Review on non-directional direct dark matter searches

B. Censier, IPNL (CNRS, Lyon)

Cygnus workshop 2011

Dark matter direct detection

constraints

Main constraints for WIMPs detection:

- Energy deposit : **~ 10keV**, nuclear recoil
- Rate : **<0.01 evt/kg/day** *(from best current limits)*

Requires :

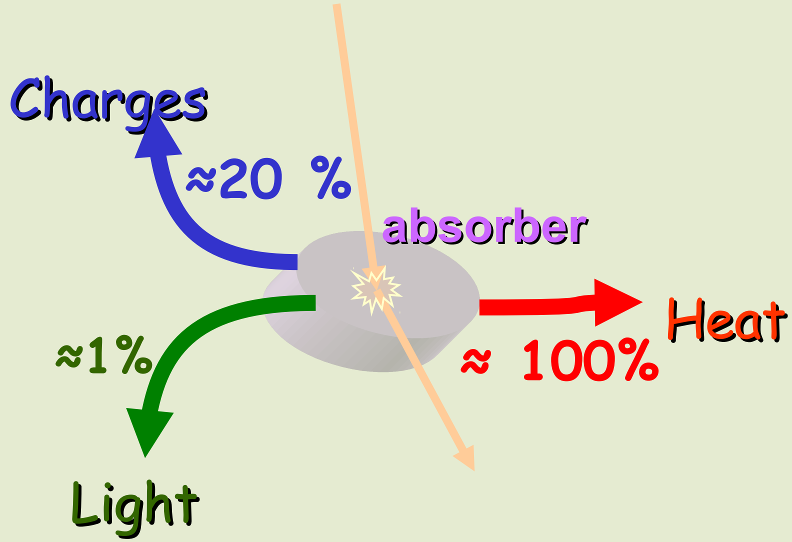
- Sensitive & massive detectors *(~kg target, ~keV threshold)*
- Long term runs & stability *(~ year, calibration & environment control)*
- Very low background *(passive shielding & ultra-low radioactivity materials)*
- (and/or) Excellent background discrimination *(mostly ionizing radiations rejection)*

