Dark Matter roadmap strategy

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For the WG5 working group

WG5 Dark Matter

(direct detection only)

Composition of the Working Group

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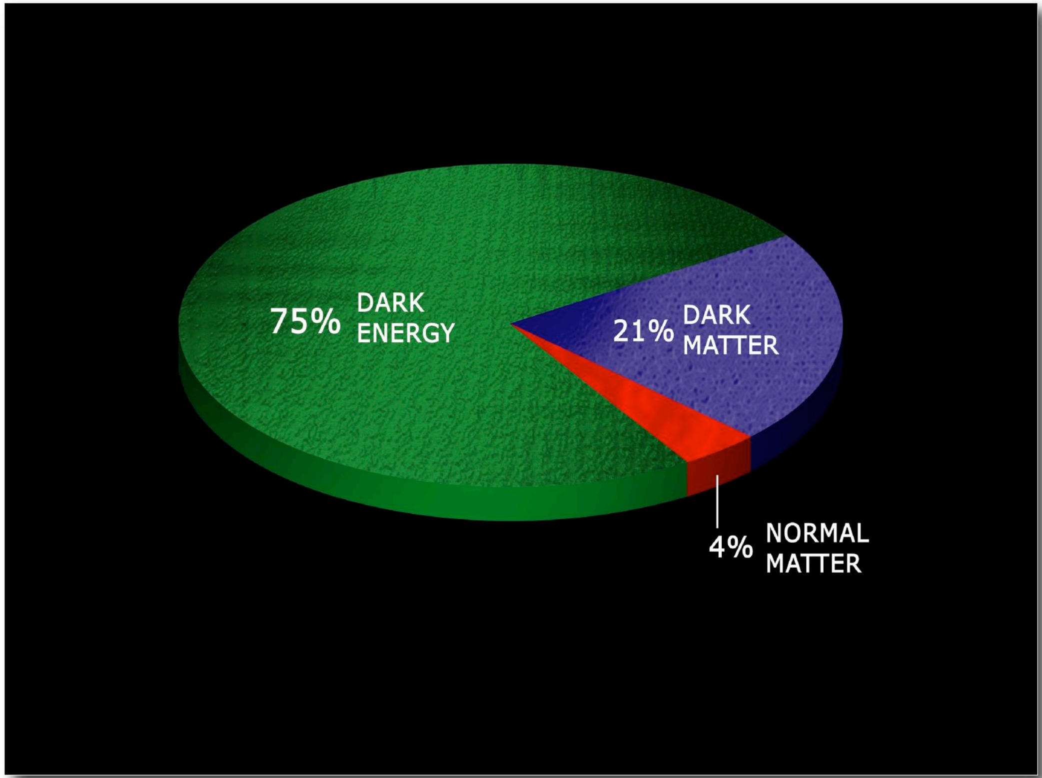
Dark Matter and Dark Energy

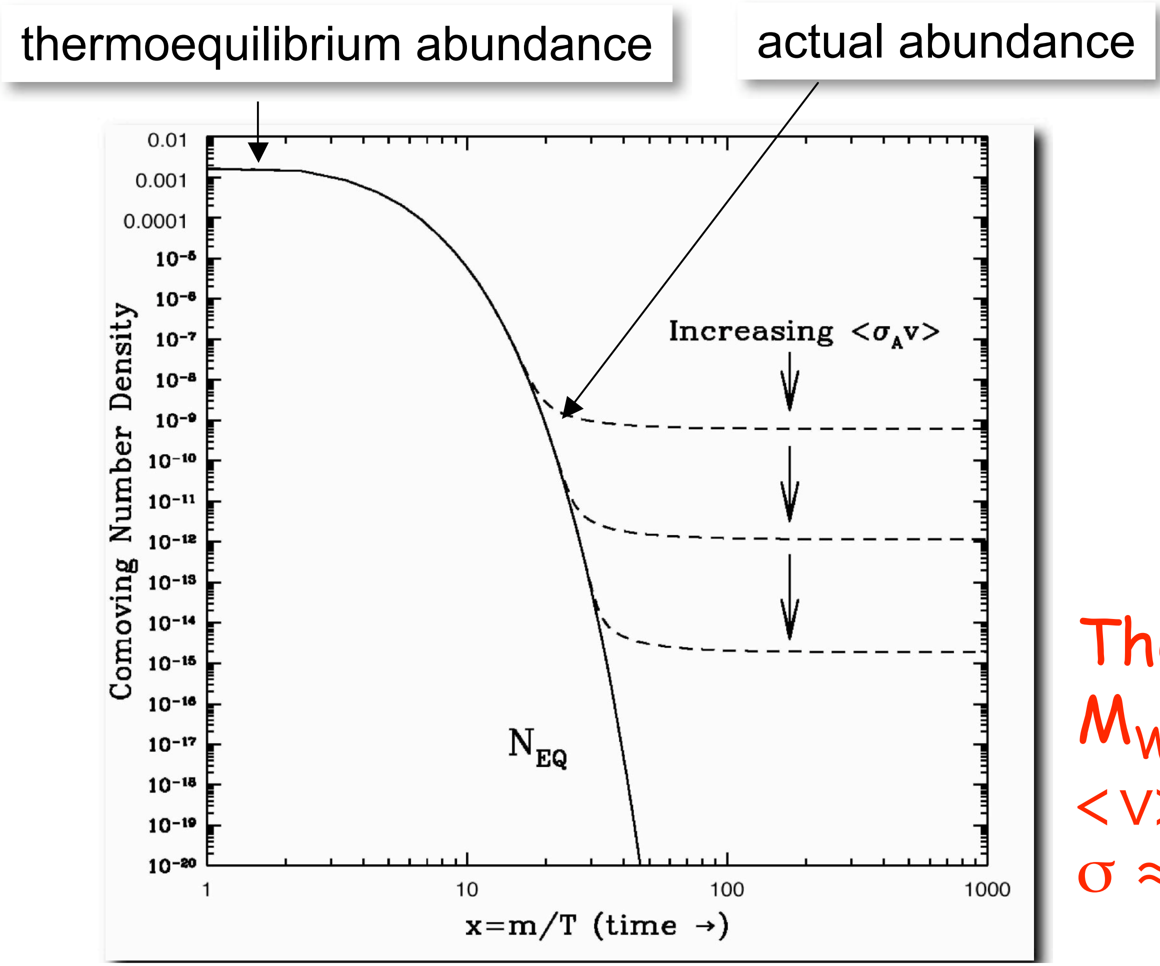
Outstanding question of the Universe composition

- $\Omega_{tot} = 1.00 \pm 0.02$
- $\Omega_{baryon} = 0.045 \pm 0.005$
- $\Omega_{matter} \approx 0.25$
- $\Omega_{\Lambda} \approx 0.75$



