Experimental Prospects of Charged Lepton Flavour Violation

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Kavli IPMU, Kashiwa, Japam

Why Charged Lepton Flavour Violation?

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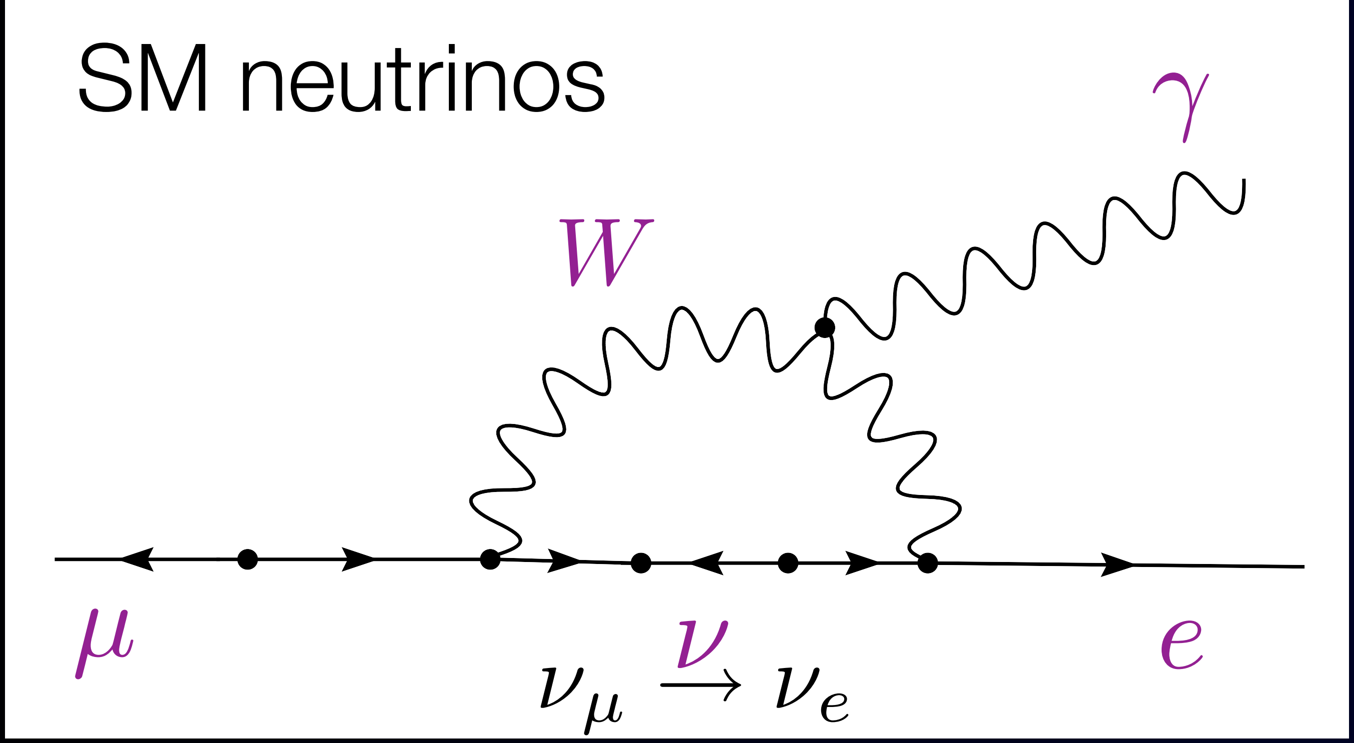
Neutral lepton flavour violation has been observed.
Lepton mixing in the SM has been known.

Why CLFV ?

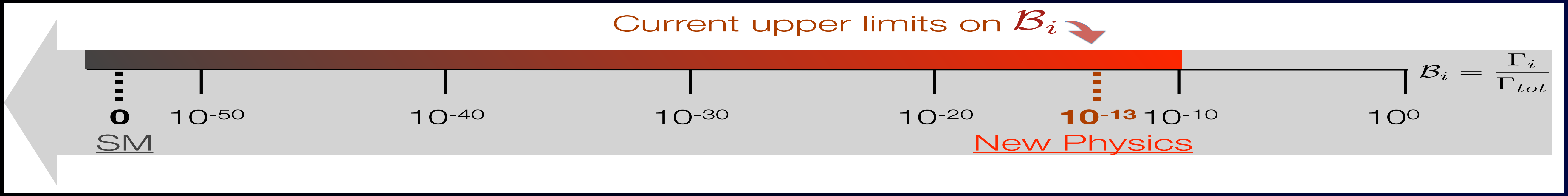
SM Contribution of Lepton Mixing to CLFV



BR~O(10^{-54})

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

S.T. Petcov, Sov.J. Nucl. Phys. 25 (1977) 340



Search for New Physics Beyond the SM

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Effective Field Theory Approach

$$\mathscr{L}_{eff} = \mathscr{L}_{\mathrm{SM}} + \sum_{d>4} \frac{C^{(d)}}{\Lambda^{d-4}}$$

Λ is the energy scale of new physics
$C^{(d)}$ is the coupling constant.

from BR($\mu \to e\gamma$)<4.2×10^{-13}

$$\frac{C^6}{\Lambda^2}\mathscr{O}^6 \to \frac{C^6}{\Lambda^2}\bar{e}_L \sigma^{\rho\nu} \mu_R \Phi F_{\rho\nu} \quad \Rightarrow \quad \Lambda \sim \mathscr{O}(10^3)\ \mathrm{TeV}$$

Future planned improvements by an additional factor of 10000 would probe $\Lambda \sim \mathscr{O}(10^4)\ \mathrm{TeV}$

CLFV is sensitive to very high energy scale.

Outline

- CLFV of Muons
  - Magnificent three ($\mu^+ \to e^+\gamma$, $\mu^+ \to e^+e^+e^-$, $\mu^- N \to e^- N$)
  - Muon bound states
- CLFV of Tau leptons, Z and Higgs
- CLFV in exotics
- CLFV/LNV of Muons
- Muon sources
- Summary

Muon CLFV

Muon LFV History

First CLFV search

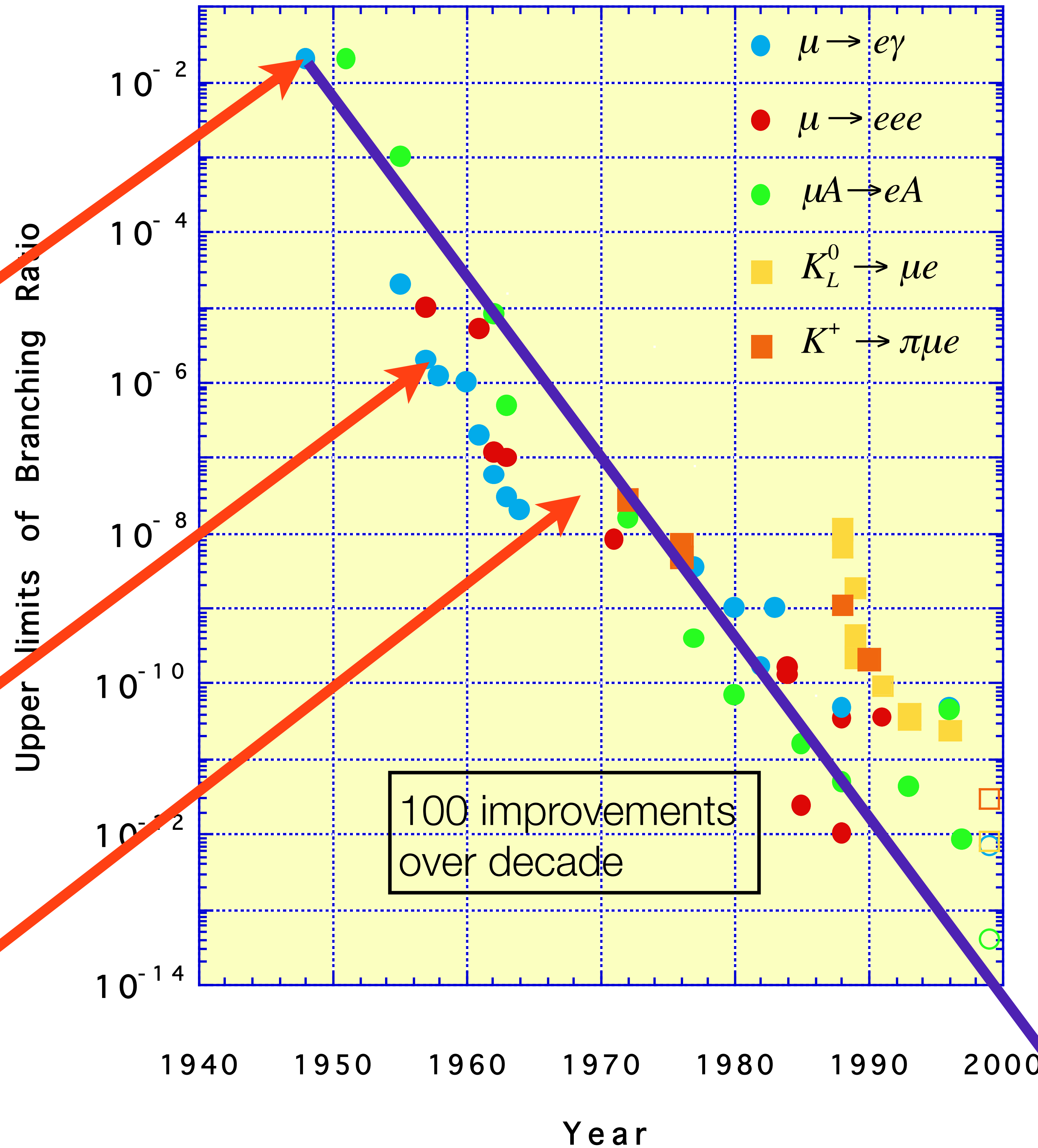
Pontecorvo in 1947

Muon Michel decay (1948)

Accelerators producing muons

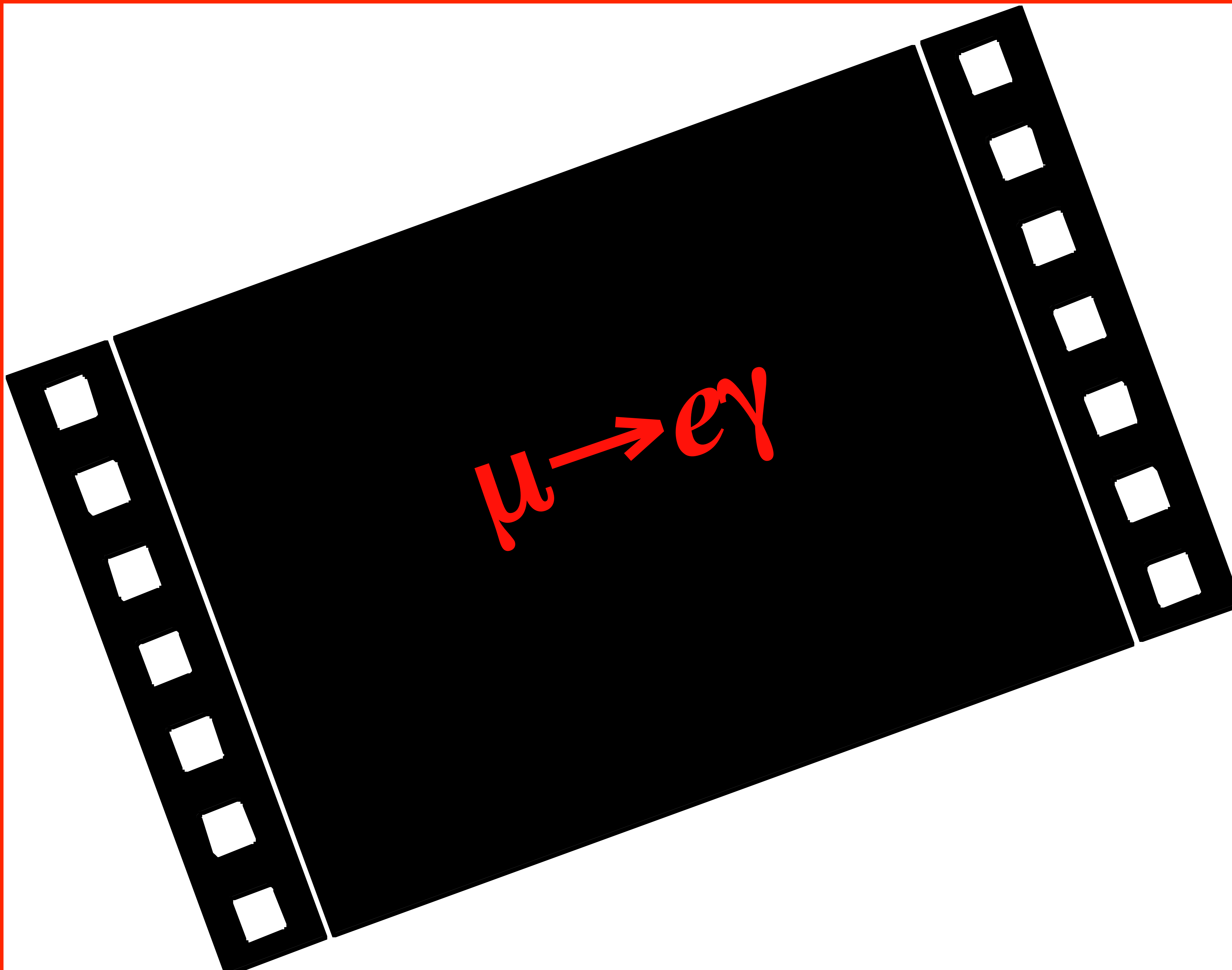
Feinberg's μ→eγ crisis (1955)

Meson Factory Era



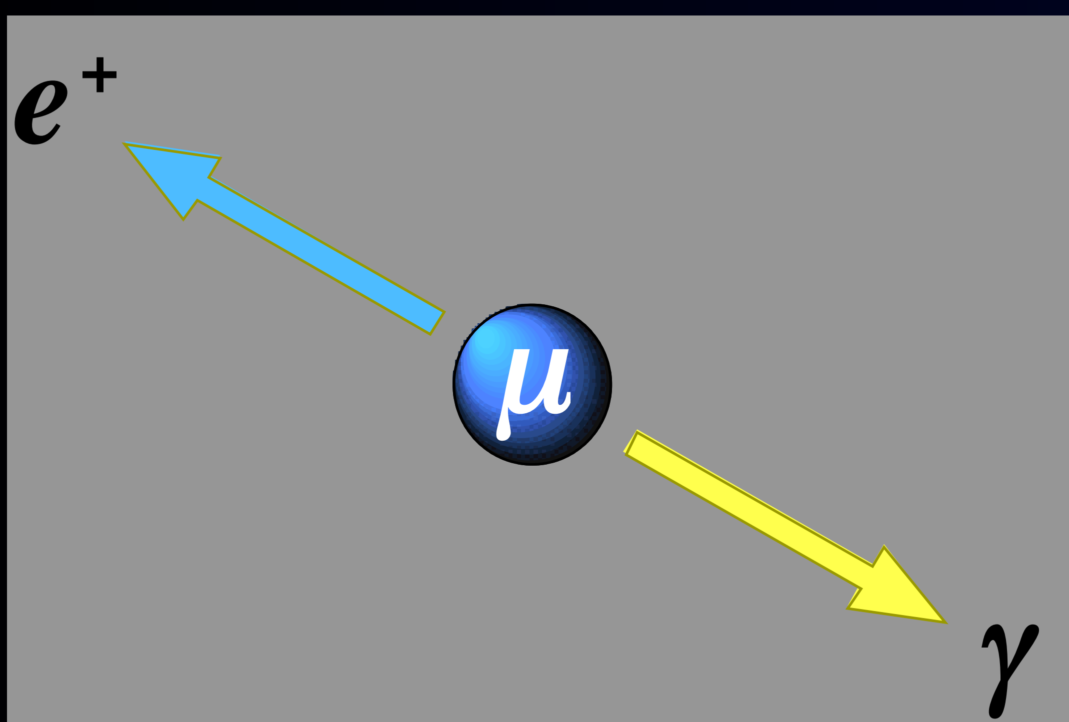
Magnificent Three
CLFV Processes with Muons

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


μ→eγ

CLFV Decay of Muons : $\mu^+ \to e^+\gamma$

- 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.
- Experimental
  - positive muon decays at rest are used.

