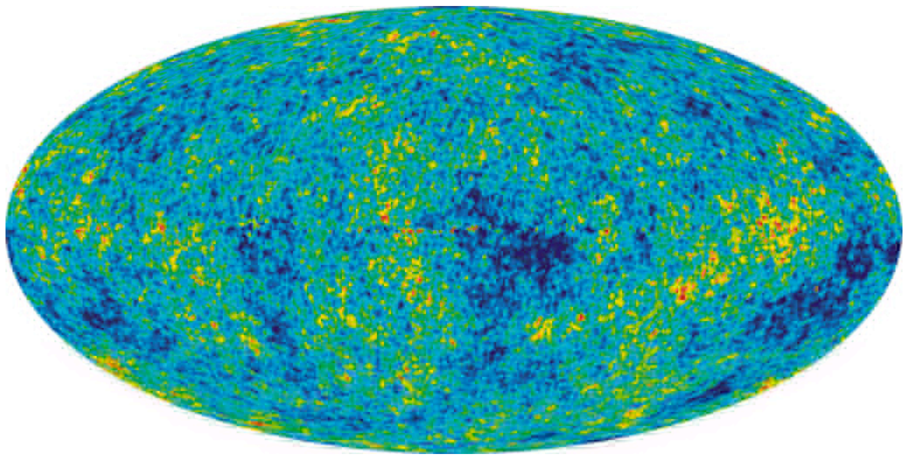
A survey of recent dark matter direct detection results

- I where we stand
- II recent results (CDMS, XENON10, etc)
- III DAMA results
- IV a bit about modulation
- V issues with DAMA results
- VI what to look for next year

Dark matters and Λ-CDM



WMAP 5-year data (2008)

+

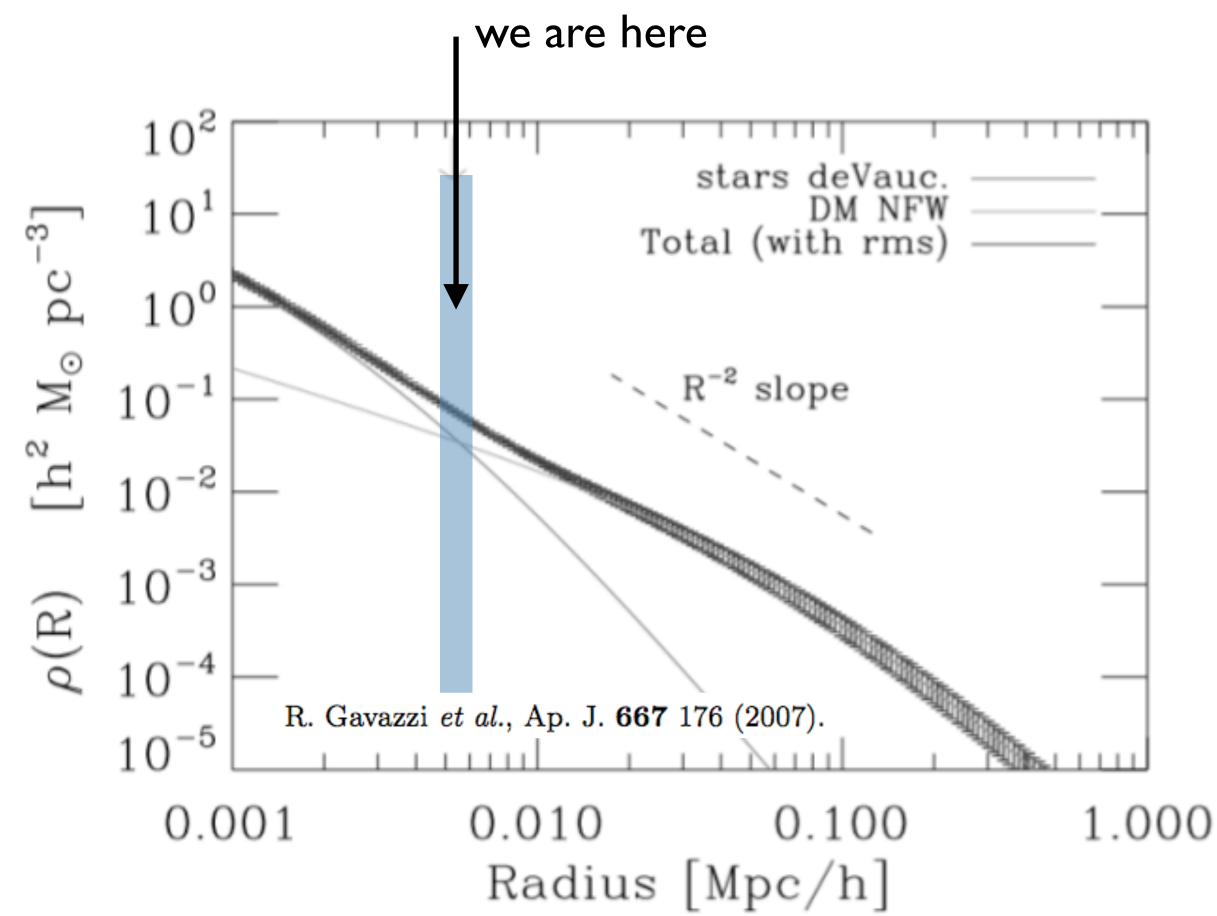
SDSS and SN

based on best fit to Λ-CDM cosmological model:

↓

- Ω_{total} = 1.02 ± 0.02
- Ω_c = 0.233 ± 0.013
- Ω_b = 0.0462 ± 0.0015
- Ω_Λ = 0.721 ± 0.015
- Ω_ν < 0.0076
- H_0 = 70.1 ± 1.3 km s^{-1} Mpc^{-1}

Dark matter particles by definition **do not interact electromagnetically**, and so should **scatter** preferentially from **nuclei**



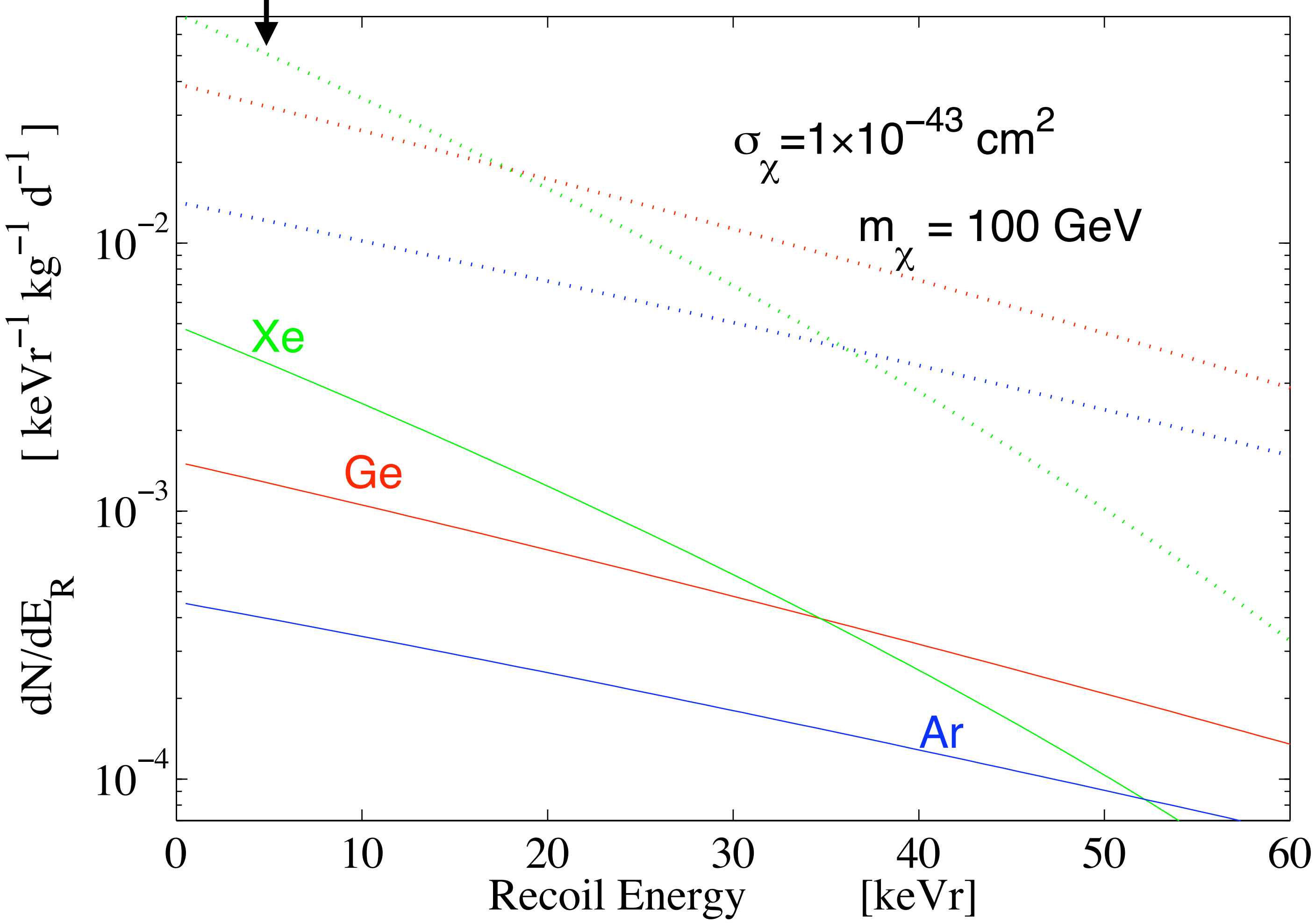
> galactic mass density profile (22 galaxies)
> obtained from combined (weak + strong) lensing observations

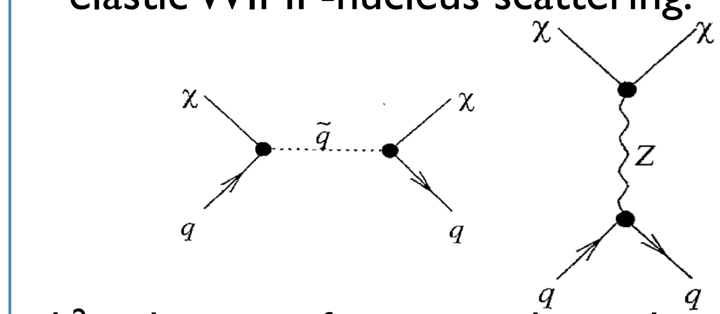
our local DM density ~ 0.3 GeV c^{-2}
(about 3 100 GeV DM particles / liter)

Event rates in earth-bound detectors

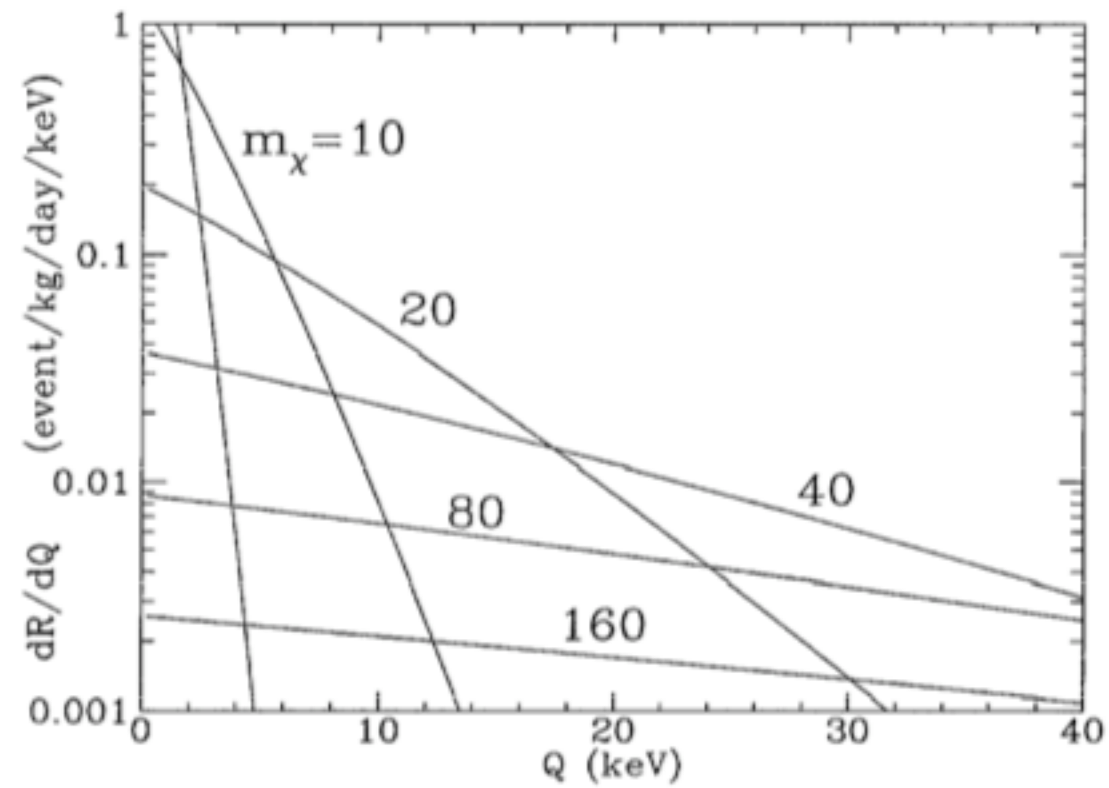
for E_{thr} = 4 keVr and a 5 kg Xe target, expect ~ 90 events in 1 year

Predicted event rate (standard* halo assumptions)





Predicted event rate Ge target (varying M_χ) for σ = 4 x 10^{-36} cm^2.

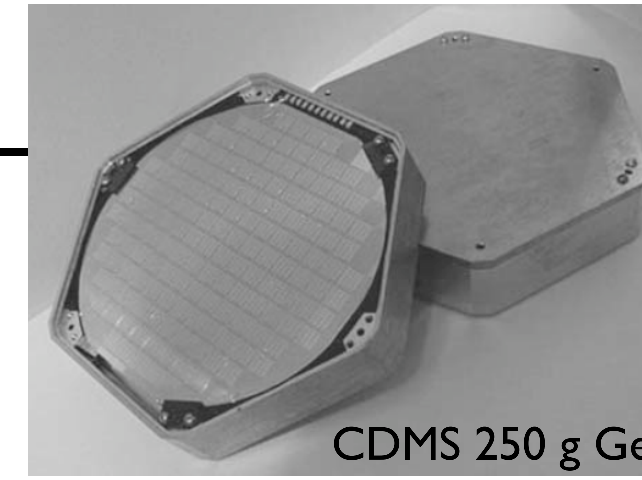


G. Jungman et al. Physics Reports 267 195 (1996)

* ρ=0.3 GeV c^{-2} and v_0=170 km/s
(DAMA takes ρ=0.17 GeV c^{-2} and v_0=170 km/s as "standard")

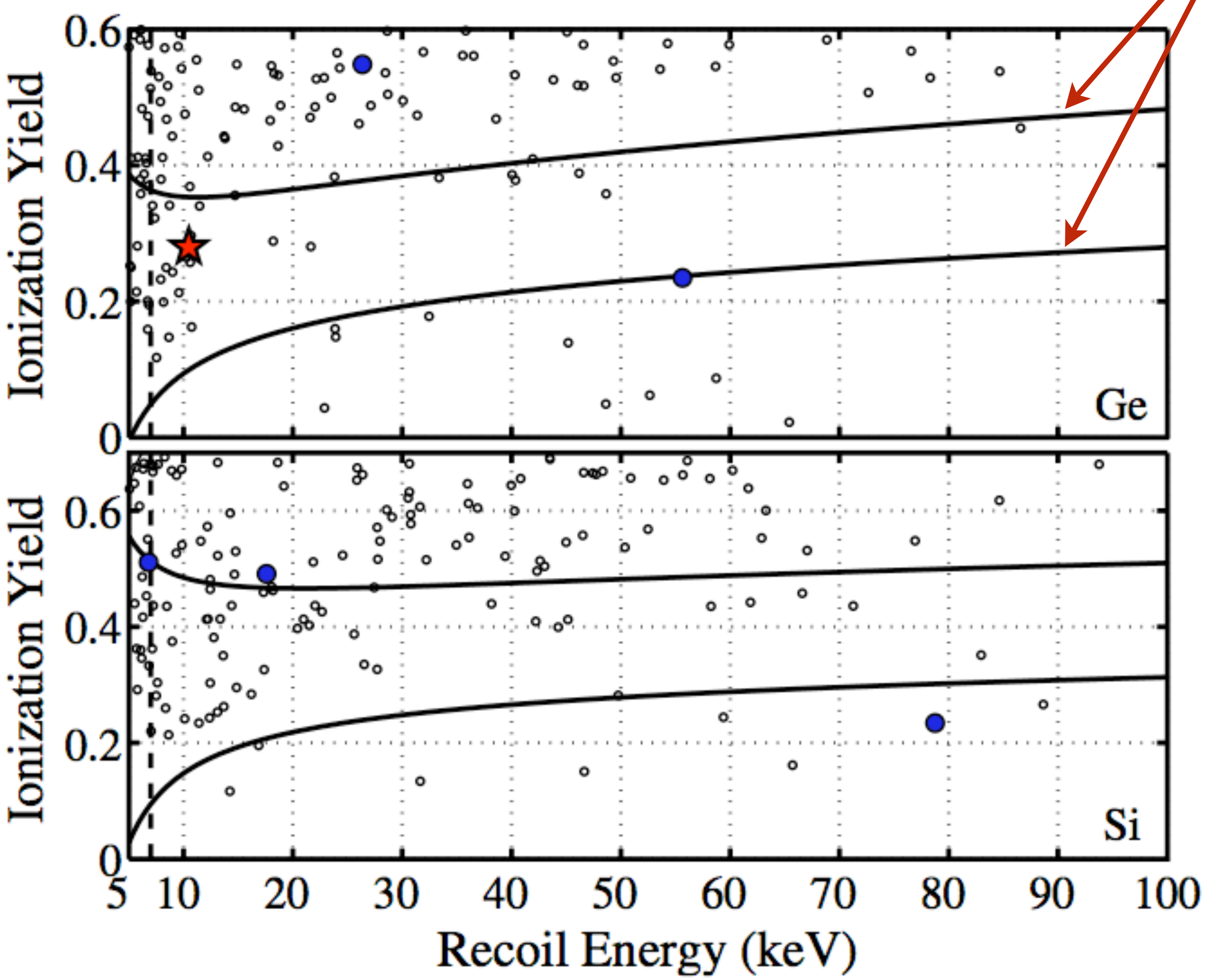
CDMS results (2006)

(1) mitigate radioactive background
(2) obtain a “large” exposure (kg-days)
(3) look at the event spectrum with blind cuts
(4) decide if you see (or exclude) dark matter

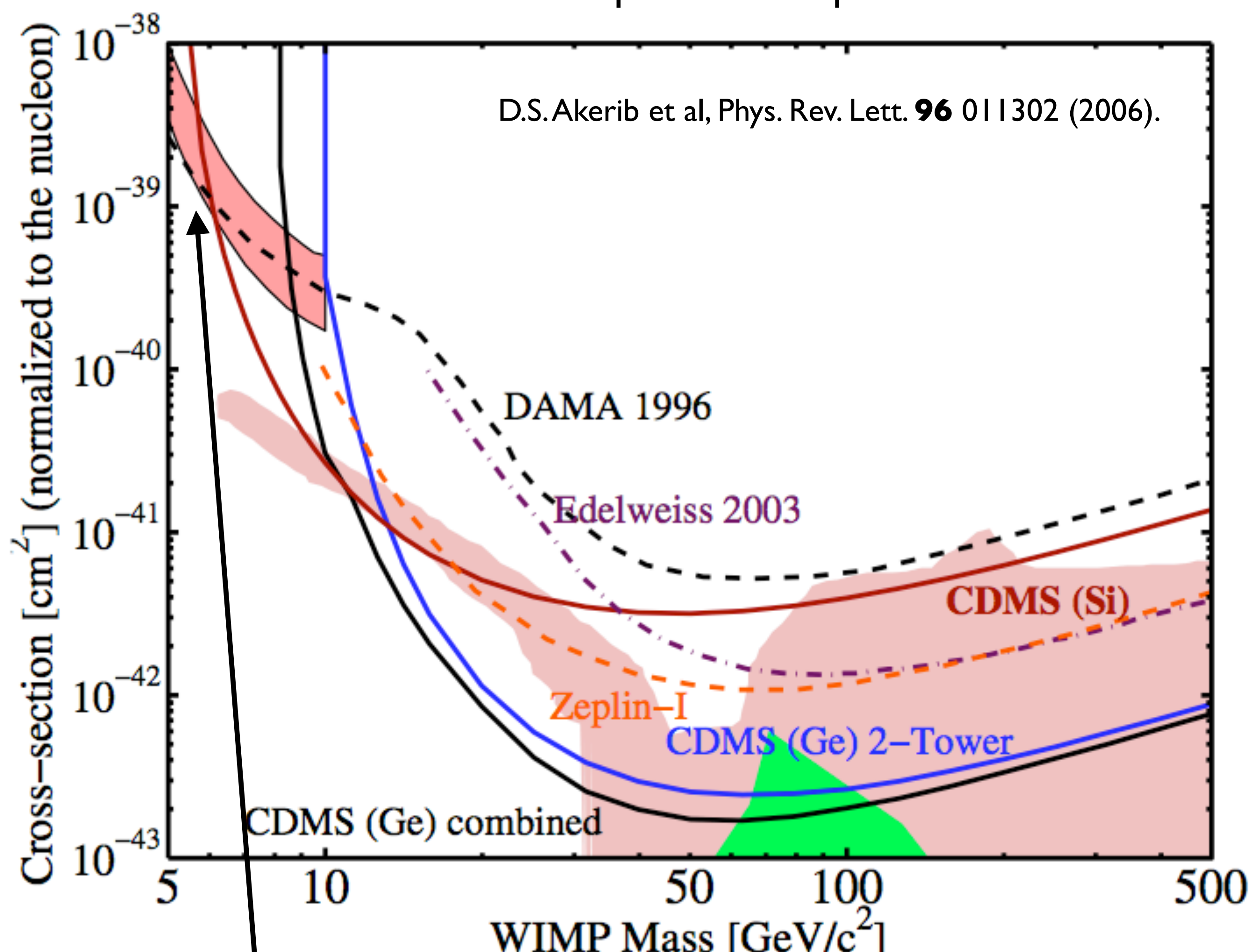


NR band (from neutron cal.)

