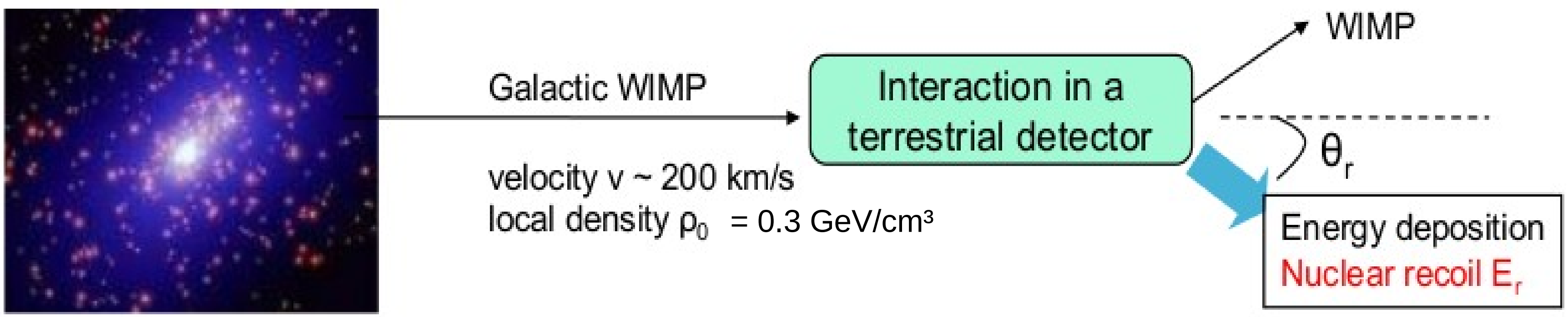
WIMPS & Axion searches with EDELWEISS

GDR Terascale
June 2014

Outline

- EDELWEISS : introduction
- WIMP searches with EDELWEISS
- Axions in a nutshell
- Axions: new results

EDELWEISS primary goal: WIMP direct detection



Weak scale

$$R = \sigma \, \Phi \, N$$

σ = Cross section (Spin independent part dominates with Ge target nuclei)

Φ= Incoming WIMP flux

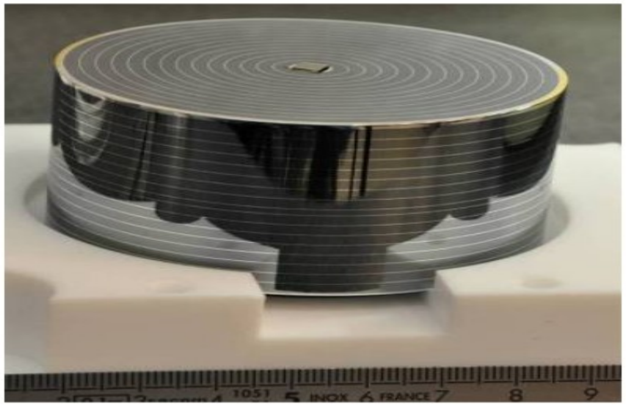
N= Target nuclei

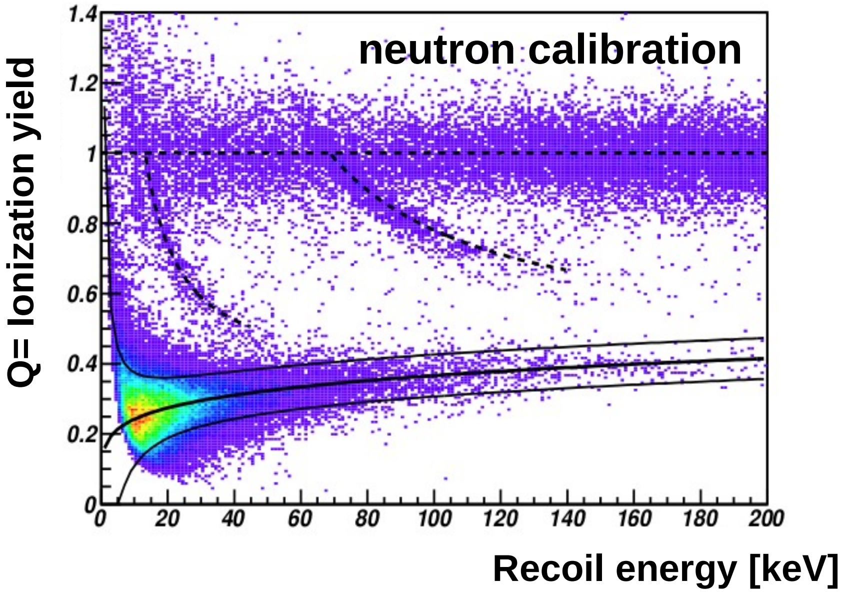
$R \approx 10^{-3}$ events/kg/day

Er: typically ~ keV to ~10keV

$\Rightarrow$ **We need low thresholds, low backgrounds and high mass targets!**

EDELWEISS Ge bolometers



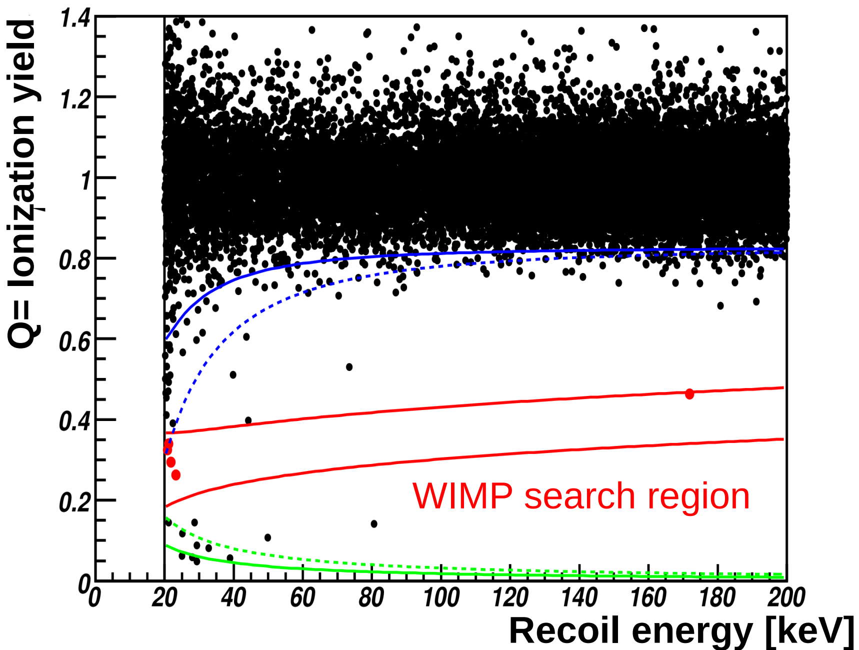


- Interdigit Bolometers working underground @ **LSM**, cooled @ **18 mK.**

- Simultaneous measurement of **Heat** (NTD thermometer) and **Ionization** (Al electrodes)

