

Segundo Taller
“Más allá del Modelo Estándar y Astropartículas”



Sensitivity of reactor experiments to Axion-Like Particles

Laura Duque Herrera

Centro de Investigación y de estudios Avanzados del IPN

In collaboration with:

Diego Aristizabal, Omar Miranda and Hiroshi Nunokawa.

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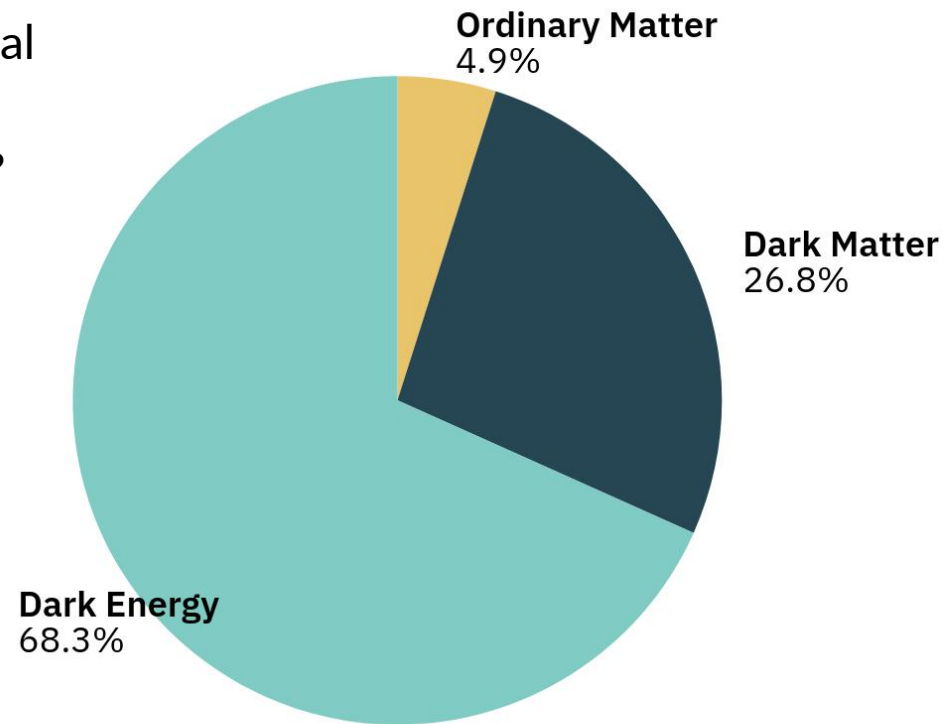


Introduction

Particles beyond the Standard Model

The **Standard Model** describes all visible matter, but this only accounts for ~5% of the universe.

- This "dark sector" implies a fundamental problem:
 - Is our theory of **particles** incomplete?
- **Key Question:** What is Dark Matter made of?
- **Some Candidates:** WIMPs, Sterile Neutrinos, Axions, and **Axion-like particles**.

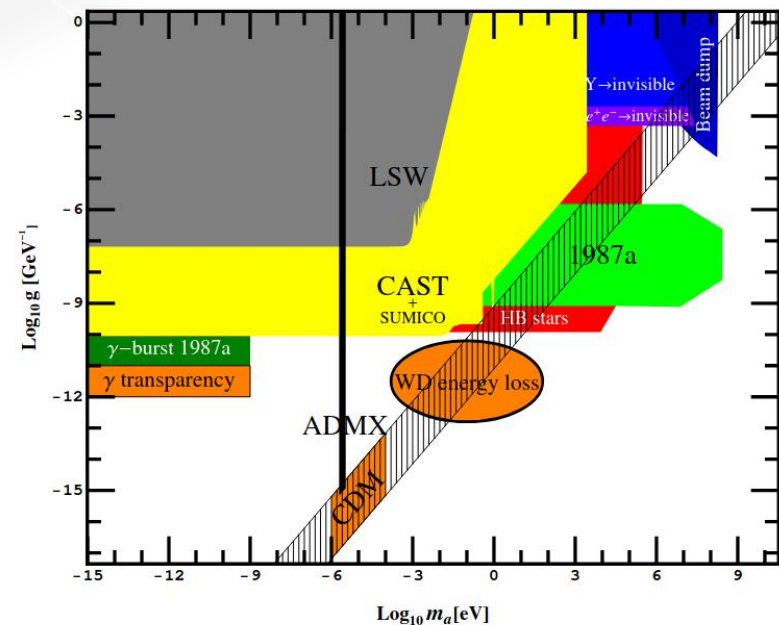


Axion-Like Particles (ALPs)