Events prior to ***“surface electron recoil rejection”*** *cut (open circles), and after all blind cuts (blue/red)*



WIMP parameter space



DAMA modulation signal still allowed at low WIMP mass

CDMS detector

From the Theses of G Wang (2005) and M Attisha (2006)

1.25 kg Ge target
0.40 kg Si target

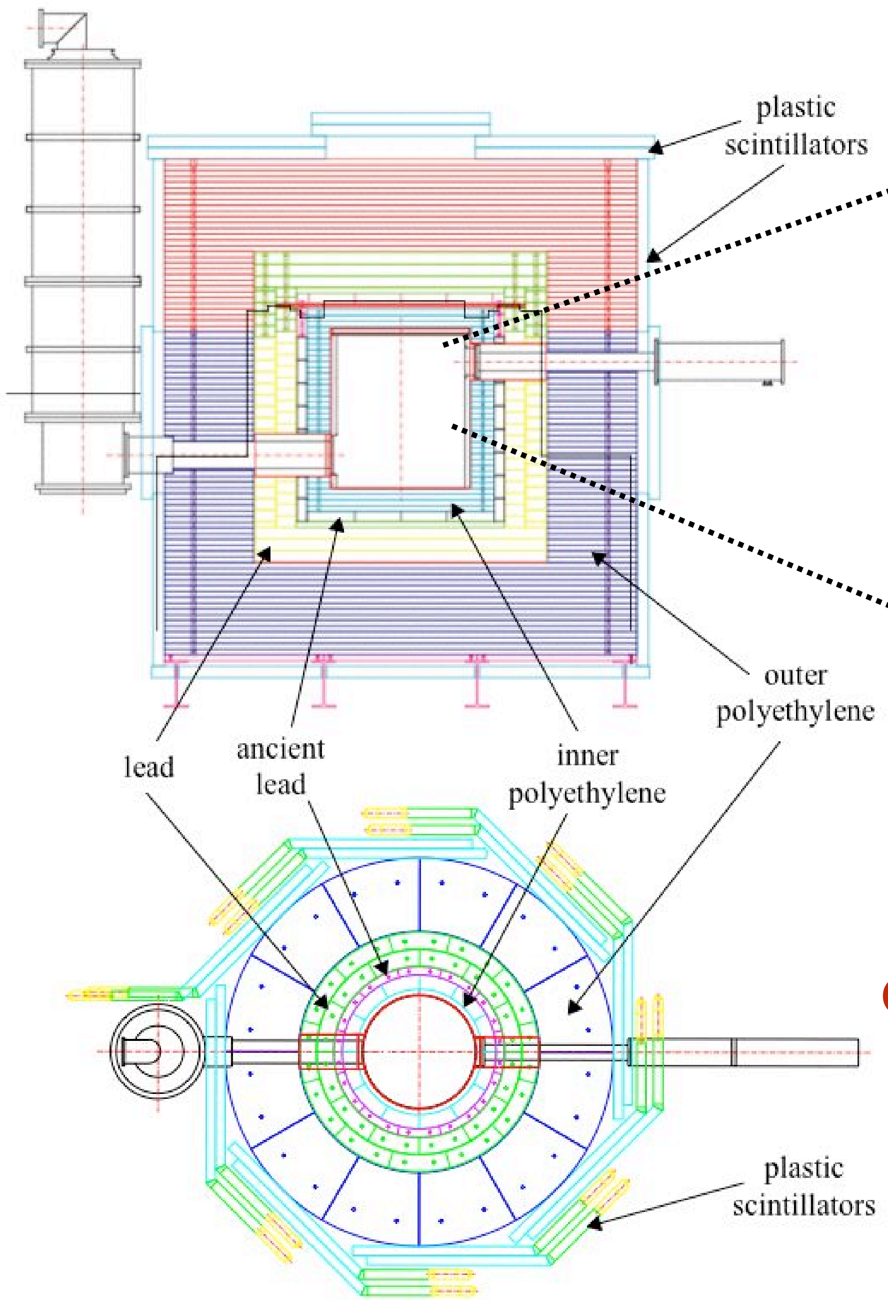


Figure 3.5: Schematic of the CDMS detector shielding. The uppermost image (side view) shows the central icebox surrounded by the polyethylene and lead shields, with dilution refrigerator affixed. The upper sections of the primary shield are colored differently in the diagram since these are the parts that are lifted away in order to access the icebox (eg. for detector installation).

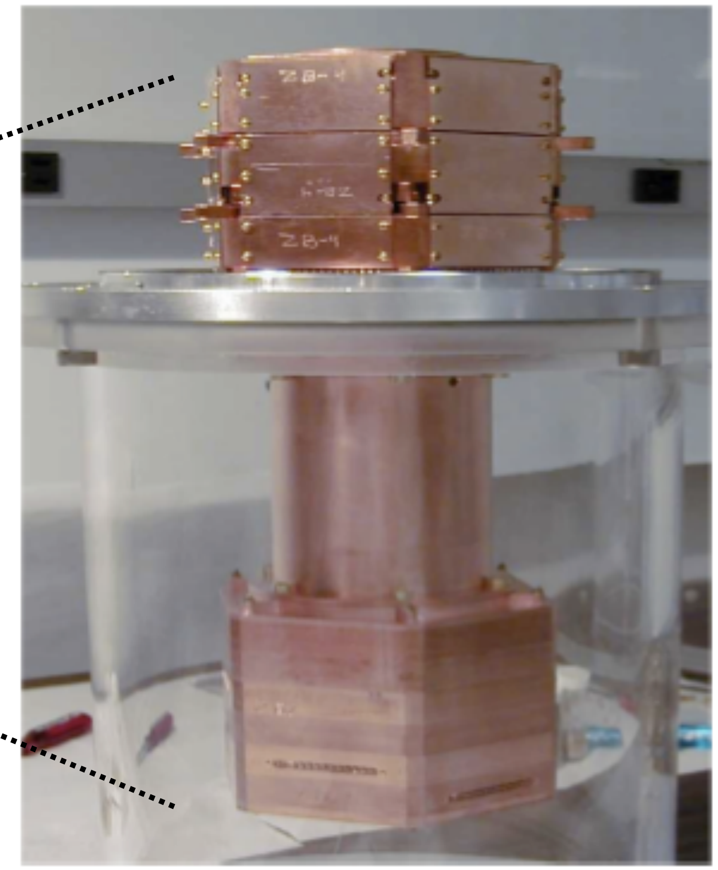
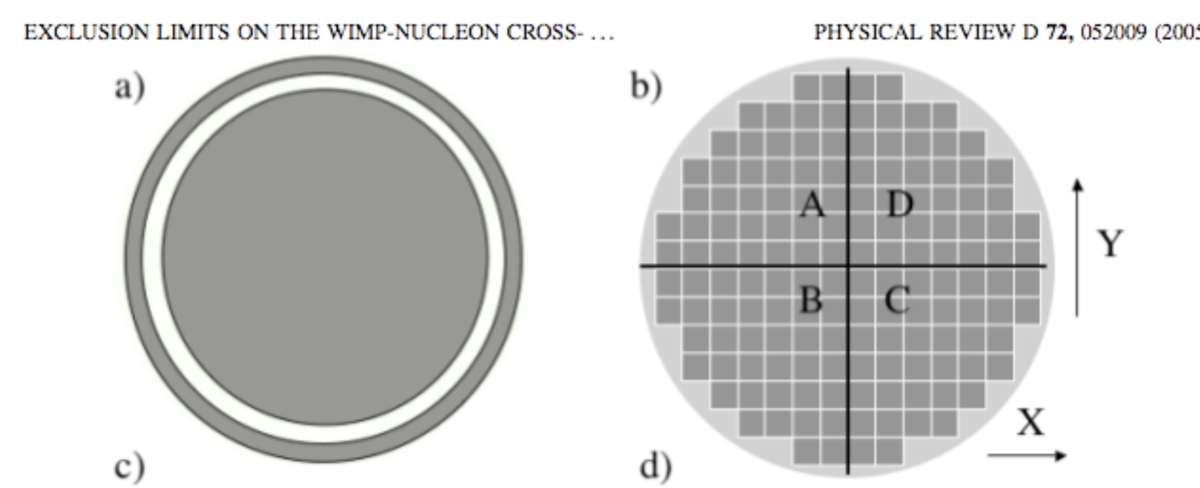
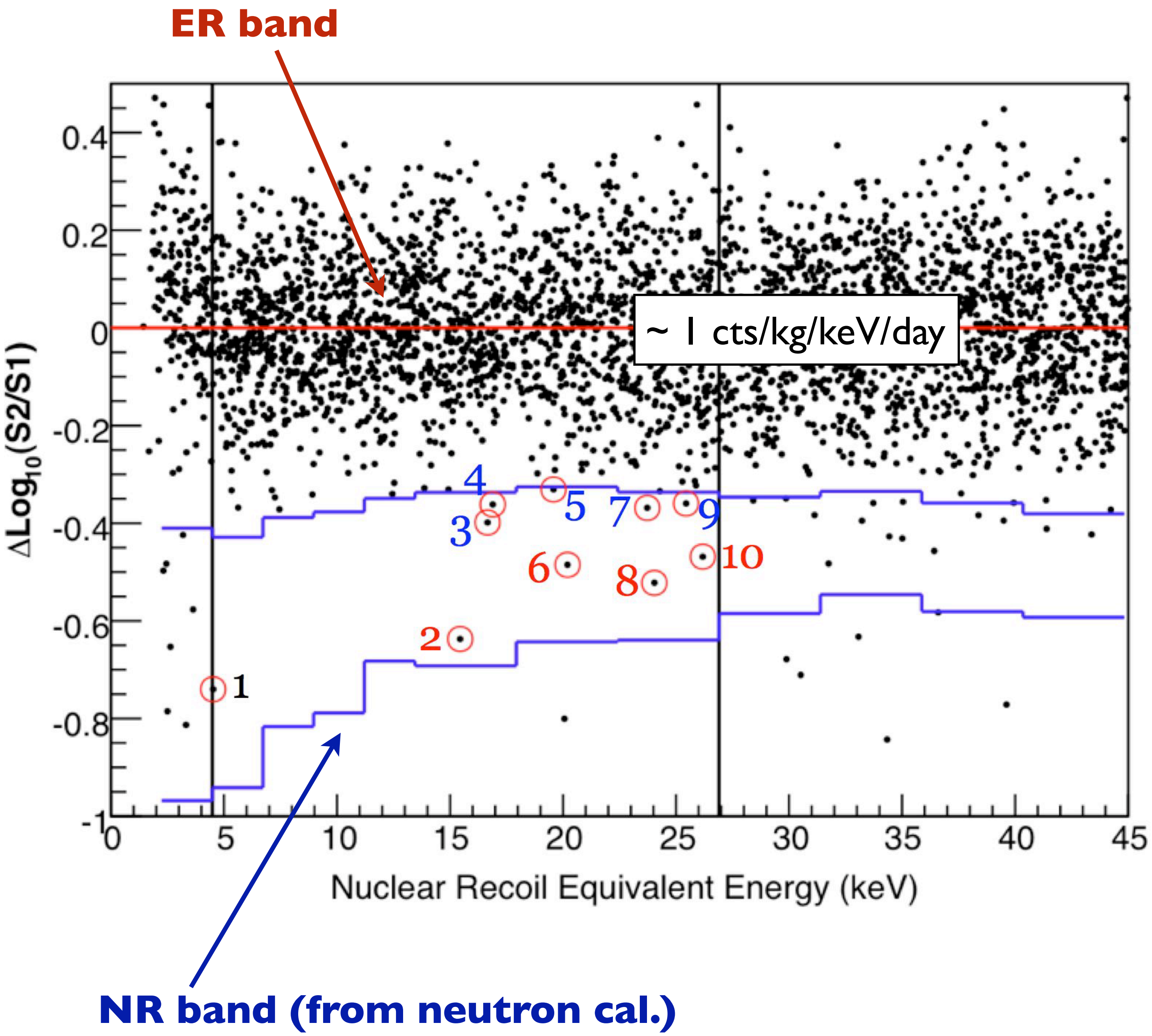


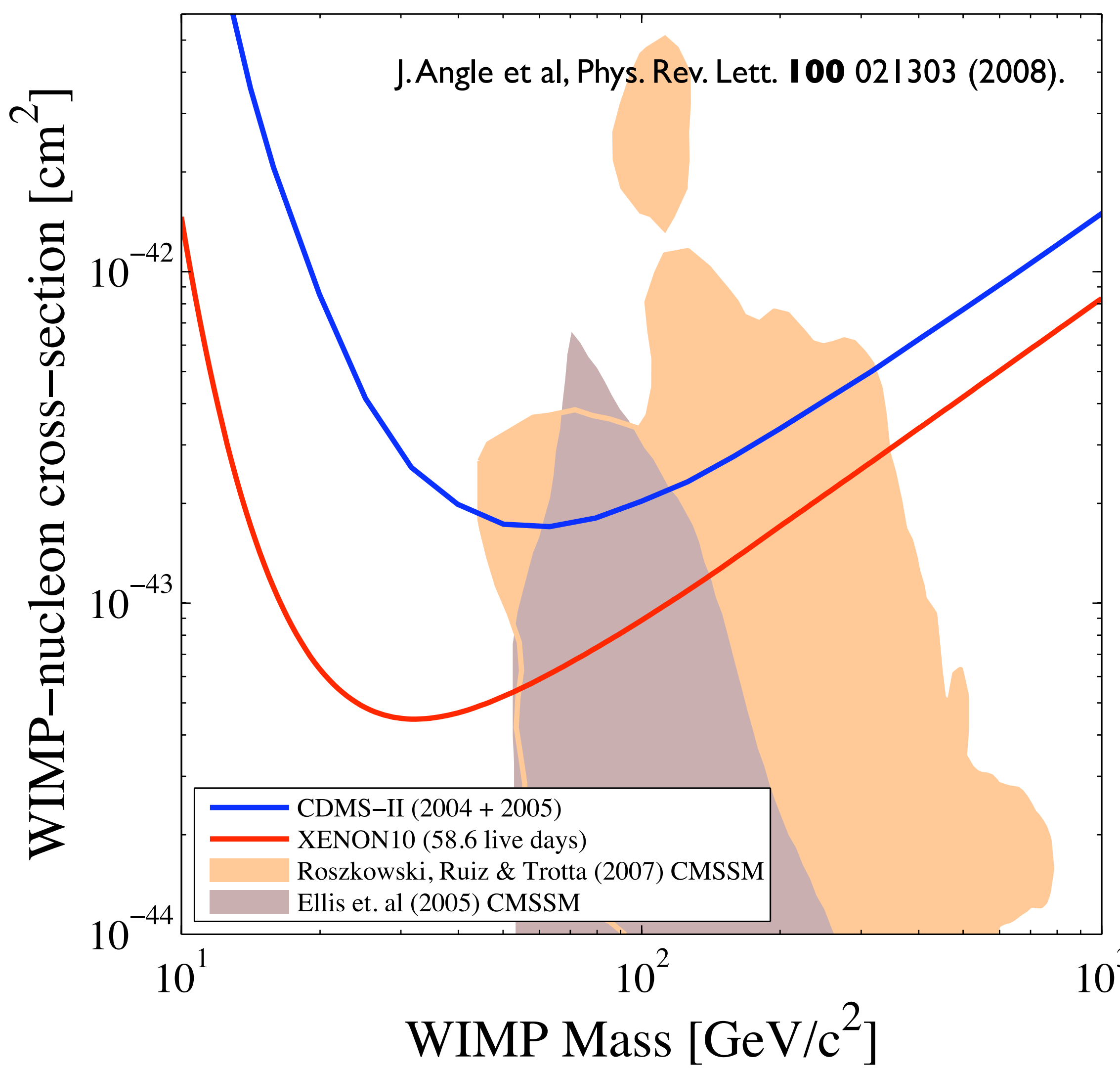
Figure 3.4: The tower that houses six CDMS ZIP detectors.

each detector has 3D sensitivity to event vertex



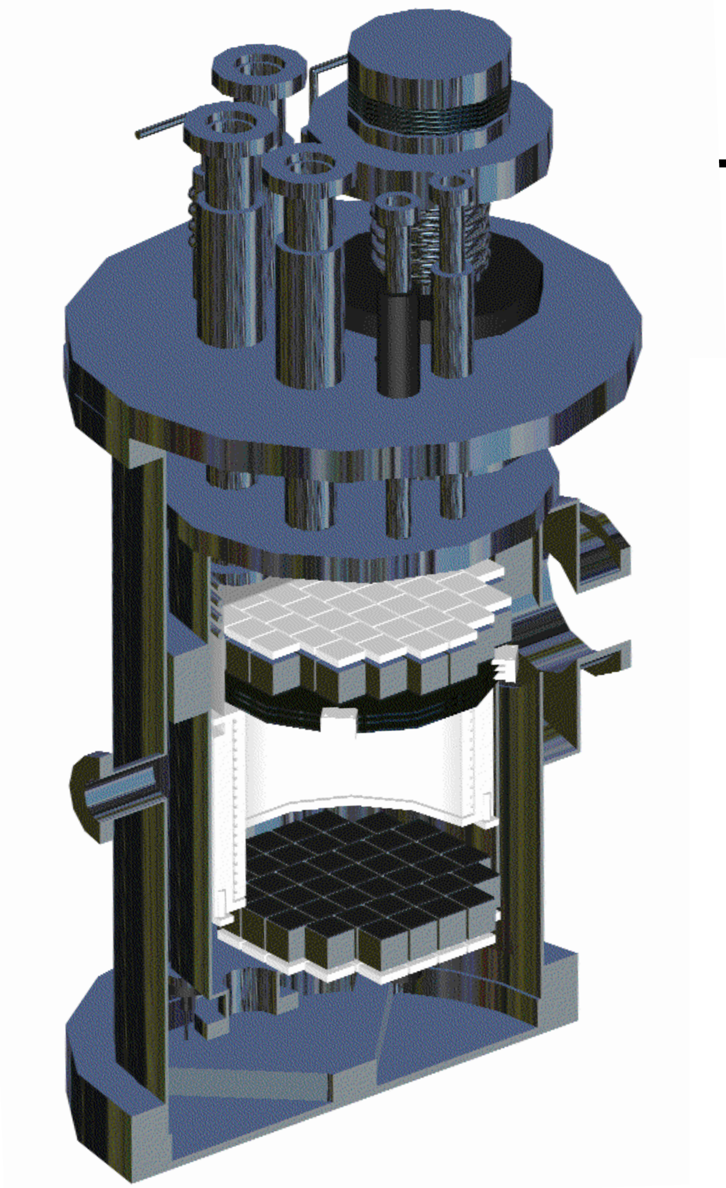
XENON10 results (2008)

