# What can we learn about signal when studying the background?

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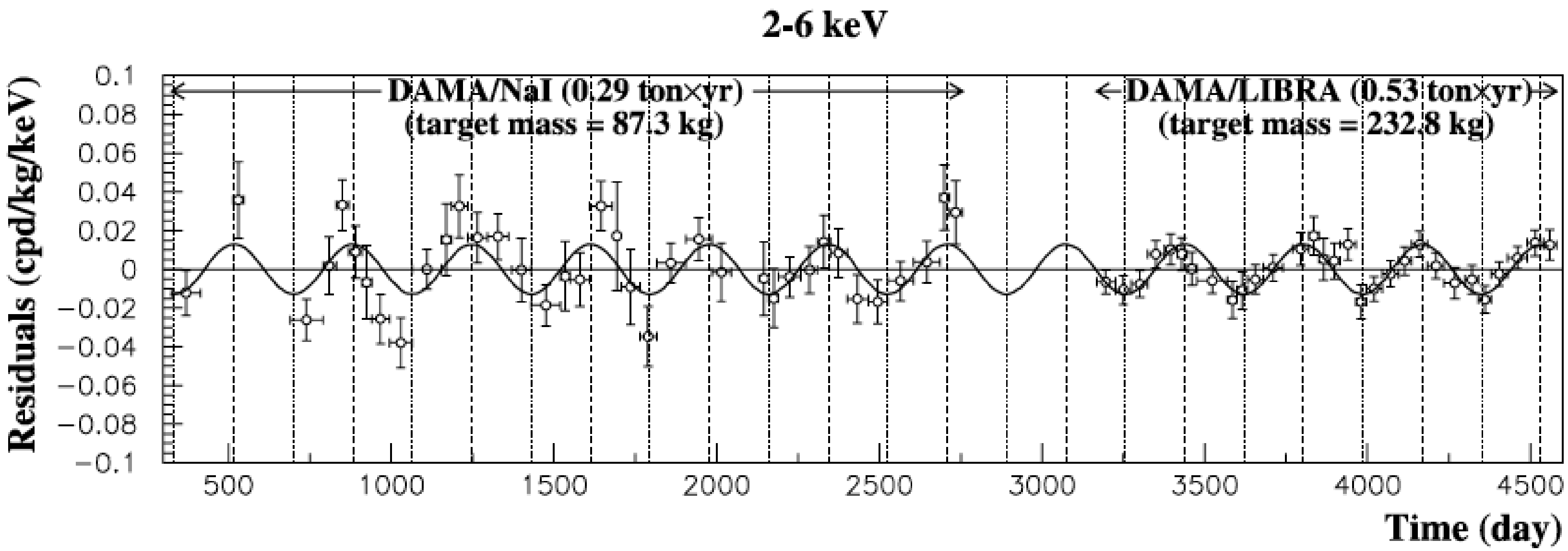
# Introduction

- Why background studies are so important?
- How can the background help to understand the signal?
- Many discussions about DAMA and CoGeNT.
- Is a possible signal real?
- I will consider DAMA as an example.
- No proper simulations of the radioactive background by DAMA or CoGeNT.
- Currently many speculations about annual modulation seen.
- However, all possible scenarios should contain a fit of the measured spectrum as the sum of the background and the signal.
- This talk is based on the paper: V. A. Kudryavtsev et al. Astroparticle Physics 33 (2010) 91–96.

# DAMA signal




- DAMA/NaI - 100 kg of NaI(Tl), 7 annual cycles.
- DAMA/LIBRA - 250 kg of NaI(Tl), >7 years of running.
- Annual modulation of the total rate of single hits at 2-6 keV.
- No modulation at higher energies.
- No modulation of multiple hit events.
- R. Bernabei et al. Eur. Phys. J. C, 56 (2008) 333.

# DAMA analysis

- **Annual modulation analysis:**

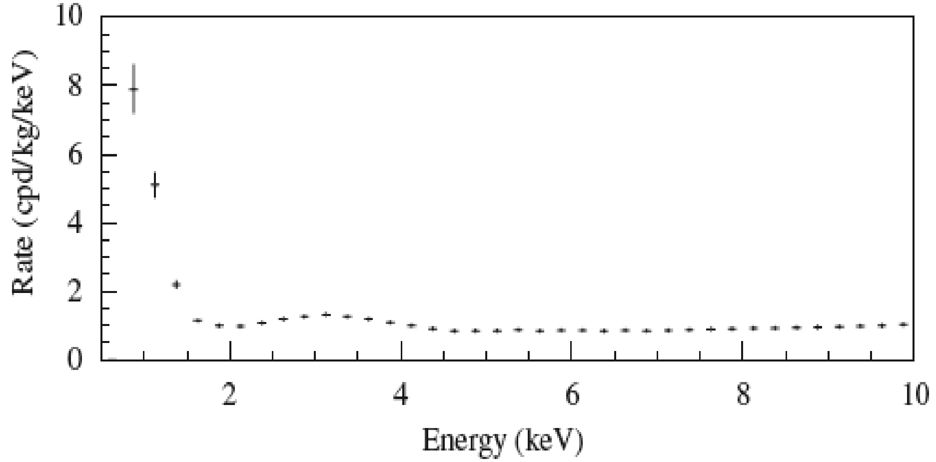
$$R(E,t) = B(E) + S_0(E) + S_m(E)\cos[\omega(t - t_0)]$$

