Charged Lepton Flavor Violation Experiments

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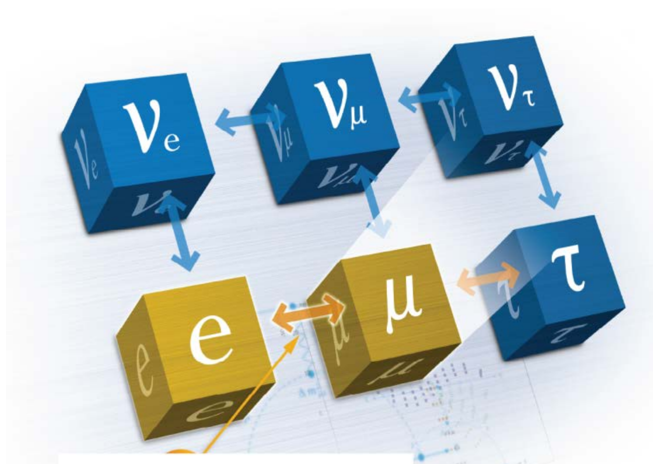
Outline

- Emphasis on Charged Lepton Flavor Violation with Muon and Tau Decays
- Brief CLFV Introduction and Motivation
- Range of Experiments and current limits
- CLFV Experiments with Muons in more detail
- Summary

Lepton Flavor Violation

- We have observed quark mixing

- We have observed neutrinos mix

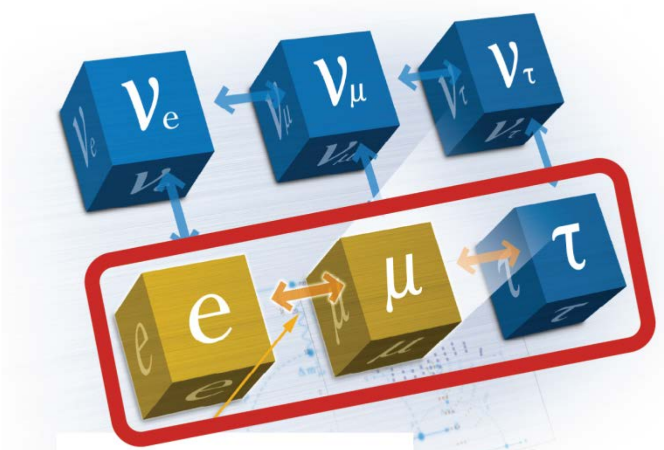


$$\ell_e = 1 \quad \ell_\mu = 1 \quad \ell_\tau = 1$$

Lepton Flavor Violation

- We have observed quark mixing

- We have observed neutrinos mix, but we have not seen charged lepton flavor mixing



$\ell_e = 1 \quad \ell_\mu = 1 \quad \ell_\tau = 1$

CLFV Status and Plans

Current and Planned Experiments

- τ decays at Babar, Belle, LHCb
- Future τ decays: Belle II, LHCb
- MEG at PSI: $\mu \rightarrow e\gamma$
- **μe conversion:**
  - **Mu2e at FNAL**
  - **COMET at J-PARC**
  - **DeeMe at J-PARC**

Reaction	Current Limit	Future limit	Who/where?
$\mu \rightarrow e\gamma$	5.7×10^{-13}	$<6 \times 10^{-14}$	MEG at PSI
$\mu \rightarrow eee$	1.0×10^{-12}	$<10^{-15}$-10^{-16}	PSI
$\mu N \rightarrow eN$ (Au)	7×10^{-13}	$<10^{-18}$	PRISM/ Mu2e II
$\mu N \rightarrow eN$ (Al)	-----	$<10^{-16}$ /10^{-18}	Mu2e, COMET/ upgrades
$\mu N \rightarrow eN$ (Ti)	4.3×10^{-12}	$<10^{-18}$	PRISM/ Mu2eX
$\mu^+ e^- \rightarrow \mu^- e^+$	8.3×10^{-11}		
$\tau \rightarrow \mu\gamma$	4.4×10^{-8}	$<10^{-9}$	Flavor factory
$\tau \rightarrow e\gamma$	3.3×10^{-8}	$<10^{-9}$	Flavor factory
$\tau \rightarrow \mu\mu\mu$	2.1×10^{-8}	$<10^{-9}$-10^{-10}	Flavor factory
$\tau \rightarrow eee$	2.7×10^{-8}	$<10^{-9}$-10^{-10}	Flavor factory
$\tau \rightarrow \mu ee$	1.5×10^{-8}	$<10^{-9}$-10^{-10}	Flavor factory

Sampling of Sensitivities of Models to CLFV

Altmannshofer, Burus, Gori, Paradisi, Straub, 0909.1332

Process\Model	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0 - \bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{CP}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

AC	U(1) flavor symmetry
RVV2	Non-abelian SU(3)-flavored MSSM
AKM	SU(3)-flavored SUSY
δLL	LH CKM-like currents
FBMSSM	Flavor-blind MSSM
LHT	Little Higgs w/T parity
RS	Randall-Sundrum

★★★ Large effect

★★ Small but visible effect

★ No observable effect

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$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
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$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
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$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
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$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
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$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
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$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

AC	U(1) flavor symmetry
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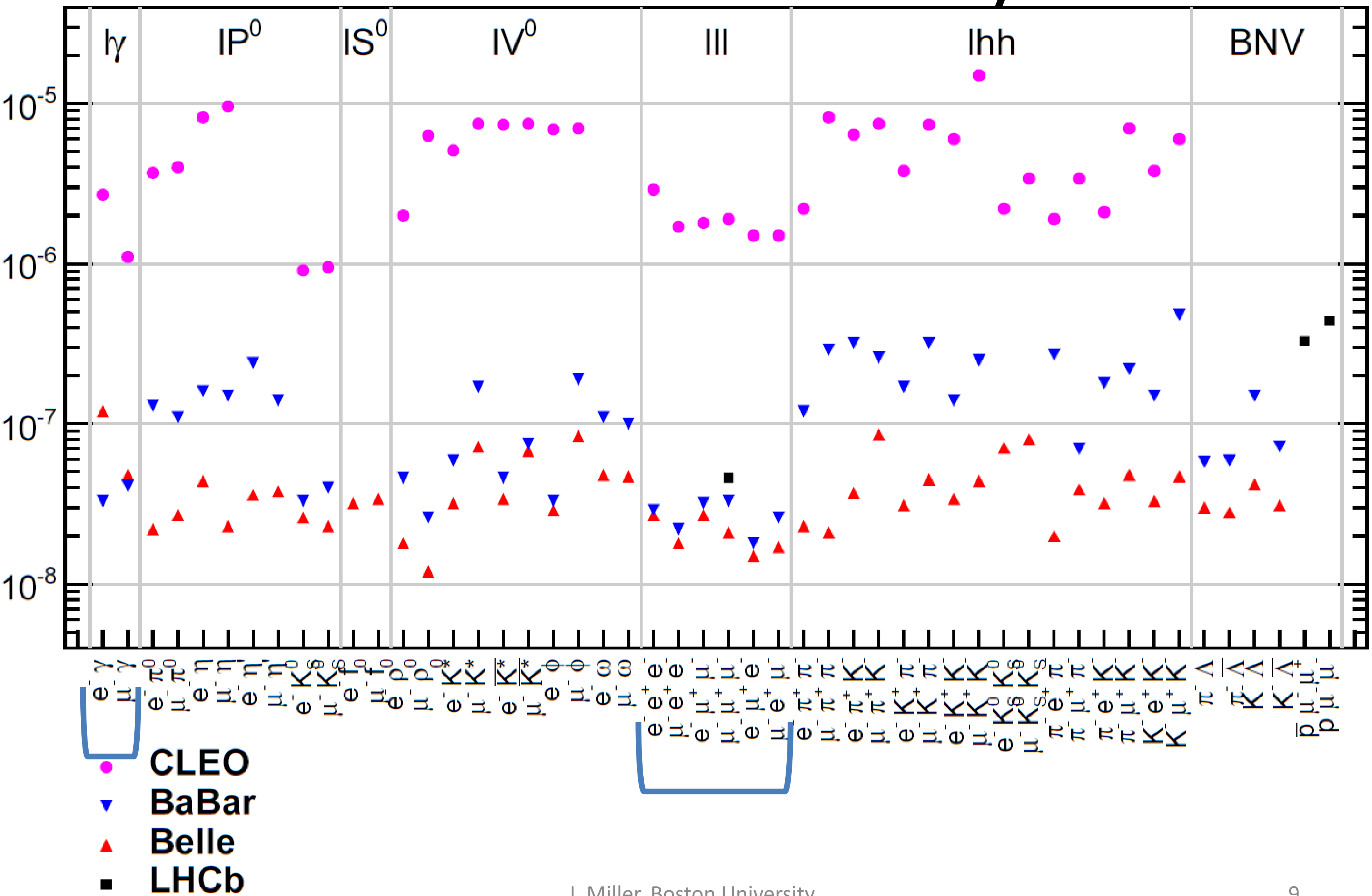
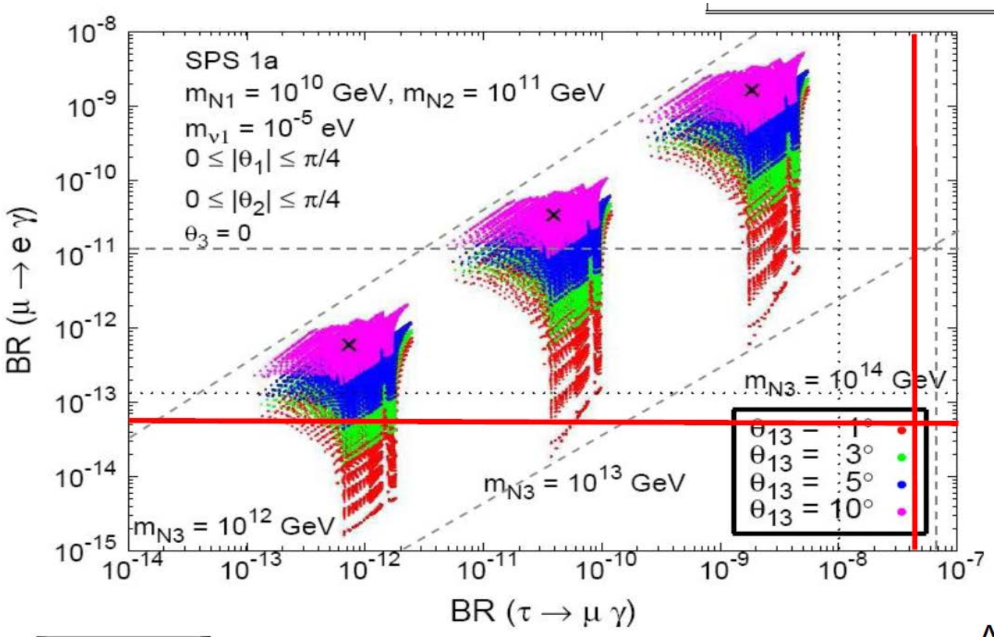
CLFV in tau decays
B-factory collider: ~3 GeV e+ and ~8 GeV e-

Physics process	Cross section (nb)
$\Upsilon(4S) \to B\bar{B}$	1.2
$e^+e^- \to$ continuum	2.8
$\mu^+\mu^-$	0.8
$\tau^+\tau^-$	0.8
Bhabha ($\theta_{\rm lab} \geq 17^\circ$)	44
$\gamma\gamma$ ($\theta_{\rm lab} \geq 17^\circ$)	2.4
2γ processes ^{b}	~ 80
Total	~ 130

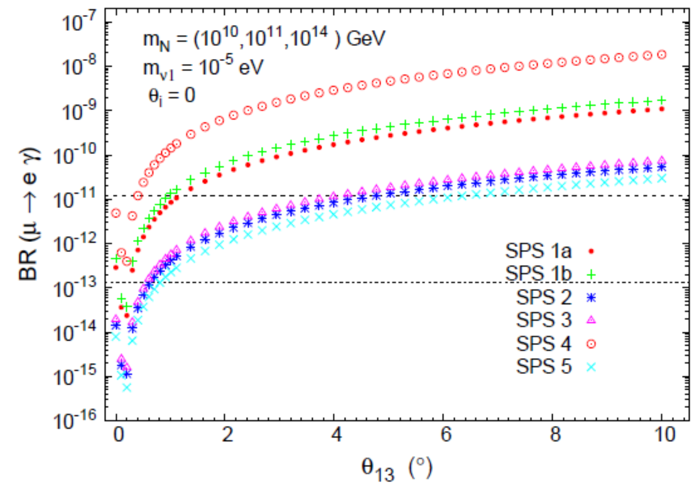
CLFV limits in τ decays



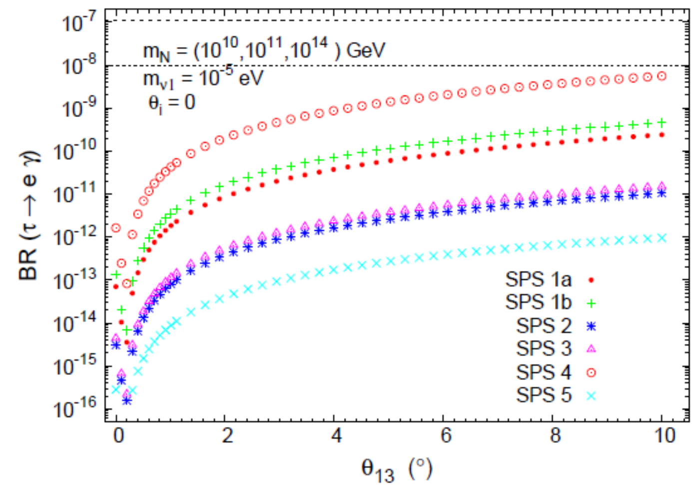
A range of New Physics models predict measurable CLFV



