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Fully differential NLO predictions for rare and radiative lepton decays

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Based on 1611.03617 and 1705.03782
Outline

Introduction

The radiative decay

Rare decay
Introduction

- Radiative ($\mu \rightarrow e\nu\bar{\nu} + \gamma$) and rare ($\mu \rightarrow \nu\bar{\nu} + e^+e^-$) muon decays are a background to $\mu \rightarrow e\gamma$ and $\mu \rightarrow e^+e^-$ searches.

- 4-Fermi interaction, fierzed at the Lagrangian

$$L = L_{\text{QED}} + \frac{G_F}{\sqrt{2}} j_{V-A}(\mu, e) \cdot j_{V-A}(\nu_\mu, \nu_e)$$

- Calculate decays at NLO fully differentially

$\Rightarrow$ Arbitrary distributions with arbitrary cuts.
• 3.5 $\sigma$ discrepancy between BaBar measurement and branching ratio NLO calculation [Fael, Mercalli, Passera 2015]

• Unlikely due to large logarithms or uncomputed higher order corrections

Proposal:

• Experimental cuts are very restrictive and unfolding of acceptance is not trivial

• Correct fiducial acceptance by simulating full cuts of boosted system

• Effect is large! Reduces discrepancy to 1.2 $\sigma$

• We do not claim that this is the full solution

⇒ Fully differential NLO corrections are very important!
Theorist’s version of the MEG detector ($B = 0$)

$E_{\gamma} > 40 \text{ MeV}$

$E_e > 45 \text{ MeV}$

No 2nd photon $E_{\gamma'} > 2 \text{ MeV}$ in the detector
Invisible energy spectrum at MEG

\[ \mathcal{B}_{\text{NP}} \approx 4.2 \cdot 10^{-13} \]
$E_\gamma > 10 \text{ MeV and } \theta > 30^\circ$

Our prediction $B_{\text{PSU}} = (4.26 - 0.04_{\text{NLO}}) \cdot 10^{-3}$ agrees perfectly with [Fael, Mercoll, Passera 2015]

2006: $B_{\pi^\beta}^{2006} = 4.40(9) \cdot 10^{-3}$ (cf. $B_{\text{theo}}^{\pi^\beta} = 4.3 \cdot 10^{-3}$)

2012: $B_{\pi^\beta}^{2012} = 4.37(4) \cdot 10^{-3}$ (cf. $B_{\text{theo}}^{\pi^\beta} = 4.34 \cdot 10^{-3}$)

Assuming $m_e = 0$: $B_{\text{PSU}}^{m_e=0} = (4.35_{\text{LO}} + 0.06_{\text{NLO}}) \cdot 10^{-3}$
Global comparison: \( \mathcal{B}(10 \text{ MeV}) \)

- Relate all data using NLO Monte Carlo to \( E_\gamma > 10 \text{ MeV} \)
- Compute kinematic acceptance \( \epsilon \)

\[
\mathcal{B}(10 \text{ MeV}) = \frac{\mathcal{B}_{\text{PSU}}(10 \text{ MeV})}{\mathcal{B}_{\text{PSU}}(\text{exp. cuts})} \frac{\mathcal{B}_{\text{exp}}(\text{exp. cuts})}{\epsilon}
\]

- \( \epsilon_{\text{MEG}} \approx 2 \cdot 10^5, \epsilon_{\pi\beta} \approx 3 \)
- Combined experimental \( \bar{\mathcal{B}}(10 \text{ MeV}) = 1.27(1) \cdot 10^{-2} \) (1\( \sigma \) above theory)
Rare muon decay

- $4_{\text{Born}} + 40_{\text{1-loop}} + 20_{\text{real}}$ diagrams up to pentagons
- Good parametrisation of phase space very important
- Approximate Mu3e cuts
  $E_{e\pm} > 10 \text{ MeV}$,
  $|\cos \angle(p_{e\pm}, e_z)| < 0.8$
\[ B_{\text{NP}} \approx 10^{-12} \]
BSM potential in $\mu \rightarrow e\nu\bar{\nu} + e^+ e^-$

- Very preliminary!

$$A(\mu \rightarrow e\nu\bar{\nu} + e^+ e^-) = \left| \begin{array}{c}
\gamma \\
\mu^+ \rightarrow e^- e^+ \\
\bar{\nu}_e \\
\bar{\nu}_\mu \\
\end{array} \right|^2 + \left| \begin{array}{c}
X \\
\mu^+ \rightarrow e^- e^+ \\
\bar{\nu}_e \\
\bar{\nu}_\mu \\
\end{array} \right|^2$$

⇒ Looking for light new mediators
- Can New Physics be extracted from precise measurement of shapes in rare muon decay?
- NNLO uncertainties are likely to be very small.
**BSM potential in** \( \mu \rightarrow e\nu\bar{\nu} + e^+ e^- \)

- Distributions for the **hard** \( e^+ \), **soft** \( e^+ \) and **e^-**
- \( K \approx 0.98 \Rightarrow \) shape very precise (small NNLO)
Conclusion

- Fully differential NLO prediction are available for both $\ell \rightarrow l\nu\bar{\nu} + \gamma$ and $\ell \rightarrow l\nu\bar{\nu} + l^+l^-$

- Radiative corrections can be extremely important when unfolding fiducial acceptance to ‘PDG values’

- There is some confusion ($\pi\beta$, BaBar, treatment of 2nd photon)

- MEG & Mu3e: Corrections are negative, normally small (percent level) but can reach $\mathcal{O}(10\%)$