DAMA and WIMP dark matter

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COSMO
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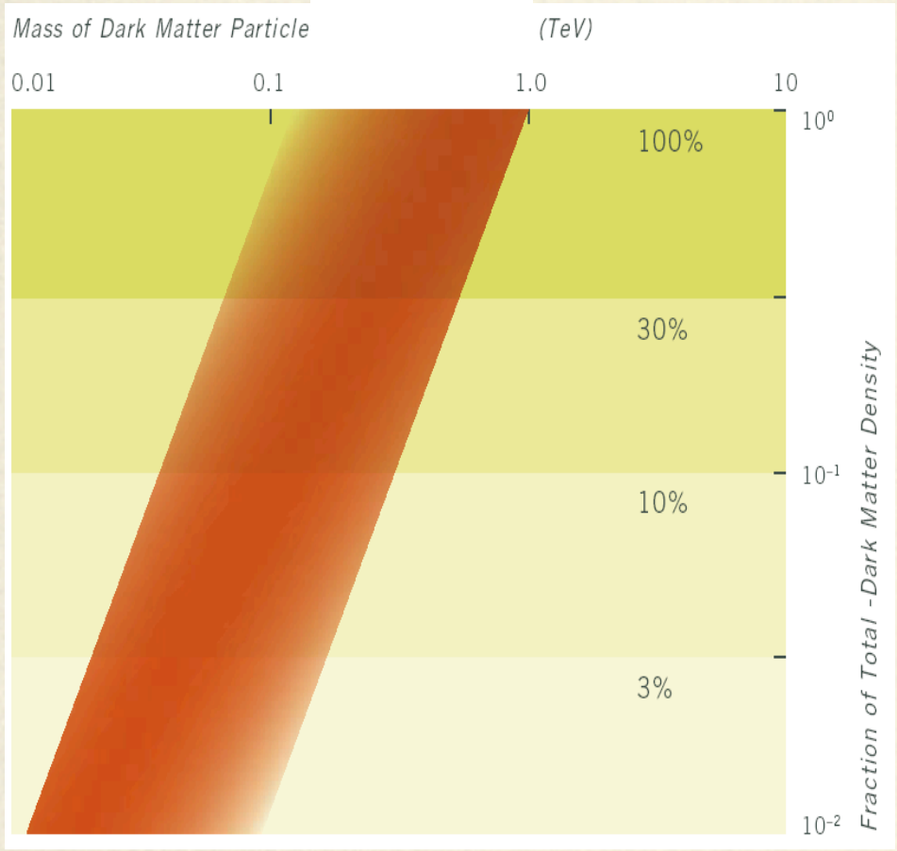
Frank Petriello, KZ, arXiv: 0806.3989
Dan Hooper, FP, KZ, Marc Kanionkowsi arXiv: 0808:2464

The WIMP paradigm



HEPAP LHC/ILC Subpanel (2006)

[band width from k = 0.5 – 2, S and P wave]

5-year WMAP+BAO+SN

$$\Omega_c h^2 = 0.114 \pm 0.003$$

$$\Omega h^2 \approx \frac{2 \times 10^{-10}\mathrm{GeV}^{-2}}{\langle \sigma v \rangle}$$

$$\frac{v}{c} \approx 10^{-3}$$

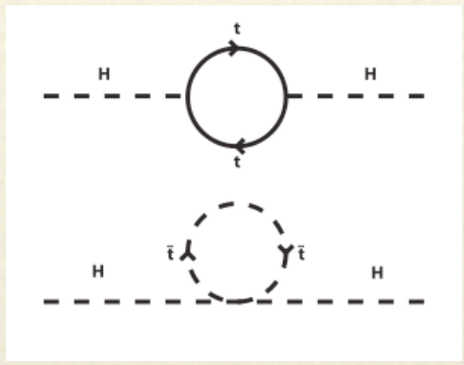
$$\sigma \approx \frac{g^4}{(1\ \mathrm{TeV})^2}$$

$$g \approx 1$$

→ WIMPs at EWSB scale!

$$\Gamma_{ann} \lesssim H$$

Fits other theoretical prejudices



$$\Delta m_h^2 \approx \Lambda^2 \lesssim m_h^2$$
$$\Rightarrow \Lambda \approx 1\ \mathrm{TeV}$$

Theoretical prejudice

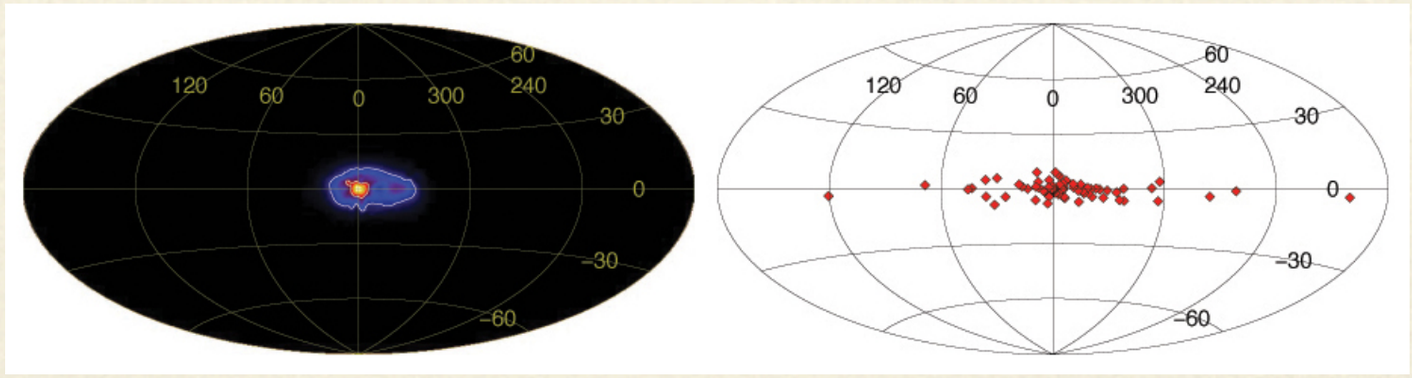
Could just as well pick

Feng, Kumar, Strigari '08: $m \approx 1$ GeV, $g \approx 10^{-1}$

Hooper, Zurek '07: $m \approx 1$ MeV, $g \approx 10^{-3}$

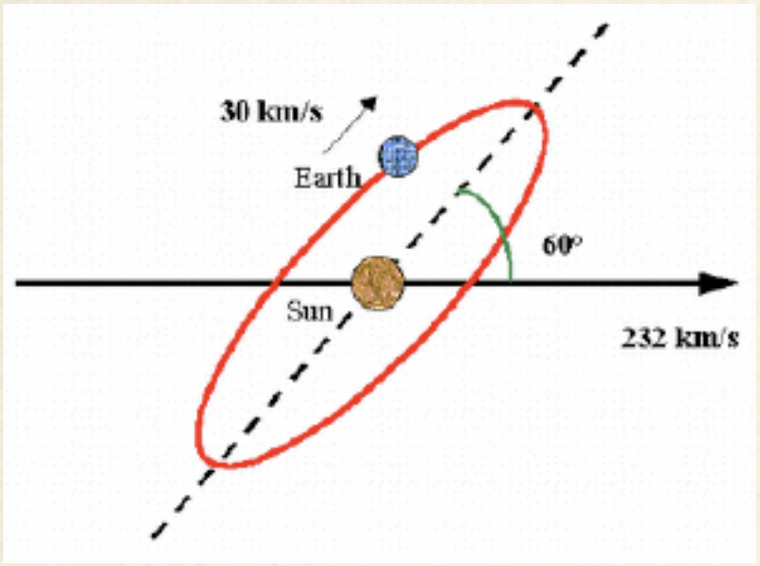
Natural with hidden sector+SUSY

Could explain INTEGRAL 511 keV photons

(but, 

)

