Axion searches with the EDELWEISS Ge bolometers

Rencontres IphT/SPP
Les Axions
Jeudi 6 décembre 2012

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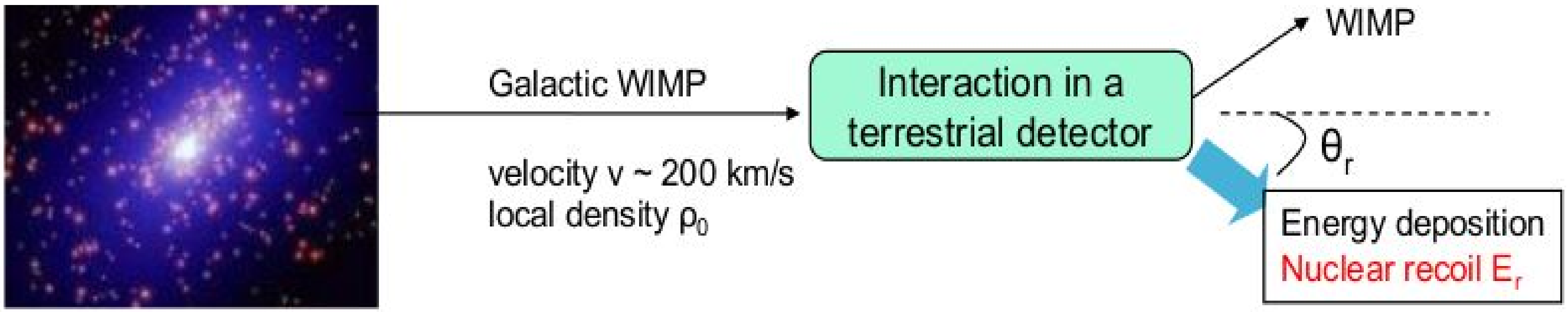
Outline

- Edelweiss : a presentation
- WIMP search with Edelweiss
- Axions: recap & possible detection channels in Edelweiss
- Primakoff detection of axions with Edelweiss
- Other channels (work in progress)

Edelweiss primary goal: WIMP direct detection



$R = \sigma \Phi N$

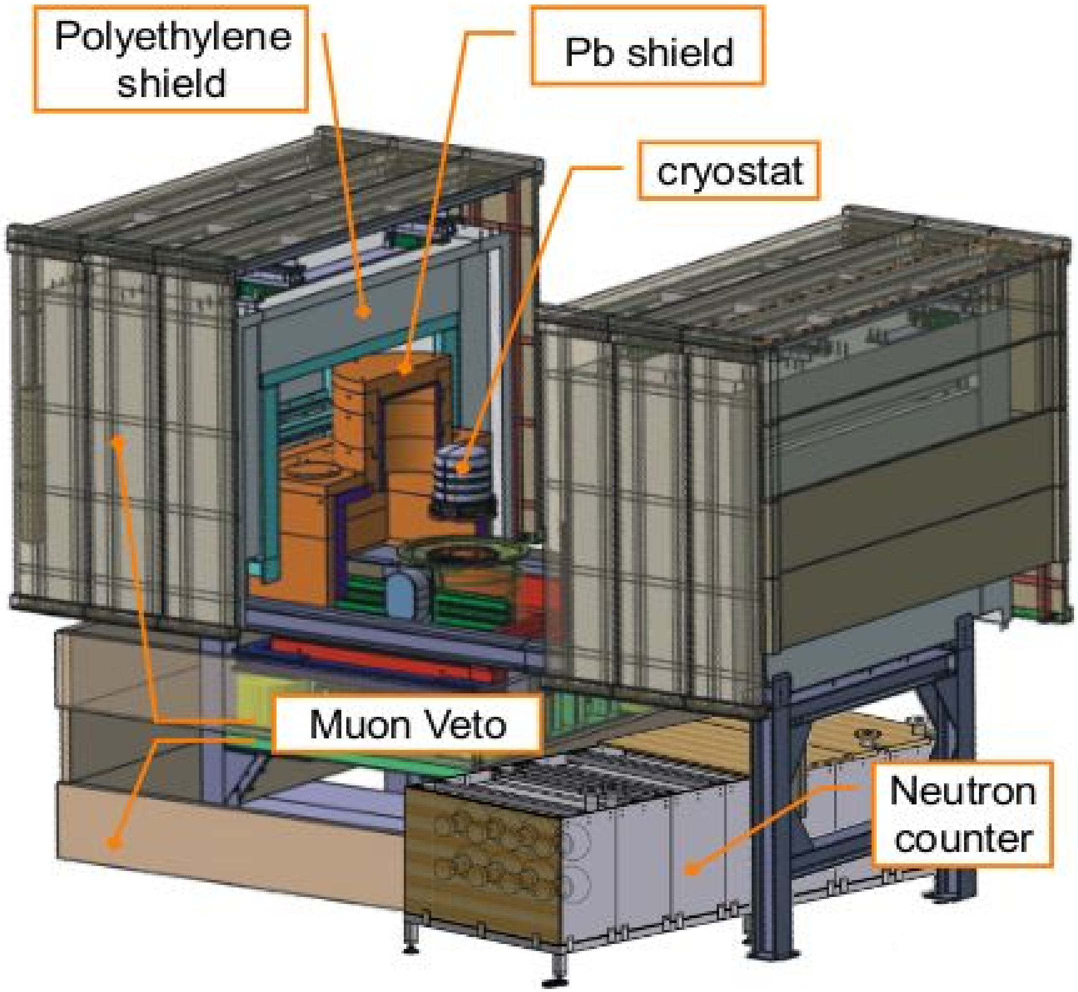
σ = Cross section (Spin independent part dominates with Ge target nuclei)

Φ= Incoming WIMP flux

N= Target nuclei

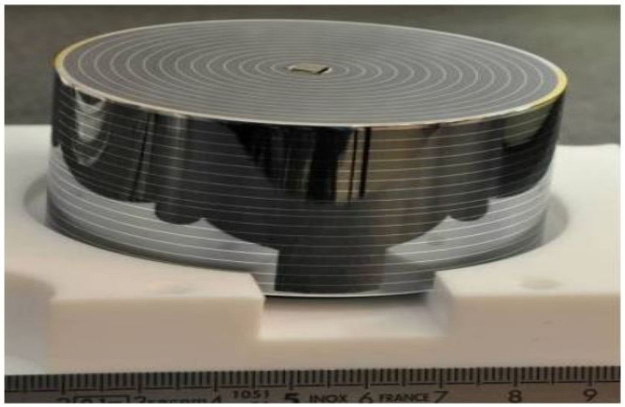
Weak scale

Edelweiss setup

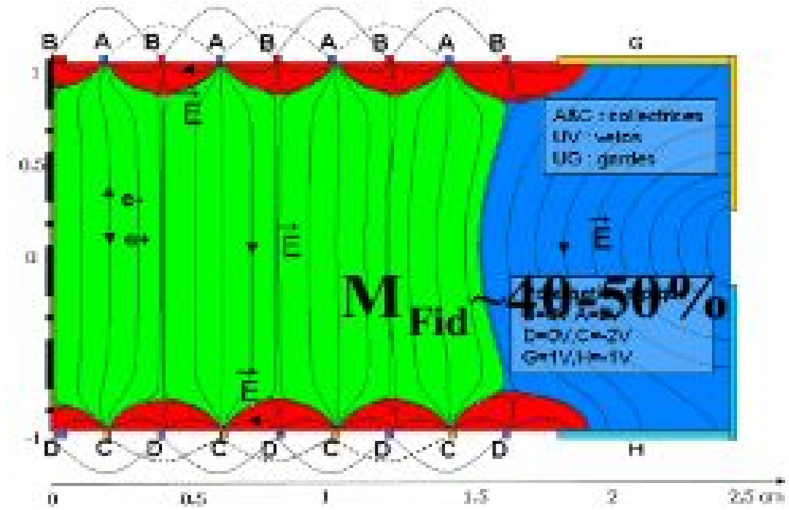


- In **LSM underground laboratory**
- **Cryogenics** at 18 mK
- **Various shieldings:** muon veto, lead and PE shield, clean room and deradonized air

