Light new physics at LFV experiments

Snowmass Townhall Meeting

Rare processes & Precision Frontier

Friday October 2nd

Diego Redigolo

Joint effort with

L. Calibbi, Y. Kuno, R. Essig, A. Papa, C. Wu, T. Xing Y.M. Zhong, R. Ziegler, J. Zupan

3 letters of Interests

Letter of Interest: physics potential with MEGII-fwd

Lorenzo Calibbi,[a] **Angela Papa,**[b,c] **Diego Redigolo,**[d,e] **Robert Ziegler,**[f] **Jure Zupan,**[g]

[a] *School of Physics, Nankai University, Tianjin 300071, China*
[b] *Paul Scherrer Institut (PSI), Forschungsstrasse 111, 5232, Villigen, Switzerland*
[c] *Dipartimento di Fisica dell'Università di Pisa, Largo B. Pontecorvo 3, 56127, Pisa, Italy & INFN Sezione di Pisa, Largo B. Pontecorvo 3, 56127, Pisa, Italy*
[d] *INFN Sezione di Firenze, Via G. Sansone 1, I-50019 Sesto Fiorentino, Italy and Department of Physics and Astronomy, University of Florence, Italy*
[e] *CERN, Theory Division, CH-1211 Geneva 23, Switzerland*
[f] *Institute for Theoretical Particle Physics, Karlsruhe Institute of Technology, Engesserstrasse 7, D-76128 Karlsruhe, Germany*
[g] *Department of Physics, University of Cincinnati, Cincinnati, Ohio 45221, USA*

E-mail: calibbi@nankai.edu.cn, angela.papa@psi.ch, d.redigolo@gmail.com, robert.ziegler@kit.edu, zupanje@ucmail.uc.edu

Snowmass2021 - Letter of Interest

Possibility of Search for Bound $\mu^- \to e^- a$ Decay

Thematic Areas: (check all that apply □/■)

□ (RF1) Weak decays of b and c quarks
□ (RF2) Weak decays of strange and light quarks
□ (RF3) Fundamental Physics in Small Experiments
□ (RF4) Baryon and Lepton Number Violating Processes
■ (RF5) Charged Lepton Flavor Violation (electrons, muons and taus)
□ (RF6) Dark Sector Studies at High Intensities
□ (RF7) Hadron Spectroscopy
□ (Other) *[Please specify frontier/topical group]*

Contact Information: (authors listed after the text)
Submitter Name/Institution: Chen Wu / Osaka University
Collaboration (optional):
Contact Email: wuchen@rcnp.osaka-u.ac.jp

Authors: (names and institutions)

Yoshitaka Kuno, Department of Physics, Graduate School of Science, and Research Center of Nuclear Physics (RCNP), Osaka University, Japan.

Chen Wu, Research Center of Nuclear Physics (RCNP), Osaka University, Japan.

Tianyu Xing, Institute of High Energy Physics, Beijing, China.

Letter of Interest: rare muon decays and light new physics

Lorenzo Calibbi,[a] **Rouven Essig,**[b] **Angela Papa,**[c,d] **Diego Redigolo,**[e,f] **Yi-Ming Zhong,**[g] **Robert Ziegler,**[h] **Jure Zupan,**[i]

[a] *School of Physics, Nankai University, Tianjin 300071, China*
[b] *C.N. Yang Institute for Theoretical Physics, Stony Brook University, Stony Brook, NY 11794*
[c] *Paul Scherrer Institut (PSI), Forschungsstrasse 111, 5232, Villigen, Switzerland*
[d] *Dipartimento di Fisica dell'Università di Pisa, Largo B. Pontecorvo 3, 56127, Pisa, Italy & INFN Sezione di Pisa, Largo B. Pontecorvo 3, 56127, Pisa, Italy*
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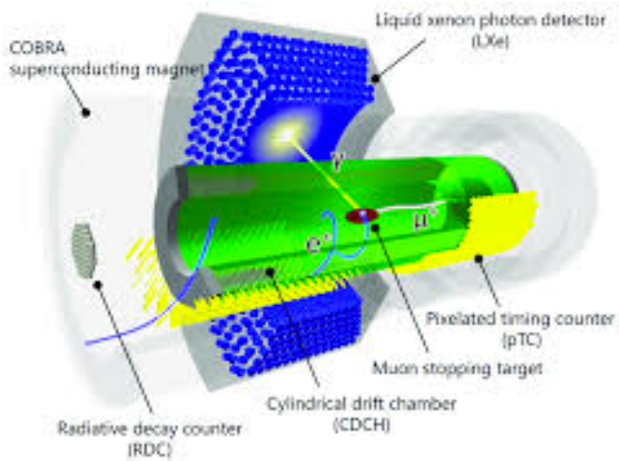
[f] *CERN, Theory Division, CH-1211 Geneva 23, Switzerland*
[g] *Kavli Institute for Cosmological Physics, University of Chicago, Chicago, IL 60637, USA*
[h] *Institute for Theoretical Particle Physics, Karlsruhe Institute of Technology, Engesserstrasse 7, D-76128 Karlsruhe, Germany*
[i] *Department of Physics, University of Cincinnati, Cincinnati, Ohio 45221, USA*

