The Current and Future Status of the Search for Dark Matter

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Topics

1. The Expectations for SUSY DM from LHC Results

2. The Results from XENON 100

3. Future Ton to Multi-ton Dark Matter Detectors and Expectations -XENON (1 Ton)

4. Status of the Critique of DAMA

5. The Different Types of Annual Variations in Underground Detectors

6. The Search for Low Mass WIMPS Pros and Cons

Summary

Search for Supersymmetry in pp Collisions at 7 TeV in Events with Jets and Missing Transverse Energy

The CMS Collaboration*

Abstract

A search for supersymmetry with R-parity conservation in proton-proton collisions at a centre-of-mass energy of 7 TeV is presented. The data correspond to an integrated luminosity of 35 pb^{-1} collected by the CMS experiment at the LHC. The search is performed in events with jets and significant missing transverse energy, characteristic of the decays of heavy, pair-produced squarks and gluinos. The primary background, from standard model multijet production, is reduced by several orders of magnitude to a negligible level by the application of a set of robust kinematic requirements. With this selection, the data are consistent with the standard model backgrounds, namely $t\bar{t}$, W + jet and Z + jet production, which are estimated from data control samples. Limits are set on the parameters of the constrained minimal supersymmetric extension of the standard model. These limits extend those set previously by experiments at the Tevatron and LEP colliders.

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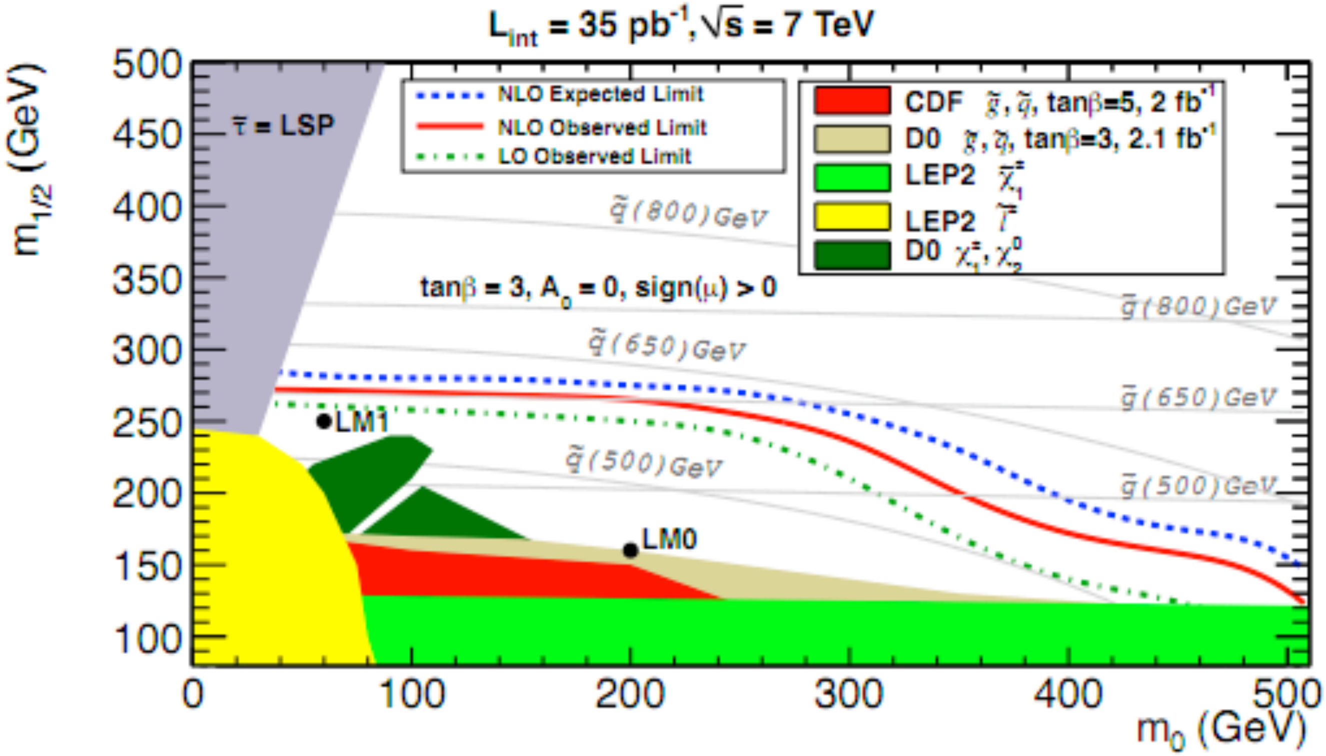
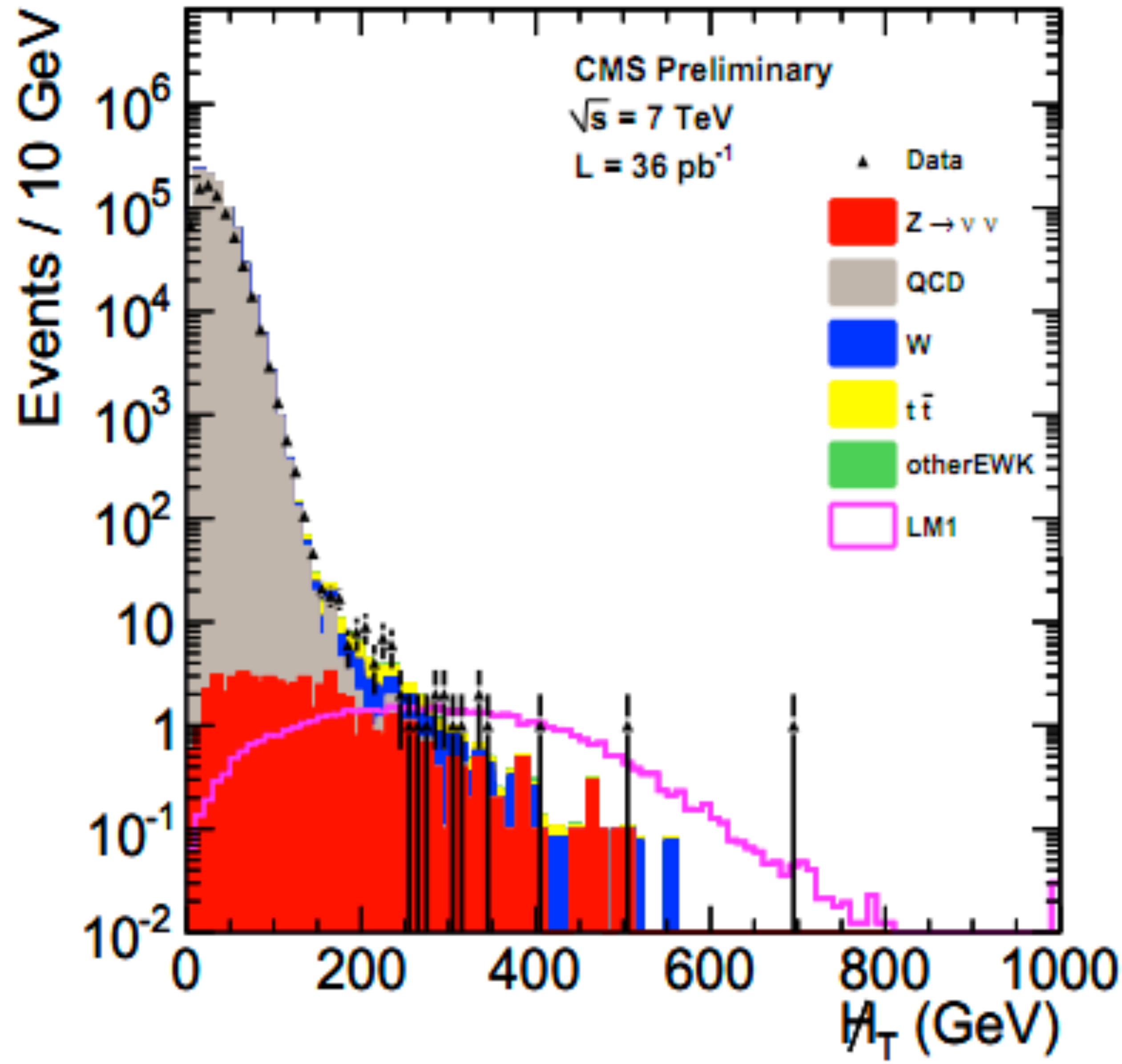
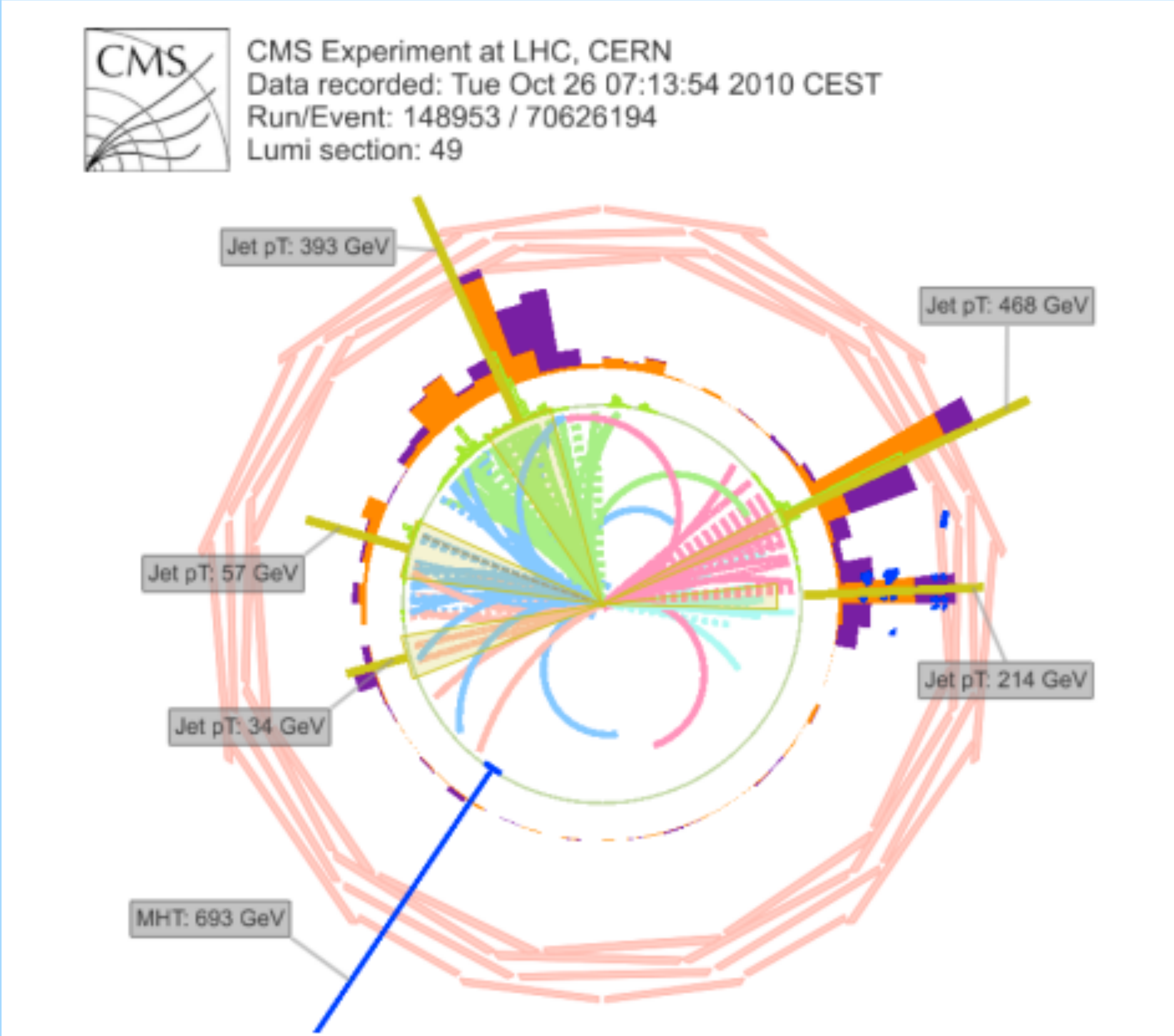


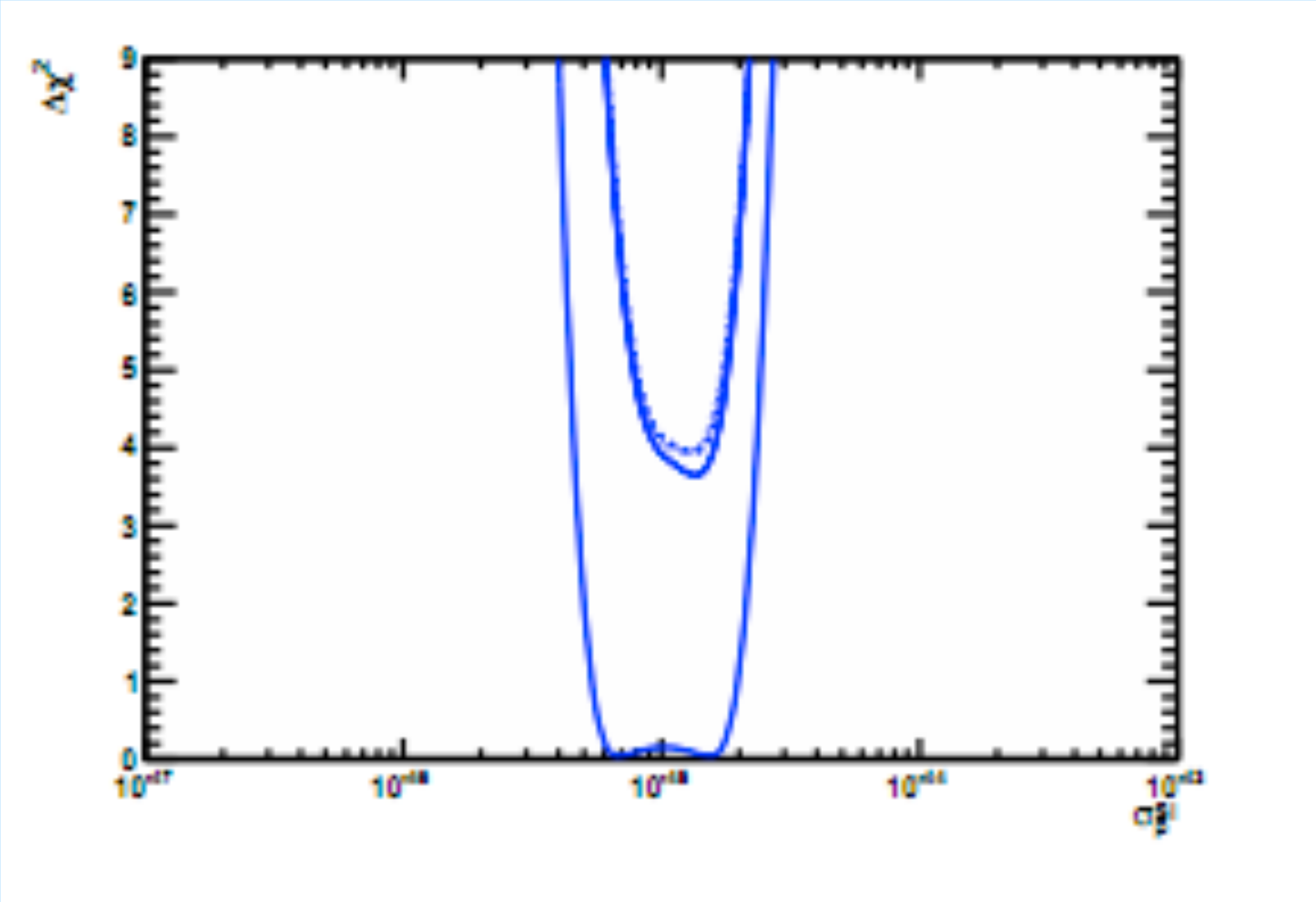
Figure 5: Measured (red line) and expected (dashed blue line) 95% CL exclusion contour at NLO in the CMSSM $(m_0, m_{1/2})$ plane for $\tan\beta = 3$, $A_0 = 0$ and $\mathrm{sign}(\mu) > 0$. The measured LO exclusion contour is shown as well (dot-dashed green line). The area below the curves is excluded by this measurement. Exclusion limits obtained from previous experiments are presented as filled areas in the plot. Grey lines correspond to constant squark and gluino masses. The plot also shows the two benchmark points LM0 and LM1 for comparison.