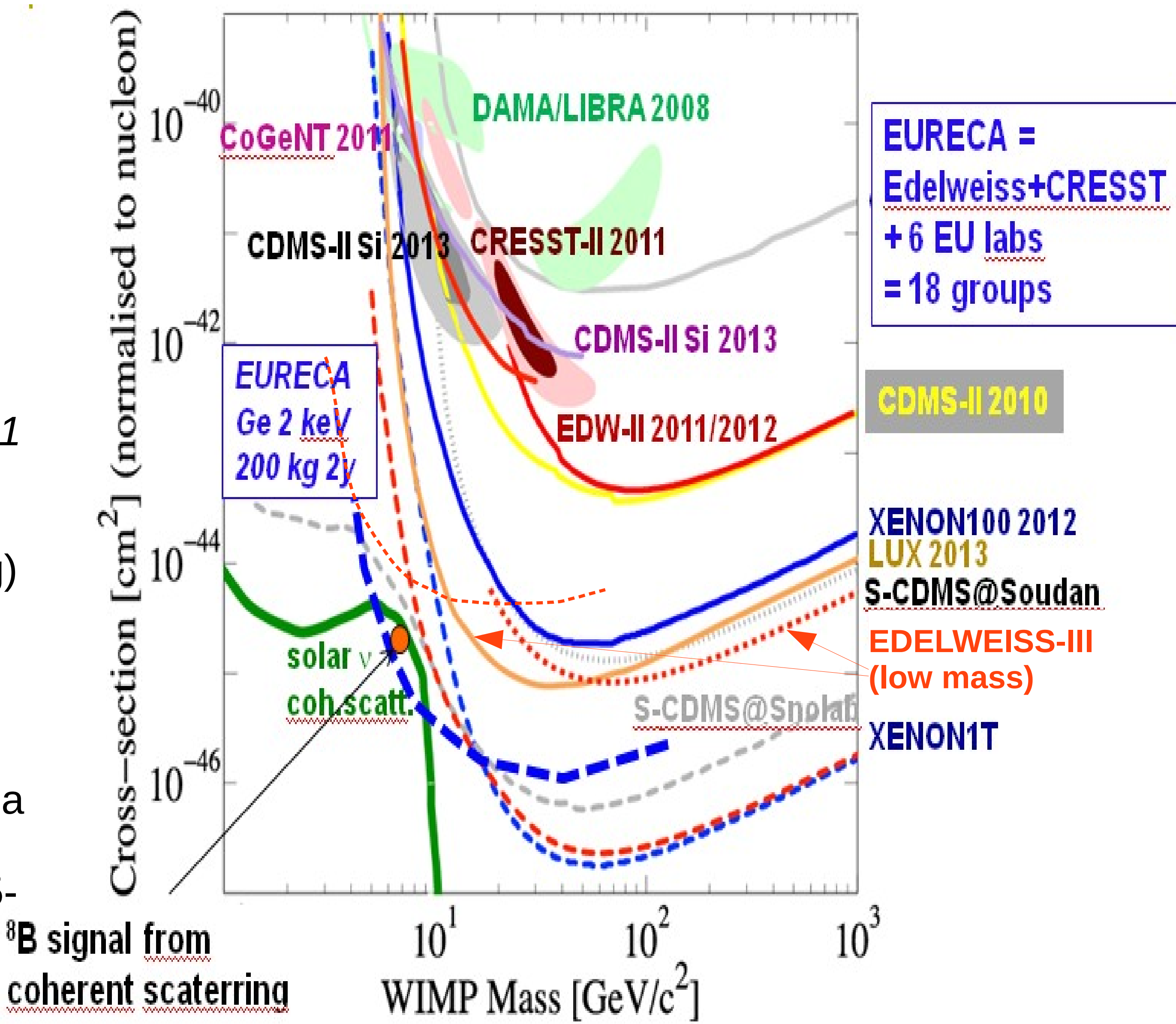
- Select events in fiducial volume from ionization (segmented electrodes).

- Discriminate events with **Q= Eionization / Erecoil**
  - **Q=1** for electron recoils (mostly due to gammas and possible axions)
  - **Q=0.3** for nuclear recoils (due to neutrons and possible WIMP candidates)



EDELWEISS results and prospects

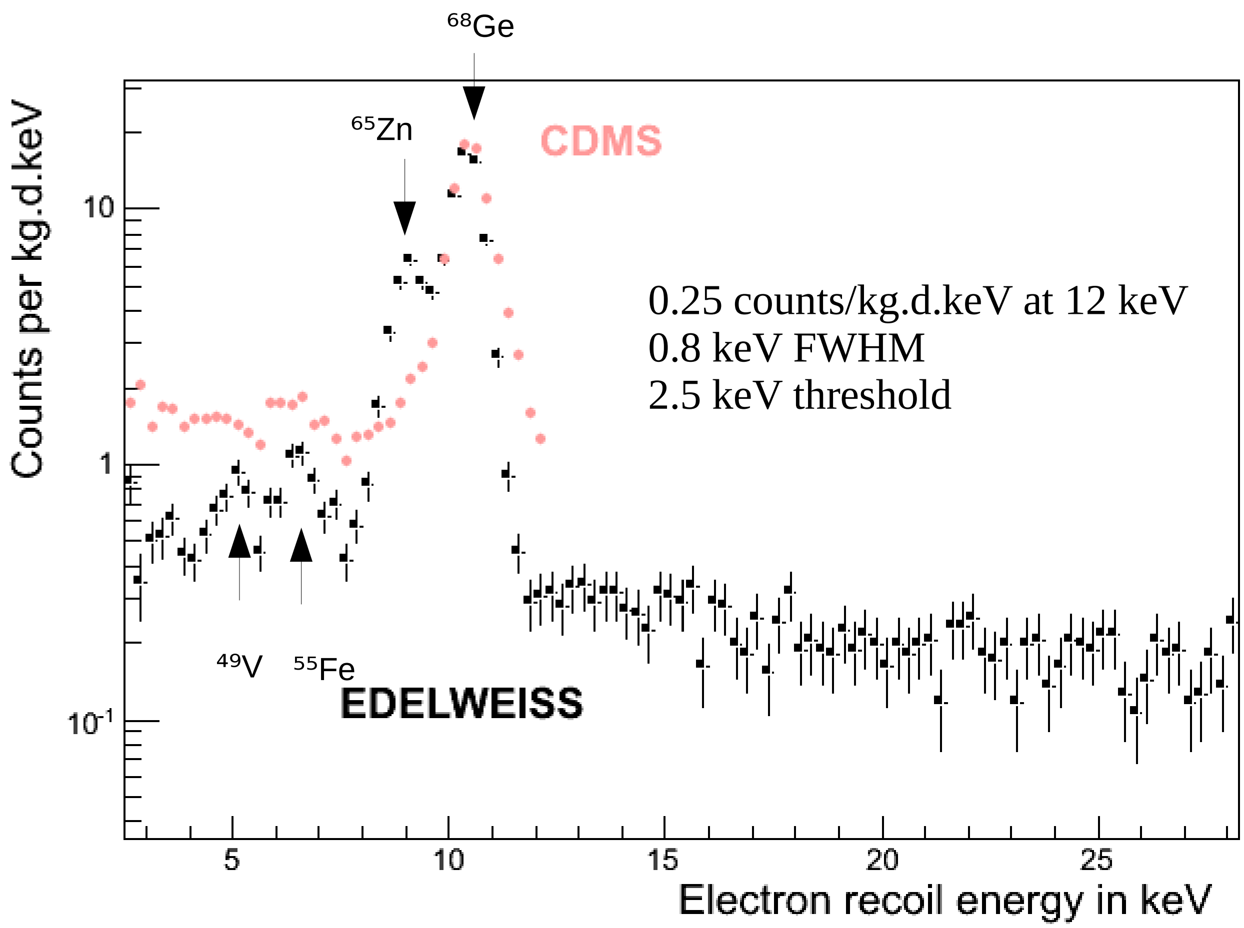
- 1 year, 10 detectors limit from *Physics Letters B 702 (2011) 329-335.*
  $\sigma = 4.4\times10^{-8}$ pb at 85 GeV
- Also shown are the dedicated **low-mass analysis results** from *Phys. Rev. D 86, 051701 (R) (2012)*
- **EDW III** (40 detectors of 800g) is in commissionning. Goals: 12 t.d (1.2 t.d @ low masses) $\sigma=10^{-9}$ pb
- Long term project: **EURECA**, a next-generation experiment
  - focus on low mass WIMPs 5-15 GeV.
  - Goal: reach solar neutrino limit (^{8}B)
  - cooperation with superCDMS



EDELWEISS III status: 36 detectors!

Electronic recoil and axions

- 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 counts/kg.d.keV at 12 keV
0.8 keV FWHM
2.5 keV threshold

Axions in a nutshell

- **Axions** are elementary particles first theorized by Peccei and Quinn to solve the strong CP problem

$$L = \left(\overline{\Theta} - \frac{\phi_A}{f_A}\right) \frac{\alpha_s}{8\pi} G^{\mu\nu a} \tilde{G}^{a}_{\mu\nu}$$

Axion field and decay constant

- In this framework, axions interact with SM particles: there are **model dependent couplings**.

