Bernard Sadoulet
Dept. of Physics /LBNL UC Berkeley
UC Institute for Nuclear and Particle
Astrophysics and Cosmology (INPAC)

Strategies for the Detection of Dark Matter

What do we know?

What have we achieved so far?

Entering interesting domain

Strategies for the future

Exciting new technologies

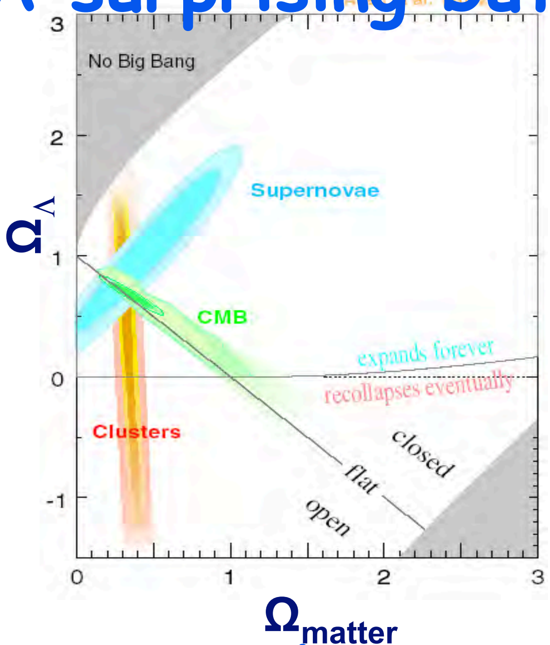
=> zero background experiments

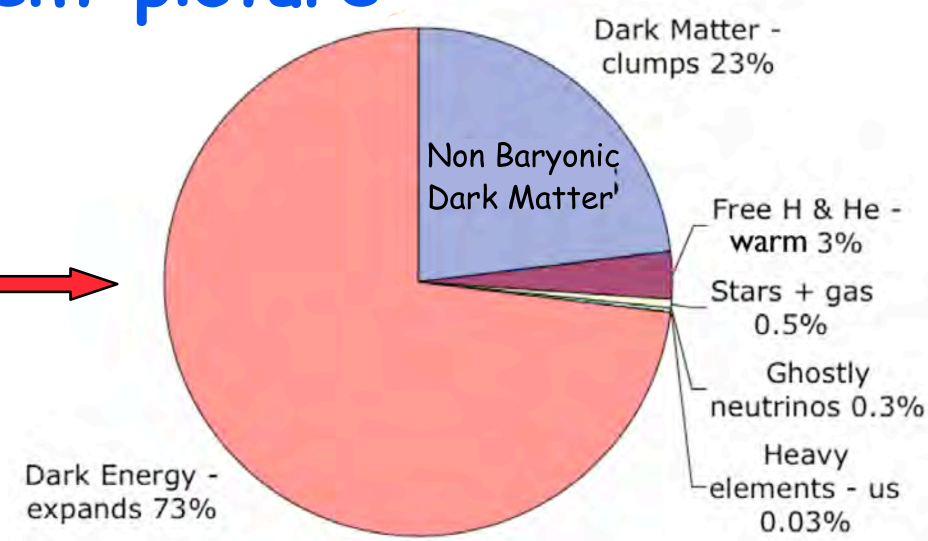
cross checking each other

+ consistency with LHC

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

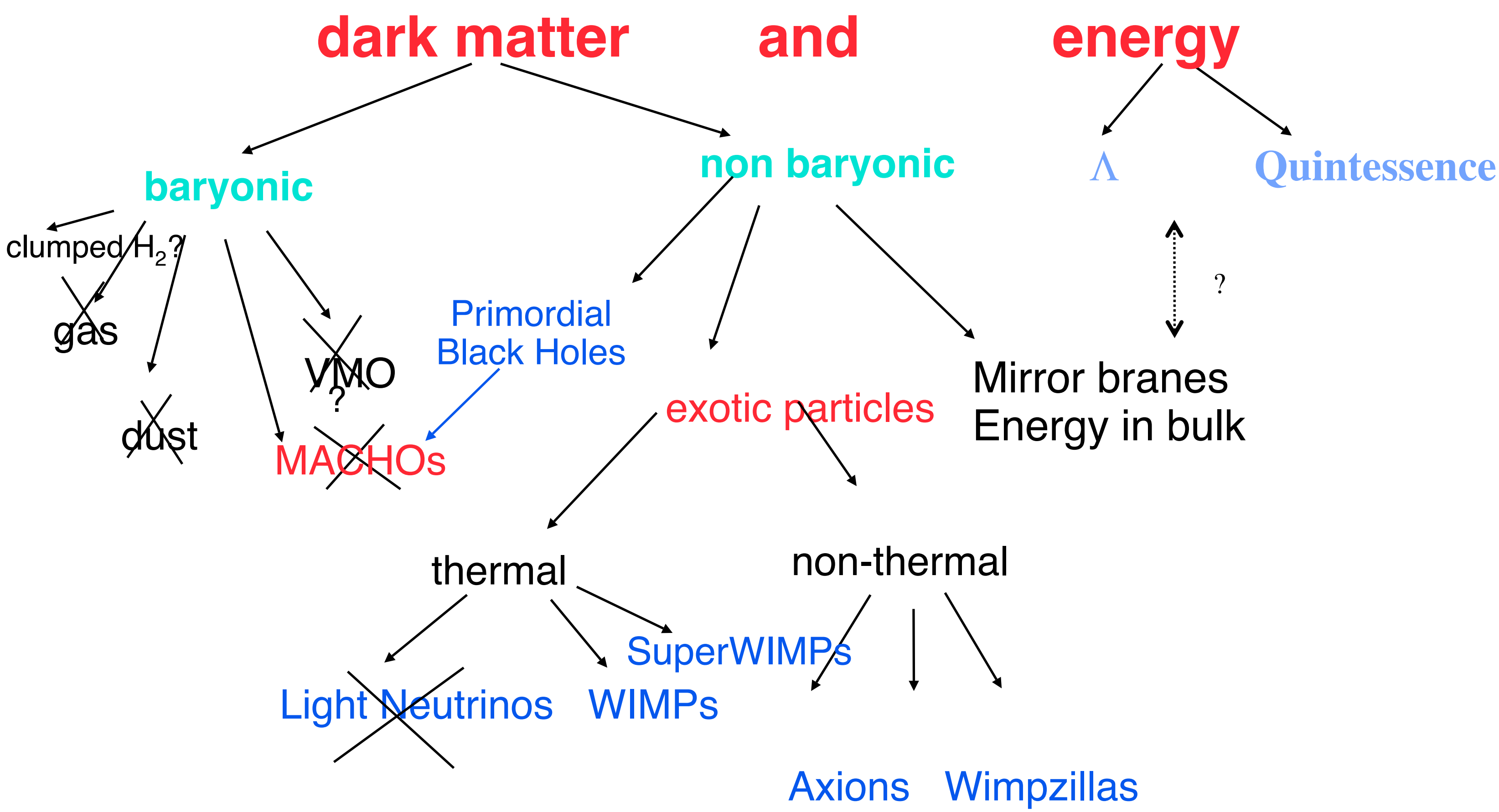
+ internally to WMAP

$\Omega_m h^2 \neq \Omega_b h^2$ ≈15 σ's

Mostly cold: Not light neutrinos ≠ small scale structure

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

Ongoing Systematic Mapping



Most baryonic forms excluded (independently of BBN, CMB)

Particles: well defined if thermal (model dependent when athermal)

Additional dimensions?

