Detecting Axion-Like Particles, originating from the Sun, with large neutrino detectors such as SNO+

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Outline

- What is an ALP?
- How are ALPs produced?
- How do ALPs interact?
- A good ALP detector
- SNO+ Sensitivity to ALP couplings
- Conclusion

What is an ALP?

- Strong CP Problem: No experimentally known violation of CP-symmetry in QCD (with no clear reason)

$$\mathcal{L}_{QCD} = ... + \Theta \frac{g^2}{32\pi^2} G^a_{\mu\nu} \tilde{G}^{a\mu\nu}$$

CP violating term

Make a Dynamical variable: $\Theta = \frac{a}{f_a}$ ***Peccei, Quinn (1977)***

Adds new global symmetry spontaneously broken U(1)

PQ Symmetry —-> neutral pseudoscalar particle ***Weinberg, Wilzcek (1978)***

KSVZ or Hadronic Model (http://journals.aps.org/prl/abstract/10.1103/PhysRevLett.43.103

DFSZ or GUT Model (http://www.sciencedirect.com/science/article/pii/0370269381905906)

How are ALPs produced?

Solar ALP Production:

$$p + d \rightarrow {}^3\mathrm{He} + \gamma \ (5.5\ \mathrm{MeV})$$

p + d ——> 3He + **A**

Normal pp Fusion flux

$$m_A < 1\ \mathrm{MeV}$$

$$\Phi_{A0} = \Phi_{\nu pp}(\omega_A/\omega_\gamma) = 3.23 \times 10^{10}(g_{3AN})^2(p_A/p_\gamma)^3$$

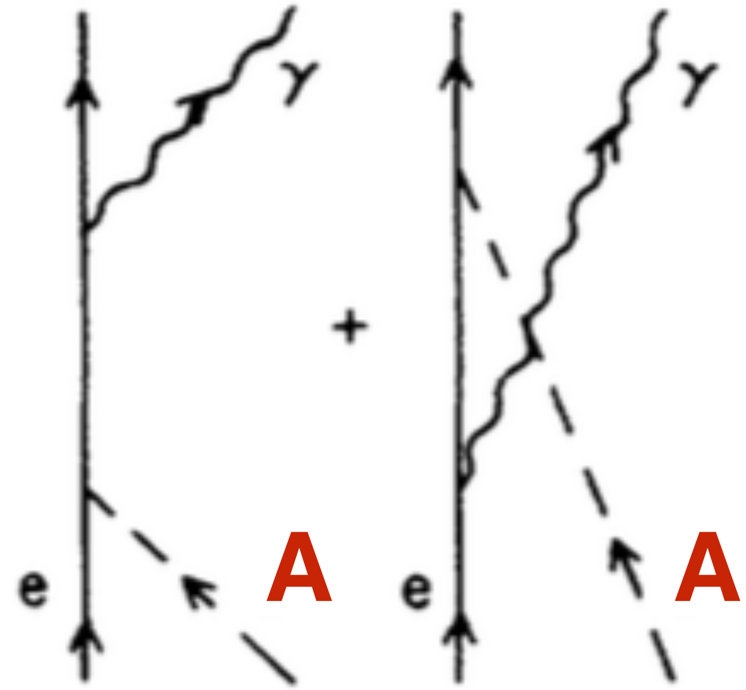
ALP Flux at Sun

ALP to Photon production ratio

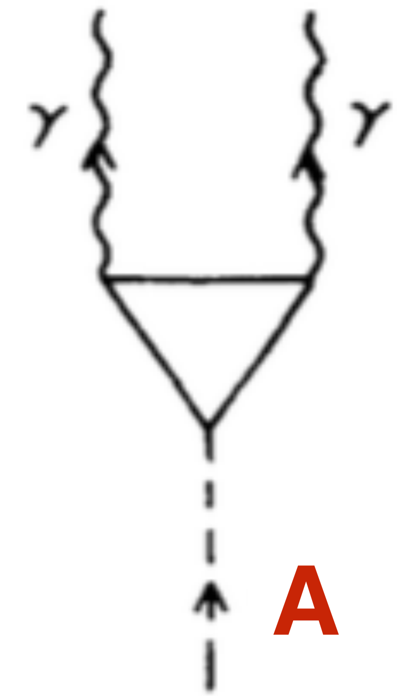
isovector coupling to ALPs

Borexino Axion Paper (http://journals.aps.org/prd/abstract/10.1103/PhysRevD.85.092003)