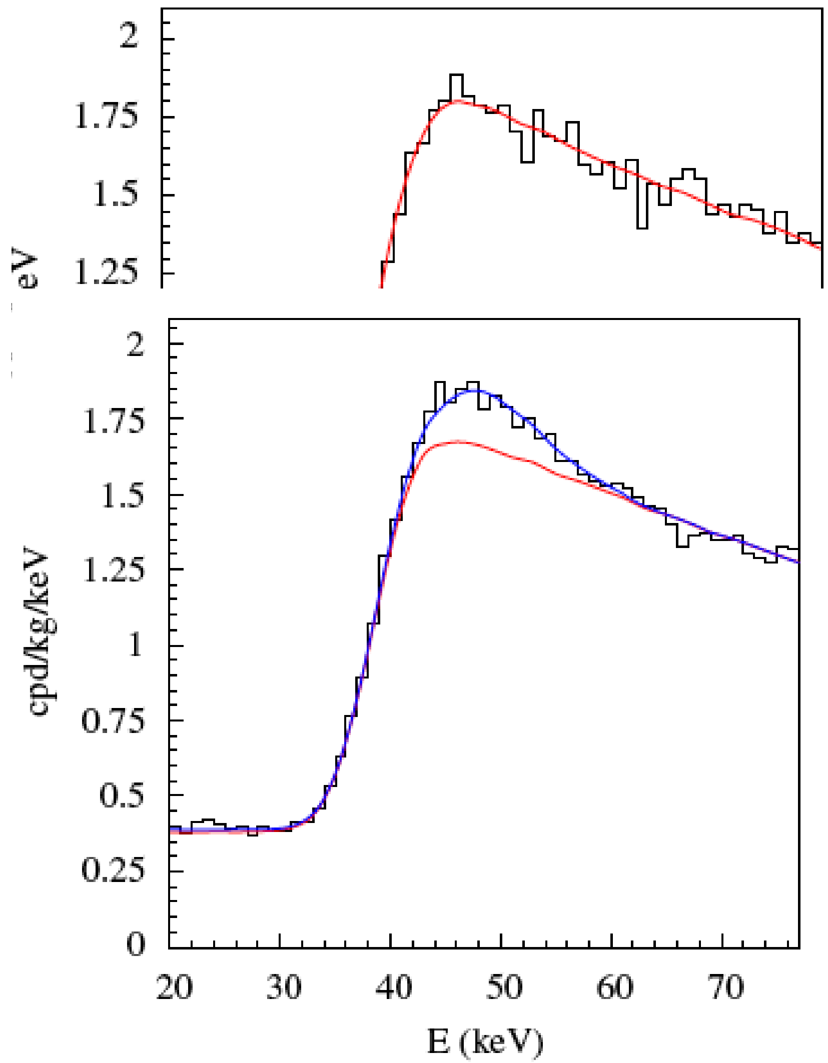
**where $\omega = 2\pi / T$, $T$ = 1 year.**

- **Most analyses so far did not include correlation between $S_0$ (average rate - non-modulated part of the signal) and $S_m$ (modulated part of the signal).**
- **Background $B(E)$ and $S_0$ are summed together and no information about possible background spectrum is used.**
- **Example analyses:** **M. Fairbairn, T. Schwetz, JCAP, 01 (2009) 037; arXiv:0808.0704v2 [hep-ph]; C. Savage et al., arXiv:0808.3607v3 [astro-ph].**

# DAMA spectra

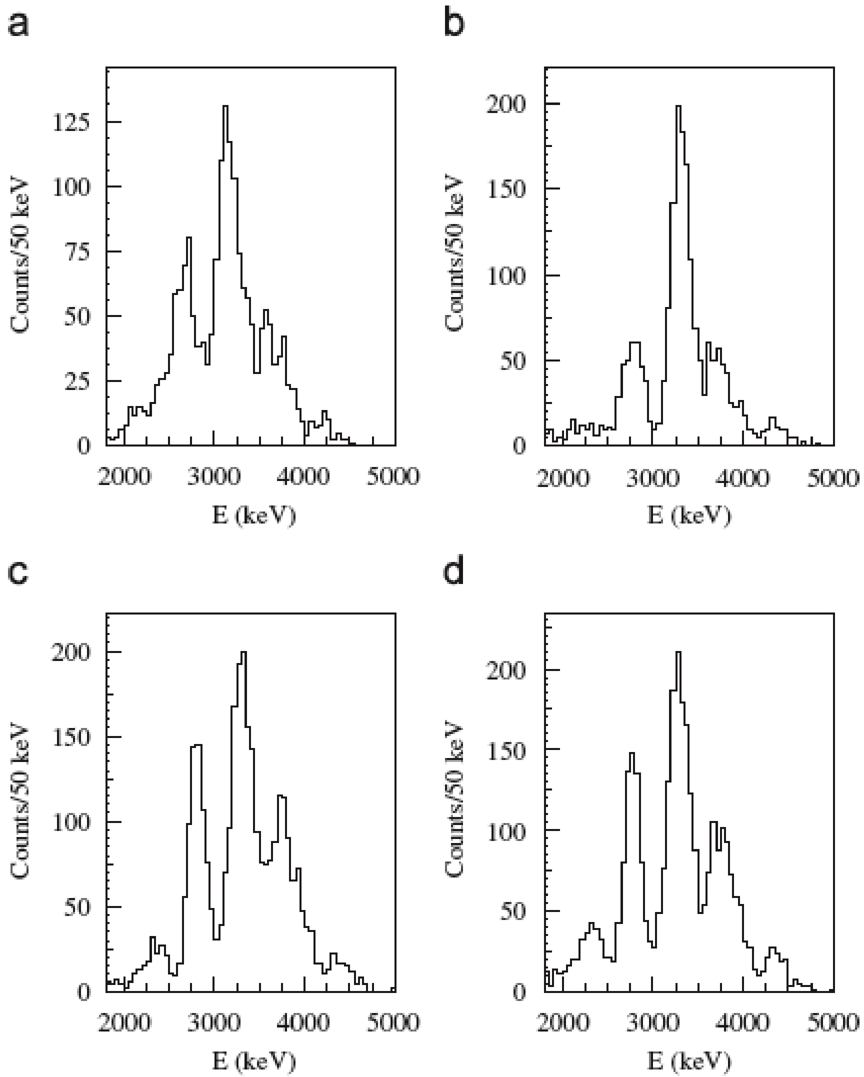
Bernabei et al. NIMA 592 (2008) 297.



