The Search for Low-mass WIMPs

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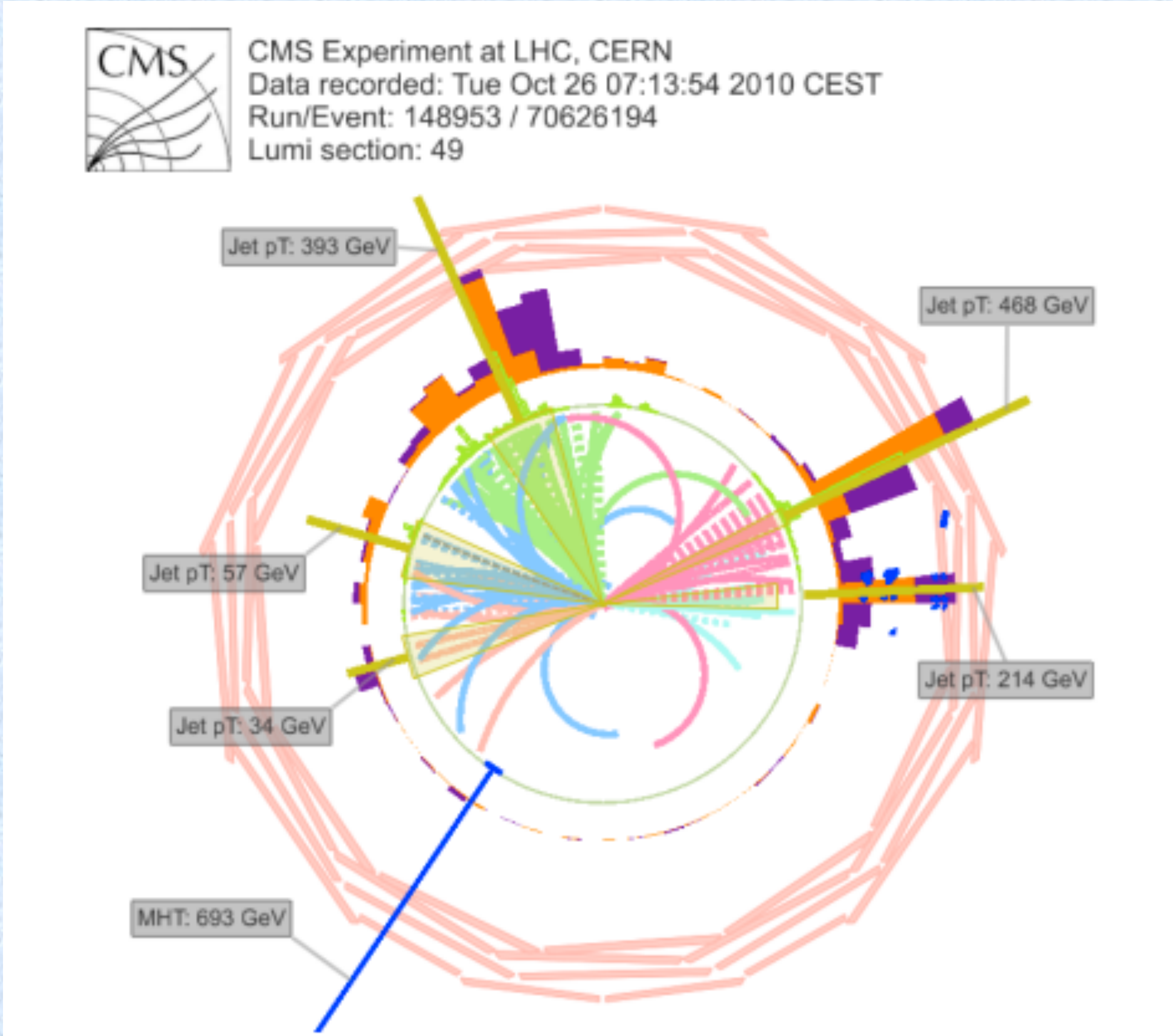
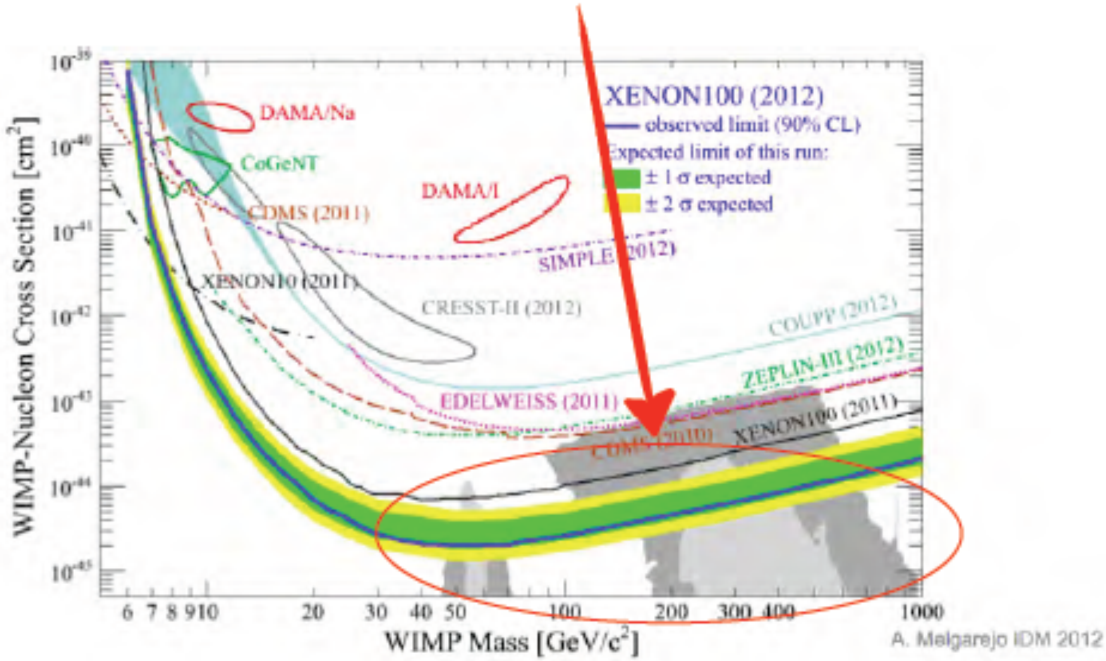

CMS
CMS Experiment at LHC, CERN
Data recorded: Tue Oct 26 07:13:54 2010 CEST
Run/Event: 148953 / 70626194
Lumi section: 49
Jet pT: 393 GeV
Jet pT: 468 GeV
Jet pT: 57 GeV
Jet pT: 214 GeV
Jet pT: 34 GeV
MHT: 693 GeV

