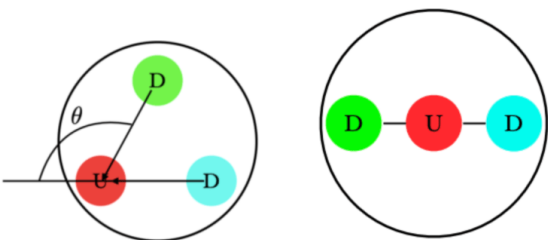


Axion-like Particle Searches in the Laboratory

Adrian Thompson

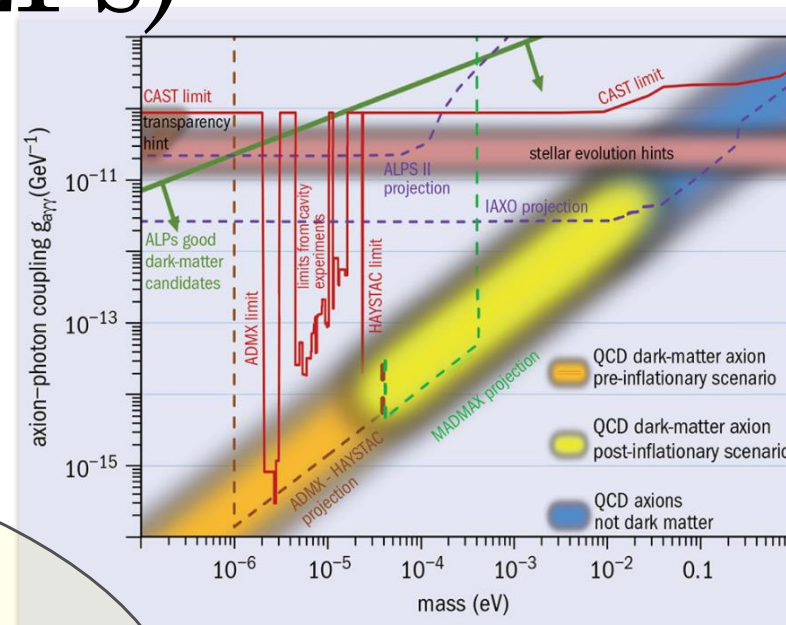
APS Division of Particles and Fields 2021

Axion-like Particles (ALPs)



Hook, 1812.02669

- Strong CP
- Stringy CP-odd operators
- Dark Matter
- Heavy axions and High-quality axions



Majorovits 2018

$$ig_{a\ell} a \bar{\ell} \gamma^5 \ell$$

$$\frac{1}{4} g_{a\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu}$$

$$ig_{aN} a \bar{N} \gamma^5 N$$

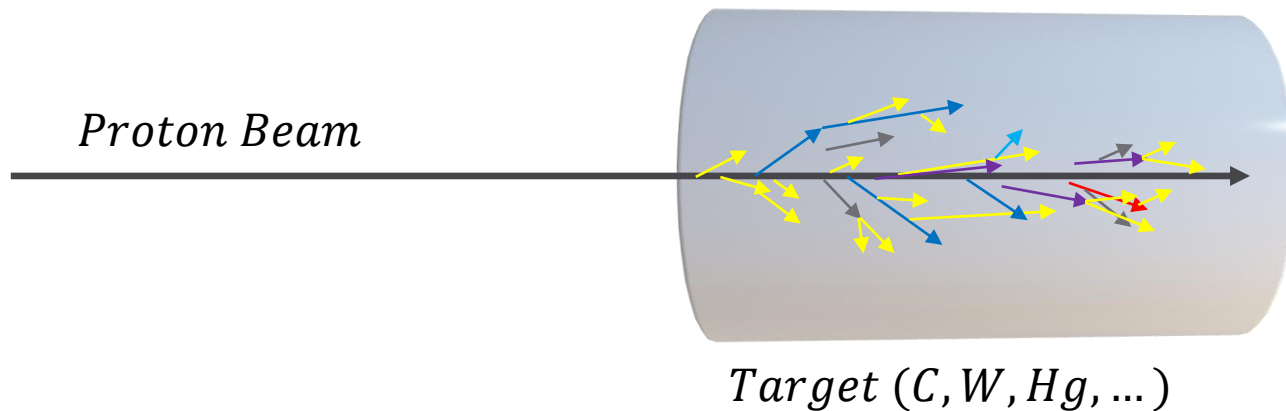
$$\frac{1}{4} g_{aGG} a G_{\mu\nu} \tilde{G}^{\mu\nu}$$

