Light new physics at Mu3e and MEG II

Simon Knapen

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J. Jho, SK, D. Redigolo: arXiv 2203.11222
SK, K. Langhoff, T. Opferkuch, D. Redigolo: arXiv 2311.17913 and 2311.17915

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Why muons?

Some tiny coupling

3 x 10^{17}

$$\mathrm{Br}[\mu \to X] \approx \frac{\epsilon^2}{8\pi}\frac{m_\mu}{\Gamma_\mu}$$

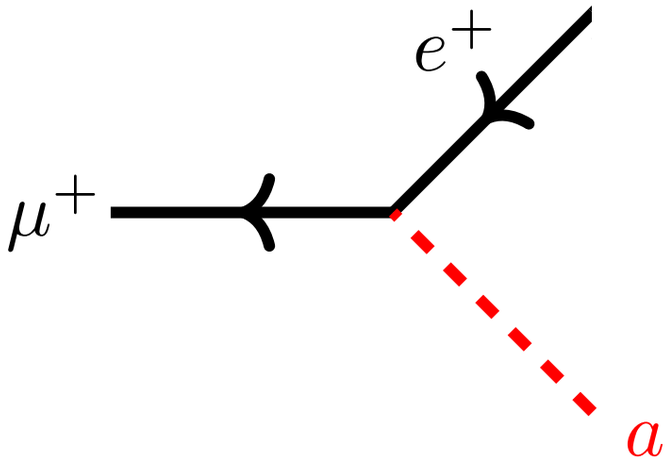
Some hidden sector stuff

We can also make a ton of these things (up to ~10^{18} depending on experiment)

Also works for pions, kaons, B's and to lesser extent Higgs

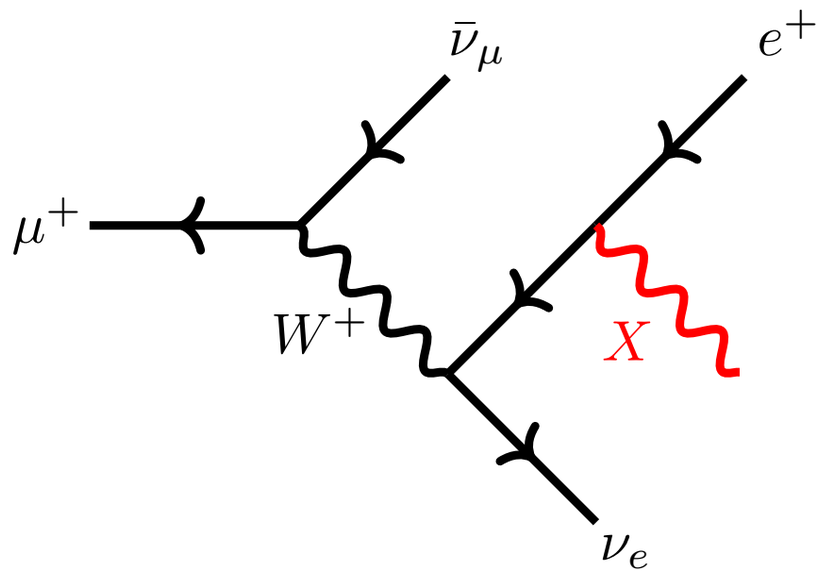
Signatures

Flavor violating



Strong theory prior for *a* to be stable or very long-lived

Flavor conserving



X can decay promptly, displaced or be stable

(Ann-Kathrin already talked about this)

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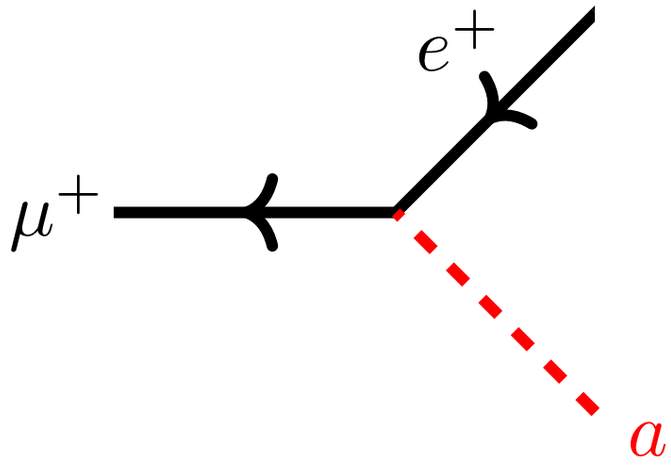

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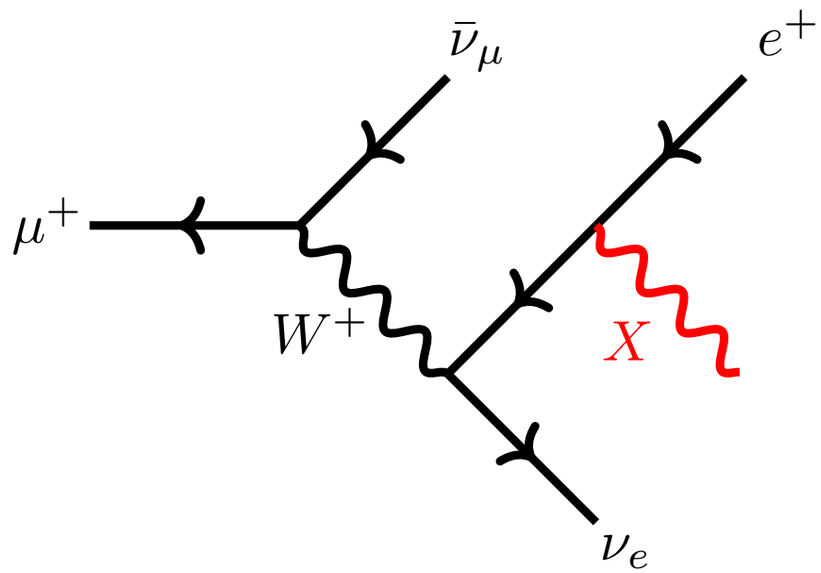

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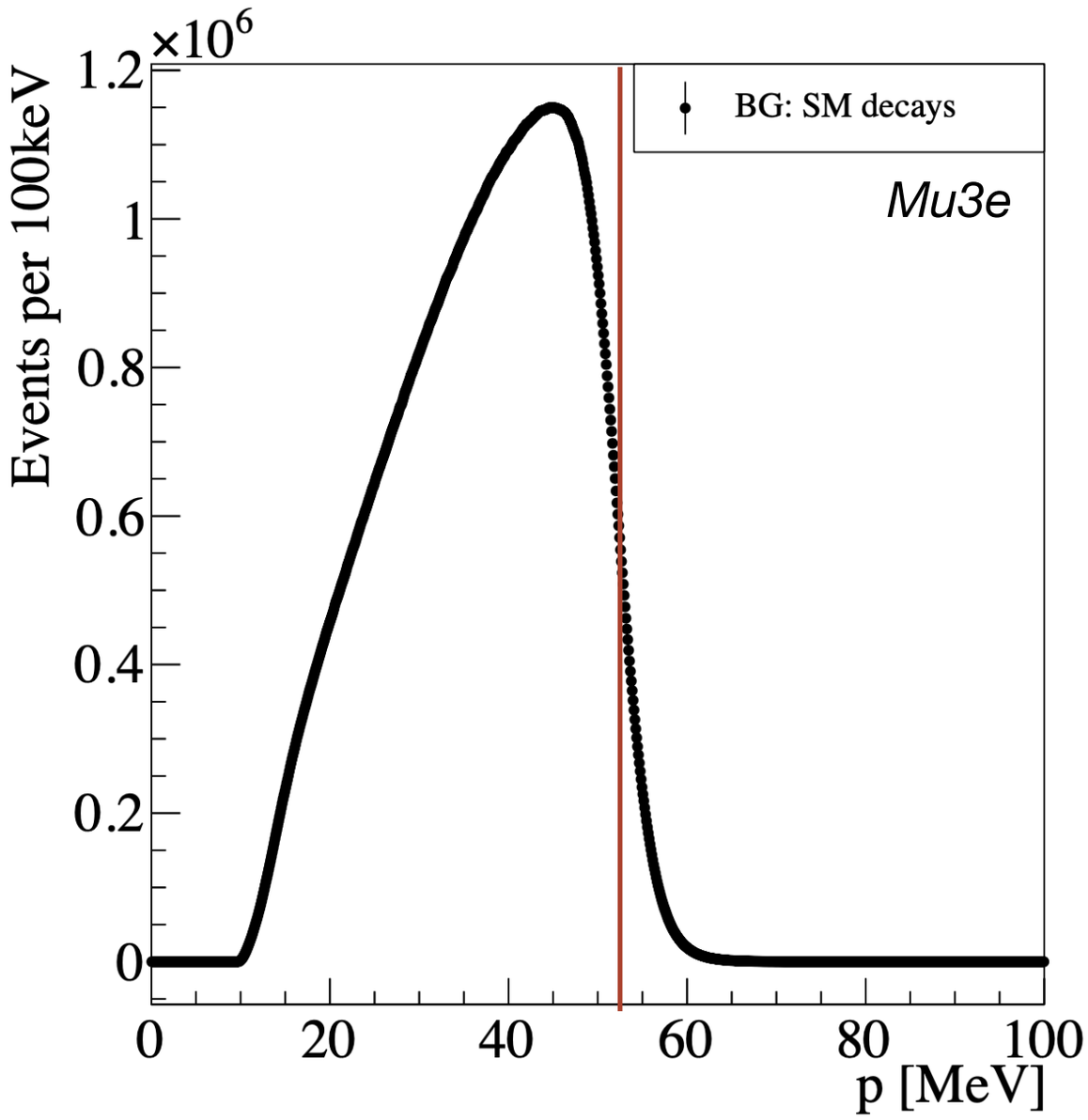
Dealing with the endpoint

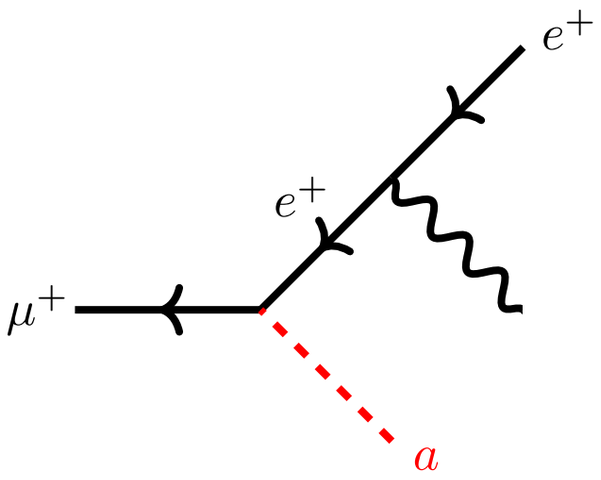


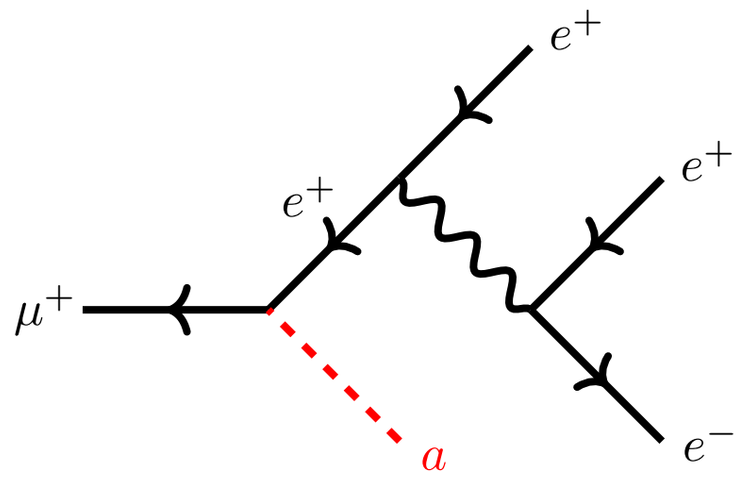
For $m_a <$ MeV, the monochromatic E_e line sits on the Michel endpoint

