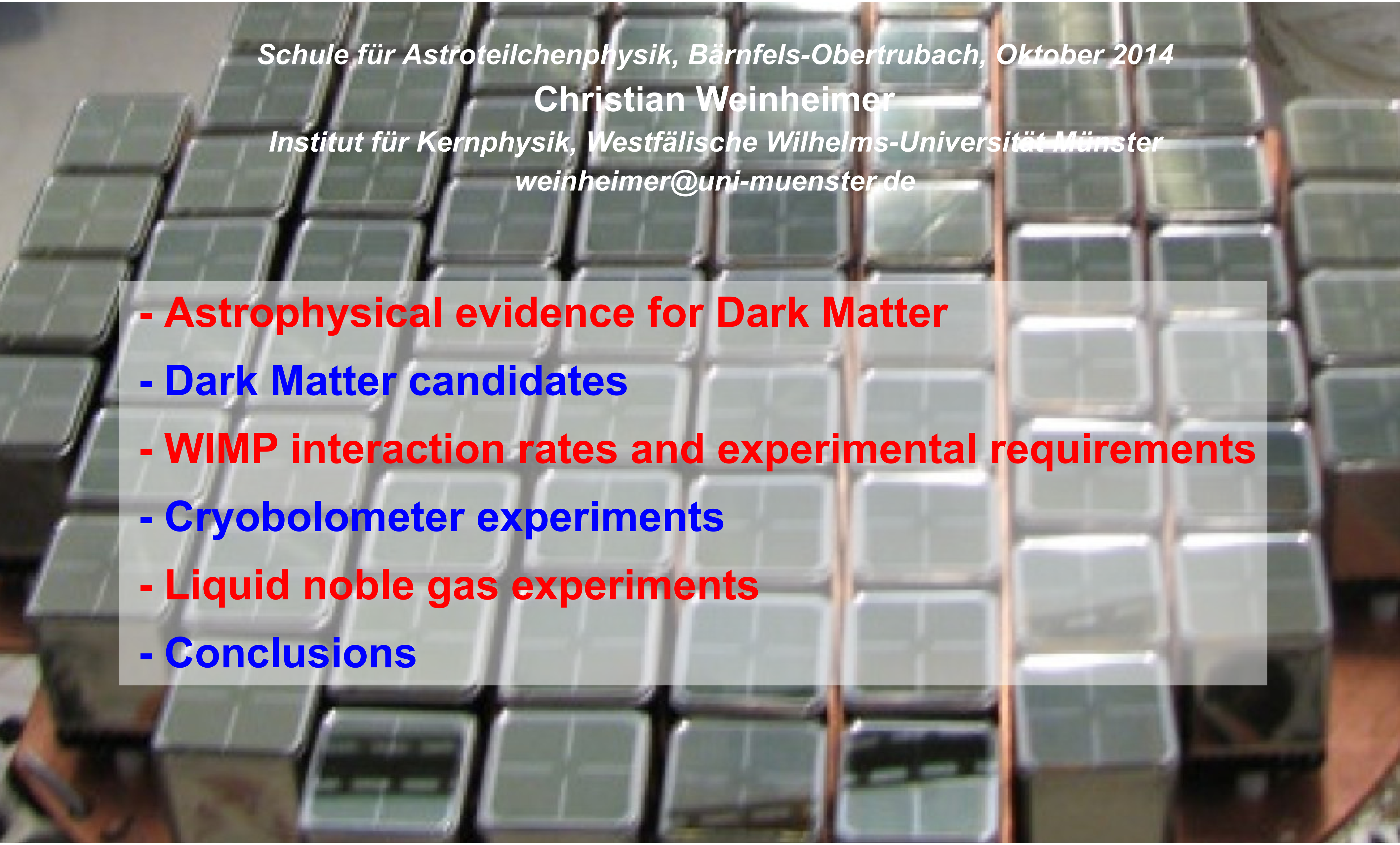
Westfälische Wilhelms-Universität Münster

Direct Search for Dark Matter



Schule für Astroteilchenphysik, Bärnfels-Obertrubach, Oktober 2014
Christian Weinheimer
Institut für Kernphysik, Westfälische Wilhelms-Universität Münster
weinheimer@uni-muenster.de

- Astrophysical evidence for Dark Matter
- Dark Matter candidates
- WIMP interaction rates and experimental requirements
- Cryobolometer experiments
- Liquid noble gas experiments
- Conclusions

Summary of 2nd lecture

Expected nuclear recoil spectrum is a feature-less exponentially falling spectrum

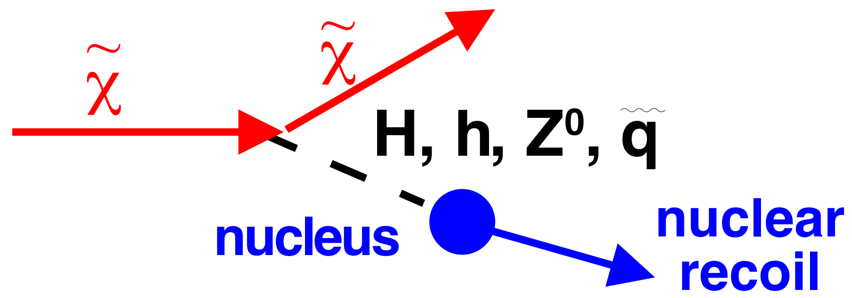
$$\frac{dR}{dE_r} = \frac{\rho_0 \cdot \sigma_0 \cdot F^2(q^2)}{2 \cdot m_{\tilde{\chi}} \cdot \mu_r{}^2} \cdot \langle \frac{1}{v} \rangle = \frac{\rho_0 \cdot \sigma_0 \cdot F^2(q^2)}{\sqrt{\pi} \cdot m_{\tilde{\chi}} \cdot \mu_r{}^2 \cdot v_0} \cdot e^{-\frac{E_r \cdot m_A}{2 \cdot \mu_r^2 \cdot v_0^2}}$$

Including earth movement around sun leads to a annual modulation of the rate and the spectrum

Require experimental threshold of O(10 keV) !

Larger nucleus mass is preferred, since scalar coherent interaction (SI) scales with A^2, but then smaller recoil energies !

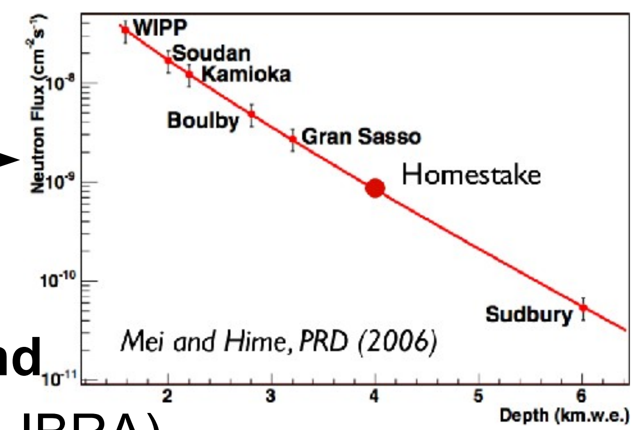
Difficulties to search for WIMPs



2 generic problems:
- **very low rate**
- **very low recoil energy**

⇒ **go underground to reduce μ\`s and $\mu$-induced n\`s**

& shielding, very clean materials, ..



⇒ **very special techniques to suppress γ, e, α background**

a) large detector mass to see annual modulation (DAMA/LIBRA)

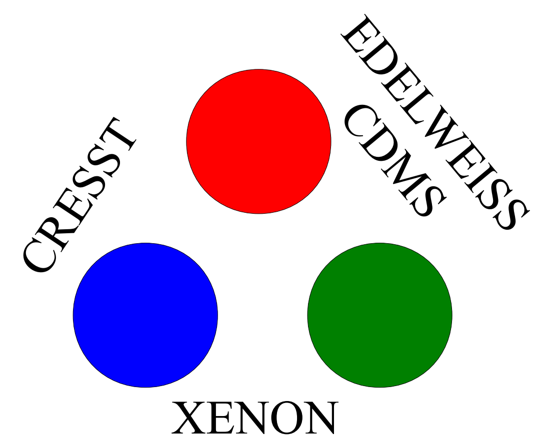
b) double read-out to distinguish nuclear recoil from others

- cryobolometers:

  heat + ionsiation or heat + light

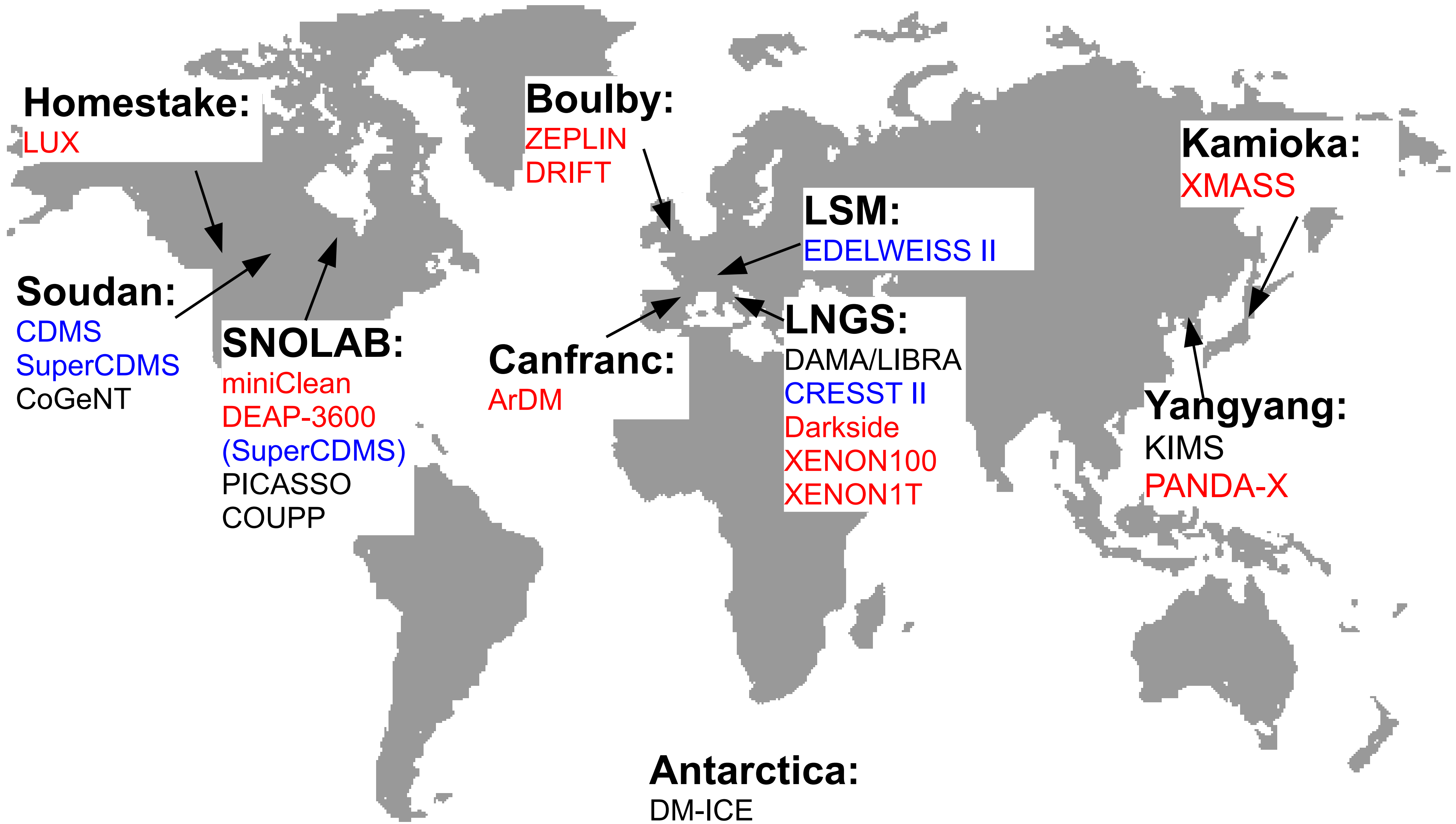
- liquid noble gas detectors:

  light + ionisation

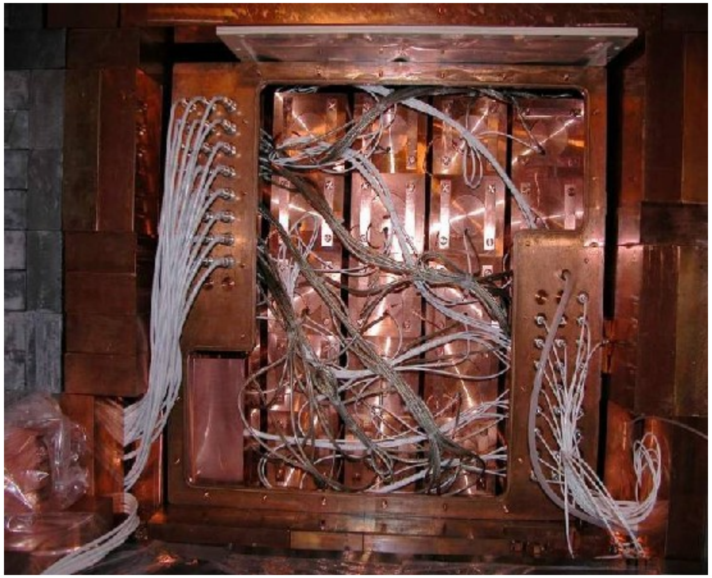


c) directional (but not enough target mass)

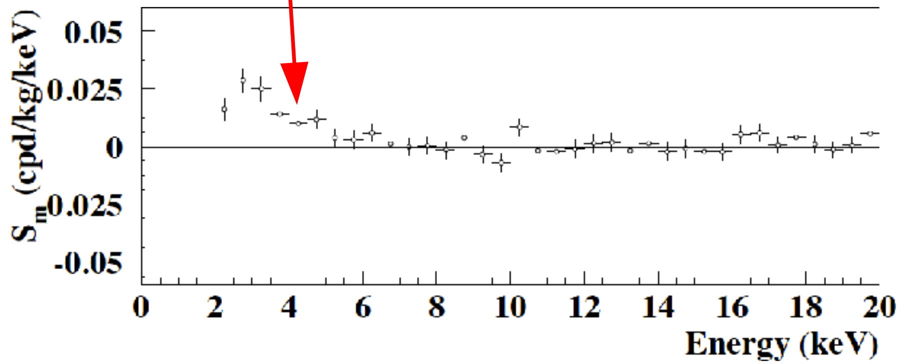
Direct Cold Dark Matter (WIMP) searches
cryo bolometer / liquid noble gases / others

