Technical aspects and dark matter searches

TAUP July, 3rd, 2009 Roma

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A) Are precise Monte Carlo simulations at keV region reliable? What you put in is what you get out! but, is it correct?

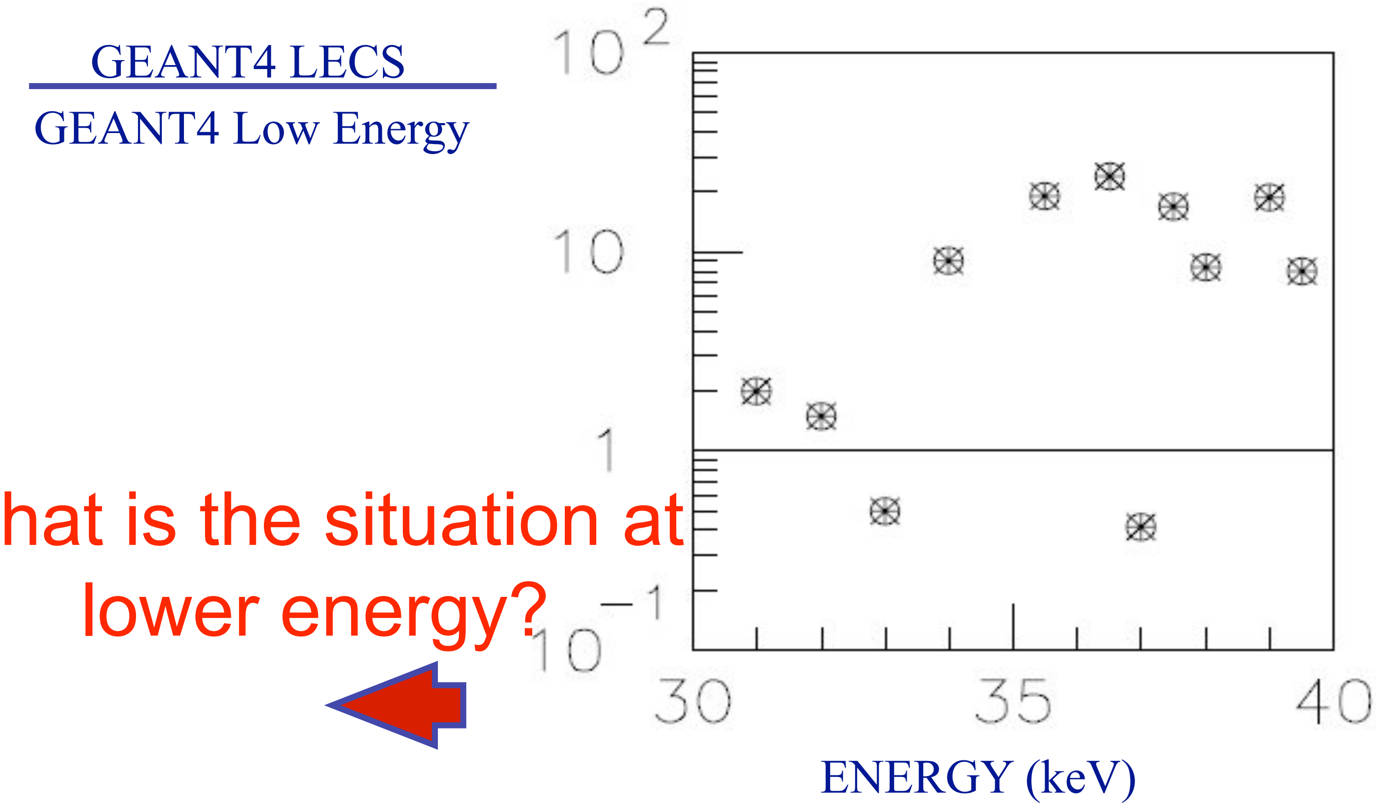
- Detailed knowledge of exact geometry of the set-up (detector or detectors' matrix, assembling, shield layers, site, etc…) necessary
  (Always possible only for people in the experimental group)
- Is the exact location of all contaminants known? (NO)
- Measurements and/or upper limits on known contaminants in each detector must be respected. Upper limits are consistent with every values down to zero (not unique response)
- Are all the non-standard contaminants precisely known and simulated? (Generally, NO)
- Are the contributions external to the detectors properly included in the calculation? (!)
- Is the multiple-hit energy threshold well managed in the simulation when the energy distribution refers to single-hit events, that is when the events are collected by each detector having all the others in anticoincidence (the case of DAMA/NaI and DAMA/LIBRA)? (!)
- Experimental energy resolution as a function of the energy as measured down to the energy threshold (many experiments "extrapolate" it from much higher energy)
- Is the energy threshold of the experiment correctly accounted as well as all the used values for other quantities? (!)
- Detector response function (e.g. α/β ratio, channeling, etc…) (some features are poorly known at very low energy)
- Are all atomic physics effect well managed by the MC code? (very hardly in keV region)
- Are the uncertainties associated to the whole MonteCarlo calculation correctly estimated? (NO, generally they refer just to the Monte Carlo output!)
- Etc. Etc.

Therefore claimed precise determinations are arbitrary, even more when they come from outside the experimental group

Are all atomic physics effect well managed by the MonteCarlo code at very low energy?

An example: X-ray scattering on carbon

data from: New Astronomy Reviews 48 (2004) 221–225



←also a factor 10!
due to un-proper description
of atomic bound electrons
in Geant4 Low Energy
(NIMA506 (2003) 250)
respect to Geant4 LECS
(NAR48 (2004) 221)

what is the situation at lower energy?

what might be discovered after?

+ who checks and validates the cooking in the “external” authors code?

Precise Monte Carlo simulations at keV region - if any reliable - would offer an alternative way to DM direct investigations !?

- Over more than 20 years Monte Carlo subtractions in keV region discouraged being recognized the large existent uncertainties
- Only DAMA experiments have measured and published many details on the residual contaminations of the detectors and of the low background materials used in the apparatus
- Only DAMA/NaI has published energy distributions from single photoelectron to tens MeV
- Reliable Monte Carlo analyses in suitable energy regions assured in DAMA consistencies with low energy features within the uncertainties

Example of scintillation energy spectra measured by various NaI(Tl) detectors

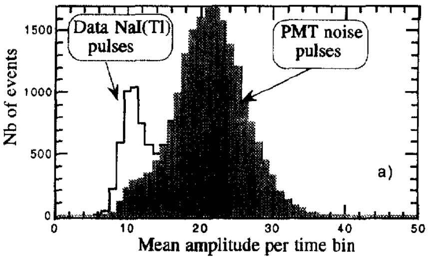
- Shapes/scintillation rates quite different
- All of them cannot be easily/uniquely simulated by a MC code
- None in agreement with the shape by NAIAD 2003 even not NAIAD 1996 ….

