12TH PATRAS WORKSHOP ON AXIONS, WIMPS AND WISPS
20 - 24 June 2016
Jeju Island, South Korea

Axion searches with CDEX-1 experiment

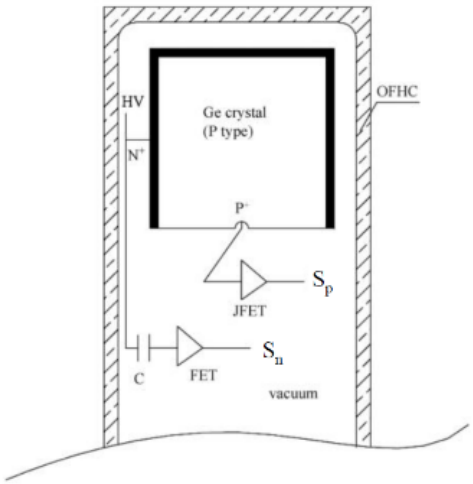
- ✓ Introduction of CDEX and CJPL
- ✓ Axion sources and expected rates in CDEX-1
- ✓ Data analysis
- ✓ Results
- ✓ Summary and prospect

On behalf of CDEX Collaboration
Shukui Liu, Tsinghua University
2016-06-21

CDEX in CJPL

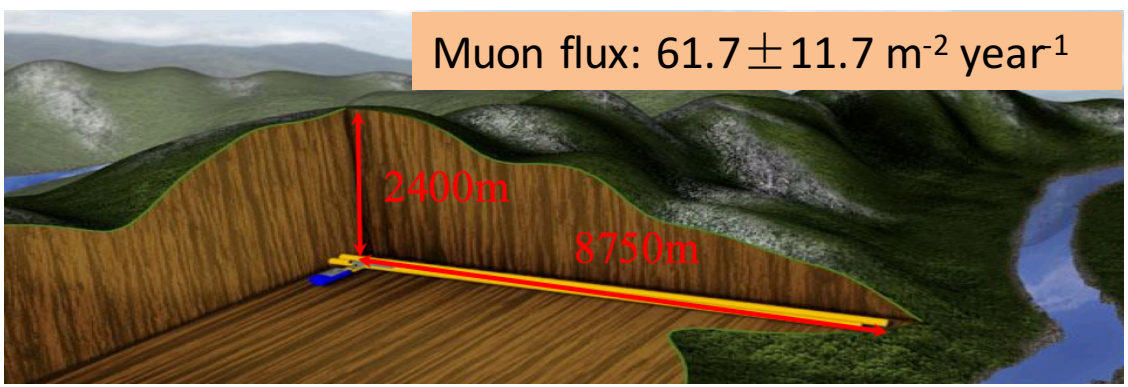
- CDEX: China Dark matter Experiment (Established in 2009)

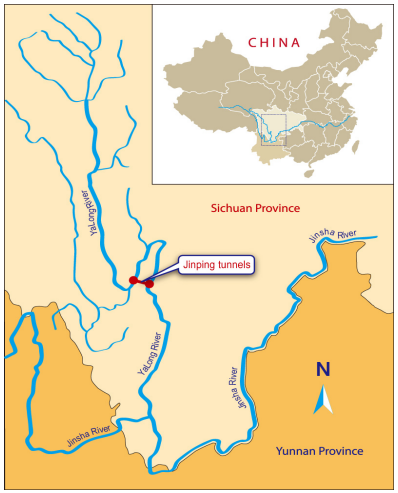
  Direct detection of low mass dark matter with PCGe (Point-Contact Germanium) array.



- Detector technology (PCGe)
  - ✓ ***Low energy threshold (~ 100eVee)***
  - ✓ ***Very good energy resolution***
  - ✓ ***Easy to scale up***

- Located at the CJPL—the deepest Laboratory (China Jinping Underground Laboratory)





Hao Jiang's talk.

CDEX-1 Experiment

- **HPGe technology**

✓ **1 kg-scale p-type point-contact Ge detector**

Large-mass "prototype" (~1 kg)

Low energy threshold (<500 eVee)

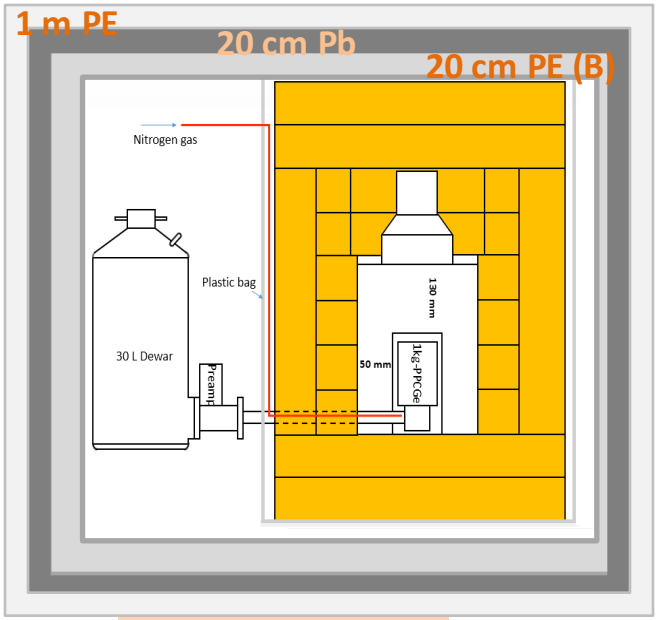
Good energy resolution (~200 eV @ 10.37 keV)

