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WIMP Direct Detection: an outlook

Particle Cosmology

Non baryonic dark matter

WIMPs: a generic consequence of new physics at TeV scale

we need three approaches: accelerators, direct detection and indirect detection

Current status

Results

DAMA: tension with other experiments

Immediate plans

The road to larger mass

Comparison of the various technologies

Conclusions

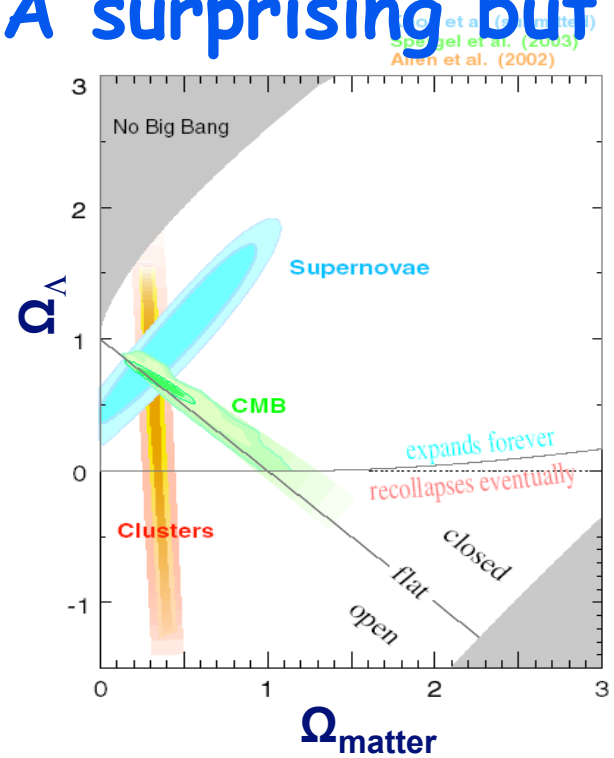
Importance of the science

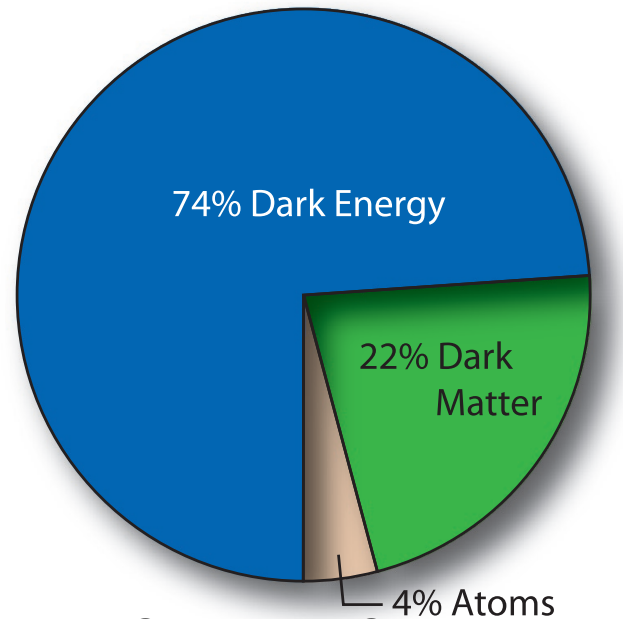
Complementarity of Direct/Indirect Detection and LHC

We need at least two technologies

Standard Model of Cosmology

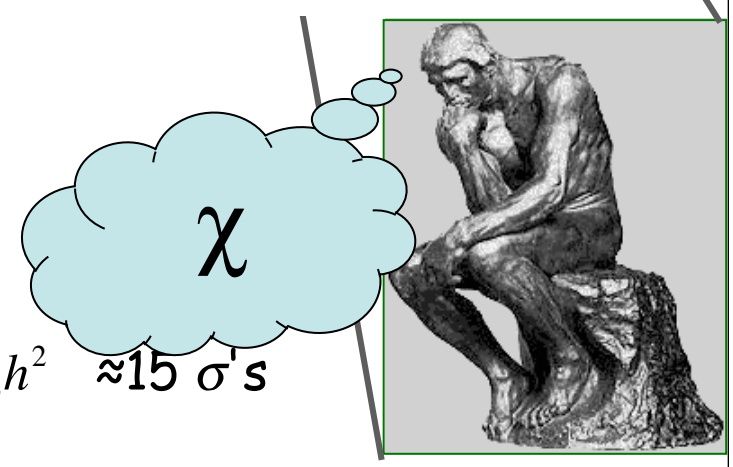
A surprising but consistent picture





Not ordinary matter (Baryons)

$\Omega_m >> \Omega_b = 0.047 \pm 0.006$ from Nucleosynthesis / WMAP



+ internally to WMAP $\Omega_m h^2 \neq \Omega_b h^2$ ≈15 σ's

Mostly cold: Not light neutrinos≠ small scale structure

Standard Model of Particle Physics

Fantastic success but Model is unstable

Why is W and Z at ≈100 M_p?

Need for new physics at that scale

supersymmetry

additional dimensions

In order to prevent the proton to decay, a new quantum number

=> Stable particles: Neutralino

Lowest Kaluza Klein excitation

Bringing both fields together: a remarkable concidence

Particles in thermal equilibrium + decoupling when nonrelativistic

Freeze out when annihilation rate ≈ expansion rate

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

Cosmology points to W&Z scale

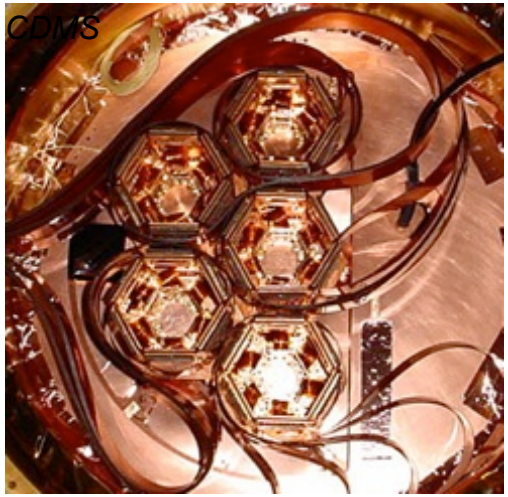
Inversely standard particle model requires new physics at this scale

(e.g. supersymmetry or additional dimensions)

=> significant amount of dark matter

Weakly Interacting Massive Particles

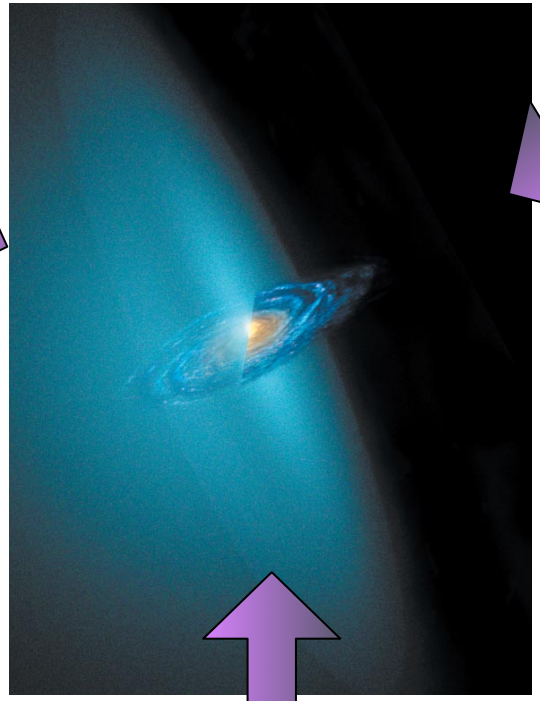
3 Complementary Approaches

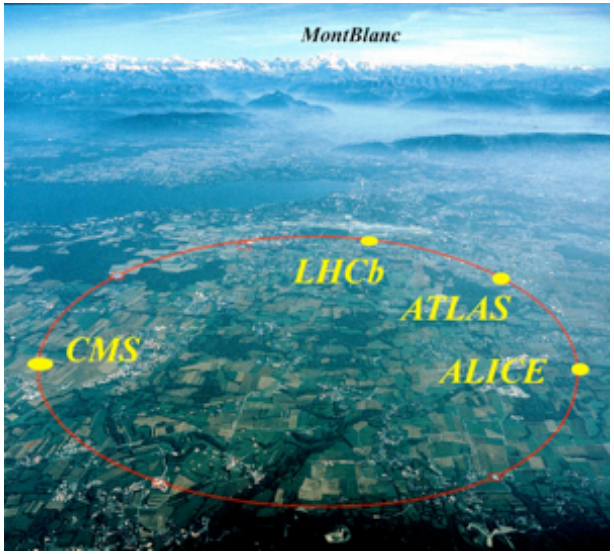


WIMP scattering on Earth:
e.g. CDMS : currently leading the field

Halo made of WIMPs

1/2 shown for clarity





WIMP production on Earth

WIMP annihilation in the cosmos

GLAST/Fermi
Launched 11 June 2008

We need all three approaches

Direct detection

May well provide a detection + ≈ cross section and mass
But what is the fundamental physics behind it?
What can we learn about the galaxy?

