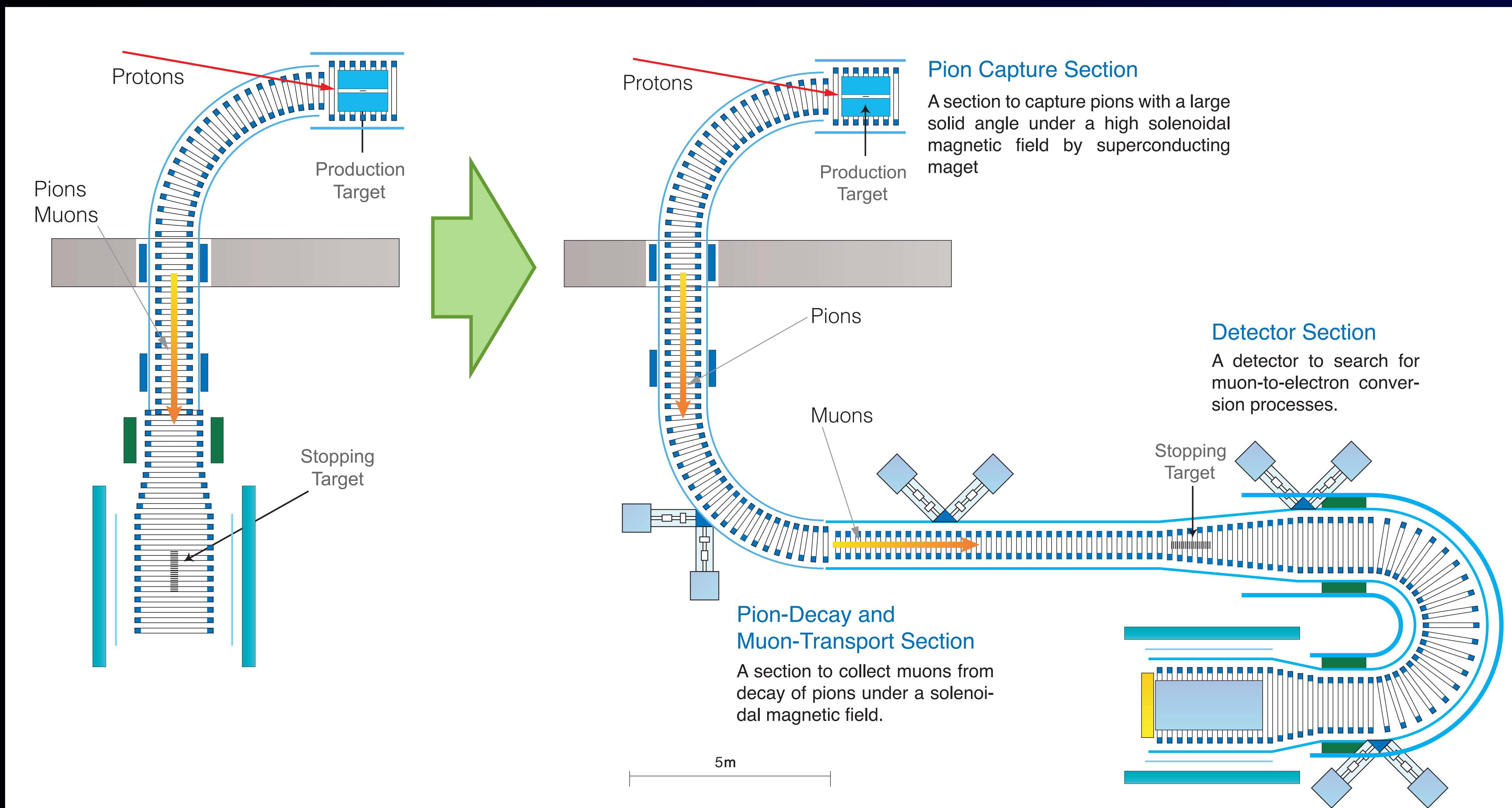
Mu2e	COMET
Sensitivity / 2×10^{7} sec $= 7.5\times10^{-17}$	Sensitivity / 2×10^{7} sec $= 1.0\times10^{-17}$
proton beam ~ 8kW	proton beam ~ 56kW
down to 0.5×10^{-17} 15 years	2 years

COMET Staged Approach (2012~)

COMET Staged Approach (2012~)

COMET Phase-I

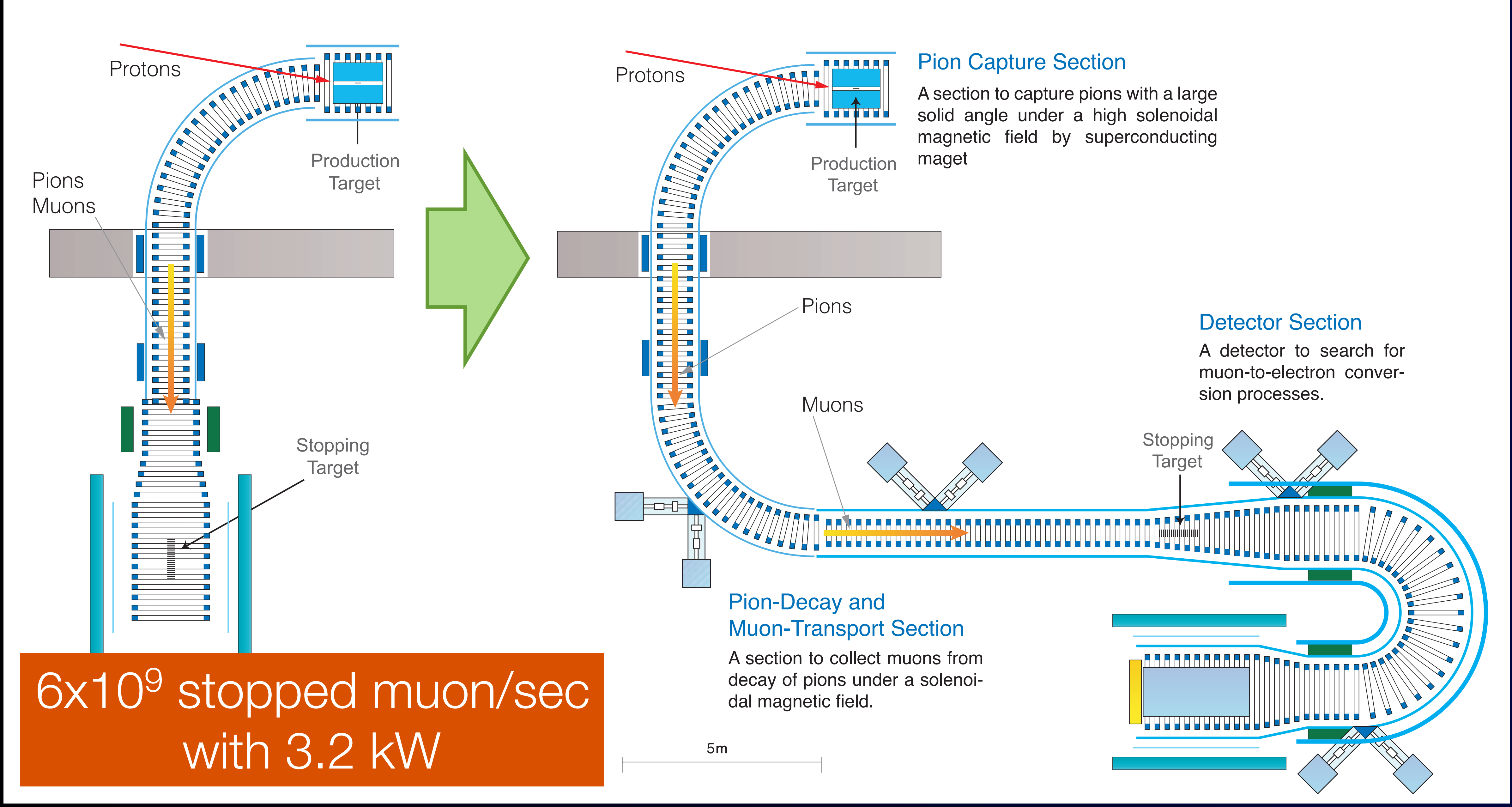
COMET Phase-II



COMET Staged Approach (2012~)