Search likely systematics limited, good to explore alternatives

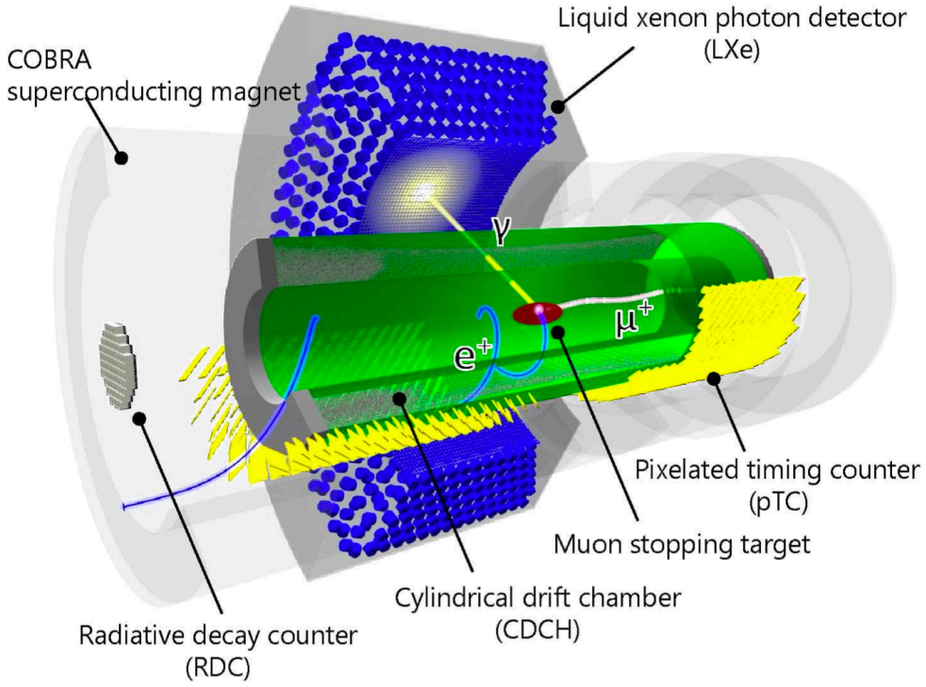
A-K Perrevoort: arXiv 1812.00741

Trading systematics for statistics

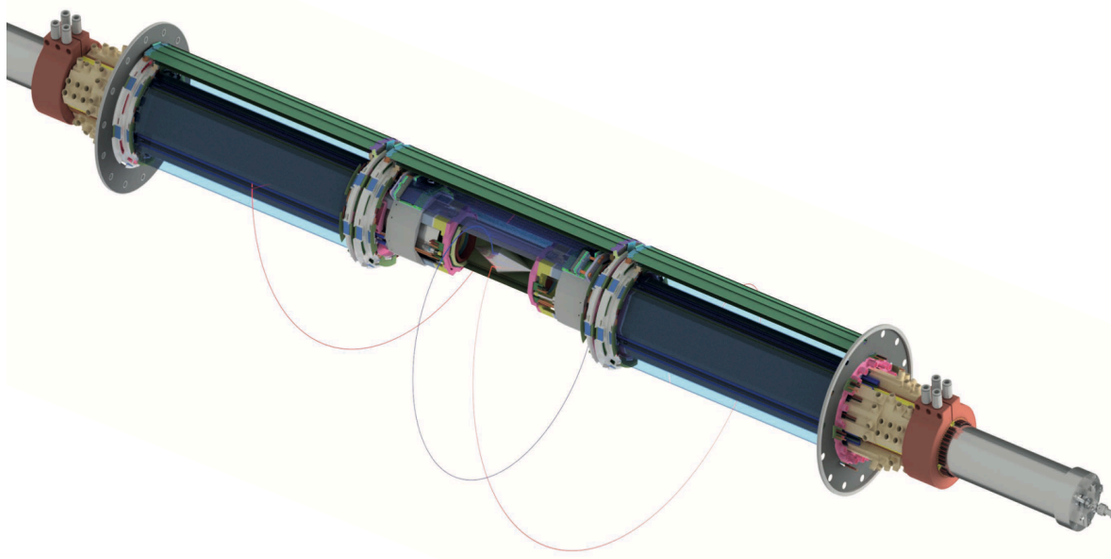




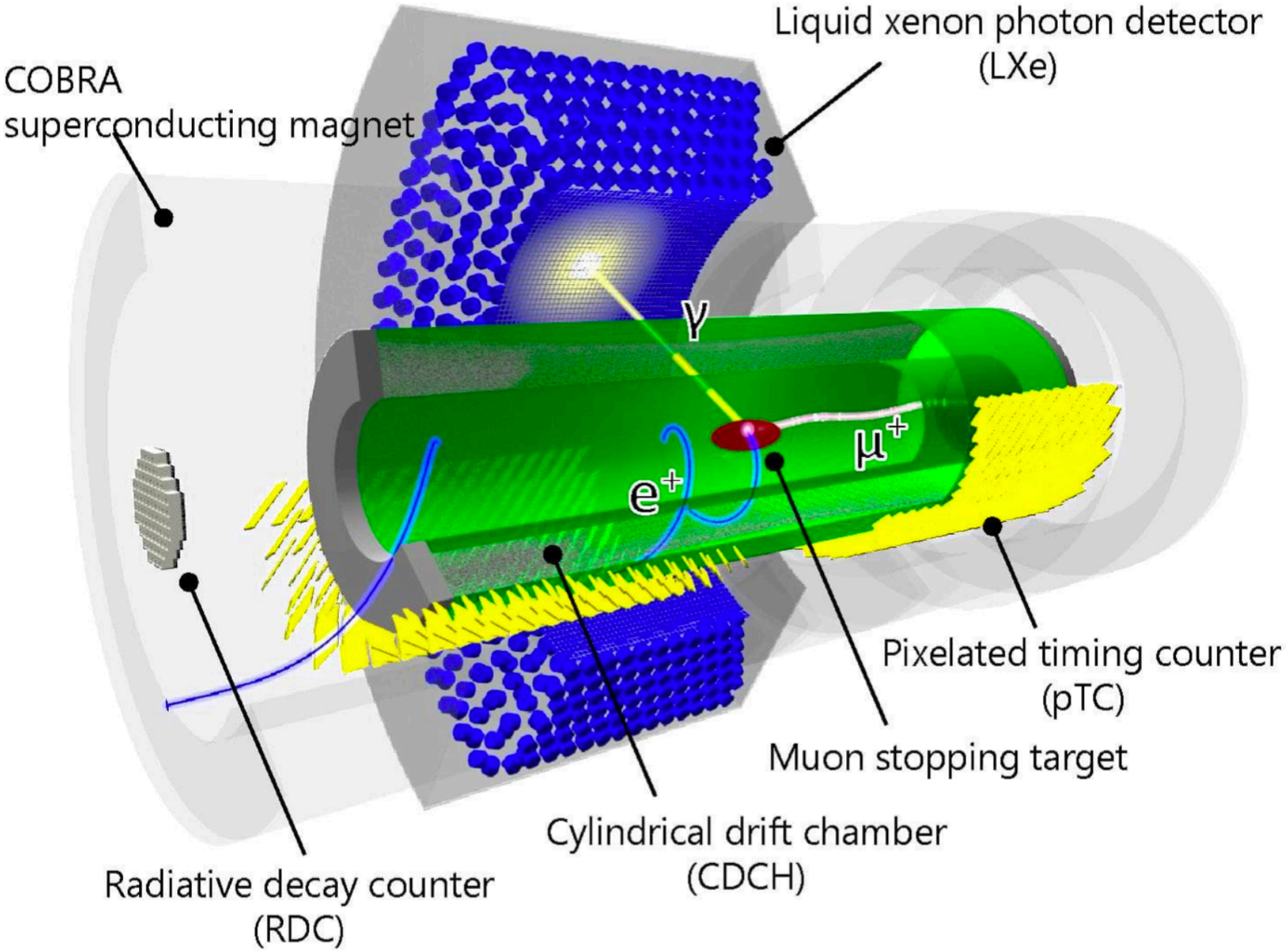
MEG II



Mu3e



MEG II detector



Detector geometry and trigger assume:

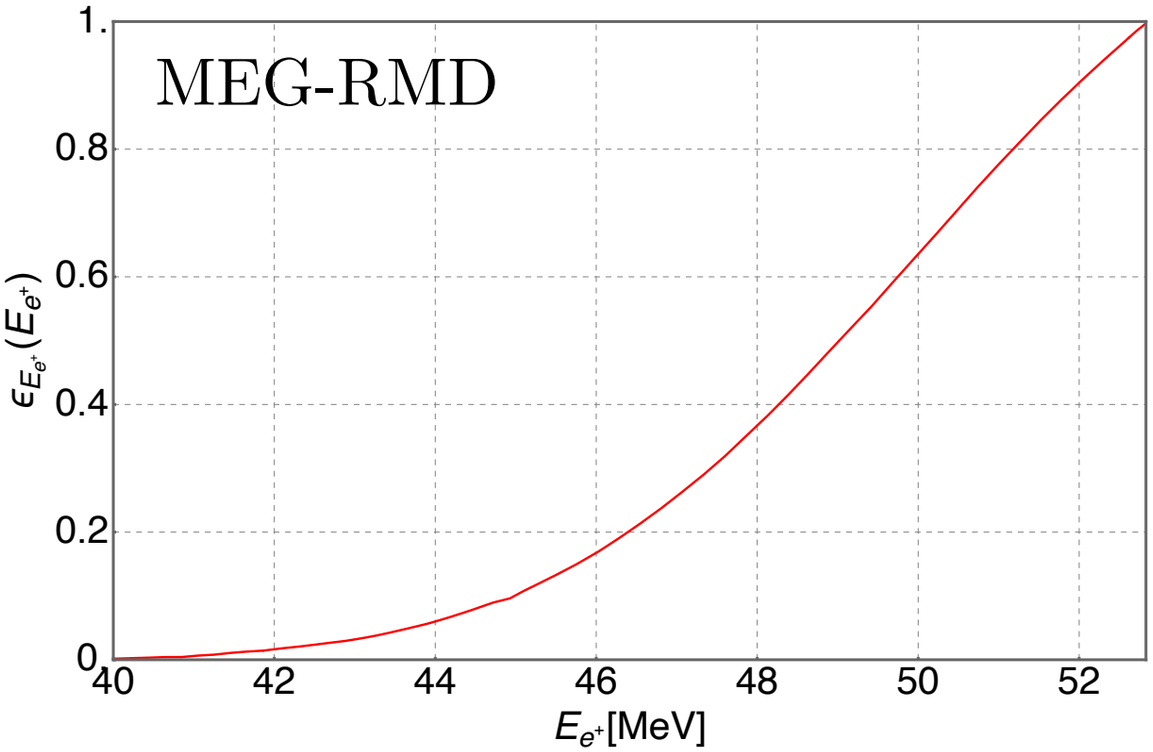
- e^+ and γ back-to-back
- $E_e \approx m_\mu/2$

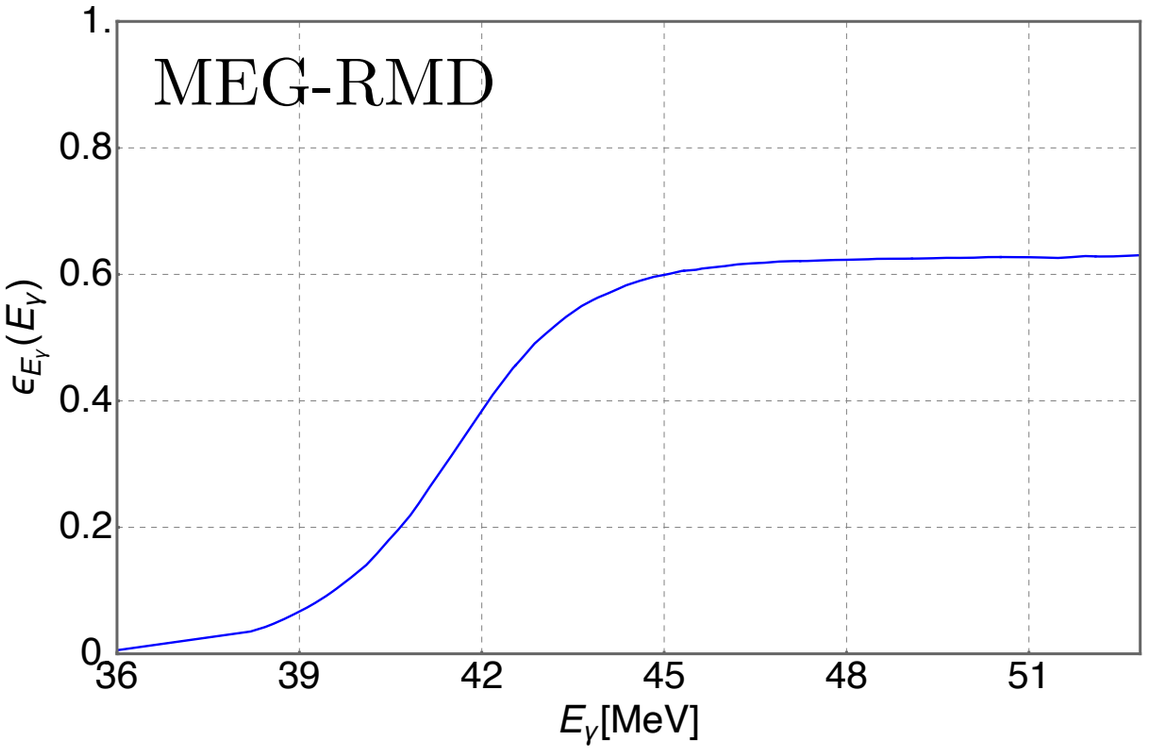
e.g. B-field is non-uniform designed to sweep soft e^+ away from tracker

Assumptions needed to estimate $\mu \rightarrow e + a + \gamma$ acceptance & trigger rate

Trigger at *MEG II* (very oversimplified)

Extracted from MEG's μ→e$\gamma\nu\nu$ measurement (arXiv:1312.3217)





Hardware

Software

J. Jho, SK, D. Redigolo: arXiv 2203.11222

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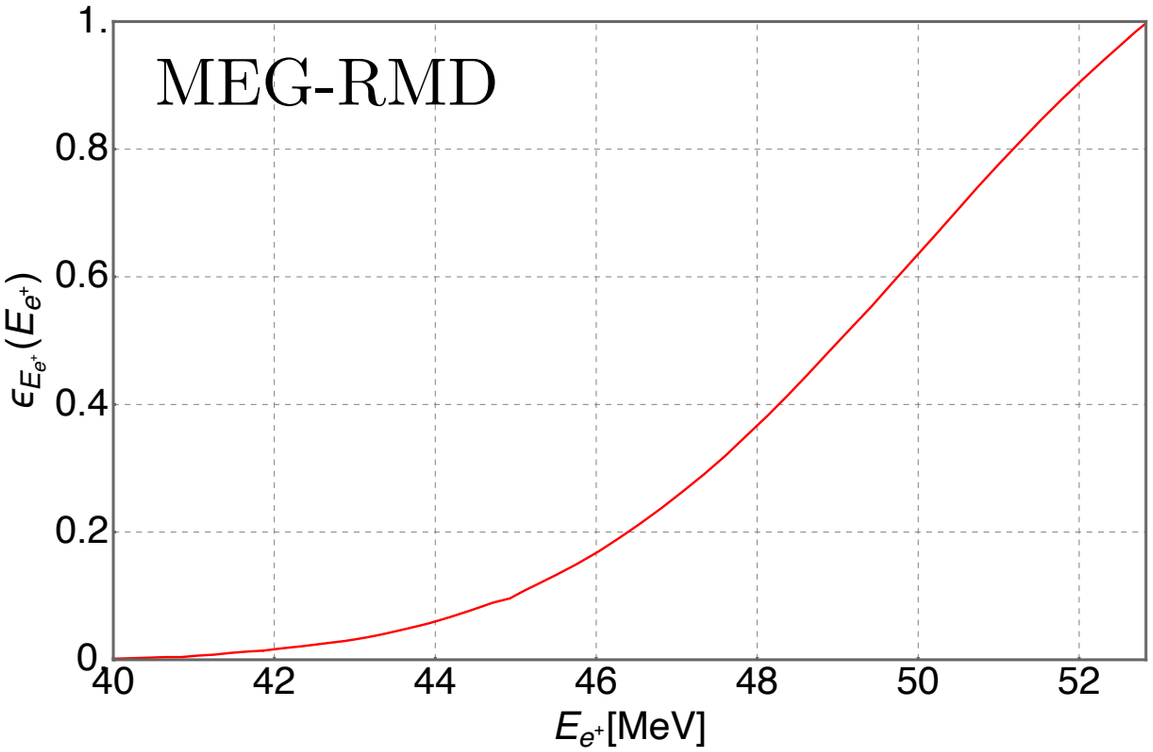
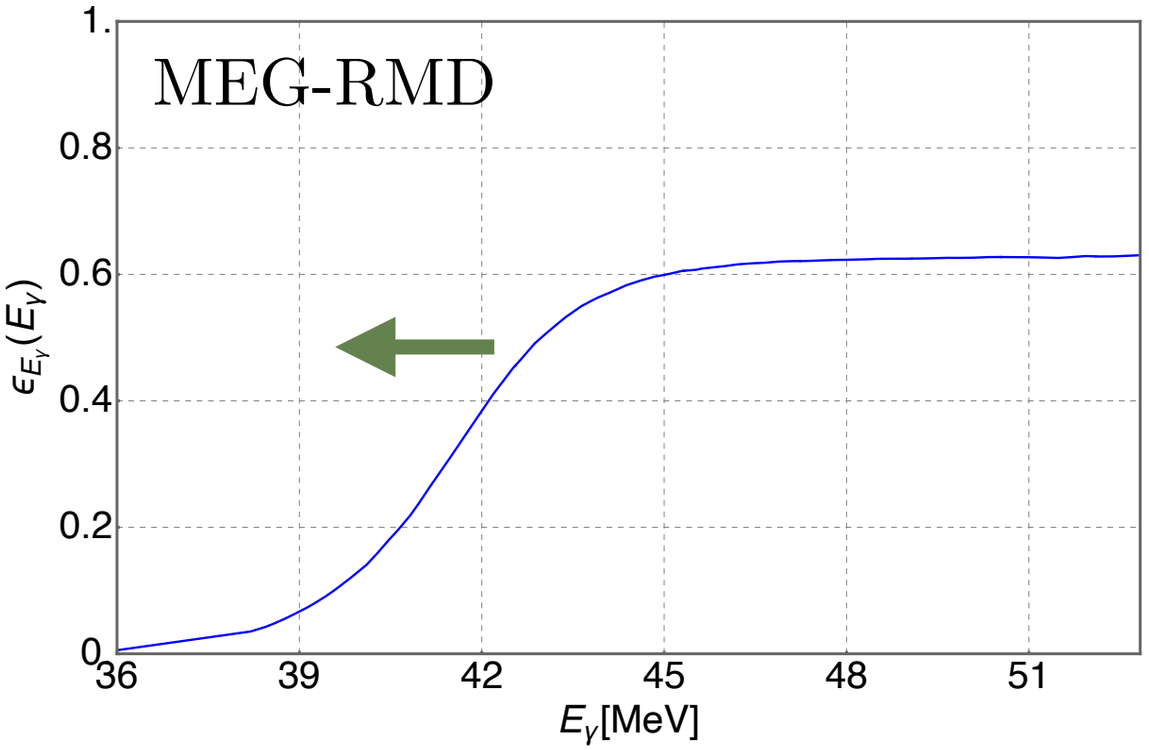




