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Dark Matter Searches

Particle Cosmology

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

Current status 2007: entering the interesting region 10^{-44} cm^2/nucleon
Next generation of experiments ≈5 years: 10^{-45} cm^2/nucleon
Longer term 10^{-46-47} cm^2/nucleon: next ten years?

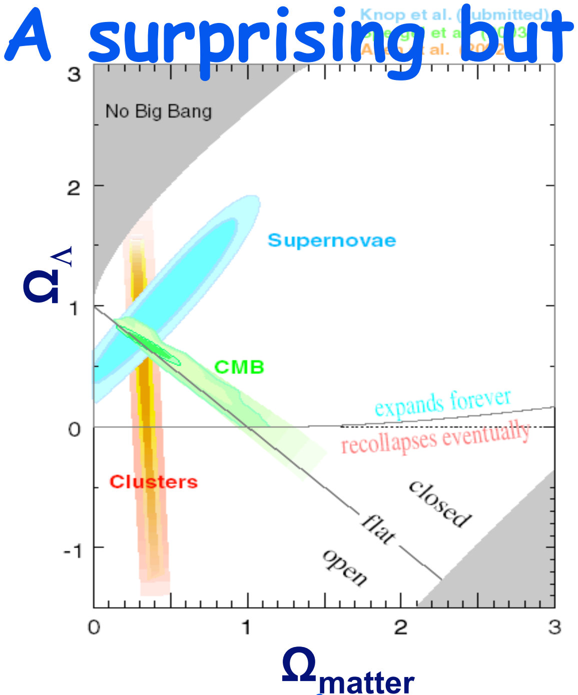
Complementarity with accelerators and indirect

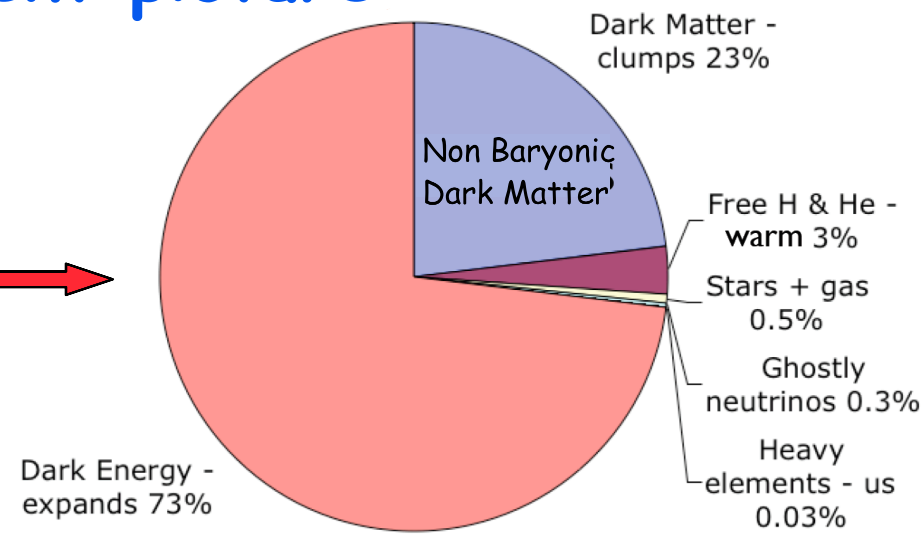
- Large Hadron Collider 2008-2012 critical tests of our ideas
- GLAST Jan 08-2013 could be smoking gun

B.Sadoulet, Science 315 (2007) 61

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

$m_\nu < .17 eV$ 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

QCD violates CP

Dynamic stabilization by a Peccei-Quinn axion?

Gravity is not included and we do not understand vacuum energy

Always the danger of a failure of General Relativity

and that dark matter is part of a new set of “epicycles” that we invent to adjust theory to increasingly accurate data

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

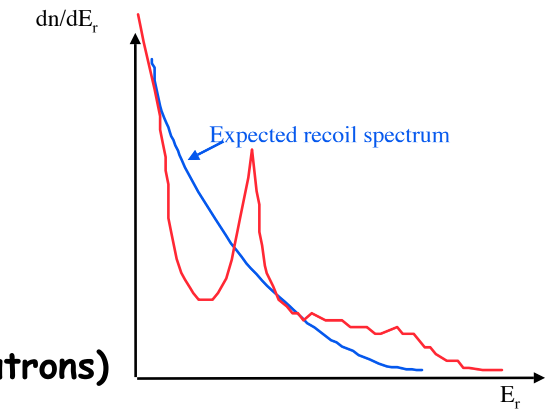
Indirect: Annihilation products

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

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

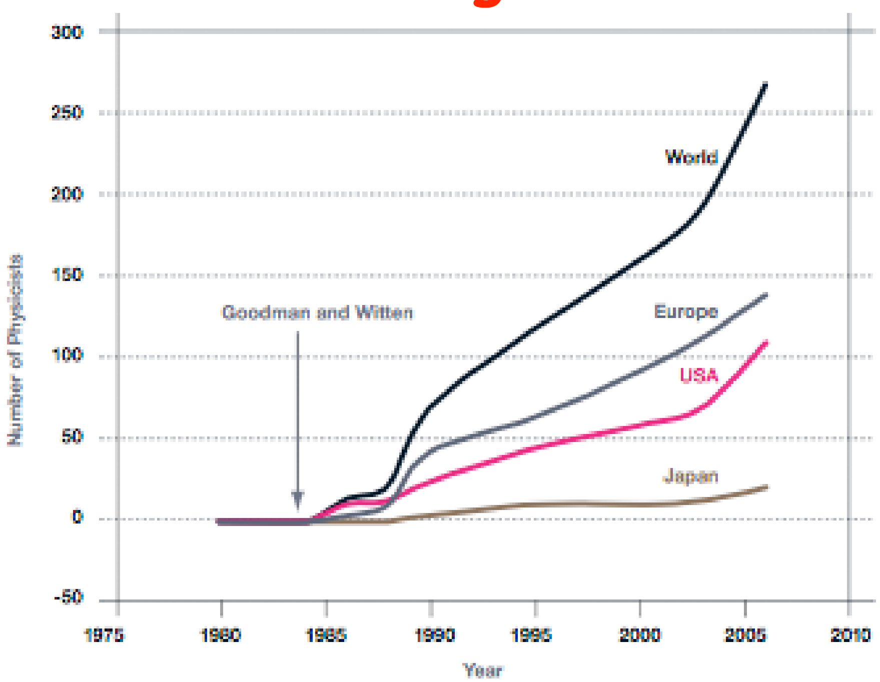
- Nuclear recoil
- Single scatter ≠ neutrons/gammas
- Uniform in detector

Linked to galaxy

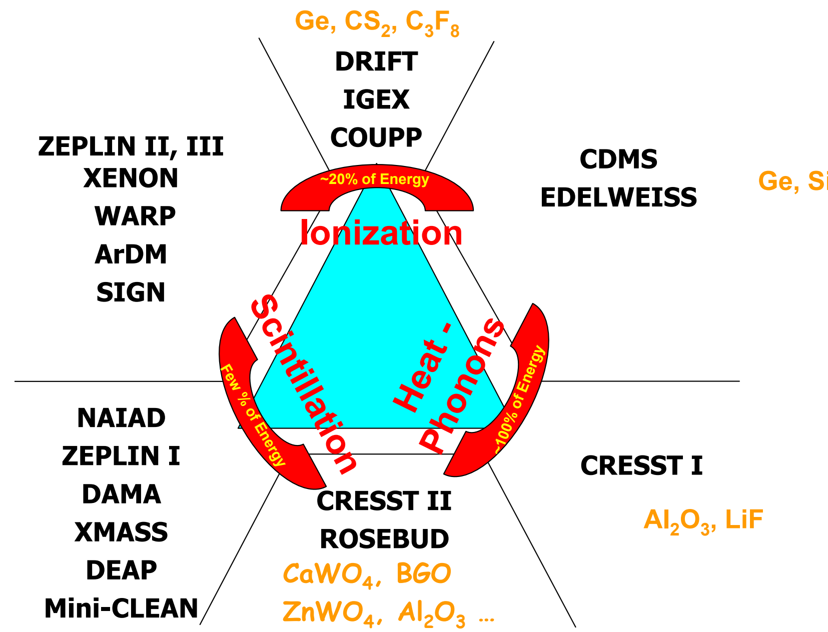
- Annual modulation (but need several thousand events)
- Directionality (diurnal rotation in laboratory but 100 Å in solids)

