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Direct Detection Of Galactic Dark Matter

Why WIMPs?

Experimental situation

- Situation in Summer 2009
- Recent action Dec 2009-July 2010
  - CDMS II 2 events
  - Xenon 100
  - CoGeNT and DAMA

The future of direct detection

- Need for at least 2 technologies
- Complementarity with LHC and indirect detection

Dark Matter Could Be Due to New Physics at the TeV Scale!

A remarkable coincidence

Particles in thermal equilibrium + decoupling when nonrelativistic

$$\Rightarrow \Omega_x h^2 = \frac{3 \cdot 10^{-27} cm^3/s}{\langle \sigma_A v \rangle} \approx 0.12 \quad \Rightarrow \sigma_A \approx \frac{\alpha^2}{M_{EW}^2}$$

Cosmology points to W&Z scale
Inversely standard particle model requires new physics at this scale
(e.g. supersymmetry, global symmetry or additional dimensions)
=> significant amount of dark matter

Weakly Interacting Massive Particles

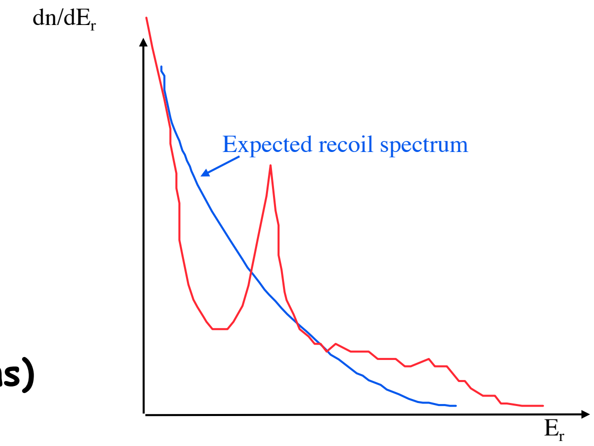
Three methods:

Direct Detection in the Cosmos= Halo WIMP elastic scattering
Indirect Detection in the Cosmos= Annihilation products $\gamma, e^+, \bar{p}, \nu$
Production at the large Hadron Collider

Halo WIMP Scattering "Direct Detection"

Elastic scattering

Expected event rates are low
(<< radioactive background)
Small energy deposition (≈ few keV)
<< typical in particle physics
Signal = nuclear recoil (electrons too low in energy)
≠ Background = electron recoil **(if no neutrons)**



Signatures

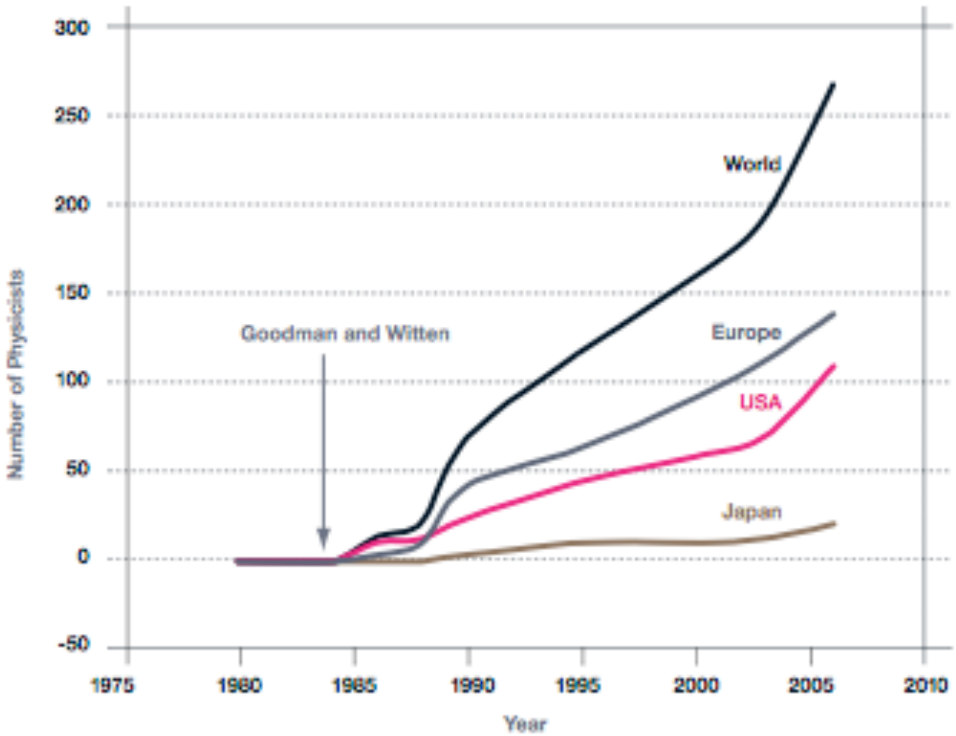
- Nuclear recoil
- Single scatter ≠ neutrons/gammas
- Uniform in detector

Linked to galaxy

- Annual modulation (but need several thousand events)
- Directionality (diurnal rotation in laboratory but 100 Å in solids)

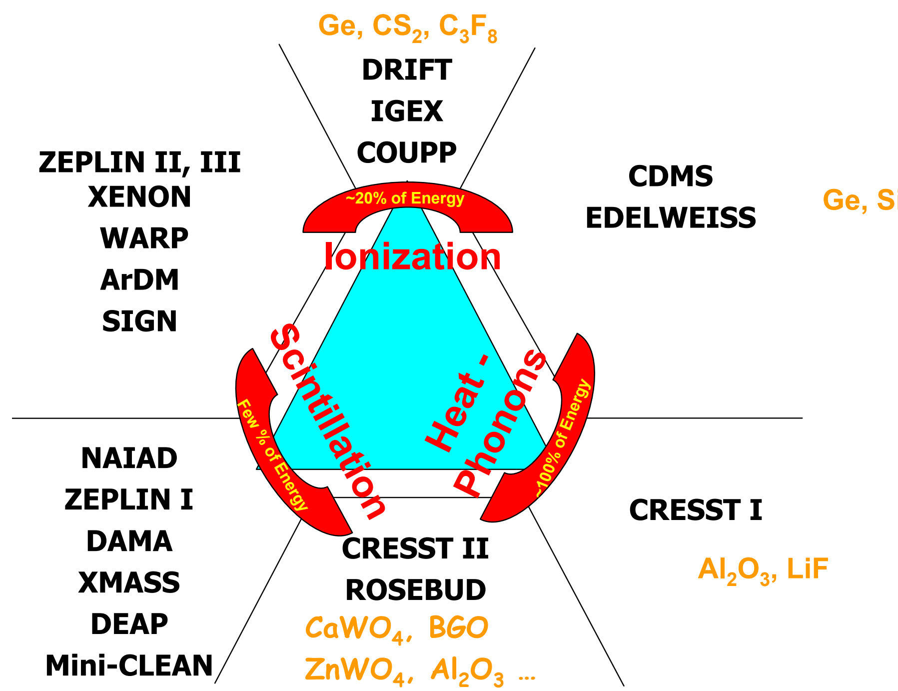
Experimental Approaches

A blooming field



As large an amount of information and a signal to noise ratio as possible

Direct Detection Techniques



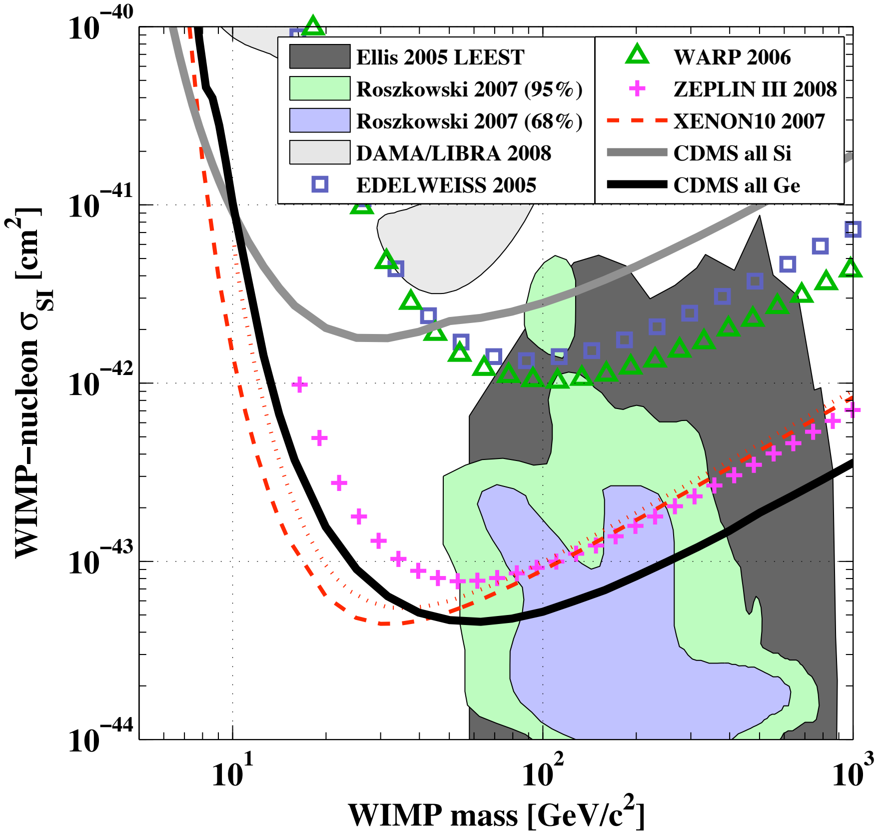
At least two pieces of information in order to
- recognize nuclear recoil
- extract rare events from background (self consistency)
- + fiducial cuts (self shielding, bad regions)

