Combined constraints for axion-like particles from $(g-2)_l$ and e^+e^- colliders

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Marc Vanderhaeghen

Axions in Stockholm

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

JG|U

July 09, 2025

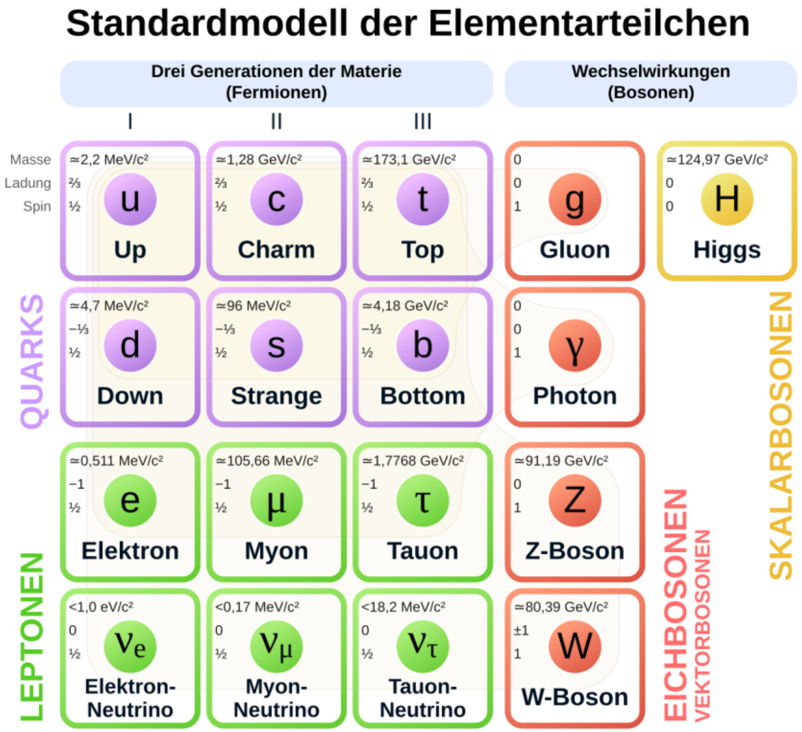
Research Unit FOR 5327 Photon-photon interactions in the Standard Model and beyond
Exploiting the discovery potential from MESA to the LHC

Outline of the talk

The talk will cover the following topics:

- **An overview of ALP** properties and their phenomenology
- **Experimental constraints**: rare decays, magnetic moments, and others
- **Searches** for potential scalars and pseudoscalars **at e^+e^- colliders**
- A brief aside on **dark photon**
- **BSM** searches at **MESA** and with polarized positron beams at **JLab**
- The current status and implications of the **X17 ATOMKI anomaly**

We have an incredible theory to describe ¾ of what is observable with (**almost**) no flaws



$$\mathcal{L}_{QCD} \propto \frac{\theta}{32\pi^2} G_a^{\mu\nu} \tilde{G}_{\mu\nu}^a$$

Still, some shameful stains persist…

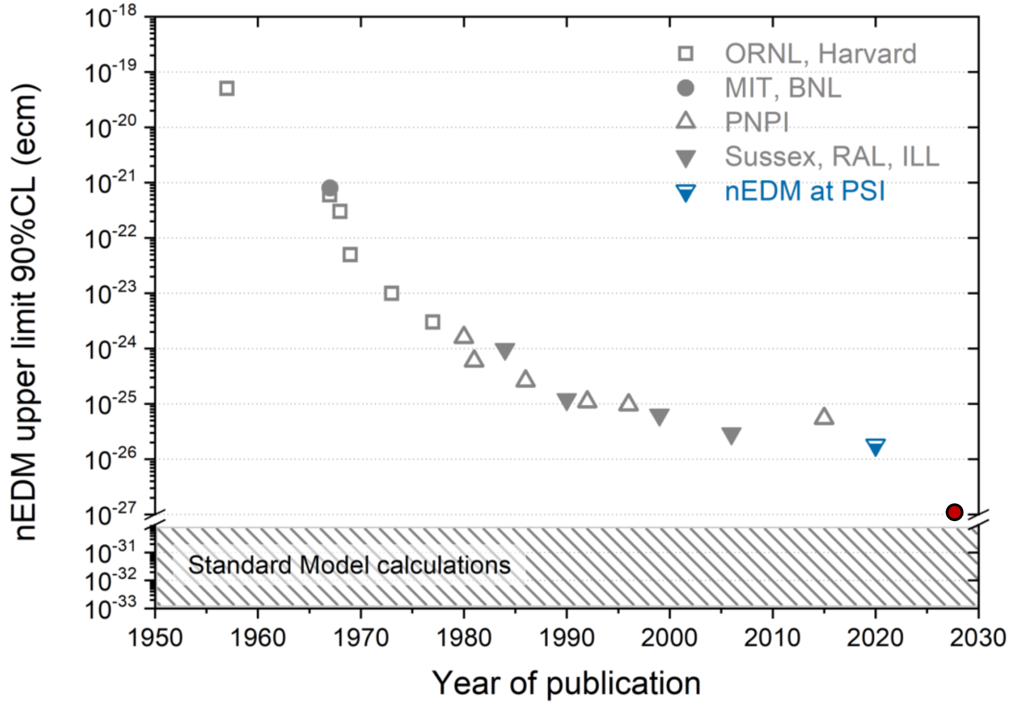
Probably the most unpleasant ones are the **strong CP problem** and dark matter

Let's focus on the **first one** for a second. $\theta \neq 0$ naturally gives rise to a relatively large neutron Electric Dipole Moment. Meanwhile:

As if the only contribution to nEDM is from CKM matrix (marked as **Standard Model calculations**)

This also implies $\theta \lesssim 10^{-10}$ – finely tuned?

Numerous experiments to further improve this by reaching $10^{-27}\mathrm{e}\cdot\mathrm{cm}$ bound (red dot on the plot)



Acknowledgments

The **idea is very simple** (to "clean up" the strong CP-problem):

1) Postulate a **new $\boldsymbol{U(1)}$ symmetry** (Peccei-Quinn)
2) Spontaneously **break it** at some scale Λ
3) The **(pseudo)-Goldstone boson** cancelling θ is called axion:

$$\mathcal{L}_{total} \rightarrow \mathcal{L}_{SM} + \frac{a}{\Lambda} G_a^{\mu\nu} \tilde{G}_{\mu\nu}^a$$

The exact mechanism of axion-gluon coupling is model-dependent, but typically through **quark triangle** or **mixing with pion**

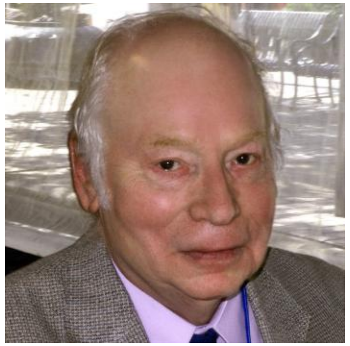
Two "benchmark" models (along with their variations) are widely used:

KSVZ: **heavy, electrically neutral quarks** carrying PQ charge

DFSZ: SM quarks carry PQ charge, **additional Higgs doublet**

Roberto Peccei

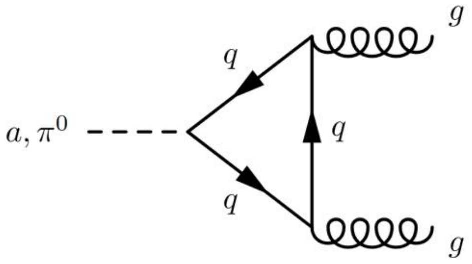
Helen Quinn



Steven Weinberg

Frank Wilczek

In both models scale $\boldsymbol{\Lambda}$ **is the only dimensonfull parameter**, $m_a \propto \Lambda$, coupling to SM particles $\propto 1/\Lambda$



Axion-Like Particles

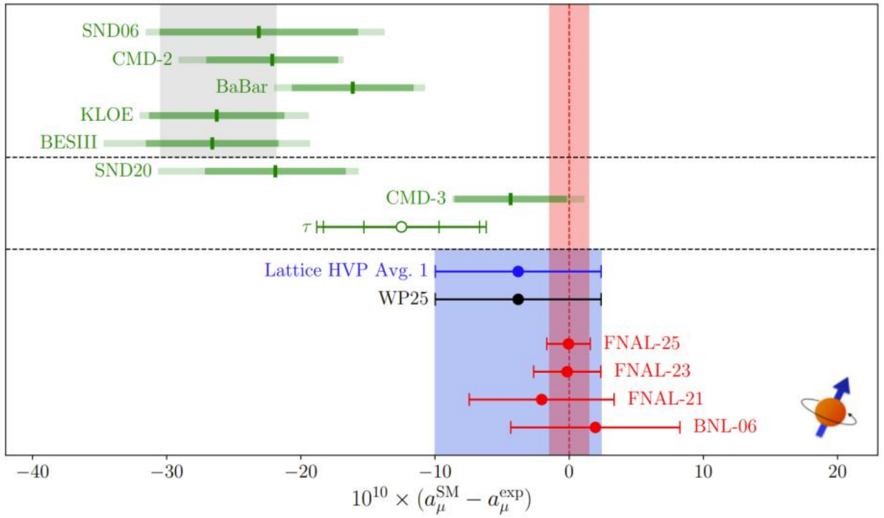
Beyond QCD-motivated benchmark models ⇒ Axion-Like Particles – broader theory framework!

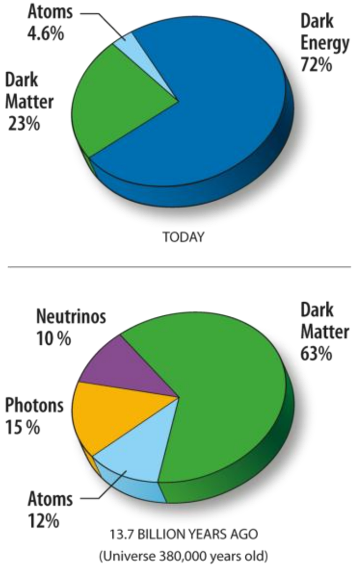
Sometimes cover not only **pseudoscalars**, but also **scalars, as well as their combinations**. Mass and coupling are generally independent!

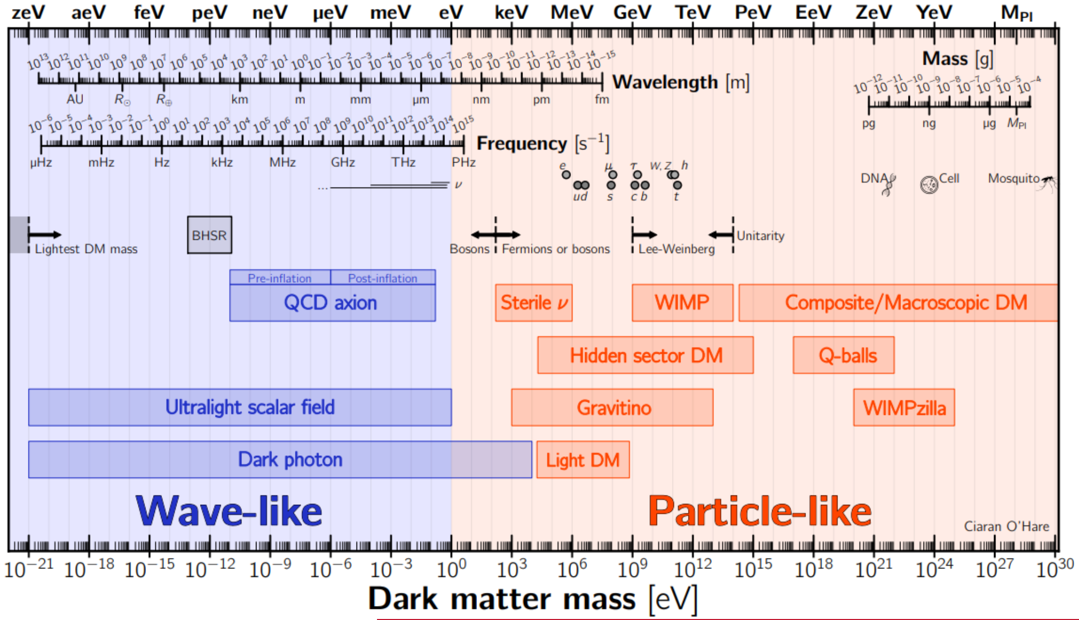
Relevant to **variety of problems**:

1) Initial motivation is to **cancel QCD θ**
2) Some are potentially **dark matter**
3) May explain anomalous **star cooling**
4) Could fix **TeV transparency of Universe**
5) ~~Contributes to $(g-2)_\mu$ without spoiling $(g-2)_e$~~
6) General feature of ***string theories***
7) ...