Hardware

Software

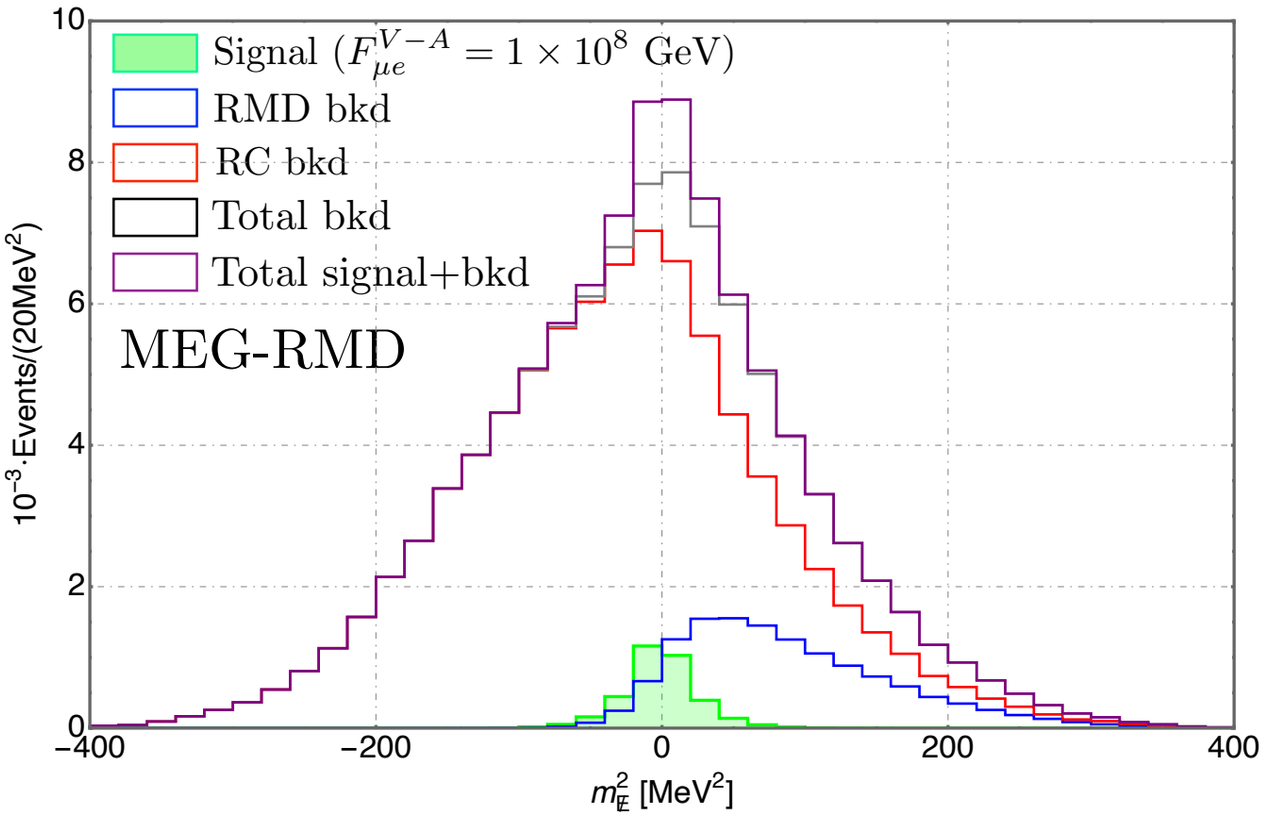
Photon threshold can in principle be lowered, but beam intensity must be reduced

J. Jho, SK, D. Redigolo: arXiv 2203.11222

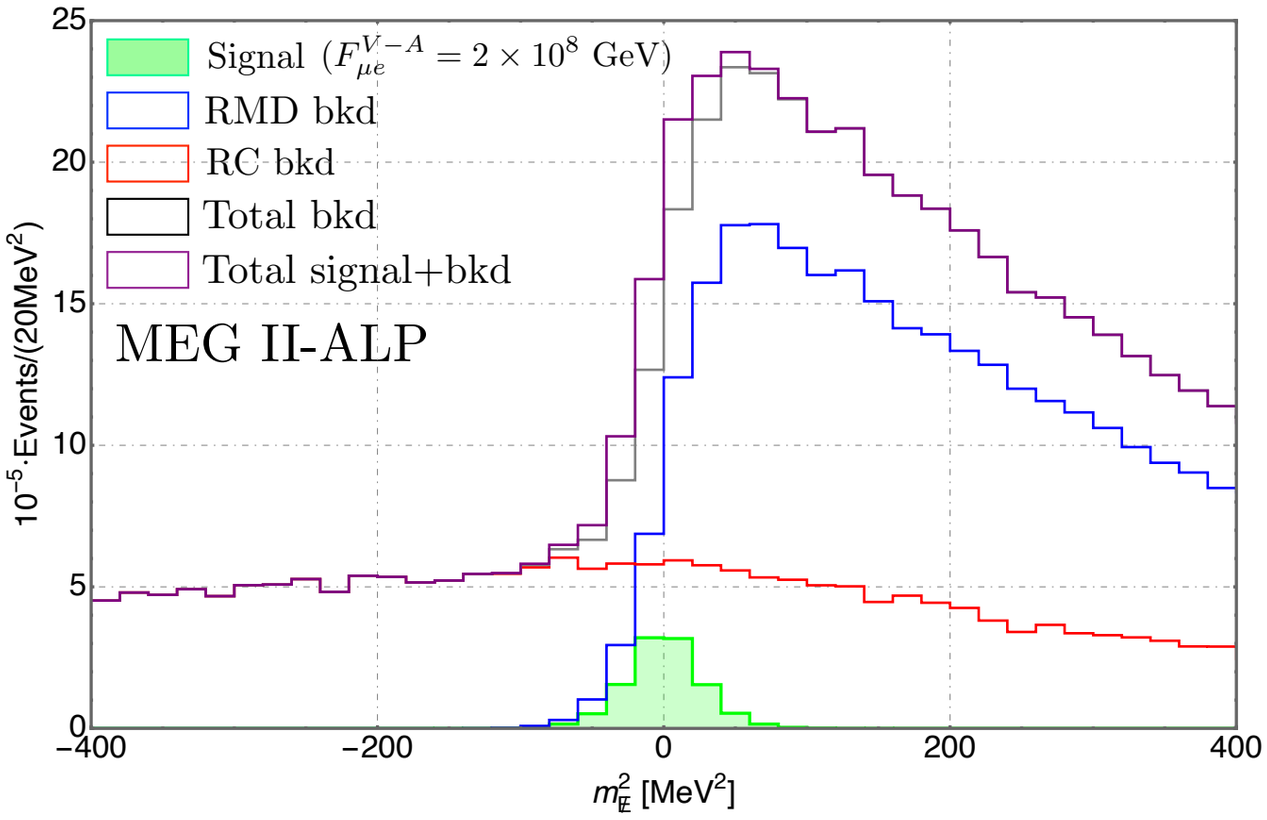
Missing mass at *MEG II*

Can reconstruct the missing invariant mass from the e + γ

Parasitic on normal MEG II run



Dedicated low intensity run



J. Jho, SK, D. Redigolo: arXiv 2203.11222

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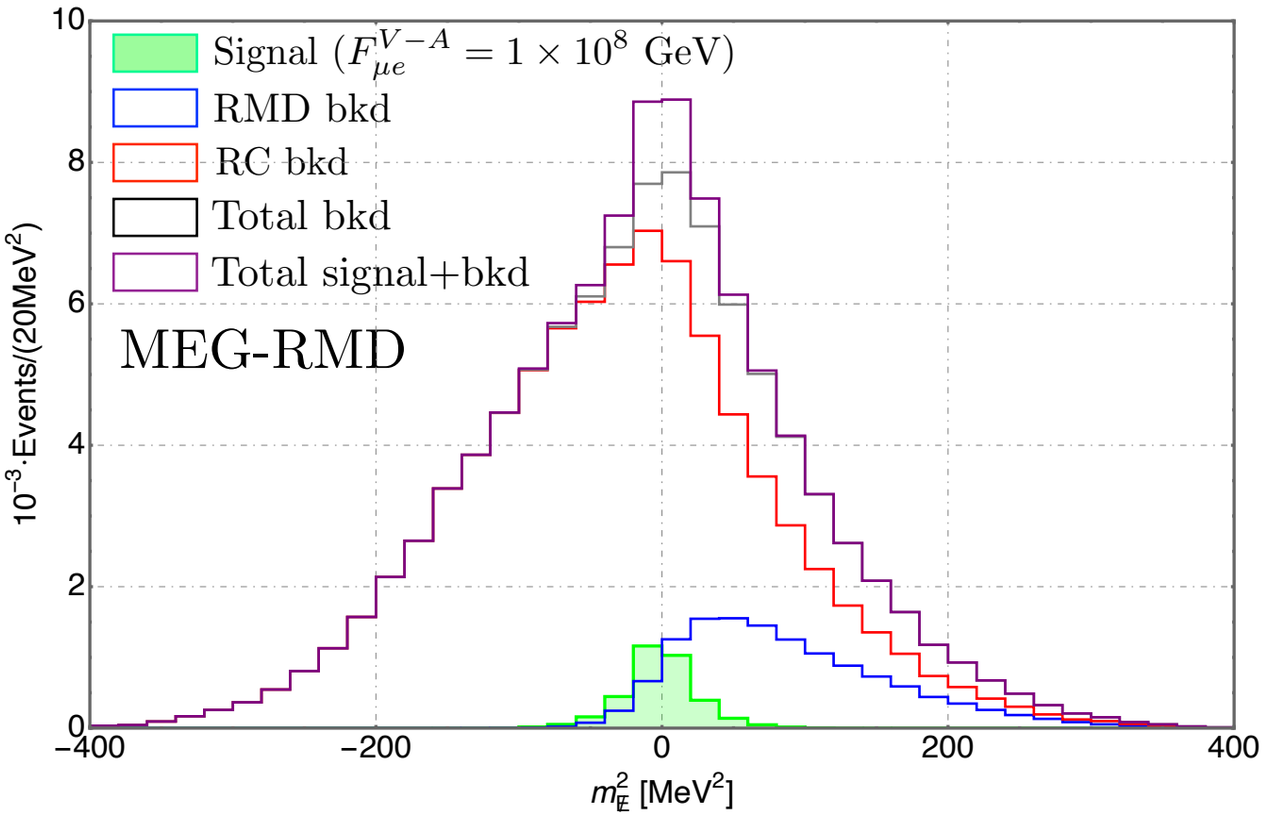

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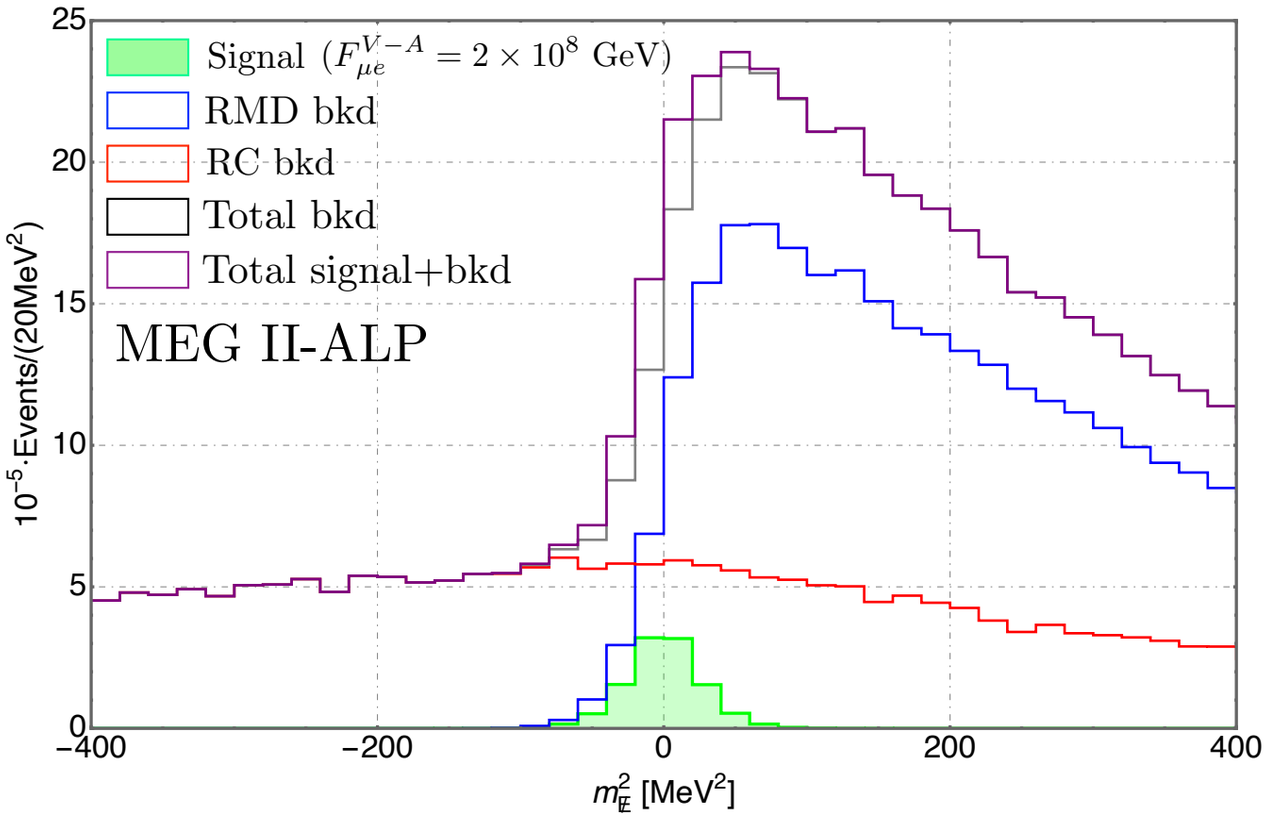
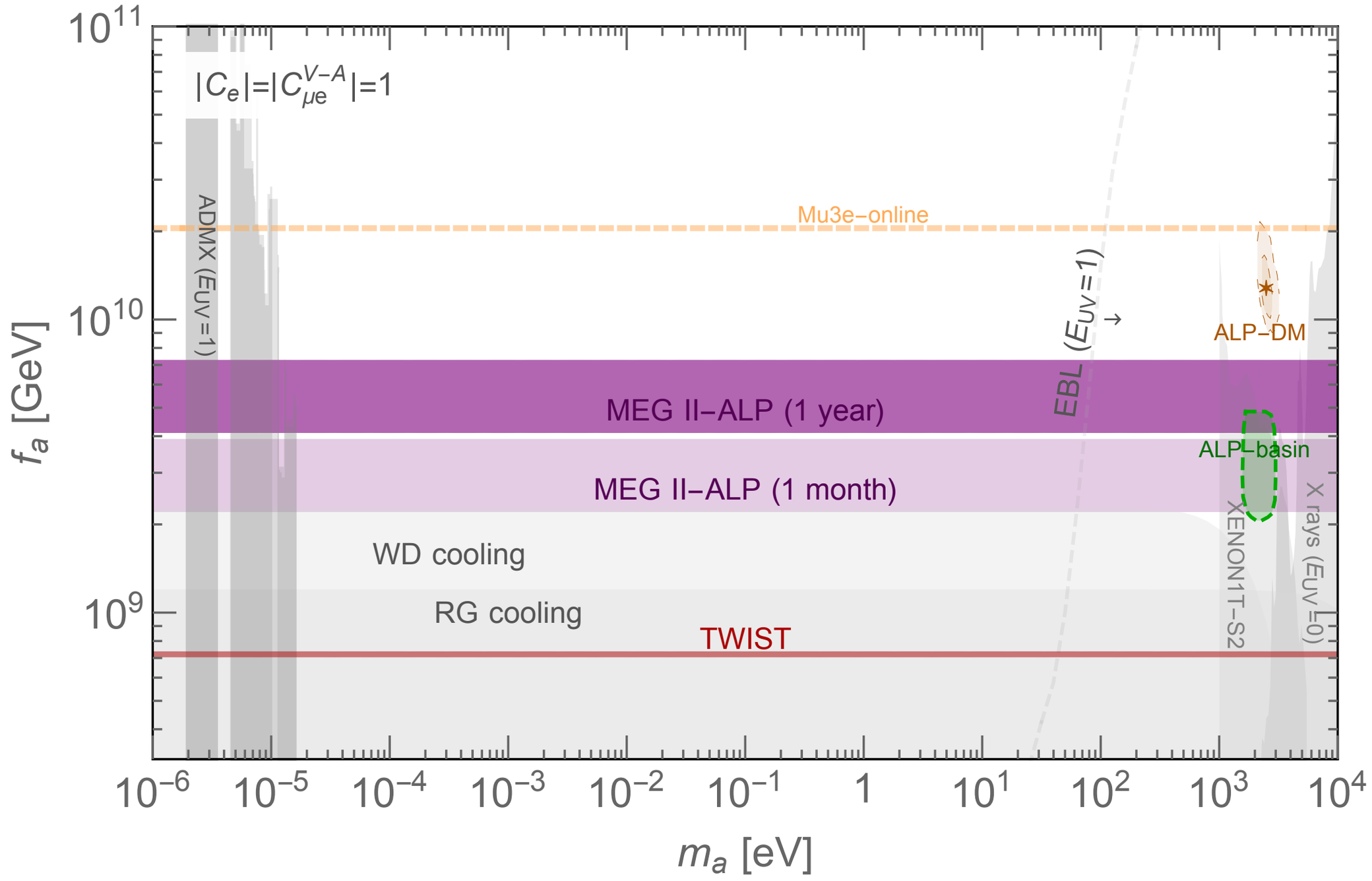