Weakly interacting massive particles

- long lived or stable particles left over from the BB
- Axions not discussed here



$$\Omega_\chi \propto \frac{1}{\langle \sigma_A v \rangle}$$

$$\sigma_A \approx \sigma_{weak}$$

The "WIMP miracle"

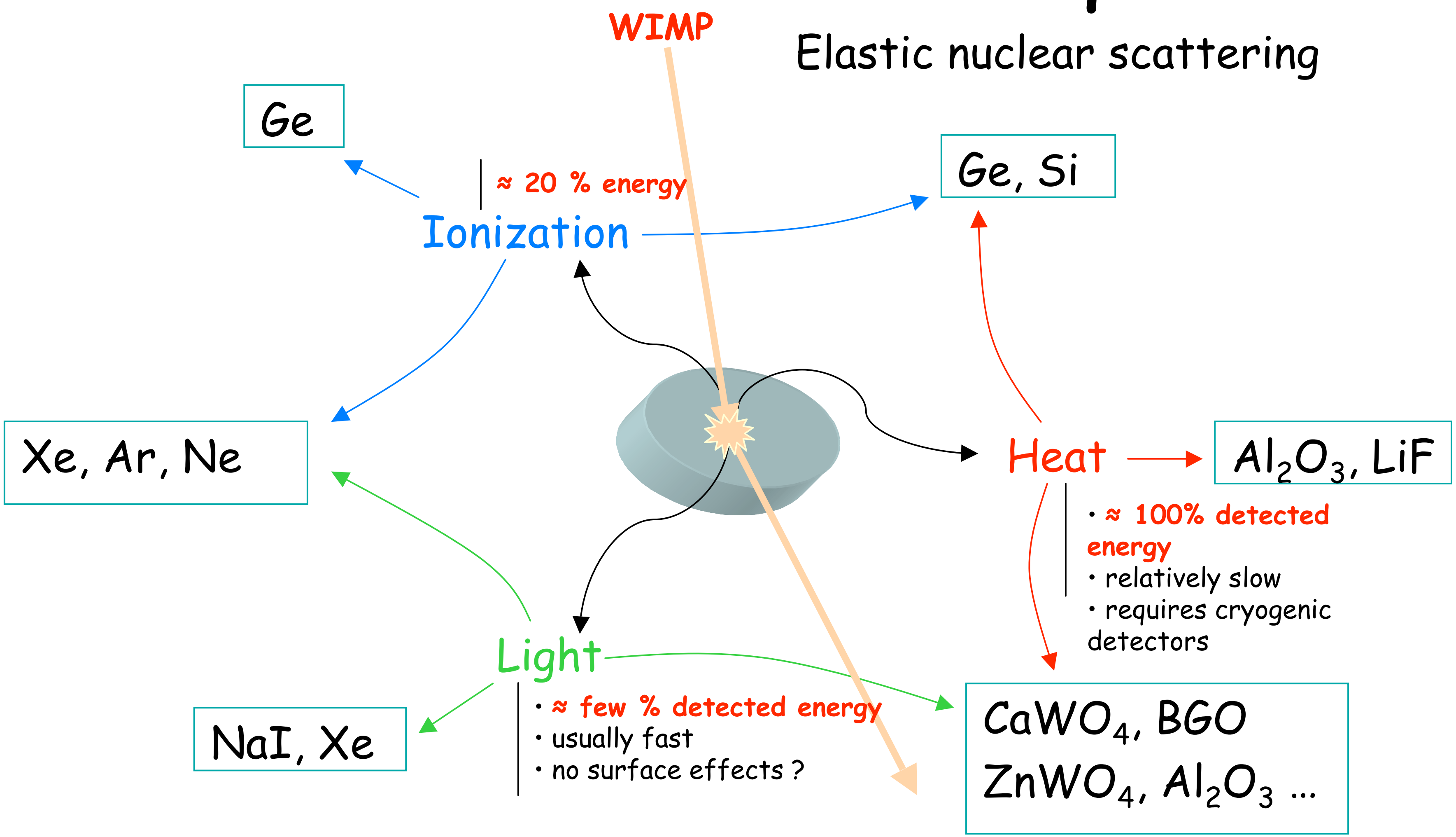
$M_W \approx 50\text{-}500$ GeV

$\langle v \rangle \approx 250$ km/s

$\sigma \approx 10^{-6}\text{-}10^{-10}$ pbarn

after Drukier and Stodolsky, PRD 30 (1984) 2295
(and Goodman and Witten (1985))

Direct detection techniques



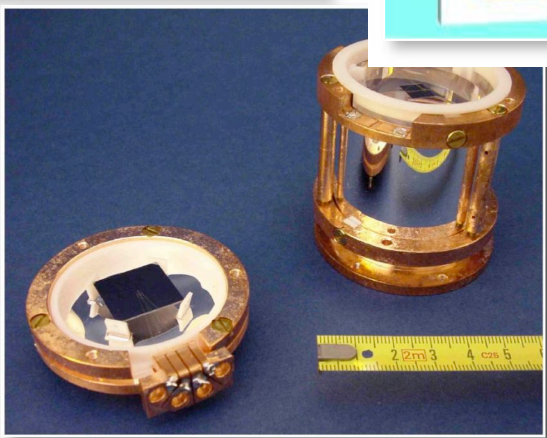
Natural WIMP candidate: SUSY LSP neutralino

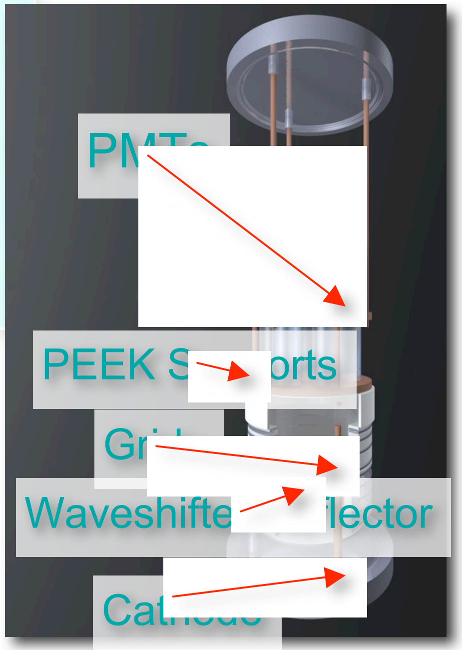
$$\tilde{\chi}_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W}^3 + N_{13}\tilde{H}_1^0 + N_{14}\tilde{H}_2^0$$

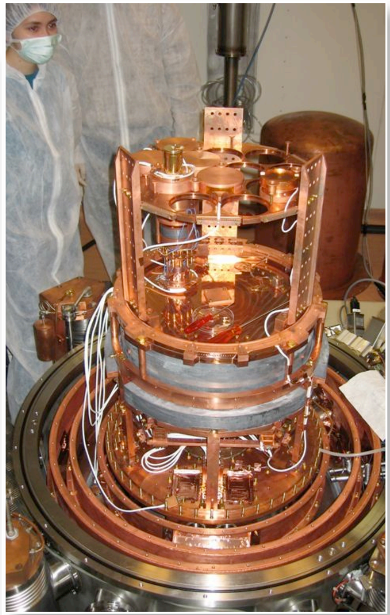
gaugino fraction: $Z_g = |N_{11}|^2 + |N_{12}|^2$