CLFV Decay of Muons : $\mu^+ \rightarrow e^+\gamma$

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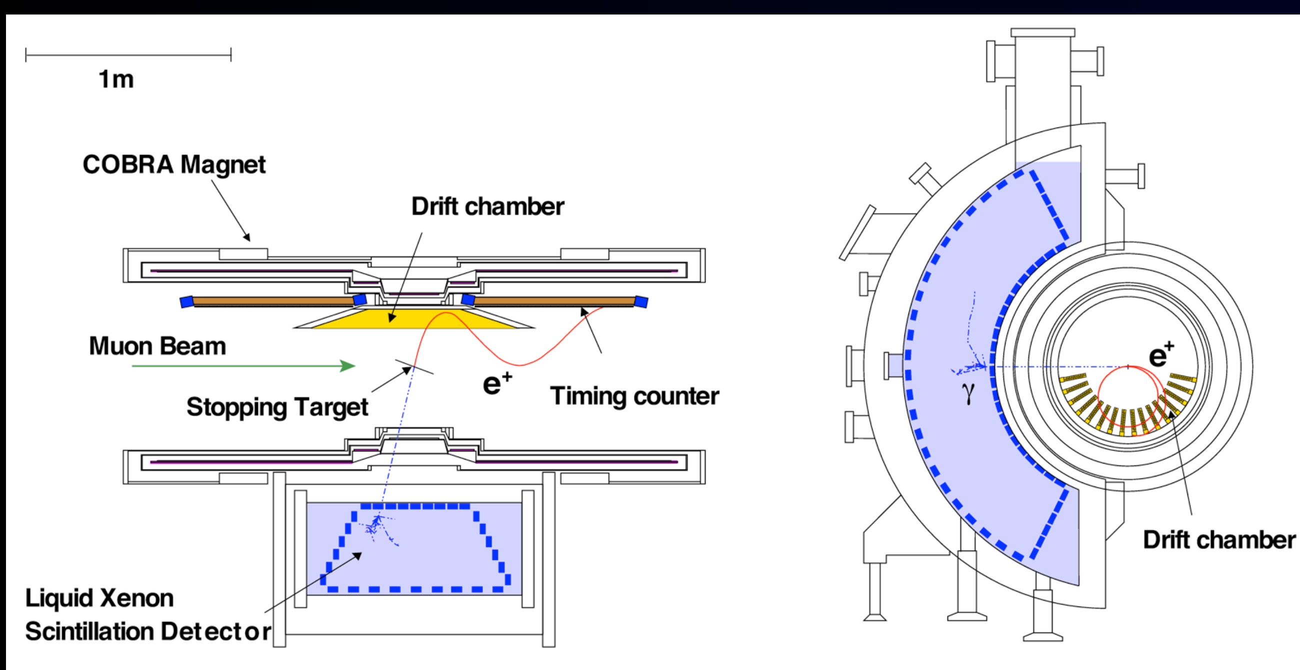
MEG @PSI (2016)

- drift chamber for positrons
- liquid Xe detector for gammas
- DC muon beam at PSI

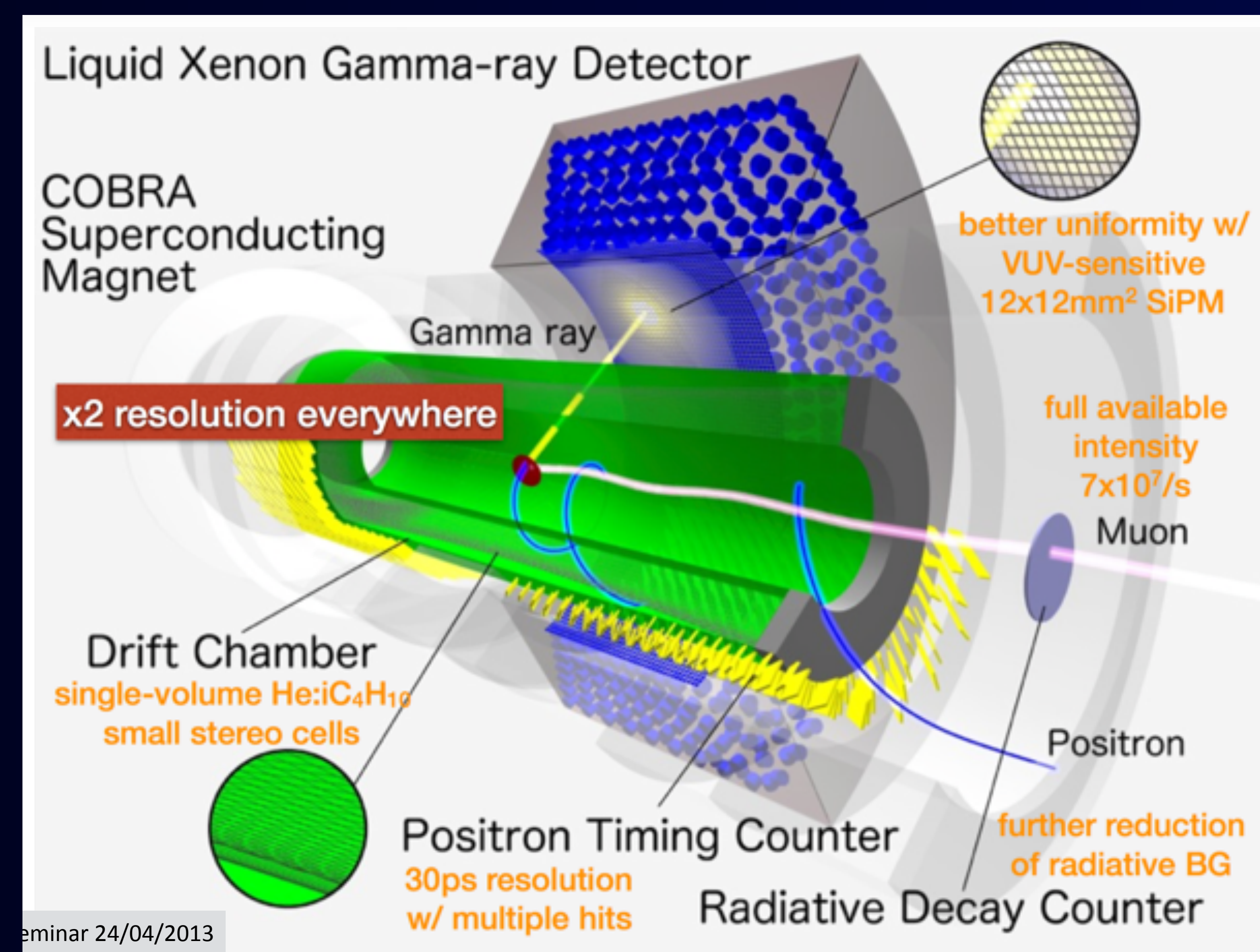


$$B(\mu^+ \rightarrow e^+\gamma) < 4.2 \times 10^{-13}$$

- a factor of 30 improvement

MEG II

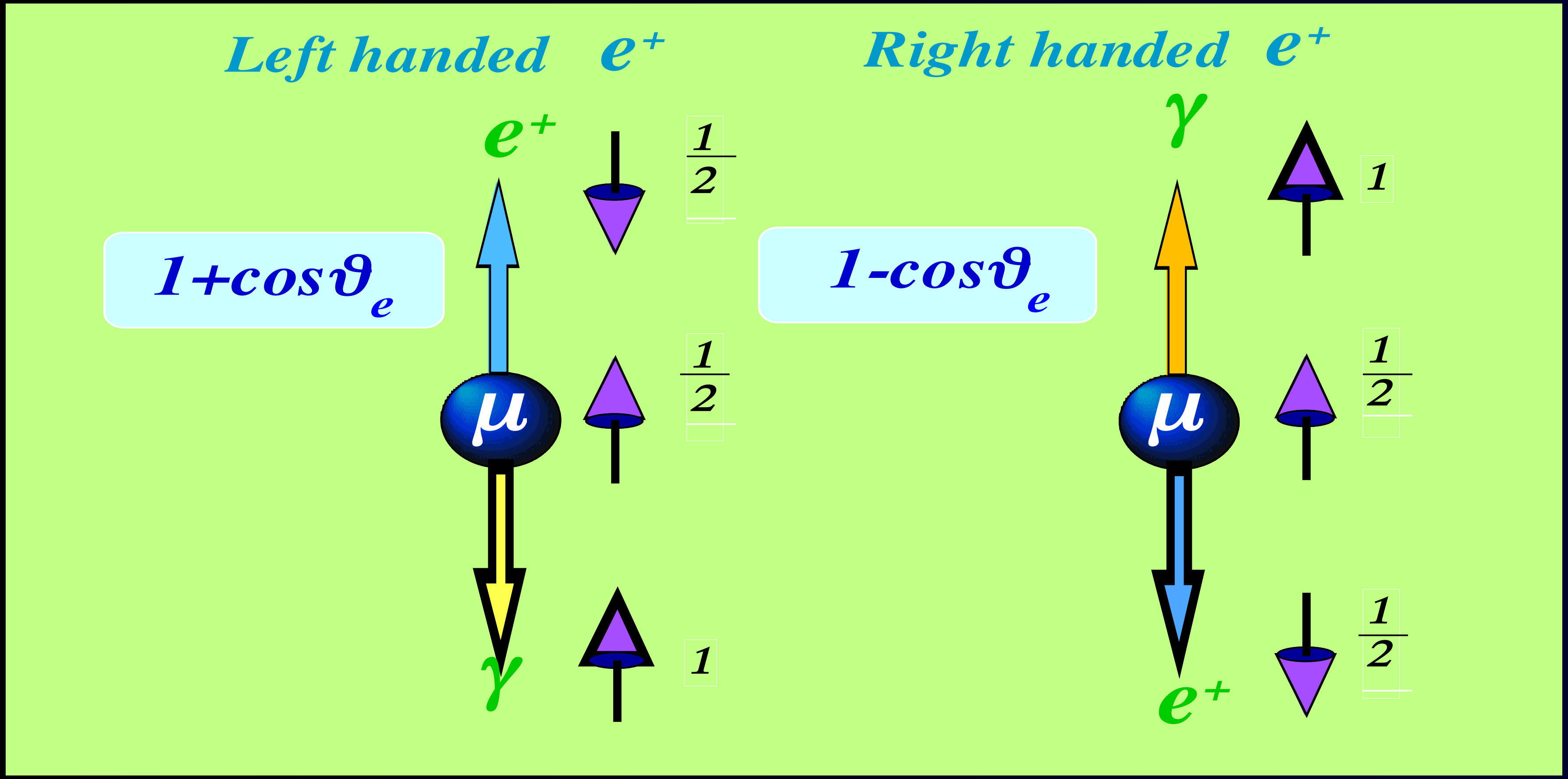
- all detectors upgraded
- full muon beam intensity
- Goal ~ $6\text{x}10^{-14}$ (2019-2021)



Future:
Parity Violating $\mu^+ \to e^+\gamma$ decay

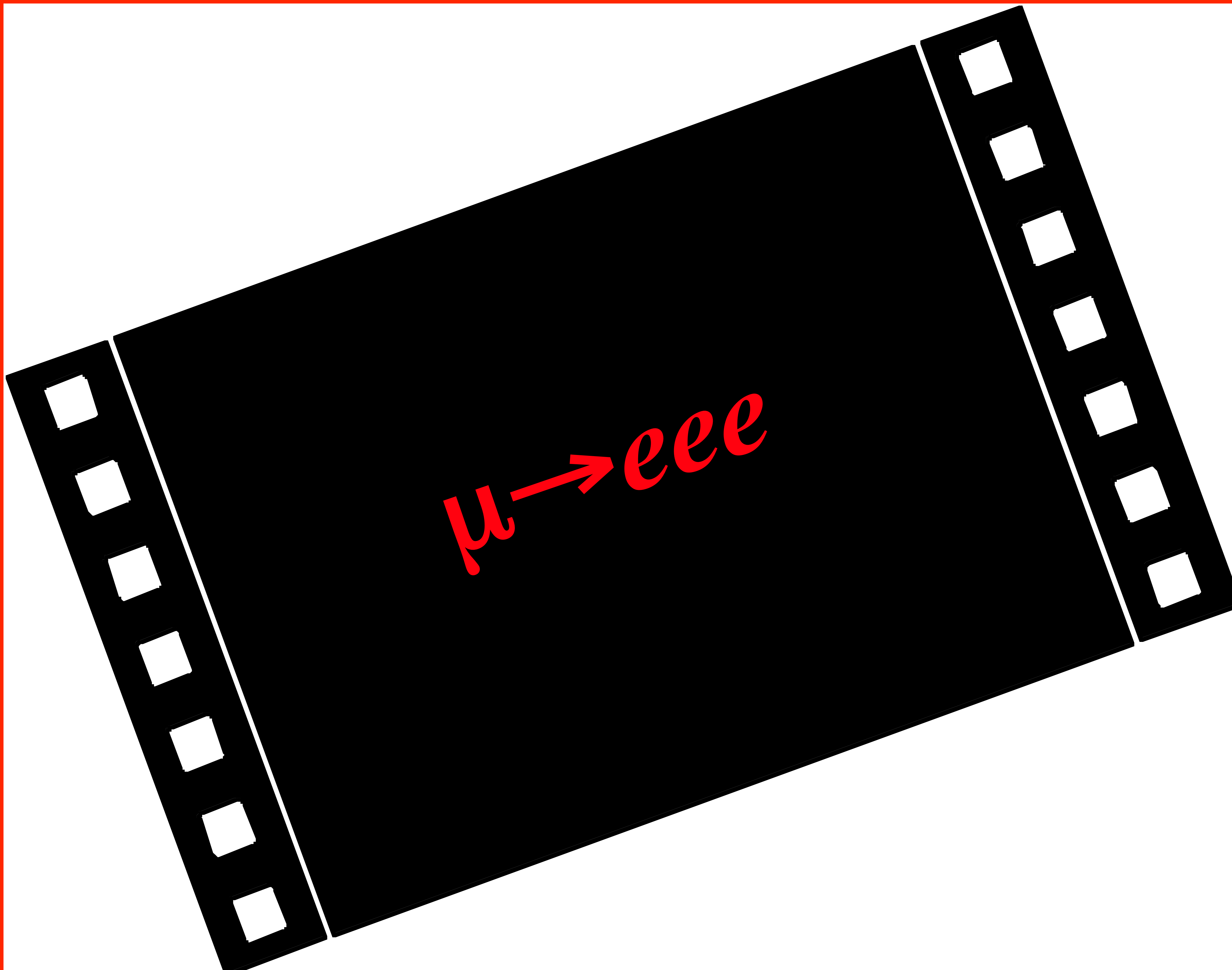
$$\mathcal{L}_{\mu\to e\gamma} = -\frac{4G_F}{\sqrt{2}}\left[m_\mu A_R \overline{\mu_R}\sigma^{\mu\nu}e_L F_{\mu\nu} + m_\mu A_L \overline{\mu_L}\sigma^{\mu\nu}e_R F_{\mu\nu} + H.c.\right]$$

$$B(\mu^+ \to e^+\gamma) = \frac{\Gamma(\mu^+ \to e^+\gamma)}{\Gamma(\mu^+ \to e^+\nu\overline{\nu})} = 384\pi^2(|A_R|^2 + |A_L|^2)$$



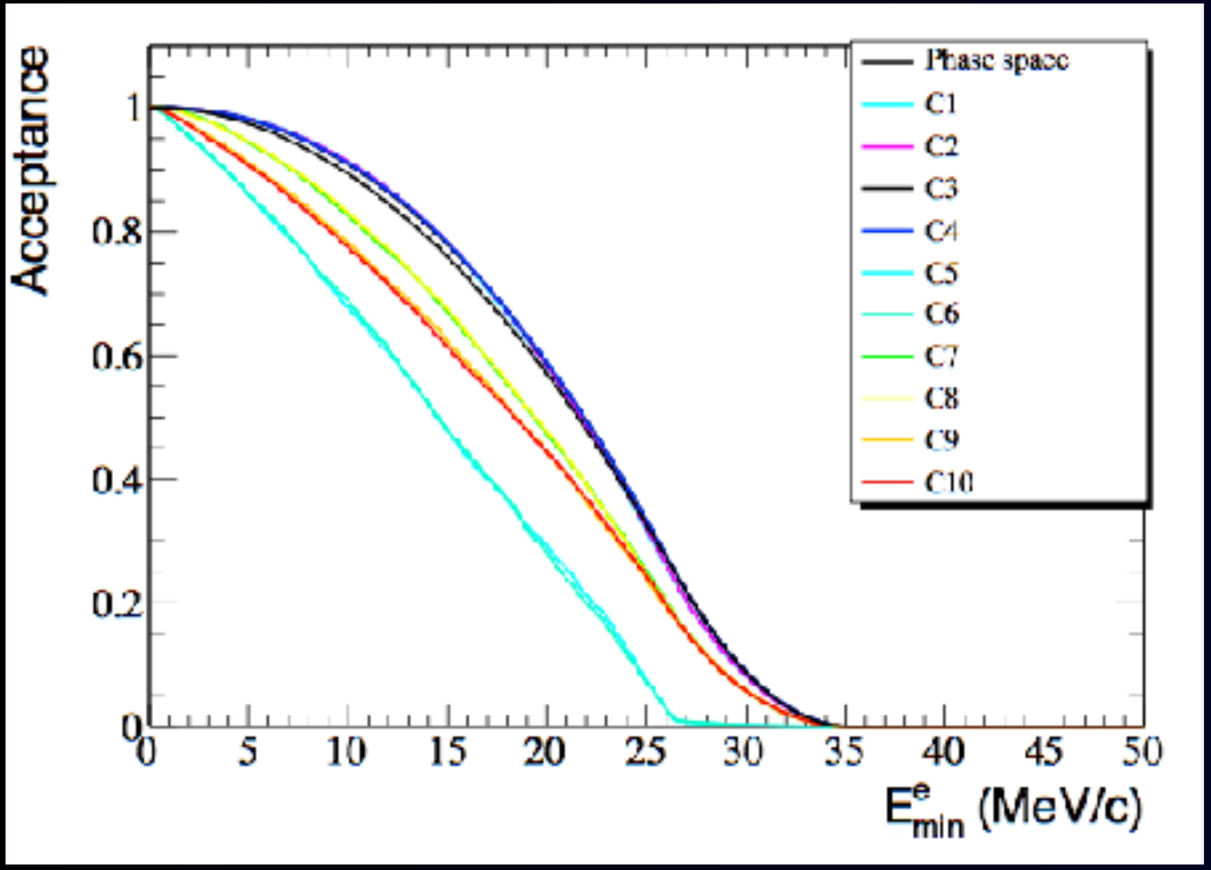
polarized muons (surface muons)

YK, Y. Okada, Phys. Rev. Lett. 77 (1996) 434


μ→eee

CLFV Decay of Muons : $\mu^+ \to e^+e^+e^-$

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



acceptance as E(min) of $e^\pm$

- Backgrounds
  - physics backgrounds
    - $\mu \to e\nu\nu ee$ decay ($B=3.4\times10^{-5}$) when two neutrinos carry very small energies.
  - accidental backgrounds
    - positrons in $\mu \to e\nu\nu$
    - electrons in $\mu \to eee\nu\nu$ or $\mu \to e\nu\nu\gamma$ ($B=1.2\times10^{-2}$) with photon conversion or Bhabha scattering.
- Experimental
  - positive muon decays at rest are used.