Antusch, Arganda, Herrero, Teixeira, hep-ph/0610439



	$\tau \to 3\mu$	$\tau \to \mu\gamma$	$\tau \to \mu\pi^+\pi^-$	$\tau \to \mu K \bar{K}$	$\tau \to \mu\pi$	$\tau \to \mu\eta^{(\prime)}$
$O^{4\ell}_{S,V}$	✓	–	–	–	–	–
O_D	✓	✓	✓	✓	–	–
O^q_V	–	–	✓ (I=1)	✓(I=0,1)	–	–
O^q_S	–	–	✓ (I=0)	✓(I=0,1)	–	–
O_{GG}	–	–	✓	✓	–	–
O^q_A	–	–	–	–	✓ (I=1)	✓ (I=0)
O^q_P	–	–	–	–	✓ (I=1)	✓ (I=0)
$O_{G\tilde{G}}$	–	–	–	–	–	✓



Celis, Cirigliano, Passemar, PRD89, 013008(2014)

Relative Importance Depends on NP

Ratio of Tau LFV decay BF: discrimination of NP models

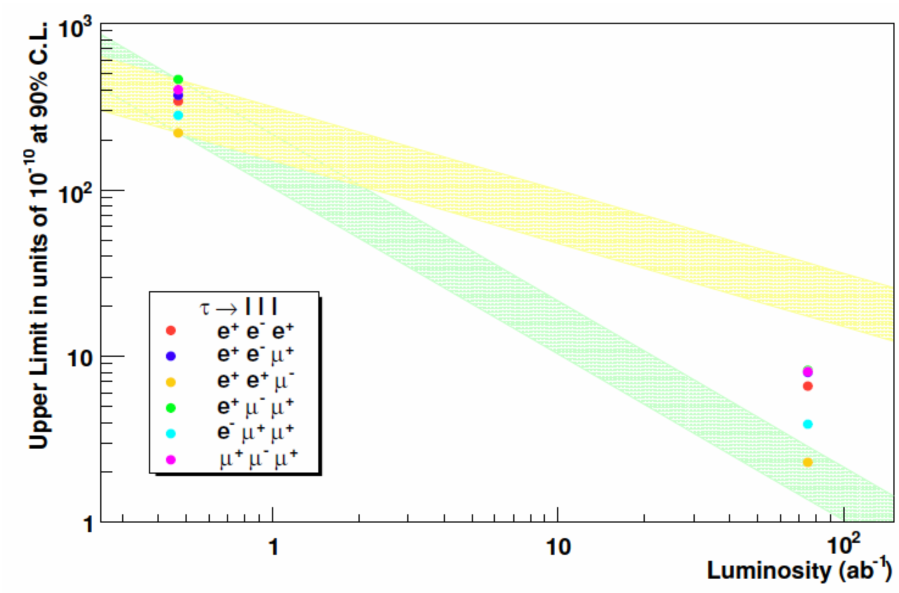
JHEP 0705, 013(2007), PLB54 252 (2002)

	SUSY+GUT (SUSY+Seesaw)	Higgs mediated	Little Higgs	non-universal Z' boson
$\left(\frac{\tau \to \mu\mu\mu}{\tau \to \mu\gamma}\right)$	$\sim 2 \times 10^{-3}$	0.06~0.1	0.4~2.3	~16
$\left(\frac{\tau \to \mu ee}{\tau \to \mu\gamma}\right)$	$\sim 1 \times 10^{-2}$	$\sim 1 \times 10^{-2}$	0.3~1.6	~16
$Br(\tau \to \mu\gamma)$ @Max	$<10^{-7}$	$<10^{-10}$	$<10^{-10}$	$<10^{-9}$

8/22/13 C. Cecchi 4

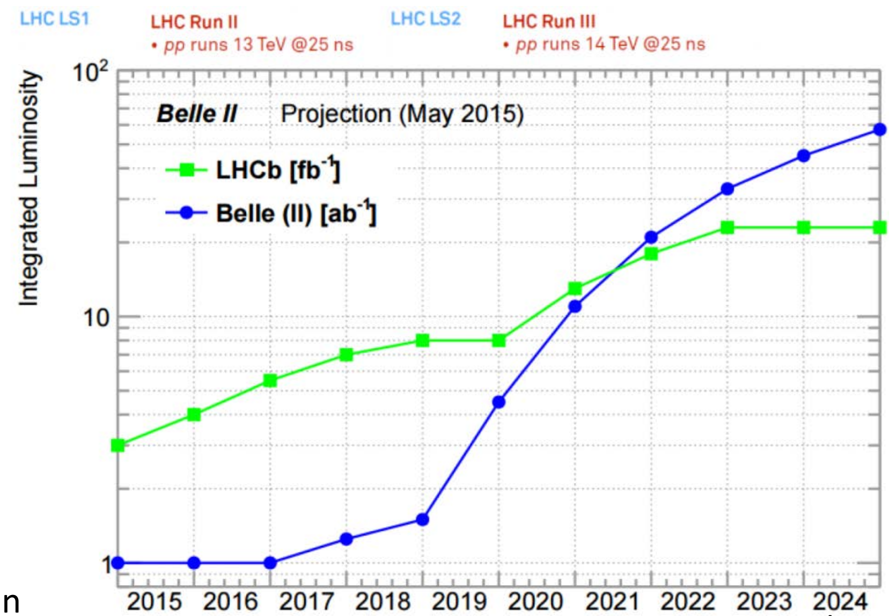
Expected Sensitivity and Luminosity Improvement

- No-background regime improves as $1/\int L\,dt$
- If there are backgrounds, the improvement is $1/\sqrt{\int L\,dt}$



Belle to Belle II

From D. Hitlin

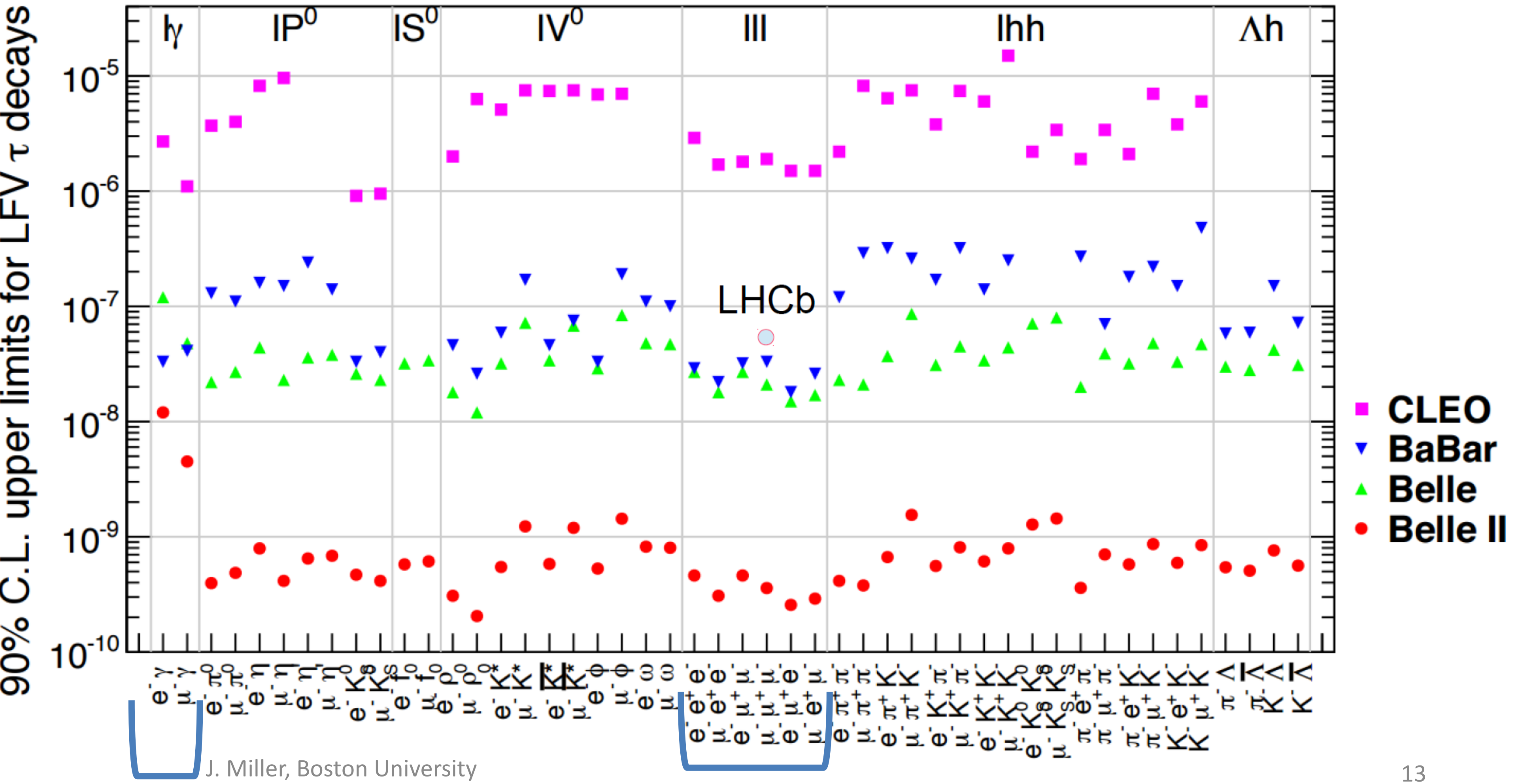


From M. Heck

- Previous: BaBar/Belle ~ 1 ab^{-1}
- Future: Belle II ~ 50 ab^{-1}

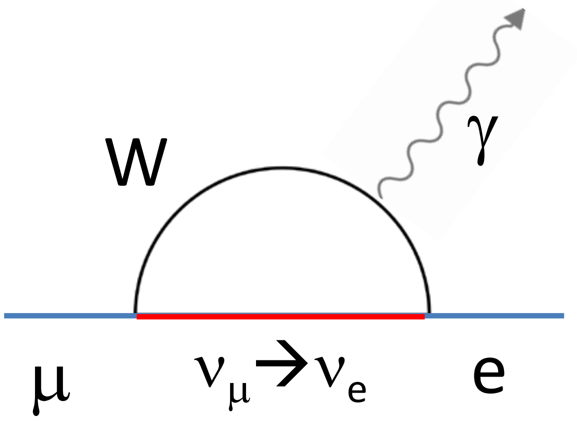
Expected Luminosities Belle II and LHCb

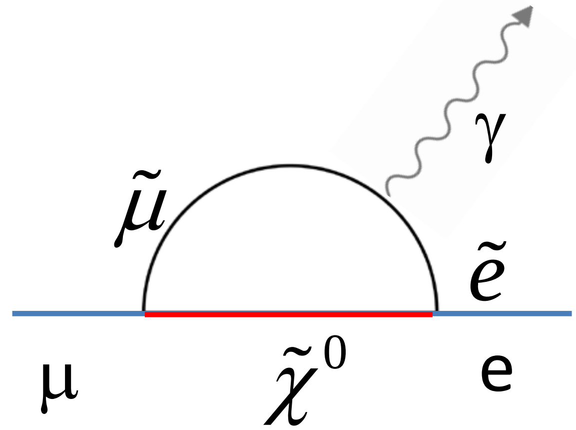
Belle II compared to CLEO, Babar, Belle, LHCb



CLFV in muon decays

CLFV Example: μ→eγ





- SM prediction
- SM + ν oscillation

$$\mathcal{B}(\mu \to e\gamma) = \frac{3\alpha}{32\pi} \sum_i | U^*_{\mu i} U_{ei} \frac{m^2_{\nu i}}{m^2_W} |^2$$

$$< 10^{-50}$$

- Negligible!!!