Weak Scale WIMP



From: G. Buchmueller et al
June 2011

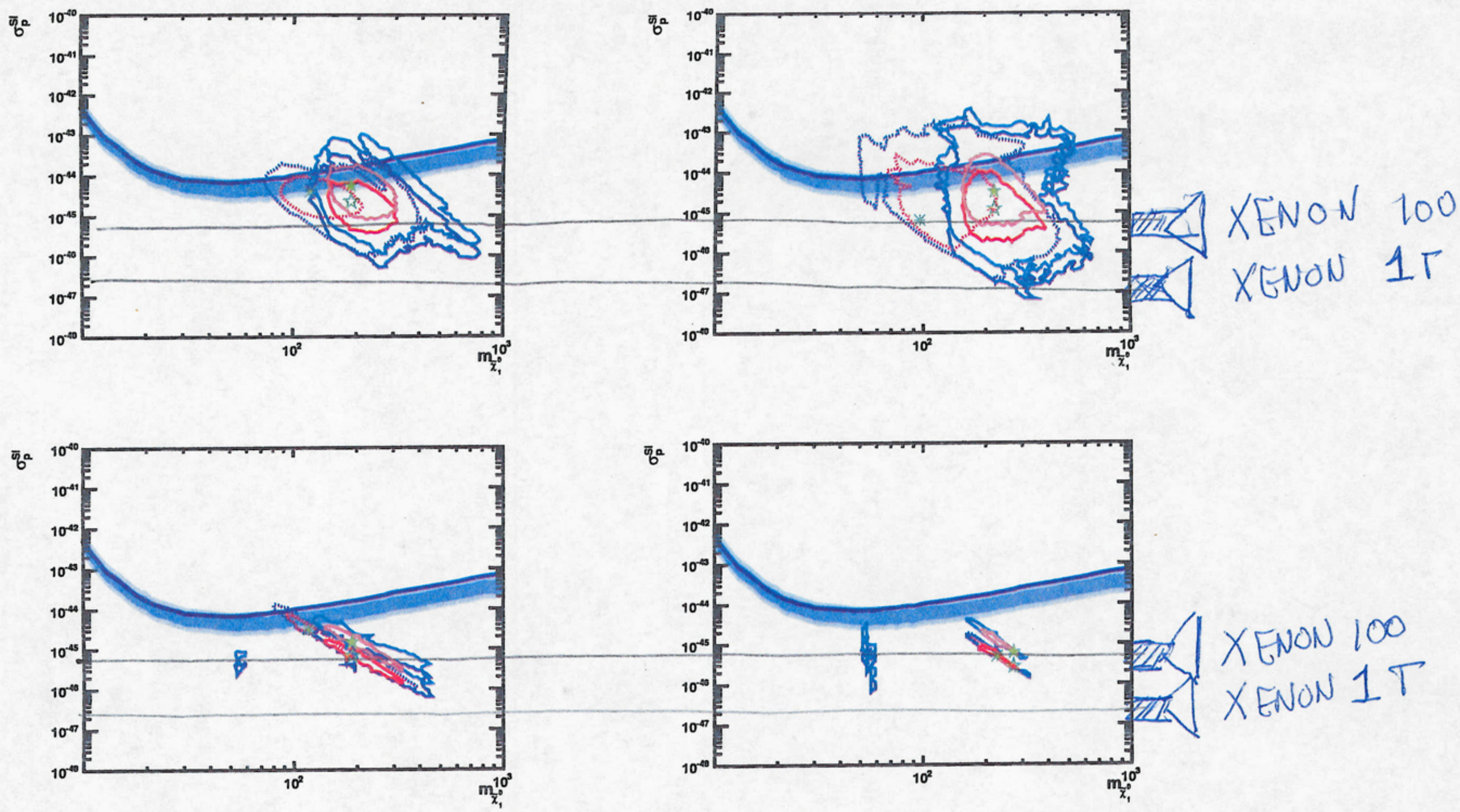
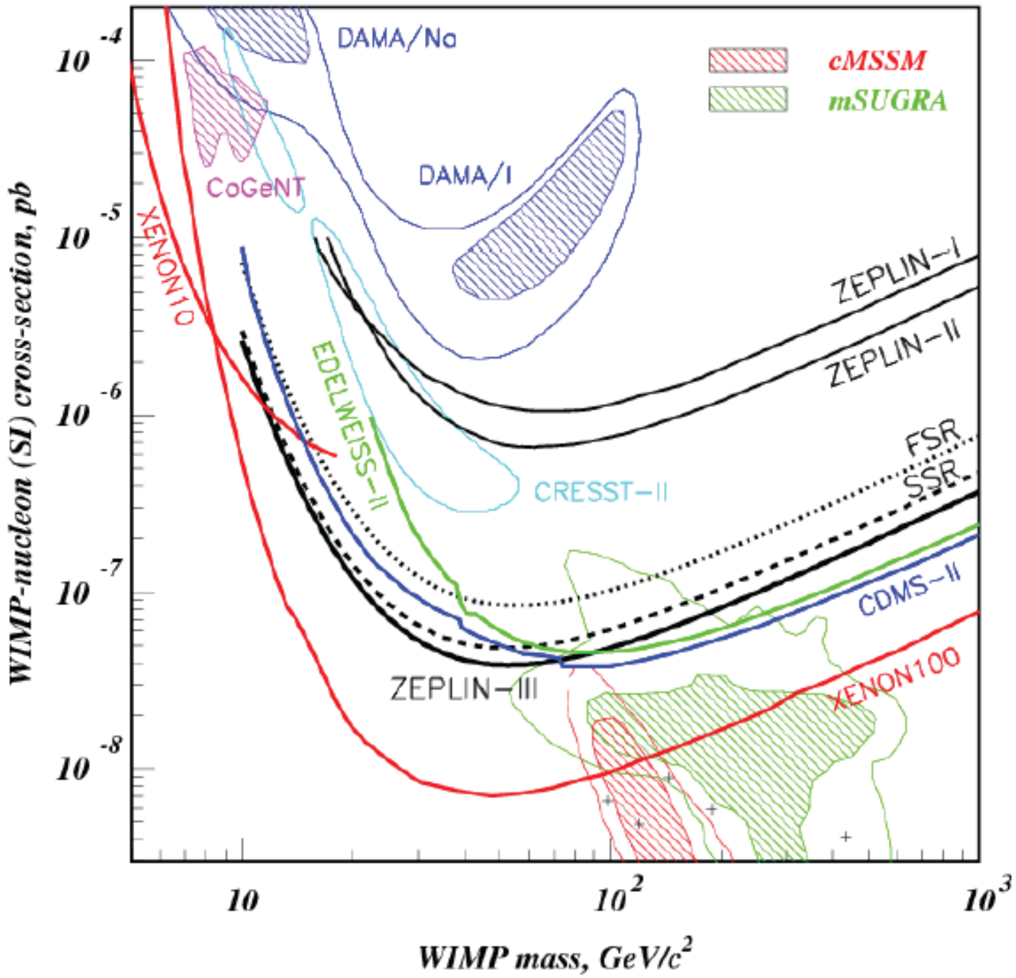


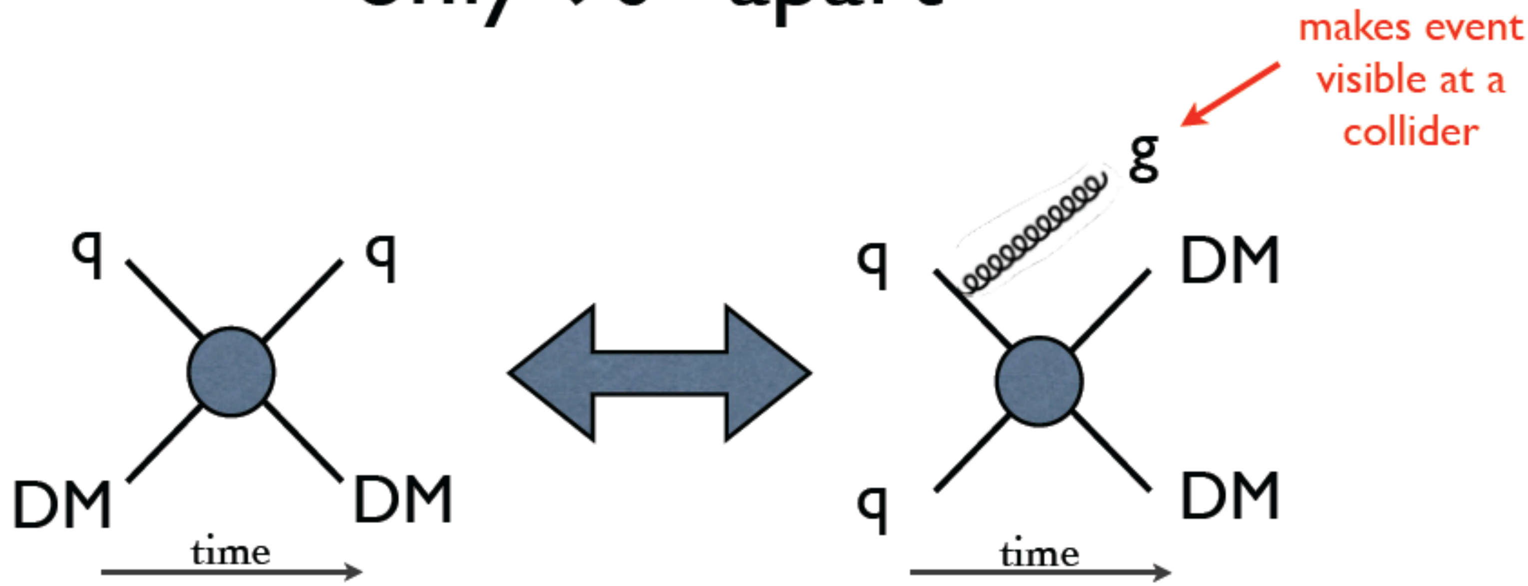
Figure 10. *The correlation between the spin-independent dark matter scattering cross section* σ_p^{SI} *and* $m_{\tilde{\chi}_1^0}$ *prior to the inclusion of the current Xenon100 results in the CMSSM (upper left panel), in the NUHM1 (upper right panel), in the VCMSSM (lower left panel) and in mSUGRA (lower right panel). In each panel, we show the 68 and 95% CL contours (red and blue, respectively), the dotted curves correspond to our pre-2010-LHC results, and the solid lines include the 2010 LHC results. Results assuming* $\Sigma_{\pi N} = 50$ MeV *are shown as brighter coloured curves and* $\Sigma_{\pi N} = 64$ MeV *as duller coloured curves, in each case disregarding uncertainties. The green 'snowflakes' (open stars) (filled stars) are the best-fit points in the corresponding models. Also shown is the 90% CL Xenon100 upper limit [24] and its expected sensitivity band.*

DAMA Interpretation and Current Limits



From ZIII Araujo
2008 results - no channeling

Monojets and direct detection, only 90° apart



Birkedal, Matchev, Perelstein (2004)

Beltran, Hooper, Kolb, Krusberg, Tait (2010)

Goodman, Ibe, Rajaraman, Shepherd, Tait, Yu (2010)

Bai, Fox, Harnik (2010)

Rajaraman, Shepherd, Tait, Wijanco (2011)

Fox, Harnik, Kopp, Tsai (2011)