$$\frac{1}{4} g_{aZ} a Z_{\mu\nu} \tilde{Z}^{\mu\nu}$$

$$\frac{1}{4} g_{aW} a W_{\mu\nu} \tilde{W}^{\mu\nu}$$

$$\frac{1}{4} g_{a\gamma Z} a F_{\mu\nu} \tilde{Z}^{\mu\nu} \dots$$

Neutrino and Dark Matter Frontier: Beam Target Physics

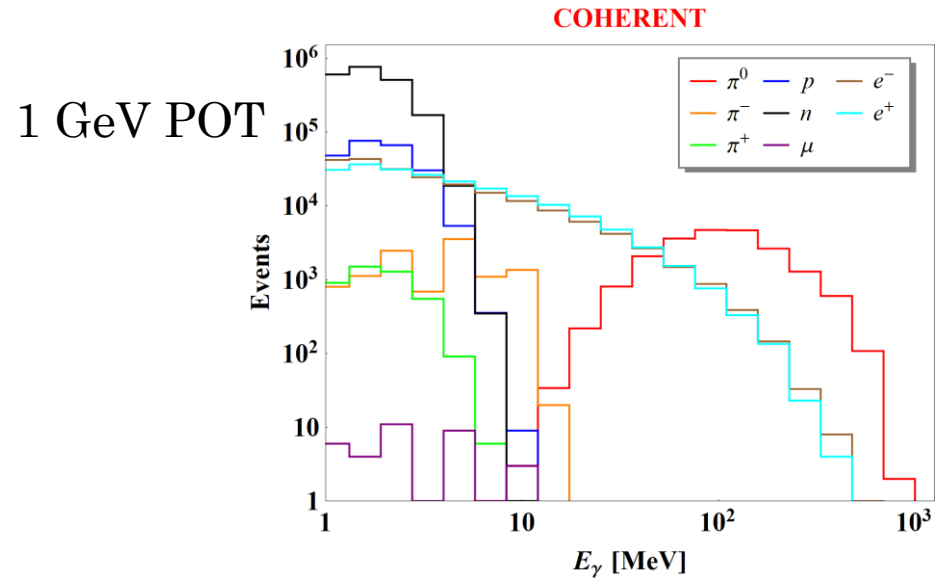
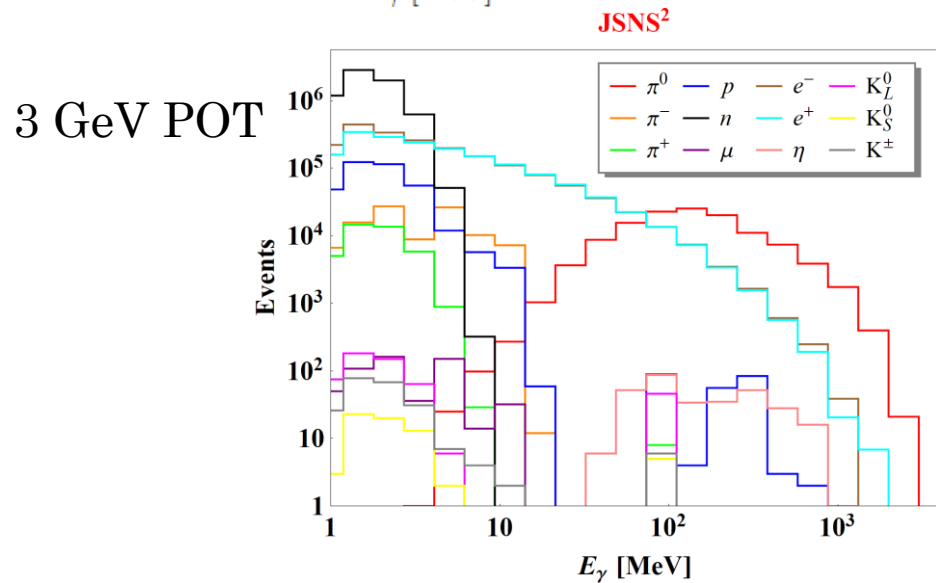
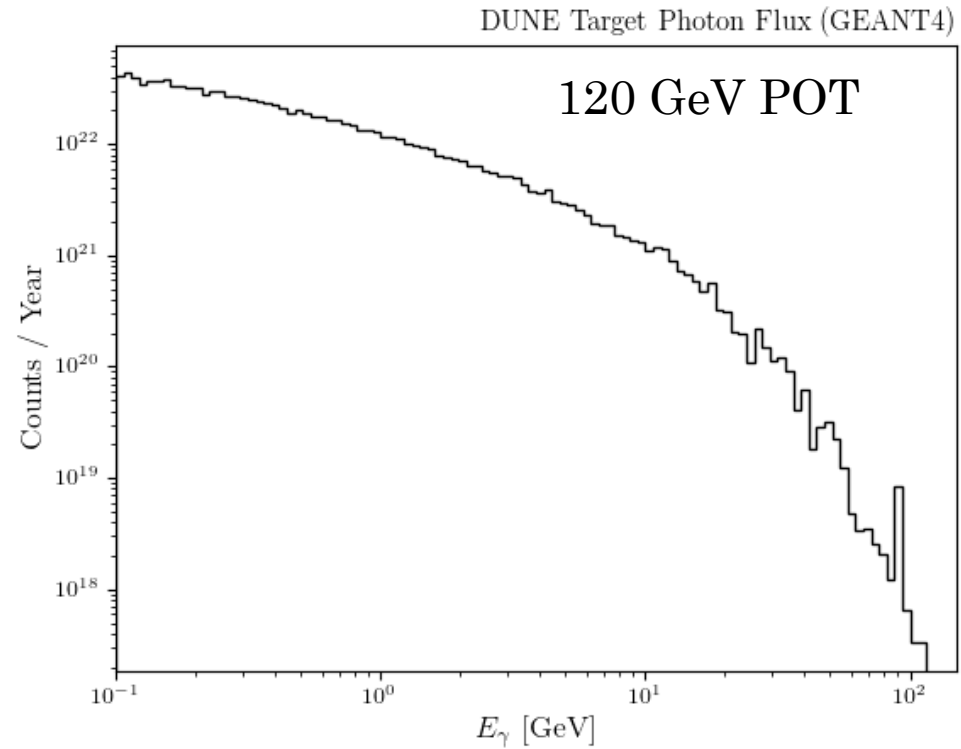
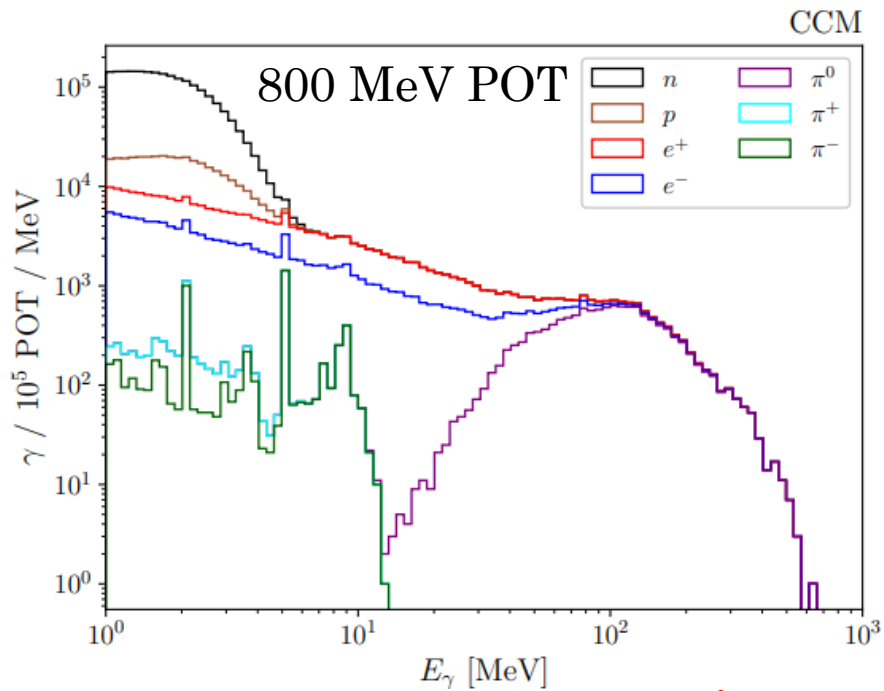