LHC

May well give rapidly evidence for new physics: missing energy
But is it stable? => need direct or indirect detection
Ambiguity in parameters: mass/cross section

Indirect detection

May well provide smoking gun for both dark matter and hierarchical structure formation (subhalos)
But possible ambiguity in interpretation => need direct detection

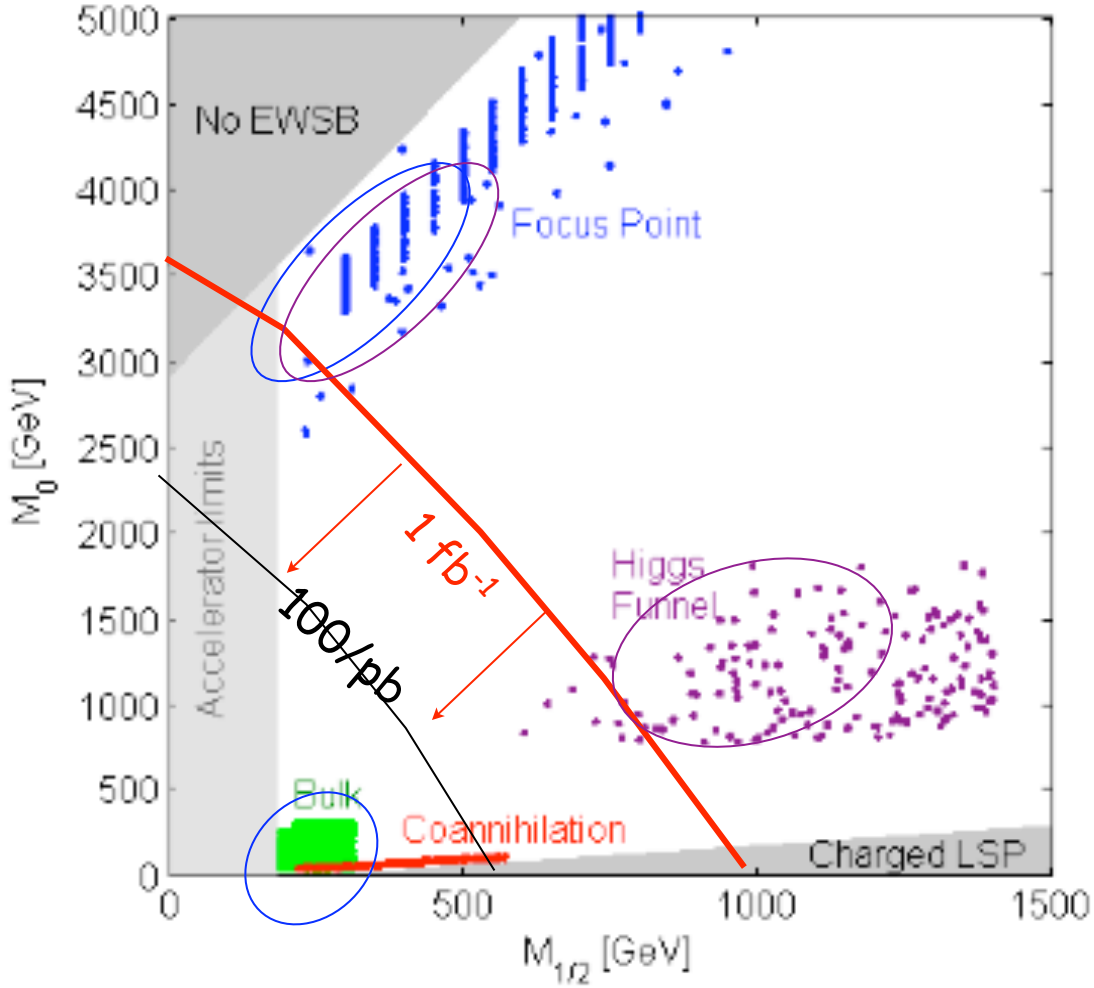
Complementary sensitivity to different parameter space region

Complementarity mSugra/CMSSM

Direct Detection:
Bulk
+Focus point

LHC
"low energy"

Fermi
Focus
+ Higgs funnel

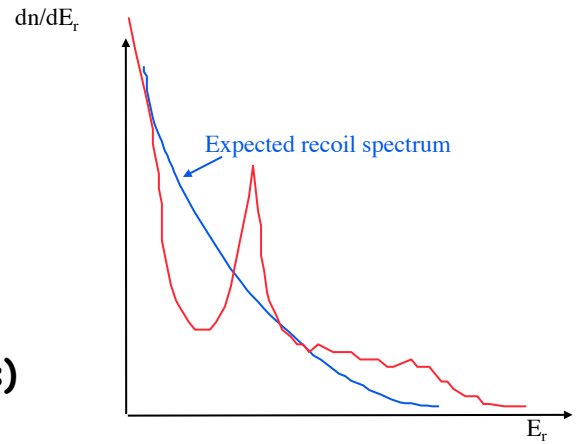


cf. J. Ellis' talk: apologies for inversion of axes

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

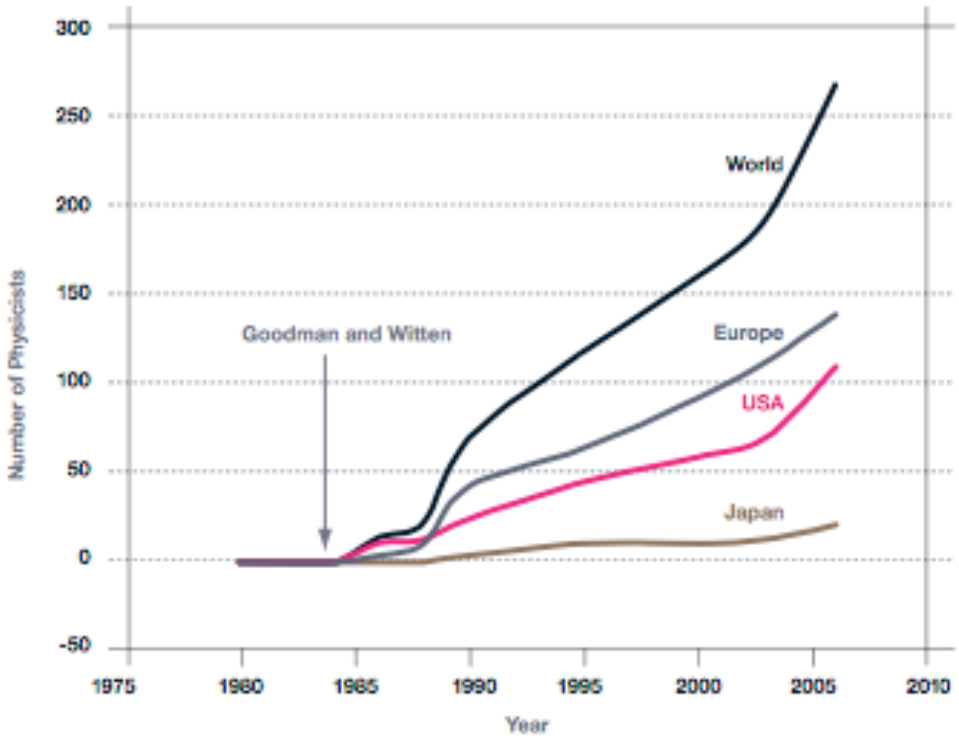
- Nuclear recoil
- Single scatter ≠ neutrons/gammas
- Uniform in detector

