Underground Searches for Cold Relics of the Early Universe

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The Cosmic Food Chain

ordinary matter : 4%

0.4 % stars, hot/cold gas, people, pacifiers

3.6 % intergalagctic gas

matter 1/3

dark matter : 23%

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

cal

73%

Most of the Universe is made of something fundamentally different from the 'ordinary matter' we are made of!

Motivation from Particle Physics

Standard Model extremely successful … but incomplete!

Neutrinos oscillate -> are massive!
Hierarchy problem: 10^3 GeV << 10^{19} GeV

Popular extensions:

Supersymmetry (bosons - fermions)
LSP (neutralino)

Extra dimensions (3 +   +1)
LKP (first KK excitation of the photon)

Generic: WIMPs, M ~ 10 GeV - 1 TeV

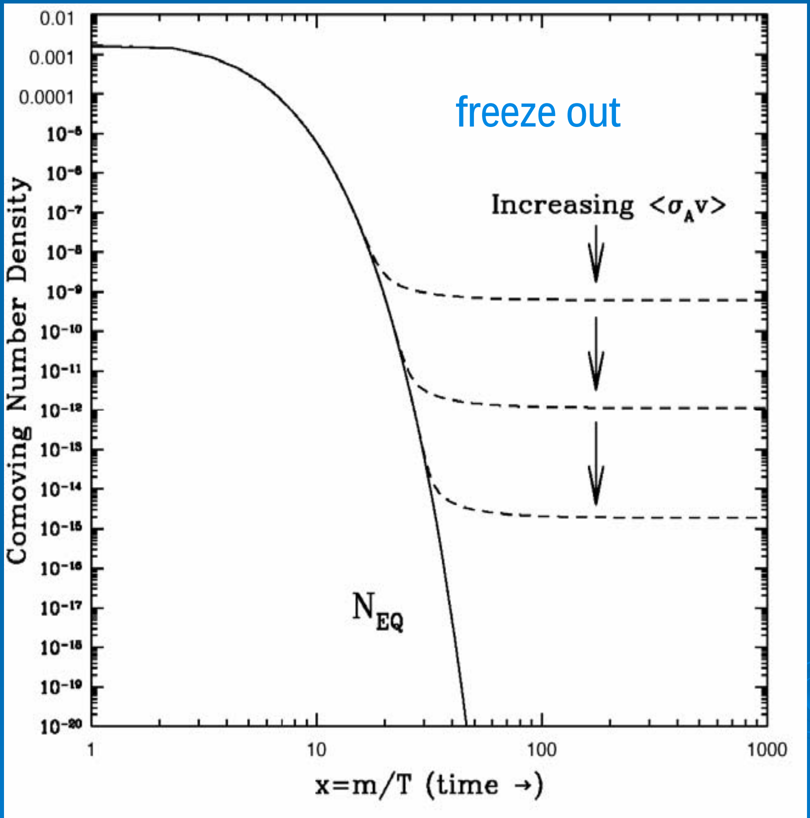
Weakly Interacting Massive Particles

Particles in thermal equilibrium
Decoupling when non-relativistic

Freeze out when annihilation rate
≈ expansion rate

Relic abundance:
$\Omega_\chi\, h^2 \approx 10^{-27}\, \mathrm{cm}^3\, \mathrm{s}^{-1} / \langle \sigma_{ann}\, v \rangle$

if m and $_{ann}$ determined by
electroweak physics, then ~ 1



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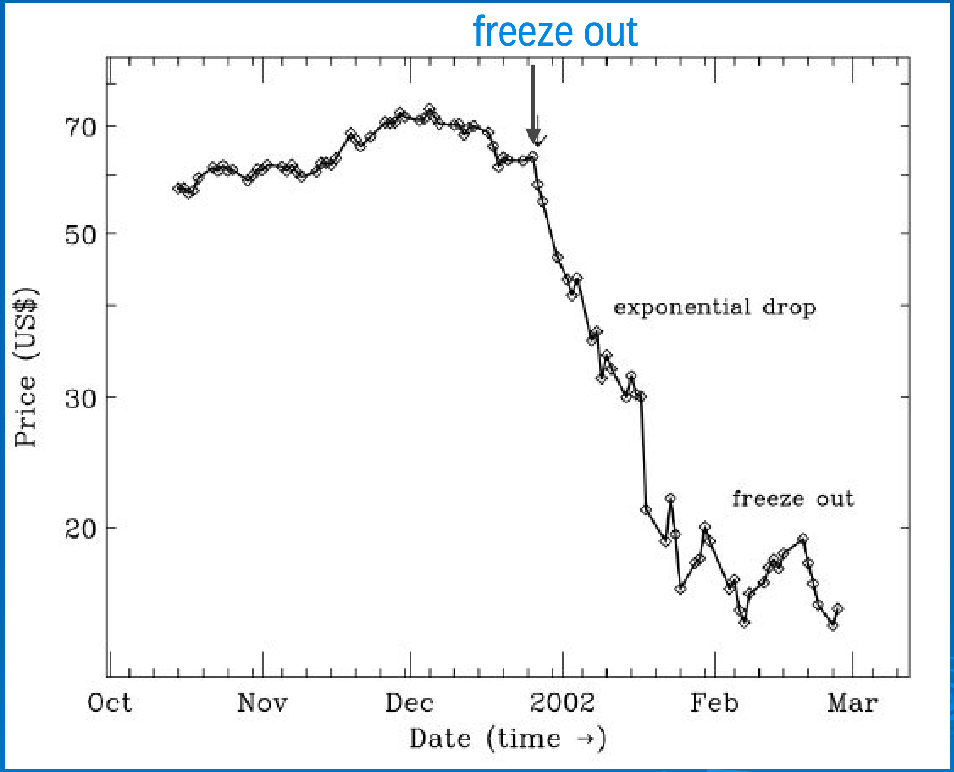
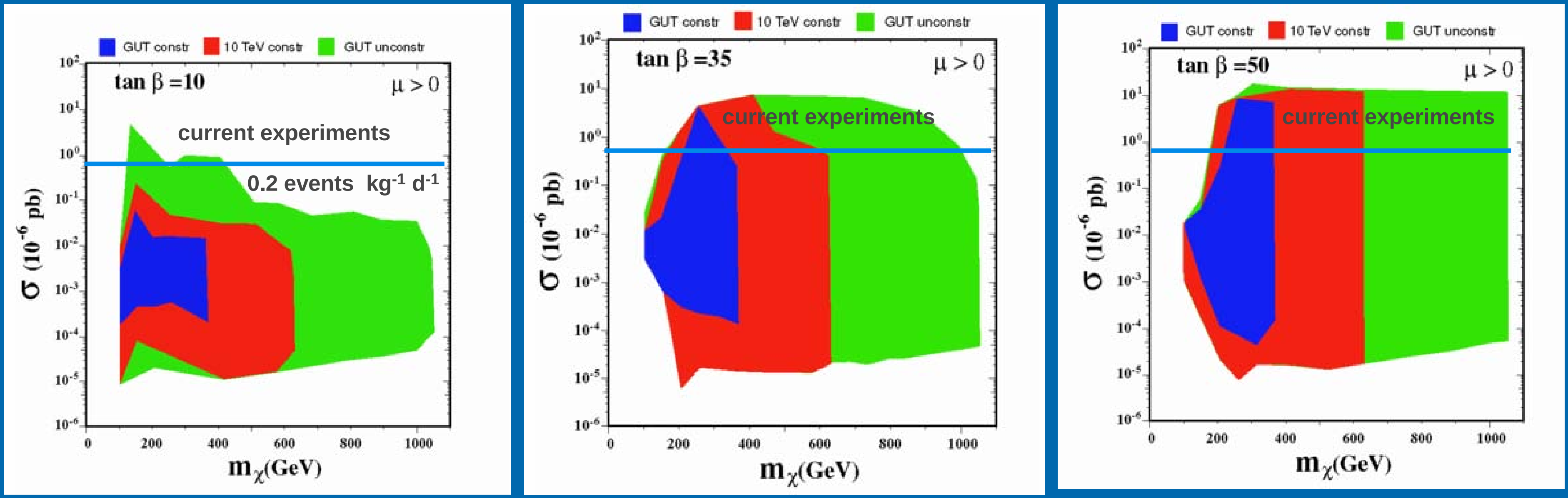
Martha Stewart sells ImClone stock



J.Feng astro-ph/0405479

WIMP nucleus cross section

In MSSM/CMSSM (neutralino):



Ellis, Olive, Santoso, Spanos: hep-ph/0308075

No tachyons before GUT scale

No tachyons before 10 TeV

No constraints: low energy effective SUSY

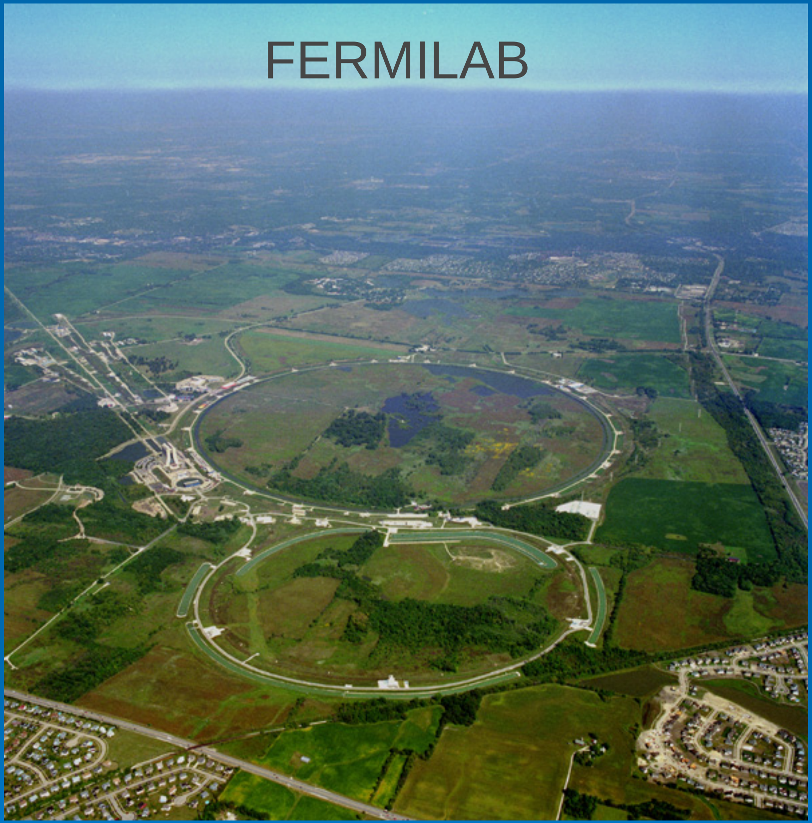
WIMPs:

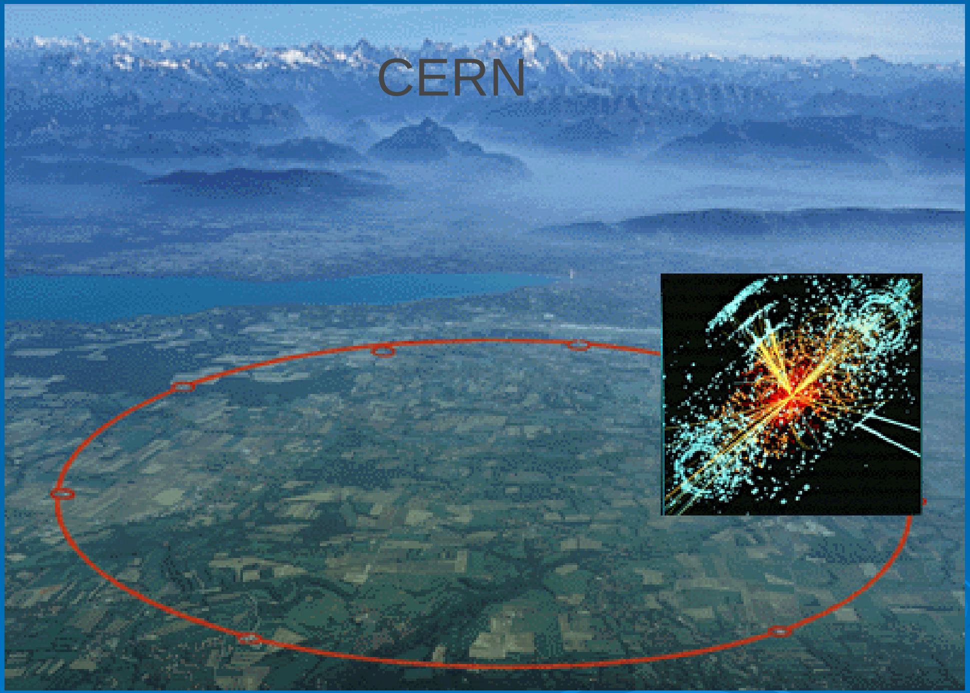
10^6 per second through your thumb without being noticed!

10^{15} through a human body each day: only < 10 will interact, the rest is passing through unaffected!

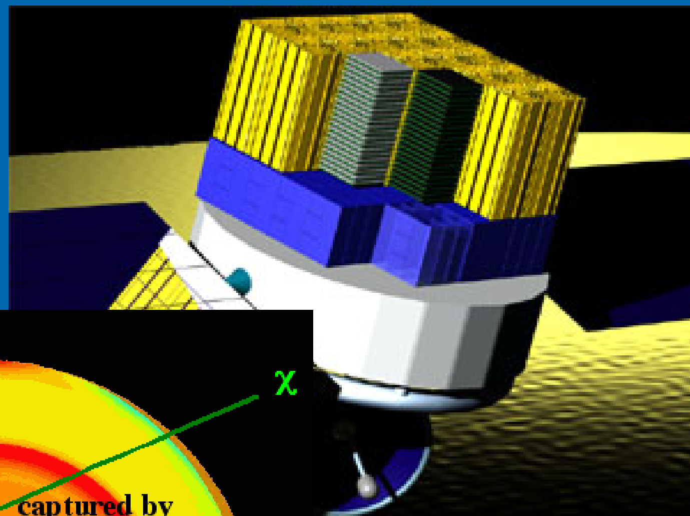
If their interaction is so weak, how can we detect them?

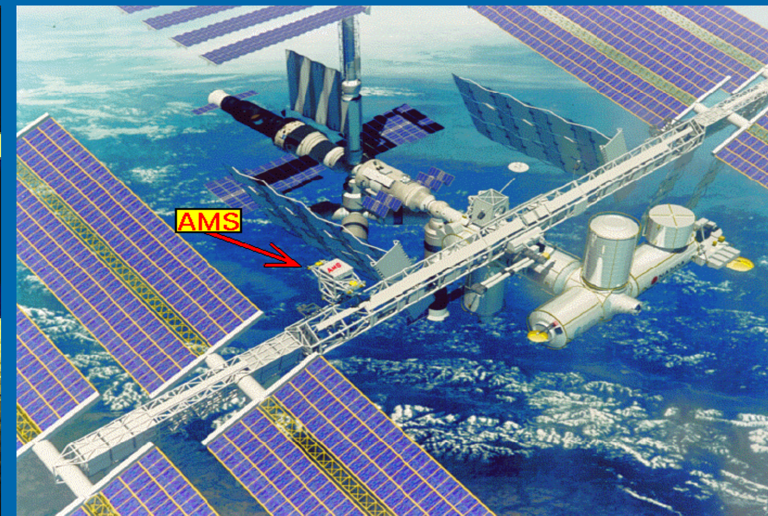
We can make them in accelerators…

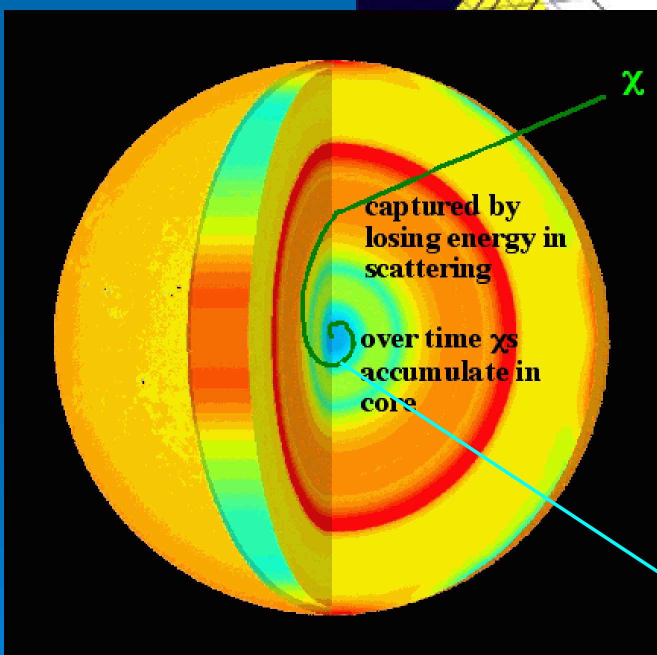


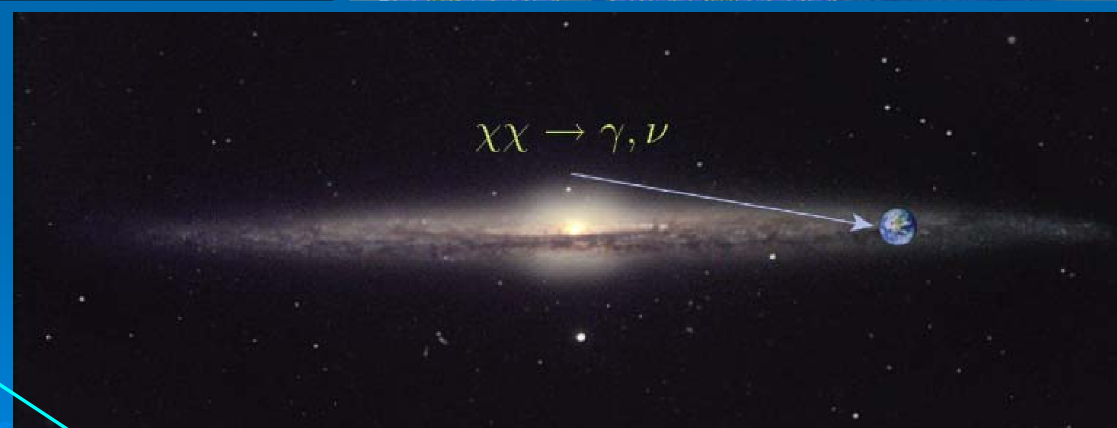


We can look at the Sun or go into space…

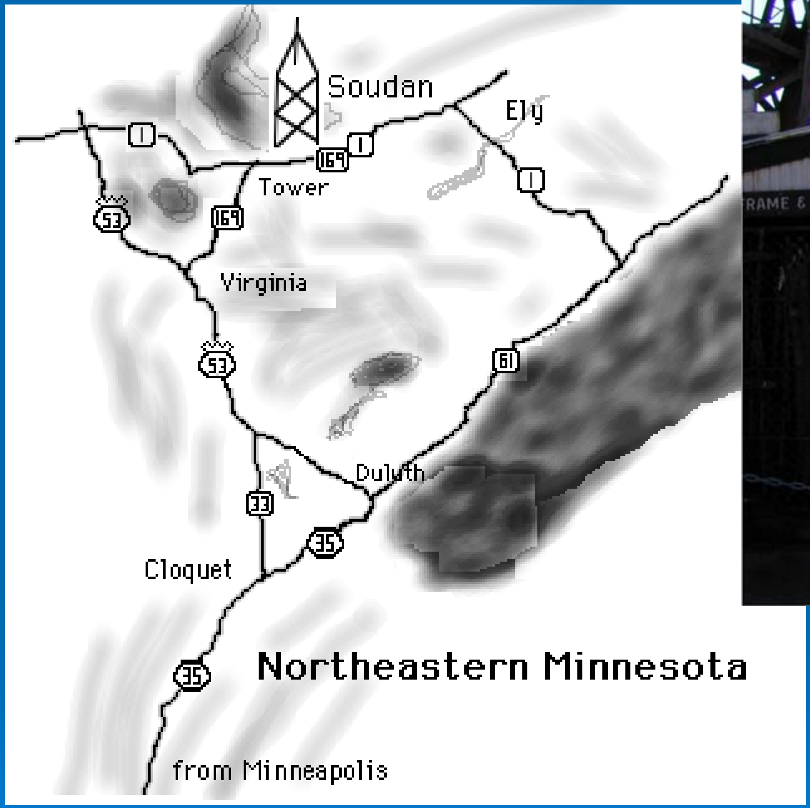






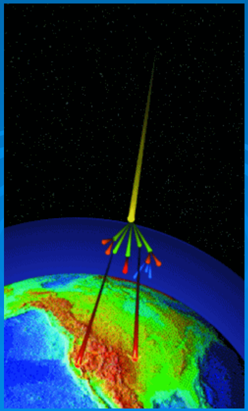


Or we can go to Minnesota…



deep down an old iron mine…

… to get rid of
COSMIC RAYS



…and directly detect WIMPs in the lab

Every liter of space: 10-100 WIMPs,
moving at 1/1000 the speed of light

WIMPs scatter elastically with nuclei:

Rate ~ N n_χ <σ_χ>

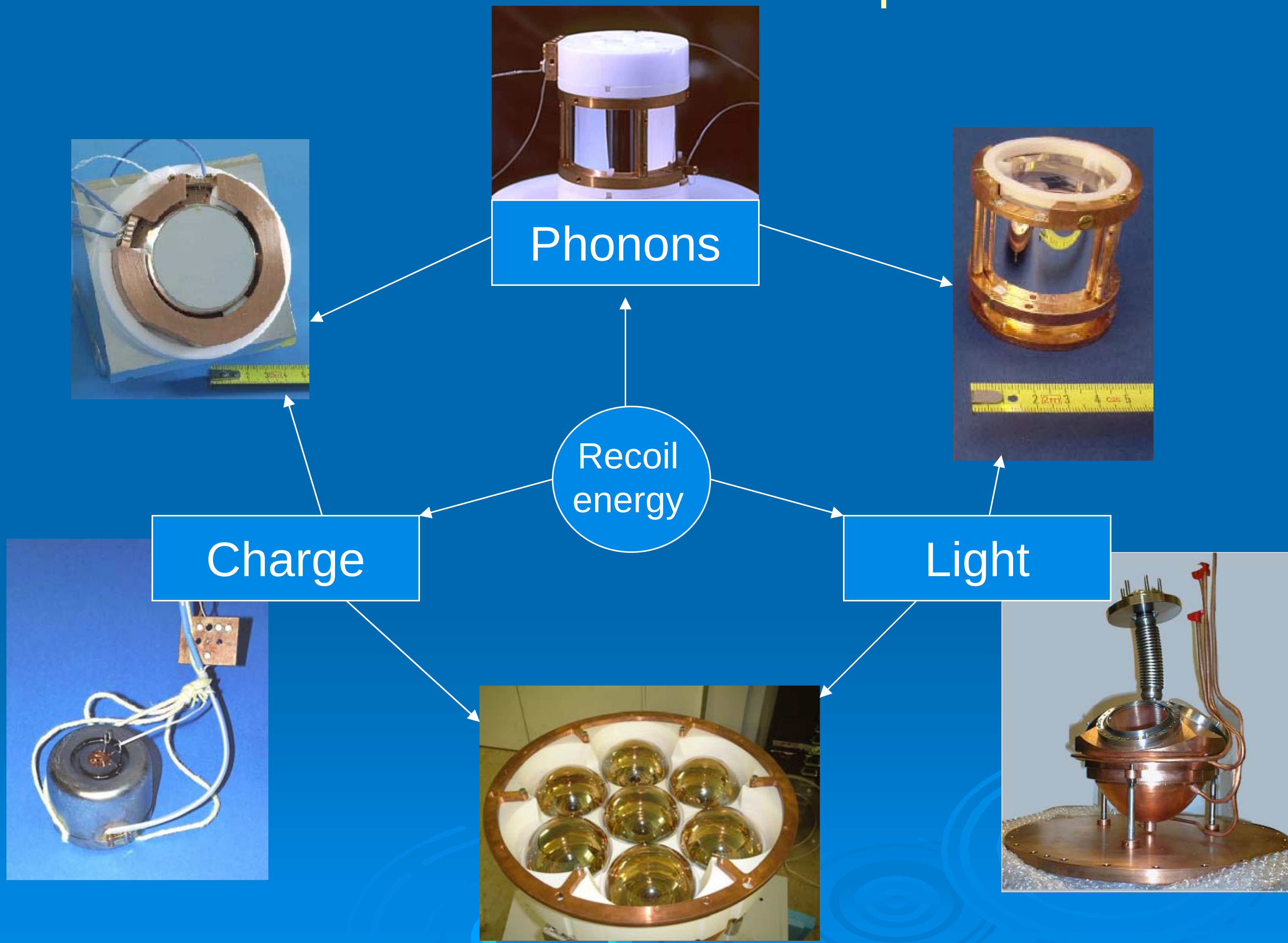
N = number of target nuclei in detector

n = local WIMP density

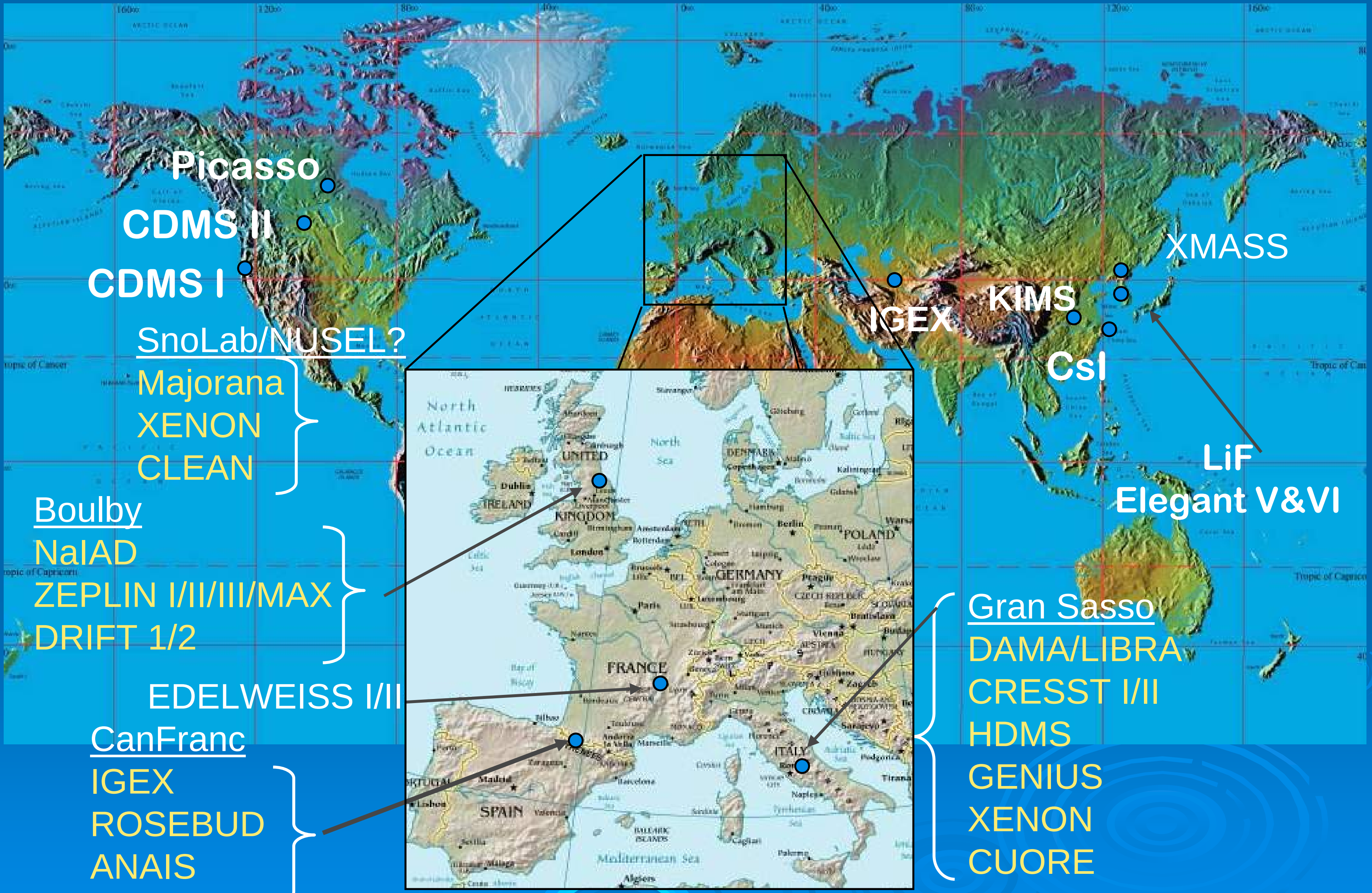
< > = scattering cross section
(mean over relative WIMP-detector velocity)

Signal = WIMPs interact with nuclei
≠ Background = electron interactions
(if no neutrons)

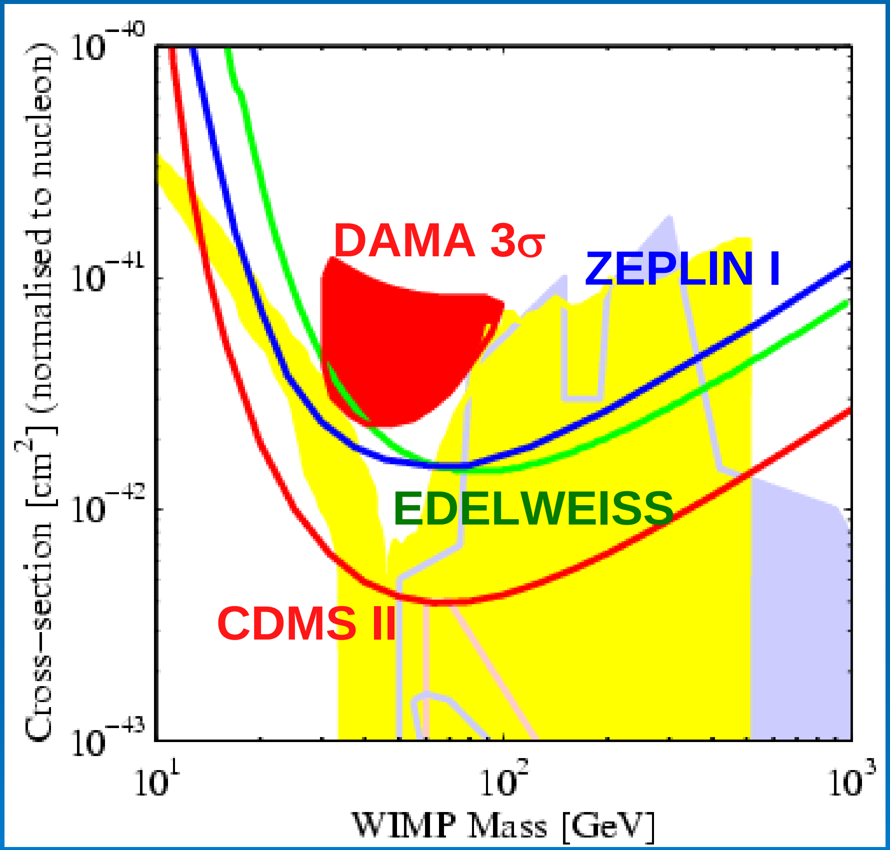
Direct Detection Techniques



World Wide WIMP Search



Where do we stand?



~ 0.2 events/kg/day

Most advanced experiments start to test the predicted SUSY parameter space

One evidence for a positive WIMP signal (DAMA NaI)

Not confirmed by other experiments

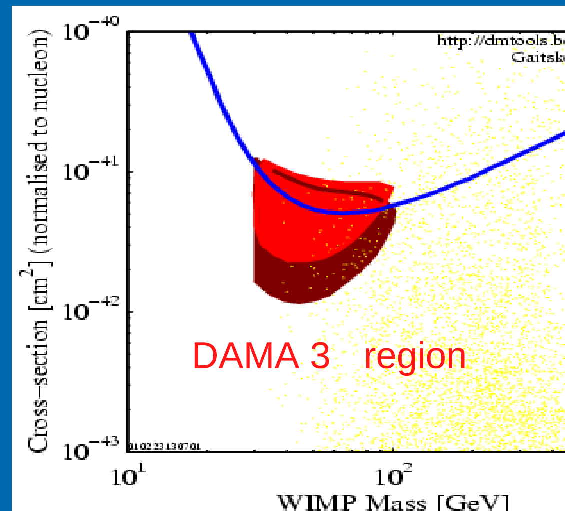
Predictions: Ellis & Olive, Baltz & Gondolo, Mandic & all

The DAMA experiment

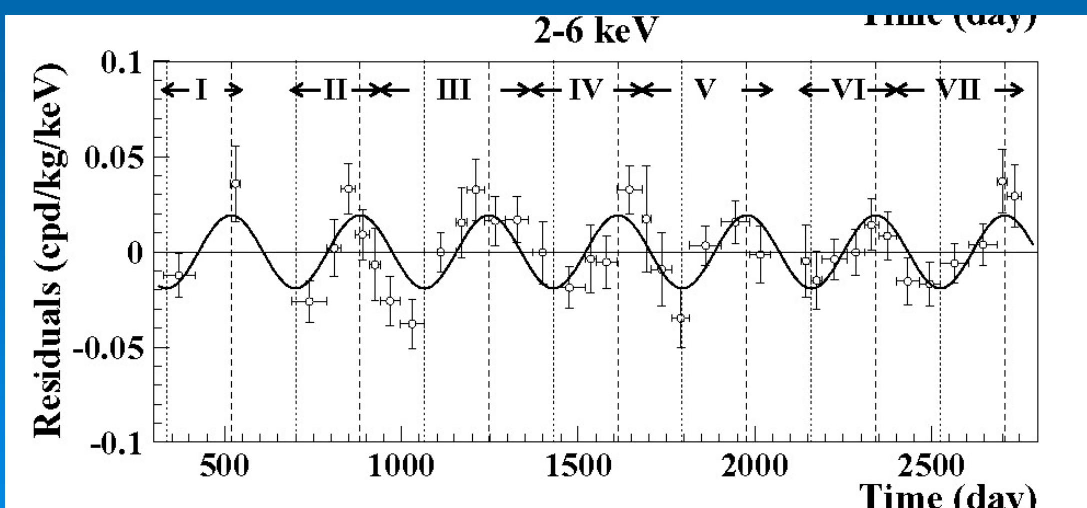
At Gran Sasso (3800 mwe)
9 x 9.7 kg low activity NaI crystals,
each viewed by 2 PMs (5-7 pe/keV)

Annual modulation analysis:

7 annual cycles: 107731 kg x days
positive signal (6.3   CL)
(astro-ph/0307403, Riv. N. Cim. 26, 2003)



A cos [(t-t_0)]; t_0 = 152.5 d; T = 1yr   A = 0.0195 +/- 0.031 dru



Studied variations of:
T, P(N_2), radon, noise,energy scale,
n-background,   -background

WIMPs? UNCLEAR!

Efficiency?
Shape of energy spectrum?
Stability?…

The LIBRA experiment

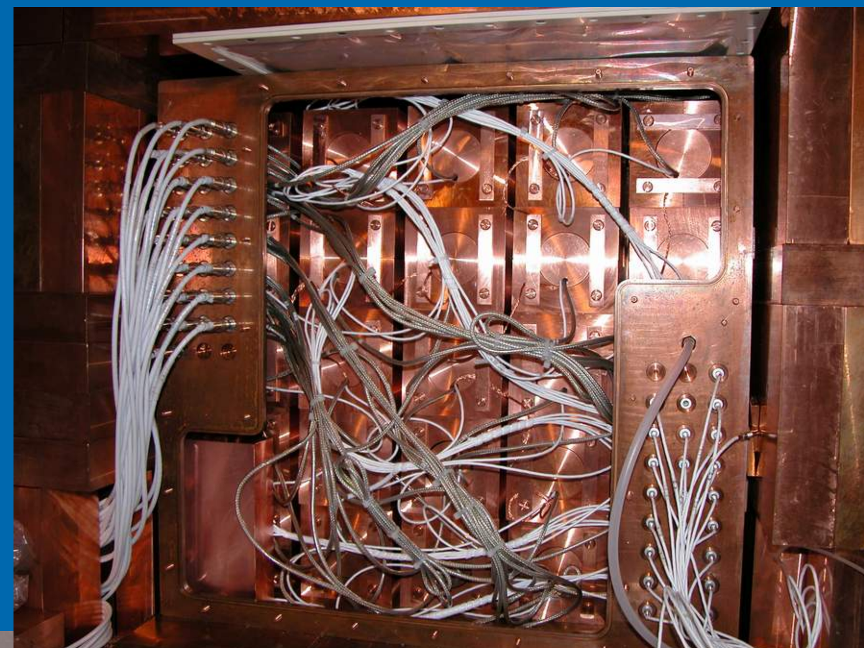
DAMA upgrade:

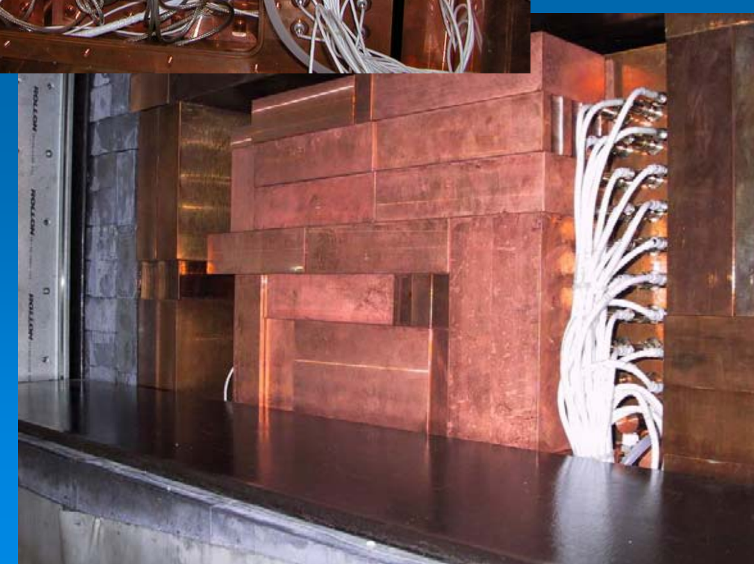
250 kg of radio-pure NaI
new electronics and DAQ

improved background (~few)
improved light yield

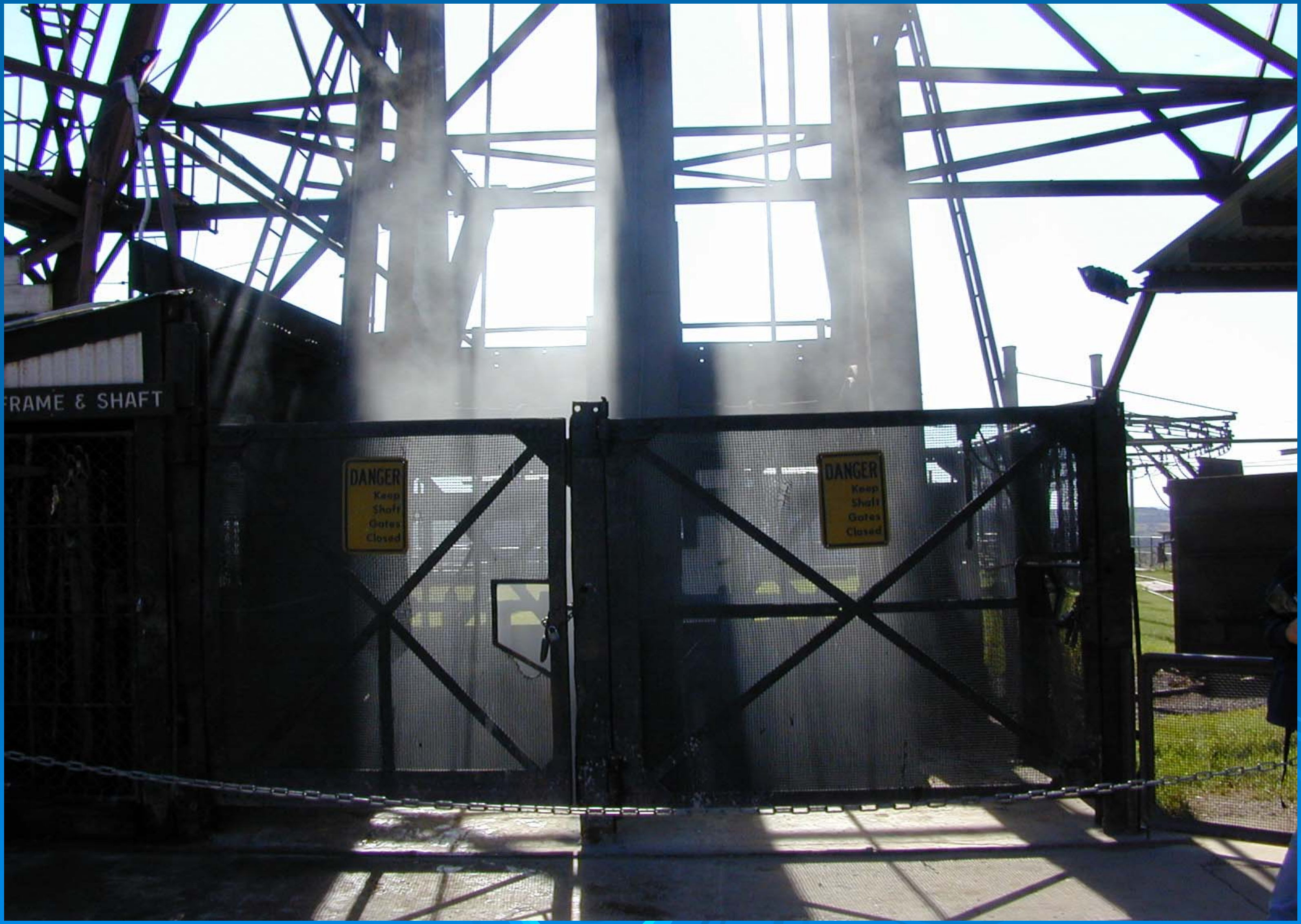
installation completed end 2002
runs since March 2003

DAMA collab: analyze data
after similar stats as DAMA





The CDMS experiment



The CDMS Collaboration

(Berkeley, Brown, Case Western, Fermilab, Florida, Minnesota, NIST, Santa Barbara, Santa Clara, Stanford)

