Axion and ALP searches with devices dedicated to WIMP [and neutrino] physics

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« Axion theory and searches » meeting
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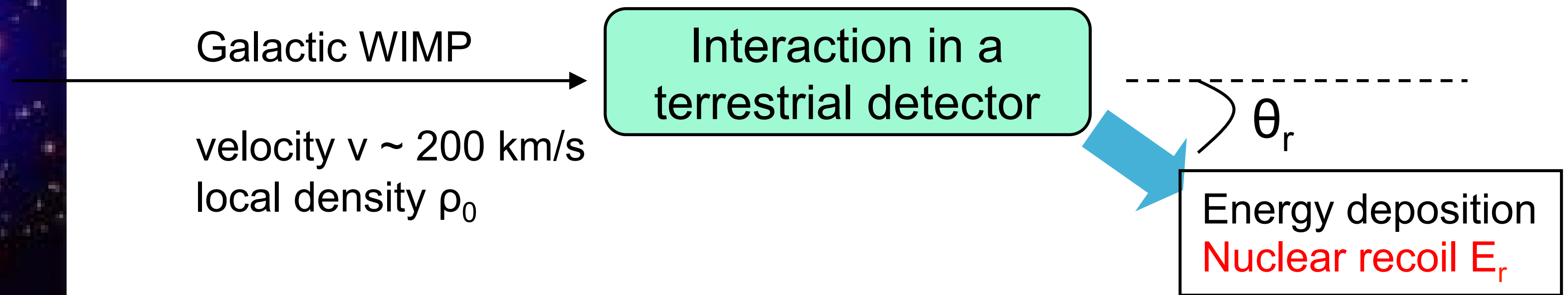
WIMP dark matter direct search experiments



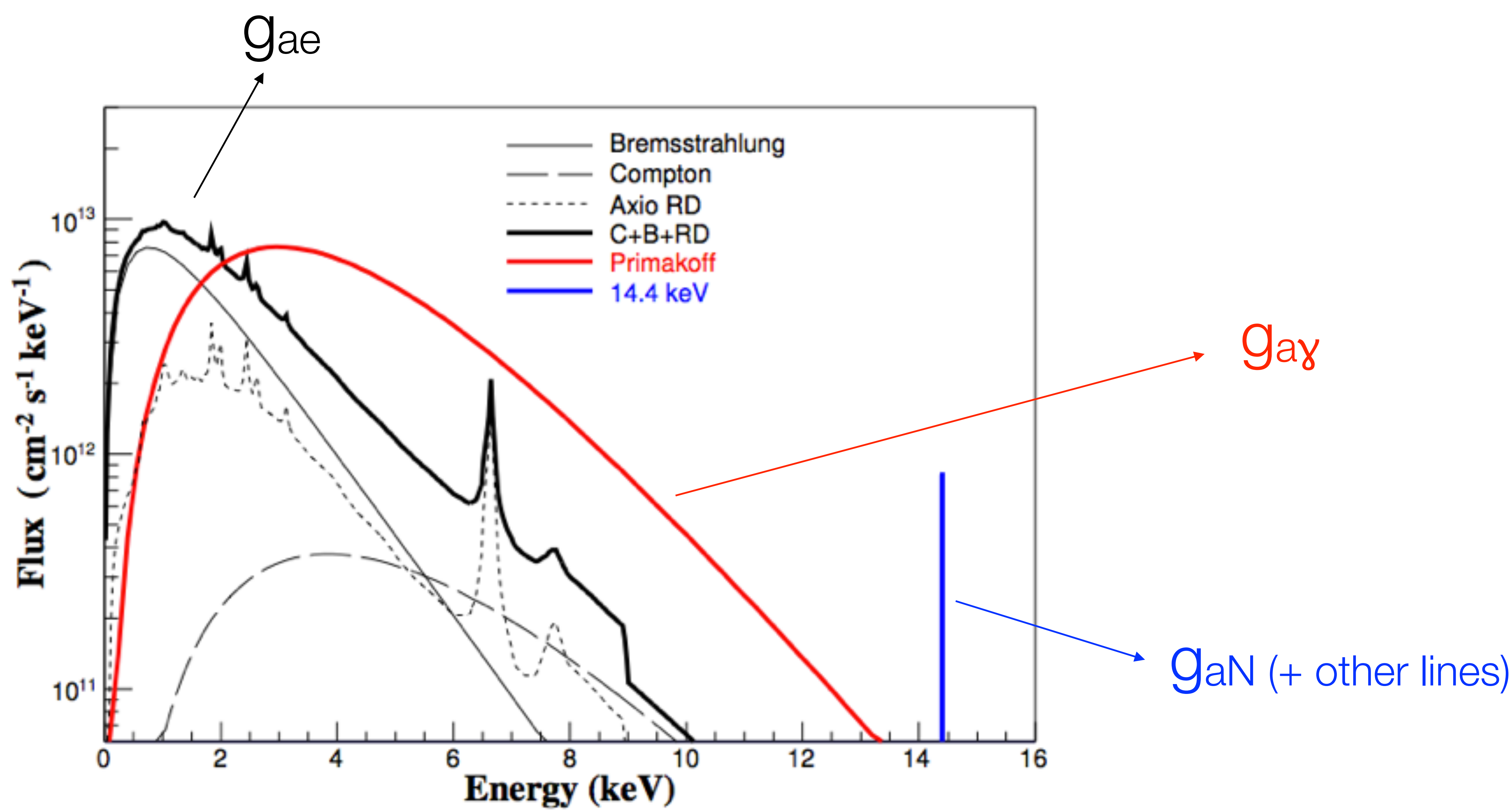
- keV - 10s keV energy deposition [good for axions]
- nuclear recoils [not useful for axions, use electron recoils for axion searches]
- very low event rate → low backgrounds, high exposures [good for axions]