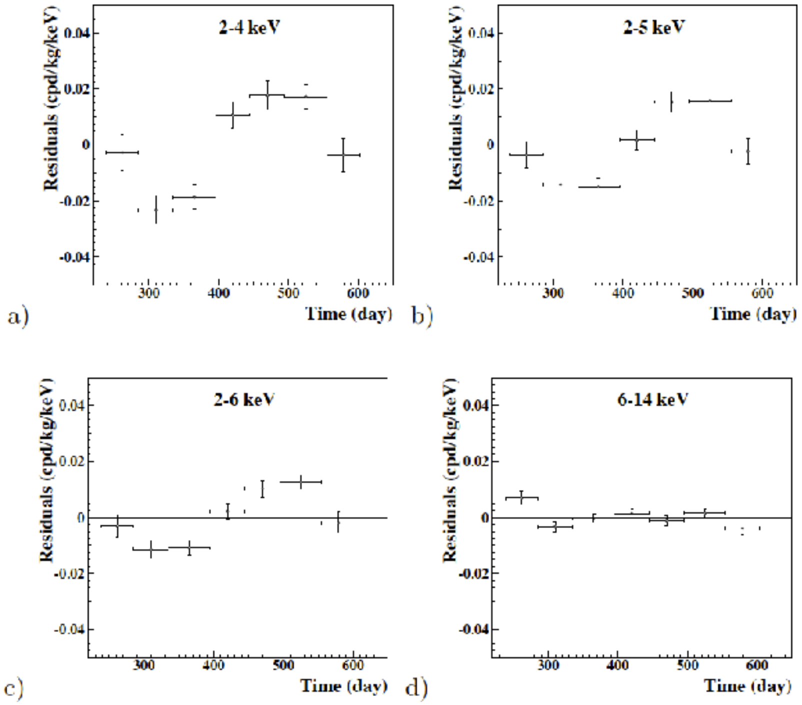


DAMA/LIBRA experiment: signal for Dark Matter ?



at LNGS / Italy, 250 kg NaI crystals
detection of scintillation light
WIMPs should show up at low energies





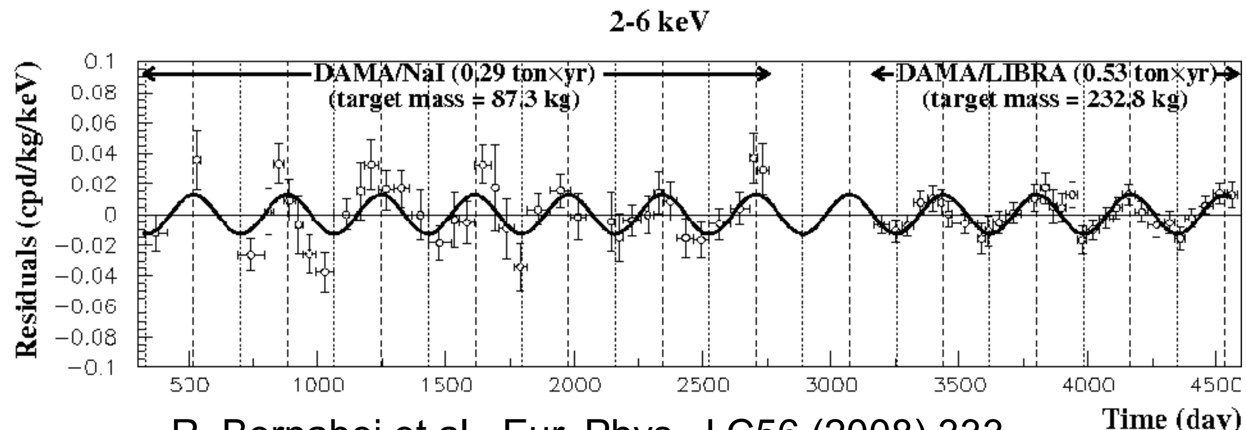
annual modulation of low energy signal !

arXiv:0804.2741

DAMA/LIBRA experiment: signal for Dark Matter ?

at LNGS / Italy
250 kg NaI crystals
detection of scintillation light

clear annual modulation signal



R. Bernabei et al., Eur. Phys. J C56 (2008) 333

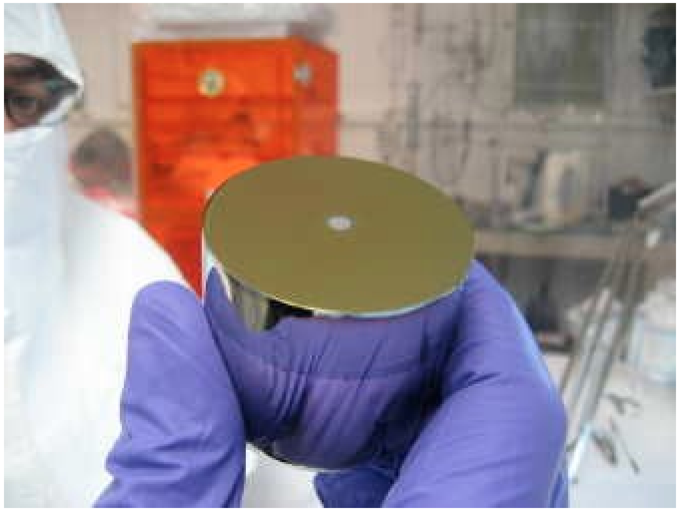
Are these really WIMPs ?

Not seen by any other experiment

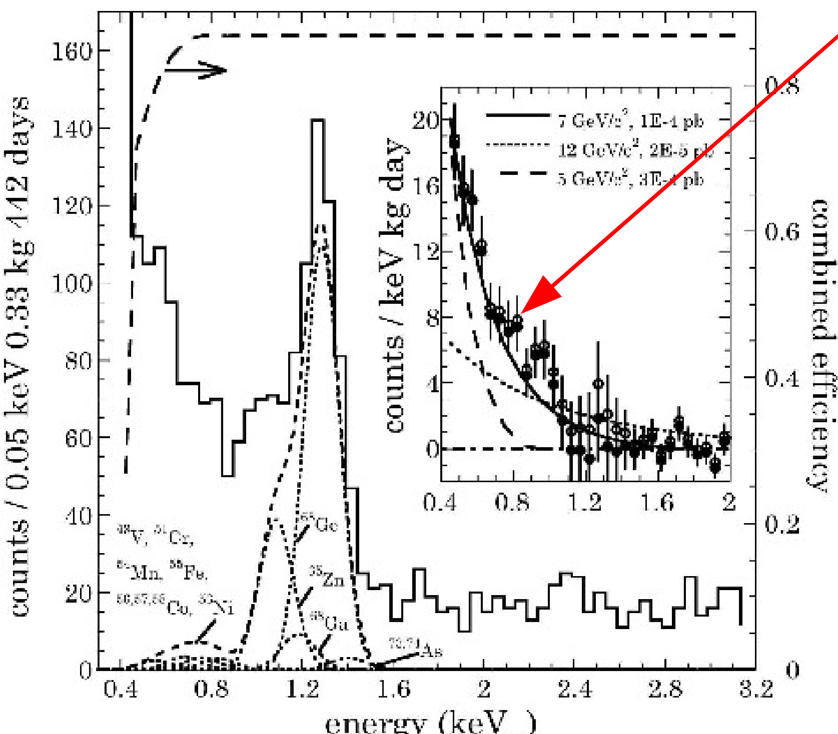
KIMS (CsI) sees no oscillation at the DAMA amplitude: a < 0.0119 cts /(d kg keV) (90% C.L.)

⇒ non-understood detector feature of DAMA/LIBRA or something very interesting and unexpected ?

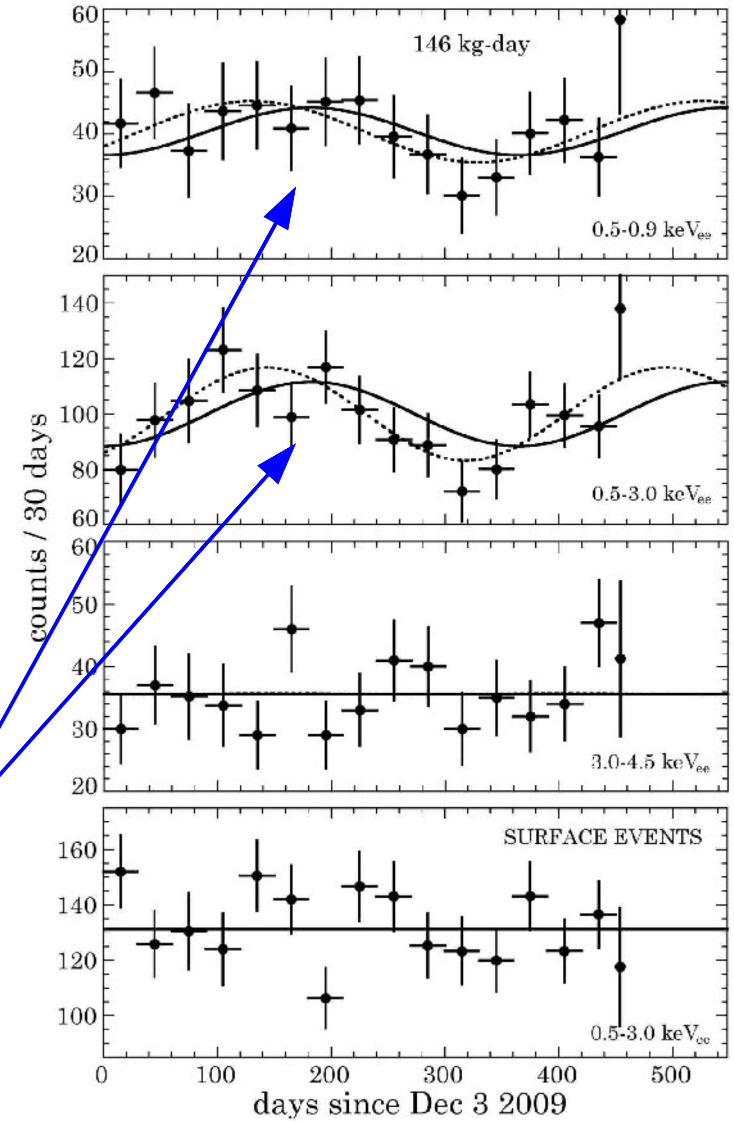
CoGeNT at Soudan mine
excess and anual modulation: low mass WIMPs ?



p-type point contact germanium detector
→ ultra-low threshold
at Soudan mine



"irreducible background"
after subtraction of lines and
flat background
→ WIMP-signal ?

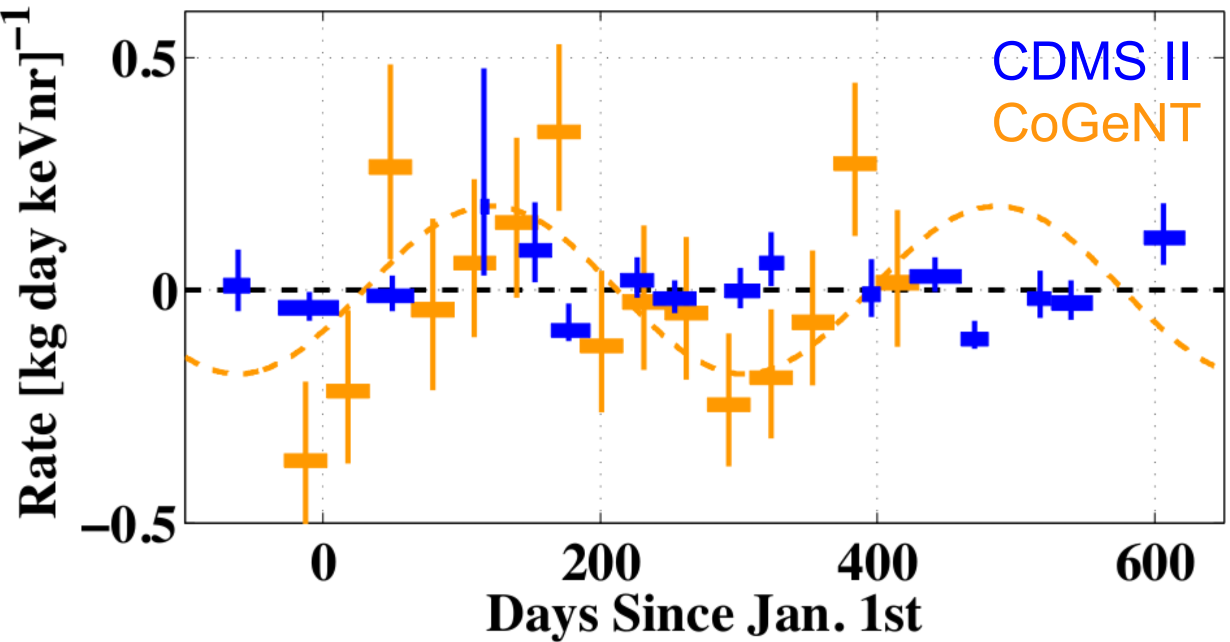


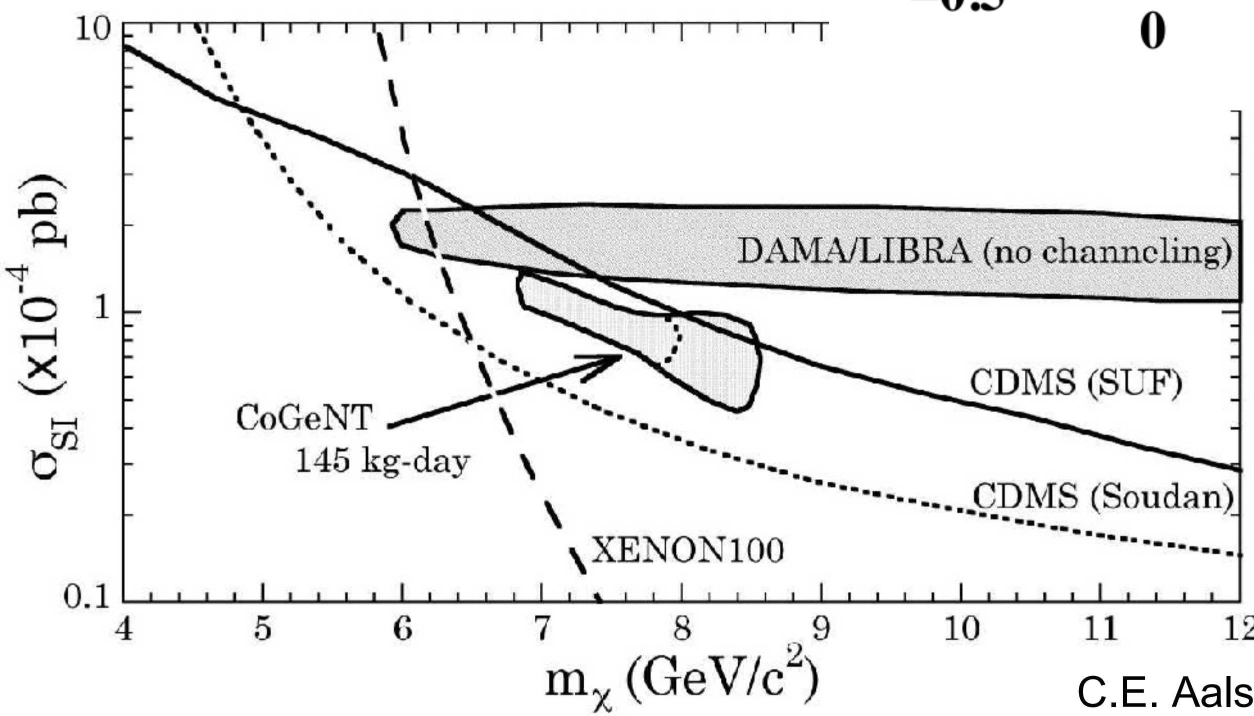
2.8 σ annual modulation
in low energy part, but
large amplitude
(> 10%)