The Fellowship of the Phonon

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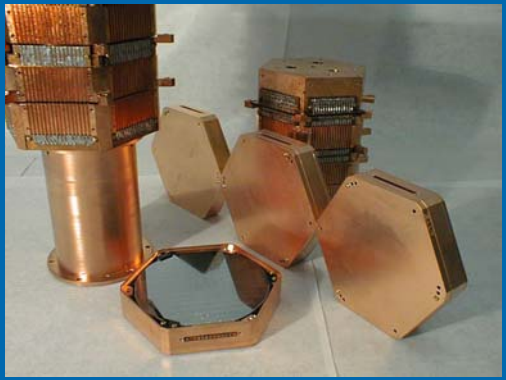
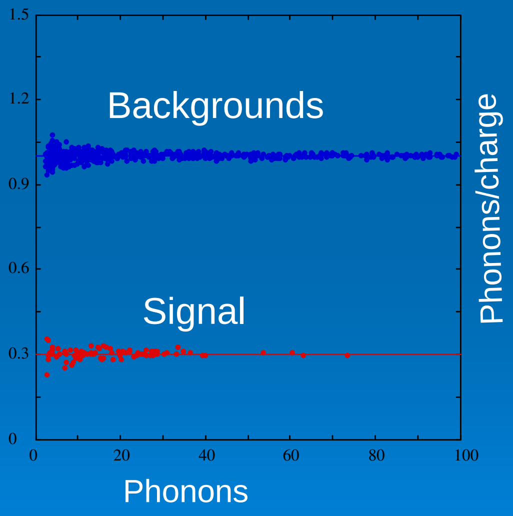
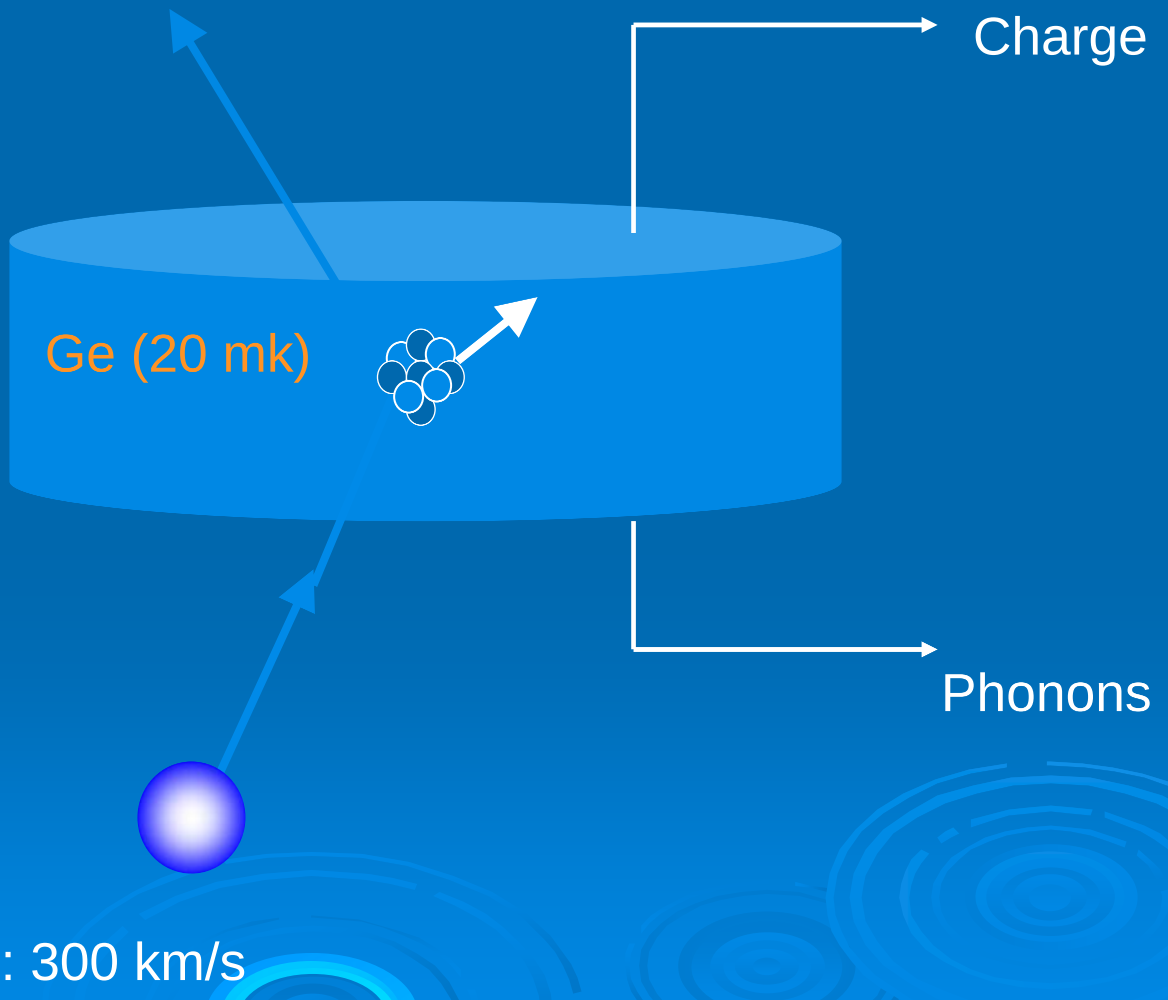
CDMS Detectors







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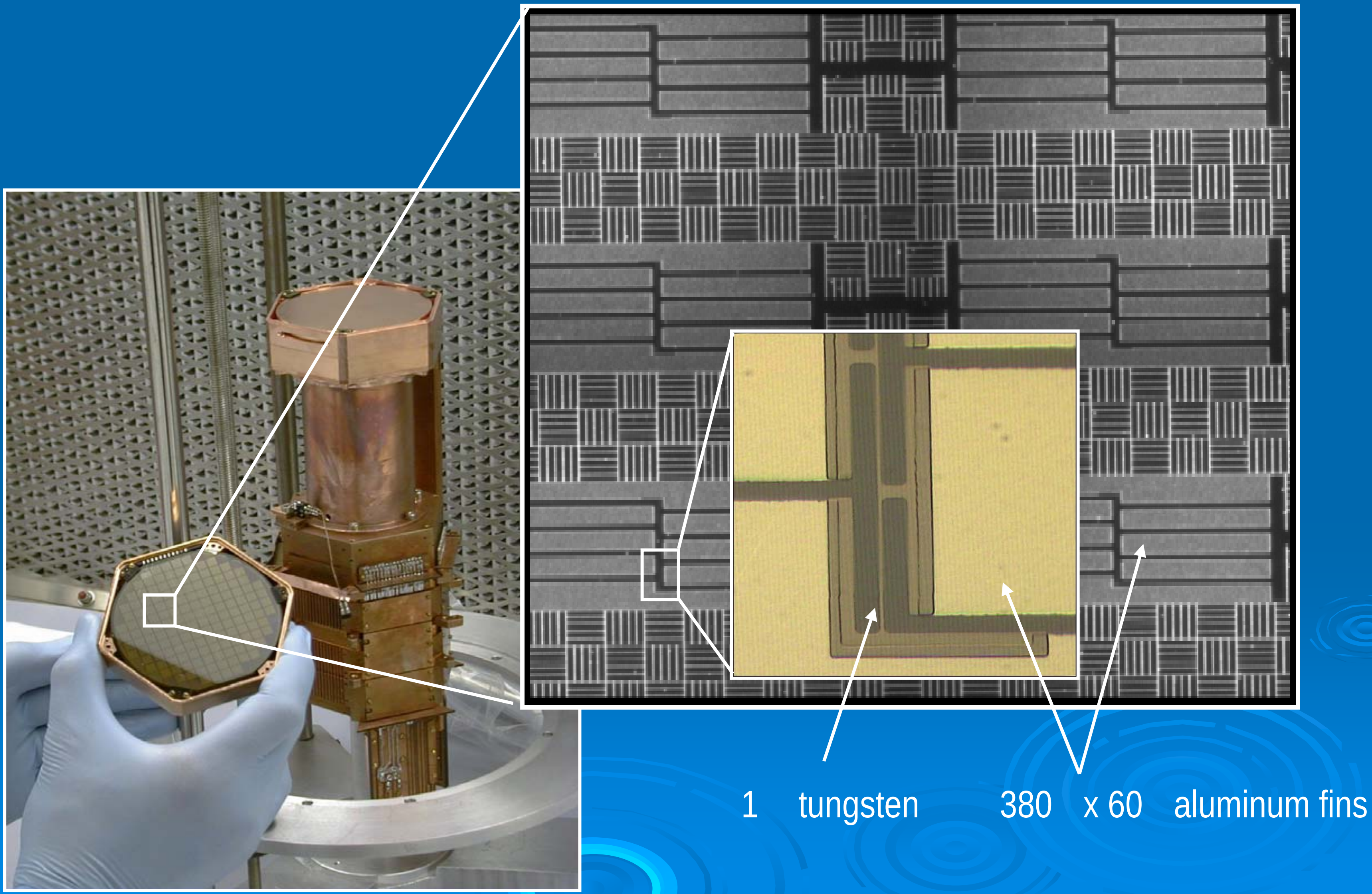
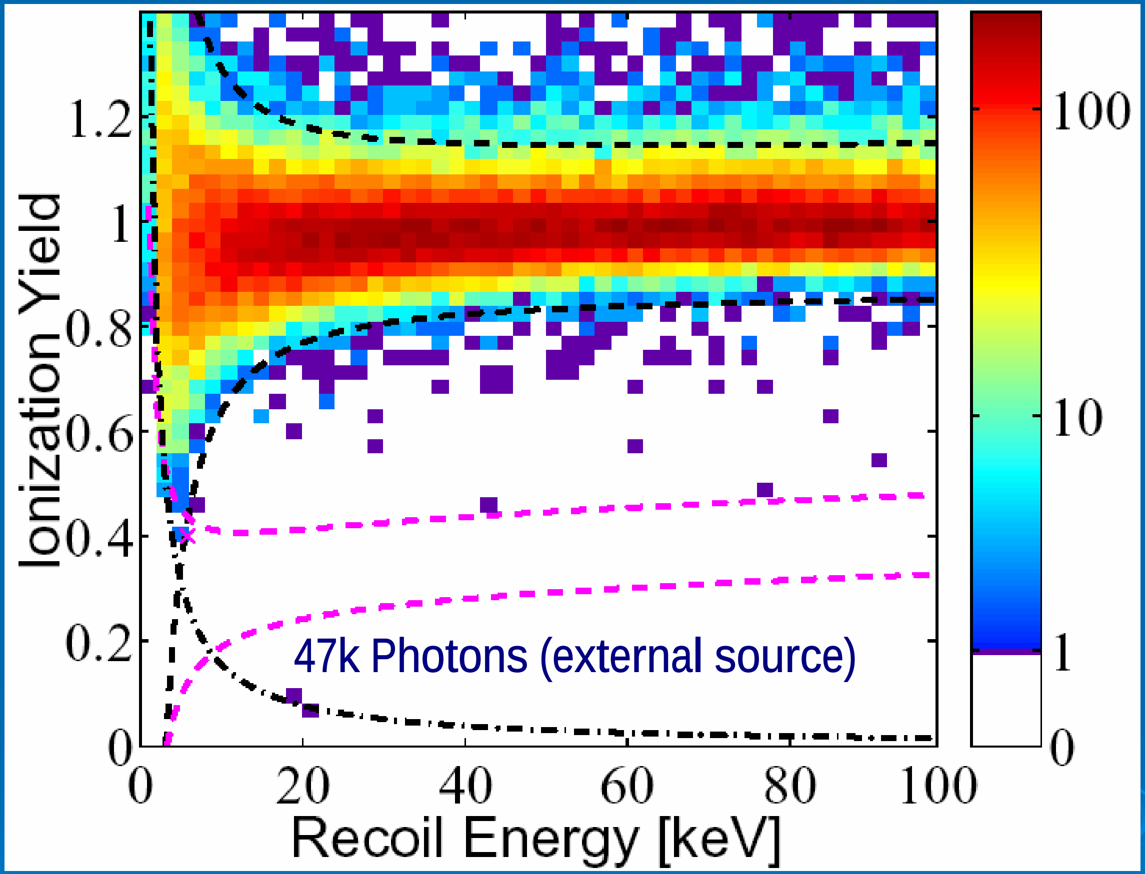


CDMS II Background Discrimination

Ionization Yield depends strongly on type of recoil

Most background sources (photons, electrons) produce electron recoils



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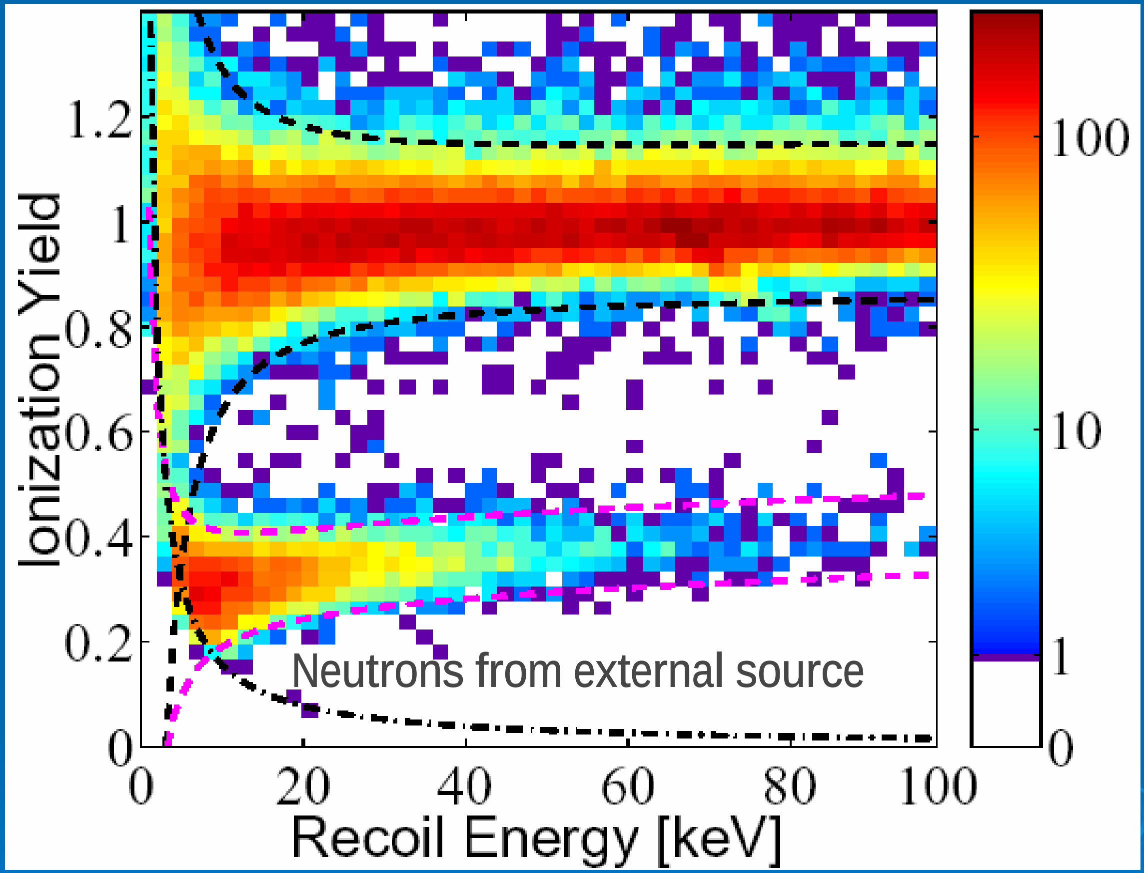
WIMPs (and neutrons) produce nuclear recoils

Photons from external source



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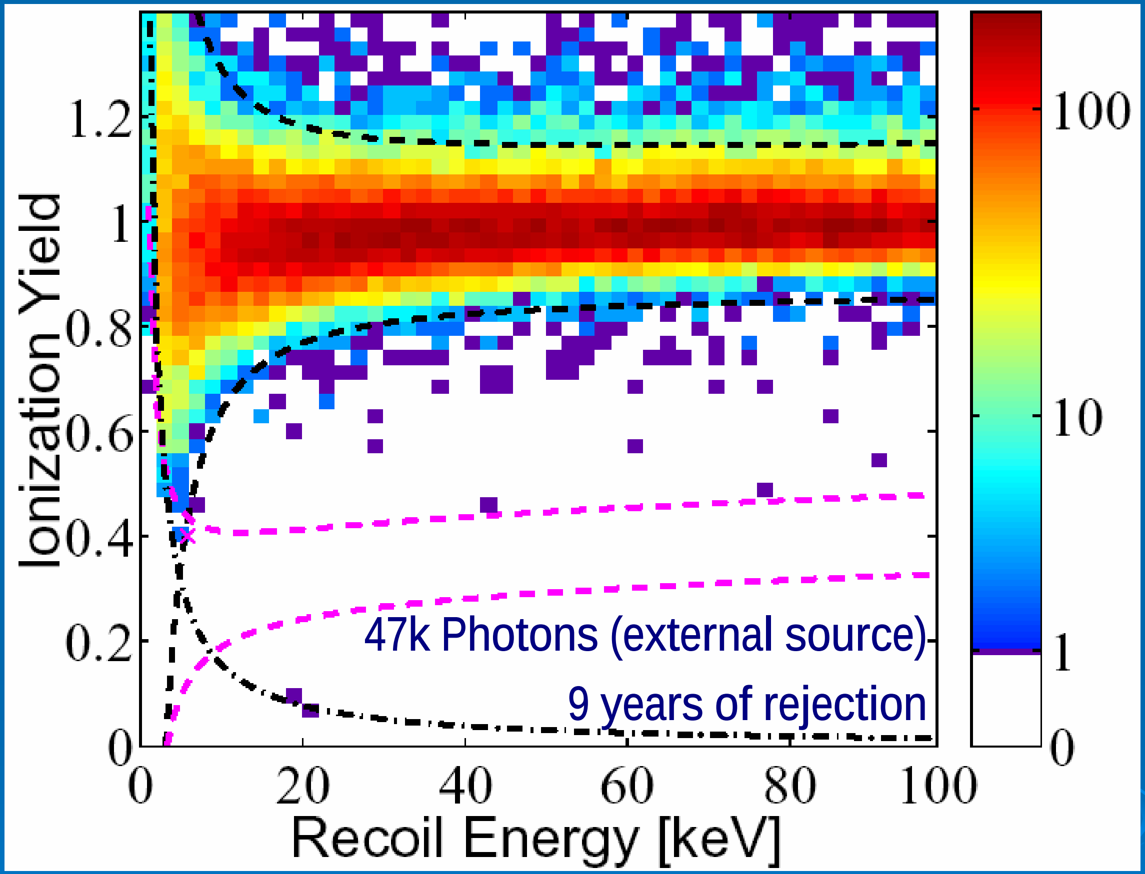

Detectors provide near-perfect event-by-event discrimination against otherwise dominant bulk electron-recoil backgrounds

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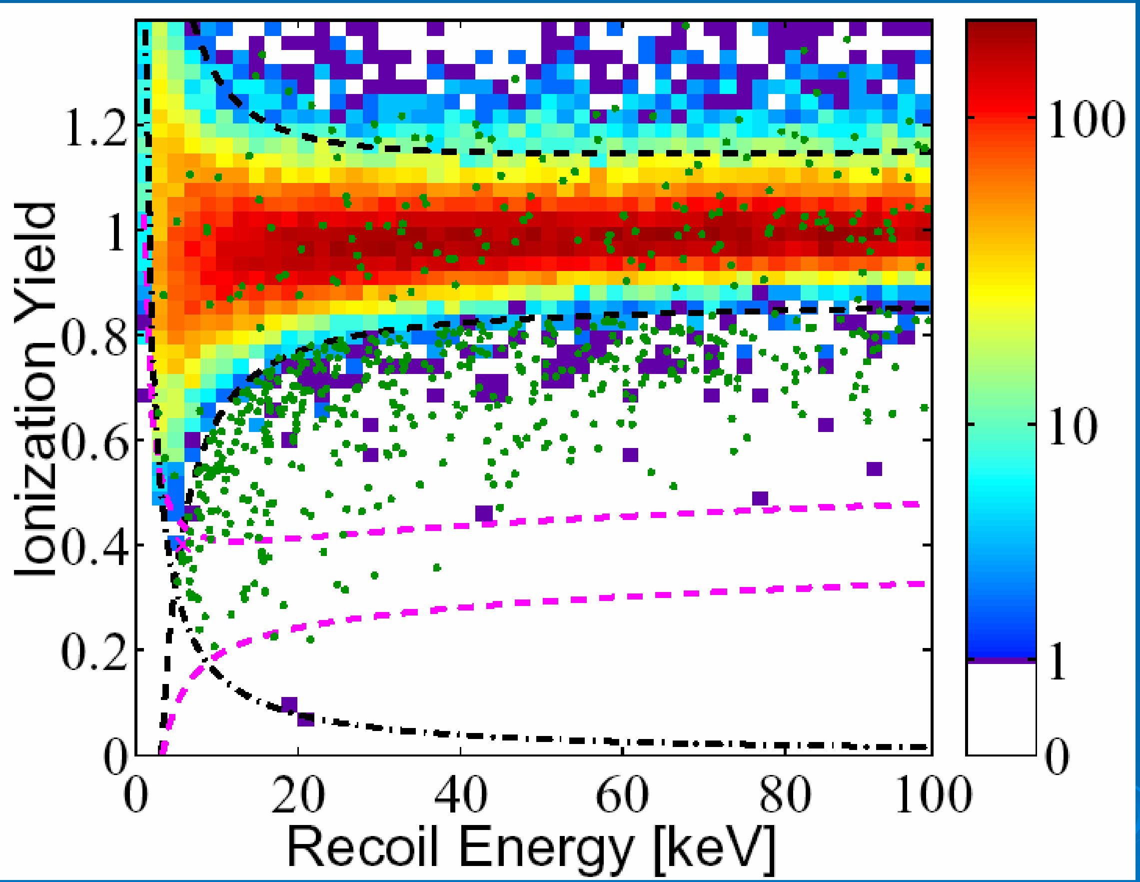


