Charged Lepton Flavor Violation Experiments

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Boston University
Lomonosov, August 21, 2021

Outline

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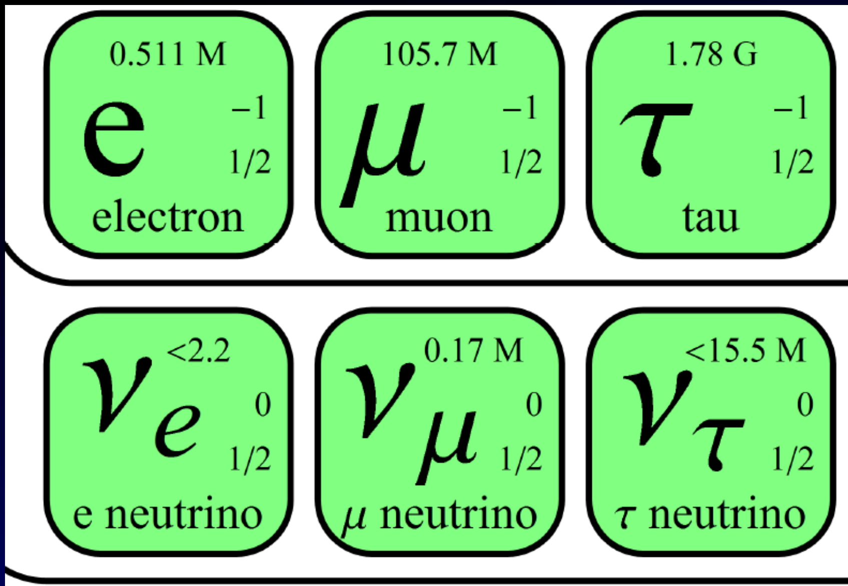
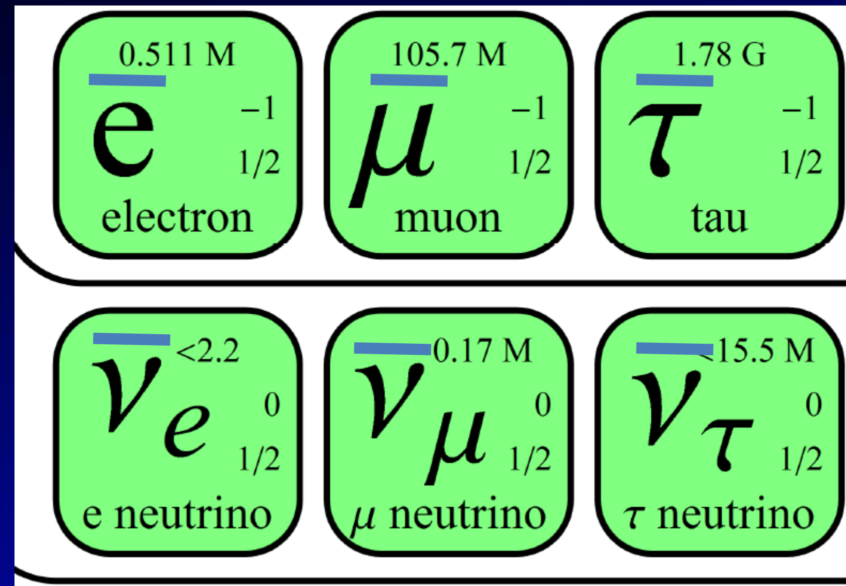
1) Introduction to cLFV Experiments and current status of some of the measurements
2) Dedicated, ongoing or developing, *muon* experiments
3) The outlook for the future

Lepton Flavor Conservation





$L(e) = +1 \quad L(\mu) = +1 \quad L(\tau) = +1 \qquad L(e) = -1 \quad L(\mu) = -1 \quad L(\tau) = -1$

- The sum of each lepton flavor is conserved!

Muon Decay: $\mu^- \not\to e^- + \gamma \qquad \mu^- \to e^- + \bar{\nu}_e + \nu_\mu$

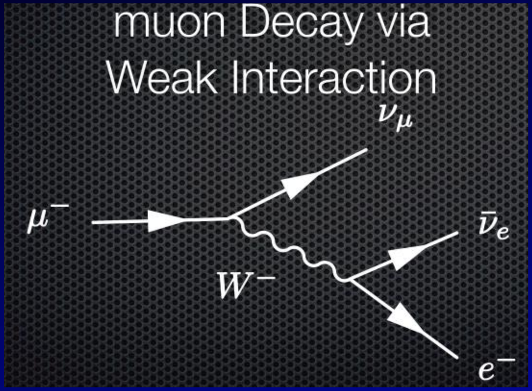
Muon to electron conversion: $\mu^- + N \not\to e^- + N$

Lepton Flavor Conservation

- Neutrinos oscillate! e.g. $\nu_e \Leftrightarrow \nu_\mu$
- Lepton flavor is not conserved in this process
- Lepton Flavor Violation has not been observed when charged leptons are involved
- It is not known what the mechanism are for Lepton Flavor conservation or for it s violation
- Necessary to study lepton conservation properties of charged leptons to help figure this out

Charged Lepton Flavor Violation (CLFV) in the Standard Model

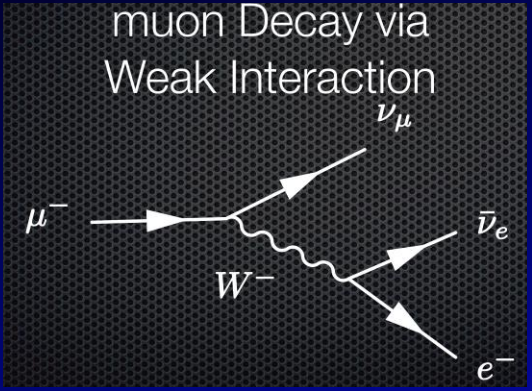
- Forbidden in pre-neutrino osc. SM

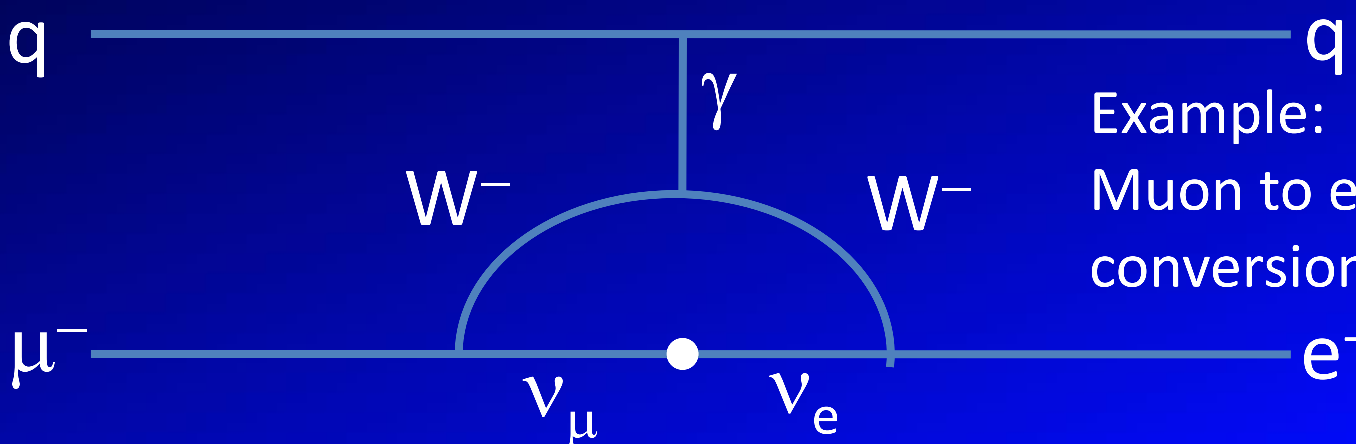


Charged Lepton Flavor Violation (cLFV) in the Standard Model

- Forbidden in the SM
- In ν-SM, possible but extremely suppressed

  (rate ~ $\Delta m_\nu^4 / M_W^4 < 10^{-50}$)





Example:
Muon to electron conversion

Charged Lepton Flavor Violation (CLFV) in the Standard Model

- Forbidden in the SM
- In ν-SM, extremely suppressed
  (rate ~ $\Delta m_\nu^4 / M_W^4 < 10^{-50}$)
- However, many New Physics models are compatible with rates observable at next generation cLFV experiments

SUSY

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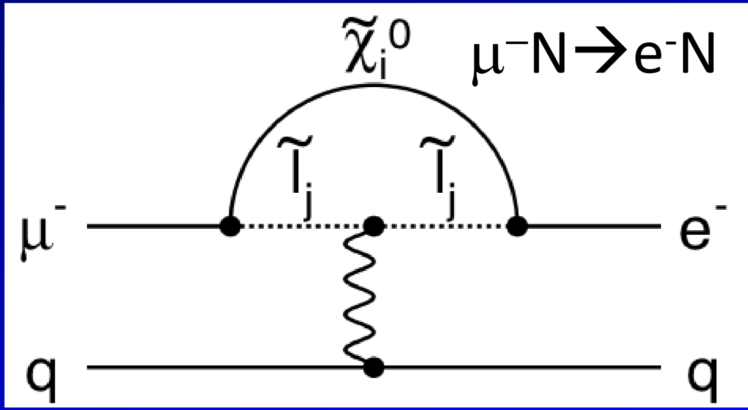
$\tau \to \mu\gamma$