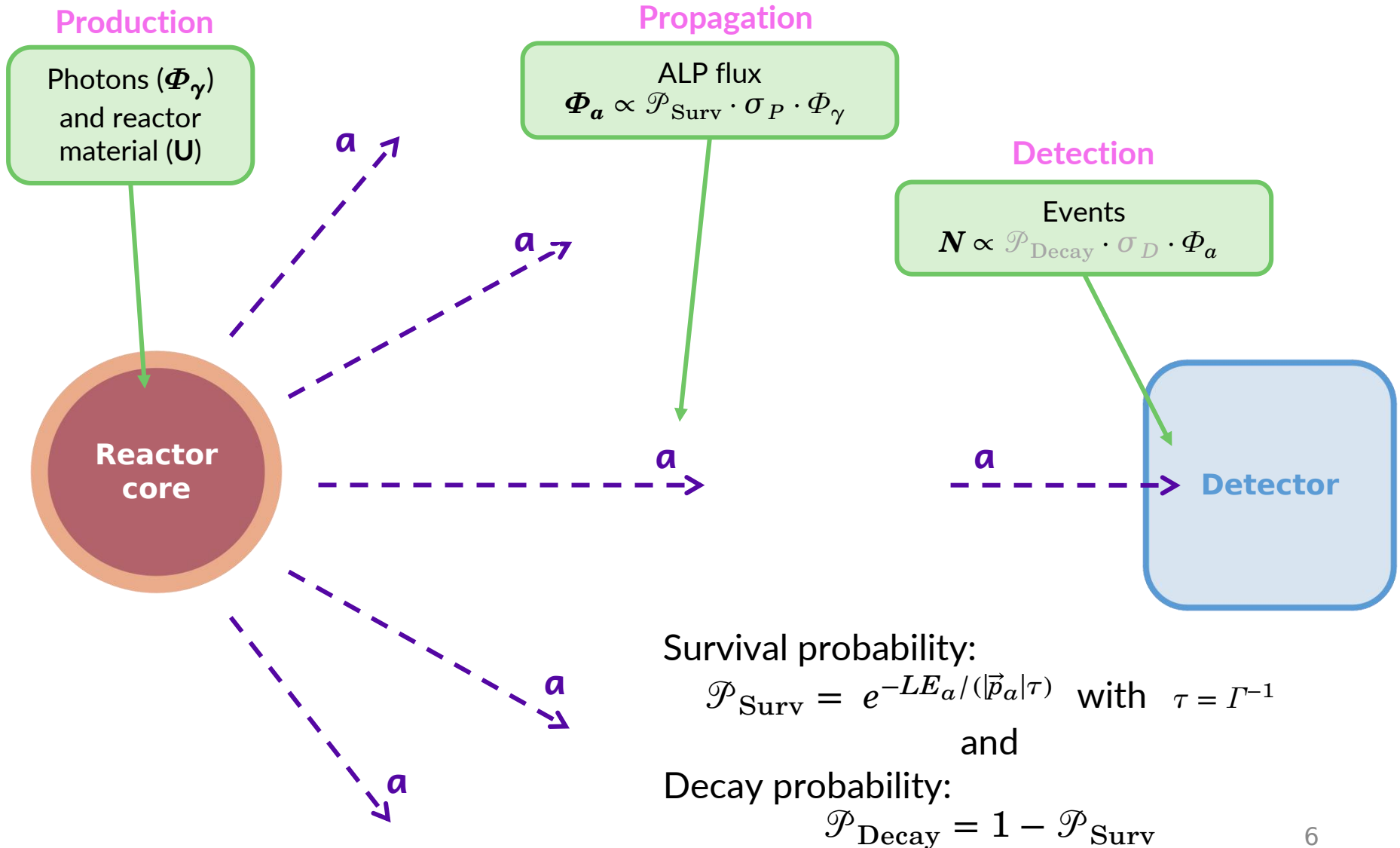
ALPs are pseudoscalar Nambu-Goldstone bosons from the spontaneous breaking of a global U(1) symmetry.

- Well-motivated by the **QCD Axion**, the leading solution to the **Strong CP Problem**.
- A compelling cold **dark matter candidate**.
- Arise naturally in many Beyond the Standard Model (BSM) theories, such as string theory.

Unlike the QCD Axion, ALP mass (m_a) and couplings (e.g., $g_{a\gamma\gamma}$) are independent parameters.

