Search for Axions with the CDMS-II Experiment

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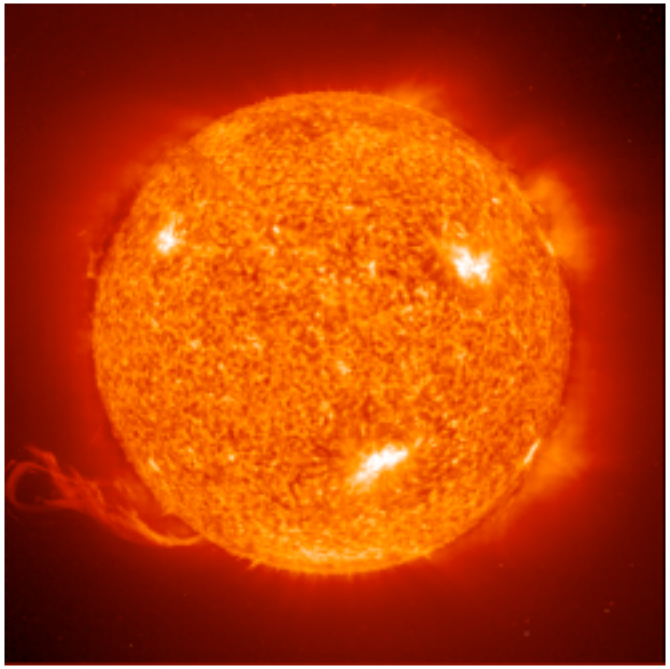
Axions from the Sun

The axion has been postulated to solve the strong CP problem in QCD.

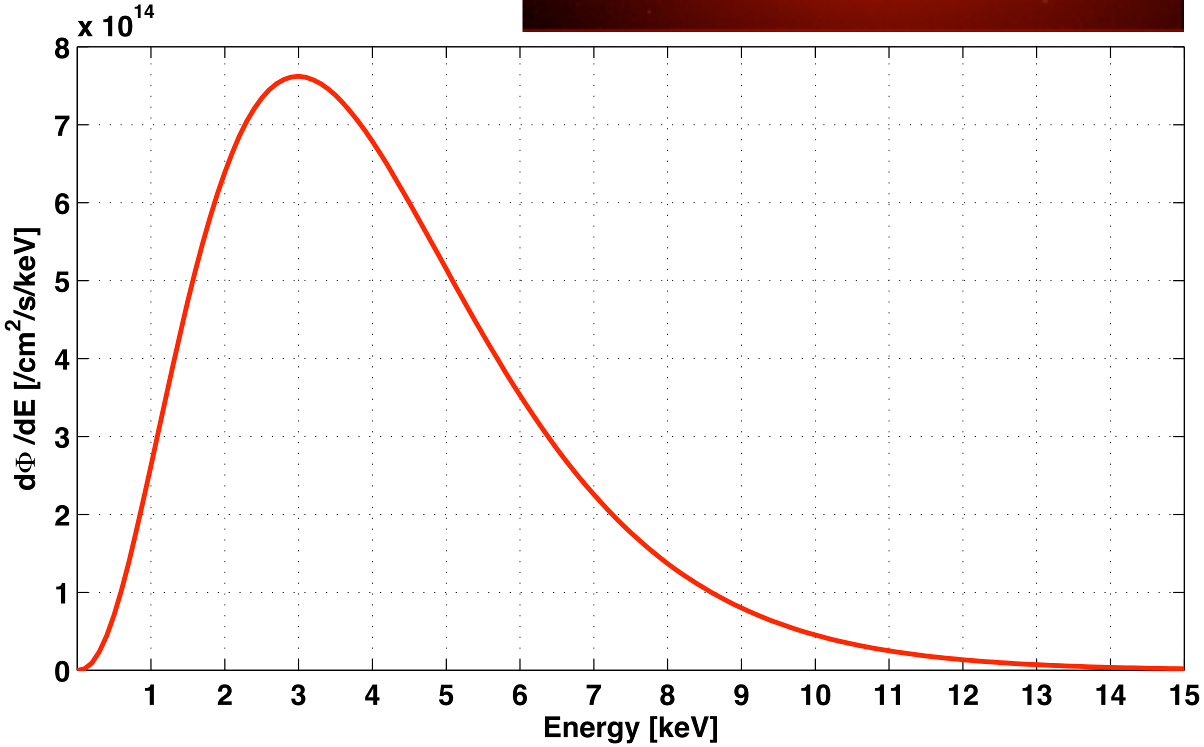


Stars are expected to be a strong source of axions if they couple to photons.

The strong EM field in the stars interior may convert photons into axions.

A well known source would be the Sun.

From the standard solar model we can calculate the flux of solar axions at the Earth.



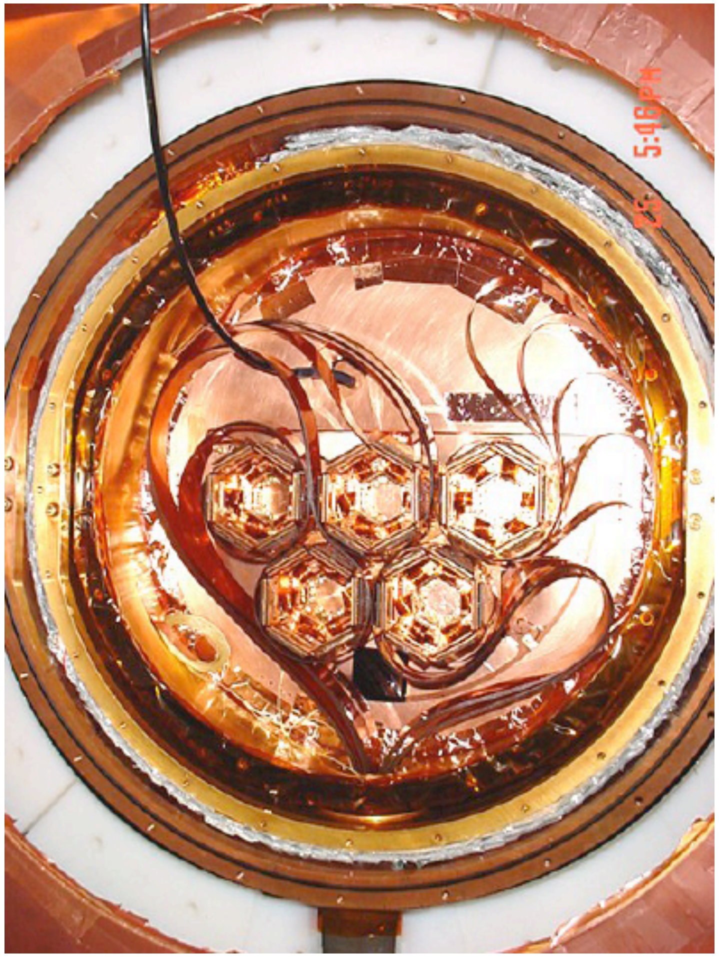
Solar physics underground

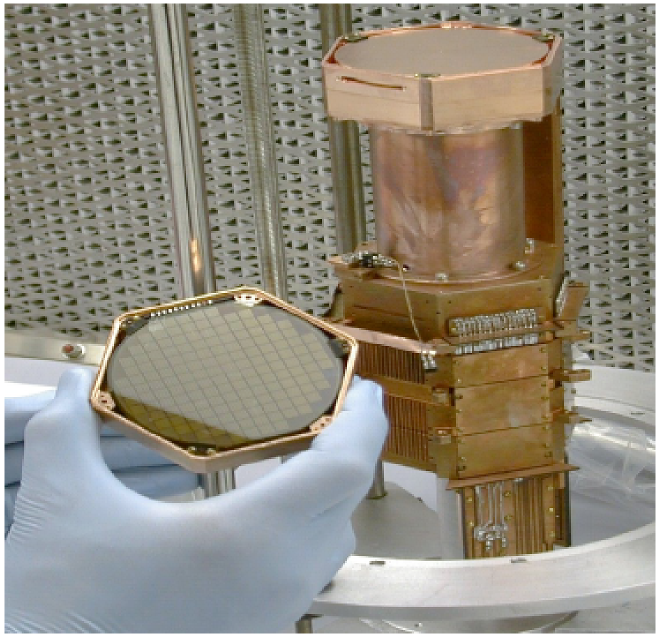
The CDMS Experiment

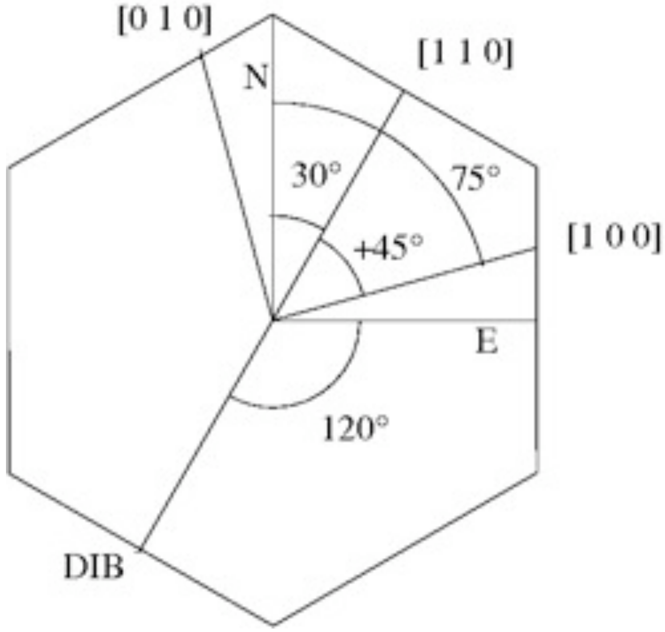
CDMS operates 19 Ge and 11 Si detectors at mk (~40mk) temperatures.

The detectors are stacked in 5 towers with 6 detectors each.