C.E. Aalseth et al., arXiv:1106:0650

CoGeNT at Soudan mine
do low mass WIMPs fit with other experiments ?

Z. Ahmed et al., (CDMS II)
arXiv:1203.1309v1



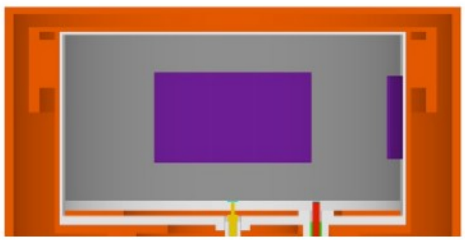


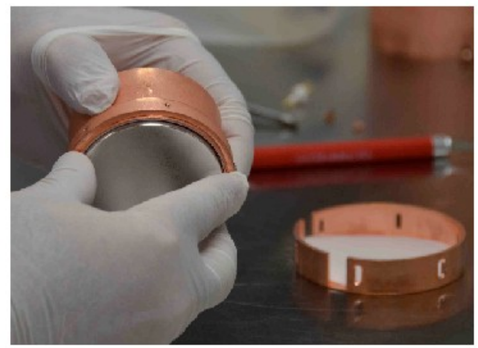
Similar to CoGeNT:
Majorana demonstrator

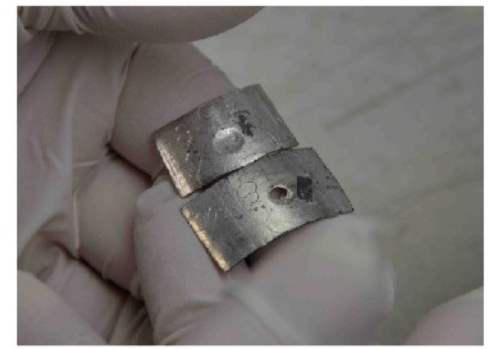
C.E. Aalseth et al., arXiv:1106:0650

MALBEK point contact Ge detector underground from MAJORANA

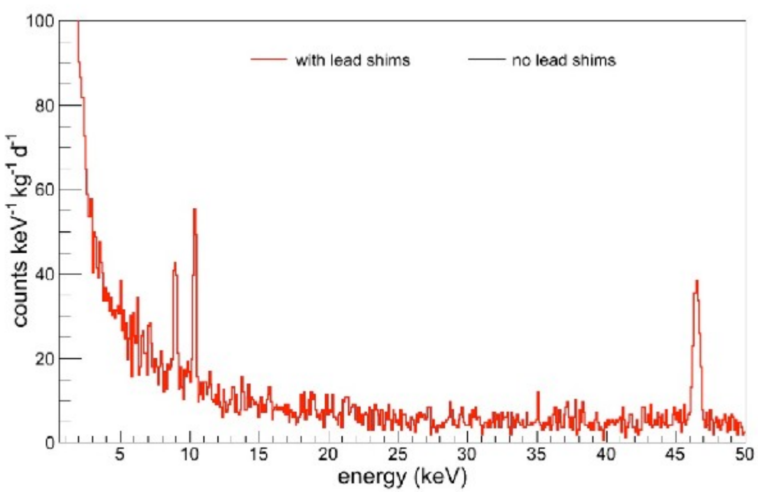
MALBEK Spectra Before/After



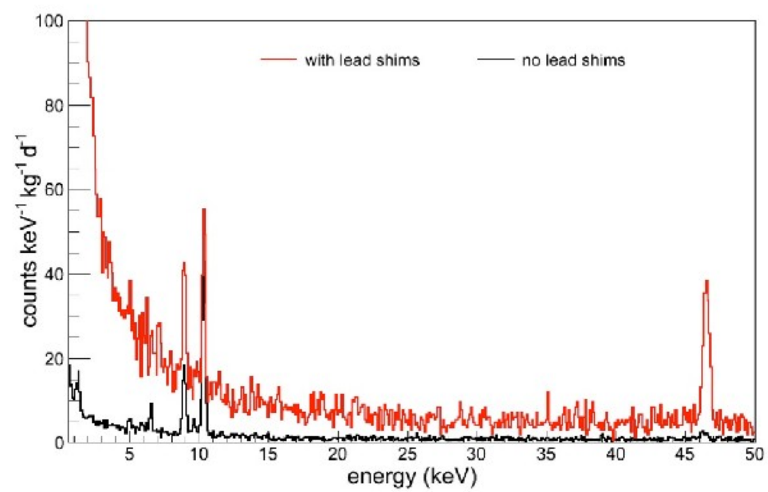




with lead shims



without lead shims



P. Finnerty, UNC, Thesis 2013

Perspectives on Fundamental Symmetries and Neutrinos Symposium

Sept. 7, 2013

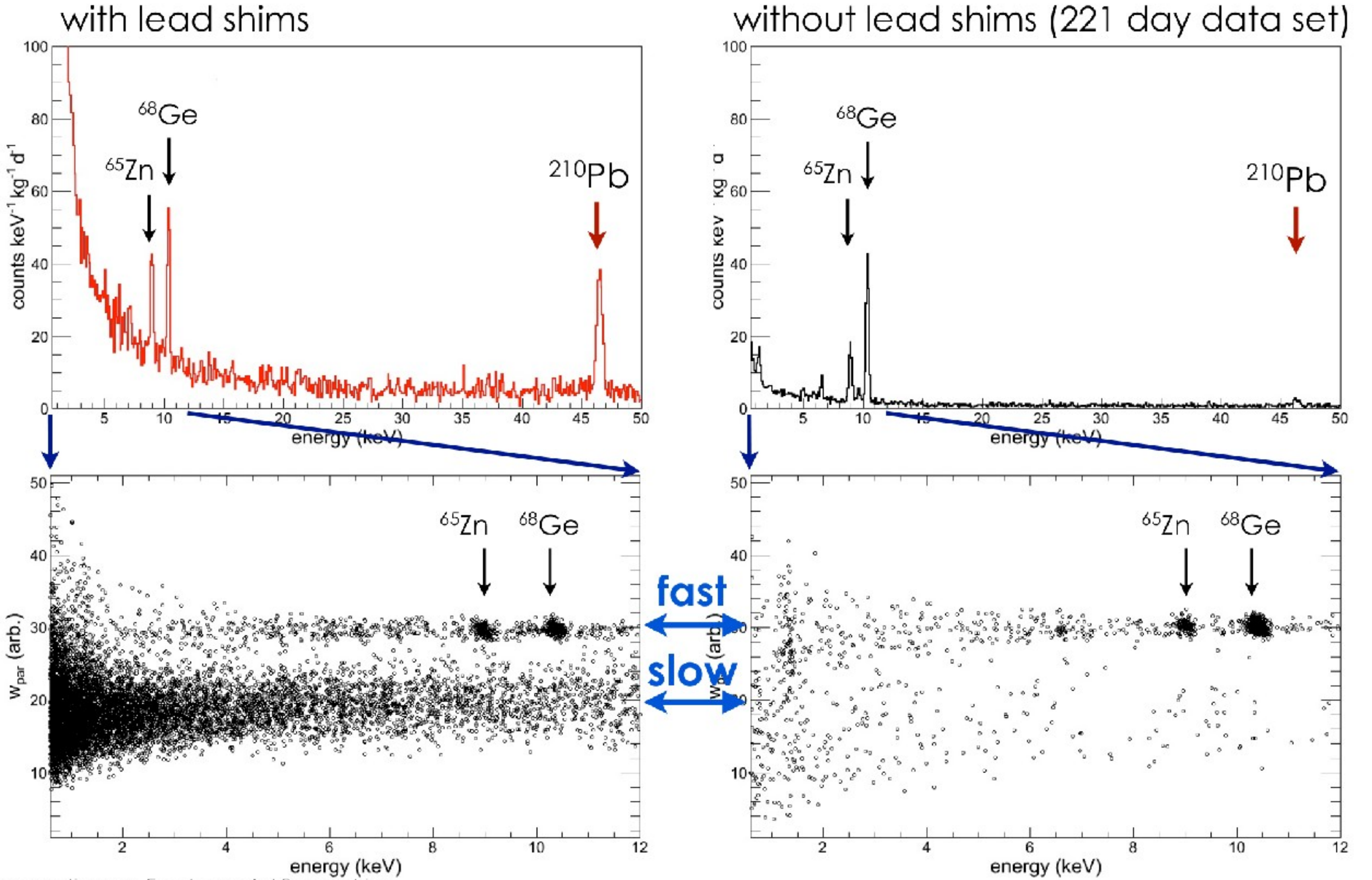
19

JFW Wilkerson, Symposium Perspectives on Fundamental Symmetries and Neutrinos, Sept. 2013

Westfälische Wilhelms-Universität Münster

MALBEK sees background compenent with different rise time

an inadvertent slow pulse source



Perspectives on Fundamental Symmetries and Neutrinos Symposium

Sept. 7, 2013

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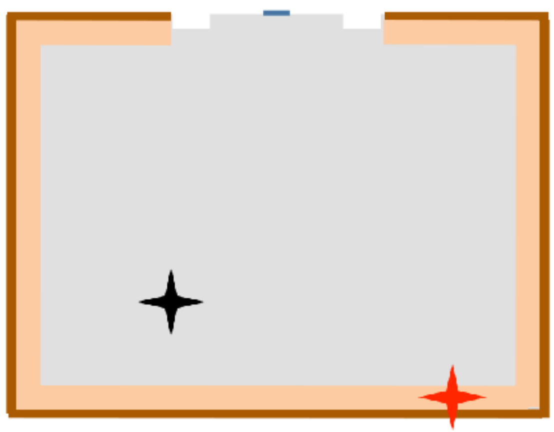
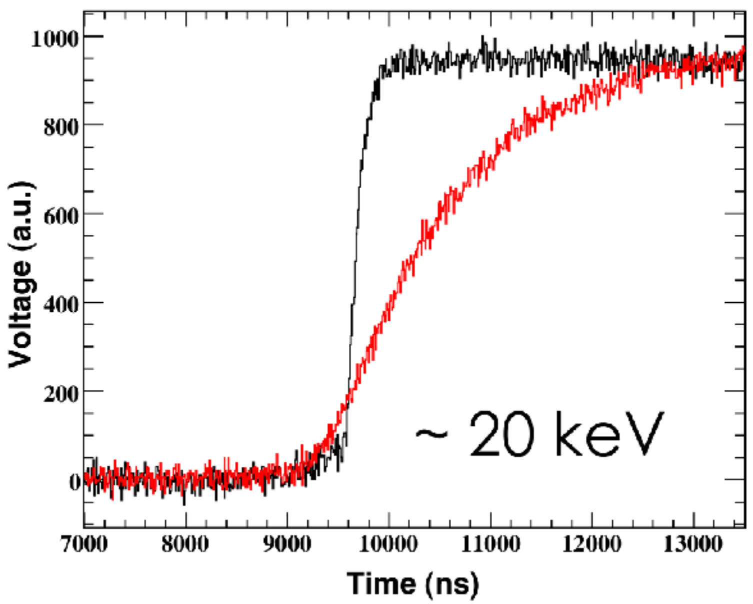
JFW Wilkerson, Symposium Perspectives on Fundamental Symmetries and Neutrinos, Sept. 2013

Events in the transition region between detector and dead layer

slow surface events





- active volume
- n+ dead layer
- transition region – partial charge collection

"Characteristics of signals originating near the lithium-diffused N+ contact of high purity germanium p-type point contact detectors", E. Aguayo *et al.* (MAJORANA Collaboration), *Nucl. Instr. and Methods A* **701** 176 (2013).