→ Stable if SUSY exists and R-parity is conserved

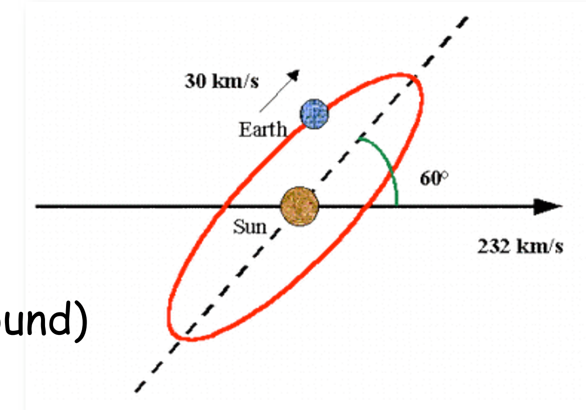
- Direct detection:
  - WIMP scattering off nuclei



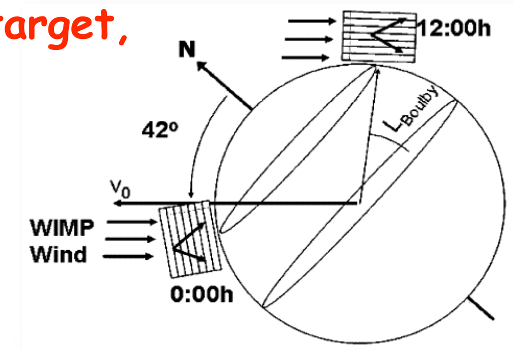




Possible WIMP Signatures



- **Nuclear vs electronic recoil**
  - **(discrimination almost required now)**
- No multiple interactions
  - (usually only removes limited fraction of background)
- Recoil energy spectrum shape
  - (exponential, **rather similar to background**…)
- Annual flux modulation
  - (**tricky, most events close to threshold, small effect,**
  - **Requires > 500 kg Ge target for > 5 years and 5 σ detection**)
- Diurnal direction modulation
  - (nice signature, but **requires low pressure gaseous target,**
  - **Not convincingly demonstrated yet in my opinion**)
- Consistency between **targets of different nuclei**
  - (essential once first signal is clearly identified)



Experimental challenges

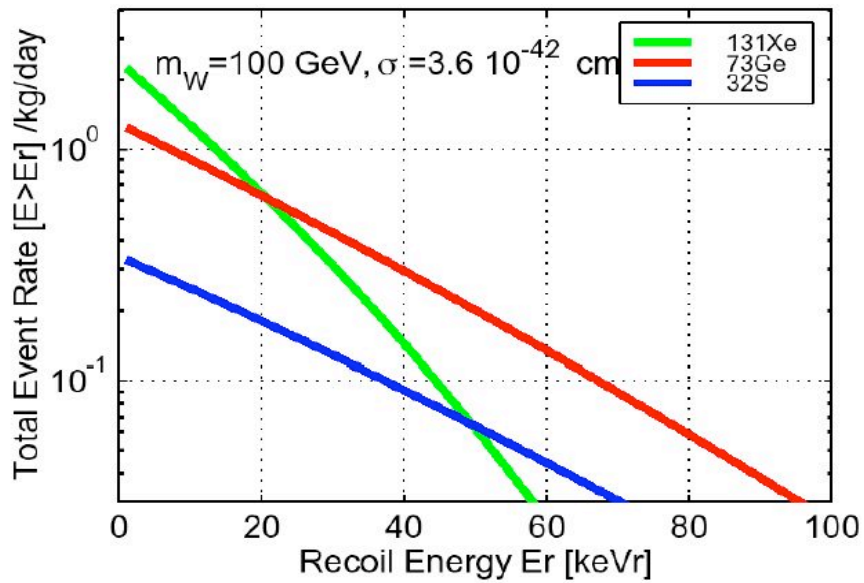
- Background suppression
  - Deep underground sites
  - Radio-purity of components
  - Active/passive shielding

- Large target mass required

- ~ few keV energy threshold

- Stability and reproducibility

- **Discriminate recoil populations**
  - **Photons scatter off electrons**
  - **WIMPs/neutrons off nuclei**
  - radon heavy nuclear recoils, alpha tails…



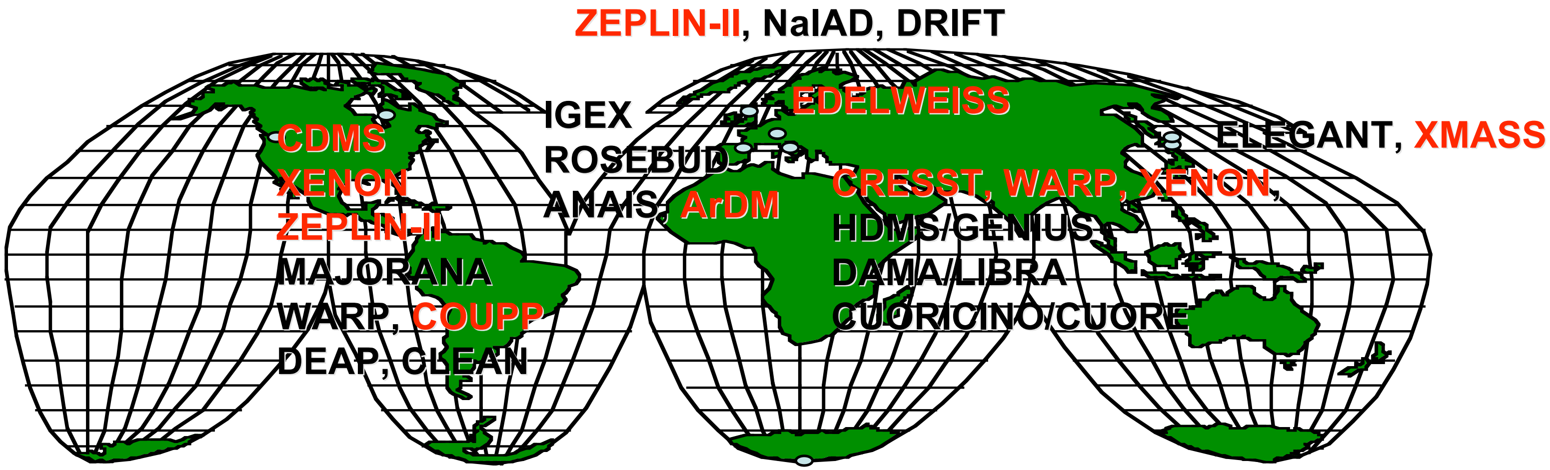
Expected Energy Spectra for a 100 GeV WIMP, illustrating the importance of the choice of detector material