Situation Summer 2009

Scalar couplings: Spin independent cross sections

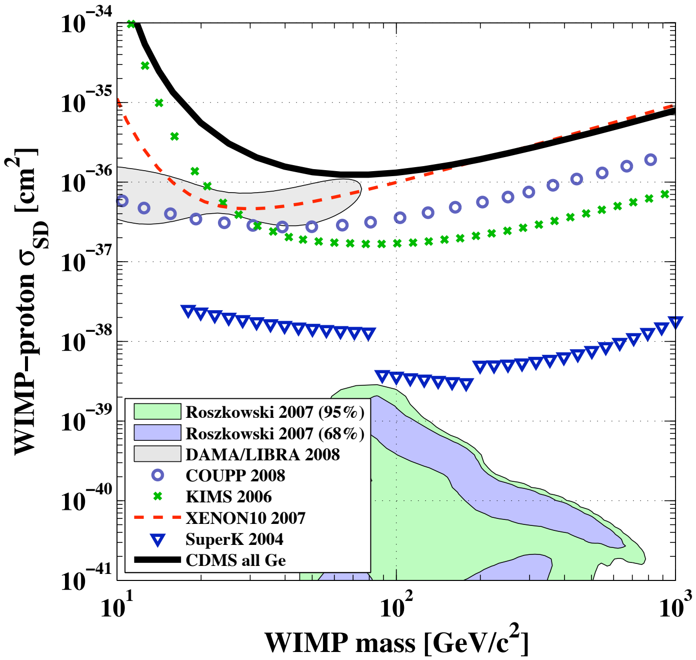
January 2009 compilation by Jeff Filippini

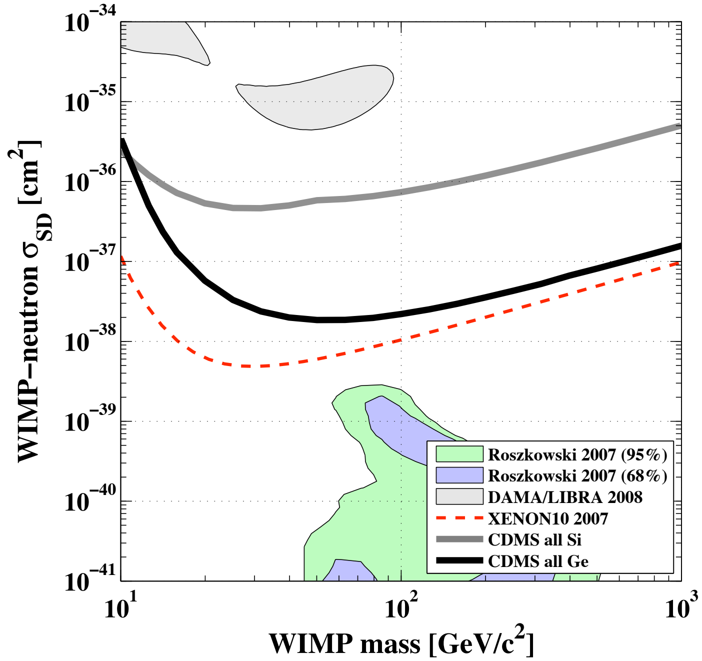
Gray=DAMA 2 regions(Na, I) from Savage et al.