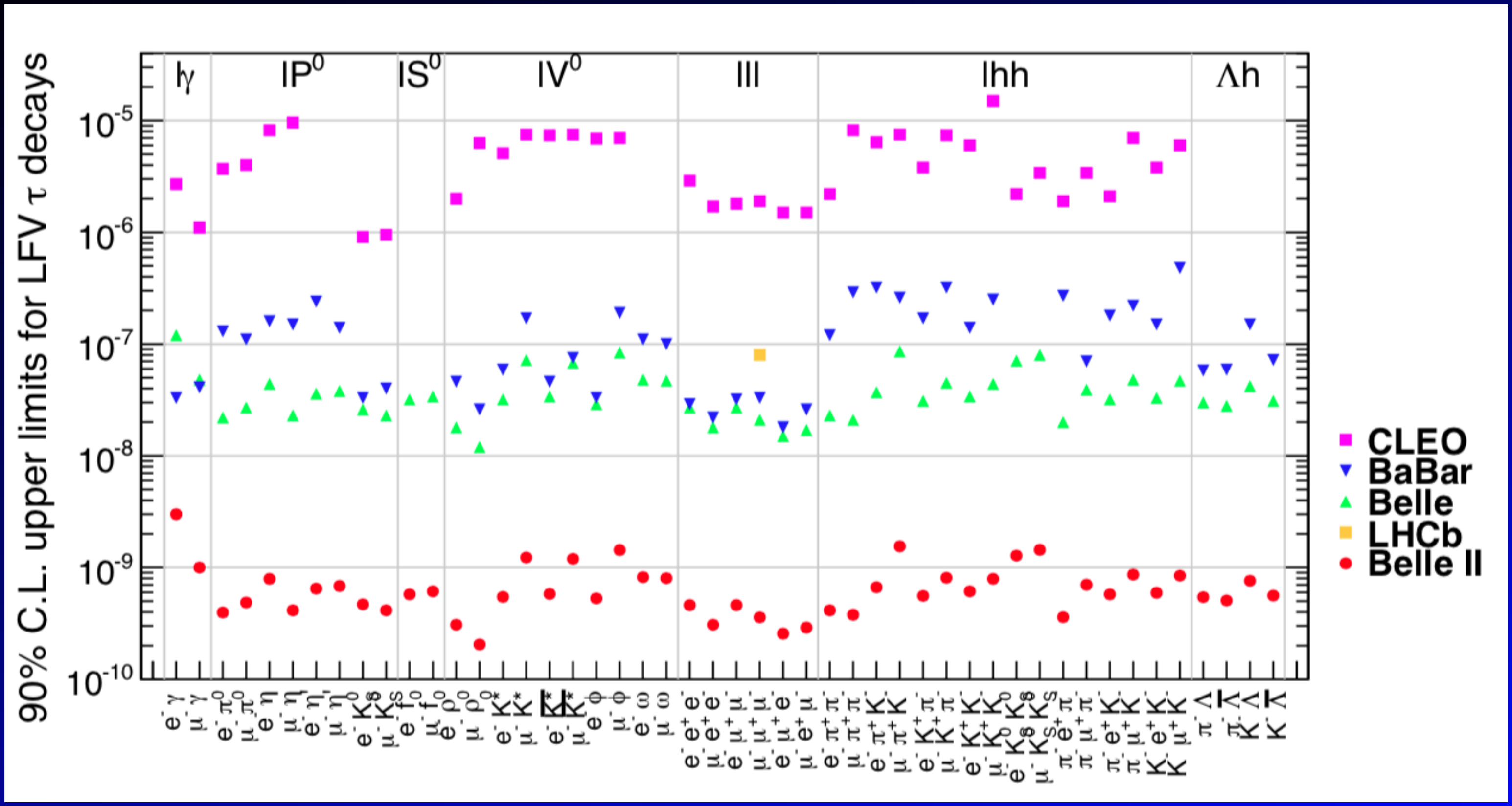


Some cLFV Processes

Process	Current Limit	Next Generation exp
D decays	BR< ~1E-9	LHC
$\tau \rightarrow \mu\gamma$	BR < 6.8 E-8	10^{-9} - 10^{-10} (Belle II)
$\tau \rightarrow \mu\mu\mu$	BR < 3.2 E-8	
$\tau \rightarrow eee$	BR < 3.6 E-8	
$K_L \rightarrow e\mu$	BR < 4.7 E-12	
$K^+ \rightarrow \pi^+e^-\mu^+$	BR < 1.3 E-11	
$B^0 \rightarrow e\mu$	BR < 1.0 E-9	LHCb, Belle II
$B^+ \rightarrow K^+e\mu$	BR < 9.1 E-8	
$\mu^+ \rightarrow e^+\gamma$	BR < 4.2 E-13	6×10^{-14} (MEG 2)
$\mu^+ \rightarrow e^+e^+e^-$	BR < 1.0 E-12	10^{-16} (Mu3e Phase 2-PSI)
$\mu^-N \rightarrow e^-N$	$R_{\mu e}$ < 7.0 E-13	Few x 10^{-17} (Mu2e, COMET)
$\mu^+e^- \rightarrow \mu^-e^+$	$P_{M\bar{M}} \leq 8.2E-11$	
$\mu^-N \rightarrow e^+N$	R < 1.7 E-12	Mu2e
$0\nu\beta\beta$		

- Some of the most promising cLFV measurements use muons

Current tau decay limits and projected Belle II



2018

https://scipost.org/SciPostPhysProc.1

Charged Lepton Flavor Violation: ATLAS-LHC

Current ATLAS limits on the branching fractions for the LFV decays of Z and Higgs bosons, as obtained at 95% of CL, along with the corresponding dataset.

Process	Current limit	Dataset	HL-LHC prospects (3000 fb^{-1})
$Z \to e\mu$	$B < 7.5 \times 10^{-7}$	8 TeV, 20 fb^{-1}	
$Z \to e\tau$	$B < 5.8 \times 10^{-5}$	13 TeV, 36 fb^{-1}	$B \ll 9.8 \times 10^{-6}$ (LEP)
	$B < 8.1 \times 10^{-6}$	13 TeV 139 fb-1	Oct 2020, better than LEP!
$Z \to \mu\tau$	$B < 1.3 \times 10^{-5}$	8 TeV, 20 fb^{-1} and 13 TeV, 36 fb^{-1}	$B \ll 1.2 \times 10^{-5}$ (LEP)
	$B < 9.5 \times 10^{-6}$	13 TeV 139 fb-1	Oct 2020, better than LEP!
$H \to e\mu$	$B < 6.1 \times 10^{-5}$	13 TeV, 139 fb^{-1}	
$H \to e\tau$	$B < 0.47\%$	13 TeV, 36 fb^{-1}	$B<0.05\%$
$H \to \mu\tau$	$B < 0.28\%$	13 TeV, 36 fb^{-1}	$B <0.05\%$

The symbol "≪" are current LEP limits that will be improved upon at LHC.

T. Davodek, L. Fiorini, Frontiers in Physics, https://doi.org/10.3389/fphy.2020.00149 (2020)

Related Issue: Lepton Non-universality

Recent result from LHCb, arxiv:2103.11769v1

γ

$$R_K = \frac{Br(B^+ \to K^+ + \mu^+ + \mu^-)}{Br(B^+ \to K^+ + e^+ + e^-)} = 0.846^{+0.044}_{-0.041}$$

3.1 s.d. from the SM prediction of 1

New Physics models generally predict Lepton Flavor Violation if Universality is violated

Why Muons?

Different SUSY and non-SUSY BSM models

★★★ Large effects

★★ Visible, but small

★ No sizable effect

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

Table 8: "DNA" of flavour physics effects for the most interesting observables in a selection of SUSY and non-SUSY models ★★★ signals large effects, ★★ visible but small effects and ★ implies that the given model does not predict sizable effects in that observable.

Altmannshofer et al., NPB 830, 17 (2010)

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

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Why Muons(2)?

- Relatively easy to produce copious numbers of muons
- Muons are relatively long-lived
- Muons can be stopped in material and localized
- Several experiments now under development are dedicated to looking for cLFV with stopped muons

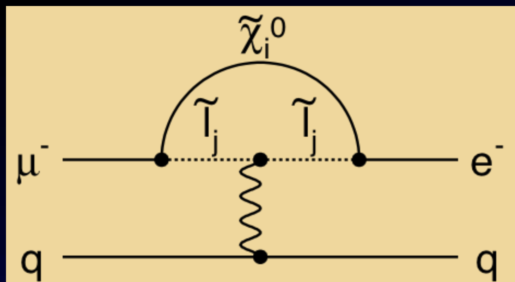
$\mu^+ \to e^+\gamma$ (MEG at PSI)

$\mu^+ \to e^+e^+e^-$ (Mu3e at PSI)

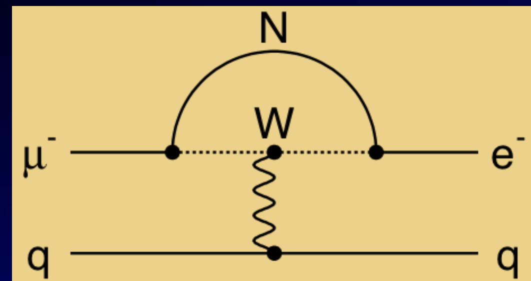
$\mu^- N \to e^- N$ (Mu2e at FNAL, COMET at J-PARC, DeeMe at J-PARC)