Some current direct detection experiments

Discrim.	Name	Location	Technique	Target	Status
None	CUORICINO	Gran Sasso	Heat	41 kg TeO2	running
	GENIUS-TF	Gran Sasso	Ionization	42 kg Ge in liq. N_2	running
	HDMS	Gran Sasso	Ionization	0.2 kg Ge diode	stopped
	IGEX	Canfranc	Ionization	2 kg Ge Diodes	stopped
Statistical	DAMA	Gran Sasso	Light	100 kg NaI	stopped
	LIBRA	Gran Sasso	Light	250 kg NaI	running
	NaIAD	Boulby mine	Light	65 kg NaI	stopped
	DRIFT	Boulby mine	Low pressure TPC	CS_2	running
	ZEPLIN-I	Boulby mine	Light	4 kg Liquid Xe	stopped
	XMASS	Kamioka	Light	100 kg Xe	running
Event-by-event	CDMS-I	Stanford	Heat + Ionization	1 kg Ge + 0.2 kg Si	stopped
	CDMS-II	Soudan mine	Heat + Ionization	5 kg Ge + 1 kg Si	running
	CRESST-II	Gran Sasso	Heat + Light	10 kg CaWO4	running
	ArDM	Canfranc	Ionization + light	1 ton Ar	starting
	EDELWEISS-II	Modane	Heat + Ionization	10 kg Ge	running
	XENON-10	Gran Sasso	Ionization + Light	10 kg Xe	running
	WARP	Gran Sasso	Ionization + Light	3 kg Ar	running
	ZEPLIN-II	Boulby mine	Ionization + Light	10 kg Xe	running
	PICASSO	SNO	Metastable gel		
	SIMPLE	Rustrel	Metastable gel		
	COUPP	Fermilab	Bubble chamber	Freon-type liquids	prototype

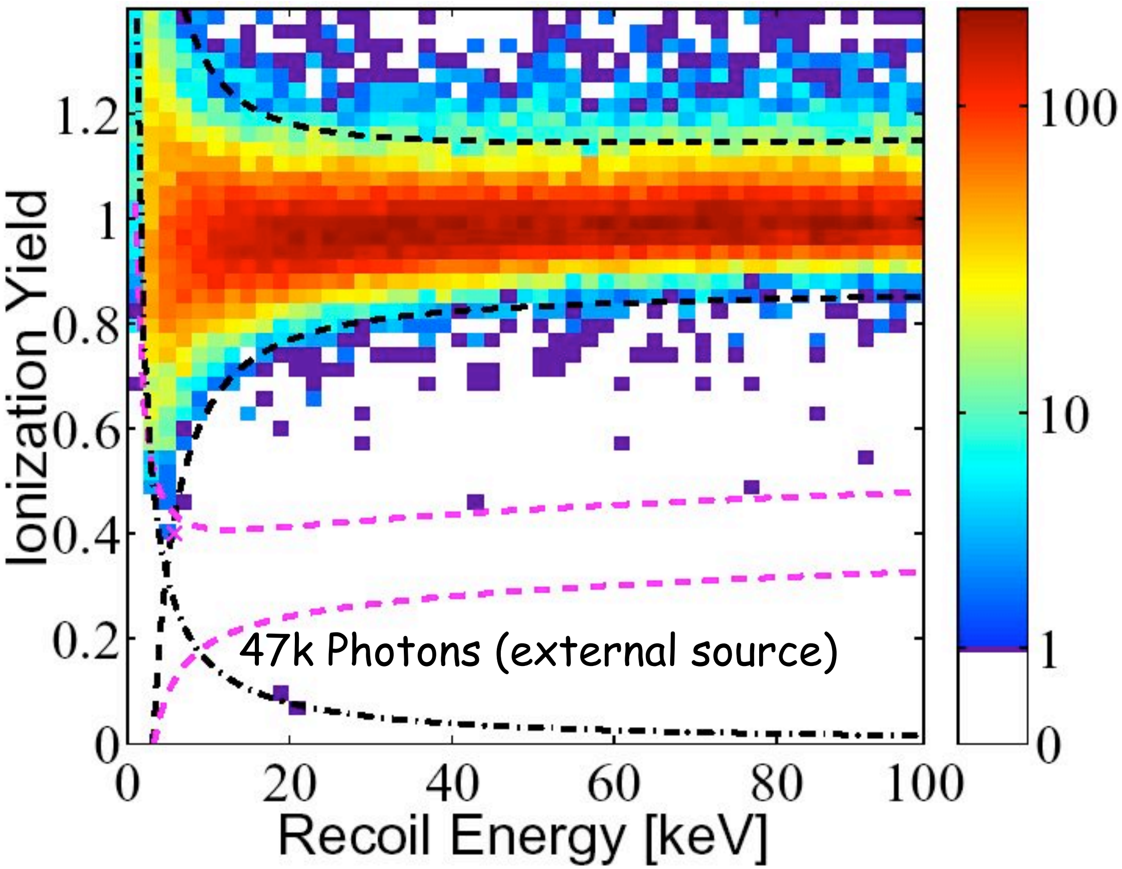
Main Wimp direct detection experiments

- CDMS-II @ Soudan Mine (US project)
- EDELWEISS-II (cryo Ge @ Fréjus) → EURECA
- CRESST-II (cryo $CaWO_4$, $ZnWO_4$) @ Gran Sasso → EURECA
- XENON-10 @ Gran Sasso, ZEPLIN-II and -III @ Boulby → ELIXIR
- ArDM @ Canfranc, WARP @ Gran Sasso → common project ?
- DRIFT + MIMAC → CYGNUS
- LIBRA (NaI) @ Gran Sasso, , NaIAD (Boulby), ANAIS (Canfranc)
- IGEX @ Canfranc, HDMS/GENIUS-TF (Ge) @ Gran Sasso
- CUORICINO/ CUORE (TeO_2) @ Gran Sasso
- SIMPLE, MACHe3, ORPHEUS (Bern)
- XMASS, ELEGANT, LiF @Japan
- (Future experiments: SuperCDMS, EURECA , XENON-100, GERDA, LUX...)



