Germanium-phobic exothermic Dark Matter and the CDMS-II Silicon excess

Stefano Scopel

Based on work done in collaboration with K. Yoon (JCAP 1408, 060 (2014)) and J.H. Yoon (arXiv:1411.3683, accepted on PRD)

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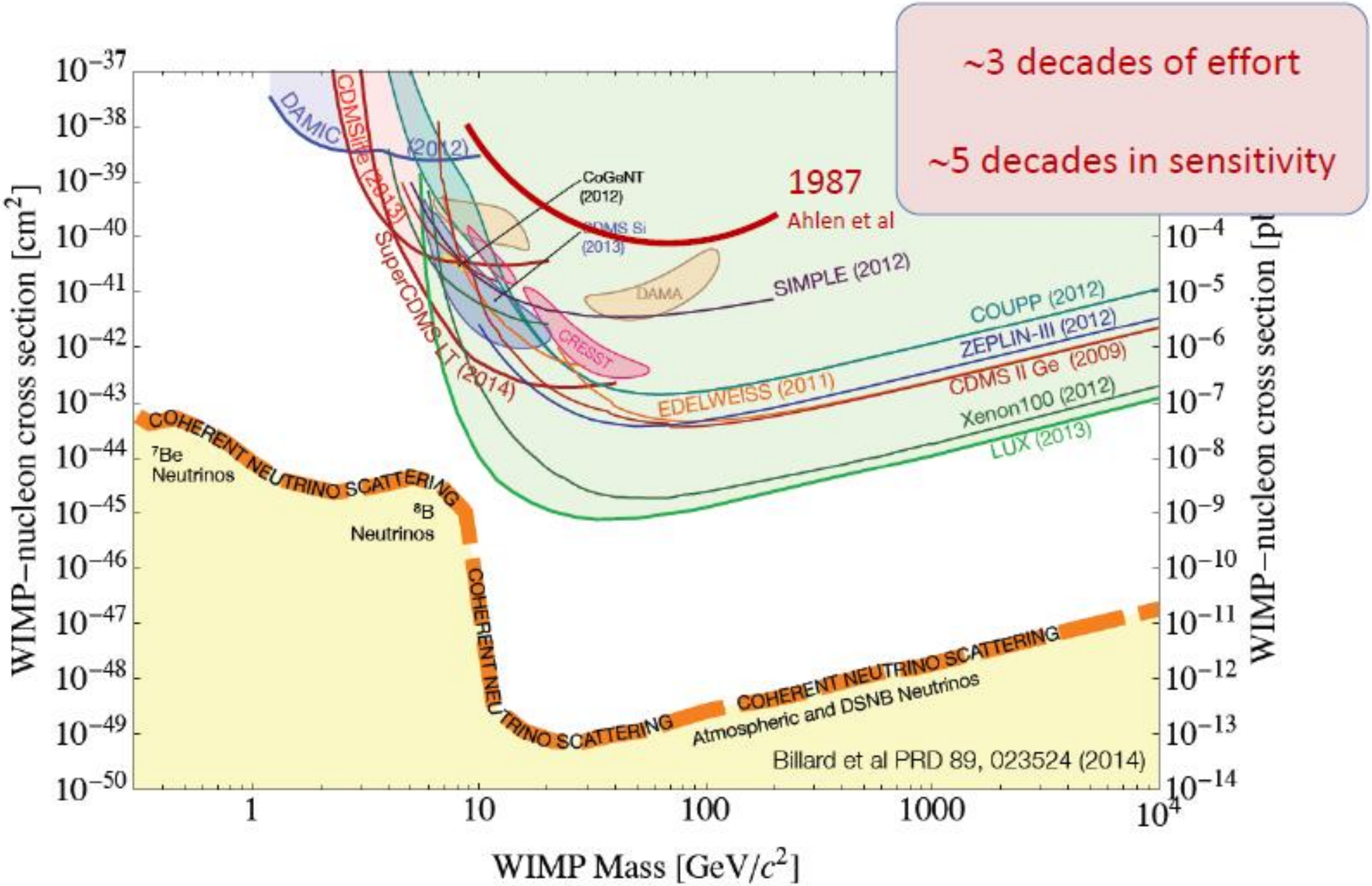
WIMP direct searches: an ever expanding field…

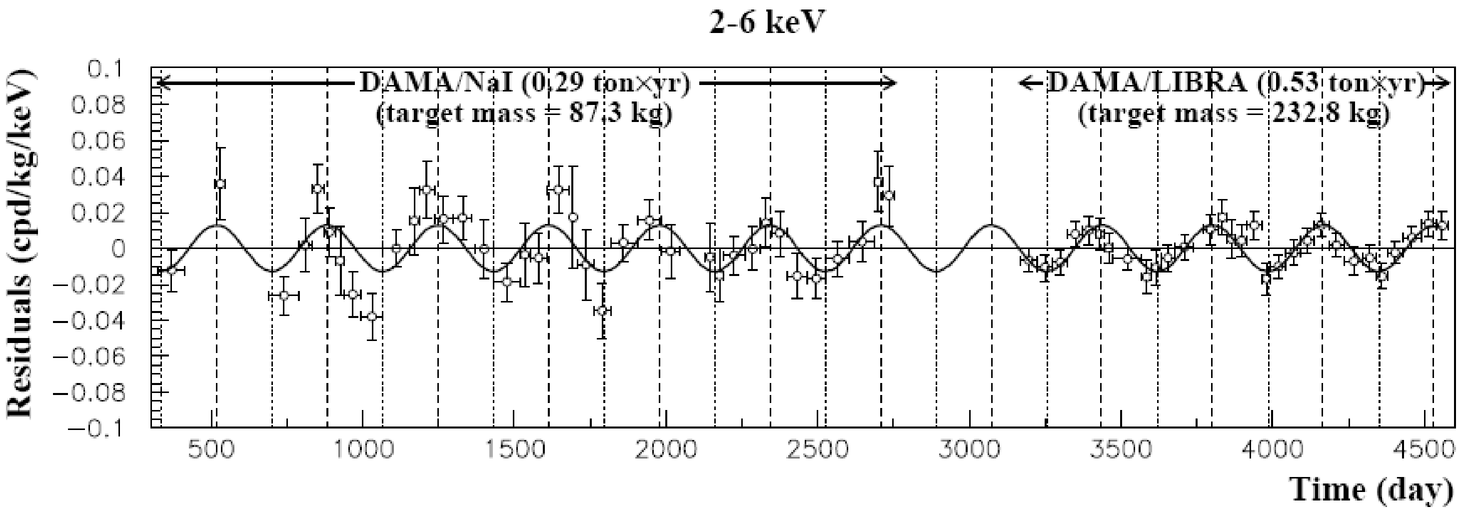


Will the race discover DM before eventually reaching the irreducible background of solar and atmospheric neutrinos???

(from H. Araujo talk @SUSY 2014, July 2014)

DAMA/Libra result (Bernabei et al., Eur.Phys.J.C56:333-355,2008, arXiv:0804.2741)

0.53 ton x year (0.82 ton x year combining previous data)
8.2 σ C.L. effect

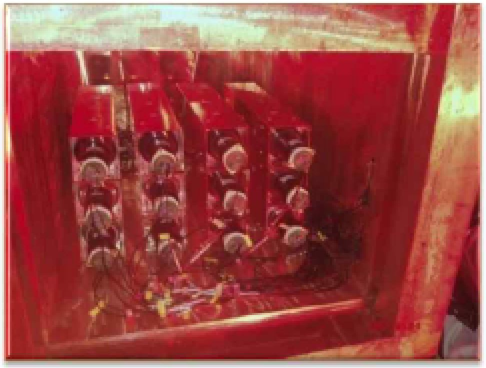


	A (cpd/kg/keV)	$T = \frac{2\pi}{\omega}$ (yr)	t_0 (day)	C.L.
DAMA/NaI				
(2–4) keV	0.0252 ± 0.0050	1.01 ± 0.02	125 ± 30	5.0σ
(2–5) keV	0.0215 ± 0.0039	1.01 ± 0.02	140 ± 30	5.5σ
(2–6) keV	0.0200 ± 0.0032	1.00 ± 0.01	140 ± 22	6.3σ
DAMA/LIBRA				
(2–4) keV	0.0213 ± 0.0032	0.997 ± 0.002	139 ± 10	6.7σ
(2–5) keV	0.0165 ± 0.0024	0.998 ± 0.002	143 ± 9	6.9σ
(2–6) keV	0.0107 ± 0.0019	0.998 ± 0.003	144 ± 11	5.6σ
DAMA/NaI+ DAMA/LIBRA				
(2–4) keV	0.0223 ± 0.0027	0.996 ± 0.002	138 ± 7	8.3σ
(2–5) keV	0.0178 ± 0.0020	0.998 ± 0.002	145 ± 7	8.9σ
(2–6) keV	0.0131 ± 0.0016	0.998 ± 0.003	144 ± 8	8.2σ

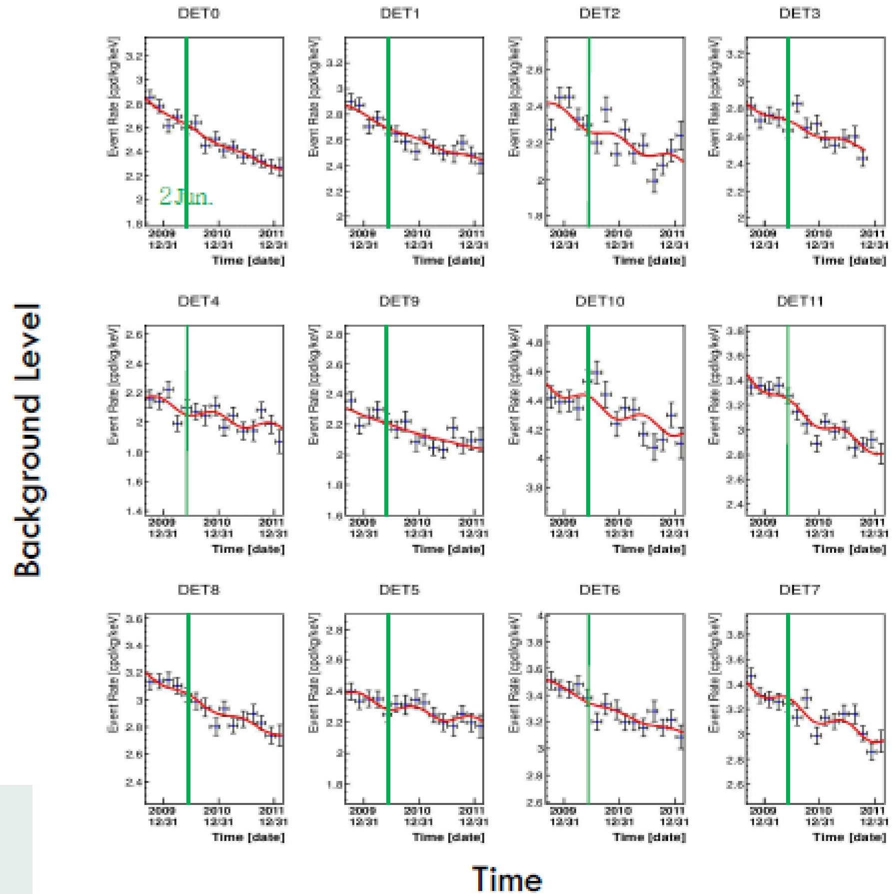
$A \cos[\omega (t-t_0)]$

$\omega=2\pi/T_0$

KIMS-CsI annual modulation data



- 12 crystals (104.4kg).
- 2.5 year data (Sep. 2009–Feb. 2012)
- Background Level : 2~3 cpd/kg/keV



