Dark Matter Direct Detection roadmap strategy

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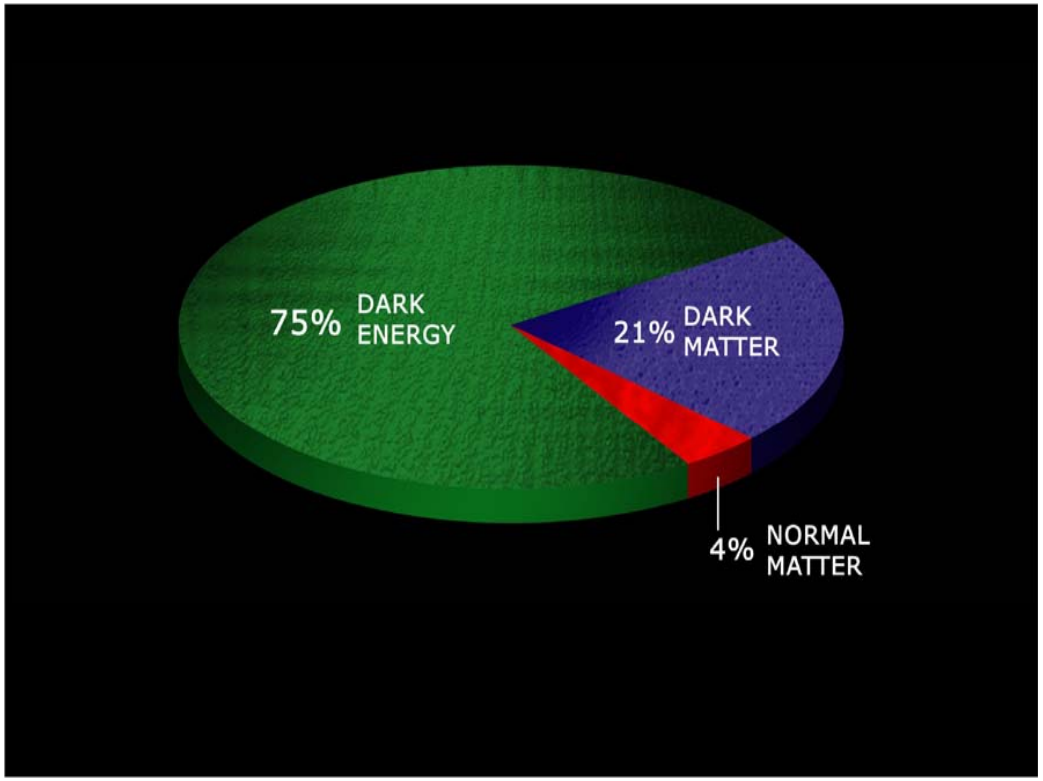
For the WG5 working group

Dark Matter and Dark Energy

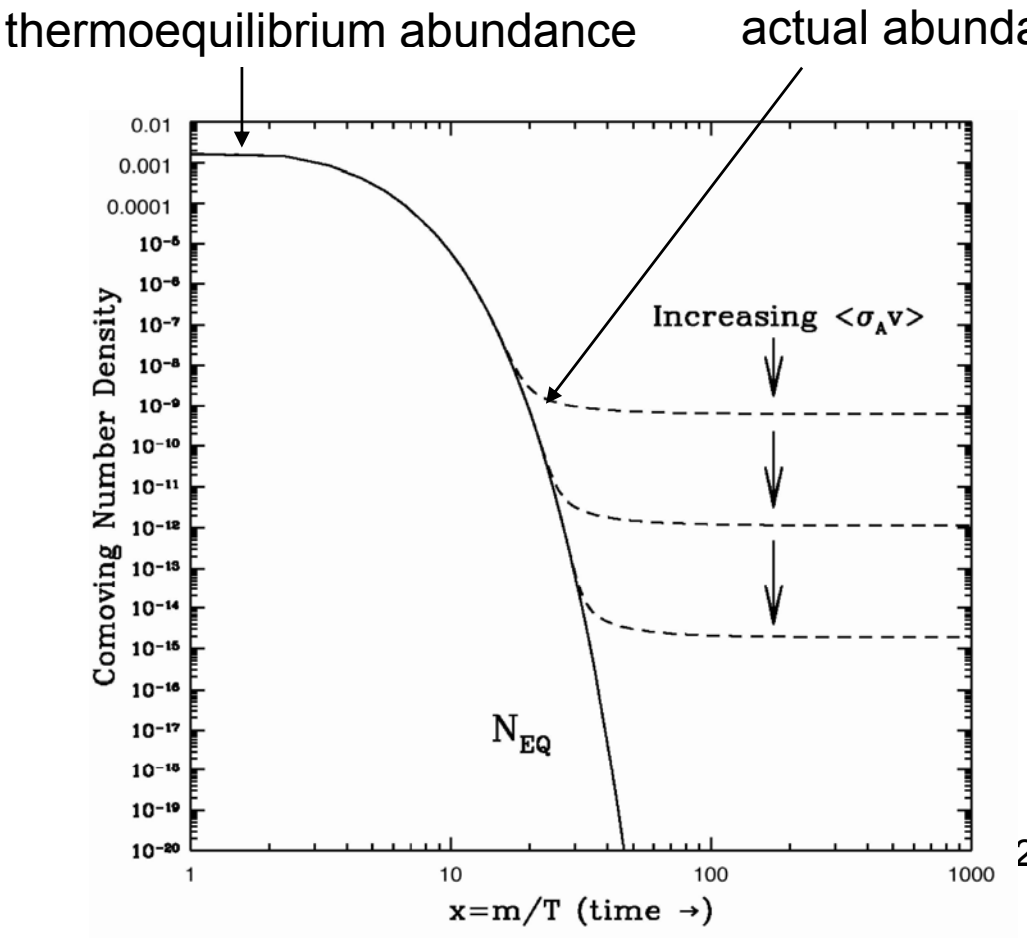
Outstanding question : What is the Universe made of ?

- Ordinary (baryonic) matter only represents only **≈ 4%** of the Universe energy content



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
$\langle v \rangle \approx 300$ km/s
$\sigma_A \approx 10^{-6}\text{-}10^{-10}$ pbarn

search for
physics beyond
the Standard Model

new elementary particles

Supersymmetry ???

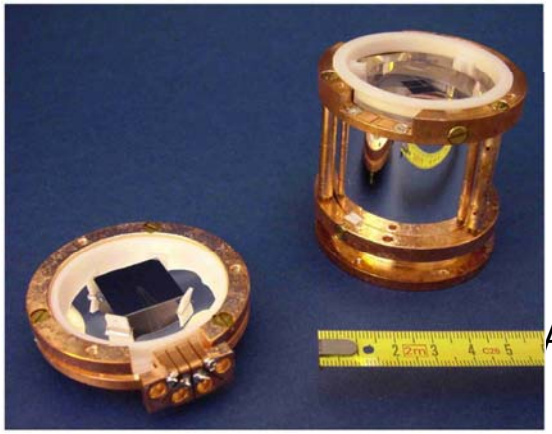
Natural WIMP : SUSY Lightest particle

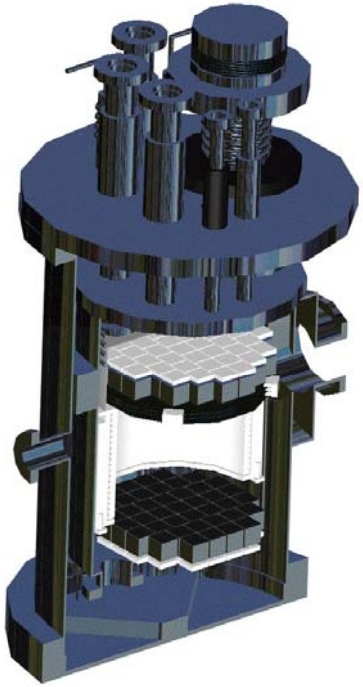
$$\tilde{\chi}_1^0 = N_{11}\tilde{B} + N_{12}\tilde{W}^3 + N_{13}\tilde{H}_1^0 + N_{14}\tilde{H}_2^0$$

