# ALP Searches without the DUNE Target

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**Adrian Thompson**

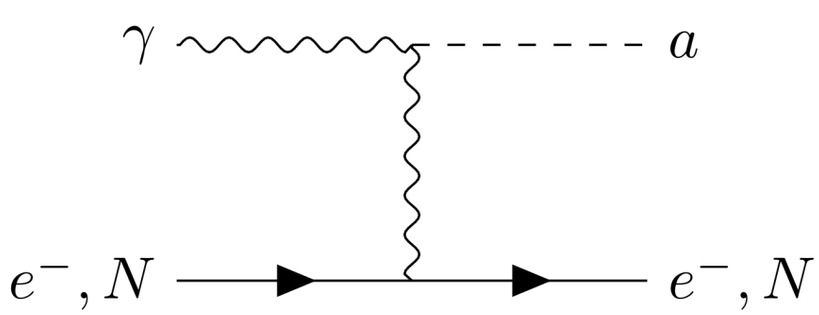
# Axion-like Particles (ALPs)

## ALP-Photon Coupling

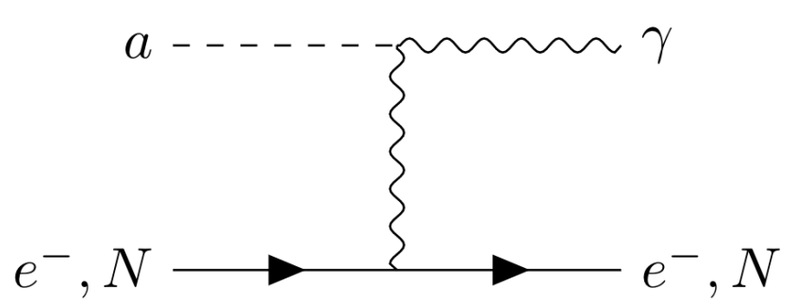
$$\mathcal{L} \supset \frac{1}{2}(\partial^\mu a)(\partial_\mu a) - \frac{1}{2}m_a^2 a^2 - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}g_{a\gamma\gamma}aF_{\mu\nu}\tilde{F}^{\mu\nu}$$

$$\frac{d\sigma_P}{d\cos\theta} = \frac{1}{4}g_{a\gamma\gamma}^2\alpha Z^2 F^2(t)\frac{|\vec{p}_a|^4\sin^2\theta}{t^2}$$

$F(t)$ is the atomic form factor (modulo polarization factors)

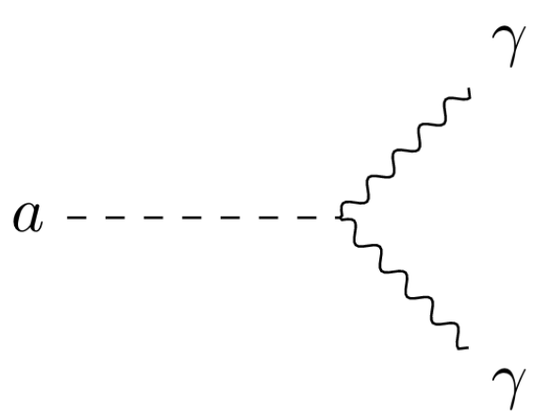



Production via photon-ALP conversion




Detection via ALP-photon conversion and decays

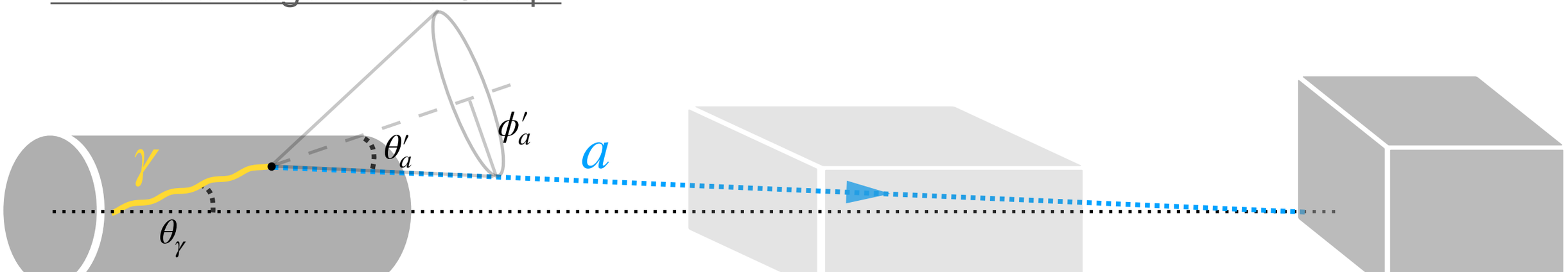
$$\Gamma(a \to \gamma\gamma) = \frac{g_{a\gamma\gamma}^2 m_a^3}{64\pi}$$