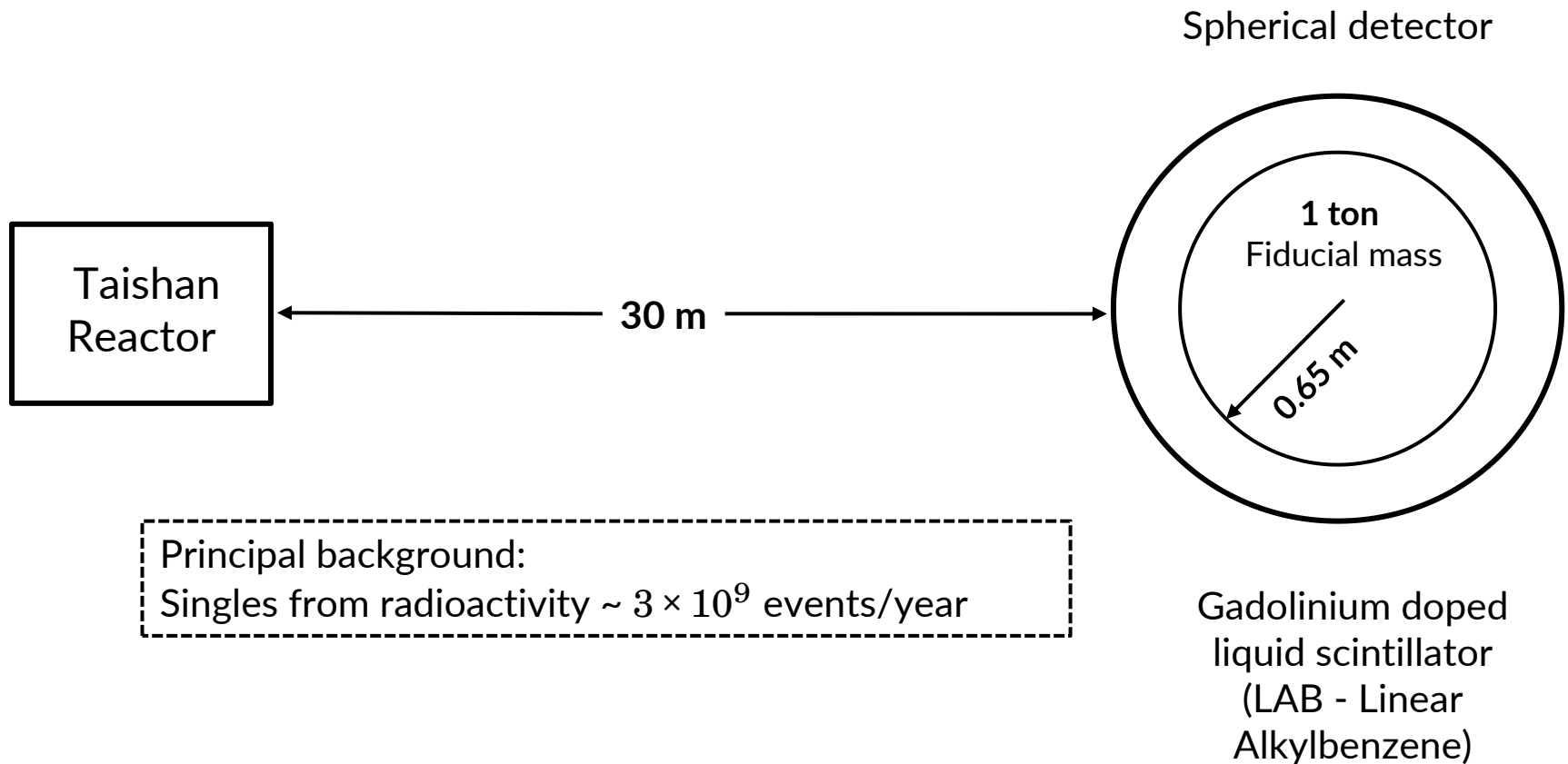


ALPs production at reactors and detection processes



JUNO-TAO like experiment

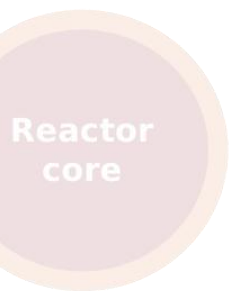
The Taishan Antineutrino Observatory (TAO) → Satellite experiment of the Jiangmen Underground Neutrino Observatory (JUNO).



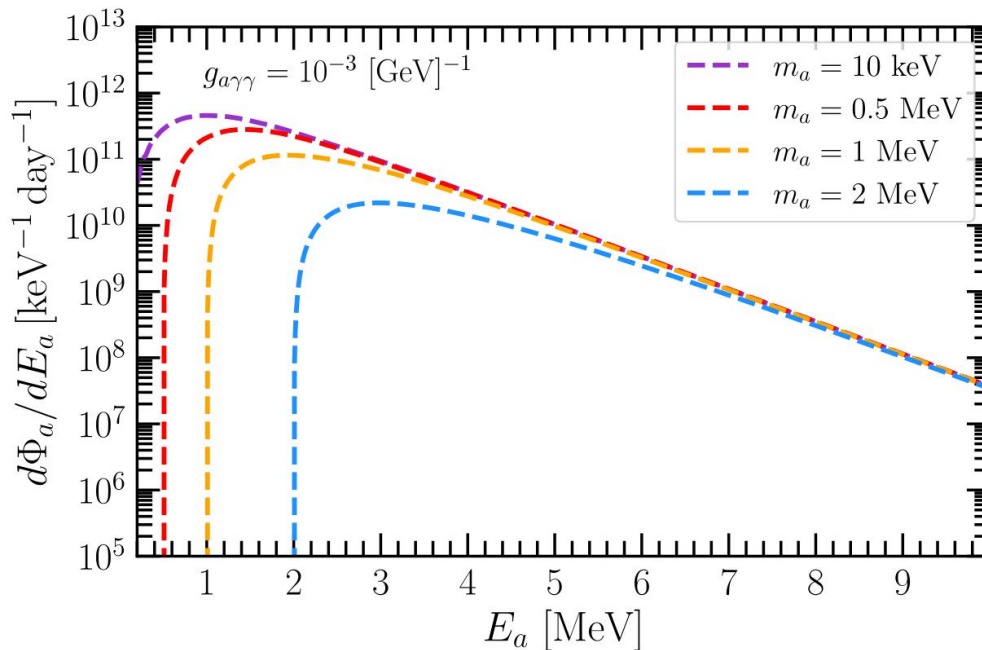
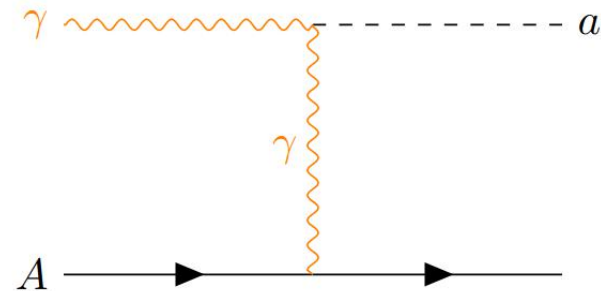
Production and detection through ALP-photon coupling