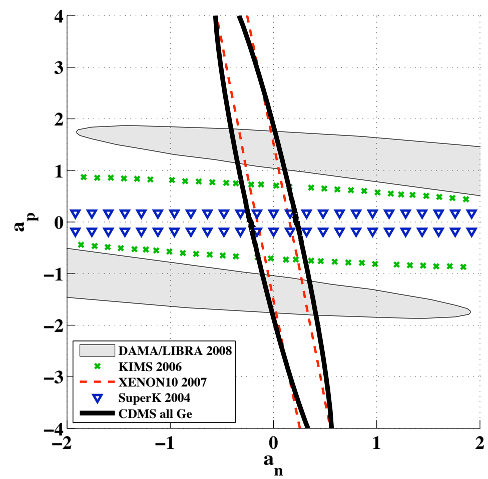
Situation Summer 2009

Spin dependent couplings





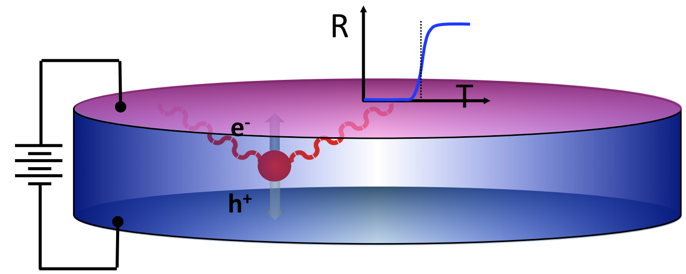
a_p vs a_n at mass of 60GeV/c^2



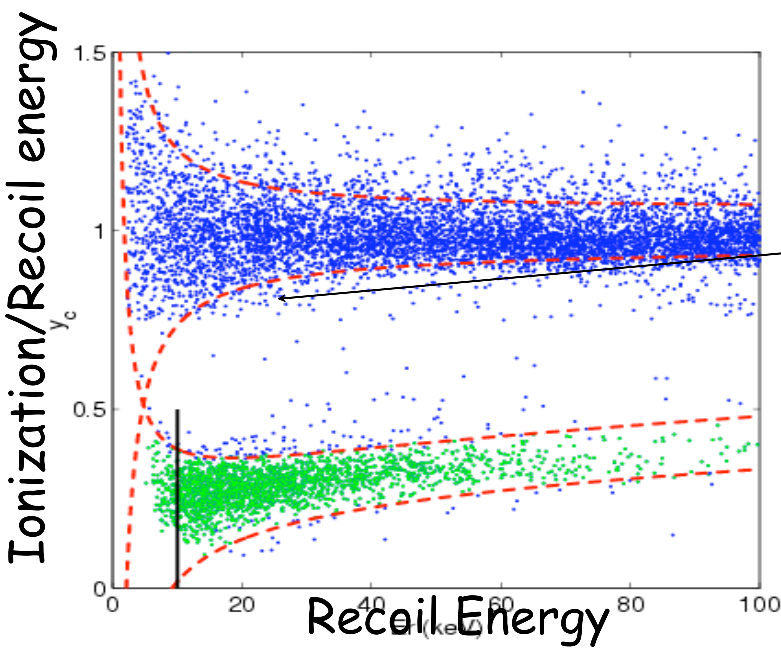
CDMS II December 2009

Ionization + Athermal Phonons

7.5 cmØ 1 cm thick ≈250g
4 phonon sensors on 1 face
2 ionization channel

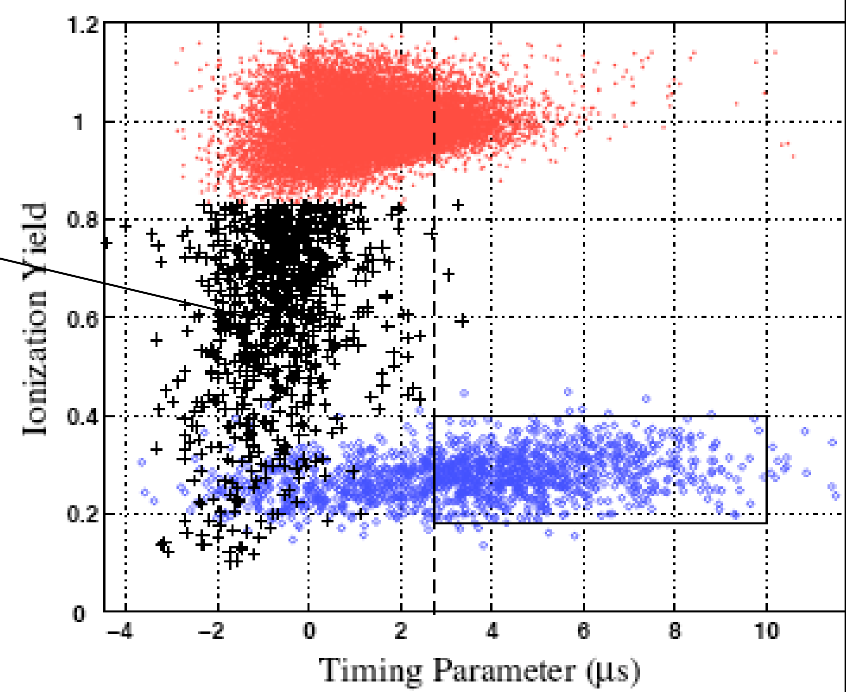


Ionization yield

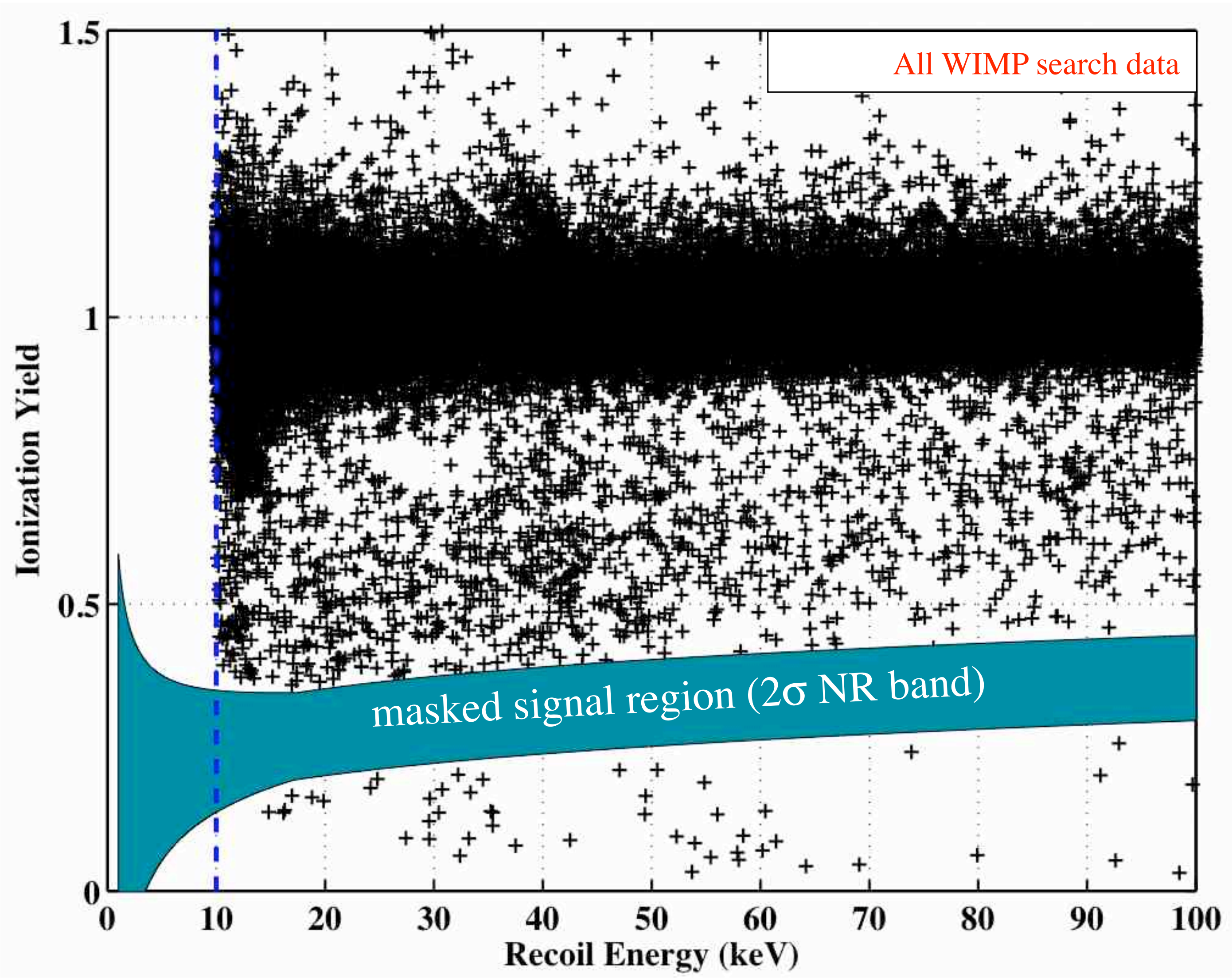


Surface Electrons

Timing -> surface discrimination

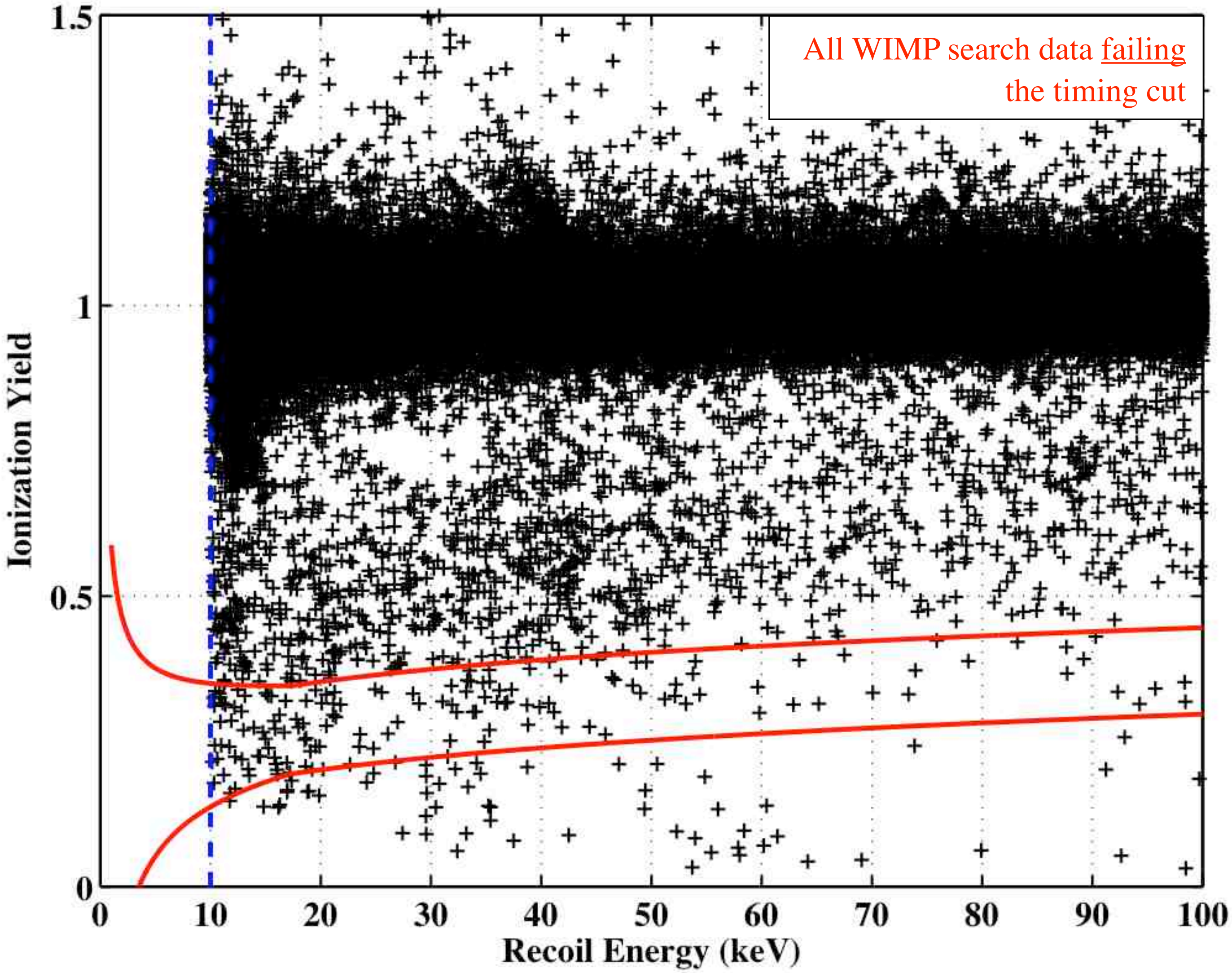


CDMS Blind Analysis



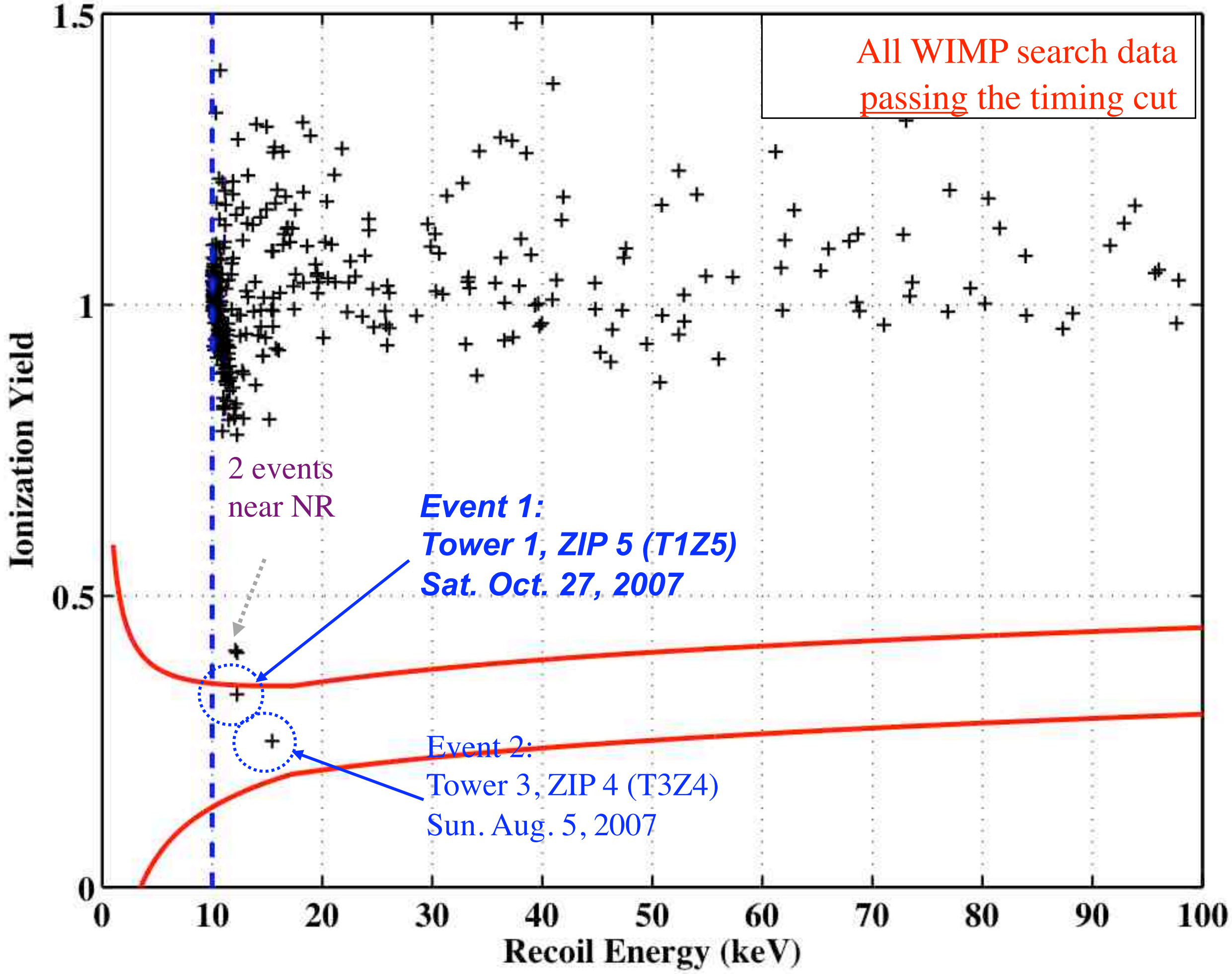
We unblinded the signal region November 5, 2009

Unblind Events Failing Timing Cut



150 events in the NR band <u>fail</u> the timing cut, consistency checks deemed ok

