19th International Workshop on Neutrinos from Accelerators

Fully differential NLO predictions for rare and radiative lepton decays

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29TH SEPTEMBER 2017

Based on 1611.03617 and 1705.03782

Outline

Introduction

The radiative decay

Rare decay

Introduction

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

- 4-Fermi interaction, fierzed at the Lagrangian

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

- Calculate decays at NLO fully differentially

$\Rightarrow$ Arbitrary distributions with arbitrary cuts.

$\tau \to e\nu\bar{\nu}\gamma$ decay at BaBar

- $3.5\,\sigma$ discrepancy between BaBar measurement and branching ratio NLO calculation [Fael, Mercolli, Passera 2015]
- Unlikely due to large logarithms or uncomputed higher order corrections

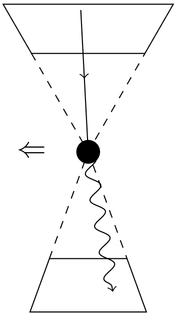
Proposal:

- 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

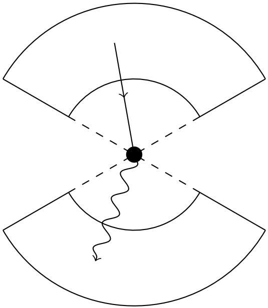
$\Rightarrow$ Fully differential NLO corrections are very important!

MEG geometry

Theorist's version of the MEG detector ($B = 0$)



$E_\gamma > 40\,\mathrm{MeV}$

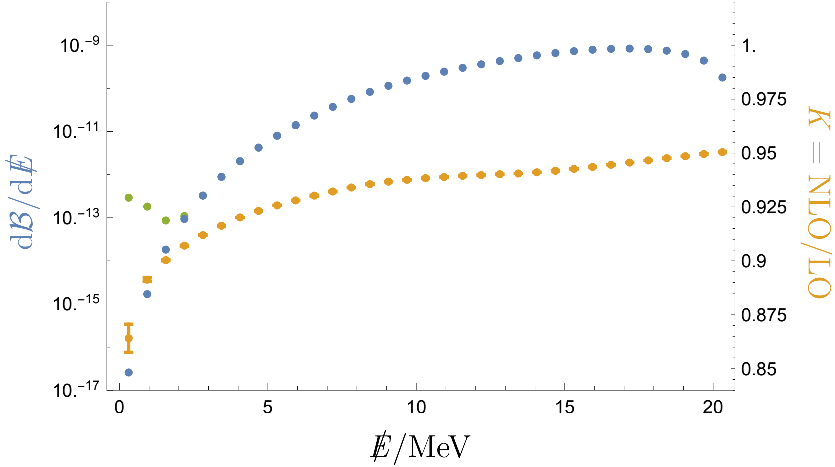


$E_e > 45\,\mathrm{MeV}$

No 2nd photon $E_{\gamma'} > 2\,\mathrm{MeV}$ in the detector

Invisible energy spectrum at MEG

- $\mathcal{B}_{\text{NP}} \simeq 4.2 \cdot 10^{-13}$



$\pi\beta$ branching of $\mu \to e\nu\bar\nu + \gamma$

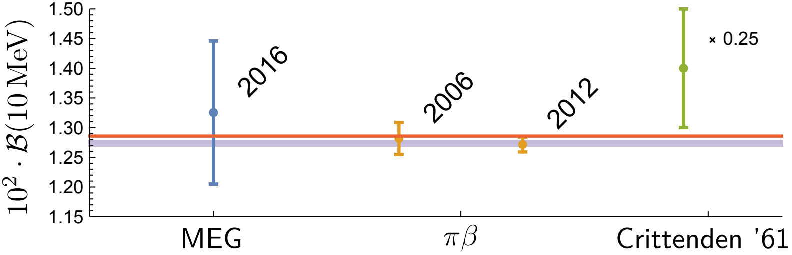
- $E_\gamma > 10\,\mathrm{MeV}$ and $\theta > 30^\circ$
- Our prediction $\mathcal{B}_{\mathsf{PSU}} = (4.26 - 0.04_{\mathrm{NLO}}) \cdot 10^{-3}$ agrees perfectly with [Fael, Mercolli, Passera 2015]
- 2006: $\mathcal{B}^{\pi\beta}_{2006} = 4.40(9) \cdot 10^{-3}$ (cf. $\mathcal{B}^{\pi\beta}_{\mathsf{theo}} = 4.3 \cdot 10^{-3}$)
- 2012: $\mathcal{B}^{\pi\beta}_{2012} = 4.37(4) \cdot 10^{-3}$ (cf. $\mathcal{B}^{\pi\beta}_{\mathsf{theo}} = 4.34 \cdot 10^{-3}$)
- Assuming $m_e = 0$: $\mathcal{B}^{m_e=0}_{\mathsf{PSU}} = (4.35_{\mathrm{LO}} + 0.06_{\mathrm{NLO}}) \cdot 10^{-3}$

