Direct Dark Matter Searches

Context

Detection principle: signal and backgrounds

Review of current experiments

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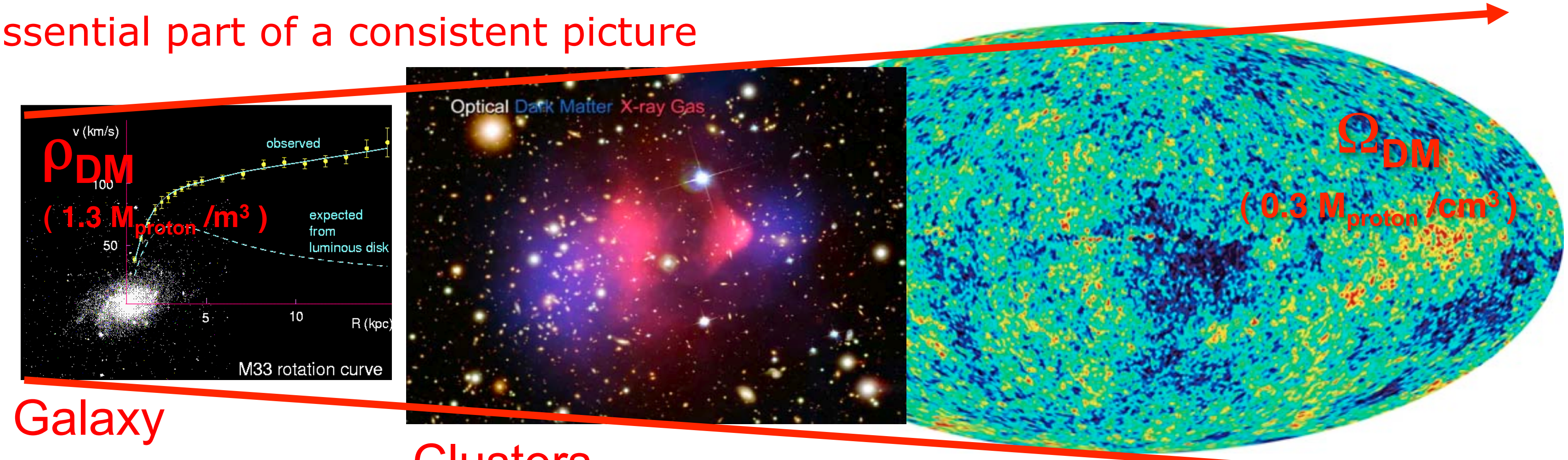
DIRECT SEARCH: CONTEXT

Cold Dark Matter in the Universe

- Cold Dark Matter present at all scales in the Universe…

Essential part of a consistent picture



Galaxy

Clusters

CMB

- Searched as a new particle at LHC
- Searched via the remains of its decay in cosmic rays (γ, ν, e+, antimatter)
- *… Direct seach: collision of WIMPs from our galactic halo on target nuclei I a laboratory on Earth*
  - Proof that Dark Matter is present in our environment
  - After discovery: observatory for WIMP velocity distribution in our environment?
  - Sensitive to local WIMP density ρ_{DM} (not to the cosmological density Ω_{DM})

(shortened) list of candidates

- **Axions**
  - Non-thermal relics (μeV->meV, CDM->HDM)
- **WIMPs**
  - Stable thermal relics
  - Electroweak physics (~ prediction on annihilation/creation/scattering cross-sections)
  - Mass 10-100-1000 GeV/c^2 (atomic nucleus are interesting targets: maximal momentum transfer)
- **Other models**
  - Many are also covered by WIMP search (KK…)
  - Models without detectable particles are not excluded!

See many other talks this week

Three complementary search strategies

Identification of a Dark Matter particle

See many other talks this week

1. **Creation at collider - LHC ($\sigma_{creation}$)**

2. **Detect annihilation products** (γ, ν, antimatter) **in cosmic rays ($\sigma_{annihilation}$)**

   [Antares, IceCube, FERMI, HESS, AMS, …]

3. **Scattering on target nuclei in Earth laboratory ($\sigma_{scattering}$)**

   [Direct Searches: this talk]

Is the halo of our Galaxy made of the same WIMPs that can be produced at colliders?

Risk Analysis

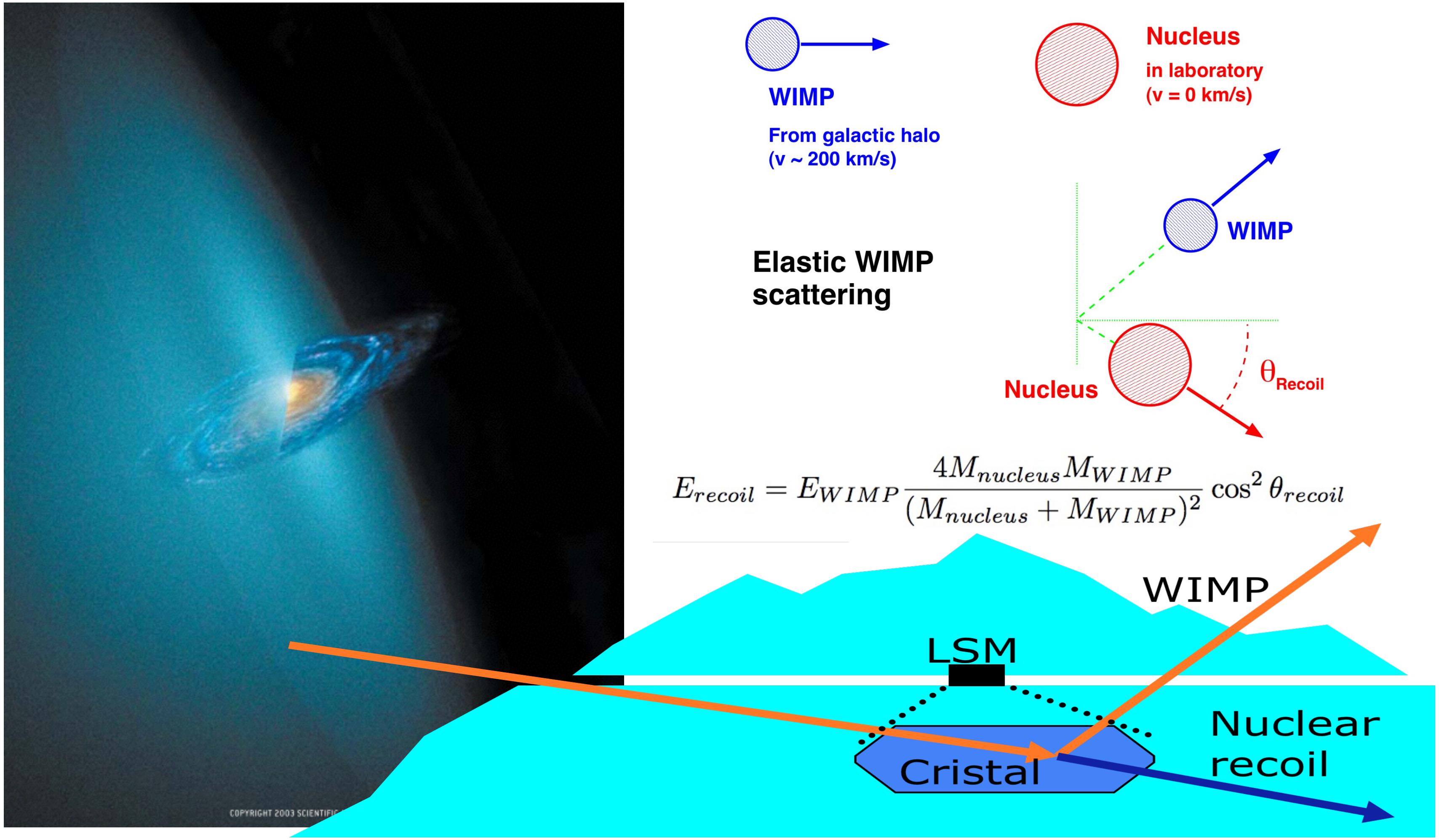
- One, two or three of the detection methods can fail:
  - *Dark matter may not exist as a particle*
  - *Dark matter particles may have decayed since the Big Bang*
  - *By accident, the local Dark Matter density is very small*
  - *Dark matter particle exists, but their non-gravitational interaction with normal matter is strongly suppressed (e.g.: the “WIMP miracle” is a fluke: there was no thermal production …)*

- Given the uncertainties on WIMPs, positive or negative results are needed on the three search methods. Each method has advantages and drawbacks

- LHC and indirect searches are performed in experiments dedicated to other physics anyways (particle physics, cosmic rays). Direct Searches are on dedicated instruments (although some can perform other type of rare event searches)

- New “proof” of absence/presence of Dark Matter per ~month: should we wait before investing in a Direct Search experiment? No, too many clues are pointing to that direction… and it takes decades to develop proper experimental techniques

Direct search schematics



$$E_{recoil} = E_{WIMP} \frac{4M_{nucleus}M_{WIMP}}{(M_{nucleus}+M_{WIMP})^2} \cos^2\theta_{recoil}$$

Observables: Event rate, E_{recoil} , θ_{recoil} (recoil range is related to E_{recoil})

WIMP-nucleon collision

Astrophysics

(standard convention)

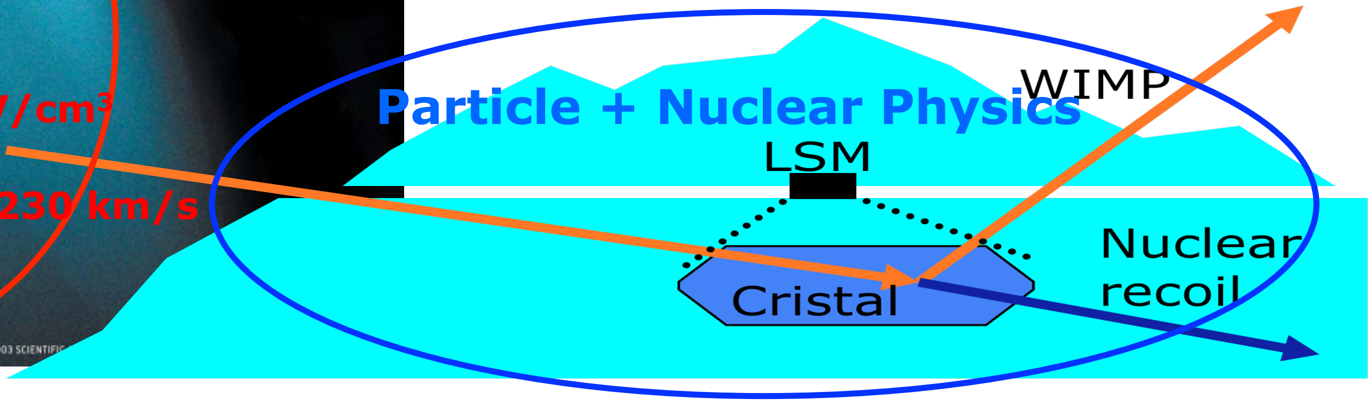
ρ_{wimp} **= 0.3 GeV/cm³**

$v_{WIMP} \sim v_{SUN} \sim$ **230 km/s**

Free parameters: M_{WIMP}, $\sigma_{WIMP\text{-}nucleon}$

Coherence factor

- ~A^2 for scalar coupling (spin-indep. interactions, *dominates for A>~20*)
- ~J(J+1) for axial coupling (spin-dep. interactions)
- Nuclear Form factor (reduce A^2 enhancement at large A)



PHYSICAL REVIEW D VOLUME 31, NUMBER 12 15 JUNE 1985

Detectability of certain dark-matter candidates

Mark W. Goodman and Edward Witten
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544
(Received 7 January 1985)

We consider the possibility that the neutral-current neutrino detector recently proposed by Drukier and Stodolsky could be used to detect some possible candidates for the dark matter in galactic halos. This may be feasible if the galactic halos are made of particles with coherent weak interactions and masses $1-10^6$ GeV; particles with spin-dependent interactions of typical weak strength and masses $1-10^2$ GeV; or strongly interacting particles of masses $1-10^{13}$ GeV.

Method suggested in 1985 (28 years ago!) by Goodman + Witten

- Predict rates between 4 and 1400 events/kg/day for heavy ν.
  $M\nu$ = 100 TeV ↵ ↳ $M\nu$ = 100 GeV

- As early as 1987, first significant constraints (*exclusion of a heavy* ν) with ionization Ge and Si detectors: sensitivity to ~ few evts/kg/day
  - Ge: S. P. Ahlen, et al., Phys. Lett. B 195 (1987) 603
  - Ge: D. O. Caldwell, et al., Phys. Rev. Lett., 61 (1988) 510
  - Si: D. O. Caldwell, et al., Phys. Rev. Lett. 65 (1990) 1305
- To do better, need better rejection of radioactive backgrounds
  - Competition between techniques: Pulse-shape discrimination in NaI? Phonon+ Ionization detectors *[Shutt et al, PRL 69 (1992) 3531]*? CsI? Liquid Ar? 2-phase Xenon? Bubbles? Etc …

Basic questions

- Direct Dark Matter searches are simple: just look at a large number of nuclei and see if any of them recoils due to a hit-and-run collision with a WIMP, but…

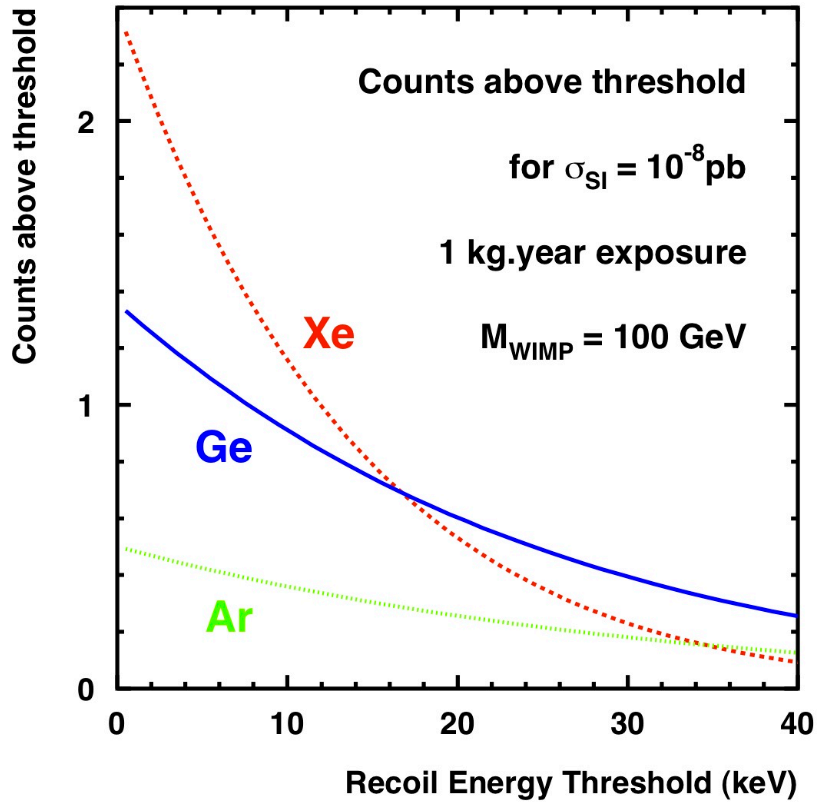
- How many such events can we expect per unit time and per number of target nuclei?

- How big is the kinetic energy involved in such collisions?

- What is the fake rate and how can we reject it?

- 10^{-8} pb ~ 1 evt/kg/year
  - Rate depends on *energy threshold* and *atomic mass*

Calculation based on Lewin & Smith convention [Astrop 6 (1996) 87]



Main challenge:

extreme suppression of background from natural radioactivity at low energy
(ex.: people = 10^{10} decay/kg/year)

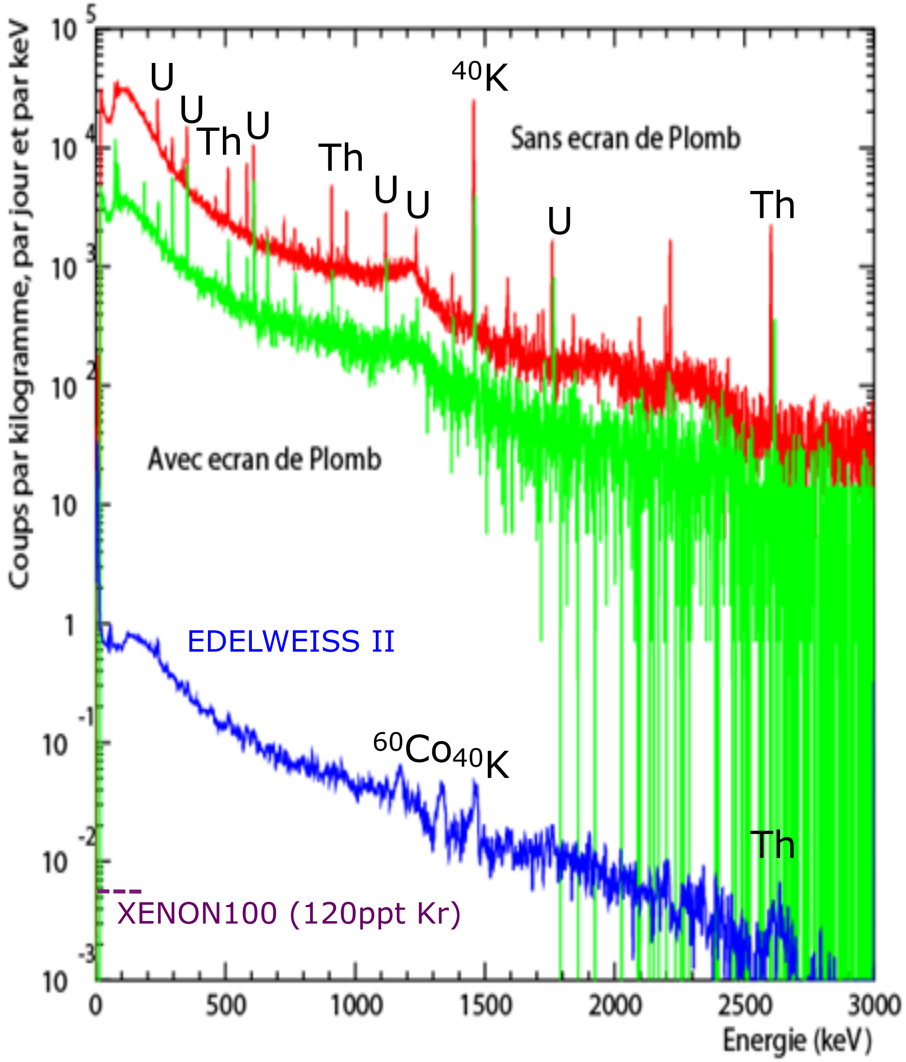
- *Material selection*
- *Shielding (surround.+cosmics)*
- *Rejection*
- *Detailed understanding of background tails and detector imperfections.*

Example of gamma background in Ge detector

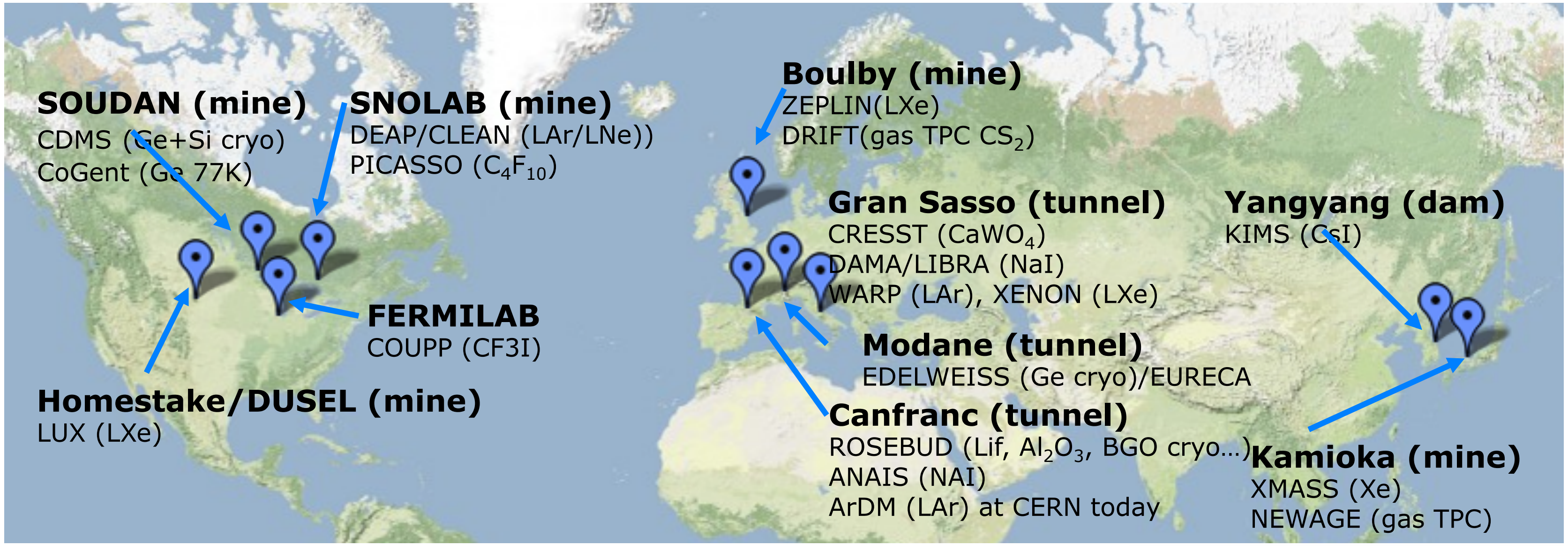
- Red: natural background in a « normal » environment (here…)
- Green: ~5 cm lead shield (large Z), reduction x ~10
- Blue: EDELWEISS-II in LSM, before the rejection of electron recoils.

  Reduction 3×10^4 at ~50 keV (Pb shield, material selection)

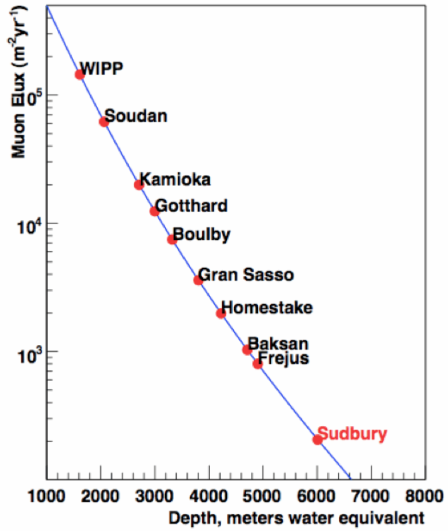
- Further reduction $>10^4$ after nuclear recoil identification



Dark Matter Searches around the world



- Underground sites (cosmic rays)
- Combine signals for ion/electron recoil identification
  - Heat (or thermalized phonons): “true” calorimetric energy
  - Ionization Yield
  - Scintillation Yield
  - Pulse shape discrimination: useful in some cases (Ne, Ar)
  - Also: dE/dx in superheated medium: COUPP, PICASSO



WIMP signatures

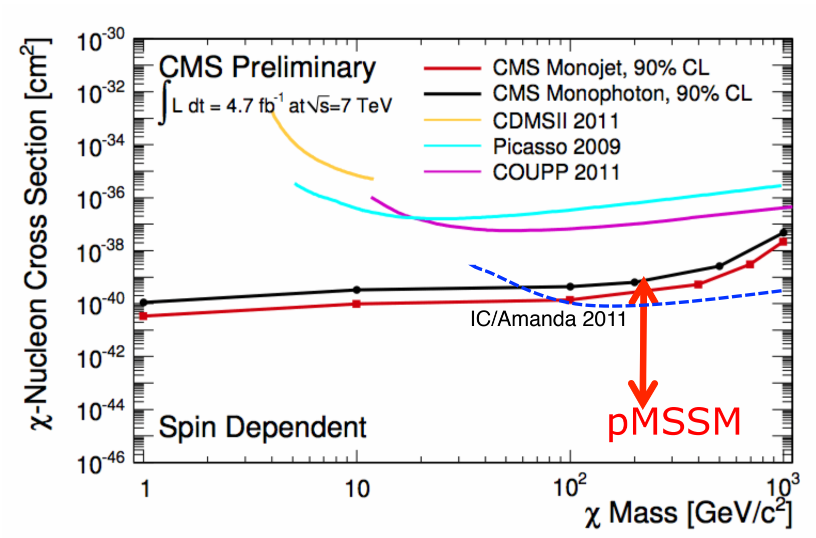
- Directionality (correlation with v_{sun})
  - Challenge: ~20 nm recoil in solid, ~30μm in gas
  - Low-pressure TPC? -> Still in R&D [DRIFT, DMTPC, MIMAC…]
  - *Small annual modulation of flux (~2%) requires large statistics + depends more on velocity distribution details.*
- Nuclear (and not electron = dominant bkg) recoils
  - **Particle identification**
- A^3 dependence of coherent scattering rate/kg
  - Motivates **diversity of target materials**
- Large scattering length
  - **Self-shielding** *[Xenon, Argon]* or **segmentation+multiplicity** *[Ge, Scintillators]*
- Control of systematics also favours target/expt. diversity

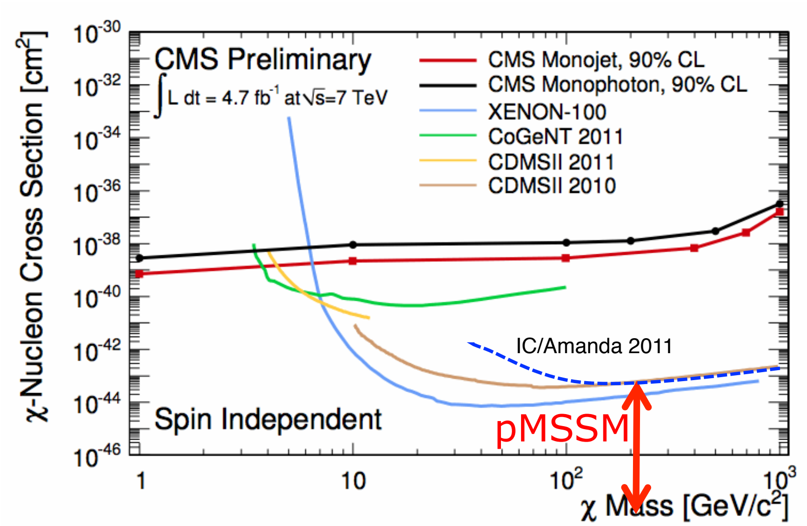
Spin-dependent interactions

- In many models (like SUSY) axial, spin-dependent (SD) interaction are either already excluded, or mixed with spin-independent (SI) component.

