

The expected background spectrum in NaI dark matter detectors and the DAMA result

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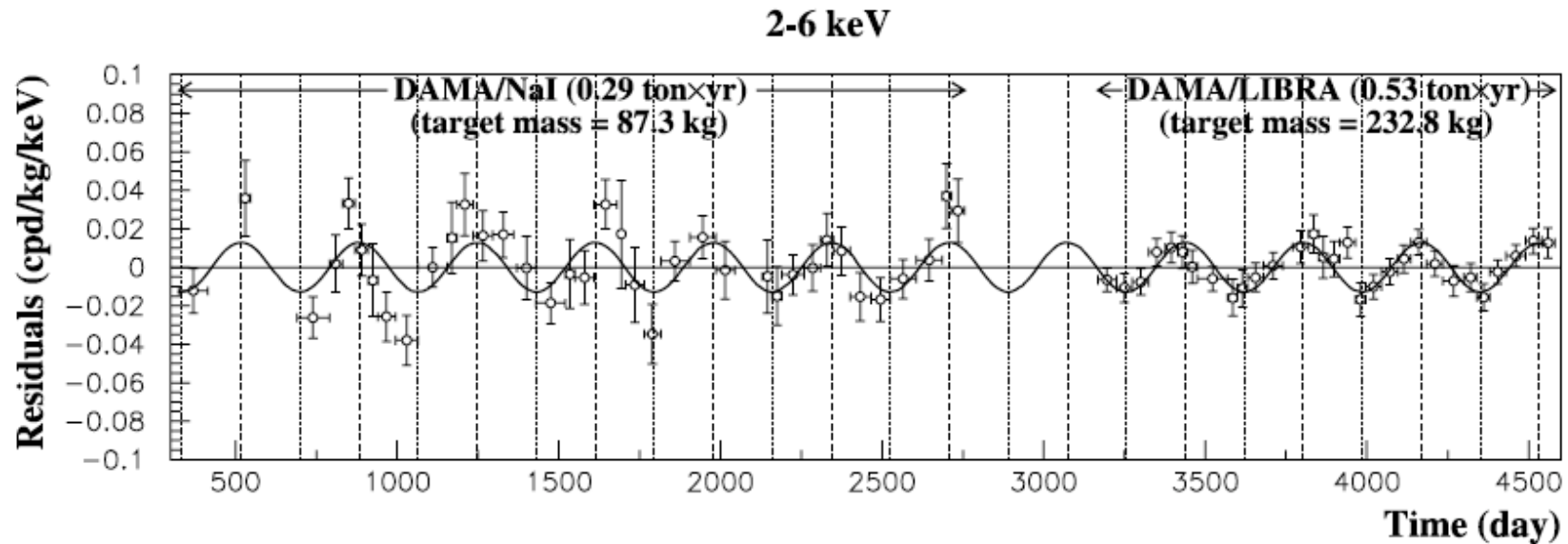
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Outline

- DAMA analysis and DAMA spectrum.
- Modelling of radioactive background in NaI.
- Implications for interpreting the DAMA signal.
- Some conclusions.

Also discussed with Gilles Gerbier and Rachid Lemrani (CEA-Saclay, France).

DAMA signal



- DAMA/NaI - 100 kg of NaI(Tl), 7 annual cycles.
- DAMA/LIBRA - 250 kg of NaI(Tl), 4 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:

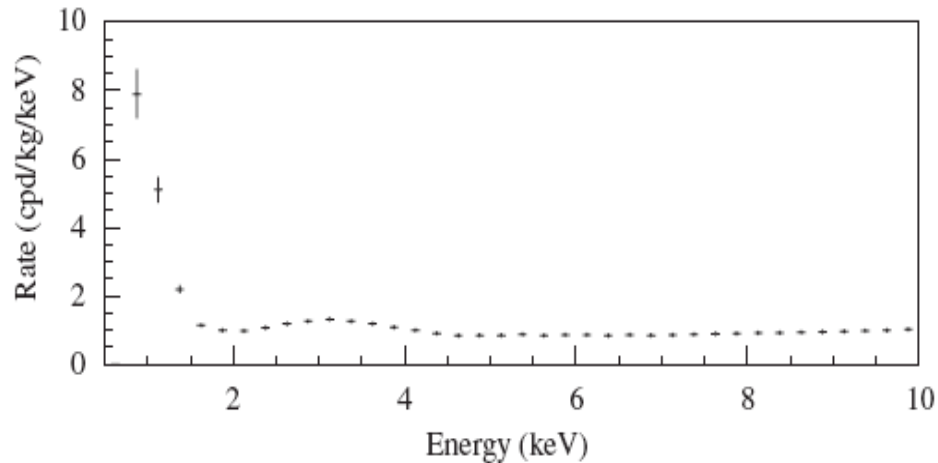
$$R(E,t) = B(E) + S_0(E) + S_m(E) \cos[\omega(t - t_0)]$$