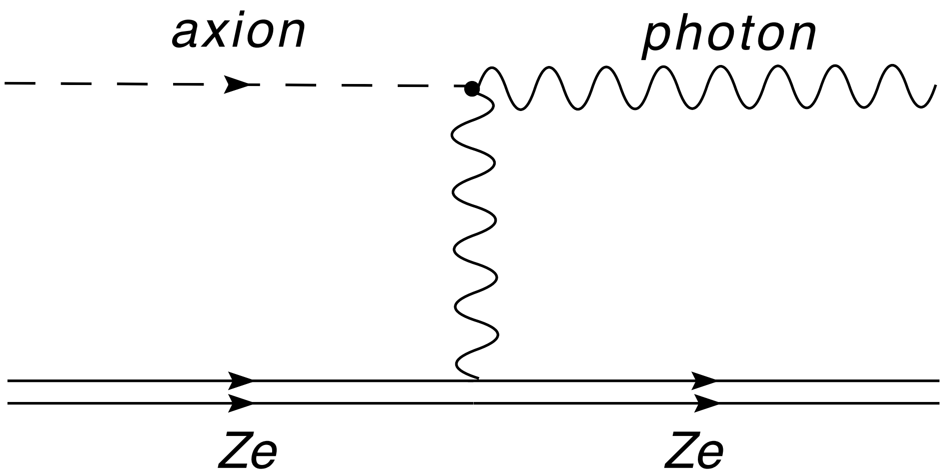
The direction of each crystal axis for each detector is known from installation.

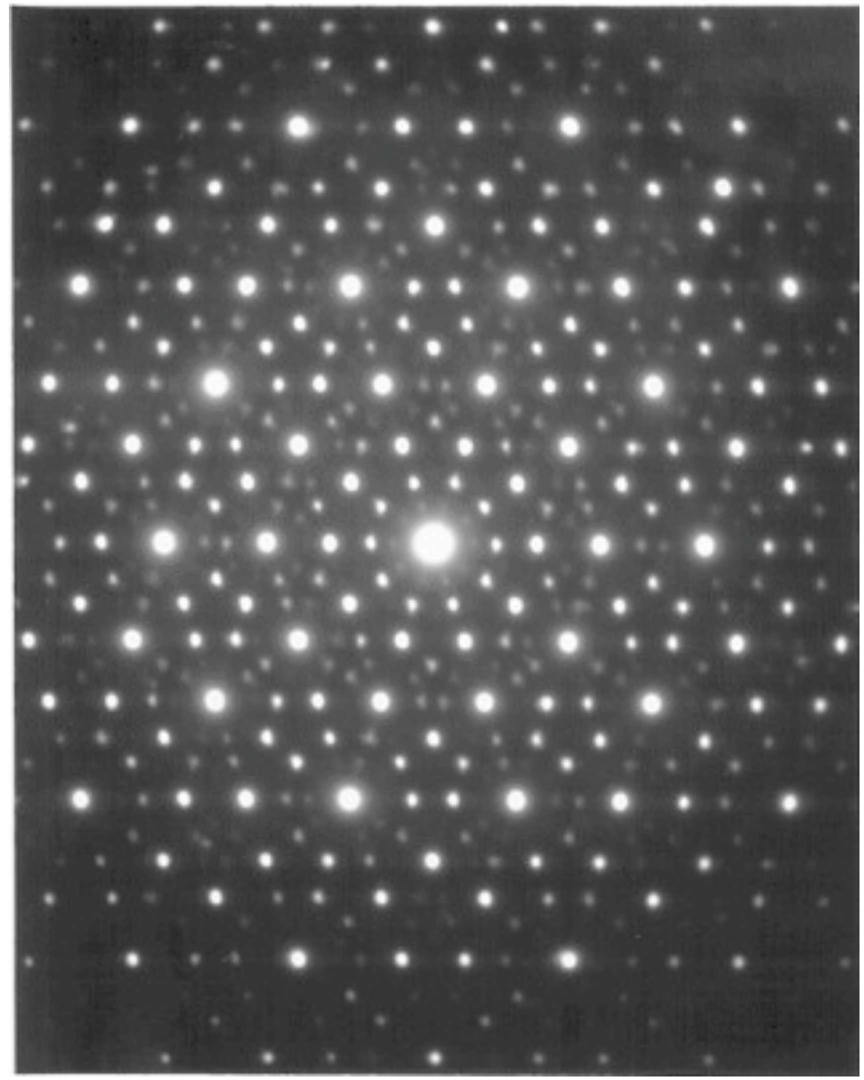






Primakov effect in crystals





Coupling to the coulomb field of the nucleus converts axions back into photons.

Bragg condition for momentum transfer in a crystal :

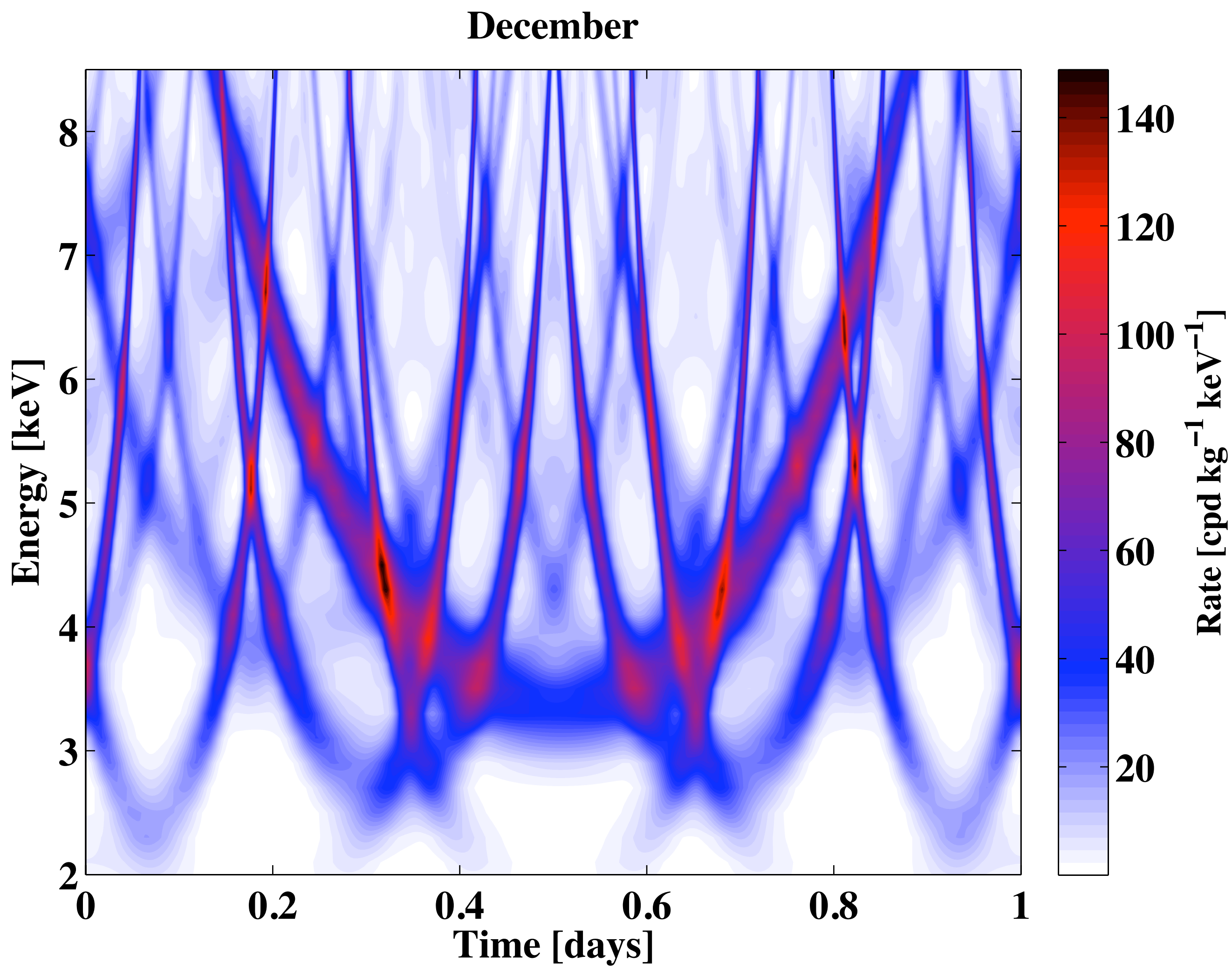
➜ coherent amplification of the Primakov effect.

The conversion rate will depend on the incident beam direction.

Expected conversion rate

The changing position of the Sun with respect to the crystal axes changes the incident beam direction throughout a day.