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

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

Generic

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

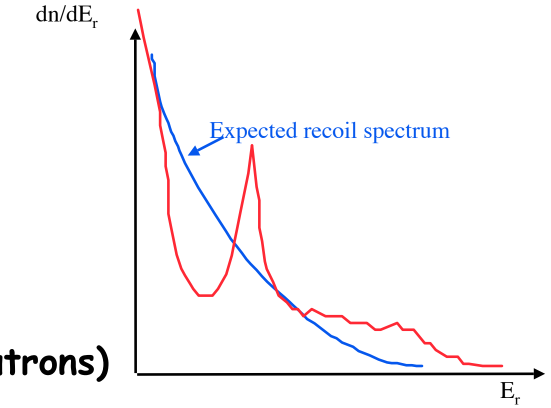
(<< radioactive background)

Small energy deposition (≈ few keV)

<< typical in particle physics

Signal = nuclear recoil (electrons too low in energy)

≠ Background = electron recoil **(if no neutrons)**



Signatures

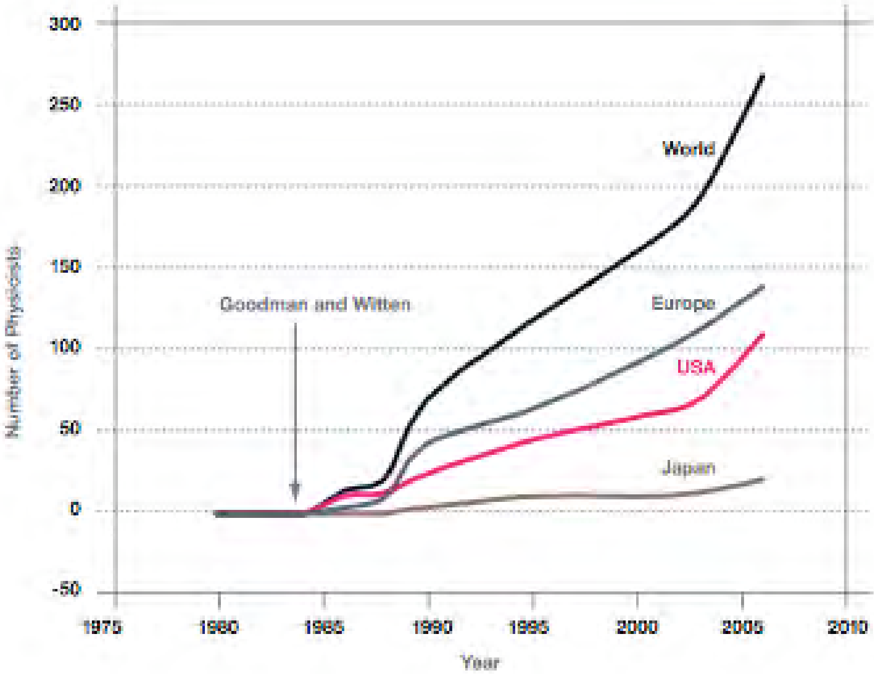
- Nuclear recoil
- Single scatter ≠ neutrons/gammas
- Uniform in detector

Linked to galaxy

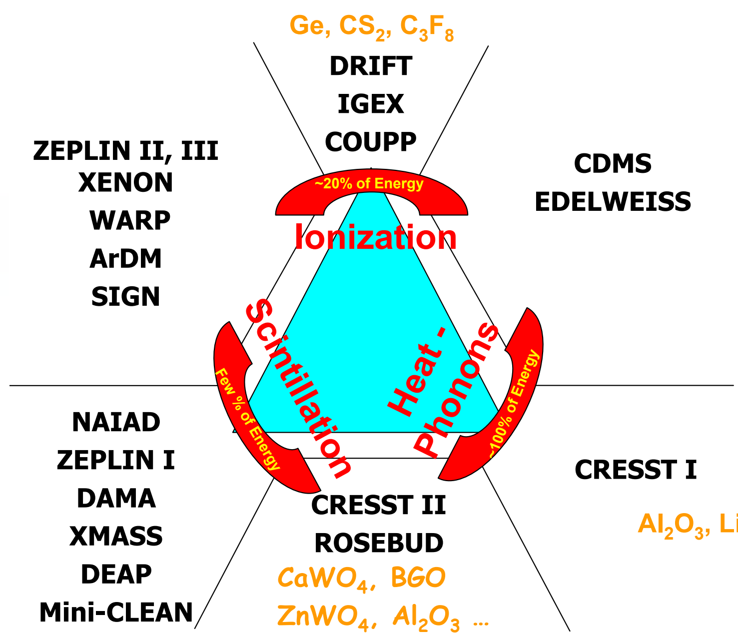
- Annual modulation (but need several thousand events)
- Directionality (diurnal rotation in laboratory but 100 Å in solids)

Experimental Approaches

A blooming field



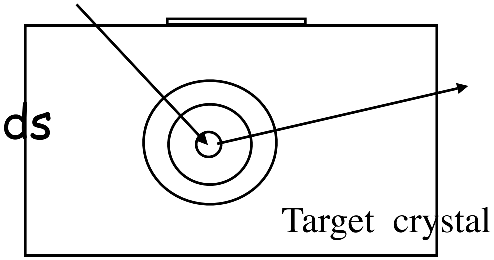
Direct Detection Techniques



As 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)

Phonon Mediated Detectors



Principle: Detect lower energy excitations

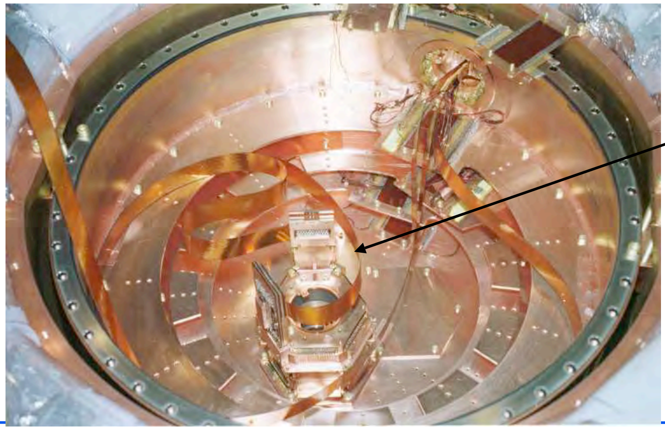
15 keV large by condensed matter physics standards

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
    - e.g. CDMS I and II
    - EDELWEISS
  - or photon (CRESST II)

But: operation at very low temperature!