DAMA and annual modulation



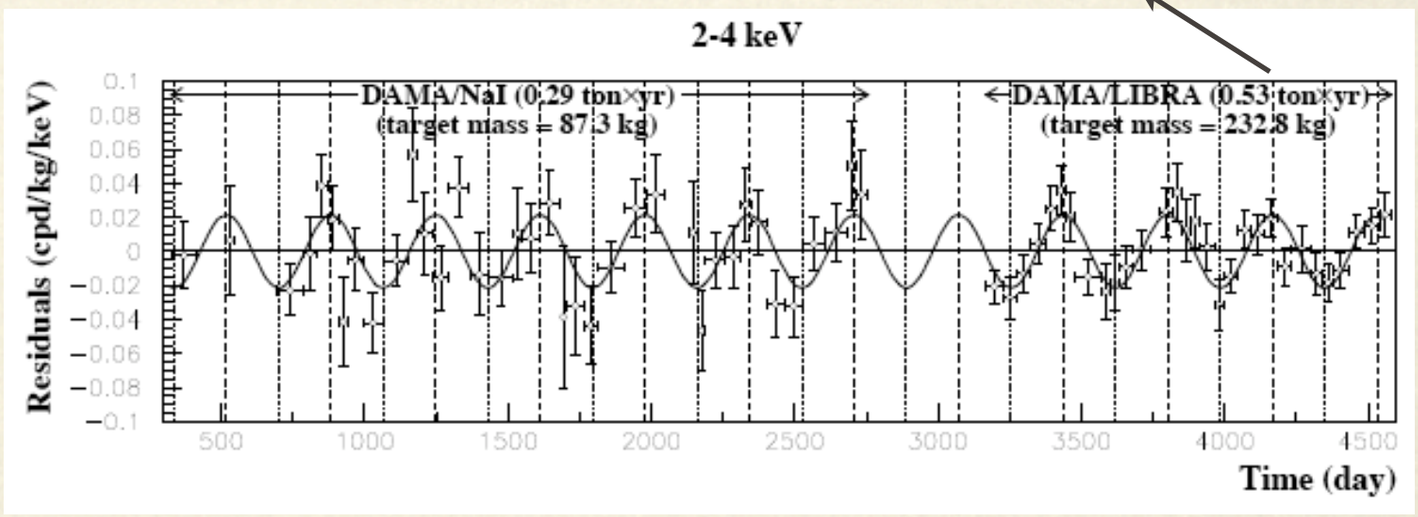
Rate: $R_i = R_i^0 + S_i^1 \cos[\omega(t - t_0)]$

$t_0 = \text{June 2nd}, \quad \omega = \dfrac{2\pi}{1 \text{ year}}$

Only direct detection experiment to claim observation

8.2σ signal: DAMA '08

tough to repeat!

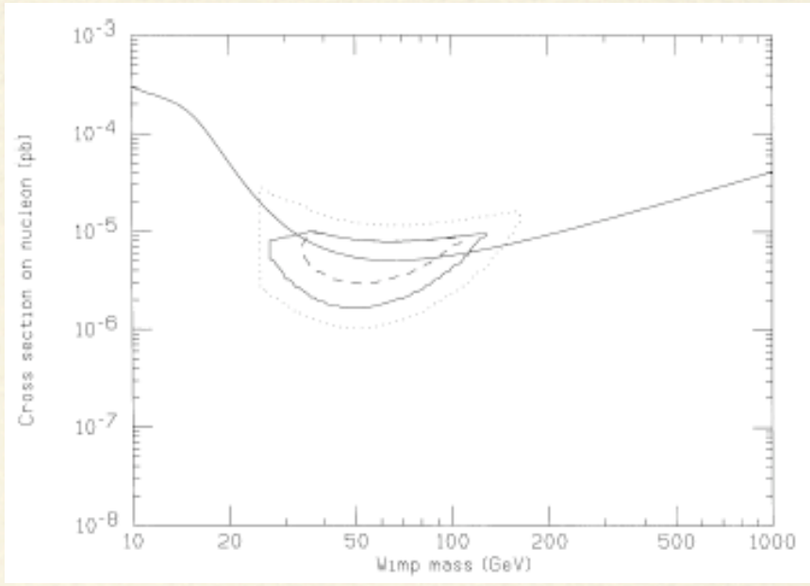


NaI scintillator

Brief history of DAMA signal

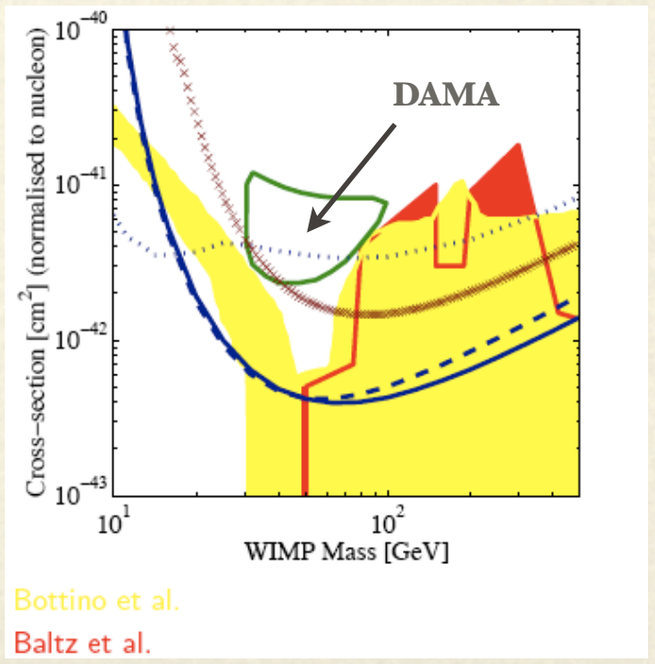
DAMA '98-99, 14962 kg-days

Energy (keV)	S_o (cpd/kg/keV)	$S_{m,k}$ (cpd/kg/keV)
2–3	0.54 ± 0.15	0.018 ± 0.009
3–4	0.23 ± 0.08	0.012 ± 0.004
4–5	0.09 ± 0.04	0.006 ± 0.002
5–6	0.04 ± 0.02	0.003 ± 0.001



Analyzed with constraint $m_{DM} \geq 25$ GeV

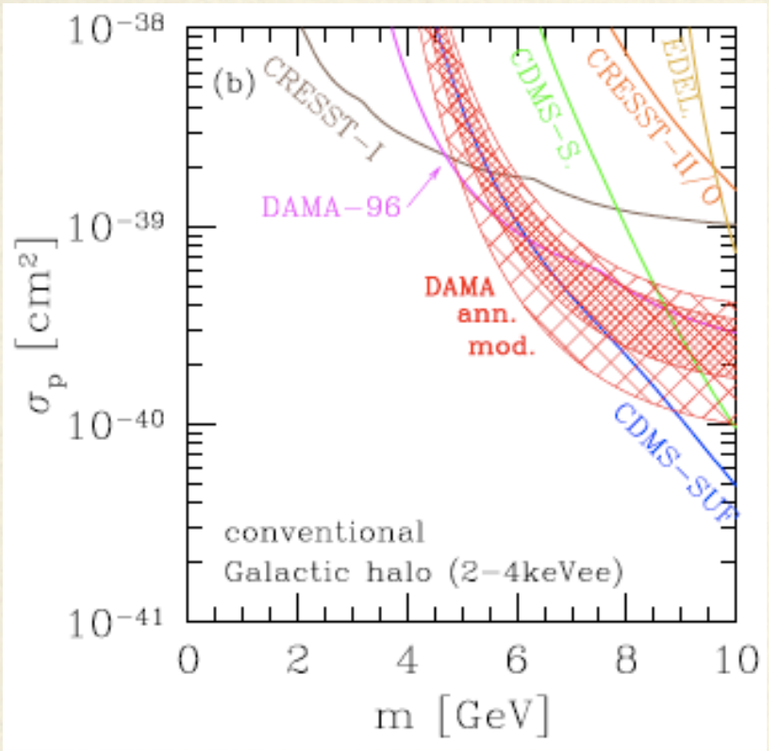
Region ruled out by CDMS, Eidelweiss



Brief history of DAMA signal

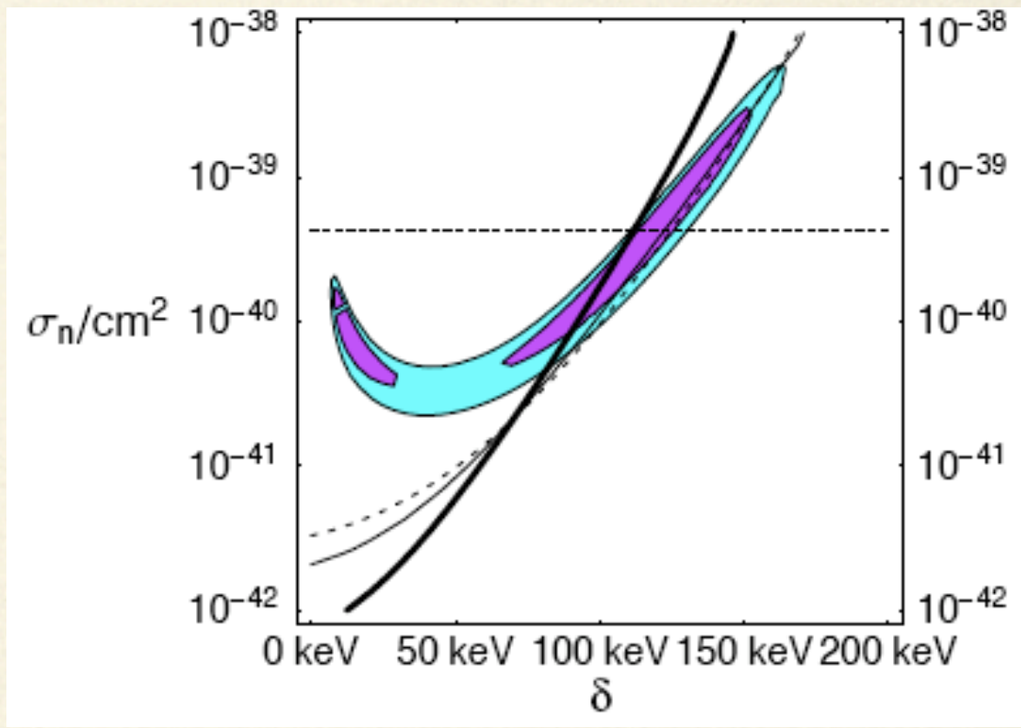
Several attempts to reconcile constraints