XENON100

Many technologies (and data) available

EDELWEISS-II

The solar axion flux

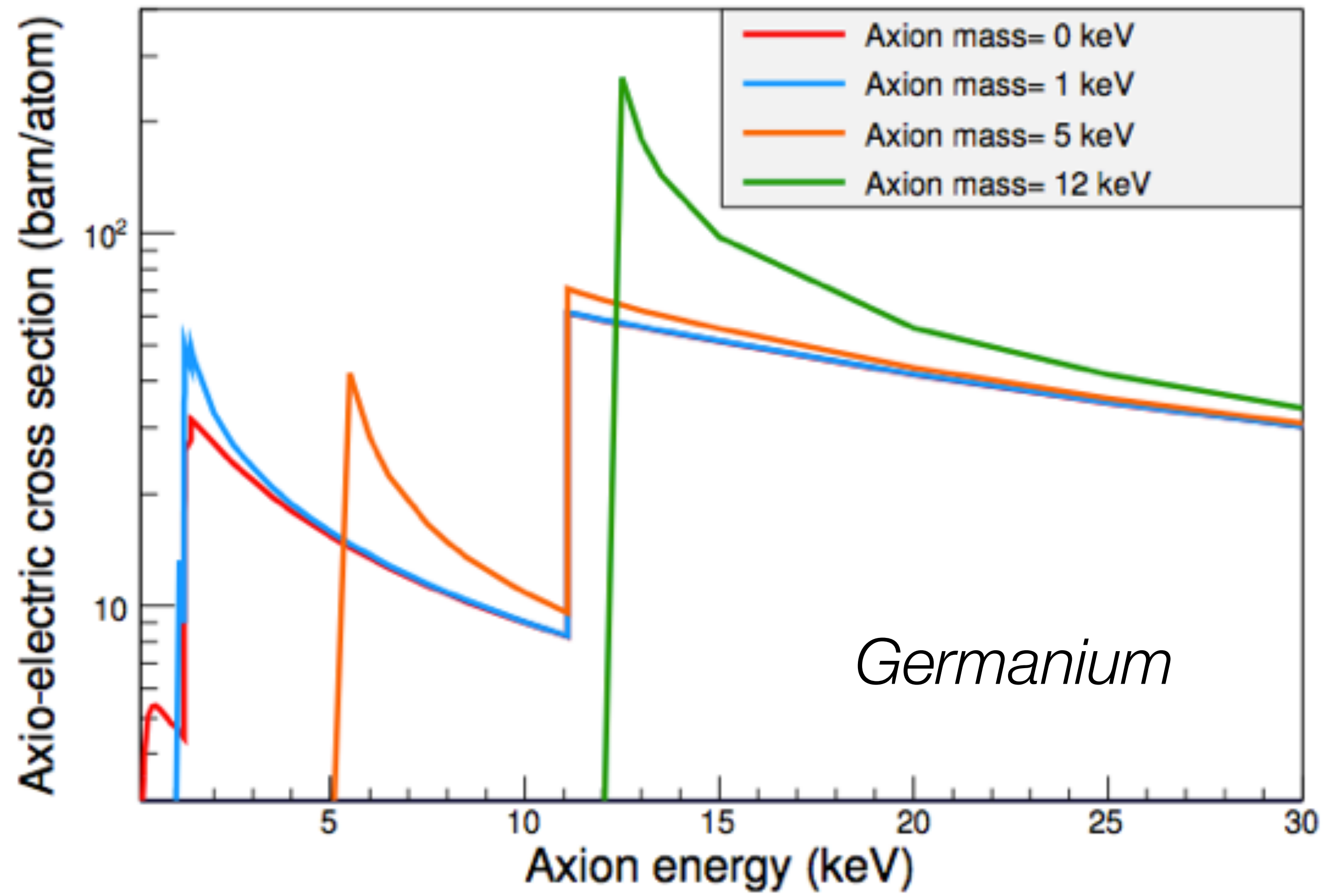


⇒ Carry out with WIMP/neutrino detectors searches in the same spirit as CAST, but in general with sensitivity to higher-mass axions

Constraining g_{ae} from solar axions

Detection of Bremsstrahlung (+…) axions using axioelectric effect

$$\sigma_{Ae}(E) = \sigma_{pe}(E)\frac{g_{Ae}^2}{\beta}\frac{3E^2}{16\pi\alpha m_e^2}\left(1-\frac{\beta^{\frac{2}{3}}}{3}\right)$$



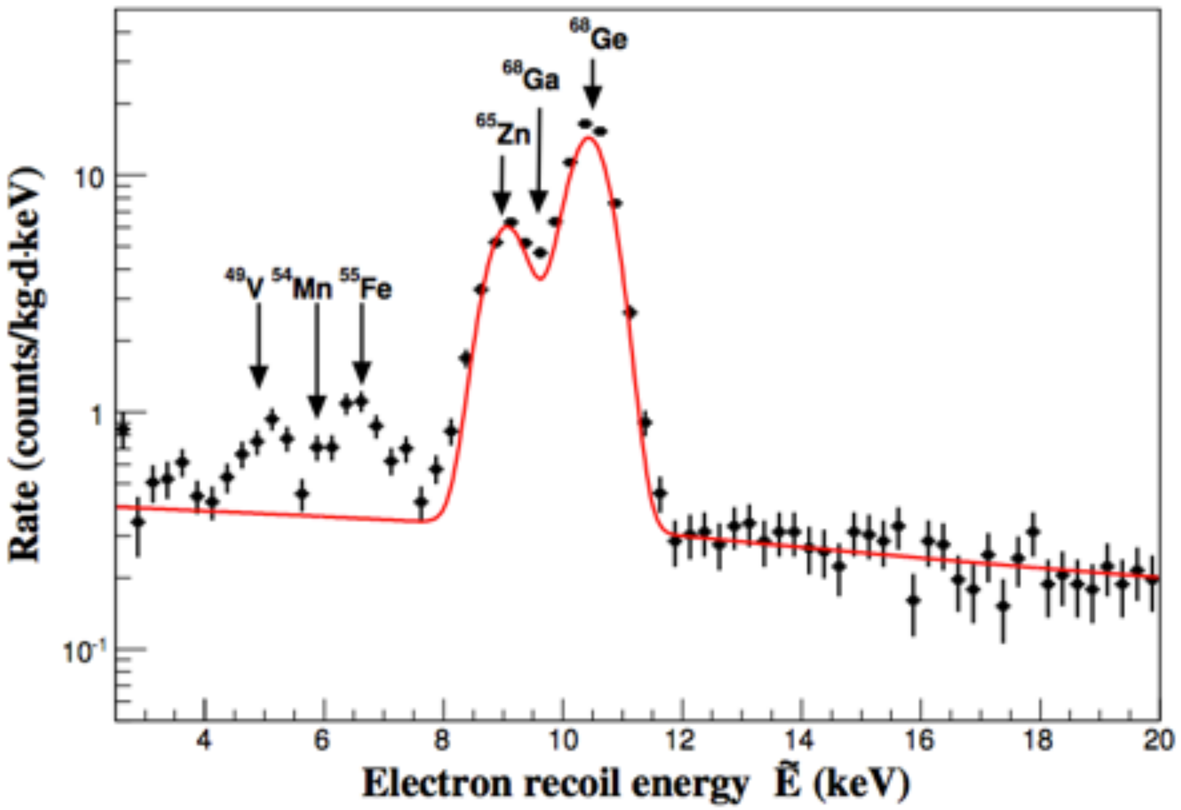
⇒ Expected signal :

spectral feature @ few keV in electron recoil background

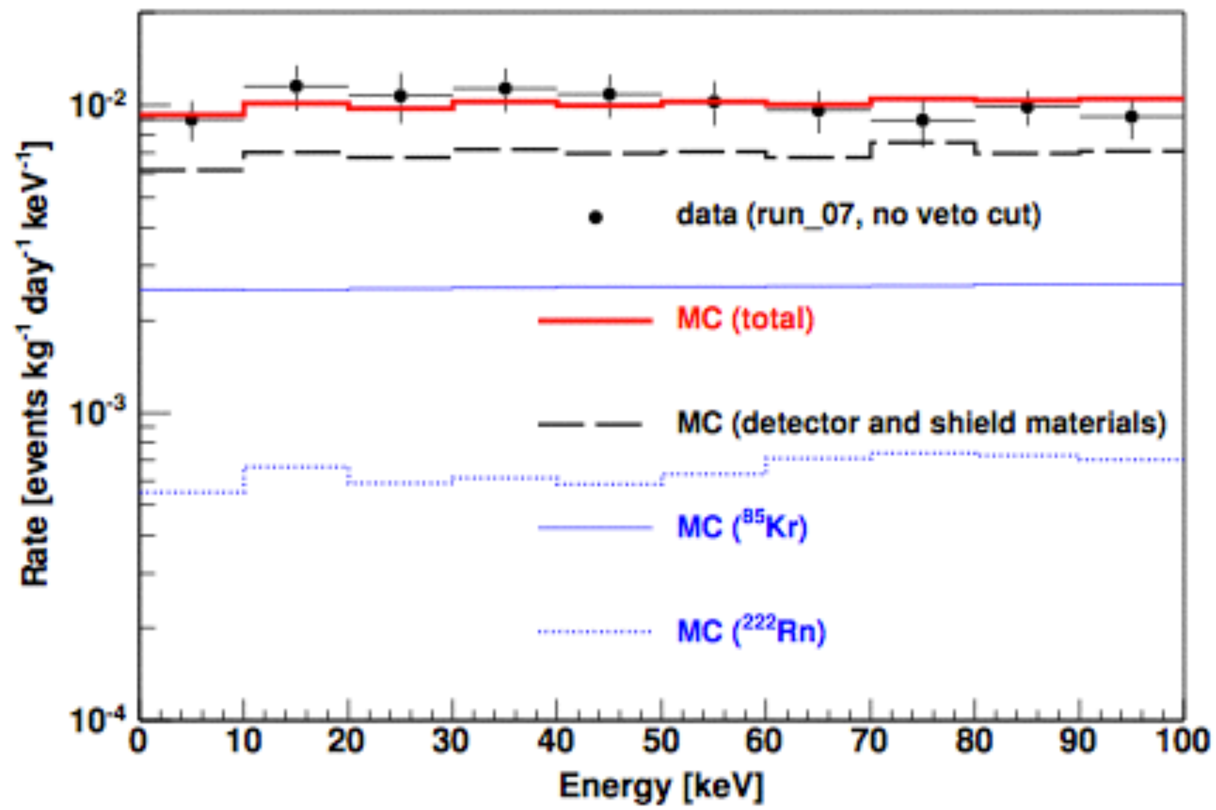
$$R_{\mathrm{C-B-RD}}(\tilde{E}) = \int dE_A\,\sigma_{\mathrm{A}}(E_A)\left(\frac{d\Phi^{\mathrm{C-B-RD}}}{dE_A}\right)\times\sum_i \epsilon_i(\tilde{E})M_iT_i\frac{1}{\sqrt{2\pi}\sigma_i}\times e^{-\frac{(\tilde{E}-E_A)^2}{2\sigma_i^2}}$$