  (… but this statement is model-dependent)

- SI component amplified by A^2 coherence tends to dominate.
- SD most efficiently probed by indirect searches (ν detectors) or even LHC, as SD searches don't benefit from A^2 coherence factor.



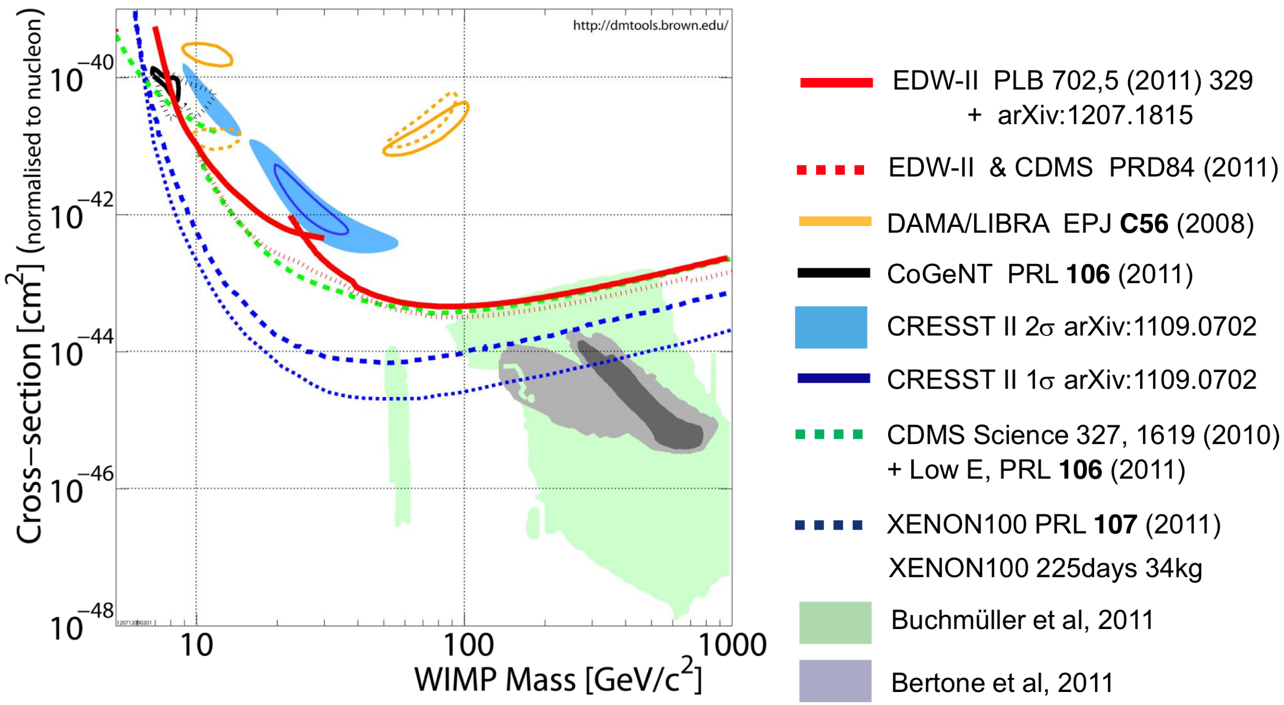


CMS Moriond EW 2012 + PRD85 (2012) 042002

The search domain

- We don't know (yet) what is the mass of the WIMPs
- We don't know (yet) what is the cross-section for WIMP-nucleus scattering
- Generic searches for ALL WIMPs masses M_W and ALL cross-section σ.
- A given experiment will be able to probe a certain region of (M_W, σ):

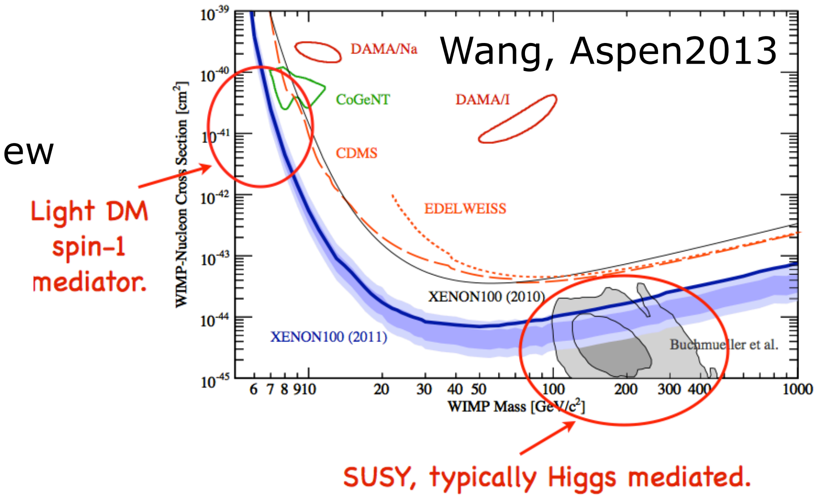
"exclusion plots"



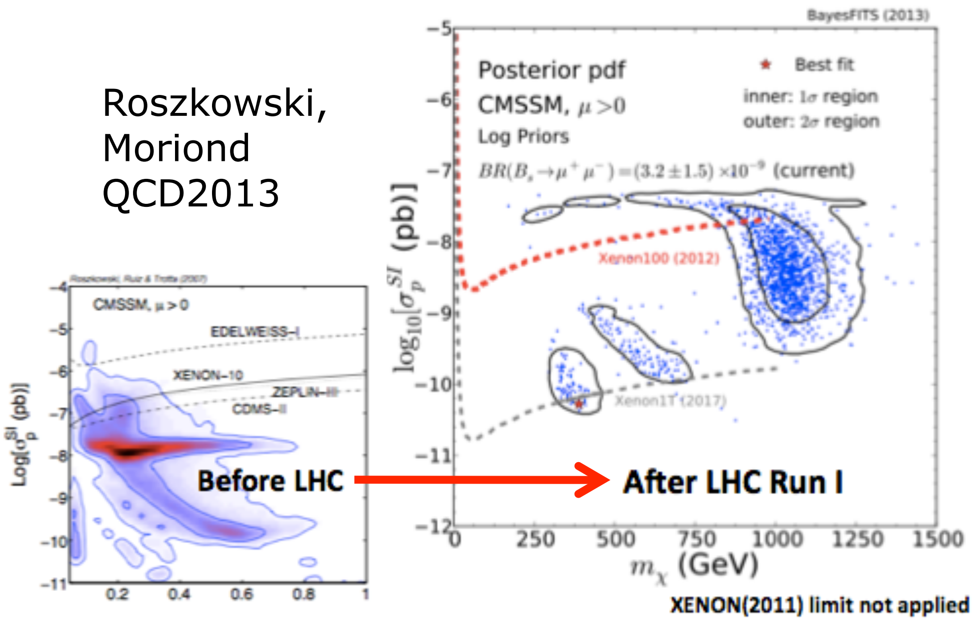
See many other talks this week

Light or Heavy? - predictions

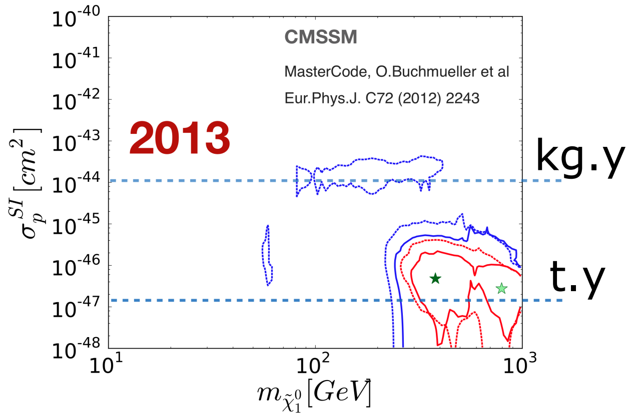
- Absence of “minimal” SUSY at LHC opens SUSY phase space
- Less predictive in terms of M_{WIMP}
- Two (opposing?) biases:
    - heavy SUSY suggests heavy WIMPs
    - absence of SUSY calls for something new
    - … lighter than conventional SUSY?



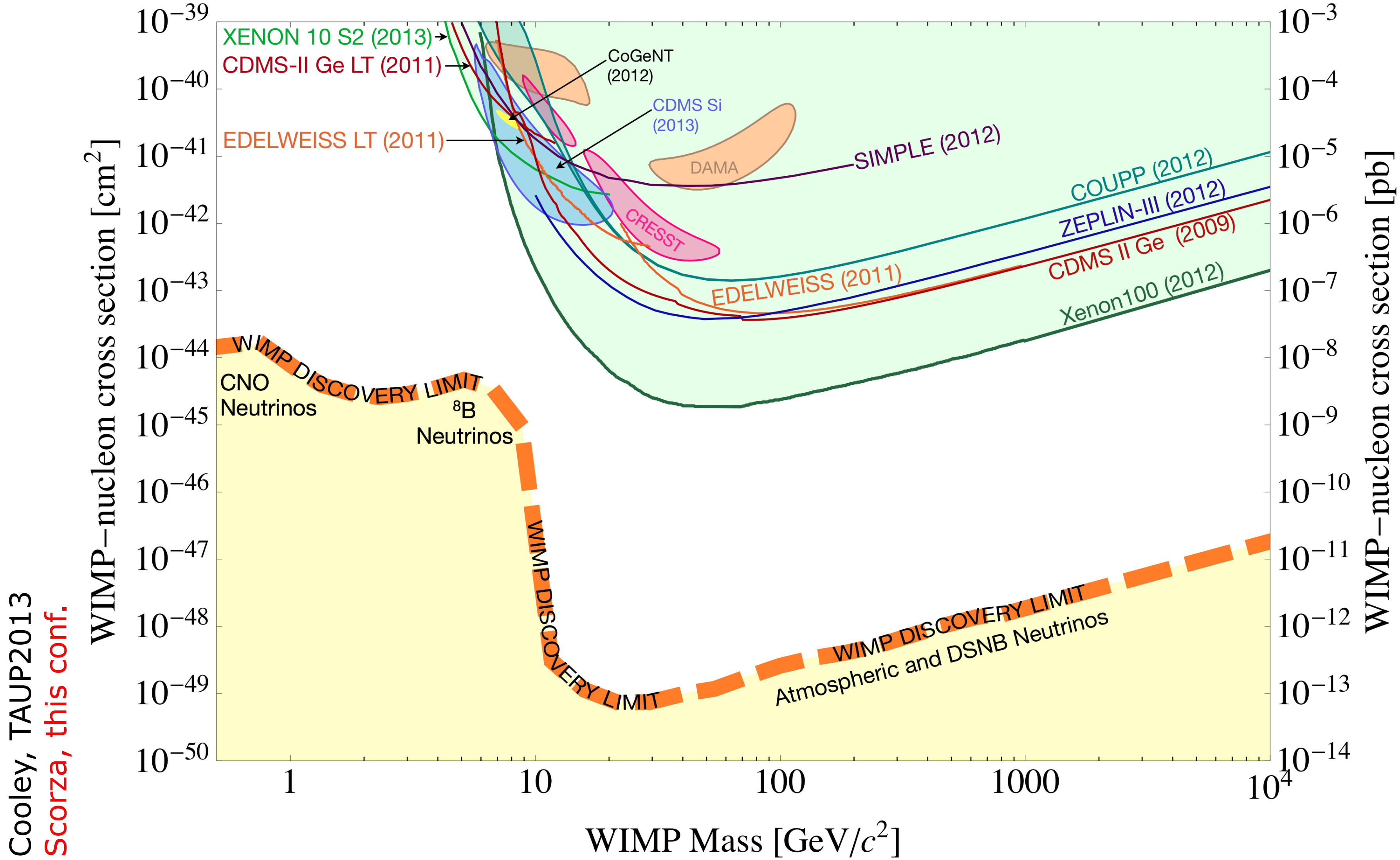
Roszkowski, Moriond QCD2013



Baudis, TAUP2013



The experimental search domain



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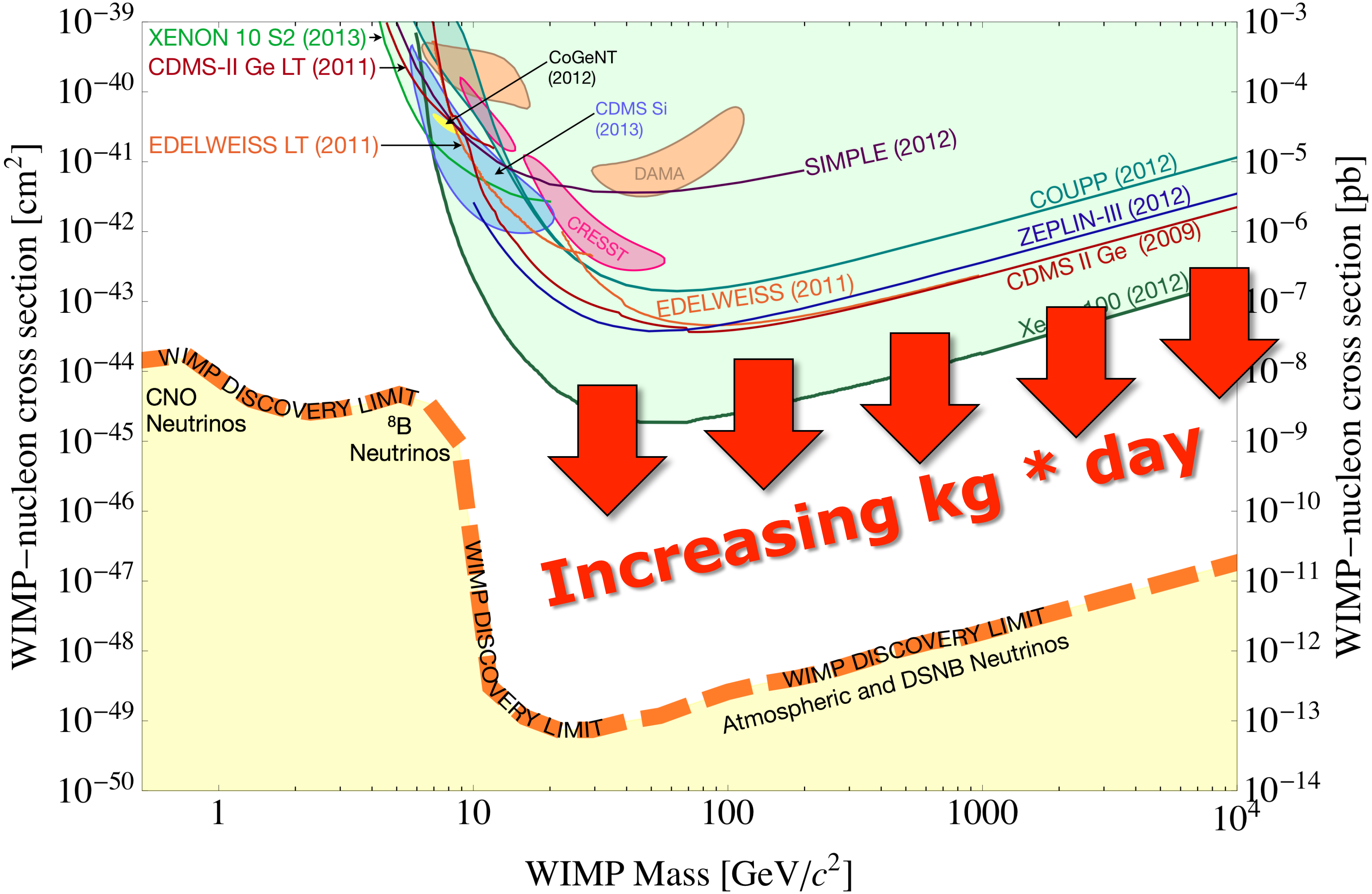
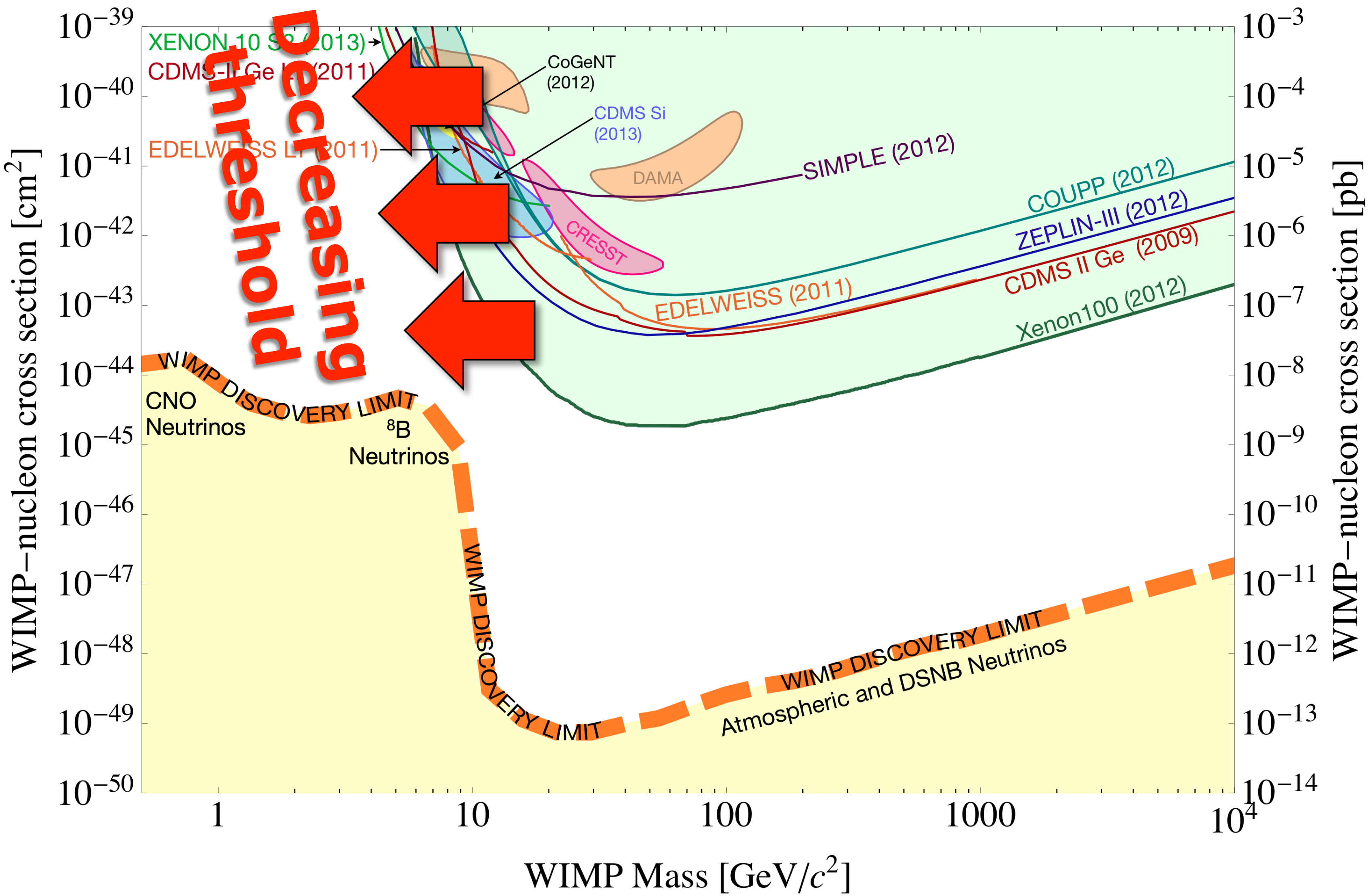


Cooley, TAUP2013
Scorza, this conf.

The experimental search domain



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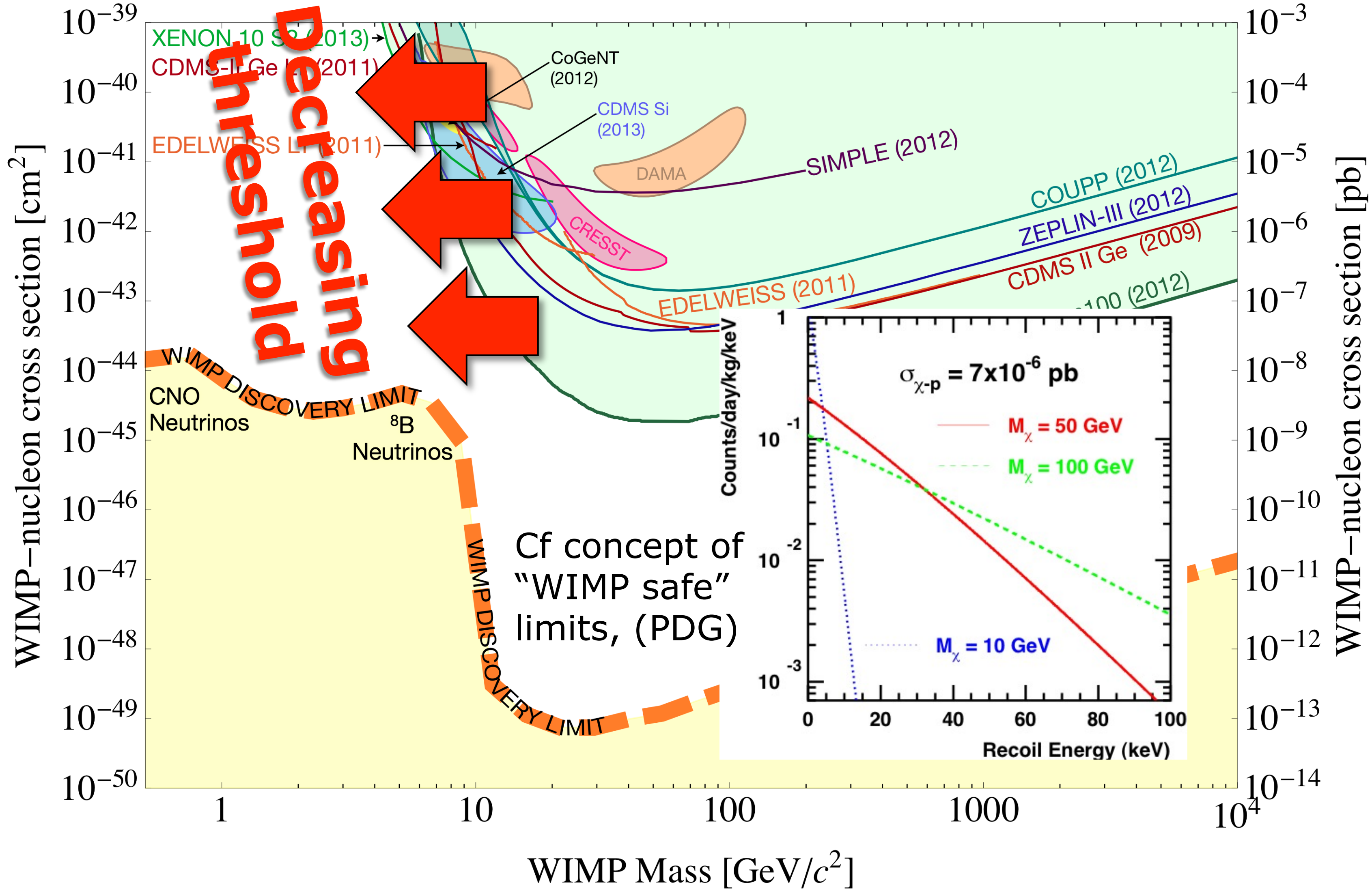

Cooley, TAUP2013
Scorza, this conf.