New Physics Contributions to μN→eN

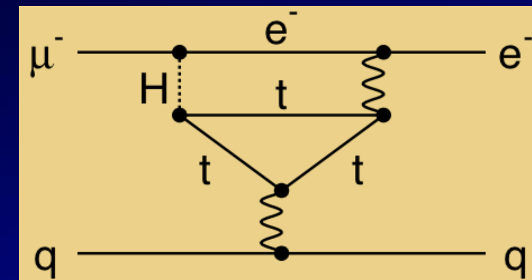
Loops



Supersymmetry

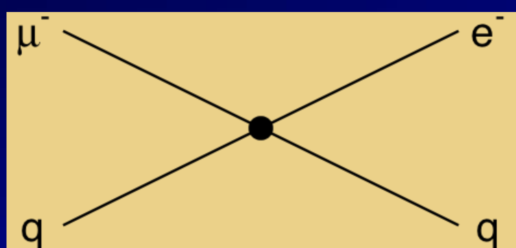


Heavy Neutrinos

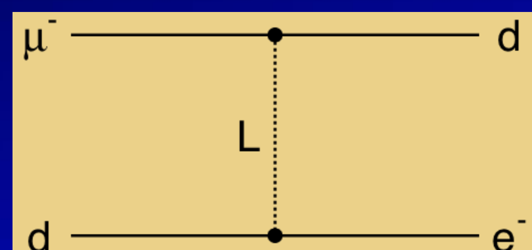


Two Higgs Doublets

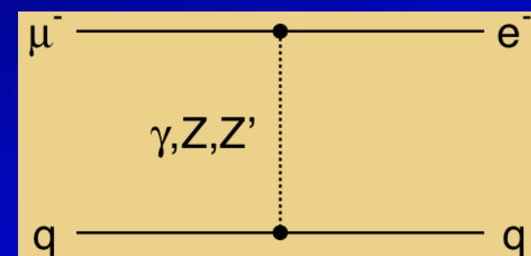
Contact Terms



Compositeness



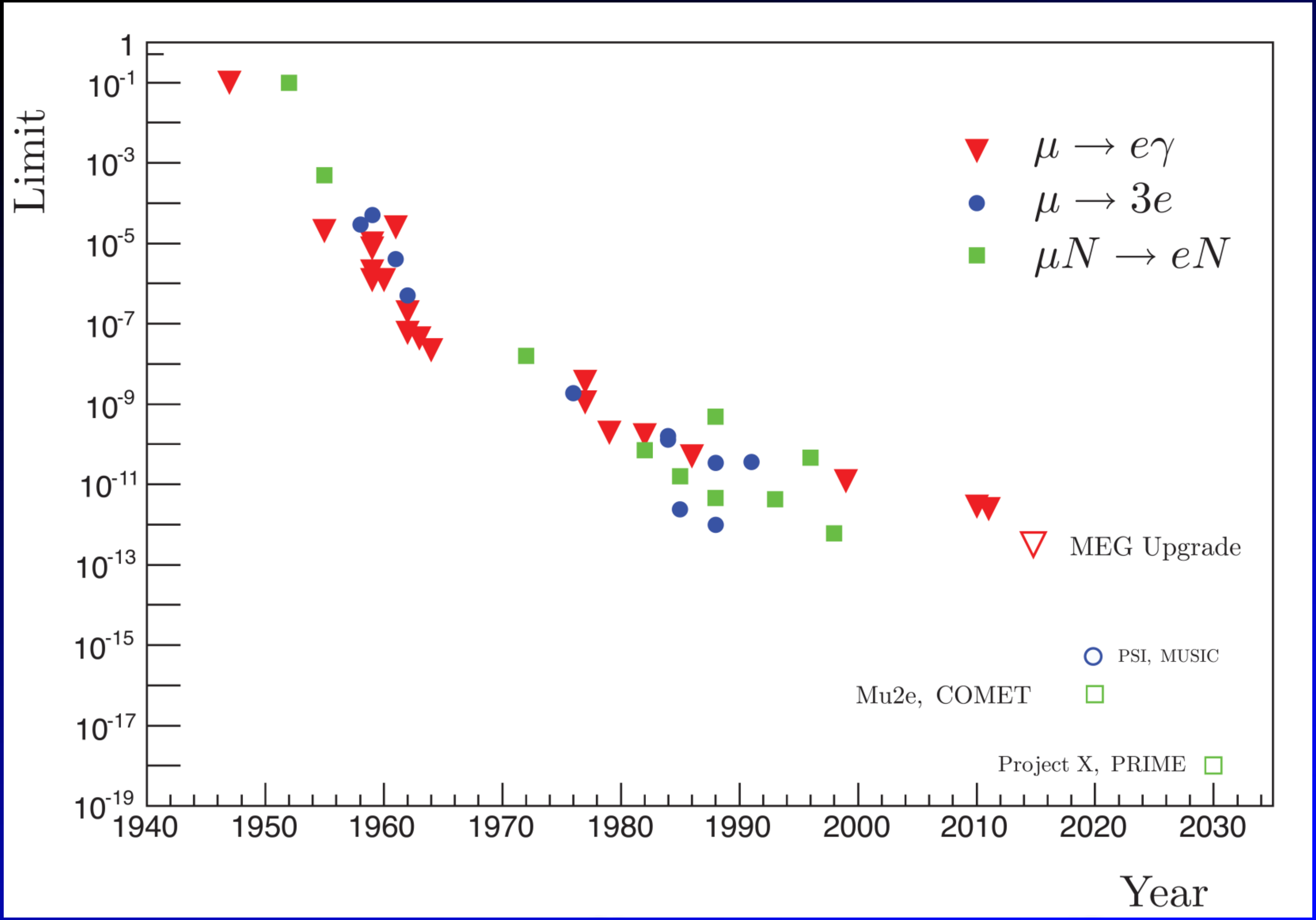
Leptoquarks



New Heavy Bosons /
Anomalous Couplings

μN→eN sensitive to wide array of New Physics models

Many Muon Experiments over the Years

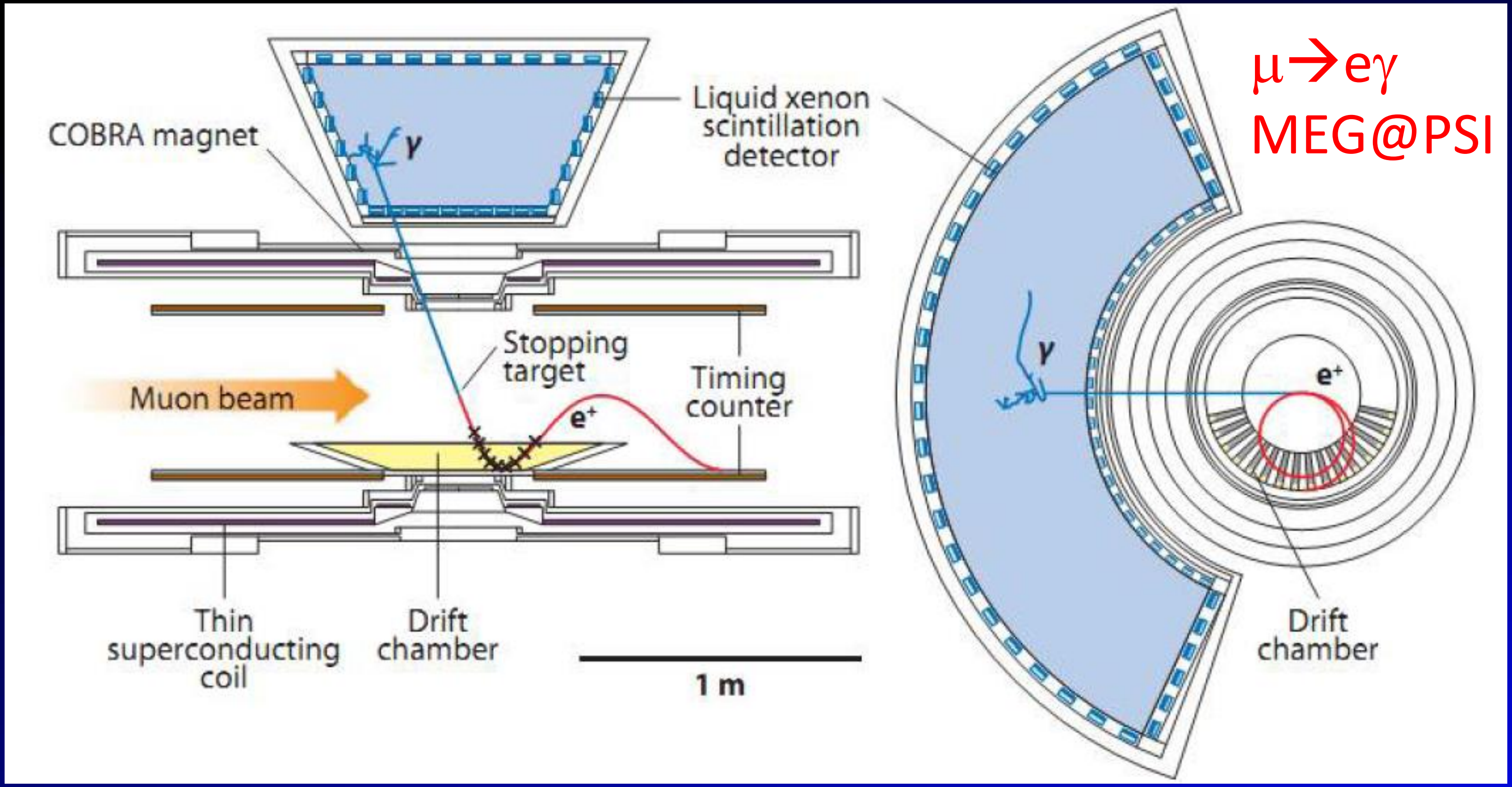


$\mu^+ \rightarrow e^+\gamma$ (MEG at PSI)

