Dark Matter Searches

Experimental Status and Projects

Direct Detection

H Kraus
University of Oxford

Direct Detection of WIMPs

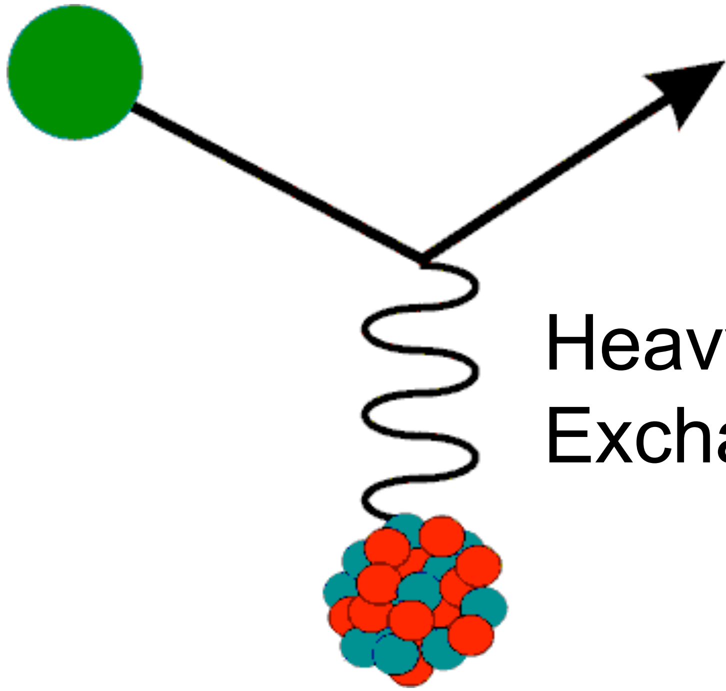
WIMP

$30 < M_W\ [\text{GeV}] < 1000$

$46 > \lambda_W\ [\text{fm}] > 1.4$

$v_{rms} \sim 270$ km/s

$\rho_{CDM} \sim 0.3$ GeV/c^2



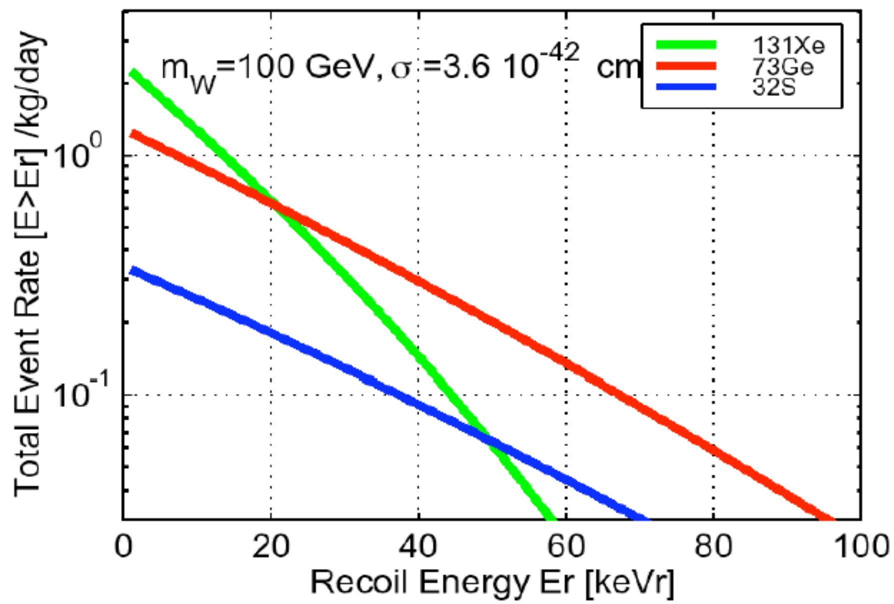
$$E_R = E_0 \cdot \frac{4M_W M_N}{(M_W + M_N)^2} \cdot \frac{1}{2}\left(1 - \cos\theta^*\right) \approx 0.4\ \text{keV} \cdot \frac{M_W}{\text{GeV}}$$