# Target vs. Off-Target Modes

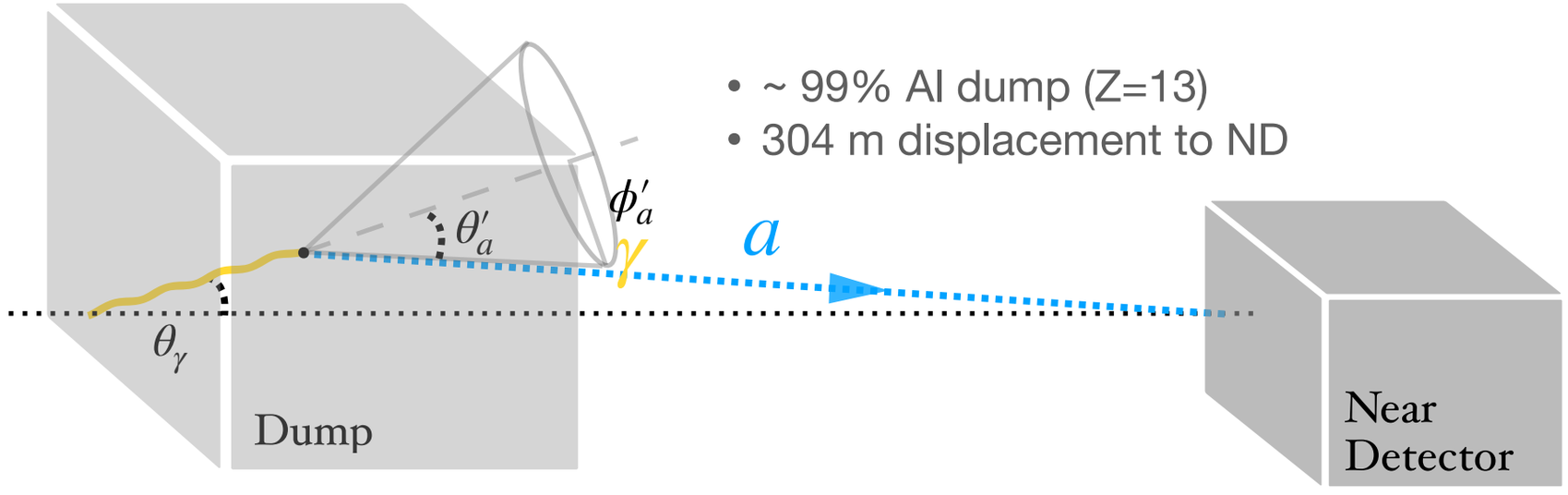
## Production and Detection Strategy Comparison

Traditional Target-mode Setup:




- Graphite (Z=6)
- 1.5 m
- 574 m displacement to ND

Targetless / Off-target Setup:

