Status and Perspectives of Dark Matter Searches

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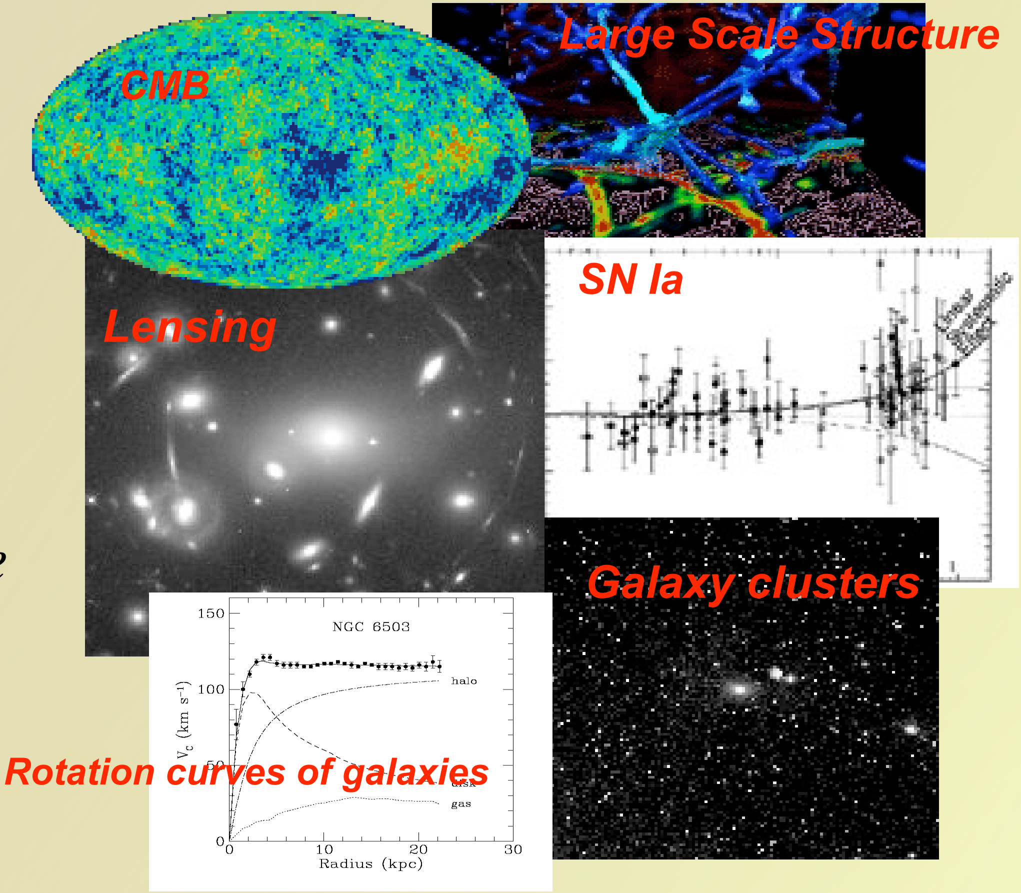
Overview

- *Quick review of evidence for and nature of dark matter*
- *Detection techniques*
- *Current and future experiments*
- *Summary and outlook*

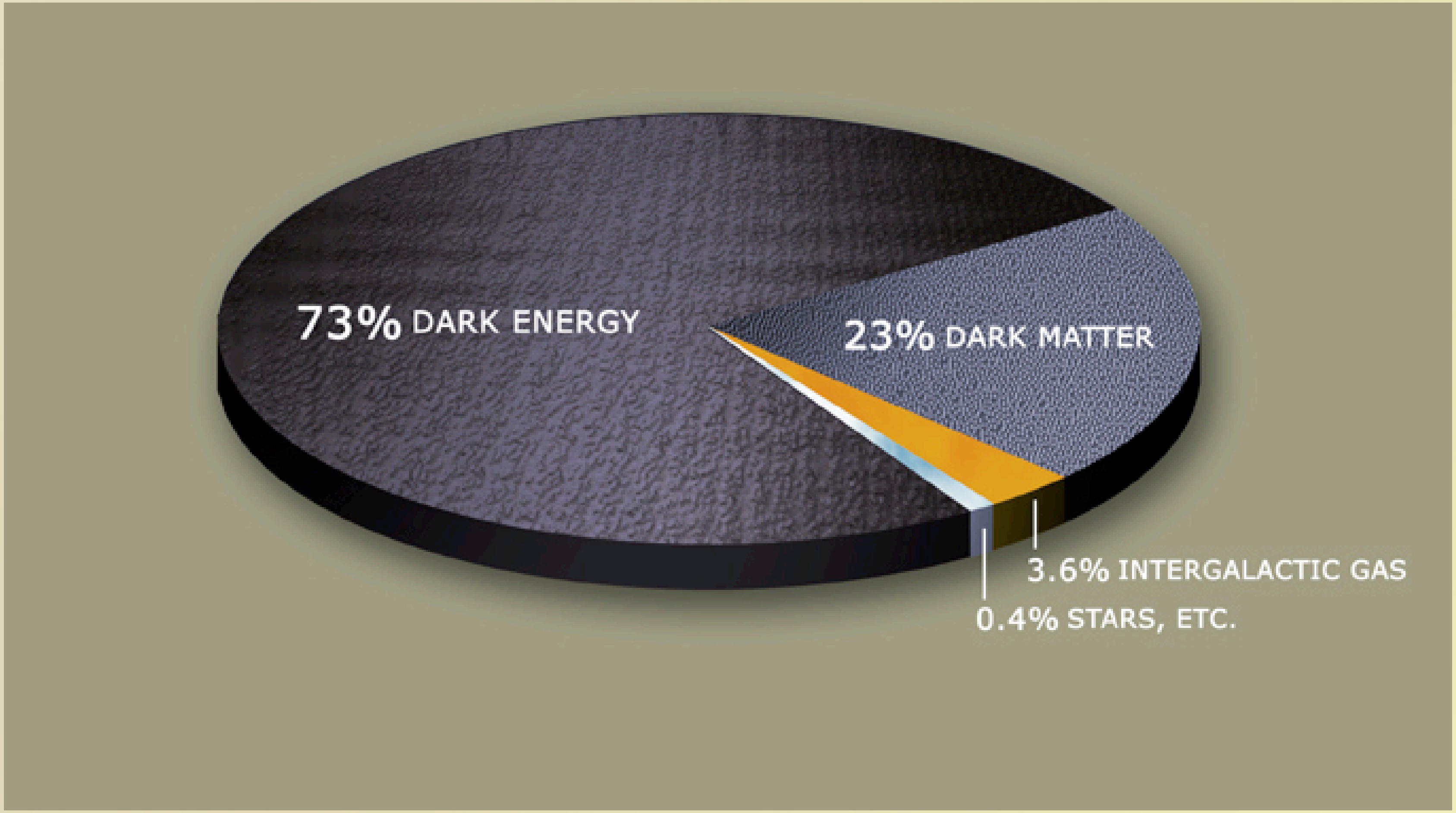
Evidence for Dark Matter

First evidence for dark matter came from studies of galaxy clusters by Zwicky in 1933.

Since that time we have accumulated even more evidence that dark matter exists and more information about the nature of dark matter itself.



The Cosmic Pie



Weakly Interacting Massive Particles (WIMPs)

10^6 per second through your thumb without being noticed!

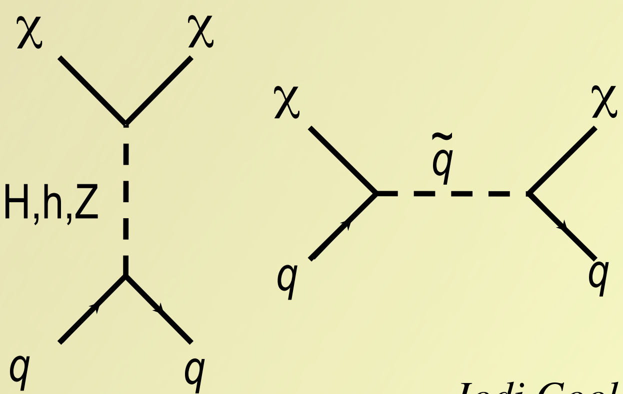
10^{15} through a human body each day:
only < 10 will interact
the rest pass through unaffected!
(less than 1 per kg material per week)

One intriguing WIMP candidate is the neutralino.

Neutralinos scatter elastically with nuclei:

$$\textbf{Rate} \sim N\, n_\chi \langle\sigma_\chi\rangle$$

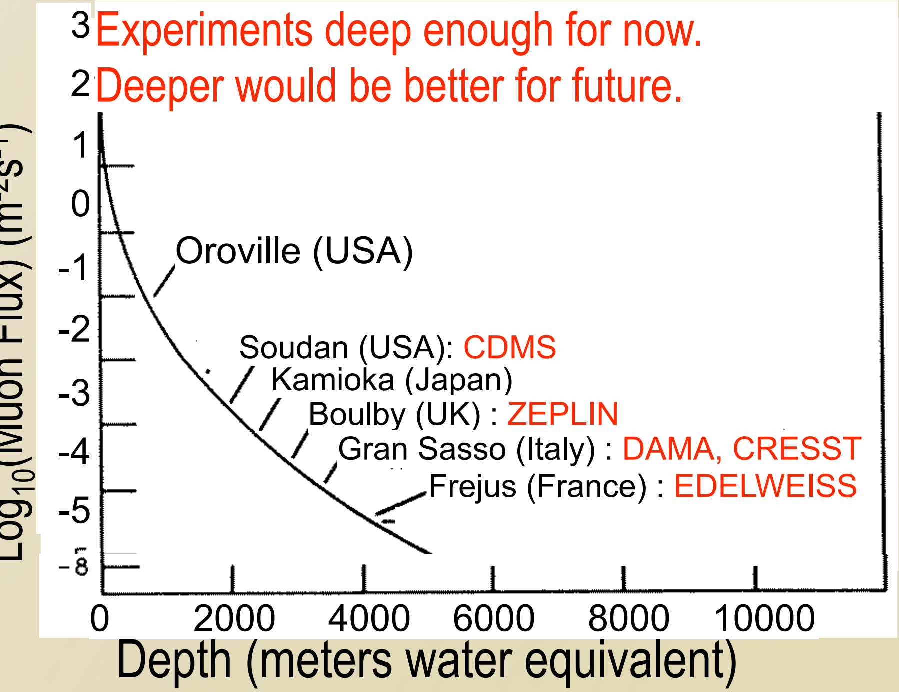
N = number of targets in detector
n_χ = local neutralino density
$\langle\sigma_\chi\rangle$ = scattering cross section
(mean over relative WIMP-detector velocity)



How Do We Find Dark Matter?

- ***Indirect Detection:***
  - ***Look for products of annihilations of χ in the sun or earth. (AMANDA, IceCube, Super-K, EGRET ...)***
  - ***Make dark matter in accelerators and detect products of interactions. (LHC)***
- ***Direct Detection:***
  - ***Go into deep underground laboratories (Soudan, MN; Gran Sasso, Italy; etc.) and measure them directly when they elastically scatter off nuclei in the target***

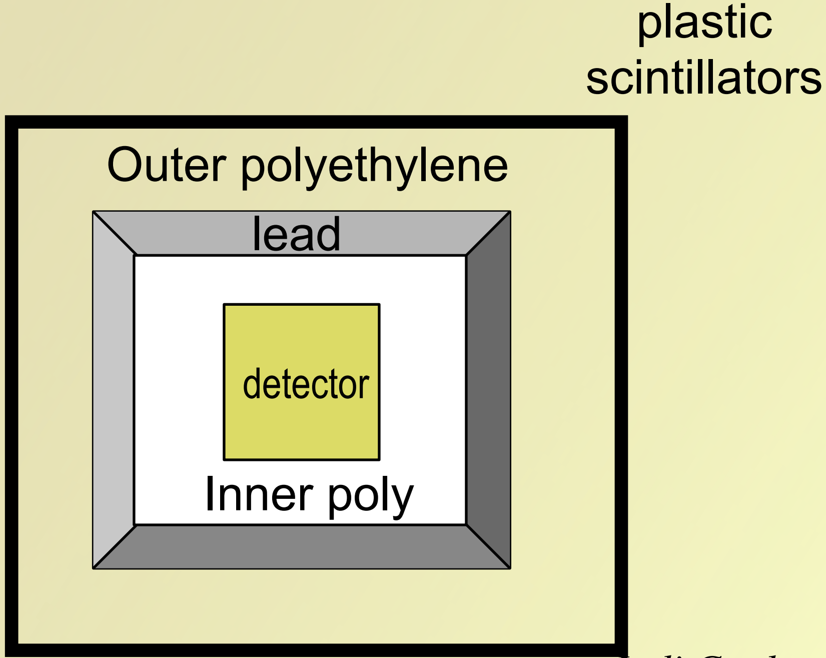
Backgrounds



Eliminating background is a main concern for dark matter experiments.

Put deep underground to reduce cosmic rays which can create neutrons.

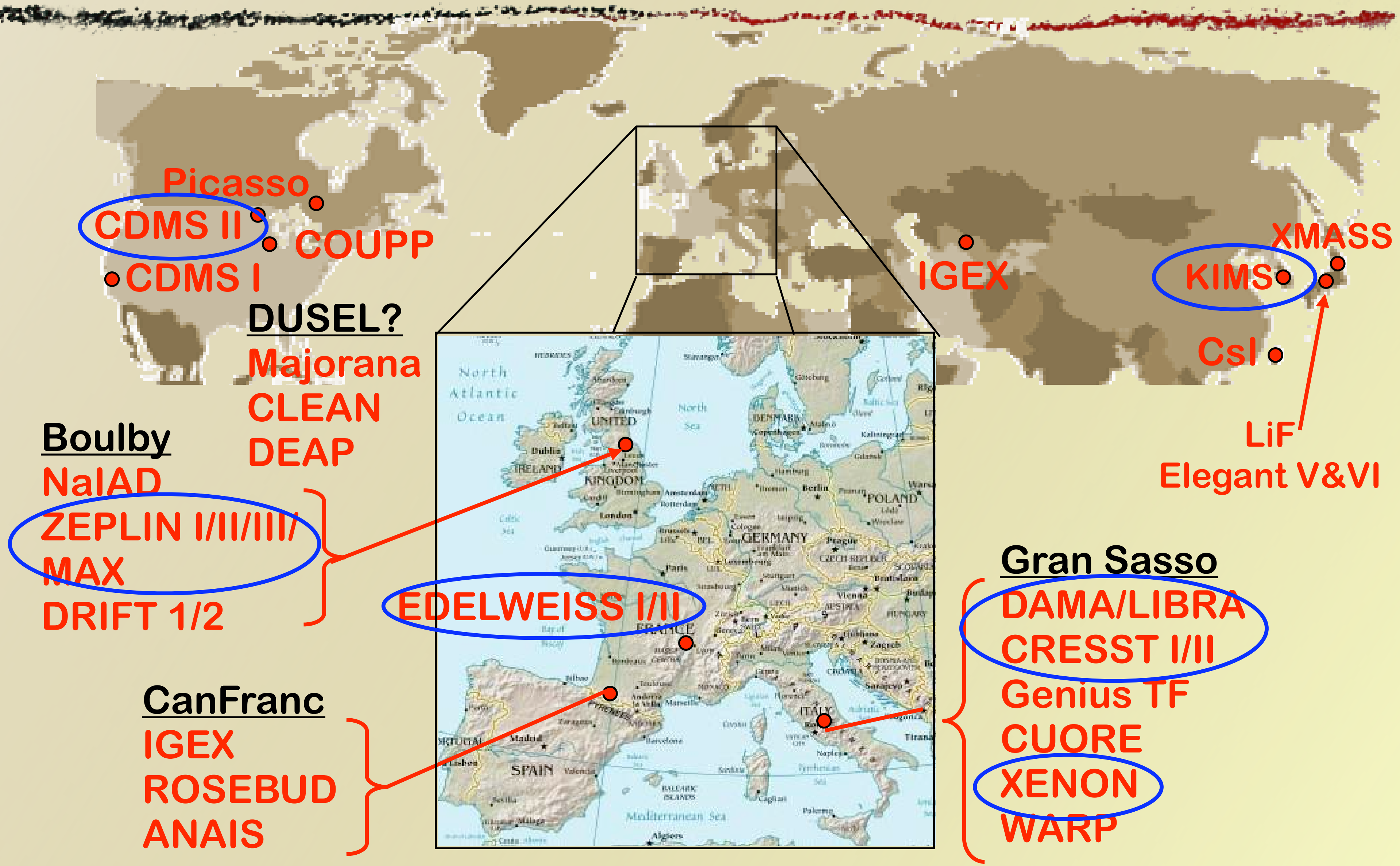
Surround with active muon vetos.