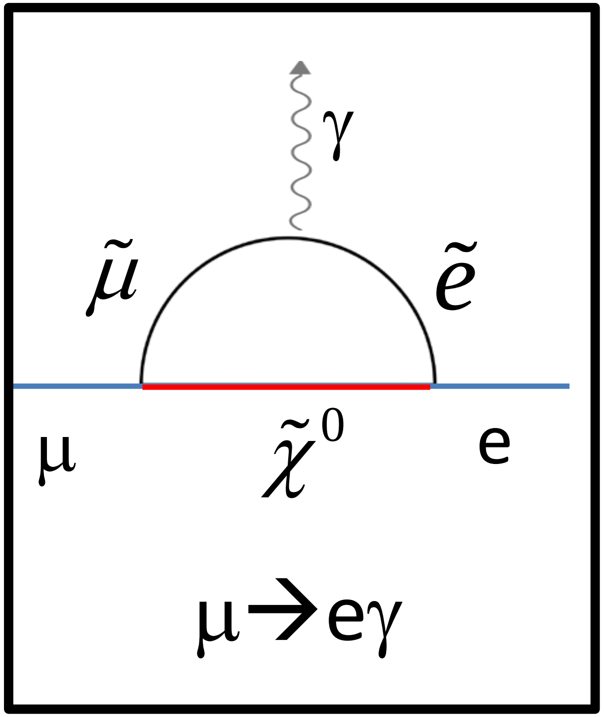
- Beyond SM (e.g. SUSY)

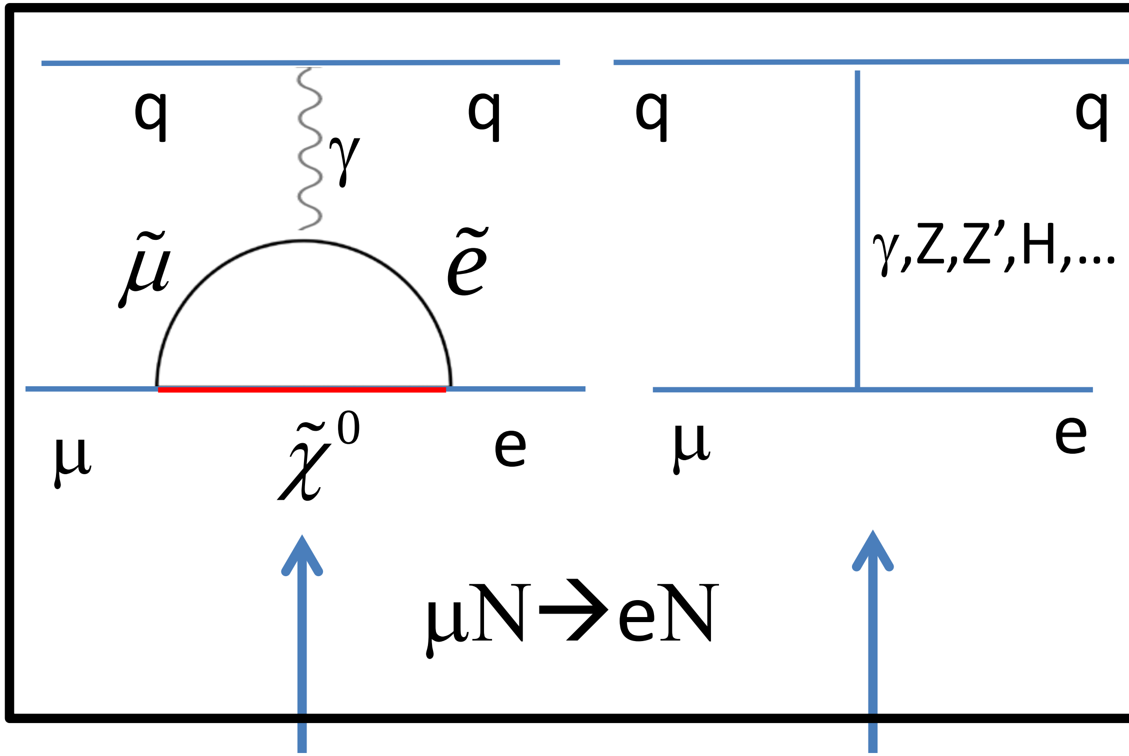
$$\mathcal{B}(\mu \to e\gamma) \simeq 10^{-15} \sim 10^{-12}$$

- Accessible!!!

Experimental detection of CLFV is a clear sign of new physics

μ→eγ and μN→eN are Complementary

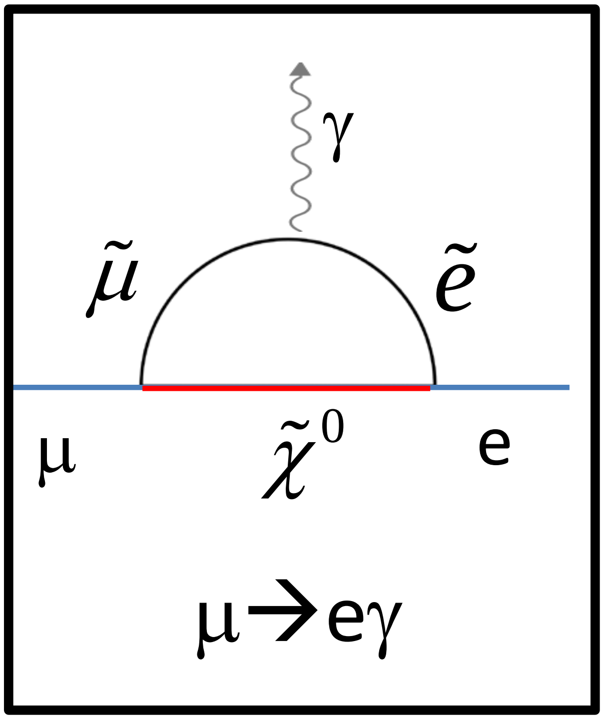


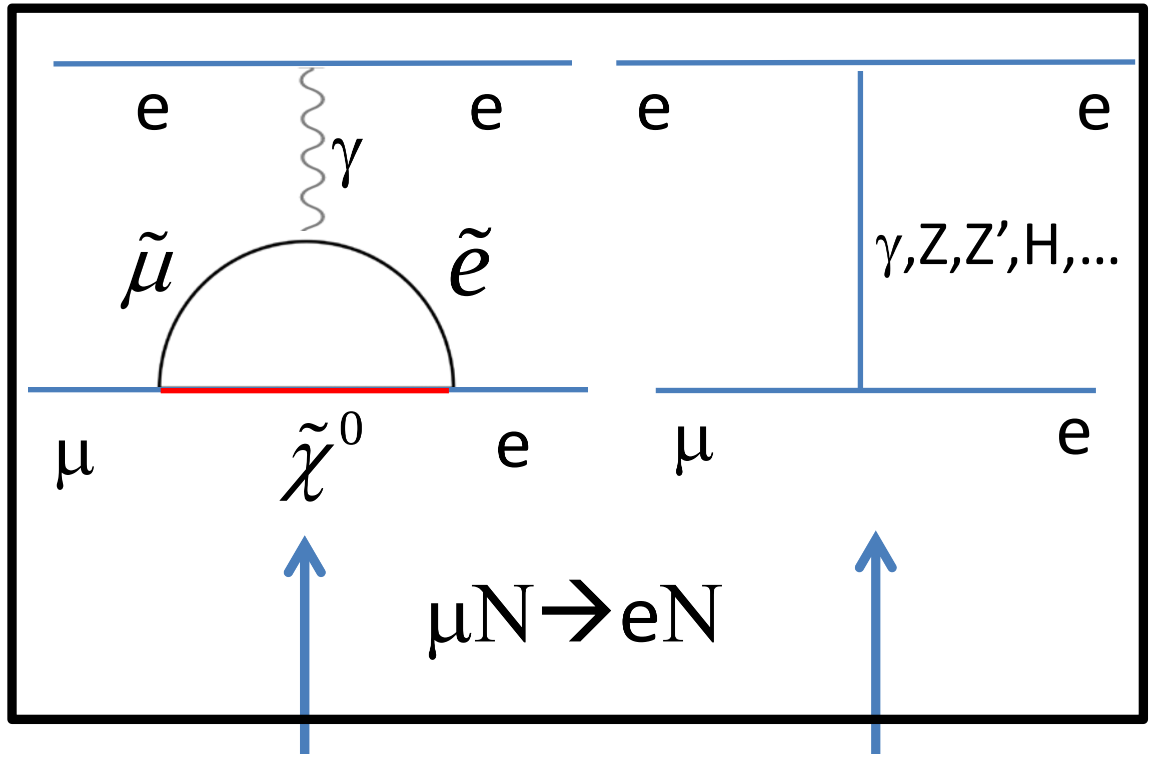


$$\frac{\mathcal{B}(\mu \to e\gamma)}{\mathcal{B}(\mu N \to eN)} \sim O(100)$$

Not accessible to μ→eγ

μ→eγ, μN→eN, and μ→eee are Complementary

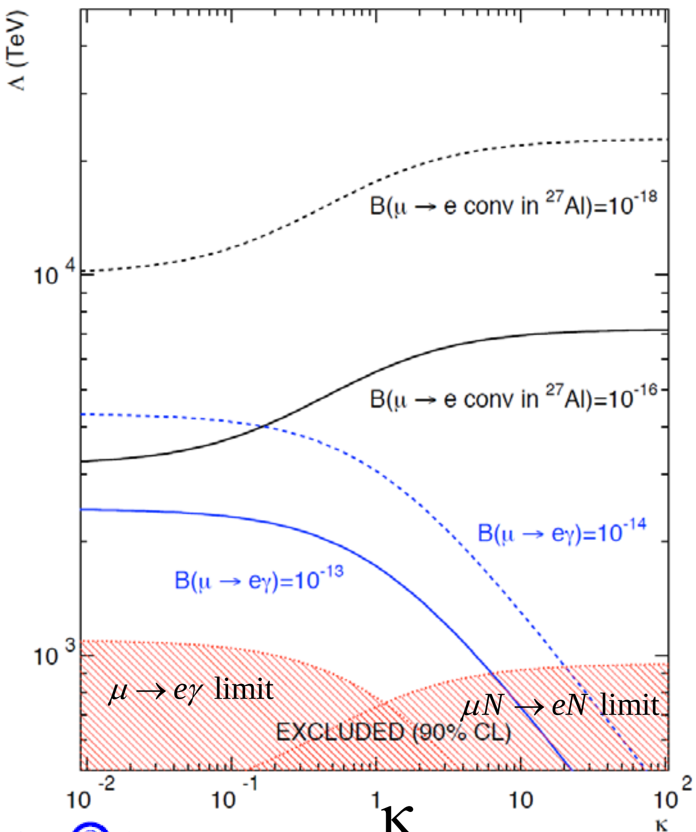


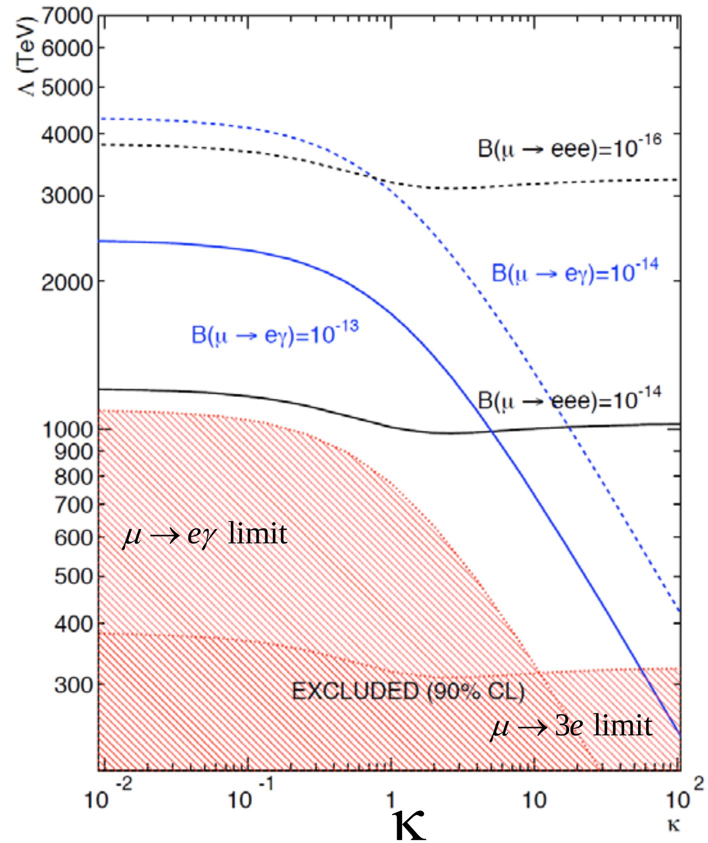


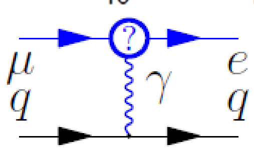
$$\frac{\mathcal{B}(\mu \to e\gamma)}{\mathcal{B}(\mu \to eeeN)} \sim O(100)$$

