SOLAR PRODUCTION OF MEV ELECTROPHILIC ALPS & DIRECT DETECTION

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Outline

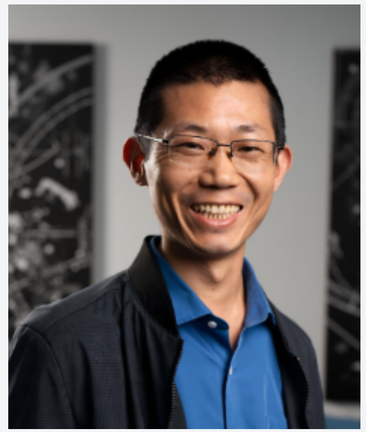
- Introduction to ALP
- Sun as astrophysical laboratory
- Why MeV ALP?
- Solar production
- Direct detection: Results
- Conclusion

Based on arXiv: 2607.21168,

Shao-Feng Ge, SJ, Tao Li

"MeV Elctrophilic ALP from Sun"

Shao-feng Ge



Tao Li

Light BSM particles:ALP

- Strong CP Problem:

$$\mathscr{L} \supset -\frac{\theta g_s^2}{32\pi^2} G\tilde{G} - \left(\bar{u}_L M_u u_R + \bar{d}_L M_d d_R + \text{h . c . }\right) \qquad \theta_{\text{QCD}} = \theta + \arg\left[\det\left[M_u M_d\right]\right]$$

Neutron EDM constrains! $\theta_{\text{QCD}} \lesssim 1.3 \times 10^{-10}$

- $U(1)_{PQ}$ symmetry: The goldstone after SSB is called "Axion"
  QCD scale Chiral symmetry breaking leads to tiny mass -> pNGB

Pecci, Quinn, 1997

- Plethora of BSM model predicts such pseudoscalar not necessarily related to Strong CP=> Broadly called Axion like particles (ALP).

Probing ALPs

- In EFT approach one can have effective couplings ALP& SM

$$\mathcal{L}_{ae} \supset -ig_{ae}\bar{e}\gamma^5 ea - i\bar{N}\gamma^5(g^0_{aN}I + \sigma_3 g^3_{aN})Na - \frac{1}{4}aF_{\mu\nu}\tilde{F}^{\mu\nu}$$ ....+other gauge bosons

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- Several approach to probe from astrophysics, ground based experiments, and Direct searches : Sun can emit ambient light particles!

Caputo, Raffelt 2401.13728

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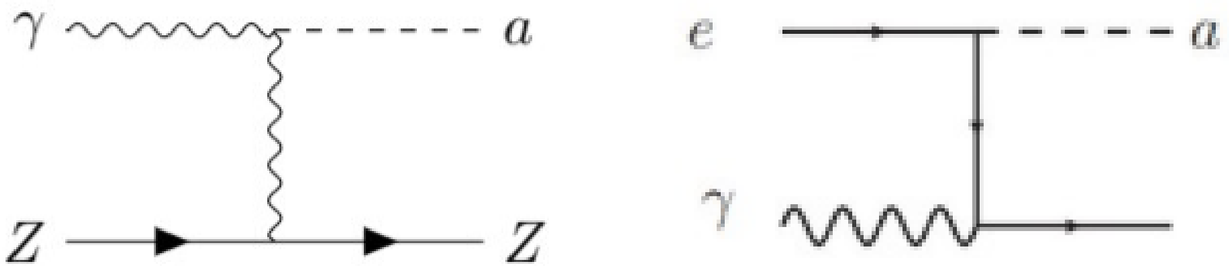

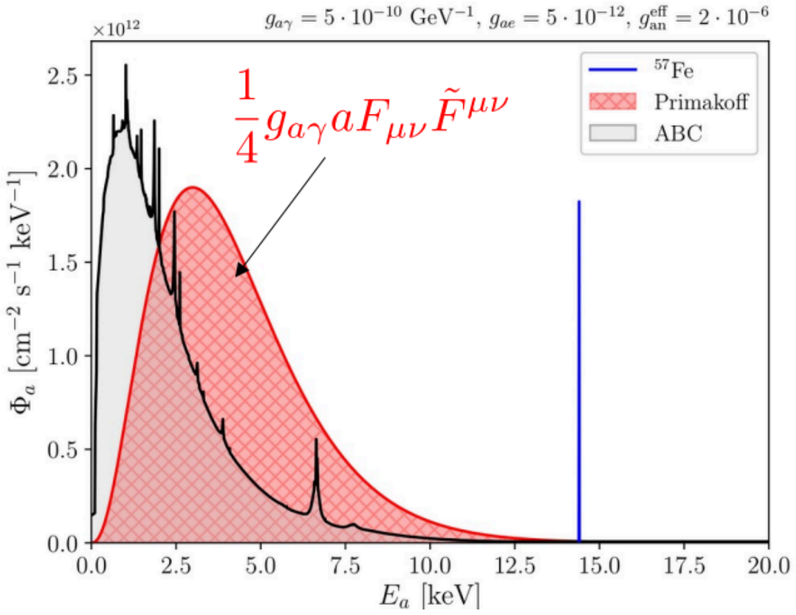

J.B. Dent B. Dutta, J.L. Newstead, A. Thompson, PRL 2020

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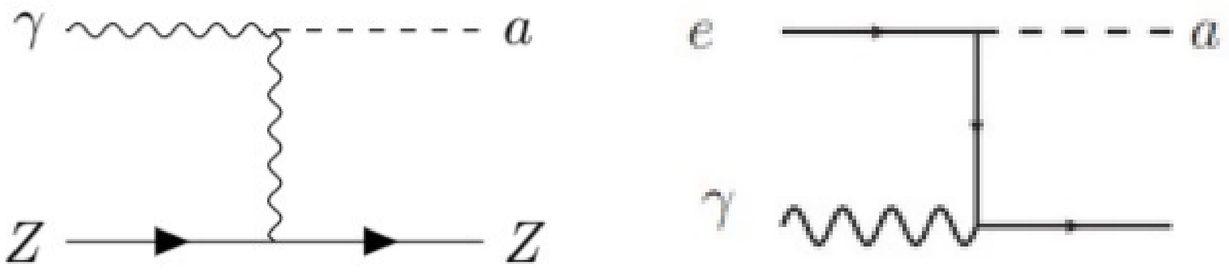
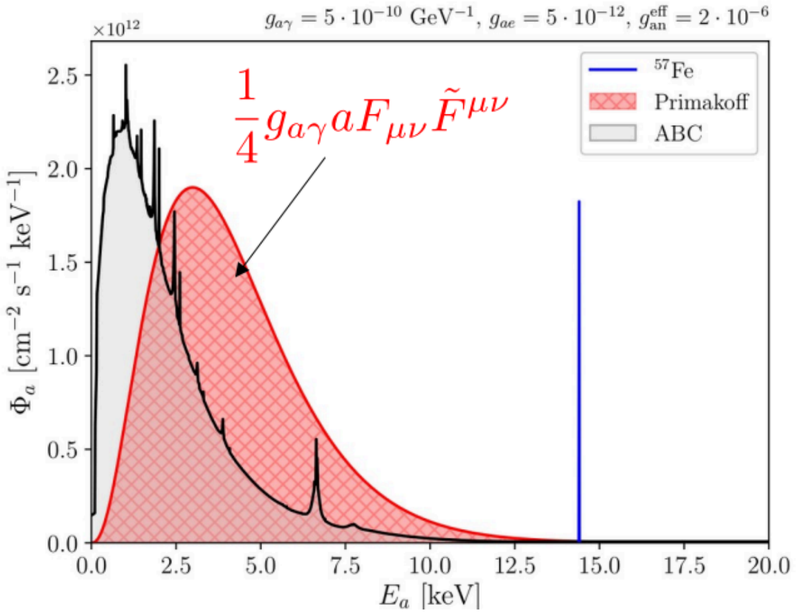
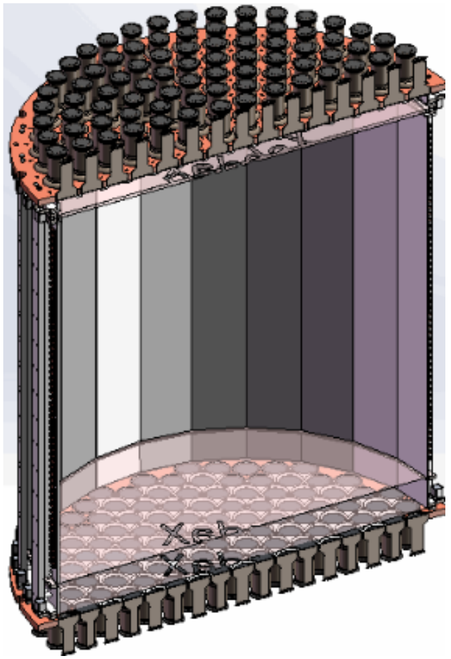