- **Active shielding technology**

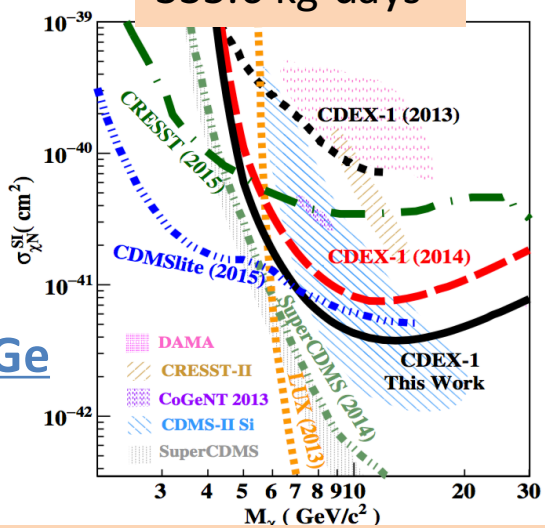
✓ **NaI(Tl) used as anti-Compton detector**

Low energy threshold (~ 10 keV)

"bucket"-like: enclosed the cryostat of Ge



335.6 kg-days



Excellent energy resolution and low threshold of PCGe

⇩

Well Constrain the g_{Ae} couplings of axions

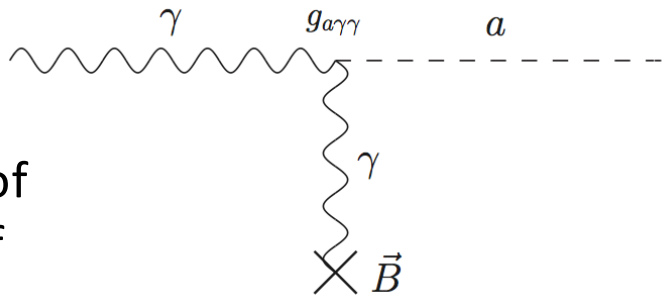
W.ZHAO et al., PRD 93 092003 (2016)

The sources of Axion

➢ Axion from Sun

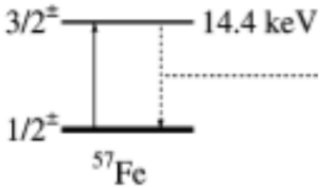
✓ Primakoff production

Produced by the inverse Primakoff conversion of thermal photons in the electromagnetic field of the solar plasma.

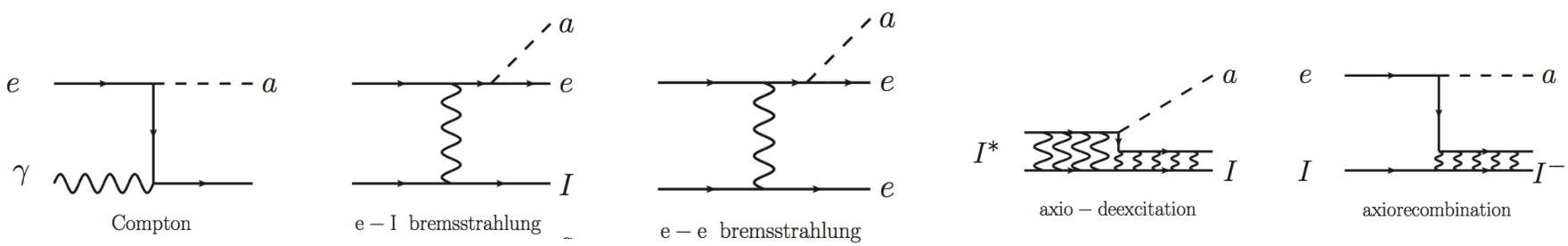


✓ M1 transition from ^{57}Fe (axion-nucleons)

1. Monochromatic axions of **14.4 keV** emmited in **M1 transition** of **^{57}Fe** with remarkable abundance in the Sun.
2. Low enough to be thermally excited in the hot interior.

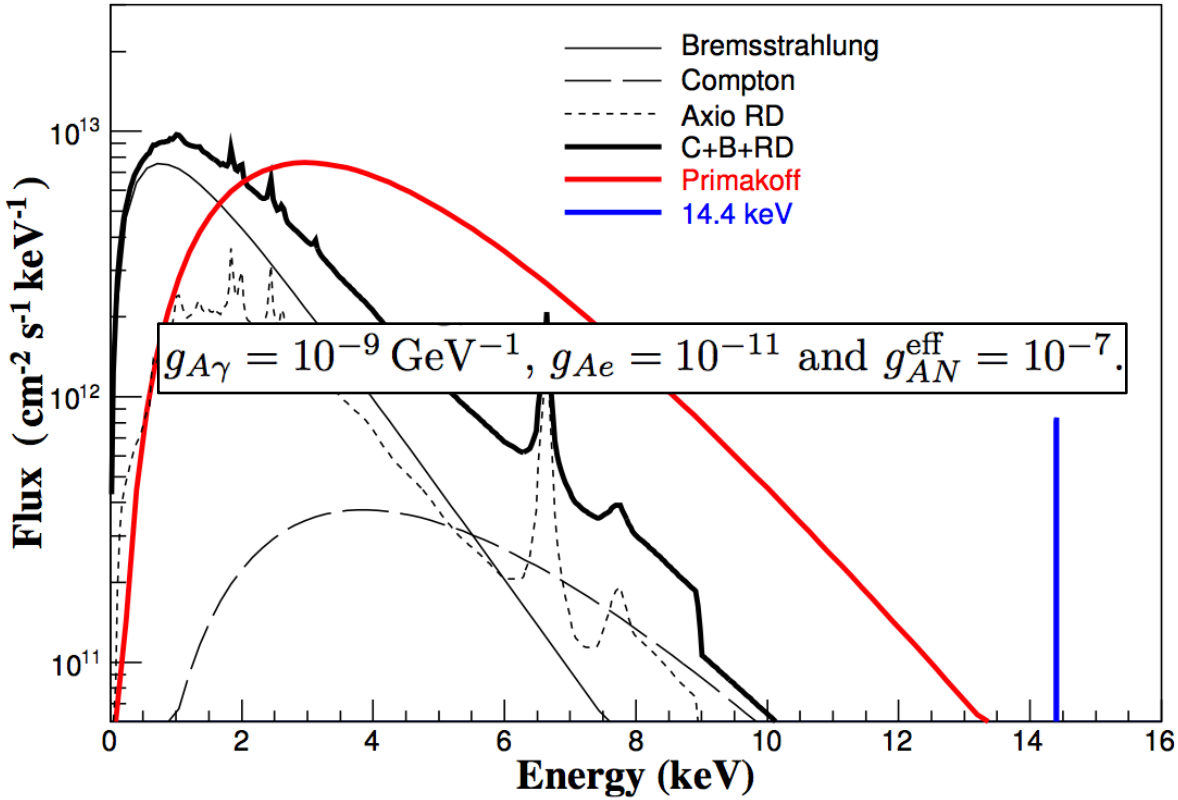


✓ C+B+RD — Compton, bremsstrahlung and axio-RD (recombination & de-excitaion) (axion-electron)