Electron recoil backgrounds in WIMP experiments

EDELWEISS-II (Germanium)



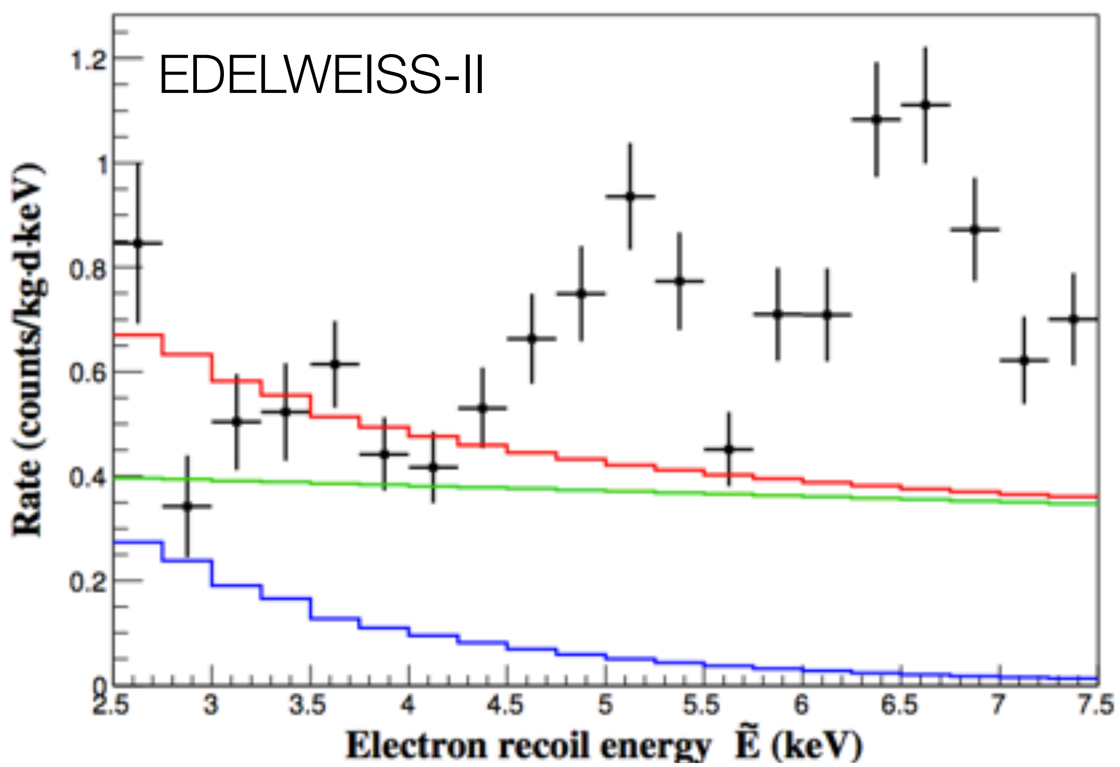
XENON100

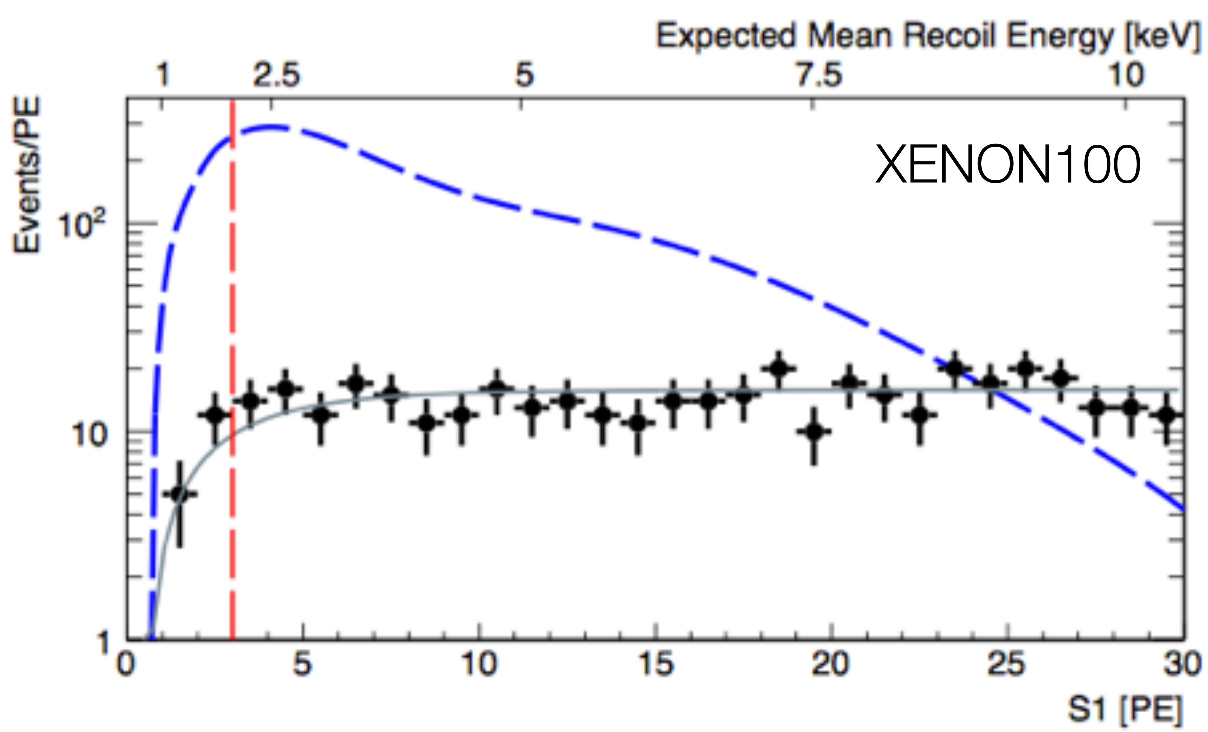


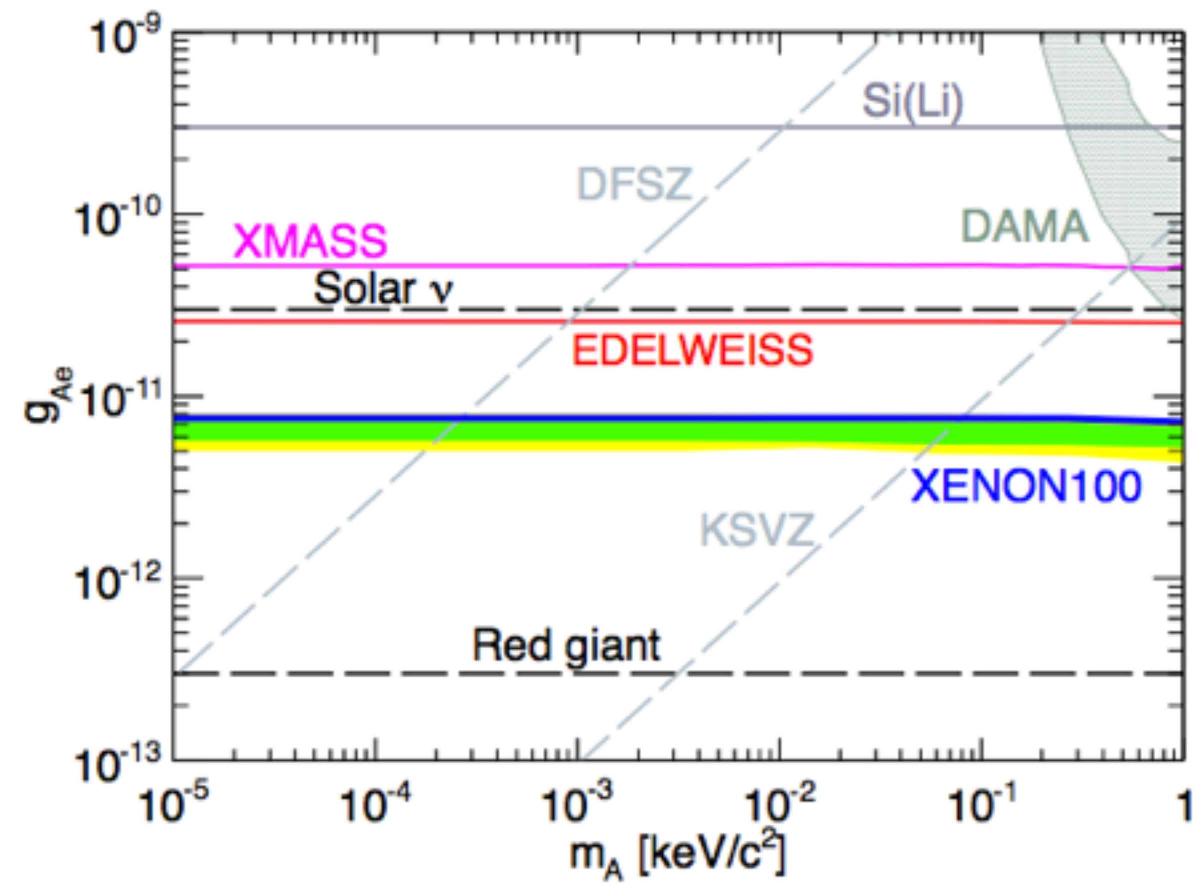
Xenon TPCs have the lowest background intensity

Germanium detectors have the best energy resolution and the best thresholds

Constraints on g_{ae} from WIMP experiments







EDELWEISS : JCAP11 (2013) 067
XMASS : PLB 724, 46 (2013)
XENON : PRD90 (2014) 062009

Constraining $g_{a\gamma}$ from solar axions

- Solar Primakoff flux ~ $g_{a\gamma}^2$
    - Detection with CAST/IAXO : Primakoff conversion in big magnet « pointing » to the Sun