E-mail: calibbi@nankai.edu.cn, rouven.essig@stonybrook.edu, d.redigolo@gmail.com, ymzhong@kicp.uchicago.com, robert.ziegler@kit.edu, zupanje@ucmail.uc.edu

Links for further readings

MEGII-fwd	https://www.snowmass21.org/docs/files/summaries/RF/SNOWMASS21-RF5_RF6-006.pdf
Light NP	https://www.snowmass21.org/docs/files/summaries/RF/SNOWMASS21-RF5_RF0-080.pdf
COMET	https://www.snowmass21.org/docs/files/summaries/RF/SNOWMASS21-RF5_RF0_C_Wu-120.pdf

FUTURE LFV experiments

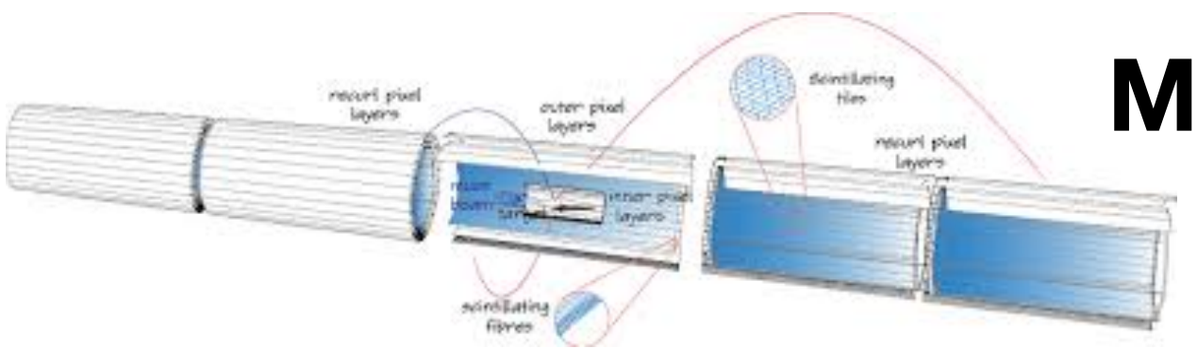


MEGII $\mu^+ \to e^+\gamma$

~ engineering run

Very Intense muon beams:

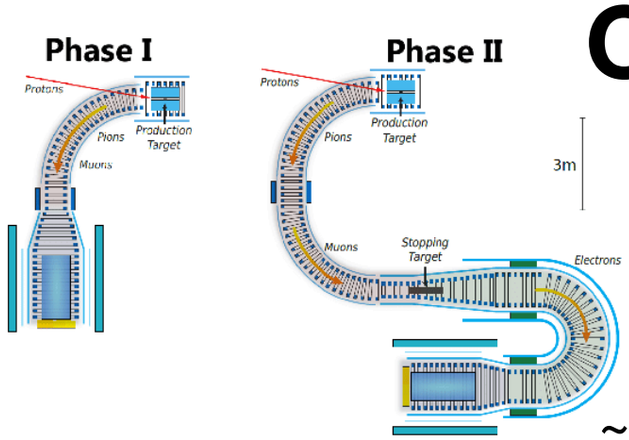
$$10^8 - 10^{10}\mu/\mathrm{sec}$$



Mu3e

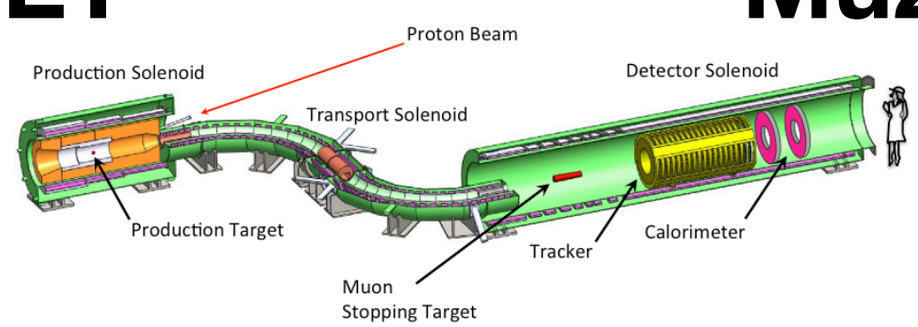
$$\mu^+ \to e^+e^-e^+$$

~ detector construction



COMET

Mu2e



$$\mu^- + N \to e^- + N$$

~similar timelines: construction nearly completed

Broad question

Are there light new physics opportunities at LFV experiments?