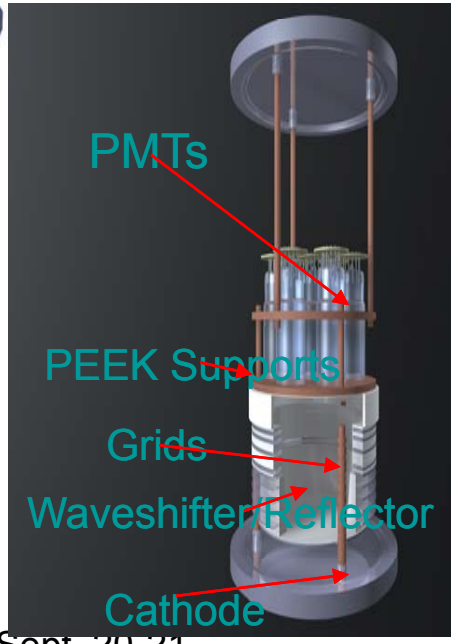
gaugino fraction: $Z_g = |N_{11}|^2 + |N_{12}|^2$

→ Stable if SUSY exists and R-parity is conserved

- Direct detection:
  - WIMP scattering off nuclei

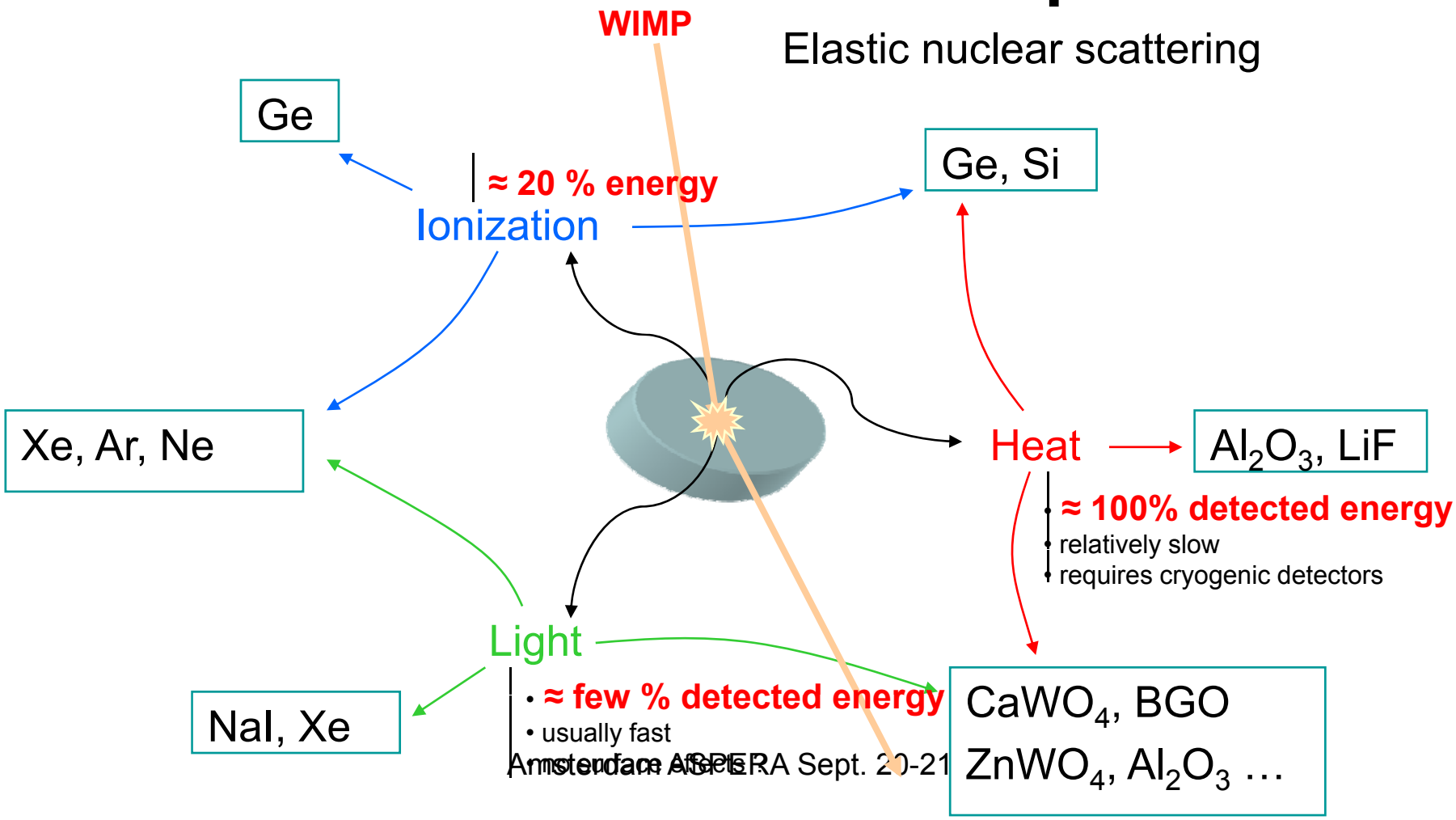






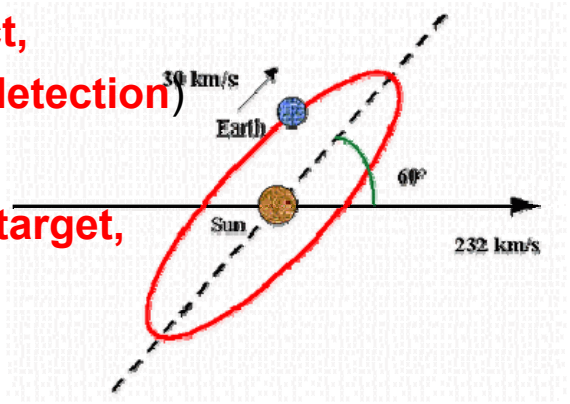
After Drukier and Stodolsky, PRD 30 (1984) 2295 (and Goodman and Witten (1985))

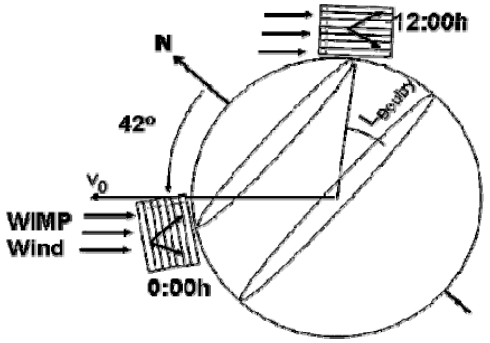
Direct detection techniques



Possible WIMP Signatures

- **Nuclear vs electronic recoil**
  - **discrimination almost required now**
- 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**
- No multiple interactions
  - (usually only removes limited fraction of background)
- Recoil energy spectrum shape
  - (exponential, **rather similar to background**…)
- Consistency between **targets of different nuclei**
  - (essential once first signal is clearly identified)