- **Axions**, being charge-neutral and weakly interacting, are also a prime candidate to explain dark matter in the Universe

We work with **effective couplings:**

Axion nucleon coupling	Axion electron coupling	Axion photon coupling
g_{aN}	g_{ae}	$g_{a\gamma}$

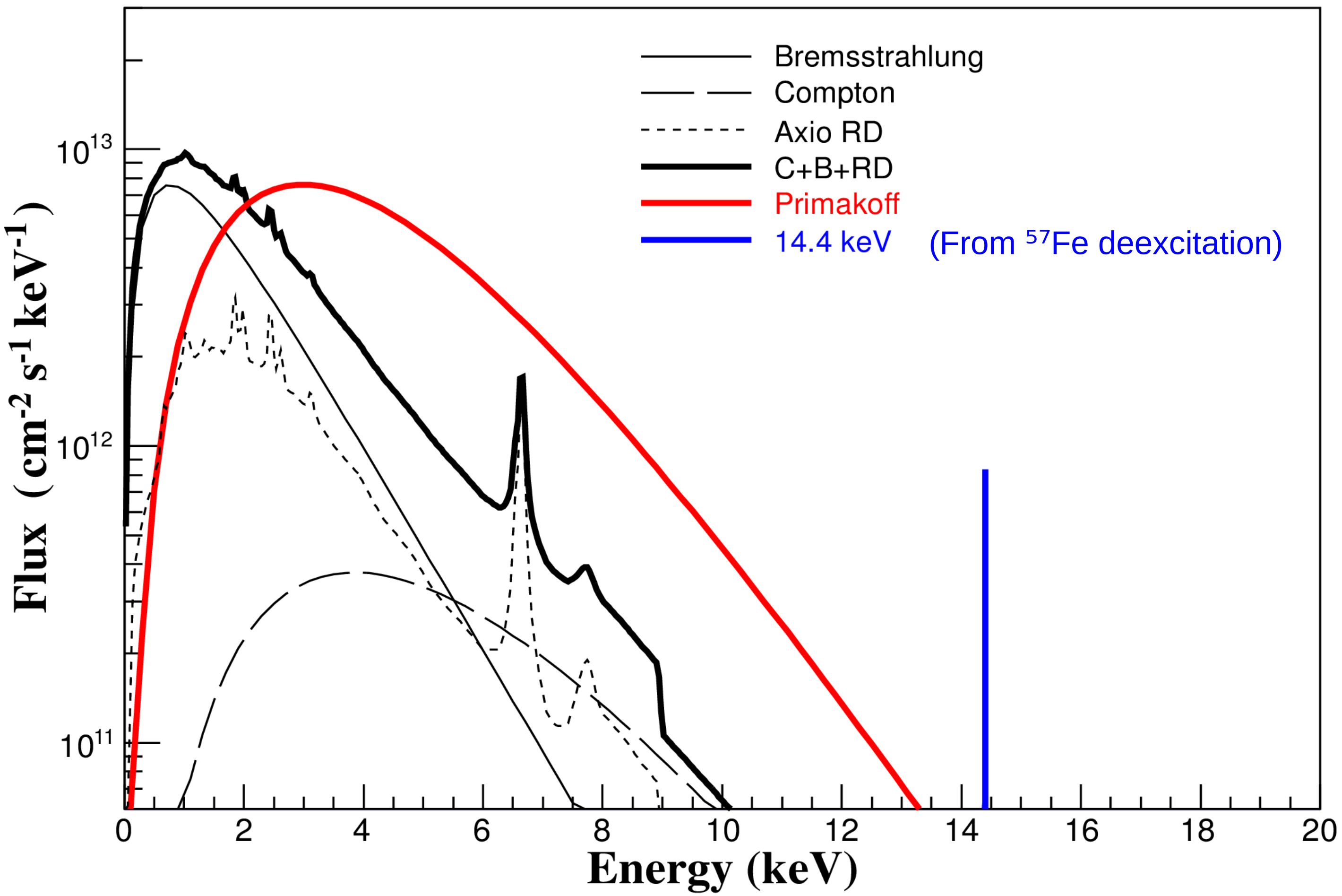
Axion searches: sources

1) The sun: many production channels

1. Primakoff production: $\gamma \rightarrow \mathrm{A}$ in the presence of charged particles $(g_{A\gamma})$
2. Nuclear magnetic transition of ^{57}Fe nuclei: $^{57}\mathrm{Fe}^* \rightarrow ^{57}\mathrm{Fe} + \mathrm{A}$ (g_{AN})
3. Compton-like scattering: $\mathrm{e}^- + \gamma \rightarrow \mathrm{e}^- + \mathrm{A}$ (g_{Ae})
4. Axion bremsstrahlung: $\mathrm{e}^- \rightarrow \mathrm{e}^- + \mathrm{A}$ in the presence of charged particles (g_{Ae})
5. Axio-recombination: $\mathrm{e}^- + \mathrm{I} \rightarrow \mathrm{I}^- + \mathrm{A}$ where I is an ion (g_{Ae})
6. Axio-deexcitation: $\mathrm{I}^* \rightarrow \mathrm{I} + \mathrm{A}$ where I^* is an excited state of I (g_{Ae})

2) Dark matter: assume axions form part of dark matter.

Solar axion : Fluxes



B: Bremsstrahlung
RD: Recombination-Deexcitation

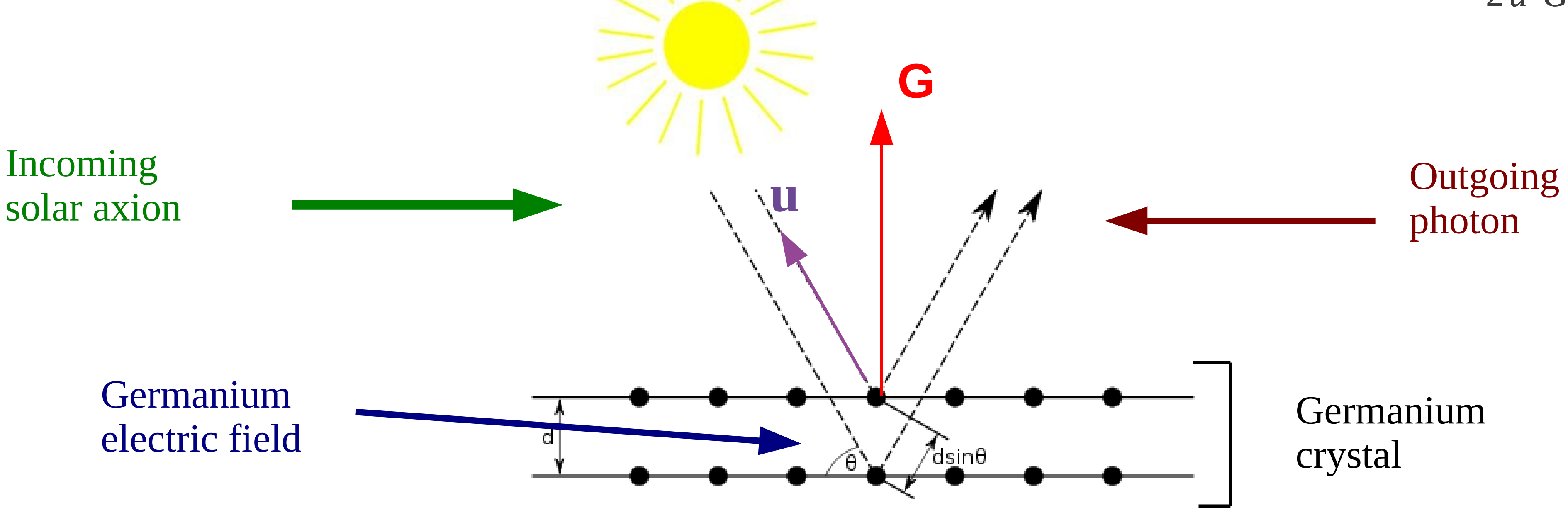
Coupling values are arbitrary

Axion detection: Primakov effect

Typical transferred momentum has wavelength close to interatomic spacing.