Linked to galaxy

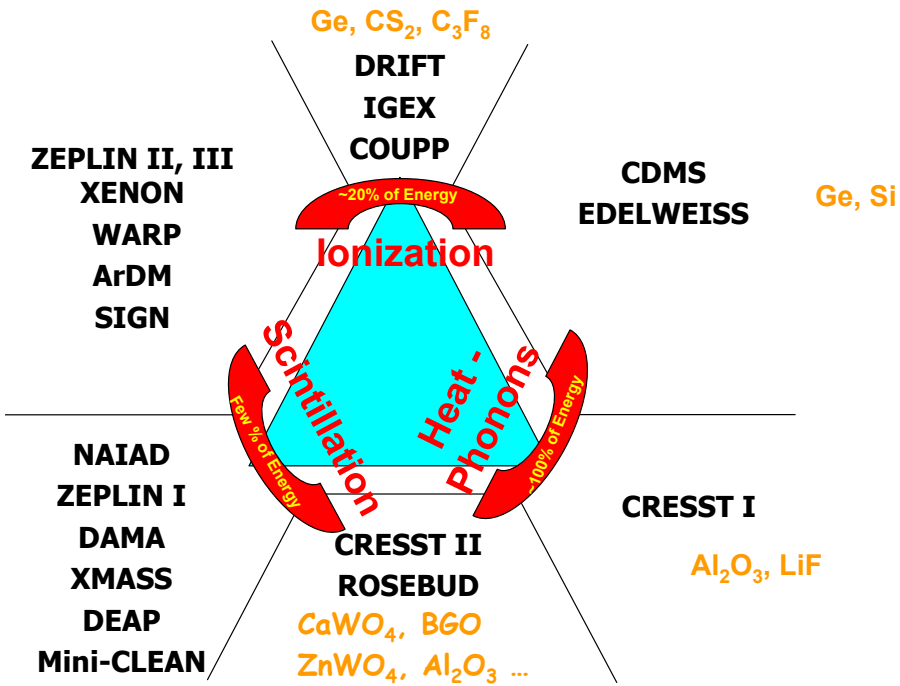
- Annual modulation (but need several thousand events)
- Directionality (diurnal rotation in laboratory but 100 Å in solids)

Experimental Approaches

A blooming field



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)

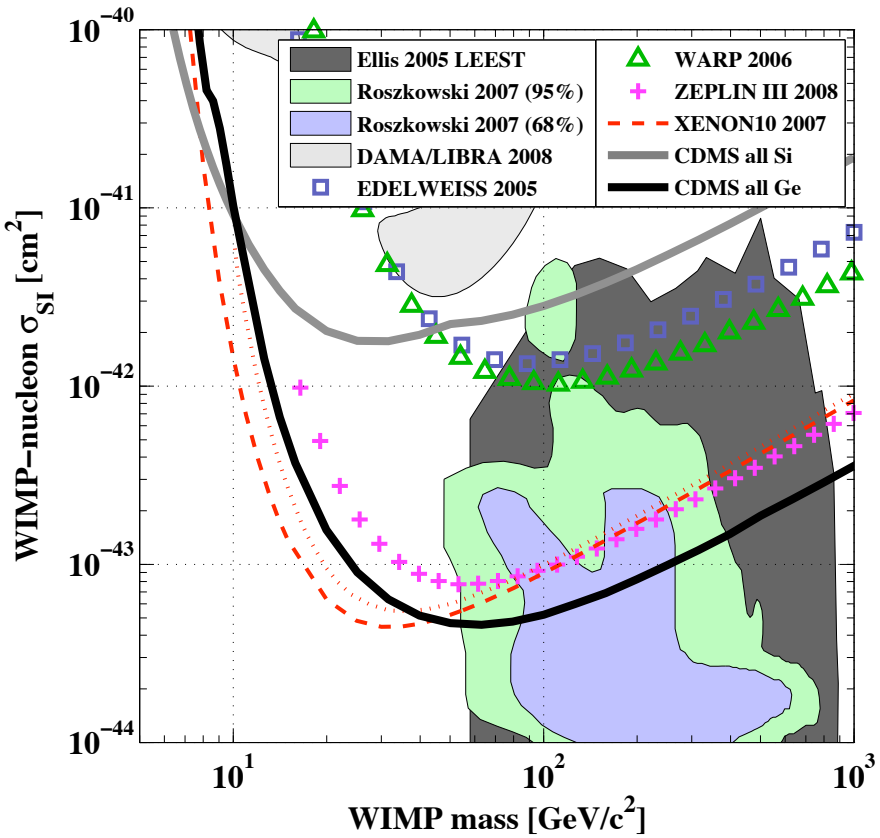
As large an amount of information and a signal to noise ratio as possible

Where are we? January 09

Scalar couplings: Spin independent cross sections

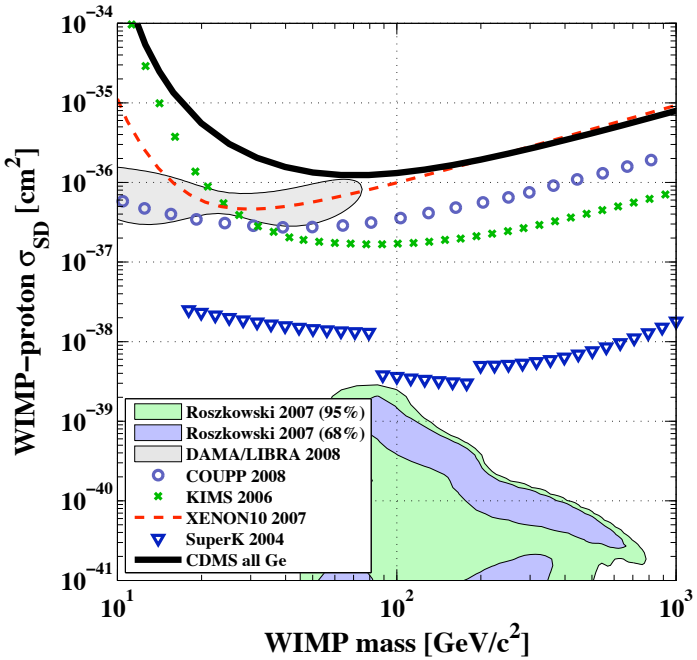
latest compilation by Jeff Filippini

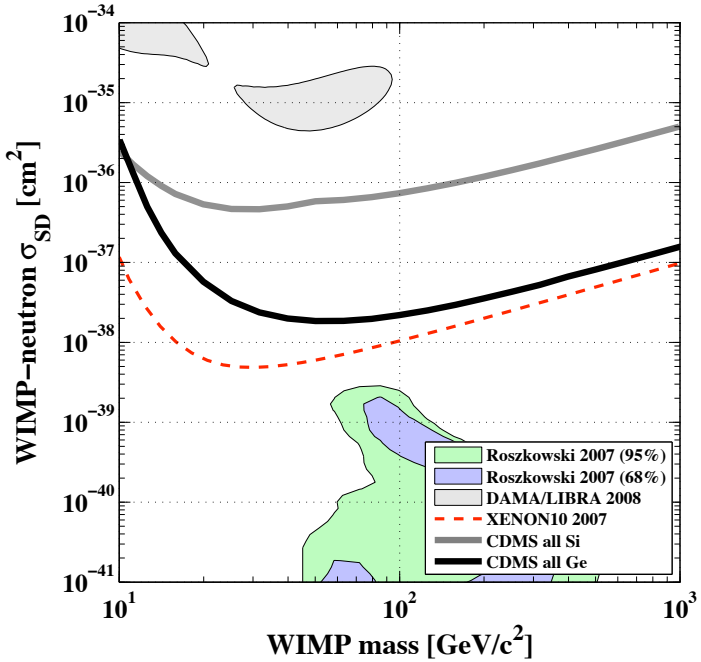
Gray=DAMA 2 regions(Na, I) from Savage et al.