Dark matter direct detection

detection channels & background discrimination

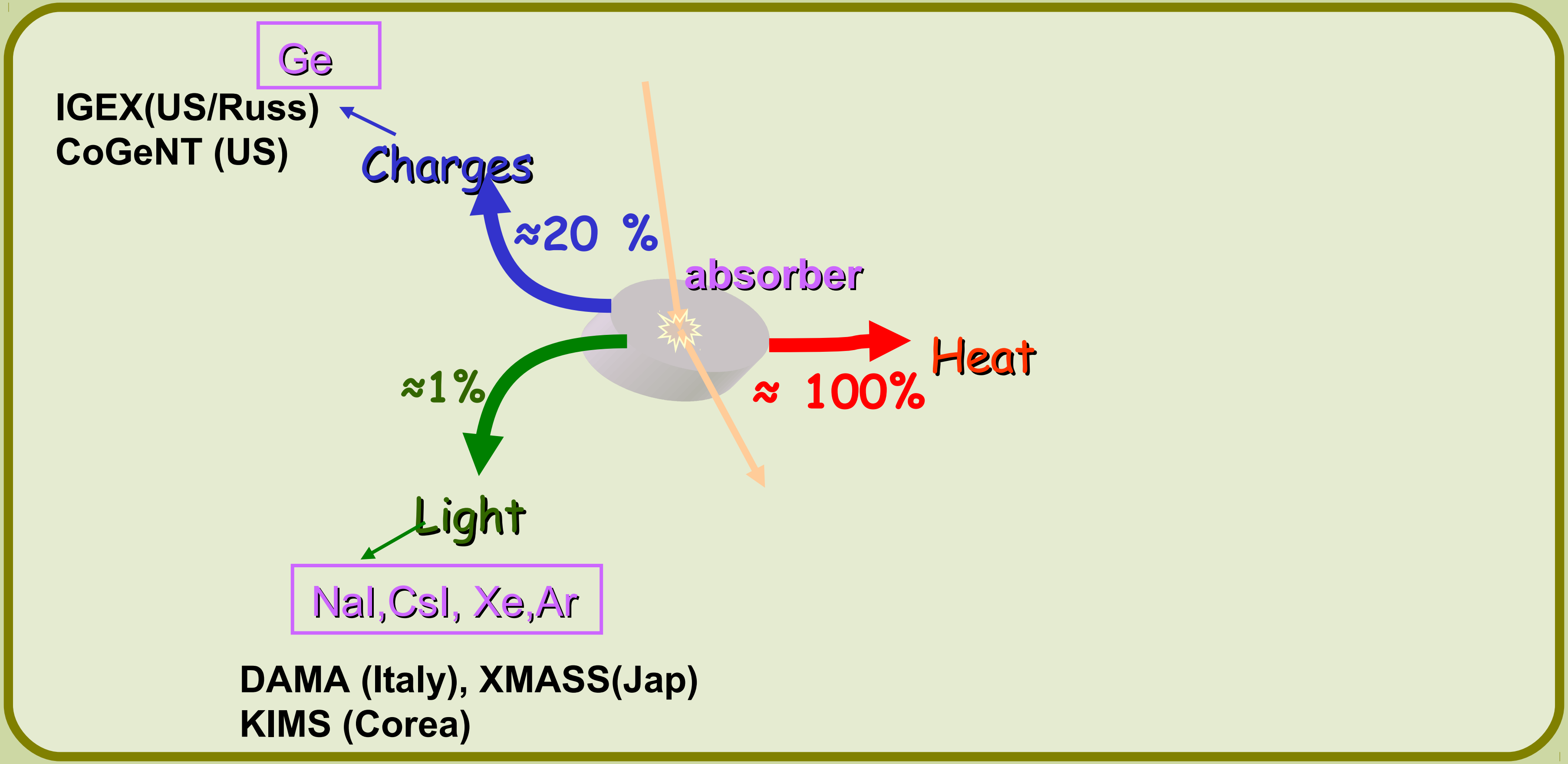
Dark matter direct detection

detection channels & background discrimination



Dark matter direct detection

detection channels & background discrimination



Dark matter direct detection

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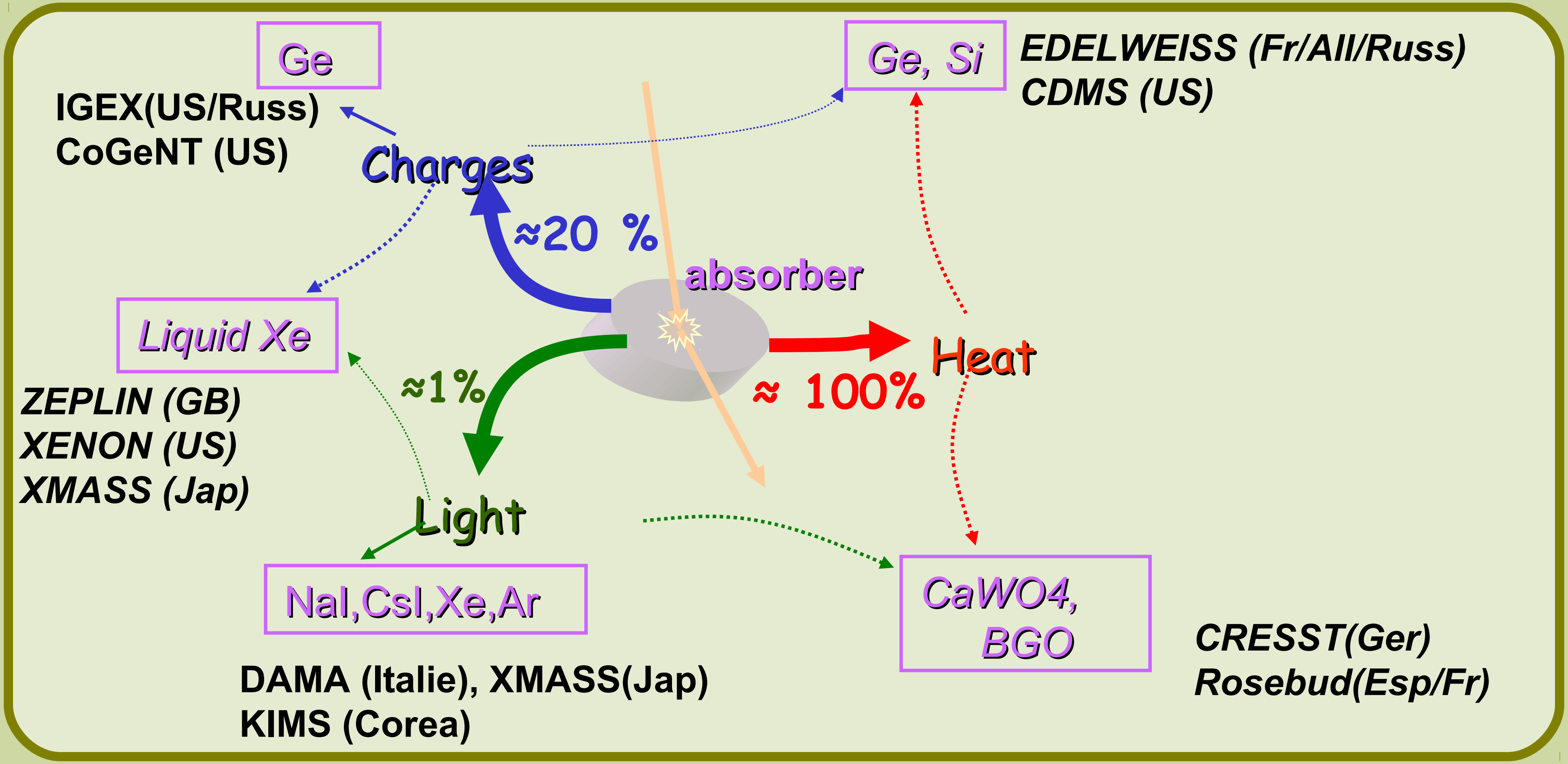
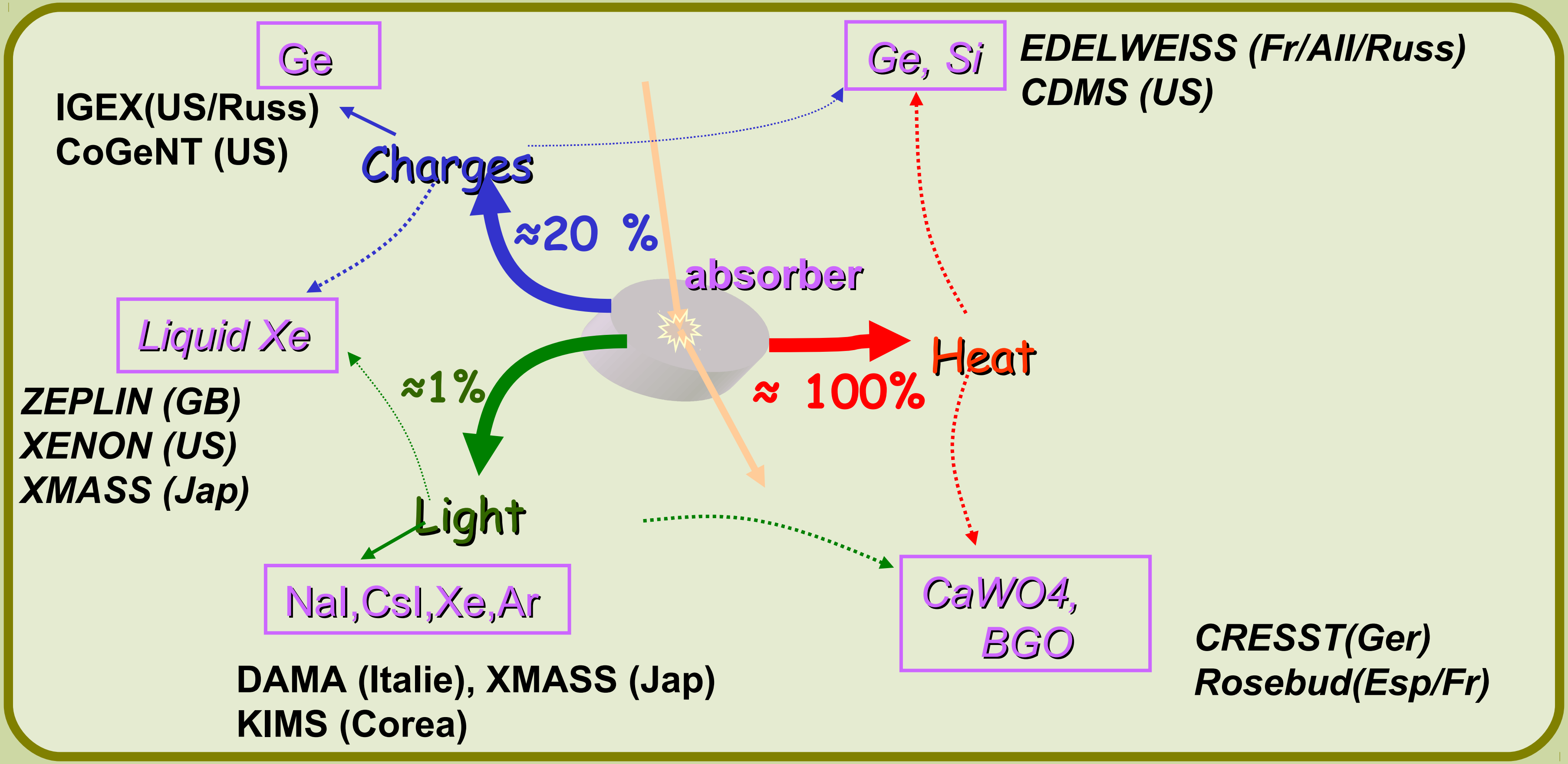


Dark matter direct detection

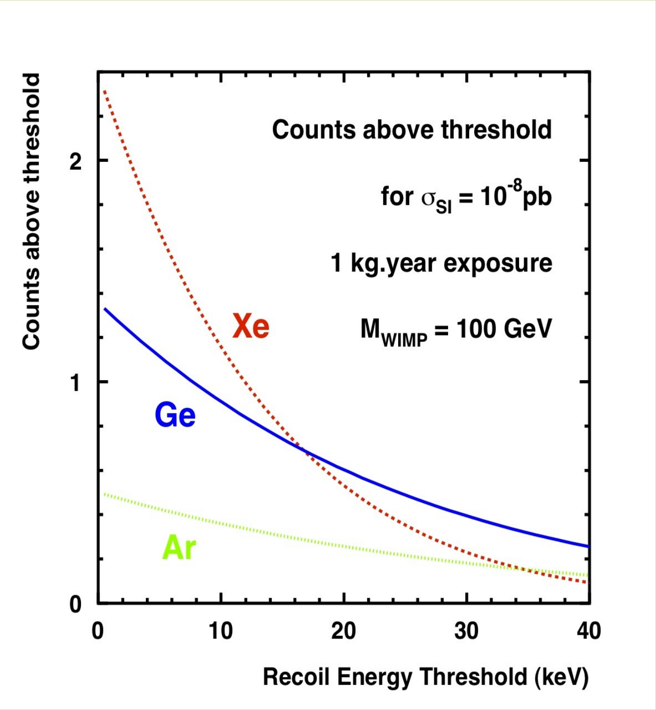
detection channels & background discrimination

+ metastable absorbers :
- COUPP (bubble chambers)
- PICASSO & SIMPLE (superheated droplets)



Dark matter direct detection

(non-directional) signatures



With event-by-event background discrimination :

- WIMPs candidates identification

(nuclear recoils + additional cuts)

- Energy spectrum shape

(inelastic interaction)

- Comparison of different absorbers

(coupling of candidate with 'ordinary' matter)

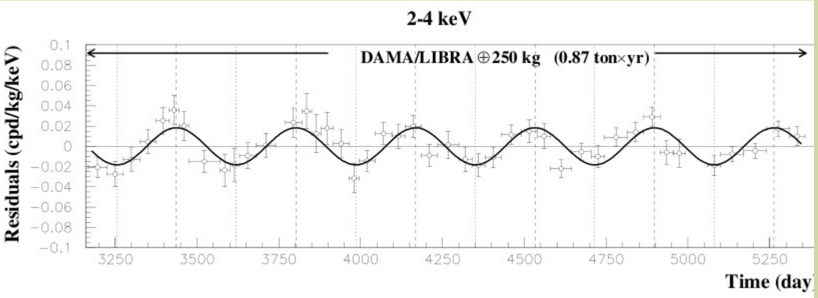
Without :

- Excess rate at low energies

(needs sufficient knowledge of background)

- Annual modulation

(lack of discrimination BUT high mass exposed)



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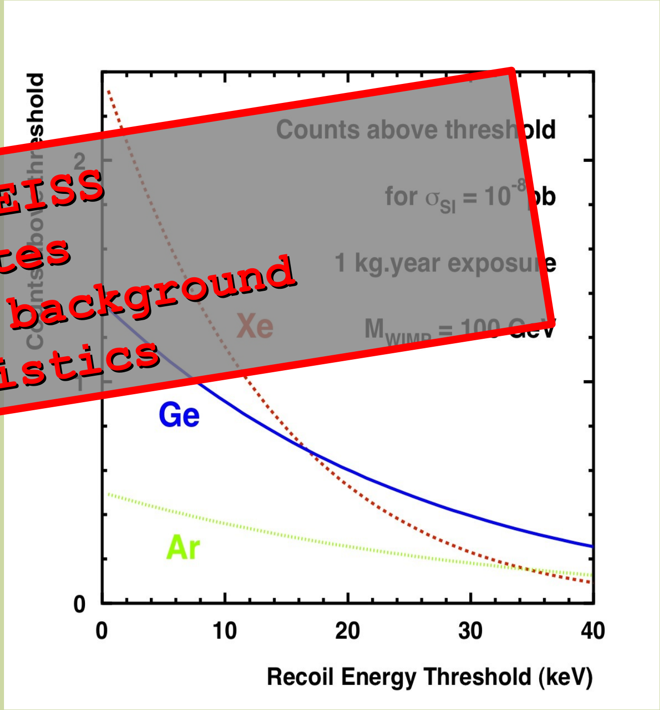
CDMS/XENON/EDELWEISS
- some candidates
- just above expected background
- need more statistics



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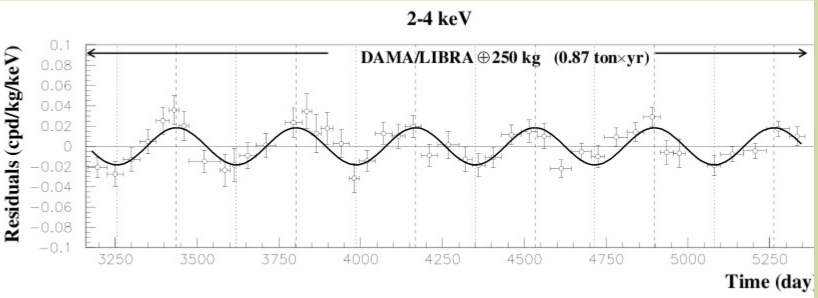