Perspectives on Fundamental Symmetries and Neutrinos Symposium

Sept. 7, 2013

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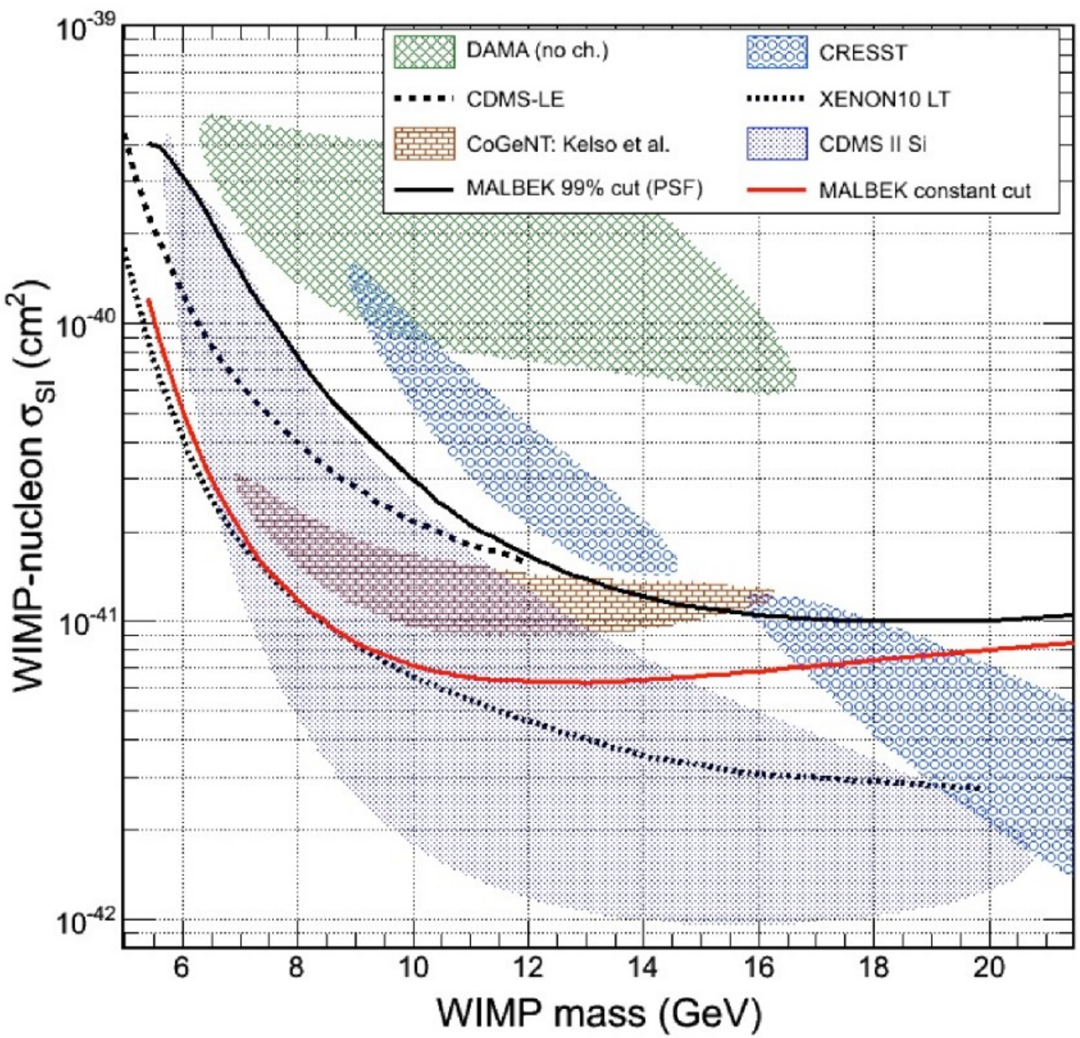
JFW Wilkerson, Symposium Perspectives on Fundamental Symmetries and Neutrinos, Sept. 2013

MALBEK excludes the CoGeNT signal

90% exclusions from 221 day



Perspectives on Fu
and Neutrinos Symposium

Sept. 7, 2013

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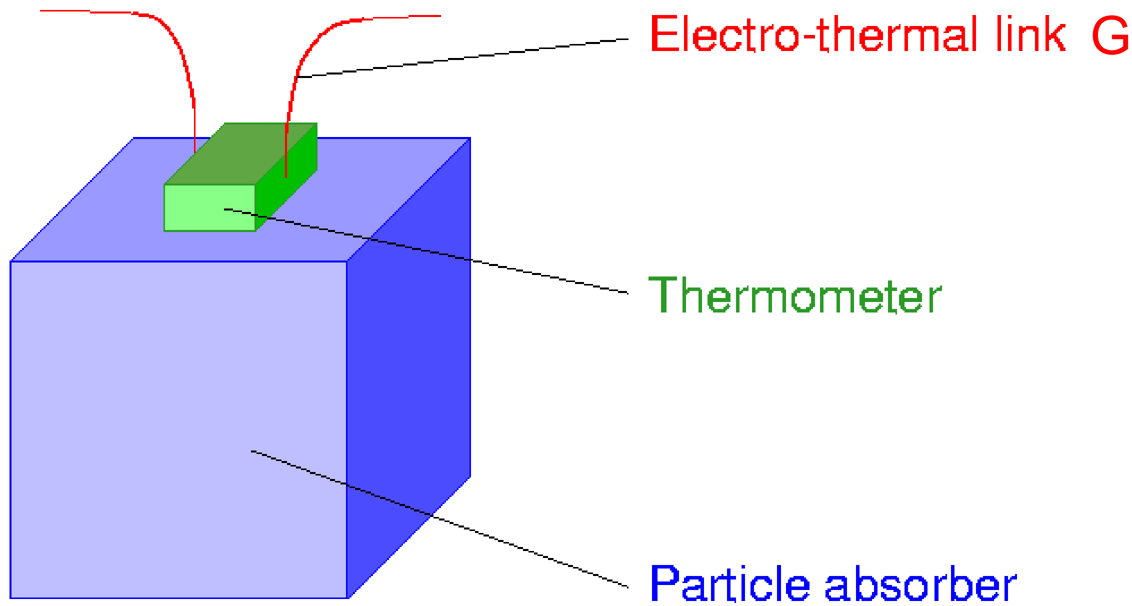
JFW Wilkerson, Symposium Perspectives on Fundamental Symmetries and Neutrinos, Sept. 2013

Cryocalorimeter / cryobolometer

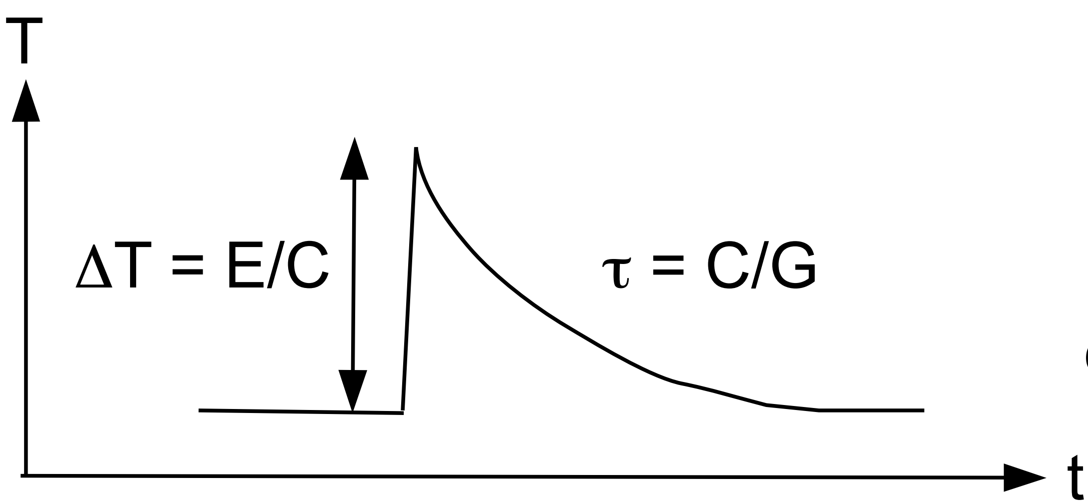


$\Delta T = \Delta E / C$

Debye:
$C \sim (T/\theta)^3$

irreducibal thermal fluctuations:
$< \Delta E^2 > = k_B T^2 C$

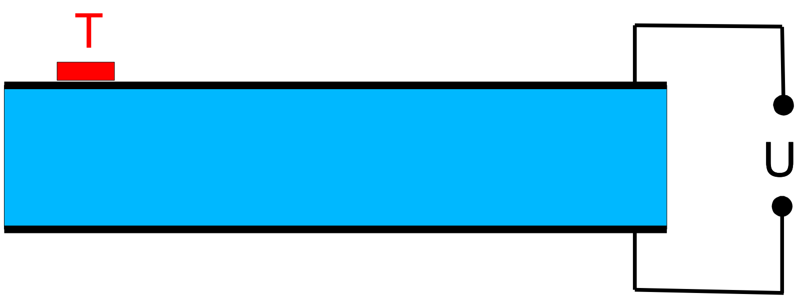
$\rightarrow T = O(mK)$



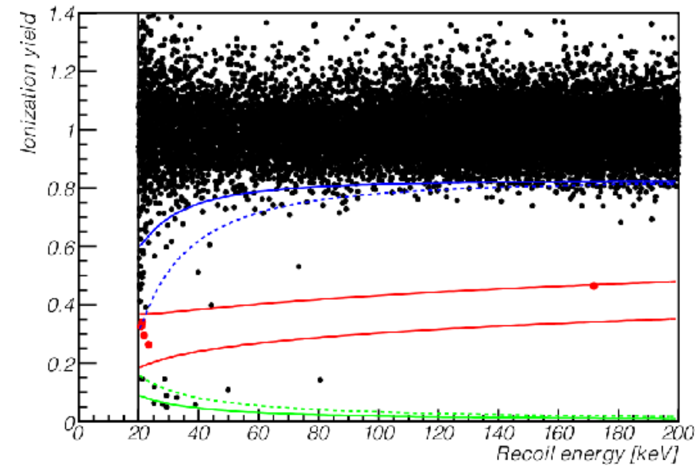
rise time typically several μs
decay time typically ms

Cryo bolometers for WIMP search

Dual read-out:
heat (thermal + athermal phonons)
+ ionisation
Super-CDMS, EDELWEISS, ...

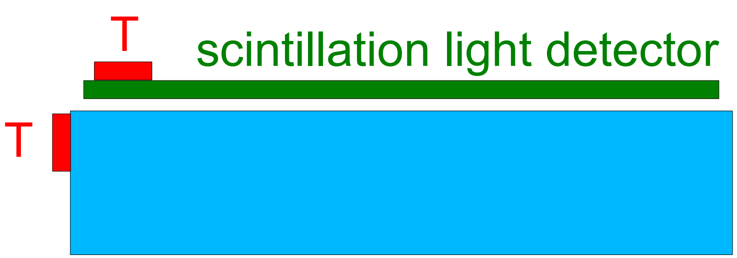


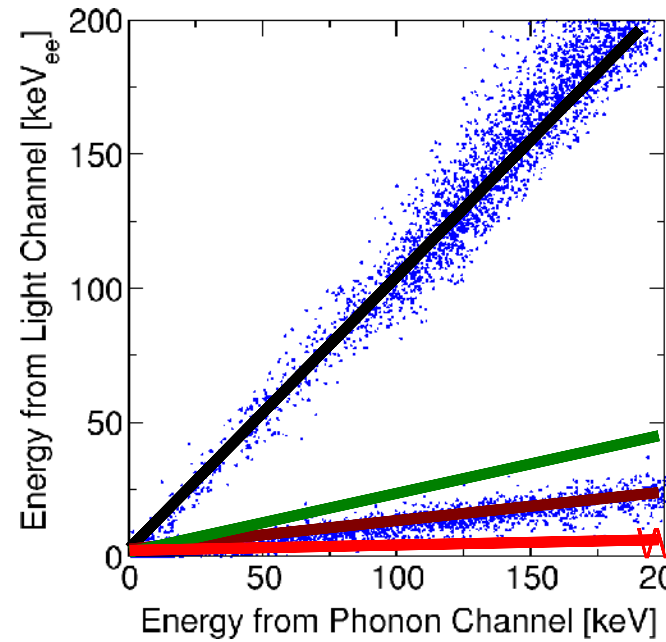
Nuclear recoil – electronic recoil separation:



EDELWEISS

Dual read-out:
heat (thermal + athermal phonons)
+ scintillation light
CRESST, AMORE, ...