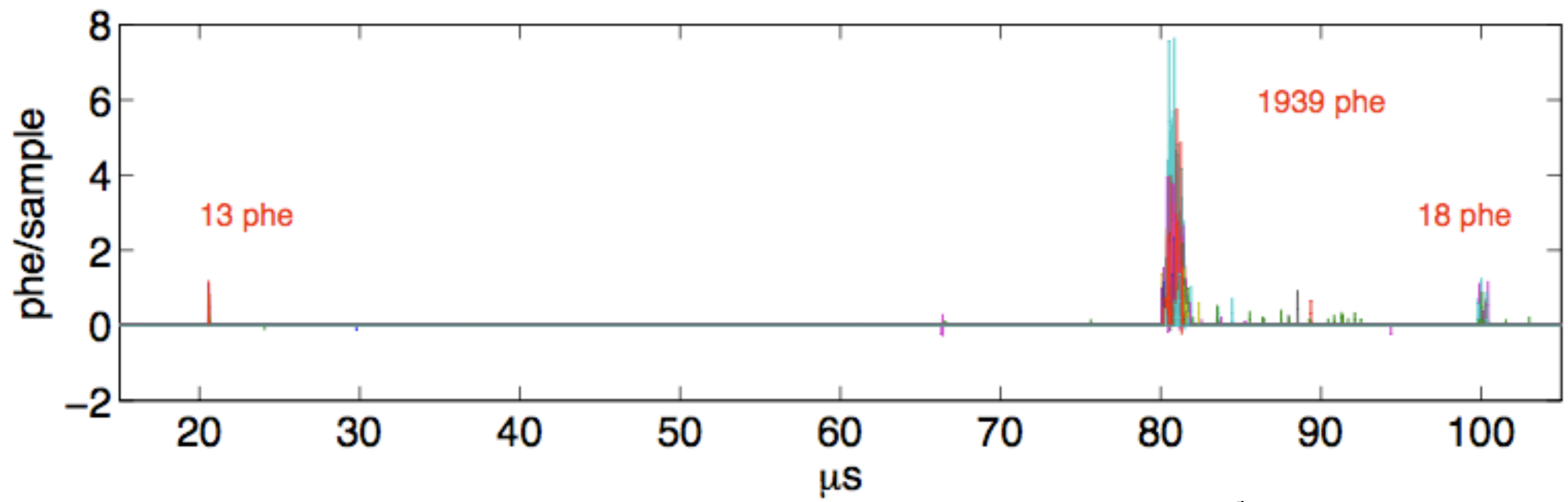


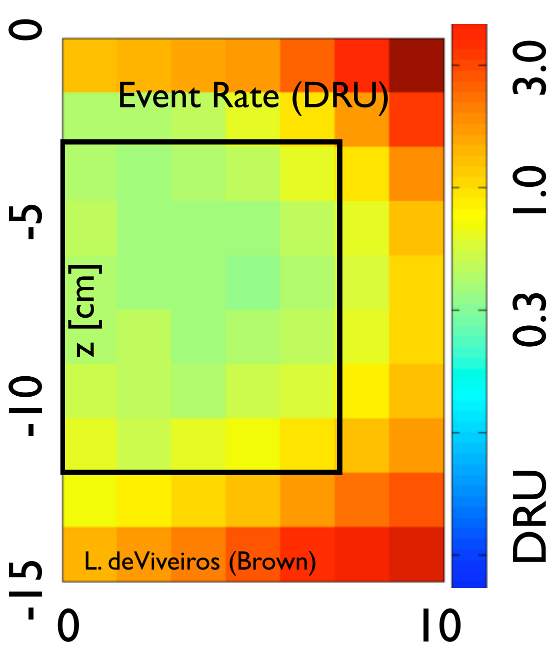


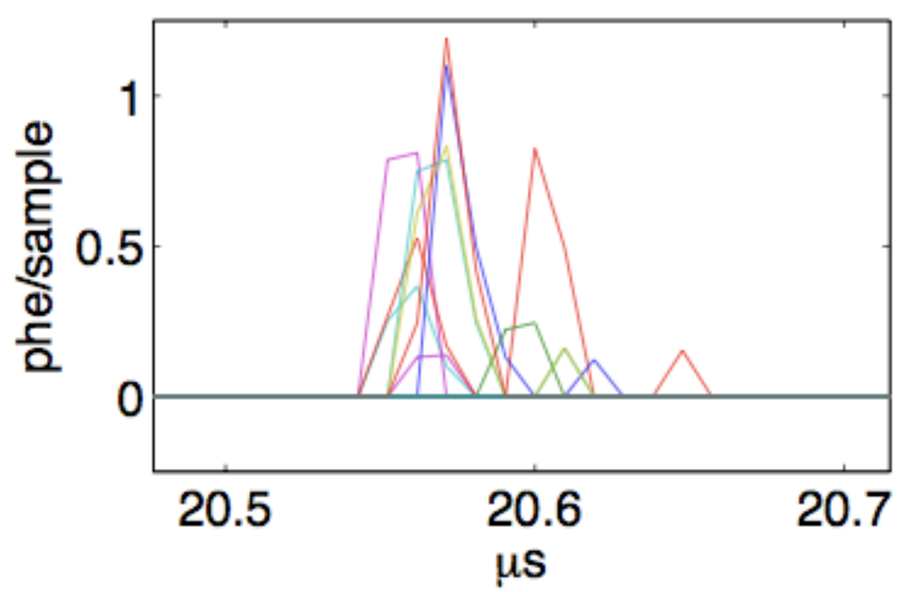
XENON10 detector

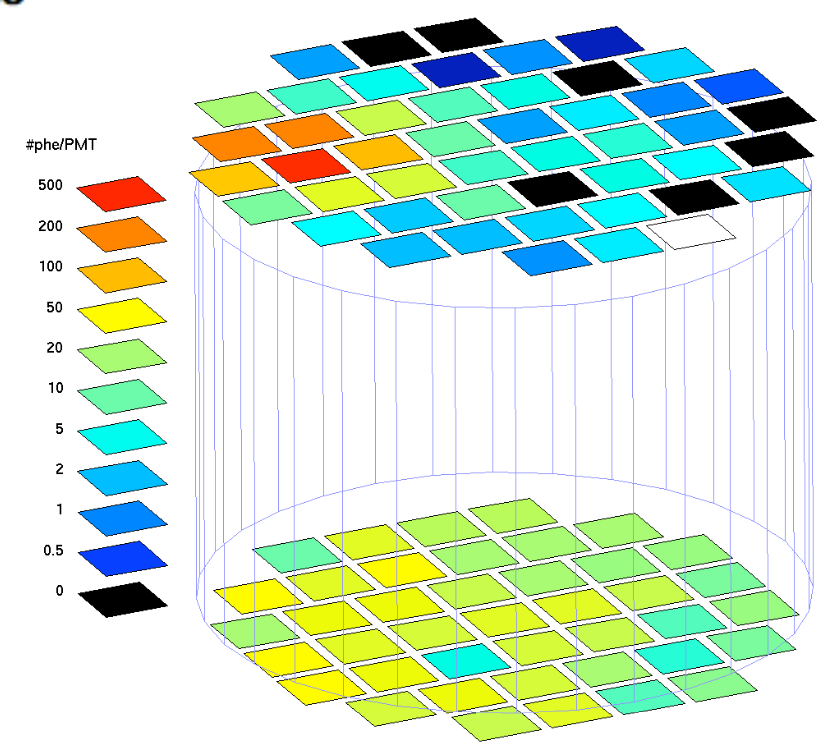
13 kg Xe target
(5.3 kg after cuts)





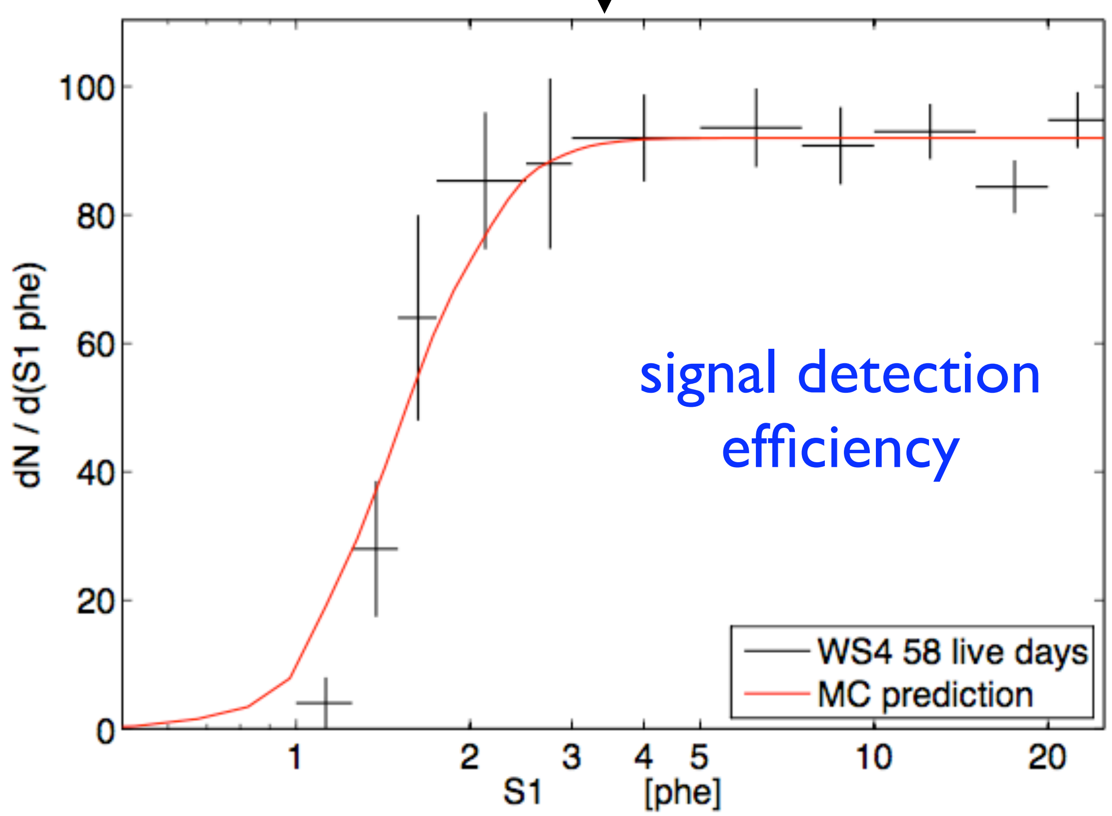




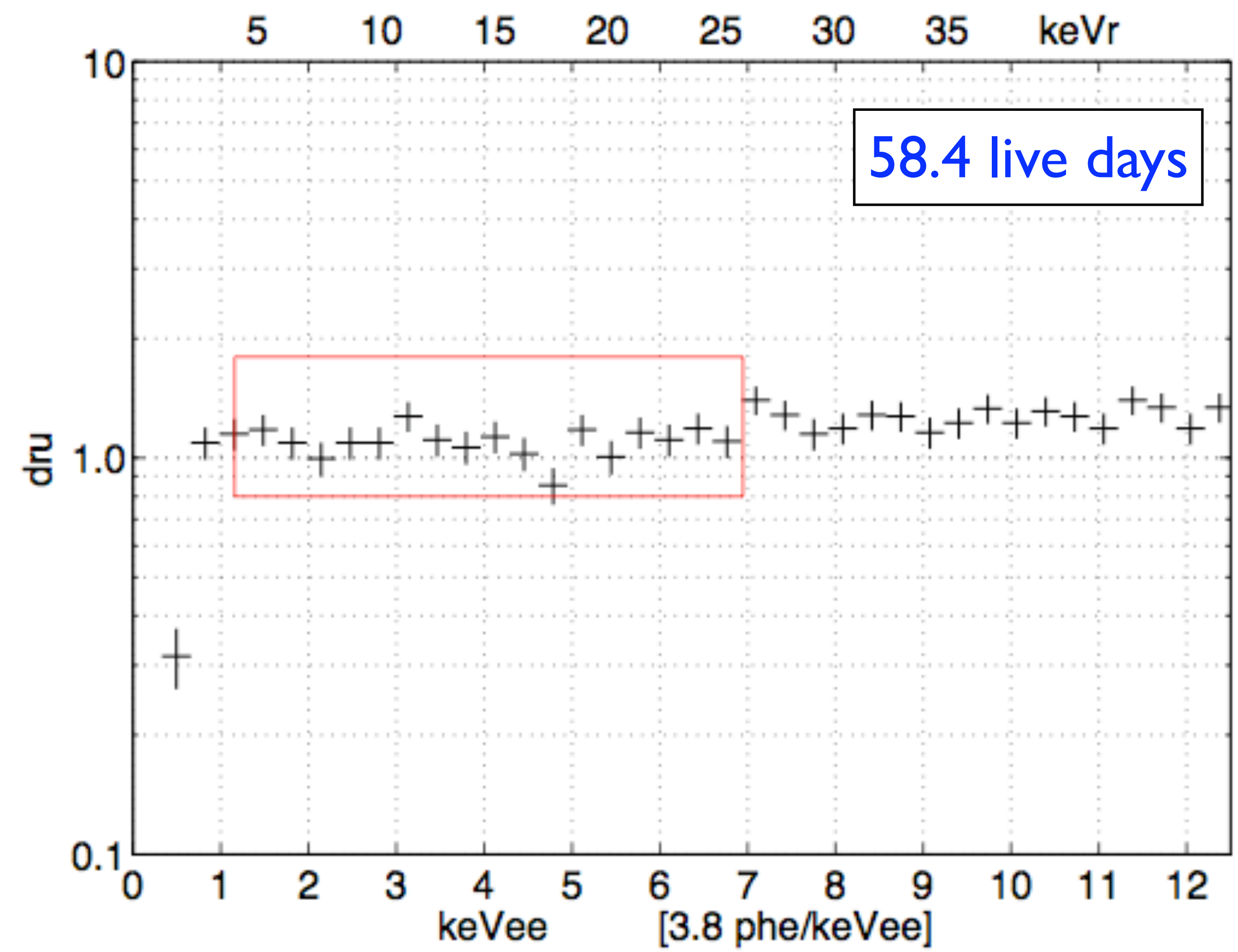


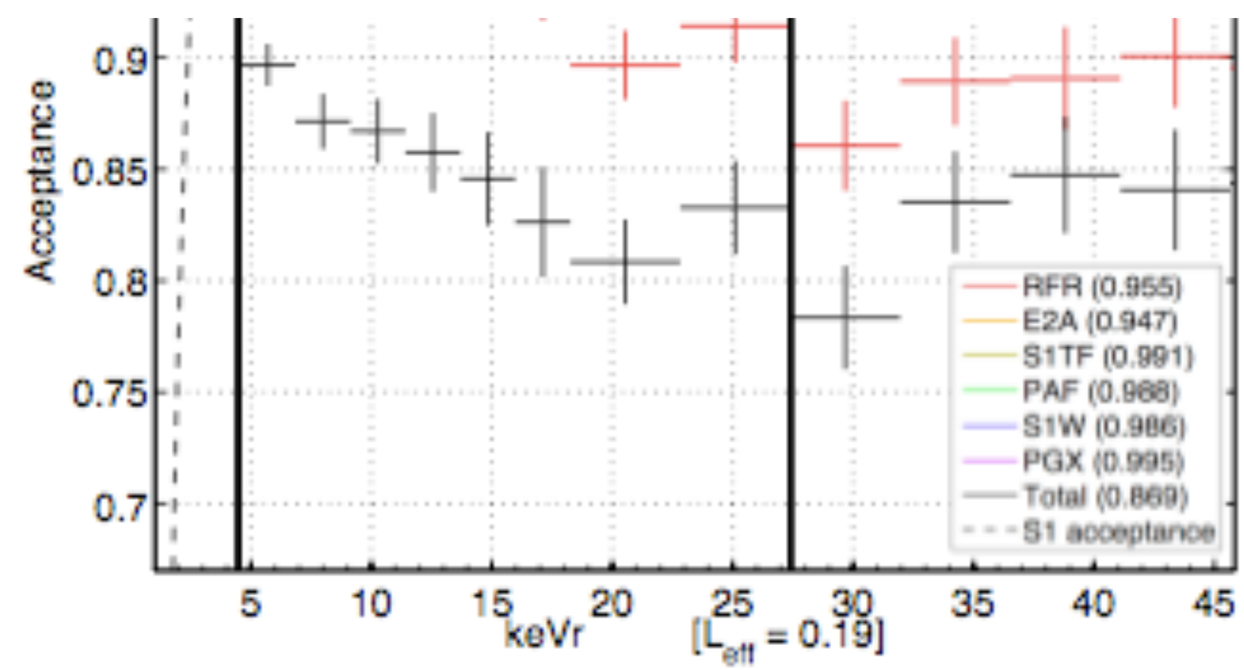
XENON10 single scatter data

~1 keVee



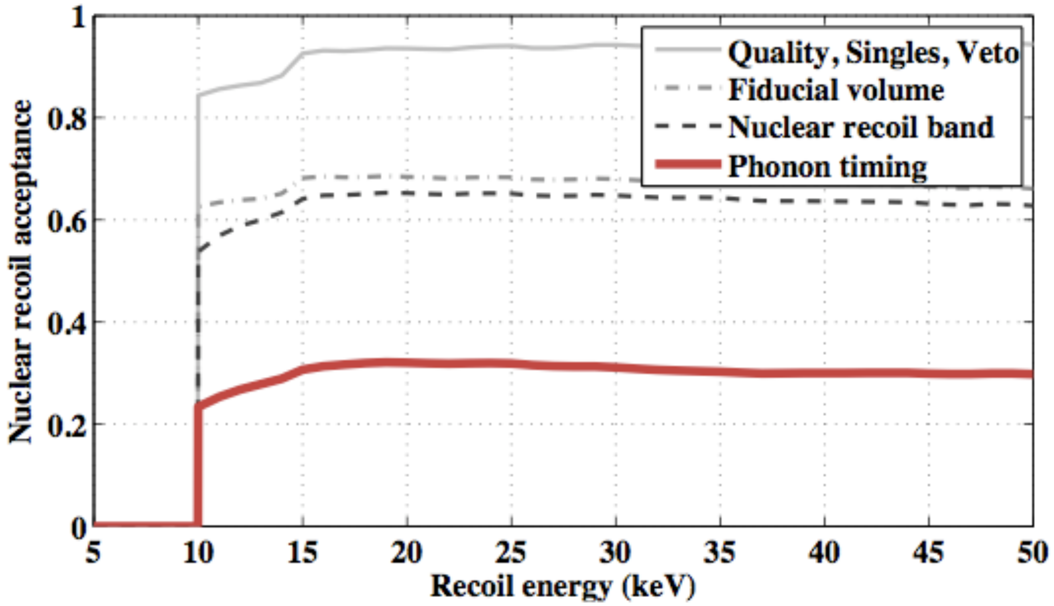
1 S1 phe ~ 1 keVr



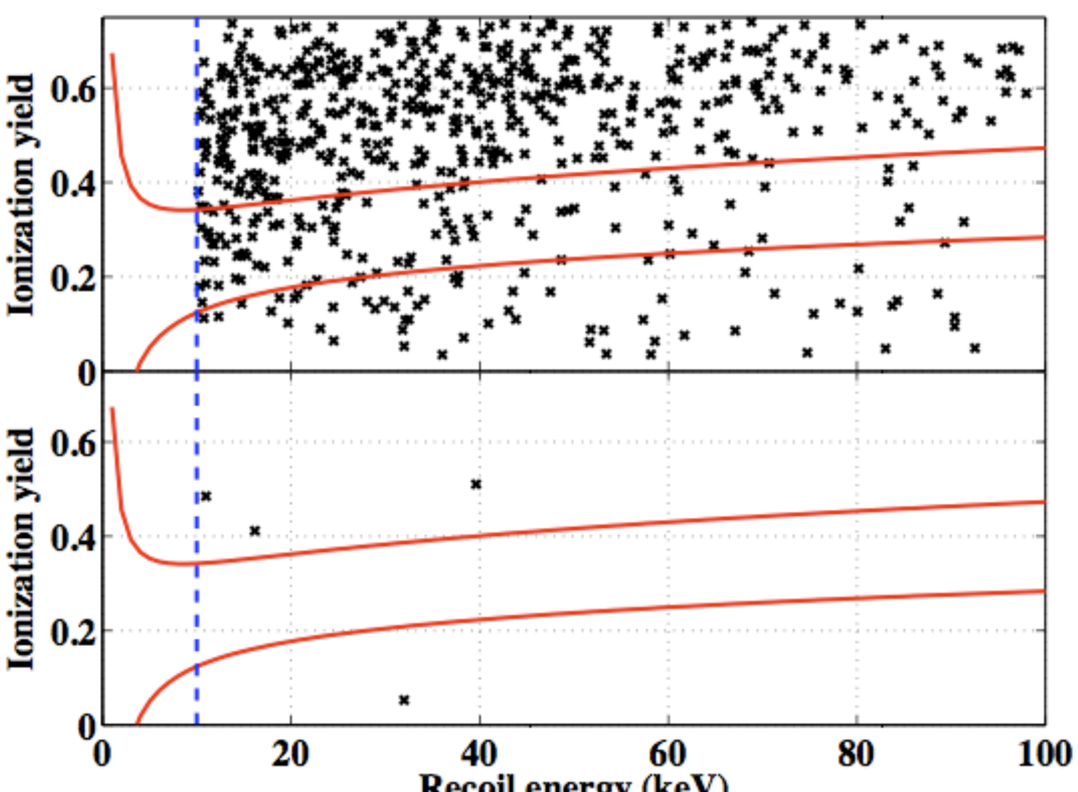


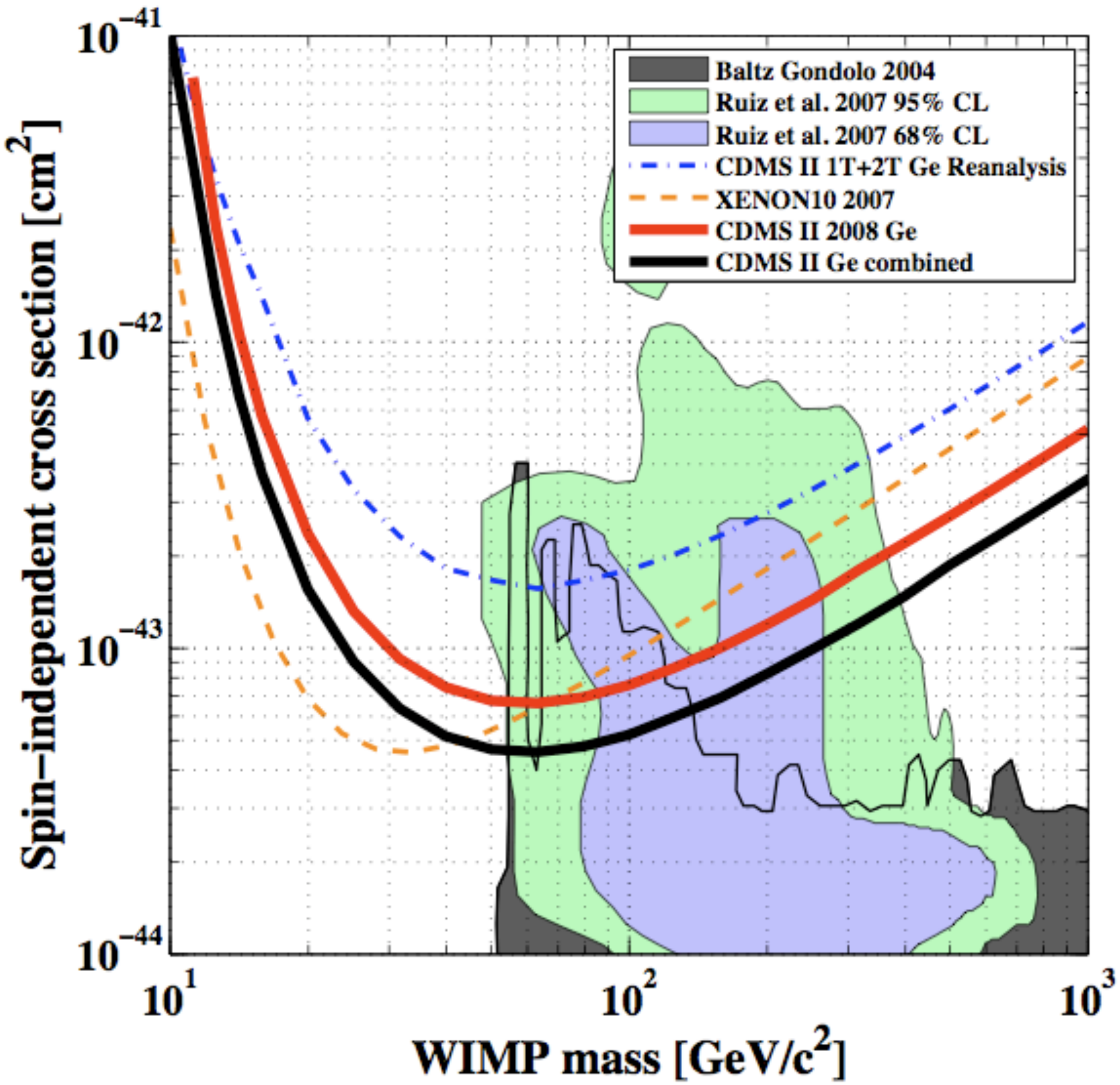
CDMS results (2008)