Gelmini, Gondolo '04



Few-GeV WIMP above threshold only for Na in DAMA

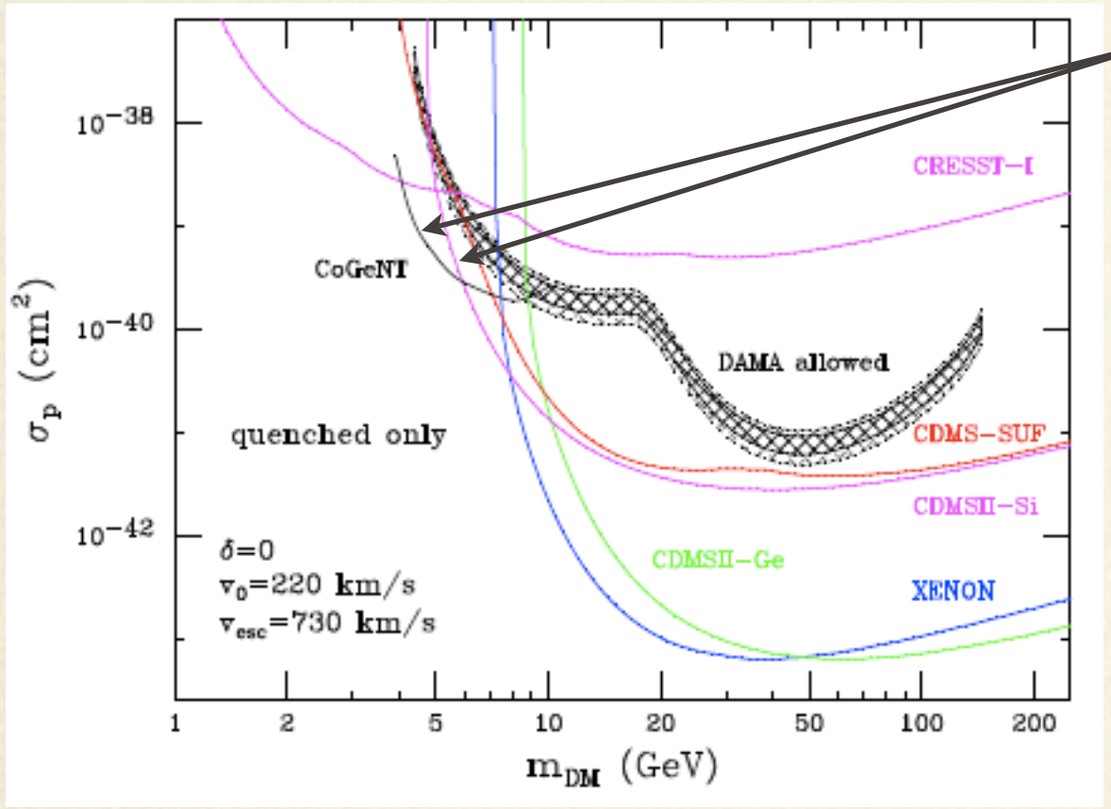
Tucker-Smith, Weiner '04



Inelastic $\chi \to \chi'$ off I
Thought to have *higher* 22 keV threshold

Light WIMPS before...

Petriello, KZ '08



Several new results (7 keV CDMS silicon, CoGeNT) seem to close the light-WIMP window

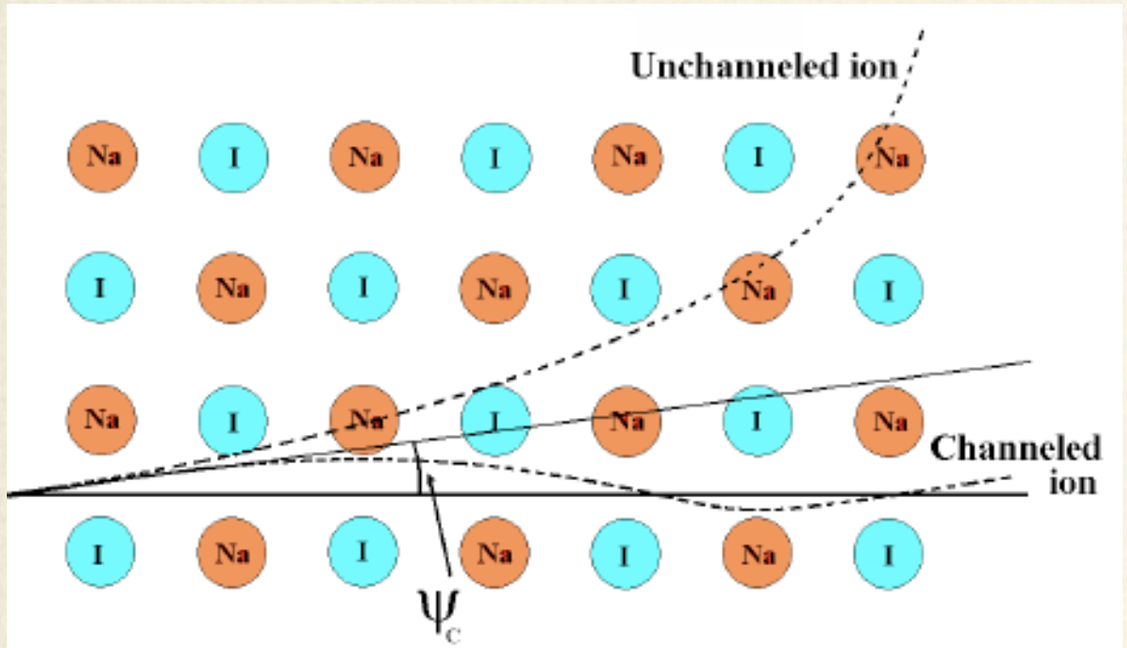
DAMA '08, 0.82 ton-years

Energy	S_i^1 (cpd/kg/keVee)
$2-4$ keVee	0.0223 ± 0.0027
$2-5$ keVee	0.0178 ± 0.0020
$2-6$ keVee	0.0131 ± 0.0016
$6-14$ keVee	0.0009 ± 0.0011

However...

Channeling

DAMA ‘08



$$\frac{dE_{ion}}{dx}(E) = \frac{dE_{ion-n}}{dx}(E) + \frac{dE_{ion-e}}{dx}(E)$$

Normally,

$$E_{meas} = \frac{E_{nuc.\ rec.}}{q_N}$$

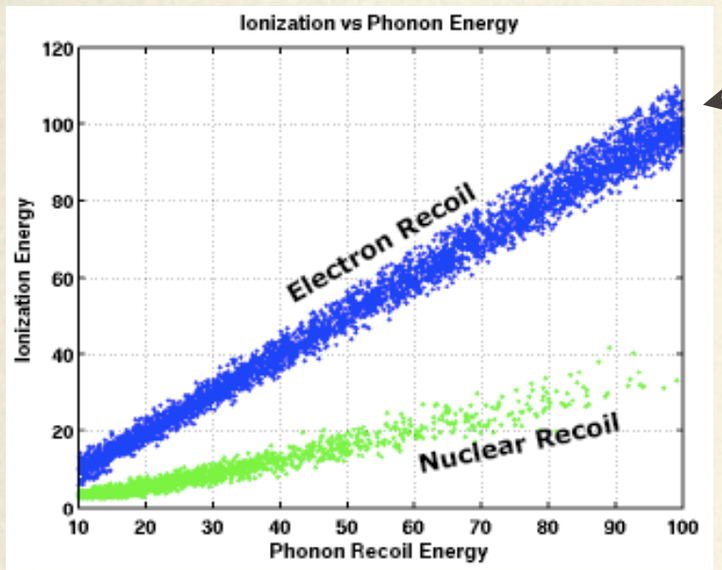
$$q_{Na} \approx 0.3, \quad q_I \approx 0.1$$

Ions moving down crystal “channel” interact with electrons only: $q \approx 1$

Channeling

Does it occur in other experiments?