Expected axion fluxes from Sun

✓ **Expected axion fluxes from Sun**

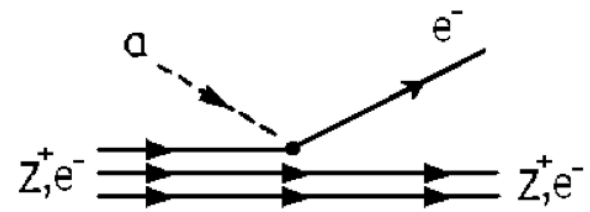


JCAP 11 (2013) 067; JCAP 05 (2013) 010

➢ **The axion-like particles (ALPs) can be one of the cold dark matter candidates.**

Axion detection with CDEX-1 Ge detector

- **axio-electric effect**
  - ✓ It is the equivalent of a photo-electric effect with the absorption of axion instead of a photon.



Axioelectric
or Photoelectric-like

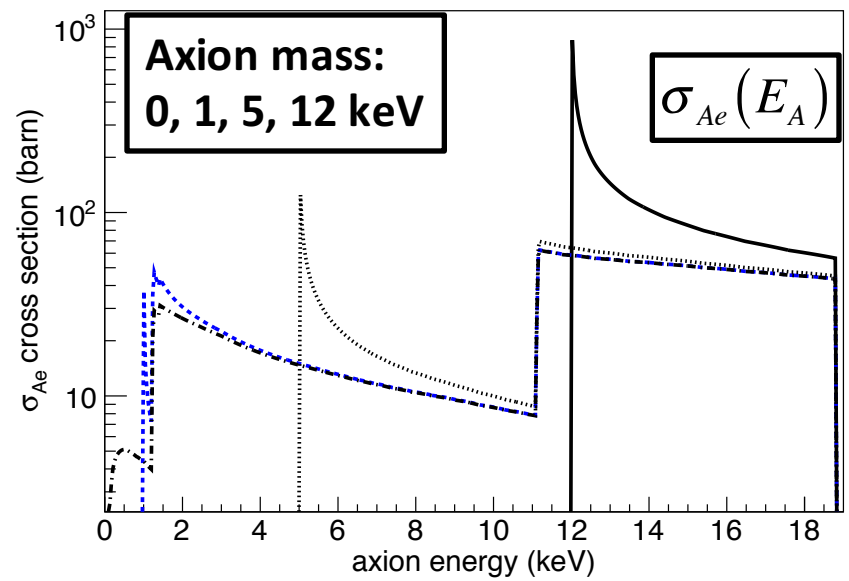
- $$\sigma_{Ae}(E) = \sigma_{\mathrm{pe}}(E)\frac{g_{Ae}^2}{\beta}\frac{3E^2}{16\pi\alpha m_e^2}\left(1-\frac{\beta^{\frac{2}{3}}}{3}\right)$$

β is the ratio of the axion velocity to the speed of light

α is the fine structure constant

$\sigma_{\mathrm{pe}}(E)$ is the photoelectric cross section

m_e is the electron mass



$g_{Ae} = 1$

Expected axion event rates in CDEX-1

$$R_i(E) = \int dE_A \sigma_{Ae}(E_A)\left(\frac{d\Phi_i}{dE_A}\right) \times \frac{1}{\sqrt{2\pi}} e^{-\frac{(E-E_A)^2}{2\sigma^2}}$$
$$\equiv \lambda_i(g_{Ae}) \times \overline{R}_i(E)$$

- **C+B+RD**

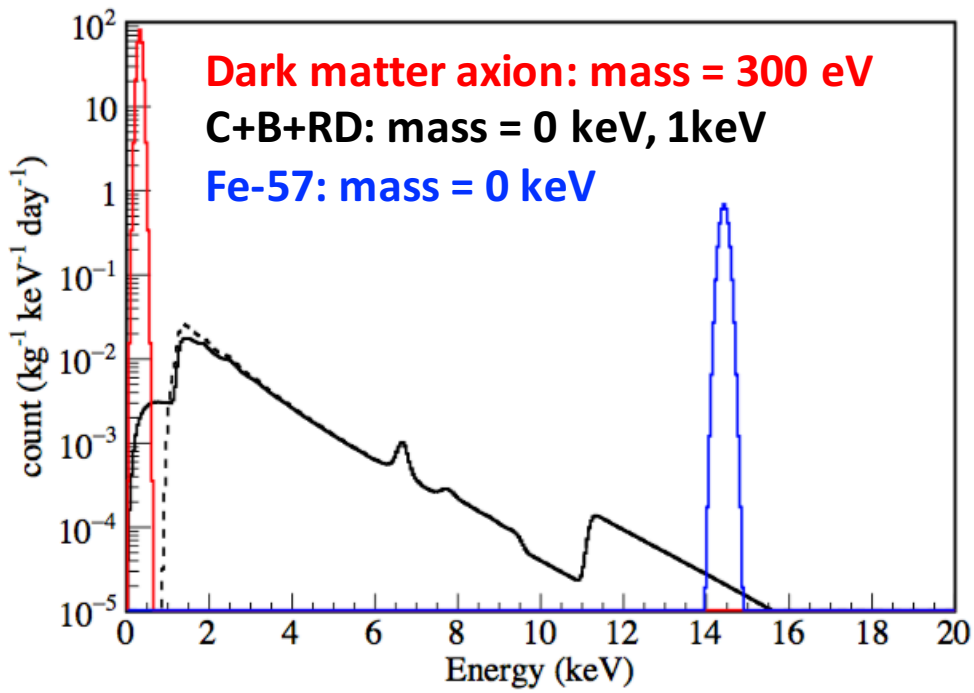
$$\lambda_{\mathrm{C+B+RD}} = g_{Ae}^4$$