Not just for neutrino/neutron production:

- Proton bremsstrahlung
- Meson production and subsequent decay ($\pi^0, \pi^\pm, K, \rho, \dots$)
- e^+/e^- production, bremsstrahlung and annihilation
- Neutron scattering and capture
- ...and more subprocesses

This is a $p + A$ collider!

Photon Spectra



ALP-photon Coupling

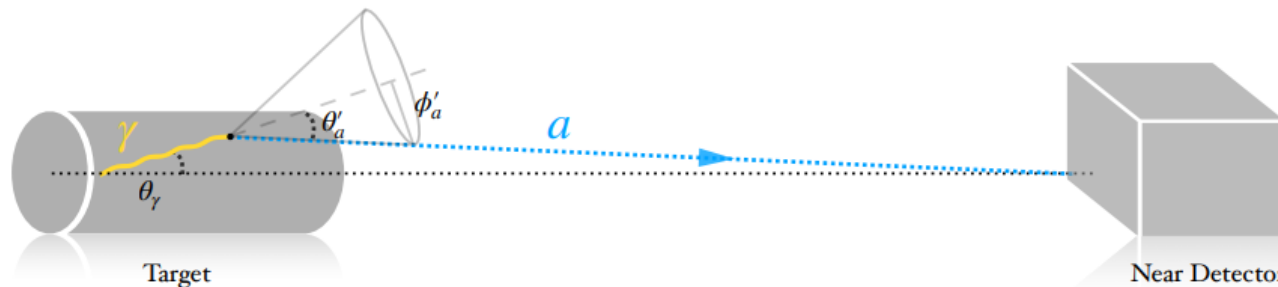
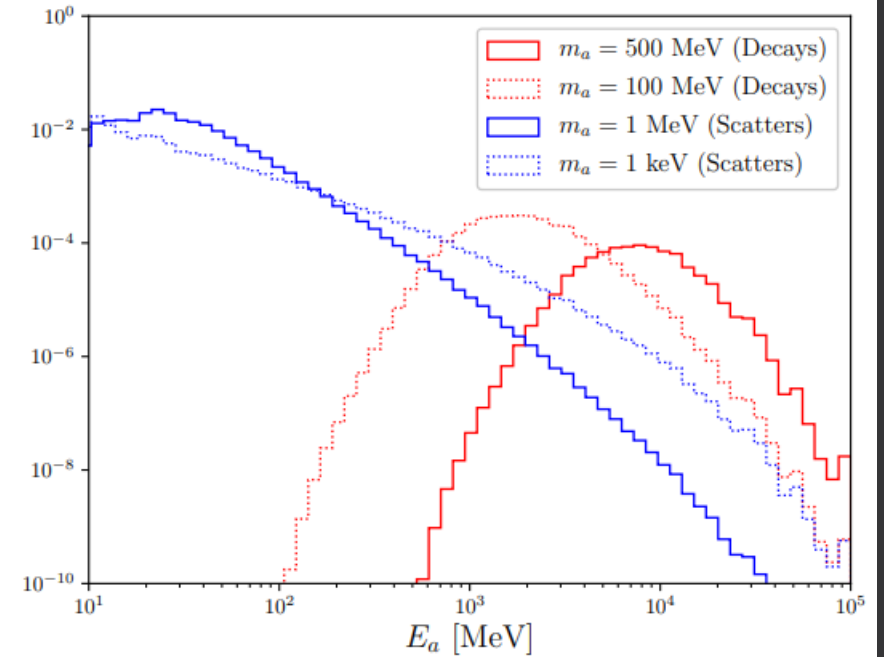
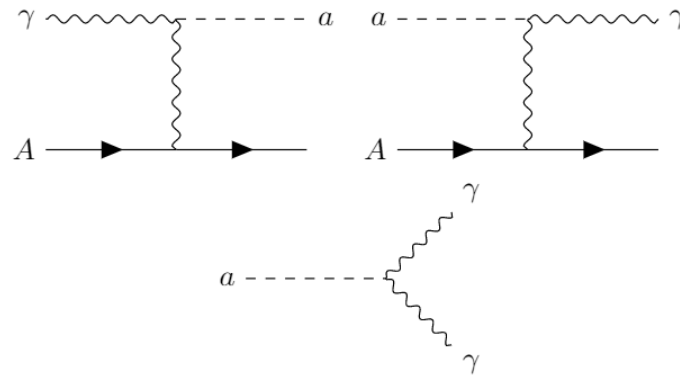
$$\mathcal{L} = \frac{1}{4} g_{a\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu}$$

Production Mechanism

- Primakoff Scattering
 - Coherent ($\propto Z^2$)
 - Very forward for $m_a \ll E_\gamma$