- Measure back-to-back monoenergetic positron and gamma
- MEG set current best limit on $\mu \rightarrow e\gamma$ branching ratio set by MEG at 4.2e-13 (90% CL)
- Upgrade under way to improve to achieve 6e-14 limit
- Challenges:
  - Need to suppress backgrounds
    - Radiative muon decay (RMD) $\mu^+ \rightarrow e^+\nu_e\bar{\nu}_\mu\gamma$
    - Accidental coincidences between e^+ from $\mu^+ \rightarrow e^+\nu_e\bar{\nu}_\mu$ and a gamma from RMD or positron annihilation in flight
      - Need best possible measurement of energies and of the angle between the gamma and the positron $N_{acc} \propto R_\mu^2 \times \Delta E_\gamma^2 \times \Delta p_e \times \Delta\Theta_{e^+\gamma}^2 \times \Delta t_{e^+\gamma} \times T$
- MEG currently in engineering runs to commission new equipment
  - Major improvements in calorimeter energy and position resolutions, new thinner drift chamber, improved timing counters, DAQ handles higher rates
- Increase flux up to 3e7 continuous stopped muons/s compared to ~1e7 previously
  - May be the ultimate rate limit, limiting ultimate $\mu \rightarrow e\gamma$ sensitivity

arXiv:1801.04688v1

$\mu^+ \rightarrow e^+\gamma$ (MEG at PSI)(2)



- Stop μ+ in a thin target using 'surface' muons (28 MeV/c, 7% FWHM)
- Look for back-to-back 53 MeV electron and gamma
- Measure electron momentum and direction in drift chamber in magnetic field
- Measure positron time in timing counters
- Measure energy, position, time of gamma in liquid xenon scintillating calorimeter, UV-sensitive PMT's

$\mu^+ \rightarrow e^+ e^+ e^-$ (Mu3e at PSI)(2)

- Current best experimental limit BR<1e-12 (SINDRUM 1988)
- Phase 1 under construction now at PSI
  - goal SES 2e-15
  - Use same muon beamline at PSI as MEG (πe5)
    - Currently the most powerful in the world
    - 1e8 stopped muons/s for 2.5e7 seconds to reach sensitivity goal
- Phase 2 goal BR<1e-16 (90% CL)
  - Use high Intensity Muon Beam (HiMB) at PSI planned for >2025?
- Main backgrounds
  - Internal conversions $\mu^+ \rightarrow e^+ e^+ e^- \bar{\nu}_\mu \nu_e$ (with very low energy neutrinos)
  - Radiative muon decay followed by conversion in target, $\mu^+ \rightarrow e^+(\gamma \rightarrow e^+ e^-)\bar{\nu}_\mu \nu_e$
  - Accidental coincidence between e^+e^- pair from Bhabha scattering of Michel positron from ordinary muon decay, and a Michel positron from another decay
  - Suppress with
    - better than 1 MeV FWHM resolution on energy of eee
      - » Minimize multiple scattering Ultra-thin pixelated Si tracker
      - » challenge is cooling with helium gass
    - Better than few 100 ps time resolution on tracks- use thin timing scintillators
    - High resolution on vertex reconstruction

arXiv:2009.11690v2

$\mu^+ \rightarrow e^+ e^+ e^-$ (Mu3e at PSI)

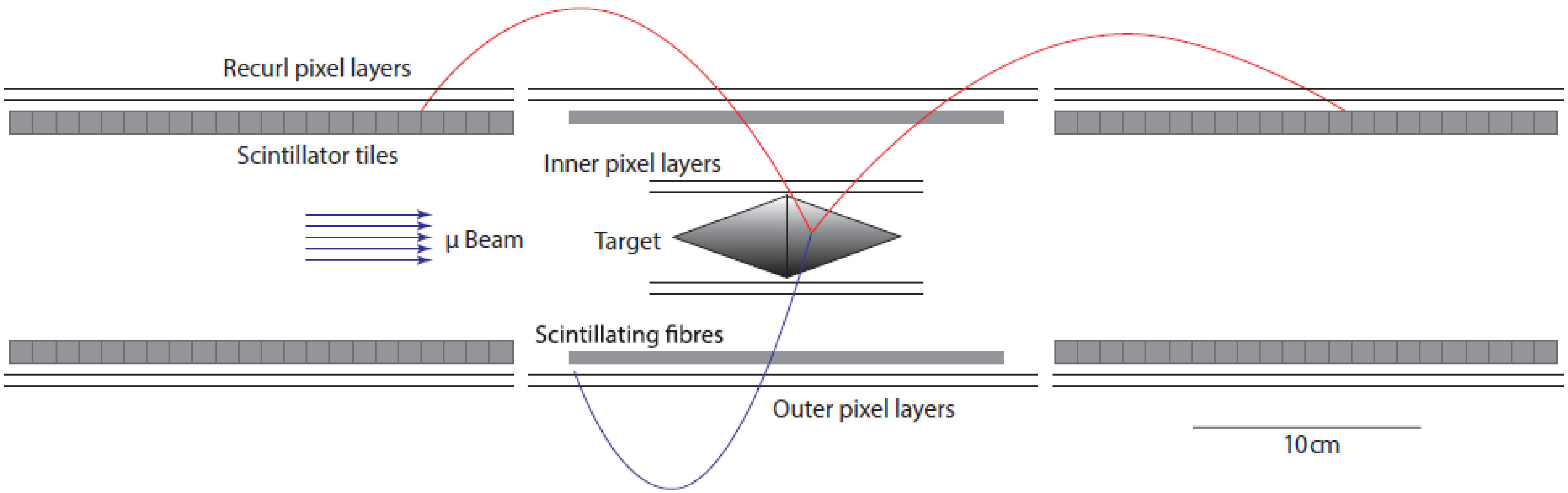
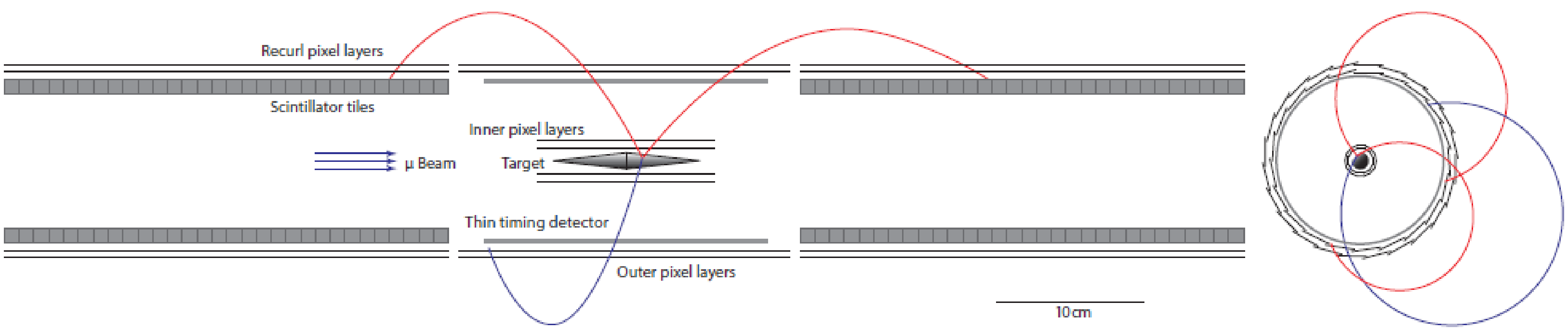


Figure 2.6: Schematic view of the experiment cut along the beam axis in the phase I configuration.



What it is and how to Search for $\mu^- N \to e^- N$

- Stop negative muons in material
- Muon rapidly (10^{-16}s) cascades to 1S state (Al binding ~460 keV, r~20 fm), forming muonic atom
- Two things most likely happen:

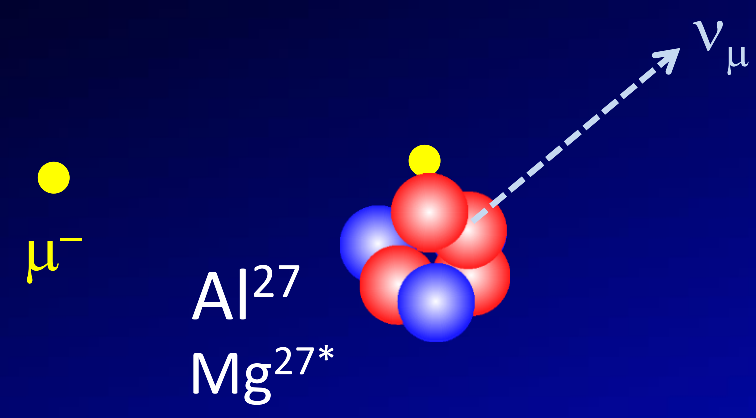
  1. muon is captured by the nucleus (61%): $\mu^- N_{A,Z} \to \nu_\mu N_{A,Z-1}$