Edelweiss Ge detectors



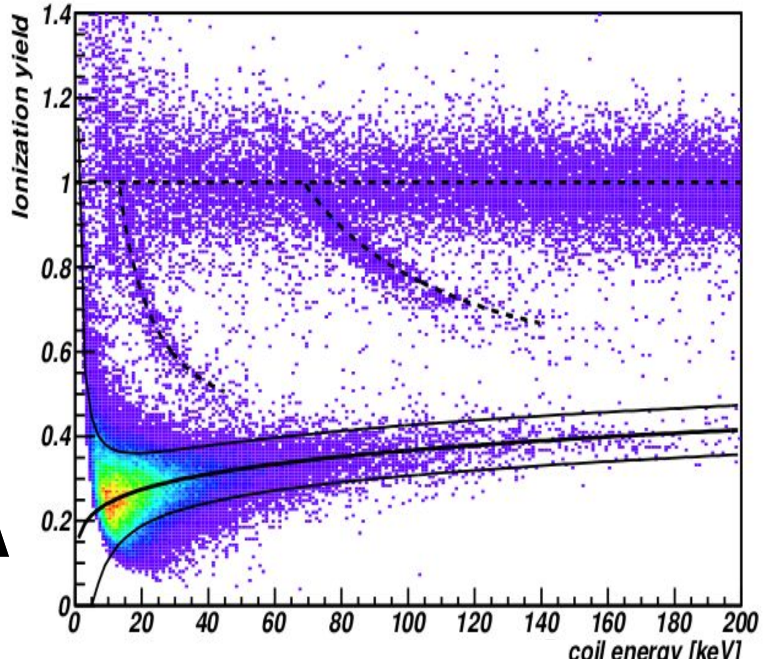
2nd Generation Ge detector.
Concentric electrodes



Electric field in the detector

- Simultaneous measurement of **Heat** (NTD thermometer) and **Ionization** (Al electrodes)
- Select events in fiducial volume from ionization.
- Reconstruct the **recoil energy**
- Discriminate events with **Q= Eionization / Erecoil**
- **Q=1** for electron recoils (mostly due to gammas)
- **Q=0.3** for nuclear recoils (due to neutrons and possible WIMP candidates)

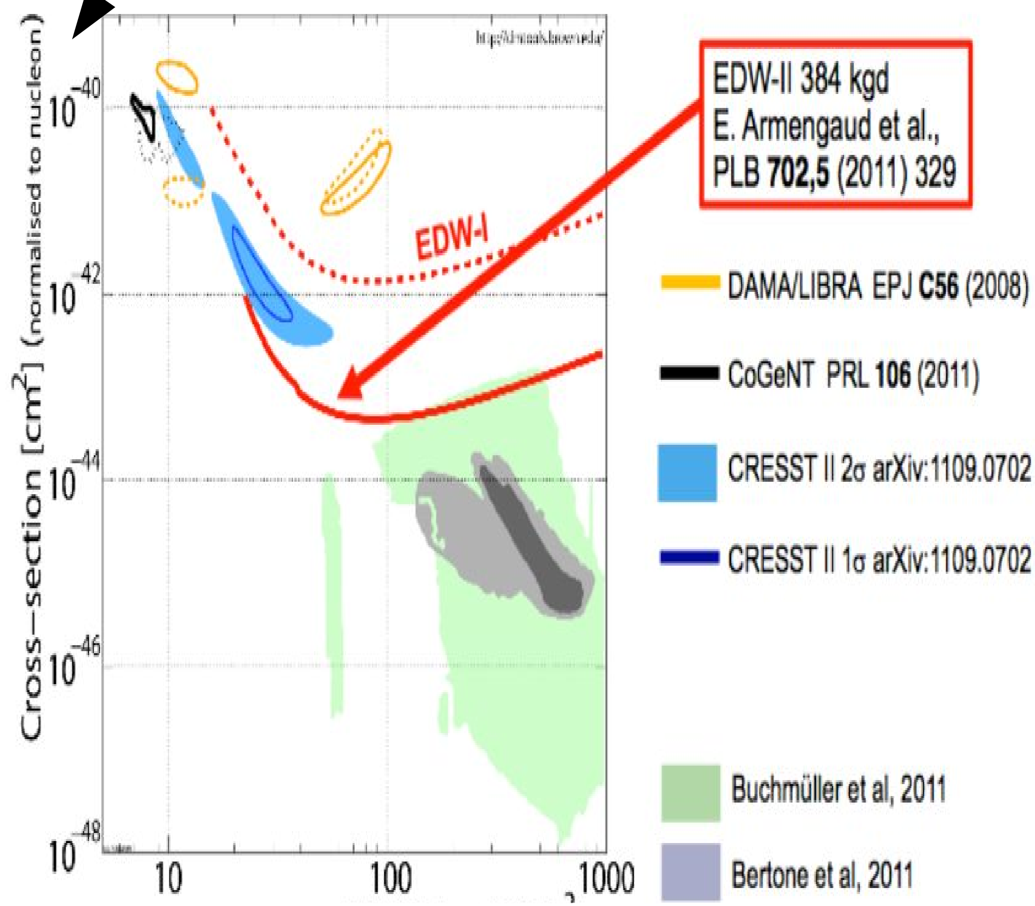
Edelweiss II WIMP search (2011)



Recoil energy

Q=Eionization / Erecoil

Cross section



WIMP mass ~ 10 GeV to 1TeV

Axion recap

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

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

- The **sun** should be an intense source of axions through various processes:
  - **Reactions of the main solar cycle** e.g. : **$p + d \rightarrow {}^3He + A$ (5.5 MeV) (g_{AN})**
  - Production in low lying (eg Fe at 14.4 keV) **magnetic transitions (g_{AN})**
  - Primakoff effect: **photon** axion **conversion $\gamma + \gamma \rightarrow A$ ($g_{A\gamma}$)**
  - Axion **Bremsstrahlung $e^- + Z \rightarrow e^- + Z + A$ (g_{Ae})**
  - Axion **Compton scattering** process **$\gamma + e^- \rightarrow e^- + A$ (g_{Ae})**

Axion recap

Couplings involved:

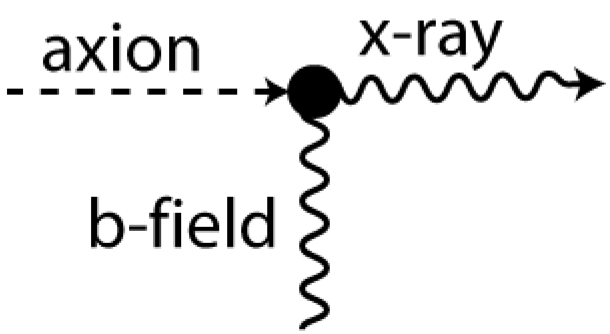
- Coupling to electrons : **gAe**
- Coupling to nucleons : **gAN**
- Coupling to photons : **gAγ**

Couplings involved in detection in Ge detectors:

gAe: conversion of the incoming axion into electrons
gAγ: conversion of the incoming axion into photons

Question: How can we combine these production channels to the detection channels in the Ge detectors in the most efficient/model independent way?