Modane 1999

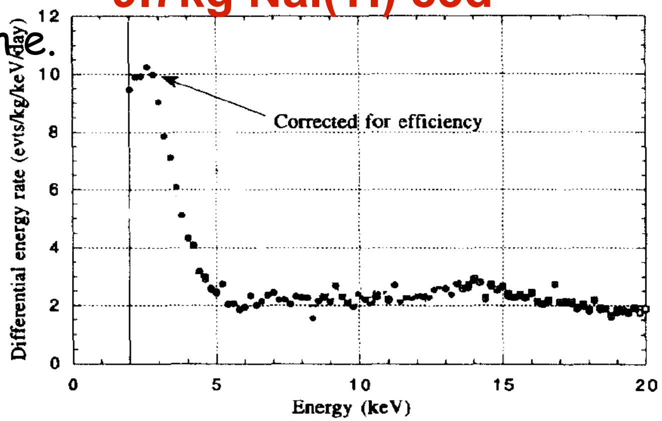
Astrop.Phys.11(1999)287

poor noise rejection although high n. of phe. claimed

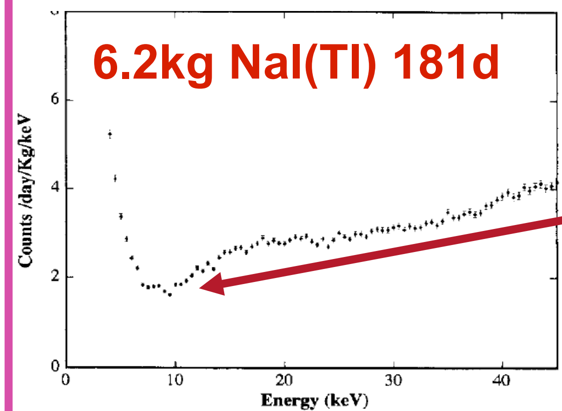
$\sigma/E=1.2\%/\sqrt{E(\mathrm{MeV})}$



9.7kg NaI(Tl) 83d

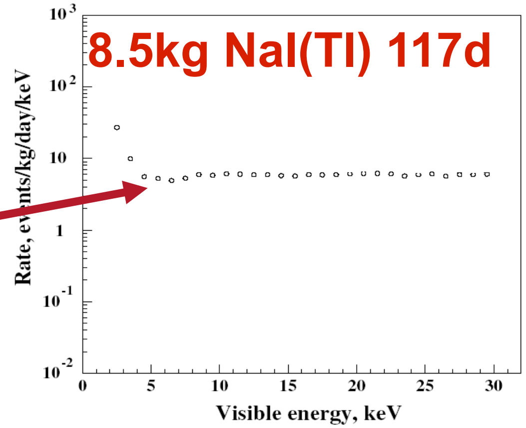


NAIAD 1996



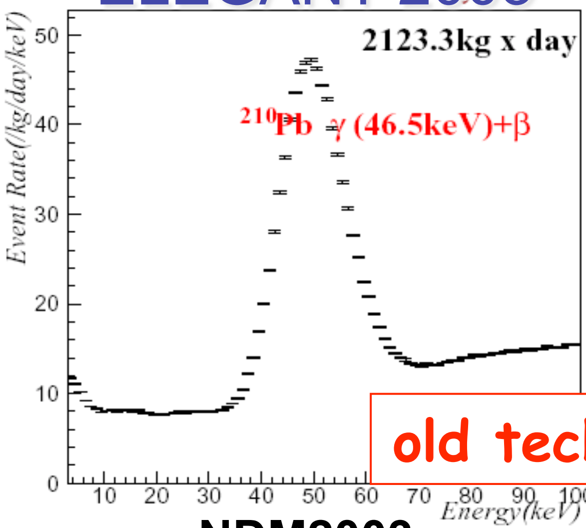
Astrop.Phys.5(1996)249

NAIAD 2003



Astrop.Phys.19(2003)691

ELEGANT 2003

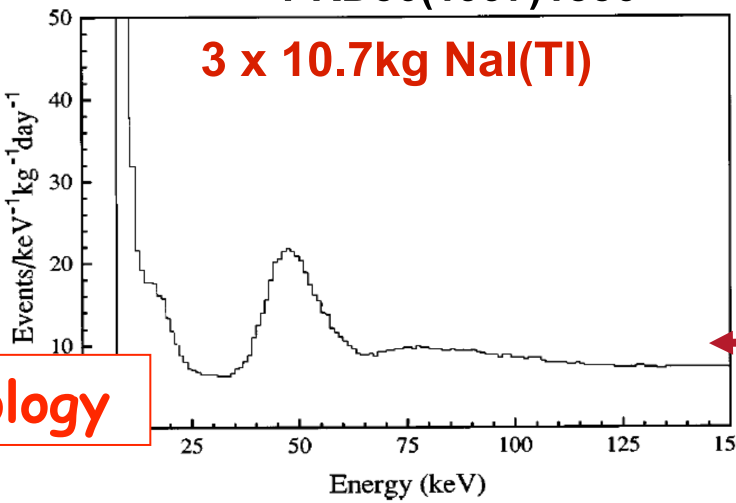


NDM2003

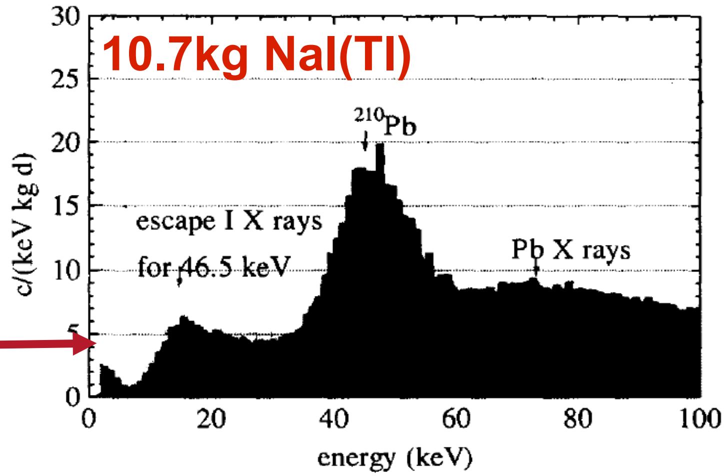
old technology

ANAIS

PRD56(1997)1856

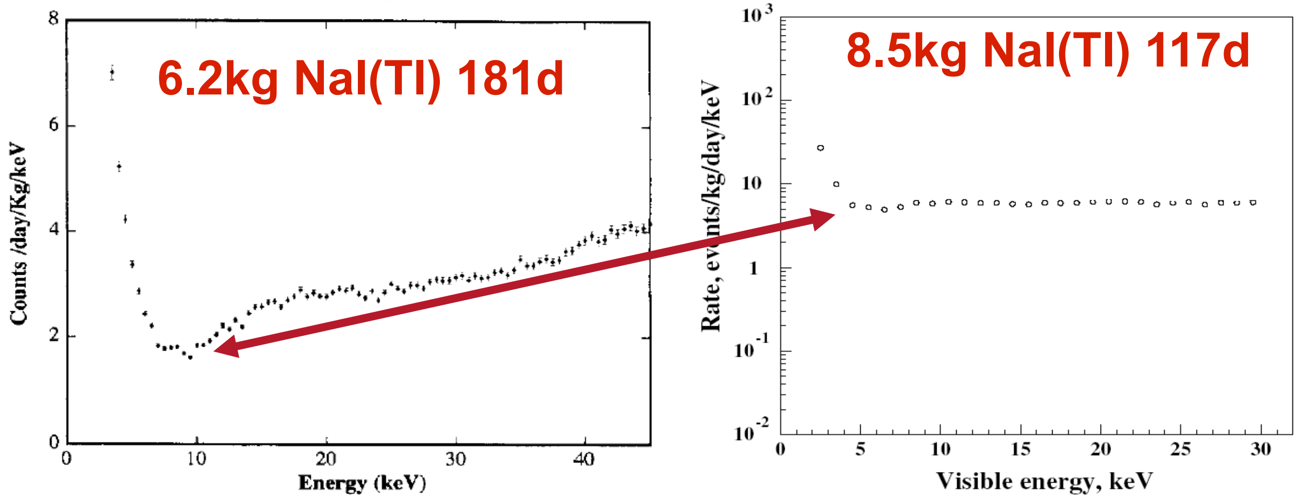


NPB114(Proc.Supp)(2003)111



NAIAD 1996 - vs- 2003

NAIAD 1996 NAIAD 2003



Astrop.Phys.5(1996)249 **Astrop.Phys.19(2003)691**

In 7 years of developments the measured rate increases a factor ≈ 4; why?