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

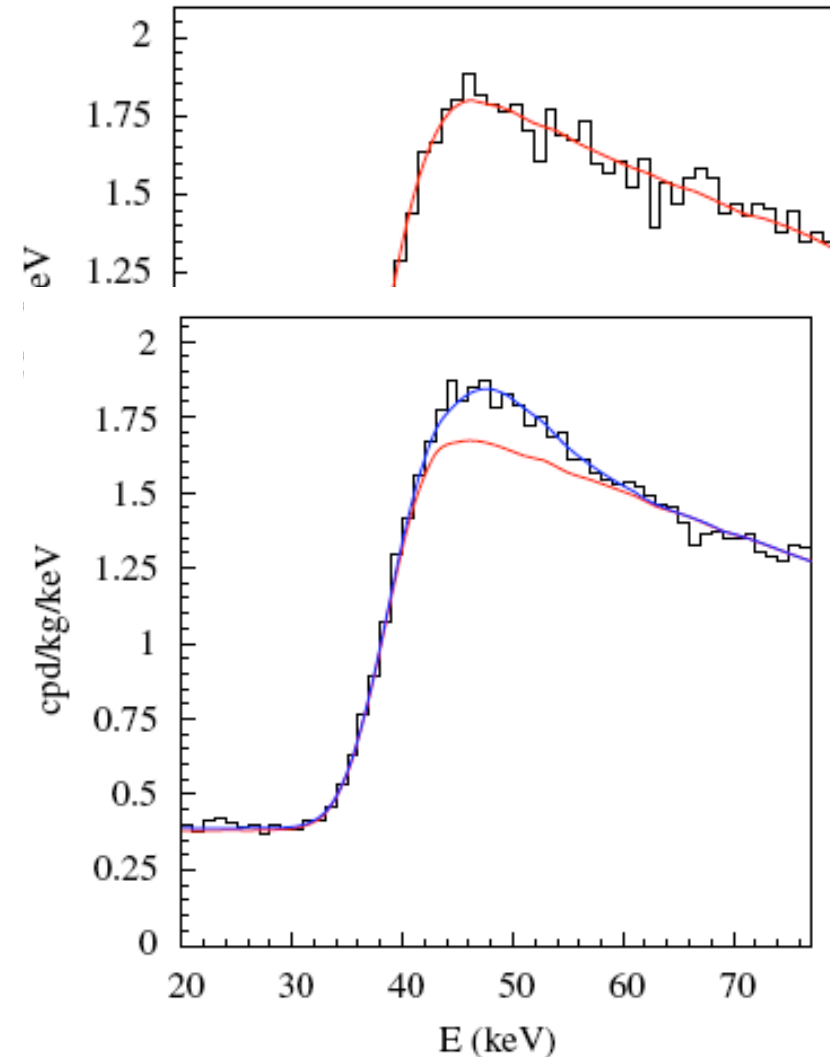
- Most analyses so far did not include correlation between S_0 (average rate - non-modulated part of the signal) and S_m (modulated part of the signal).
- Background $B(E)$ and S_0 are summed together and no information about possible background spectrum is used.
- Recent analysis: M. Fairbairn, T. Schwetz,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

DAMA spectra

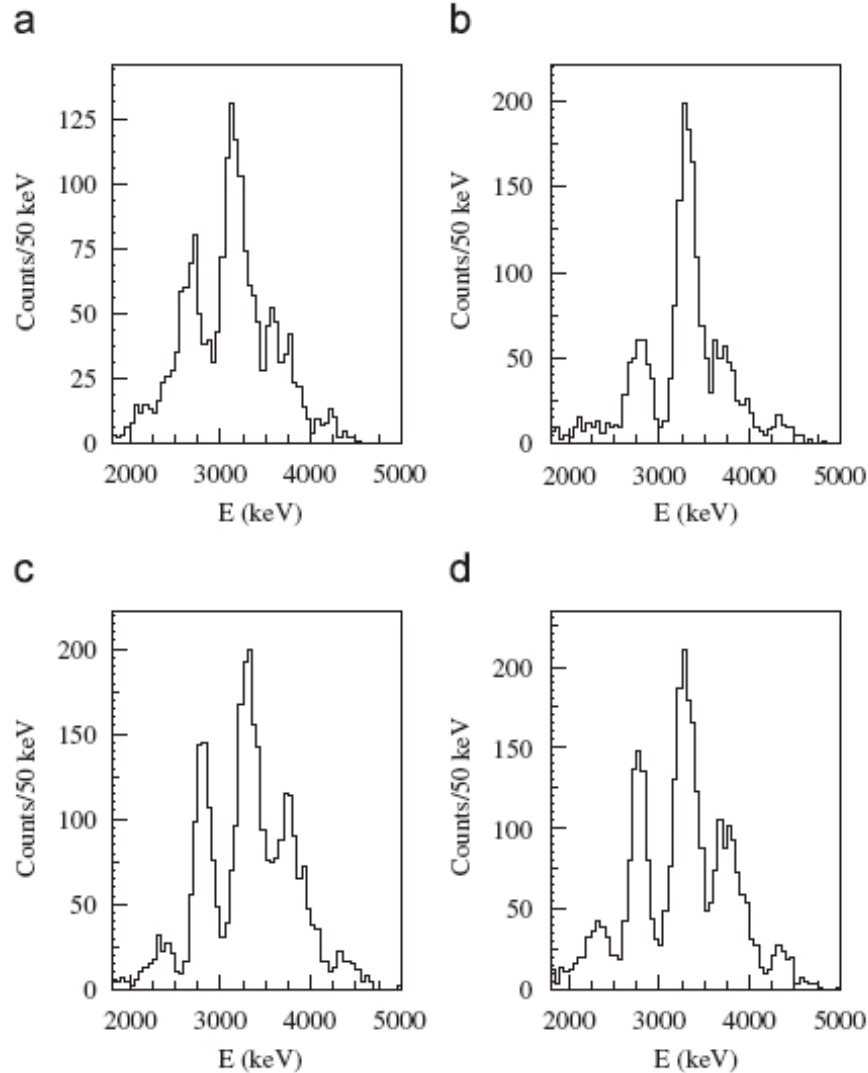
Bernabei et al. NIMA 592 (2008) 297.