CMS Preliminary
$\sqrt{s}$ = 7 TeV
L = 36 pb^{-1}
Data
$Z \rightarrow \nu\nu$
QCD
W
$t\bar{t}$
otherEWK
LM1
Events / 10 GeV
$H\!\!\!/_T$ (GeV)


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

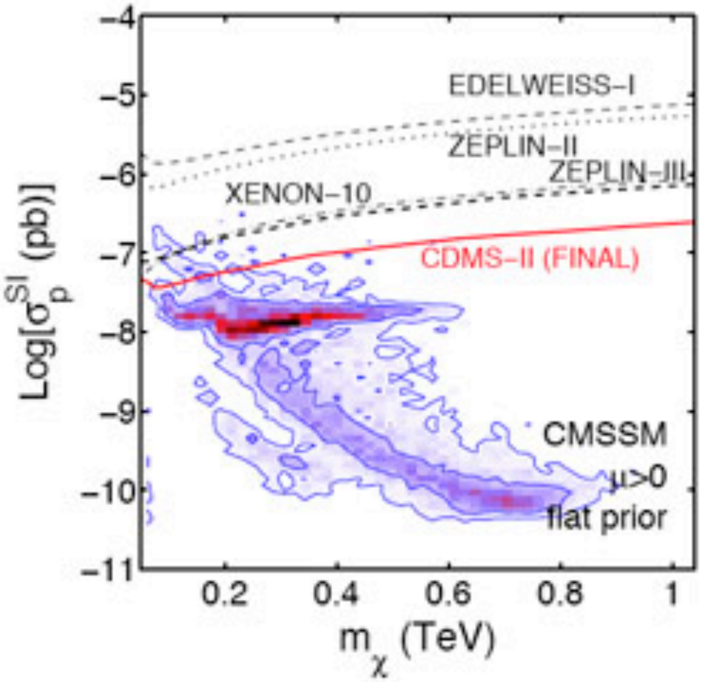
SUGRA model
Cross Section



SUSY: Prospects for direct detection

Bayesian analysis, MCMC scan of 8 params (4 SUSY+4 SM)

CMSSM: global scan



internal (external): 68% (95%) region

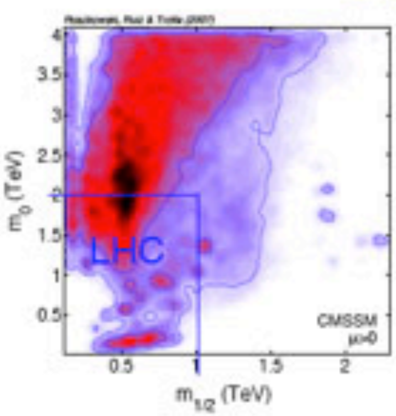
CDMS-II (Dec 09):

$\sigma_p^{\mathrm{SI}} \lesssim 10^{-7}$ pb:

also XENON and Zeplin–III

$\Rightarrow$ already explore 68% region

(large $m_0 \gg m_{1/2}$ $\Rightarrow$ heavy squarks) largely beyond LHC reach



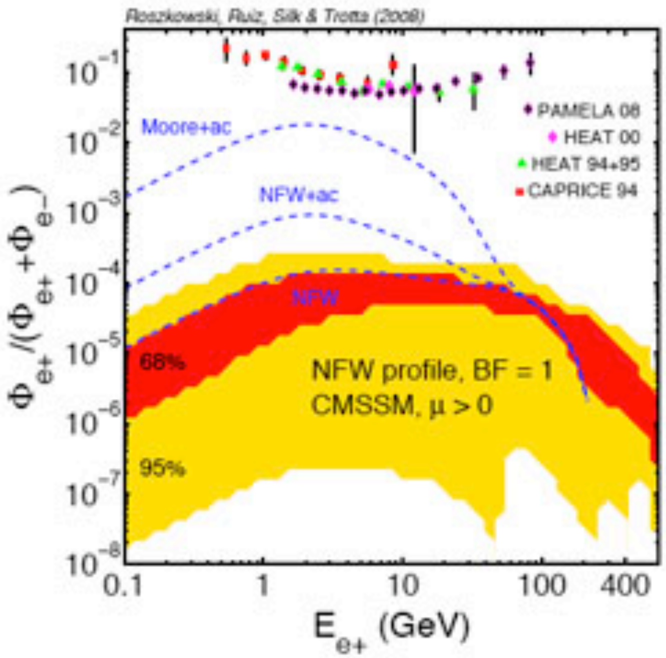
$\Rightarrow$ $\boxed{\text{DD: prospects look very good}}$

SUSY and positron flux

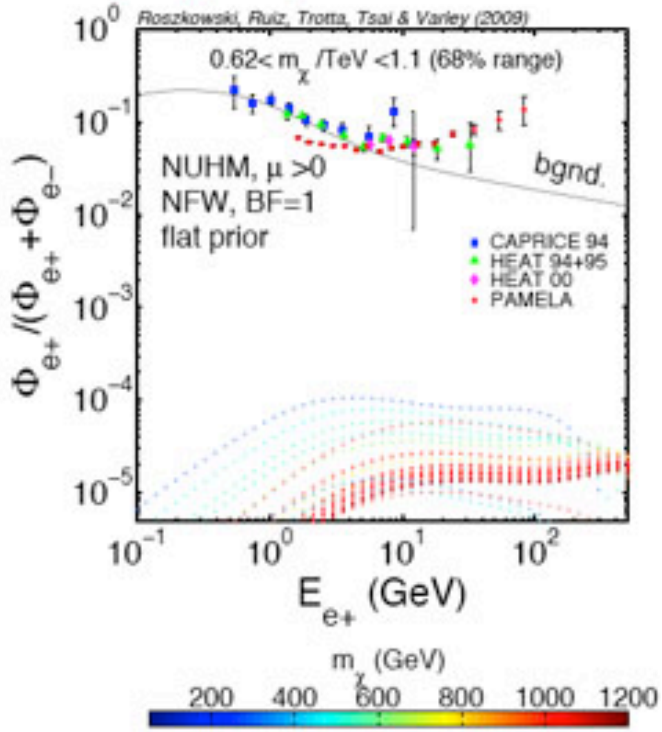
Bayesian posterior probability maps

BF=1

CMSSM, flat priors, NFW



NUHM, flat priors, NFW



Dark Matter Results from 100 Live Days of XENON100 Data

E. Aprile,[1] K. Arisaka,[2] F. Arneodo,[3] A. Askin,[4] L. Baudis,[4] A. Behrens,[4] K. Bokeloh,[5] E. Brown,[5] T. Bruch,[4] G. Bruno,[3] J. M. R. Cardoso,[6] W.-T. Chen,[7] B. Choi,[1] D. Cline,[2] E. Duchovni,[8] S. Fattori,[9] A. D. Ferella,[4] F. Gao,[10] K.-L. Giboni,[1] E. Gross,[8] A. Kish,[4] C. W. Lam,[2] J. Lamblin,[7] R. F. Lang,[1,*] C. Levy,[5] K. E. Lim,[1] Q. Lin,[10] S. Lindemann,[11] M. Lindner,[11] J. A. M. Lopes,[6] K. Lung,[2] T. Marrodán Undagoitia,[4] Y. Mei,[12,9] A. J. Melgarejo Fernandez,[1] K. Ni,[10] U. Oberlack,[12,9] S. E. A. Orrigo,[6] E. Pantic,[2] R. Persiani,[13] G. Plante,[1] A. C. C. Ribeiro,[6] R. Santorelli,[4] J. M. F. dos Santos,[6] G. Sartorelli,[13] M. Schumann,[4,†] M. Selvi,[13] P. Shagin,[12] H. Simgen,[11] A. Teymourian,[2] D. Thers,[7] O. Vitells,[8] H. Wang,[2] M. Weber,[11] and C. Weinheimer[5]

(The XENON100 Collaboration)

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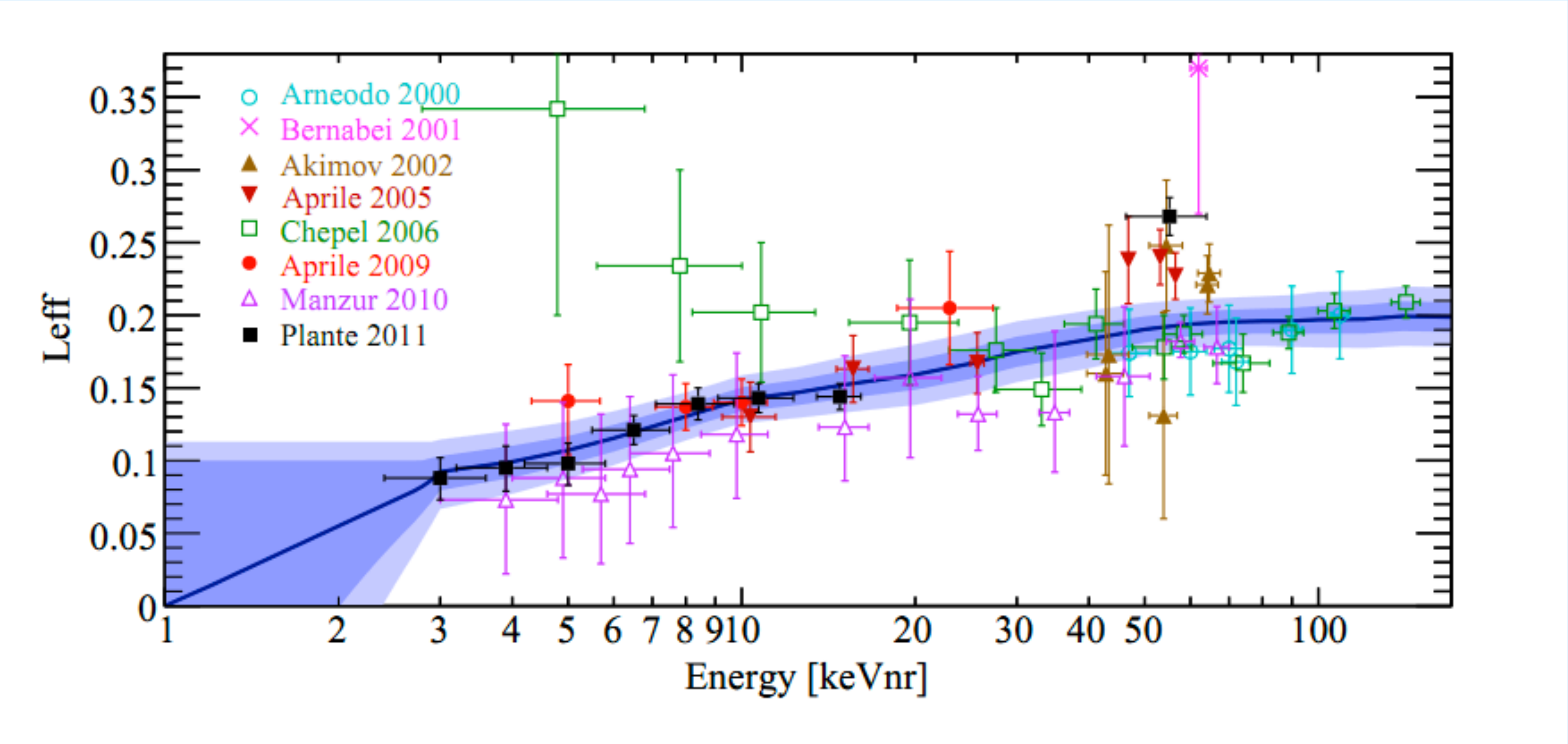
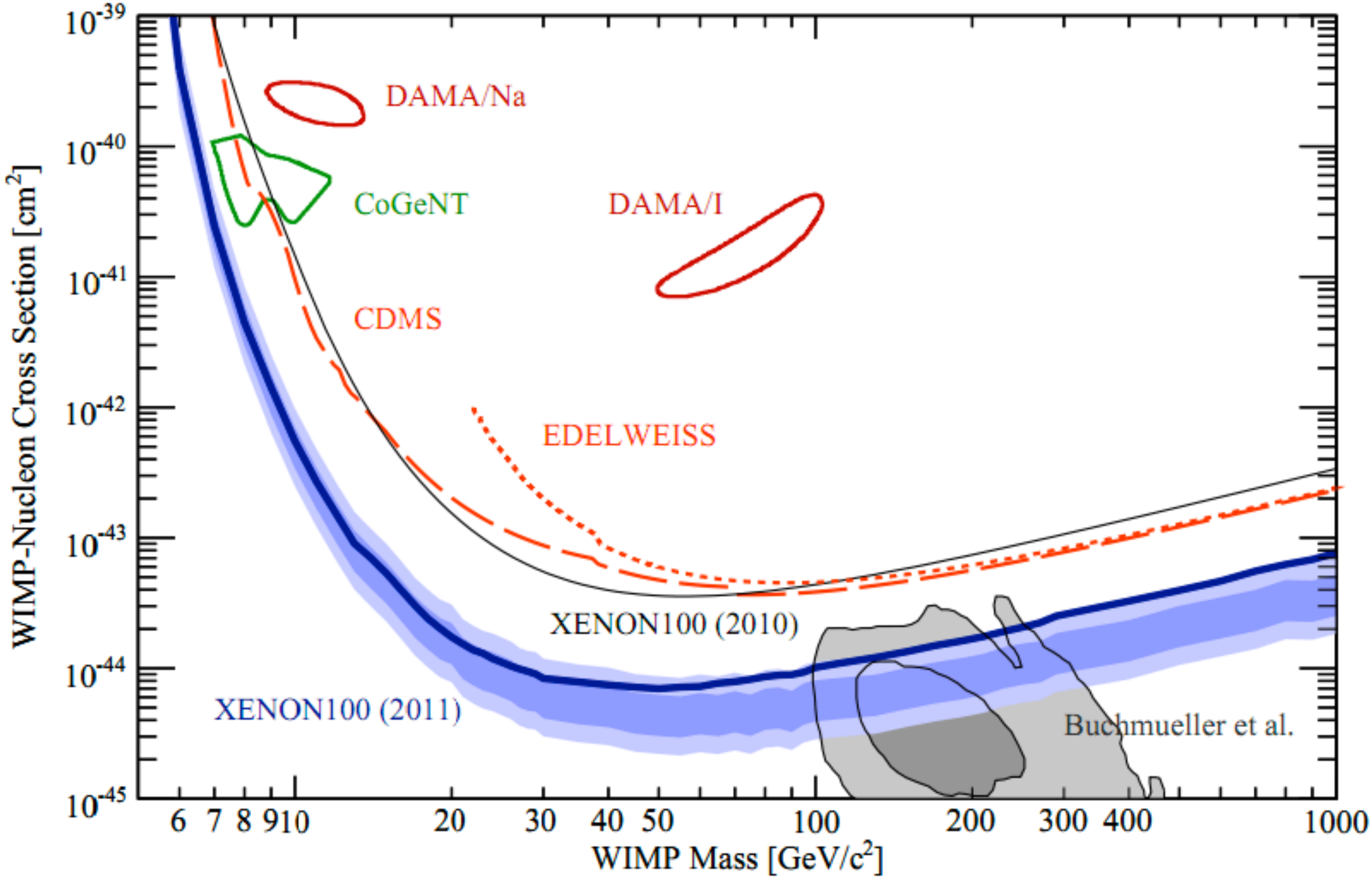
We present results from the direct search for dark matter with the XENON100 detector, installed underground at the Laboratori Nazionali del Gran Sasso of INFN, Italy. XENON100 is a two-phase time projection chamber with a 62 kg liquid xenon target. Interaction vertex reconstruction in three dimensions with millimeter precision allows to select only the innermost 48 kg as ultra-low background fiducial target. In 100.9 live days of data, acquired between January and June 2010, no evidence for dark matter is found. Three candidate events were observed in a pre-defined signal region with an expected background of (1.8 ± 0.6) events. This leads to the most stringent limit on dark matter interactions today, excluding spin-independent elastic WIMP-nucleon scattering cross-sections above $7.0 \times 10^{-45}\,\mathrm{cm}^2$ for a WIMP mass of $50\,\mathrm{GeV/c^2}$ at 90% confidence level.