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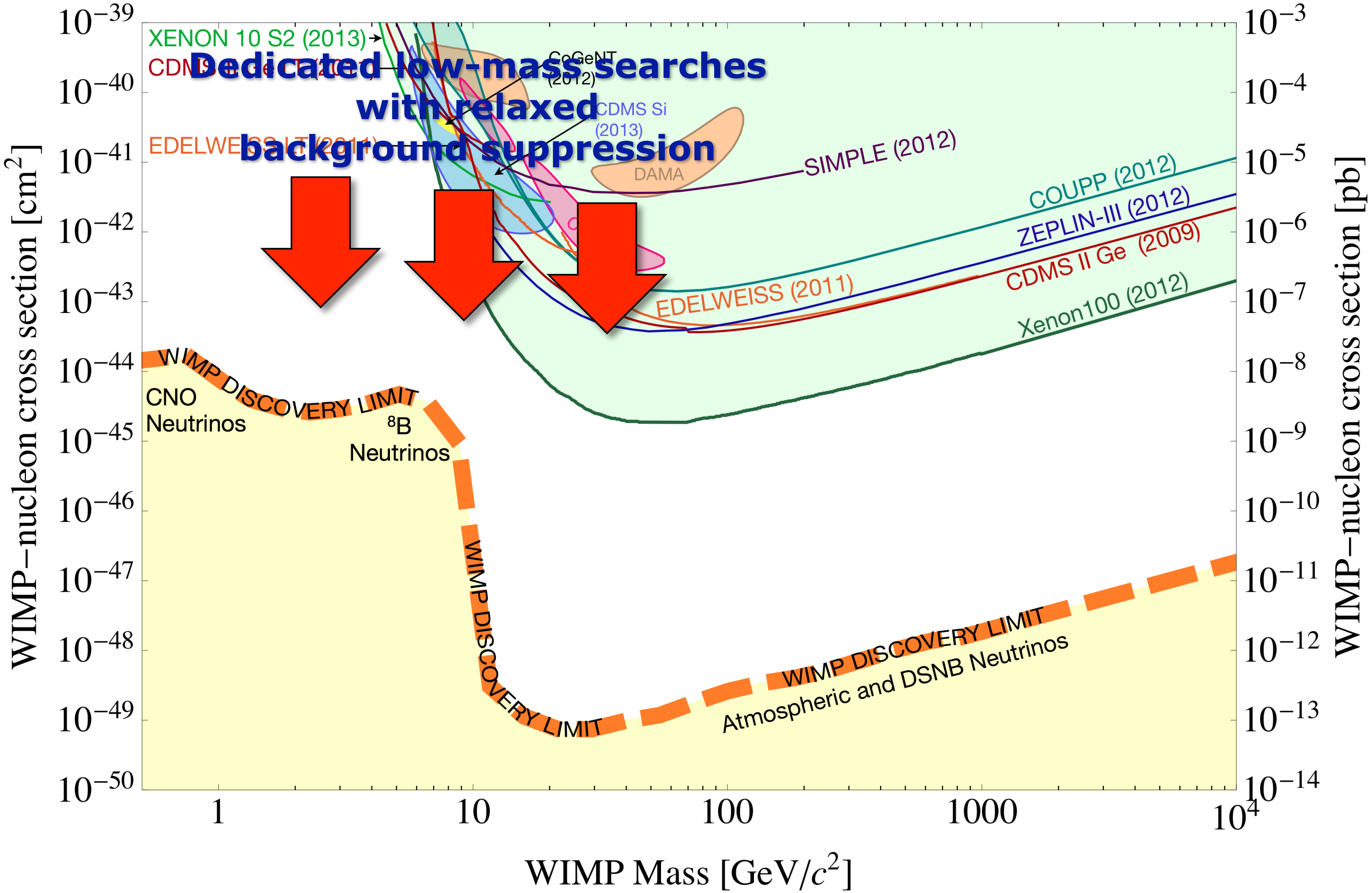


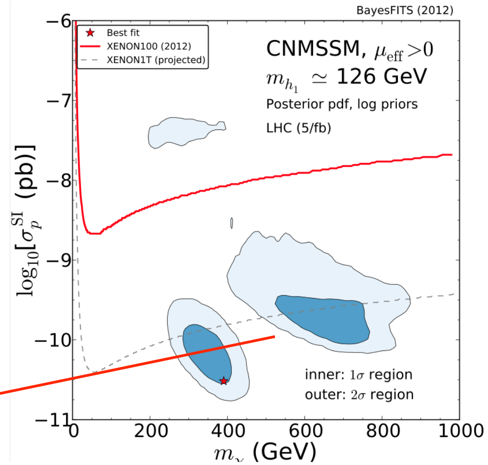
Cooley, TAUP2013
Scorza, this conf.

Apply to any particle able to scatter elasticaly on an atomic nucleus

(Neutralino χ, Kaluza-Klein, mirror, scalar...)

- *... If the kinetic energy of the WIMP* E_{WIMP} *is not too small*
  - $M_{WIMP} \sim 100$ GeV/c^2 (supersymmetry) and v ~ 200 km/s correspond to an average $E_{WIMP} \sim 20$ keV (hard X ray).
- *… If* $M_{WIMP} \sim M_{nucleus}$
  - Optimal momentum transfer for $M_{WIMP} = M_{nucleus} \sim 100$ GeV/c^2 corresponding to A ~ 100 g/mol
- *... If the scattering probability is not zero*
  - Small, otherwise already seen?
  - WIMP miracle suggests Weak scale
  - Weak force, supersymmetry:

    kilo.day… to ton.year (10^{-10} pb).



PRD 87 (2013) 115010

2- DETECTION TECHNIQUES

Signals in direct searches

- Exponential recoil spectrum
- A^3 dependence of rate

It's not a neutron-induced nuclear recoil ($\sigma = \pi R^2 \propto A^{2/3}$)

- No coincidence between adjacent detectors (detector array)
- Uniform rate within the fiducial volume (large detectors)

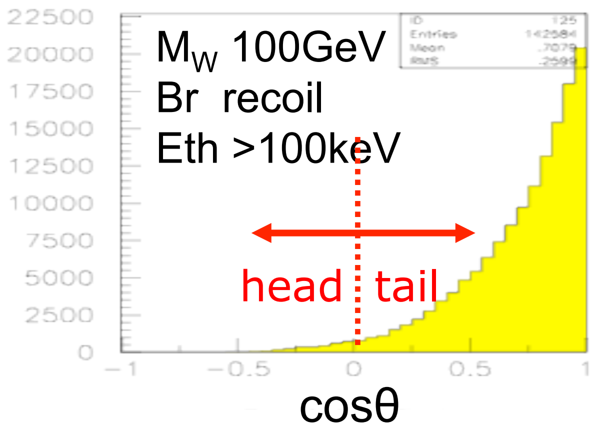
- Directionality (correlation with $\vec{v}_{SUN}$ direction): need to measure nuclear recoil trajectory
- Annual modulation (large statistics needed)

- ***Identification of nuclear recoils (vs electron recoils)***

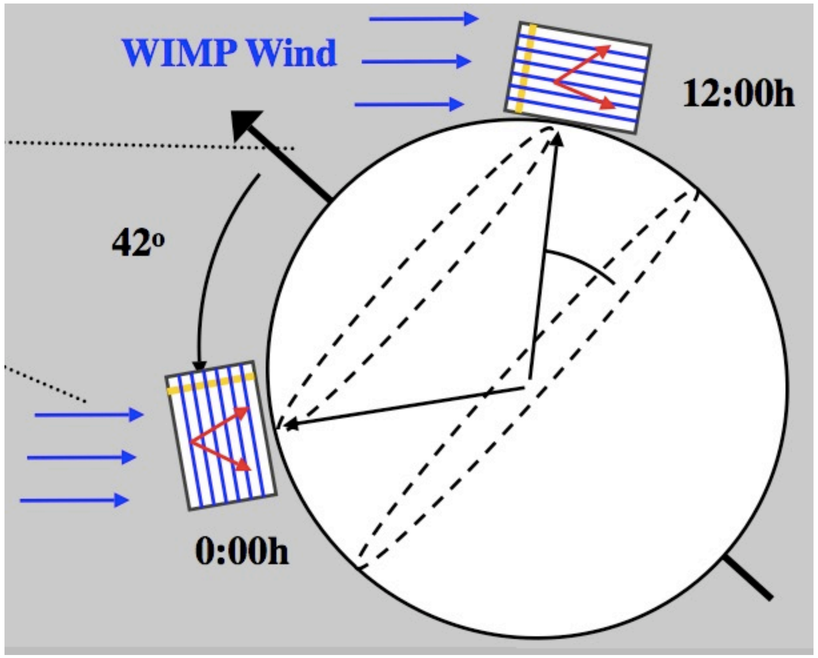
Directionality: use v_{Earth} to detect WIMP wind

- Average WIMP wind direction due to v_E
- $\theta_{RECOIL} \neq \theta_{WIMP}$

  but $<\theta_{RECOIL}> = <\theta_{WIMP}>$



Naka, IDM2008

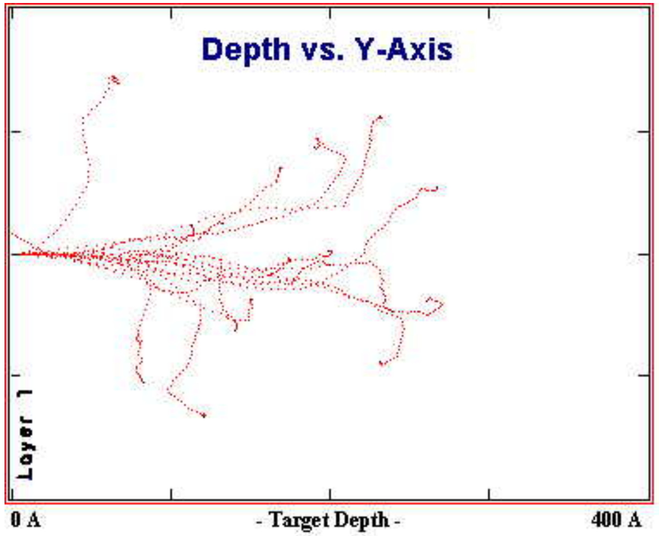


Spooner, IDM2008

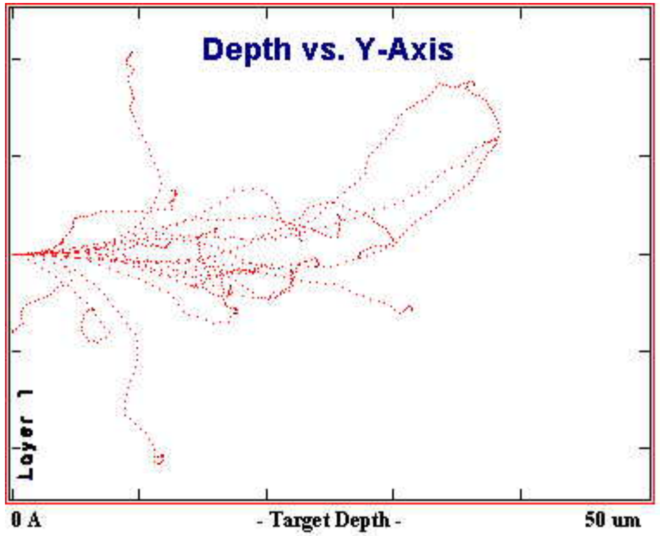
- Need a good resolution on the recoil direction (and head/tail discrimination) despite the very short range of the recoil
- Astrophysics bonus: measure of f(v)

Range of nuclear recoils in matter

20 keV Ge recoils
in crystal Ge:
Range ~20 nm



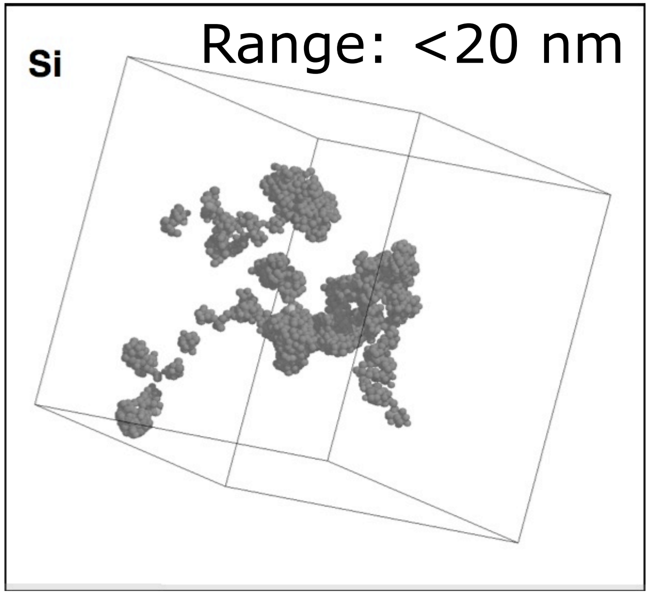
20 keV Kr recoils
in gaseous Kr:
Range ~30 µm

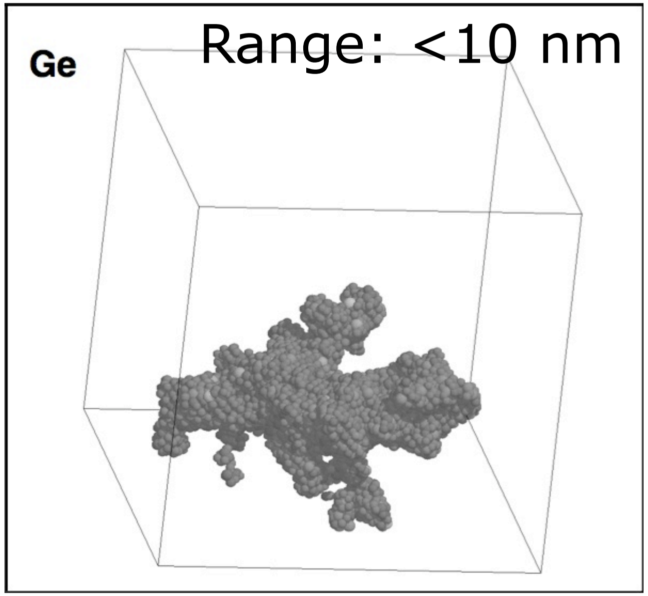


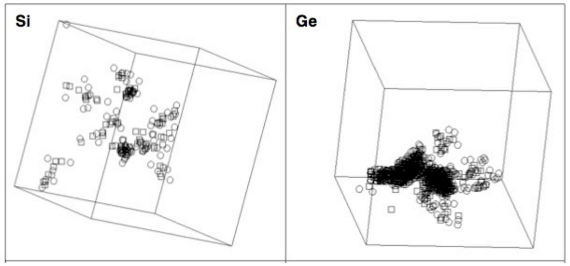
SRIM

Directionality of nuclear recoils

- Molecular Dynamic Simulations of « hot » atoms produced by a 10 keV Si or Ge recoil (Nordlund, 1998)







Permanent damages due to this « femtoGray » dose (negligible in metals, but maybe not in semiconductors?)

R&D on direction-sensitive techniques

- Idea: check for recoil tracks in ancient mica, $\theta_{recoil} \sim -v_{sun}$
  - *Problem: direction of v_{sun}, v_{earth} changes constantly, continental drift…*
- Idea: low-pressure gas TPC detector

Expt		Target (bar)	F mass (g)	Vol. (L)	Thresh. (keV)
DRIFT	UK	CS_2 (0.04) CF_4 (0.01)	33	800	50
NEWAGE	JPN	CF_4 (0.2)	9	15	140
MIMAC	F	CF_4+CHF_3 (0.05)	1	5	20
DM-TPC	US	CF_4 (0.1)	3	9	80

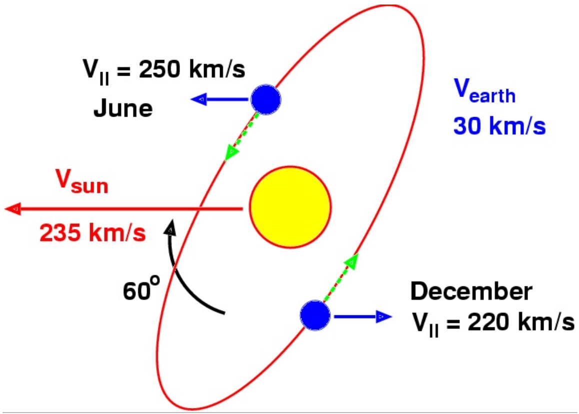
  - *Problems: low-density target to expand track length to ~cm, reduce diffusion of e−/ion (negative CS_2 ions instead of e^-)*
- Idea: scan tracks in emulsions
  - *~100 nm resolution; ~200 keV threshold for Br recoils (200 nm)*

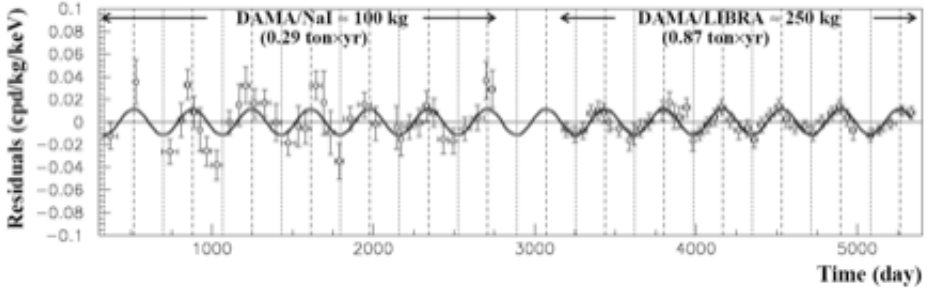
Annual modulation in DAMA

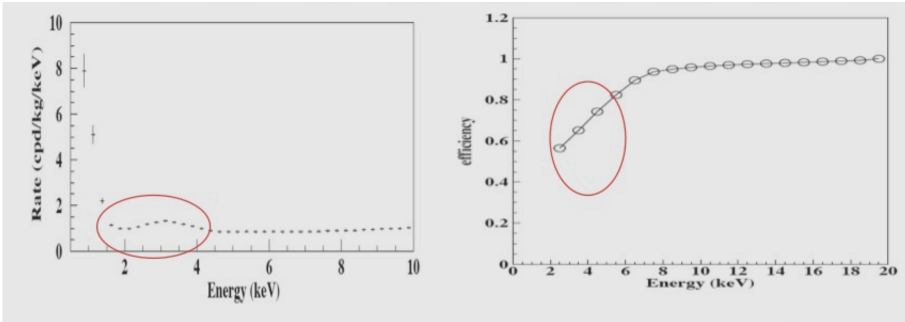
- Need large statistics: flux modulation is ~½ (±15/235) = ±3%, or less when considering experimental thresholds

- Claimed to be observed (~±2%) at low-energy in NaI (DAMA)

- Non-modulating component (~1 evt/kg/day) is ~total rate in NaI, but not observed in Ge, Xenon, $CaWO_4$ and CsI.
- Signal in low-efficiency, near-threshold region
- No "source off" expt. possible

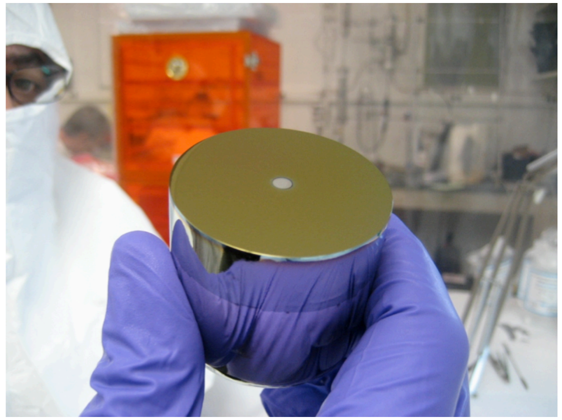


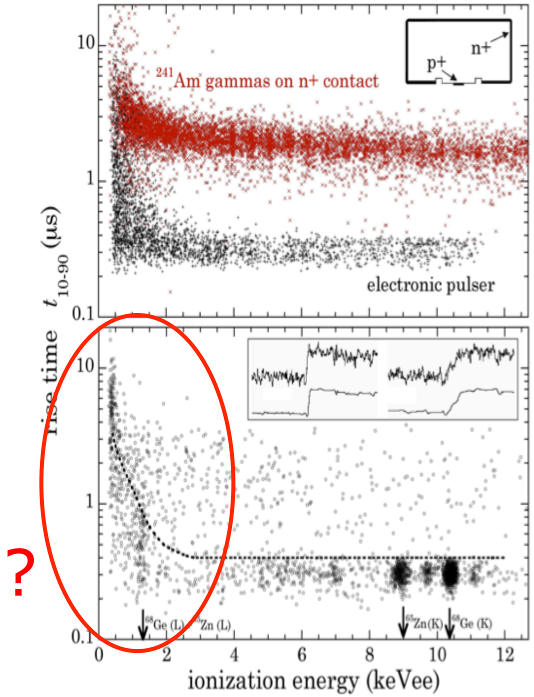


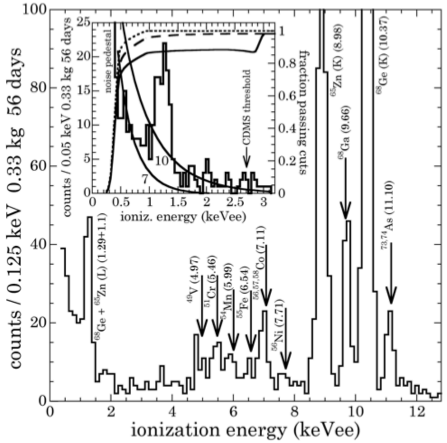


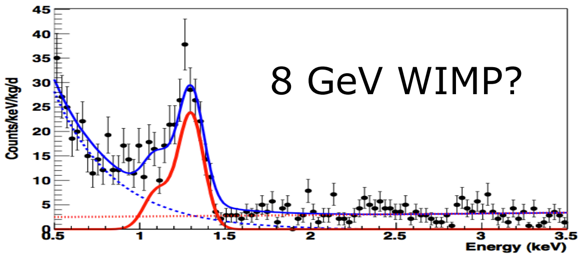
CoGeNT Modulation

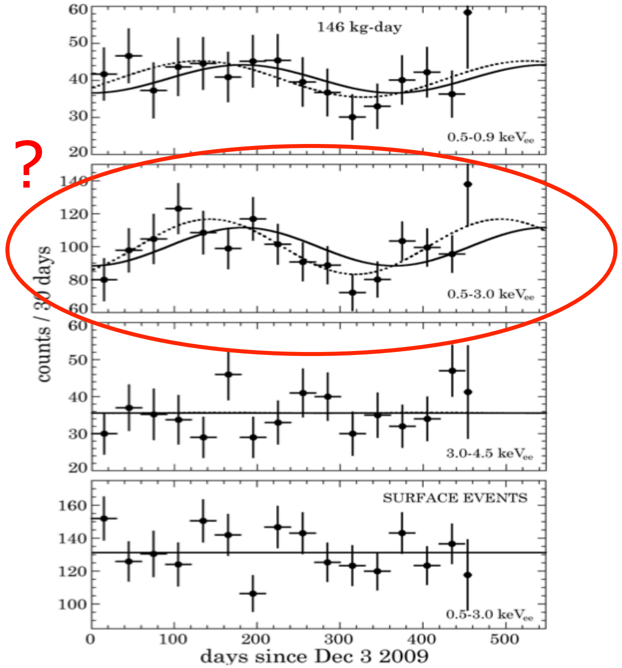
- 440 g Ge diode, point-contact electrode
- Arxiv:1002.4703 (Risetime discr. of surface evts)
- Arxiv:1106.0650 (Annual modulation)
- Arxiv:1208.5737 (Revised evaluation of rejection performance, *reduction of annual modulation*)



