Axion searches with the EDELWEISS Ge bolometers

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9th Patras Workshop on Axions, WIMPs and WISPs

Schloß Waldthausen
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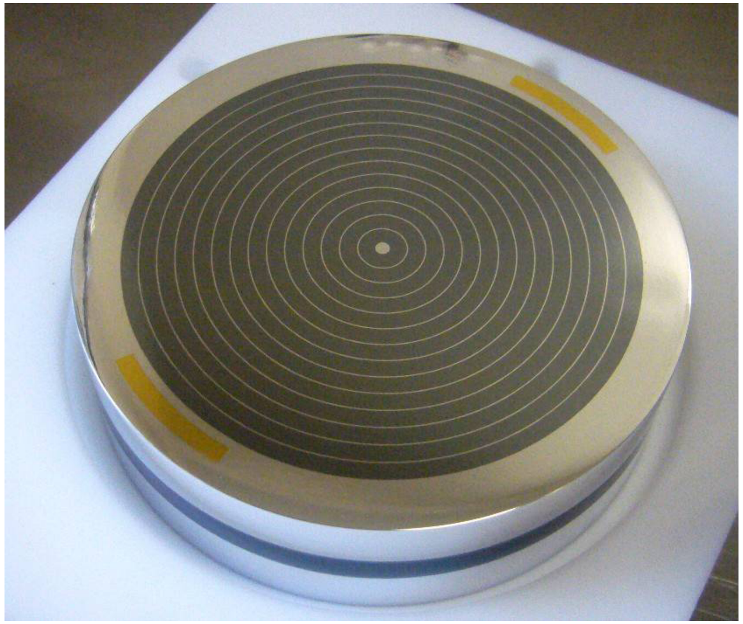
Outline

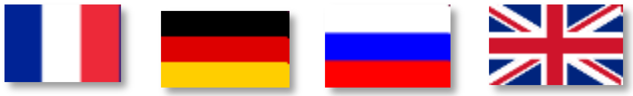
- The EDELWEISS-II experiment in a nutshell -> Valentin Kozlov's talk for more details
- The EDELWEISS Ge hybrid detectors
- Different axion sources
- Axion detection with EDW Ge detectors
- New results on different channels
- Conclusions



E. Armengaud et al. – in preparation

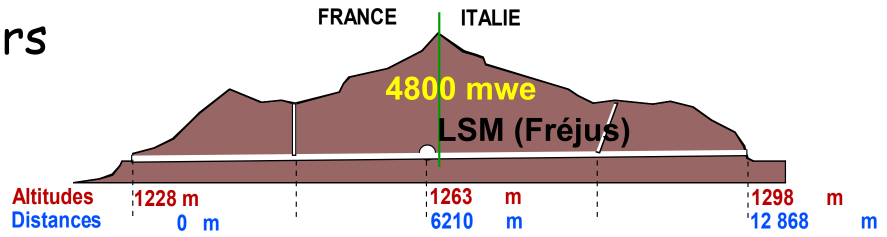
EDELWEISS-II in a nutshell

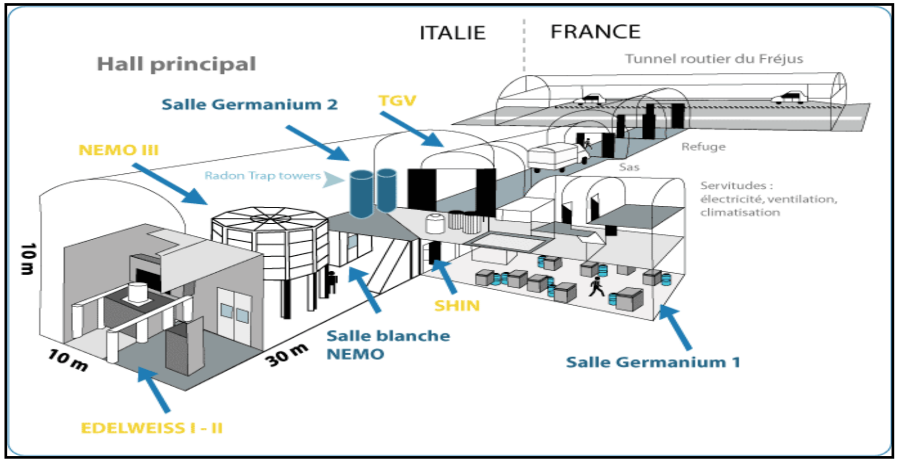
EDELWEISS-II → ~ 50 people / 4 countries



It is located at the Underground Laboratory of Modane.

Main goal: direct detection of WIMPs with Ge double-readout (heat + ionization) detectors



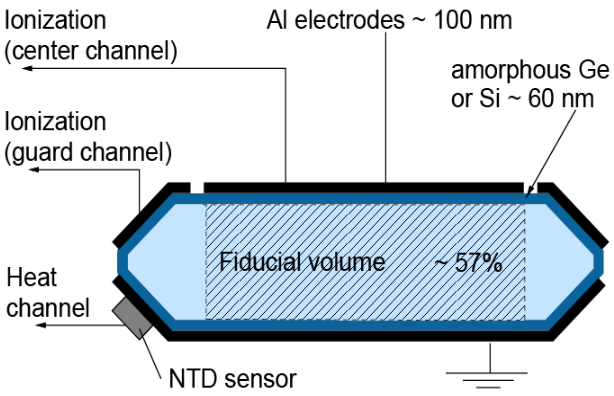


- EDELWEISS experiment shows that this technology is mature for detection of WIMPs and rare events in general.
- EDELWEISS has obtained competitive results in the search for WIMPs, also in the controversial low-mass region.
- The low raw background achieved (including electron recoil signals) close to threshold makes EDELWEISS an interesting set-up to search for axions and ALPs.

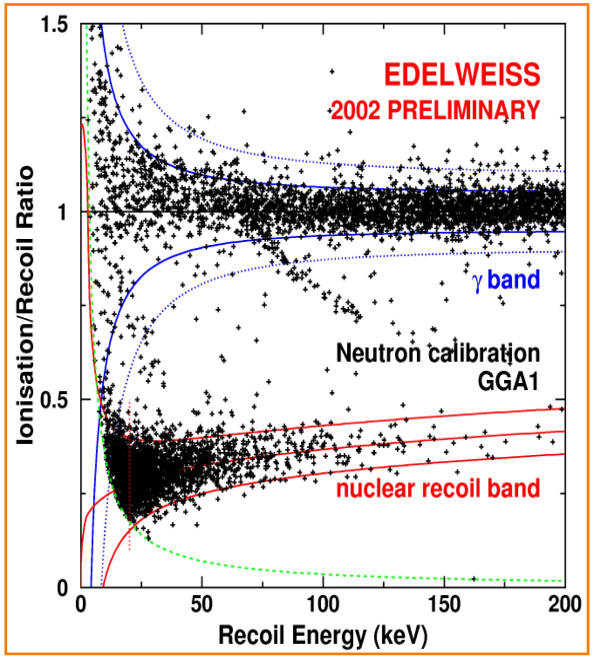
The EDELWEISS hybrid detectors

1st generation – GeNTD

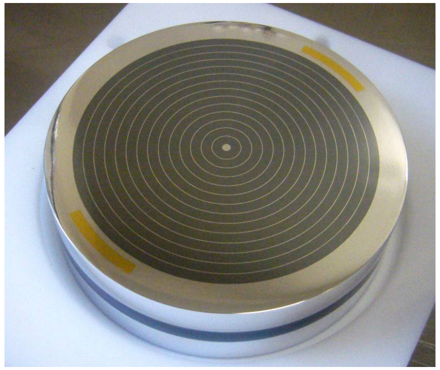
320 gr - All planar electrodes



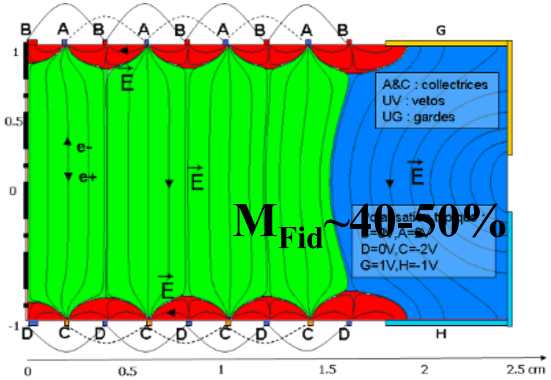
- **Simultaneous measurement**
  - **Heat @ 20 mK** with Ge/NTD thermometer
  - **Ionization @ few V/cm** with Al electrodes
- **Evt by evt identification** of the recoil
- $Q=E_{ionization}/E_{recoil}$
  - **Q=1 for electron recoils**
  - **Q≈0.3 for nuclear recoils**



2nd generation - ID400 – used in this analysis



Φ 70mm, H 20mm, 410g
14 concentric electrodes (width 100µm, spacing 2mm) without beveled edge.