Direct detection via WIMP scattering by nuclei: E_R ~ tens of keV

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

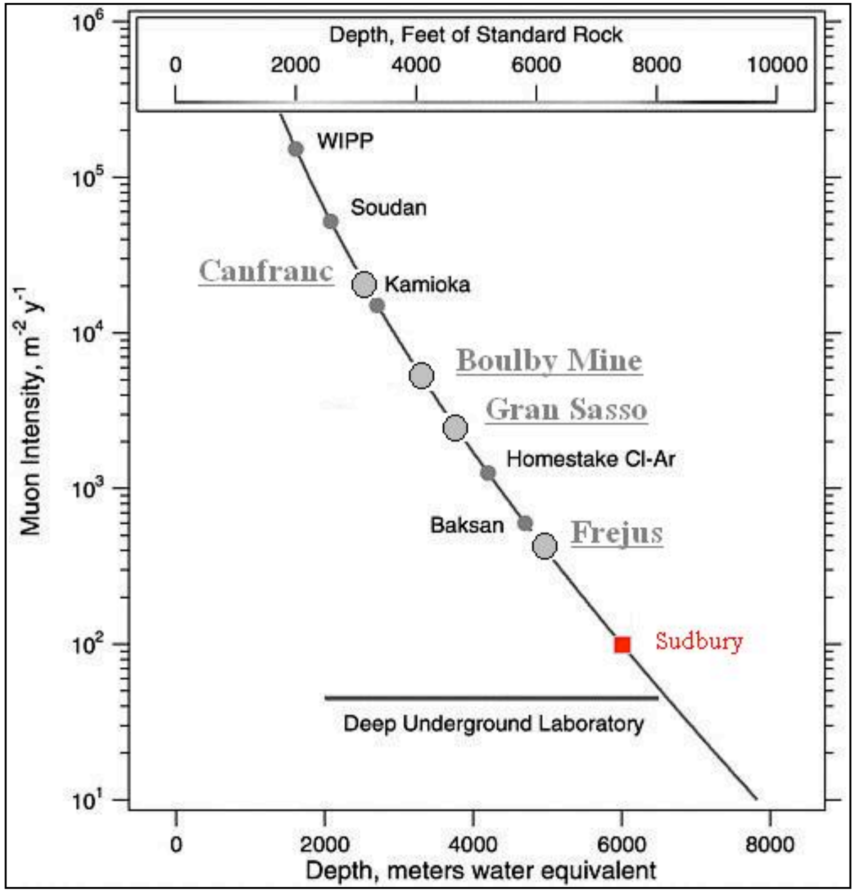
- Discriminate recoil populations
  - Photons scatter off electrons
  - WIMPs/neutrons off nuclei
  - radon heavy nuclear recoils, alpha tails…



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

Underground Laboratory

The EURECA infrastructure
A unique opportunity for integration between experiment and laboratory –



Deepest site in Europe (4800 mwe)

Known and good site (low convergence, dry, stiff rock)

Central location in Europe, easy access (plane, train, car)

23 years experience in running such platform

Dark Matter Signatures

1. Recoil energy spectrum — **Energy resolution**
   exponential, **similar to background**.
2. Nuclear (not electron) recoils — **Discrimination**
   is really **required** now.
3. Coherence: A dependence — **Multi-target**
   essential once **first signal** is identified.
4. Absence of multiple interactions — **Large Array**
   removes some fraction of background.
5. Diurnal modulation
   nice, but needs low-pressure gaseous target.
6. Annual modulation (requires many events)
   tricky; most events are close to threshold, small effect.

Experiments – MSSM Predictions

$\sigma = 10^{-6}$ pb:

~1 event/kg/day

~0.1 now reached

$\sigma = 10^{-8}$ pb:

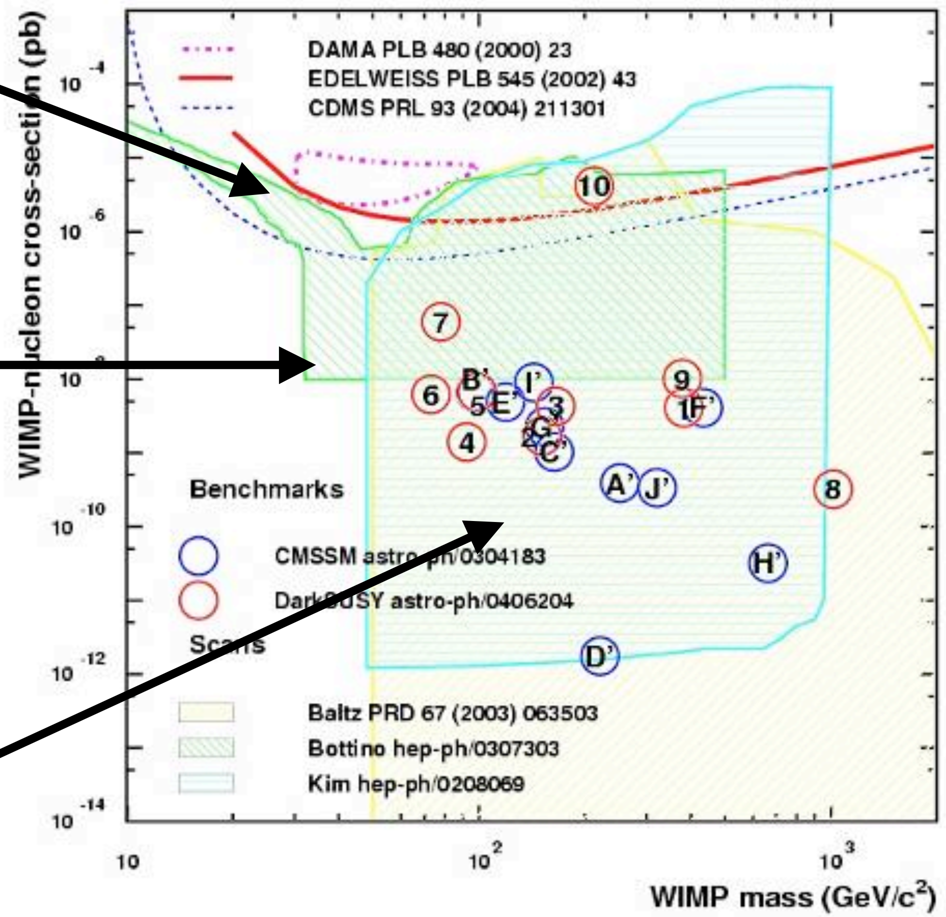
~3 events/kg/year

Aims of phase II experiments

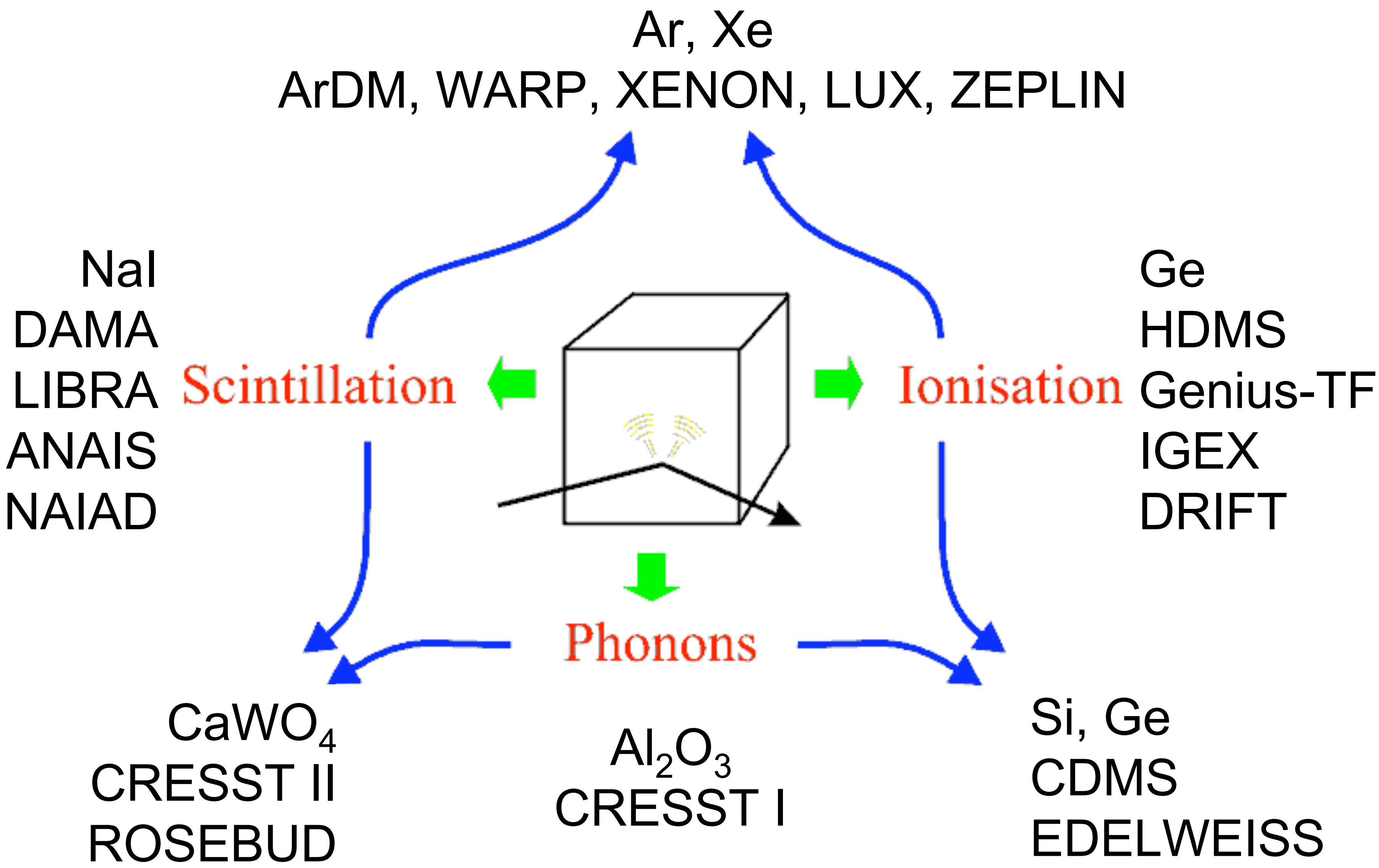
$\sigma = 10^{-10}$ pb:

~30 events/ton/year

Next generation requires further x100 improvement!