- **standard (known) contaminants were not under control.**
- **non-standard (or uncontrolled) contaminants contribution.**
- **or?** **... did not they investigate these results by Monte Carlo code?**

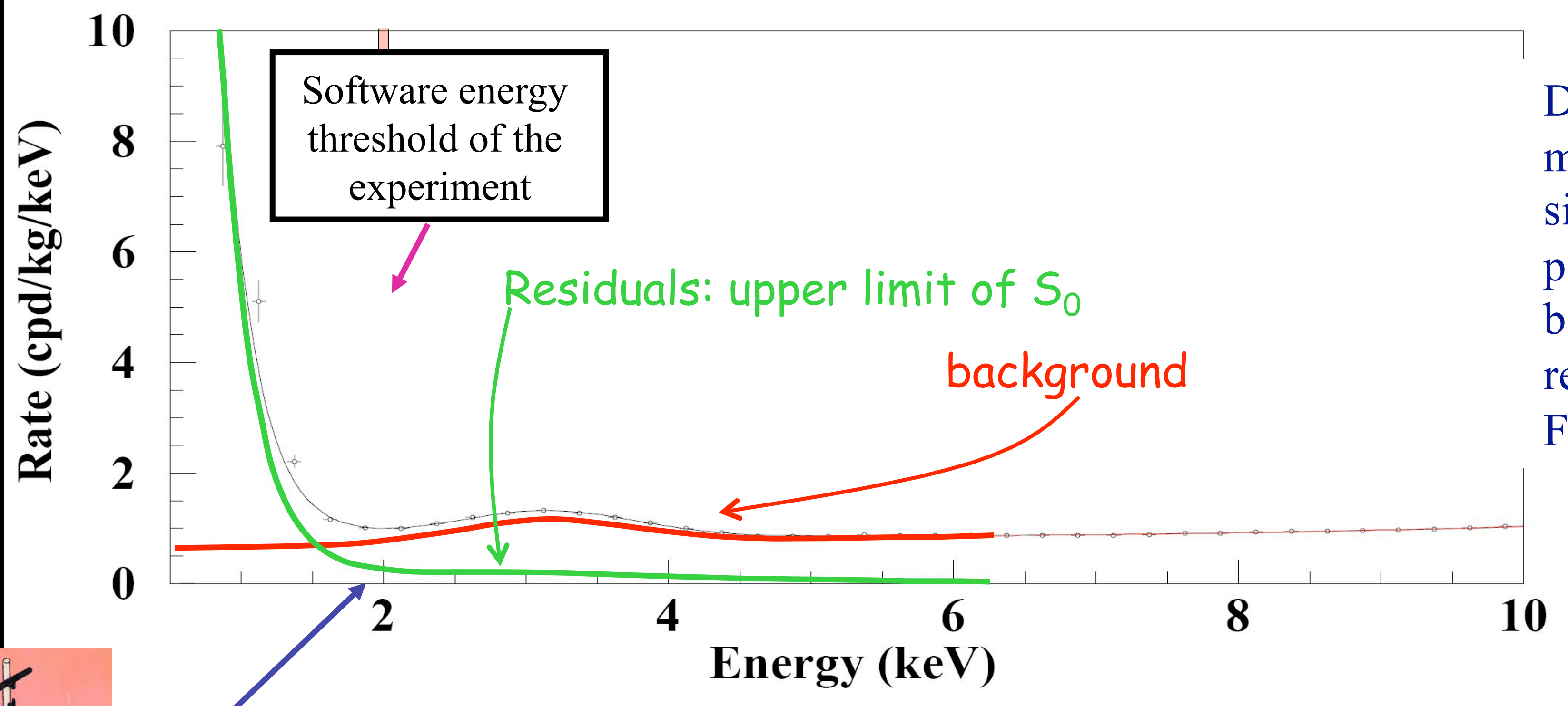
Not all wines improve with age

Example of a correct approach: S_0 vs background

0.53 ton×yr

background around 2-6 keV:

- straight line extrapolation from higher energy
- <^{nat}K> (≈13 ppb)

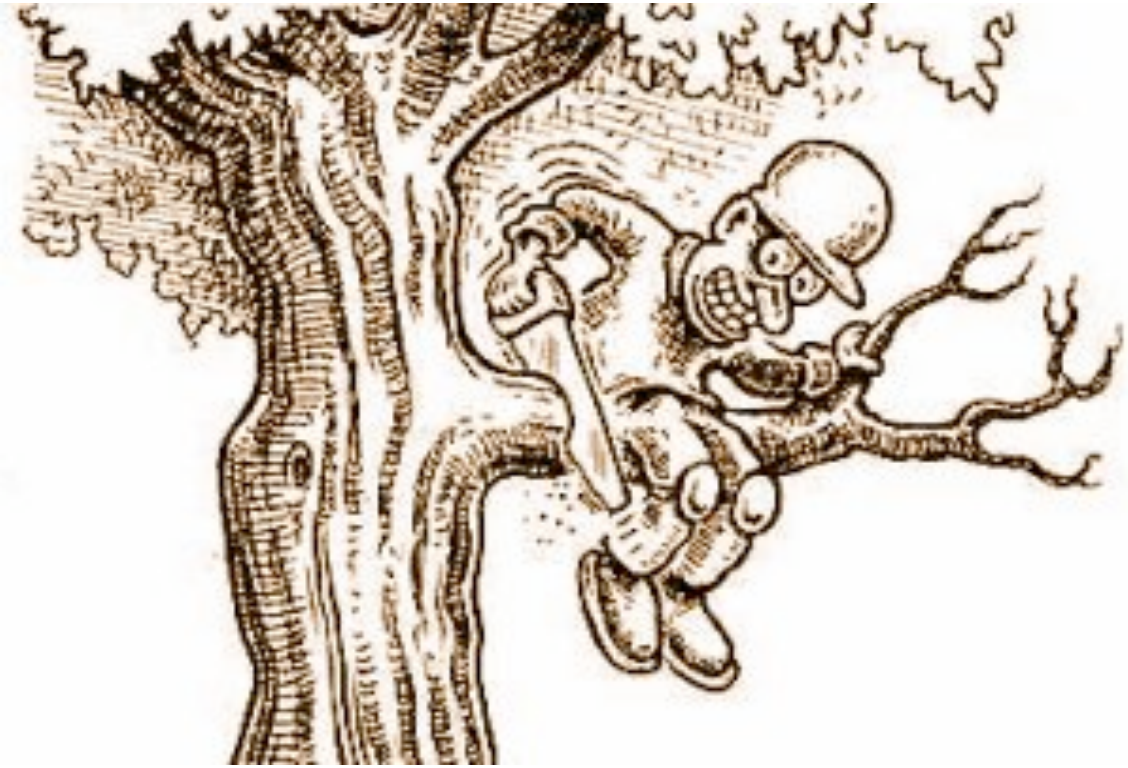


DM annual modulation signature offers a powerful tool for background rejection (see in Freese et al.)