Mahapatra, CDMS '08

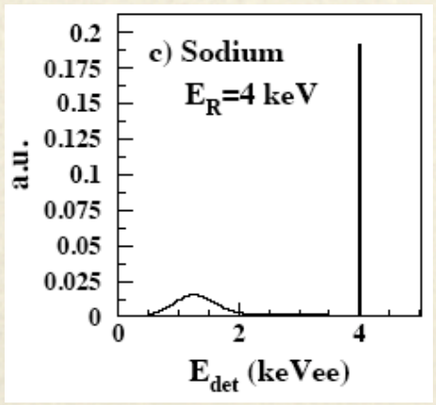


Looks like background, would be removed by cuts; re-analysis?

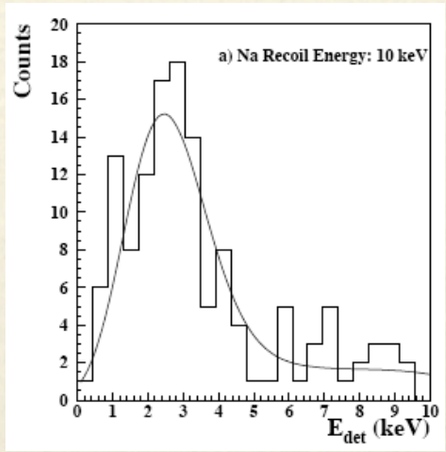
Need crystal structure (CDMS, CoGeNT, KIMS)

Does it occur at all?

MeV range: Newman, Smith, Steigart '60; Luntz, Bartram '68; Altman, Dietrich, Murray, Rock '73; Birkmire, Murray, Luntz '77; Graichen et al. '02



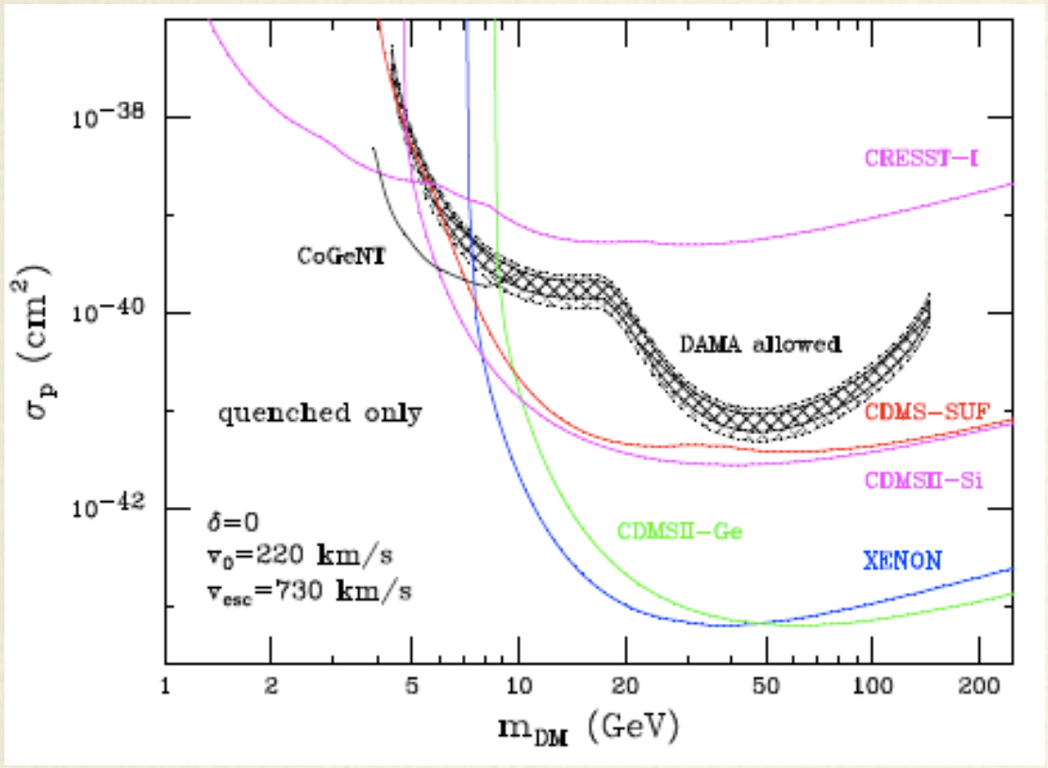
energy resolution



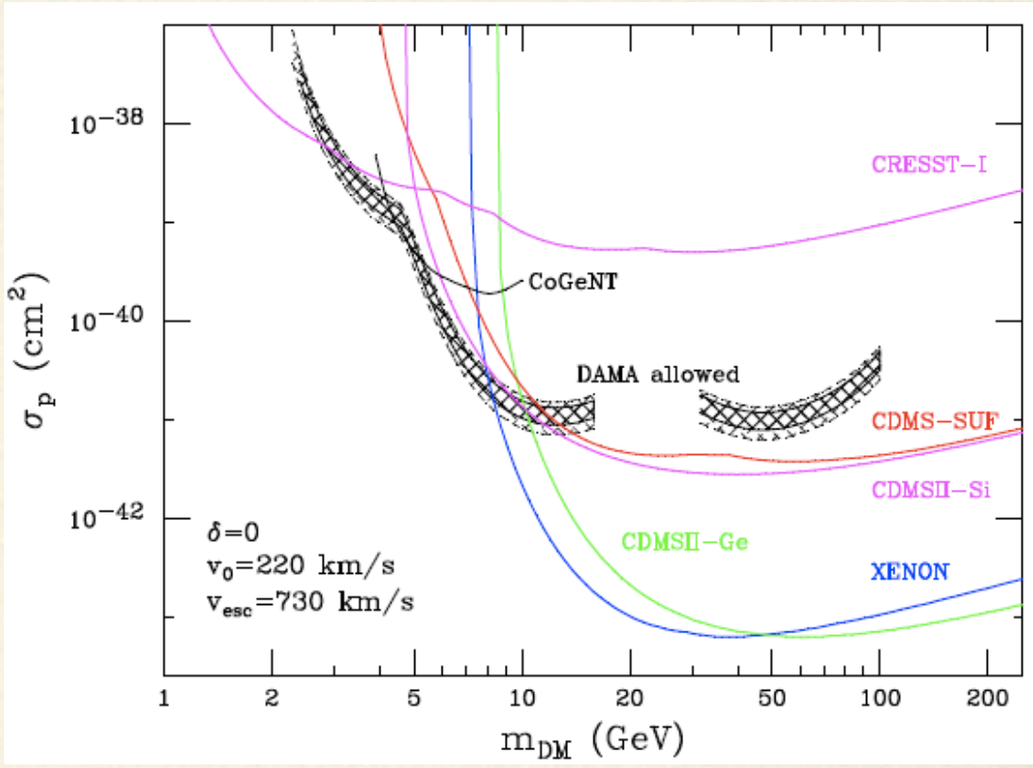
Dedicate data taking to determine?