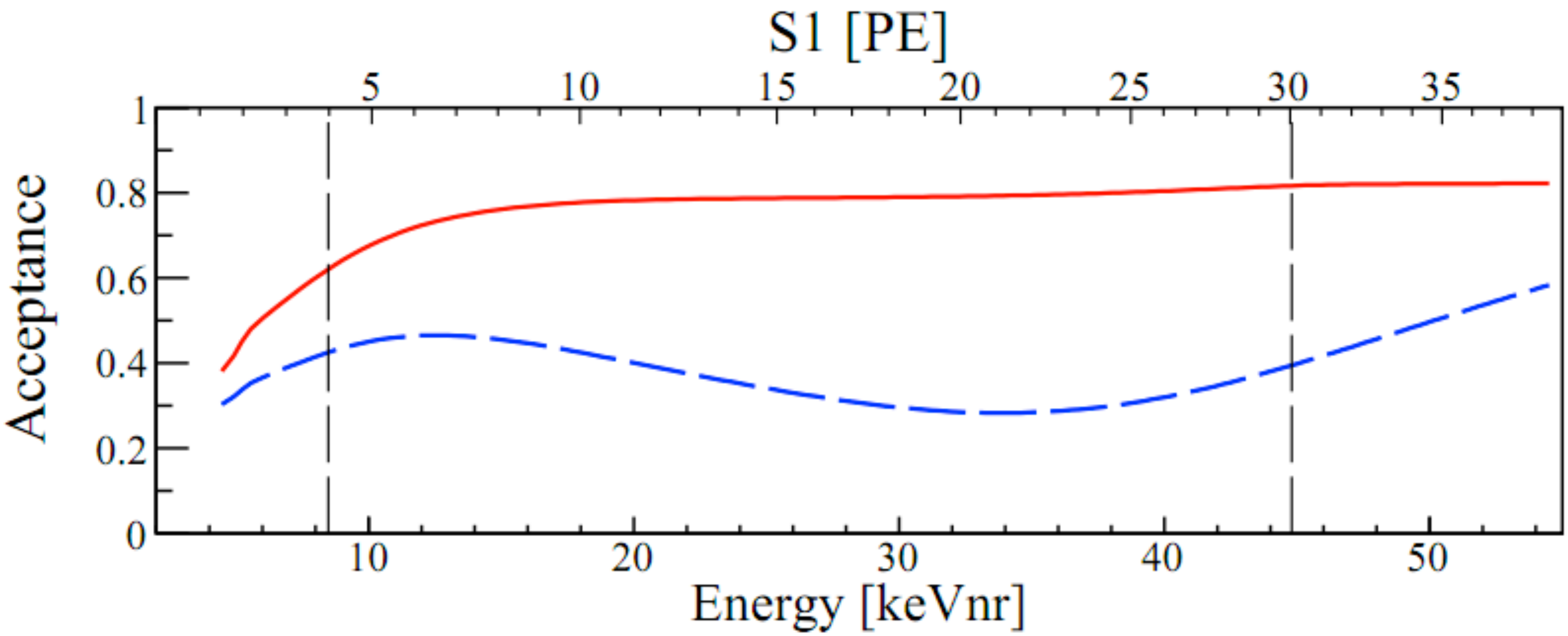
PACS numbers: 95.35.+d, 14.80.Ly, 29.40.-n,
Keywords: Dark Matter, Direct Detection, Xenon

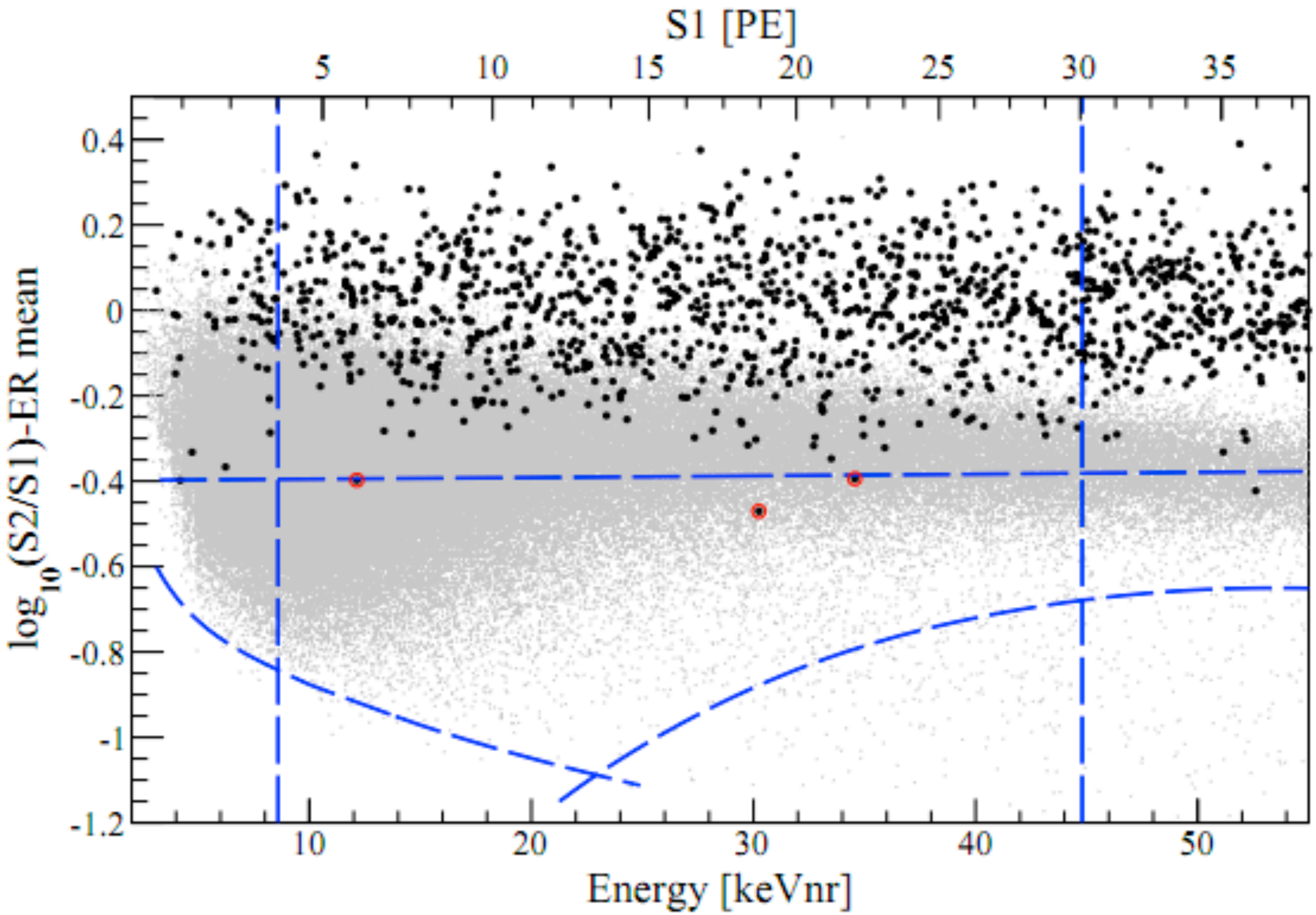


Arneodo 2000
Bernabei 2001
Akimov 2002
Aprile 2005
Chepel 2006
Aprile 2009
Manzur 2010
Plante 2011
Leff
Energy [keVnr]
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1
2
3
4
5
6
7
8
9
10
20
30
40
50
100

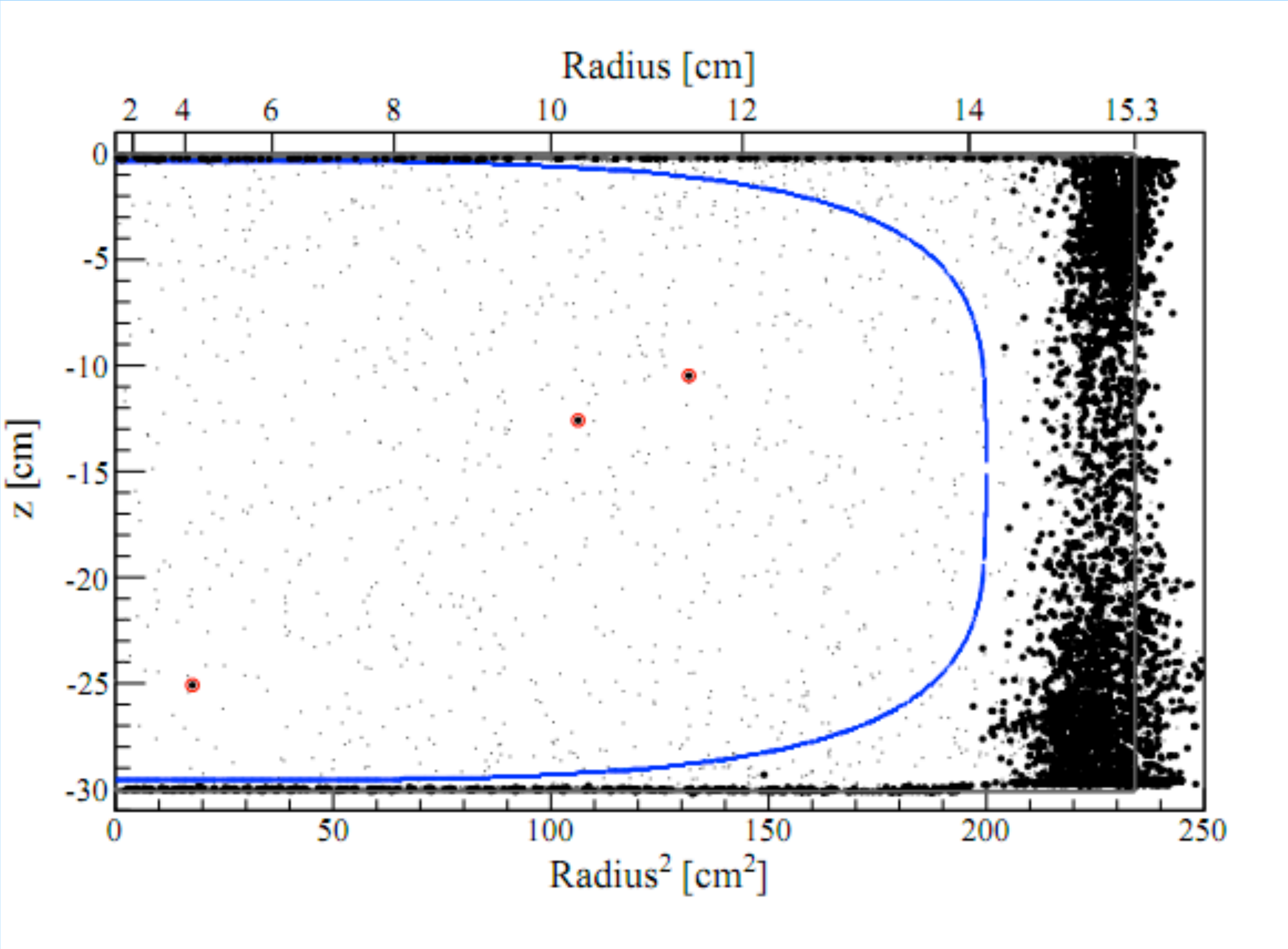


DAMA/Na
CoGeNT
DAMA/I
CDMS
EDELWEISS
XENON100 (2010)
XENON100 (2011)
Buchmueller et al.
WIMP-Nucleon Cross Section [cm^2]
WIMP Mass [GeV/c^2]
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
6 7 8 9 10 20 30 40 50 100 200 300 400 1000


S1 [PE]
5
10
15
20
25
30
35
1
0.8
0.6
0.4
0.2
0
Acceptance
10
20
30
40
50
Energy [keVnr]



S1 [PE]
5
10
15
20
25
30
35
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
$\log_{10}$(S2/S1)-ER mean
10
20
30
40
50
Energy [keVnr]



Radius [cm]
2
4
6
8
10
12
14
15.3
0
-5
-10
-15
-20
-25
-30
z [cm]
0
50
100
150
200
250
Radius^2 [cm^2]

Figure 6: TPC schematic view

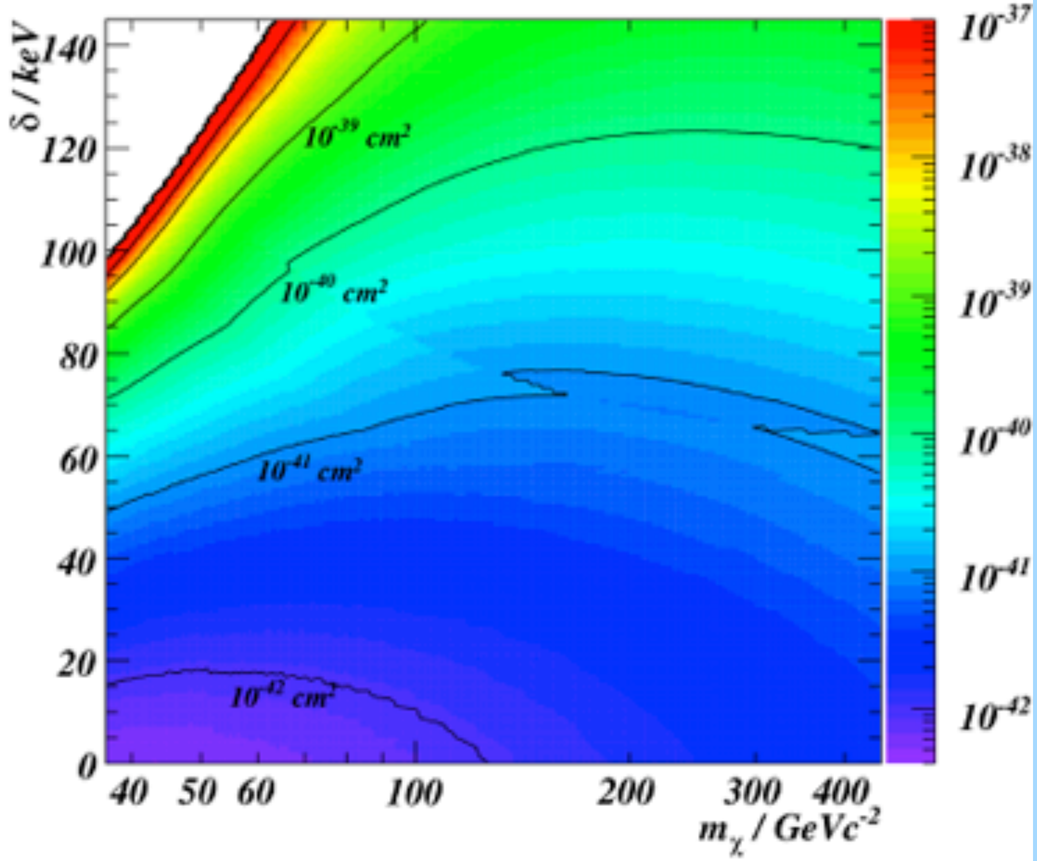
TPC Dimension and Fields	
Height	95 cm
Diameter	96 cm
Active LXe Mass/Volume	2000 kg/ 0.708 m^3
PTFE Mass/Volume	85 kg/ 0.04 m^3
Copper Support Mass/Volume	112 kg/ 0.013 m^3
Nominal Drift Field	1.0 kV/cm
Drift Length	90 cm
Operating Cathode Voltage	−90.0 kV
Nominal Extraction Field	13.0 kV/cm
Operating Anode Voltage	4.5 kV
Xenon Gas Gap	2.5 mm
TPC Grids	
Grid Diameter	100 cm
Frame Thickness	5 mm
Ring Material	low radioactivity SS 316Ti
Wire Diameter	140 μm
Wire Spacing	5 mm
Grid Optical Transparency	97%
Inner Cryostat	
Height	160 cm
Diameter	104 cm
Volume	1.389 m^3
Total LXe Mass/Volume	**2400 kg/0.85 m^3**