A low intensity run (1/50 of normal) is better because:

- Allows for looser cut on photon energy
- Reduced background from coinciding decays

J. Jho, SK, D. Redigolo: arXiv 2203.11222

MEG II reach



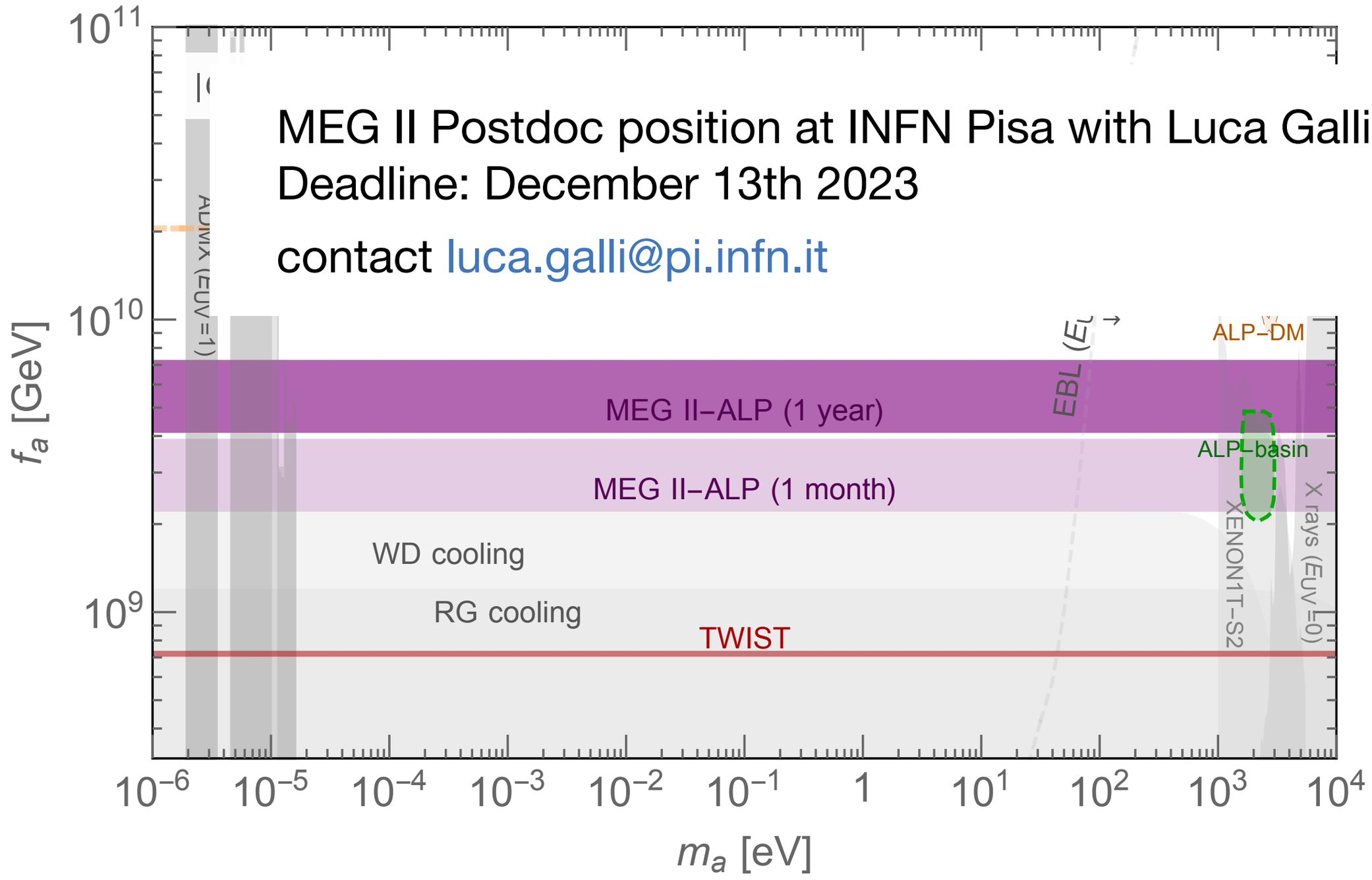
New parameter space with ~ few days of dedicated data taking

J. Jho, SK, D. Redigolo: arXiv 2203.11222

MEG II reach

MEG II Postdoc position at INFN Pisa with Luca Galli
Deadline: December 13th 2023

contact luca.galli@pi.infn.it

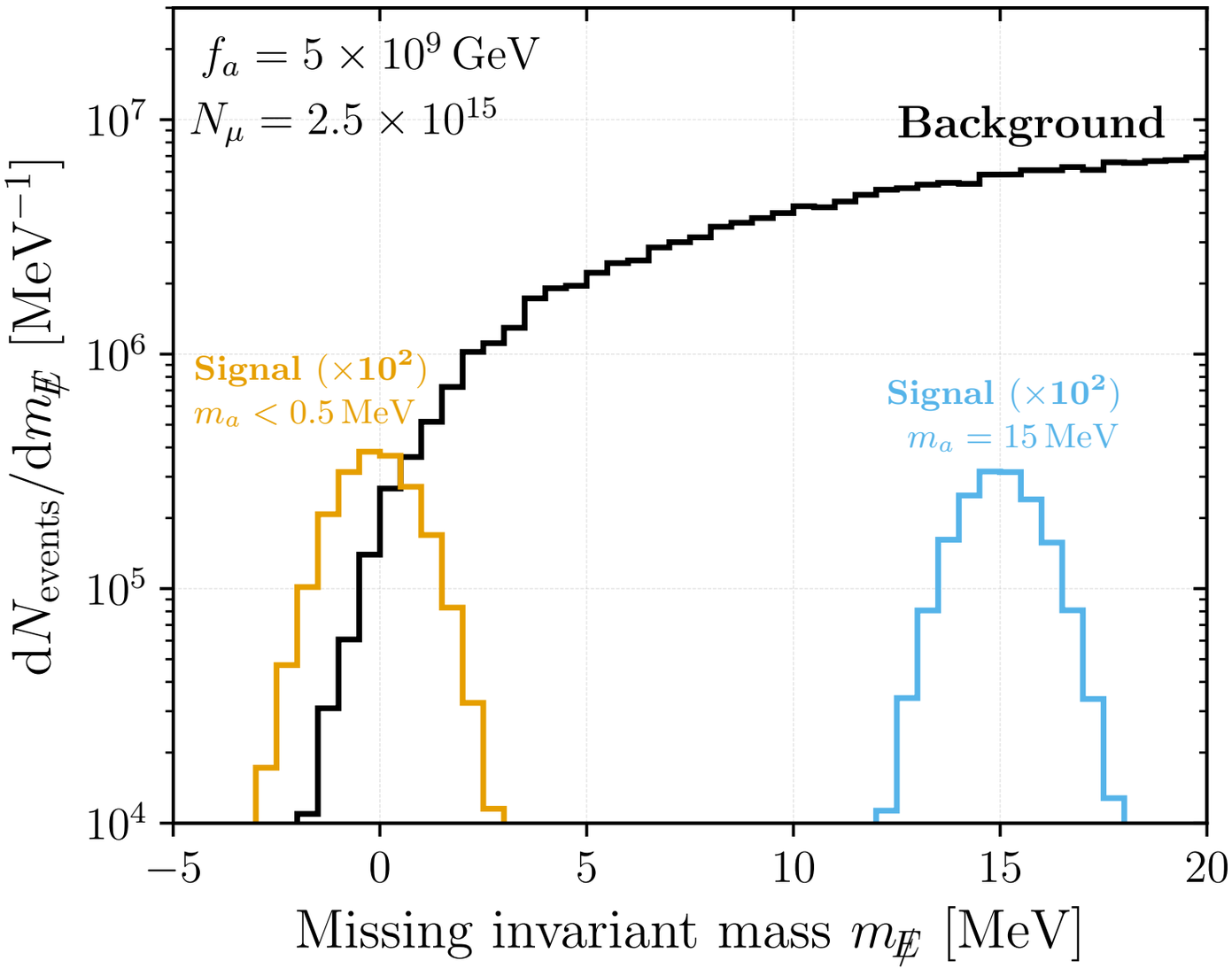


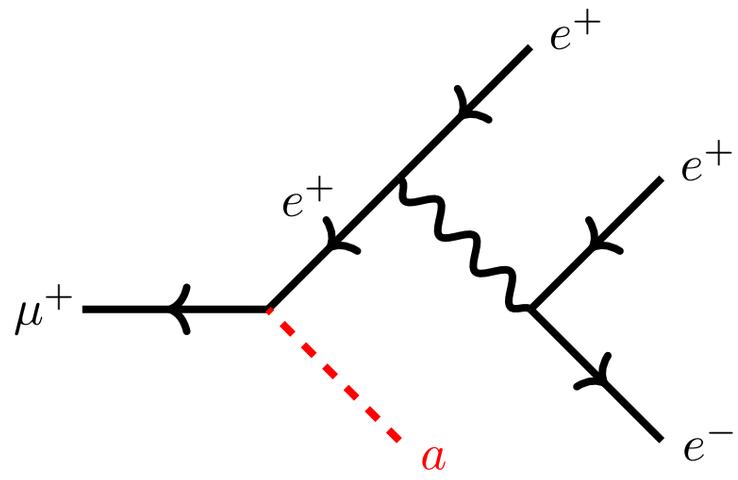
New parameter space with ~ few days of dedicated data taking