    - Detection with crystals : Primakoff conversion in the detector's electrostatic field ; Bragg enhancement ~ effective « pointing » to the Sun
- Crystals vs CAST :
    - less sensitivity
    - small detectors : no coherence loss effect for high axion masses

Axio-Bragg-Primakoff detection

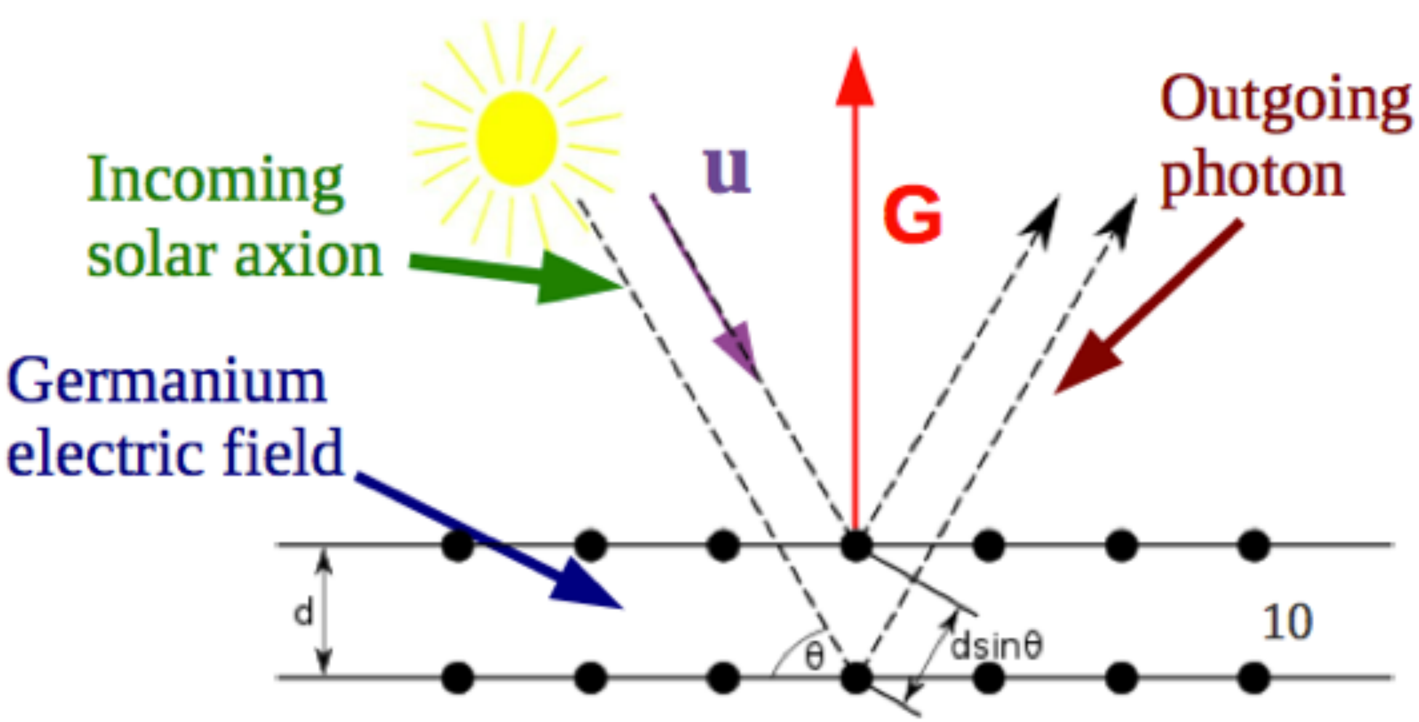
$$R(\tilde{E}, t, \alpha) = 2(2\pi)^3 \frac{V}{v_a^2} \sum_G \frac{d\phi}{dE_A} \frac{g_{A\gamma}^2}{16\pi^2} \sin(2\theta)^2 \frac{1}{|\mathbf{G}|^2} \left|S(\mathbf{G}) F_A^0(\mathbf{G})\right|^2 W(E_A, \tilde{E})$$

flux x cross-section

crystallography
(G = reciprocal lattice)

electrostatic form factor

energy resolution



electrostatic form factor :

