Background in NaI dark matter detectors and the DAMA signal

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Outline

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

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

DAMA analysis

- **Annual modulation analysis:**

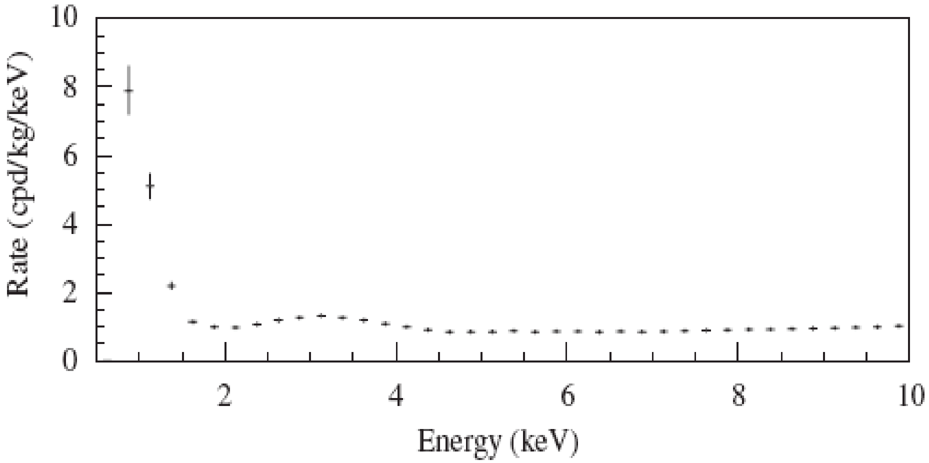
$$R(E,t) = B(E) + S_0(E) + S_m(E)\cos\left[\omega(t - t_0)\right]$$

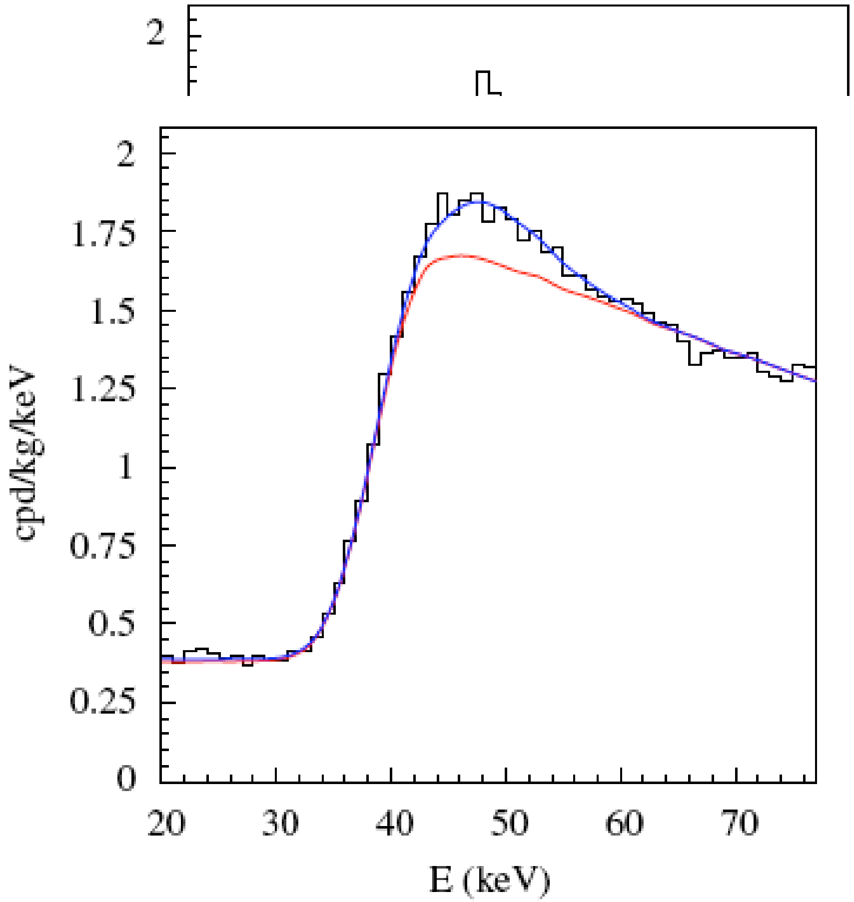
where $\omega = 2\pi / T$, $T = 1$ year.

- **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, arXiv:0808.0704v2 [hep-ph].**