3.75 kg Ge target



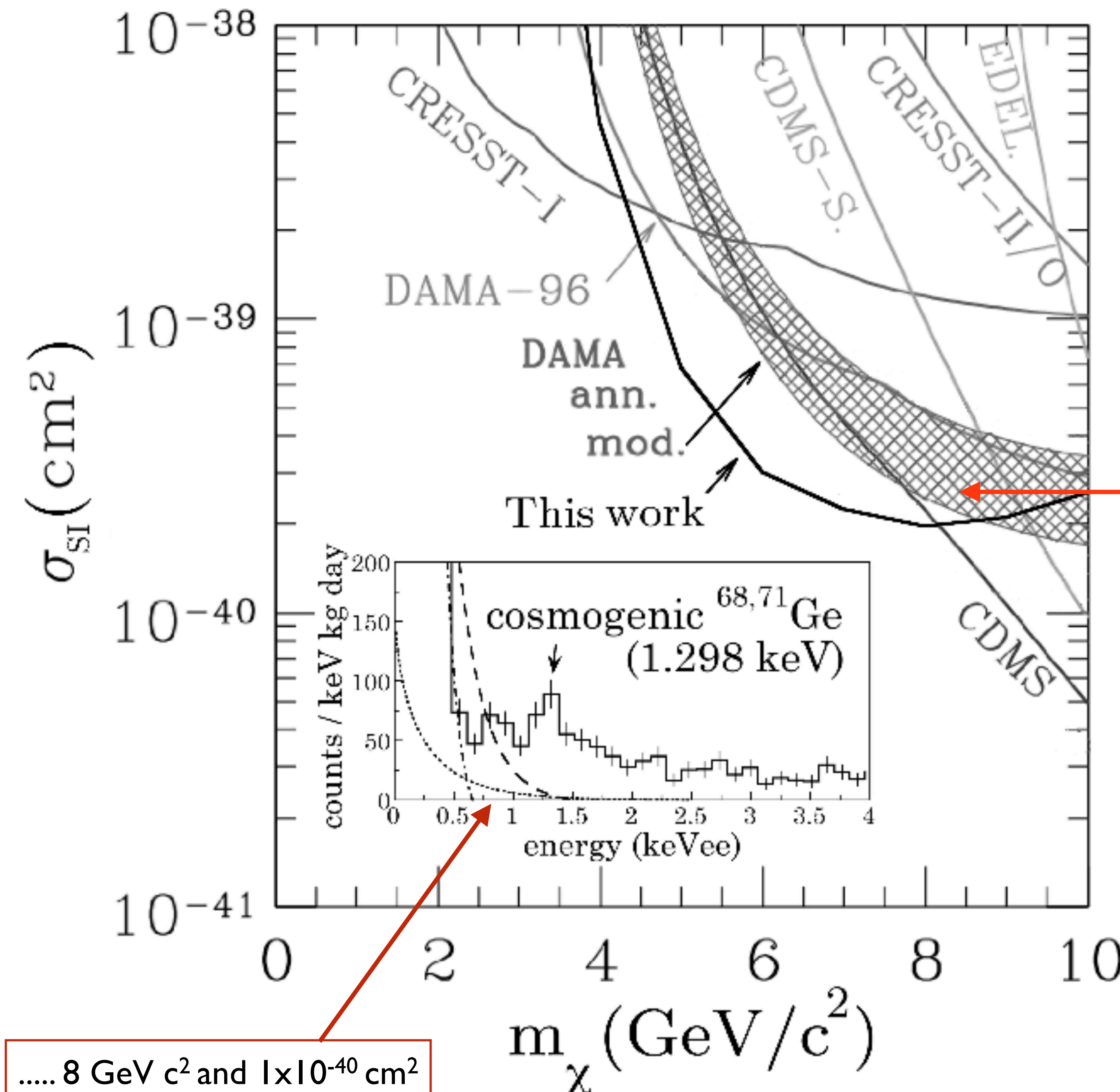
(top) prior to ***"surface electron recoil rejection"*** *cut*





CoGeNT results (2008)

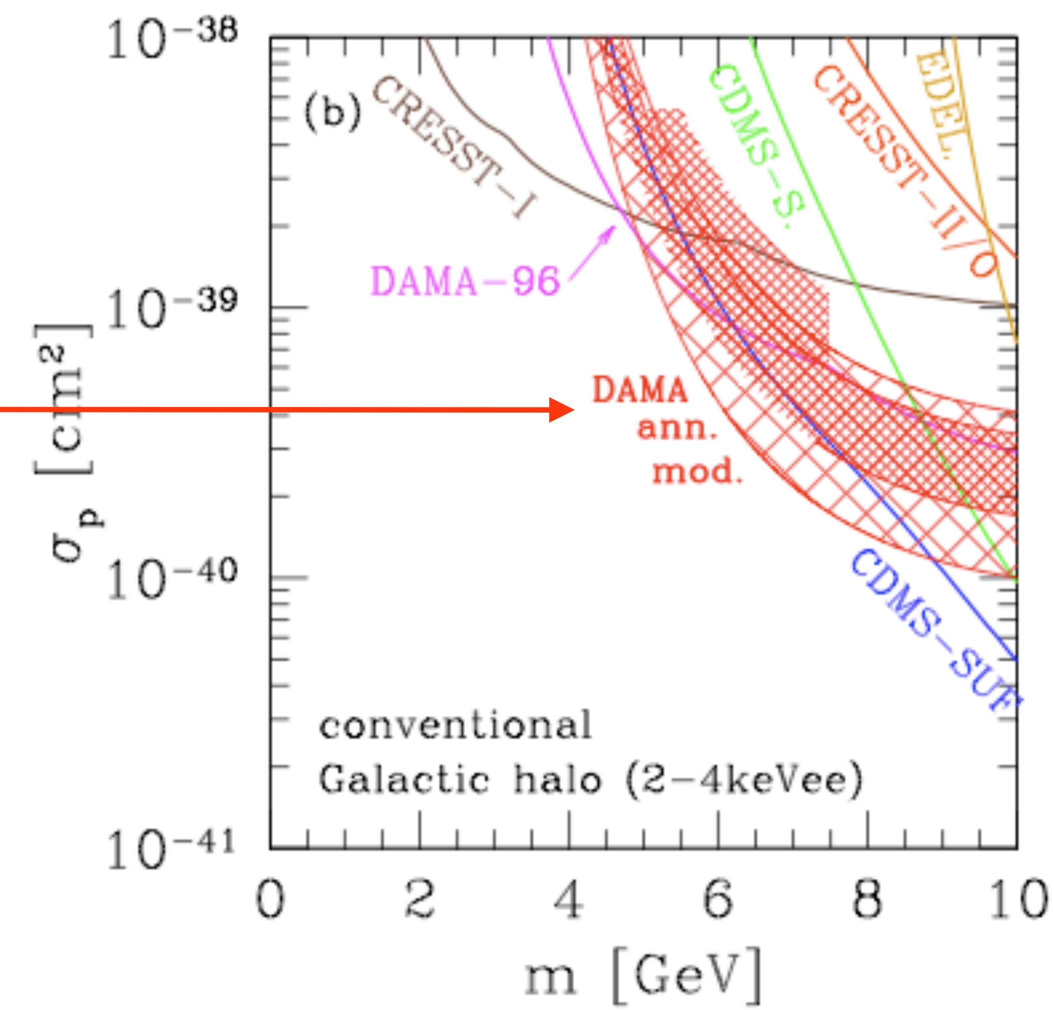
arxiv:0807.0879v1 [astro-ph]



..... 8 GeV c^2 and 1x10^{-40} cm^2
--- 6 GeV c^2 and 2x10^{-39} cm^2
-.-. 4 GeV c^2 and 1x10^{-38} cm^2

standard halo model, recoils off Na nuclei

PHYSICAL REVIEW D **71**, 123520 (2005)



CoGeNT single scatter data

~ 1 kg Ge target

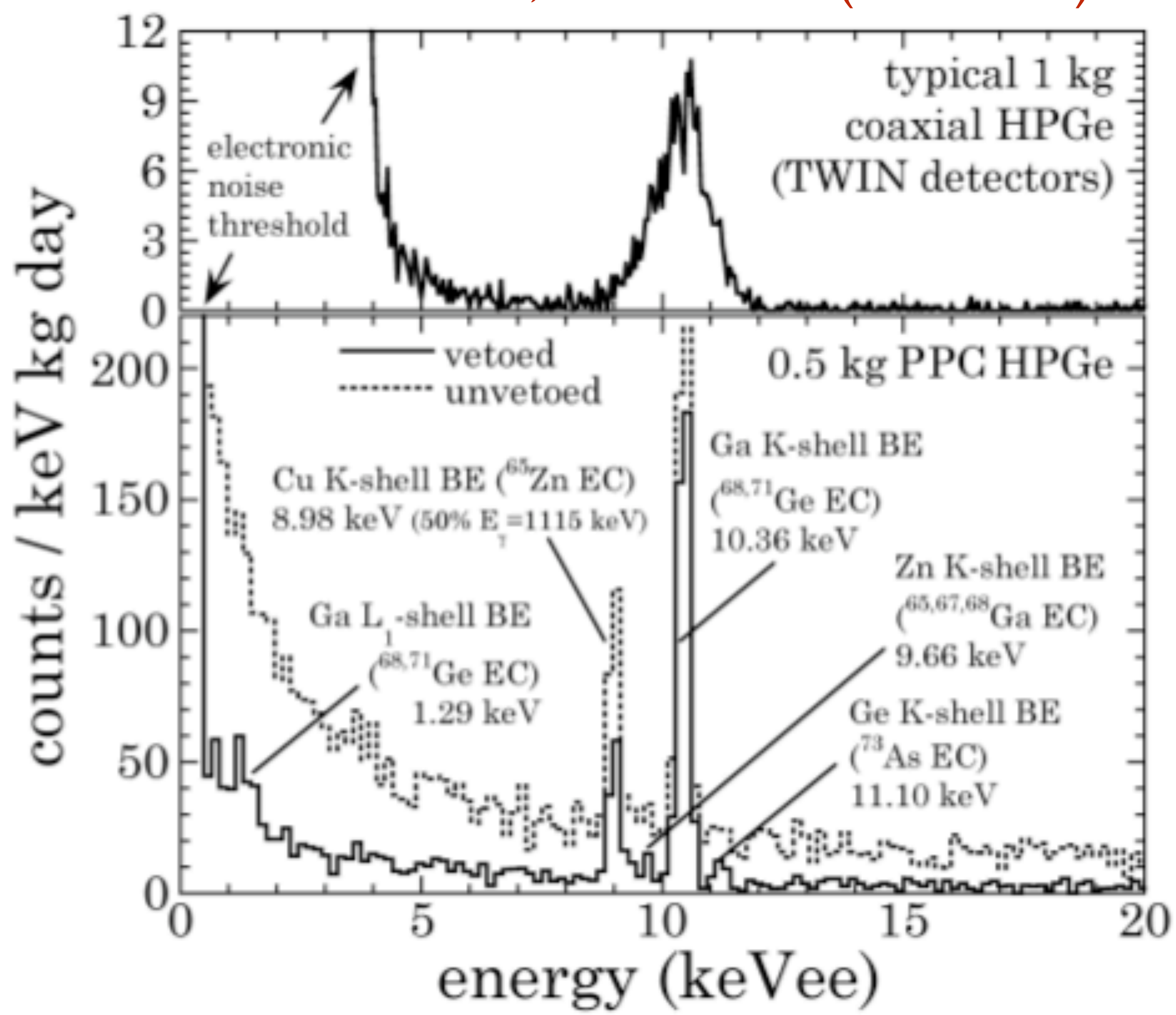
A ~1 kg p-type point contact (PPC) HPGe detector

Improvement over standard HPGe detectors (top right)

At 330 m.w.e -- NOT deep (yet?)

NOTE: no discrimination (not detecting phonons)

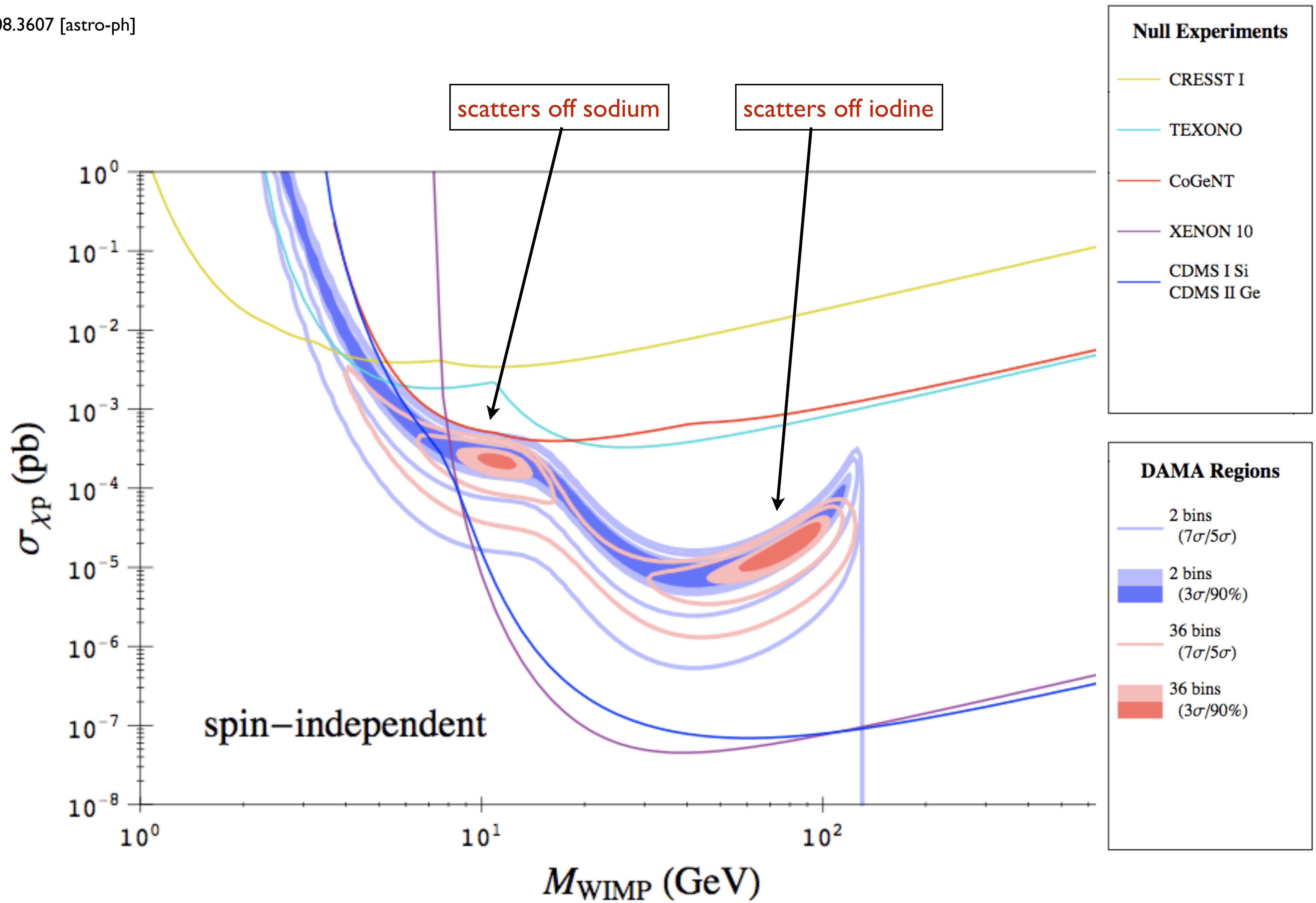
standard HPGe, Soudan Mine (2090 mwe)



CoGeNT PPC HPGe, Chicago Sewars (330 mwe)

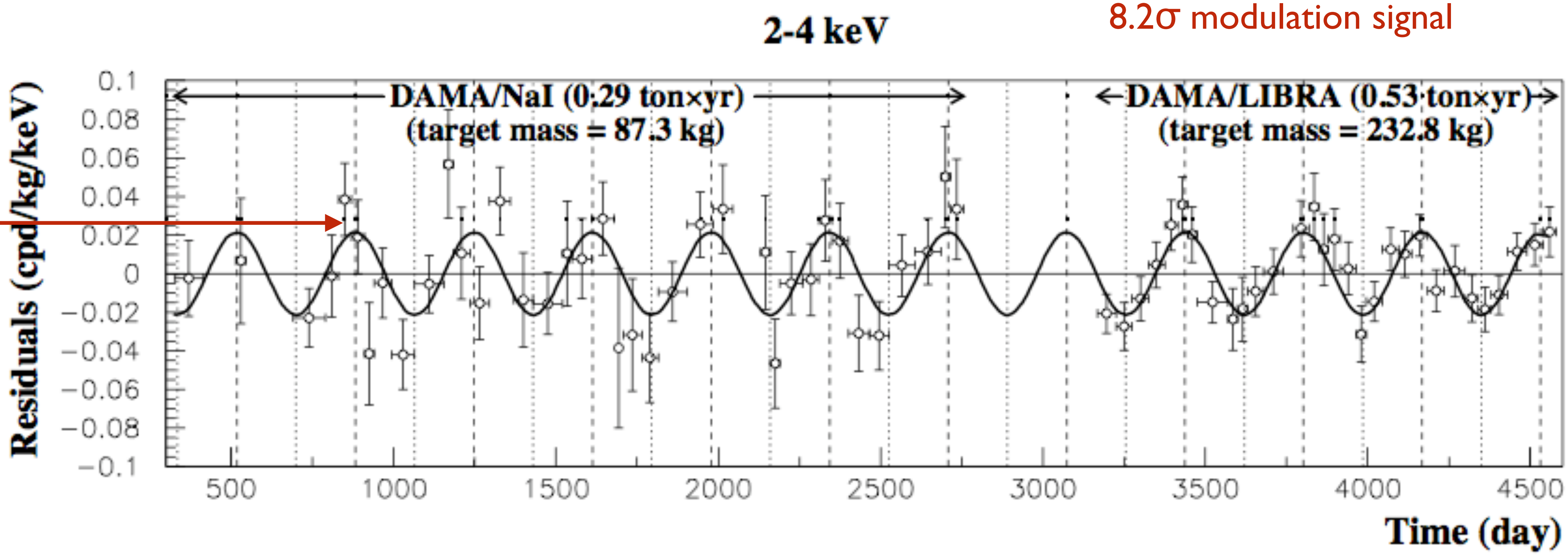
Other results

arxiv:0808.3607 [astro-ph]



DAMA/LIBRA results (2008)

8.2σ modulation signal



2.5% effect

For completeness, we also further note that no experiment exists whose result can be directly compared in a model independent way with the ones by DAMA/NaI and DAMA/LIBRA. Thus claims for contradictions are arbitrary, in fact, e.g.: 1) the

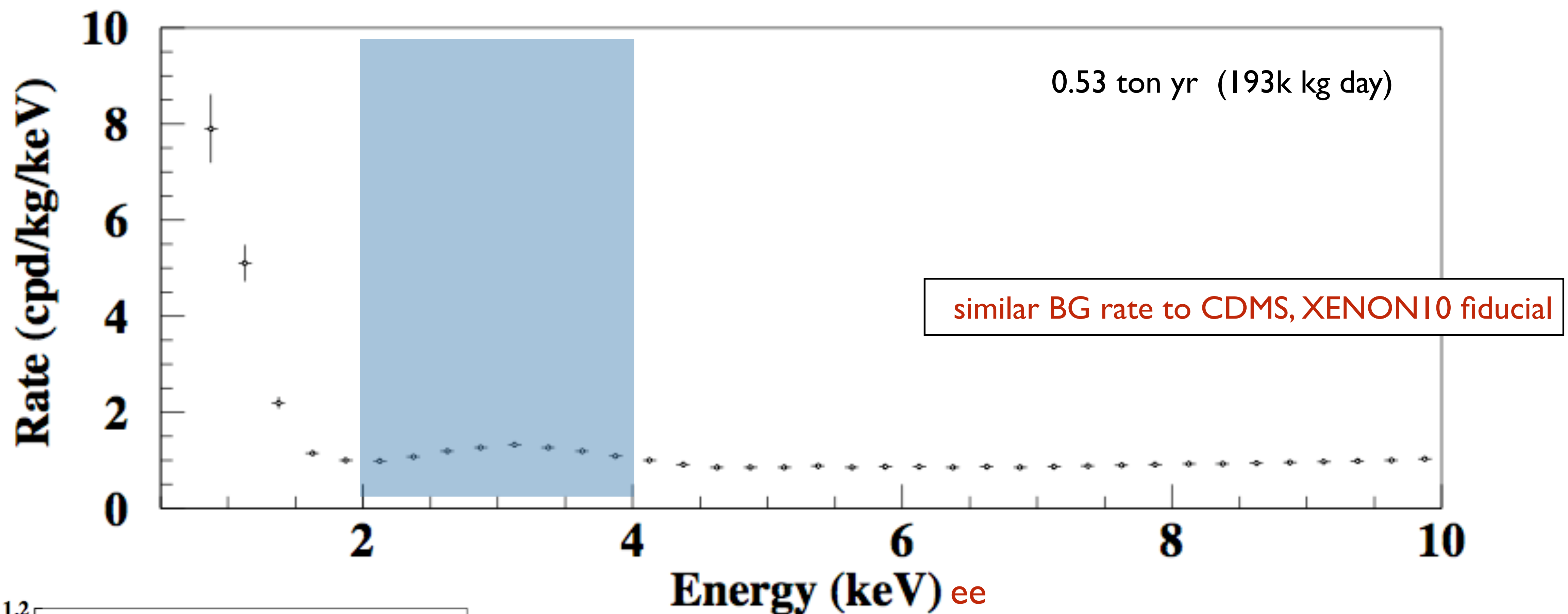
...insert here a slew of reasons why one should not doubt the authenticity of the DAMA result... including

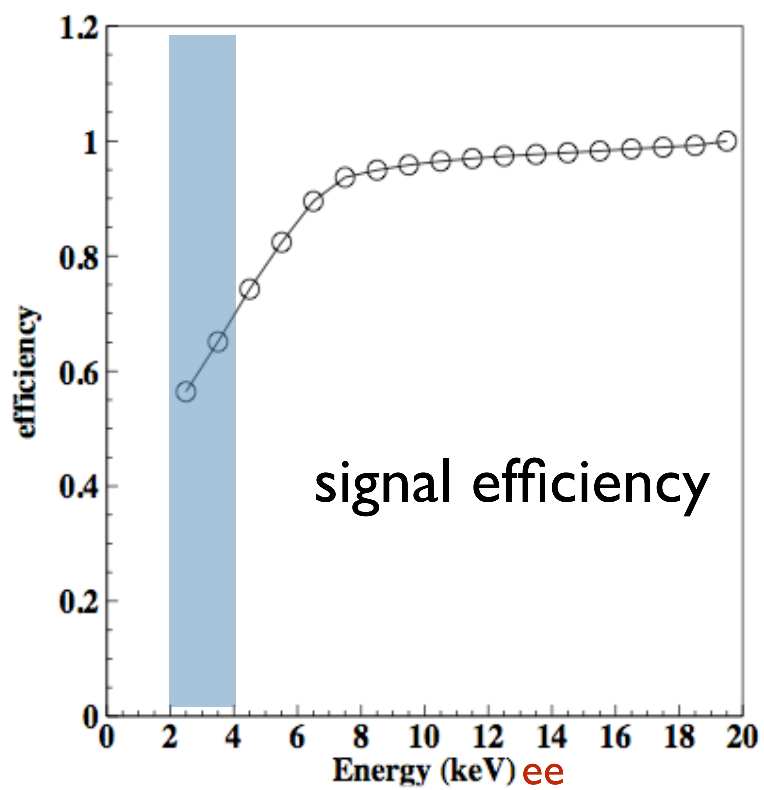
more, additional realistic limitations in those claimed model dependent sensitivities (just for "nuclear recoils" and a single assumed scenario and parameters set) arise so