Unblind Events Passing Timing Cut



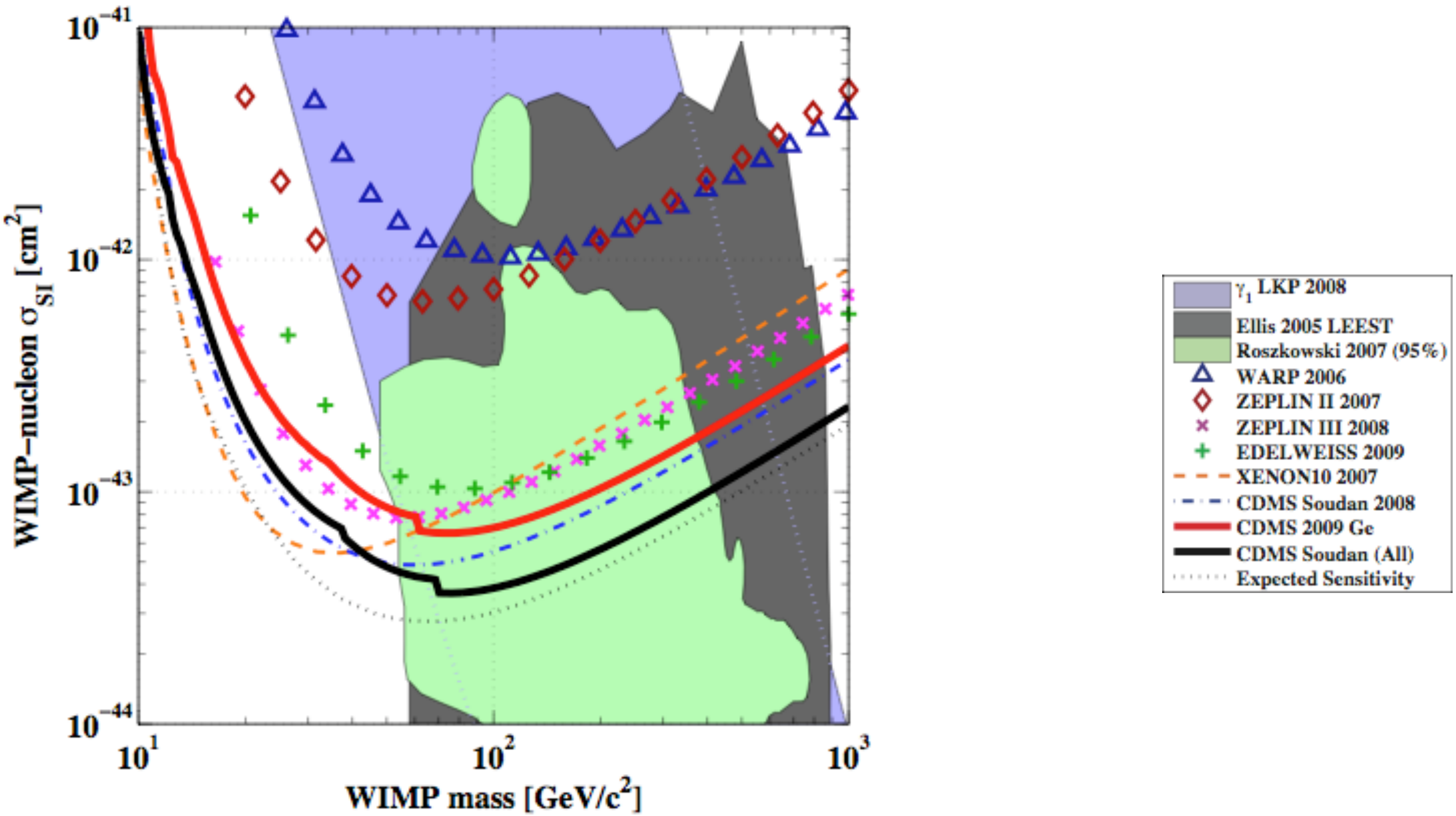
2 events in the NR band pass the timing cut!

Background 0.8 ± 0.1 (stat) ± 0.2 (syst) surface events

+ 0.1 ± 0.05 (syst) neutron => 23% Probability

90% C.L. Spin-Independent Limit

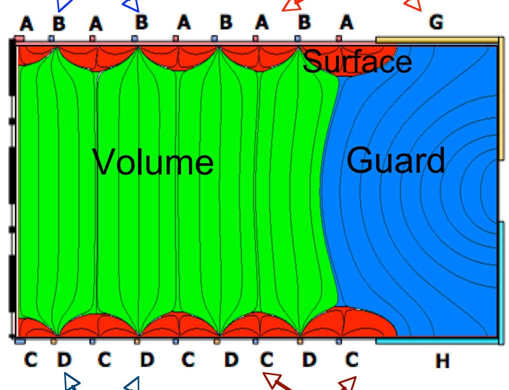
Science 12 February 2010



Upper limit at the 90% C.L. on the WIMP-nucleon cross section :

3.8×10^{-44} cm^2 for a WIMP of mass 70 GeV/c^2

The future of Ge



Breakthrough: Interdigitated detectors

Positive and ground electrodes on top side
Negative and ground on negative
=> separate surface (asymmetric) from bulk (symmetric)
CDMS + EDELWEISSS

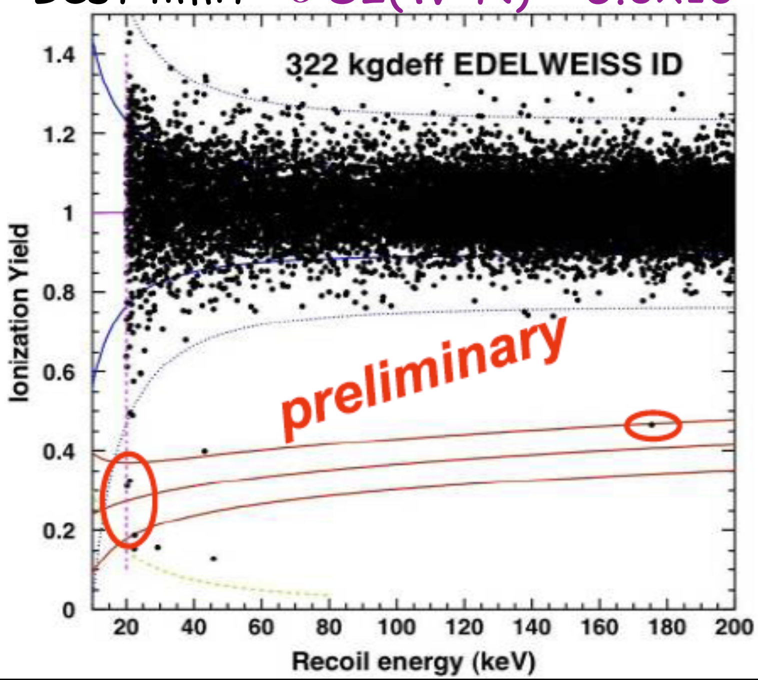
The surfaces are gone!

Rejection should be good enough-> ton scale

Is this true? EDELWEISS results presented Sunday 7/18

3 evts near threshold + 1 evt at 175 keV in the nuclear recoil region (1.6 evt expected)

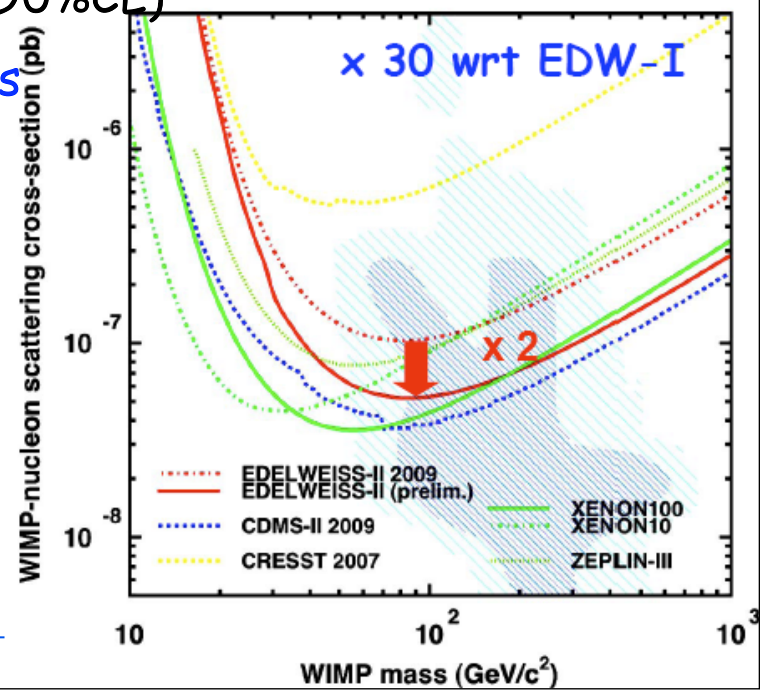
Best limit: σ SI(W-N) = 5.0x10^{-44} cm^2 at M_W= 80 GeV(90%CL)



→background starts

to appear?

Gammas?



The future of Ge 2

SCDMS Soudan 15kg

2011-2012: 5 10^{-45} cm^2

SCDMS SNOLAB 100kg

2014-2017 3 10^{-46} cm^2

GEODM DUSEL 1.5 tonne

2017-2021 2 10^{-47} cm^2

Challenge is to produce detector at low enough cost ($50M)

EDELWEISS

2012: 5 10^{-45} cm^2

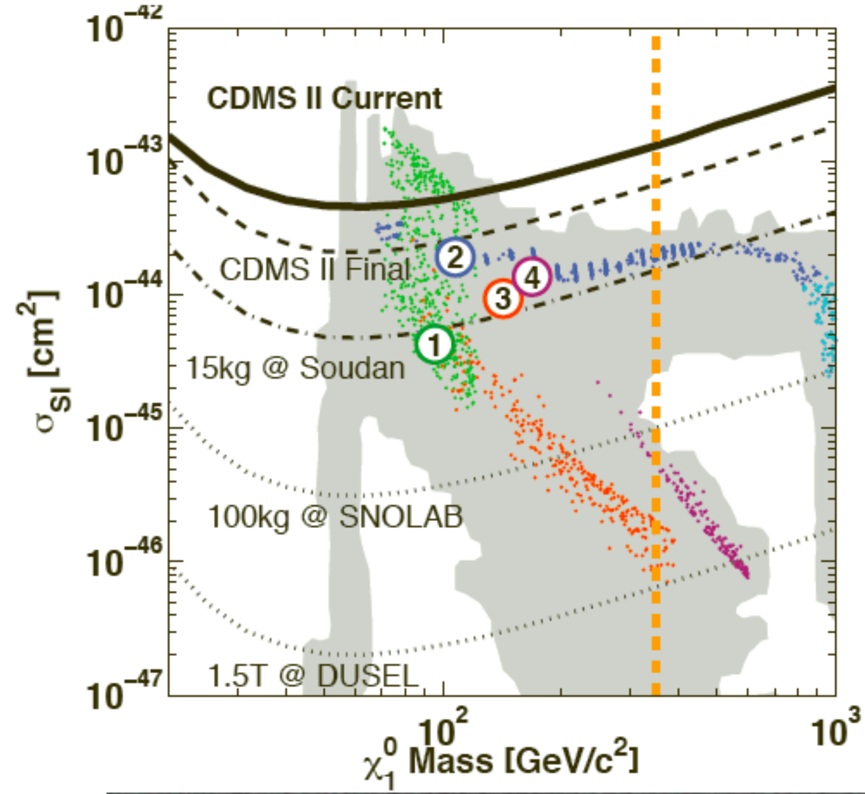
40 detectors 800g + improvement background, electronics