DAMA spectra

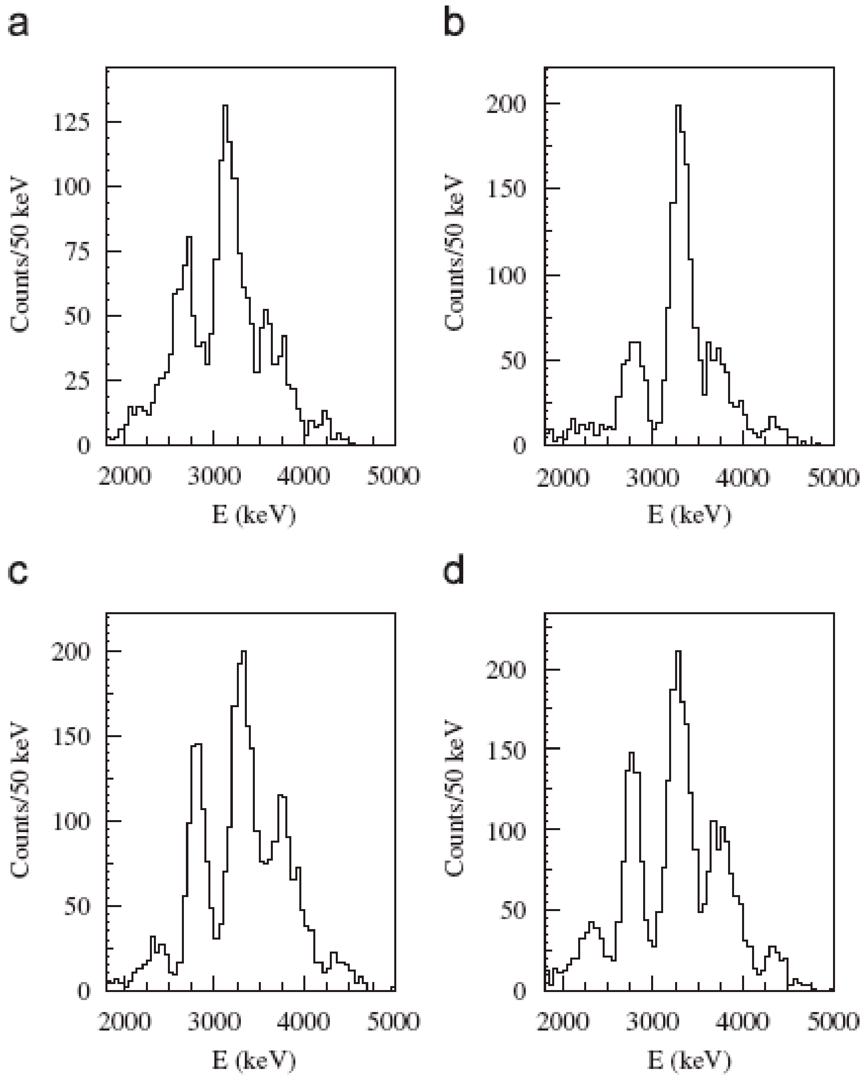
Bernabei et al. NIMA 592 (2008) 297.





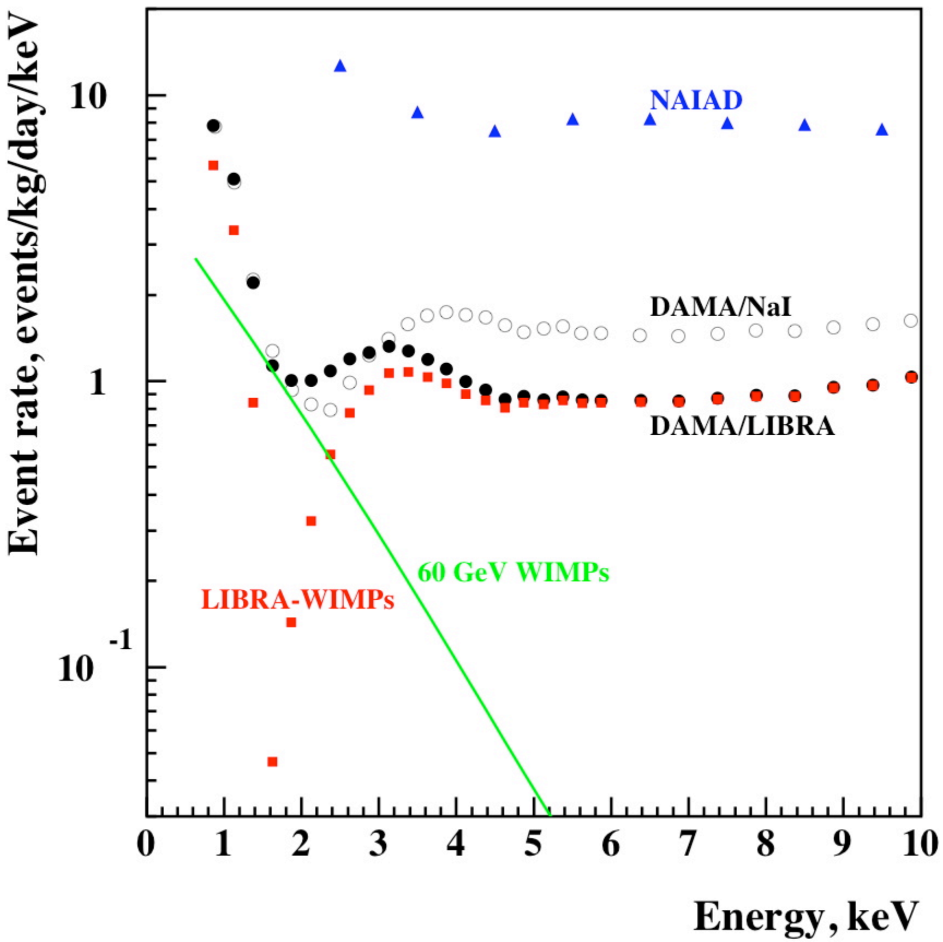
- Rate drops from 1 dru to 0.5 dru between 10 and 20 keV (spectrum at 1-10 keV is averaged over all crystals, at 20-80 keV it is given for two individual crystals).
- It looks like ^{129}I dominates the spectrum, at least at 30-80 keV.