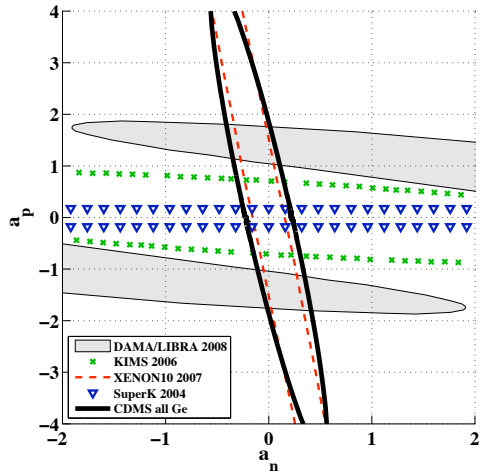
Where are we? January 2009

Spin dependent couplings





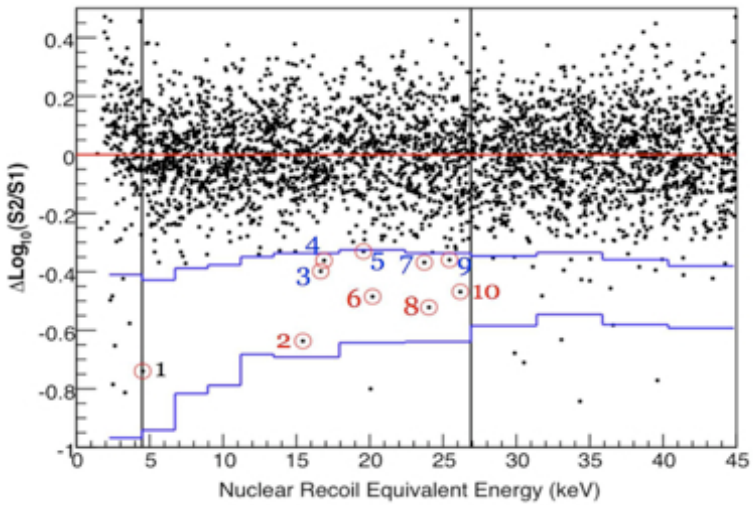
a_p vs a_n at mass of 60GeV/c^2

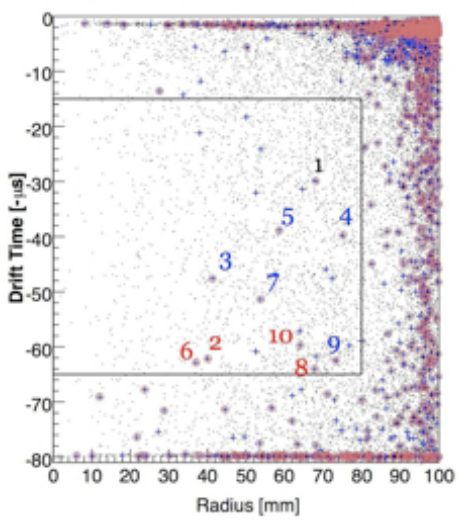


The 2 best experiments so far

Xenon 10 April 2007

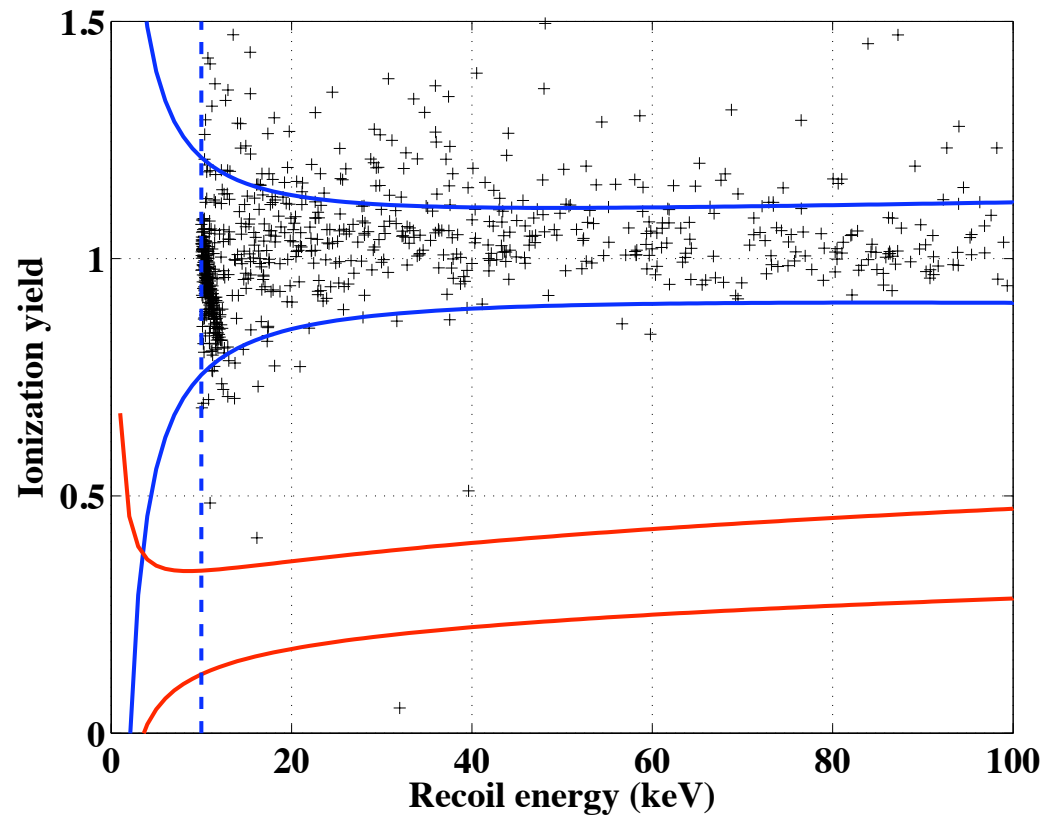
10 background events





CDMS II 0802.3530 PRL 102(2009)

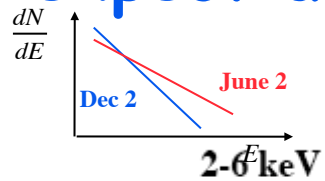
0 background event (Expected 0.6±0.5)

