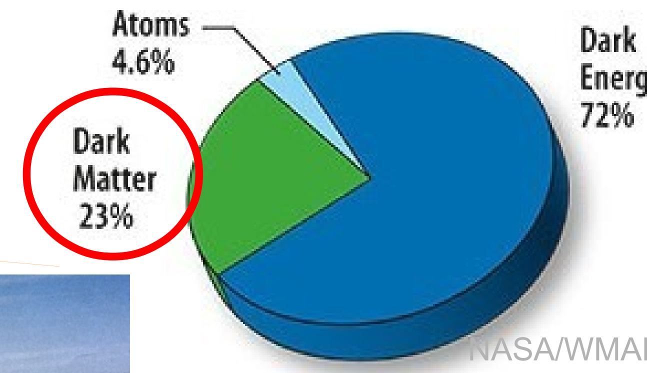
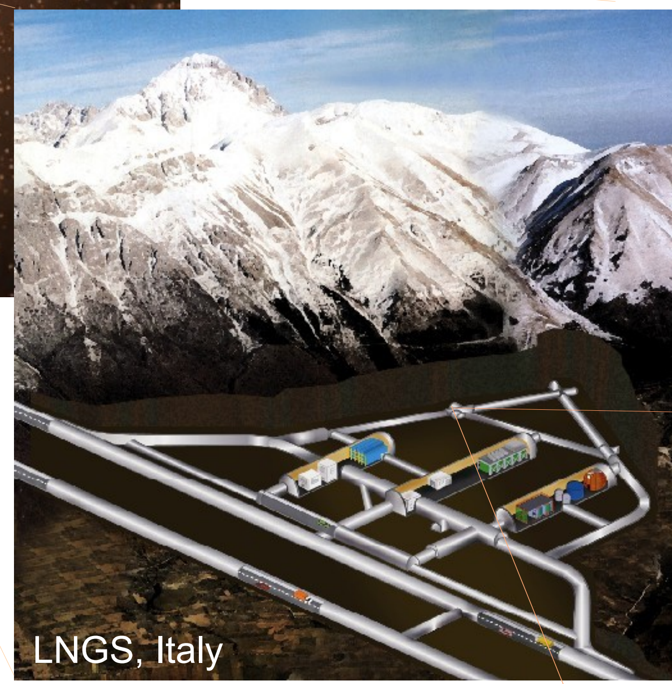
Searches for Dark Matter





Lecture for *Astroteilchenschule*

Obertrubach-Bärnfels October 11-13, 2011

Uwe Oberlack

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Part 3:
DM Direct Detection Experiments

Outline of Lectures at Astroteilchenschule

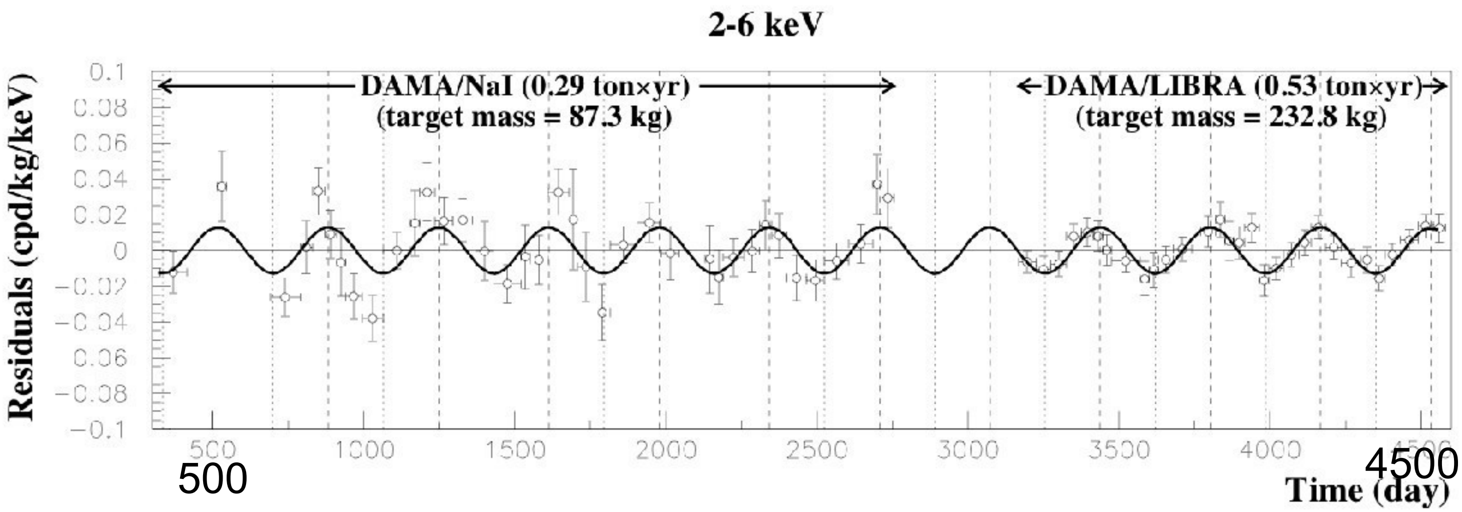
Part 3

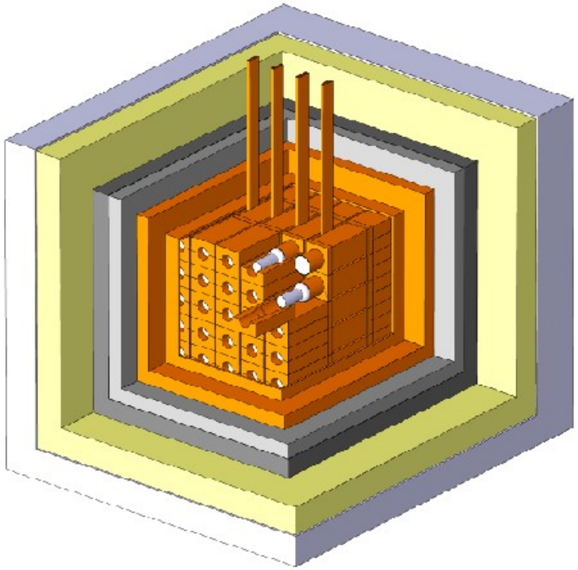
- Signals (?)
  - DAMA / LIBRA annual modulation
  - CoGeNT
  - CRESST-II
- and Limits
  - CDMS-II
  - EDELWEISS-II
  - COUPP
  - XENON100
- Future

1. Signals ?

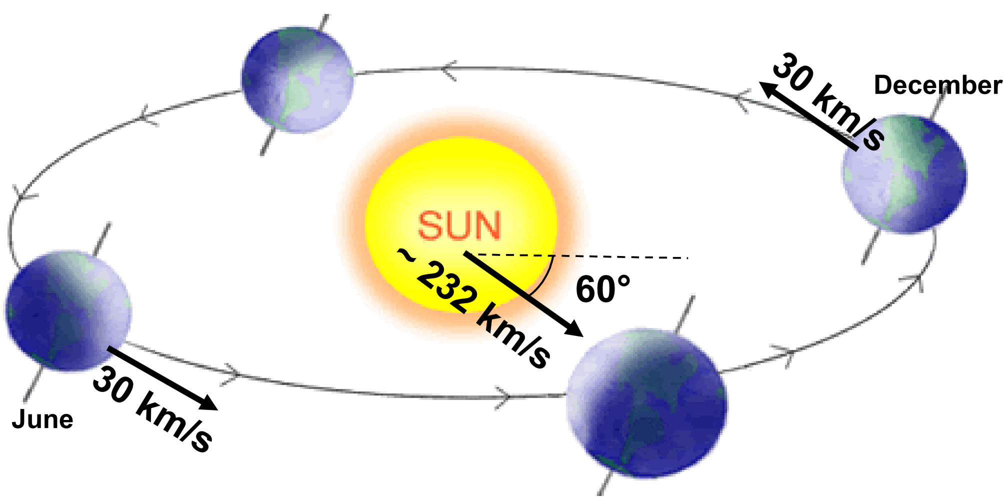
DAMA/LIBRA Annual Modulation

R. Bernabei et al. EPJ C 56, 333 (2008), arxiv:0804.2741
EPJ C 67, 39 (2010), arxiv:1002.1028





- ~250 kg of NaI counters
- 1.17 ton-year exposure (2010)



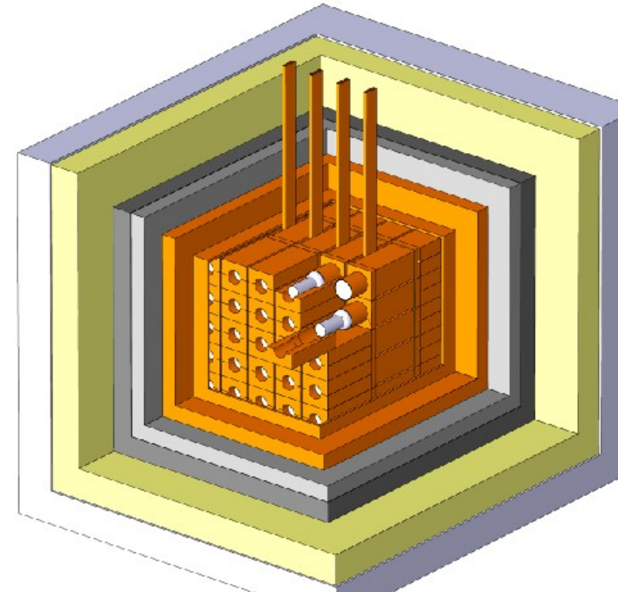
Drukier, Freese, Spergel PRD 86
Freese et al. PRD 88

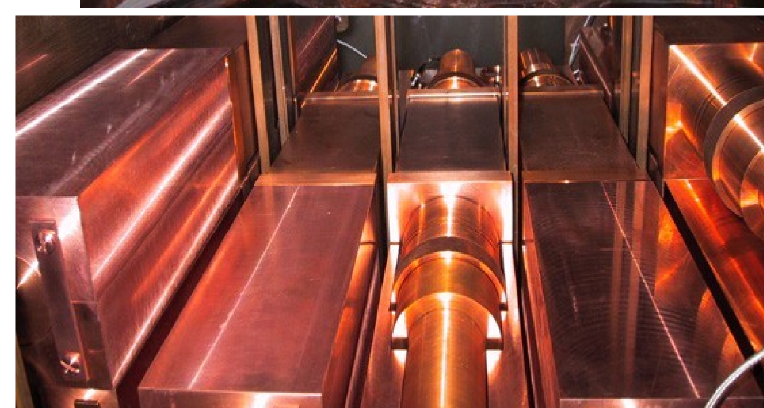
- Modulation in 2-6 keV single hits: 8.9 σ
- Mostly in 2-4 keV, ~0.02 cts/d/kg/keV
- Total single rate ~1 cts/d/kg/keV
- Standard DM distribution: < ~5% modulation
- Period & phase about right for DM.
- No annual modulation in 6-14 keV.
- No annual modulation in multiple hits. (which?)
- **DM detection?**
- Conflict with other experiments in standard scenarios that test the larger steady state effect.

DAMA/LIBRA

R. Bernabei et al. arXiv:0804.2738, arxiv:1002.1028

- Successor of DAMA/NaI experiment
- 5x5 array of 9.7 kg NaI(Tl) crystals viewed by 2 PMTs each.
- PMTs with single photoelectron threshold, operating in coincidence.
- Total mass:
  - DAMA/NaI 1996-2002: ~100 kg
  - DAMA/LIBRA 2003-2008: 232.8 kg
  - DAMA/LIBRA: since 11/2008: 242.5 kg
- Heavy shield:
  >10 cm of Cu, 15 cm of Pb + Cd foils,
  10/40 cm PE/paraffin, ~1 m concrete
- Radon sealing





DAMA/LIBRA

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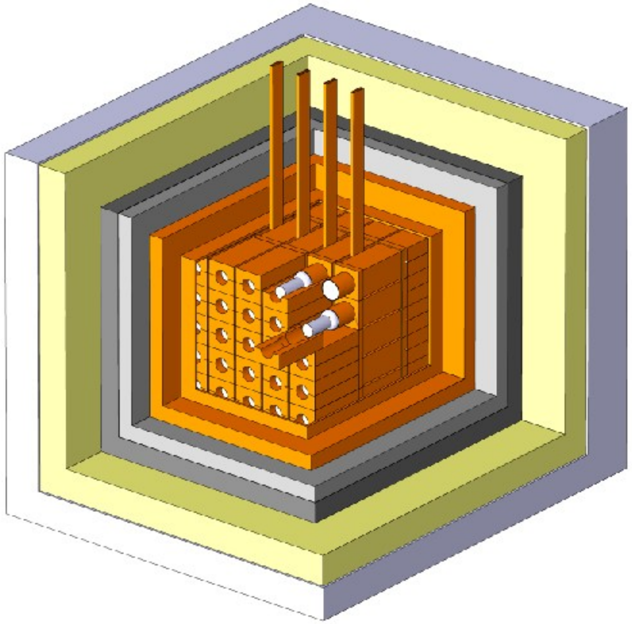
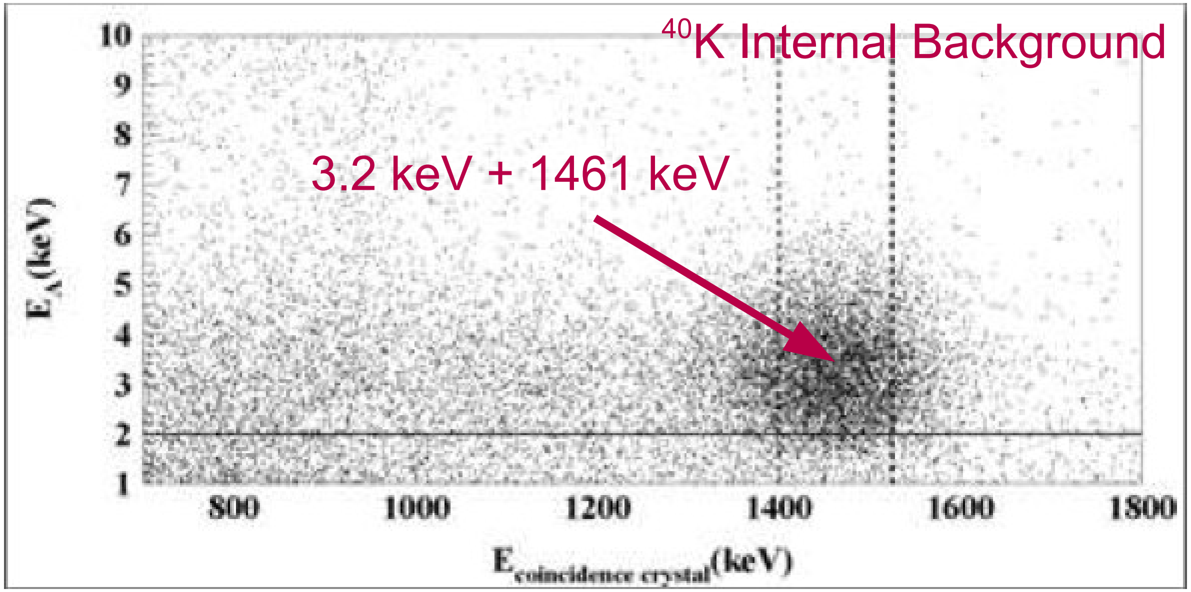


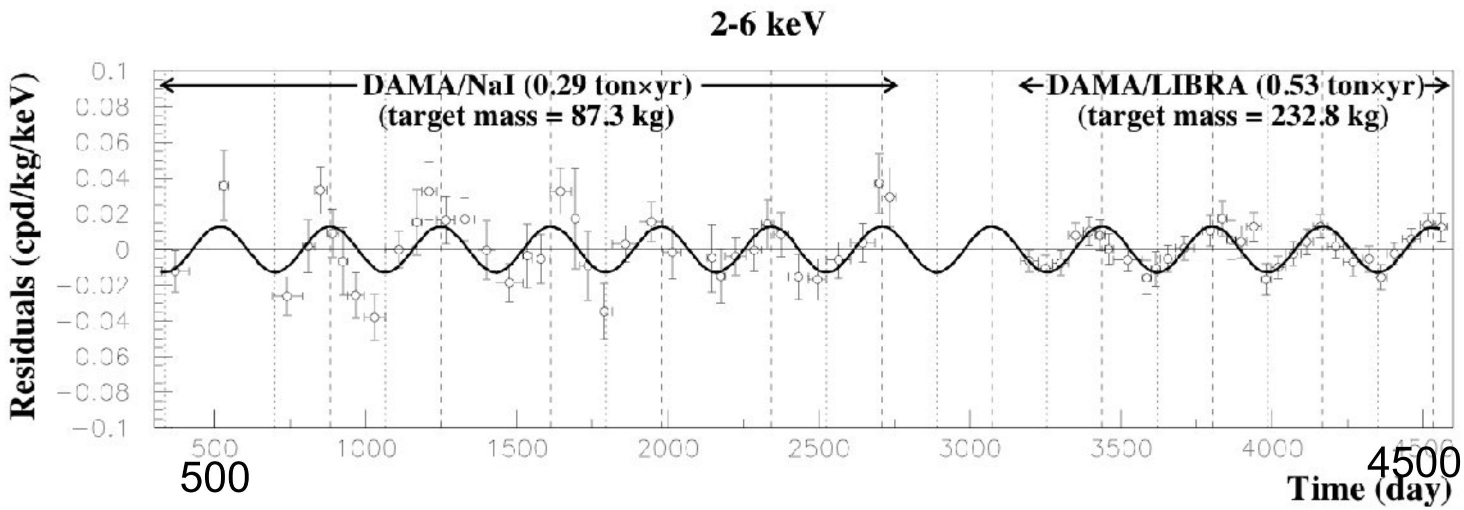
- Dominant multiple step background:



DAMA/LIBRA (NaI) Annual Modulation

Details from the 2008 Result

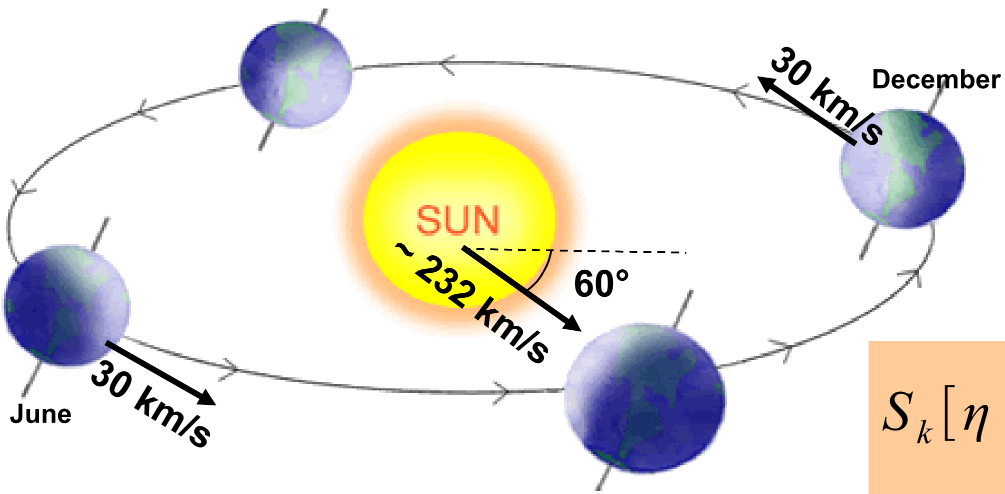
(R. Bernabei et al. arXiv:0804.2741)



Fit: $A\cos(\omega(t-t_0))$	A (cpd/kg/keV)	$T = \frac{2\pi}{\omega}$ (yr)	t_0 (day)	C.L.
DAMA/NaI 0.29 ton × yr				
(2–4) keV	0.0252 ± 0.0050	1.01 ± 0.02	125 ± 30	5.0σ
(2–5) keV	0.0215 ± 0.0039	1.01 ± 0.02	140 ± 30	5.5σ
(2–6) keV	0.0200 ± 0.0032	1.00 ± 0.01	140 ± 22	6.3σ
DAMA/LIBRA 0.53 ton × yr				
(2–4) keV	0.0213 ± 0.0032	0.997 ± 0.002	139 ± 10	6.7σ
(2–5) keV	0.0165 ± 0.0024	0.998 ± 0.002	143 ± 9	6.9σ
(2–6) keV	0.0107 ± 0.0019	0.998 ± 0.003	144 ± 11	5.6σ
DAMA/NaI+ DAMA/LIBRA				
(2–4) keV	0.0223 ± 0.0027	0.996 ± 0.002	138 ± 7	8.3σ
(2–5) keV	0.0178 ± 0.0020	0.998 ± 0.002	145 ± 7	8.9σ
(2–6) keV	0.0131 ± 0.0016	0.998 ± 0.003	144 ± 8	8.2σ

DAMA/LIBRA (NaI) Annual Modulation Signal

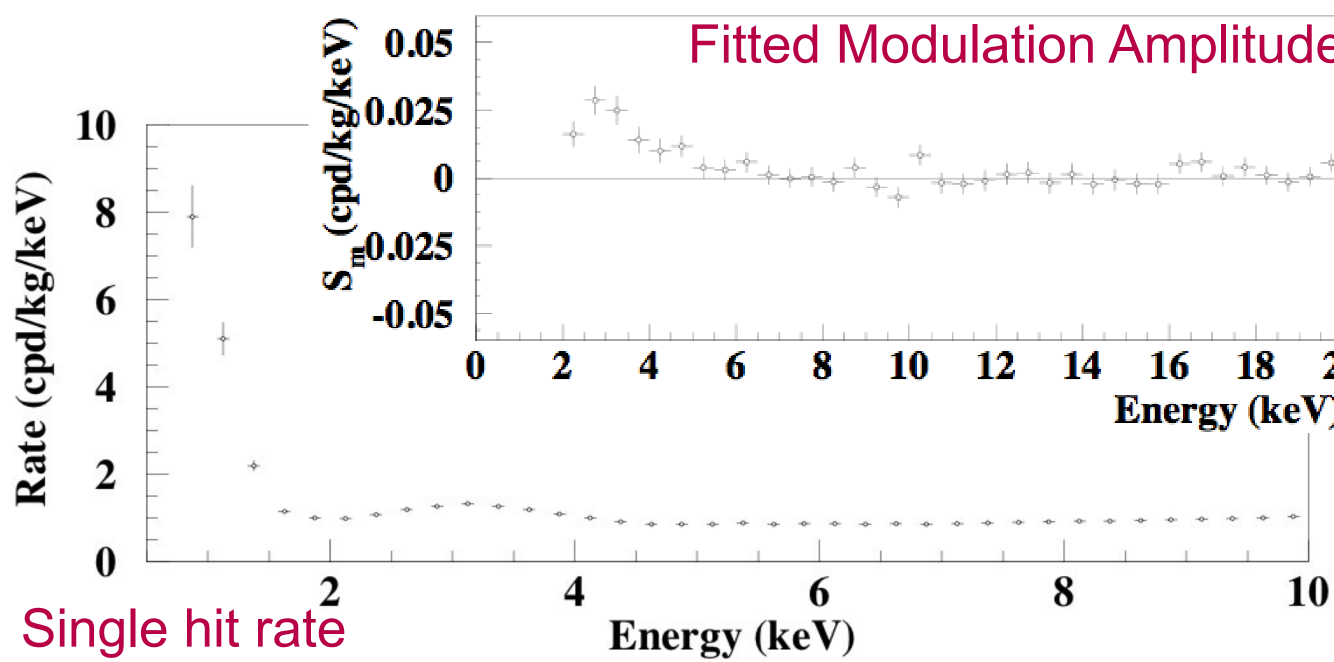
(R. Bernabei et al. arXiv:0804.2741)



$$v(t) = v_{sun} + v_{orb} \cos\nu \cos[\omega\,(t-t_0)]$$

$$S_k[\eta(t)] = \int_{\Delta E_k} \frac{dR}{dE_R}\, dE_R \simeq S_{0,k} + S_{m,k} \cos[\omega(t-t_0)]$$

- Annual modulation rate ~3-5% total interaction rate in standard DM distributions.
- DAMA/LIBRA modulation: ~0.02 cts/d/kg/keV (ee)
- i.e., ~0.4 cts/d/kg/keV total DM interaction rate
- In "standard" WIMP scenario: already XENON10 should have observed >50 events.



Single hit rate

Low Mass WIMPs?
Inelastic Dark Matter?
Luminous DM?

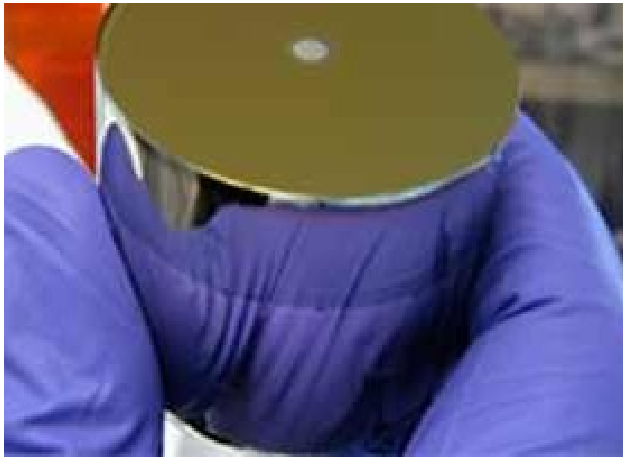
…

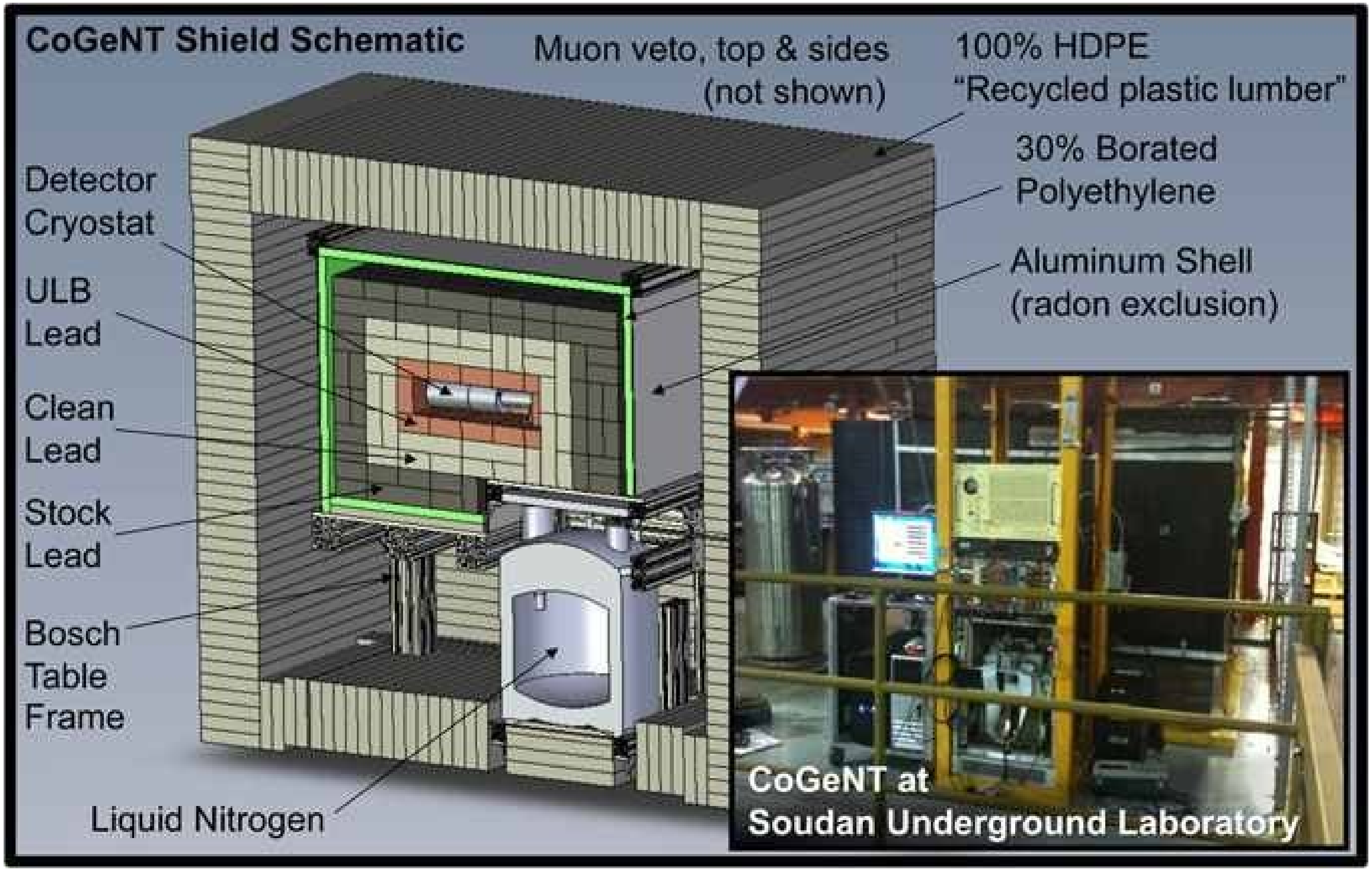
… or some yet to be understood detector or background effect?

e.g.,
J. Ralston, arXiv:1006.5255
D. Nygren, arxiv:1102.0815

CoGeNT: What are these excess events?