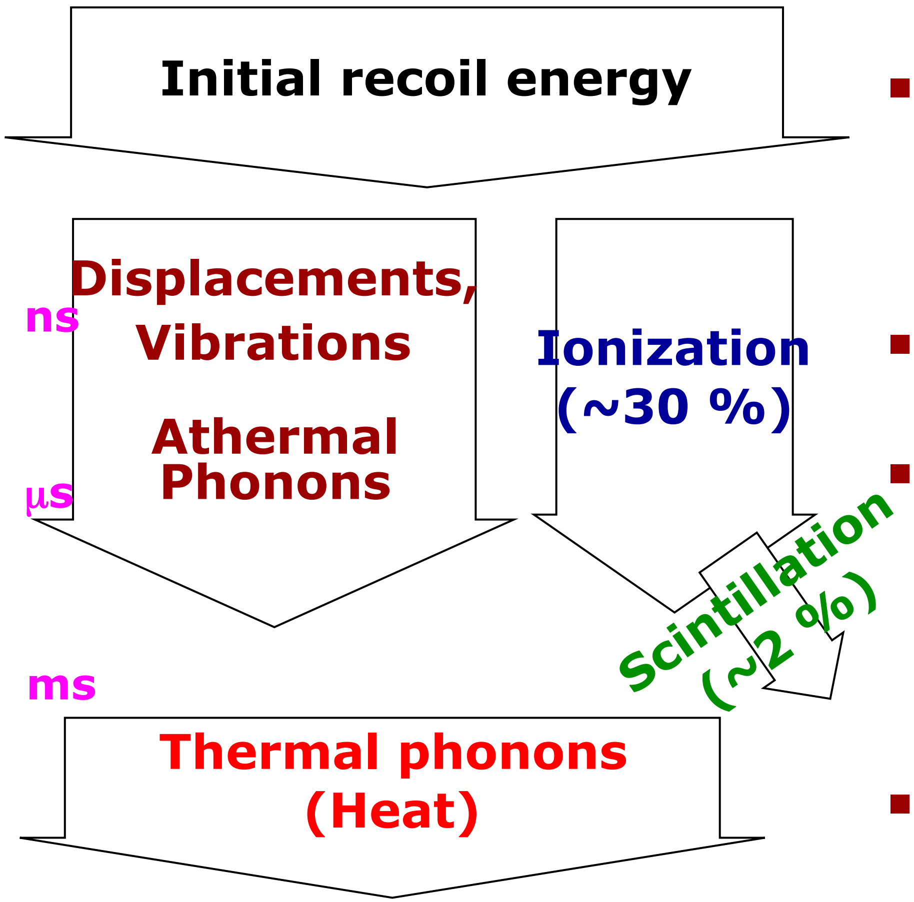








Effect of a nuclear recoil in matter

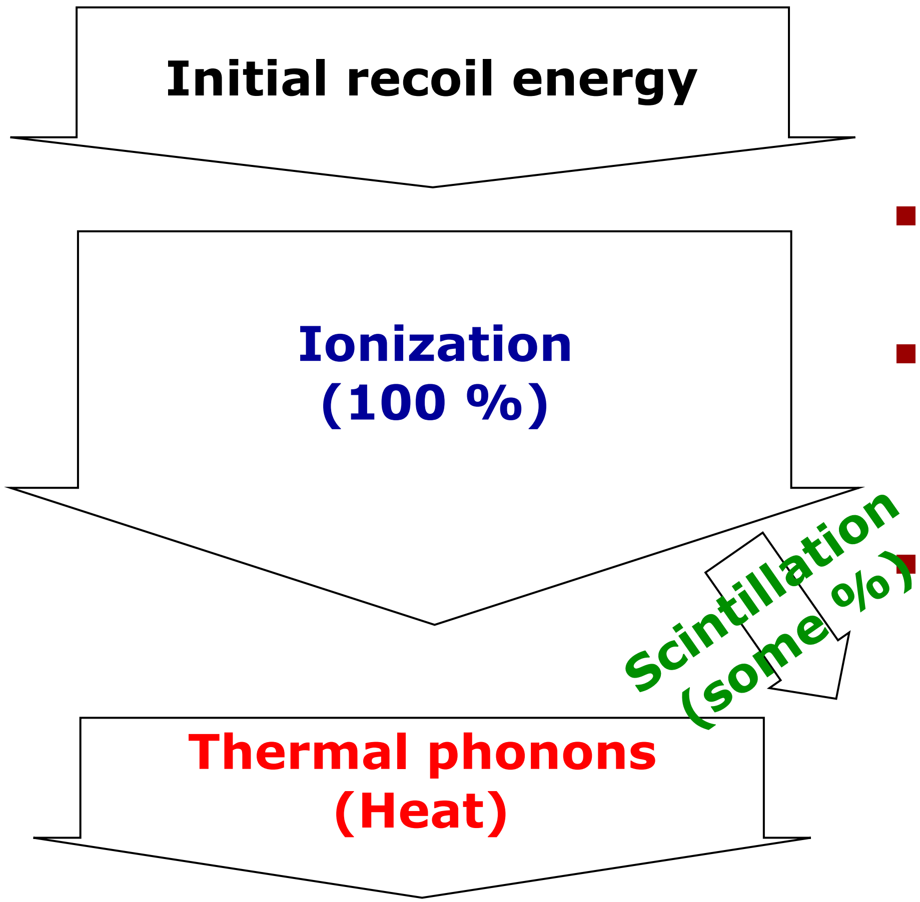


(+ Permanent crystaline defects?)

Two type of energy losses:

- Ion-ion collisions (producing displacements and vibrations in the crystal: athermal phonons): nuclear dE/dx.
- Ionization (electronic dE/dx)
- Cascade of collisions and mix of nuclear & electronic dE/x well described by Lindhard's theory + measured dE/dx
- In a closed system, after a while, all excitation decays into thermal energy -> rise in temperature

Effect of an electron recoil in matter

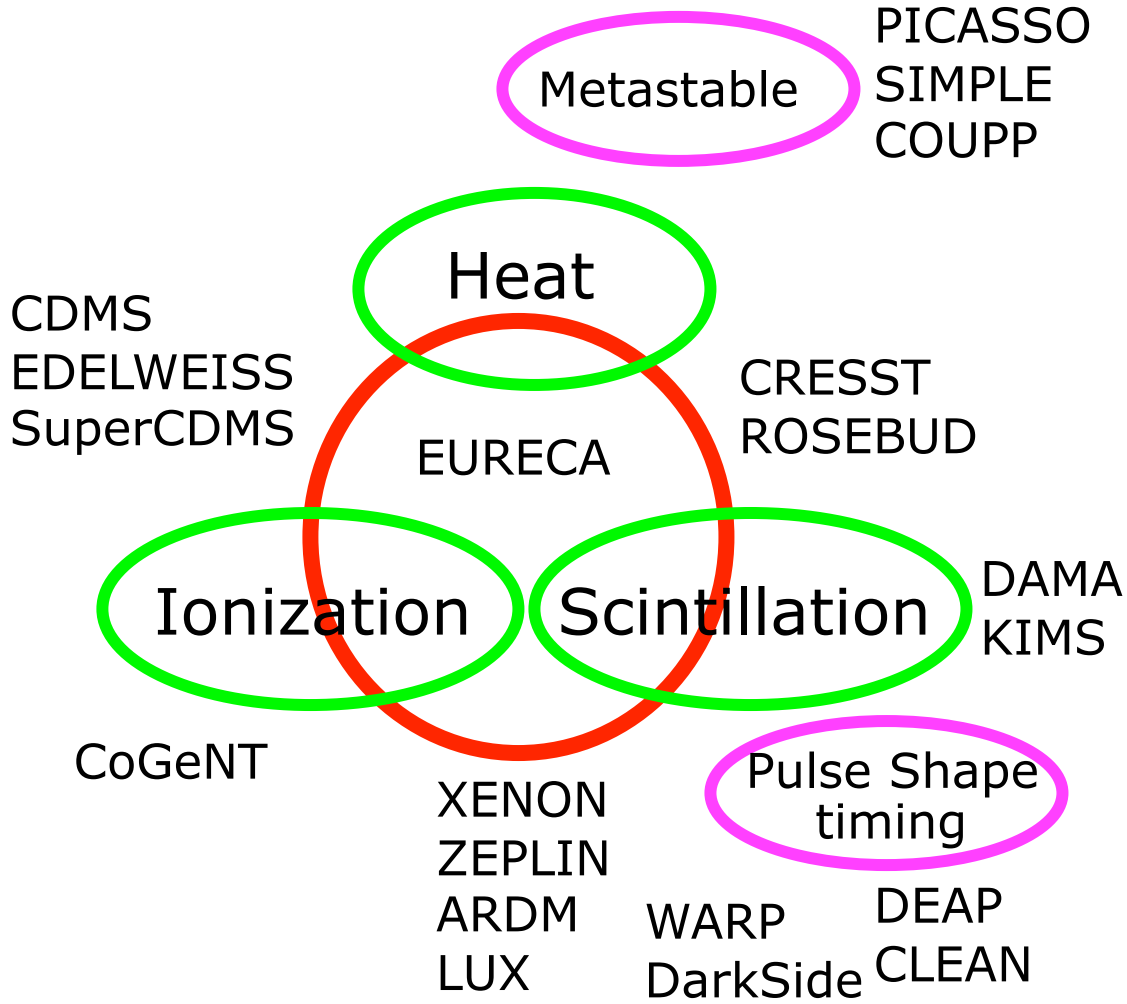


(+ No permanent crystaline defects?)

- Most common (long range) radioactive background: γ-rays, producing electron recoils (photoelectron, Compton)
- No ion-ion collisions only electronic dE/dx
- Comparing ionization and scintillation yields is a powerful tool to separate nuclear and electron recoils
- Other effects due to difference in dE/dx: density of energy deposit are not the same. This may also affect the risetime of the scintillation signal (pulse shape discrimination)

γ, β discrimination:

- Two simultaneous signals
  - Heat/Phonon
  - Ionisation
  - Scintillation
- Pulse shape discrimination
  - Noble gas/liq.
  - Cristal
- Other "dE/dx" related ideas



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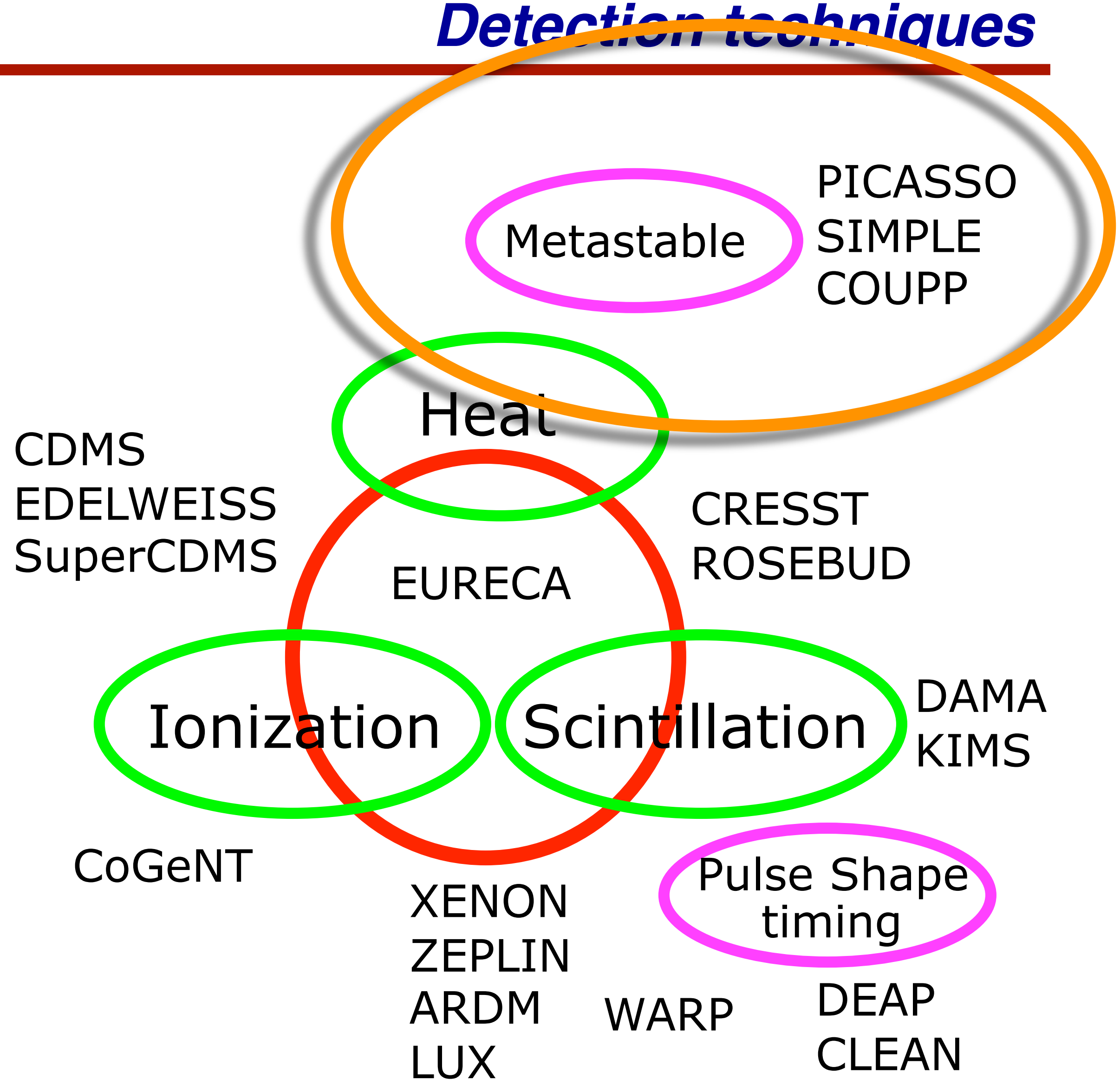
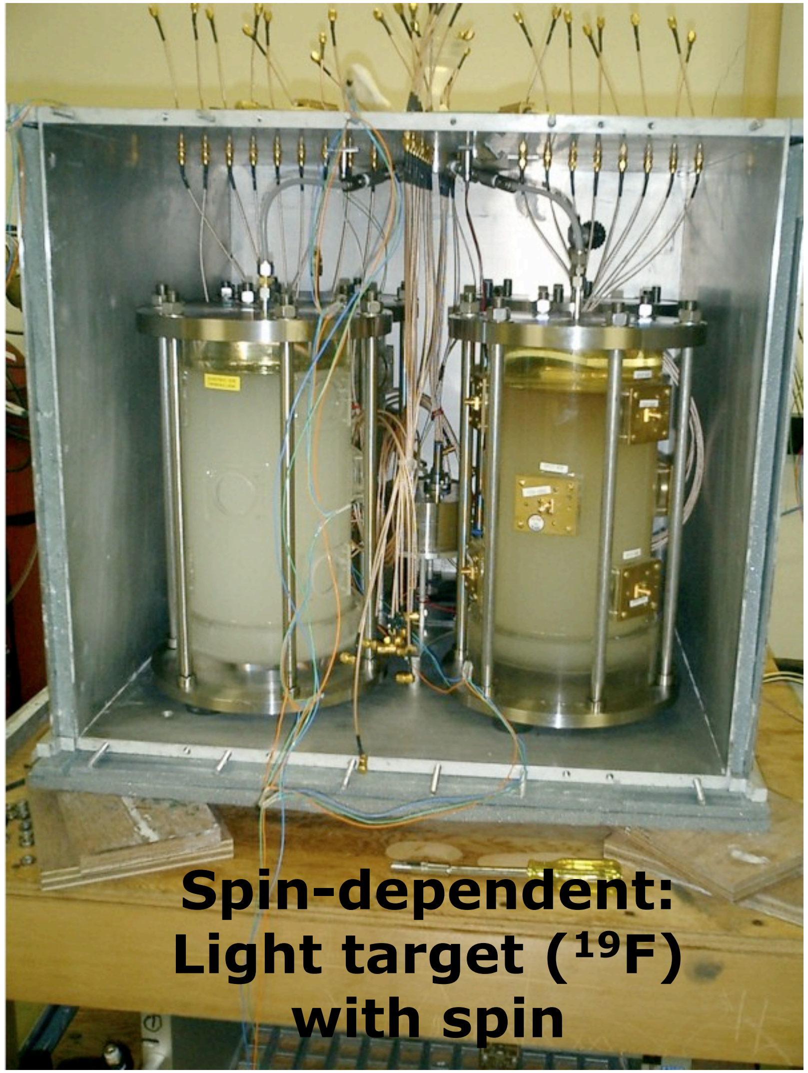


dEdx discrimination: Picasso detectors (Canada)

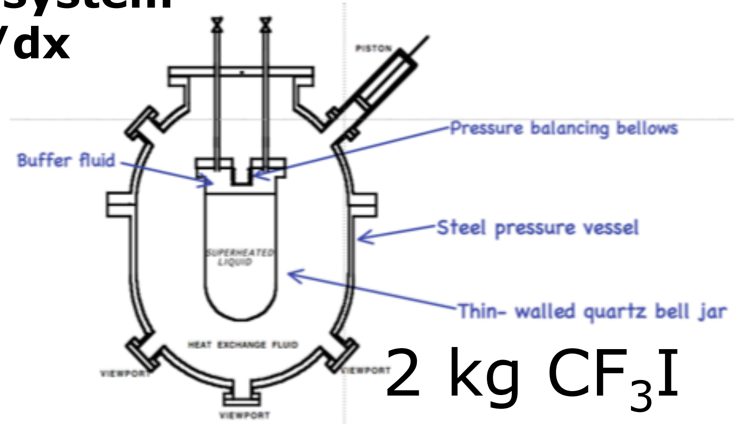
- Derives from a neutron dosimeter technique
- Tiny (200µm) liquid droplets of freon suspended in a gel as active material.
- The droplets are kept in a superheated state.
- When a WIMP hits the droplet the freon changes phase to a gaseous bubble.
- Shock wave that is detected by a piezo-electric sensor
- Temperature adjusted so that α dE/dx can't burst droplets
- Further α discrimination using audio pulse shape



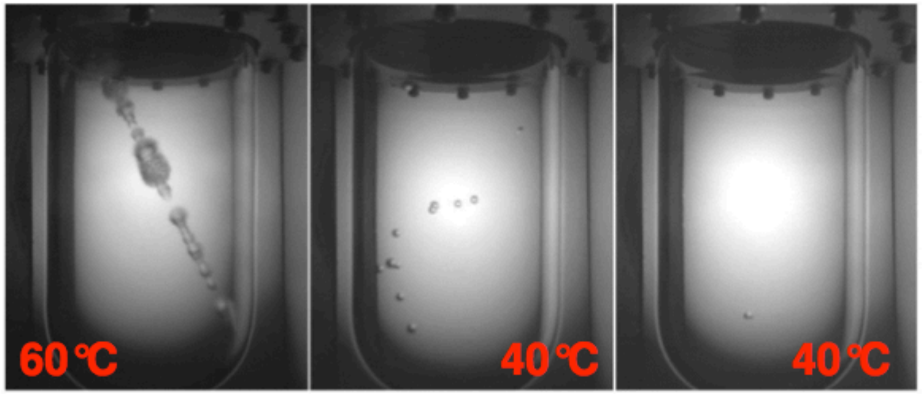
Spin-dependent: Light target (^{19}F) with spin

Discrimination « dE/dx» : COUPP

Bubble formation in metastable system triggered by large+localized dE/dx



2 kg CF_3I



muon | Neutron(s) | WIMP

Spin-dependent:
Light target (^{19}F) with spin

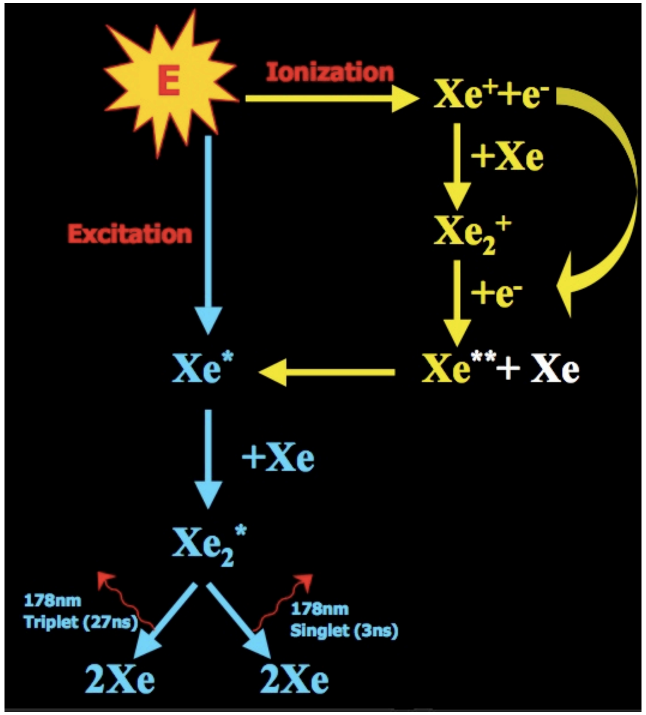
A CCD camera takes pictures at 50 Hz. Chamber triggers on appearance of bubble in the frame.

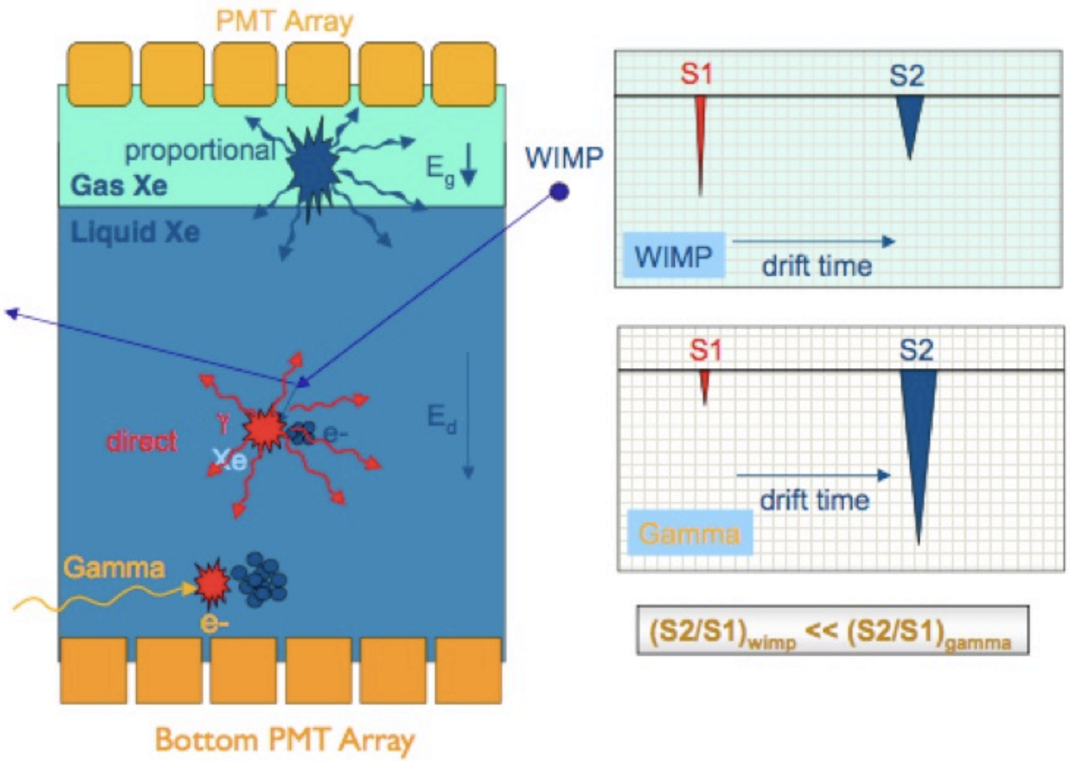
See Luca Scotto Lavina's talks this Friday

NOBLE LIQUID + GAS

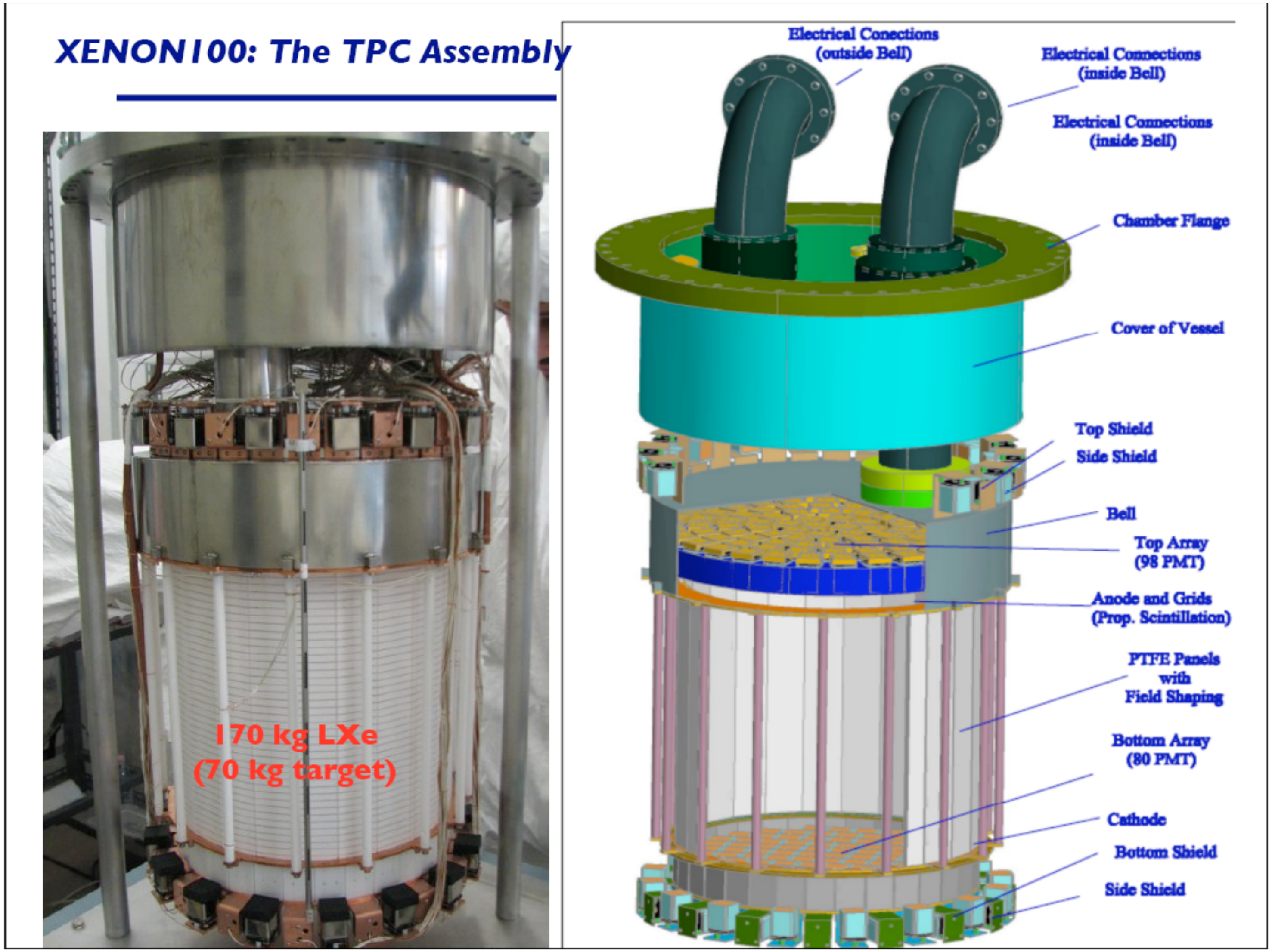
XENON S1/S2 discrimination

- Different scintillation (S1) and ionisation (S2) yields for nuclear / electronic recoils
- PMT array for (x,y), drift time for z : fiducial volume
- **Xenon 100**: 170 kg LXe, 34 kg fiducial, 30 cm drift, 98(top)+80(bottom) PM's
- *Trigger on 3 PM coincidence: bad energy resolution, but excellent noise suppression*
- 10 keV nuclear recoil: S1 ~ 5 P.E. S2 ~ 800 P.E. (from ~30 ionization e^-)