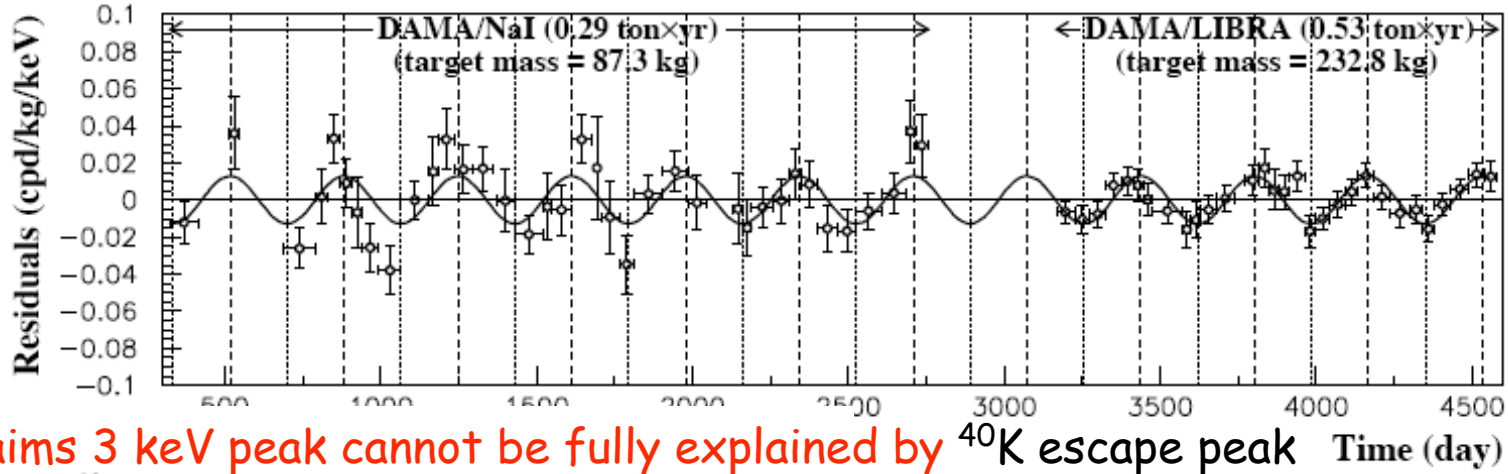


Discovery potential ≈5 times Xenon 10

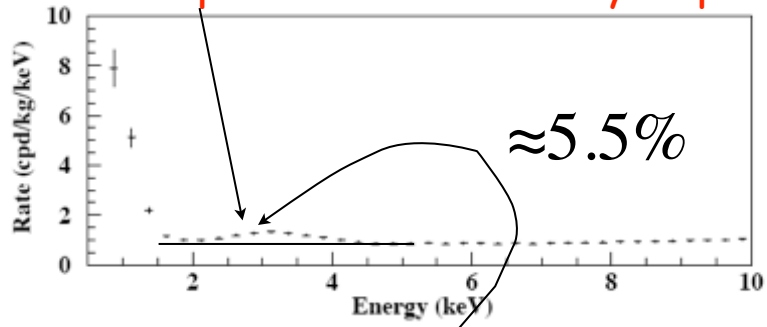
DAMA Claim April 2008

If WIMPs exist, we expect a modulation in event rate



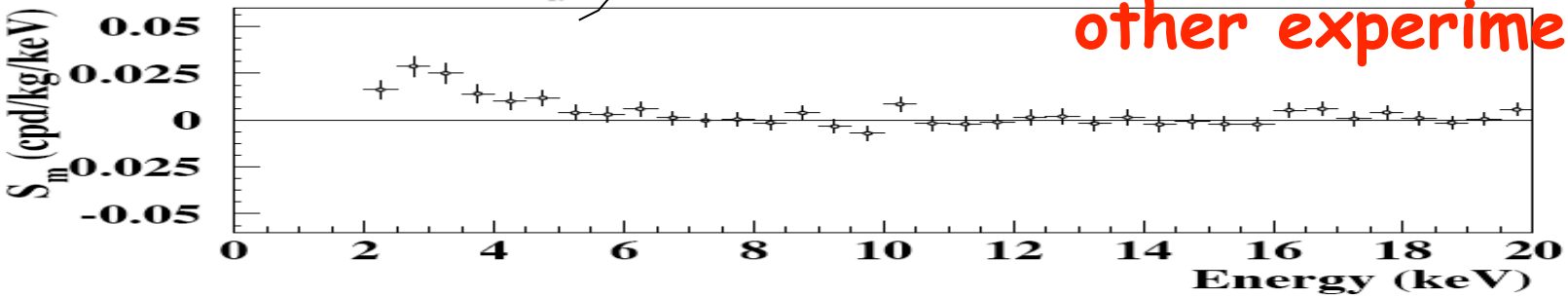


DAMA claims 3 keV peak cannot be fully explained by ^{40}K escape peak



Clearly a modulation

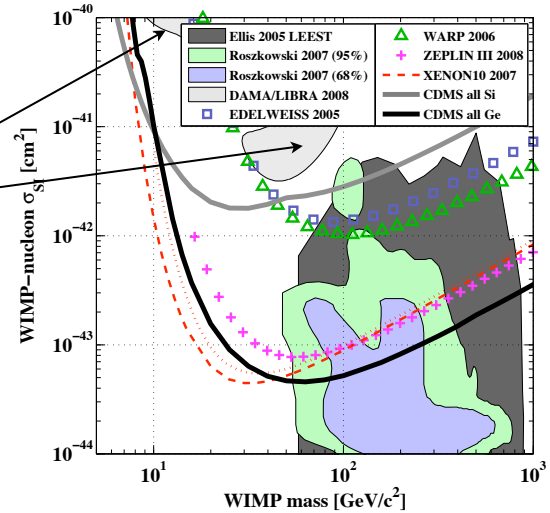
Not a WIMP: incompatible with other experiments



Tension with Other Expts.

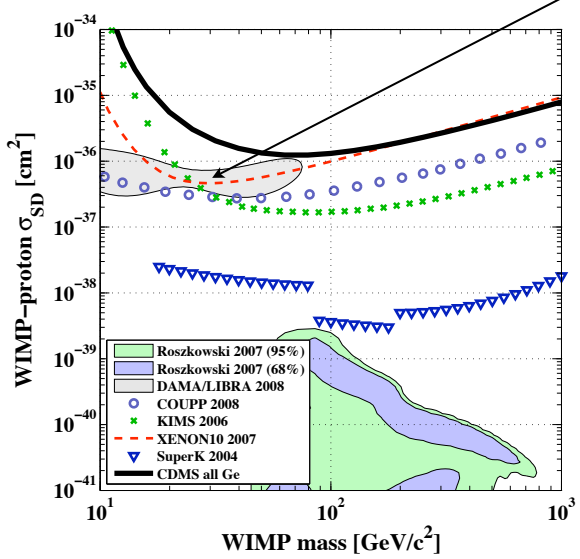
Spin independent interactions

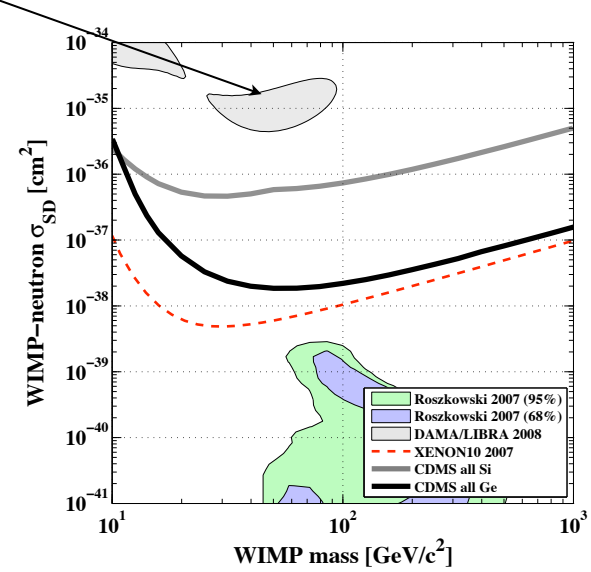
DAMA



Spin dependent

DAMA





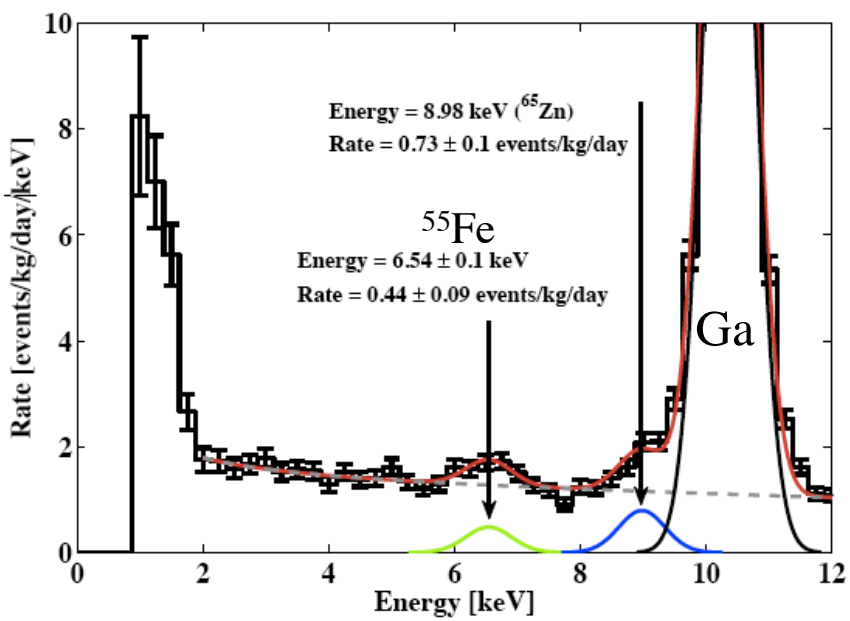
What could it be: Physics?