COMET Phase-I

COMET Phase-II



6×10^9 stopped muon/sec with 3.2 kW

COMET Phase-I

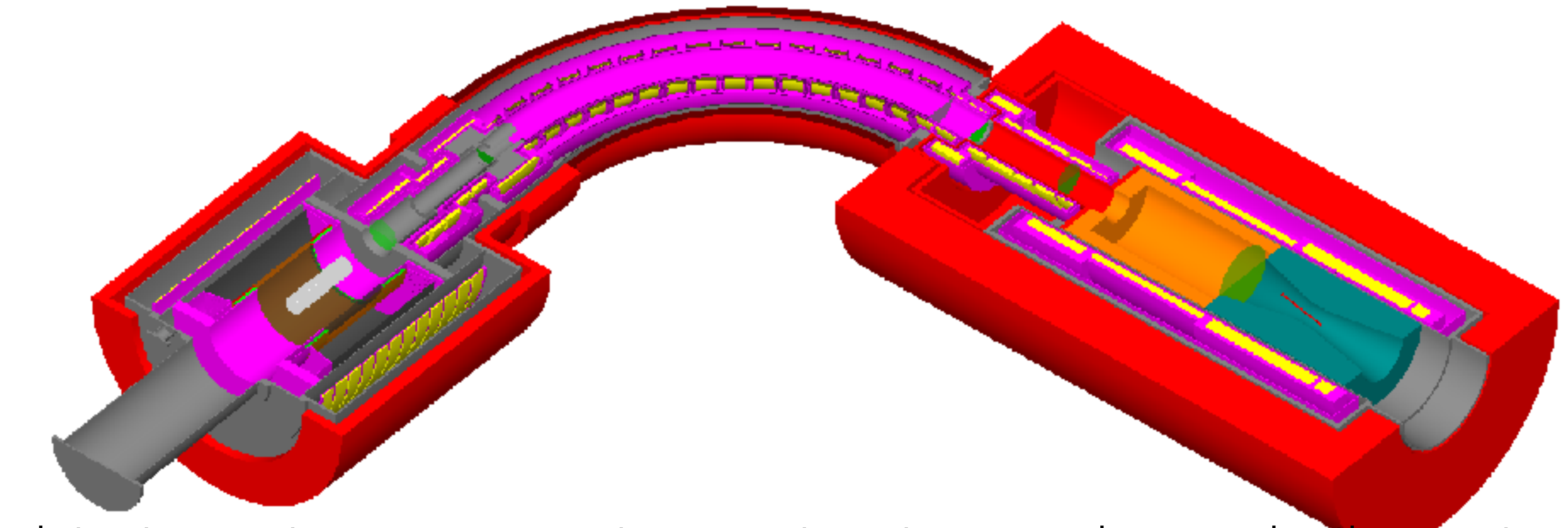
Single-event sensitivity : 3×10^{-15}

Total background : 0.2 events

Expected limits : $< 6 \times 10^{-15}$ @90%CL

Running time: 150 days

COMET Phase-I



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Curved Solenoids for Muon Transport Completed and Delivered!

