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Dark Matter Searches

Particle Cosmology

- Non baryonic dark matter
- (Axions)
- WIMPs: a generic consequence of new physics at TeV scale
  - Direct Detection of WIMPs

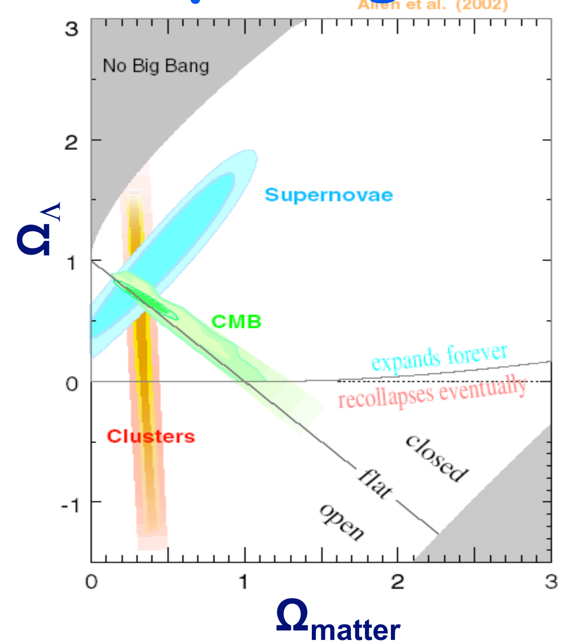
Noble Liquids

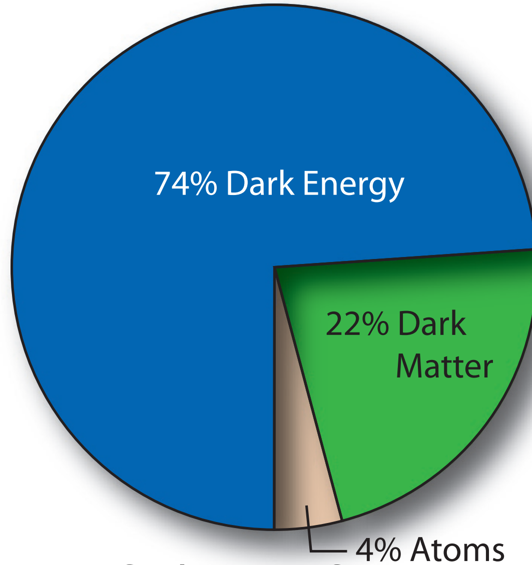
Phonon Mediated Detectors

DAMA

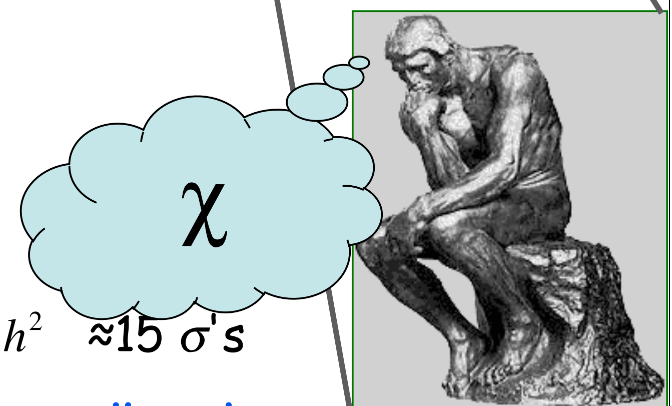
Standard Model of Cosmology

A surprising but consistent picture





NASA/WMAP Science Team 2006



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

$m_\nu < .17 eV$ Large Scale structure+baryon oscillation + Lyman α

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

Flat: Cheng et al. PR 66 (2002)

Warped: K.Agashe, G.Servant hep-ph/0403143

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

=> Stable particles: Neutralino

Lowest Kaluza Klein excitation

Particle Cosmology

Bringing both fields together: a remarkable concidence

Particles in thermal equilibrium
+ decoupling when nonrelativistic

Freeze out when annihilation rate ≈ expansion rate

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

Generic Class

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

2 generic methods:

Direct Detection= elastic scattering

Indirect: Annihilation products

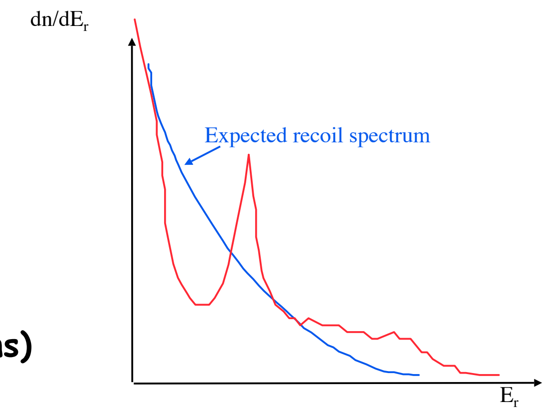
γ's e.g. 2 γ's at E=M is the cleanest
ν from sun &earth ≈ elastic scattering
dependent on trapping time
$e^+, \bar{p}$

+ Large Hadron Collider

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

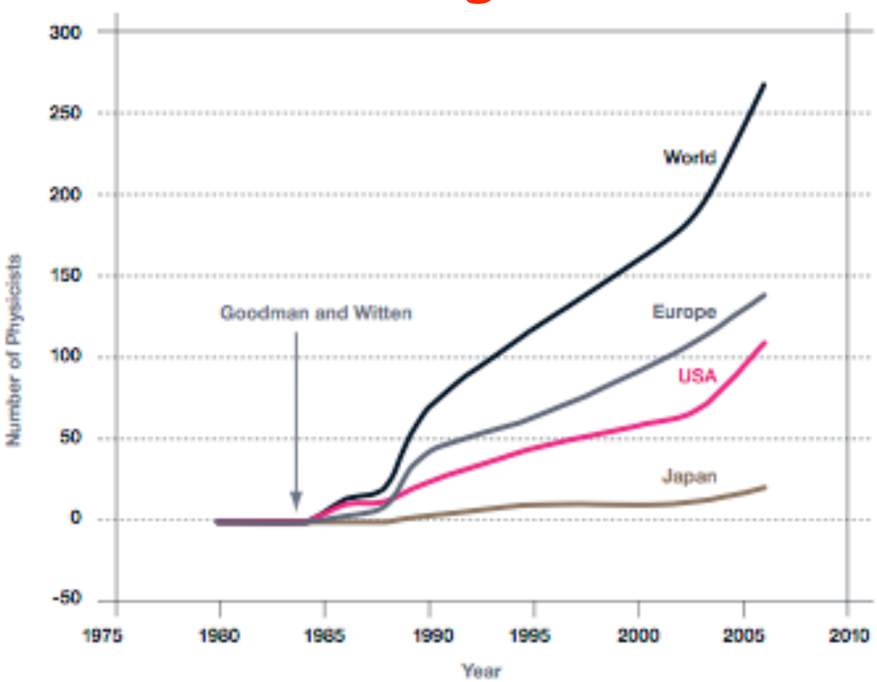
- Nuclear recoil
- Single scatter ≠ neutrons/gammas
- Uniform in detector

Linked to galaxy

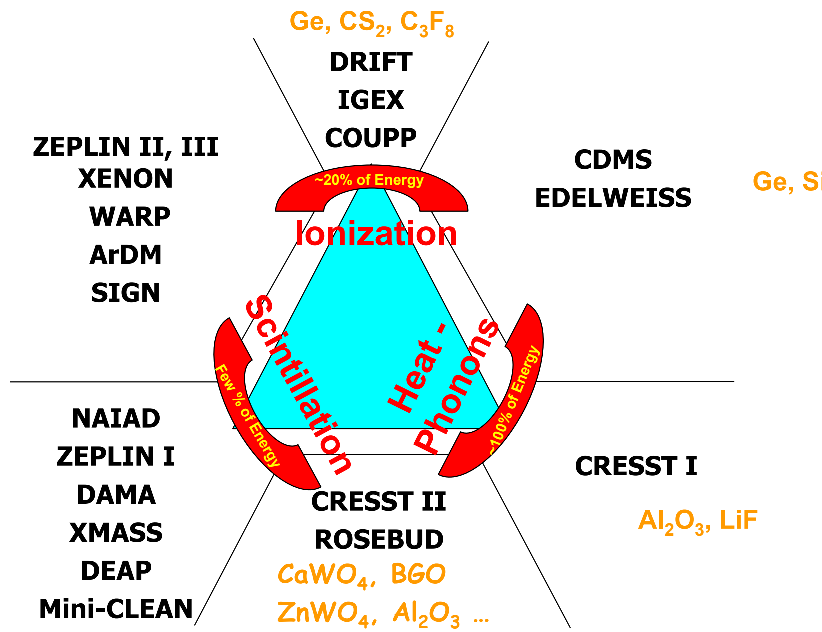
- Annual modulation (but need several thousand events)
- Directionality (diurnal rotation in laboratory but 100 Å in solids)