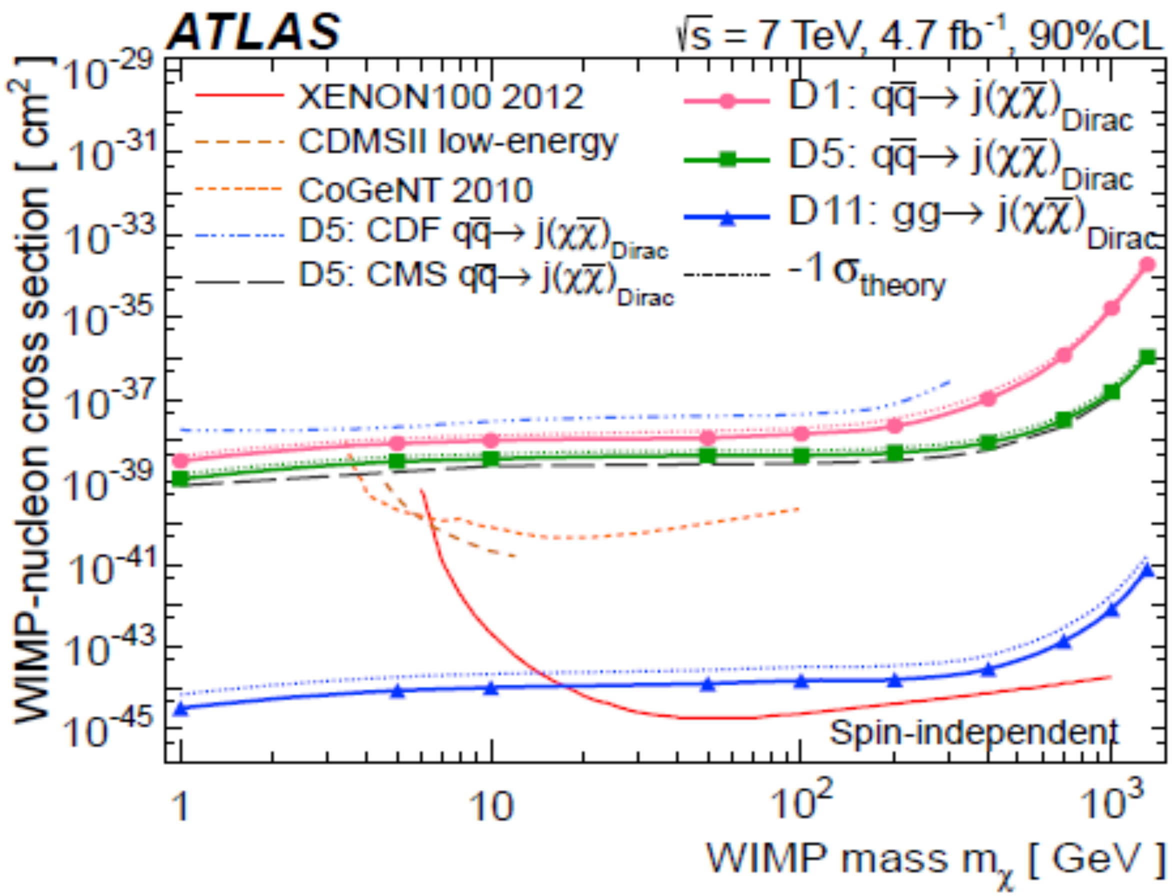


Figure 5. Inferred 90% CL ATLAS limits on spin-independent WIMP-nucleon scattering. Cross sections are shown versus WIMP mass m_χ. In all cases the thick solid lines are the observed limits excluding theoretical uncertainties; the observed limits corresponding to the WIMP-parton cross section obtained from the $-1\sigma_{\text{theory}}$ lines in figure 4 are shown as thin dotted lines. The latter limits are conservative because they also include theoretical uncertainties. The ATLAS limits for operators involving quarks are for the four light flavours assuming equal coupling strengths for all quark flavours to the WIMPs. For comparison, 90% CL limits from the XENON100 [70], CDMSII [71], CoGeNT [72], CDF [19], and CMS [21] experiments are shown.

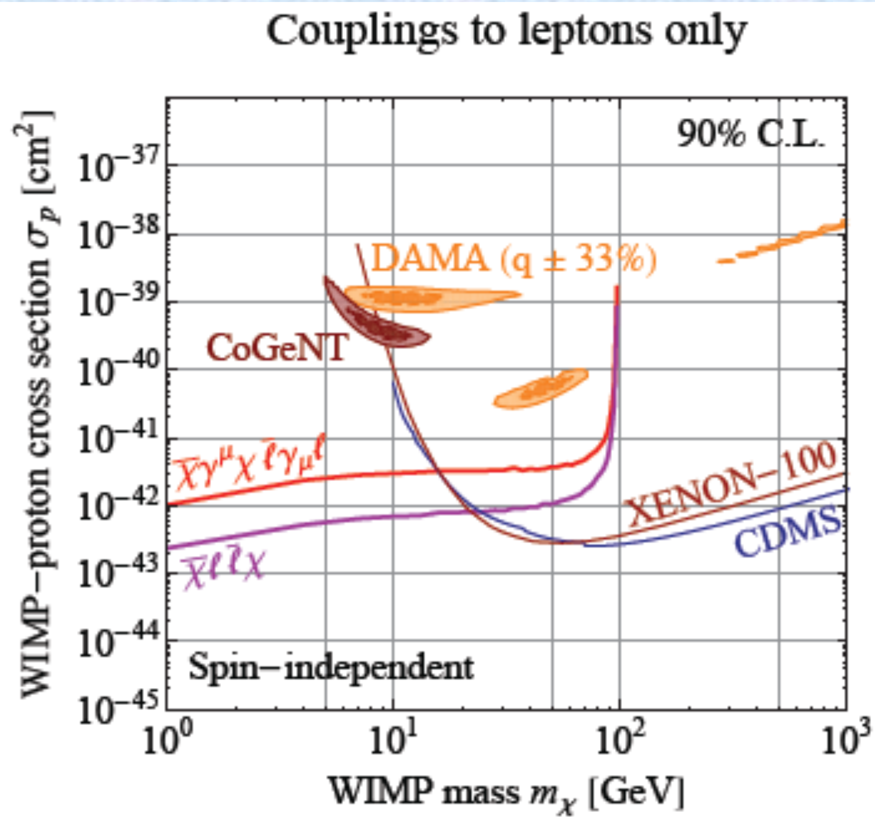
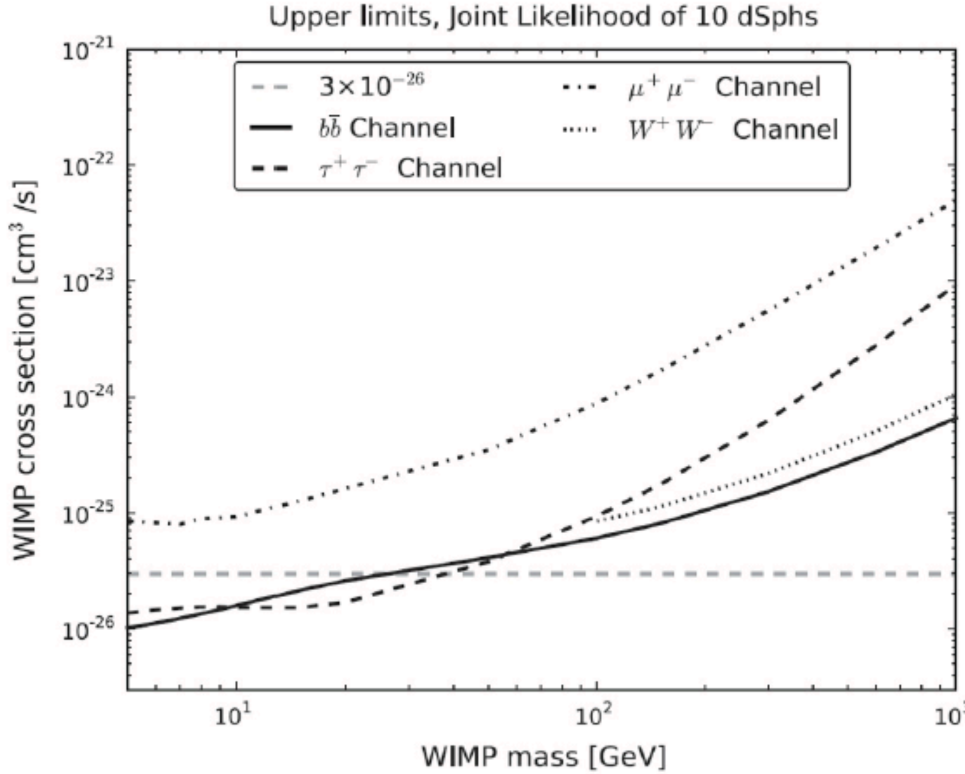


Figure 5: DELPHI upper limits on the cross section for spin-independent dark matter–nucleon scattering for the case of dark matter with tree level couplings only to electrons, but loop level couplings also to quarks, compared to results from the direct detection experiments DAMA [10], CoGeNT [11], CDMS [30], and XENON-100 [31]. The DAMA and CoGeNT allowed regions are based on our own fit [36] to the data from refs. [10, 11]. We conservatively assume $q_{\rm Na} = 0.3 \pm 0.1$ and $q_{\rm I} = 0.09 \pm 0.03$ for the DAMA quenching factors. All limits are computed at the 90% confidence level, while the DAMA and CoGeNT allowed regions are shown at the 90% and 3σ confidence levels.

Dwarf Spheroidal Galaxies

PRL 107, 241302; arXiv:1108.3546

- **Robust constraints come from a joint likelihood analysis of**
  - **10 dwarf galaxies**
  - **200 MeV - 100 GeV gamma-rays**
  - **2 years of data**
  - **4 annihilation channels**
- **Exclude the conventional thermal cross section for a WIMP with mass < 30 GeV annihilating to $b\bar{b}$ or $\tau^+\tau^-$.**
- **Include uncertainties in the solid-angle-integrated J-factor.**



Surpassing the 2012 XENON100 exclusion limit with 2011 data and information theory

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Tremendous progress in the field of dark matter direct detection has allowed modern experiments to reach the sensitivity that is required to exclude large regions of parameter space. The strongest exclusion limit has been set by the XENON100 collaboration which has recently updated the constraint on the dark matter parameter space to an even greater degree. The method used by the collaboration to set this limit is based on a profile Likelihood analysis, which separates the experimental data into bands to better discriminate a potential dark matter nuclear-recoil signal from the electronic-recoil background. However the use of bands is not strictly necessary and tends to make the limit over-conservative. Here we propose an alternative method based on information theory and apply it to the 2011 data-set from the XENON100 experiment. We derive a new exclusion limit with this data which is both stronger than that derived by XENON100 with their profile Likelihood analysis using the same data, and competitive with the new limit which was derived using the recent 2012 data-set.