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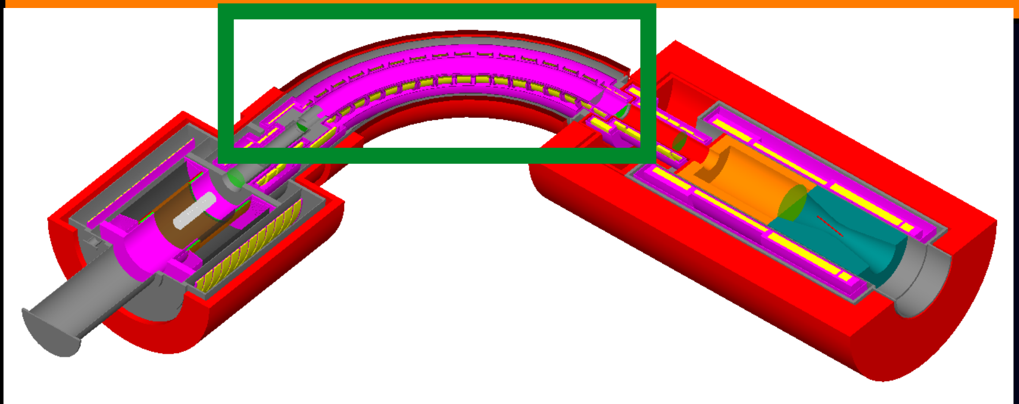
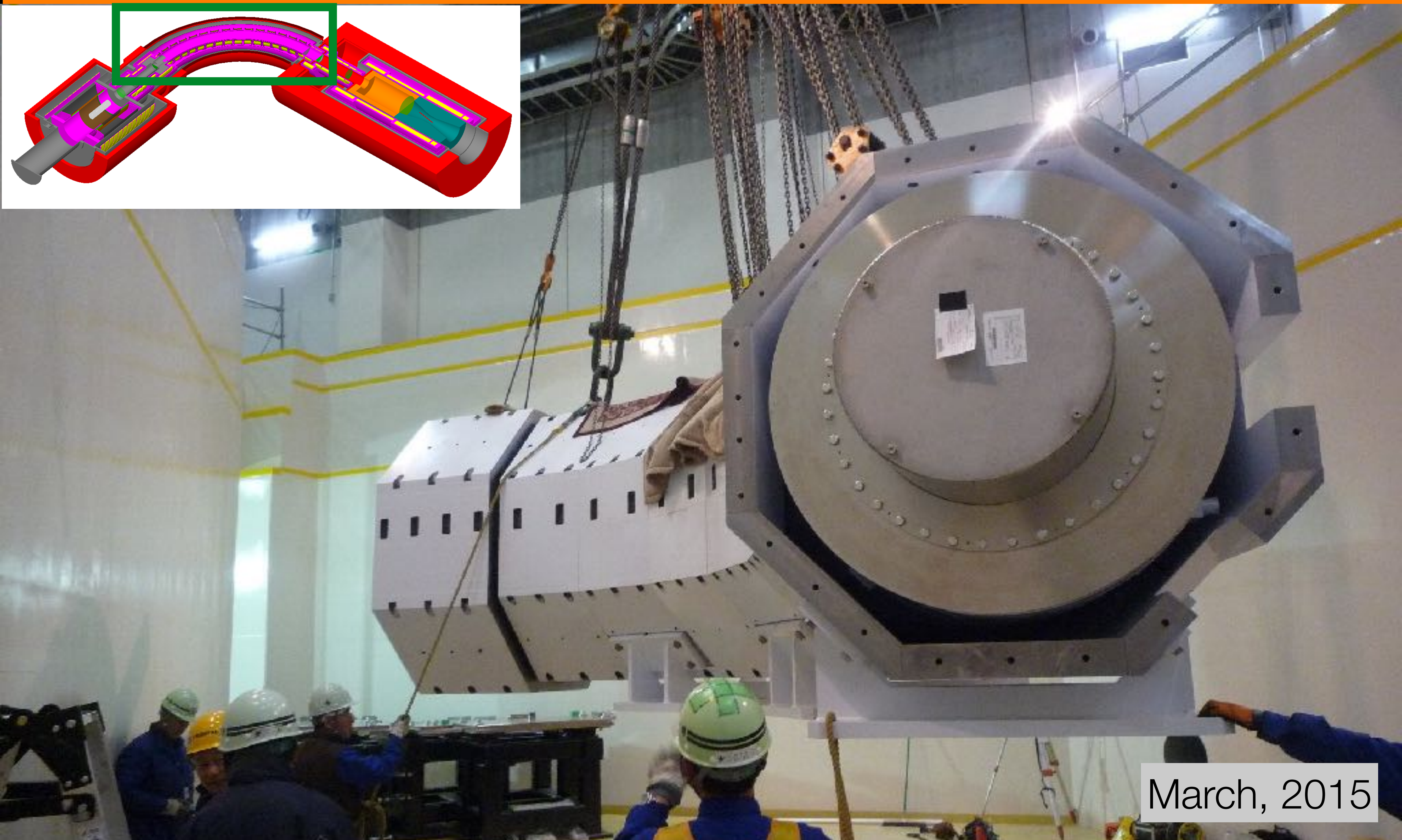
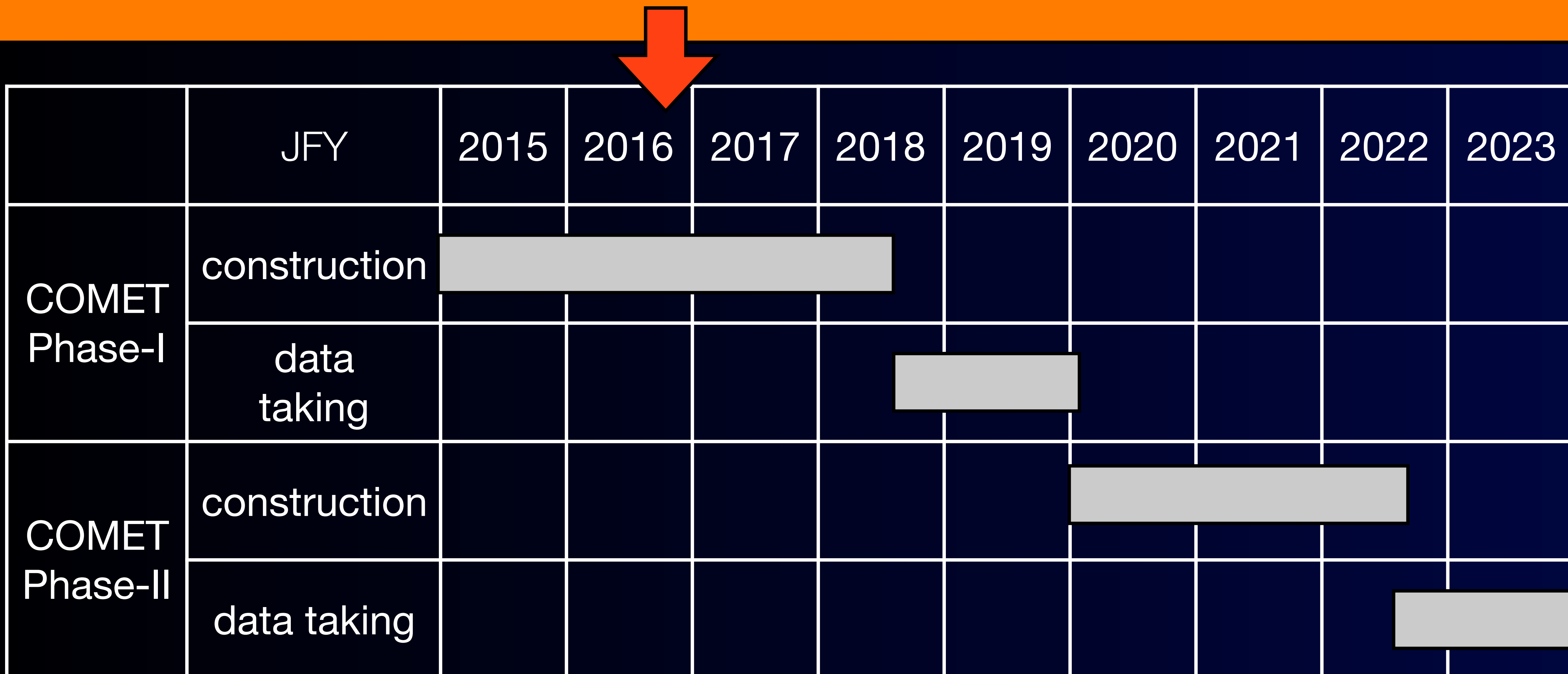


Curved Solenoids for Muon Transport Completed and Delivered!