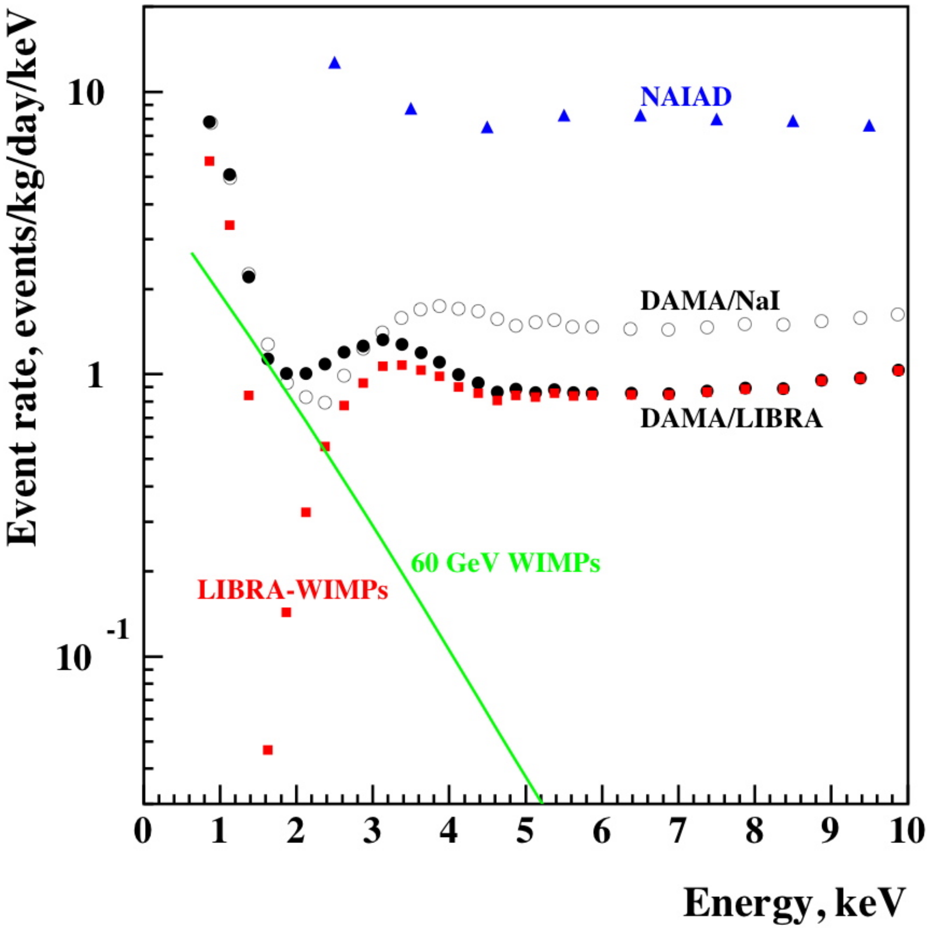

- Published spectrum is corrected for all efficiencies.
- $^{129}I$ dominates at 30-80 keV.

# Spectra at high energies




- Alpha spectra (energy is in keV electron equivalent).
- Used by DAMA (together with measured coincidences to determine concentrations of radioactive isotopes).
- Spectra at intermediate energies (0.1-2 MeV)?

# DAMA spectra

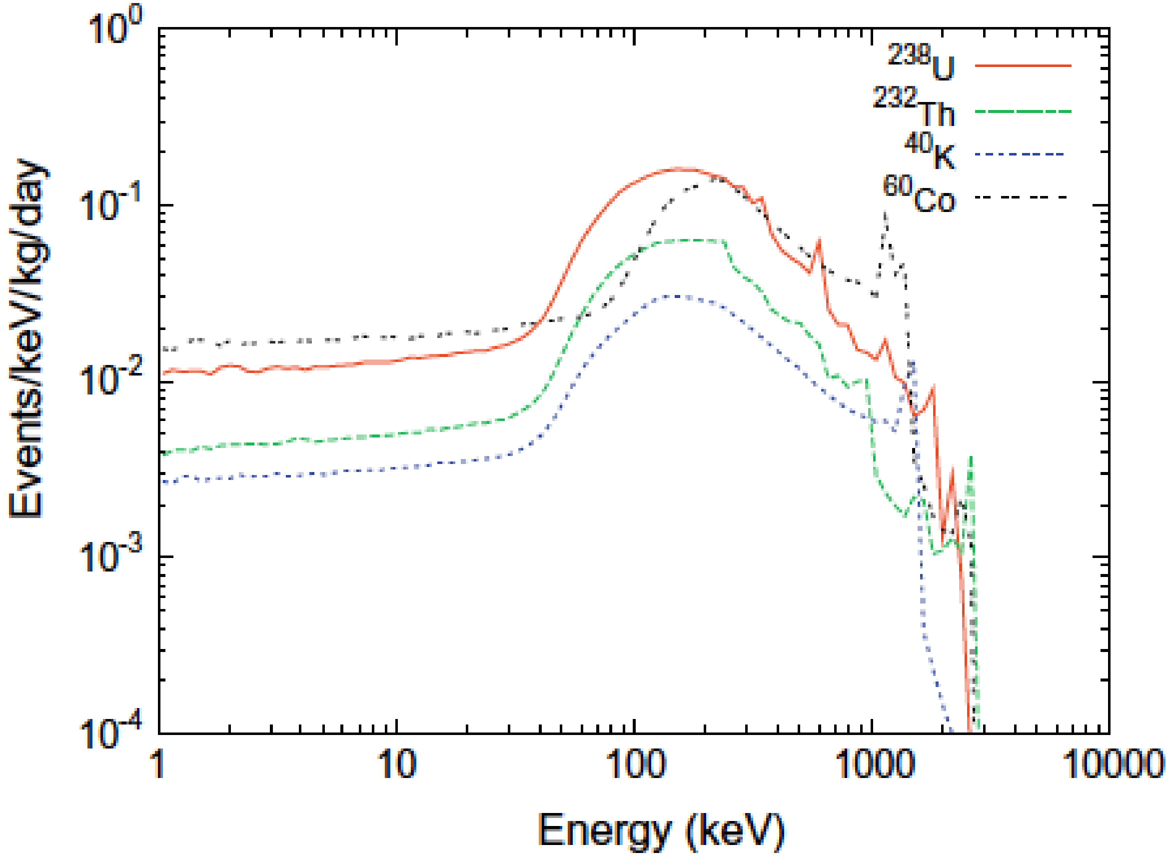



- Different spectra for DAMA/NaI and DAMA/LIBRA.
- Peak at 3.2 keV is at a slightly different position.
- 60 GeV WIMP signal ($7 \times 10^{-6}$ pb SI) leaves little room for background at 1-2 keV (energy resolution as reported by DAMA has been taken into account).
- Background = LIBRA - WIMPs should have a minimum at 1.5-2 keV.
- The depth of the minimum and its position depends on the WIMP and halo model.