e,γ LY=1

CRESST

α LY=1/5

O recoils LY=1/10

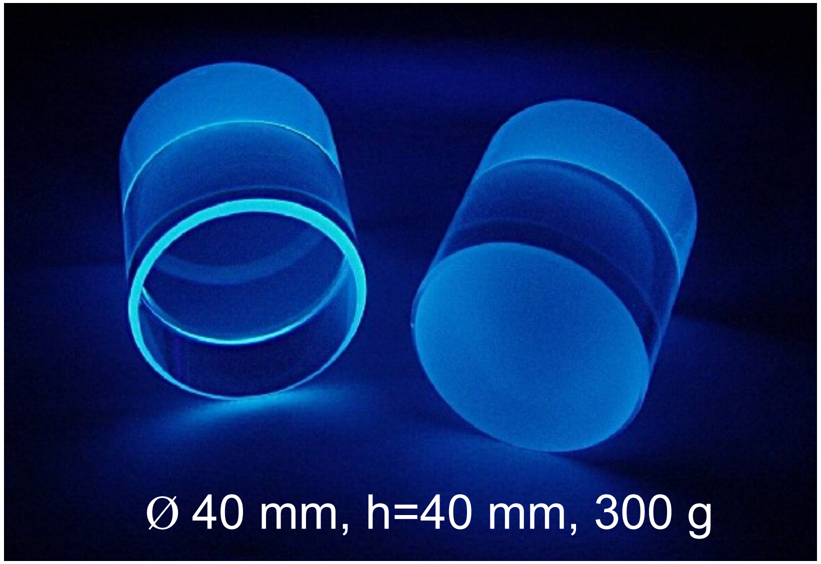
W recoils LY=1/40

CRESST II

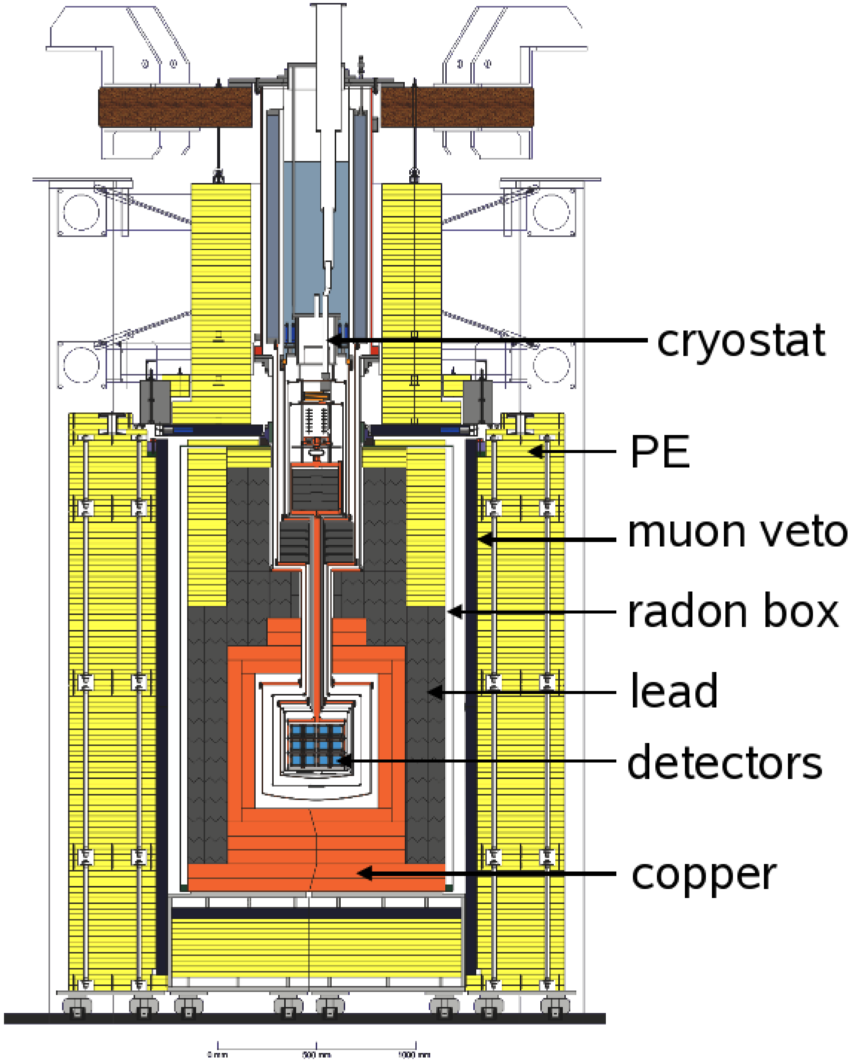
Collaboration: MPIPH Munich, TU Munich, U Tübingen, (U Oxford/UK), LNGS/Italy

located in Gran Sasso underground laboratory LNGS

Detectors: 10 cryobolometers $CaWO_4$ of 400g
(shielded cryostat can house 33)
with heat (thermal phonons) and light readout



J. Schmaler, LTD Stanford, July 2009

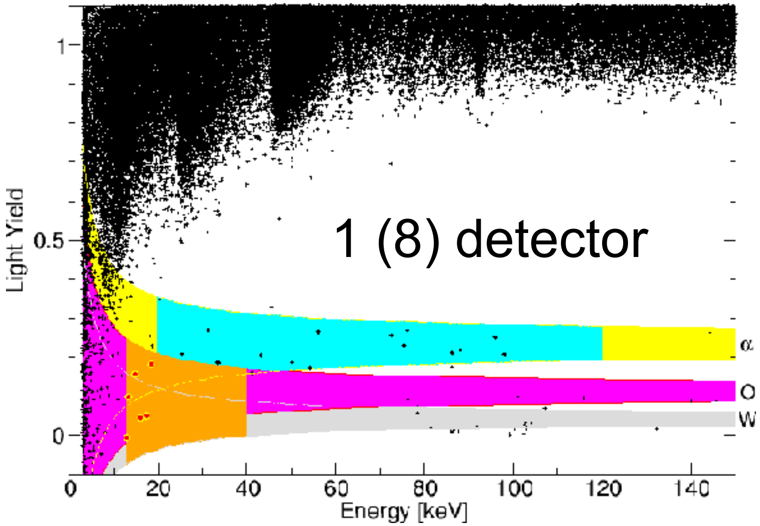


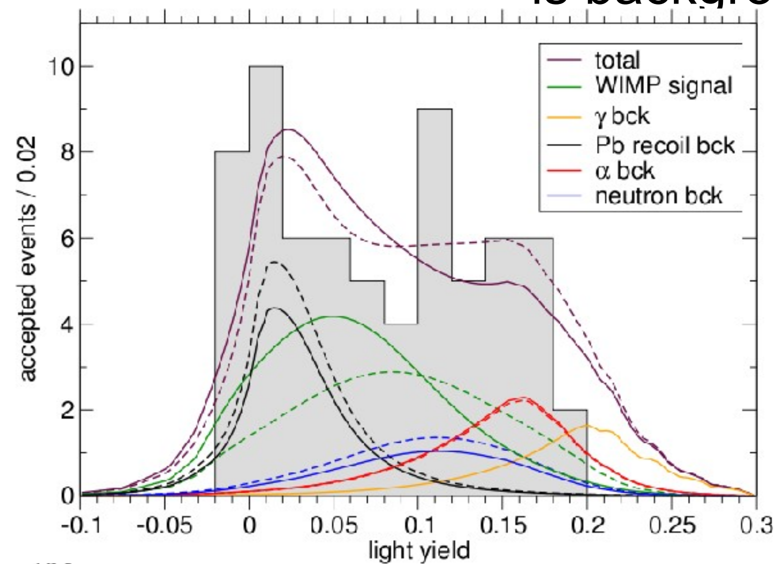
CRESST II – excess of events low mass WIMPs ?

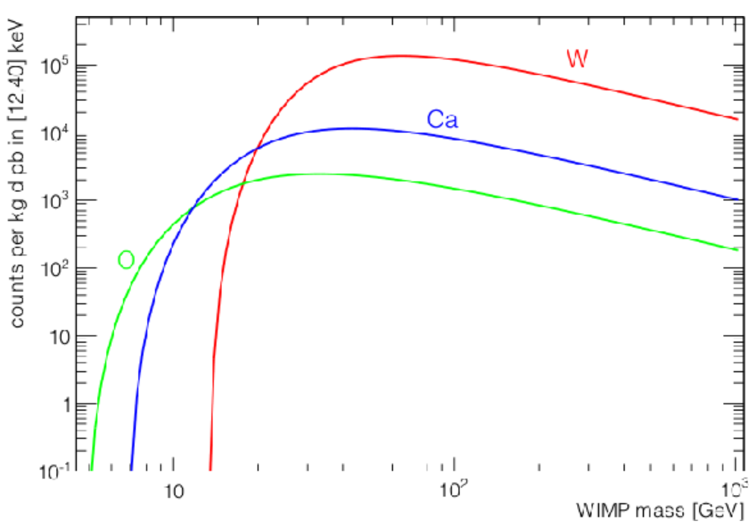
WESTFÄLISCHE WILHELMS-UNIVERSITÄT MÜNSTER

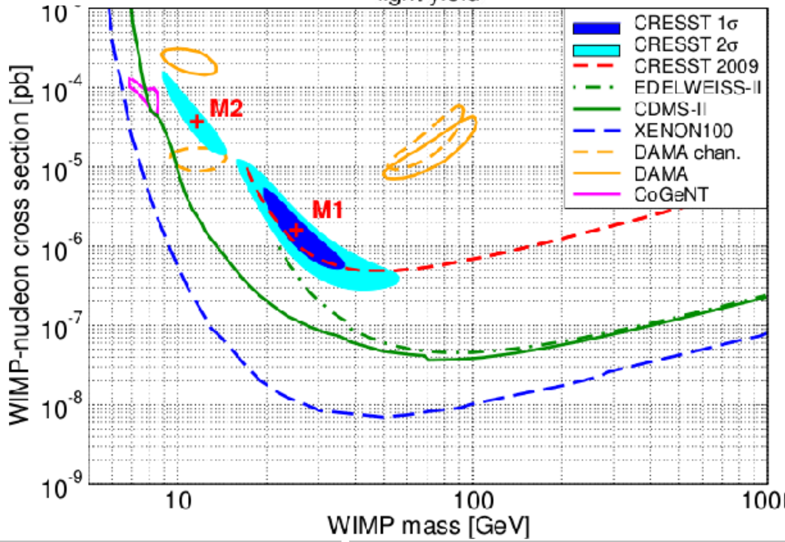
8 detectors, in total 730 kg d: 67 events in signal region
→ background is leaking into the signal region → max likelihood fit → ½ of candidates is background

G. Angloher et al., arXiv:1109.0702





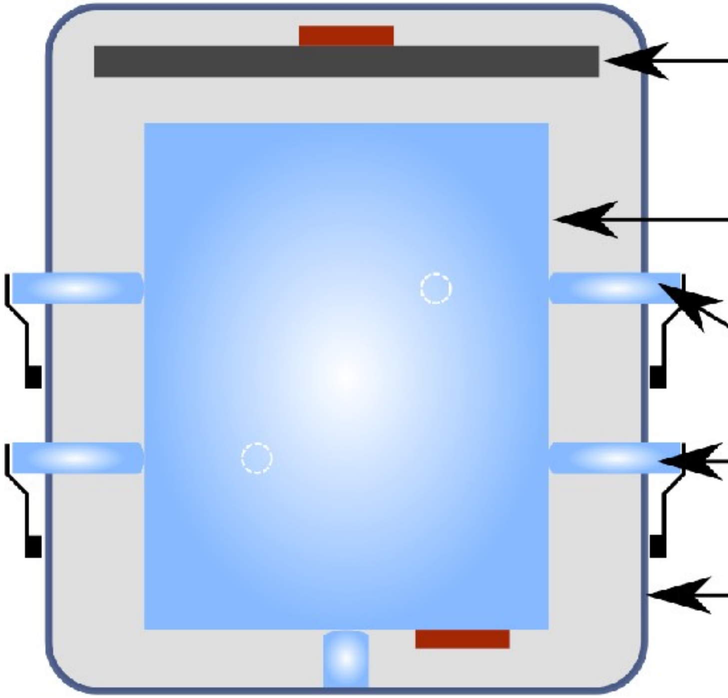




CRESST II – new detector design avoids camps near detector

CRESST-II Phase 2

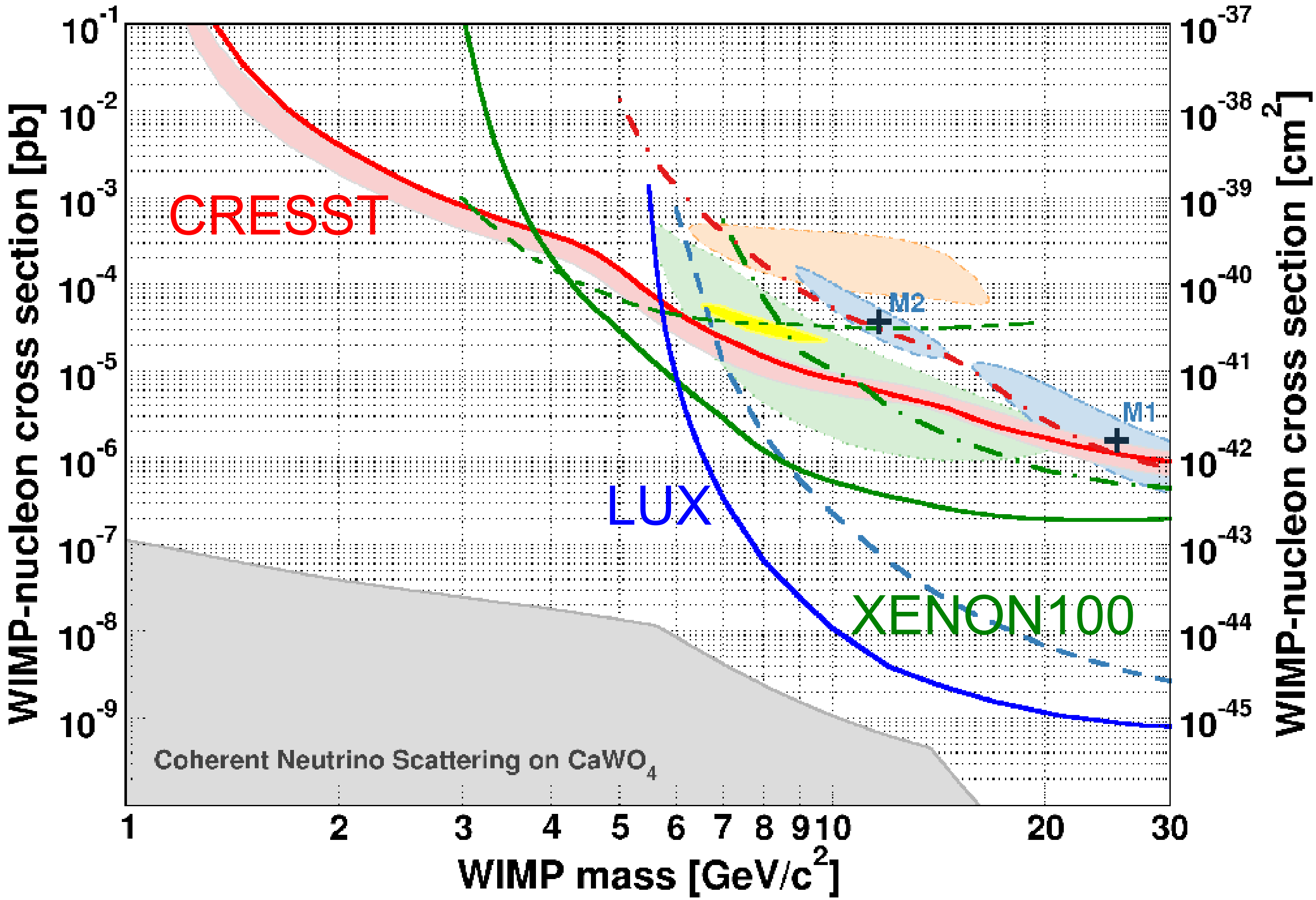
Novel fully-scintillating detector design



→ Highly-efficient rejection of surface-alpha backgrounds!