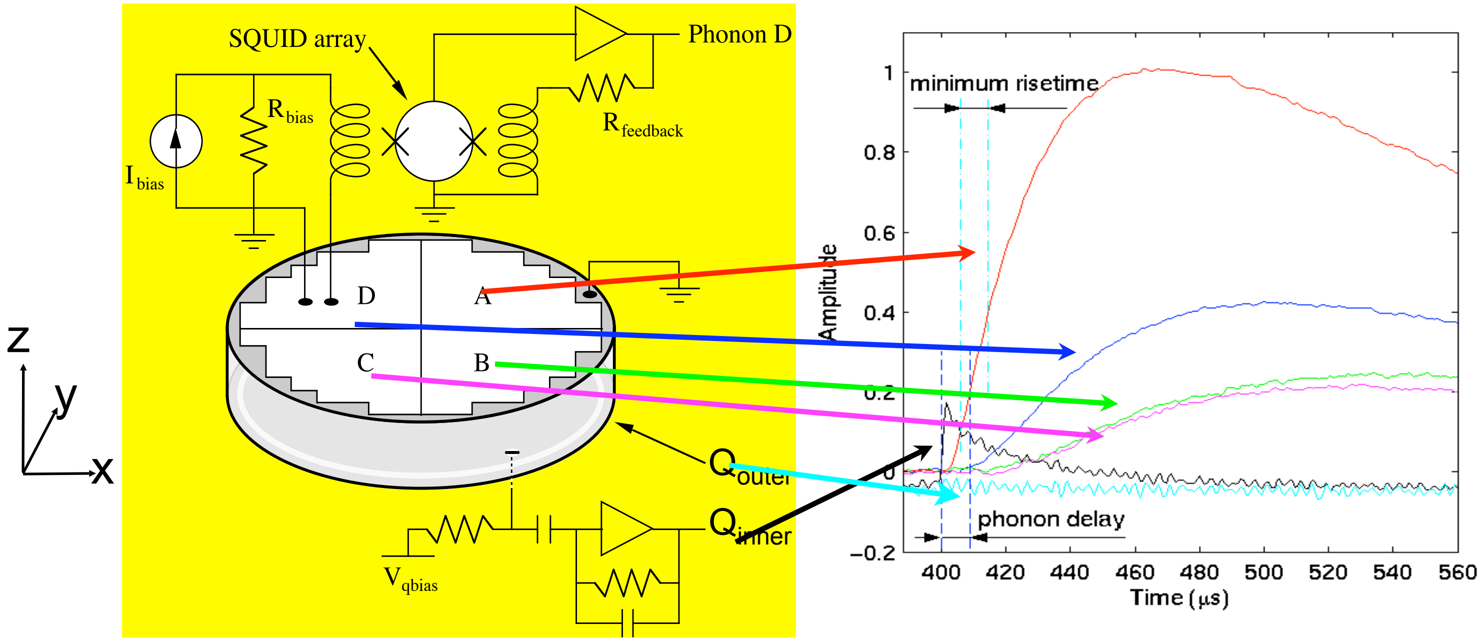
ex: CDMS I
1999



CDMS II

7.5cmØ Ge or Si disk 1cm thick @ 35mK
Athermal Phonons + ionization

=> large amount of information



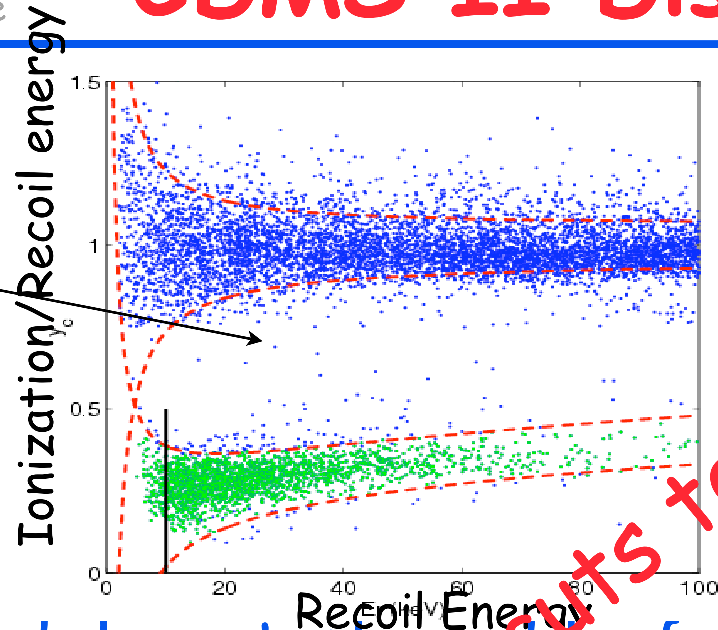
2 ionization signals (inner detector, guard)
4 phonons: Risetime and delay with respect ionization
=> 3D position of the event

In particular, in spite of "folding", proximity to the surface ≠ surface electrons

CDMS II Discrimination

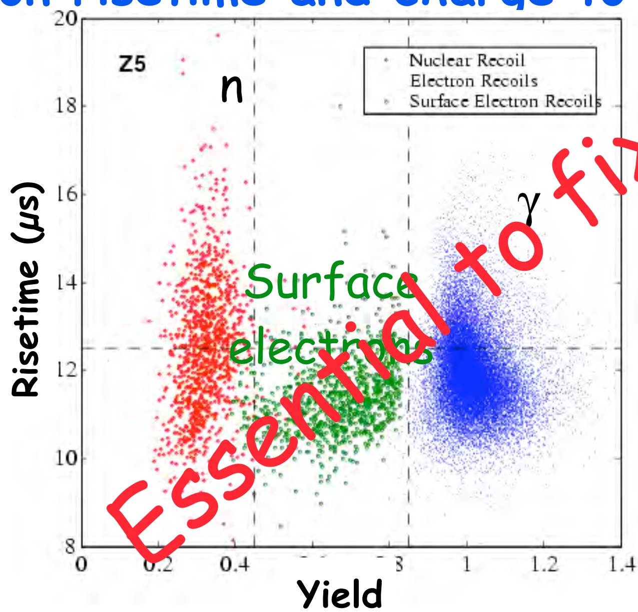
Ionization yield

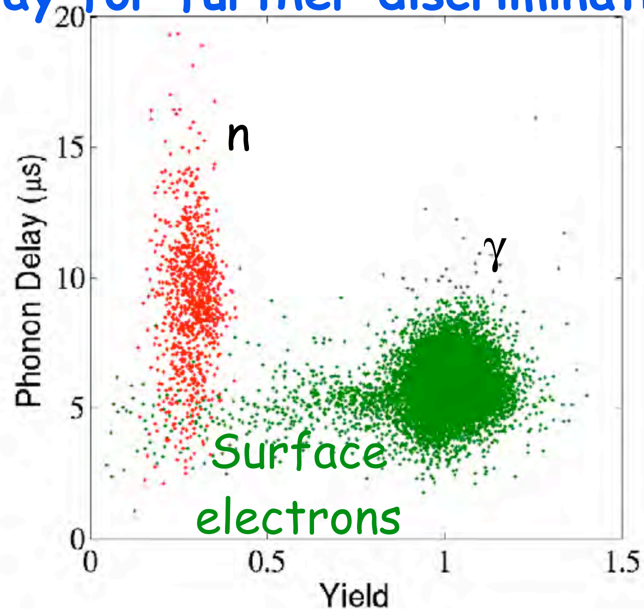
Surface Electrons



Essential to fix the cuts totally Blind

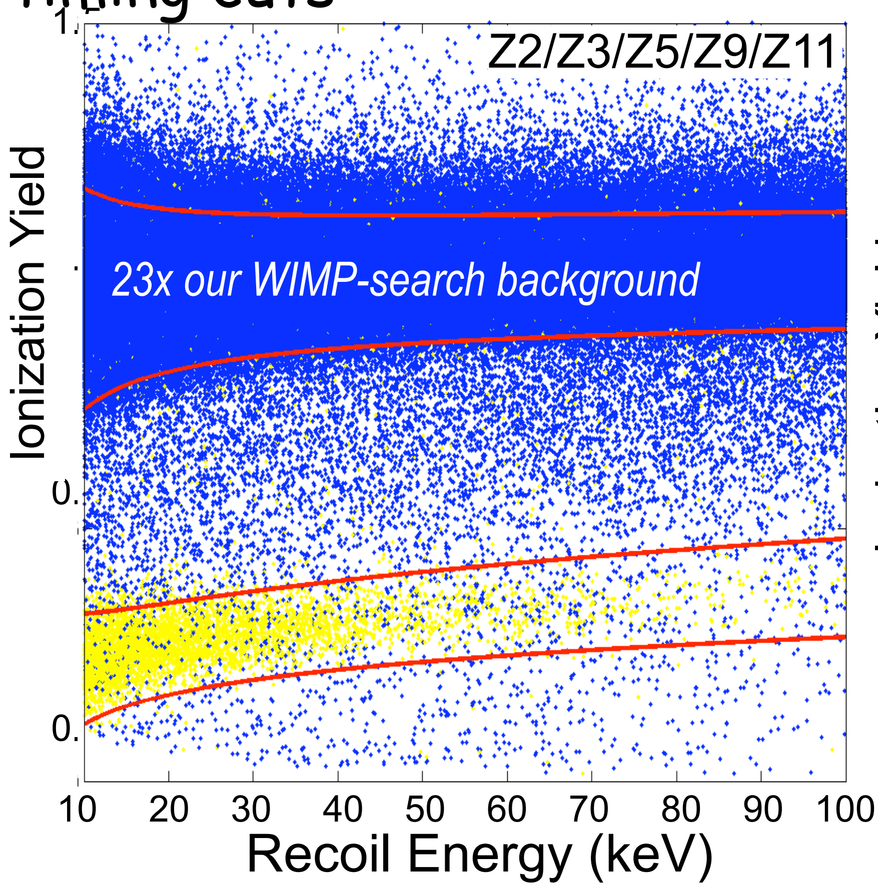
Phonon risetime and charge to phonon delay for further discrimination