Primakoff production and detection of solar axions

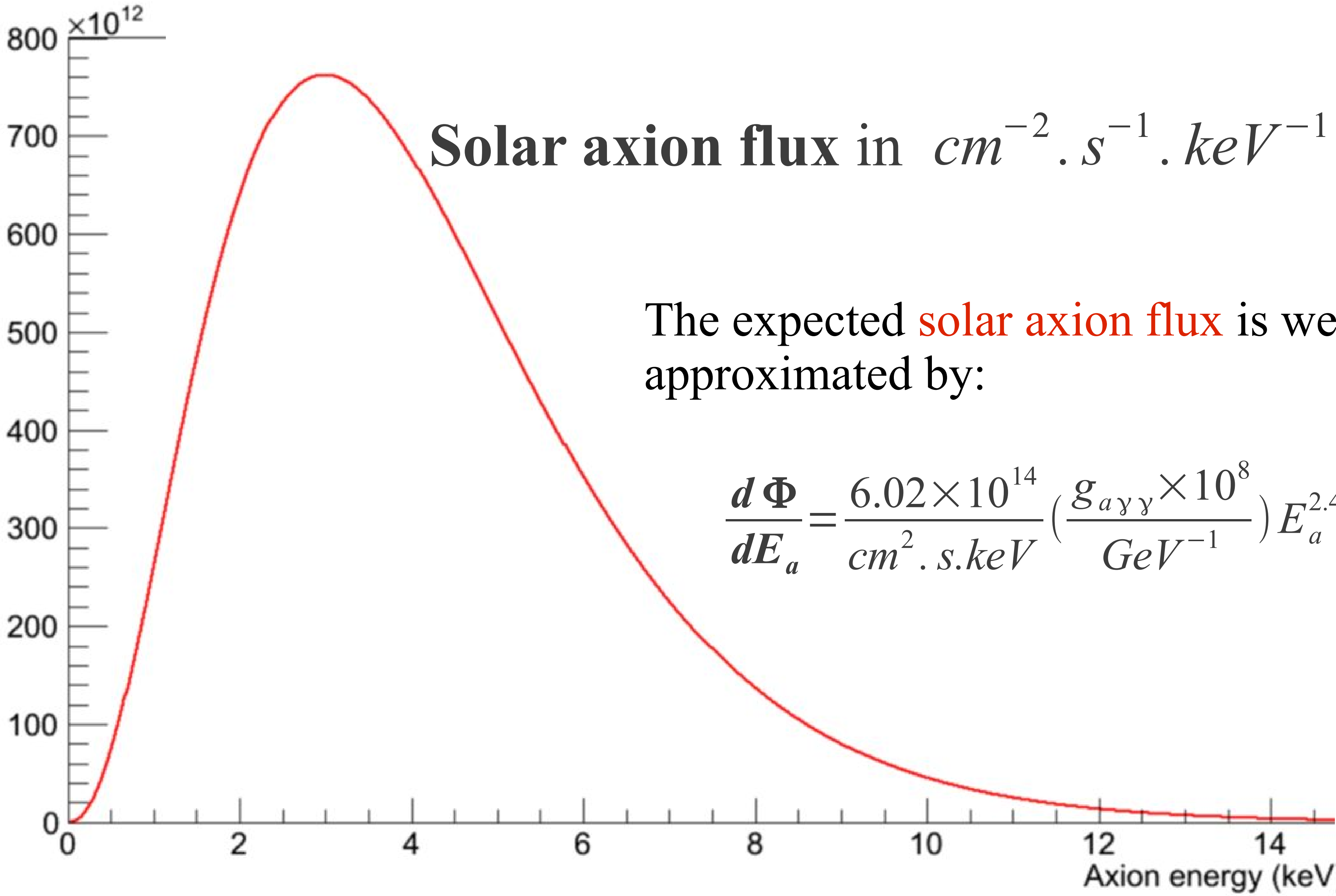


$$L = -g_{a\gamma\gamma}\,\psi_a\,\boldsymbol{B}.\boldsymbol{E}$$ [1]

The incoming solar axion can be converted into a photon through interaction with the electromagnetic field of the **Ge** detectors.

The aim is to get a limit on gAγ (the only coupling we consider in this case)

Primakoff production and detection of solar axions



Solar axion flux in $cm^{-2}.s^{-1}.keV^{-1}$

The expected solar axion flux is well approximated by:

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

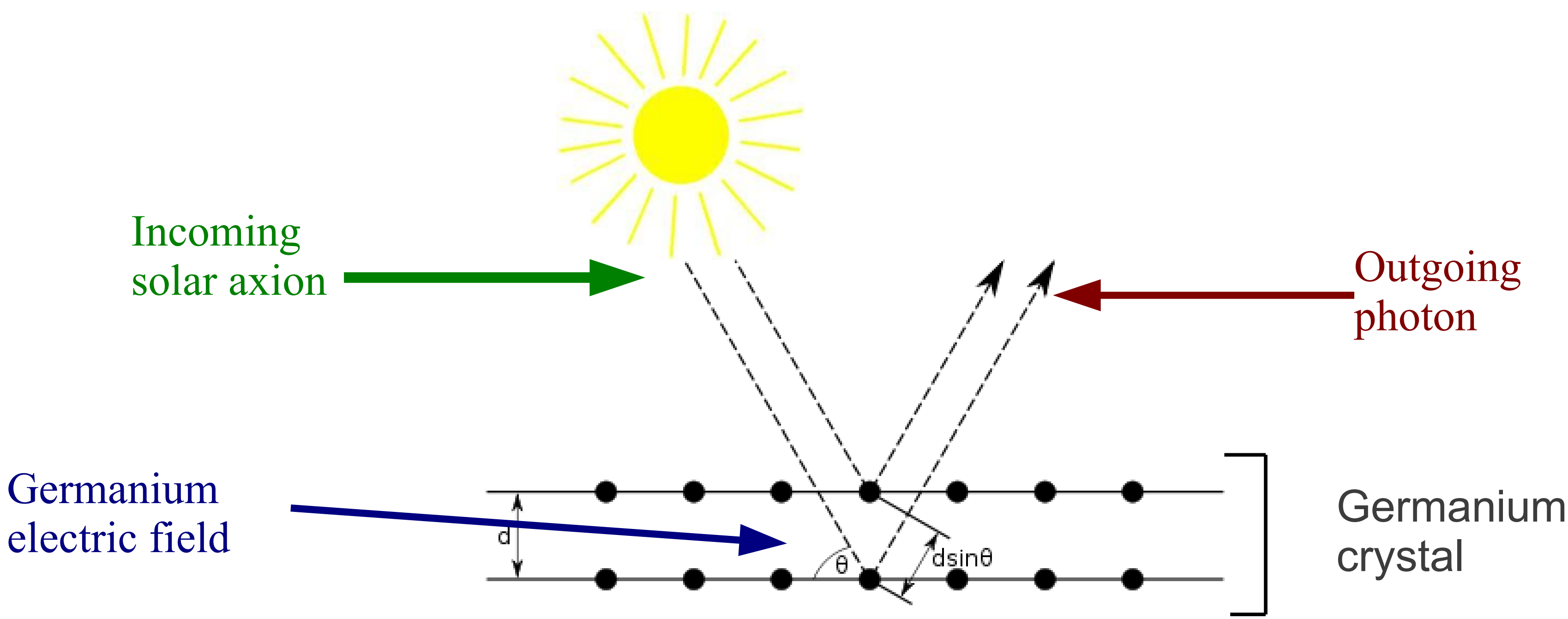
Primakoff production and detection of solar axions

$$R \propto \frac{d\sigma}{d\Omega}\frac{d\Phi}{dE_a}$$ ([1])

Where **R** is the expected axion count rate.