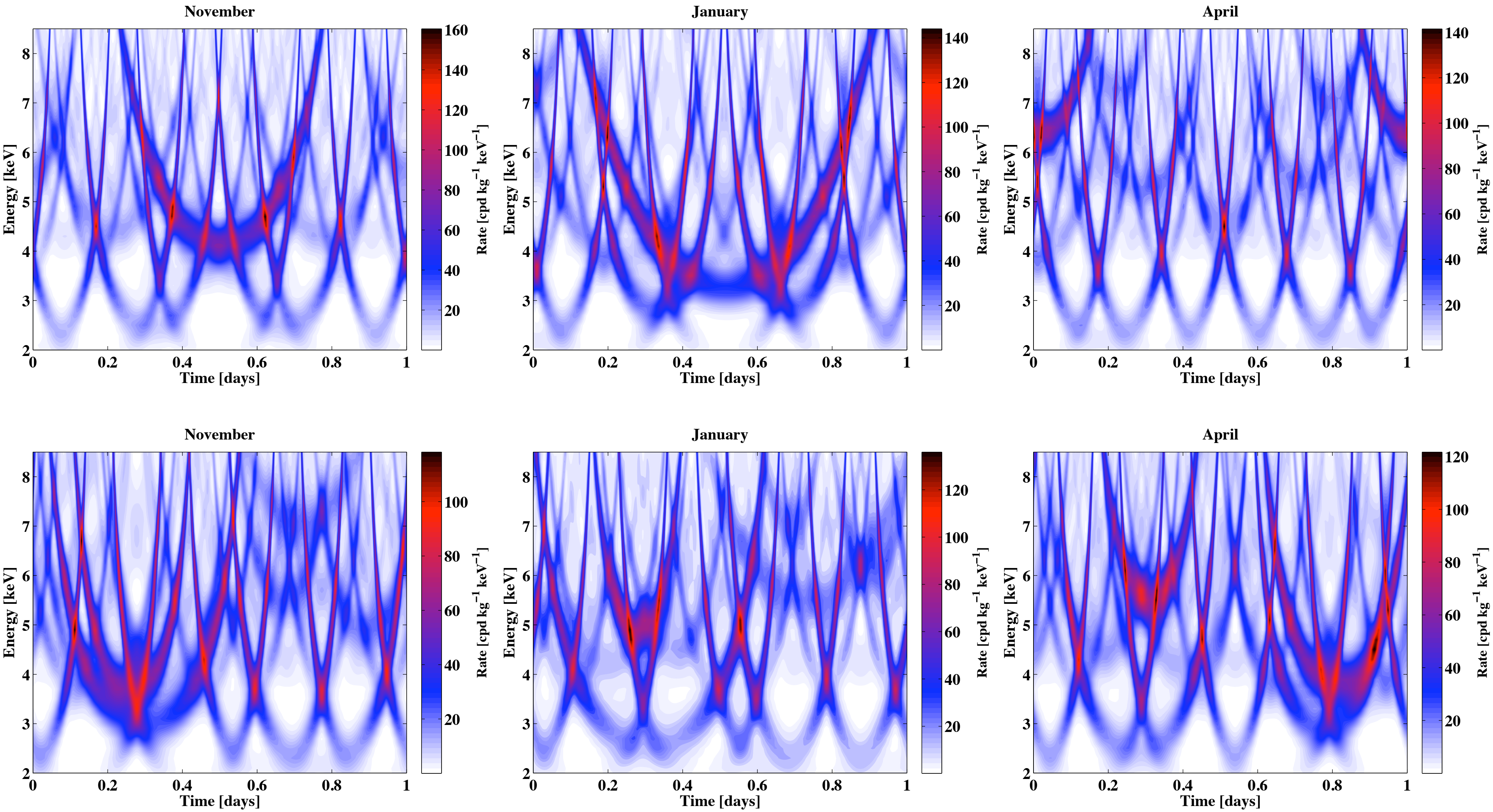
Solar axion conversions show an unique pattern in time and energy.



Solar axion fingerprints

The Sun's changing zenith angle in a year causes monthly changing patterns.

Different detector alignments cause different patterns.



Ionization signal

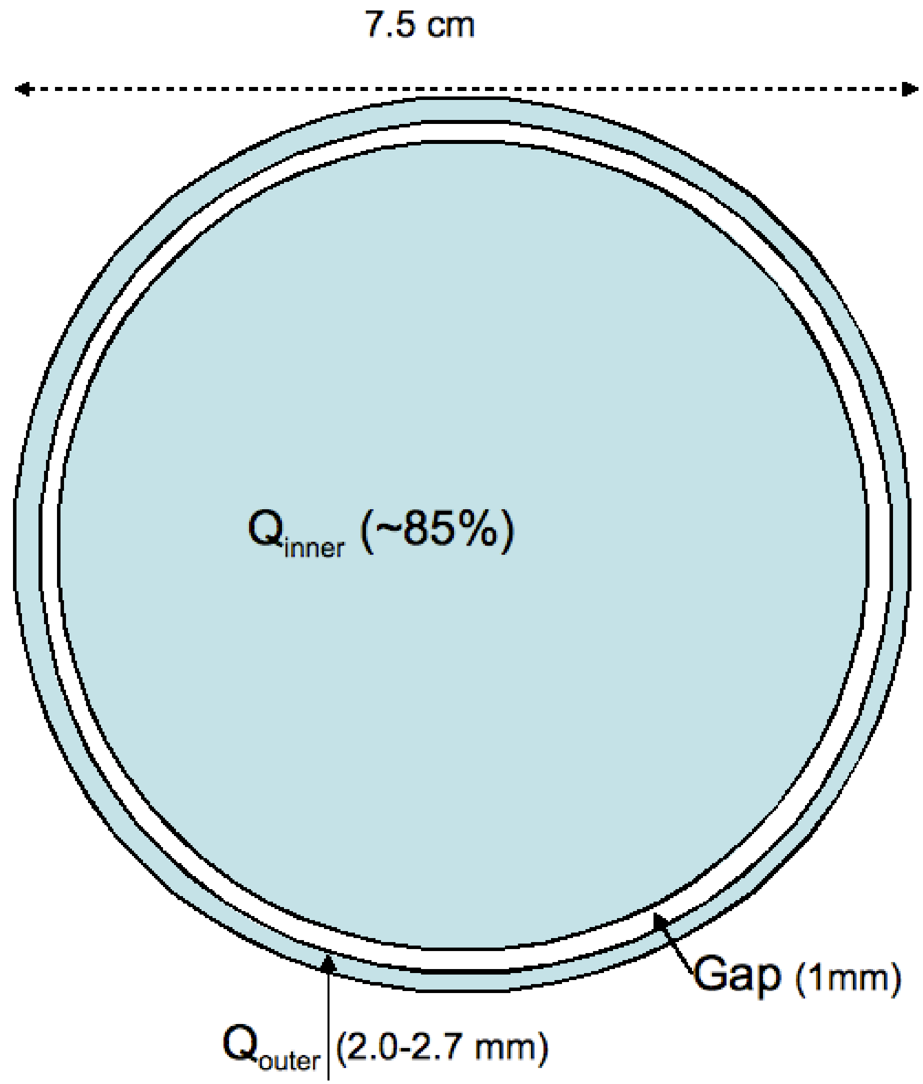
A drift field of -3V/cm (-4V/cm) is applied to the Ge (Si) detectors .

Electron-Hole pairs created by an interaction drift towards the electrodes inducing charge on the inner (Q_{inner}) and outer (Q_{outer}) electrode .

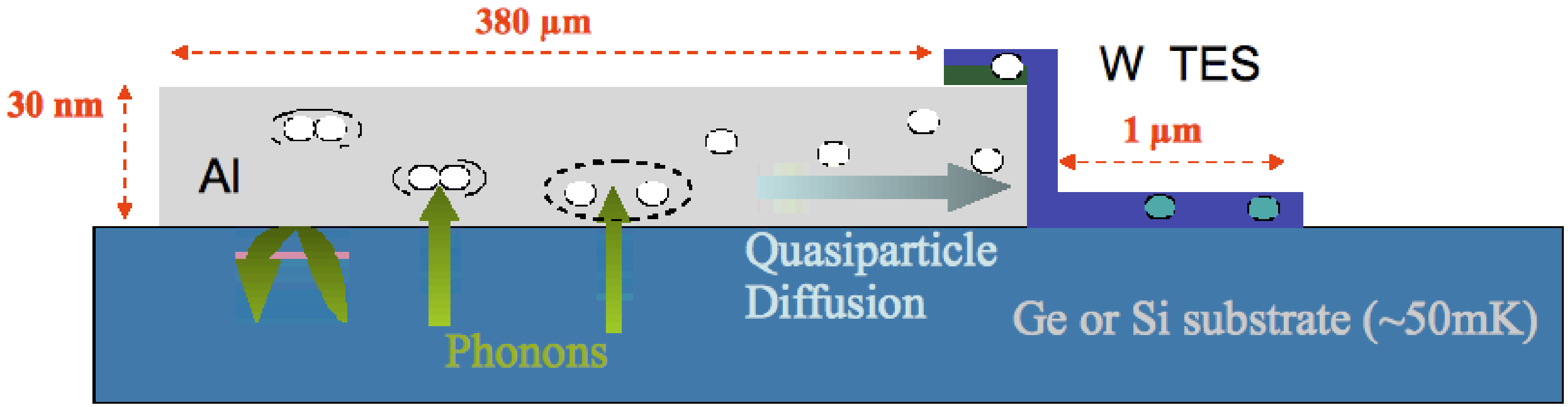
Events with a significant signal on Q_{outer} are rejected in the analysis.

Q_{outer} constrains the fiducial volume considered in the analysis.

Capacitive readout of the signal.



Calorimetry using phonons

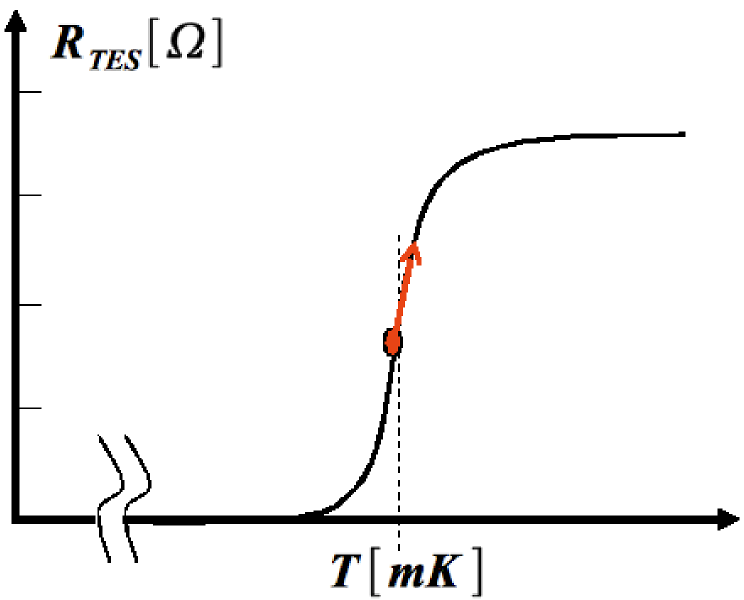


Phonons break Cooper-Pairs in super conducting Al-film.