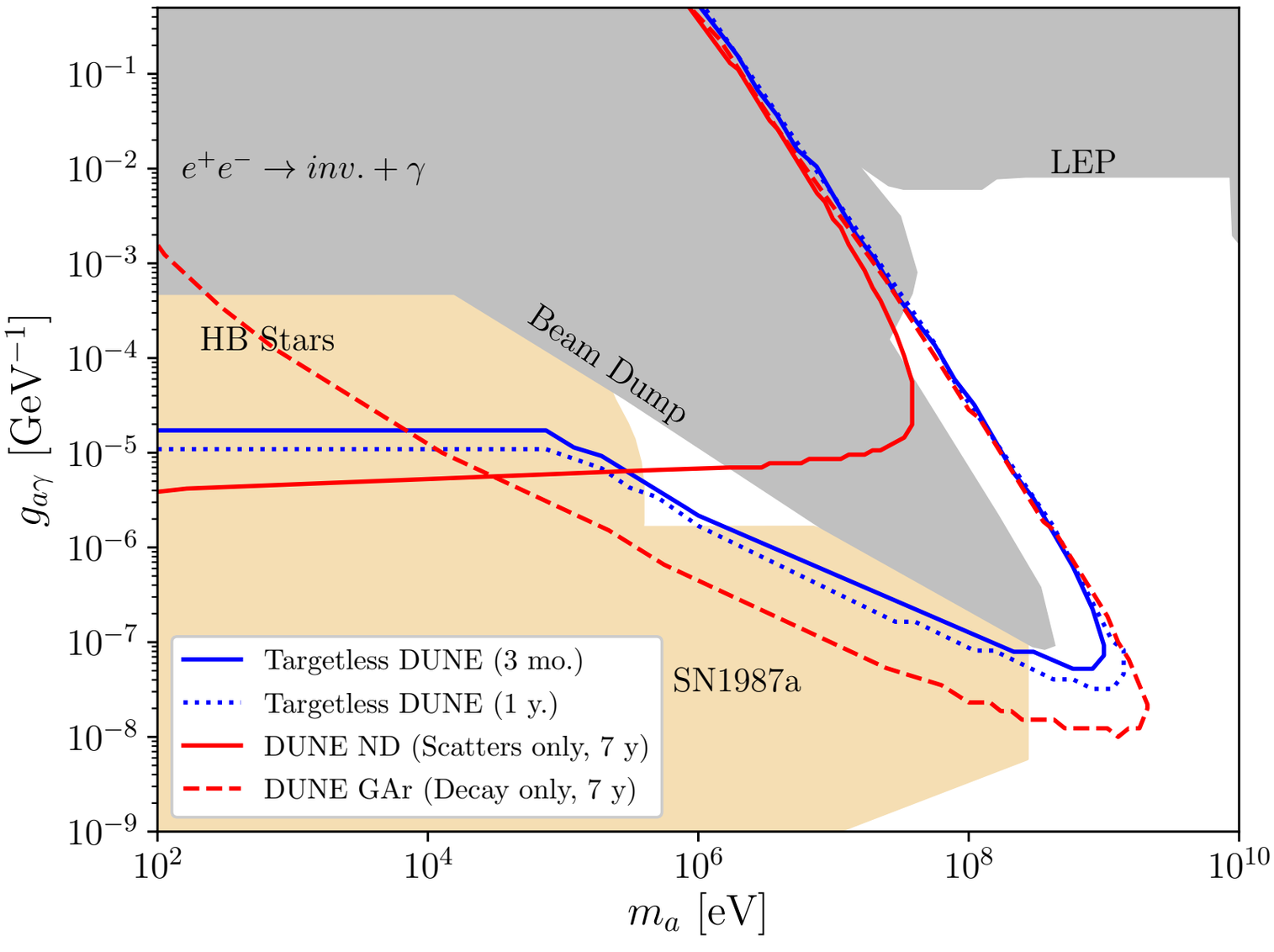



- ~ 99% Al dump (Z=13)
- 304 m displacement to ND

# Target vs. Off-target Sensitivity

## Background-free limits over 3 month exposure

Calculation based on [2011.07054](2011.07054) - Brdar, Dutta, Jang, Kim, Shoemaker, Tabrizi, Zahra, Thompson, Yu