A Bragg pattern arises $\Rightarrow$ strong enhancement of the signal.

Bragg $E_{axion} = \frac{\vec{G}^2}{2\vec{u}\cdot\vec{G}}$



Axion detection: Axio-electric effect

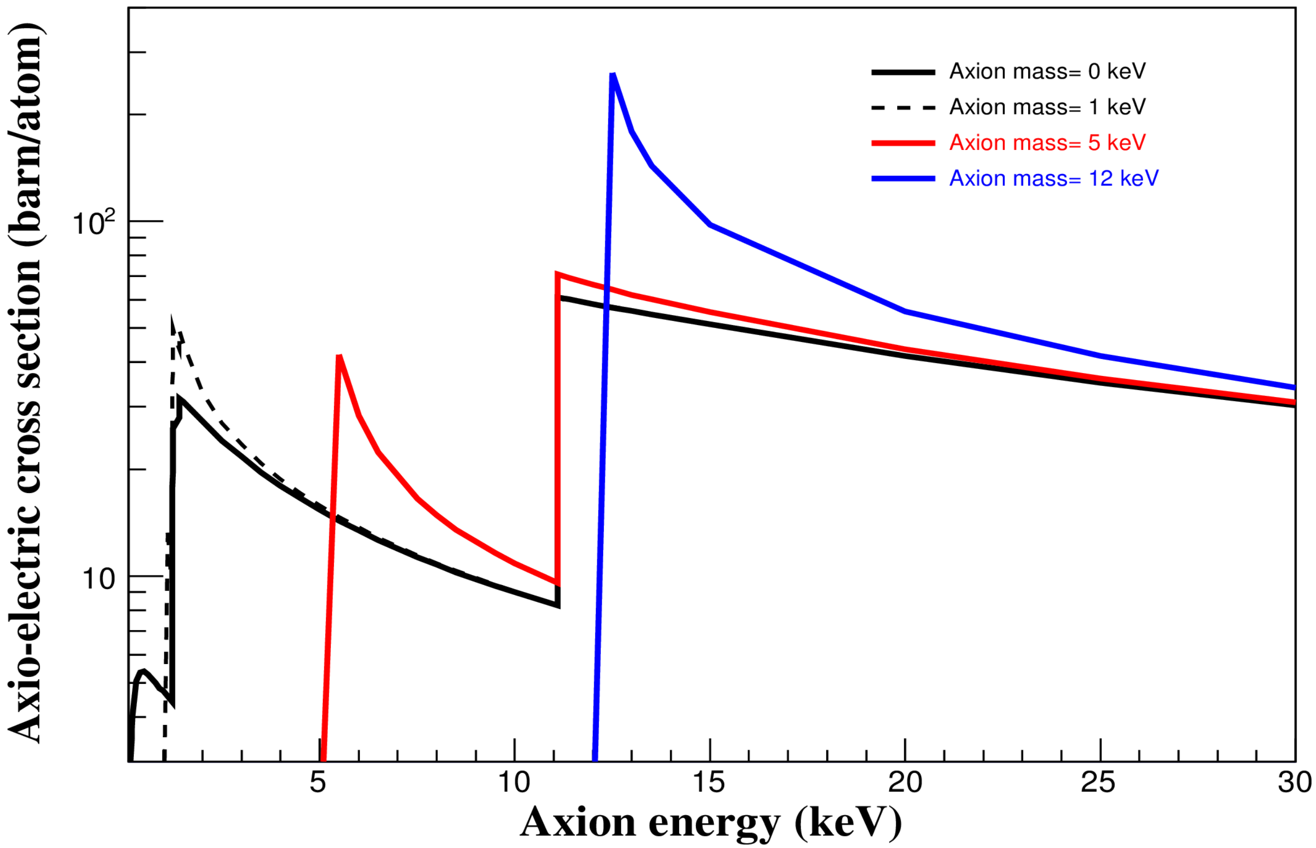
Cross section:

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

$(\beta = \frac{v}{c})$

Photo-electric cross section

Electron mass

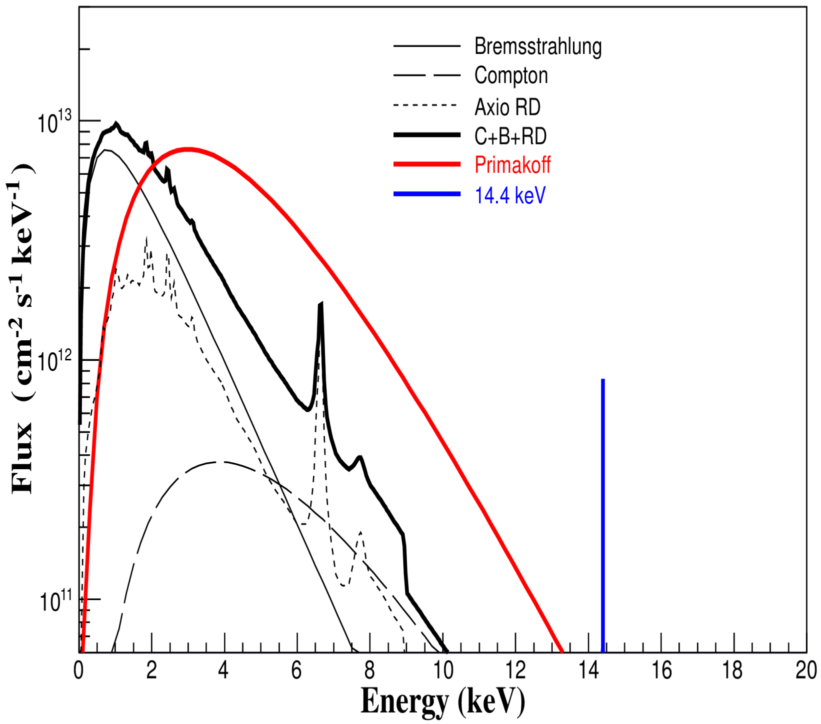


Axion searches with EDW: 4 channels

Production	Detection
Solar Primakov $g_{A\gamma}$	$g_{A\gamma}$ **Primakov** (Bragg scattering)
Solar Compton Bremsstrahlung g_{Ae}	g_{Ae} **Axio electric** effect
Solar ^{57}Fe deexcitation g_{AN}	g_{Ae} **Axio electric** effect
Assume axion (with mass $\mathbf{m_a}$) make up all of **galactic dark matter**	g_{Ae} **Axio electric** effect