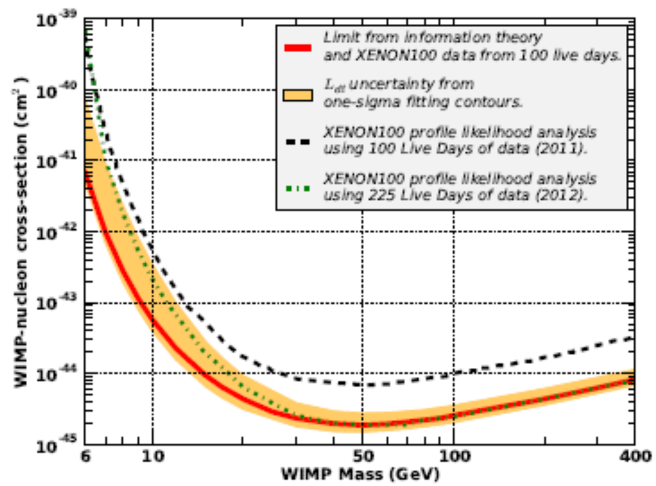

FIG. 2: Limit calculated using the method presented in this letter and 100 live days of XENON100 data [4] (solid red line) with uncertainties due to $L_{\rm eff}$ fitting as the shaded region. The 2011 [4] and 2012 [3] exclusion limits obtained by the XENON100 collaboration are shown as a black dashed line and green dot-dashed line respectively.

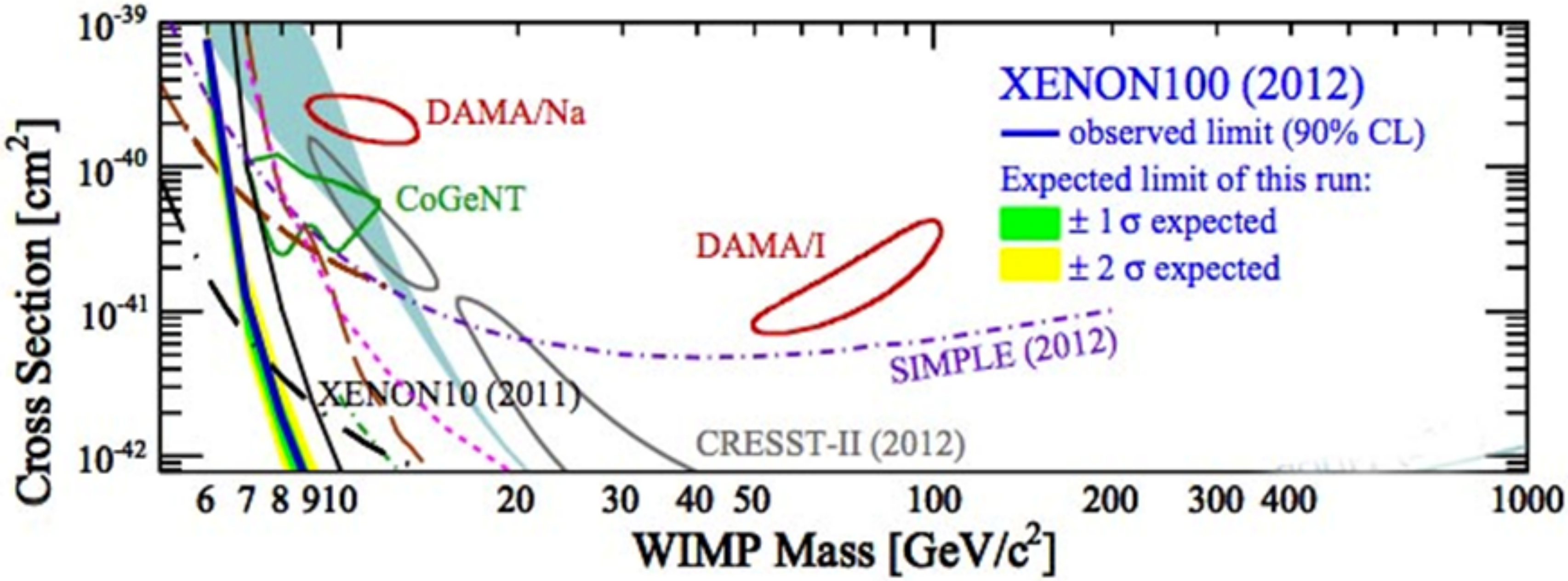

Figure 1. An enlargement of the low mass scale of WIMP searches from the recent XENON100 225 day paper (E. Aprile et al, "Dark Matter Results from 225 Live Days of XENON100 Data," http://arxiv.org/abs/1207.5988).

Astroparticle Physics 33 (2010) 91–96

Contents lists available at ScienceDirect

Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropart

The expected background spectrum in NaI dark matter detectors and the DAMA result

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A R T I C L E I N F O

Article history:
Received 6 September 2009
Received in revised form 14 November 2009
Accepted 11 December 2009
Available online 16 December 2009

Keywords:
Dark matter
WIMPs
Background radiation
Radioactivity
DAMA experiment

A B S T R A C T

Detailed Monte Carlo simulations of the expected radioactive background rates and spectra in NaI crystals are presented. The obtained spectra are then compared to those measured in the DAMA/NaI and DAMA/LIBRA experiments. The simulations can be made consistent with the measured DAMA spectrum only by assuming higher than reported concentrations of some isotopes and even so leave very little room for the dark matter signal. We conclude that any interpretation of the annual modulation of the event rate observed by DAMA as a dark matter signal, should include full consideration of the background spectrum. This would significantly restrict the range of dark matter models capable of explaining the modulation effect.

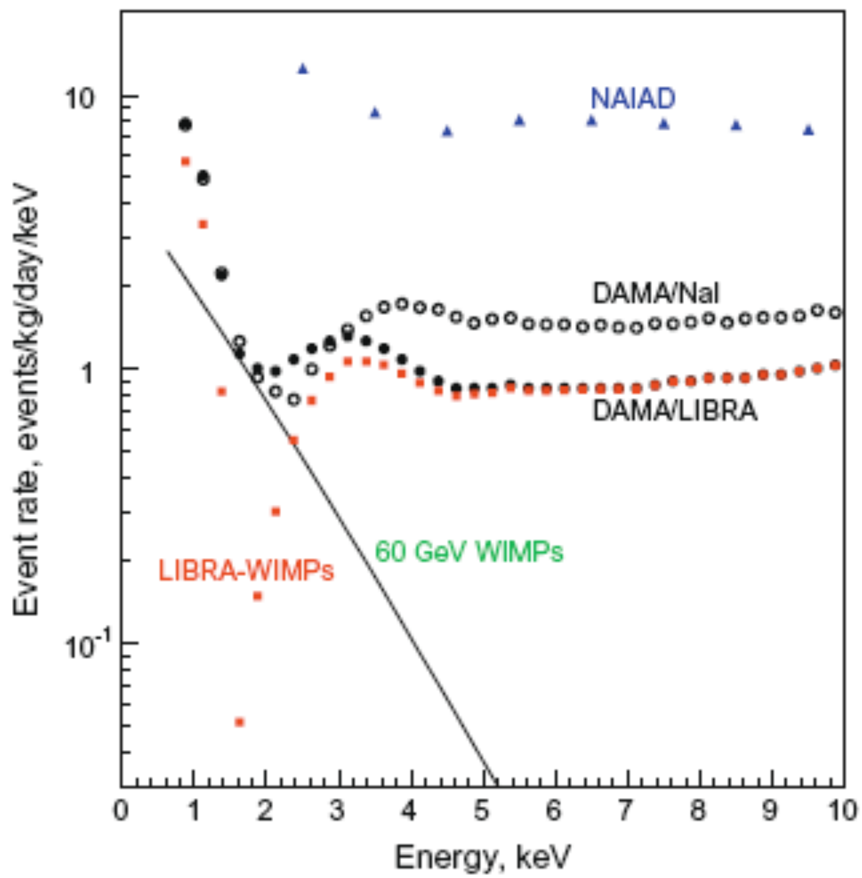


Fig. 3. Energy spectra of single hit events as reported by the DAMA/NaI [2] (open circles) and DAMA/LIBRA [3] (filled circles) experiments. The spectrum of events expected from 60 GeV WIMP interactions with the spin-independent cross-section of 7×10^{-6} pb in the isothermal halo model is shown as example by the solid curve (labeled as '60 GeV WIMPs'). The difference between the measured DAMA/LIBRA spectrum and the WIMP signal is plotted as filled squares (labeled as 'LIBRA-WIMPs'). An example spectrum from one of the NAIAD crystals is shown by filled triangles.