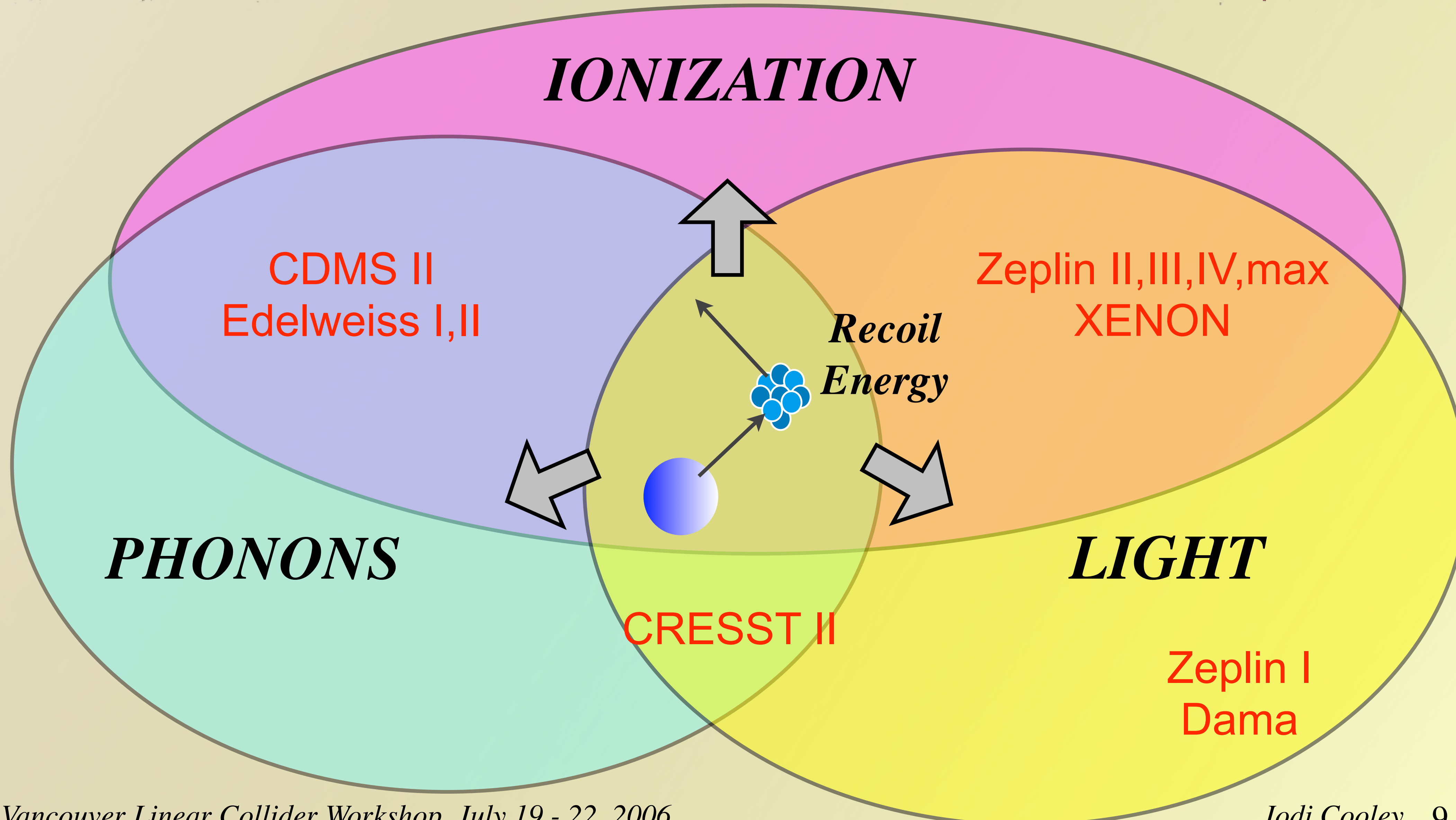
Use low-radioactivity materials.

Use passive shielding such as ancient lead, and copper to reduce photons, and hydrocarbons to reduce low energy neutrons.

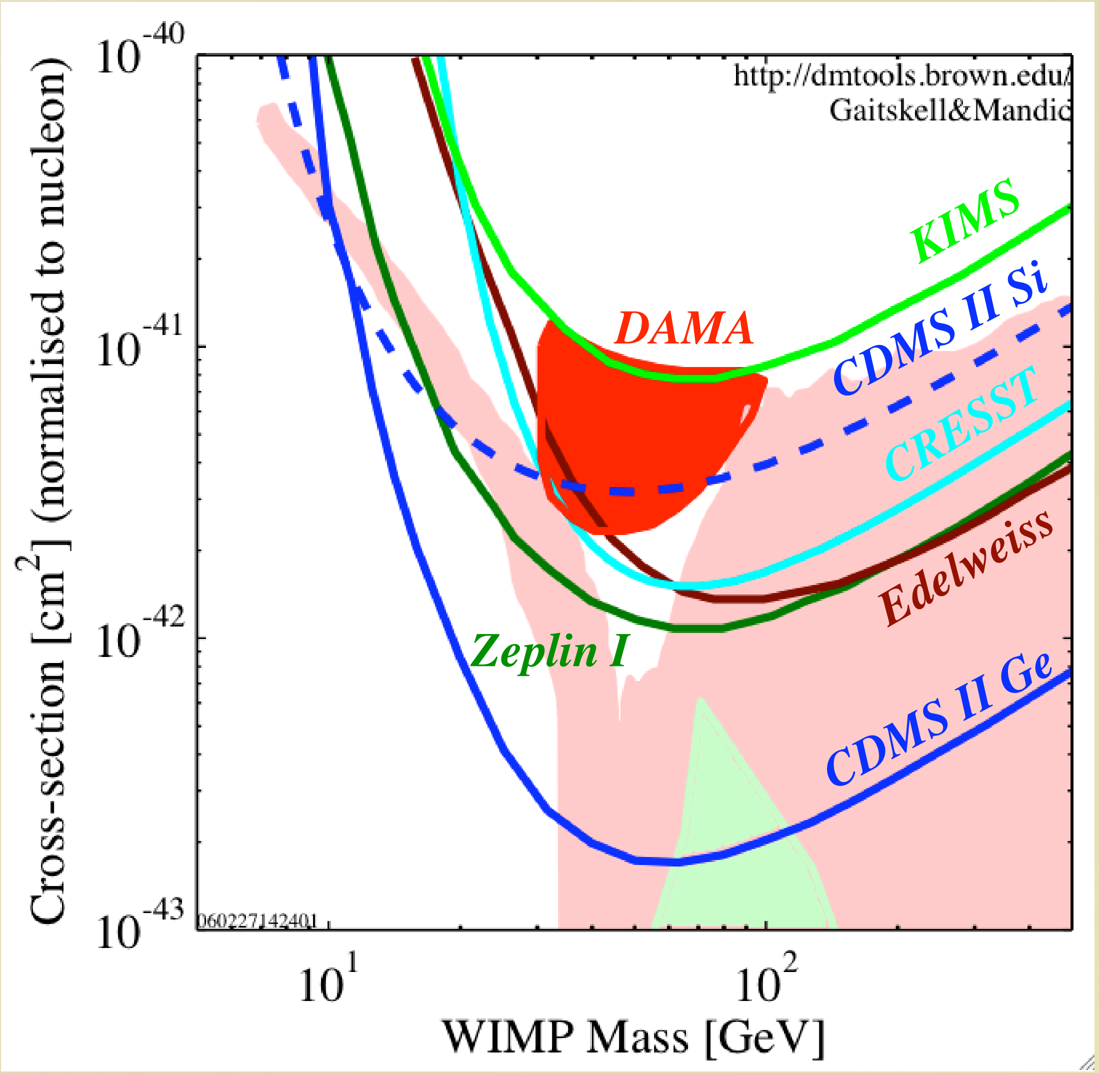
Direct Detection WIMP Experiments Worldwide



Direct Detection Techniques



Where Do We Stand?



Presently the best limit for WIMP-nucleon cross-section come from the CDMS II experiment.

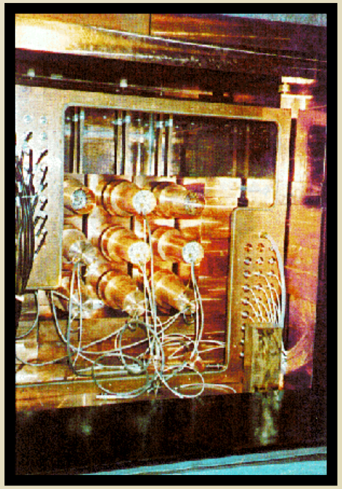
1.6 x 10^{-43} cm^2 at 60 GeV

Exclude large regions of SUSY parameter space under some frameworks.

A. Bottino et al., 2004 in light pink

J. Ellis et al. 2005 in light green

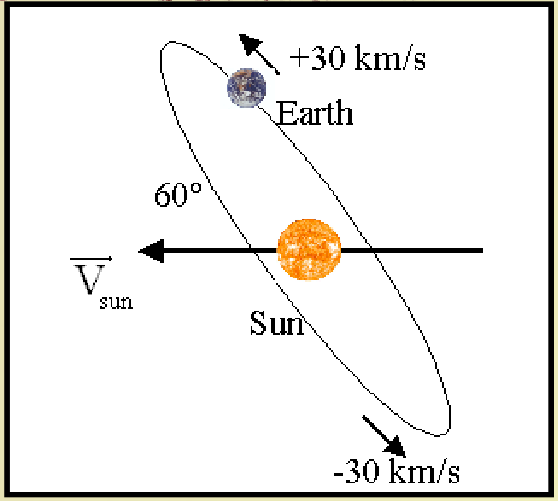
DAMA: Gran Sasso, Italy

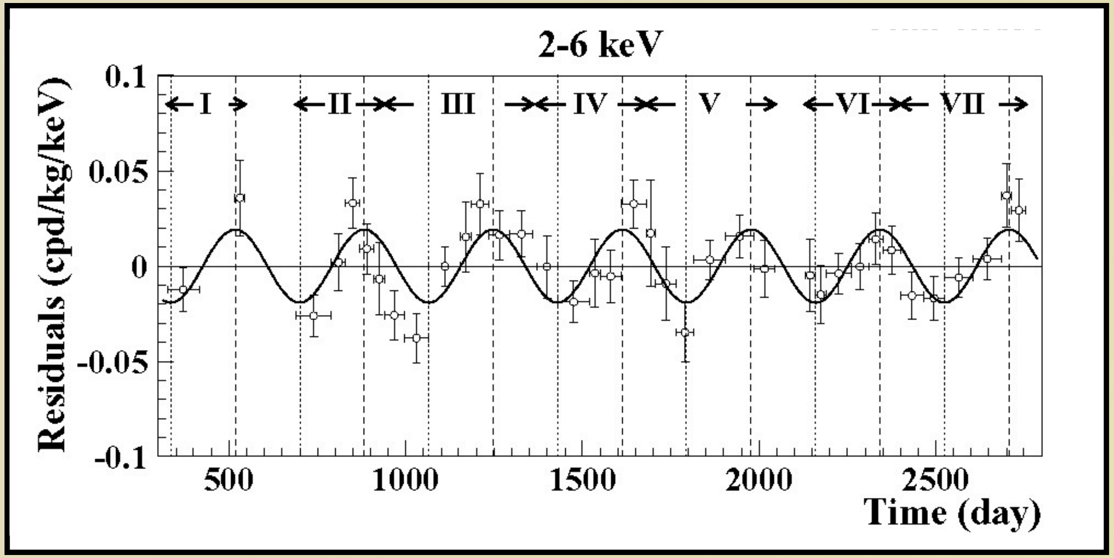


Does not distinguish between WIMP signal and background directly.

Look for WIMP signal from amplitude of annual modulation.

9 x 9.7 kg NaI crystals each viewed by 2 PMTs.





Riv. Nuovo Cim 26N1 (2003) 1-73

Annual modulation analysis over 7 years (107,731 kg days).

Positive signal at 6.3 σ.

LIBRA, a 250 kg NaI experiment has been operating since Mar. 03

KIMS
Korea Invisible Mass Search

Similar to DAMA but with CsI.

Internal background from ^{137}Cs is most problematic. Can be reduced by using purified water in processing.

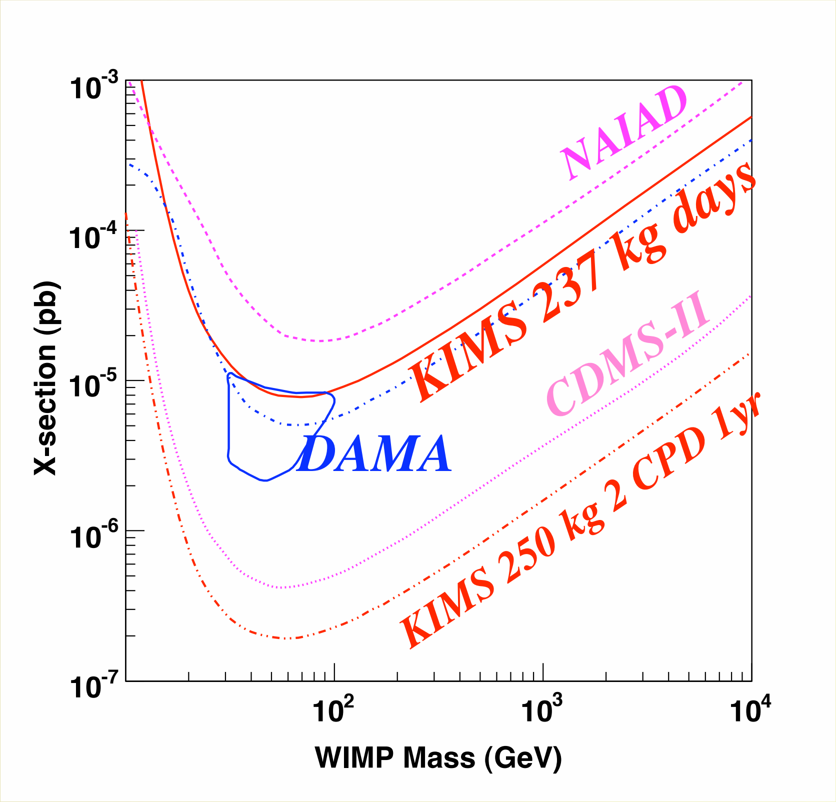
Recent result is based on 1 crystal with mass 6.6 kg and 237 kg days of data.

Currently running 4 crystals with mass 8.66 kg each.
- *2 crystals at ~ 6 CPD (counts/keV/kg/day)*
- *2 crystals at ~ 4 CPD*

Three more crystals are waiting for installation.

Plan to start taking 100 kg data this summer.

Hope to report 4 crystal result before end of summer.