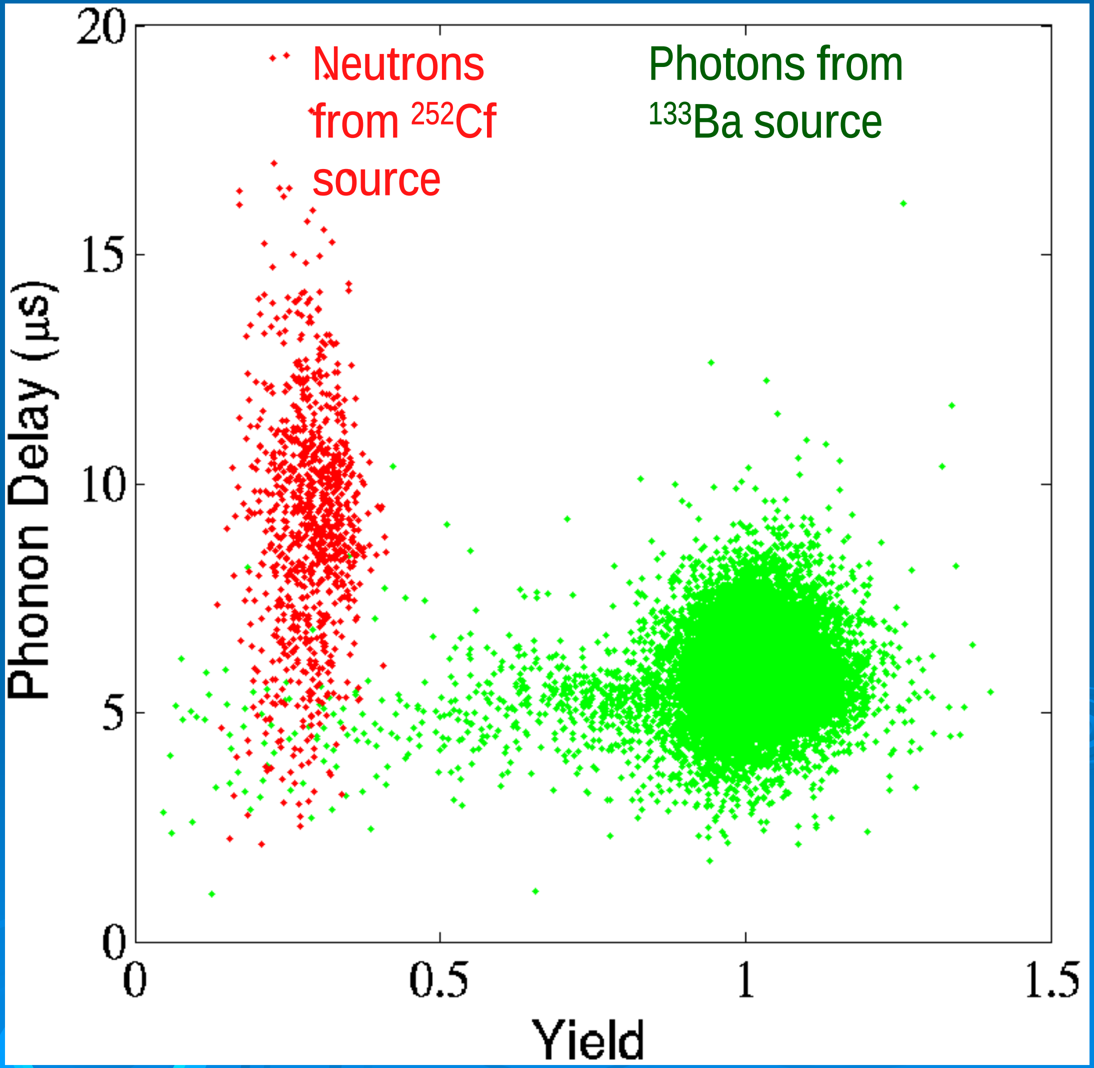
Detectors provide near-perfect event-by-event discrimination against otherwise dominant bulk electron-recoil backgrounds

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

ZIP Z-Position Sensitivity Rejects Electrons

Events near crystal surfaces produce different frequency spectrum of phonons

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



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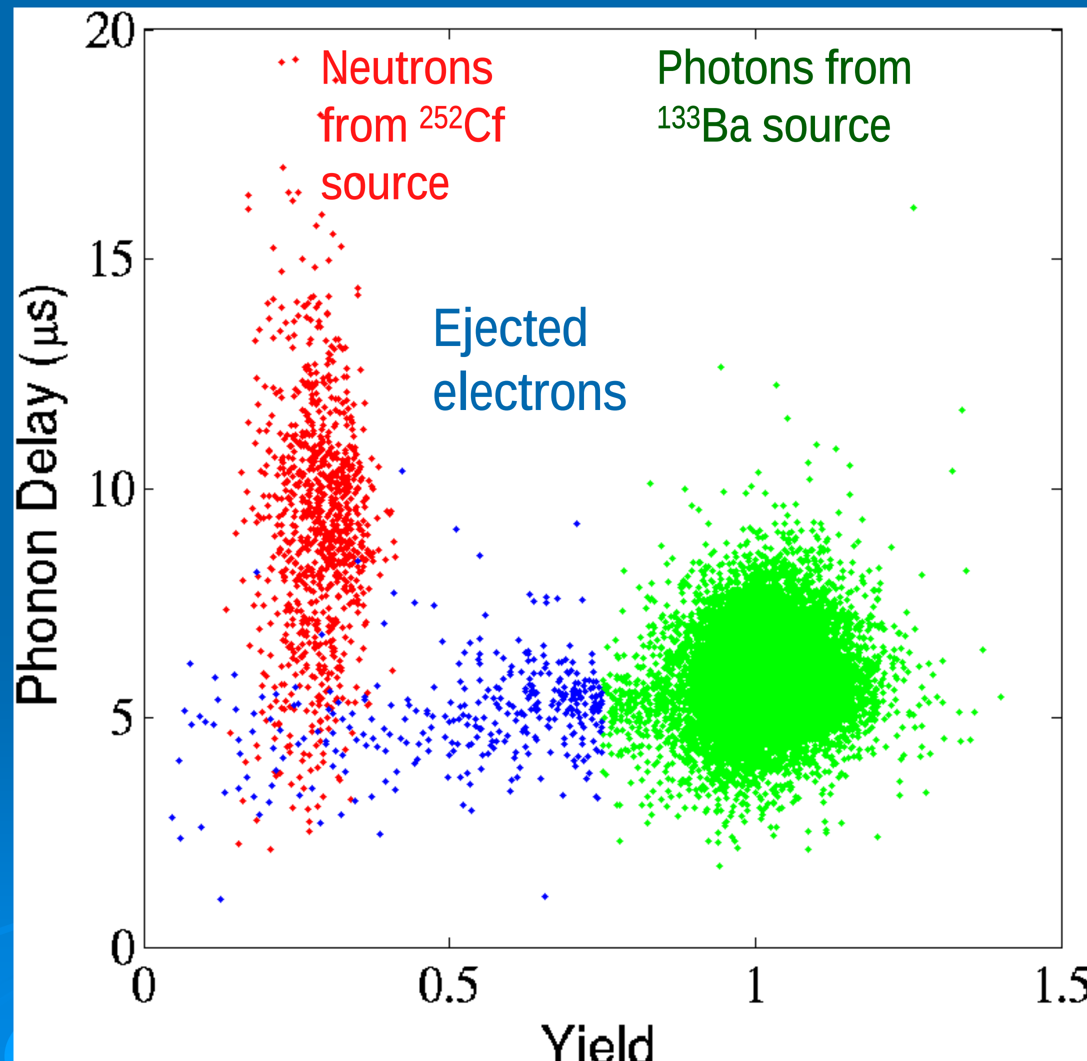
Risetime cut eliminates the otherwise troublesome background surface events

>99% above 10 keV



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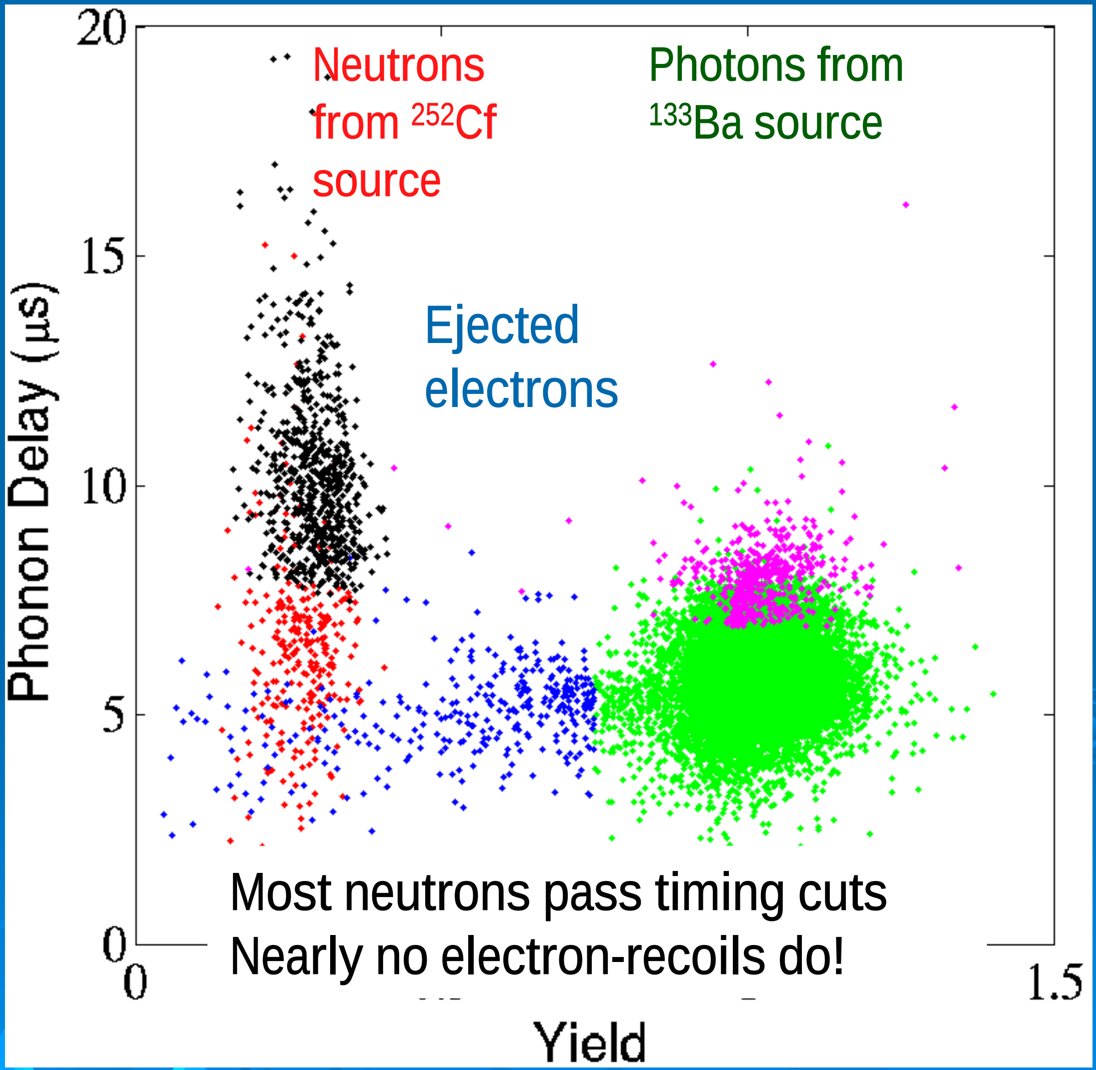
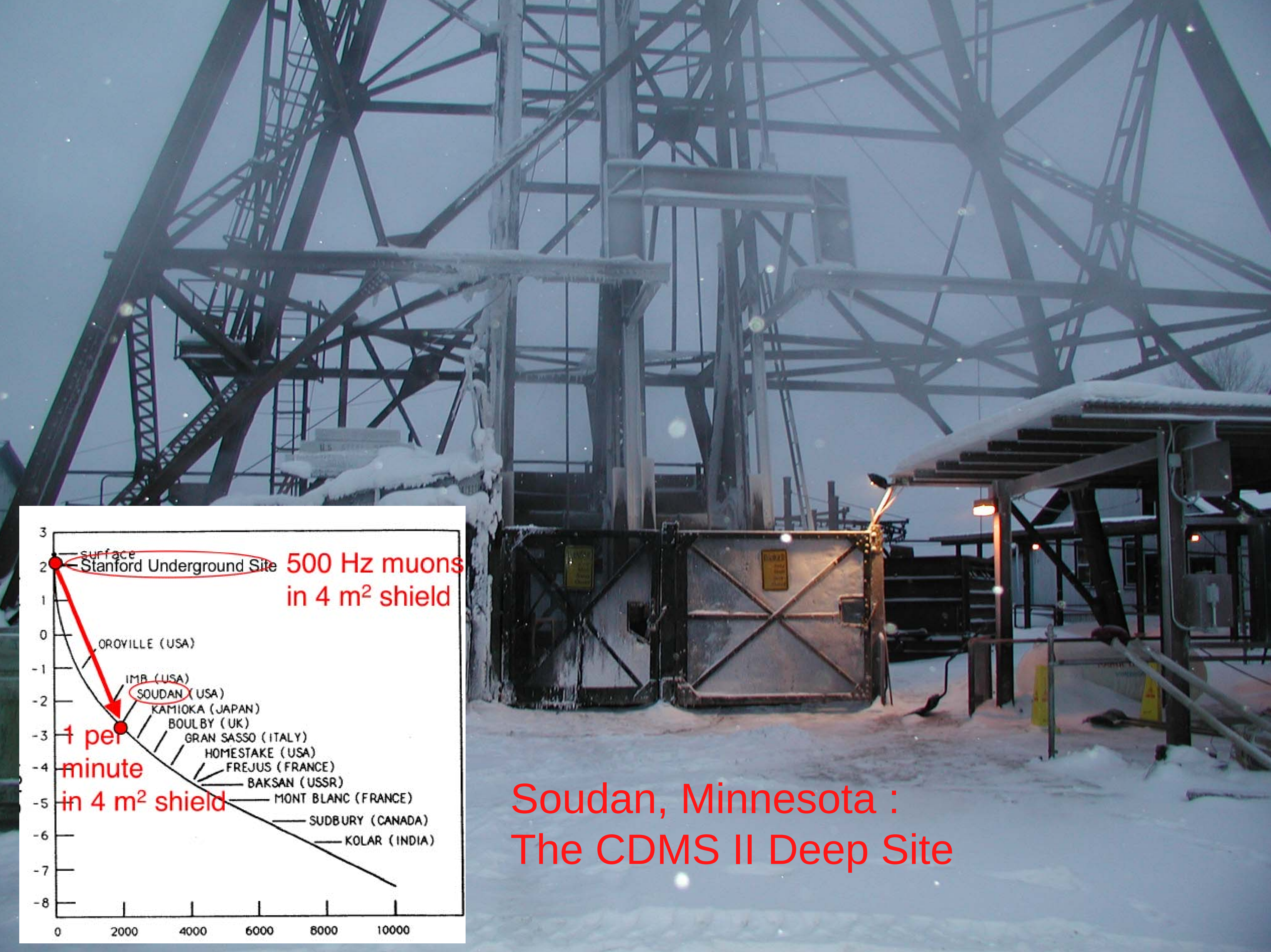
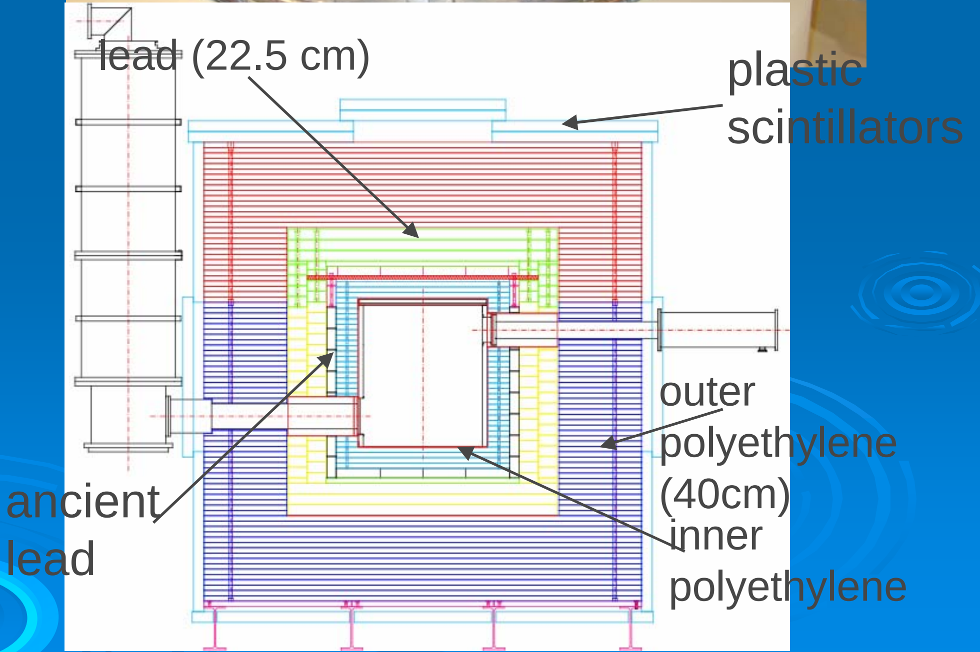




Soudan, Minnesota : The CDMS II Deep Site

CDMS II at Soudan



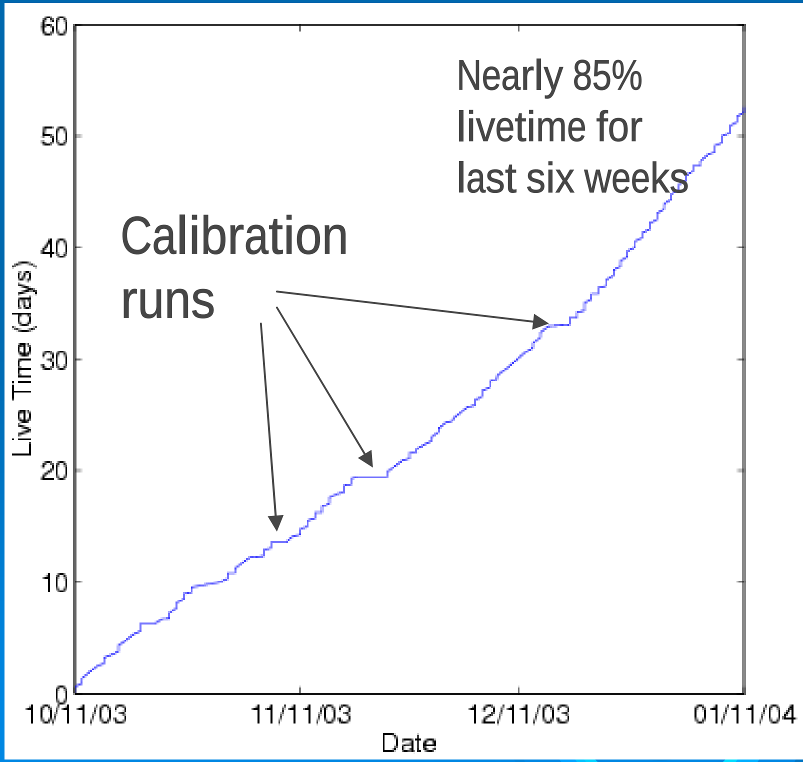
First run of CDMS II at Soudan

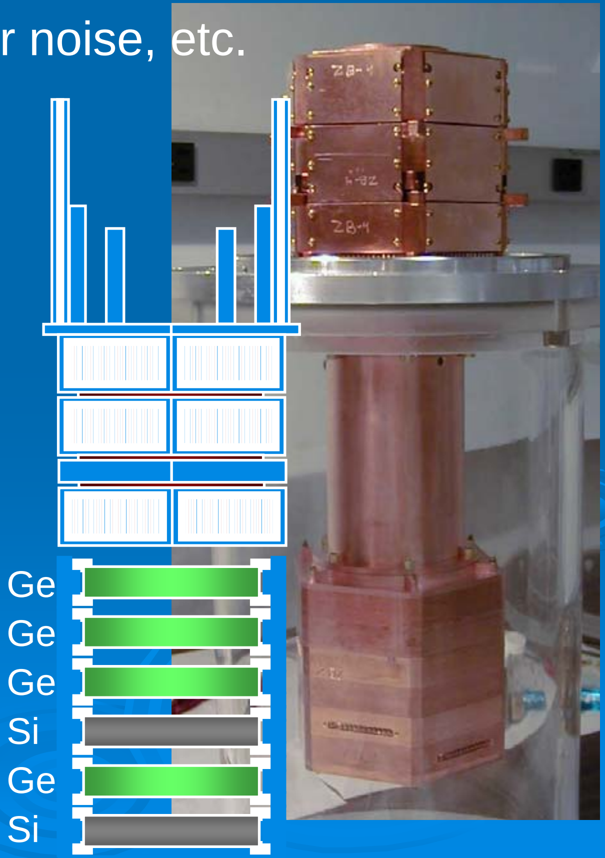
Reduced neutron background from:
1/kg/day to 1/kg/year

October 2003 - January 2004

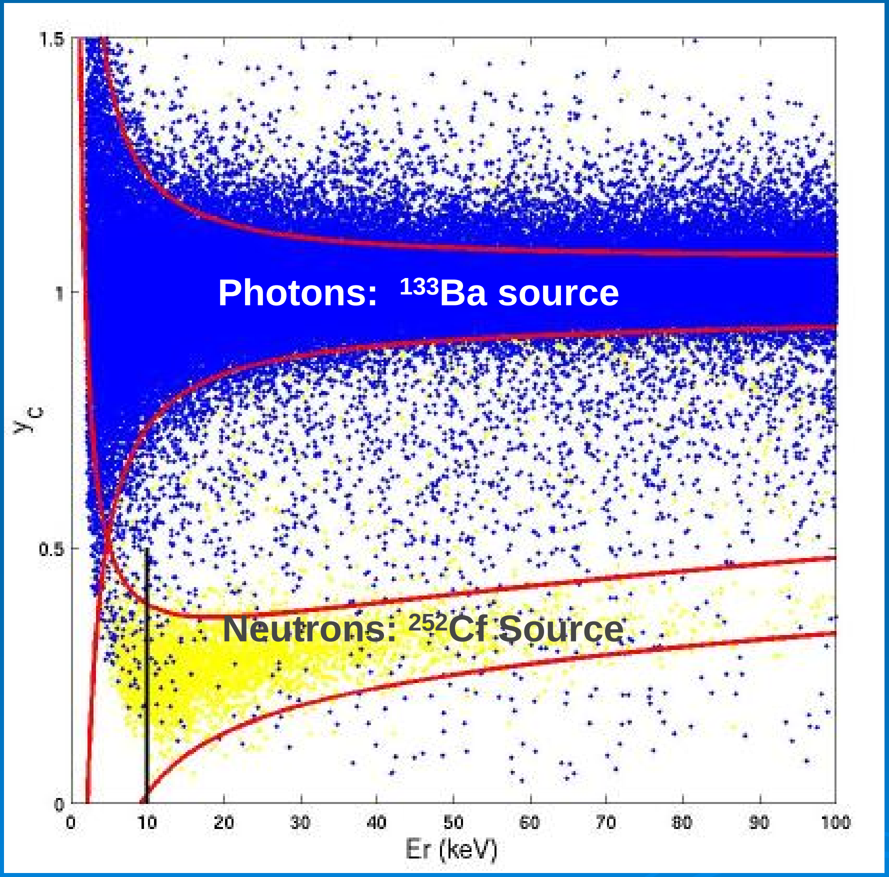
same 4 Ge, 2 Si detectors run at Stanford in 2002