Axion search: solar Primakov axions

- Only one coupling: $g_{a\gamma}$

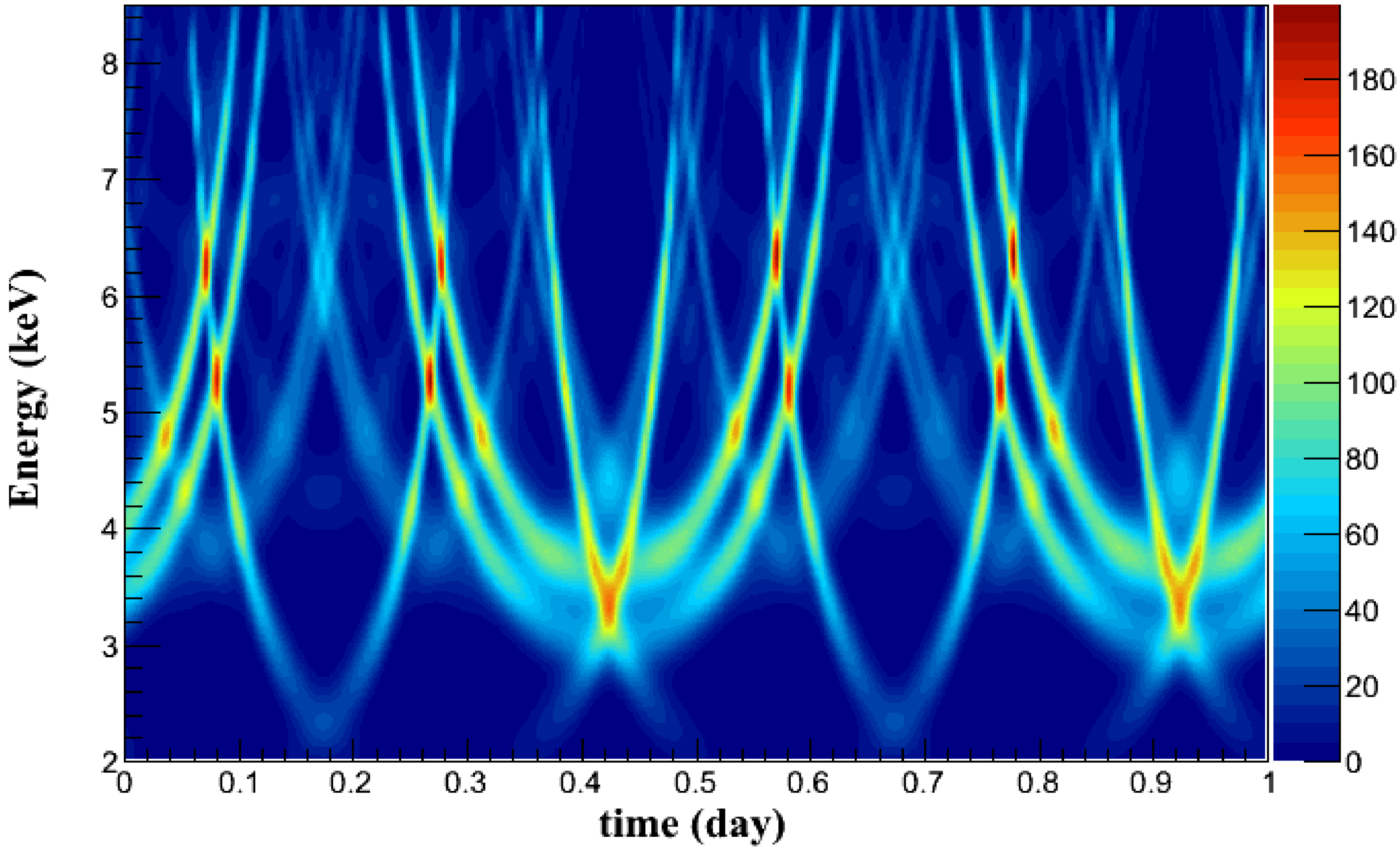


Production:
Primakov in the sun

Detection:
Primakov in the crystal

Expected count rate over 1 day

$g_{a\gamma}=1\times10^{-8}\ GeV^{-1}$



Statistical analysis: time correlation

Build the **time correlator:**

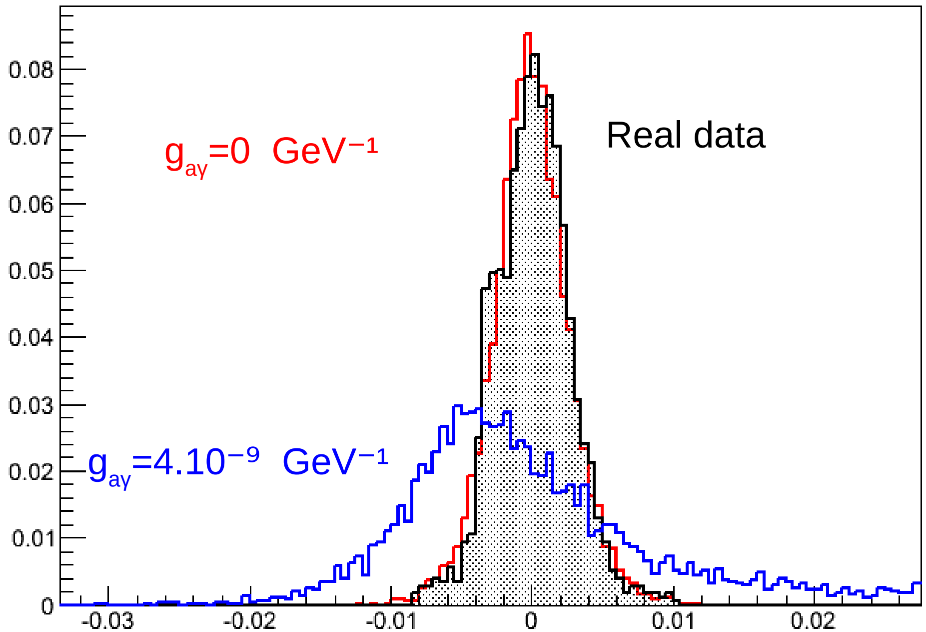
$\Longrightarrow$ Obtain $g_{a\gamma}$ at a given CL

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

Axion count rate averaged over time

This depends on the azimuthal orientation!

Distribution of $\lambda = \left(\frac{g_{a\gamma} \times 10^8}{GeV^{-1}}\right)^4$



Combine all 10 detectors with unknown orientations:

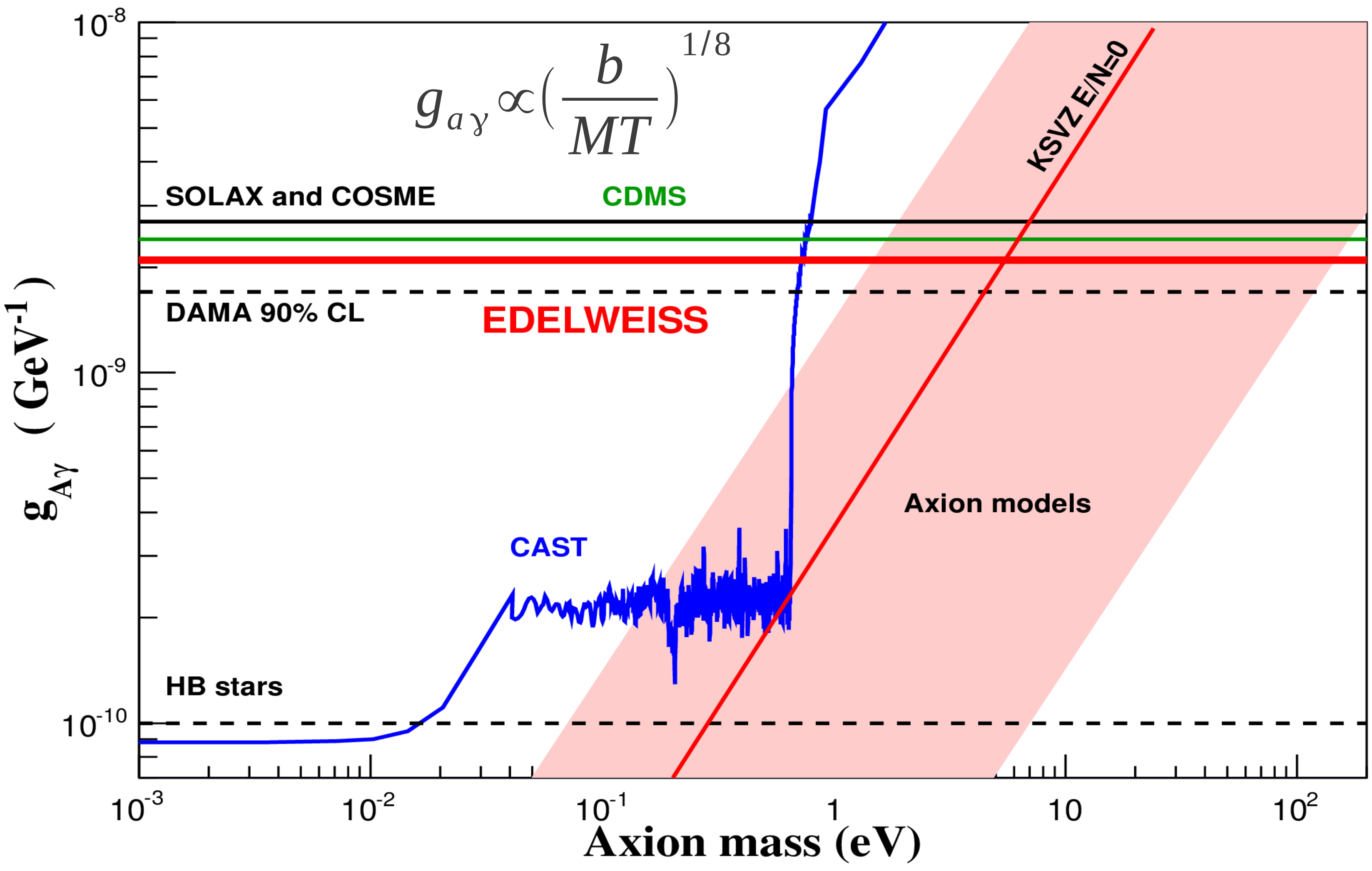
→ MC simulation of the experiment

→ Scan over orientations and possible couplings

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

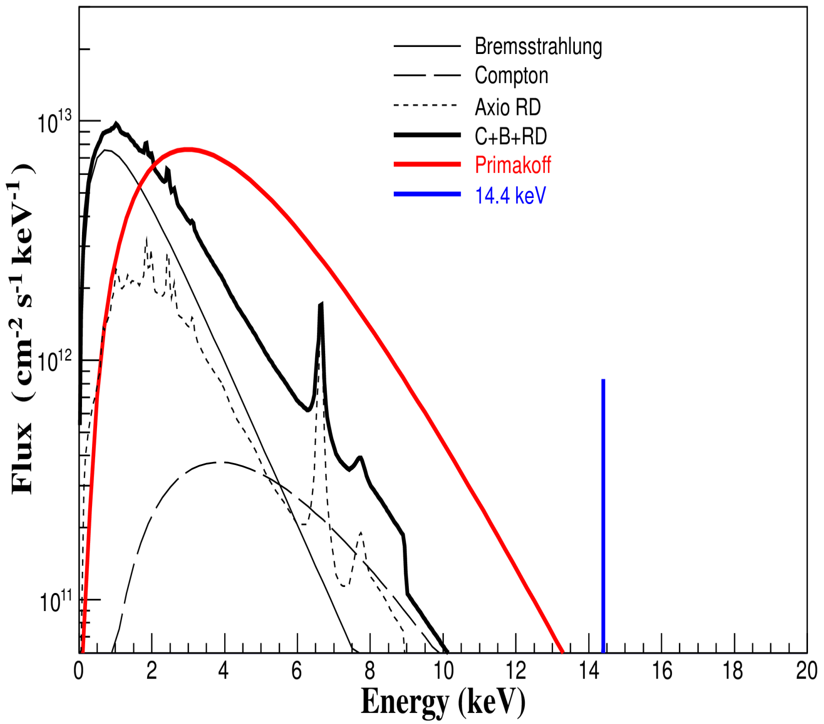
$$g_{a\gamma} < 2.13 \times 10^{-9}\, GeV^{-1}$$

Primakov Solar Axions: limit on $g_{a\gamma}$ (448.5 kg.days)