- Published spectrum is corrected for all efficiencies.
- Rate drops from 1 dru to 0.5 dru between 10 and 20 keV (spectrum at 1-10 keV is averaged over all crystals, at 20-80 keV it is given for two individual crystals).
- ^{129}I dominates at 30-80 keV.

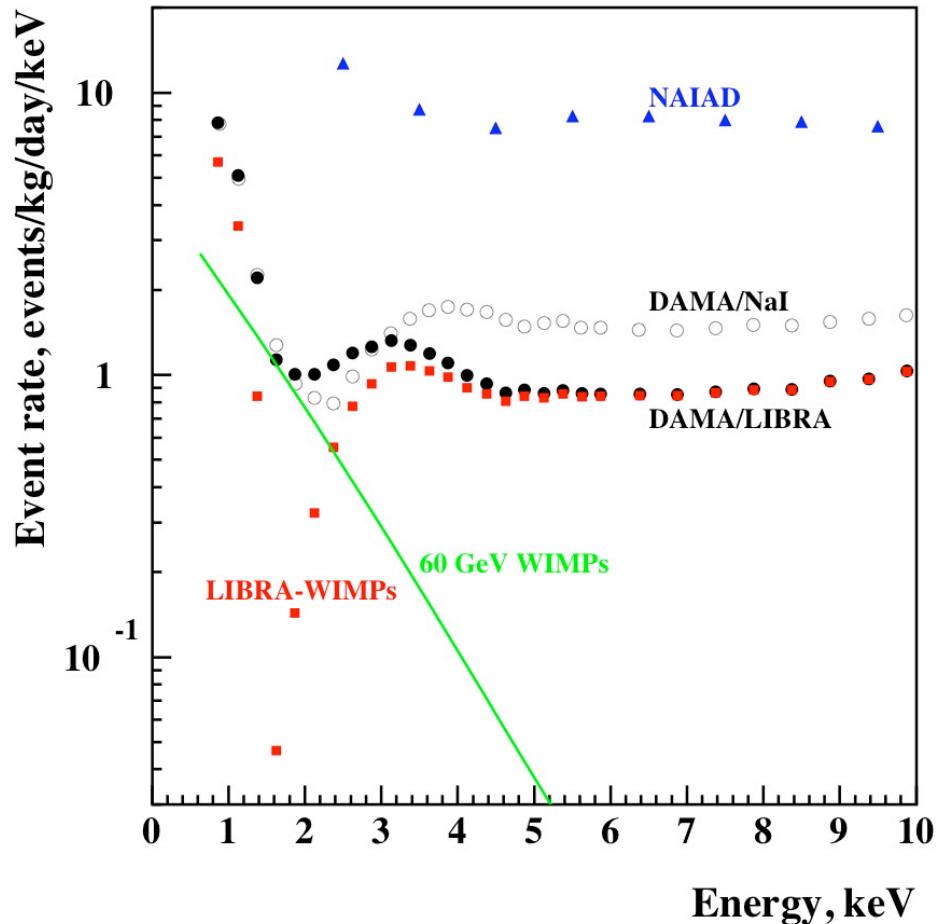


Spectra at high energies



- 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) were not reported.

DAMA spectra



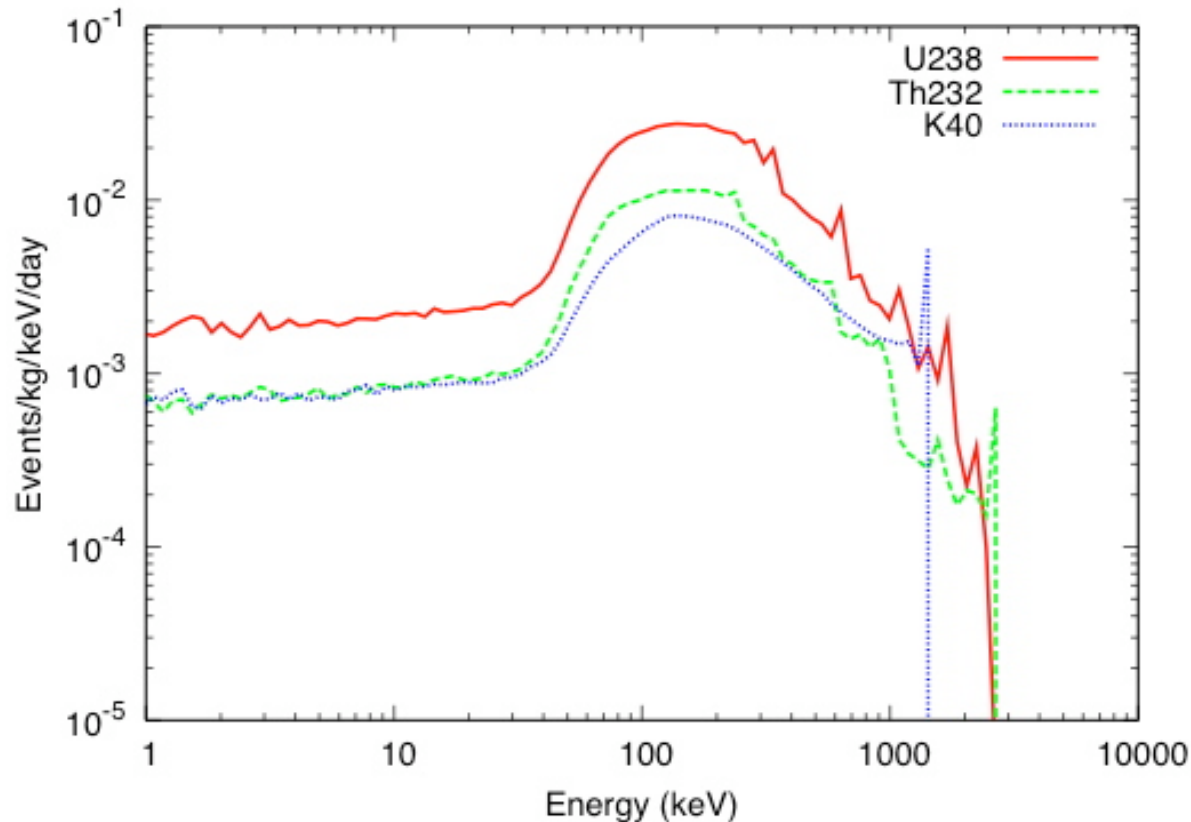
See also G. Gerbier, RPP (Experimental Detection of Dark Matter), 2007.