M_{Fid}~40-50%

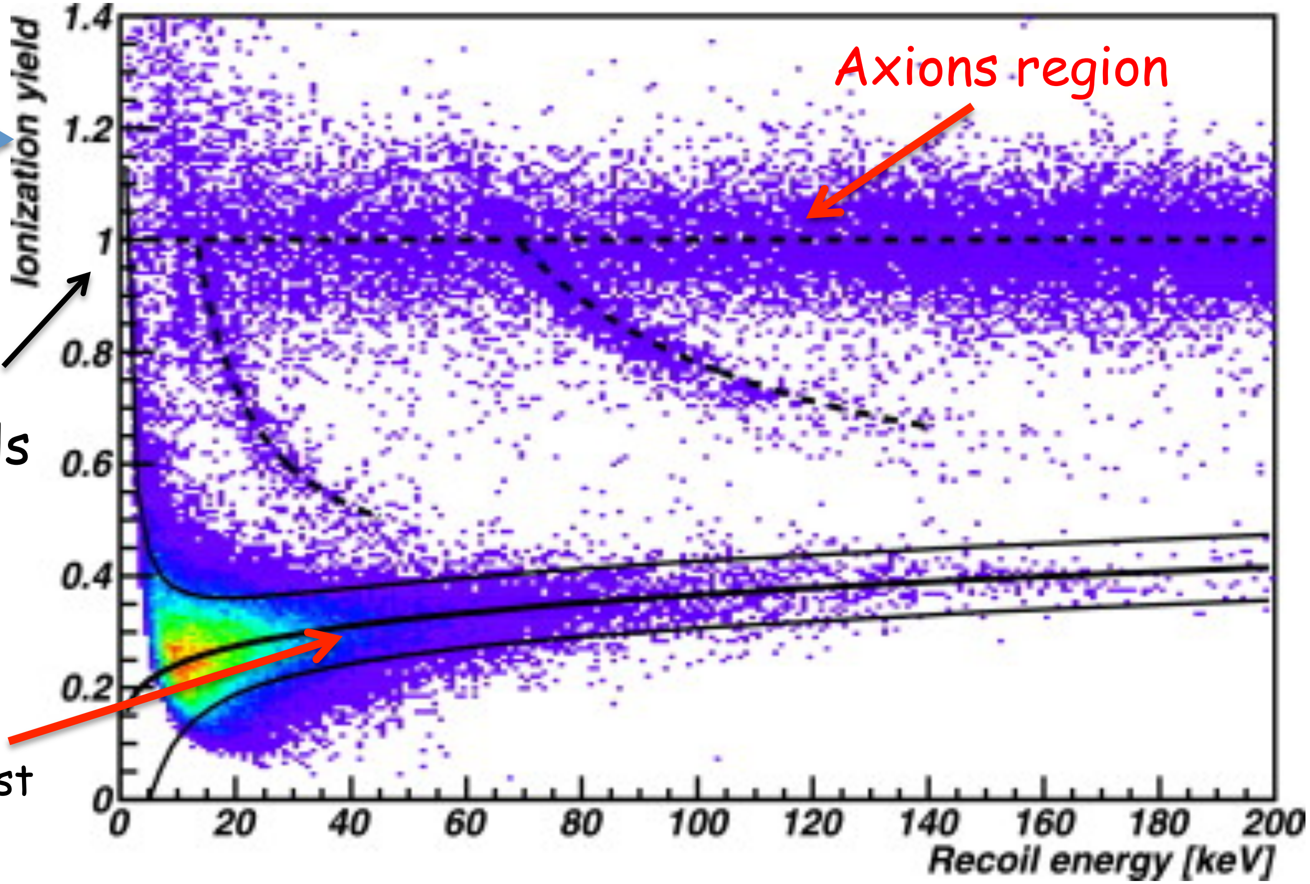
- Keep the EDW-I NTD phonon detector
- Modify the E field near the surfaces with interleaved electrodes:
  - Biases to have an electric field
    ~ horizontal near the surface and
    ~ vertical in the bulk
- The rings are alternately connected by ultra-sonic bonded wires.

→ Easy cuts on « veto » + guard electrodes define the fiducial zone

Active recoil discrimination

$$R = \frac{\text{Ionization signal amplitude}}{\text{Phonon signal amplitude}}$$

Realization of the concept in the EDELWEISS technology



Axions region

R set to 1 for ionization signals

WIMPs region (populated by a fast neutron source)

Axions? Why not…

- One can use Ge detectors originally built for WIMP dark matter (or $0\nu\beta\beta$)
- Beauty of the method: it is possible to piggyback on the existing Ge experiments

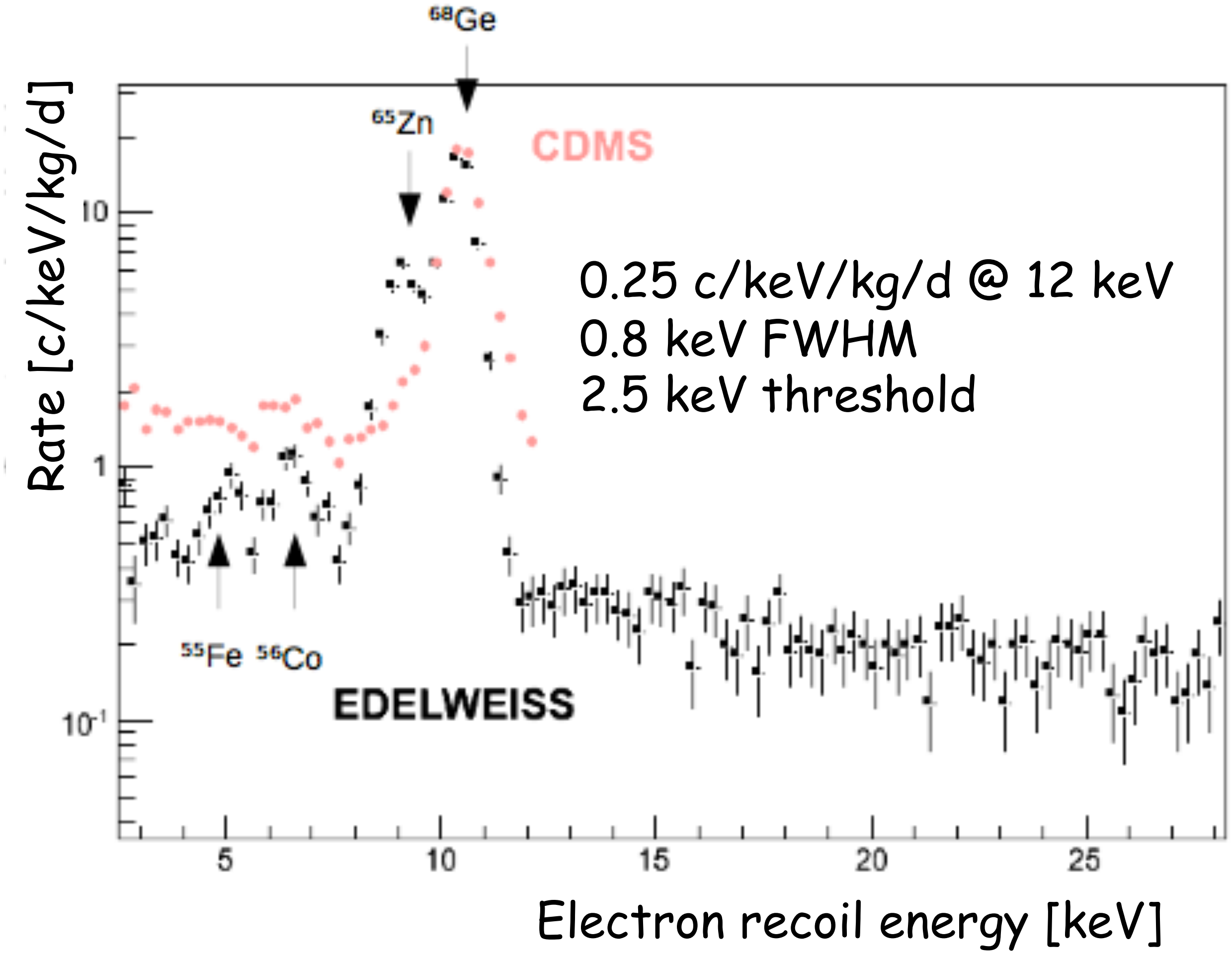
EDW is also sensitive to electronic recoils down to 2.5 keV