CLFV Decay of Muons : $\mu^+ \rightarrow e^+e^+e^-$

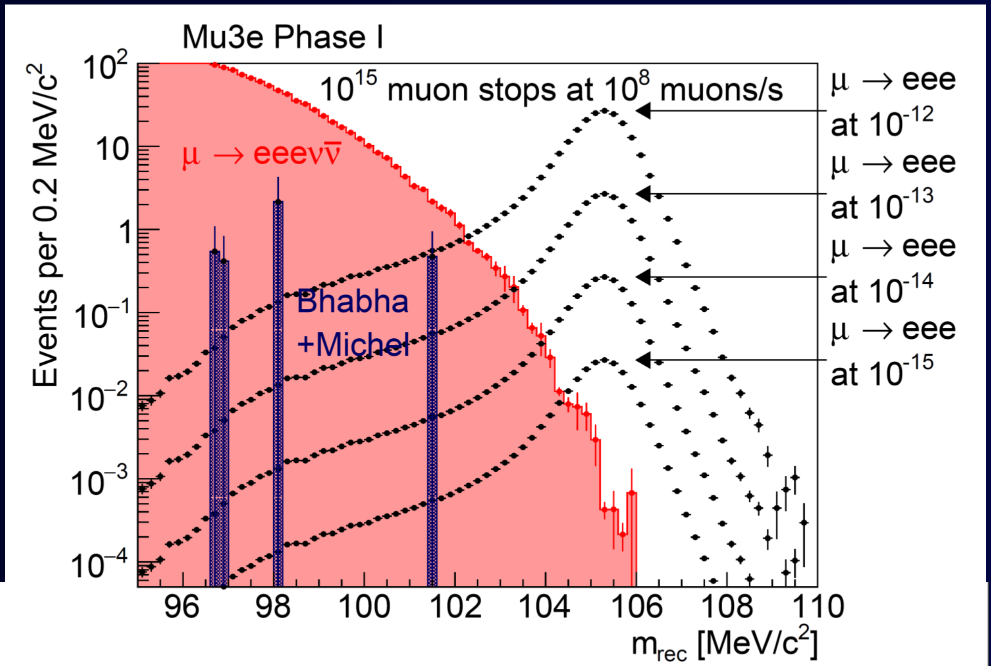
SINDRUM (1988)

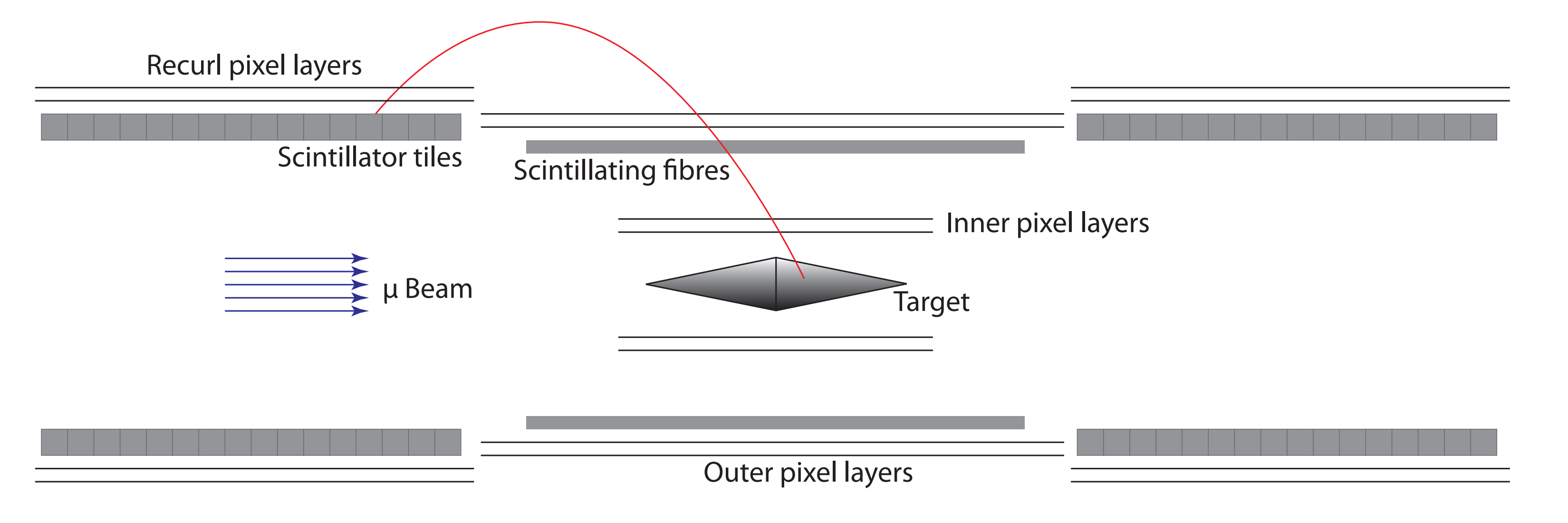
- BR<1.0×10^{-12}
  - with constant matrix element
- $\mu \rightarrow e\nu\nu ee$ decay observed.

Mu3e (@PSI)

- Silicon pixel detector (HVMAPS) for tracking
- Scintillating fibers for timing

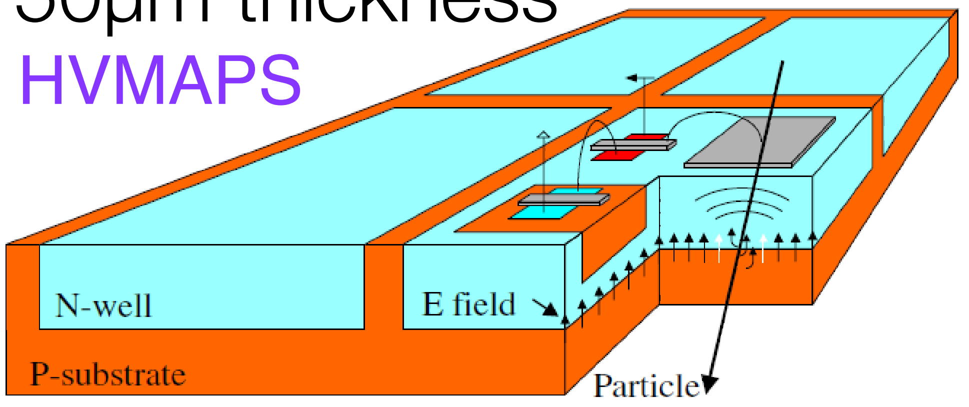
- Stage-I (2020 -)
  - B~10^{-15} at πE5
- Stage-2
  - B<10^{-16} at HiMB





50μm thickness

HVMAPS



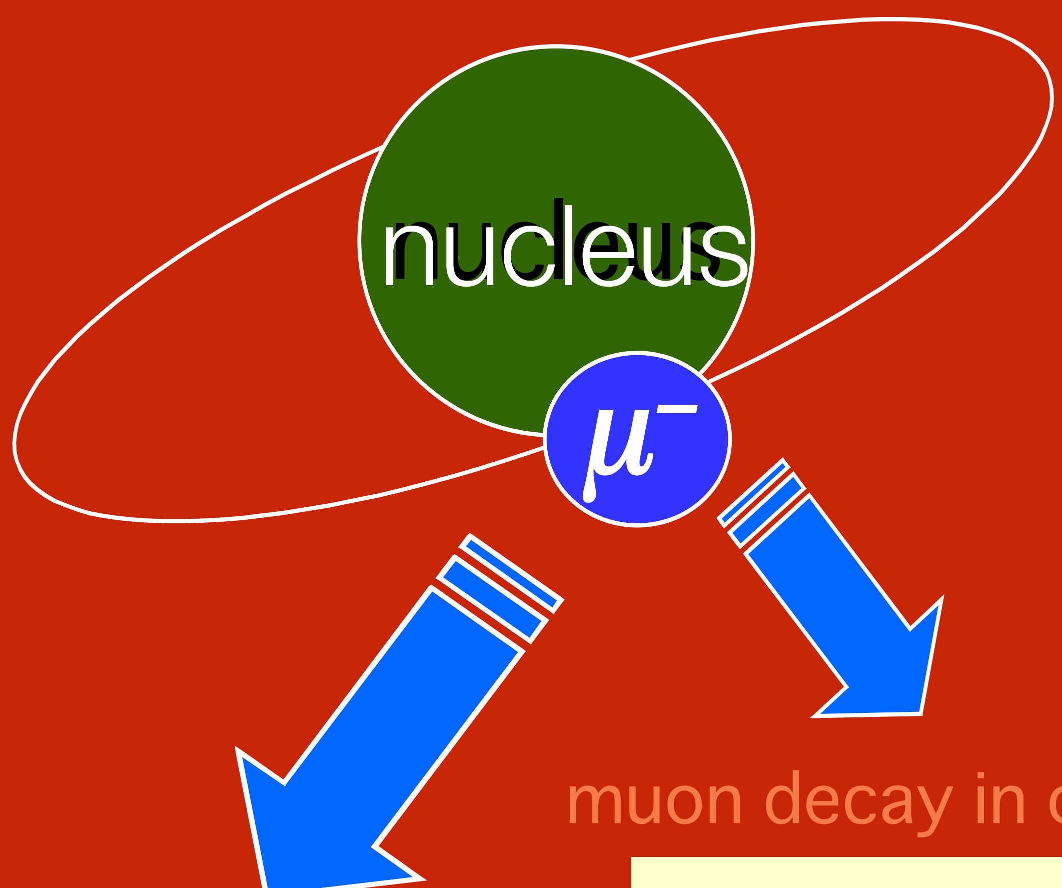
$\mu \rightarrow e$ conversion

in

a muonic atom

What is μ→e 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

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

coherent process $\propto Z^5$

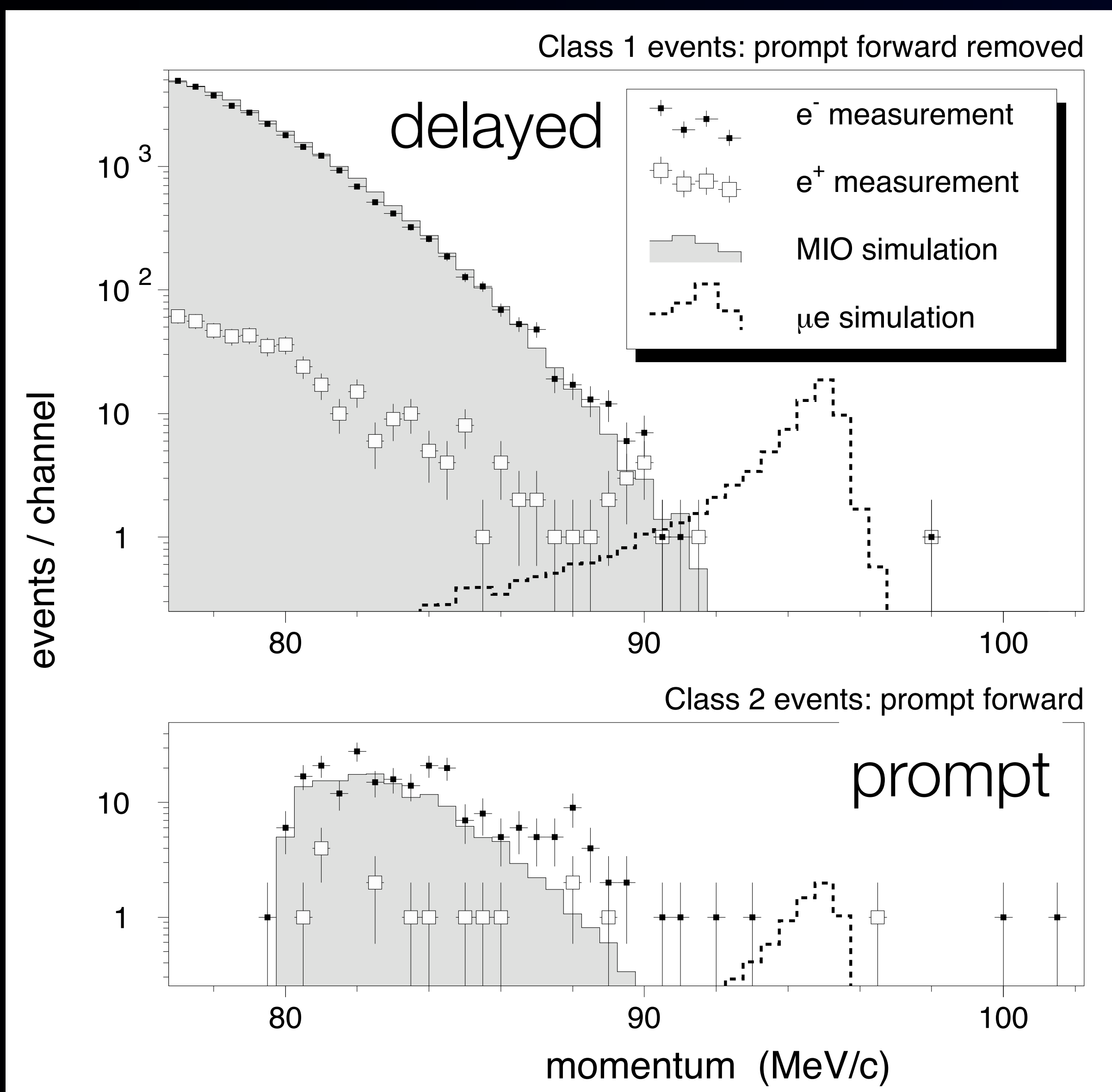
Event Signature :
a single mono-energetic electron of 105 MeV

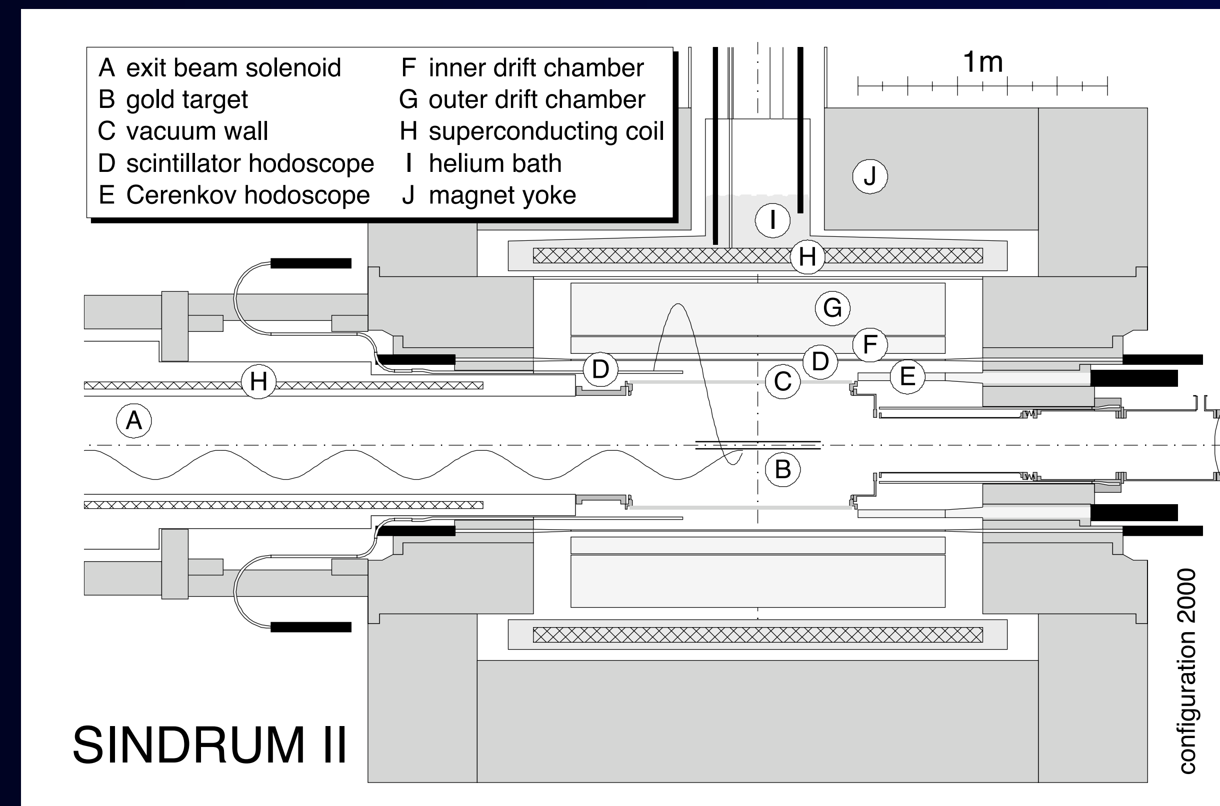
Backgrounds:
(1) physics backgrounds
(2) beam-related backgrounds
(3) cosmic rays, false tracking

$$\mathrm{CR}(\mu^- \mathrm{N} \rightarrow e^- \mathrm{N}) \equiv \frac{\Gamma(\mu^- \mathrm{N} \rightarrow e^- \mathrm{N})}{\Gamma(\mu^- \mathrm{N} \rightarrow \mathrm{all})}$$