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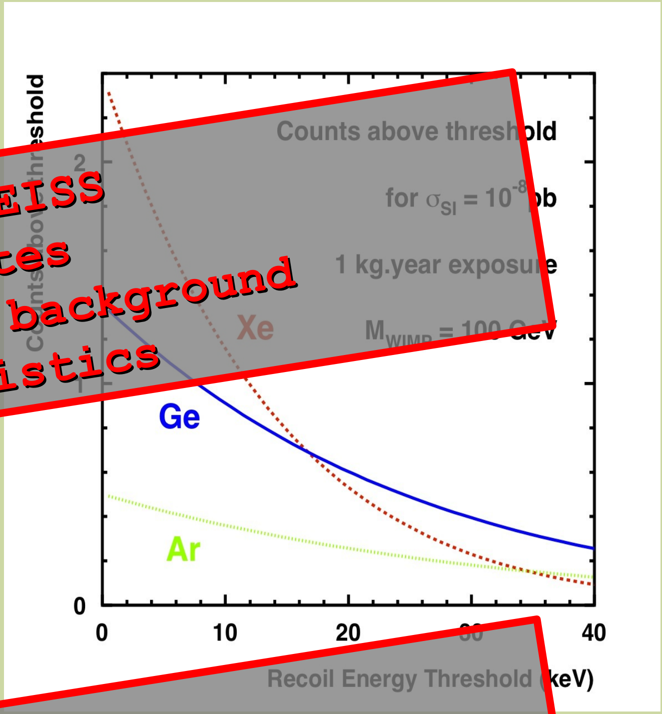

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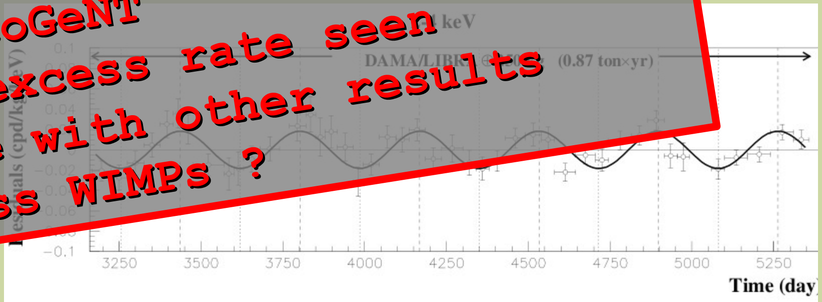


Detection claims

DAMA/CoGeNT

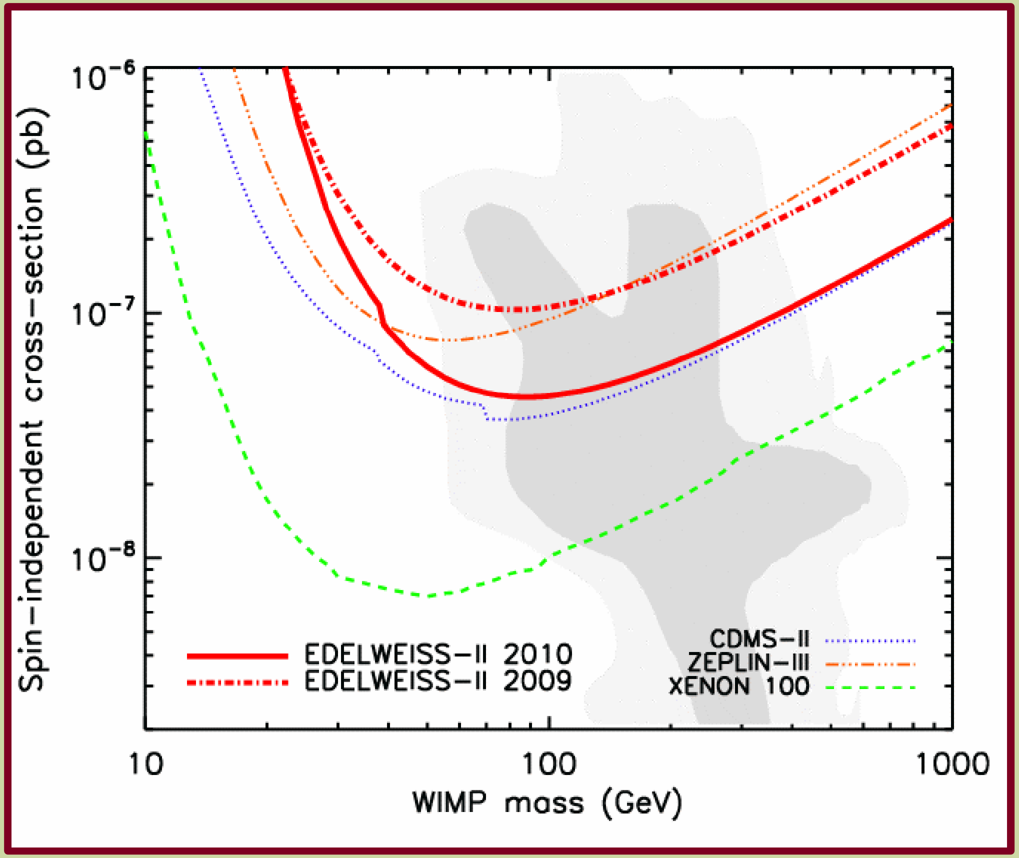
– modulation + excess rate seen

– hard to reconcile with other results

– low mass WIMPs ?

Results on spin-independant coupling

Overview



Results on spin-independant coupling

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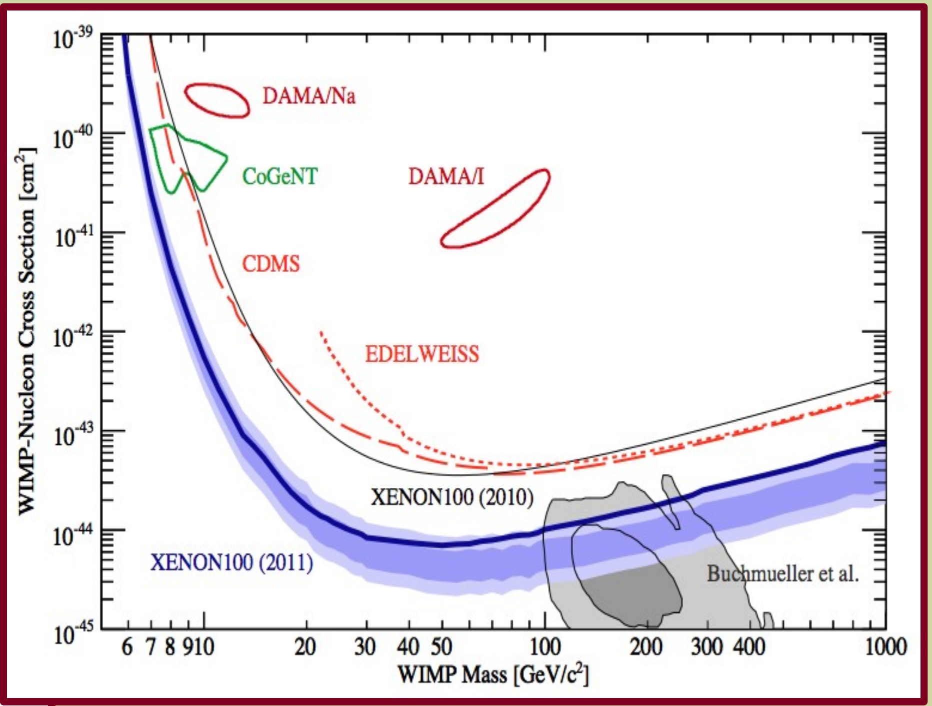
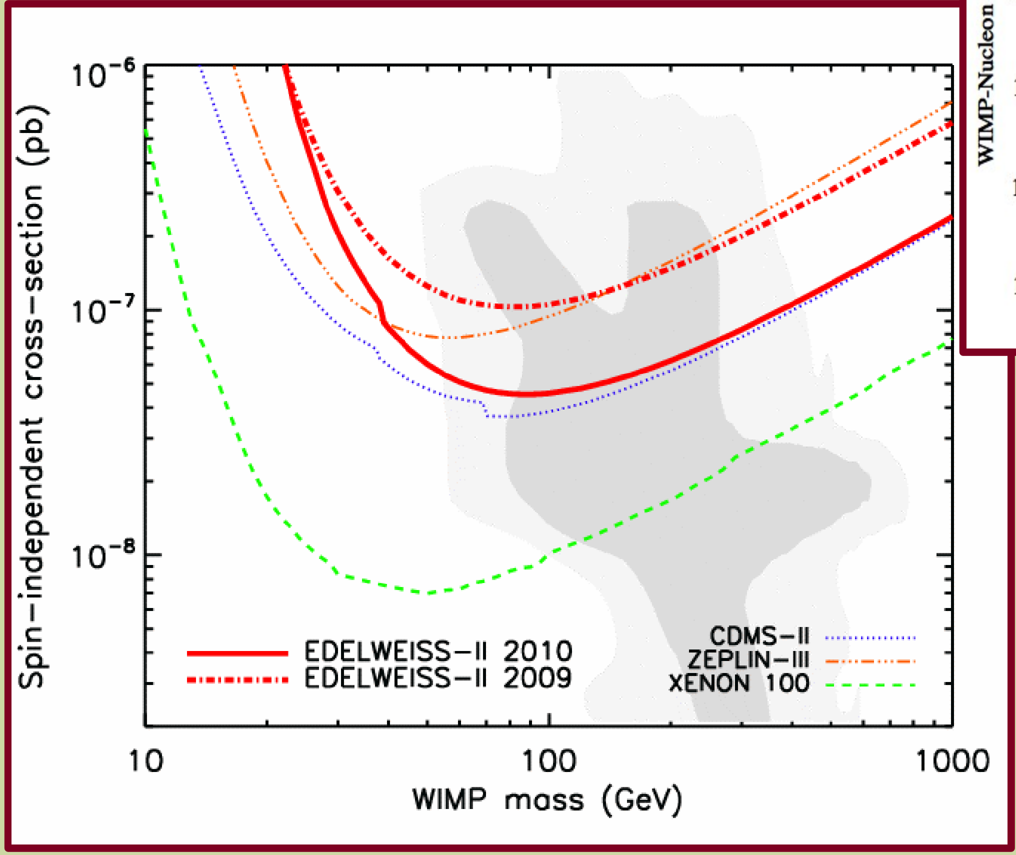
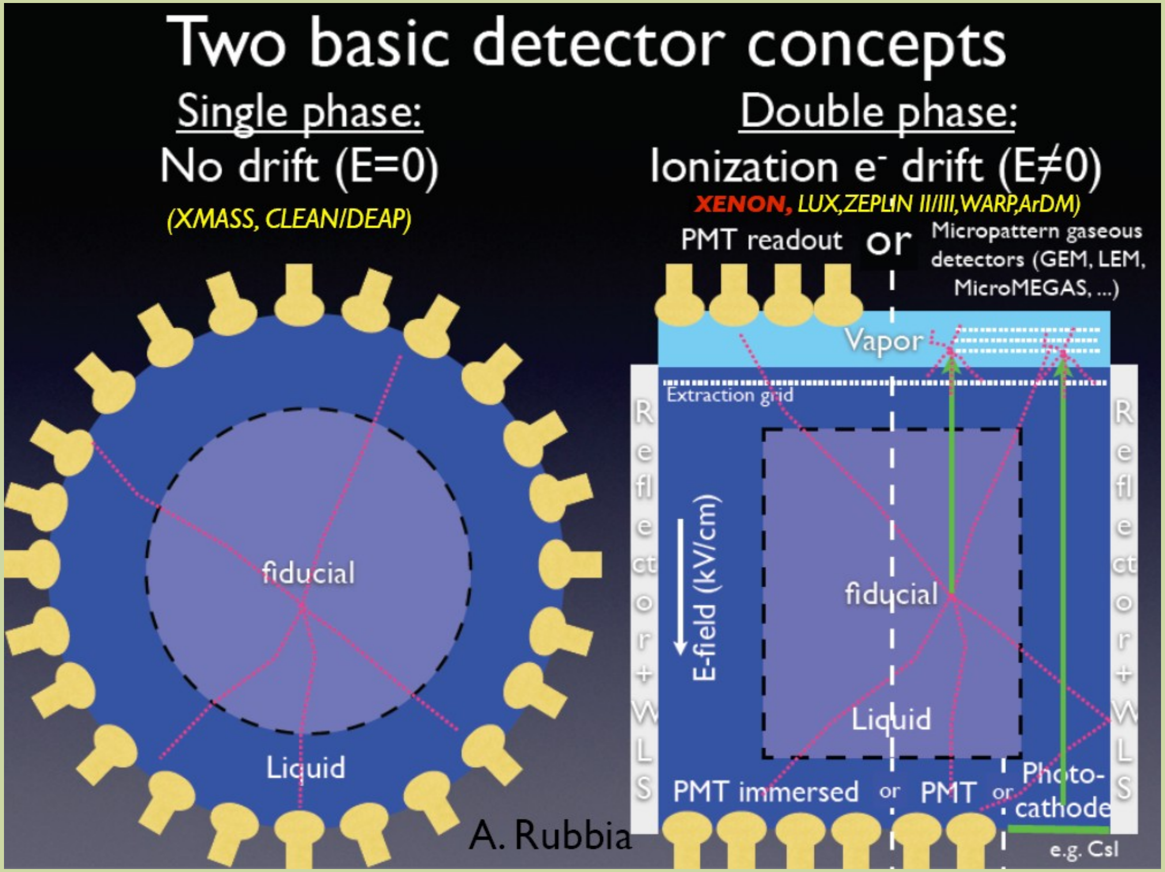