CDMS Background Discrimination

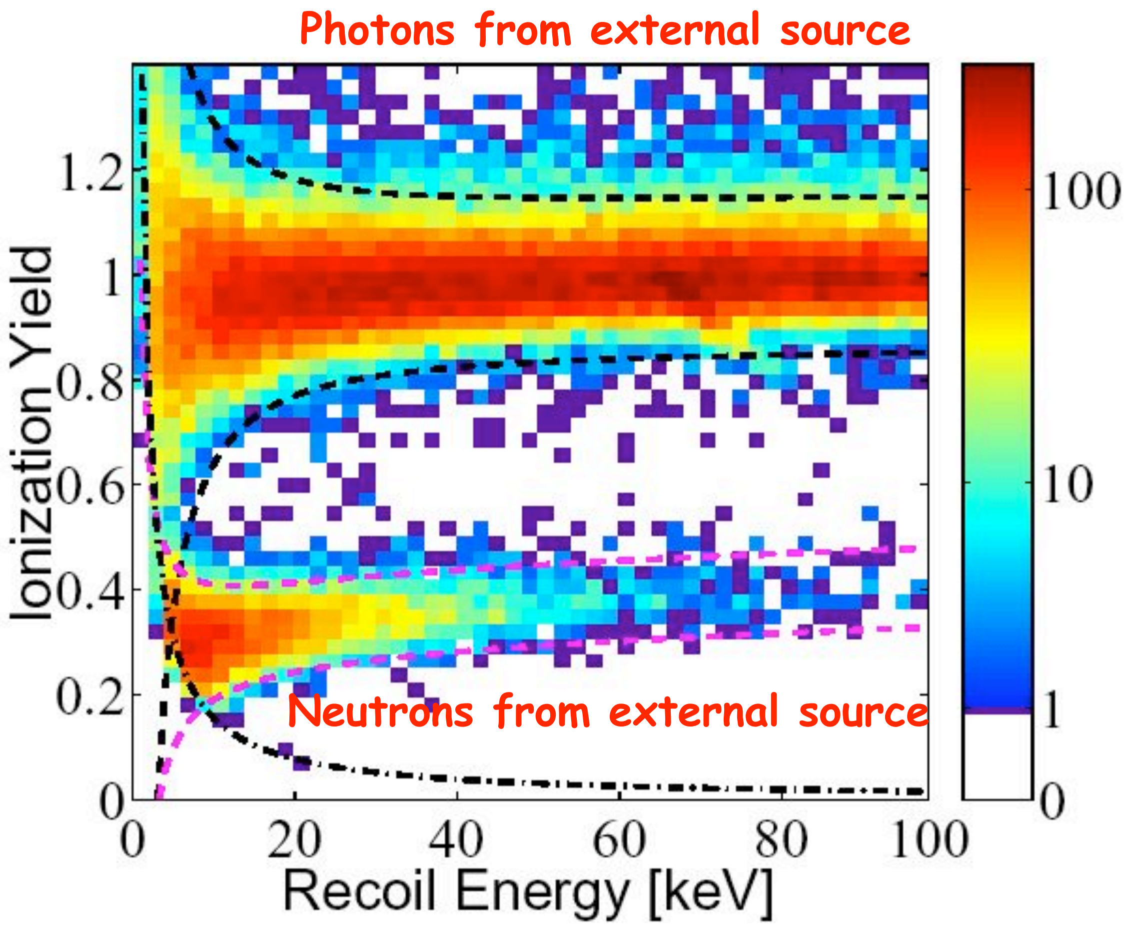
- Ionization Yield (ionization energy per unit recoil energy) depends strongly on type of recoil
- Most background sources (photons, electrons, alphas) produce electron recoils



CDMS II Background Discrimination

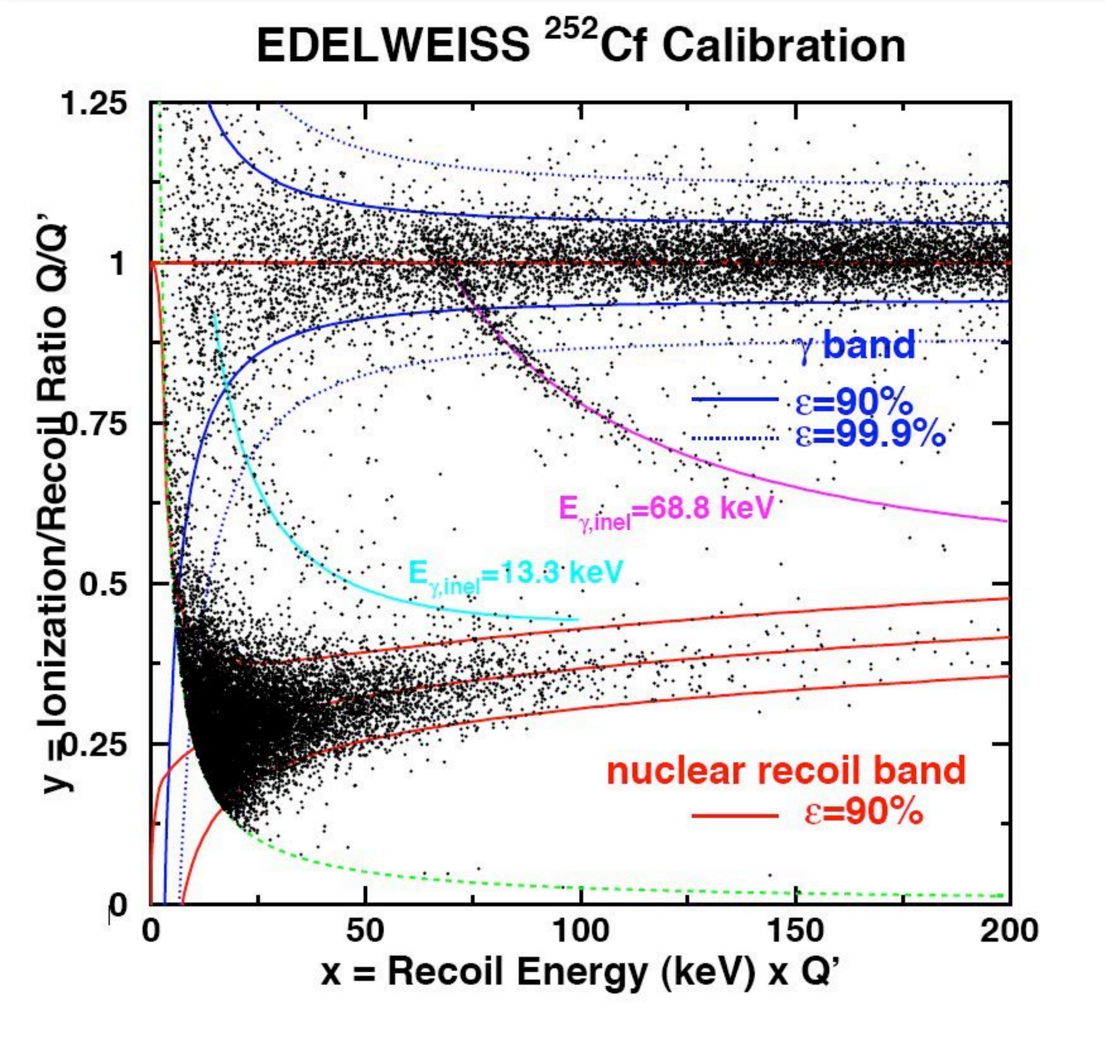
- Ionization Yield (ionization energy per unit recoil energy) depends strongly on type of recoil