Experimental Approaches

A blooming field



Direct Detection Techniques

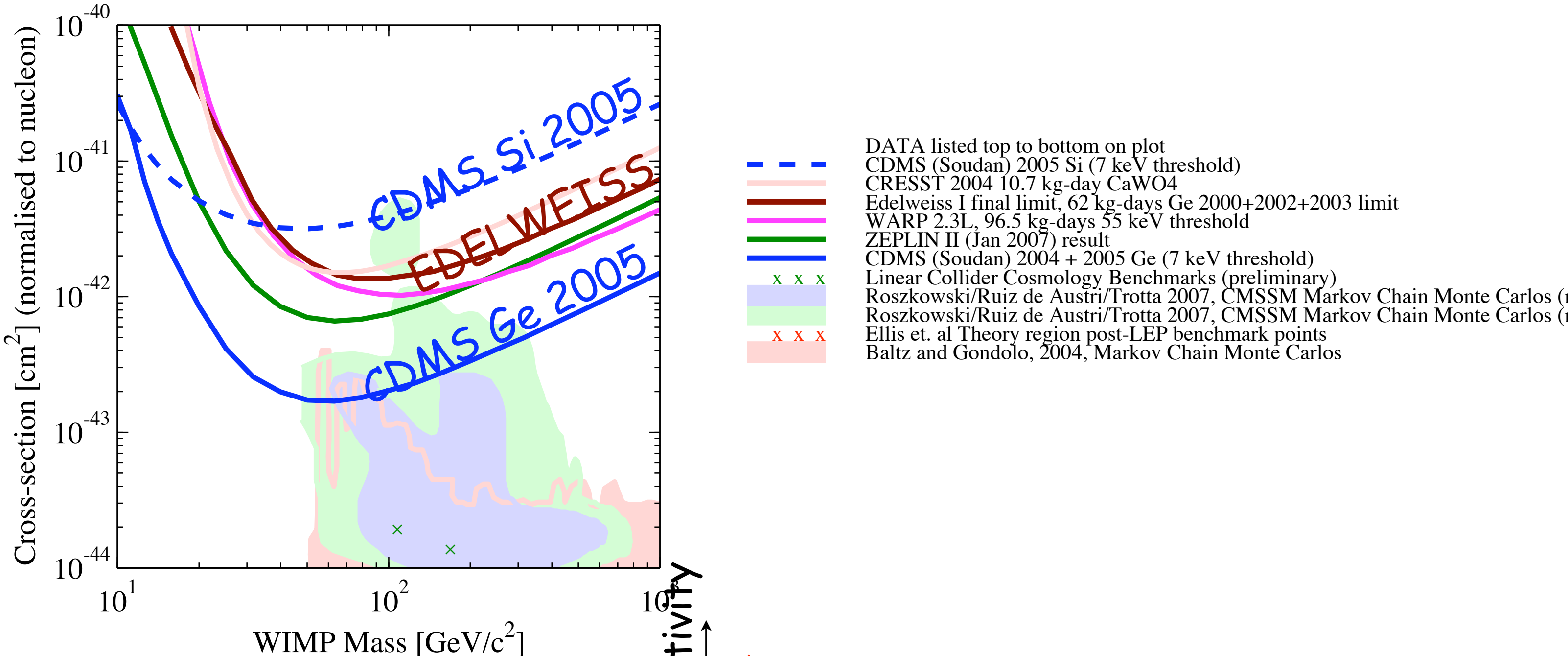


As large an amount of information and a signal to noise ratio as possible

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)

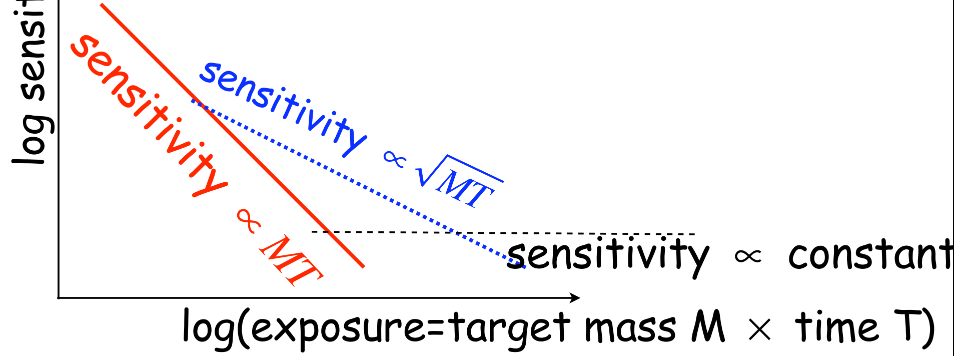
Status early 2007

Scalar coherent interaction ≈A^2



Three Challenges

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

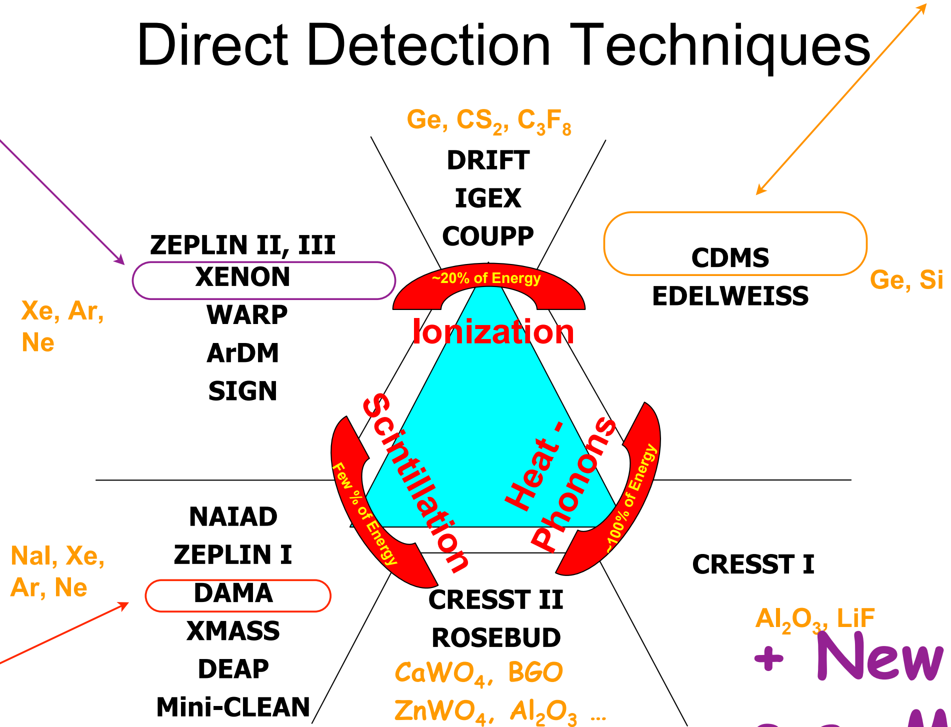


Current results

3 examples in more details

Xenon 10 as generic for ZEPLIN II ,WARP, ArDM

CDMS as generic for EDELWEISS & CRESST



DAMA/Libra new modulation result

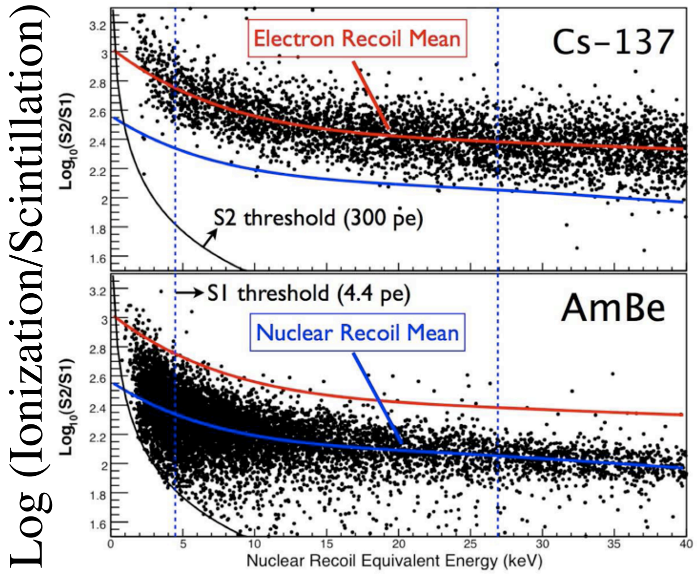
+ New ideas e.g. Monroe Nygren

The Noble Liquid Revolution

Noble liquids are both excellent scintillators and ionization collectors
=> **get to large mass** while maintaining excellent background by self shielding and discrimination

Liquid Xenon

Ionization + scintillation



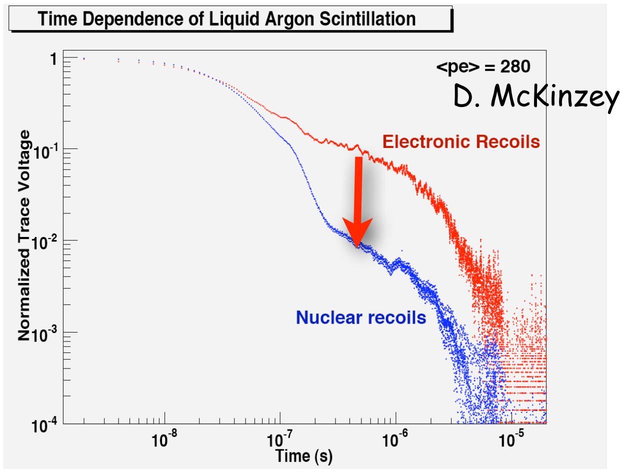
2 breakthroughs:

- ✳ Extraction of electrons from the liquid to the gas
- ✳ At low energy, separation between electron recoils and nuclear recoils increases

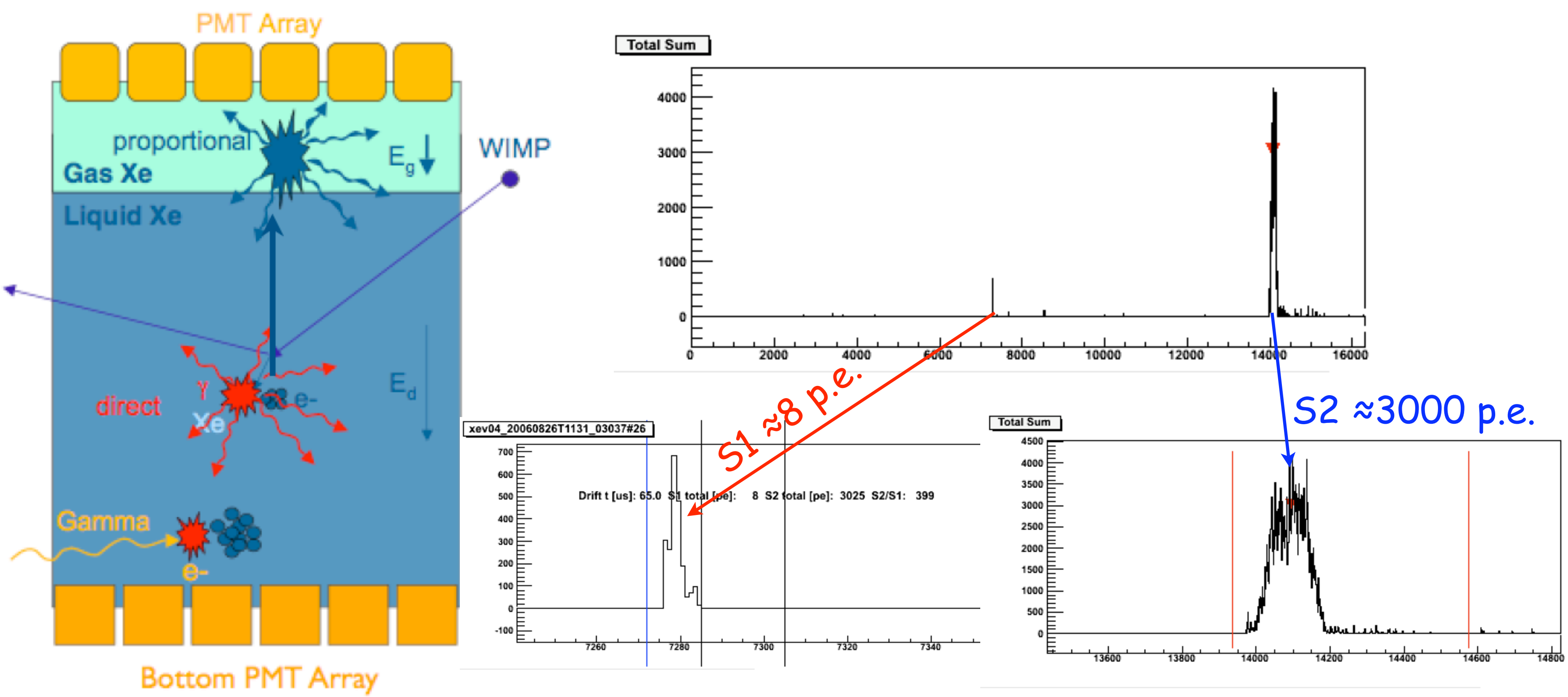
=> work down to ≈4.5 photo electrons with 99% electron rejection efficiency with 50% nuclear recoil efficiency

Liquid Argon (or Neon)

For light liquids, **one additional handle : rise time**
Triplet (long decay time) killed by nuclear recoil



Xenon 10



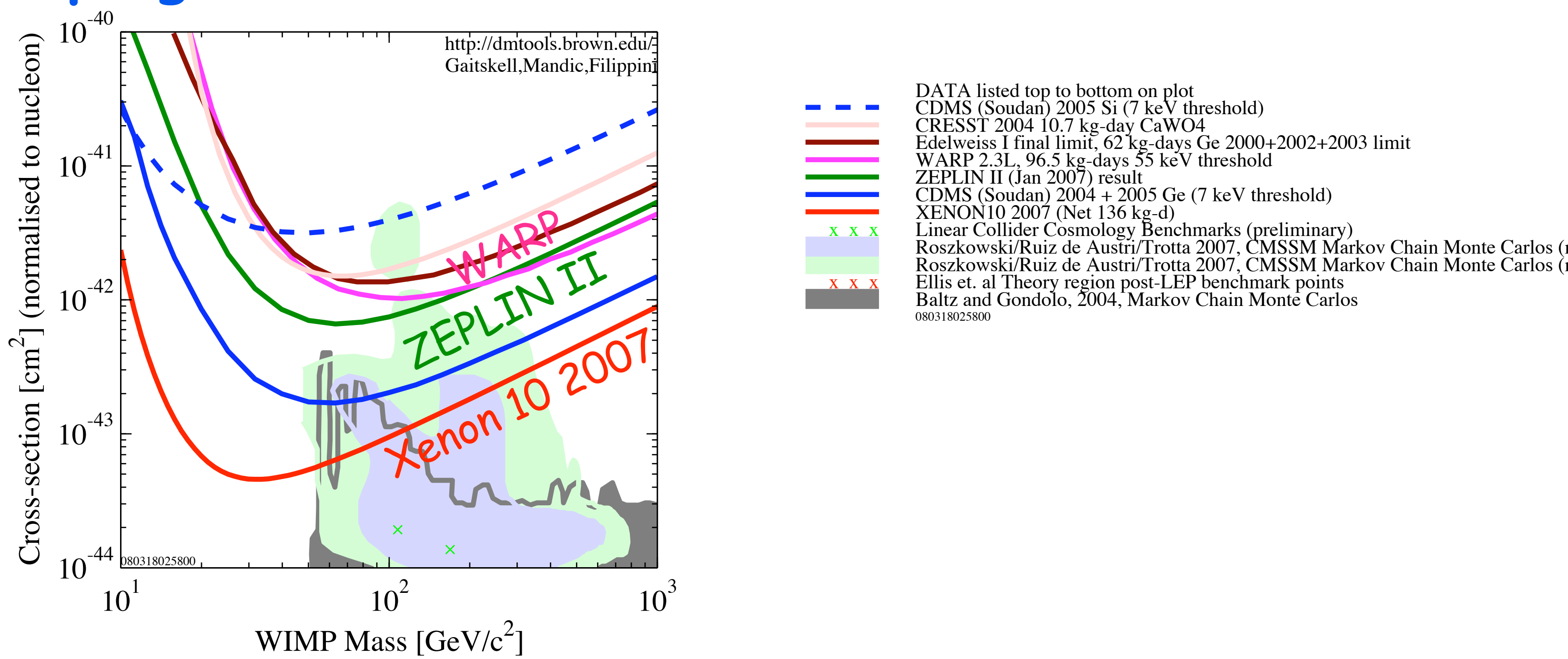
Liquid Xenon: Scintillation + ionization

two photon pulses => depth

Main differences with Zeplin II: Smaller Photomultipliers
Photomultipliers in liquid

Noble Liquids

Great progress!