Experimental Approaches

A blooming field



Direct Detection Techniques



As much information
As large 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)

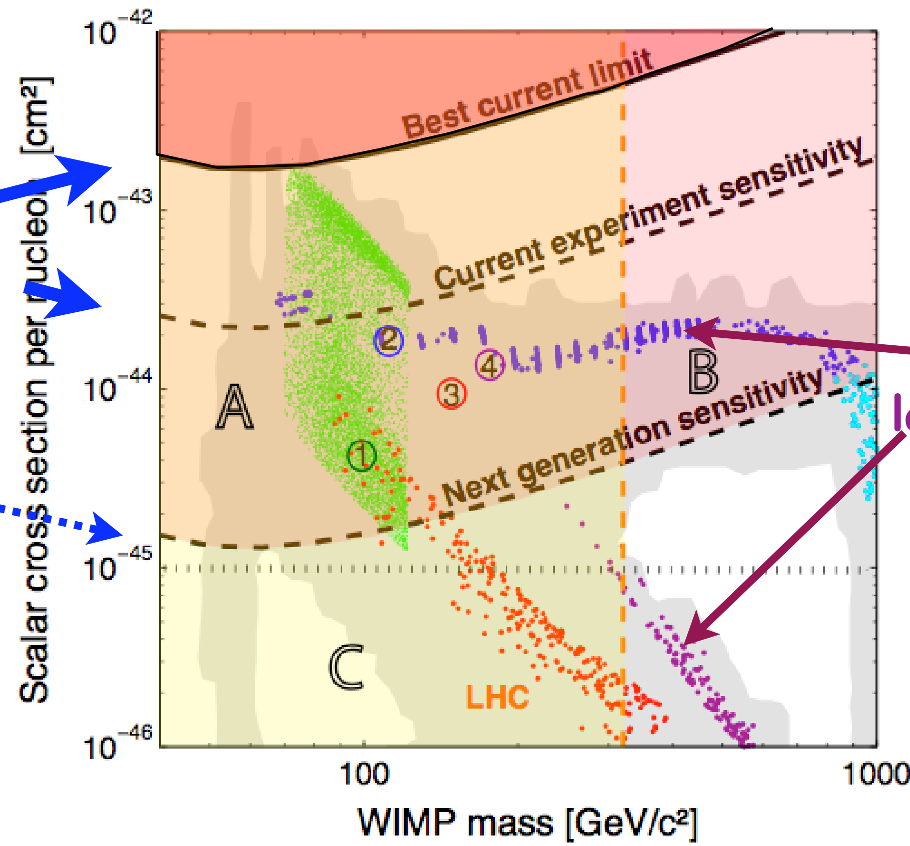
The overall picture

Generically: scalar interactions ≈A^2

Current WIMP searches

Next generation

1 generation beyond



GLAST
launched Dec 07

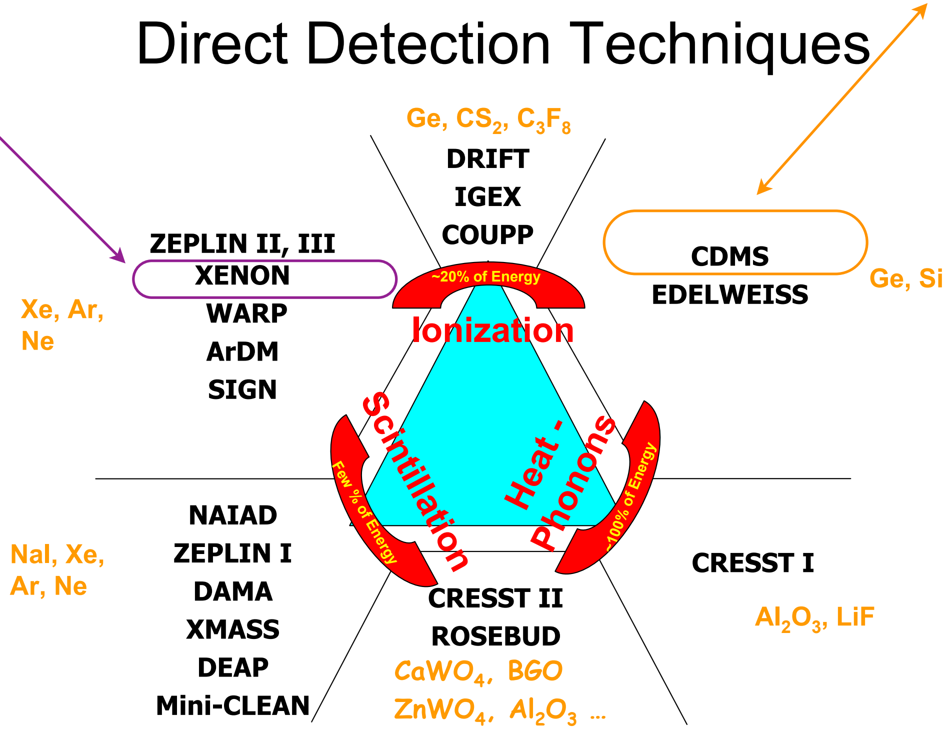
Large Hadron Collider

Current results

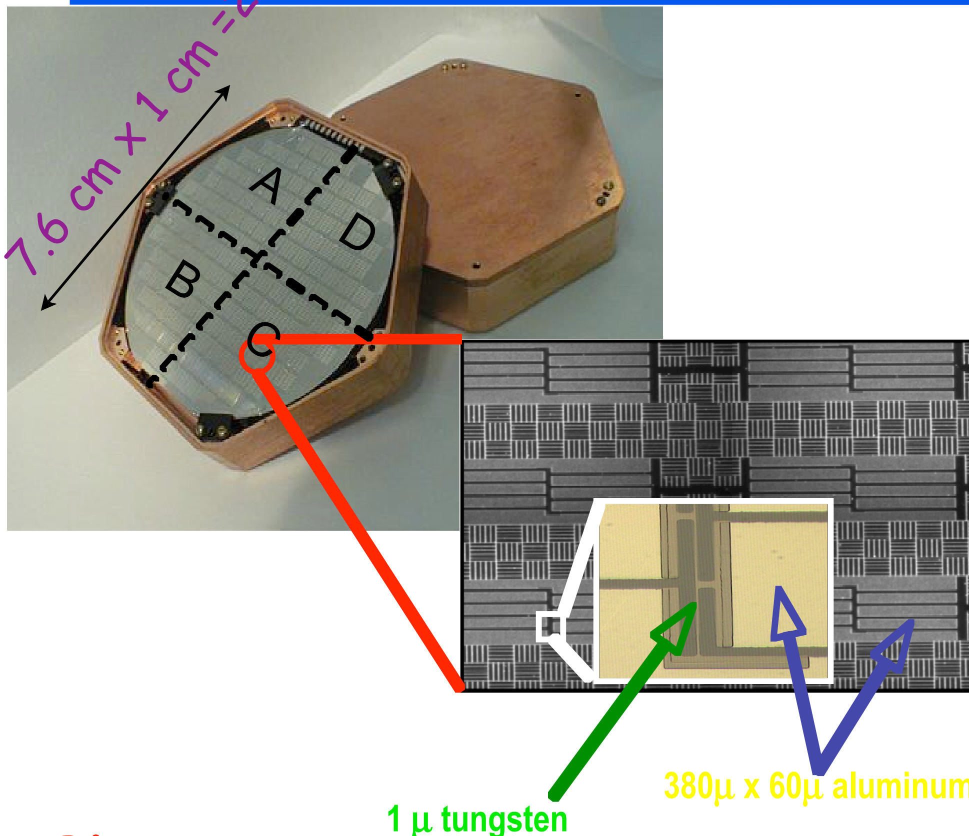
2 examples in more details

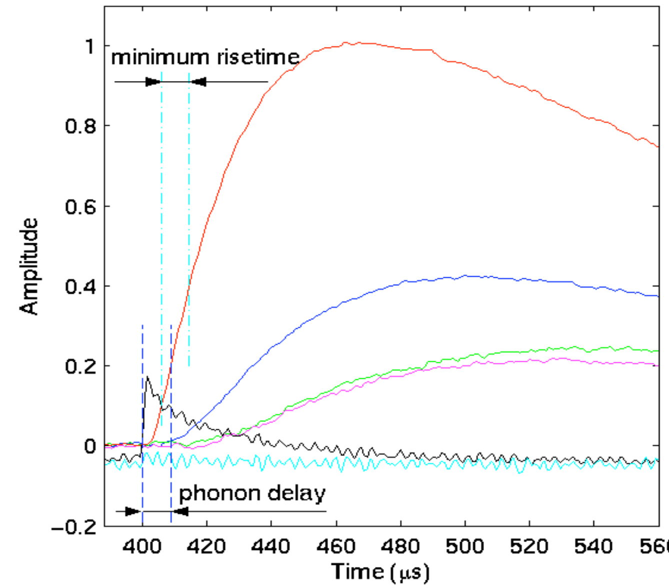
Xenon 10 as generic for
ZEPLIN II ,WARP, ArDM

CDMS as generic for
EDELWEISS & CRESST



CDMS II





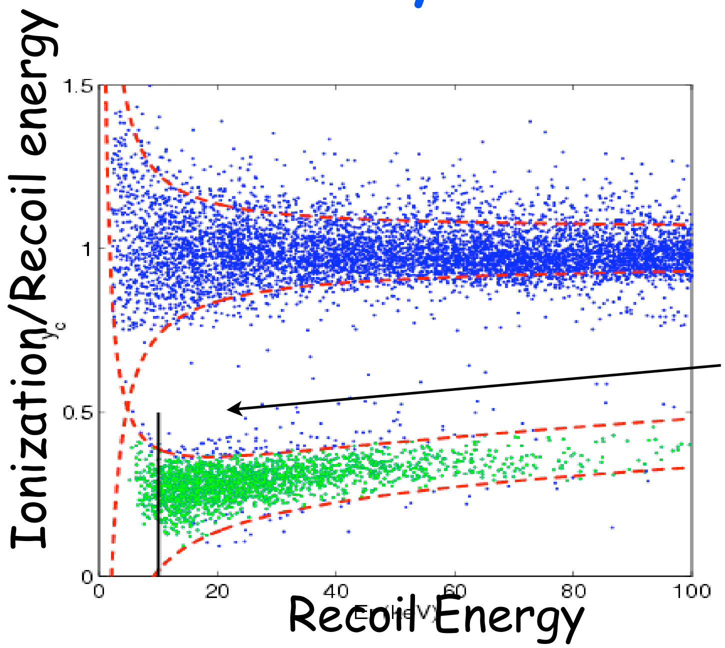
Phonons+ionization large signal to noise (cf EDELWEISS, CRESST)
=> total energy, ionization yield: discrimination of nuclear recoils

Athermal => large amount of information
=> 3D position of the event
In particular, in spite of "folding", proximity to the surface
≠ surface electrons