data under the energy threshold of the experiment: wait for the new higher Q.E. PMTs

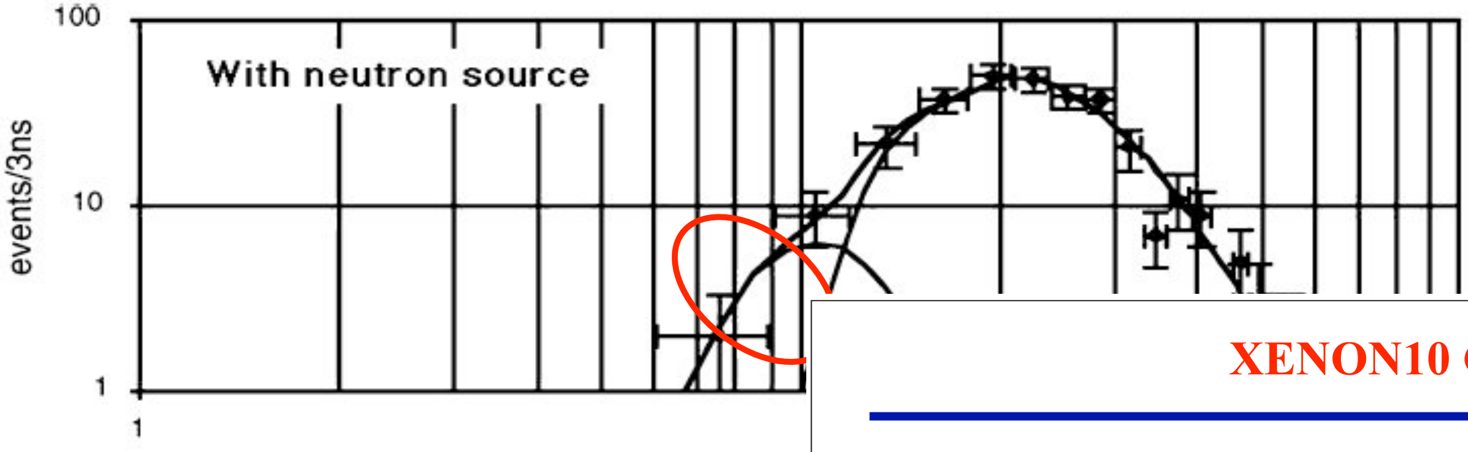
In the energy region 2-4 keV: S_0 <~ 0.25 cpd/kg/keV

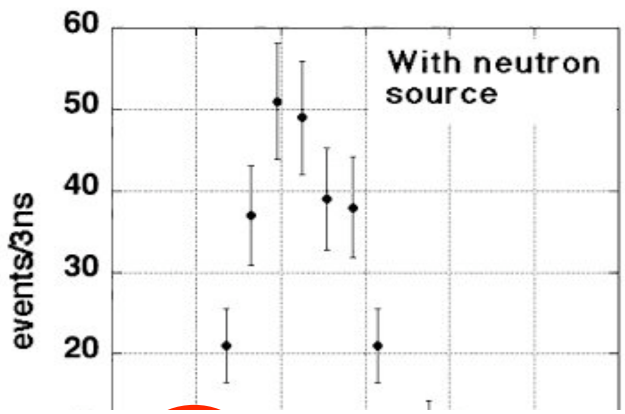
B) rejection procedures of the e.m. components of the counting rate: are systematics under control?



some examples….

The example of ZEPLIN-I from A. Benoit et al., Phys. Lett. B 637 (2006) 156.





"It is highly questionable to attribute al

no demonstration that nucl
different from electron recoi
several indications that discr

concl

Claimed for a WIMP mass of 60 GeV (in the single model they consider fixing all the parameters)

1.1 x 10^{-6} pb

3 order

XENON10 CUT LIST

QC0: Basic quality cuts

Designed to remove noisy events, events with unphysical parameters or events which are not interesting for a WIMP search

- S1 coincidence cut
- S1 single peak cut
- S2 saturation cut
- S2 single peak cut
- S2 width cut
- S2 χ^2 cut

QC1: Fiducial volume cuts

Because of the high stopping power of LXe, fiducialization is a very effective way of reducing background.

- $r < 80$ mm
- $15\,\mu s < dt < 65\,\mu s$

QC2: High level cuts

Cuts based on the distribution of the S1 signal on the top and bottom PMTs. They are designed to remove events with anomalous or unusual S1 patterns

- S1 top-bottom asymmetry cut
- S1 top RMS cut
- S1 bottom RMS cut

see Guillaume Plante, Columbia, APS Talk

Noble Liquids / Dark Matter

Rick Gaitskell, Brown University, DOE

similar problems also in other cases, e.g. XENON10

… non-uniformity of the two-phases detectors: intrinsic limit?

Detector non-uniformity and position dependent corrections

Position dependent correction on S1 and S2 signals with maps obtained from activated Xe XENON10 (astro-ph0706.0039v1)

Effects of non-uniform light collection accounted in WARP (NIMA 574 (2007) 83)

A geometrical correction is performed via a "rebinning matrix" evaluated by MonteCarlo in ZEPLIN-I, (AP 23(2005)444).

The position dependent correction is still applied in ZEPLIN-II, (AP 28 (2007) 287)

…are systematics under control?

(see also discussions in arXiv: 0806.0011v2)

… non-uniformity of the two-phases detectors: intrinsic limit

tor after the WIMP search data taking. The $S1$ and $S2$ response from the ^{131m}Xe 164 keV gamma rays, which interact uniformly within the detector, were used to correct the position dependence of the two signals.

position dependent correction on S1 and S2 signals with maps obtained from activated Xe XENON10 (astro-ph0706.0039v1)
.

where $a_0 = 9.5$ keV, $a_1 = 1.2$ keV and $a_2 = 0.04$. The three terms take into account the effects from non-uniform light collection (a_2 term), statistical

effects of non-uniform light collection accounted in WARP (NIMA 574 (2007) 83)

To convert the observed pulse height (in mV or photoelectrons) to electron equivalent energy for each event we calibrate with one or more gamma sources of known energy. We used ^{57}Co (122 keV) and ^{137}Cs (660 keV) sources placed under the xenon vessel. The ^{137}Cs source gave a measured light yield 25% lower than the ^{57}Co. Since previous laboratory work [7] had shown a response linear with energy, this difference is due to a position-dependent light collection, the

A geometrical correction is performed via a "rebinning matrix" evaluated by MonteCarlo in ZEPLIN-I, (AP 23(2005)444).

E being the γ-ray energy in keV. This has the effect of mixing the events between energy bins, which can at the final stage of analysis be accounted for by applying a compensating rebinning matrix to the energy-binned spectral terms, as shown in detail in [7].