# Sources of background

- **Can we get the background spectrum from simulations that matches observations?**
- **Mainly U/Th/K decay chains: gamma-rays, X-rays and electrons accompanying alpha or beta decays.**
- **Location: inside the crystals and in the surrounding materials (PMTs etc.).**
- **Three locations of the background source were considered:**
  - **External source (windows of PMTs and $^{60}Co$ in copper) - only gammas.**
  - **Internal source (intrinsic crystal contamination) - all particles.**
  - **Surface source (only surface layer of the crystal, 50 $\mu$m, was contaminated) - this would require very large concentrations of radioactive isotopes - all particles.**
- **Uranium, thorium in secular equilibrium, and potassium were considered. Also $^{129}I$ as internal source.**
- **Simulations were carried out with GEANT4.**

# External source (PMTs)



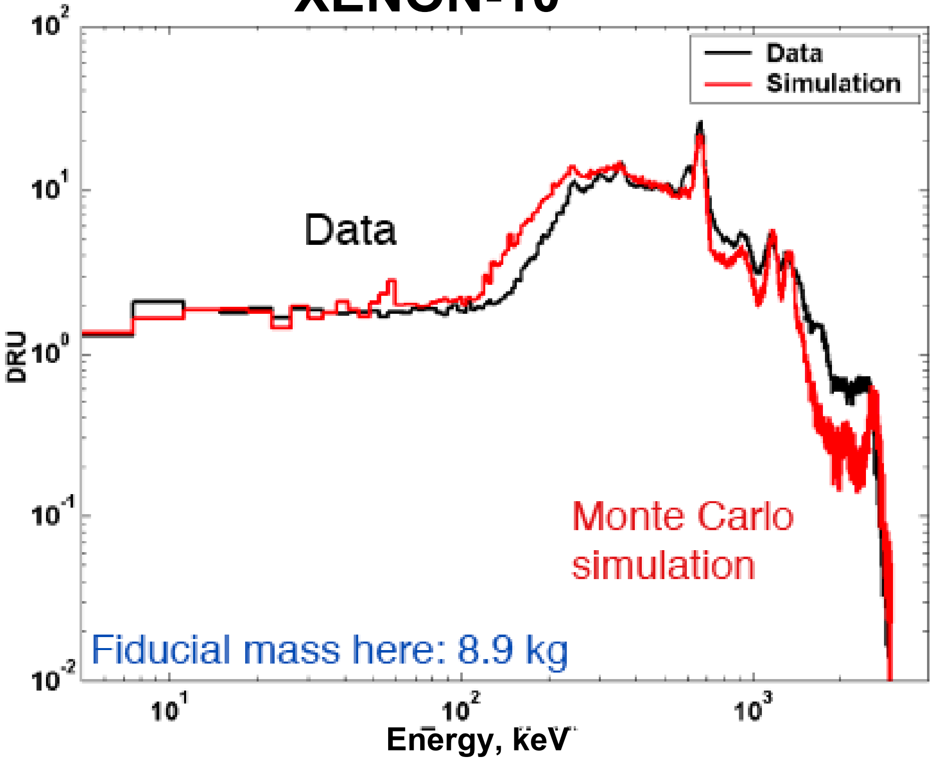

- Flat spectrum at low energies due to Compton electrons from high-energy gamma-rays.
- Back-scatter peak - scattering of photons on surrounding materials prior to entering the crystal.
- Typical spectra from external sources.
- Rate is much lower than measured.

Typical contaminations in low background PMTs: 30 ppb U/Th, 60 ppm K.

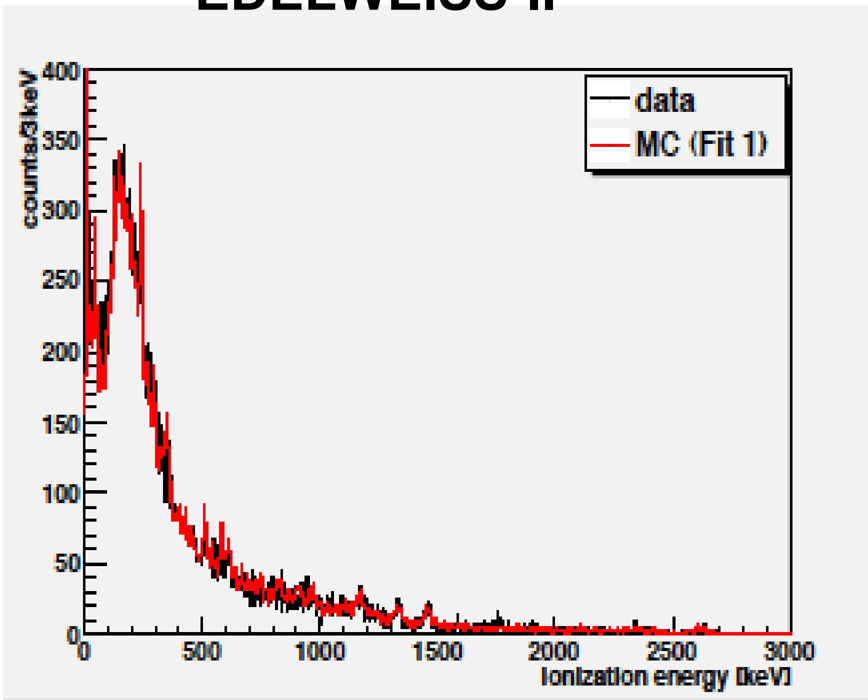
10 mBq/kg of $^{60}Co$ in copper.