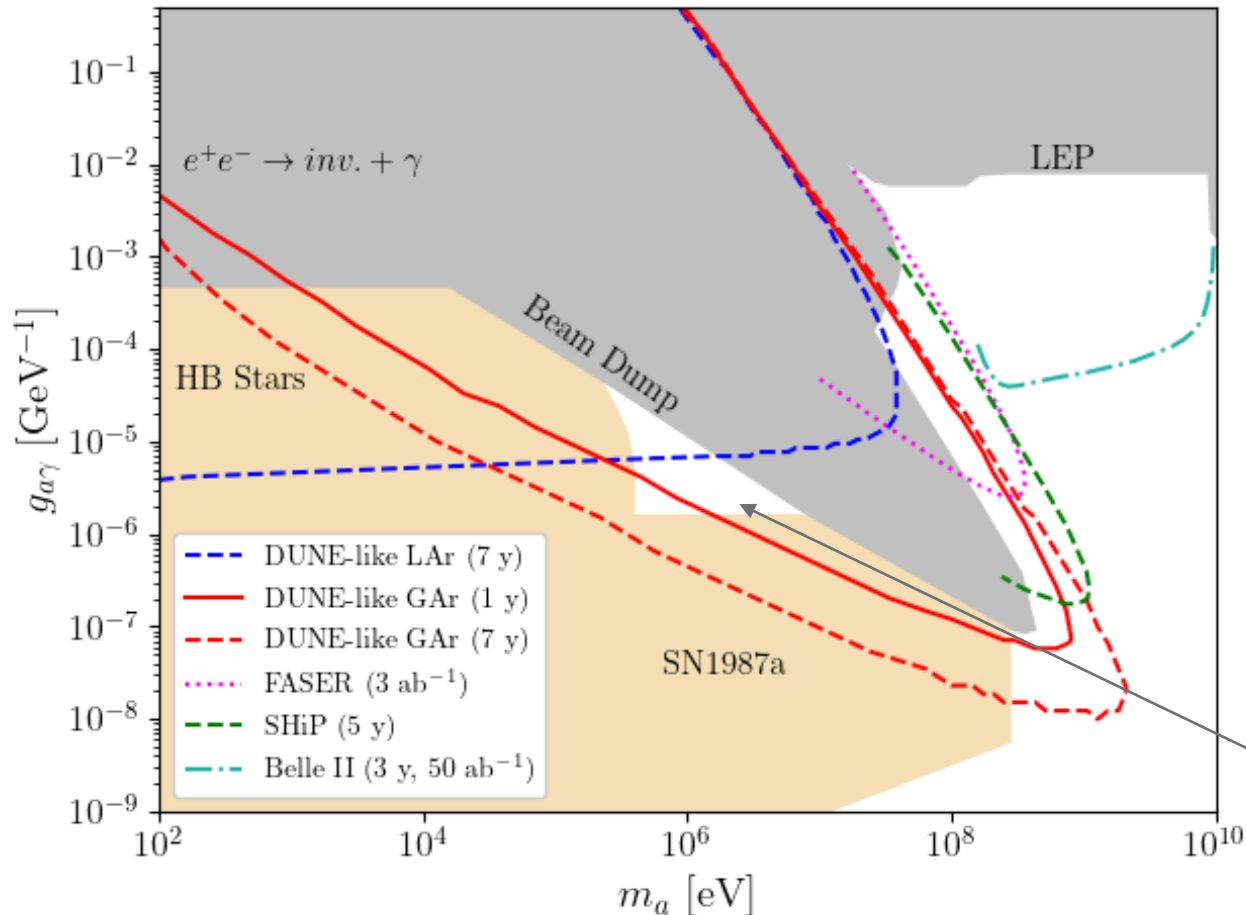
Detection Mechanisms

- Inverse Primakoff Scattering
- $a \rightarrow \gamma\gamma$ decays



ALP-photon Sensitivity (DUNE)

Vedran Brdar, Bhaskar Dutta, Wooyoung Jang, Doojin Kim, Ian M. Shoemaker, Zahra Tabrizi, **Adrian Thompson**, Jaehoon Yu *Phys.Rev.Lett.* 126 (2021) 20, 201801 ([2011.07054](https://arxiv.org/abs/2011.07054))