Thus the WIMP-nucleon cross-section limit setting procedure is

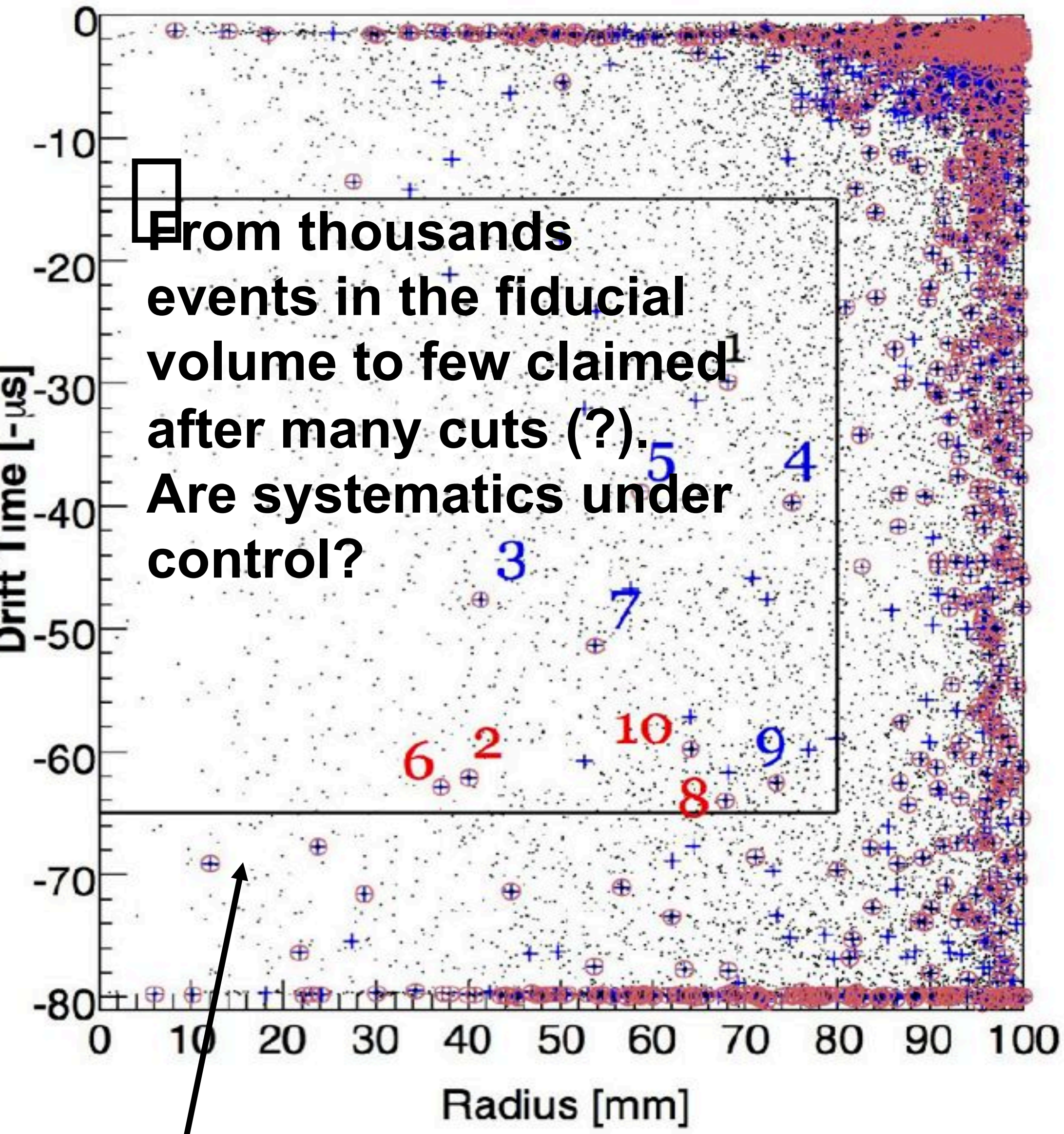
(1) Apply an energy resolution correction as described in greater detail in a previous paper [7], by numerically applying the resolution rebinning matrix to the vector of binned spectral terms given by the right hand side of (1)

[7] G. J. Alner *et al.* (2005) *Astroparticle Phys.* **23(5)**, 444–462

the position dependent correction is still applied in ZEPLIN-II, (AP 28 (2007) 287)

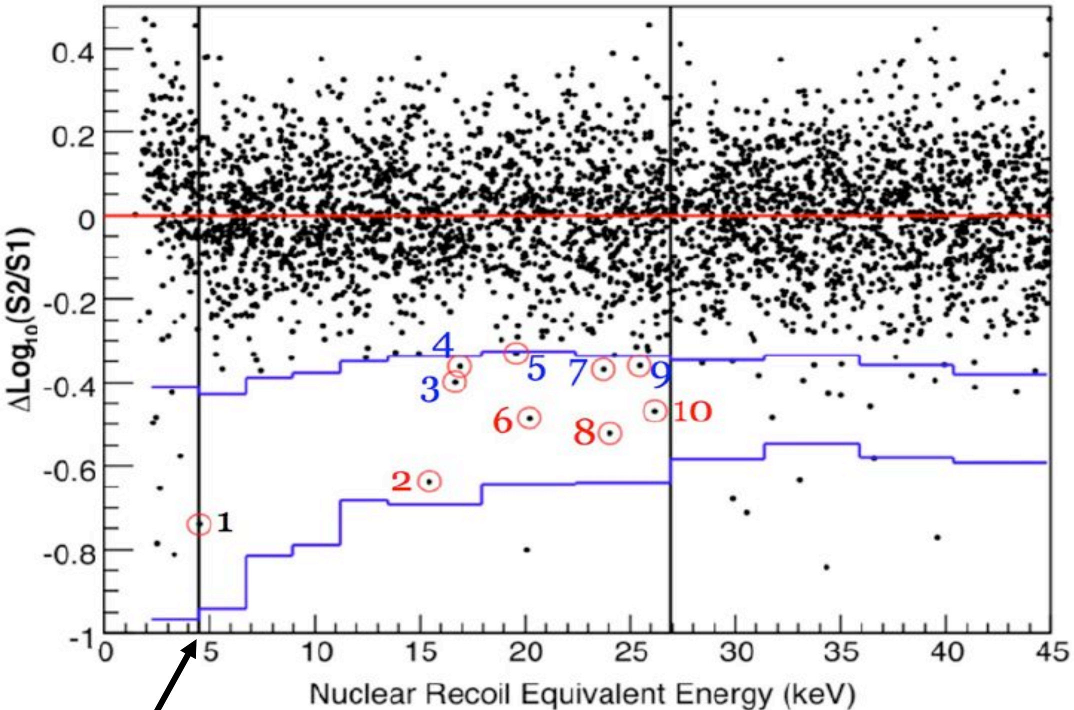
Just an example of related aspects: XENON10

Position dependent correction on S1 and S2 signals with maps obtained from activated Xe
Is the fiducial volume reliable? Are the ≈1.5keVee threshold and the energy scale extrapolated from 122 keV reliable?