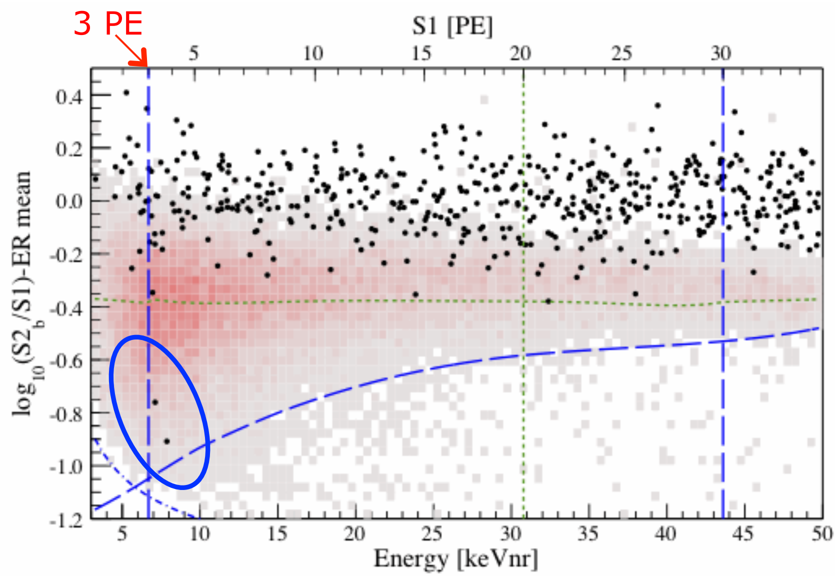


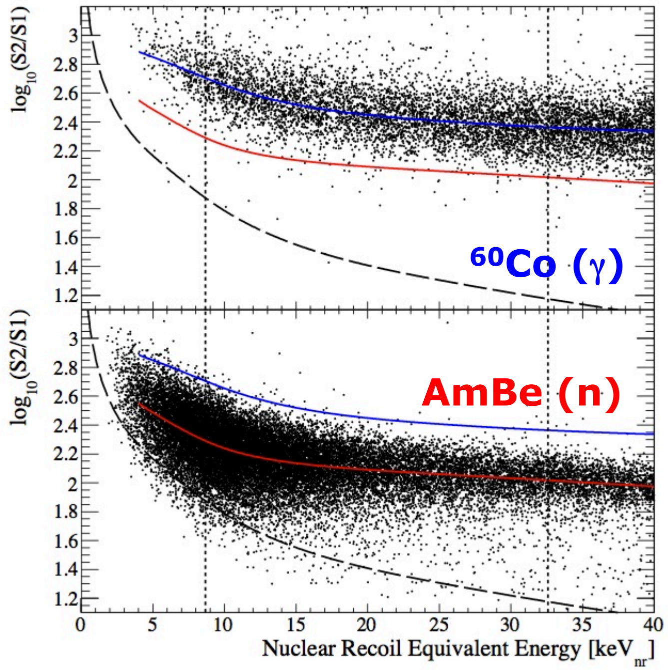
XENON100

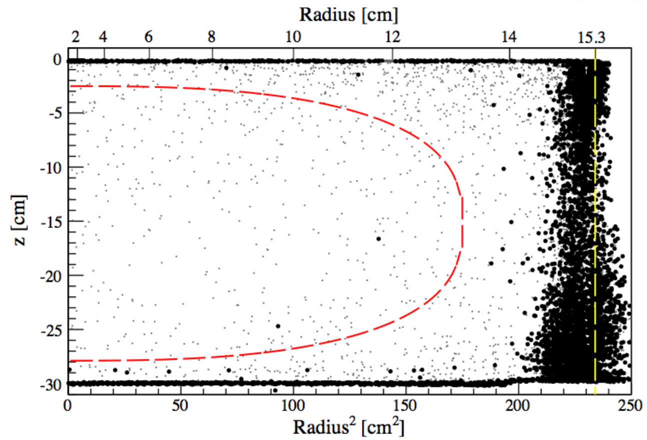

XENON100: The TPC Assembly
170 kg LXe
(70 kg target)
Electrical Conections
(outside Bell)
Electrical Connections
(inside Bell)
Electrical Connections
(inside Bell)
Chamber Flange
Cover of Vessel
Top Shield
Side Shield
Bell
Top Array
(98 PMT)
Anode and Grids
(Prop. Scintillation)
PTFE Panels
with
Field Shaping
Bottom Array
(80 PMT)
Cathode
Bottom Shield
Side Shield

XENON-100 Discrimination

- 34kg Xe fiducial (h~ 25 cm, r ~13 cm)
- 225 day exposure, 3 PE S1 threshold
- Profile Likelihood analysis of ~7600 kg.day
  (Equivalent to ~2300 kg.d max. gap analysis)
- Low g background (19 ppt ^{85}Kr)
- Observe 2 evts, compatible with expected bkg = 1.0±0.2 evt (0.2 n + 0.8 Compton)

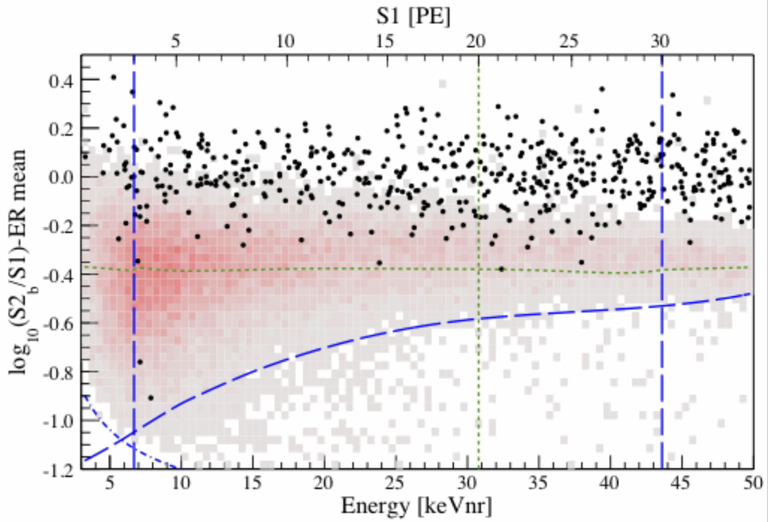


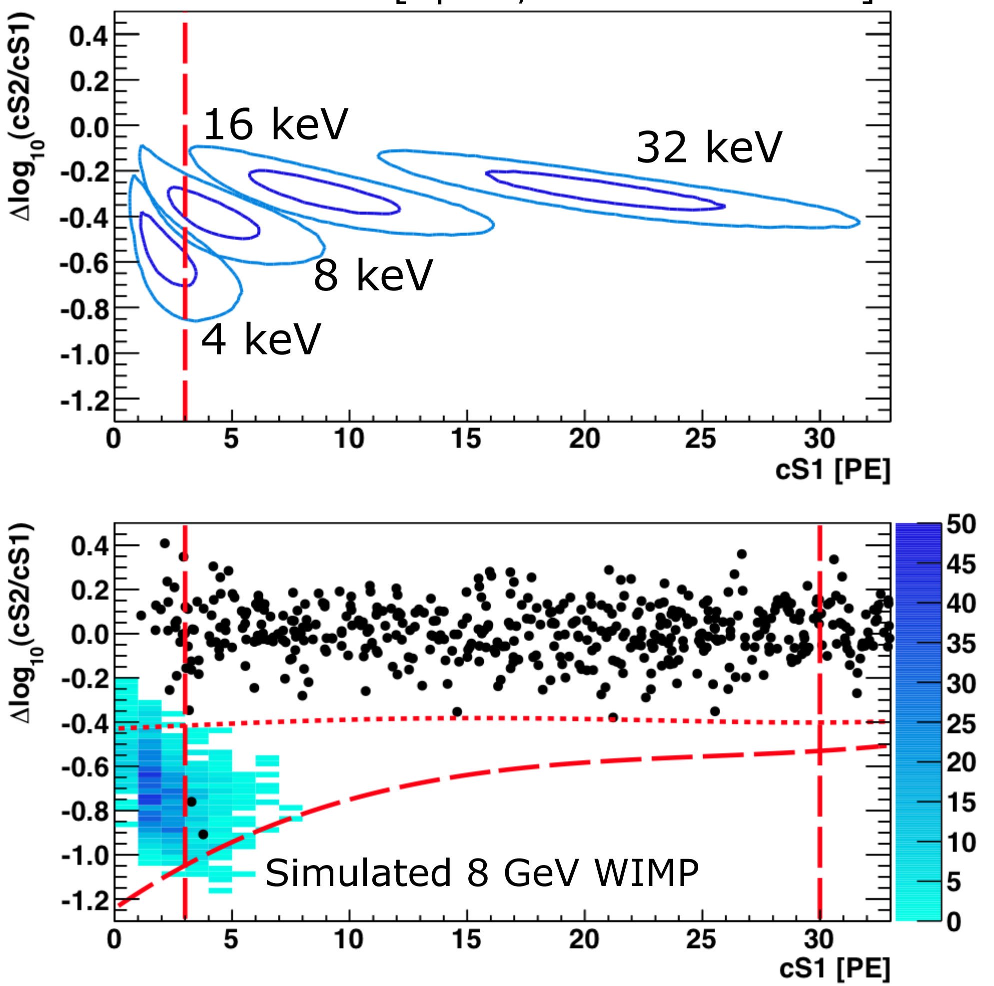




XENON events at low energy

[Aprile, arXiv:1304.1427]

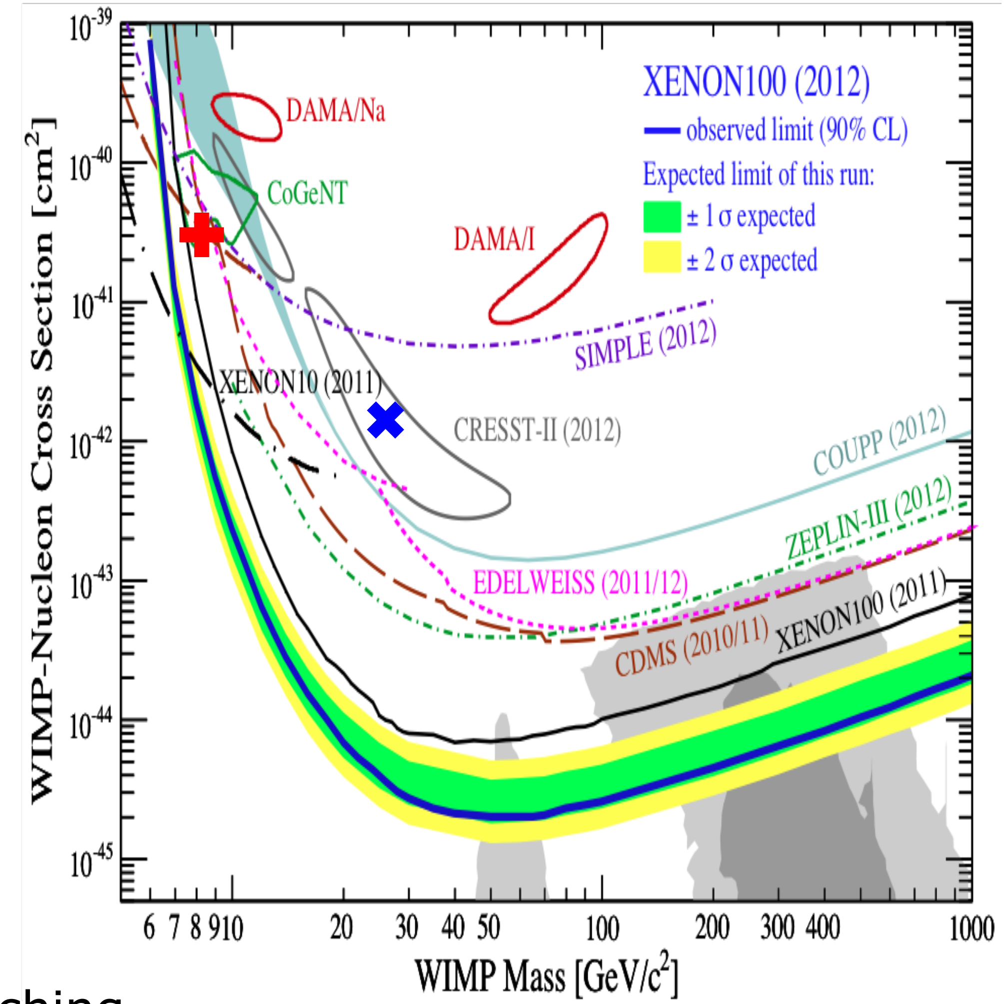




[See also Sorensen, PRD86 (2012) 101301, + Aprile, arXiv:1208.5762]

XENON limits

- $<2\times10^{-9}$ pb at 55 GeV/c^2
- Steep increase at low M_W
- Below ~12 GeV/c^2, efficiency relies on Poisson fluctuations from evts below S1 threshold
- The full simulations of the S1 S2 response of a 8 GeV WIMP at ✚: should have seen $223\pm^{303}_{85}$ evts.
- 25 GeV WIMP at ✖: should have seen $1409\pm^{53}_{4}$ evts
- Uncertainties: S1 S2 Quenching



XENON10 S2-only analysis

1. Intrinsic ratio hν/e⁻ decreases at low energy
2. Higher efficiency to collect electrons than photons

- Difficult to use S1 at low energy

  … but nuclear recoil discrimination may not be required to exclude relevant cross-sections of WIMPs below 10 GeV/c²

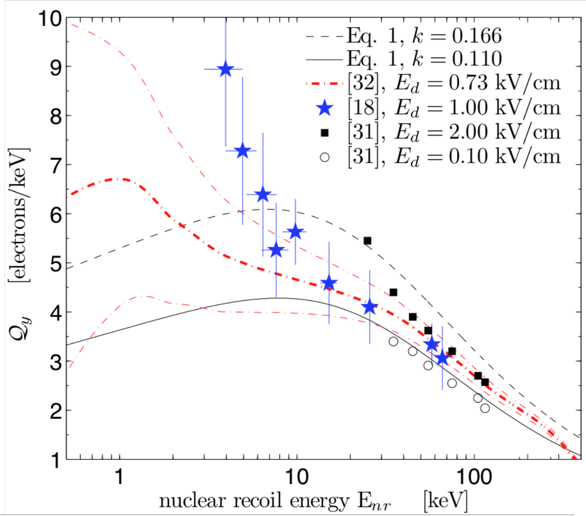
XENON10 analysis using S2 only

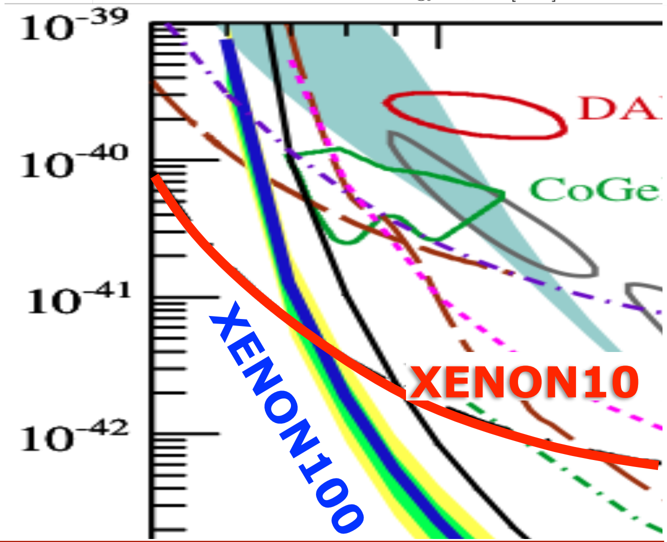
E_{recoil} = S2 / Ionization quenching

- Delicate: not well known below 5 keV
- New bkgs appear (single-photon S2 events)

- For now not very competitive with normal XENON100 analysis > 7 GeV/c²
- XENON100 + improved studies to come

[PRL 107 (2011) 051301]





Some LXe and LAr projects

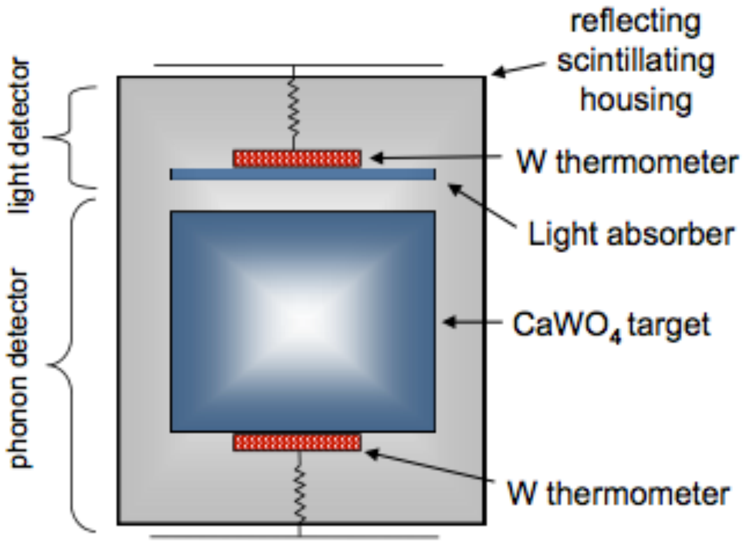
- XENON 1t: in construction. *Reduction of radioactive background (cryostat, PM, purification)*.
- LUX (Homestake): 300 kg + improved light collection. Results soon?
- XMASS (Kamioka): 100 kg + 642 PMs. Monophase, rejection based on fiducialization. Need to study and reduce internal radioactive background.

- DEAP-CLEAN (SNOLAB): 100 kg Ar, *need 10^8 rejection of radioactive ^{39}Ar* (pulse shape discr., τ = 1.6 μs)
- DarkSide-50: 33 kg fiducial Ar, *depleted in ^{39}Kr* (underground source, depletion 10^{-2} to 10^{-3})
- PANDA: Low-mass Xe in JinPing tunnel, China

SCINTILLATION+HEAT

Heat-scintillation: CRESST

- 300 g $CaWO_4$ Crystals with Tungsten film thermometer
- Light detector = thin Si wafer + same type of thermometer
- 3 targets in same detector
  A = 16, 40 and 184
  Q = 0.10, 0.06 and 0.04

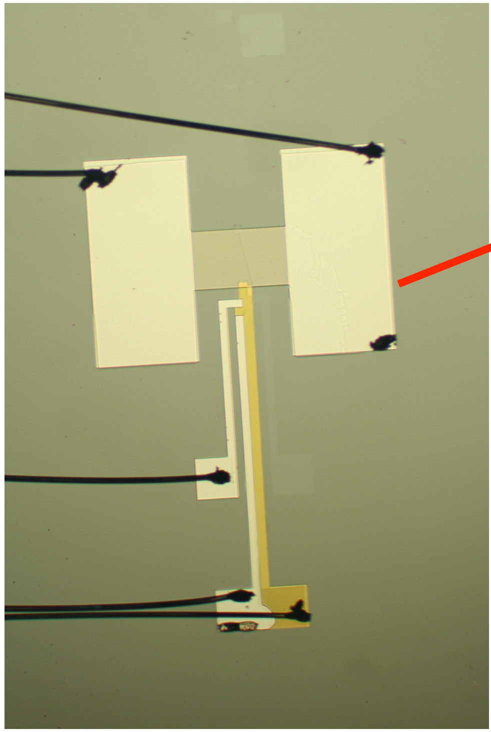


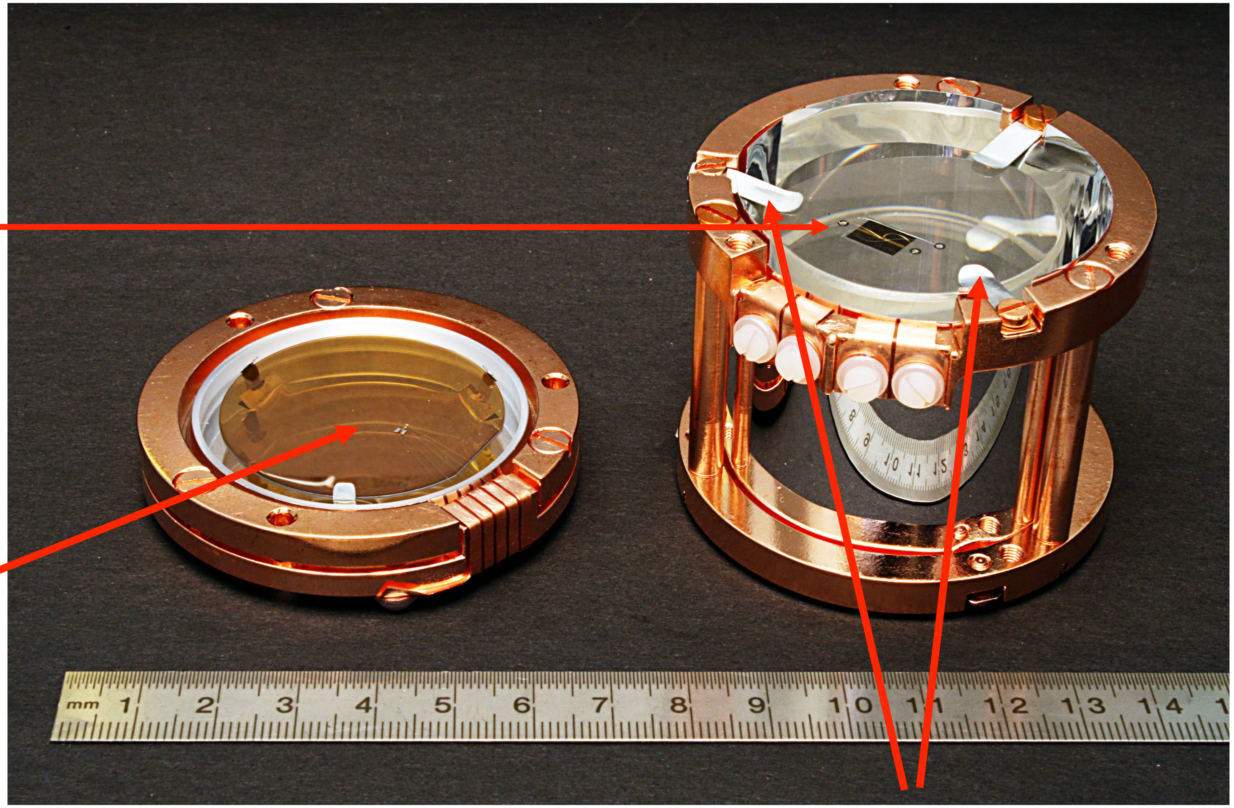
Reflecting scintillating housing to increase light yield

BONUS: tags $^{210}Po \rightarrow \alpha + ^{206}Pb$ two body decay
^{206}Pb recoil ~ W recoil

CRESST detectors

The phonon detector:
300 g cylindrical $CaWO_4$ crystal.
Evaporated tungsten thermometer with attached heater.