Quasiparticles diffuse to the W-TES and deposit their energy
→Temperature rises

Rising temperature → higher resistance
→ lower current

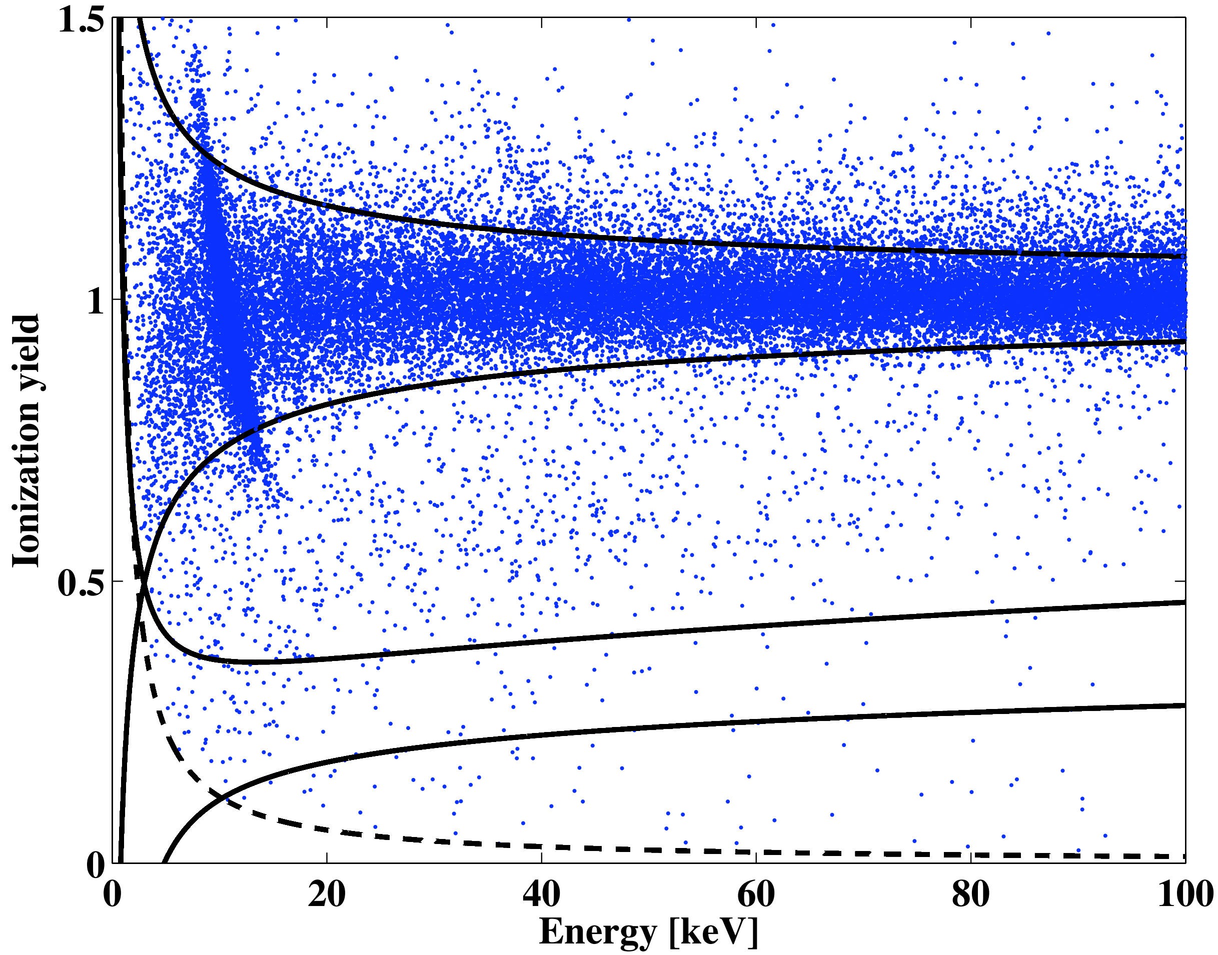
Signal is a dropdown in current, which is read out by a SQUID.



Where to search for a signal ?

CDMS ZIP detectors allow discrimination of nuclear recoil events from electron recoil events.

Electron and nuclear recoil band are determined from in-situ calibrations.

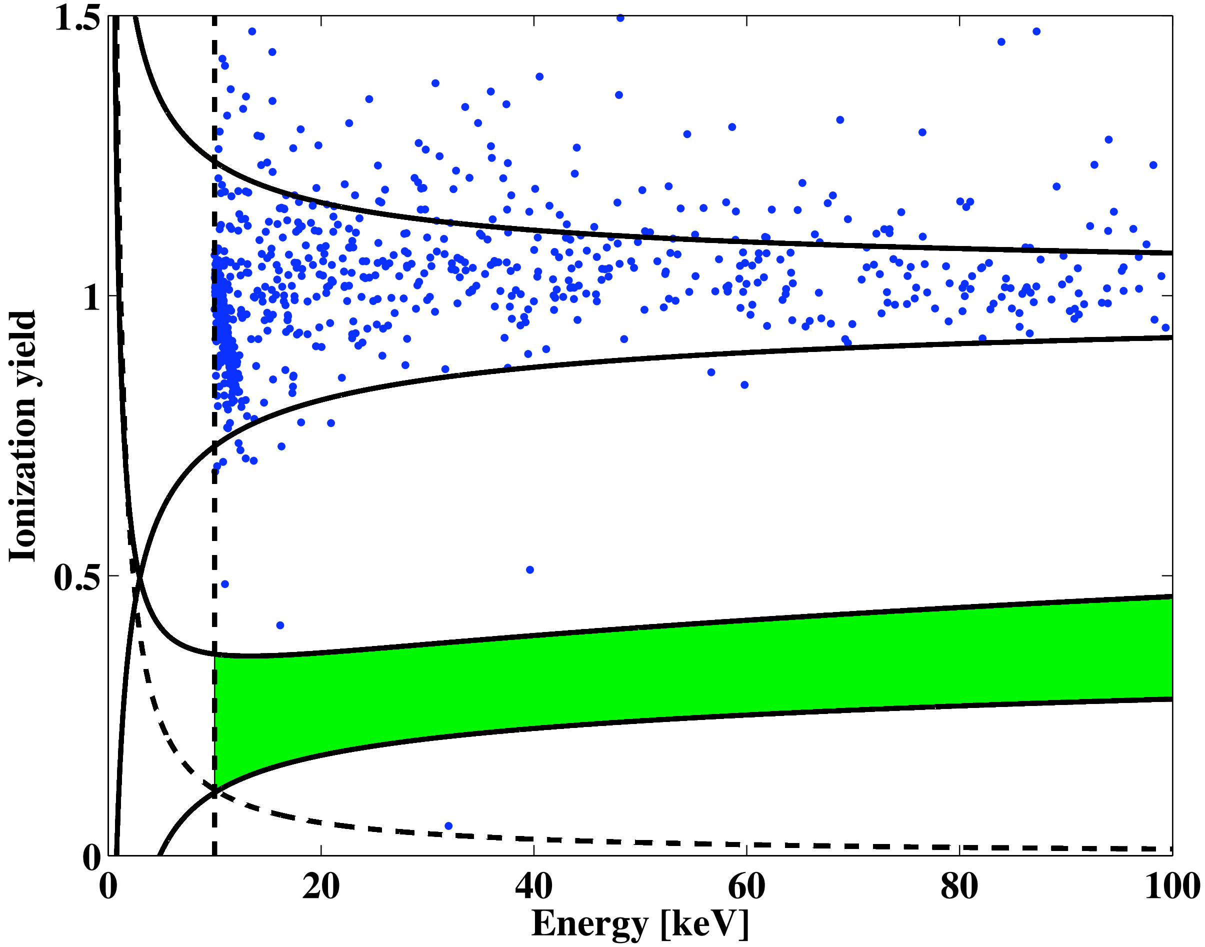


Where to search for a signal ?

CDMS ZIP detectors allow discrimination of nuclear recoil events from electron recoil events.

WIMP search analysis looks for the detection of nuclear recoil events.

Electron recoil events are background events.



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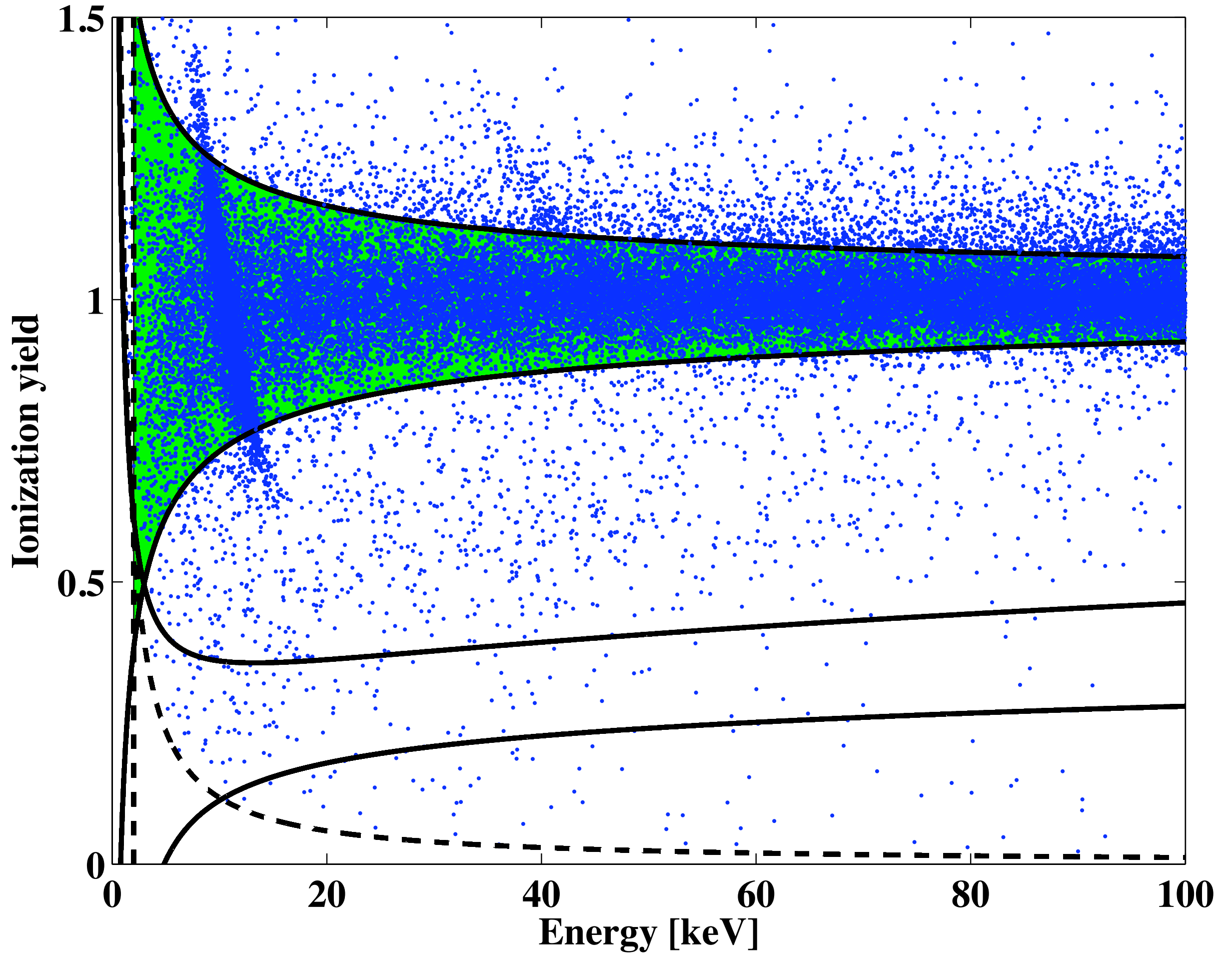


WIMP search analysis looks for the detection of nuclear recoil events.