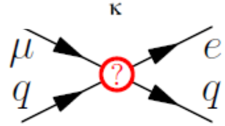
Not accessible to μ→eγ

μ→eγ, μ→eee, μN→eN have different sensitivities to new physics









$$L_{CLFV} = \frac{m_\mu}{(1+\kappa)\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + \frac{\kappa}{(1+\kappa)\Lambda^2}\bar{\mu}_L\gamma_\mu e_L(\bar{e}\gamma^\mu e)$$

$$L_{CLFV} = \frac{m_\mu}{(1+\kappa)\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + \frac{\kappa}{(1+\kappa)\Lambda^2}\bar{\mu}_L\gamma_\mu e_L(\bar{\mathrm{u}}_L\gamma^\mu \mathrm{u}_L + \bar{\mathrm{d}}_L\gamma^\mu \mathrm{d}_L)$$

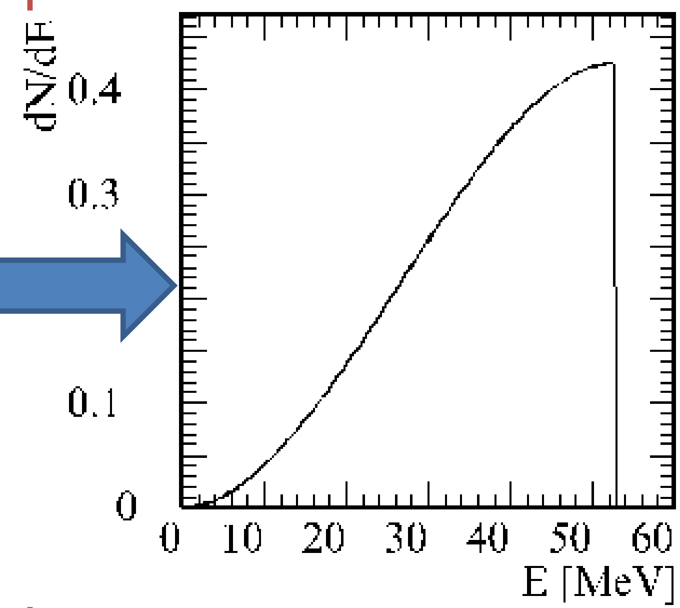
From Ramsey-Musolf and Vogel

Experimental Aspects of μ→eγ

- Stop *positive* muons in a thin target
- Look for back-to-back gamma and electron, each 53 MeV
- Regular muon decay, $\mu^+ \rightarrow e^+ \nu_e \overline{\nu}_\mu$,

produces lots of positron background near 53 MeV

- Also gamma background from $\mu^+ \rightarrow e^+ \nu_e \overline{\nu}_\mu \gamma$, and e+ or e-conversions
  - lead to accidental coincidences that currently limit ultimate rates and achievable sensitivity: MEG upgrade may be at limit
- Accidental Bkg→ Use a continuous beam



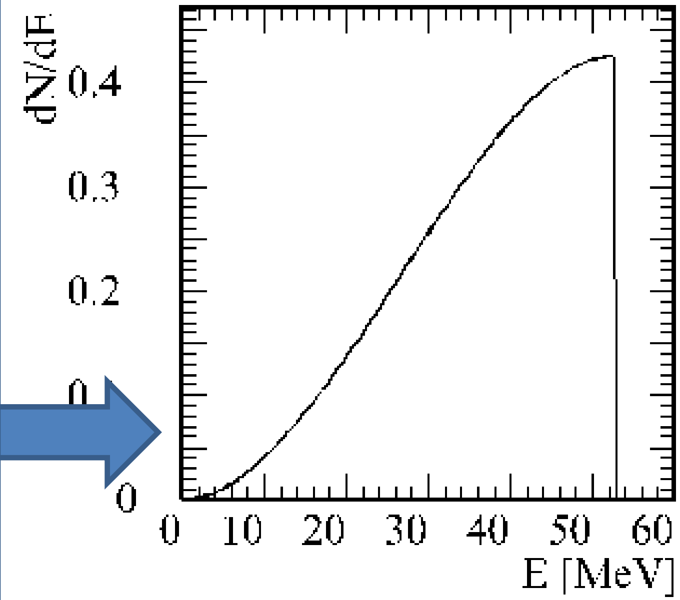
Positron spectrum
From μ→eνν

Experimental Aspects of μ→eee

- Stop *positive* muons in a thin target
- Muon at rest gives 3-body decay: Look for $m_{\mu}c^2$ MeV and Σp_i in three electrons/positrons emanating from a common point
- Regular muon decay, $\mu^+ \rightarrow e^+ \nu_e \overline{\nu}_\mu$,

and radiative decay, produce lots of background e^+, γ below 53 MeV

- These lead to accidental coincidence backgrounds, believed to limit ultimate rates and achievable sensitivity
- Accidentals→Use continuous beam



Positron spectrum
From μ→eνν

Experimental Aspects of Muon to Electron Conversion, μN→eN

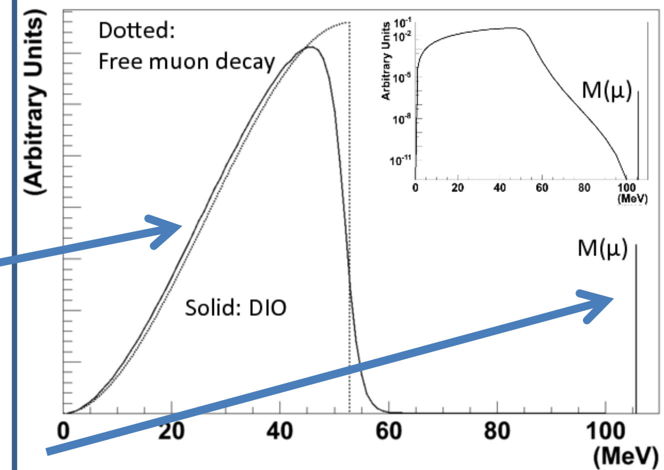
- Stop *negative* muons in a thin target,

where they quickly form 1S muonic atoms

- Look for 105 MeV electron (case of Al)
- Regular muon decay, $\mu^- N \to e^- \nu_\mu \bar{\nu}_e N$

produces lots of electrons below 53 MeV

- Signal electron energy way above most of the background. Allows >> data rates compared to μ→eγ



Electron spectrum from μN→eννN

→ Substantial experimental advantage for μN→eN

- Decay electron energies do go all the way up to 105 MeV(rarely)-
- Still a background- but rate fortunately falls very fast near

endpoint: can control with good electron energy resolution

Experimental Aspects of Muon to Electron Conversion, μN→eN (2)

- In muonic atom, three main reactions (example Aluminum):

(1) Capture (61%): $\mu^- + {}^{27}_{13}Al \rightarrow {}^{A}_{Z}X + \nu_\mu + an + bp + c\gamma,\ a \approx 1,\ b \approx 0.1,\ c \approx 2$

(2) Decay: (39%): $\mu^- + {}^{27}_{13}Al \rightarrow {}^{27}_{13}Al + e^- + \overline{\nu}_e + \nu_\mu$

(3) Conversion: ($<10^{-13}$) $\mu^- + {}^{27}_{13}Al \rightarrow {}^{27}_{13}Al + e^-$

- Historically the 'BR' is defined by ⇒ $R_{\mu e} = \dfrac{\Gamma(\mu N \rightarrow eN)}{\Gamma(\mu N \rightarrow \text{capture})}$
- Most severe backgrounds(leading to electrons>100 MeV) (pions, electrons) are prompt relative to the proton production, and disappear early
- Use a pulsed beam, wait for prompt backgrounds to subside before data collection.

Experimental Aspects of Muon to Electron Conversion, $\mu N \rightarrow eN$ (3)

- Major noise (low energy) backgrounds in detectors come from low energy n, p emitted when muon captures on the aluminum nucleus.
- AlCap: Joint effort of COMET and Mu2e at PSI
  - Ongoing measurements, just had June run, next run in November
  - Measure p, n, gamma spectra from candidate Mu2e/COMET targets and support materials (Al, Si, Ti, SS,….)
  - Invaluable for design of shielding and for rate studies

MEG: μ→eγ at PSI

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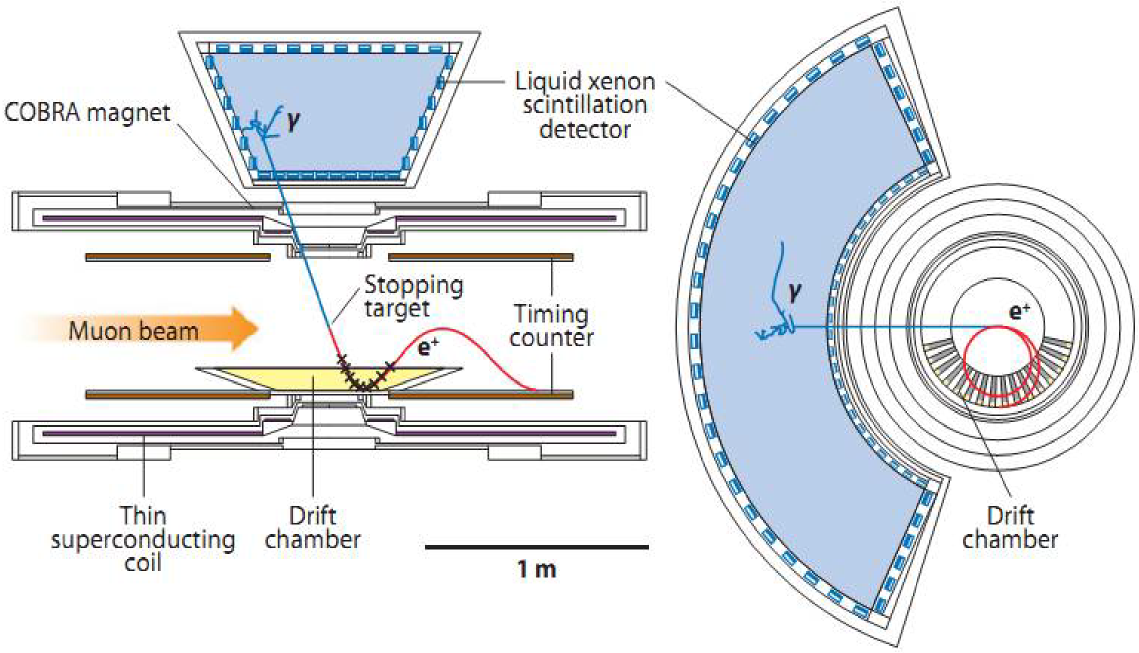
PSI



- PSI piE5 beam line 29 MeV/c
- 3×10^7/s stopped μ^+ in a 205 μm polyethylene target
- e^+ detection: solenoidal magnetic spectrometer w/drift chambers for momentum, plastic scintillators for timing
- γ detection: Liquid xenon based on scintillation light
  - Fast
  - High LY ~0.8*NaI
  - Short X_0 2.77 cm

Summary of MEG Results

- Latest result, 2009-2011 data sets

$$\mathcal{B}(\mu^+ \to e^+\gamma) < 5.7 \times 10^{-13} \text{ (90\% CL)}$$

Phy. Rev. Lett. 110, 201801 (2013)

- X4 Better than previous best upper limit from MEG 2009-2010 data :

$$\mathcal{B}(\mu^+ \to e^+\gamma) < 2.4 \times 10^{-12} \text{ (90\% CL)}$$

- X20 better than MEGA experiment result

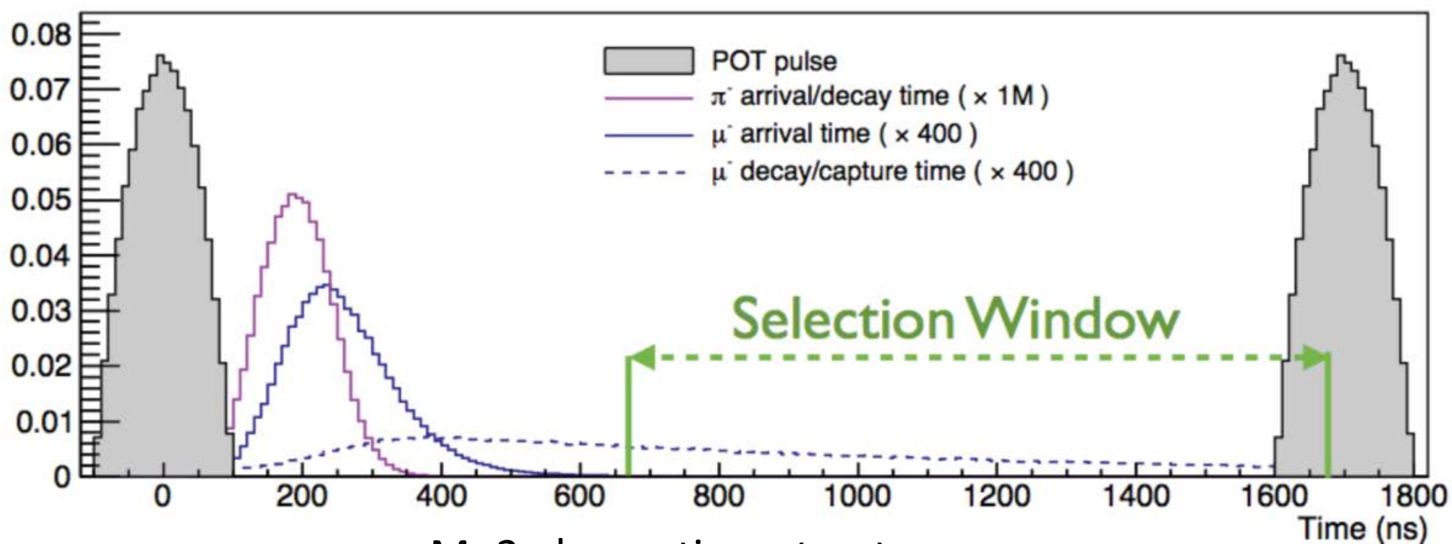
$$\mathcal{B}(\mu^+ \to e^+\gamma) < 1.2 \times 10^{-11} \text{ (90\% CL)}$$