⬇

Excellent electron recoil background at low energies (use fiducial volume discrimination)

⬇

Axions can generate an electronic recoil: we can detect or constrain axions



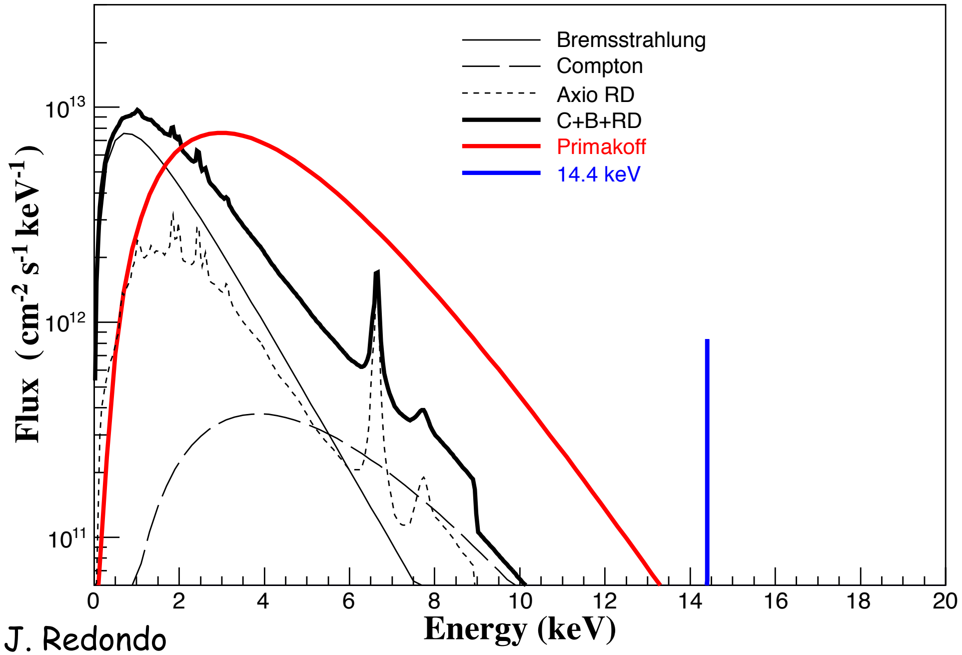
0.25 c/keV/kg/d @ 12 keV
0.8 keV FWHM
2.5 keV threshold

Axion searches – Different studied sources

1) The Sun

- Primakoff production (**$g_{A\gamma}$**)
- Nuclear de-excitation (^{57}Fe) (**g_{AN}**)
- Bremsstrahlung and Compton scattering (**g_{Ae}**)
- Axio-recombination and Axio-deexcitation (**g_{Ae}**)

$g_{A\gamma}$ = 10^{-9} GeV^{-1}, g_{Ae} = 10^{-11} and g_{AN}^{eff}= 10^{-7}



New flux evaluation by J. Redondo

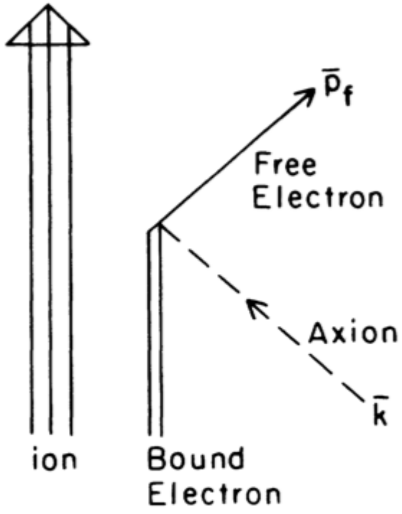
We are sensitive to different axion-couplings to particles

2) The Galactic halo

Hypothesis: Axions make up all of galactic dark matter and they have a mass in the keV region.

Axion detection with Ge hybrid detectors

1) Axio-electric effect

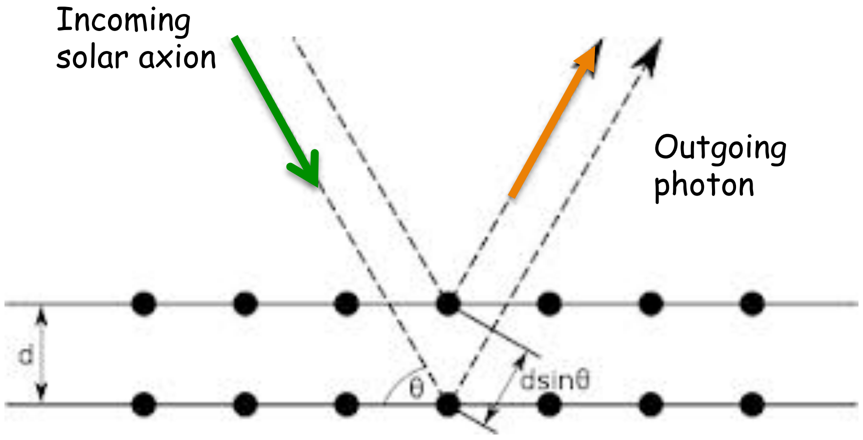


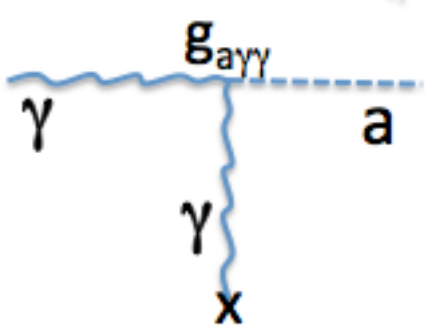
Axio-electric effect: it is the equivalent of a photo-electric effect with the absorption of an axion instead of a photon.

g_{Ae}

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

2) Bragg's diffraction





$g_{A\gamma}$

Summary table: production & detection

Production	Detection	Signature
Primakoff channel $g_{A\gamma}$	Bragg diffraction $g_{A\gamma}$	Energy depencence and time correlator
Compton, Bremsstrahlung, axio-recombination&deexcitation g_{Ae}	Axio-electric effect g_{Ae}	Energy dependence (spectral bump)
Solar ^{57}Fe de-excitation $g_{Ae} x g_{AN}^{eff}$	Axio-electric effect g_{Ae}	Energy dependence (line @ 14.4 keV)
Axions as dark matter	Axio-electric effect g_{Ae}	Energy dependence (line @ m_A)

Data selection: EDELWEISS-II

Axions can trigger an electronic recoil: event selection in the electron recoil band

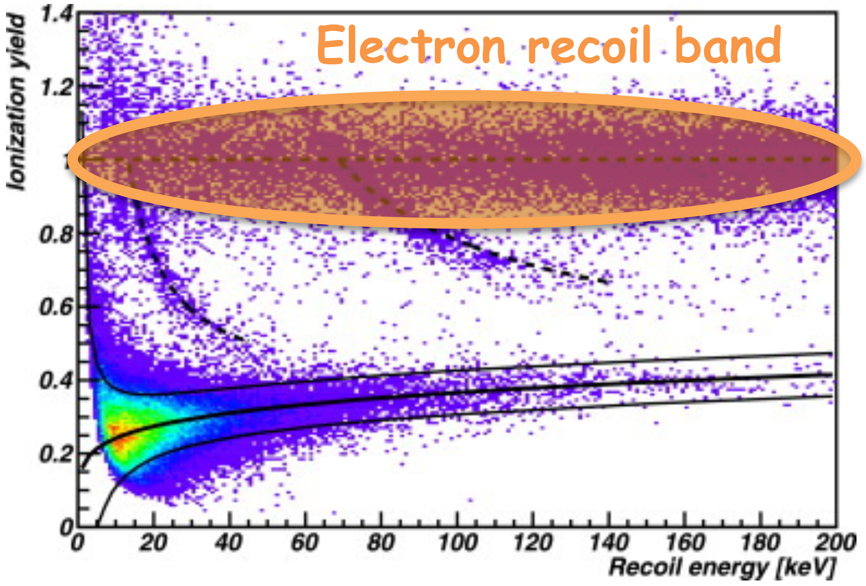
Use of the **fiducial volume** to discriminate surface events

