Search for Lorentz Violations in Mu2e Background Processes

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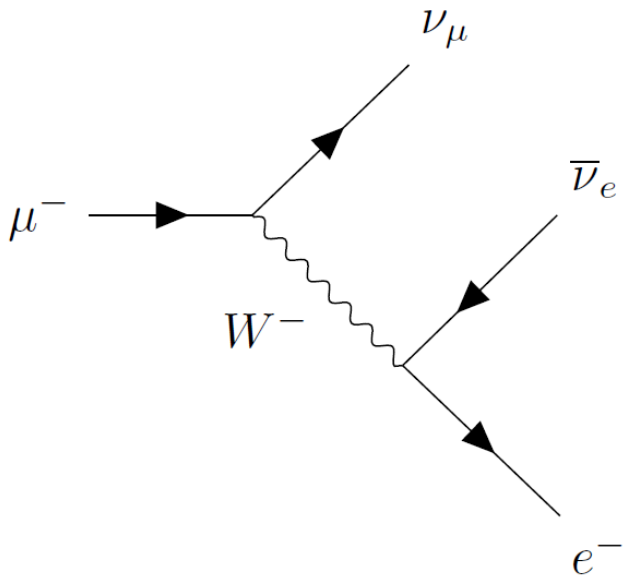
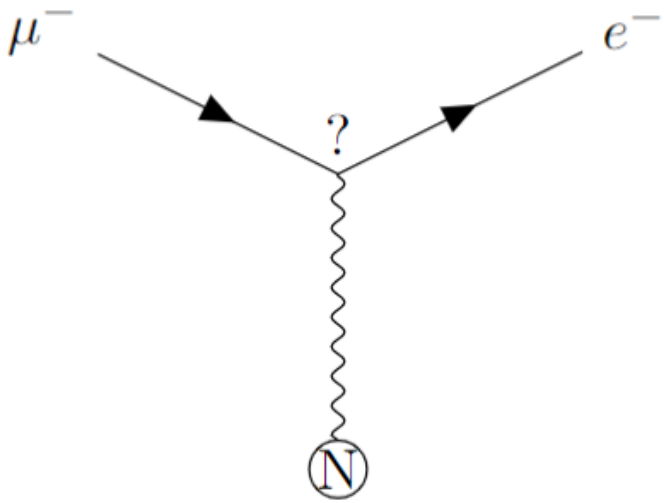
What is Mu2e?

- Free Muon Decay - $\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$
  - ~ 50 MeV

- Electron Conversion - $\mu^- N \rightarrow e^- N$
  - ~ 105 MeV
  - no neutrinos produced
  - Has not been observed yet