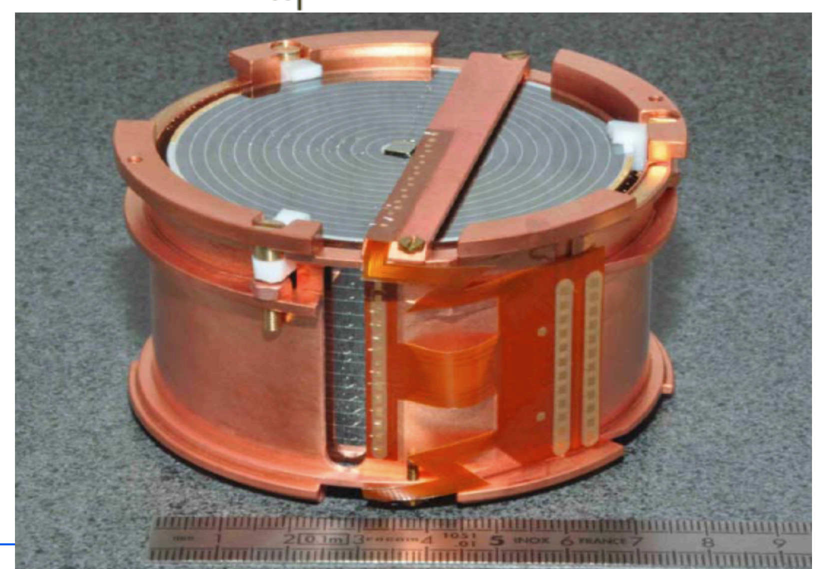
EURECA 100kg

2013-2016

few 10^{-46} cm^2

-> tonne

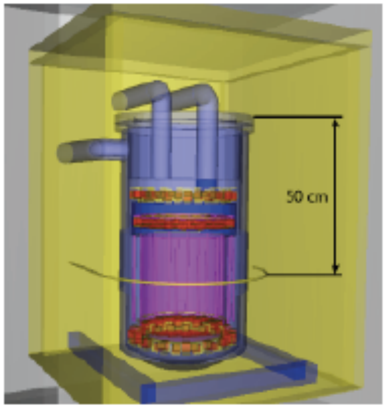




New results of Xenon 100 May 2010

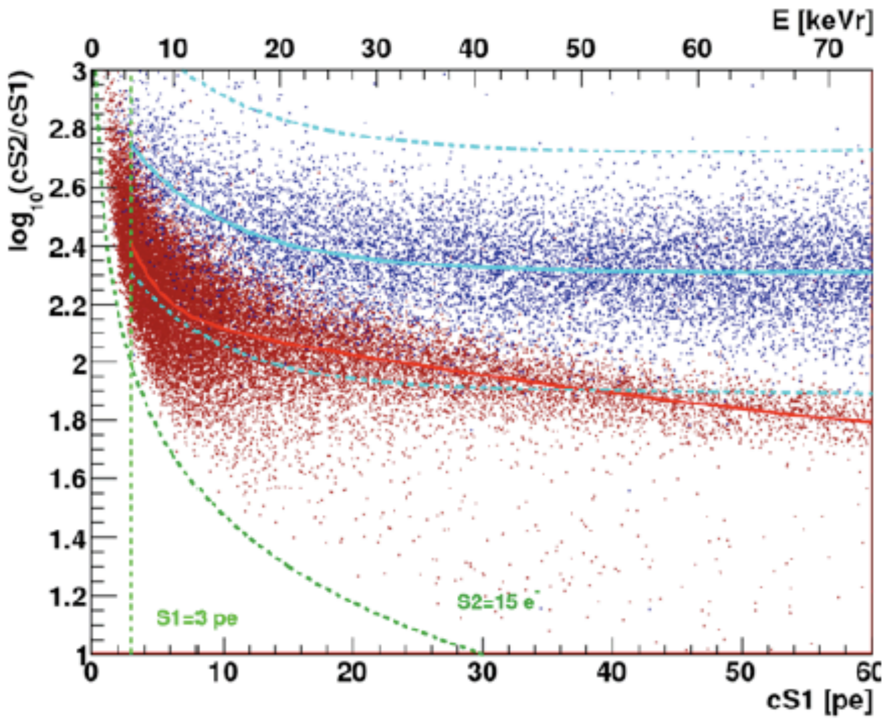
Liquid Xenon

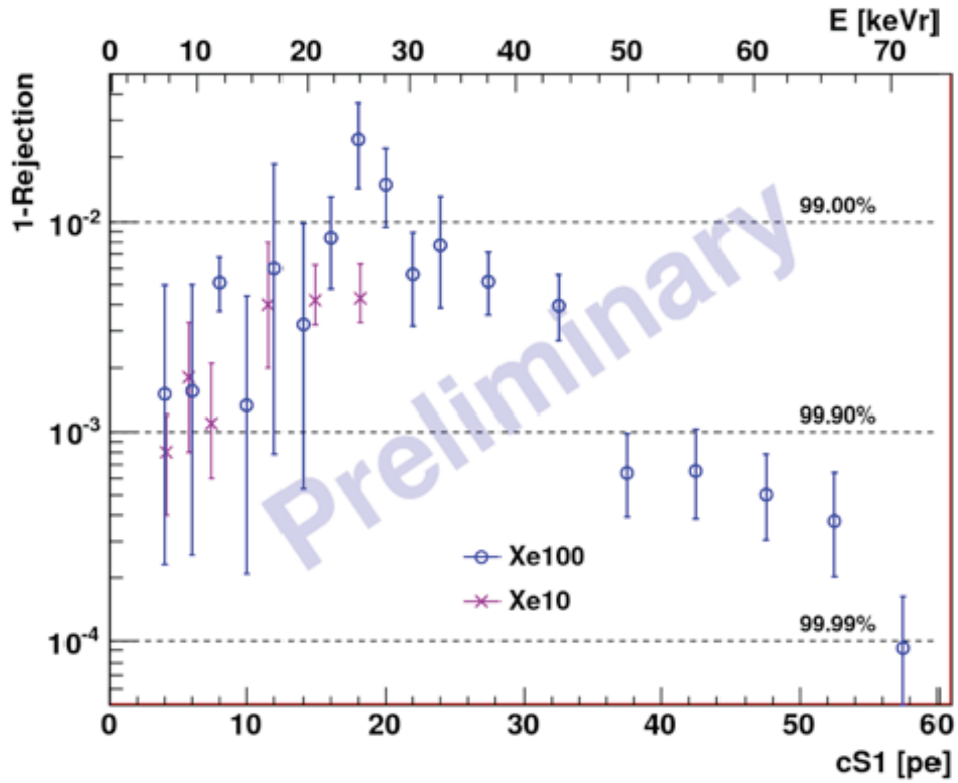
161kg Xe
40kg active volume



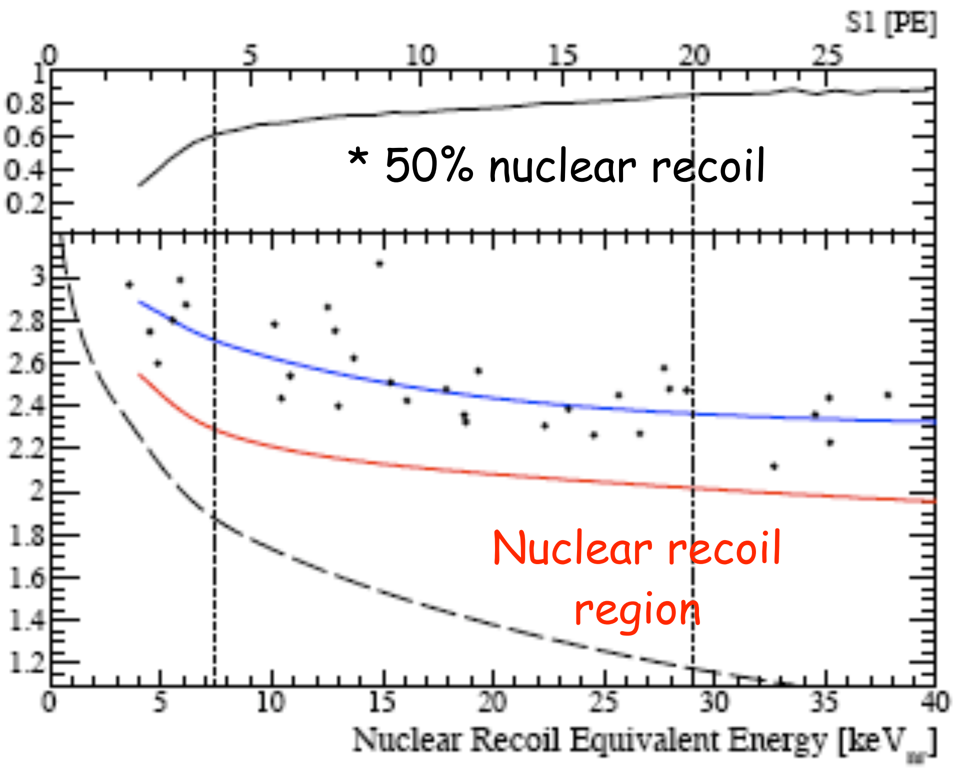
Scintillation (S1) + Ionization (S2)