MEG Future

- MEG is now in a major upgrade mode
- Goal: ~few x 10^{-14}
- Improve the terms in $B_{acc} \approx R_{\mu} \Delta E_e \Delta E_{\gamma}^2 \Delta \theta^2 \Delta t$
  - Replace e+ tracker reducing radiation length and improving resolution
  - Improve timing counter granularity
  - Extend γ-ray detector acceptance and resolution, granularity for shallow events
  - ….
- Increase stopping rate in target and data throughput
- Engineering run 2015
- Data runs 2016-2018

Muon Conversion, $\mu N \rightarrow eN$: Mu2e and COMET

- Mu2e @ Fermilab and COMET@JPARC have similar approaches
- Both Experiments are based partly on beam solenoid concepts from MELC proposal R.M. Dzhilkibaev, V.M. Lobashev, Sov.J.Nucl.Phys 49, 384 (1989)
- Goals: $R_{\mu e}<6\times10^{-17}$ which is x10000 improvement over current
- Pulsed beams and new high intensity muon beam lines are key

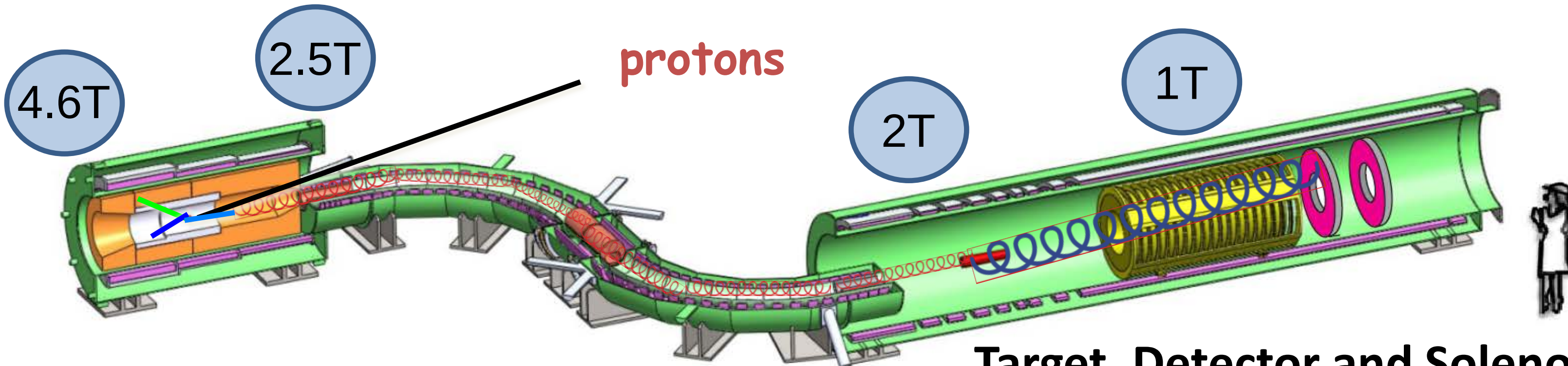


Mu2e beam time structure

Mu2e Overview

Production Target / Solenoid (PS)

- Proton beam strikes target, producing pions which decay to muons
- Graded magnetic field contains backwards pions/muons and reflects slow forward pions/muons



Target, Detector and Solenoid (DS)-

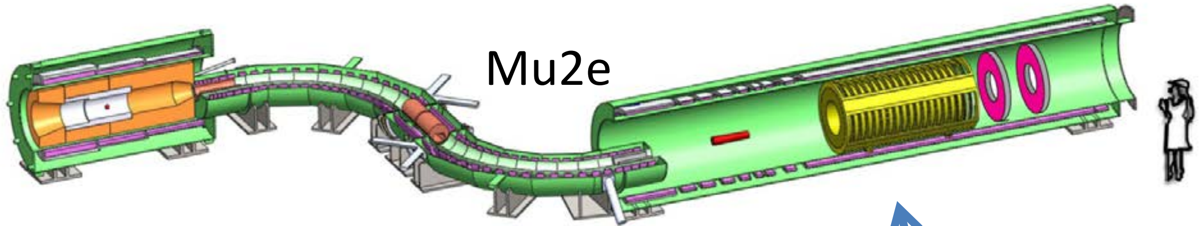
- Capture muons on Al target
- Measure momentum in tracker and energy in calorimeter

Transport Solenoid (TS)

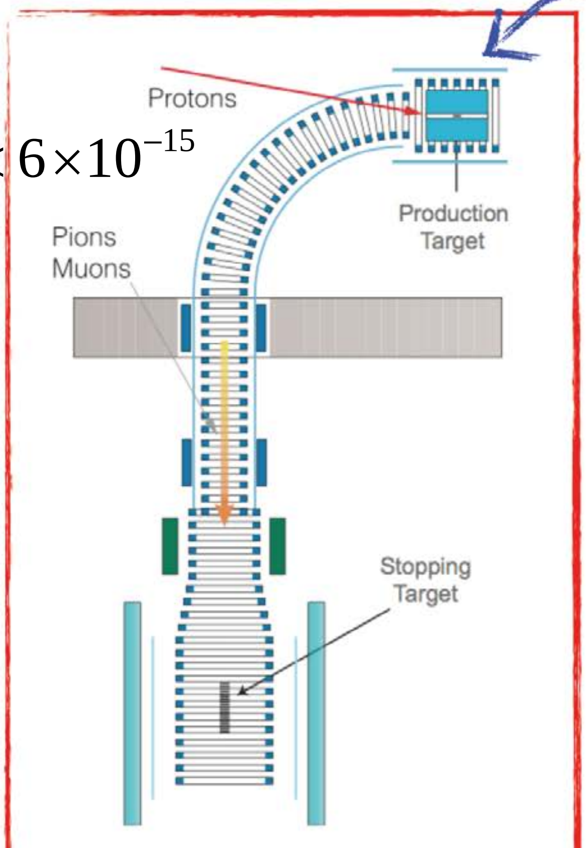
Selects low momentum, negative muons; Eliminates straight-line path for neutrals between target and detectors

Delivers ~0.002 stopped muons per 8 GeV proton and ~10^{10} Hz stopped μ

Muon Conversion, μN→eN: COMET

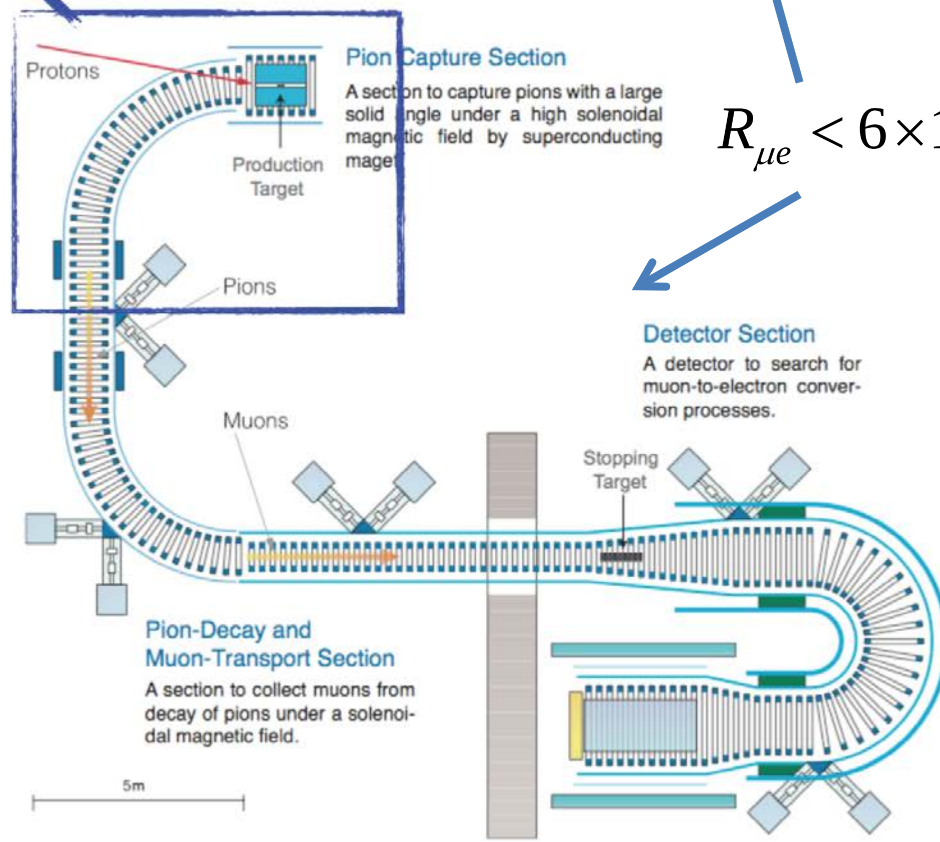


$R_{\mu e} < 6\times10^{-15}$



(phase-I)

$R_{\mu e} < 6\times10^{-17}$



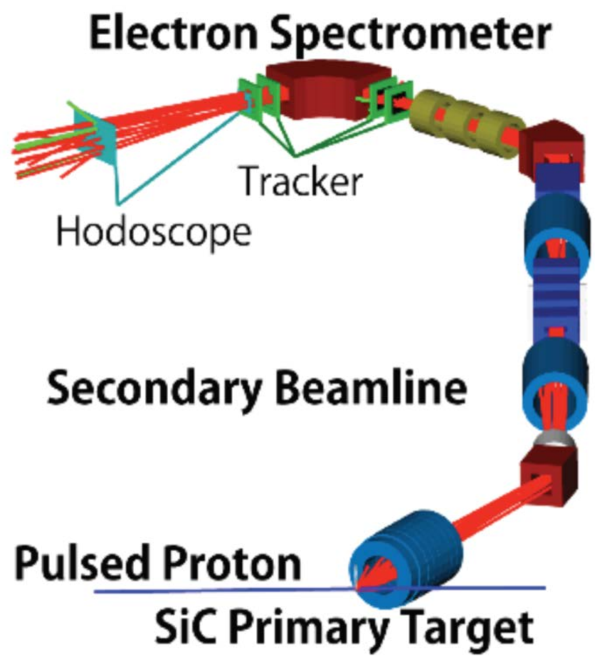
full COMET (phase-II)

Mu2e and COMET Schedules

- Mu2e
  - Building foundation poured, superconducting wire acquired, TS coil packs tested
  - Preliminary magnet designs completed by Fermilab; PS and DS designs now being completed in industry
  - Simulations and detector development in advanced state
  - CD3: funds for remainder of project expected early 2016
  - Begin data collection late 2020
- COMET
  - Building complete
  - Phase I 2018 or 2019 depending on budget
  - Phase II 2020+ depending on Phase I schedule

Conversion Experiment #3: DeeMe

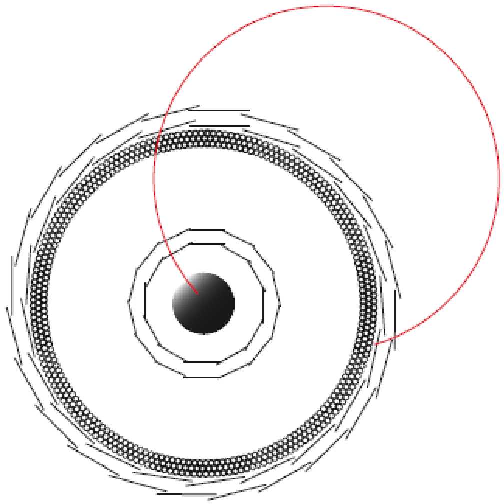
- 1 MW, 3 GeV pulsed proton beam at J-PARC/RCS
- Expect 2×10^{-14} sensitivity for $\mu N \rightarrow eN$ (compare 6×10^{-15} for COMET Phase I)
- One target, graphite or SiC, for both Production and conversion
- Expect to begin data-taking next year