an example:

LFV axions

$$c\tau_a \gg L_{\text{detector}}$$

Experimental status

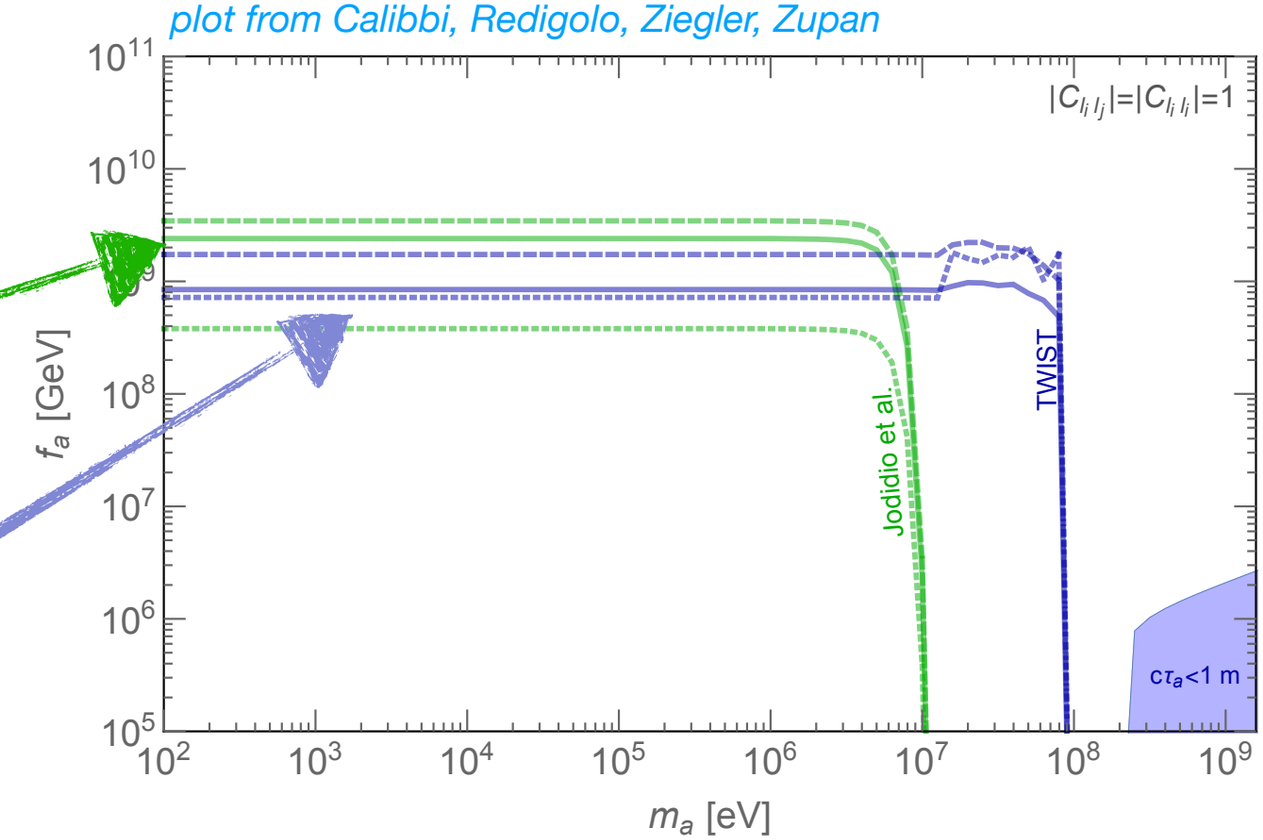
astro-cooling **VS** **LFV decays**

$$\sum_i \frac{\partial_\mu a}{2f_a}\bar{f}_i C^A_{f_i}\gamma_5 f_i + \sum_{i\neq j}\frac{\partial_\mu a}{2f_a}\bar{f}_i\gamma^\mu(C^V_{f_i f_j} + C^A_{f_i f_j}\gamma_5)f_j$$