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



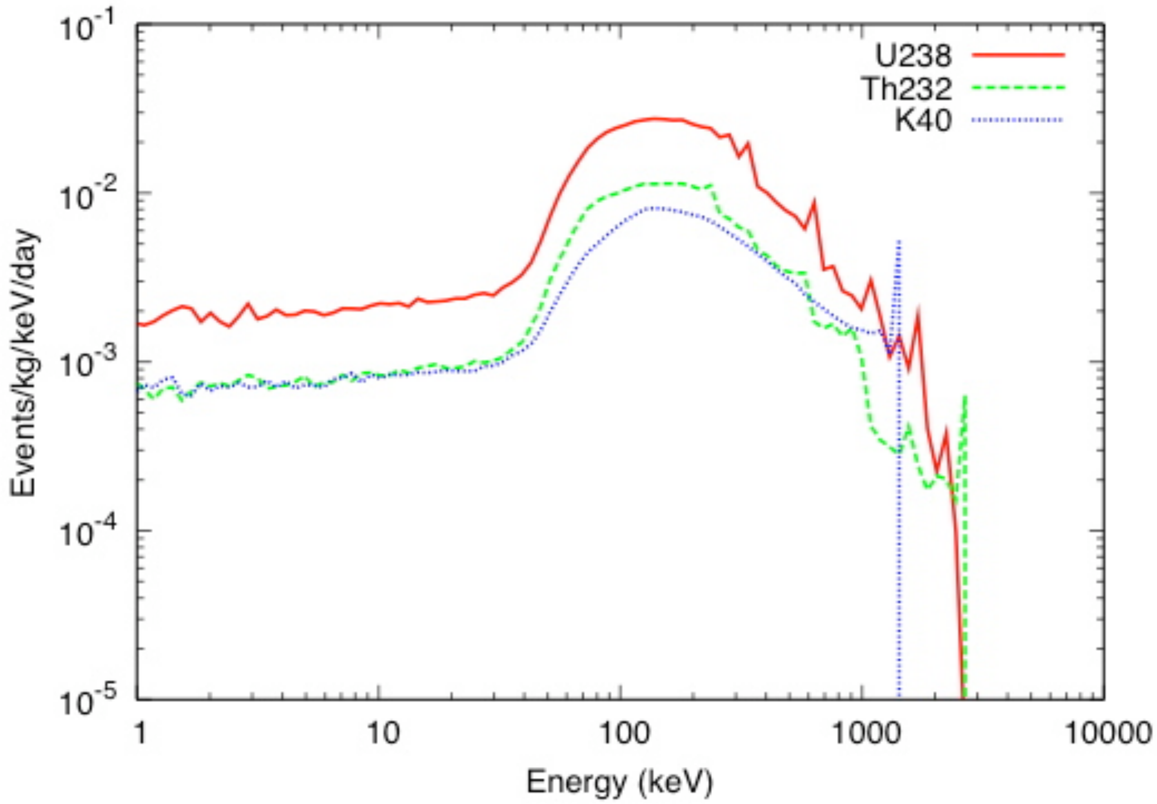
- Different spectra for DAMA/NaI and DAMA/LIBRA.
- Peak at 3.2 keV is at a slightly different position.
- 60 GeV WIMP signal (7×10^{-6} pb SI) leaves little room for background at 1-2 keV.
- Background = LIBRA - WIMPs should have a deep minimum at 1.5-2 keV.
- The depth of the minimum and its position depends on the WIMP and halo model.

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

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.

External source (PMTs)

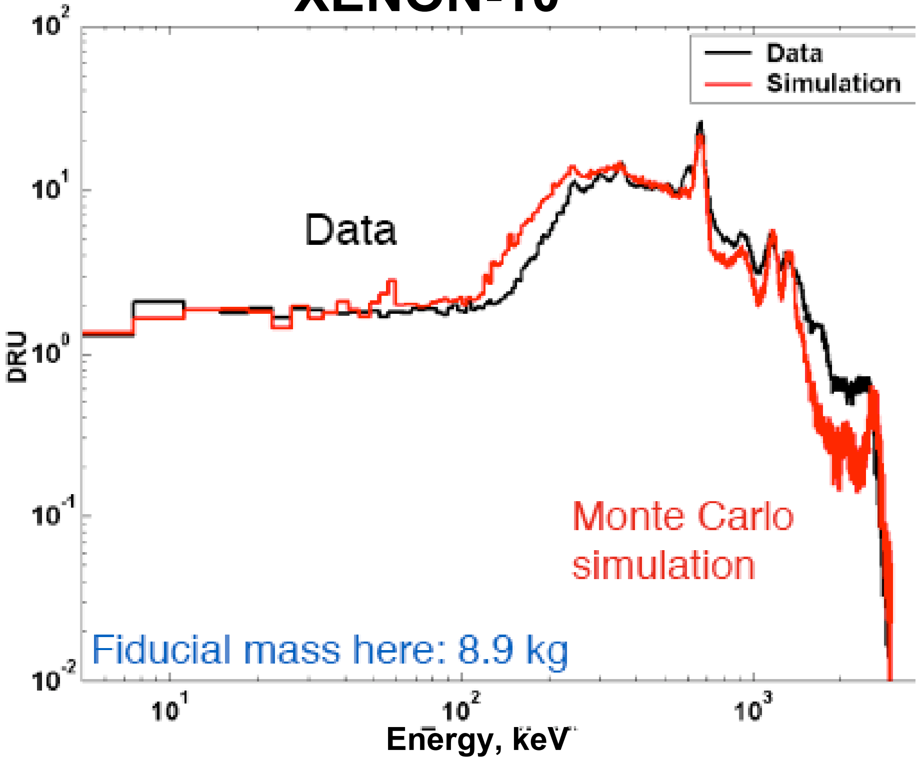


Typical contaminations in ultra-low background PMTs from ETL.