Current Limits on μ→e Conversion

SINDRUM-II (PSI)





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

	Z	S	CR limit
sulfur	16	0	7×10^{-11}
titanium	22	0,5/2,7/2	4.3×10^{-12}
copper	39	3/2	1.6×10^{-8}
gold	79	0,5/2	7×10^{-13}
lead	82	0 (1/2)	4.6×10^{-11}

COMET = COherent Muon to Electron Transition

COMET Phase-I : J-PARC E21

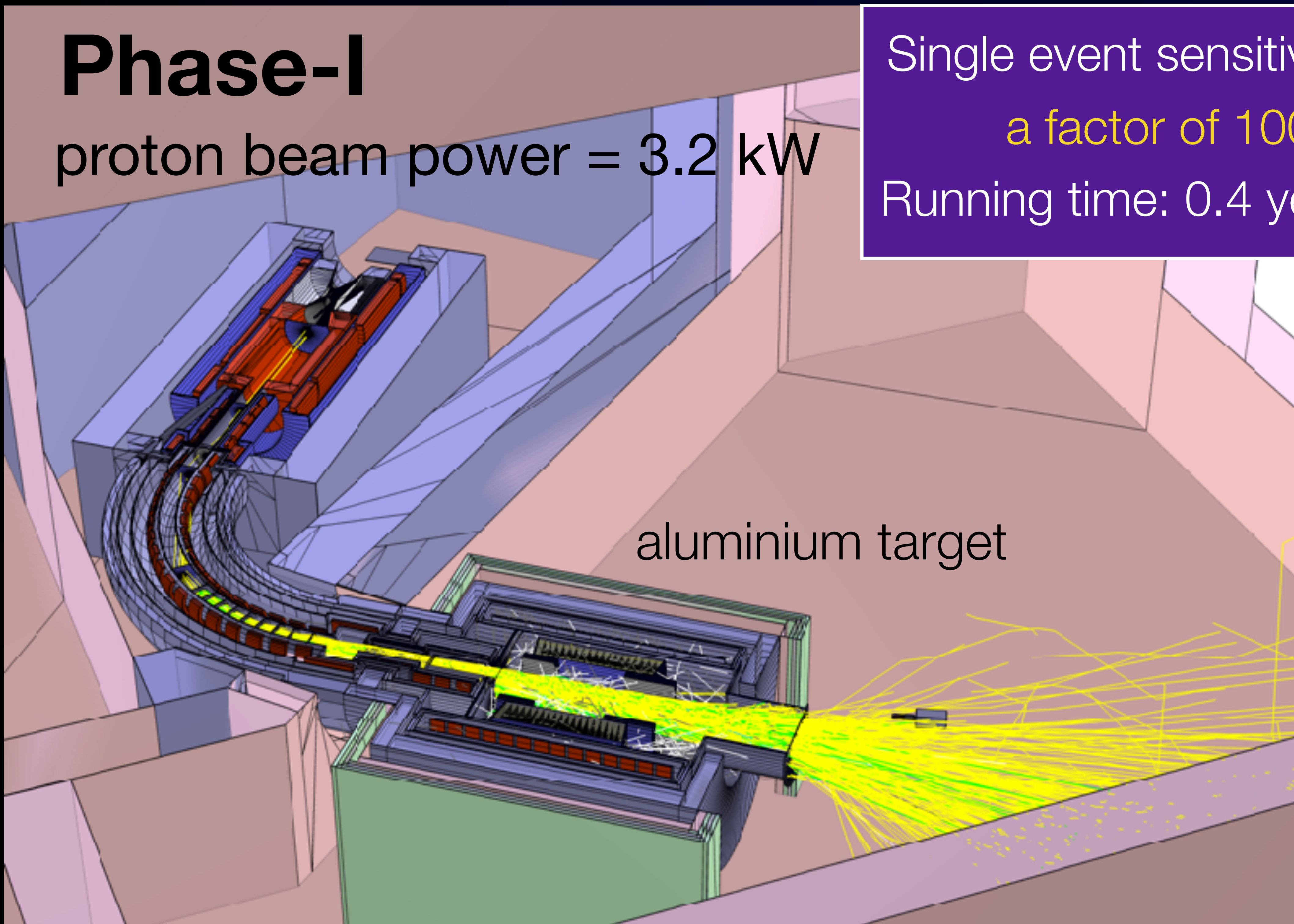
Phase-I

proton beam power = 3.2 kW

Single event sensitivity : 2×10^{-15}

a factor of 100 improvement

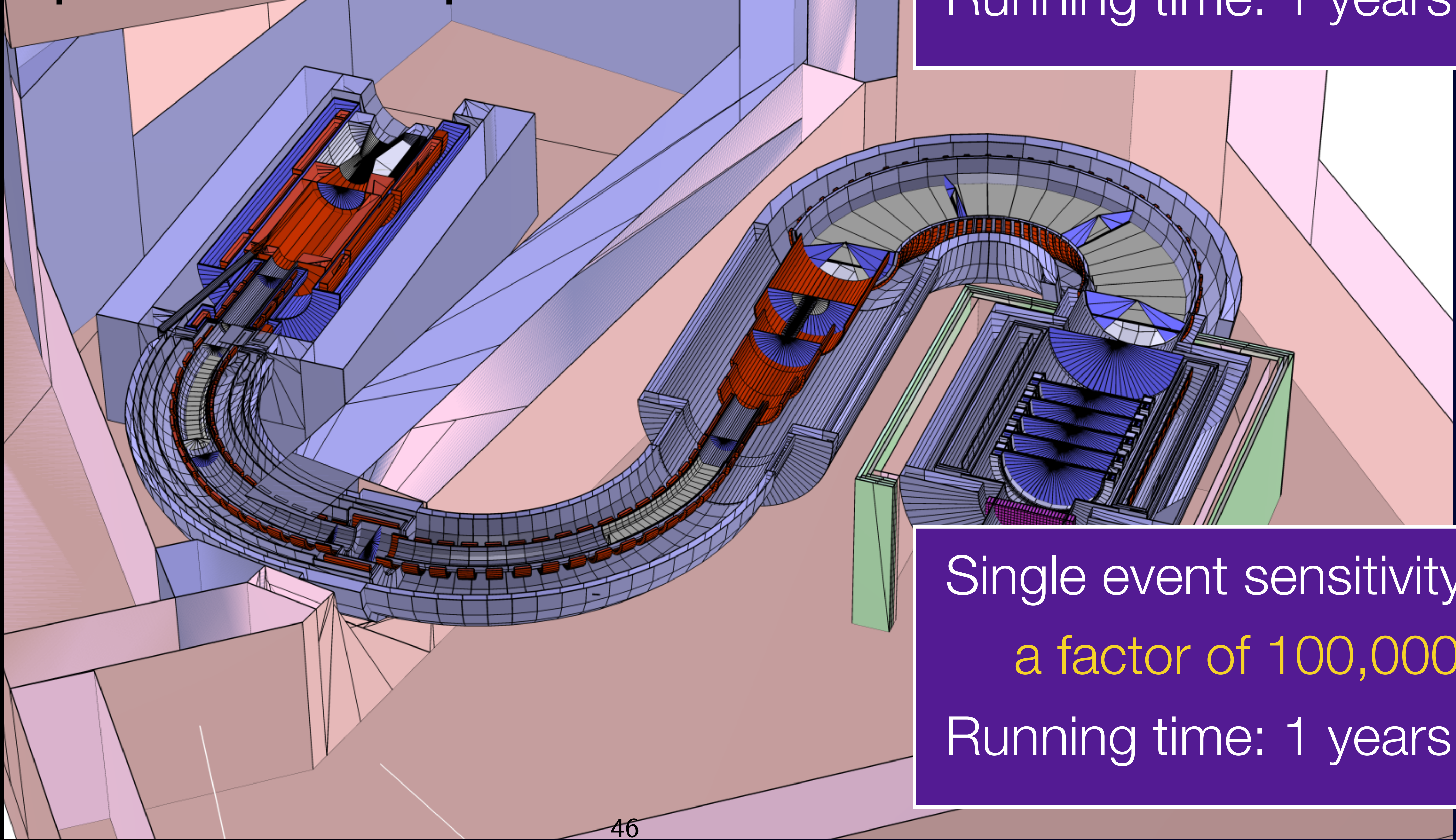
Running time: 0.4 years (1.2×10^{7}s)



COMET Phase-II : J-PARC E21

Phase-II

proton beam power = 56 kW



Single event sensitivity : 2.6×10^{-17}

a factor of 10,000 improvement

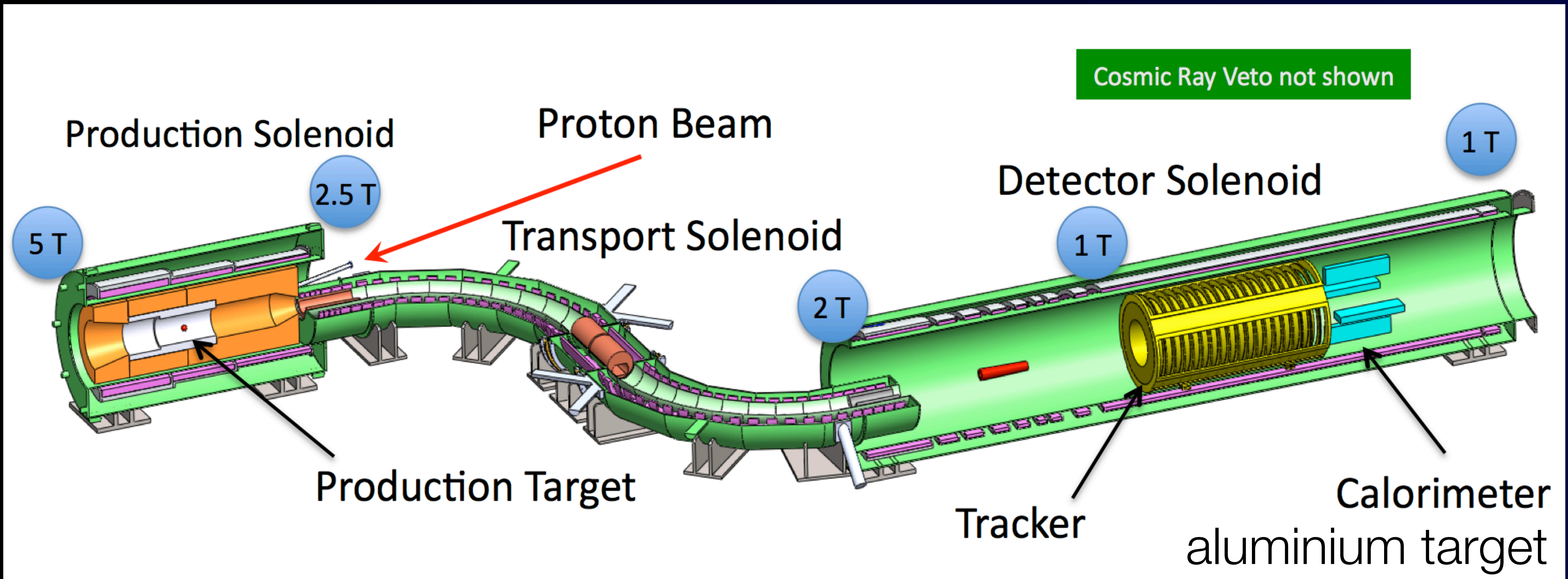
Running time: 1 years (2×10^{7}sec)

Single event sensitivity : $O(10^{-18})$

a factor of 100,000 improvement

Running time: 1 years (2×10^{7}sec)

Mu2e at Fermilab



Single-event sensitivity : 2.5×10^{-17}
a factor of 10,000 improvement
Running time: 3 years
(2×10^{7} sec/year)

Mu2e-II

- 800 MeV, 100 kW from PEP-II
- aim at 2×10^{-18} with 3 years

  a factor of 100,000 improvement

Experimental Comparison

	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

continuous beam (cyclotron) or pulsed (synchrotron)

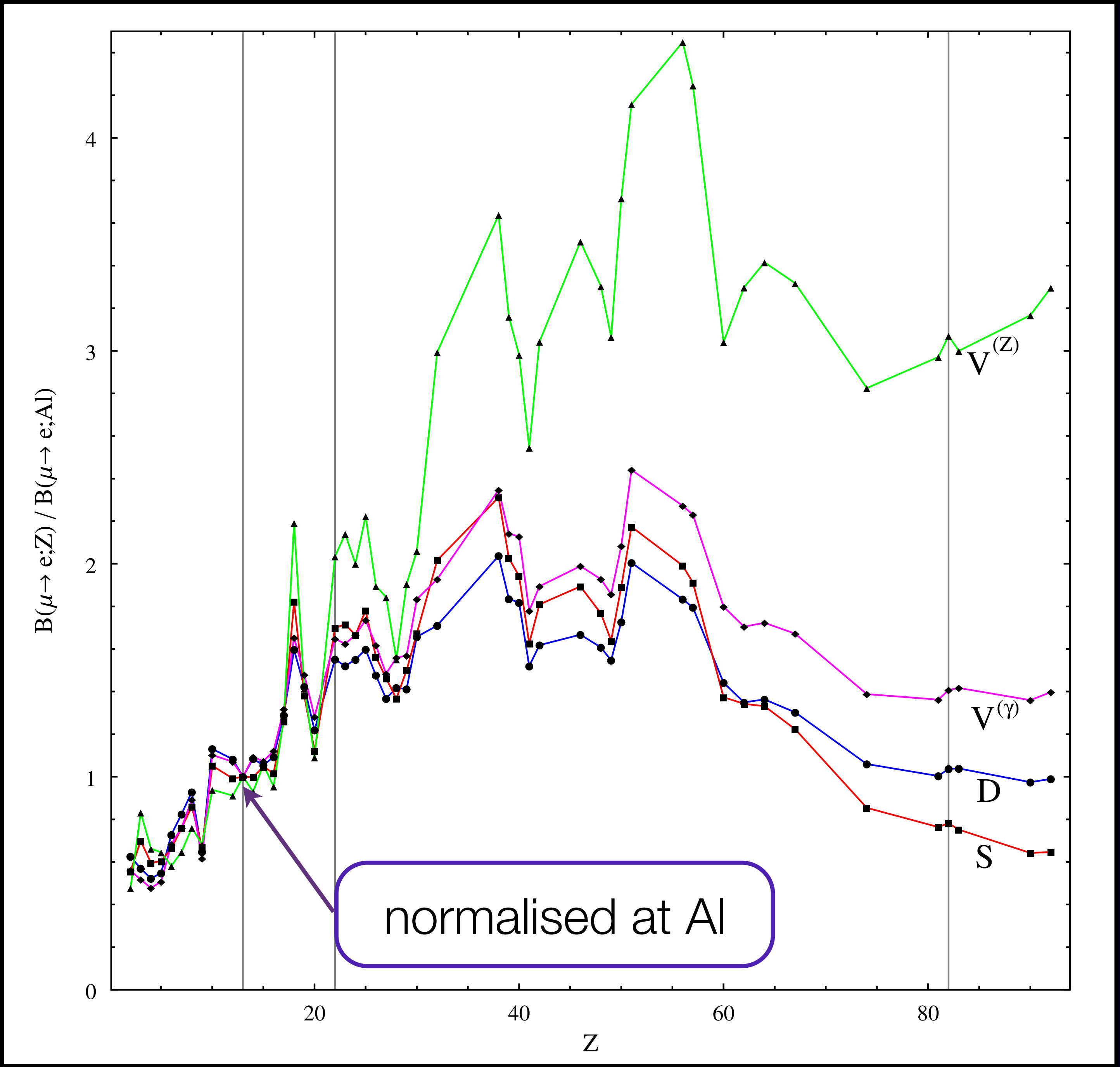
μ→e Conversion Phenomenology

Lagrangian

$$
\begin{aligned}
\mathcal{L}_{\mu-e\ conv}^{non-photo} = & -\frac{G_F}{\sqrt{2}} \sum_{q=u,d,s\ldots} \Big[(g_{LS(q)}\overline{e_L}\mu_R + g_{RS(q)}\overline{e_R}\mu_L)\overline{q}q \\
& +(g_{LP(q)}\overline{e_L}\mu_R + g_{RP(q)}\overline{e_R}\mu_L)\overline{q}\gamma_5 q \\
& +(g_{LV(q)}\overline{e_L}\gamma^{\mu}\mu_L + g_{RV(q)}\overline{e_R}\gamma^{\mu}\mu_R)\overline{q}\gamma_{\mu} q \\
& +(g_{LA(q)}\overline{e_L}\gamma^{\mu}\mu_L + g_{RA(q)}\overline{e_R}\gamma^{\mu}\mu_R)\overline{q}\gamma_{\mu}\gamma_5 q \\
& +\frac{1}{2}(g_{LT(q)}\overline{e_L}\sigma^{\mu\nu}\mu_R + g_{RT(q)}\overline{e_R}\sigma^{\mu\nu}\mu_L)\overline{q}\sigma_{\mu\nu}q + H.c. \Big]
\end{aligned}
$$

In addition to the photonic part, the four-fermion contact interaction, where the scalar, pseudo scalar, vector, axial vector and tensor interactions for left-handed and right-handed are included.