- **The mean amplitude from 3 keV to 6 keV is 0.0008±0.0068 cpd/kg/keV**

modulation amplitude in DAMA for the same energy interval is ~0.02 cpd/kg/keV

Particularly compelling for m_{DM} >20 GeV: WIMPs scatter on Iodine both in KIMS and in DAMA
→ cannot fiddle with theoretical "epicycles"

Yeongduk Kim, TAUP2013

• First DAMA NaI modulation result dates back to 1997, now the excess exceeds 8 sigma

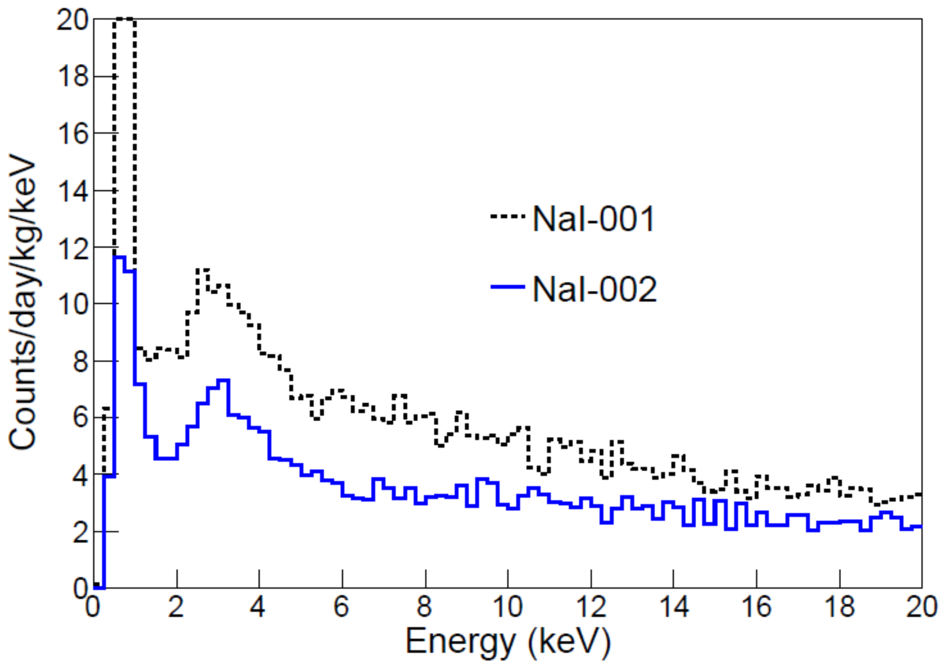
• Since then no independent check using the same target has been successfully made.

• Is the long wait about to be over?

Tests on NaI(Tl) crystals for WIMP search at the Yangyang Underground Laboratory

1487.1506

K.W. Kim[b], W.G. Kang[a], S.Y. Oh[e], P. Adhikari[e], J.H. So[a], N.Y. Kim[a], H.S. Lee[c,*], S. Choi[b], I.S. Hahn[d], E.J. Jeon[a], H.W. Joo[b], B.H. Kim[b], H.J. Kim[f], Y.D. Kim[a,e,*], Y.H. Kim[a,g], J.K. Lee[b], D.S. Leonard[h], J. Li[a], S.L. Olsen[b], H.S. Park[g]

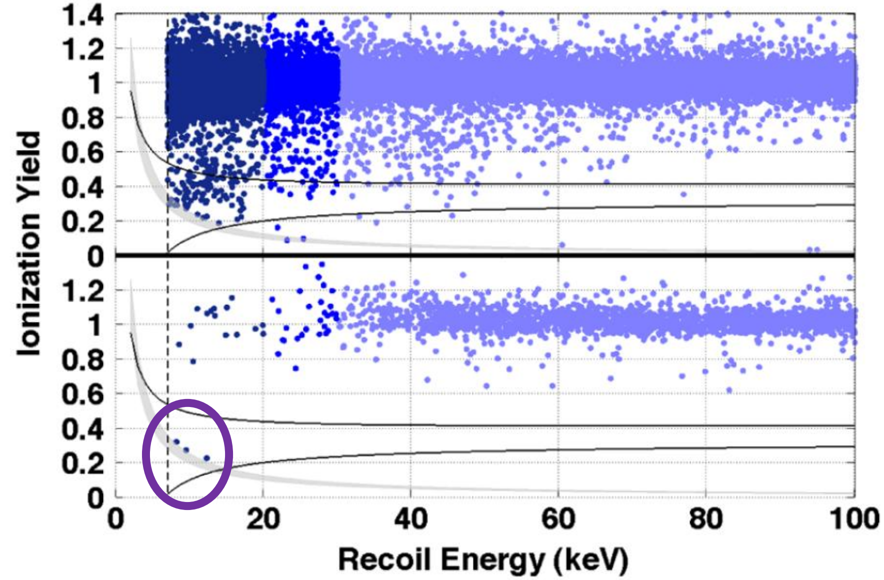


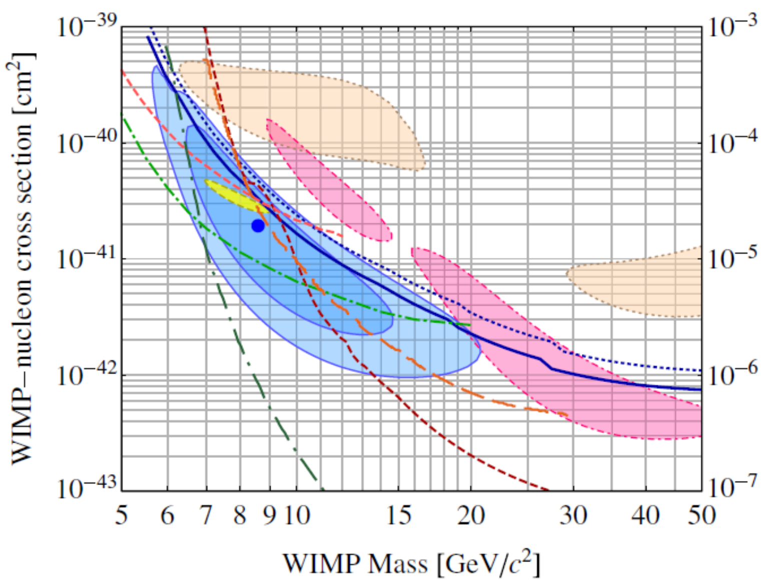
bck~3 counts/keV/kg/day @6 keV
(DAMA: bck~1 counts/keV/kg/day @2 keV)

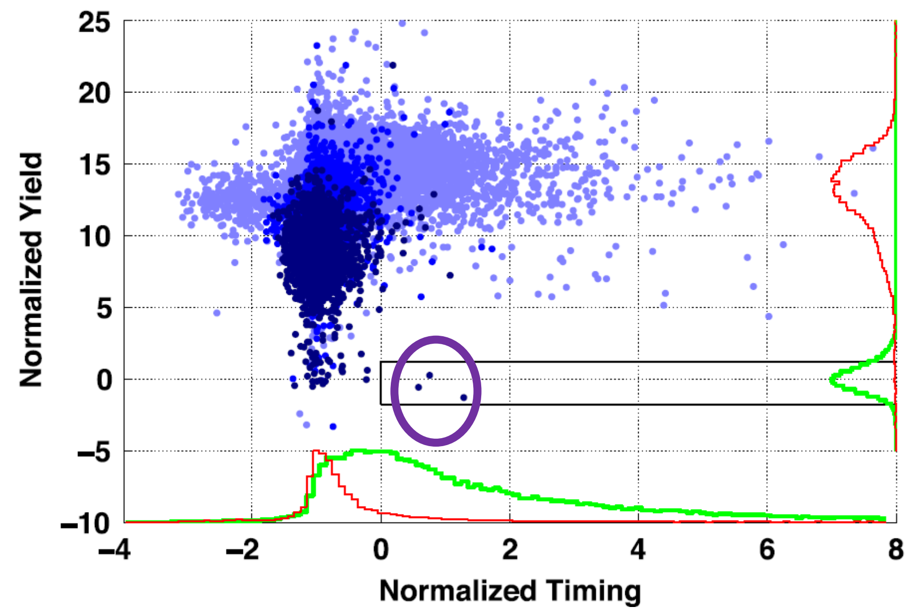
threshold <2 keV

The CDMS II Silicon excess

- dual signal (phonons+ionization) used to discriminate background
- total exposure of 140.2 kg days with eight Silicon detectors of ~106 g each in the energy range 7-100 keV
- ~23.4 kg day equivalent exposure after selection cuts for 10 GeV WIMP
- 3 WIMP-candidate events survive with expected background <0.6 events (~5% probability of bck fluctuation)





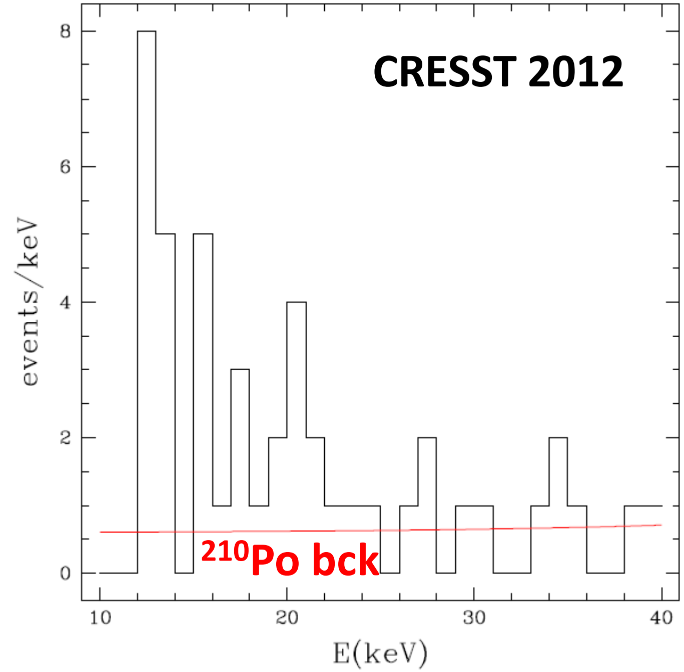


R.Agnese et al. (CDMS Collaboration), Phys.Rev.Lett.111, 251301 (2013),1304.4279

The CRESST excess (btw: is it gone)?

