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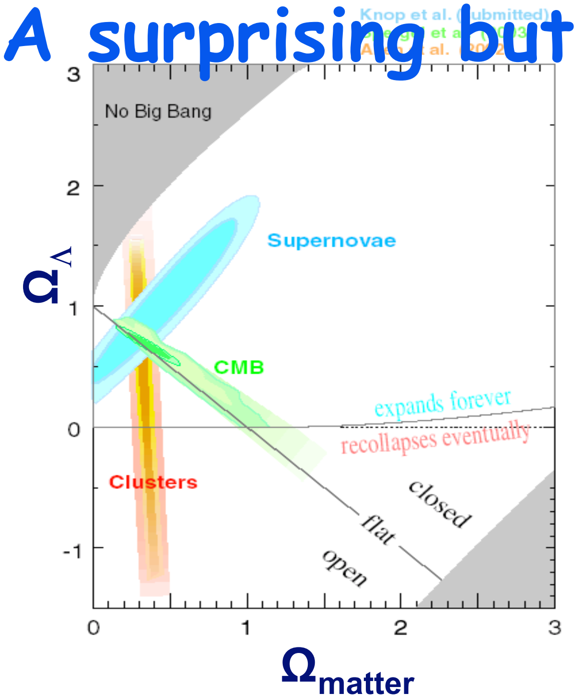
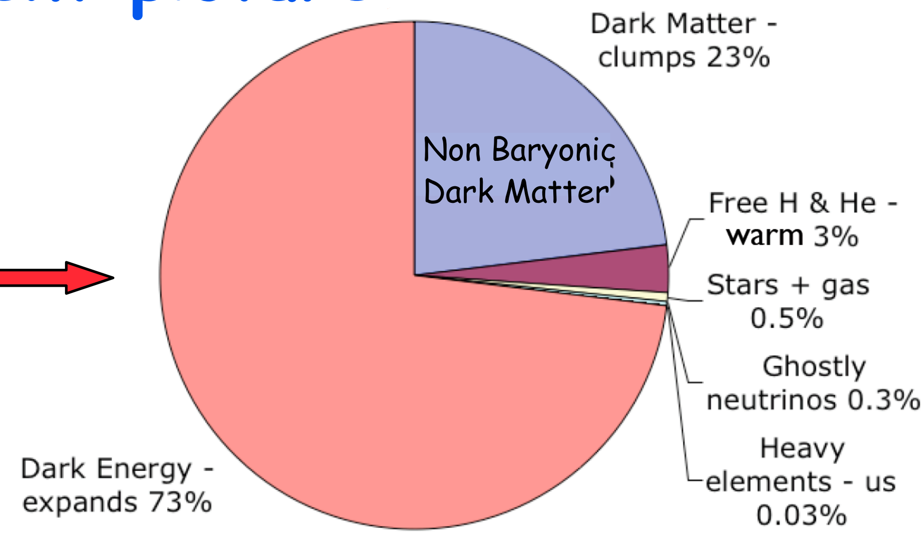
Strategies for the Detection of Dark Matter

What do we know?
What have we achieved so far?
Strategies for the future

Standard Model of Cosmology

A surprising but consistent picture





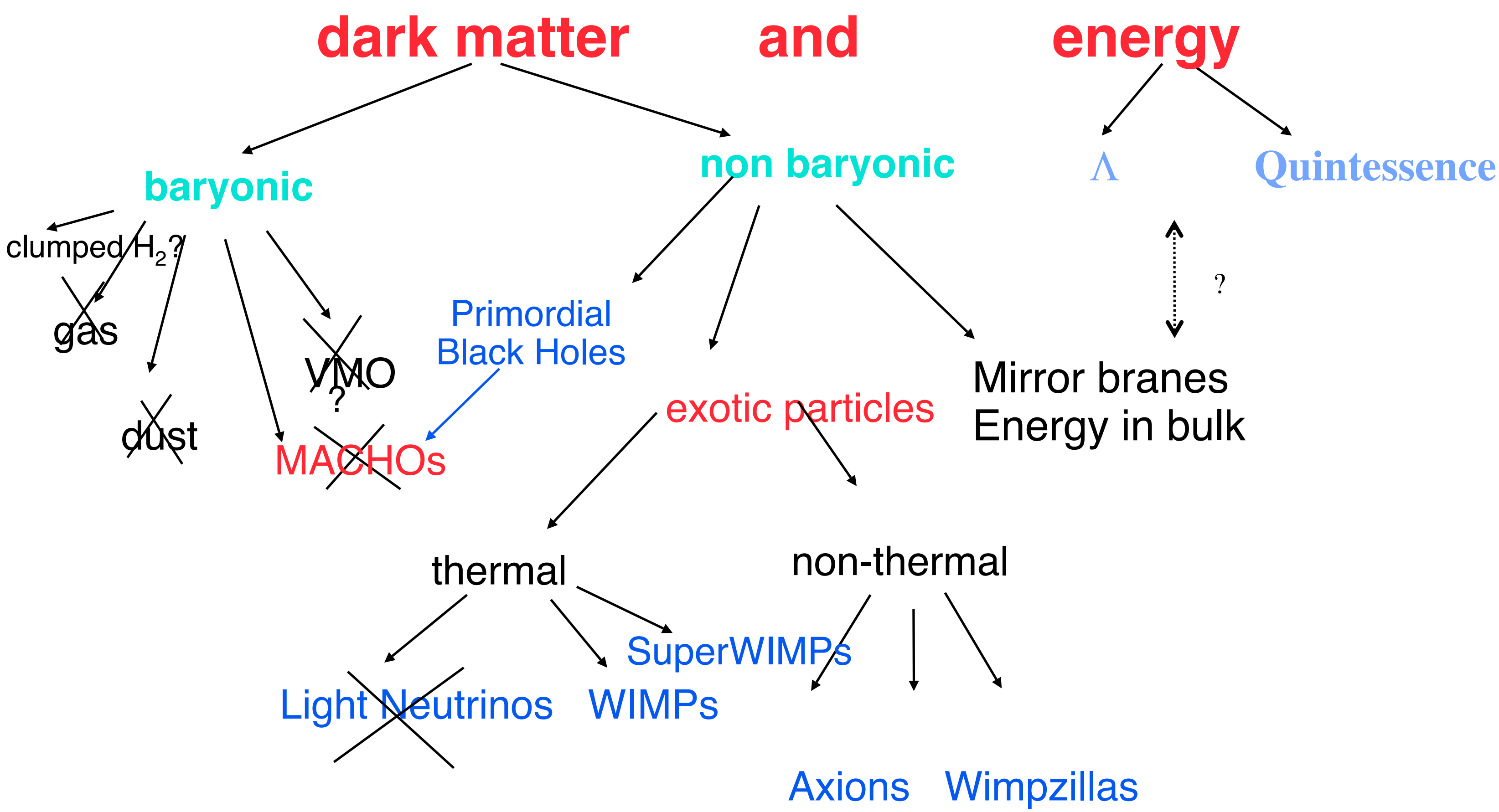
Not ordinary matter (Baryons)

$$\Omega_m >> \Omega_b = 0.047 \pm 0.006 \text{ from} \left| \begin{array}{l} \text{Nucleosynthesis} \\ \text{WMAP} \end{array} \right.$$

Mostly cold: Not light neutrinos ≠ small scale structure

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

Ongoing Systematic Mapping



Most baryonic forms excluded (independently of BBN, CMB)

Particles: well defined if thermal (difficult 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?