# Background in other experiments

XENON-10

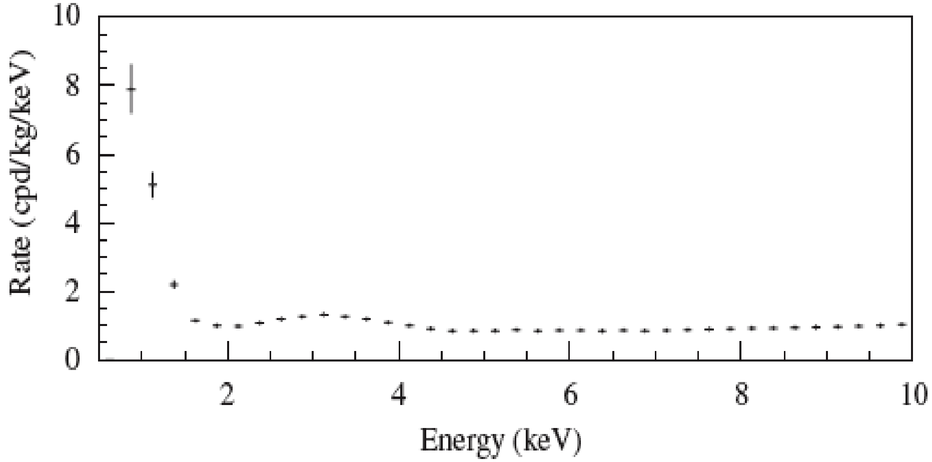


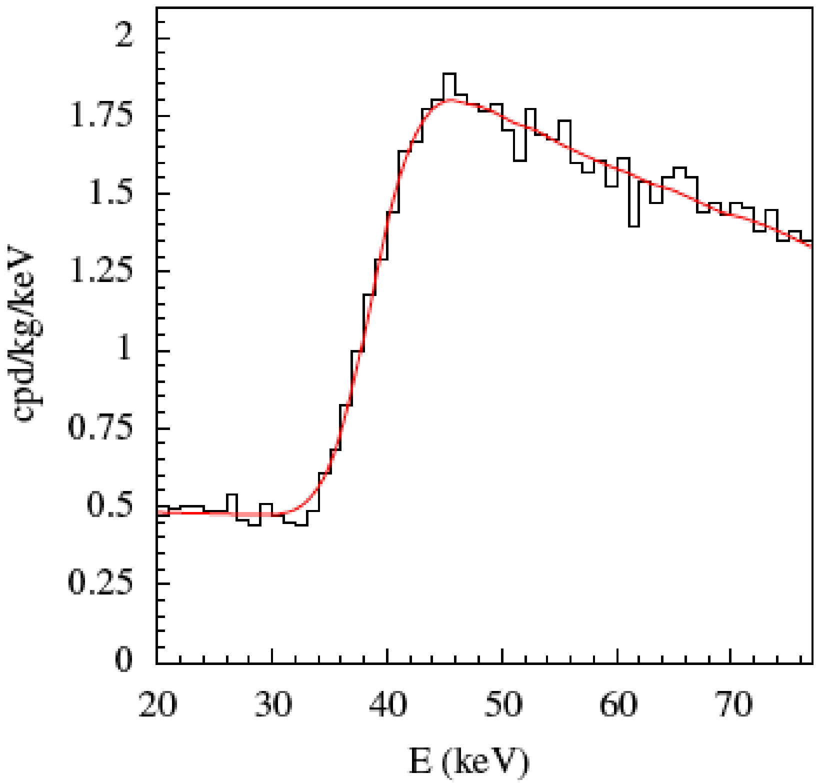

EDELWEISS-II




- **Background is dominated by an external source.**

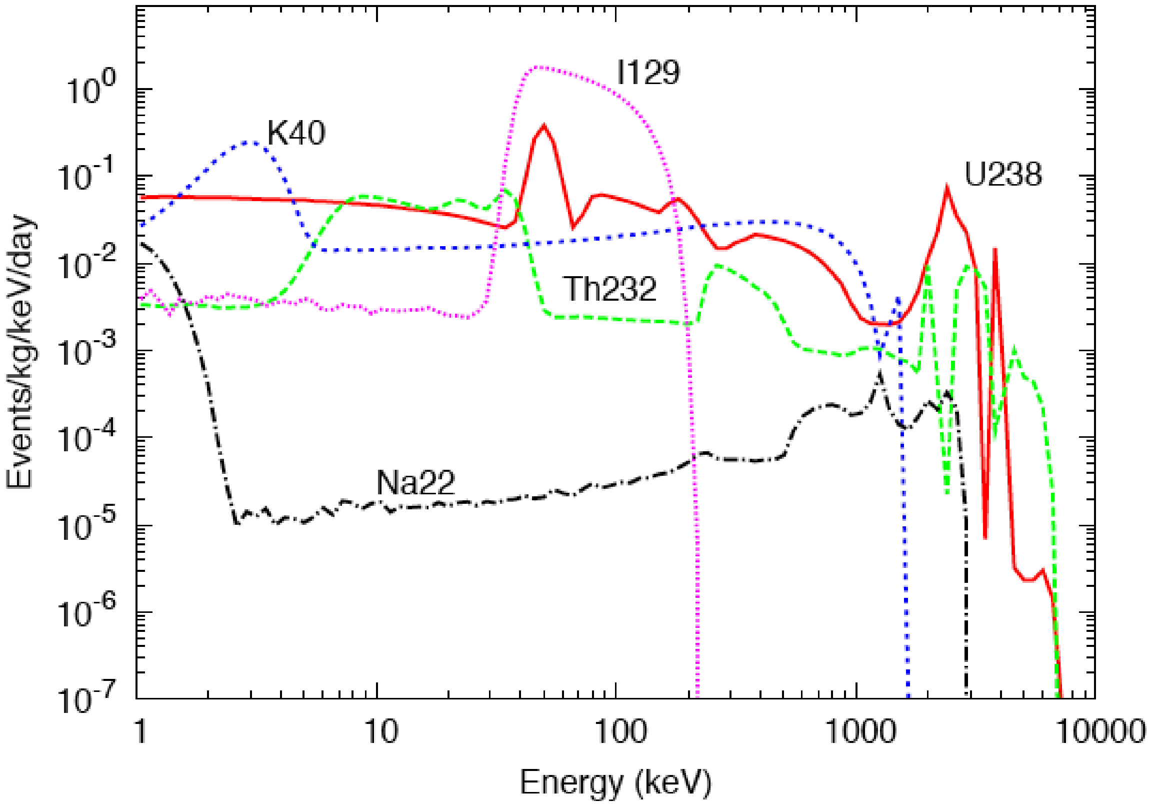
# DAMA spectra




- **The contribution of external sources can be estimated from the intensity of the back-scatter peak (probably not seen by DAMA).**