$$F_{\mathrm{atom}}(\mathbf{q}) = \frac{Zek^2}{\frac{1}{r_0^2} + \mathbf{q}^2}$$

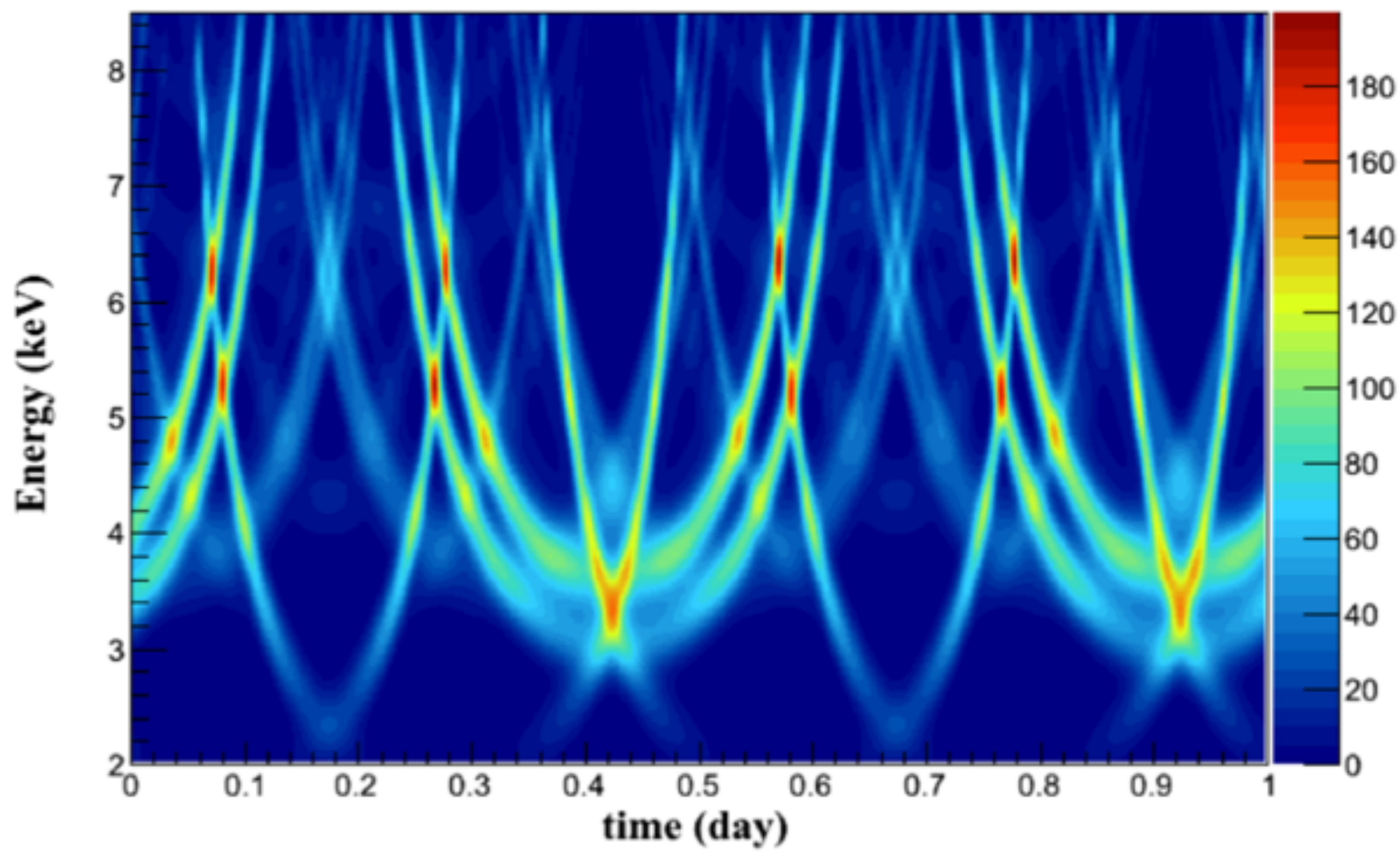
Bragg condition :

$$E_a = \frac{|\mathbf{G}^2|}{(2\mathbf{u} \cdot \mathbf{G})}$$

Axio-Bragg-Primakoff pattern

Energy-time variation of the expected signal
→ Effective background reduction

Use correlator between observed events and expected signal variations



$$\chi_k(\alpha) = \epsilon_k \sum_i \left[\overline{R_k}(t_i) - \langle \overline{R_k} \rangle\right] \cdot n_{ik}$$

expected axion signal variations

nb of events observed in energy bin (k) and time interval (i)

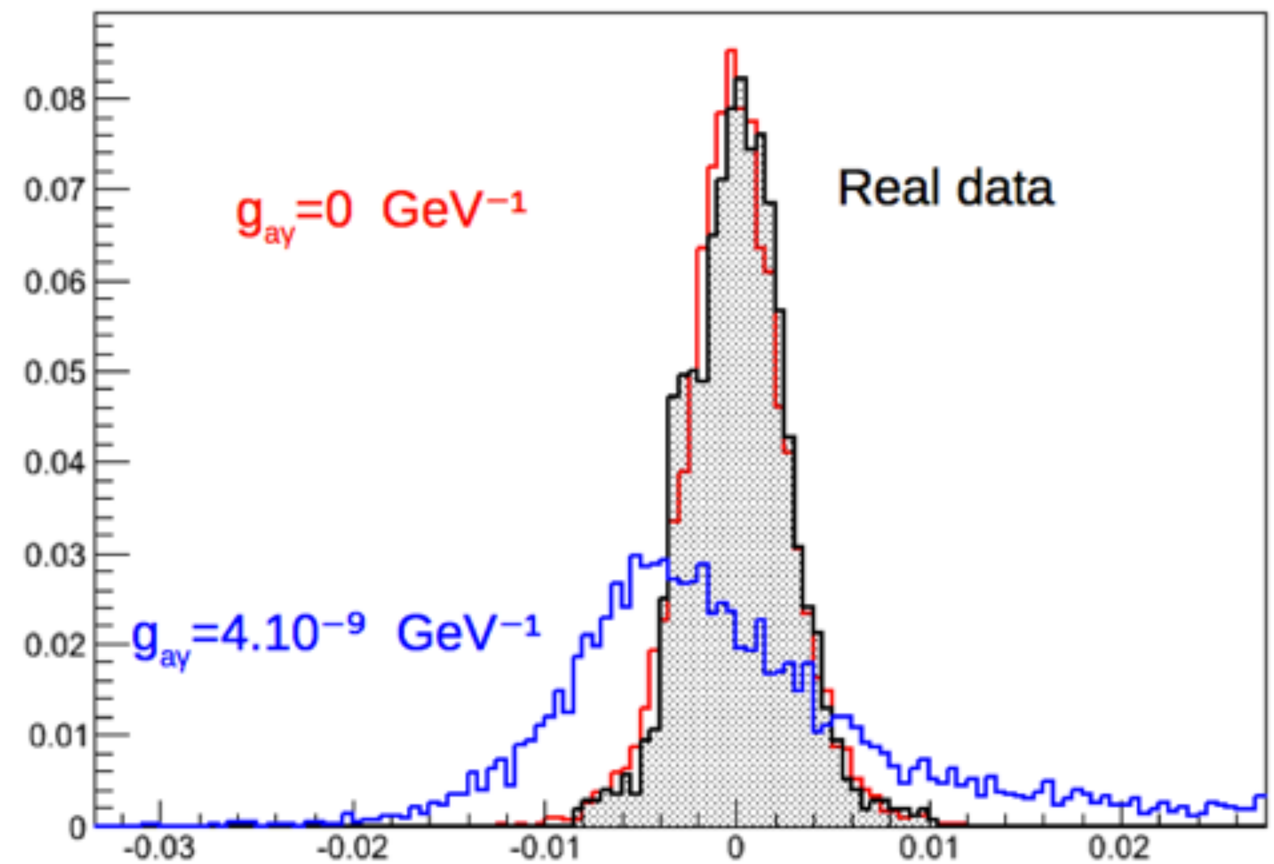
EDELWEISS-II example

- Same electron recoil bg as before
- Crystallographic axis not known (1 angle) !