R. Bernabei et al, 0804.2738 [astro-ph] The DAMA/LIBRA apparatus

R. Bernabei et al, 0804.2741 [astro-ph] First Results from DAMA/LIBRA

DAMA/LIBRA single scatter data

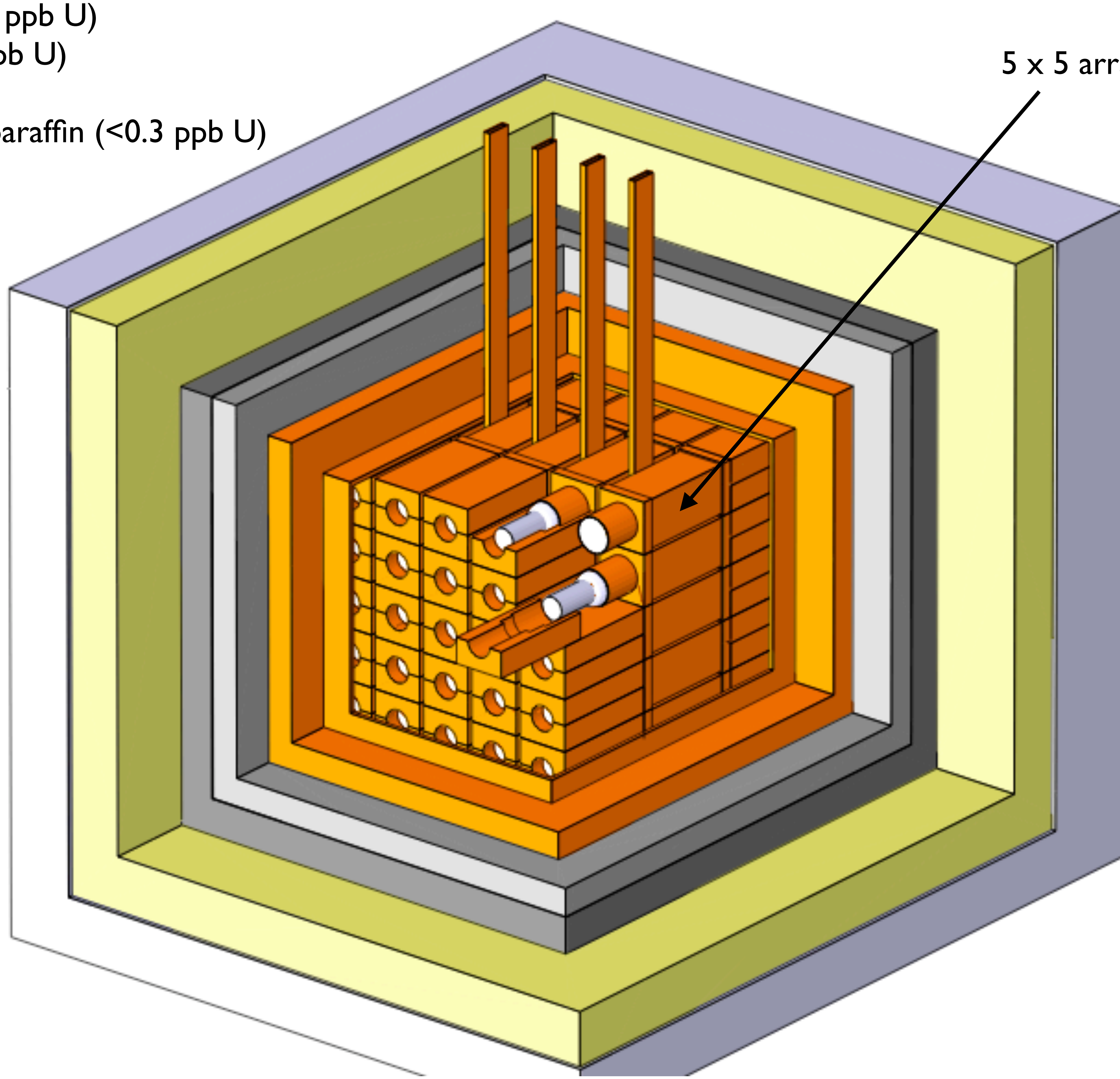




- stated energy threshold of the experiment is 2 keVee
- what is the bump at 3 keVee?
- why can't we see the modulation signal in the 1-2 keVee bin?

DAMA detector

shield:
10 cm Cu (<0.5 ppb U)
15 cm Pb (~7 ppb U)
0.15 cm Cd
10-40 cm poly/paraffin (<0.3 ppb U)



5 x 5 array of 9.7 kg NaI crystals

$(10.2 \times 10.2 \times 25.4)$ cm^3 each

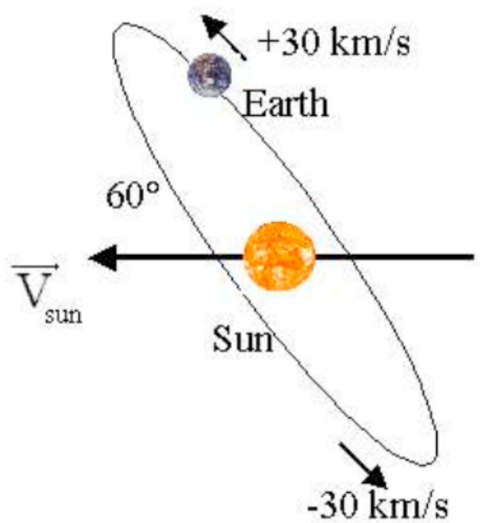
NaI(Tl) crystals:
$\rho = 3.67$ g/cm3
$\lambda_{scint} = 410$ nm
$\tau_{scint} \sim 240\text{-}250$ ns

DAMA assembly, with N_2 purge in effect

most DAMA materials
~1 ppb U/Th , ~1 ppm K

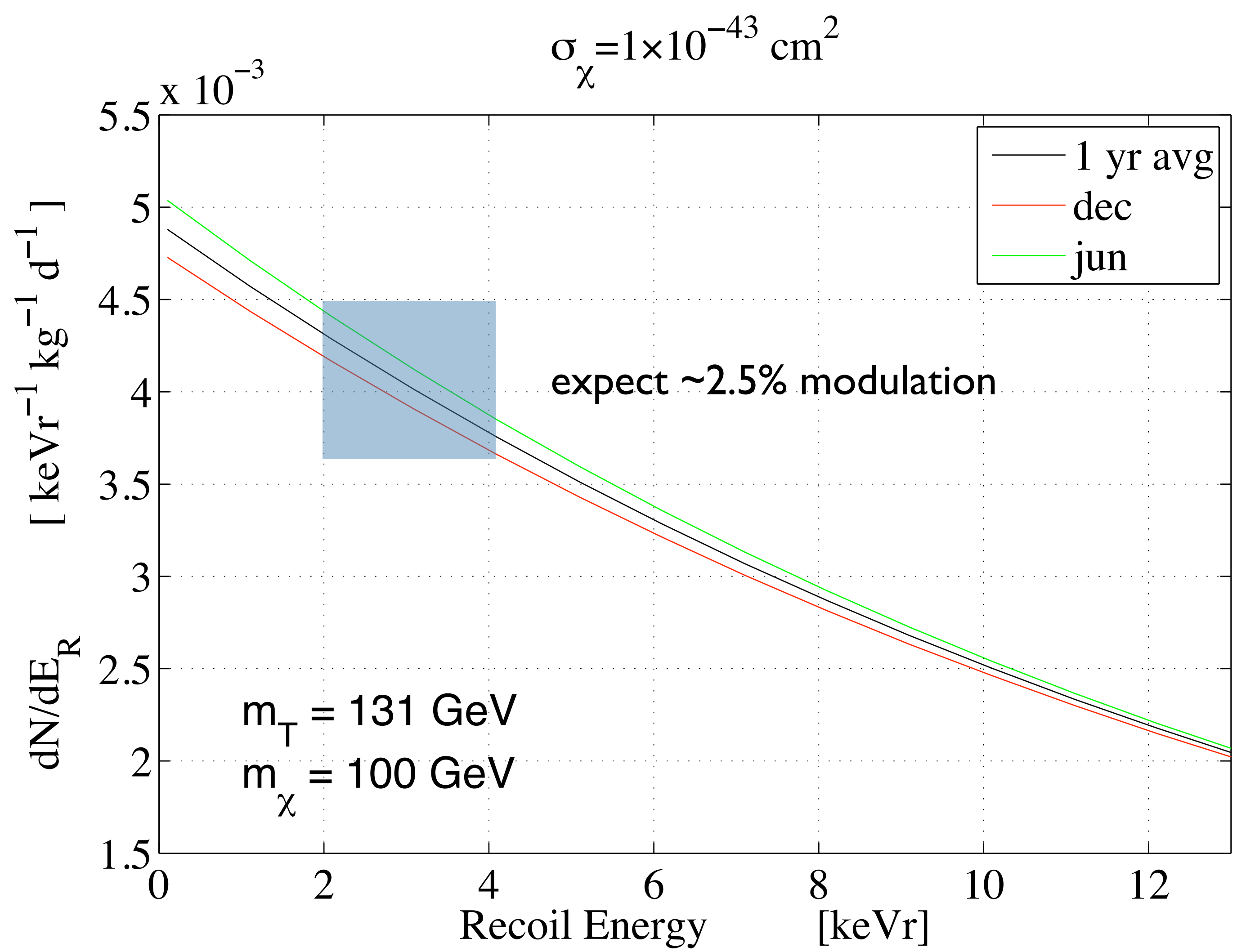
NaI crystals
~0.1 ppb U/Th , ~0.1 ppm K

WIMPs and annual modulation



$$\mathbf{v}_{obs}(t) = \mathbf{v}_{\odot} + V_{\oplus}\left[\hat{\varepsilon}_1 \cos\omega(t-t_1) + \hat{\varepsilon}_2 \sin\omega(t-t_1)\right]$$

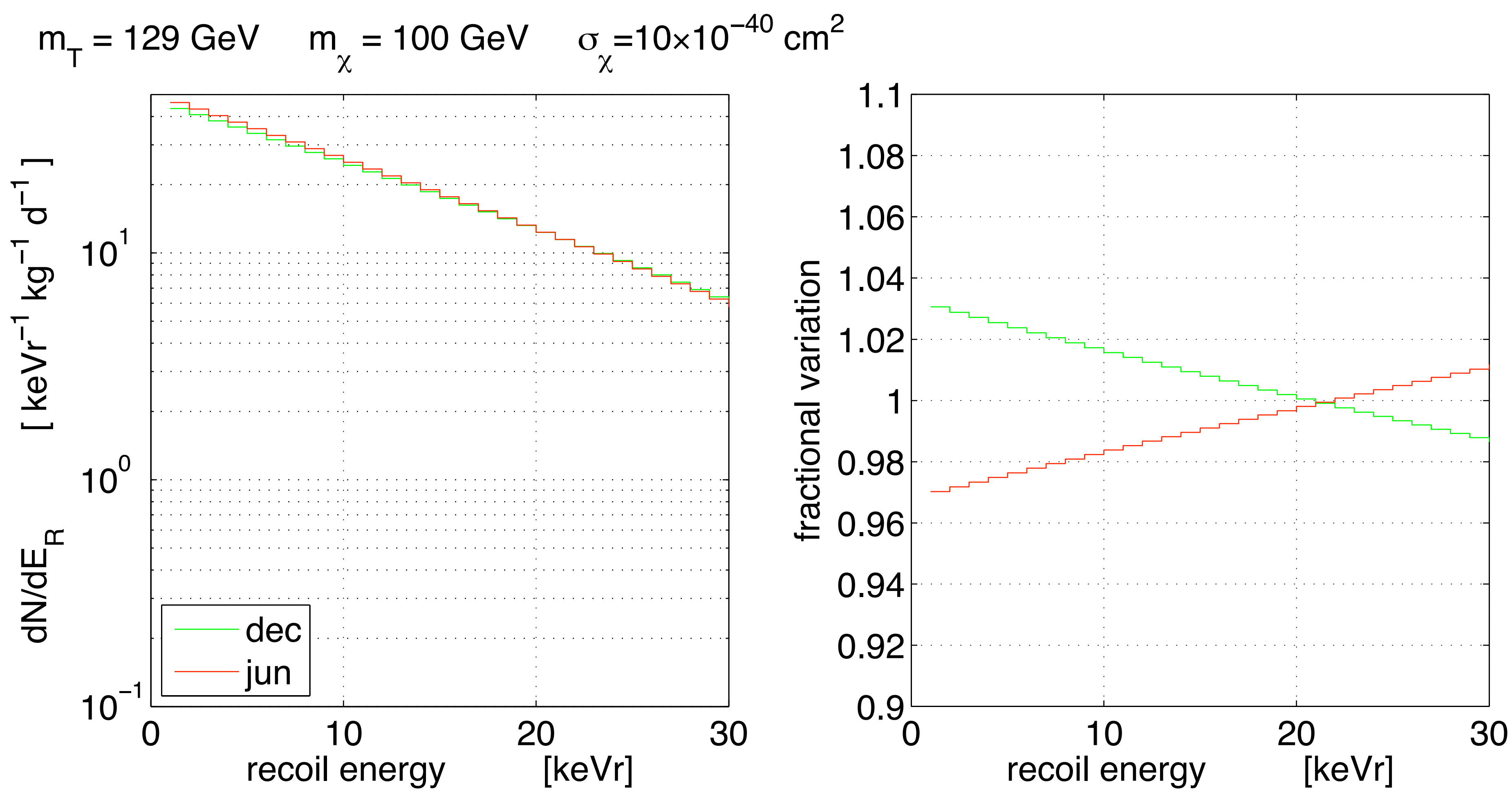
220 km/s   30 km/s



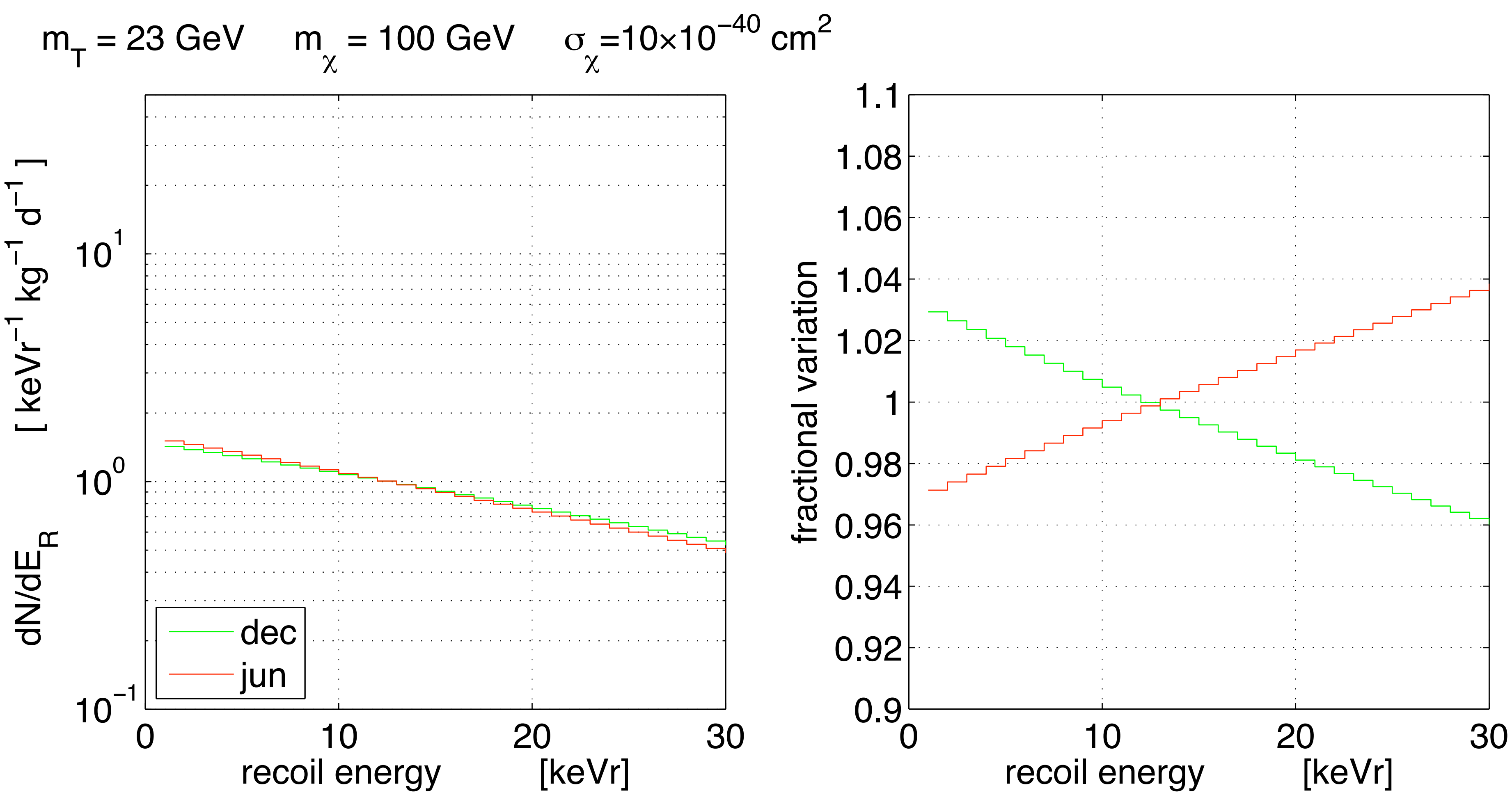
small complication: difficult to see a modulation when there are so few events...

XENON10 had:
- ~1 NR event 2-4 keVee (**max. expected signal**)
- ~250 ER events 2-4 keVee **(background)**

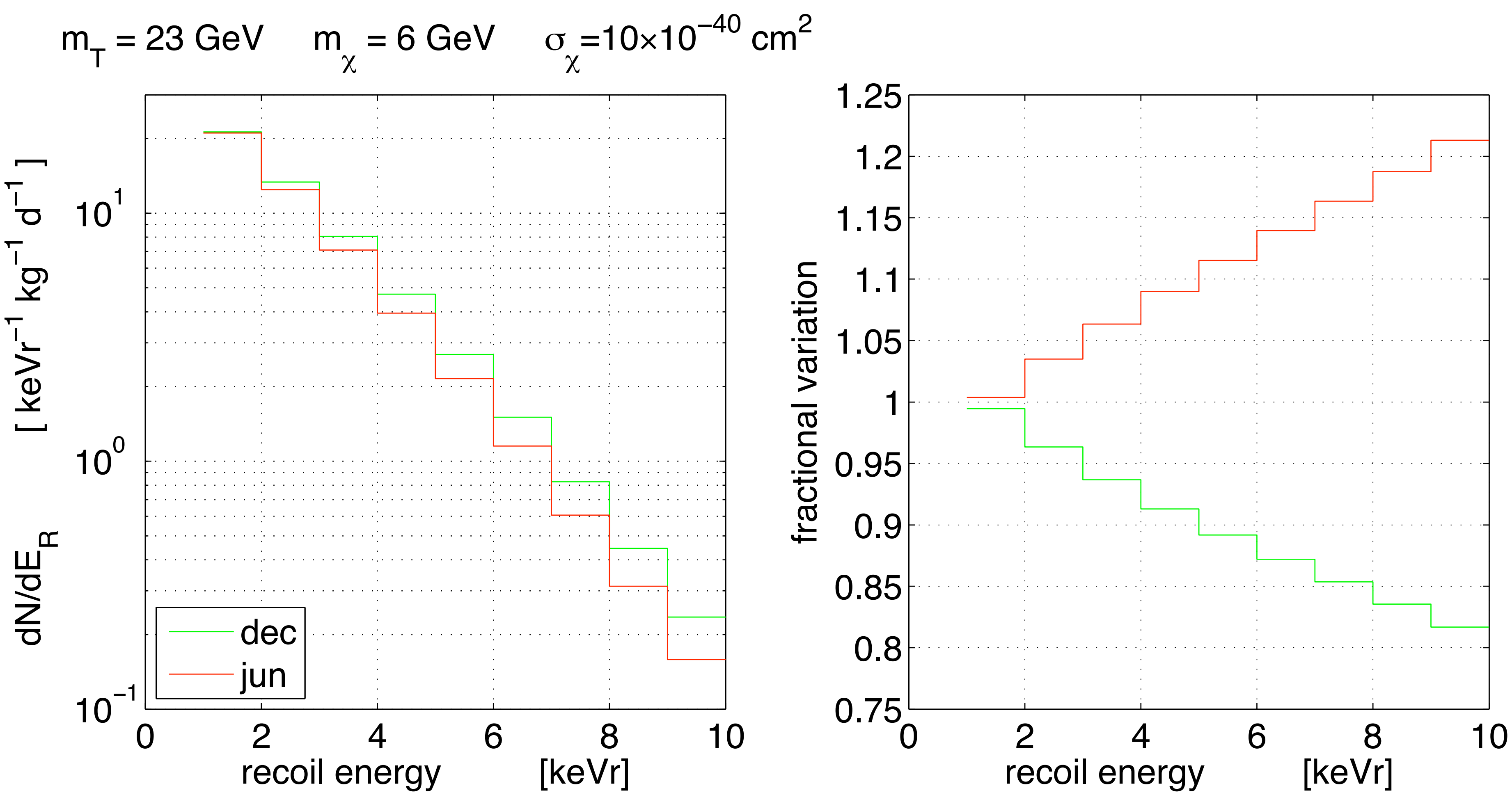
Example: rate and modulation amplitude



Example: rate and modulation amplitude



Example: rate and modulation amplitude



Issues

(a) No fiducial cuts

(b) No mention of quenching

(c) 3 keVee signal , 3 keVee background

(d) Channeling

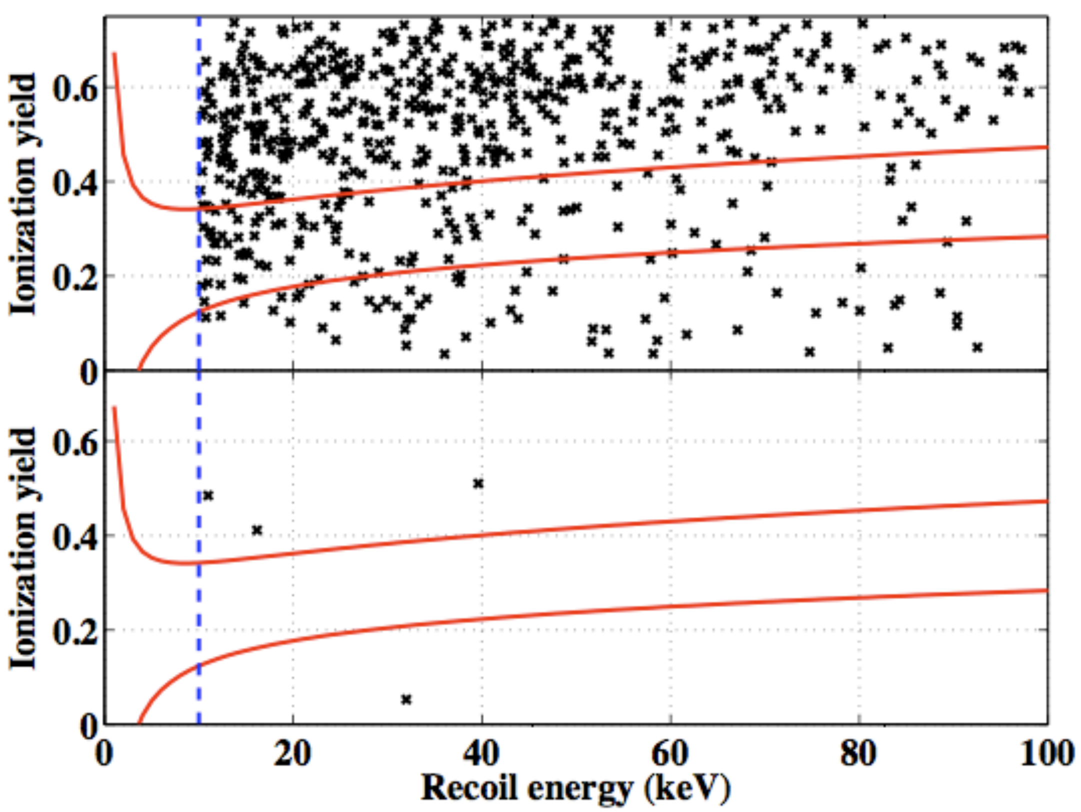
(e) Refusal to show <2 keVee modulation data