What about our 3 challenges

? • Understand/Calibrate detectors

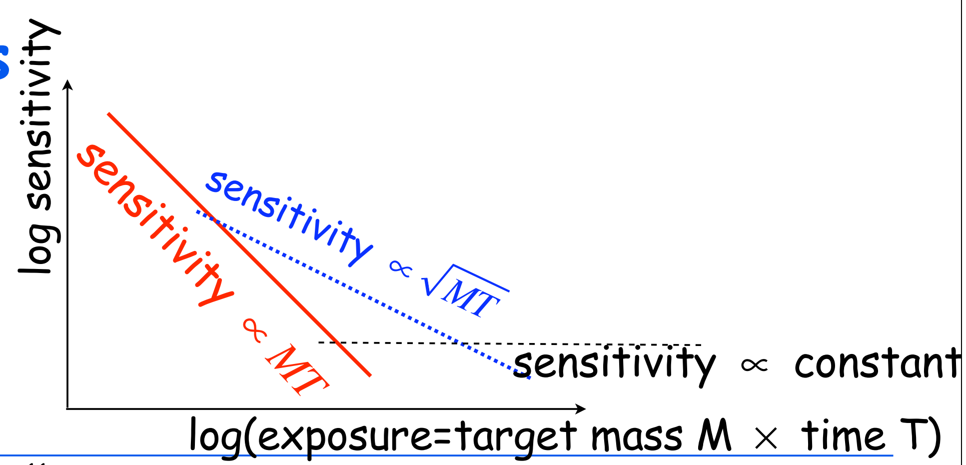
? • Be background free

much more sensitive than

background subtraction

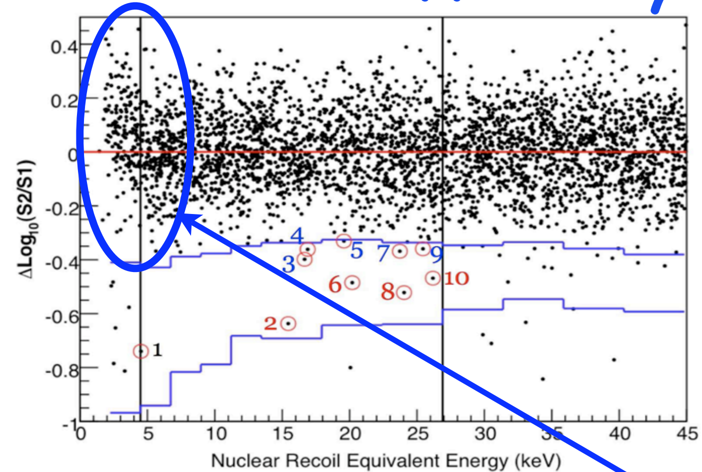
eventually limited by systematics

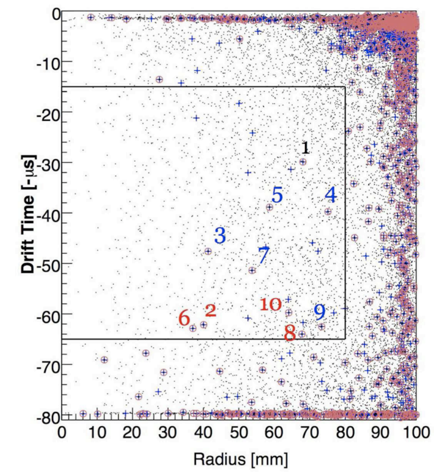
√ • Increase mass



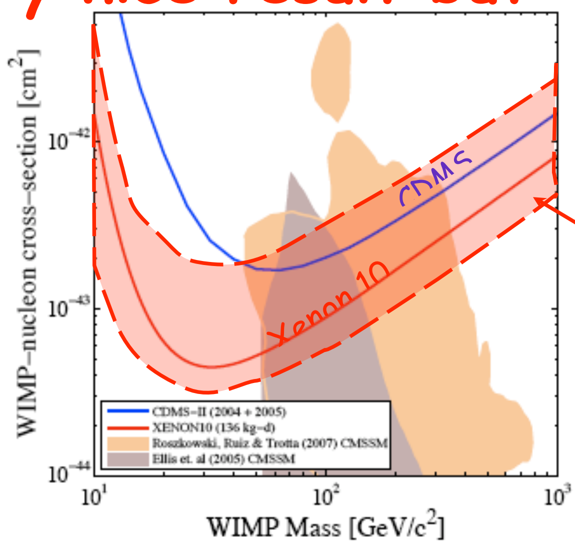
e.g. Xenon 10

After pattern recognition, 10 background events with 50% nuclear recoil efficiency





Very nice result but:



Large gap at small energy

Could it be disguised threshold

Why no flaring of electron at low S1?

Detector used in a region with no calibration

Large uncertainty

CDMS estimate July 2007

Noble Liquids: Current Plans

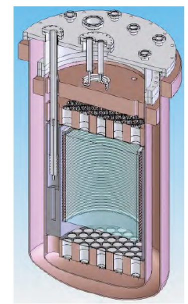
Single phase detectors

Xenon: Rely on self shielding + position reconstruction: XMASS 800kg
Argon: Rely on pulse shape discrimination: DEAP/Mini Clean

Dual phase Xenon

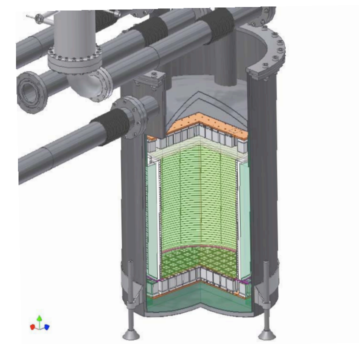
Xenon 100 : Assembly being finished in Gran Sasso (170kg- 50kg fiducual)
LUX 300kg : SUSEL (Homestake) Summer 09

Lux 300kg



http://www.luxdarkmatter.org

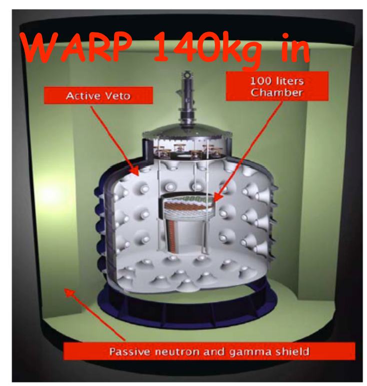
Xenon 100kg



Dual phase Argon

WARP 140kg: Assembly nearly finished
ArDM: Being assembled

WARP

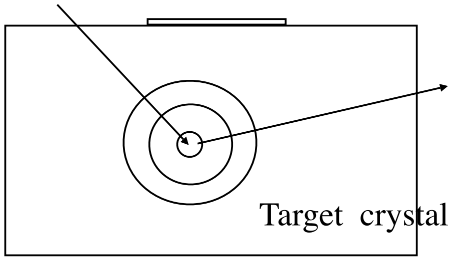


ArDM

A clear danger

"My detector is bigger than yours!"
Not the whole story: Detailed understanding of the phenomenology
Zero background!

Phonon Mediated Detectors



Principle: Detect lower energy excitations

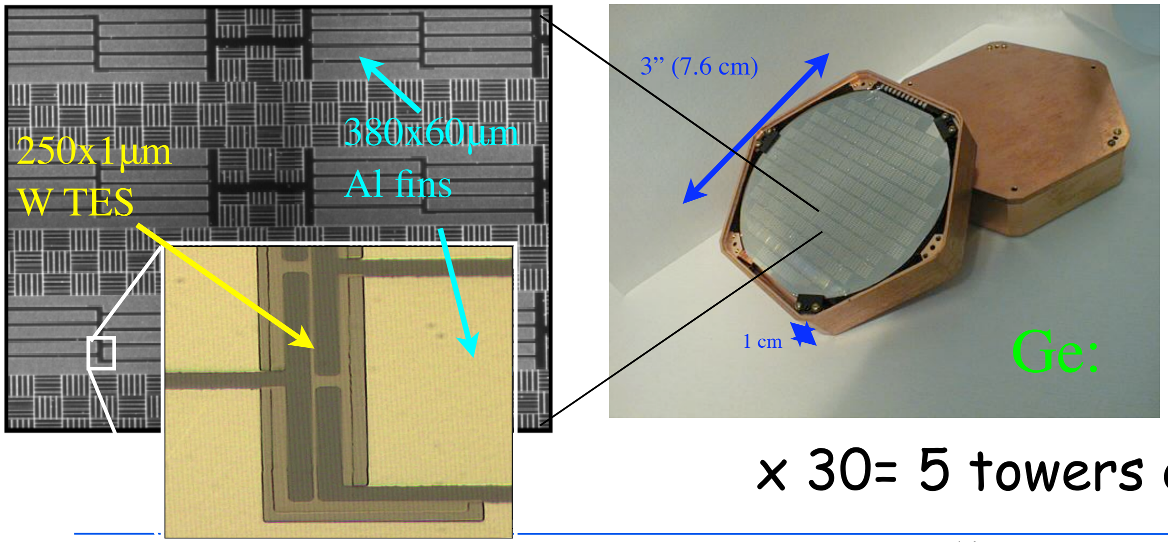
15 keV large by condensed matter physics standards

Goals

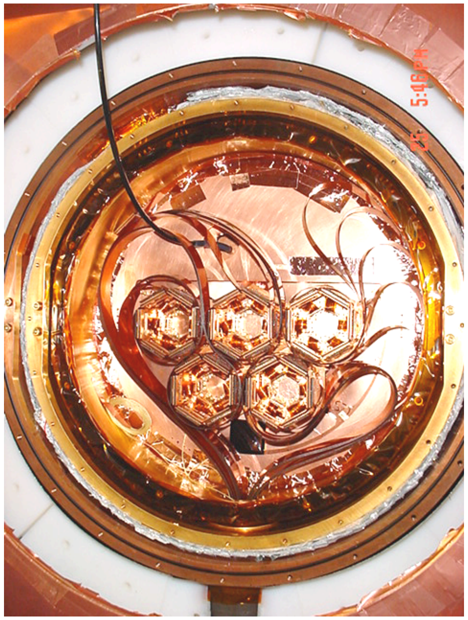
- Sensitivity down to low energy
  - Phonons measure the full energy
- Active rejection of background: recognition of nuclear recoil
  - Combine with low field ionization measurement CDMS EDELWEISS
  - or scintillation (CRESST II)

But: operation at very low temperature!