Phys. Lett. B 633 (2006) 201

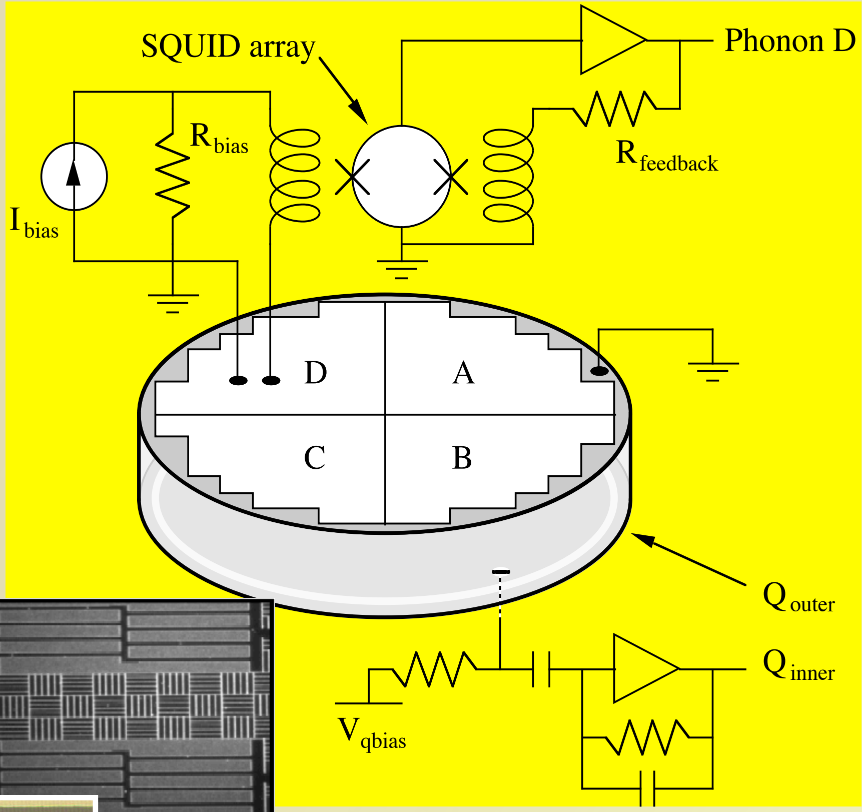
CDMS II ZIP Detectors

250 g Ge or 100 g Si crystal

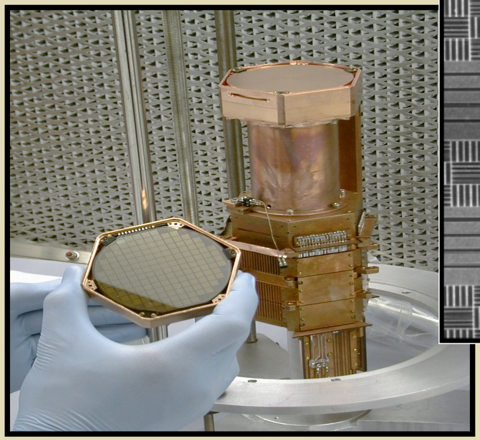
1 cm thick x 7.5 cm diameter

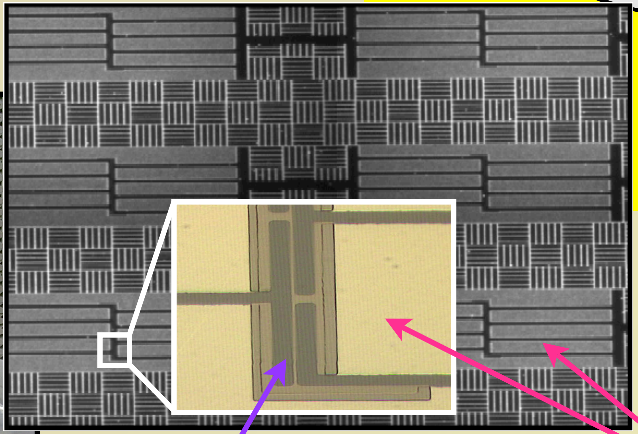
Photolithographic patterning

Collect athermal phonons:
XY position imaging
Surface (Z) event veto based on pulse shapes and timing



Z-sensitive **I**onization and **P**honon-mediated



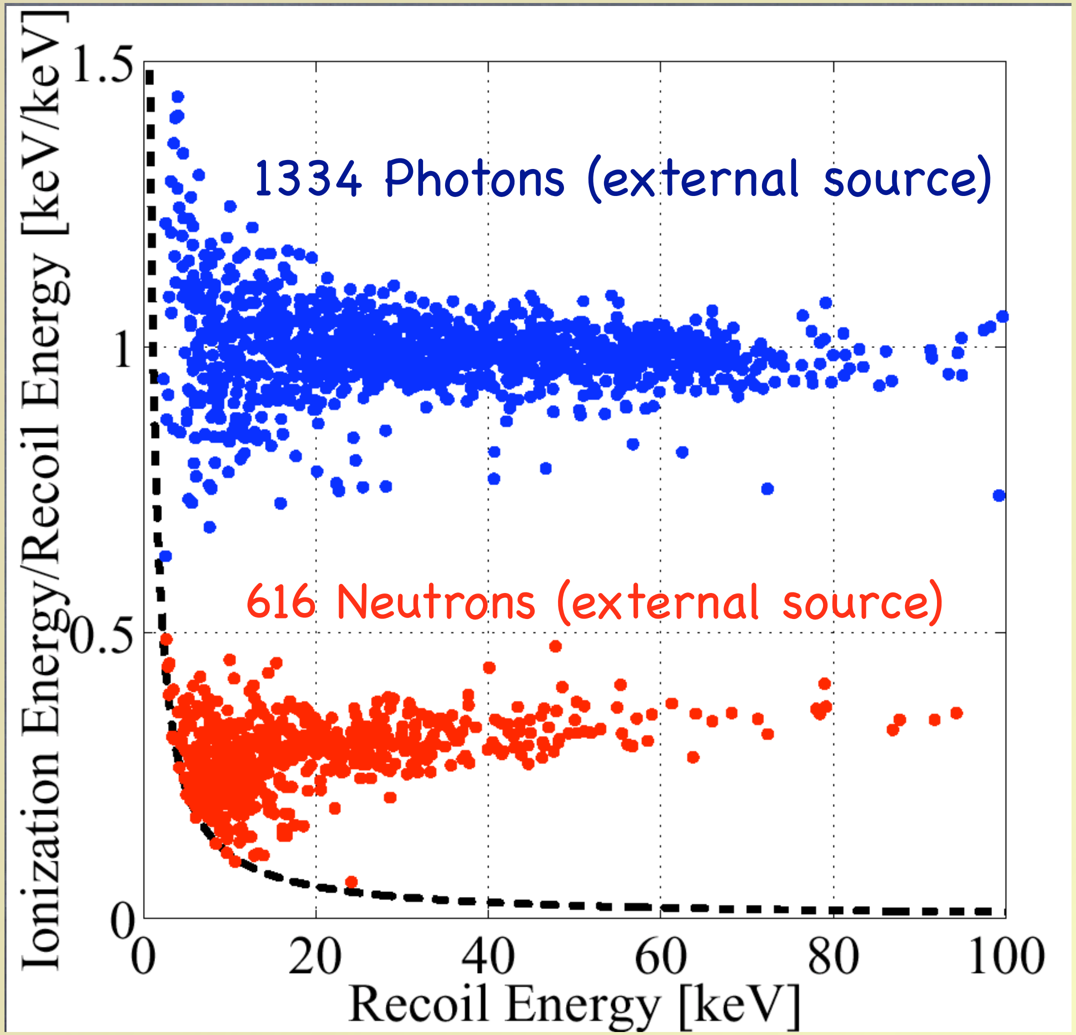


CDMS II Background Rejection

Ionization Yield (ionization energy per unit recoil energy) depends strongly on type of recoil

> *Most backgrounds (γ, e ,α) produce electron recoils*
>
> *WIMPs (and neutrons) produce nuclear recoils*

Detectors provide near- perfect event-by-event discrimination against otherwise dominant bulk electron-recoil backgrounds



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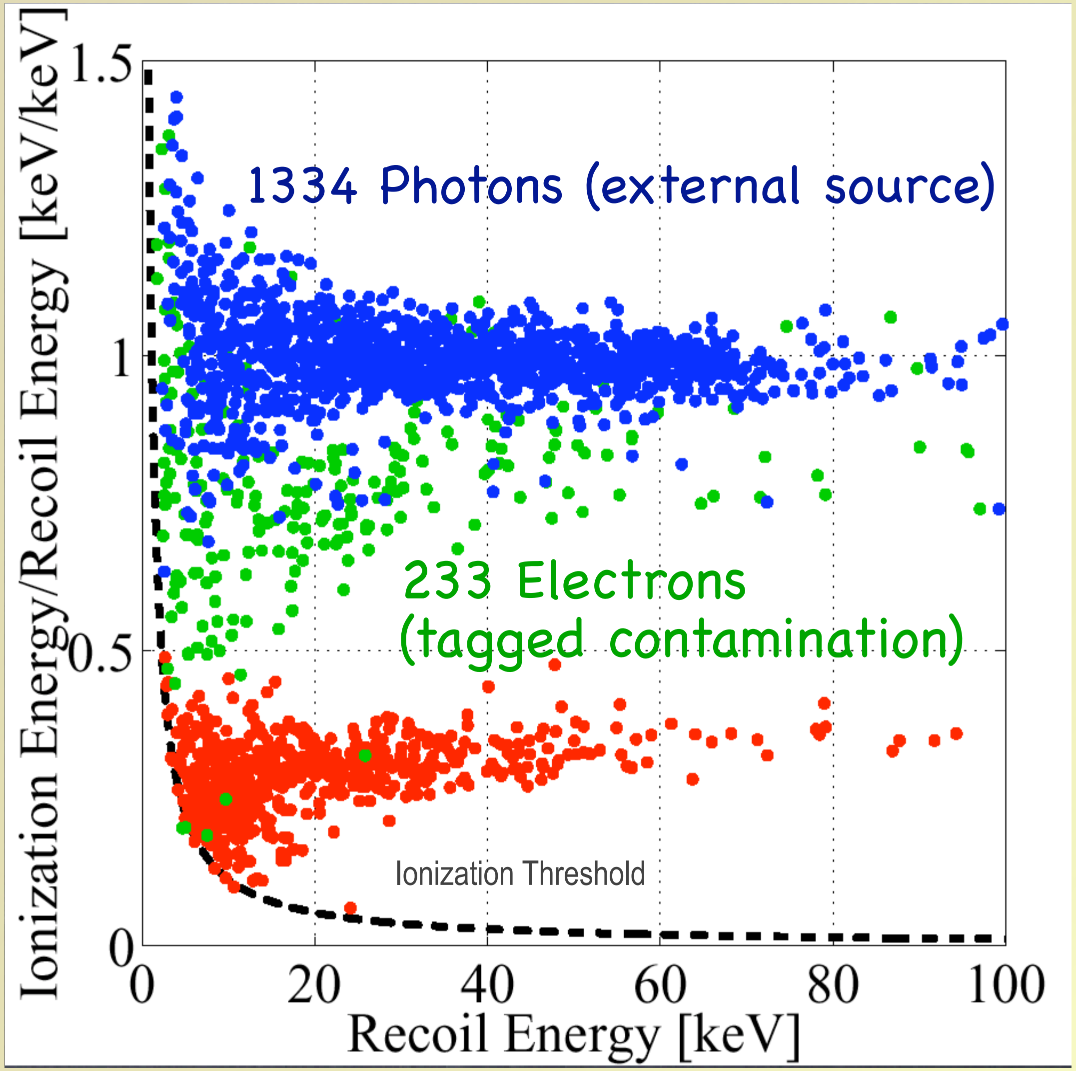
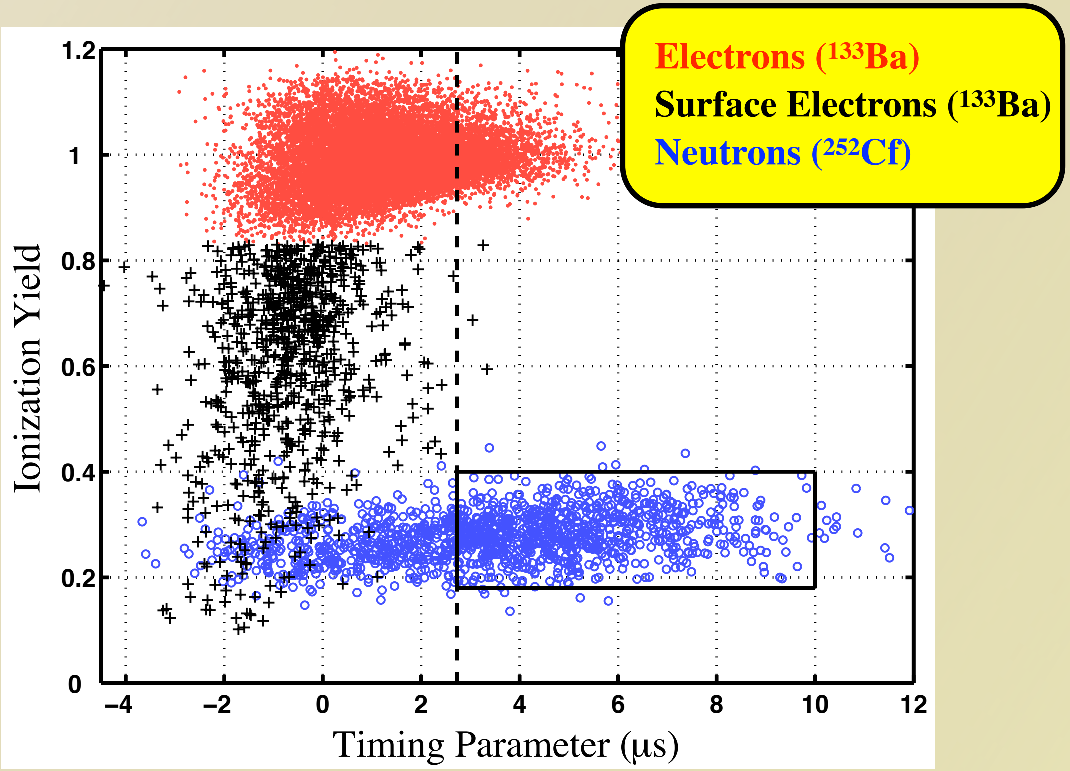
Particles (electrons) that interact in surface "dead layer" of detector result in reduced ionization yield



CDMS II Surface Event Rejection



Phys. Rev. Lett. 96 (2006) 011302

Events near the crystal's surface produce a different frequency spectrum of phonons.

These phonons travel faster, resulting in a shorter risetime of the phonon pulse.

A risetime cut eliminates most of the troubling background.