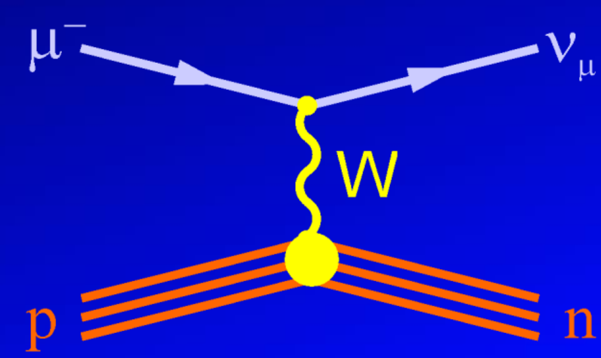
  Cause low energy background

  2. muon decays in orbit(39%): $\mu^- N_{A,Z} \to e^- \nu_\mu \nu_e N_{A,Z}$

  Muonic aluminum lifetime 864 ns

  3. Rare, not seen: Muon to electron conversion $\mu^- N_{A,Z} \to e^- N_{A,Z}$

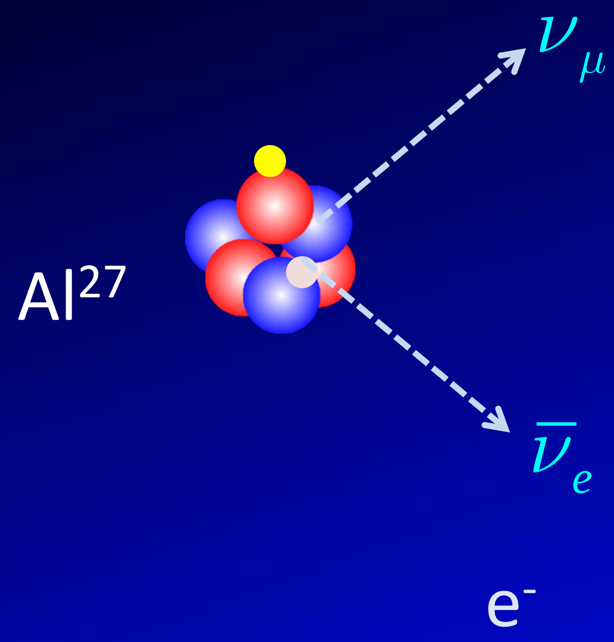


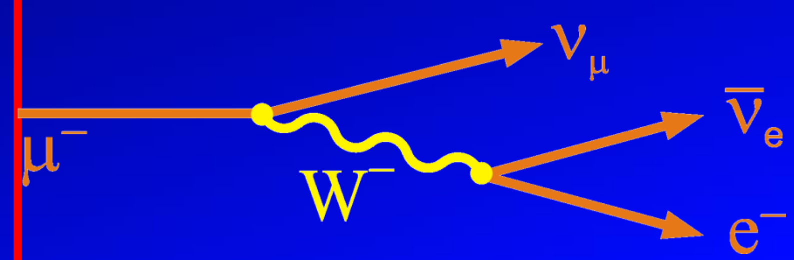


Muon Capture

How to Search for $\mu^- N \rightarrow e^- N$

- Stop muon in atom
- Muon rapidly (10^{-16}s) cascades to 1S state (binding ~460 keV, r~20 fm), forming muonic atom
- Circles nucleus, lifetime ~864 ns
- Two things most likely happen:
  1. muon is captured by the nucleus: (61%) $\mu^- N_{A,Z} \rightarrow \nu_\mu N_{A,Z-1}$
  2. muon decays in orbit (39%): $\mu^- N_{A,Z} \rightarrow e^- \nu_\mu \nu_e N_{A,Z}$
  Muonic aluminum lifetime 864 ns
  3. Rare, not seen: Muon to electron conversion $\mu^- N_{A,Z} \rightarrow e^- N_{A,Z}$





Muon Decay-in-Orbit

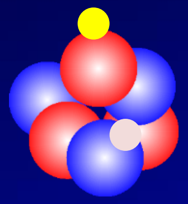
Searching for $\mu^- N \rightarrow e^- N$

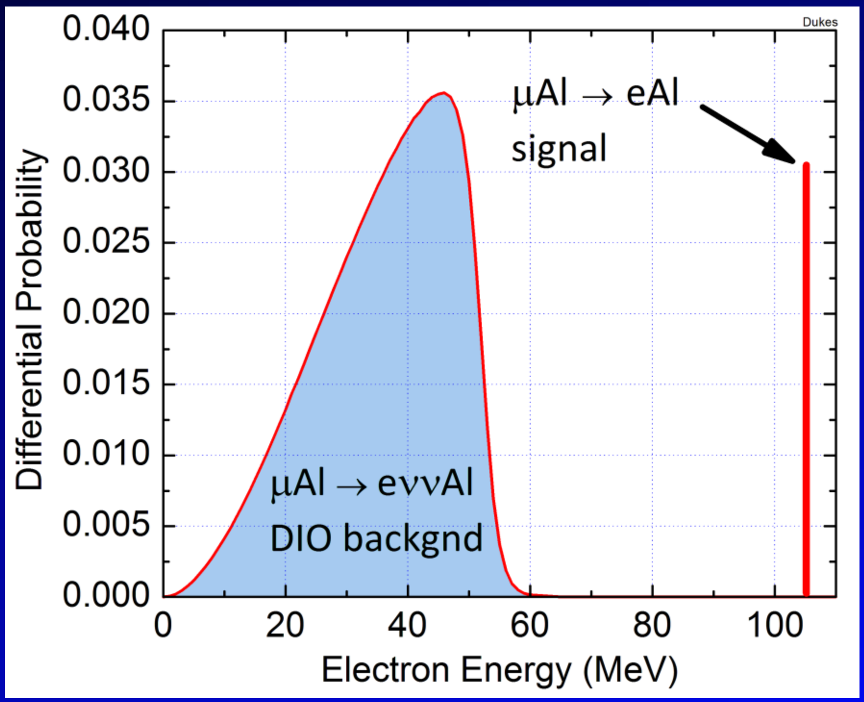
In $\mu^- N \rightarrow e^- N$ the muon interacts with nucleus leaving it in ground state

- Signature: delayed single isolated electron
- Electron energy is rest mass of the muon minus the nucleus recoil + binding energy:

$E_e = m_\mu - E_{NR} - E_b \sim 104.97$ MeV (Al)

Al^{27}





e^-

Decay of free muon, τ=2200 ns:

$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$ Max $E_e \approx 53$ MeV

Muon bound in atomic orbit, τ=864 ns:

$\mu^- + Al \rightarrow e^- + \bar{\nu}_e + \nu_\mu + Al$

Max $E_e \approx 104.96$ MeV

Decay in orbit (DIO) background

Searching for $\mu^- N \rightarrow e^- N$

In $\mu^- N \rightarrow e^- N$ the muon interacts with nucleus leaving it in ground state

- Signature: delayed single isolated electron
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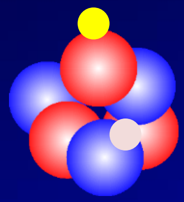
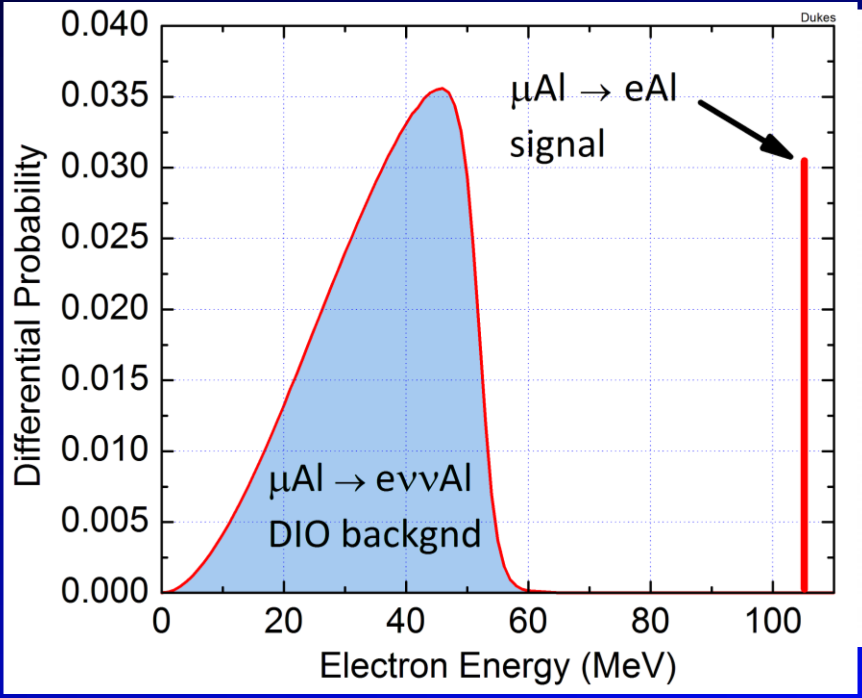
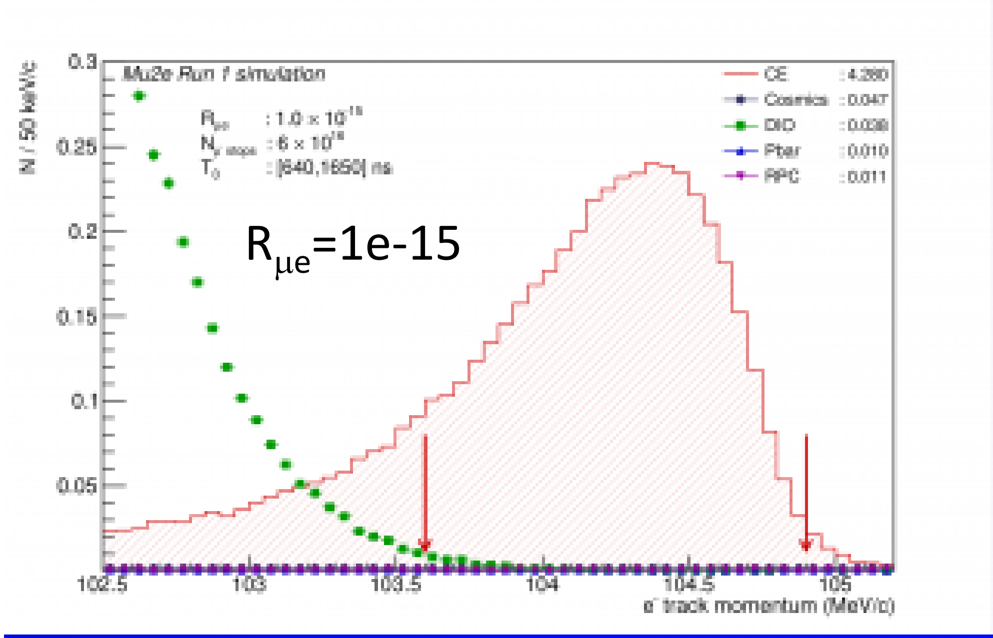