Noble liquid & Gas (Xe, Ar)

Principles



→ Simple but no active evt by evt rejection

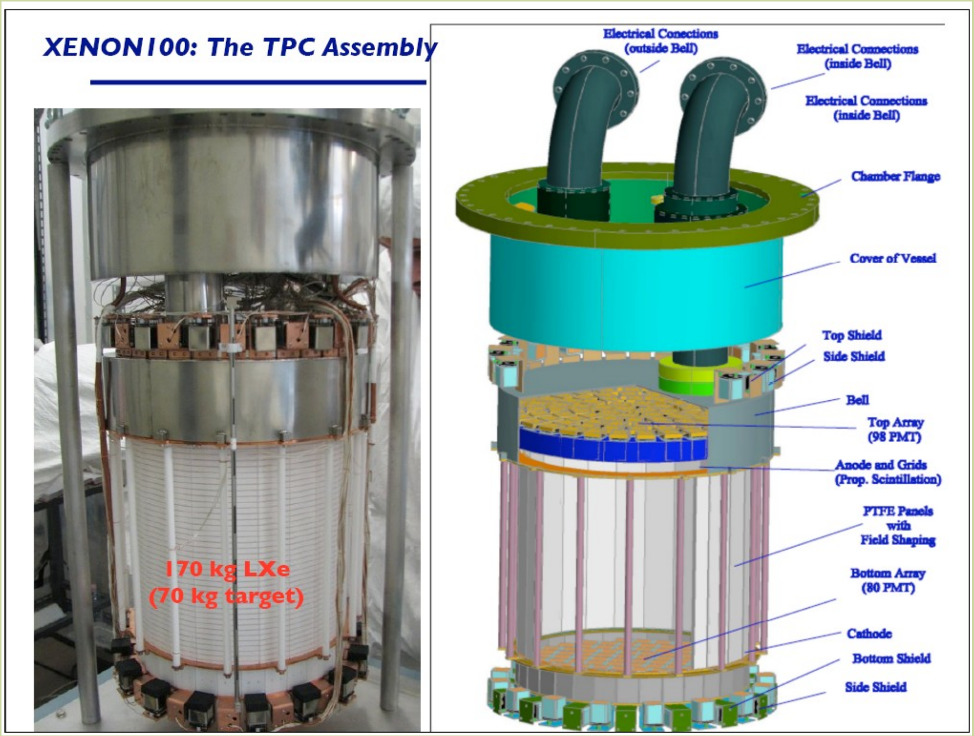
→ PSD possible (especially for Ar, ≠ lifetime singlet-triplet)

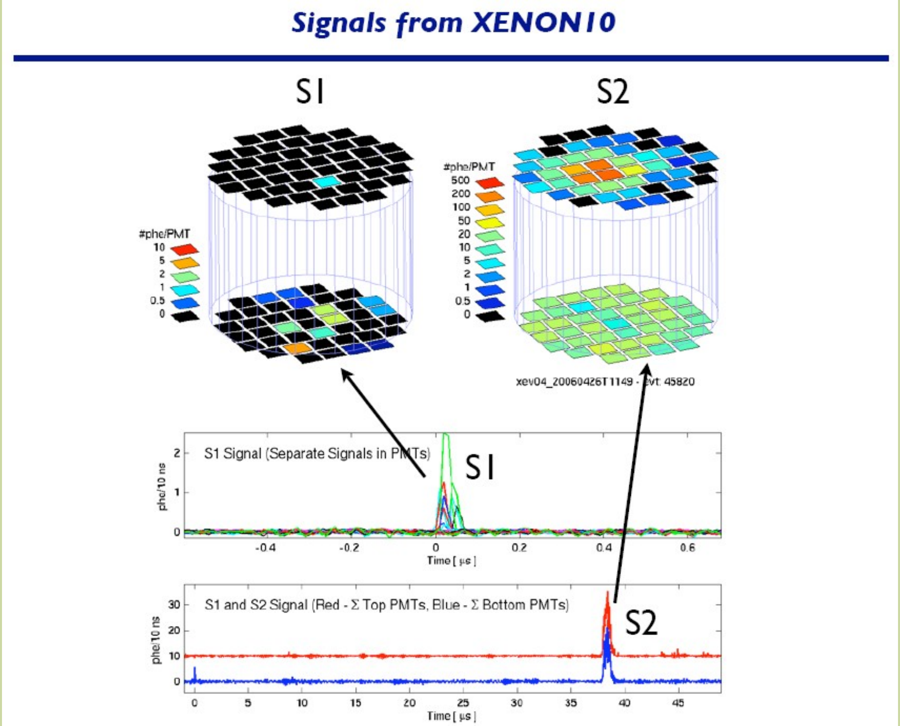
→ More complex but active evt by evt rejection.

→ ≠ technologies for charge readout

The Xenon experiment

Experimental setup





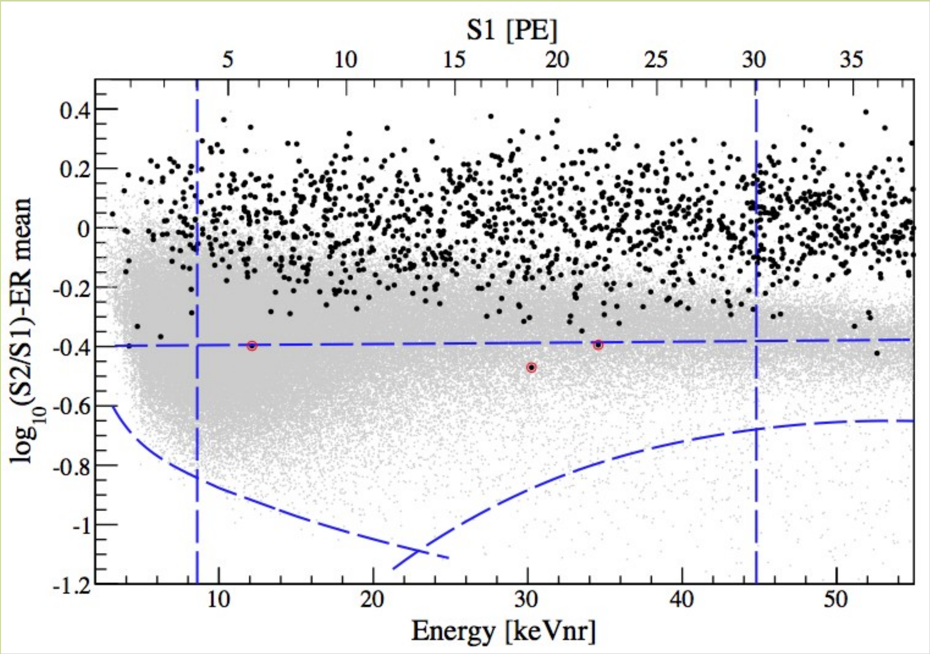
- **Xenon 10** : 22 kg LXe, 15 kg actif, **5 kg fiduciel**, Drift charge on 15 cm
- **Xenon 100 : 170 kg LXe, 65 kg fiduciel (≈ 45 kg after cut), Drift charge on 30 cm + 105 kg Veto**