CDMS II Multiple Targets

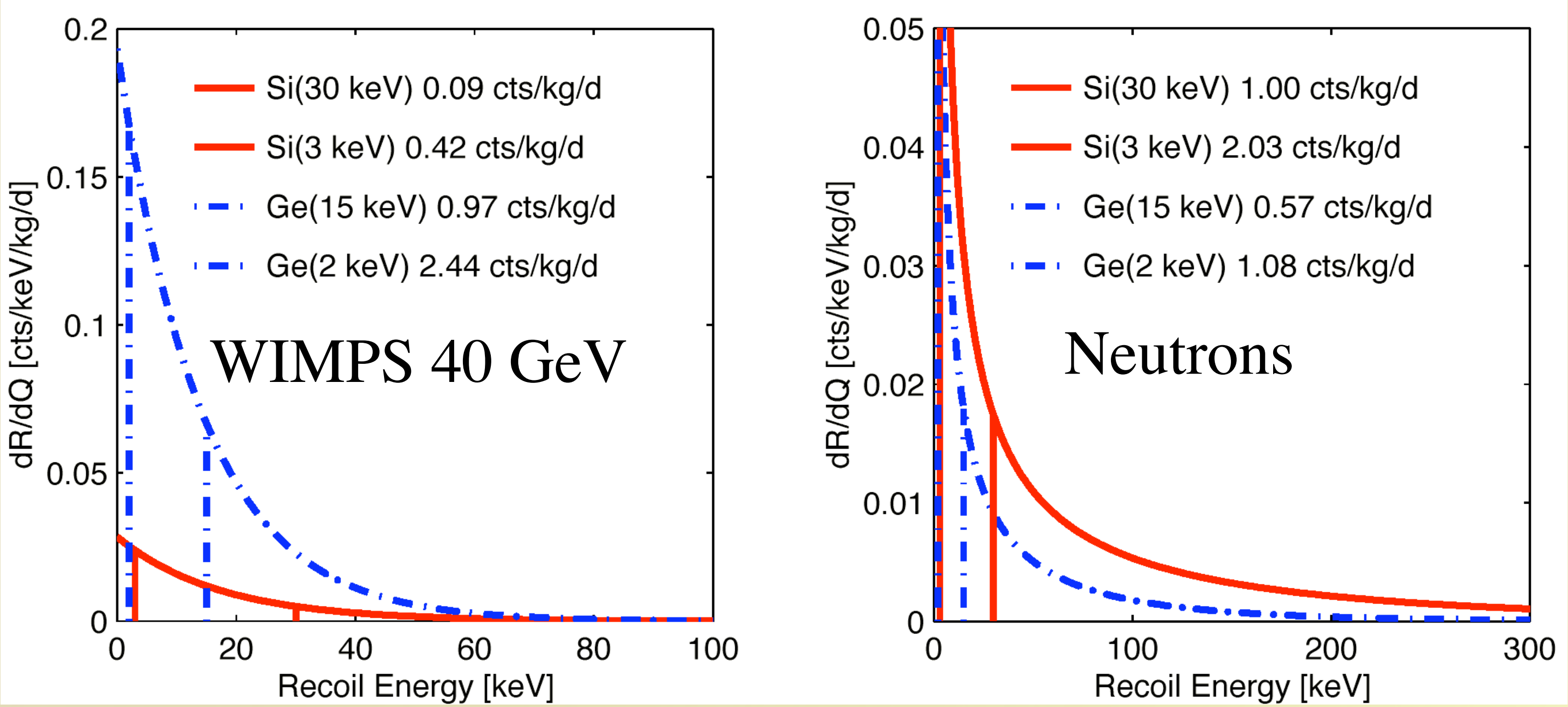
For neutrons 50 keV - 10 MeV

Si has ~2x higher interaction rate per kg than Ge

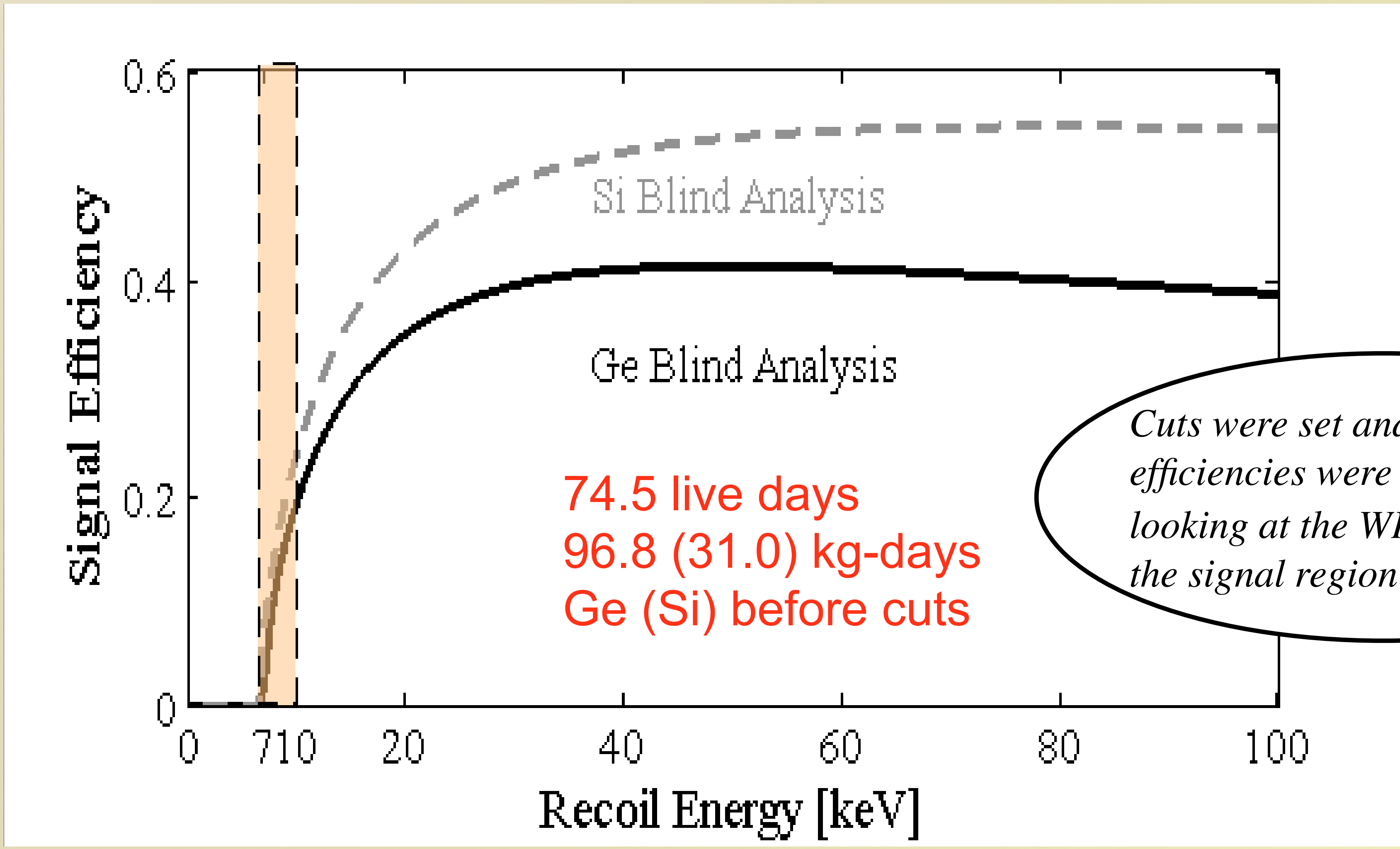
For WIMPs

Si has ~6x lower interaction rate per kg than Ge

If nuclear recoils appear in Ge, and not in Si, they are WIMPs!



CDMS II Signal Efficiency



Cuts were set and leakages and efficiencies were calculated without looking at the WIMP-search data in the signal region.

CDMS II Results

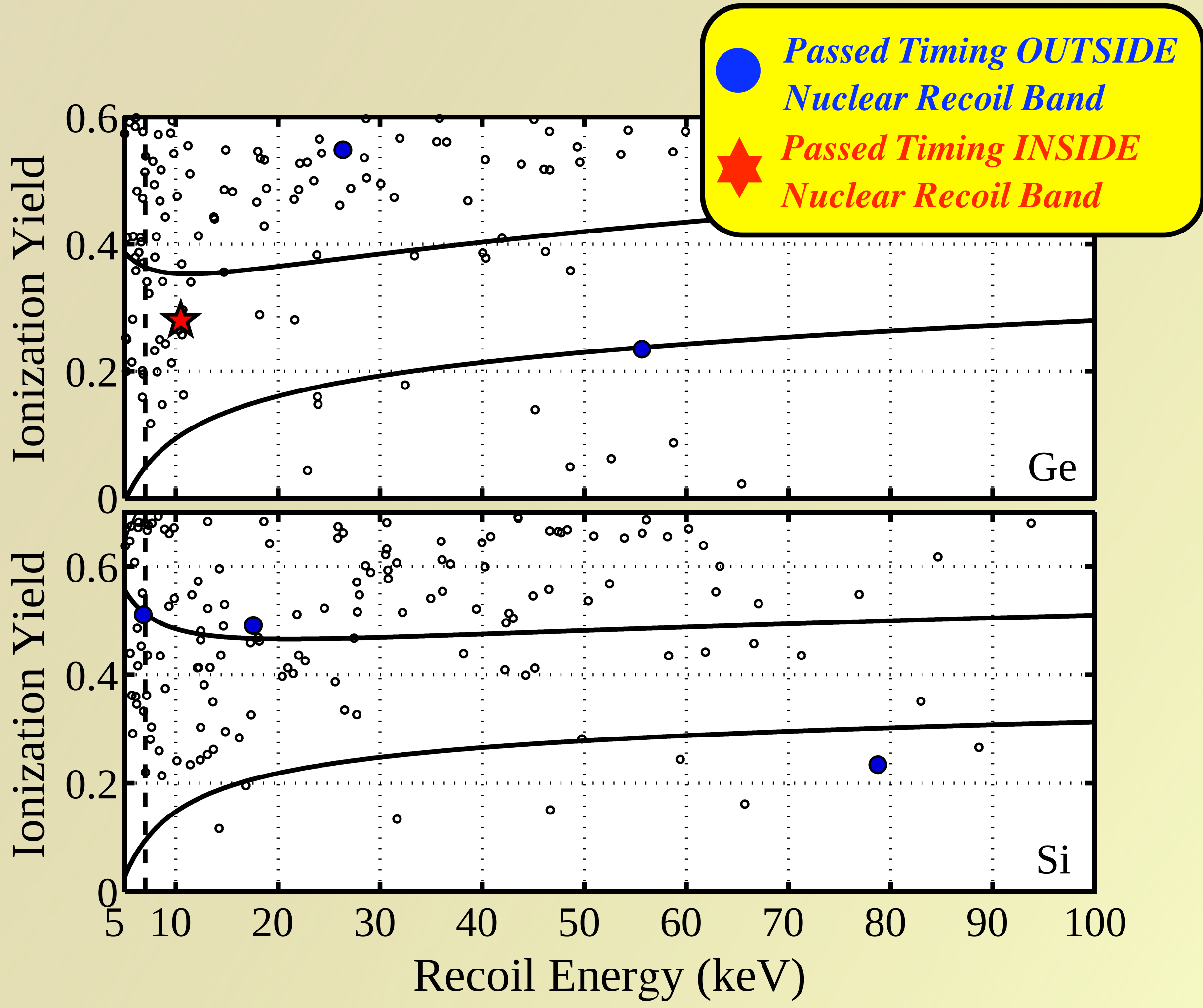
Estimated number of events to pass surface cut in Ge and Si

$0.4 \pm 0.2(stat) \pm 0.2(syst) Ge$
$1.2 \pm 0.6(stat) \pm 0.2(syst) Si$

Estimated number of neutron background events is 0.06 in Ge and 0.05 in Si.

After timing cuts 6 events remained.

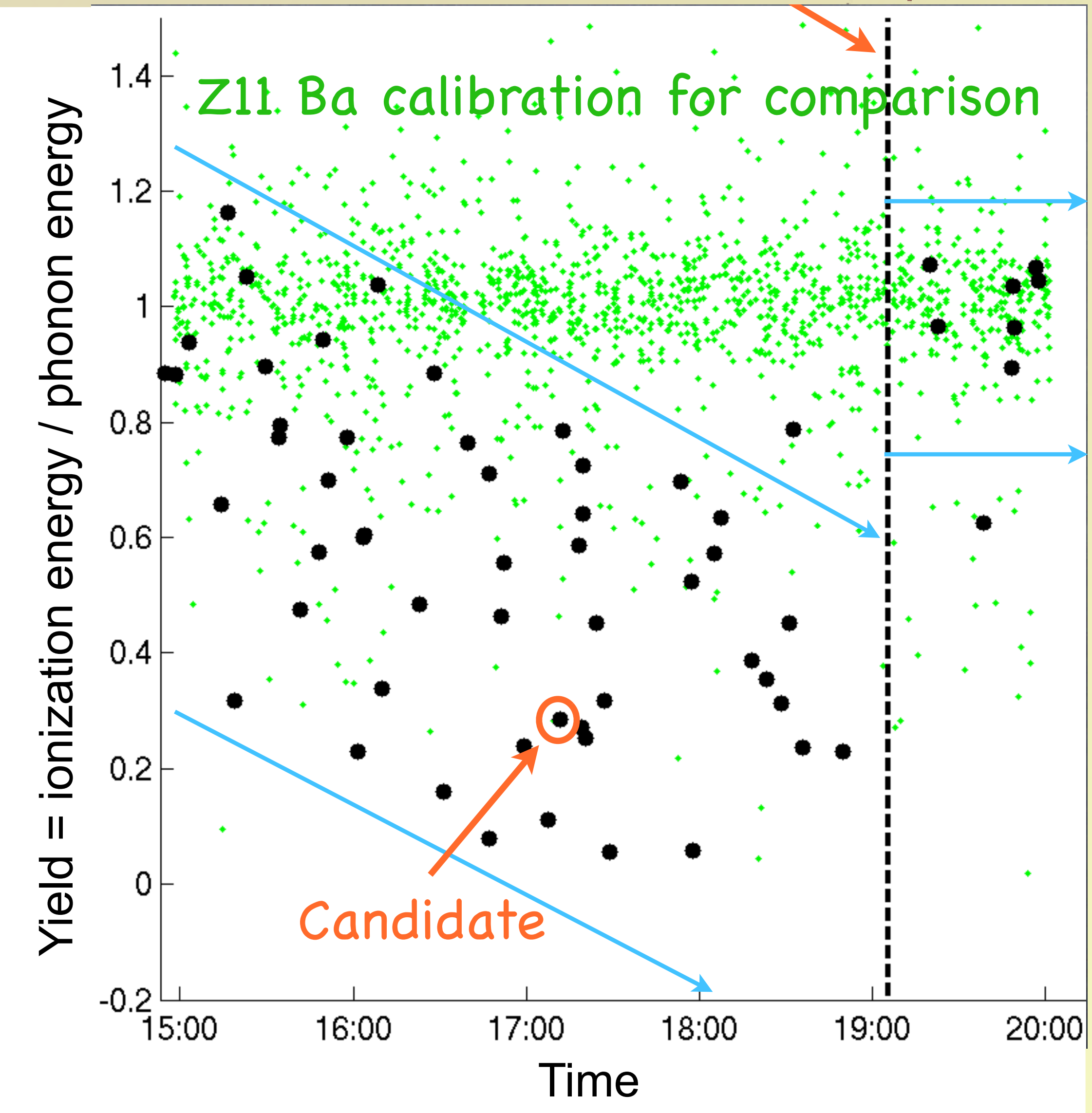
Of the remaining events only one was inside the nuclear recoil region (red star).



Was This Event a WIMP?

Probably Not!

Event occurred during a time of known poor detector performance.



CDMS-II

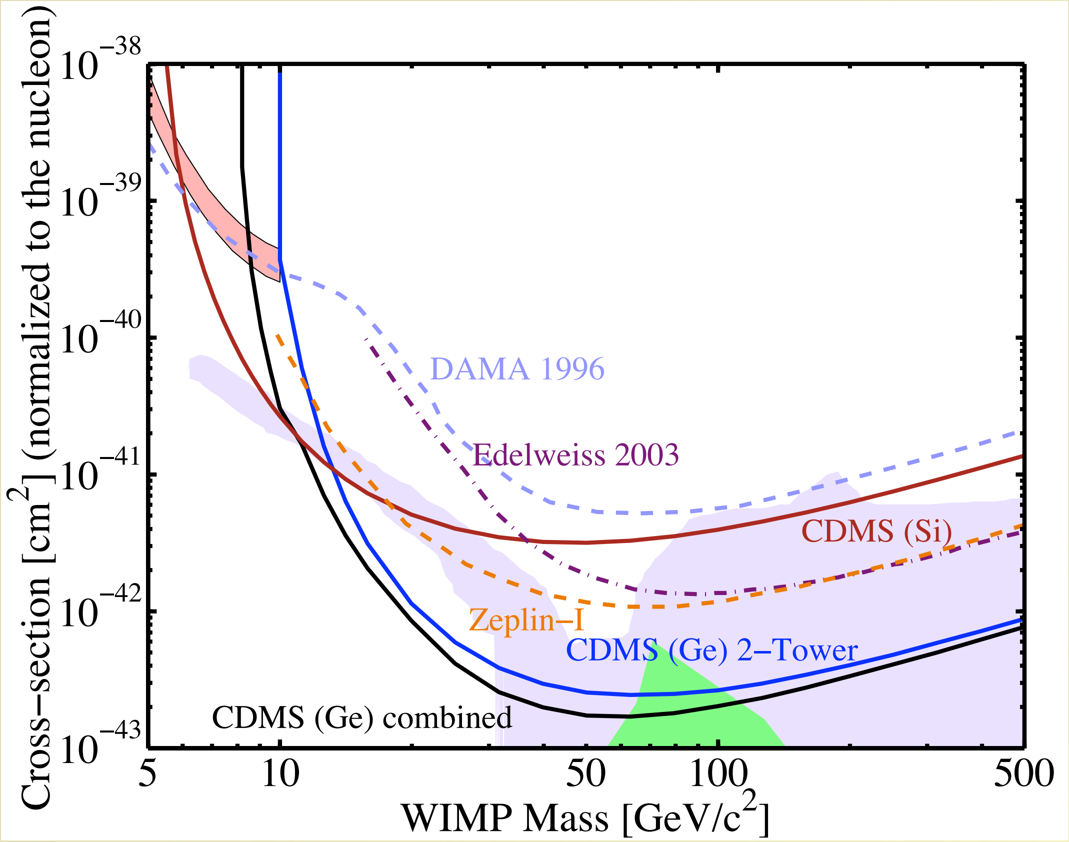
Upper limit on the WIMP-nucleon spin-independent cross section is ***1.6×10^{-43} cm²*** *for a WIMP with mass of* ***60 GeV/c²***.

Factor of 10 lower than any other experiment.

Excludes large regions of SUSY parameter space under some frameworks

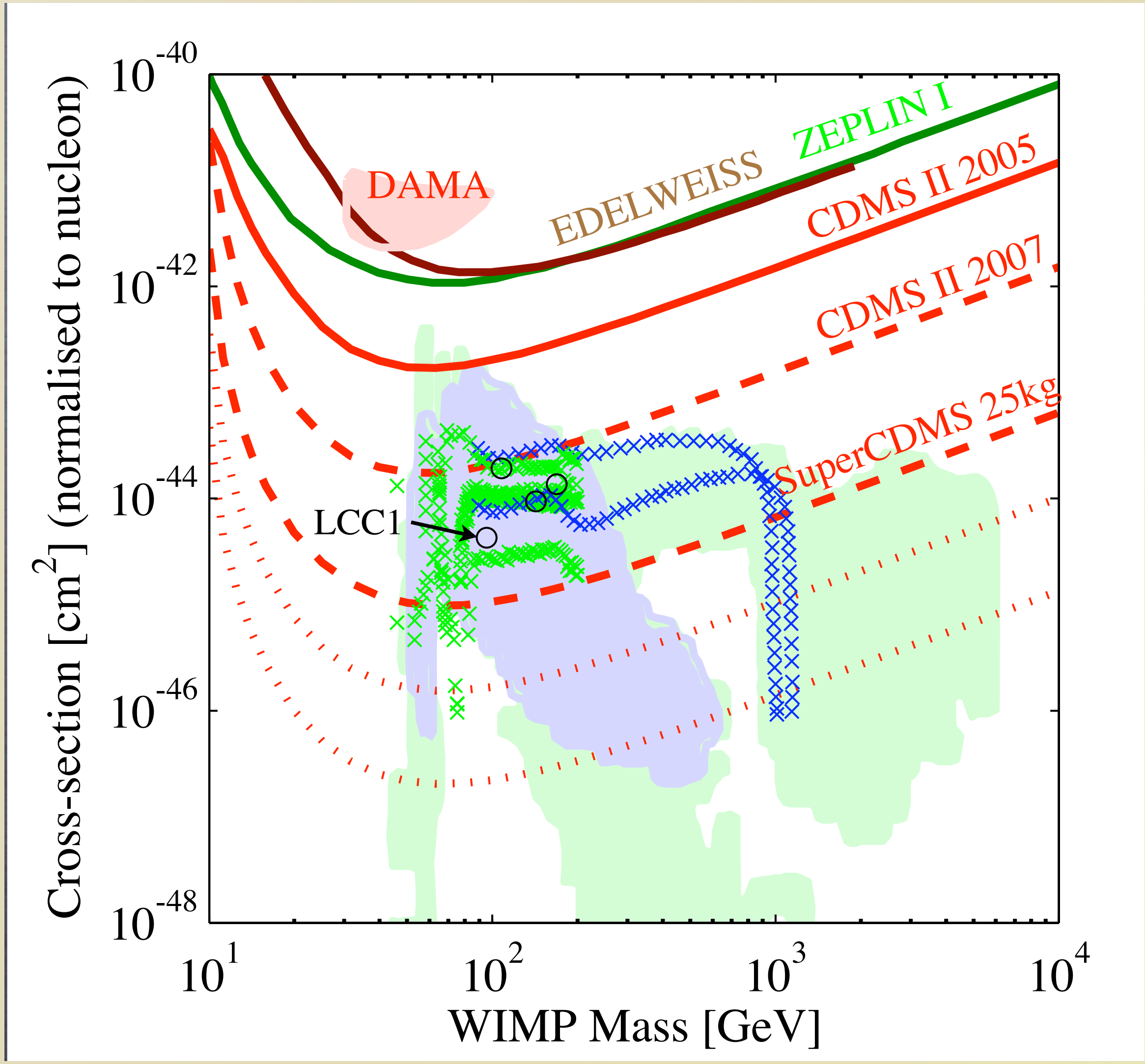
A. Bottino et al, Phys. Rev D 69, 037302 (2004) in purple.