- Single P-type point contact (PPC) Germanium detector:
  - 440 g mass, 330 g fiducial (CDMS: 250 g per detector)
  - Low electronic noise, hence low threshold (0.4 keVee)
- Located in Soudan mine (2100 mwe), Minnesota, USA
- Passive shield + Muon veto





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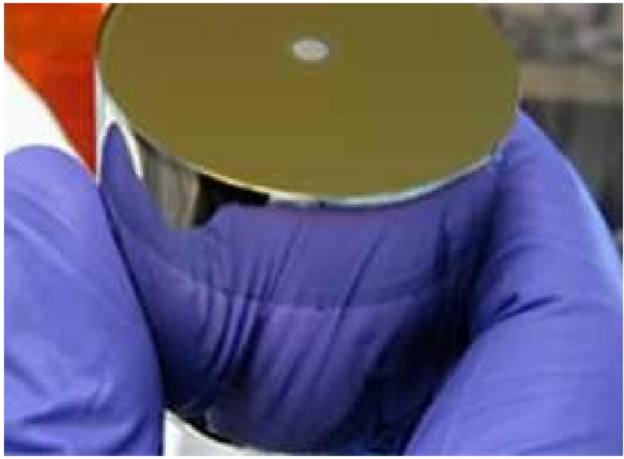
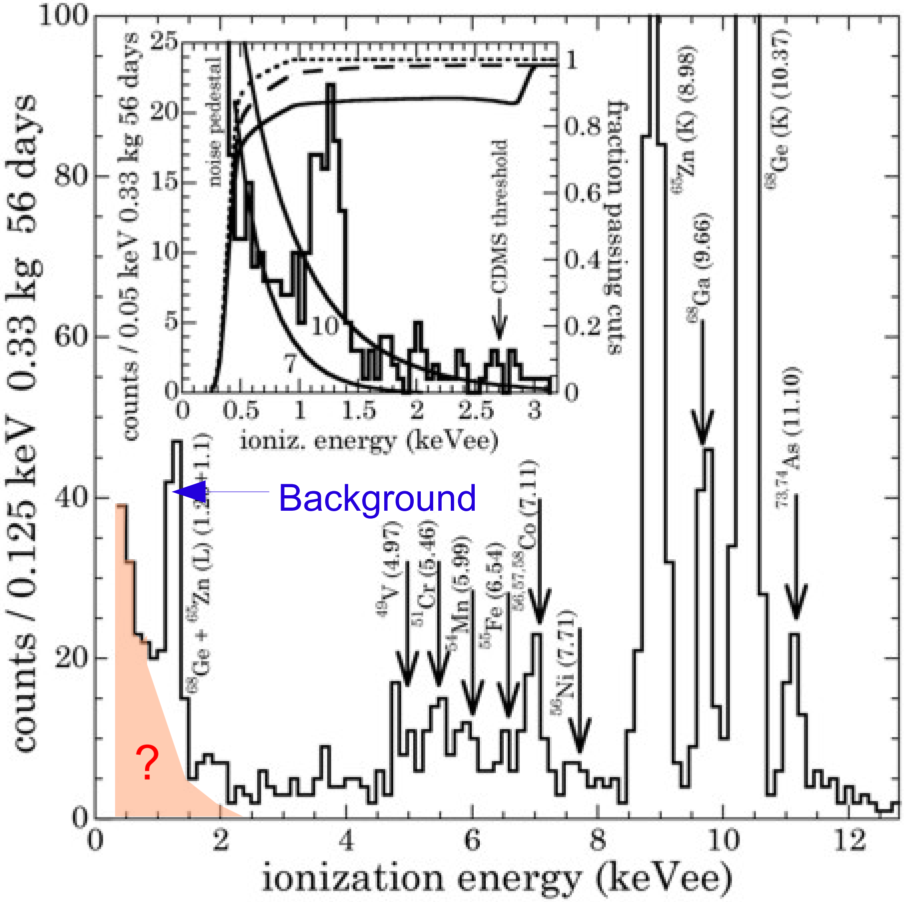
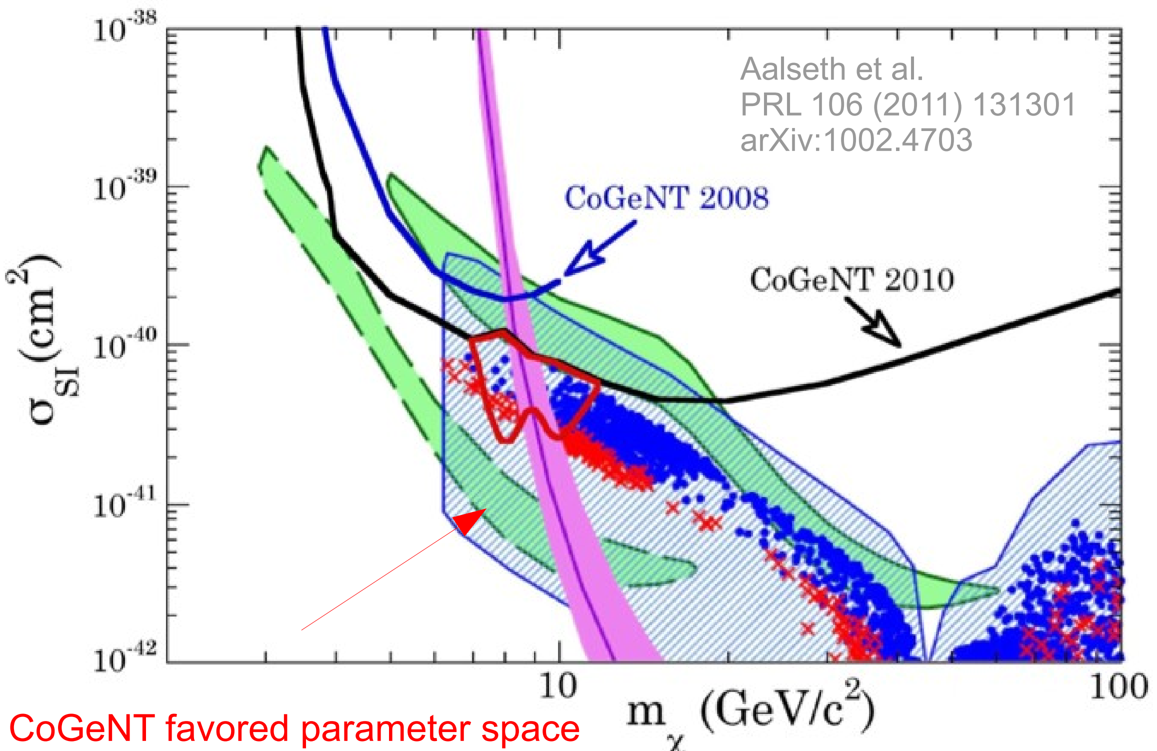
  - Low electronic noise, hence low threshold (0.4 keVee)
- Located in Soudan mine (2100 mwe)
- Passive shield + Muon veto
- Result 2010: Exposure: 18.5 kg d



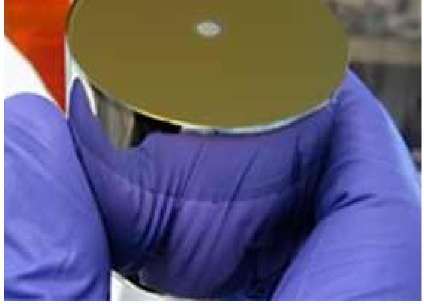




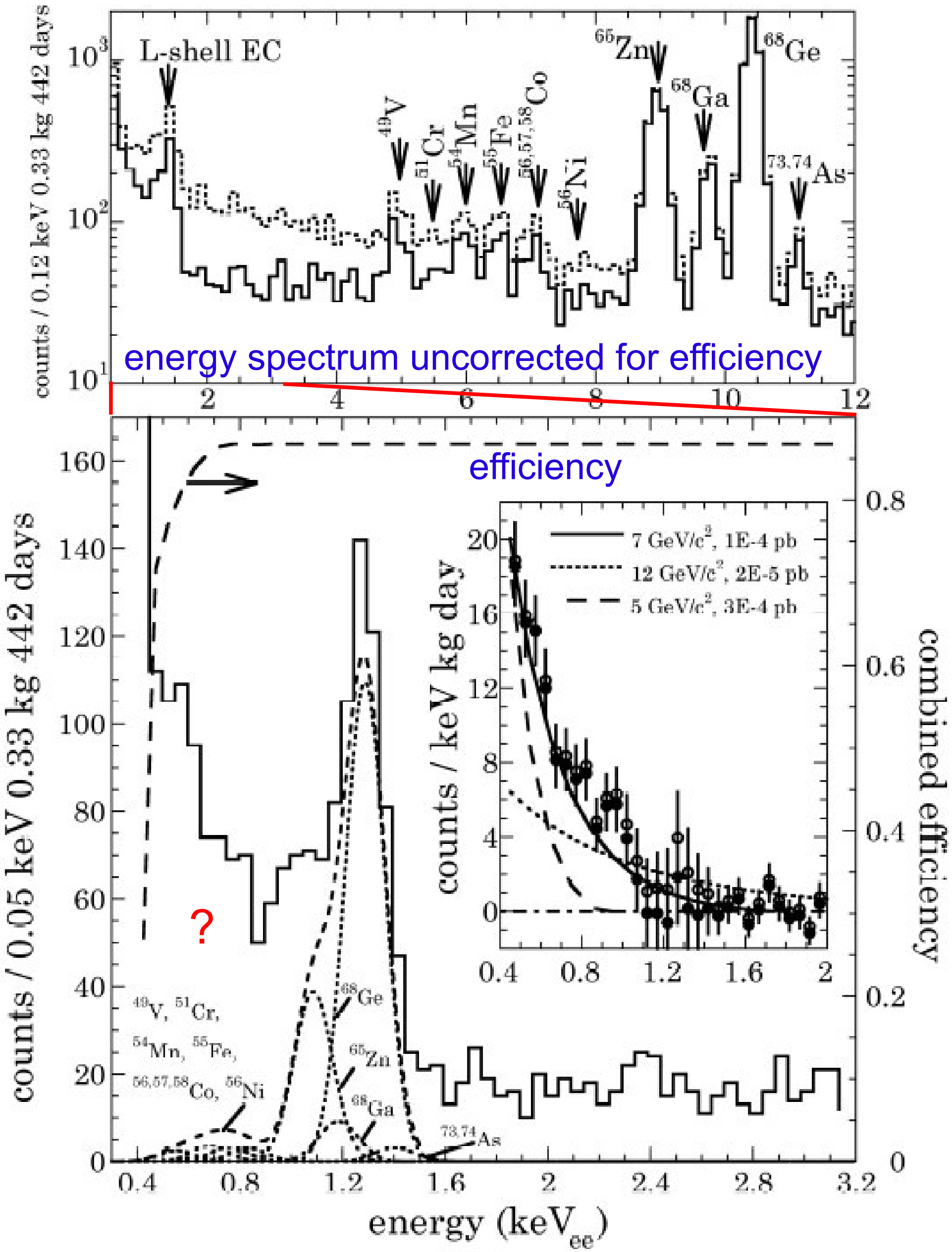
CoGeNT favored parameter space
if excess is interpreted as SI WIMP
scattering

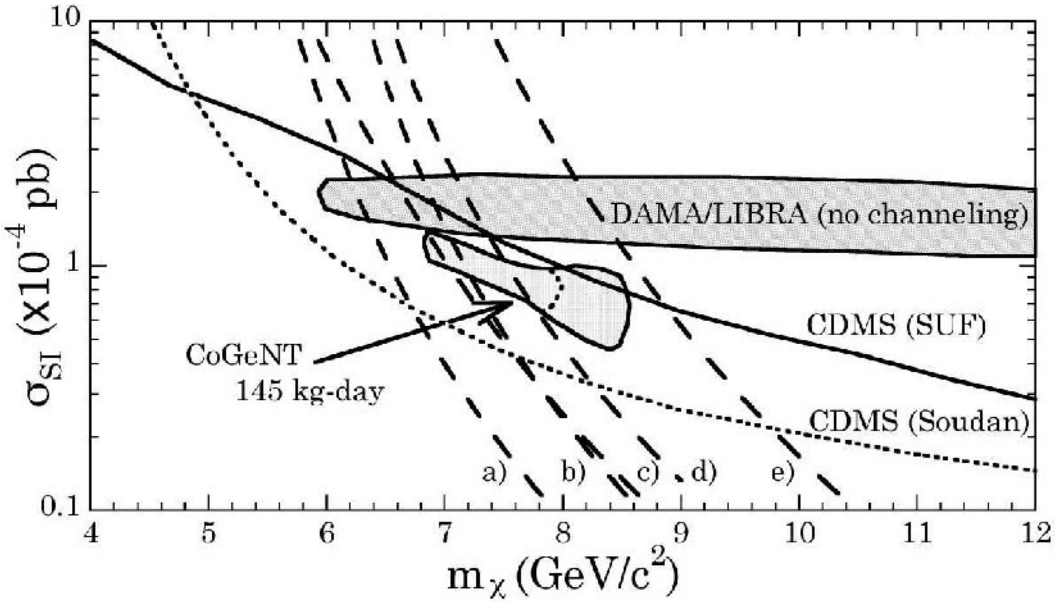
CoGeNT: New Result June 2011

arxiv:1106.0650



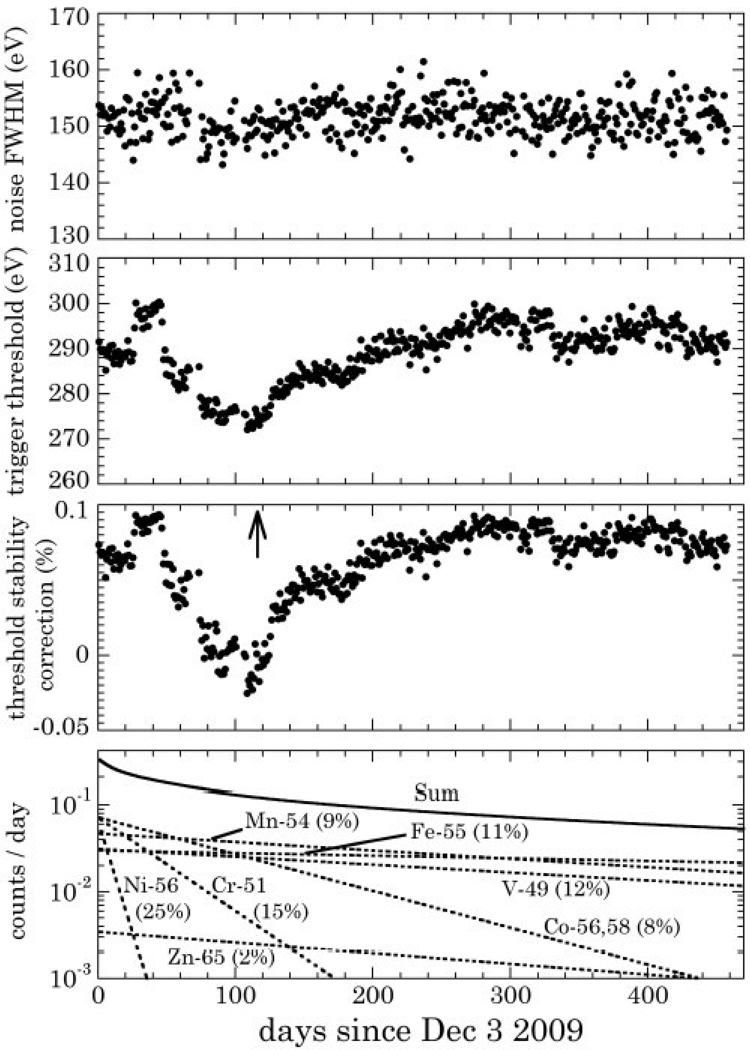
- 145 kg day exposure
- Fire in mine stopped data taking.

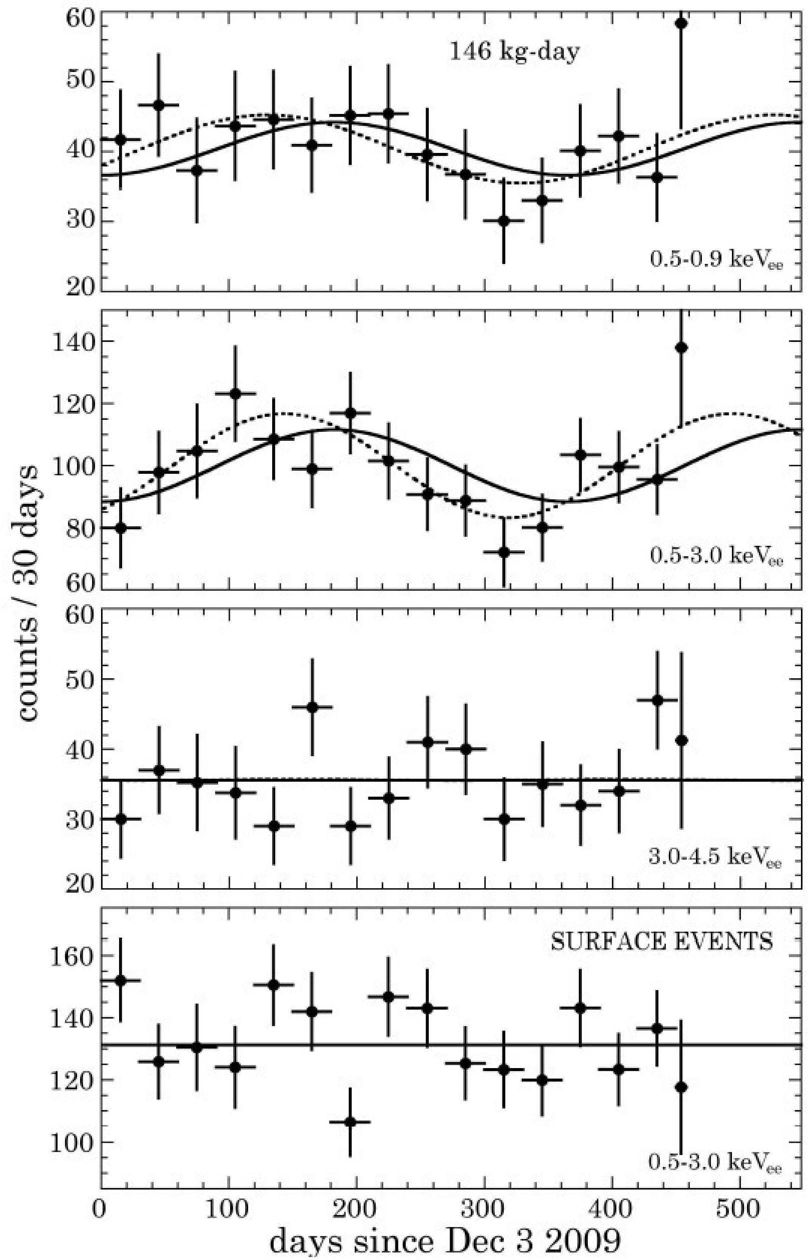


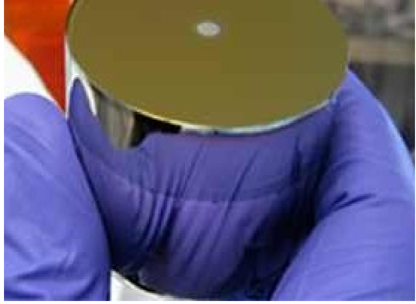


CoGeNT: Annual Modulation?

arxiv:1106.0650







- 145 kg day exposure
- ~2.8 σ effect
- solid line: expected DM phase
- dotted line: best fit

Electronic noise and threshold stability

Low Mass WIMPs?

…

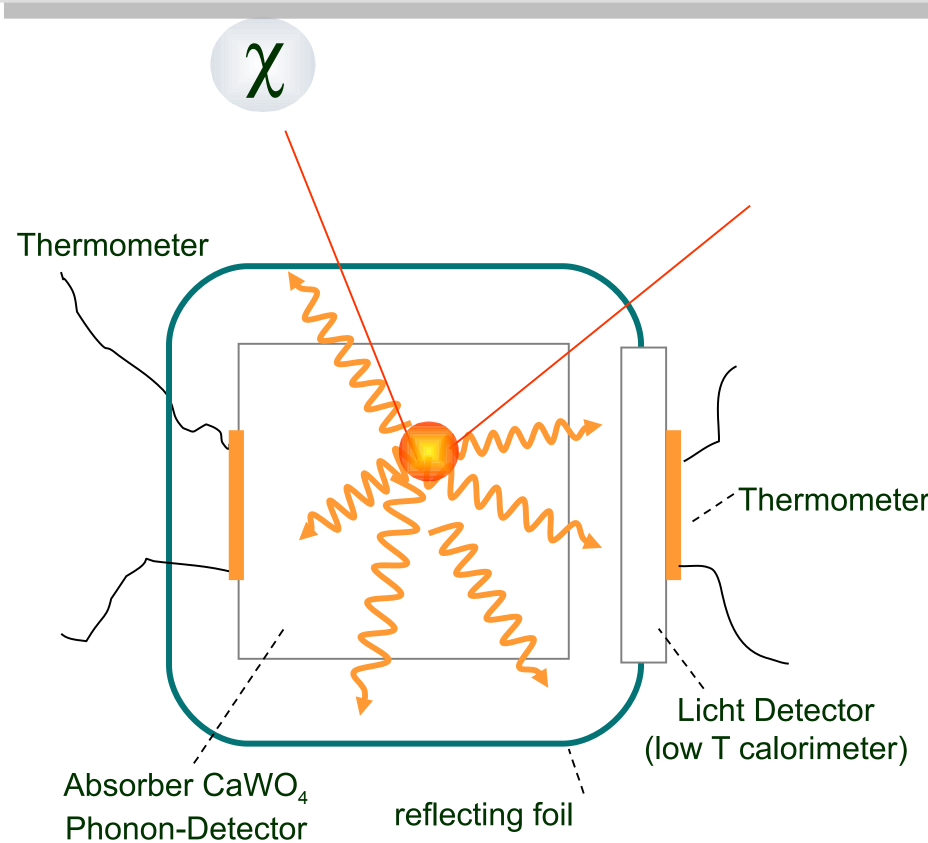
… or some yet to be understood detector or background effect?

CRESST II: Phonons + Scintillation

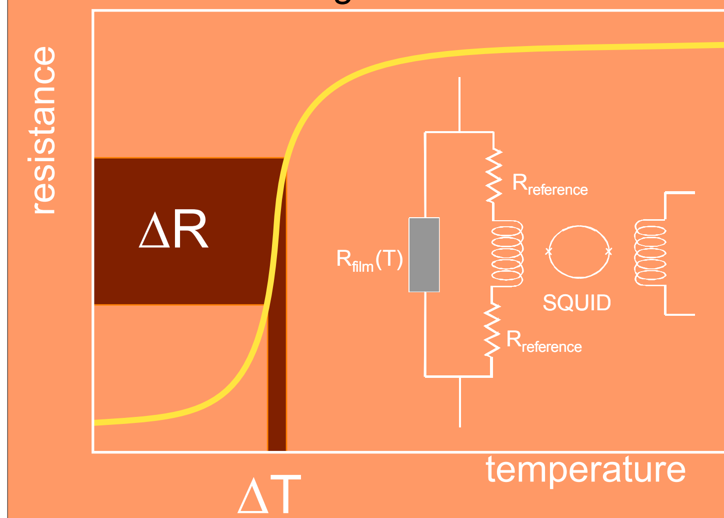
CRESST
Cryogenic Rare Event Search with Superconducting Thermometers

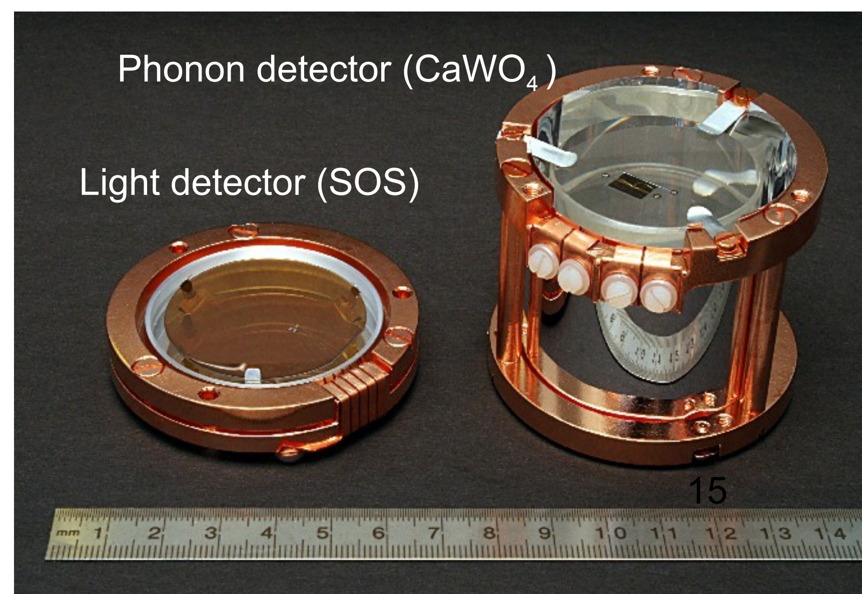
light + phonons (scintillating crystals)

Max-Planck-Institut München, TU München
Universität Tübingen, Oxford University, Gran Sasso

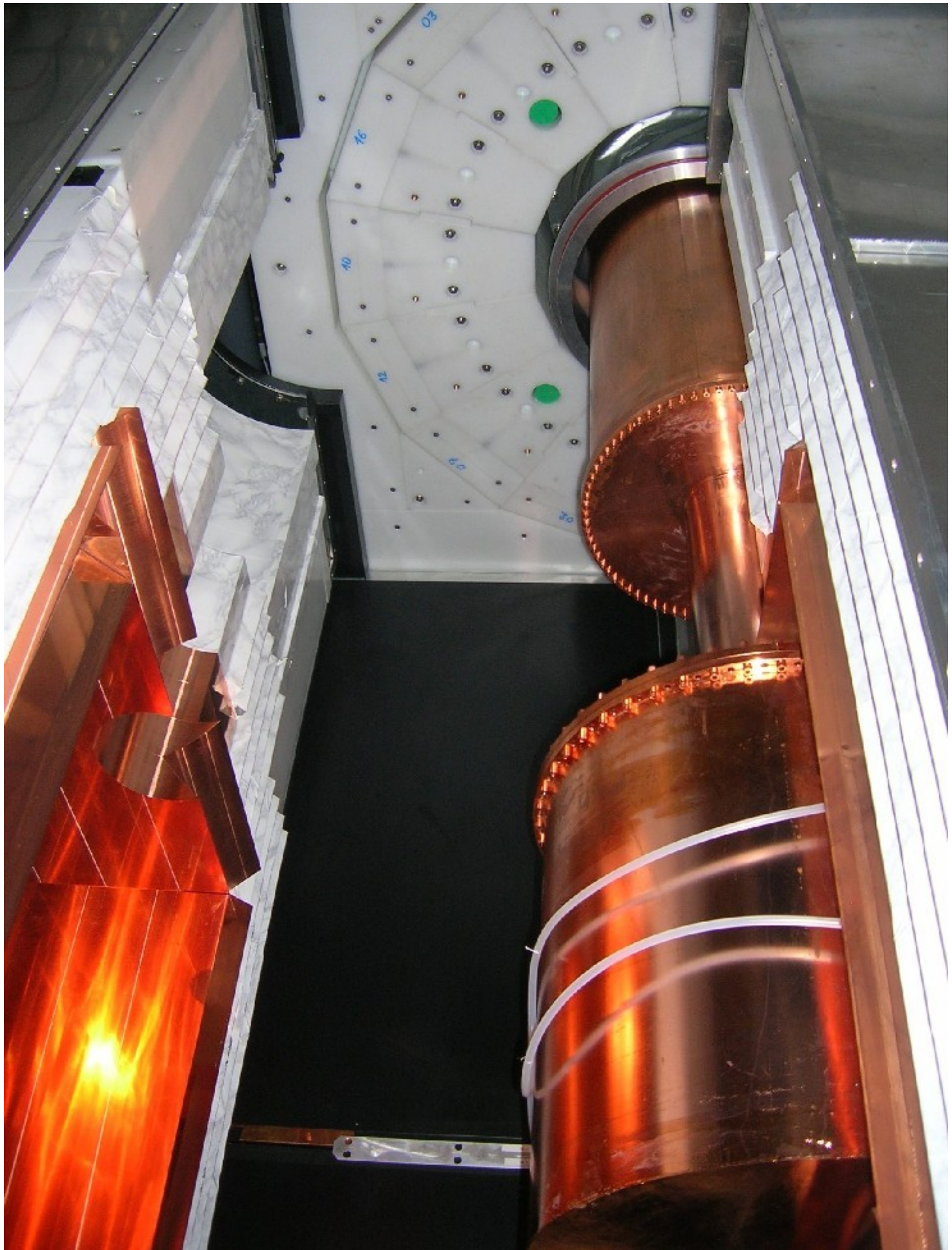


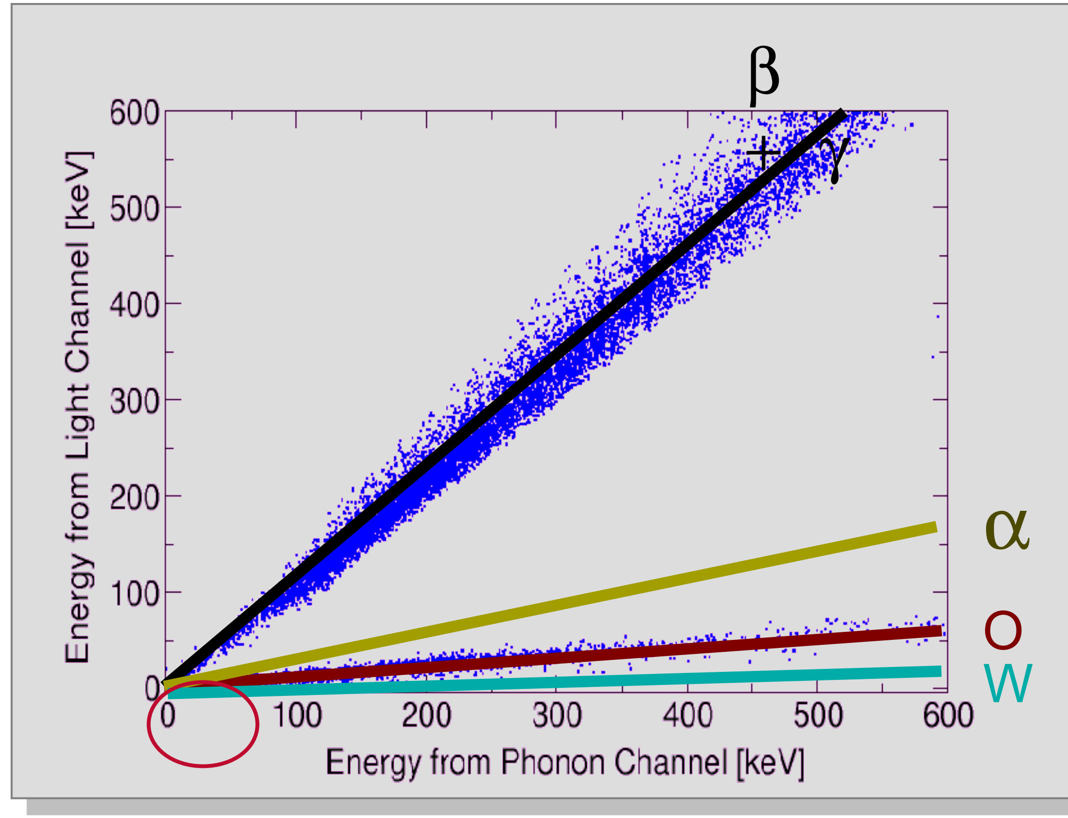
Transition Edge Sensors (TES)
superconducting phase-transition-thermometer tungsten Tc≈15mK





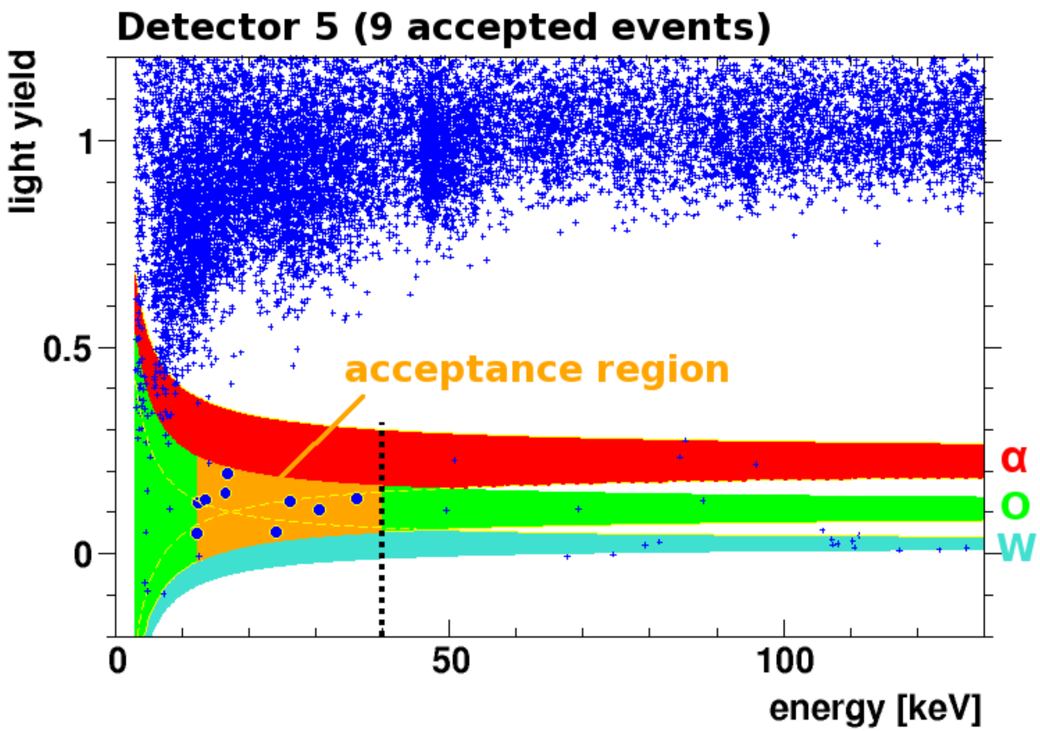
CRESST II Background Suppression & Discrimination