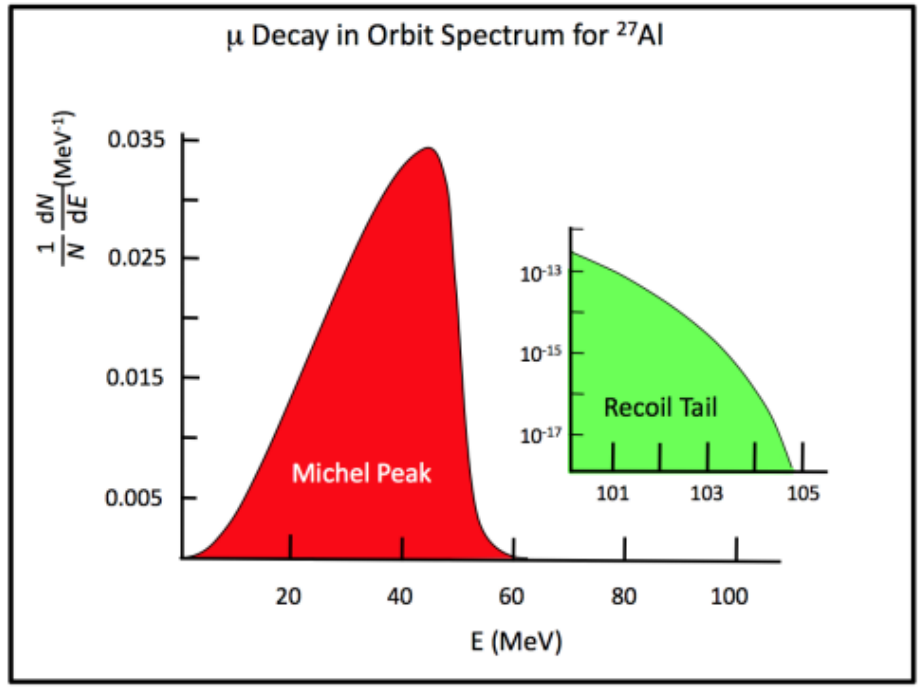


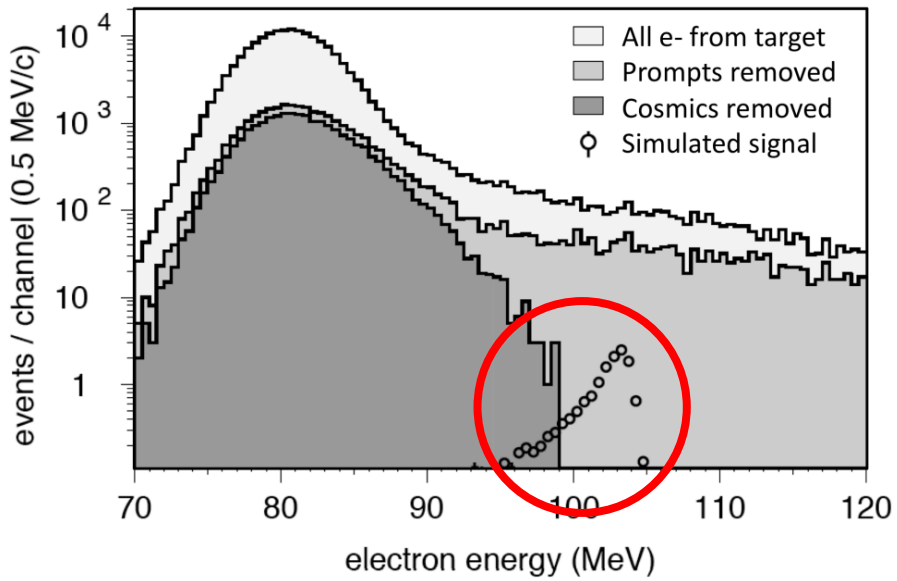


Background Processes

- Muon Decay in Orbit (DIO) – free muon decay from the 1s orbital of the atom
- DIO decays can look like muon conversions

- Our Goal: determine DIO background spectrum with the inclusion of Lorentz-violating terms
  - Similar effects being studied in the muon $g-2$ experiment