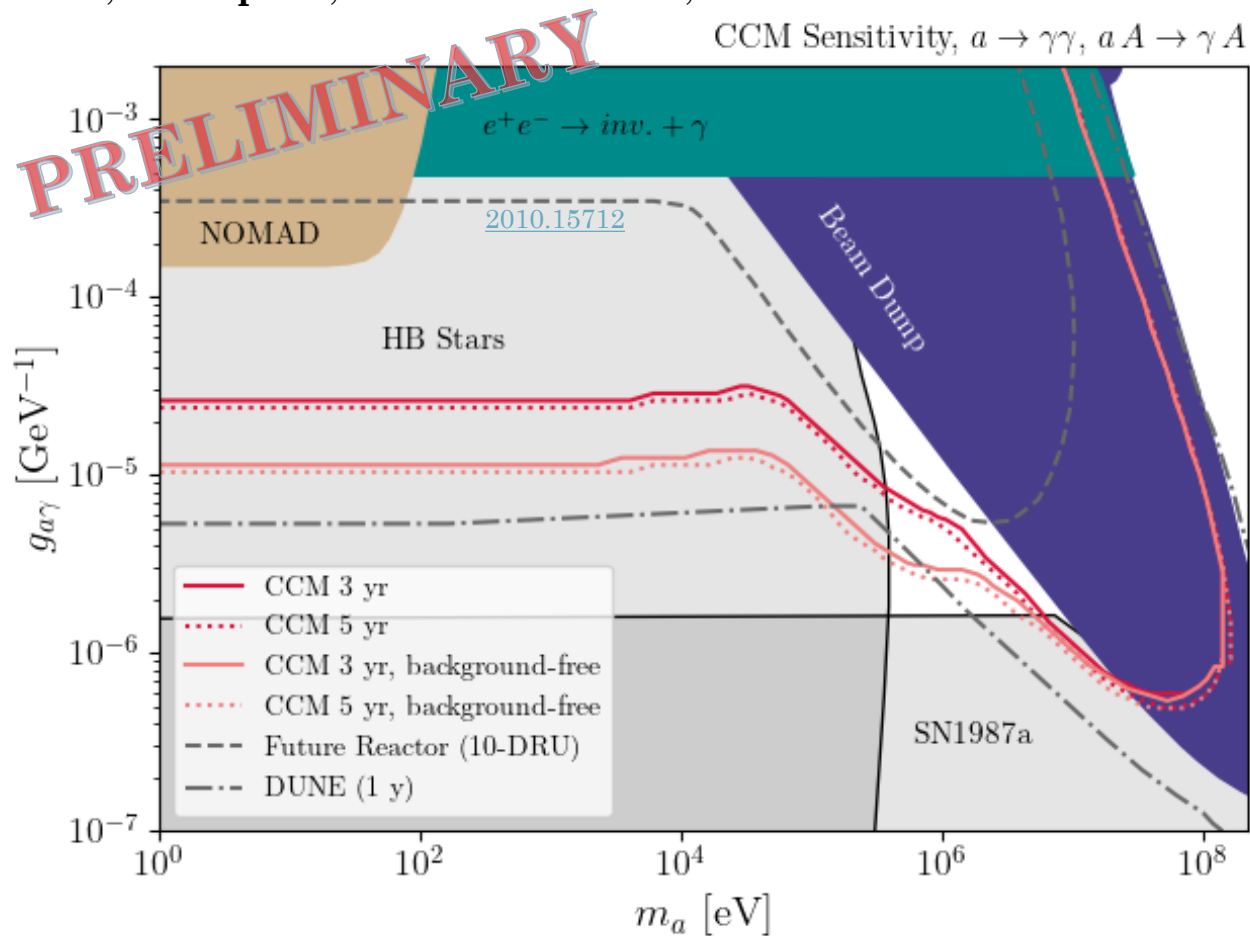


- DUNE:
 - 120 GeV beam, $1.1 \cdot 10^{21}$ POT/yr on 1.5m graphite target ([GEANT4](#))
 - 574m target-to-detector complex
- Decays searched for in the GAr detector
 - Lower density gaseous Ar suppresses scattering backgrounds, while $\gamma\gamma$ final state has relatively high efficiency
- Scatters searched for in the LAr detector (50t fiducial)
 - Backgrounds can be reduced further by looking at γ angle w.r.t. beam line

“Cosmological Triangle”

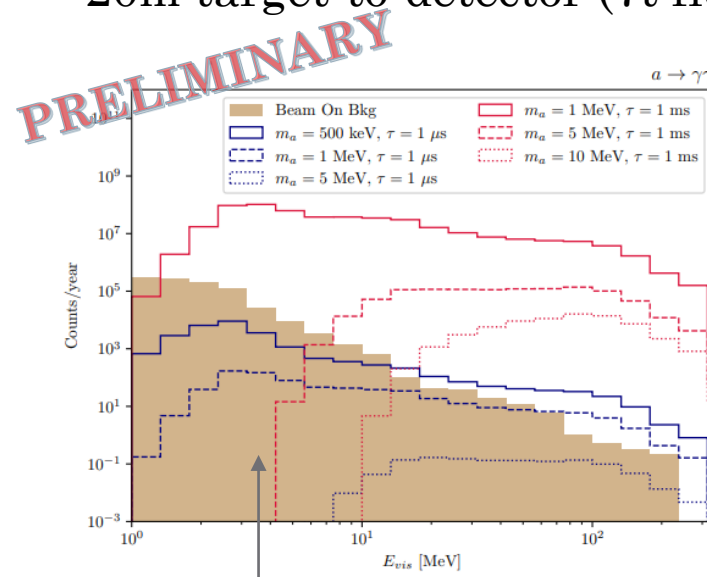
ALP-photon Sensitivity (CCM)

Dutta, Thompson, CCM Collaboration, 2021



• CCM:

- 800 MeV beam, $7.5 \cdot 10^{21}$ POT/yr on tungsten target
- 20m target-to-detector (7t fiducial Lar)



Work ongoing to reduce beam-on background

ALP-electron coupling

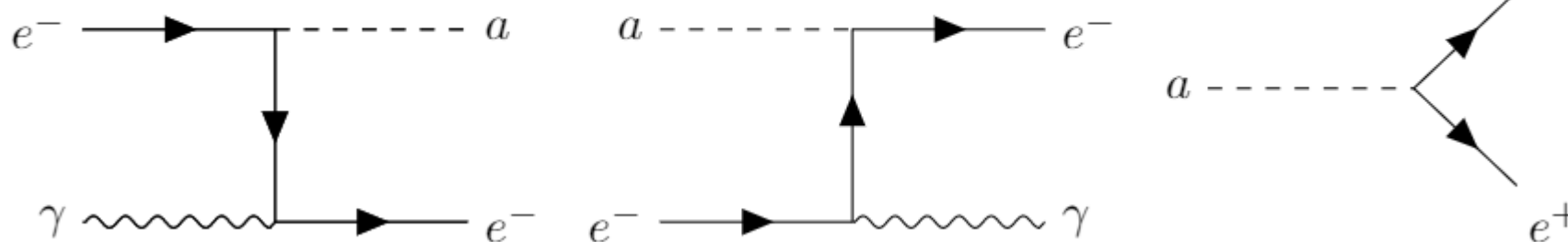
$$\mathcal{L} = ig_{ae} a \bar{e} \gamma^5 e$$