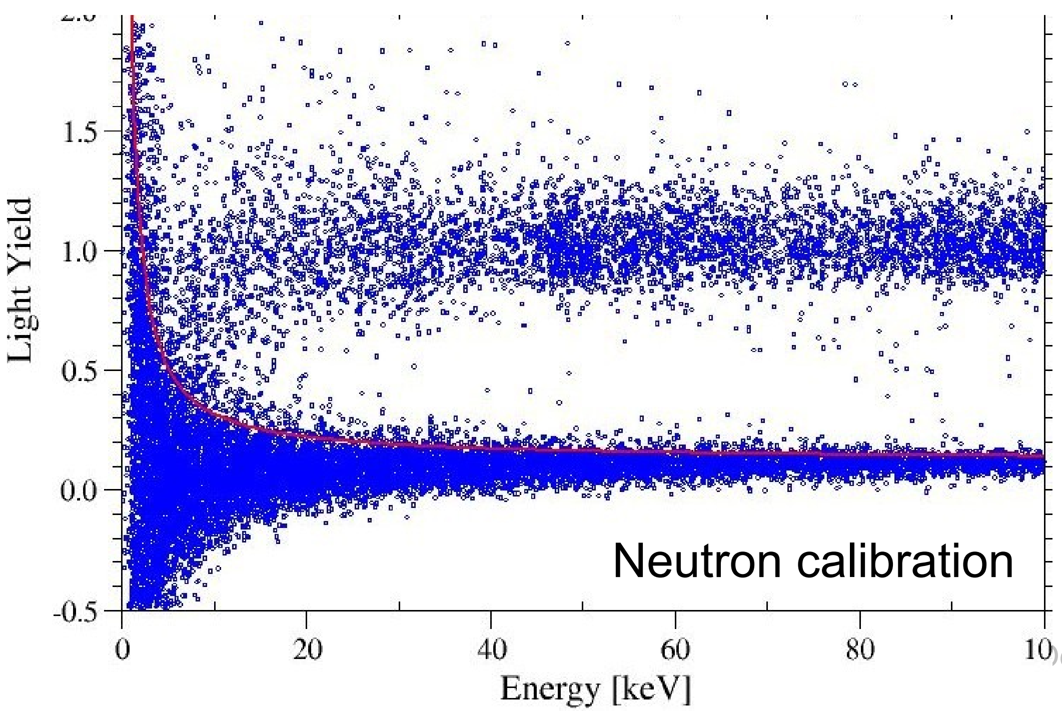




- Polyethylene / Lb / Cu passive shield
- Plastic muon veto
- Light yield / Phonon Energy = background discriminator
- CRESST unique feature: multi-target possible

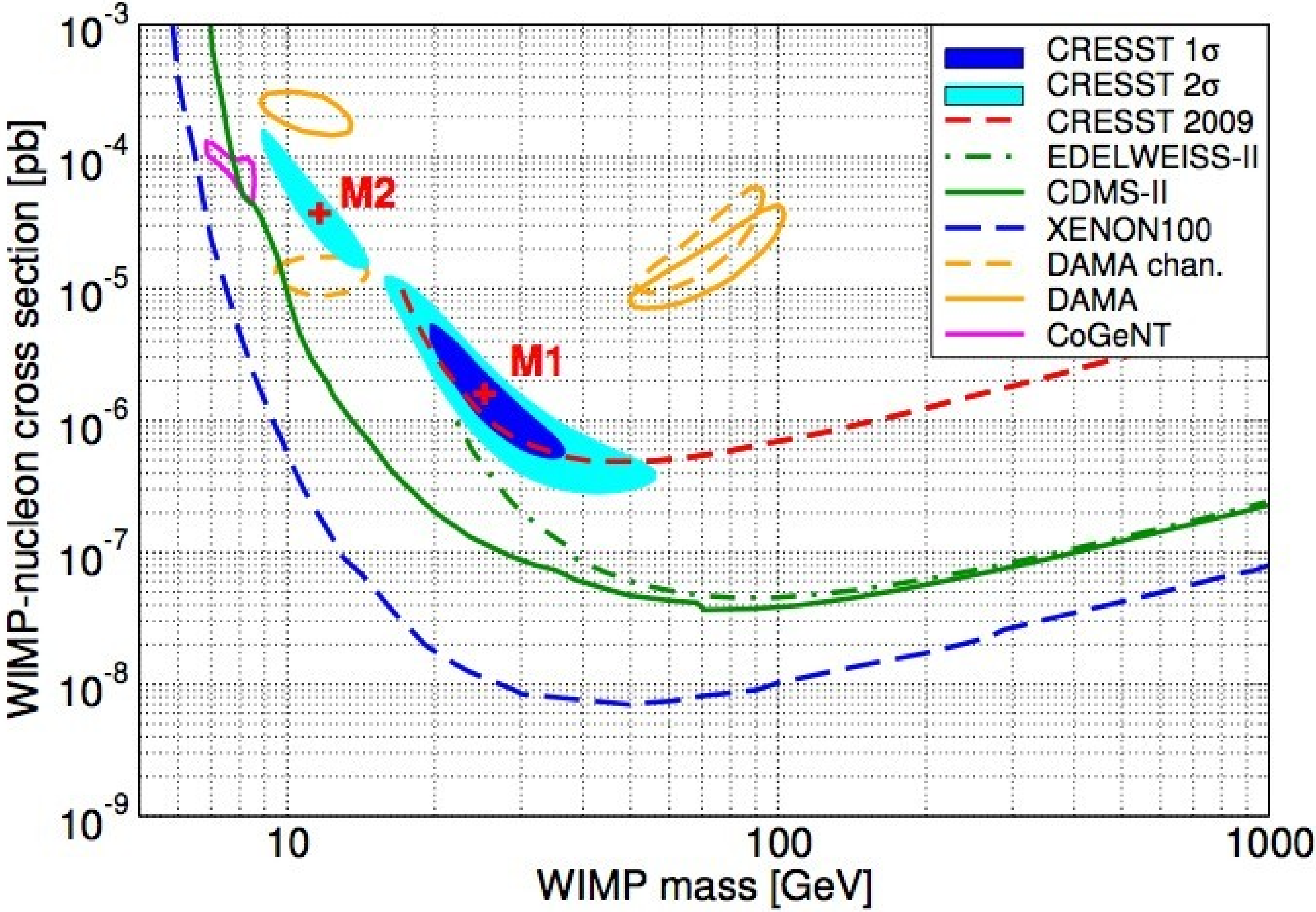
CRESST II: What are these excess counts?





- Data from 9 $CaWO_4$ detectors
- Exposure: 730 kg d
- 57 events observed in O-band (in allen Detektoren)
- Acceptance region (detector specific): O-band in ~10-40 keV

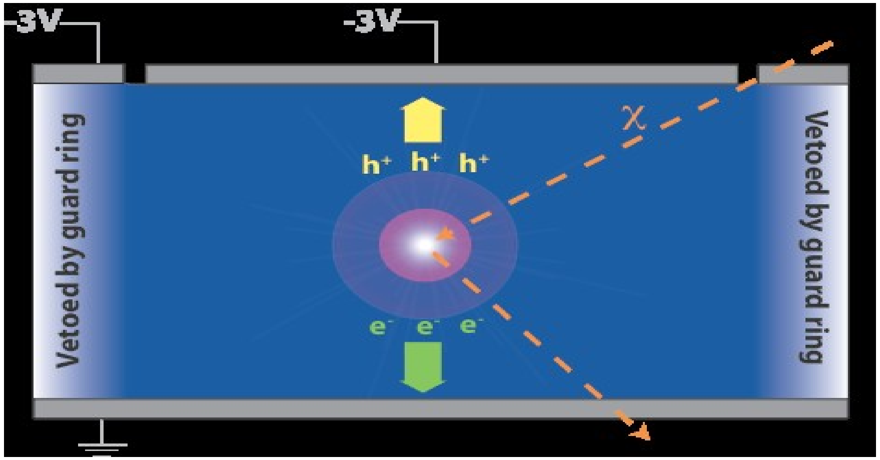
- Background estimated from sidebands:
  - α-events: 9.3
  - neutrons (generate mostly O-recoils): 17.3
  - e/γ leakage: 9.0
- Excess events not explained by modeled background: 4.6 σ (?)
- Hint of low-mass WIMPs?
  - best fit: $M_\chi \sim 13$ GeV/c^2, $\sigma \sim 3\times10^{-5}$ pb = 3×10^{-41} cm^2
  - confidence region?
- Systematic background uncertainty?
- Further background reduction planned.

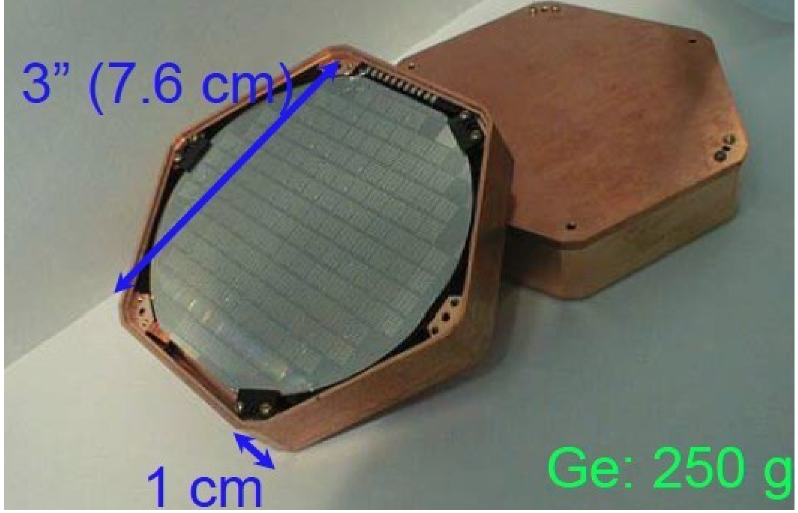


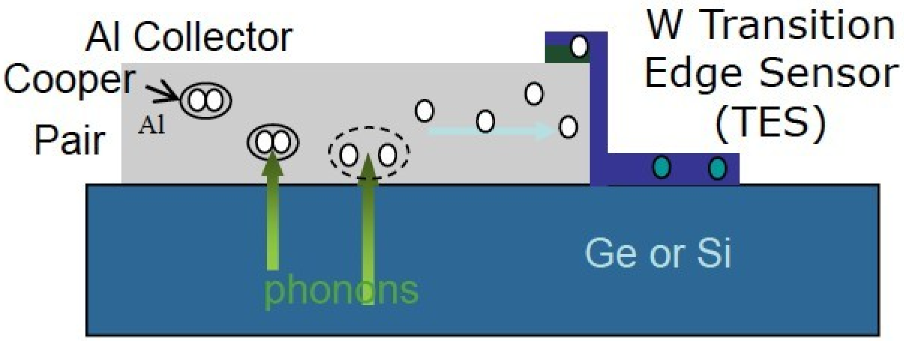
CRESST 1σ
CRESST 2σ
CRESST 2009
EDELWEISS-II
CDMS-II
XENON100
DAMA chan.
DAMA
CoGeNT
M2
M1
WIMP-nucleon cross section [pb]
WIMP mass [GeV]
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10
100
1000

2. Limits

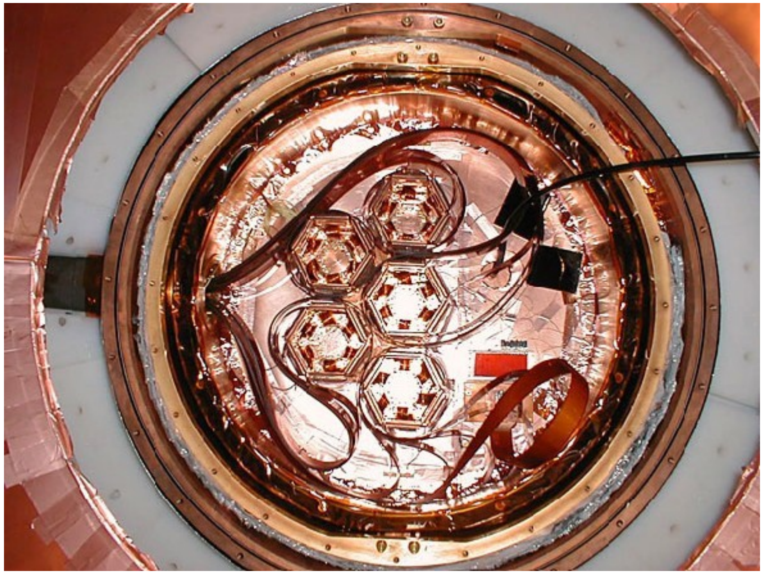
CDMS-II: Phonons + Charge
(Cryogenic Germanium)

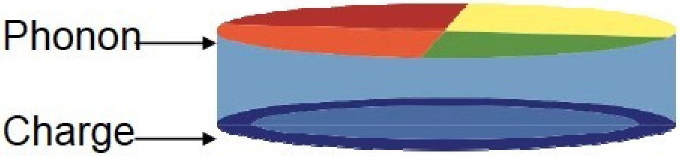




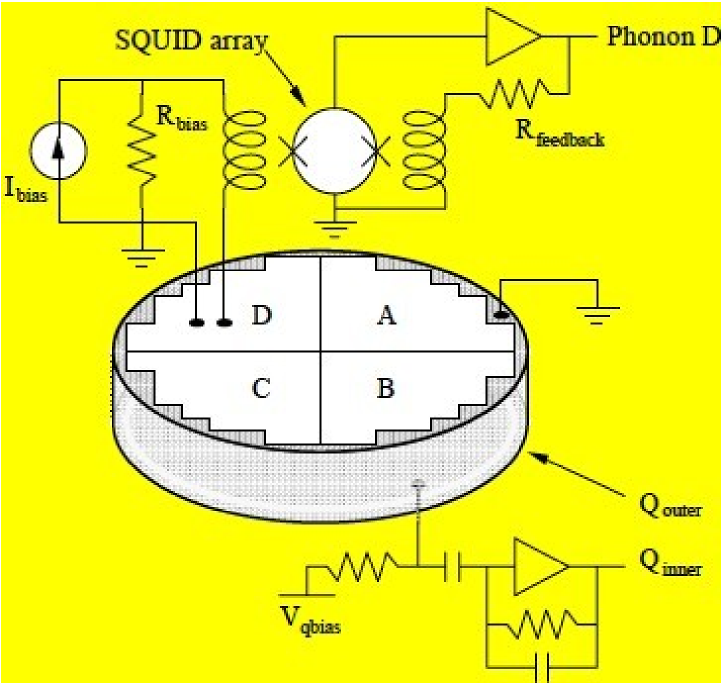


- Located at Soudan mine (Minnesota)
- Ge crystals operated at ~40 mK
- Fast phonon read-out with Tungsten Transition-edge sensors (TES)
  - direct measurement of nuclear recoil energy
  - SQUID Readout
- Low-voltage drift for charge read-out
  - e.m. background suppression with charge / phonon ratio
- Suppression of surface events with phonon timing signal

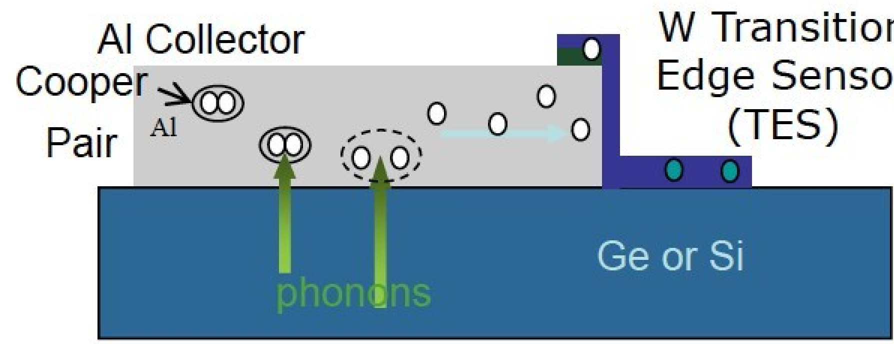


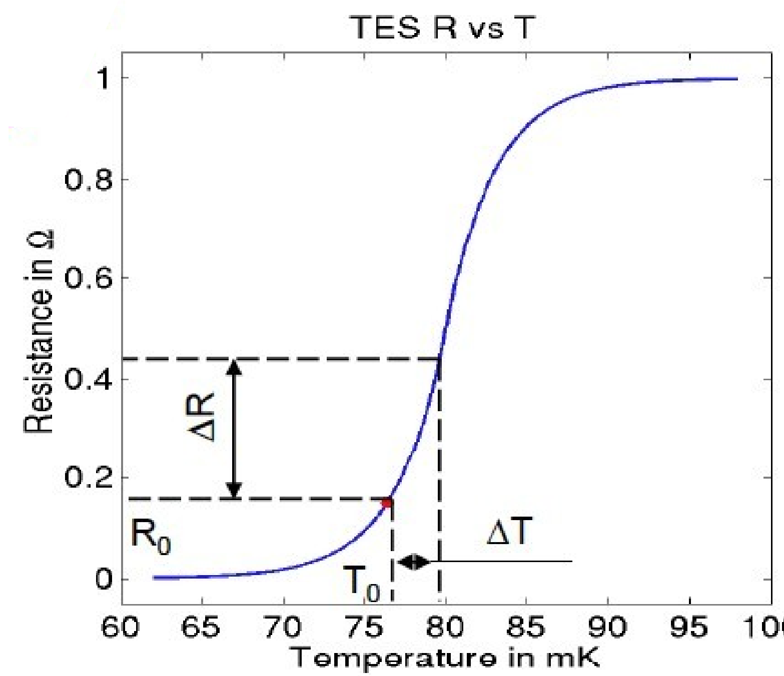


CDMS II: Transition Edge Sensors with Electrothermal Feedback for Fast Phonons



K. D. Irwin et al., 1995, Rev. Sci. Inst. 66, 5322



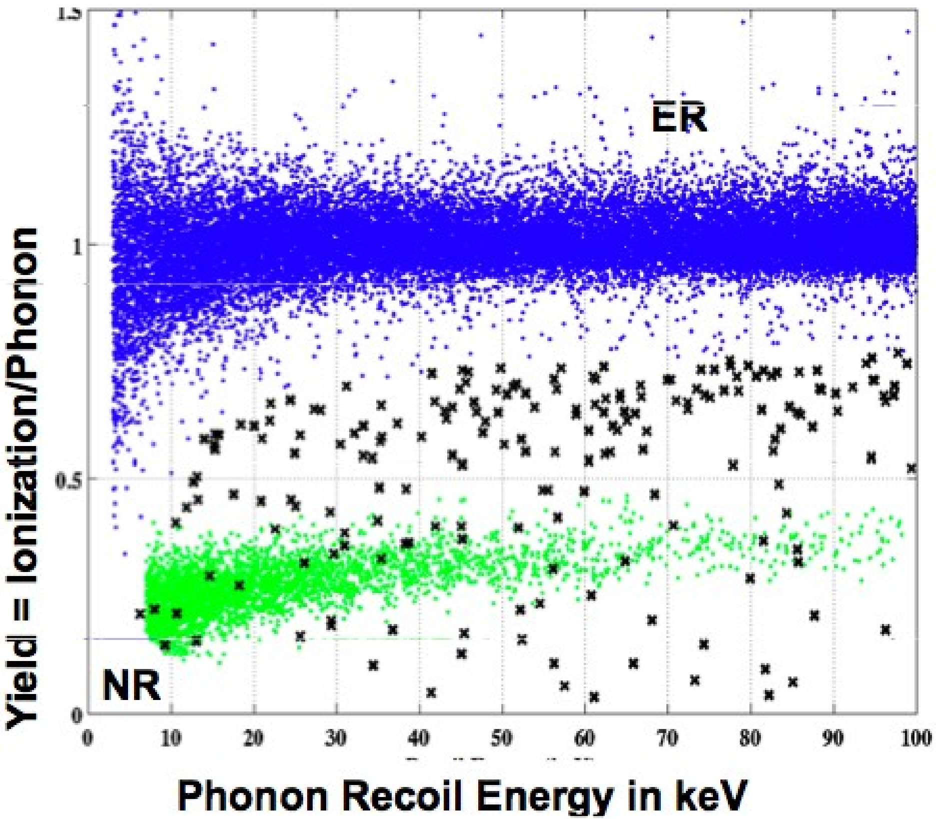


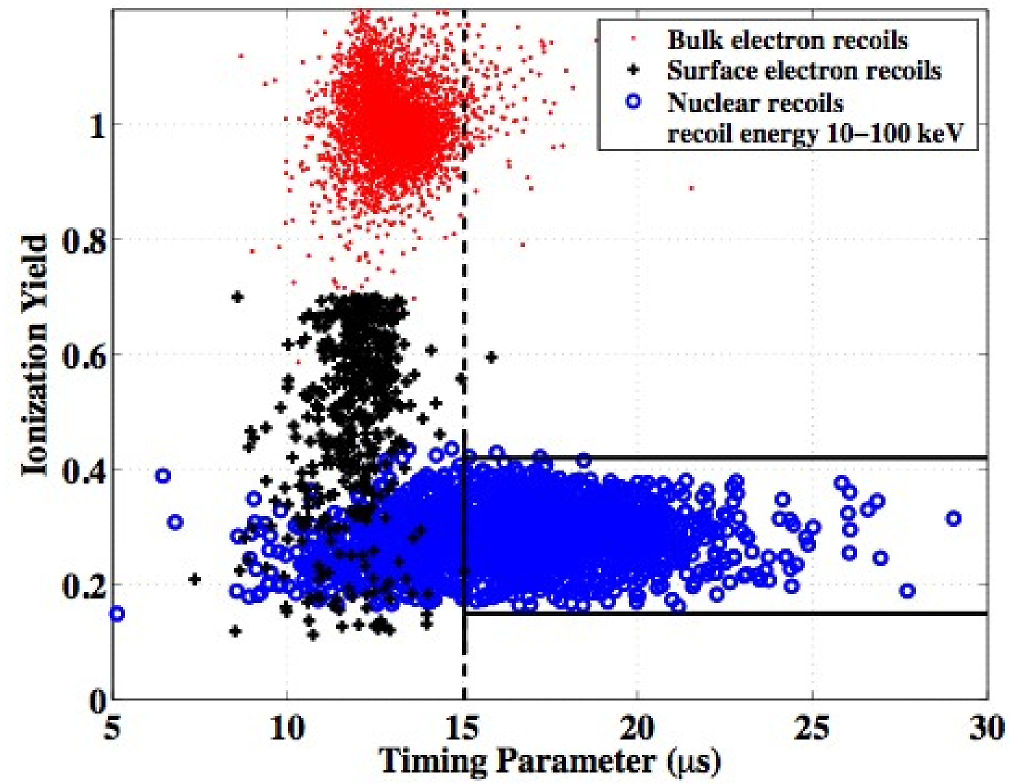
- Ge crystals operated at ~40 mK
- Fast phonon read-out with Tungsten Transition-edge sensors (TES)
  - direct measurement of nuclear recoil energy
  - readout using a superconducting quantum interference device (SQUID) array
- Energy deposited:
  R up → I down by ΔI
  → Feedback signal: $P = V_{bias}\, I = R\, I^2$

$$E = -V_{bias} \int \Delta I(t)\, dt$$

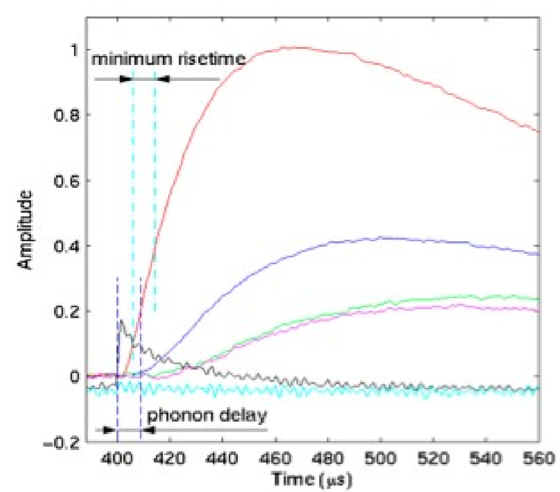
CDMS II Background Discrimination

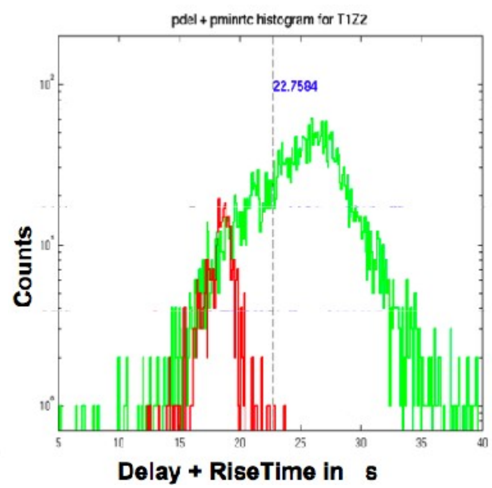
arXiv:08020350





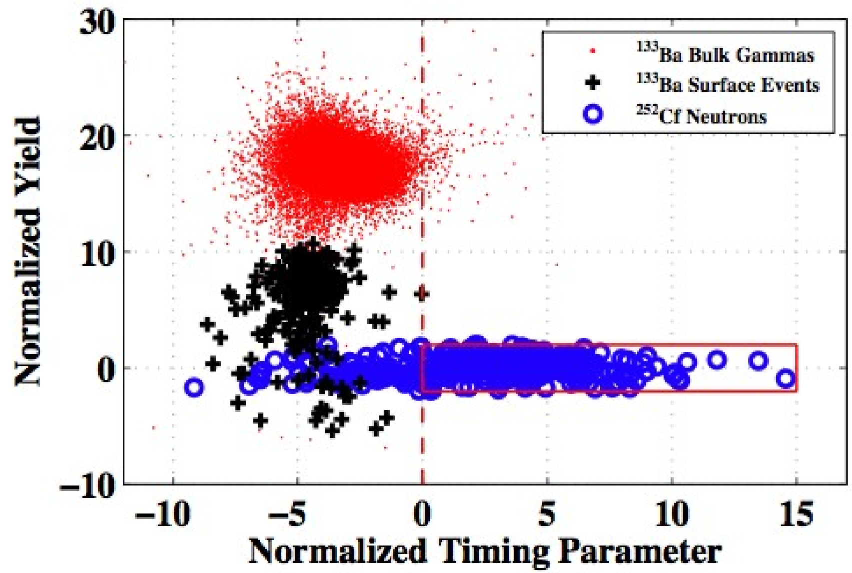
- Solution for surface events: measurement of risetime of athermal phonon signal

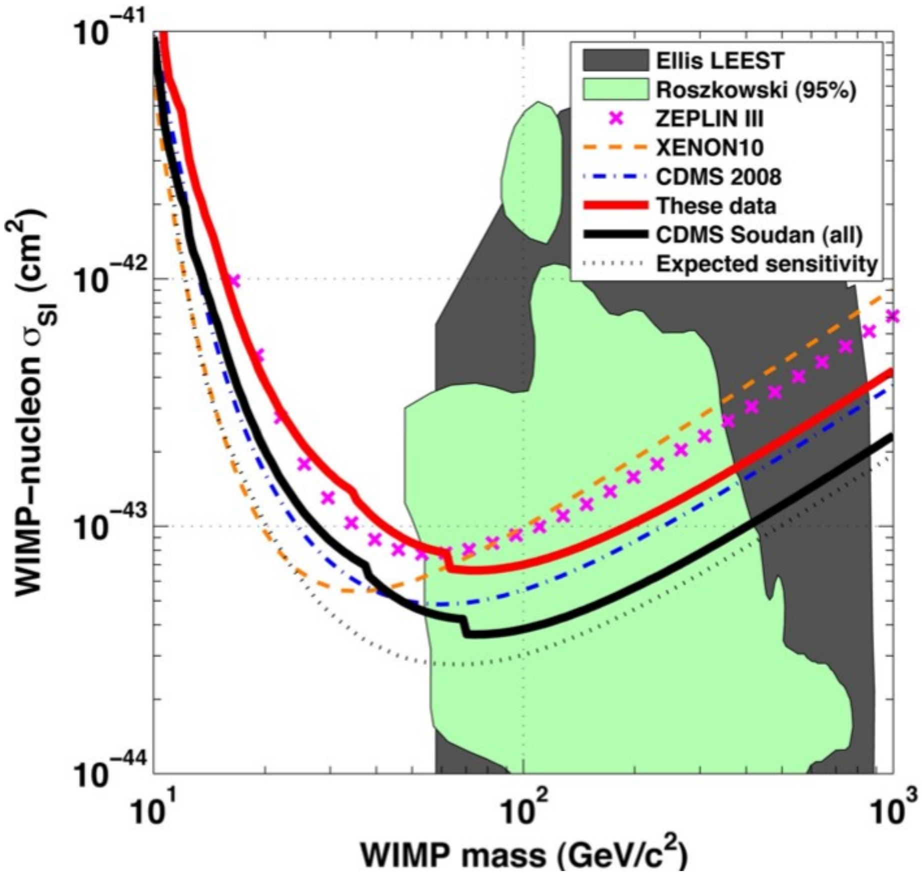




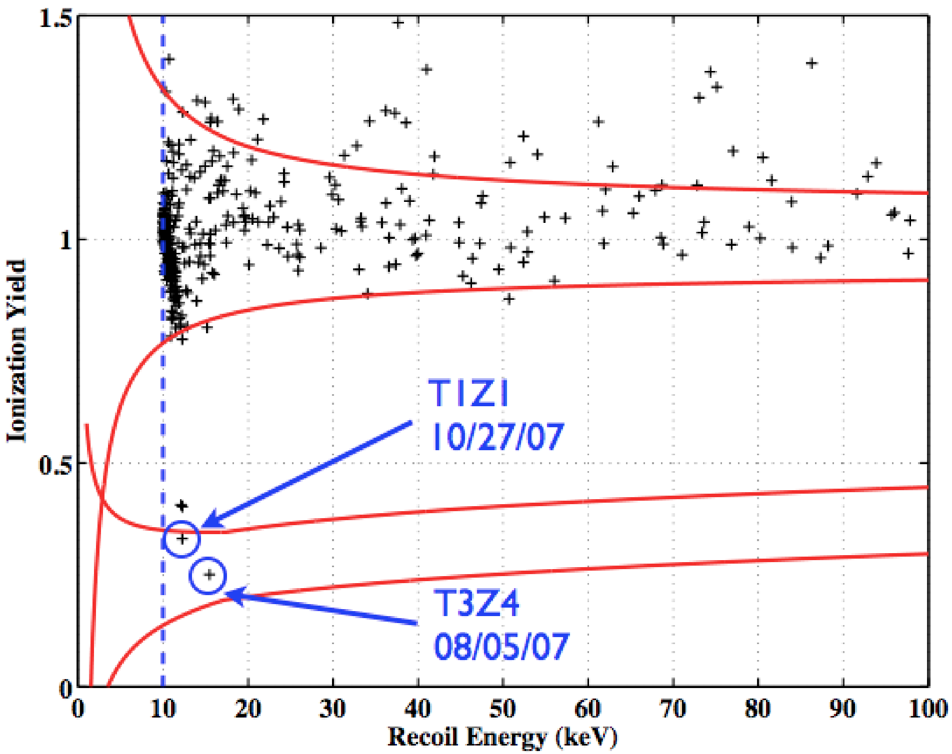
CDMS-II
Spin-Independent Limit

- 2 events observed after all cuts.
- Pre-opening background estimate: 0.6 events
- Revised estimate: 0.8 +/- 0.1 events
- 23% chance for background.
- CDMS-II completed.
- Next phase: Super-CDMS (15 kg) at Soudan mine construction and first operation in parallel