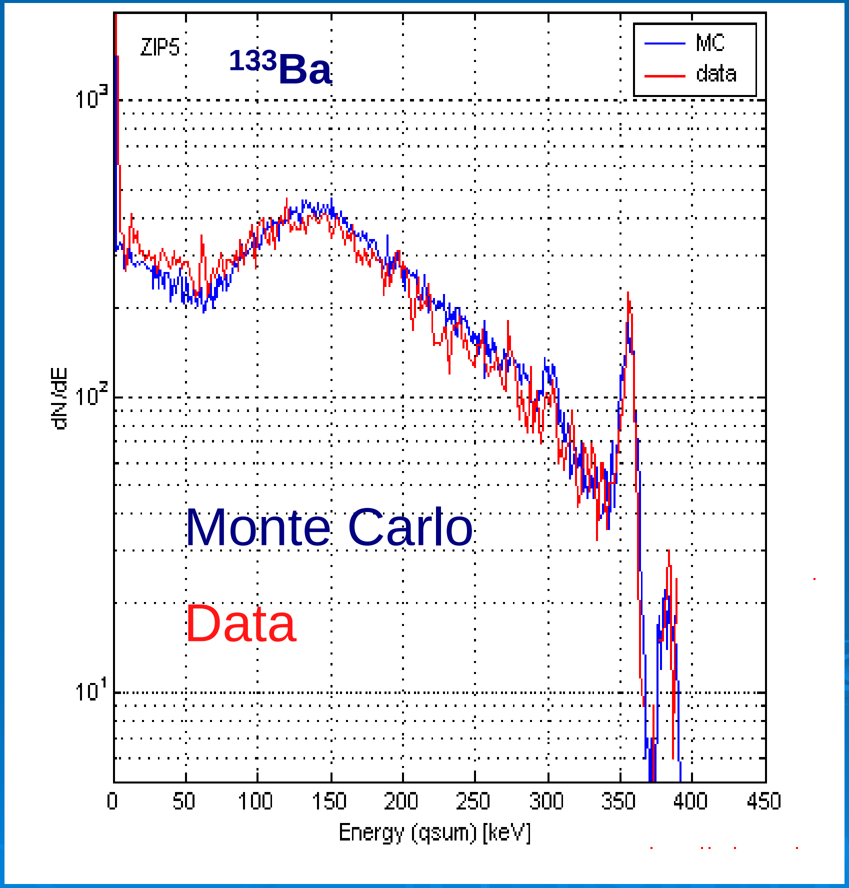
62 “raw” livedays, 53 livedays after cutting times of poor noise, etc.





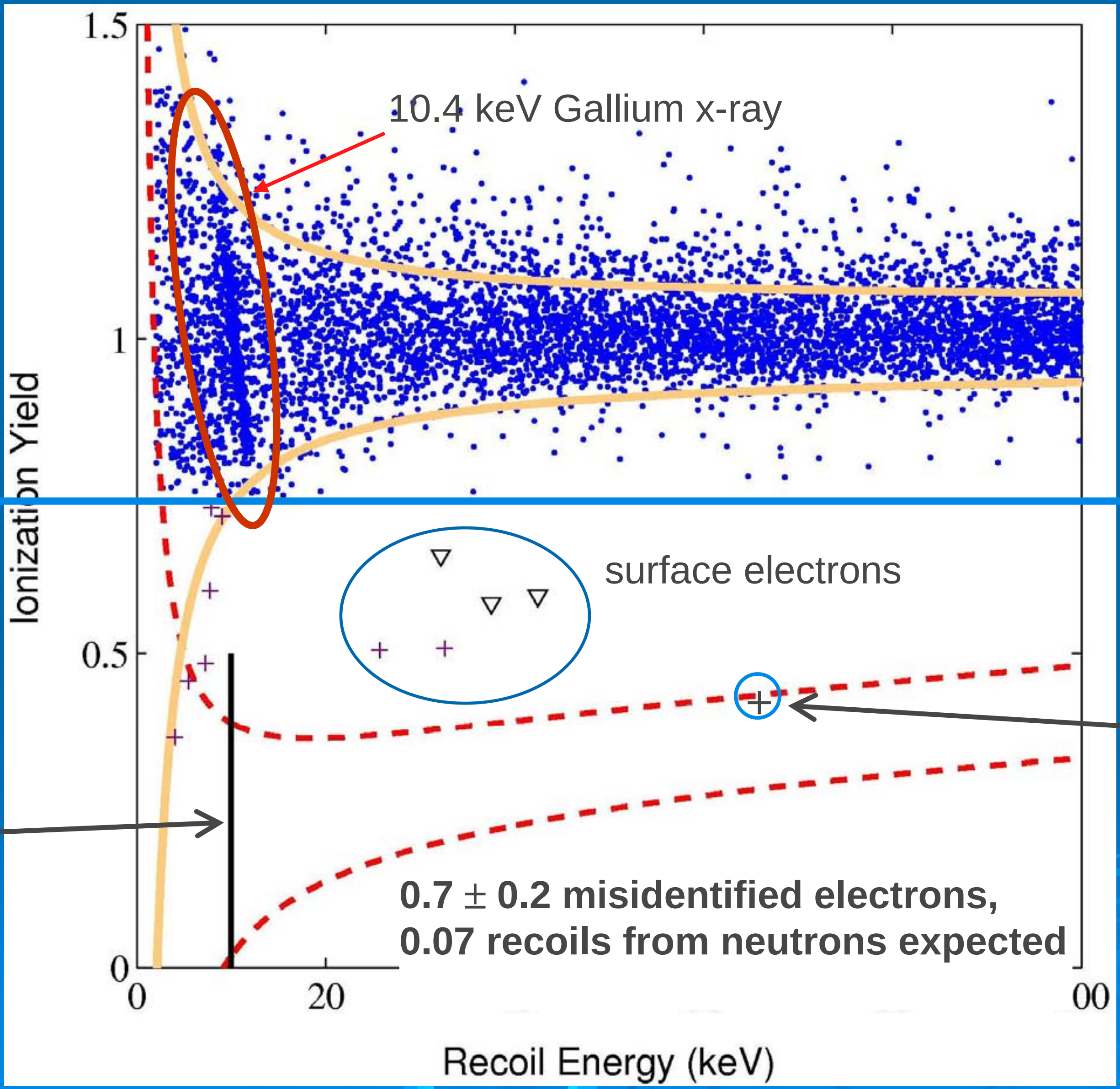
In Situ Photon Calibration with ^{133}Ba and ^{252}Cf





(poster 2512, W. Ogburn)

WIMP Search Data



Timing Cuts for Surface Rejection:

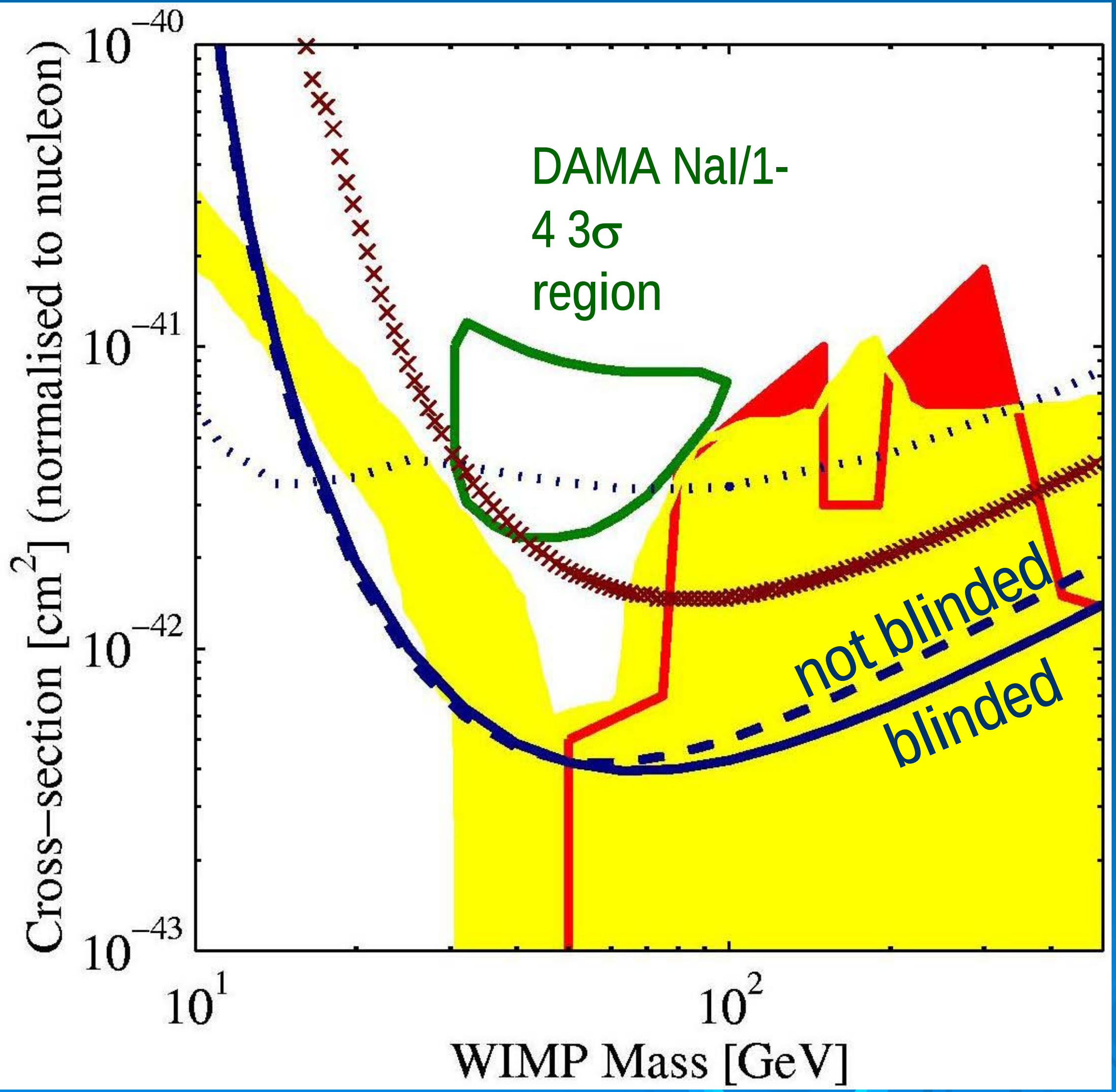
Omitted Applied

10 keV threshold (1@20 keV)

1 NR candidate consistent with backgr

Resulting experimental upper limits

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



Upper limits on the WIMP-nucleon cross section are $4 \; 10^{-43}$ cm^2 for WIMP mass of 60 GeV/c^2

Phys. Rev. Lett. 93, 211301, (2004)

Factor of 4 below best previous limits (EDELWEISS)

Factor of 8 below CDMS-SUF

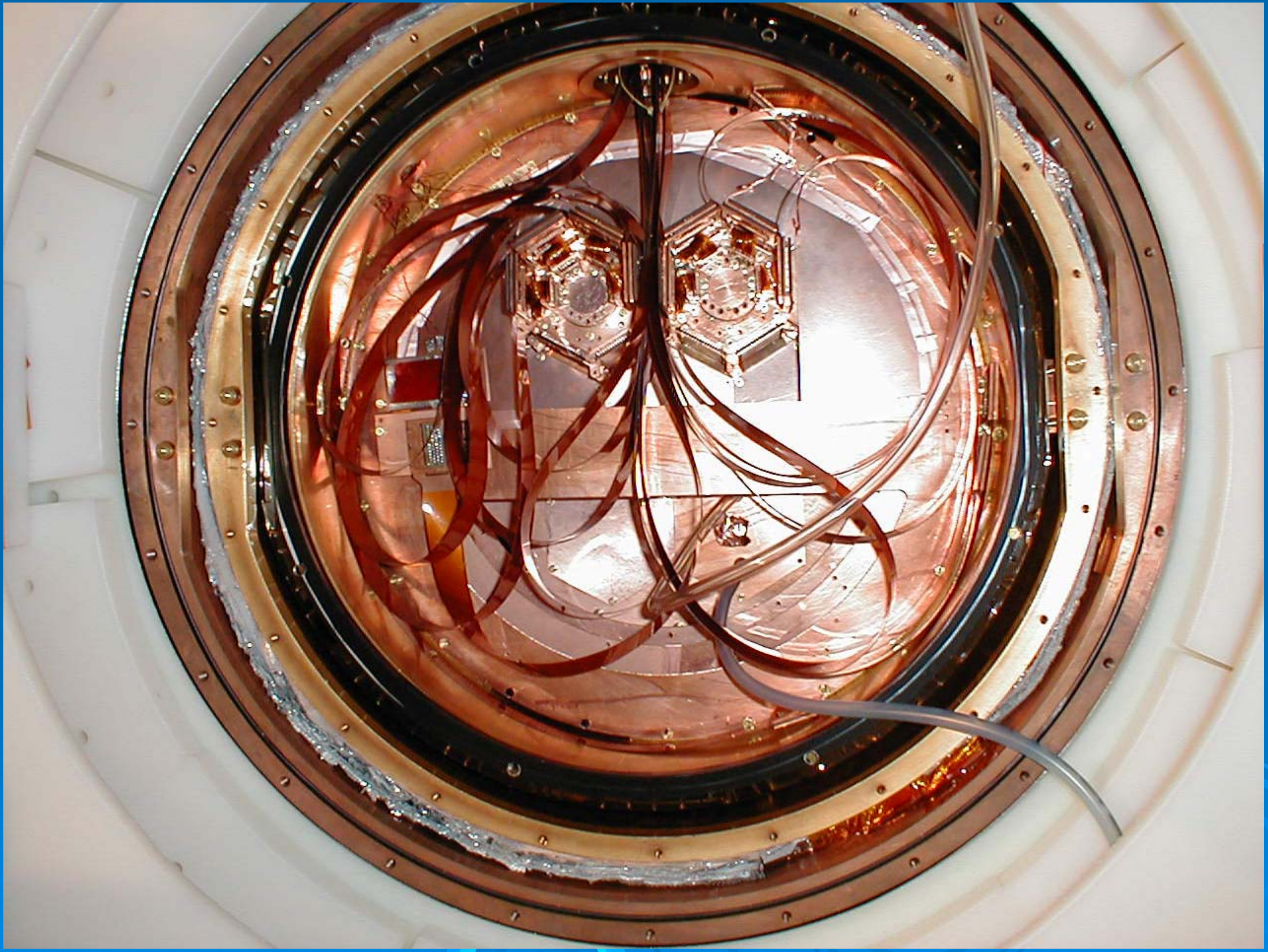
Excludes large regions of SUSY parameter space and DAMA

Bottino et al. 2004 in yellow

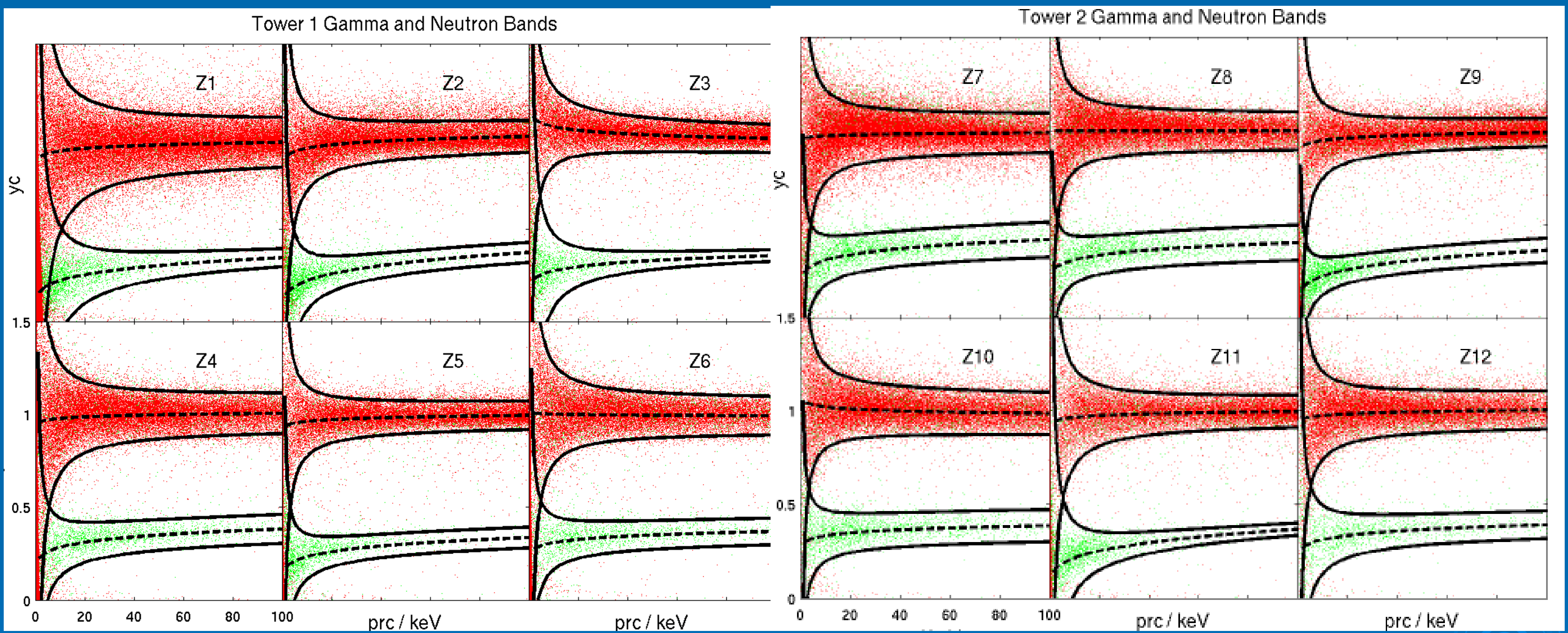
Baltz&Gondolo 2003 in red

(poster 2531, J. Filippini, SD limits)

The Two Towers



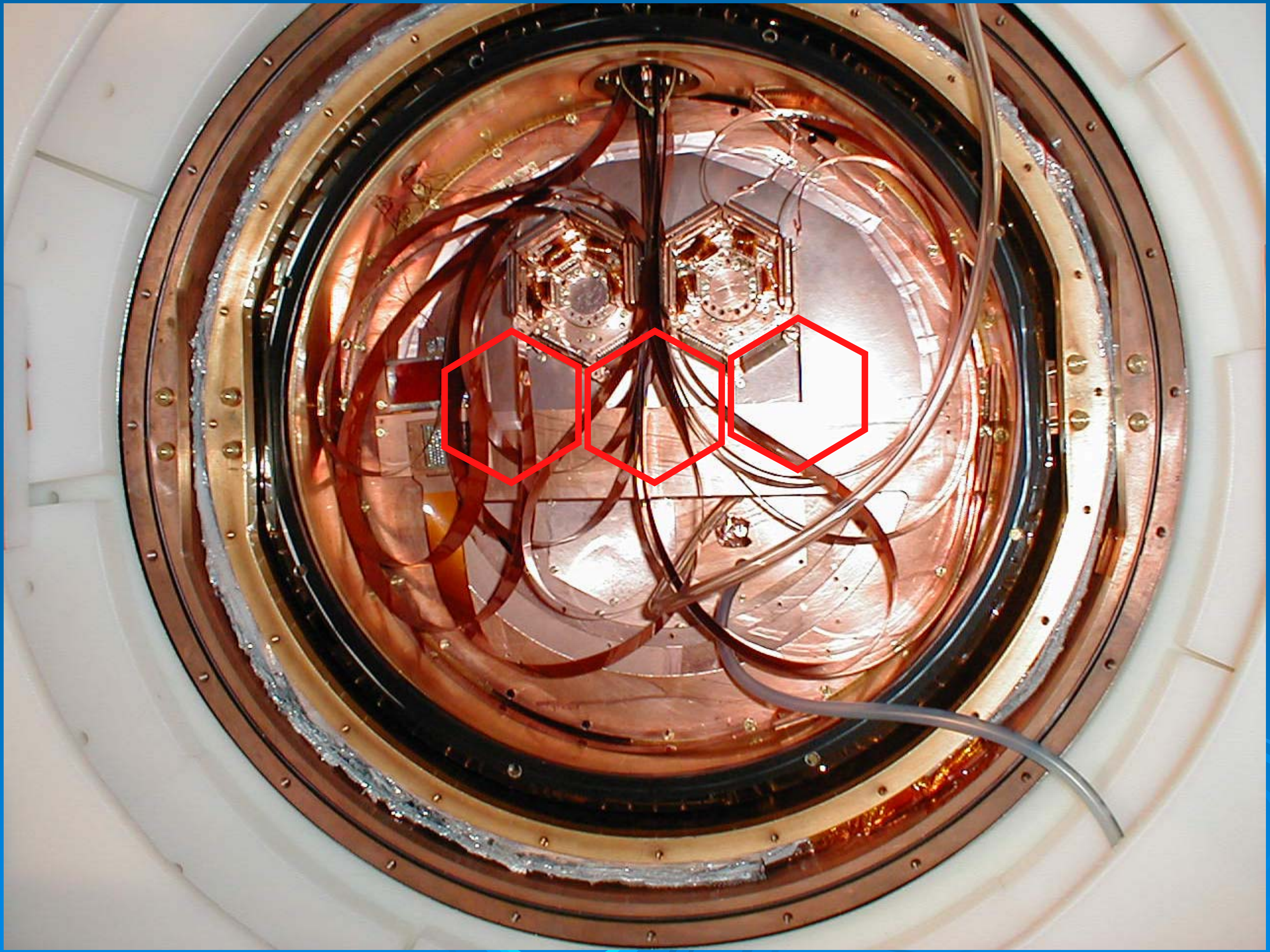
The Two Towers: Feb - Aug ‘04



High stats ^{133}Ba and ^{252}Cf calibration data

Now: analysis of WIMP-search data: more than 72 live days
Results: ~ February; increased sensitivity by factor of ~3