⇒ adapted method by scanning

over angles of each detector : moderate loss of sensitivity

$g_{a\gamma}$ < 2.15 x 10^{-9} GeV^{-1}

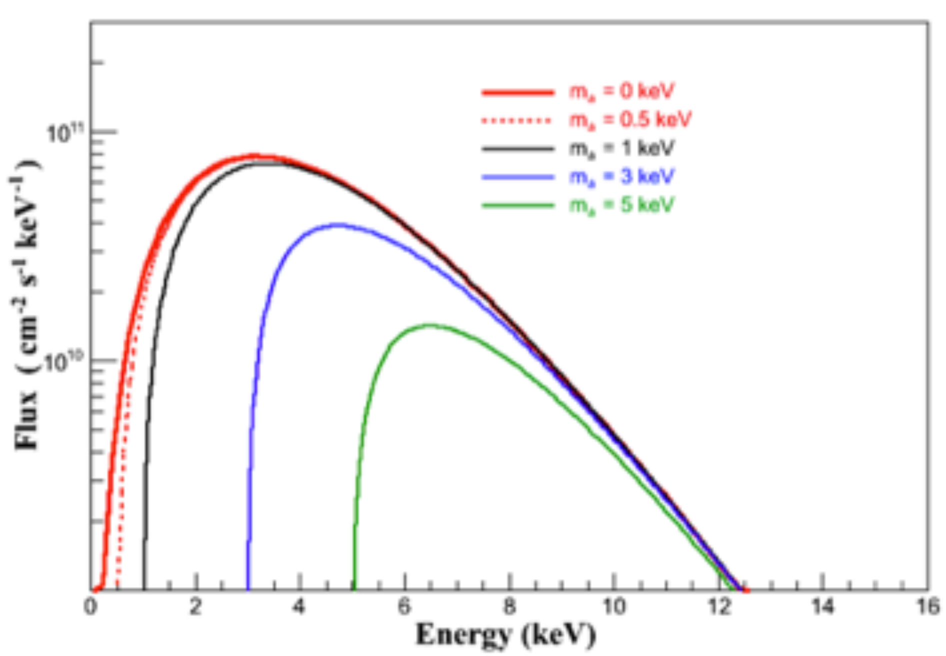


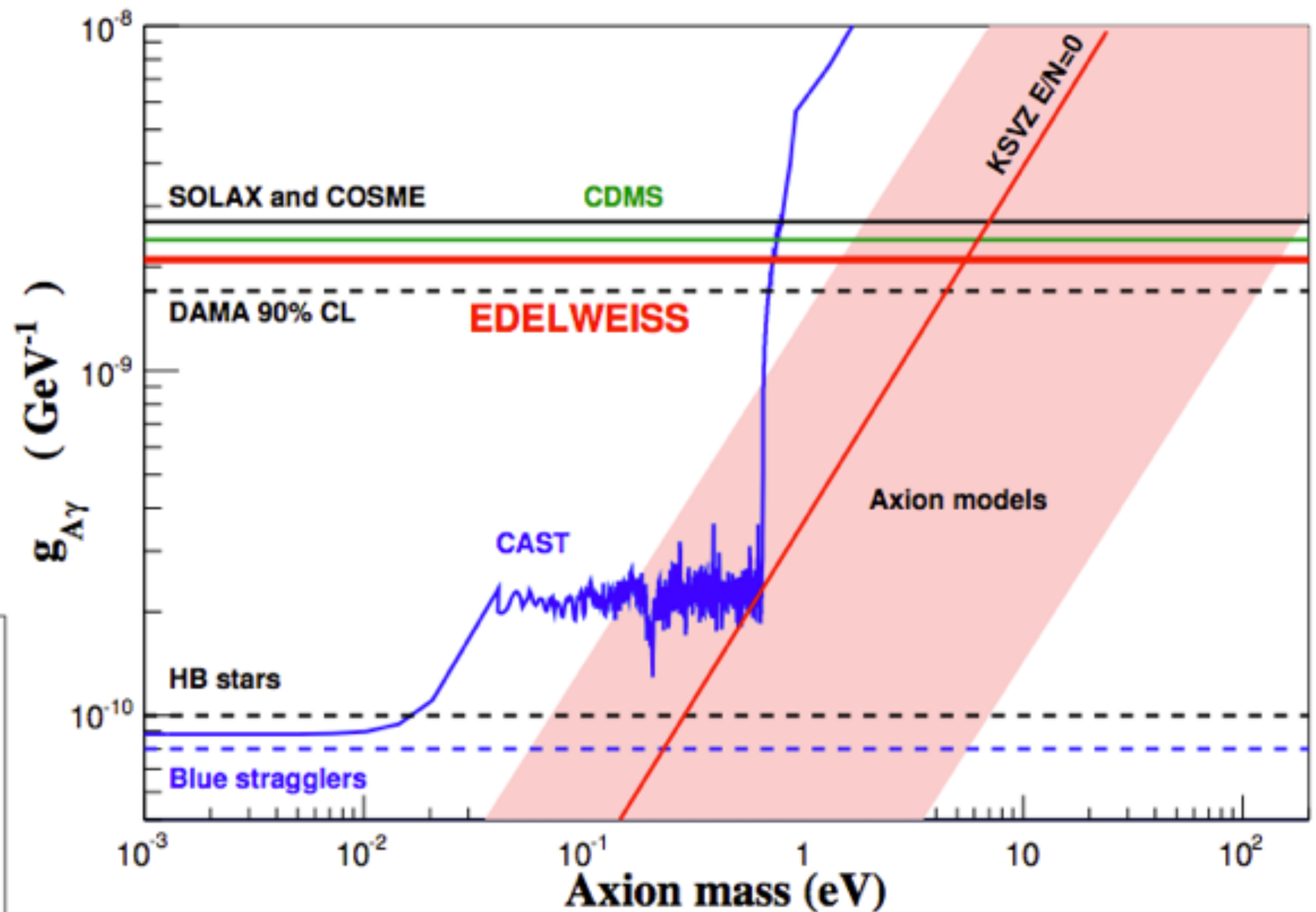
distribution of correlators obtained by scanning over unknown angles

Constraints on $g_{a\gamma}$ from WIMP experiments

Sensitivity valid up to 200 eV at least :

- Primakoff solar flux unchanged
- Bragg condition unchanged given the expt energy resolution





Axion fluxes from the coupling g_{aN}

- Axion coupling to nucleon $\mathcal{L} = i\bar{\psi}_N\gamma_5(g^0_{AN} + g^3_{AN}\tau_3)\psi_N\phi_A$

$$g^0_{AN} = -7.8\times10^{-8}\left(\frac{6.2\times10^6\mathrm{GeV}}{f_A}\right)\left(\frac{3F-D+2S}{3}\right)$$

$$g^3_{AN} = -7.8\times10^{-8}\left(\frac{6.2\times10^6\mathrm{GeV}}{f_A}\right)\left[(D+F)\frac{1-z}{1+z}\right]$$

(KSVZ)

- Nuclear deexcitation at high solar temperature : M1 transition of ^{57}Fe generates monochromatic 14.4 keV axions

$$\Phi_{14.4} = \left(\frac{k_A}{k_\gamma}\right)^3 \times 4.56\times10^{23}\,(g^{\mathrm{eff}}_{AN})^2\ \mathrm{cm}^{-2}\,\mathrm{s}^{-1}.$$

- Production in fusion reactions : p (d , ^{3}He) A : monochromatic 5.5 MeV axions