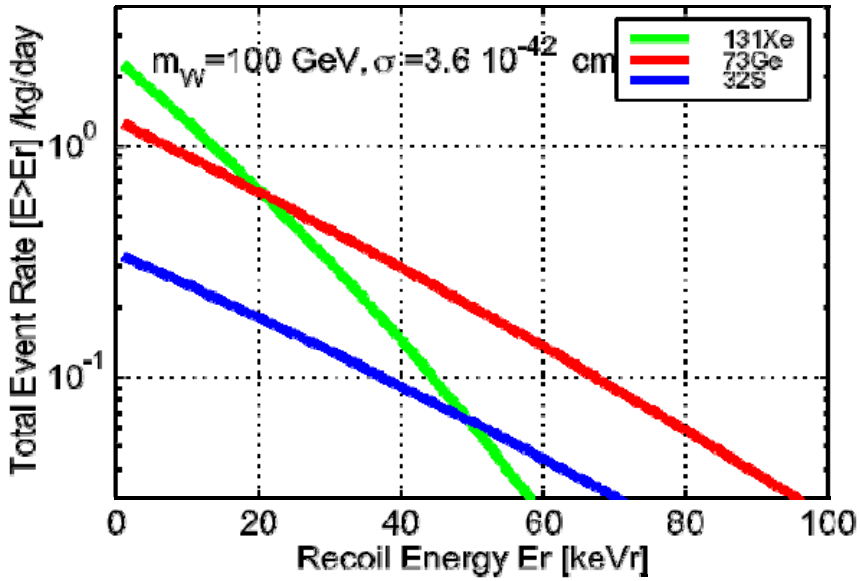




Experimental challenges

- 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

Main Wimp direct detection experiments

- CDMS-II @ Soudan Mine (US project)
- EDELWEISS-II (cryo Ge @ Fréjus) → **EURECA**
- CRESST-II (cryo $CaWO_4$, $ZnW0_4$) @ Gran Sasso → **EURECA**
- XENON-10 @ Gran Sasso, ZEPLIN-II and -III @ Boulby → **ELIXIR**
- ArDM @ Canfranc, WARP @ Gran Sasso → **common Ar-Xe Design Study ?**
- DRIFT + MIMAC → **CYGNUS**
- LIBRA (NaI) @ Gran Sasso, , NaIAD (Boulby), ANAIS (Canfranc)
- IGEX @ Canfranc, HDMS/GENIUS-TF (Ge) @ Gran Sasso
- CUORICINO/ CUORE ($Te0_2$) @ Gran Sasso
- COUPP, SIMPLE, MACHe3, ORPHEUS (Bern)
- XMASS, ELEGANT, LiF @Japan
- (Future experiments: SuperCDMS, EURECA , XENON-100, GERDA, LUX…)

WG5 Dark Matter

(direct detection only)

Composition of the Working Group

- Laura BAUDIS
- Yuryi BUNKOV
- Gilles GERBIER
- **Josef JOCHUM**
- Pierre de MARCILLAC
- Fabrice PIQUEMAL
- Daniel SANTOS
- Nigel SMITH (ApPEC PRC)
- Tim SUMNER
- Pierluigi BELLI
- **Gabriel CHARDIN (coord)**
- Tom GIRARD
- Hans KRAUS
- Claudio MONTANARI
- **André RUBBIA**
- Wolfgang SEIDEL
- Neil SPOONER

  - **Nearly all European Dark Matter experiments represented, together with CDMS and XENON**

Main meetings of WG5

- Valencia Nov. 7-8, 2006 meeting :

  ASPERA kick-off meeting

  ApPEC roadmap discussion

- Paris Feb. 1st, 2007 meeting:

  all major European groups represented

- CERN July 13th, 2007 meeting:

  all major European groups except WARP

Main meetings of WG5

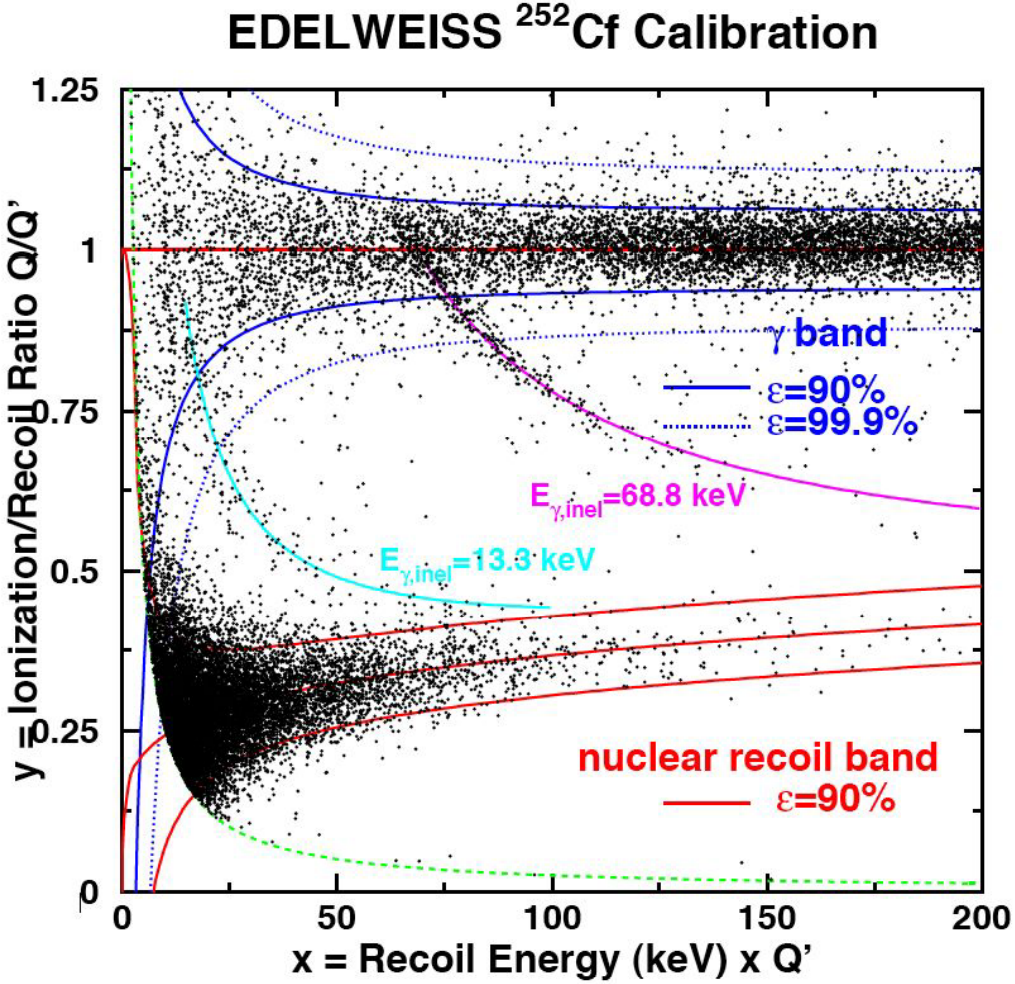
- Paris Feb. 1st and CERN July 13th meetings:
  - Presentation and discussion of basically all Direct Detection DM European projects
  - Discussion of European and US roadmaps
  - Definition of strategy and prioritization (CERN meeting)