Future:
μ-e Conversion : Disentangle Interaction



vector interaction (with Z boson)	with Z penguin
vector interaction (with photon - charge radius)	left-right models
dipole interaction	SUSY-GUT
scalar interaction	SUSY seesaw

V. Cirigliano, R. Kitano, Y. Okada, and P. Tuzon, Phys. Rev. D80, 013002 (2009)
S. Davidson, YK, M. Yanaka, Phys. Lett. B790 (2019) 380-388

Spin Dependent μ-e conversion and Spin Independent μ-e conversion

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dipole interaction

vector interaction

scalar interaction

Coherent μ-e Conversion (spin independent)

axial vector interaction

tensor interaction

Incoherent μ-e Conversion (spin dependent)

compare zero-spin and non-zero-spin nuclear targets

V. Cirigliano, S. Davidson, YK, Phys. Lett. B 771 (2017) 242

S. Davidson, YK, A. Saporta, Eur. Phys. J. C78 (2018) 109

White Paper: muonCLFV

muon CLFV white paper to the 2020 update of the European Strategy for Particle Physics, by COMET, MEG, Mu2e and Mu3e collaborations.

arXiv:1812.06540v1 [hep-ex] 16 Dec 2018

Charged Lepton Flavour Violation using Intense Muon Beams at Future Facilities

A. Baldini, D. Glenzinski, F. Kapusta, Y. Kuno, M. Lancaster,
J. Miller, S. Miscetti, T. Mori, A. Papa, A. Schöning, Y. Uchida

A submission to the 2020 update of the European Strategy for Particle Physics on behalf of the COMET, MEG, Mu2e and Mu3e collaborations.

Abstract

Charged-lepton flavour-violating (cLFV) processes offer deep probes for new physics with discovery sensitivity to a broad array of new physics models — SUSY, Higgs Doublets, Extra Dimensions, and, particularly, models explaining the neutrino mass hierarchy and the matter-antimatter asymmetry of the universe via leptogenesis. The most sensitive probes of cLFV utilize high-intensity muon beams to search for $\mu \to e$ transitions.

We summarize the status of muon-cLFV experiments currently under construction at PSI, Fermilab, and J-PARC. These experiments offer sensitivity to effective new physics mass scales approaching $\mathcal{O}(10^4)$ TeV/c^2. Further improvements are possible and next-generation experiments, using upgraded accelerator facilities at PSI, Fermilab, and J-PARC, could begin data taking within the next decade. In the case of discoveries at the LHC, they could distinguish among alternative models; even in the absence of direct discoveries, they could establish new physics. These experiments both complement and extend the searches at the LHC.

Contact: André Schöning [schoning@physi.uni-heidelberg.de]

CLFV Schedule in 2025 and beyond

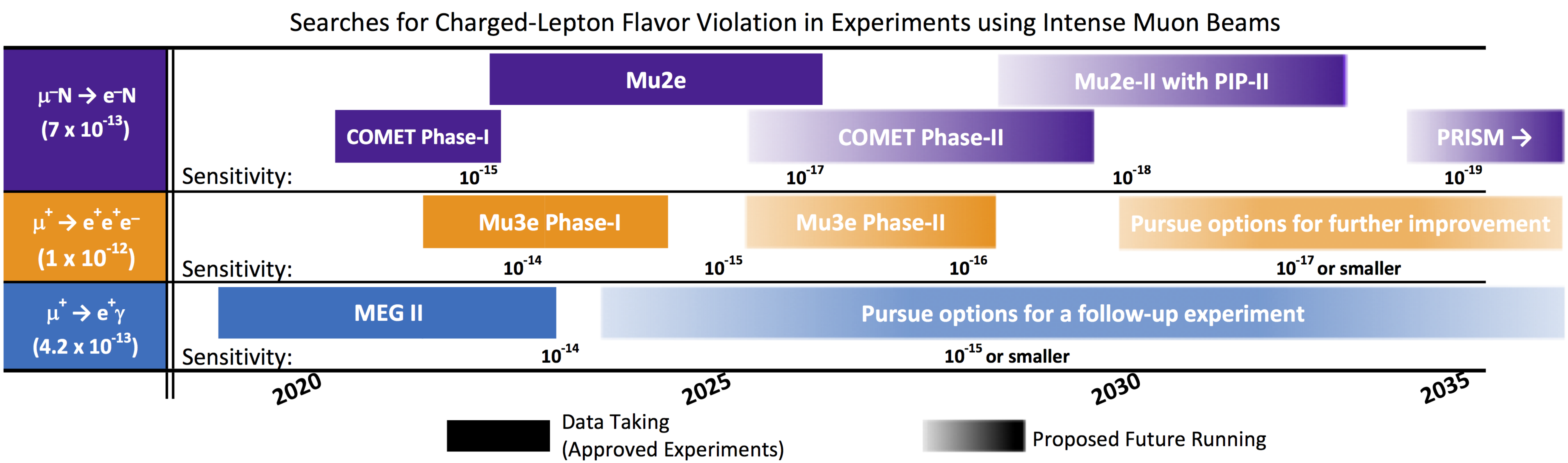
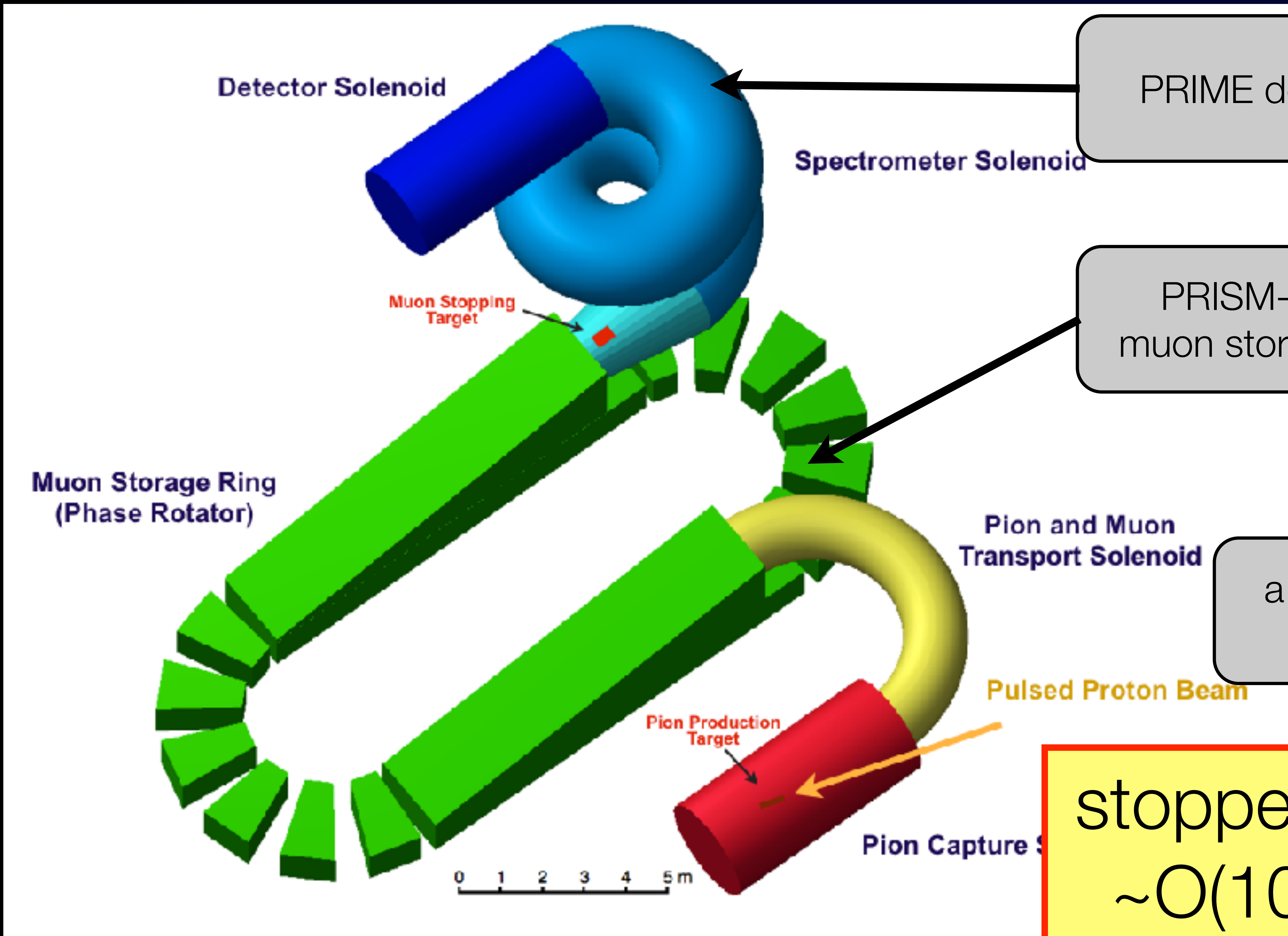


Figure 1: *Planned data taking schedules for current experiments that search for charged-lepton flavor violating $\mu \to e$ transitions. Also shown are possible schedules for future proposed upgrades to these experiments. The current best limits for each process are shown on the left in parentheses, while expected future sensitivities are indicated by order of magnitude along the bottom of each row.*

PRISM (=Phase Rotated Intense Slow Muon source)

PRISM/PRIME



PRIME detector

PRISM-FFAG muon storage ring

a few MW proton beam

stopped muons ~$O(10^{20})$/year

Other CLFV Processes with Muons

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

CLFV of Muon Bound States

Muonium to Antimuonium Conversion
Mu (μ^+e^-) →anti-Mu (μ^-e^+)

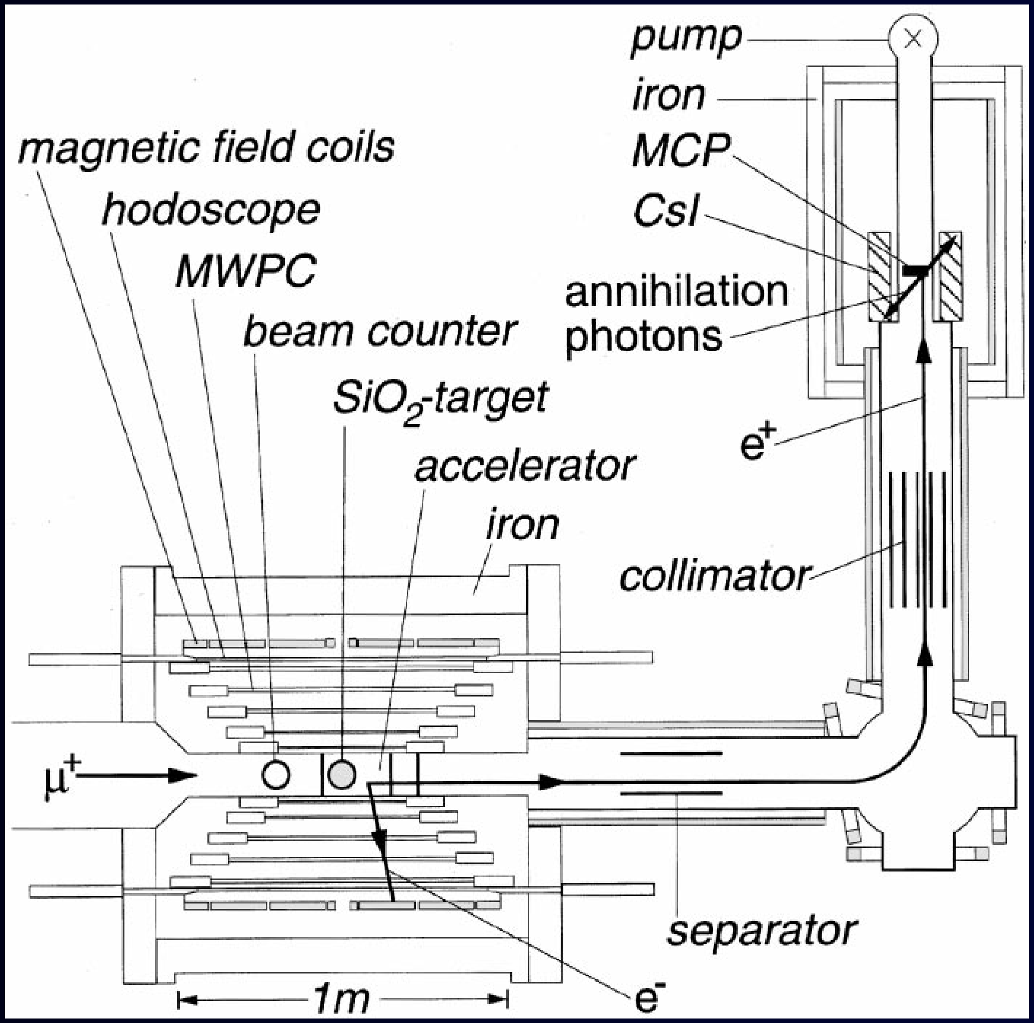
$$\boxed{\mu^+ + e^- \to \mu^- + e^+}$$

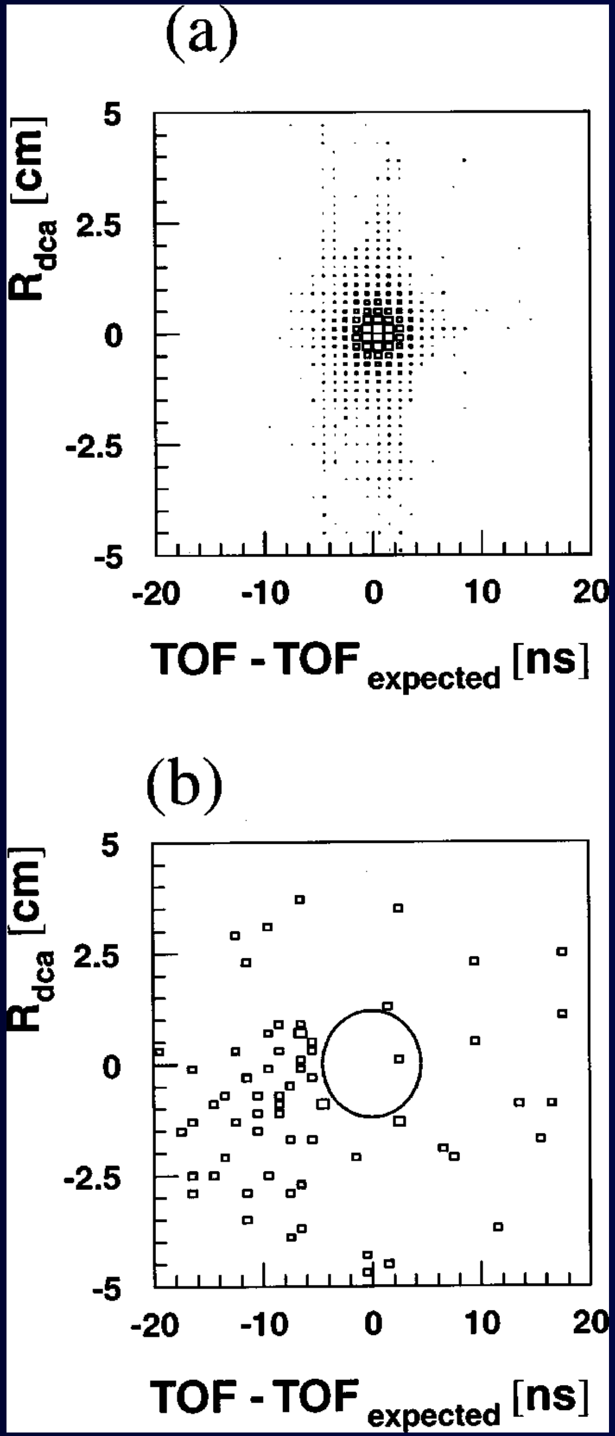
$$|\Delta L_{\mu/e}| = 2$$

- doubly-charged Higgs model etc.
- muonium production in vacuum

previous experiment at PSI (1999)

$$G_{Mu\overline{Mu}} < 3 \times 10^{-3} G_F$$





Future prospects:

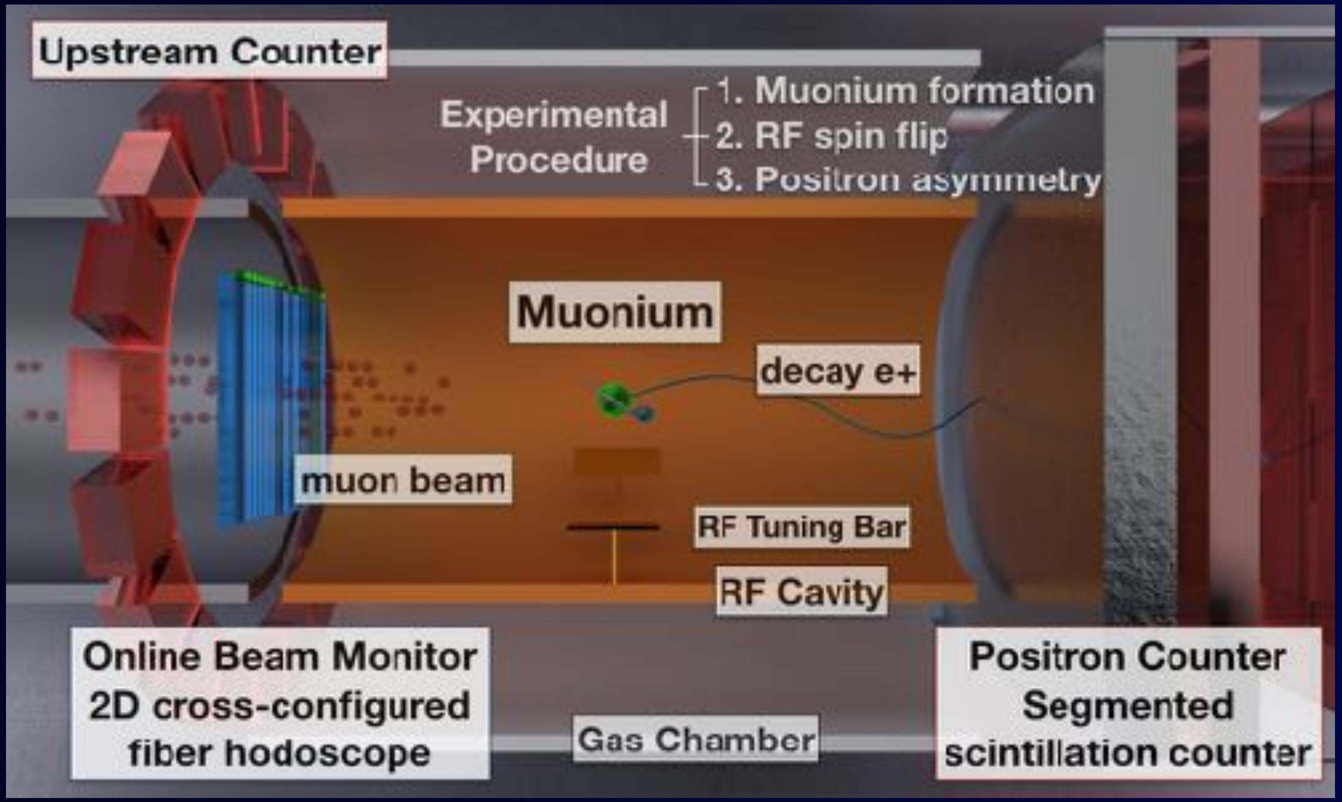
- new attempt at MUSE/ J-PARC ?
  - laser ionization
- new attempt in China?
  - new accelerator

Muonium CLFV Decay

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

- similar to μ→eee
  - may be useful to distinguish different couplings
  - 2 body final state
- disadvantage
  - poor-wave function overlap between μ and e
    - Coulomb bound state

Museum detector
@J-PARC

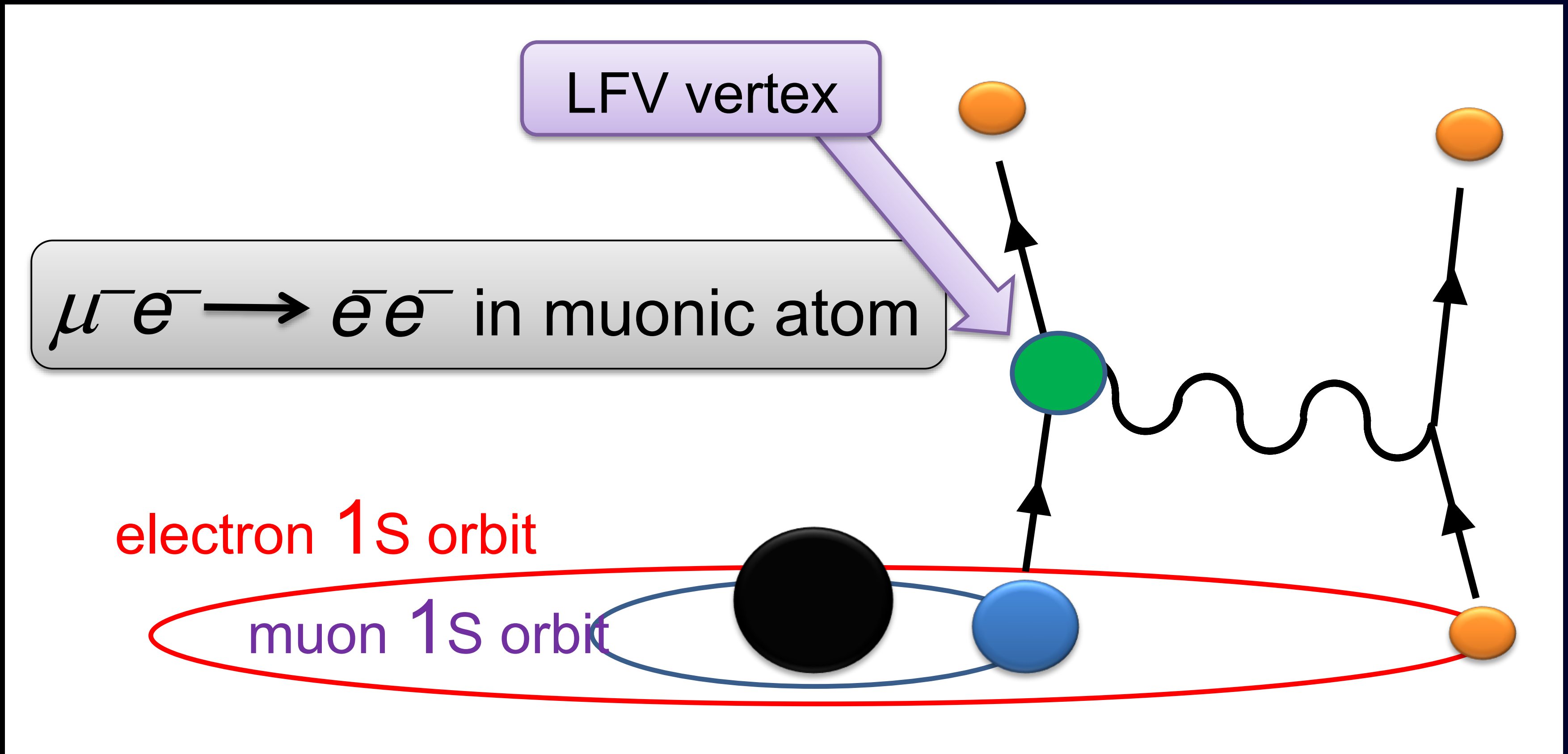


Future prospects:

- no experiments so far
- muonium production in MUSEUM at MUSE @ J-PARC
  - measurement of hyperfine splitting
  - 10^{15} for 2×10^{7} sec

$\mu^- + e^- \rightarrow e^- + e^-$ in a muonic atom

$$\boxed{\mu^- + e^- \rightarrow e^- + e^-}$$



$\mu^- e^- \rightarrow e^- e^-$ has the overwrap of μ^- and e^- which is proportional to Z^3. (almost compatible to $\mu^+ \rightarrow e^+ e^+ e^-$)

Experimentally a pair of e^- and e^- in the final state is measured.

Z dependence discriminate dipole and contact contributions.

M. Koike, YK, J. Sato and M. Yamanaka, Phys. Rev. Lett. 105 (2010)
Y. Uesaka, YK, J. Sato, T. Sato and M. Yamanaka, Phys. Rev. D93 (2016) 076006
Y. Uesaka, YK, J. Sato, T. Sato and M. Yamanaka, Phys. Rev. D97 (2018) 015017

CLFV of Tau Lepton, Z and Higgs

CLFV of Tau Leptons - radiative and leptonic

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$$\tau^\pm \to \ell^\pm \gamma$$

- Event Signature
  - energy $E_{\ell\gamma} \sim \sqrt{s}/2$
  - mass $M_{\ell\gamma} \sim M_\tau$

$$\tau^\pm \to \ell_i^\pm \ell_j^\pm \ell_k^\mp$$

- Event Signature
  - energy $E_{3\ell} \sim \sqrt{s}/2$
  - mass $M_{3\ell} \sim M_\tau$

$$\mathrm{BR}(\tau \to \mu\gamma) \le 4.4 \times 10^{-8}$$

$$\mathrm{BR}(\tau \to e\gamma) \le 3.3 \times 10^{-8}$$

3ℓ final state	BR (BaBar)	BR (Belle)
$\boldsymbol{e^- e^+ e^-}$	2.9×10^{-8}	$\mathbf{2.7 \times 10^{-8}}$
$\mu^- e^+ e^-$	2.2×10^{-8}	1.8×10^{-8}
$\mu^- e^- e^-$	1.8×10^{-8}	1.5×10^{-8}
$e^+ \mu^- \mu^-$	2.6×10^{-8}	1.7×10^{-8}
$e^- \mu^+ \mu^-$	3.2×10^{-8}	2.7×10^{-8}
$\boldsymbol{\mu^- \mu^+ \mu^-}$	3.3×10^{-8}	$\mathbf{2.1 \times 10^{-8}}$

Future prospects at Super KEK-B factory, Tau-charm factory, LHCb

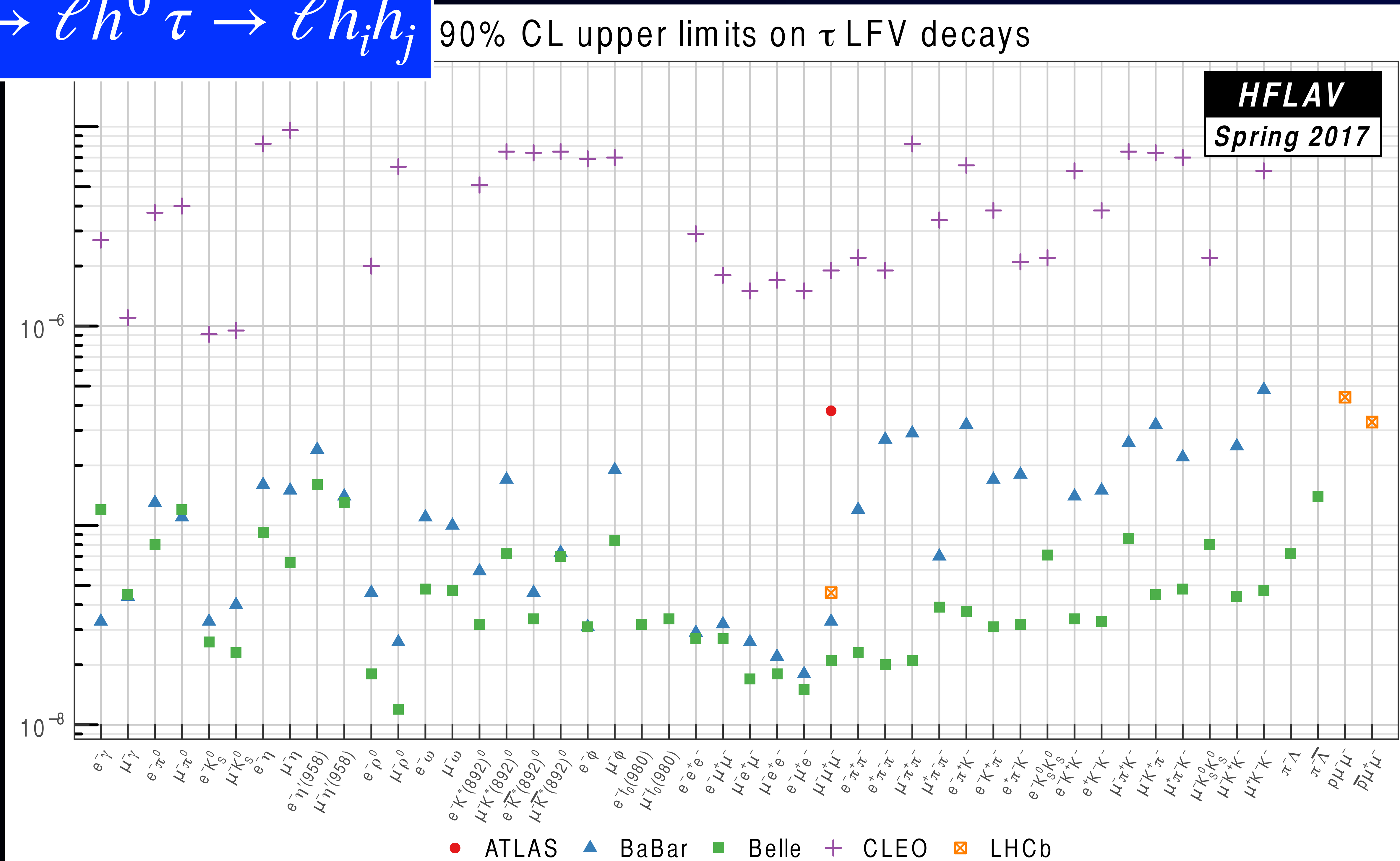
$$\mathrm{BR}(\tau \to \ell\gamma) \le (1-3) \times 10^{-9} \qquad \mathrm{BR}(\tau \to 3\ell) \le (1-2) \times 10^{-10}$$

CLFV of Tau Leptons - semi-leptonic

$\tau \to \ell h^0 \; \tau \to \ell h_i h_j$

10^{-6}

10^{-8}



CLFV of Z Bosons and Higgs Bosons

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$\boxed{Z^0 \to \ell_i \ell_j}$

$\mathrm{BR}(Z^0 \to e\mu) \leq 7.5 \times 10^{-7}$ ATLAS, CMS

$\mathrm{BR}(Z^0 \to \mu\tau) \leq 1.2 \times 10^{-5}$ LEP, (ATLAS, CMS)

$\mathrm{BR}(Z^0 \to e\tau) \leq 9.8 \times 10^{-6}$ LEP, (ATLAS, CMS)

(note : indirect limit from low energy $\mathrm{BR}(Z^0 \to e\mu) \leq 10^{-13}$

$\boxed{H^0 \to \ell_i \ell_j}$

$\mathrm{BR}(H^0 \to e\mu) \leq 0.035\,\%$ CMS (2012)

$\mathrm{BR}(H^0 \to e\tau) \leq 0.37\,\%$ CMS (2016)

$\mathrm{BR}(H^0 \to \mu\tau) \leq 0.25\,\%$ CMS (2016)

(note : not confirm the CMS 2012 excess)

$\boxed{X^0 \to \ell_i \ell_j}$

new massive BSM resonance

- limits are model-dependent
- R-parity violating SUSY particle or QBH

Future Prospects

HL-LHC, ILC, FCC-ee, CEPC and others

Others CLFV

CLFV of K Mesons

- Lepton flavour violating K decays

$$K^+ \to \pi^+\mu^-e^+ : BR < 5.2 \times 10^{-10}$$ BNL E865

$$K^+ \to \pi^+\mu^+e^- : BR < 1.3 \times 10^{-11}$$ BNL E777/E865

$$K^0 \to \mu^\pm e^\mp : BR < 4.7 \times 10^{-12}$$ BNL E871

- Lepton number violating K decays

$$K^+ \to \pi^-\mu^+\mu^+ : BR < 1.1 \times 10^{-9}$$ NA48/2

$$K^+ \to \pi^-\mu^+e^+ : BR < 1.1 \times 10^{-9}$$ BNL E865

$$K^+ \to \pi^-e^+e^+ : BR < 1.1 \times 10^{-9}$$ BNL E865

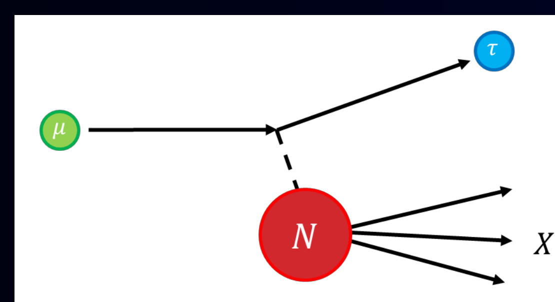
Future Prospects

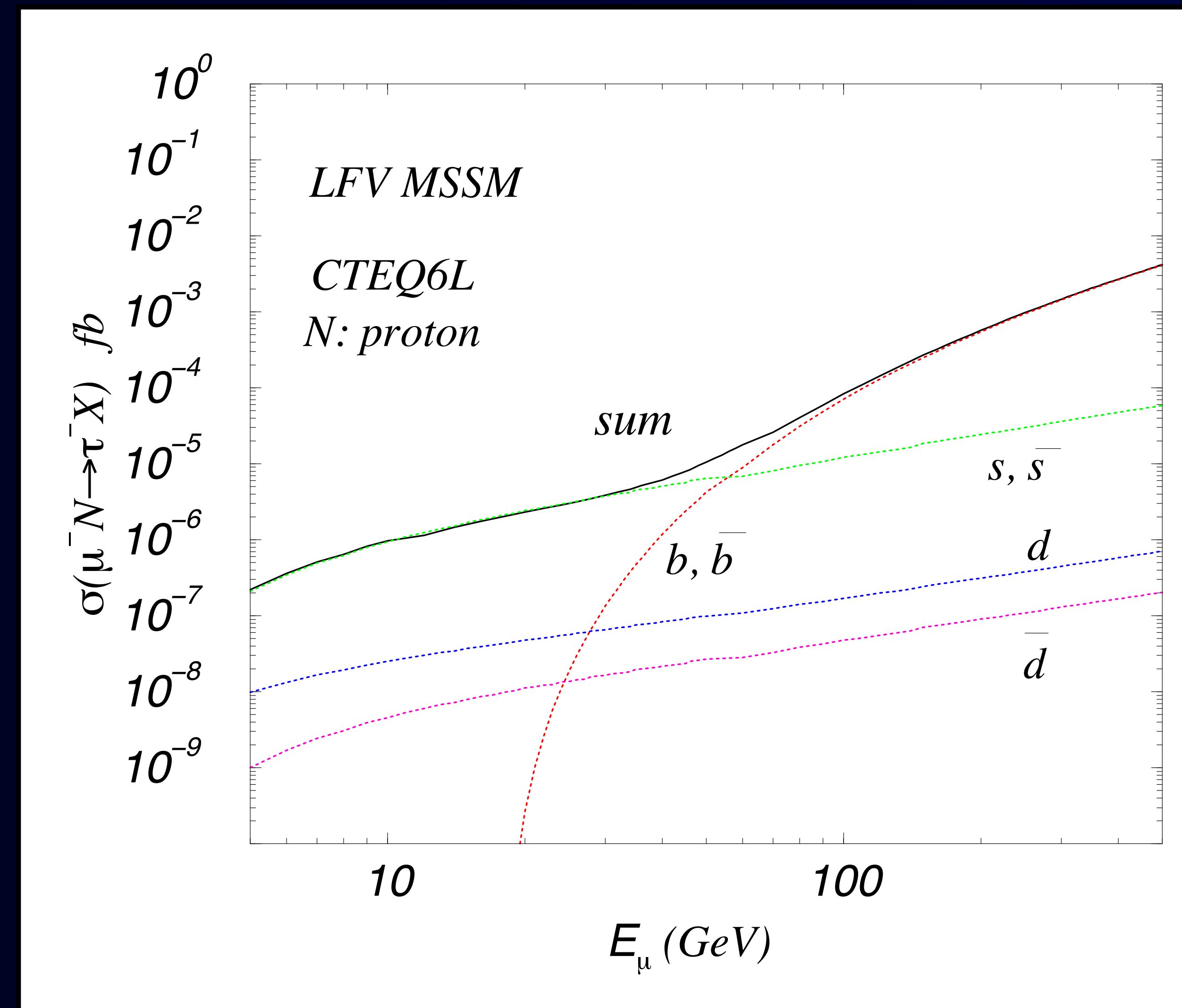
NA62 ~O(10^{-11})