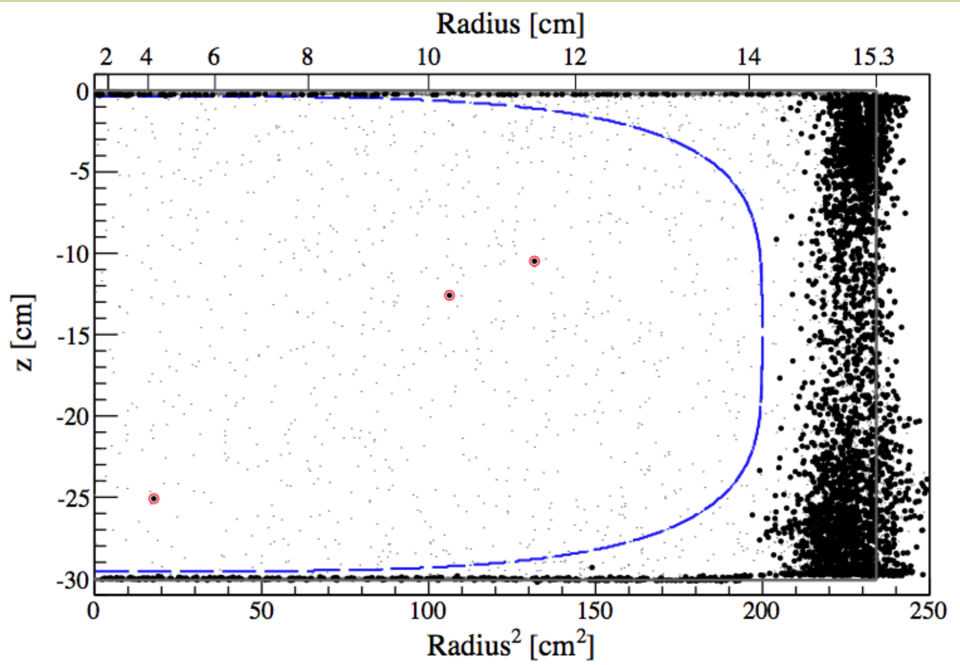
Luminescence channel :
- 98 PMTs top, 80 PMTs bottom array
- Hamamatsu R8520-AL 2.5× 2.5 cm PMTs
QE ~30% @ 178 nm, < 1 mBq/PMT in 238U/232Th)

Ionization channel :
- 16 kV cathode: Ed=0.53 kV/cm (drift)

Event position :
x-y position : σx-y≈ 3 mm
z-position from Δtdrift , σZ<2 mm

The Xenon experiment
Latest results





100.1 live days (Jan-June 2010)
48kg fiducial mass
≈ 1471 kg.days (acceptance corrected)

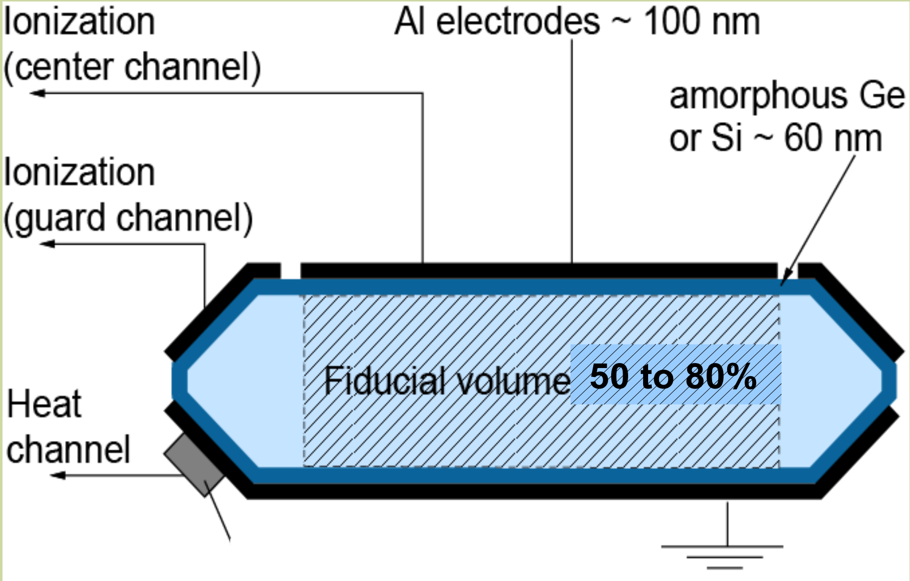
3 nuclear recoil candidates, 1.8±0.6 evts expected background

HPGe heat-and-ionization bolometers

Principles

Charge collection &
fiducial volume definition

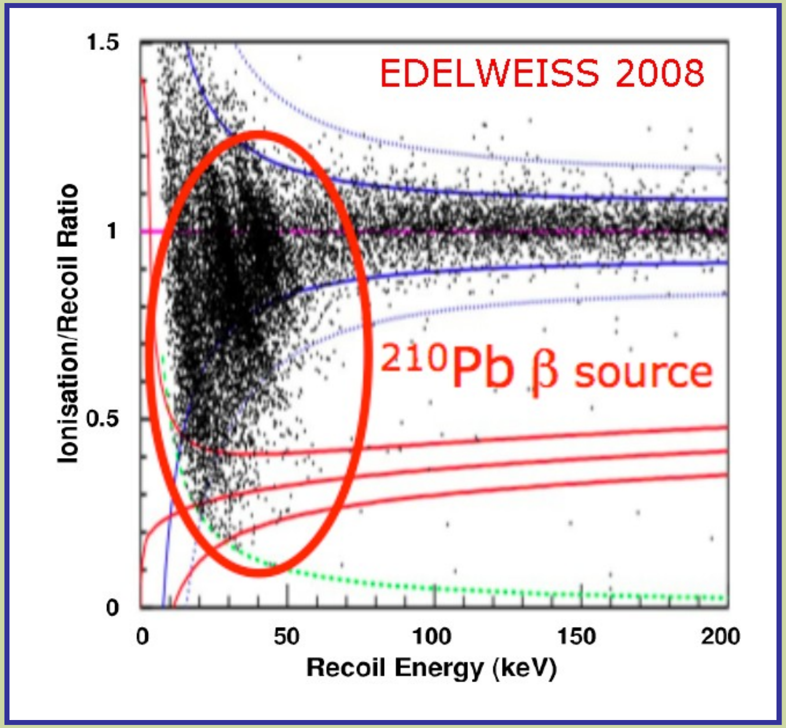
Heat measurement
- low impedance (CDMS)
- high impedance (EDELWEISS)



- Cryogenic temperature for heat measurement (~10mK, $^3He/^4He$ dilution fridge)
- Electric field for charge collection ~V/cm
- Some 100s grams per detector
- Ionization : 3eV/pair, micro-second collection time
  - *Fiducial volume definition*
  - *Electronic recoil discrimination*
- Heat : ~micro-kelvins temperature rise, milliseconds rise time
  - *Absolute energy (independant of interacting particle)*
  - *Trigger*

HPGe heat-and-ionization bolometers

The « surface events » background



Bad charge collection may cause leakage from electron recoil band

HPGe heat-and-ionization bolometers

The CDMS experiment: setup

250g detectors

Charge channel :

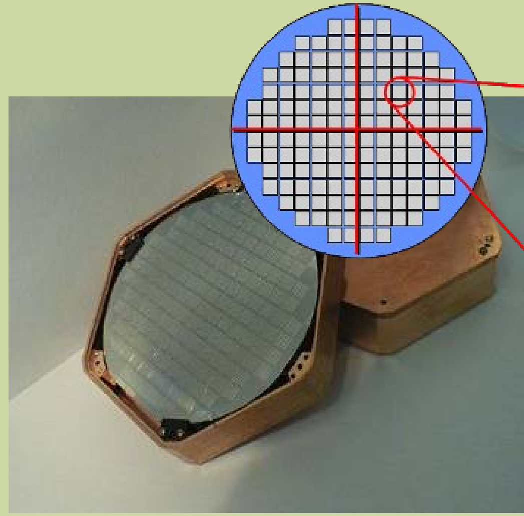
- Guard + centre electrodes
- FET preamp @ 4K

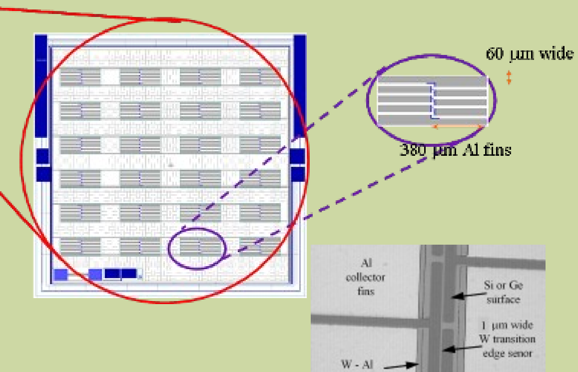
Heat channel :

- Superconducting W thermometers :

Photolithographic patterning
4 quadrants, 37 cells per quadrant
6x4 array of 250µm x 1µm W TES per cell
Each W sensor "fed" by 8 Al fins