And offers a **variety of scenarios**, *sometimes unexpected!*

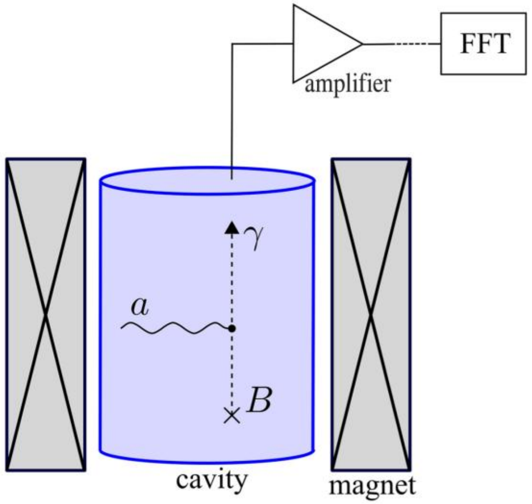


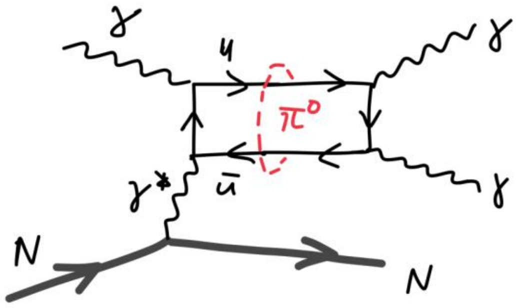




How Do We Look for ALPs

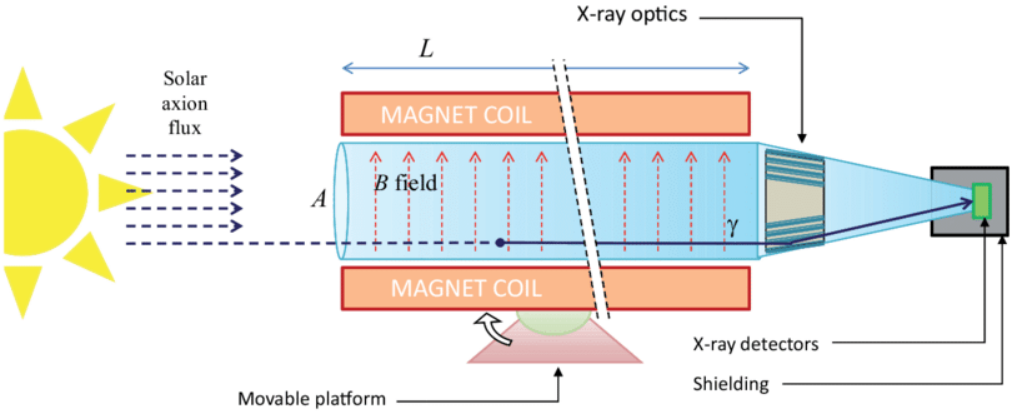
In this work we focus on scalar and pseudoscalar BSM candidates, trying to keep as few assumptions as possible





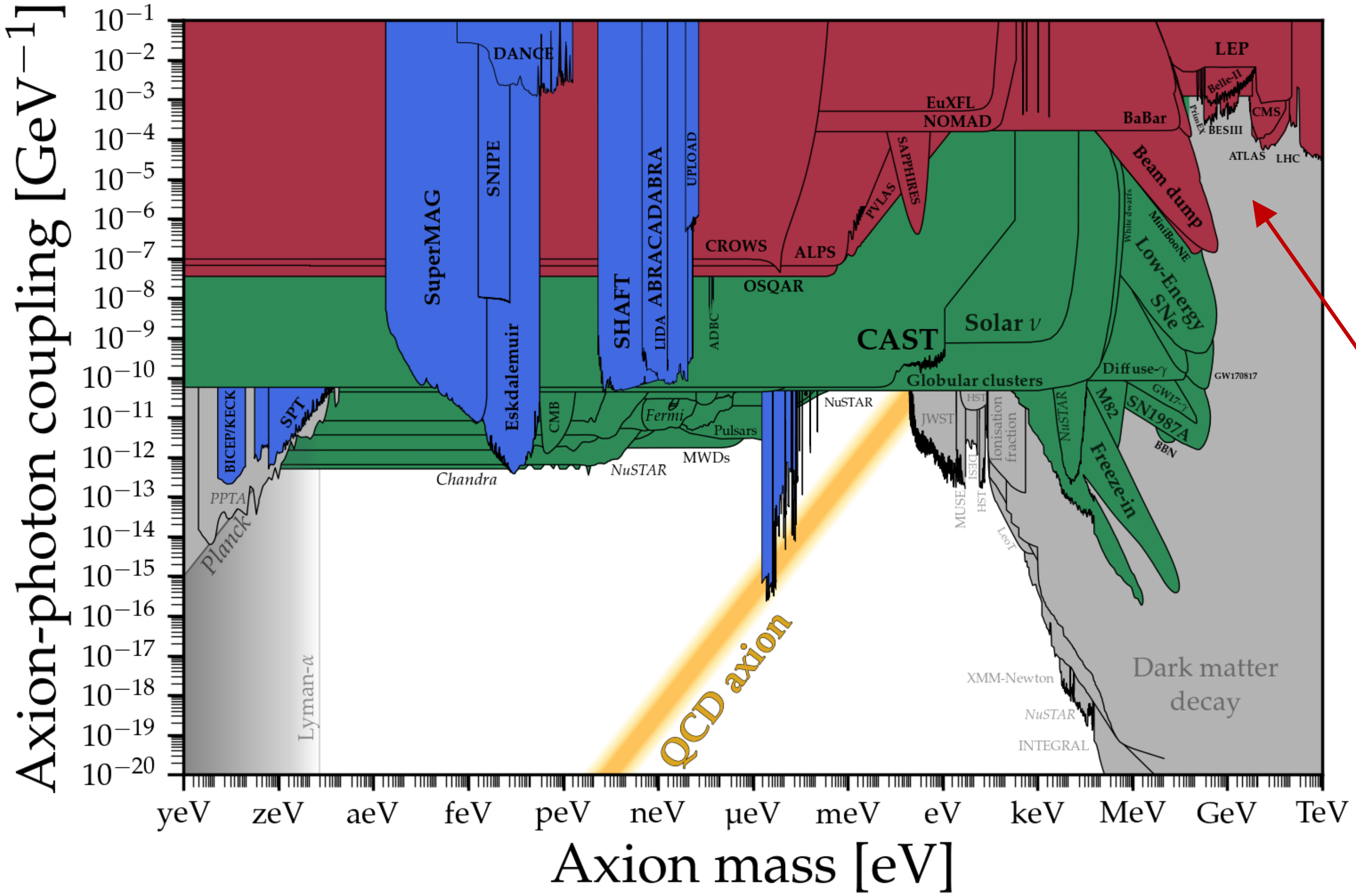
Photon coupling is a ubiquitous property, allowing for a broad spectrum of possibilities for experimental searches, including (but not limited to):

1) Atomic and molecular **transitions**
2) Resonant **cavity** experiments
3) Helio**scopes** and halo**scopes**
4) Lepton **magnetic moments**
5) Beam **dump** and **collider** experiments



Together, they cover more than 30 orders of magnitude in mass searching, from yeV to TeV

Where Do We Look for ALPs

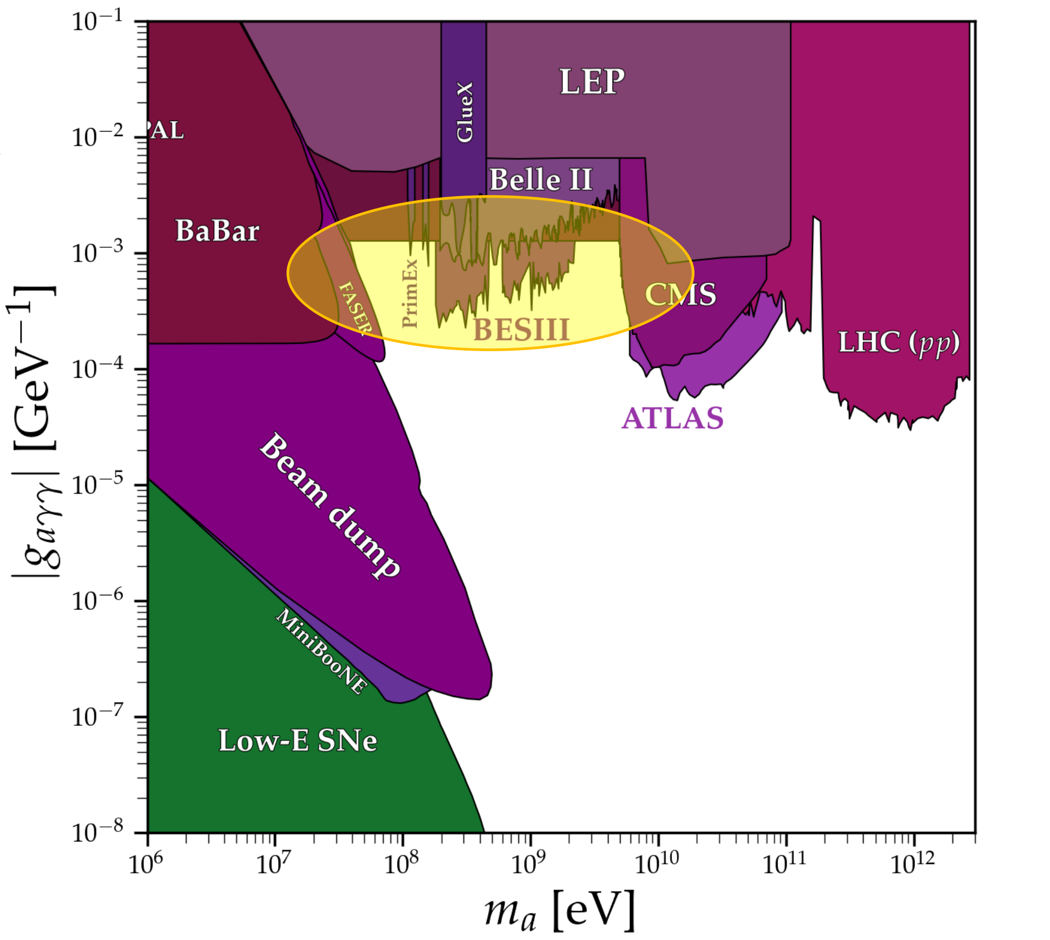


Strong astrophysical bounds (model-independence from low to moderate) in the low-mass region are in contrast with the high-mass region
QCD axion stands for original KSVZ/DFSZ models

Credits for the figure to https://cajohare.github.io/

A “striking” **gap – few hundred MeV to GeV** mass

This domain almost entirely relies on e^+e^- colliders.
A lot of attention during the past few years!



Why So Heavy?

MeV-GeV mass range is typically not associated with axions, but this is **just a question of a clever model-building**:

1) A viable **strong CP problem** solution is not only **possible** with MeV mass axion
2) … But also can simultaneously **generate enough baryon asymmetry**
3) Just a **right amount of dark matter** is included
4) Interesting **interplays with Higgs physics** for even heavier ALPs

ABSTRACT: We demonstrate that the observed cosmological excess of matter over anti-matter may originate from a heavy QCD axion that solves the strong CP problem but has a mass much larger than that given by the Standard Model QCD strong dynamics. We investigate a rotation of the heavy QCD axion in field space, which is transferred into a baryon asymmetry through weak and strong sphaleron processes. This provides a strong cosmological motivation for heavy QCD axions, which are of high experimental interest. The viable parameter space has an axion mass m_a between 1 MeV and 10 GeV and a decay constant $f_a < 10^5$ GeV, which can be probed by accelerator-based direct axion searches and observations of the cosmic microwave background.

Dark Matter through the Axion Portal

Yasunori Nomura and Jesse Thaler

Berkeley Center for Theoretical Physics, University of California, Berkeley, CA 94720 and Theoretical Physics Group, Lawrence Berkeley National Laboratory, Berkeley, CA 94720

Motivated by the galactic positron excess seen by PAMELA and ATIC/PPB-BETS, we propose that dark matter is a TeV-scale particle that annihilates into a pseudoscalar "axion." The positron excess and the absence of an anti-proton or gamma ray excess constrain the axion mass and branching ratios. In the simplest realization, the axion is associated with a Peccei-Quinn symmetry, in which case it has a mass around 360 – 800 MeV and decays into muons. We present a simple and predictive supersymmetric model implementing this scenario, where both the Higgsino and dark matter obtain masses from the same source of TeV-scale spontaneous symmetry breaking.

A viable QCD axion in the MeV mass range

Daniele S. M. Alves[1,2,3,*] and Neal Weiner[1,†]

[1]*Center for Cosmology and Particle Physics, Department of Physics, New York University, New York, NY 10003*

[2]*Department of Physics, Princeton University, Princeton, NJ 08544*

[3]*Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA*

(Dated: September 15, 2020)

"Give me an axion, and I'll find a model for it"

Existing Constraints

Our objective is to systematically search for ALP signals at e^+e^- colliders. **Generic CP-even coupling to fermions**:

$$\mathcal{L} = -\frac{g_{aff}}{2m_f}\partial_\mu a \cdot \bar{\psi}\gamma^5\gamma^\mu\psi$$

In the domain of interest **QCD couplings** typically lead to severely constrained flavour-changing processes – they can only be **subdominant**

M. Dolan et al. JHEP 171 (2015)

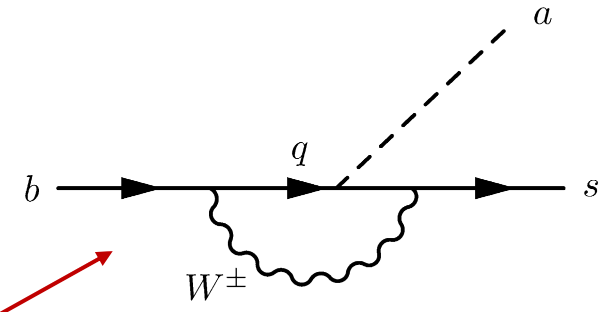
Lepton coupling is much less constrained and **must be taken into account**, but off-diagonal couplings seem to be ruled out

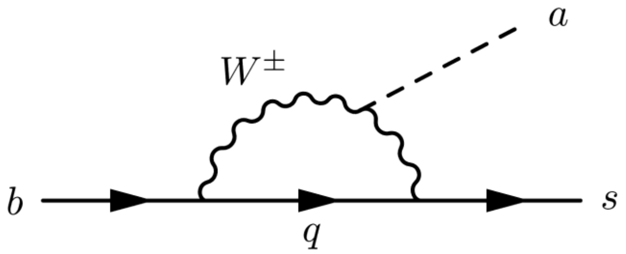
M. Bauer et al. JHEP 44 (2017)

Lowest-order coupling to **Electroweak sector**:

$$\mathcal{L} = -\frac{g_{aBB}}{4} aB_{\mu\nu}\tilde{B}^{\mu\nu} - \frac{g_{aWW}}{4} a\boldsymbol{W}_{\mu\nu}\widetilde{\boldsymbol{W}}^{\mu\nu}$$

Where $\tilde{T}^{\mu\nu} = \varepsilon^{\alpha\beta\mu\nu}T_{\alpha\beta}$





$$\mathcal{L} \subset -\frac{g_{a\gamma\gamma}}{4} aF_{\mu\nu}\tilde{F}^{\mu\nu} - \frac{g_{a\gamma Z}}{2} aF_{\mu\nu}\tilde{Z}^{\mu\nu}$$

$$g_{a\gamma\gamma} = g_{aBB}\cos^2\theta_w + g_{aWW}\sin^2\theta_w$$

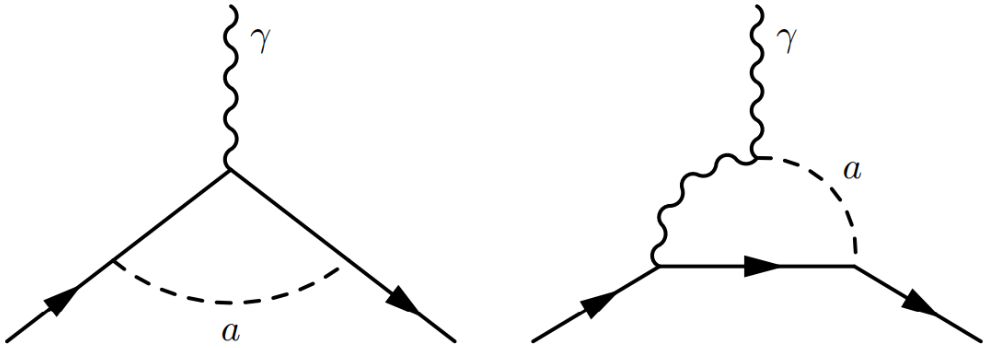
$$g_{a\gamma Z} = (g_{aWW} - g_{aBB})\sin\theta_w\cos\theta_w$$