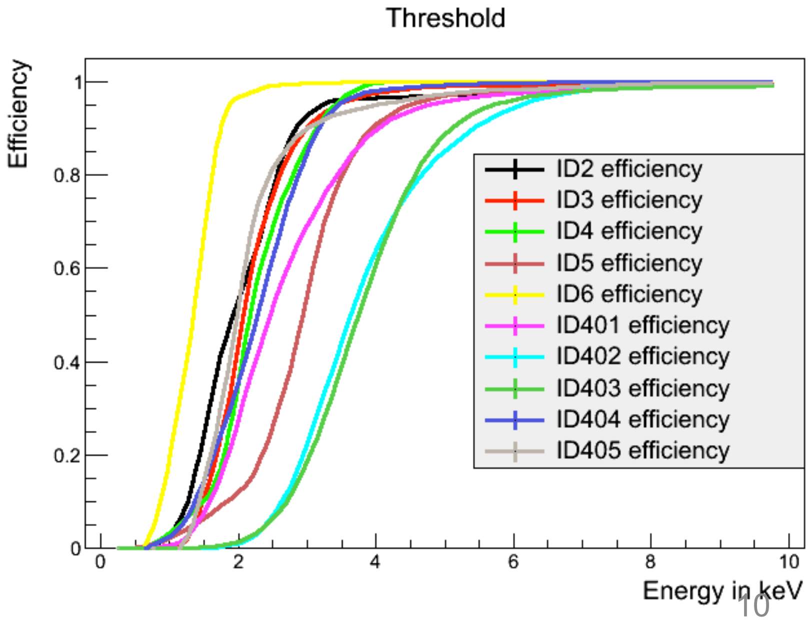
Selection of periods with **good baseline on heat and fiducial ionization**: homogeneous data set of 450 kg d

Define **"best" energy fiducial estimator** by combining heat and fiducial ionization

Threshold definition: impose online trigger efficiency > 50% and other cut efficiency > 95%

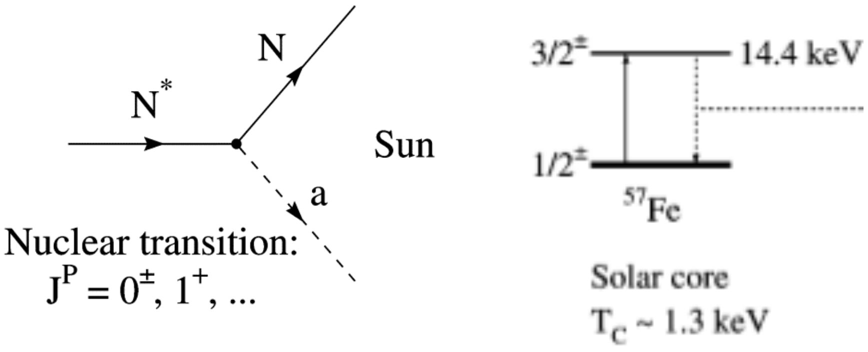
3 detectors have a **threshold @ 2.5 keV** 2 @ 3 keV annd 5 @ 3.5 keV. **FWHM** at low energy is **0.8 keV**.





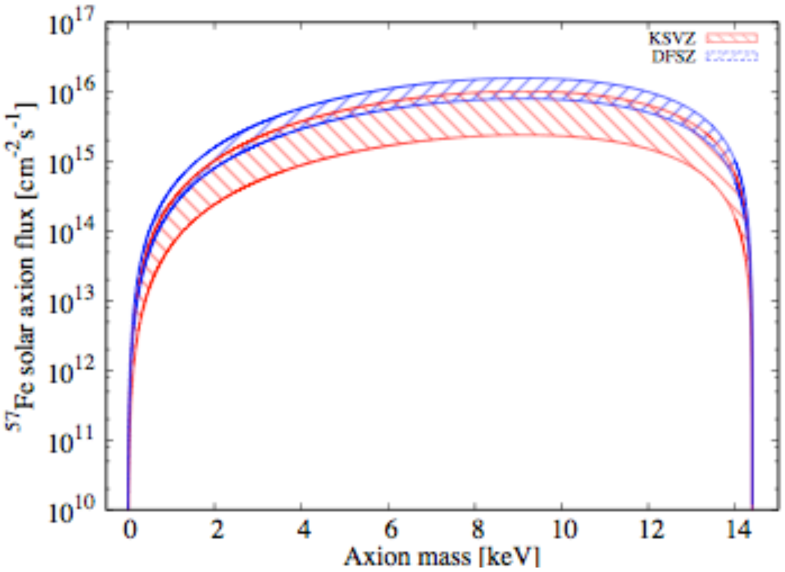
An example: the 14.4 keV case (1)

Production: 14.4 keV monochromatic axions emitted in the M1 transition of ^{57}Fe nuclei



Flux [cm^2*s^{-1}]