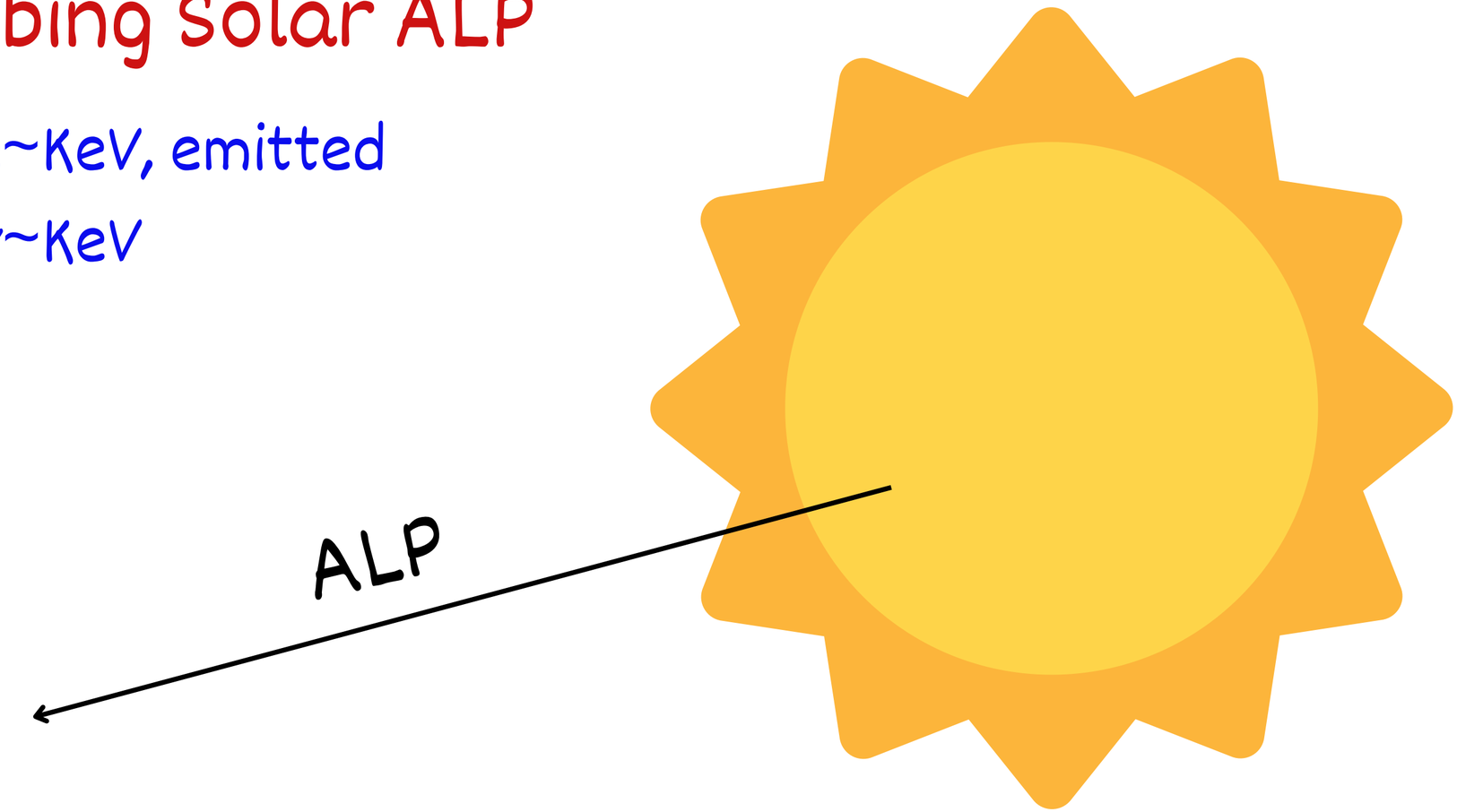


J.B. Dent B. Dutta, J.L. Newstead, A. Thompson, PRL 2020

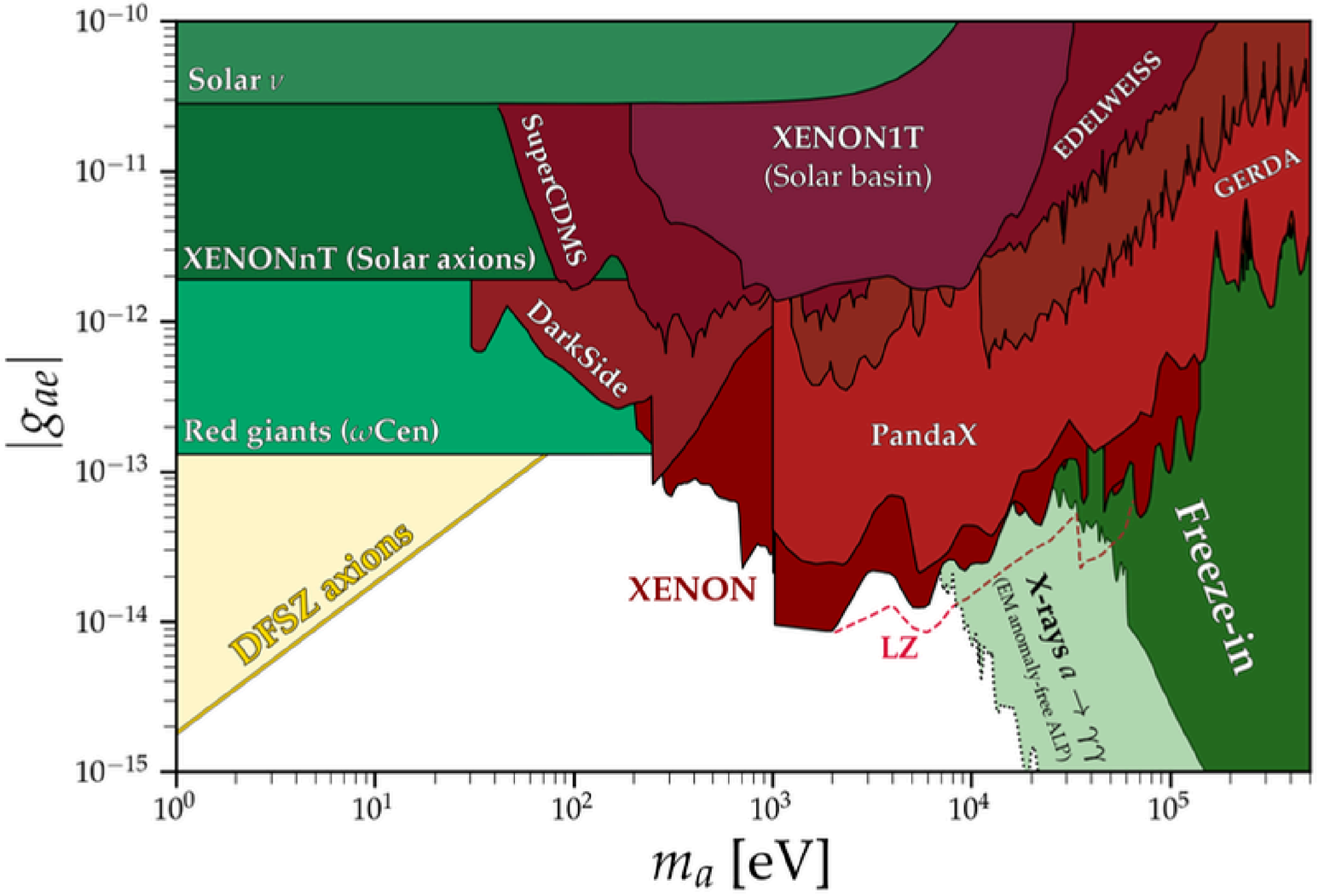
Probing Solar ALP

- Sun has Temperature~KeV, emitted particles with energy~KeV





Existing constraints on e-philiv ALP



cajohare/github

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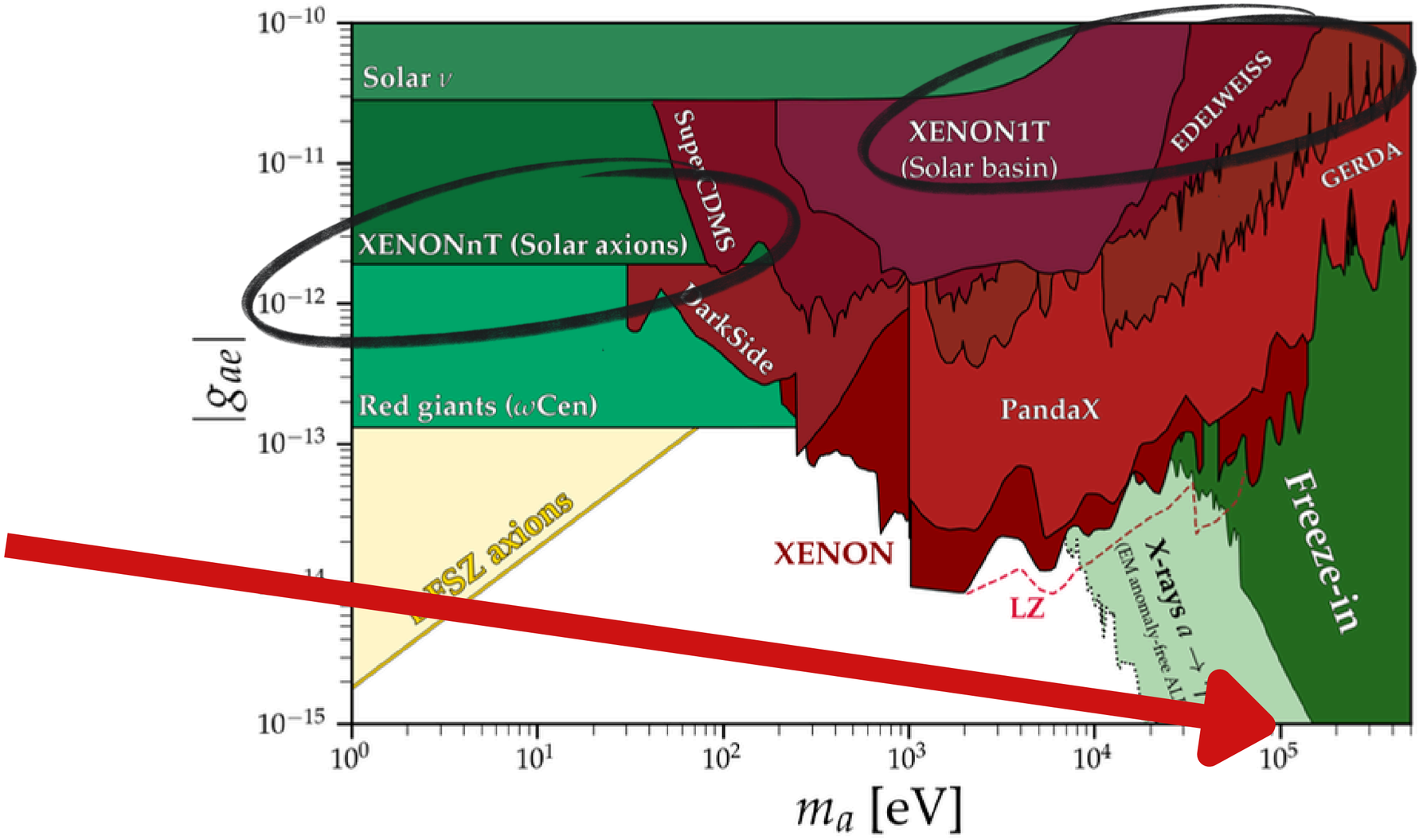
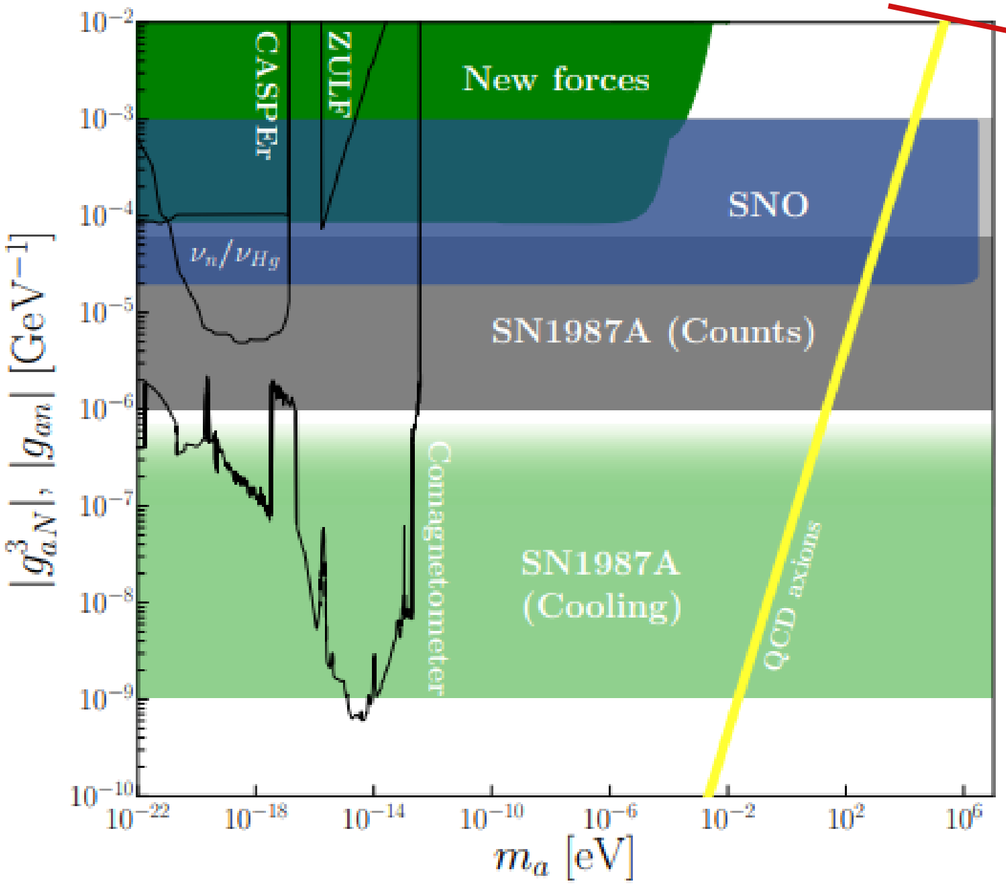