θ_w – Weinberg angle. **Flavour constraints** also require

$$g_{aWW} \ll g_{aBB}$$

E. Izaguirre et al. Phys. Rev. Lett. 118 (2017)

Constraints from Lepton Magnetic Moments



Yukawa type   Barr-Zee type

Other vital **constraints** are **from lepton dipole moments** – for instance, **tight bounds on CP-odd couplings**

If we assume **lepton universality**, then the derivative coupling motivated by the **Goldstone theorem** leads to an **enhanced ALP-muon coupling**

$$g_{a\mu\mu} \approx \frac{m_\mu}{m_e} g_{aee}$$

$\Rightarrow$ resolving $\boldsymbol{(g-2)_\mu}$ without spoiling $\boldsymbol{(g-2)_e}$

The left (Yukawa-like) diagram from leptonic coupling gives a negative contribution to the $(g-2)_l$:

$$\Delta a_l^Y = -\frac{g_{all}^2}{8\pi^2}\frac{m_l^2}{m_a^2}\int_0^1 \frac{(1-z)^3}{z + m_l^2 m_a^{-2}(1-z)^2} dz < 0$$

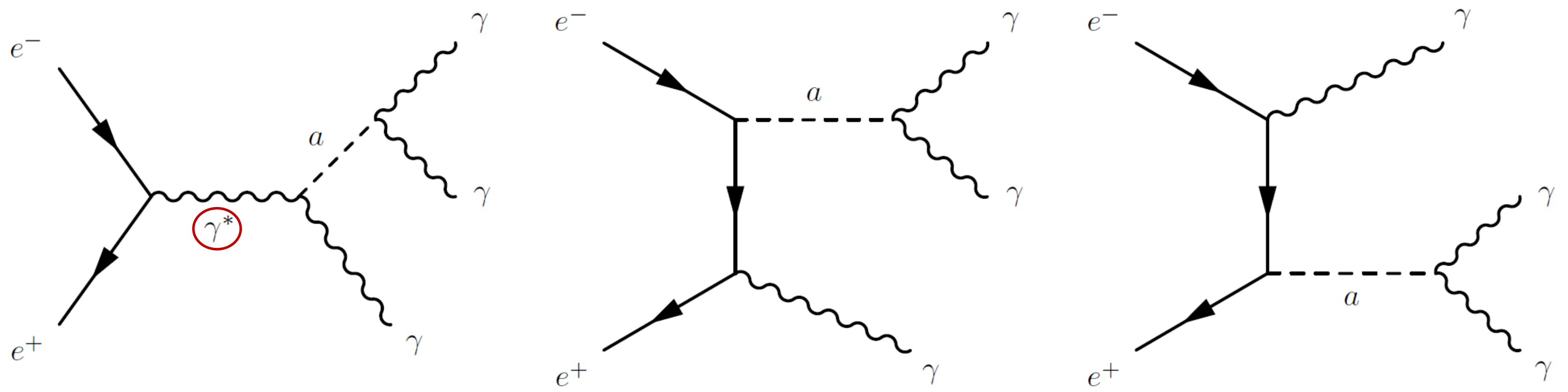
The right diagram is proportional to $g_{all} g_{a\gamma\gamma}$ and its positive contribution can dominate:

$$\Delta a_l^{BZ} \simeq \frac{g_{all} m_l}{8\pi^2} \ln \Lambda^2 \left(g_{a\gamma\gamma} - \frac{4\sin^2\theta_w - 1}{4\sin\theta_w \cos\theta_w} g_{a\gamma Z} \right)$$

Λ requires UV-complete theory. However, large Λ means bigger effects and more stringent bounds
We set $\boldsymbol{\Lambda = 1}$ **TeV – conservative estimate**

W. J. Marciano et al., Phys. Rev. D 94 (2016)
A. Pustyntsev and M. Vanderhaeghen, Phys. Rev. D 110 (2024)

Resonant Searches at e^+e^- Colliders



Non-resonant contributions to ALP productions at e^+e^- colliders

Relevant for lower-energy facilities, e.g. Belle II

In earlier works only the left one was considered

Existing constraints imply that the width

$$\Gamma = \Gamma_{a\gamma\gamma} + \sum_l \Gamma_{all}$$

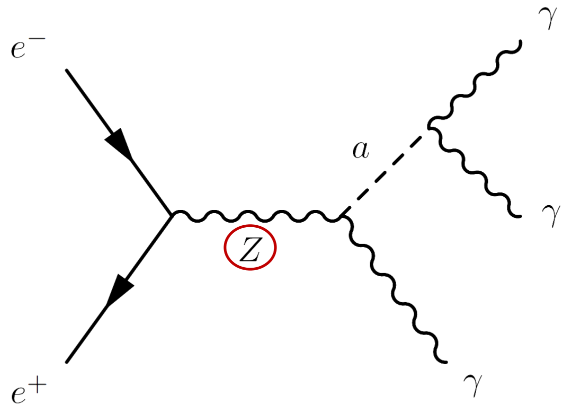
is much smaller than the experimental resolution ⇒ **narrow width approximation** shrinks the phase space. We look for a narrow spike in $m_{\gamma\gamma}$ or a recoil photon

Different scaling of two couplings ⇒ the **left** diagram is **less important** when $m_a^2 \ll s$

More contributions does not mean better constraints, they are weakened by the branching ratio!

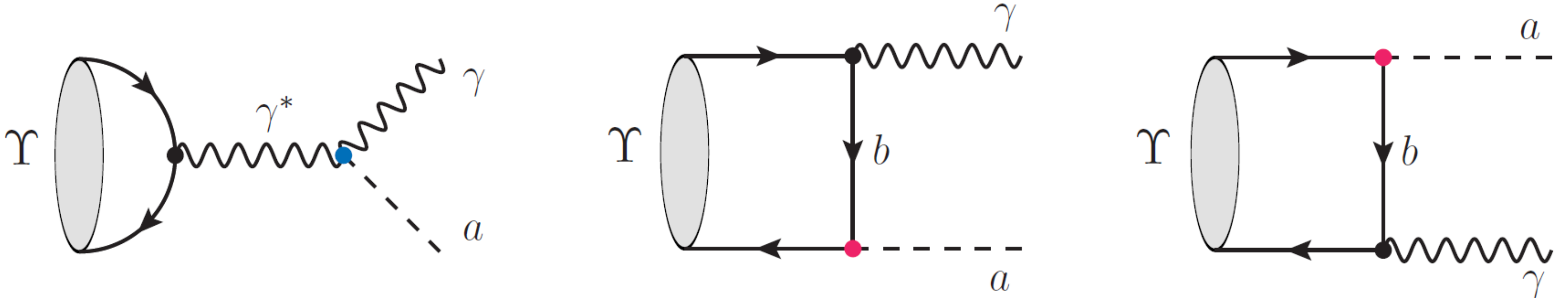
At high energies resonant ALP-production at ***Z*-pole becomes possible**:

1. Orders-of-magnitude enhancement over other contributions
2. Huge statistics from LEP



Searches at Vector Meson Decays

L. Merlo et al. JHEP 91 (2019)



Vector meson contributions to ALP productions at e^+e^- colliders

Only the left diagram is relevant, as quark couplings are very constrained by rare decays

BESIII applies a different search strategy, relying on $J/\psi \to 3\gamma$ decays, which produces a comparable signal strength to the non-resonant searches:

Advantages:

1) **Lepton** couplings enter only **via branching ratio**

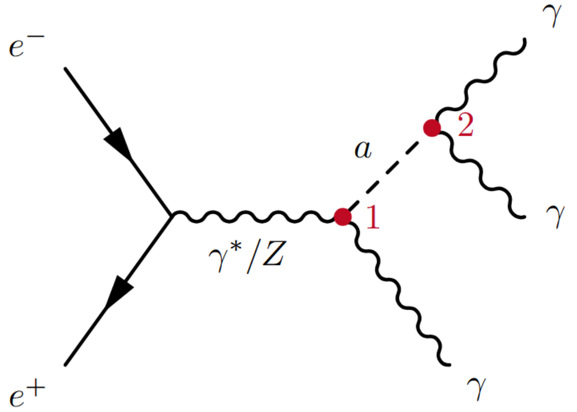
2) **Easily scalable** – BESIII dataset keeps growing*, 10 billion decays in 2024 vs. 2.7 billion decays in 2022

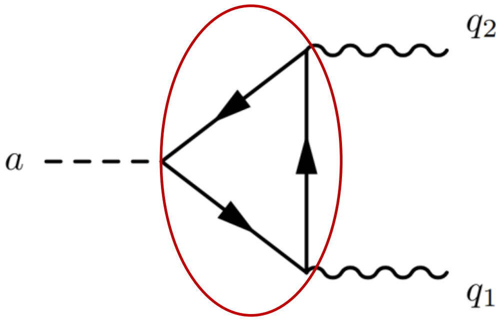
- This type of search **could exploit** the large luminosity collected at $\sqrt{s} = m_{\Upsilon(4S)}$ at **Belle II** and potentially provide one of most stringent limit of a photon coupling

- Although **some suppresion** is expected due to the **beam energy spread**, in combination with non-resonant searches it could provide very promising results

*BESIII, Phys. Lett. B 838 (2022), BESIII, Phys. Rev. D 110(2024)

Loop-Induced Effects





An important observation is that **couplings** at 1 and 2 are **essentially different** couplings, as the correction to $g_{a\gamma\gamma}$ induced by the electron triangle is

$$\delta g_{a\gamma\gamma} = \frac{\alpha g_{aee}}{\pi m_e}\left[1 + F(q_1^2, q_2^2)\right]$$

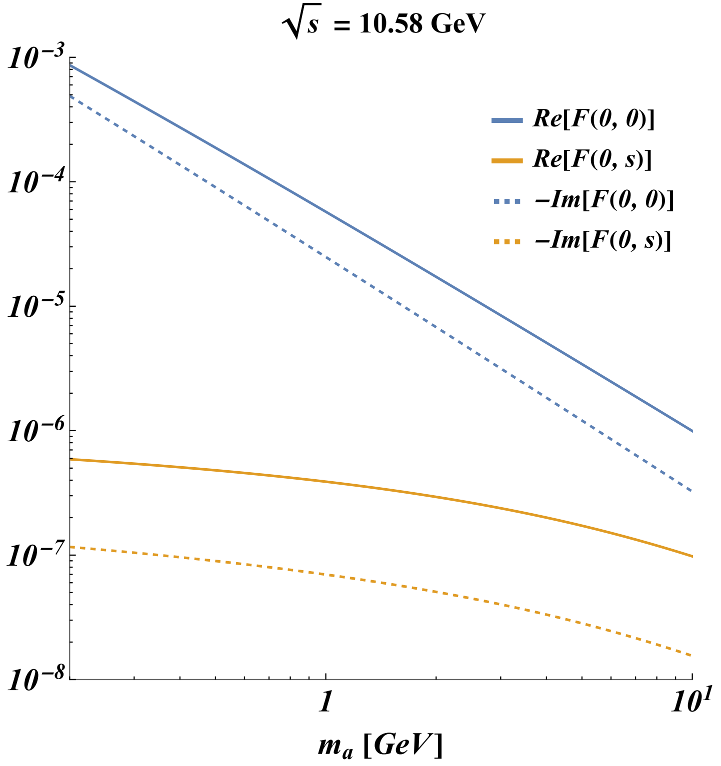
Related to the Passarino-Veltman triangle function C_0

Is significantly different depending on whether a **Primakoff-like process** occurs, involving an off-shell photon, $q_1^2 = 0, q_2^2 \neq 0$, or the **ALP decays into a photon pair** with $q_1^2 = q_2^2 = 0$

Ricardo Z. Ferreira et. al JCAP11(2022)057

This has **important implications** for the physics of ALPs **in hot and dense environments**, such as supernovae

At e^+e^- collider energies the effect, however, **becomes negligible** – the correction is too small



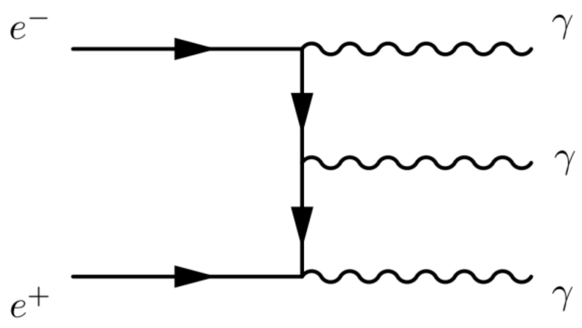
...Nevertheless, it reminds us that **we only have sensitivity to effective couplings**!

$1/m_e$ enhancement in $\delta g_{a\gamma\gamma}$ is also **meaningless** unless the tree-level $g^0_{a\gamma\gamma}$ coupling is fixed

A. Pustyntsev and M. Vanderhaeghen, EPJ C 84, 546 (2024)

Background Summary

- **High-mass ALPs** decay into di-photon pair with a wide opening angle – **clear signal**, dominant background – QED 3-photon annihilation



The 95% c.l. signal over background ratio

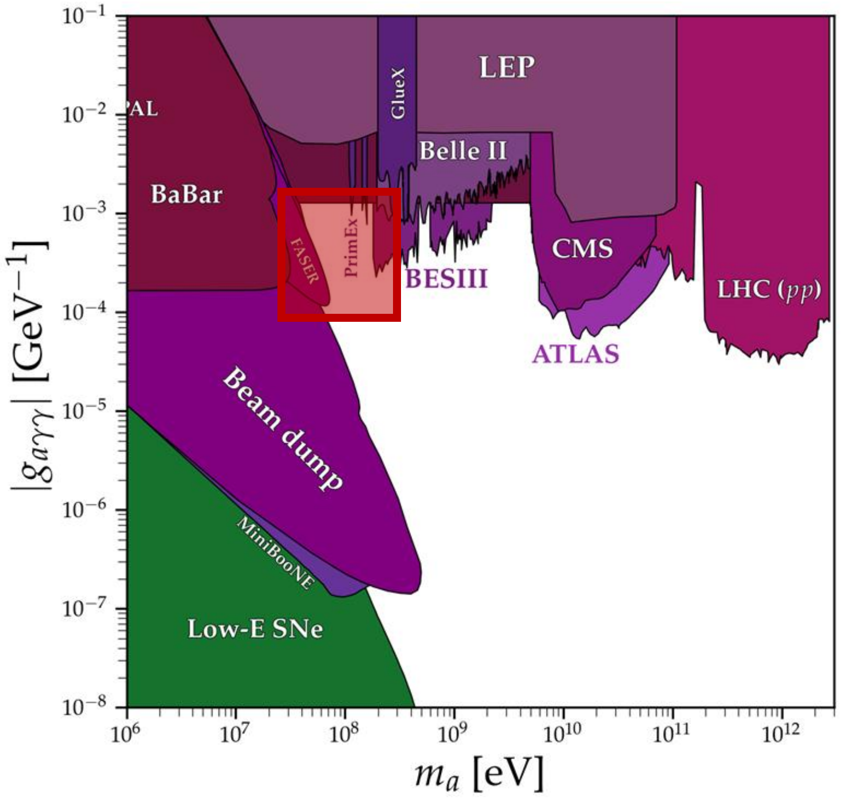
$$\frac{\sigma_{ALP}}{\sigma_{QED}} = \frac{2}{\sqrt{L \cdot \sigma_{QED}}}$$

$\mathrm{Reach}[g_{a\gamma\gamma}] \propto \sqrt[4]{L}$ – **huge luminosity** L to get a signal and an **optimized event selection** procedure

- **A small portion** of background also arises from $e^+e^- \to e^+e^-\gamma$, etc.