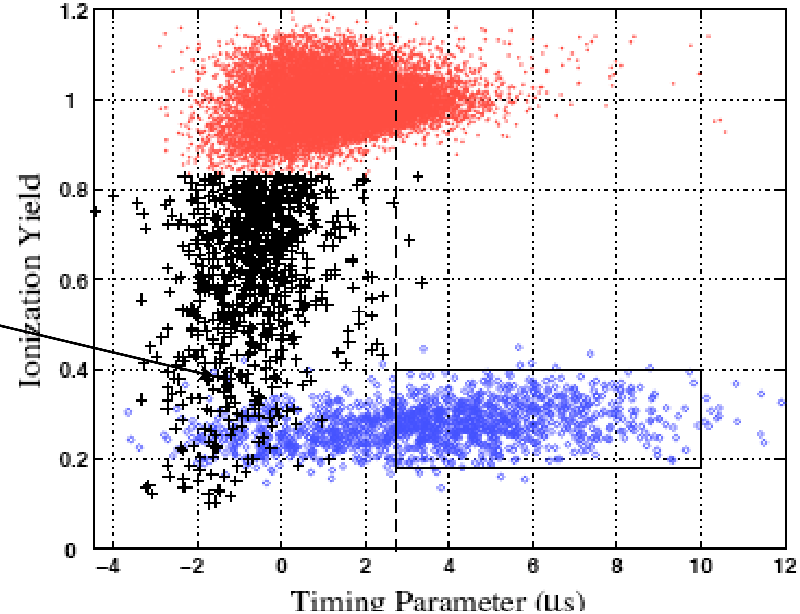
Multidimensional Discrimination

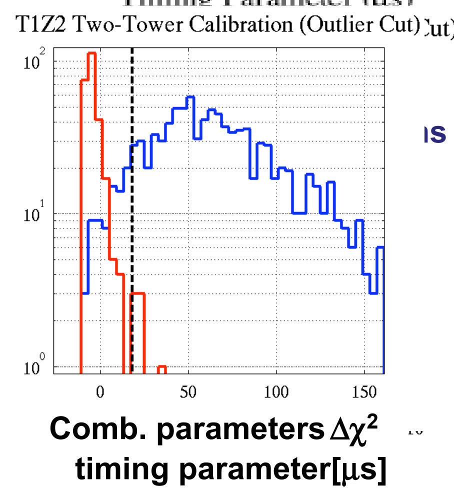
Ionization yield

Timing -> surface discrimination



Surface
Electrons



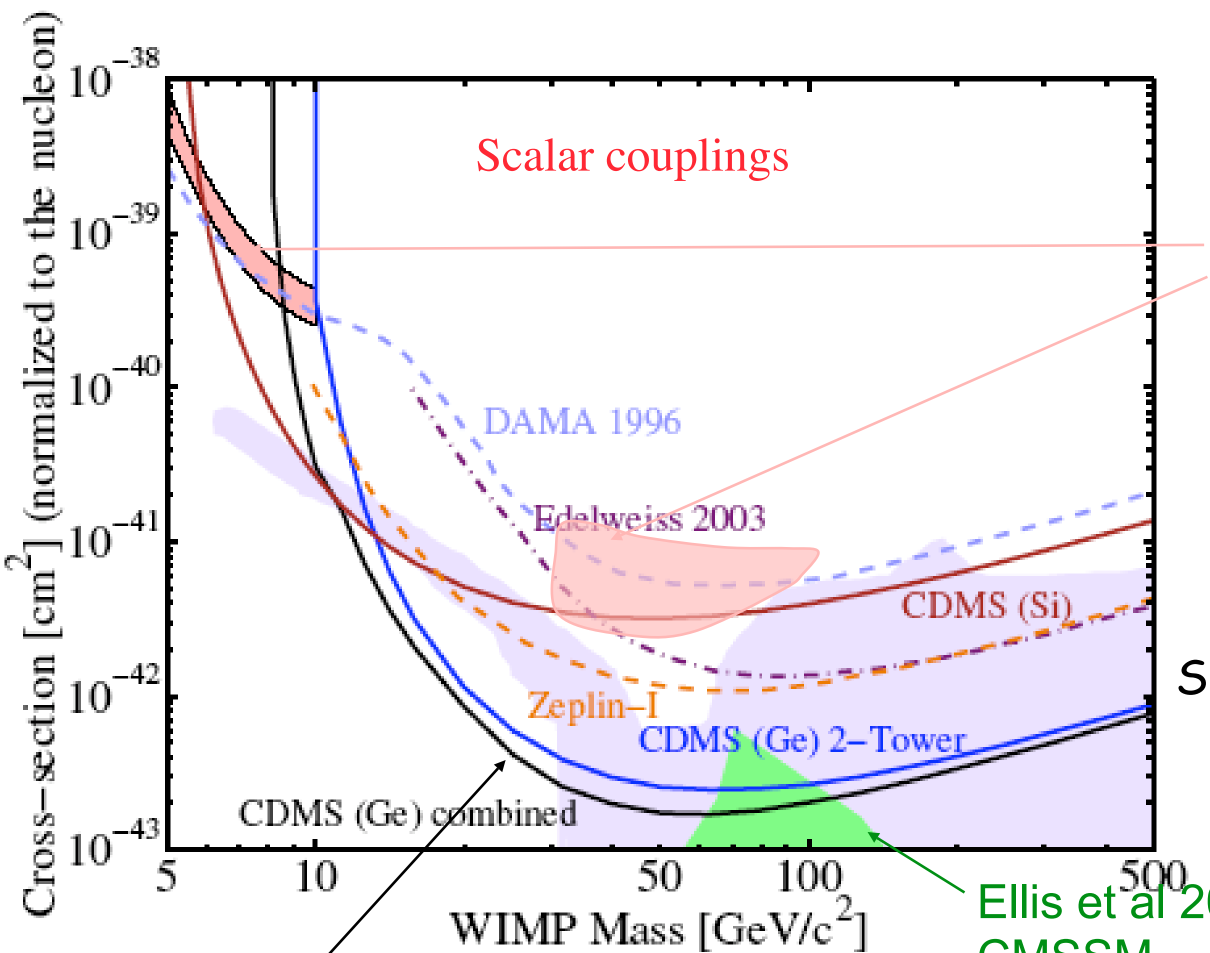


Fix cuts blind (with calibration sources)

to get ≈0.5 events background

53% nuclear recoil efficiency
Expected backgrounds:
0.37 ±0.15(stat.) ± 0.20(sys.) electron recoils,
0.05 recoils from neutrons expected

CDMS II (2005)



10 times more sensitive than any other expt. in 2005

Increasing tension with DAMA who claims a signal (NaI)