New result by PVLAS (Zavattini et al.) 1-1.5 10^{-3} eV $M_{PQ} \approx$ 2-6 10^{5} GeV very low!

would need a way to escape Giant limits

very small experimental effect

Gravity is not included and we do not understand vacuum energy

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

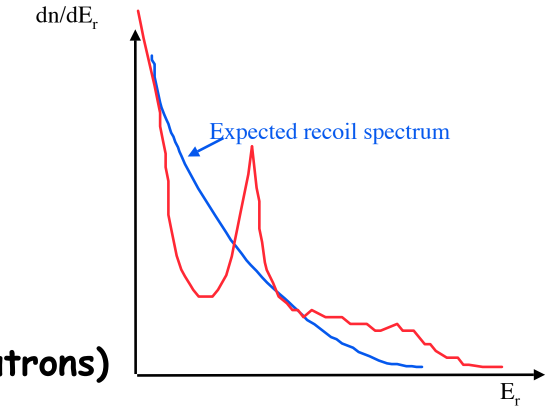
Indirect: Annihilation products

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

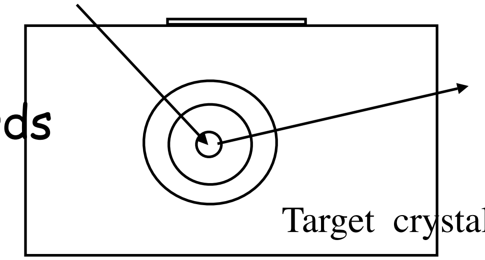
Linked to galaxy

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

An example

Phonon mediated detectors
CDMS: my own experiment, best sensitivity at the moment
cf. Elena Aprile's talk

Phonon Mediated Detectors



Principle: Detect lower energy excitations

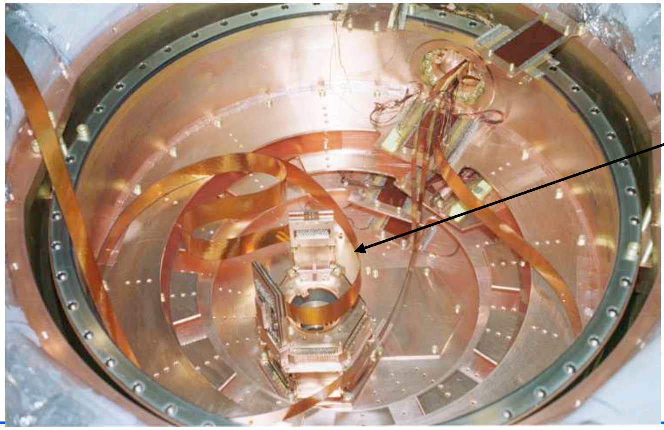
15 keV large by condensed matter physics standards

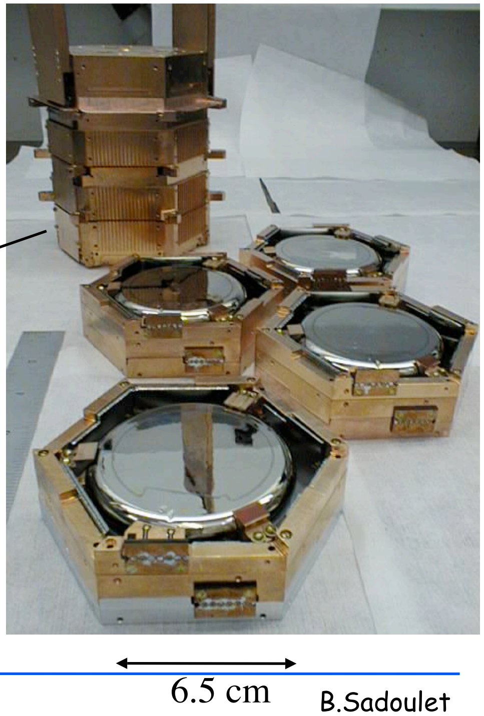
Goals

- 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





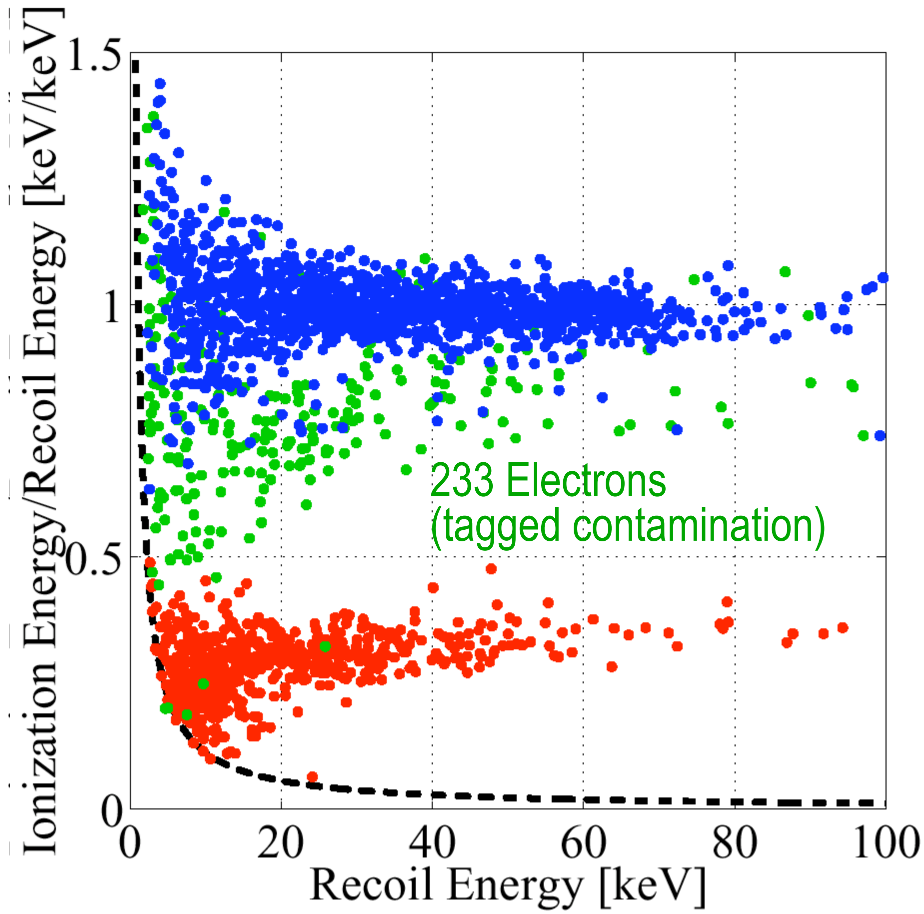
CDMS Background Discrimination

It works!

Use Ionization Yield (ionization energy per unit recoil energy) to reject the background

But

Particles (electrons) that interact in surface "dead layer" of detector result in reduced ionization yield



CDMS II

The CDMS Collaboration

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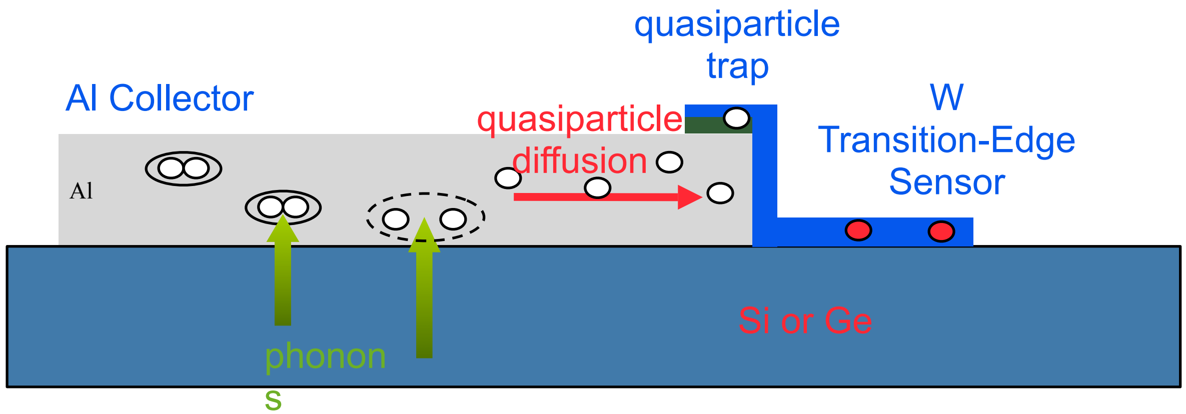
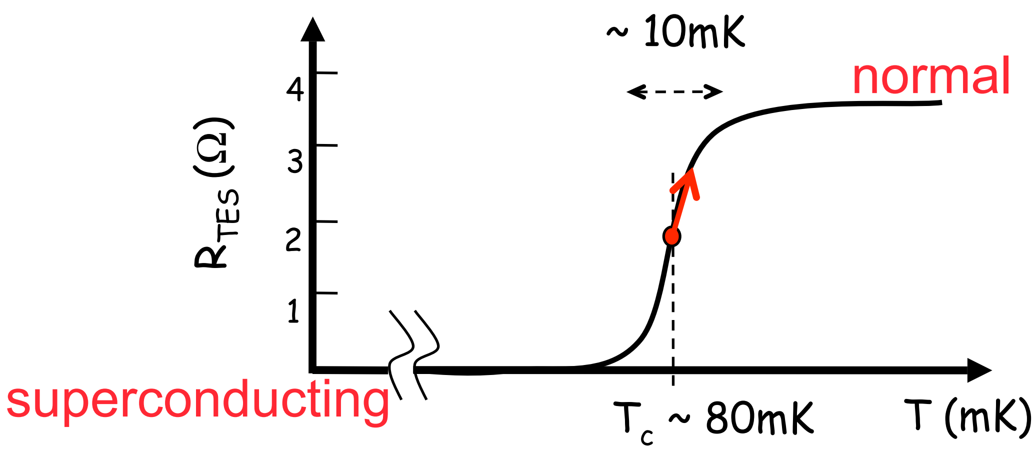
Athermal Phonon Sensor Technology