Production through $g_{a\gamma\gamma}$ couplings



Primakoff photon-ALP conversion



Resulting ALP Flux:

$$\frac{d\Phi_a^P}{dE_a} = \mathcal{P}_{\text{Surv}} \frac{\sigma_P^P}{\sigma_{\text{Tot}}} \frac{d\Phi_\gamma}{dE_\gamma} \Big|_{E_\gamma=E_a}$$

(Survival probability) $\times$ (Production Probability) $\times$
(Initial Photon Flux)

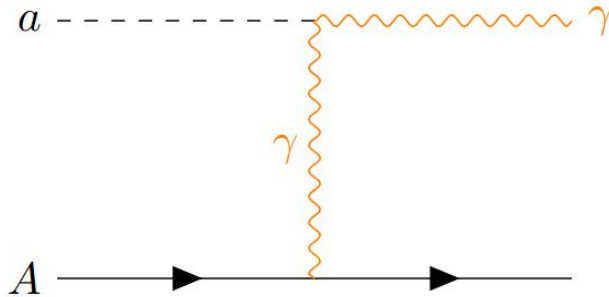
where $\sigma_{\text{Tot}} = \sigma_{\text{SM}} + \sigma_a^P$

ALP decay width (determine lifetime $\tau = \Gamma^{-1}$):

$$\Gamma(a \rightarrow \gamma\gamma) = g_{a\gamma\gamma}^2 \frac{m_a^3}{64\pi}$$

Detection through $g_{a\gamma\gamma}$ couplings

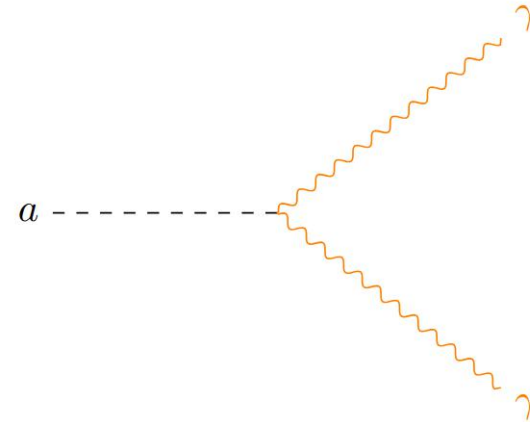
Inverse Primakoff



Event Rate from ALP Conversion

$$\left(\frac{dN}{dE_a}\right)_{IP} = \frac{m_{\text{det}}}{2\pi L^2} N_A \sigma_D^P(E_a) \frac{d\Phi_a^P}{dE_a}$$

Decay into a γ -pair



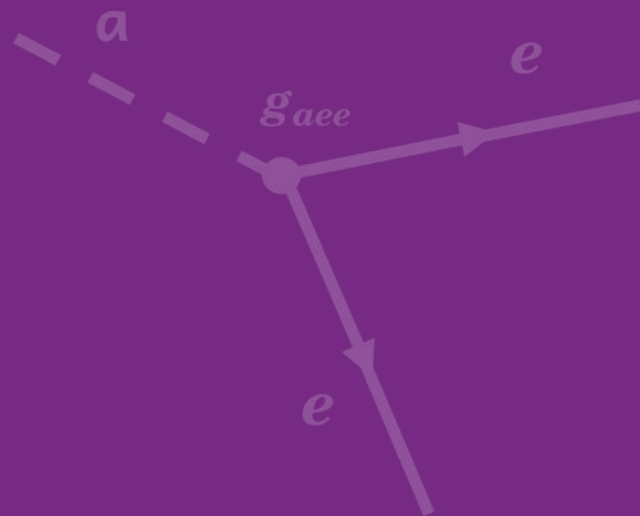
Event Rate from ALP Decay

$$\left(\frac{dN}{dE_a}\right)_{\text{Decay}} = \mathcal{P}_{\text{Decay}} \frac{A}{4\pi L^2} \frac{d\Phi_a^P}{dE_a}$$