J. Jho, SK, D. Redigolo: arXiv 2203.11222

At *Mu3e*

Can reconstruct the missing invariant mass from the 3 tracks

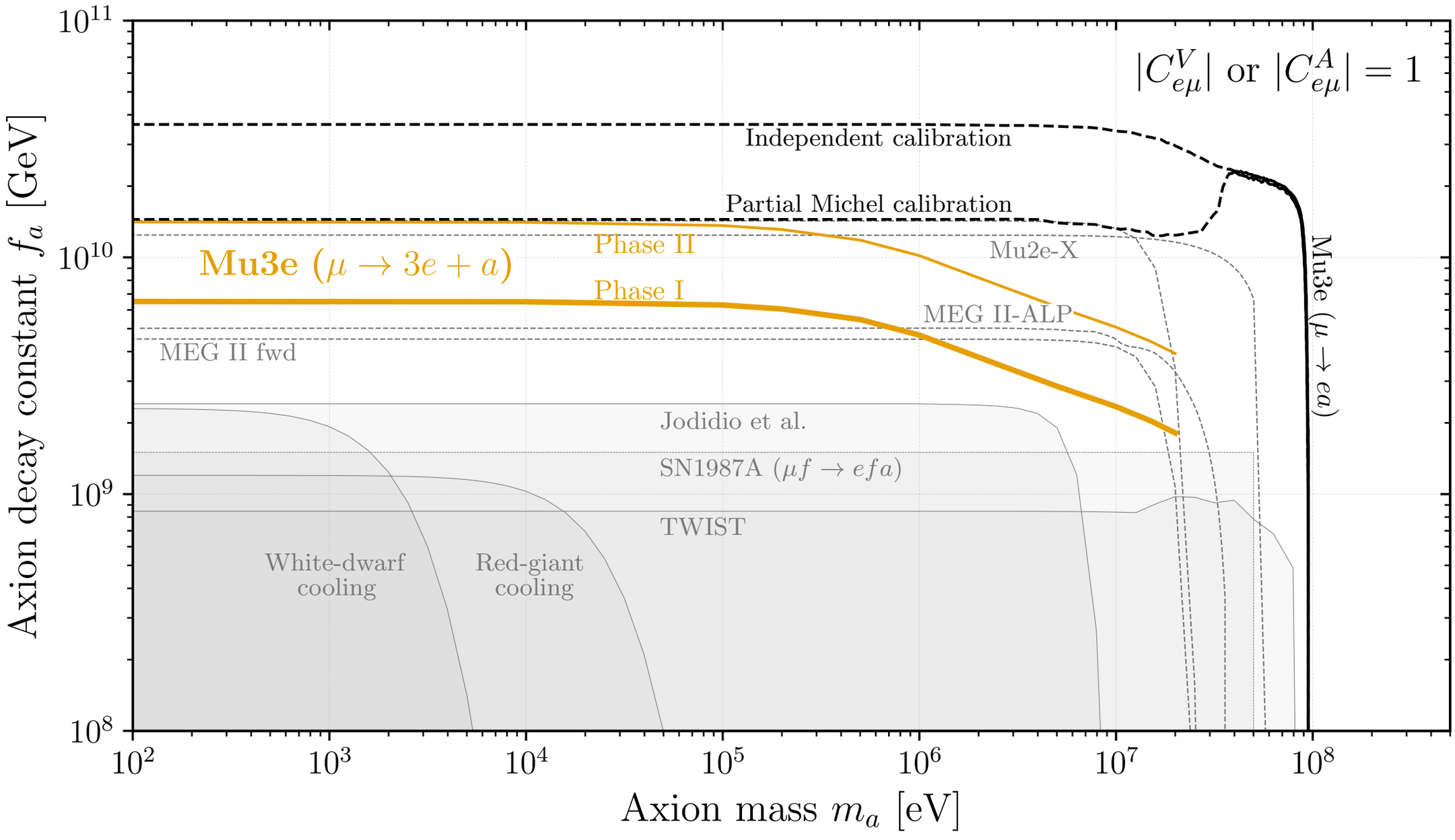




Background fall sharply as both neutrino's are forced to be co-linear

SK, K. Langhoff, T. Opferkuch, D. Redigolo: arXiv 2311.17915

At *Mu3e*

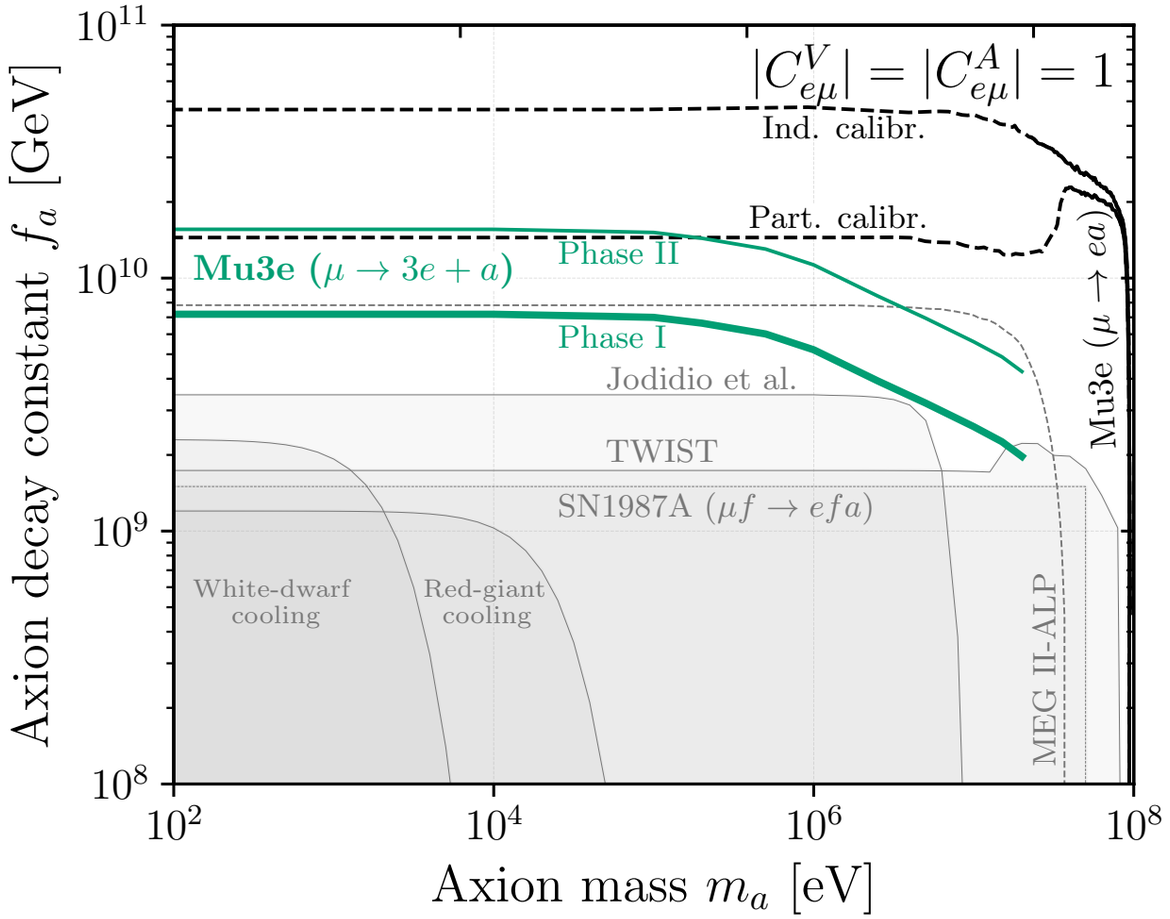


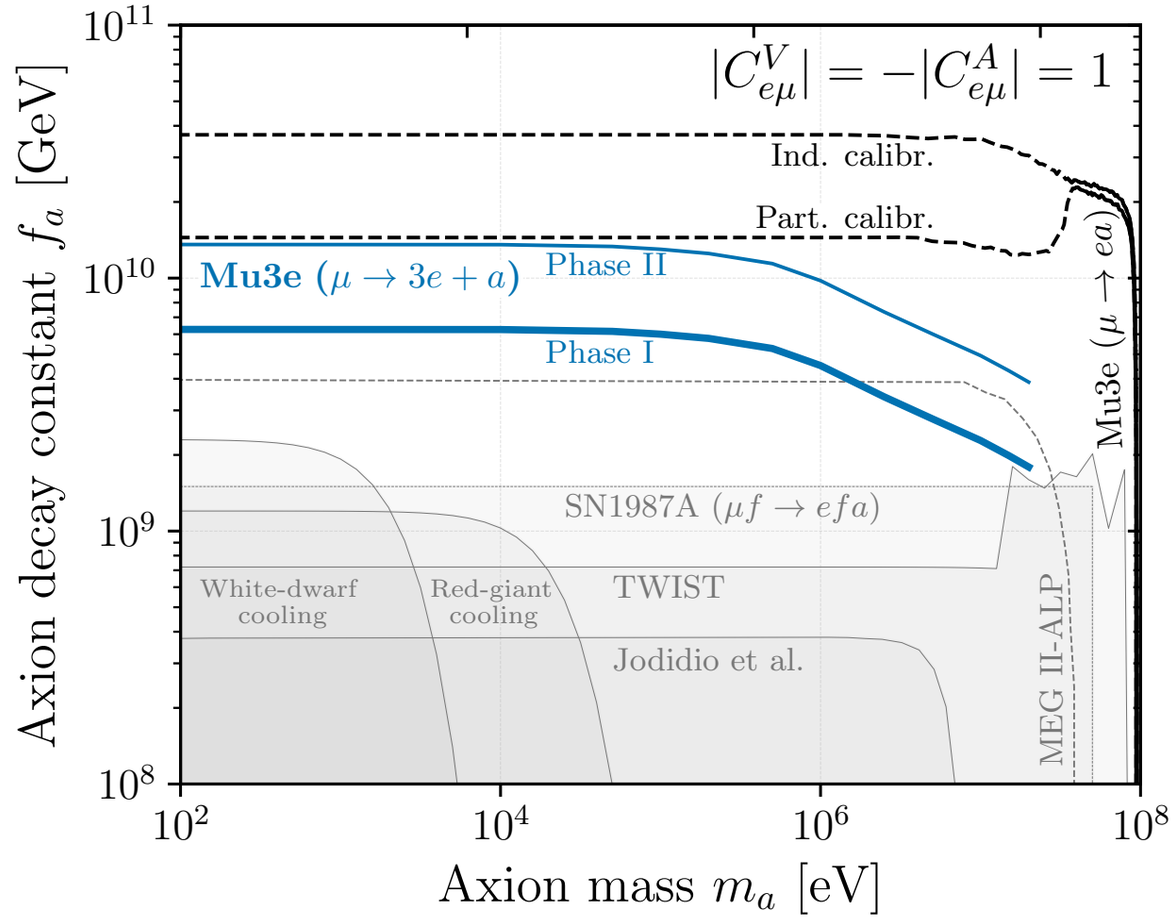
Works better than MEG II-ALP with 1 month of running

Without systematics, μ → e + a is better regardless of calibration technique

SK, K. Langhoff, T. Opferkuch, D. Redigolo: arXiv 2311.17915

At *Mu3e*



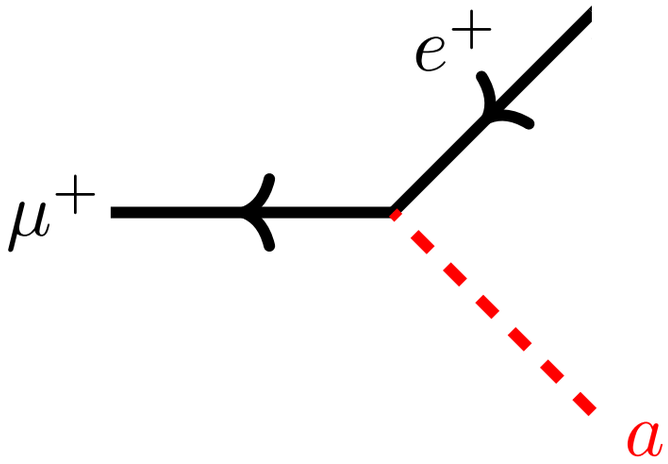


Can leverage the angular correlation with the muon polarization to get slightly better reach for right-handed currents

SK, K. Langhoff, T. Opferkuch, D. Redigolo: arXiv 2311.17915

Signatures

Flavor violating



Strong theory prior for *a* to be stable or very long-lived

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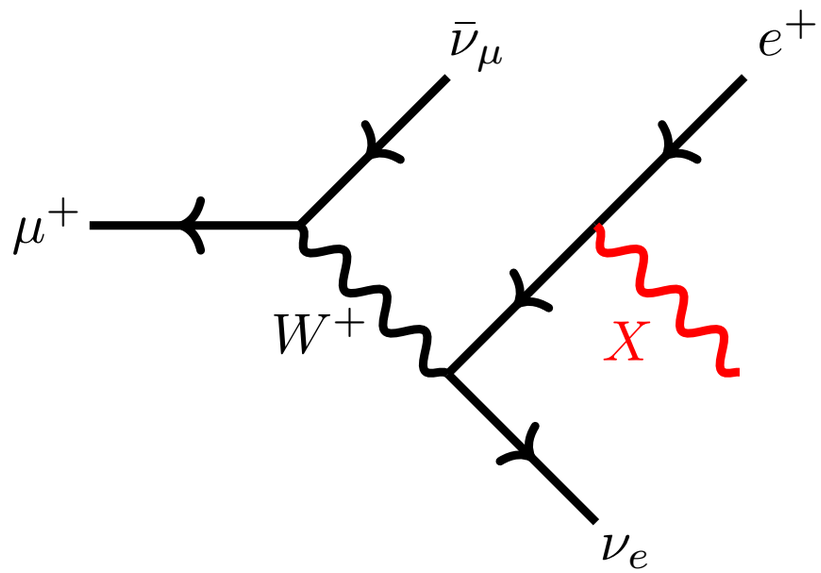

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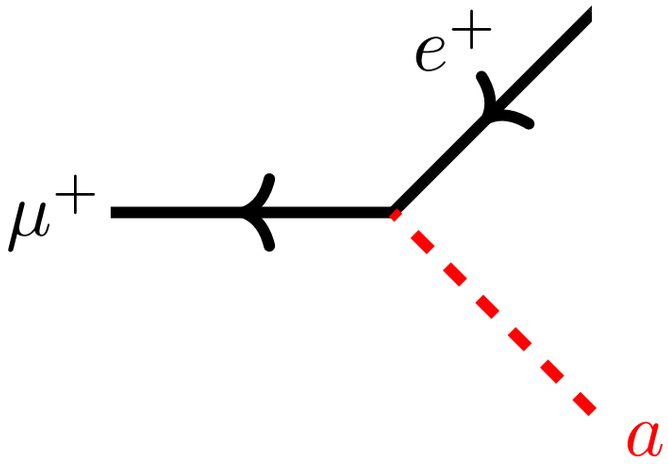

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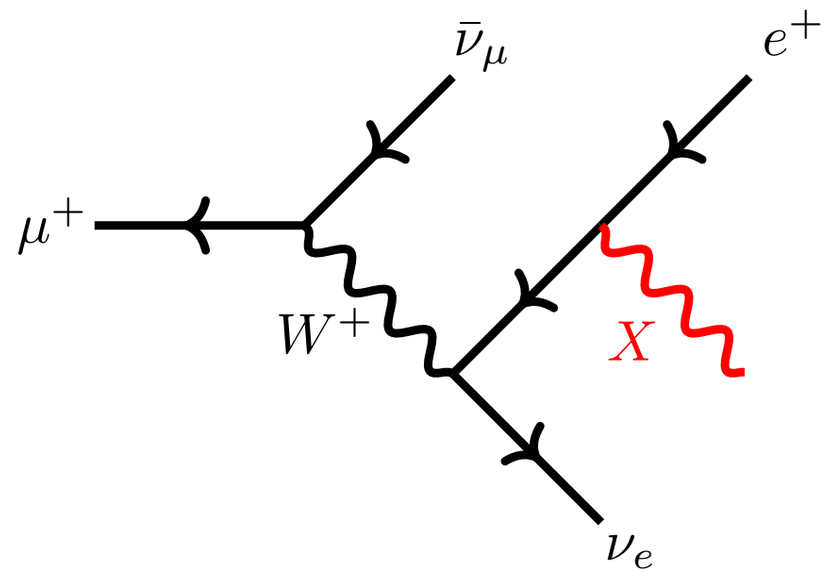
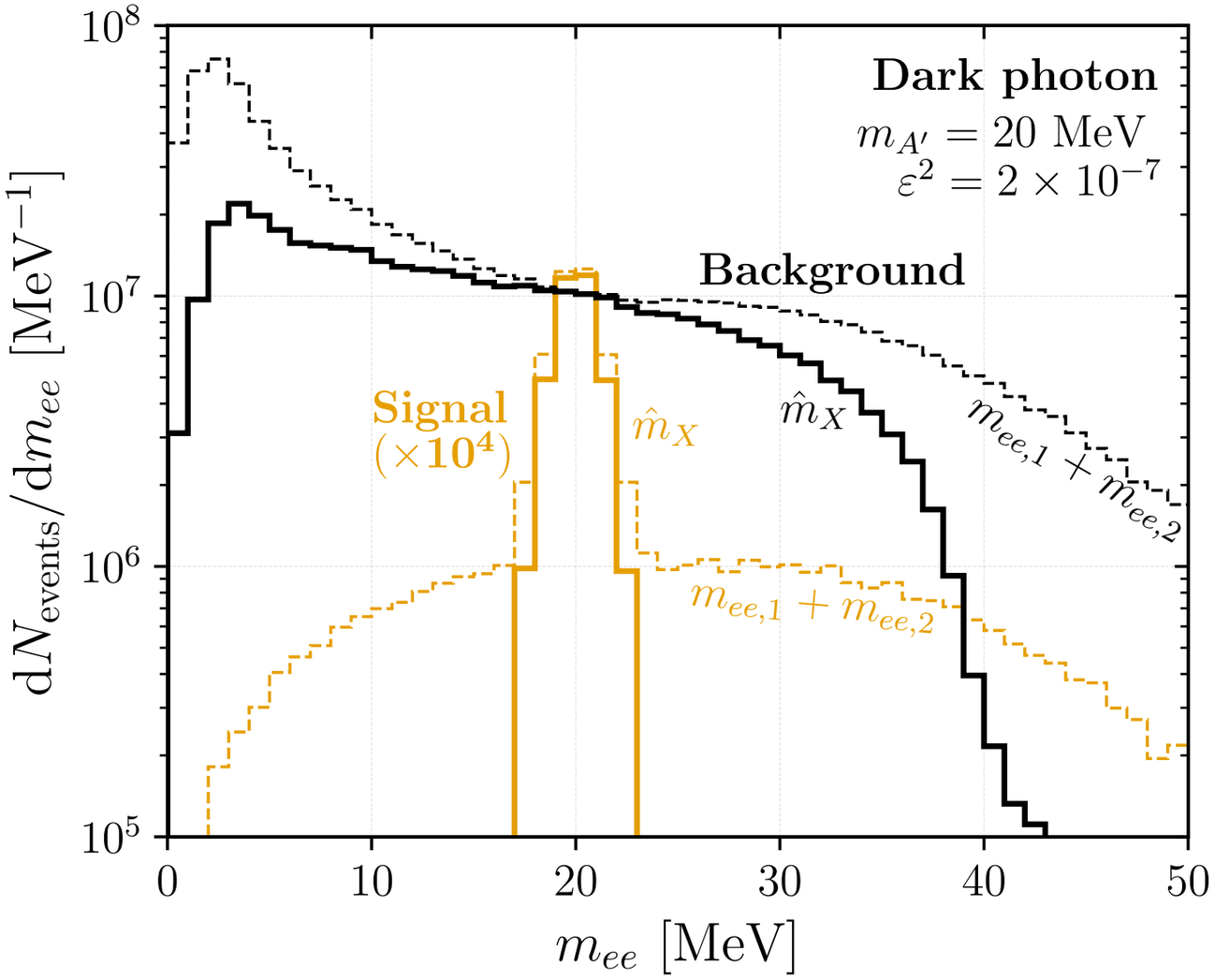
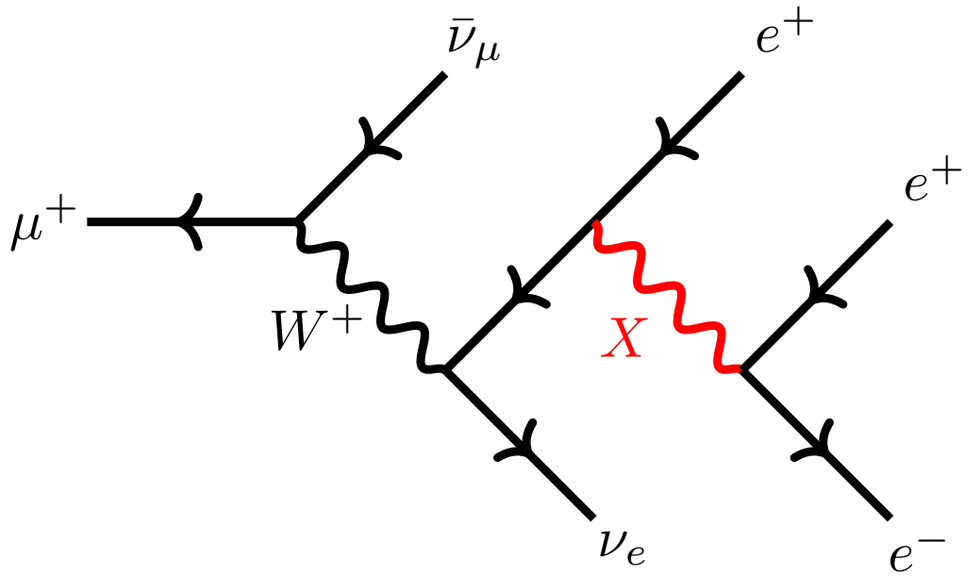