Iodidio et al. @ TRIUMF 1988
still gives the best bound as long as the axion has a R.H coupling to the SM

TWIST et al. @ TRIUMF 2014
has the best limit on purely L.H axions!

plot from Calibbi, Redigolo, Ziegler, Zupan



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$\mu^+ \to e^+ a$

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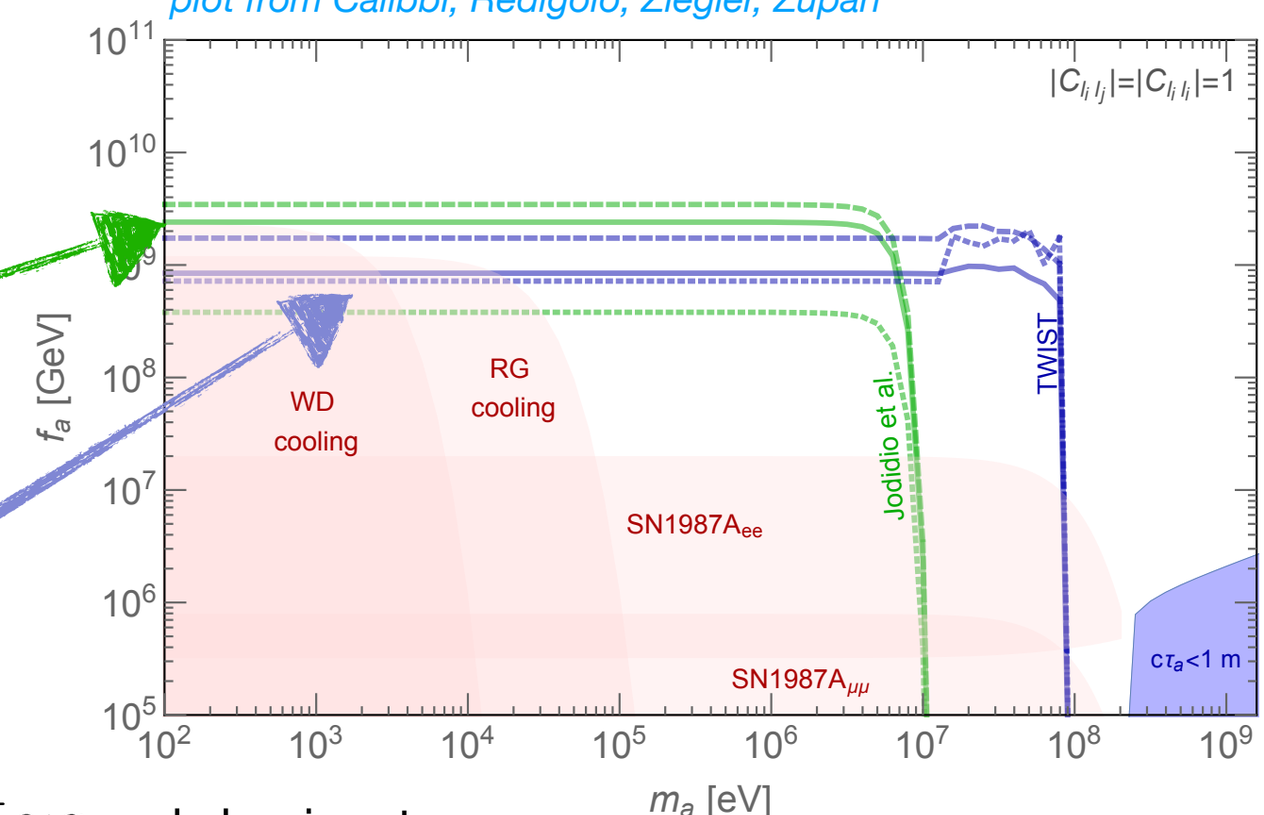