Table 1: XENON1T TPC characteristics

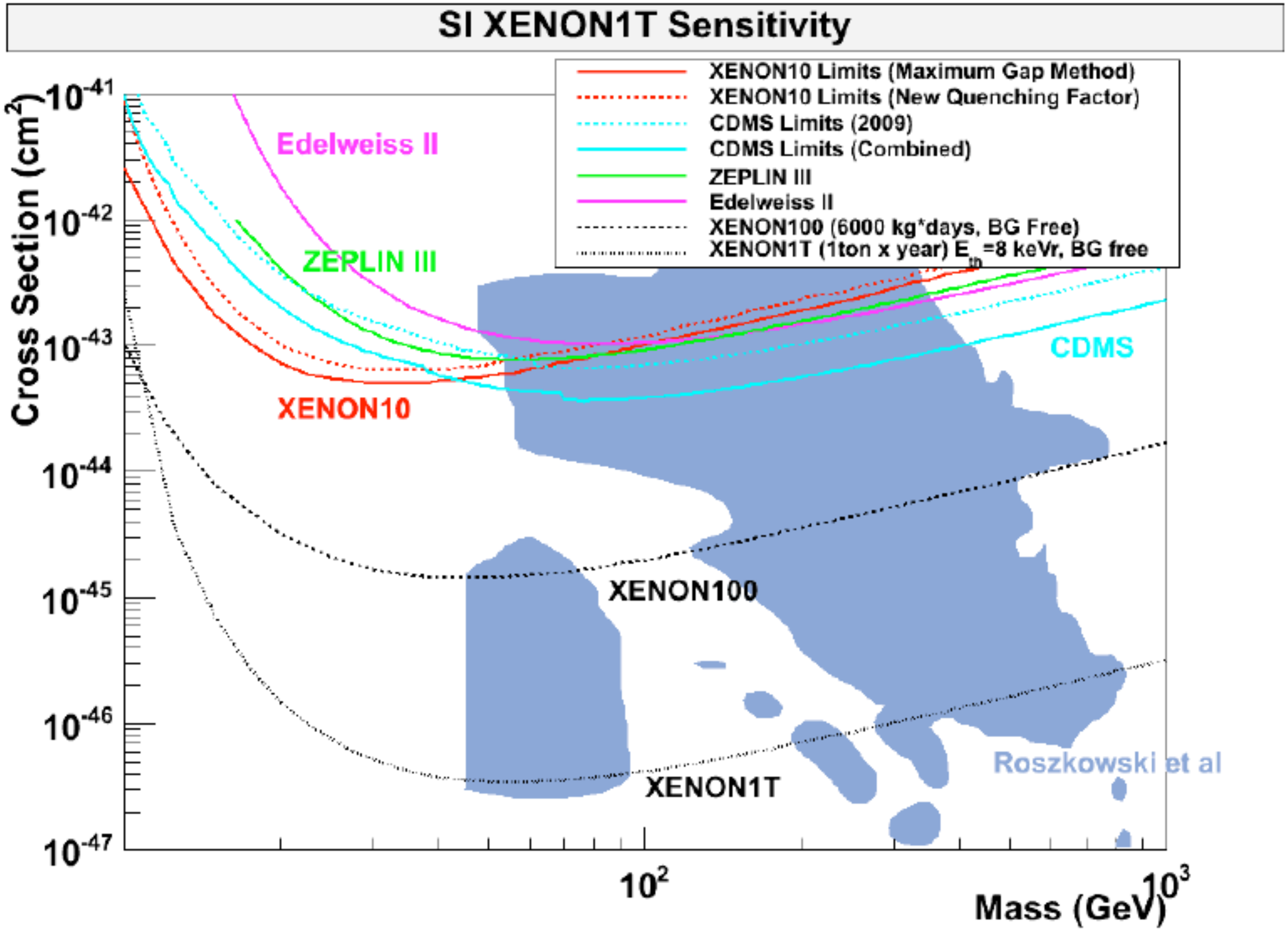
Limit calculation

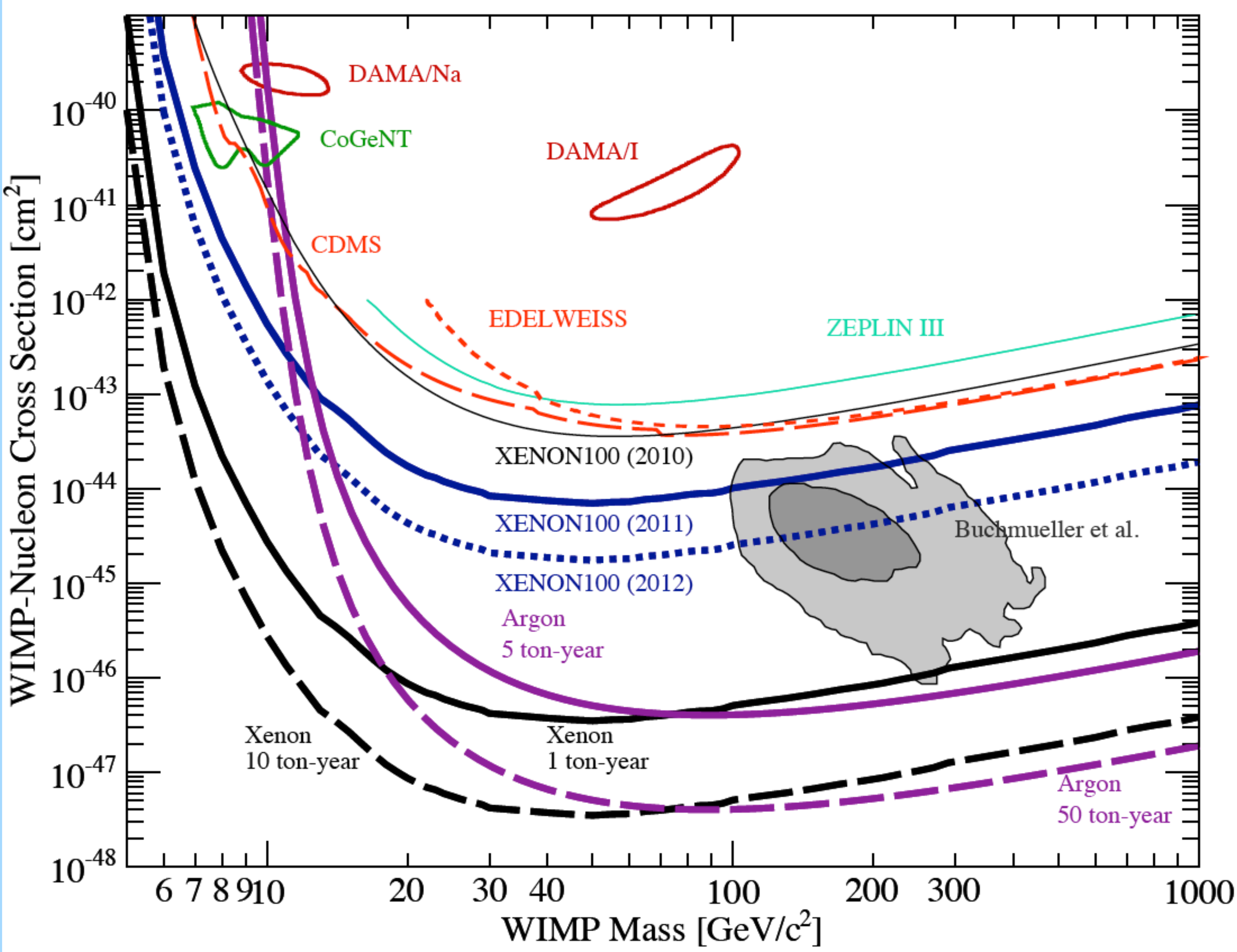
- Yellin p_{max} in E_R
  - Test statistic is energy interval least likely to contain as few events as observed
- Single-sided limit: no discovery potential
- ...but no background model required.

90% CL upper limit on σ_n / cm²

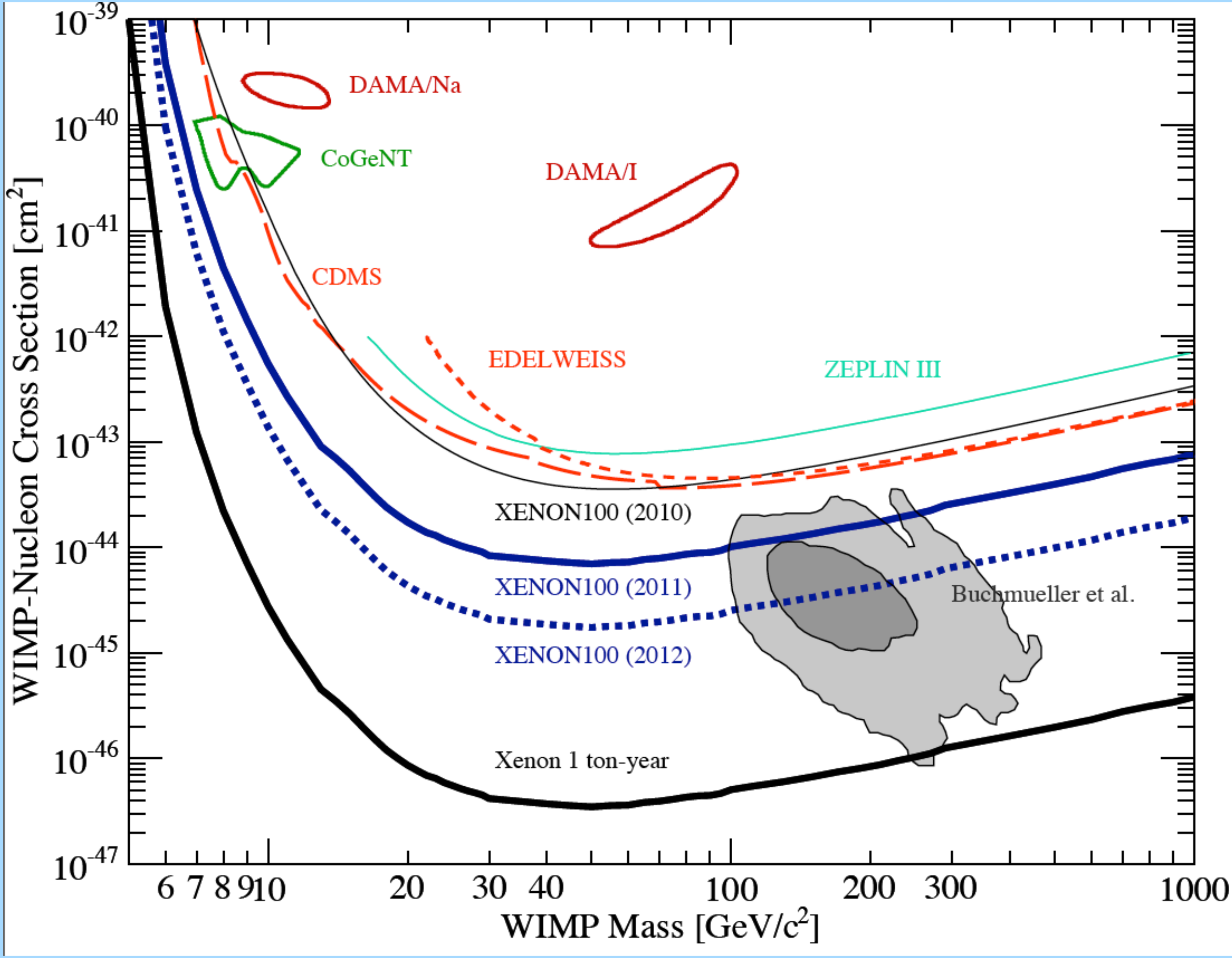


Spin-Independent Projected Sensitivity



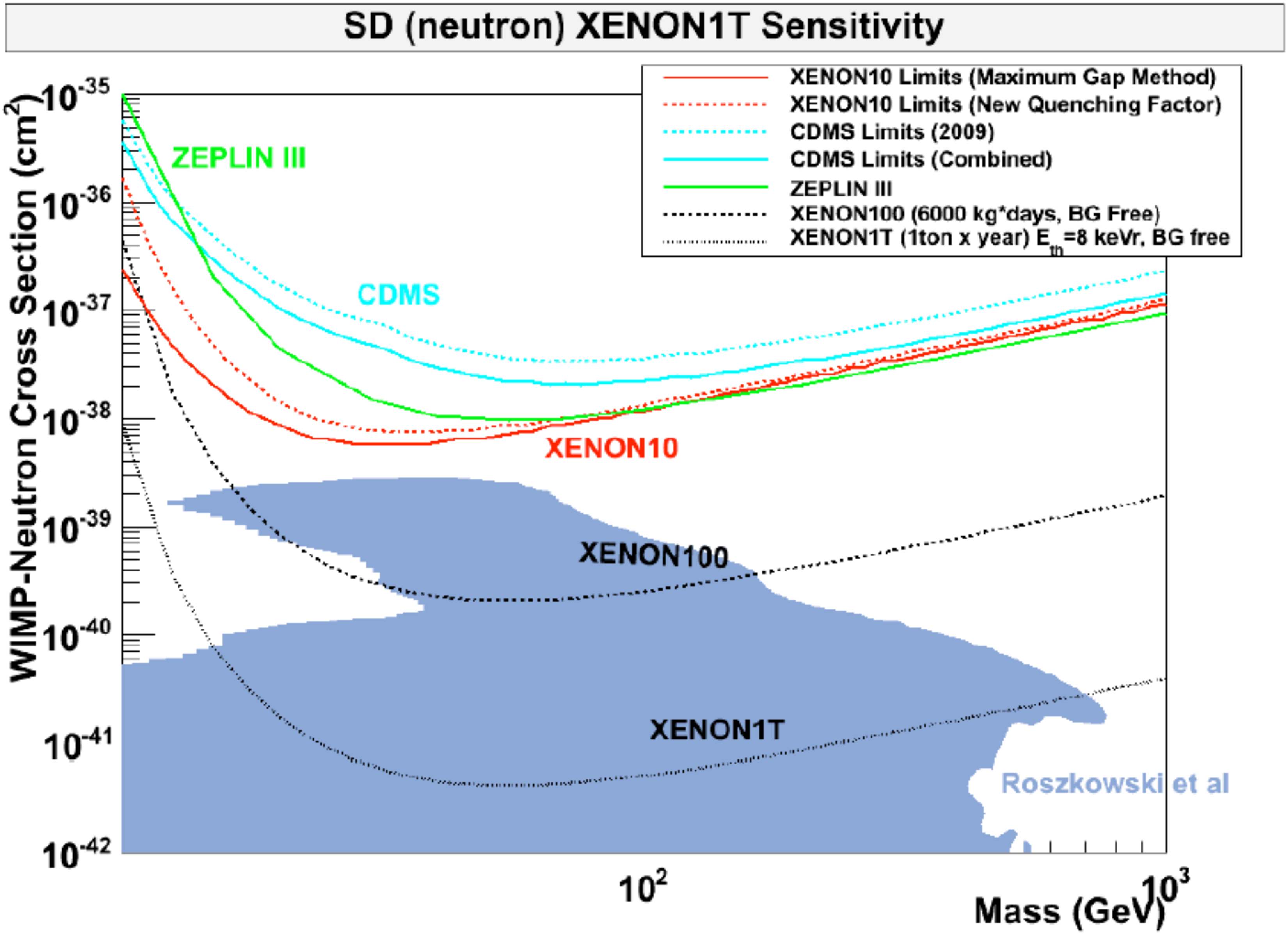


DAMA/Na
CoGeNT
DAMA/I
CDMS
EDELWEISS
ZEPLIN III
XENON100 (2010)
XENON100 (2011)
XENON100 (2012)
Buchmueller et al.
Argon
5 ton-year
Xenon
10 ton-year
Xenon
1 ton-year
Argon
50 ton-year
WIMP-Nucleon Cross Section [cm²]
10⁻⁴⁰
10⁻⁴¹
10⁻⁴²
10⁻⁴³
10⁻⁴⁴
10⁻⁴⁵
10⁻⁴⁶
10⁻⁴⁷
10⁻⁴⁸
6 7 8 9 10
20
30 40
100
200 300
1000
WIMP Mass [GeV/c²]