See PRL 96 (2006) 011302

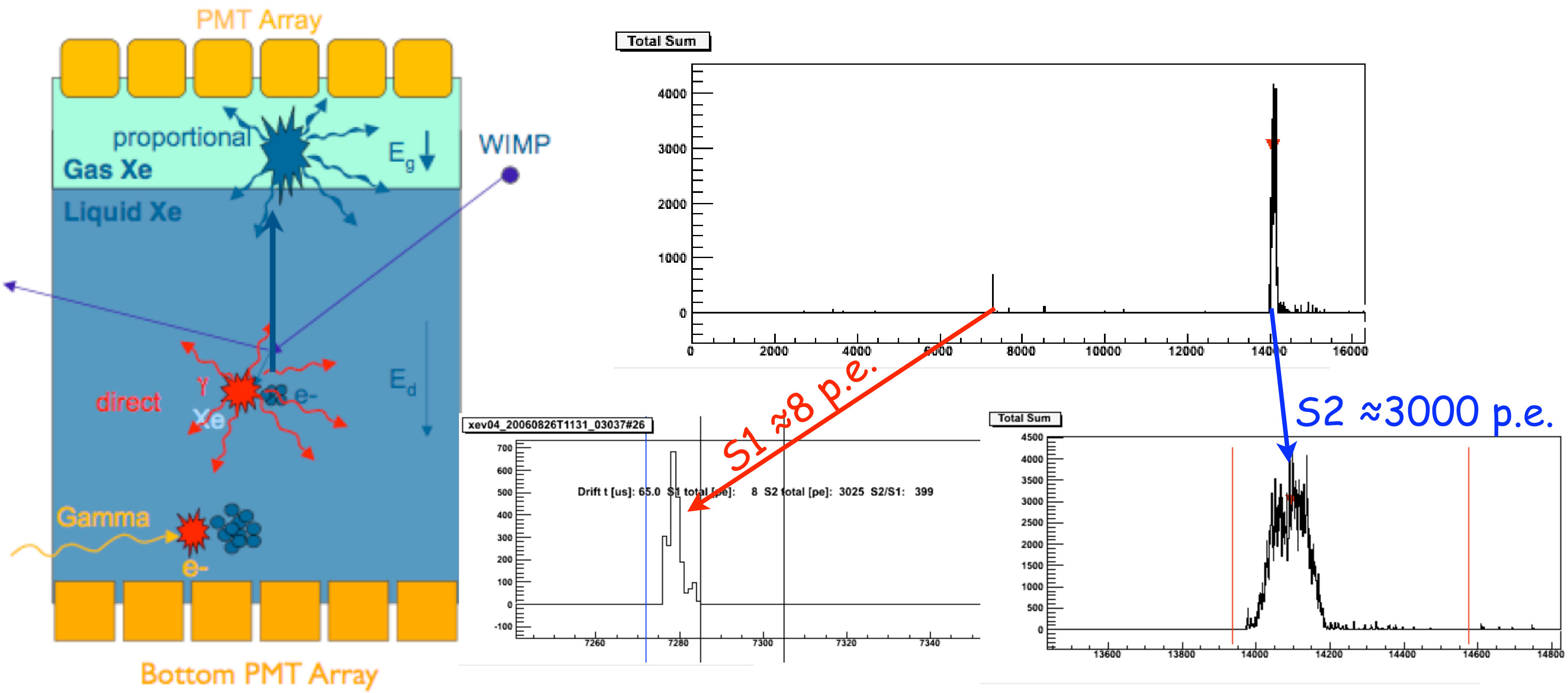
Ellis et al 2005
CMSSM

Entering in interesting territory

Adding 1st Soudan run, 53kg.day-> 19kg.day after cut

Total 53 kg.day after cut

Xenon 10



Liquid Xenon: Scintillation + ionization

two photon pulses => depth

Breakthrough: extraction of electrons from liquid

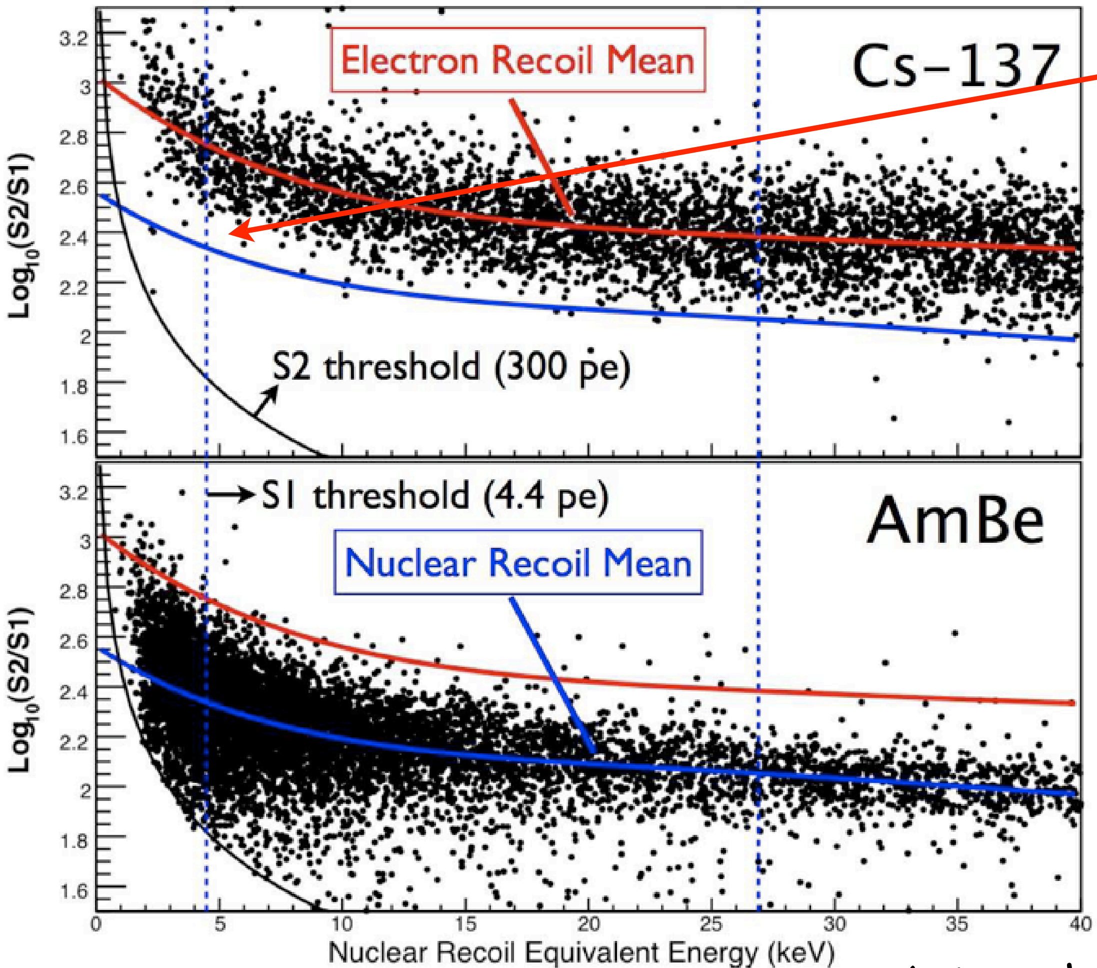
importance of having photon detector at the bottom + high spatial resolution ≠ ZEPLIN II

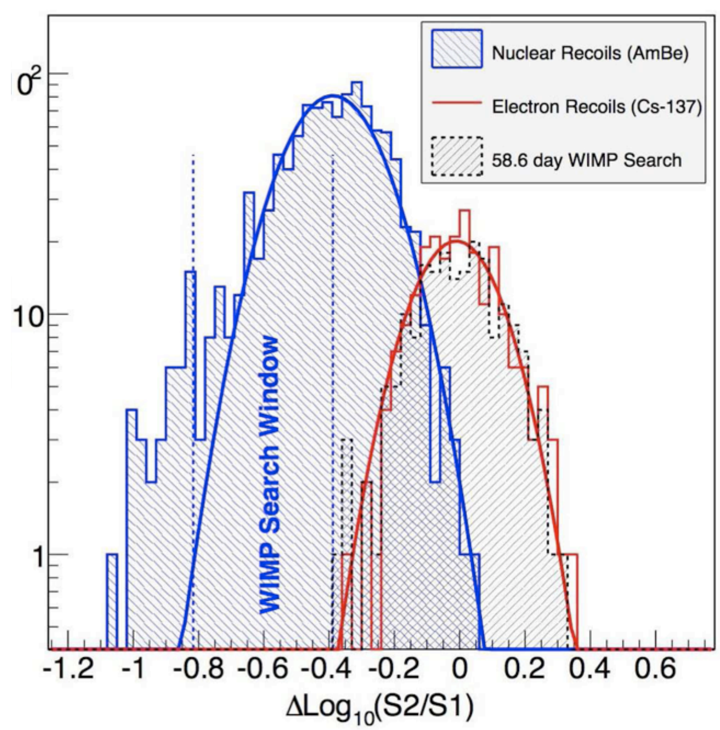
Rejection Xenon 10

Good rejection down to 4.5 keV nuclear recoil

With 4 p.e!

Why no flaring of electrons at low energy?