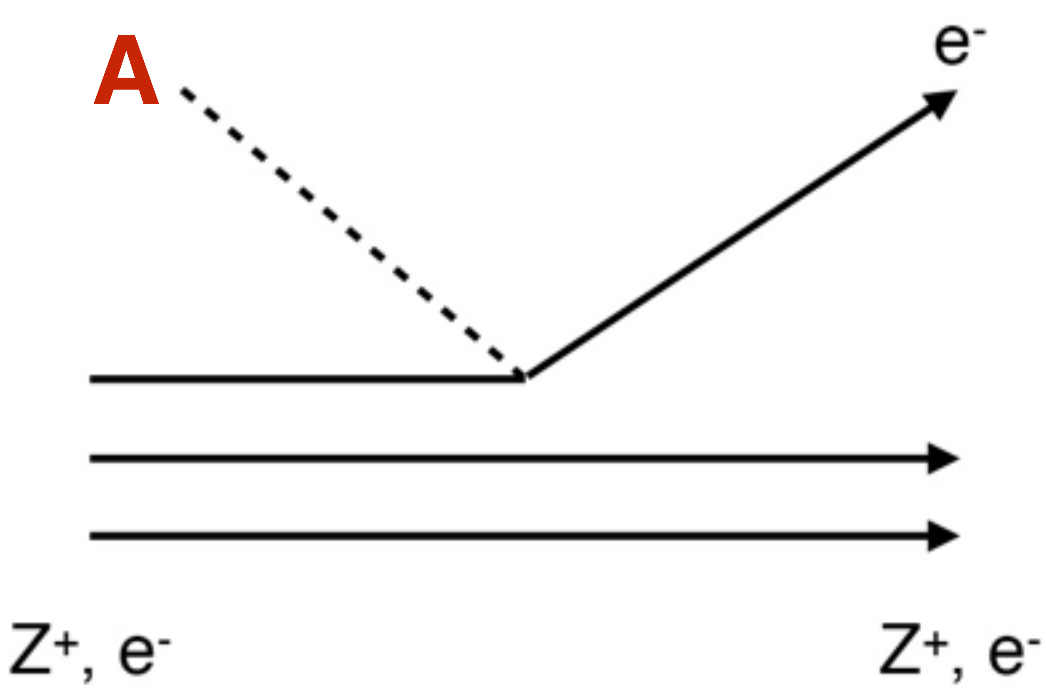
Compton Conversion



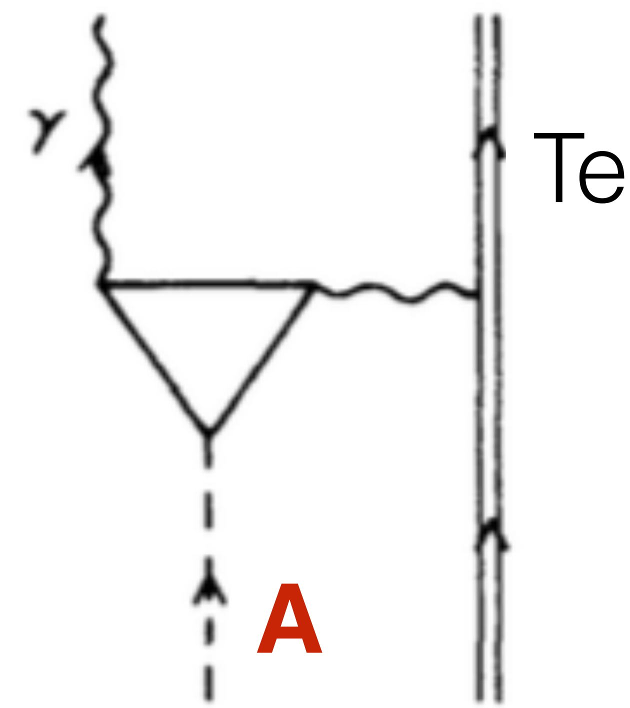
Axion Decay



Axioelectric Effect

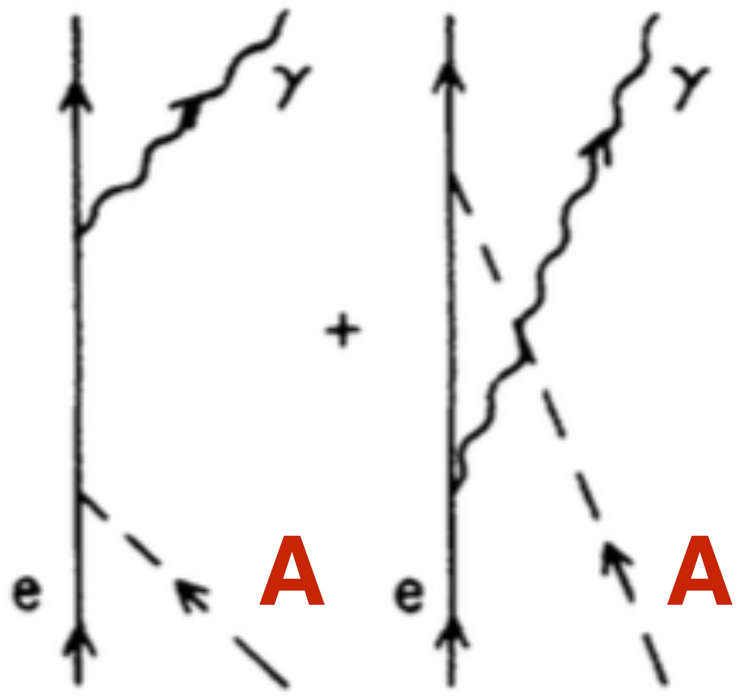


Inverse Primakoff



How do ALPs interact? (I)

Compton Conversion



Typically:
~1.7 MeV Gamma
~3.8 MeV e-
Forward peaked w.r.t Sun

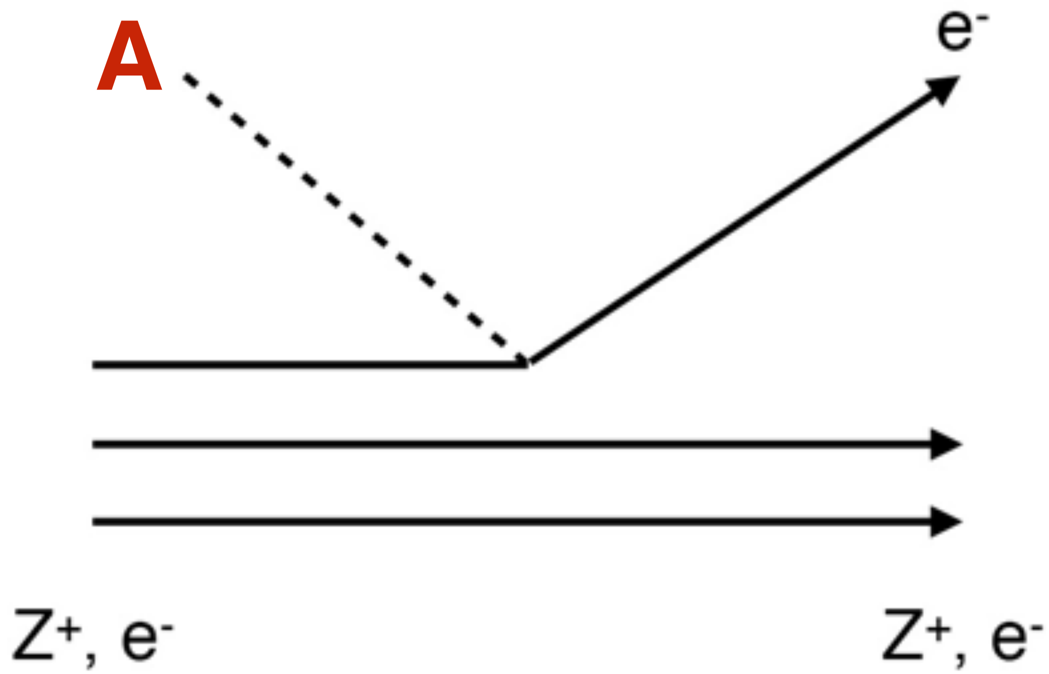
Water Cherenkov and liquid scintillator

$$S_{CC} = \Phi_{\nu pp}(\omega_A/\omega_\gamma)\sigma_{CC}N_eT\varepsilon$$
$$S_{CC} = g_{Ae}^2 \times g_{3AN}^2 \times 1.4 \times 10^{-14}N_eT\varepsilon$$

Borexino Limit:
$$|g_{Ae} \times g_{3AN}| \leq 5.5 \times 10^{-13}$$
$$m_A < 1\text{ MeV}$$

How do ALPs interact? (II)

Axioelectric Effect



- ~5.5 MeV e-
- Mono-energetic
- Point like interaction
- Limited Directionality
- Lower cross section