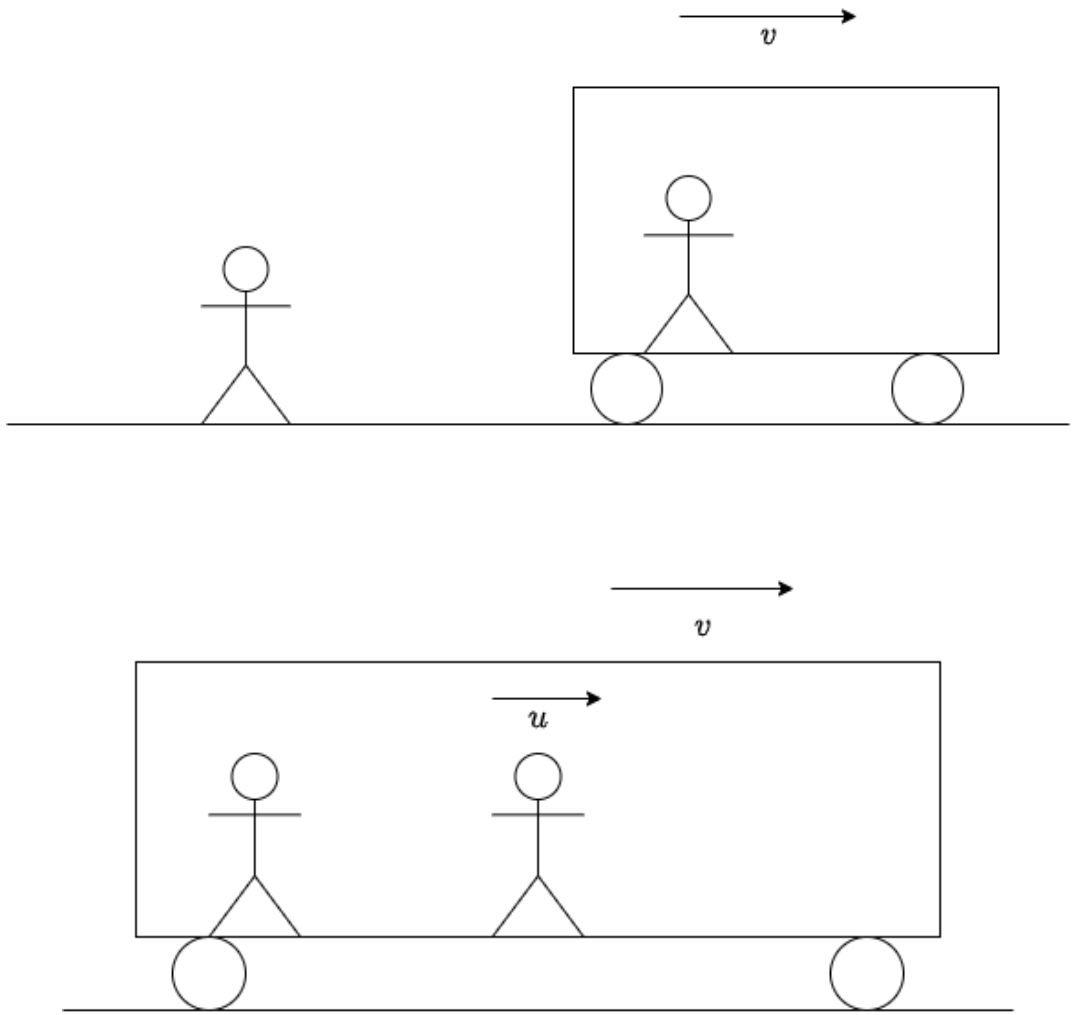




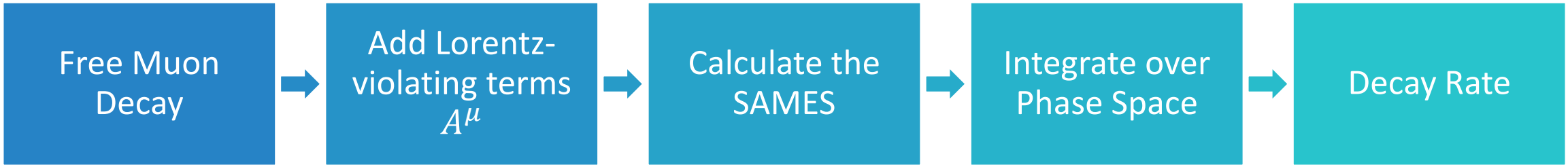
What are Lorentz Violations?

- OBSERVER Lorentz transformation
  - Special relativity
  - Fix particles & their fields
  - Transform IFR

- PARTICLE Lorentz transformation
  - Fix IFR
  - Transform particles & their fields
  - Background fields DON'T change



Roadmap


Free Muon Decay
Add Lorentz-violating terms A^{μ}
Calculate the SAMES
Integrate over Phase Space
Decay Rate