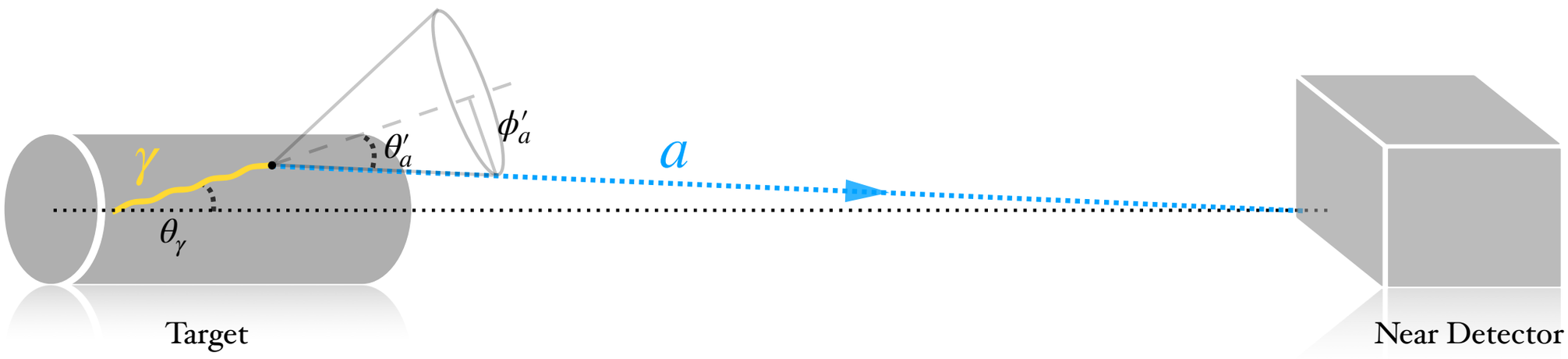

- **Shorter baseline** to the ND (304m vs. 574m) allows us to probe different characteristic ALP lifetimes
    - This manifests as the ``tongue" region shifting upward
- The dump material (99% Al) has a **higher Z**, giving a (13^2 / 6^2) ~ 4.7 enhancement to the production cross section
- With a 3 month data taking period (given optimistic backgrounds) we can test open parameter space

# Summary / Future Direction

- An off-target search allows us to probe different characteristic ALP lifetimes/decay lengths and therefore expand coverage of the beam dump upper limits, while still being sensitive to the ``cosmological triangle”
- In-house background study
- Understand the range of limitations (beam power, dump cooling etc.) to an off-target operational mode

# Backup

# DUNE Axion Strategy




ALP Flux:

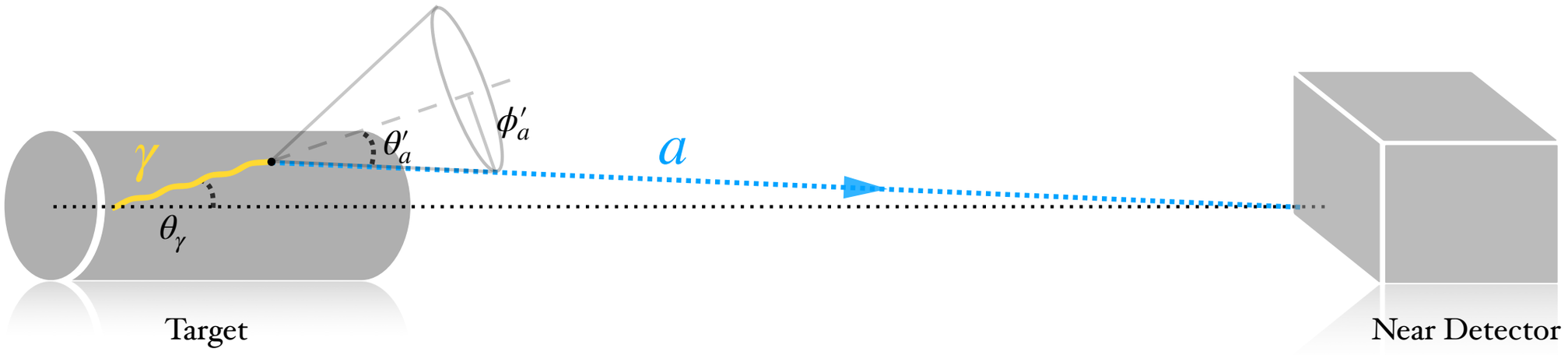
GEANT4 Flux

$$\frac{d\Phi_a}{dE_a} = \frac{1}{\sigma_{PE}} \int_0^{\pi} \int_0^{\pi} \int_0^{2\pi} \frac{\partial^2 \Phi_\gamma}{\partial E_\gamma \partial \theta_\gamma} \frac{d\sigma^{\gamma \to a}}{d\theta_a} \delta(E_a - E_\gamma) \times \Theta(\theta_{ND} - \theta_{a,z}) d\phi'_a d\theta'_a d\theta_\gamma$$

Together these form an approximate branching ratio – fraction of ALP production to SM photoabsorption

Heaviside theta function used as a kernel to select only the region of phase space that produces ALPs within the ND solid angle

# DUNE Axion Strategy




Production angle w.r.t. beam axis:

$$\theta_{a,z} = \arccos\left\{\cos\theta'_a \cos\theta_\gamma + \cos\phi'_a \sin\theta'_a \sin\theta_\gamma\right\}$$

Solid angle spanned by near detector is given by

$\theta_{ND} \simeq \arctan \dfrac{R_{ND}}{\ell_{ND}}$ where the ND area is smeared out to a circular aperture

approximation; $R_{ND} \equiv \sqrt{\dfrac{A_{ND}}{\pi}}$ with $A_{ND}$ = 3m x 7m and $\ell_{ND}$

We then require $\theta_{a,z} \leq \theta_{ND}$