$$\boxed{\Phi_{14.4} = \beta^3 \cdot \Phi_0 \cdot \left(g_{AN}^{eff}\right)^2}$$

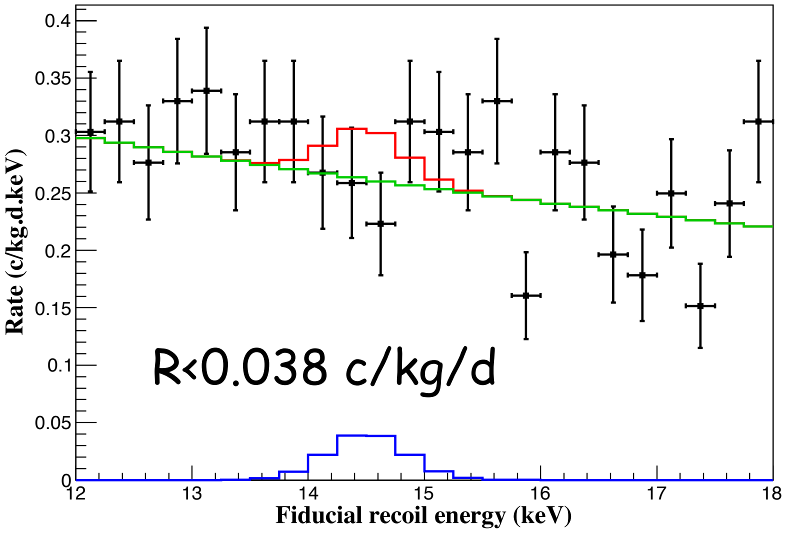


Detection: axio-electric effect

$$\boxed{R_{14.4} = \Phi_{14.4} \times \sigma_a \times W \times \varepsilon}$$

We assume a Poisson background and construct a likelihood function

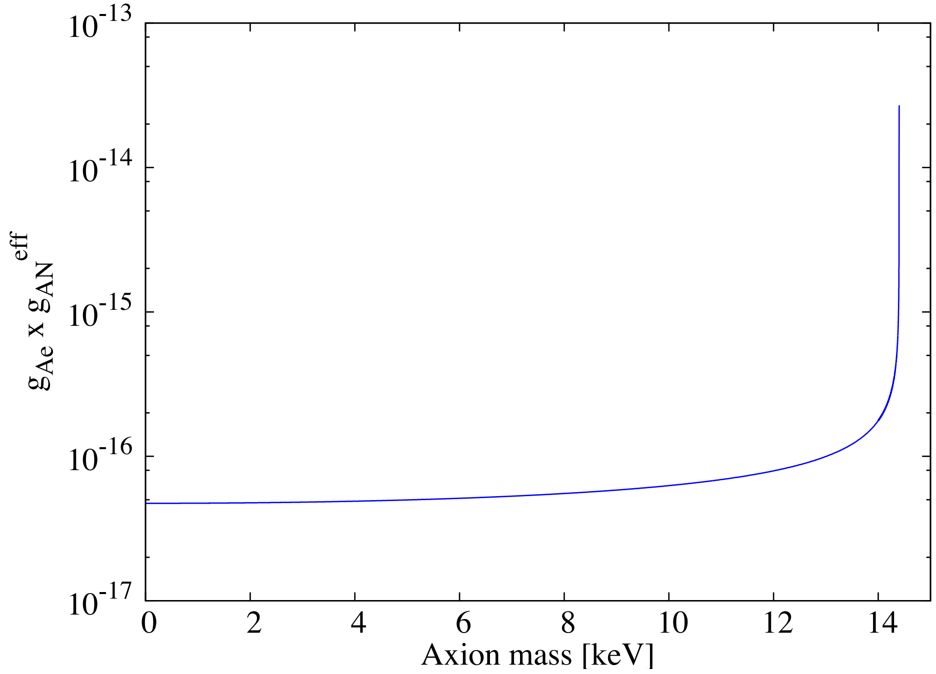
Extraction of a limit



R<0.038 c/kg/d

$$g_{Ae} \times g_{AN}^{eff} < 4.7 \cdot 10^{-17}$$

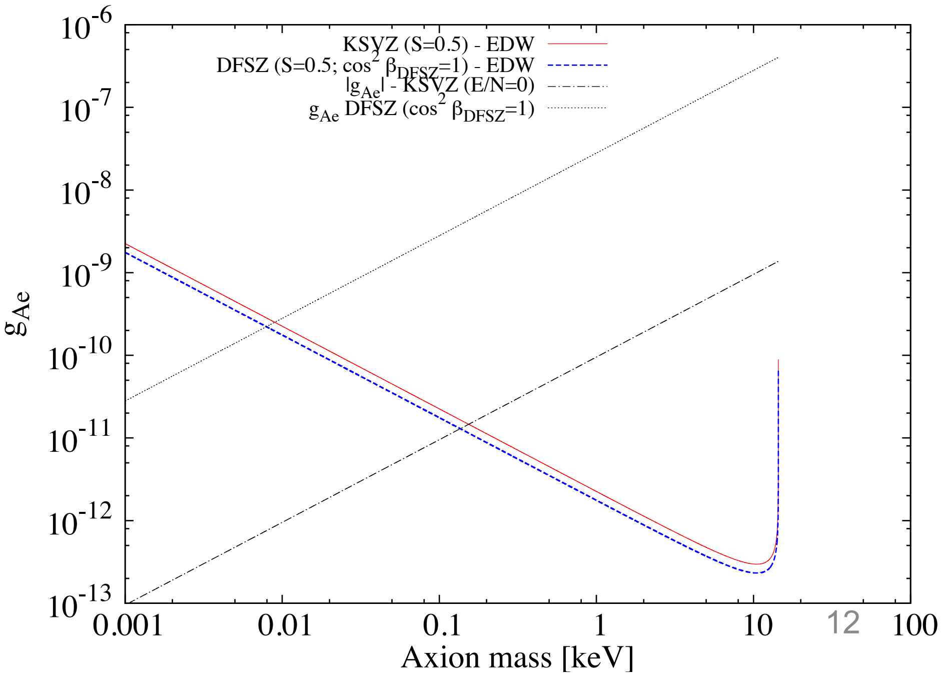
An example: the 14.4 keV case (2)



Model independent limit

$$g_{Ae} \times g_{AN}^{eff} \text{ vs. Axion mass}$$

Model dependent limit



Limits on g_{Ae} assuming values predicted by the DFSZ and KSVZ models for the couplings g^0_{AN} and g^3_{AN}.

Assumptions: **S = 0.5** for the flavor-singlet axial vector matrix element in both models and **$\cos^2 \beta_{DFSZ}$ = 1** for the DFSZ model.

Dark Matter axions

Hypothesis: Axion make up all of galactic dark matter and they have a mass in the keV region.

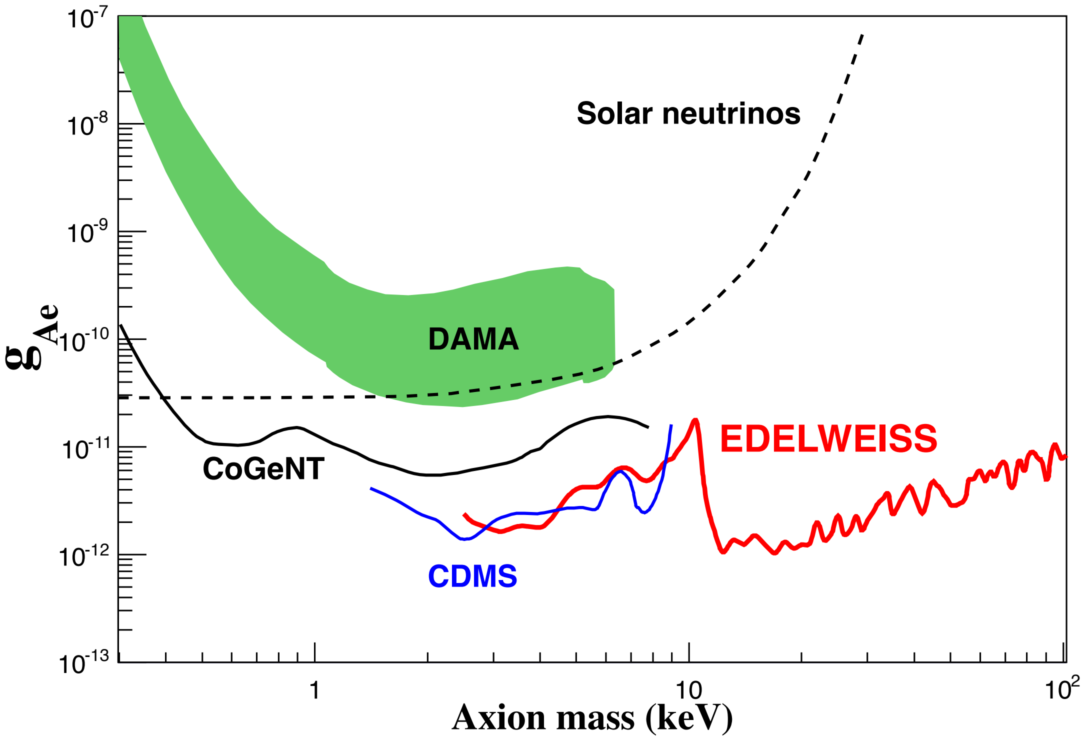
$$\Phi_{DM} = \underset{\displaystyle \downarrow \approx 0.3\frac{GeV}{cm^3}}{\rho_{DM}} \frac{v_A}{m_A} = \frac{9\cdot 10^{15}}{cm^{-2}\cdot s^{-1}}\frac{keV}{m_A}\beta$$

The flux does not depend on any axion coupling.

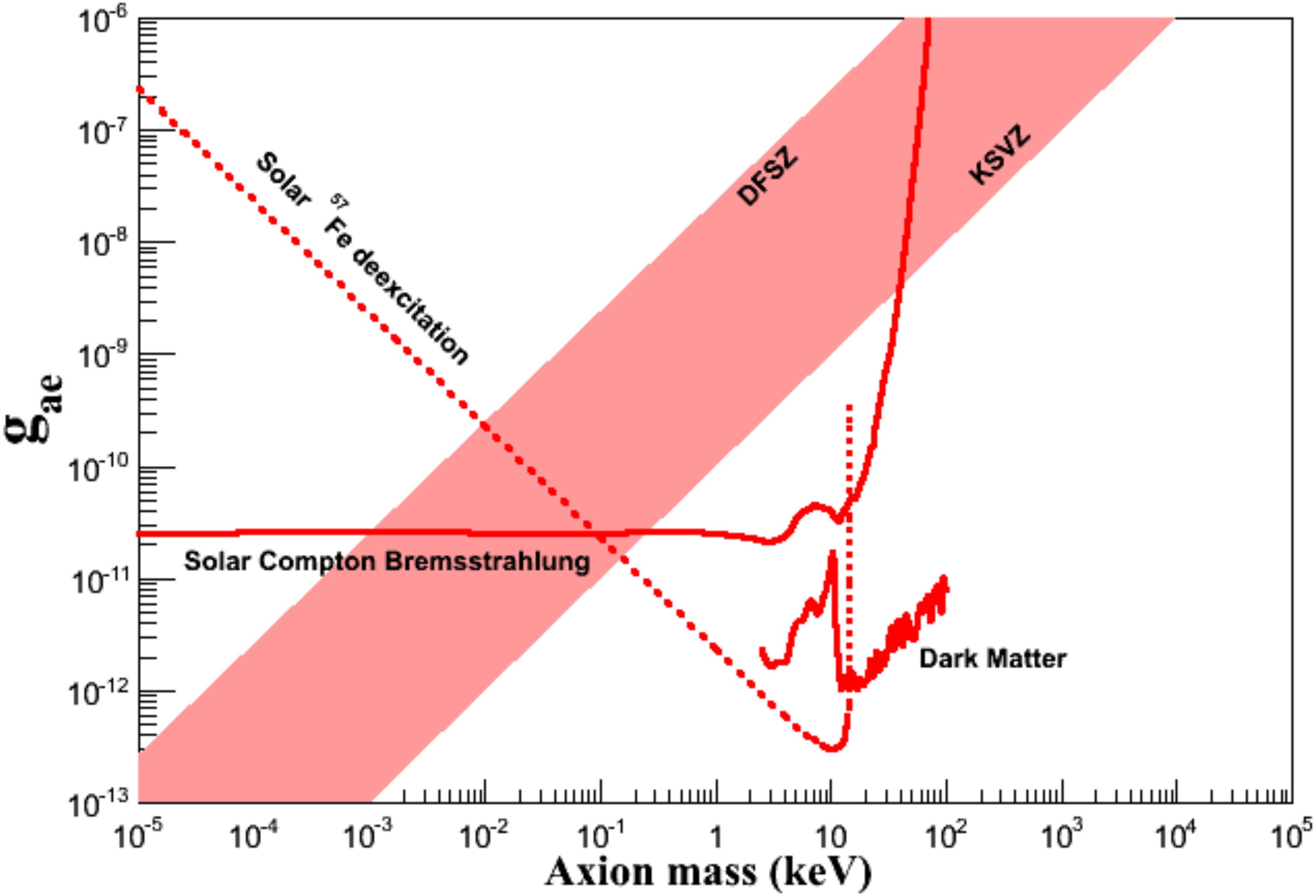
Axions are not relativistic: $\beta \sim 10^{-3}$