- **^{57}Fe (14.4 keV)**

$$\lambda_{14.4} = (g_{Ae} \times g_{\mathrm{AN}}^{\mathrm{eff}})^2$$

- **Dark matter ALPs**

$$\lambda_{\mathrm{DM}} = g_{Ae}^2$$



$$g_{Ae} = 10^{-11} \text{ and } g_{AN}^{\mathrm{eff}} \times g_{Ae} = 10^{-16}.$$

Data Analysis—Data selection

- **Basic Cuts (BC):**

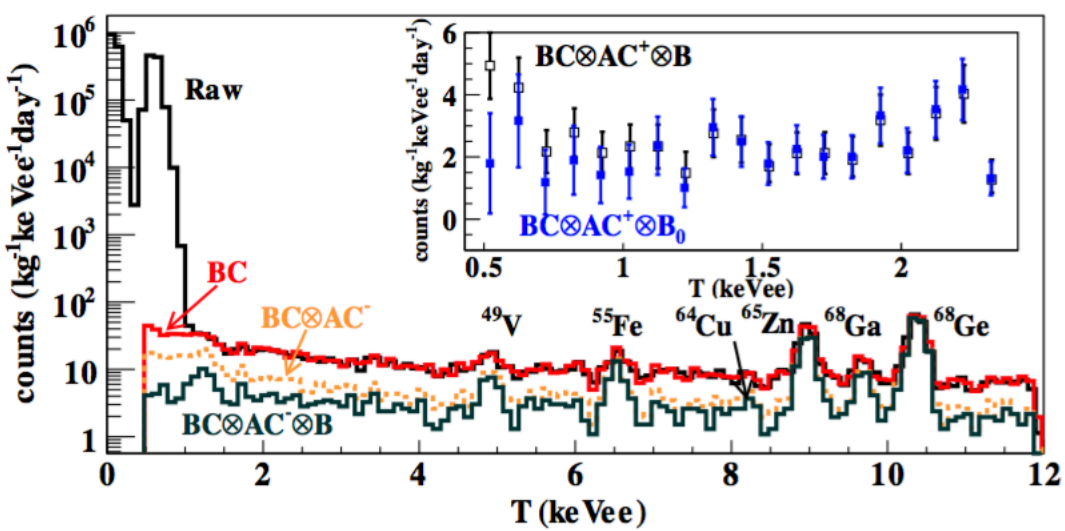
  Physical events vs. electronic noise & spurious signals