LFV Scattering Process

$$\mu + N\ (e + N) \rightarrow \tau + X$$

inelastic scattering (DIS) region with high-intensity and high-energy muon (electron) beams





muon beam from muon collider or electron beam from the ILC (at beam dump)

M. Sher and I. Turan, Phys. Rev. D 69, 017302 (2004).

S. Kanemura, YK, M. Kuze and T. Ota, Phys. Lett. B607 (2005) 165

M. Takeuchi, Y. Uesaka, M. Yamanaka, Phys. Lett. B772 (2017) 279

Lepton Number and Charged Flavour Violation

μ^- to e^+ conversion in muonic atom

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

Lepton number violation (LNV) and
Lepton flavour violation (LFV)

Final can be the ground or excited states.

signal signature

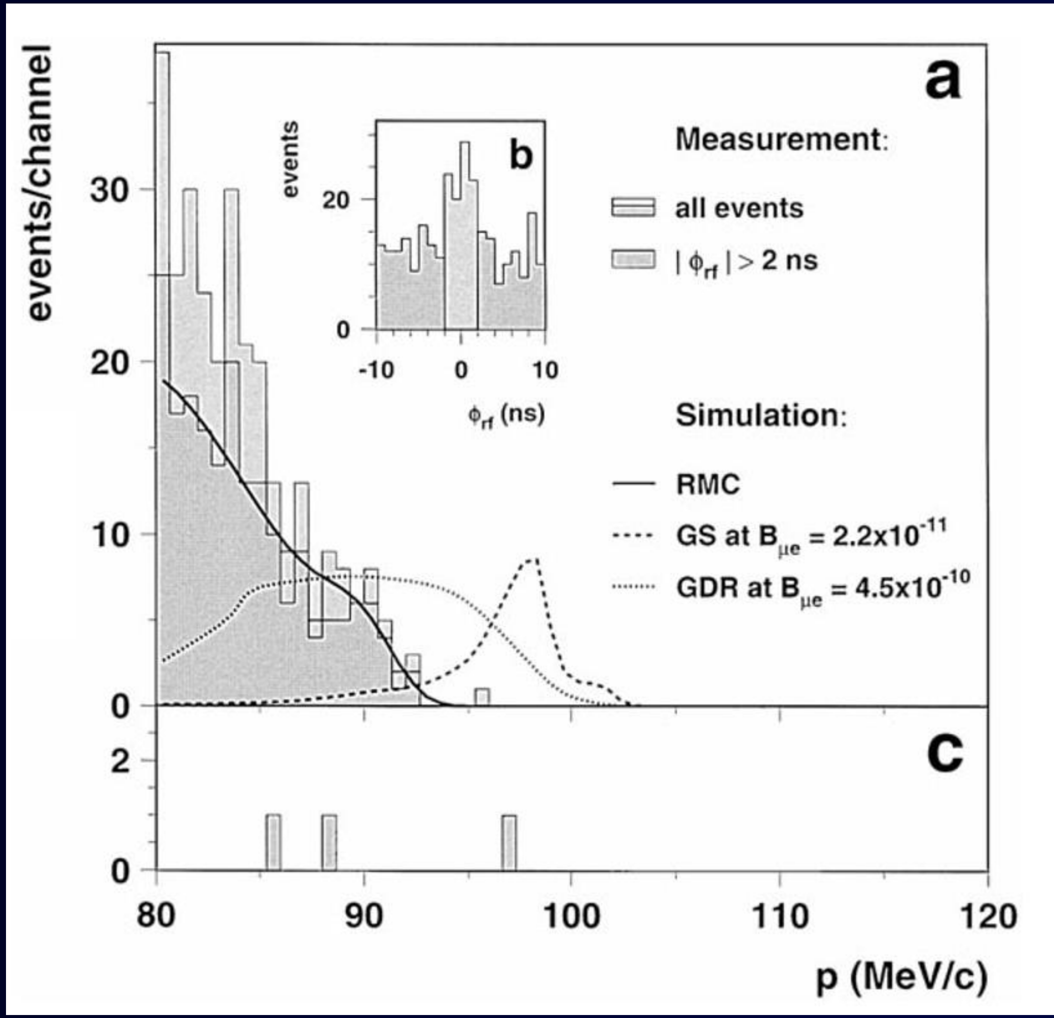
$$E_{\mu e^+} = m_\mu - B_\mu - E_{rec} - (M(A,Z-2) - M(A,Z))$$

backgrounds

- radiative muon nuclear capture (RMC)

$$\mu^- + N(A,Z) \rightarrow N(A,Z-1) + \nu + \gamma$$

$$E_{RMC} = m_\mu - B_\mu - E_{rec} - (M(A,Z-1) - M(A,Z))$$



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

J. Kaulard et al. (SINDRUM-II)
Phys. Lett. B422 (1998) 334.

μ^- to e^+ conversion : Target Selection

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

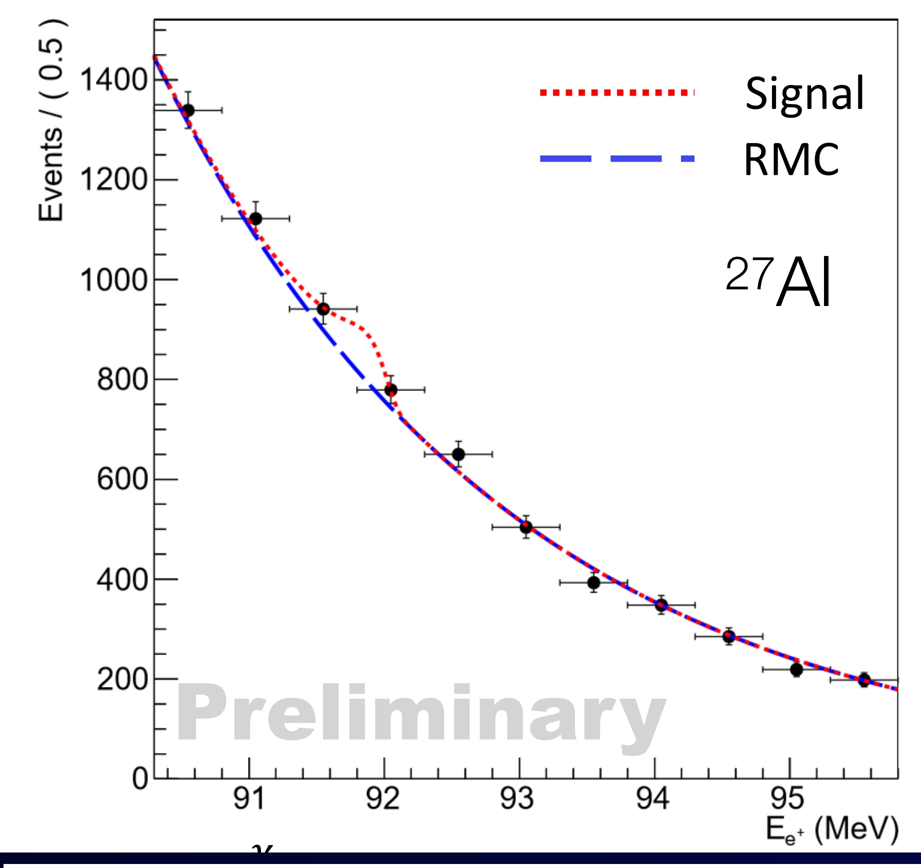
Requirement on targets

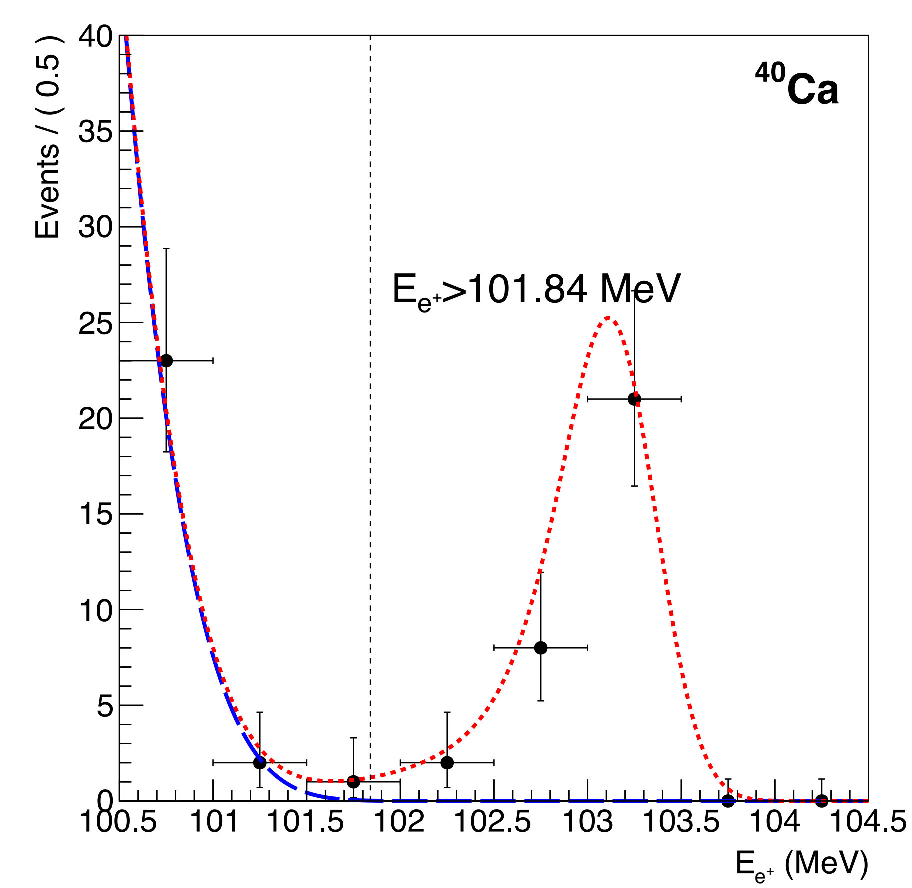
$$E_{\mu e^+} > E_{RMC} \longrightarrow M(A,Z-1) < M(A,Z-2)$$

Atom	$E_{\mu^- e^+}$ (MeV)	$E_{\mu^- e^-}$ (MeV)	E_{RMC}^{end} (MeV)	N.A. (%)	f_{cap} (%)	τ_{μ^-} (ns)	A_T
^{27}Al	92.30	104.97	101.34	100	61.0	864	0.191
^{32}S	101.80	104.76	102.03	95.0	75.0	555	0.142
^{40}Ca	103.55	104.39	102.06	96.9	85.1	333	0.078
^{48}Ti	98.89	104.18	99.17	73.7	85.3	329	0.076
^{50}Cr	104.06	103.92	101.86	4.4	89.4	234	0.038
^{54}Fe	103.30	103.65	101.93	5.9	90.9	206	0.027
^{58}Ni	104.25	103.36	101.95	68.1	93.1	152	0.009
^{64}Zn	103.10	103.04	101.43	48.3	93.0	159	0.011
^{70}Ge	100.67	102.70	100.02	20.8	92.7	167	0.013

Aluminum (for COMET & Mu2e) is not good.

10^{18} muons, signal~1x10^{-12}



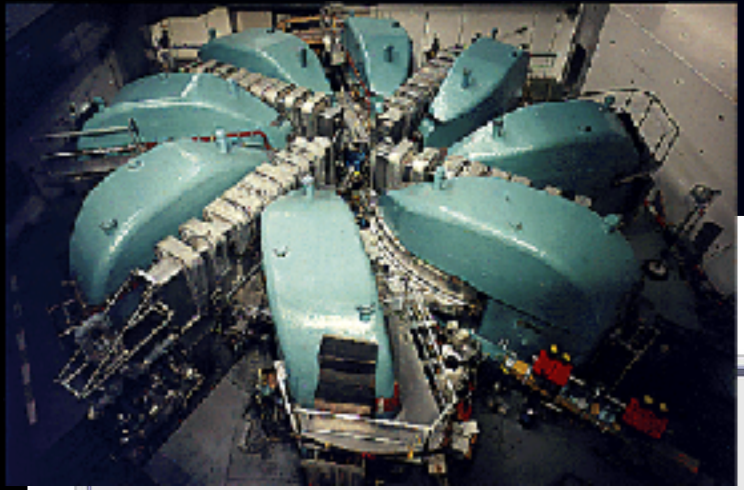


B. Yeo, YK, M. Lee and K. Zuber, Phys. Rev. D96 (2017) 075027

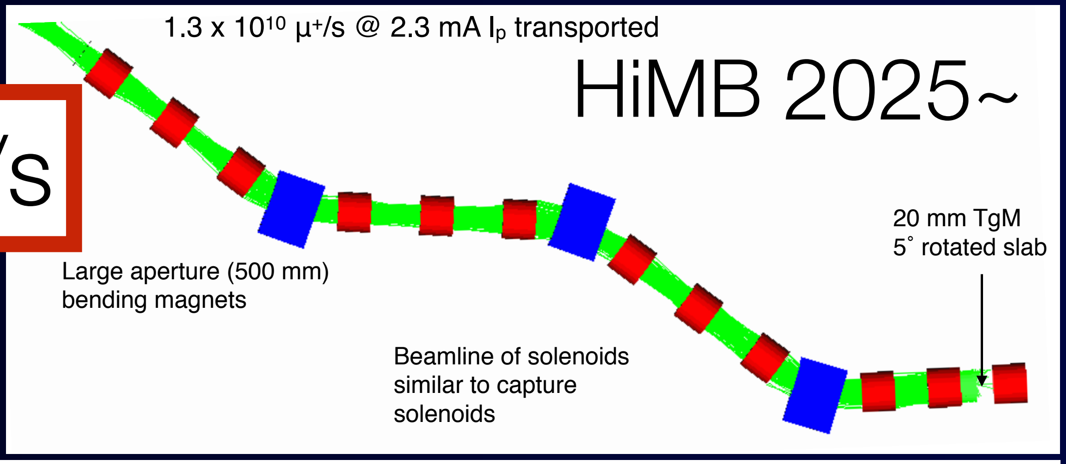
Sources

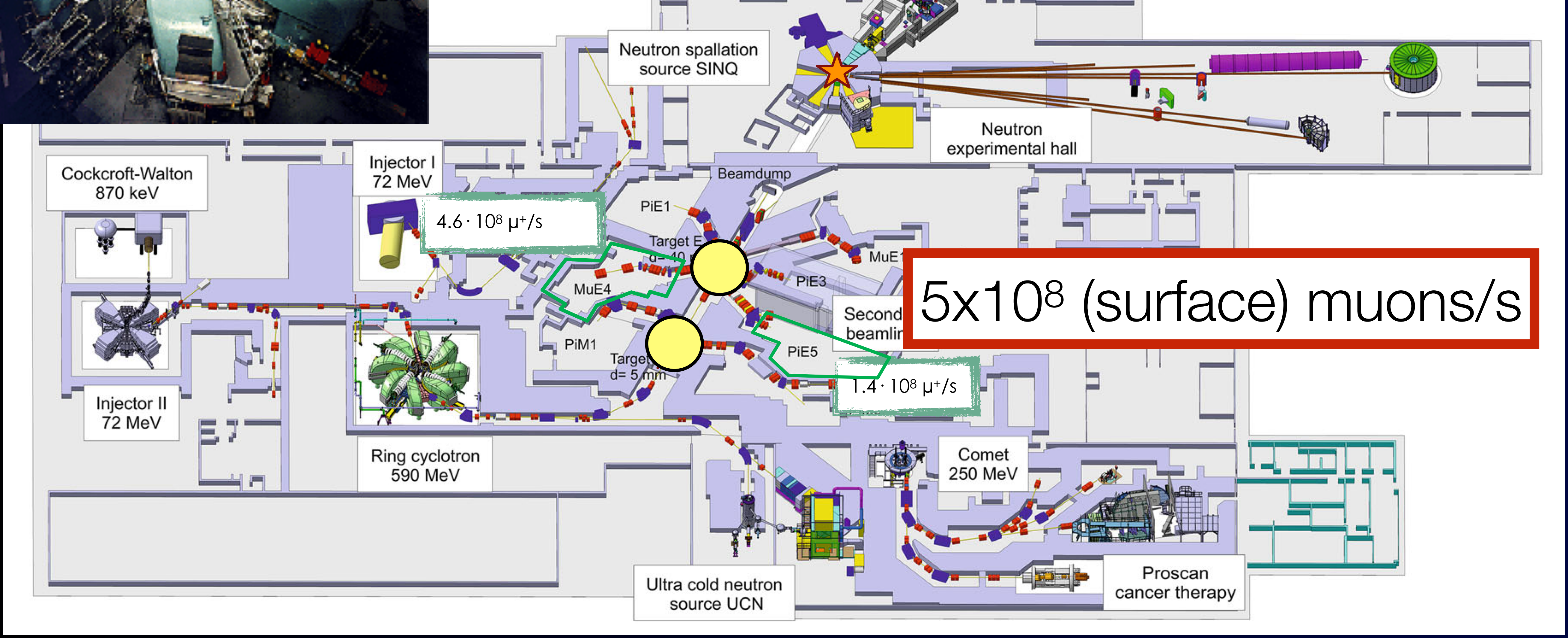
Paul Sherrer Institute (PSI)