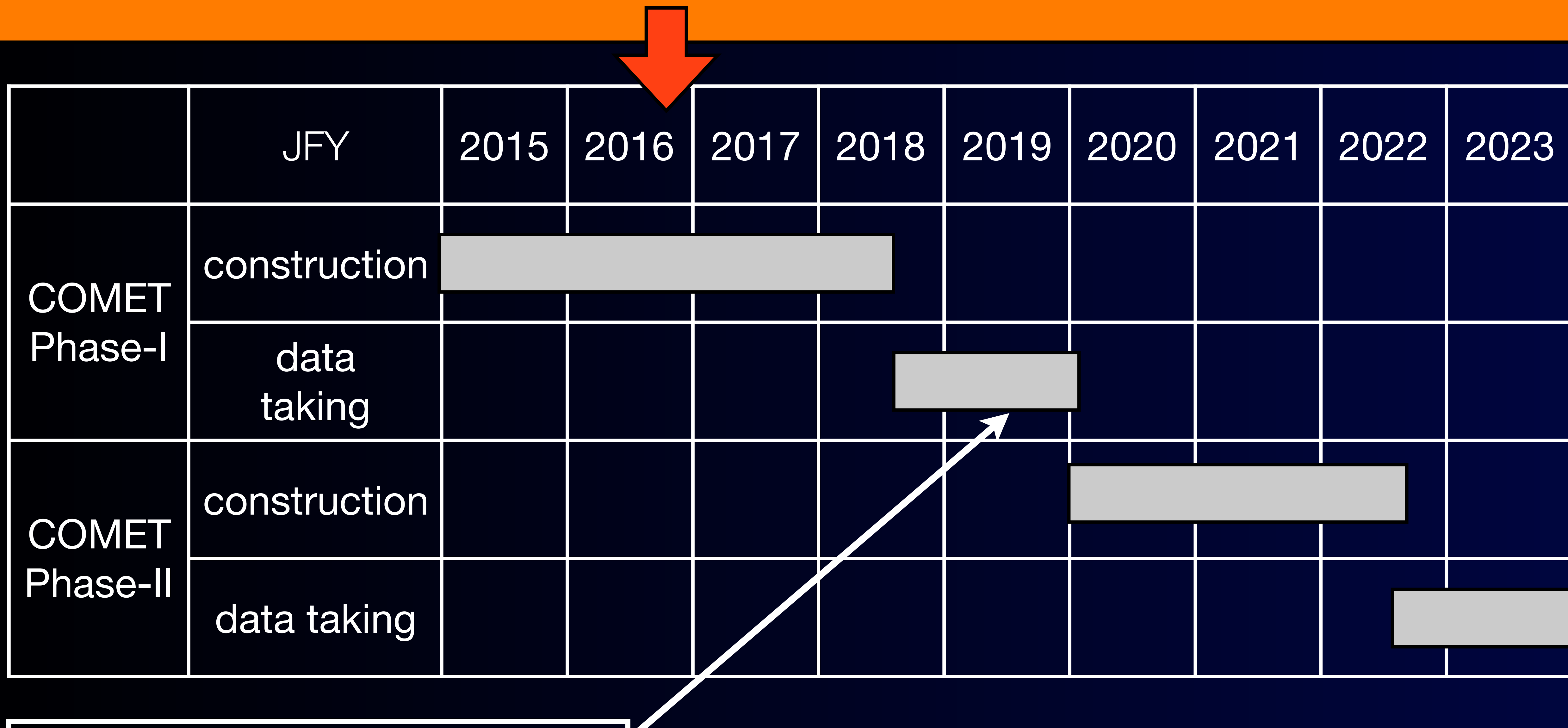


March, 2015

Schedule of COMET Phase-I and Phase-II

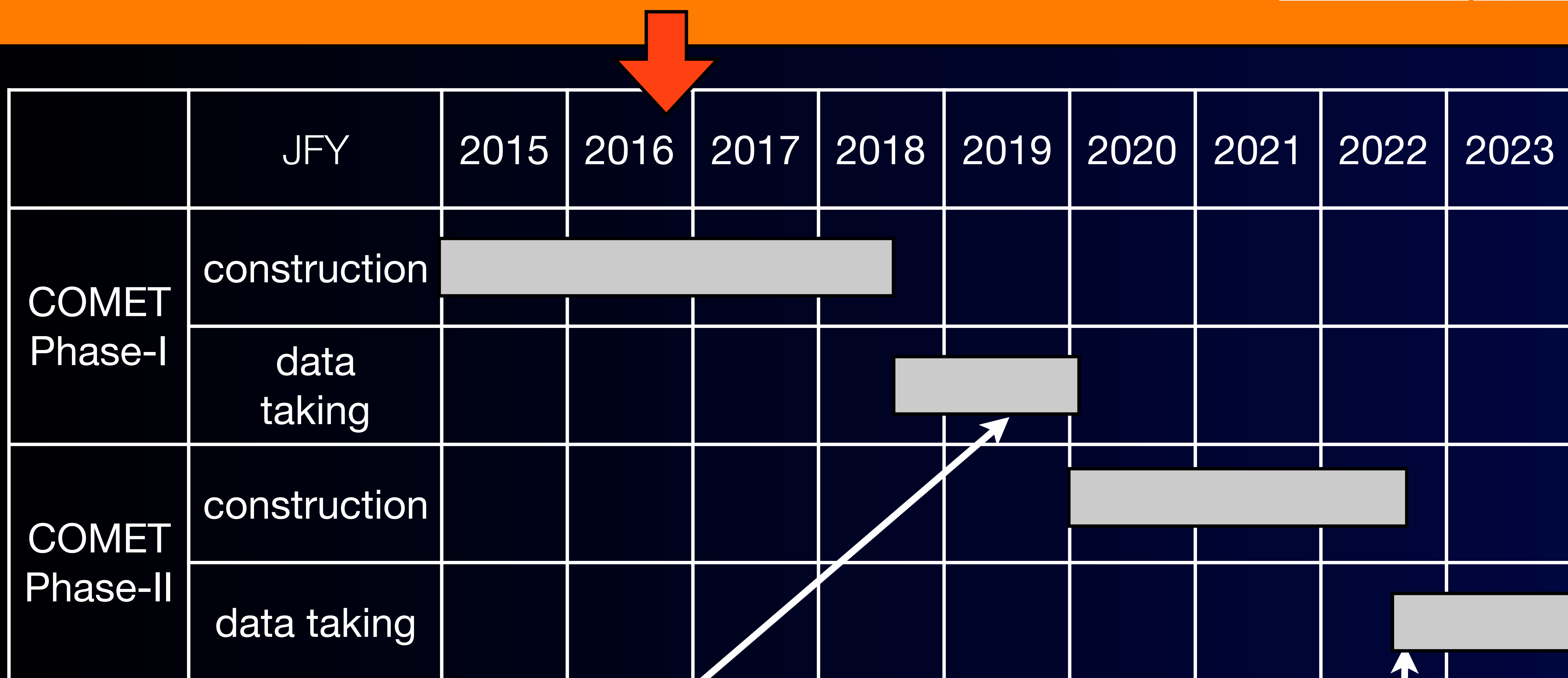


Schedule of COMET Phase-I and Phase-II



COMET Phase-I :
2018 ~
S.E.S. ~ 3×10^{-15}
(for 150 days
with 3.2 kW proton beam)

Schedule of COMET Phase-I and Phase-II



COMET Phase-I :
2018 ~
S.E.S. ~ 3×10^{-15}
(for 150 days
with 3.2 kW proton beam)

COMET Phase-II :
2022 ~
S.E.S. ~ $(1.0\text{-}2.6) \times 10^{-17}$
(for 2×10^{7} sec
with 56 kW proton beam)

Other Physics at COMET Phase-I

$\mu^- + \mathrm{Ti} \to e^+ + \mathrm{Ca(gs)}$ 1.7×10^{-12}
$\mu^- + \mathrm{Ti} \to e^+ + \mathrm{Ca(ex)}$ 3.6×10^{-11}

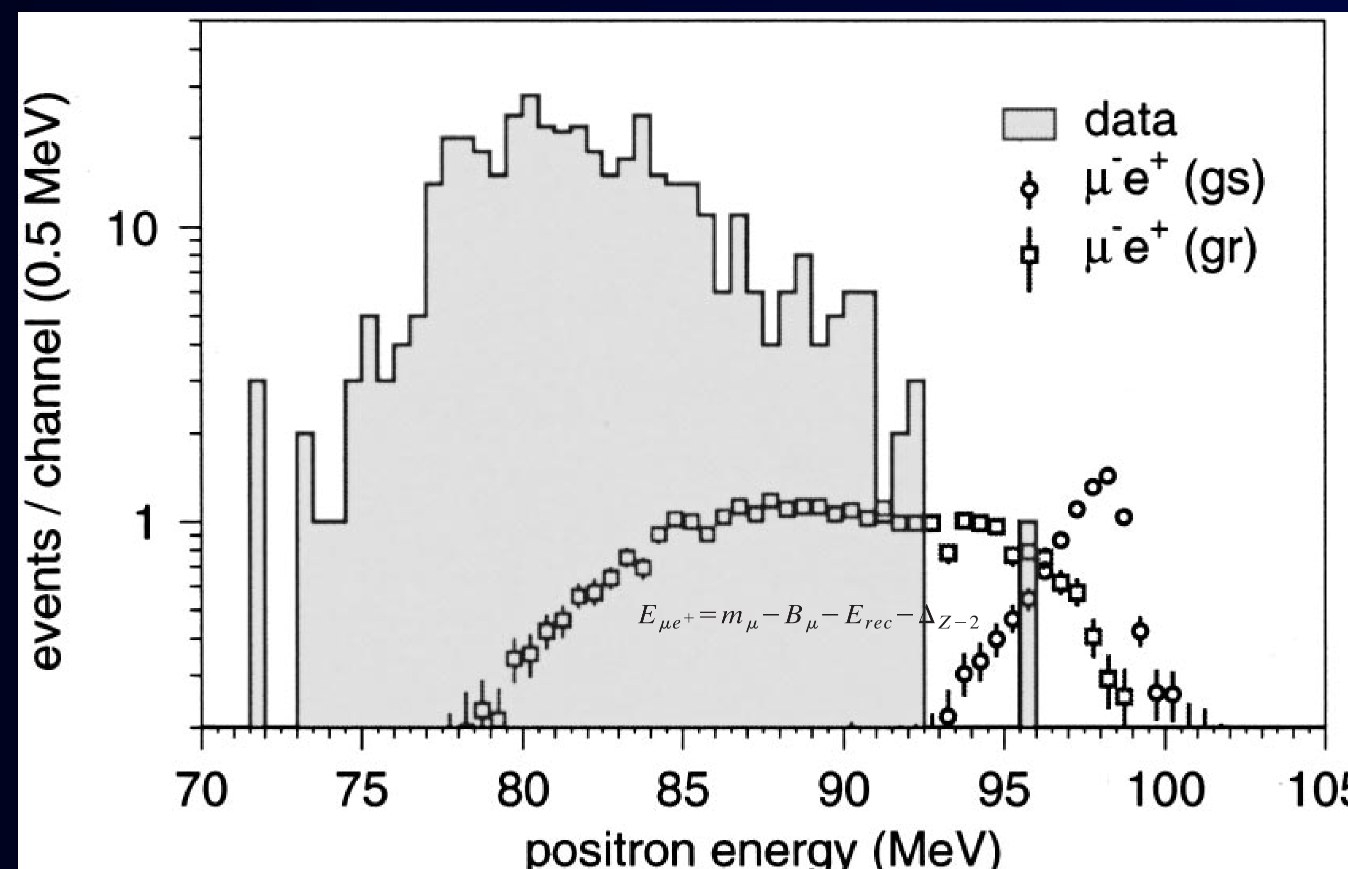
Lepton number violation (LNV)