Now installed towers 3,4,5 in Soudan



SuperCDMS

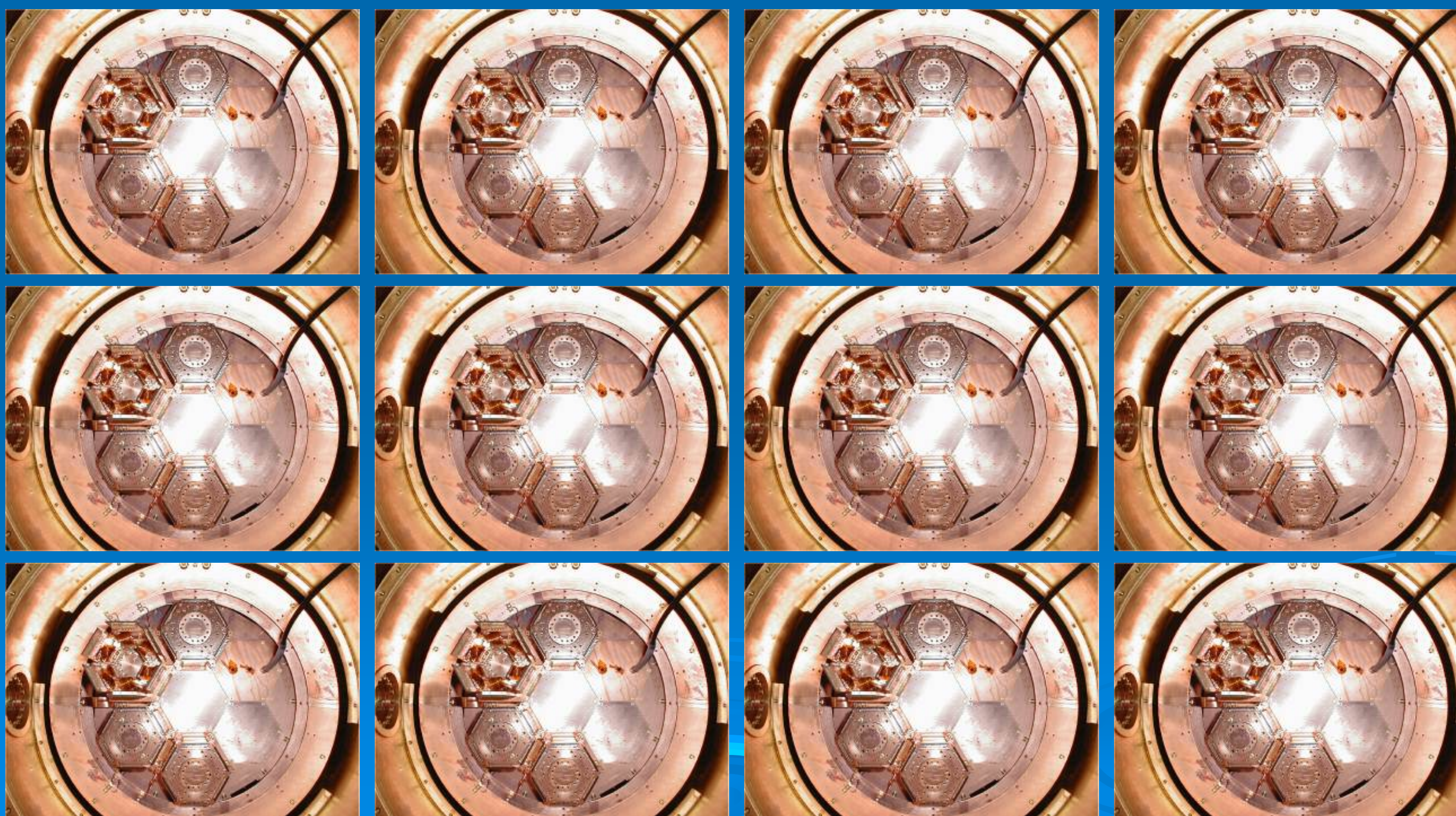
(poster 2529, P. Brink)

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

Move from Soudan to SNOlab

Reduce muon flux by 500

Reduce HE neutron flux by >100



The Return of the WIMP

(poster 2529, P. Brink)

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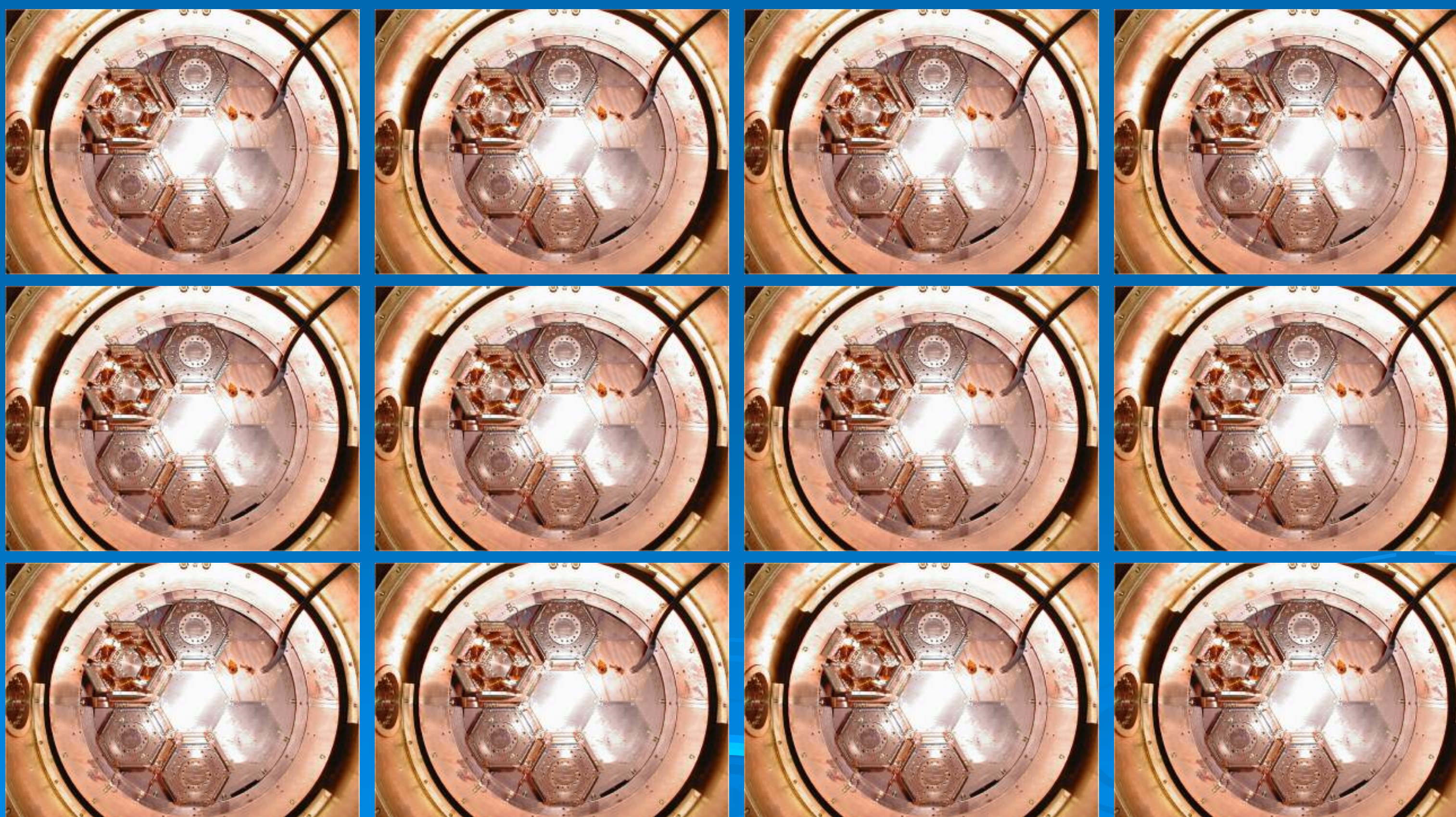
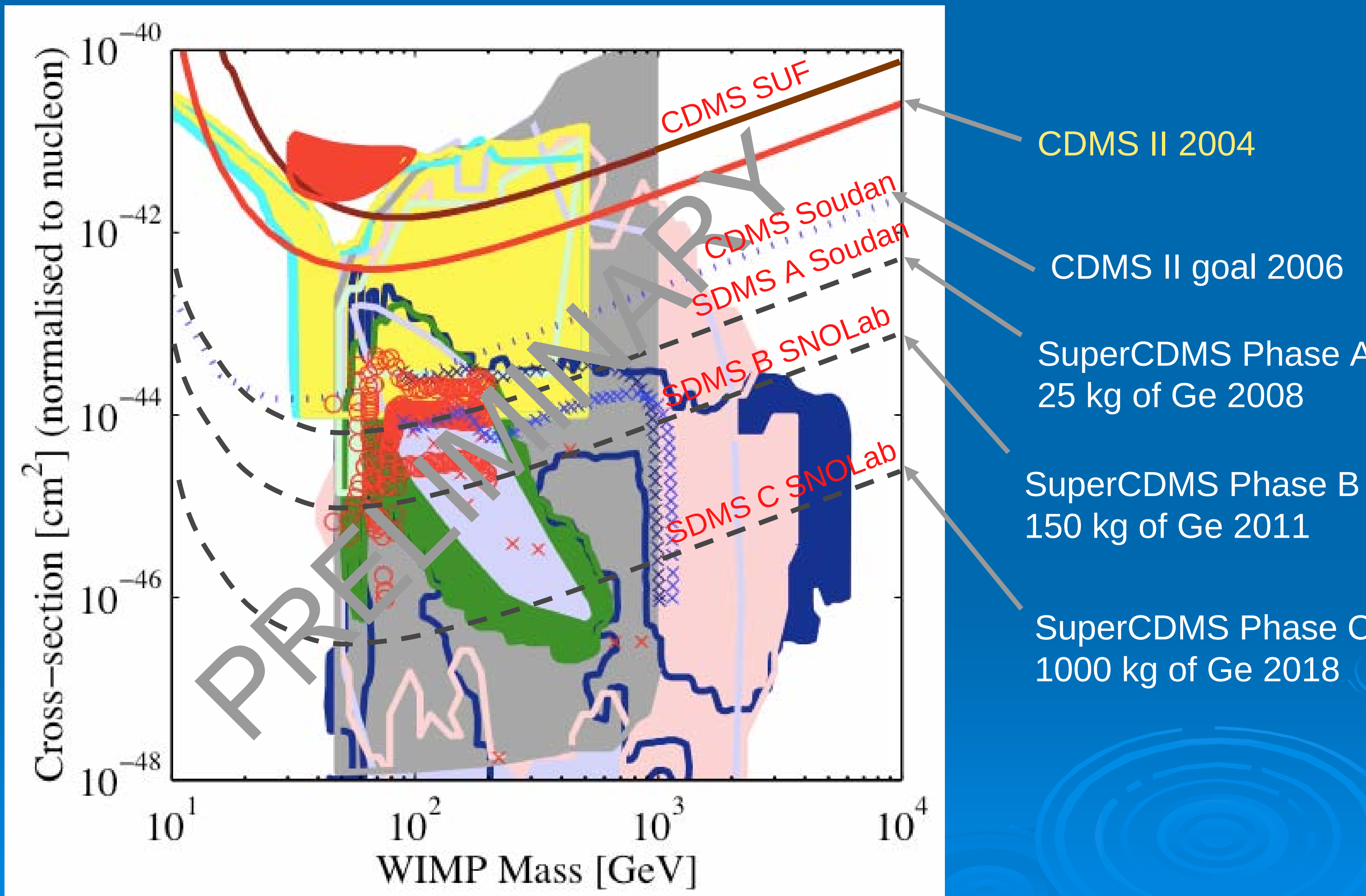


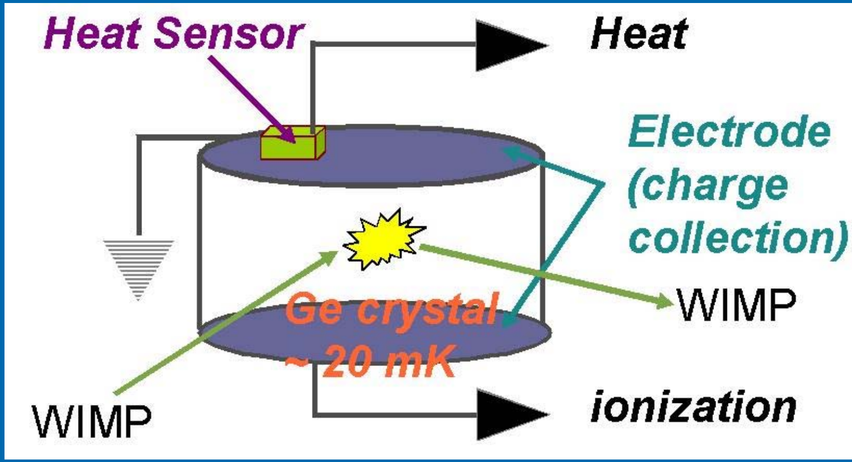
SuperCDMS Reach

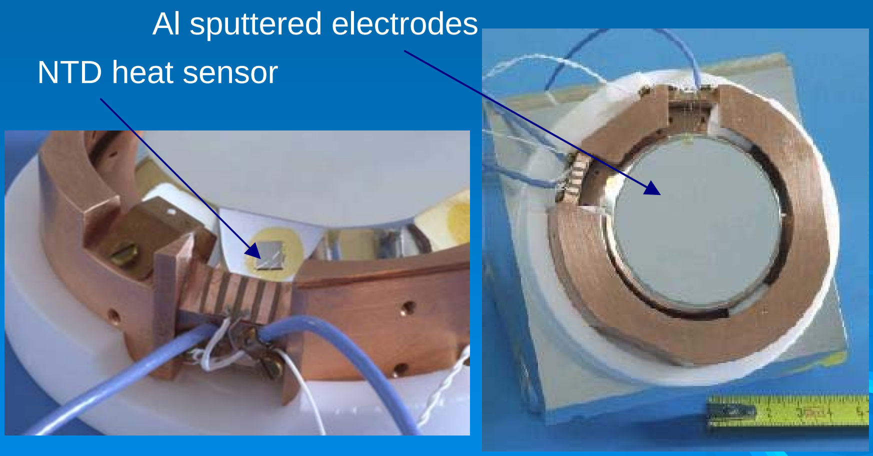


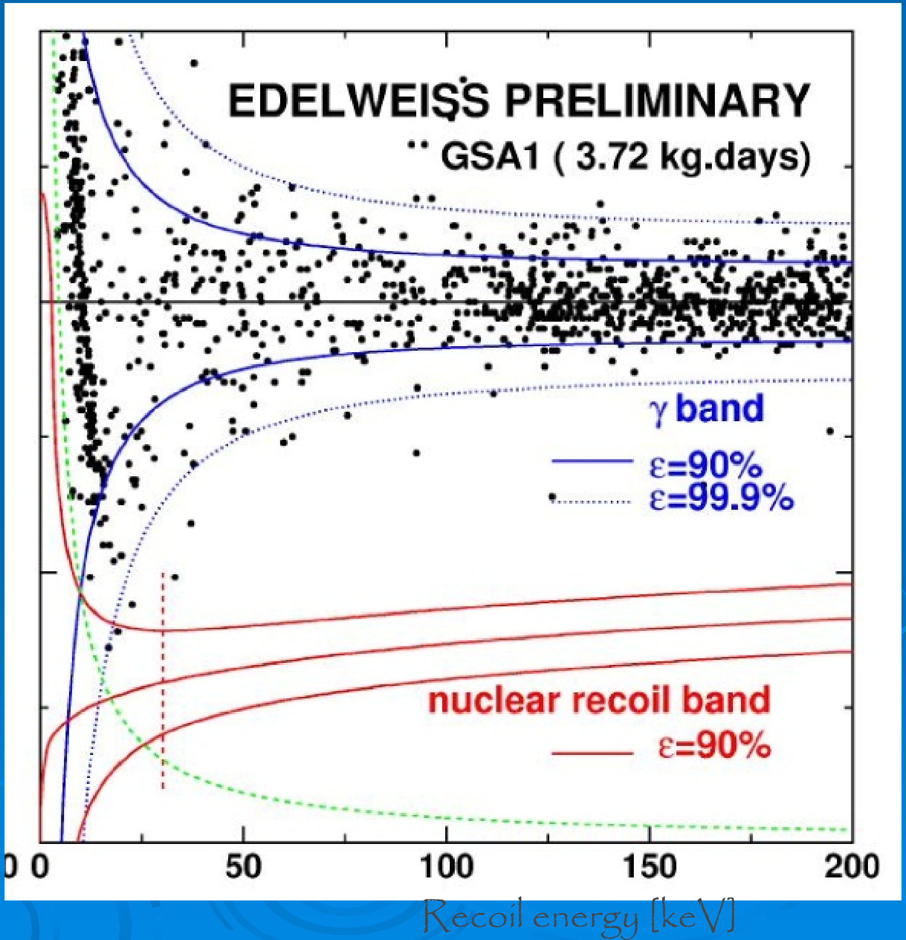
The EDELWEISS Experiment

In Frejus (4800 mwe)

20 kg d (1 kg Ge); 3 ev in NR region > 20 keV







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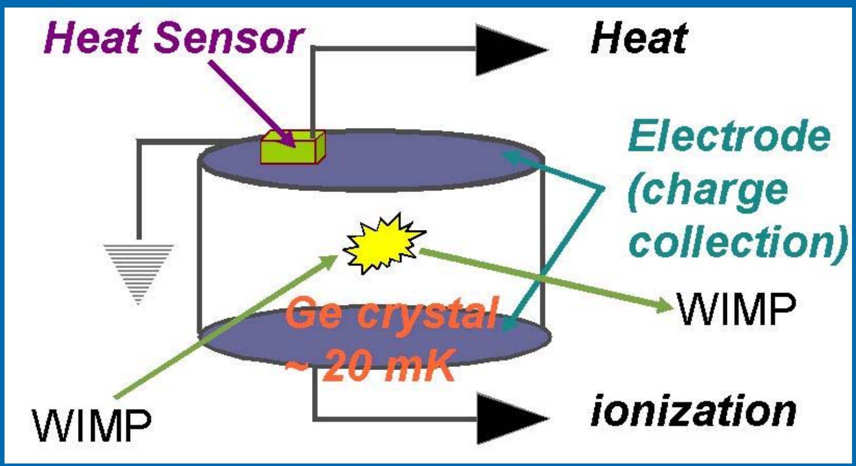
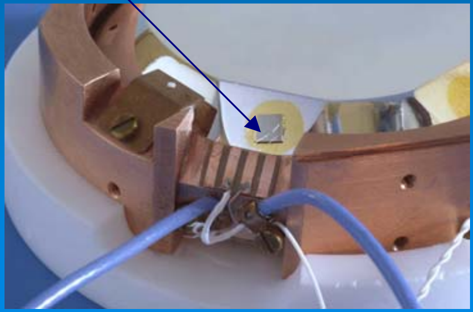
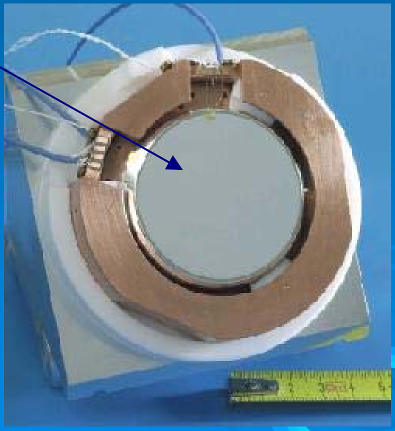
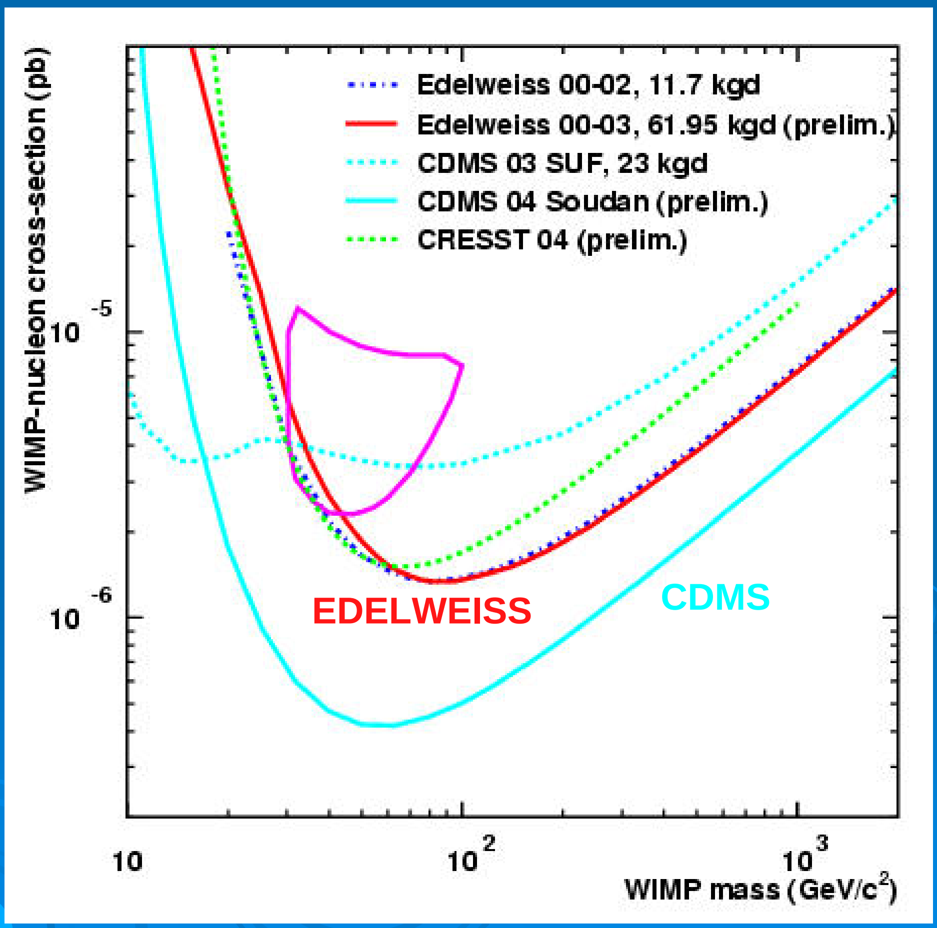