- **ASPERA Questionnaires + presentations + US and ApPEC roadmaps can be found on ASPERA Plone Website**

Projects discussed in WG5

- Cryogenic: CRESST + EDELWEISS
  → EURECA
- Xenon TPC: XENON10, 100, ZEPLIN-II, -III
  → ELIXIR
- Argon TPC: ArDM, WARP → ?
- DRIFT + MIMAC → CYGNUS
- DAMA-1ton, ULTIMA, SIMPLE
- Underground facility ULISSE

Edelweiss: event-by-event discrimination



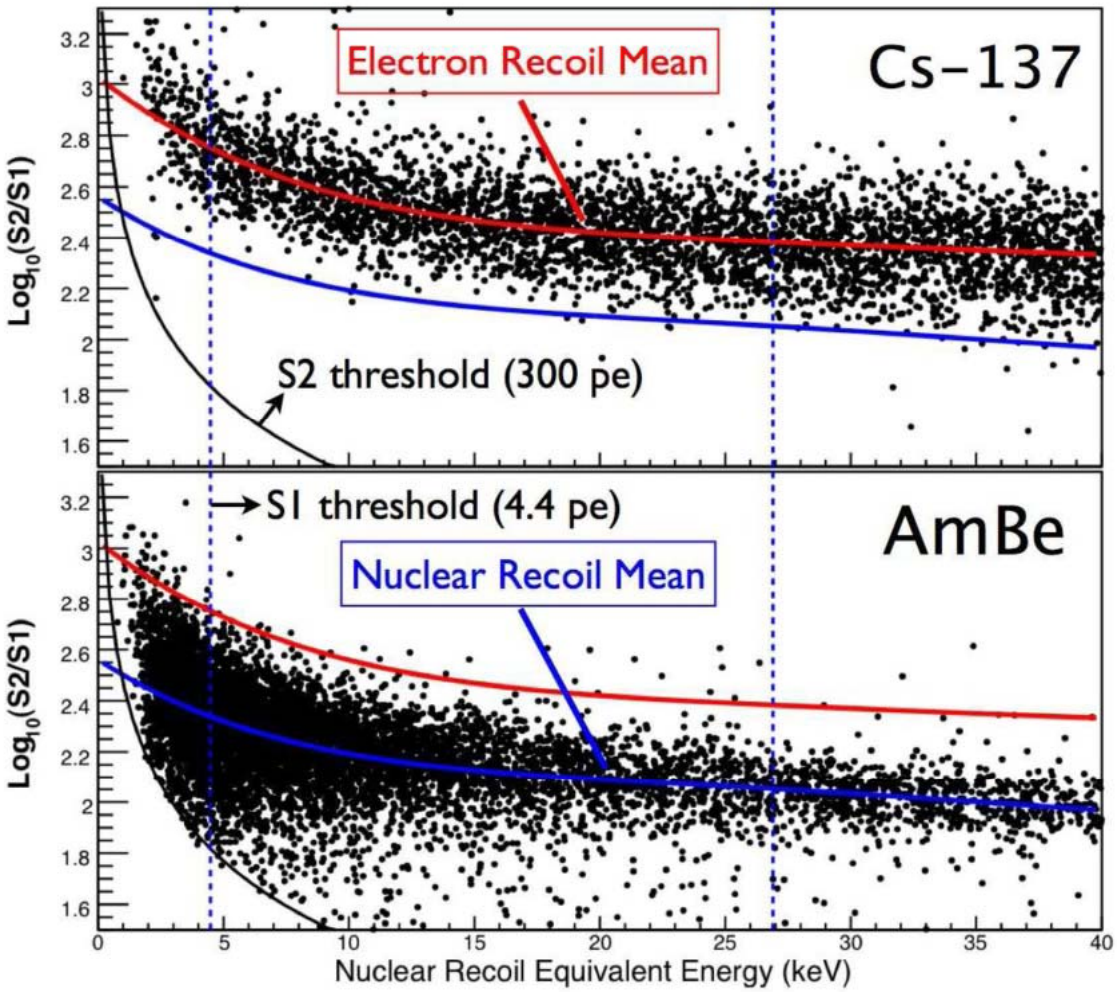
Charge + Heat Measurement

Neutron + gamma calibration

Nuclear recoil discrimination down to 20 keV threshold :