signal signature

$$E_{\mu e^+} = m_\mu - B_\mu - E_{rec} - \Delta_{Z-2}$$

backgrounds

positrons from photon conversion after radiative muon/pion nuclear capture



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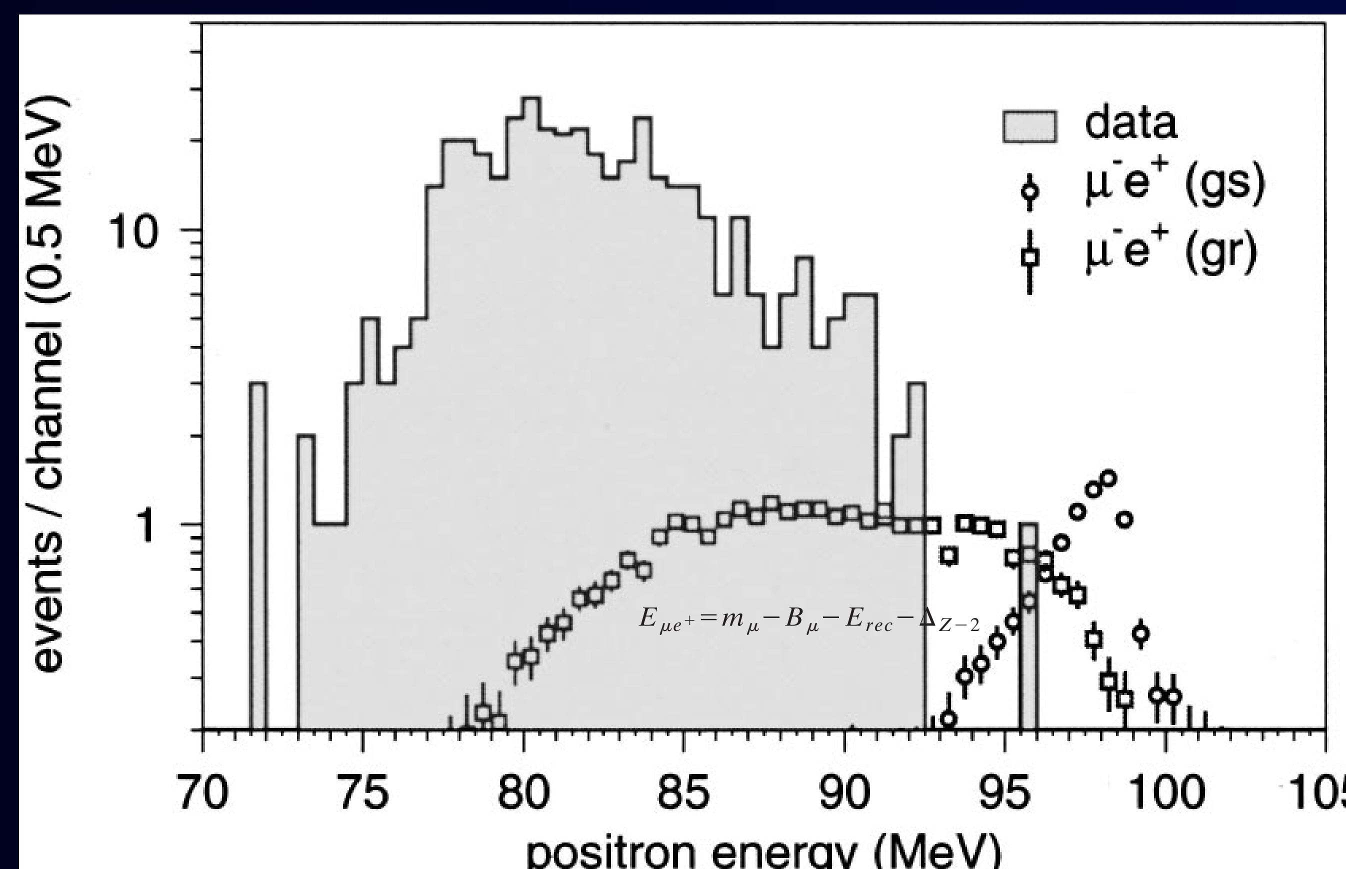
$\mu^- + N(Z) \rightarrow e^+ + N^*(Z-2)$

Lepton number violation (LNV)



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Other CLFV Physics at COMET Phase-I

PRL **105,** 121601 (2010) PHYSICAL REVIEW LETTERS week ending 17 SEPTEMBER 2010

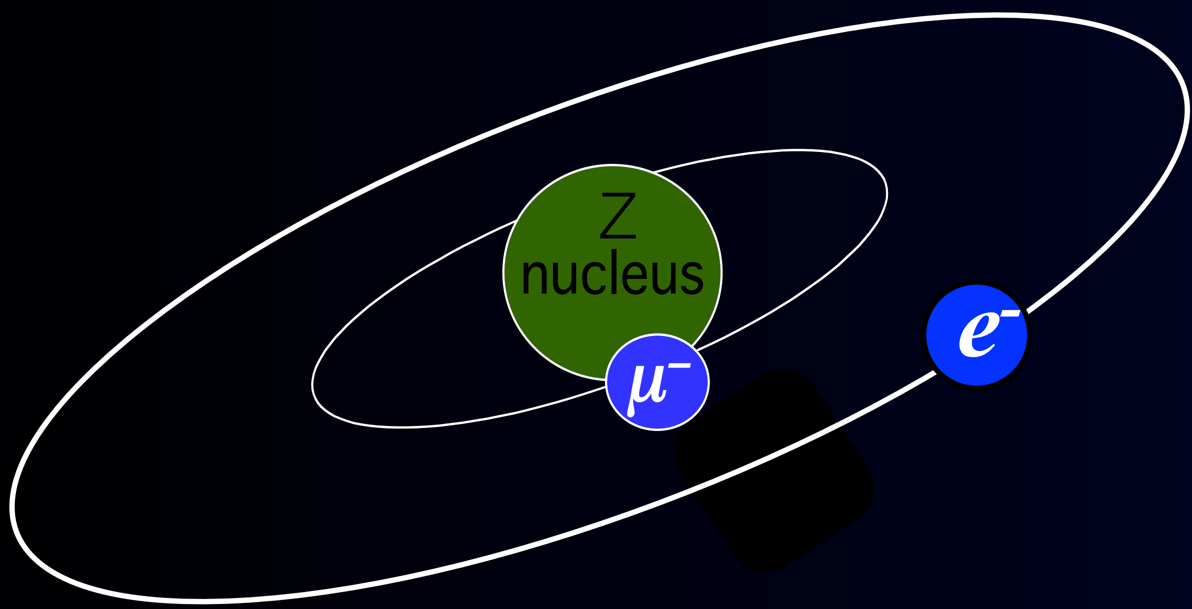
New Process for Charged Lepton Flavor Violation Searches: $\mu^- e^- \rightarrow e^- e^-$ in a Muonic Atom