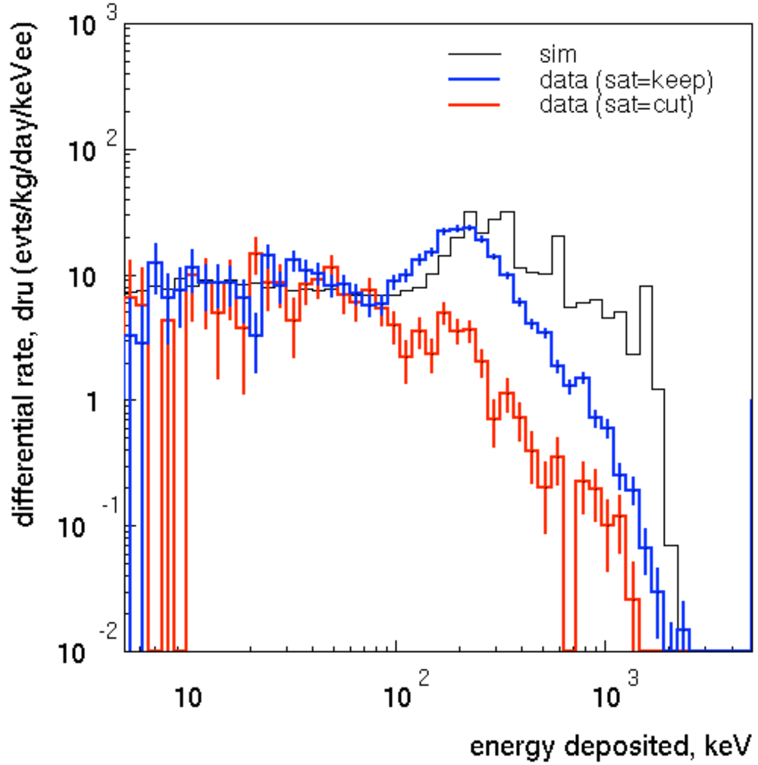
- **Flat spectrum at low energies due to Compton electrons from high-energy gamma-rays.**
- **Back-scatter peak at about 150 keV - scattering of photons on surrounding materials prior to entering the crystal.**
- **Typical spectra from external sources.**
- **Rate is much lower than measured.**