The Germanium atomic form factor

$$\frac{d\sigma}{d\Omega} \propto F_a(q) \propto$$ Fourier transform of the electric field.



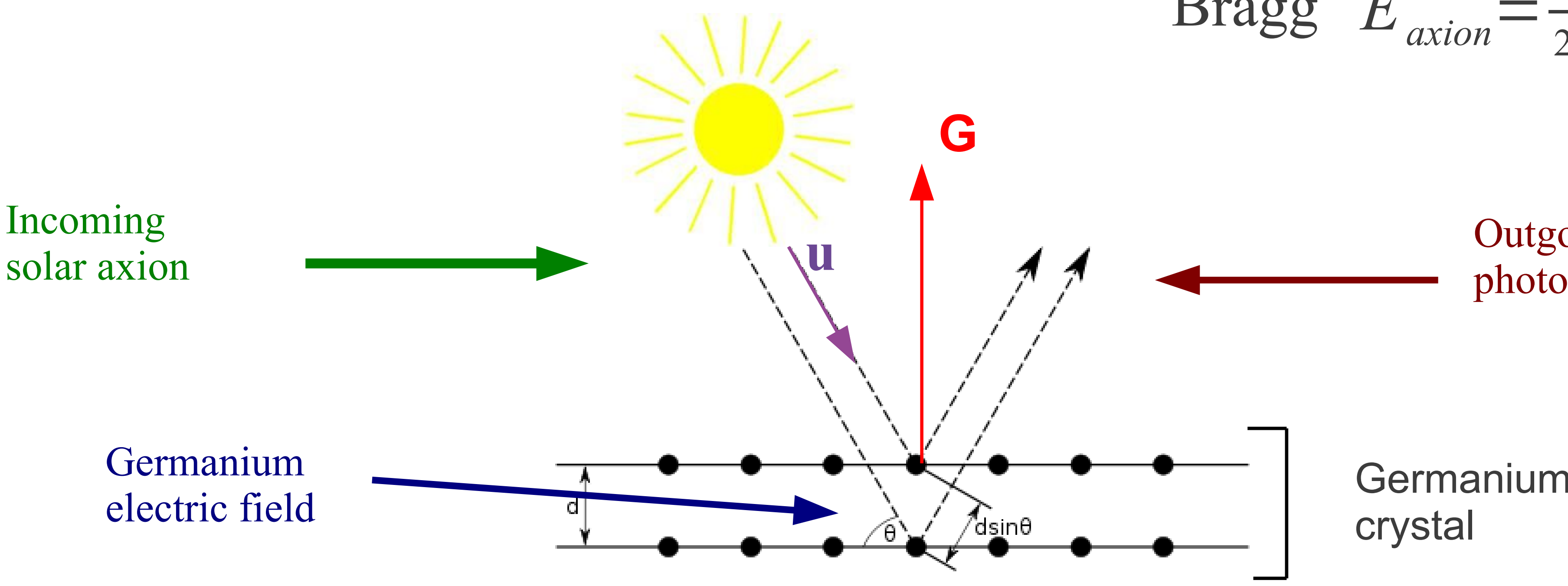
Primakoff production and detection of solar axions

Typical transferred momentum has wavelength close to interatomic spacing.

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

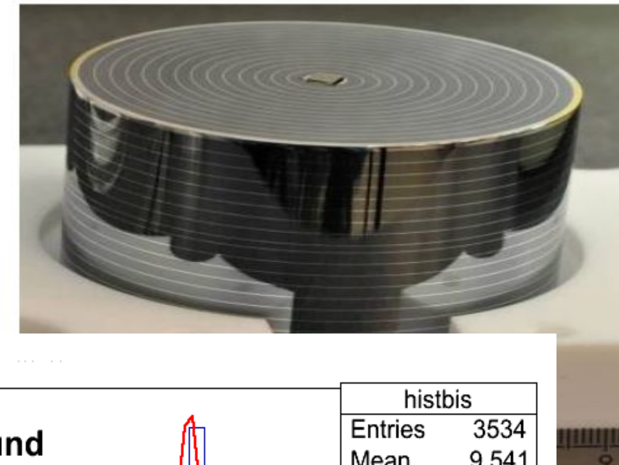
CDMS , SOLAX, COSME have already published results on axion Primakoff conversion in Ge crystals.

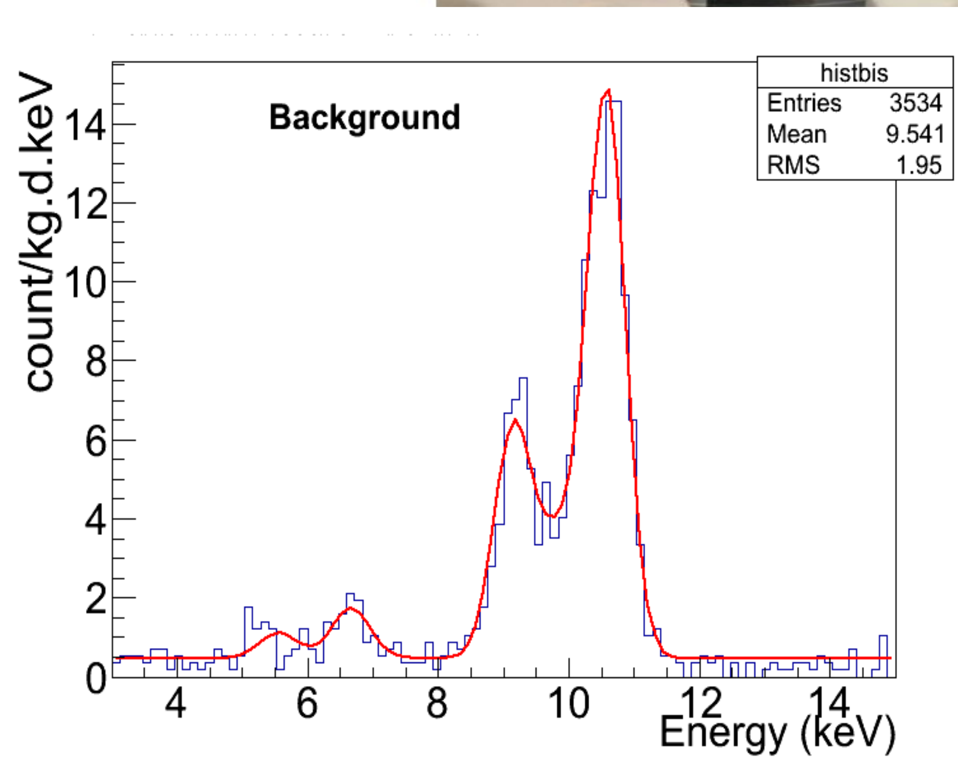
Bragg $E_{axion} = \frac{\vec{G}^2}{2\vec{u}\cdot\vec{G}}$