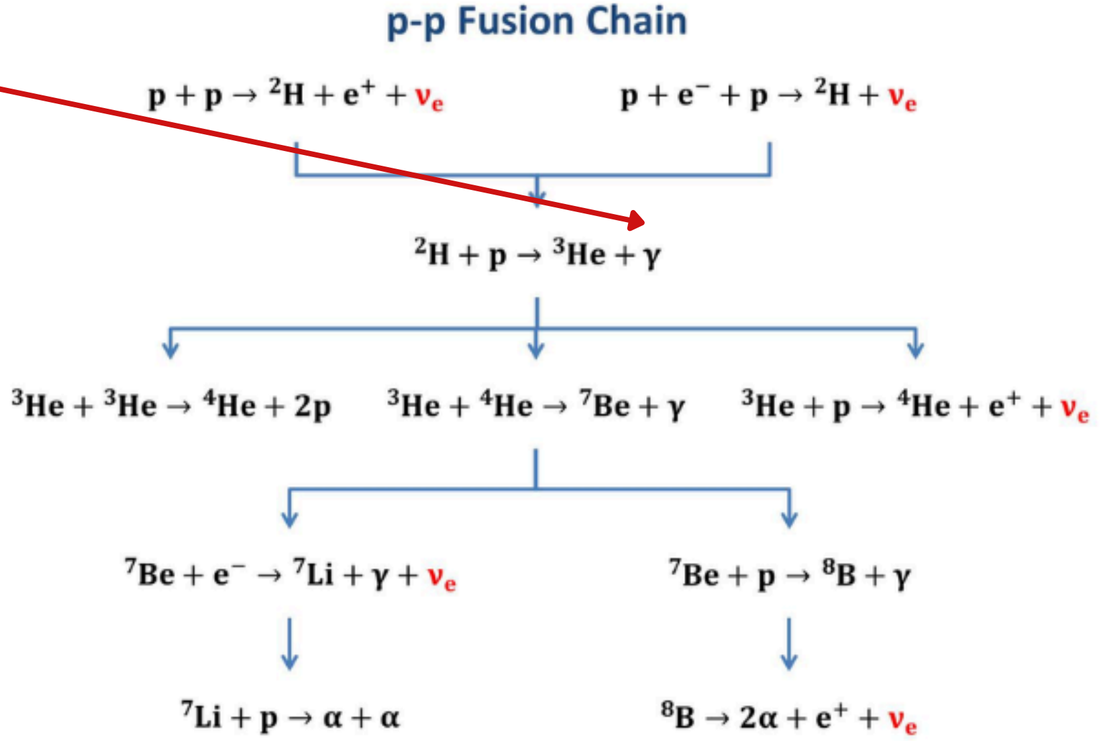
cajohare/github

Probing Solar ALP

- Sun has Temperature~KeV, emitted particles with energy~KeV
- Can emit 5.5 MeV ALP from nuclear fusion: depends on g_{aN}

$$\frac{\Gamma_a}{\Gamma_\gamma} \simeq \frac{1}{2\pi\alpha}\frac{m_n^2}{1+\delta^2}\left(\frac{\beta g_{aN}^1 + g_{aN}^3}{(\mu_0 - 0.5)\,\beta + \mu_3 - \eta}\right)^2 \left(\frac{p_a}{p_\gamma}\right)^3$$