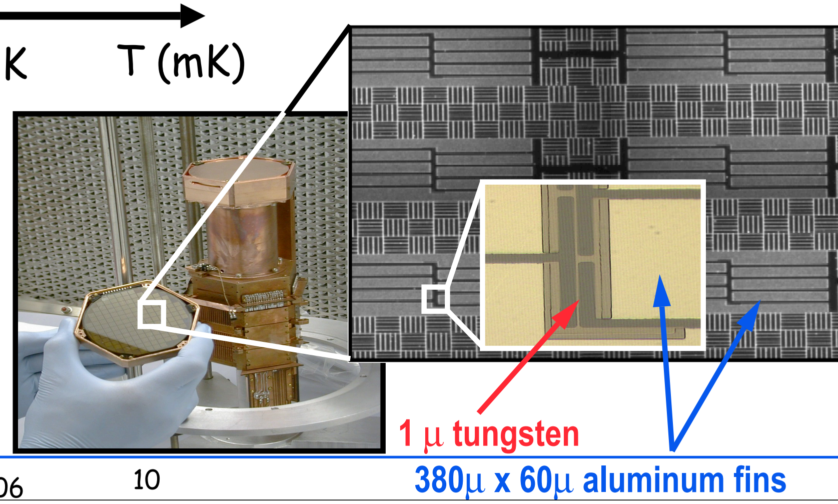
Measurement of athermal phonon signals maximizes information



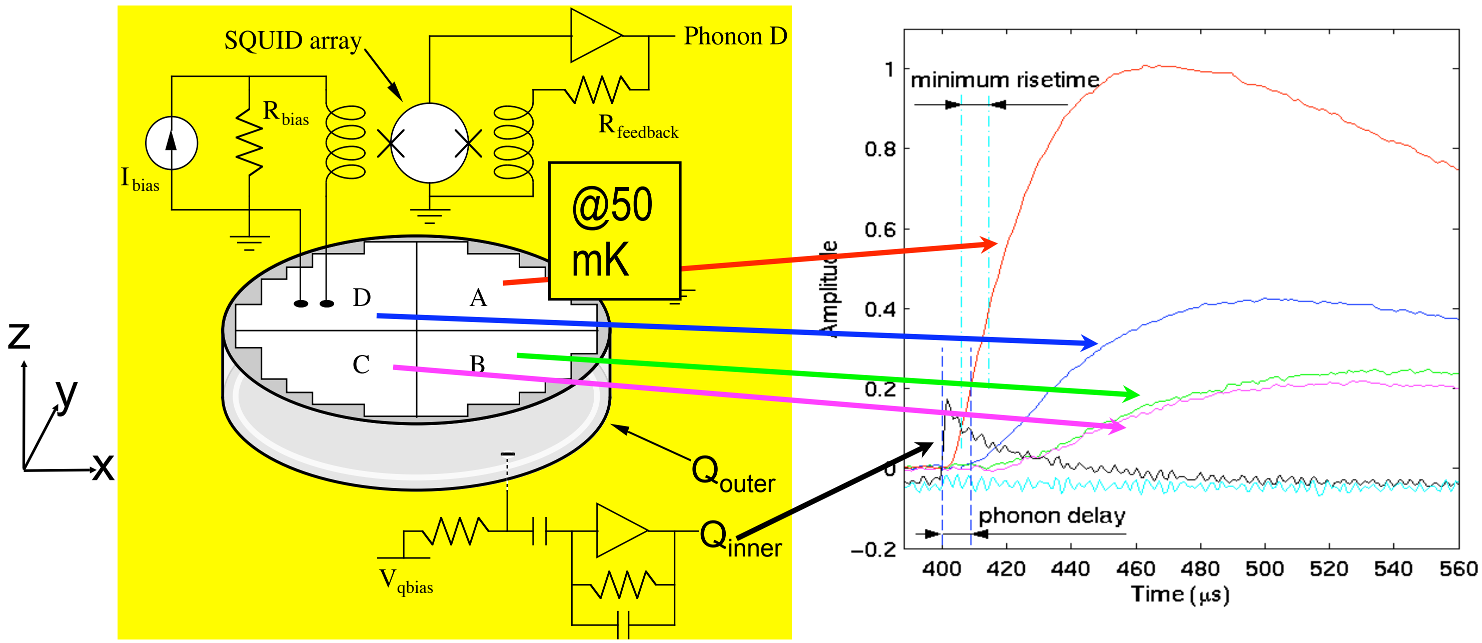
Voltage biased W Transition-Edge Sensor

1µ photolythography

3"Ø, 1cm thick



Large Amount of information



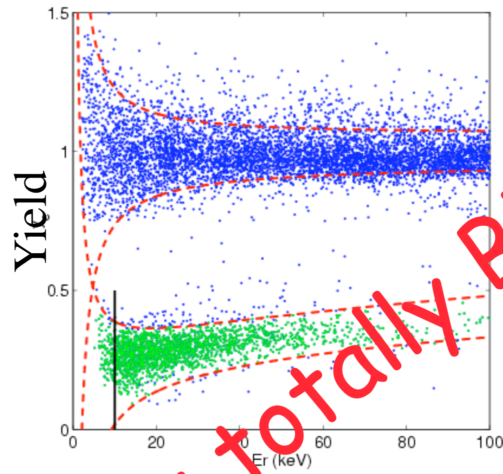
2 ionization signals (inner detector, guard)

4 phonons: Risetime and delay with respect ionization

gives information about the 3D position of the event, in particular the proximity to the surface