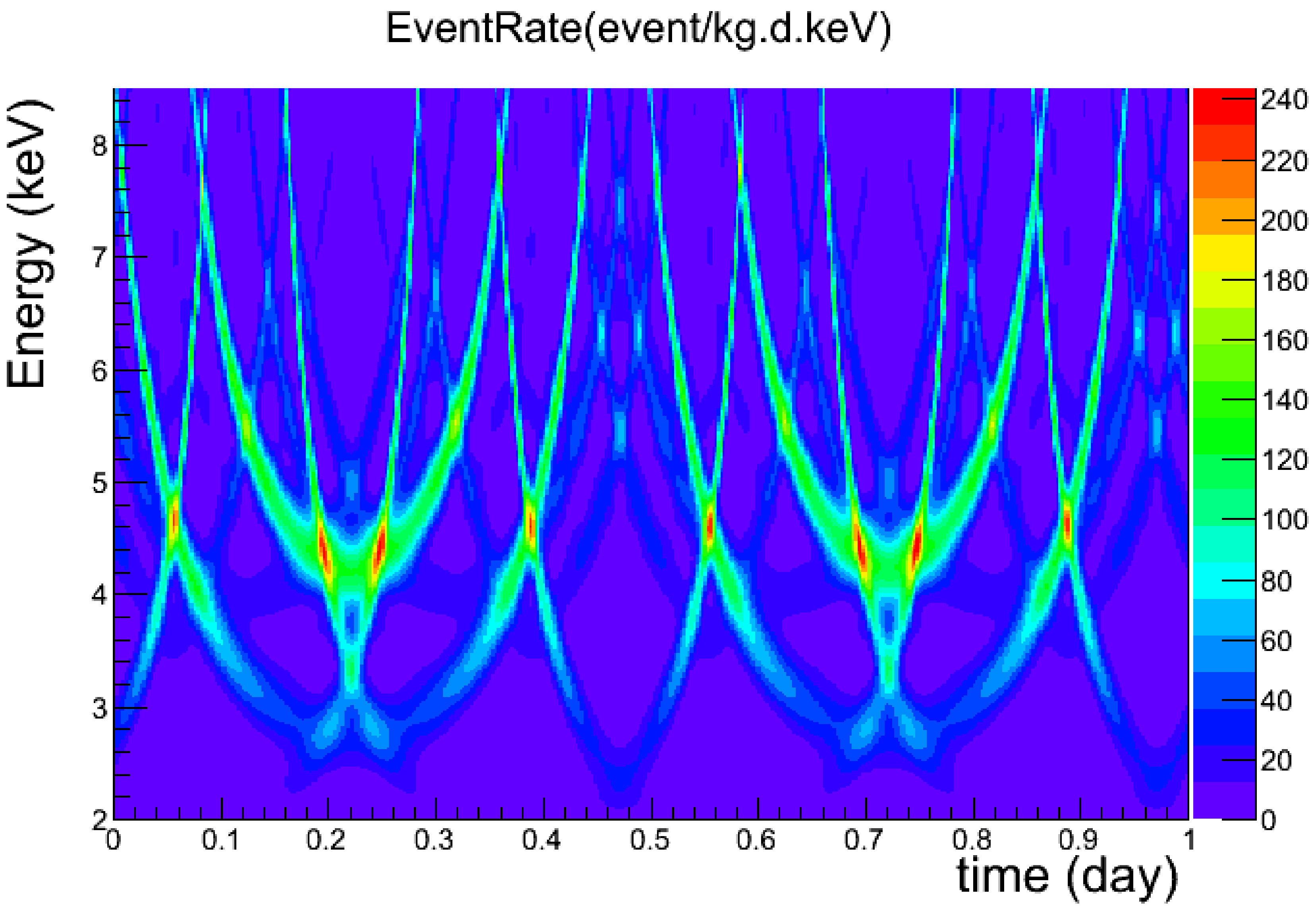
Preliminary Ge detectors parameters

- **Detector resolution**: FWHM ~ 0.5 keVee
- **Detector exposure** ~ 50kg.d (only one detector was studied here)
- **Detector threshold**: ~ 3 keVee
- **Background:**
  cst+peaks due to natural decays/Auger electrons...