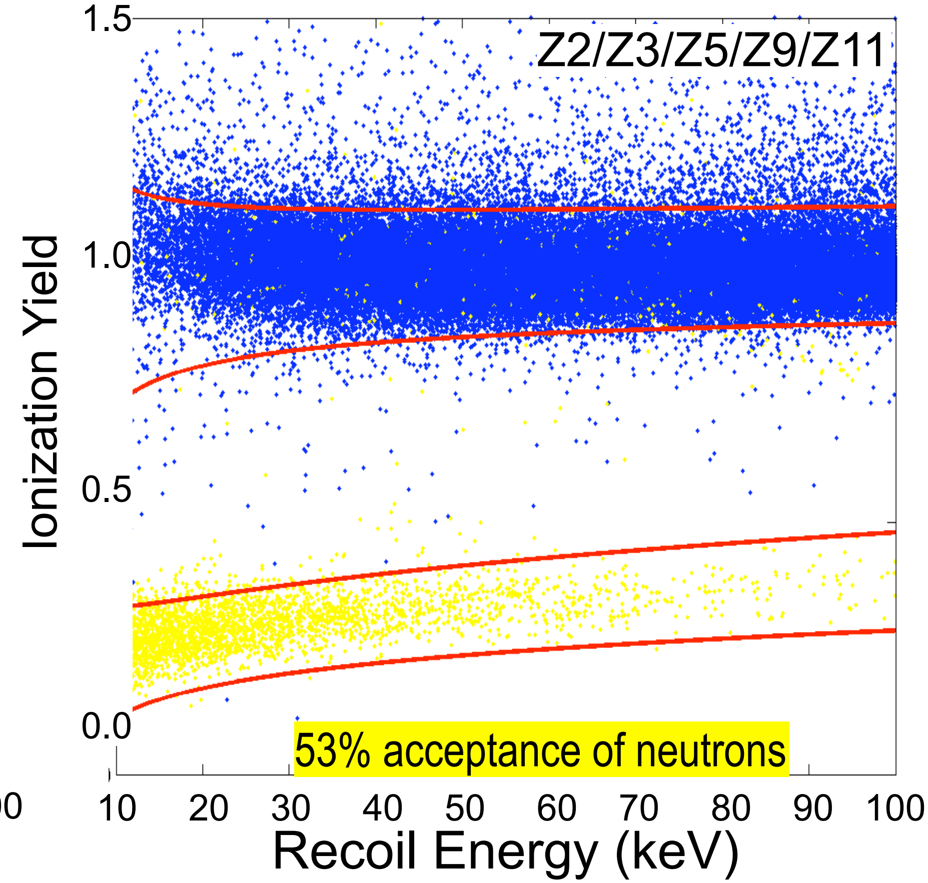


In Situ Calibrations

Calibration data, prior to timing cuts



After timing cuts



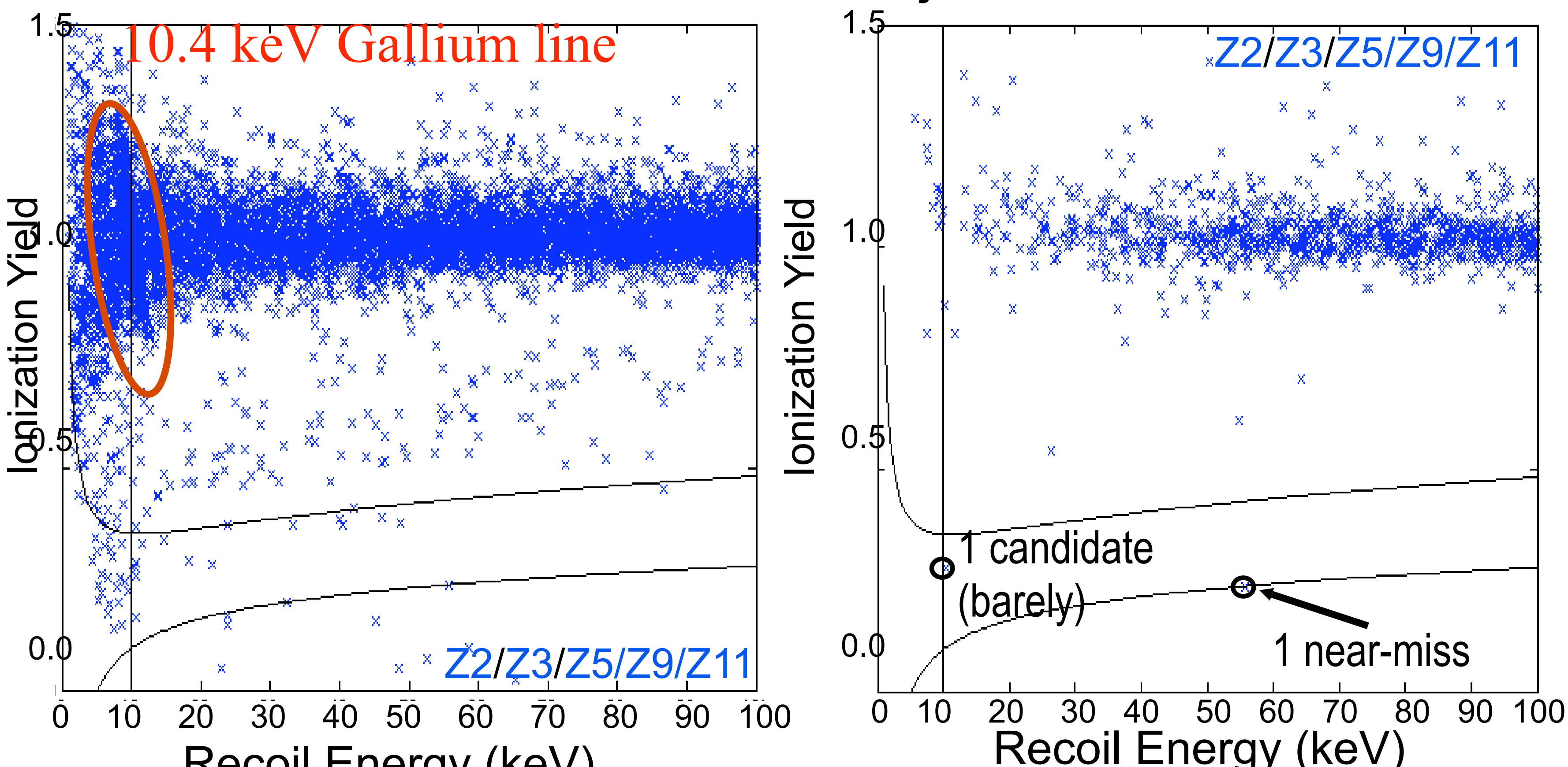
Blue points: electron recoils induced by a ^{133}Ba γ source