- Different spectra for DAMA/NaI and DAMA/LIBRA.
- Peak at 3.2 keV is at a slightly different position.
- 60 GeV WIMP signal (7×10^{-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) - only gamma-rays.
 - Internal source (intrinsic crystal contamination) - all particles.
 - Surface source (only surface layer of the crystal, 50 μm , 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 (with the help from Luciano Pandola - ILIAS work).

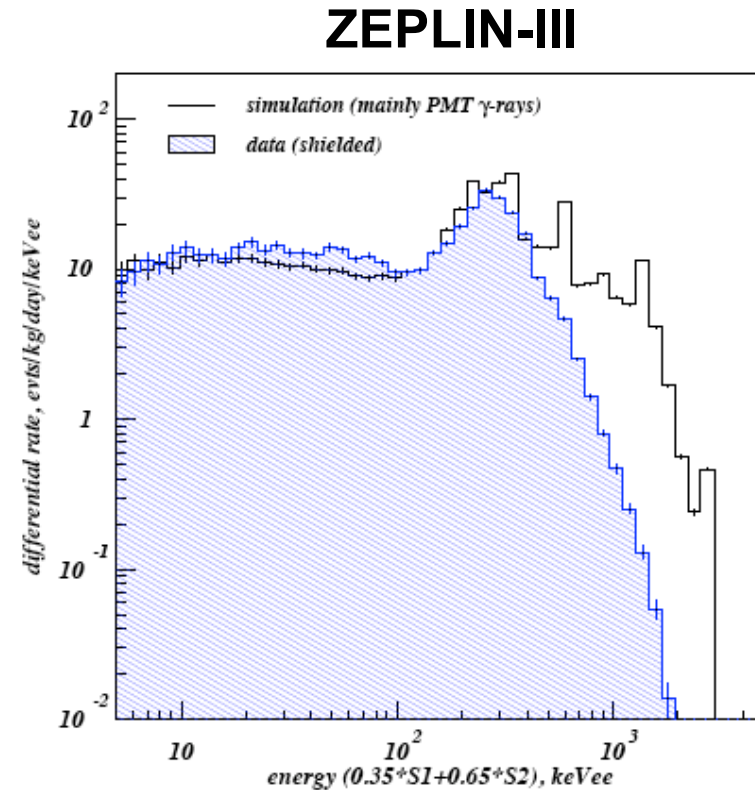
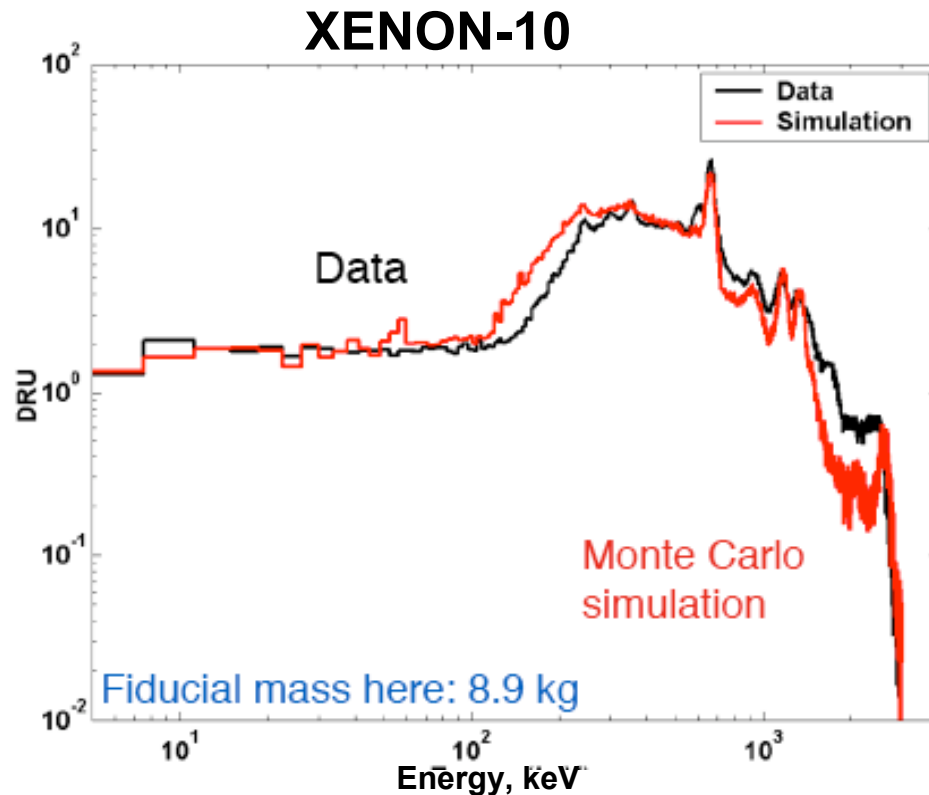
External source (PMTs)