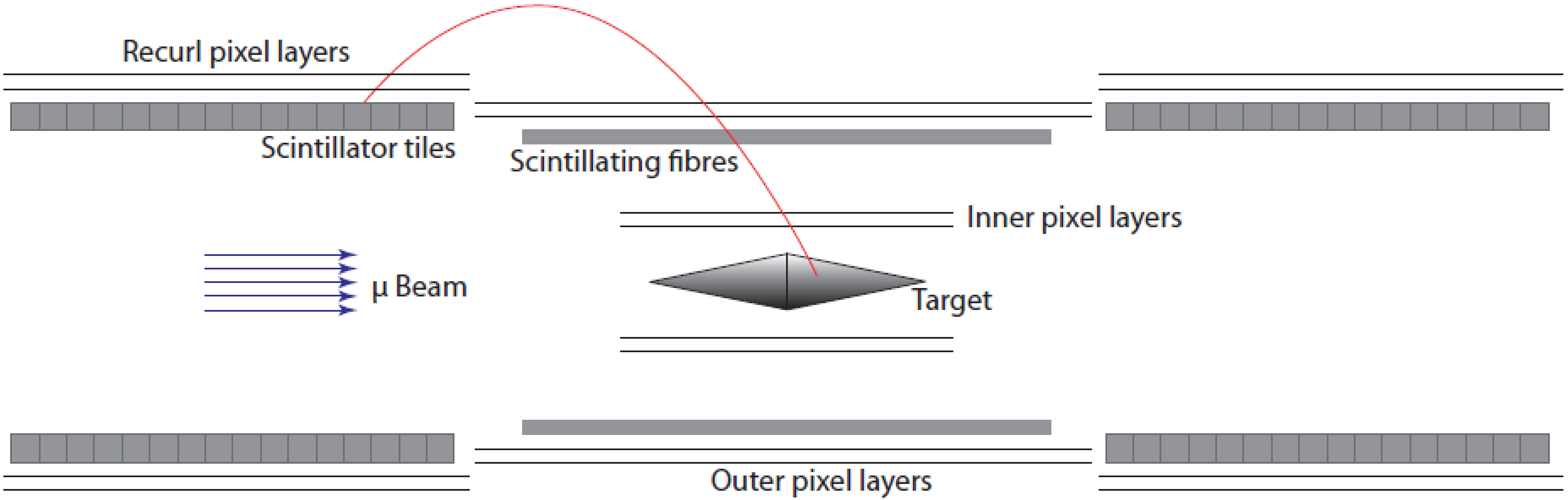


$p \rightarrow \pi \rightarrow \mu \rightarrow e$

Mu3e at PSI

- Search for $\mu^+ \rightarrow e^+e^+e^-$
  - Phase I- 10^{-15} sensitivity (reminder: currently $<10^{-12}$)
    - 2017 data taking up to few x 10^8 μ/s
  - Phase II- 10^{-16} sensitivity (needs new beam line)
    - 2019 Construction of new beam line
    - 2019 + data taking up to 2×10^9 μ/s
- Double-cone target
- Ultra-thin pixelated silicon detectors
- Scintillating fibers for timing





LHC: Recent H→μτ Data

- CMS: $\mathfrak{B}(H \to \mu\tau) = (0.84^{+0.39}_{-0.37})\%$ and $\mathfrak{B}(H \to \mu\tau) < 1.51\% (95\%\ \text{CL})$

  arXiv:1502.07400
- ATLAS: $\mathfrak{B}(H \to \mu\tau) = (0.77 \pm 0.62)\%$ and $\mathfrak{B}(H \to \mu\tau) < 1.85\% (95\%\ \text{CL})$

  arXiv:1508.03372

Note:

$$\mathfrak{B}(\mu \to e\gamma) < 10^{-12} \;\Rightarrow\; \mathfrak{B}(H \to \mu e) < \text{O}(10^{-8})$$

$$\mathfrak{B}(\tau \to \mu\gamma), \mathfrak{B}(\tau \to e\gamma),\ \text{e}, \mu\ \text{EDM's, (g-2)}_{e,\mu} \;\Rightarrow\; \mathfrak{B}(H \to \mu\tau) < \text{O}(10\%)$$

Summary

- Any detection of CLFV is a sign of new physics
- Active worldwide experimental program in muon and tau LFV, now and in the future
  - MEG (PSI) improved $\mu \rightarrow e\gamma$ limit by x20: $<5.7\text{x}10^{-13}$@90%CL
  - MEG upgrade down to $<6\text{x}10^{-14}$@90%CL
  - Muon to electron conversion, $\mu N \rightarrow eN$
    - Current limit best limit on $\mu Au \rightarrow eAu$ $<7\text{x}10^{-13}$ (SINDRUM II, PSI)
    - Mu2e plans to improve limit by x10000 to $<6\text{x}10^{-17}$ FNAL
      - » Major consideration in Fermilab upgrades, x10
    - COMET I $<7\text{x}10^{-15}$, COMET II $<6\text{x}10^{-17}$
    - DeeMe $<10^{-14}$
  - $\mu \rightarrow eee$, current limit $<1\text{x}10^{-12}$
    - Mu3e being developed at PSI, Phase I $<1\text{x}10^{-15}$, Phase II $<1\text{x}10^{-16}$
  - Babar, Belle achieved ~10^{-8} BR limits on a broad range of tau decay channels with ~ 1 ab $^{-1}$ data. LHCb is also a significant contributor.
    - Belle II plans ~ 50 ab $^{-1}$ data, 3 lepton tau decay channels especially promising
  - ATLAS, CMS will do direct searches in selected channels , LHCb can competitive tau decay data.

END

LHC: Z→μe Data

ATLAS: $\mathfrak{B}(Z \to e\mu) < 7.5\times10^{-7}$

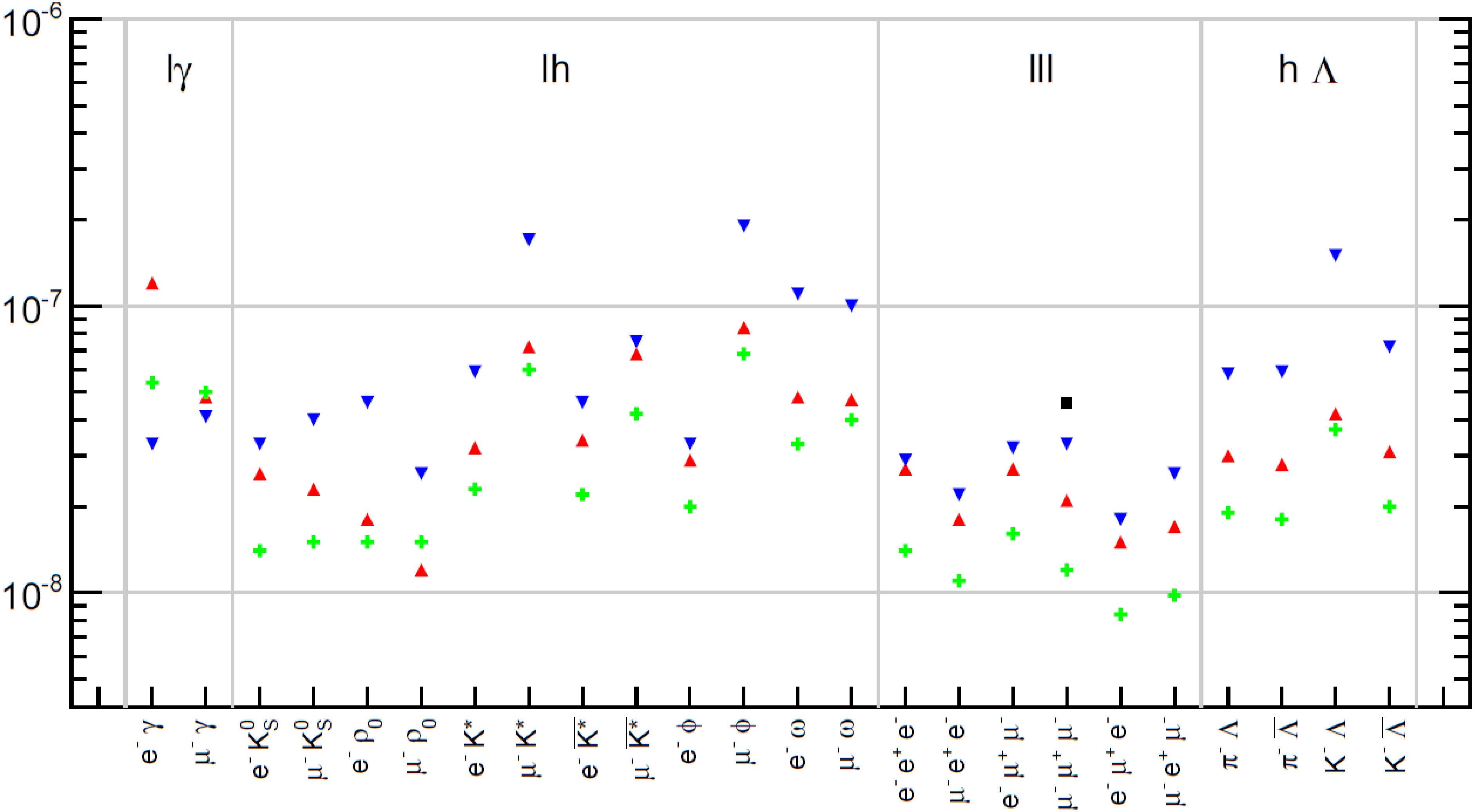
arXiv:1408.5704

Note: $\mathfrak{B}(\mu \to eee) < 10^{-12} \;\Rightarrow\; \mathfrak{B}(Z \to \mu e) < 10^{-12}$

CMS: $\mathfrak{B}(Z \to e\mu) < 7.3\times10^{-7}$

(LEP: $\mathfrak{B}(Z \to e\mu) < 1.6\times10^{-6}$)

Summary from Heavy Flavor Averaging Group

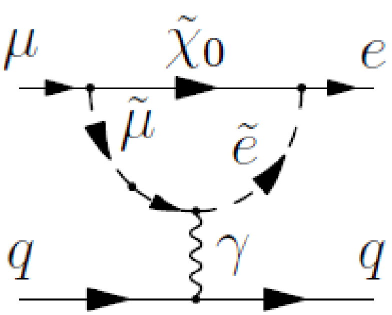


HFAG 2014 sets preliminary combined 90% CL upper limits using PDG method

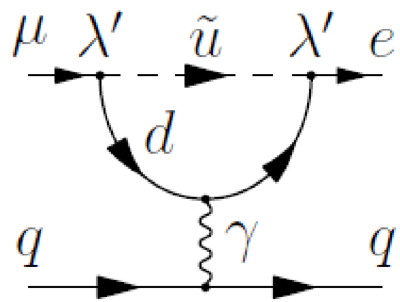
1412.7515

μN→eN can measure

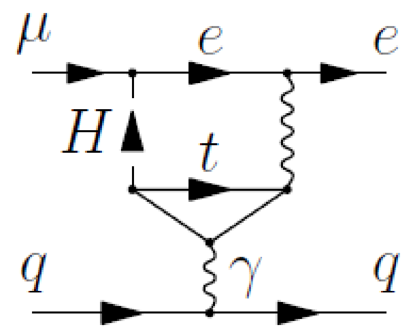
SUSY



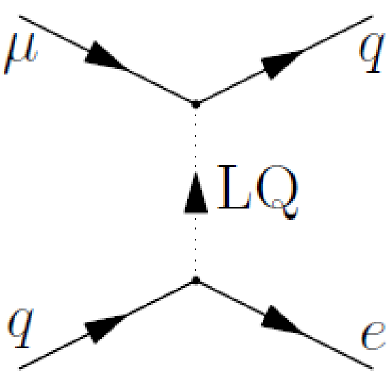
RPV SUSY



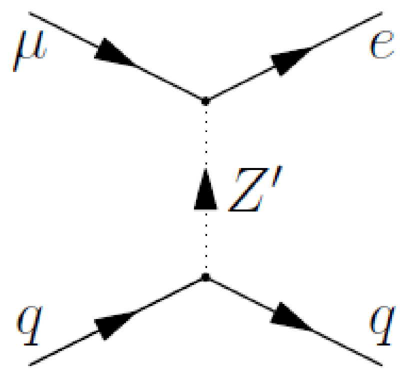
Second Higgs doublet



Leptoquarks



Z'/anomalous couplings



Extra dimensions, etc.