- The search is additionaly complicated by **peaking backgrounds** from pseudoscalar mesons $\boldsymbol{\pi^0, \eta}$, …

- **Low-mass ALPs** are highly boosted, the decay photons merge into one – **very challenging.** The main obstacle in accessing the low-mass ALP region

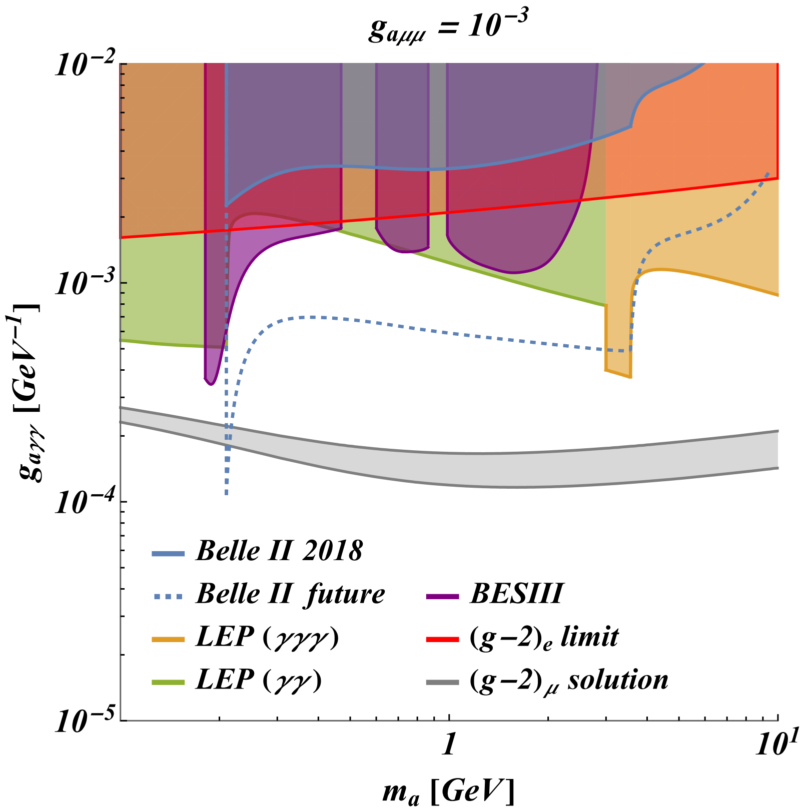


The strongest limit in this region so far is from **LEP** constraints for $\boldsymbol{Z \to 2\gamma}$

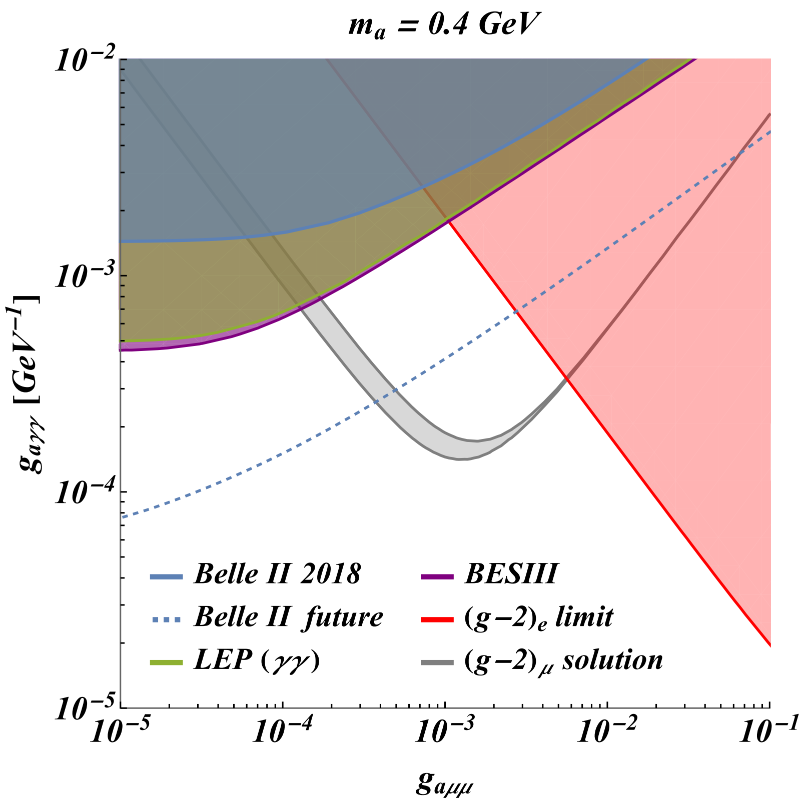
Requires further **technical advancements or a complementary experiments** in the low-energy region

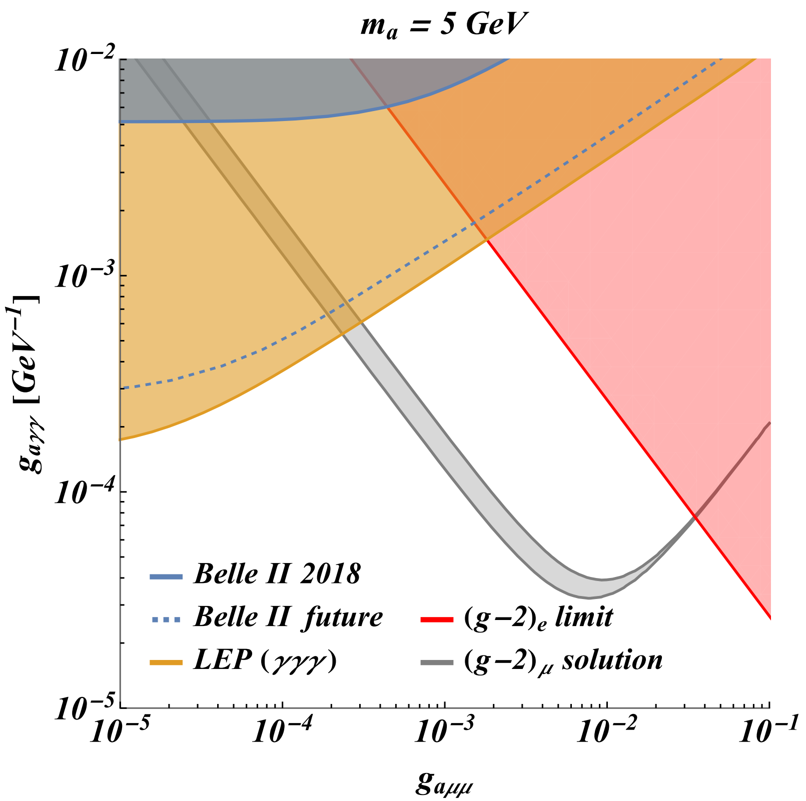
Results for Pseudoscalar – before 2025 $(g-2)_\mu$

Projection onto the $(m_a, g_{a\gamma\gamma})$ plane



Projection onto the $(g_{a\mu\mu}, g_{a\gamma\gamma})$ plane





Despite a significant improvement of possible with Belle II data in the near future, still **no full access** to parameter space relevant for the $(g-2)_\mu$

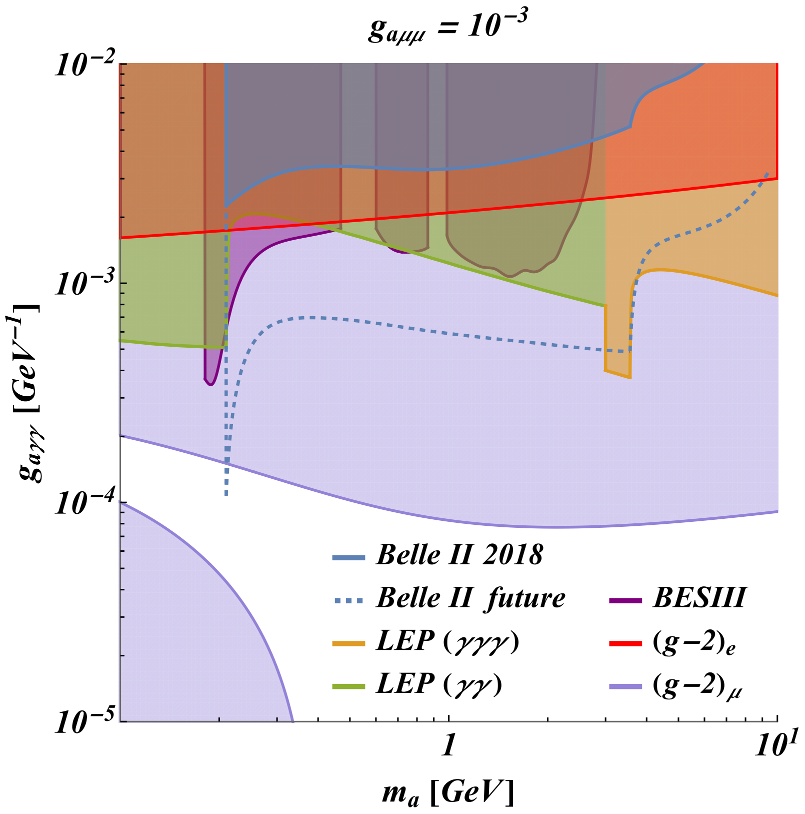
LEP data at Z-pole are still highly competitive. Lepton universality is assumed for collider bounds and $(g-2)_e$

BESIII and Belle II access to the **lower mass region is limited by the spatial resolution** of a di-photon pair

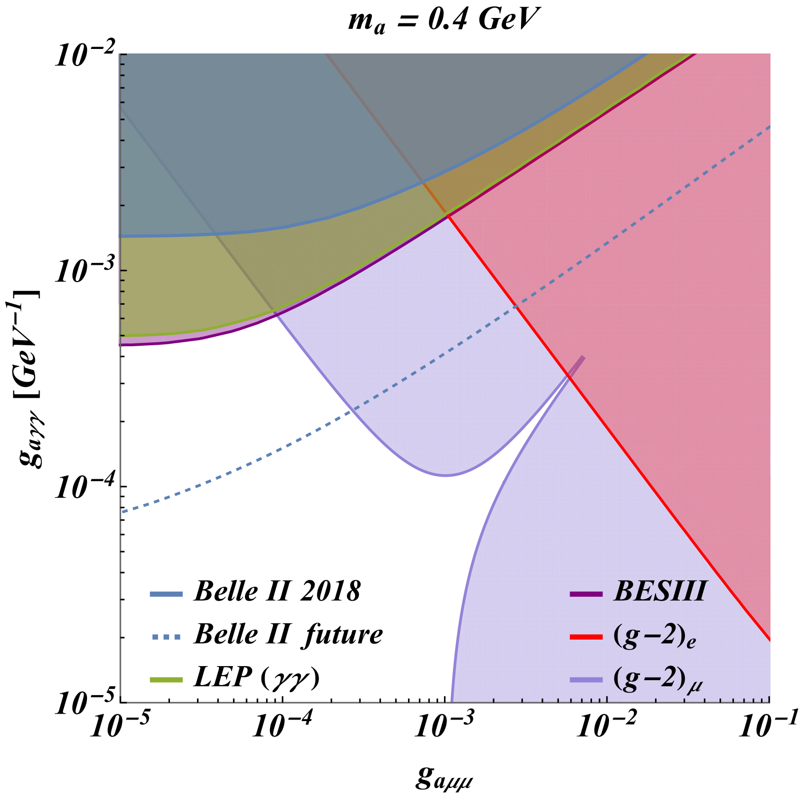
A. Pustyntsev and M. Vanderhaeghen, Phys. Rev. D 110 (2024)

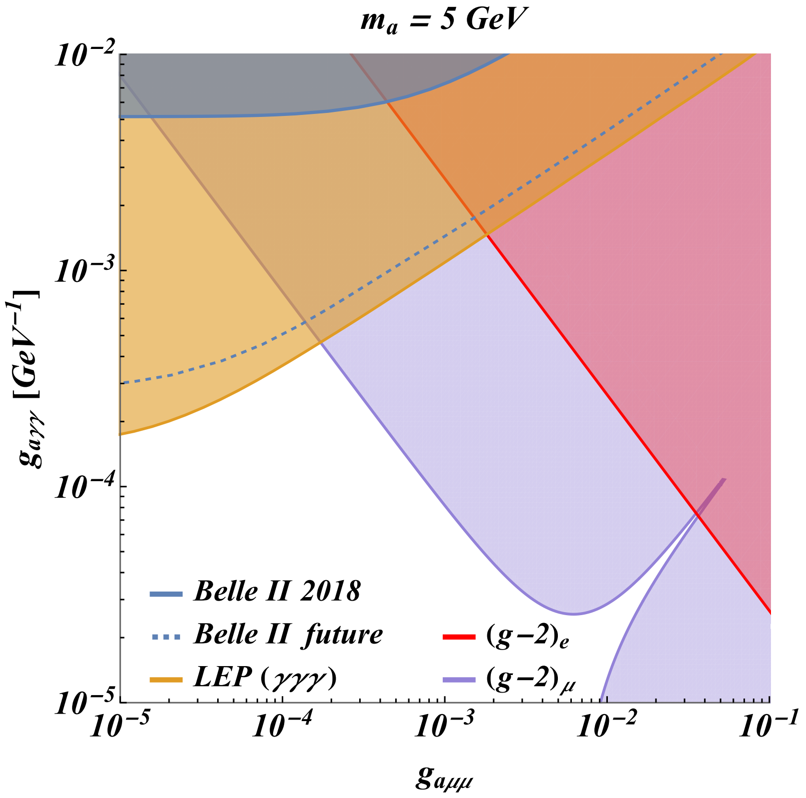
Results for Pseudoscalar – after 2025 $(g-2)_\mu$