# Internal source

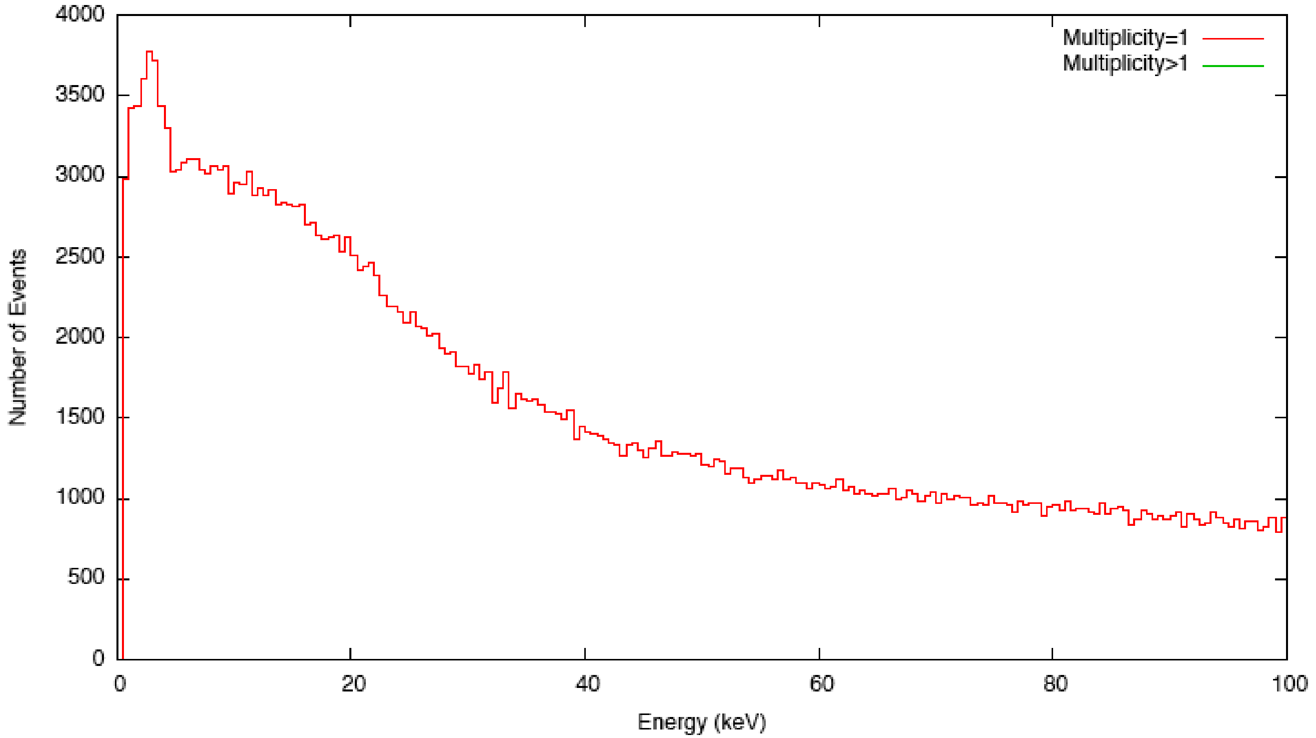



Contaminations (or limits) were taken from DAMA estimates: 5 ppt U/Th, 10 ppb K, 0.2 ppt $^{129}$I.

- Uranium chain was assumed to be in equilibrium - DAMA claims no equilibrium (higher decay rate of daughters at the end of the chain - $^{210}$Pb), but the spectrum at low energies is flat - no effect.
- Peaks from $^{40}$K and $^{129}$I as measured.
- Rate is lower than observed.
- Each source has a spectrum different from other sources.

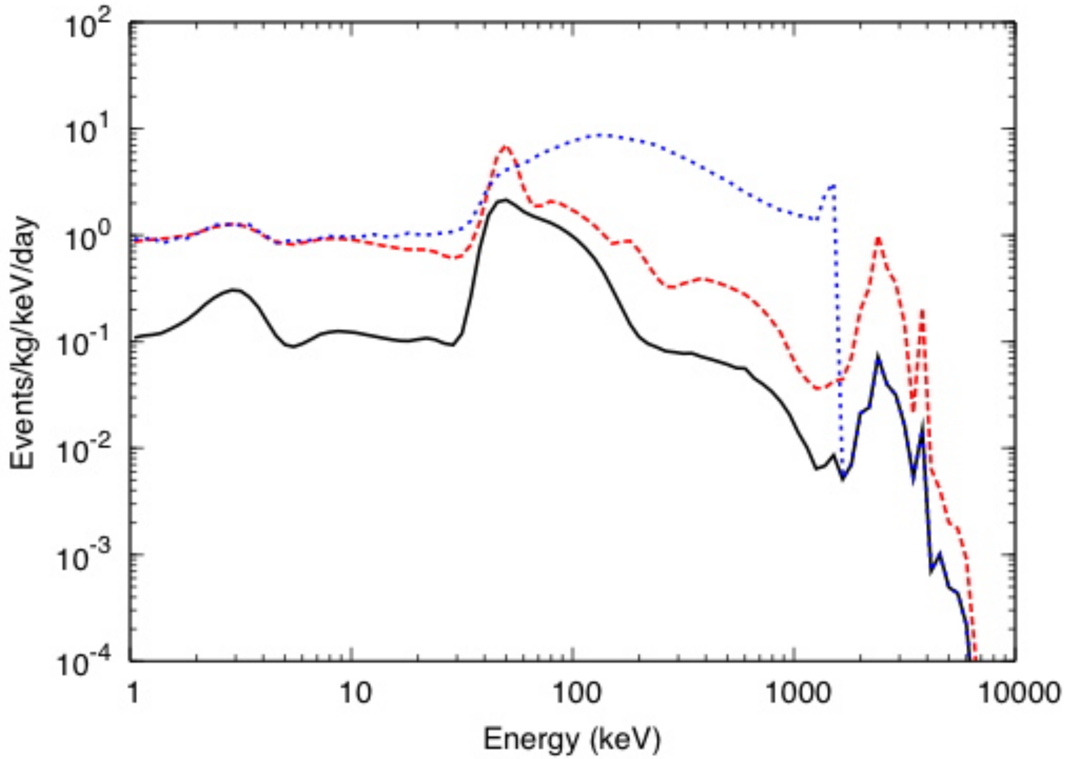
# Surface source

$^{40}K$

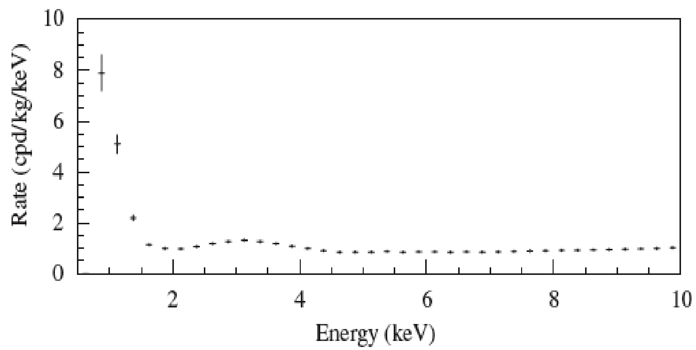



- Surface source - similar spectra to internal source but more events at low energies and the rate is smoothly decreasing with energy at 10-30 keV due to the escape of particles from the crystal.
- The contaminations should be huge to explain measured spectra.