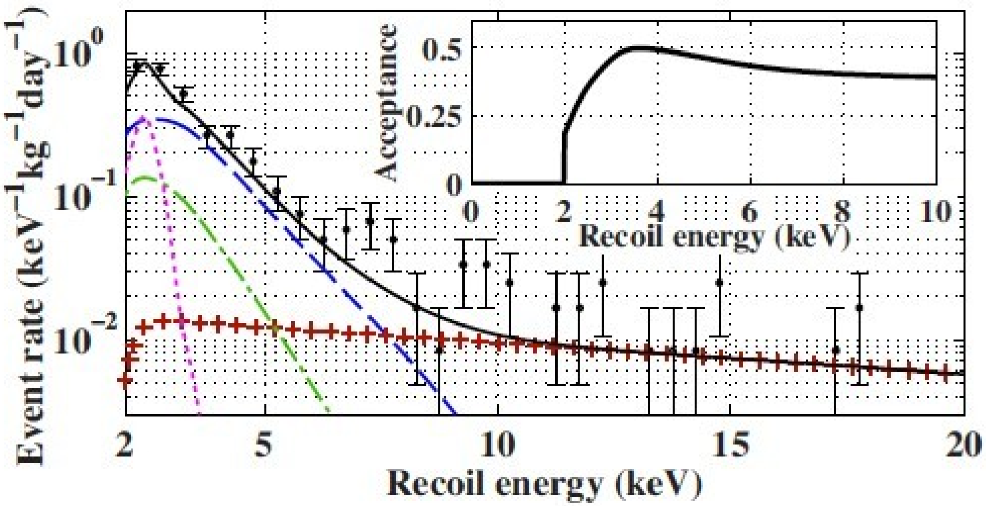


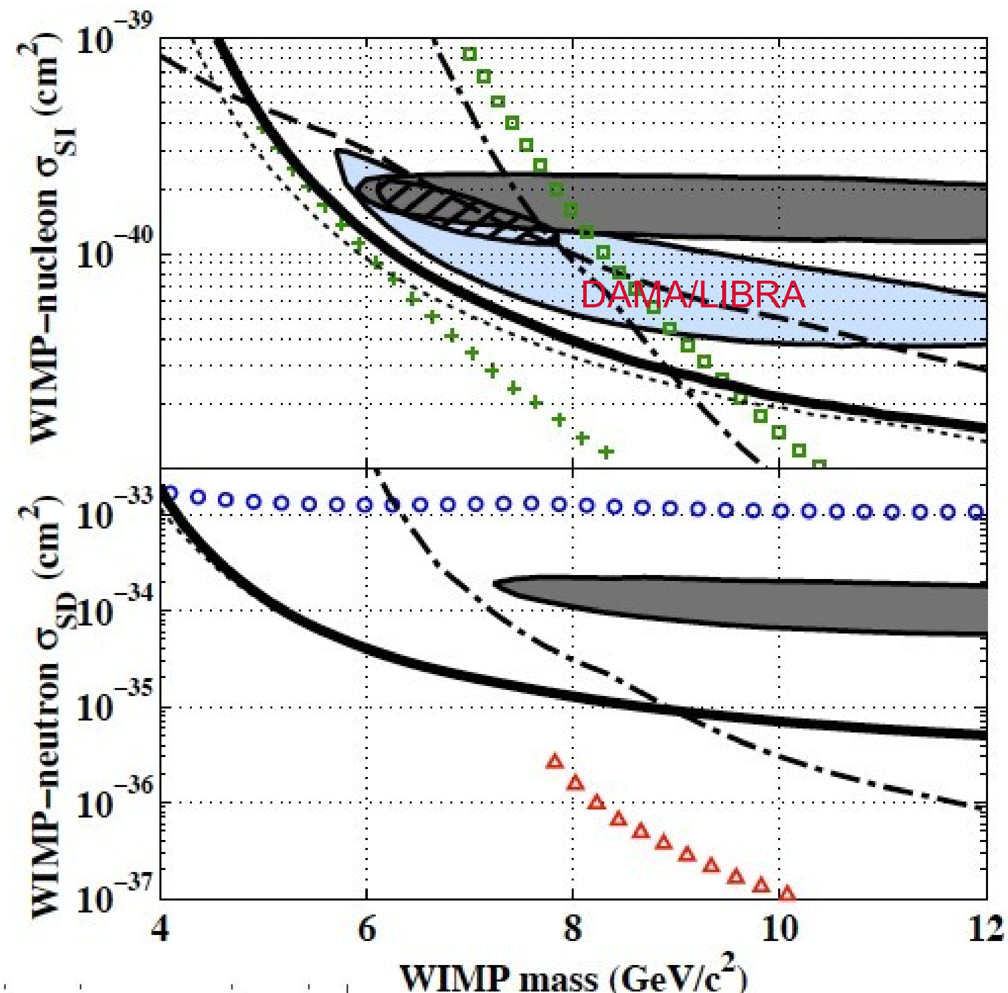
Science 327, Issue 5973, 1619 (2010)



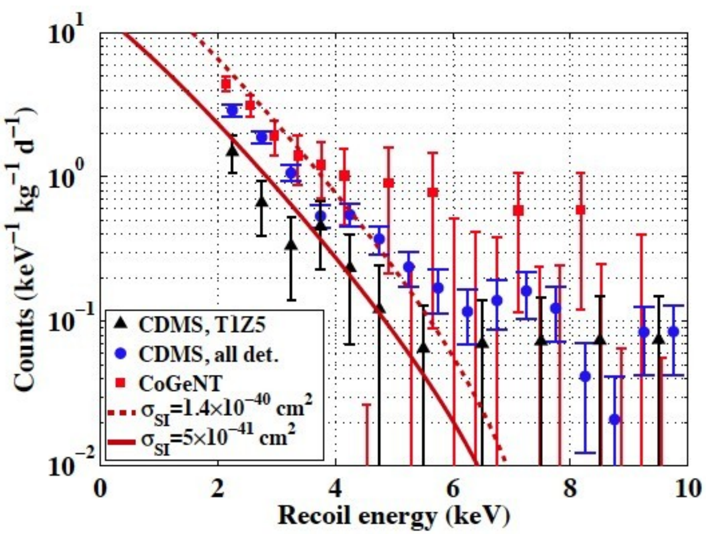
CDMS Low Threshold Limit

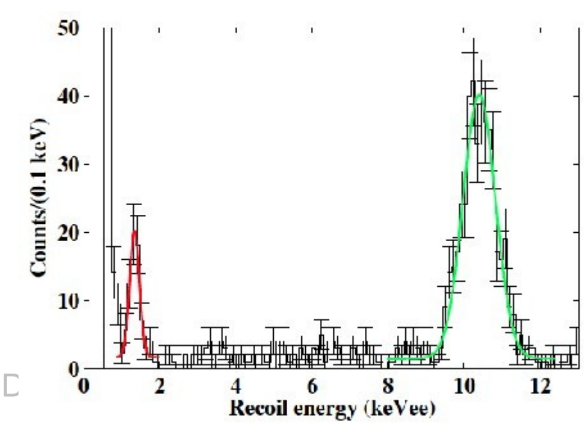
PRL 106, 131302 (2011), arXiv:1011.2482





- Strong tension with low mass WIMP interpretation of CoGeNT & DAMA/LIBRA results
- Discussion about background subtraction





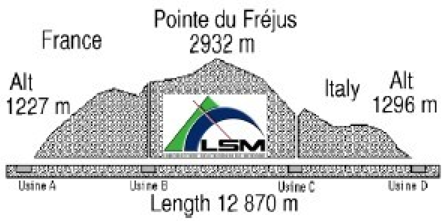
Edelweiss-2: Phonons + Charge

Cryogenic Germanium (2)

EDELWEISS

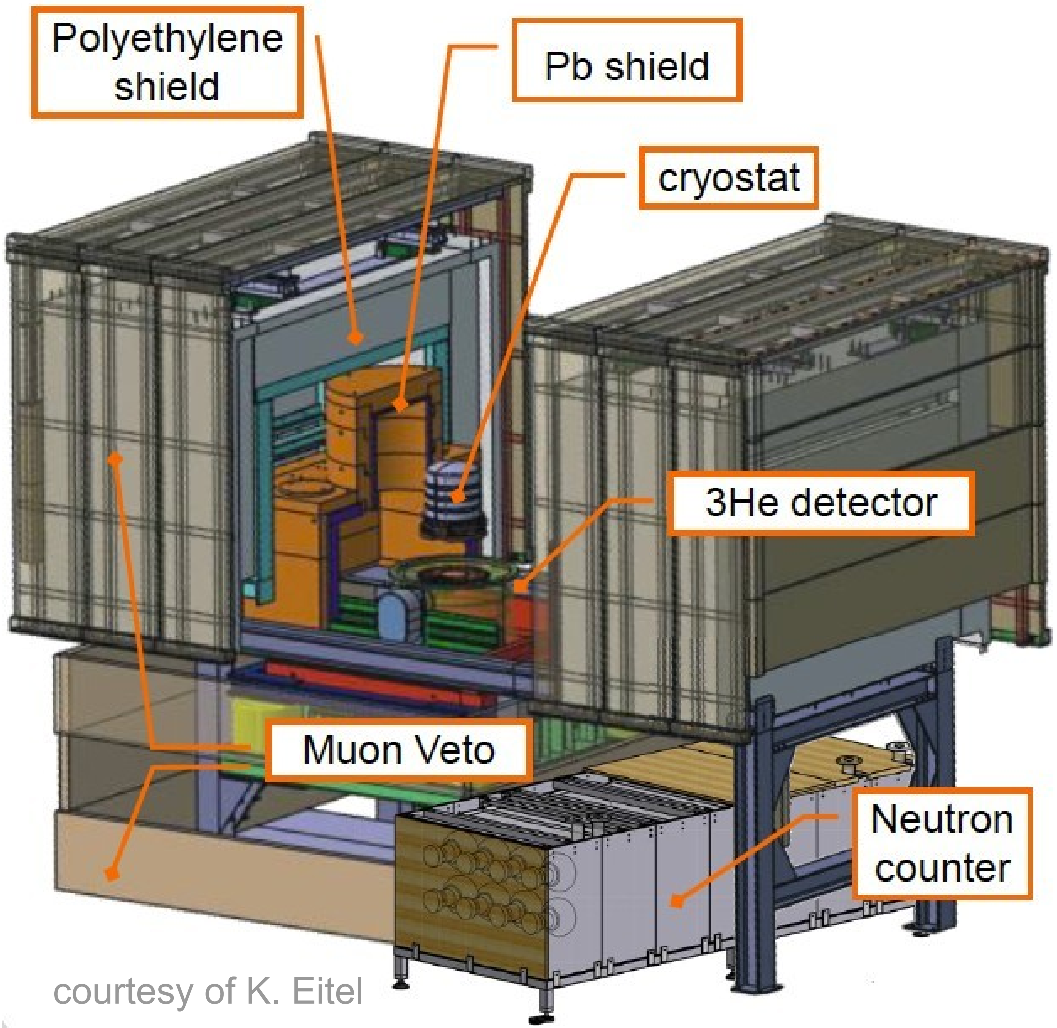
Experience pour DEtecter Les Wimps En Site Souterrain

CEA, CNRS, Oxford, Dubna, Sheffield, Karlsruhe



Shielding: ~ 4800 mwe

μ-flux: ~ 5 / m² / day



courtesy of K. Eitel

- Goal: $\sigma(\chi\text{-}n) = 5{\cdot}10^{-9}$ pb
- Cryogenic installation (18 mK):
  - Hosts up to 40 kg of detectors

Shielding:

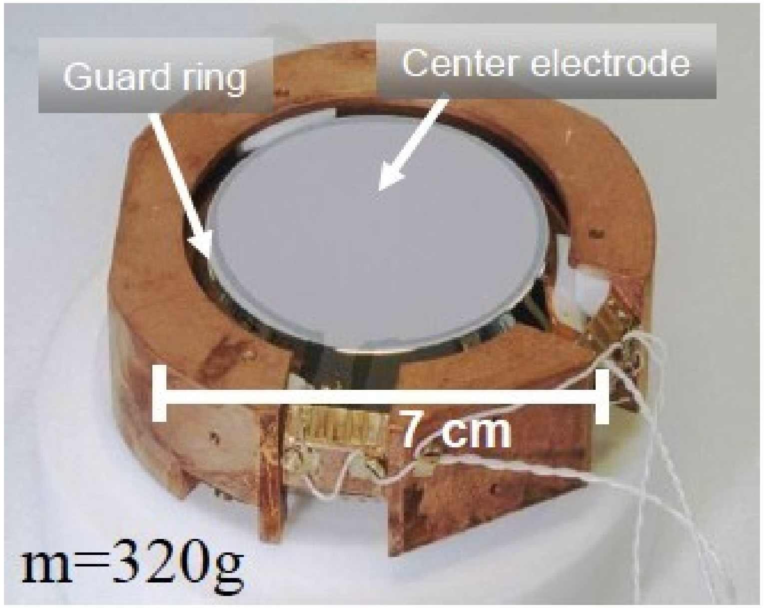
- Clean room + deradonized air
- Active muon veto (>98% coverage)
- PE shield 50 cm
- Lead shield 20 cm

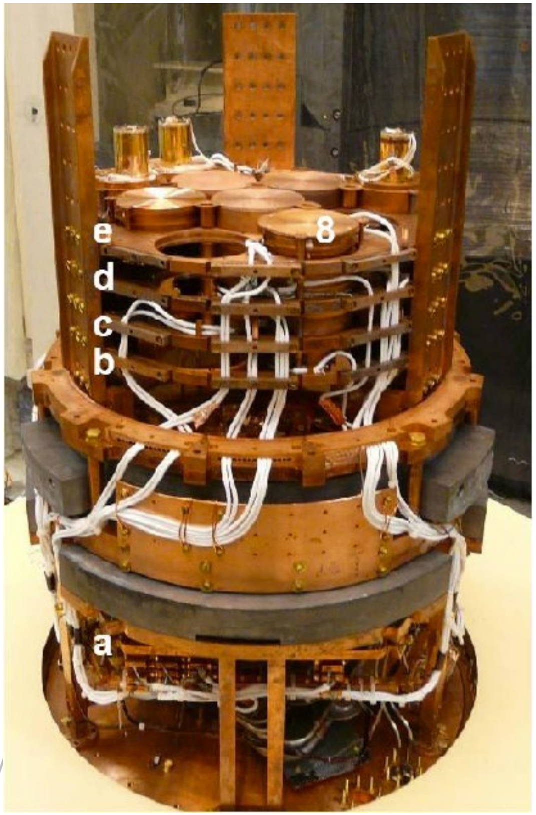
⇒ γ background reduced by ~3 wrt EDW-1

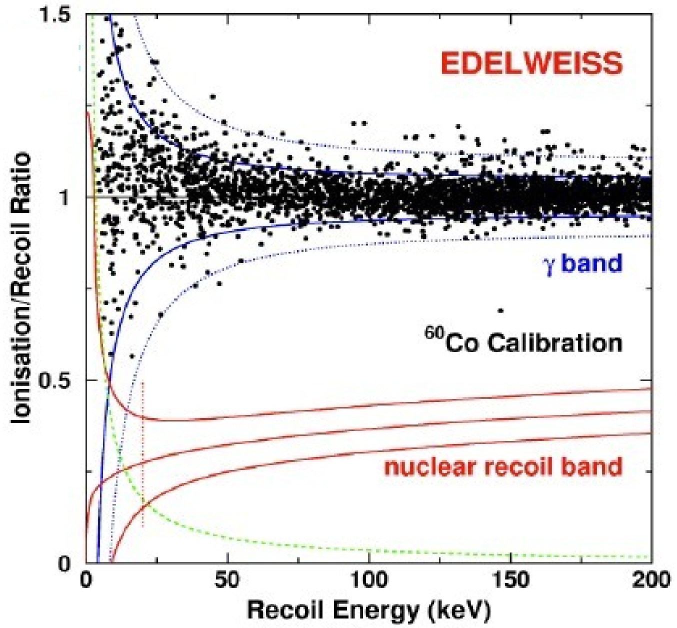
Edelweiss-2

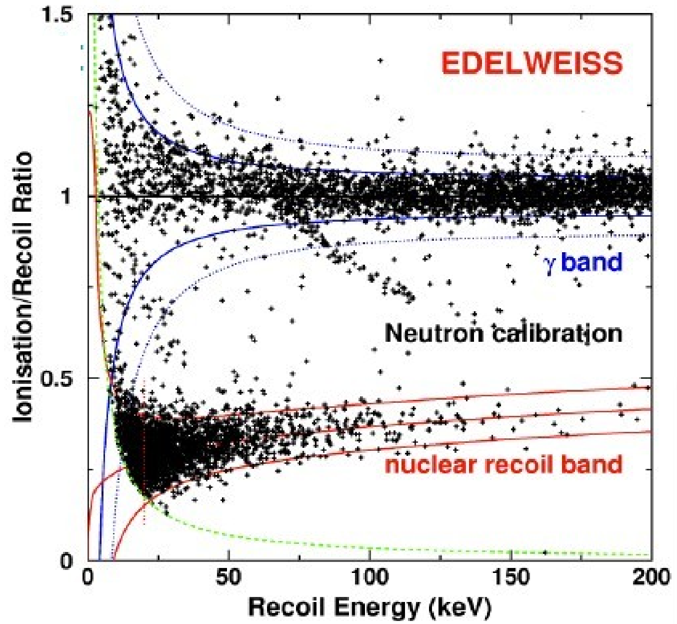
(Phonons + Charge: Cryogenic Ge)

- Simultaneous measurement
  - Heat @ 18 mK
    with Ge/NTD (neutron transmutation doped) thermometer
  - Ionization @ few V/cm
    with Al electrodes
- Event by event identification of recoil type by ratio Ionization / E_{recoil}



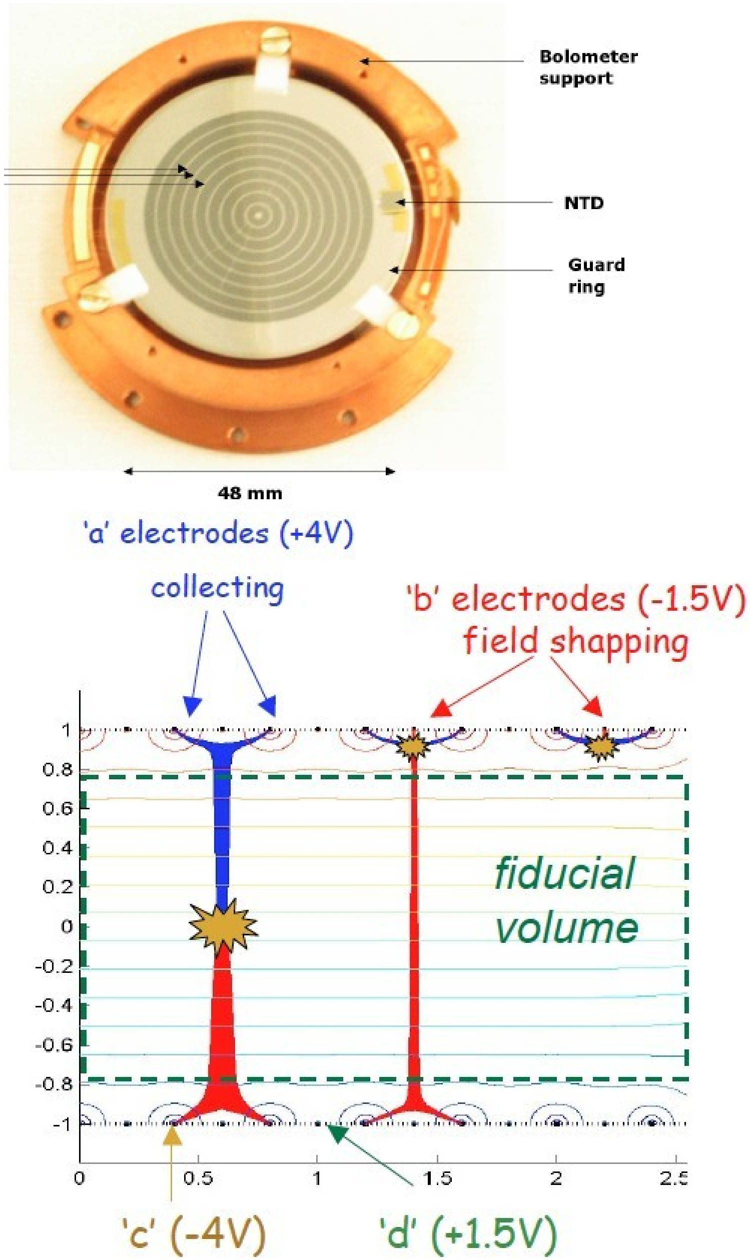


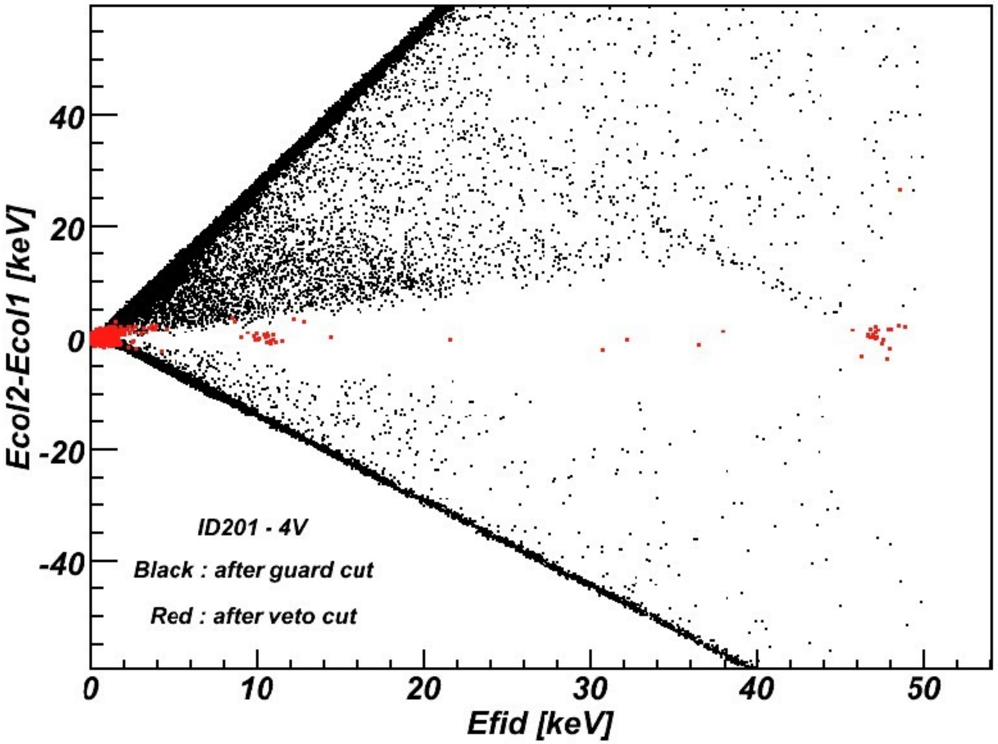




Edelweiss-2 – Interleaved Electrodes

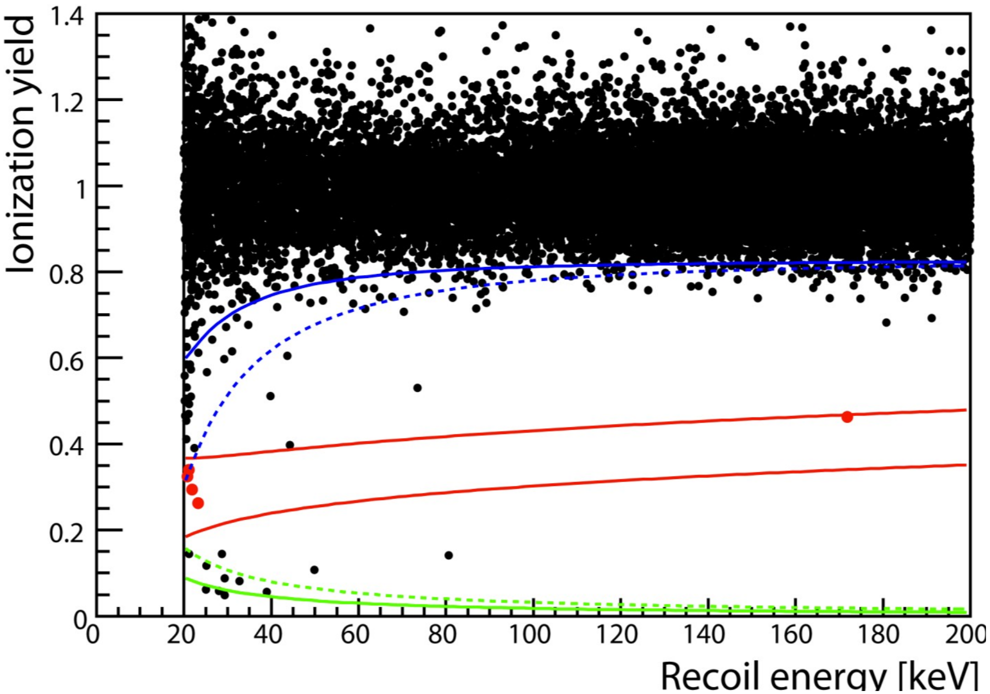
PLB 681 (2009) 305-309
[arXiv:0905.0753]

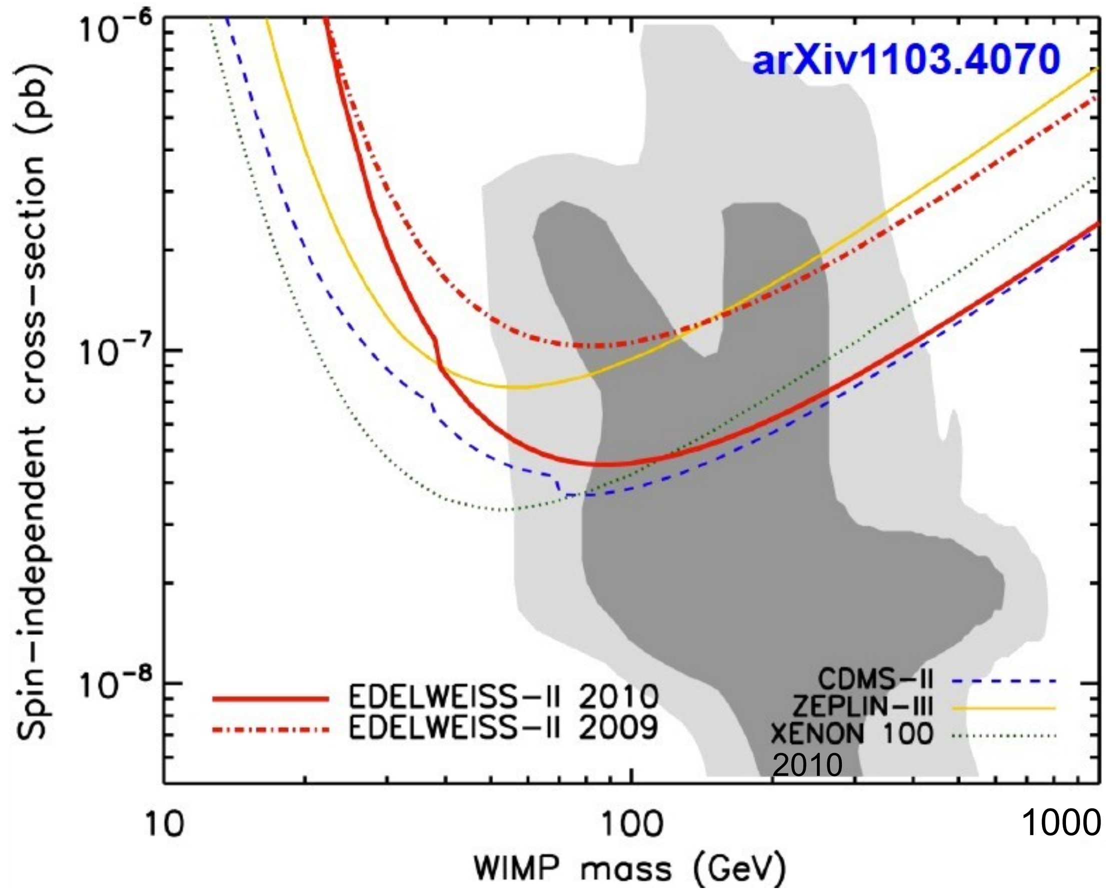




- Modification of E field near the surfaces with interleaved electrodes
- Use 'b' and 'd' signals as vetos against surface events
- Separation of surface and volume events.
- Beta rejection ~ 10^{-5}
- Substantial improvement over discrimination based on phonon timing (CDMS)

Edelweiss-2 WIMP Search Result 2009-2010 data





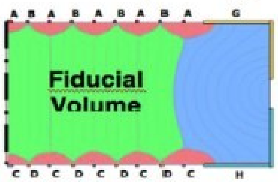
- total exposure of 427 kg.d
  - 384kg.d in 90% NR band (WIMP RoI)
- 5 events observed
  - 4 with E<22.5keV
  - 1 with E=172keV
- Expected background: ~ 3 events

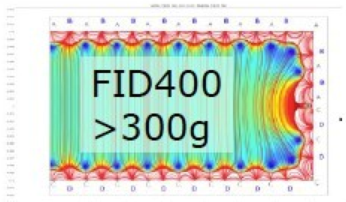
$\sigma_{SI} < 4.4 \times 10^{-8}$ pb (90% CL) for $M_\chi = 85$ GeV/c^2

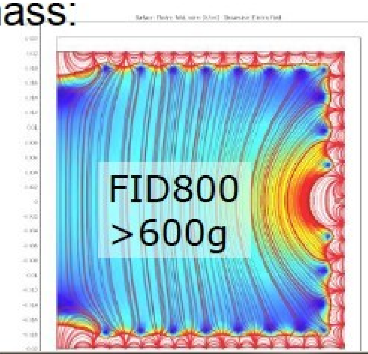
Next Steps: Edelweiss-3

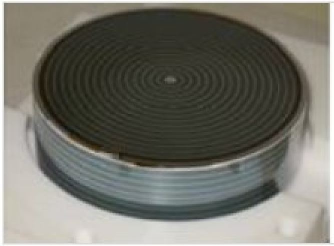
- Doubling/Quadrupling the fiducial mass:
  ID400 => FID400 => FID800

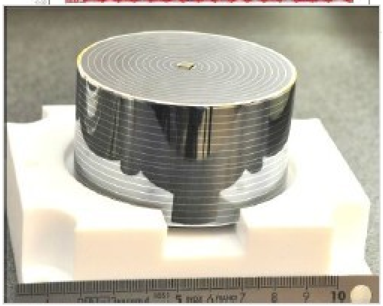
ID400 (160g)







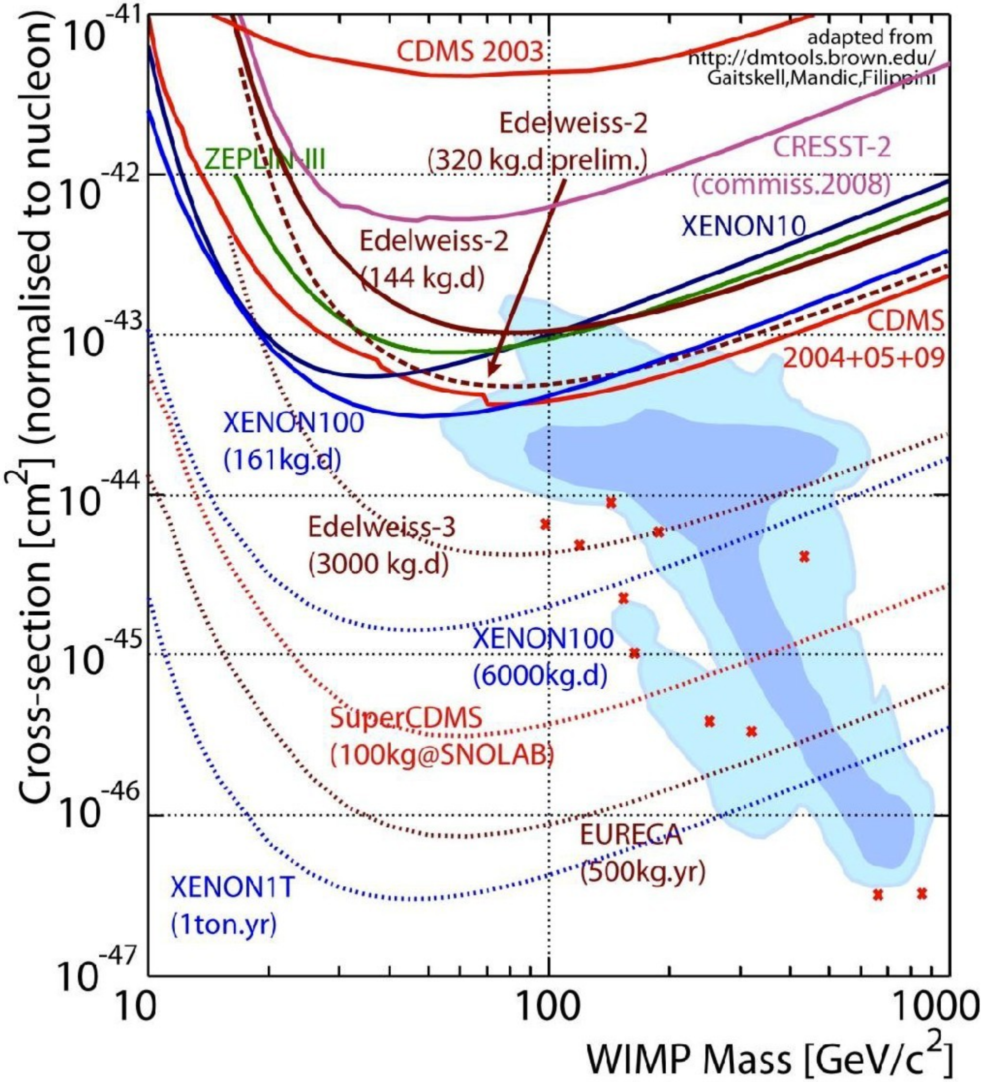




- **Goals:** with FIDs 400+800g program, continue doubling of accumulated exposure every year

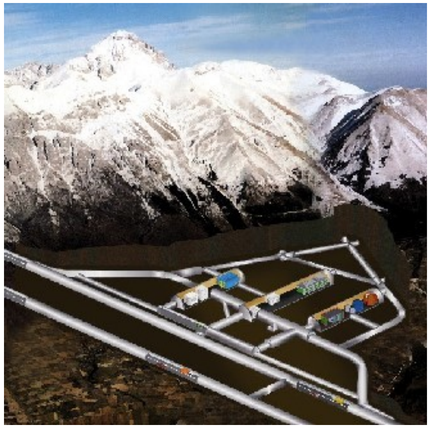
  2011/12 => 1000 kg.d

  2013 => 3000 kg.d



The XENON Program

Collaboration: US (3)+ Switzerland (1) + Italy (2) + Portugal (1) + Germany (3) + France (1) + Netherlands (1) + Israel (1) + China (1)



GOAL: Explore WIMP Dark Matter with a sensitivity of $\sigma_{SI} \sim 10^{-47}$ cm^2.