...Light WIMPs after

Petriello, KZ '08



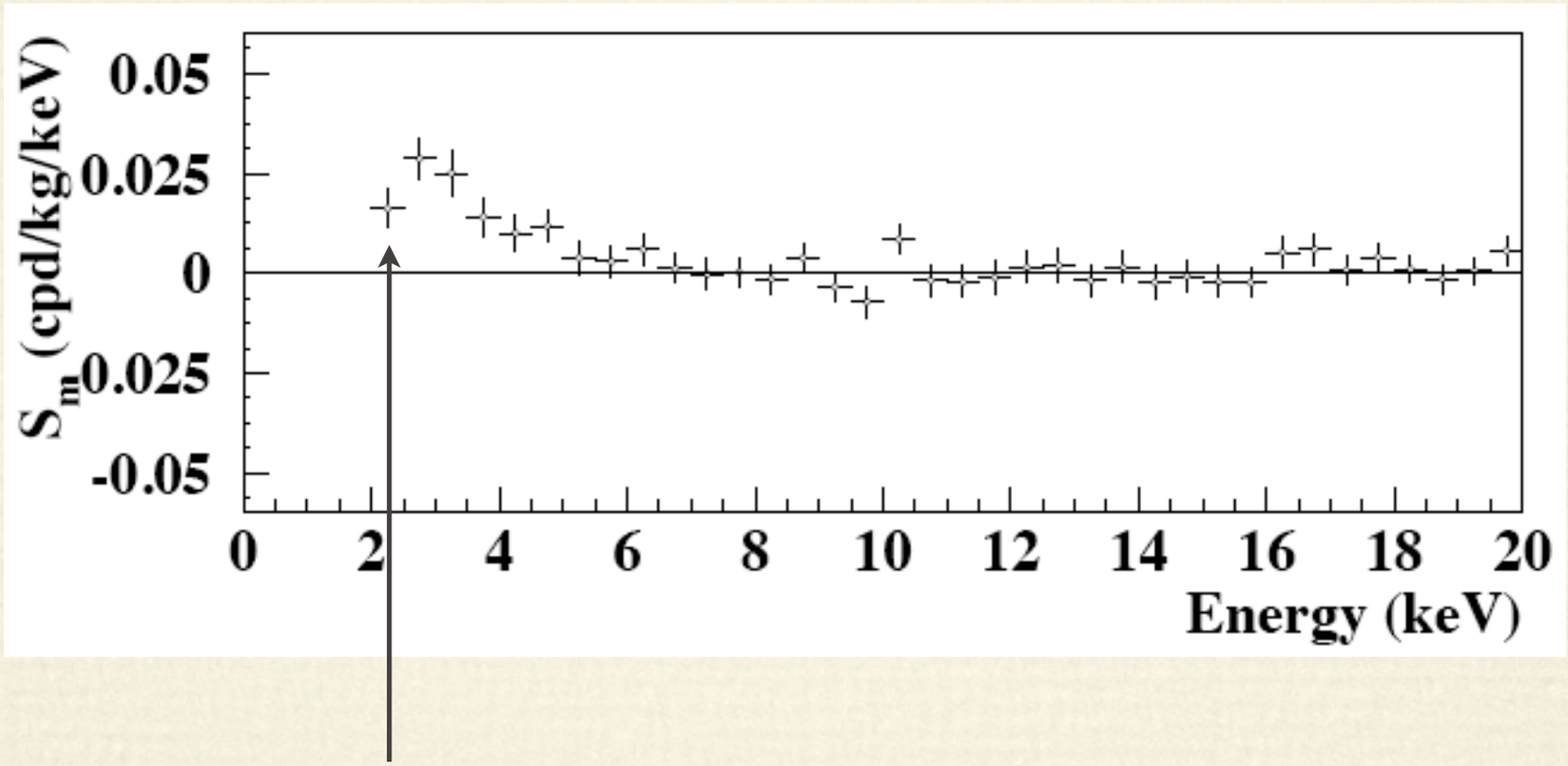
$E_{thresh} = 7$ keV (Na), 22 keV (I)



$E_{thresh} = 2$ keV

DAMA spectrum

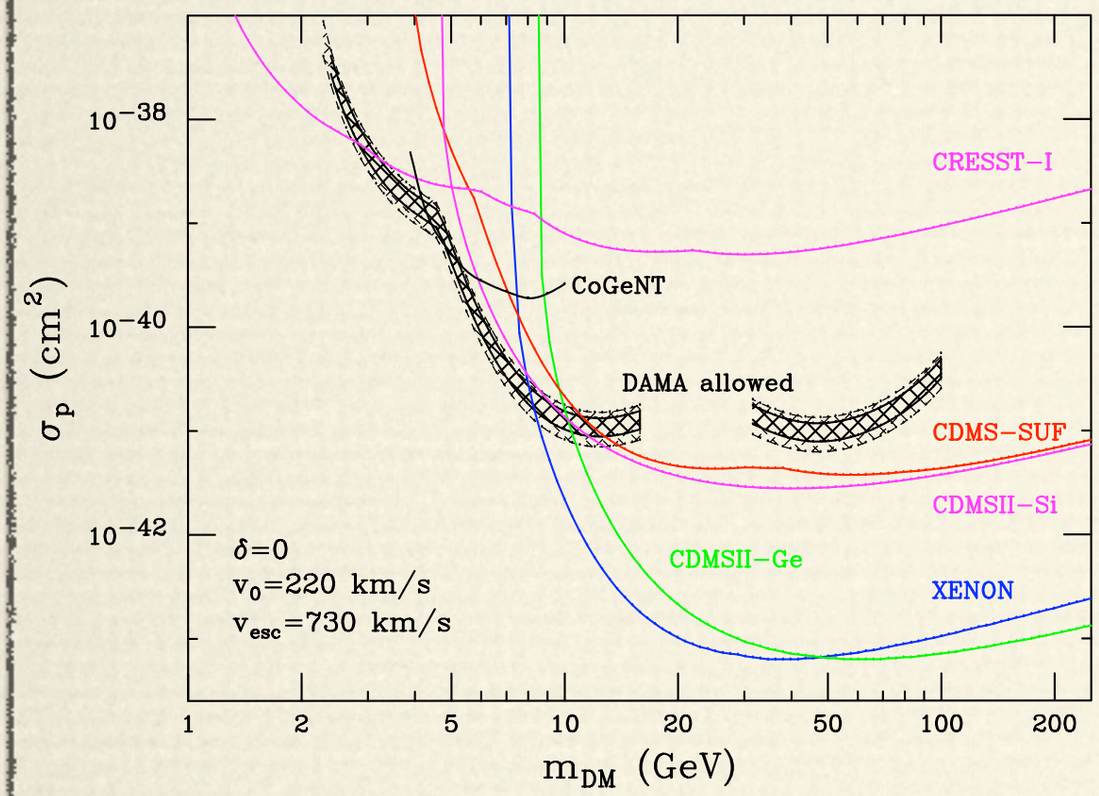
Latest DAMA results binned in 0.5 keV



Is the 2-2.5 keV bin a hint of structure?