- Ionization yield alone rejects >99.9% of gammas, >75% of 'betas'
- Ionization+phonon timing rejects >99.9999% of gammas, >99% of 'betas'



Edelweiss: event-by-event discrimination

O. Martineau et al., astro-ph/0310657/



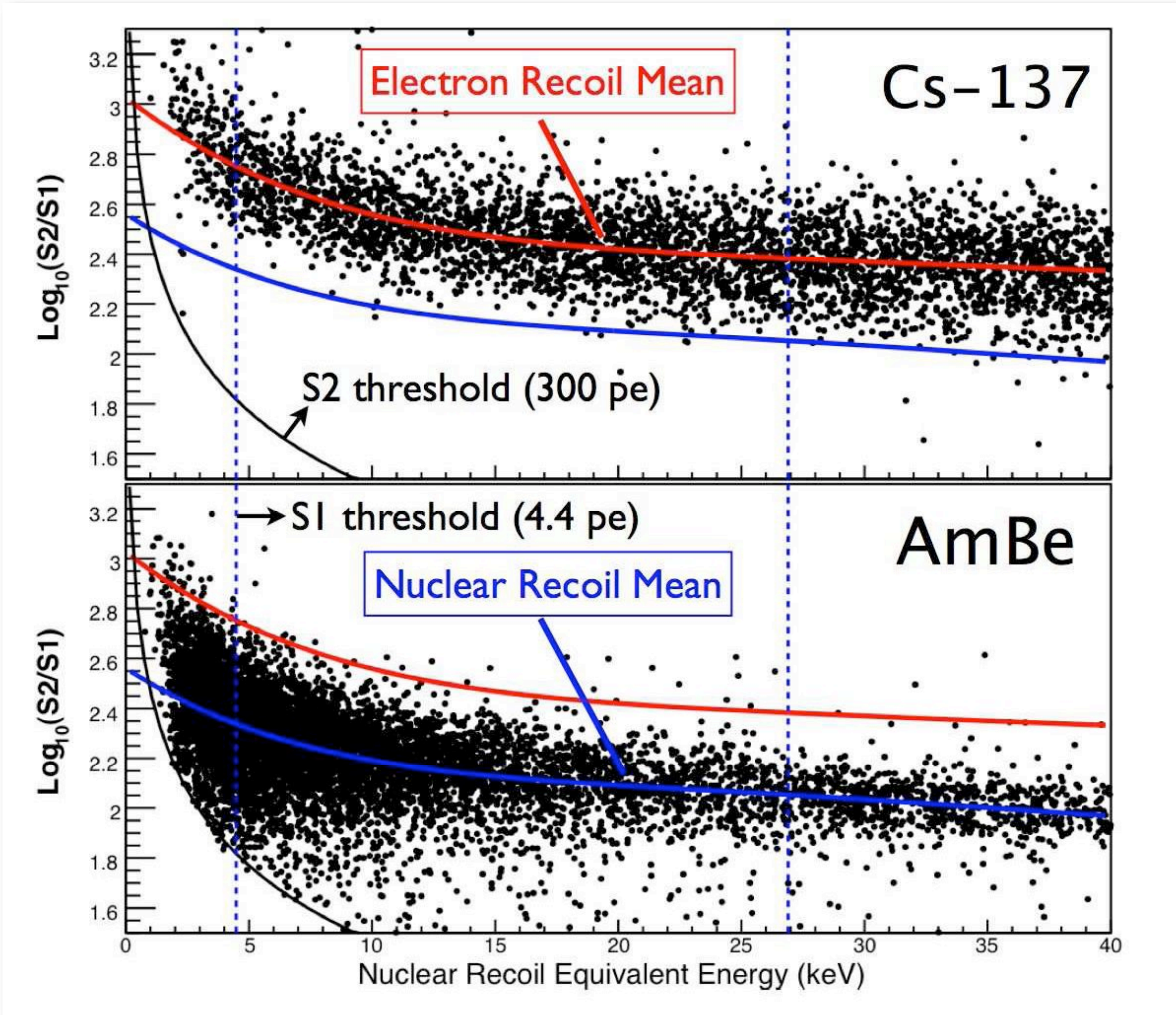
Neutron + gamma calibration

Nuclear recoil discrimination down to 20 keV threshold :