How To Measure the Correct Annual Variation Due To WIMP Interactions and the Earth's Movement Around the Sun

$$\text{Expected Variation of WIMP Signal } V = \frac{\text{Observed Variation of WIMP Interaction}}{\text{Fraction of Data that has WIMPs}}$$

Most models give an expected value of less than 10% but could go to 20%

DAMA Observation of V

$$V = \frac{\text{DAMA Annual Variation of Energy}}{\text{Fraction of Data with WIMPs}}$$

DAMA Annual Variation: 2-4 KeV ~2.5-3%
Fraction of Data with WIMPs: [0-20%]

4. Recent studies of the effect of K(40) in the DAMA experiment

In reference 11 it is shown that the bulk of the singles signal in DAMA is due to radioactive background. Now a new study (see Fig. 3) shows that less than 0.14 Cpd (Fig. 3) can at most be due to WIMPs. This means that the annual variation of the possible WIMPs signal would have to exceed 20%, which is outside any DM model. Reference 12 gives the results presented in Fig. 3. The excellent agreement with Ref. 11 and the excellent fit strongly suggest this is little or no WIMP signal in the data.

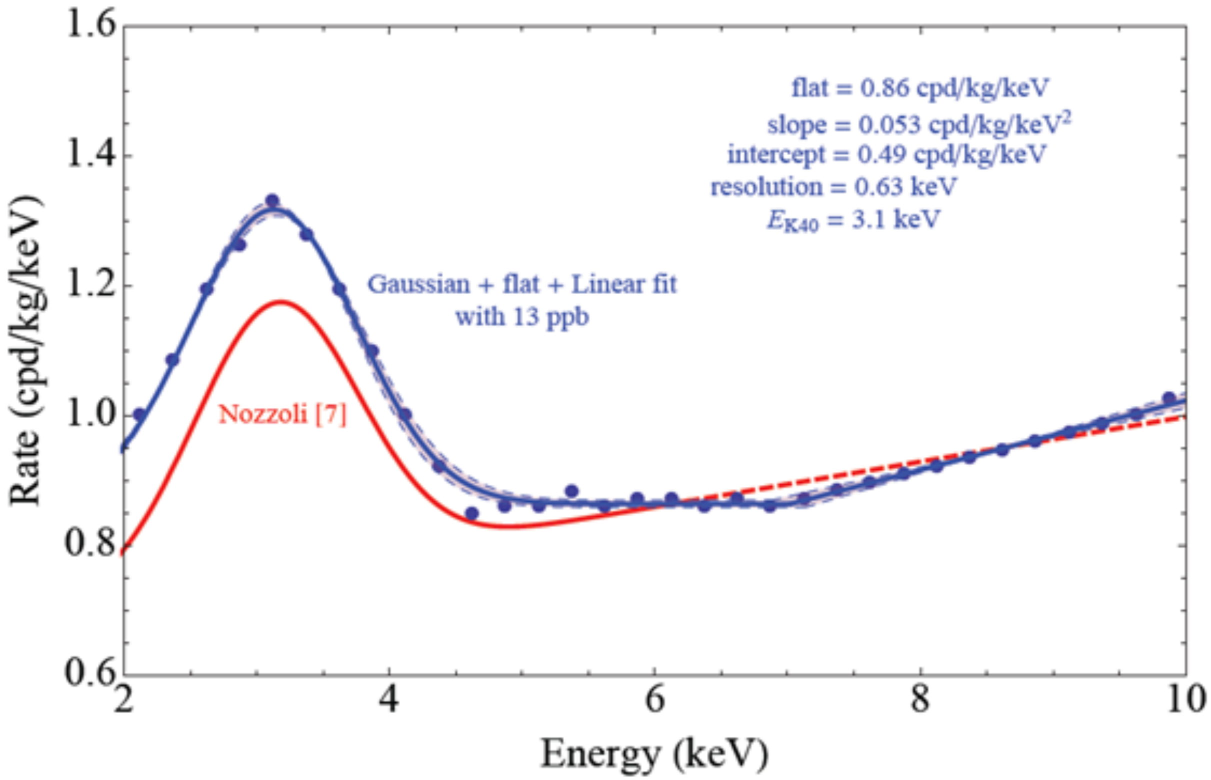
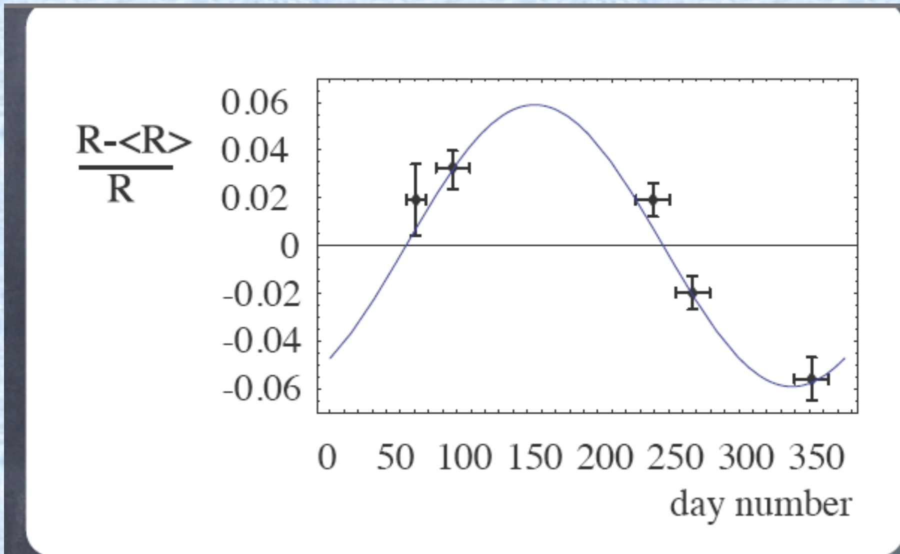


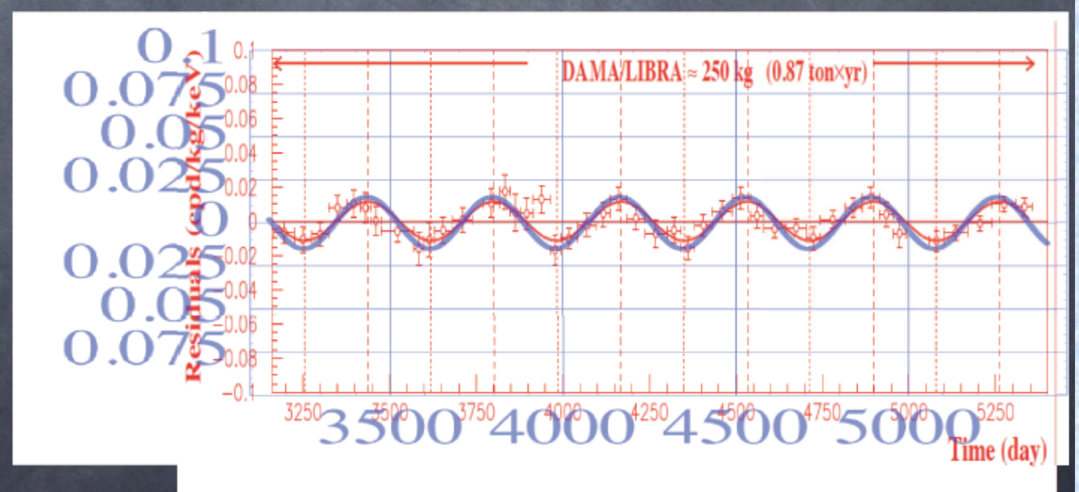
Figure 3. This figure shows the Dama/Libra (dots) and a fit to the data with the correct K (40) and the background from Ref. 11. There is also an estimate by DAMA (red). Even under these circumstances the amount of possible WIMP signal is very low. (Josef Pradler et al, "A reply to criticism of our work (arXiv:1210.5501) by the DAMA collaboration," http://arxiv.org/abs/1210.7548) [12]



ICARUS
neutron
time dependence...

predicts
DAMA/LIBRA
time
dependence...

arXiv:1006.5255 [hep-ph]