CRESST 2012:
G. Angloher et al (CRESST Coll.) Eur. Phys. J.C72, 1971 (2012), 1109.0702

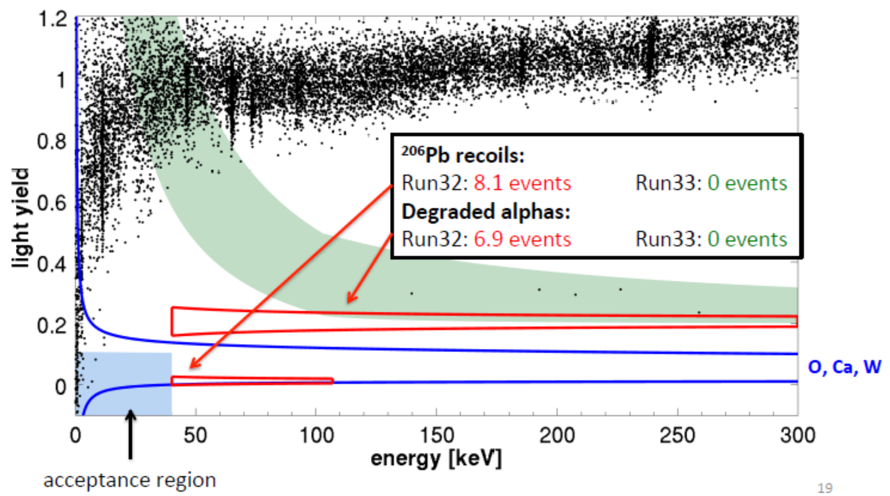
- 730 kg day with $CaWO_4$ (light+phonons)
- “excess” (total of 34 events in Tungsten recoil band for 12 keVnr<E_R<24 keVnr vs. 7.4 expected due to lead recoil background from ^{210}Po decay)
- sizeable surface background from non-scintillating clamps holding the crystals.



CRESST 2014:
G. Angloher et al(CRESST-II Collaboration),1407.3146

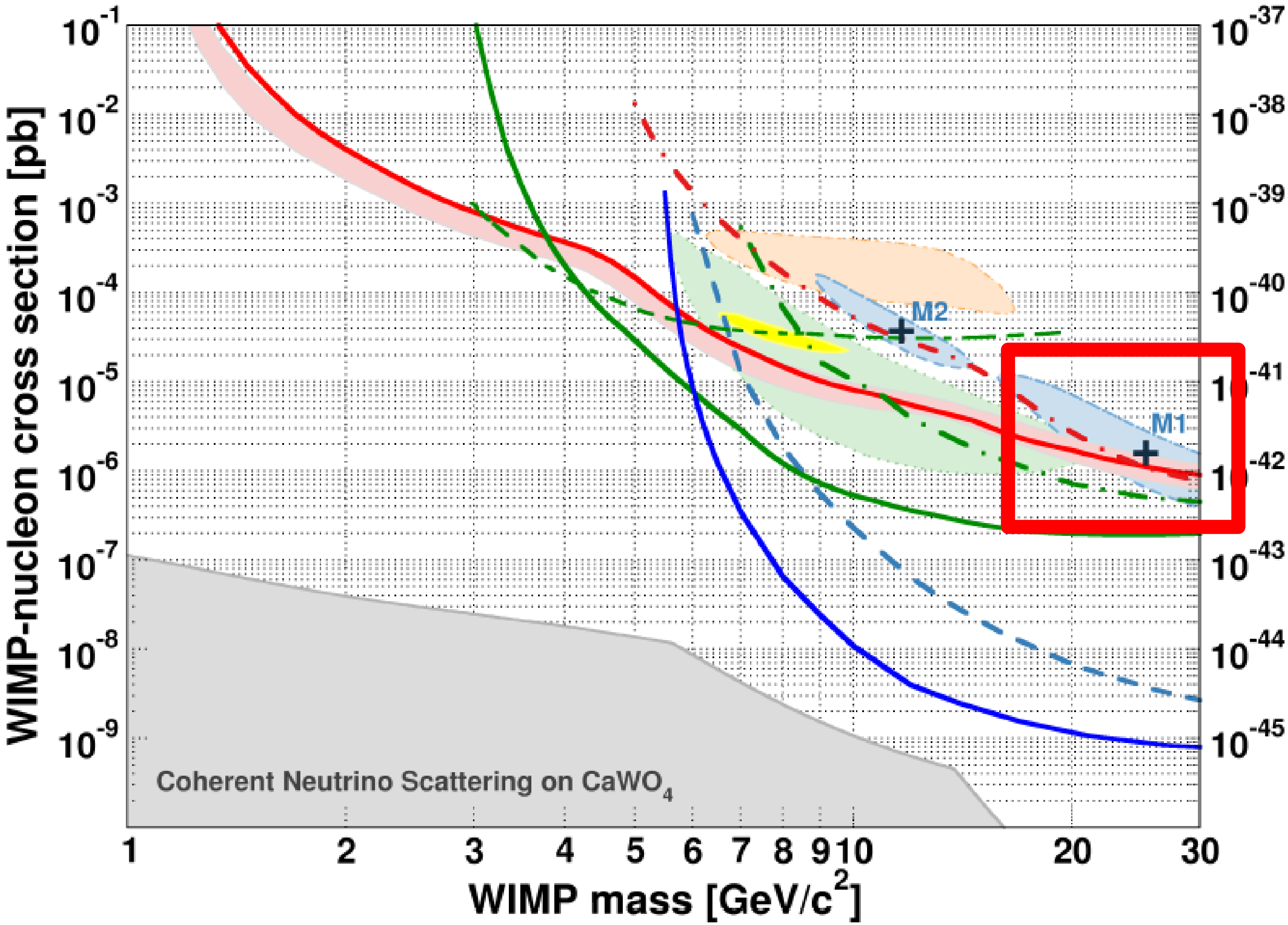
- Improved radiopurity and fully-scintillating design for one 250 g detector module (TUM-40)
- total exposure: 29 kg days
- additional light from surface events allows efficient veto of surface background
- no longer events in previous excess region and **lower threshold**: low-mass WIMP solution ruled out **while high-mass WIMP solution survives**
- back-of-the-envelope estimation: 30*29/730~1.2 events. 90% CL upper bound of 0 is 2.3, simply exposure is too low to rule out previous effect → need more statistics

CRESST 2014



The CRESST excess

G. Angloher et al(CRESST-II Collaboration),1407.3146



- still marginal compatibility for high-mass solution assuming isothermal sphere
- full compatibility relaxing assumptions on velocity distribution

N.B. All considerations until now have been based upon the assumption of an "Isothermal Sphere" modeling the DM velocity distribution in our Galaxy

On the other hand compatibility among different experiments (ex. DAMA/Libra vs. CoGeNT) can be verified without assuming any model for the halo

Write expected WIMP rate as:

$$\frac{dR}{dE_R} = \frac{\rho_\chi \sigma_n}{2m_\chi \mu_{n\chi}^2} \frac{C_T}{f_n^2} F^2(E_R)\epsilon(E_R) g(v_{\min}, t)$$

$F^2(E_R)$ is the form factor, and the function:

$$g(v_{\min}, t) = \int_{v_{\min}}^{\infty} \frac{f_{\text{local}}(\vec{v}, t)}{v} d^3 v$$

contains all the dependence on the halo model with:

$$v_{\min} = \sqrt{\frac{m_N E_R}{2\mu^2}}$$

So there is a one-to-one correspondence between the recoil energy E_R and v_{min}

→ map the event rate expected in different experiments into the same intervals in v_{min} (P.J. Fox, J. Liu, N. Weiner, PRD83,103514 (2011))

In this way the dependence on the galactic model cancels out in the ratio of the expected count rates of the two experiments because they depend on the same integrals of $f_{local}(v)$

In particular, given an energy interval in one experiment, it is easy to find the energy interval of the second experiment corresponding to the same values of v_{min} (this means that the same part of the velocity distribution is sampled in the two cases):

$$[E_{\rm low}^{(2)}, E_{\rm high}^{(2)}] = \frac{\mu_2^2 M_T^{(1)}}{\mu_1^2 M_T^{(2)}}[E_{\rm low}^{(1)}, E_{\rm high}^{(1)}]$$

Besides the energy mapping, there is also a rate mapping between the two experiments:

$$\frac{dR_1}{dE_1} \Leftrightarrow g(v_{\rm min}) \Leftrightarrow \frac{dR_2}{dE_2}$$

with:

$$\frac{dR_2}{dE_R}(E_2) = \frac{\kappa^{(2)}\mu_1^2}{\kappa^{(1)}\mu_2^2}\frac{\sigma_2(E_2)}{\sigma_1(\frac{\mu_1^2 M_T^{(2)}}{\mu_2^2 M_T^{(1)}}E_2)}\frac{dR_1}{dE_R}\left(\frac{\mu_1^2 M_T^{(2)}}{\mu_2^2 M_T^{(1)}}E_2\right)$$