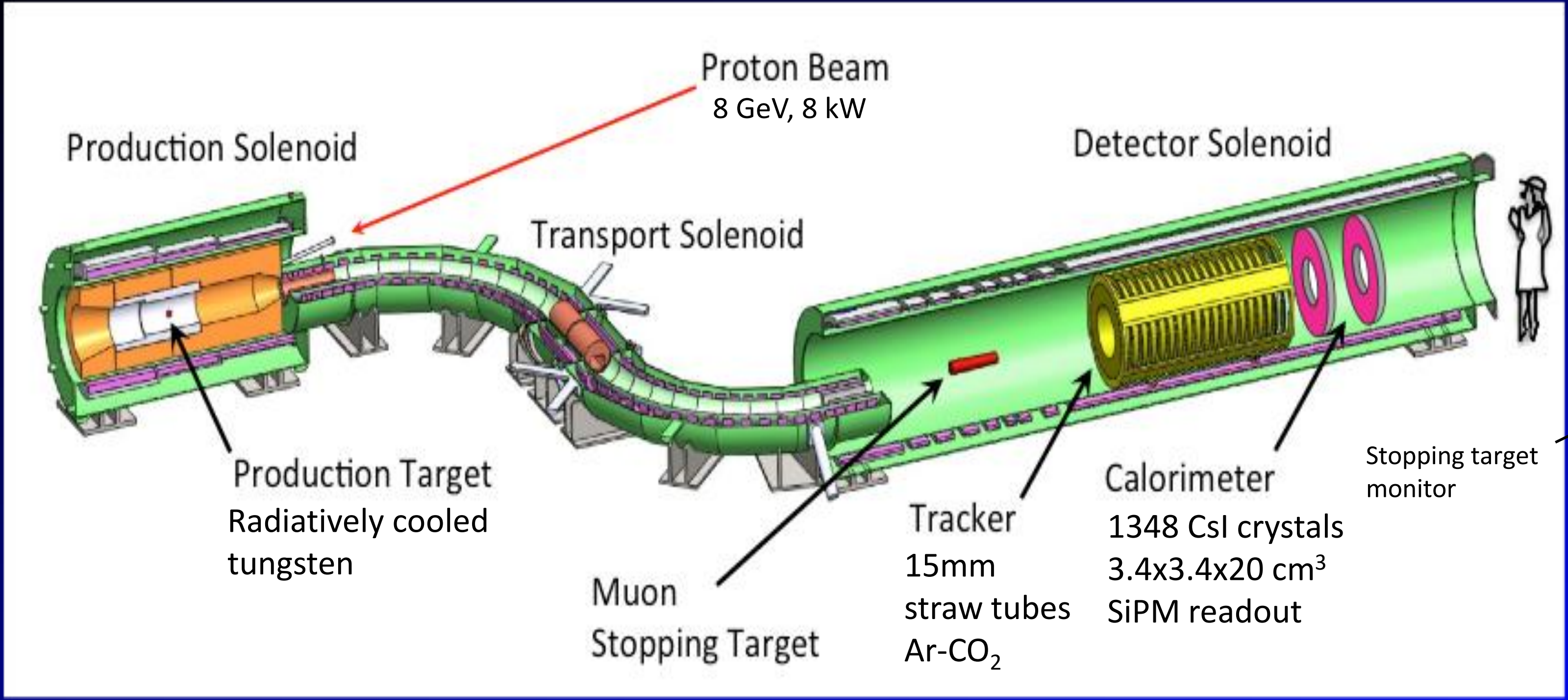
Current and future experimental status of $\mu^- N \to e^- N$

The ratio of production rate of a monoenergetic conversion electron to the muon nuclear capture rate

$$R_{\mu e} \equiv \frac{\Gamma(\mu^- N(A,Z) \to e^- N(A,Z))}{\Gamma(\mu^- N(A,Z) \to \nu_\mu N(A,Z-1)^*)}$$

- Current limit $7\text{x}10^{-13}$ (90% CL) on Au [SINDRUM II, EJP C **47**(2006)337]
- COMET phase I (J-PARC), under construction, begins data 4taking 2024
  - goal of expected sensitivity (SES) ~ $3\text{x}10^{-15}$, on Al
- Mu2e (FNAL), under construction
  - Run 1 (2025-2026) Al: (SES) 2.3e-16, 5.9e-16 (90% CL), 1.1e-15 (discovery)
    Also, ΔL=2 $\mu^{-}\,{}^{27}_{13}Al \to e^{+}\,{}^{27}_{11}Na^{*}$ SES 4.0×10^{-16}
  - Run 2 (2029-) Al: (SES) $3\text{x}10^{-17}$, $8\text{x}10^{-17}$ (90% CL), $2\text{x}10^{-16}$ (discovery)
- COMET phase II , planned, goal of expected SES ~ $3\text{x}10^{-17}$, on Al
- Mu2e-II, under study, goal of expected SES ~ $3\text{x}10^{-18}$, on Al
- More distant future
  - COMET PRISM (COMET upgrade) develop muon storage ring ~10^{-18}-10^{-19}
  - High intensity muon facility and upgrade of Mu2e at FNAL, ~10^{-18}

Mu2e (Fermilab)



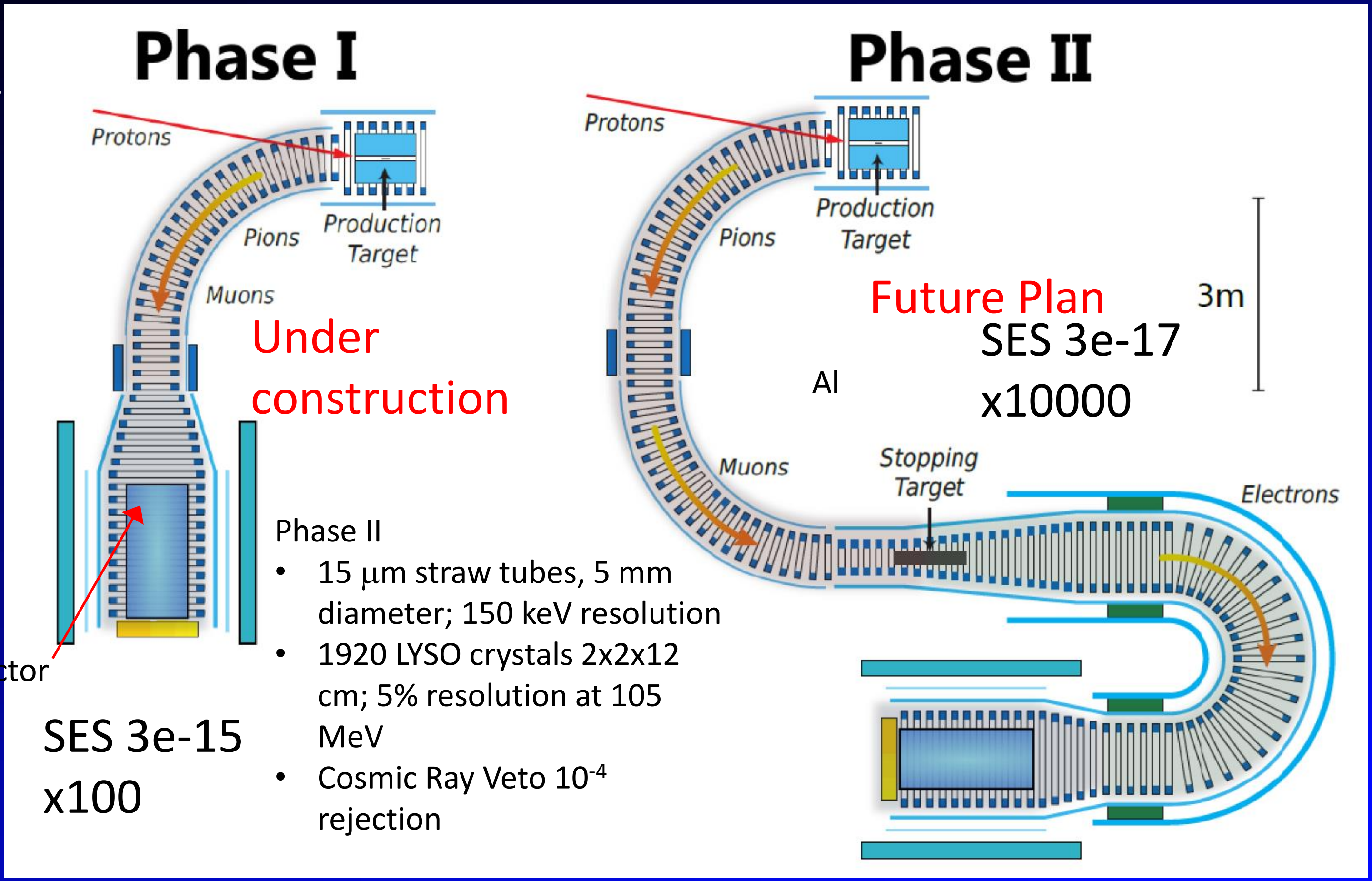
Run 1 (2025-2026) SES 2.3e-16 x1000 improvement

Run 2 (starts 2029) SES 3e-17 x10000 improvement

COMET (J-PARC), Phase I and II

(COherent Muon to Electron Transitions)

8 GeV protons
100 ns bunches,
1.17 μs gap



Under construction

SES 3e-15
x100

Future Plan

SES 3e-17
x10000

1 T detector solenoid

Phase II

- 15 μm straw tubes, 5 mm diameter; 150 keV resolution
- 1920 LYSO crystals 2x2x12 cm; 5% resolution at 105 MeV
- Cosmic Ray Veto 10^{-4} rejection

How can COMET and Mu2e make such a big leap in sensitivity over previous experiments?