- Low impedance SQUIDs read-out @ 4K

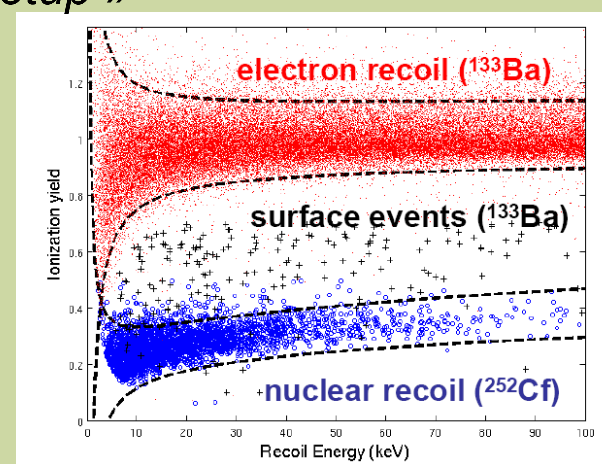


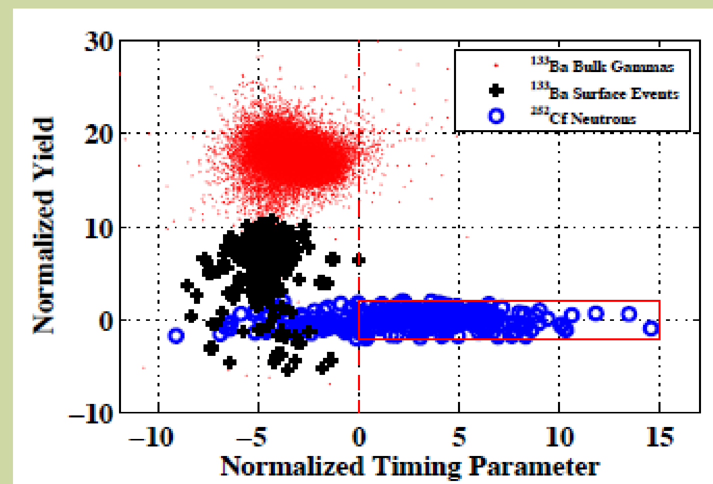


TES 1 micron wide

« Powerful but complex setup »

Surface events rejection : cut on athermal phonons timing parameter

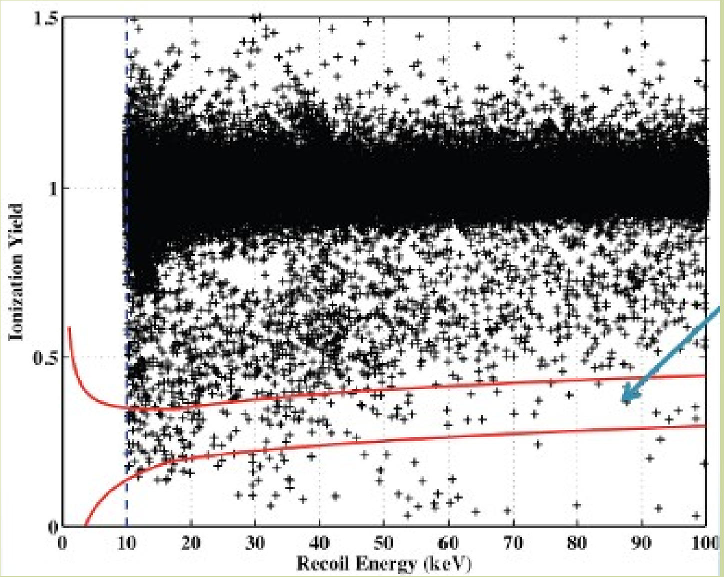




HPGe heat-and-ionization bolometers

The CDMS experiment: latest results

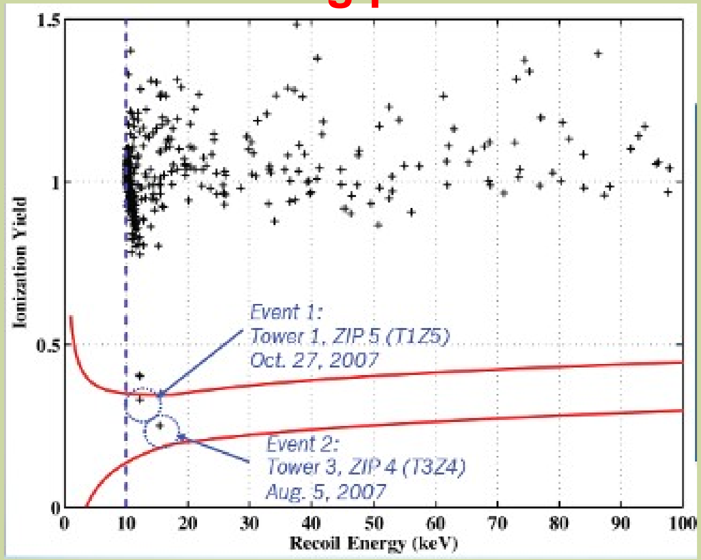
All data



« Open the box »
(Nov 4, 2009)

612 kd.day

After timing parameter cut



194 kd.day, **efficiciency < 30 %**
exp backg **0.8 ± 0.1(stat) ± 0.2(sys)**
2 candidates...
Probability to observe 2 or more events is 23%

"Our results cannot be interpreted as significant evidence for WIMP interactions. However, we cannot reject either event as signal either."

[*Science* 327 (2010) no 5973 p.1619; arXiv:0912.4025]

HPGe heat-and-ionization bolometers
The EDELWEISS experiment: setup

400g detectors (soon 800g)

Charge channel :

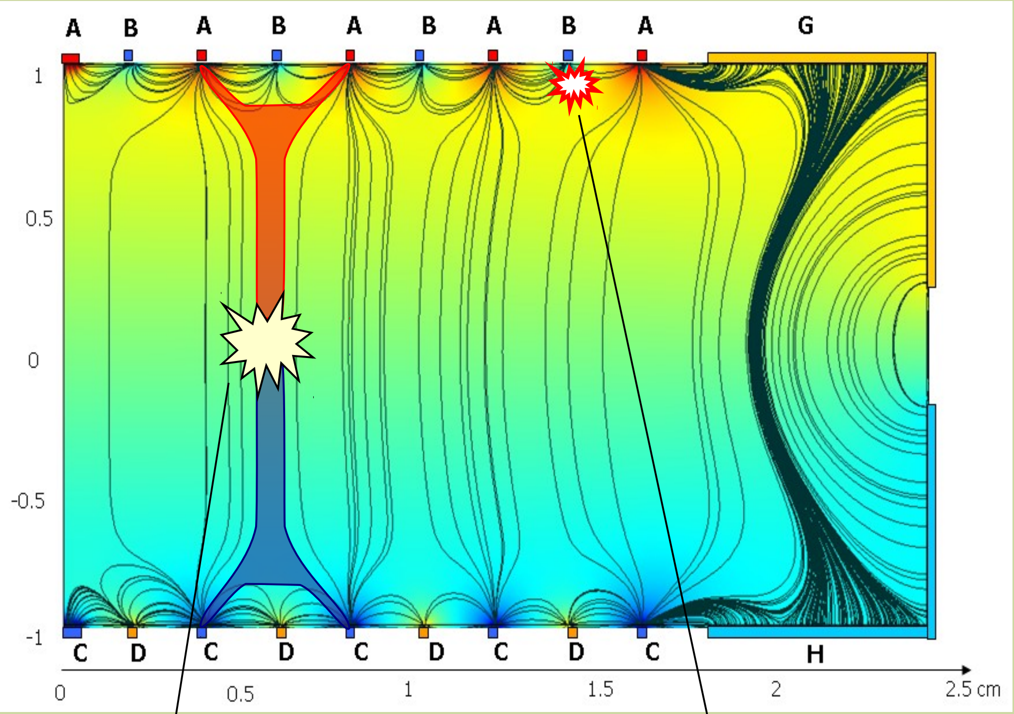
- 2 Fiducial + 2 Veto + 2 guard electrodes
- FET preamp @ 80K

Heat channel :

- Neutron Transmutation Doped thermistor (NTD)
- FET high impedance read-out @ 80K

« Simple but robust setup »

EDELWEISS II « Interdigit » detector (ID)



Bulk events:
charge only on fiducial electrodes (B&D)

Surface events:
charge on veto electrodes (A & C + guard rings)

Beta rejection > 1/15000

A. Broniatowski et al ***Phys Lett B 681 (2009) 305*** *[arXiv:0905.0753]*

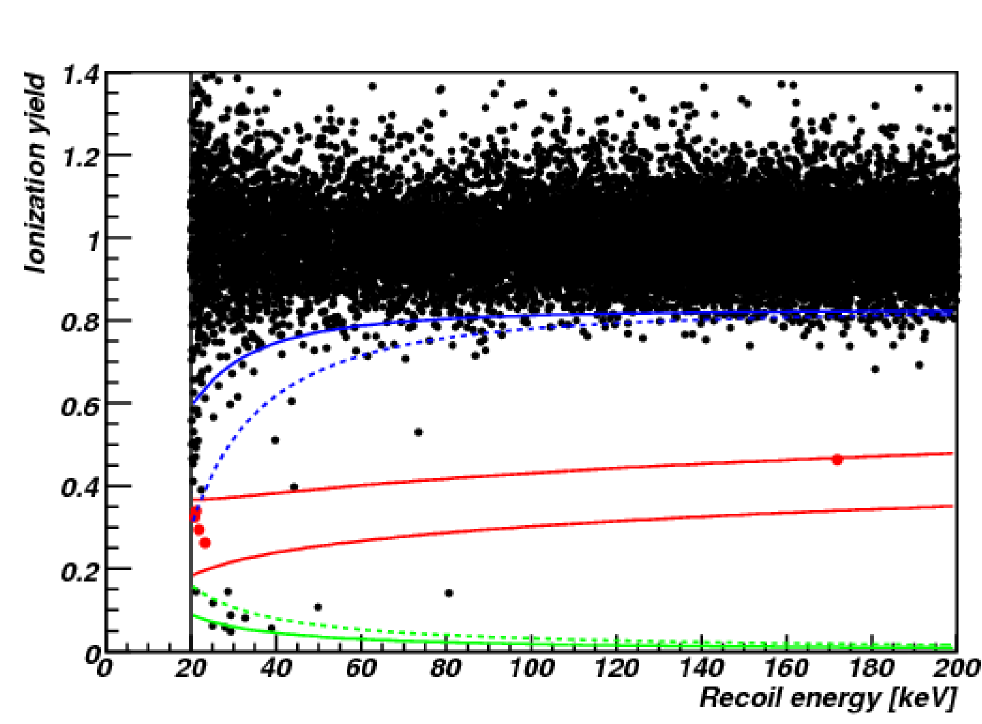
HPGe heat-and-ionization bolometers
The EDELWEISS experiment: latest results