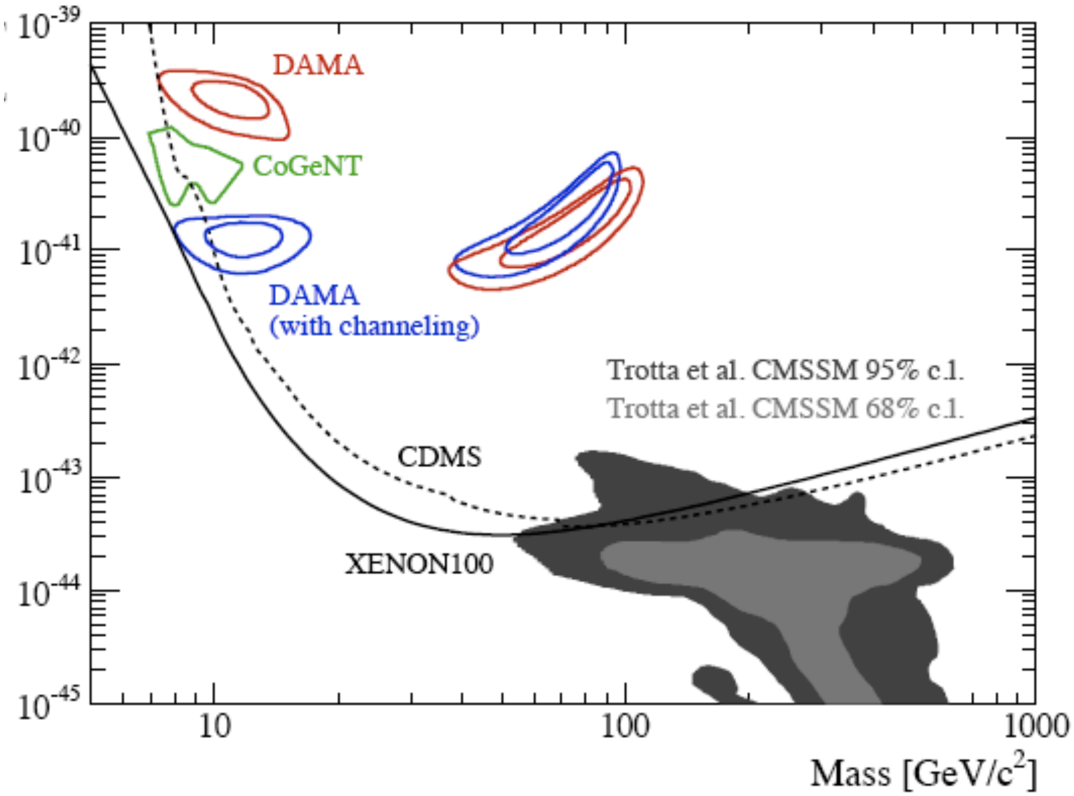
Log scale





Exclusion limit





11 days preliminary run (not blind)

Very few events in fiducial region

Sensitivity ≈ CDMS

- Increasing tension with DAMA
- Do not see evidence for low mass seen by CoGeNT

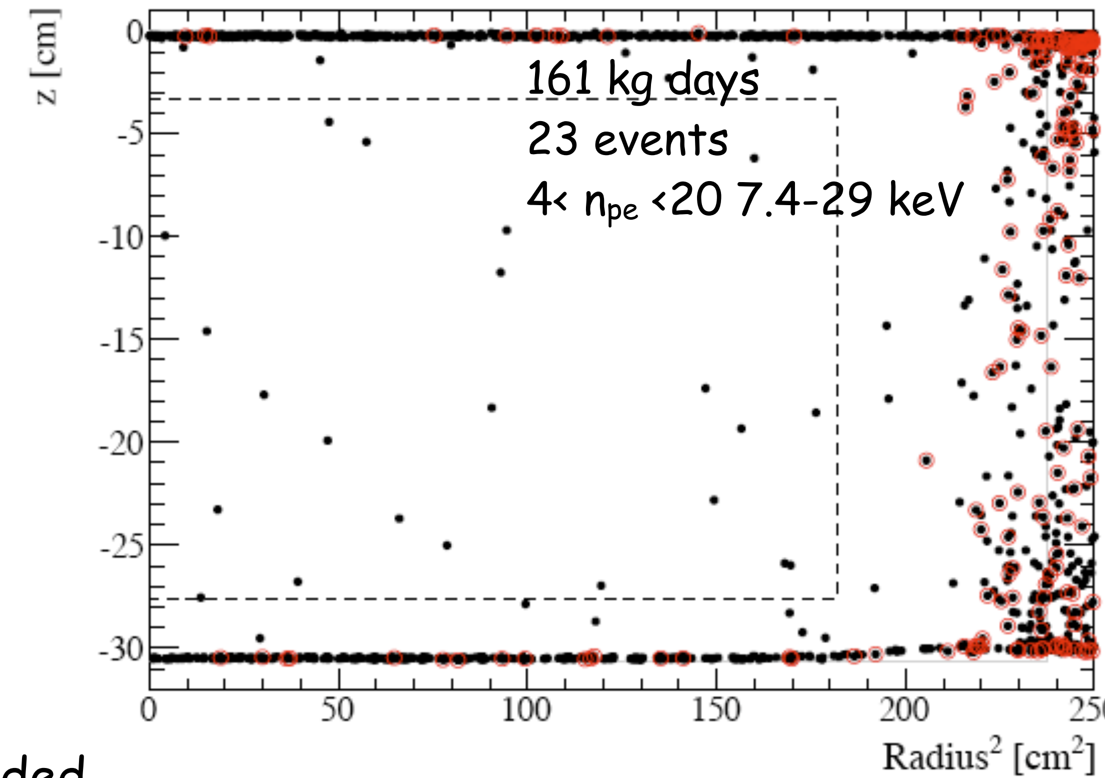
The future of Xenon

3 experiments

XMASS (single phase)
Xenon 100-> 1t
LUX 350kg-> few tons

Exciting

Currently running
With rejection of ≈7 10^{-3}
could improve by factor 5
≈ 5 10^{-45} cm^2/nucleon



But clearly see volume contamination

Will have to understand

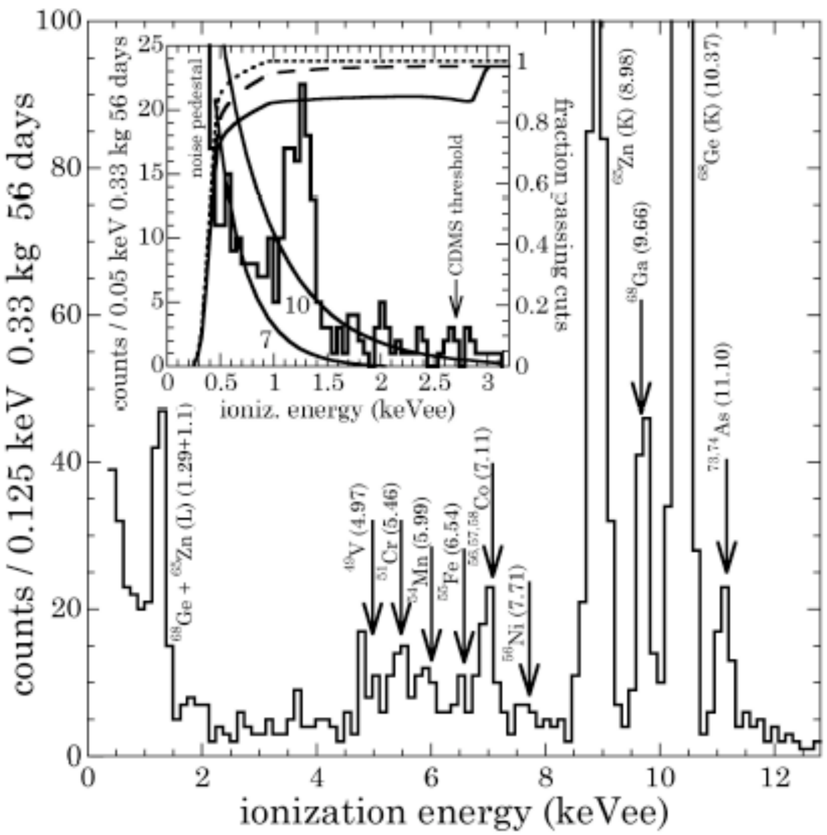
Still far from performance needed
for 10^{-47} cm^2/nucleon (Generation 3 experiment goal!)

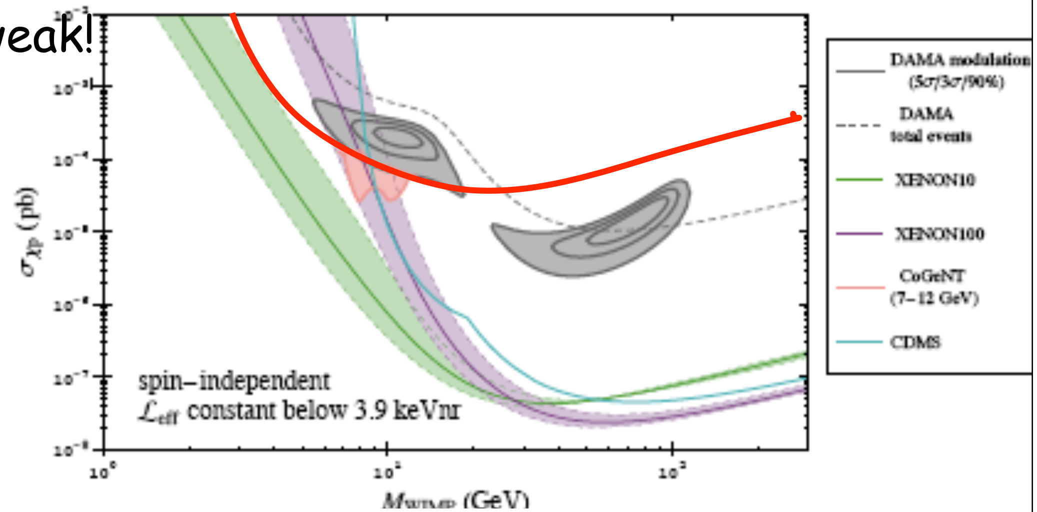
CoGeNT Feb 2010

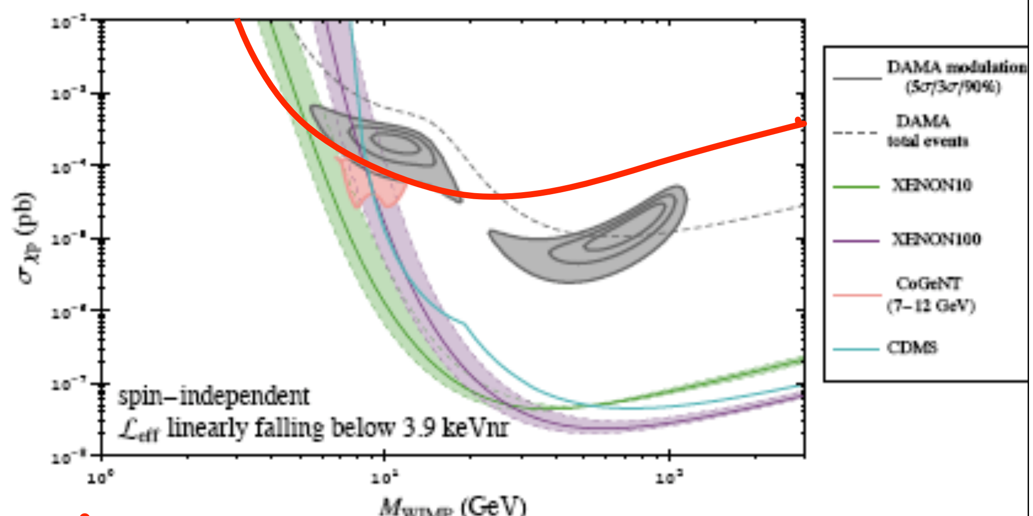
Small Ge liquid N_2 high resolution

Evidence for a signal ?