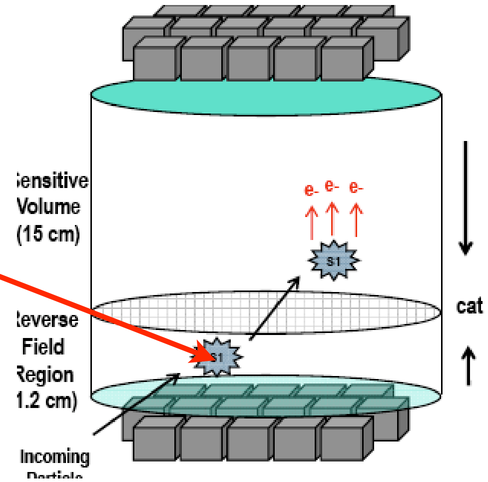
Astro-ph/0706.0039

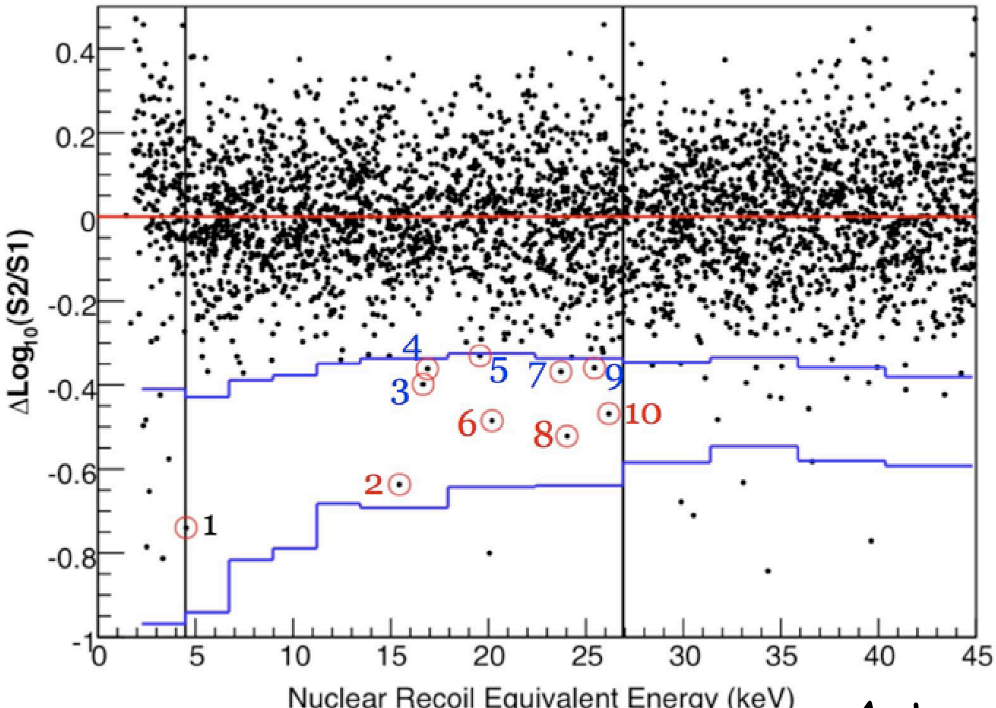
Low background running

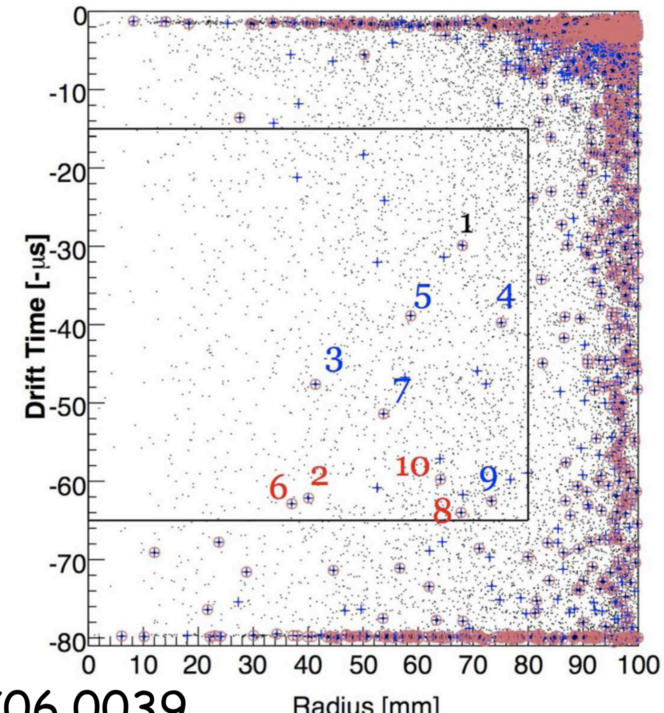
Events with depressed S2

Region where ionization is not collected

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





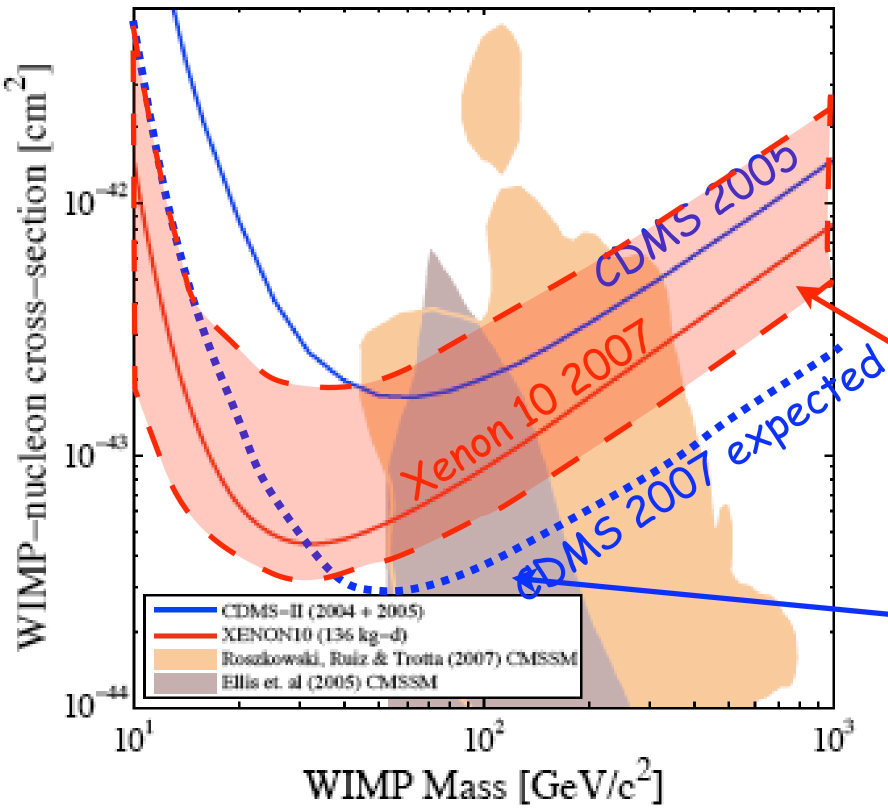


Astro-ph/0706.0039

Xenon 10 Results

Very nice result

Clean demonstration of power of the technology



Large gap at small energy