X can decay promptly, displaced or be stable

Bump hunting in e^+ e^-

Original work by Bertrand (1411.1770) and Ann-Kathrin (1812.00741, 10.11588/heidok.00024585)



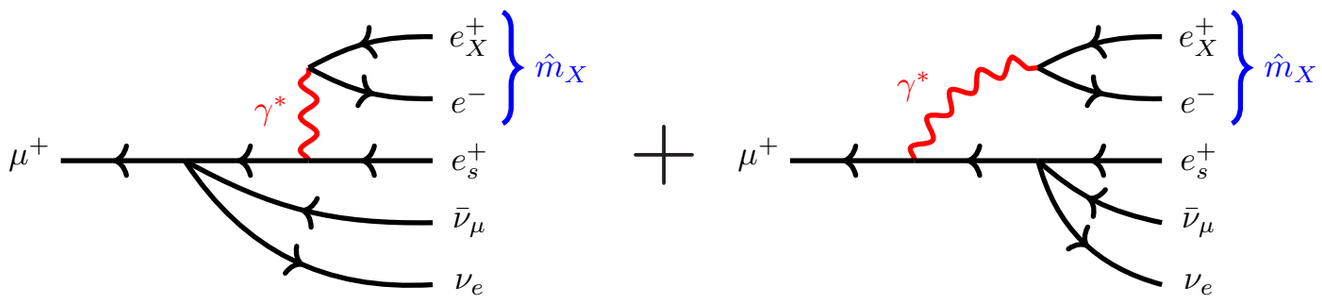


For a given m_X hypothesis, we pick the m_{ee} combination that is closest to m_X

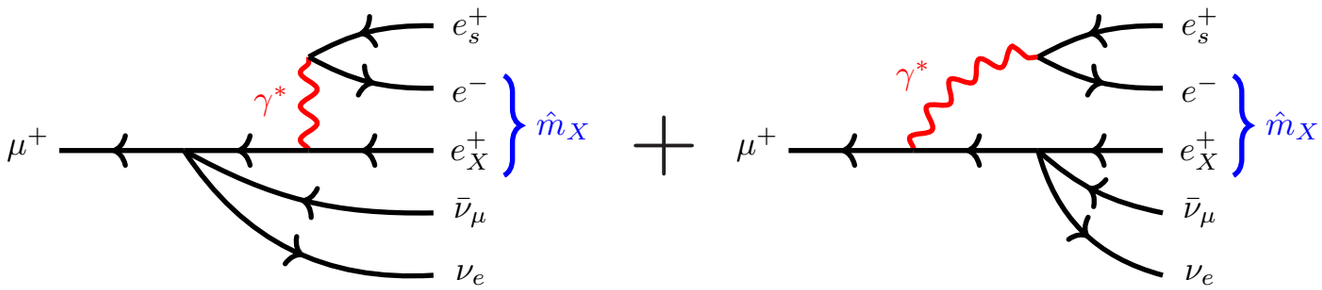
SK, K. Langhoff, T. Opferkuch, D. Redigolo: arXiv 2311.17913

Background diagrams

There are 4 diagrams for the SM background



$$\sim \frac{1}{p_{e^-} \cdot p_{e_X^+}} \sim \frac{1}{m_X^2}$$



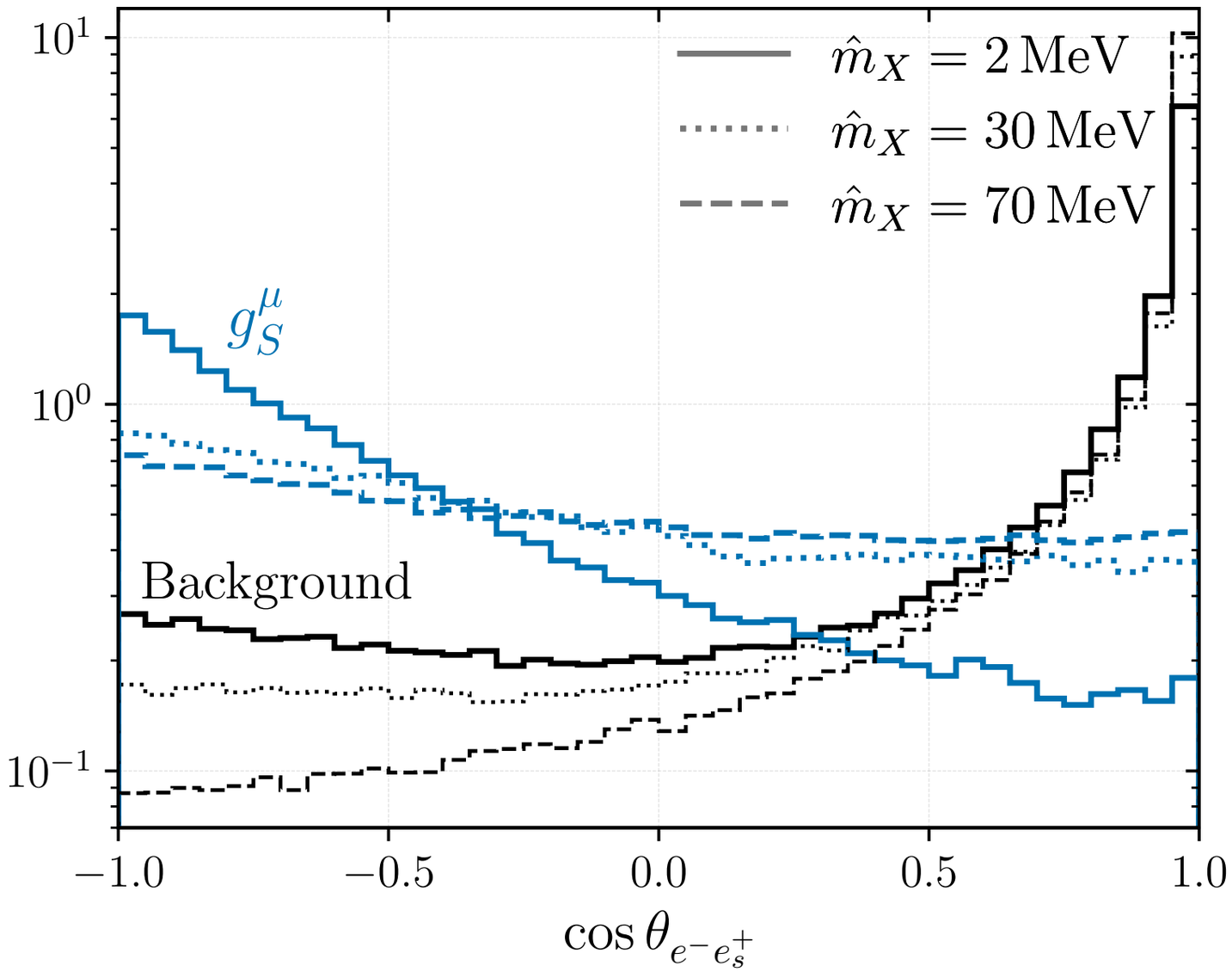
$$\sim \frac{1}{p_{e^-} \cdot p_{e_s^+}} \sim \frac{1}{E_{e^-} E_{e_s^+} (1 - \cos\theta_{e^- e_s^+})}$$

Colinear singularity, absent in the signal amplitudes

SK, K. Langhoff, T. Opferkuch, D. Redigolo: arXiv 2311.17913

Kinematic correlations

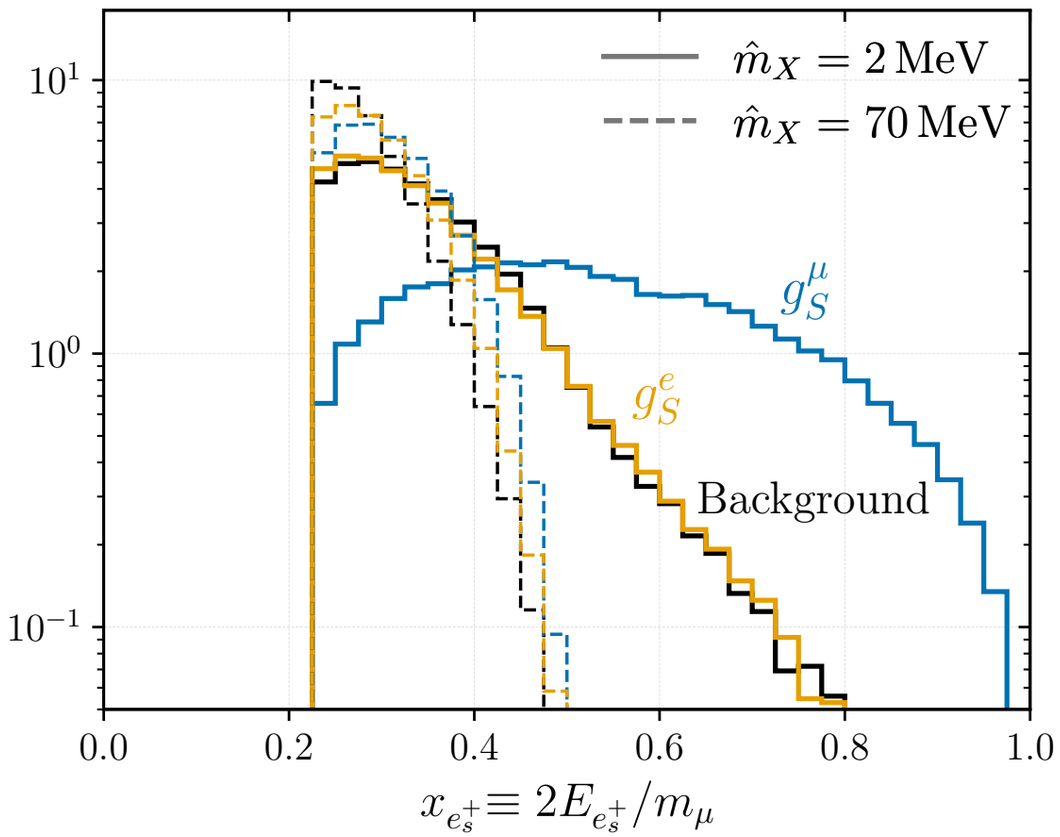
Compare with an example signal model (blue)

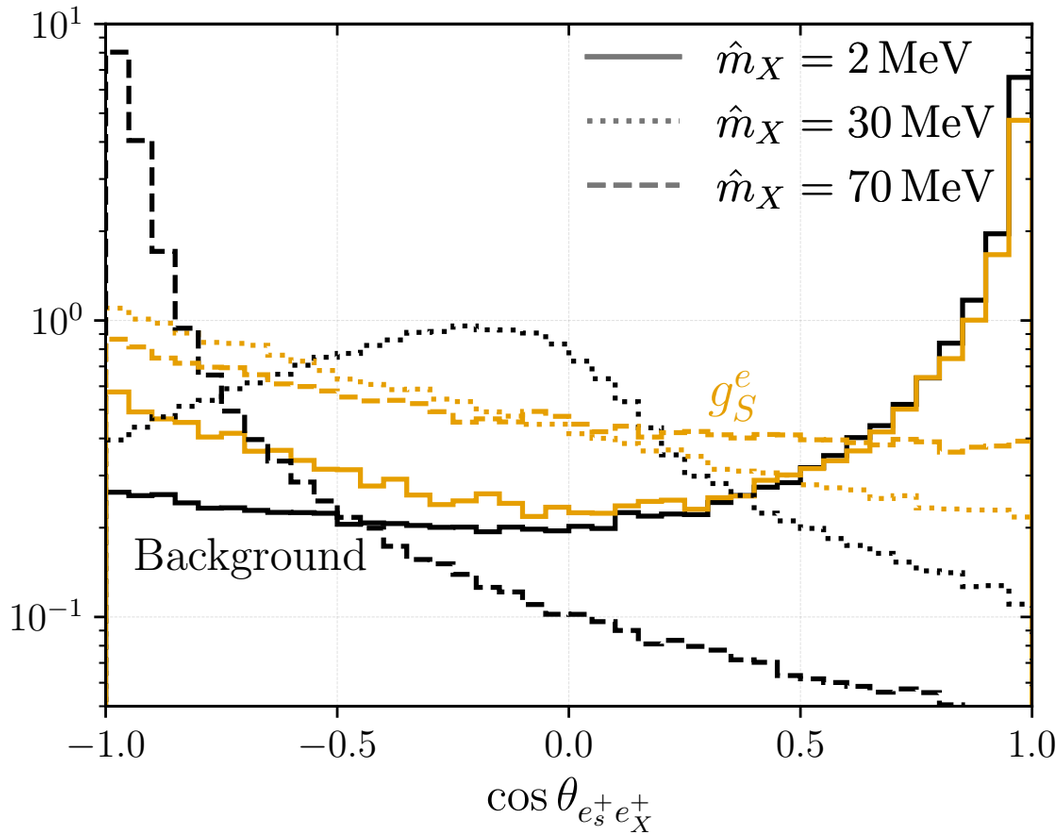


SK, K. Langhoff, T. Opferkuch, D. Redigolo: arXiv 2311.17913

Kinematic correlations

We find two more (model-dependent) discriminating variables





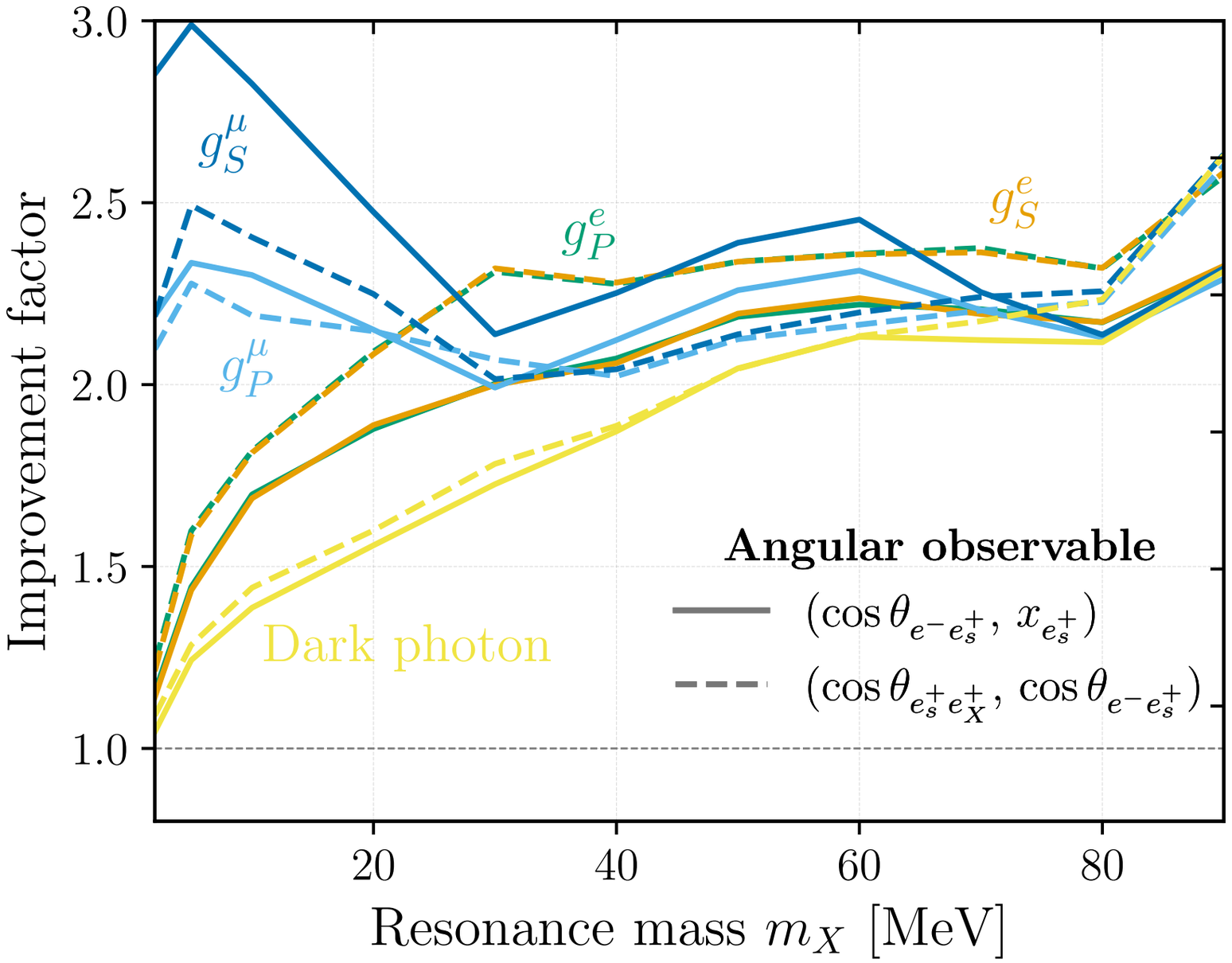
For a scalar *X* coupling to either muons or electrons through:

$$\mathscr{L} \supset X\left[g_S^\mu\,\bar{\mu}\mu + g_S^e\,\bar{e}e\right]$$

SK, K. Langhoff, T. Opferkuch, D. Redigolo: arXiv 2311.17913

Kinematic correlations: summary

Gain in sensitivity relative to a normal bump hunt:



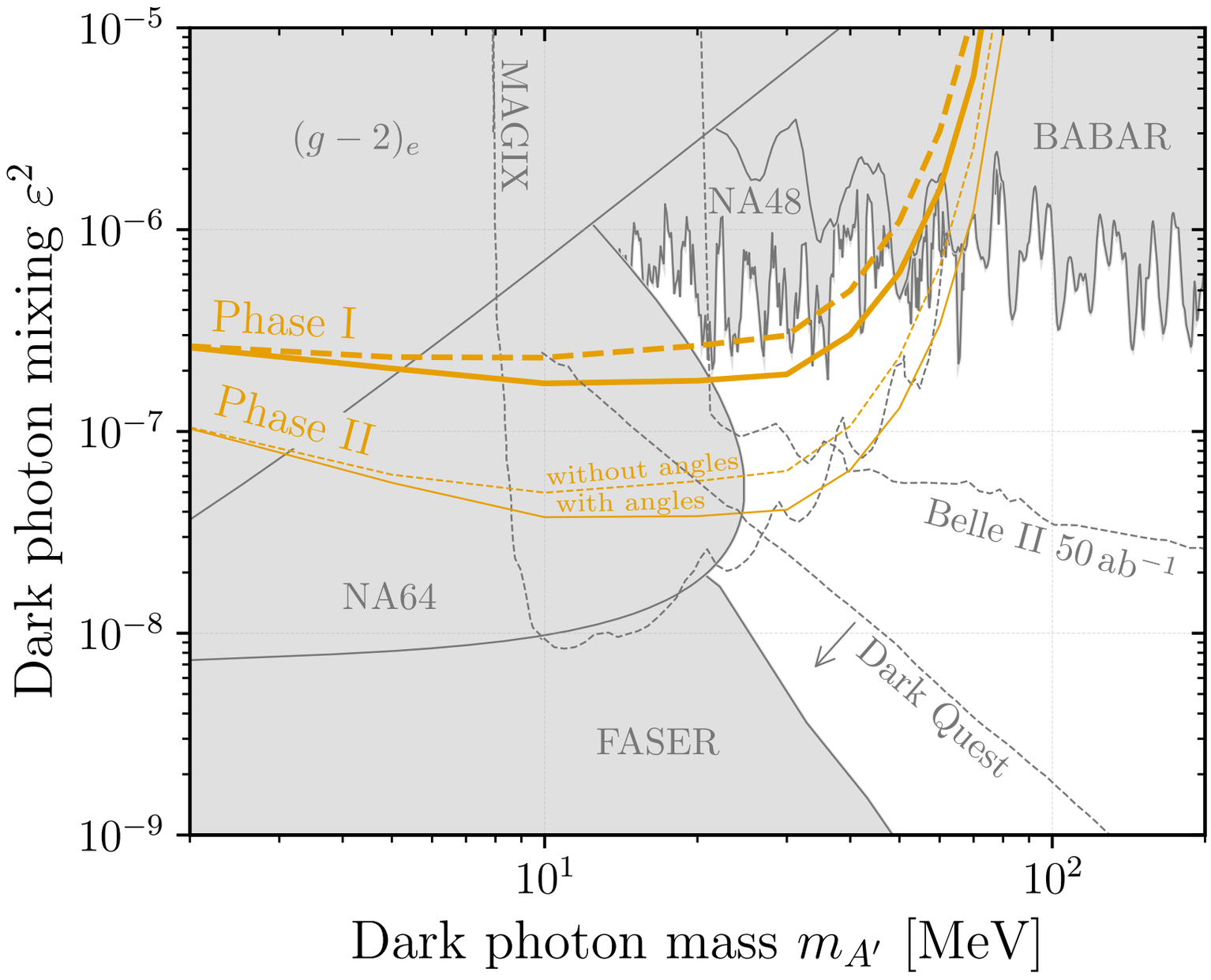
Now also including parity-odd couplings:

$$\mathscr{L} \supset X\Big[g_S^\mu\,\bar{\mu}\mu + g_P^\mu\,\bar{\mu}\gamma_5\mu + g_S^e\,\bar{e}e + g_P^e\,\bar{e}\gamma_5 e\Big]$$

Limited by MC statistics to binning in 2 variables only

Mu3e can extract full kinematic info with data-driven BG estimate

Example 1: dark photon

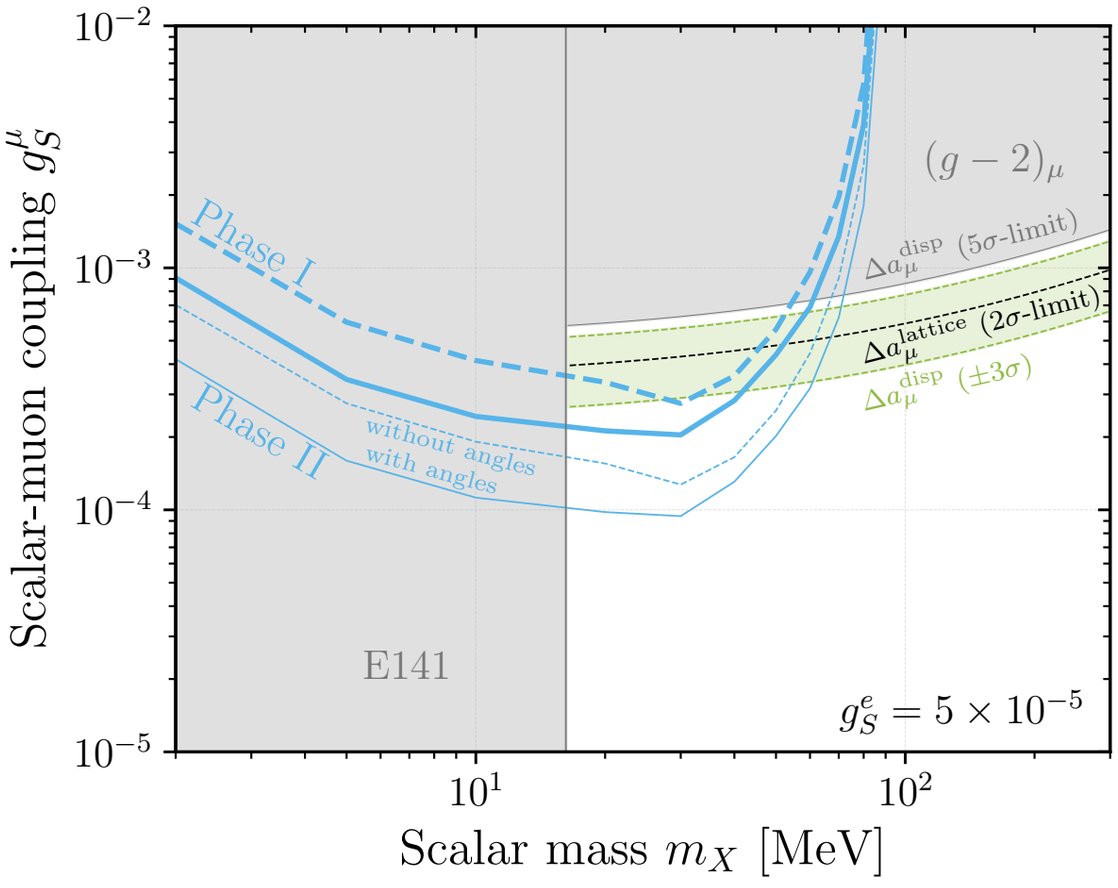


(Without including angles we reproduce prior results by Bertrand and Ann-Kathrin)

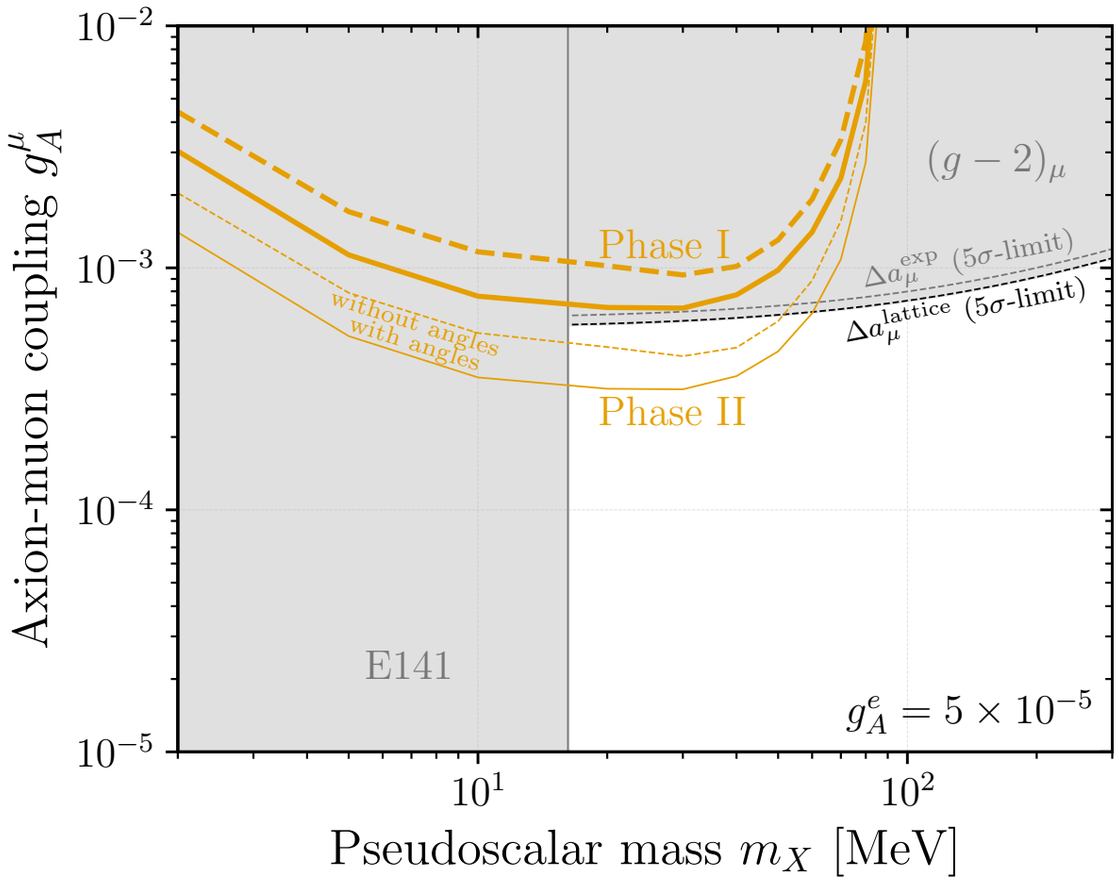
SK, K. Langhoff, T. Opferkuch, D. Redigolo: arXiv 2311.17913

Example 2: Scalar predominantly coupling to muons

Scalar



Pseudoscalar



Current best bound from muon g-2 measurement

Pseudoscalar less promising due to suppression in signal amplitude

SK, K. Langhoff, T. Opferkuch, D. Redigolo: arXiv 2311.17913

Conclusions

If needed, we may by-pass the challenging μ→ e + a channel with

- μ→ e + a + γ at *MEG II*
- μ→ 3e + a at *Mu3e*

Mu3e is likely better and doesn't require dedicated run, but *MEG II* may get a result sooner.