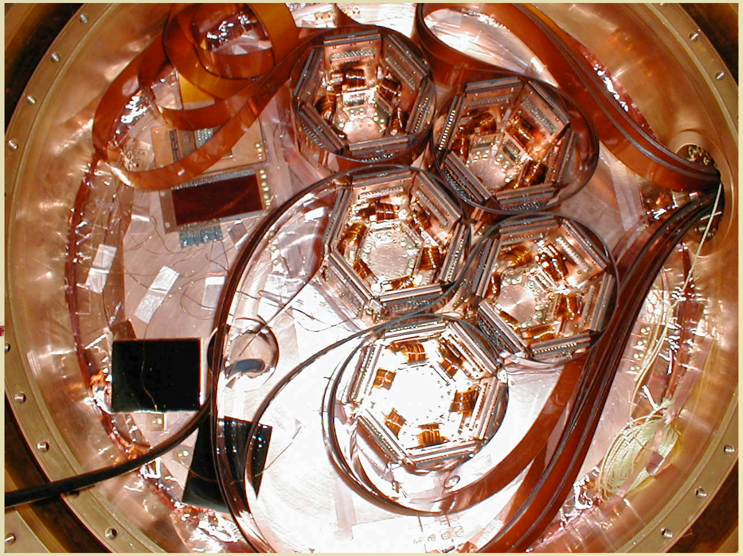
J. Ellis et al., Phys. Rev. D 71, 095007 (2005) in green



Phys. Rev. Lett. 96 (2006) 011302

CDMS-II Projections





Installed 3 additional towers

Additional improvements

Cryogenics, backgrounds, DAQ

Took first engineering run 5 tower on data June 29, 2006

Plan to start WIMP-search data run September 1, 2006

30 detectors in 5 towers containing 6 detectors each

4.75 kg of Ge, 1.1 kg of Si to run through 2007

Improve sensitivity ~ x10

Super-CDMS

25 kg - 150 kg - 1 ton of ultra-cold Ge detectors

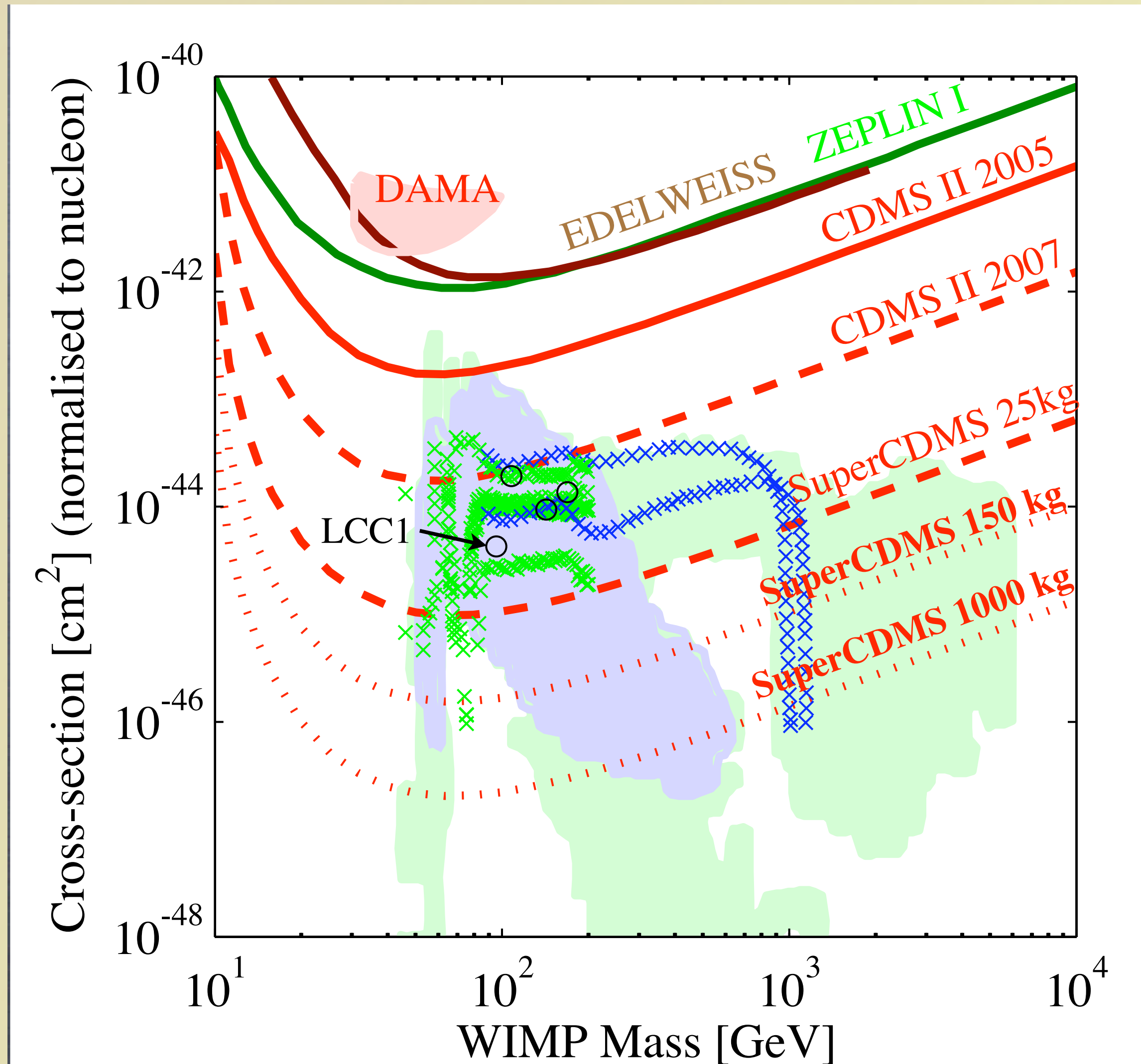
Move from Soudan to SNOlab

Reduce muon flux by 500

Reduce HE neutron flux by >100

CDMS II ZIPs:
3” diameter x 1 cm ⇒ 0.25 kg Ge

SuperCDMS ZIPs:
3” diameter x 1” ⇒ 0.64 kg Ge



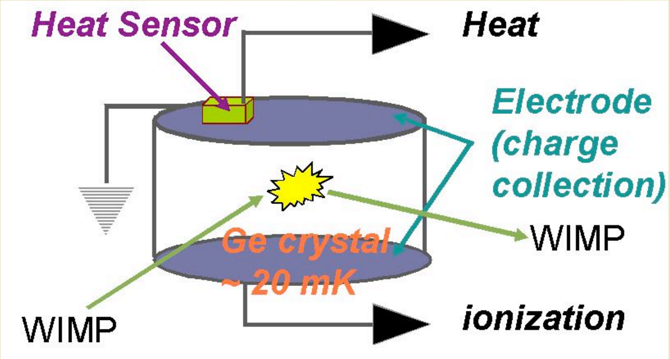
Edelweiss-I

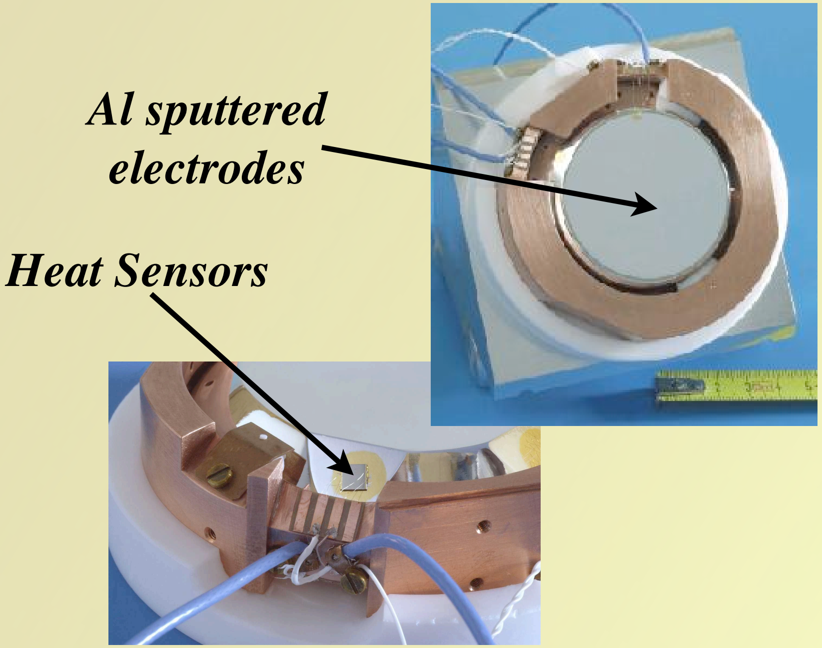
Located in the Frejus tunnel under the French-Italian Alps (4800 mwe).

Detection technique similar to CDMS
Heat measurement made by a neutron transmutation doped (NTD) Ge thermometric sensor.

Measured neutron flux in lab of E < 1 MeV
1.6 x 10^{-6} n/cm^2/s

Results from three 320 g cryogenic detectors and total fiducial exposure of 62 kg days.





Edelweiss-I

Results from several data runs.

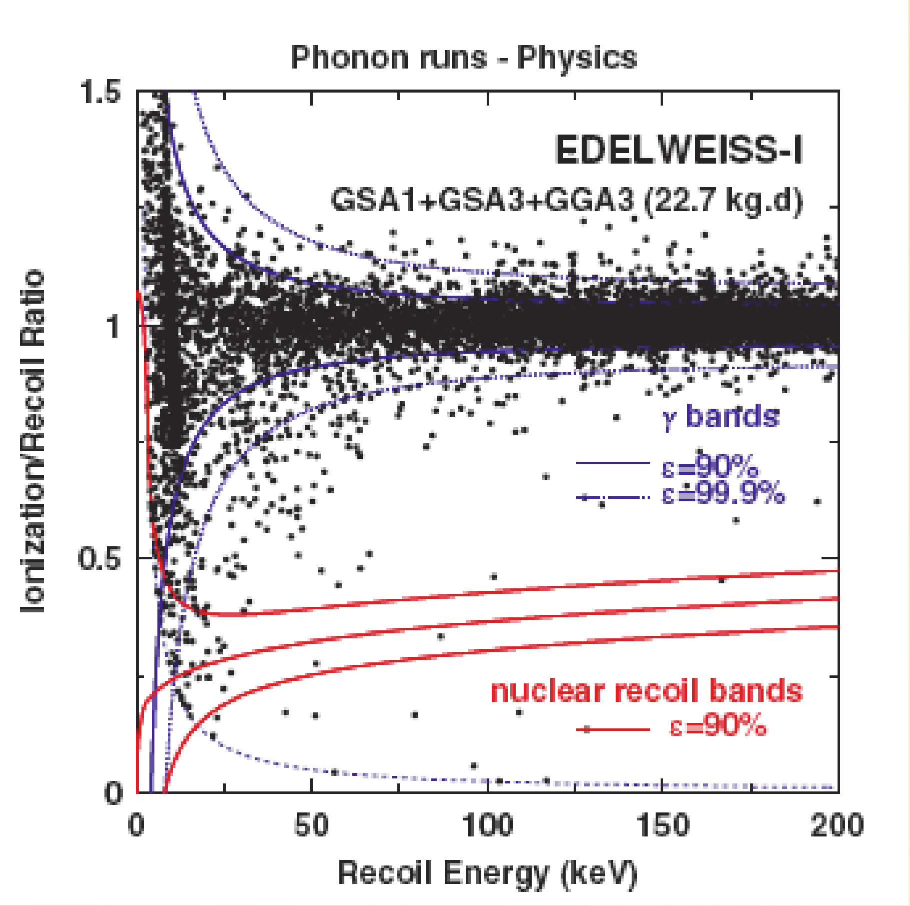
2000 - 2002 exposure 13. 6 kg days with 1 (320 g) heat-and-ionization Ge detector.

2003 exposure 48.4 kg days with 3 (320 g) heat-and-ionization Ge detectors.

Total fiducial exposure of 62 kg days.

40 nuclear recoil candidates in the E_R>15 keV

3 nuclear recoil candidates in the 30<E_R<100 keV region



Phys. Rev. D 71, 122002 (2005)

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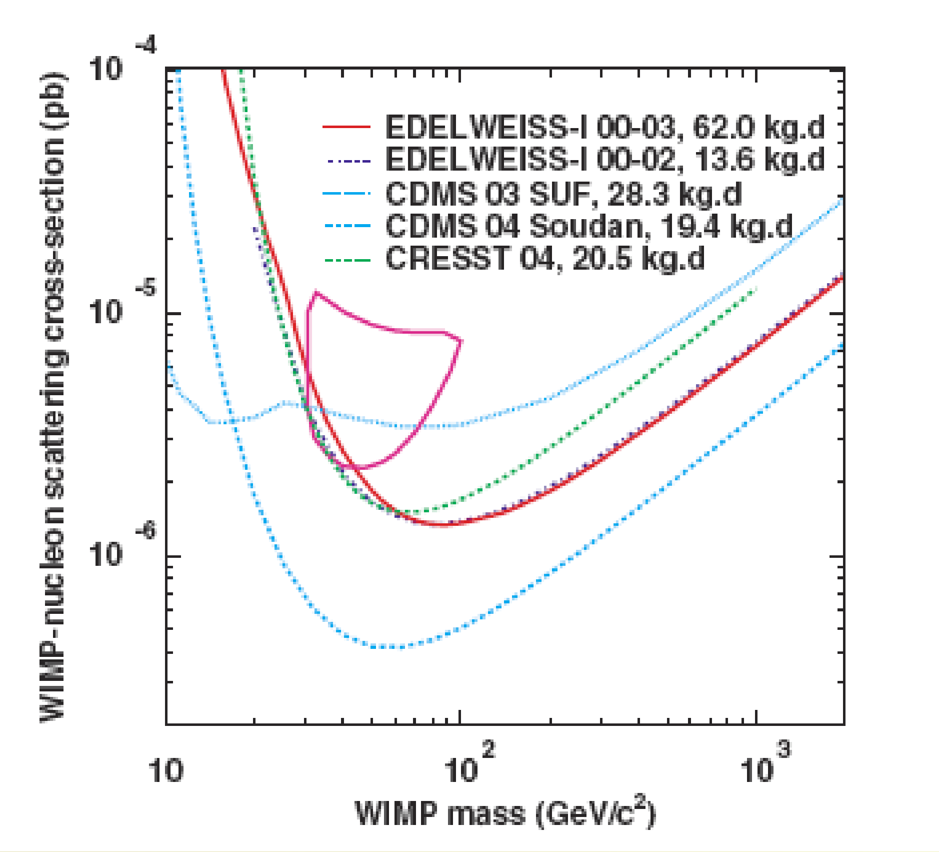
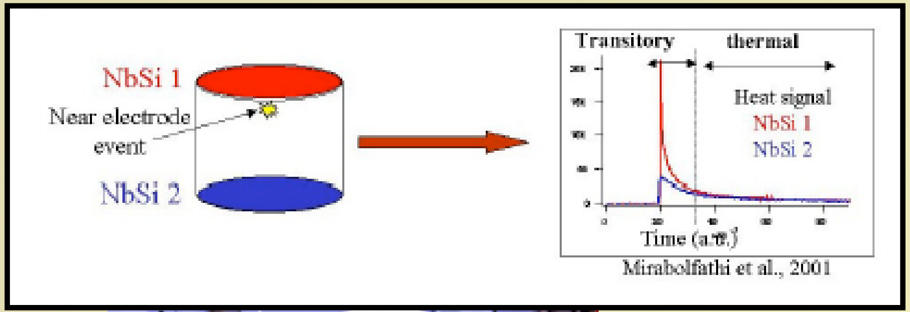