Yellow points: nuclear recoils induced by a ^{252}Cf neutron source

WIMP-search data

Prior to timing cuts

After timing cuts, which reject most electron recoils

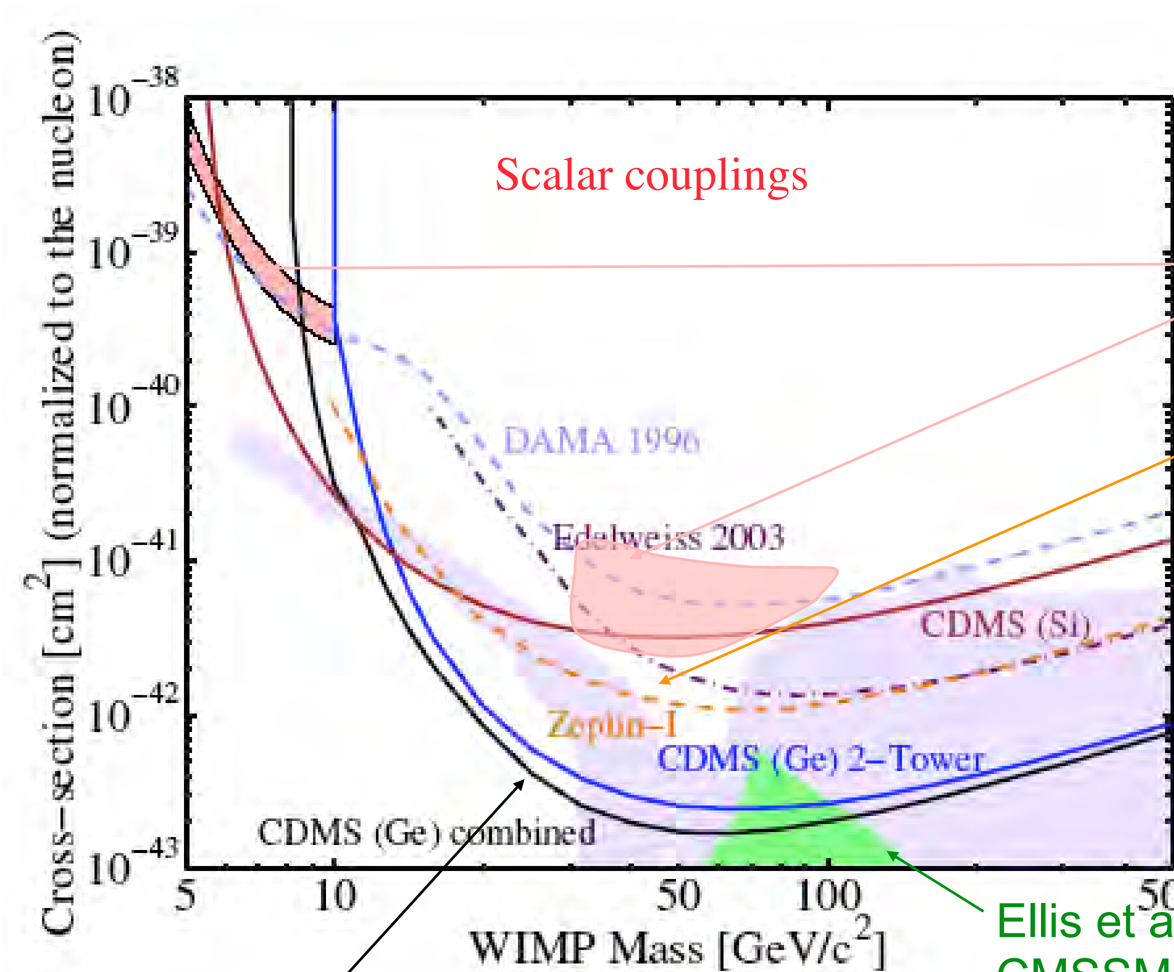


90 kg.days

34kg.days after cuts

ESTIMATE: 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 experiment

Increasing tension with DAMA who claims a signal (NaI)