- Run April 2009 - May 2010

14 months of continuous operation@20mK (85% duty cycle)

- Ten 400g ID Ge detectors,
  427kg.day before cuts
  384kg.day final data set

- Five nuclear recoil events (above 20keV analysis threshold)



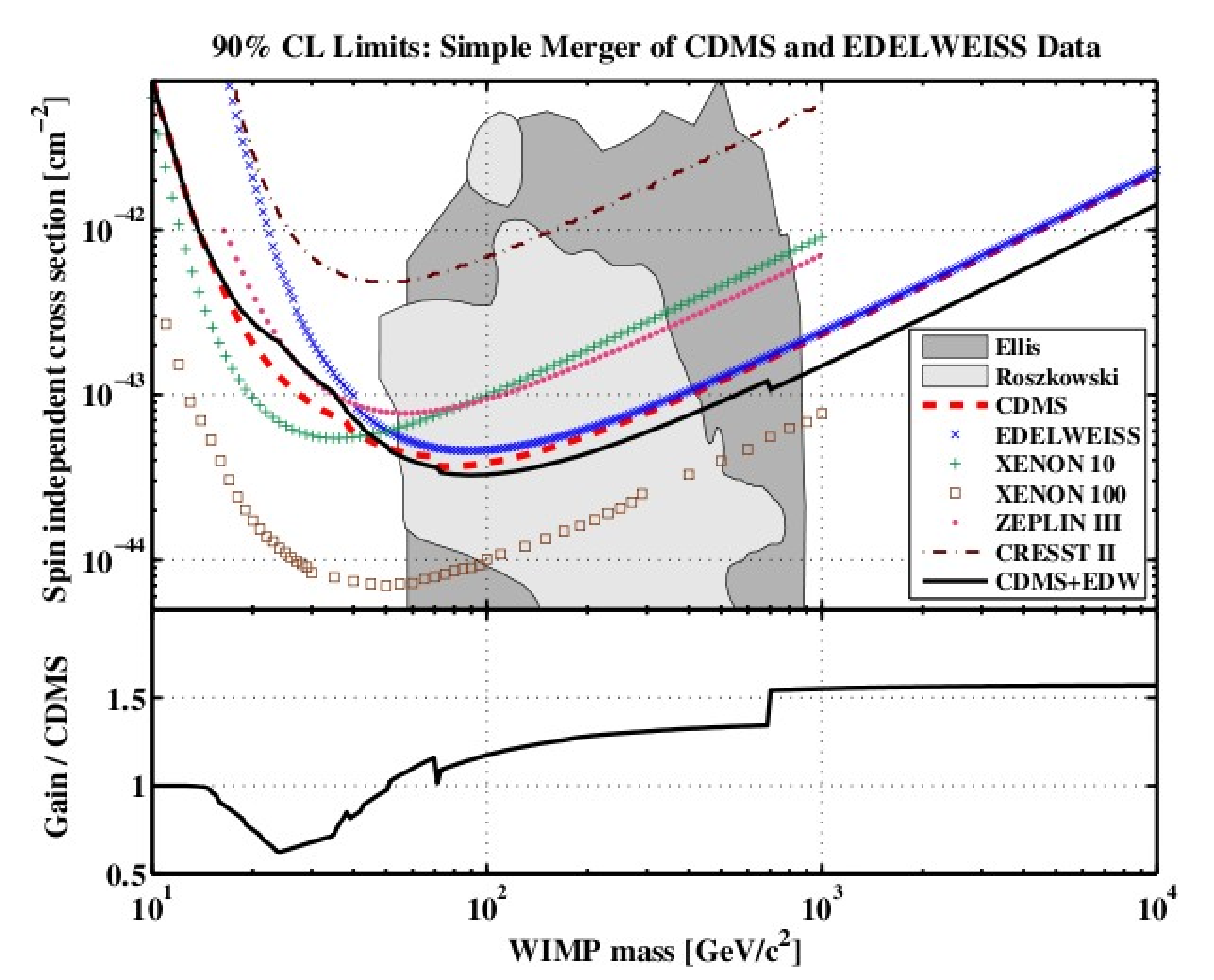
Submitted to Physics Letters B.
arXiv:1103.4070v2

→ Five WIMP candidates:
- 4 with 20.8 < E < 23.2 keV
- 1 @ 172 keV

- Expected background estimate : 3

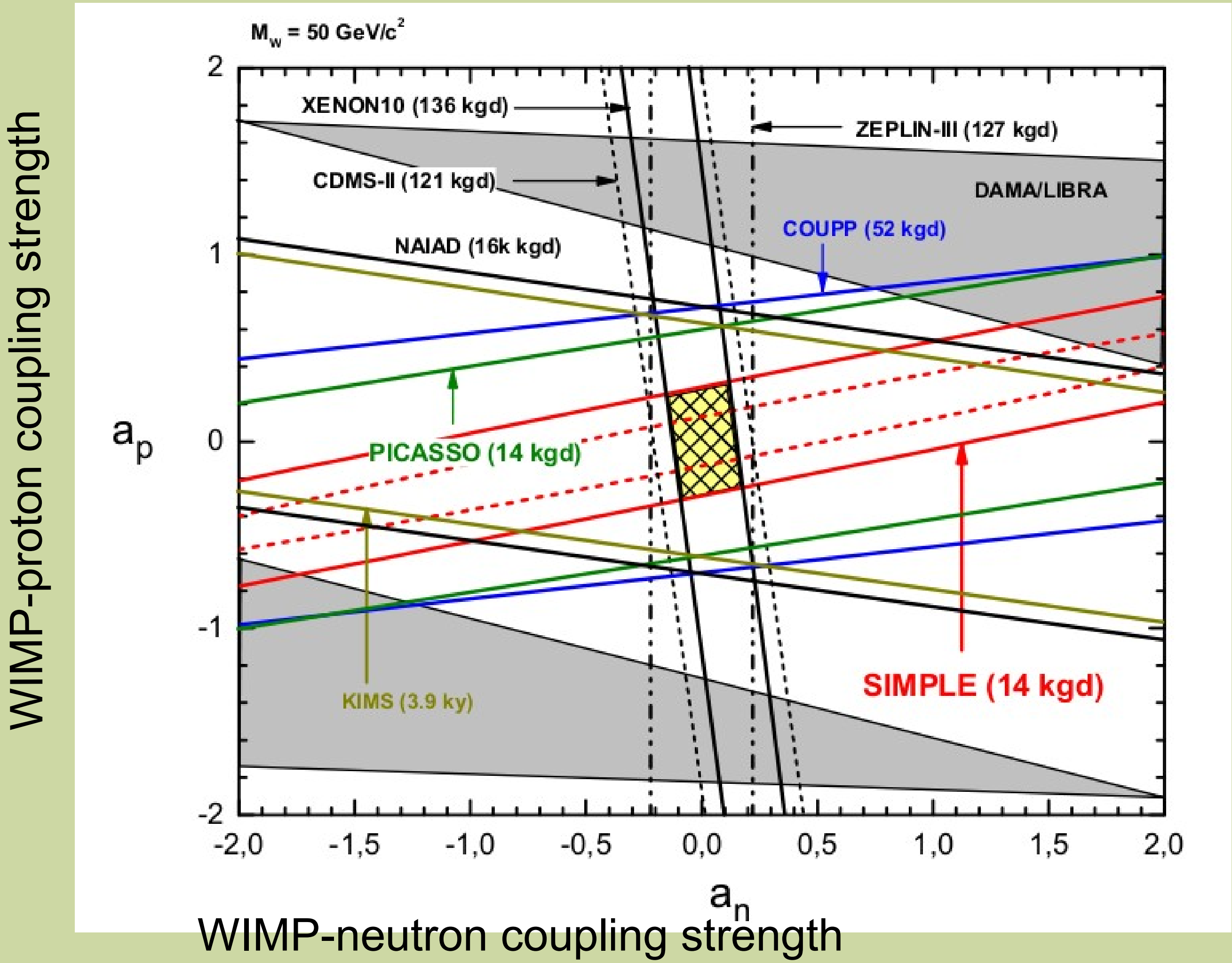
HPGe heat-and-ionization bolometers

EDELWEISS-CDMS combined limits



Results on spin-dependant coupling

Overview



(from SIMPLE, 2010 : arXiv:1003.2987v4)