A variation of R of 5% and DT of 10% will provide 20 events in the fiducial volume

A variation of the extrapolated low energy scale will reduce dramatically the sensitivity to low WIMP mass + effects in the Yellin limit procedure

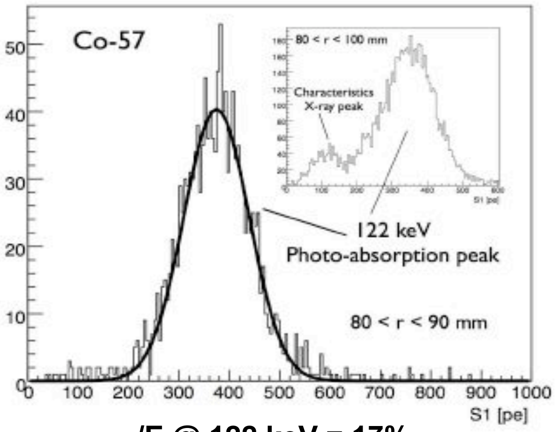


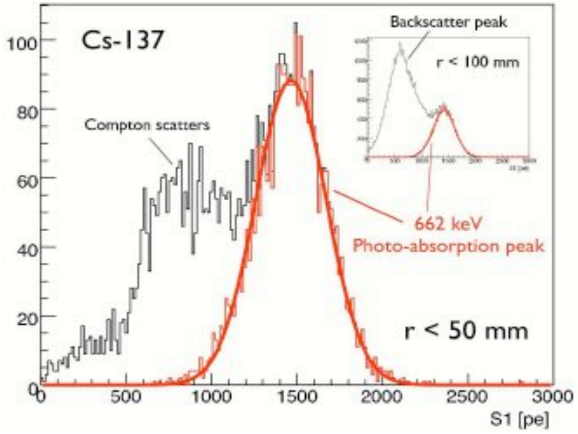
Only 3 ph.e/keV claimed (but 2.2 ph.e/keV at 662 keV) and threshold extrapolated from 122 keV source after position dependent corrections

Examples of energy resolutions

XENON10

JoP: Conf. Ser. 65 (2007) 012015

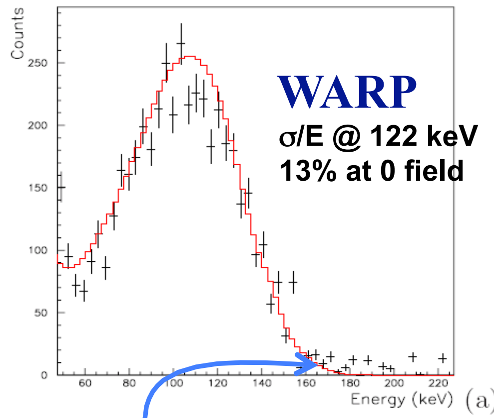




σ/E @ 122 keV = 17%

Figure 3. (left) S1 scintillation spect... photo-absorption peak is 3.1 p.e./keV. (... light yield for the 662 keV photo-absorpt...

NIMA 574 (2007) 83



WARP

σ/E @ 122 keV
13% at 0 field

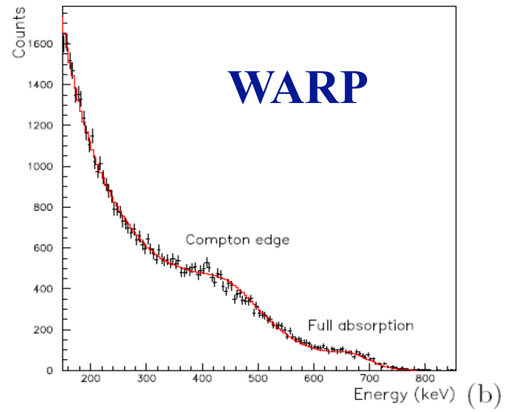


Fig. 2. Energy spectra taken with external γ-ray sources, superimposed with the corresponding Monte Carlo simulations. (a) ^{57}Co source ($E = 122$ keV, B.R. 85.6%, ... $E = 662$ keV).

...e spectrum ?

All experiments – except DAMA – use calibration points at higher energy with extrapolation to low energy.

ZEPLIN

AP 28 (2007) 287

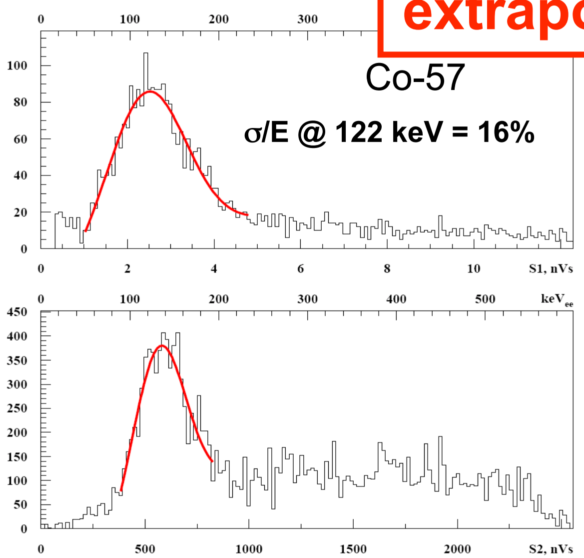
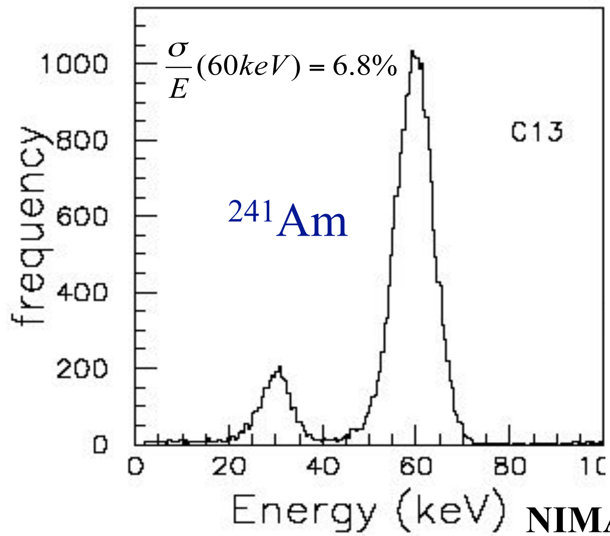
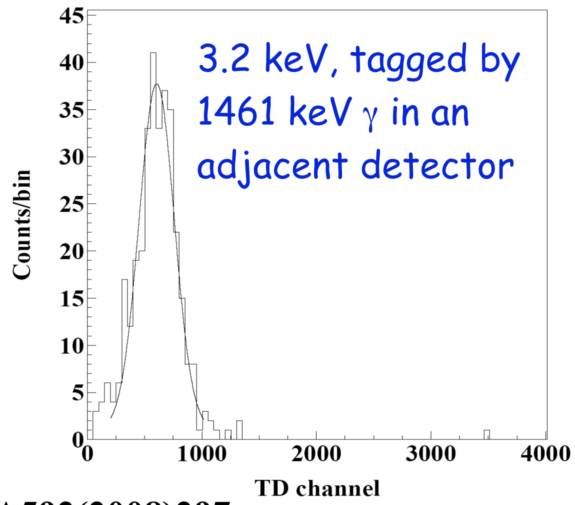


Fig. 5. Typical energy spectra for ^{57}Co γ-ray calibrations, showing S1 spectrum (upper) and S2 spectrum (lower). The fits are double Gaussian fits which incorporate both the 122 keV and 136 keV lines in the ^{57}Co γ-ray spectrum. The energy resolution of the detector is derived from the width of the S1 peak, coupled with calibration measurements at other line energies.

DAMA/LIBRA





NIMA592(2008)297

C) Regarding model dependent aspects

- ✓ Not a unique reference model for Dark Matter particles
- ✓ Not a single set of assumptions for parameters in the astrophysical, nuclear and particle physics related arguments
- ✓ Often comparisons are made in inconsistent way

How to compare?