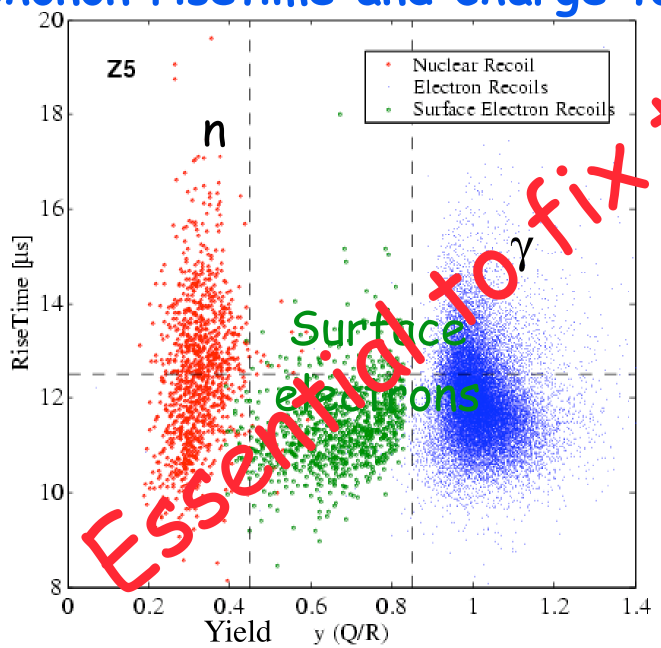
Athermal Phonon Advantage

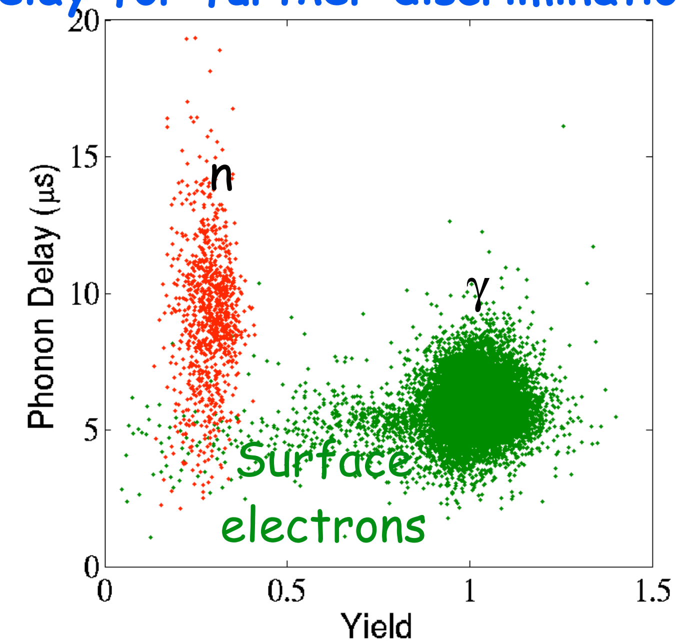
In addition to ionization yield



Use phonon risetime and charge to phonon delay for further discrimination

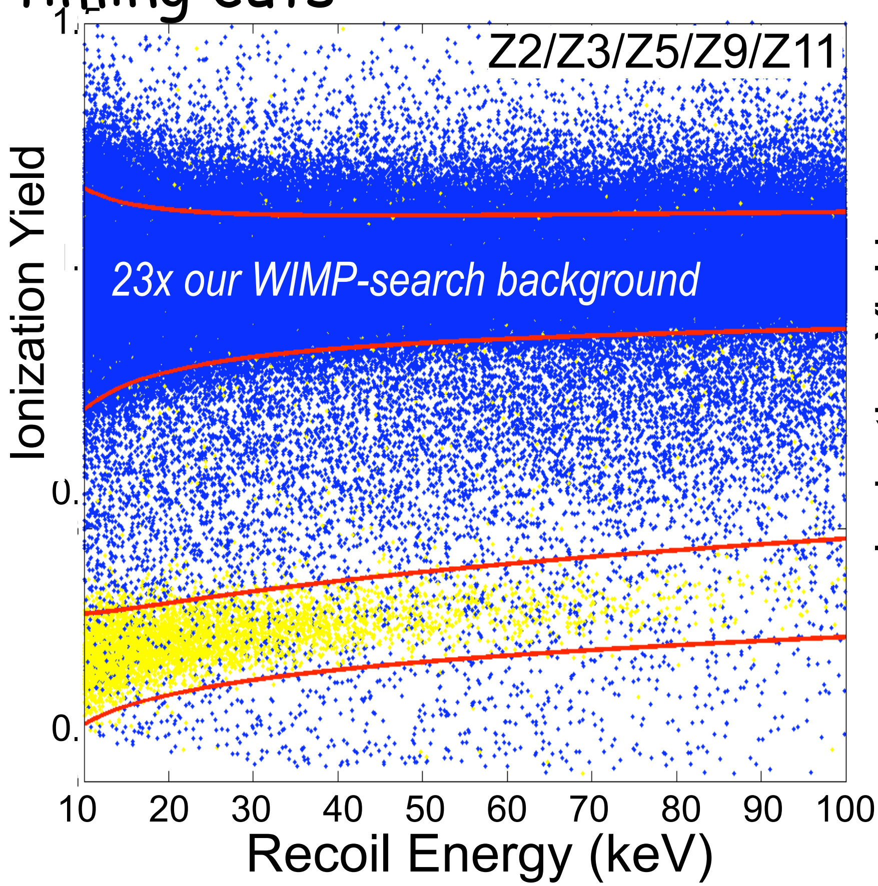
Essential to fix the cuts totally Blind



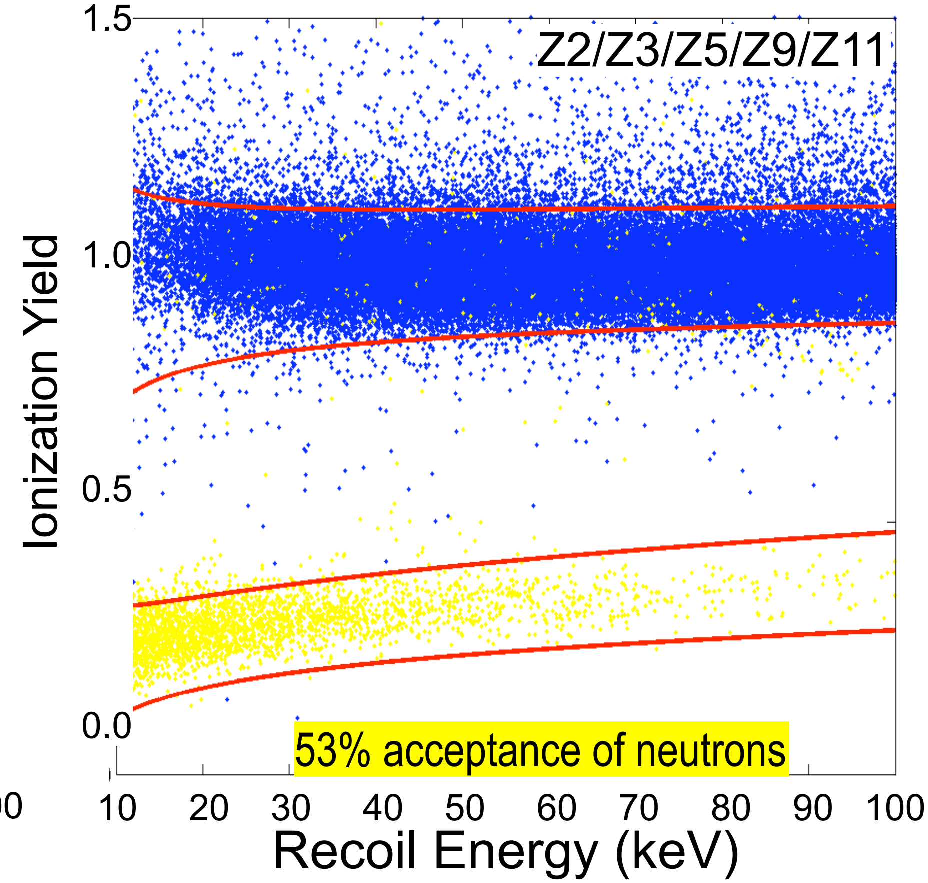


In Situ Calibrations

Calibration data, prior to timing cuts



After timing cuts

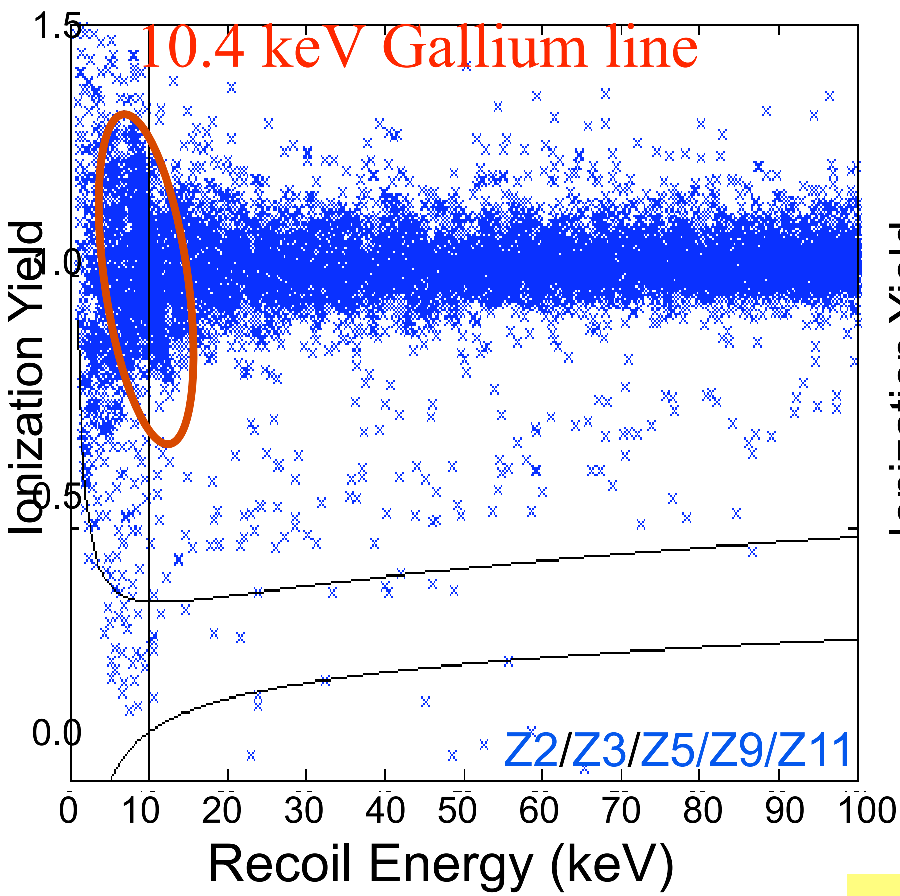


Blue points: electron recoils induced by a ^{133}Ba γ source