Background in other experiments

XENON-10

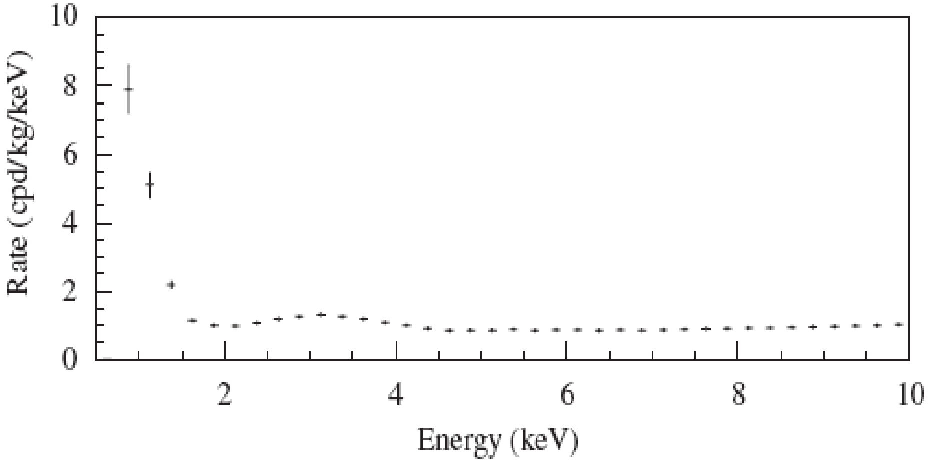


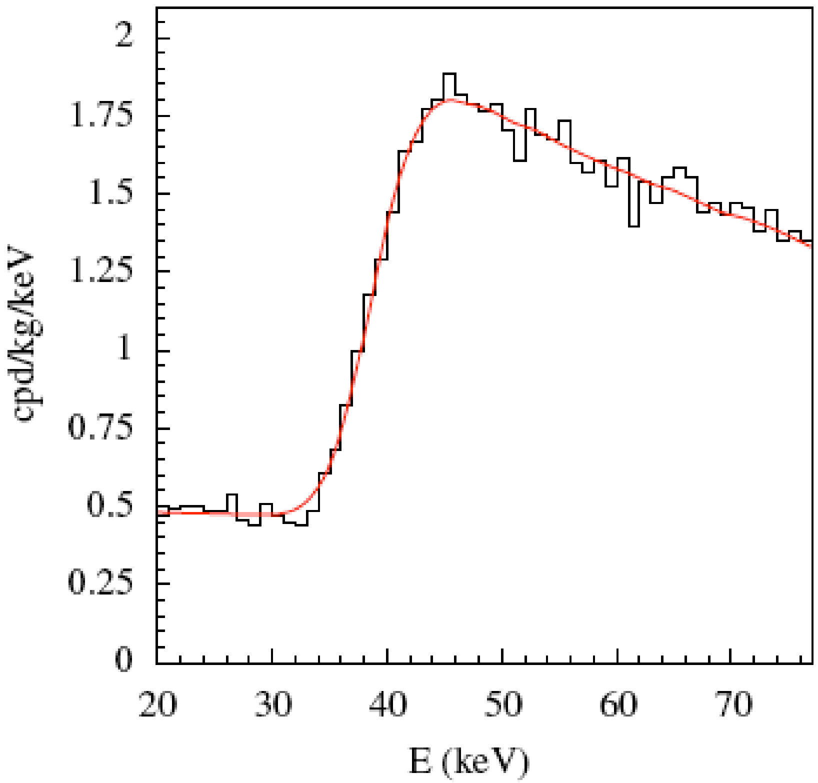
ZEPLIN-III



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

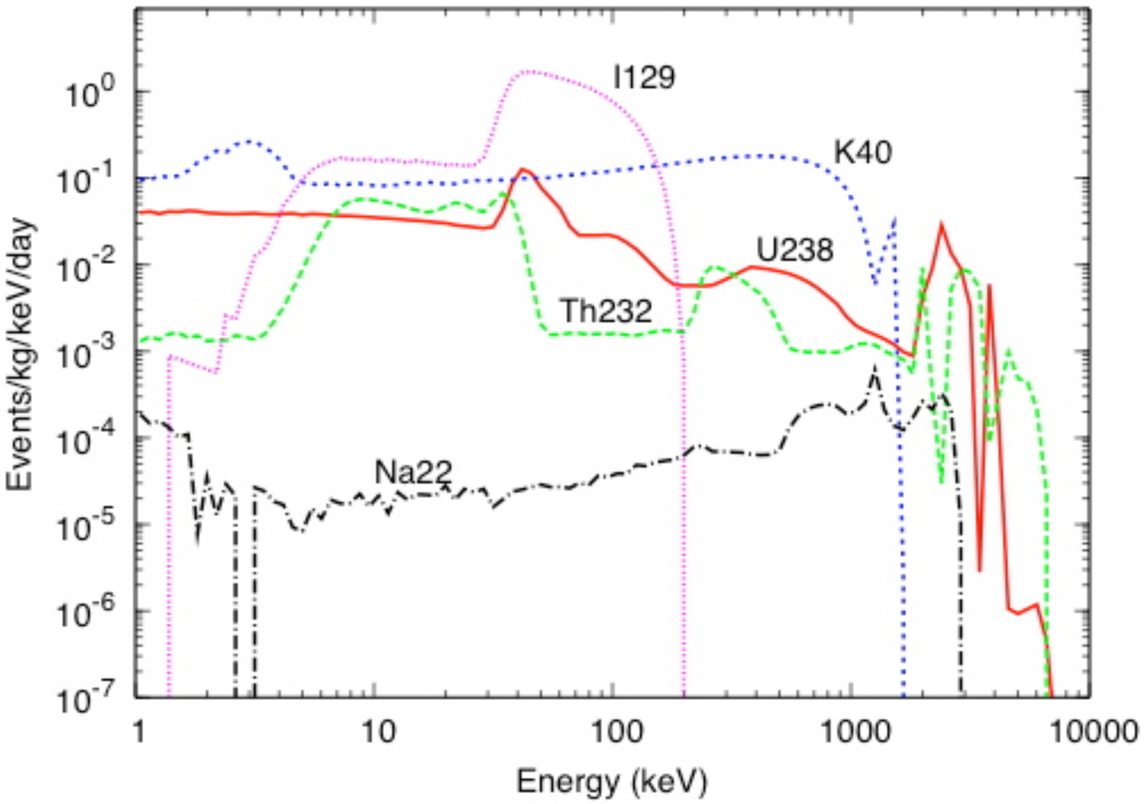
DAMA spectra





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

Internal source

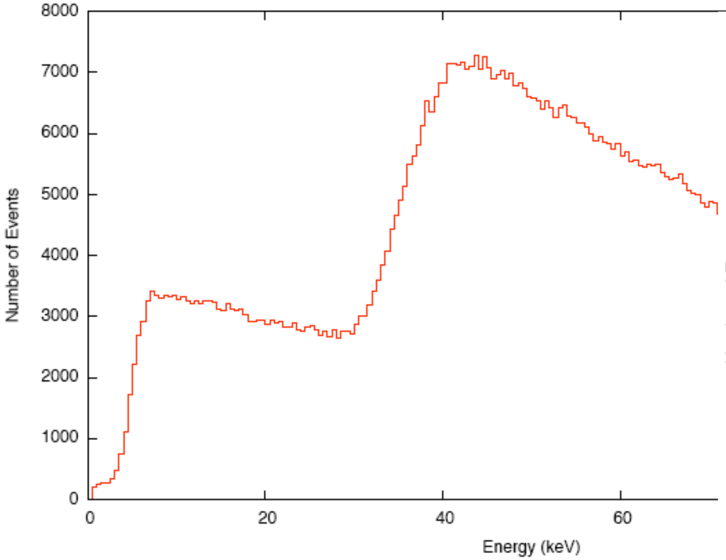


Contaminations (or limits) were taken from DAMA estimates.

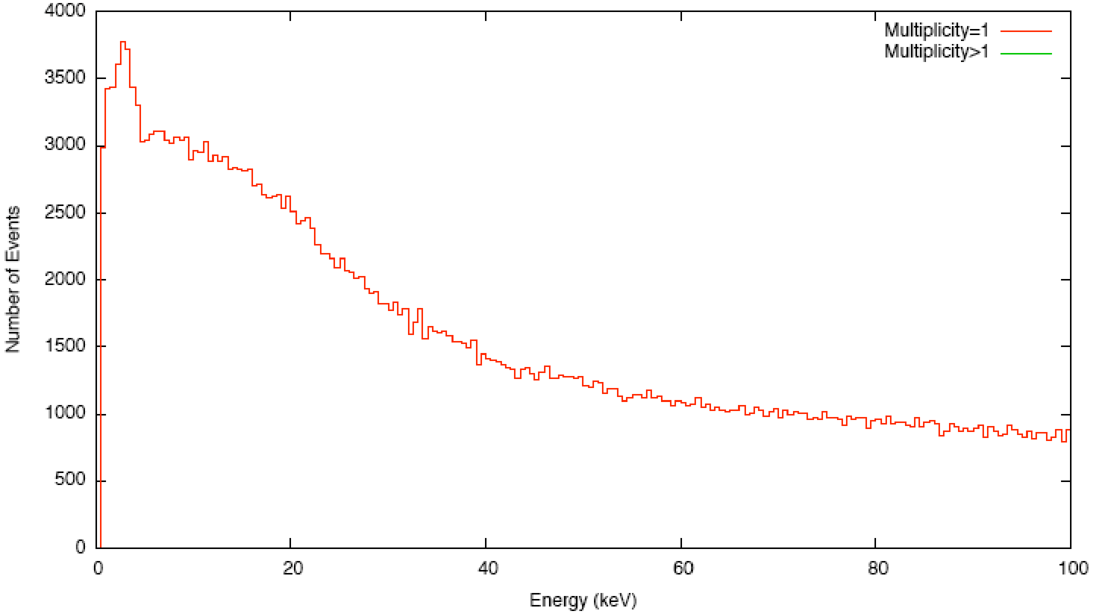
- Uranium chain was assumed to be in equilibrium - DAMA claims no equilibrium (higher decay rate of daughters at the end of the chain - ^{210}Pb), but the spectrum at low energies is flat - no effect.
- Peaks from ^{40}K and ^{129}I as measured.
- Rate is lower than observed.
- Each source has a spectrum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