Raimund Strauss, MPI Munich

CRESST II
new low mass WIMP exclusion



arXiv:1407.3146

EDELWEISS II

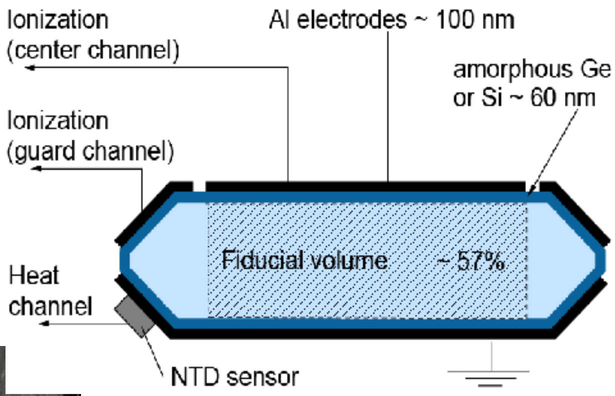
Collaboration: 5 institutions from France, JINR/Russia, U Oxford/UK, KIT

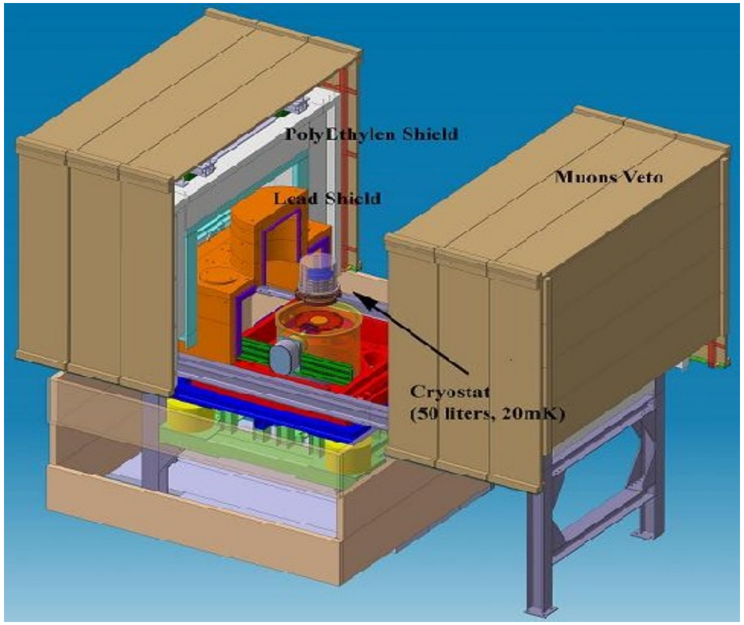
located in Modane underground laboratory LSM

Detectors: 10 cryobolometers Ge of 400g (166g fiducial)

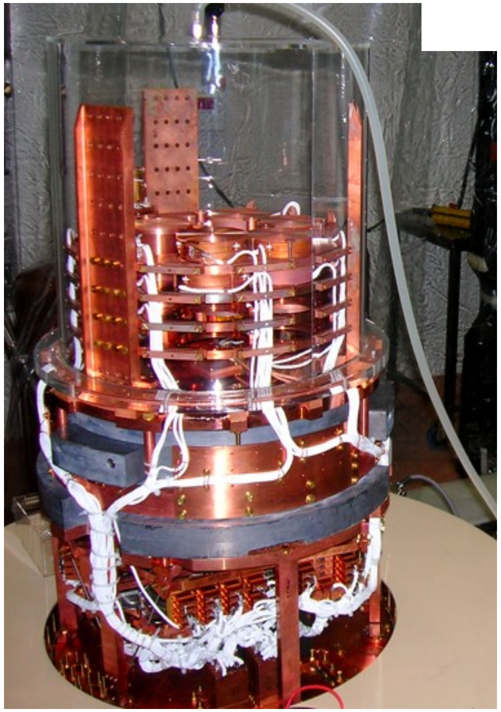
with heat (NTD sensor) and ionisation readout

shielded cryostat with active μ-veto





E. Armengaud, Colliquium APC, Feb 2010

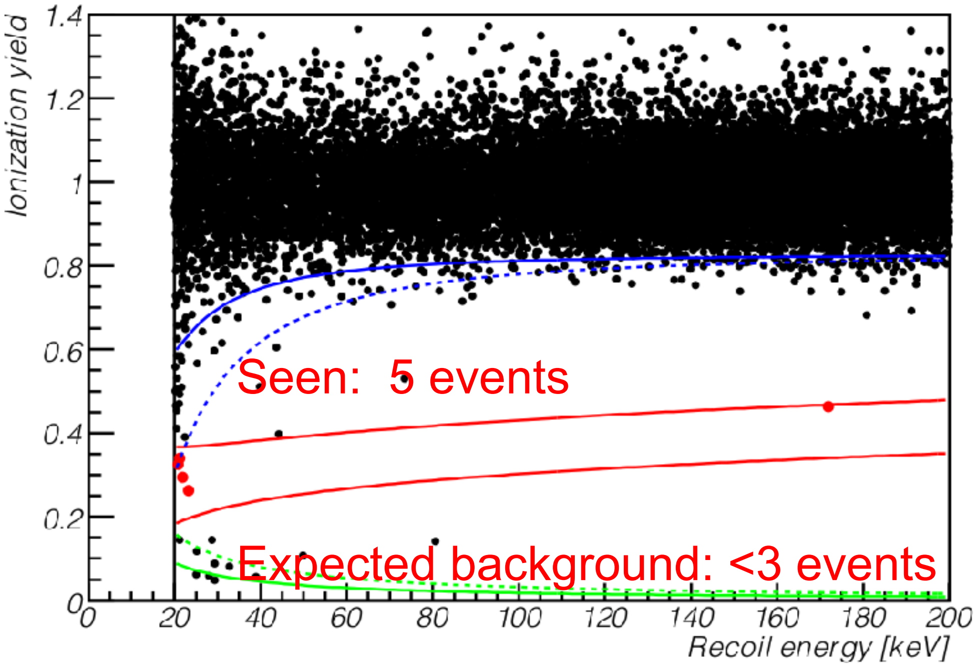


Idea: measure ioniszation and heat: temperature rise ΔT caused by energy release ΔE:

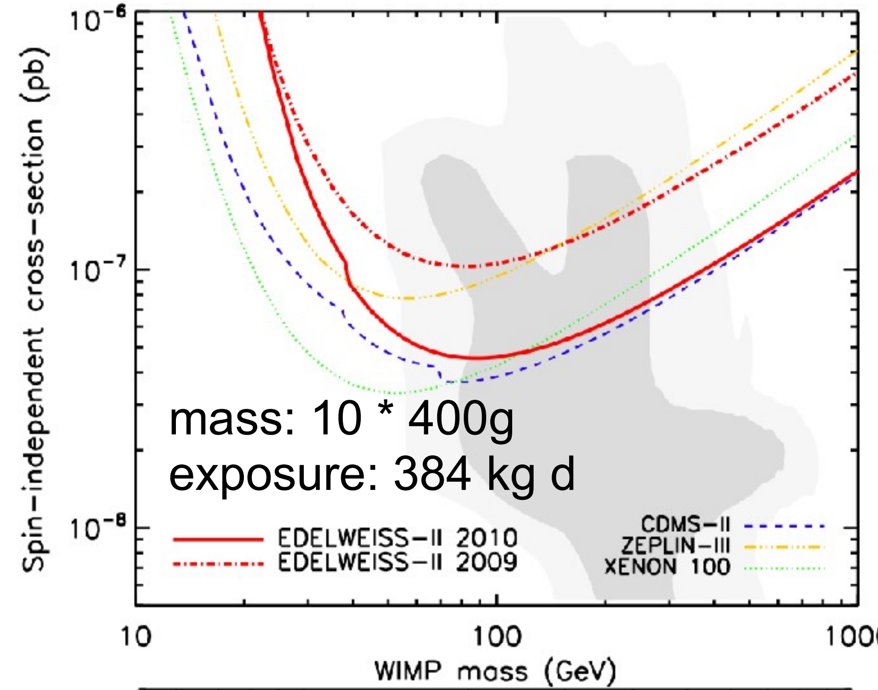
$\Delta T = \Delta E / C$

→ require small $C \sim (T/\Theta_D)^3$

EDELWEISS II: results

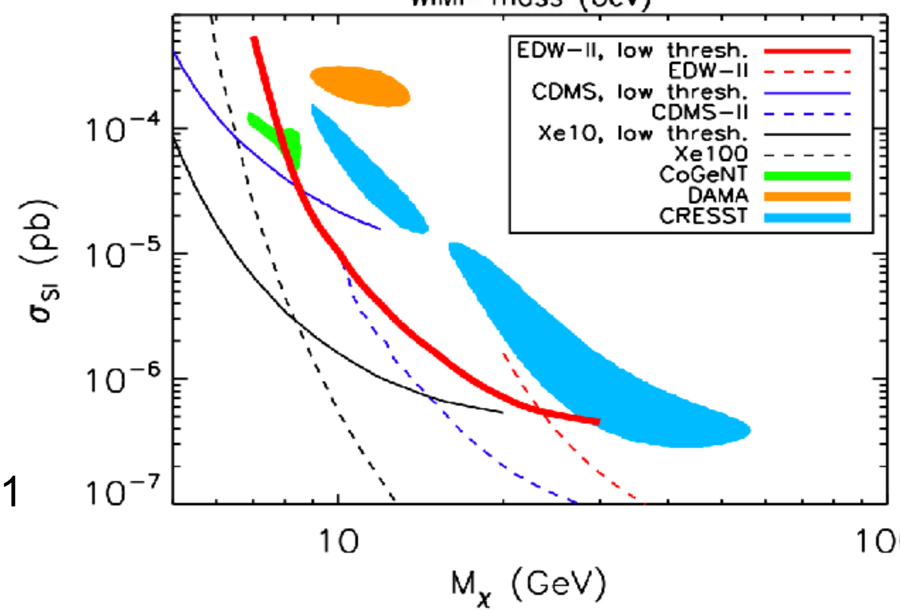


E. Armengaud et al.,
Phys.Lett. B702 (2011) 329



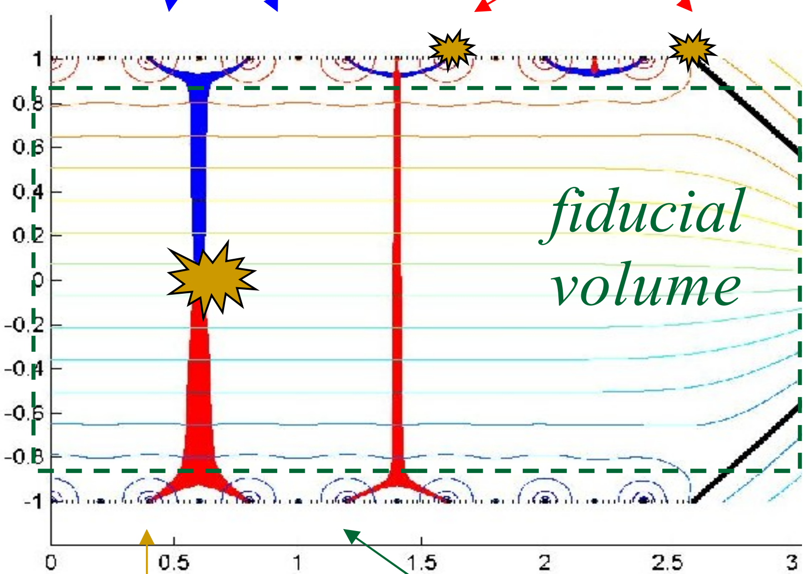
EDELWEISS II
low threshold:

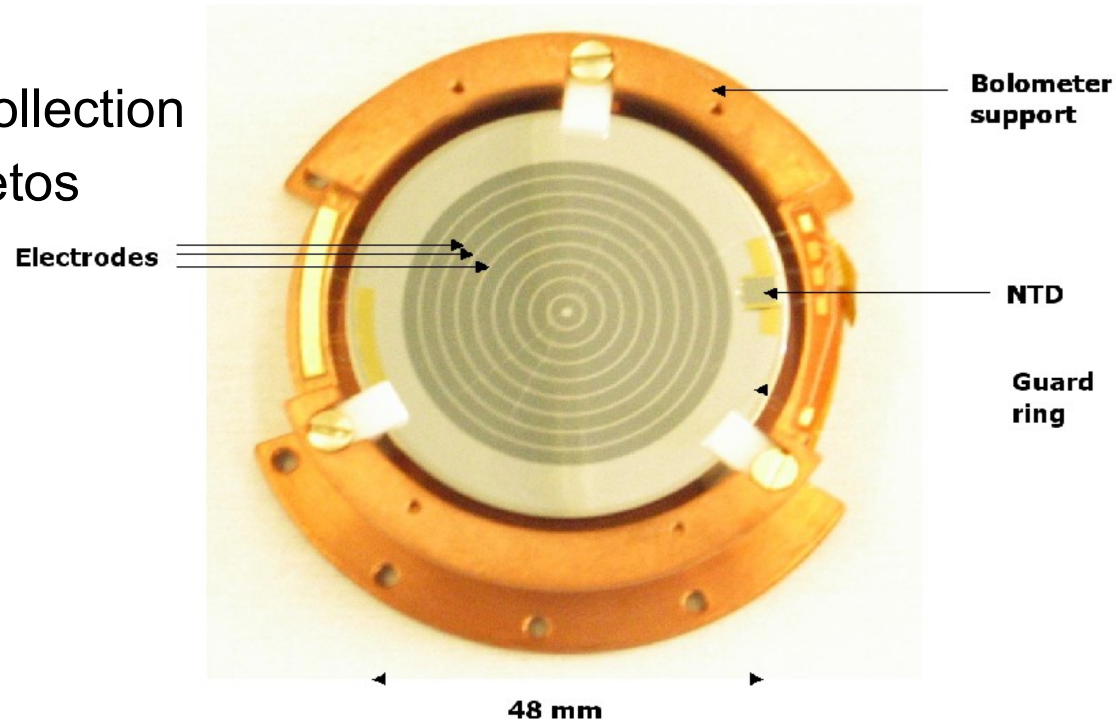
E. Armengaud et al.,
Phys.Rev. D86 (2012) 051



Rejecting surface events with interleaved electrodes

Near surfaces:
Transversal E field to suppress charge collection to other side, use 'b' and 'd' signals as vetos without changing bulk field





First detector built 2007
1x200g + 3x400g tested in 2008
10x400g running since beginning 2009