Zeplin-I result in doubt astro-ph/0512120

See PRL 96 (2006) 011302

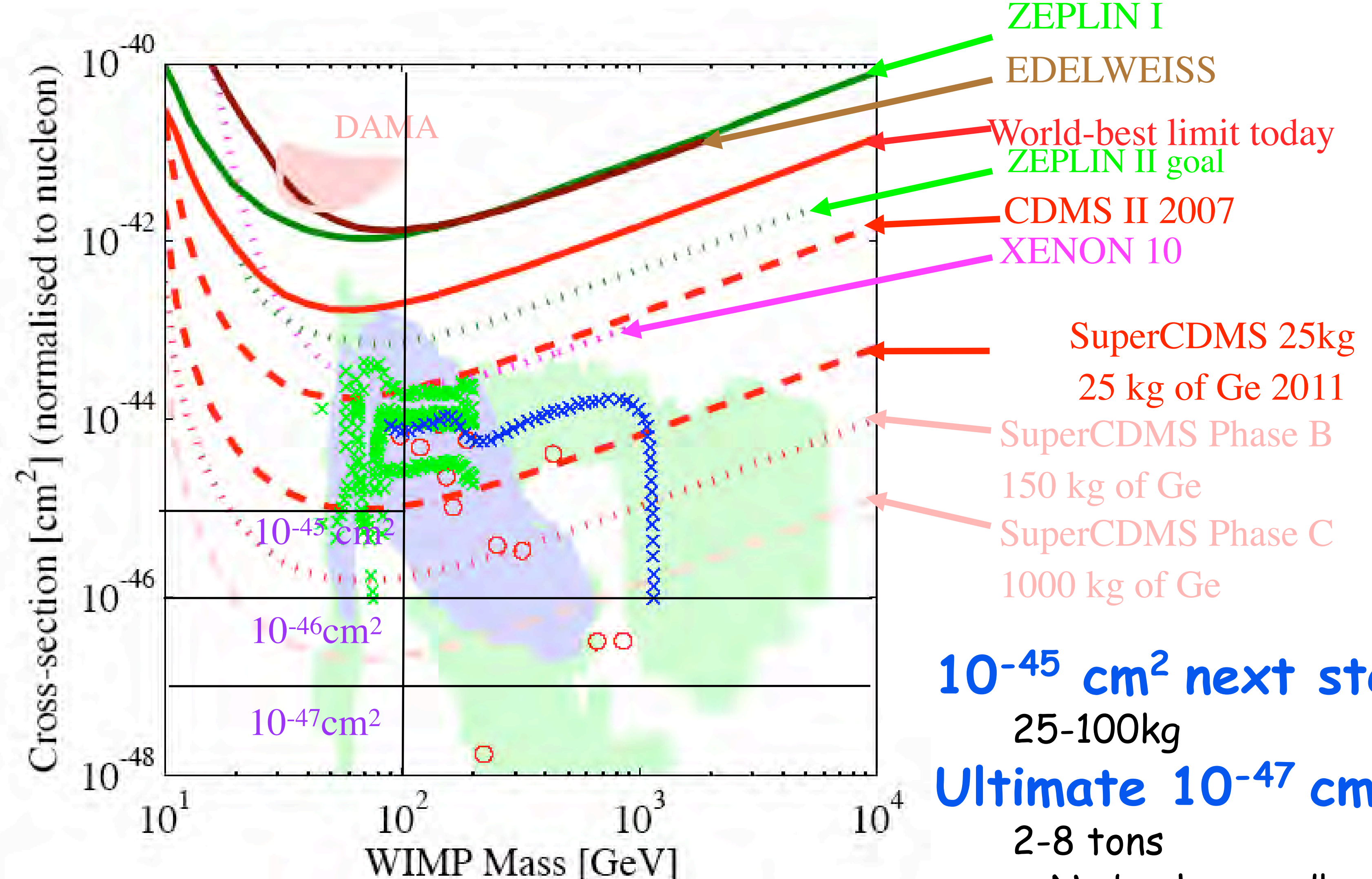
Ellis et al 2005 CMSSM

Entering in interesting territory

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

Total 53 kg.day after cut

Goals: Cover Supersymmetry



10^{-45} cm^2 next step

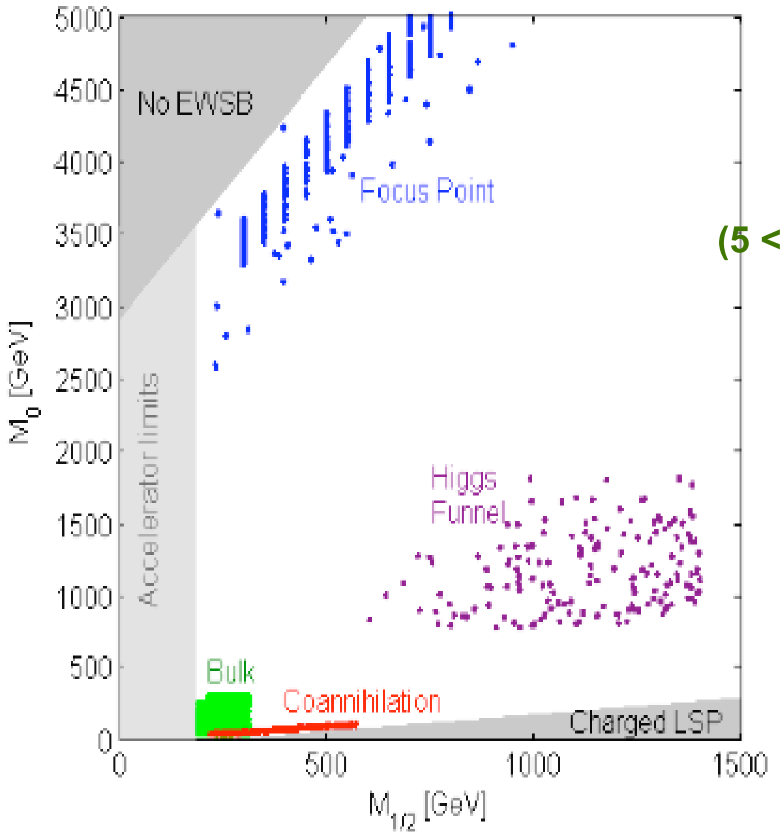
25-100kg

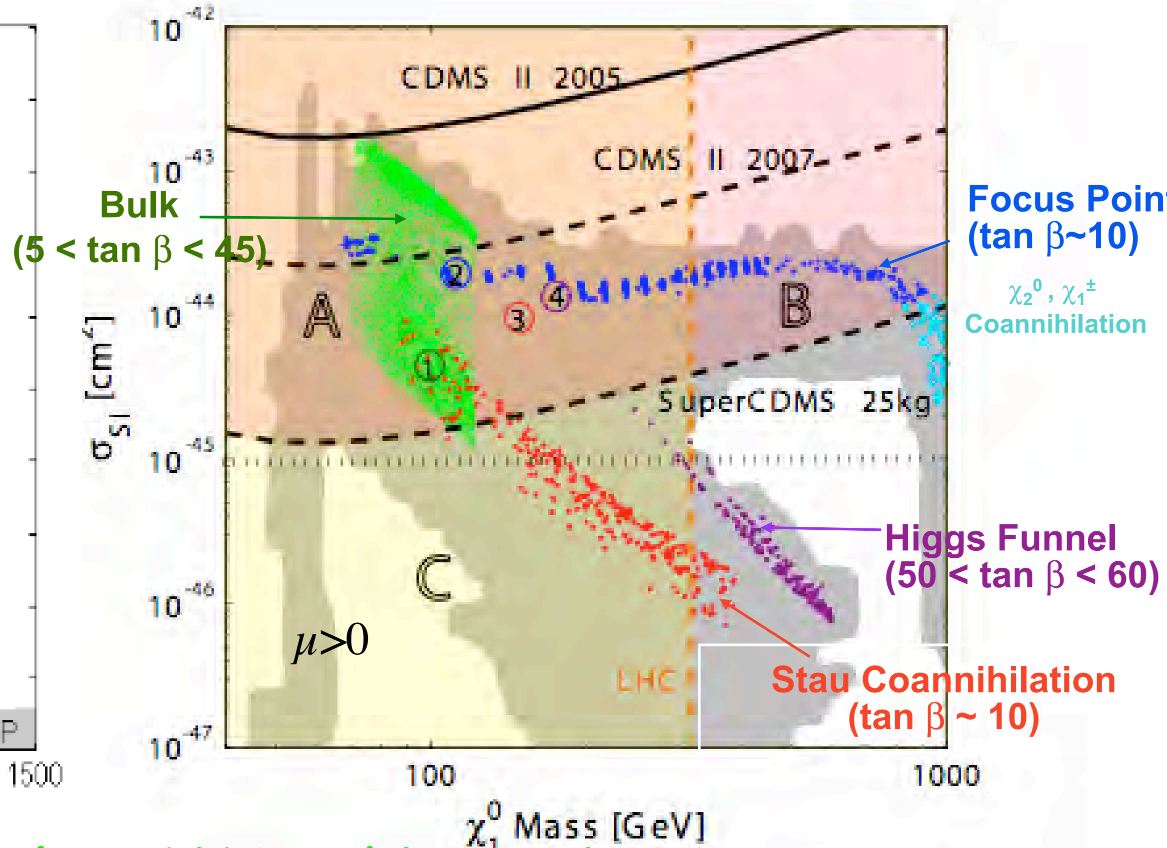
Ultimate 10^{-47} cm^2

2-8 tons

≈ No background!

Why 1 Zeptobarn ≡ 10^{-45} cm^2





Bulk region is accessible both to LHC and Direct Detection

Rich physics in region of overlap (stability, couplings)

Direct Detection can access readily Focus region

LHC has trouble above 350GeV/c^2

LHC can access low cross section but fine tuning

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

$10^{-45}cm^2$ is a natural scale

Strategies for the Future

Lessons from CDMS & Edelweiss

Search for rare events requires maximum amount of information

Large signal/noise =>efficient cut and identification of background

≠ threshold detectors (Simple, Picasso, COUPP)

- which can play useful role however for rapid exploration of large masses

Active discrimination of the background event by event:

-> zero background

≠ Statistical methods (cf. DAMA, ZEPLIN I)

≥ 2 promising technologies with

Phonon mediated detectors" phonons +ionization/scintillation

Liquid Noble Gases:Scintillation pulse shape +ionization

Other ideas: high pressure gas

Several experiments with different technologies/targets

Beware: "A background may hide another one" R&D at real scale

Importance of the physics requires cross checks

Interesting science in target comparison ≈A^2

Phonon mediated detectors

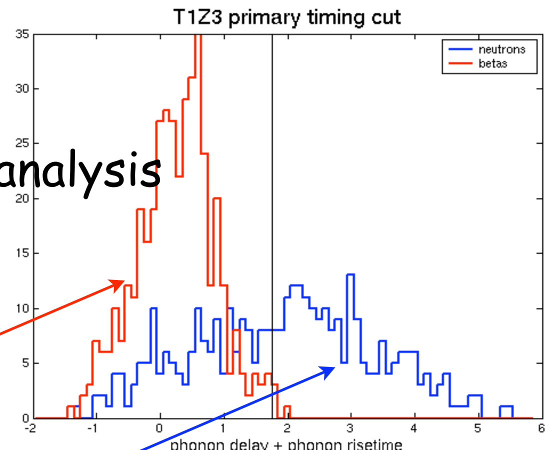
Current technology capable to go to 25kg region