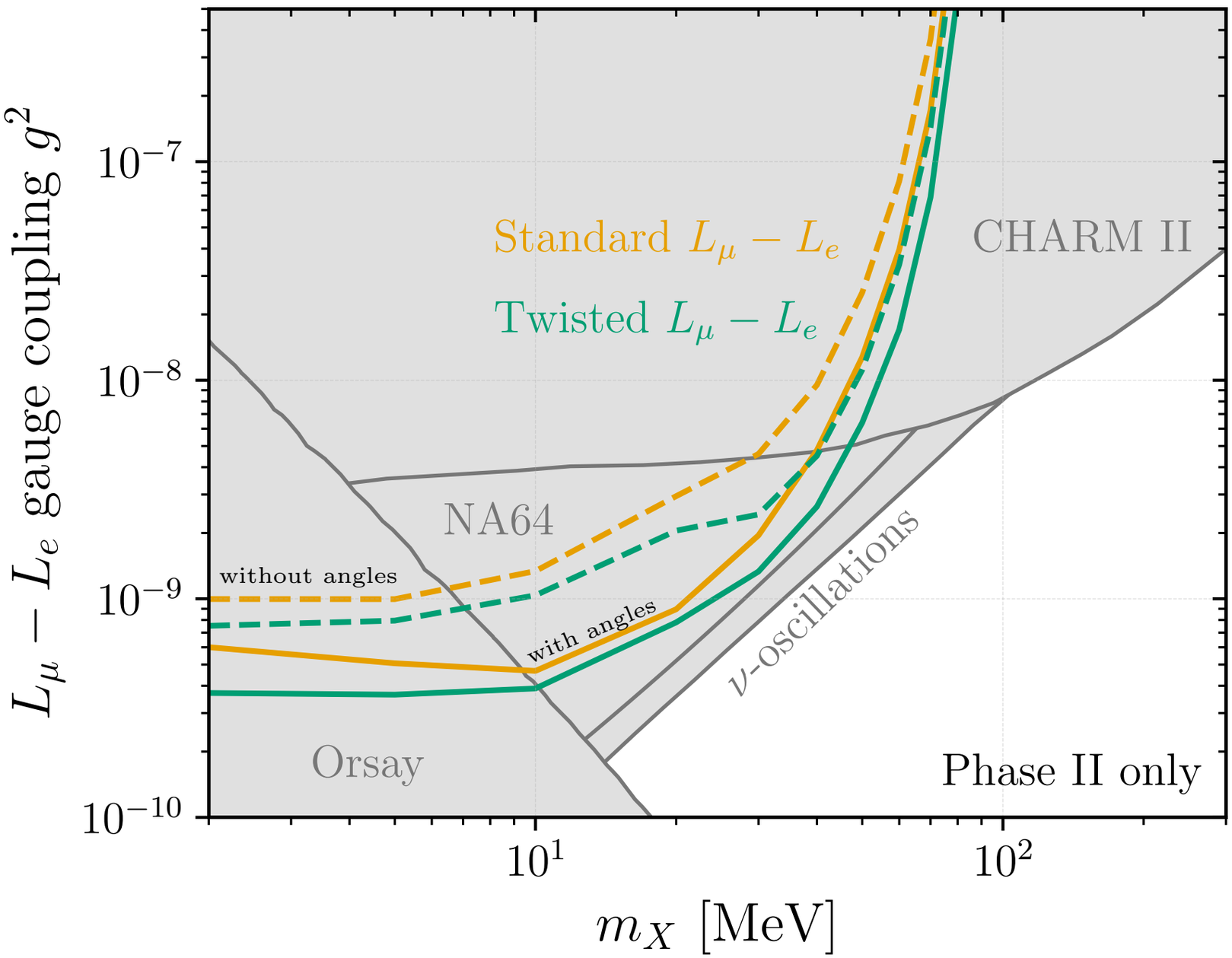
Searches for flavor conserving light particles at *Mu3e* can be enhanced by including at angular correlations

Systematically explored where *Mu3e* is competitive:

- ✔ Dark photon
- ✔ Scalar which couples mostly to muons
- ❌ Scalar which couples equally to muons and electrons (back-up slides)
- ❌ $L_\mu - L_e$ (back-up slides)

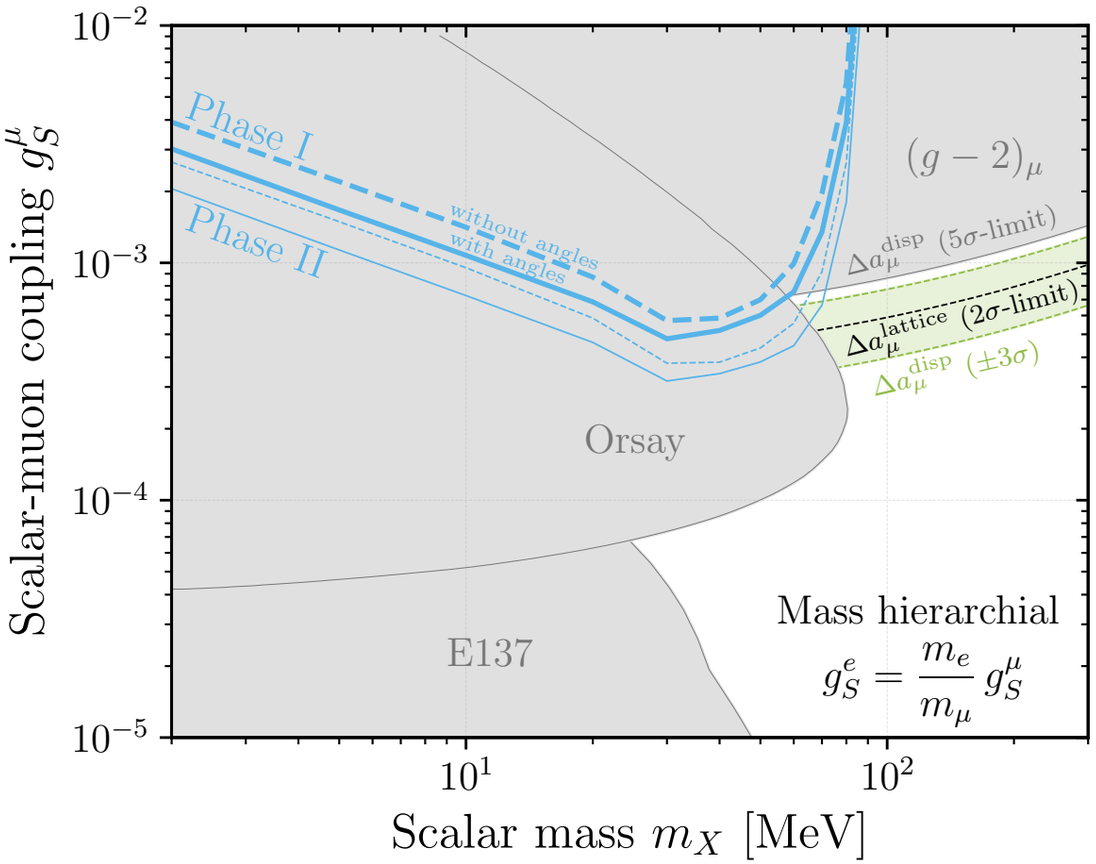
Back-up

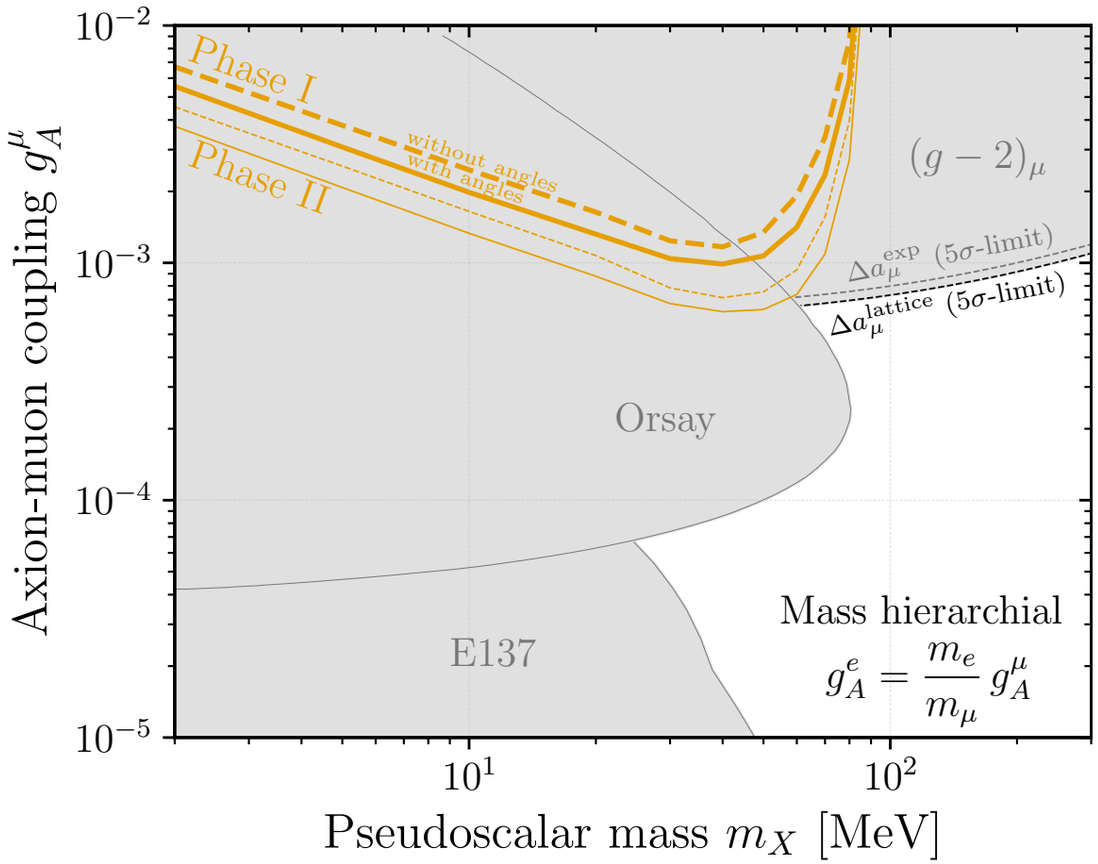
L_μ - L_e



Not competitive with bounds from neutrino oscillations and neutrino-electron scattering

More scalars

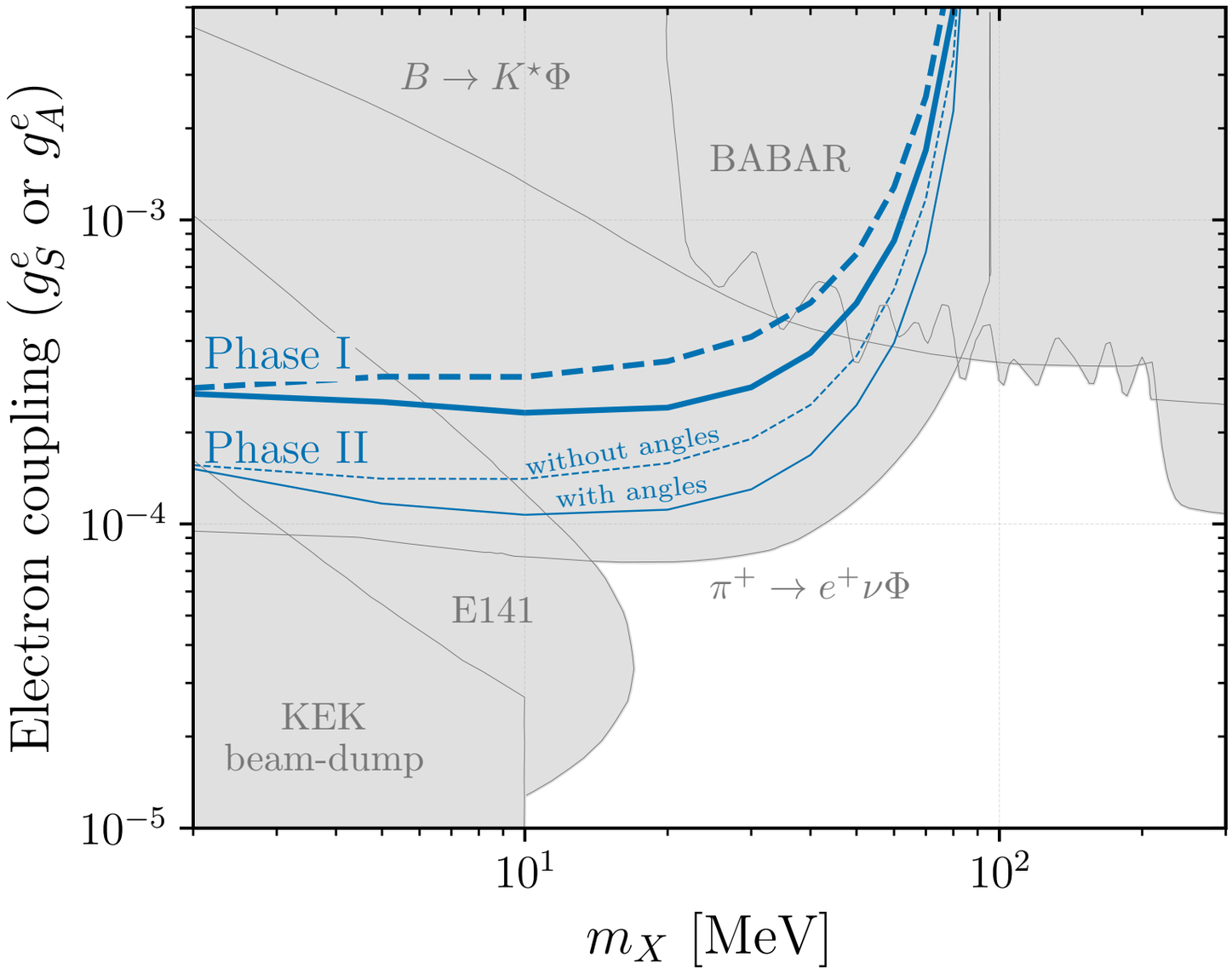




Not competitive with Orsay e^- beam dump

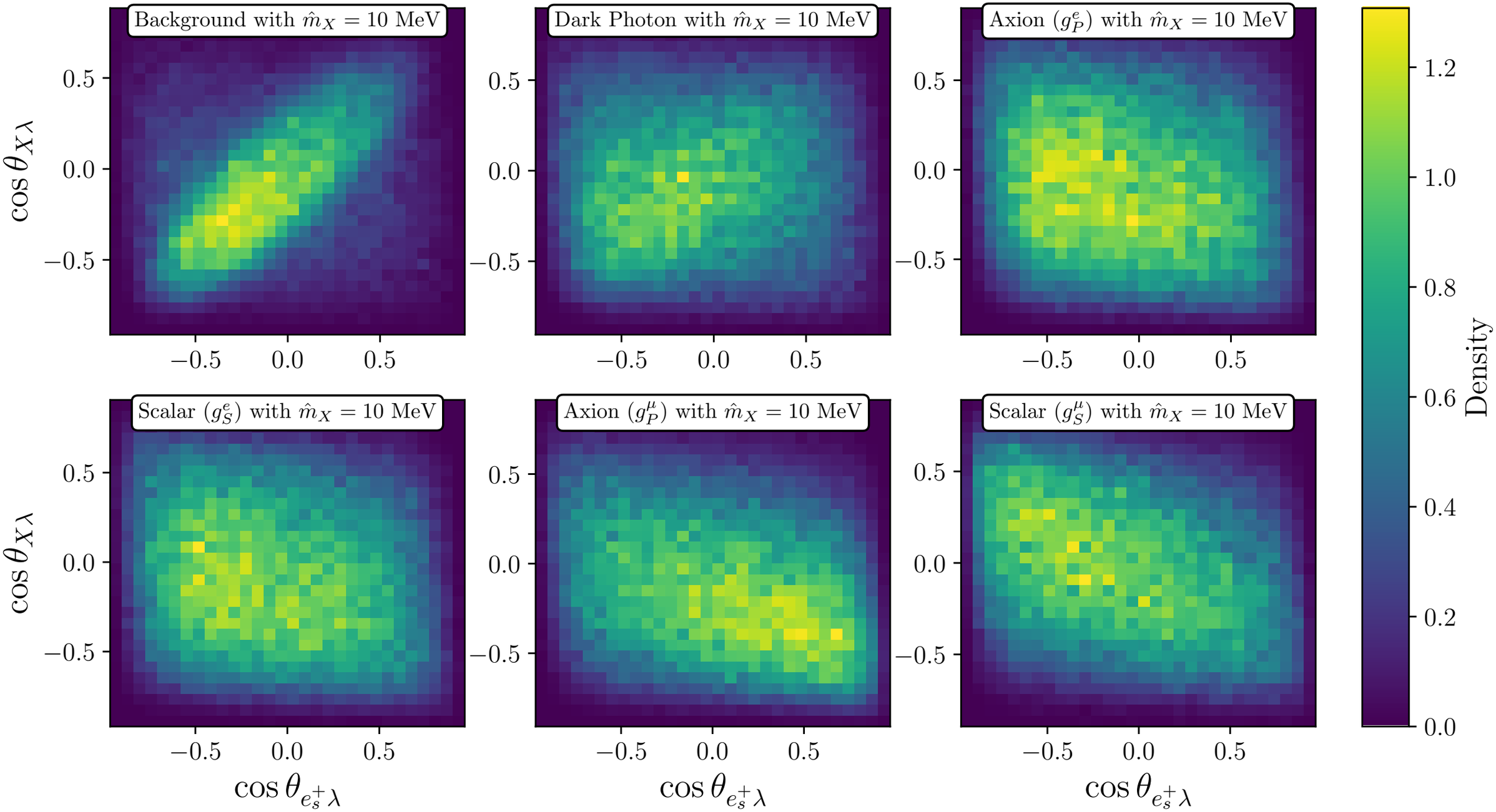
Displaced analysis may be competitive (future work)

More scalars



Not competitive with pion decays

Effect of muon polarization



Effect of muon polarization