S. Yellin CDMS analysis code

- Statistically lucky?
- Characteristics of background?
- Or disguised threshold?

non flaring of e recoils

Detector used in a region with no calibration

Large uncertainty

CDMS estimate July 2007

New calibration this summer

CDMS run 123+ 124 630kg days

Blind analysis

Expect to be background free

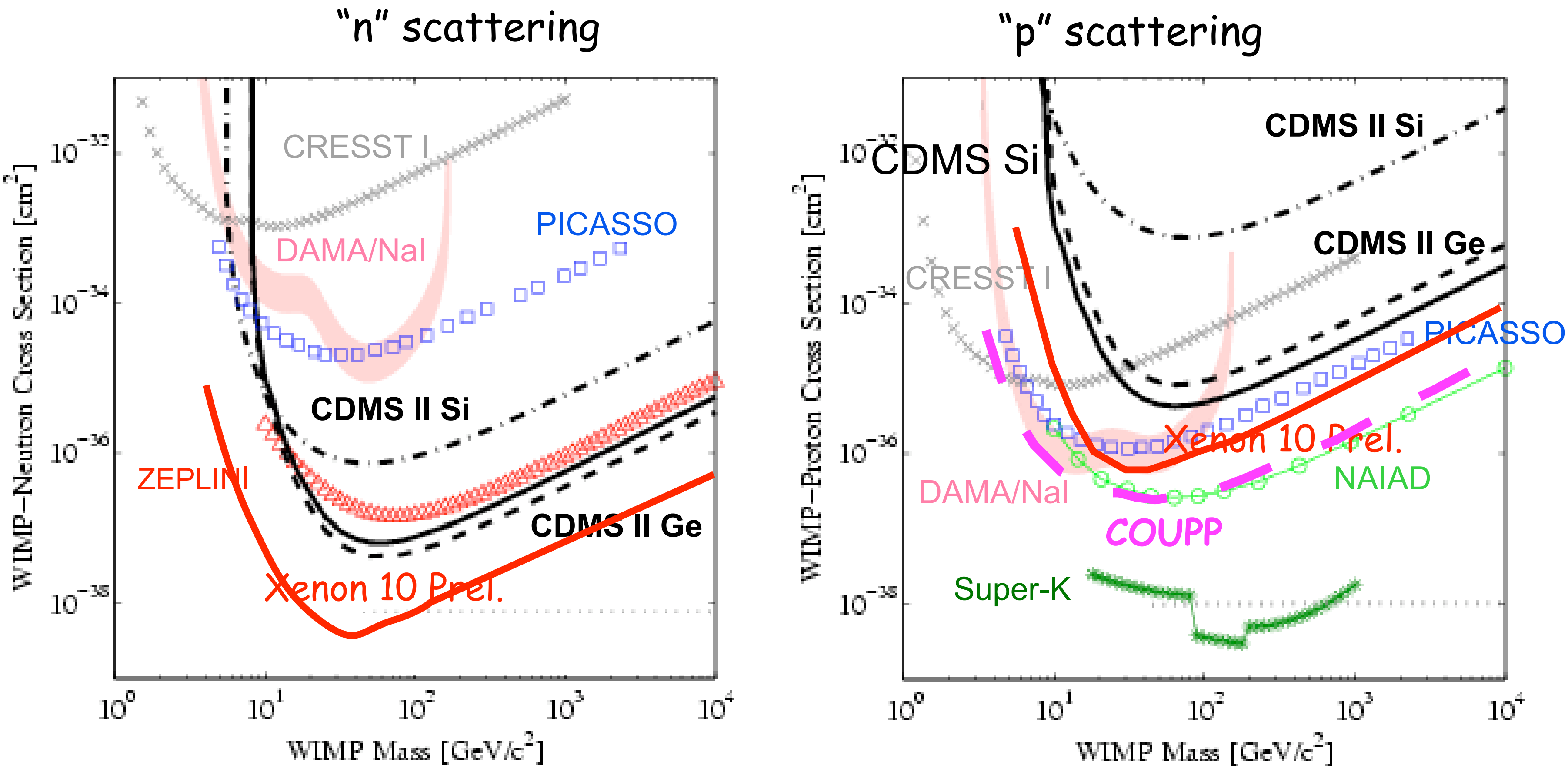
$3\ 10^{-44}$ cm^2/nucl @ 60GeV/c^2

If true, about 7*Xenon 10 discovery potential!