- **Anti-Compton Cut (AC):**

  AC^- vs. AC^+ events

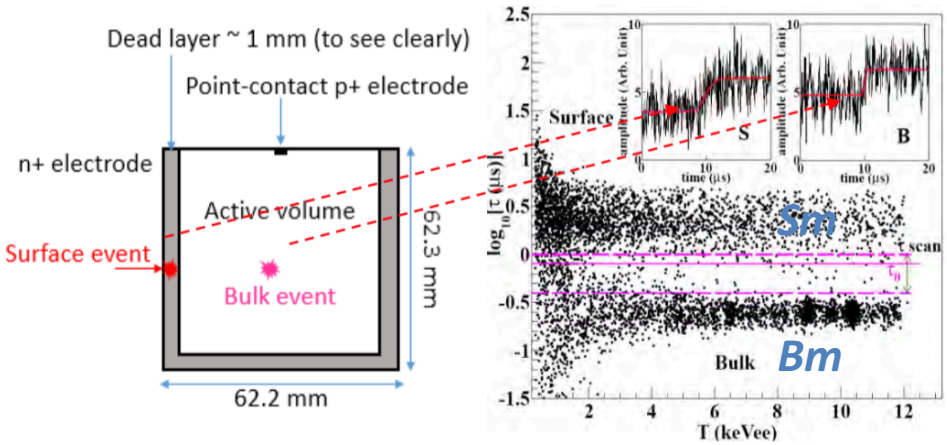
- **Bulk/Surface Cut (BS):**

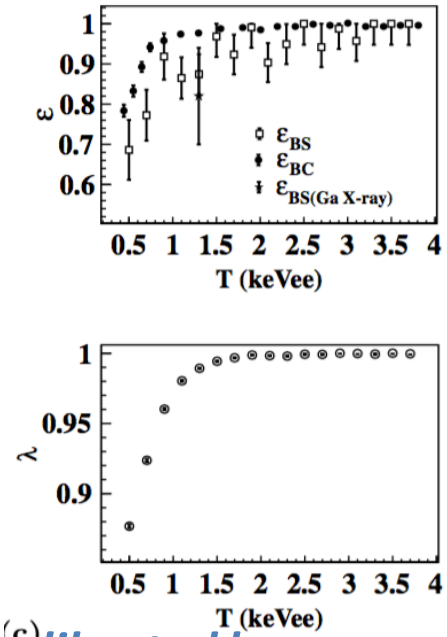
  Bulk/Surface events discrimination



Data Analysis—Bulk surface discrimination

➢ Bulk/Surface Discrimination





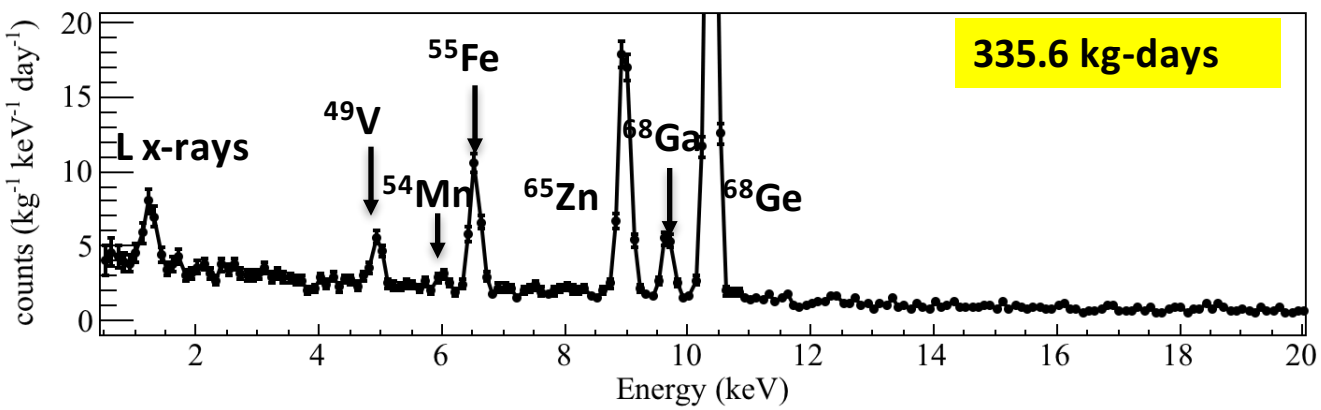
$$B_m = \varepsilon_{BC} \cdot [\varepsilon_{BS} \cdot B_r + (1 - \lambda_{BS}) \cdot S_r]$$
$$S_m = \varepsilon_{BC} \cdot [\lambda_{BS} \cdot S_r + (1 - \varepsilon_{BS}) \cdot B_r]$$

✓ *ε_{BS} and λ_{BS} can be calibrated by surface richer and bulk richer sources.*

➢ The bulk spectrum

✓ *Cosmogenic K/L x-rays*

✓ *Continuous background*



Data Analysis—statistical method

maximum likelihood

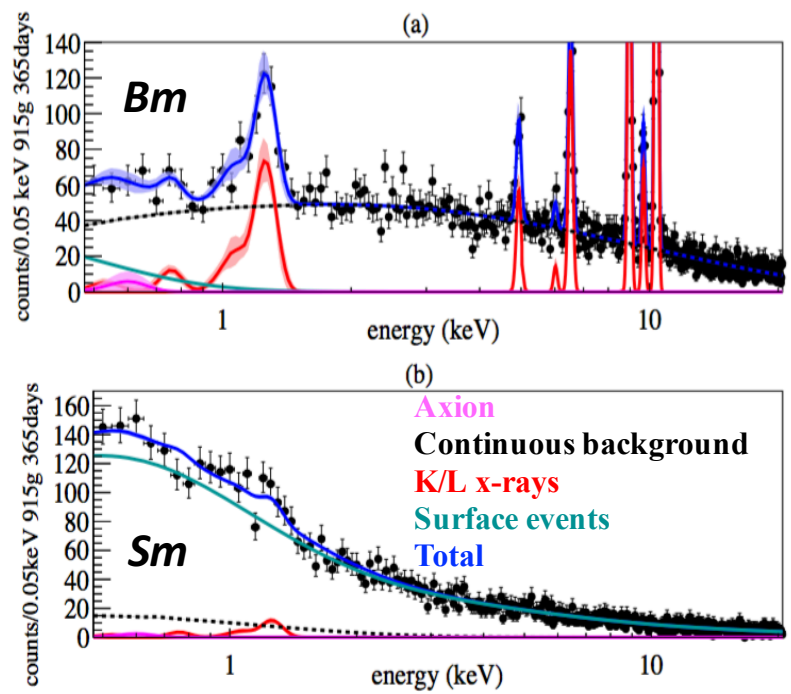
- ✓ *Unbinned, event-by-event fit*
- ✓ *Simultaneously fitting both Bm and Sm*

$$\mathcal{L}(E;\lambda) = \mathcal{L}_{B_m}(E;\lambda,\theta)\cdot\mathcal{L}_{S_m}(E;\lambda,\theta)$$

$$\log(\mathcal{L}) = -R_T + \sum_{i=1}^{N_{B_m}} B_m + \sum_{j=1}^{N_{S_m}} S_m$$

$$B_m = \varepsilon_{BC}\cdot[\varepsilon_{BS}\cdot B_r + (1-\lambda_{BS})\cdot S_r]$$
$$S_m = \varepsilon_{BC}\cdot[\lambda_{BS}\cdot S_r + (1-\varepsilon_{BS})\cdot B_r]$$

$$B_r = \lambda(g_{Ae})\cdot\overline{R}(E) + \theta_1\cdot b_{x-rays}(E) + \theta_2\cdot b_{con.}(E)$$



- ✓ *Local fit focus on the energy range of axion signature.*

Data Analysis—Systematic uncertainties

- **Background assumption uncertainties**

  Evaluated by different continuous background function.