Electron recoil events are background events.

Photons from solar axion conversion are detected as electron recoil events.

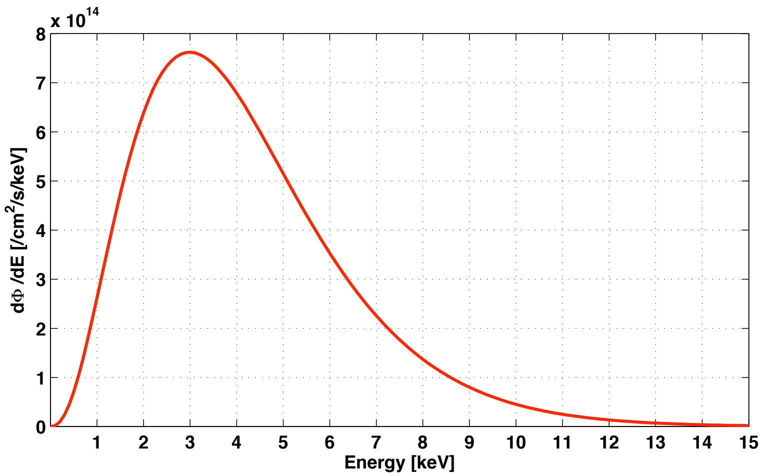
A possible signal will show up in the electron recoil distribution.

Use background to perform different physics analyses.

Low energy spectrum

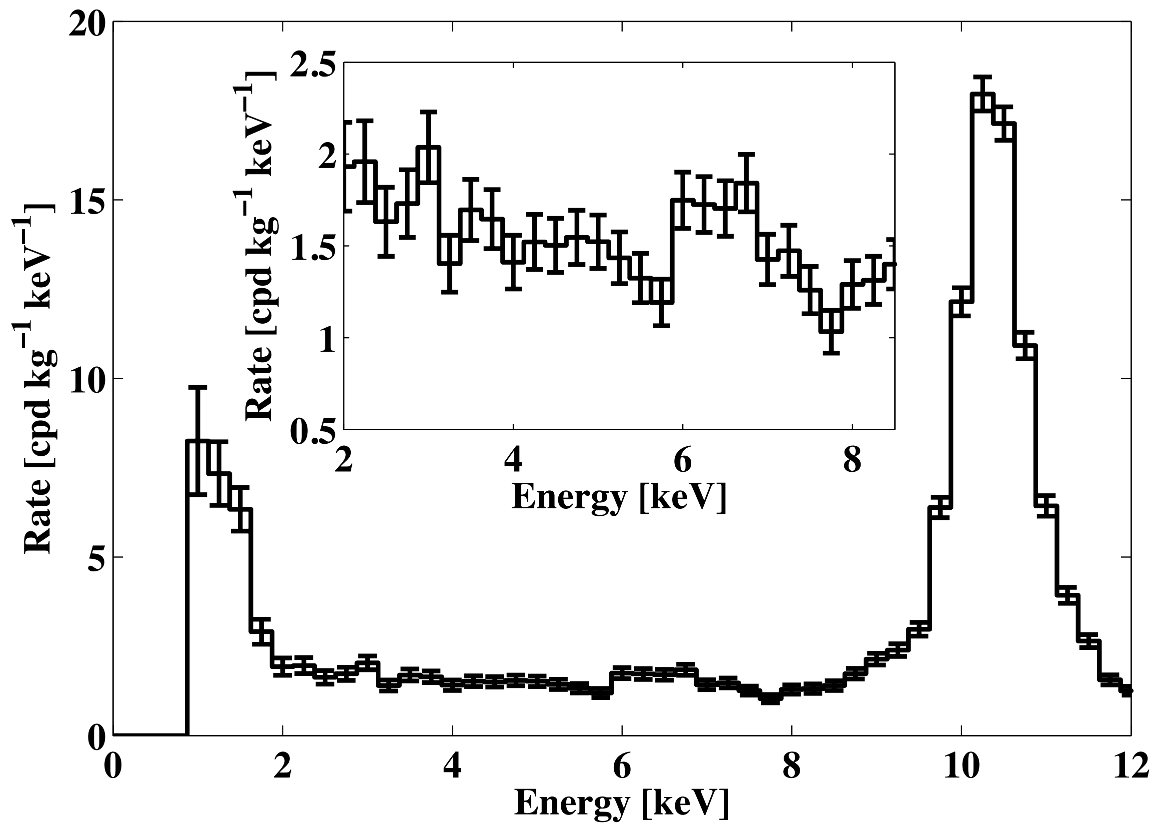
The analysis window (2-8.5 keV) is determined by:

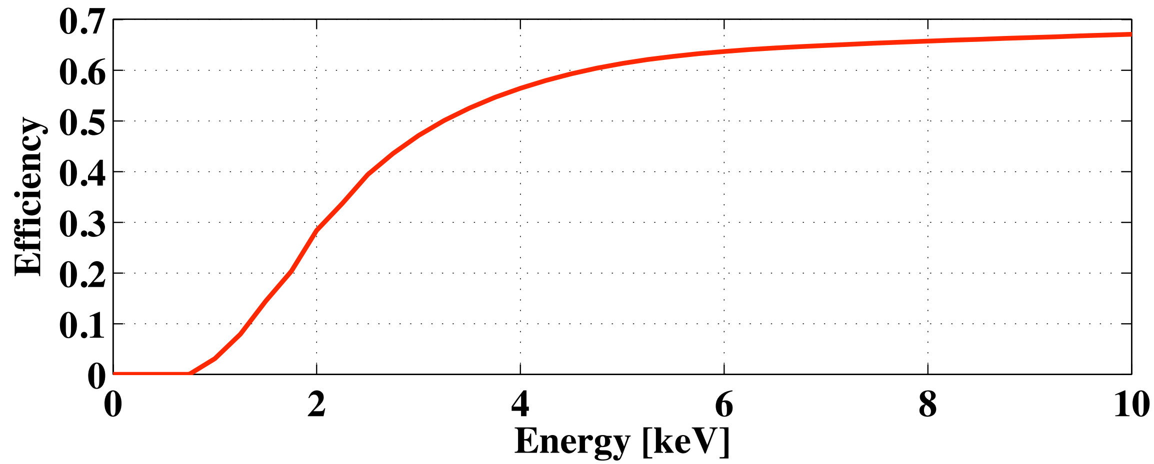
- Expected signal



- Background
- Detection efficiency

Excess rate at ~6.5 keV is likely caused by remnant ^{55}Fe decays (6.54 keV) from cosmogenic activation.

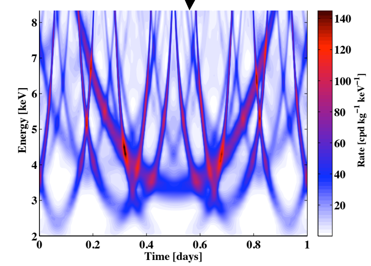




Likelihood analysis

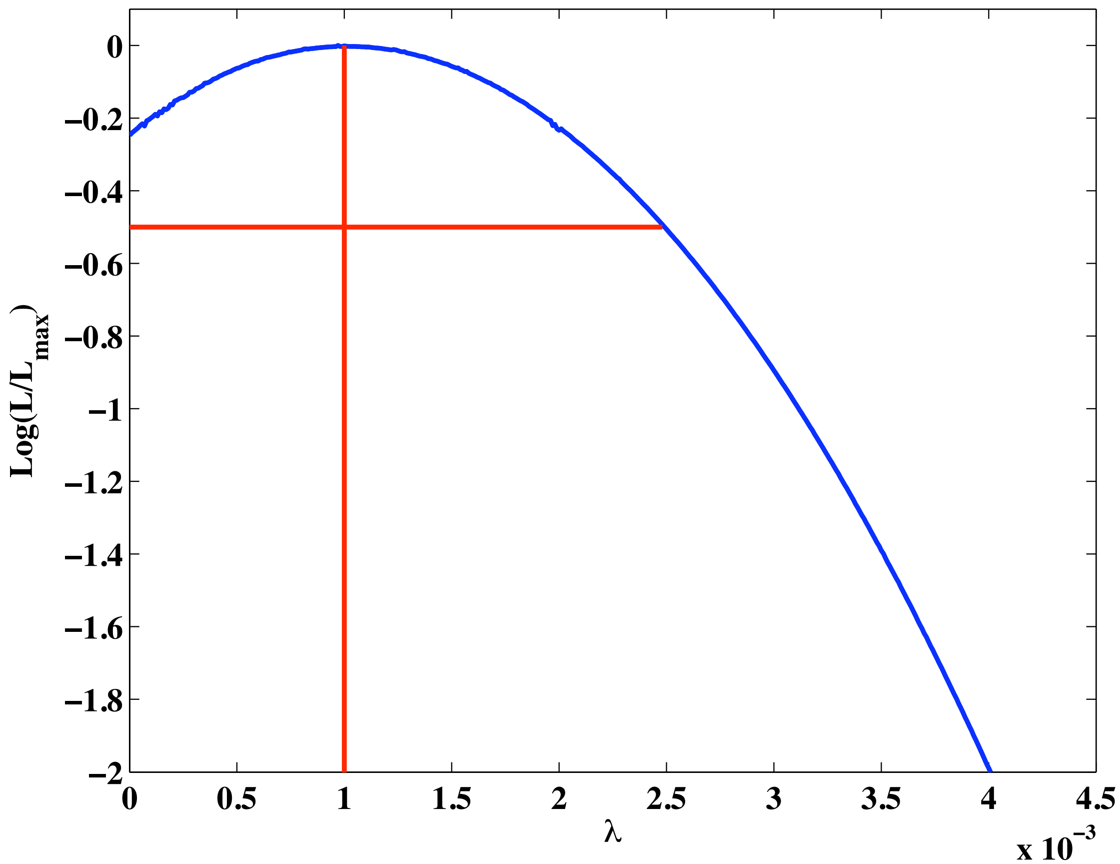
Maximise the unbinned log likelihood function.

$$Log(\mathcal{L}) = -R_T + \sum_{i,j} Log(\lambda \cdot \mathcal{R}(E_i, t_i, d_j) + B(E_i, t_i, d_j))$$



Uniform in time

Consider time, energy and detector of each detected event.