curve: icarus phase
points: Dama/Libra data

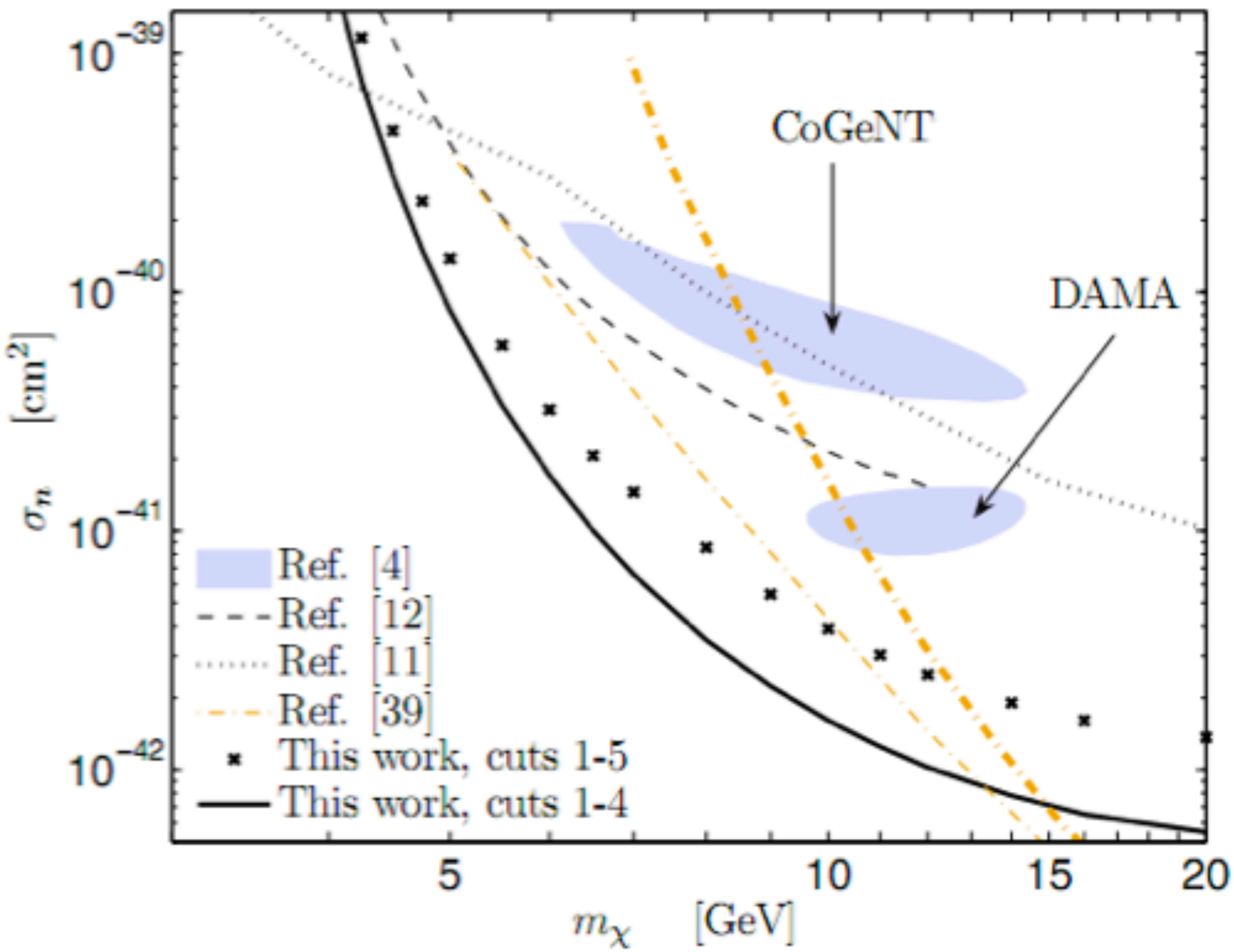
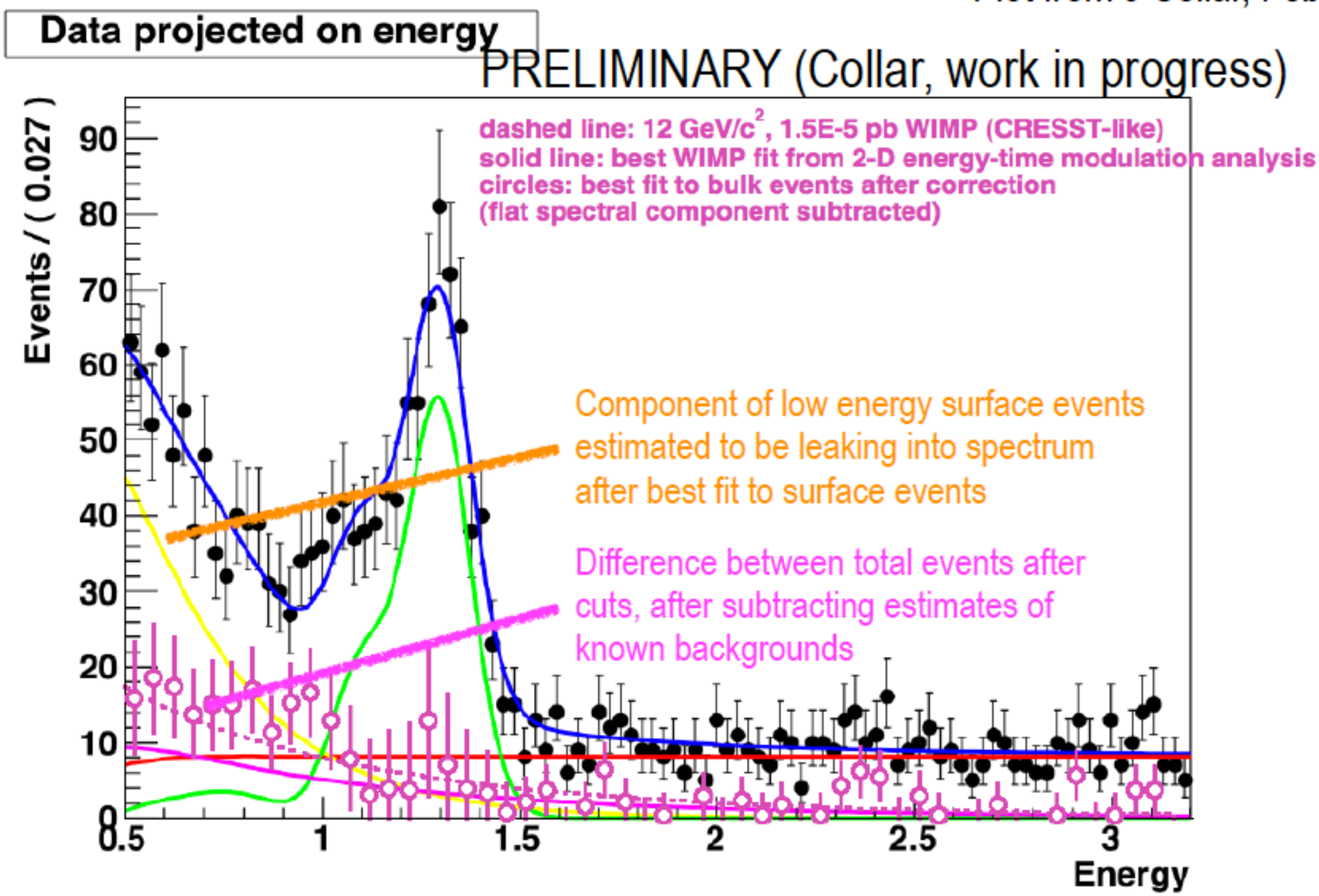


Figure 10. Curves indicate 90% C.L. exclusion limits on spin-independent σ_n for elastic dark matter scattering, obtained by CDMS (dotted [11] and dashed [12]), XENON100 (dash-dot [39]). 99% C.L. allowed regions consistent with the assumption of a positive detection are also shown, for signals from DAMA (with ion channeling) [4], and CoGeNT (assuming 30% exponential background) [4].

Recent GoGeNT Analysis

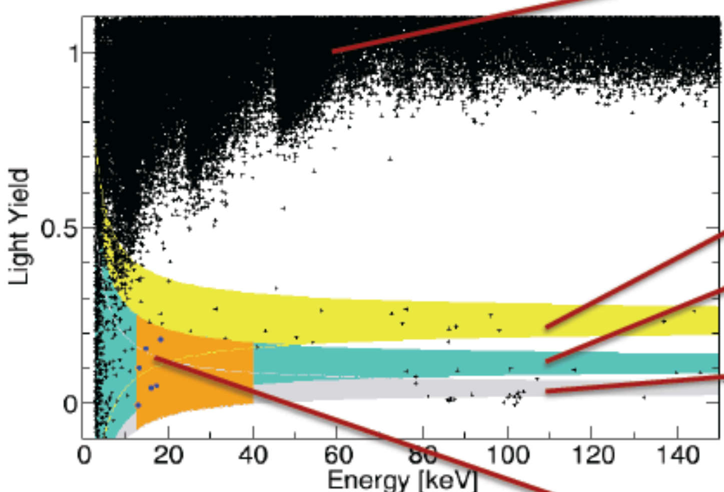
Plot from J Collar, Feb 2012



Spectral and modulation analysis in CoGeNT seem to point to a similar WIMP mass & coupling,
BUT then modulated amplitude is definitely not what you would expect from a vanilla halo (way too large).

Results of Run32 (2009-2011)

Data of one single 300g detector module in Run32:



Electron recoils: excellent discrimination of from e/γ−band and nuclear band

α−events: from surfaces

O-band: neutrons or „light"-WIMPs

W-band: expect „heavy"-WIMP interaction -> band is contaminated by recoiling ^{206}Pb nuclei from ^{210}Po α-decays (clamps), 103keV downwards

67 events at low energy observed in O, Ca and W-bands in all detector modules (~730kg d)

Acceptance region:

includes O, Ca and W recoil bands

E_{max}: 40keV (WIMP signal negligible above)

E_{min}: e/γ-leakage of 1 event per module in whole data set (10 – 19keV, module dependent)

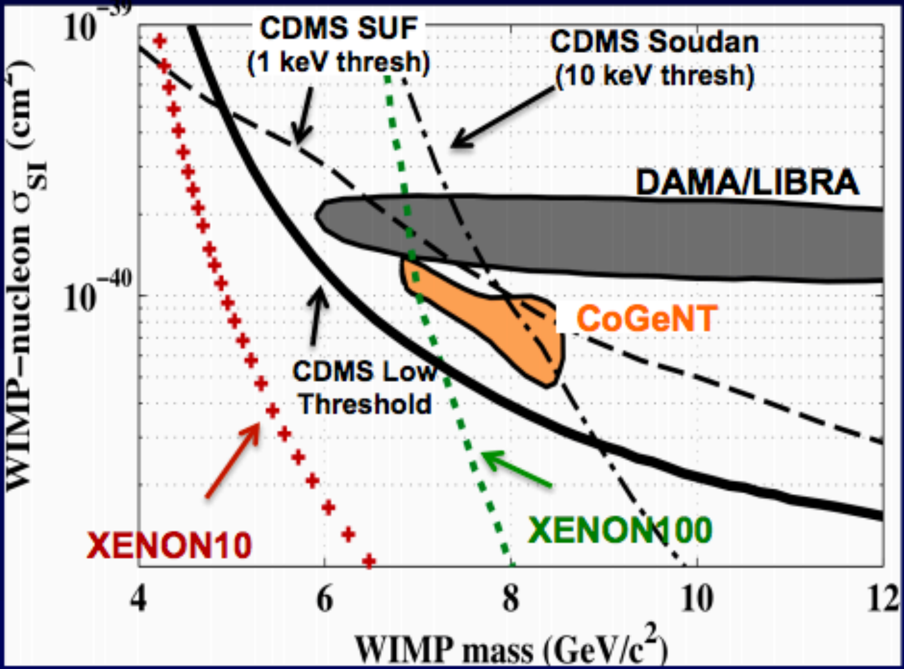
Low WIMP Mass Limits

- Conservatively assume all candidates could be from WIMP
  NO background subtraction!