Expected count rate during 1 day

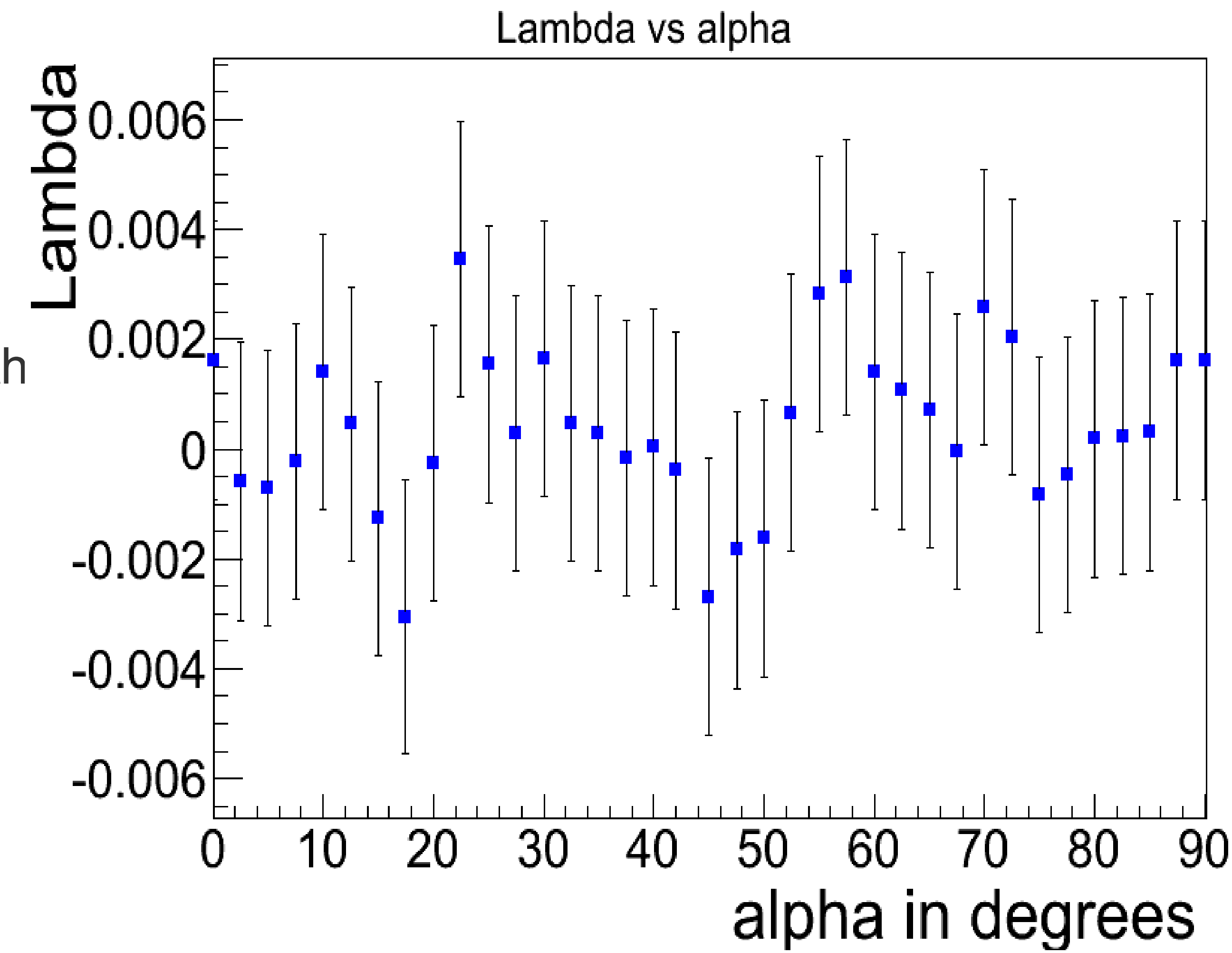


Preliminary results

$$\lambda = g_{a\gamma\gamma} \times (10^8 / GeV^{-1})^4$$

Error bars are 1.64 σ

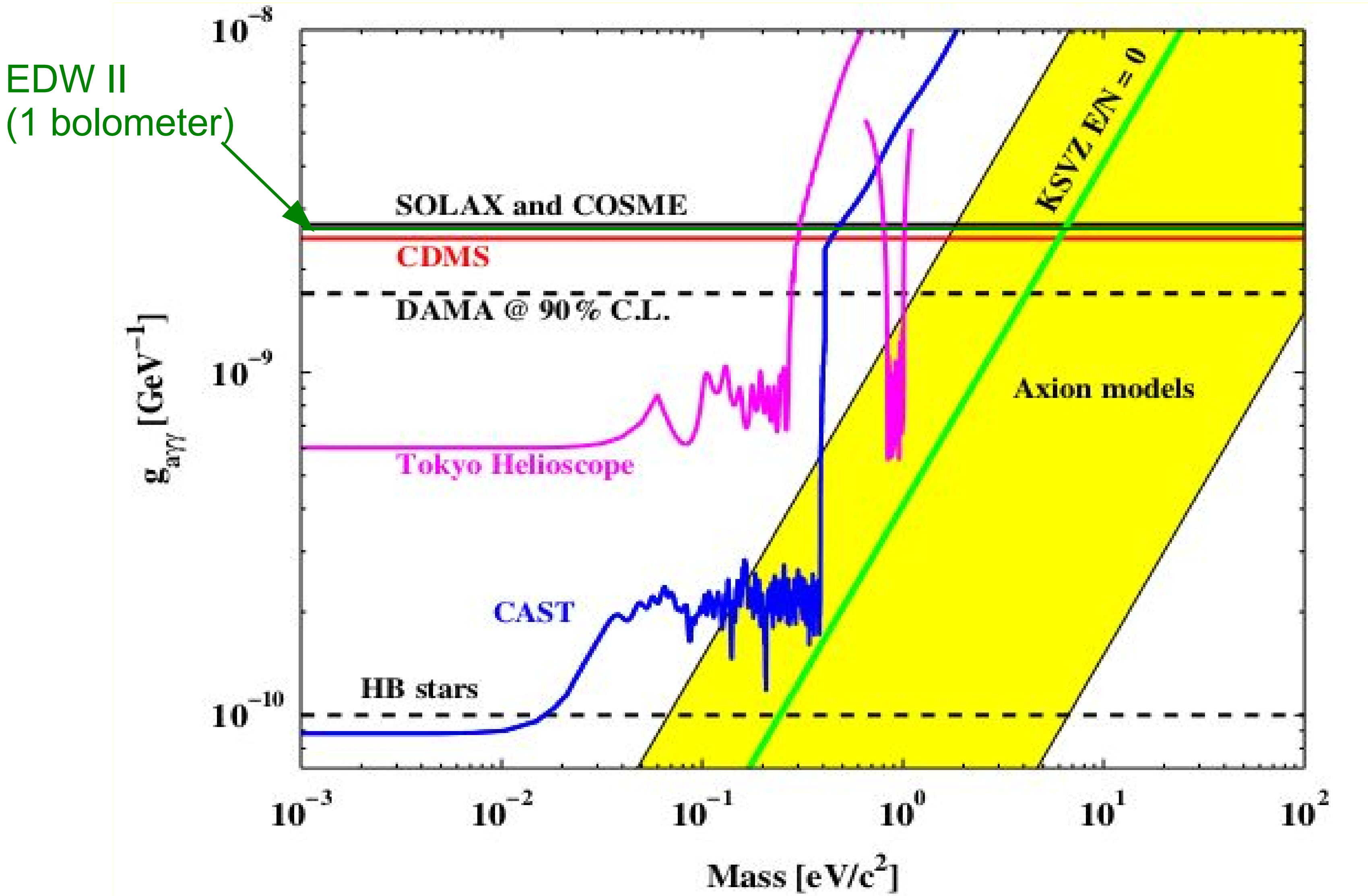
α is the azimuth orientation of th detector: **in EDW II, the orientation is unknown.**



Most **conservative limit:**

$$g_{a\gamma\gamma} < 2.78 \times 10^{-9}\, Gev^{-1}$$

Preliminary results



Future Prospects

- Possible improvements using EDW III upcoming data:

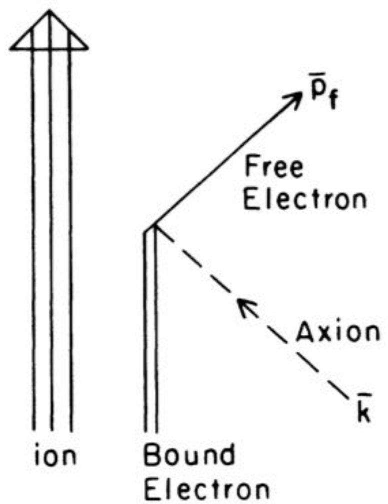
  background, resolution, exposure and knowledge of the orientation of the crystal

$$g_{a\gamma\gamma} \sim \left(\frac{b}{M_d T}\right)^{1/8}$$

- But the margin is tiny due to the power of 1/8

Axion detection with Axio-Electric effect

gae: Axio-electric effect: equivalent of photoelectric effect



Solar axions

Production:
gAN (14.4 keV)
gAe (Compton/Bremsstrahlung)
Relativistic

Detection:
gAe

DM axions

Hypothesis:
Axions constitute all DM.
Not relativistic.

Detection:
gAe

A **positive axion** signal would be seen as a peak at the axion mass, spread by the energy resolution.

In the **absence of peaks,** statistical limits can be placed on the number of axion events

Figure from:

A.V. Derbin et al.,
Search for solar axions produced by Compton process and bremsstrahlung using axioelectric effect

arXiv:1206.4142v2

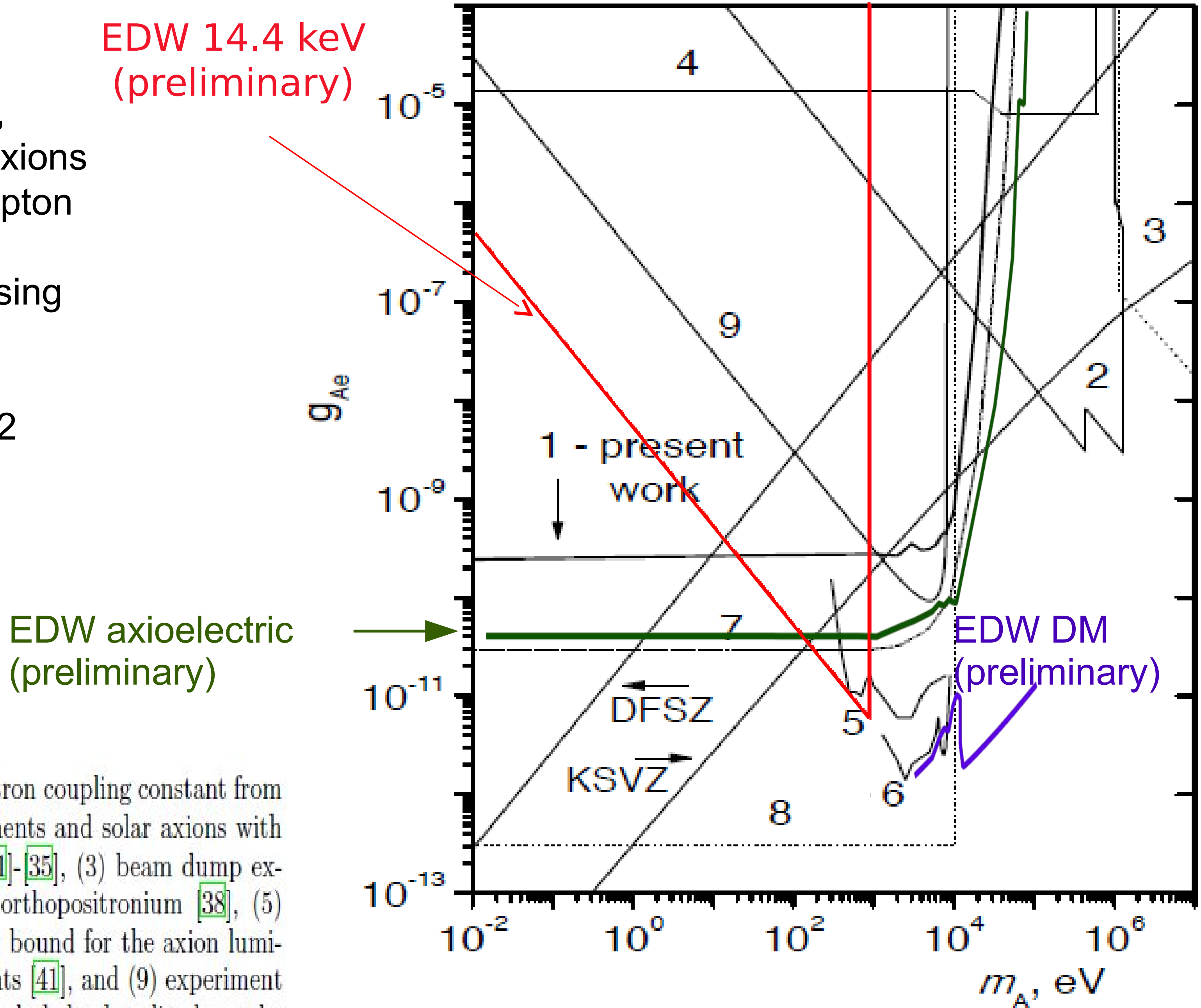


FIG. 6. Bounds for the axion-electron coupling constant from (1) this work, (2) reactor experiments and solar axions with energies of 0.478 and 5.5 MeV [31]-[35], (3) beam dump experiments [36, 37], (4) decay of orthopositronium [38], (5) CoGeNT [39], (6) CDMS [40], (7) bound for the axion luminosity of the Sun [22], (8) red giants [41], and (9) experiment with ^{169}Tm [26]. The regions of excluded values lie above the corresponding lines. The inclined lines show the g_{Ae} values in the DFSZ and KSVZ ($E/N = 8/3$) models.

Conclusion

- EDW can analyse a wide variety of channels. Limits are not as good as astrophysical boundaries but usually much safer.
- Primakoff production and detection: results so far competitive with other experiments (COSME, CDMS...) and will be improved with EDW III.
- Other channels are currently under investigation and we are working to find the best way to combine them.

Preliminary results on gAe

VERY PRELIMINARY

$$g_{AE}(90\% C.L.) = \left(\frac{2 * r_{sn}}{\sigma_{pe} * m_A} \right)^{1/2} * \left(\frac{A}{1.29 \cdot 10^{19}} \right)^{1/2} * \left(\frac{\sigma_{bol} \cdot dN/dE}{W \cdot T} \right)^{1/4}$$

90% CL limits on axion-electron coupling constant versus axion mass. The shaded band shows the predicted band for g_{Ae} for ALPs under the assumption $\Omega_{DM} = 0.23$.

m_A Axion mass

r_{sn} significance level (signal to noise ratio)