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

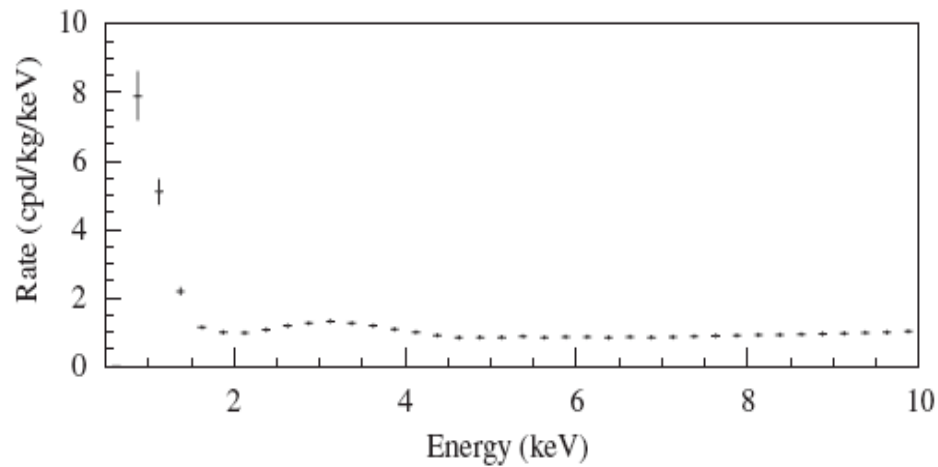
- Flat spectrum at low energies due to Compton electrons from high-energy gamma-rays.
- Back-scatter peak - scattering of photons on surrounding materials prior to entering the crystal.
- Typical spectra from external sources.
- Rate is much lower than measured.

Background in other experiments

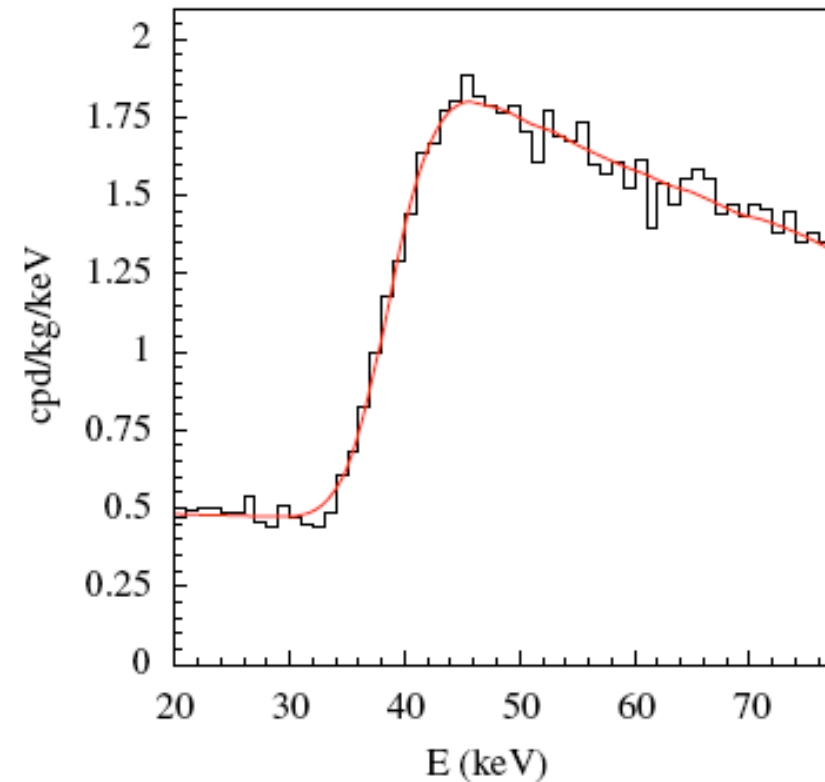


- Background is dominated by an external source.