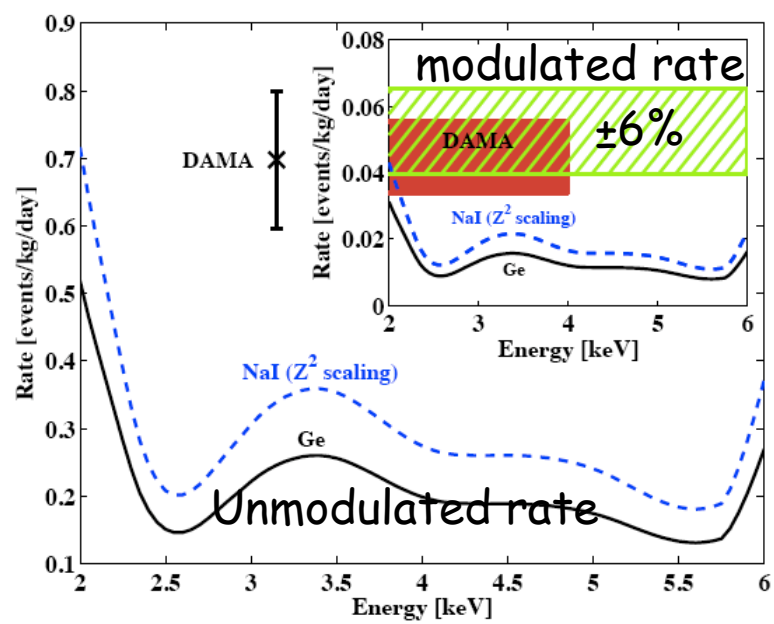
An axionic type particle of 3 keV converting its mass into electromagnetic energy in detector

Modulation by flux Electron recoil line at 3 keV
Checked by other detectors: CoGeNT, CDMS!

3 keV peak excluded cf. CDMS arXiv:0907.1438

3 keV peak in DAMA single rate is not physical (if Z^2 scaling)
Probably ^{40}K escape (1.46MeV missed)
Excludes as modulation signal as big as DAMA (even in optimistic case of ±6%)
Note that cross sections of exothermic radiations tend to be inversely proportional to velocity => modulation very much suppressed (Pospelov et al. 2008)





What could it be?

Most likely very subtle detector problem

Modulation is basically summer-winter

Example of the cosmic muon rate which is modulated with the same phase (decay path of the pions change with temperature)

Many things change: temperature, water in mountain, humidity, electric voltage

What seems excluded

Neutron from muons

Direct effect of muons on detector

Examples of effects which have not been excluded convincingly

Modulation of the efficiency

e.g. of the PM noise rejection algorithm

Modulation of the ^{40}K 1.46 MeV gamma detection efficiency

(e.g. varying humidity in purge gas=> modulation of dead layer=> 3 keV escape

Not blind analysis!

Sociological problem:

Nobody finds the result plausible enough to repeat the experiment!

However, as a field we need to cross check the only claim.

A different team has to redo the experiment in Southern Hemisphere

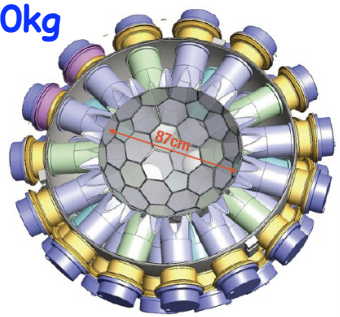
e.g. NaI detectors in a hole in Antarctic Ice (Stubbs, Fisher, IceCube, B.S.)

Noble Liquids: Current Plans

Single phase detectors

Xenon: Rely on self shielding + position reconstruction:
XMASS 800kg
Argon: Rely on pulse shape discrimination:
Mini Clean 150kg fiducial Ar 2010 6-7 pe/keV
DEAP-3600 1000kg fiducial 2011

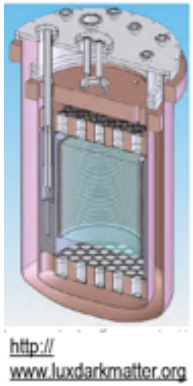
MiniClean 500kg



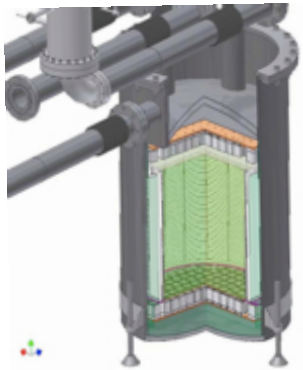
Dual phase Xenon

Xenon 100 : Assembled in Gran Sasso.
Currently purifying (100kg- 30kg fiducial)
LUX 300kg -> 100kg fid : SUSEL (Homestake)
Surface: Summer 2009
4850 ft: early 2010?

Lux 300kg



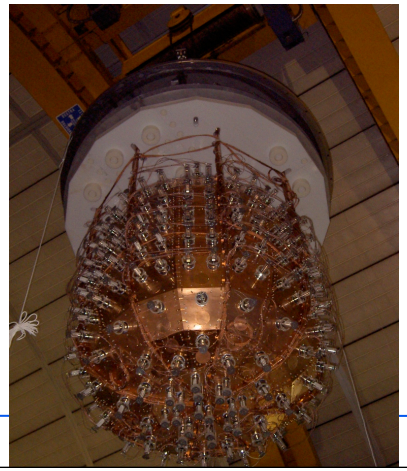
Xenon 100kg



Dual phase Argon

WARP 140kg: Commissioning 1.7pe/keV
result 2010 Goal: 10^{-44}cm
ArDM: 500kg commissioning at CERN
Liquid Ar run May 09
Purity difficulties

WARP



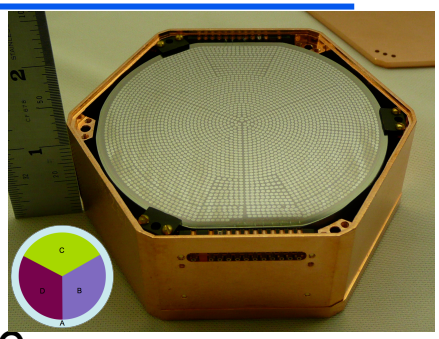
ArDM

Depleted ^{39}Ar

Underground source: Princeton: <1/25

Immediate Future (cryogenic)

CDMS: Finished data this winter 09



≈ 4kg Ge 750 kg day after quality cuts being analyzed

=> 1370 kg day total

Hope to be still background free

Sensitivity ≈ 2 10^{-44} cm^2/nucleon: This Summer 09!

New 1" thick detectors => 1 Supertower of 3kg => 15kg in 2010

Edelweiss

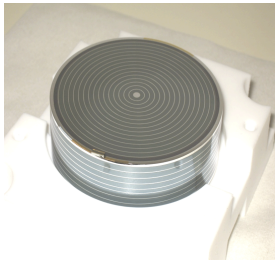
Switching to interdigitated detectors

(Concept initially proposed by CDMS)

Underground demonstration of excellent rejection of the surface events <1/40000 >50keV

12 such detectors 400g

2010 -> 9kg with 800g detectors



CRESST II

Major upgrade 66 SQUIDs for 33 detectors + neutron shield

Commissioning run with 3 detectors 2007-2008

9 detectors ≈300g currently (July 09) cooling down

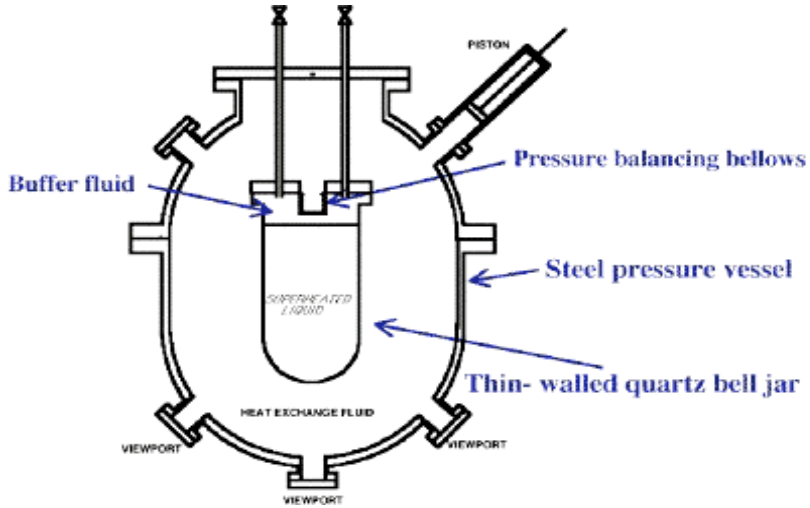
COUPP

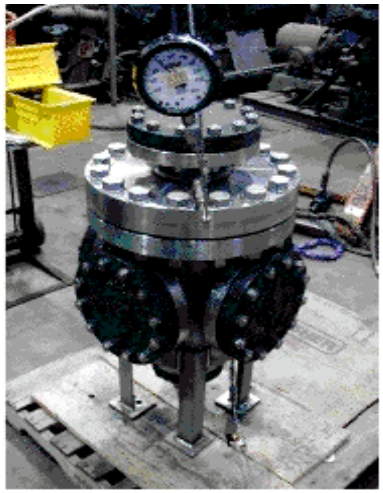
COUPP: Bubble chamber

Long duration metastable state broken by large ionization events

nuclear recoil or nuclear recoil from alpha (purity level ≈ Borexino)