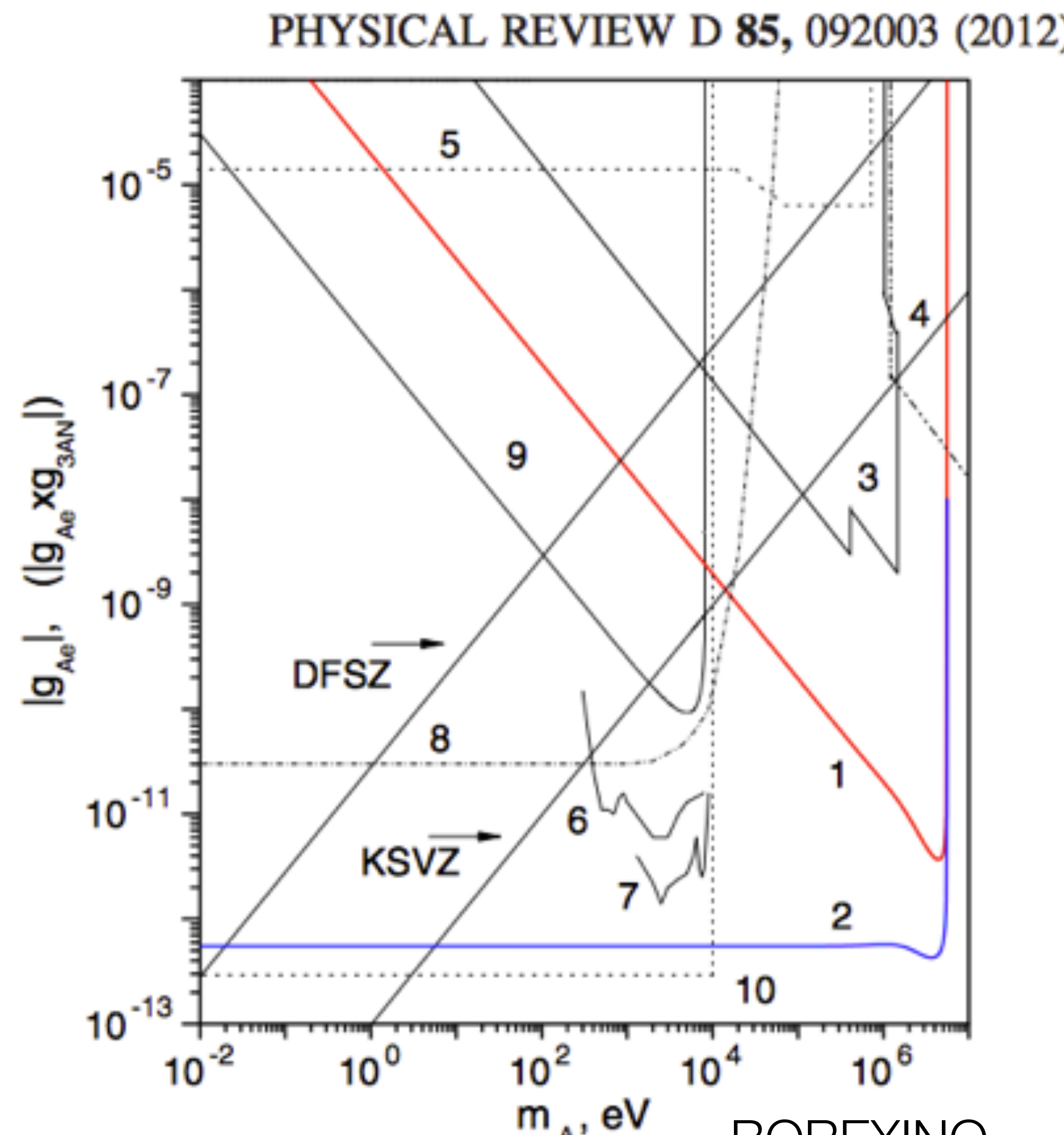
$$\Phi_{A0} = \Phi_{\nu pp}(\omega_A/\omega_\gamma) = 3.23\times10^{10}(g_{3AN})^2(p_A/p_\gamma)^3$$

Constraints on g_{aN}

- Detection by axioelectric effect / Compton-like process

  $\Longrightarrow$ constrain g_{aN} x g_{ae} or g_{aN} x $g_{a\gamma}$.

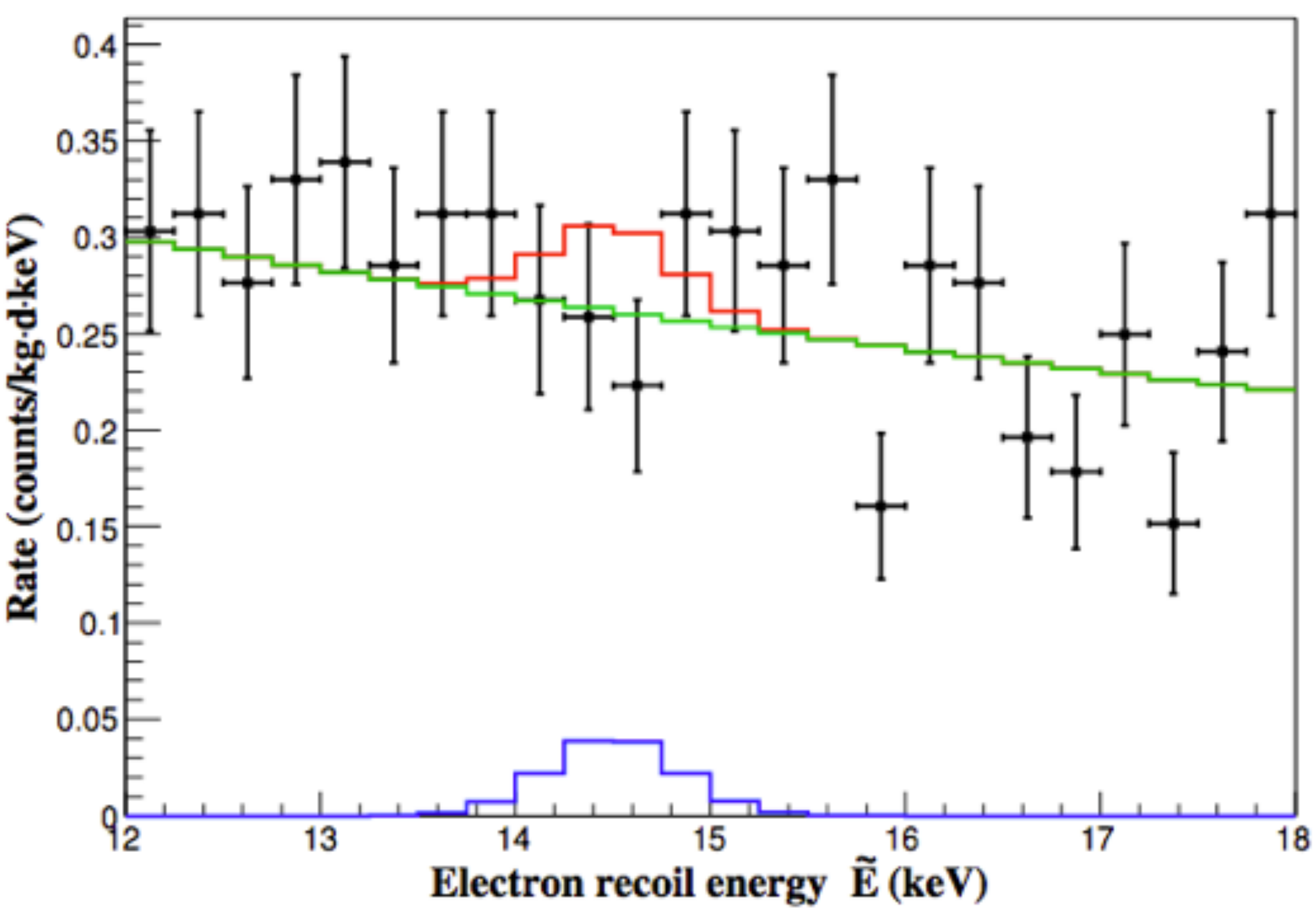
- **14.4 keV axions** : low energy electron recoil, DM expts
  - EDELWEISS-II : g_{ae} x $g_{aN}^{eff} < 4.8 \times 10^{-17}$
  - Exclude $0.15 < m_A < 14.4$ keV (KSVZ axions)
- **5.5 MeV axions** : « high energy », neutrino expts
  - Borexino : g_{ae} x $g_{3aN} < 5.5 \times 10^{-13}$
  - Exclude ~10 keV $< m_A <$ 5.5 MeV (KSVZ)