Projection onto the $(m_a, g_{a\gamma\gamma})$ plane



Projection onto the $(g_{a\mu\mu}, g_{a\gamma\gamma})$ plane





If $(g-2)_\mu$ discrepancy is resolved within the SM, it **puts one of the most stringent constraints** on the ALP parameter space

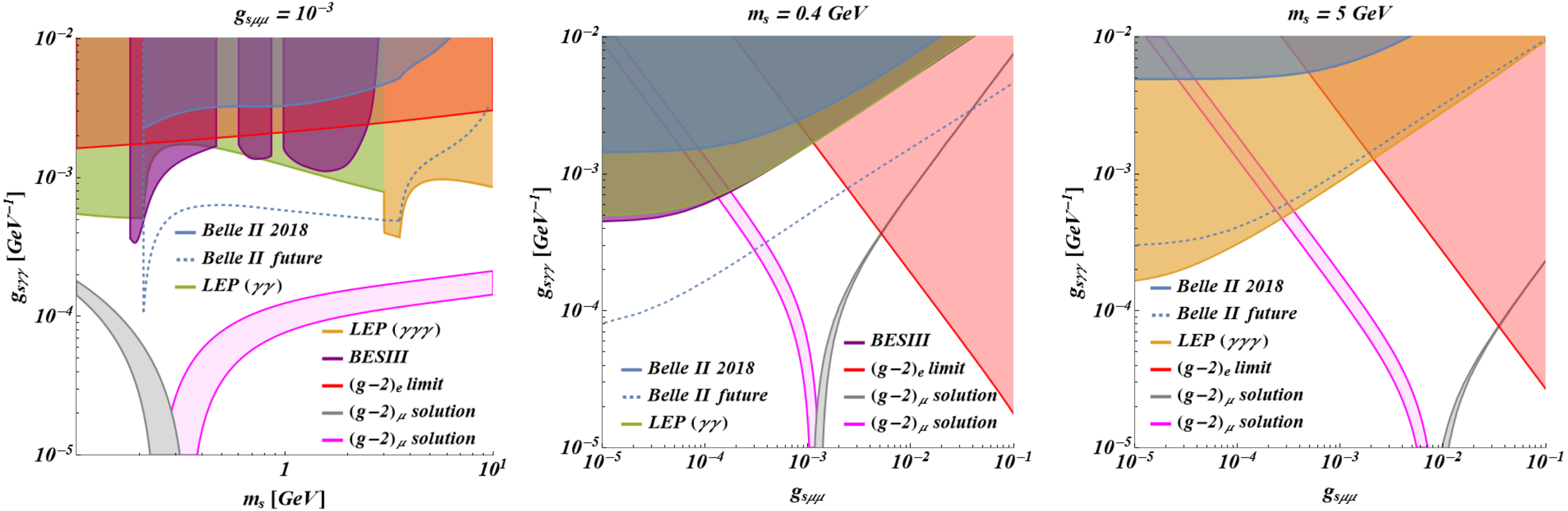
Theory and experiment errors added in quadrature, $\boldsymbol{\Delta a = 63.7 \times 10^{-11}}$, 2σ limit is taken

$(g-2)_\mu$ boundary is essentially model-independent

Results for Scalars – before 2025 $(g-2)_\mu$

This analysis can be **extended to scalars** if we make use of the Lagrangian:

$$\mathcal{L} = -g_{sff}\, s\bar{\psi}\psi - \frac{g_{sBB}}{4} sB_{\mu\nu}B^{\mu\nu} - \frac{g_{sWW}}{4} s\boldsymbol{W}_{\mu\nu}\boldsymbol{W}^{\mu\nu}$$



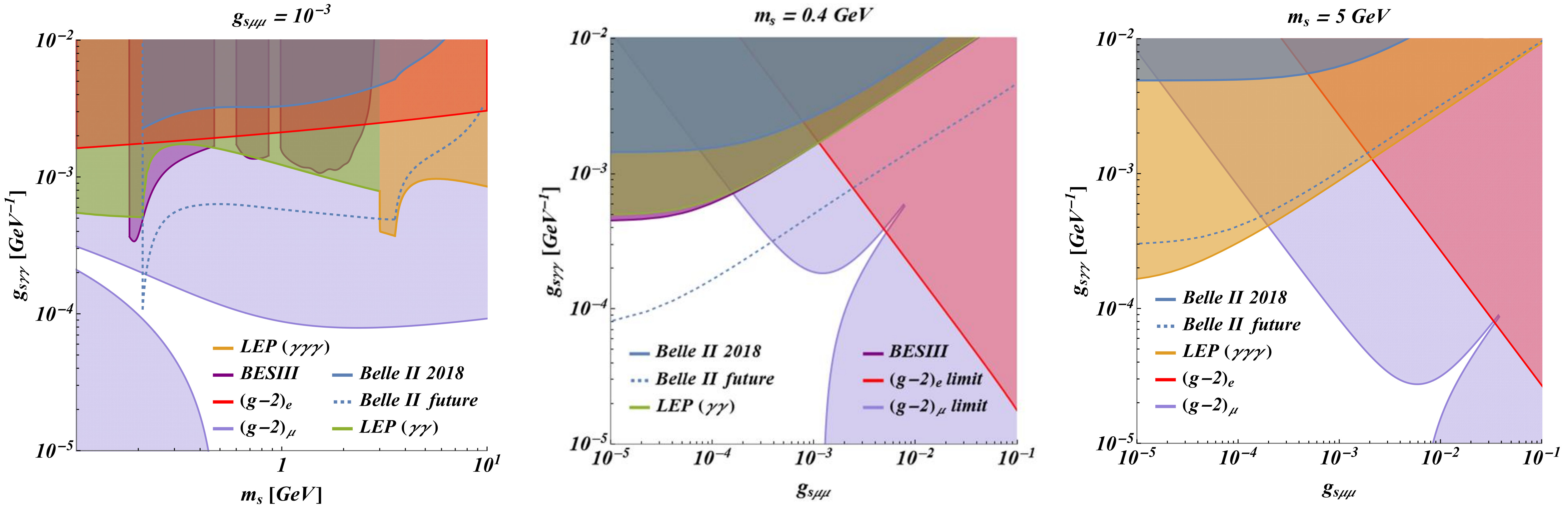
$(g-2)_\mu$ solution **is ambiguous** in this case, both options $g_{s\mu\mu}g_{s\gamma\gamma} > 0$ and $g_{s\mu\mu}g_{s\gamma\gamma} < 0$ are allowed

Search for photon decays combined with the $(g-2)_l$ measurements – one of the most efficient strategies to scan the MeV-GeV mass range

Constraints are of comparable strength to those in the ALP scenario

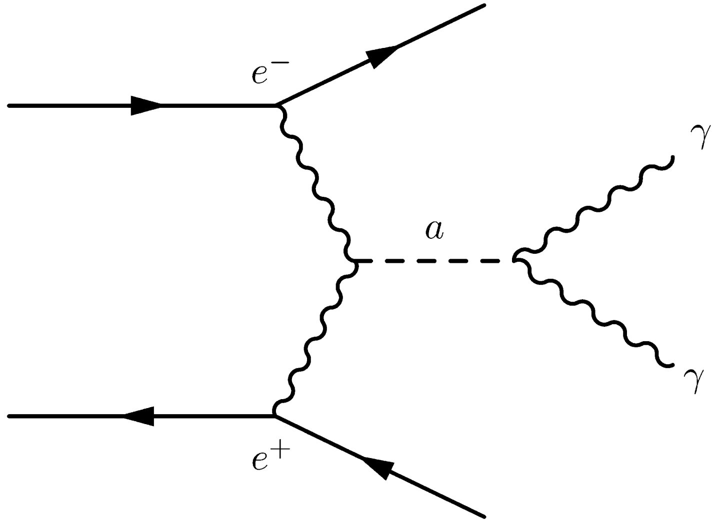
Results for Scalars – after 2025 $(g-2)_\mu$

The rest of our conclusions regarding the **pseudoscalar** case also apply to the **scalar** case



Future improvements in both lepton dipole moments and collider searches are strongly warranted both as a way to potentially unveil a new source of CP violation and to explore ALP parameters

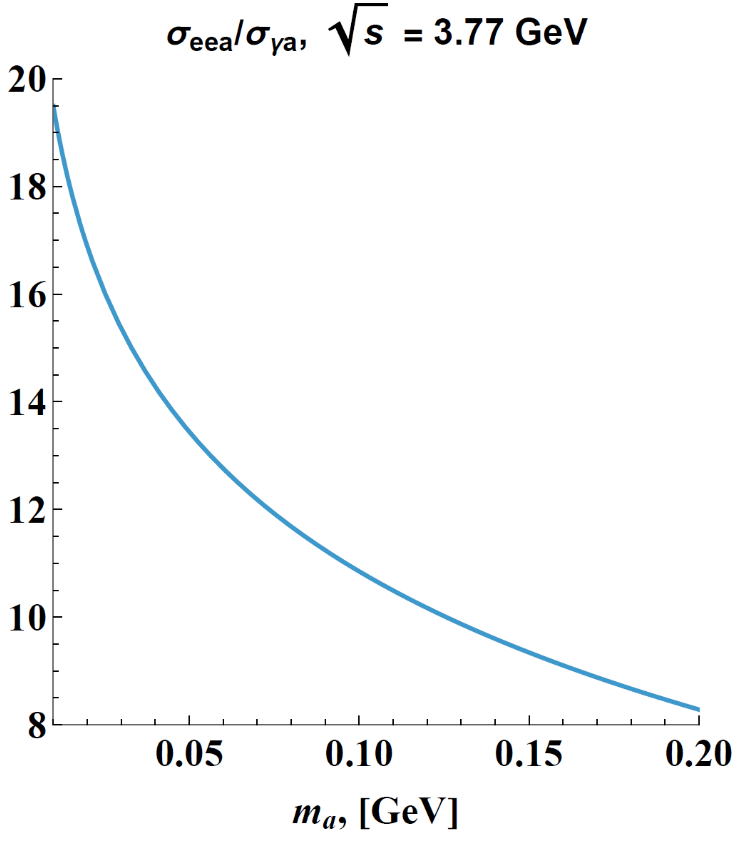
Photon Fusion



Another potential search channel is **photon fusion**:

1) ALPs production at rest is enhanced – two photons are back-to-back
2) Most photons end up in the electromagnetic calorimeter
3) And, most importantly, at low m_a it dominates over the other ALP production contributions

W. J. Marciano et al., Phys. Rev. D 94 (2016)



Despite all of that, **not investigated so far** – extremely complicated event selection and large backgrounds, but at the same time very promising

Same challenges as before:

M. Dolan et al. JHEP 94 (2017)

1) Charged tracks reconstruction – to be improved, multiple challenges
2) Irreducible peaking backgrounds from π_0 production

Addressing these issues could significantly **tighten bounds on ALP-photon coupling** in the region where the existing constraints are especially loose

A Note on Dark Photons

Dark photons, mediating **gauge forces within the dark sector**, are another commonly discussed BSM scenario

$$\mathcal{L} = \varepsilon e \cdot \bar{\psi}(\gamma A')\psi$$

M. Fabbrichesi et al., arXiv:2005.01515

$$\Delta a = \frac{\alpha \varepsilon^2 m_l^2}{\pi} \int_0^1 \frac{z^2(1-z)}{m_l^2 z^2 + m_A^2(1-z)} dz > 0$$

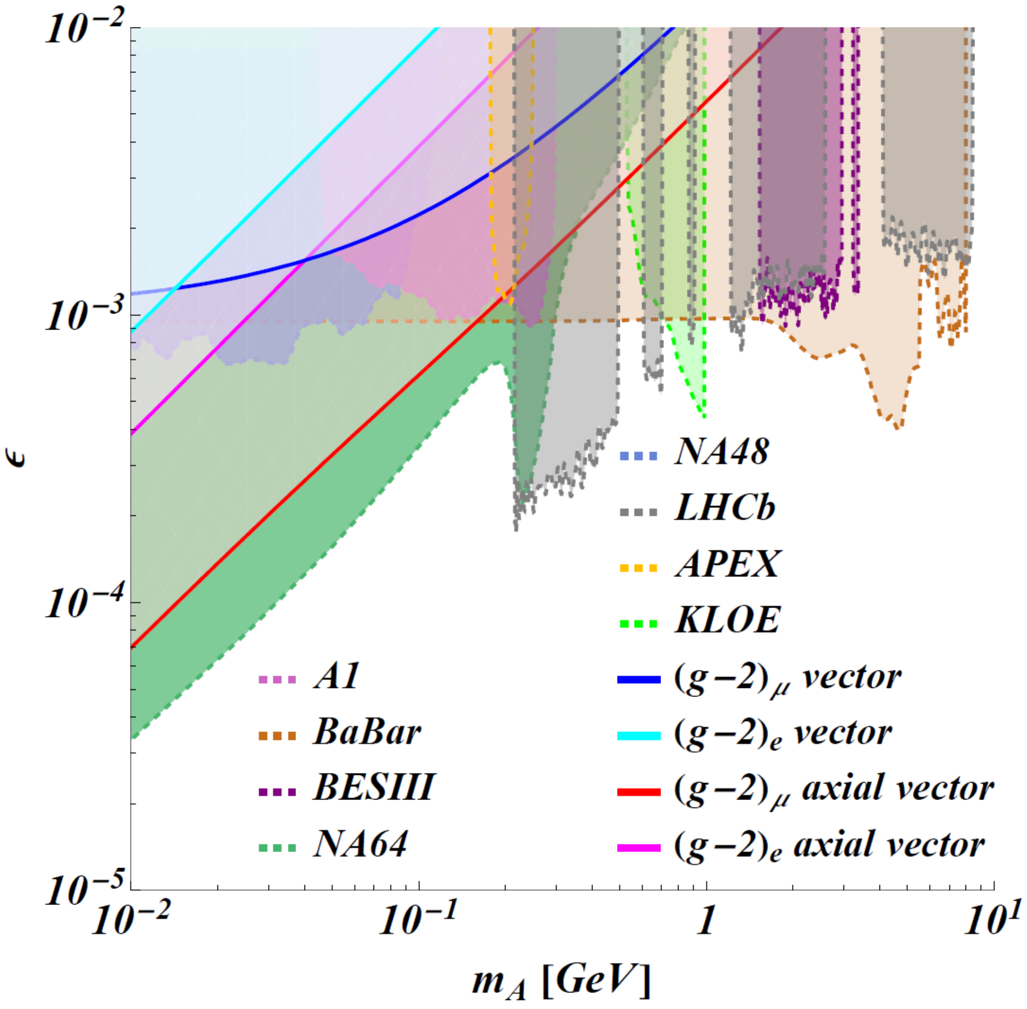
ε is a mixing parameter between dark and SM photons