Production Mechanism:

- Compton-like scattering $\gamma e^- \rightarrow a e^-$, sourced by the intense photon flux (GEANT4) induced by POT
- Additionally, e^+ / e^- ALP-bremsstrahlung and resonance production are potentially strong channels (W.I.P.)

Detection Mechanisms:

- Inverse Compton scattering $a e^- \rightarrow \gamma e^-$
- ALP decays ($a \rightarrow e^+ e^-$)



ALP Energy Spectra

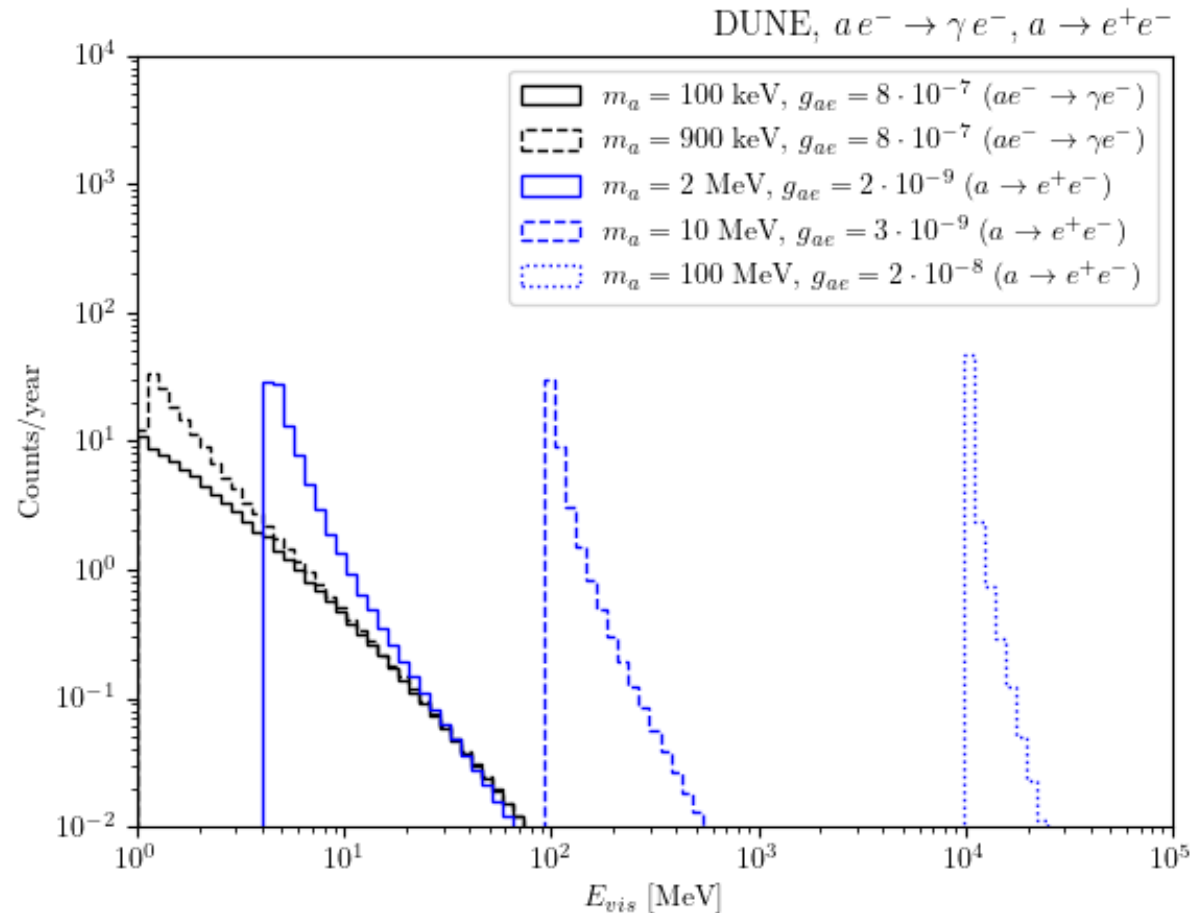
- DUNE and CCM will be sensitive to both scattering and decays
- The Compton production channel has a threshold