Al sputtered electrodes

NTD heat sensor





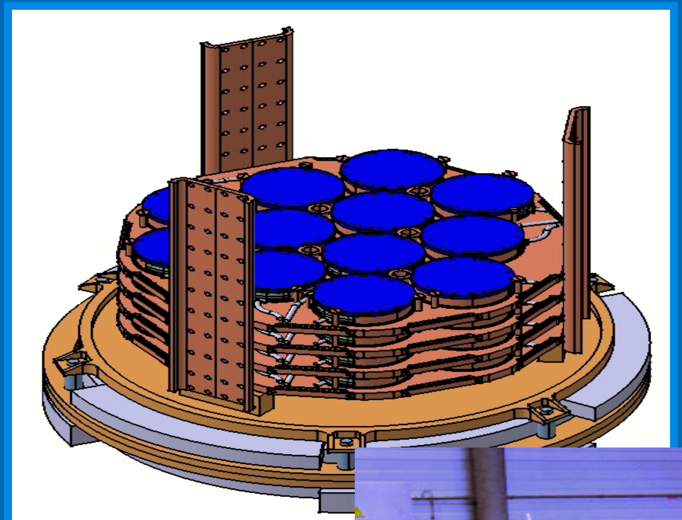


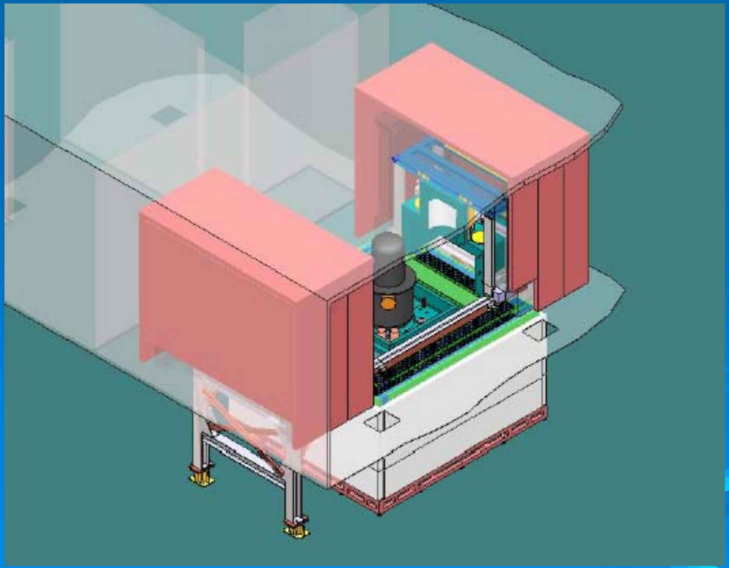
EDELWEISS II

Aim: factor 100 in sensitivity

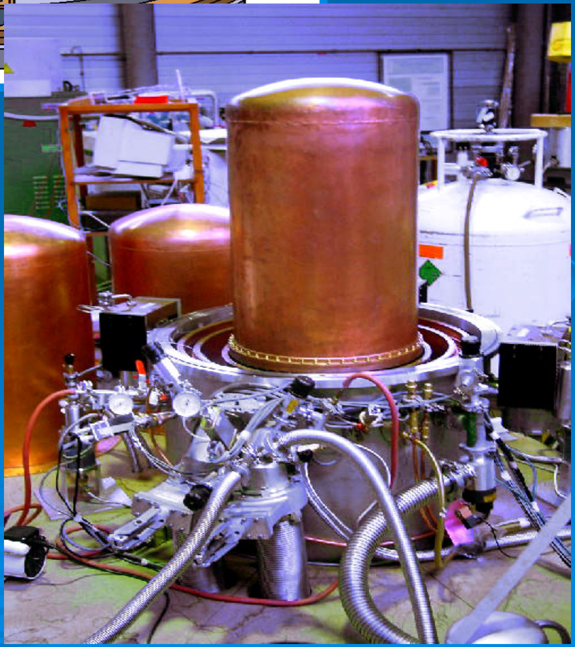
21 320 g Ge-NTD detectors
7 thin film (NbSi) 200 g Ge detectors
(28 detectors, up to 120)

Installation started in April 2004
Data taking in 2005



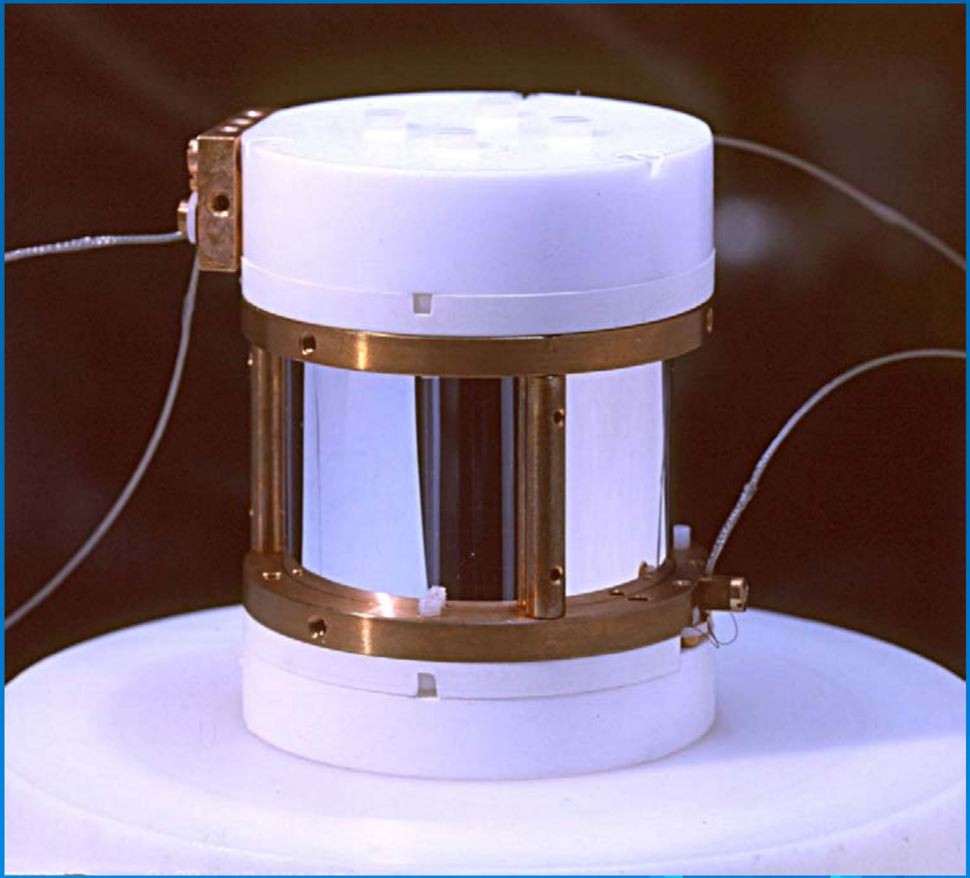


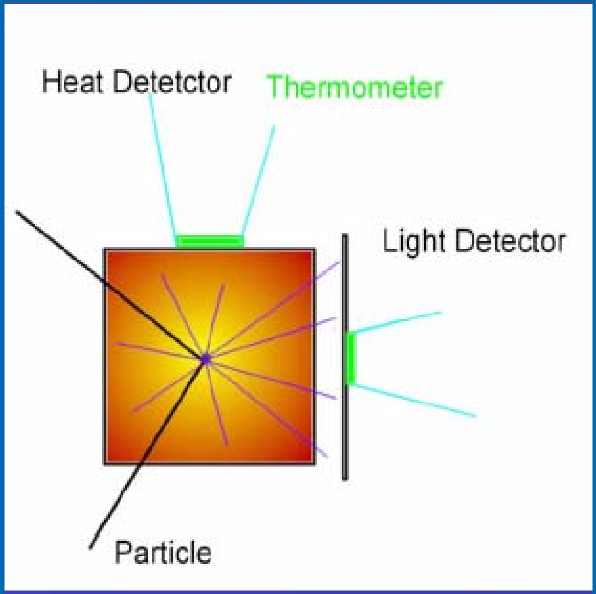
100 l dilution
cryostat for up to
120 detectors (36 kg Ge)



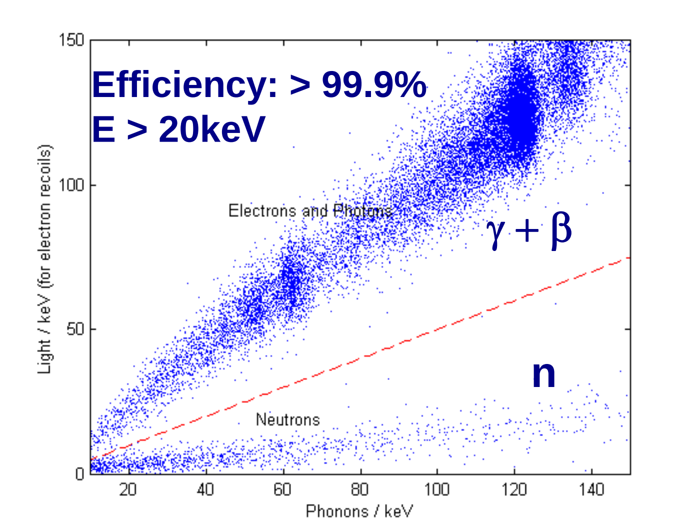
The CRESST II Experiment

In Gran Sasso (3800 mwe)
$CaWO_4$ phonon + light detectors @12 mK
Discrimination between e^- and nuclear recoils



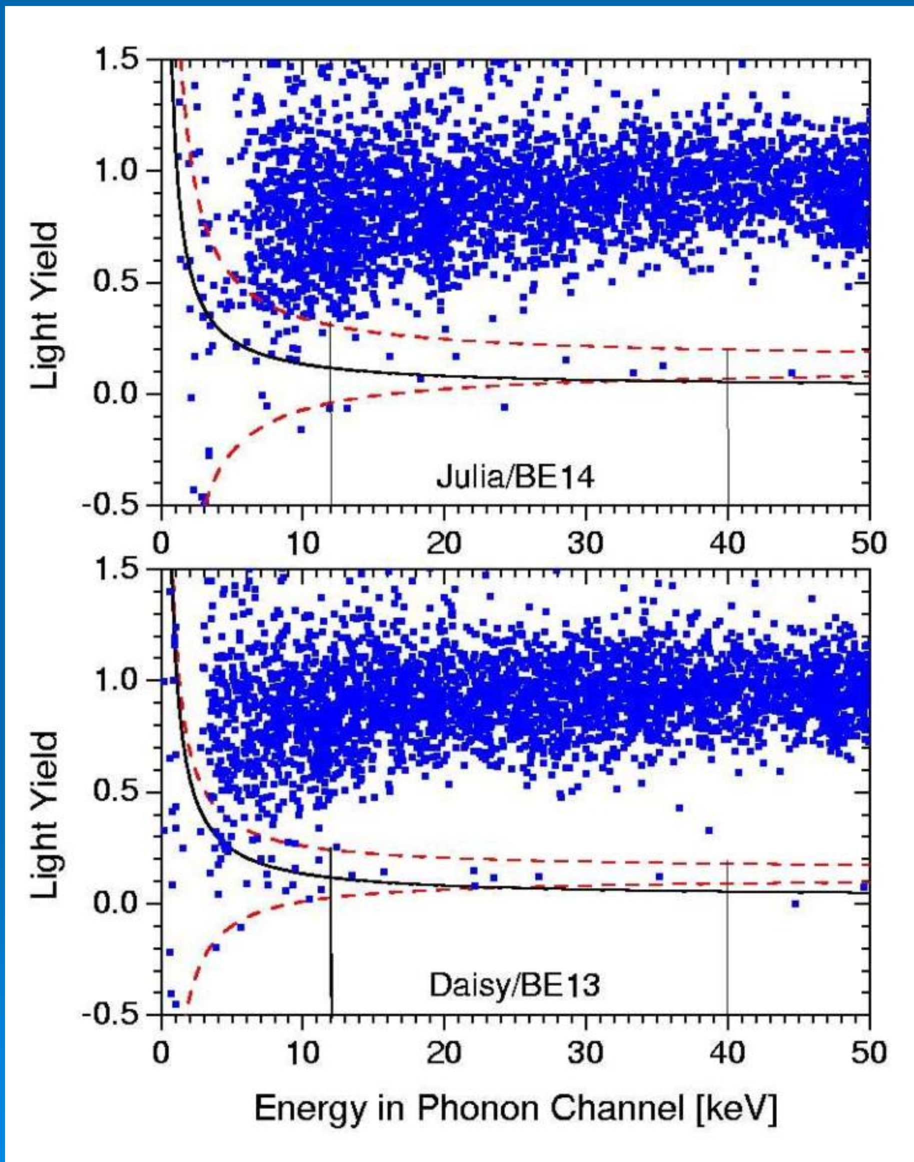


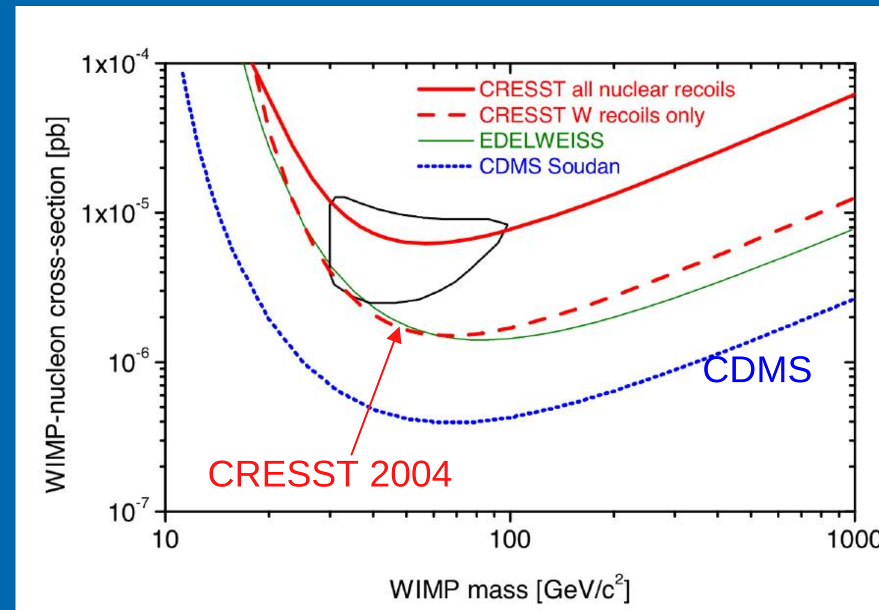
Calibration: 6g test detector



Energy in light vs energy in phonon channel

CRESST II results

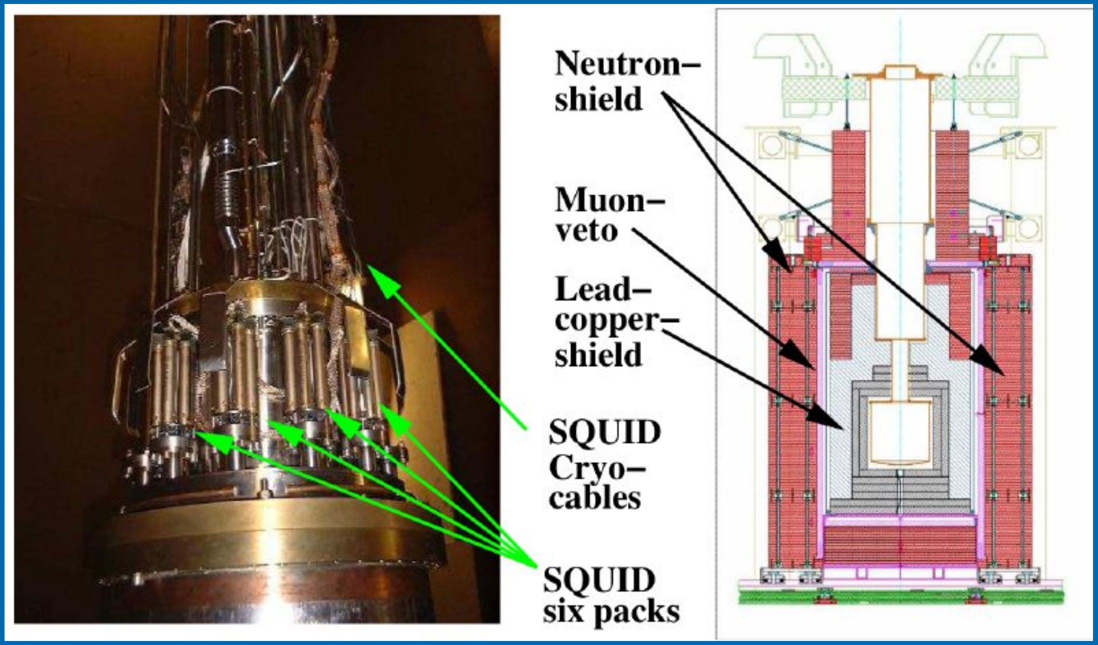




No neutron shield, result limited by neutron flux at Gran Sasso

Upgrade: 33 detector modules with 10 kg of material (66 channels); poly shield and muon veto in construction

CRESST II upgrade

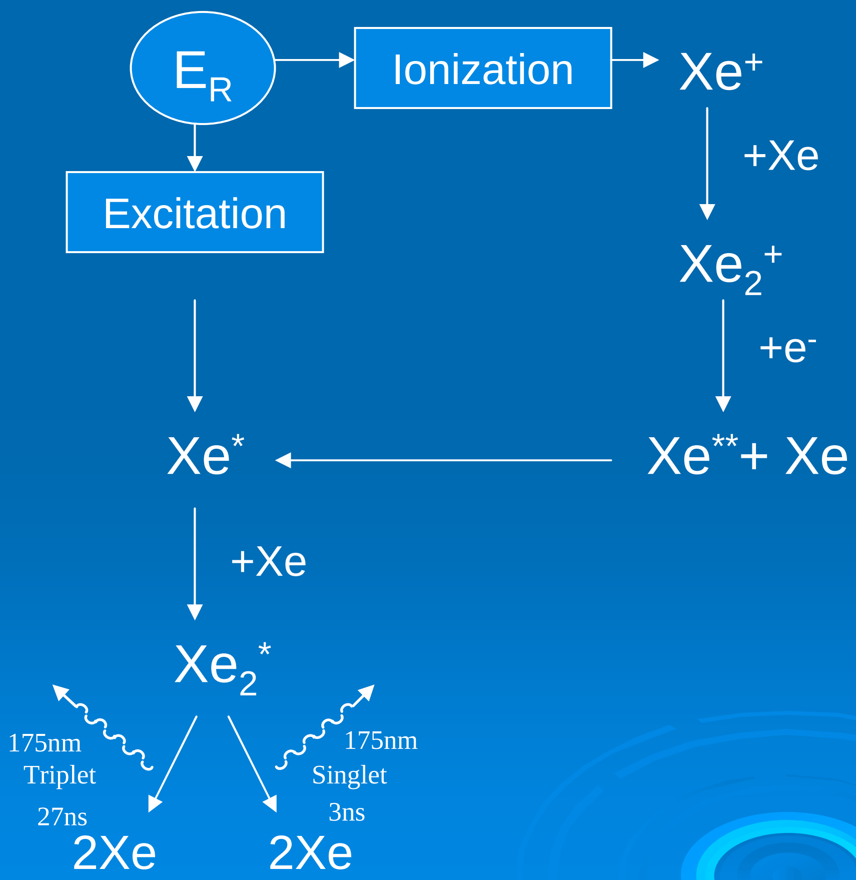


No neutron shield, result limited by neutron flux at Gran Sasso

Upgrade: 33 detector modules with 10 kg of material (66 channels); poly shield and muon veto in construction

Liquid Xenon

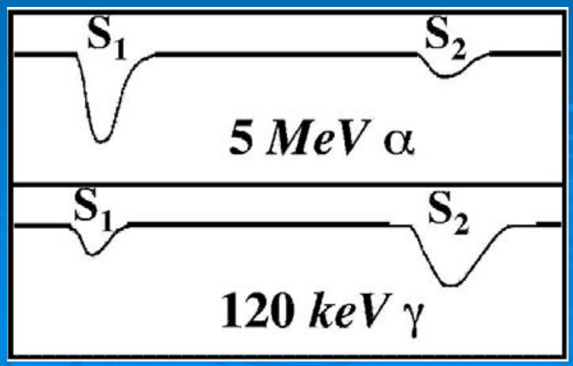
High A = 131, density, compact, self-shielding geometry
'Easy' cryogenics at -100 C
No long-lived radioisotopes
Scintillation + ionization => background discrimination