Pseudovectors are also of interest in many models (Δa enhanced by the axial anomaly)

arXiv:2506.17750

$$\mathcal{L} = \varepsilon e \cdot \bar{\psi}\gamma^5(\gamma A')\psi$$

$$\Delta a = -\frac{\alpha \varepsilon^2 m_l^2}{\pi} \int_0^1 \frac{z(1-z)(4-z) + 2\frac{m_l^2}{m_A^2} z^3}{m_l^2 z^2 + m_A^2(1-z)} dz < 0$$



NA64 is model-dependent, relying on the specific assumption of an invisible decay into dark fermions! $(g-2)_l$ **is assupmtion-free**

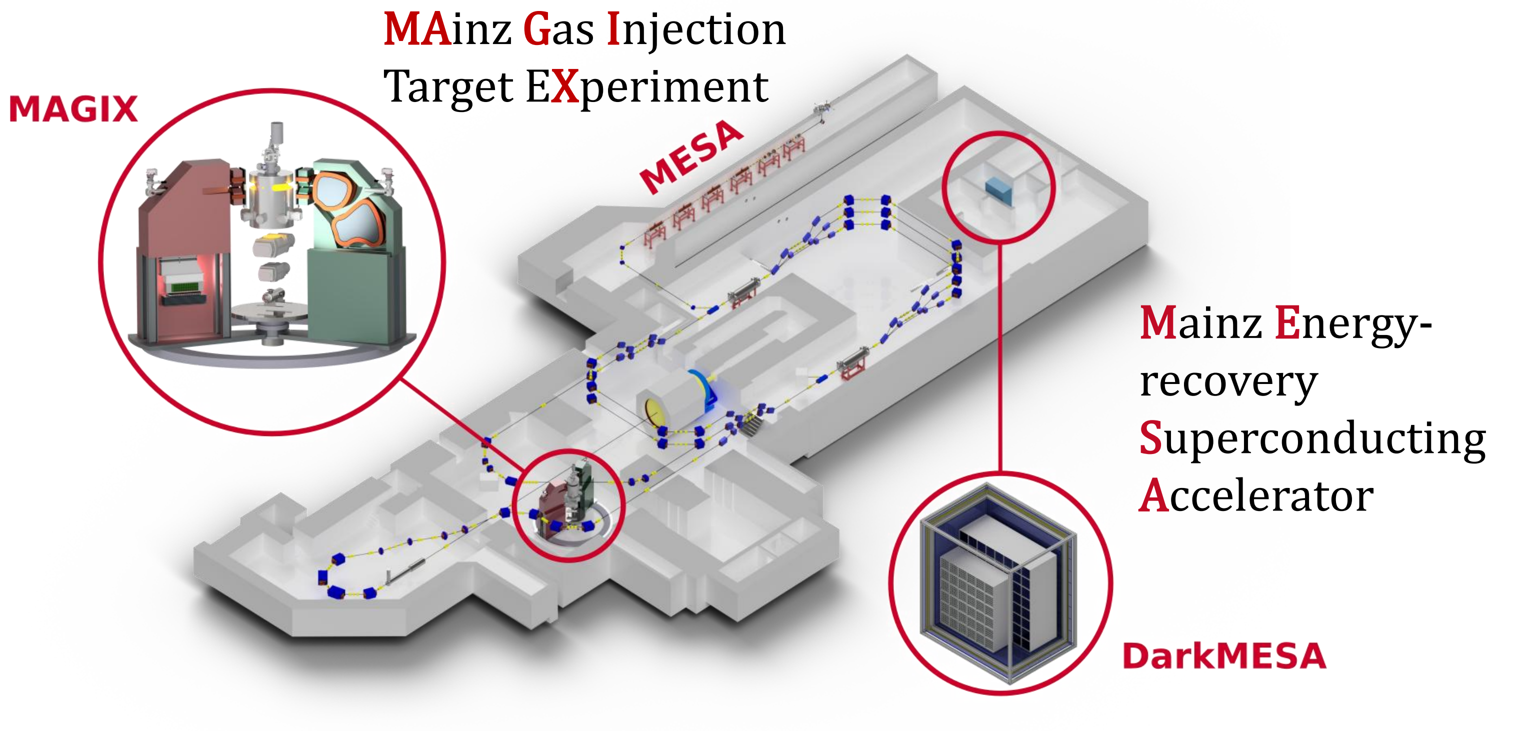
BSM Searches at MESA

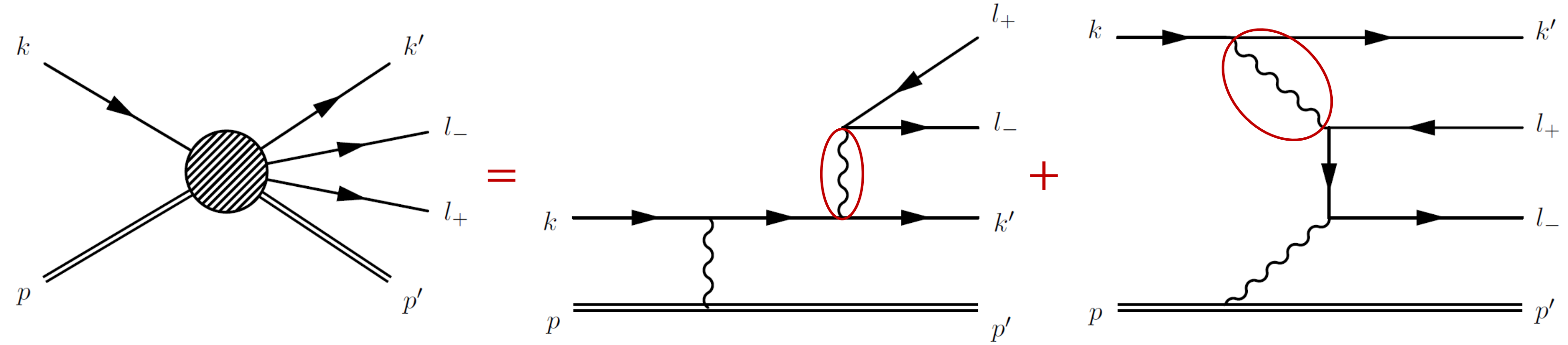
MESA beam dump setup is perfect for scanning the low-energy range for the New Physics:

1) Very high **intensity**
2) State-of-the-art **precision**
3) **Uncertainties** are under **control**

Lepton coupling is much more **promising** to probe than the photon one

Can provide an insight into mass range of $10 - 100$ MeV





Timelike production

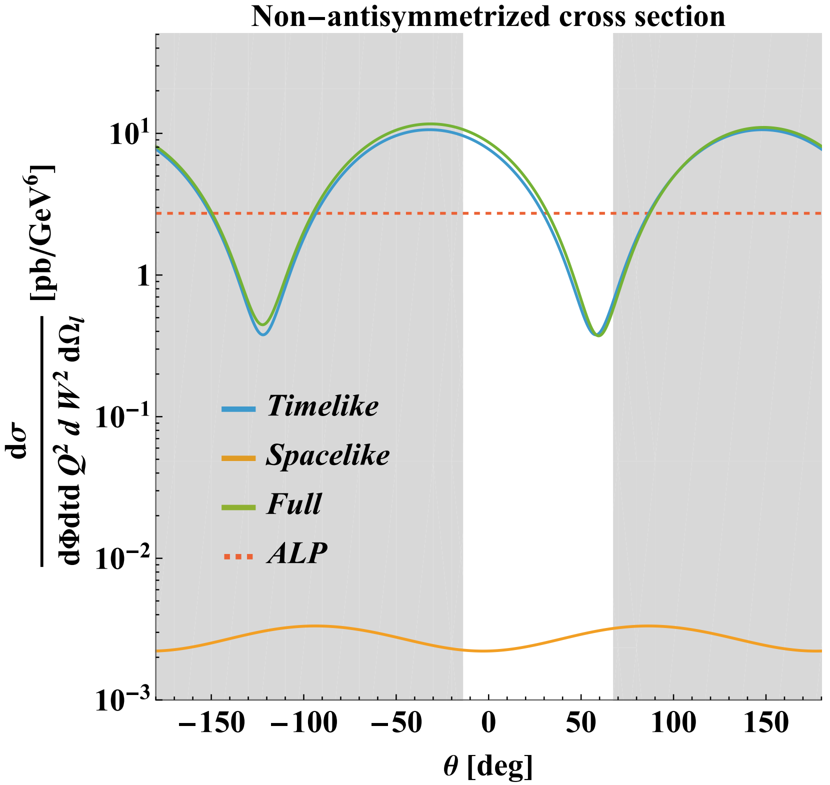
Spacelike production

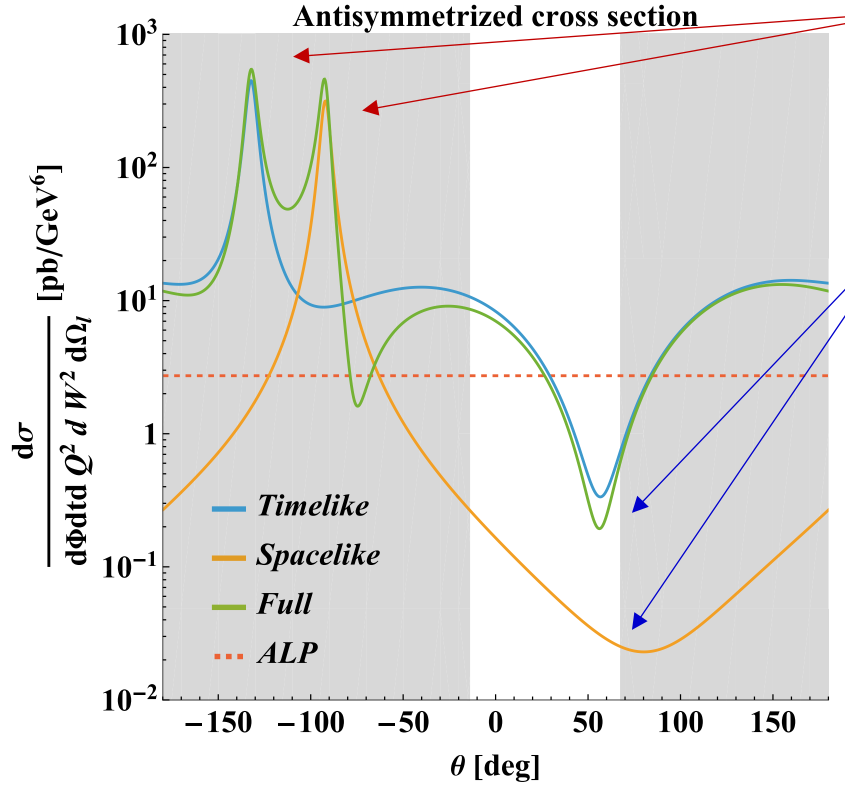
can be (pseudo)scalar, (pseudo)vector, …

Weak interacting ⇒ stable ⇒ tiny decay width, **bump search** in the invariant mass distribution

MESA Signal Estimation

Cross section must be antisymmetrized with respect to the electrons in the final state!





Sharp spikes are collinear singularities, positioned outside of the detector's range (white band)

Dips are the Pauli principle manifestations

We choose $\boldsymbol{g_{aee} = 10^{-4}}$

At MESA kinematics **even for the value this small** we can achieve a **comparable signal strength***, suggesting at least an order of magnitude potential improvement

… or a possible discovery

Proton target is assumed, $E_{beam} = 105$ MeV

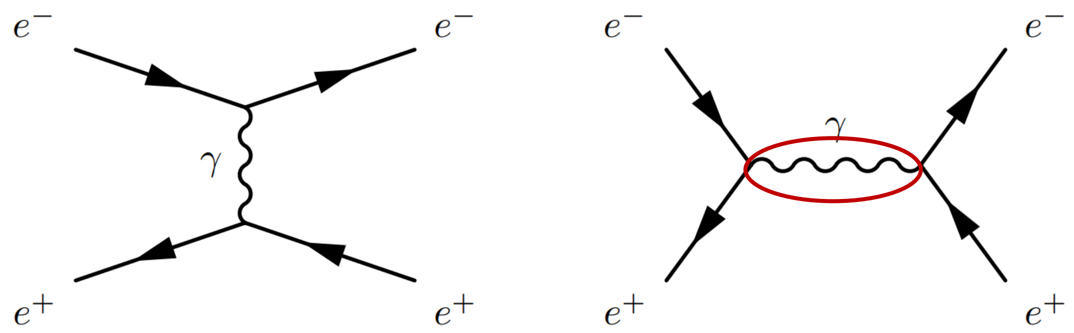
Form-factors are in **dipole × polynom parameterization**

[Bernauer:2010zga]

***can be enhanced even further** by improving the invariant mass resolution

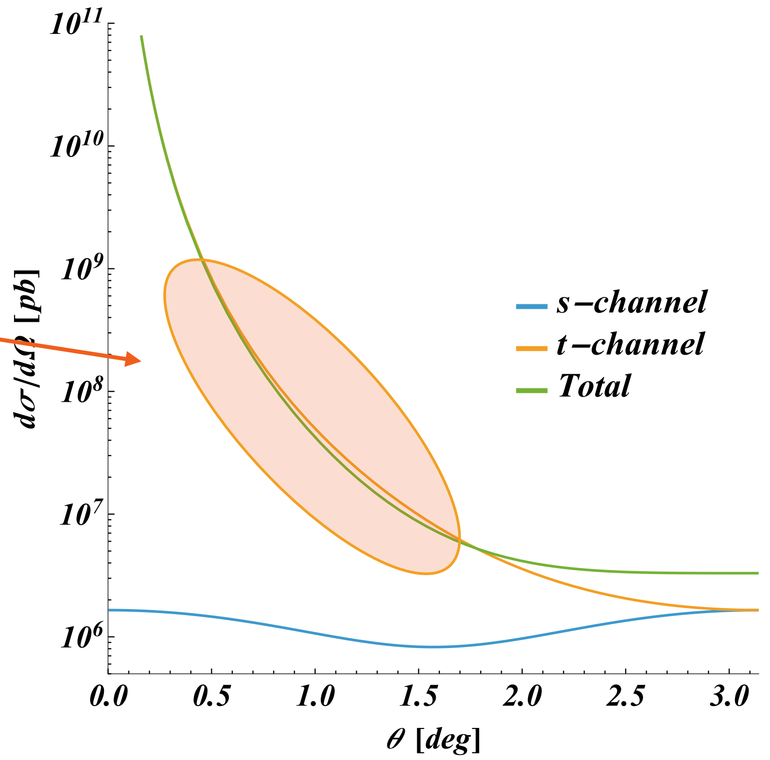
Searches in Bhabha Scattering

JLab is to launch the high-energy polarized **positron beam**
$E = 6$ GeV



- Scattering against **atomic electrons**, $\sqrt{s} \approx 80$ MeV
- **BSM** particles can be **exchanged**
- If a small signal is present and a **resonance is crossed**, a signal would be enhanced by orders of magnitude
- Large ***t*-channel 1-photon** exchange in the intermediate region could **interfere with a small BSM** signal and enhance it
- Could **set extremely competitive exclusions** which are independent of how BSM mediator might decay
- **Energy scan – via initial state radiation**