Global comparison: $\mathcal{B}(10\,\mathrm{MeV})$

- Relate all data using NLO Monte Carlo to $E_\gamma > 10\,\mathrm{MeV}$
- Compute kinematic acceptance ϵ

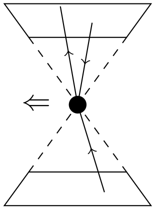
$$\mathcal{B}(10\,\mathrm{MeV}) = \underbrace{\frac{\mathcal{B}_{\mathsf{PSU}}(10\,\mathrm{MeV})}{\mathcal{B}_{\mathsf{PSU}}(\text{exp. cuts})}}_{\epsilon}\mathcal{B}_{\mathsf{exp}}(\text{exp. cuts})$$

- $\epsilon_{\mathsf{MEG}} \approx 2\cdot 10^5$, $\epsilon_{\pi\beta} \approx 3$
- Combined experimental $\bar{\mathcal{B}}(10\,\mathrm{MeV}) = 1.27(1)\cdot 10^{-2}$ (1σ above theory)



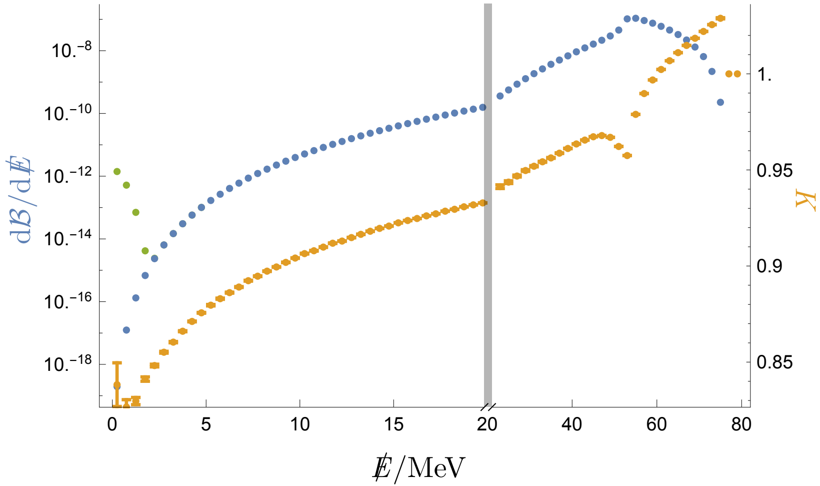
Rare muon decay

- $4_{\text{Born}} + 40_{\text{1-loop}} + 20_{\text{real}}$ diagrams up to pentagons
- Good parametrisation of phase space very important
- Approximate Mu3e cuts
  $E_{e^\pm} > 10\,\text{MeV}$,
  $|\cos\sphericalangle(\boldsymbol{p}_{e^\pm}, \boldsymbol{e}_z)| < 0.8$



Invisible energy spectrum at Mu3e

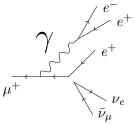
- $\mathcal{B}_{\text{NP}} \simeq 10^{-12}$



BSM potential in $\mu \to e\nu\bar{\nu} + e^+e^-$

- Very preliminary!

$\mathcal{A}(\mu \to e\nu\bar{\nu} + e^+e^-) = \Bigg|$



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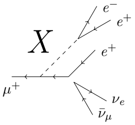


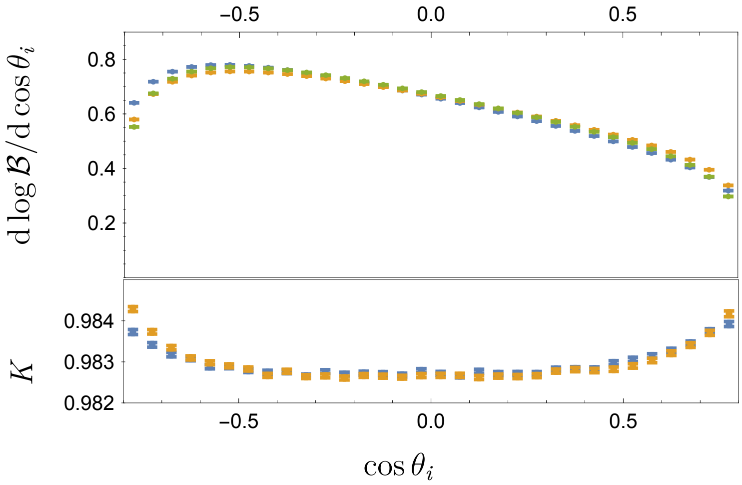
$\Bigg|^2$

$\Rightarrow$ 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 $\mu \to e\nu\bar{\nu} + e^+e^-$

- 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 $\ell \to l\nu\bar{\nu} + \gamma$ and $\ell \to l\nu\bar{\nu} + l^+l^-$
- Radiative corrections can be extremely important when unfolding fiducial acceptance to 'PDG values'
- There is some confusion ($\pi\beta$, BaBar, treatment of 2$^{\text{nd}}$ photon)
- MEG & Mu3e: Corrections are negative, normally small (percent level) but can reach $\mathcal{O}(10\%)$