Signal: a line at the axion mass in the recoil spectrum

$$g_{Ae} < 1.05\times 10^{-12} \text{ @ } m_a = 12.5\ keV$$

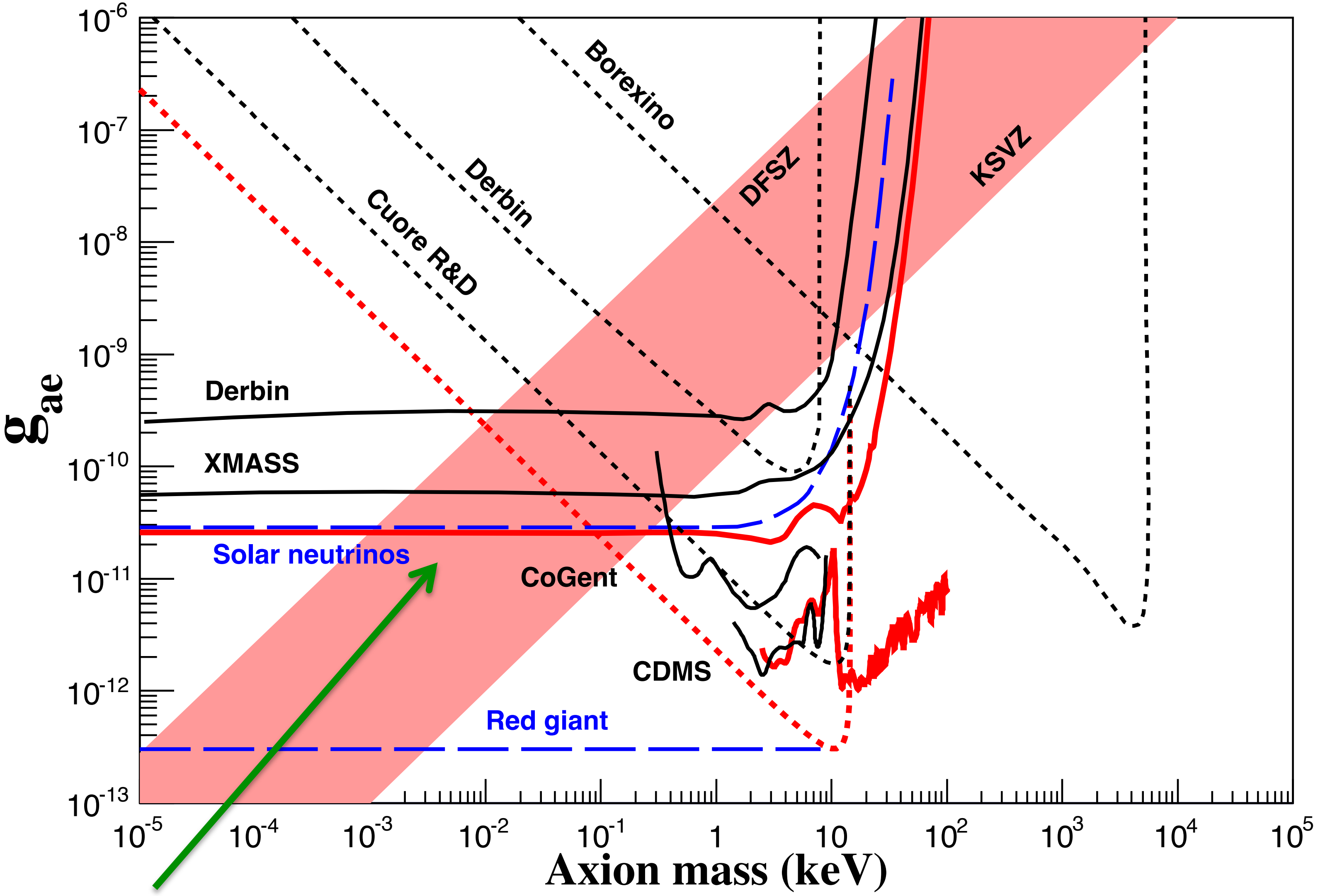


g_{Ae} limits with the EDELWEISS-II data



g_{Ae} limits: EDELWEISS-II & the others

---- model dependent limit
RED curves – EDW results

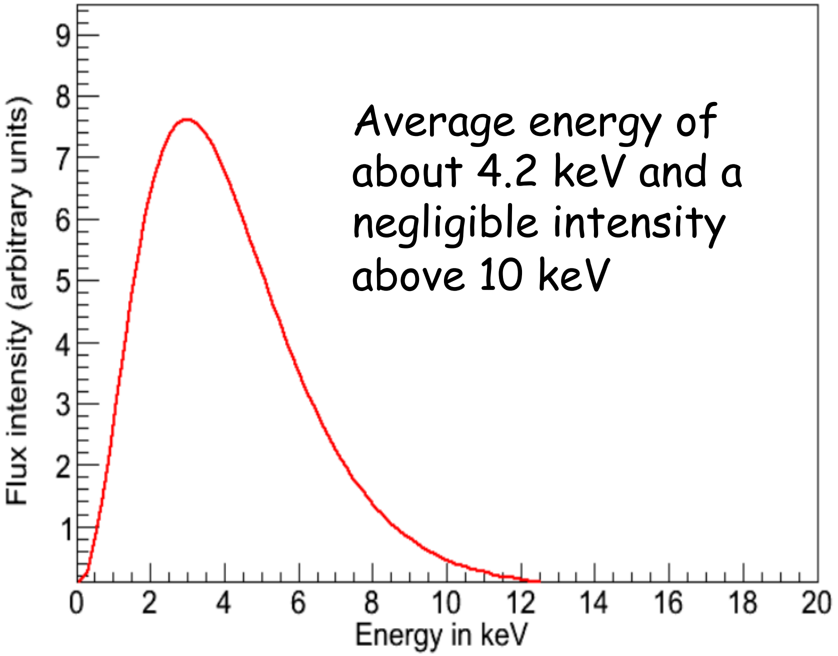


Competitive with astrophysical limit

$g_{A\gamma}$: Primakoff effect

Production: Primakoff process in the Sun

$$\frac{d\Phi}{dE_a} = \frac{6.02\times10^{14}}{cm^2.s.keV}\left(\frac{g_{a\gamma}\times10^{8}}{GeV^{-1}}\right)^2 E_a^{2.481}\, e^{\frac{-E_a}{1.205}}$$