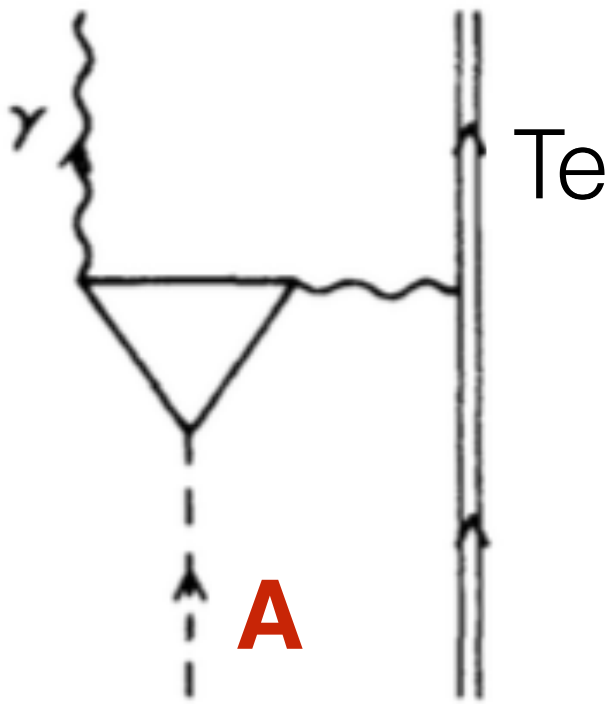
$\sigma \propto g_{Ae}^2 Z^5$ Z(Te) = 52

Isotope-Loaded
Scintillator Experiments

$$|g_{Ae} \times g_{3AN}| \propto \left[\frac{S_{90\%}}{(N_C Z_C^5 + N_{Te} Z_{Te}^5) T \epsilon} \right]^{\frac{1}{2}}$$

How do ALPs interact? (III)

Inverse Primakoff



Isotope-Loaded Scintillator Experiments

~5 MeV Gamma

Point like interaction

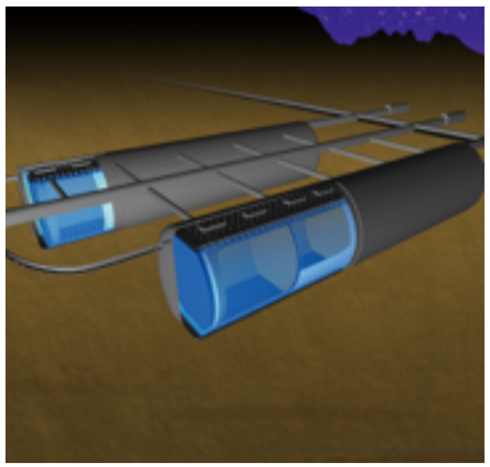
Limited Directionality

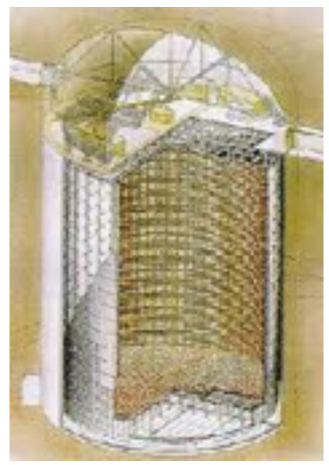
$\sigma \propto g_{A\gamma}^2 Z^2$ Z(Te) = 52