$\lambda = (1.0 \pm 1.5) \times 10^{-3}$

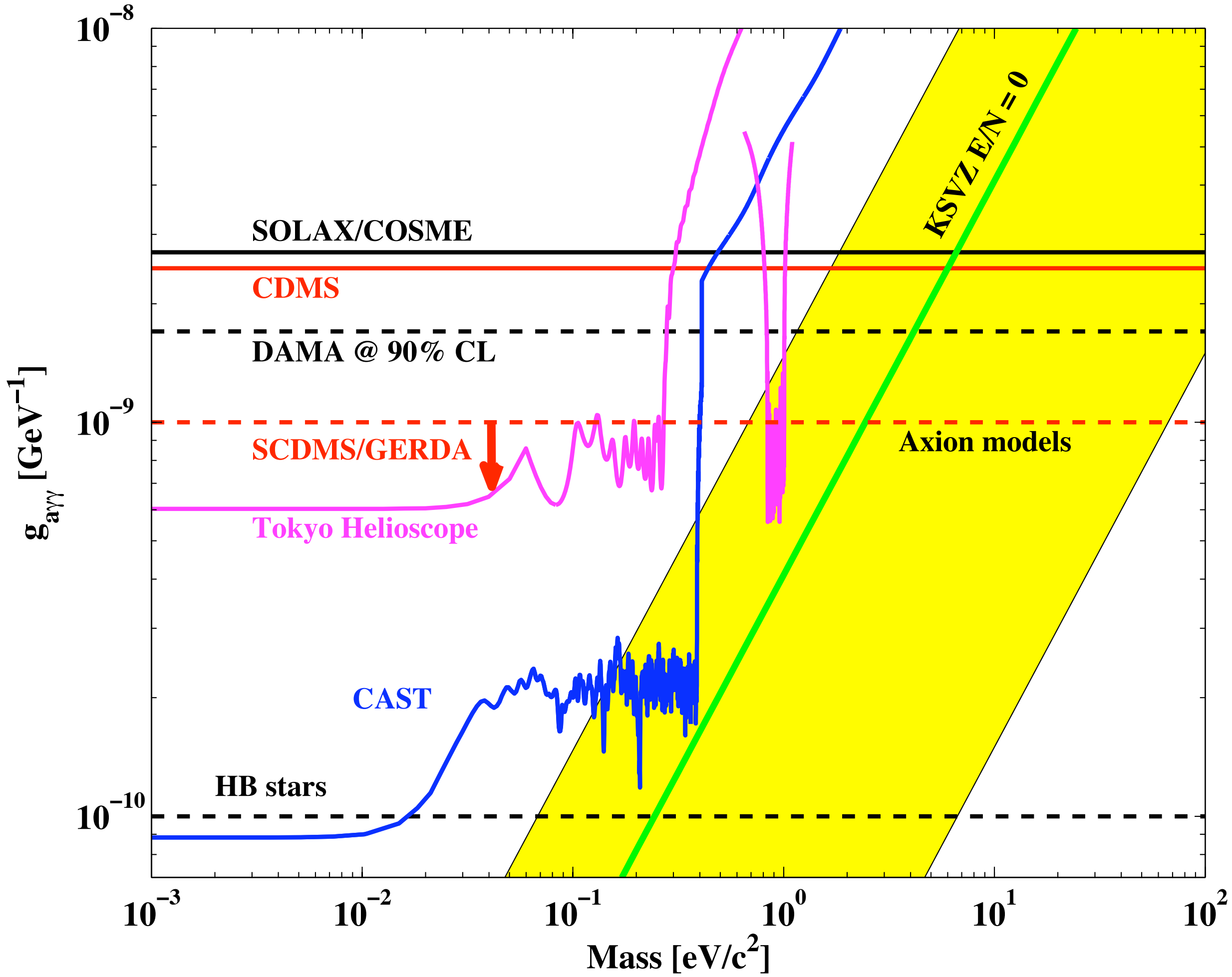
No indication of solar axion conversions to photons is observed.

Tuesday, June 2, 2009

Solar axion result

First upper limit with precise knowledge of all crystal orientations.

Future large crystal detector arrays may become competitive to helioscopes.



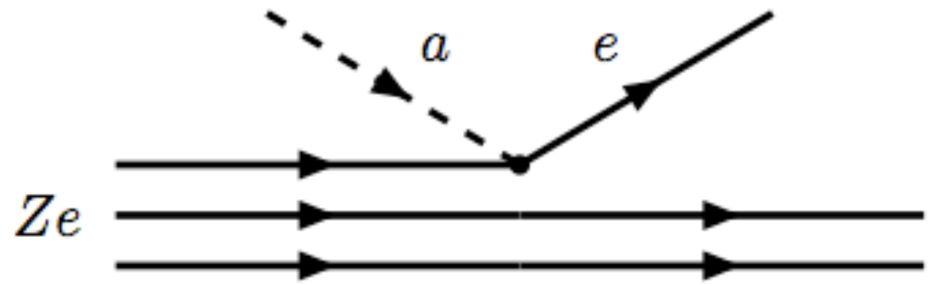
See also arXiv:astro-ph/0902.4693

Relic axion-like particles in the local halo

As dark matter candidates axions may be distributed in the local halo.

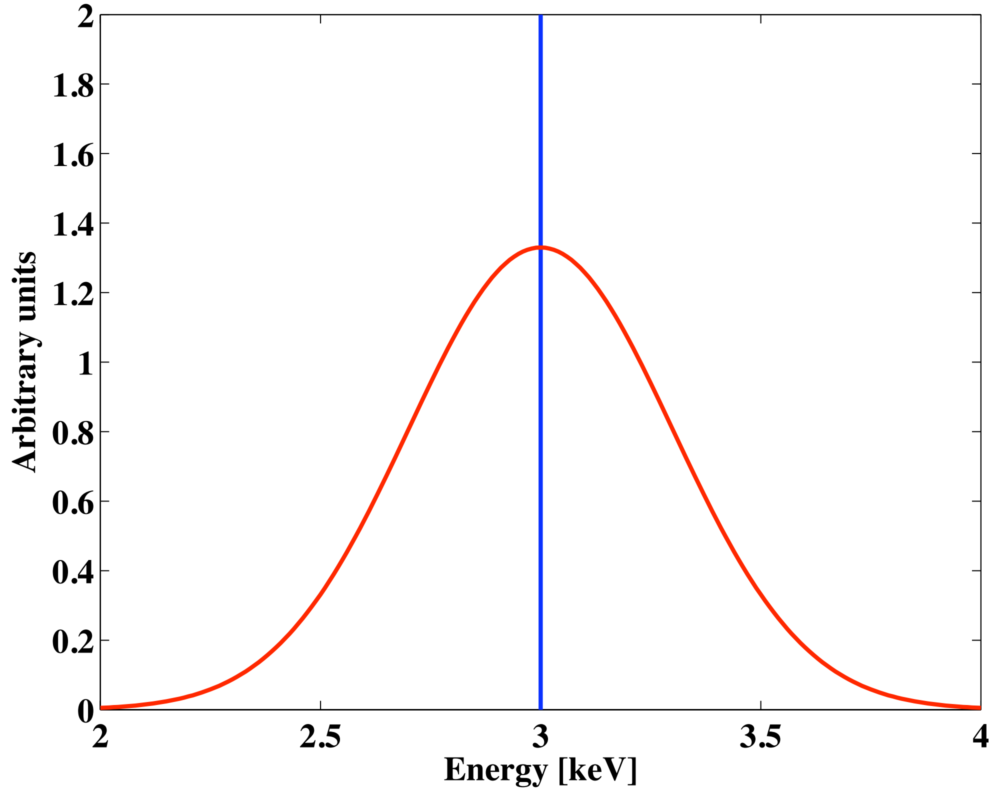
May materialize in the detectors via an axio-electric coupling:

➜ Axio-electric effect



Energy of the electron is given by the mass of the axion.

Conversion results in a gaussian distribution with width given by the detector's energy resolution.