e.g. CDMS II: 40mK

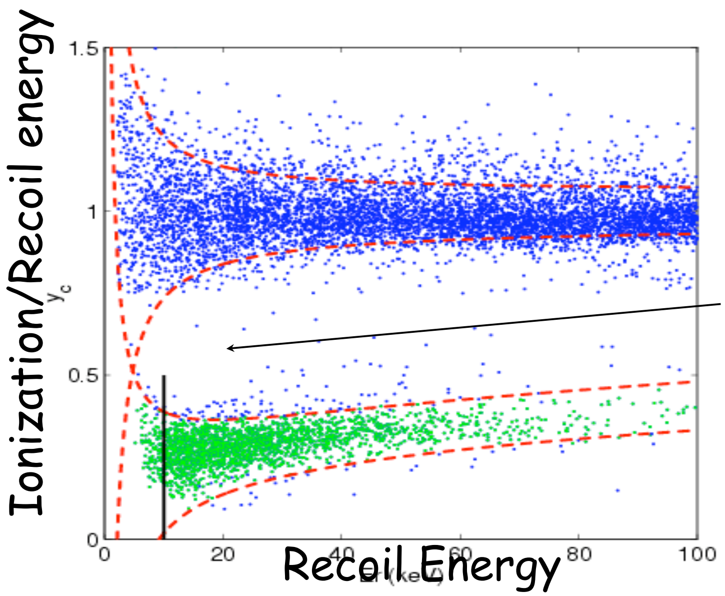


x 30= 5 towers of 6

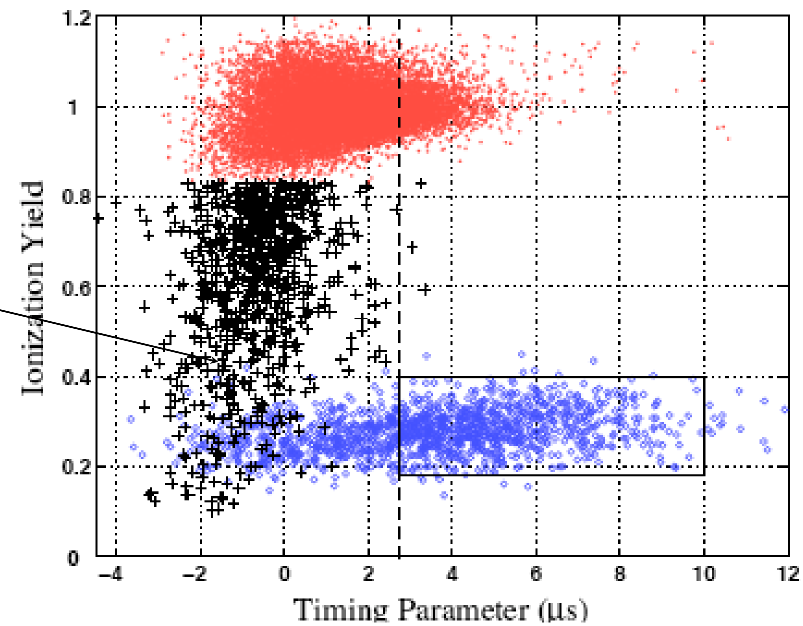


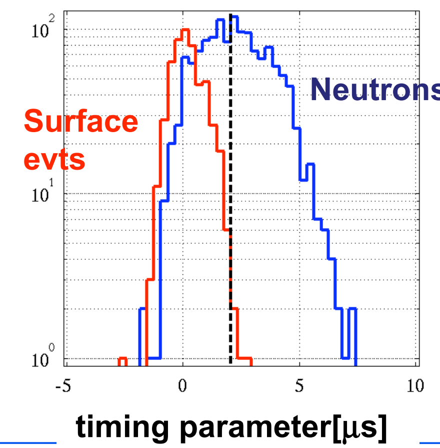
Multidimensional Discrimination

Ionization yield



Timing -> surface discrimination





Fix cuts blind (with calibration sources)

to get ≈0.5 events background

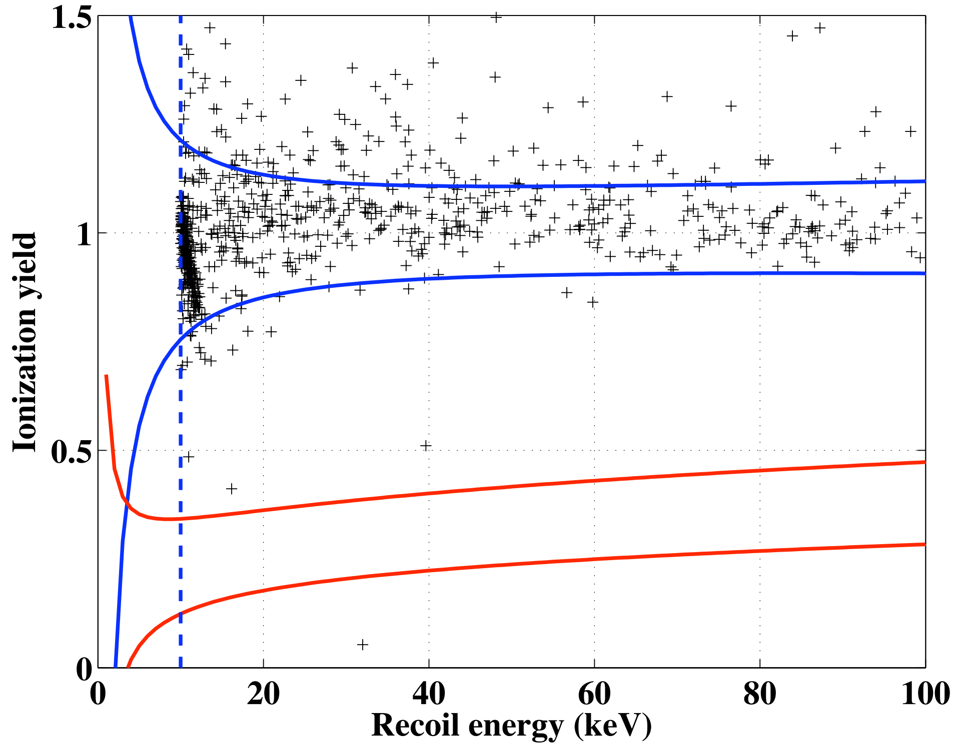
Opening the Box

Box opened Monday, February 4 for 15 Ge ZIPs
Remaining 8 Si and 1 Ge undergoing further leakage characterization

3σ region masked
=> Hide unvetoed singles

Lift the mask, see 97
singles failing timing cut

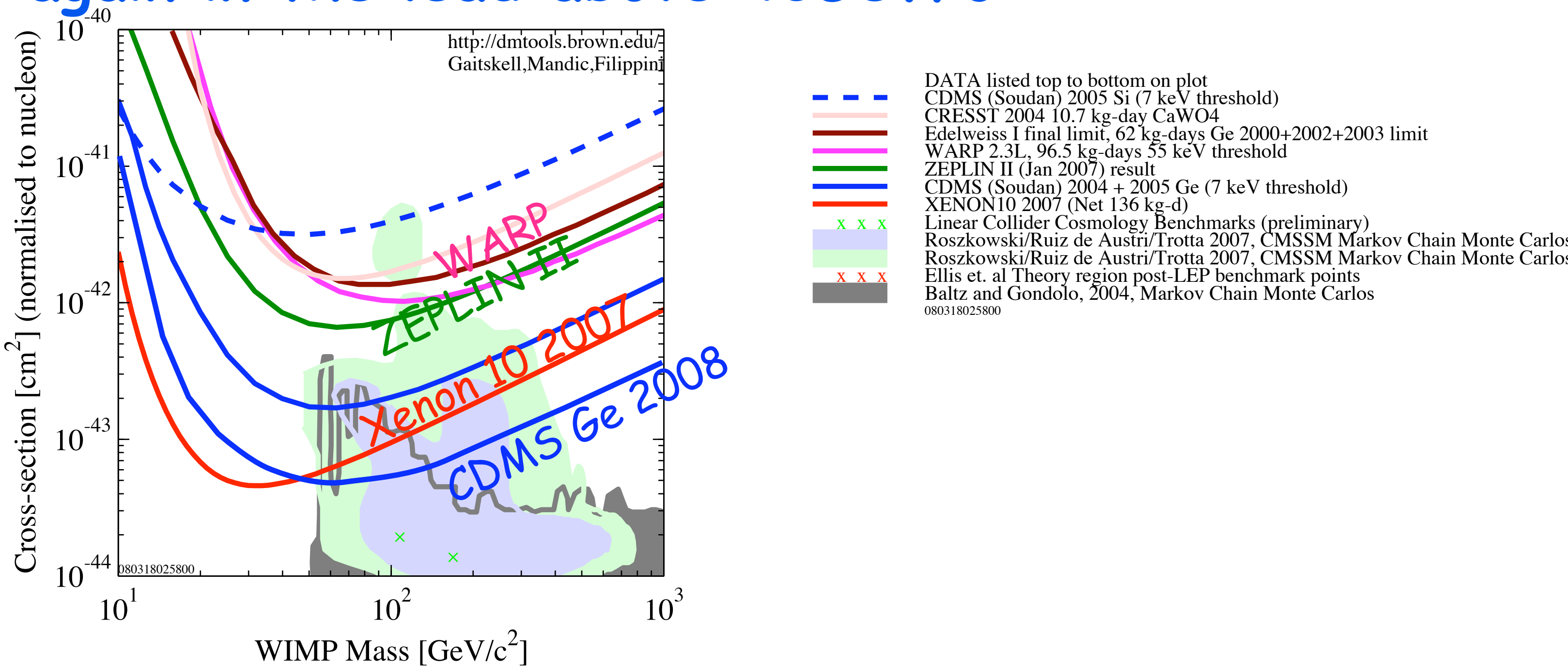
Apply the timing cut,
count the ~~candidates~~