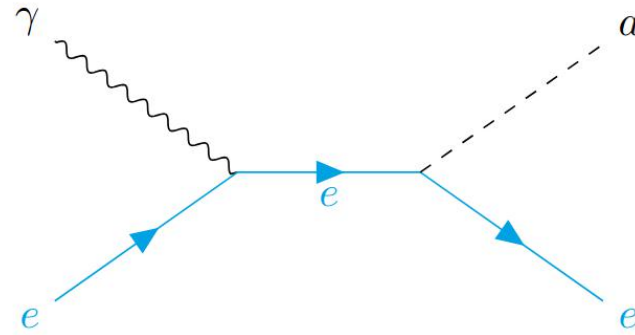
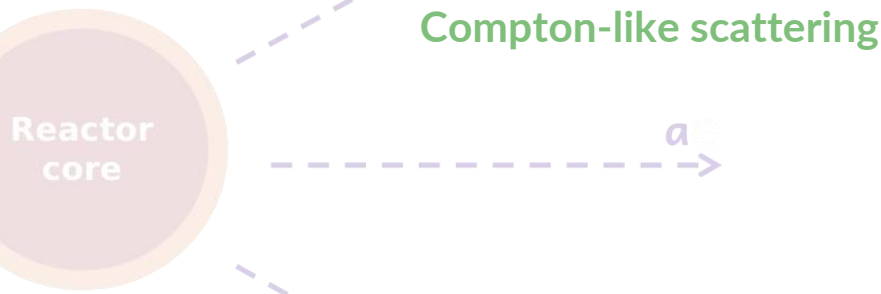
$$\left(\frac{dN}{dE_a}\right)_{\text{Total}} = \left(\frac{dN}{dE_a}\right)_{IP} + \left(\frac{dN}{dE_a}\right)_{\text{Decay}}$$

a   Detector

Production and detection through ALP-electron coupling



Production through g_{aee} couplings



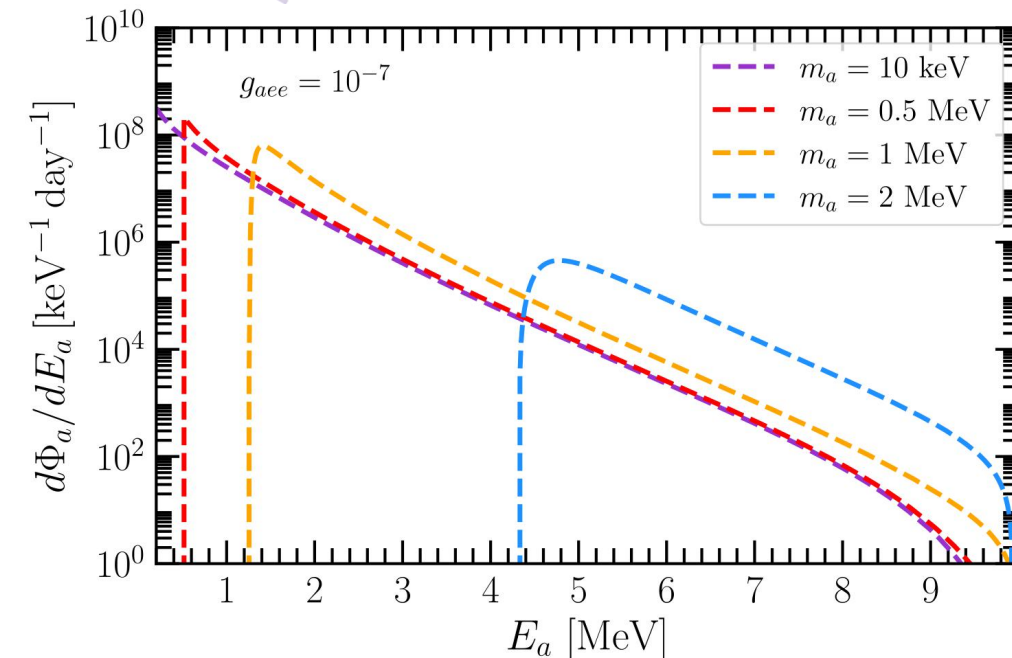
Resulting ALP Flux:

$$\frac{d\Phi_a^C}{dE_a} = \mathcal{P}_{\text{Surv}} \int \frac{1}{\sigma_{\text{Tot}}} \frac{d\sigma_P^C}{dE_a} \frac{d\Phi_\gamma}{dE_\gamma} dE_\gamma$$

(Survival probability) $\times$ (Production Probability) $\times$
(Initial Photon Flux)

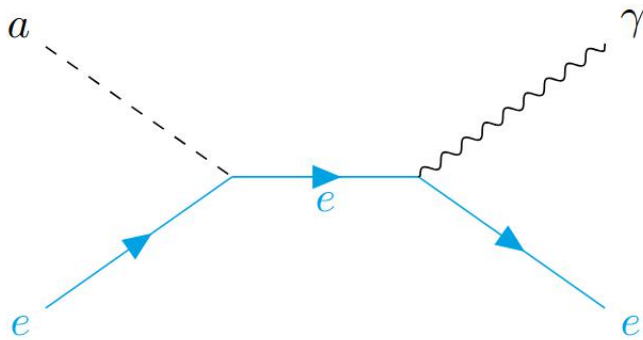
ALP decay width (determine lifetime $\tau = \Gamma^{-1}$):

$$\Gamma(a \rightarrow e^+e^-) = \frac{m_a g_{aee}^2}{64\pi} \sqrt{1 - 4 \frac{m_e^2}{m_a^2}}$$