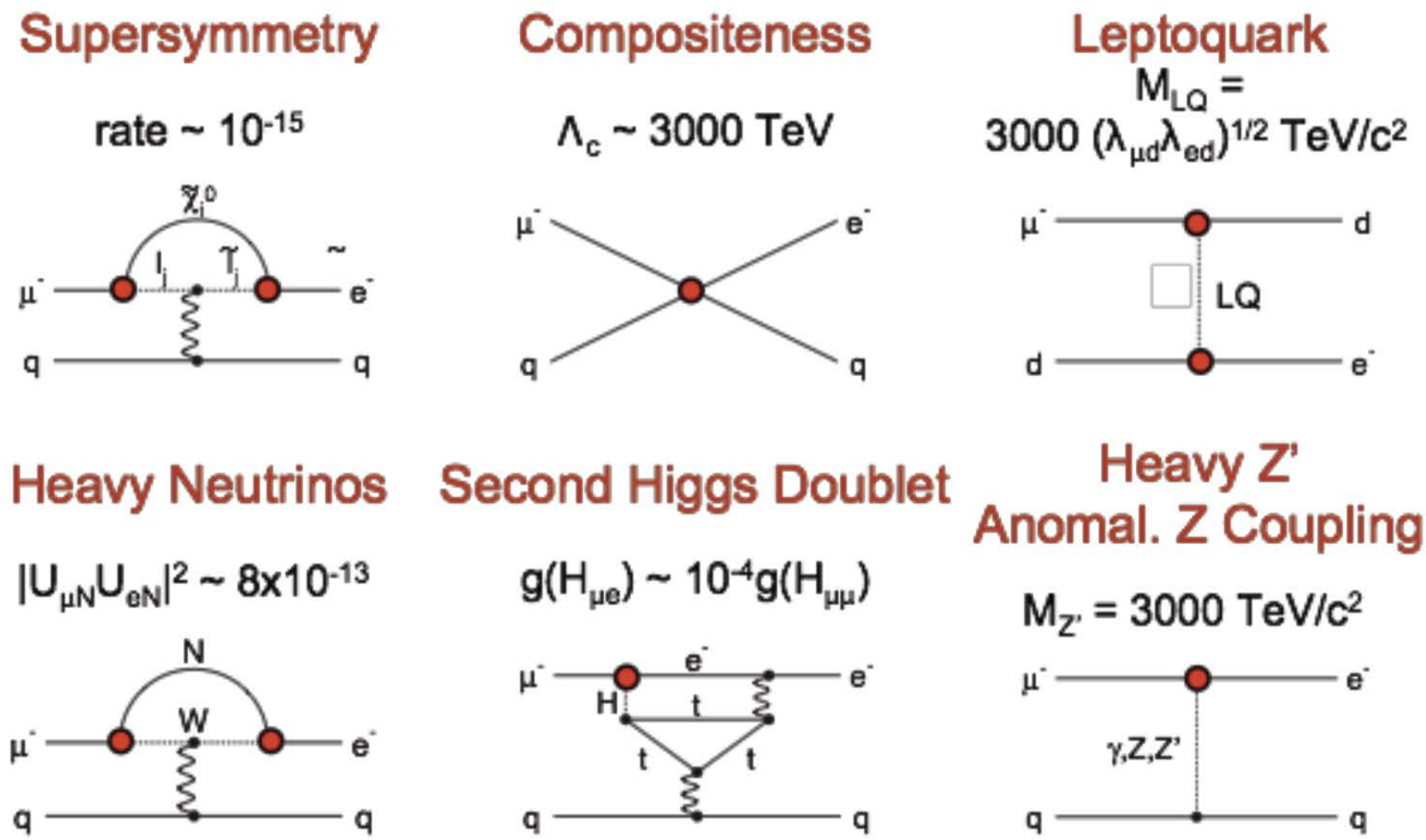
Theory reviews:

Y. Kuno, Y. Okada, 2001

M. Raidal *et al.*, 2008

A. deGouvea, P. Vogel, 2013

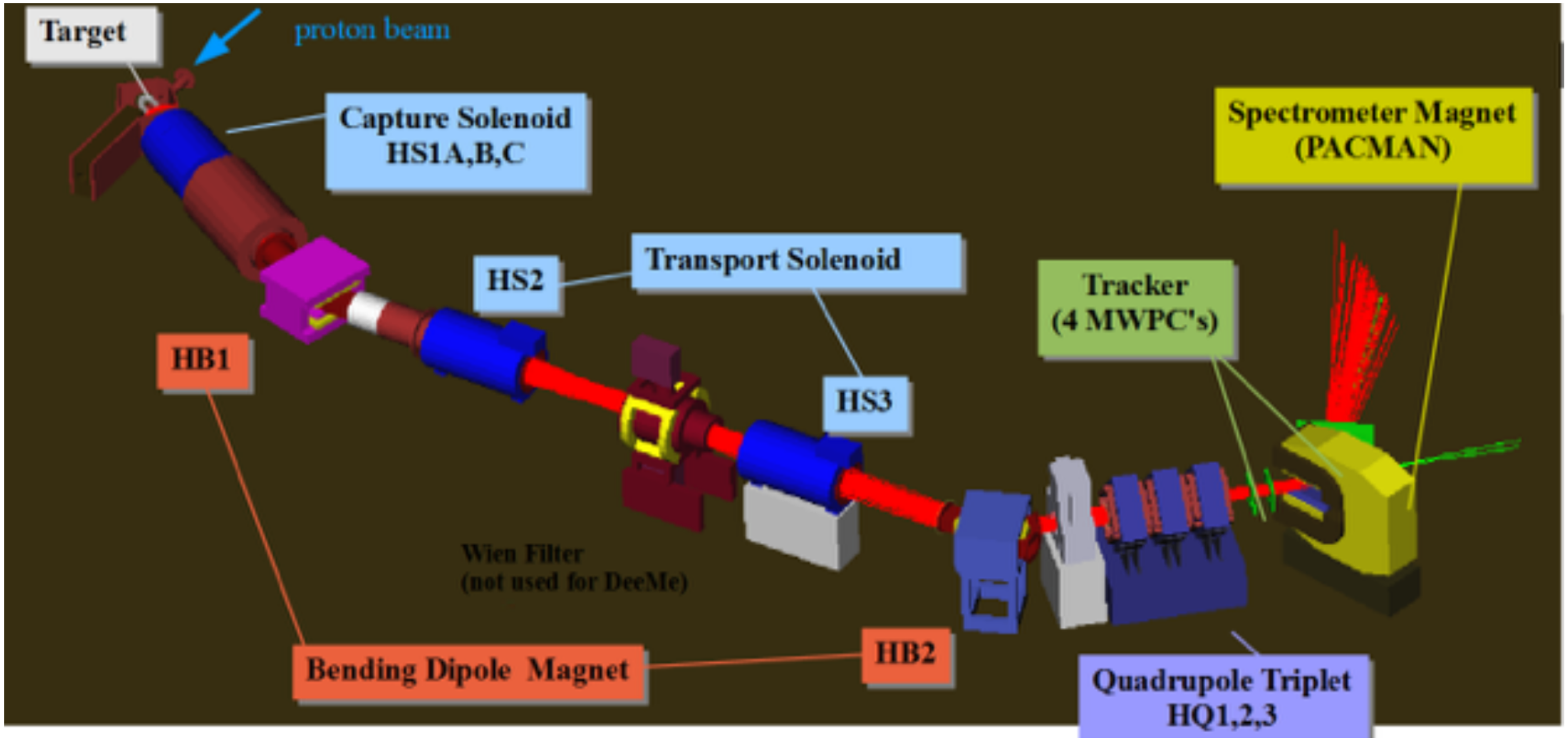
Sample diagrams: μ-e conversion



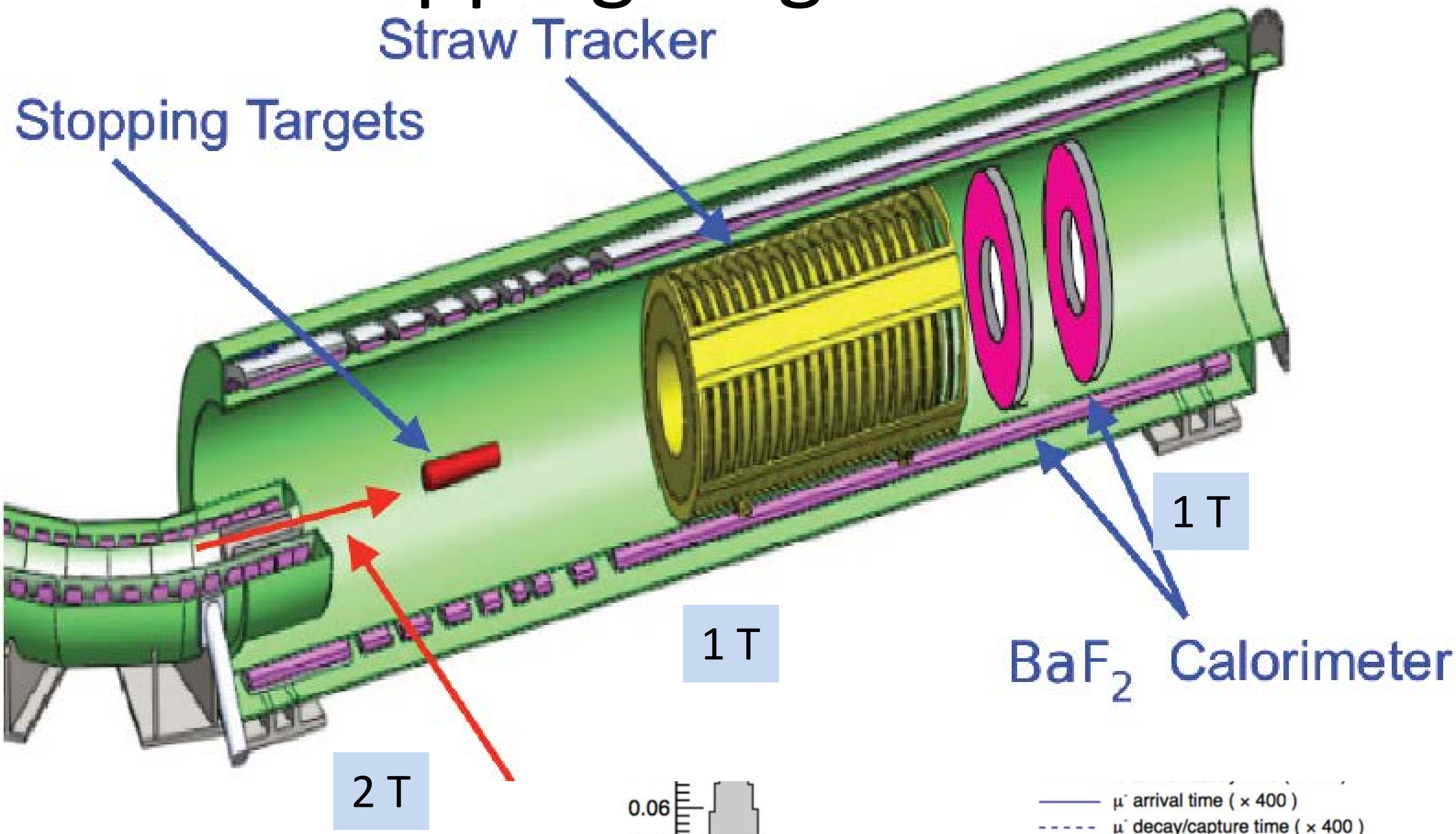
DeeMe Project

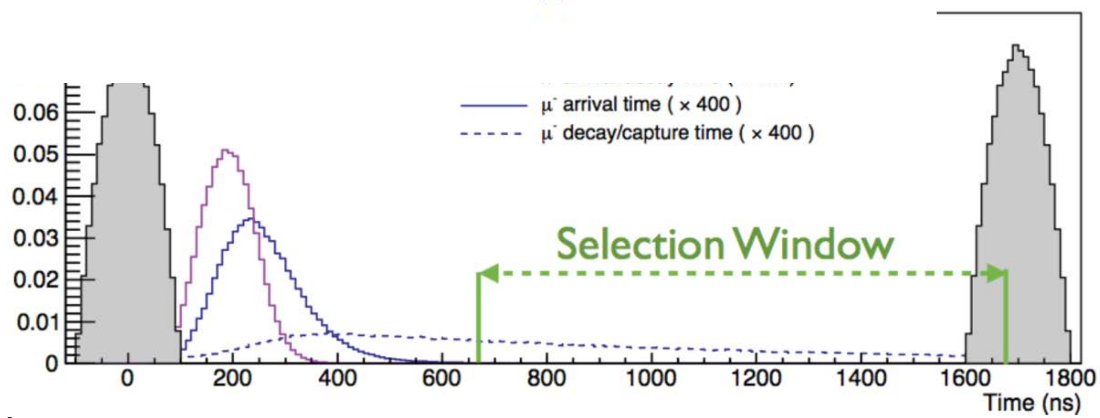
- High-Power High-Purity Pulsed Proton from J-PARC RCS
- Start with Graphite Target
  - Upgrade to a SiC Target
- Large-Acceptance Beam line (H-Line)
- State-of-the-Art HV-Switching MWPC
- Single Event Sensitivity
  - 1×10^{-13} (Graphite, 2×10^{7}sec)
  - 2×10^{-14}(SiC)、 5×10^{-15}(8×10^{7}sec)

- Schedule
  - Stage-2 Approved from Muon PAC IMSS
  - Grant-in-Aid for detector construction
    - detector completed in 2015
  - H-Line under construction
    - upstream-half completed
    - beamline shield under a bid
    - downstream at 2016 summer
  - Aiming to start in 2016.