- Requires ton-scale fiducial volume with extremely low background.

CONCEPT:

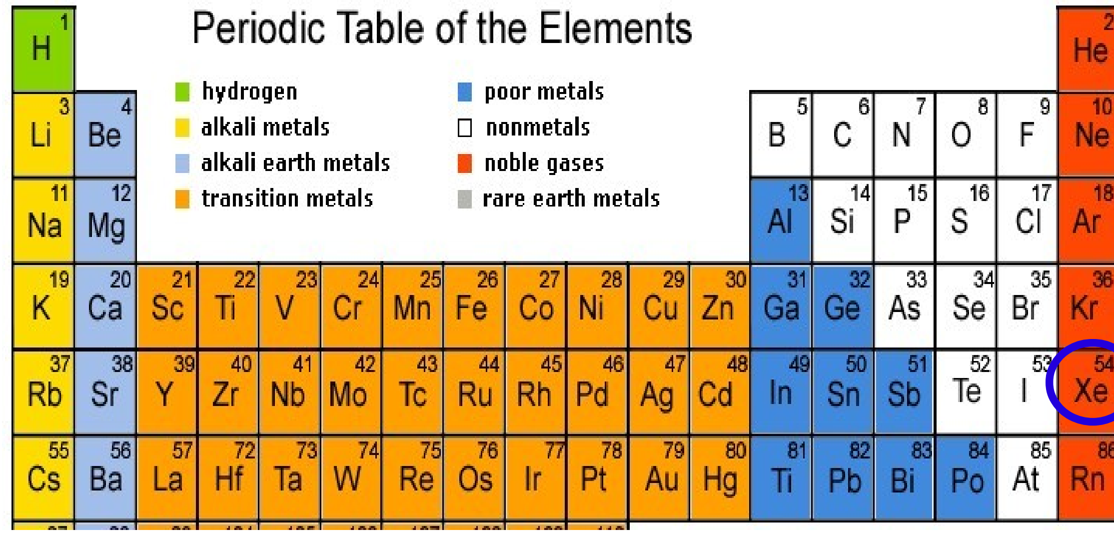
- Target LXe: excellent for DM WIMPs scattering.
  - Sensitive to both axial and scalar coupling.
- Detector: two-phase XeTPC: 3D position sensitive, self-shielding.
- Background discrimination: simultaneous charge & light detection (>99.5%).
- PMT readout with >3 pe/keV. Low energy threshold for nuclear recoils (~5 keV).

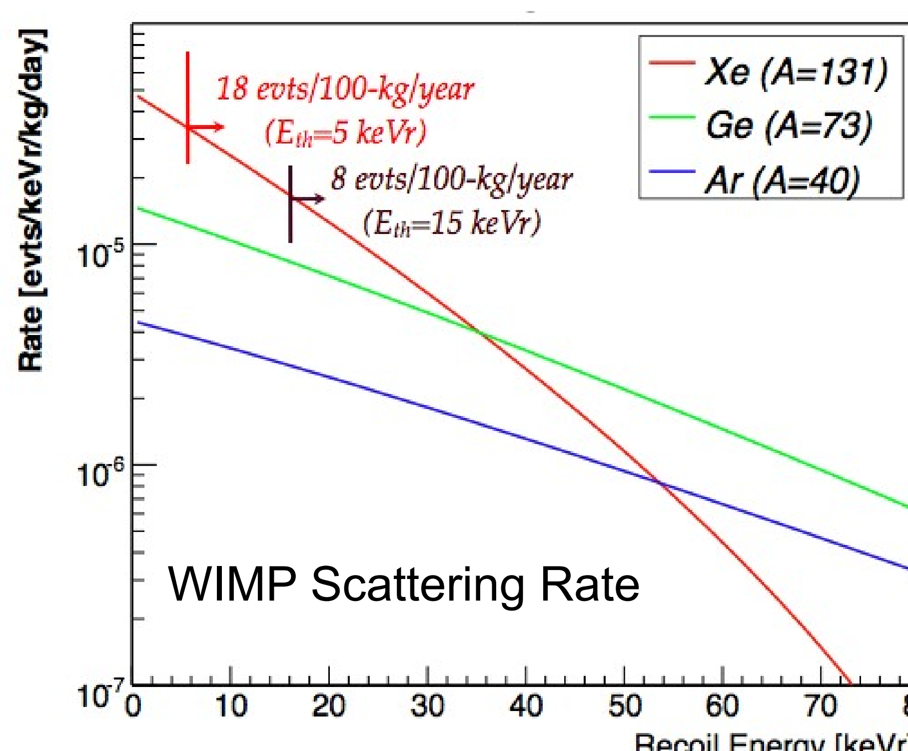
PHASES:

R&D	XENON10	XENON100	XENON1T
Start: 2002	2005-2007	2008-2011+	2011-2015
	Proof of concept. Total mass: 14 kg 15 cm drift. Best limit in '07: $\sigma_{SI} \sim 10^{-43}$ cm^2	Dark Matter run ongoing. Total mass: 170 kg 30 cm drift. 2011: $\sigma_{SI} \sim 7 \times 10^{-45}$ cm^2 Goal: $\sigma_{SI} \sim 2 \times 10^{-45}$ cm^2	Technical design studies. Total mass: ~2.5 t 90 cm drift. Goal: $\sigma_{SI} \sim 3 \times 10^{-47}$ cm^2

Liquid Xenon for Dark Matter Search

- Large atomic number A~131 best for SI interactions ($\sigma \sim A^2$).
  Need low threshold.
- ~50% odd isotopes: SD interactions
  If DM detected: probe physics with the same detector using isotopically enriched media.
- No long-lived isotopes.
  Proven Kr-85 reduction to ppt level.
- High Z (54) and density:
  compact & self-shielding
- Scalability to large mass for $\sigma \sim 10^{-47}$ cm^2 ~ 1 evt/ton/yr.
- "Easy" cryogenics (-100°C).
- Efficient and fast scintillator.
- Background discrimination in TPC.
  - Ionization/Scintillation
  - 3D imaging of TPC



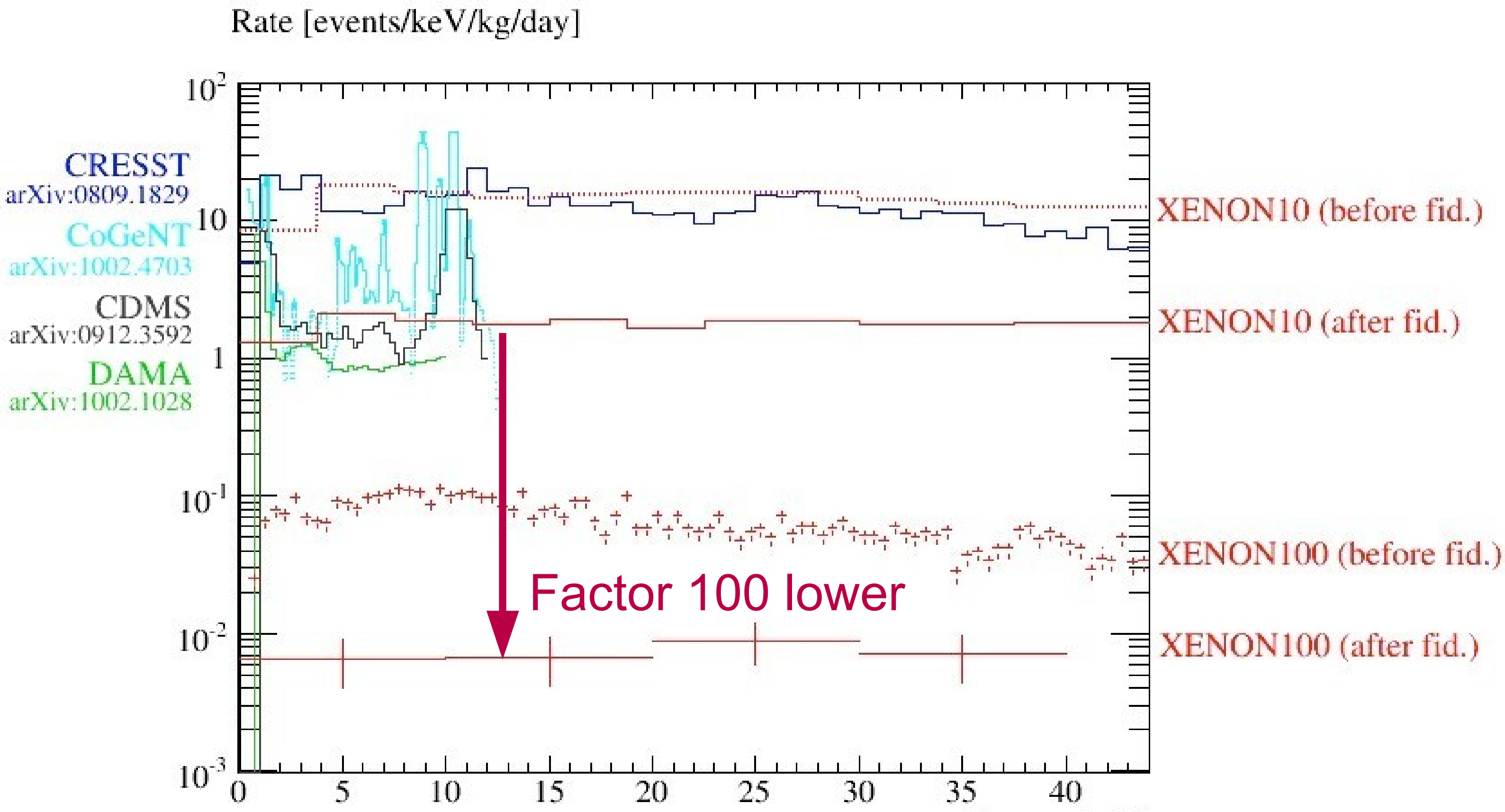


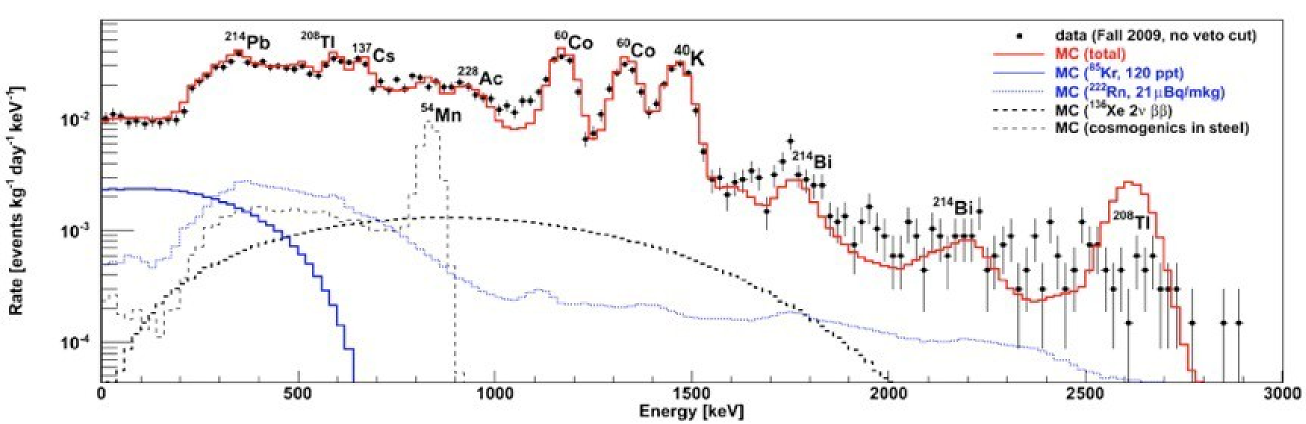
XENON100 (2008-2011+)

- 100 times lower background than XENON10
  - Material screening
  - Active LXe Veto
  - Upgrade of XENON10 shield (Cu, water)
  - Cryocooler/Feedthroughs outside shield
  - Low activity stainless steel
  - LXe self-shielding
- ~7 times larger target mass
  - 62 kg in target volume, 165 kg total LXe
- New PMTs with lower activity and high QE
- Improved electronics, grids, ...
- Gamma & neutron calibrations.
- DM search Jan – June 2010.
  Next run started ~2 months ago.

New results!

XENON100:
The Lowest Background Dark Matter Detector

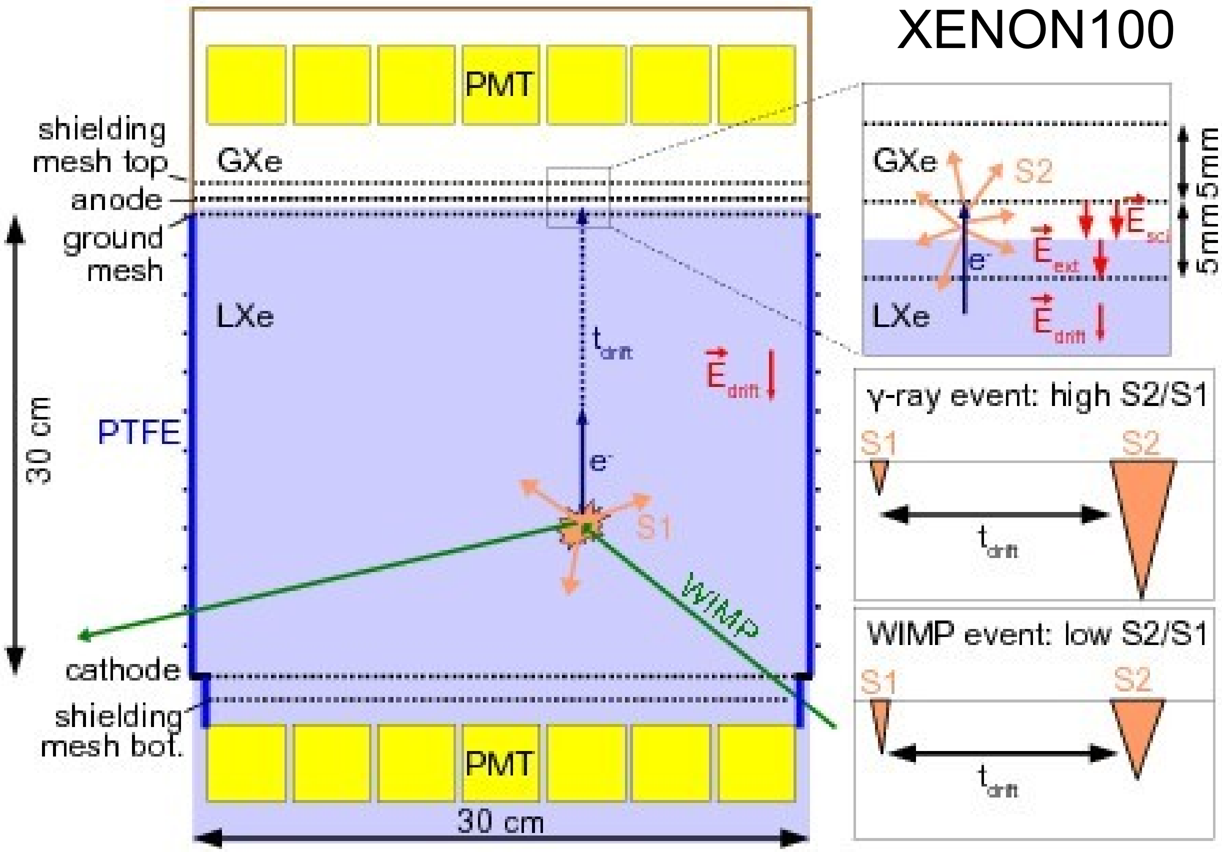




Phys. Rev. D 83, 082001 (2011)

The Liquid Xenon Dual Phase TPC
Ionization + Scintillation

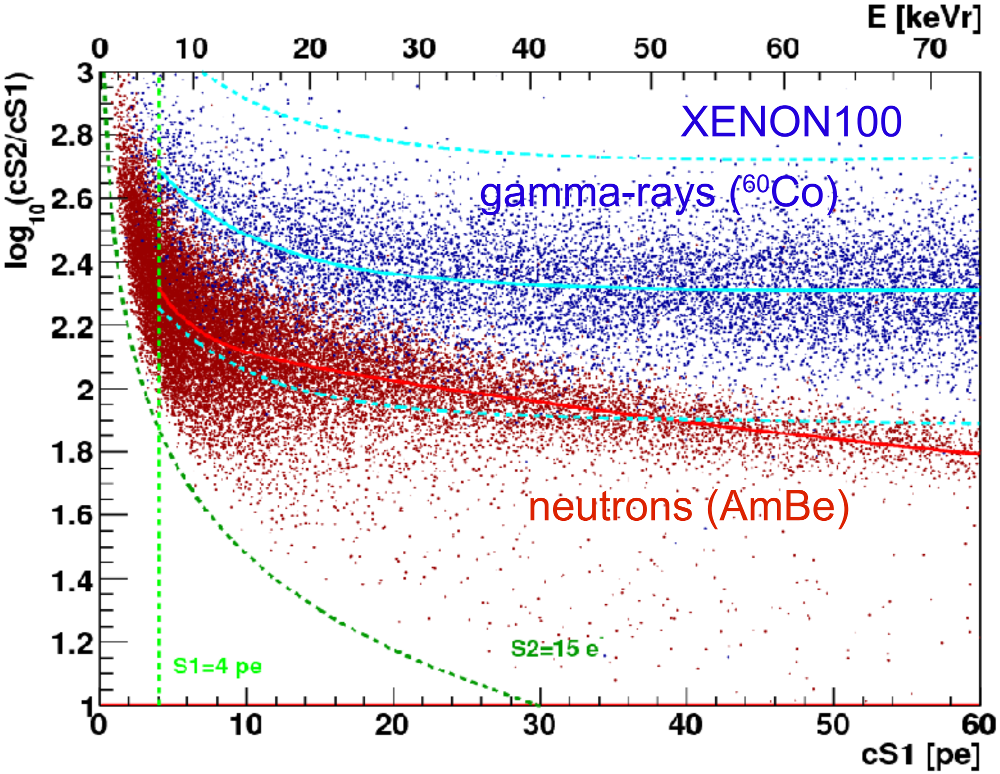
- Wimp recoil on Xe nucleus in dense liquid (2.9 g/cm^3)
  → Ionization + UV Scintillation
- Detection of primary scintillation light (S1) with PMTs.
- Charge drift towards liquid/gas interface.
- Charge extraction liquid/gas at high field between ground mesh (liquid) and anode (gas)
- Charge produces proportional scintillation signal (S2) in the gas phase (10 kV/cm)



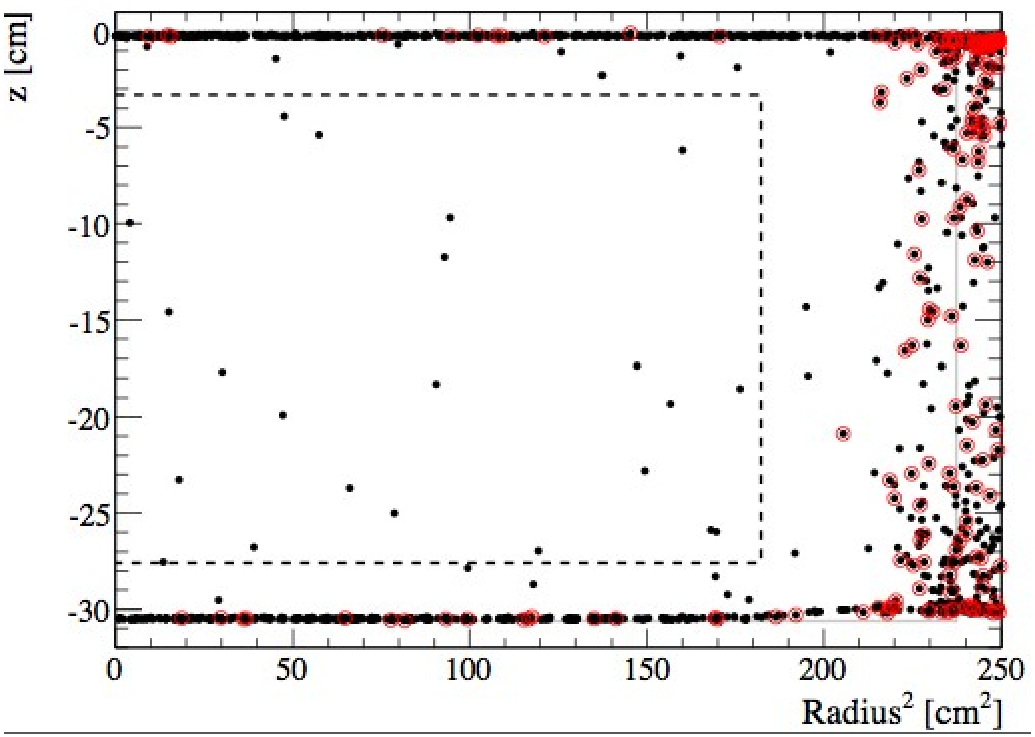
- 3D position measurement:
  - X/Y from S2 signal. Resolution few mm.
  - Z from electron drift time (~1 mm).

Background Discrimination in Dual Phase Liquid Xenon TPC's

Ionization/Scintillation Ratio S2/S1



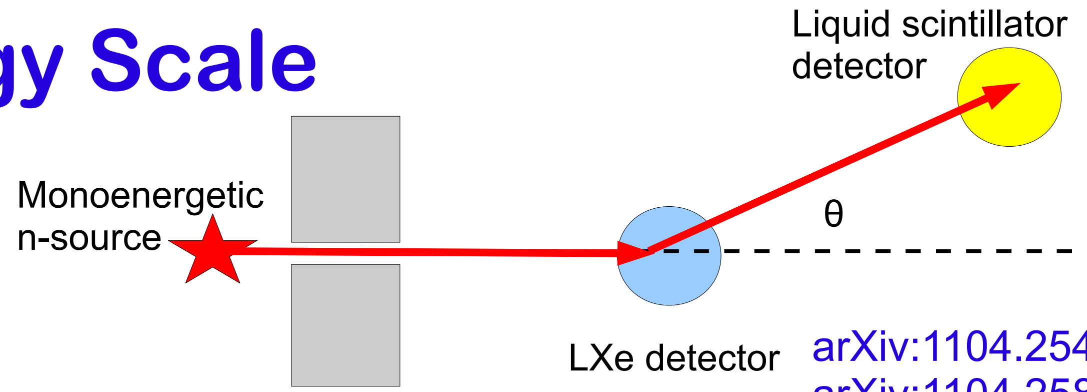
3D Position Resolution: fiducial cut, singles/multiples



New Measurement!

Nuclear Recoil Energy Scale

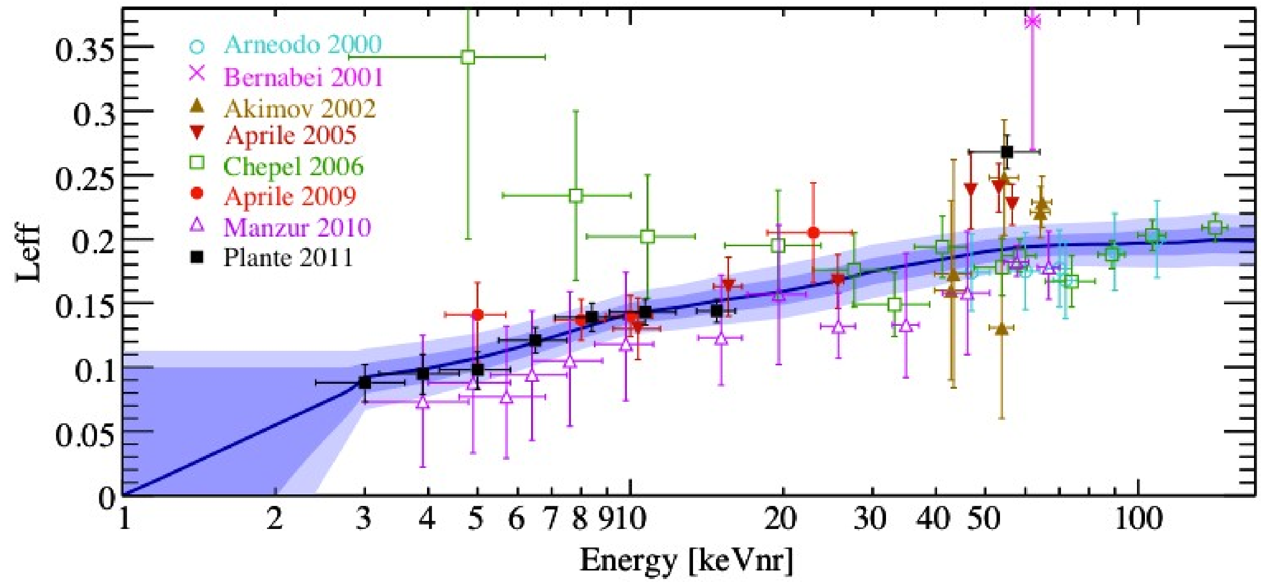
$$E_n \times L_{eff}(E_n) = \frac{S1}{L_e} \times \frac{S_e(\vec{\epsilon})}{S_n(\vec{\epsilon})}$$



arXiv:1104.2549
arXiv:1104.2587

$$L_{eff}(E) = \frac{L_n(E)}{L_e(E_0)}$$

- L_{eff}: Relative scintillation efficiency of nuclear recoils at zero field
- L_e: Light yield [p.e./keV] for electron recoils at reference energy E_0 (122 keV)
- $S1$: primary scintillation signal
- S_e: Light quenching due to field for electron recoils at energy E_0
- S_n: Light quenching due to field for nuclear recoils



- Fit of available data to relative scintillation efficiency for nuclear recoils.
- Ongoing efforts to measure L_{eff} with higher accuracy.
- XENON100: [4-20] pe ~ [8.7-32.6] keVr

Data:
Arneodo 2000
Bernabei 2001
Akimov 2002
Aprile 2005
Aprile 2009
Sorensen 2009
Manzur 2010

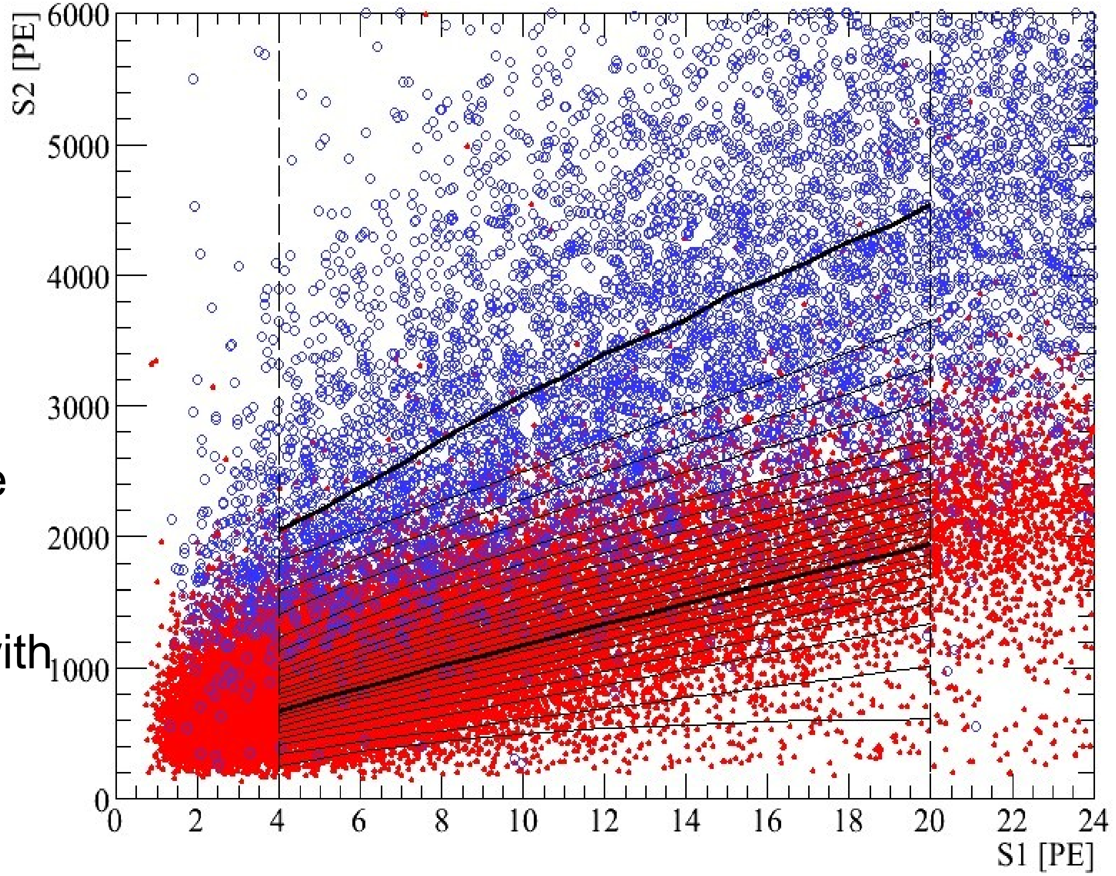
Profile Likelihood Analysis

arxiv:1103.0303
PRD accepted

- Goal: use one method for both upper limits and potential discovery.
- Construct a likelihood function from calibration data, including all the uncertainties as nuisance parameters.

$$\begin{aligned}\mathscr{L} &= \mathscr{L}_1(\sigma, N_b, \epsilon_s, \epsilon_b, \mathcal{L}_{\text{eff}}, v_{\text{esc}}; m_\chi) \\ &\quad \times \mathscr{L}_2(\epsilon_s) \times \mathscr{L}_3(\epsilon_b) \\ &\quad \times \mathscr{L}_4(\mathcal{L}_{\text{eff}}) \times \mathscr{L}_5(v_{\text{esc}}).\end{aligned}$$

- Subdivide the data space and count the number of events in each region.
- Dark Matter search (1- or 2-sided confidence region): compute ML ratio with a varying cross-section σ until set confidence level is reached.