Detection through g_{aee} couplings

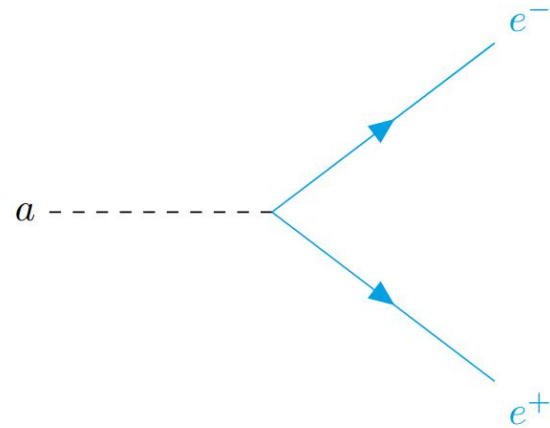
Inverse Compton-like scattering



Event Rate from Inverse Compton Scattering:

$$\left(\frac{dN}{dE_a}\right)_C = \frac{m_{\text{det}}}{4\pi L^2} N_A \int \frac{d\sigma_D^C}{d\gamma}(E_\gamma, E_a) \frac{d\Phi_a^C}{dE_a} d\gamma$$

Decay into an electron-positron pair

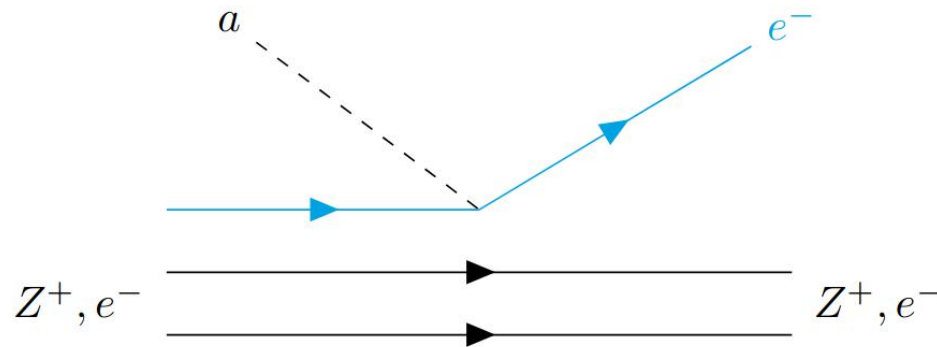


Event Rate from Decay

$$\left(\frac{dN}{dE_a}\right)_{\text{Decay}} = \mathcal{P}_{\text{Decay}} \frac{A}{4\pi L^2} \frac{d\Phi_a^C}{dE_a}$$