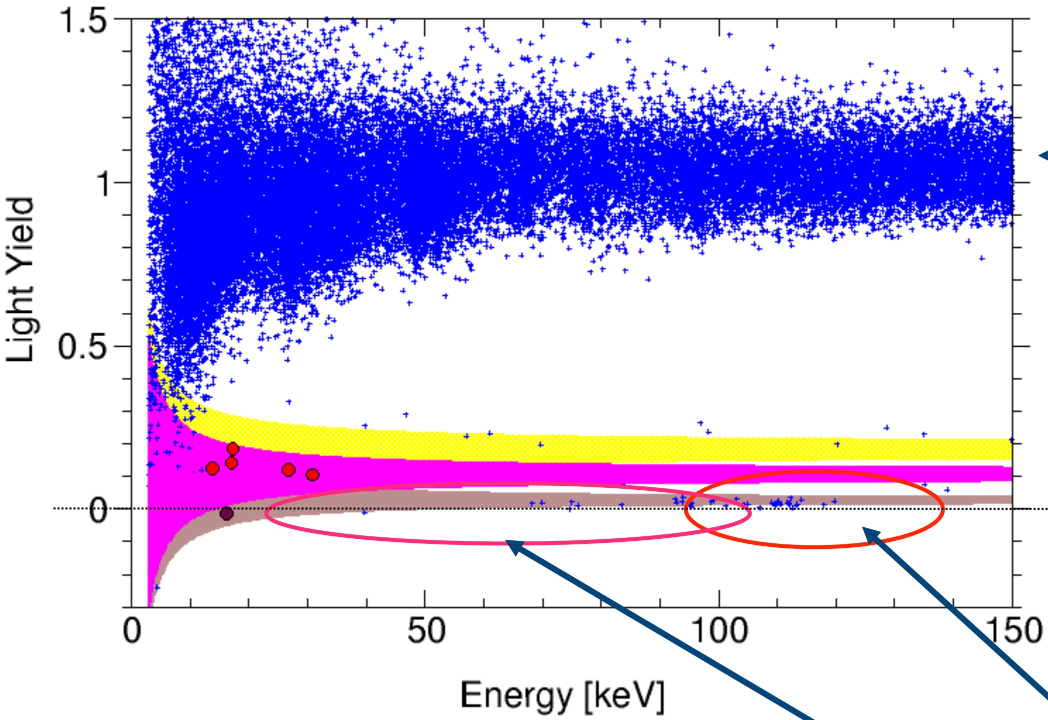




Clamps not scintillating

Light detector:
Ø=40 mm silicon on sapphire wafer.
Tungsten thermometer with attached aluminum phonon collectors and thermal link.
Part of thermal link used as heater

730 kg.day CRESST



γ + β band

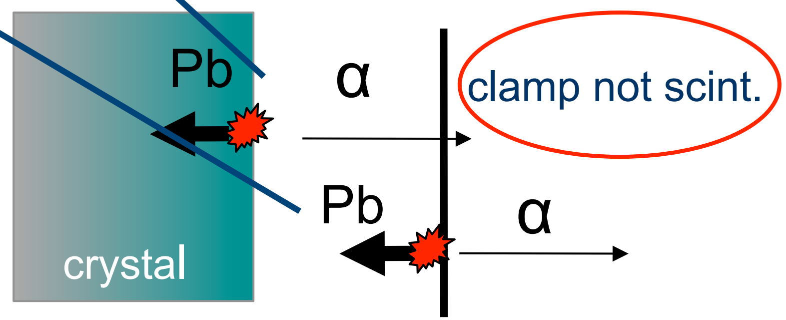
67 WIMP candidates over estimated bkg of ~45

α band

O-recoil-band

W-recoil-band (+Pb)

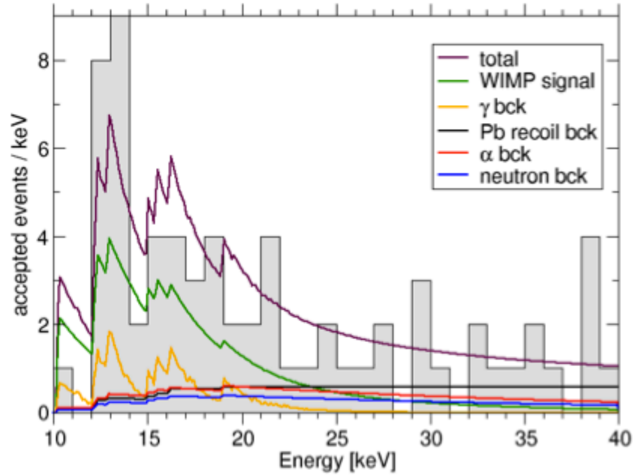
Need to reduce bkg from γ, neutrons, αs, surface Pb recoils, no-light evts



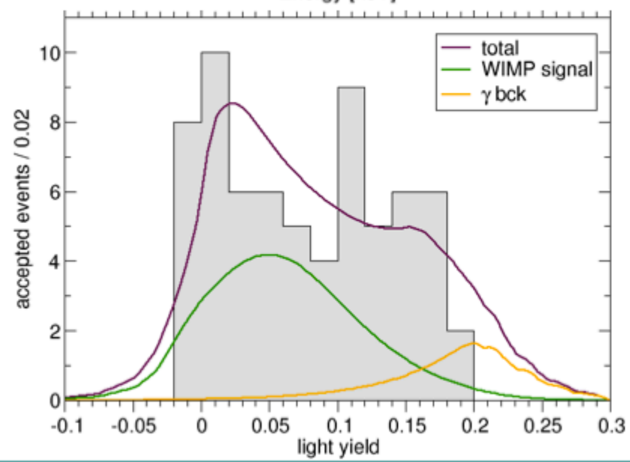
^{210}Po ⟶ ^{206}Pb (104 keV) + α (5.4 MeV)

Results of Likelihood Analysis

- Energy spectra of α, neutron or Pb backgrounds do not resemble the expected WIMP signal and only the e/γ contribution has a similar shape



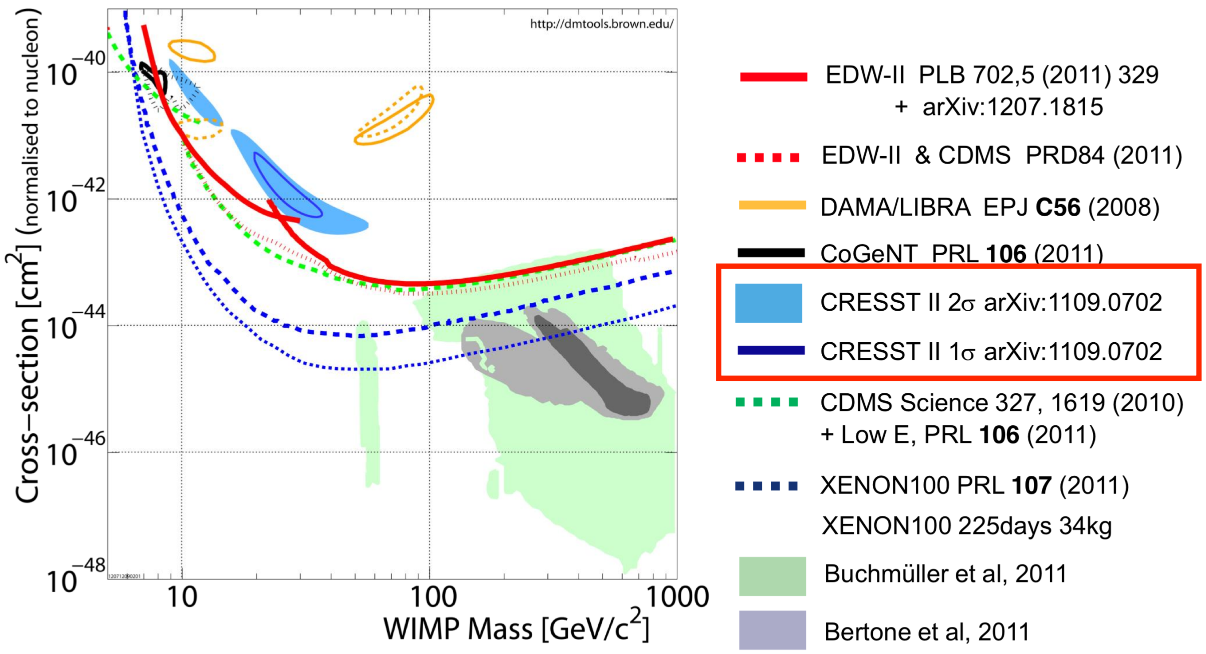
- Light yield spectrum of e/γ differs significantly from the expected WIMP signal and thus cannot explain the total LY distribution



06.09.2011 Results from 730 kg days of the CRESST-II Dark Matter Search
Federica Petricca on behalf of the CRESST collaboration 15

CRESST results and status

- Favored regions not compatible with other direct searches



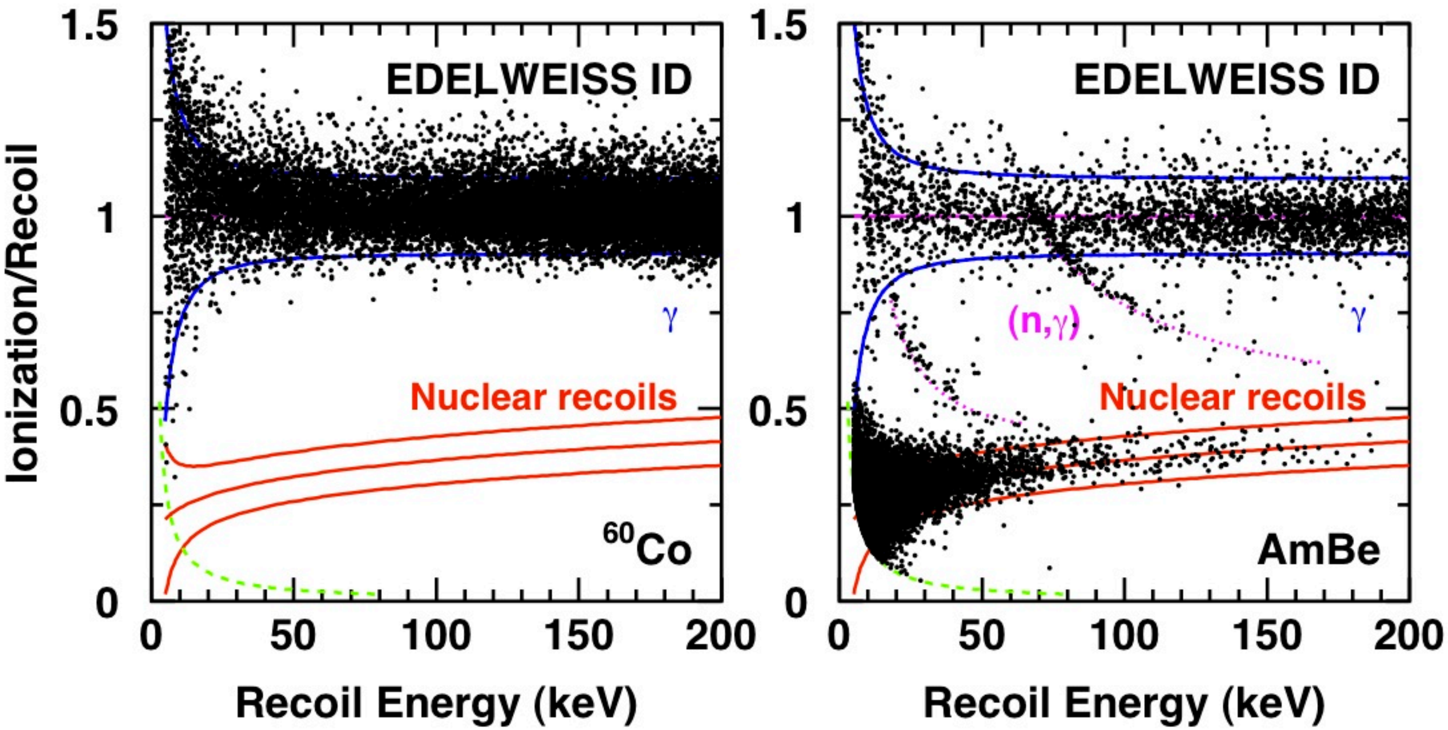
- New run with 18 detectors started
  - Improved neutron shielding
  - Radio-pure clamps + improved scintillation coverage
  - Reduce exposure to radon

See also Silvia Scorza's talk this Thursday

GE IONIZATION + PHONON

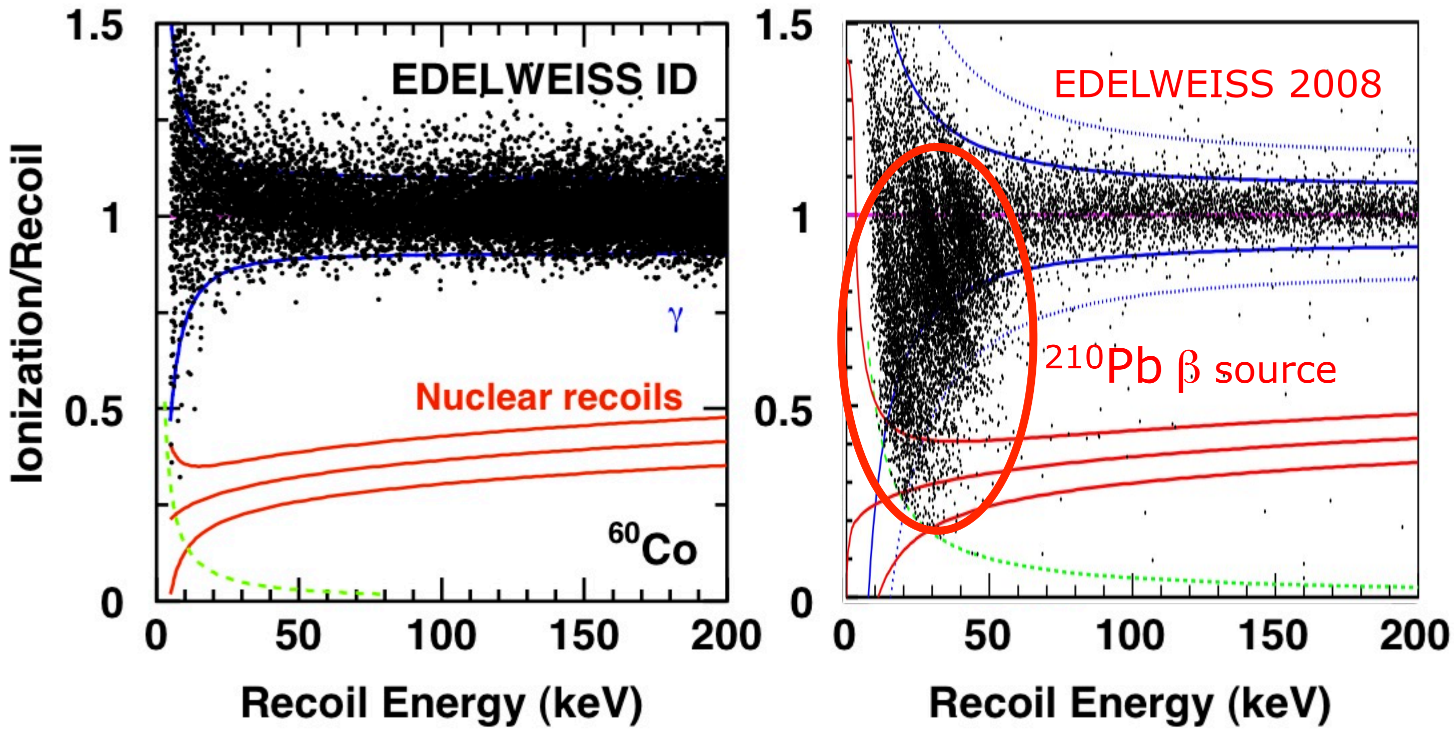
Nuclear recoil / gamma discrimination

- With good resolution on both ionization & heat, very clear discrimination based on the different ionization yields for *nuclear recoils* (WIMP or neutron scattering) and *electronic recoils* (β,γ decays)
  - discrimination of dominant background
  - Stable and reliable rejection performances

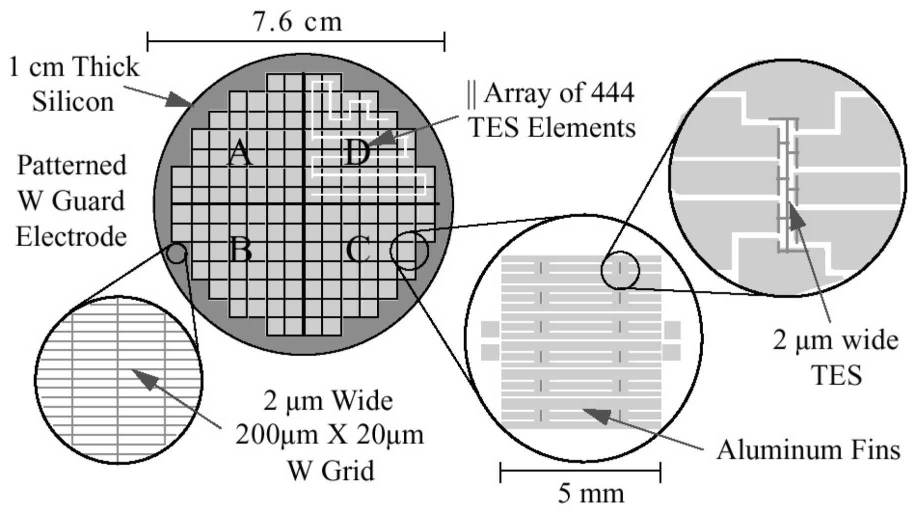


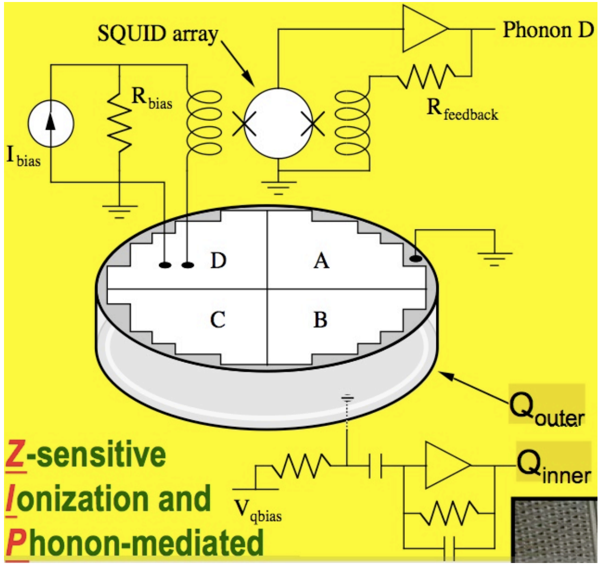
Limitation: poor ionization yield for surface events

- With good resolution on both ionization & heat, very clear discrimination based on the different ionization yields for *nuclear recoils* (WIMP or neutron scattering) and *electronic recoils* (β,γ decays)
- *Limitation: deficient charge collection near surface (trapping, dead layer)*
  => different surface rejection strategy for CDMS & EDELWEISS



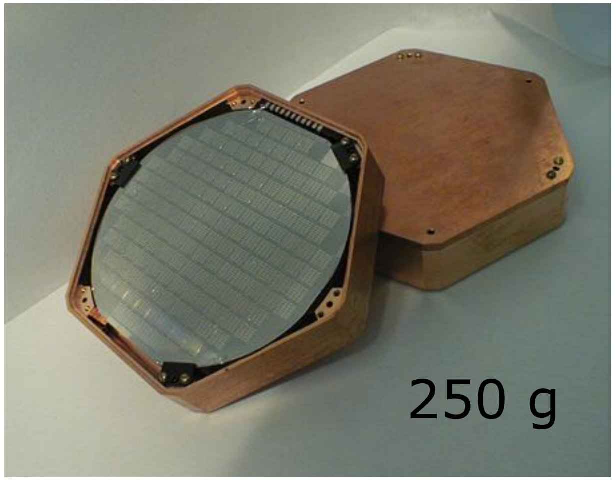
- Large area: sensitivity to athermal phonons
- *Phonon time distribution*
- Photolithographic patterns of W-TES + Al collector (CDMS)





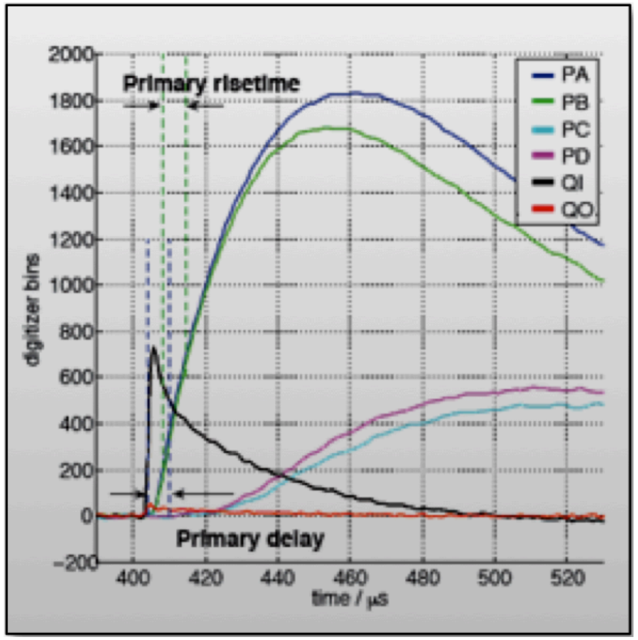
Heat signals:
4 quadrants

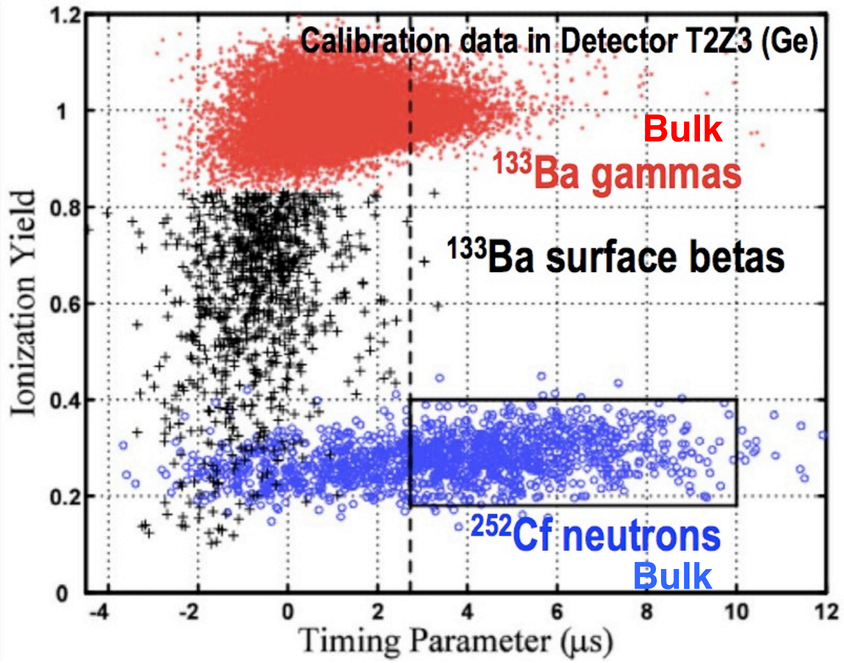
Ionization signals:
Q_inner
Q_outer



Phonon time discrimiation

- Phonon risetime < 50 μs
- Ionization risetime < 1 μs
- « Timing parameter » combines *rise time* and *phonon-ionization delay*
- Nuclear/electronic recoil discrimination!

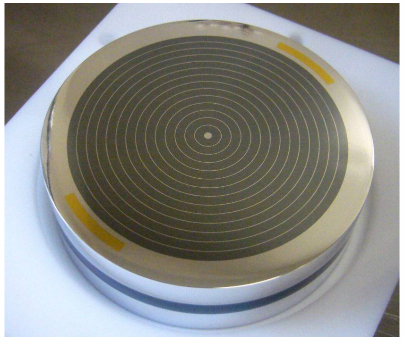


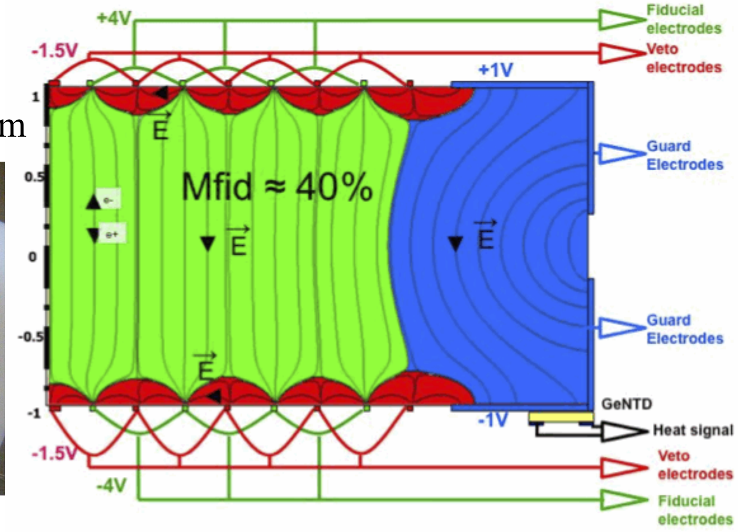


- Sensivity to « z »? (no, works even if sensors on only one side)
- Due instead to a difference between the phonons produced in the primary interaction and in the Luke-Neganov process.