- ✓ Dark matter (< 1keV): ~6 %
- ✓ C+B+RD: <5%
- ✓ ^{57}Fe: ~20 %

- **Energy resolution uncertainties**

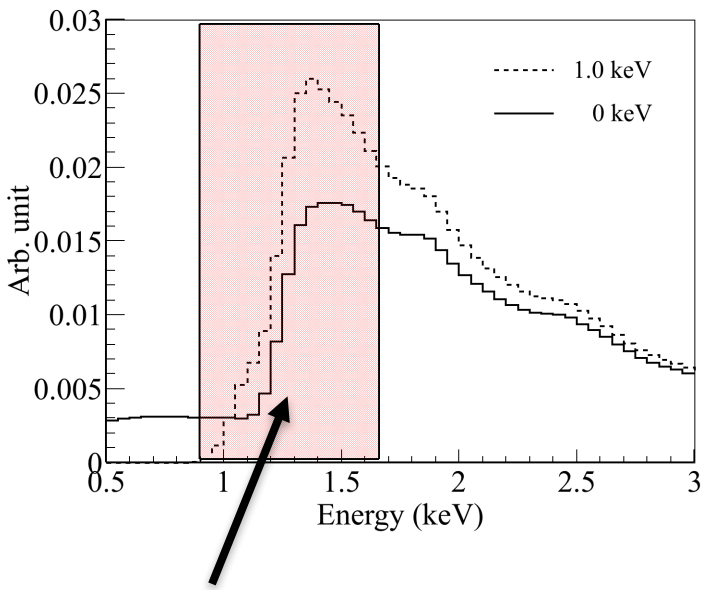
  Vary the energy resolution of axion by 10%.

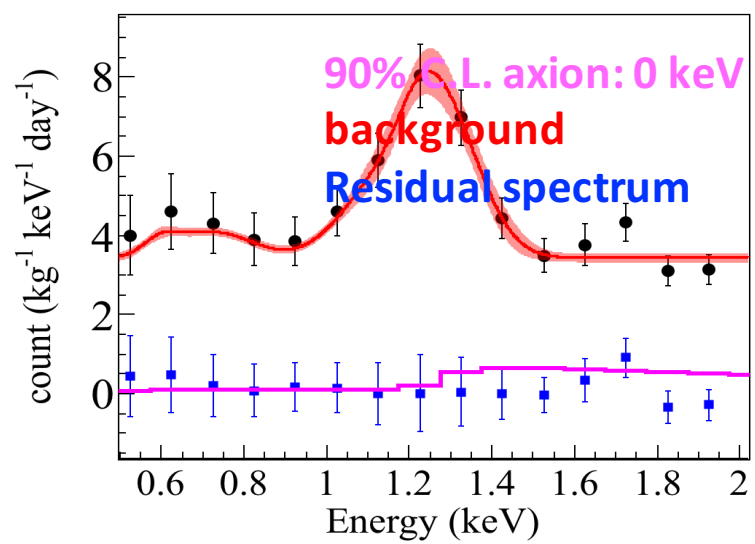
- ✓ Dark matter (< 1keV): ~3 %
- ✓ C+B+RD, ^{57}Fe : <1%