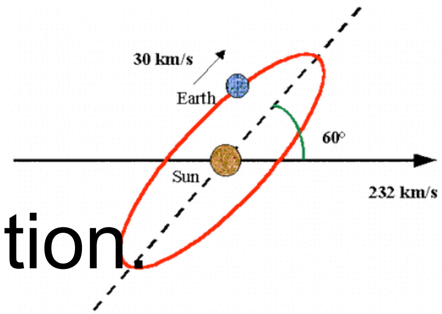


Detection Techniques

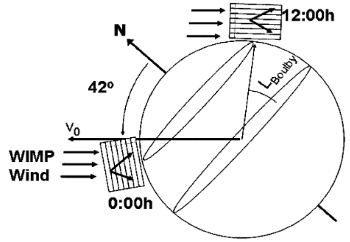


Outline of Talk

Annual modulation



and diurnal



DAMA **LIBRA** **DRIFT**

Liquefied Noble Gases

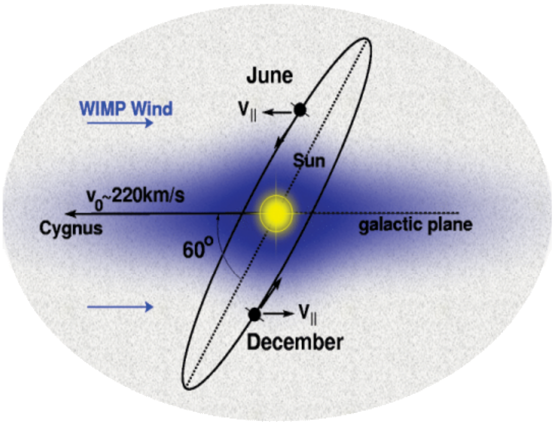
XENON (US), ZEPLIN, WARP

Cryogenic Techniques

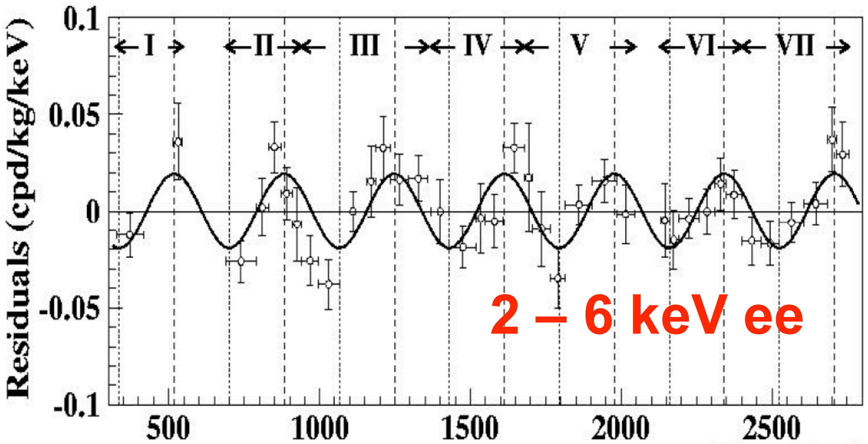
EDELWEISS, CRESST, CDMS (US)

Status and Future

DAMA / LIBRA



- Data taking completed in July 2002
- Total exposure of 107,731 kg.d
- See annual modulation at 6.3σ
- Claims model-independent evidence for WIMPs in the galactic halo
- 2nd phase: LIBRA 250 kg



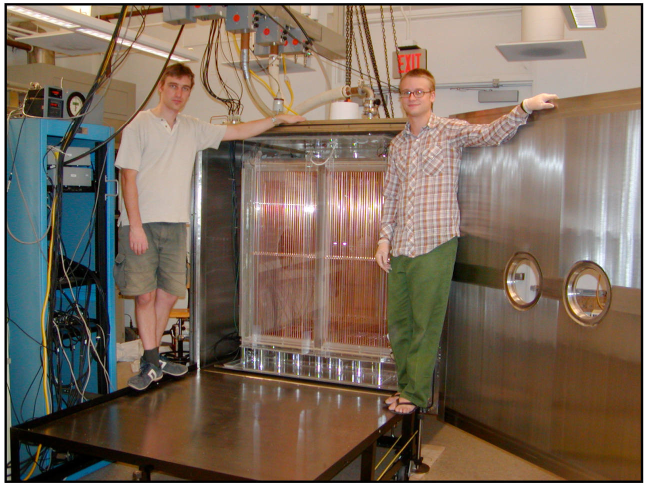
WIMP candidate, using standard halo parameters:

$M_X = (52^{+10}_{-8})$ GeV and

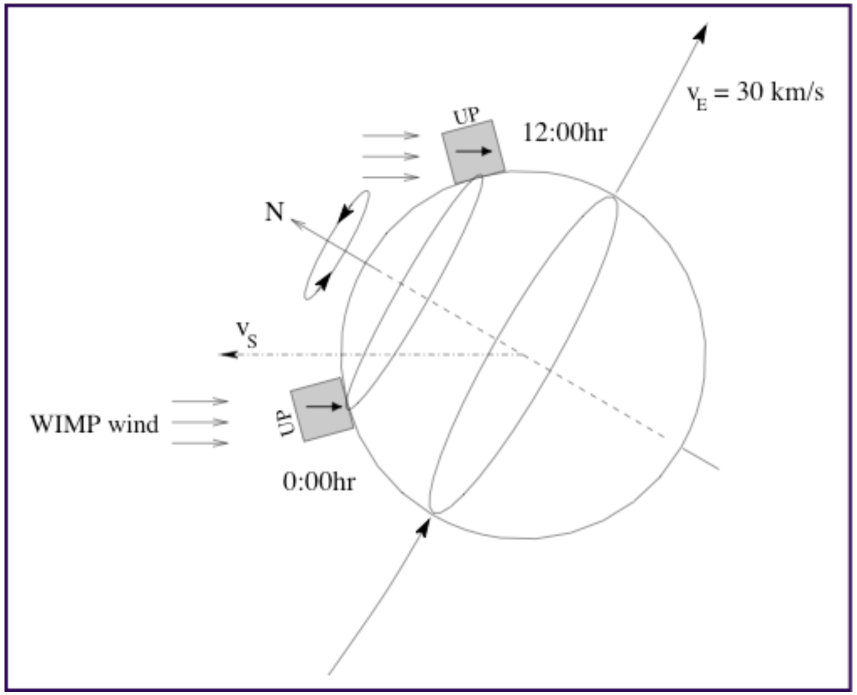
$\sigma_{X\text{-}N} = (7.2^{+0.4}_{-0.9})\ .10^{-6}$ pb

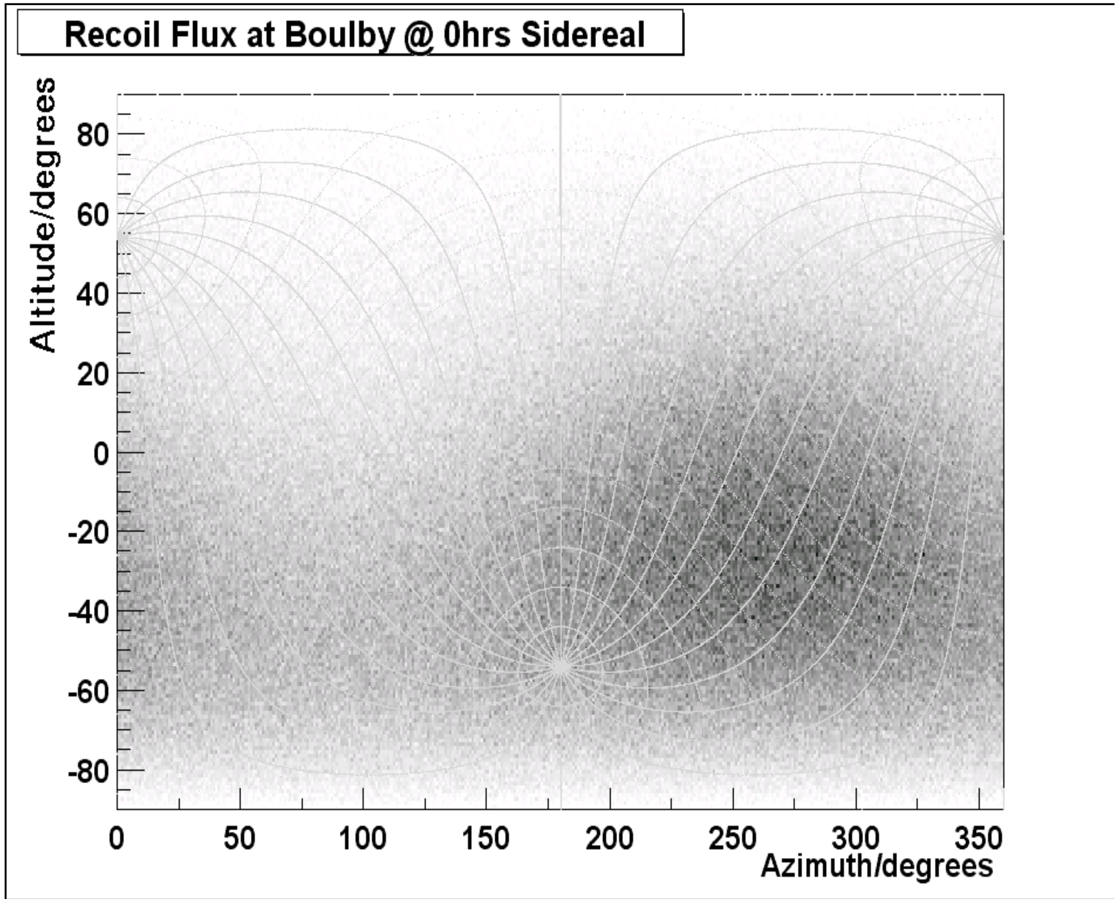
DAMA / LIBRA running 250 kg; wait at least until 2008 …