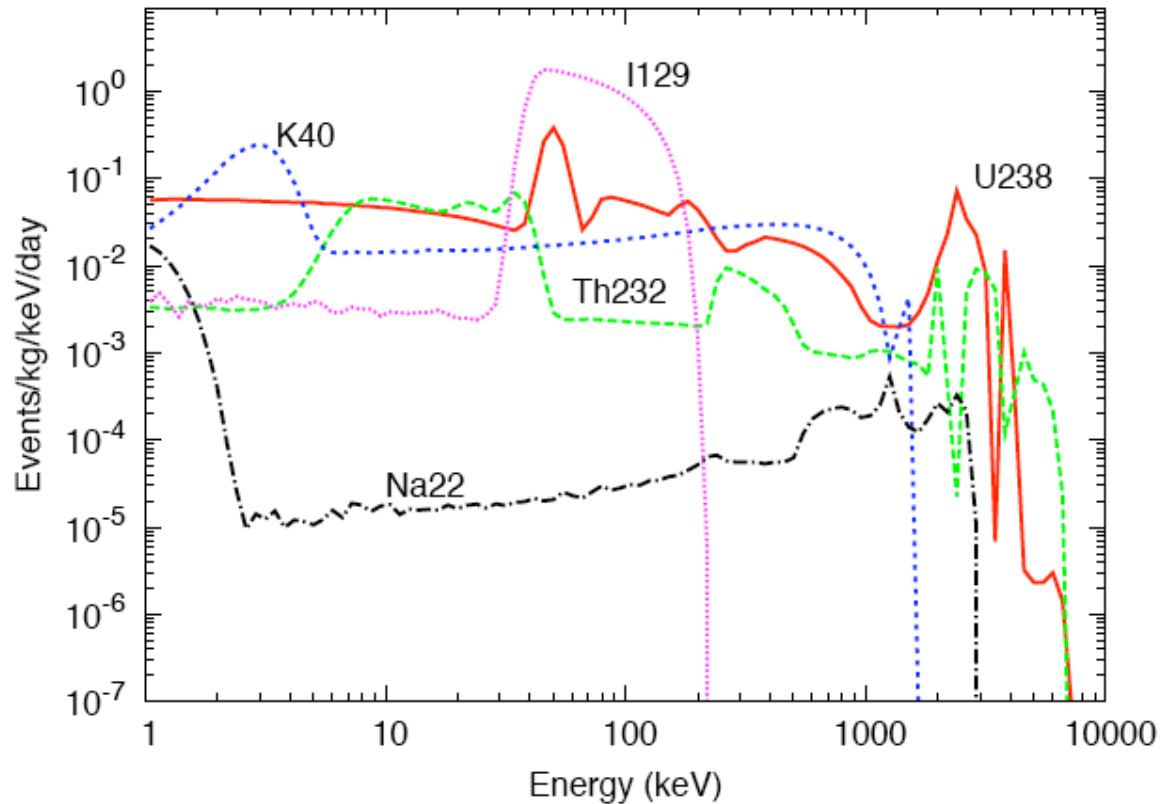
DAMA spectra



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



Internal source

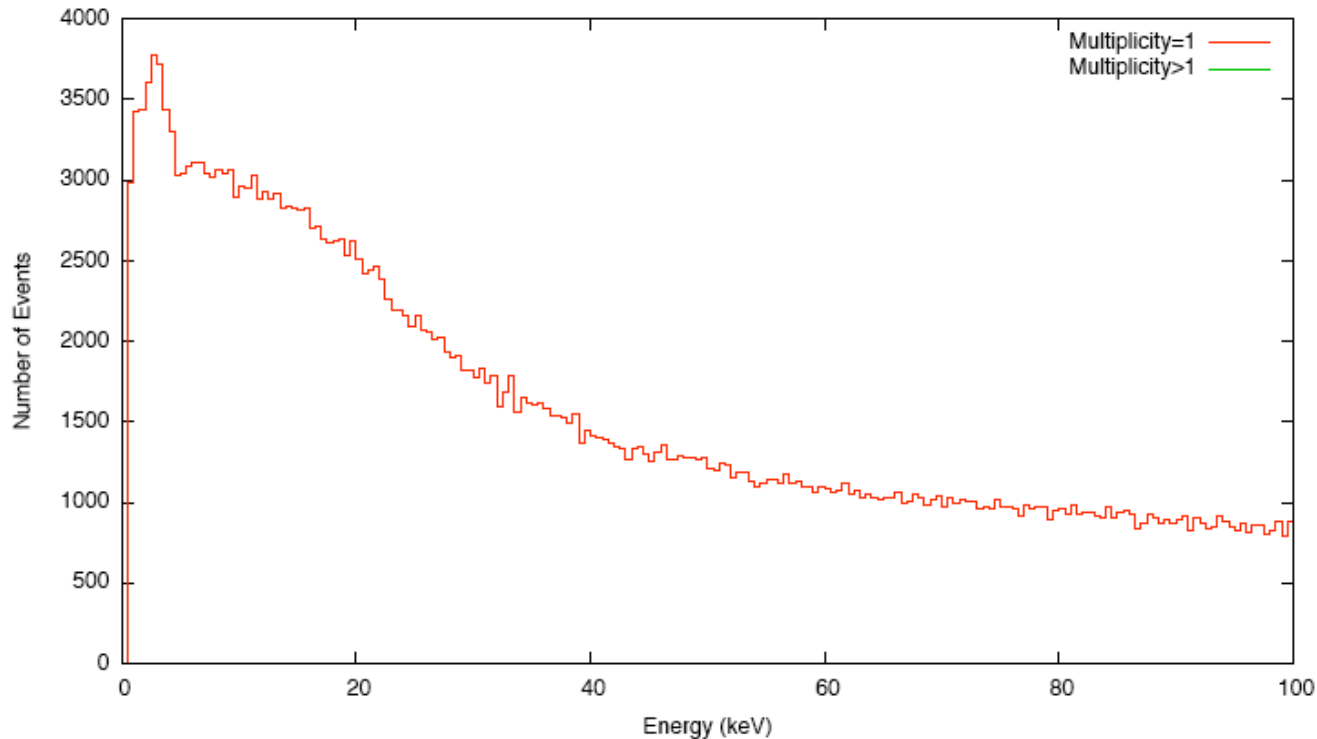


Contaminations (or limits) were taken from DAMA estimates: 5 ppt U/Th, 10 ppt K, 0.2 ppt ^{129}I .