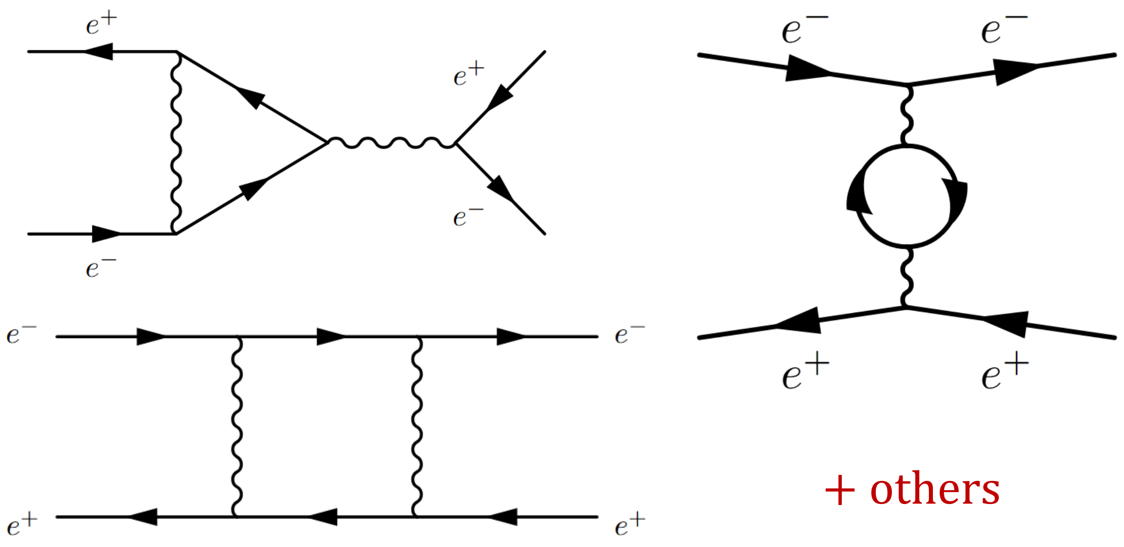
But maybe there is a better way to do it…



Searches in Polarized Bhabha Scattering

Think outside the box – instead of bump searches, look for **BSM traces in polarization effects**

- JLab aims for **Bhabha spin asymmetry measurements of unprecedented precision**
- **Scalar/axial vector/tensor interactions** between ψ_R and ψ_L could provide **a clear signal over QED**
- Requires **at least full one-loop** calculation!



+ others

Work in progress!

More technical: **16 helicity amplitudes involved**

- **Parity invariance** reduces the number from **16 to 8**
- **Time reversal** invariance further reduces to **6**
- **Charge conjugation** removes one more, leaving **5**

The remaining expression can be brought to the form:

$$M = \sum_{i=S,P,V,A,T} A_i \cdot \bar{v}' \Gamma_i \, v \cdot \bar{u} \, \Gamma_i \, u'$$

$$\Gamma_S = \mathbb{1}, \qquad \Gamma_P = \gamma^5, \qquad \Gamma_V = \gamma^\mu,$$
$$\Gamma_A = \gamma^5\gamma^\mu, \qquad \Gamma_T = \sigma^{\mu\nu}$$

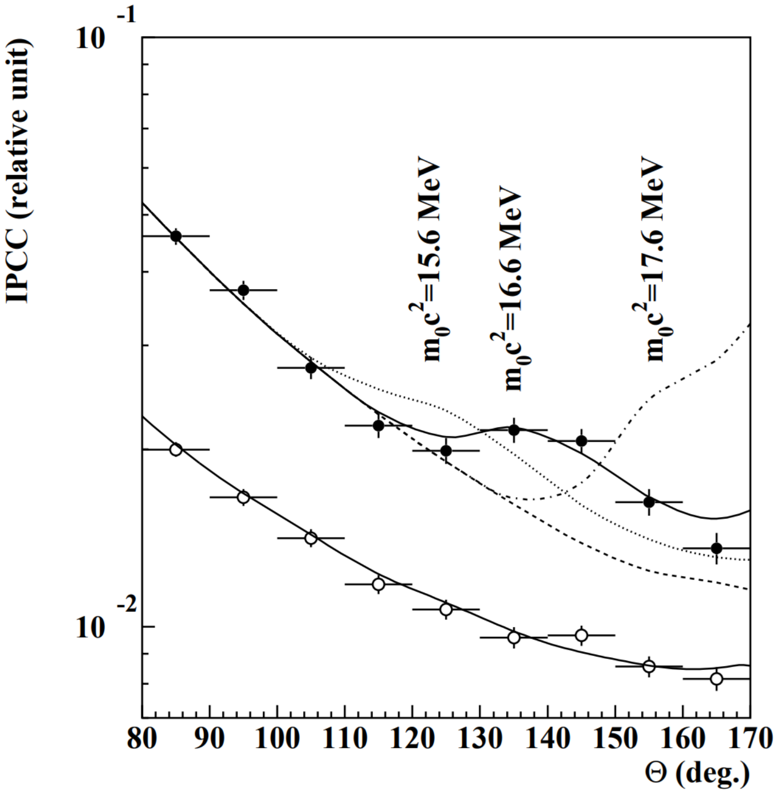
A single spin asymmetry then parameterized as:

$$B_n = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} = \frac{\sqrt{stu}}{4\pi s \sigma_0} \mathrm{Im}[(A_S - A_A)(A_V^* + 2A_T^*)]$$

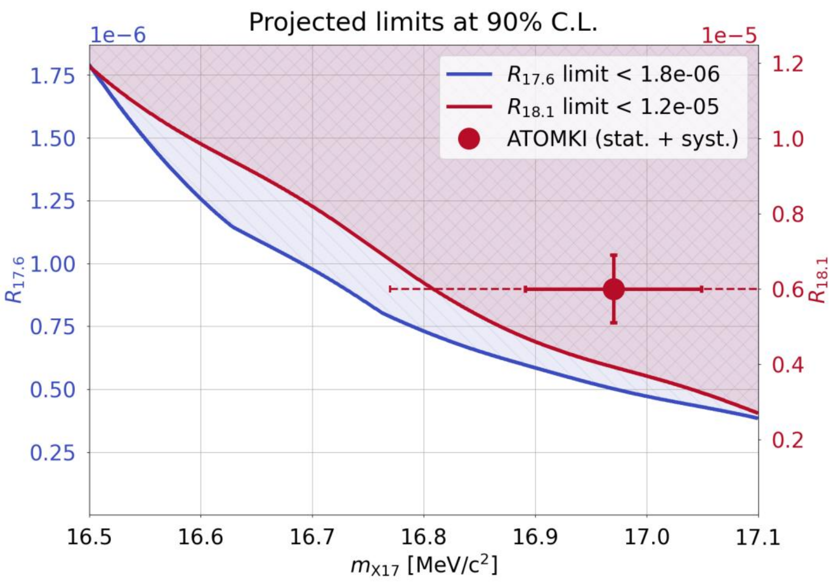
Where σ_0 is the unpolarized cross section

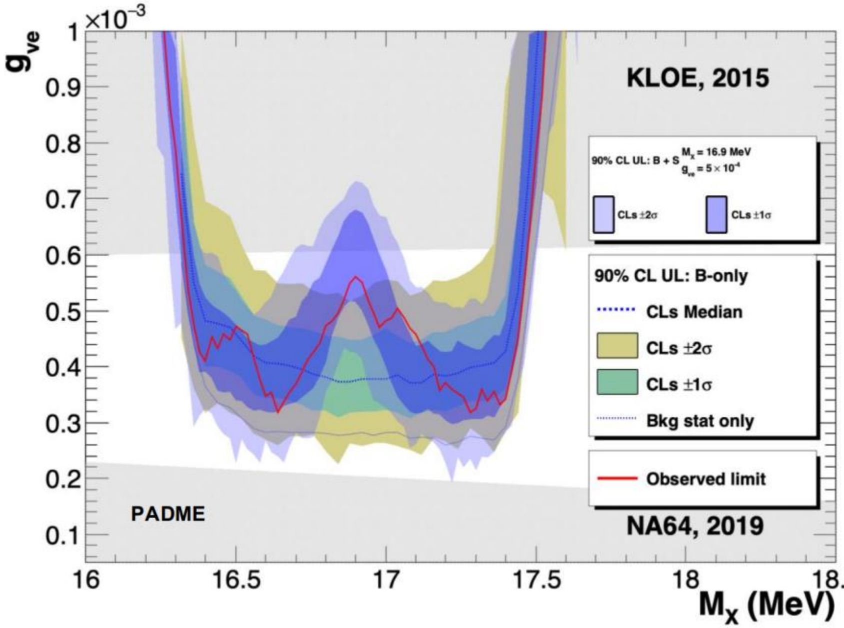
X-17 Searches

- **ATOMKI** experiment: X-17 seen in decays $^8\mathrm{Be}^* \to {}^8\mathrm{Be} + \underbrace{e^+e^-}_{X}$ (2015)
- **MEG II** studied $^8\mathrm{Be}^*$ decays to (dis)-prove – no X-17 signal (2024)
- **PADME**: local 2.5σ excess at 16.90 MeV, data taking is ongoing (2025)



Also reported narrow resonance in the e^+e^- decay spectra of ^{4}He and ^{12}C excited states





It is the **subject of an intense, global research program**; an experiment at an electron accelerator would complement the ongoing effort to verify X-17's existence

Constraining X-17

Further analyses speak in favor of **either vector or pseudovector** interpretation of the ATOMKI results

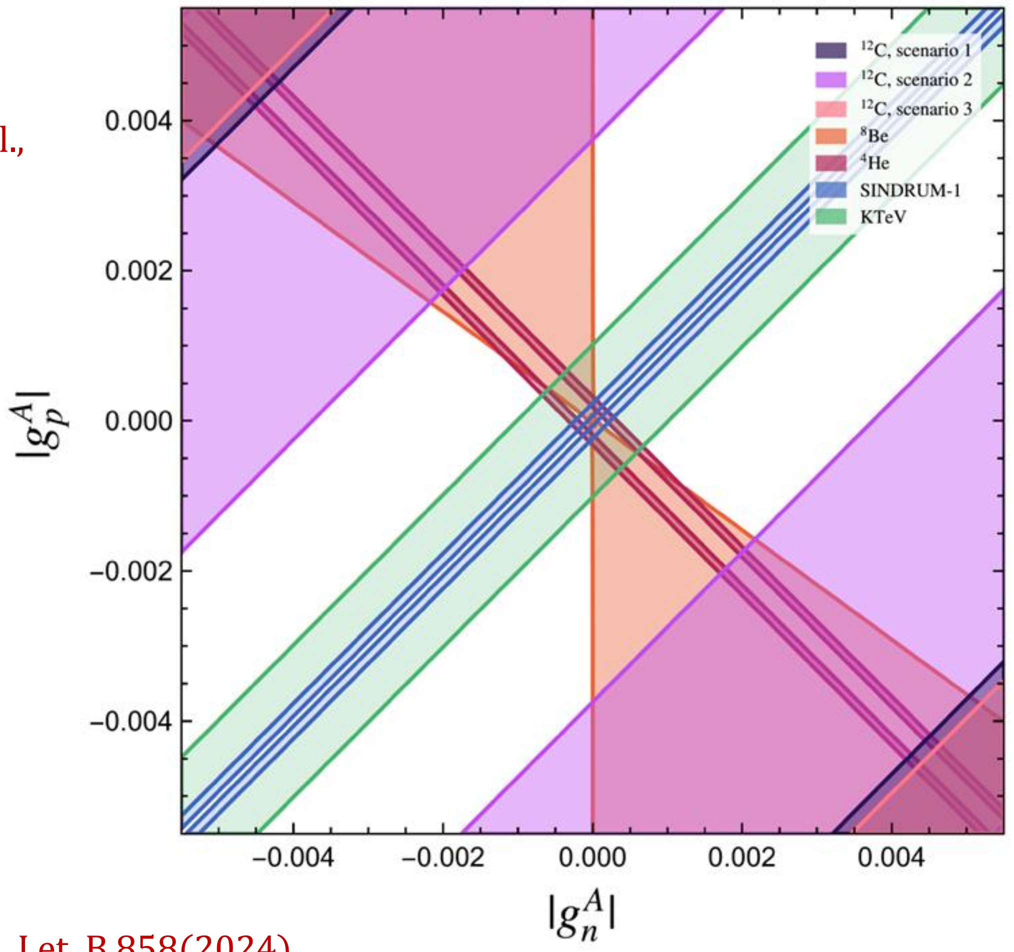
Daniele S. M. Alves et al., EPJ C 83, 230 (2023)

Vector interpretation was later found **to have inconsistencies** between different observations and preexisting bounds on the effective nucleon couplings

M. Hostert and M. Pospelov., Phys. Rev. D 108 (2023)

Axial-vector explanation is the most **promising** – could simultaneously accommodate other KTeV anomaly in $\pi_0 \to e^+e^-$ decay while being compatible with the measurements $(g-2)_e$ D. Barducci and C. Toni, JHEP 154 (2023)

- However, **strong tensions** were discovered in further analyses, **but not completely ruled out yet** C. J. G. Mommers and M. Vanderhaeghen, Phys. Let. B 858(2024)
- **More comprehensive calculation** of the spin-dipole operator matrix elements **could shed some light**