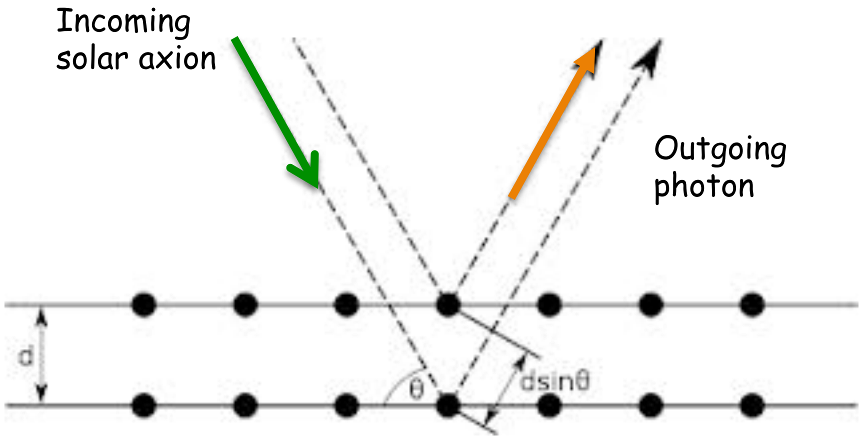


Average energy of about 4.2 keV and a negligible intensity above 10 keV

Detection: Bragg diffraction in Ge crystals

The typical transferred momentum has a wavelength close to the interatomic spacing

A Bragg pattern arises -> strong enhancement of the signal



$g_{A\gamma}{}^4$

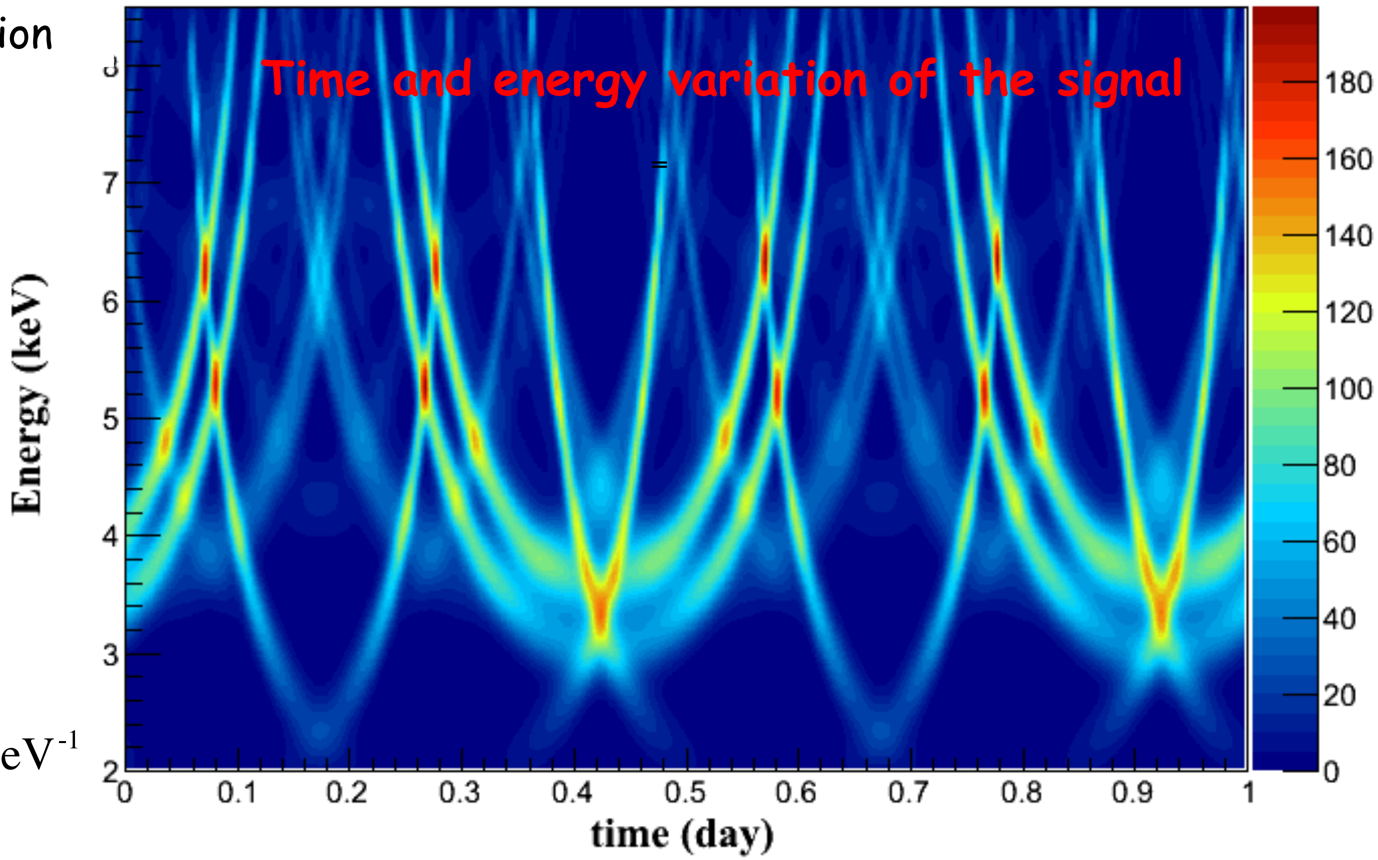
The expected rate in 1 day

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

$$= \left(\frac{g_{A\gamma}\cdot 10^8}{GeV^{-1}}\right)^4 \cdot \overline{R}(\tilde{E},t,\alpha) \equiv \lambda\cdot \overline{R}(\tilde{E},t,\alpha)$$

Bragg condition

$$E_a = \frac{\vec{G}^2}{2\vec{u}\cdot\vec{G}}$$



$g_{A\gamma} = 1\cdot 10^{-8}\ \mathrm{GeV}^{-1}$

The statistical analysis

The vertical axis of the bolometer tower is aligned with the [001] axis of each detector (one degree precision) BUT the individual azimuthal orientation a of each detector was not measured.

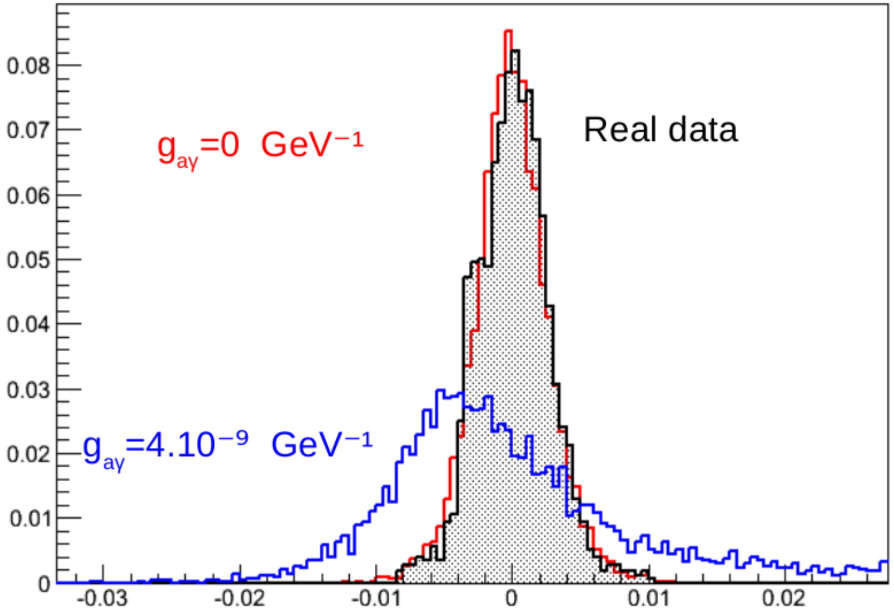
Axion rate averaged over time

$$\chi \propto \sum_{events} R(E,t) - \boxed{\langle R \rangle}$$

Build a time correlation function

$$\lambda = \left(\frac{g_{A\gamma} \cdot 10^{8}}{GeV^{-1}} \right)^{4}$$

Dependency on the azimuthal orientation



Combine all 10 detectors with unknown orientations:

→ MC simulation of the experiment`

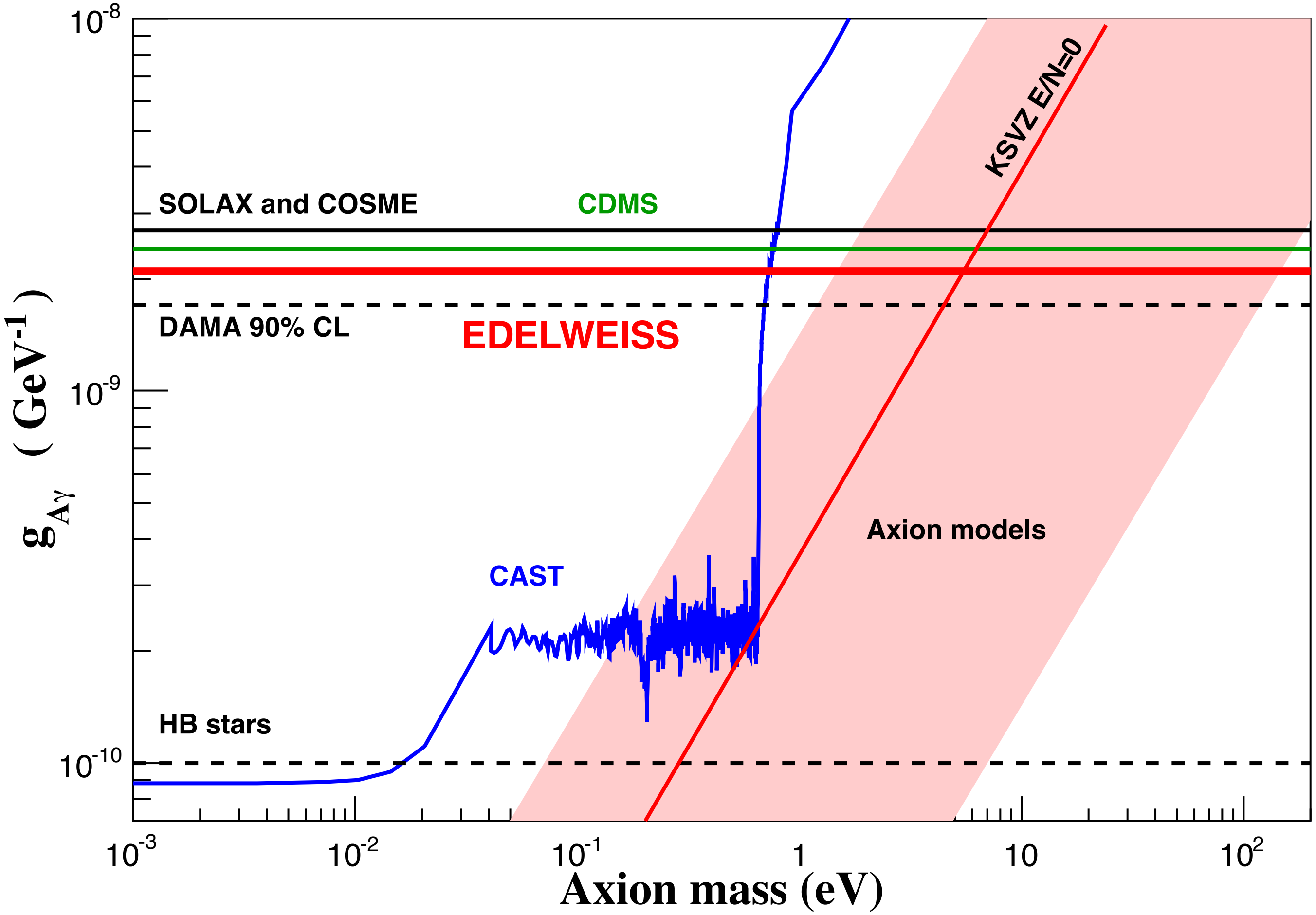
→ Scan over orientations and possible couplings

→ Rule out coupling from the comparison between simulation and real data.

Energy analysis window: 3-8 keV

$g_{A\gamma}$ limits with the EDELWEISS-II data

$$g_{A\gamma} < 2.13 \cdot 10^{-9} \ \mathrm{GeV}^{-1}$$



Room of improvement ?

$$g_{A\gamma} \propto \left(\frac{b}{Mt} \right)^{1/8}$$

Conclusions (1)

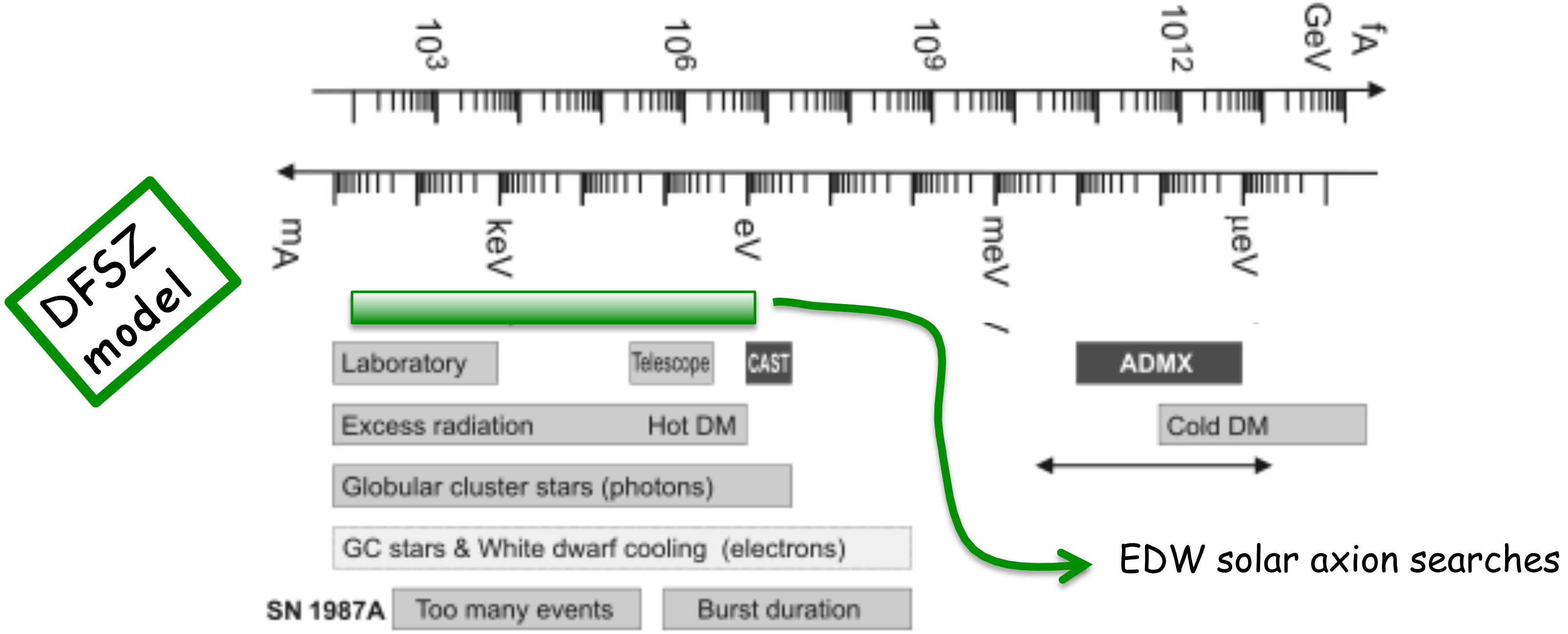
Bkg data from the EDELWEISS-II detectors, originally used for WIMP search, have been used to constrain the couplings of axion-like particles within different scenarios.

Production	Detection	Coupling limits
Primakoff channel $g_{A\gamma}$	Bragg diffraction $g_{A\gamma}$	$g_{A\gamma} < 2.13\mathrm{x}10^{-9}$ GeV^{-1}
Compton, Bremsstrahlung, axio-recombination&deexcitation g_{Ae}	Axio-electric effect g_{Ae}	$g_{Ae} < 2.56\mathrm{x}10^{-11}$
Solar ^{57}Fe de-excitation $g_{Ae} \mathrm{x} g_{AN}^{eff}$	Axio-electric effect g_{Ae}	$g_{Ae} \mathrm{x} g_{AN}^{eff} < 4.7\mathrm{x}10^{-17}$
Axions as dark matter	Axio-electric effect g_{Ae}	$g_{Ae} < 1.05\mathrm{x}10^{-12}$ @ 12.5 keV

Conclusions (2)

EDELWEISS-II data: axion mass limits

Channel	^{57}Fe	C-B-RD	Primakoff
KSVZ	154 eV<m_A<14.4 keV	269 eV<m_A<40 keV	5.73 eV<m_A<200 eV
DFSZ	7.93 eV<m_A<14.4 keV	0.914 eV<m_A<80 keV	14.86 eV<m_A<200 eV



DFSZ model

EDW solar axion searches