- 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.

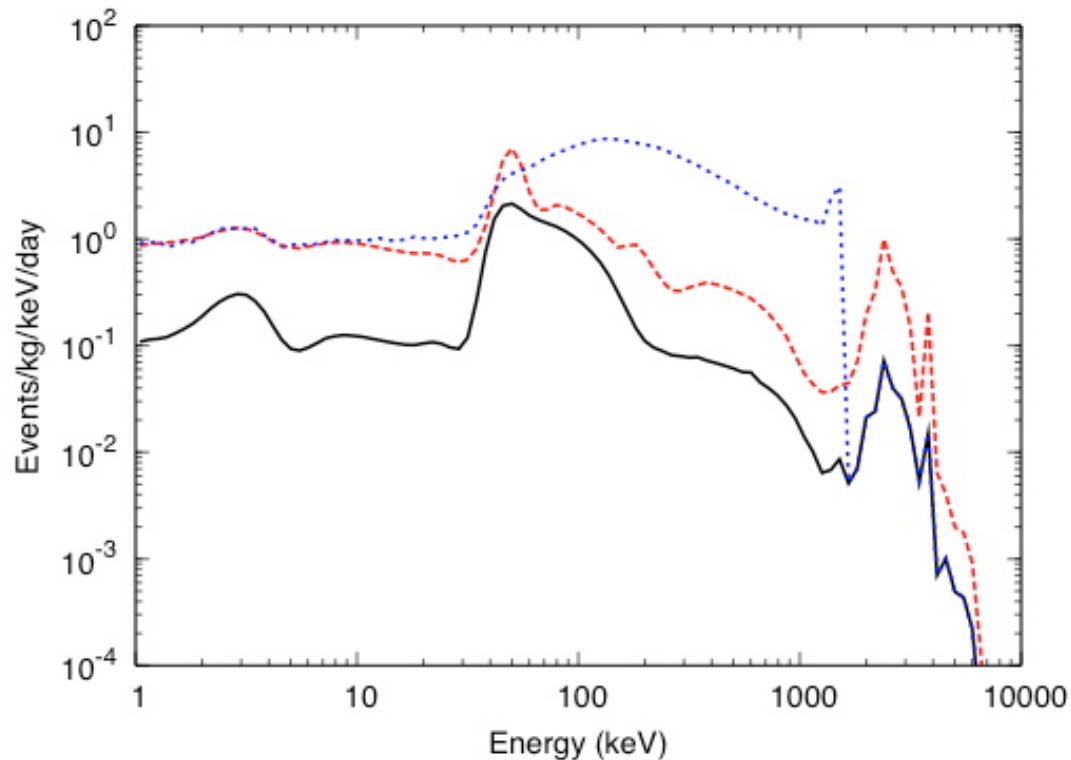
Surface source

^{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.