# Combined spectrum



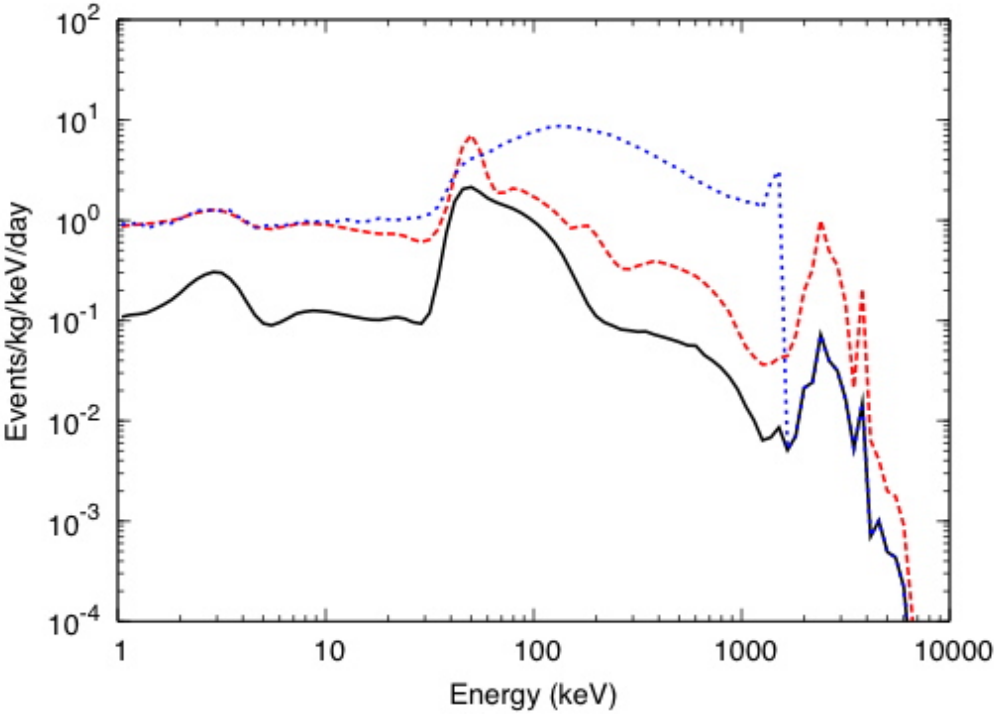

- The sum of external and internal sources.
- Black: estimated contaminations.
- Blue: enhanced external K - flat spectrum but back-scatter peak is clearly visible (not observed by DAMA?).
- Red: enhanced intrinsic U, Th, K - flat spectrum but wrong shape of the peak at 45 keV.