γ-ray rejection > 99.99 %

XENON neutron and gamma calibrations

J. Angle et al., astro-ph:0706.0039

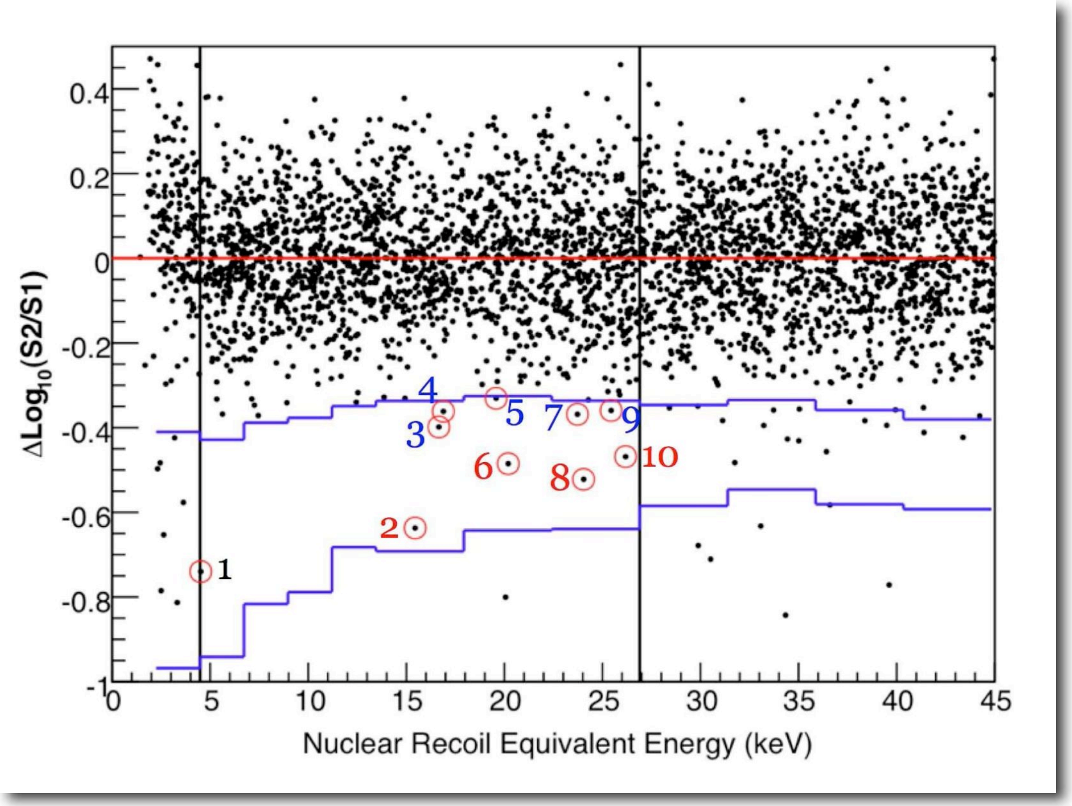


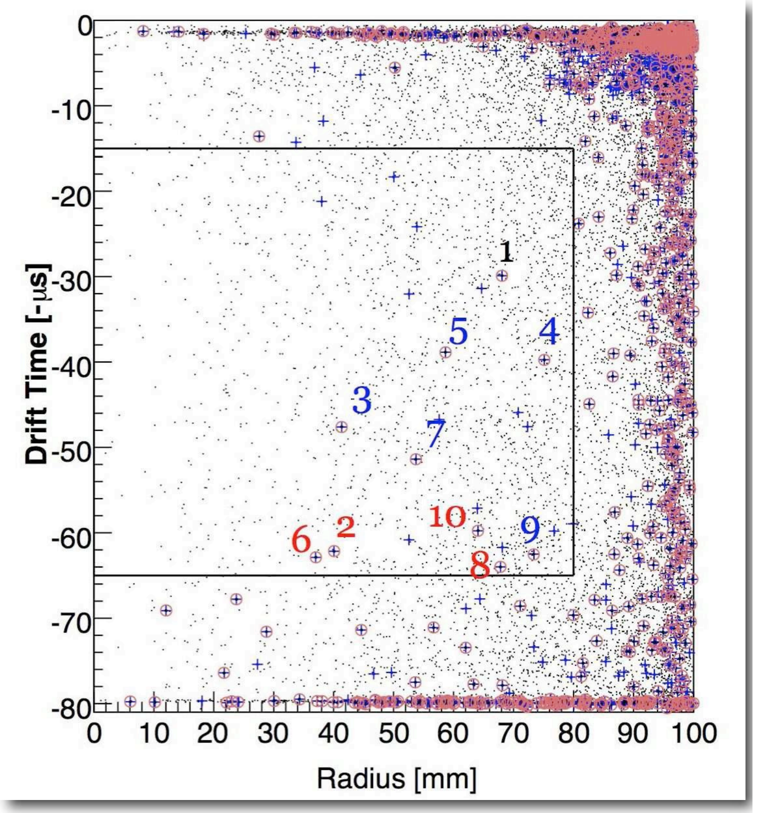
Gamma calibration

Nuclear recoil AmBe calibration

Experimental status and strategy

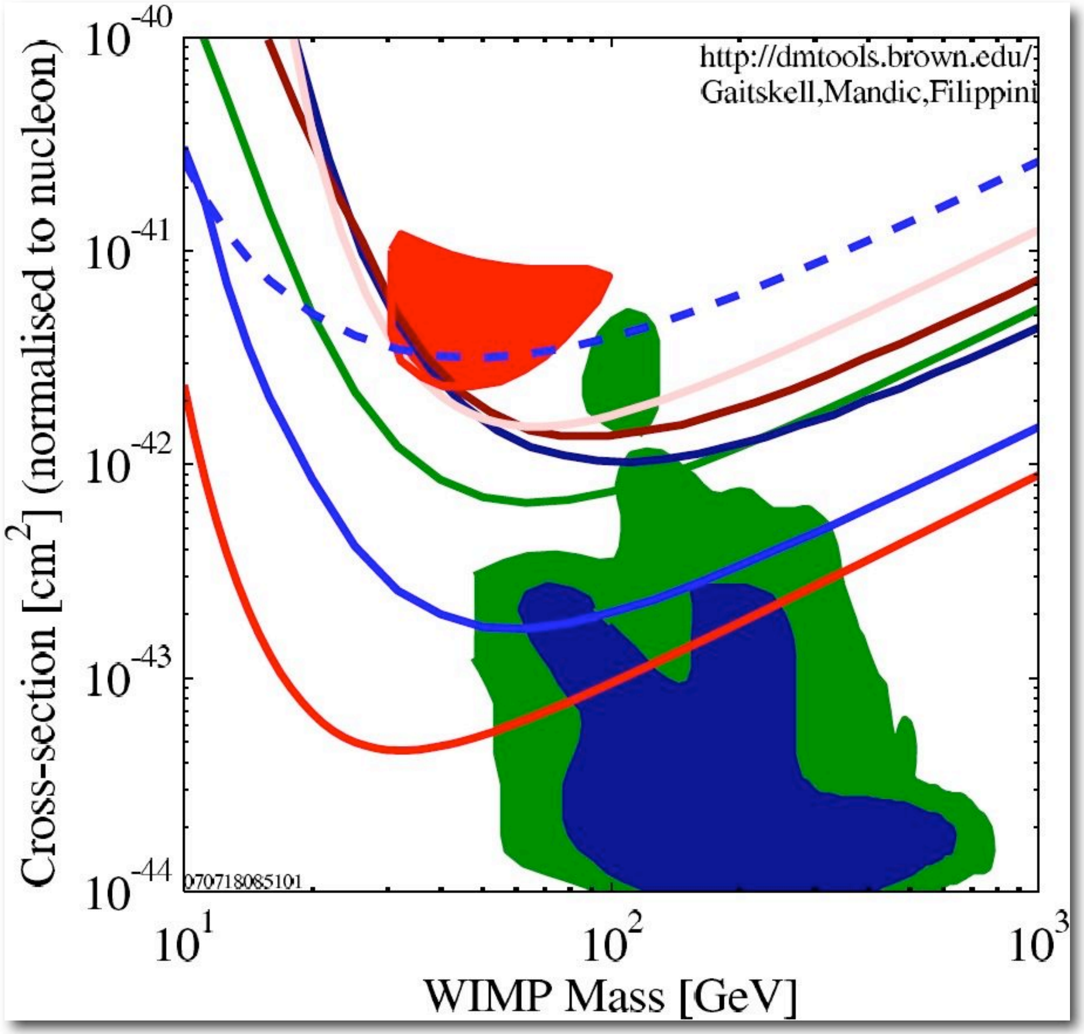
- Most experiments (below, XENON) are already recording background events, and testing strategies to remove them