Surface source

^{129}I

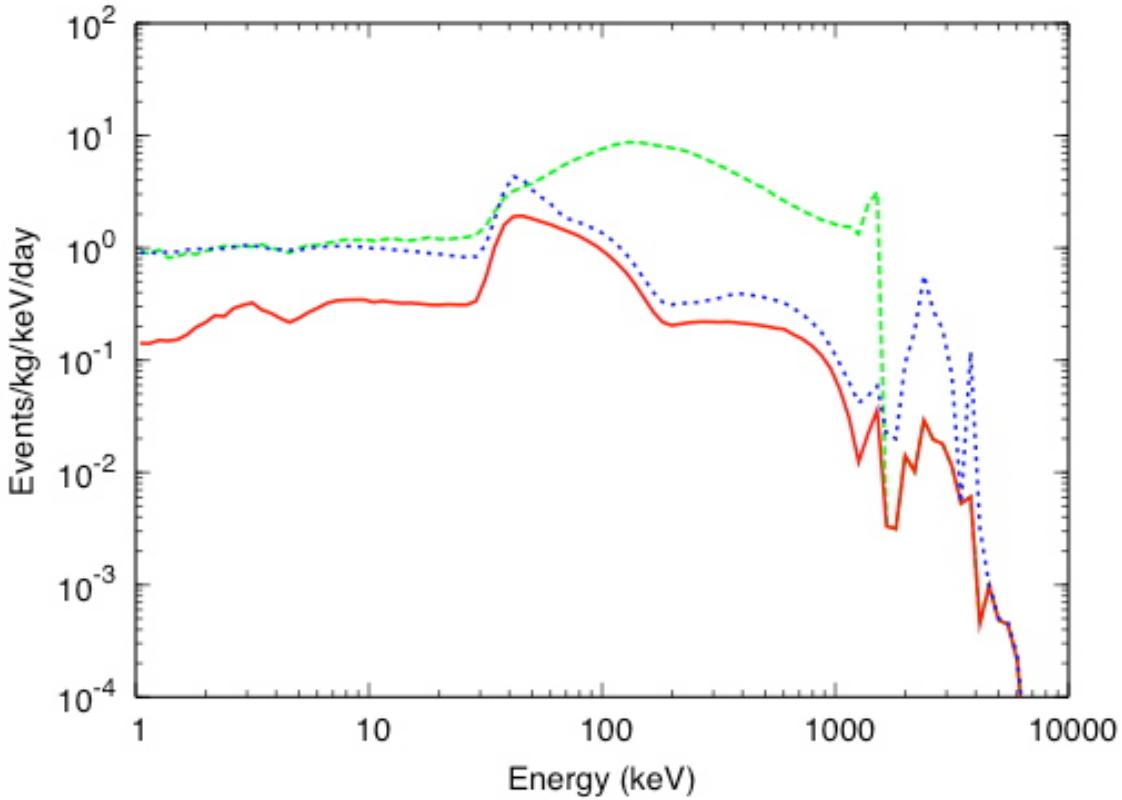


^{40}K



- **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.**

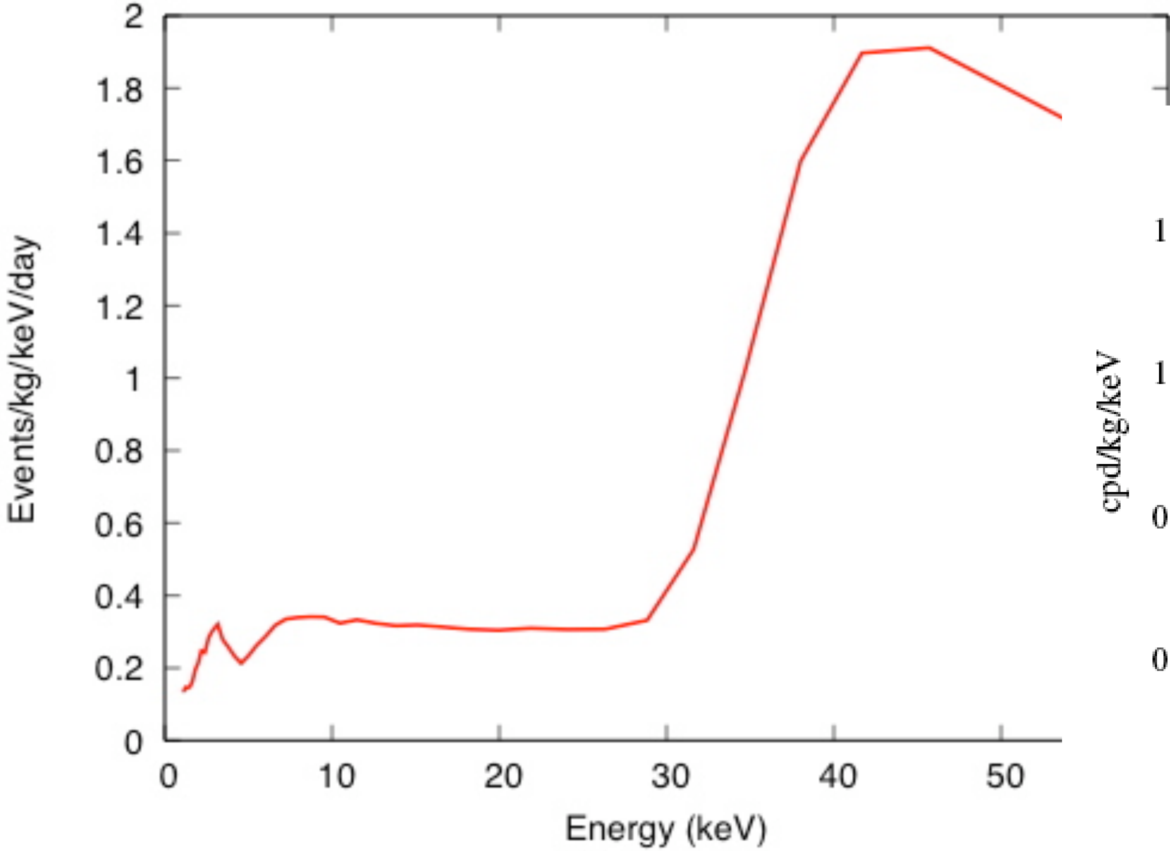
Combined spectrum

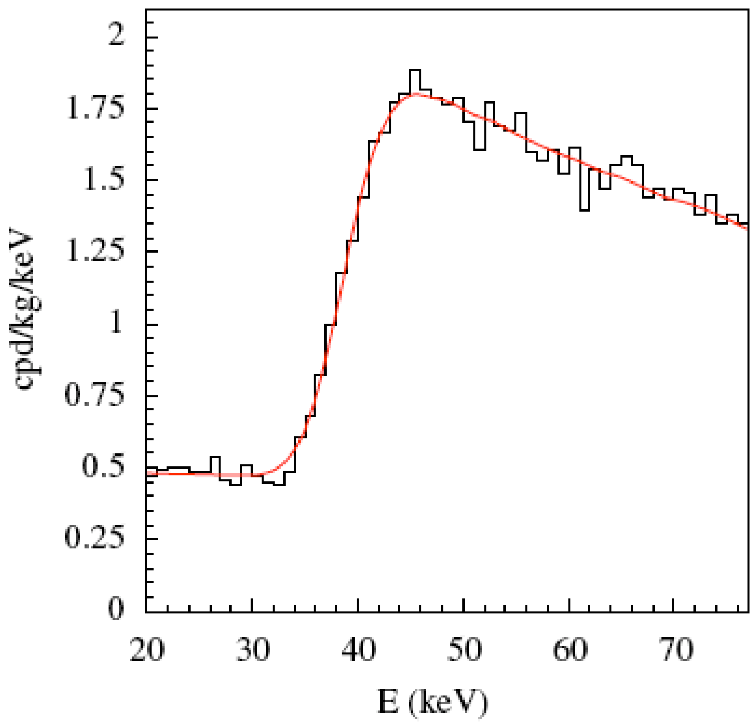


- The sum of external and internal sources.
- Red: estimated contaminations.
- Blue: enhanced intrinsic uranium - flat spectrum but wrong shape of the peak at 45 keV.