590 MeV proton ring cyclotron 1.4MW



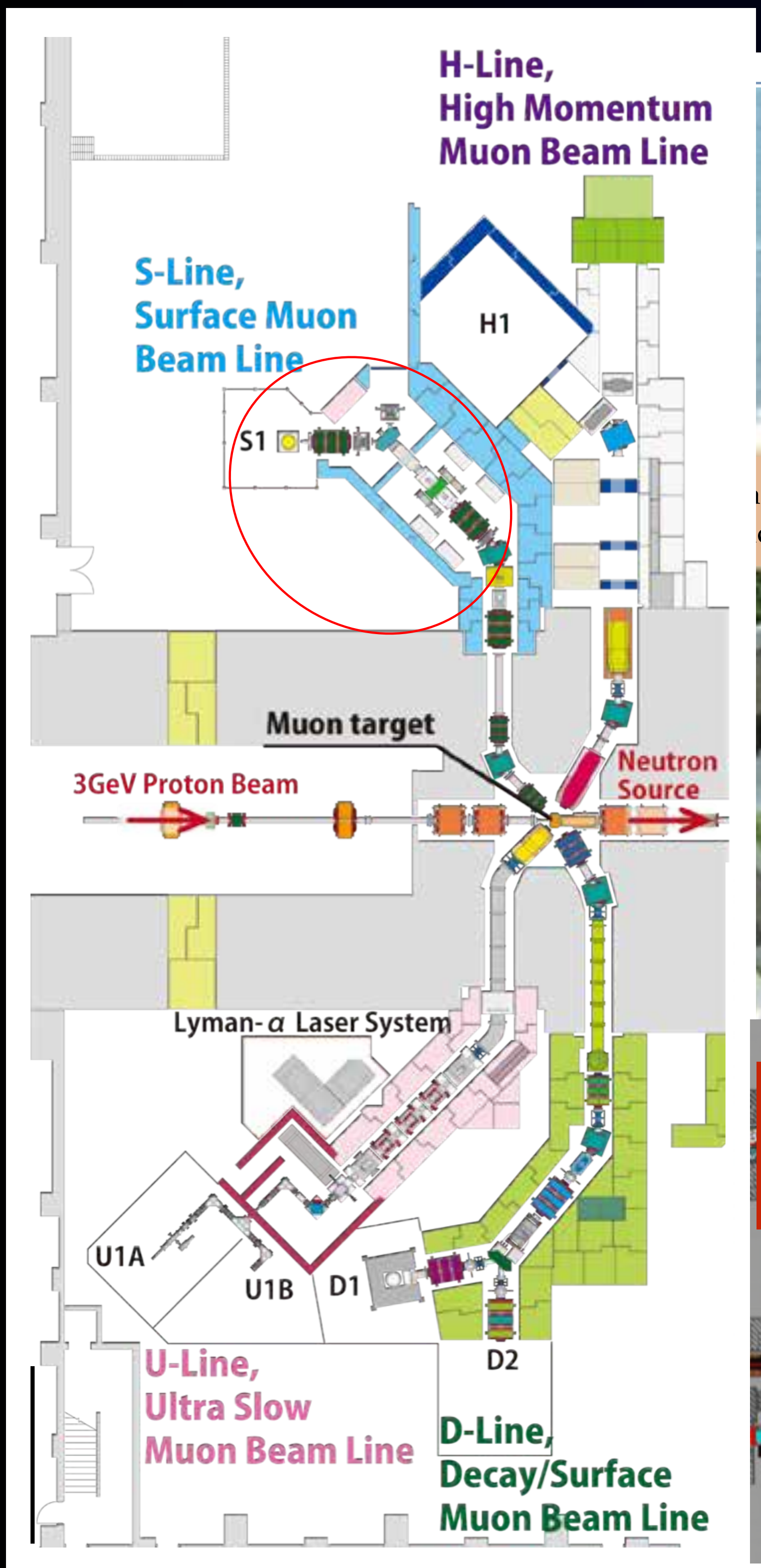
1.3x10^{10} muons/s



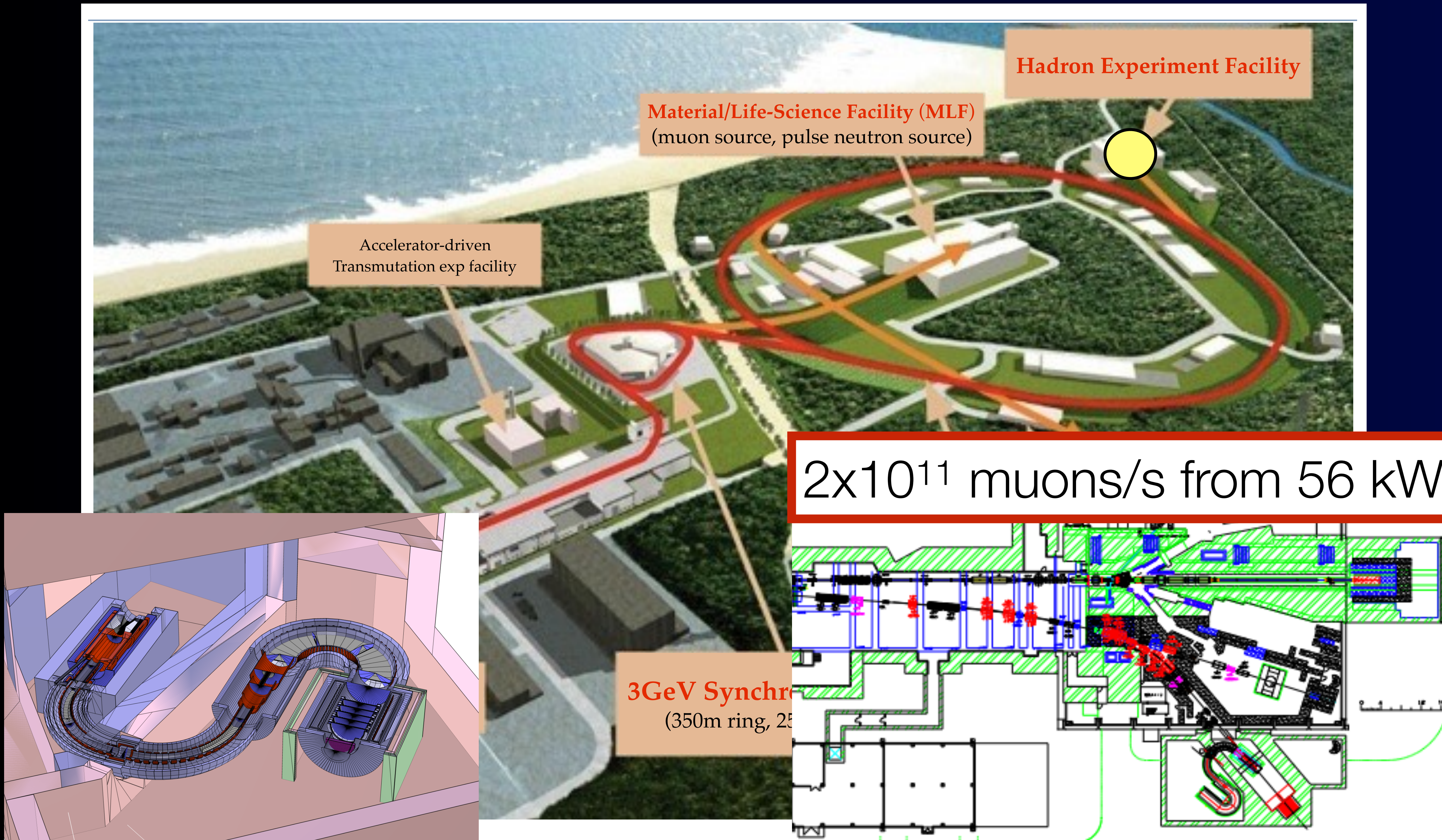


5x10^8 (surface) muons/s

J-PARC (MUSE@MLF)

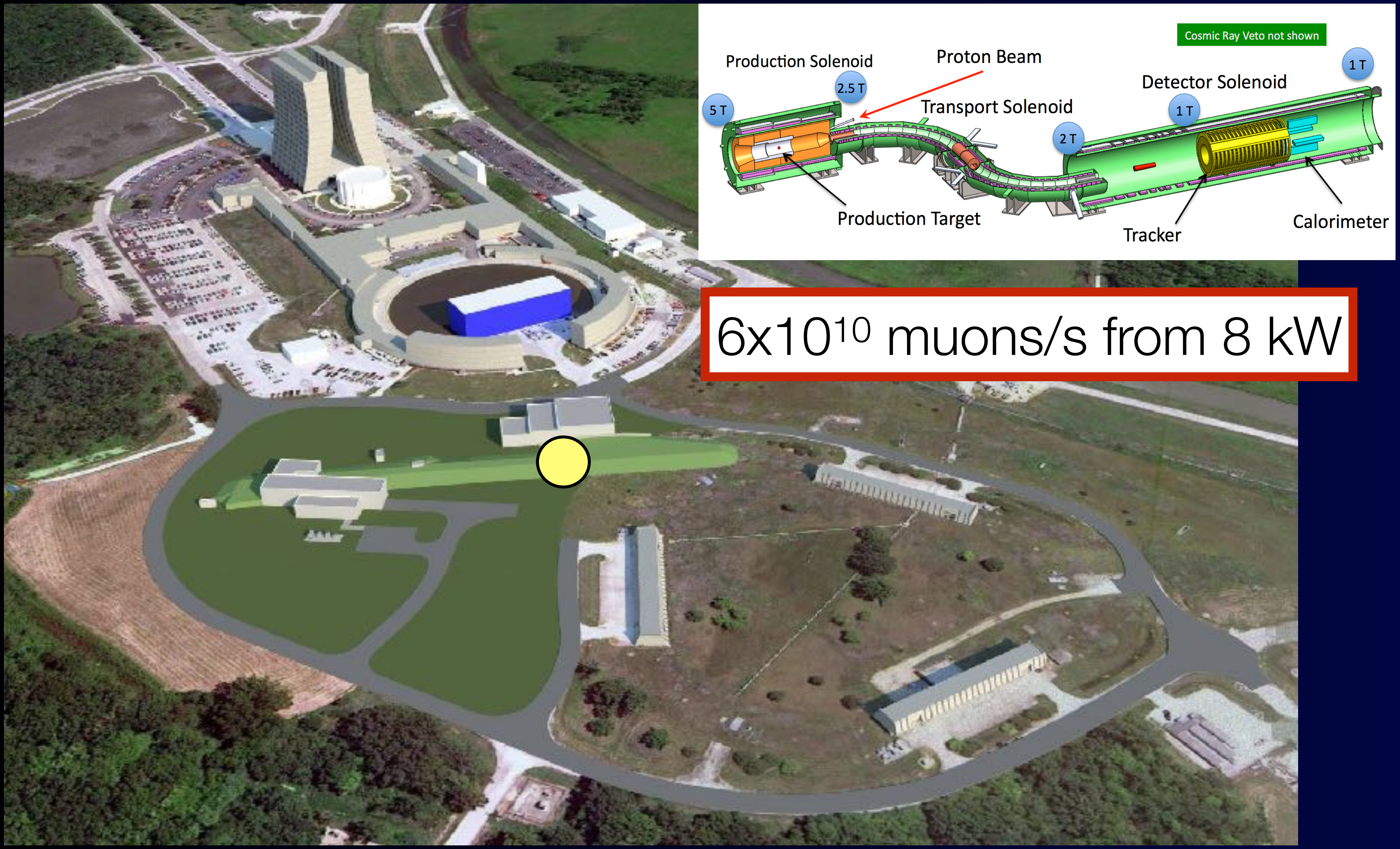


J-PARC (COMET@Main Ring)



2×10^{11} muons/s from 56 kW

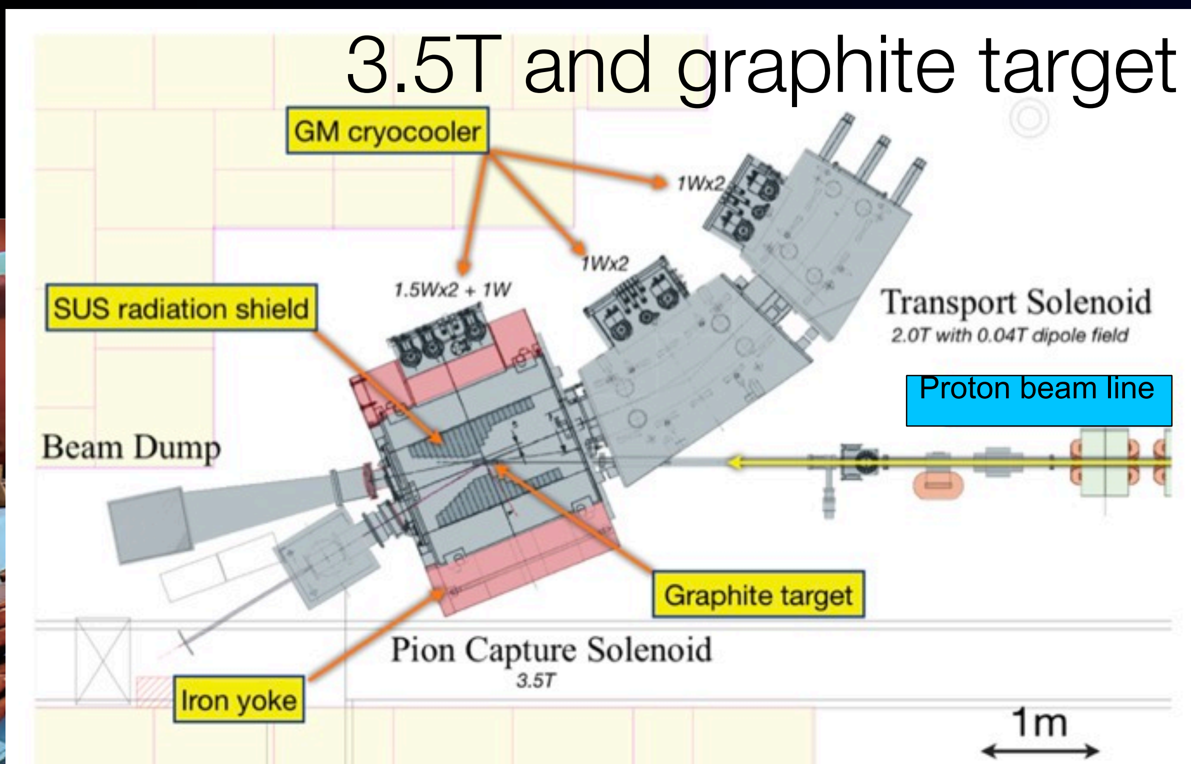
Fermilab Muon Campus



6×10^{10} muons/s from 8 kW

MuSIC Facility at RCNP, Osaka University

S. Cook et al., Phys. ReV. Accel. and Beam, 20, 030101 (2017)



muon/proton~x1000

Summary

- CLFV processes provide an unique discovery potential for physics beyond the Standard Model (BSM), exploring new physics parameter space in a manner complementary to the collider, dark matter, dark energy, and neutrino physics programs.

- CLFV experimental programs are rich, being covered by low energy to high energy measurements.

- In particular, the muon CLFV programs are expecting significant progress owing to improvement of the muon sources in coming years.

my dog, IKU

Thank you for your attention!