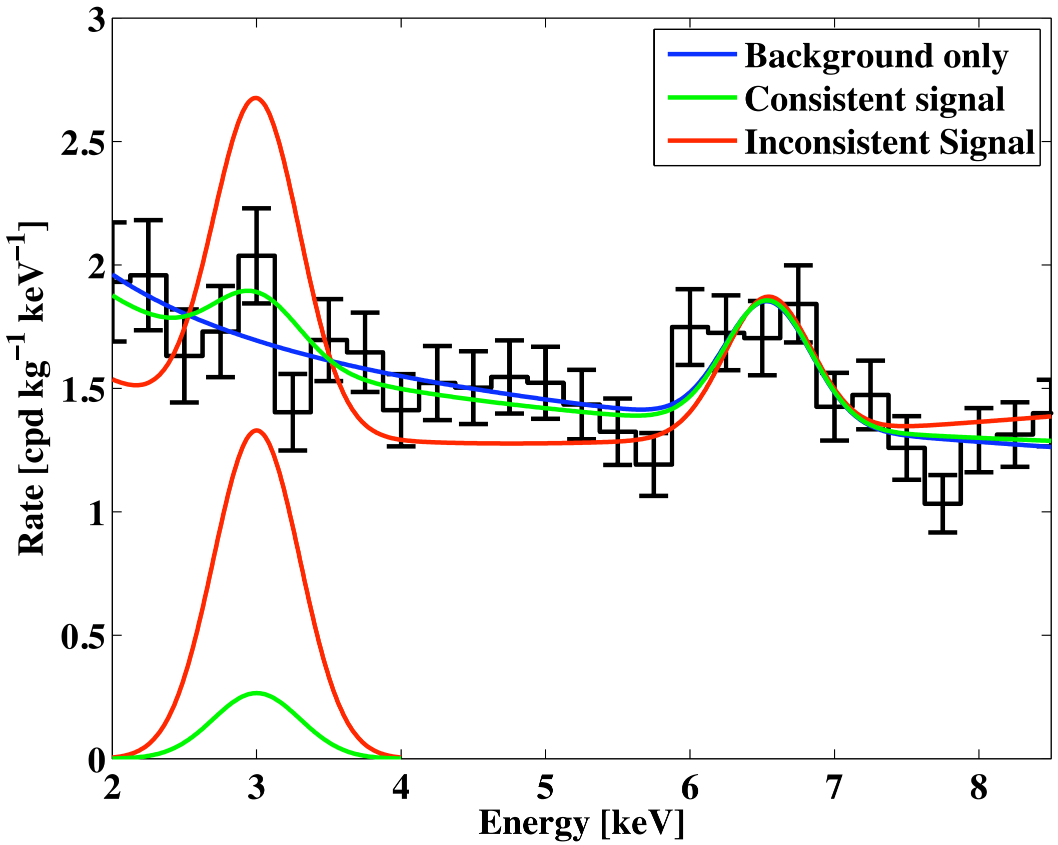


Likelihood analysis II

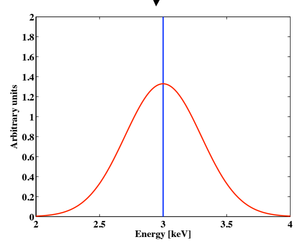
Take possible contribution from Fe decays into account when modeling the background.

Do not subtract this contribution while approaching this energy range.

Maximise the unbinned log likelihood function for each energy/axion mass.



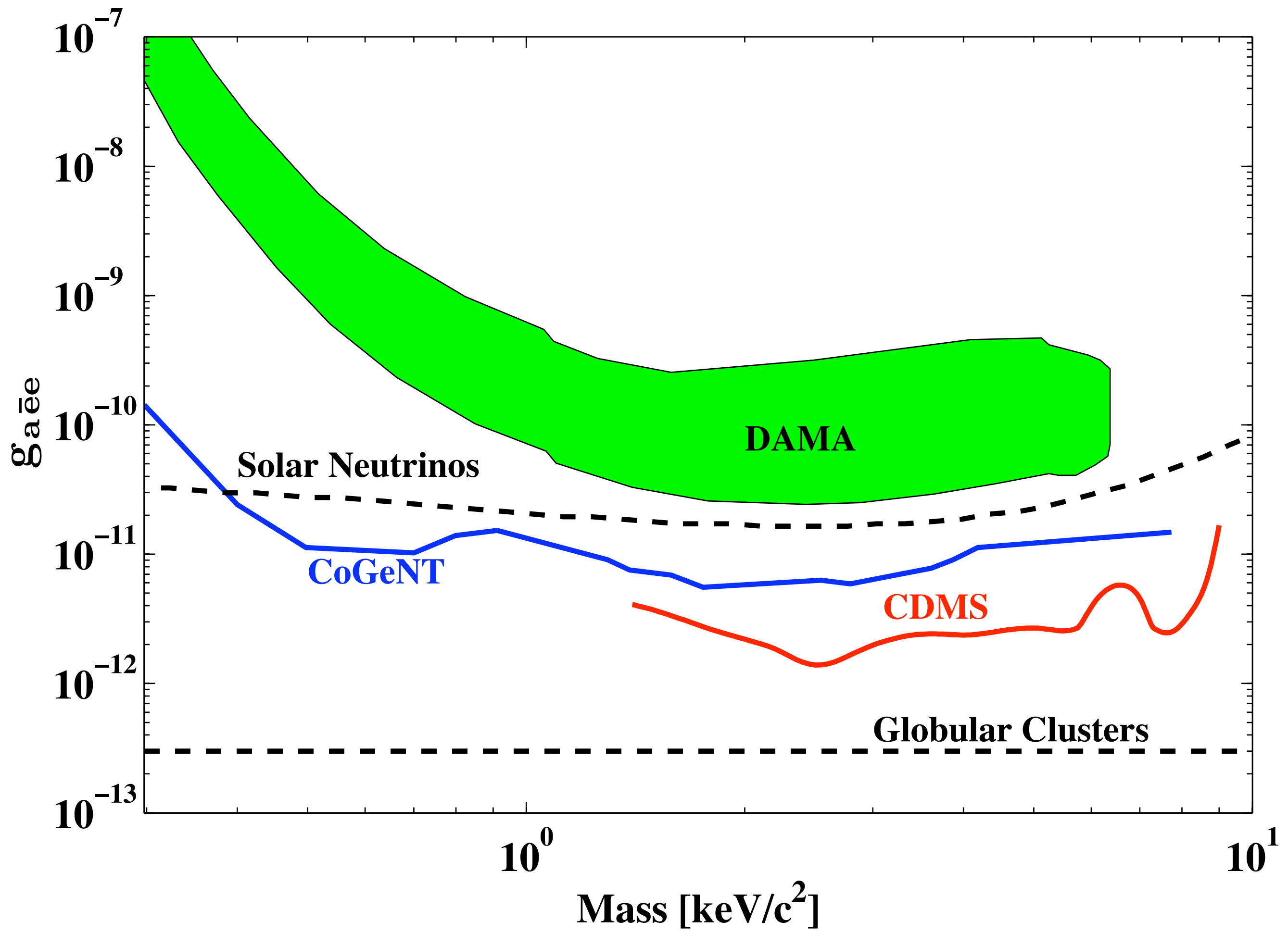
$$Log(\mathcal{L}) = -R_T + \sum_{i,j} Log(\lambda \cdot \mathcal{R}(E_i, d_j) + B(E_i, d_j))$$



Determine total rate λ for which a signal contribution is rejected at a 90% C.L.

Relic axion result

Excludes the relic axion interpretation of the DAMA signal claim.
World-leading experimental upper limit on the axio-electric coupling.



See also arXiv:astro-ph/0902.4693

Conclusions

Solar axion search:

- First demonstration of new physics analyses with the CDMS experiment.
- Sets an upper limit on the axion-photon coupling of $g_{a\gamma\gamma} < 2.4 \times 10^{-9}$ GeV^{-1} @ 95 % CL
- First result on the axion-photo coupling from a crystal experiment with precise knowledge of all crystal axes orientations.
- Future large crystal detector arrays may provide competitive sensitivity to helioscopes.

Relic axion search:

- Excludes the axio-electric interpretation of the DAMA signal claim in the mass range of 1.4 - 6 keV.
- Sets a world-leading experimental upper limit on the axio-electric coupling.

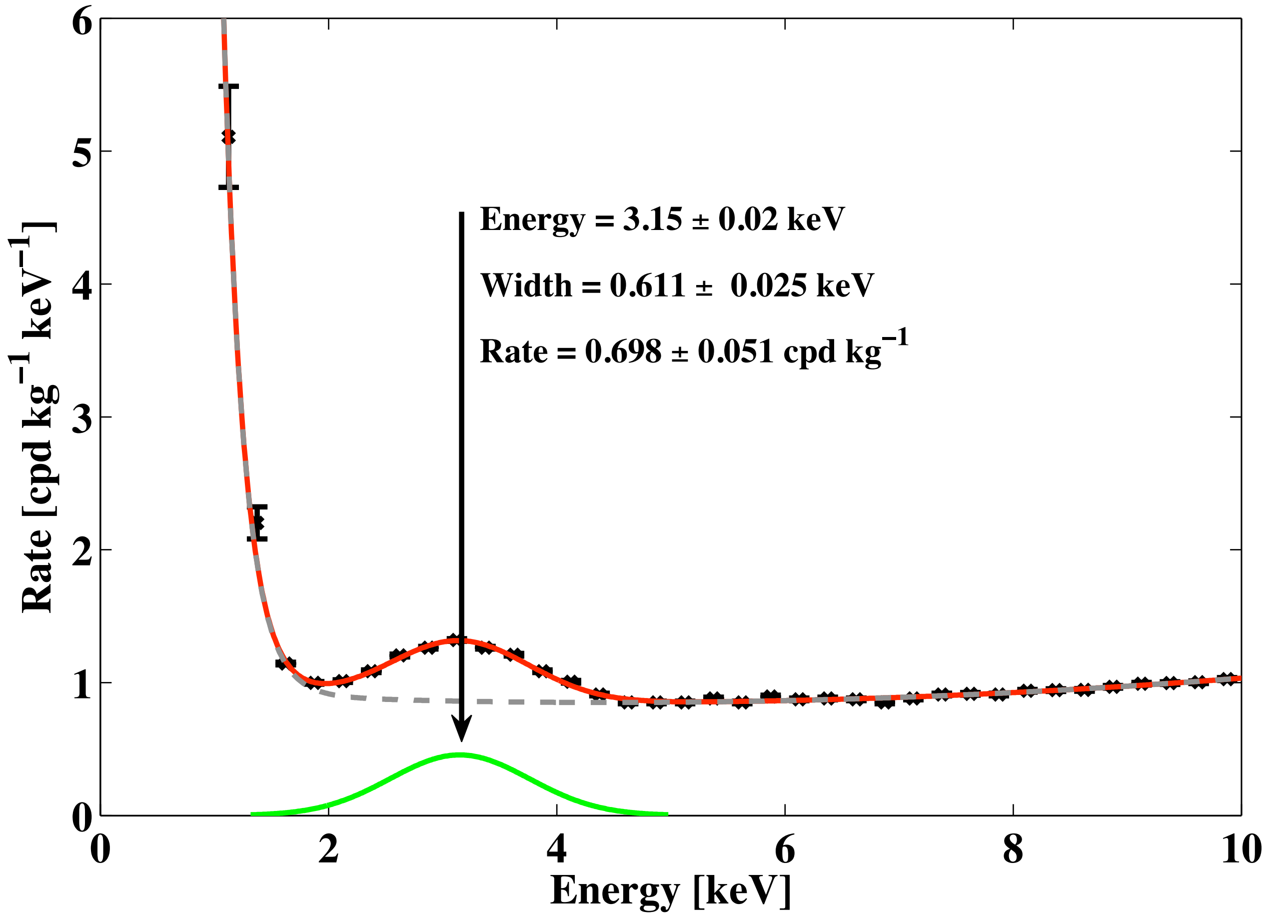
DAMA/LIBRA rate excess

The DAMA/LIBRA result confirmed the DAMA/NaI observation of an annual modulation of the counting rate at low energies (8.2σ) .