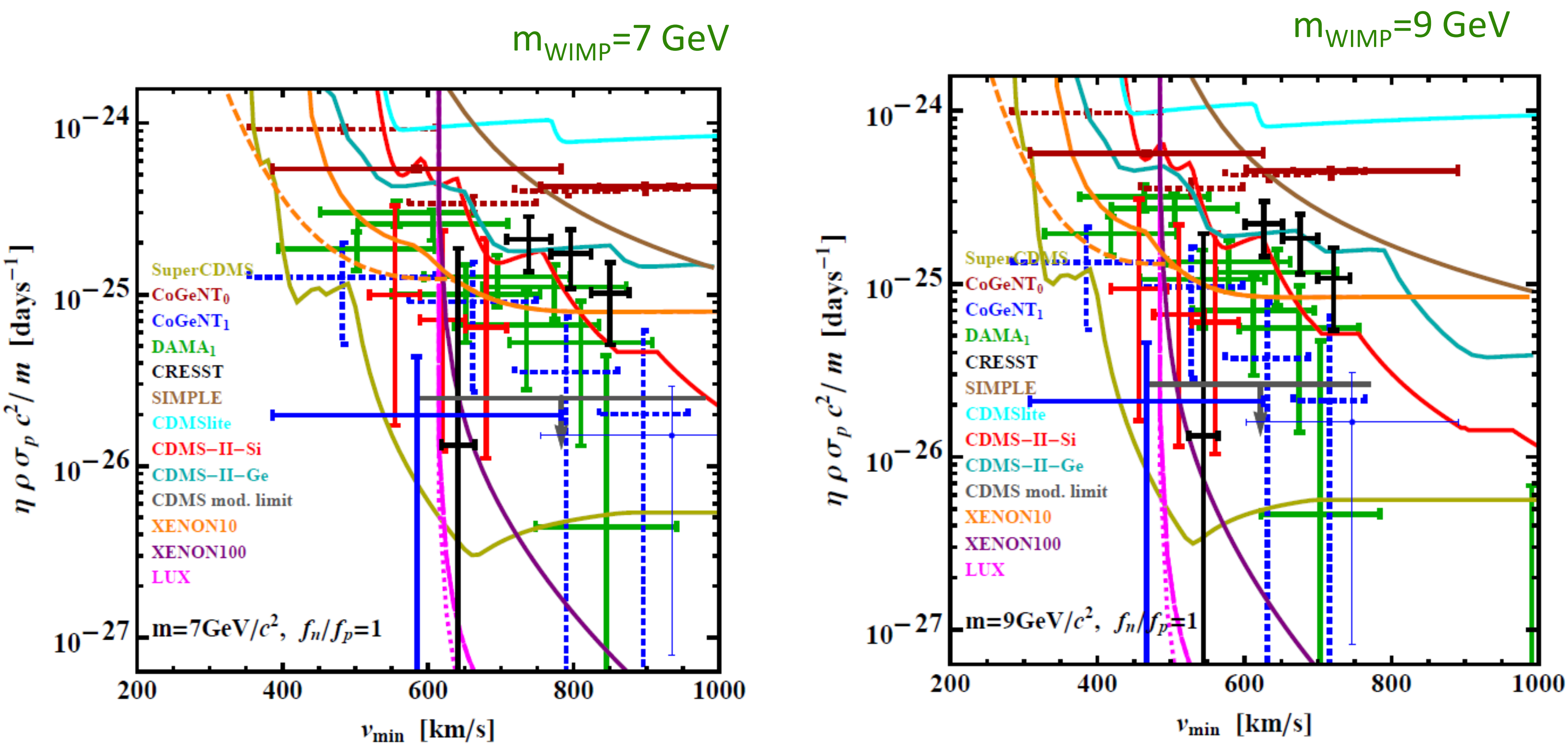
($k^{(1,,2)}$=target-specific coefficient, e.g. A^2)

N.B. this method is only valid when there is no background, and is affected by the large uncertainties on quenching factors

(P.J. Fox, J. Liu, N. Weiner, PRD83,103514 (2011))

Updated **halo-independent** analysis **for elastic scattering** (May 2014)

Del Nobile, Gelmini, Gondolo, Huh, arXiv:1405.5582



$$R^{\rm SI}_{[E'_1,E'_2]}(t) = \int_0^\infty dv_{\rm min}\,\tilde{\eta}(v_{\rm min},t)\,\mathcal{R}^{\rm SI}_{[E'_1,E'_2]}(v_{\rm min}) \qquad \tilde{\eta}(v_{\rm min},t) \equiv \frac{\rho\sigma_p}{m}\int_{v\geqslant v_{\rm min}} d^3v\,\frac{f(\mathbf{v},t)}{v}$$

$$\tilde{\eta}(v_{\rm min},t) \simeq \tilde{\eta}^0(v_{\rm min}) + \tilde{\eta}^1(v_{\rm min})\cos[\omega(t-t_0)]$$

N.B. : only halo dependence factorized. Results depend on assumptions on other quantities such as quenching factors, L_{eff}, Q_y etc.

Summarizing, the minimal requirements for halo functions $\eta_{0,1}$ are:

$$\tilde{\eta}_0(v_{\min,2}) \leq \tilde{\eta}_0(v_{\min,1}) \quad \text{if } v_{\min,2} > v_{\min,1}$$ (decreasing function)

$$\tilde{\eta}_1 \leq \tilde{\eta}_0 \quad \text{at the same } v_{\min}$$ (modulated part<100%)

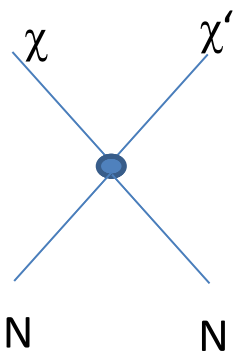
$$\tilde{\eta}_0(v_{\min} \geq v_{\rm esc}) = 0.$$ (no bound WIMPs<escape velocity)

Inelastic Dark Matter

D. Tucker-Smith and N.Weiner, Phys.Rev.D 64, 043502 (2001), hep-ph/0101138

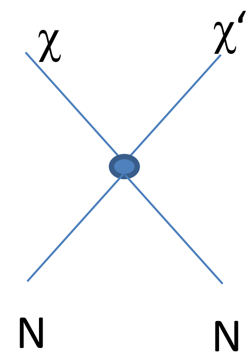
Two mass eigenstates χ and χ' very close in mass: $m_\chi - m_{\chi'} \equiv \delta$ with $\chi + N \rightarrow \chi + N$ <u>forbidden</u>

"Endothermic "scattering ($\delta>0$)



Kinetic energy needed to "overcome" step → rate no longer exponentially decaying with energy, maximum at finite energy E_*

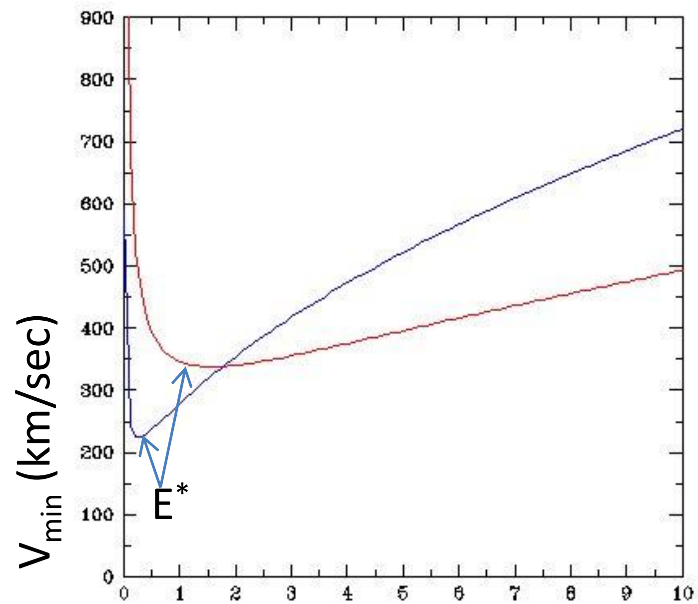
"Exothermic" scattering ($\delta<0$)



χ is metastable, δ energy deposited independently on initial kinetic energy (even for WIMPs at rest)

Inelastic DM and the halo-independent approach: recoil energy E_{ee} is no longer monotonically growing with v_{min} (energy E^* corresponds to minimal v_{min})

$$v_{min} = \frac{1}{\sqrt{2 m_N E_R}} \left(\frac{m_N E_R}{\mu} + \delta \right) = a\sqrt{E_r} + \frac{b}{\sqrt{E_R}}$$



E_{ee}(keV)

→even for very light m_{WIMP} ,Na dominance in DAMA is not guaranteed

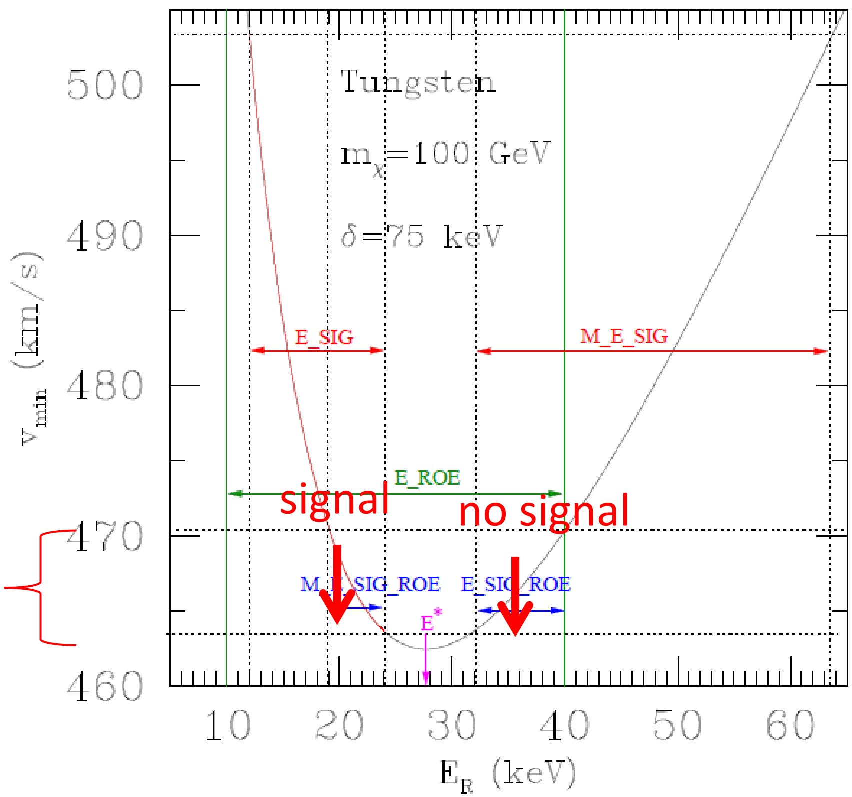
Need to rebin the data in such a way that the relation between v_{min} and E_R is invertible in each bin (easy: just ensure that for all target nuclei E^* corresponds to one of the bin boundaries)