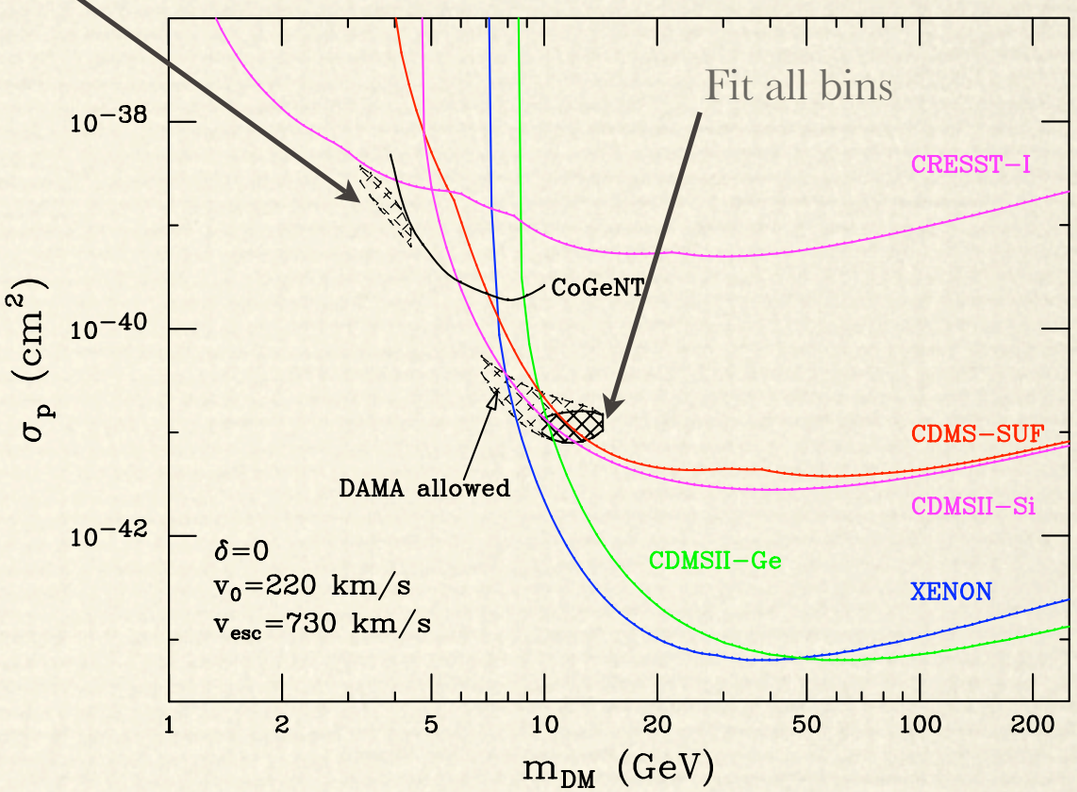
Full spectral analysis

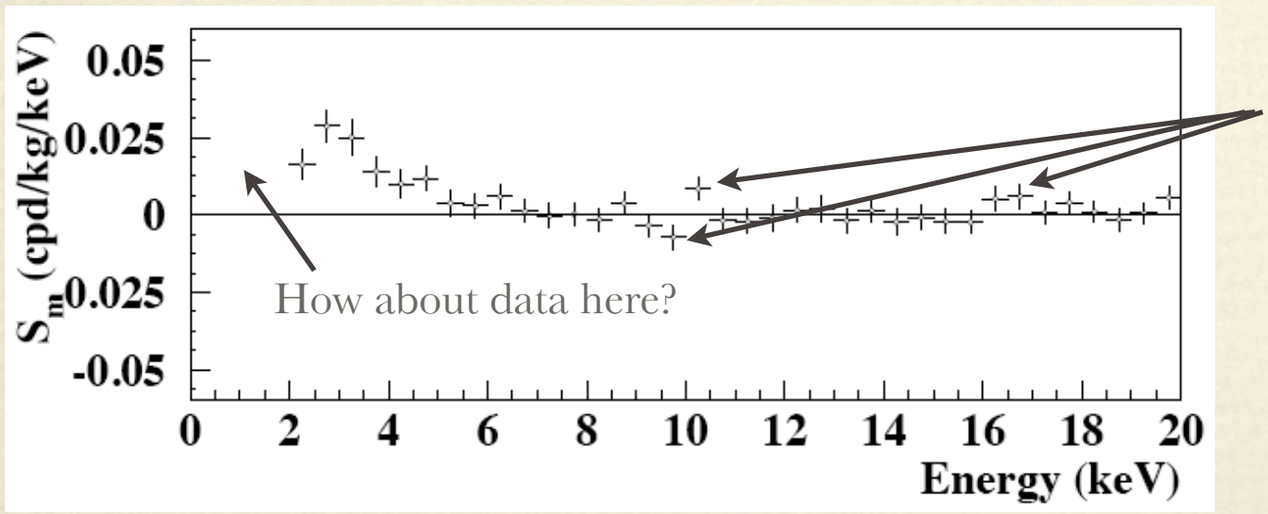
Petriello, KZ'08



Drop 2-2.5 keV bin

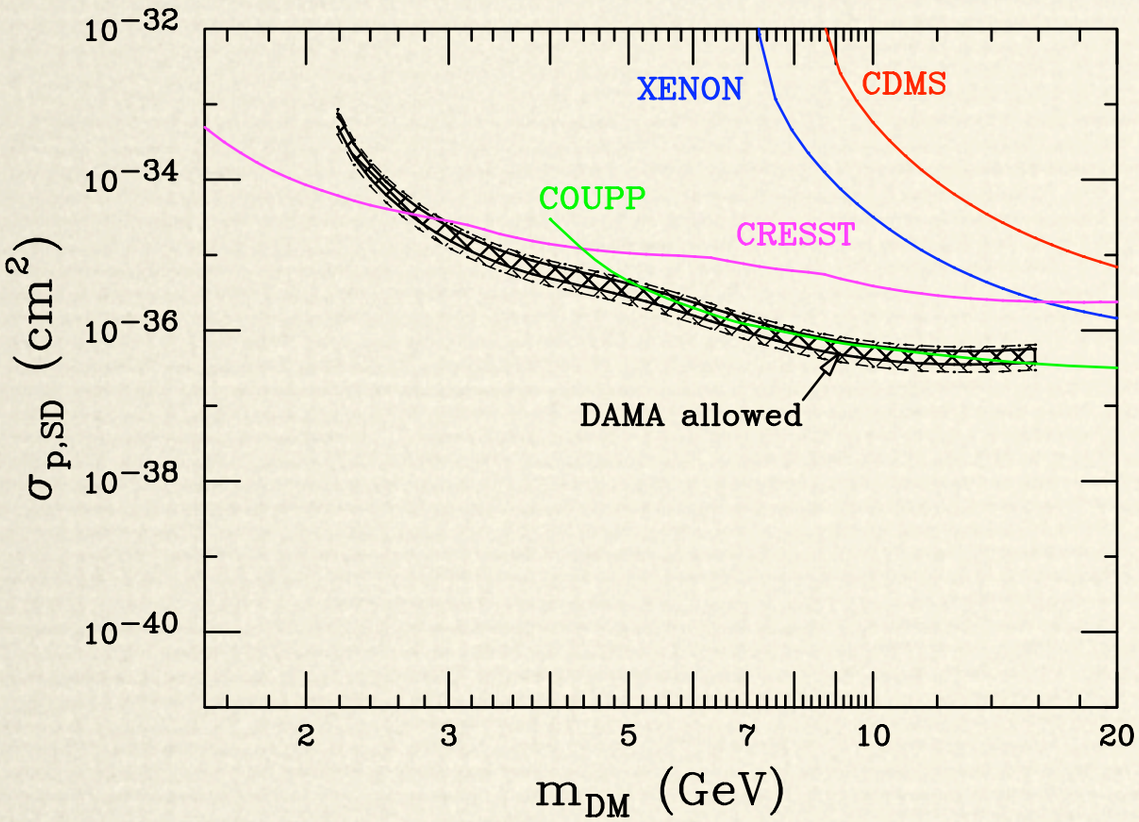
Fairbairn, Schwetz; Cheng et al.; Petriello, Hooper, KZ, Kamionkowski '08

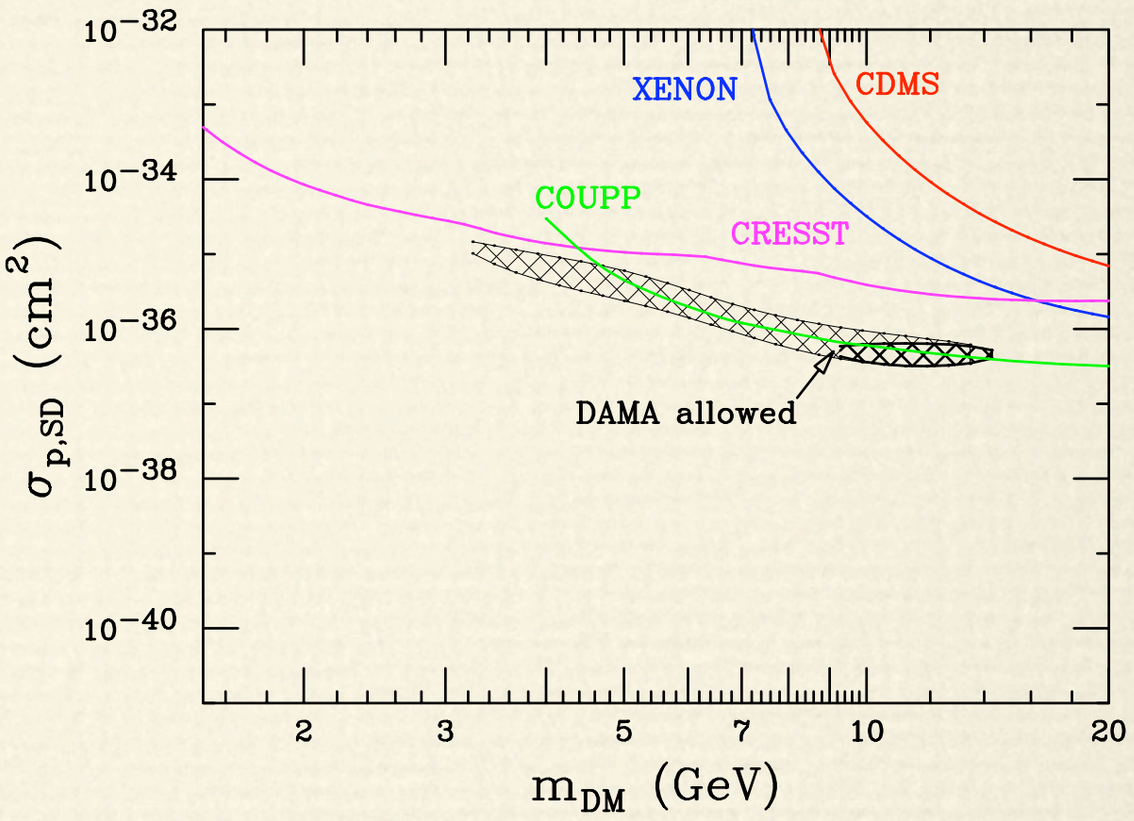




Personal feeling: may be premature to exclude based on one bin (rhetorically, other hints of structure?)