DAMA/Na
CoGeNT
DAMA/I
CDMS
EDELWEISS
ZEPLIN III
XENON100 (2010)
XENON100 (2011)
XENON100 (2012)
Buchmueller et al.
Xenon 1 ton-year
WIMP-Nucleon Cross Section [cm^2]
WIMP Mass [GeV/c^2]
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
6 7 8 9 10 20 30 40 100 200 300 1000

Spin-Dependent Projected Sensitivity



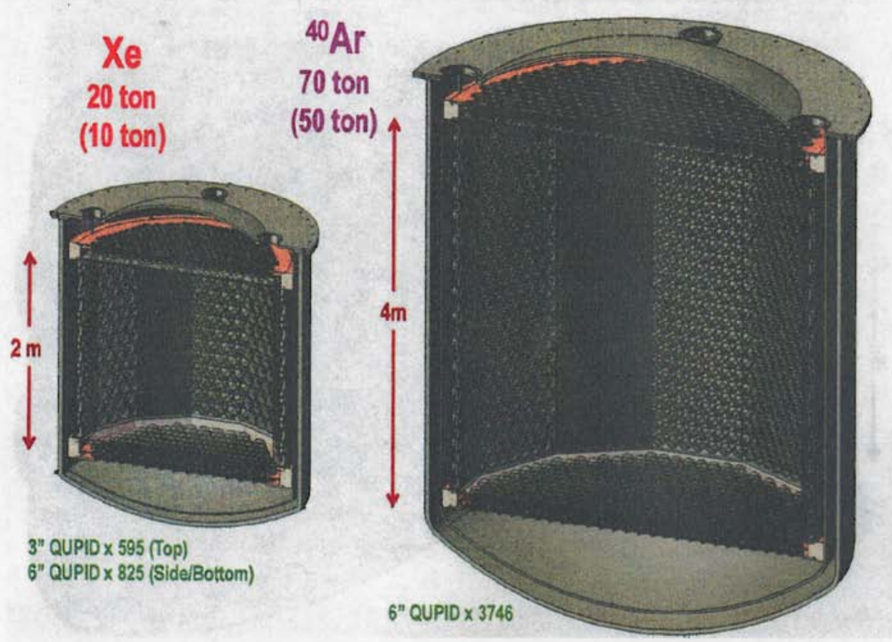


Fig 1.2 Main parameters of the 10-ton/50-ton (fiducial) G3 system

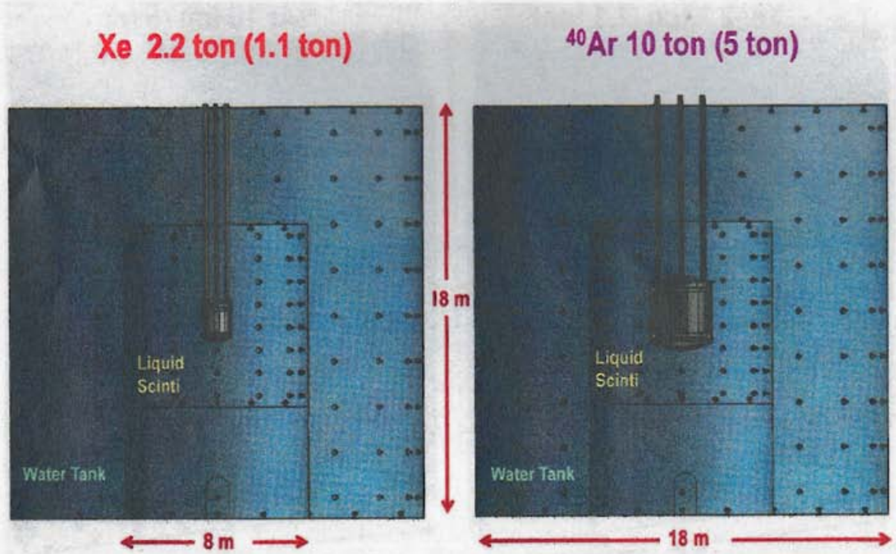


Fig 1.3 G2 system (1t Xe/5t Ar) in water and liquid scintillator shields

sides (if instrumented)	520 (3")	670 (6")	670 (6")	2400 (6")	2400 (6")	8000 (6")
bottom	120 (3")	160 (6")	160 (6")	670 (6")	670 (6")	2000 (6")

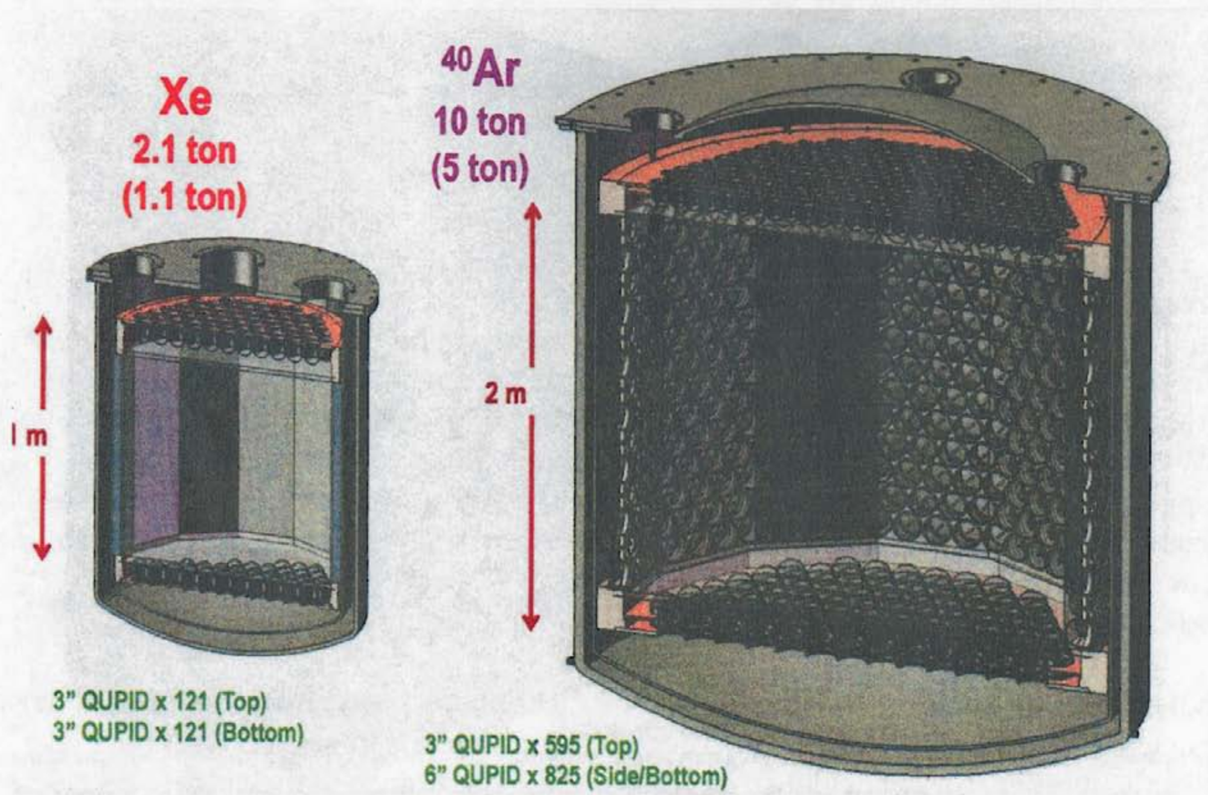
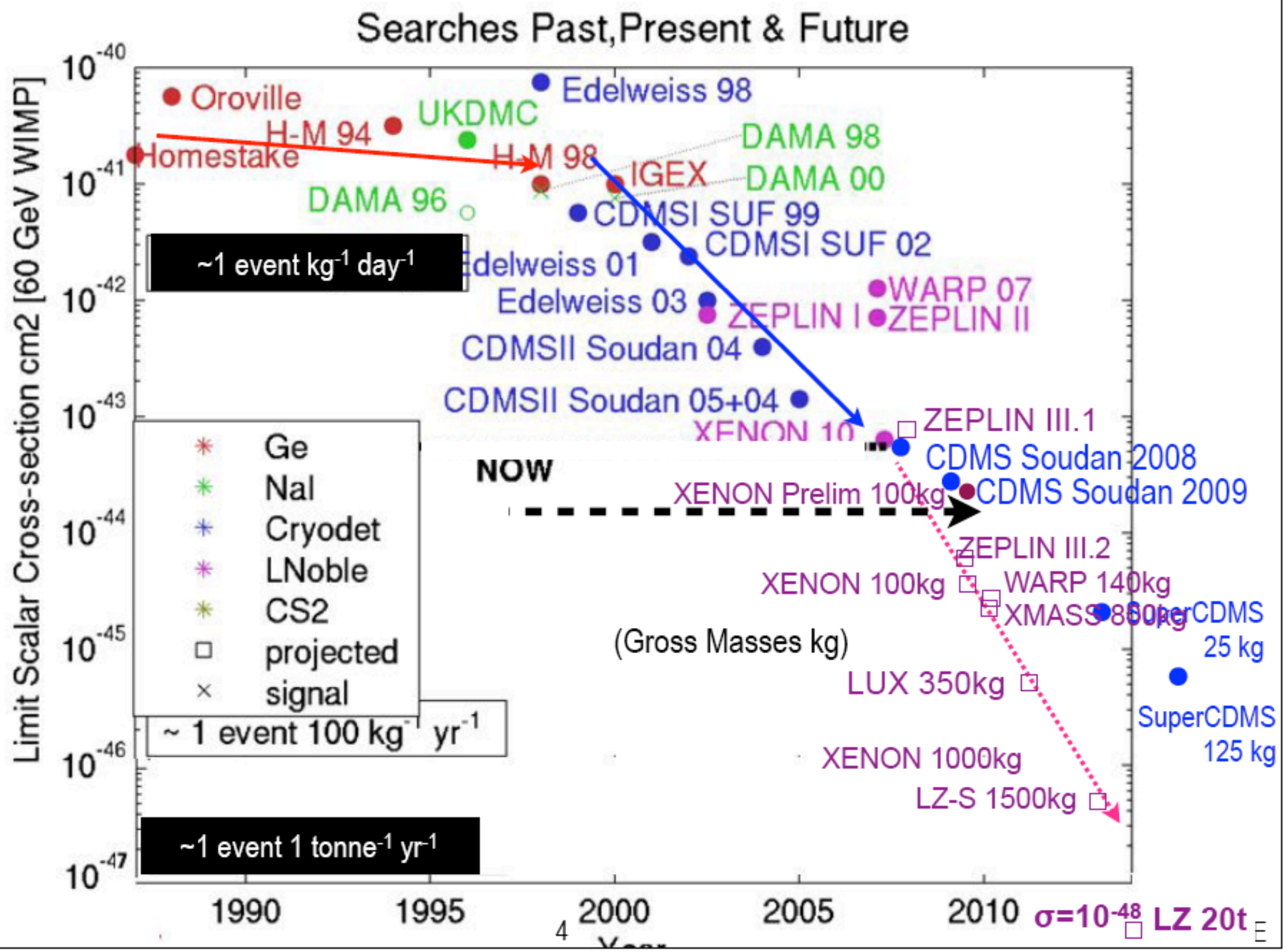


Fig 1.1 Main parameters of the 1-ton/5-ton (fiducial) G2 system

DM Direct Search Progress Over Time (2010)



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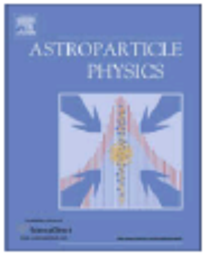

The expected background spectrum in NaI dark matter detectors and the DAMA result

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ABSTRACT

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.

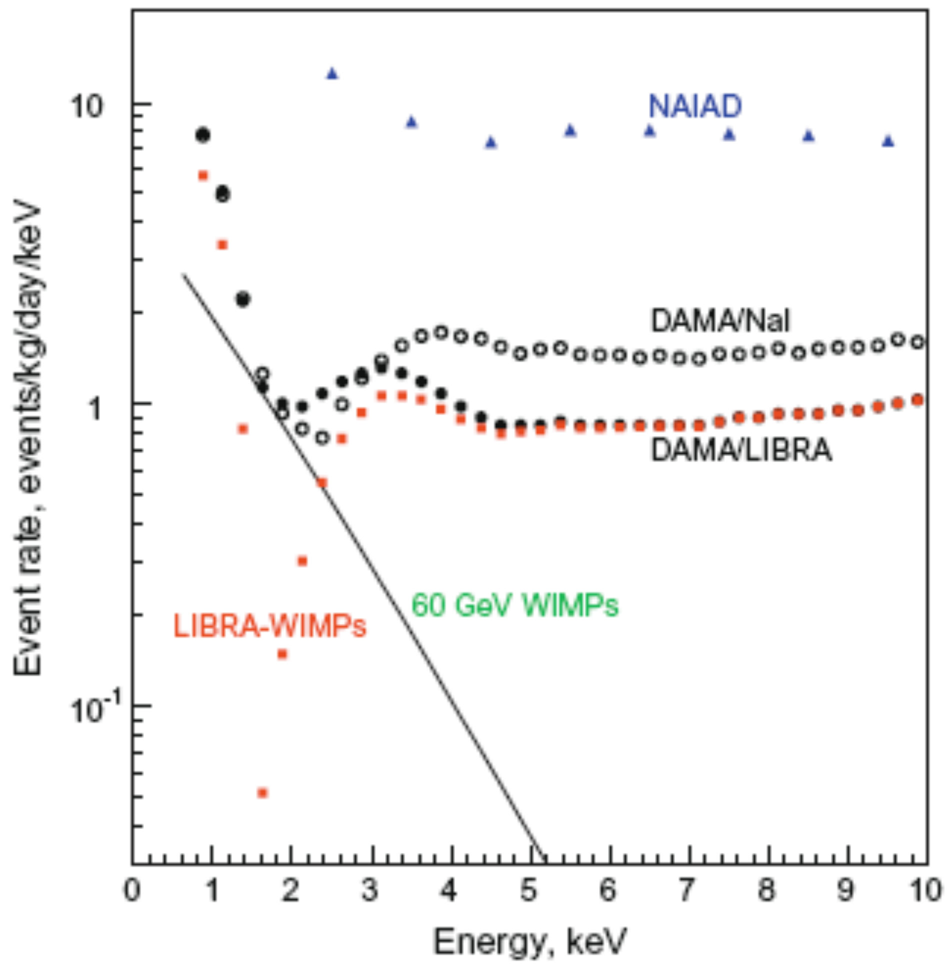
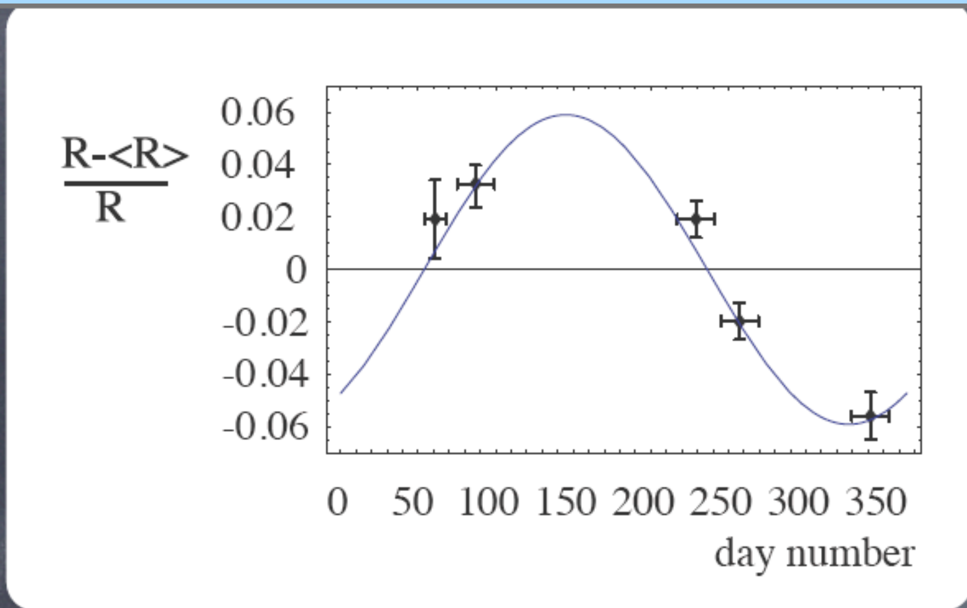