Super CDMS 25kg -> 10^{-45}cm^{2}

EDELWEISS II, CRESST II -> EURECA

CDMS=large background rejection margin

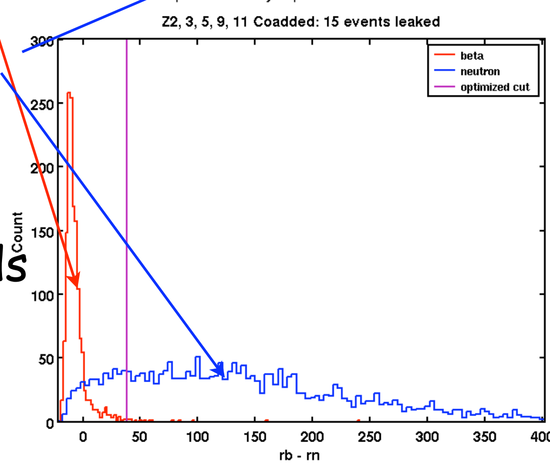
Used for PRL06 analysis



Surface events

Nuclear recoils

Current methods



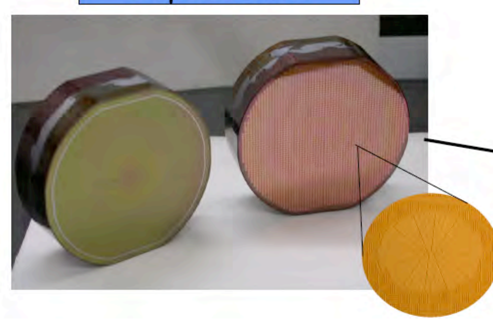
Baseline detector for SuperCDMS

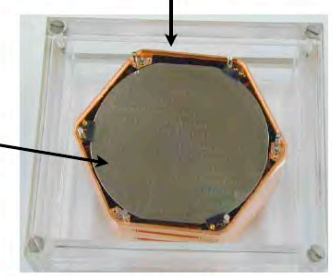
CDMS-II ZIPs:
3" dia x 1 cm => 0.25 kg of Ge

Existing ZIPs

SuperCDMS ZIPs:
3" dia x 1" => 0.64 kg of Ge

ZIPs for SuperCDMS





Completed 1" thick Si ZIP

Significant change of production testing methods -> 1 Ton

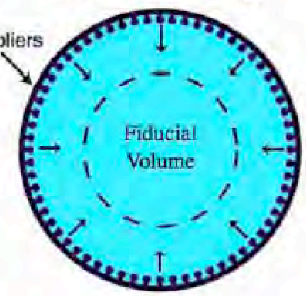
Noble Liquids 1

Single-Phase Techniques

DEAP, Mini-CLEAN, XMASS

- Pulse shape discrimination to discriminate electrons from nuclear recoils.

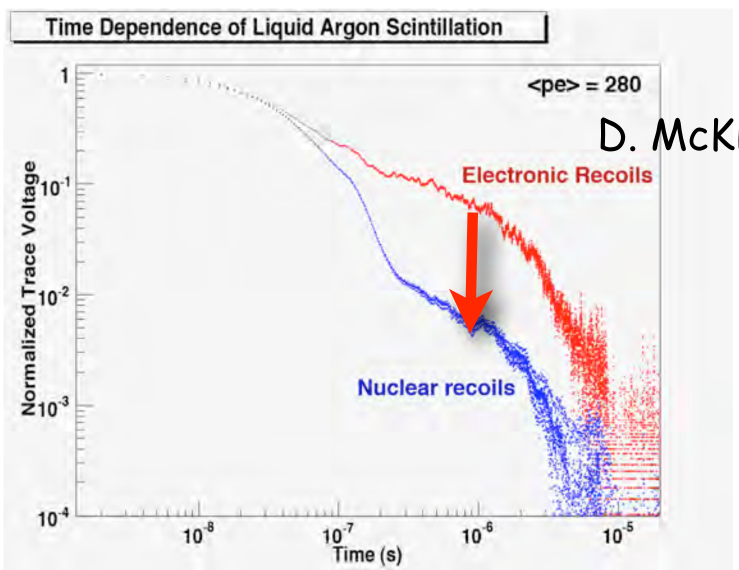
\+ Self-shielding



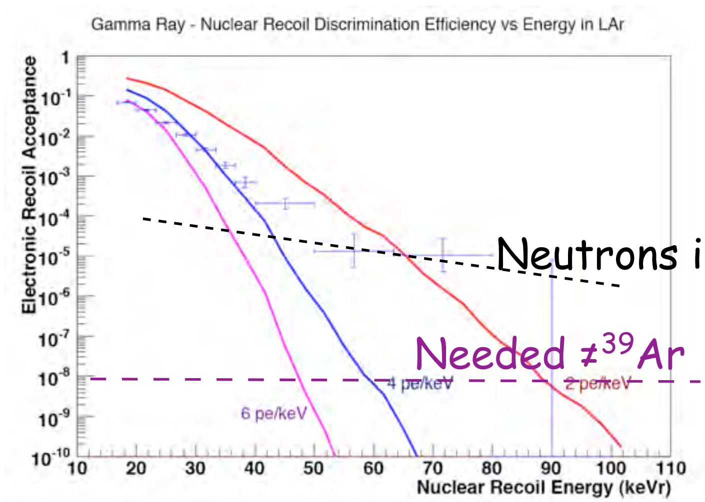
Gets better as size increases.

Recent breakthrough

Triplet killed in nuclear recoils



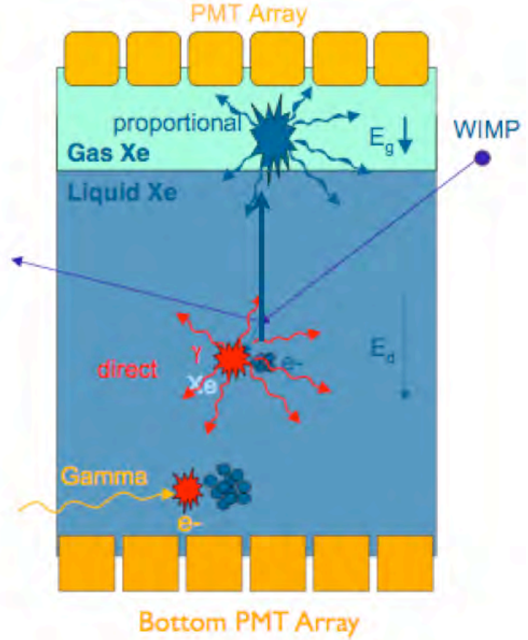
D. McKinsey

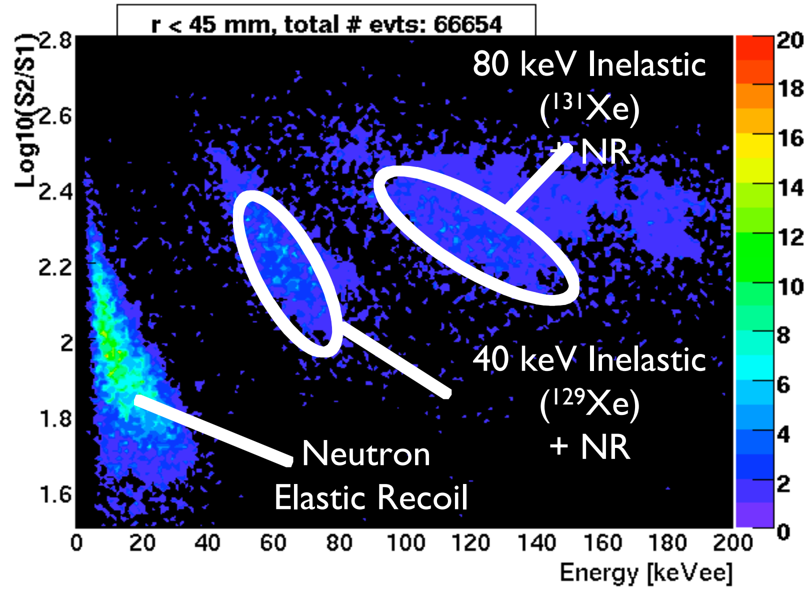


but ^{39}Ar, radial resolution (Rayleigh scattering +few photons)

Liquid Noble Gases 2

Another breakthrough: extraction of electrons from liquid

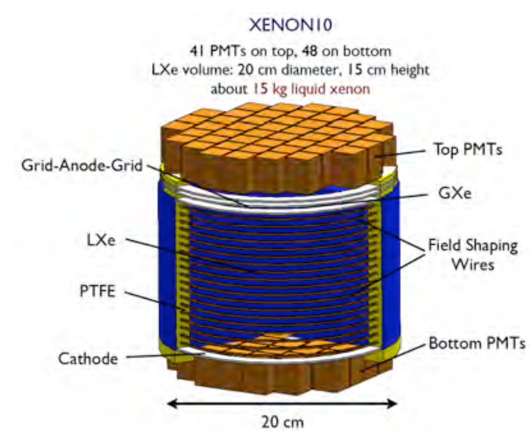




"Xenon 10":

≈ 10kg taking data: results soon!