Importance of position sensitivity

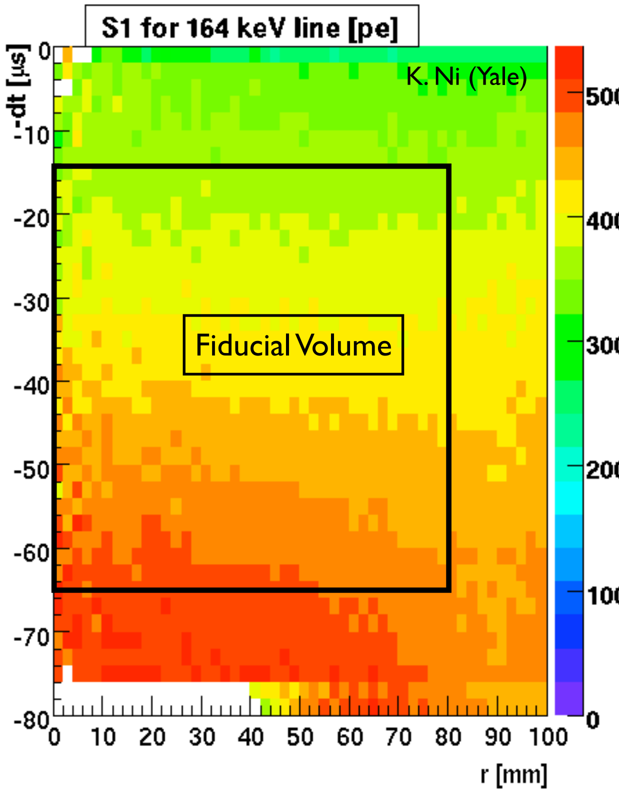
addressing (a)

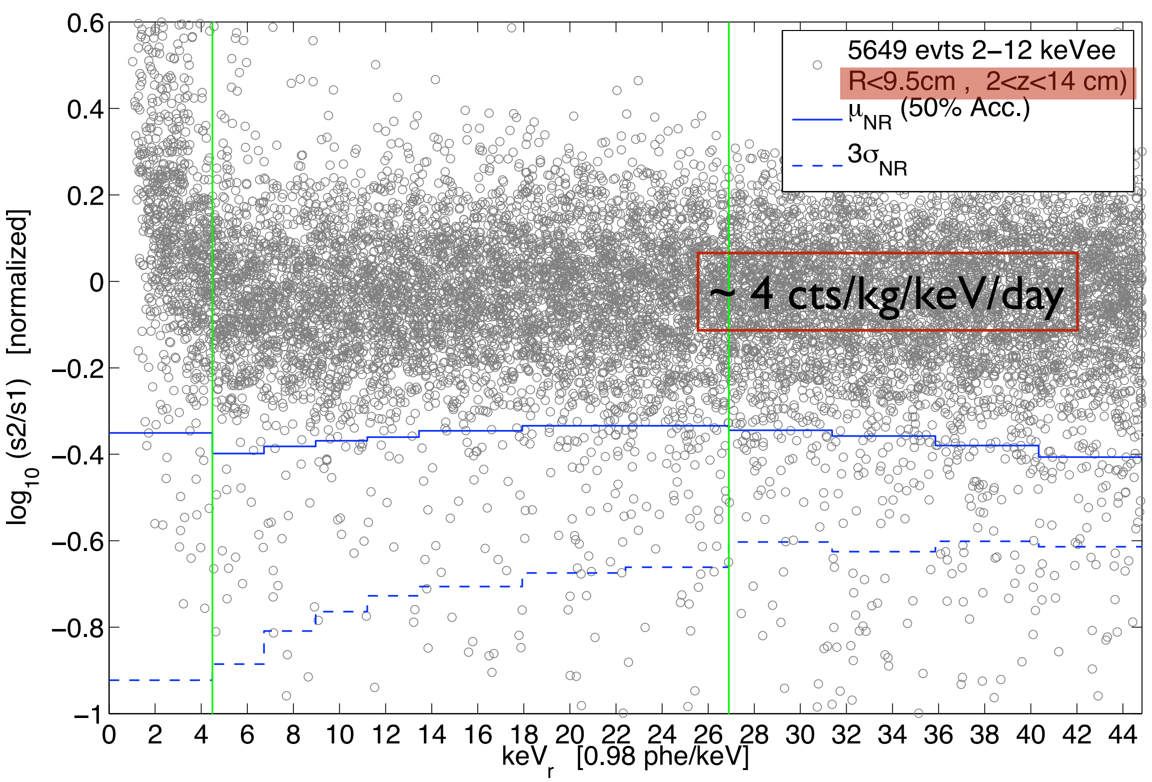
surface effects / edge pathologies

CDMS (2008) Ge



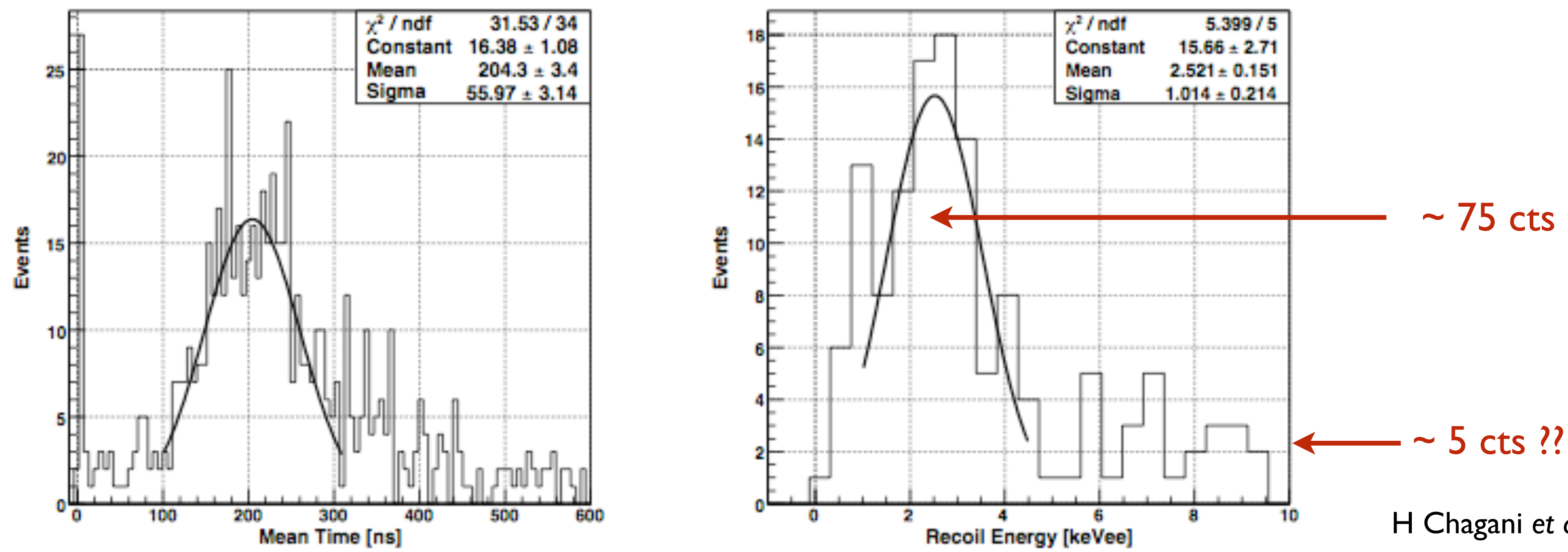
XENON10 (2008)





Recent measurements of Na recoils in NaI(Tl)

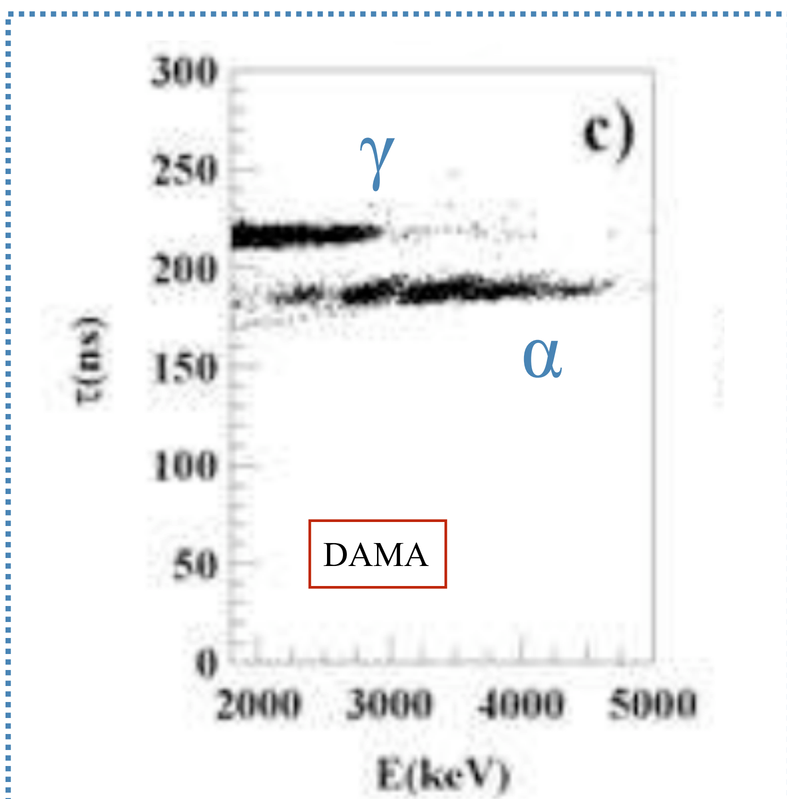
addressing (b)



H Chagani *et al* JINST **3** P06003 (2008)

(a) (b)

Figure 11. (a) Mean time of pulses from 10 keVnr Na recoils. (b) Recoil energy in electron equivalent scale after events that lie more than half a standard deviation from the mean in (a) are excluded. The result in (b) indicates the quenching factor for 10 keVnr Na recoils in NaI(Tl) is 25.21%.



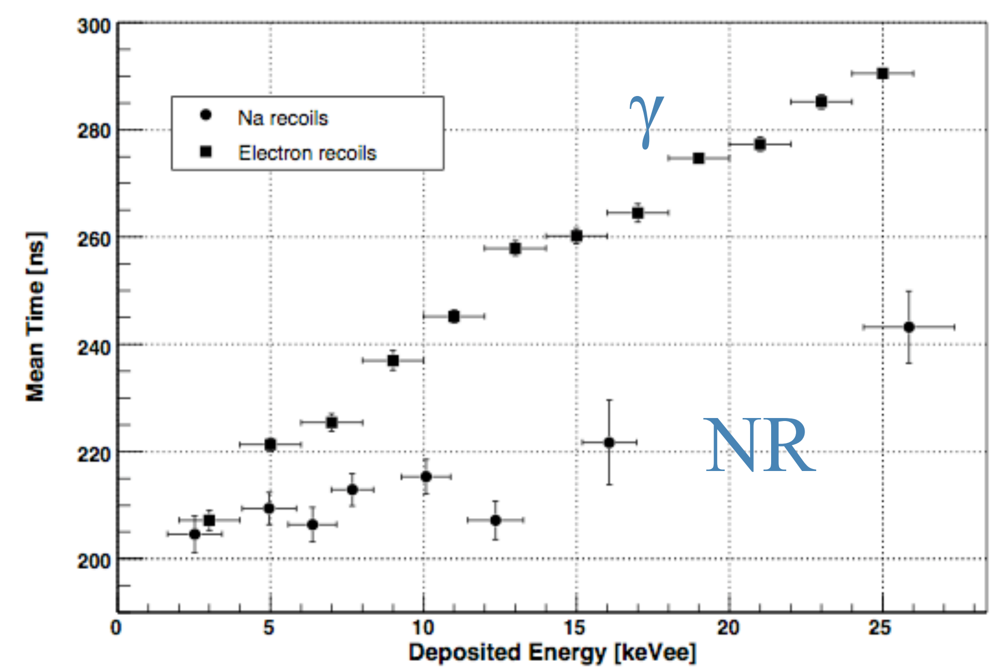


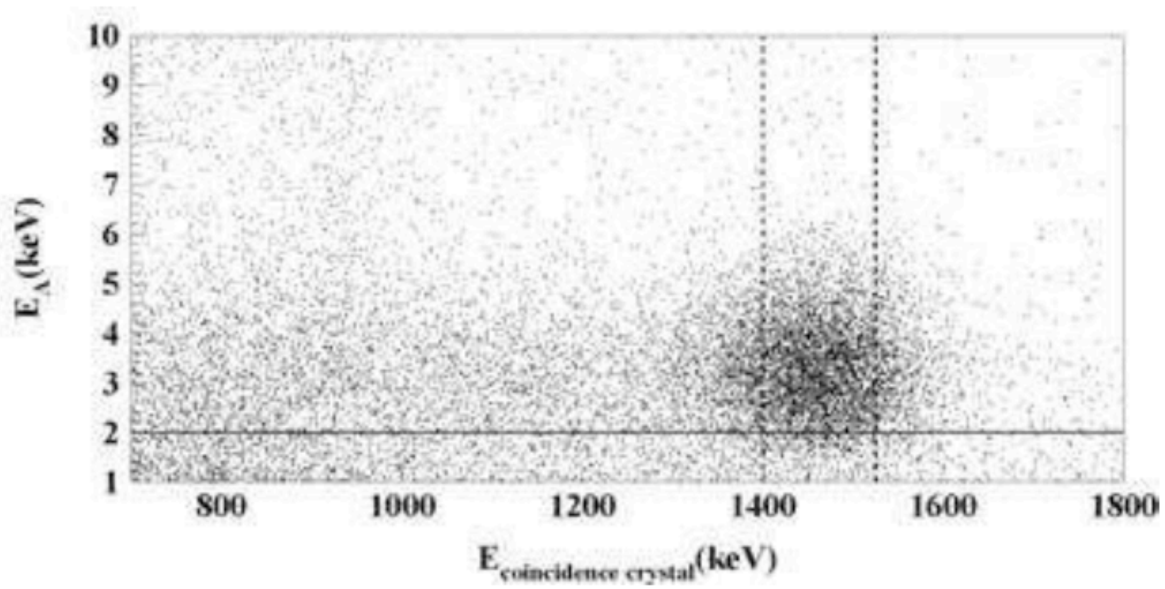
Figure 12. Mean time as a function of deposited energy for sodium (Na) and electron recoils. Measurements of Na recoils are performed with the neutron beam. Compton electrons are induced by gamma-rays from a ^{22}Na source.

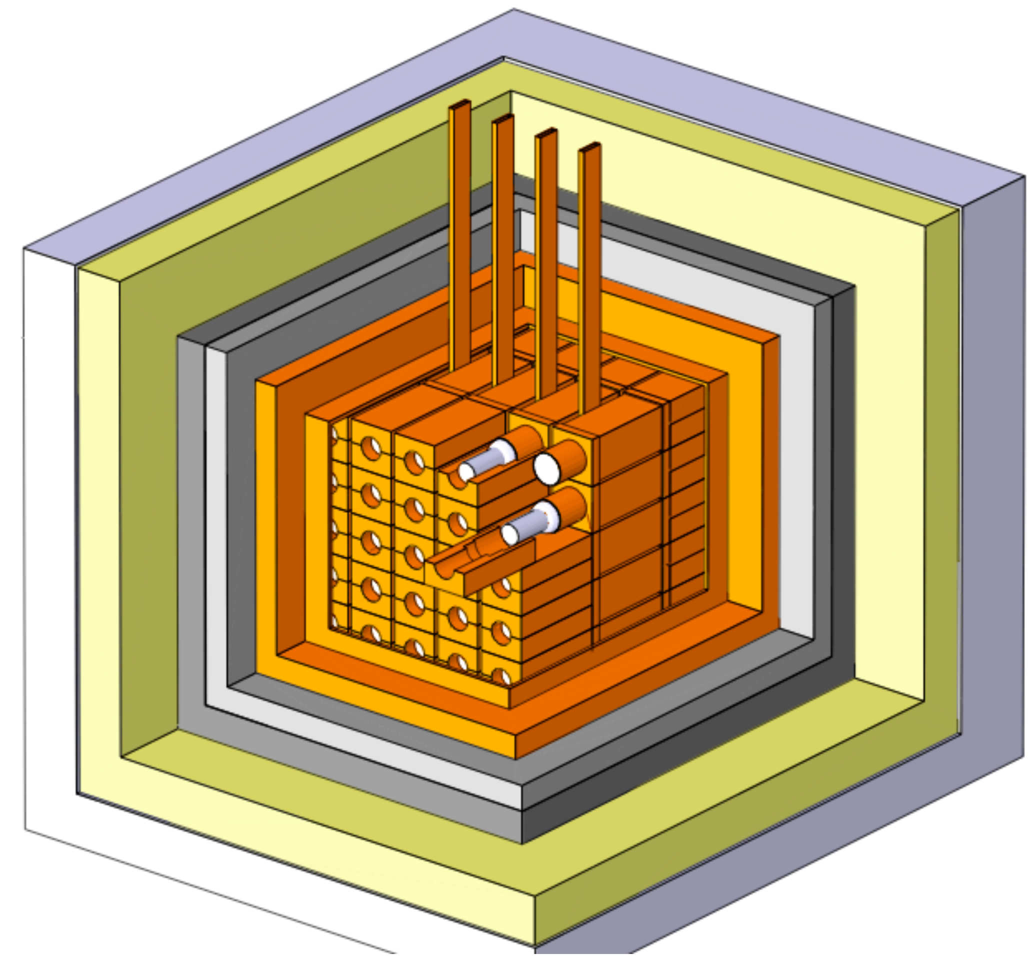
^{40}Ar k shell (3 keV) and EC γ (1460 keV)

addressing (c)