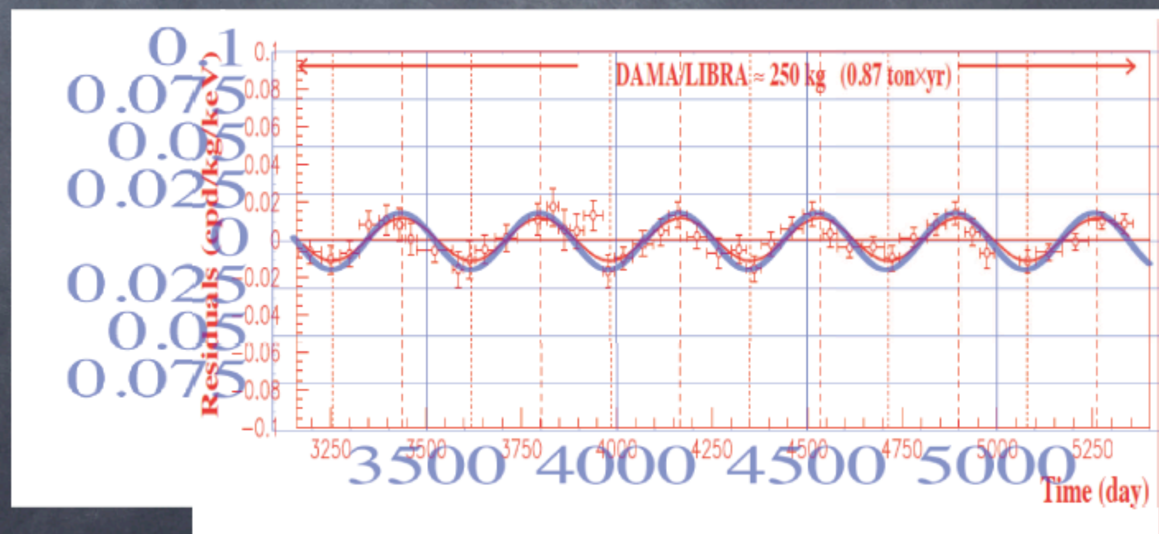
Fig. 3. Energy spectra of single hit events as reported by the DAMA/NaI [2] (open circles) and DAMA/LIBRA [3] (filled circles) experiments. The spectrum of events expected from 60 GeV WIMP interactions with the spin-independent cross-section of 7×10^{-6} pb in the isothermal halo model is shown as example 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.



ICARUS
neutron
time dependence...

predicts
DAMA/LIBRA
time
dependence...

arXiv:1006.5255 [hep-ph]



curve: icarus phase
points: Dama/Libra data

The Search for Dark Matter (WIMPS) at Low Mass

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Astroparticle Physics Group

Abstract

We review the constraints on the search for low mass wimps (< 15 GeV) and the various experimental methods. These experiments depend on the response of detectors to low energy signals (less than 15 KeV equivalent energy). We then describe recent fits to the data and attempt to determine L_{eff}, the energy response at low energy. We find that the use of a liquid Xenon 2-phase detector that employs the S_2 data near threshold is the most sensitive

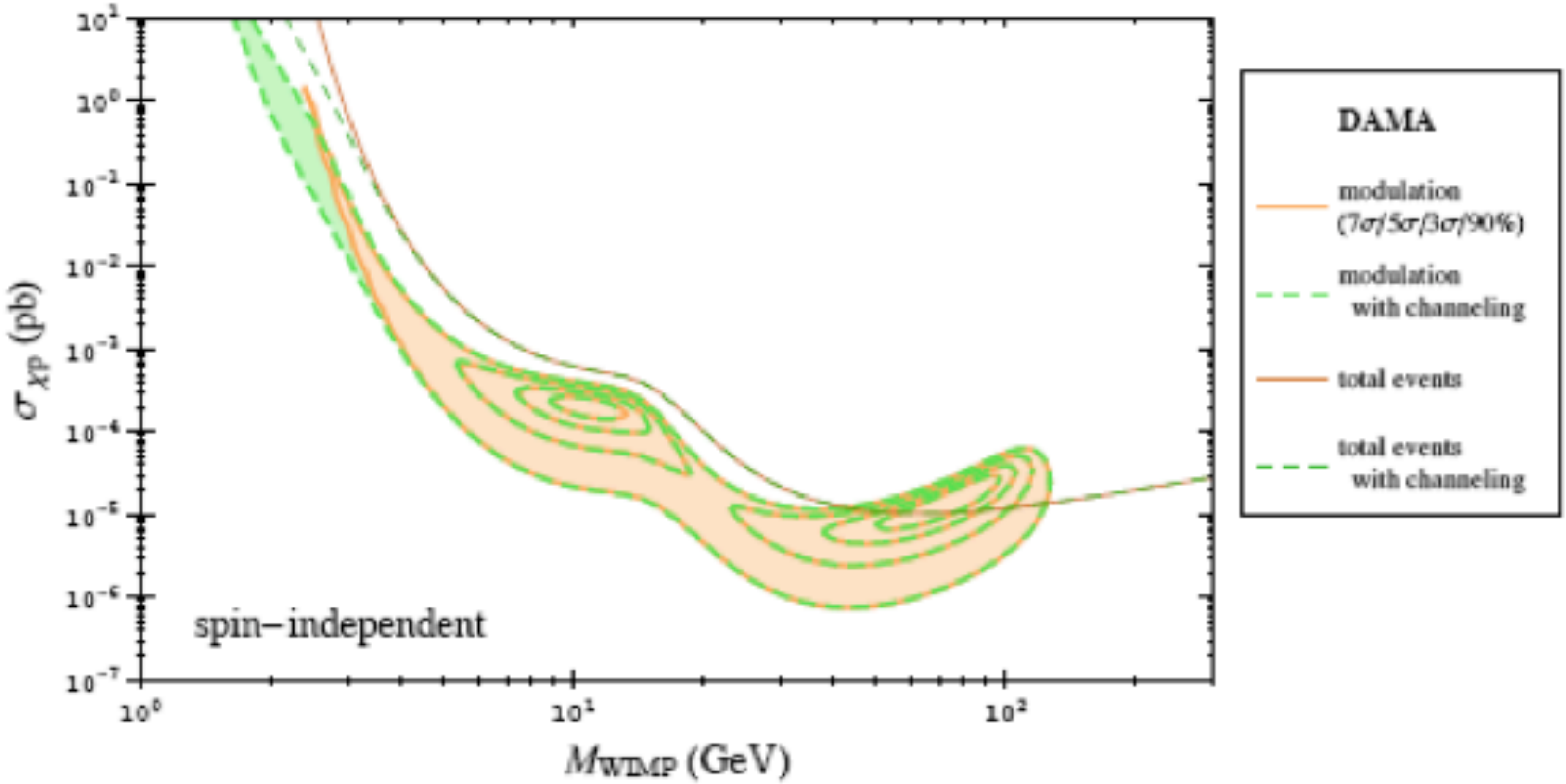


Figure 1. WIMP masses and spin-independent (SI) cross-sections compatible with the DAMA modulation signal and total number of events, determined with (dashed green) and without (solid orange) the channeling effect included. The largest channeling fractions shown in Figure 1 (taken from Ref. [3]) are used here for the channeling case. Comparing the cases with or without channeling, we find negligible difference in the DAMA modulation regions at the 90%, 3σ, and 5σ levels; only the 7σ contours differ and only for WIMP masses below 4 GeV. The lower and higher mass DAMA regions correspond to parameters where the modulation signals arise from scattering predominantly off of NA and I, from Reference 2.

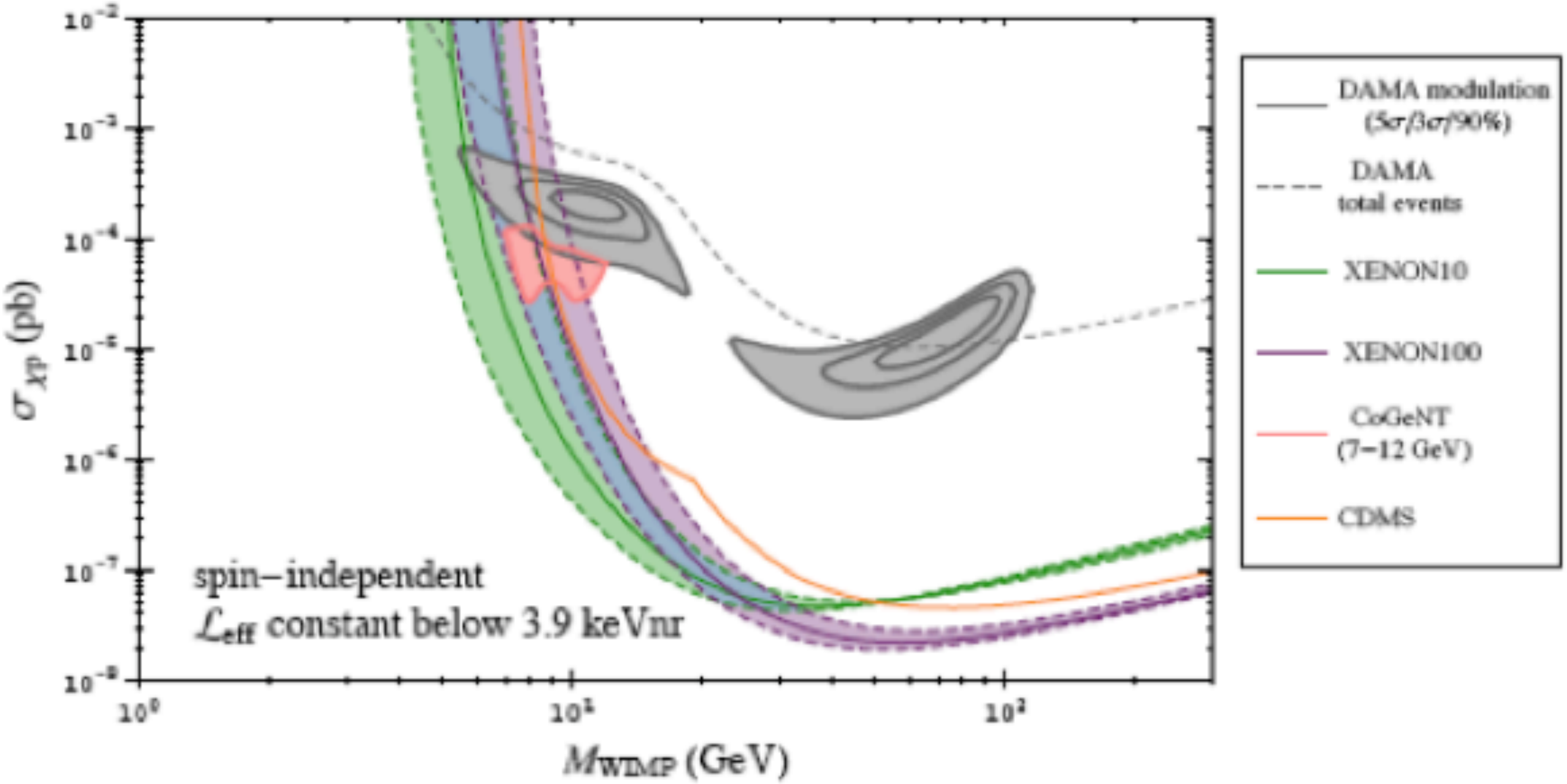


Figure 2. XENON10 (green) and XENON100 (purple) 90% C.L. constraints for a constant $\mathcal{L}_{\rm eff}$ at recoil energies below 3.9 KeVnr. The solid curves are the constraints using the central values of $\mathcal{L}_{\rm eff}$ as described in the text; dashed curves and lighter filled regions indicate how these 90% constraints vary with the 1σ uncertainties in $\mathcal{L}_{\rm eff}$. The blue region indicates an overlap between the XENON10 (green) and XENON100 (purple) 1σ regions. Also shown are the CDMS constraint (orange curve), DAMA modulation compatible regions (gray contours/region), and the CoGeNT 7-12 GeV region (pink contour/region). The lower and higher mass DAMA regions correspond to parameters where the modulation signals arise from scattering predominantly off of Na and I, from Reference 4.

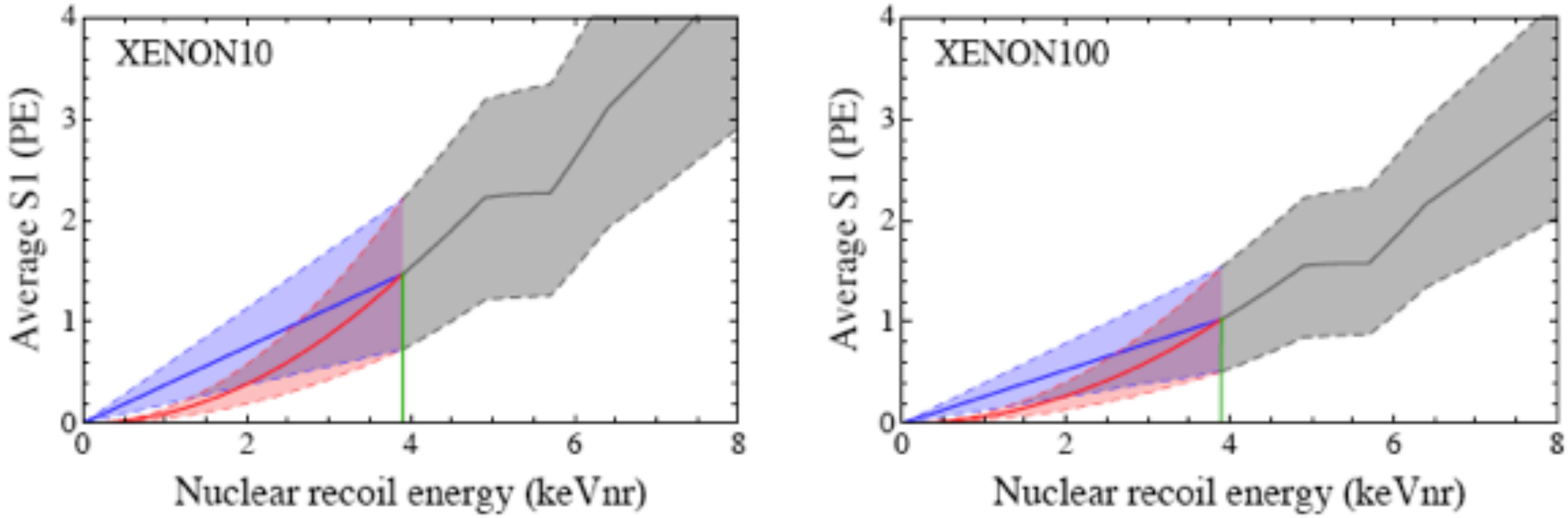


Figure 6. Study of Savage et al on $\mathcal{L}_{eff}$.