EDELWEISS surface rejection: Interleaved electrodes

Φ 70mm, H 20mm, 410g
14 concentric electrodes
width 100µm, spacing 2mm





Interleaved electrodes + guards rings biased to produce an electric field:

➔ horizontal near the surface (~1 mm)

↓ vertical in the bulk

Simple Surface event selection:

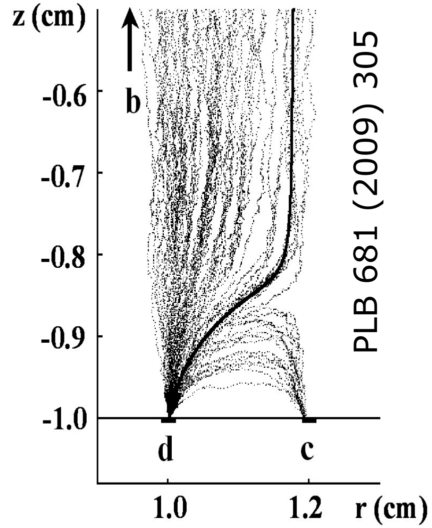
- First criteria: absence of signal on “veto” rings
- ***Redundancy:*** requires equality between “fiducial” rings on both sides

Added bonus: “Grid effect”:

- High-field region close to the fiducial electrodes improves charge collection in that critical region close to the surface

Charge transport effects:

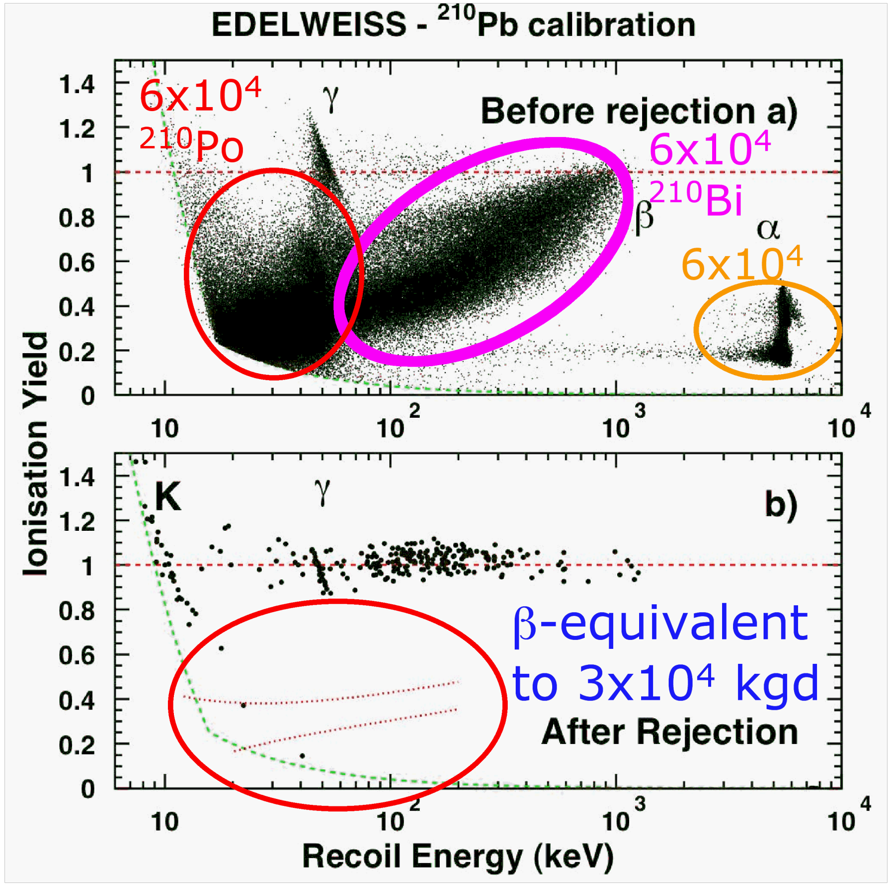
- Diffusion (T=20mK) and charge repulsion insures that charges are never “stuck” in zero-field regions



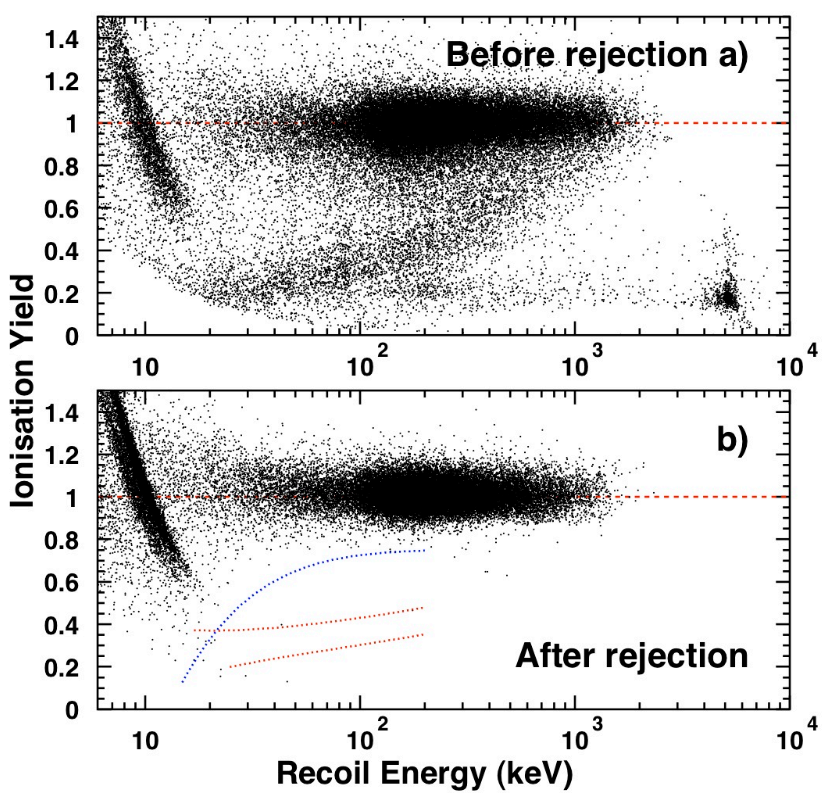
PLB 681 (2009) 305

Identification of surface events

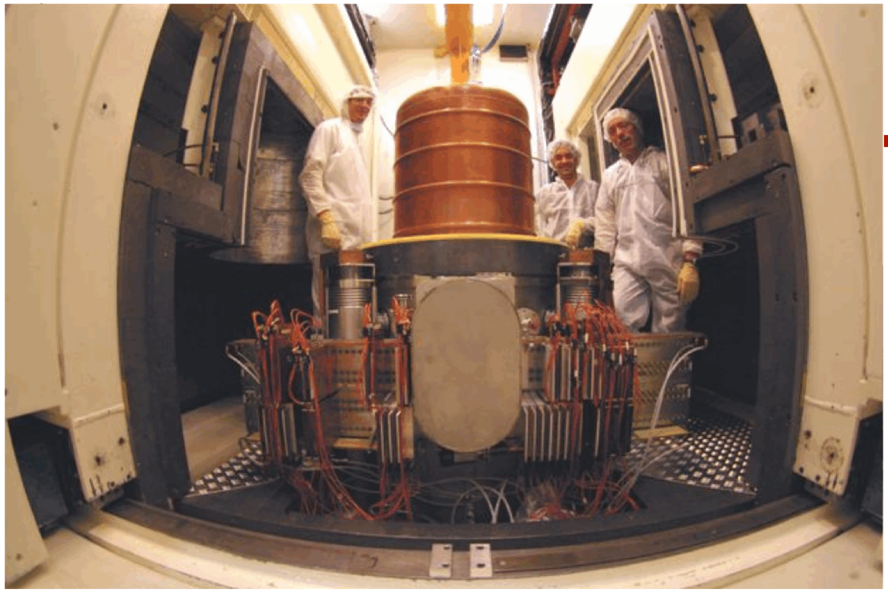
- Surface rejection tested with ^{210}Pb source of surface events
- Technique applied to WIMP search with 10 x 400 g detectors

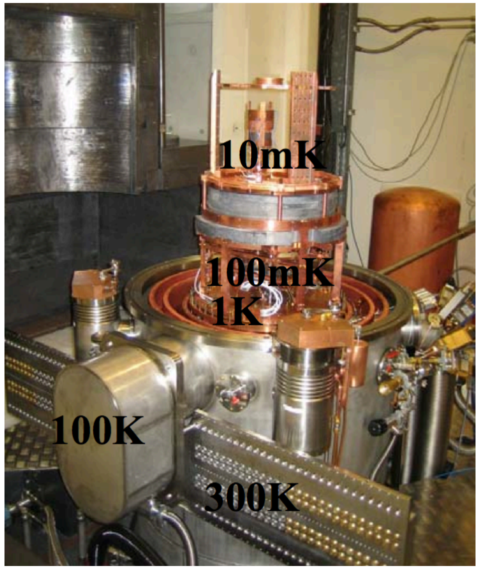


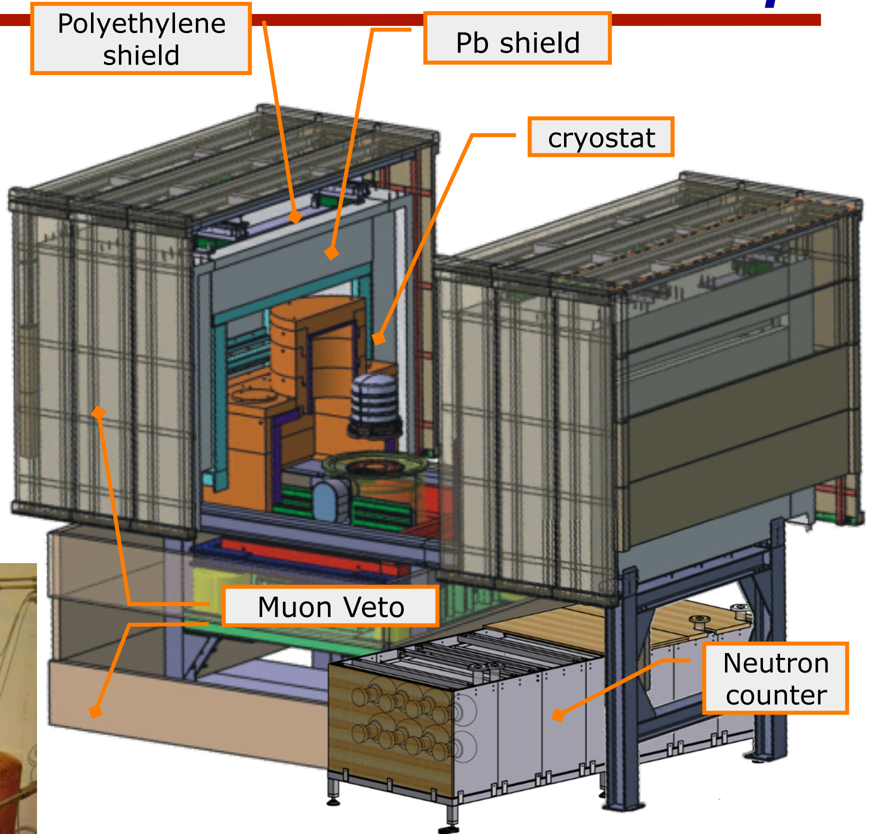
WIMP search data – 2013 live days

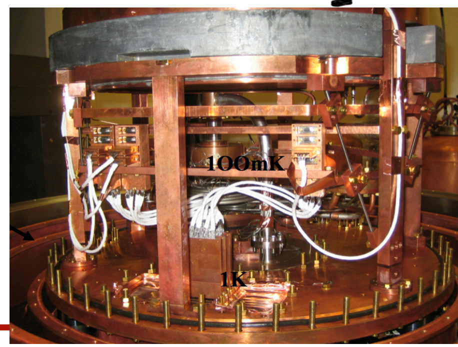


EDELWEISS setup









CDMS-II and EDELWEISS-II WIMP searches

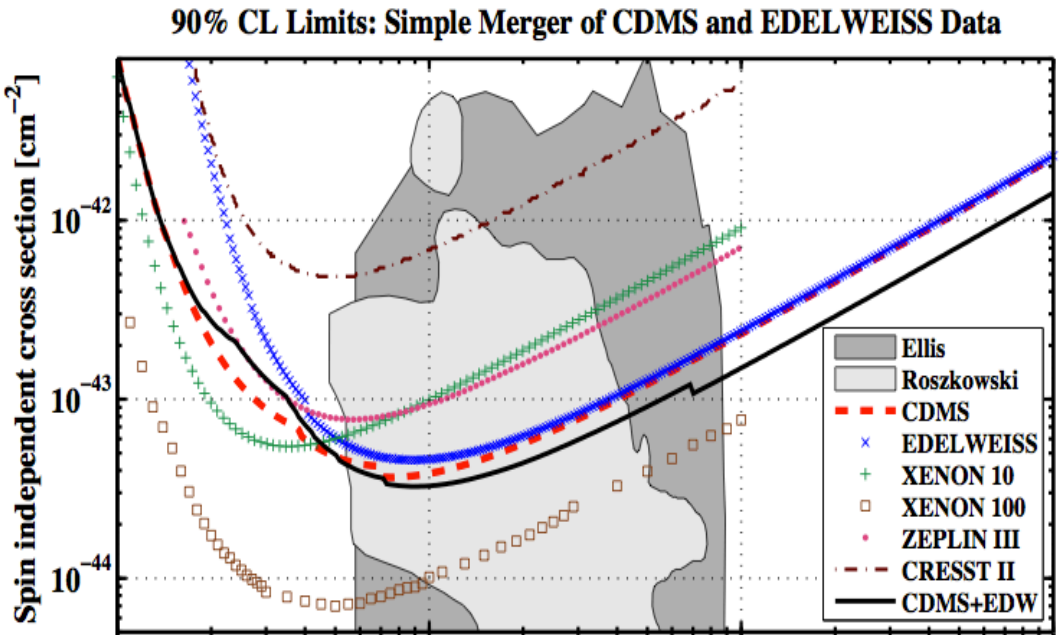
- Combined results: PRD 84 (2011) 011102

	kg.day fiducial	Recoil range (keV)	Ge mass (kg)	NR candidates	Estimated bkg
CDMS	379	5-100	15x0.25	4	~2
EDW	384	20-200	10x0.40	5	~3

* Comparable and consistent results

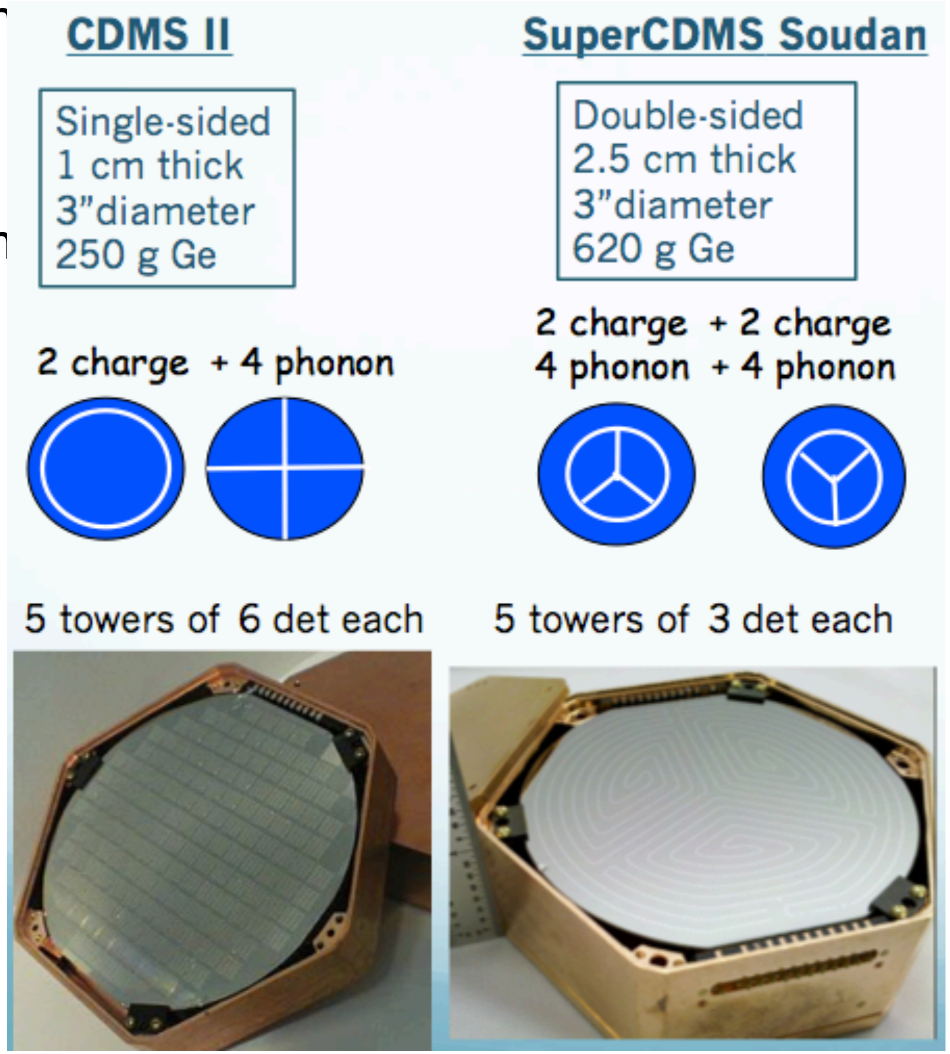
* Limits improved by 1.6 a high mass

* Confirms that bkgs must be present



SuperCDMS Soudan: 650g iZIPs

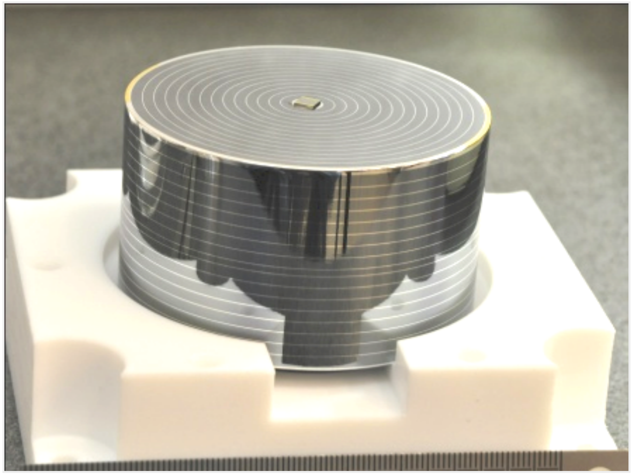
- ZIP Phonon-based rejectior not reliable enough: go to bigger detectors, more phonon channels with better geometry and **ID electrodes** *(but no "veto" electrode readout)*
- Data started in 2012 with 9 kg (6 kg fiducial
- 2200 kgd by 2014
  6×10^{-9} pb for 100 GeV/c^2
- Also: goals for lowering thresholds for low-mass WIMPs (at the expense of surface event rejection from phonon timing)

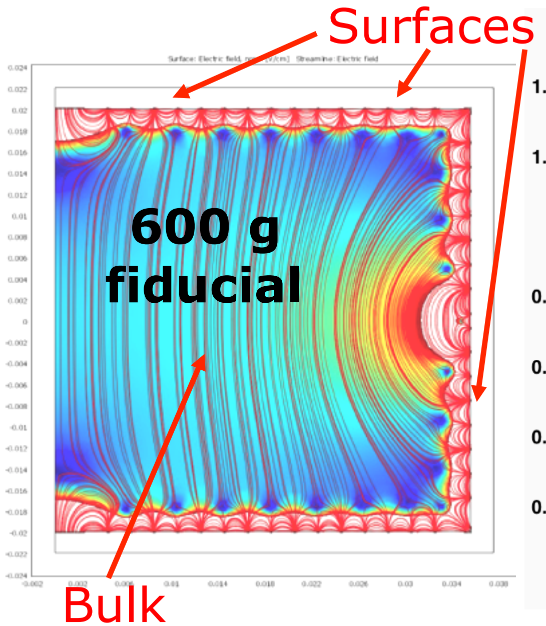


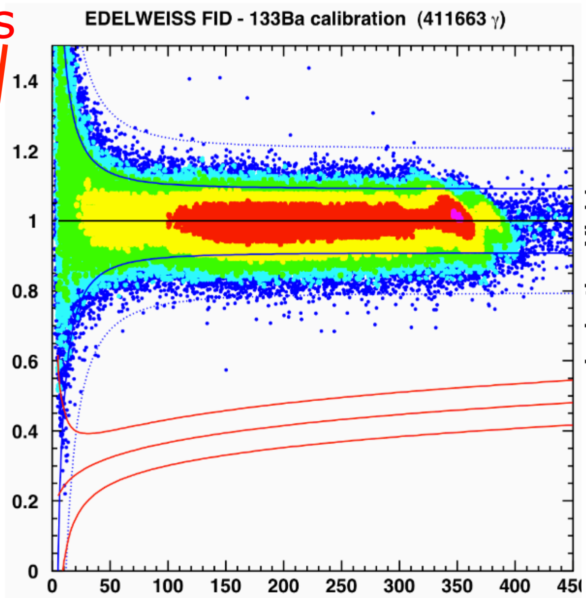
Cushman, IDM2012

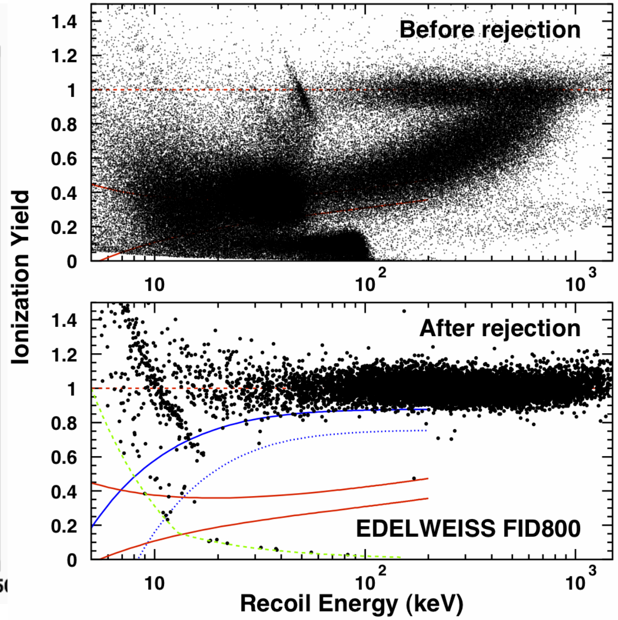
EDELWEISS-III new FID800 design

- FID: Ge fully covered with interleaved electrodes (and go from 400 -> 800 g)
- Commissioning 15 FID800 now
- **Improved γ and surface rejection**
- 40 detectors for end 2013: 24kg fiducial mass (x16 EDELWEISS II)