S. Scopel and K.H. Yoon, JCAP1408, 060 (2014)

internal consistency checks

The double mapping from v_{min} to the recoil energy E_R implies that twin energy bins exist where the ratio of expected rates is fixed→can compare to experimental data:

- if both bins contain an excess (“shape test”, Bozorgnia et al, 1305.3575)
- even stronger bound if one bin contains an excess and the other doesn’t (S.S. and K.H.Yoon, 1405.0364)



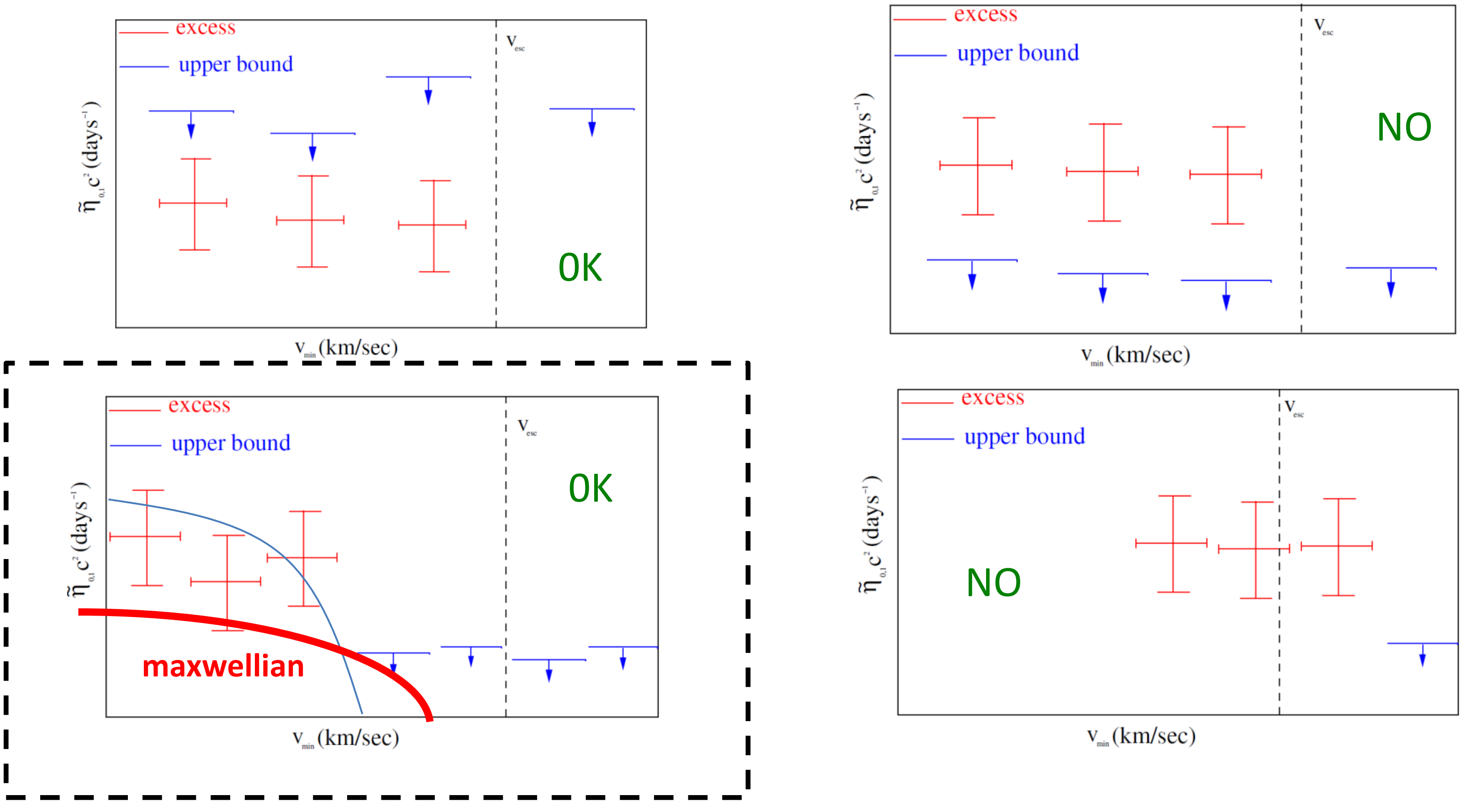
“twin” energy bins map same v_{min} interval
the bin with no signal constraints the
other with excess

S. Scopel and K.H. Yoon, JCAP1408, 060 (2014)

comparison among different experiments for Inelastic DM

if conflicting experimental results can be mapped into non-overlapping ranges of v_{min} and if the v_{min} range of the constraint is at higher values compared to the excess (while that of the signal remains below v_{esc}) the tension between the two results can be eliminated by an appropriate choice of the $\eta_{0,1}$ functions

Four cases:

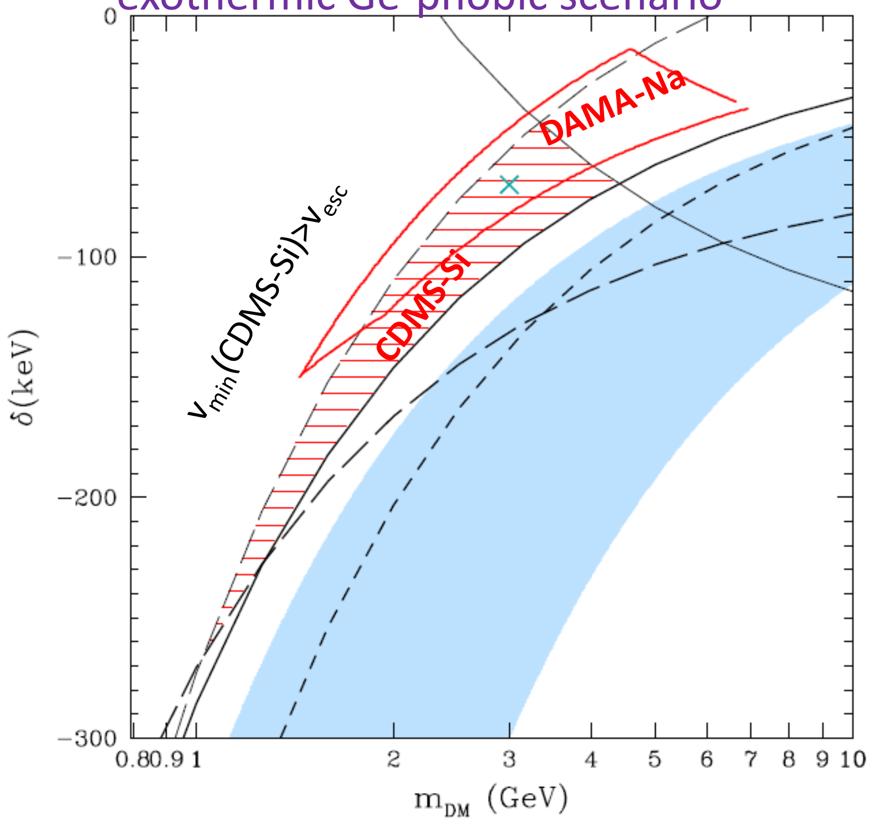


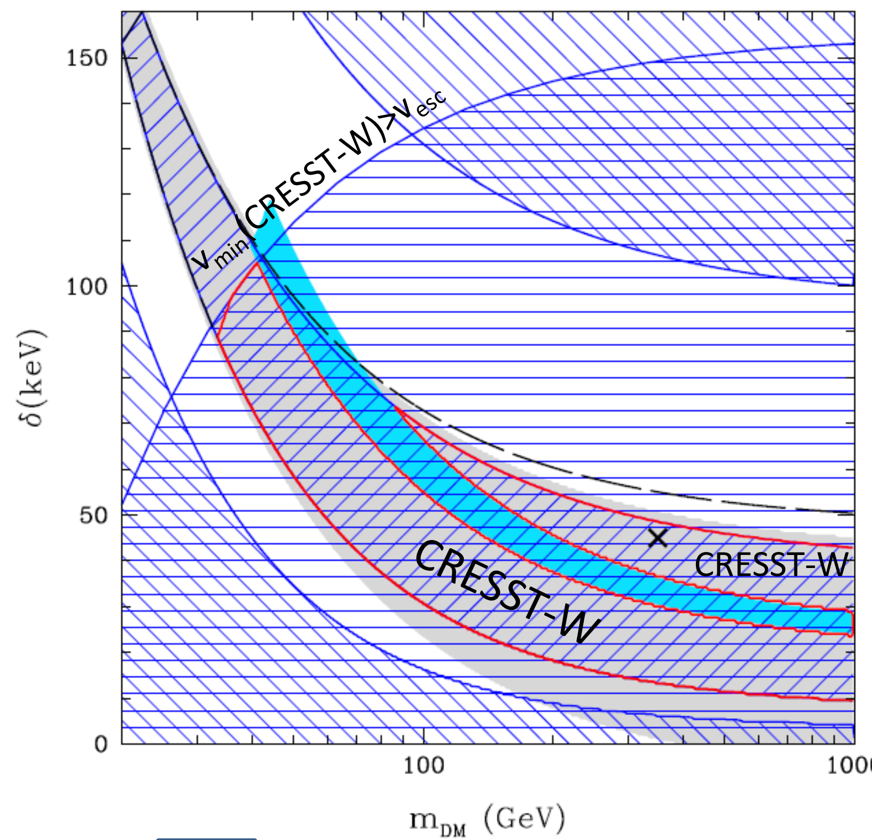
N.B: the effect of inelastic scattering (δ≠0) only implies a “horizontal shift” of η estimations (up to negligible effects) → pick appropriate m_{DM} , δ combination to shift-away the bounds without shifting away the signal! S. Scopel and K.H. Yoon, JCAP1408, 060 (2014)

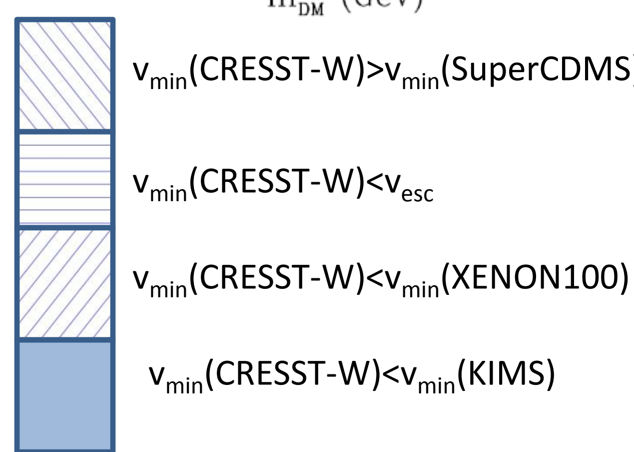
Halo-independent analysis of inelastic Dark Matter