Spin-dependent scattering

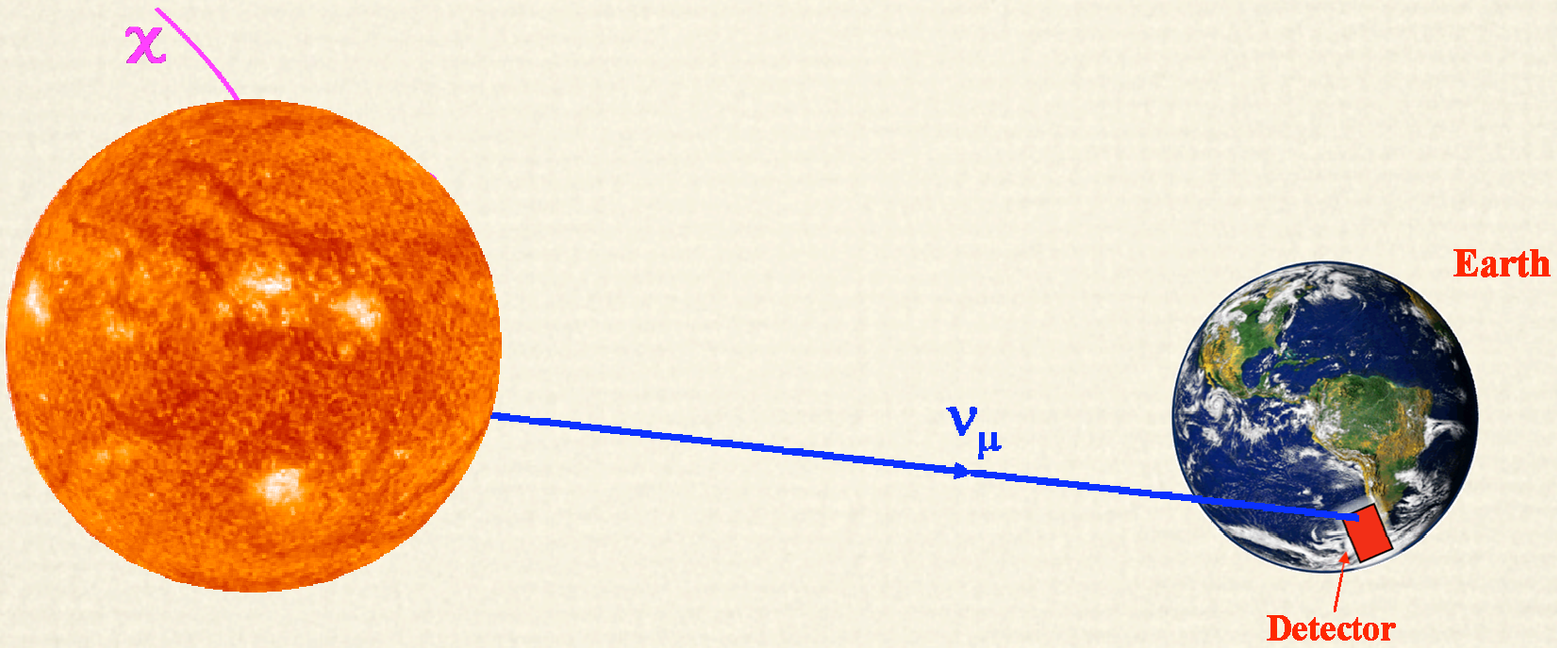




Seems a region with spin-dependent scattering is consistent with both 2-bin, full spectrum

WIMP capture

Elastically scatter, lose energy come to rest in stellar core



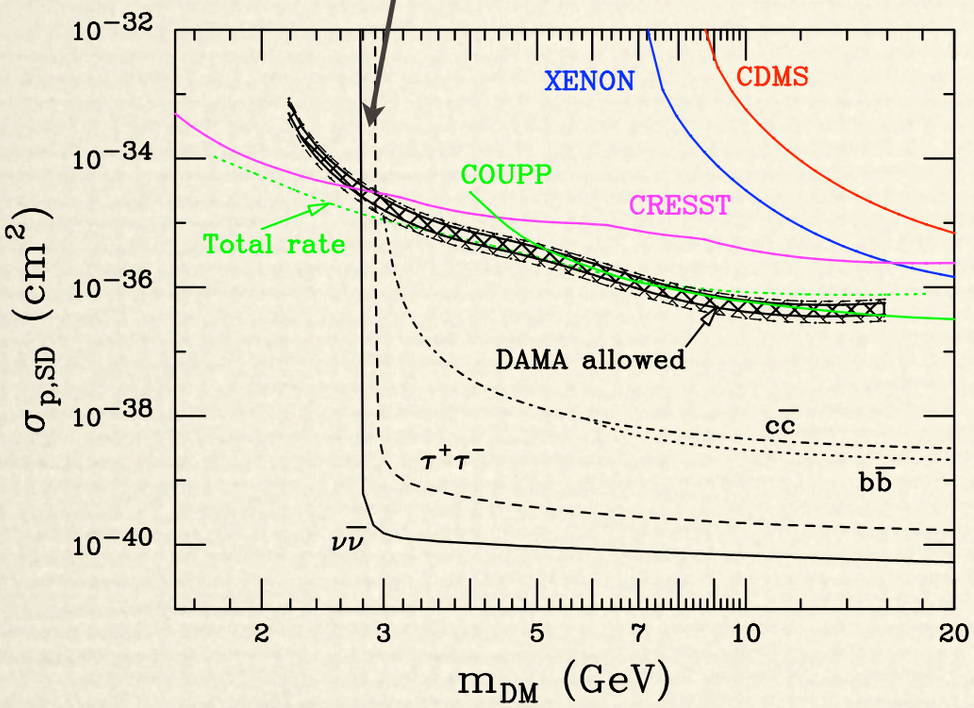
Annihilate to neutrinos, produce muons

Few-GeV WIMPs ➡ Super-K (below ICECUBE, ANTARES, etc, threshold)