Masafumi Koike,[1,*] Yoshitaka Kuno,[2,†] Joe Sato,[1,‡] and Masato Yamanaka[3,§]

[1]*Physics Department, Saitama University, 255 Shimo-Okubo, Sakura-ku, Saitama, Saitama 338-8570, Japan*
[2]*Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan*
[3]*Institute for Cosmic Ray Research, University of Tokyo, Kashiwa 277-8582, Japan*
(Received 8 March 2010; published 15 September 2010)

Other CLFV Physics at COMET Phase-I

$\mu^- + e^- \rightarrow e^- + e^-$



- $\mu^- e^- \rightarrow e^- e^-$ has two-body final state, although $\mu^+ \rightarrow e^+ e^+ e^-$ is a 3-body decay.
- A muonium CLFV decay such as $\mu^+ e^- \rightarrow e^+ e^+$ is a 2-body decay having a larger phase space, but the overwrap of μ^+ and e^- is small.

The overwrap between μ^- and e^- is proportional to Z^3. For Z=82 (Pb), the overwrap increases by a factor of 5×10^5 over the muonium. The rate is 10^{-17} to 10^{-18}.

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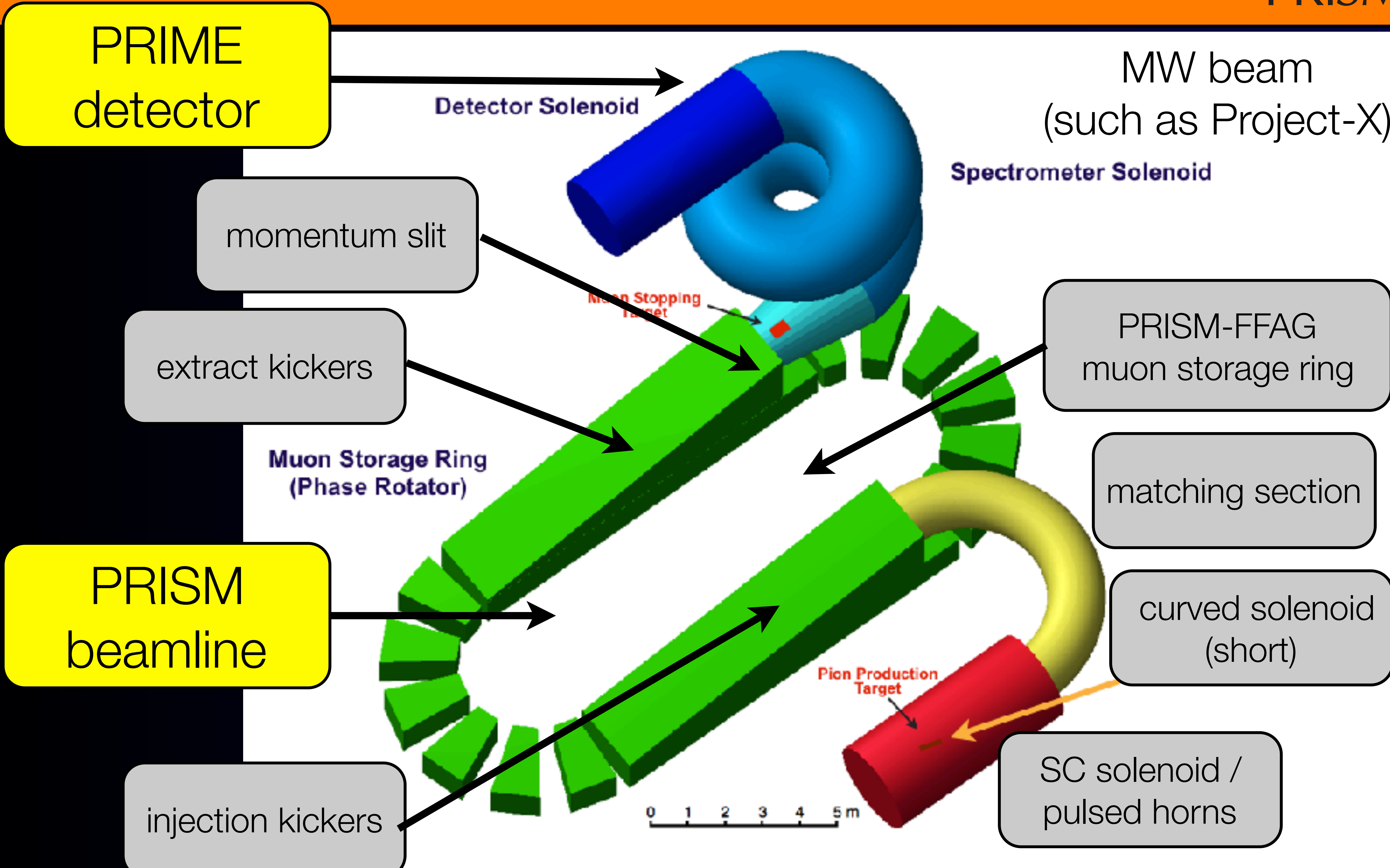
PRISM ($\sim 10^{-19}$)

μ-e conversion at S.E. sensitivity of 3×10^{-19} PRISM/PRIME (with muon storage ring)



Go further to O(10^{-19})

- Reduce pions and other background particles in a muon beam
- Reduce energy spread of a muon beam