Bhusal et al PRL 2021

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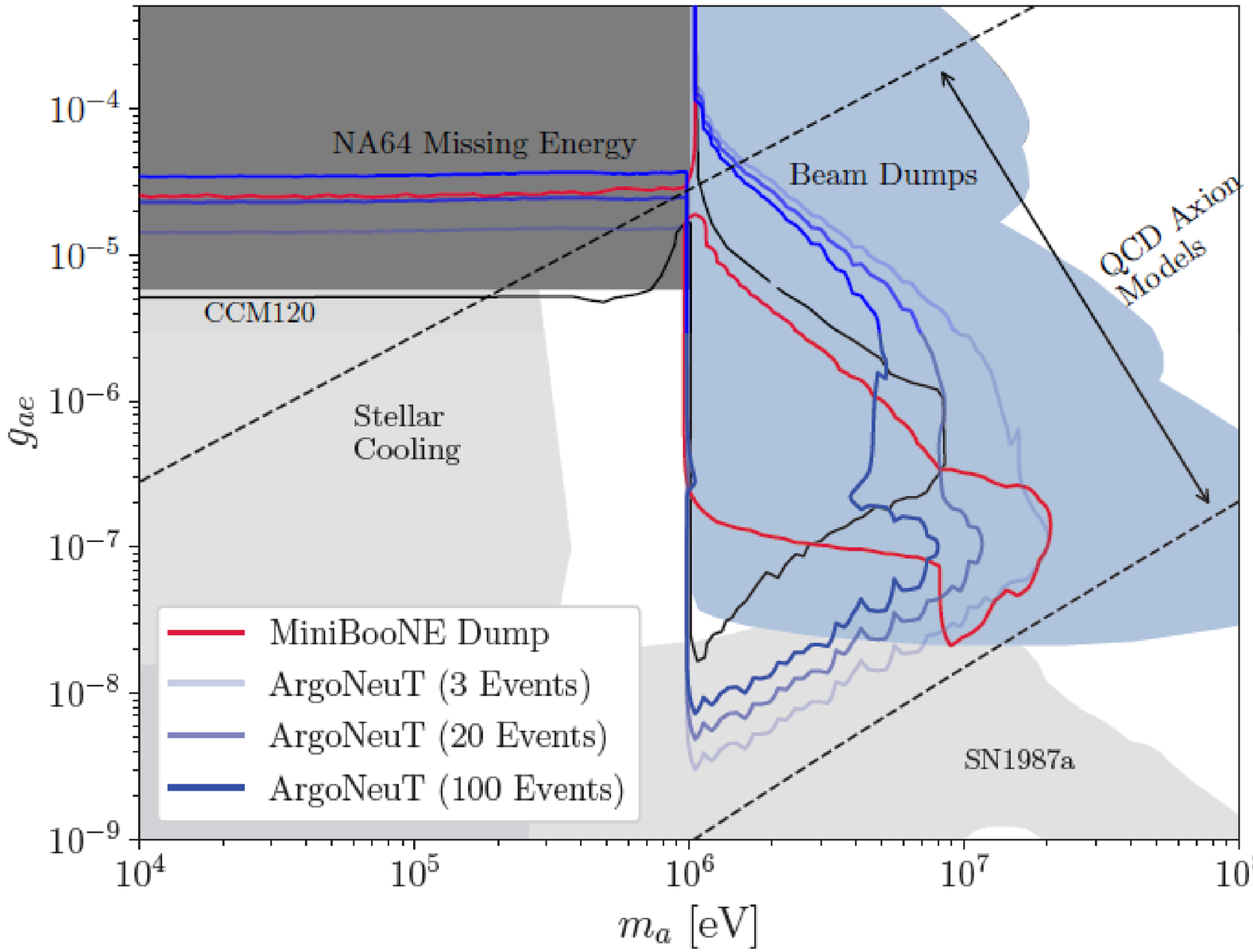
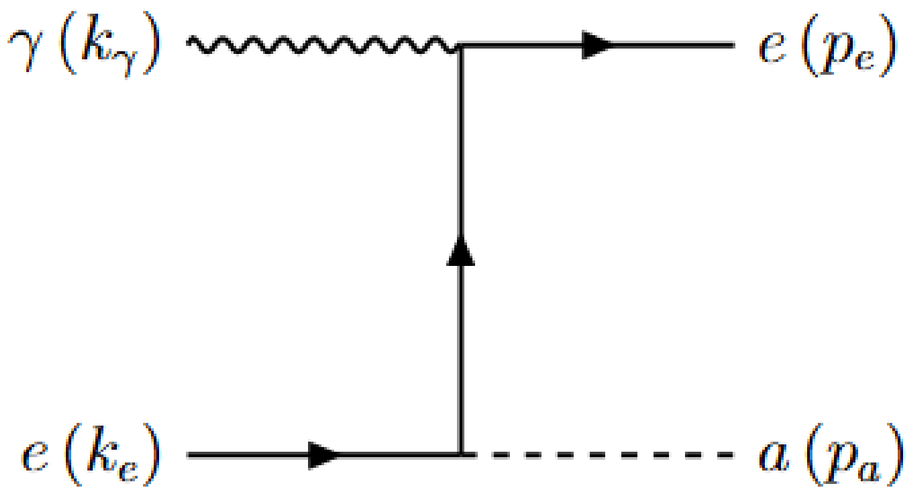


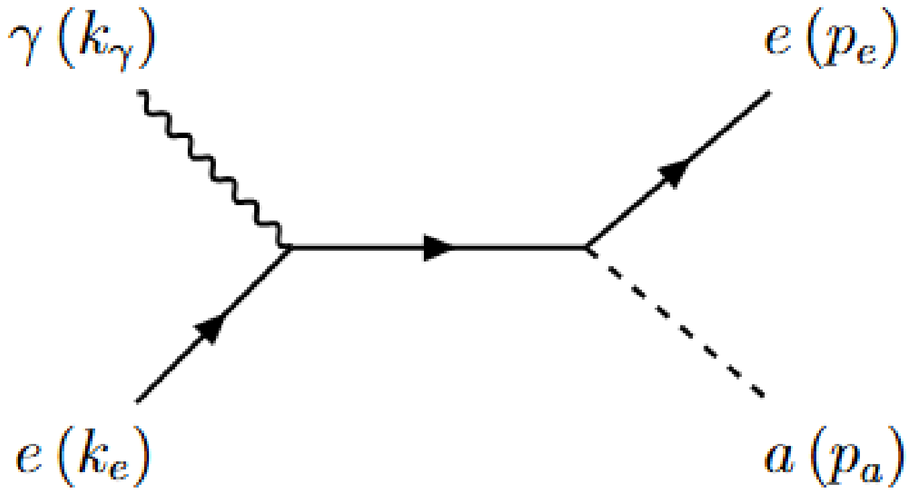
Capozzi et al
PRD 2023

Probing Solar ALP

- Sun has Temperature~KeV, emitted particles with energy~KeV
- 5.5 MeV photon can be used to produce electrophilic ALP : without nucleon coupling

$$\mathcal{L} = \frac{1}{2}\partial^\mu a \partial_\mu a - \frac{1}{2}m_a^2 a^2 - i g_{ae} a \bar{e}\gamma^5 e$$

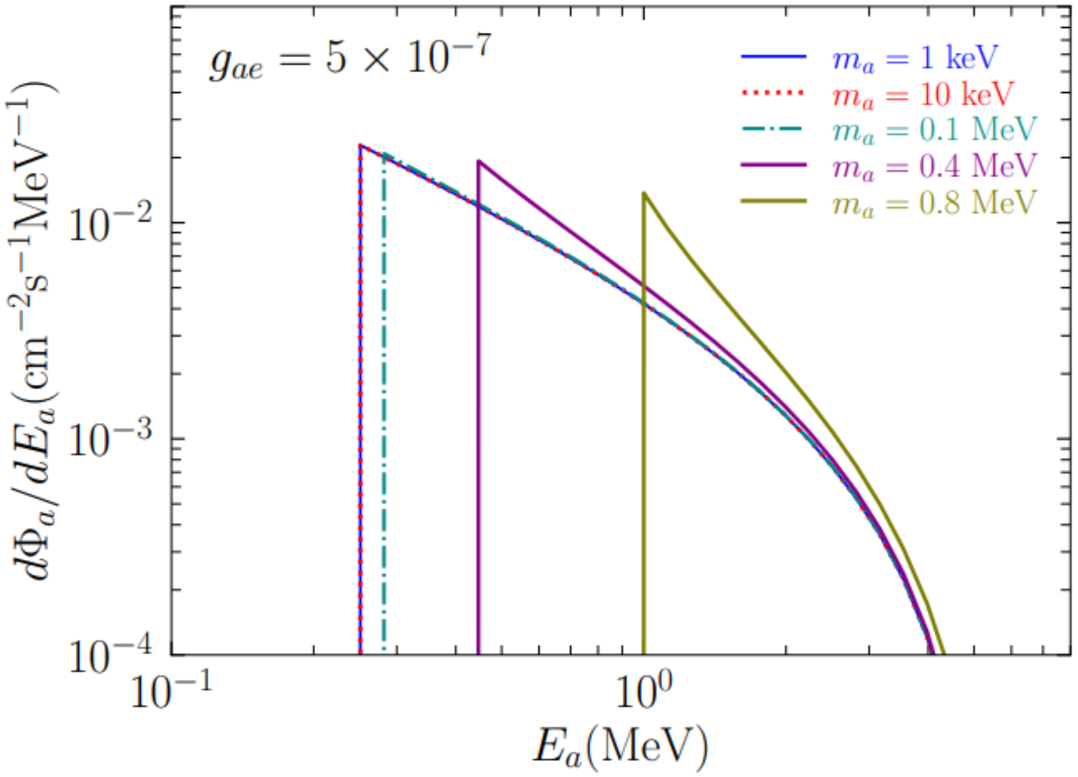




Continuous MeV Solar ALP flux

$$\frac{d\Phi_a(E_a)}{dE_a} = \frac{1}{4\pi d_\odot^2} \int dE_\gamma \frac{dN_\gamma}{dE_\gamma} \frac{1}{\sigma_{\rm tot}} \frac{d\sigma}{dE_a}\, \Theta(E_a - E_a^{\rm min})\Theta(E_a^{\rm max} - E_a)$$