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

WIMP-search data

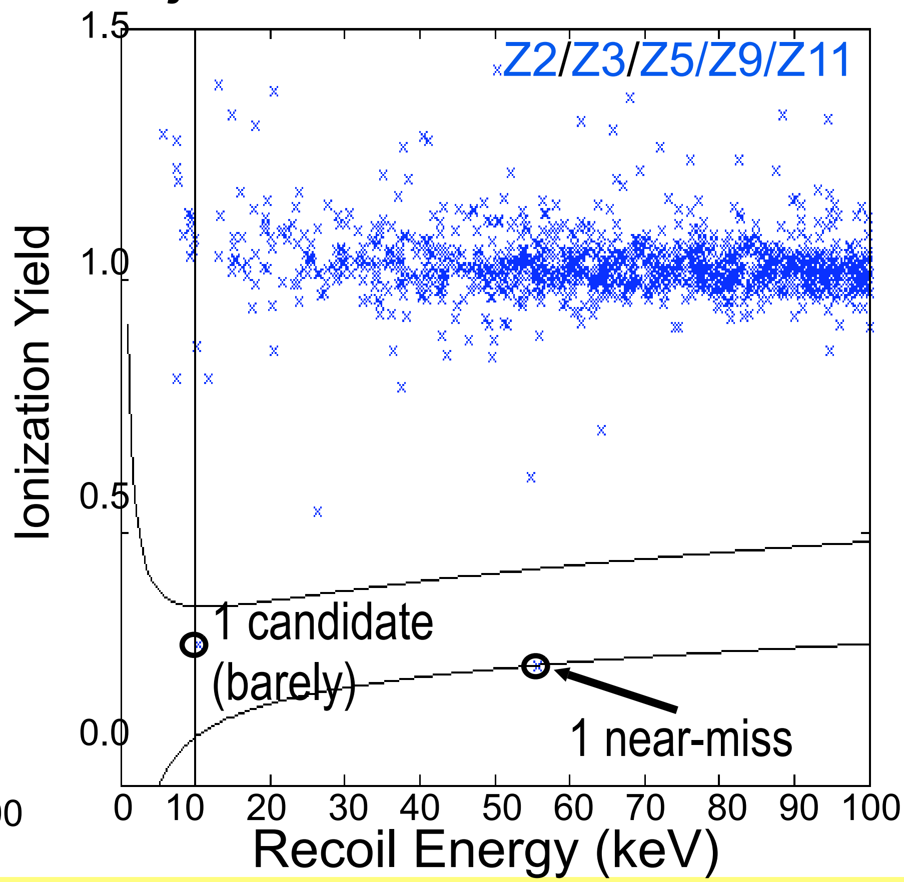
Prior to timing cuts



90 kg.days

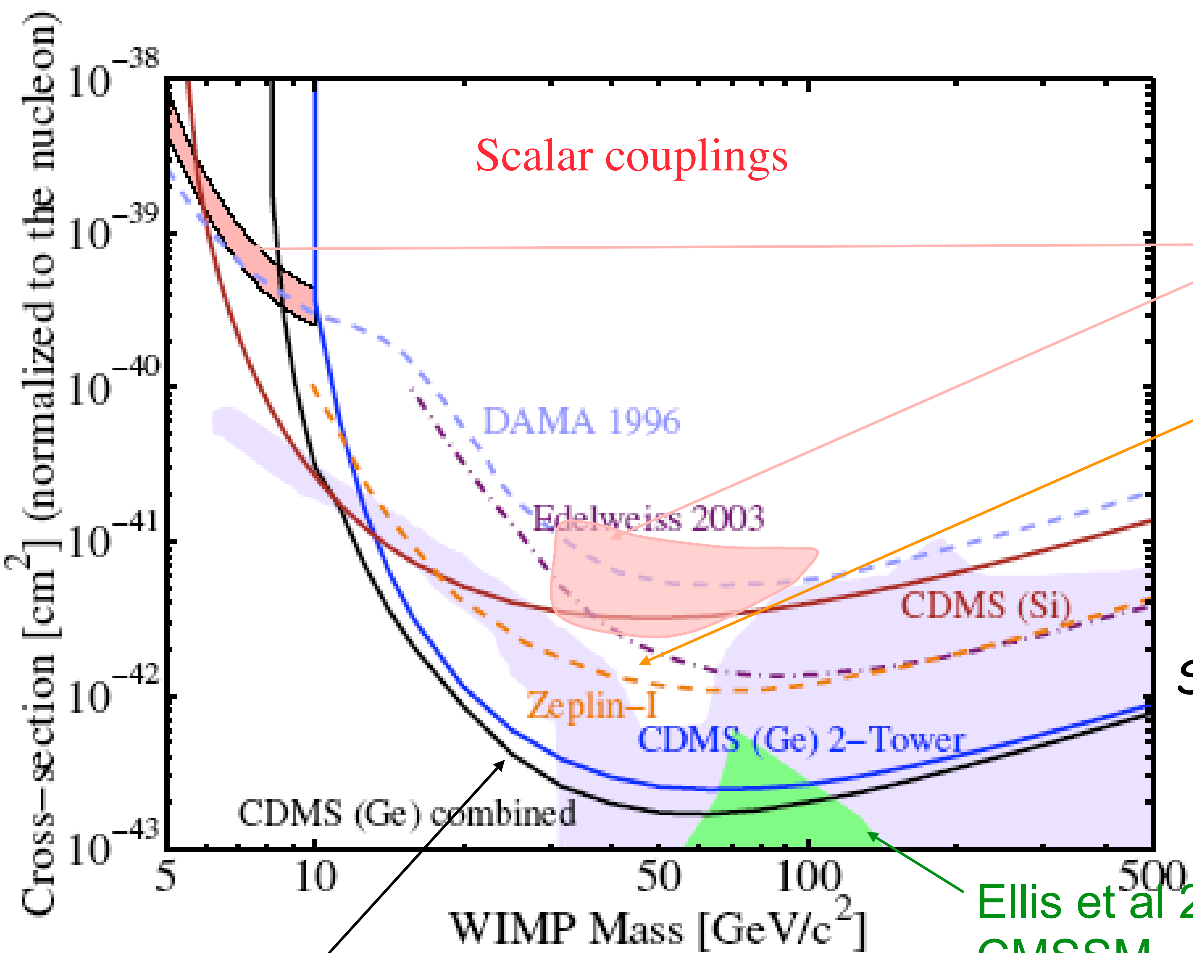
34kg.days after cuts

After timing cuts, which reject most electron recoils



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

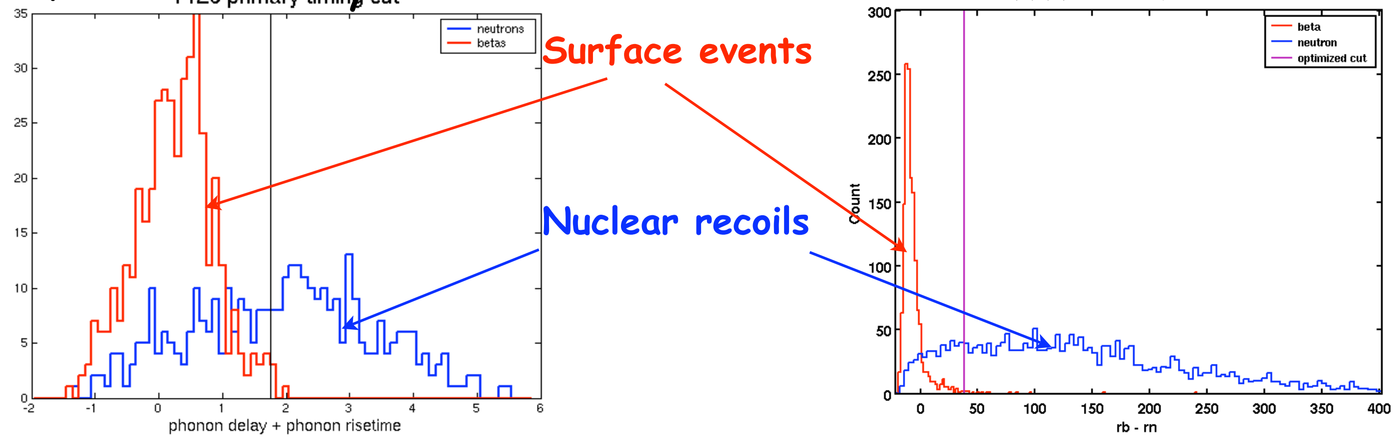
Adding 1st Soudan run, 53kg.day-> 19kg.day after cut

Total 53 kg.day after cut

CDMS II Reach

Large background rejection margin

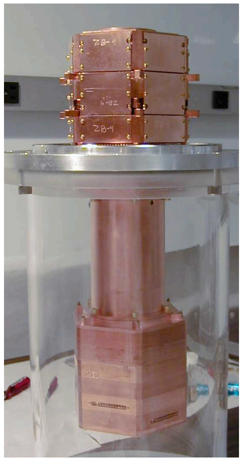
Used for this analysis | Current methods