No events observed

Current WIMP Limits

CDMS again in the lead above 40GeV/c^2



Preprint at:
- http://cdms.berkeley.edu
- arXiv:0802.3530

Immediate Future (cryogenic)

CDMS: run till ≈ December 08 ≈2000kg days

sensitivity ≈10^{-44} cm^2/nucleon

stay background free: - new towers 3 lower back grounds

- better discrimination tools

Edelweiss-> 10^{-43} cm

21 330g Ge detectors with NTD

+ 7 400g Nb Si (athermal phonons)

first commissioning run April -May 07

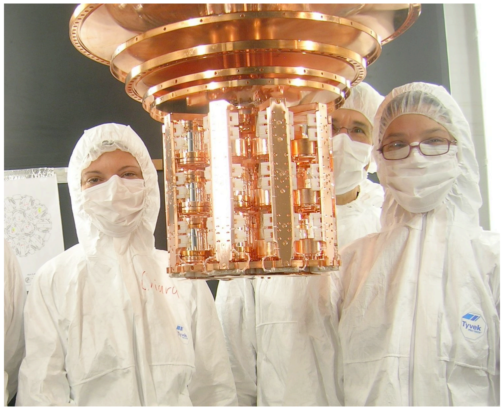
encouraging

no event > 30keV for eight NTD detectors (19 kg day) (cf 3 in EdelI)

first underground test of two 200g Nb Si

Interdigitated detectors

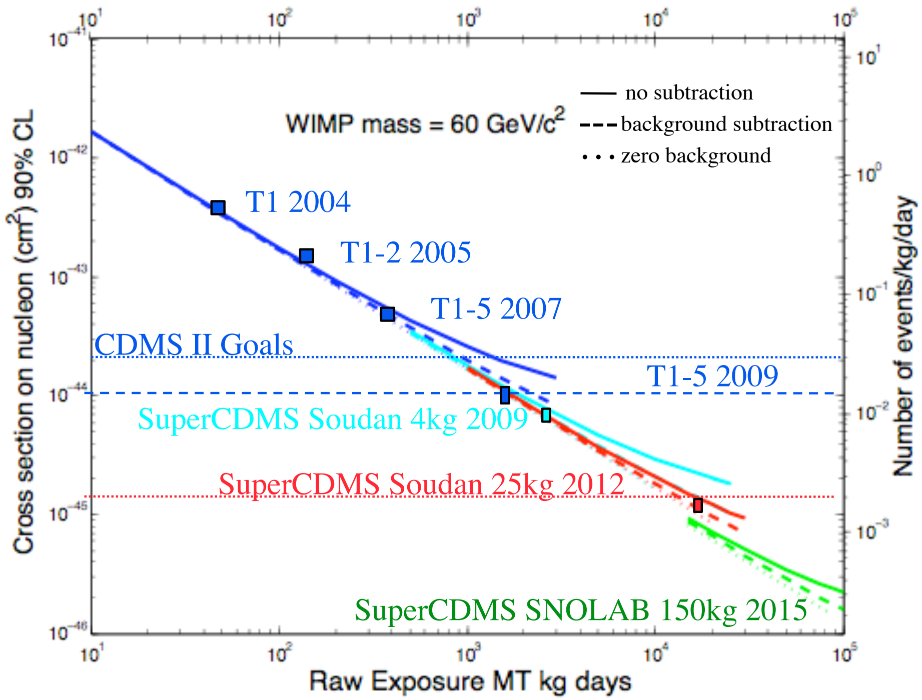
CRESST II-> 10^{-43} cm

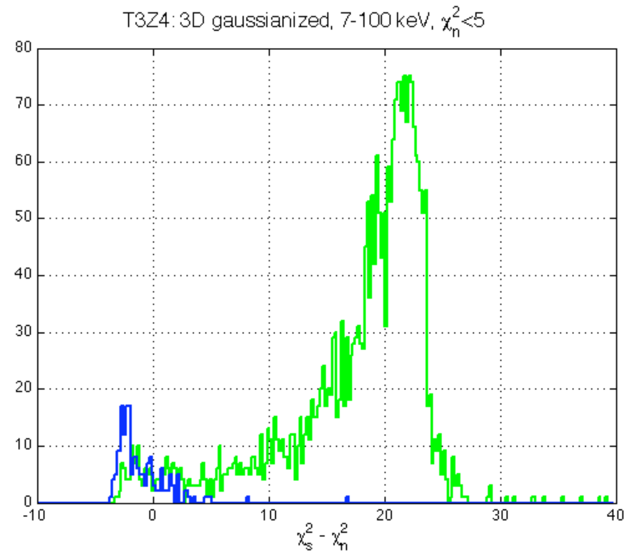


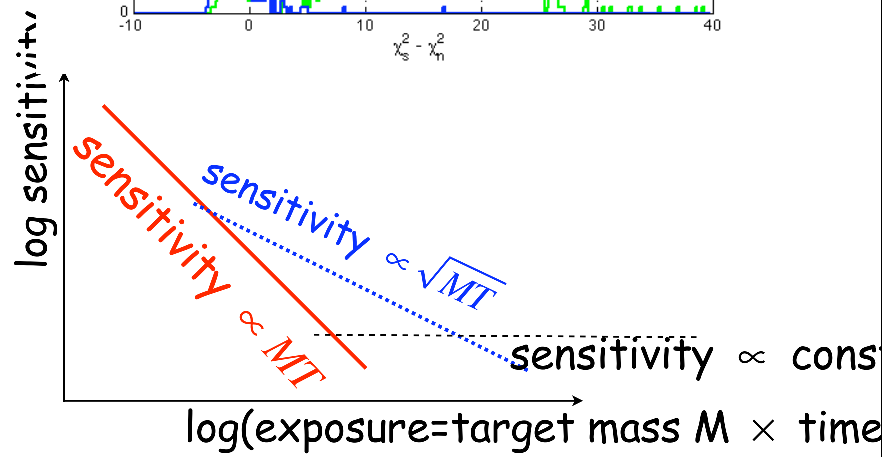
Major upgrade 66 SQUIDs for 33 detectors + neutron shield

Three detectors running since 4/07.

Low Temperature Detector Future







Three General Challenges

√ • Understand/Calibrate detectors

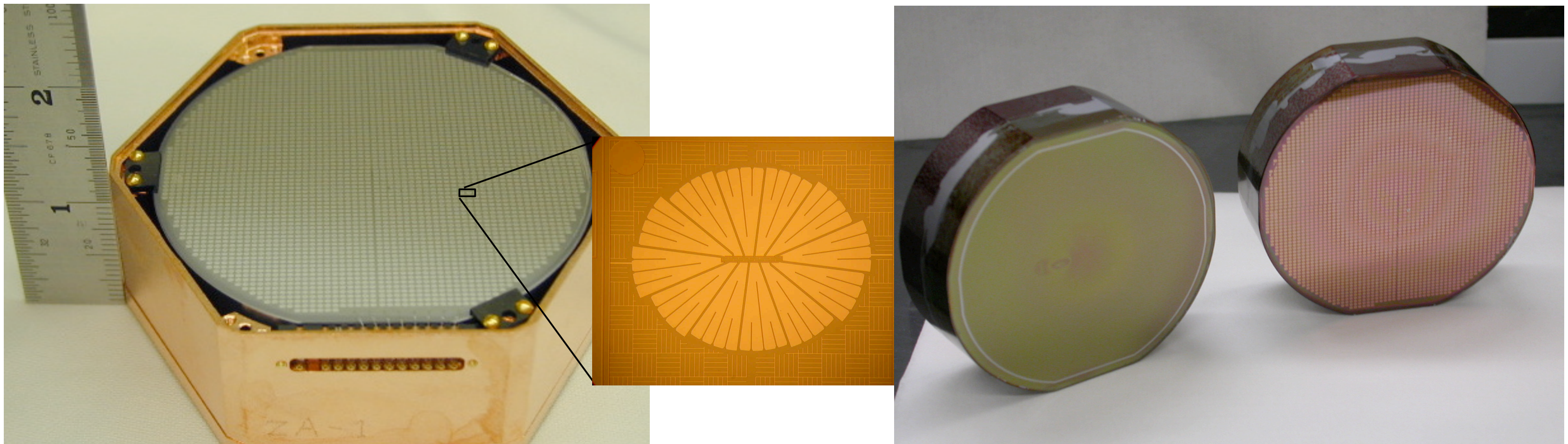
√ • Be background free

much more sensitive than
background subtraction
eventually limited by systematics

√ • Increase mass while staying background free

Larger Detector Mass

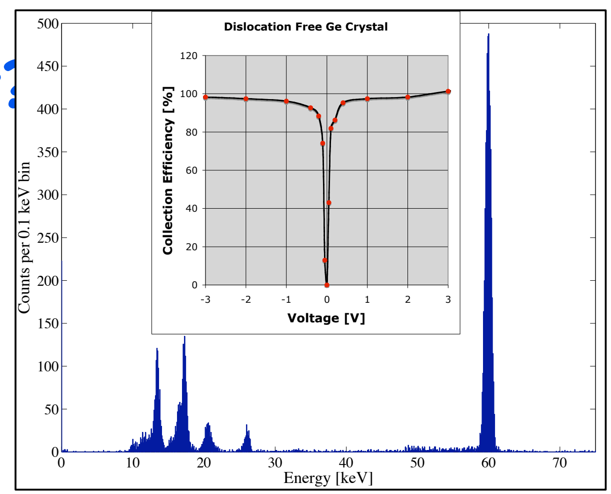
SuperCDMS 25 kg detectors: 1cm-> 1" 250g ->635 g



First tests encouraging (we need to add a radial measurement)
Double face   35% -> 70%?