$$\frac{dN_\gamma}{dE_\gamma} \rightarrow 4\pi d_\odot^2 \Phi_{pp\nu}$$



$$E_a^{\rm min,\ max} = \frac{1}{2(m_e^2 + 2m_e E_\gamma)} \Big\{ (2m_e E_\gamma + m_a^2)(E_\gamma + m_e) \mp E_\gamma \sqrt{[m_e^2 + 2m_e E_\gamma - (m_a + m_e)^2]\,[m_e^2 + 2m_e E_\gamma - (m_a - m_e)^2]} \Big\}$$

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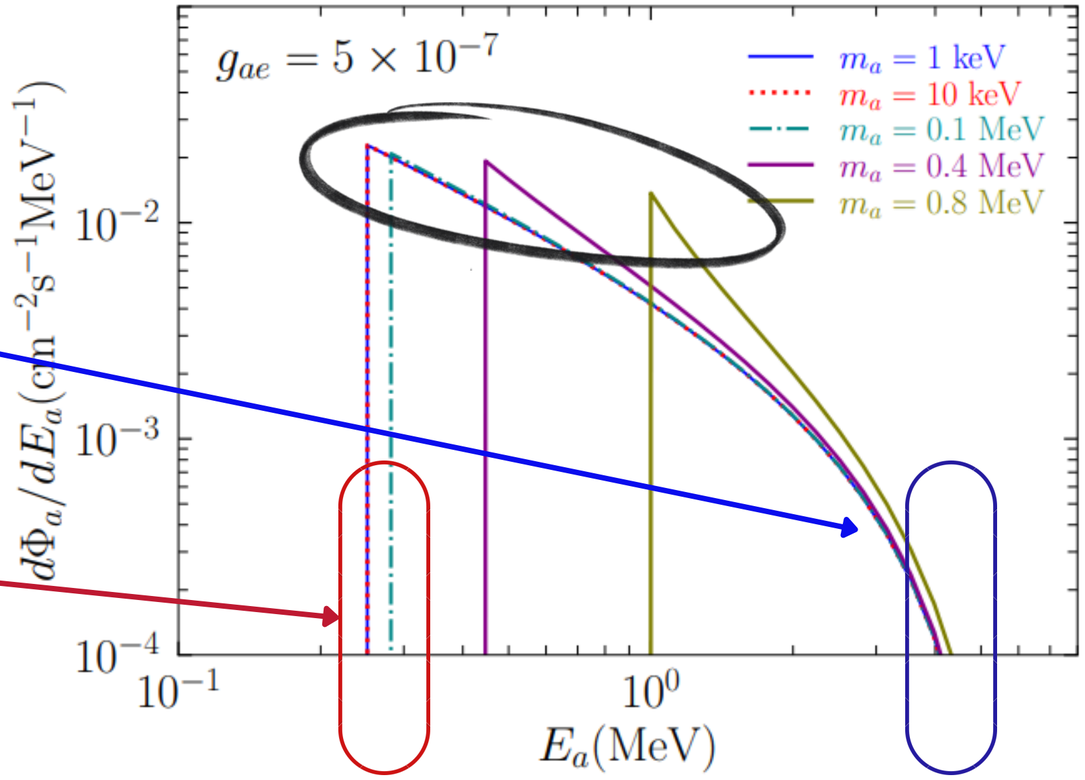
E_γ

$\frac{m_e}{2}$



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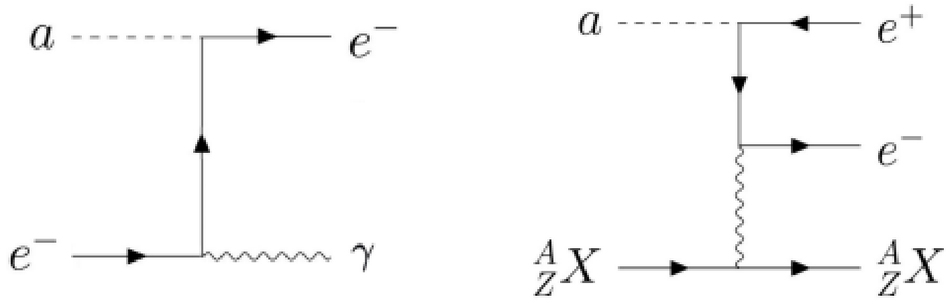
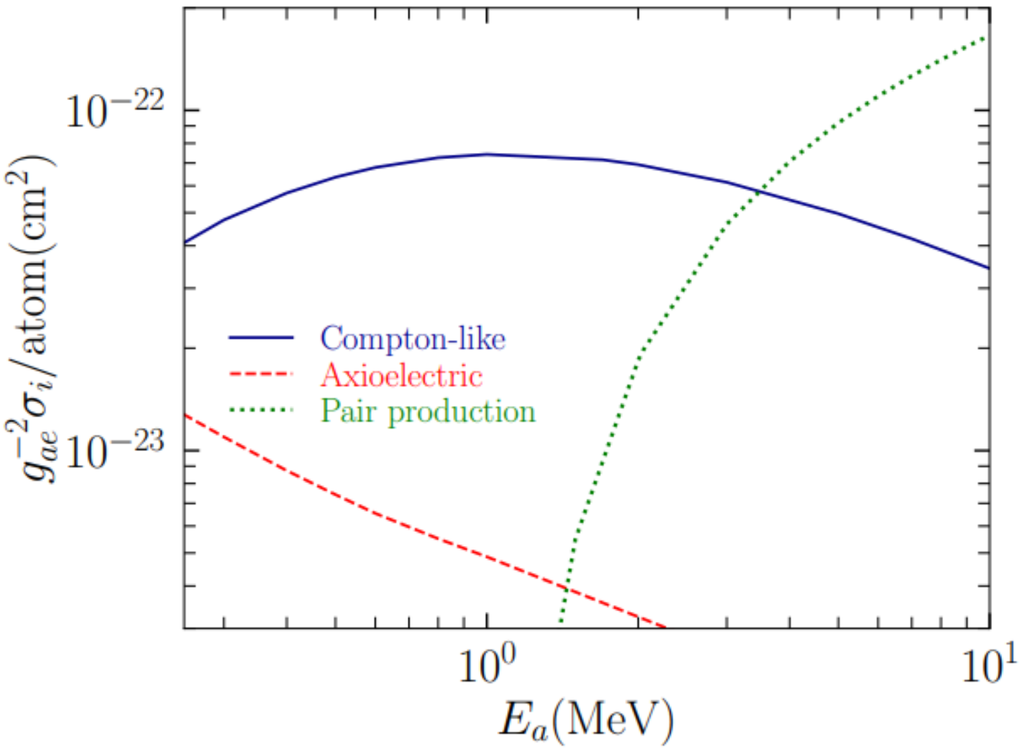
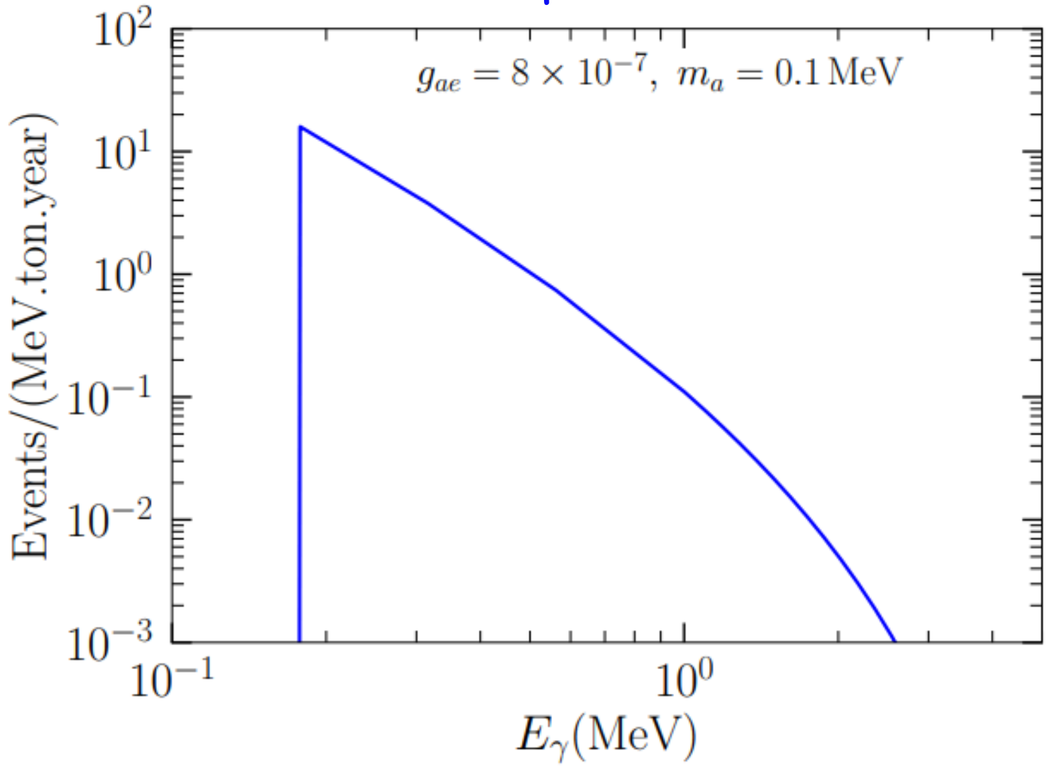
Detection of MeV electrophilic Solar ALP