This gives a maximum sensitivity of 1.5×10^{-6} pb at 80 GeV

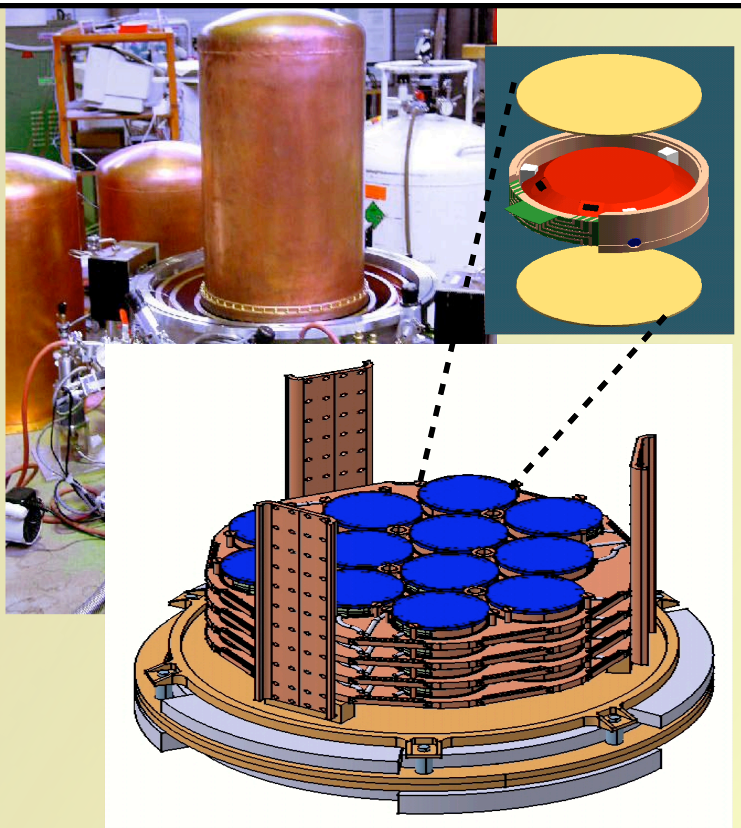
Phys. Rev. D 71, 122002 (2005)

Edelweiss-II



Aim for a factor of 100 improvement.

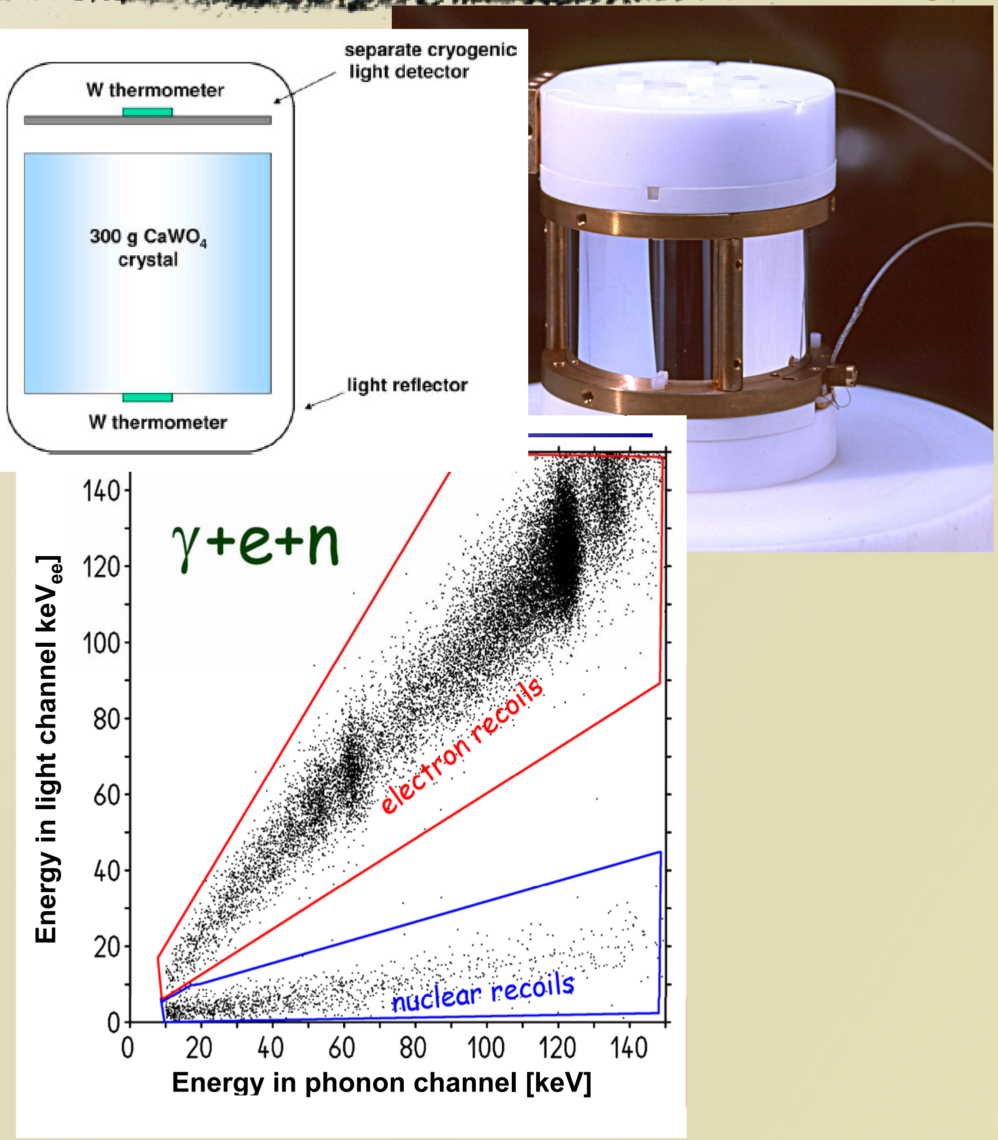
Began installation in 2004
- *21 (320 g) Ge detectors with NTD heat sensors.*
- *7 (400 g) Ge detectors with NbSi thin film sensors*



Installed a new cryostat to hold up to 120 detectors (36 kg Ge).

Improvements to neutron shielding.
- *Add muon veto*
- *Add 20 cm lead*
- *Increasing to 50 cm polyethylene*

CRESST II



Experiment located in Gran Sasso (3500 mwe).

Data taken with two 300 g $CaWO_4$ prototype detectors which measure phonon signals and light.

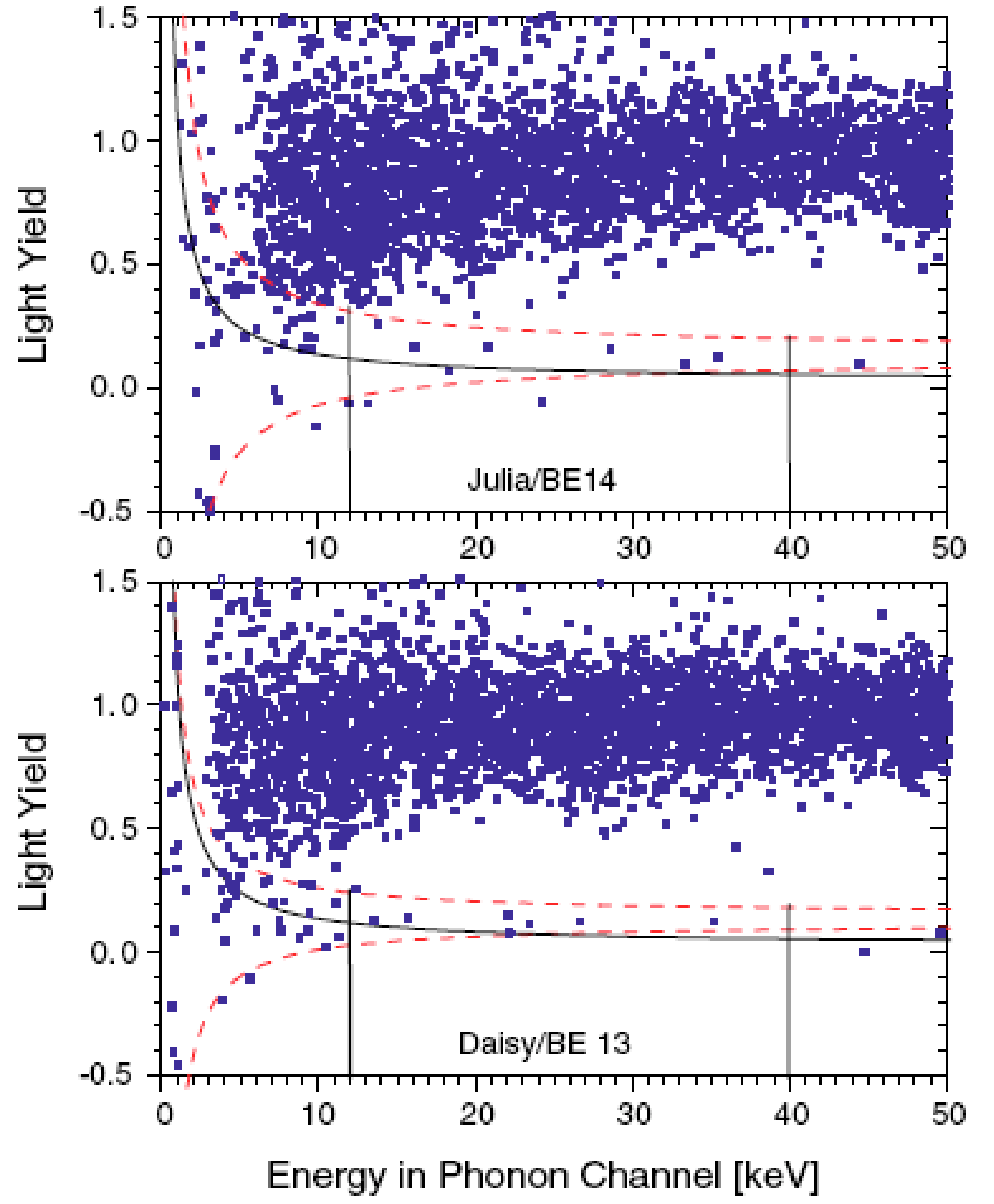
20.5 kg day exposure from Jan 31 - Mar 23, 2004.

CRESST II

16 event total; agrees with predicted neutron background.

Below solid line contains 90% of W recoils. Below dashed line contains 90% of all recoils.

Data taken with no active neutron veto.

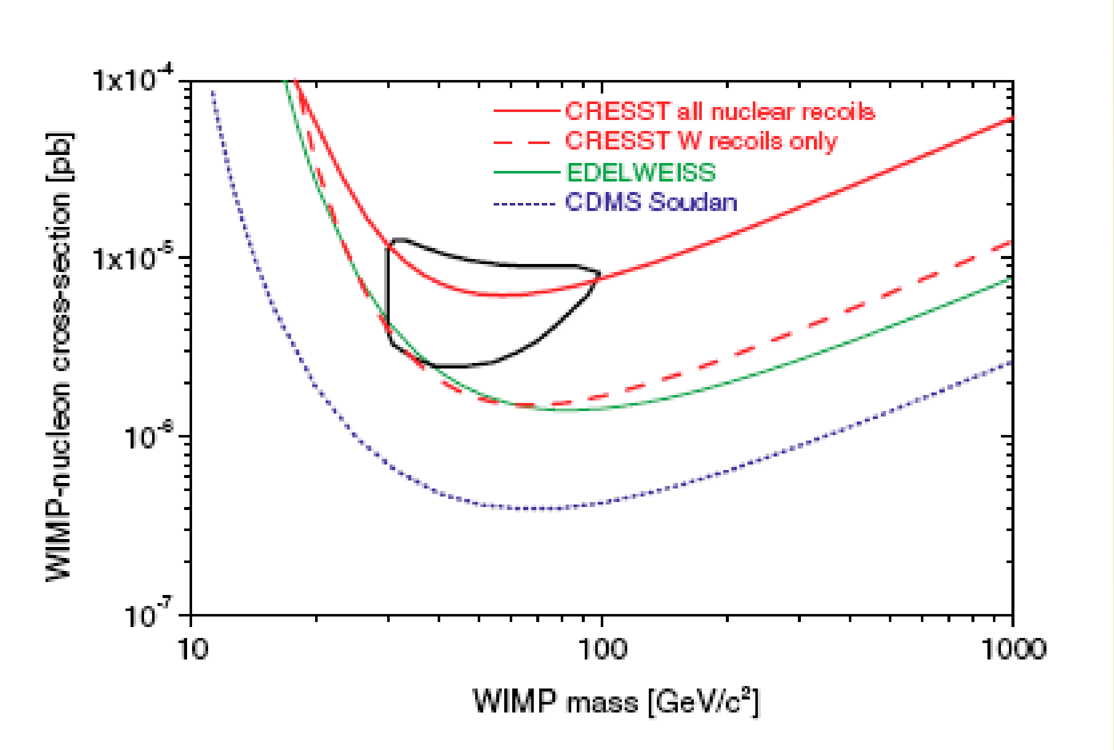


Astropart. Phys. 23, (2005) 325

CRESST II

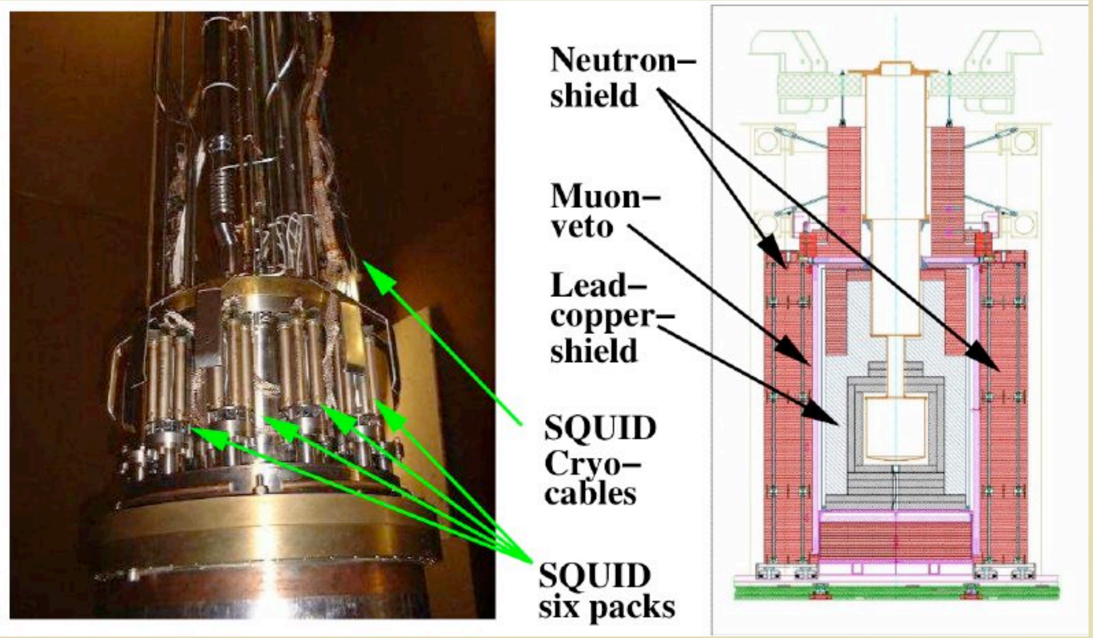
16 event total; Agrees with predicted neutron background.

No active neutron veto for this data.



Astropart. Phys. 23, (2005) 325

CRESST II Upgrades



March 2004 operation stopped to install neutron veto, 66 channel SQUID readout to enable operation of 33 detector modules.

The work on the neutron veto and SQUID readout is complete.

Currently working on the detector-holder system and new analysis software.

Expect to be taking data by end of summer 2006.