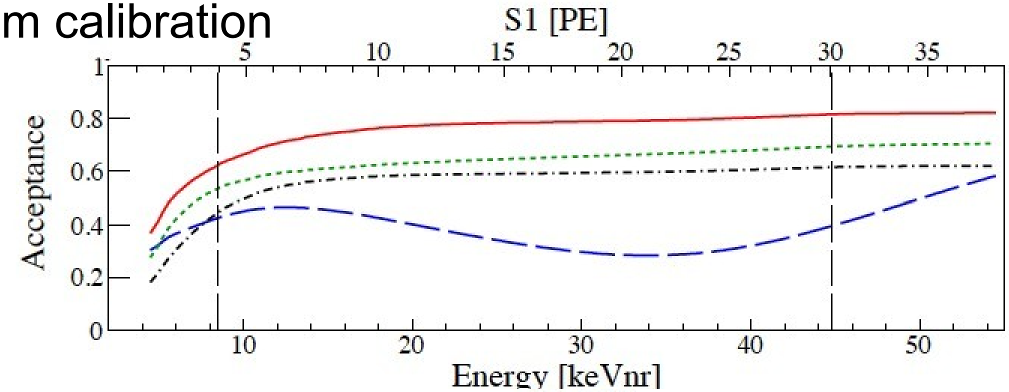
$$\lambda(\sigma) = \frac{\max\limits_{\sigma \text{ fixed}} \mathscr{L}(\sigma; \mathcal{L}_{\text{eff}}, v_{\text{esc}}, N_b, \epsilon_s, \epsilon_b)}{\max \mathscr{L}(\sigma, \mathcal{L}_{\text{eff}}, v_{\text{esc}}, N_b, \epsilon_s, \epsilon_b)}$$

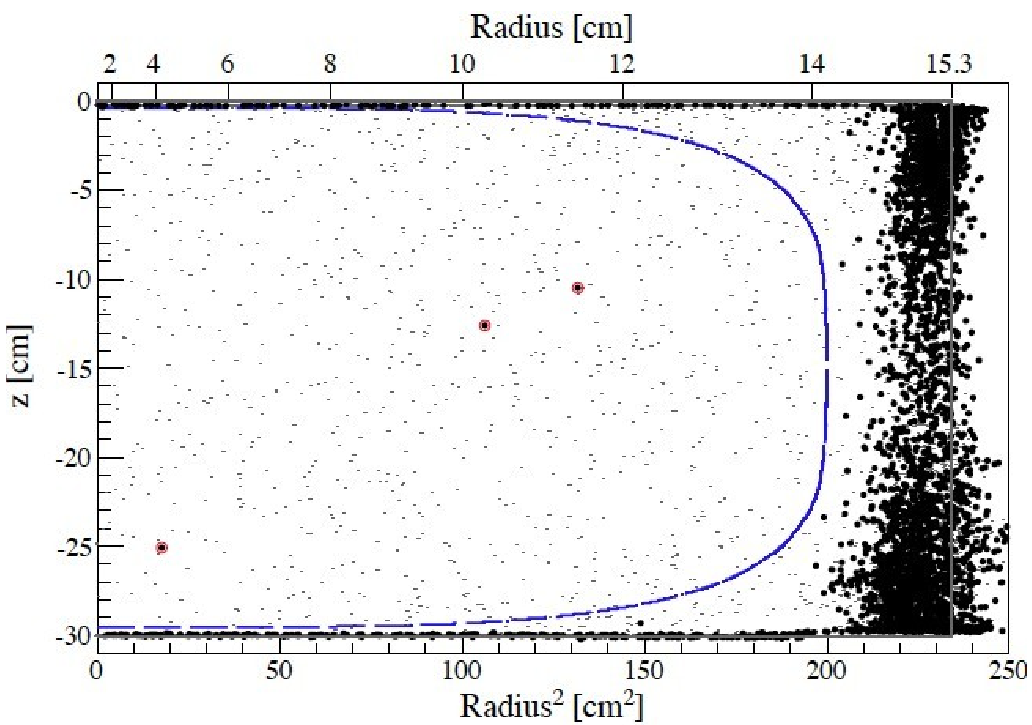
XENON100 – 2010 Run

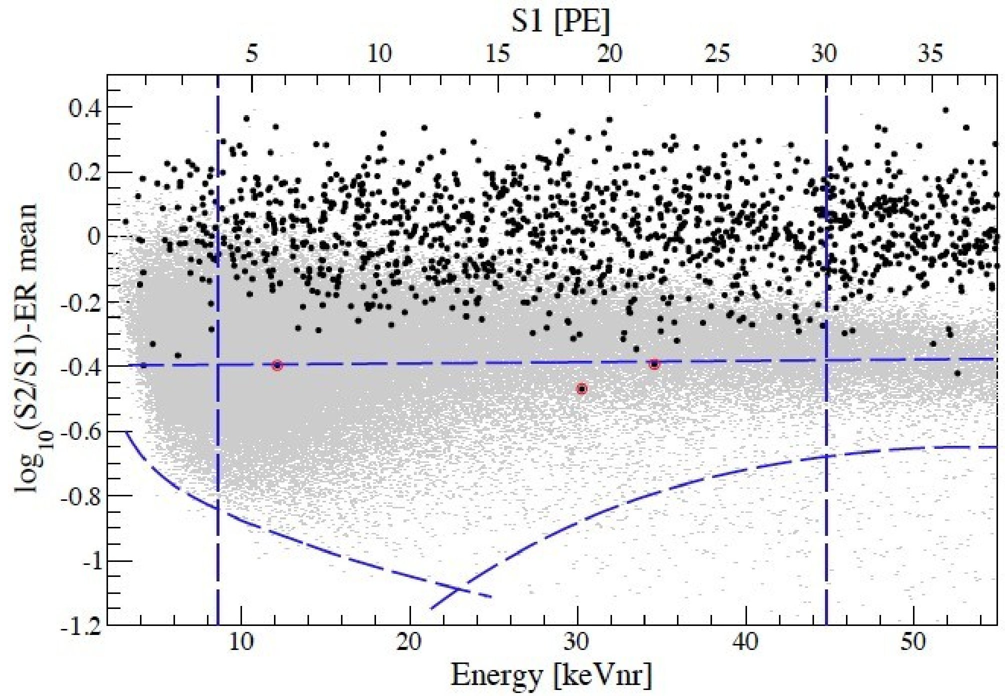
New Result!

arXiv:1104.2549
PRL accepted

- 100.9 live days, exposure: **1471 kg×d**
- Energy window: 4 – 30 PE S1 / 8.4 – 44.6 keVnr
- Observed after all cuts: 3 events. Expected background: (1.8 ± 0.6) events (25% probability)
- Profile Likelihood limit based on side-bands from calibration







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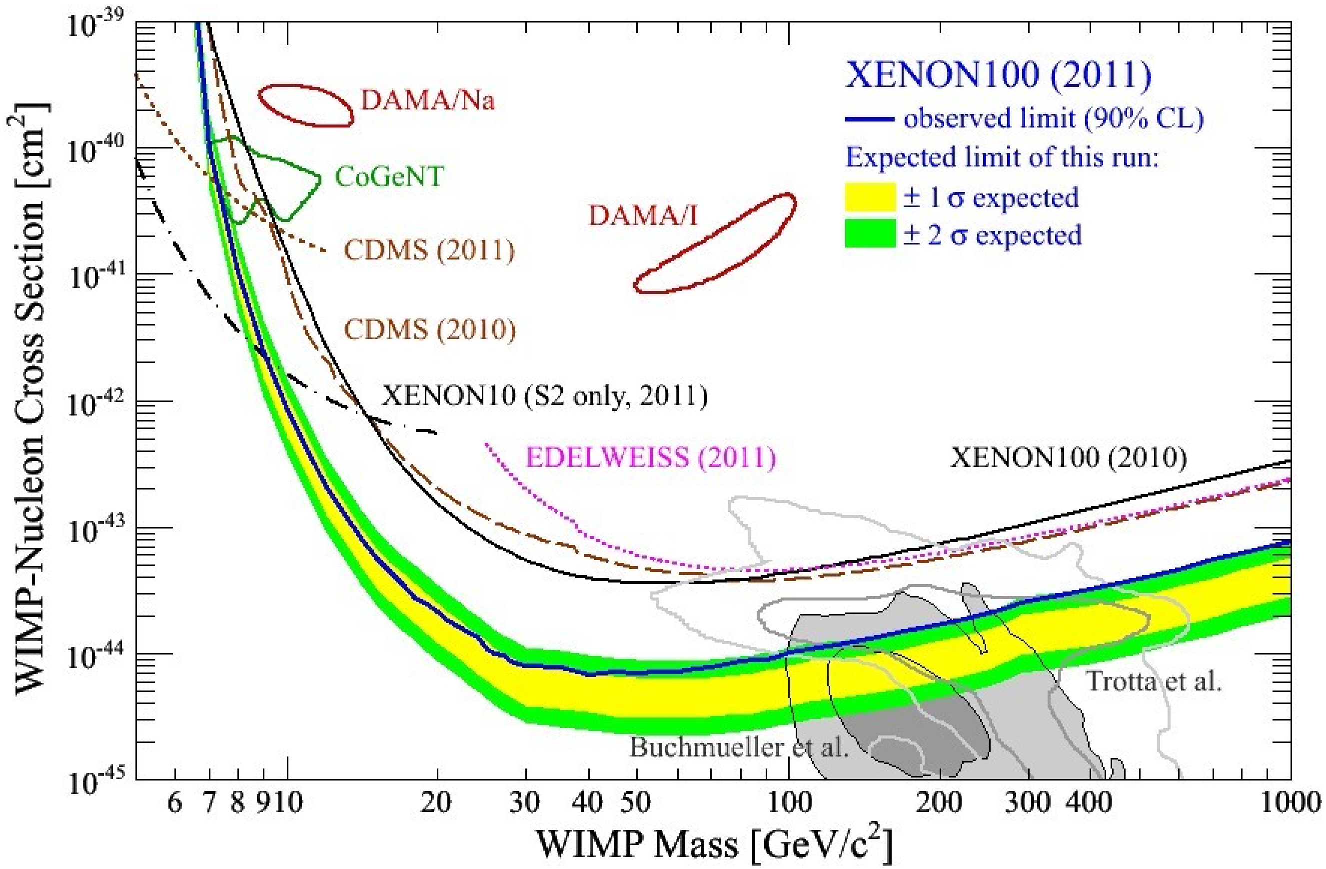
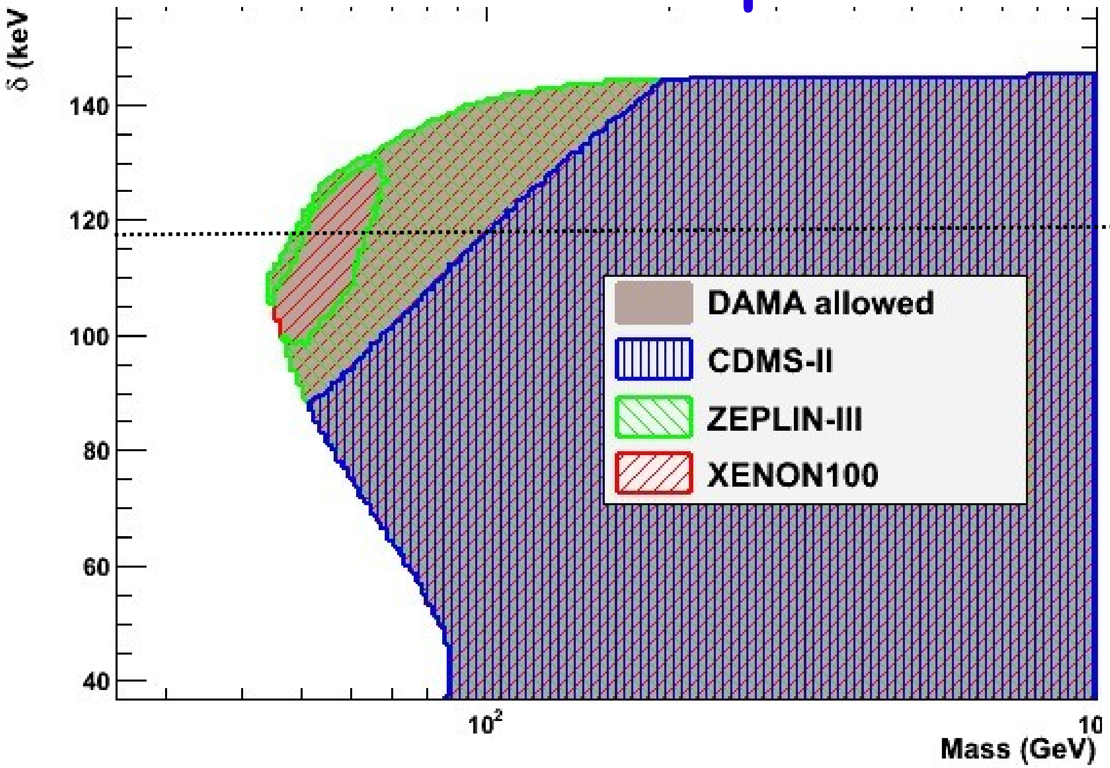
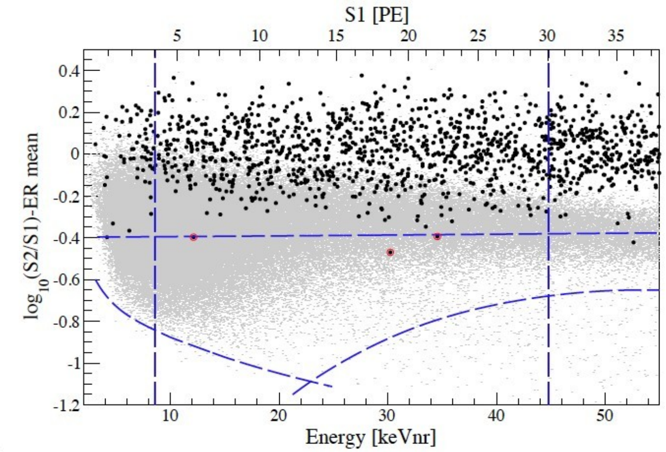
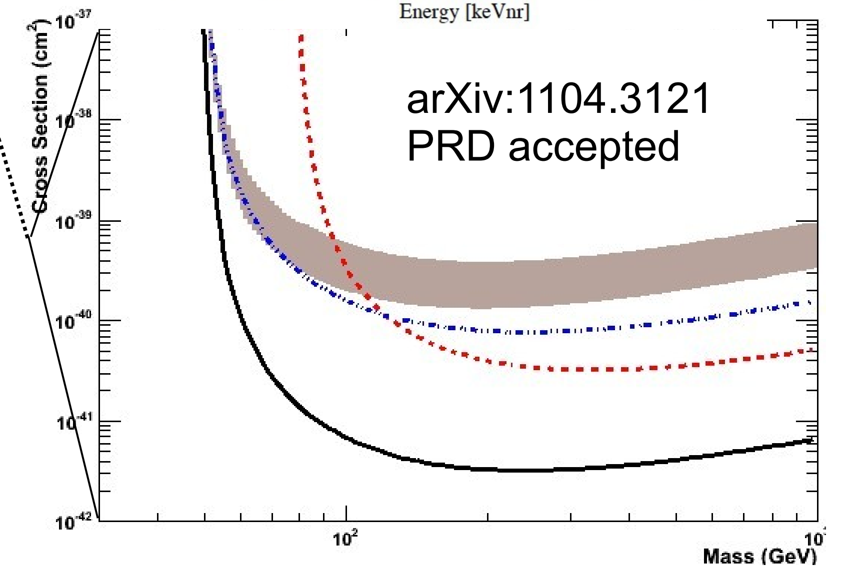
- 100.9 live days, exposure: **1471 kg×d**
- Energy window: 4 – 30 PE S1 / 8.4 – 44.6 keVnr
- Observed after all cuts: 3 events. Expected background: (1.8 ± 0.6) events (25% probability)
- Profile Likelihood limit based on side-bands from calibration
- Best SI limit. Minimum $\sigma_S = 7.0\times10^{-45}$ cm^2 @ 50 GeV/c^2
- SUSY (CMSSM) parameter space further constrained in updated models incl. LHC limits.
- Strong tension with low mass WIMP interpretation for DAMA, CoGeNT, CRESST

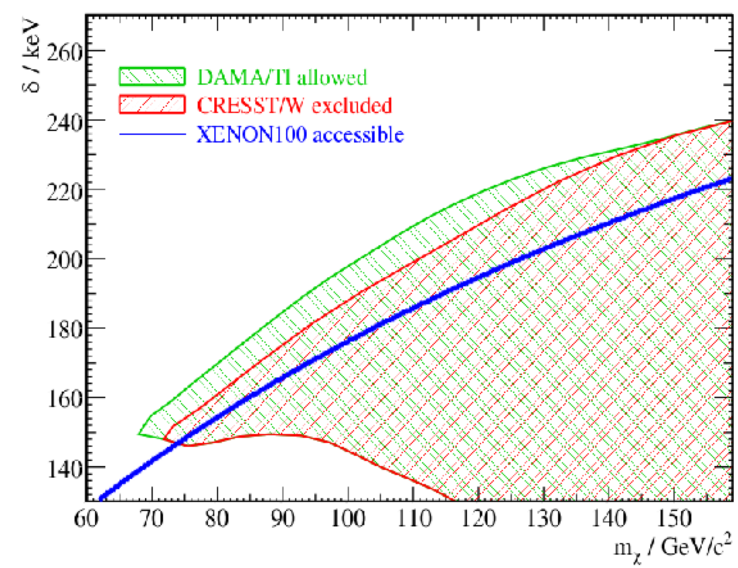


Inelastic Dark Matter – dead for DAMA interpretation?









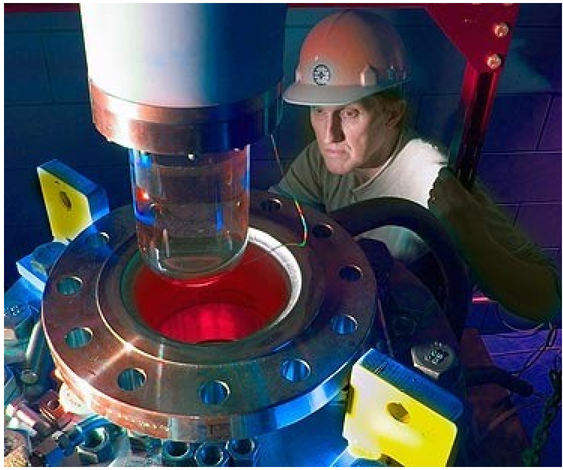
- Model: Elastic scattering is suppressed. DM scatters preferentially in a low-lying excited state.
- Motivation: make DAMA/LIBRA annual modulation compatible with SI limits at energy splitting ~90 – 140 keV and WIMP masses 50 – 140 GeV/c^2.
- XENON100 rules this scenario out (for Na, I).
- Caveat: WIMP scattering off heavy Tl (A=204) 10^{-3} abundance in NaI(Tl) – fine-tuned parameters survive for Xe target. Use W in CRESST?

Superheated Liquids for DM Search: COUPP

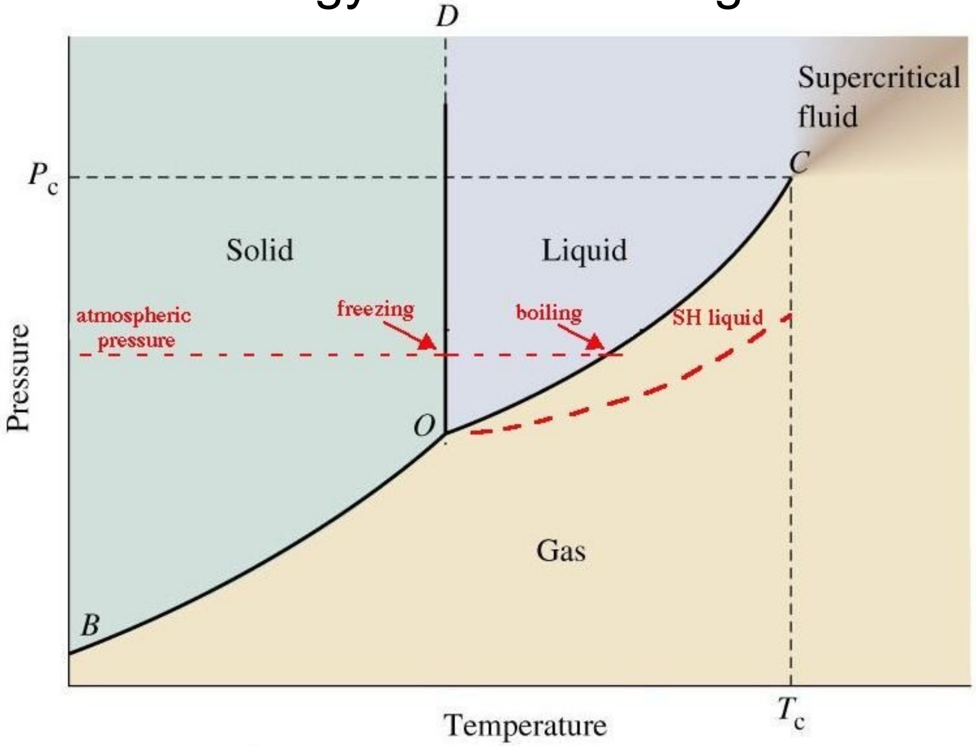
COUPP: Chicagoland Observatory for Underground Particle Physics

Erik Ramberg, SNOLAB 2009

- University of Chicago
- Fermi National Accelerator Laboratory
- Indiana University of South Bend



- Bubble chamber technology for dark matter search
  - optical readout
  - acoustic readout (new)
- Detector extremely insensitive to electron recoil events
- Technology scalable to large detector masses



Disadvantage: threshold detector.

- energy spectrum by changing (P, T) , hence moving threshold.

Features of the Bubble Chamber Technique

Advantages:

- Scalability to large mass
  - low cost
  - reliability
  - easy fabrication
  - multiple copies of an optimized model (e.g. given by size of fused silica vessel)
- Current liquid (CF_3I) sensitive to both spin-dependent and spin-independent WIMP interactions
- If DM discovery: fluid exchangeable to test WIMP physics (e.g. CF_3Br, C_4F_{10}, CH_3I, CCl_2F_2)

Disadvantages:

- Threshold detector (only integral rate measured)
  - but energy threshold tunable by changing pressure. Scan of threshold used to fit and subtract backgrounds.
- Background-dominated so far
  - but improving with acoustic discrimination

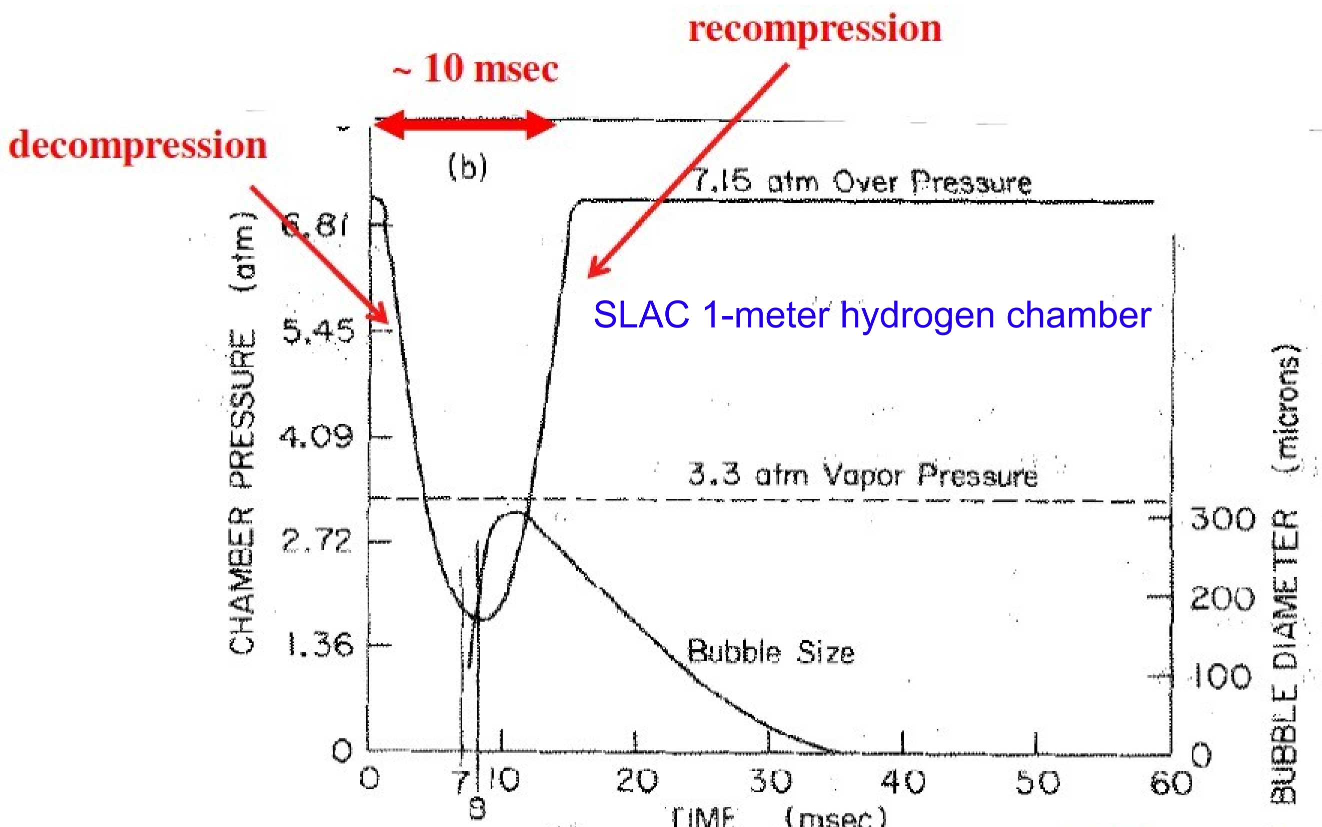
COUPP 60 kg prototype vessel

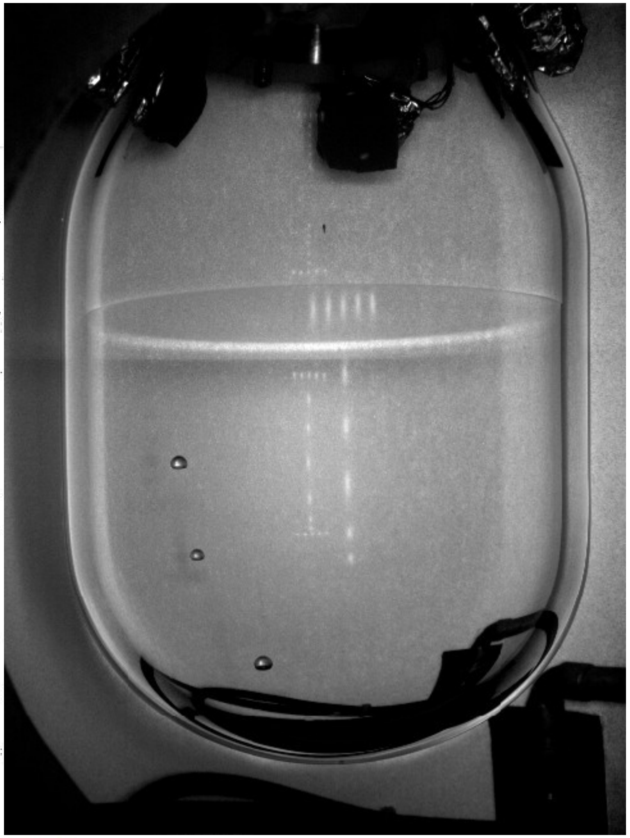
From Milliseconds to 30 Minutes

- Classical bubble chambers: only sensitive for a few milliseconds per cycle
- Immediate nucleation due to electron recoil backgrounds and imperfections

COUPP: CF_3I only mildly superheated.

- Seitz model:
  - low ionization density events (electron recoils) below threshold
  - nuclear recoils above threshold

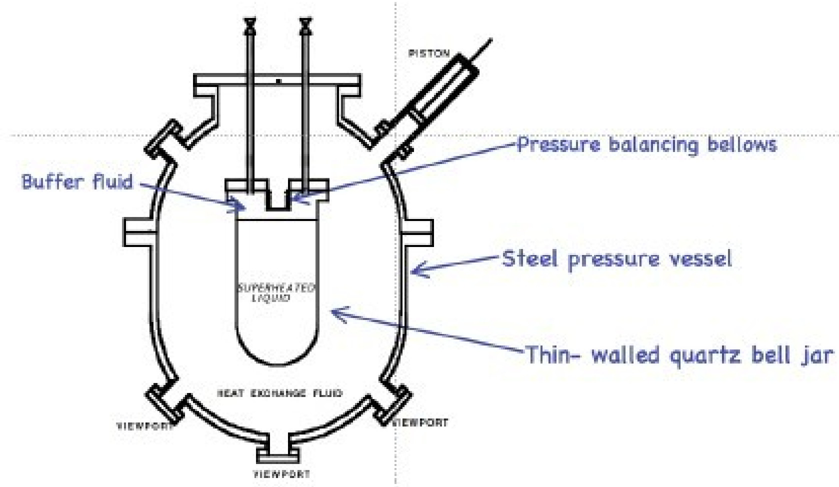


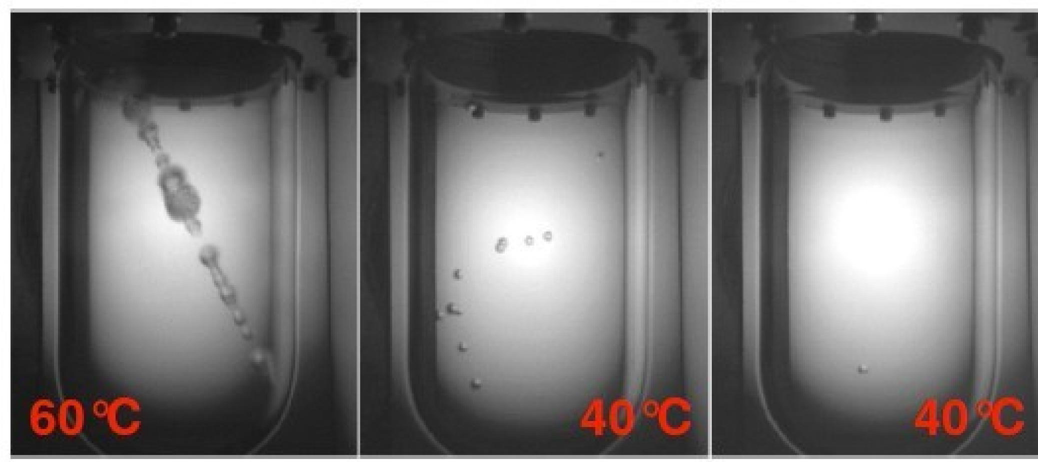


Ballam and Watt, 1977.