γ-ray rejection > 99.99 %

XENON neutron and gamma calibrations



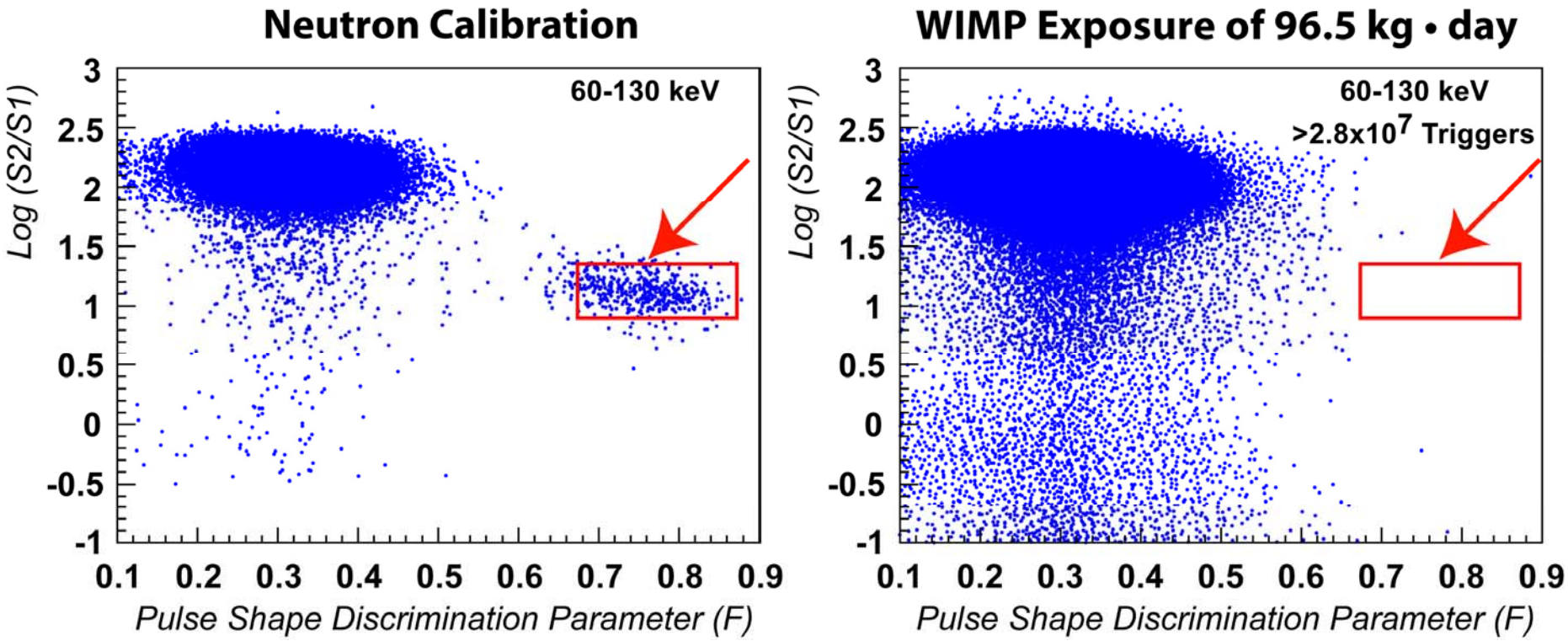
Charge + Light Measurement

Gamma calibration

Nuclear recoil AmBe calibration

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

"Dirty" liquid WARP 2.3 lt at LNGS

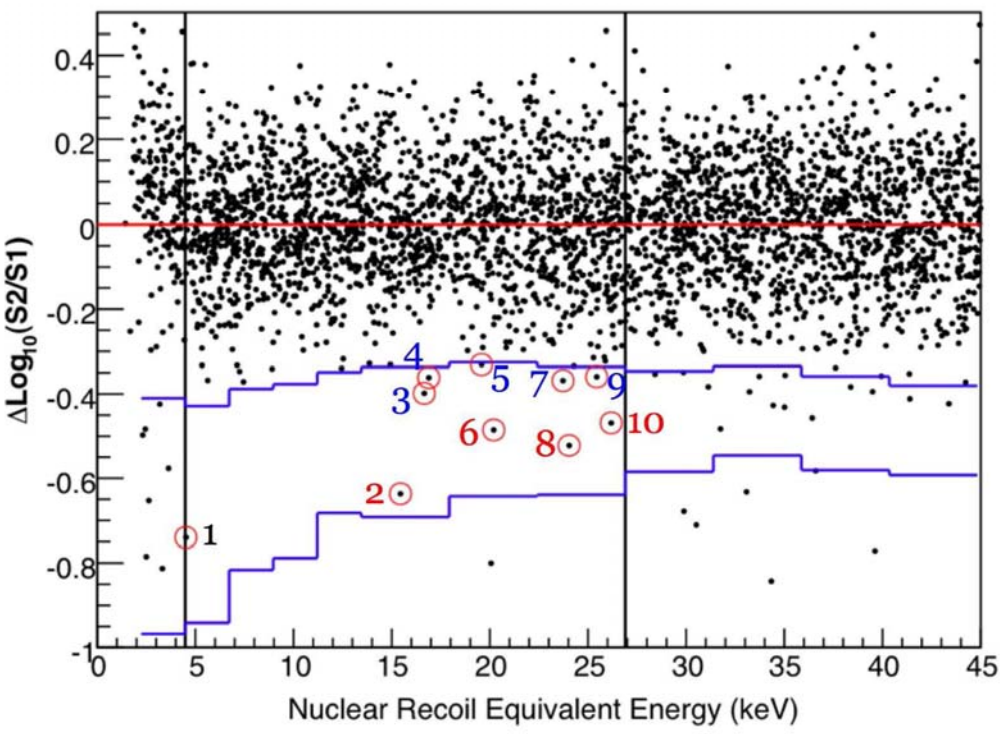


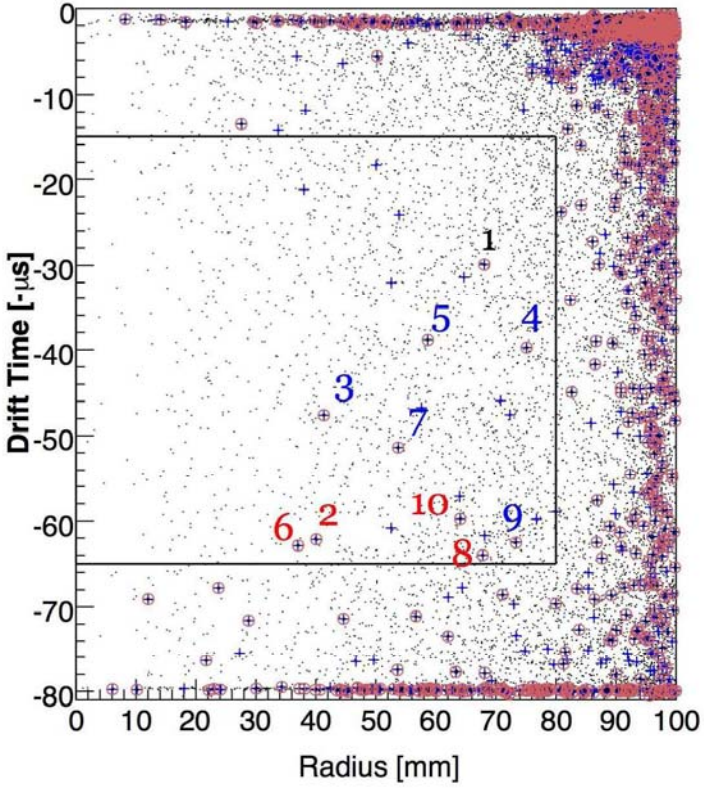
Impressive > 10^7 background rejection factor

Procurement of ^{39}Ar depleted argon in future

Experimental status and strategy

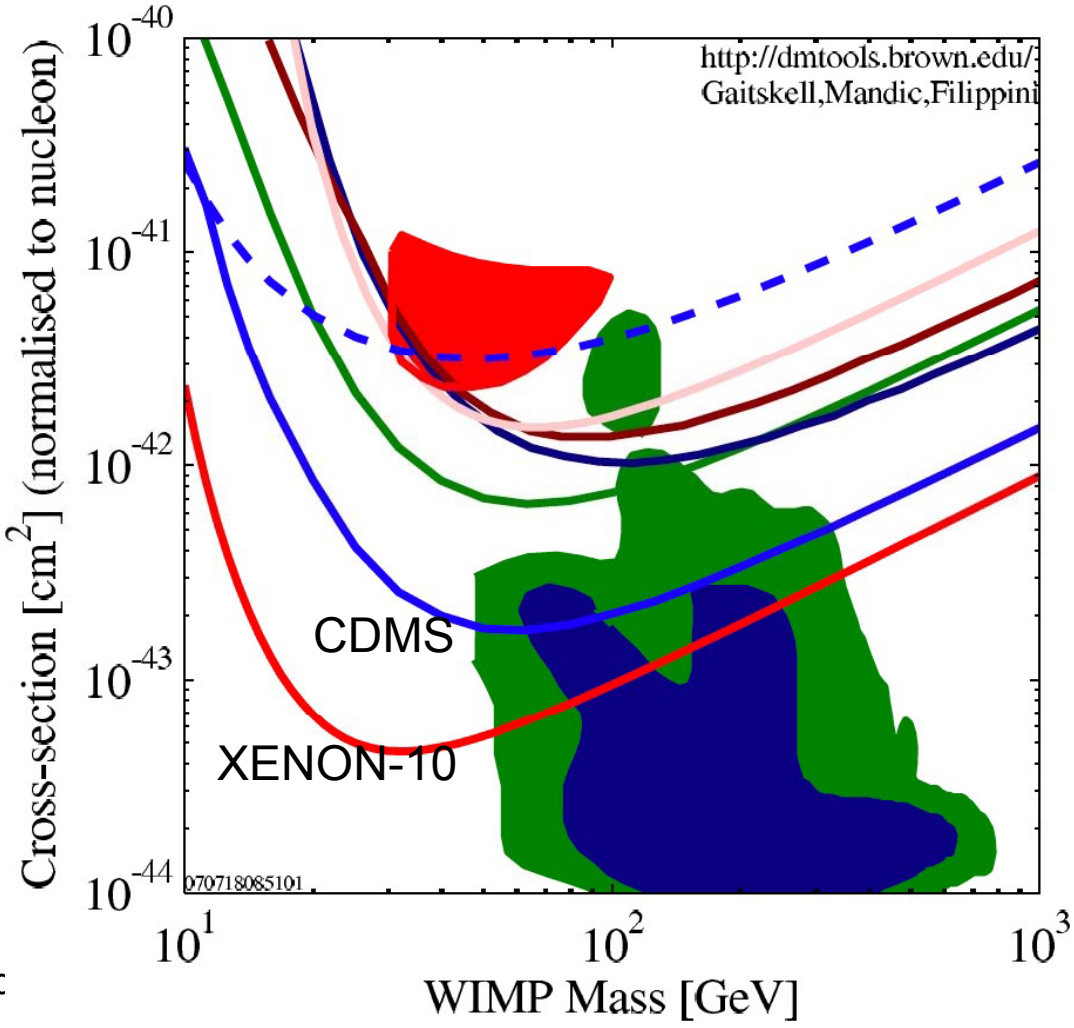
- Most experiments (below, XENON) are recording background events, and testing strategies to remove them