The WIMP interpretation is excluded by experiments sensitive to nuclear recoils (except for light masses < 10 GeV).

So what if the signal is caused by an electromagnetic interaction (neglecting detector systematics) ?

In addition to the modulation in the 2-4 keV range they observe an excess in rate at 3.15 keV.

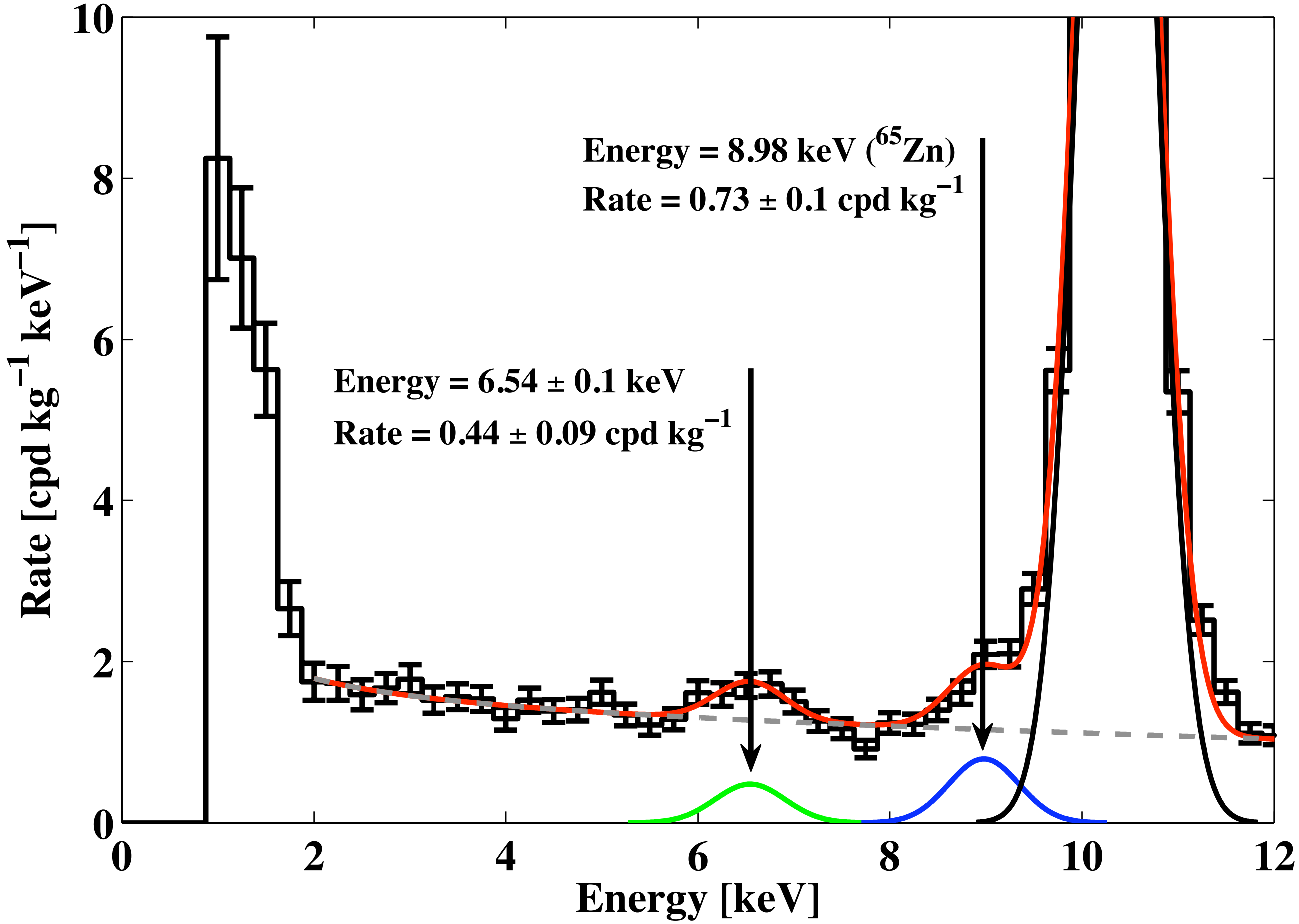


Fit to the CDMS low energy spectrum

If the signal is of EM origin it should in general also be visible in the CDMS low energy electron recoil spectrum.

Bullseye match to the de-exitation Energy of ^{55}Mn (6.54 kev).

Model assumption: dark matter decays to an X-Ray. So far not a well motivated assumption.



Set limits on an excess in rate with the same procedure used in the search for relict axions.

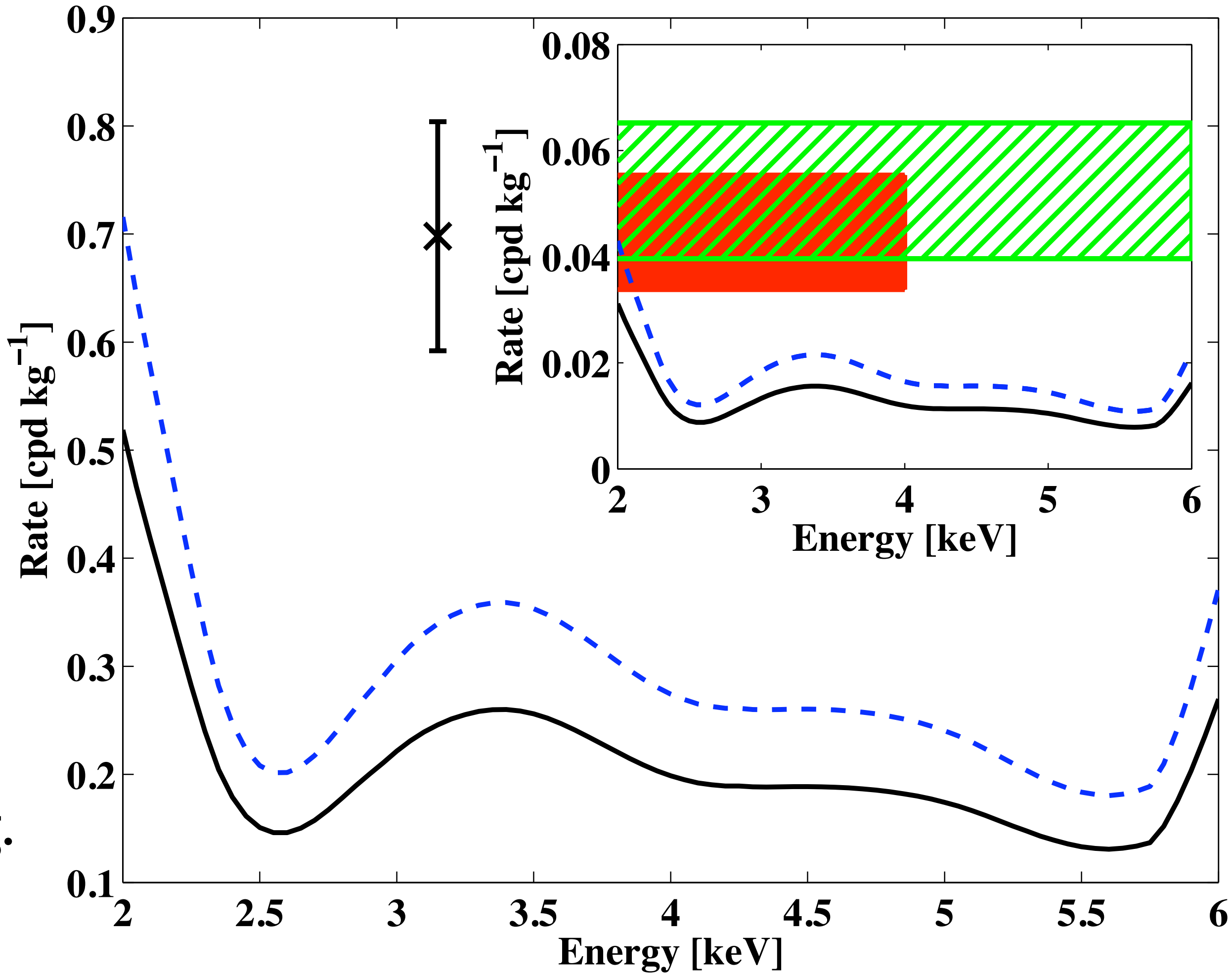
CDMS vs DAMA

Upper limits set by CDMS are inconsistent with the rate observed by DAMA, for the total rate as well as for a 6% modulation amplitude (inset).

Direct comparison is shown as the black line.

Z^2 scaling of the dark matter interaction cross section comparison is shown as blue/ dashed line.

More or less arbitrary choice of scaling, need real particle model to provide actual scaling.



Does such a model exist? We are not aware of such an model!

Summary

- Analysis of the low energy electron recoil spectrum did not reveal an unexplained excess in detected rate.
- If the DAMA signal is of electromagnetic origin it should also be detectable in CDMS.
- The analysis of the CDMS low energy electron recoil spectrum should help to constrain or identify models which can explain the DAMA signal.
- Without a well motivated model at hand the rate detected by DAMA is inconsistent with the CDMS result with more than 6σ.
- Need an actual model to perform a fair comparison between the two experimental results.