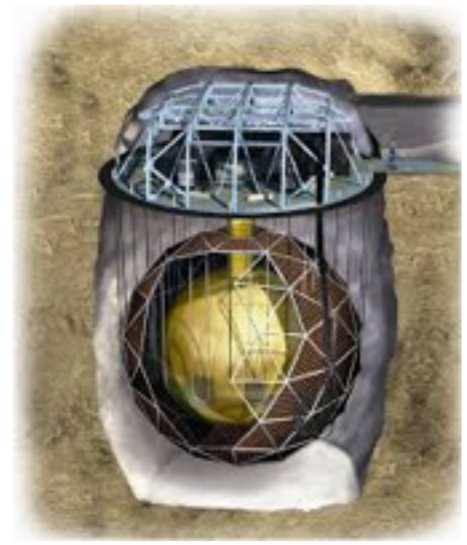
A good ALP Detector

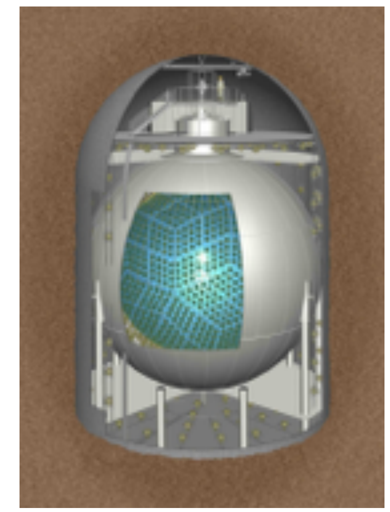
Water Cherenkov | Liquid Scintillator

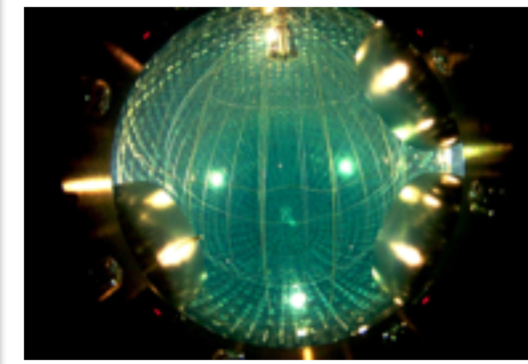
Isotope-loaded







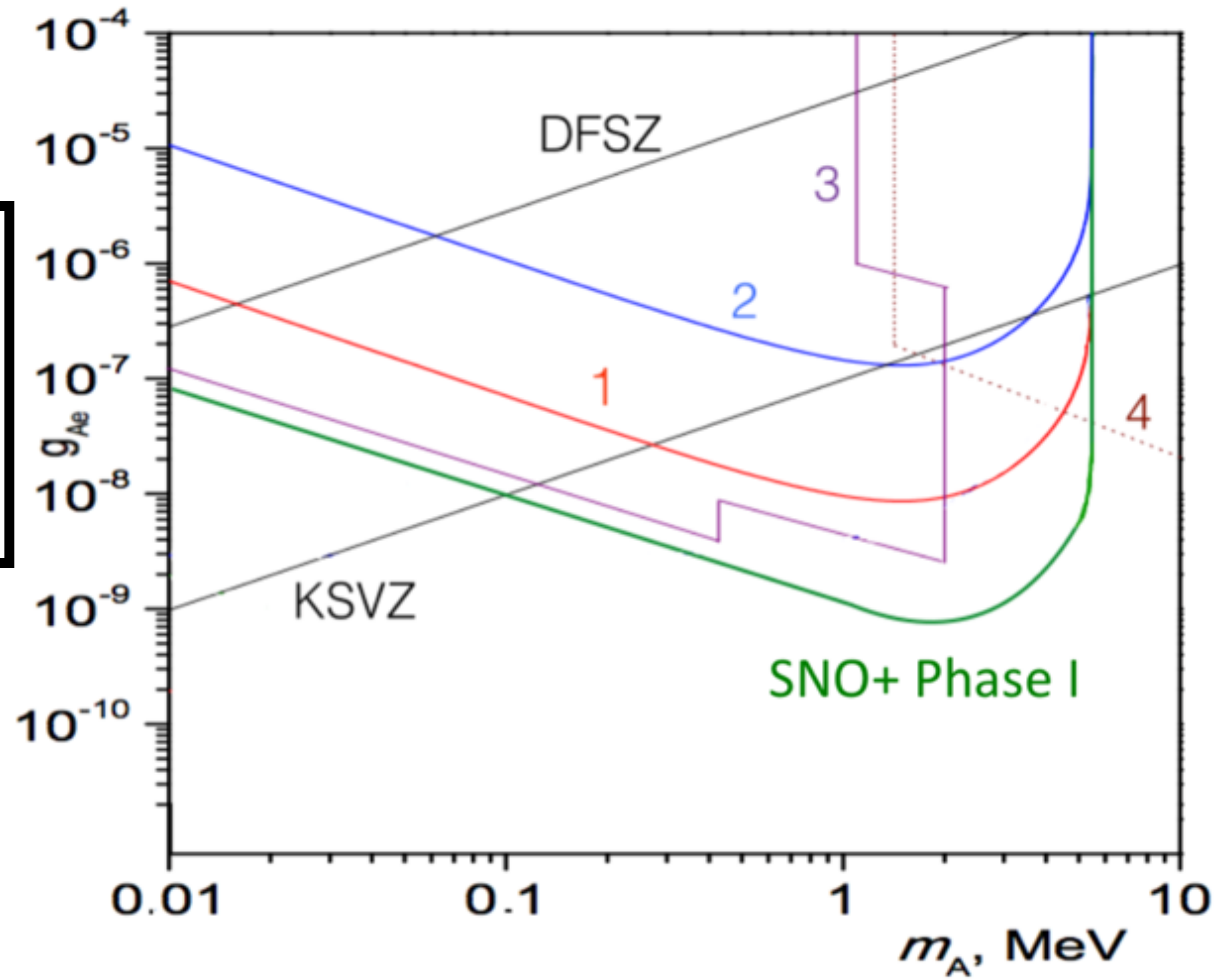




Water Cherenkov	Liquid Scintillator
Low Light yields	Higher light yields
Directional Information	Isotropic Light
Higher U/Th content	Lower U/Th content