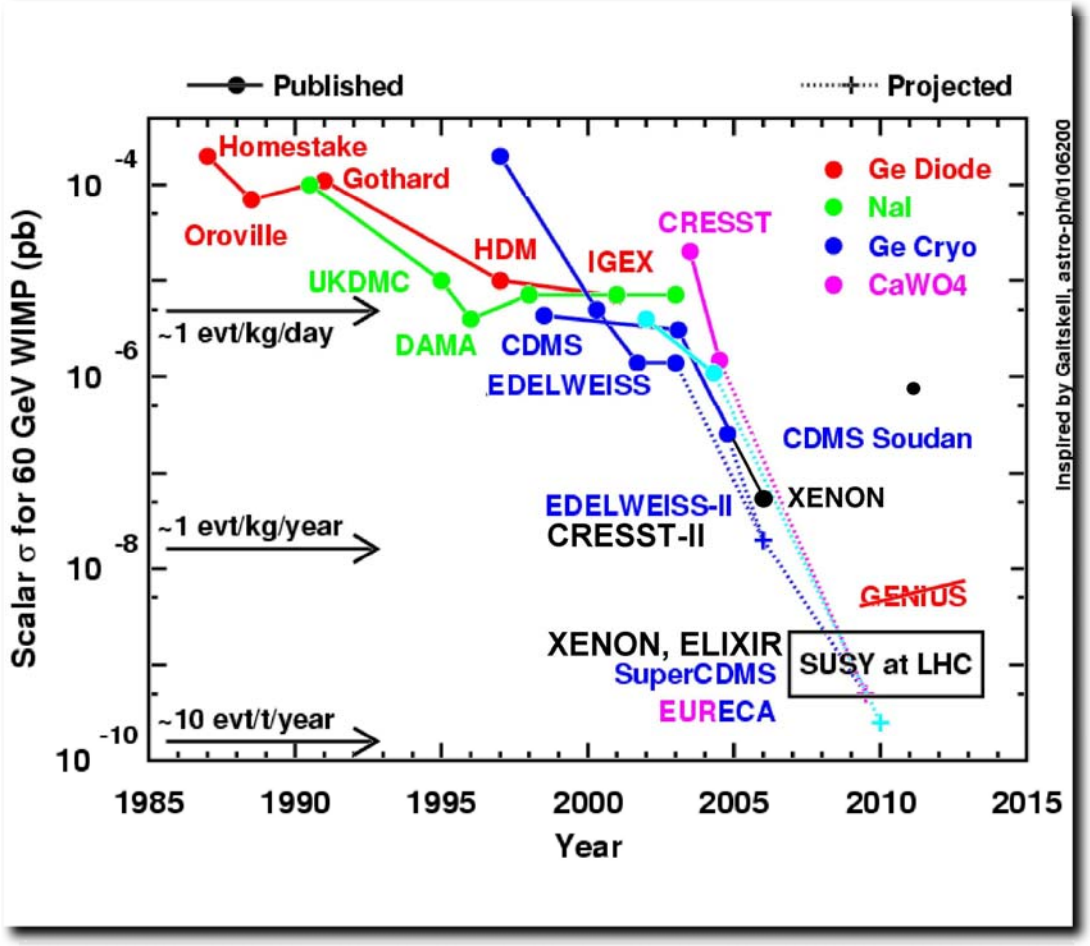
Experimental status and strategy

- Goal ≈ 2018
  10^{-10} pbarn
- Factor ≈ 300 progress in sensitivity still required compared to best present sensitivities



Time evolution of sensitivity

- Rapid evolution of sensitivity of discriminating experiments (**factor > 100 since 2000**) (XENON, CDMS, CRESST, EDELWEISS, WARP, ZEPLIN-II…)
- But goals are **still ≈2-3 orders of magnitude** beyond present best performances



(After Gaitskell)

Experimental status

- Impressive progress has been realized over the last year by liquid target DM experiments (XENON, WARP, ZEPLIN-II)
- Cryogenic detector experiments (CDMS, CRESST, EDELWEISS) are 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 ≈ 2.5 orders of magnitude improvement in sensitivity when compared to best present sensitivity (XENON)
- Important task: identifying a signal as Dark Matter WIMP
  => requires confirmed detection by
  more than one nuclear target
- => We recommend to pursue **in parallel 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/Liquid Argon
  - 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

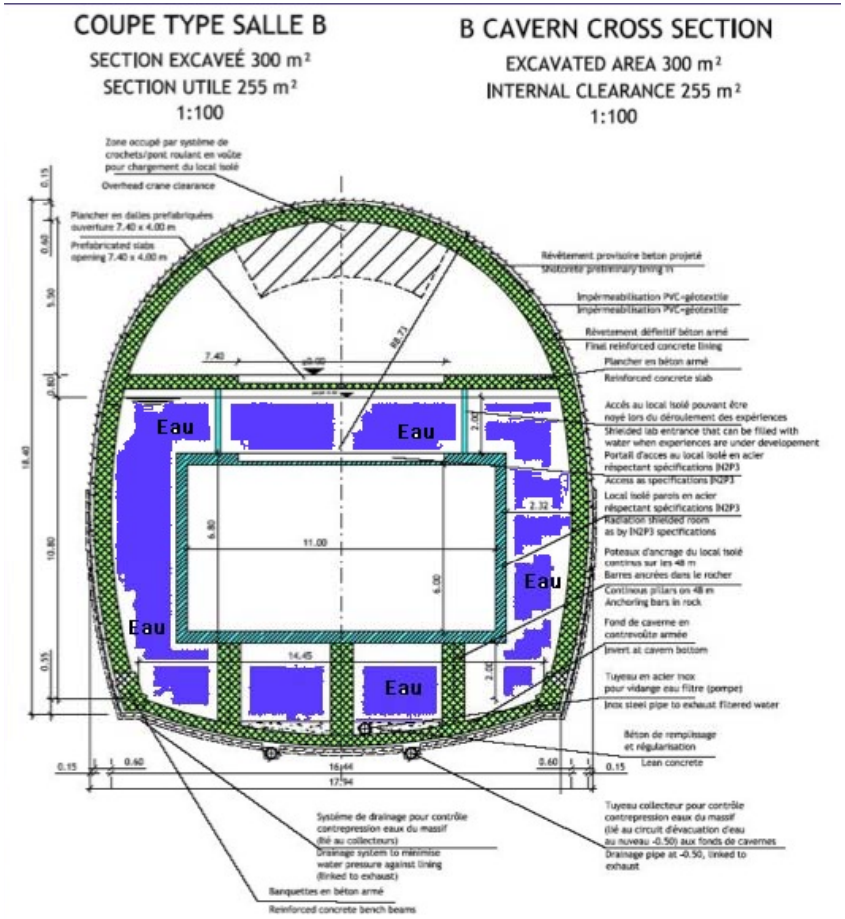
- Nobody has demonstrated yet an experimental method able to reach with **reasonable certainty 10^{-10} pbarn sensitivity** (that would give access to **fair fraction of SUSY** models)
- Continuation of **significant R&D** activities during the first phase is therefore essential
- Main goal :
  improvement 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