Kinematic conditions for v_{min}(bounds)>v_{min}(signals) and v_{min}(signals)<v_{esc}

"exothermic Ge-phobic scenario"







N.B. only kinematics involved (valid for different scaling laws)

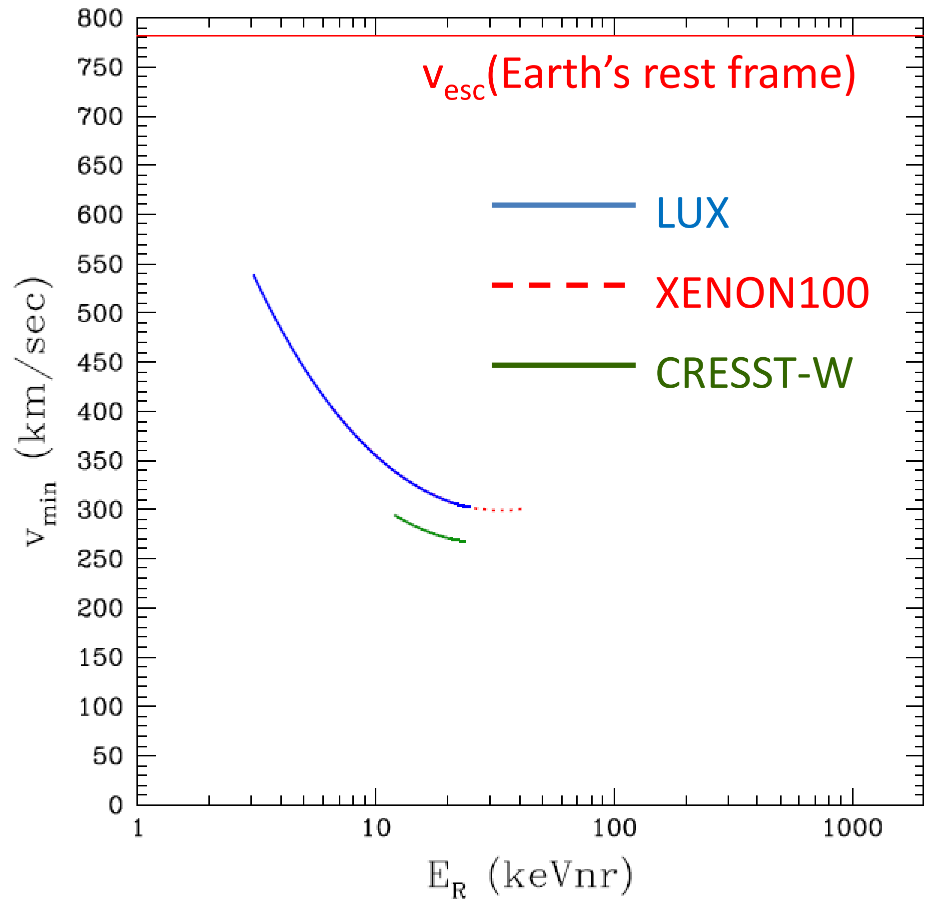
At higher masses upper bound of ROI is constraining

In LUX, XENON100→XENON100 more constraining than LUX due to lower light yield

S. Scopel and K.H. Yoon, JCAP1408, 060 (2014)

Sometimes a lower threshold is not the key, and the constraint comes from the highest energy range

Both LUX and XENON100 limited by S_1<30 PE to avoid cosmogenic ^{127}Xe activity. However higher light-yield for LUX (L_y=8.8 PE/keV vs L_y=2.2 PE/keV in XENON100) converts into lower upper value for recoil energy



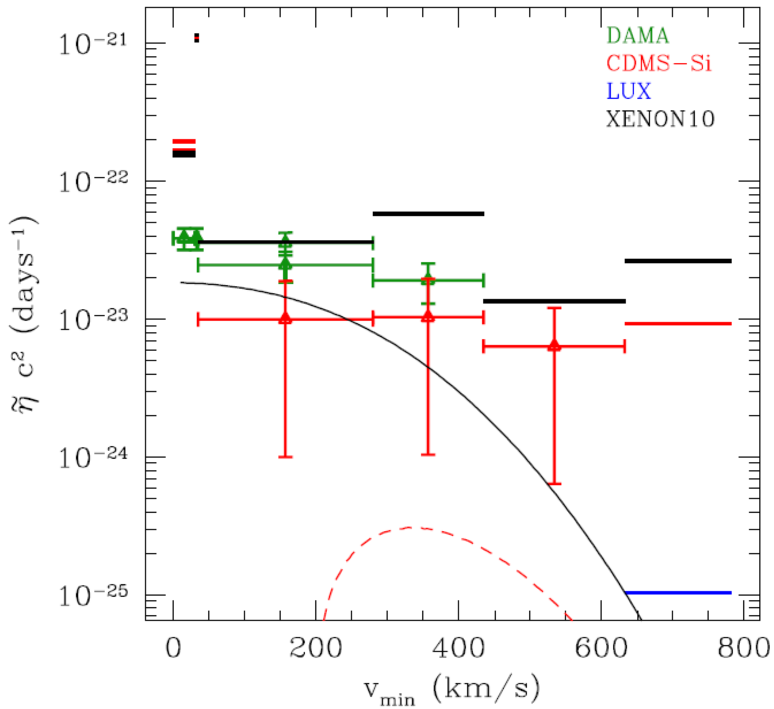
m_{DM}=350 GeV, δ=45 keV

NB:inelastic scattering is not the only example of WIMP differential rate not exponentially decaying with energy

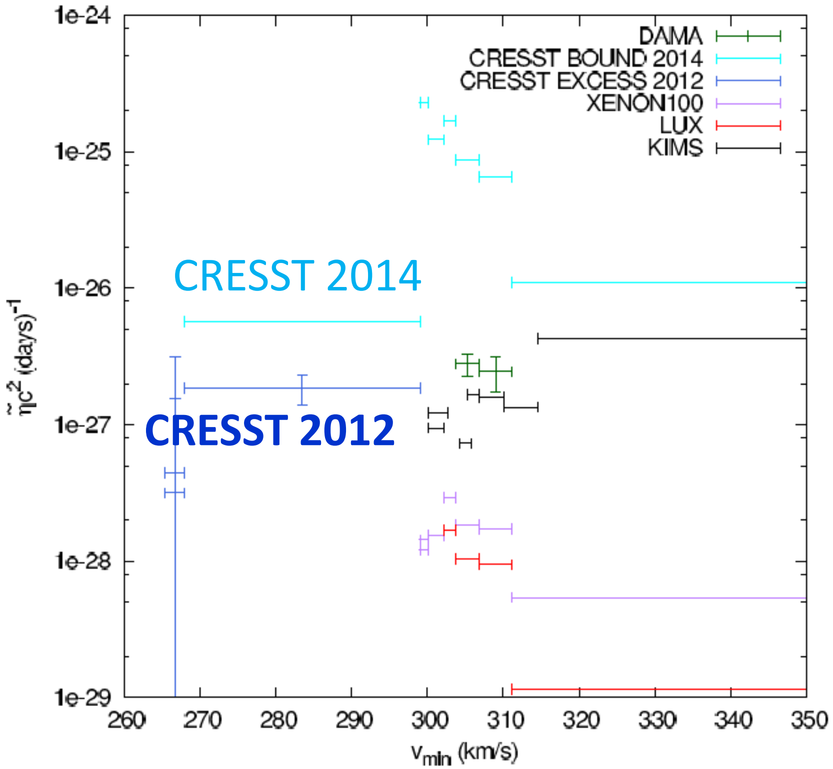
Halo-independent analysis of inelastic Dark Matter

"Agnostic" approach about velocity integral: a constraint does not affect values of v_{min} below its covered range, i.e. if v_{min}(bound)>v_{min}(signal)

m_{DM} =3 GeV, δ=-70 keV, f_n/f_p =-0.79



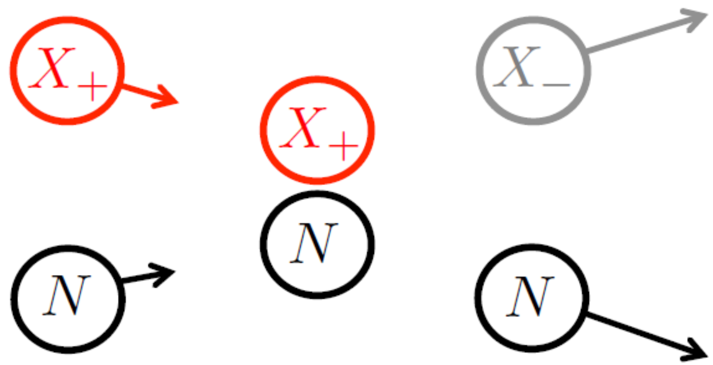
m_{DM} =350 GeV, δ=45 keV, f_n/f_p =1



- DAMA and CDMS-Si can be separately OK with bounds, but are always in tension between themselves
- Assuming standard Maxwellian more tension arises
- high-mass CRESST solution not affected by recent reanalysis due to low statistics

S. Scopel and K.H. Yoon, JCAP1408, 060 (2014)

A comment on exothermal DM ($\delta<0$) and the modulation effect



In exothermic scattering ($\delta<0$) the deposited recoil energy is dominated by the energy deposited in the exothermic process ~m'-m, and is independent on the WIMP incoming velocity. In this case if a yearly modulation is observed, it can hardly be produced by the boost from the galactic to the Earth rest frame→ solar-system scale features in the DM spatial distribution?