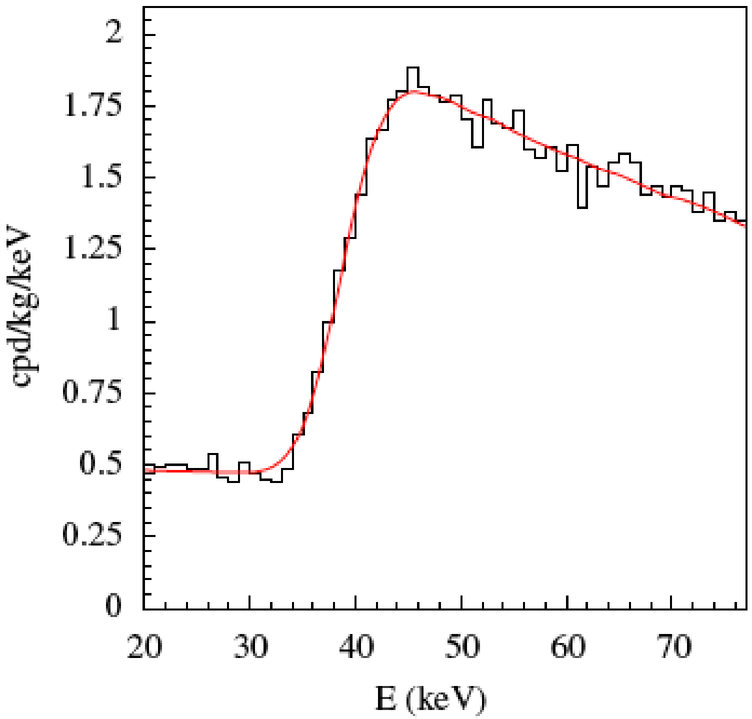



**Peak from $^{40}K$ at 3.2 keV, low rate below 10 keV, almost flat up to 30 keV.**

**We can get compatible rate at 1-10 keV only assuming higher concentrations of certain isotopes.**

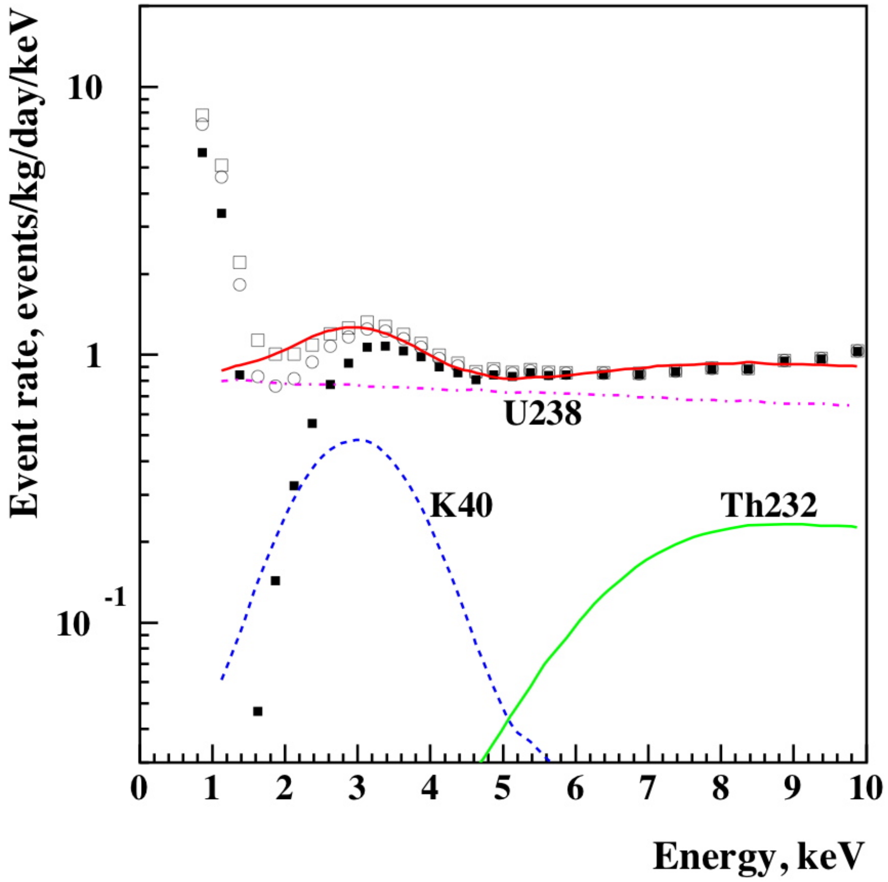
# Combined spectrum



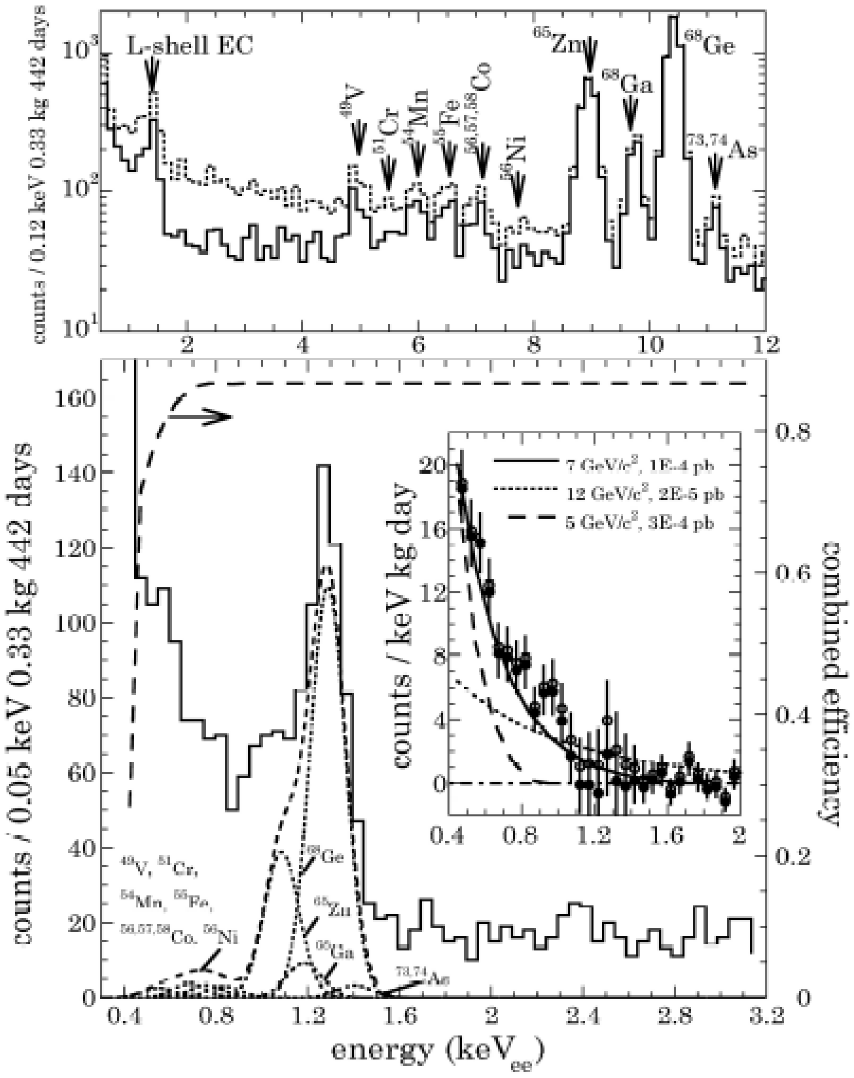

- Intensity of the $^{129}$I peak at 45 keV is similar to the observed one for estimated concentrations.
- Higher concentrations of certain isotopes help at low energies but this does not agree with DAMA measurements at higher energies 30-80 keV (although reported for 2 crystals only).

# Combined spectrum




- Red curve: the sum of the simulated background spectra with increased internal concentrations: U - 70 ppt, Th - 20 ppt, K - 20 ppt.
- Open squares: data.
- Filled squares: background = data - signal (60 GeV, $7\times10^{-6}$ pb).
- Open circles: background = data - signal (60 GeV, $2\times10^{-6}$ pb SI).
- Difficult to reconcile the measurements (minus signal) with simulations even for small cross-section (ratio below 10 at 2-4 keV of non-modulated (average) to modulated part of the spectrum).

# CoGeNT




- CoGeNT data (left) - C.E. Aalseth et al. arXiv:1106.0650v1.
- Cosmogenics has been studied.
- What's about exponential shape below 2 keV.
- Part of it is assumed to be a background. Where from?

# Conclusions

- To investigate the background we need to know the measured average spectrum at a wide range of energies 1 keV - 10 MeV averaged over all crystals (not published by DAMA).
- It is hard to fit the measured spectrum at low energies (even without signal) to the simulated background assuming reported concentrations of radioactive isotopes.
- The assumption of higher concentrations of certain isotopes, although improving agreement with the low-energy part of the spectrum, results in some features that are probably not seen by DAMA at higher energies.
- If a signal is present, then the background (measured spectrum minus signal) should have a minimum. Its position and depth depend on the model but it is very hard to obtain such a minimum with simulations.
- Dark mater models that predict a large ratio (above 10 at 2-4 keV) of non-modulated (average) to modulated parts of the spectrum can be excluded.
- Interpretation of the DAMA result should include the background spectrum restricting the range of models compatible with the signal.
- Dark matter experiments should show the measurements and simulations of the background, in particular if a possible WIMP signal is claimed.