The interpretation of the results: not a single framework

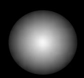
- Scatterin
  → detecti

DMp

- Excitatio
  → detect

- Conve
  → det

- Interacti
  electrons
  → detecti



a single "STANDARD MODEL" does not exist

+

Nature of the candidate and couplings

Halo models & Astrophysical scenario

Scaling laws

Form Factors + Spin Factors

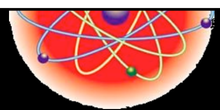
Instrumental quantities

Quenching Factor + Channeling + Migdal

and more...

Even fixing a template mass there are many differences due to the used assumptions

DM expectations cannot be safely used and subtracted from the measured spectra obtaining the unknown background behaviour!



... even WIMPs

on e⁻ c
of a lig
→ dete
recoil

e.g. sterile ν

... also other ideas ...

→ **DM* + N**

χ- with δ

inelastic

signals from
se candidates
completely
in
eriments
ed on
"rejection
procedures" of
the e.m.
component of
their rate

- **... and more**

Examples of uncertainties in models and scenarios

Nature of the candidate and couplings

- WIMP class particles (neutrino, sneutrino, etc.): SI, SD, mixed SI&SD, preferred inelastic
+ e.m. contribution in the detection
- Light bosonic particles
- Kaluza-Klein particles
- Mirror dark matter
- Heavy Exotic candidate
- Electron interacting DMp
- …etc. etc.

Halo models & Astrophysical scenario

- Isothermal sphere ⇒ very simple but unphysical halo model
- Many consistent halo models with different density and velocity distribution profiles can be considered with their own specific parameters (see e.g. PRD61(2000) 023512)
- Caustic halo model
- Presence of non-thermalized DM particle components
- Streams due e.g. to satellite galaxies of the Milky Way (such as the Sagittarius Dwarf)
- Multi-component DM halo
- Clumpiness at small or large scale
- Solar Wakes
- …etc. …

Form Factors for the case of recoiling nuclei

- Many different profiles available in literature for each isotope
- Parameters to fix for the considered profiles
- Dependence on particle-nucleus interaction
- In SD form factors: no decoupling between nuclear and Dark Matter particles degrees of freedom + dependence on nuclear potential

Spin Factors for the case of recoiling nuclei

- Calculations in different models give very different values also for the same isotope
- Depend on the nuclear potential models
- Large differences in the measured counting rate can be expected using:

  either SD not-sensitive isotopes

  or SD sensitive isotopes depending on the unpaired nucleon (compare e.g. odd spin isotopes of Xe, Te, Ge, Si, W with the ^{23}Na and ^{127}I cases).

Instrumental quantities

- Energy resolution
- Efficiencies
- Quenching factors
- Channeling effects
- Their dependence on energy
- …

Quenching Factor

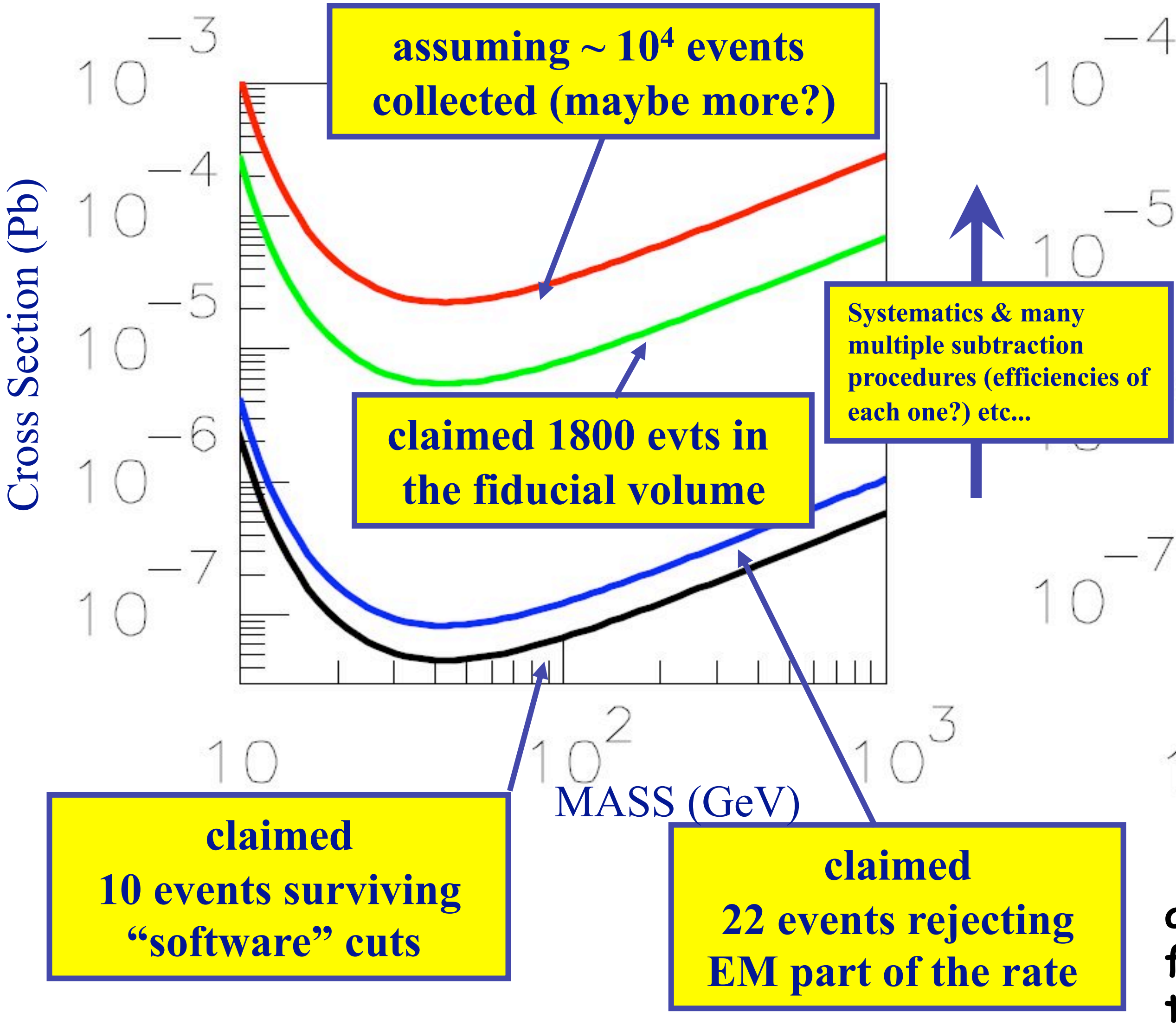
- differences are present in different experimental determinations of *q* for the same nuclei in the same kind of detector depending on its specific features (e.g. in doped scintillators *q* depends on dopant and on the impurities/trace contaminants; in LXe e.g.on trace impurities, on initial UHV, on presence of degassing/releasing materials in the Xe, on thermodynamical conditions, on possibly applied electric field, etc)
- Sometime increases at low energy in scintillators (dL/dx)