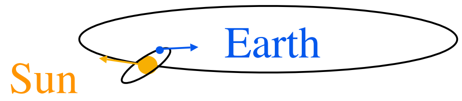
Much larger detectors -> 1ton expt?

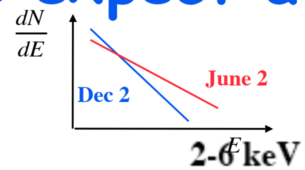
Liquid N2 Ge crystals limited to 3"
  ≈ 100 dislocation/cm^3
But we showed recently that dislocation free
  works at low temperature!
  Umicore grows (doped) 8" crystal
6"x2" or 8"x1" ≈ 5kg + Multiplexing

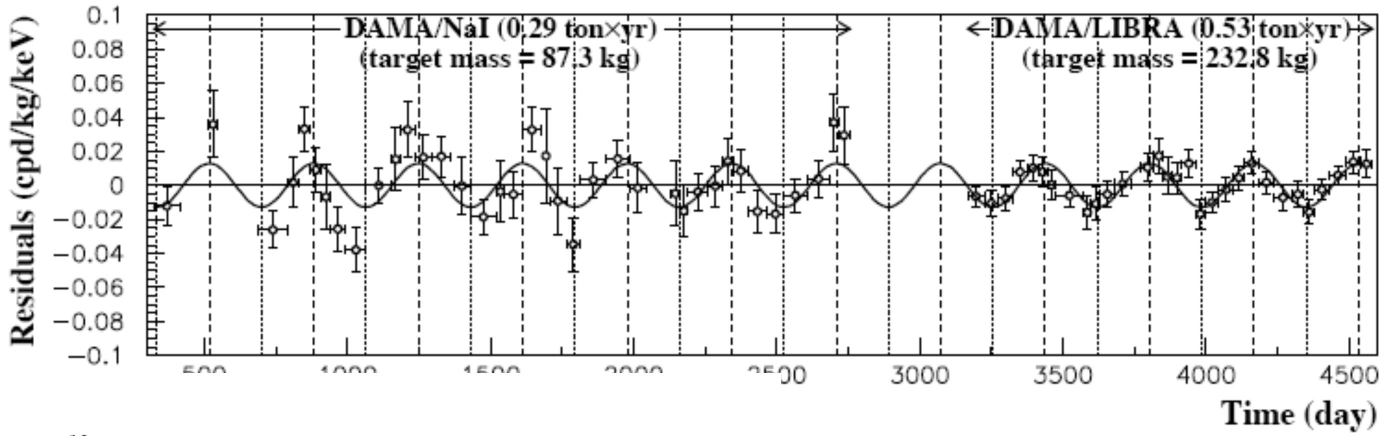


DAMA Claim April 2008

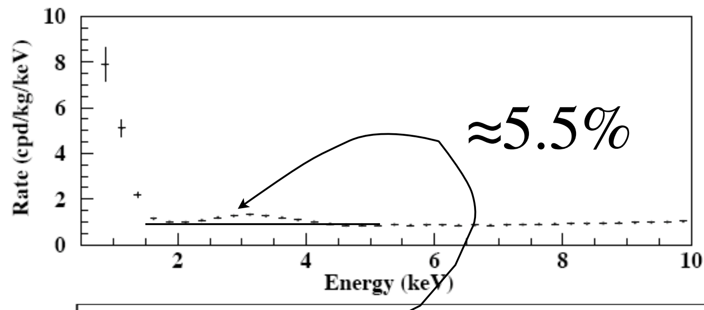
If WIMPs exist, we expect a modulation in event rate





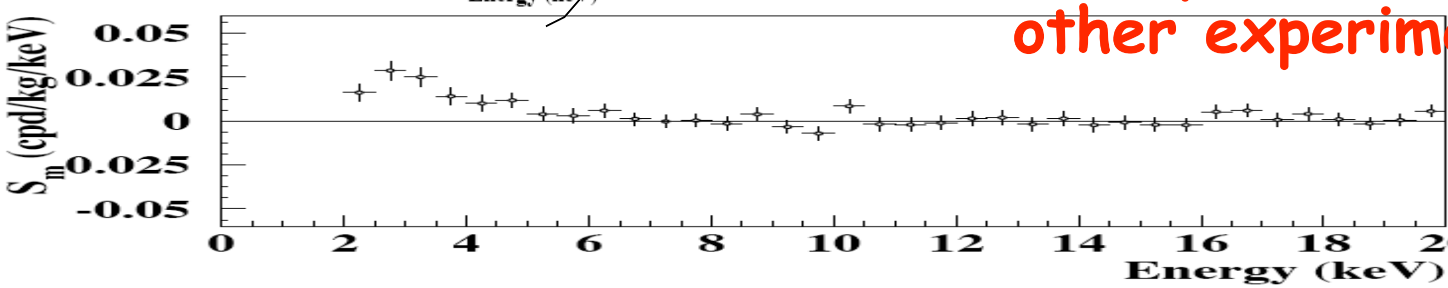


Clearly a modulation



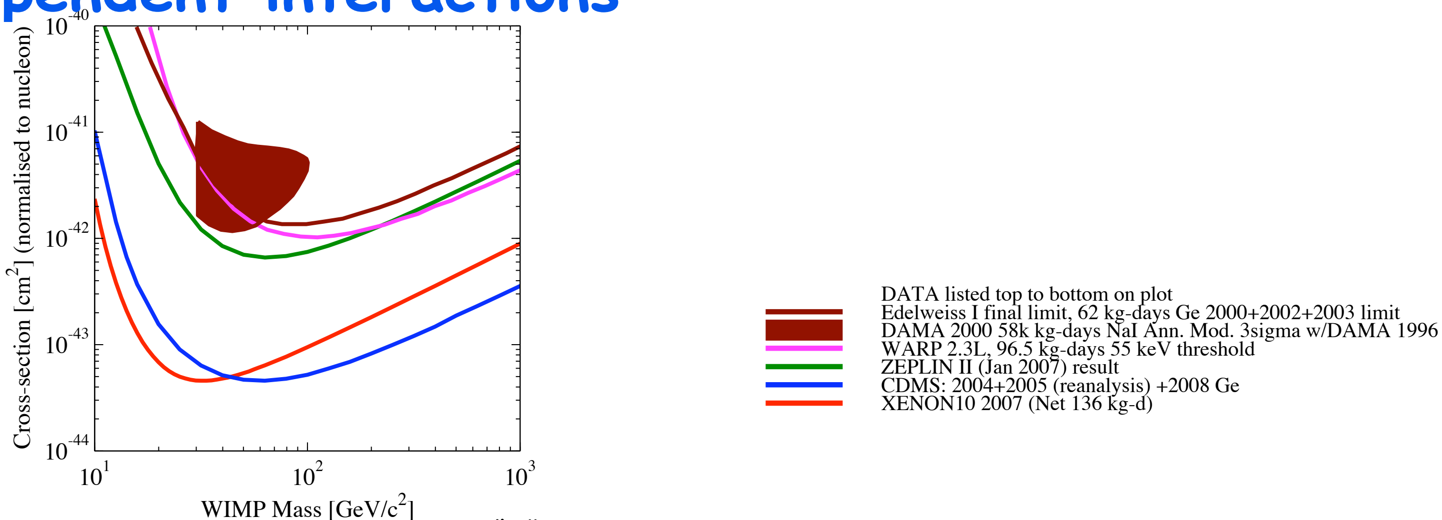
≈5.5%

Not a WIMP: incompatible with other experiments



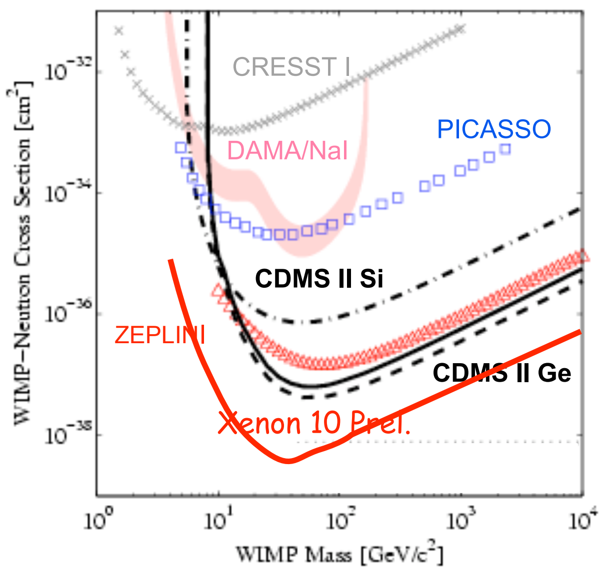
Tension with Other Expt.