Free Muon Decay

Fermi interaction – describes the muon decay

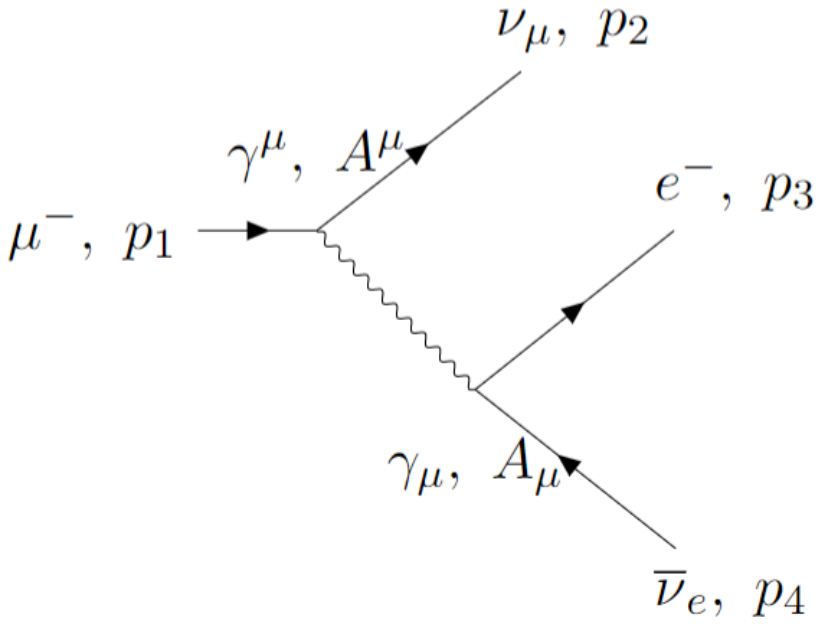
Matrix Element

Electron Current

Muon Current

$$\mathcal{M} = 2\sqrt{2}G_F[\bar{u}(p_3)(\gamma^\mu P_L + A^\mu)v(p_4)][\bar{u}(p_2)(\gamma_\mu P_L + A_\mu)u(p_1)]$$

Interaction Terms



Spin Averaged Matrix Element Squared

$$\langle|\mathcal{M}|^2\rangle = \sum_{spins} \mathcal{M}\mathcal{M}^\dagger$$

$\vdots$ (lots of math)

$$= 32\, G_F^2 \left[2(p_1 \cdot p_4)(p_2 \cdot p_3) + m_\mu\big((p_2 \cdot p_3)(p_4 \cdot A) + (p_2 \cdot p_4)(p_3 \cdot A) - (p_3 \cdot p_4)(p_2 \cdot A)\big)\right]$$

Free Muon Decay

Lorentz-Violating Contributions

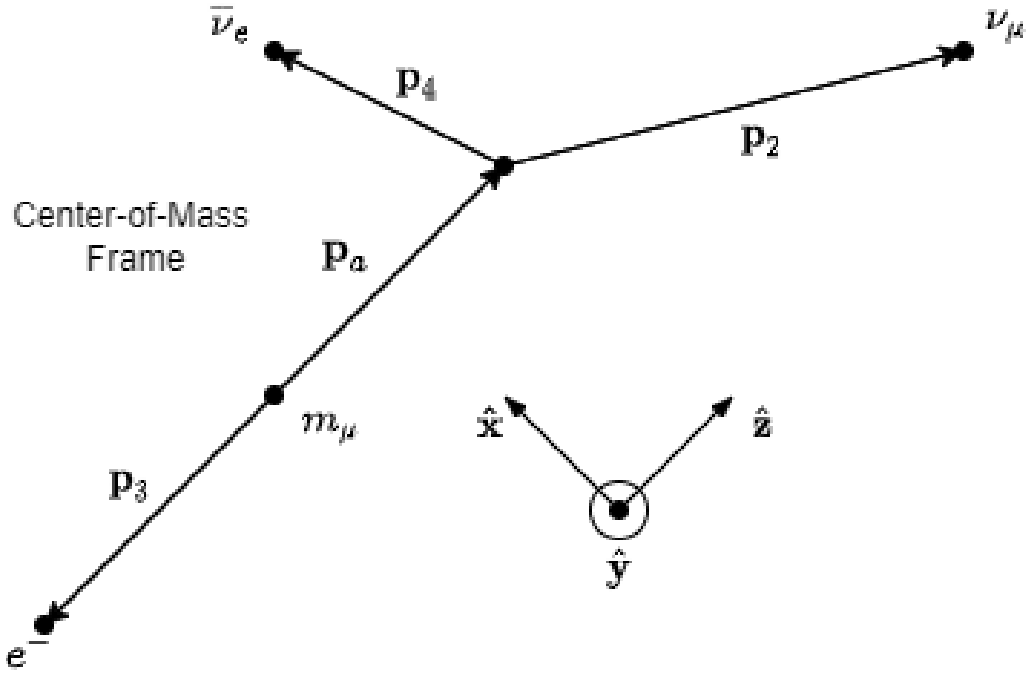
Make some decisions about the nature of A^μ

- Scalar only?
- Parallel to one of the momenta?
- Arbitrary?