σ_{bol} sigma

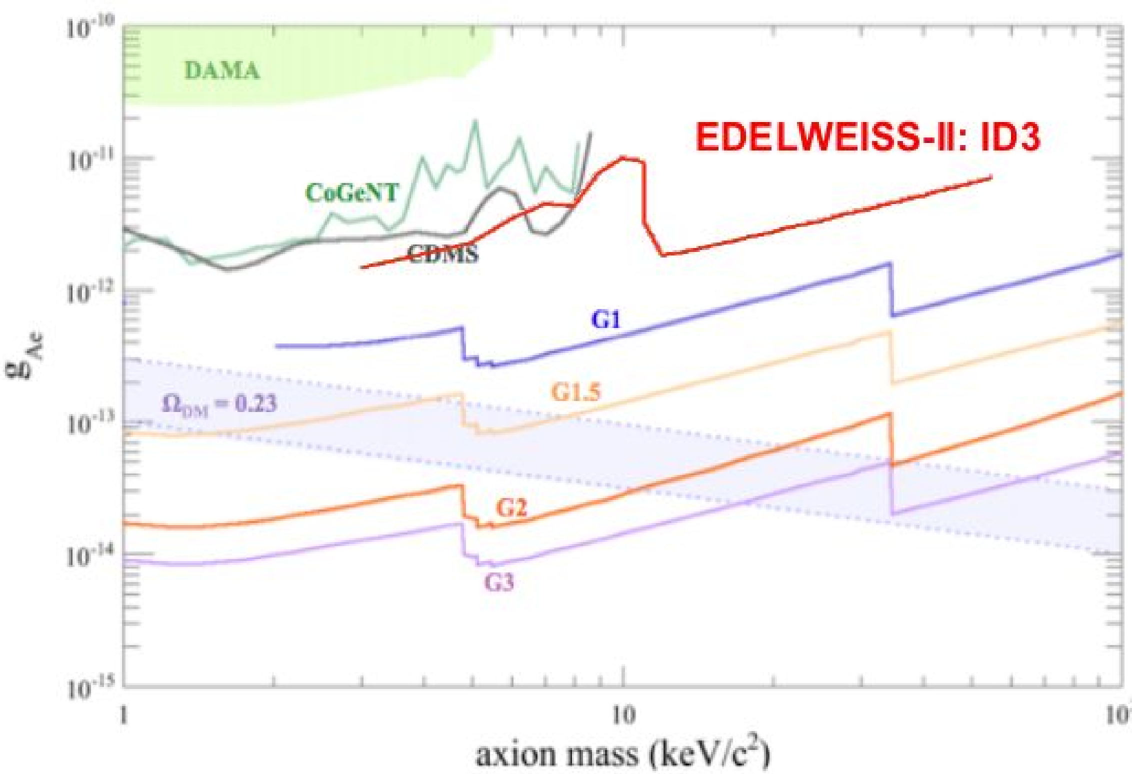
W fiducial mass

σ_{pe} photoelectric cross section

dN/dE differential bkg rate

T data-taking live-time

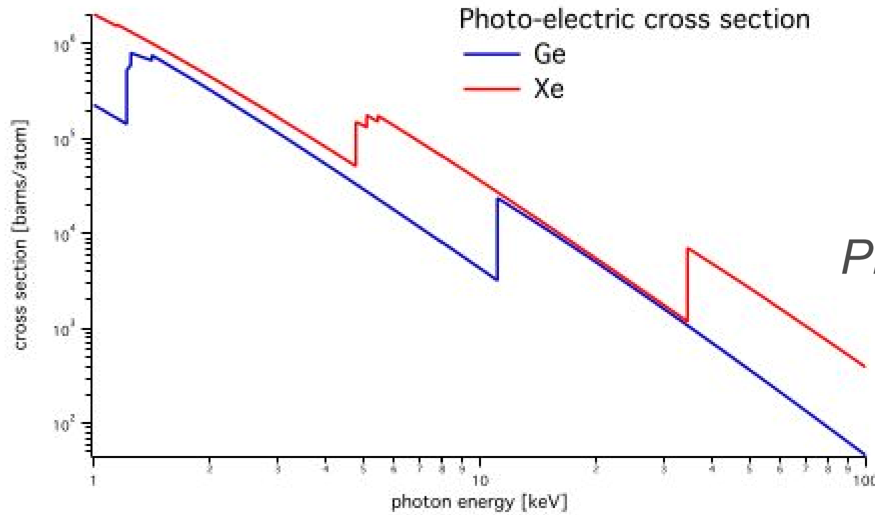
From Feldman-Cousins



G1	XENON100
G1.5	LUX/XMASS
G2	XENON1T
G3	XAX

Galactic (DM) axions through axioelectric effect

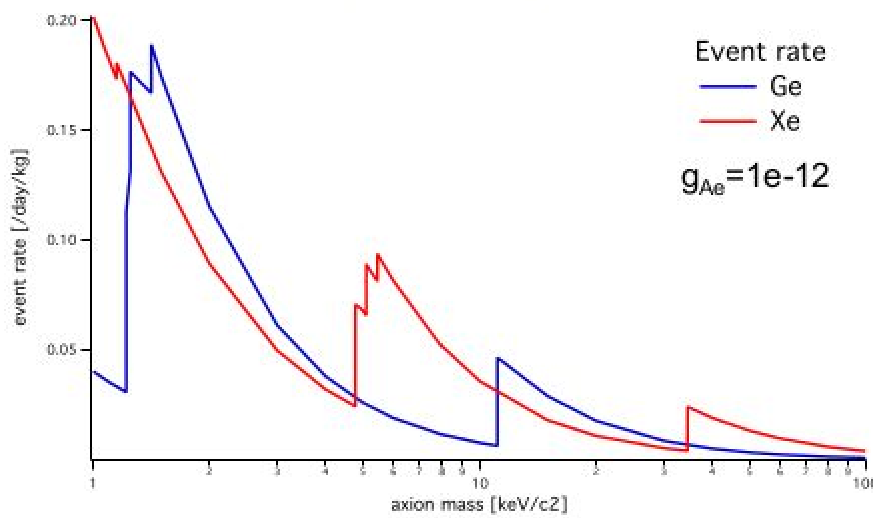
Cross section



Phys Rev D 78 115012

$$R[/\mathrm{kg/day}] = \left(\frac{1.29 \times 10^{19}}{A}\right) g_{Ae}{}^2 m_A[\mathrm{keV/c^2}]\sigma_{\mathrm{pe}}[\mathrm{barns}]$$

Event rate



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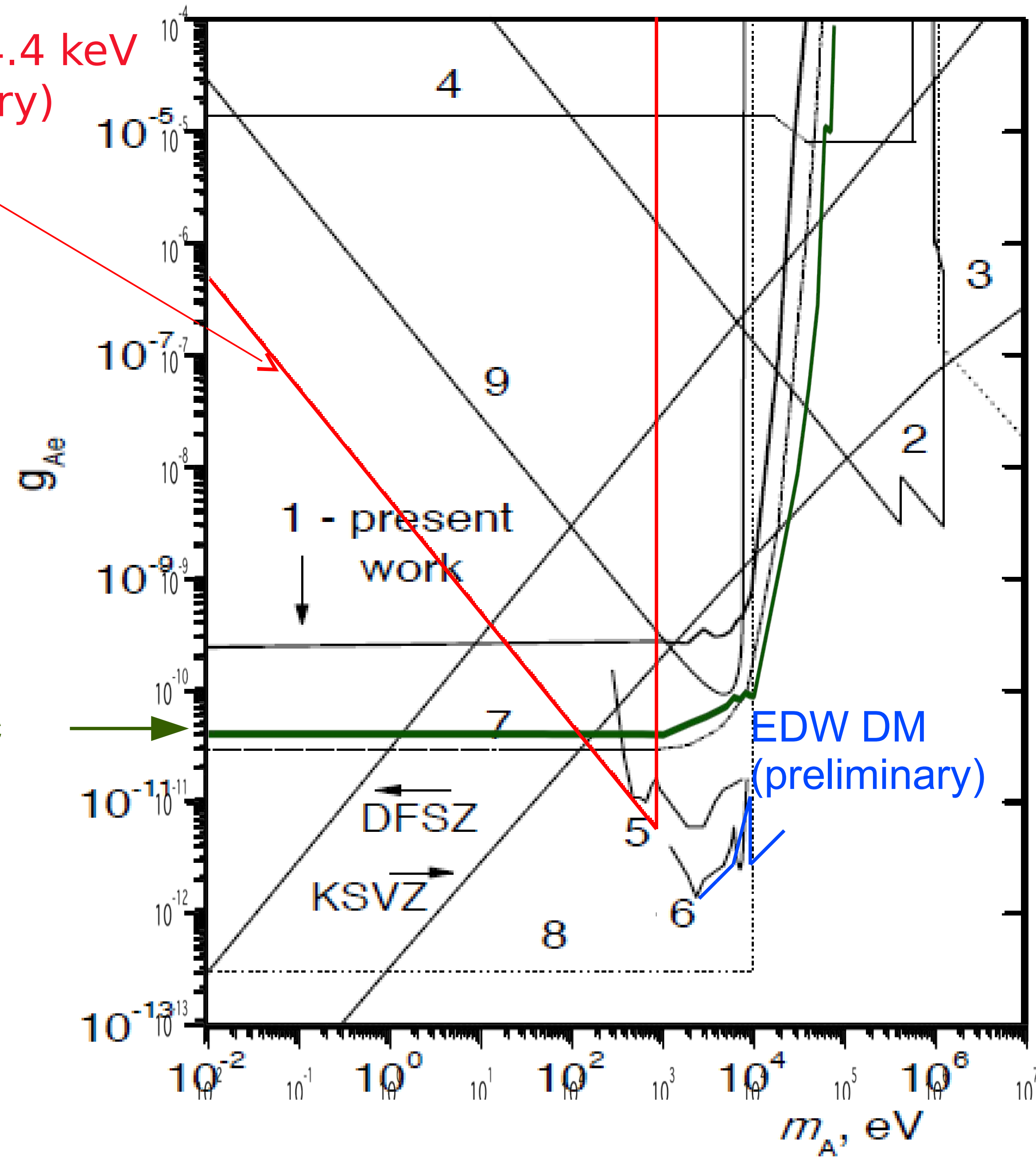

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