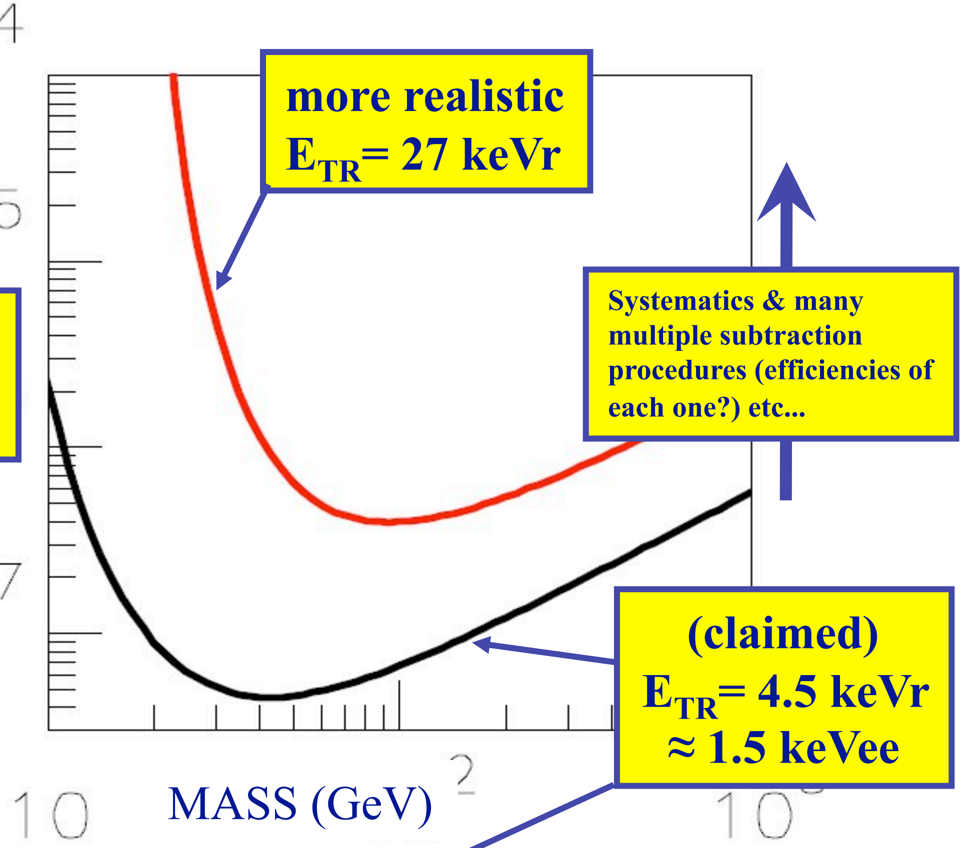
  → energy dependence

… and more …

A model dependent example considering a single case for a particular WIMP candidate e.g. XENON10: robust limit?

Assuming the single model framework and the fixed parameters values they consider.
Assuming 4.5 keVr threshold (but 2-3 ph.e/keV and last calibration point at 122 keV)
Assuming Ø systematics in the multiple subtraction procedures
Assuming linearity in the energy scale with keV region "extrapolated" from 122 keV after position dependent corrections. etc ...



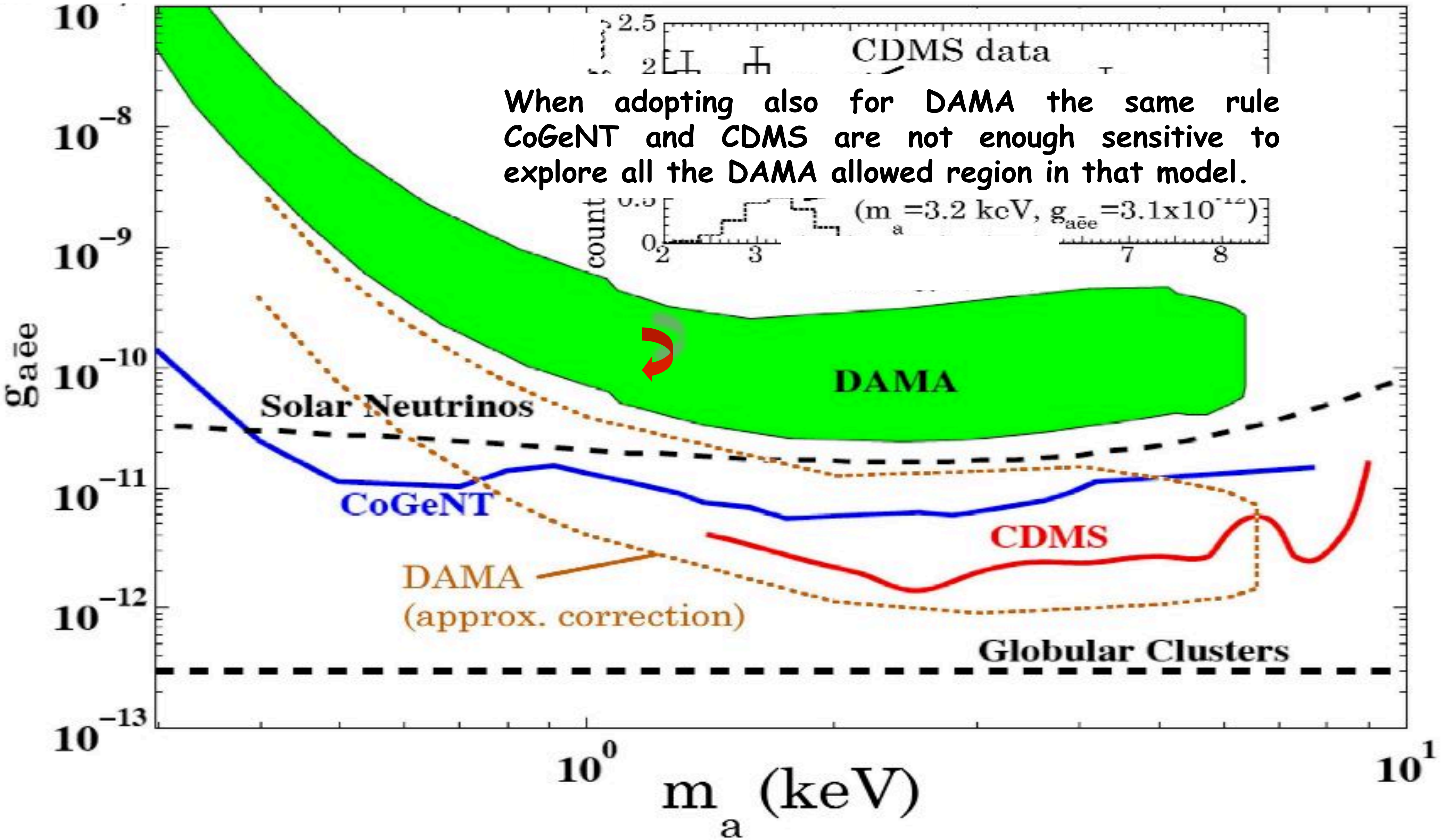


and assuming that the q.f. they measure at Ø field is boosted in presence of the field as they claim

An example of uncertainties in the comparisons (from Collar et al. arXiv:0902.4693v1)

CoGeNT and CDMS limits are based on a different Axion-like Hamiltonian assumption.

$$R\ [\text{cpd kg}^{-1}] = 1.2 \times 10^{43} A^{-1} g_{a\bar{e}e}^2 m_a \sigma_{p.e}$$



When adopting also for DAMA the same rule CoGeNT and CDMS are not enough sensitive to explore all the DAMA allowed region in that model.

CONCLUSIONS

- Robust techniques are necessary for DM searches.
- Monte Carlo simulations can help as order of magnitude but large uncertainties and not applicable for subtraction at keV region (well known and stated in DM direct field in the past)
- Use detectors with good responses
- Not use too heavy and uncertain data reduction
- Calibrate near the energy threshold
- Full proved control of stability
- Be sensitive to many scenarios

…

→ **Good (and hard) work**