Compton-like



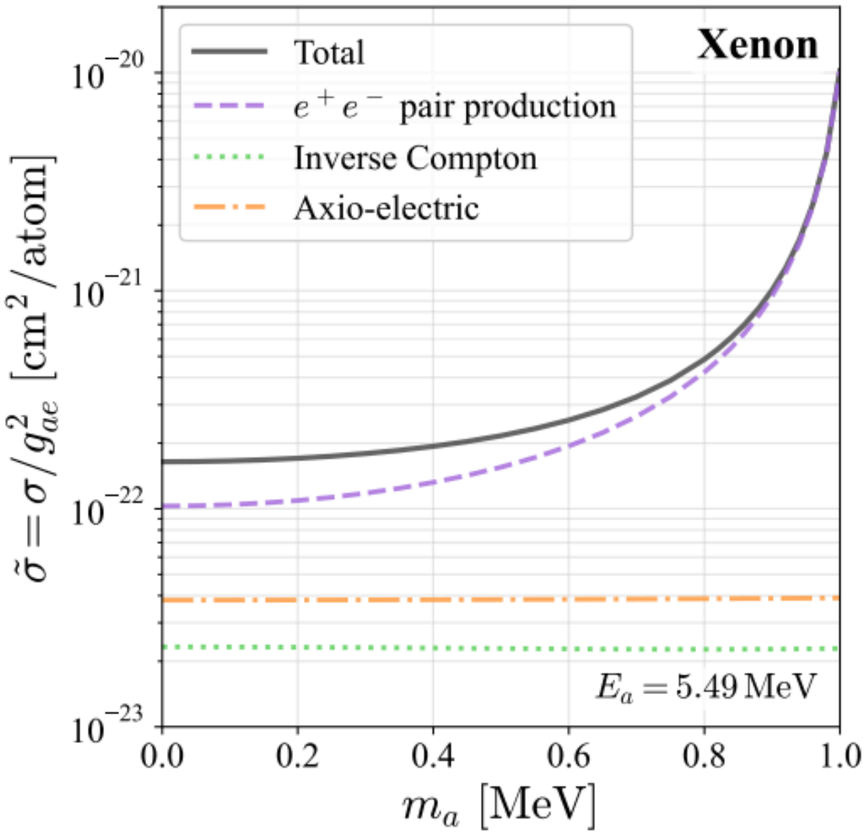
Unfortunately present setup
can't distinguish photon and e recoil

Detection of MeV electrophilic Solar ALP

$$\frac{dR_C}{dE_\gamma} = t_{\rm exp} n_{\rm T} \mathcal{E}(E_\gamma) \int_{E_a^{\rm min}(E_\gamma)}^{E_a^{\rm max}} \frac{d\Phi_a}{dE_a} \frac{d\sigma_C}{dE_\gamma} dE_a$$ Compton

$$R_{ae} \equiv t_{\rm exp} n_A \int_{E_a^{\rm min}}^{E_a^{\rm max}} \sigma_{ae} \frac{d\Phi_a}{dE_a} dE_a$$ Axio-electric

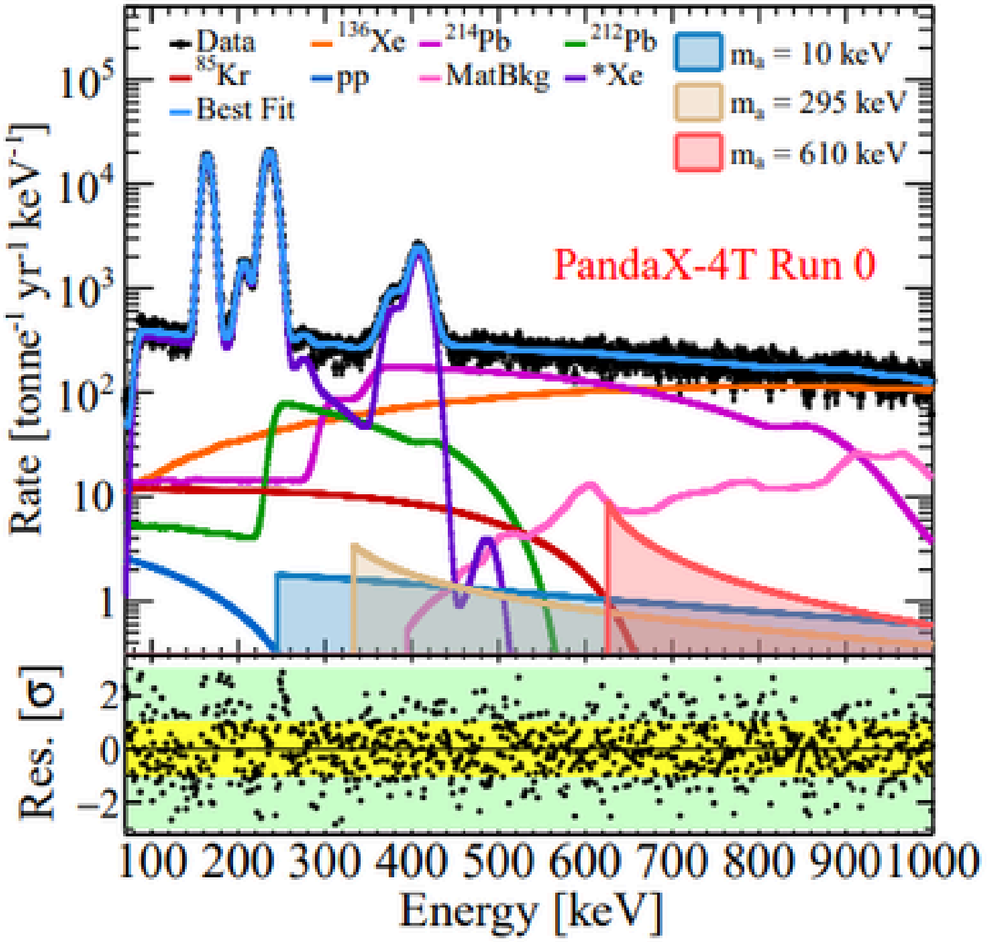
$$R_{aee} \equiv t_{\rm exp} n_A \int_{E_a^{\rm min}}^{E_a^{\rm max}} \sigma_{aee} \frac{d\Phi_a}{dE_a} dE_a.$$ pair production