DRIFT II

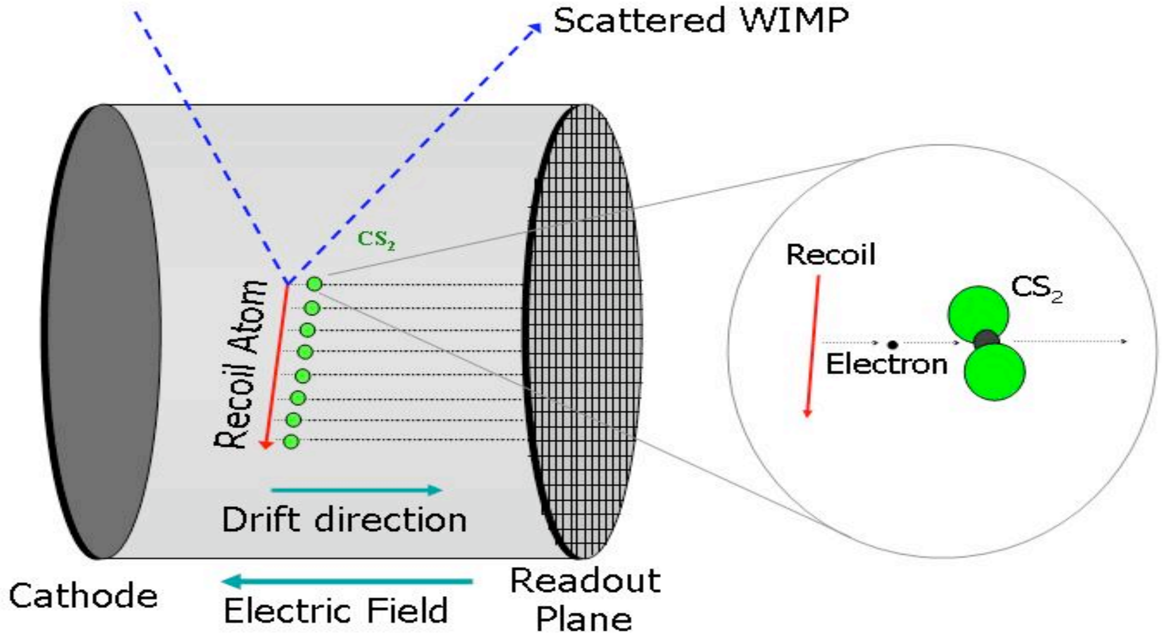


Solid or liquid targets ($E_{nuc\ rec}$ < 100keV): tracks 1nm – 100nm.
Gaseous target: a few mm.
Low-pressure CS_2 gas time projection chamber to measure directionality of nuclear recoil.