- Limits set using optimum interval method:

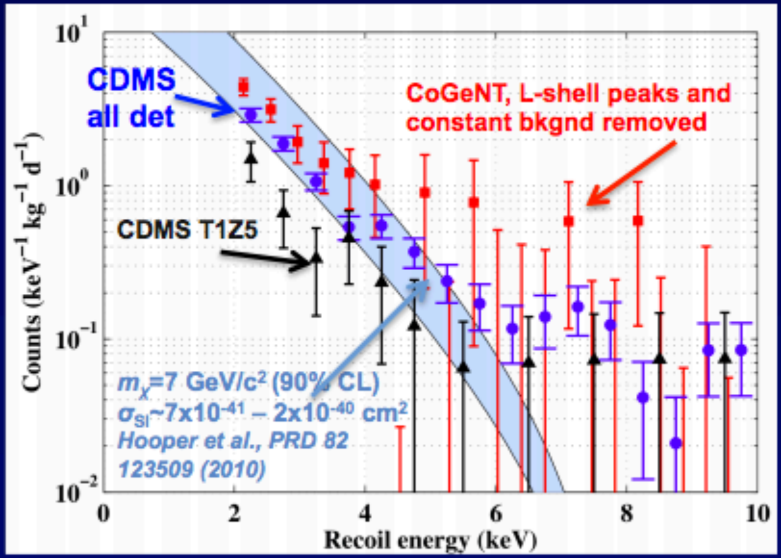
  S. Yellin, PRD, 66, 032005 (2002); arXiv:0709.2701v1 (2007)

- For spin-independent, elastic scattering, 90% CL limits incompatible with DAMA/LIBRA and CoGeNT excess



Ahmed et al., PRL 106, 131302 (2011); arXiv:1011.2482

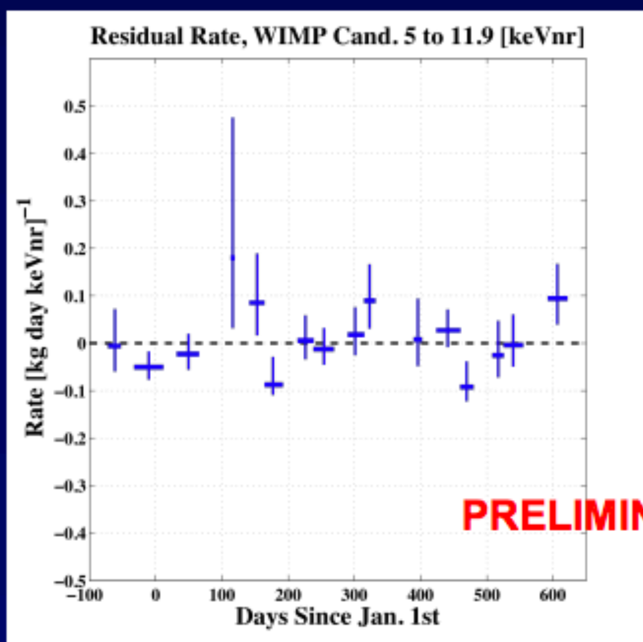
Note: CoGeNT region not updated for revision to surface event contamination

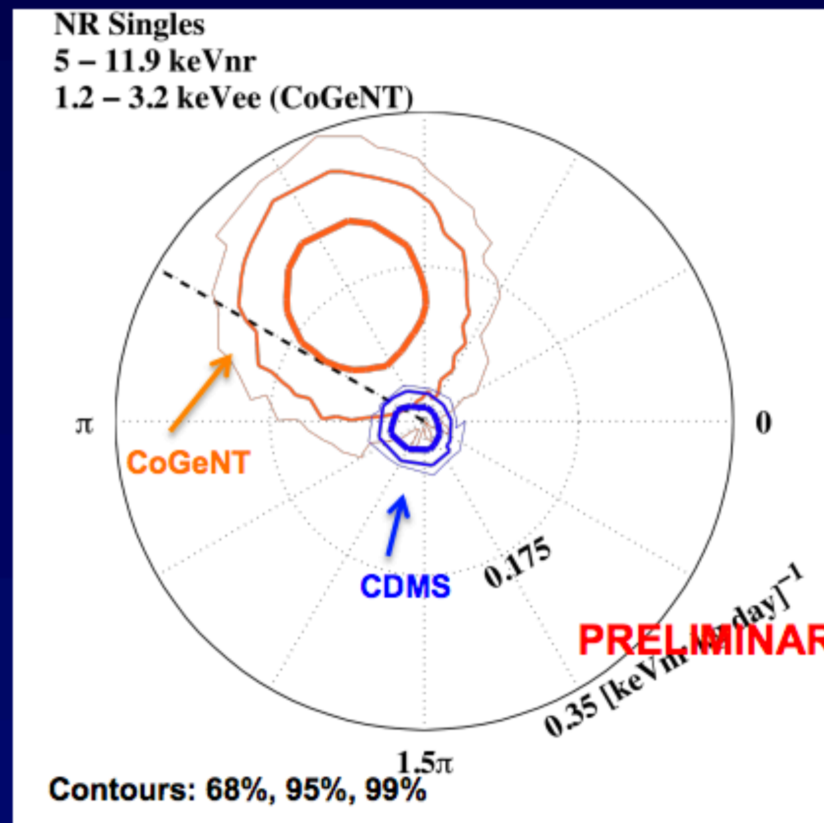


- If only a small fraction of the low-energy excess events in CoGeNT are due to WIMPs, then constraints from CDMS II can be avoided

Results: Nuclear Recoil Singles

- No significant evidence for annual modulation
- In the energy range [5, 11.9] keV_{nr}, all modulated rate with amplitudes greater than 0.07 $[keV_{nr}\ kg\ day]^{-1}$ are ruled out with a 99% confidence.
    - Annual modulation signal of CDMS and CoGeNT are incompatible at >95% C.L. (preliminary) for the full energy range (if CoGeNT signal originates in a nuclear-recoil population)





$M_X = 8$ GeV

Ge with $E_R = 8$ KeV DM

Xe with $E_R = 5$ KeV

$\nu = 709$ km/sec

$\nu \sim 720$ km/sec

Ge Atom $E_R = 8$ KeV 587e^-

Xe Atom $E_R = 5$ KeV 21-29e^-

2-3pe

From Peter Sorenson (private communication)

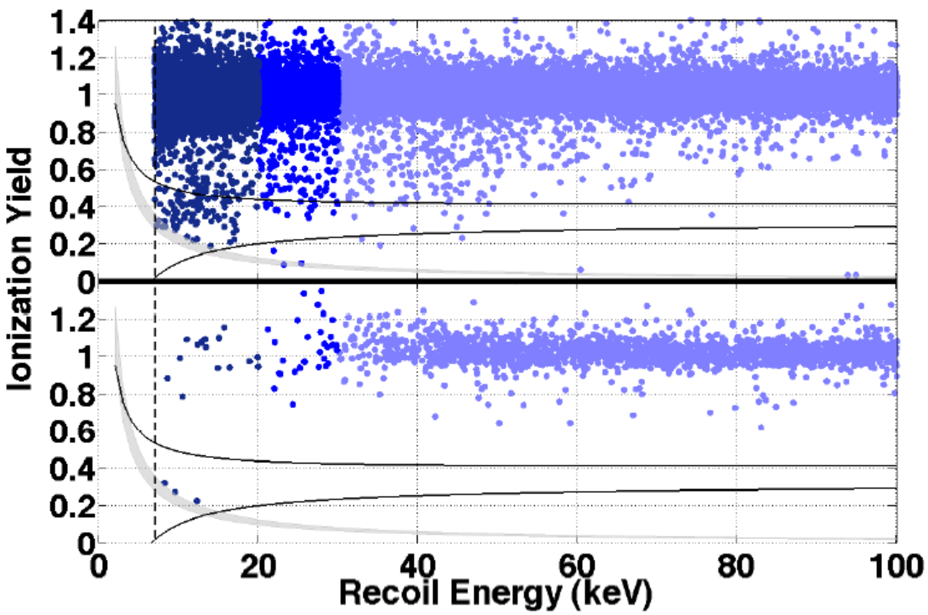


FIG. 2. Ionization yield versus recoil energy in all detectors included in this analysis for events passing all signal criteria except (*top*) and including (*bottom*) the phonon timing criterion. The curved black lines indicate the signal region (-1.8σ and +1.2σ from the mean nuclear recoil yield) between 7 and 100 keV recoil energies, while the gray band shows the range of charge thresholds. Electron recoils in the detector bulk have yield near unity. The data are colored to indicate recoil energy ranges (dark to light) of 7–20, 20–30, and 30–100 keV to aid the interpretation of Fig. 3.