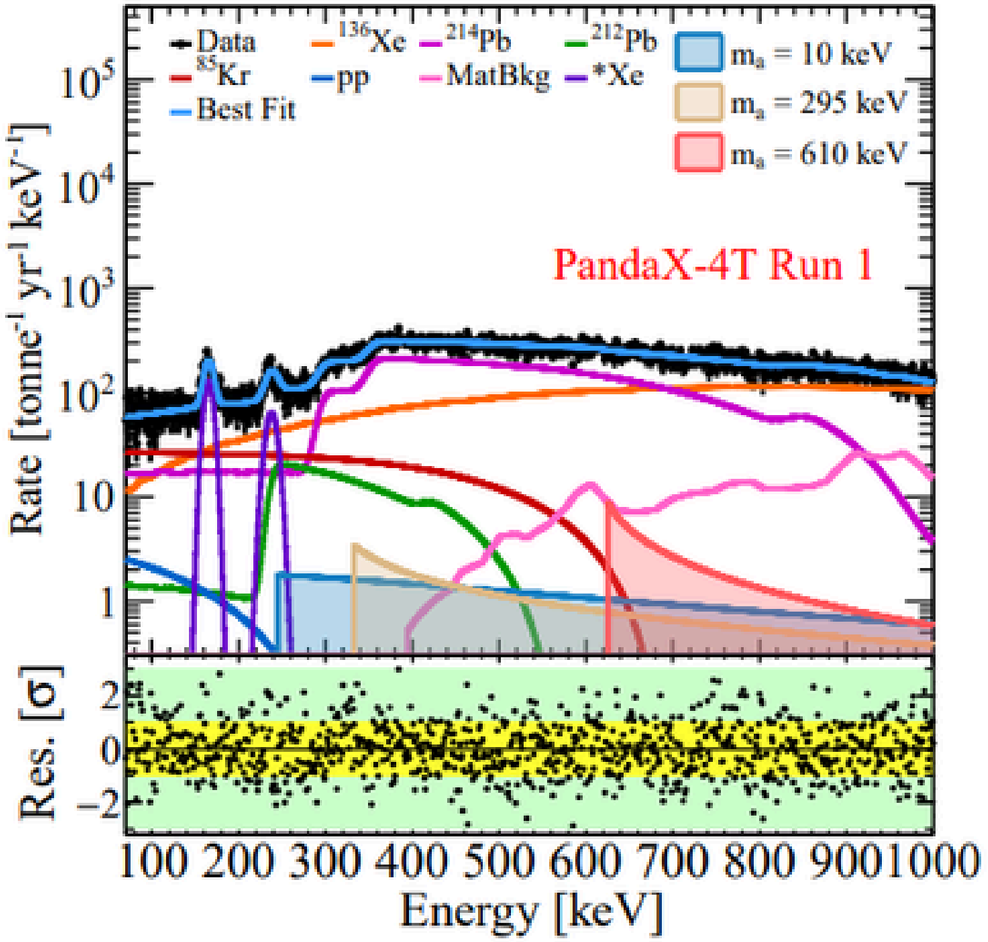


Feng et al 2608.15699

Total rate: $R_{\rm tot} \equiv R_C + R_{ae} + R_{aee}$

Recoil Spectrum





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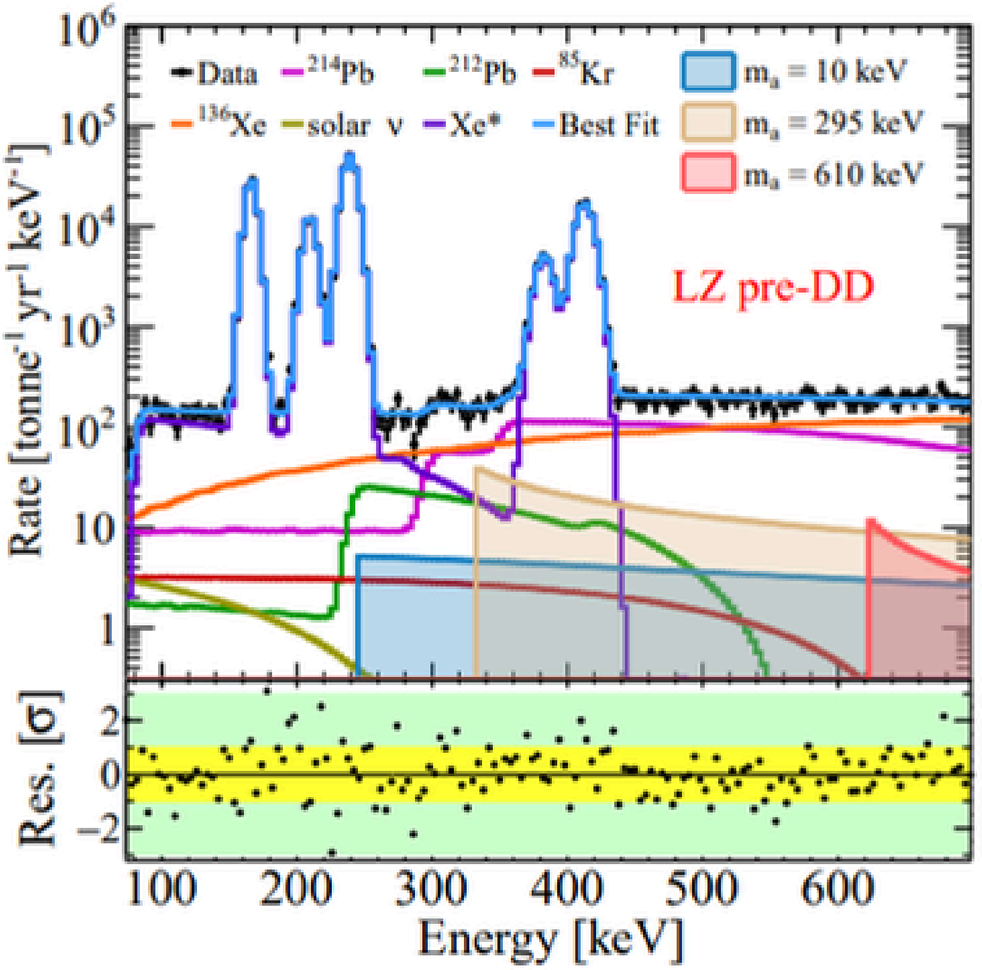
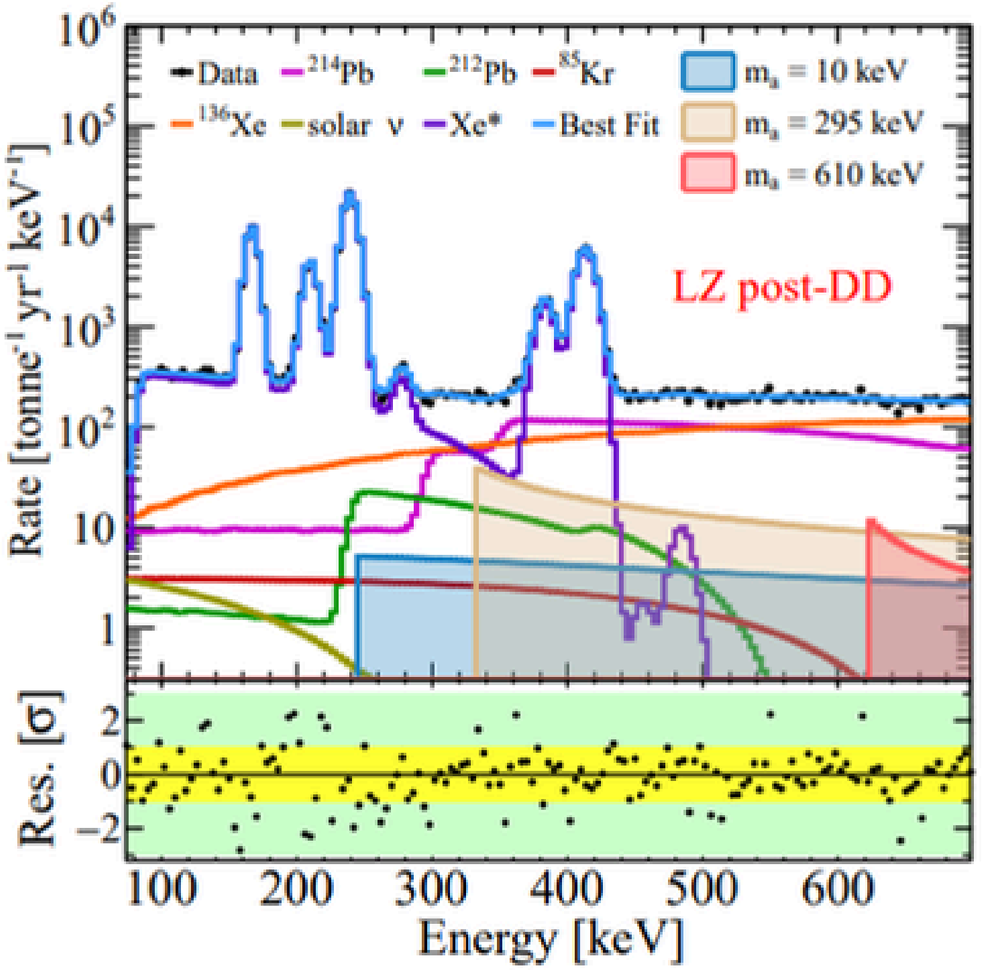
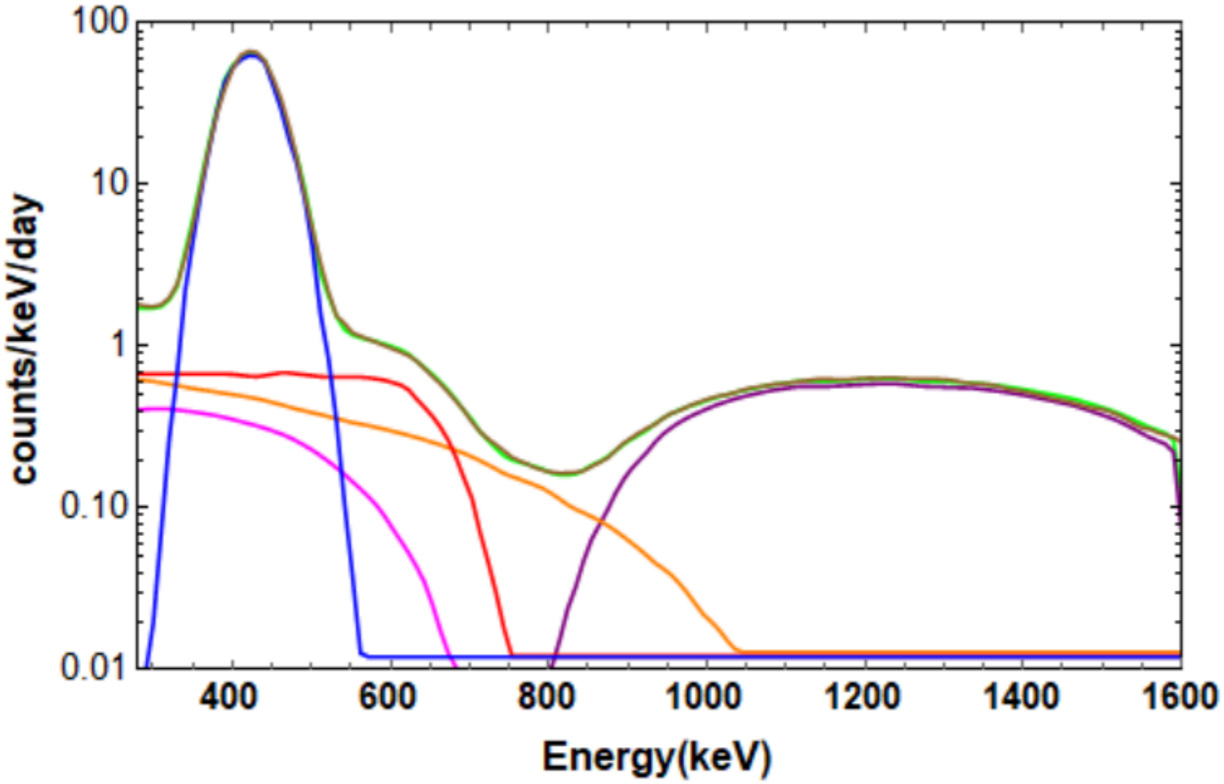
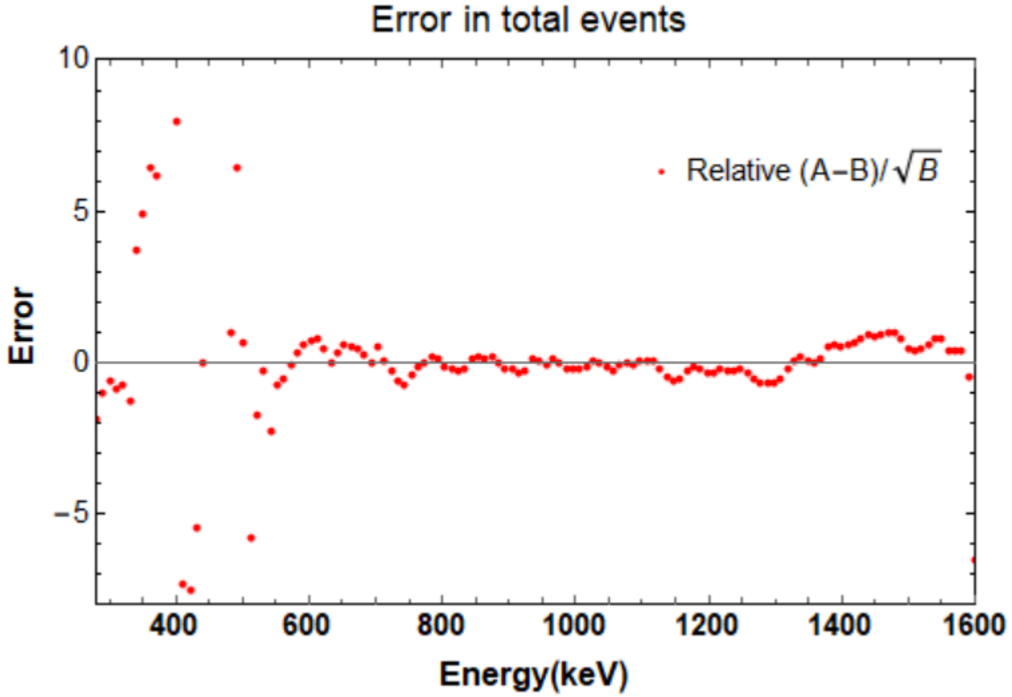