Detection through g_{aee} couplings

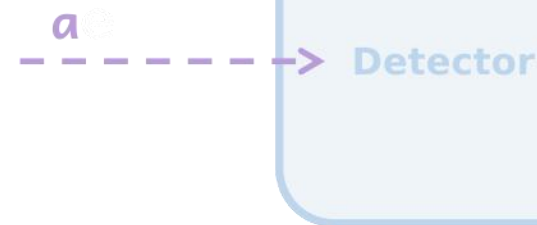
Axio-electric effect

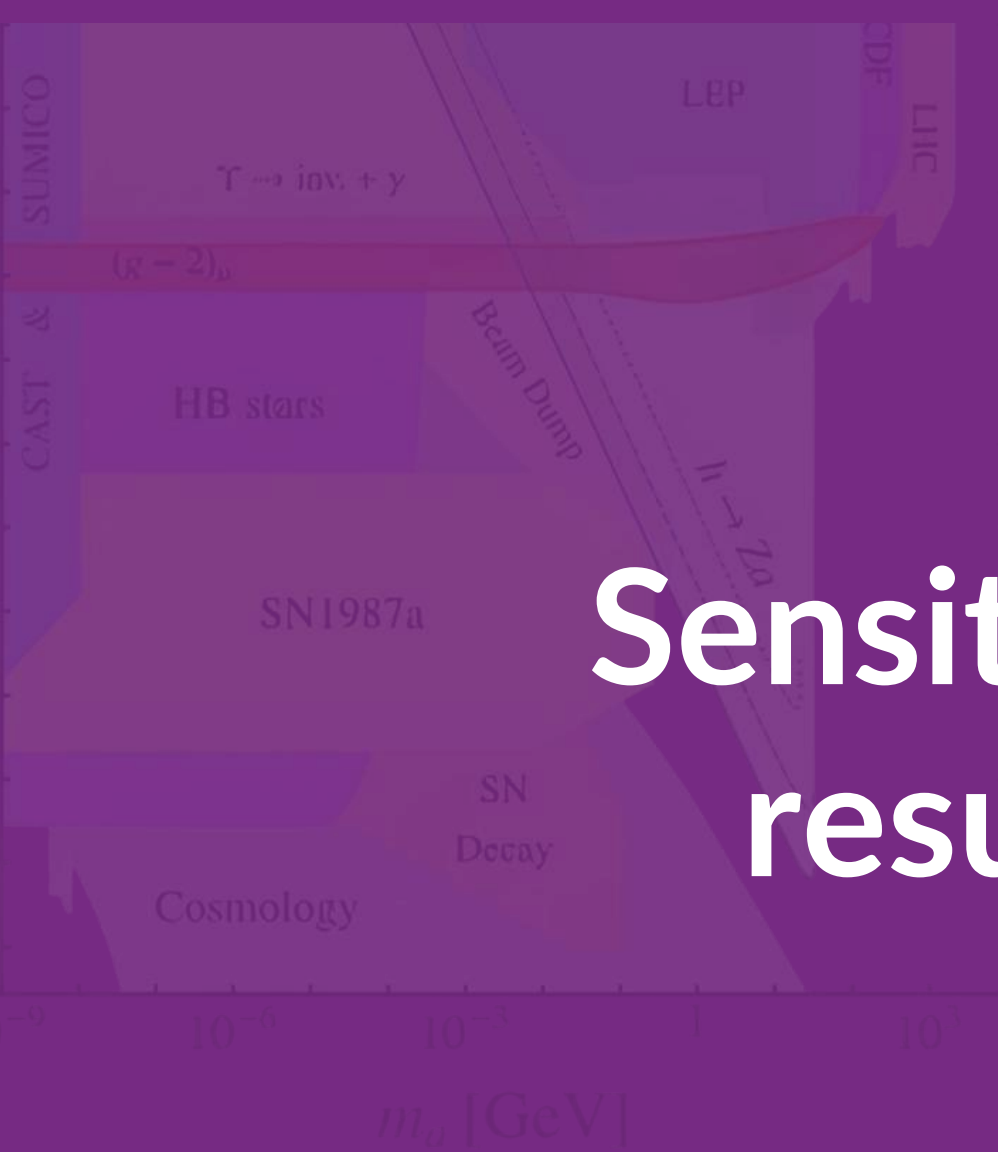


Event Rate from Axio-electric Effect

$$\left(\frac{dN}{dE_a}\right)_A = \frac{m_{\text{det}}}{4\pi L^2} N_A \sigma_D^A \frac{d\Phi_a^C}{dE_a}$$

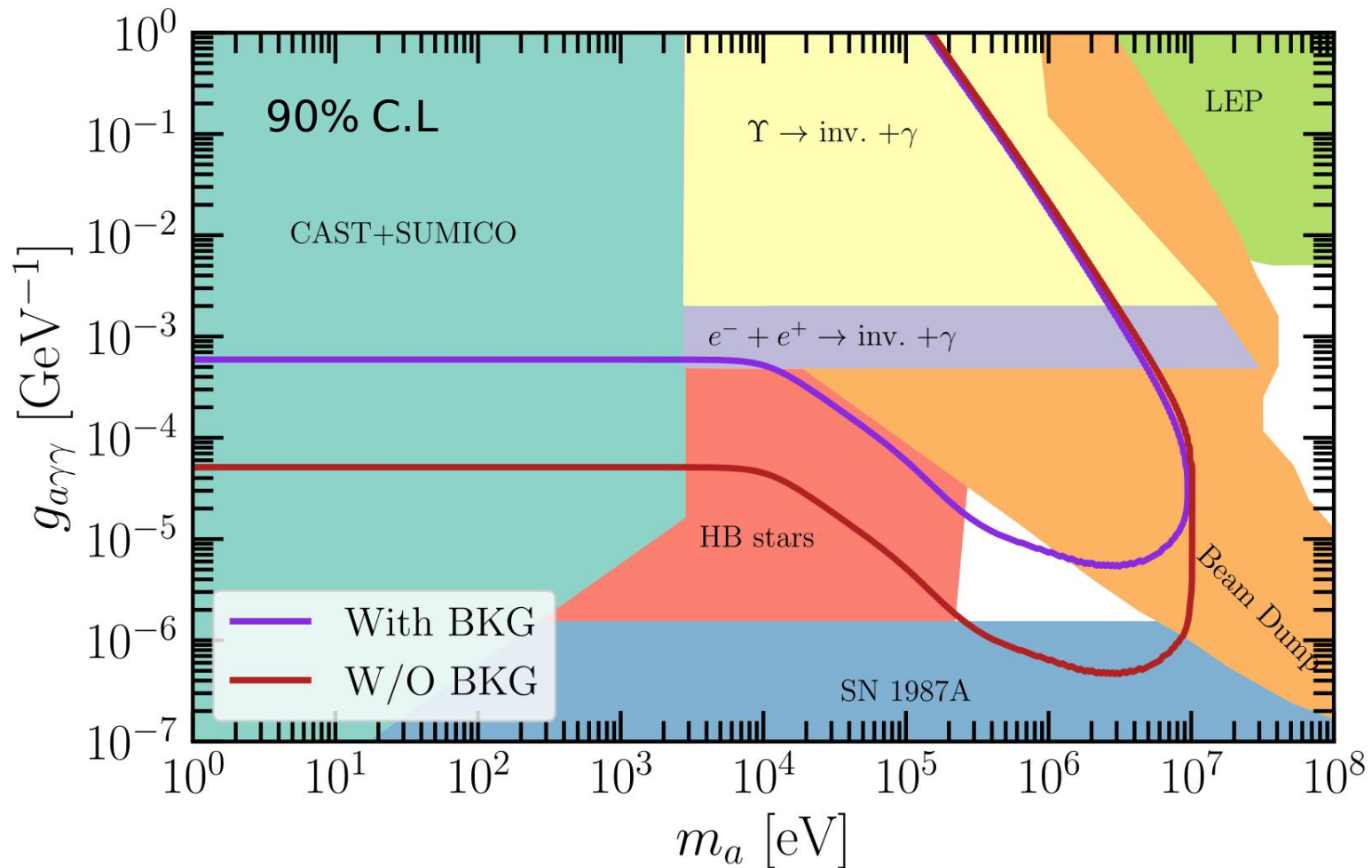
$$\left(\frac{dN}{dE_a}\right)_{\text{Total}} = \left(\frac{dN}{dE_a}\right)_C + \left(\frac{dN}{dE_a}\right)_A + \left(\frac{dN}{dE_a}\right)_{\text{Decay}}$$