- Green: enhanced external potassium - flat spectrum but back-scatter peak is clearly visible (not observed by DAMA?).

We can get compatible rate at 1-10 keV only assuming higher concentrations of certain isotopes but this does not agree with DAMA measurements at higher energies.

Combined spectrum (low energies)



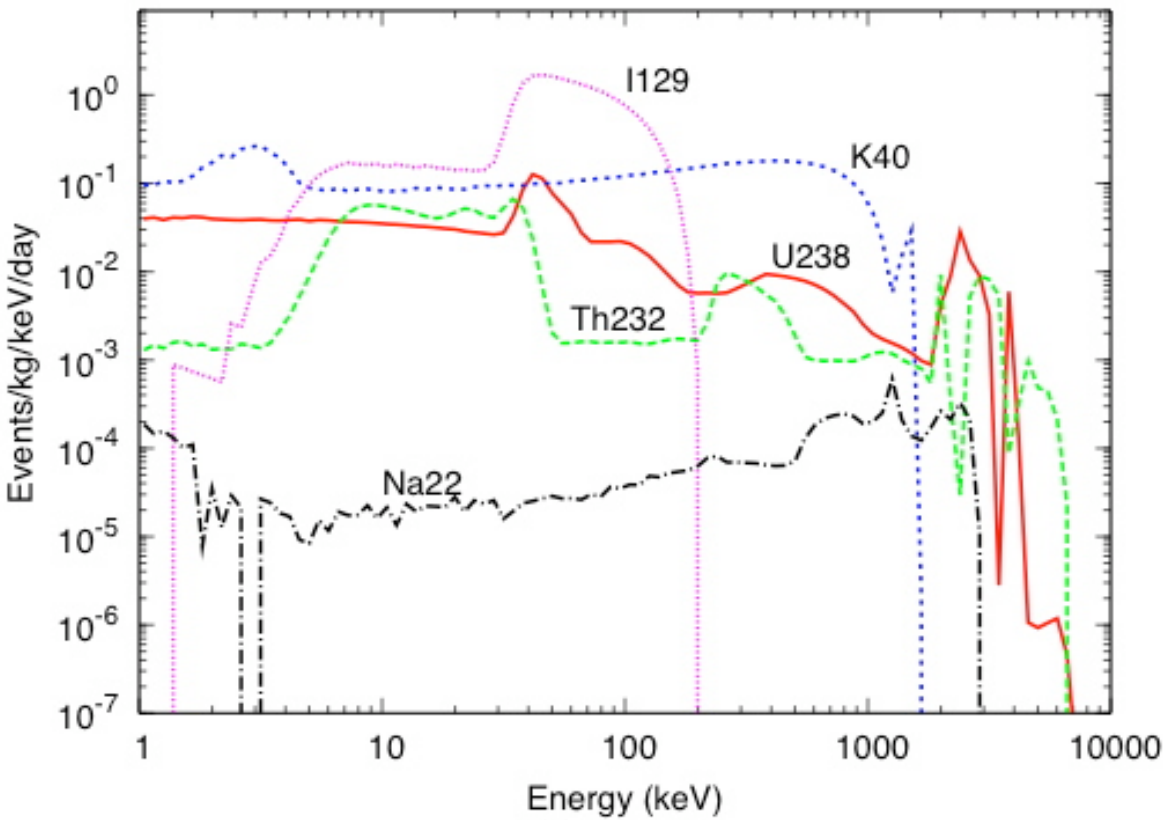


- Peak from ^{40}K at

similar to the
observed one.