$\mu^+ \to e^+\gamma a$ subdominant

LFV axions

Experimental status

Future exp. proposals

new exp proposal

new analysis

new trigger

MEG-II fwd

$$\mu^+ \to e^+ a$$

with polarized muon beams

Calibbi,Redigolo,Ziegler,Zupan

Mu3e-online

$$\mu^+ \to e^+ a$$

bump hunt online

A-K Perrevoort

COMET

$$\mu^- + N \to e^- a + N$$

DIO shape analysis

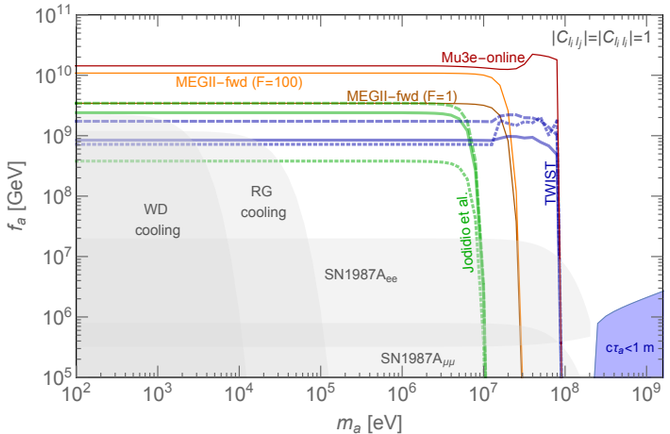
on-going Kuno,Wu,Xing

MEG-II

$$\mu^+ \to e^+ \gamma a$$

missing mass

on-going



Future ground-based LFV experiments can exceed astrophysical limits!!!

Towards a complete list of targets

signature	$\mu \to eX_{\rm NP}$	$\mu \to e\gamma X_{\rm NP}$	$\mu \to e\nu X_{\rm NP}$	$\mu \to e\nu\bar{\nu} X_{\rm NP}$
$\mu \to e + \text{inv}$	$a\|_{\rm inv}, \gamma_d\|_{\rm inv}$	–	$N\|_{\rm inv}$	$a\|_{\rm inv}, \gamma_d\|_{\rm inv}$
$\mu \to 3e$	$a, \gamma_d \to e^+e^-$	–	–	–
$\mu \to e\,2\gamma$	$a \to \gamma\gamma$	–	–	–
$\mu \to e\gamma + \text{inv}$	$a, \gamma_d \to \gamma + \text{inv}$	$a\|_{\rm inv}, \gamma_d\|_{\rm inv}$	$N \to \gamma + \text{inv}$	$a, \gamma_d \to \gamma + \text{inv}$
$\mu \to 3e\,\gamma$	$a \to e^+e^-\gamma$	$a, \gamma_d \to e^+e^-$	–	–
$\mu \to e + 3\gamma$	$\gamma_d \to 3\gamma$	$a \to \gamma\gamma$	–	–
$\mu \to e2\gamma + \text{inv}$	$a, \gamma_d \to \gamma\gamma + \text{inv}$	$N \to \gamma + \text{inv}$	–	$a \to 2\gamma$
$\mu \to 3e + \text{inv}$	$a, \gamma_d \to e^+e^- + \text{inv}$	–	$N \to e^+e^-\nu$	$a, \gamma_d \to e^+e^-$

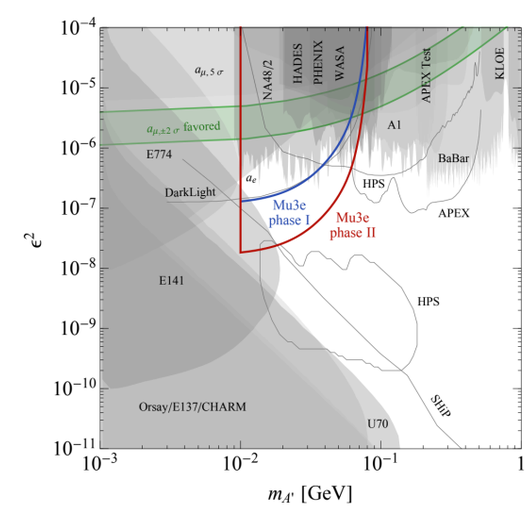
Table 1. Common signatures expected in the $\mu \to X_{\rm NP} X_{\rm SM}$ decays, where $X_{\rm NP}$ is for illustration taken to be either a (pseudo)scalar a, a dark vector, γ_d, or a heavy neutral lepton N.

Invisible decays: see before

Prompt decays: $\mu^+ \to e^+\nu\bar{\nu}\gamma'(e^+e^-)$

B. Echenard, R. Essig, Y. Zhong

Unexplored prompt decays with LFV?



Future effort

More realistic experimental projections:

1) *proper detector simulations*
2) *treatment of theoretical and experimental systematics (bottleneck to improve at high LUMI?)*
3) *trustful comparison of the different options…*
4) *displaced signals?* *Fernando, Hackett, McKeehan*

Help from exp. colleagues

Help from precision computations

More complete signal coverage:

- *Studying prompt/displaced decays of light new states in LFV muon decays*

$$\frac{1}{f_a}\partial a J_{\rm SM} \quad \textbf{\textit{vs}} \quad \frac{1}{g_*^2 f_a^2} J_{\rm SM}^2$$

- *Comparison with other PBC probes of light states in that mass range*