Phase Rotation

Phase Rotation

narrow energy spread of muon beam

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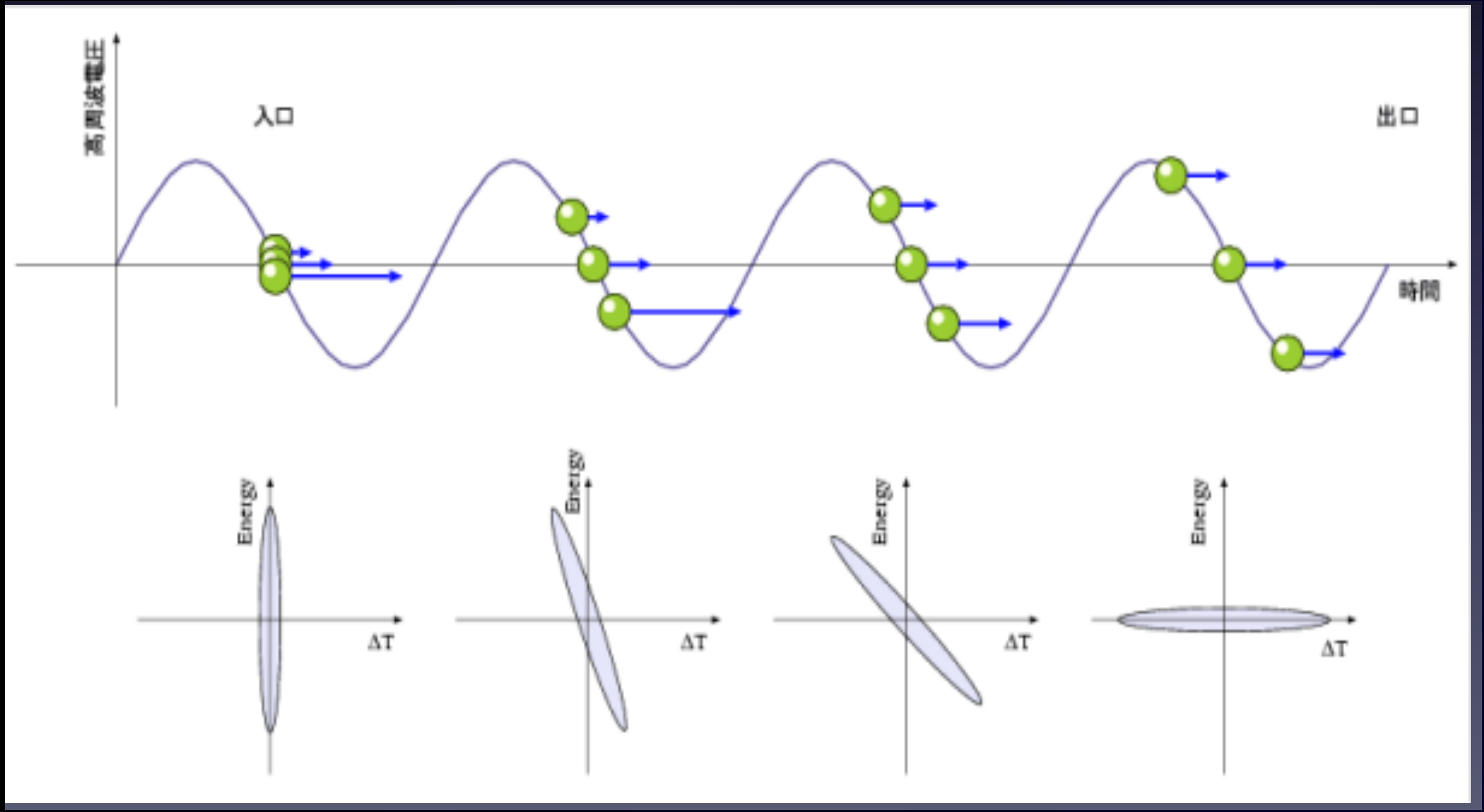
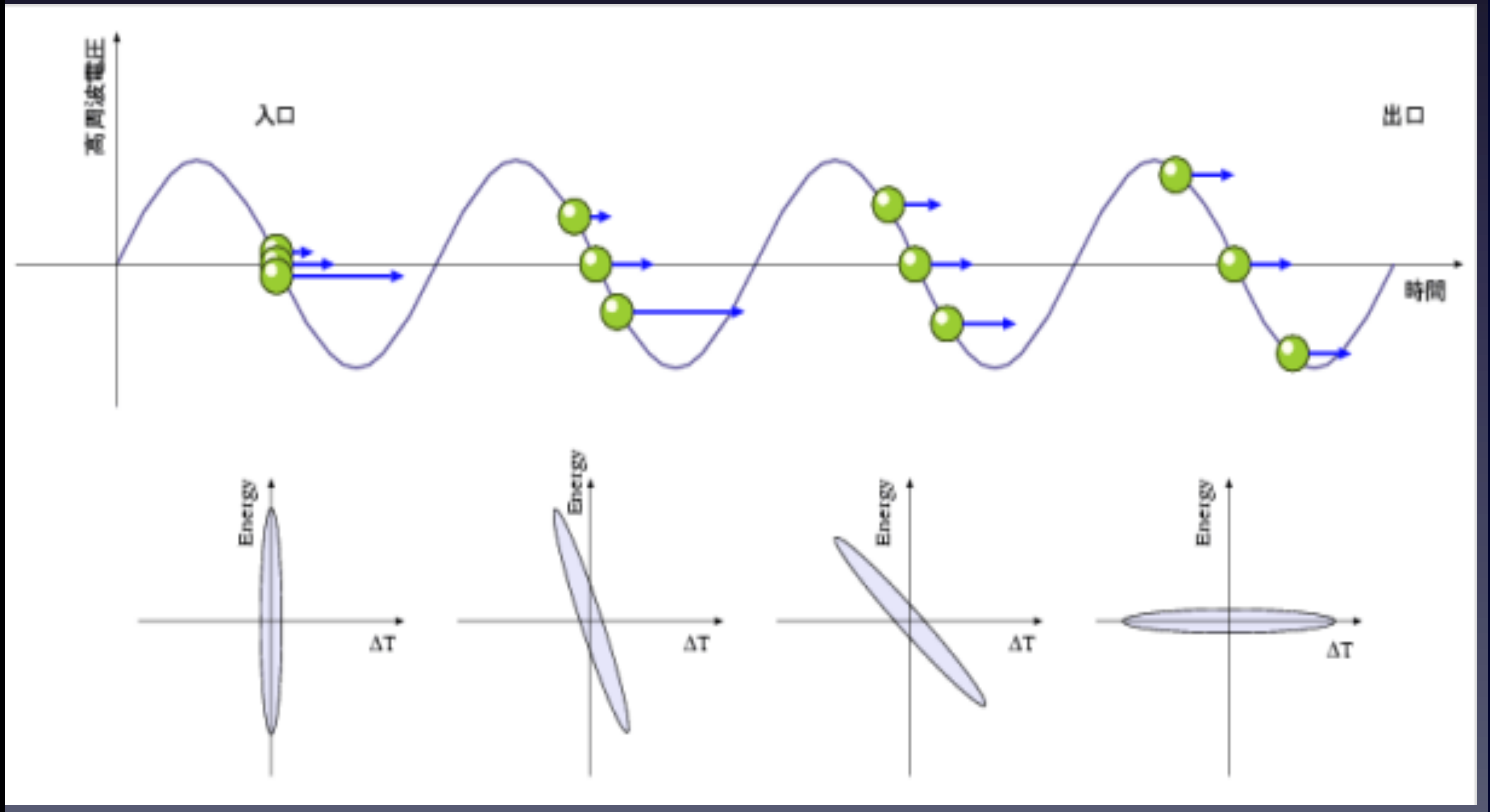
narrow energy spread of muon beam