Mu2e Stopping Target and Detectors

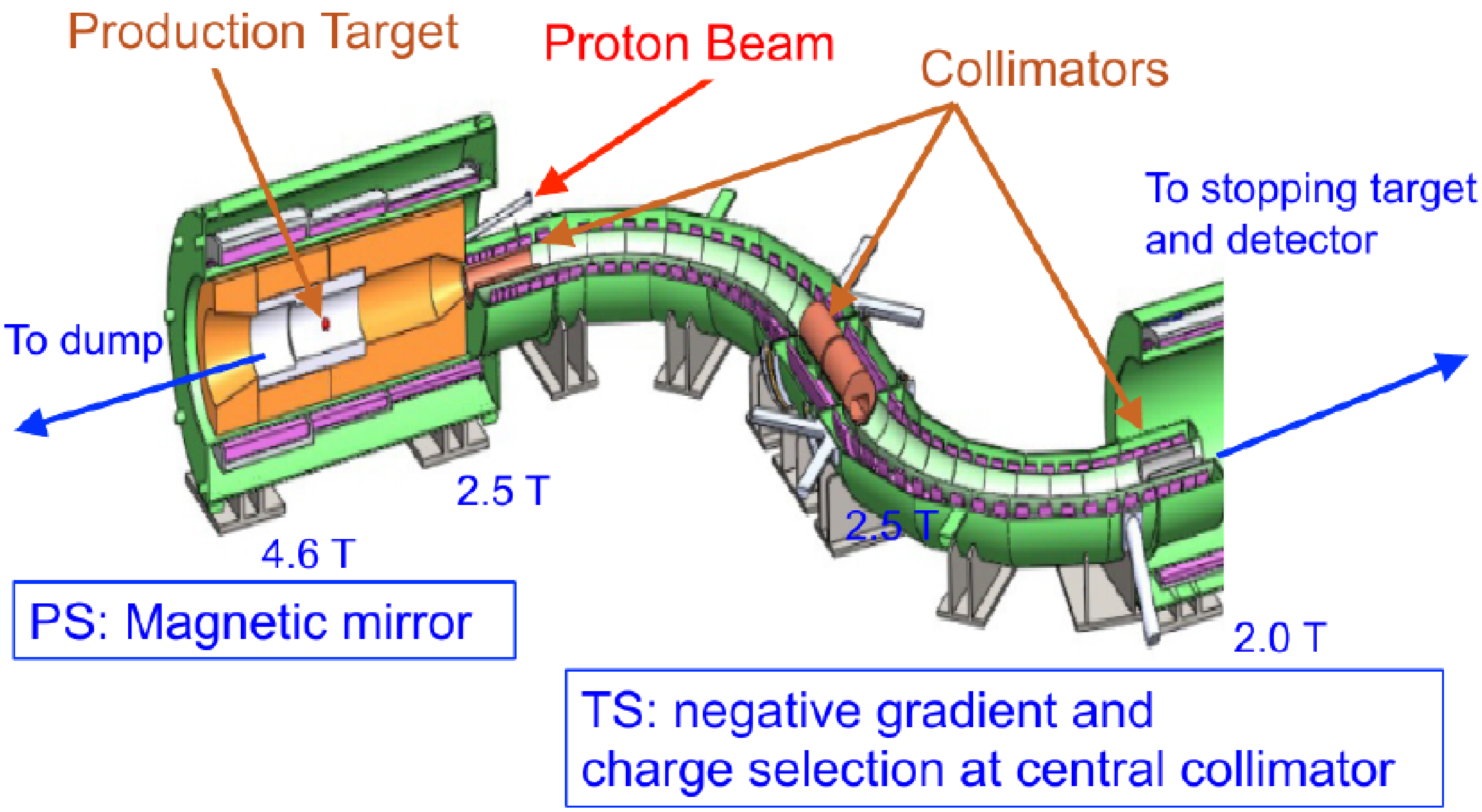




- ~10^{10} /s stopped muons
- 0.002 stopped muons/proton
- Decay electrons <53 MeV miss detectors

Muon Conversion, μN→eN: Mu2e and COMET

- Mu2e @ Fermilab (COMET@JPARC has similar approach)
- Both Experiments are based partly on beam solenoid concepts from MELC proposal
  R.M. Dzhilkibaev, V.M. Lobashev, Sov.J.Nucl.Phys **49**, 384 (1989)
- Goal: $R_{\mu e} < 6\text{x}10^{-17}$ which is x10000 improvement over current
- 8 kW proton beam @ 8 GeV, 200 ns pulses with 1.7 μs spacing



Examples of CLFV

$$\mu \to e\gamma, \mu \to eee, \mu N \to eN, (\mu^+ e^-)_{\text{muonium}} \to (\mu^- e^+)_{\text{anti-muonium}}$$

$$\tau \to e\gamma, \tau \to \mu\gamma, \tau \to eee, \tau \to \mu\mu\mu, \tau \to \mu ee, \tau \to e\mu\mu, \ldots$$

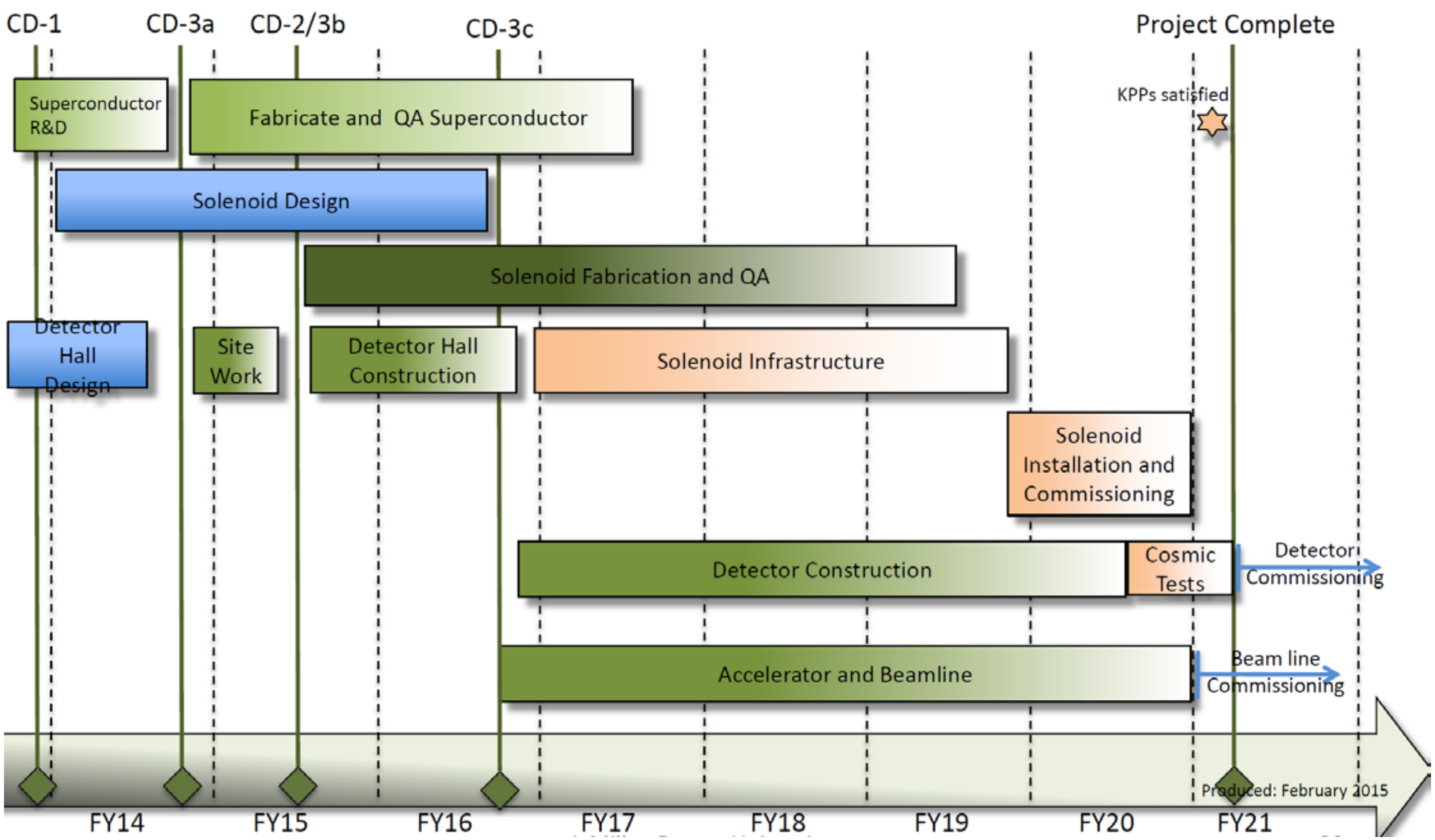
$$Z \to \mu e, H \to \mu\tau, \ldots$$

$$K \to \mu\mu, \ldots$$

$$\ldots$$

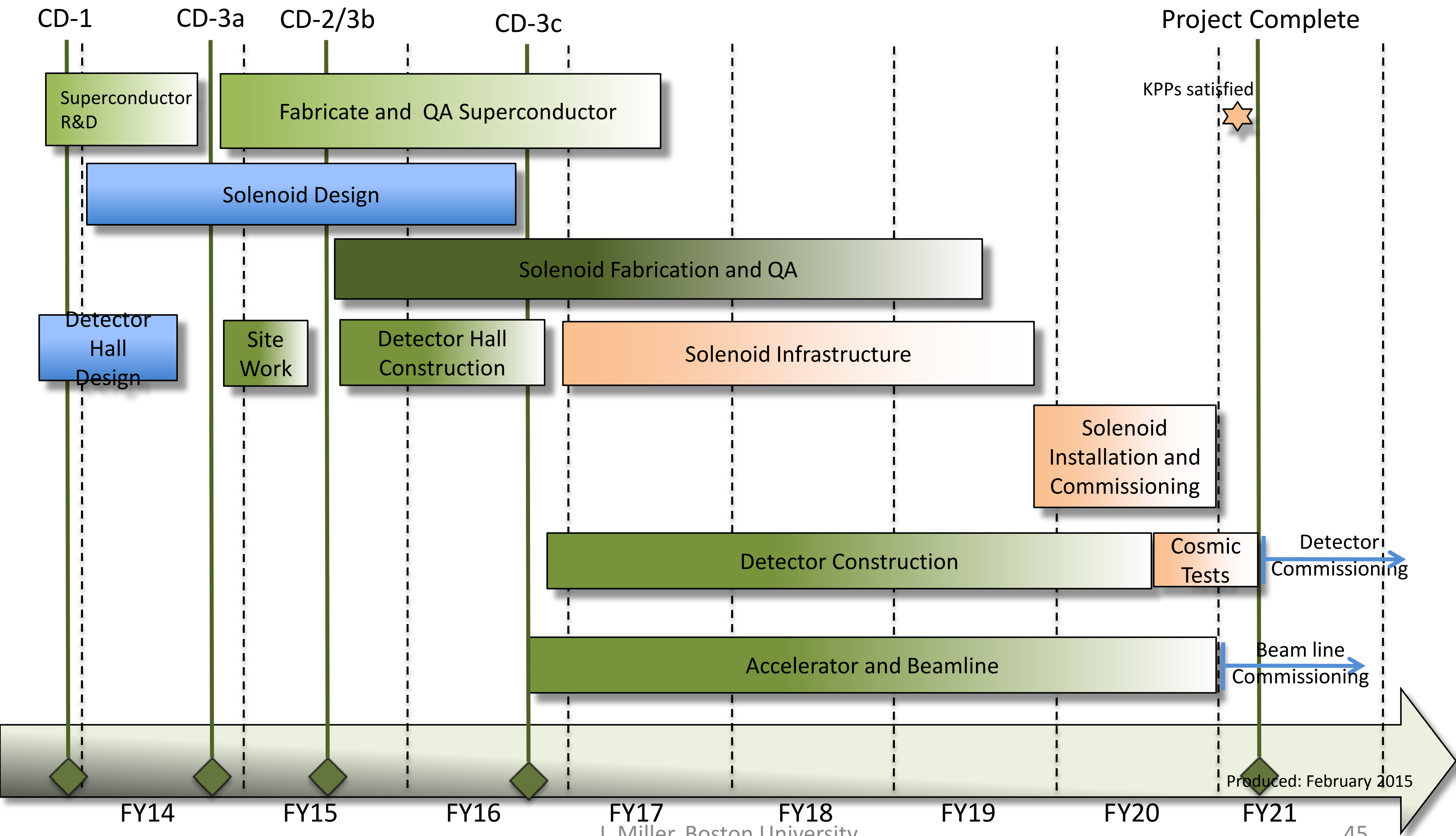
- No CLFV has yet been detected experimentally

Mu2e Schedule



- Mu2e-II upgrade is being studied for the PIP-II era accelerator upgrades: x10, perhaps eventaullay x100 more sensitivity

Mu2e Schedule



COMET Phase I and II