Additional "epicycle" required to reconcile DAMA effect or CDMS-Si 3 events with SuperCDMS bound: **isospin violation** (iso-vector couplings)

$$R = \sigma_p \sum_i \eta_i \frac{\mu_{A_i}^2}{\mu_p^2} I_{A_i} \left[Z + (A_i - Z) f_n / f_p \right]^2$$

(spin-independent cross section)

sum over isotopes

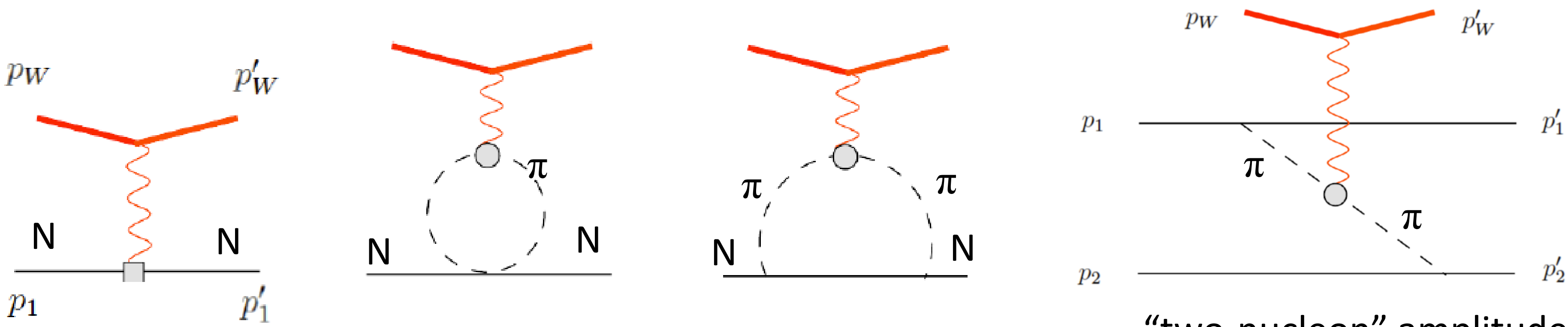
Cancellation between f_p (WIMP-proton coupling) and f_n (WIMP-nucleon coupling) when $f_n/f_p \sim -Z/(A-Z) \rightarrow$ can suppress the scattering cross section on Germanium for $f_n/f_p \sim -0.79$

Minimal "degrading factors", i.e. maximal factors by which the reciprocal scaling law between two elements can be reduced (limited by multiple isotopes, one choice of f_n/f_p ratio cannot fit all)

Element	Xe	Ge	Si	Ca	W	Ne	C
Xe (54, *)	1.00	8.79	149.55	138.21	10.91	34.31	387.66
Ge (32, *)	22.43	1.00	68.35	63.14	130.45	15.53	176.47
Si (14, *)	172.27	30.77	1.00	1.06	757.44	1.06	2.67
Ca (20, *)	173.60	31.53	1.17	1.00	782.49	1.10	2.81
W (74, *)	2.98	13.88	177.46	166.15	1.00	41.64	466.75
Ne (10, *)	163.65	28.91	4.39	4.09	726.09	1.00	11.52
C (6, *)	176.35	32.13	1.07	1.02	789.59	1.12	1.00
I (53, 127)	1.94	5.51	127.04	118.35	20.68	28.92	326.95
Cs (55, 133)	1.16	7.15	139.65	127.61	12.32	31.88	355.27
O (8, 16)	178.49	32.13	1.08	1.03	789.90	1.13	1.01
Na (11, 23)	101.68	13.77	8.45	8.33	481.03	2.27	22.68
Ar (18, 36)	178.49	32.13	1.08	1.03	789.90	1.13	1.01
F (9, 19)	89.39	10.88	12.44	11.90	425.93	3.05	33.47

(J.L.Feng, J.Kumar, D.Marfatia and D.Sanford, Phys.Lett.B703, 124 (2011), 1102.4331)

Actually, the nucleus does not contain only protons and nucleons: what about scattering on pions?



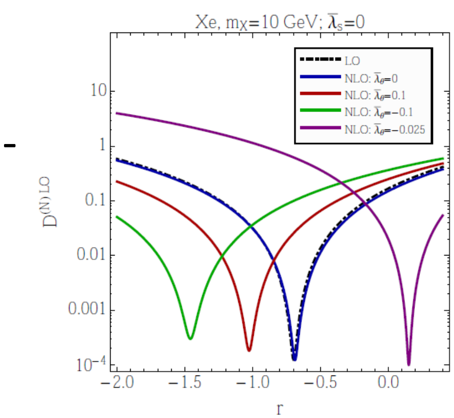
"two-nucleon" amplitude

NLO effect, so usually negligible, with the exception of specific situations where the LO contribution is suppressed → **isospin violation!**

$$\frac{dR}{dE_R}^{\mathrm{NLO}} = \frac{\sigma_p \rho_0}{2\mu^2 m_X} \left| \left[Z\left(1 + s_p E_R\right) + \left(A - Z\right)\left(r + s_n E_R\right) \right] F(E_R) + A_2(E_R) \right|^2 \times \eta\left(E_R, m_X, m_A\right)$$

Two main effects:

- different cancellation mechanism between "two-nucleon" and "single-nucleon" amplitudes leads to very different values of f_n/f_p maximizing the degrading factor
- NLO corrections are **energy dependent** so can spoil the cancellation across energy bins



V.Cirigliano, M.L.Graesser and G.Ovanesyan, JHEP1210, 025 (2012)1205.2695; V.Cirigliano,M.L.Graesser, G.Ovanesyan and I.M.Shoemaker,1311.5886

Effective scalar four-fermion interaction (S.S. and J.H. Yoon, 1411.3683)

Effective Lagrangian:

$$\mathcal{L} = \sum_{q=u,d,s,c,b,t} \frac{m_q \tilde{\lambda}_q}{\Lambda^3} \bar{\chi}' \chi \bar{q} q + \text{h.c.}$$

after integrating out heavy quarks:

$$\mathcal{L} = \sum_{q=u,d,s} \frac{m_q \lambda_q}{\Lambda^3} \bar{\chi}' \chi \bar{q} q + \sum_{q=u,d,s} \frac{m_q \lambda_\theta}{\Lambda^3} \bar{\chi}' \chi \theta^\mu_\mu + \text{h.c.}$$

with:

$$\lambda_q \equiv \tilde{\lambda}_q - \lambda_\theta$$

$$\lambda_\theta \equiv 2/27 \sum_{Q=c,b,t} \tilde{\lambda}_Q$$

Phenomenology depends only on the ratio:

$1/\tilde{\Lambda}^3 \equiv \lambda_u/\Lambda^3$ so can absorb λ_u in the suppression scale definition and only the three ratios $\bar{\lambda}_q \equiv \lambda_q/\lambda_u$ (q=d,s) and $\bar{\lambda}_\theta \equiv \lambda_\theta/\lambda_u$ remain. Fix $\bar{\lambda}_d$ to maximize Si-Ge relative degrading factor→ only two parameters remain, $\bar{\lambda}_\theta$ and $\bar{\lambda}_s$

Effective scalar four-fermion interaction (S.S. and J.H. Yoon, 1410. 3683)

From direct detection data to suppression scale

Once $\tilde{\eta}$ is fixed by experiment need f(v) to get info on the cross section and the suppression scale Λ

$$\tilde{\eta}(v_{min}) \equiv \frac{\rho_\chi}{m_\chi}\sigma_0 \eta(v_{min})$$

Can only *maximize η* and *minimize* cross section taking:

$$f(\vec{v}) = \delta(v_s - v_{min})$$

(v_s = maximal value of the v_{min} range corresponding to the CDMS–Si excess)

$$\tilde{\eta}^{max}(v_{min}) = \bar{\tilde{\eta}}_{fit}^{CDMS-Si}\theta(v_s - v_{min})$$

N.B. corresponds to fitting the exp etas to a constant value, actually compatible to data

get Λ fixing expected rate to CDMS-Si signal:

$$\frac{dR}{dE_R} = MT\frac{\rho_\chi}{2\tilde{\Lambda}^6 \pi m_\chi} N_T \sum_A f_A \left|(Z f_p^{NLO} + (A-Z) f_n^{NLO}) F(E_R) + A f_{2N}^{NLO}\right|^2 \eta(v_{min}(E_R))$$

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The LO amplitude for WIMP-nucleus interaction can be written as:

$$Z\left[M_d\bar{\lambda}_d + M(\bar{\lambda}_s, \bar{\lambda}_\theta)\right] + A\left[P_d\bar{\lambda}_d + P(\bar{\lambda}_s, \bar{\lambda}_\theta)\right]$$

with M_d,P_d some constants and $M(\bar{\lambda}_s\ \bar{\lambda}_\theta)$, $P(\bar{\lambda}_s\ \bar{\lambda}_\theta)$ functions of $\bar{\lambda}_s$and $\bar{\lambda}_\theta$. For:

$$m_s\bar{\lambda}_s + m_p\bar{\lambda}_\theta + \frac{2m_u}{m_u+m_d}\sigma_{\pi,N} = 0$$

the following relation holds:

$$\frac{M(\bar{\lambda}_s, \bar{\lambda}_\theta)}{M_d} = \frac{P(\bar{\lambda}_s, \bar{\lambda}_\theta)}{P_d} \equiv f(\bar{\lambda}_s, \bar{\lambda}_\theta)$$

and the amplitude acquires the factorization:

$$\left[\bar{\lambda}_d + f(\bar{\lambda}_s, \bar{\lambda}_\theta)\right]\left[M_d Z + P_d A\right]$$

So when λ_d =-f the amplitude vanishes for all nuclei! What happens? Simply f_p ,f_n →0 at fixed $r=f_n/f_p$: the WIMP cross sections on protons and neutrons vanish at the same time.

Interesting regime: keeping r fixed compatibility between Si and Ge can be maintained but if the expected rate is fixed to explain CDMS-Si requires a smaller suppression scale Λ

Enhancement of other signals and of coannihilation rate in the early Universe

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$$Z\left[M_d\bar{\lambda}_d + M(\bar{\lambda}_s,\bar{\lambda}_\theta)\right] + A\left[P_d\bar{\lambda}_d + P(\bar{\lambda}_s,\bar{\lambda}_\theta)\right]$$

N.B.: when energy—dependent terms are neglected also the NLO amplitude keeps the same form, although with slightly modified coefficients. So also in this case there is a straight line in the $\bar{\lambda}_s$-$\bar{\lambda}_\theta$ plane where the amplitude vanishes for all nuclei. Notice that now it is not even possible to factorize a cross section on protons or neutrons, the cancellation involves also the 2-nucleon amplitude.