5 Towers

5 Kg Ge, 2kg Si

5x



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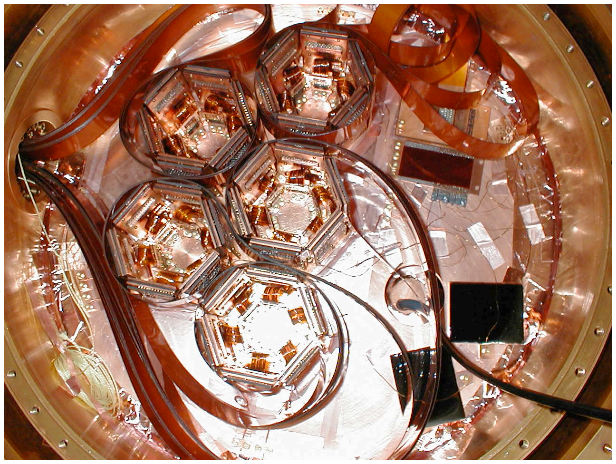


Run through December 2007

=> X 10 further   2 10^{-44} cm^2 @ 60GeV/c^2

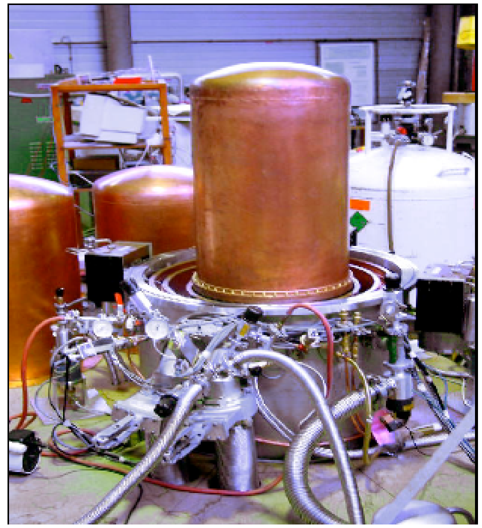
Other Phonon Mediated Detectors

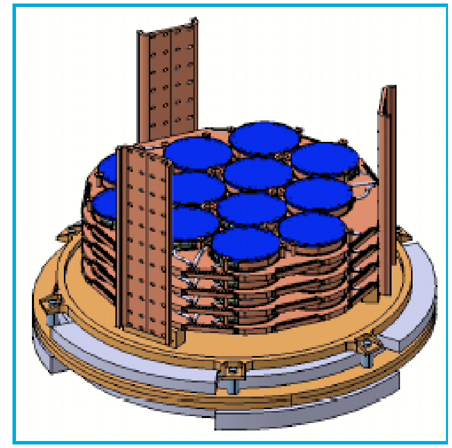
EDELWEISS II

Mounting 21x350g Ge +NTD detectors in new cryostat

Most detectors: no athermal phonon rejection of surface events

7x350g Nb/Ge fast phonon





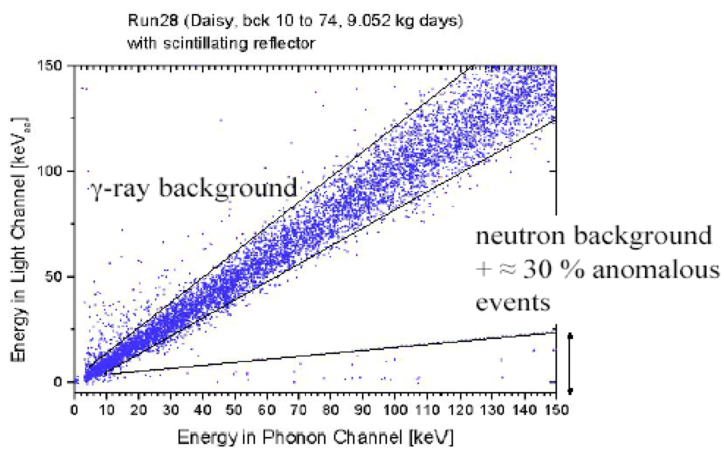
CRESST II

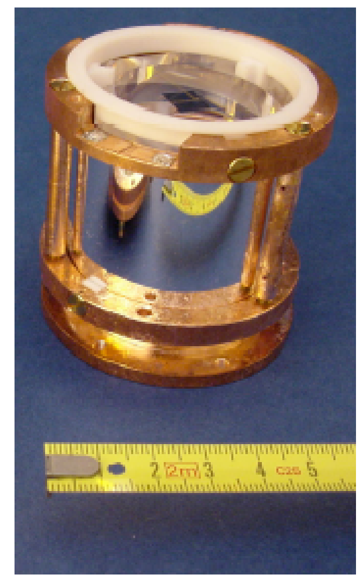
$CaWO_4$

Scintillation + phonons

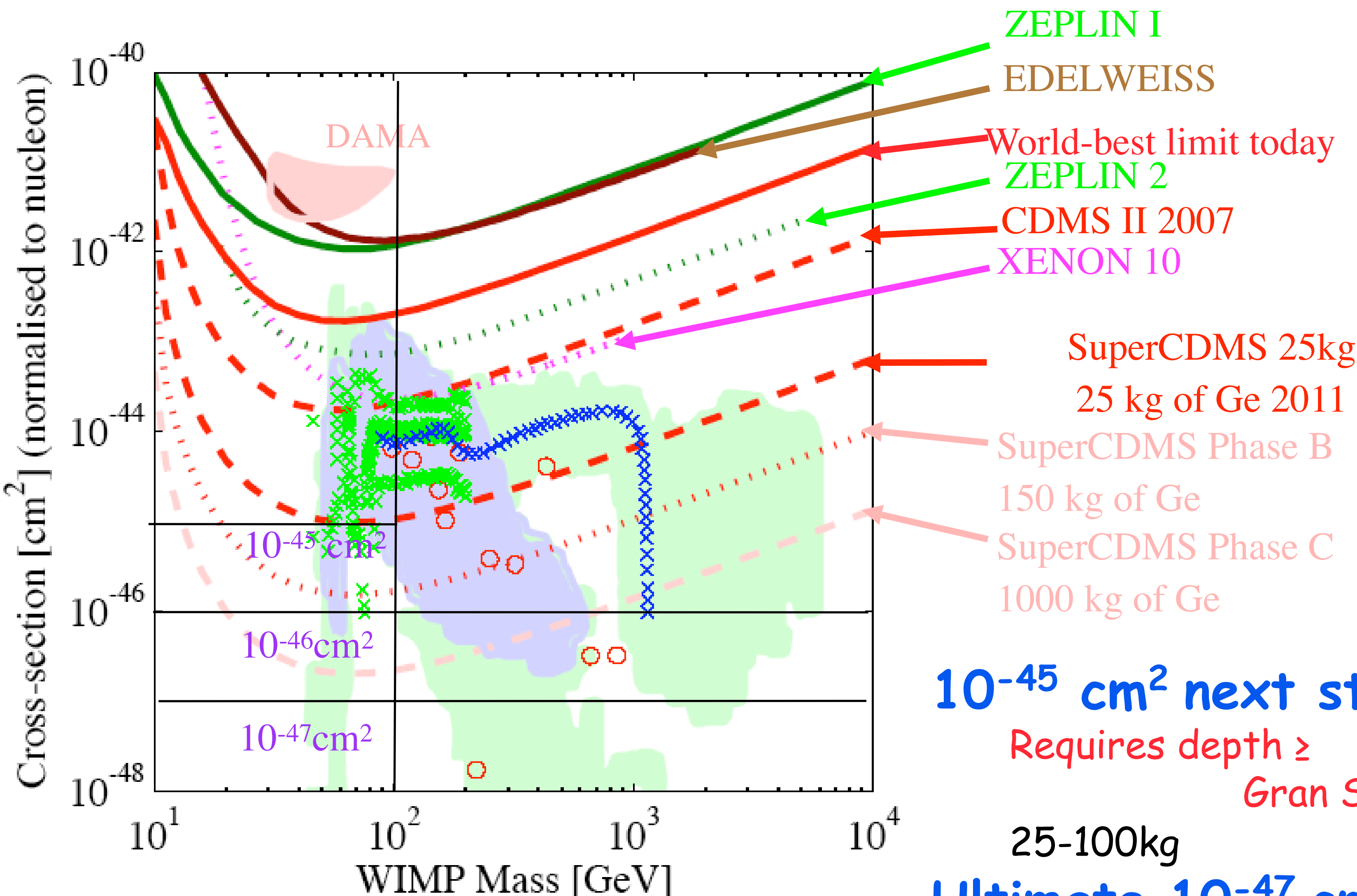
Excellent rejection, no dead layer

Insensitive to W recoil scintillation





Goals: Cover Supersymmetry



10^{-45} cm^2 next step

Requires depth ≥ Gran Sasso

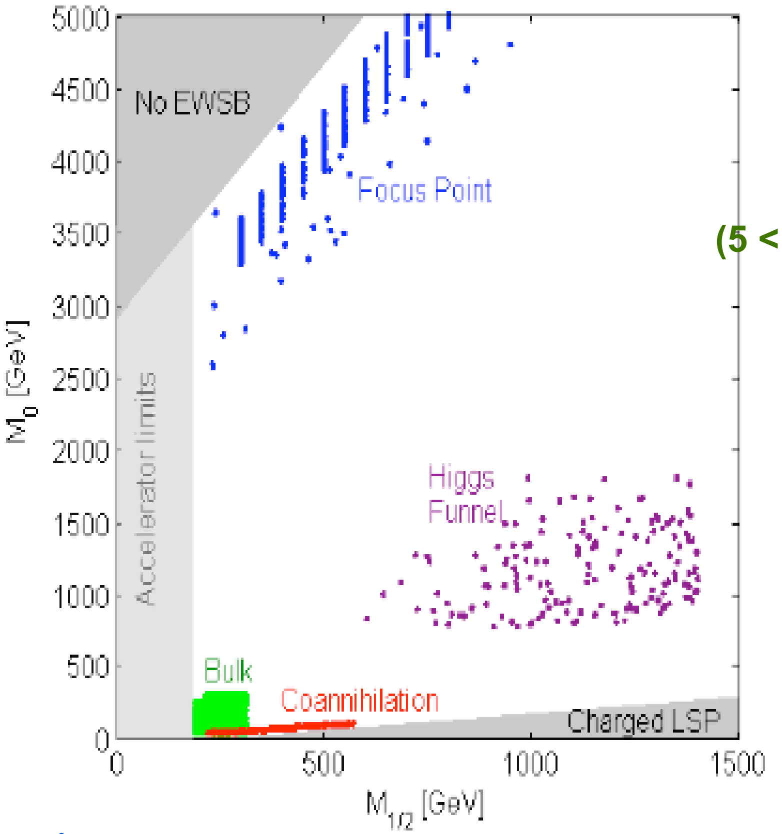
25-100kg

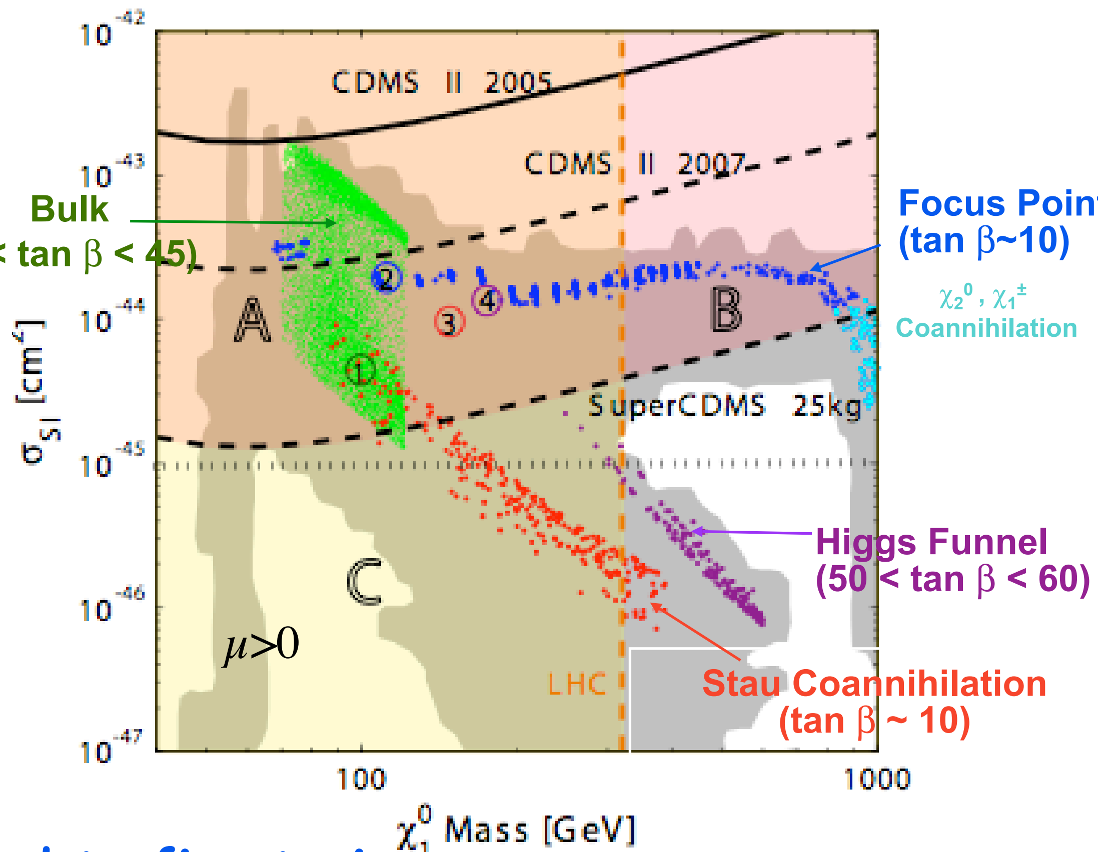
Ultimate 10^{-47} cm^2

2-8 tons

≈ No background!

Why 1 Zeptobarn ≡ 10^{-45} cm^2





Low cross sections correspond to fine tuning

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

The lower the elastic cross section, the finer the tuning!