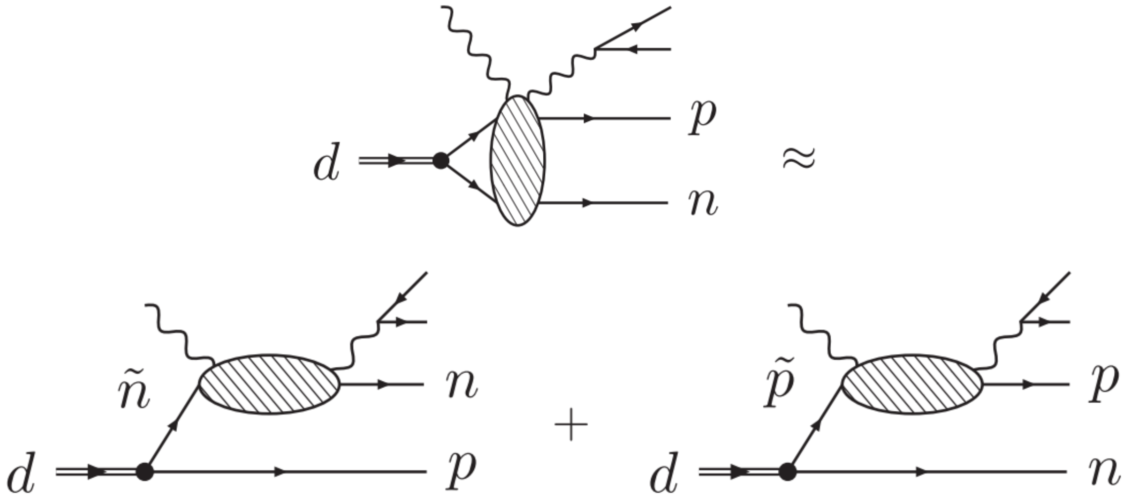
Compatibility regions for X-17. Colored regions indicate couplings to a nucleon consistent with the ATOMKI data of ^{4}He, ^{8}Be and ^{12}C as well as preexisting constraints

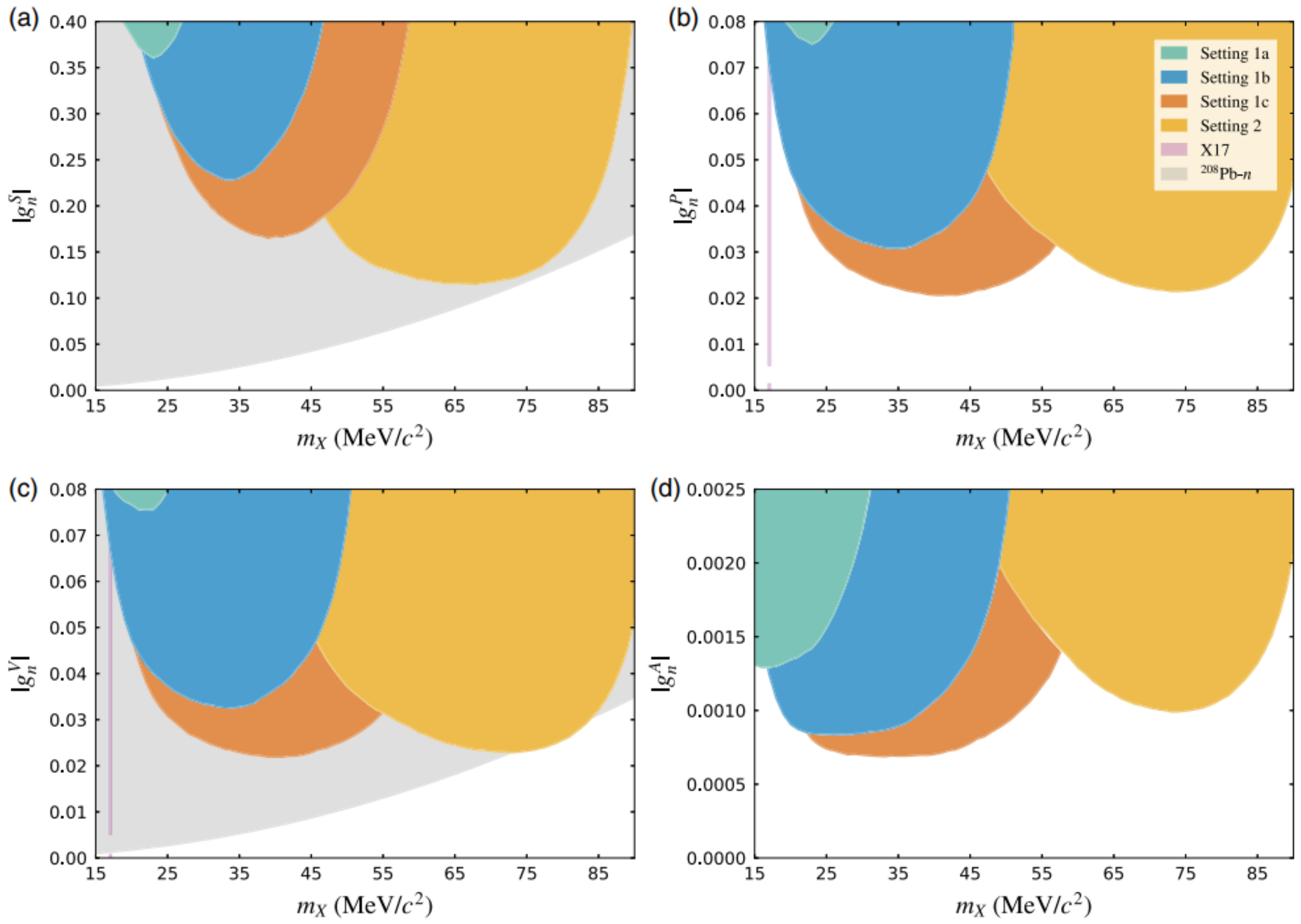
X-17 Search at MAGIX

Better **constraints for nucleon couplings** are desirable, especially in the axial-vector case

- Neutron coupling can be **probed with deuteron photodisintegration** at the high-intensity electron scattering experiment **MAGIX@MESA**

- Competitive **constraints for axial-vector** scenario were **found**





Existing constraints are shown in gray

C. J. G. Mommers and M. Vanderhaeghen, Phys. Rev. D 109 (2024)

Conclusion

- Axions and ALPs in the **MeV-GeV mass range remain viable** BSM candidates, with current constraints leaving open a lot of parameter space

- **Further improvements anticipated** from both theory and experiment perspectives

- An up-to-date summary of the **current limits on dark photon** scenarios was **included**

- Measurements of $(g-2)_l$ **remains a key benchmark** for any potential BSM scenario

- **X-17 parameter space was discussed** – only the axial vector explanation still plausible, though here tensions are faced too

A lot of possible directions for further analyses:

- **BSM search at MESA** from $e^- p \to e^- p e^- e^+$: ubiquitous way to probe mediators with various quantum numbers

- **JLab program utilizing polarized positrons** at low $\sqrt{s}$ – setting tighter bounds via beam asymmetry measurements

Join us at EINN 2025!

Conference **Topics**:

On behalf of the organizing committee

- Nucleon form factors and **low-energy hadron structure**
- Precision electroweak physics and **new physics searches**
- **Exotic hadron spectroscopy**
- Nuclear effects and **few-body physics**

... and others!

https://2025.einnconference.org/

Including 3 **workshops**:

https://agenda.infn.it/event/45343/

- **Non-perturbative approaches** for hadron structure from low to high energy (**Barbara Pasquini**)
- **AI & ML in nuclear science**: starting with design, optimization, and operation of the machine and detectors, to data analysis (**Abhay Deshpande**)
- Frontiers and Careers: **workshop for PhD students** and postdoctoral researchers, preceding the main event, **26-27 October (Aleksandr Pustyntsev)**

16th European Research Conference on Electromagnetic Interactions with Nucleons and Nuclei

28 October - 01 November
Abstract submission os open!

Chair: Martha Constantinou
Vice-chair: Achim Denig

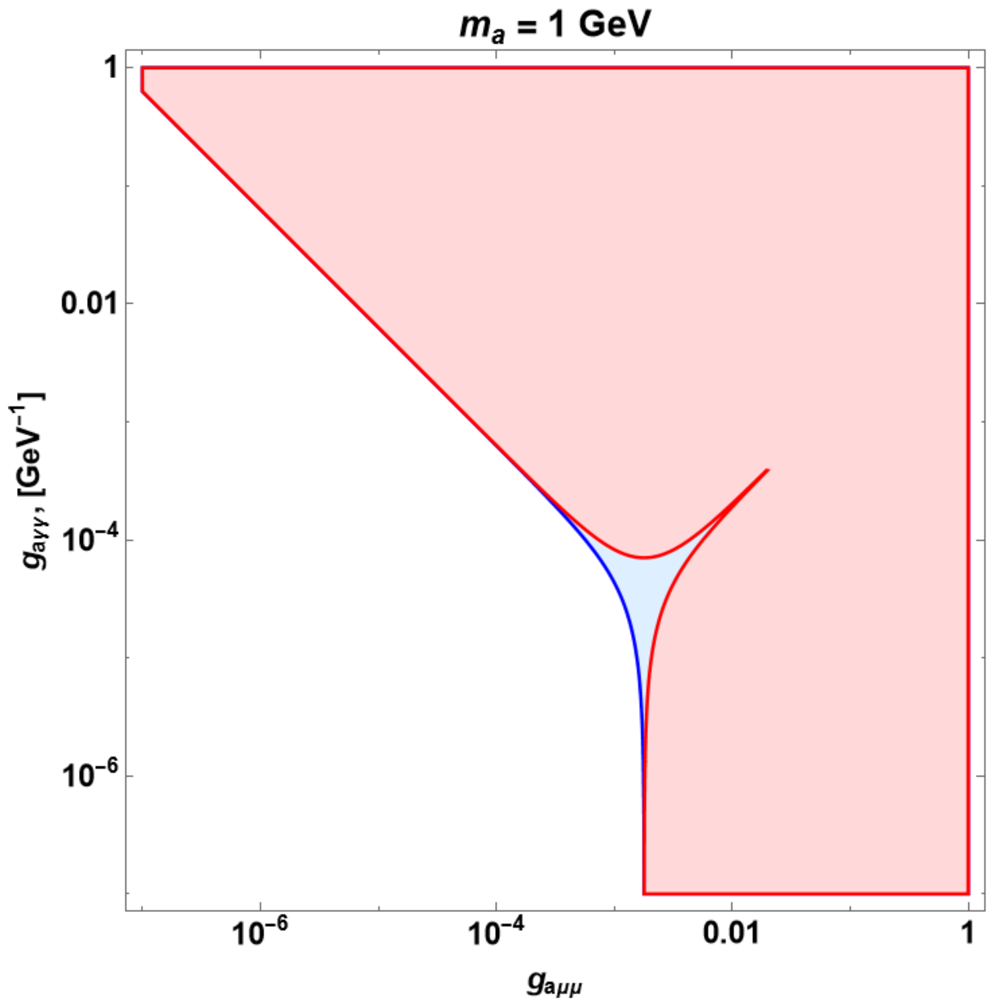
Thank you *very much* for your attention!

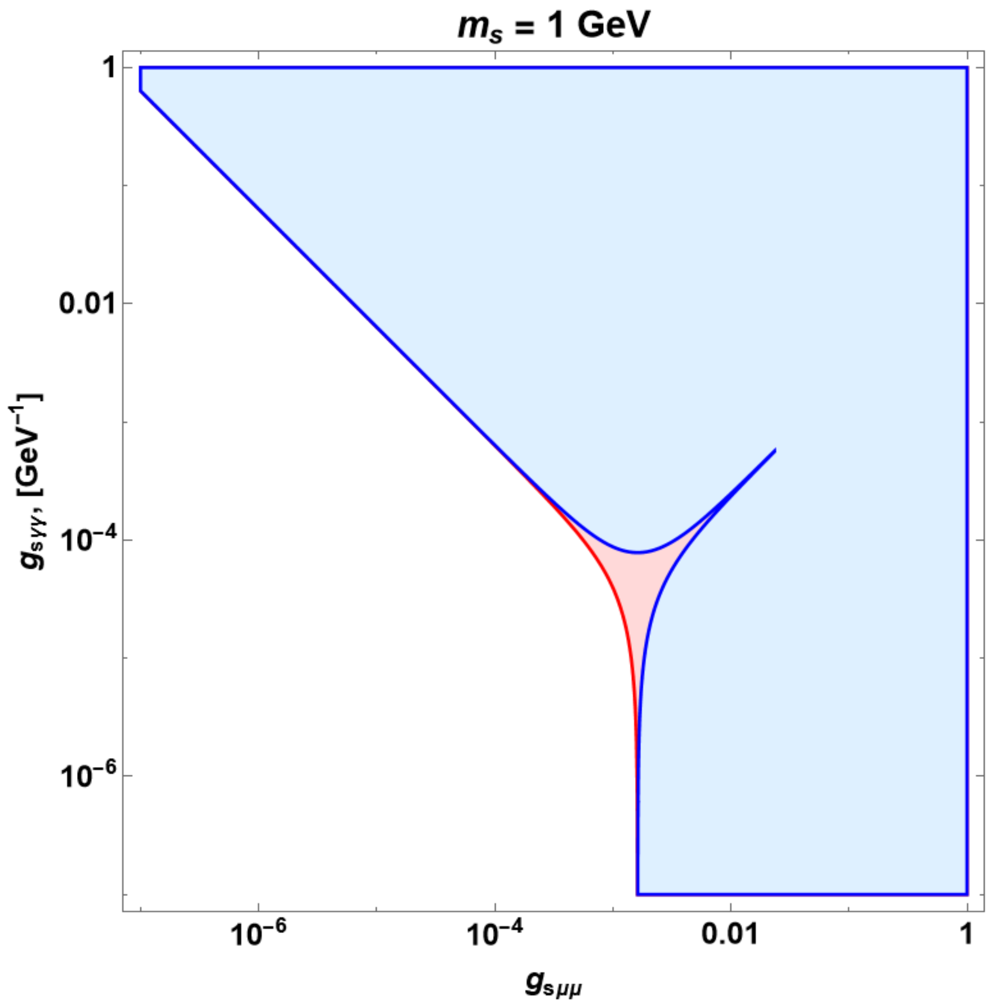
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

July 09, 2025

Research Unit FOR 5327 Photon-photon interactions in the Standard Model and beyond
Exploiting the discovery potential from MESA to the LHC

Cancellation vs Enahcement





Red refers to $g_{X\mu\mu}g_{X\gamma\gamma} > 0$ scenario, blue stands for to $g_{X\mu\mu}g_{X\gamma\gamma} > 0$. The visible thin line represents the situation where the two contributions cancel each other out. Cancellation provides weaker constraints