The Muon Rest Frame

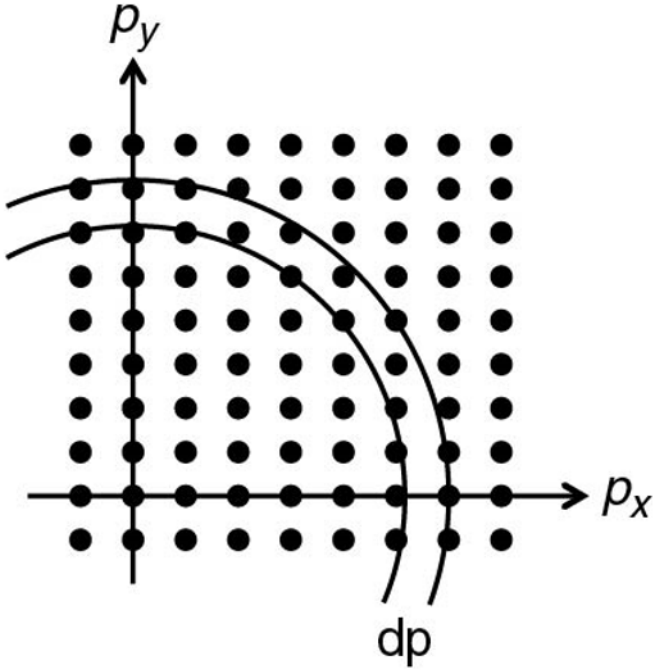
- Change IFR so muon's momentum is zero
  - This is also the COM frame

- All decay particles are co-planar
  - Choose y-axis perpendicular to the plane
  - Choose z-axis parallel to $\boldsymbol{p}_a$



Phase Space and Decay Rate

Phase Space – 2D space of allowed momenta for decay particles



How to fit the momenta of 3 particles into 2D space?

Regular mass: $m^2 = E^2 - p^2$

Invariant mass: $m_{ij}^2 = \left(E_i + E_j\right)^2 - \left(\vec{p}_i + \vec{p}_j\right)^2$

Decay Rate found by integrating $\langle|\mathcal{M}|^2\rangle$ over phase space

$$\Gamma_{fi} = \frac{1}{(2\pi)^3}\frac{1}{32m_\mu^3}\int\langle|\mathcal{M}|^2\rangle\, dm_{23}^2\, dm_{34}^2$$

Results

$$A^{\mu} = 0 \qquad \rightarrow \qquad \Gamma_{fi} = \frac{G_F^2 m_{\mu}^5}{192\pi^3} = \Gamma_0$$

$$A^{\mu} = (\mathrm{A}_0, \pm\mathrm{A}, 0, 0) \rightarrow \qquad \Gamma_{fi} = \Gamma_0 \left(\frac{70+35A_0 \pm 16\pi A}{70}\right)$$

$$A^{\mu} = (A_0, 0, \pm A, 0) \rightarrow \qquad \Gamma_{fi} = \Gamma_0 \left(\frac{2+A_0}{2}\right)$$

$$A^{\mu} = (A_0, 0, 0, \pm A) \rightarrow \qquad \Gamma_{fi} = \Gamma_0 \left(\frac{2+A_0 \pm A}{2}\right)$$

$$A^{\mu} = \left(A_0, A_x, A_y, A_z\right) \rightarrow \qquad \Gamma_{fi} = \Gamma_0 \left(\frac{70+35A_0+16\pi A_x+35A_z}{70}\right)$$

Acknowledgements

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Questions?

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