Spin independent interactions

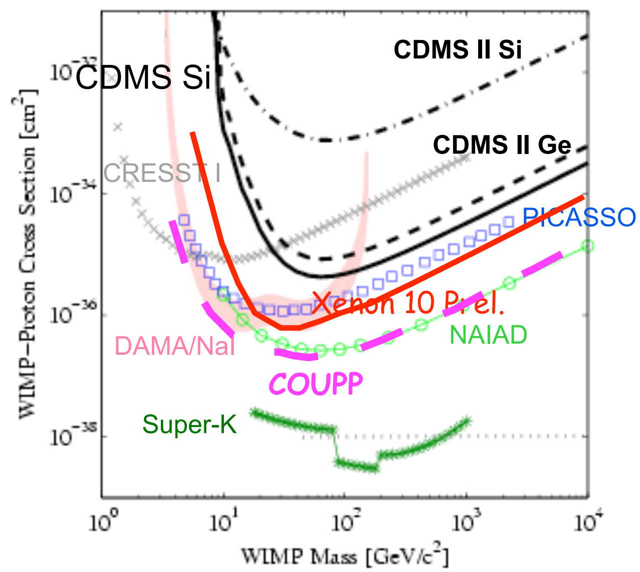


Spin dependent

"n" scattering



"p" scattering



What could it be?

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

Modulation by flux

Predict electron recoil line at 3 keV

Can be in principle checked by other detectors: being done by CDMS!

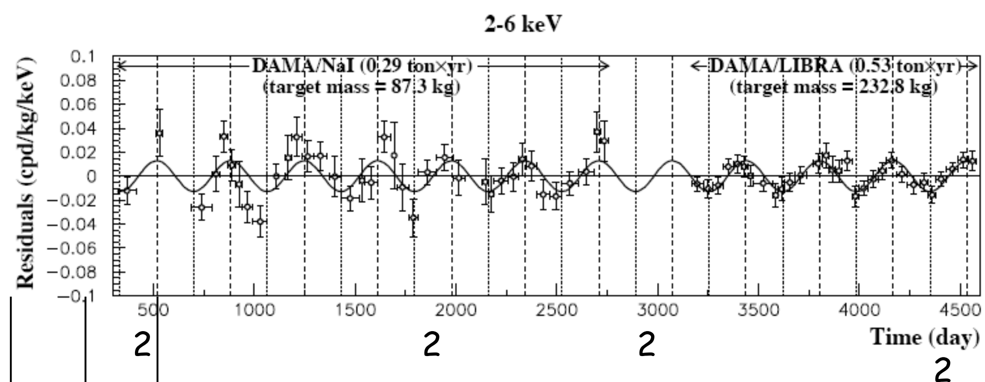
An effect related to well known modulation of muon flux, which has exactly the same phase

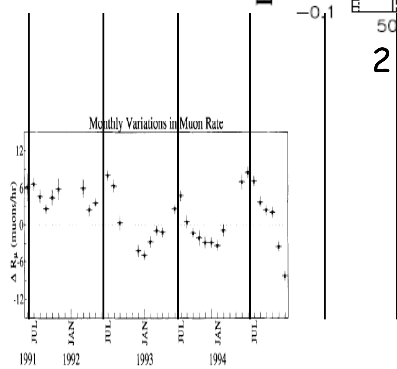
Decay path change with temperature!

DAMA claims it cannot be neutrons

What about an unknown 3 keV nuclear line with lifetime > coincidence time (Spencer Klein)?

≠ Auger in ^{40}K decay





Measurement by MACRO

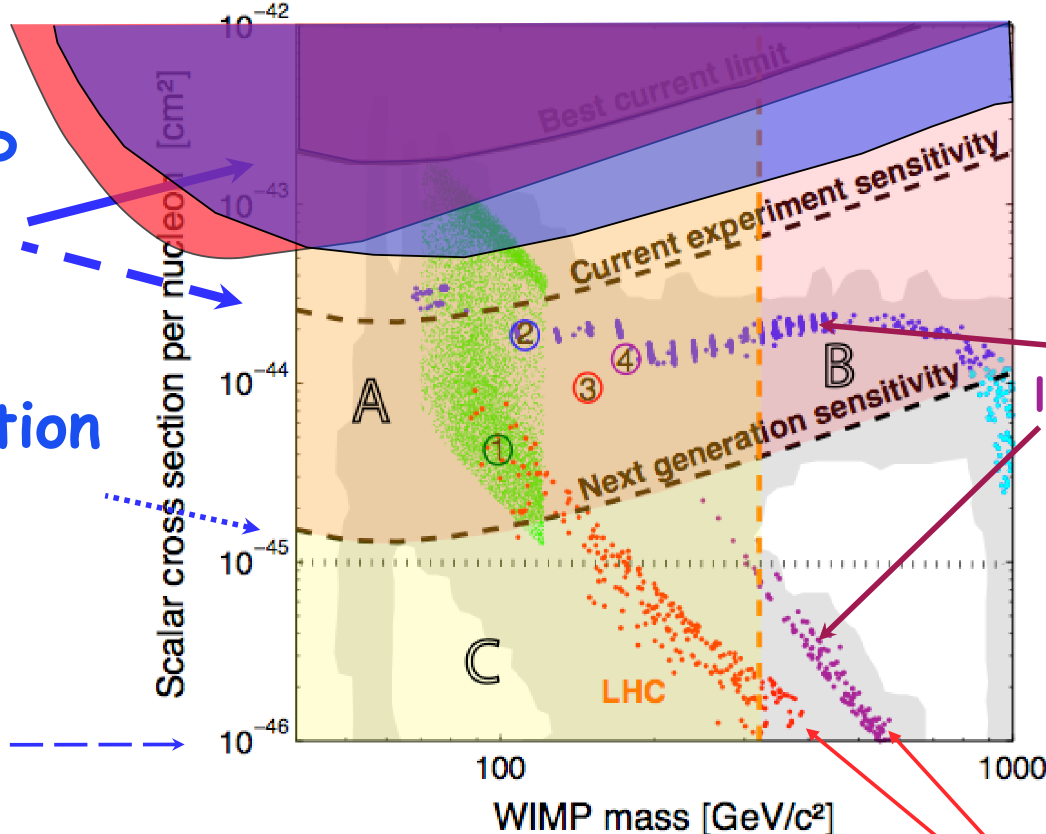
The overall picture

Generically: scalar interactions $\approx A^2$

Current WIMP searches

Next generation

1 generation beyond



GLAST launched May 08

Large Hadron Collider Jul 08

Finer and finer tuning to get right density!

Conclusions

Essential to detect Dark Matter

A key ingredient of the standard model of cosmology

At least show it is not an epicycle!

WIMPs is the generic Thermal model

The field of direct detection is very active, many ideas

We should reach $10^{-44}cm^2$/nucleon very soon (2009)

$10^{-45}cm^2$/nucleon should be reachable by

- phonon mediated detectors
- Liquid Xenon 2 phase
- Liquid Ar 2 phases+pulse shape

maybe other simpler technologies (XMASS, MiniCLEAN, COUPP)

$10^{-46-47}cm^2$/nucleon considerable challenge (≈ evt/ton/yr)

When we have a discovery: link to galaxy

(low pressure TPC≈5000 m^3)

Complementarity with accelerators and indirect detection

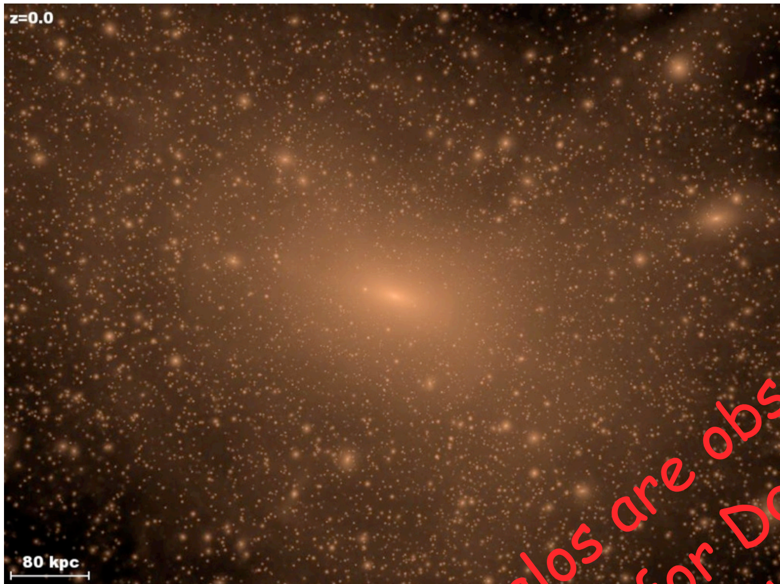
Large Hadron Collider may probe the same physics

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

We may well be at the brink of discovery!

B.Sadoulet, Science 315 (2007) 61

Gamma Rays: A smoking gun?



Via Lactea simulation

Diemand,Kuhlen,Madau

Piero Madau's talk

No gas in simulation

If subhalos are observed

Smoking gun for Dark Matter

Hierarchical merging

Simulated Glast

<= Via Lactea

$\langle\sigma v\rangle = 5\times10^{-26}$ cm^3 s^{-1}

M_x = 46 GeV

2 years