- Large increase in stopped muon rate
  - Solenoidal beamline concept first proposed by Djilkabaev and Lobashev ~1990 https://aip.scitation.org/doi/pdf/10.1063/1.50918

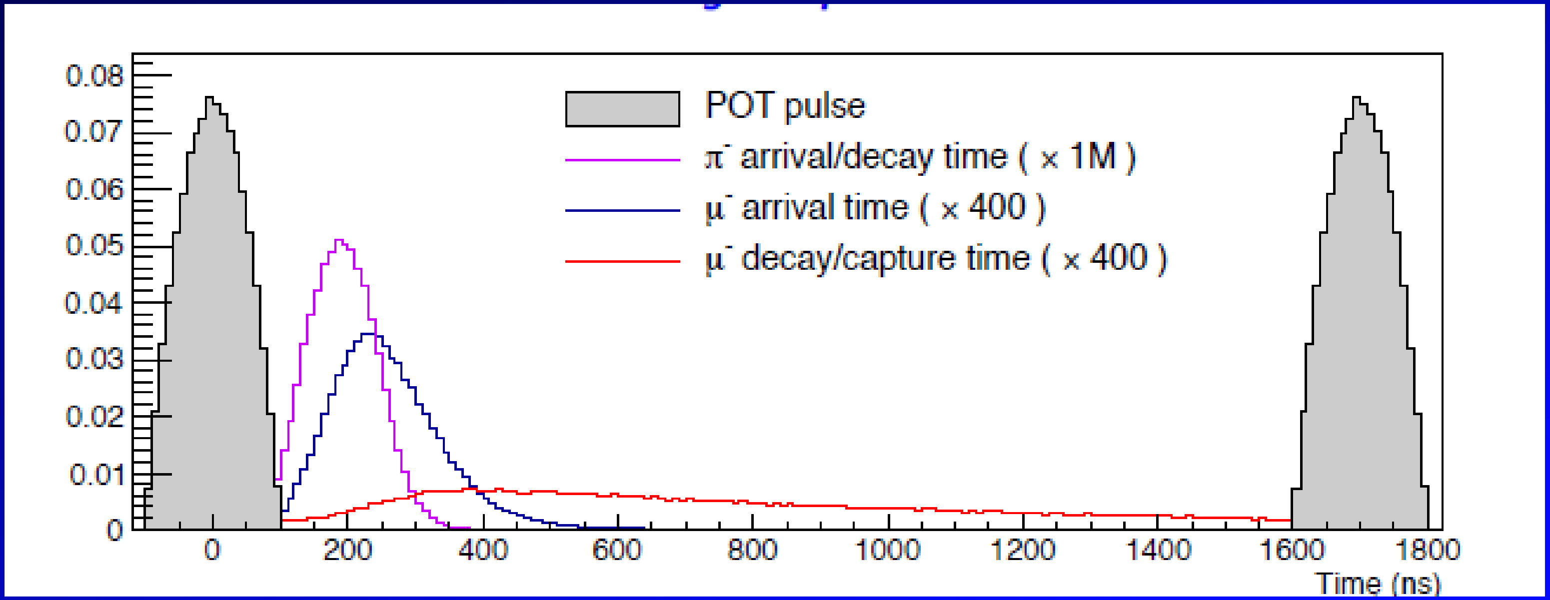
    A. Place production target in high-field solenoid

      1. Captures low E pions in spirals, they decay to muons which spiral down the beam line

    B. Use negative gradient to ‘push’ spiraling muon downstream , stop them in (Al) thin target
- Toroidal sections cause vertical drift of spirals, depending on sign and momentum, can use collimators to filter undesirable particles and momenta

How can COMET and Mu2e conversion make such a big leap in sensitivity over previous experiments?(2)

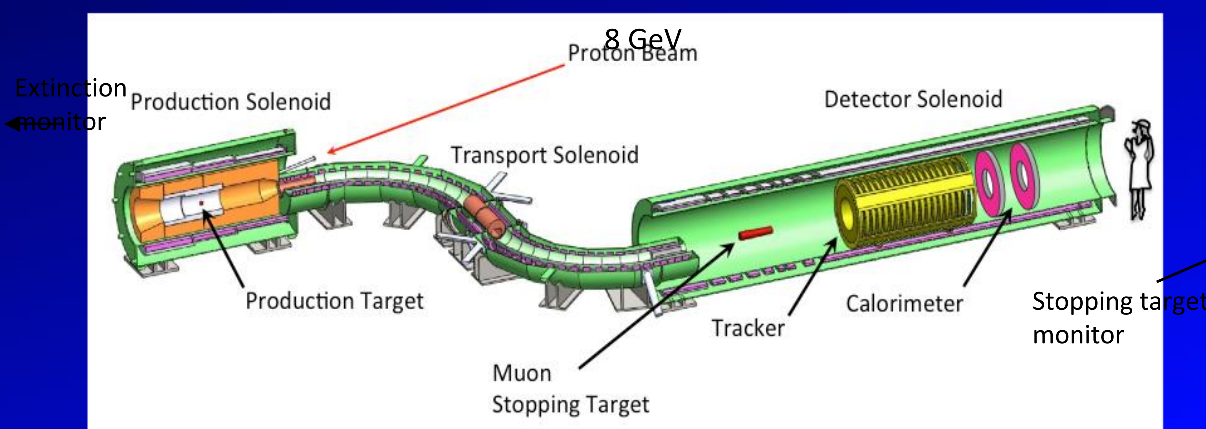
- Use a pulsed muon beam, wait for prompt background to subside before looking for the conversion electron. Most previous experiments used a continuous muon beam, with background mixed in. See details in following talk by S. DiFalco

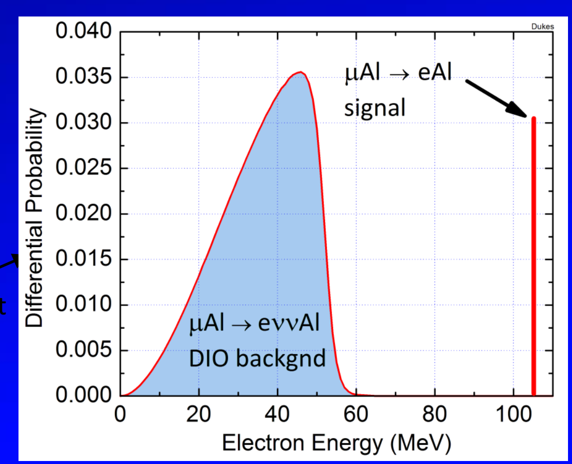


Experimental advantage of muon to electron conversion experiments compared to μ→eγ and μ→eee

3. Pro: The conversion electron energy is well above the energies of the electrons from muon decays, while the electrons, positrons, gammas from to μ→eγ and μ→eee or μ→eee are in the same energy range as μ→eνν . As a result accidentals are not nearly as big a problem, which is the limiting factor for future improvements in μ→eγ. Hole down the middle of detectors avoids almost all low energy decay electrons.

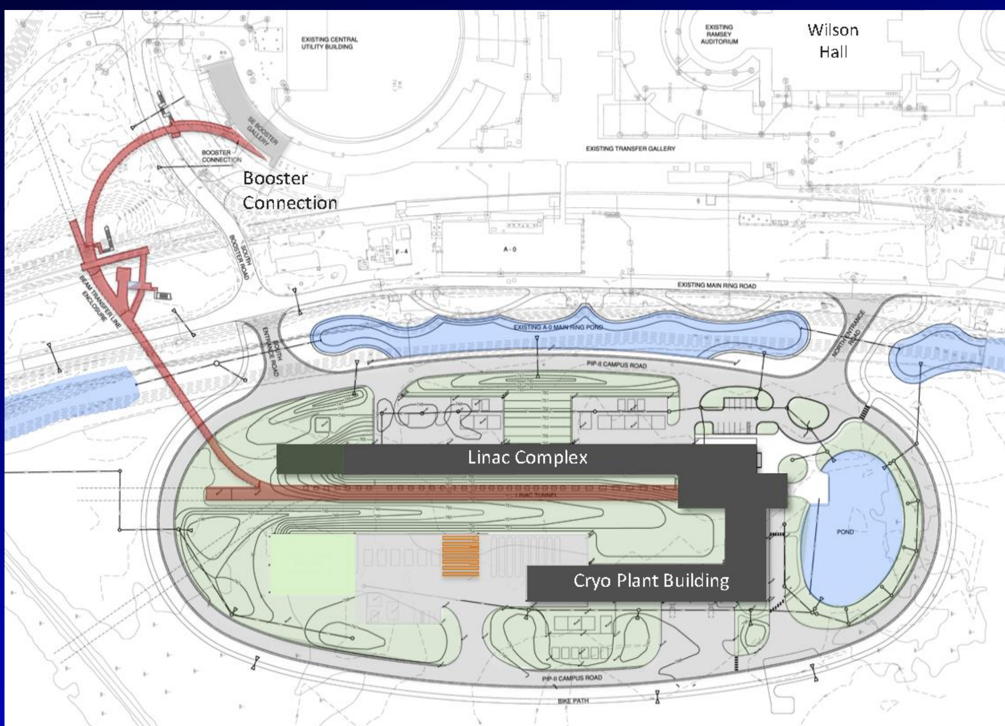
4. Con: Muon capture leads to a lot of neutrons that cause low energy background for the detectors, and some protons that deposit a lot of energy in the straw tubes. Both are manageable.