each crystal: 10.2 cm × 10.2 cm × 25.4 cm

multi-crystal coincidence from ^{40}K decay





DAMA conclusion: <20 ppb K in the crystals

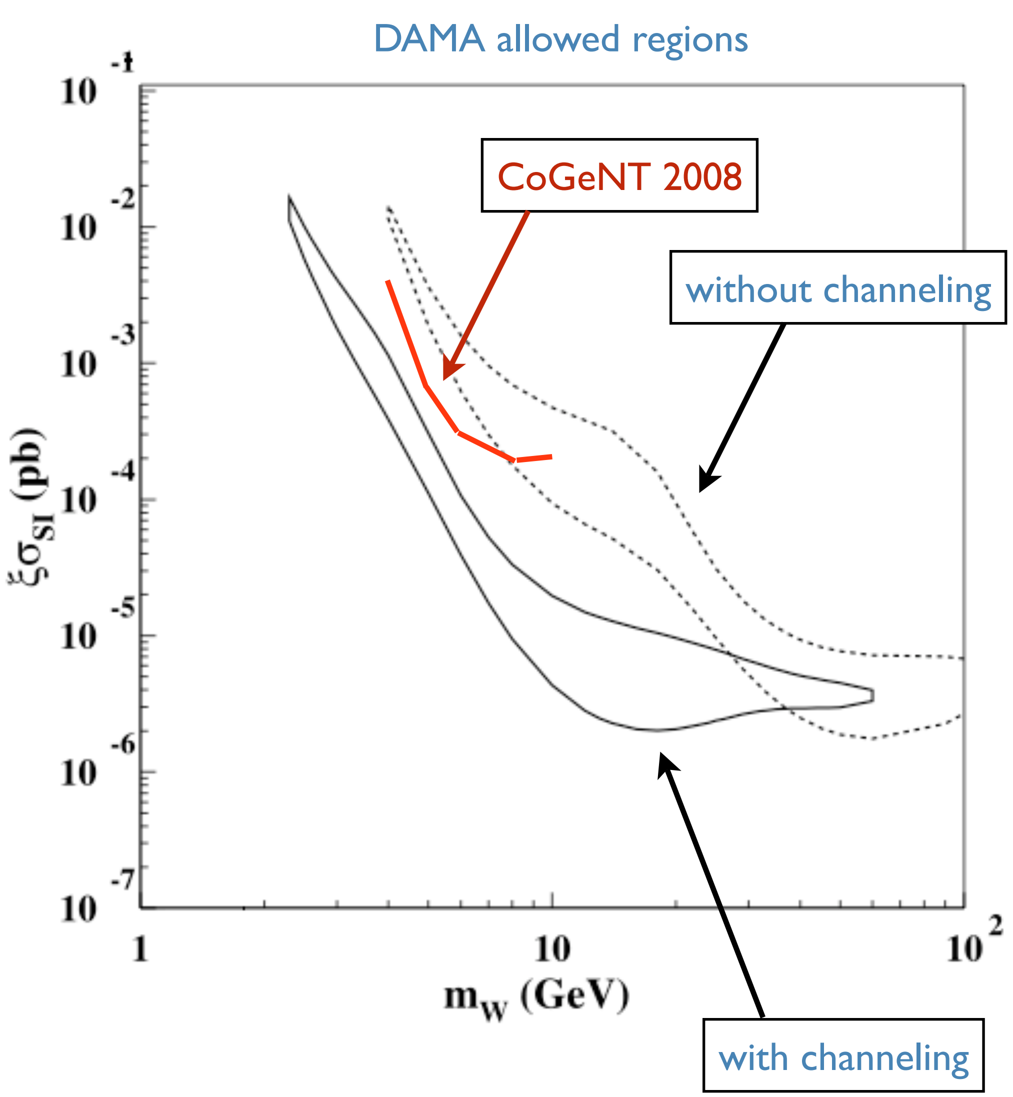
<u>mfp of 1460 keV γ</u>

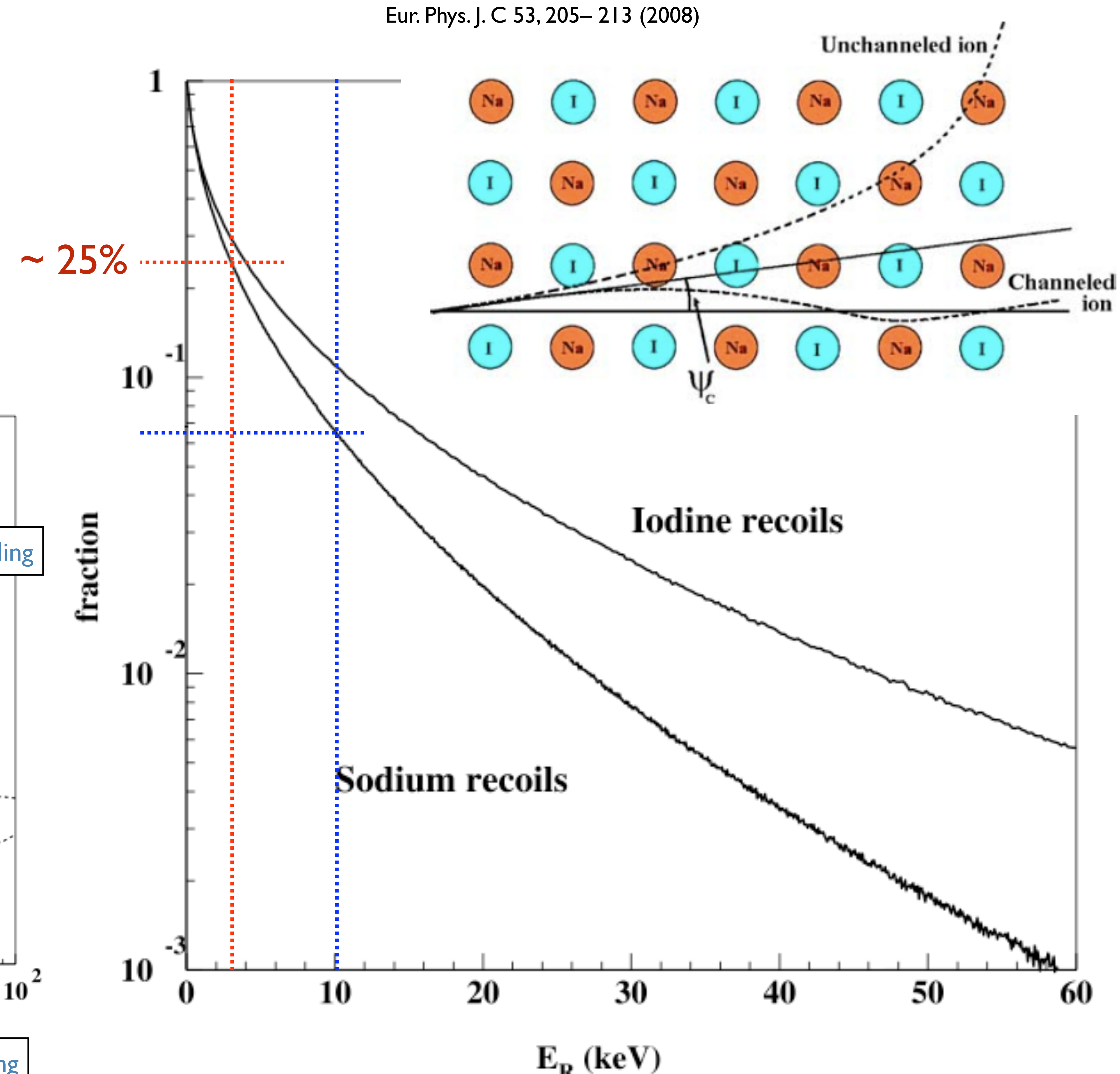
photoelectric: 6 cm

Compton: 157 cm

Channeling...

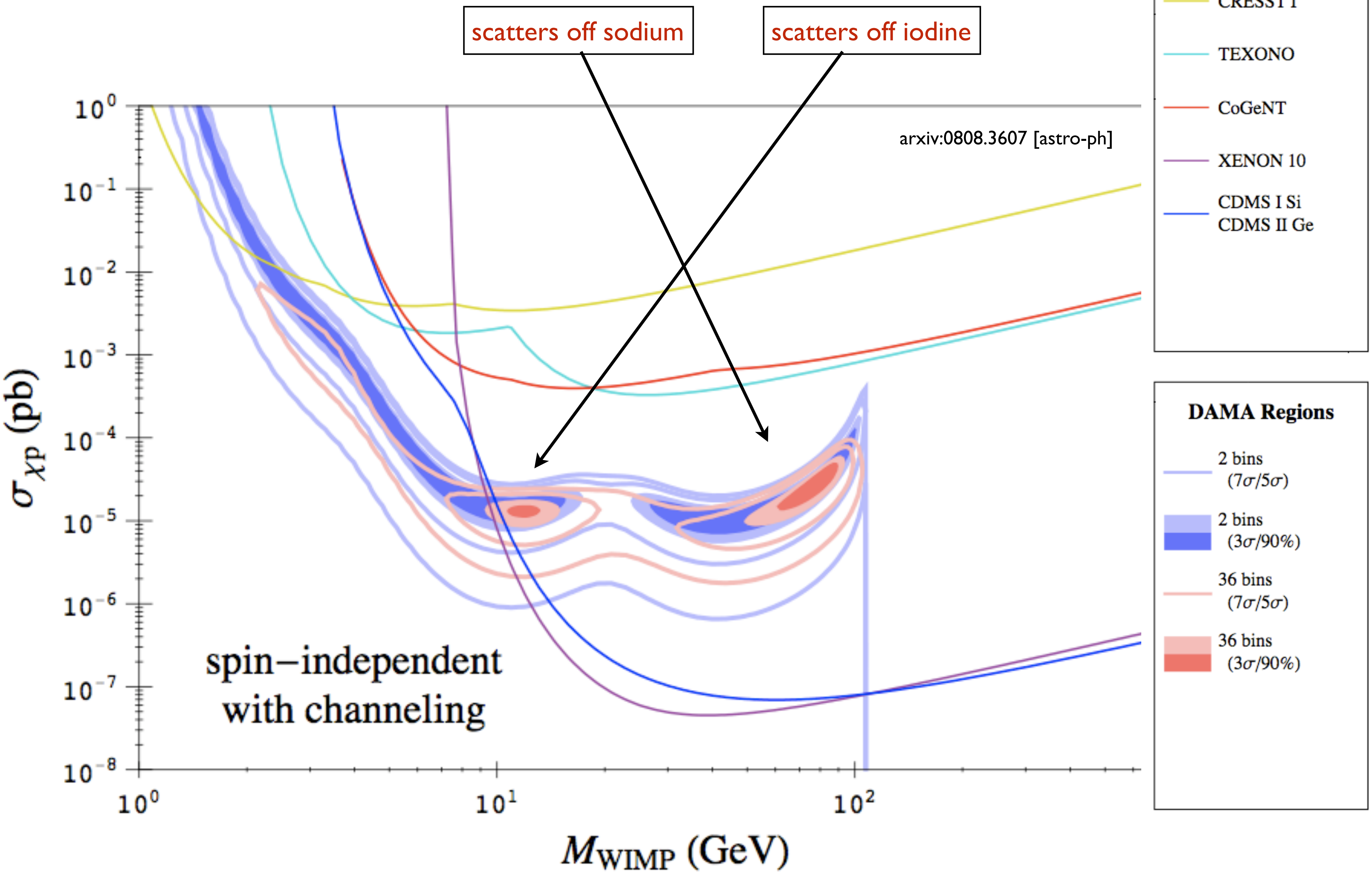
addressing (d)





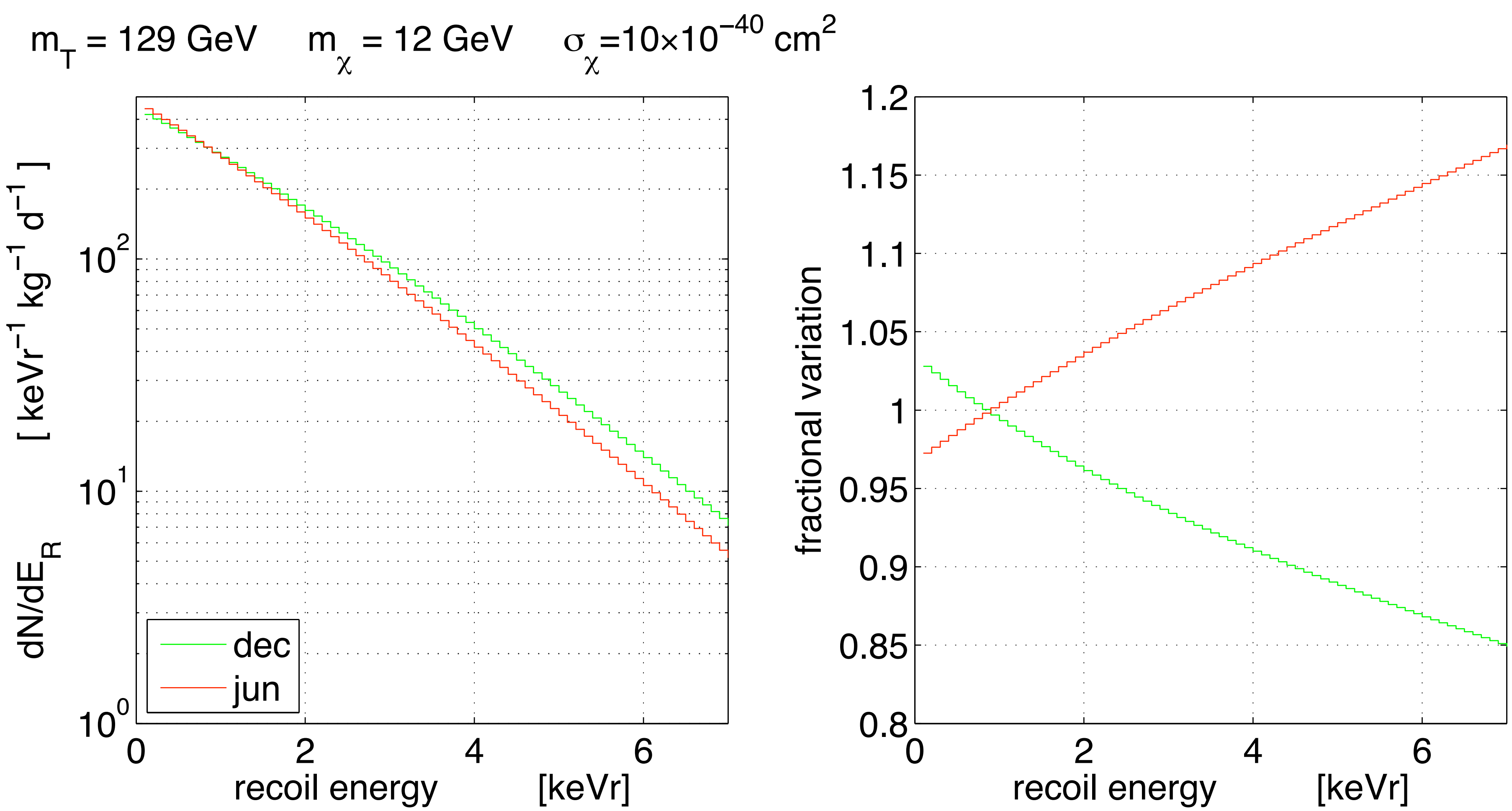
Same as slide 12, but with channeling

addressing (d)



Example: rate and modulation amplitude

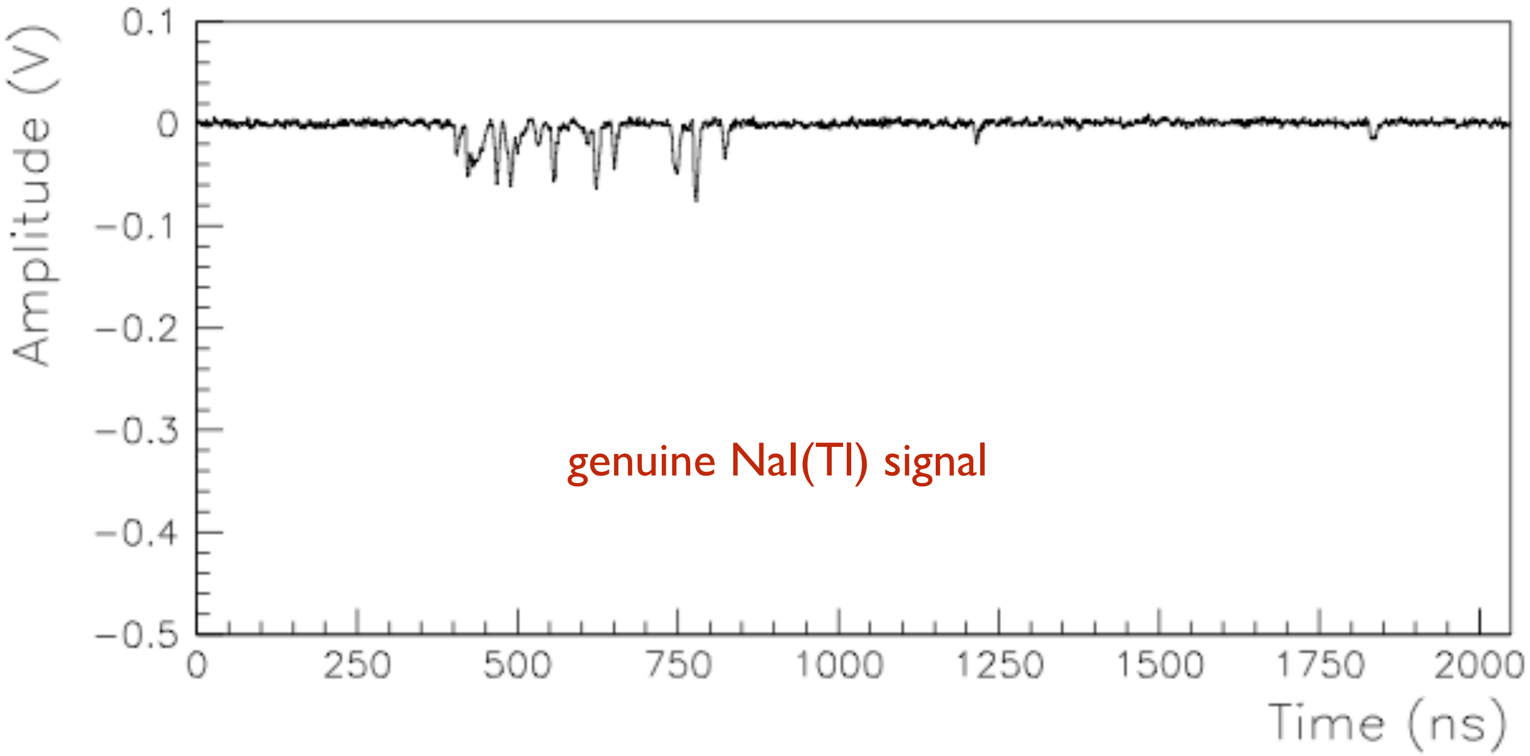
addressing (d)

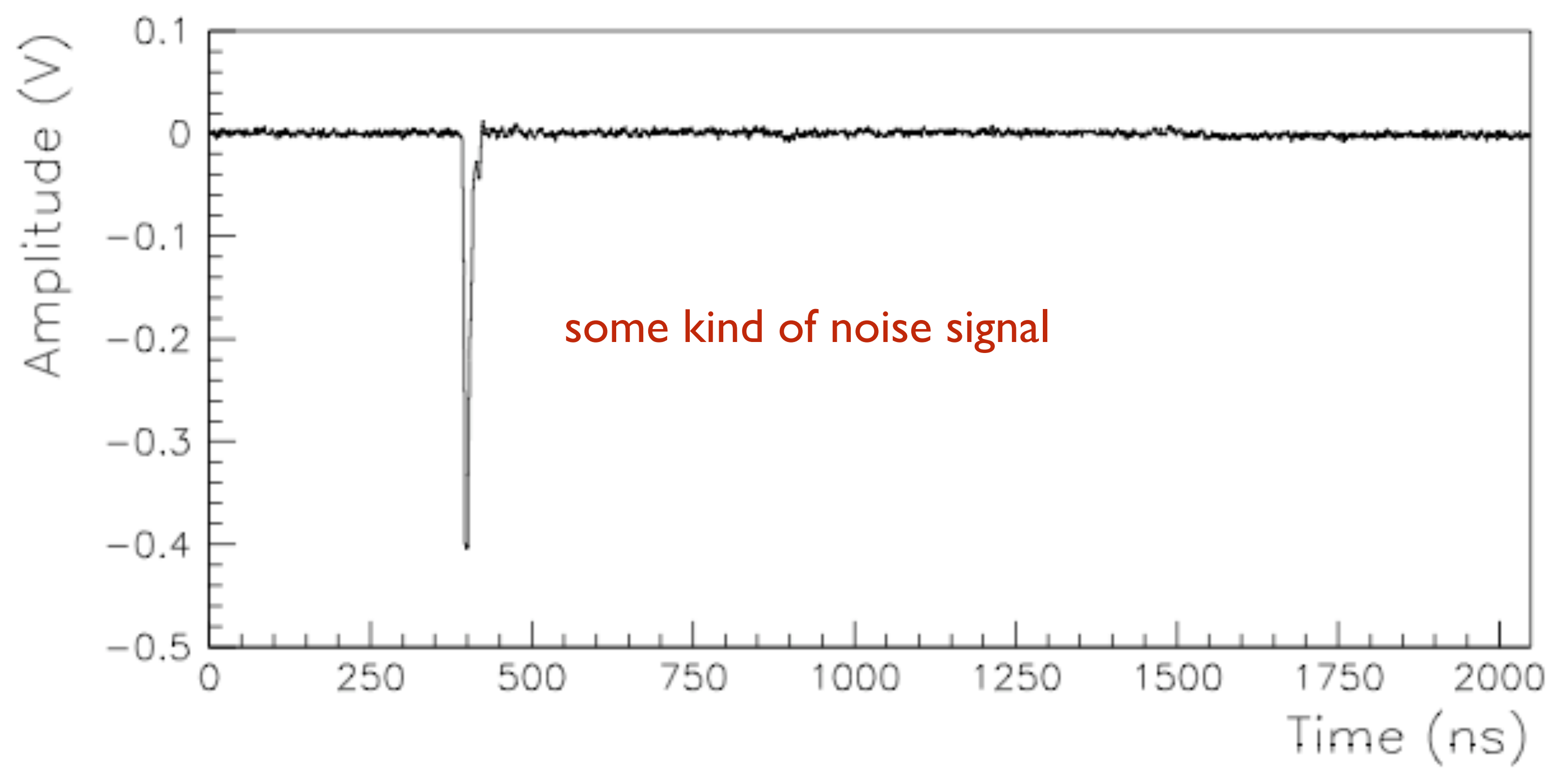


DAMA noise rejection

addressing (e)

$$X_1 = \frac{\text{Area (from 100 ns to 600 ns)}}{\text{Area (from 0 ns to 600 ns)}}; \quad X_2 = \frac{\text{Area (from 0 ns to 50 ns)}}{\text{Area (from 0 ns to 600 ns)}}$$