Results on spin-dependant coupling

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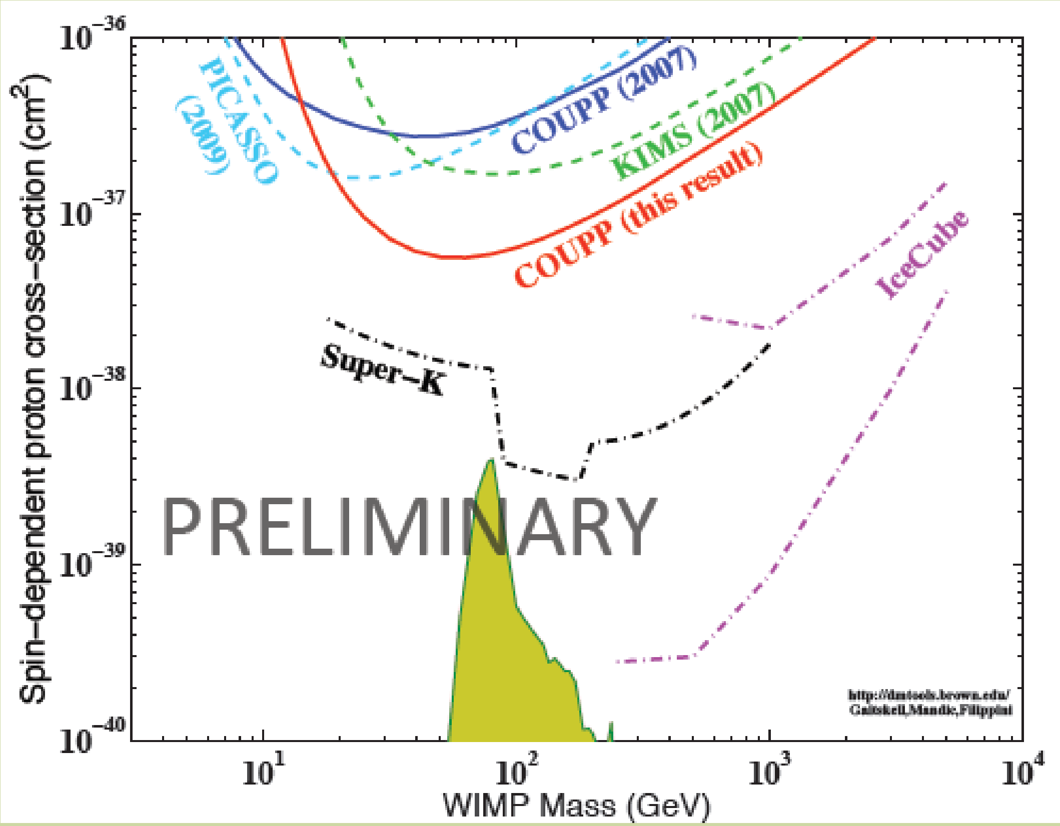
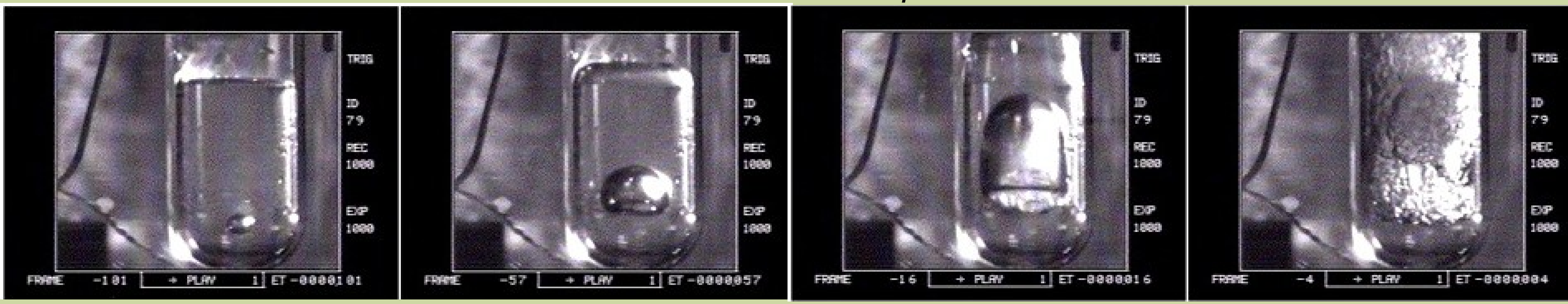


- still far from susy models
- indirect detection more competitive (SuperK, coupling on proton in the sun)
- at least 3 different technologies ahead (scintillation, bubble chamber, superheated droplets)

Results on spin-dependant coupling

The COUPP experiment: setup

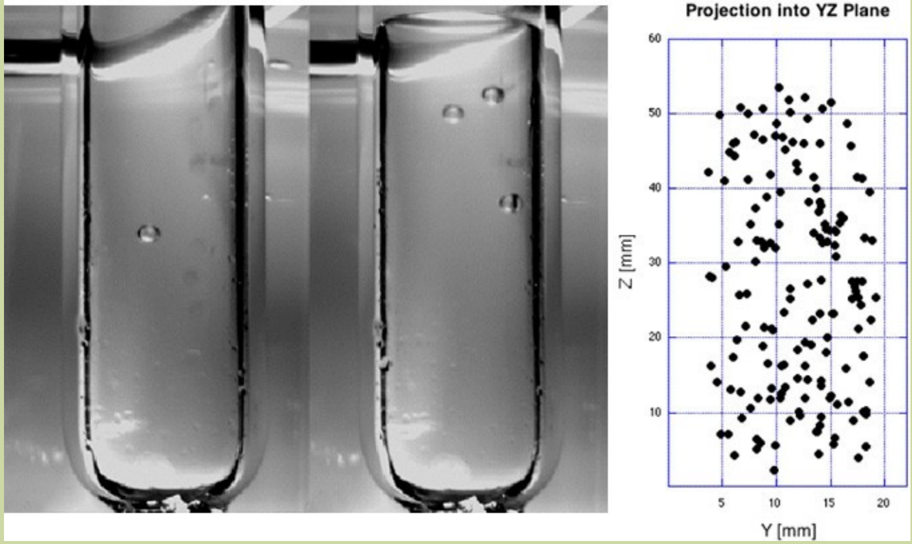
One neutron interaction in superheated CF3Br



t=0 : nucleation

t~0.1s : full boiling

Single vs. Multiple energy deposit (CF3I)



- room temperature operation
- 21 keV nuclear recoil theoretical threshold
- piezo acoustic transducers
- trigger & positioning by images capture

- impressive immunity to ionizing background : up to 10^{-11} discrimination efficiency !
- alpha background : discrimination based on ultrasonic emission (cf. PICASSO)
- neutron background : shielding + rejection by counting bubbles

Results on spin-dependant coupling

The COUPP experiment: latest results

PRL 106, 021303 (2011)

- 3.5kg of CF3I exposed in Fermilab shallow site
- 4 months operation : August 19 to December 18, 2009, only 23 days live time with muon veto ON
- 28.1 kg.days total exposure (42% quality cuts due to intermittent noise on acoustic signals)
- 3 WIMPs candidates
- 60kg bubble chamber being commissioned since January 2011

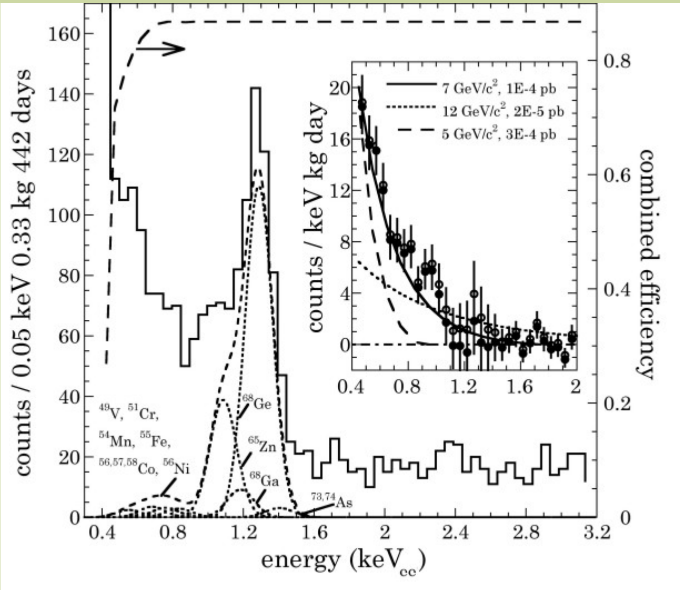
Results on spin-dependant coupling

The low-mass conspiracy

- CoGeNT (77K Ge, ultra low threshold, 145kg.days) : low energy excess compatible with M<10 GeV Wimps

- CRESST (not published) : excess of signals compatible with M<15 GeV Wimps

- DAMA annual modulation (at 8.3σ CL !) : compatible with M< 15 GeV



+ recent results from CoGeNT : modulation hint on one year data ! (2.8 σ) (arxiv:1106.0650v1)

Additional slides

Edelweiss II Background estimate

- Gamma background:
  - Total 1.8×10^{4} events in electron recoil band (20-200keV)
  - Assuming gaussian statistics, no nuclear recoil candidate due to statistical fluctuation expected
  - Non gaussianities ? Systematics ? => estimation by calibration data

  ^{133}Ba gamma calibrations $\rightarrow$ 3×10^{-5} leakage into nuclear recoil band

  $\rightarrow$ **<0.9 events**
- Surface events – 5000 events, rejection factor 6×10^{-5}
  $\rightarrow$ **0.3 events**
- Muon induced events missed by veto $\rightarrow$ **<0.4 events**
- Neutrons from rock – GEANT4 simulations $\rightarrow$ **0.11 events**
- Neutrons from contaminants in shield/cryostat $\rightarrow$ **0.21 events**
- Neutrons from cabling inside cryostat $\rightarrow$ **1.1 events**

Total background estimate < 3.0 events 90% CL

The Xenon experiment
discussion

- Scalable technology (when compared with sets of several absorbers)

- Focus on Xe purification

- **Gamma rejection power** of XENON-100 **below the cryogenics detectors : keep only ≈ 40% NR**

- **Absolute energy scale** (Erecoil) (calibration with γ gives Eee)
Quenching Factor Leff : Er~Leff.Eee + electric field effect on the charge collection
Virulent discussion on arXiv with CoGeNT
New dedicated measurements (arXiv:1104.2587v1)
And some more discussions... (arXiv:1106.0653v1)