Axion search: solar ^{57}Fe axions

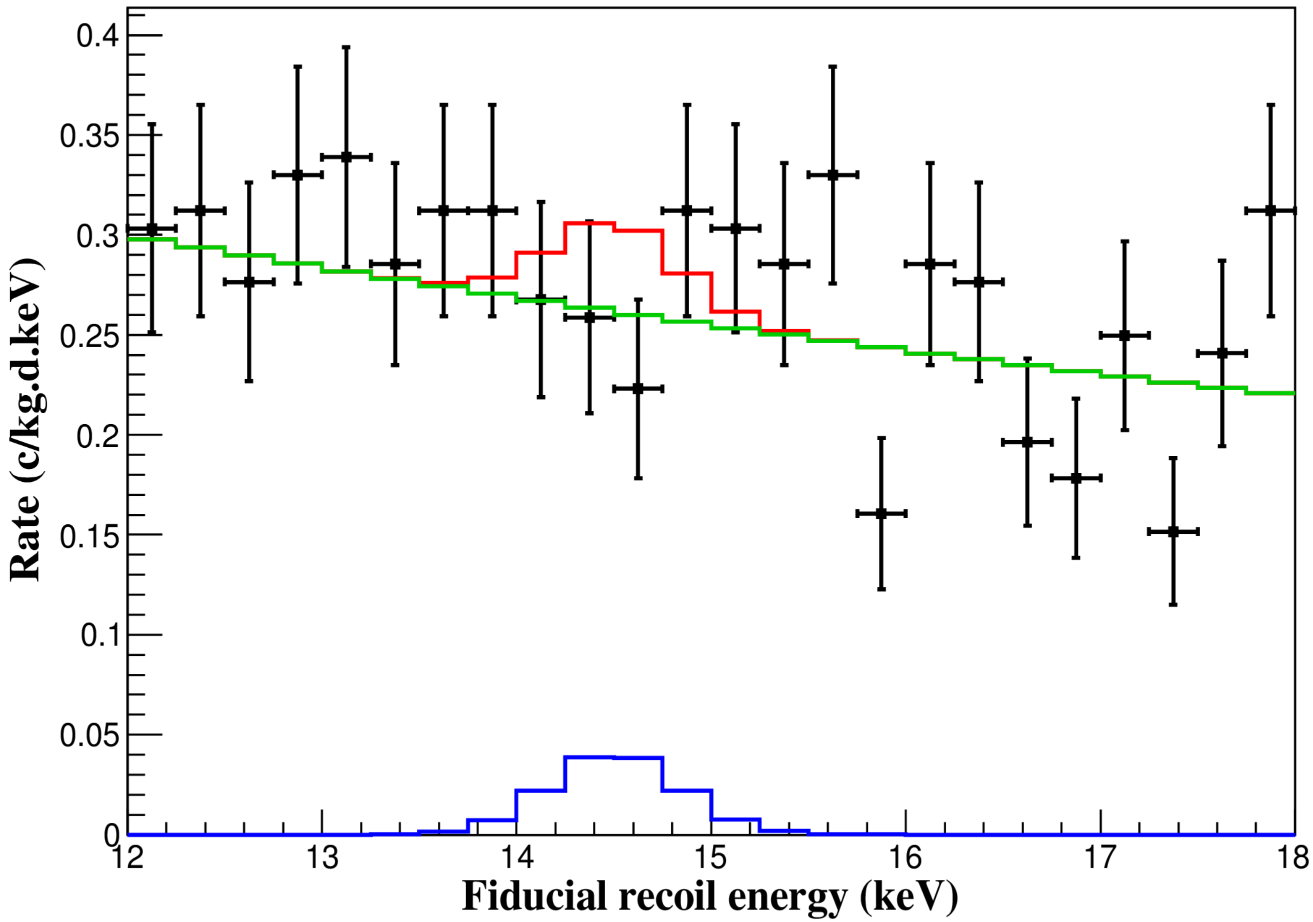
- 2 couplings: $g_{Ae} \times g_{AN}$



Production:
^{57}Fe deexcitation in the sun

Detection:
Axio-electric effect in the crystal

^{57}Fe solar axions



Background

$$N^{th}(E) = a + bE + R_{14.4}(E)$$

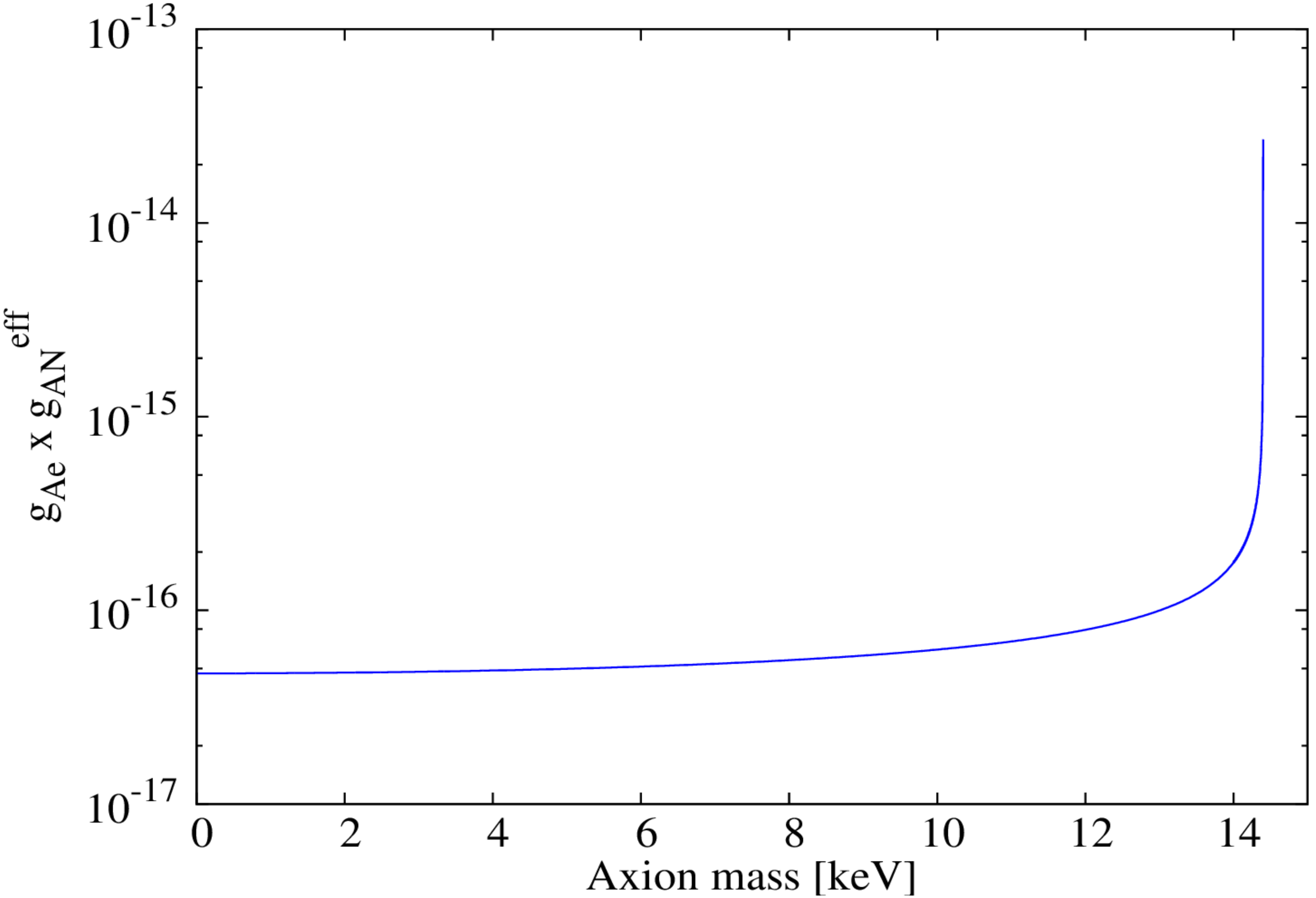
Axion signal $\propto g_{ae}^2 \times g_{aN}^2$

Likelihood:

$$L = \prod_i e^{-N_i^{\rm th}} \frac{(N_i^{\rm th})^{N_i^{\rm exp}}}{N_i^{\rm exp}!}$$

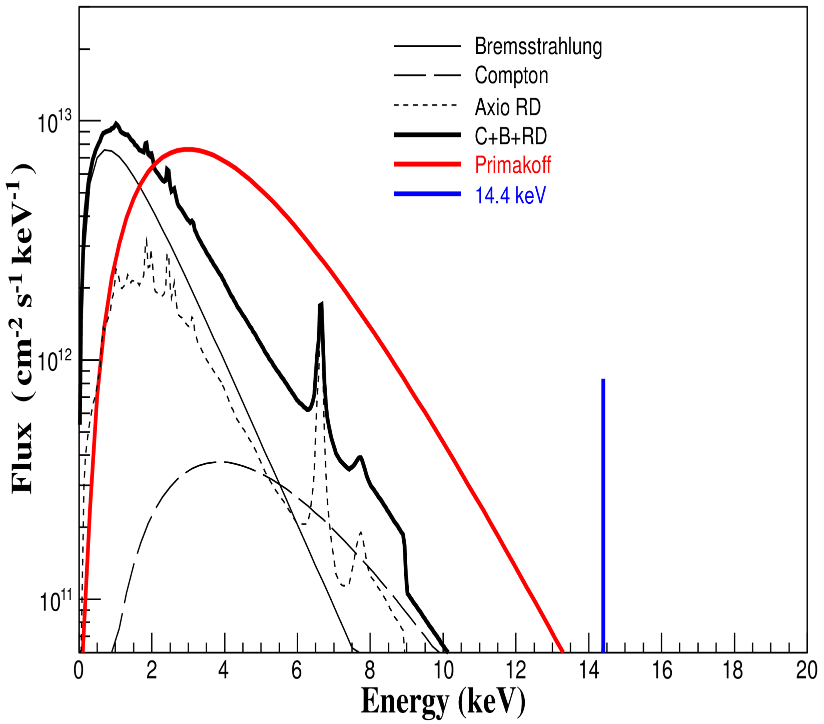
Extract limit and confidence interval
+
Cross check with MC

^{57}Fe solar axions: limit on g_{AN} x g_{Ae} (448.5 kg.days)



Axion search: solar C-B-RD axions

- Only one coupling: g_{Ae}



Production:

C-B-RD deexcitation in the sun

Detection:

Axio-electric effect in the crystal

Same statistical analysis as before

$$g_{Ae} < 2.56 \times 10^{-11}$$

Axion search: Dark Matter axions

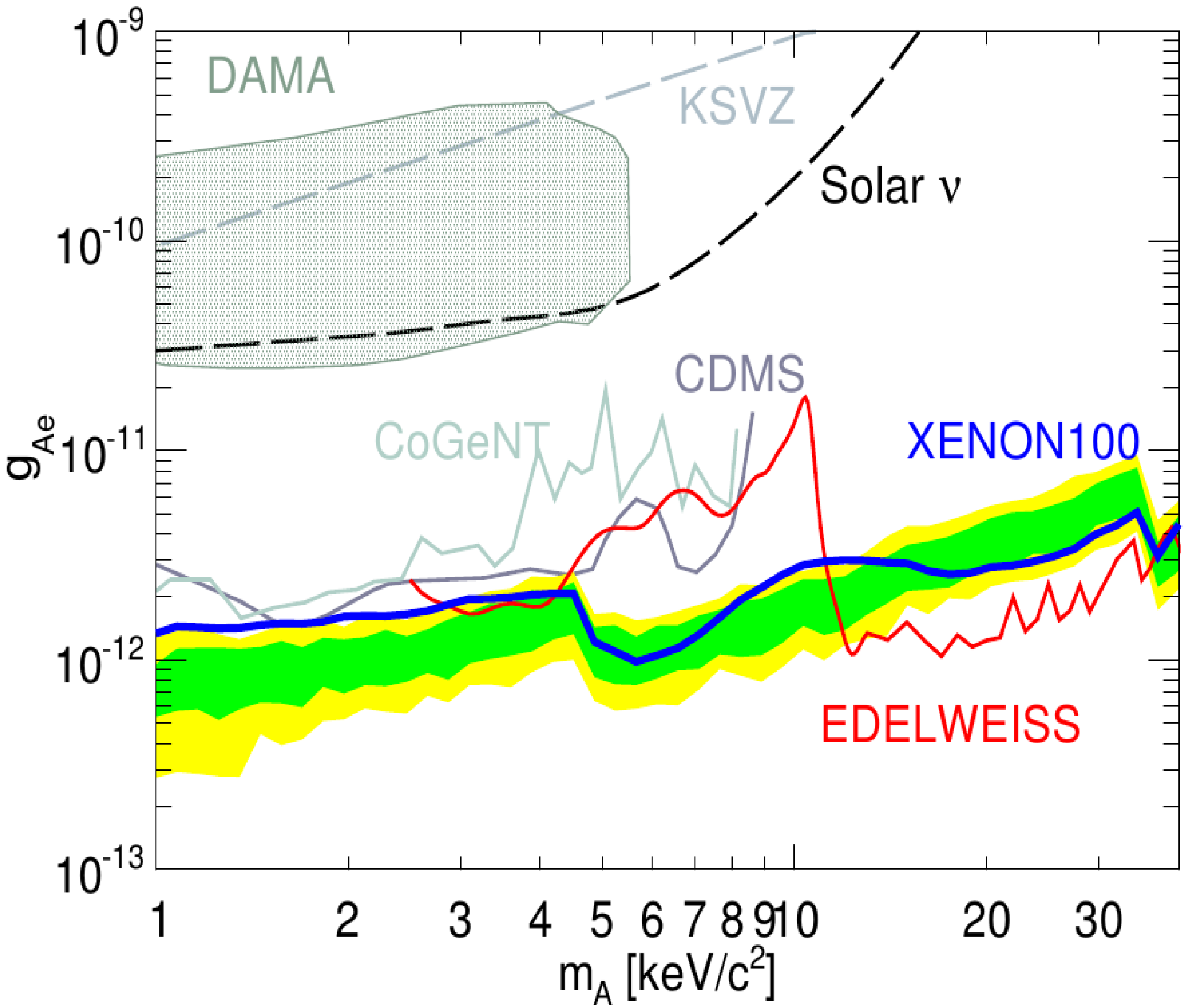
From **arXiv:1404.1455**

Assume axions **make up all of dark matter and have a mass in the keV range.**

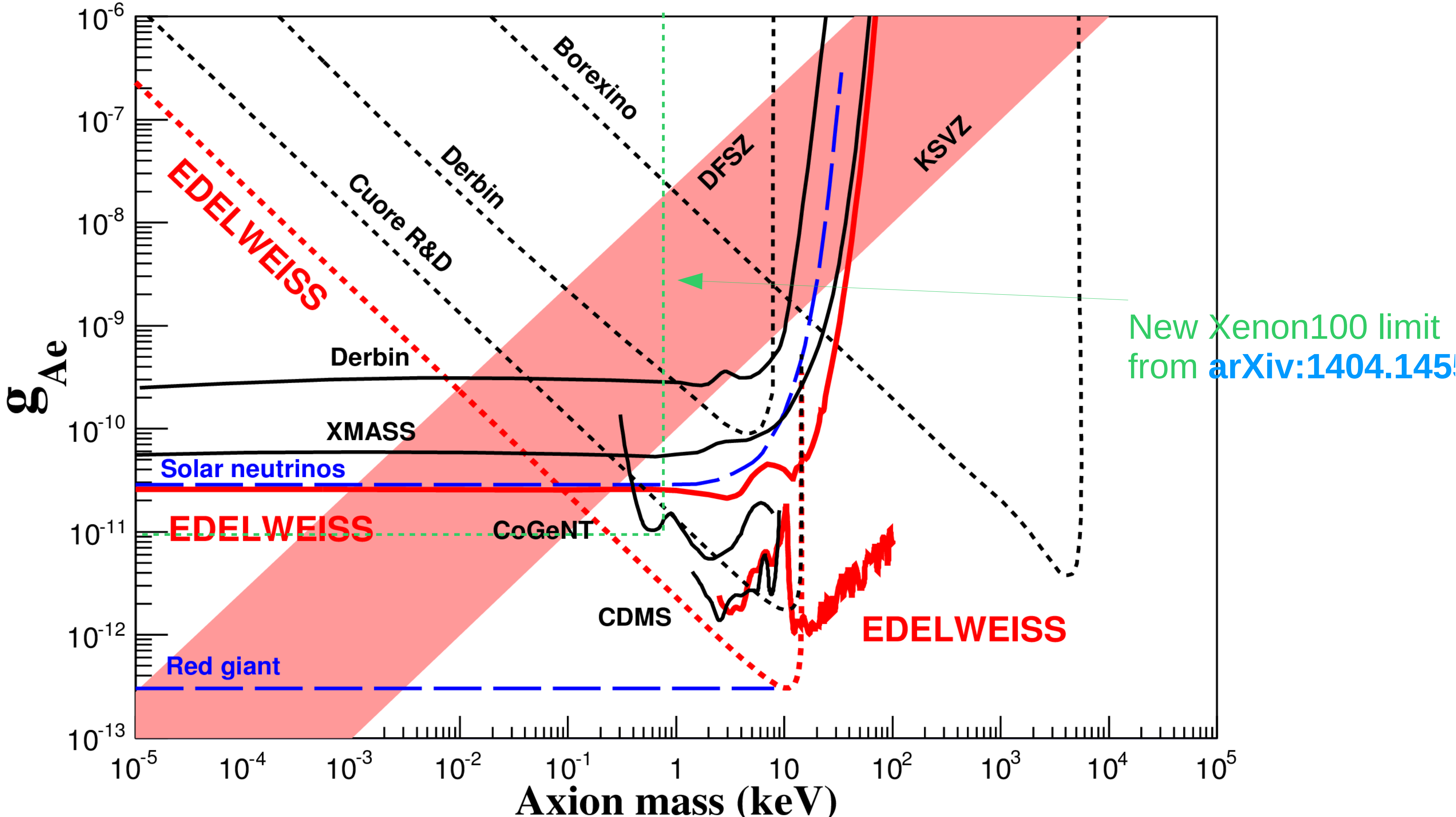
Axions are **non relativistic:** look for a line at the axion mass in the recoil spectrum

$$g_{Ae} < 1.05 \times 10^{-12}$$

(@ m_a= 12.5 keV)



Constraints on g_{ae} (448.5 kg.days)



Dotted lines are model dependent constraints.
Red curves are EDELWEISS limits

Model dependent limits: mass exclusion

- Relate coupling to the axion mass within a QCD axion model.
- Deduce exclusion on axion masses

Model independent Limits:

Channel	14.4 $(g_{Ae} \times g_{AN}^{\rm eff})$	DM (g_{Ae})	C-B-RD (g_{Ae})	P $(g_{A\gamma})$
Limit	$< 4.70 \times 10^{-17}$	$< 1.05 \times 10^{-12}$	$< 2.56 \times 10^{-11}$	$< 2.13 \times 10^{-9}$ GeV^{-1}

=> Mass exclusion (in a given model):

Channel	14.4 $(g_{Ae} \times g_{AN}^{\rm eff})$	C-B-RD (g_{Ae})	P $(g_{A\gamma})$
KSVZ	$154\,\text{eV} < m_A < 14.4$ keV	$269\,\text{eV} < m_A < 40$ keV	$5.73 < m_A \lesssim 200$ eV
DFSZ	$7.93\,\text{eV} < m_A < 14.4$ keV	$0.91\,\text{eV} < m_A < 80$ keV	$14.86 < m_A \lesssim 200$ eV

Conclusion

- **WIMP search** with EDELWEISS (EDW):
  - EDWIII all detectors commissionned, goal: $\sigma \approx 10^{-9}$ pb
  - Emphasis on the low mass region
  - EDW III will run until 2016

- **EURECA / S-CDMS:** goal: probe low-mass regions, reach the coherent neutrino scattering limit.

For the full paper:
JCAP 1311 (2013) 067

Results for axion searches: A significant part of the parameter space is excluded thanks to the combination of 4 analysis channels.

Primakov axions: Results complementary with CAST at masses above 1eV

C-B-RD* channel: Exclusion over 5 orders of magnitude of the axion mass in the DFSZ model

***Solar Compton-Bremmsstrahlung-Recombination-Deexcitation**