Complex phenomenology



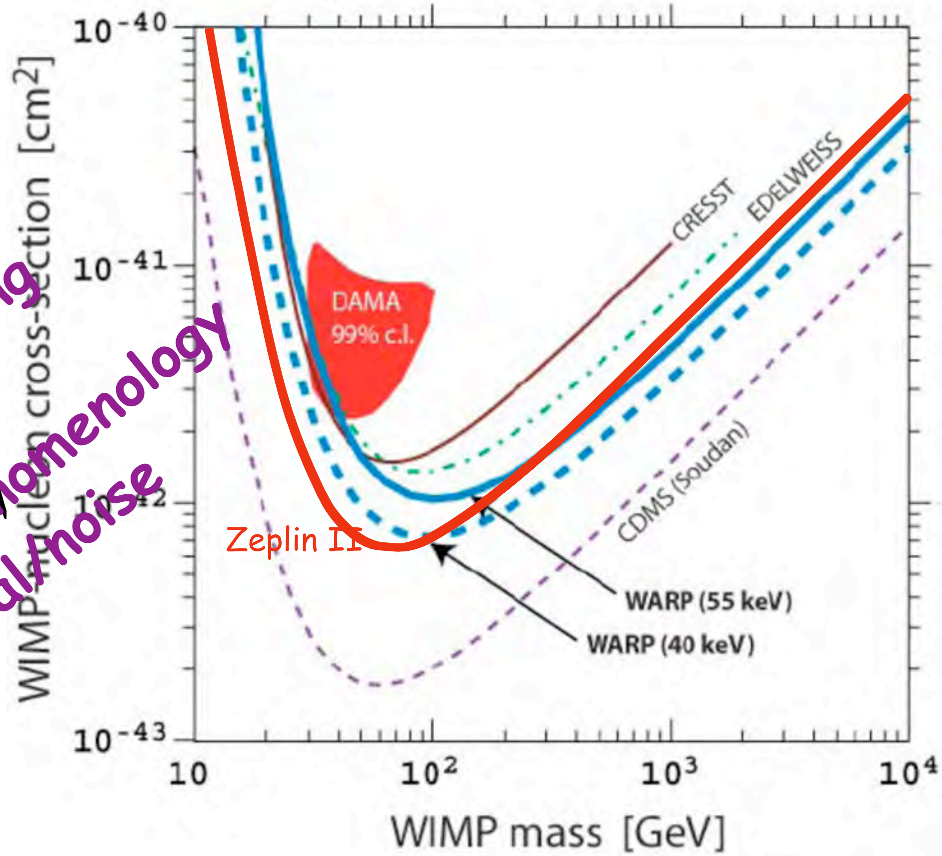
Zeplin II(result), Zeplin III

XMASS 2 phases

Liquid Noble Gases results

WARP : 2.6kgAr ionization + scintillation + pulse shape
Astro-ph/0701286

WARP prototype 97 kg days
No blind (1 event at 54 keV)
But energy scale?
- Scintillation yield still high 80%->60%
- Neutron recoil looks too steep @60keV
- 140kg module in fabrication



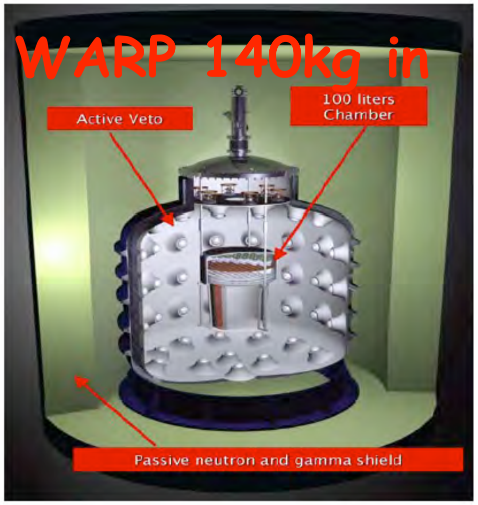
ZEPLIN II
37kg Xe ionization + scintillation
Astro-ph/0701858
1767 kg days->225 kg days

Background limited: Leakage from
- Gammas (poor S2/S1 resolution from poor photon collection)
- Rn on internal teflon reflector(radial cut ineffective at low E)

Result totally dependent on subtraction (Gaussian assumption)

Excellent progress: Encouraging
Calibration + understanding of complex phenomenology
Leakage from low signal/noise

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

Well defined roadmap for WIMP searches

Elastic scattering

- 10^{-45}cm^2 identifying event by event nuclear recoil
  Phonon mediated detectors can do it (e.g.SCDMS 25kg) +tests Noble Gas
- 10^{-46-47}cm^2 Need large mass, zero background technologies
  Liquid noble gases appears to be best complement to phonon mediated det,

When we have a discovery: link to galaxy (low pressure TPC≈5000 m^3)

Interesting role of indirect detection

GLAST could be an interesting smoking gun:
High energy neutrino from sun as probe of p spin dependent

Importance

Instrumentation (high information content)
≥2 technologies (Technical risk, Cross check, A^2 dependence)
Take full advantage of complementary information (LHC,GLAST,HE solar ν's)

CDMS II

The CDMS Collaboration

<u>Brown University</u>
M.J. Attisha, **R.J. Gaitskell**, J-P. F. Thompson

<u>Case Western Reserve University</u>
D.S. Akerib, C.N. Bailey, M.R. Dragowsky,
R. Hennings-Yeomans, R.W.Schnee

<u>University of Colorado at Denver</u>
M. E. Huber

<u>Fermi National Accelerator Laboratory</u>
D.A. Bauer, R. Choate, M.B. Crisler,
M. Haldeman, D. Holmgren, B. Johnson,
W.Johnson, M. Kozlovsky, D. Kubik, L. Kula,
B. Lambin, S. Morrison, S. Orr, E. Ramberg,
R.L. Schmitt, J. Williams

<u>Santa Clara University</u>
B.A. Young

<u>Stanford University</u>
P.L. Brink, **B. Cabrera**, J. Cooley, M. Kurylowicz,
L. Novak, R. W. Ogburn, M. Pyle, A. Tomada

<u>University of California, Berkeley</u>
M. Daal, J. Alvaro-Dean, **J. Filippini**, P.Meunier,
N. Mirabolfathi, **B. Sadoulet**, D.N.Seitz, B. Serfass,
G. Smith, K. Sundqvist

<u>University of California, Santa Barbara</u>
R. Bunker, D.O. Caldwell, D. Callahan, R.Ferril,
R. Mahapatra, J.May, **H. Nelson**, R. Nelson,
J. Sander, S.Yellin

<u>University of Florida, Gainesville</u>
L. Baudis, L. Camarota, I. Diaz, S. Leclercq,
T. Saab

<u>University of Minnesota</u>
J. Beaty, **P. Cushman**, L. Duong, X. Qiu,
A. Reisetter

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