Zeplin I

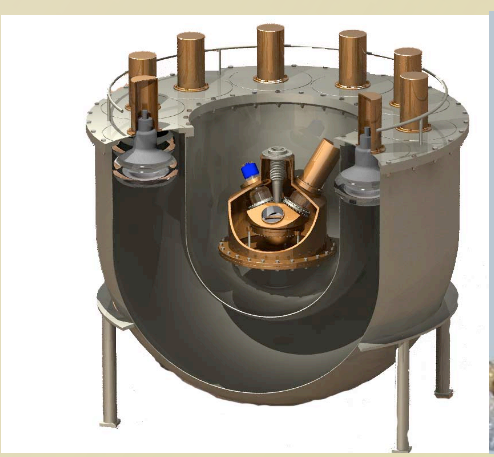
Located in UK Boulby Mine (2800 mwe).

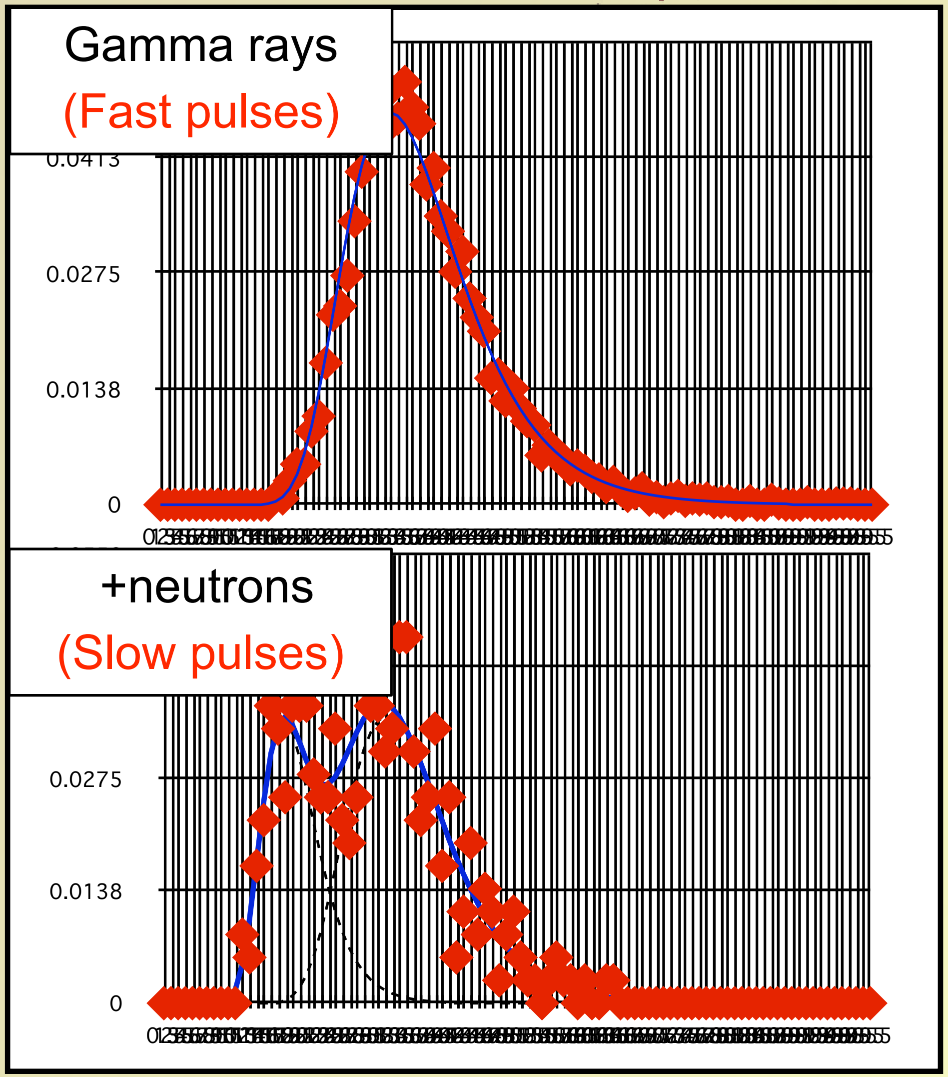
Three runs totaling 293 kg days exposure. Liquid xenon target mass ~5 kg, with fiducial mass 3.2 kg.

Discrimination factor is pulse shapes.

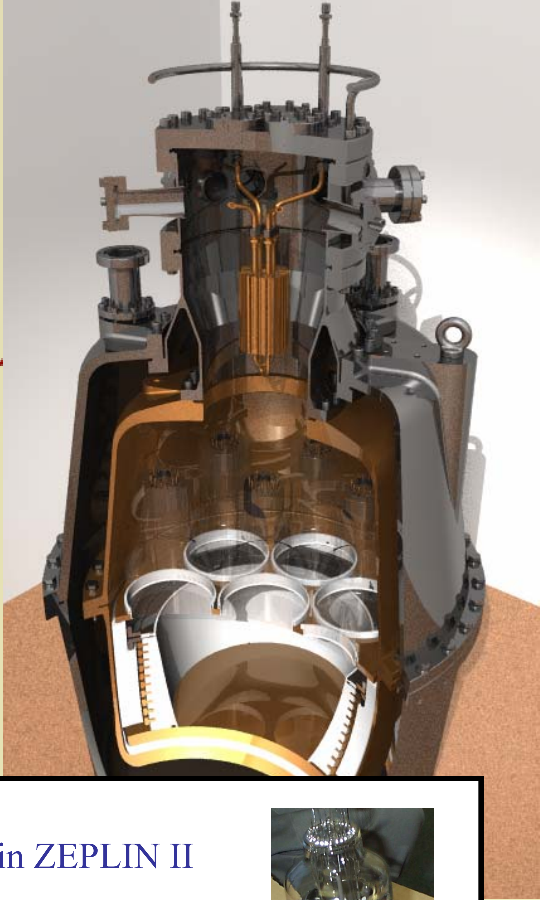
*Max sensitivity was 1.1 x 10^{-42} cm^2 (**Astropart 23 (2005) 44**).*

No in situ neutron calibration was preformed.



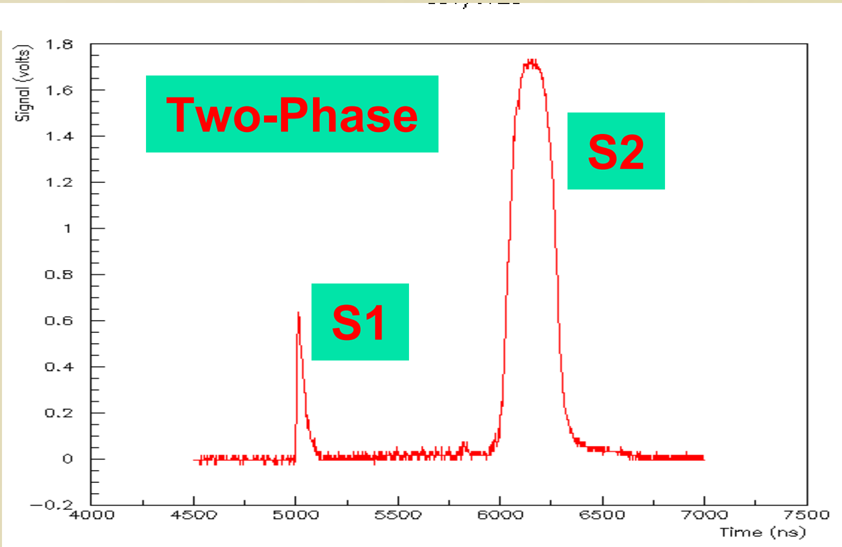
Zeplin II

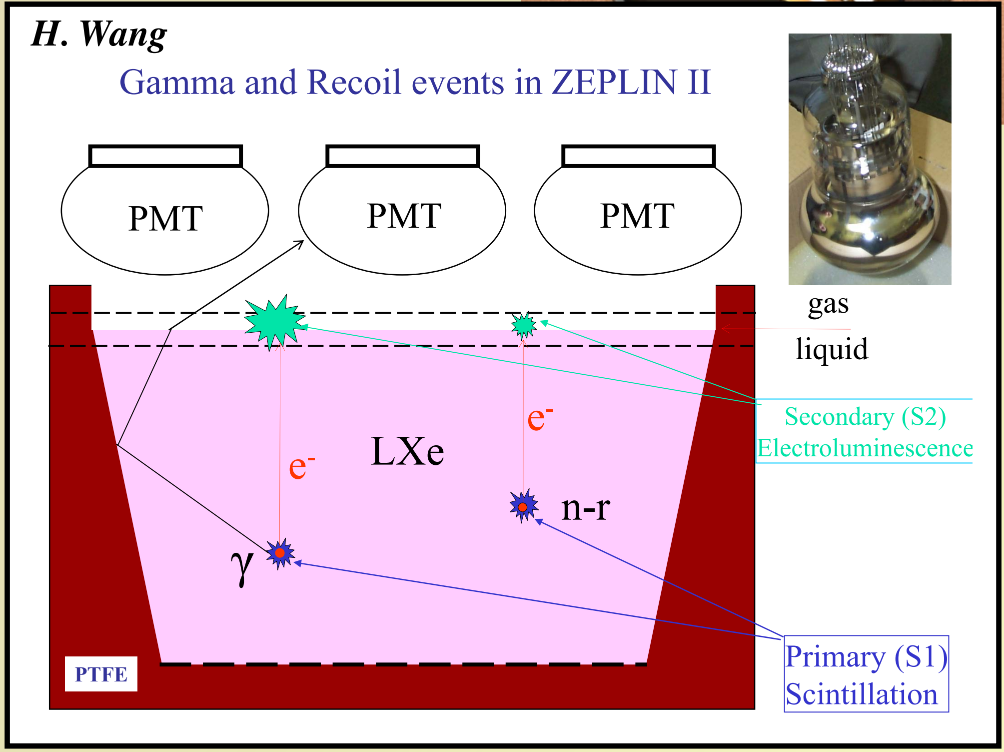


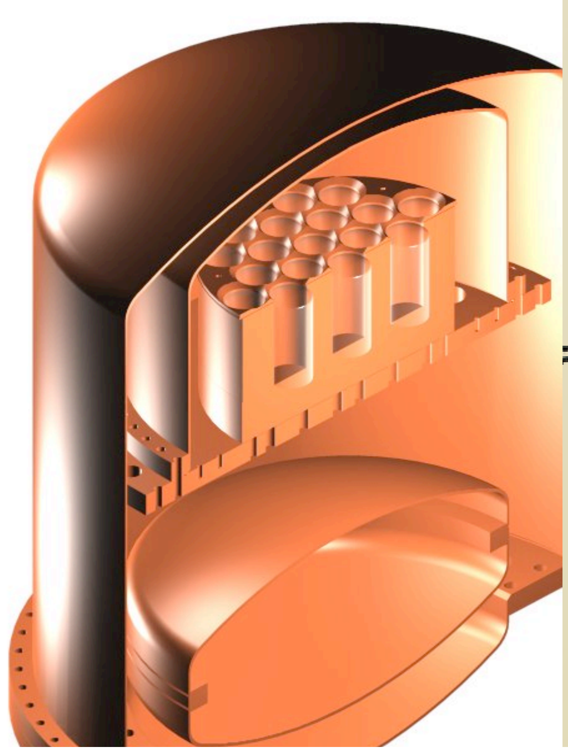
Measure primary and secondary light and drift distance with 7 (5") PMTs using a 2 phase liquid and gas Xe.

Calibrations and system checkouts under way in the Boubly mine.

Expected to run from 2007 to 2012.





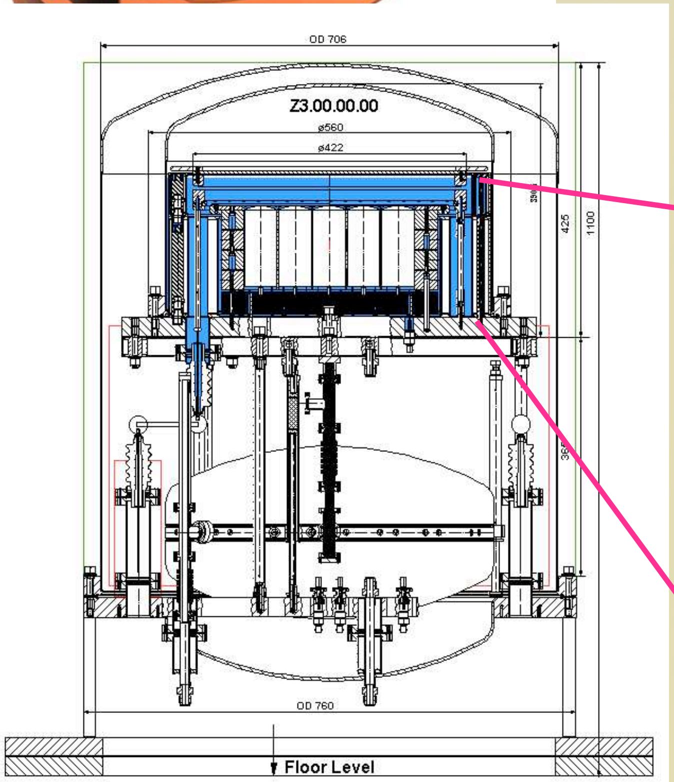


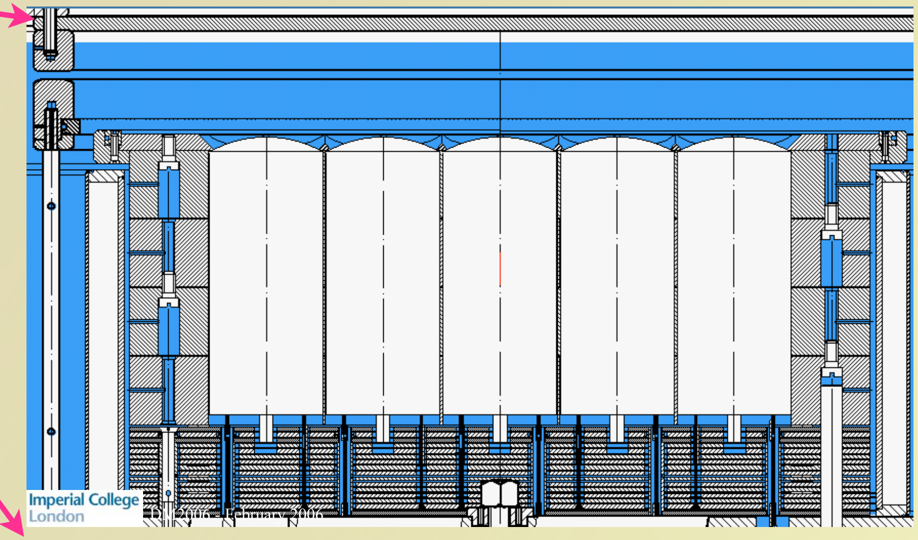
Zeplin III

Uses same 2 phase set up as Zeplin II, but with 31, smaller 2" PMTs at bottom of detector. Total mass 8 kg.

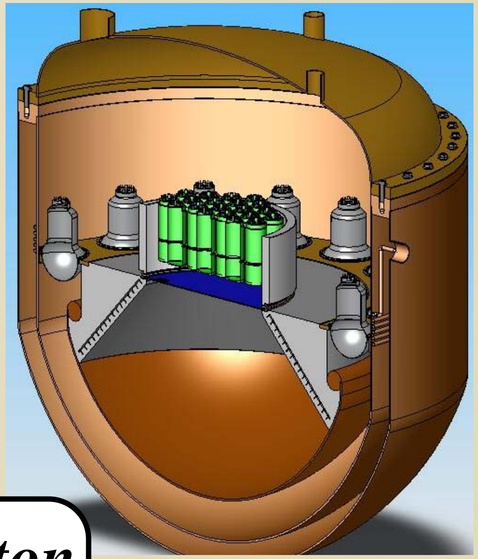
Three cool downs have been preformed at the surface for calibrations and system checks.

Continue evaluations and optimization for next 3 months. Expected to run from 2007 - 2012 in Boulby mine.