$$s > (m_a + m_e)^2,$$

this implies $E_\gamma > \frac{m_a^2}{2m_e} + m_a$. We

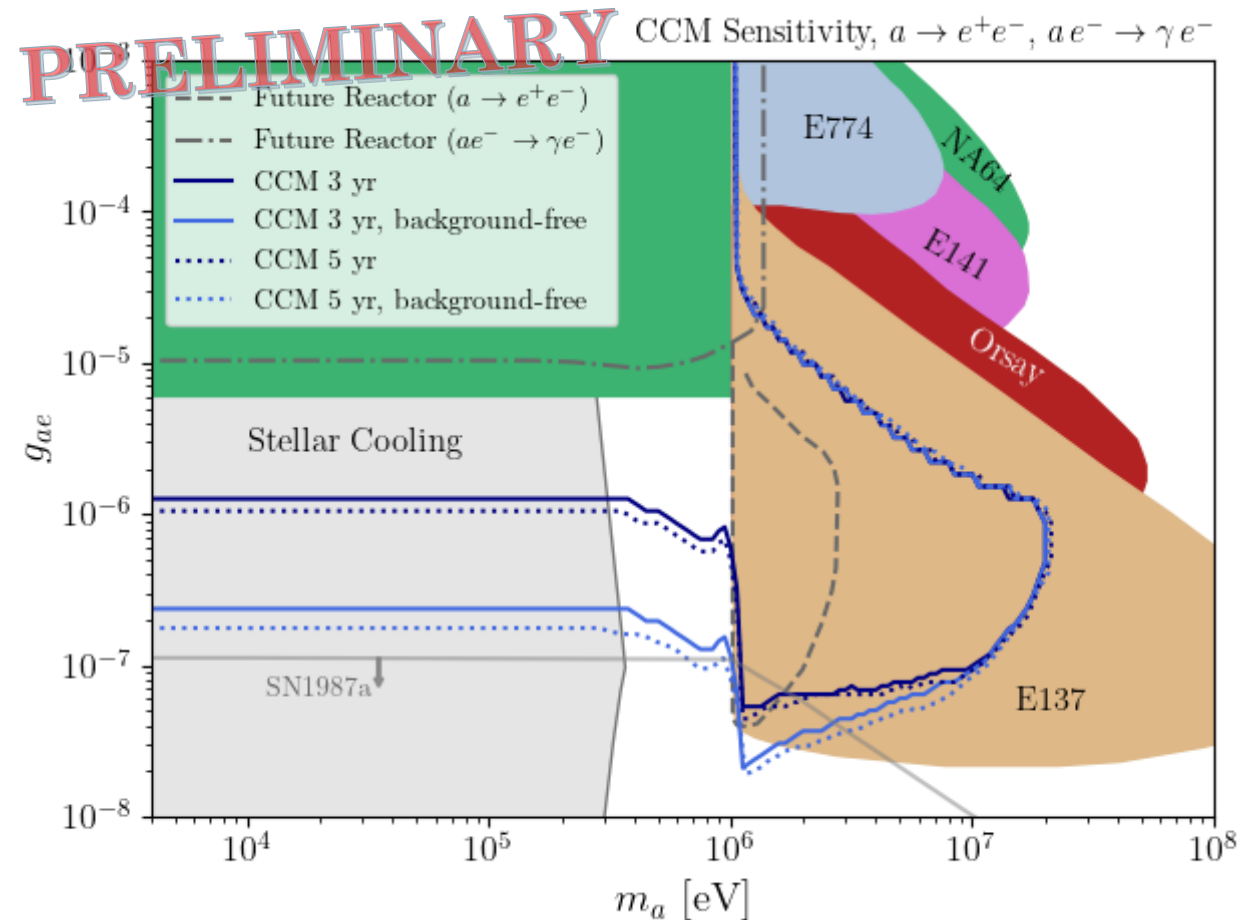
therefore detect a falling spectrum with a m_a -dependent starting point

- e^+e^- final state
 - Dominant for $m_a > 2m_e$, high energy spectrum
- γe^- final state
 - Dominant for $m_a < 2m_e$, low energy spectrum



Preliminary Sensitivity

- We forecast CCM 3 and 5 year exposures with optimistic/pessimistic background benchmarks
- Some bounds below $m_a = 1$ MeV are model-dependent;
 - Stellar cooling (RG, HB stars)
 - SN1987a (also subject to SN physics assumptions)
 - Constraints from loop-induced $a \rightarrow \gamma\gamma$ at beam dumps ignored
- Sensitivity should improve when bremsstrahlung and resonant production channels are modeled in



Going forward from here

- Experiments at the Neutrino and Dark Matter Frontier can set leading limits on MeV and heavy ALPs while also probing a broadband of ALP masses $< \text{MeV}$
- More possibilities open up when we include other couplings (gauge couplings, nuclear couplings)
- Understanding the particle spectra within these targets (photons, electrons,...) is crucial to seeing the full picture of phenomenological opportunities

Thank You!