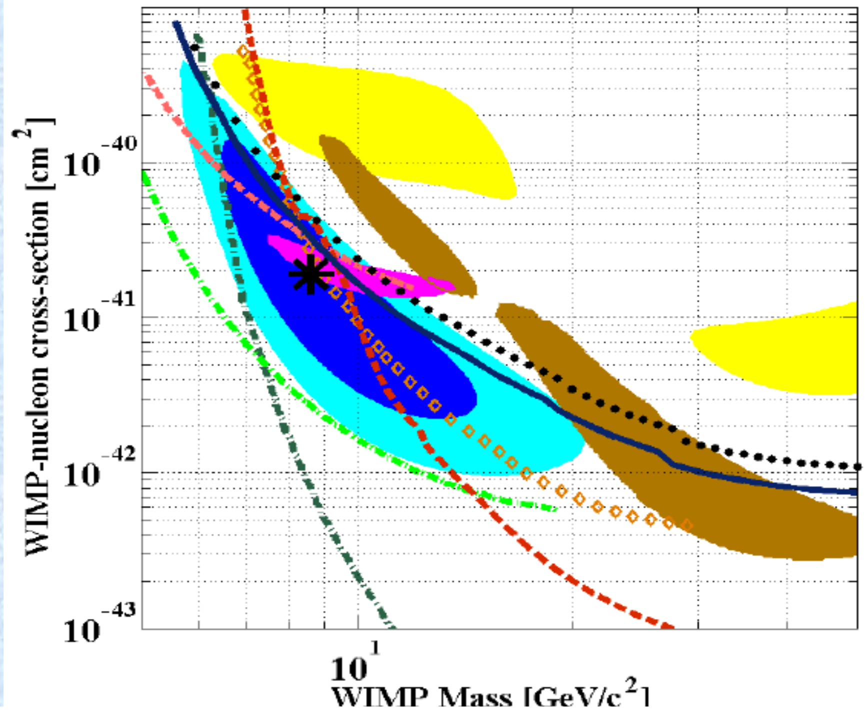
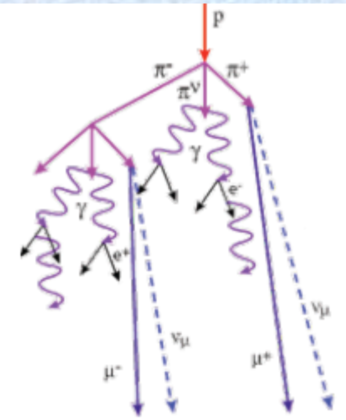
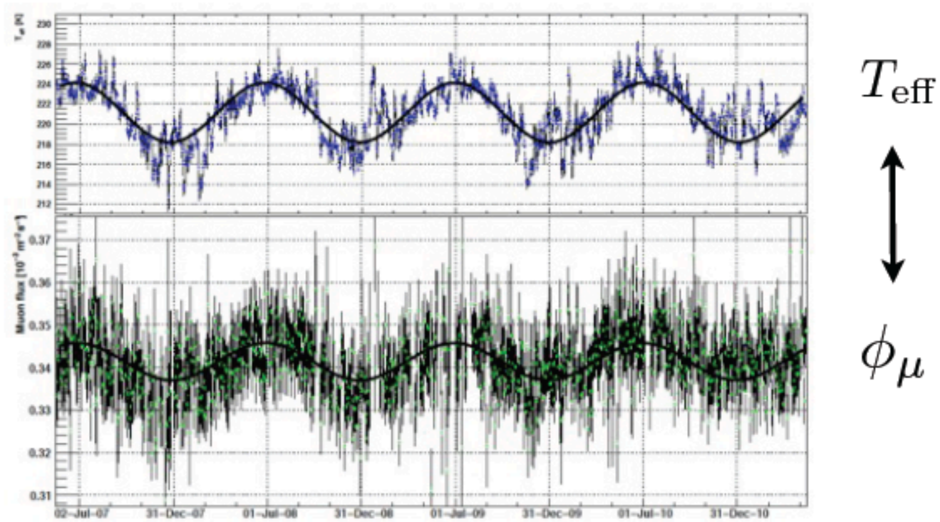


FIG. 4. Experimental upper limits (90% confidence level) for the WIMP-nucleon spin-independent cross section as a function of WIMP mass. We show the limit obtained from the exposure analyzed in this work alone (*black dots*), and combined with the CDMS II Si data set reported in [22] (*blue solid line*). Also shown are limits from the CDMS II Ge standard [11] and low-threshold [27] analysis (*dark and light dashed red*), EDELWEISS low-threshold [28] (*orange diamonds*), XENON10 S2-only [29] (*light dash-dotted green*), and XENON100 [30] (*dark dash-dotted green*). The filled regions identify possible signal regions associated with data from CoGeNT [31] (*magenta*, 90% C.L., as interpreted by Kelso *et al.* including the effect of a residual surface event contamination described in [32]), DAMA/LIBRA [16, 33] (*yellow*, 99.7% C.L.), and CRESST [18] (*brown*, 95.45% C.L.) experiments. 68% and 90% C.L. contours for a possible signal from these data are shown in blue and cyan, respectively. The asterisk shows the maximum likelihood point at (8.6 GeV/c^2, 1.9×10^{-41} cm^2).

Muon Flux underground

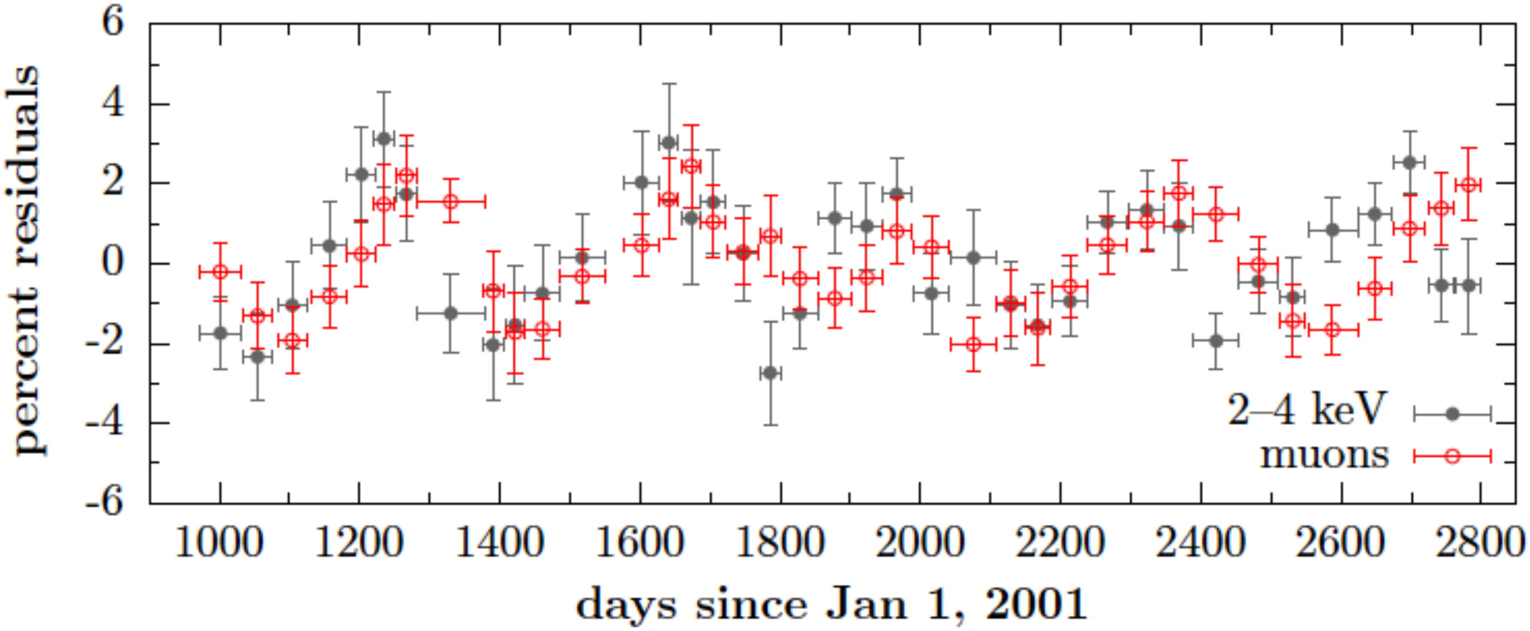


- many measurements available, correlation with $T_{\rm eff}$ firmly established
  - LNGS: Macro, LVD, Borexino (DAMA location)
  - Soudan Mine: MINOS (CoGeNT location)
  - South Pole: Icecube



[Borexino 2011]

LVD and DAMA



percent residuals
6
4
2
0
-2
-4
-6
1000
1200
1400
1600
1800
2000
2200
2400
2600
2800
days since Jan 1, 2001
2–4 keV
muons

Summary

1. The Search for Low-mass WIMPs is strongly constrained by monojet and monophoton events from LEP and LHC – Low-mass WIMPs are nearly ruled out
2. The current limits on SUSY from the LHC favor High-mass WIMPs from 200GeV to a TeV. Large Liquid Xenon and Argon detectors are needed to explore this region
3. The DAMA Annual variation occurs in the energy range of 2-3 KeV. This is also where K(40) produces a large effect, so large that there is no room for WIMPs in the data
4. There are many sources of annual variation in underground detectors. Therefore several sources may contribute to the DAMA data
5. The best current limits on WIMPs come from Xenon 100, LUX is starting to take data and Xenon 1 Ton and Darkside (Liquid Argon) are under construction now