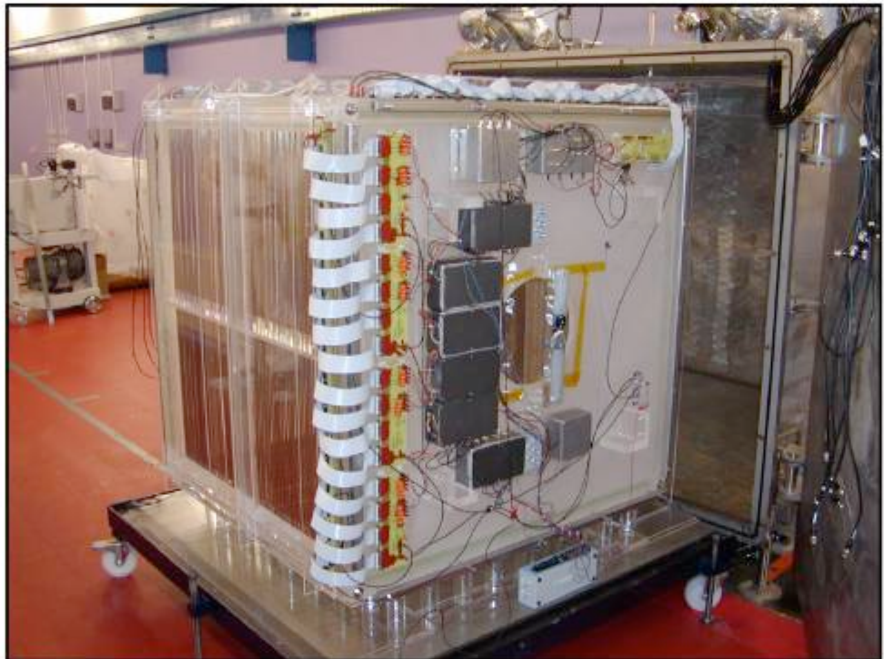


DRIFT II



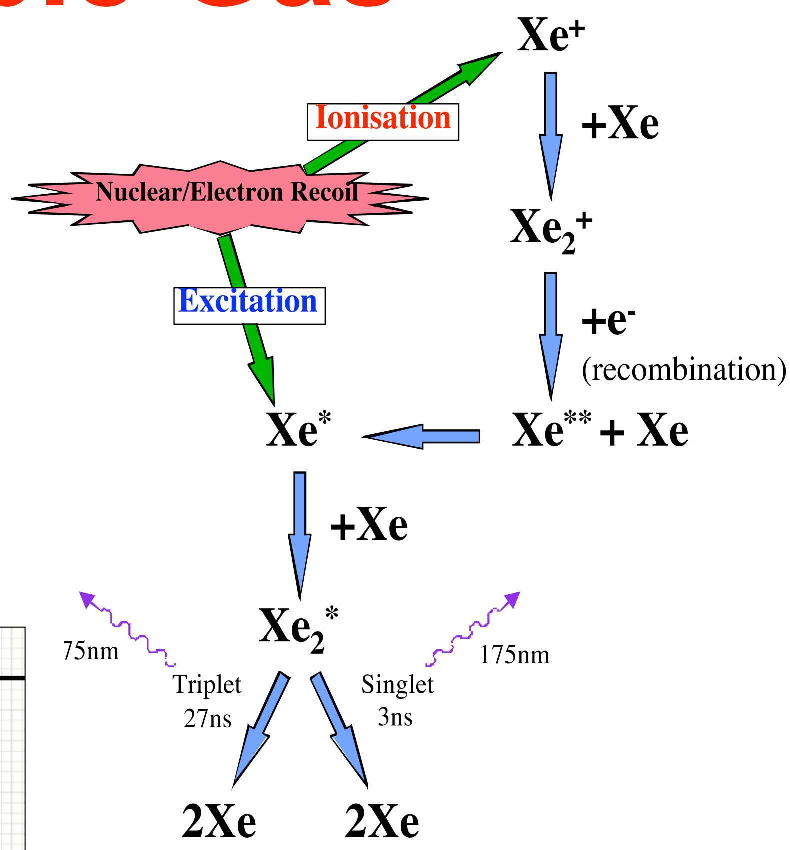
2D MPWC + timing gives 3d vertex reconstruction.

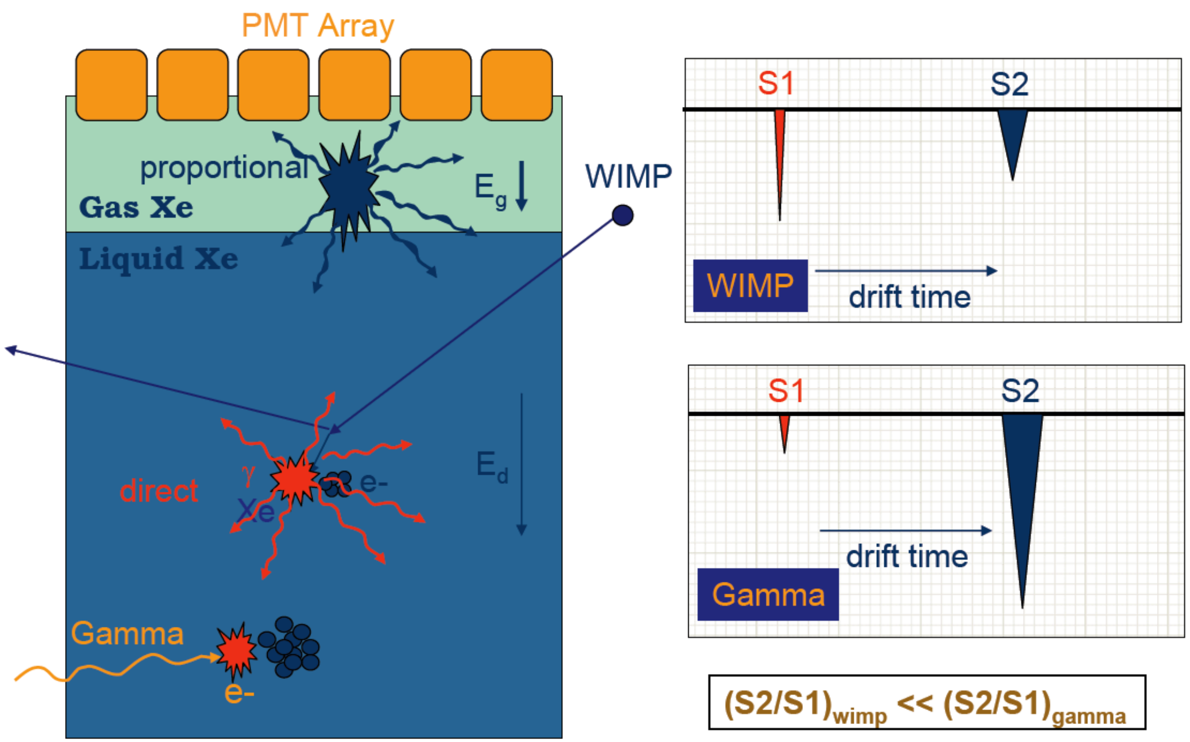
Electron capture in electro-negative gas limits diffusion during drift to 0.1% of drift distance.