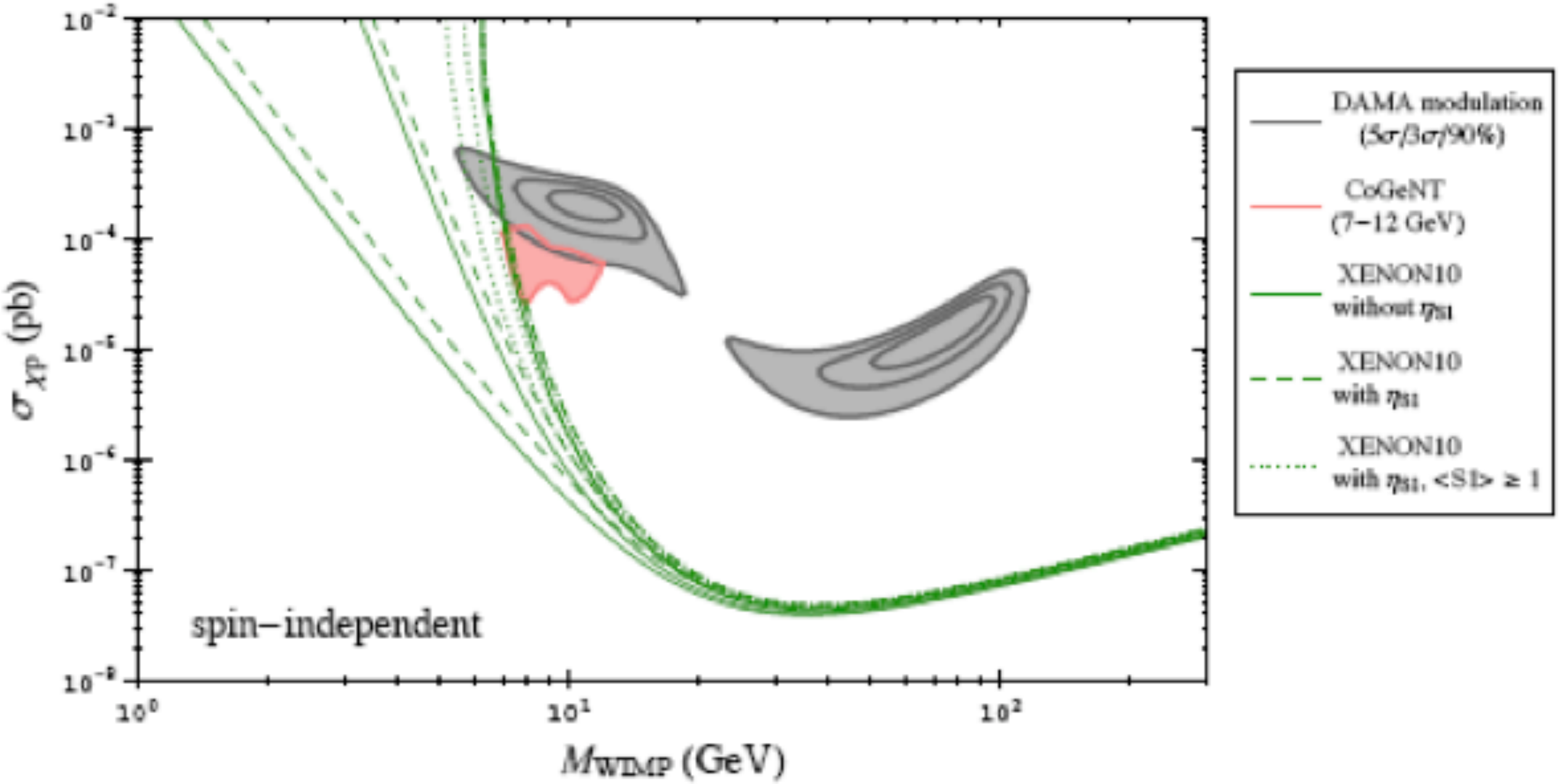


Figure 7 (Reference 6). Exclusion plot of Savage et al.

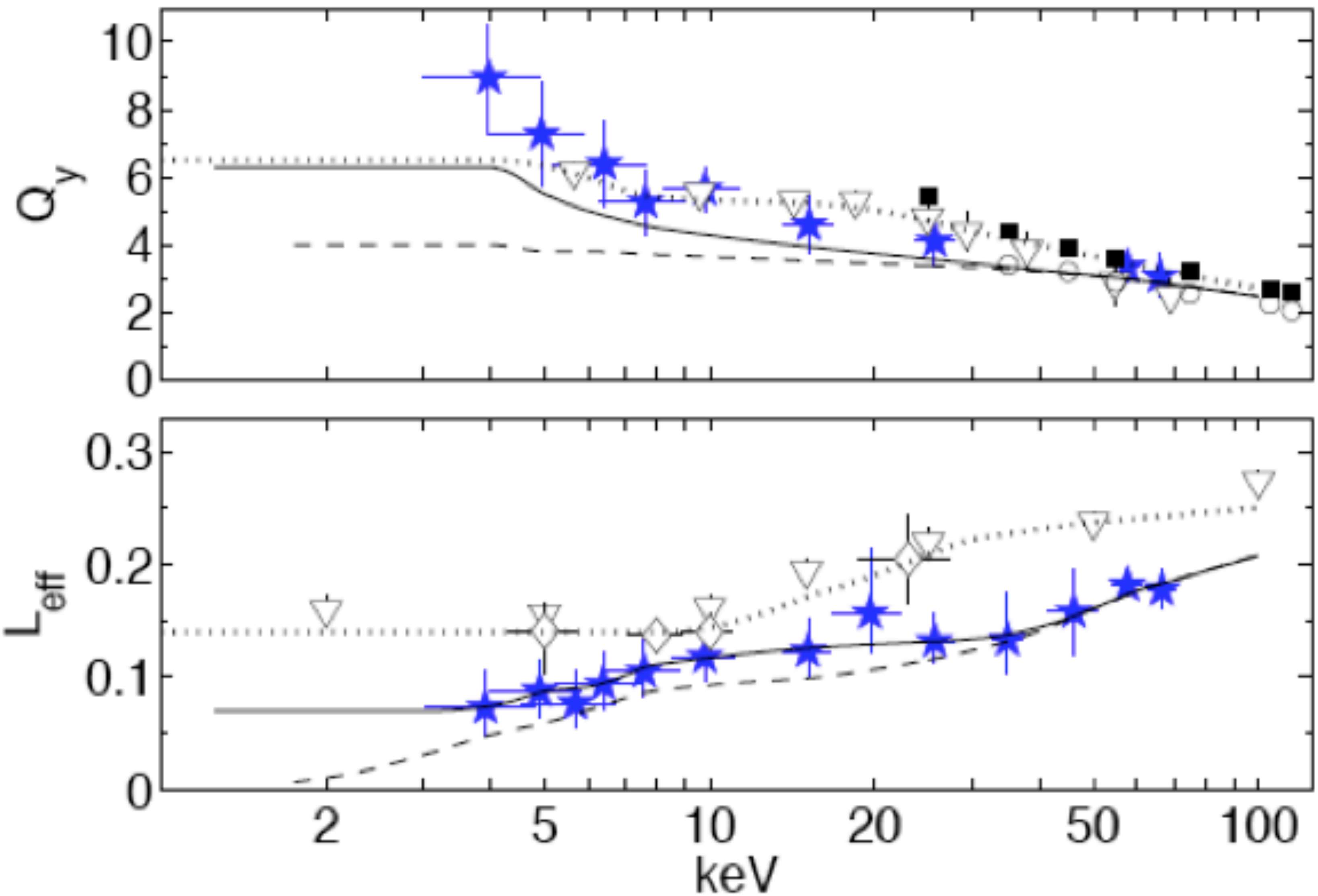


Figure 8. Study of $\mathcal{L}_{eff}$ by Sorensen using S_2 signal data.

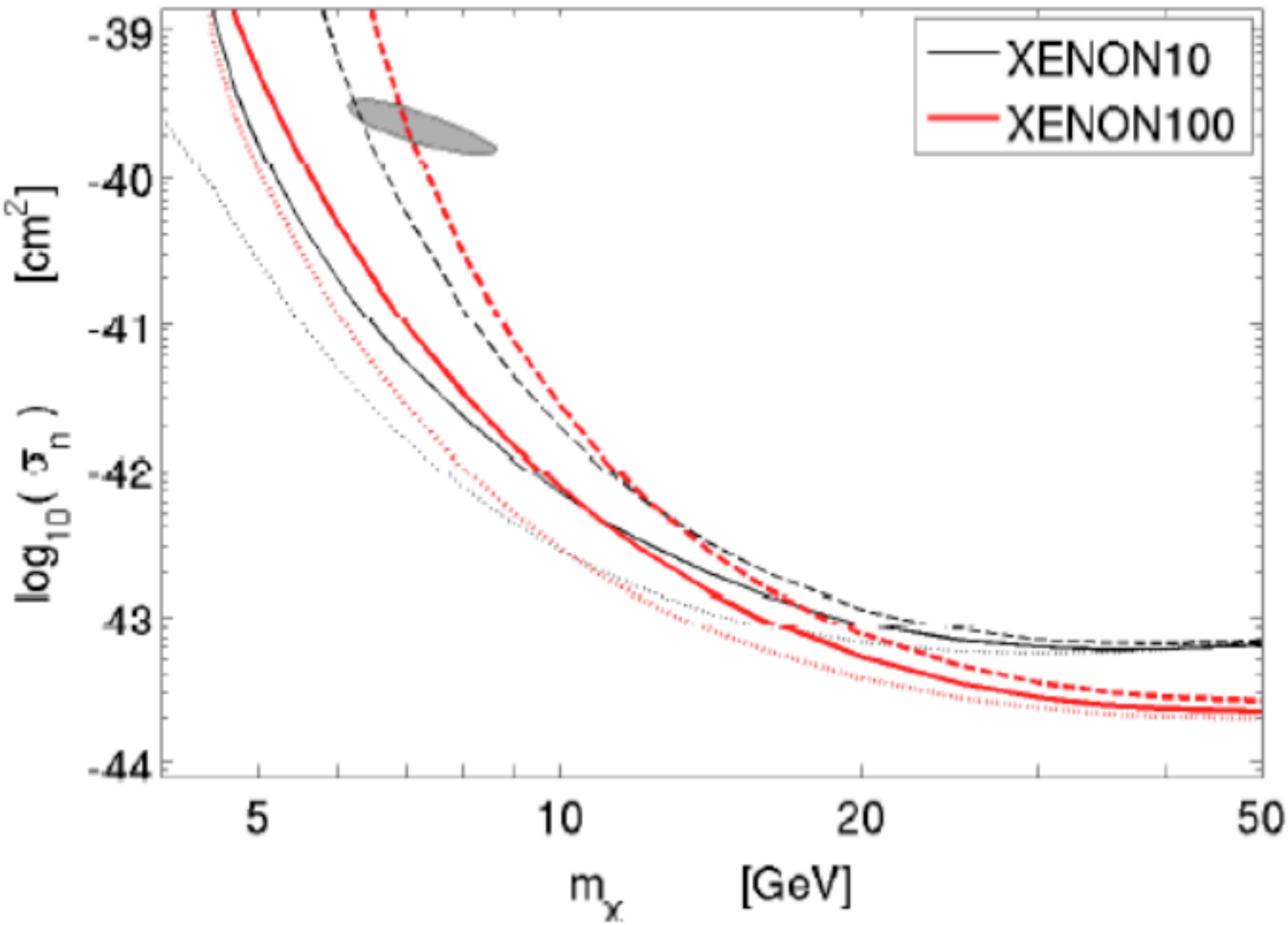


Figure 9. Study of Sorensen using S_2 to determine $\mathcal{L}_{\mathrm{eff}}$.

Giving up S2/S1 discrimination in exchange for a lower energy threshold

Peter Sorensen
on behalf of the XENON10 Collaboration

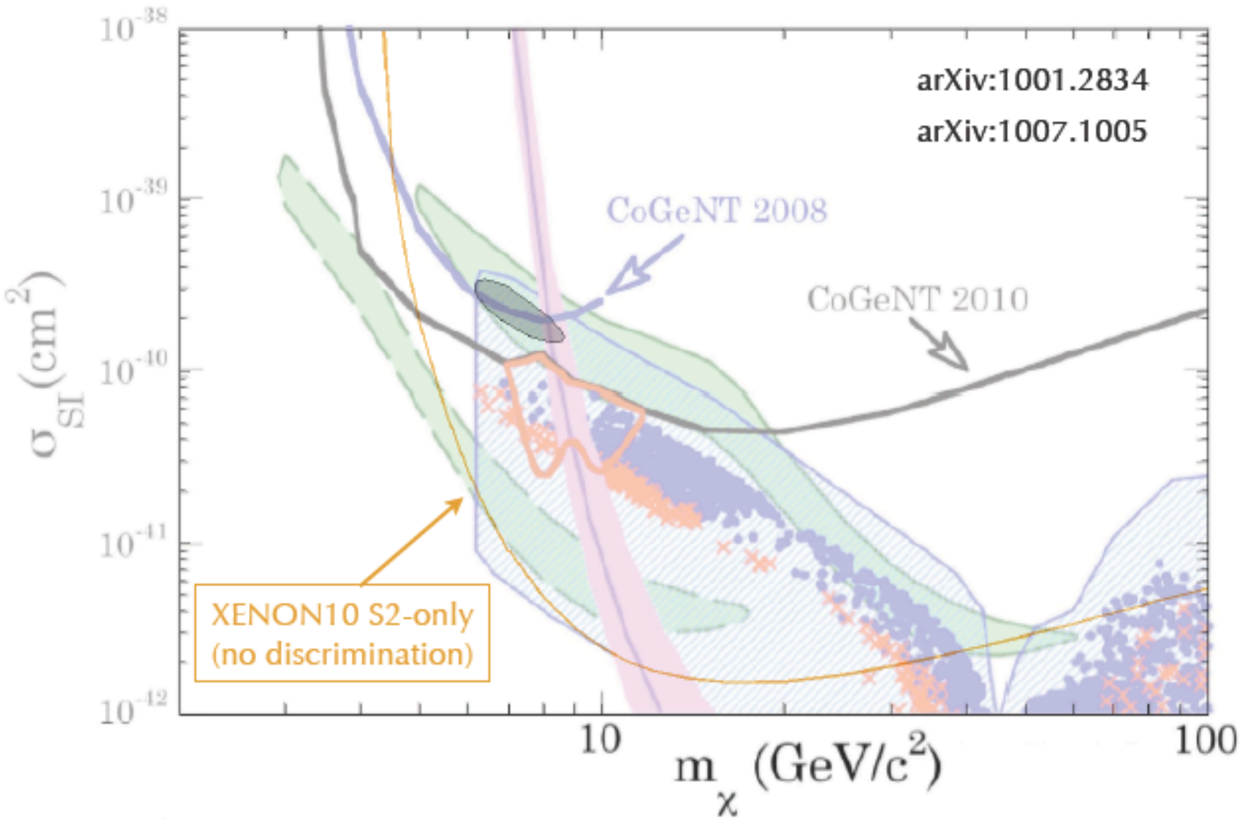
Identification of Dark Matter 2010, Montpellier

Talk Overview

- the XENON10 direct detection experiment
- limitations of S1 (scintillation signal) threshold
- new analysis of S2 (electron signal) energy scale
- using S2 width to obtain approximate z coordinate
- S2-only (no discrimination) dark matter limits

(preliminary) dark matter exclusion limits

Notice: this S2-only exclusion limit curve is preliminary, and has not been fully reviewed by the XENON10 collaboration. Pending review it is subject to change.