- Recommendation of common experimental effort on well-equipped neutron scattering facility (e.g. TU-Muenchen, or Amande Grenoble)
  - Precision calibration is necessary to assess the discrimination and energy calibration performances of competing techniques
  - High statistics neutron calibration of small-scale prototypes of all main experiments
  - Calibration of nuclear recoils at low energy of WARP and ZEPLIN, and to lesser extent XENON, 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)

Underground facility for DM search

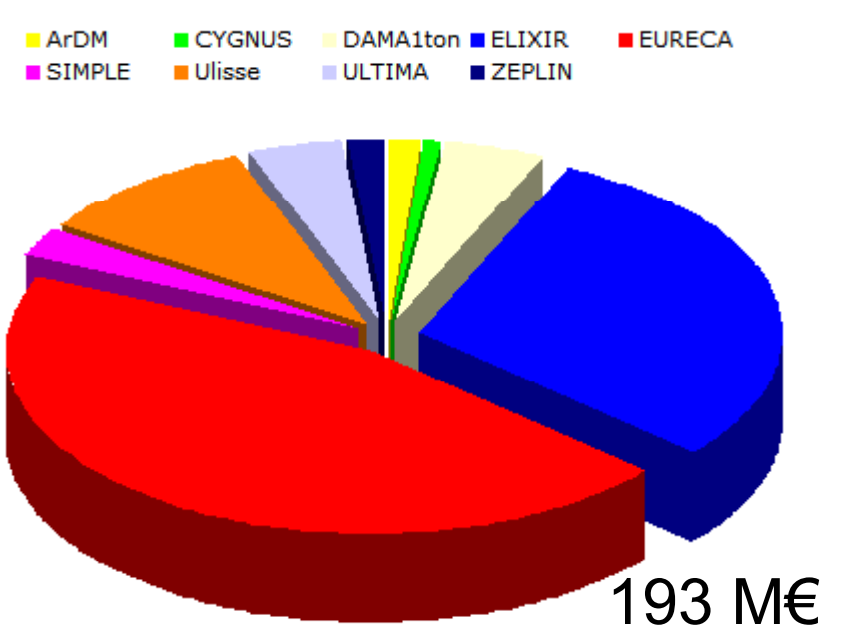
- Design study phase of ultra-low background deep underground laboratory, active rejection and identification of showers (ULISSE)
- This Design Study can be used by all Dark Matter direct detection experiments
- Active shower rejection



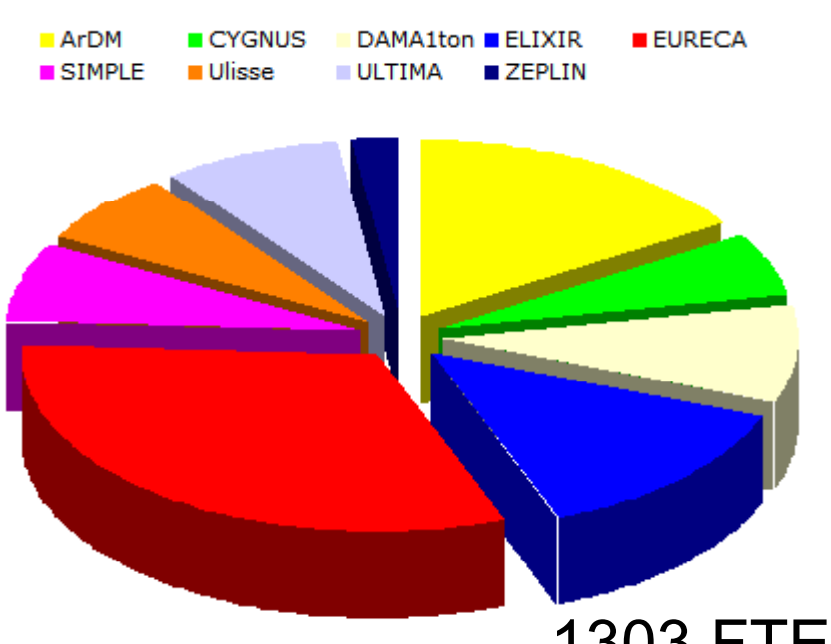
Funding requests European DM program

- Design studies (2008-2011) for:
  - cryogenic (CRESST + EDELWEISS → EURECA)
  - liquid noble targets (ArDM, WARP) + (EU XENON + EU ZEPLIN) experiments
- Unification of same target experiments recommended
- Importance of ApPEC coordination
- In parallel to these two main lines, dedicated R&D on directionality (CYGNUS)
- Overall, **20 M€ investment first stage program over next 3-4 years**
- In ≈ 2010, decision on 2 (if possible 3) DM experiments with **total investment budget in the 100 M€ range**

Projects Investment Costs 2008 - 2018



193 M€



1303 FTE

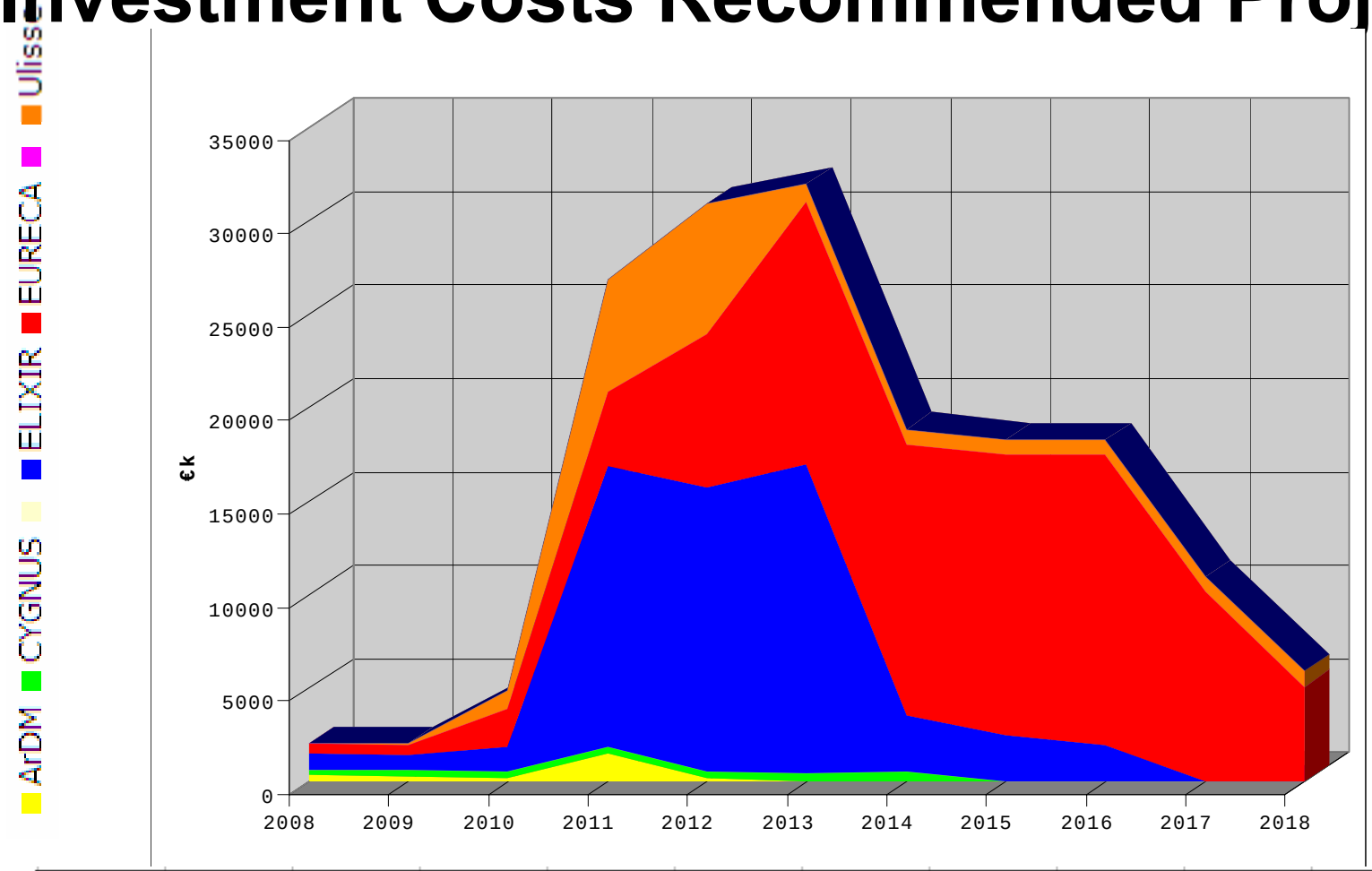
Recommendations:

Cryogenic => EURECA

Noble Liquid Gases => ELIXIR, WARP, ArDM (unify!)

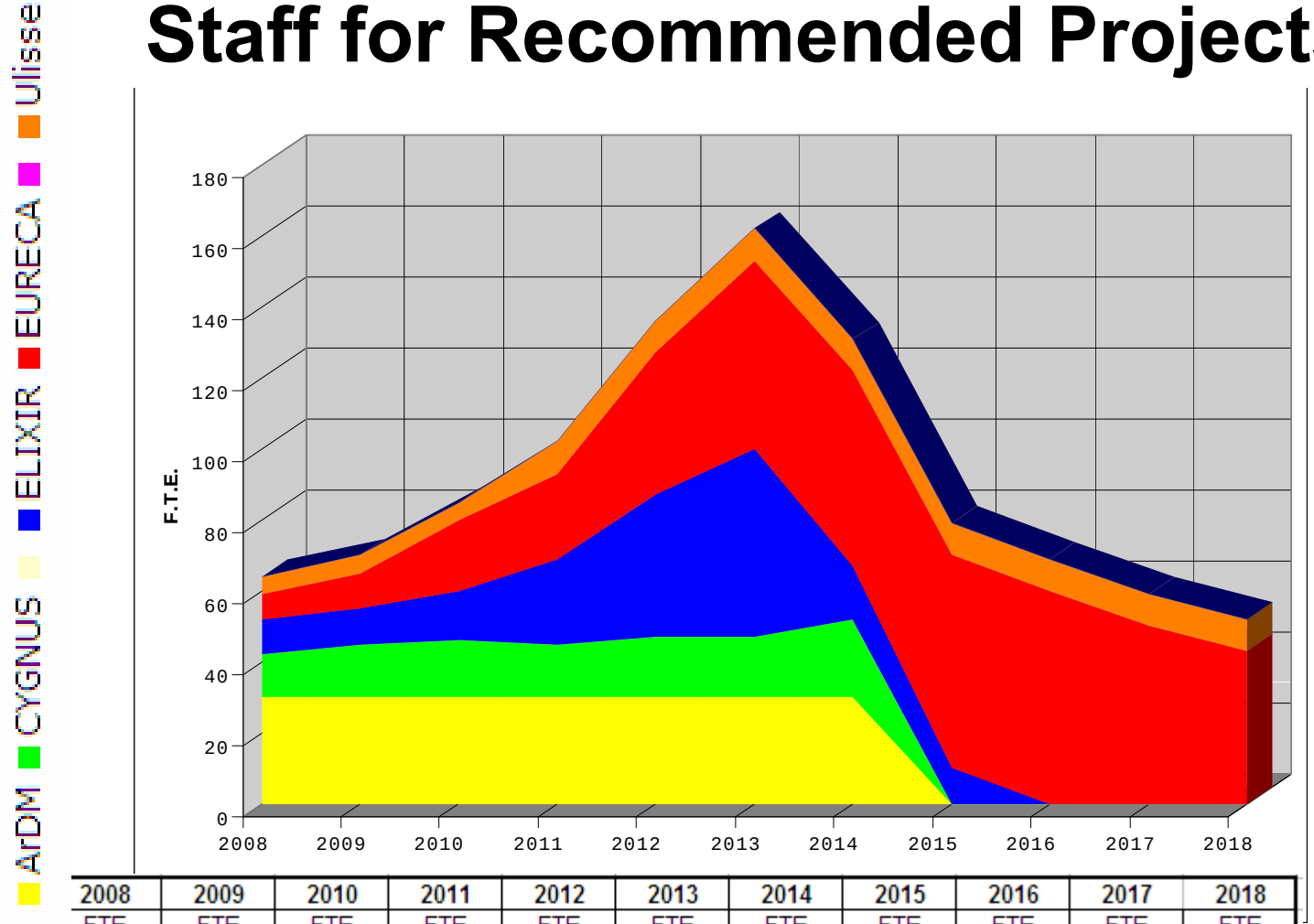
R&D (Cygnus, Ulisse, ..)

Investment Costs Recommended Projects



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Total
	Investment	Investment	Investment	Investment	Investment	Investment	Investment	Investment	Investment	Investment	Investment	
ArDM	360	260	210	1560	160	60	60	0	0	0	0	2670
CYGNUS	305	355	340	325	400	420	500	0	0	0	0	2645
ELIXIR	850	850	1350	15000	15200	16500	3000	2500	2000	0	0	57250
EURECA	500	500	2000	4000	8200	14000	14500	15000	15500	10200	5100	89500
Ulisse	50	50	1000	6000	7000	1000	800	800	800	800	800	19100

Staff for Recommended Projects



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	FTE	FTE	FTE	FTE	FTE	FTE	FTE	FTE	FTE	FTE	FTE
ArDM	30	30	30	30	30	30	30	0	0	0	0
CYGNUS	12	15	16	15	17	17	22	0	0	0	0
ELIXIR	10	10	14	24	40	53	15	10	0	0	0
EURECA	7	10	20	24	40	53	55	60	60	50	43
Ulisse	5	5	5	9	9	9	9	9	9	9	9

Conclusions

- **Progress in two stages (Design, deployment)**
- **Two main techniques**
- **R&D activities**
- **Note: two Design Studies priorities of ApPEC**
  If CTA and EURECA not funded by Europe,
  fundamental that they are by ApPEC

Agreement of
CDMS, XENON, CRESST, EDELWEISS
to make ntuples (low-background data and calibrations)
in **open access data**
after typically one year or 18 month