Phase Rotation

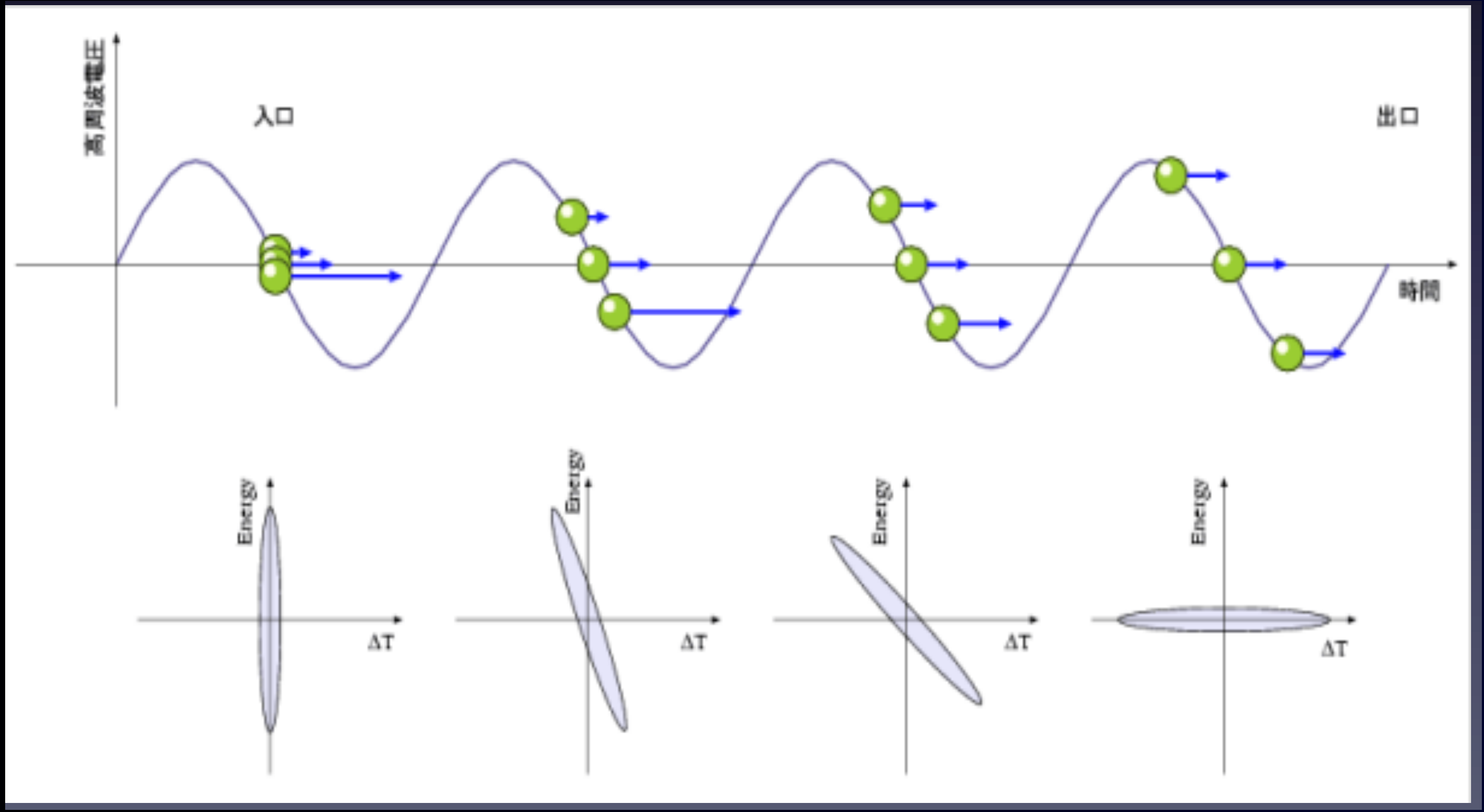
narrow energy spread of muon beam



allows a thinner muon stopping target

Phase Rotation

narrow energy spread of muon beam

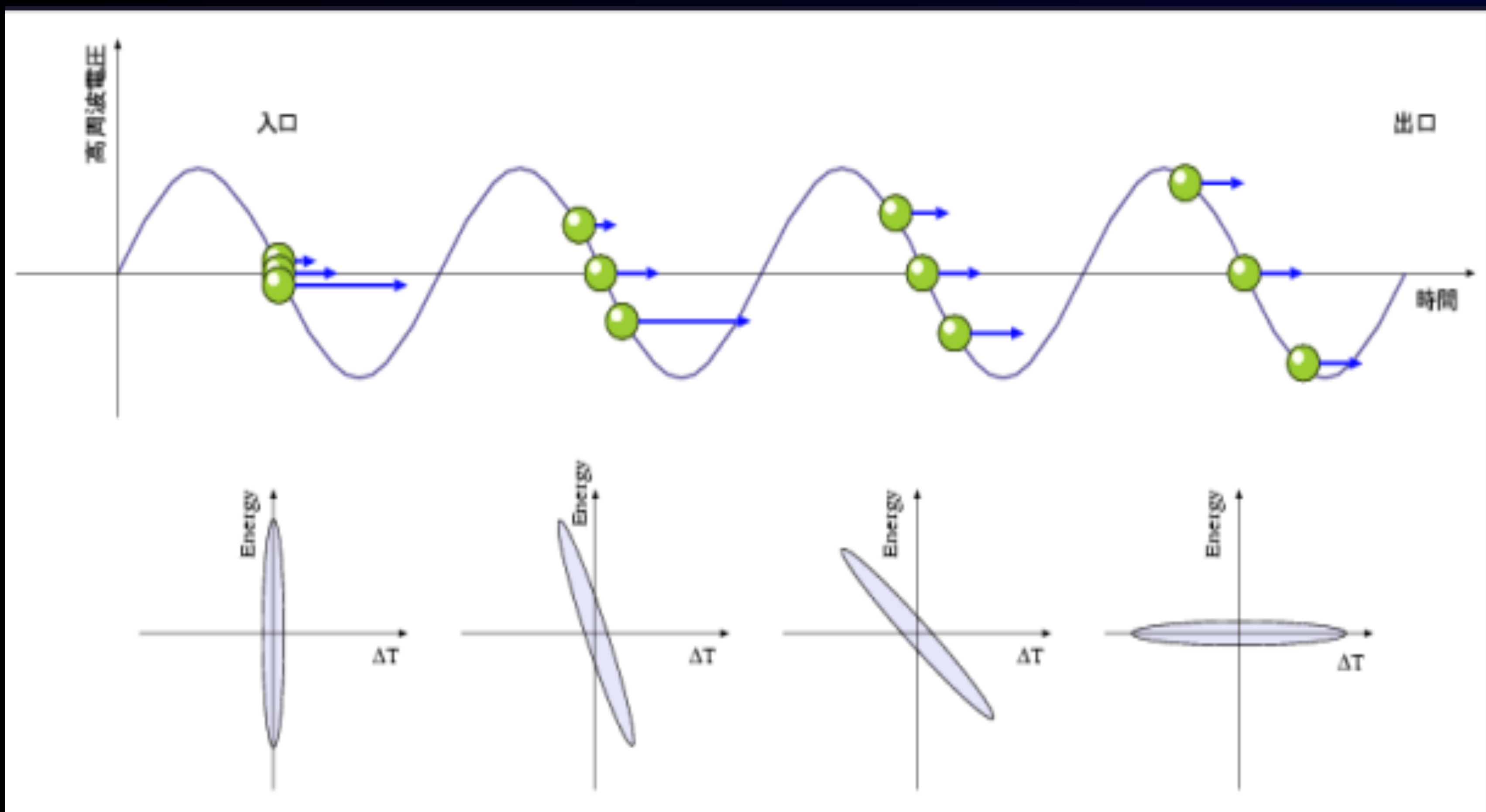


allows a thinner muon stopping target

decelerate fast muons (coming earlier) and accelerate slow muons (coming late) by RF with a narrow proton beam.

Phase Rotation

narrow energy spread of muon beam



allows a thinner muon stopping target

decelerate fast muons (coming earlier) and accelerate slow muons (coming late) by RF with a narrow proton beam.

pure muon beam (pion< 10^{-20})

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

demonstration of phase rotation has been done.

Summary

- CLFV searches with muons have good opportunity of finding new physics beyond the Standard Model (SM).
- For $\mu \rightarrow e\gamma$, MEG-II will start in 2017, aiming at $O(10^{-14})$.
- For $\mu \rightarrow eee$, Mu3e aims at 10^{-15}, starting from 2018.
- For μ-e conversion, Mu2e at FNAL aims at 10^{-17}, whereas and COMET Phase-I at J-PARC aims at 10^{-15}, starting in 2018, and COMET Phase-II aims at 10^{-17}, starting in 2022.

- COMET looks for more collaborators.

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my dog, IKU

Merci
ありがとう

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ありがとう

COMET character