Spin dependent

Xenon 10 improves n scattering limit

COUPP (Chicago-Fermilab bubble chamber) p scattering



Spin independent not good for DAMA either

Immediate Future (cryogenic)

CDMS: run till ≈ next summer ≈1500kg 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

CRESST II-> 10^{-43} cm

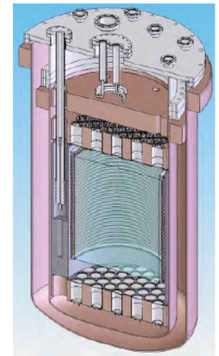
Major upgrade 66 SQUIDs for 33 detectors
+ neutron shield
Three detectors running since 4/07.
Will report≈ 60kg days at TAUP

Immediate Future (noble liquids)

Xenon 10+

Corrections of problems
installation larger vessel:
mass+veto , results in 2008

LUX 300kg

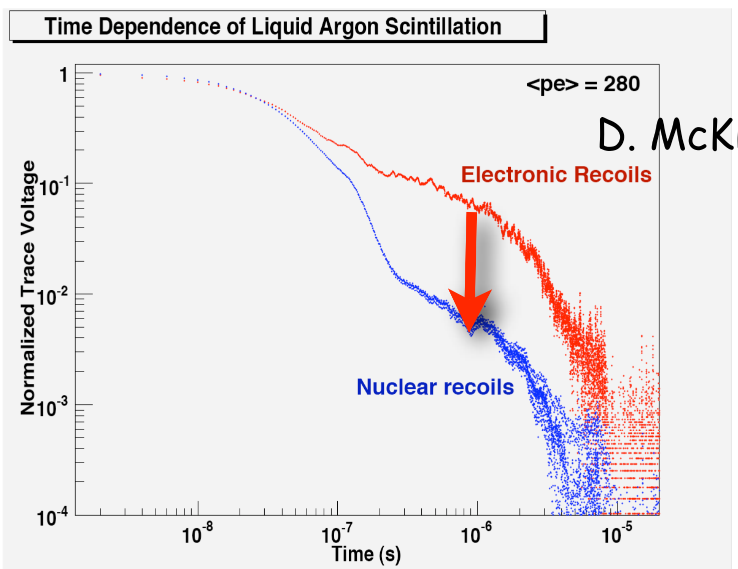


http://www.luxdarkmatter.org

Liquid argon: one additional handle : rise time

Recent breakthrough

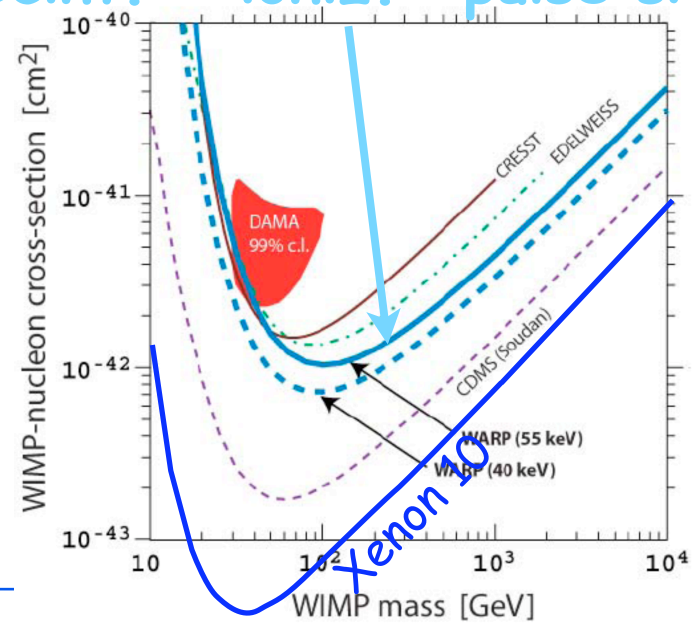
Triplet killed in nuclear recoils



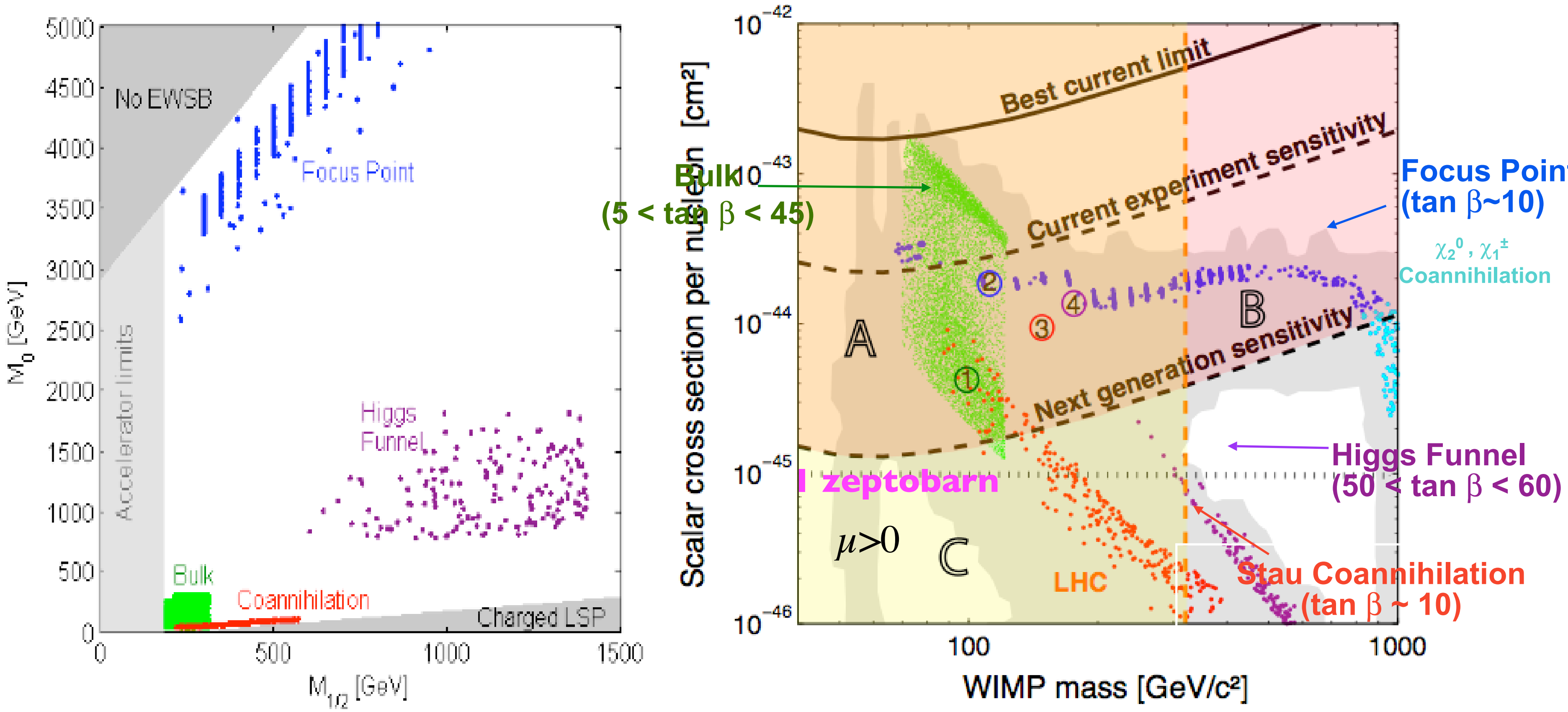
D. McKinzey

WARP: Liquid Ar

Scint. + ioniz. +pulse shape



Why 1 Zeptobarn ≡ 10^{-45} cm^2



10^{-45}cm^2 is a natural scale e.g. in mSUGRA/CMSSM (cf Roskowski et al.)