BOREXINO

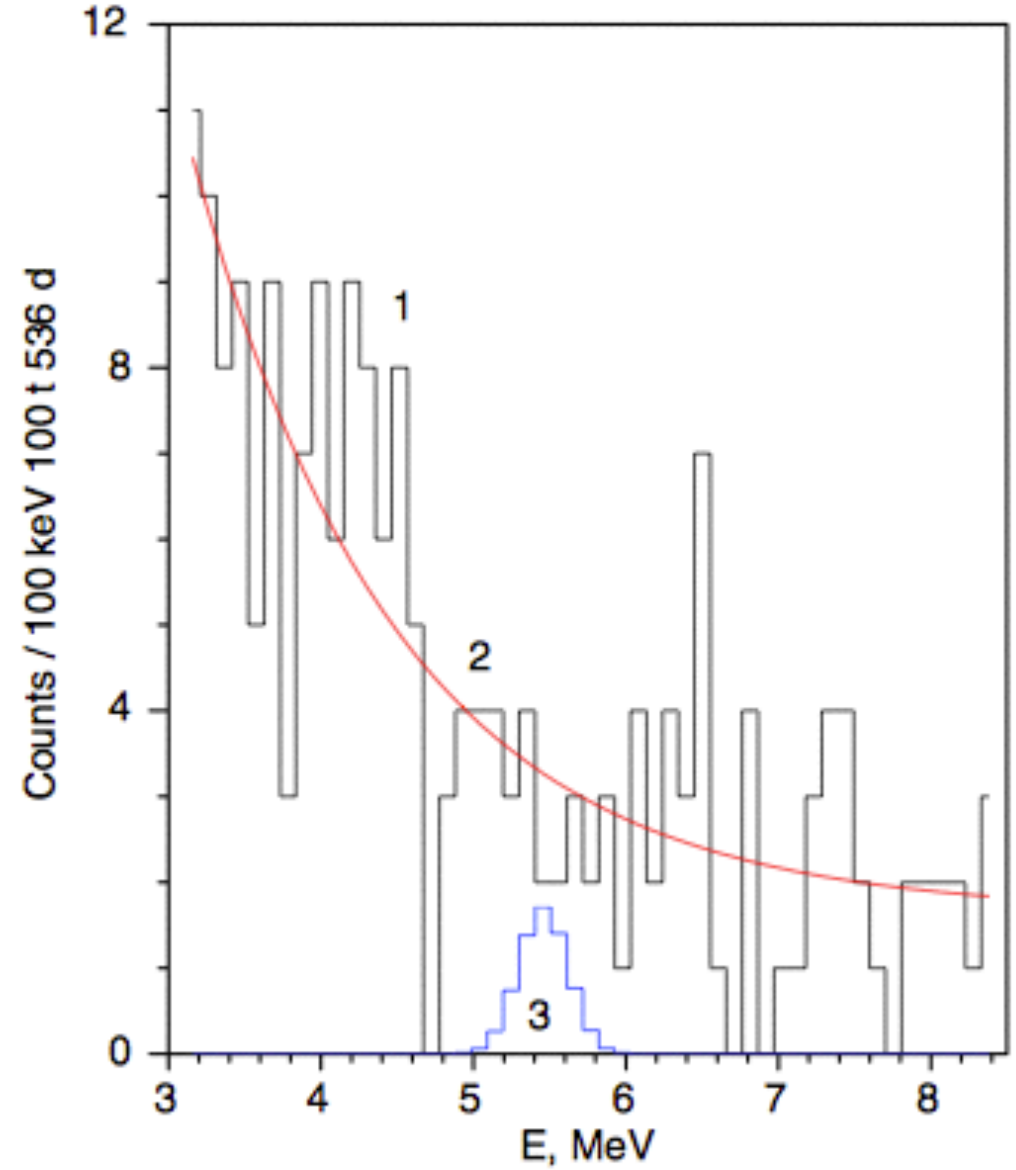
Constraints on g_{aN} : data

EDELWEISS-II



$g_{ae} \times g_{aN}^{eff} < 4.8 \times 10^{-17}$

Borexino

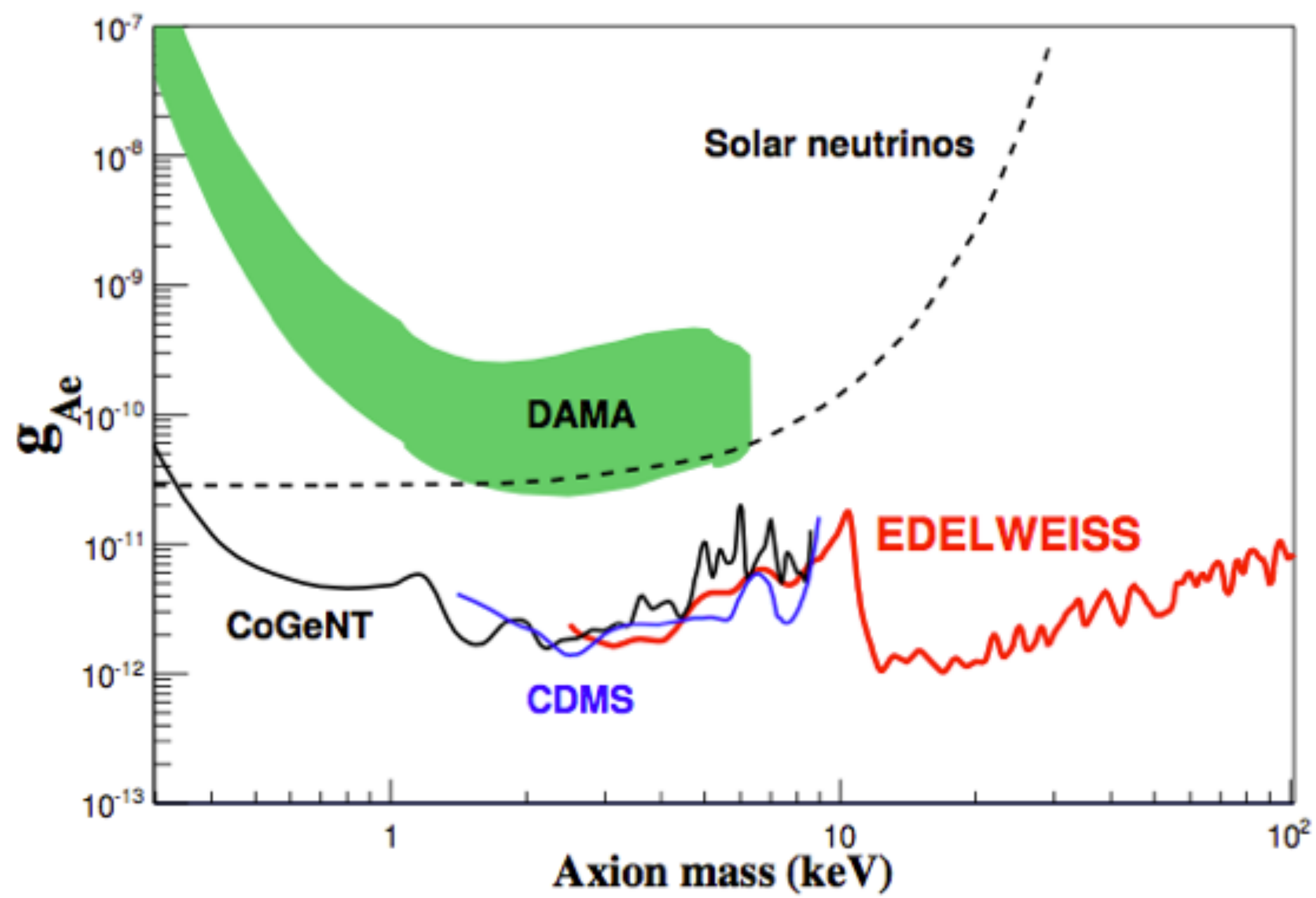


$g_{ae} \times g_{3aN} < 5.5 \times 10^{-13}$

Searches for local axion-like DM

- Assume ALPs constitute local DM halo
- Direct detection through axio-electric effect : monochromatic electron recoil line @ E = m_A
- Searches mostly motivated by an interpretation of the DAMA anomaly

$$R_{\mathrm{DM}}(\tilde{E}) = \Phi_{\mathrm{DM}}\sigma_{\mathrm{A}}(m_A) \times \sum_i \epsilon_i(\tilde{E}) M_i T_i \frac{1}{\sqrt{2\pi}\sigma_i} \times e^{-\frac{(\tilde{E}-m_A)^2}{2\sigma_i^2}}$$



Conclusions

- Neutrino detectors known to provide good, « historical » axion searches …

… So do WIMP detectors : similar, with lower energy reach.

- The combination of all search channels (gae, gaɣ) and experiments (XENON100, EDELWEISS-II, Borexino) **severely constraints QCD axions in the whole ~ eV - MeV range, <u>by directly searching for solar axions</u>**.