Scintillation: 175 nm
singlet: 3 ns, triplet: 27ns

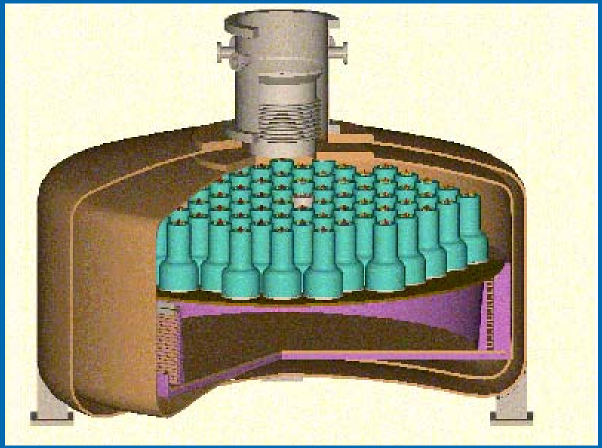
Ionization:
recombination 15 ns

Electron recoils: good charge collection
Nuclear recoils: strong recombination

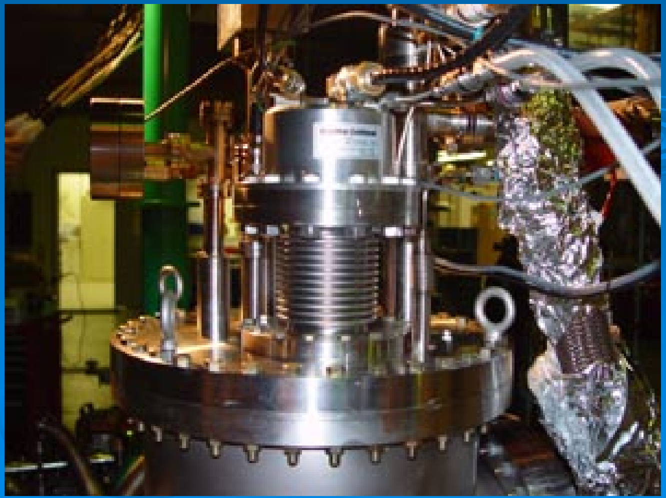


2 Approaches to Liquid Xenon

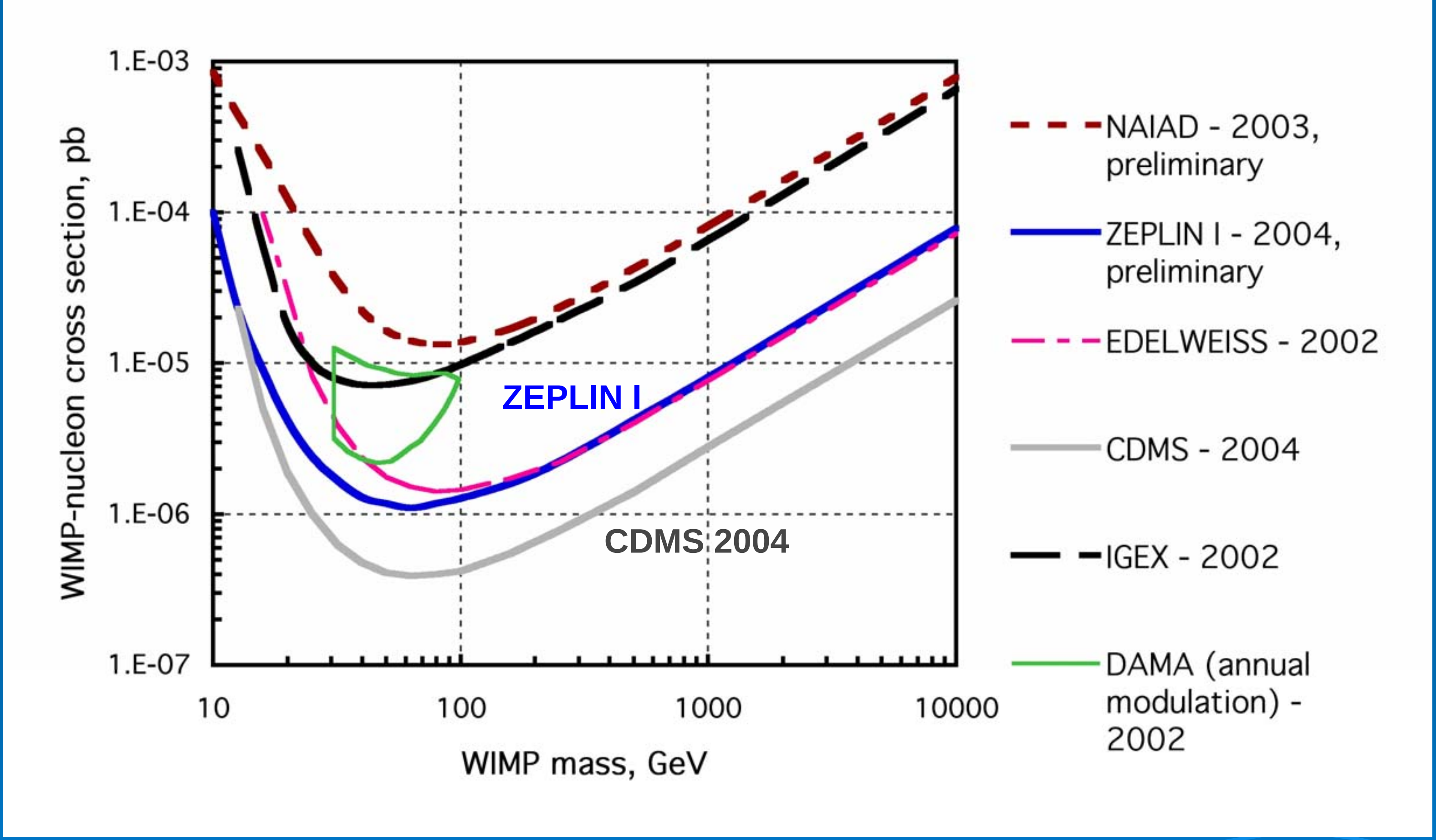
The ZEPLIN family (ZEPLIN I, II/III, IV, MAX)



The XENON Experiment



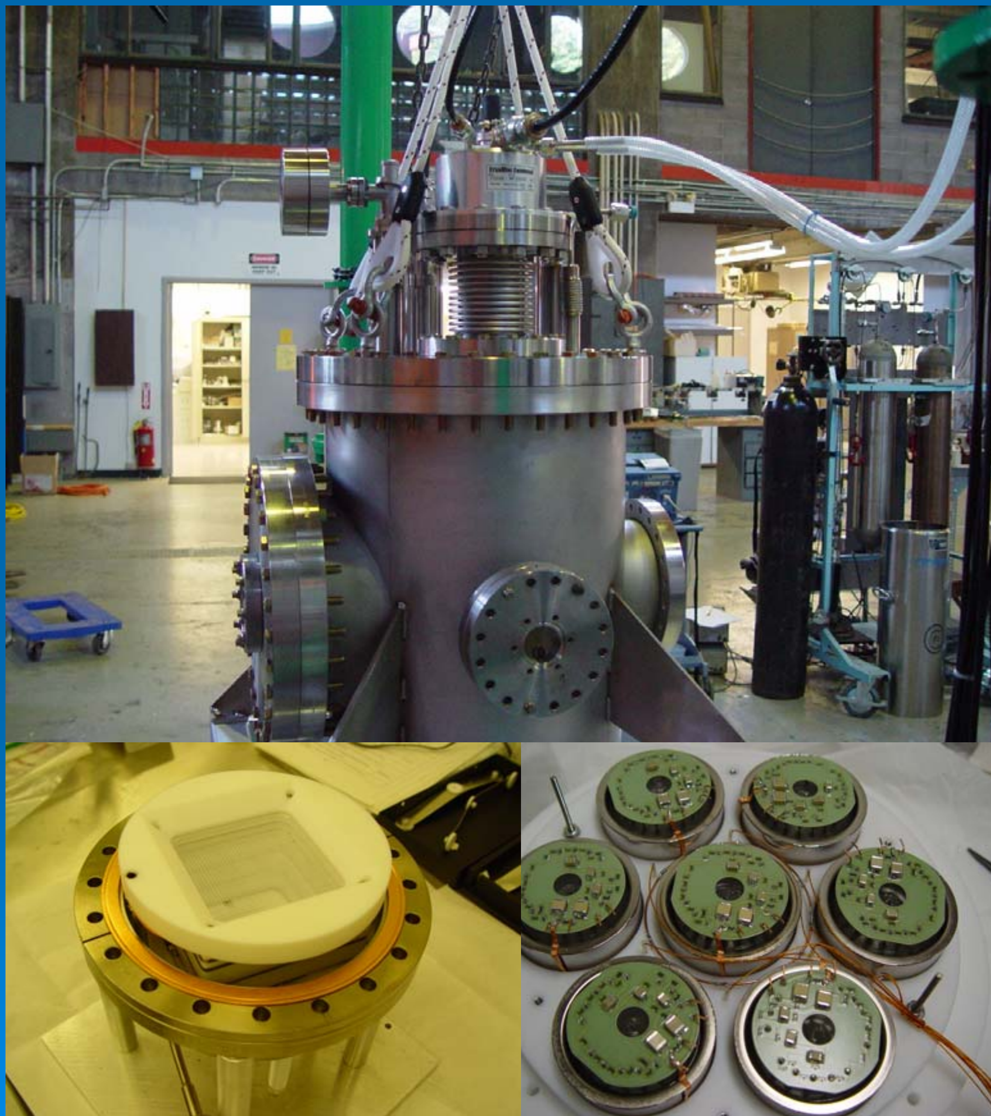
ZEPLIN I limits (preliminary)

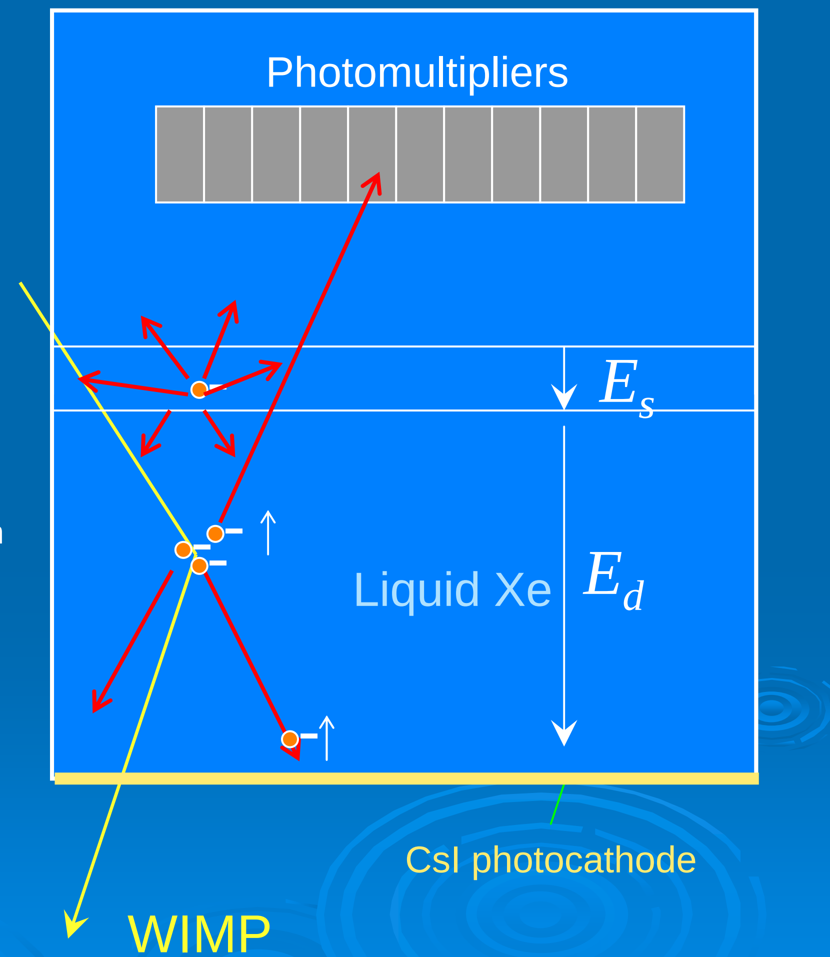


Spin-independent interactions

The XENON Project

(poster 2514, K. Ni)
(poster 2524, P. Sorensen)





The XENON Collaboration

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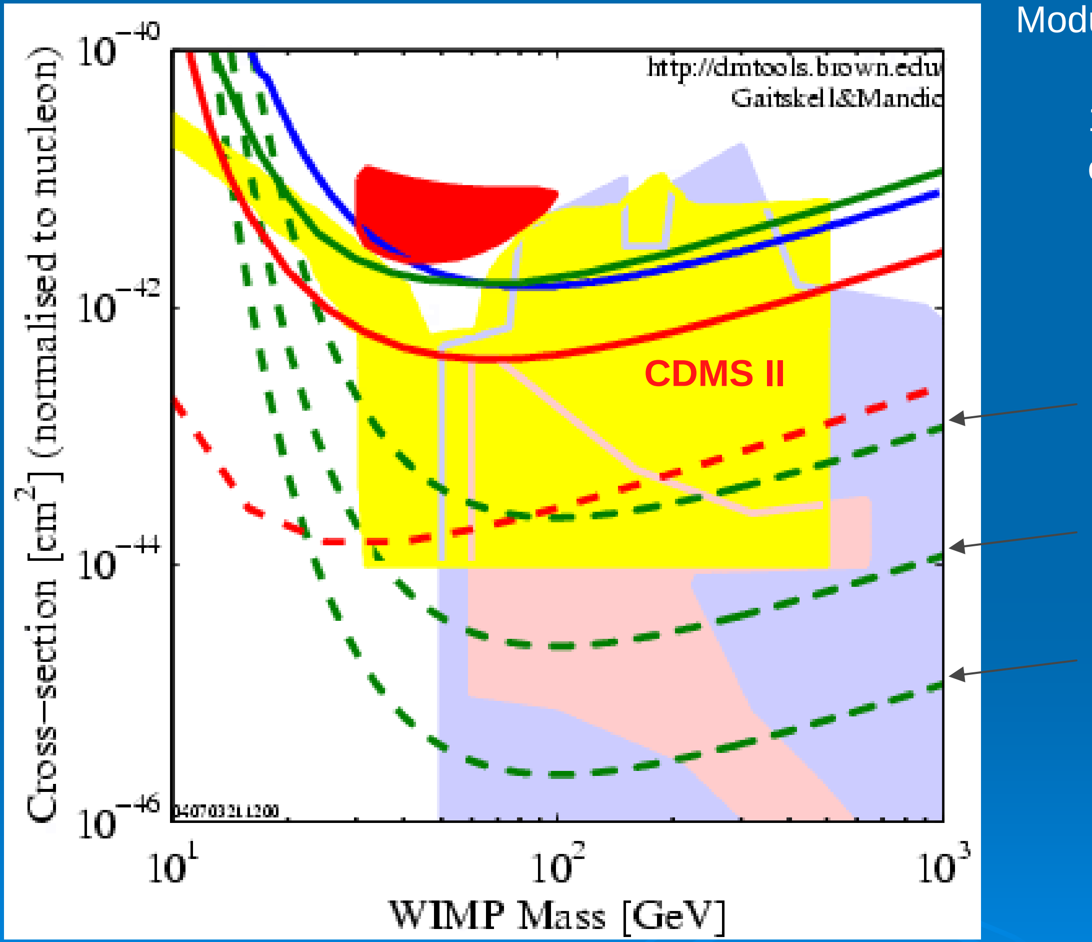
The XENON Project



Modular design:

10 LXe modules: ~ 60cm ø, 60 cm h
each 100 kg active Xe mass

Conclusions

WIMPs: excellent candidates for CDM
discovery far reaching implications for cosmology, particle physics

Direct WIMP detection - a very active field!

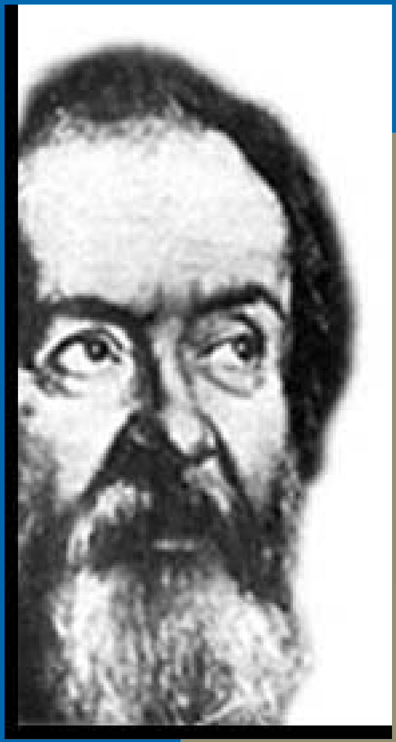
CDMS II at Soudan:
runs with first 2 towers complete
data of 1st tower analyzed: x 8 increase in sensitivity, incompatible with DAMA
(Phys. Rev. Lett. 93, 211301, (2004)
tower 1+2 data in hand: expect results by February
installed 3 more towers, resume data taking end December, increase sensitivity x 20
test more SUSY models or better: find WIMPs!

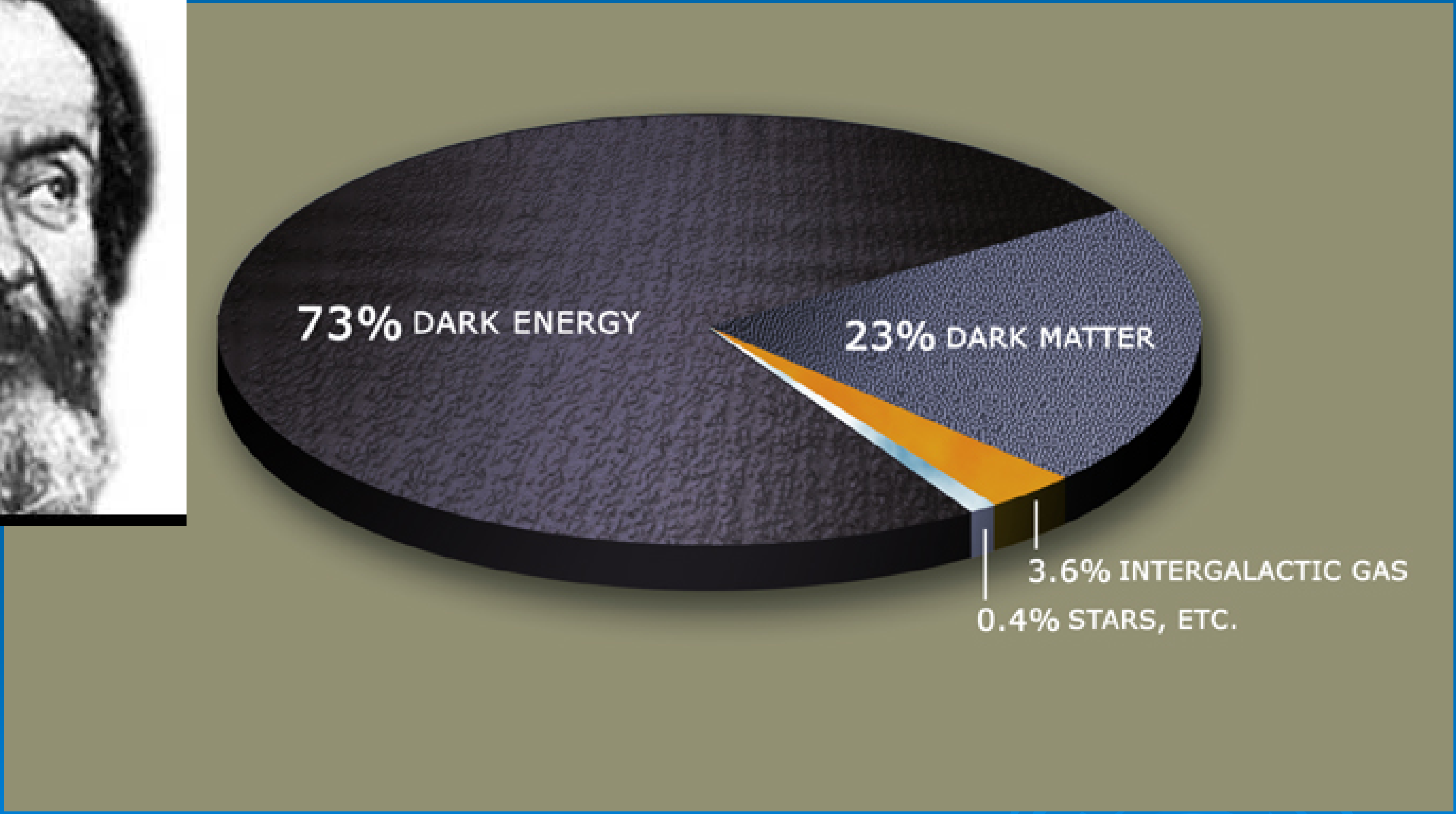
EDELWEISS, CRESST: new results, upgrades; resume data taking in 2005

Future - 1 ton, 'background free' experiments, = 10^{-46} cm^2
SuperCDMS (proposal submitted this fall)
3 phases, start SNOLab installation in 2007

XENON: 10 kg prototype in Gran Sasso mid 2005
goal: 10 x 100 kg modules in GS

The Cosmic Mystery-Pie





'The constitution of the universe may be set in first place among all natural things that can be known'
Galileo Galilei, *Dialogue*