Estimated contaminations (as on the previous slide, but low energies only).

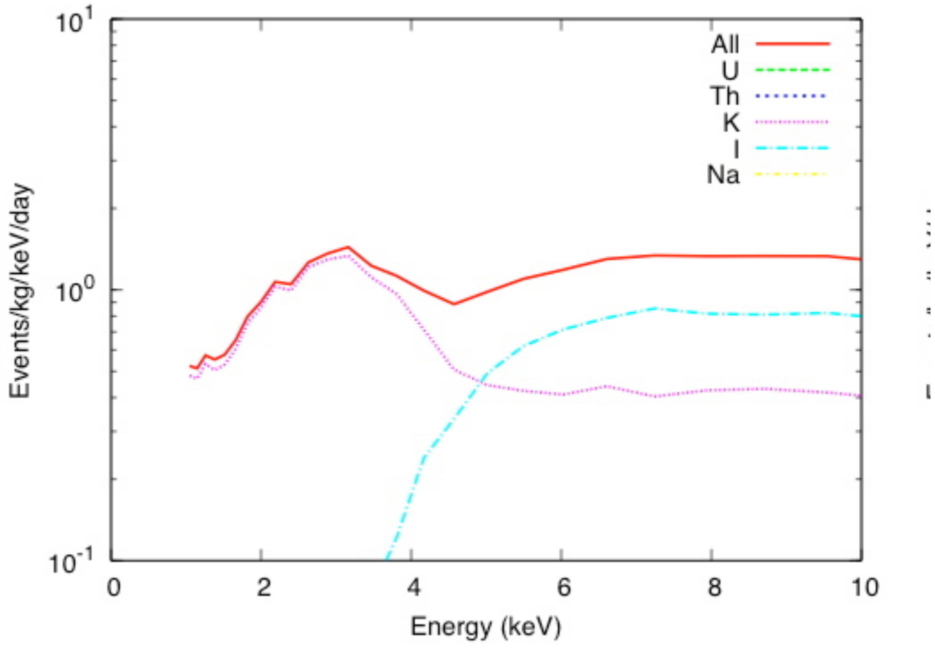
Internal source

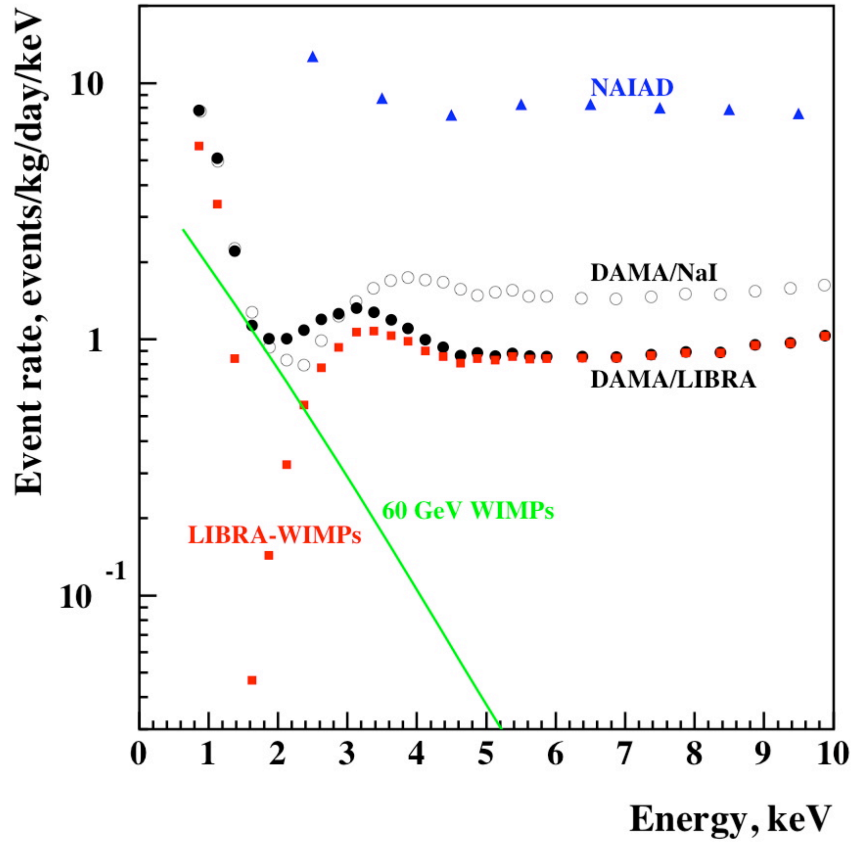


Contaminations (or limits) were taken from DAMA estimates.

- What other combinations can we construct to match the measured spectrum after subtracting signal?
- We need more ^{129}I to have a drop in intensity below 3 keV.
- We need more ^{40}K to have a peak at 3.2 keV.

Combined spectrum





- **Enhanced internal ^{129}I (minimum**
- **The minimum is probably not de intensity after the minimum is n**
- **Iodine peak (45 keV) is 5 times higher than observed. 1.46 MeV peak from ^{40}K should be higher than the measured one.**

Conclusions

- To investigate the background we need to know the measured average spectrum at a wide range of energies: 1 keV - 10 MeV. Can we ask the DAMA Collaboration to publish this?
- 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 measured concentrations of radioactive isotopes.
- If a signal is present, then the background (measured spectrum minus signal) should have a deep minimum. Its position and depth depend on the model but it is very hard to obtain such a minimum with simulations and to remain compatible with the spectrum above 10 keV (^{129}I-decay).
- Proper analysis and interpretation of the DAMA claim should include the background spectrum. This will restrict the range of dark matter models compatible with the DAMA signal.