SNO+ ALP-electron coupling

1 - 8kg of BGO Bolometer
2 - BGO Scintillator
3 - Solar/Reactor Exper.
4 - SNO+ Phase I



Adapted from A.V. Derbin Eur. Phys. J. C (2014) 74:3035

Assuming no Compton conversion

SNO+ ALP-photon coupling

Helioscopes (7) - CAST

Conversion of Axion to Photon in a large magnetic field

Large Scintillator Exper. (1a,b) - Borexino

Limits from ALP decay

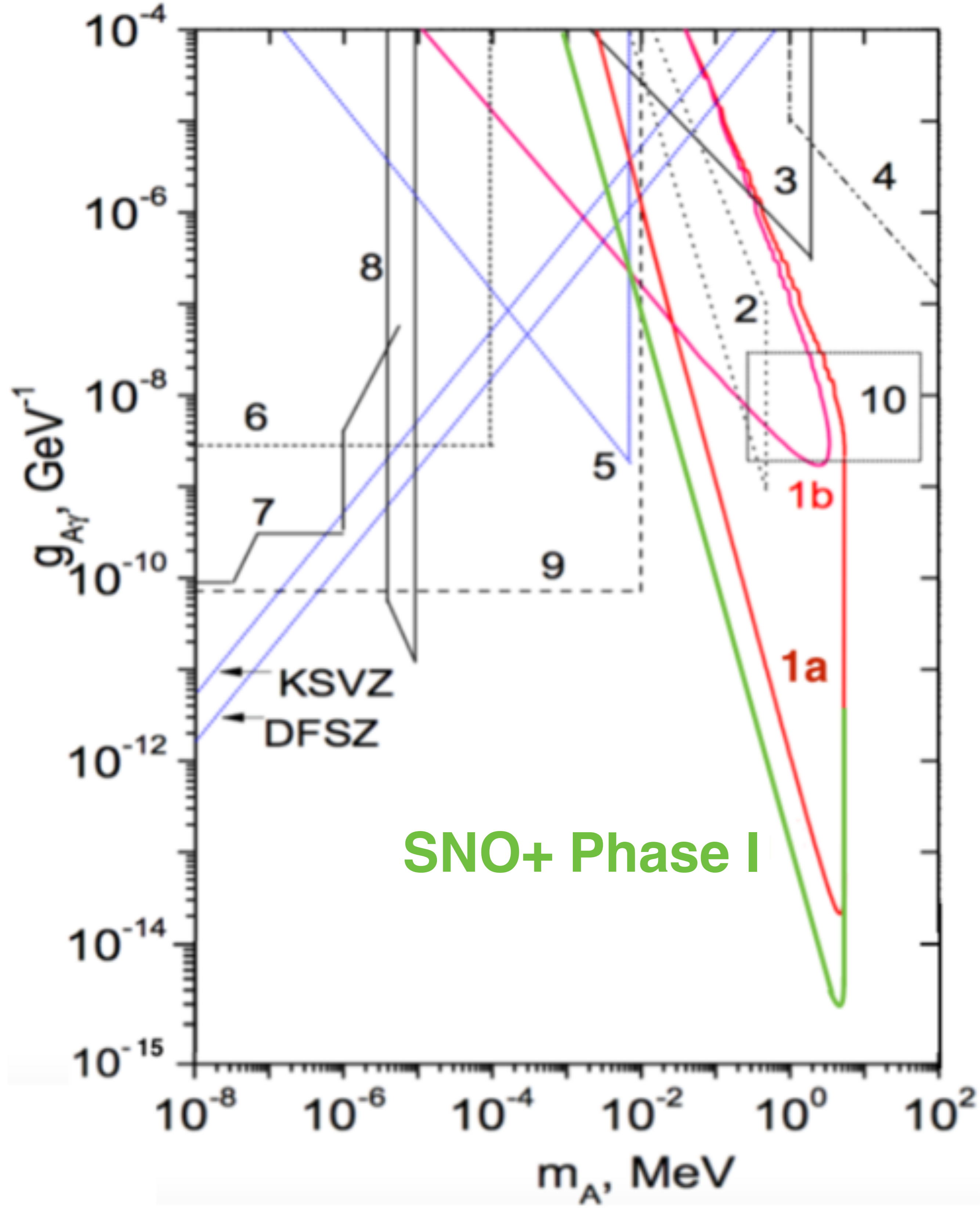
Isotope-loaded Large Scintillator Exper. (SNO+ Phase I)