- **Bulk Surface event selection uncertainties**

- ✓ Dark matter (< 1keV): ~55 %
- ✓ C+B+RD: ~15 %
- ✓ ^{57}Fe : <1%

Results—C+B+RD





- ✓ **Signature:**

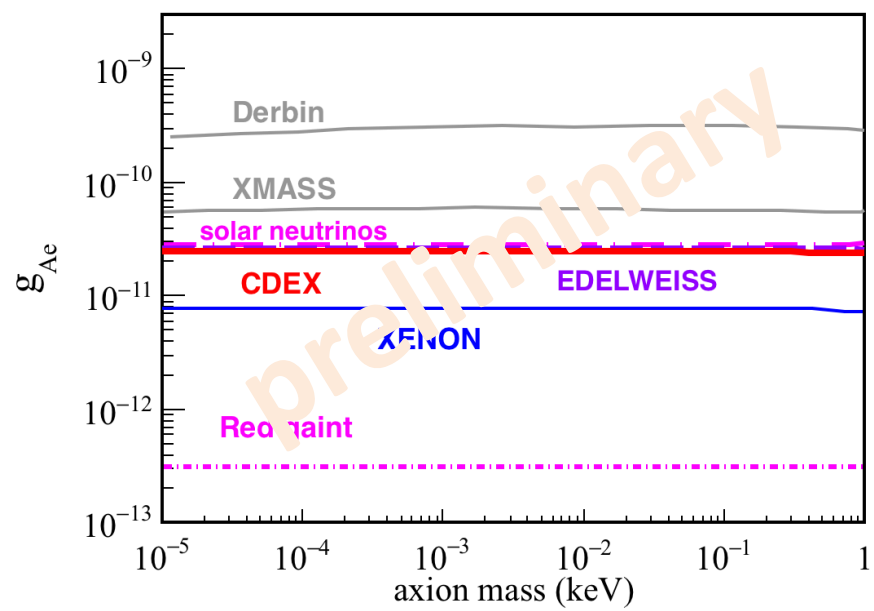
Saw-tooth at 1 keV ~ 1.6 keV

- ✓ **Local fit:**

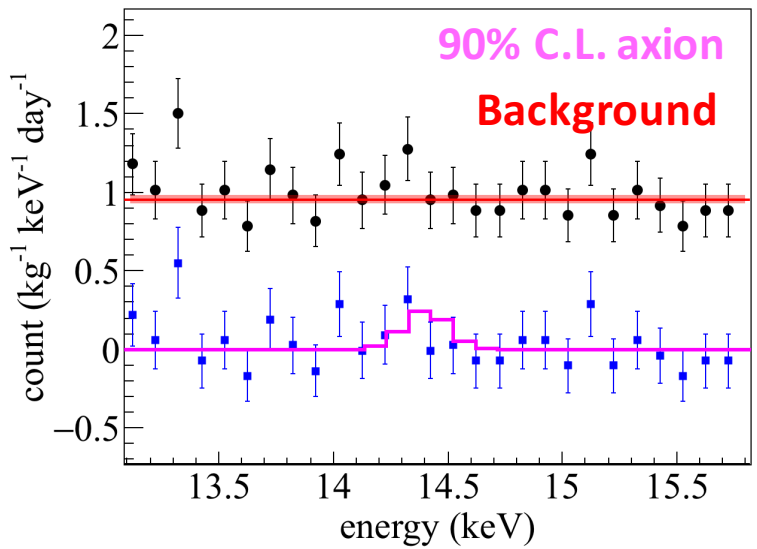
continuous background + L x-rays

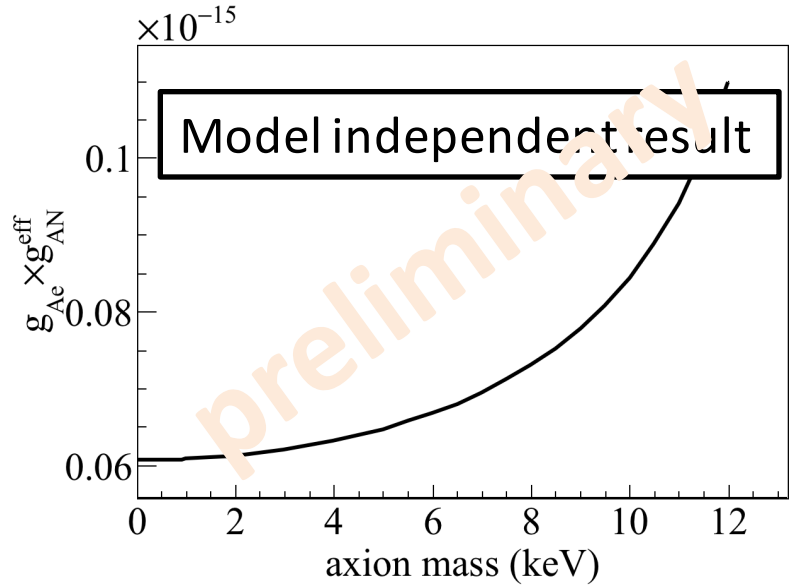
- ✓ **90% C.L. @ 0 keV**

$$g_{Ae} \sim 2.5 \times 10^{-11}$$



Results—Fe-57 (14.4 keV)