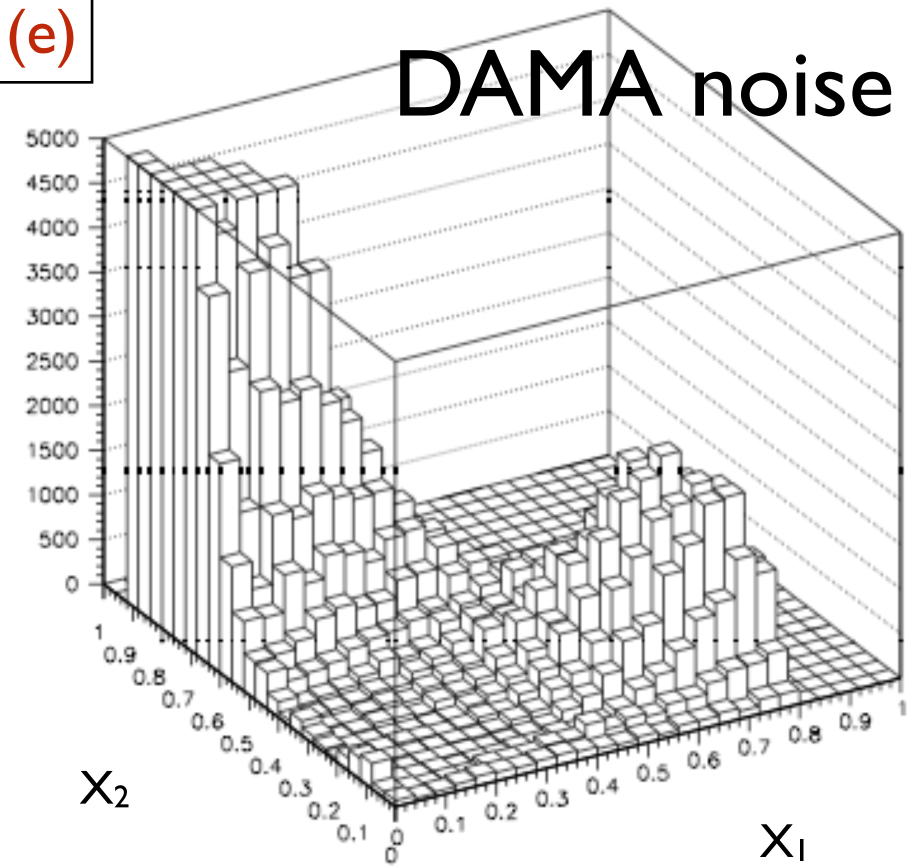


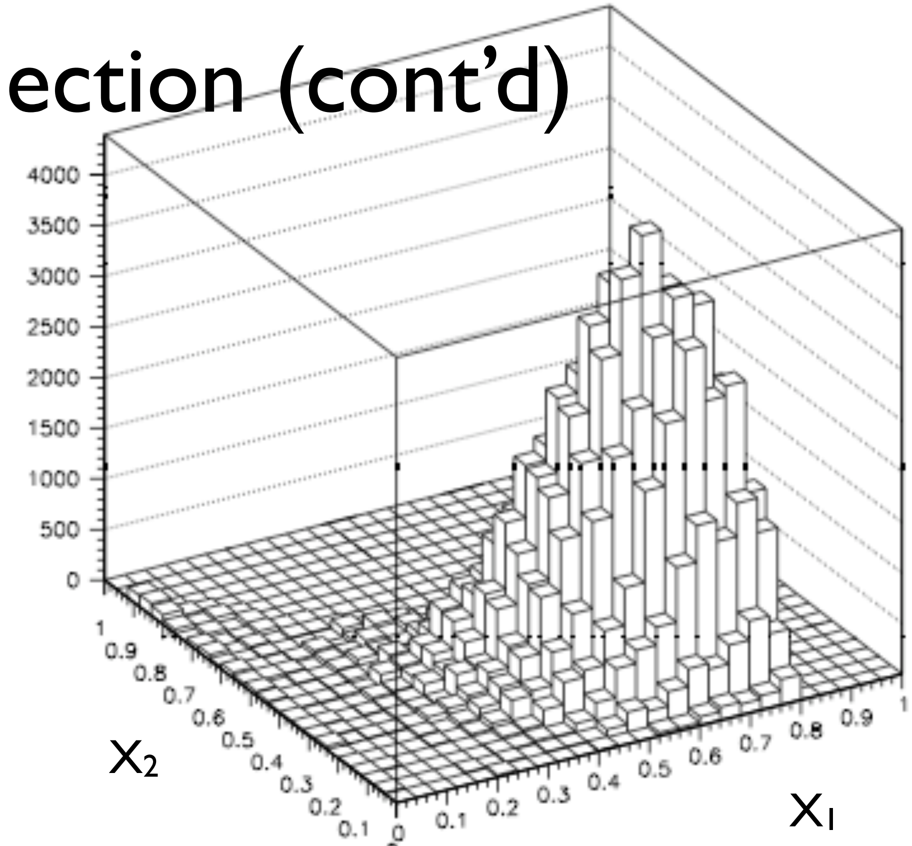


addressing (e)

DAMA noise rejection (cont'd)

2-4 keVee



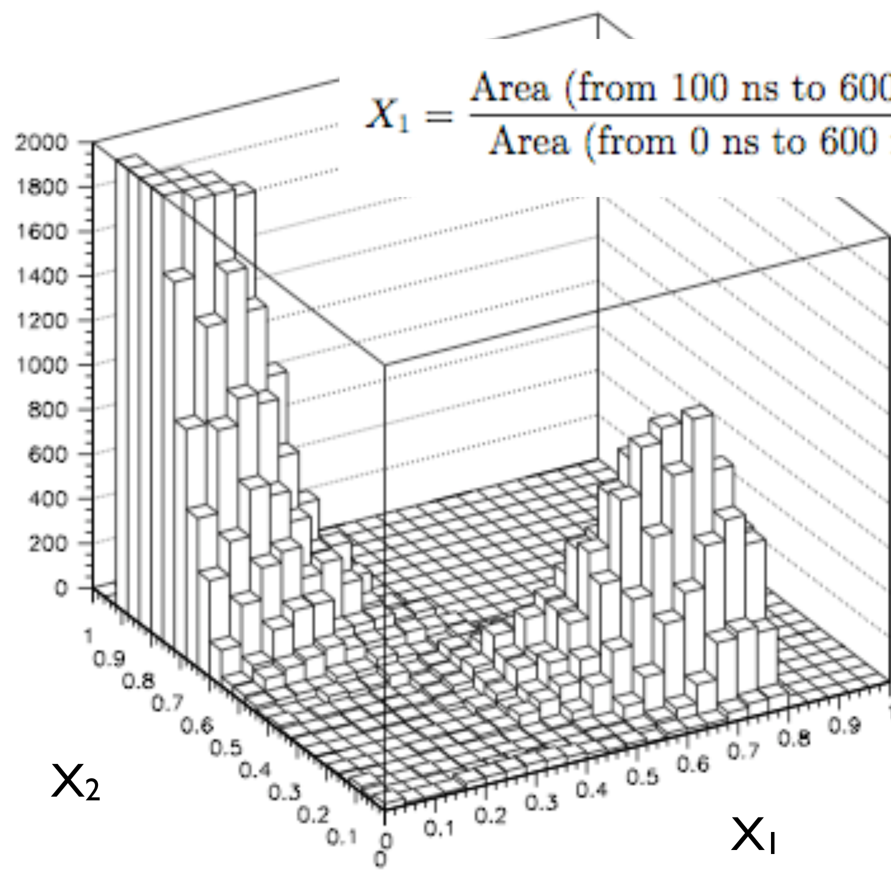


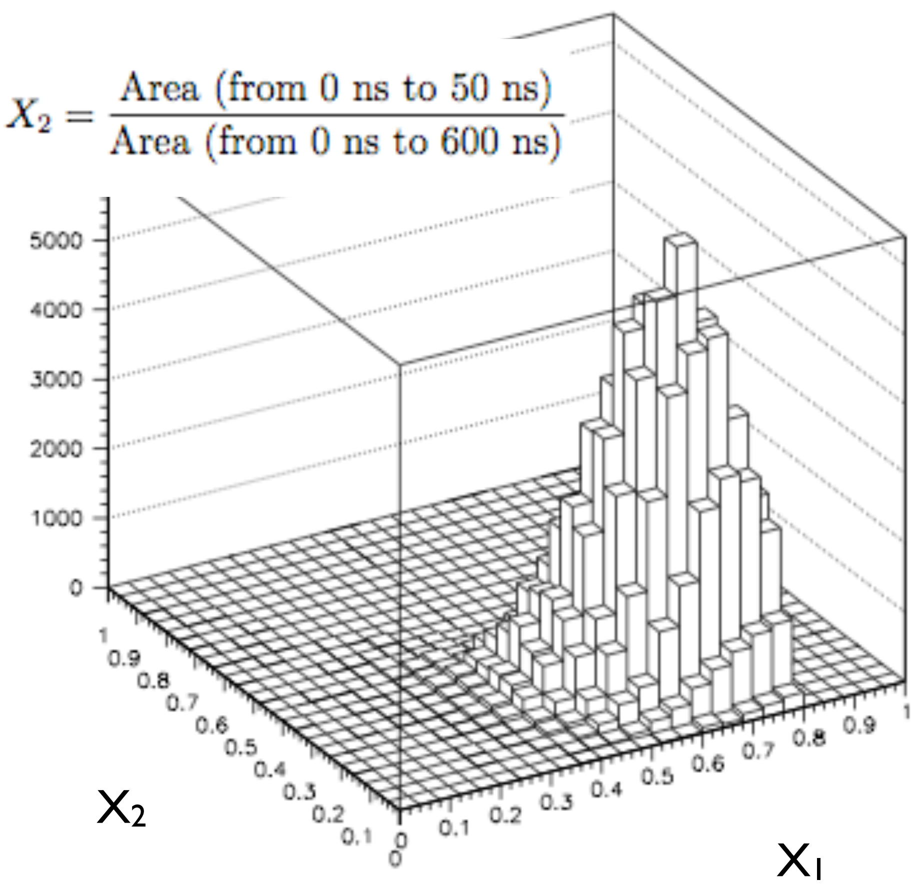
dark matter search data

γ source data

$$X_1 = \frac{\text{Area (from 100 ns to 600 ns)}}{\text{Area (from 0 ns to 600 ns)}}; \quad X_2 = \frac{\text{Area (from 0 ns to 50 ns)}}{\text{Area (from 0 ns to 600 ns)}}$$

4-6 keVee

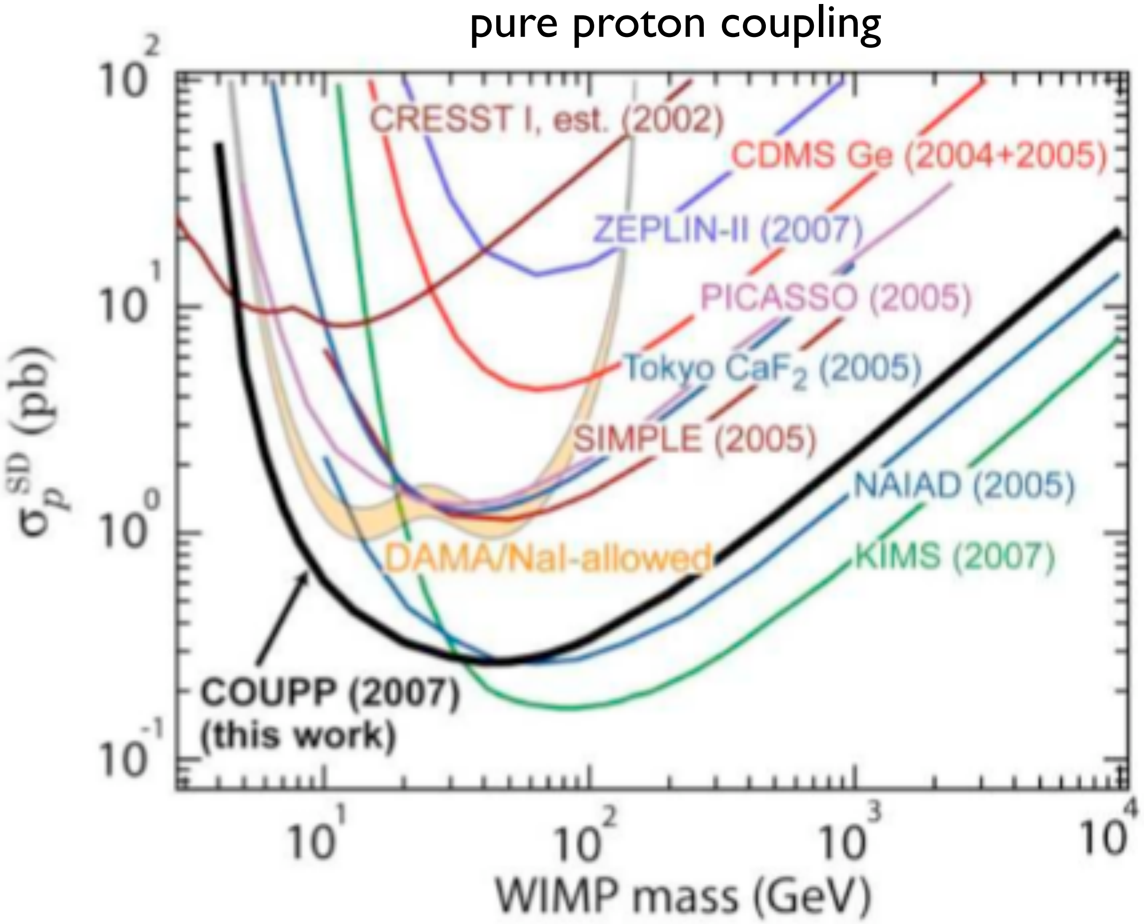




what about 1-2 keVee ?

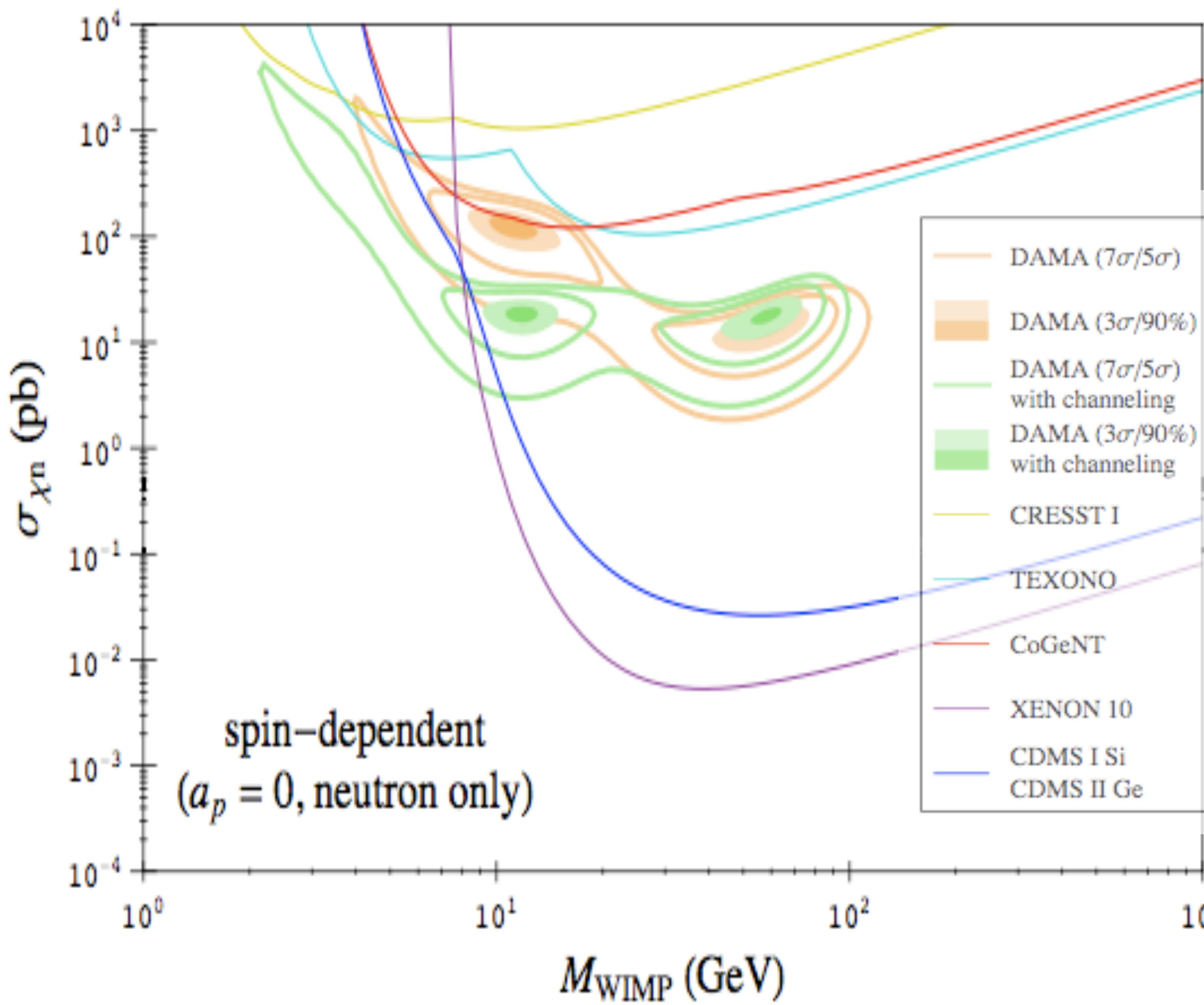
SD coupling

pure proton coupling



E. Behnke *et al.*, Science **319** (2008) 933.

pure neutron coupling

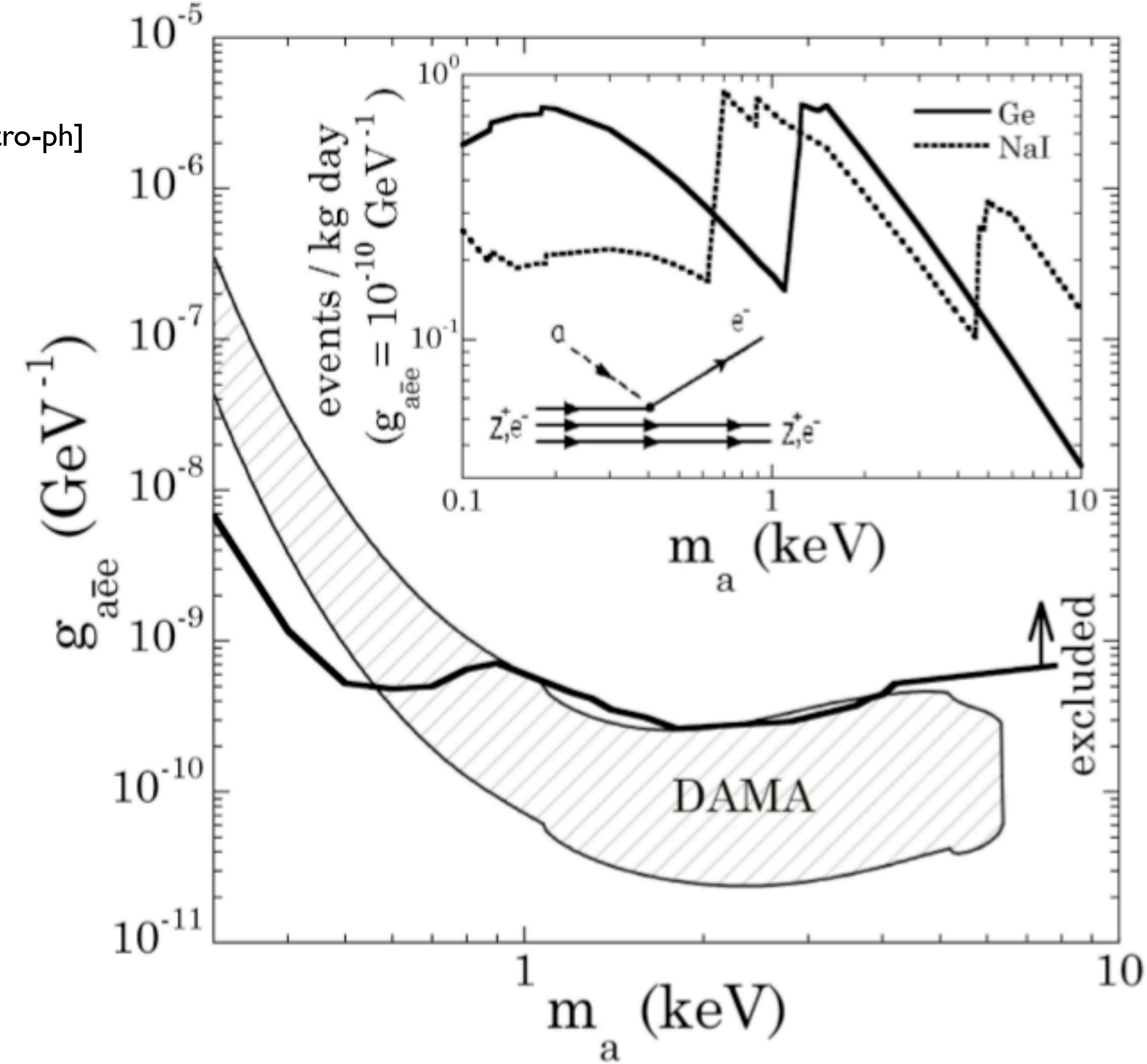


plot from: arxiv:0808.3607 [astro-ph]

XENON10 result: Phys Rev Lett **101** 091301 (2008)

Axion-like dark pseudoscalars

a DAMA-approved model !
see R Bernabei et al, 0802.4336 [astro-ph]



arxiv:0807.0879v1 [astro-ph]
(CoGeNT collaboration)

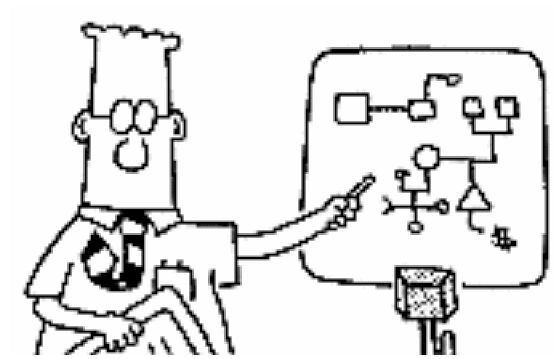
Some concluding remarks

ON DAMA:
- what does the modulation signal look like in individual detectors? Is it similar in all 25 modules ?
- what if pulse-shape discrimination is employed (to select NR) ?
    - what about the quenching for nuclear recoils?
- what about a "blank" run with a different scintillator (or none at all) ?   *(idea credit: J Collar)*
- what does the modulation signal look like 1-2 keV ?

What to look for in 2009:
- new results from XENON100 (mid-2009 ?)
- new results from LUX (late 2009 - early 2010 ?)
- longer exposure / deeper / more shielding results from CoGeNT (?)
- analysis of CDMS ER data (axions?)

Some predictions:
- possible observation of channeling effect in laboratory scattering experiments (?)
- ruling out all DAMA-allowed regions**, with or without channeling
- continued emphasis of alternative dark matter candidates / non-standard halo models

** *for standard MB halo models / neutralino dark matter particles*



Thank You