Limits from Inverse Primakoff

KSVZ/DFSZ

Theoretical upper limits from hadronic and GUT models

Adapted from G. Bellini et al. Phys. Rev. D 85, 092003 (2012)



Back-ups

Borexino Work

- Borexino* placed limits on solar axion couplings to electrons, nucleons and photons (using several interactions)

$$|g_{A\gamma} \times g_{3AN}| \leq 4.6 \times 10^{-11}\ \text{GeV}^{-1}$$

$$|g_{Ae} \times g_{3AN}| \leq 5.5 \times 10^{-13}\ \text{GeV}^{-1}$$

$$m_A < 1\ \text{MeV}$$

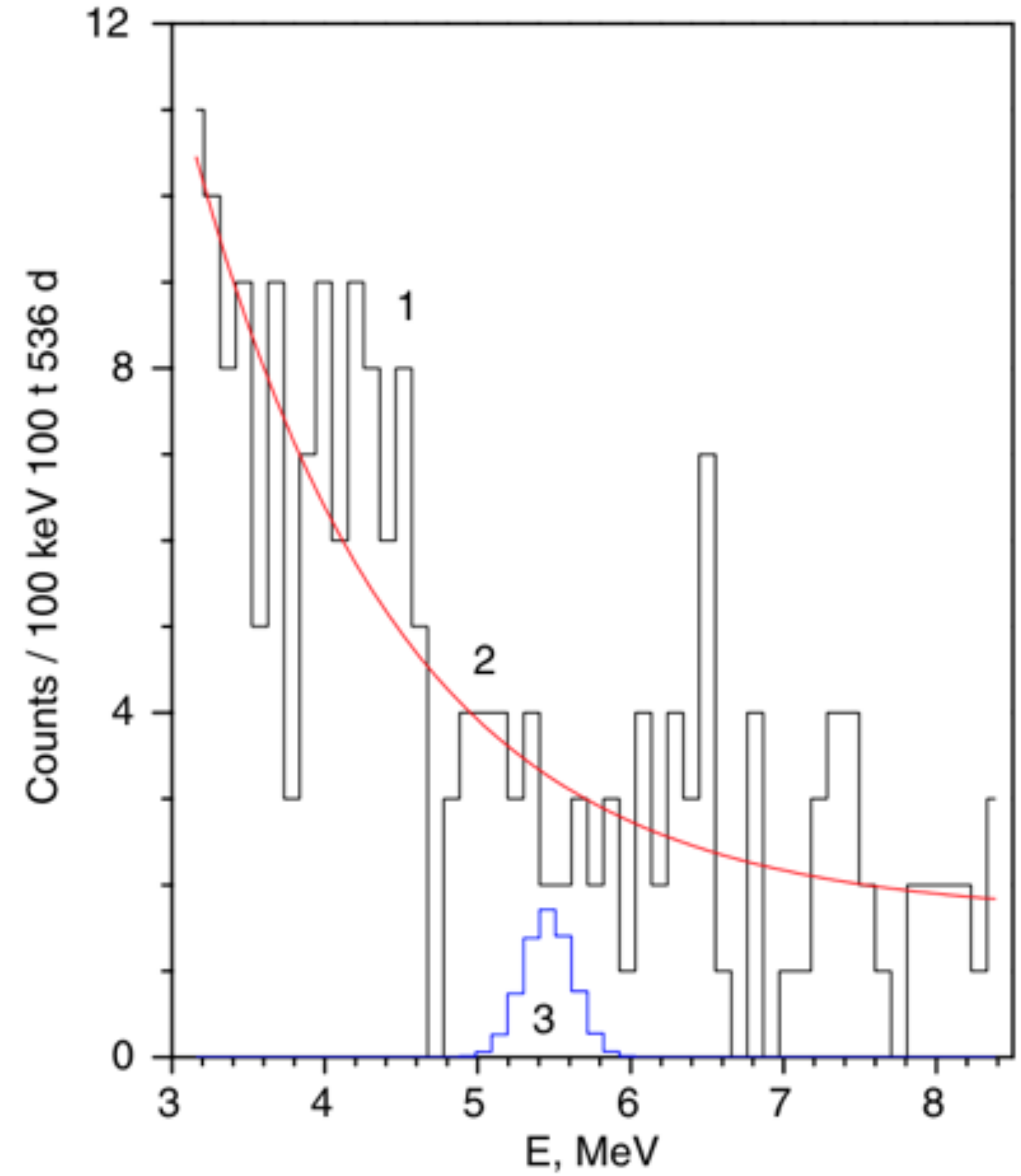


FIG. 5 (color online). The fitted Borexino spectrum in the (3.2–8.4) MeV range. Curve 3 is the detector response function for Compton axion-photon conversion at the 90% c.l. upper limit ($S = 6.9$ events).