2.5 kg prototype CF_3I bubble chamber at Fermilab (300 mwe)





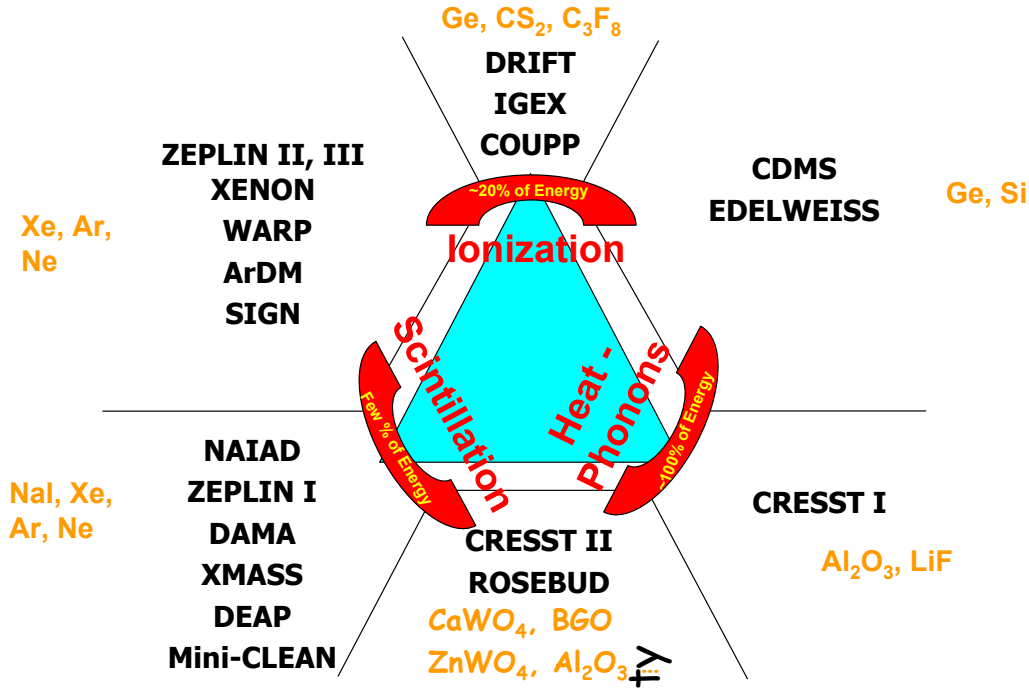
Next stage 60 kg: to be installed @ 300 mwe this fall (cf M. Szydagis)

Likely to be an excellent way to lower upper limit.

Much more difficult to get a convincing positive signal

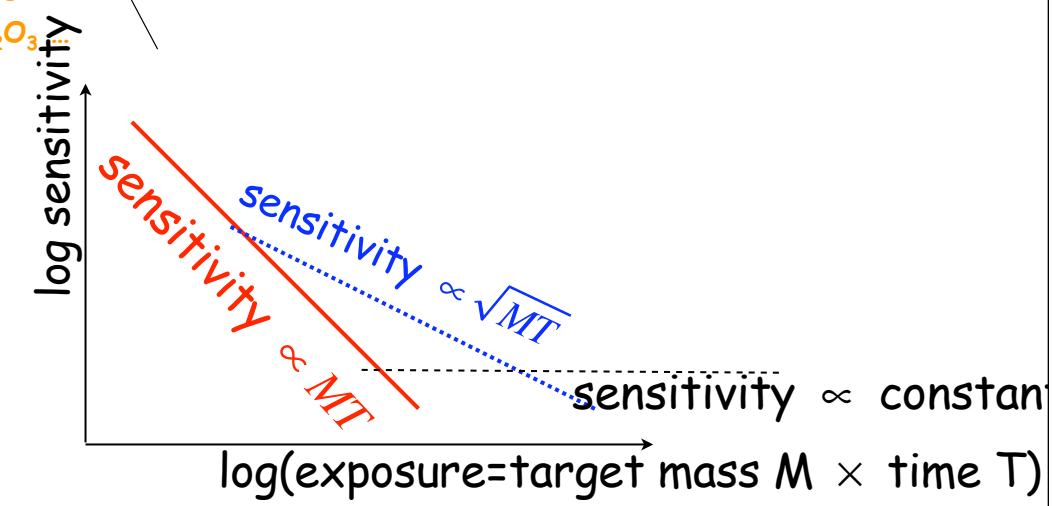
The road to larger masses

Direct Detection Techniques



Three Challenges

- Understand/Calibrate detectors
- Be background free
  much more sensitive than background subtraction
  eventually limited by systematics
- Increase mass while staying background free



The Competition (a simplified/biased view)

COUPP:

Bubble chamber 2 kg ->100 kg

Excellent upper bound machine?

sensitive to alpha contamination
not enough information for discovery

Liquid Xenon:

scintillation+ionization
self shielding ≈2.5 cm
10 kg->100 kg->20 tonne

Promising but not proven background

mediocre discrimination 99%
can be defeated by Rn diffusion
cosmogenics at DUSEL 4850ft
not cheap 1 ton of Xenon =$10M

Liquid Argon:

scintillation+ionization
pulse shape discrimination
2 kg->100 kg->50 tonne

Promising

need ^{39}Ar depletion (underground source)
far UV -> wave shifter, high threshold

Low temperature Ge:

phonons+ionization
Zero background so far
5kg->15kg->150kg->1.5 tonne

Promising extrapolation path

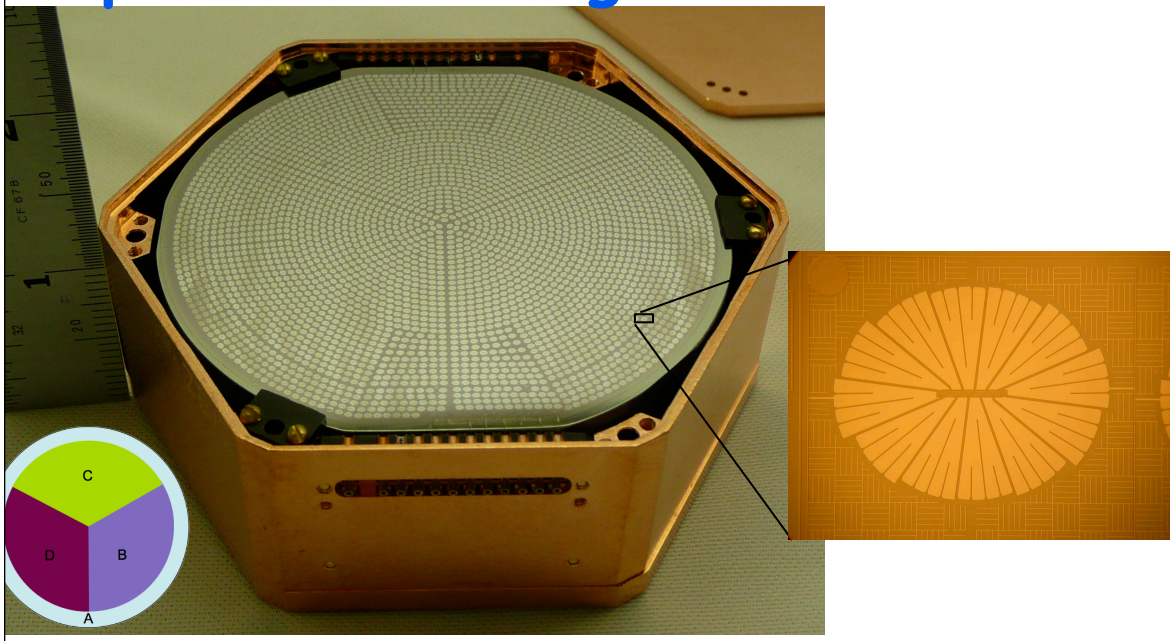
large 150 mm Ø, 50 mm thick crystal
large scale multiplexing (e.g. RF)
automation of TES process or KIDs separated function
simplification of testing