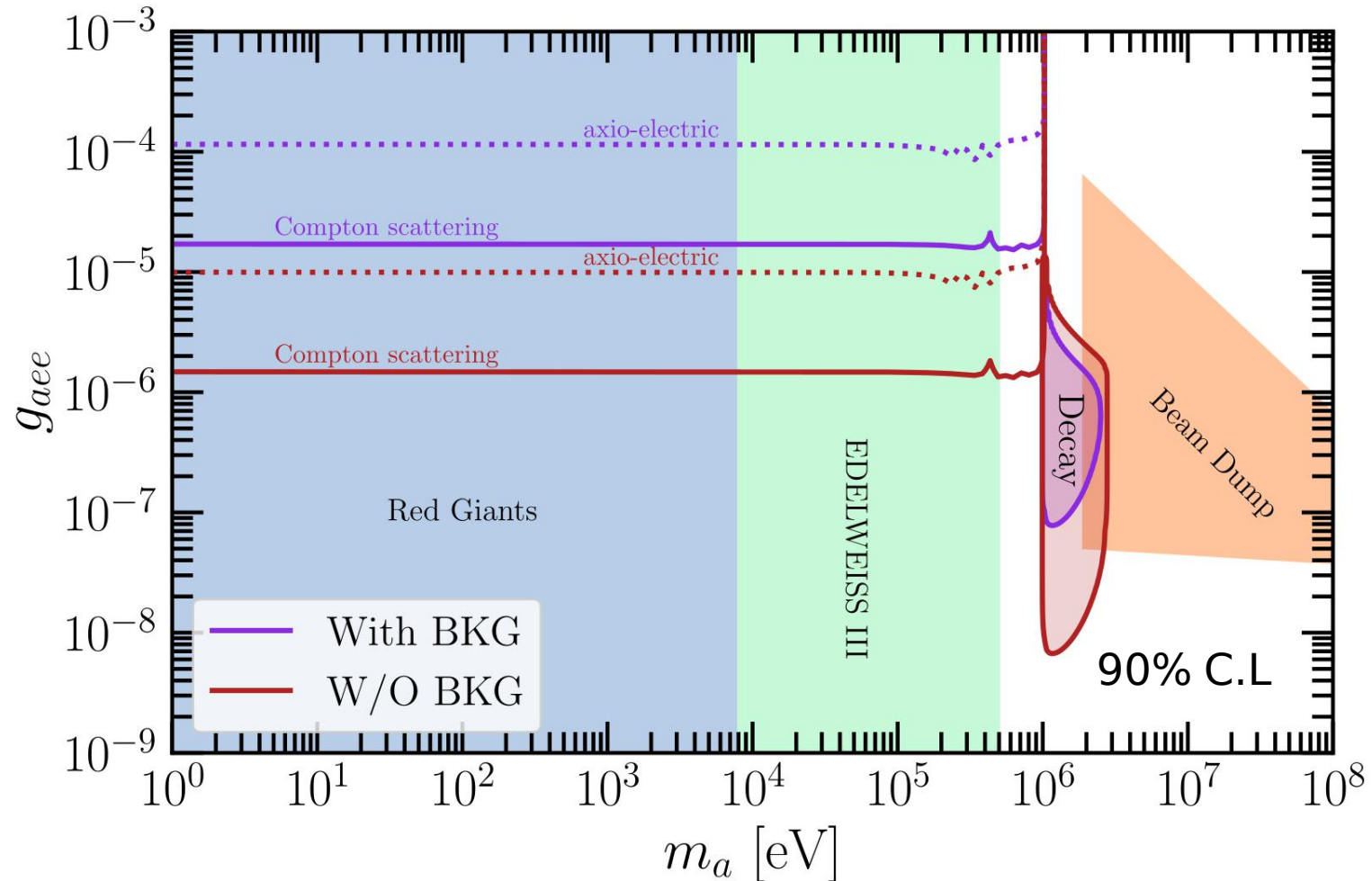


Sensitivity results

Photon-ALP coupling sensitivities



Electron-ALP coupling sensitivities



Conclusions

- Our work demonstrates that short-baseline reactor experiments such as JUNO-TAO are an effective new tool for searching for MeV-scale ALPs.
- Significant **new sensitivity** can be achieved for the **ALP-photon** coupling ($g_{a\gamma\gamma}$), probing a large, unexplored region in the MeV mass range.
- The search for the **ALP-electron** coupling (g_{aee}) can be dramatically improved, with projected sensitivities reaching as low as $g_{aee} \approx 10^{-8}$.
- **Reactor experiments** are a **key terrestrial tool** in the worldwide effort to discover ALPs, highly complementary to existing searches.



Thank you!

References

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