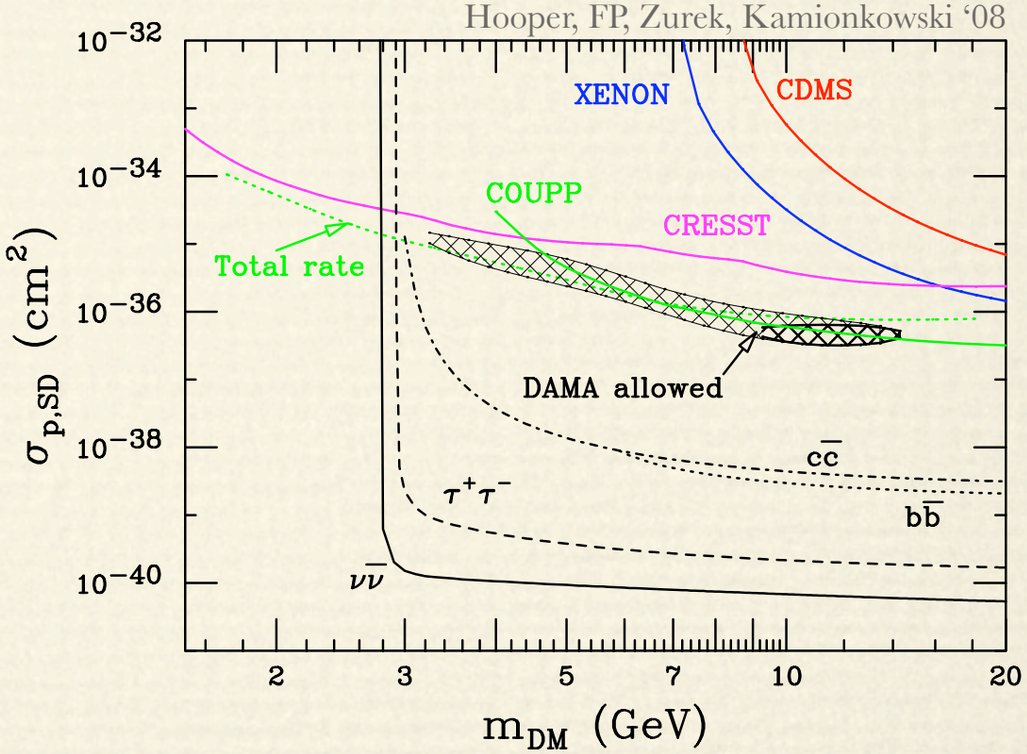
Spin-dependent constraints

Super-K has 1.6 GeV muon threshold

Each line assume 100% annihilation to final state

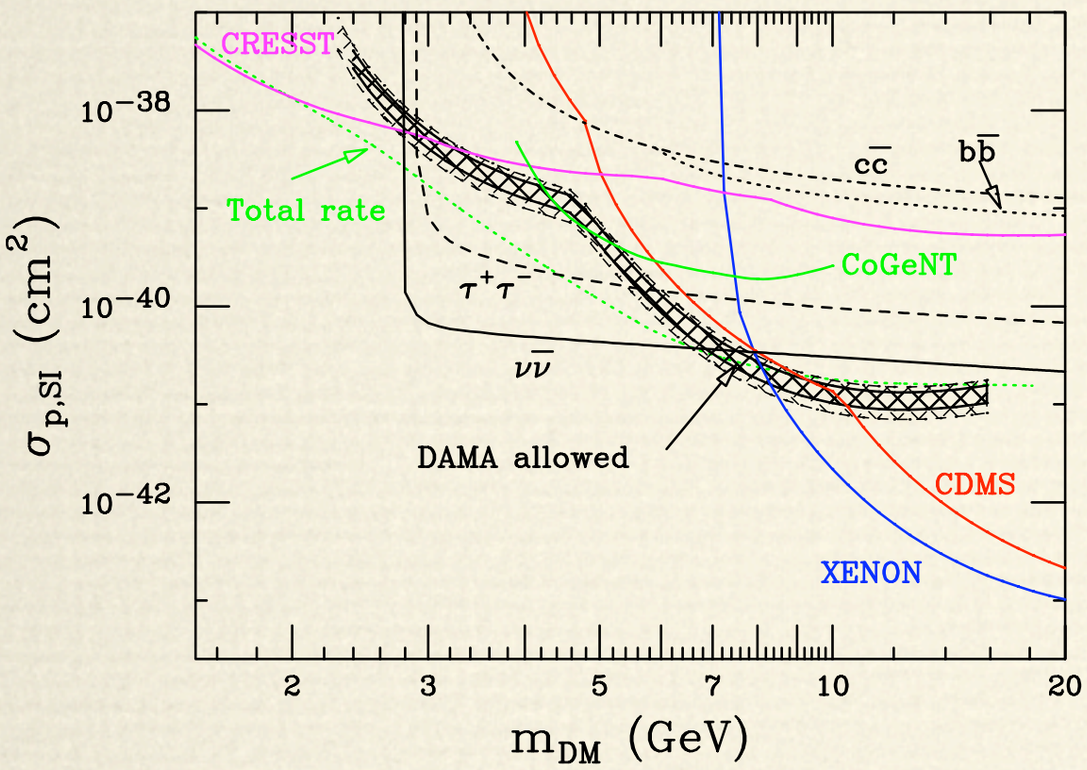


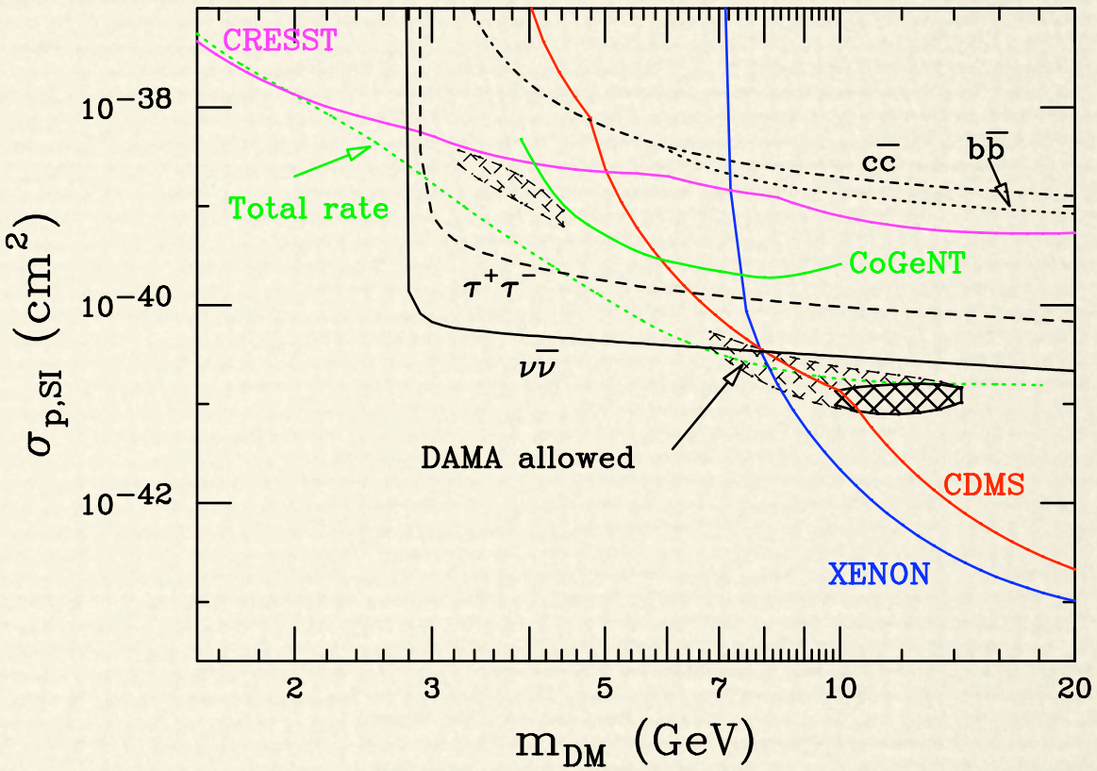
Hooper, FP, Zurek, Kamionkowski '08



Can have >1% annihilation only to electrons, muons, or light quarks; model-building challenge (FCNC)

Spin-independent constraints





Spin-independent: $\sigma_{direct} \sim A^2,\ \Gamma_{cap} \sim 1$

Spin-dependent: $\sigma_{direct} \sim 1,\ \Gamma_{cap} \sim 1$

Conclusions

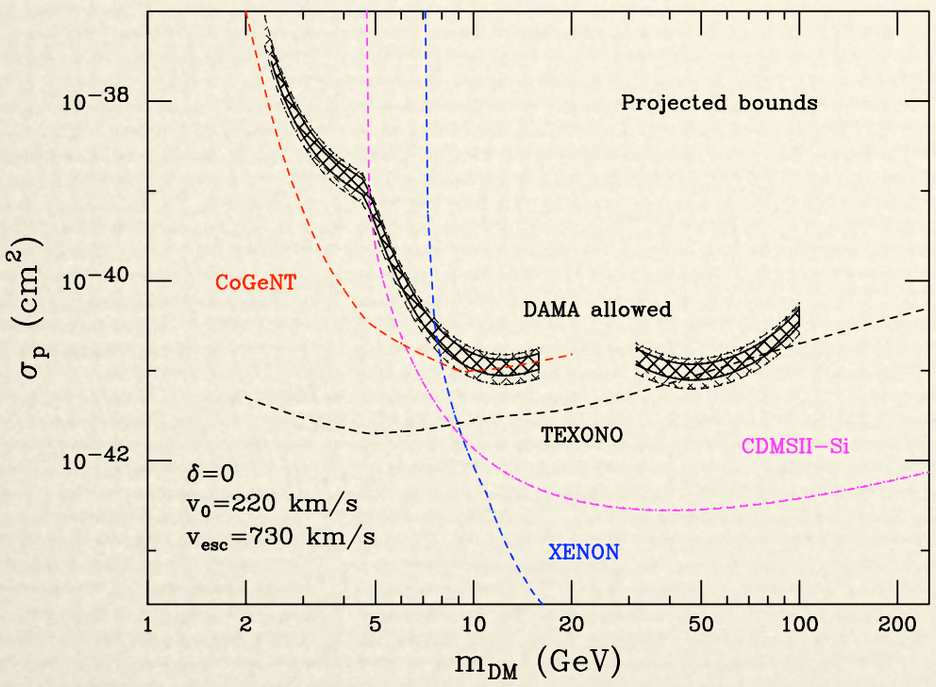
- Possible consistency of <10 GeV WIMP with direct detection
- Depends crucially on whether structure is beginning to appear in 2-2.5 keV bin
- Strong constraints on DAMA region from WIMP annihilation; spin-dependent region especially severe (<1% annihilation to neutrinos, taus, charms, bottoms)
- Evade SuperK constraints if DM does NOT self-annihilate (in progress, Kaplan, Luty, KZ)

Conclusions

Does channeling occur with keV nuclear recoils?

➡ if not, forget about light WIMP explanation

Low threshold experiments!



CDMS, Mahapatra seminar '08