COUPP: Realisation of a 2 kg Chamber

Andrew Sonnenschein guides the vessel into place in the pressure chamber



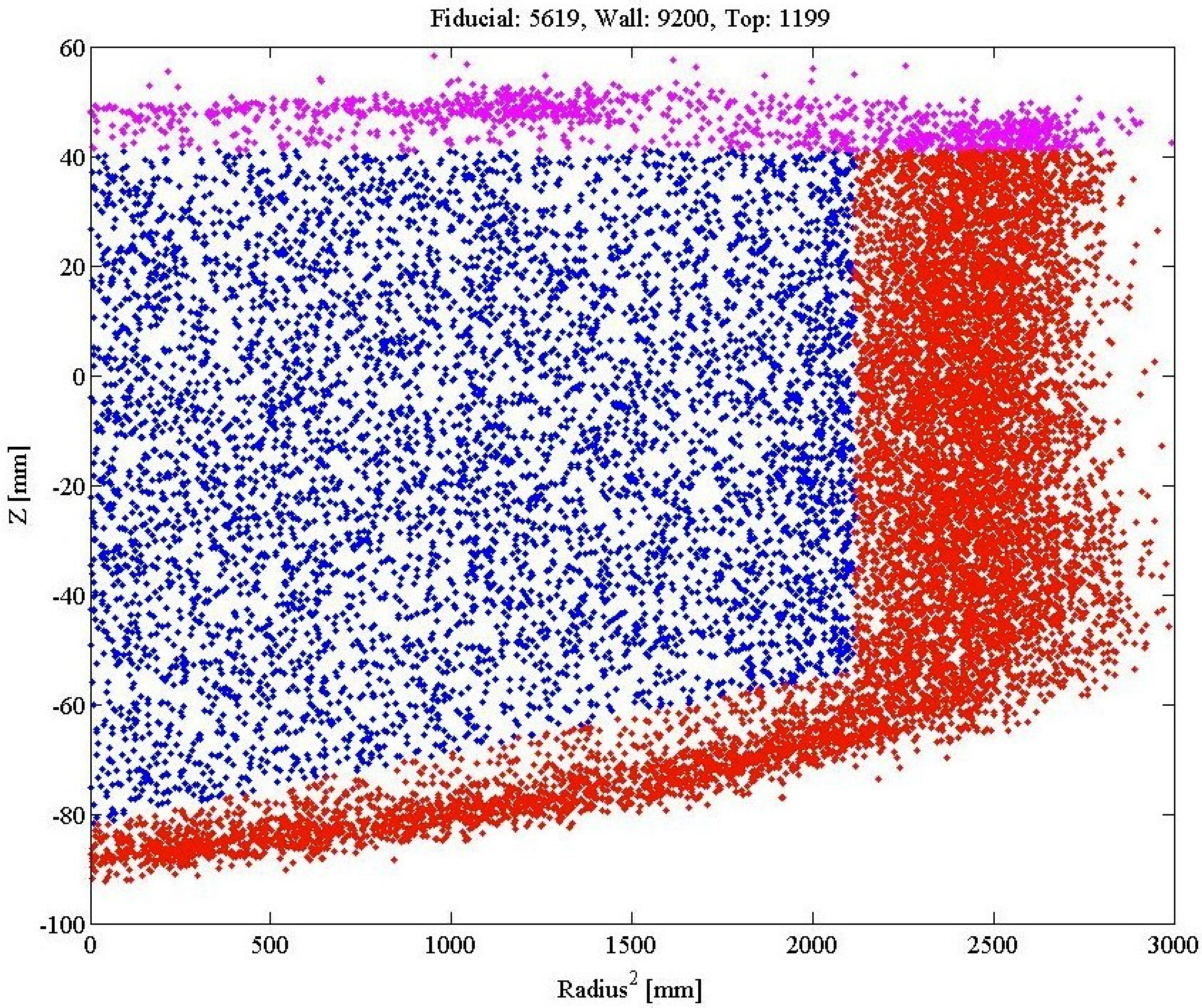


muon | Neutron(s) | WIMP

A CCD camera takes pictures at 50 Hz. Chamber triggers on appearance of bubble in the frame.

Surface Background: Alphas

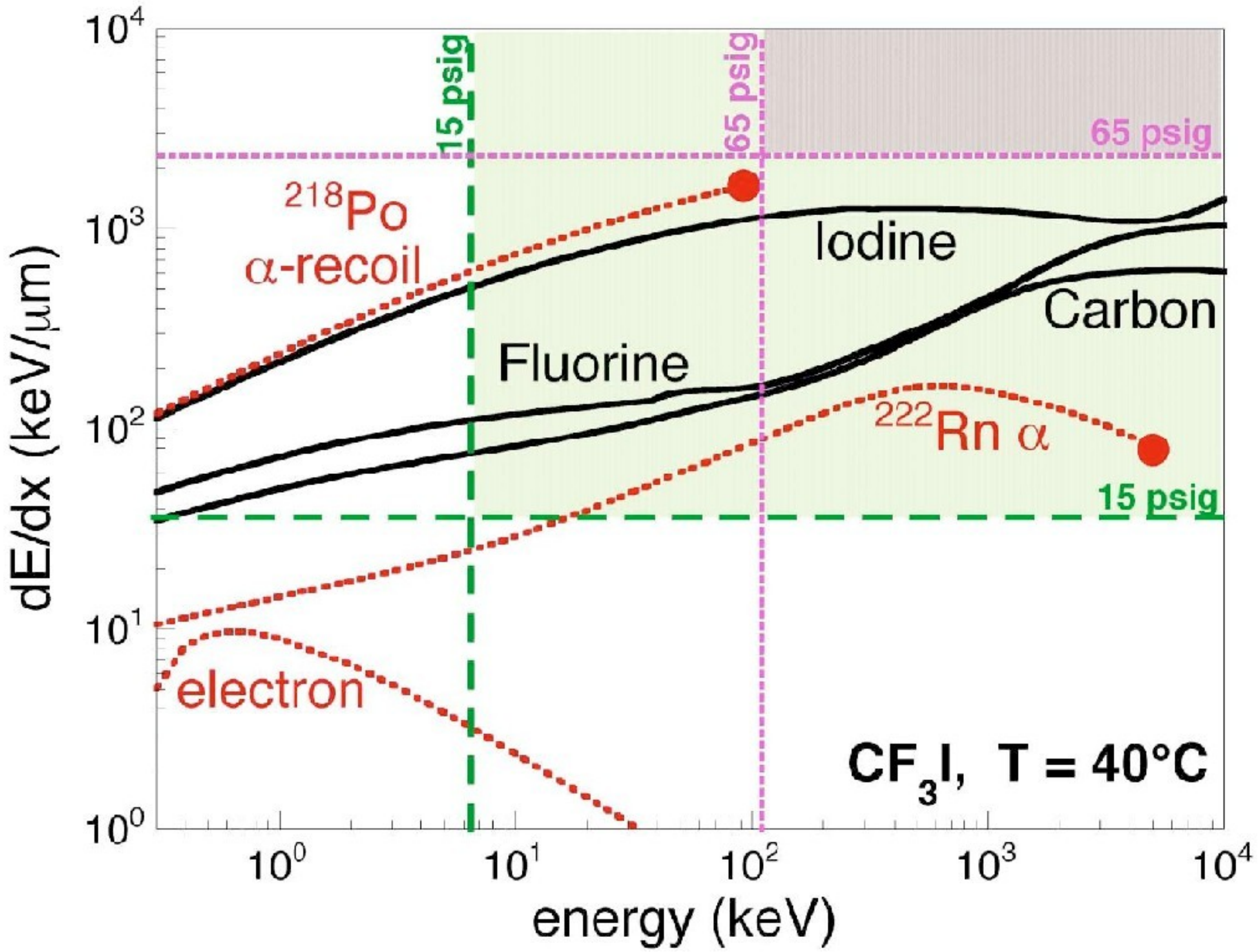
- Can be distinguished from bulk events, but reduces live time.



Setting the Threshold

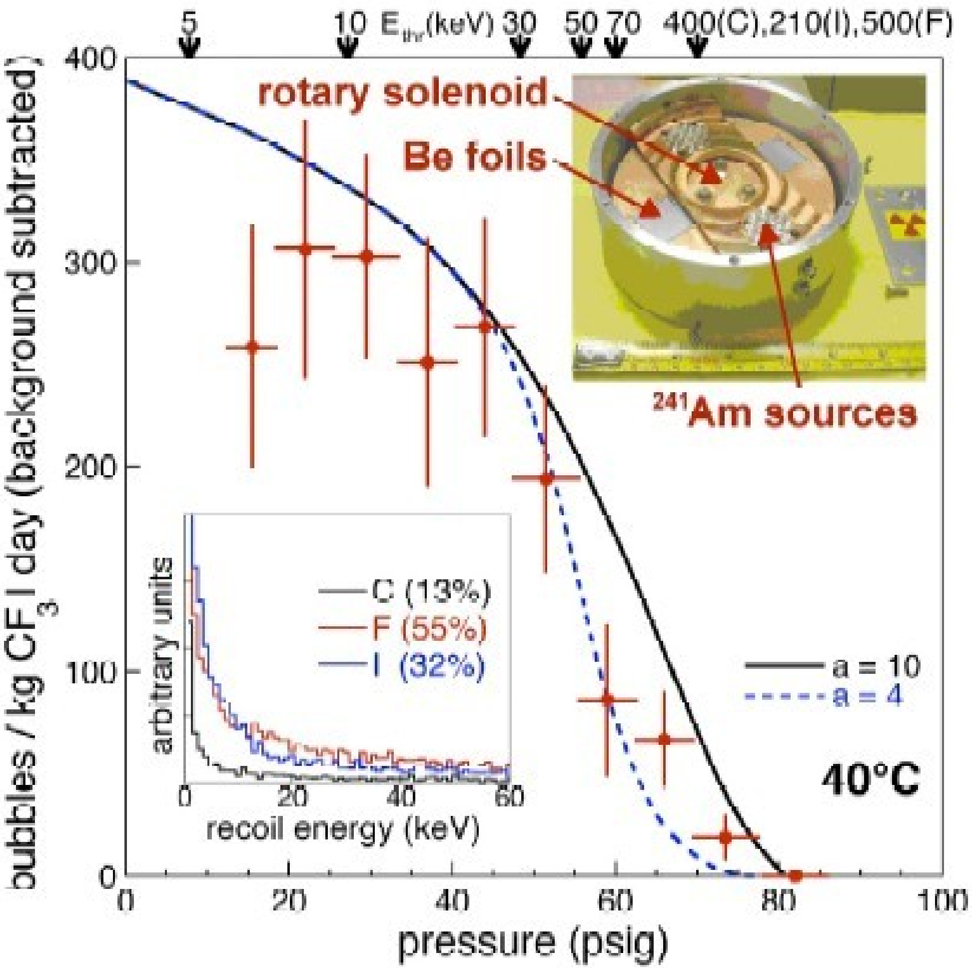
- Proto-bubbles with $r > r_{crit}$ grow
- Critical proto-bubble requires minimum dE within minimum volume
- Recoil must be over thresholds in both E and dE/dx

Erik Dahl, IDM 2010

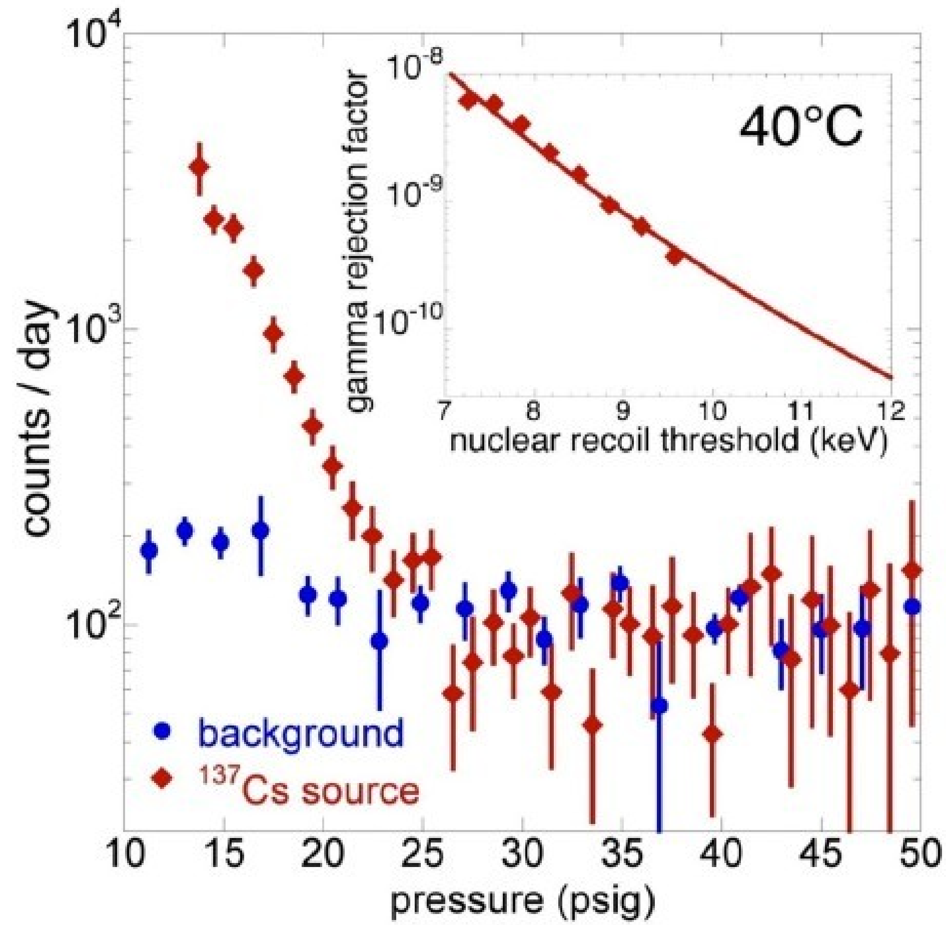


COUPP: Calibration

Neutrons

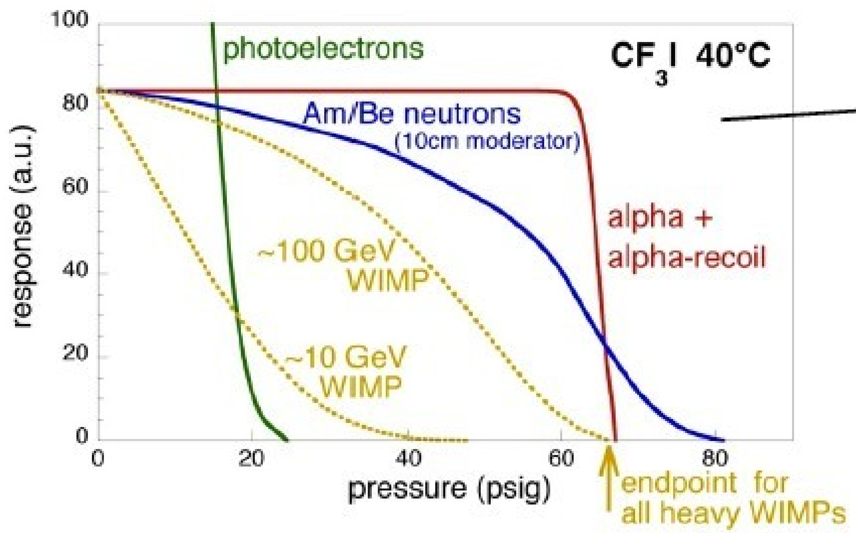


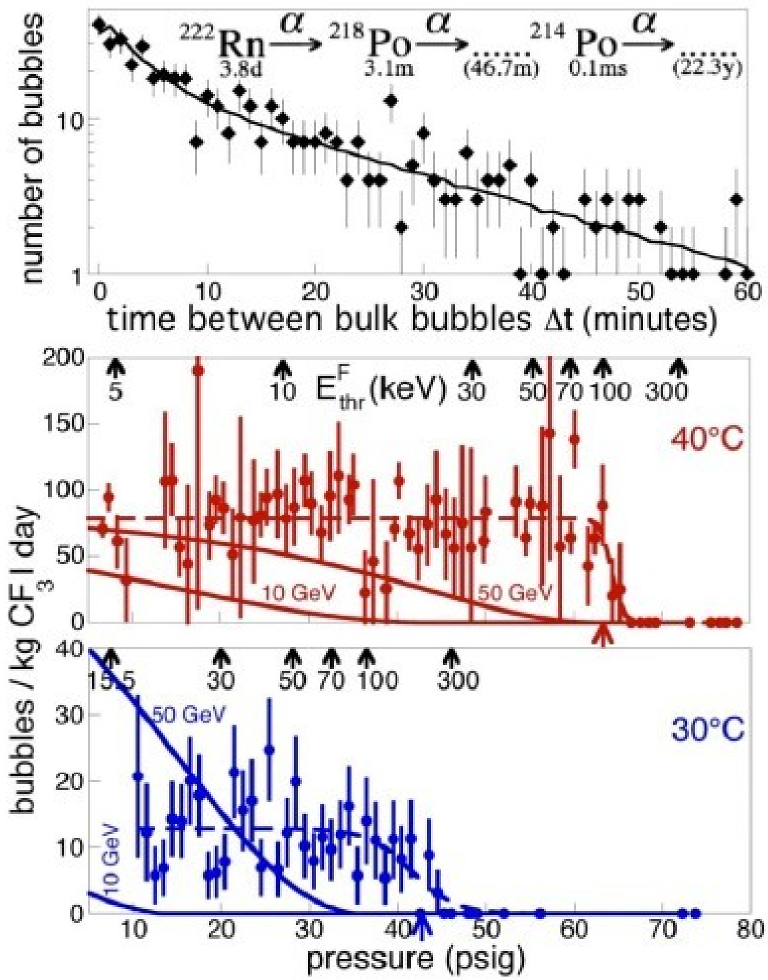
Insensitivity to Gammas



COUPP: 2006 Data from the 2 kg Chamber

- COUPP operated in an engineering run in 2006-7. We obtained data at two different temperatures (30C and 40C)
- We systematically scanned the decompression pressure from about 10 psig to 70 psig, beyond the threshold for radon decays
- Data consists of sum of different spectral shapes:

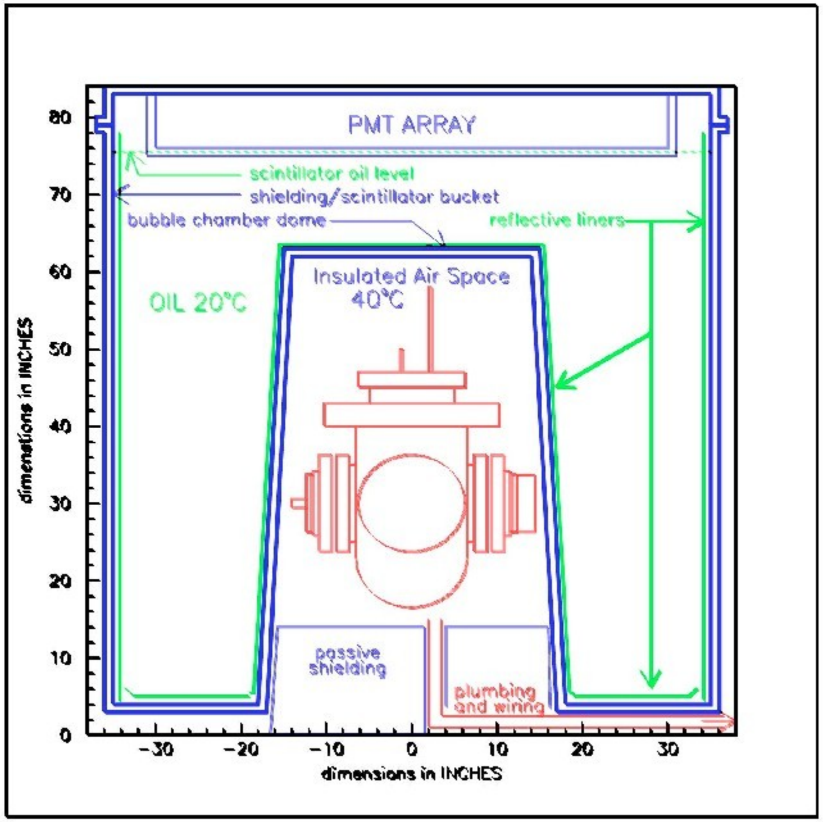


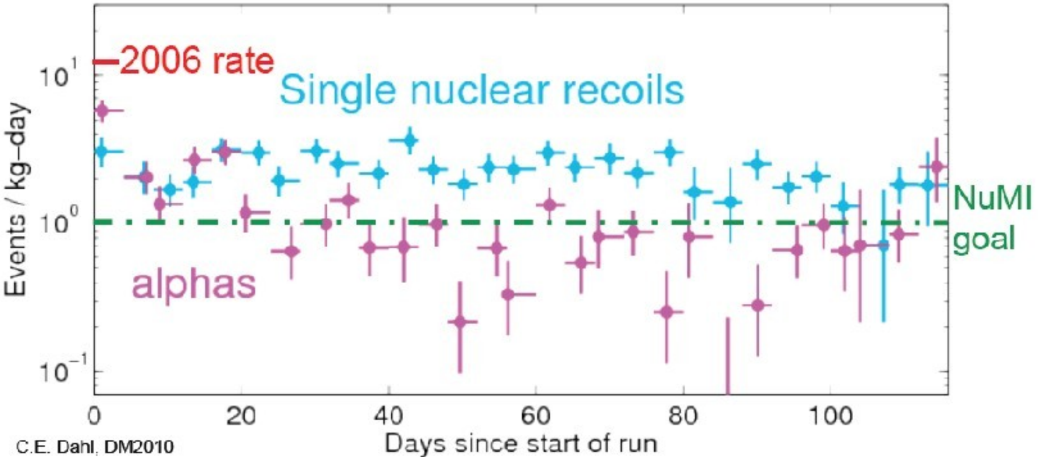


Erik Ramberg, SNOLAB 2009

COUPP 4 kg

- Reduced alpha wall background:
  - natural quartz → synthetic silica
  - $0.8/d/cm^2$ → $\leq 1e\text{-}3/d/cm^2$
- Reduced alpha bulk background:
  - Materials known to emanate Rn removed
  - No steps taken to purify CF_3I, remove ^{210}Pb, etc.
- New muon veto





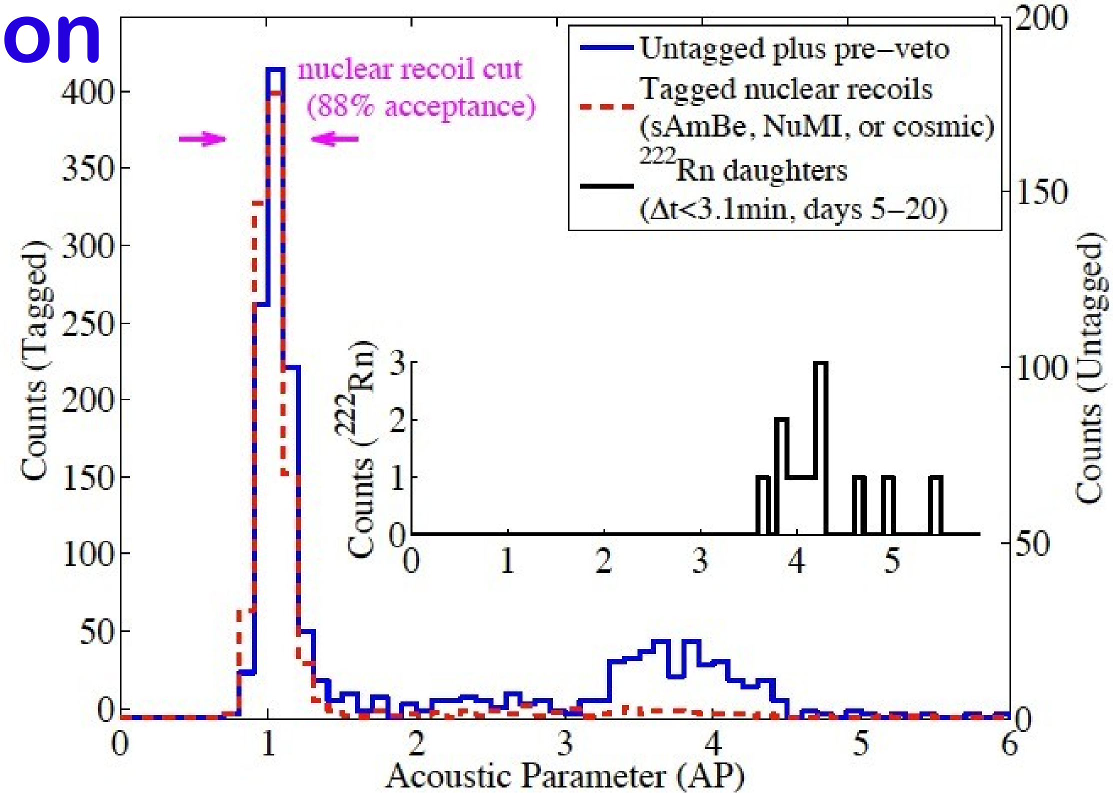
PRL 106:021303 (2011)
arXiv:1008.3518

Acoustic Discrimination

- Nuclear recoil: 1 proto-bubble
- Bulk α-decay: 2+ proto-bubbles
  - 1 proto-bubble from α-decay nuclear recoil
  - 1+ proto-bubbles from alpha

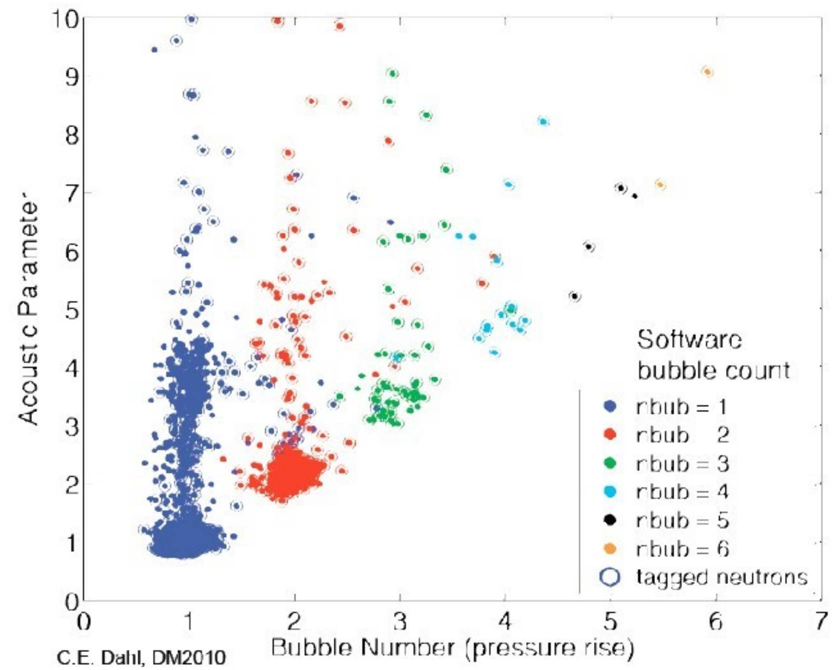
→ Alpha's should be louder.