Detailed shape of the background: very weak!







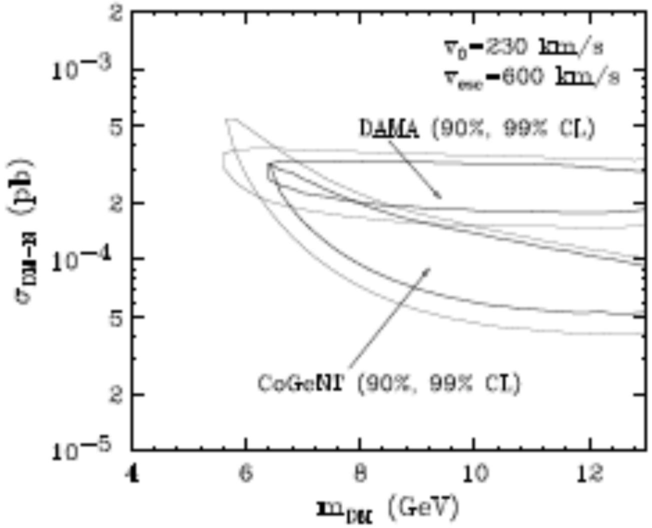
Excluded by Xenon 10-100?

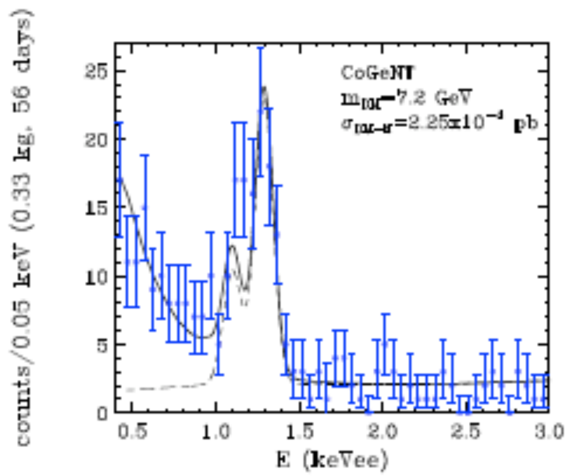
it all depends on Leff calibration

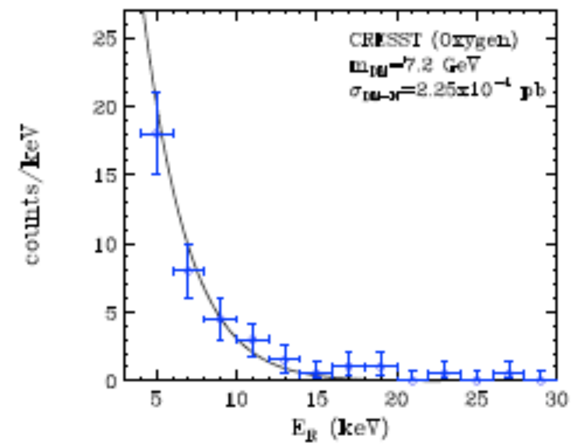
Savage et al ArXiV 1006.0972

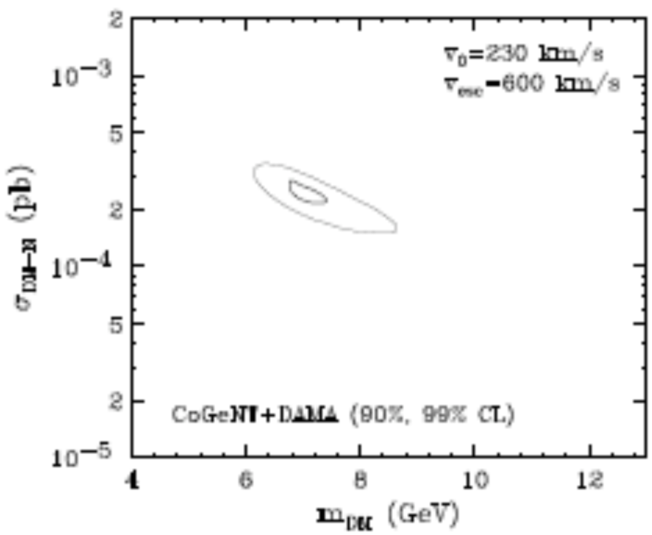
Compatibility between CoGeNT and DAMA?

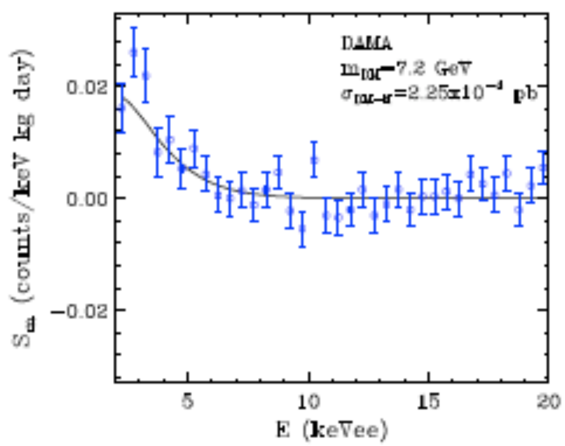
Hooper, Collar, Hall, McKinsey arXiv 1007.1005







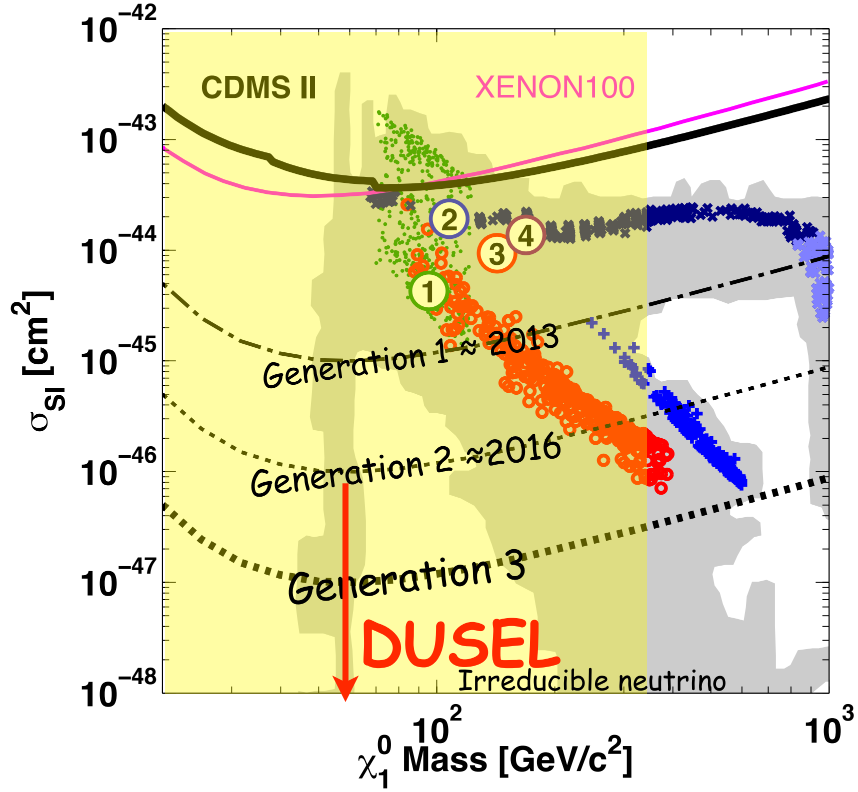




The future of Direct Detection

Technologies are rapidly reaching the needed level of sensitivity/background rejection

- Ge
- Xe
- Bubble Chamber
- Ar

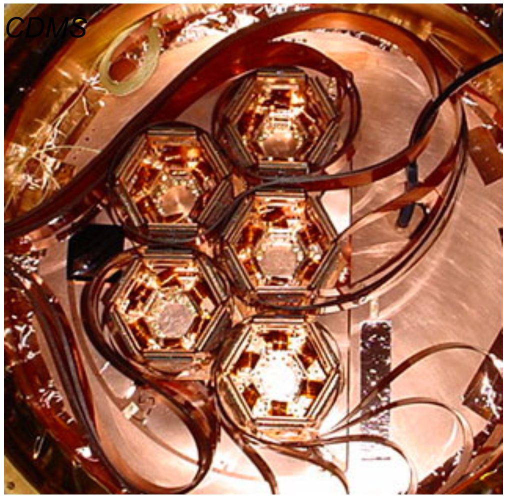


We need several technologies

Several targets to check A dependence
spin
threshold effects (e.g.
dark matter)