- ✓ **Signature:**

Monochromatic axion @ 14.4 keV

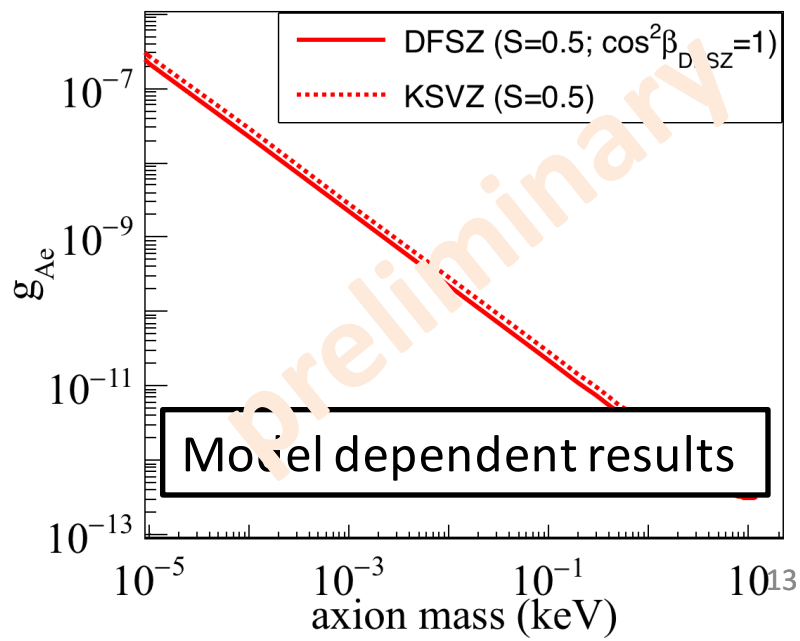
- ✓ **Local fit:**

continuous background

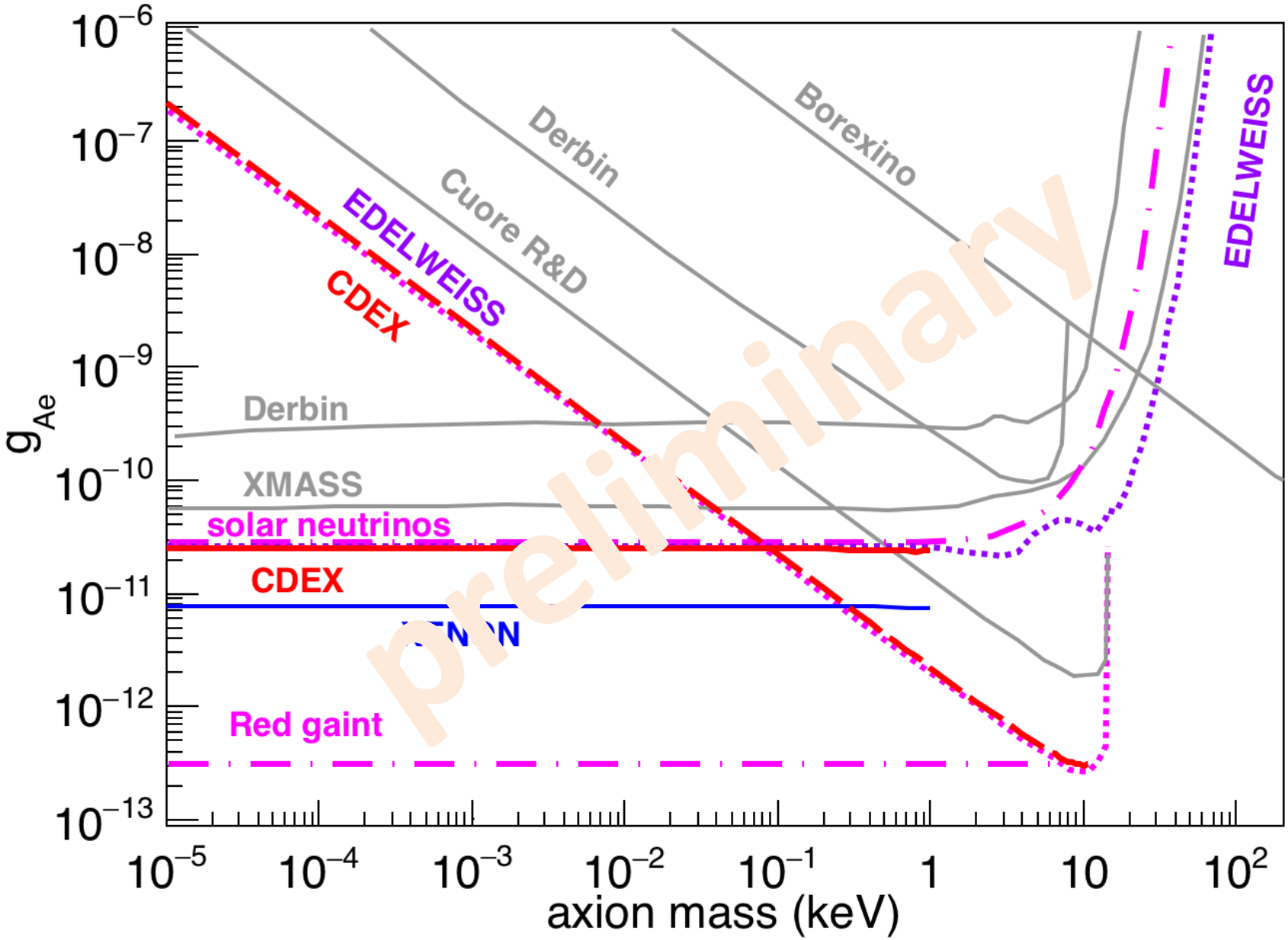
- ✓ **90% C.L. @ 0 keV**

$$g_{AN}^{\text{eff}} \times g_{Ae} \sim 6 \times 10^{-17}$$

Model independent result



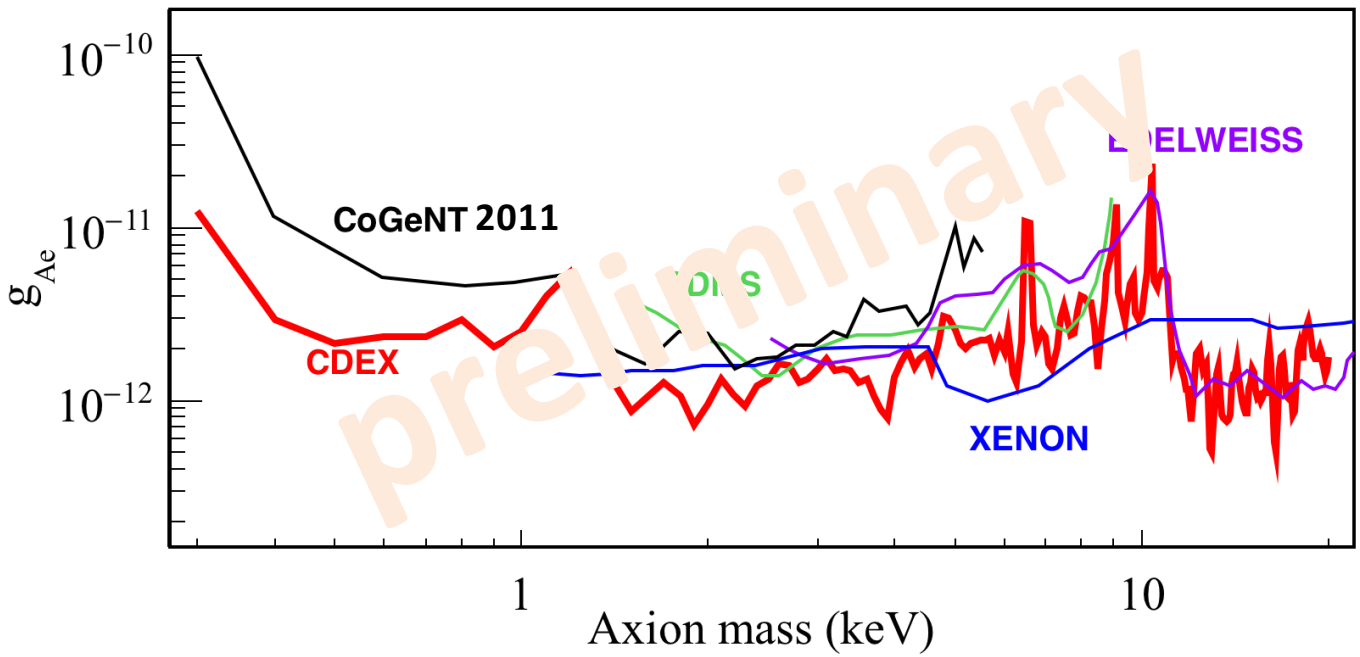
Results—g_{Ae} limits with CDEX-1 336 kg-days data



Results—Dark matter ALPs

- DM is non-relativistic, the resulting signal will consist in electron recoils at an energy equal to the axion mass m_a.
- For each axion mass, use the same statistics method as Fe-57 to get the 90% C.L. limit.

$$R = \frac{1.2 \times 10^{19}}{A} \, g_{aee}^2 \, \frac{m_a}{\text{keV}} \, \frac{\sigma_{pe}}{\text{barns/atom}} \, \frac{1}{\text{kg}} \, \frac{1}{\text{day}}$$



Competitive results below the axion mass of 1 keV.

Summary and prospect

- The g_{Ae} couplings of solar axions and galactic dark matter ALPs have been achieved.
- Competitive results of DM ALPs below 1 keV.
- Deeply understanding background sources are on-going and "annual modulation" of this dataset is processing.
- CDEX-10 with lower threshold and low background is under testing.
- CDEX is preparing for CDEX-10X
  - ✓ Ge purification and Ge crystal growth
  - ✓ HPGe detector fabrication
  - ✓ Low noise low background electronics study
- The infrastructure of CJPL-II with 200,000 m^3 is in progress.

Hao Jiang's talk will give more details about CDEX and CJPL.

Thanks!