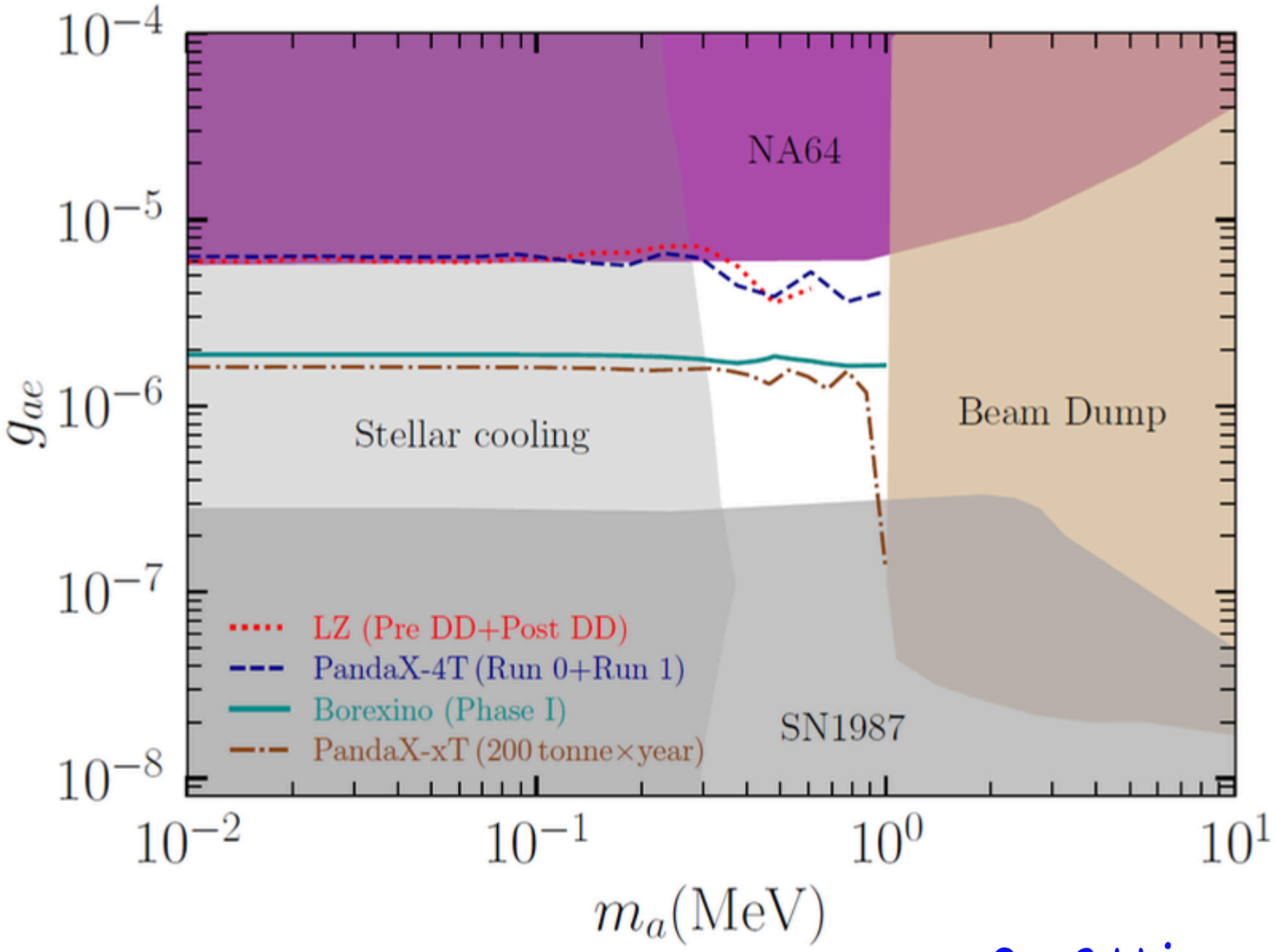
Direct search in Borexino





$$\chi^2 \equiv 2\sum_i \left[R^i_{\rm pred}(m_a, g_{ae}) - R^i_{\rm exp} + R^i_{\rm exp} \left(\frac{R^i_{\rm exp}}{R^i_{\rm pred}(m_a, g_{ae})} \right) \right]$$

Sensitivity



Ge, SJ,Li, arxiv 2607.21168

Summary

- Besides the keV dark sectors, the Sun can also produce MeV energetic electrophilic dark particles
- Future direct detection experiments in the MeV recoil energy range can be useful to probe them
- It can also offer new parameter reach and an opportunity to discover new physics!

Thank you