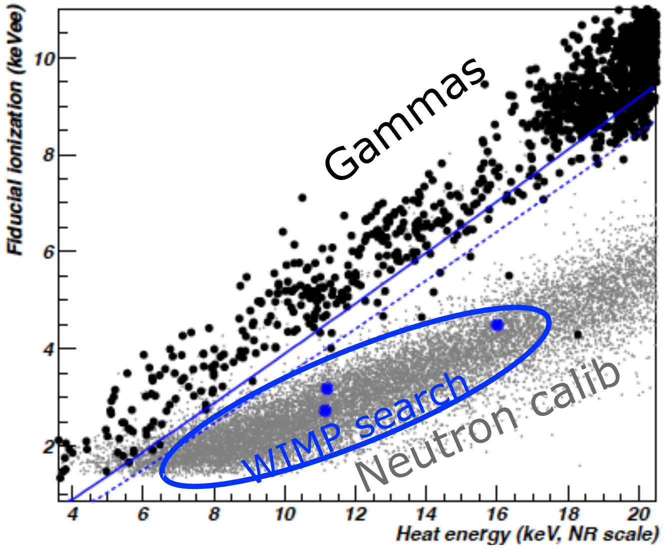


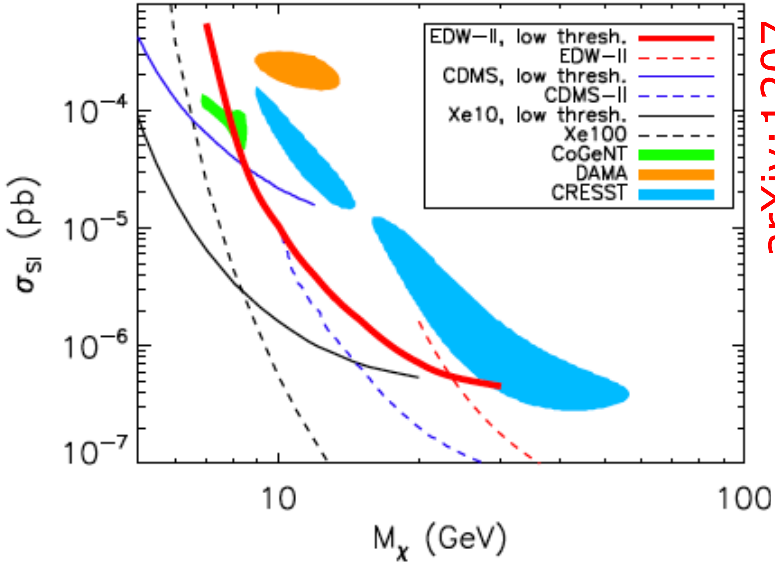




EDELWEISS low mass

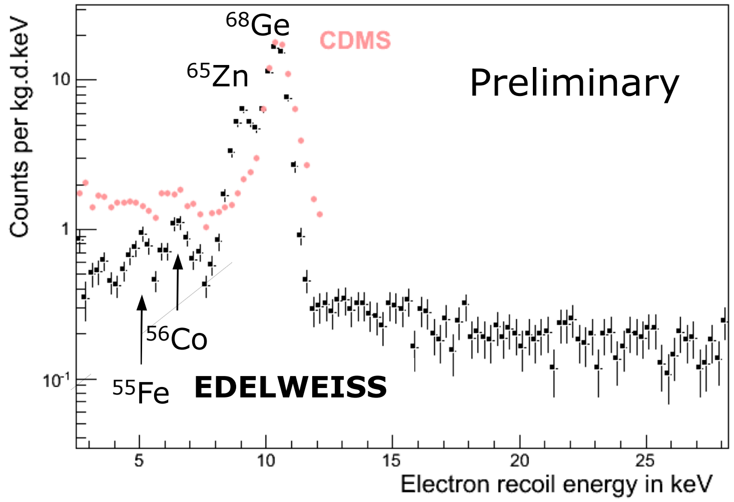
- Avg ID FWHM baselines in 384 kgd sample: 0.9 keV ionization, 1.25 keV heat (acceptable for >50 GeV WIMP search: ~100% eff. for 20 keV recoil threshold)
- Need improvement for ~10 GeV WIMPs
- Low-mass search with 113 kgd with best resolutions
  [PRD 86 (2012) 051701(R)]
- Fiducial selection applicable down to ~6 keV recoils: Surface event rejections
- Best *Ge* sensitivity at ~9 GeV





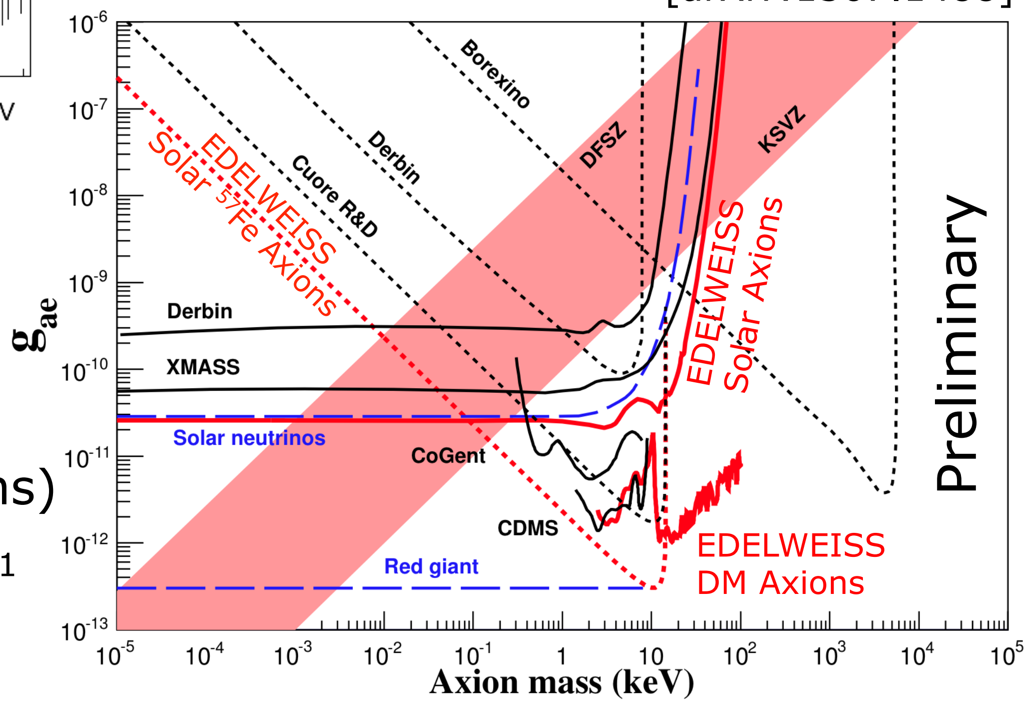
arXiv:1207.1815v1

Axions and Axion-Like Particles search



- Low-threshold sample electron recoil also used for axion search
- Fiducial selection helps reduce background at low energy

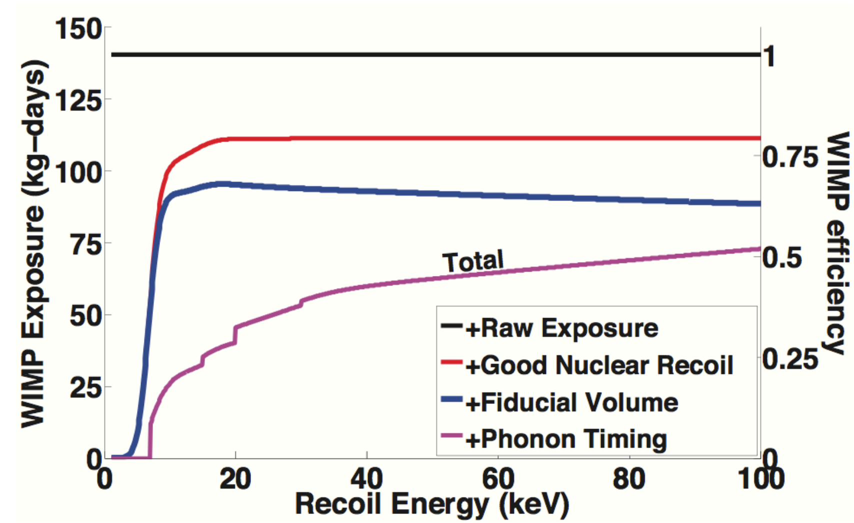
[arXiv:1307.1488]



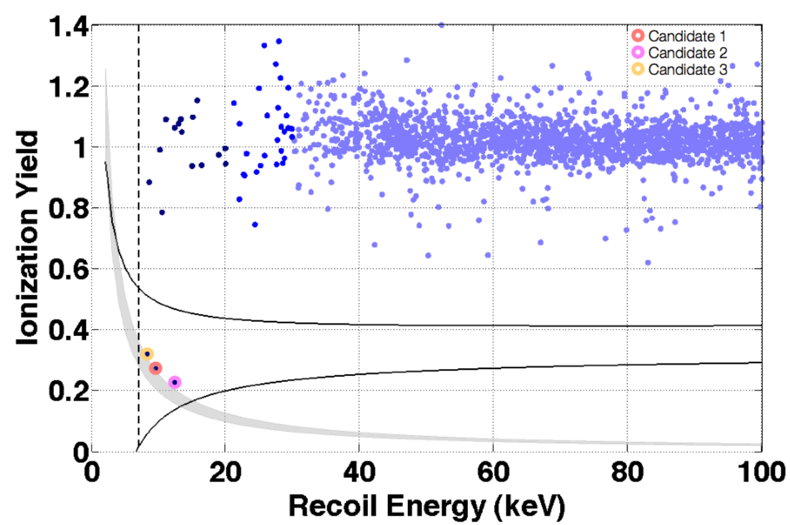
- Interesting axion limits (via Primakoff or axio-electric detection, solar & dark matter axions)
  also: $g_{A\gamma} < 2.1 \times 10^{-9}$ GeV^{-1}

- Analysis of final Soudan exposure: 140 kgd 2007-2008 Si data with better control of background than previous 56 kgd sample. [arXiv: 1304.4279]
- Estimated background: 0.4±0.3 surface events (phonon timing), <0.13 from neutrons, <0.08 from ^{206}Pb

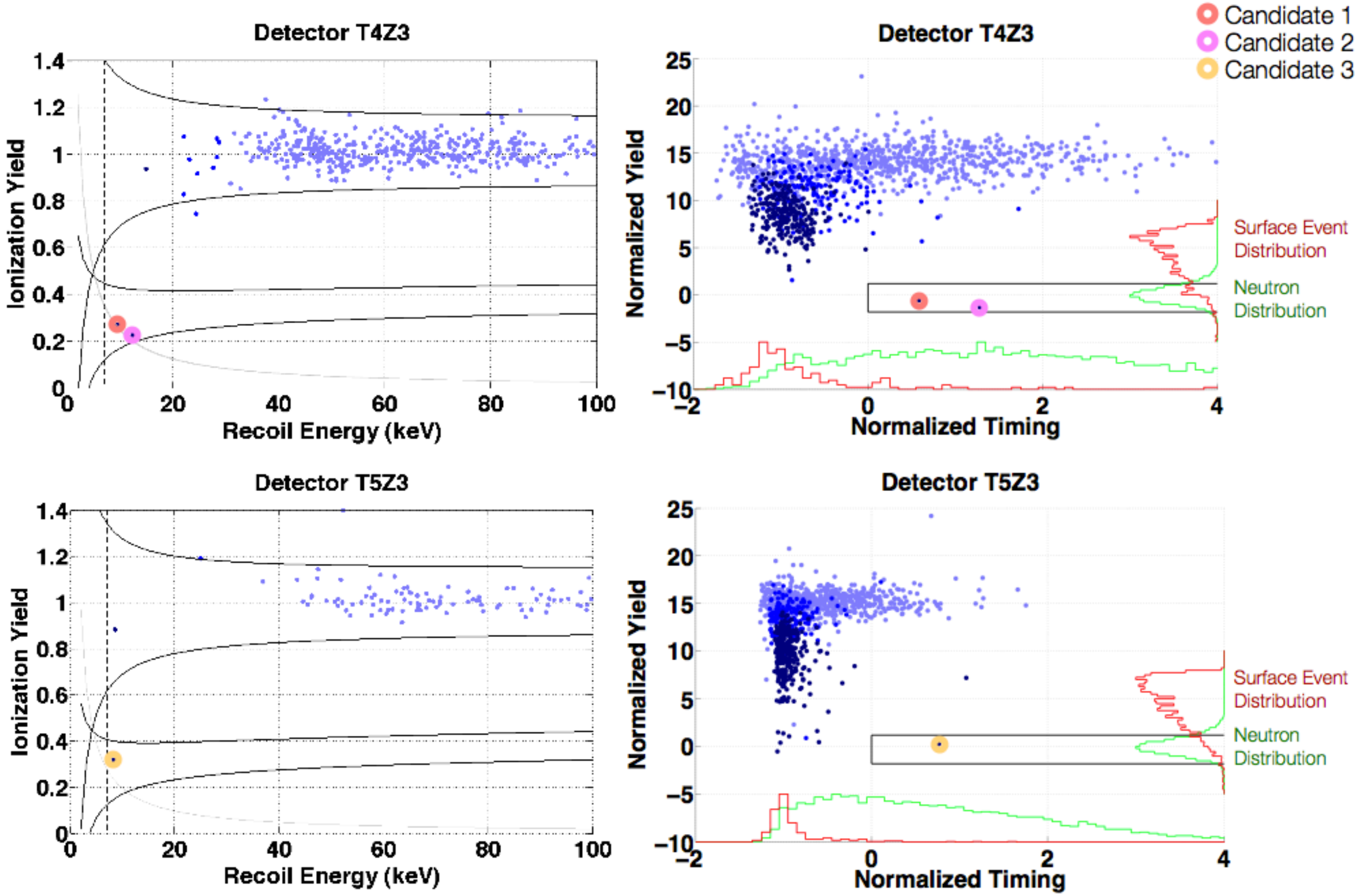
Exposure vs. Recoil Energy



Unblinding Results - after timing cut

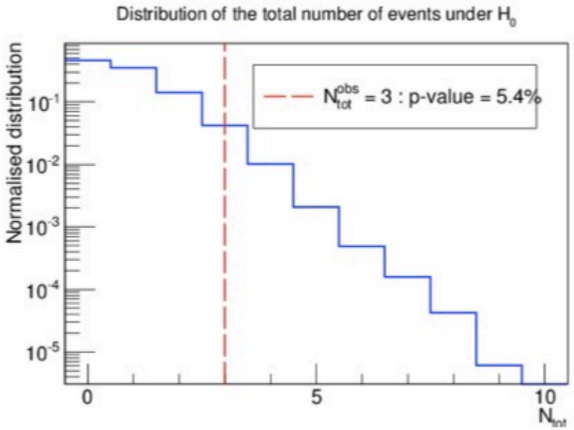


Three Events!



Profile Likelihood of Silicon data

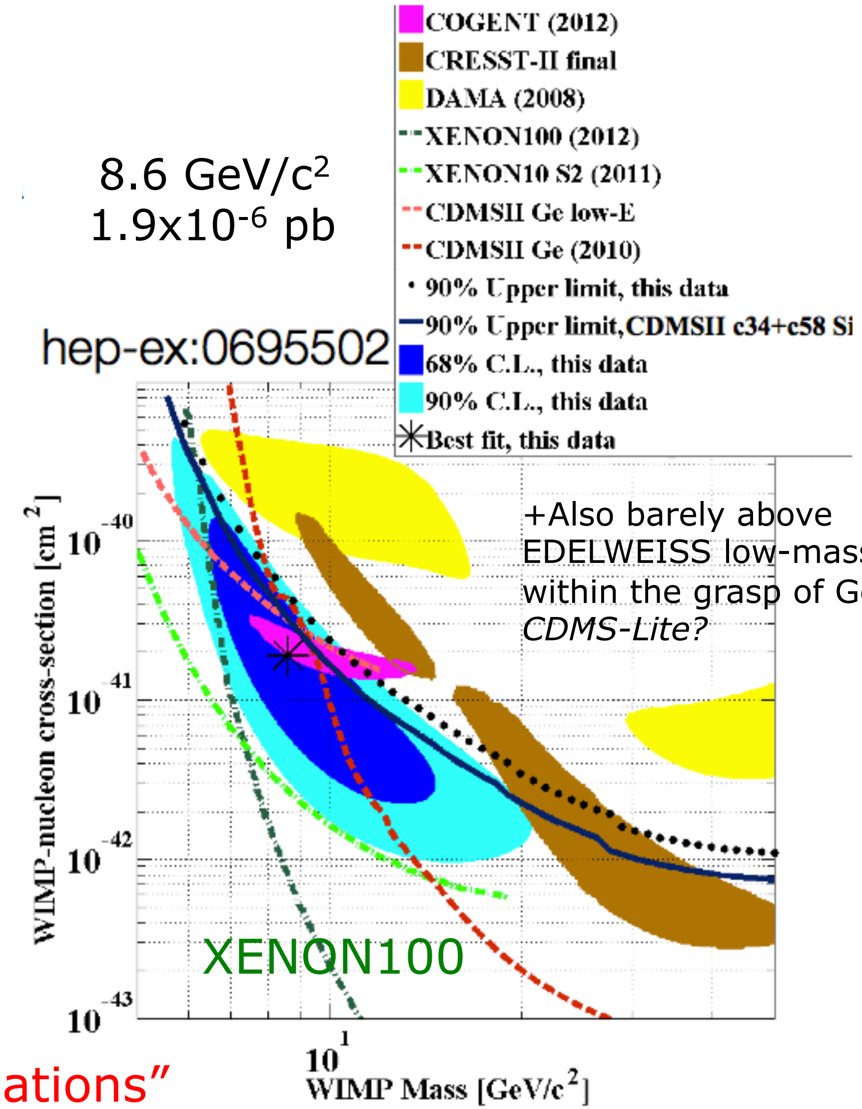
- Monte Carlo simulations of the background-only model indicate the probability of a statistical fluctuation producing three or more events anywhere in our signal region is 5.4%.



But WIMP+bkg hypothesis favored over known bkg estimate by 99.81% CL

8.6 GeV/c²
1.9x10⁻⁶ pb

hep-ex:0695502

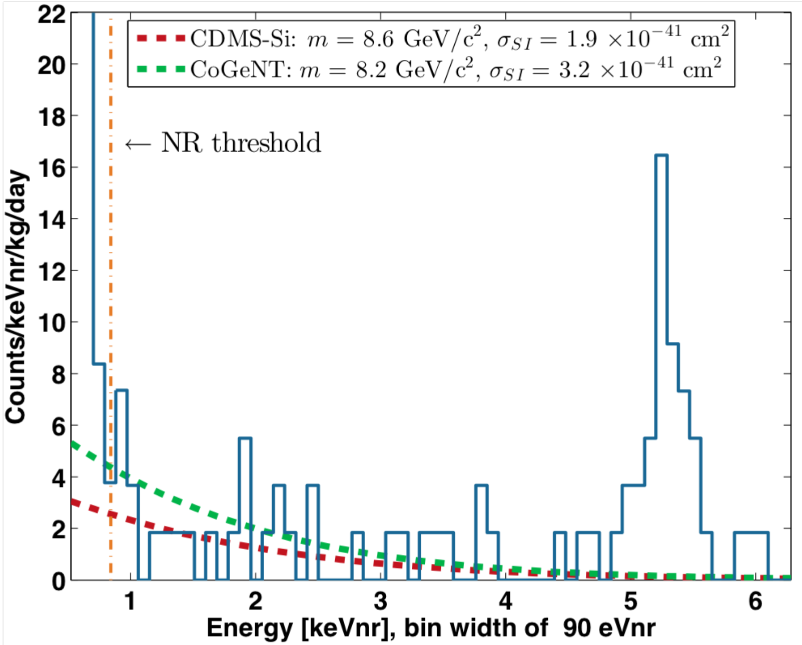


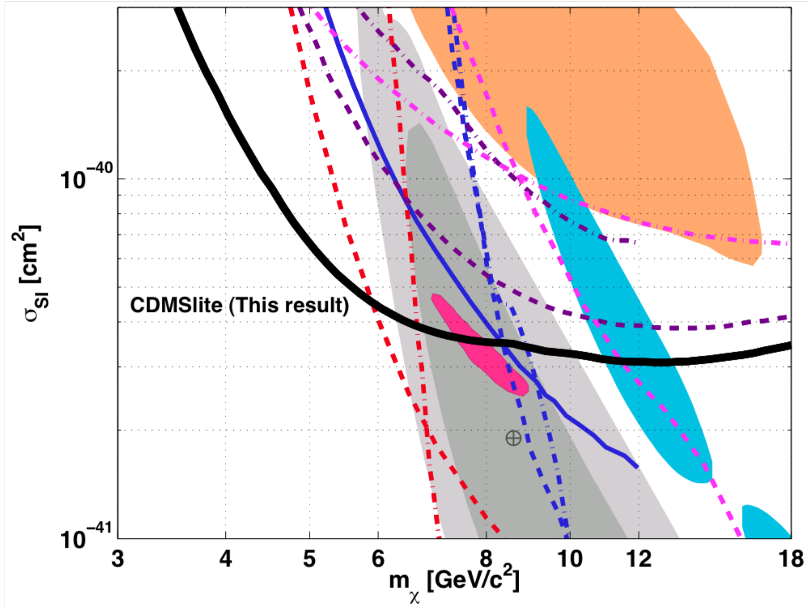
+Also barely above EDELWEISS low-mass within the grasp of Ge *CDMS-Lite?*

"Calls for futher investigations"

Dedicated low mass WIMPs

- Using Luke-Neganov amplification, can lower the threshold
- Price to pay: no nuclear recoil discrimination (but can test it by varying V_{polar})
- Current threshold on $E_{electron\text{-}equivalent}$ ~ 1 keV_{ee} with V_{polar} = 3.2V
- Biasing at 70V reduces threshold by (1+3.2/3)/(1+70/3) = 12
- 840 $eV_{NuclRecoil}$ threshold on (standard iZIP) Ge detector

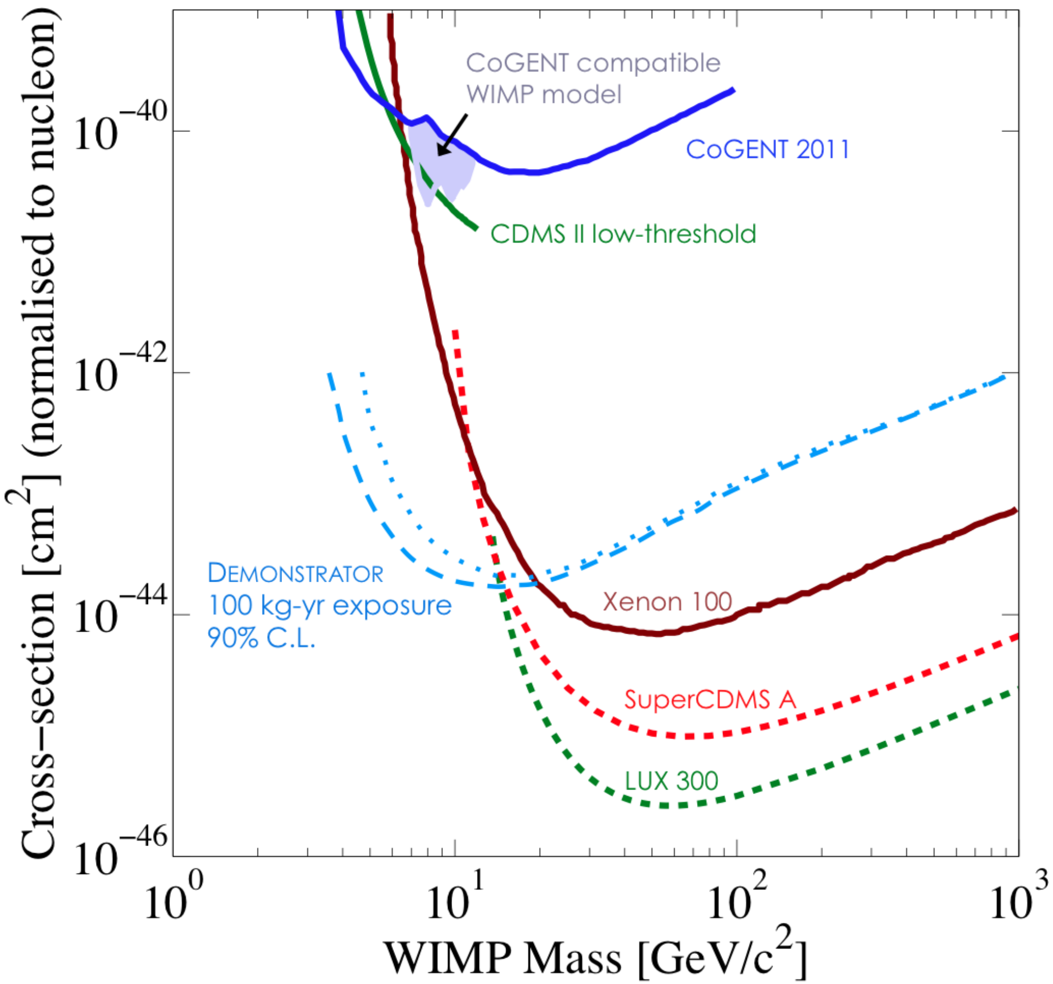




Low masses with PCCs (Majorana)

- Plans 40 kg PPCs by end 2014 (primarily for $0\nu\beta\beta$)
- Background of ~0.001 event/kg/day/keV
- 0.3 / 0.5 keV threshold

TAUP2011, J. Phys. Conf. Series 375 (2012) 012014



Future projects: USA

- 1.38 kg iZIPs
- R&D to be completed in 2013
- Funding request 2013-2014
- Goal: 200 kg Ge
  140 000 kgd
  (4 year run)
  10^{-10} pb in ~2017

Cushman, IDM2012

Future project EU

- European priority: completion of EDELWEISS-III (physics 2014-2015) and present CRESST runs
- EURECA: ~1 t combining Ge and $CaWO_4$ targets
- EURECA CDR recently completed
- Preferred site: extension of the Modane Laboratory
- 2013: discussions with SuperCDMS-SNOLAB (~2015): discussion on common strategy, collaboration for the cryogenics underway.

CONCLUSIONS

Conclusions

- Direct Dark Matter Searches: crucial experiments to attest the presence of WIMPs in our galaxy; complementary to LHC and indirect searches
- *Apparently simple, but the required extreme low-backgrounds are challenging and they foster constant technological innovations.*

- Need variety of targets (essential to validate possible discovery)
- Intense world-wide competition of R&D efforts to *reduce backgrounds* and *increase the mass of the arrays*

Recent published spin-independent results

- Little progress between original 80's experiments (~1 evt/kg/d) until 2000, when discrimination techniques finally got operational. Long development time!

- We're still two orders of magnitude away from the physics goal

- Promising results to come!