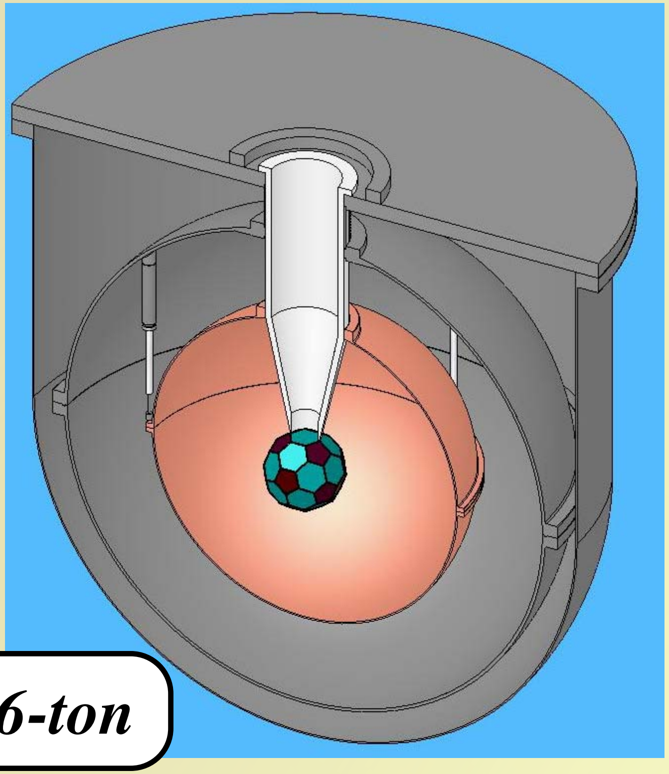


Zeplin IV/MAX and Beyond



1-ton

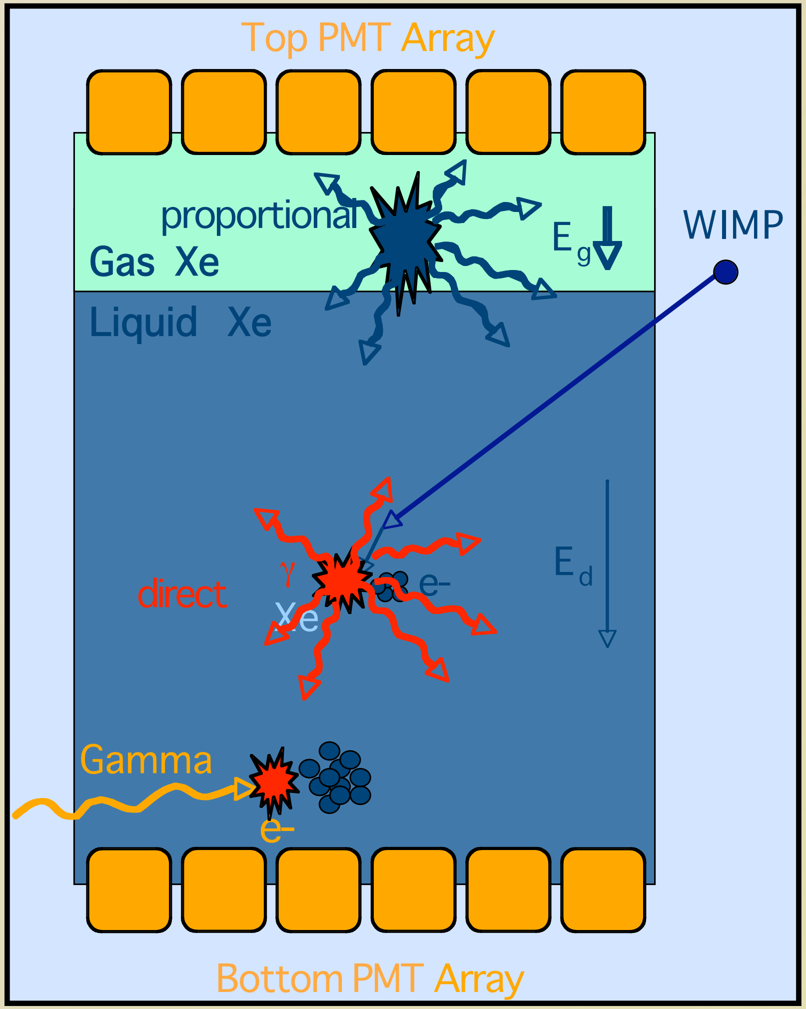
Start planning Zeplin IV/MAX to be installed in SNOLab 2008-2012.



6-ton

Explore the capabilities of nobel gases with new ideas and design technologies (2013 and beyond).

XENON10



Similar technology to Zeplin family.

Top array has 48 PMTs, bottom array has 41 PMTs of 8 inch diameter.

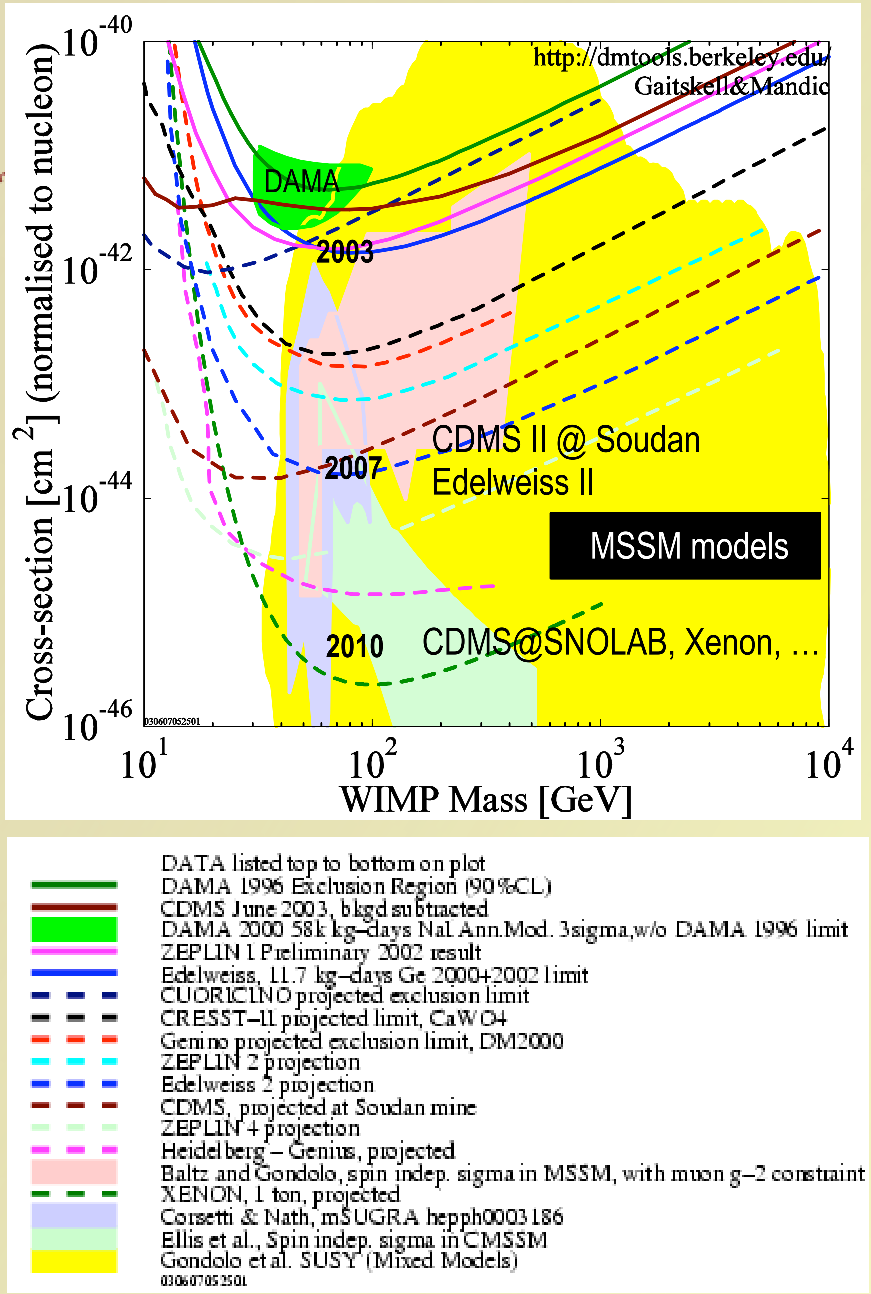
Total mass is 15 kg liquid Xe.

Currently commissioning in Gran Sasso, Italy

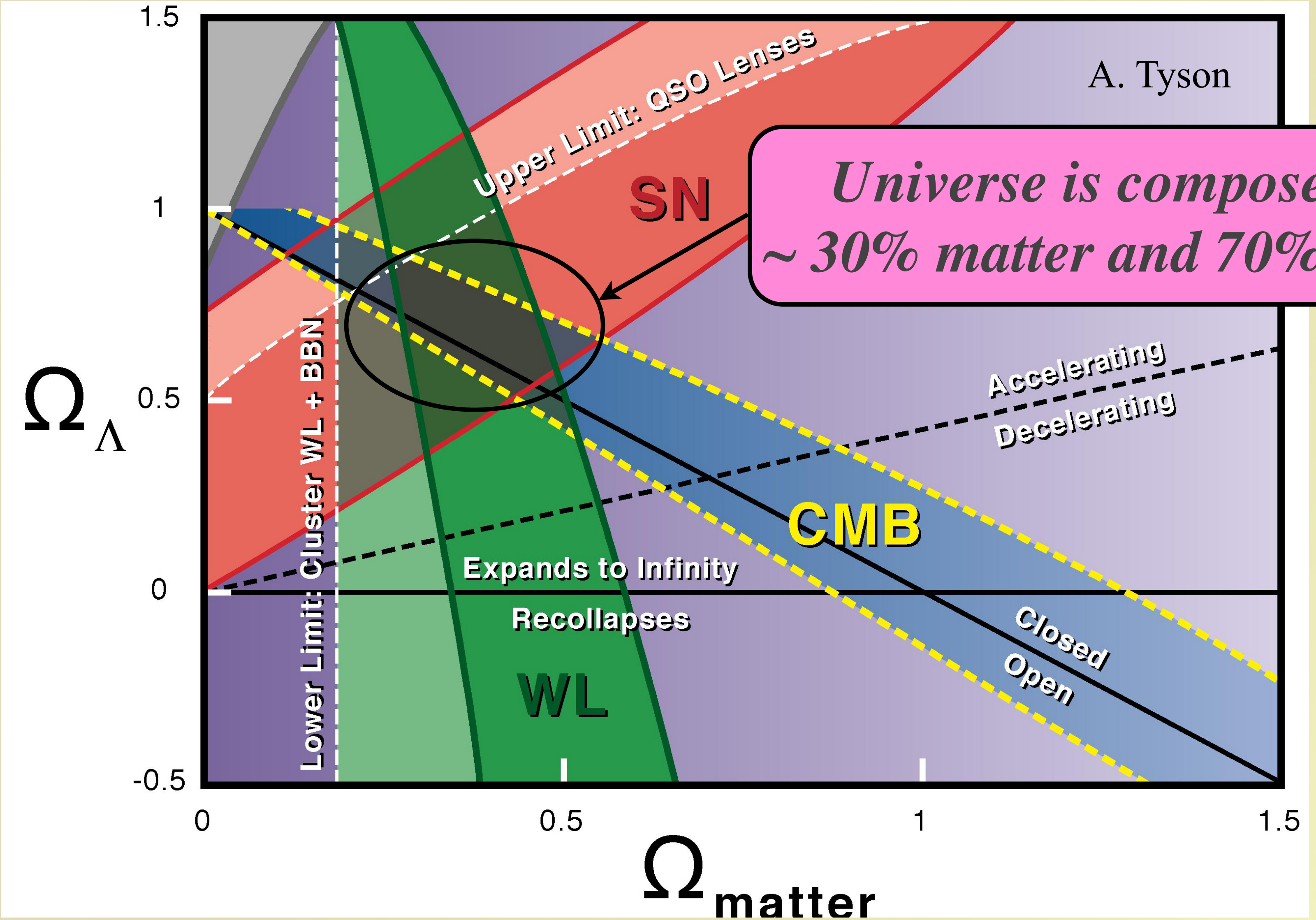
Conclusions

- *CDMS II at Soudan currently has the best limits by a factor of 10. No WIMPs have been seen and result is not compatible with DAMA for scalar coherent interactions using a standard halo model.*
- *Many experiments are getting ready to make large improvements in the next couple of years.*
- *Further into the future, ton-scale experiments would explore significant sections of parameter space.*

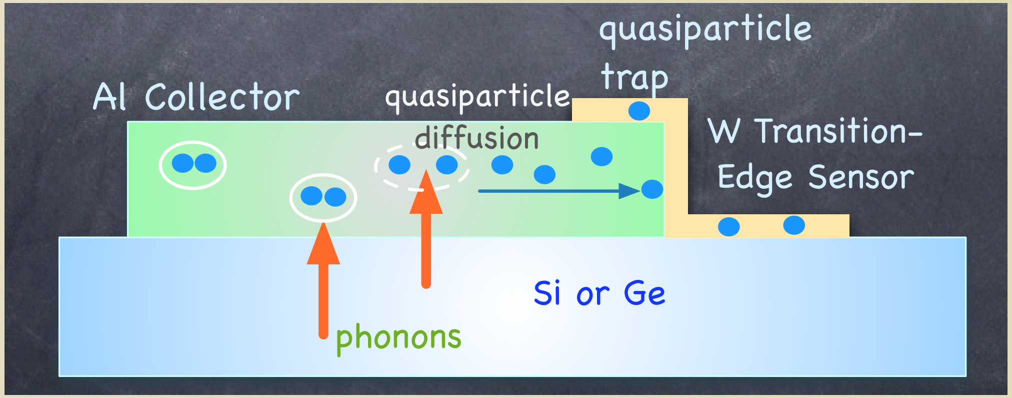
90% CL upper limits assuming standard halo, A^2 scaling



Composition of the Universe



CDMS II Phonon Signal



Phonons propagate to superconducting Al fins where they break cooper pairs.

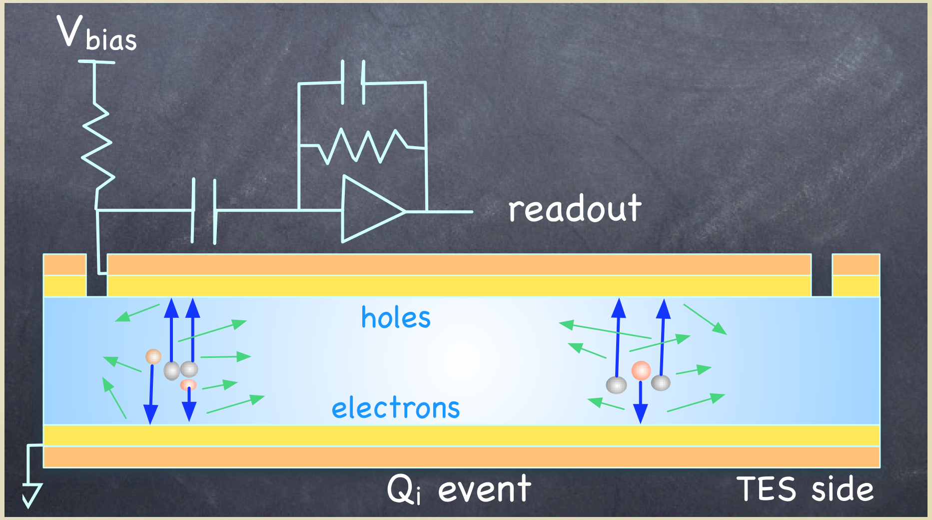
The breaking of cooper pairs create quasiparticles which diffuse into the tungsten transition-edge sensor (TES).

The quasiparticles are trapped in the TES where they release their binding energy to the W electrons.

This increases the temperature of the electron system which increases the resistance. (The TES is voltage biased).

Change in current is then measured by SQUIDS.

CDMS II Ionization Signal



The particle interaction breaks up the e^--hole pairs in the crystal.

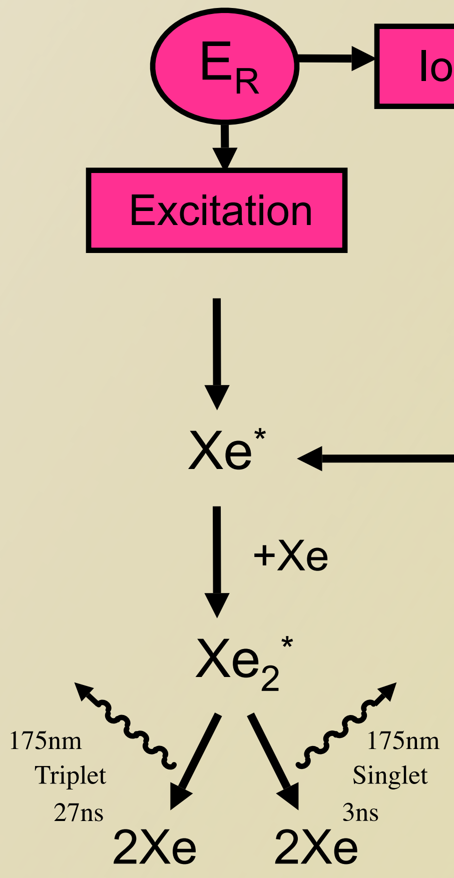
The electrons and holes are separated by an electric field.

The charge is collected by electrodes on the surface.

The detectors each have 2 charge channels. The inner channel covers ~85% of the center of the disk. The outer channel covers the remainder.

Events occurring within a few μm of the surface ("dead layer") result in a decreased charge collection.

Liquid Xenon



Nuclear-recoil pulses are faster than electron recoil ones.

Excited Xe_2^* states decay through singlet (3 ns) and triplet (27 ns) modes, emitting 175 nm photons.

Nuclear recoils result in fewer triplet decays (due to larger dE/dx of nuclei vs. electrons) and faster recombination

CRESST Calibration Plot