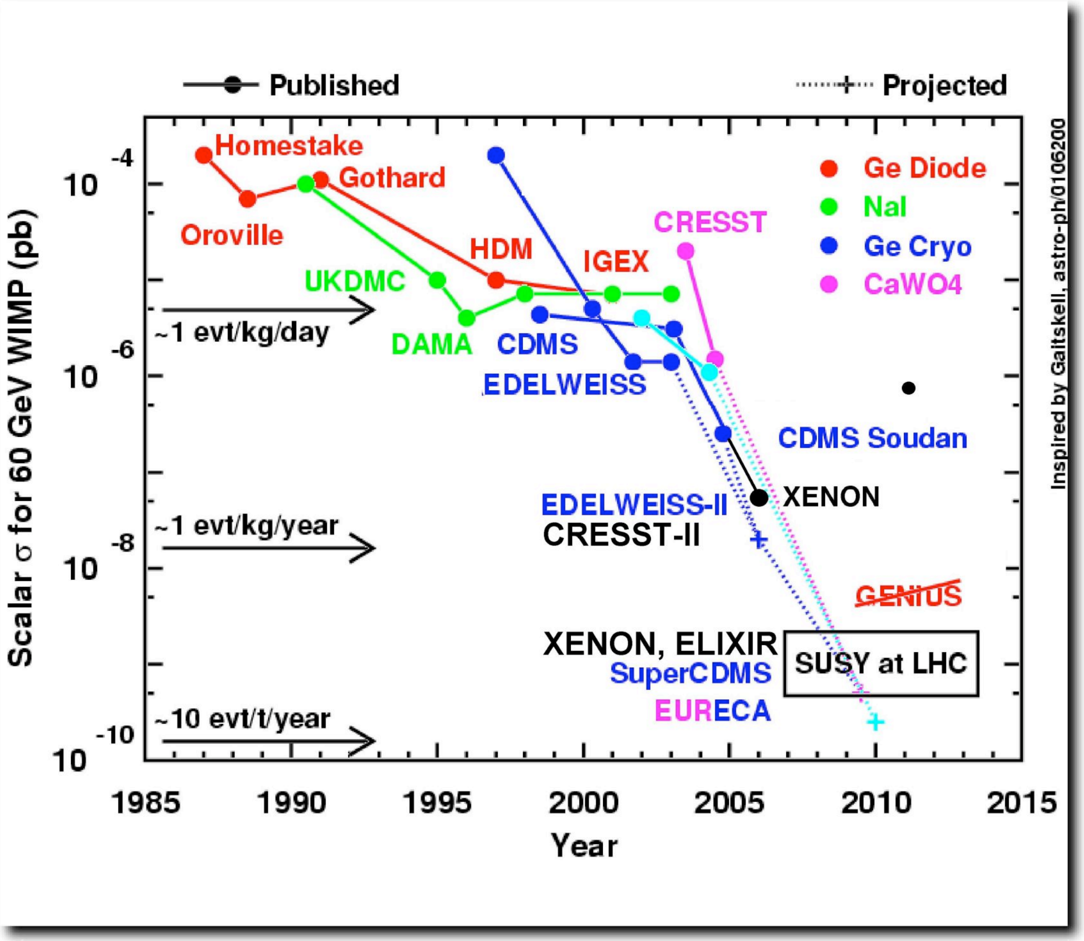
Experimental status and strategy

- Goal ≈ 2018 (roadmap) 10^{-10} pbarn
- Three orders of magnitude progress in sensitivity compared to best present sensitivities



Time evolution of sensitivity

- Rapid evolution of sensitivity of discriminating experiments (XENON, CDMS, CRESST, EDELWEISS, WARP, ZEPLIN-II…)
- But goals are still ≈3 orders of magnitude beyond present best performances



(After Gaitskell)

Main meetings of WG5

- Valencia Nov. 7-8 meeting : ASPERA kick-off meeting and ApPEC roadmap discussion
- Paris Feb. 1st meeting: all major European groups represented
- CERN July 13th meeting: all major European groups except WARP

Main meetings of WG5

- Paris Feb. 1st and CERN July 13th meetings:
  - Presentation and discussion of basically all Direct Detection DM European projects
  - Discussion of European and US roadmaps
  - Definition of strategy and prioritization (CERN meeting)
- **ASPERA Questionnaires + presentations + US and ApPEC roadmaps on Plone Website**

Projects discussed

- Cryogenic:
  CRESST + EDELWEISS → EURECA
- Xenon TPC: XENON10, XENON100, ZEPLIN-II and -III → ELIXIR
- Argon TPC: ArDM, WARP
- DRIFT + MIMAC → CYGNUS
- DAMA-1ton, ULTIMA, SIMPLE
- Underground facility ULISSE

Experimental status

- Impressive progress has been realized over the last year by liquid target DM experiments (notably XENON, WARP, ZEPLIN-II)
- Cryogenic detector experiments (CDMS, CRESST, EDELWEISS) are also progressing rapidly with their 10-kg stages
- The 10^{-8} pbarn “ SUSY-rich ” region should be reached within two years

Experimental status and strategy

- Today, there exists several approaches towards 10^{-9} pbarn sensitivity
- Still, 10^{-10} pbarn represents ≈ 3 orders of magnitude improvement in sensitivity
- Additionally, identifying a Dark Matter WIMP candidate will probably require confirmed detection by **more than one nuclear target**
- Three main experimental lines: **Ar, Xe, cryogenic detectors**

Experimental status and strategy

- It is therefore proposed to progress in two stages
- 1) Next 3-4 years, demonstrate/optimize discrimination strategy and sensitivity at ≈ 10^{-8} pbarn with 10-100 kg stages
  - Design studies: EURECA, ELIXIR
  - ArDM ton-scale detector + WARP-140
- 2) In ≈2010, decision on two (3?) complementary experiments with sensitivity in the 10^{-10} pbarn range
- In parallel, two main R&D activities:
  - Clear demonstration of directional detector: CYGNUS
  - Procurement of ^{39}Ar depleted argon (underground natural gas, isotopic separation)

R&D activities

- Nobody has demonstrated yet an experimental method able to reach with reasonable certainty 10^{-10} pbarn sensitivity (that would give access to fair fraction of SUSY models)
- Continuation of R&D activities during the first stage is therefore essential
- Main goal : improvement of background rejection and identification performances
- Clear demonstration of directionality and, if possible, of track sense determination would prepare the final stage : demonstration of galactic origin of WIMP signal if observed in « first detection » experiments

Towards experiments at 10^{-10} pbarn sensitivity

- Precision calibration is necessary to assess the discrimination and energy calibration performances
- Recommendation of common experimental effort on well-equipped neutron scattering facility (e.g. TU-Muenchen, or Amande Grenoble)
  - Precision calibration of small-scale prototypes of all main experiments
  - Calibration of nuclear recoils at low energy of WARP, and to lesser extent XENON/ZEPLIN, not yet clear and should be improved
- In parallel, design study phase of ultra-low background deep underground laboratory, active rejection and identification of showers (ULISSE)
- Material selection and strategy for internal neutron background identification and rejection

Funding requests for European DM program

- Design studies (2008-2011) for:
  - cryogenic (CRESST + EDELWEISS → EURECA)
  - liquid noble targets (ArDM, WARP) + (EU XENON + EU ZEPLIN → ELIXIR) experiments
- Unification of same target experiments recommended ? Mandatory ?
- Dedicated R&D on directionality (CYGNUS)
- Recommend significant participation (Lisbon group, others…) in COUPP (US-led program supported by Fermilab)
- Overall, 20 M€ investment first stage program over next 3-4 years
- In ≈ 2010, decision on 2 (if possible 3) ton-scale experiments with total investment budget 100 M€ range