Mu2e-II at PIP-II

1. Goal: another order of magnitude improvement in sensitivity over Mu2e starting in next decade.
2. 100 kW pulsed 800 MeV beam extracted on demand with desired time structure
3. Upgrades needed beyond Mu2e are being studied and a Snowmass whitepaper is being prepared



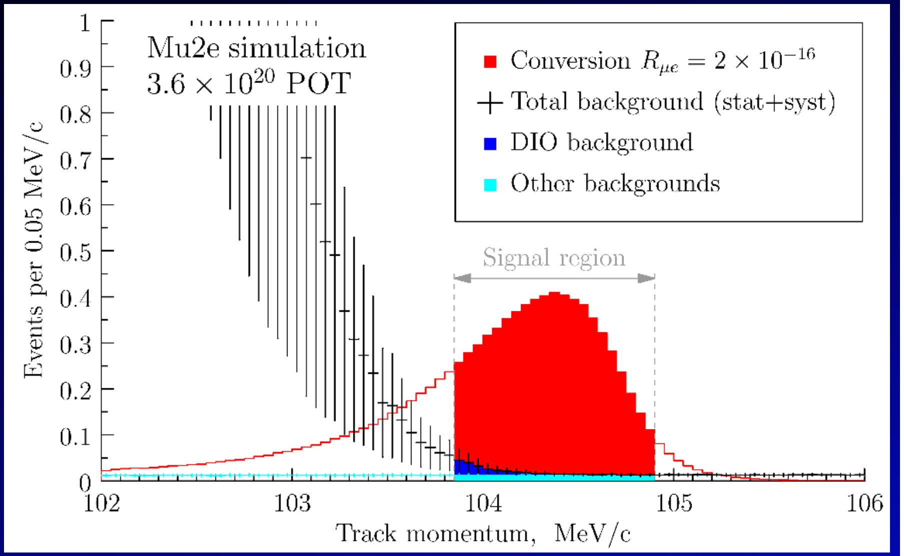
For Booster		
Beam energy	800	MeV
Average current	2	mA
Pulse length	0.55	ms
Repetition rate	20	Hz
For Mu2e-II		
Approximately CW, 162.5 MHz bunches configurable		
Power	>100	kW

Summary

- Lepton Flavor Conservation of charged leptons and violation by neutrinos are central features in the SM , however the underlying mechanism is not understood.
- Tests of charged lepton flavor violation are occurring across the board in collider experiments- LHC, B factories, muon sources…
- Hint of LFV implied from LHCb B decay : tension with SM universality
- Dedicated new high-sensitivity experiments in the muon sector may have highest sensitivity (depends on New Physics model), with mass scales in the hundreds or thousands of TeV.
- Much improved experimental information expected in next few years with improvements continuing into the next decade.

End

Mu2e Signal and Backgrounds



5σ discovery

Expected backgrounds
for livetime corresponding to 3.6×10^{20} POT

Process	Expected event yield
Cosmic ray muons	0.21 ± 0.06
DIO	0.14 ± 0.11
Antiprotons	0.04 ± 0.02
Pion capture	0.021 ± 0.002
Muon DIF	< 0.003
Pion DIF	$0.001 \pm < 0.001$
Beam electrons	$(2.1 \pm 1.0) \times 10^{-4}$
RMC	$0.000^{+0.004}_{-0.000}$
Total	0.41 ± 0.13(stat+syst)

Charged Lepton Flavor Violation

Process	Upper limit at 90% CL on branching fraction	Upper bound on $c^{e\mu}_1$ 2 + $c^{e\mu}_5$ 2 1 TeV Λ_{np} 2
$\mu^- \mathrm{Au} \rightarrow e^- \mathrm{Au}$	7×10^{-13}	9.1×10^{-6}
$\pi^0 \rightarrow e^{\pm}\mu^{\mp}$	3.6×10^{-10}	55
$D^0 \rightarrow e^{\pm}\mu^{\mp}$	1.3×10^{-8}	0.050
$K_L \rightarrow e^{\pm}\mu^{\mp}$	4.7×10^{-12}	5.0×10^{-6}

JHEP07 (2019) 022

ν-SM predicts tiny cLFV

- LFV is forbidden in the pre neutrino-oscillation SM
  - And we do not know why
- Neutrinos oscillate and therefore violate lepton flavor conservation
  - But we do not know how (what's the mechanism?)
- But LFV involving charged leptons (cLFV) has never been observed
- Given that the (near) conservation of Lepton Flavor is one of the central features of the SM, but we don't know why or how, it has long been a subject of intense experimental investigation
- Even in the ν-SM, cLFV is extremely suppressed

(rate ~ $\Delta m_\nu^4 / M_w^4 < 10^{-50}$)

- However, many New Physics models predict rates observable at next generation cLFV experiments

$$B(\pi^+ \to \mu^+ \nu_e) < 8.0 \times 10^{-3},$$

$$B(D^+ \to e^+ \nu) < 8.3 \times 10^{-5},$$

$$B(\pi^0 \to e^\pm \mu^\mp) < 3.6 \times 10^{-10},$$

$$B(D^0 \to e^\pm \mu^\mp) < 1.3 \times 10^{-8},$$

$$B(D^+ \to e^+ \nu) < 8.8 \times 10^{-6},$$

$$B(D^+ \to \pi^+ e^+ \mu^-) < 2.9 \times 10^{-6},$$

JHEP07 (2019) 022

$$B(D^+ \to K^+ e^+ \mu^-) < 1.2 \times 10^{-6},$$

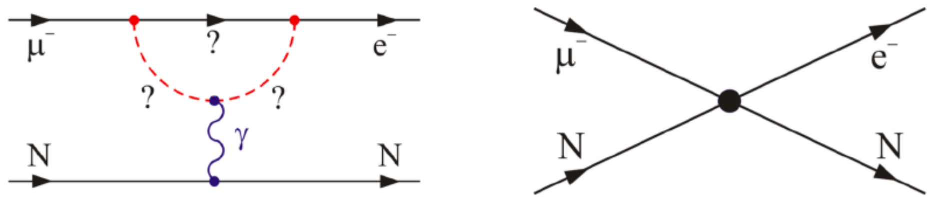
Effective Lagrangian and Mass Scale $\mu \rightarrow e\gamma$ and $\mu N \rightarrow eN$

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

A. De Gouvea and P. Vogel; arXiv:1303.4097

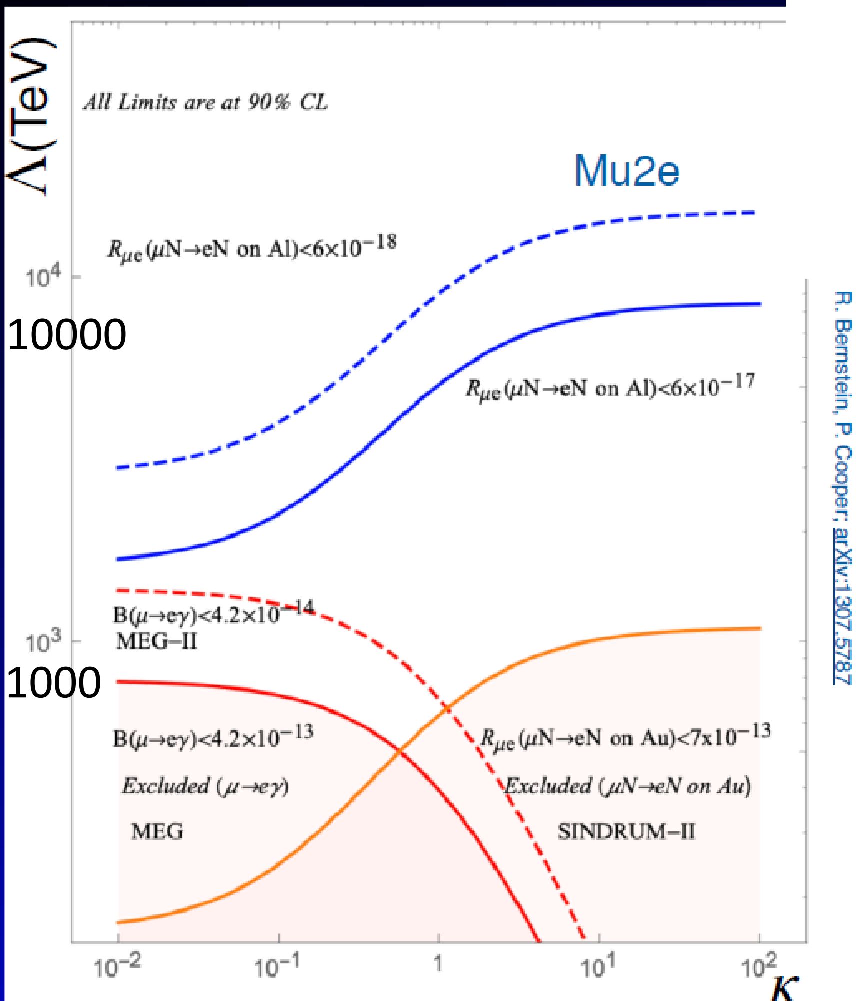
Lower κ is sensitive to the **loop** contributions to the $\mathcal{L}_{CLFV}$	Higher κ is sensitive to the **contact term** of the $\mathcal{L}_{CLFV}$

$\kappa = 0$ ⇦ ⇨ $\kappa = \infty$



Supersymmetry & Heavy neutrinos
$\mu \rightarrow e\gamma$ contribution

Leptoquarks, heavy Z ...
No contribution from $\mu \rightarrow e\gamma$



R. Bernstein, P. Cooper; arXiv:1307.5787

- Example of two types of effective LFV Lagrangian terms, one that is sensitive to loops the other to contact interactions, relative importance dialed by parameter κ
- Mass scales Λ of Mu2e (muon to electron conversion) and MEG ($\mu \rightarrow e\gamma$) extend to 1000's of TeV
- Mu2e I sensitive to both, MEG to only first term, both important to sort out type of any LFV observed