Many new ideas

Single phase-> simplicity
High or low pressure gas TPCs

e.g. Larger Ge Detector Mass

SuperCDMS 15 kg detectors: 1cm-> 1" 250g ->635 g



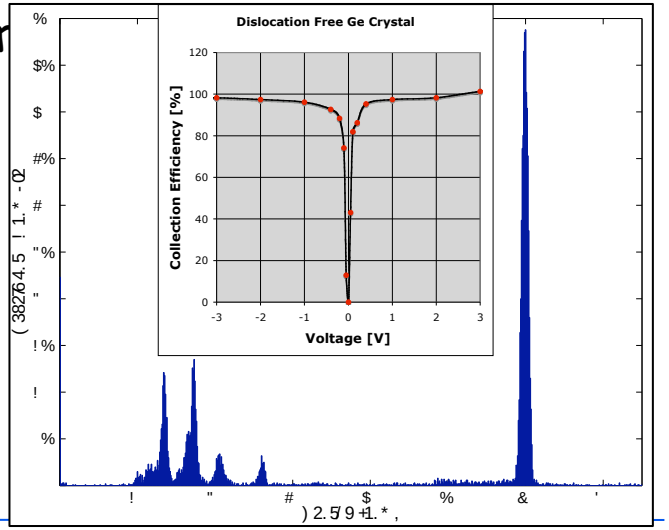
Much larger detectors -> SCDMS@SNOLAB

Liquid N2 Ge crystals limited to 3" ≈ 100 dislocation/cm

But we showed recently that dislocation free Ge works at low temperature!

Umicore grows (doped) dislocation free 8" crystal

6"x2" or 8"x1" ≈ 5kg + Multiplexing



1.5 tonne GEODM@ DUSEI for $50M

Detector mass +automation+ simplified testing

Who will be the winners?

We do not know yet...

Likely to take some time of systematic work
Need strong R&D basically at full scale

Go beyond propaganda

"My detector is bigger than yours!"
Not the whole story: Detailed understanding of the phenomenology
Zero background!
One background can/will hide another one!

In any case we need at least two different technologies (may be three worldwide)

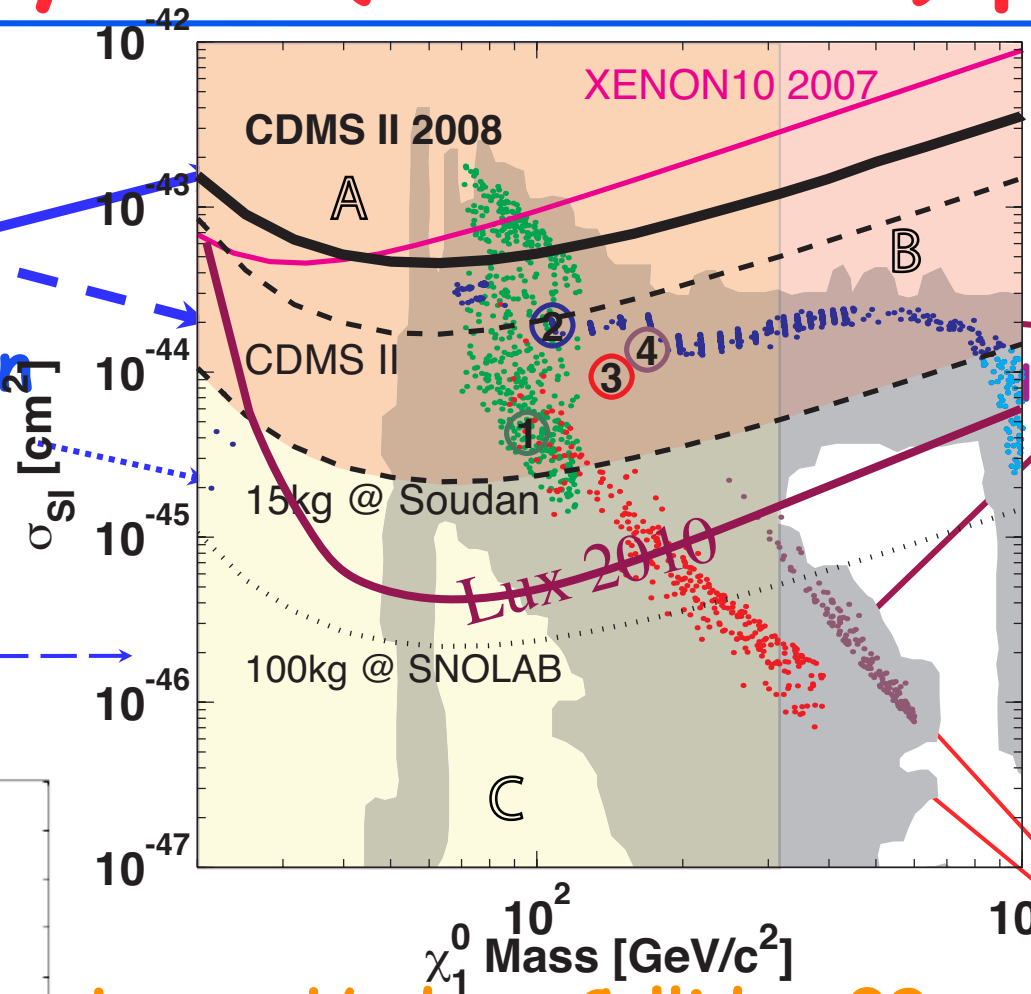
Cross checking each other
Protection against unexpected background
Physics! e.g.
Coherence additive quantum number: A^2 dependence (scalar coupling)
spin dependence
Threshold in target mass=> dark matter excited state

Next 6 years (Pre DUSEL) program

Current WIMP searches

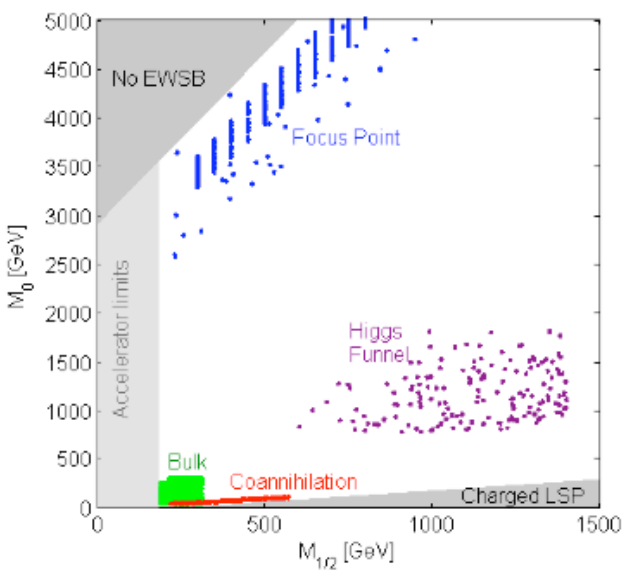
Next generation

1 generation beyond



GLAST/Fermi launched 11 June 08

Finer and finer tuning to get right density!



Large Hadron Collider 09

Significant chance of discovery

few 10^{-45} cm^2 ≤2010 10^{-46} cm^2 ≤2015

Science complementary to LHC and Fermi-GLAST/ Ice Cube

What are the technologies of the future?

Conclusions

Essential to detect Dark Matter

A key ingredient of the standard model of cosmology

WIMPs is the generic thermal model

Complementarity of direct detection, indirect detection and accelerators

The next 3 years may well allow a spectacular discovery

B.Sadoulet, Science 315 (2007) 61

Direct detection at a few 10^{-45}cm2/nucleon

Large Hadron Collider; production of Supersymmetric Particles but stable?

Fermi/GLAST + ICE Cube could be a smoking gun (Dark Matter + Hierarchical merging)

Direct detection

Entering the interesting (generic) territory with a variety of methods

at a few 10^{-45}cm2/nucleon

- Phonon mediated detectors (SuperCDMS, EDELWEISS)
- Liquid Xenon 2 phase
- Liquid Ar 2 phases+pulse shape

maybe other simpler technologies (XMASS, MiniCLEAN, COUPP)

At the same time explore the best technologies onto which to converge for the next generation (we need at least two technologies)

If no discovery: explore corners of parameter space with low elastic scattering

If/when we have a discovery:
- Get better statistics => dark matter observatory
- Link to/study galaxy (low pressure TPC≈5000 m^3)