However in this same region the LO amplitude is small, so when the parameters are too close to the straight line energy-dependent NLO terms can no longer be neglected → the cancellation in WIMP-Ge amplitude is spoiled to the point that compatibility between CDMS-Si and SuperCDMS can no longer be possible

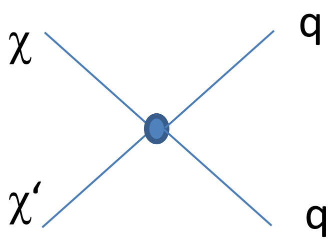
Introduce following "compatibility ratio" including energy (i.e. v_{min}) dependence:

$$\mathcal{D}(m_\chi,\delta,\bar{\lambda}_d,\bar{\lambda}_s,\bar{\lambda}_\theta) \equiv \max_{i\in\text{signal}}\left(\frac{\bar{\tilde{\eta}}_i^{CDMS-Si}+\sigma_i}{\min_{j\leq i}\bar{\tilde{\eta}}_{j,lim}}\right)$$

(when D=1 the stronger constraint "touches" the upper range of the CDMS-Si effect)

Effective scalar four-fermion interaction (S.S. and J.H. Yoon, 1410. 3683)

Thermal relic abundance



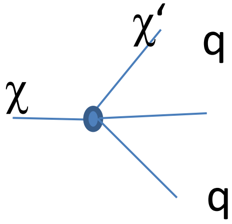
$\delta << T_{decoupling}$ chemical potential between χ and χ' negligible

→ same abundance of χ and χ' in the present Universe? In this case for m_χ ~3 GeV and $|\delta| \geq 20$ keV *all direct detection experiments would be sensitive to only one half of the DM particles* because, <u>for down-scattering :</u>

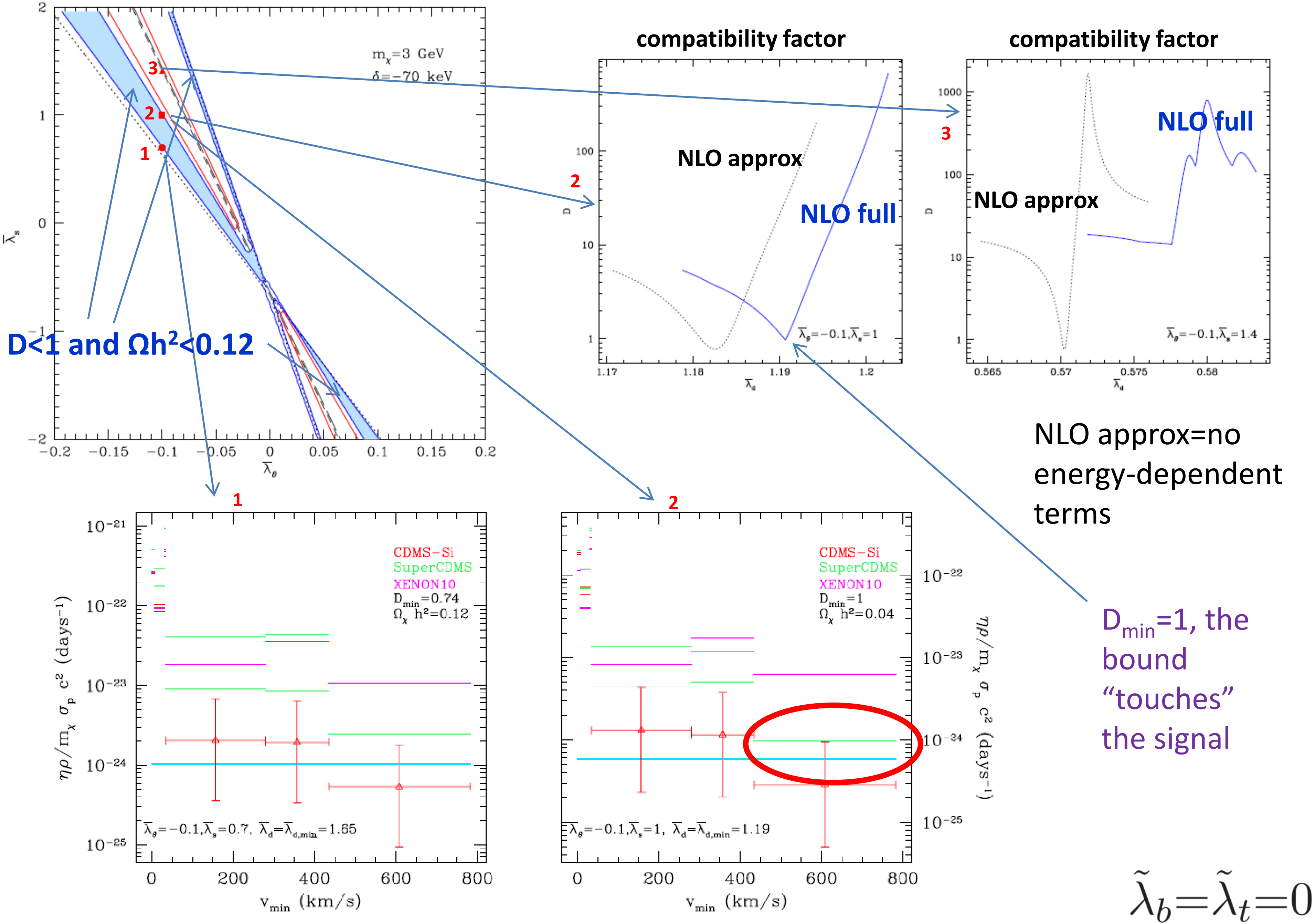
$$v^*_{min} = \sqrt{\frac{2|\delta|}{\mu_{\chi N}}}$$

>950 km/sec (larger than the escape velocity boosted in the Earth's rest frame)

N.B. Lifetime for χ' decay ~10^{26} seconds, much larger than the age of the Universe (K. R. Dienes, J. Kumar, B. Thomas and D. Yaylali, 1406.4868)



Effective scalar four-fermion interaction (S.S. and J.H. Yoon, 1410. 3683)



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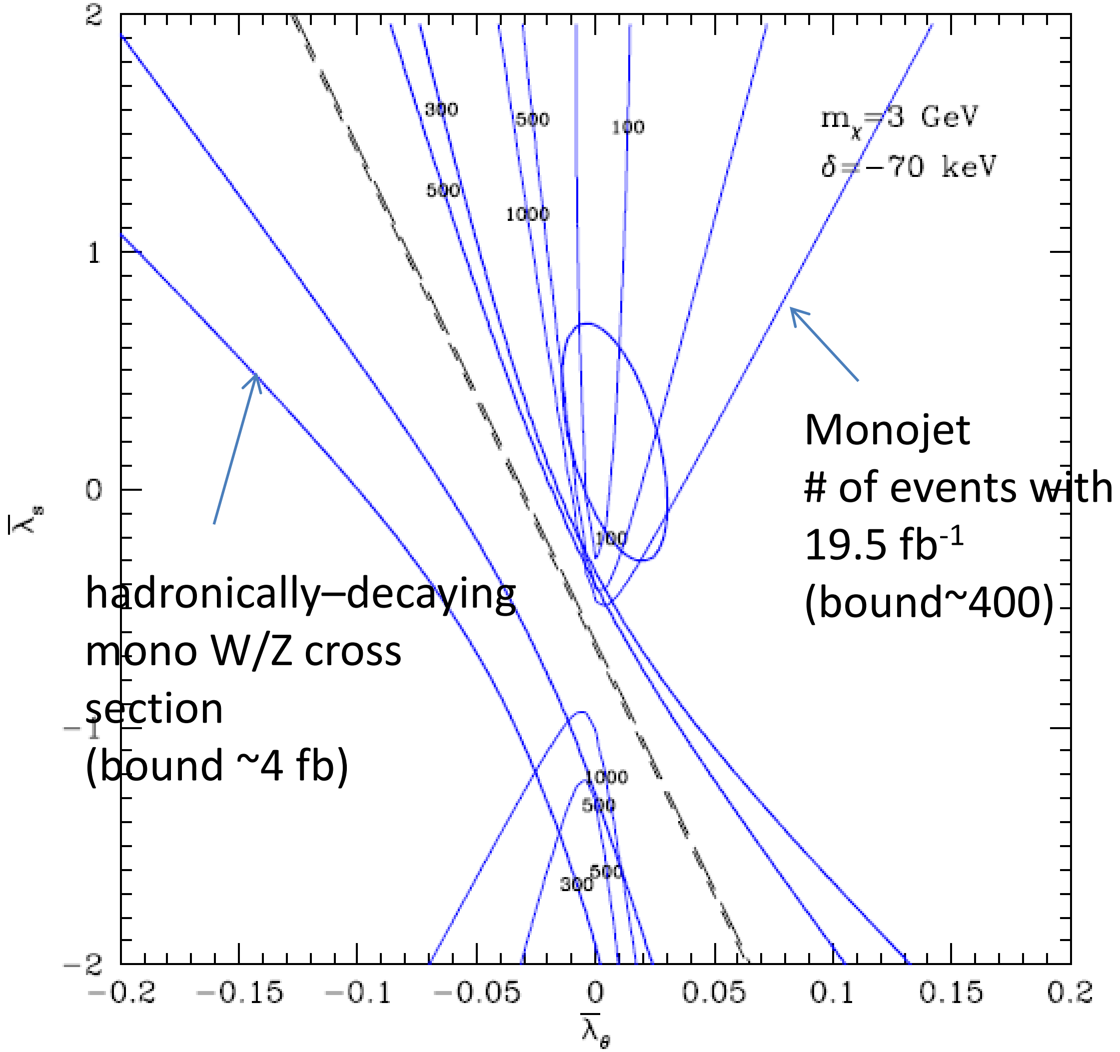
Large LHC signals



mono W/Z much larger than constraint, but validity of EFT approach questionable (required suppression scale <100 GeV)

$$\tilde{\lambda}_b = \tilde{\lambda}_t = 0$$

Conclusions

• excesses from DAMA, CoGeNT, CDSM-Si CRESST still around

• For the immovable optimists WIMP-like exlanations are not out of the game yet: DAMA+CDMS-Si can still be explained (separately) by “Ge-phobic exothermic“ DM; CRESST still compatible with inelastic DM (in both cases need to go beyond the Isothermal Sphere for WIMP velocity distribution)

• isospin violation can be tuned to kill LO WIMP-nucleon cross altogether→ can get at the same time correct thermal relic abundance and compatibility between CDMS-Si and other experiments. <u>however when LO contribution vanishes NLO corrections can become important spoiling the cancellation required by the isospin-violation mechanism.</u>

•In this scenario each of the two WIMP states provides one half of the DM in our Galaxy, but direct detection experiments are only sensitive to downscatters of the lighter state to the heavier one.