

Literature review QED Corrections for Low-Energy Experiments A. Flores-Tlalpa, G. López Castro, P. Roig JHEP 04 (2016) 185 e-Print: 1508.01822 [hep-ph] G.M. Pruna, A. Signer, Y. Ulrich Phys.Lett.B 765 (2017) 280-284 e-Print: 1611.03617 [hep-ph] M. Fael and C. Greub JHEP 01 (2017) 084. arXiv: 1611.03726 [ph-ph]. Yannick Ulrich, PhD thesis on MC tool "McMule" e-Print: 2008.09383 [ph-ph] Prepared by Jian Tang Jan. 25th, 2022

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Real Providence of the second second

- Motivations of precision calculation of $\mu \rightarrow eeevv?$
- How to calculate such a rare decay process?
- What information can we learn from it?
- Summary and outlook



Why precision calculation of $\mu \rightarrow eeevv$?



- The observation of lepton flavor violation (LFV) processes would indicate new physics beyond the standard model
- The lepton flavor violation effects in processes of μ → e conversion in a muonic atom, radiative muon decay μ⁺→e⁺γ, muon decay μ⁺→ e⁺e⁻e⁺, and μ⁺e⁻→ μ⁻e⁺ may be large enough to be detected in future experiments.
- Ideas of improvement of muon beam intensity by a few orders of magnitude lead to new possibilities in the design of new lepton flavor violation experiments.
- Analysis of rare background processes is very important for understanding the feasibility of such experiments.
- $\mu \rightarrow \text{eeevv}$ is the most important background process in searches for $\mu^+ \rightarrow e^+e^-e^+$ and $\mu^+e^- \rightarrow \mu^-e^+$.

基础前沿研究从 "0" 到 "1" 的突破口





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- 最新的实验结果是1999年PSI完成,缪子通量
- 我国加速器缪子源提供10⁸μ⁺/s?
- 20+年,探测器技术长足进步;
- 我国加速器技术和粒子探测突飞猛进:
- 目前国际上没有正在进行的相关实验;
- 新一代实验探测灵敏度相比1999年PSI实验结 果,预期提高两个数量级以上!
- MACE实验有望走到世界前列!

MACE实验的本底

A W T M

- Backgrounds:
 - μ⁺ decays to e⁺, Bhabha scattering to generate high-energy e⁻ in coincident with low-energy e⁺

$$\blacktriangleright \mu^+ \text{ decays:} \quad \mu^+ \to e^+ \nu_e \overline{\nu_\mu} e^+ e^-$$

• Anti-muonium decay signals by position-time coincidence



Ref: Shi-Han Zhao.

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MC模拟软件开发和实验方案优化









- Tree-level calculation. **Phy. Rev. D** 79, 073004 (2009)
- The current measured branching ratio for process in PDG:
- R= $(3.4 \pm 0.4) \times 10^{-5}$
- The measured branching ratio is very sensitive to the energy resolution.









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 Δ is a value measured from the total energy endpoint

$$R_{\rm exp} = \int_{m_{\mu}-\Delta}^{\infty} dE_{\rm tot}^m \int_0^{m_{\mu}} dR/dE_{\rm tot} \cdot f(E_{\rm tot}^m - E_{\rm tot})dE_{\rm tot}$$



Cut $(m_{\mu} - E_{\rm tot})$	Statistics	Branching ratio R
$1m_e$	5×10^{8}	$(2.83 \pm 0.16) \times 10^{-19}$
$5m_e$	5×10^{8}	$(4.660 \pm 0.046) \times 10^{-15}$
$10m_e$	10^{8}	$(3.091 \pm 0.032) \times 10^{-13}$
$50m_e$	10^{8}	$(7.127 \pm 0.013) \times 10^{-9}$
$100m_{e}$	10^{8}	$(2.1123 \pm 0.0022) \times 10^{-6}$
no cut	10^{8}	$(3.5908 \pm 0.0033) \times 10^{-5}$

- For a detector response function of the Gaussian form $f(x) = \frac{1}{\sqrt{2\pi} \cdot \sigma} \exp(-\frac{x^2}{2\sigma^2})$
- Because of the steep total energy spectrum near the endpoint, the detector resolution changes significantly the measured branching ratio

- A W T ST
- For each diagram, a symmetric one with $p1 \rightarrow p2$ interchanged must be considered.



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- G. M. Pruna, A. Signer and Y. Ulrich, Fully differential NLO predictions for the rare muon decay, **Phys. Lett. B**765 (2017) 280. arXiv: 1611.03617.
- M. Fael and C. Greub, Next-to-leading order prediction for the decay $\mu^+ \rightarrow e^+(e^+e^-)$ v v, **JHEP** 01 (2017) 084. arXiv: 1611.03726.
- The MC software to account for QED corrections for LFV: McMULE
- arXiv: 2007.01654, <u>https://gitlab.com/mule-tools/mcmule</u>
- At NLO there are about 40 one-loop diagrams and 20 diagrams involving a real emission.







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• LO v.s NLO





- The muon five-body leptonic decay is a tool to study the Lorentz structure of weak interactions and to test lepton flavour universality.
- It is also a source of SM background to search for the lepton-flavour-violating decays in μ \rightarrow eee and MACE.
- The NLO corrections decrease the leading-order prediction by about 10 20%.
- The MC software to account for QED corrections for LFV: McMULE <u>https://gitlab.com/mule-tools/mcmule</u>
- Check and implement it into our software for MACE study.