E. Armengaud, Colliquium APC, Feb 2010

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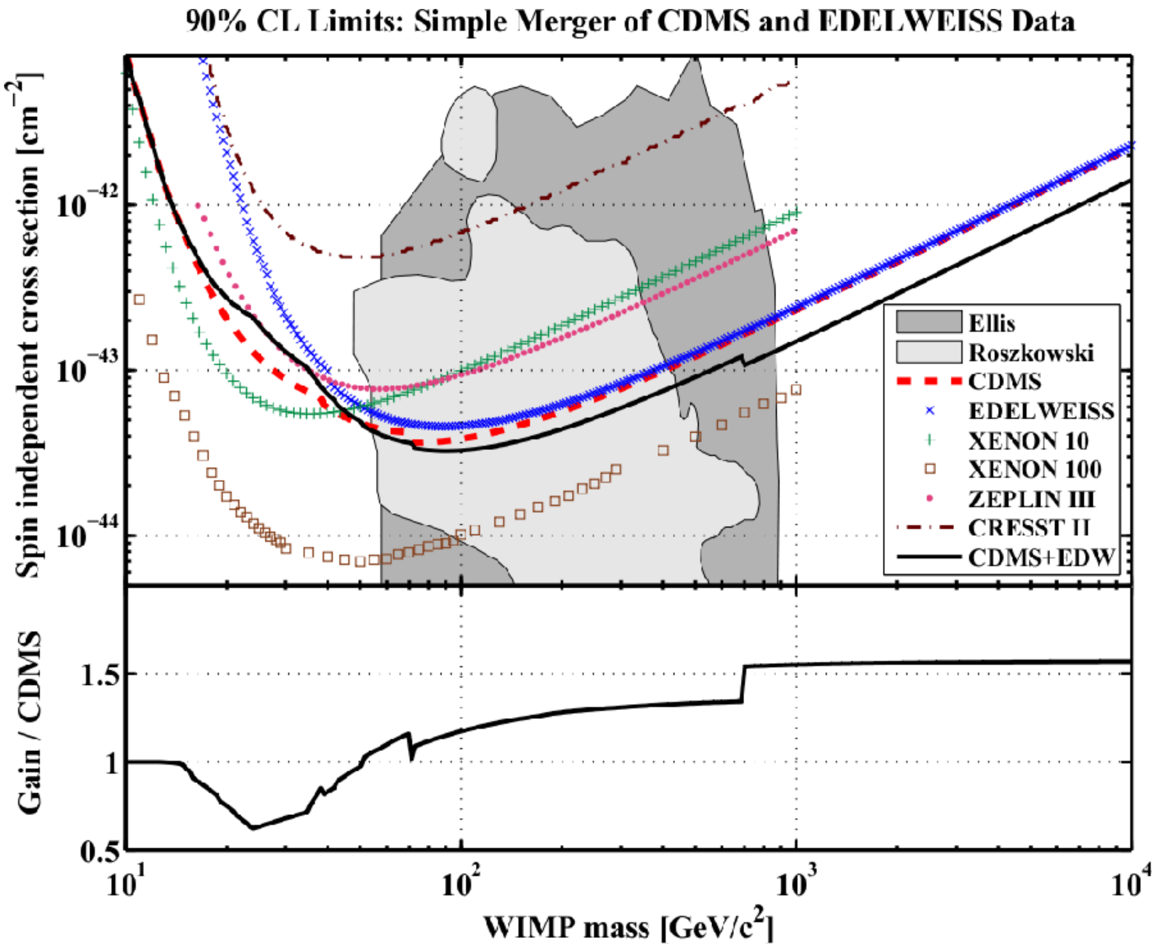
Common exclusion plot from CDMS and EDELWEISS



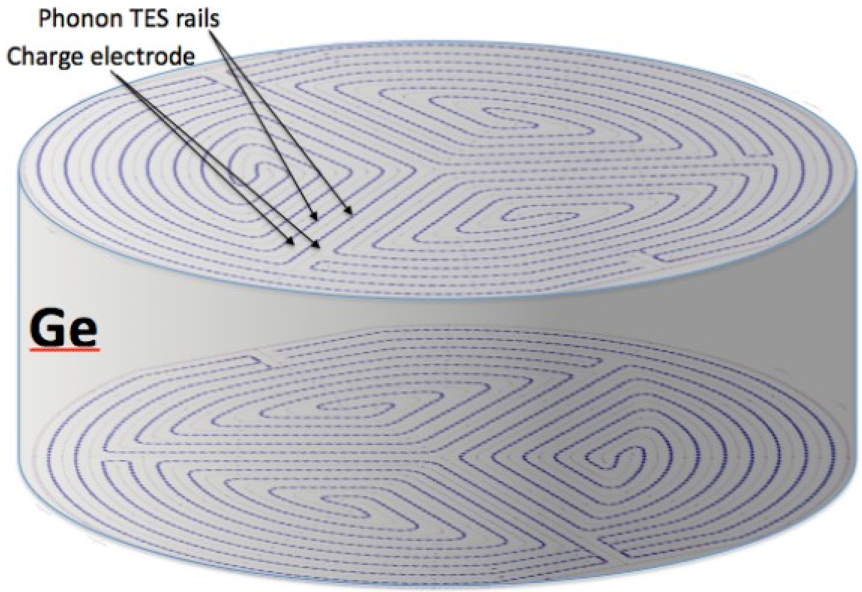
Z. Ahmed et al., Phys.Rev. D84 (2011) 011102

EDELWEISS 3: 14 FIDs in Febuary 2013
40 FIDs in summer/automn 2013
→ 3000 kg days in winter 2013/14

Super-CDMS

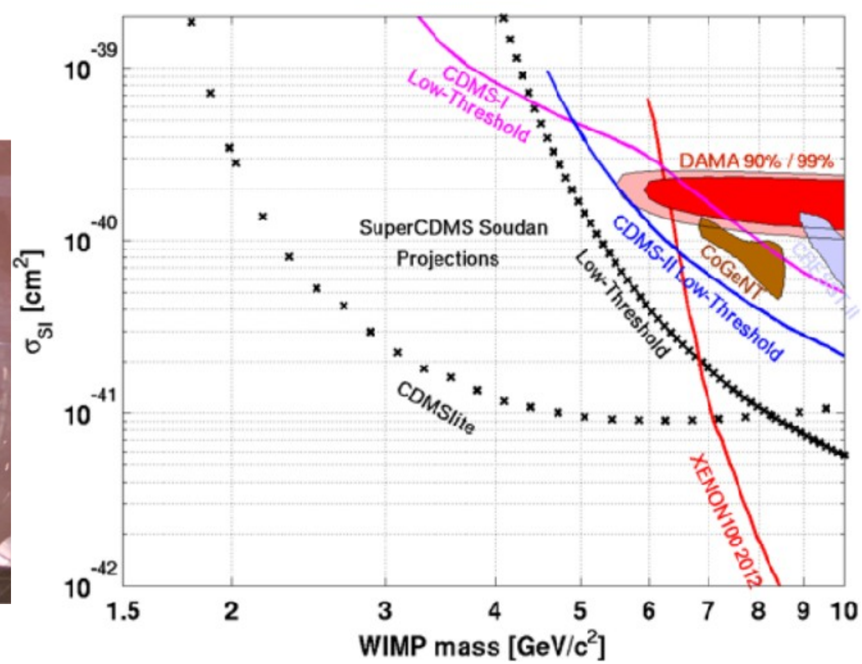
located in Soudan underground mine

- 15 iZIP-detectors, 10 kg in total:
  differentiate bulk signal from surface bg
- 170 live days collected
- aim: sensitivity $\sigma_{SI} = 2\ 10^{-45}\ cm^2$

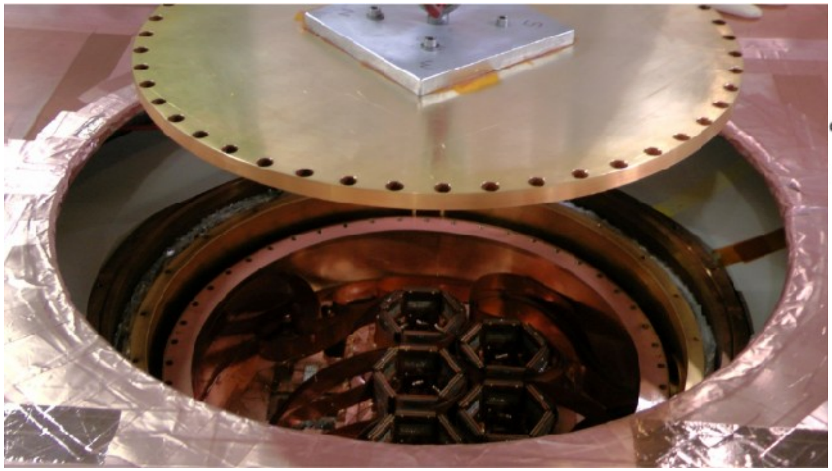


New technology for very low mass WIMPs:

- Neganov-Luke-amplification:
  phonon due to charge propagation



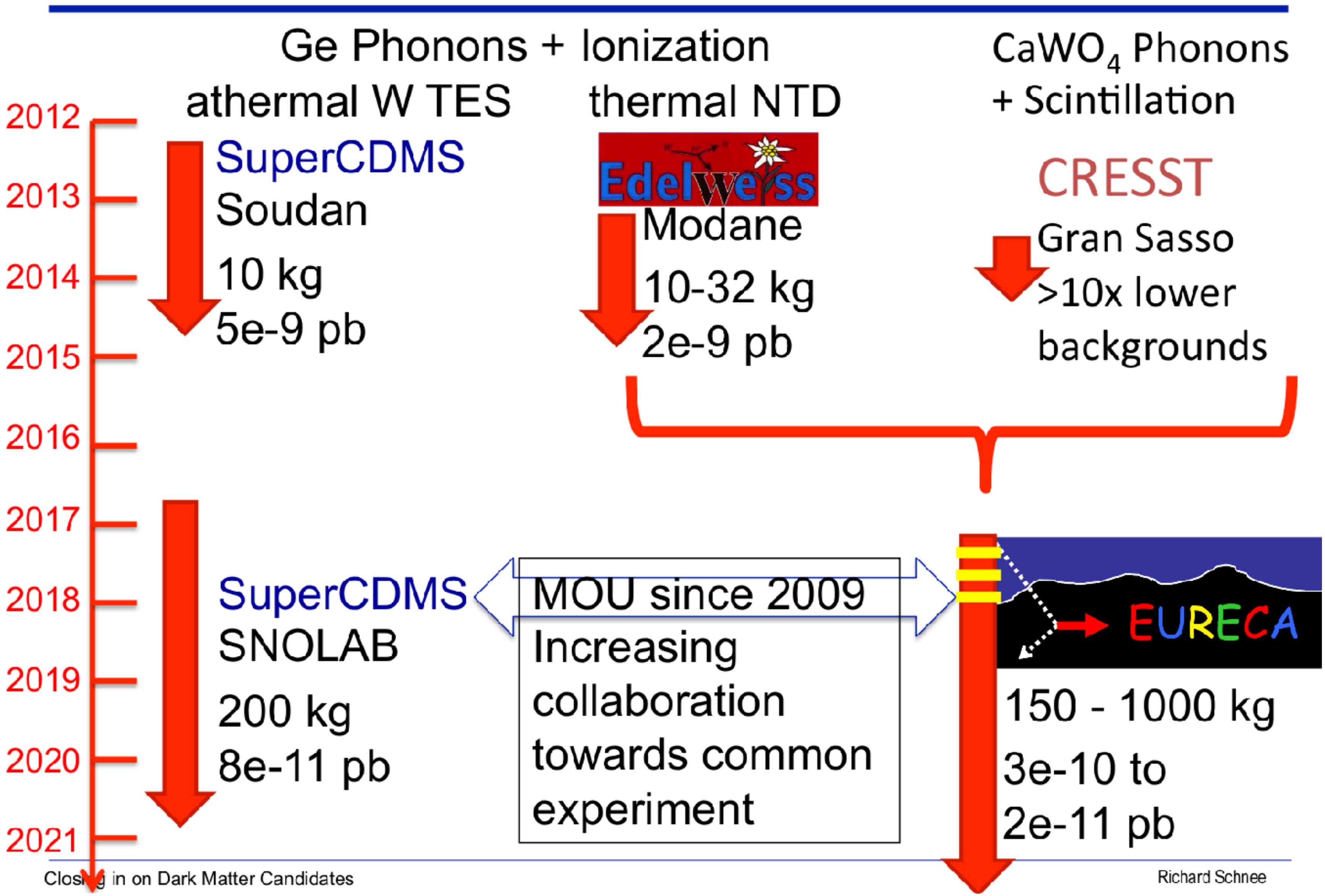
Future plans:



- 200 kg in SNOLab
- $\sigma_{SI} = 8\ 10^{-47}\ cm^2$

Future of cryo-bolometers in direct dark matter search

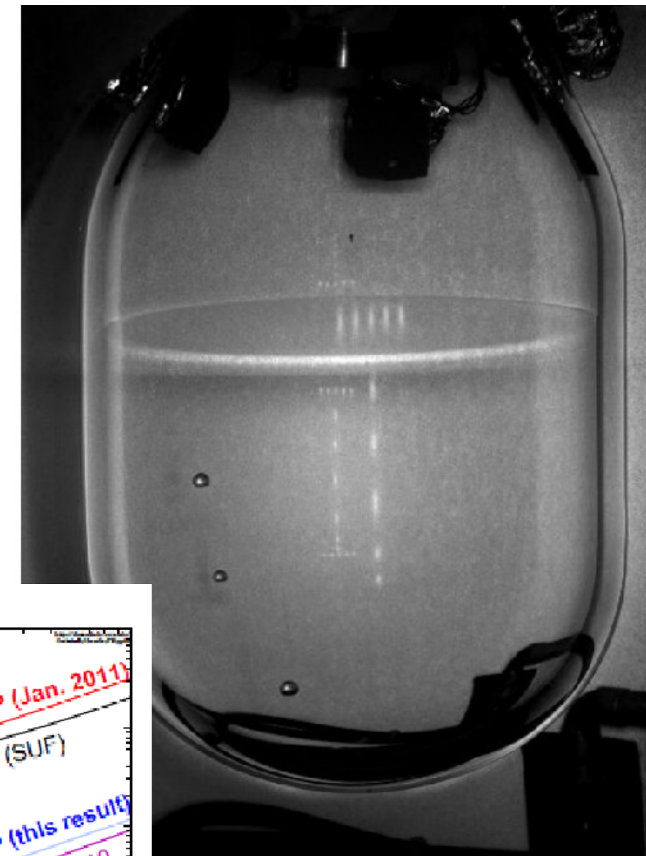
Phonons and Ionization or Scintillation

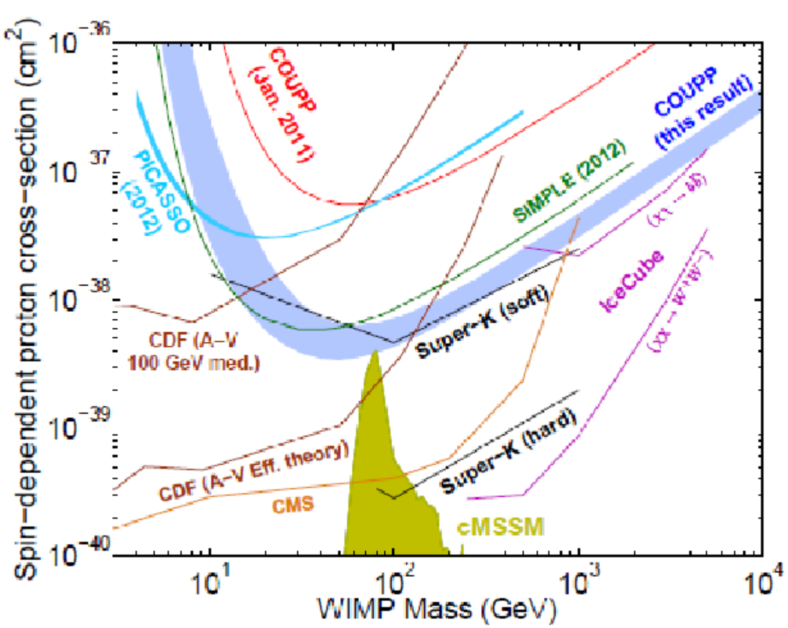


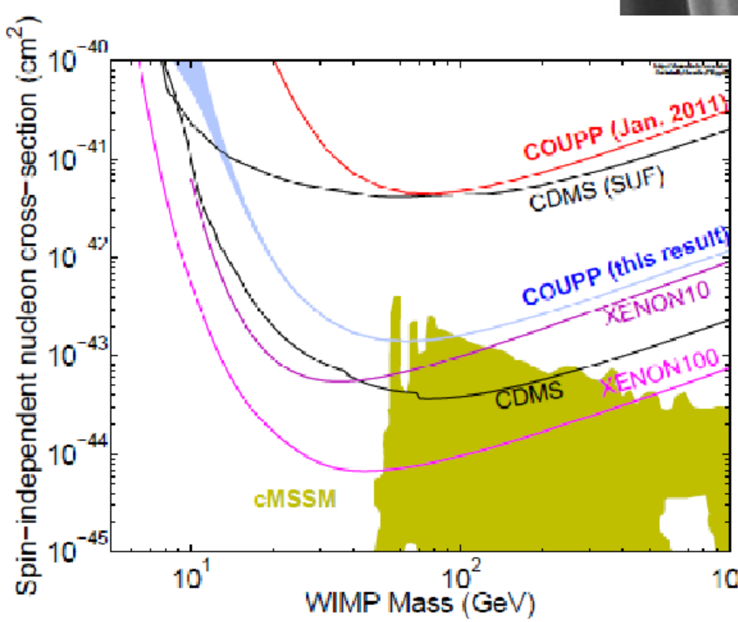
Some different detector technology: COUPP bubble chamber in SNOLab

from R. Neilson, Aspen 2013 (see also PICASSO@SNOLAB)

- Superheated fluid CF_3I
  - F for spin dependent
  - I for spin independent
- Observe bubbles with two cameras and piezo-acoustic sensors.

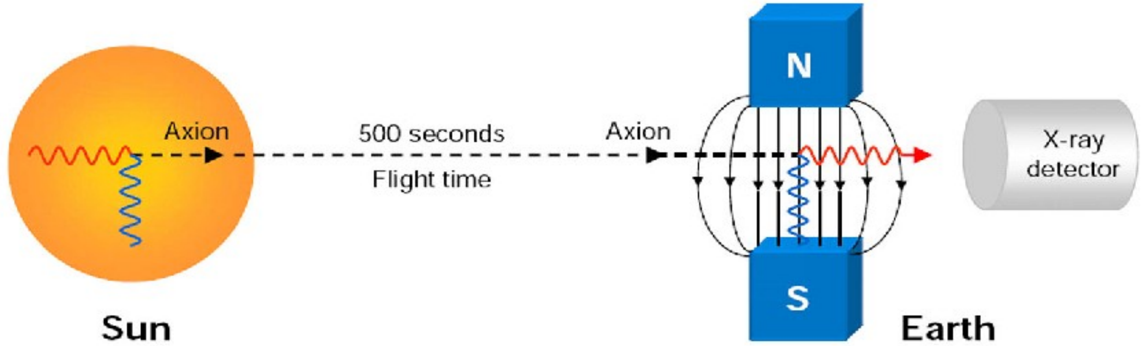






CAST: search for solar axions at CERN

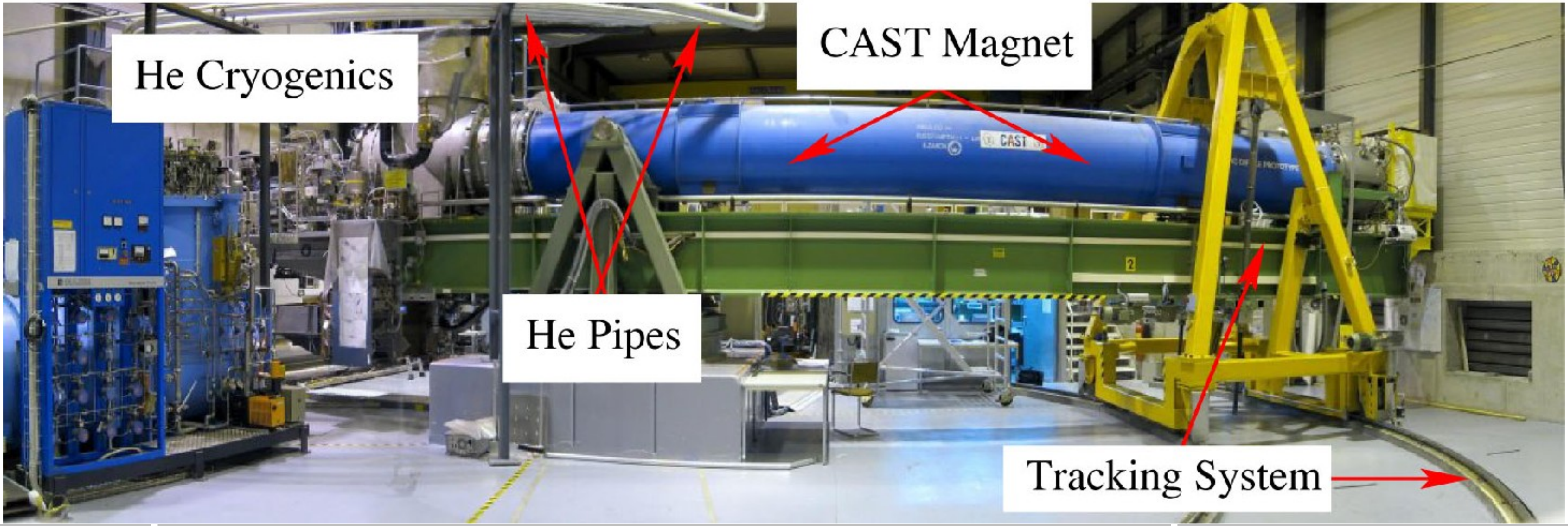
Principle of the Axion Helioscope P. Sikivie Phys. Rev. Lett. 51 (1983)



CAST in Germany:
- TU Darmstadt
- U Franfurt
- U Freiburg
- MPI Munich (ph)
- MPI Garching (et)

Assumption: Axions are produced via Primakoff effect in the Sun

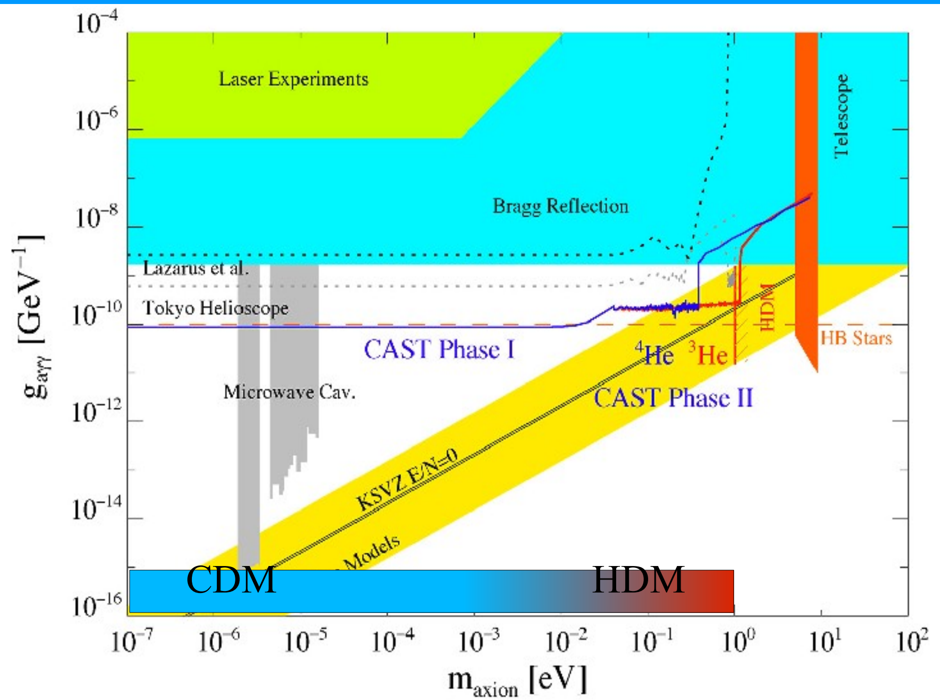
Want to detect solar axions with Primakoff effect, sensitivity to $m_a \approx 0 - 1.2$ keV



following slides from M. Kuster/Darmstadt

CAST results phase II

No signal found ⇒ exclusion plot:



The CAST collaboration JCAP 02 008 2009
[arXiv:0810.4482]

$$g_{a\gamma}(95\%) \lesssim 2.22 \times 10^{-10}\,\mathrm{GeV}^{-1} \qquad 0.02\,\mathrm{eV} \lesssim m_a \lesssim 0.39\,\mathrm{eV}$$

following slides from M. Kuster/Darmstadt

CAST probes the dark matter candidate axion but not really in the DM parameter range !

Microwave experiments probe relevant range, very small mass coverage

Search for axions

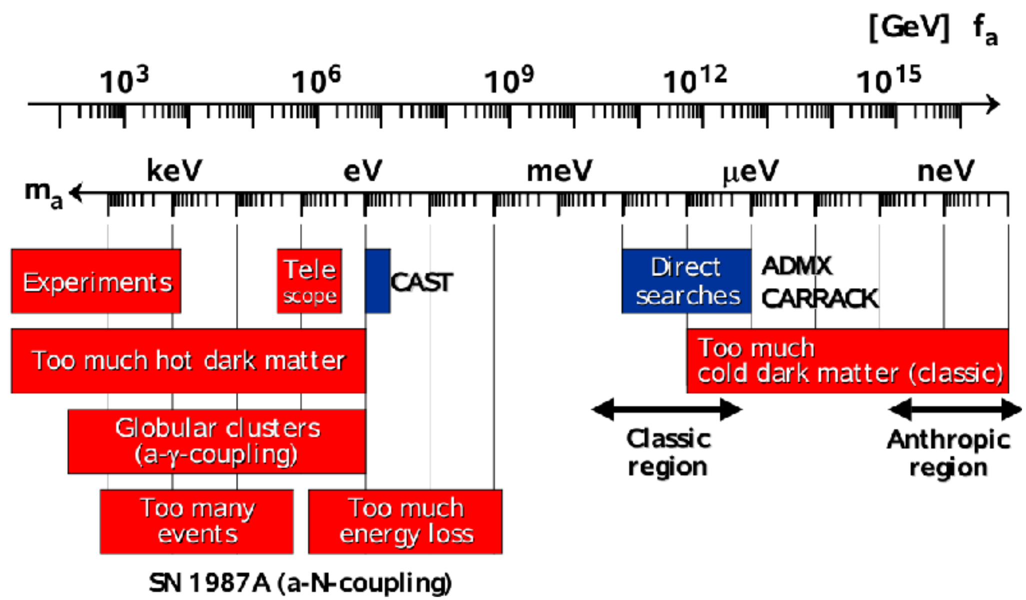
Axion couples to N, (e^-), γ

$$g_{a\gamma\gamma} \approx \frac{\alpha m_a}{2\pi f_\pi m_\pi} \sim m_a$$

Experimental searchs:

evolution of stars (extra cooling),
rare decay searches at reactors,
accelerators

$\Rightarrow$ only upper limits for m_a



G. Raffelt, LAUNCH 09

Axions from the big bang:

never in thermo-dynamical equilibrium
degenerate gas $\Rightarrow$ cold dark matter

$$\Omega_a = 1.9 * 4^{\pm 1} * (\mu eV/m_a)^{1.175} * \underbrace{\theta^2 * F(\theta)}_{\approx 1}$$

$\Rightarrow$ lower limit for m_a

$\Rightarrow$ 2 axion DM windows

Summary of 3rd lecture

Problems: background and small signal energy
→ go underground and smart screening techniques
→ observe signal in various variables:
charge, light, heat (and annual modulations)

Possible evidences at low WIMP masses
are fading away by better experimental data except DAMA/LIBRA result

DAMA signal: still under discussion, but excluded by many exp.
CoGeNT: explanation by MALBEK
CRESST: new design solves problem with too many alphas

Large progress by cryo-bolometer technology