*http://journals.aps.org/prd/abstract/10.1103/PhysRevD.85.092003

ALP detection in water

Typically:

~1.7 MeV Gamma

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Forward peaked

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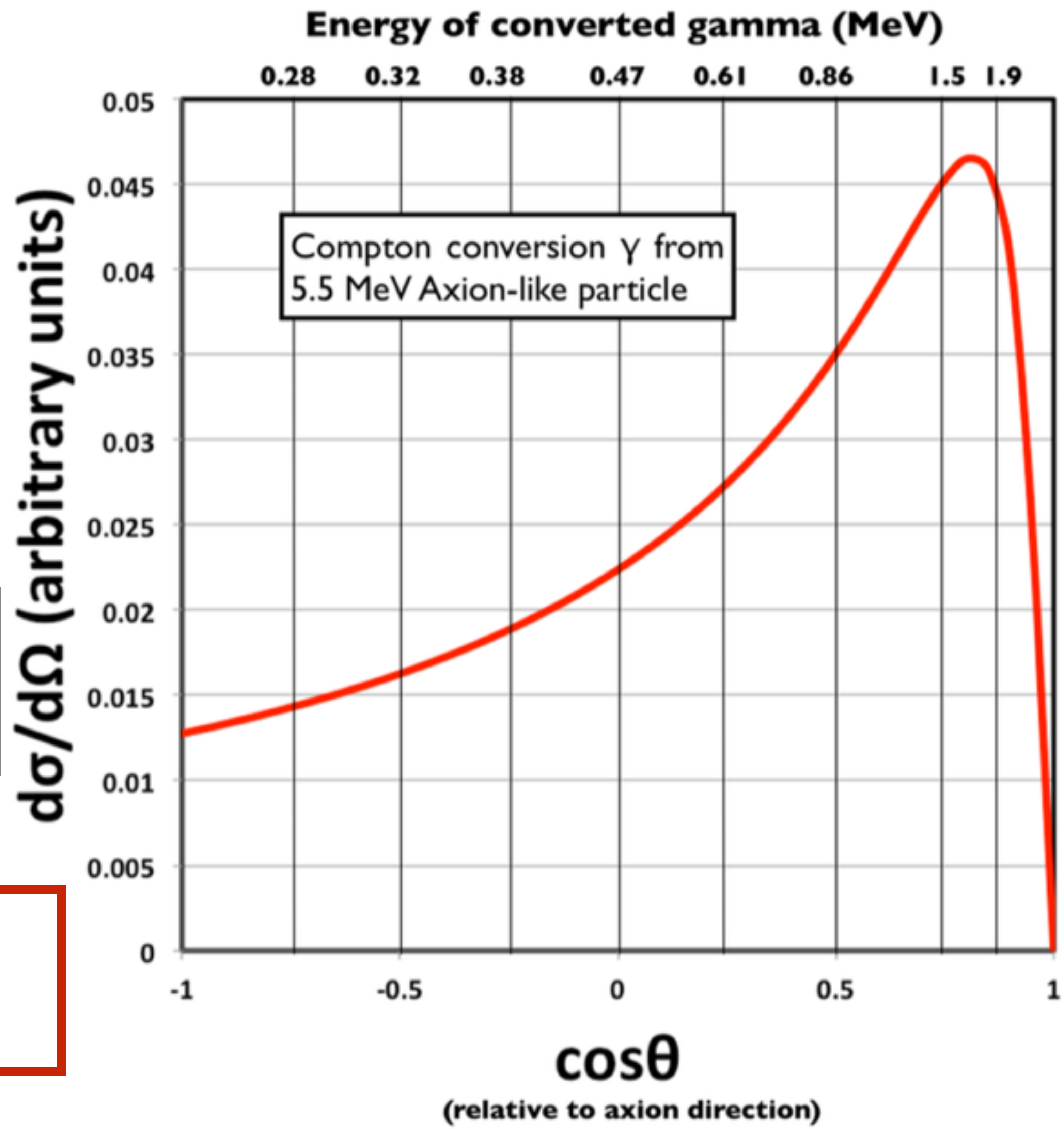

*taken from SNO+ internal doc. (Steve Biller)