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

Complementarity with LHC: Rich physics in region of overlap

Elastic scattering: Larger mass range

Strategies for the Future

Lessons from CDMS & Edelweiss

Search for rare events requires maximum amount of information

Large signal/noise => identification of background

≠ threshold detectors (Simple, Picasso, COUPP)

Active discrimination of the background event by event:

-> zero background

≠ Statistical methods (cf. DAMA, ZEPLIN1)

≥ 2 promising technologies

Phonon mediated detectors: demonstrated, but need to master complexity

Liquid Noble Gases: graceful scaling but need to demonstrate threshold and master complex phenomenology

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 $\approx A^2$

Phonon mediated detectors

Current technology capable to go to 25kg region

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

EDELWEISS II, CRESST II -> EURECA

Baseline detector for SuperCDMS

CDMS-II ZIPs:

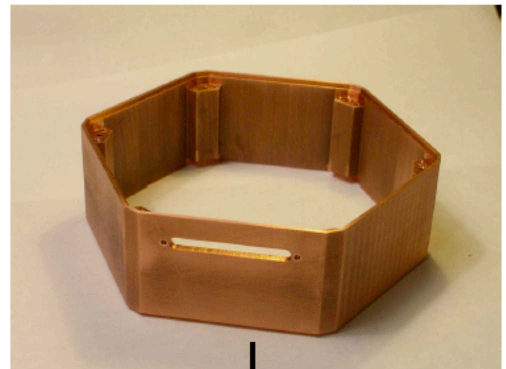
3" dia x 1 cm => 0.25 kg of Ge

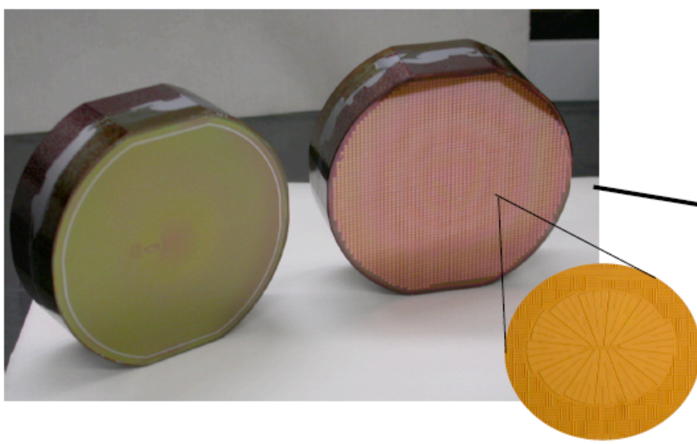
Existing ZIPs

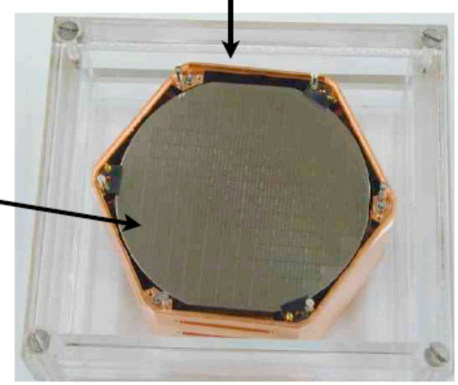
SuperCDMS ZIPs:

3" dia x 1" => 0.64 kg of Ge

ZIPs for SuperCDMS







Completed 1" thick Si ZIP

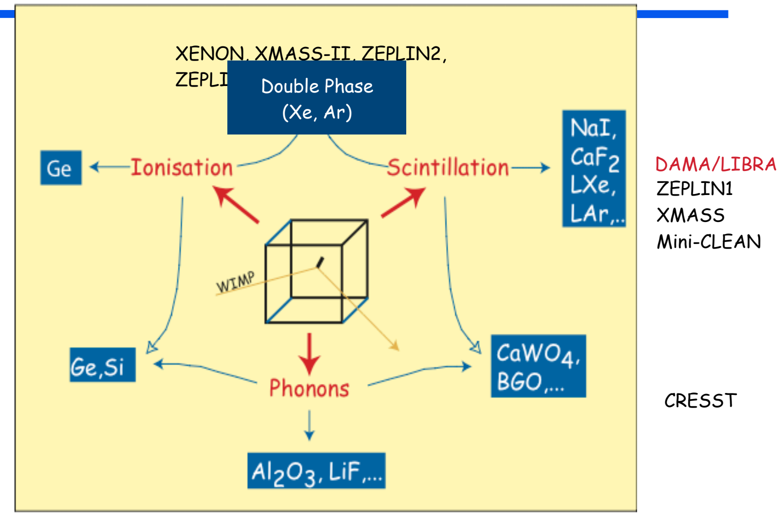
Significant change of production testing methods -> 1 Ton

Liquid Noble Gases

Liquid Argon + Xenon

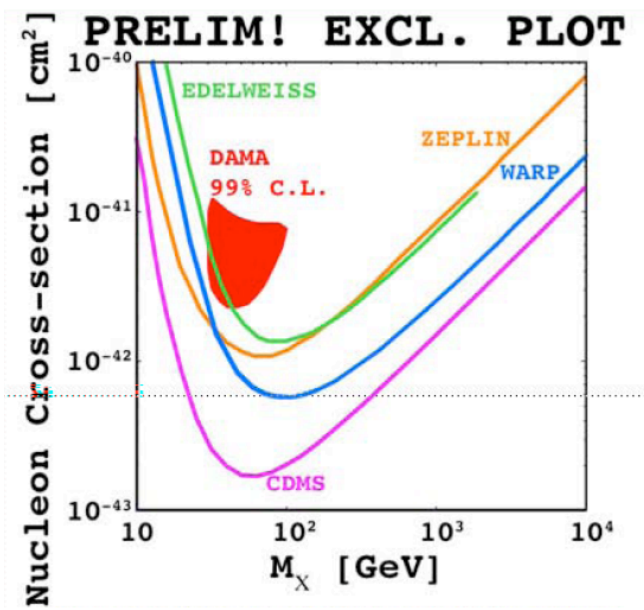
2 recent breakthroughs

- Need to extract electrons from liquid
- Ar is much better for pulse shape discrimination 6ns/1.6 μs: 6ns killed for nuclear recoil ≠ Ar 49



Xe: Zeplin,Xenon, Xmass

Ar: WARP, ArDM, MiniClean



Hot out of the press: Liq.Ar

WARP prototype 97kg days
Ionization + Scintillation including pulse shape
No event above 40 keV
Soft neutrons below?

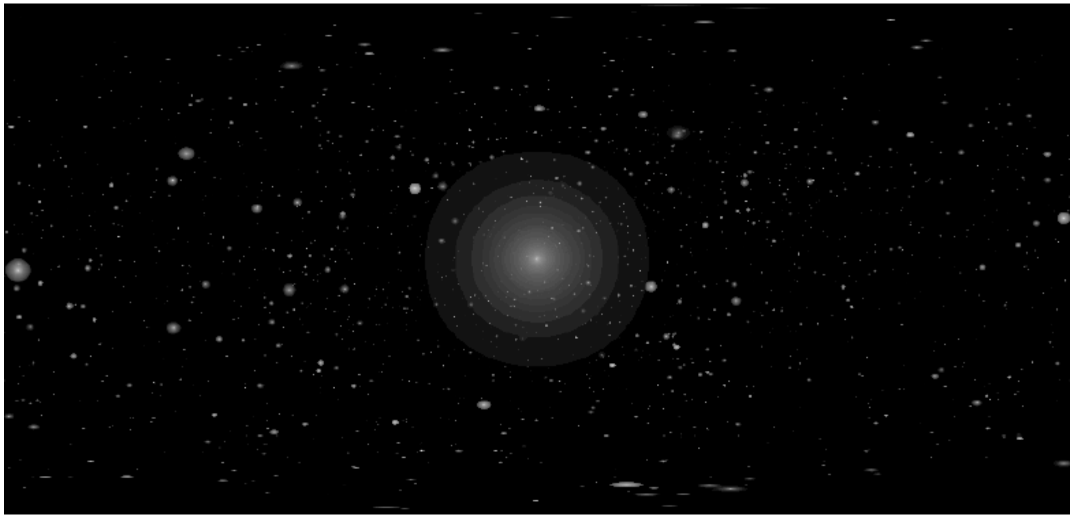
But energy scale?

Why scintillation yield is 80%

Need to map carefully phenomenology

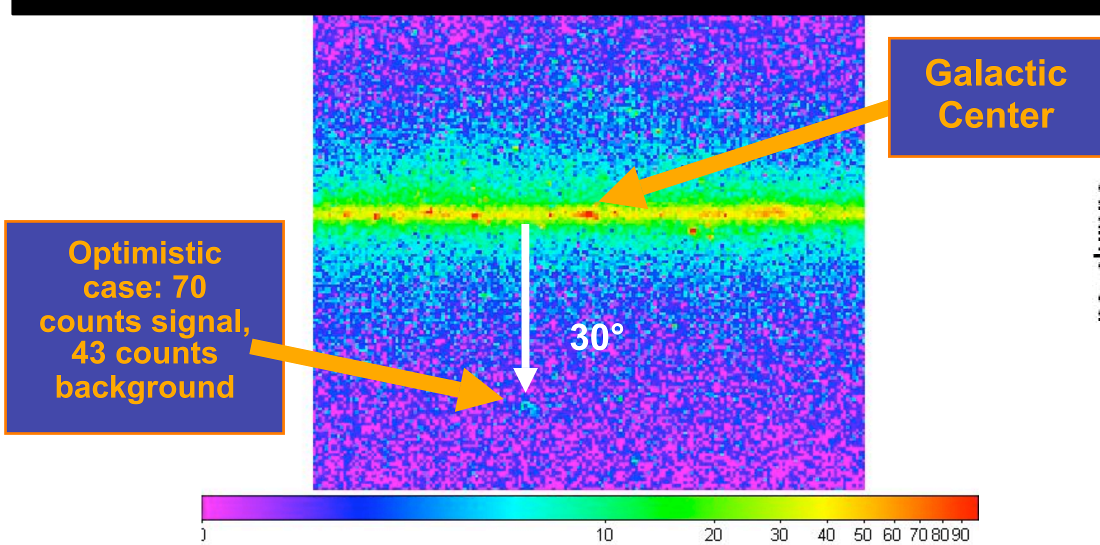
180kg module in fabrication

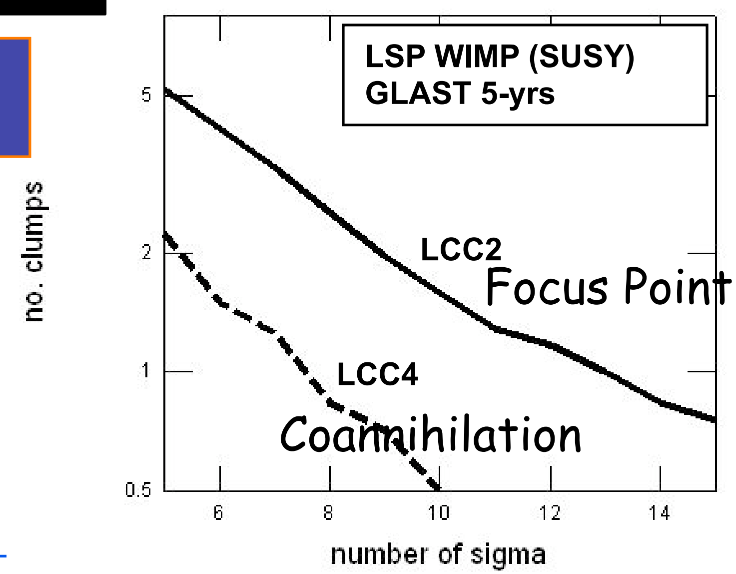
Gamma Rays: A smoking gun?



Simulation of the γ ray sky from Dark Matter annihilation
Ted Baltz 2006 (Taylor/Babul 2005)
SUSY: often maximal σ
Hierarchical clustering

55-days GLAST in-orbit counts map (E>1GeV)





B.Sadoulet

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

Interesting alignment between Cosmology and Particle Physics

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, 0 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)