- Max Gap 90% C.L. upper limit between 1.6 keVr and 3.8 keVr
- 12.5 live days
- 1.2 kg target
- conservative -1σ Q_y energy calibration
- no account of resolution (this would improve limits)

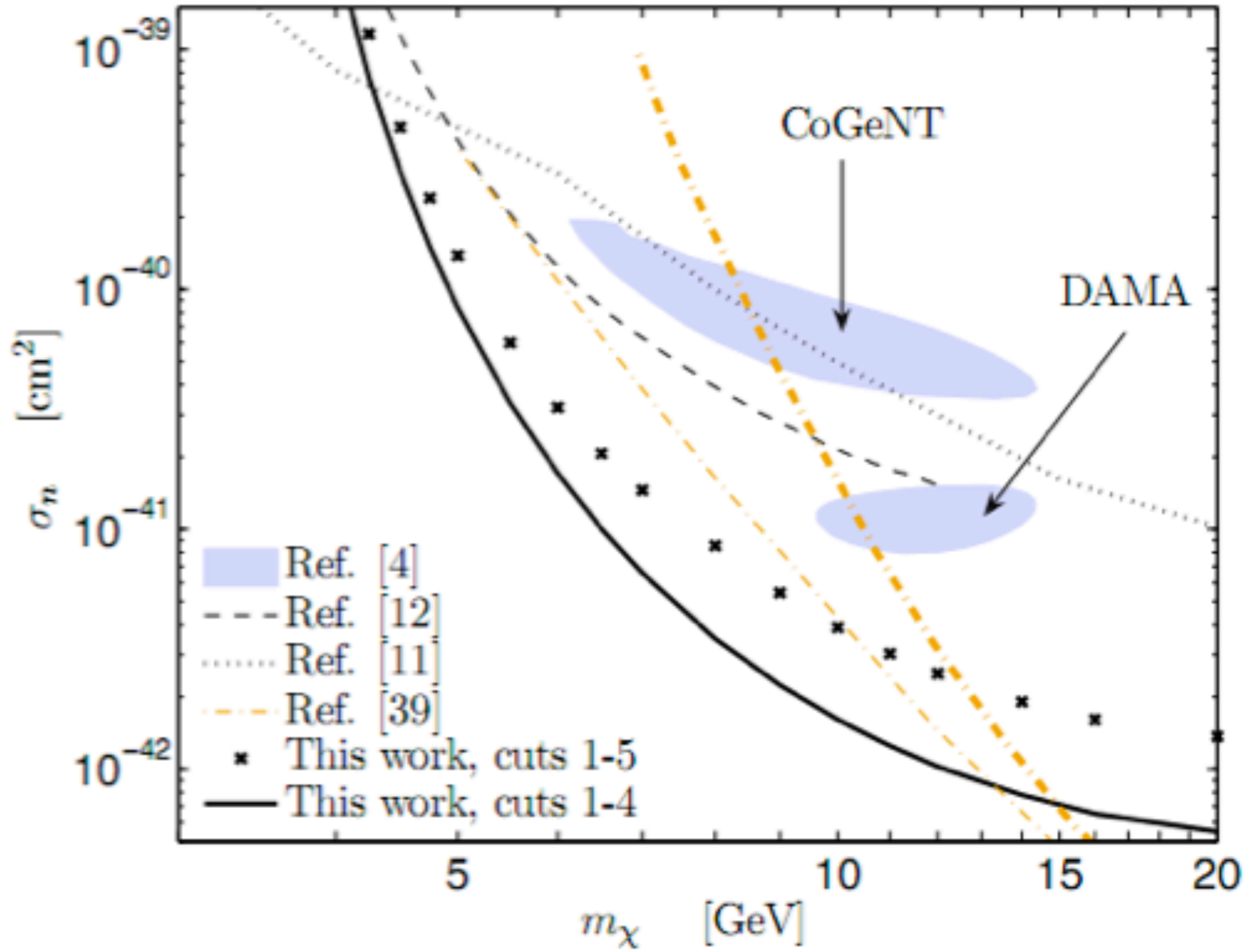


Figure 10. Curves indicate 90% C.L. exclusion limits on spin-independent σ_n for elastic dark matter scattering, obtained by CDMS (dotted [11] and dashed [12]), XENON100 (dash-dot [39]). 99% C.L. allowed regions consistent with the assumption of a positive detection are also shown, for signals from DAMA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

Low-threshold analysis of CDMS shallow-site data

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(CDMS Collaboration)

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(Dated: November 24, 2010)

Data taken during the final shallow-site run of the first tower of the Cryogenic Dark Matter Search (CDMS II) detectors have been reanalyzed with improved sensitivity to small energy depositions. Four ∼224 g germanium and two ∼105 g silicon detectors were operated at the Stanford Underground Facility (SUF) between December 2001 and June 2002, yielding 118 live days of raw exposure. Three of the germanium and both silicon detectors were analyzed with a new low-threshold technique, making it possible to lower the germanium and silicon analysis thresholds down to the actual trigger thresholds of ∼1 keV and ∼2 keV, respectively. Limits on the spin-independent cross section for weakly interacting massive particles (WIMPs) to elastically scatter from nuclei based on these data exclude interesting parameter space for WIMPs with masses below $9\,\mathrm{GeV}/c^2$. Under standard halo assumptions, these data partially exclude parameter space favored by interpretations of the DAMA/LIBRA and CoGeNT experiments' data as WIMP signals, and exclude new parameter space for WIMP masses between $3\,\mathrm{GeV}/c^2$ and $4\,\mathrm{GeV}/c^2$.

PACS numbers: 95.35.+d, 14.80.Ly, 95.30.Cq, 29.40.Wk, 95.30.-k, 85.25.Oj

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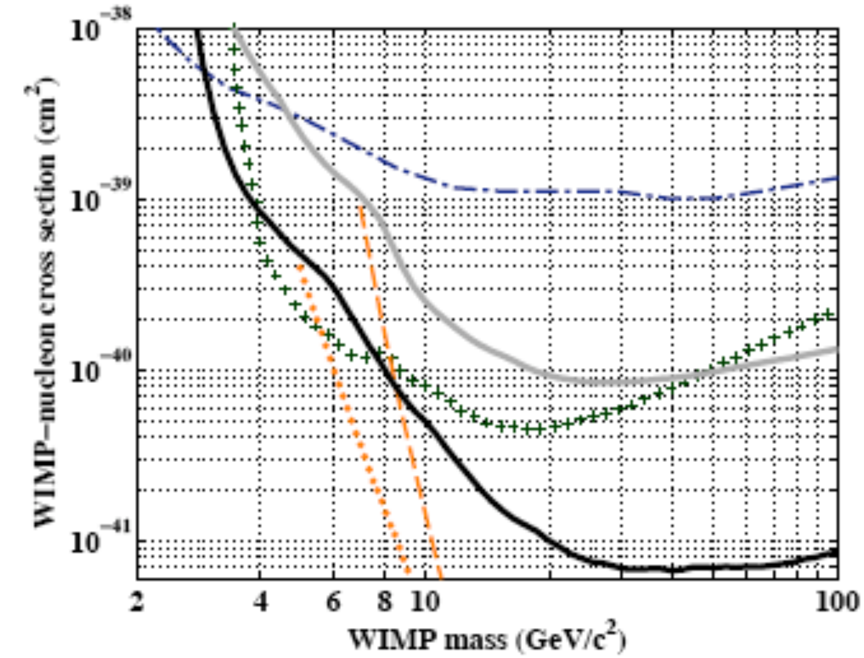
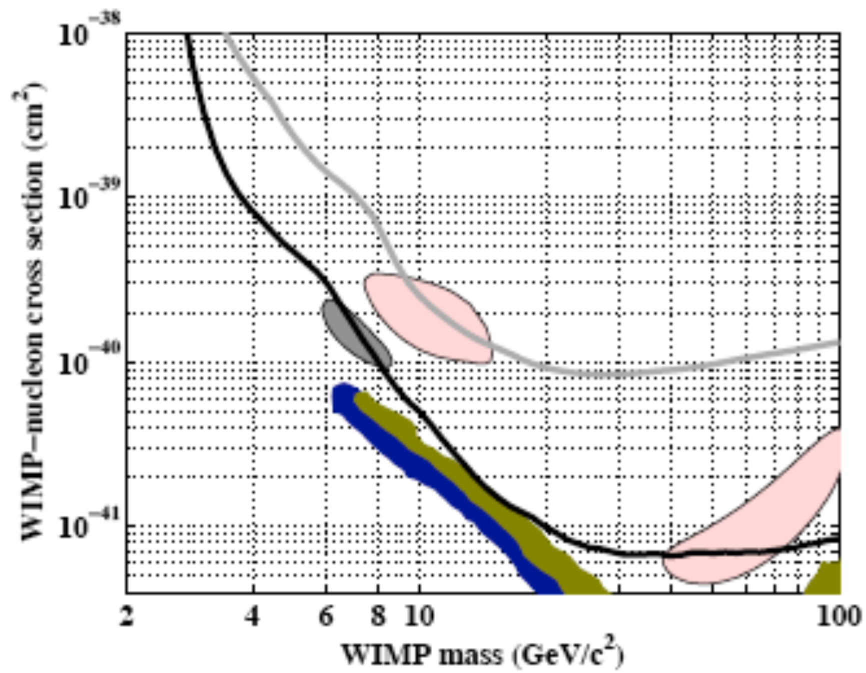

WIMP–nucleon cross section (cm^2)
WIMP mass (GeV/c^2)
10^{-38}
10^{-39}
10^{-40}
10^{-41}
2
4
6
8
10
100


WIMP–nucleon cross section (cm^2)
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10^{-38}
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2
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8
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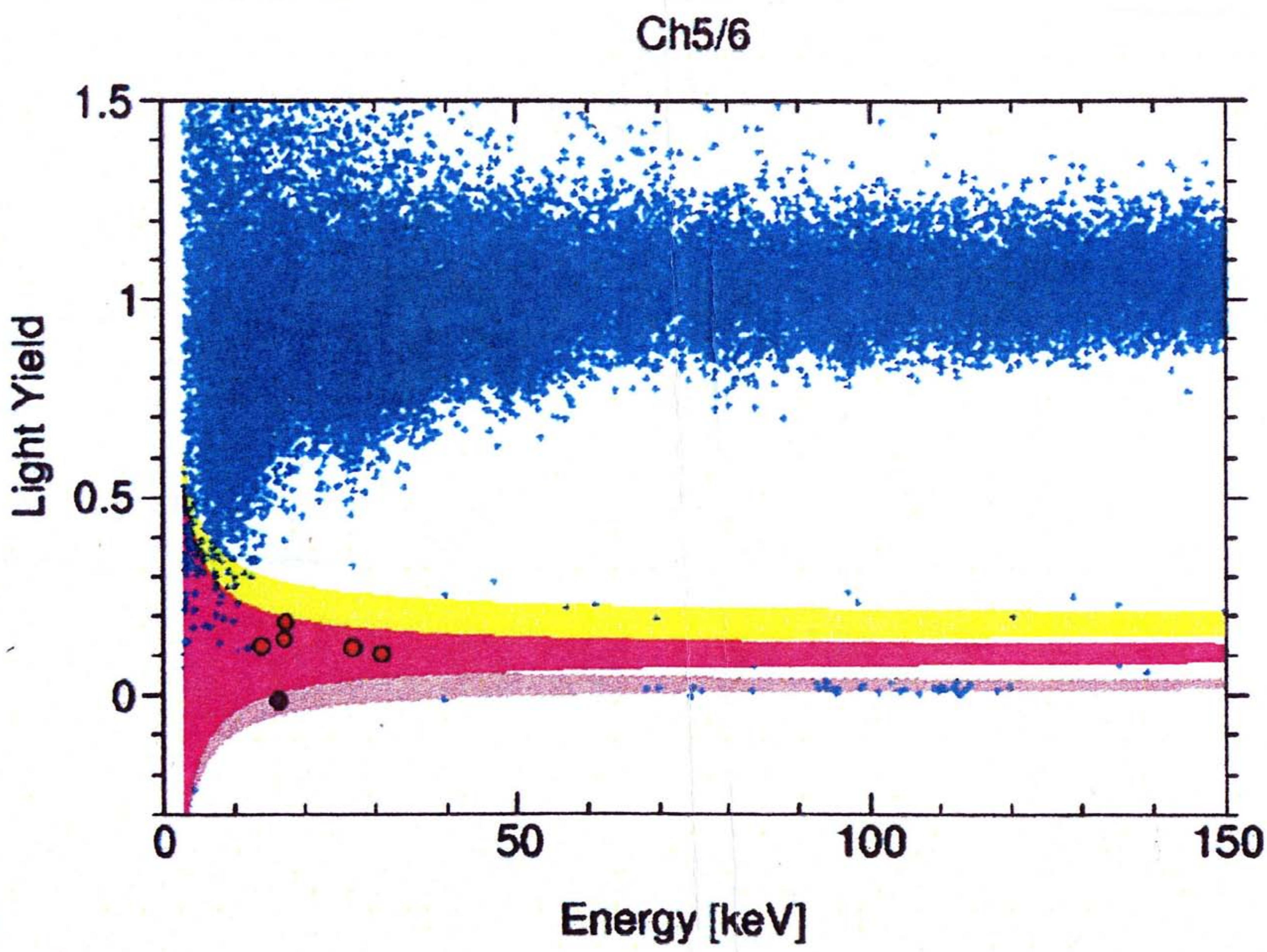
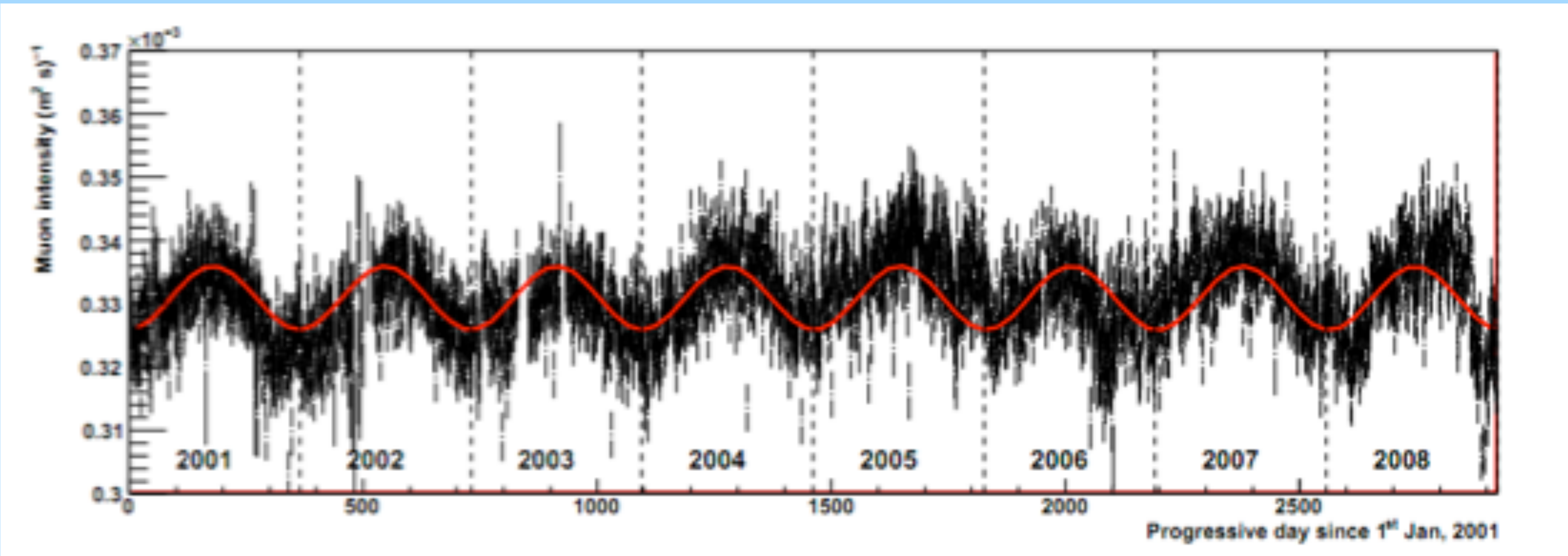
100


Ch5/6
Light Yield
Energy [keV]
1.5
1
0.5
0
0
50
100
150



Muon intensity (m² s)⁻¹
×10⁻³
0.37
0.36
0.35
0.34
0.33
0.32
0.31
0.3
2001
2002
2003
2004
2005
2006
2007
2008
0
500
1000
1500
2000
2500
Progressive day since 1st Jan, 2001

Summary

Dark energy

- All consistent with Λ
- JDEM dead, Euclid going ahead
- FNAL DES very promising, could have a robust result soon

Dark matter

- SUSY predictions for direct search 10^{-8} - 10^{-9} pb
- Indirect search: some claim that Pamela data supports WIMPS (G. Kane)
- Indirect search: FERMI unlikely to observe DM
- Galactic Center is a possible exception, D. Hopper claims a signal
- Direct searches: more problems for DAMA CDMS not confirmed XENON 100; Edelweiss and CRESST promising; COUPP and other similar detectors very sensitive to spin dependent DM; 11 days of XENON 100: best limit XENON started taking blind data January 15, 2010, can reach 2 x 10^{-9} pb in 2010
- Design of XENON 1 ton making progress, one half of detector already funded
- Low mass WIMP region likely excluded by CDMS and XENON 10 and 100