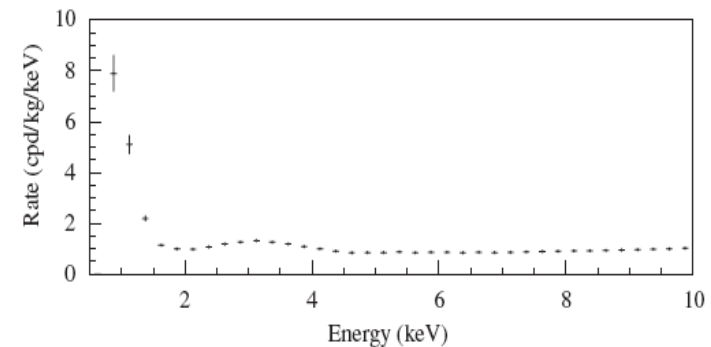
Combined spectrum



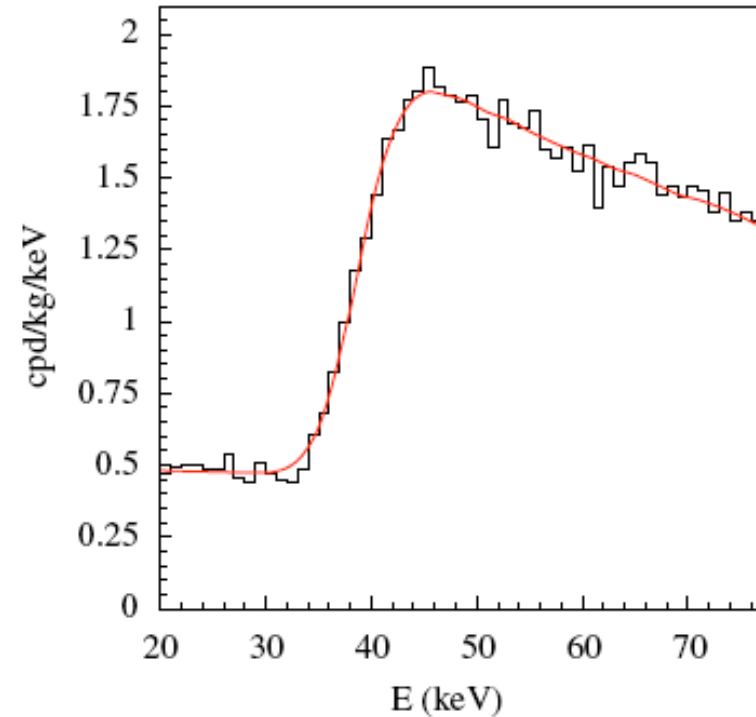
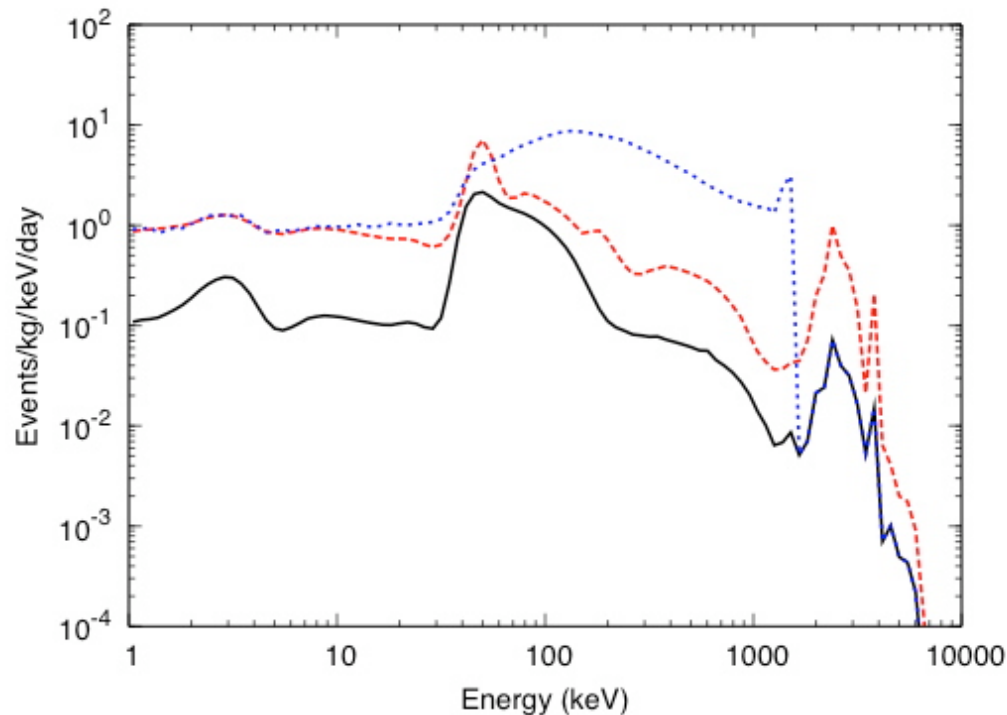
Peak from ^{40}K at 3.2 keV, low rate below 10 keV, almost flat up to 30 keV.

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

- 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.**

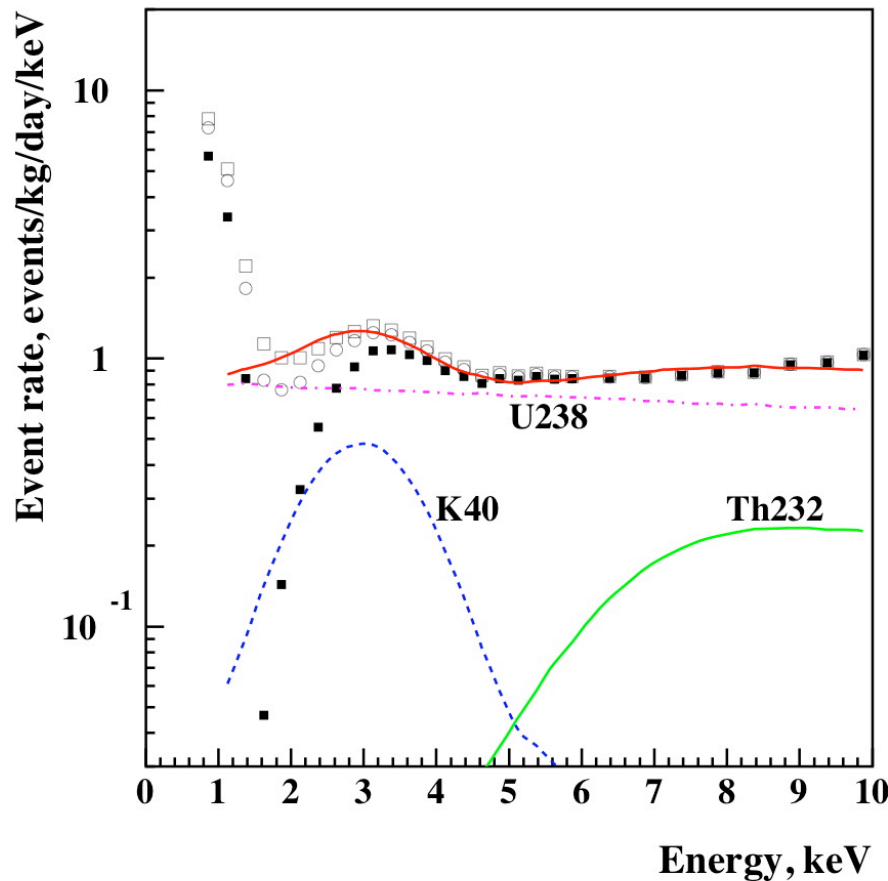


Combined spectrum



- 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, 7×10^{-6} pb).**
- **Open circles: background = data - signal (60 GeV, 2×10^{-6} pb SI).**
- **Difficult to reconcile the measurements (minus signal) with simulations even for small cross-section (small ratio (below 10 at 2-4 keV) of non-modulated (average) to modulated parts of the spectrum.**

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).
- Some features (drop in observed intensity between 10 and 20 keV, low total rate from simulations) need to be explained.
- At present 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 high 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 matter 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.