Bulk

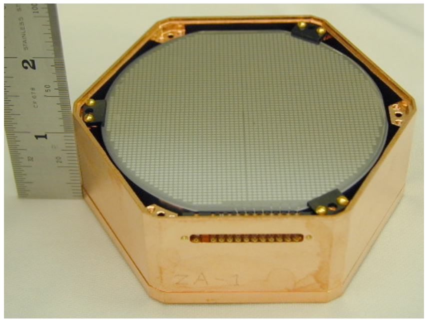
Focus point (mix of Higgsino/Bino)

The Higgs funnel and stau coannihilation are fine tuned to enhance annihilation

-> 10^{-45} cm^2/nucleon

At least 3 technologies able to go to 10^{-45} cm^2/nucleon

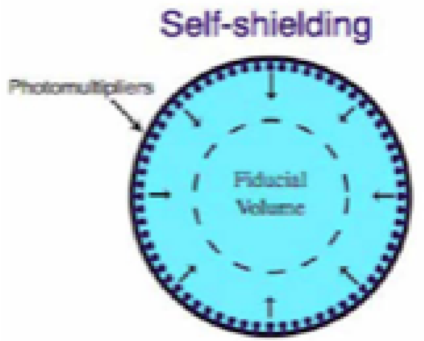
- Phonon mediated detectors
  SuperCDMS 25kg 1" detectors
  first phase approved



- 2-phase Xenon
  number of photo-electrons + reduction of reduced ionization regions
- 2 phase Argon scintillation+ionization+pulse shape
  but: Ar 39

Can we do something simpler?

Borexino/Kamland like geometry

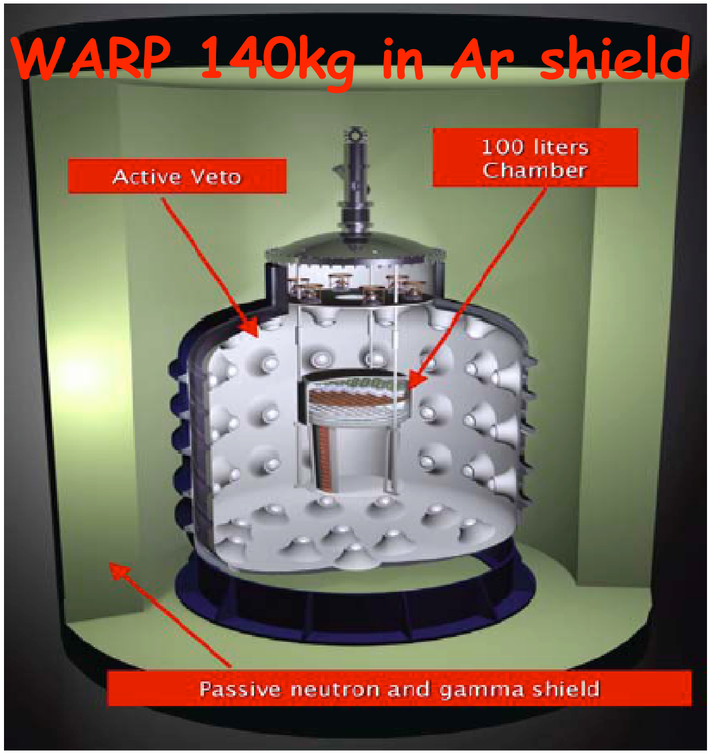


Gets better as size increases.

- single-phase Xenon (XMASS)
  use self shielding of Xe
  approved
- single phase Argon scintillation+pulse shape
  (MiniClean/DEAP) but Ar 39

Very Large masses liquid argon

WARP:
Assembly by end of 2007



ArDM:
Assembly Summer 2007

But, not enough to have large mass!

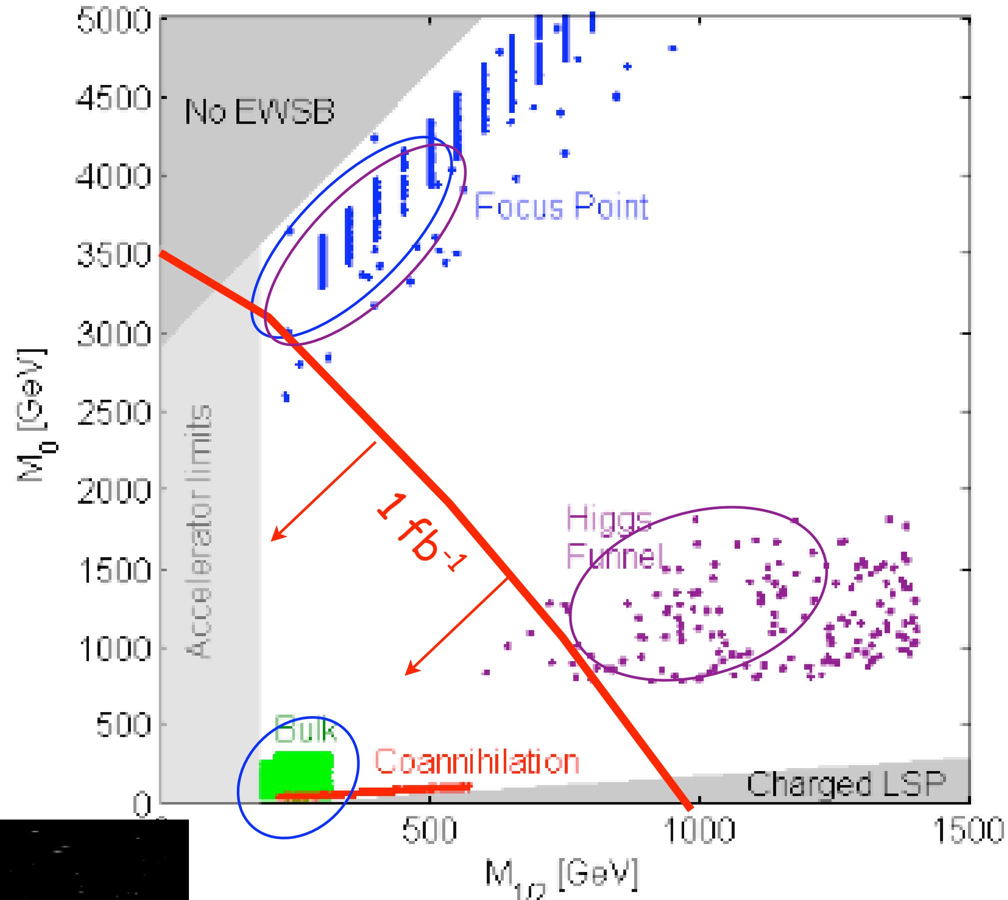
Master a complex phenomenologyy in order to
- Demonstrate discrimination close to threshold (≠Ar 39)
- Obtain good spatial reconstruction against edges
- Have proper calibration

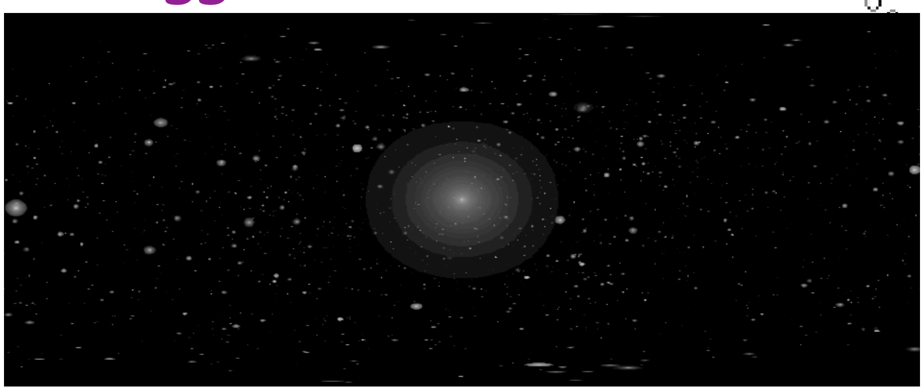
Complementarity:LHC,GLAST

Direct Detection:
- Bulk
- +Focus point

LHC
- "low energy"

GLAST
- Focus
- + Higgs funnel





Simulation of the γ ray sky from Dark Matter annihilation

Ted Baltz 2006 (Taylor/Babul)

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 $10^{-44}cm^2$ very soon (2009)
$10^{-45}cm^2$ should be reachable by
- phonon mediated detectors
- Liquid Xenon 2 phase
- Liquid Ar 2 phases+pulse shape

maybe other simpler technologies (XMASS, MiniCLEAN, COUPP)

$10^{-46-47}cm^2$ considerable challenge (1-0.1 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

We may be at the brink of discovery! B.Sadoulet, Science 315 (2007) 61