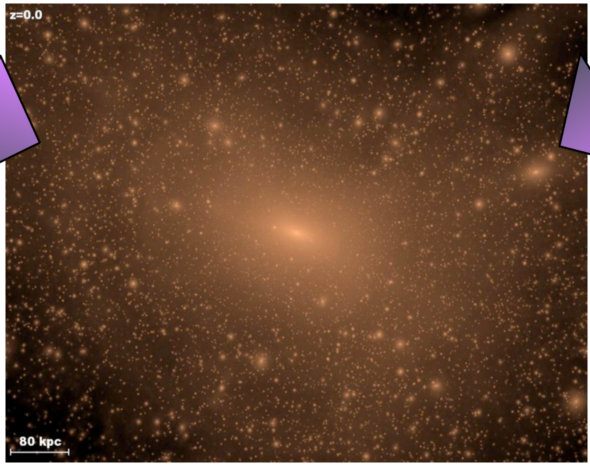
Need several technologies with different systematics
cross checks
insurance against failure
(e.g. unknown background)

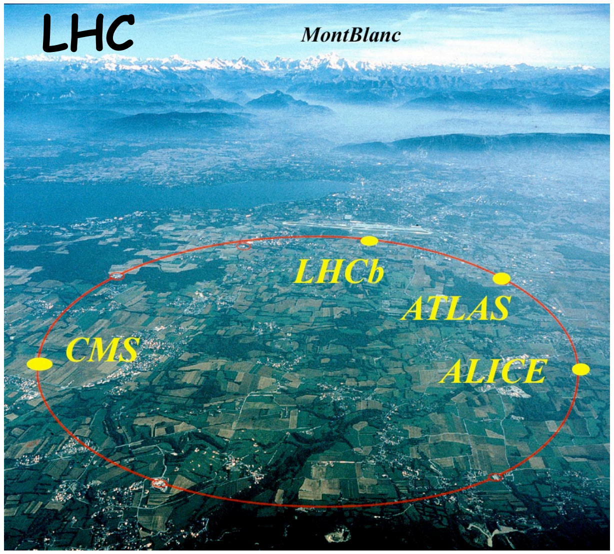
3 Complementary Approaches



WIMP scattering on Earth:
e.g. CDMS, Xenon 100 etc.

Dark Matter
Galactic Halo (simulation)





WIMP production on Earth

VERITAS, also HESS, Magic + IceCube (ν)

Fermi/GLAST

WIMP annihilation in the cosmos

We Need All Three Approaches

LHC

Could see quite rapidly some missing energy: New Physics!
But cannot prove that the new particles are stable and form the Dark Matter
e.g., χ -> gravitino +… ("Super-WIMP")

Need to detect those particles in the cosmos

Elastic scattering of halo WIMPs in the laboratory

Very clean + would prove that these particles are stable
But can only measure approximately a cross section and a mass:

Little input on the fundamental physics

Annihilation products in the galactic halo

Most evidence will be ambiguous <- variety of astrophysics phenomena

Would need confirmation

Conclusions

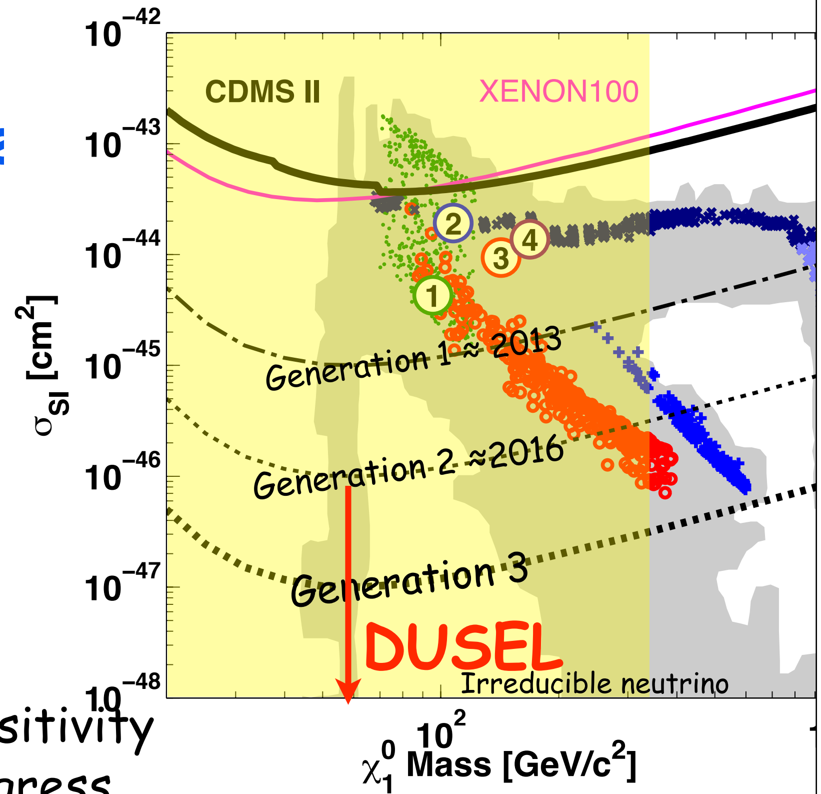
The nature of Dark Matter: Very fundamental question!

Weakly Interactive Massive Particle

Dark Matter could be due to TeV Scale

Next five years will be very important

Direct Detection: A lot of action

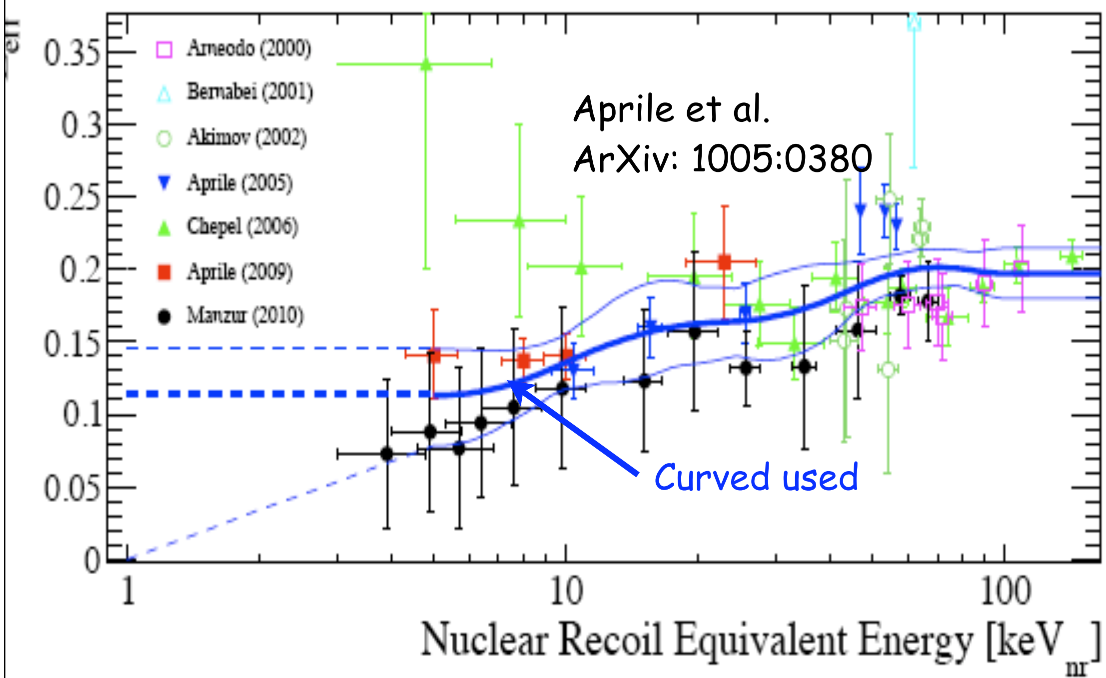


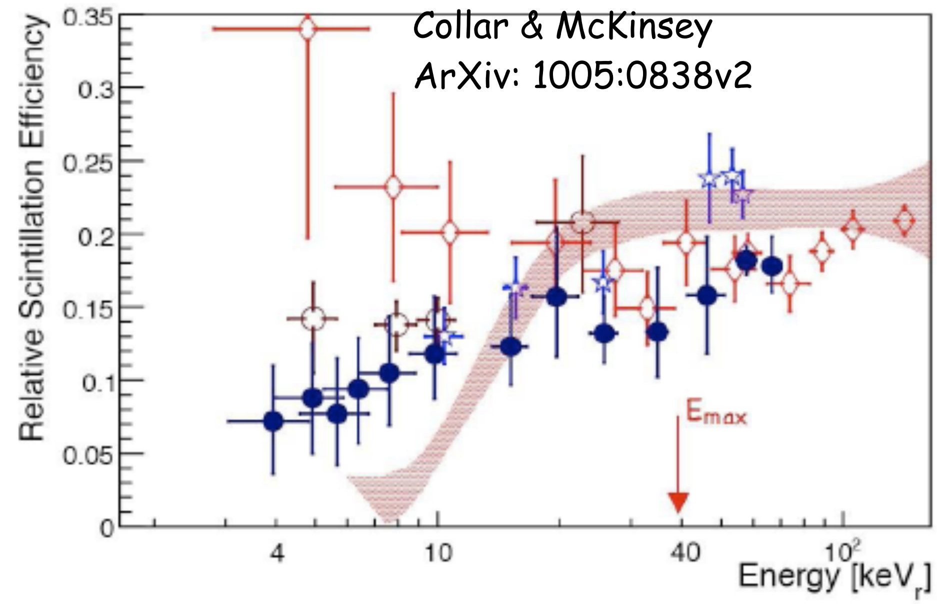
Ge and Xe are reaching interesting level of sensitivity
Bubble chamber and Ar are making a lot of progress
Indirect detection: Fermi is a powerful instrument
+ IceCube
LHC is starting to run
Complement region of sensitivities
In overlap region rich physics!

Xe 100 Criticisms

Light yield normalization ±30%

Possibility of a (soft) threshold: may not exclude CoGENT events!





$$E_{nr(keVr)} = \frac{S_1}{n_{pe}/keV}\frac{1}{\mathcal{L}_{eff}} \qquad \underbrace{\frac{S_{ee}}{S_{nr}}}_{\text{Effect of Electric Field}} \qquad = \frac{S_1}{2.20 \pm 0.09}\frac{1}{\mathcal{L}_{eff}}\frac{0.58}{0.95}$$

Poisson fluctuation assumption at 4 P.E.

+ apparent increase of rejection at low photo-electrons not understood