Method based on findings by PICASSO
New J.Phys.10:103017 (2008), arXiv:0807.1536



Acoustic Parameter:

- $(\text{Amp} \cdot \omega)^2$
  - normalized and position-corrected for each frequency bin
  - Measure of acoustic energy deposited in the chamber
- Acoustic Parameter (AP) scales with # of bubbles



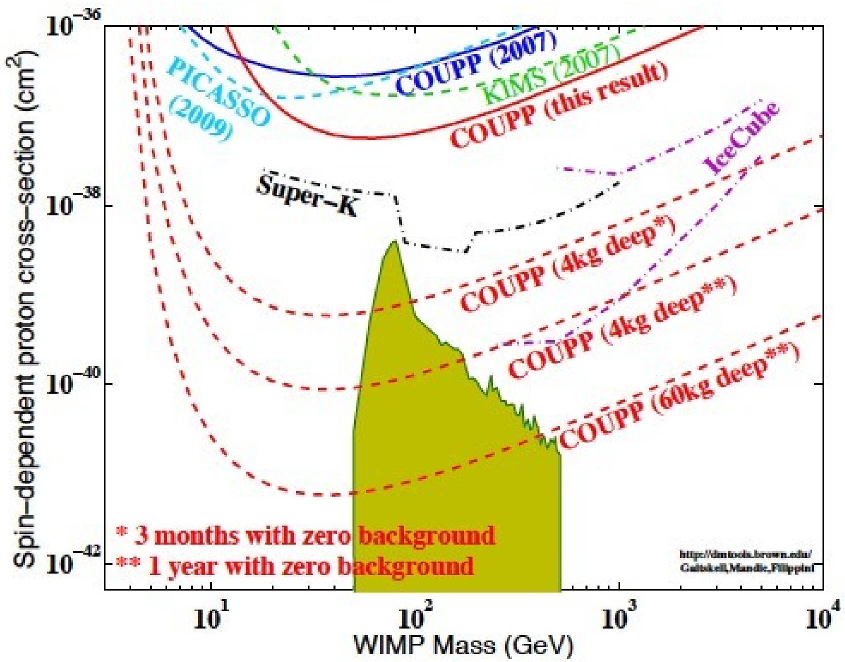
COUPP: Future Plans

Andrew Sonnenschein, Fermilab 2010

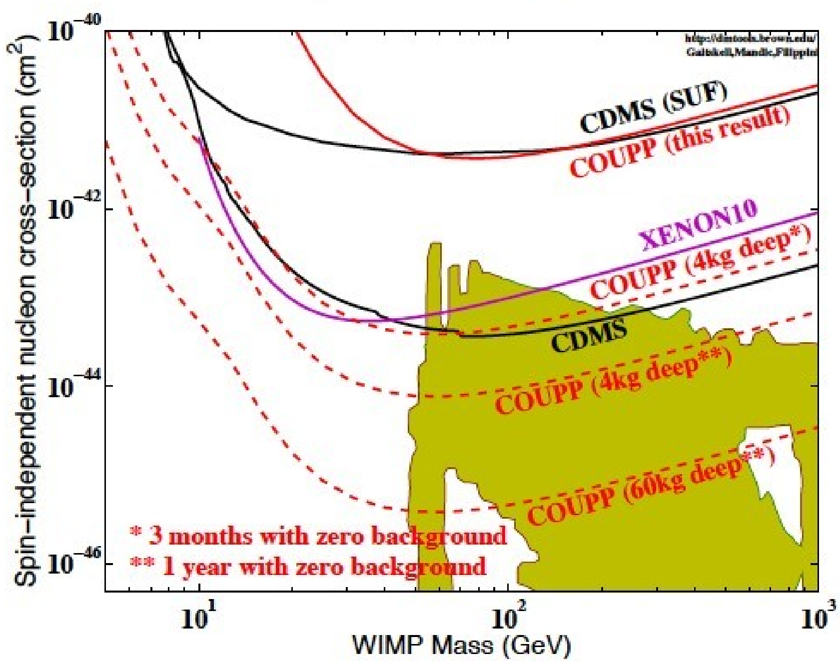
We've Become Much More Ambitious

• If alpha rejection power is as high as we think, the COUPP technique is likely to yield the best sensitivity to both spin-dependent and spin-independent channels, possibly even within the next year.
• To compete with CDMS/ Xenon-100, we need alpha rejection in the range 10^{-2}- 10^{-4}, depending on how much improvement we get in radiopurity (10^{-4} for no improvement beyond current level of 1/kg-day)

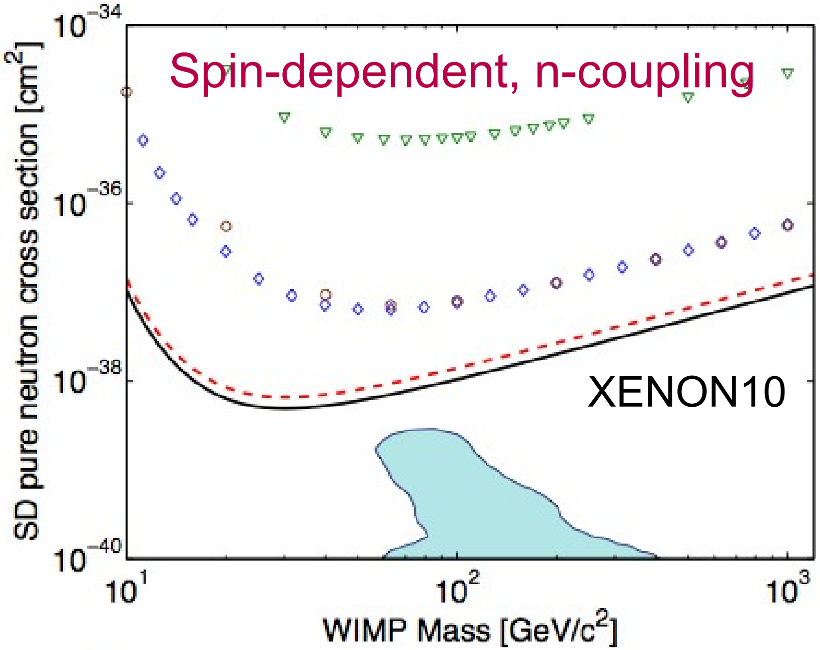
Spin-Dependent



Spin- Independent



Status in WIMP DM Sensitivities (2011)



XENON10 SD, 2008
PRL 101 091301

XENON10 SI, 2008
PRL 100 (2) 021303

XENON100 SI,
2010 PRL 105, 131302
2011 arXiv:1104.3121

CDMS-II SI, 2010
Science 327, 1619

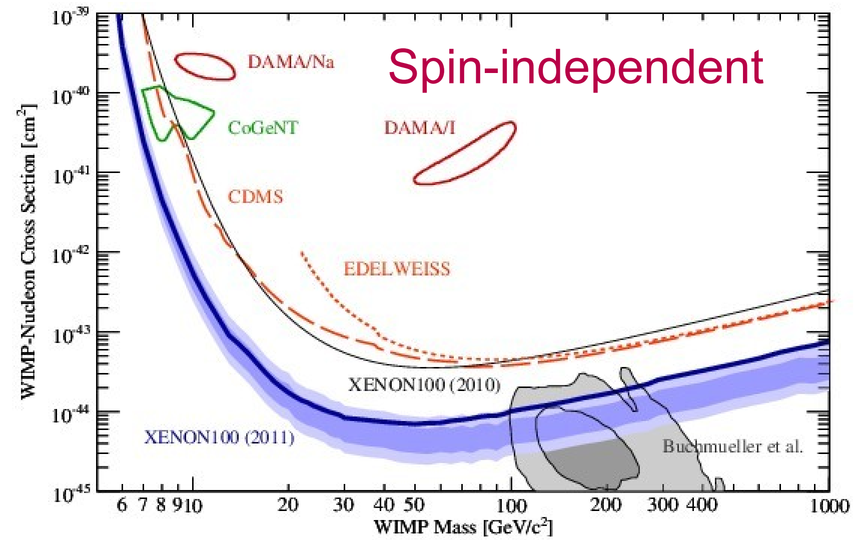
EDELWEISS-II SI, 2011
arXiv:1103.4070

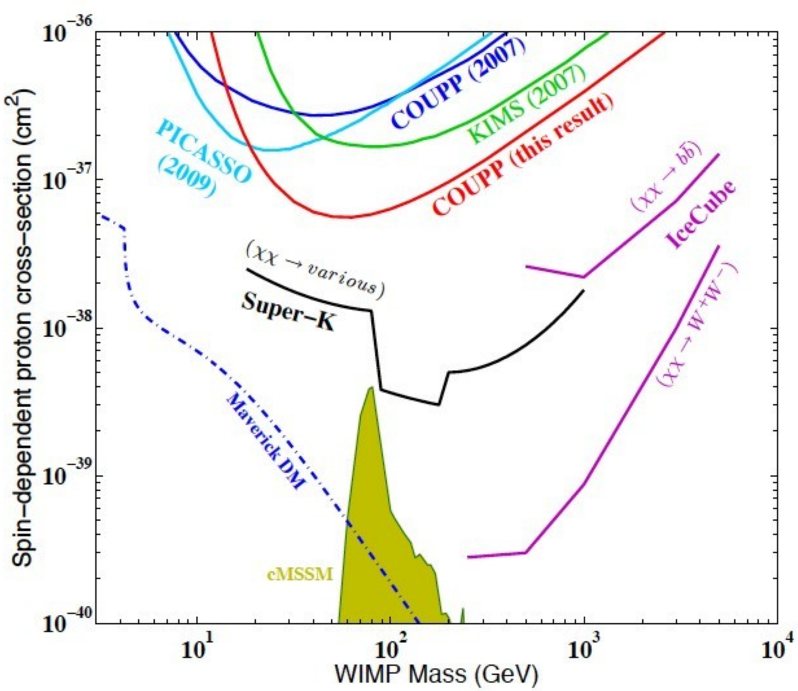
CoGeNT SI,
PRL 106 (2011) 131301
2011 (new): arxiv:1106.0650

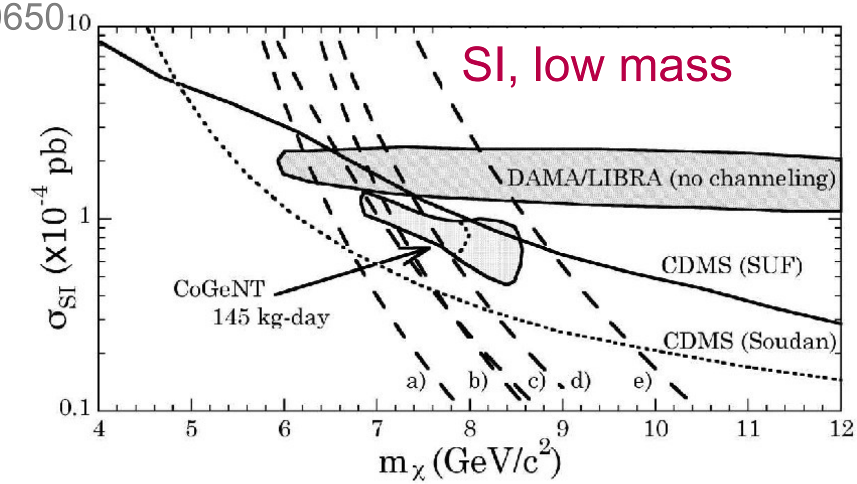
COUPP SD:
2008: Science 319, 933
2011 arXiv:1008.3518

PICASSO SD, 2009
Phys.Lett. B 682, 185

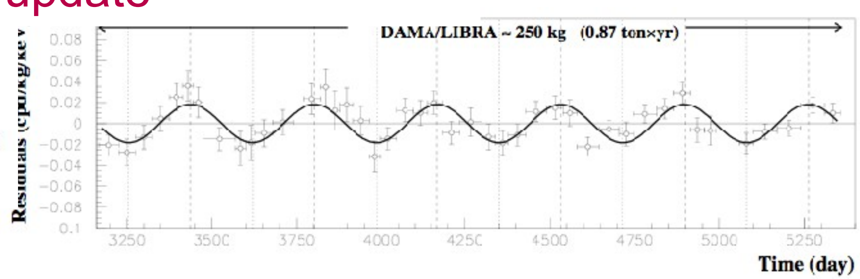
DAMA/LIBRA, 2010
arxiv:1002.1028







Annual modulation update

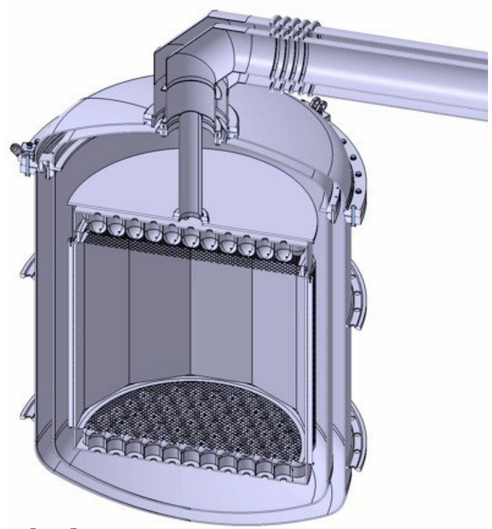


3. Future

Future Developments

Noble Liquids

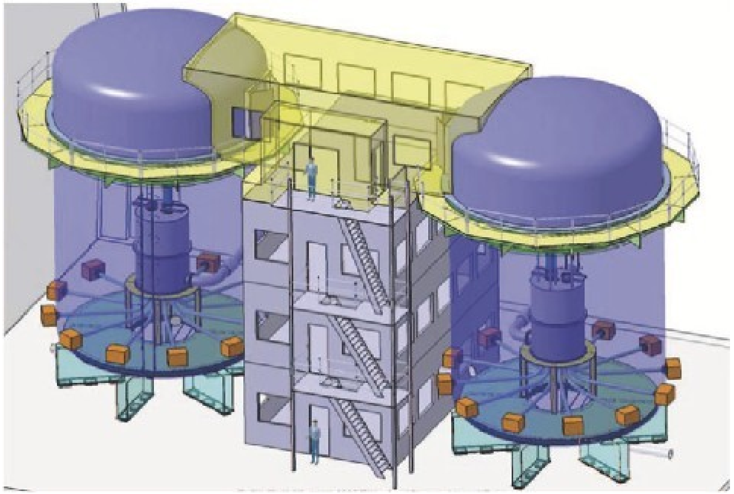
- LXe:
  - XENON100 (taking data)
  - XMASS (LXe scint., construction completed)
  - LUX (LXe, under construction)
  - XENON1T (start construction 2011)



- LAr:
  - WARP (commissioning phase)
  - ArDM (moving underground)
  - Mini-Clean (scint., under construction)
  - DEAP-3600 (under construction)

Cryogenic Germanium

- USA:
  - Super-CDMS (under construction)
  - GeoDM (R&D)
- Europe:
  - Edelweiss-3 (under construction)
  - EURECA (R&D)
    possible combination of cryogenic crystals and Ge

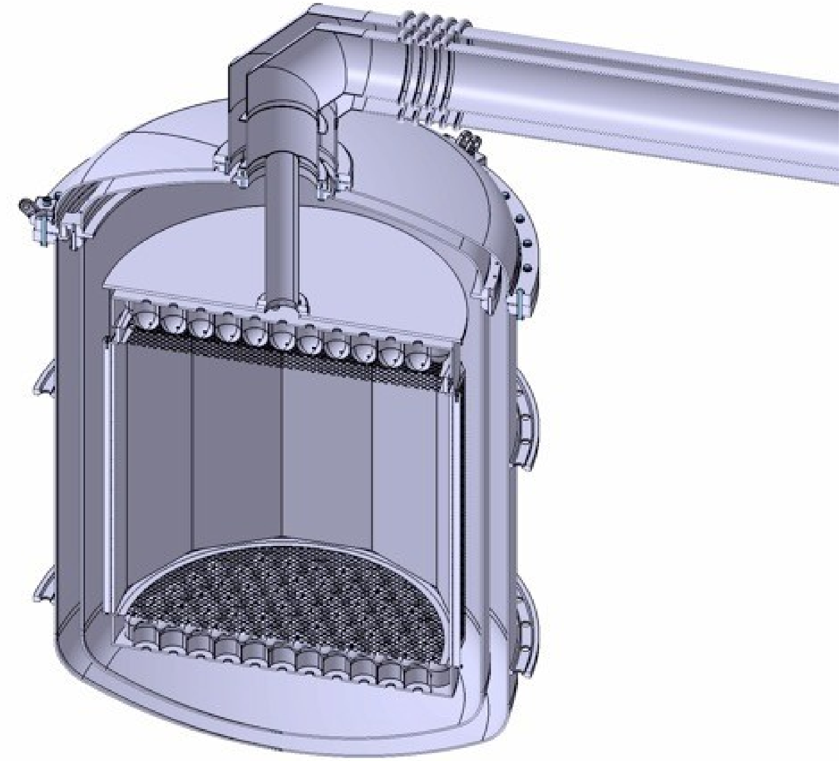


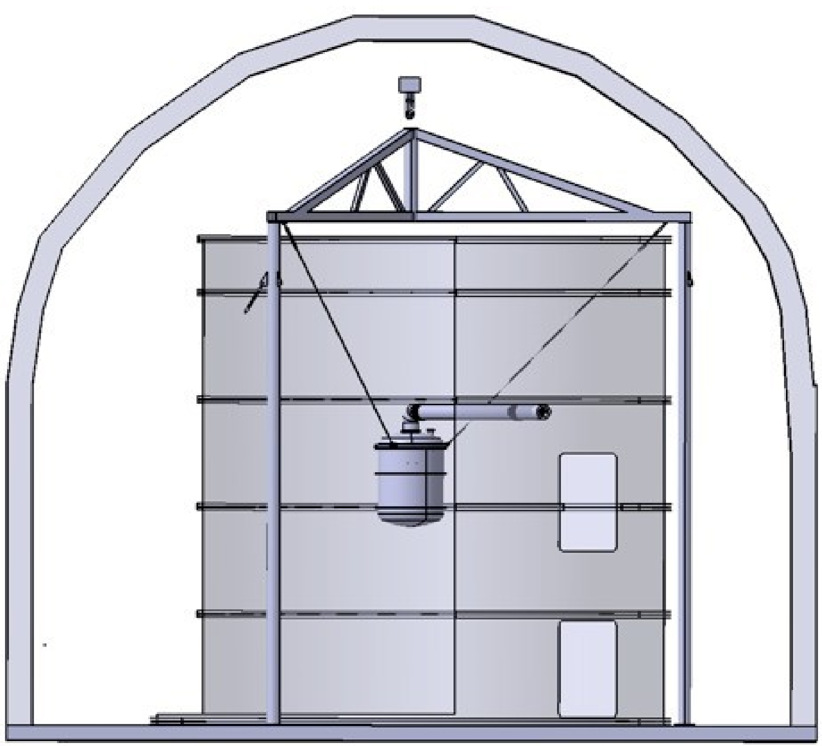
Superheated liquids

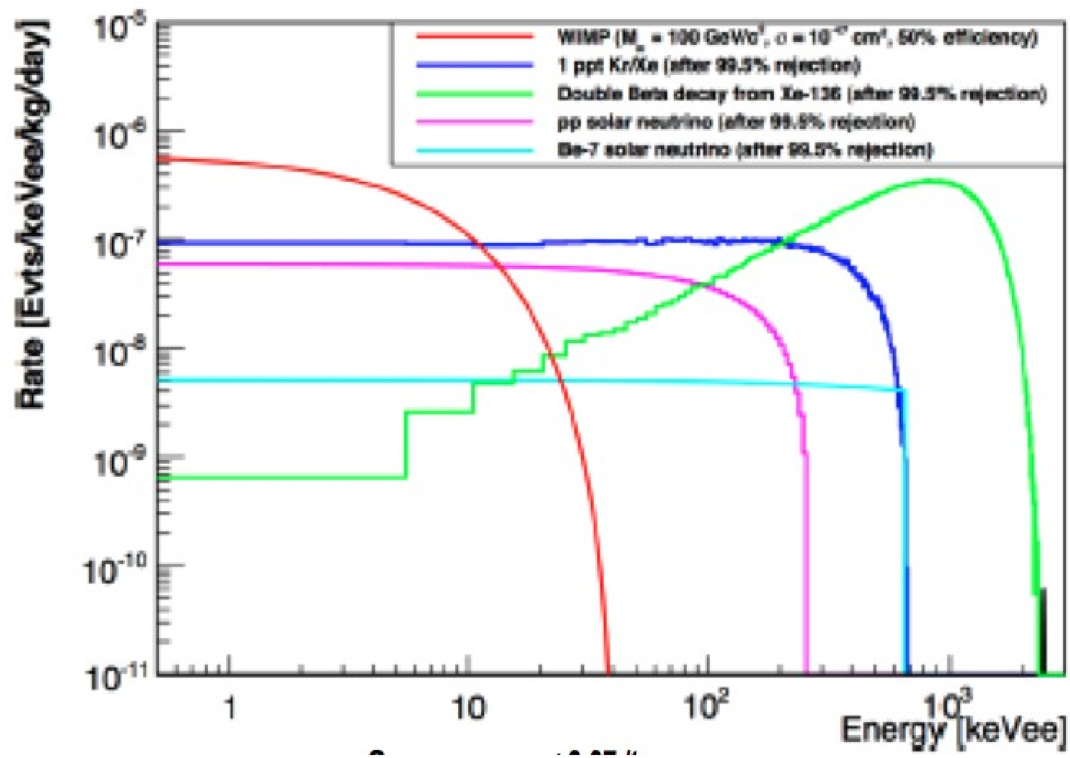
- COUPP (60 kg under construction)
- PICASSO

XENON1T
(2011-2015)

- 1t fiducial mass LXe detector to explore $\sigma \sim 3 \times 10^{-47}$ cm^2
- Water Cherenkov Muon Veto
- 2 x 121 3” photosensors: PMTs or QUPIDs
- Capital cost: ~ $8.8 M, ~80% in hand
- Approved at LNGS





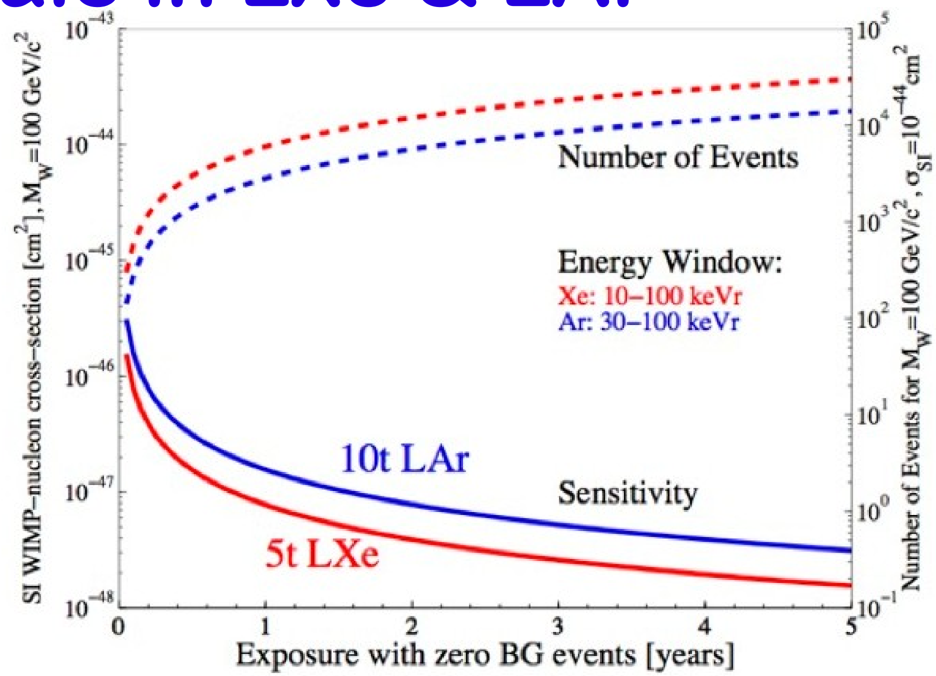


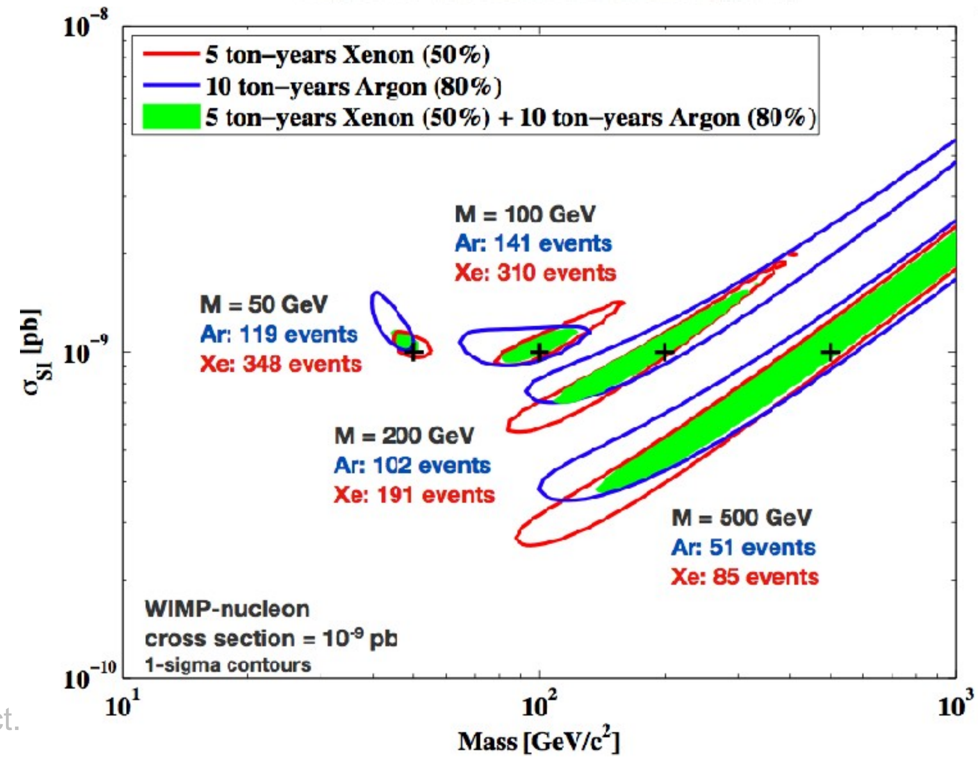
Studying the Multi-ton Scale in LXe & LAr

DARWIN

- R&D and design study over 3 years for a next-generation noble liquid facility in Europe
- Approved by ASPERA (AStroParticle ERAnet) in late 2009
- Funded in Switzerland, Italy, France, Netherlands
- Combine efforts in both LAr and LXe
- Europe: UZH, INFN, ETHZ, Subatech, Nikhef, MPIK, Münster, Mainz, KIT, IFJPAN
- USA: Columbia, Princeton, (Rice), UCLA

Details: darwin.physik.uzh.ch



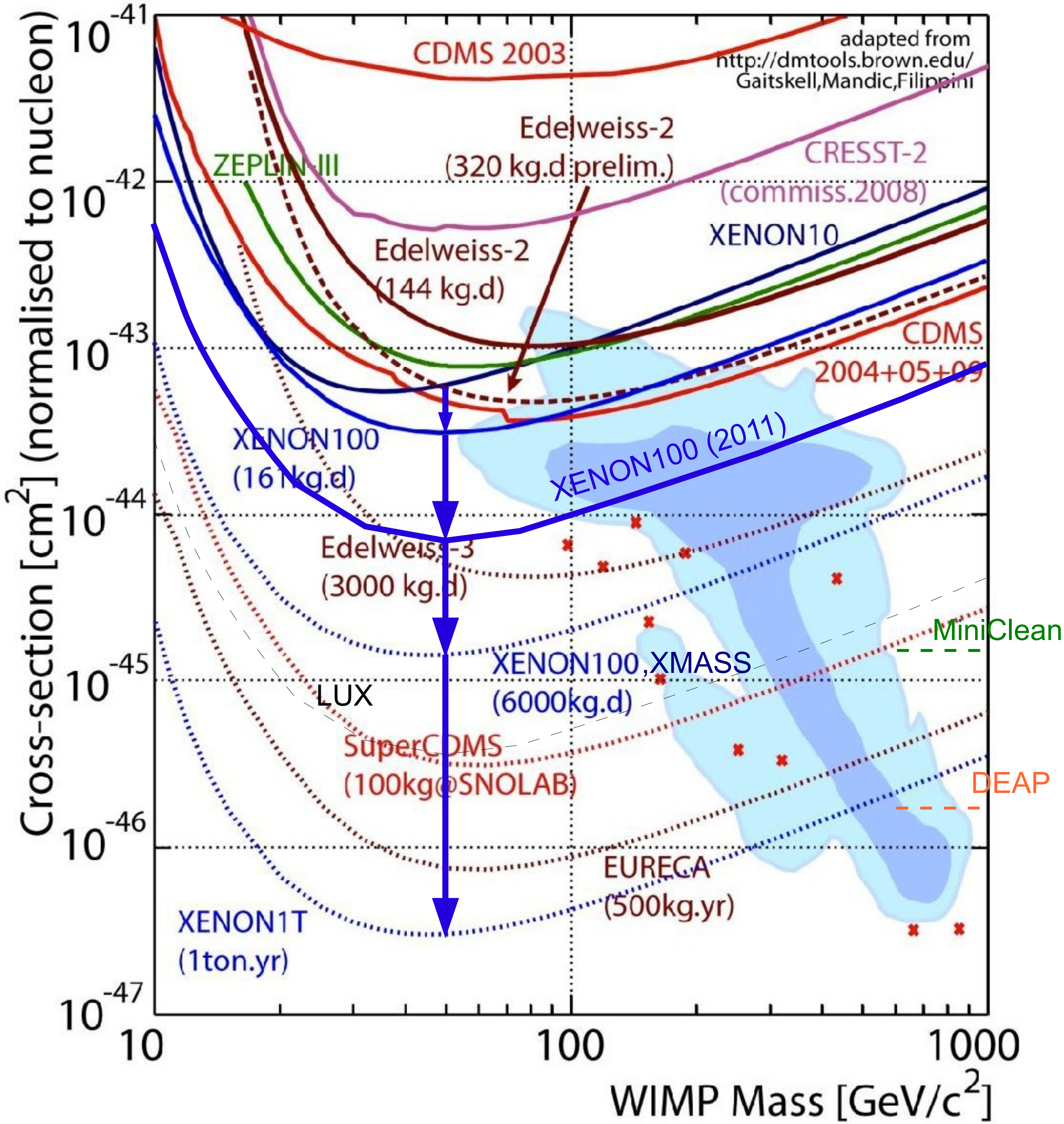


The Future of Direct Dark Matter Searches
(next ~5 years)

Spin-independent sensitivity

measured: solid
expectations: dashed

COUPP may enter the picture if acoustic background suppression works very well



Summary & Outlook

- **Progress in Dark Matter direct searches:**
  - Sensitivity advanced by ~3 orders of magnitude in the last decade, increasing pace.
  - Noble liquid detectors are starting to set the pace in sensitivity.
- **Exciting new results in the last year**:
  - CoGeNT, CRESST excess events & DAMA/LIBRA annual modulation: Low mass WIMPs with $\sigma_S \sim 10^{-40}$ cm^2 @ ~7 GeV/c^2? Or poorly understood backgrounds?

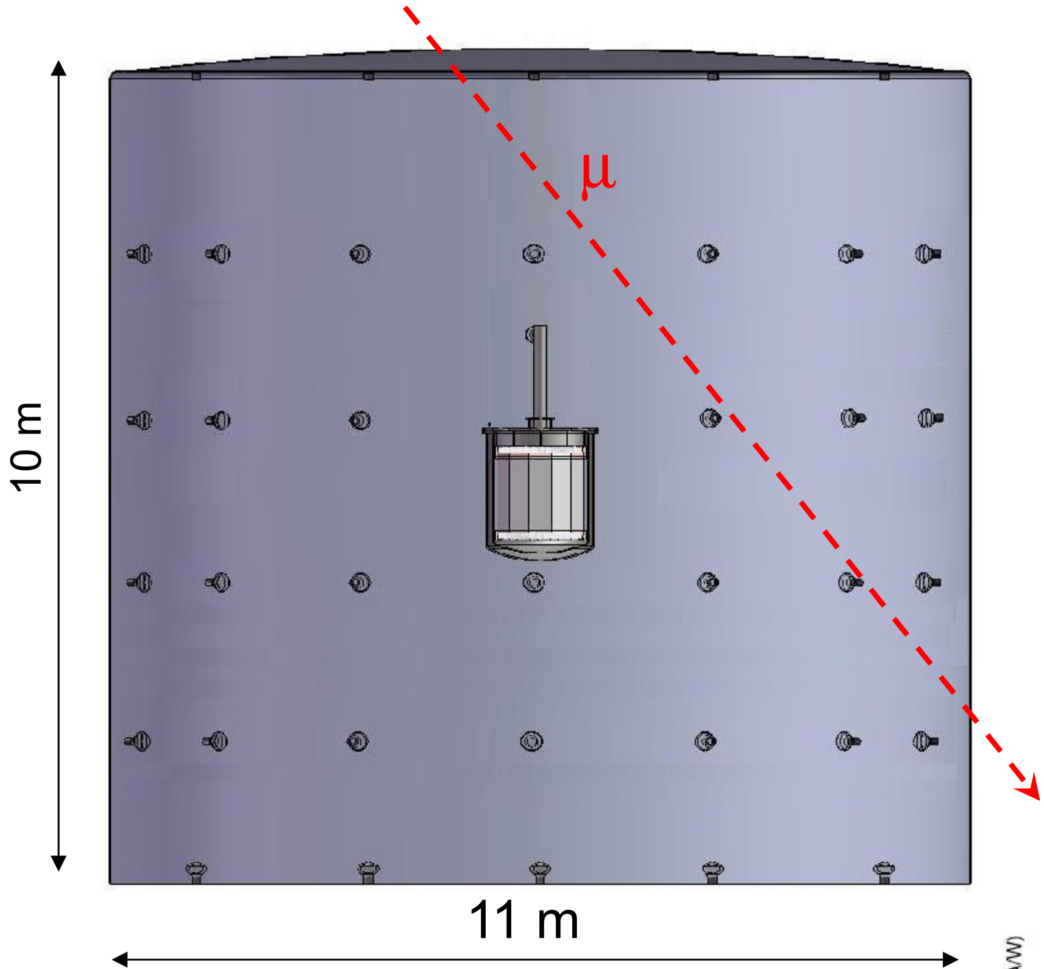
    CoGeNT new result June 2011: annual modulation?
- **New XENON100 result 2011**:
  - Upper limit on (spin-independent) WIMP-nucleon cross-section $\sigma_s = 7.0\times10^{-45}$ cm^2 @ 50 GeV/c^2

    ~ Factor 5 improvement over previous limits.
  - XENON100 challenges the low mass WIMP interpretation. (+ low threshold CDMS)
  - Inelastic DM (nearly) ruled out as explanation for annual modulation in DAMA/LIBRA.
- **The future looks exciting:**
  - Rapid progress at the LHC: Limits on new physics improving fast. Will we see SUSY soon?
  - New results in indirect searches: but fundamental problems of background subtraction remain (so far).
  - Direct + indirect searches + LHC:

    We will know much more about DM within the next 5 years.
    If DM consists of WIMPs we will likely have found signs of them.

Thank you for your attention!

XENON1T Water Cherenkov Muon Veto



- 4 rings of 12 PMTs in the lateral surface
- ~ 30 PMTs in the bottom floor in an hexagonal grid.

From the MC:

- On average 23 ph.el. / PMT
- **Muon detection efficiency ~100% for track > 1m**

PMTs:
8” Hamamatsu R5912
in the water-proof version.

Reflector foil:
ER2000MA by 3M, reflectivity 98% .