Liquefied Noble Gas

Xenon	Argon
XENON (US)	WARP (I)
ZEPLIN (UK)	ArDM(CH)

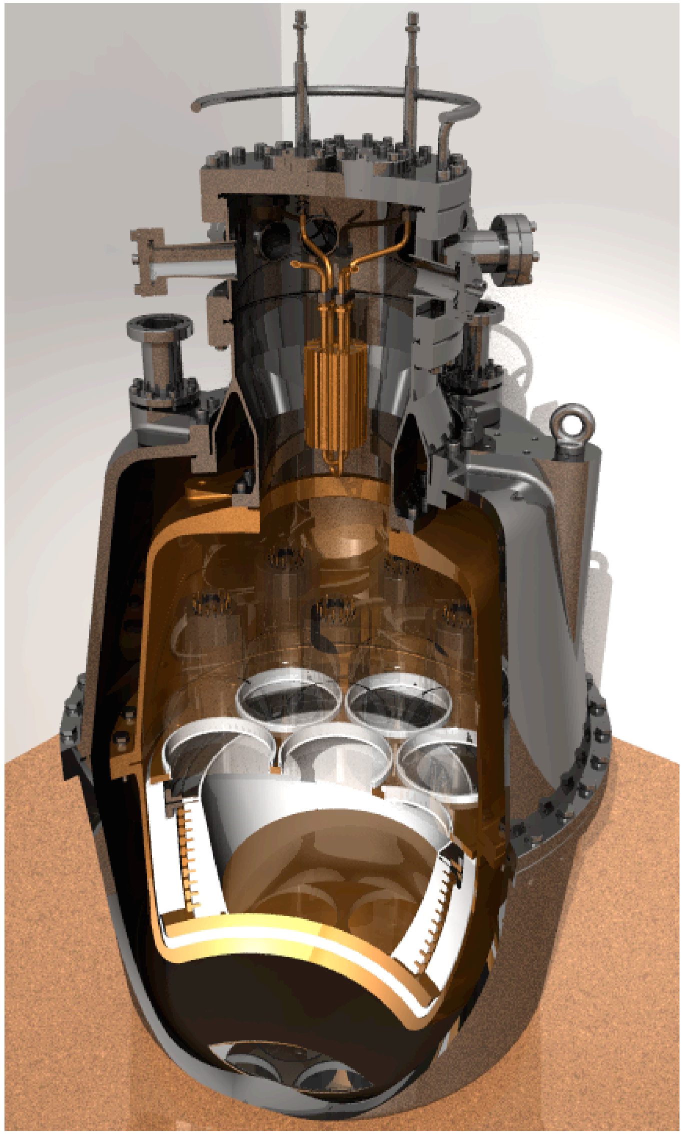




Current state of art:
two-phase detectors –
ionization / scintillation

ZEPLIN II

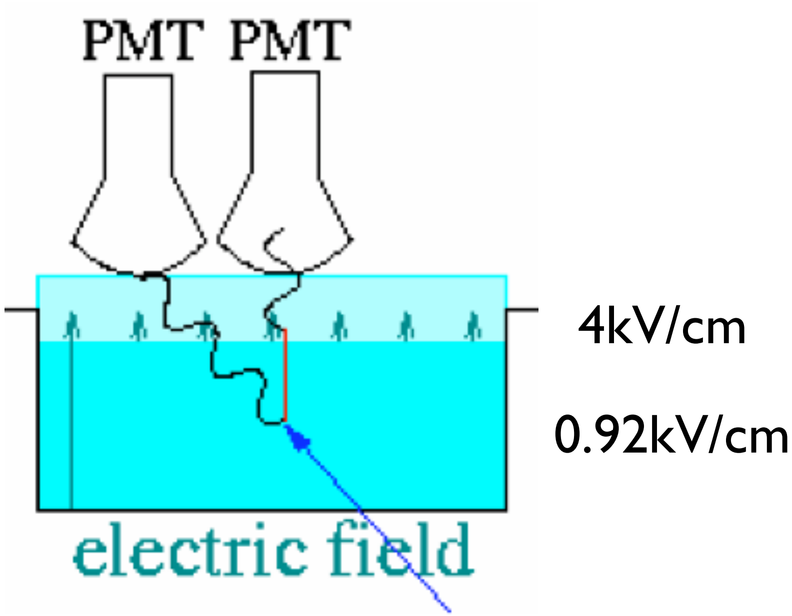
30 kg xenon, λ_{scint} = 175 nm. 7 PMT (in gas phase).



Prompt scintillation from liquid; ns time scale.

Electroluminescence pulse from avalanche in gas; μs time scale.

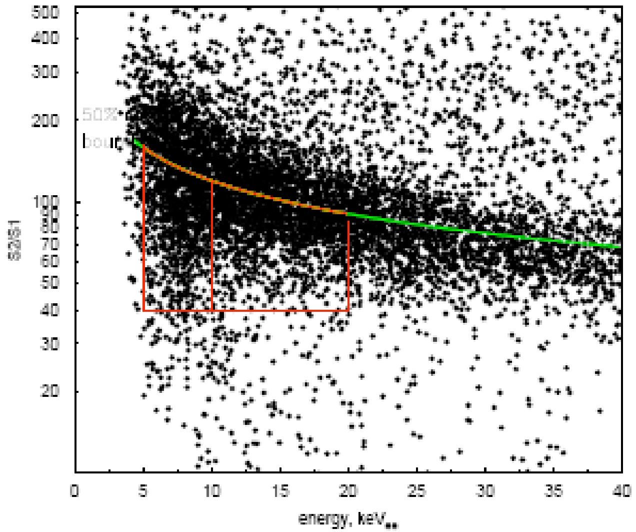
Installed underground in Boulby.



ZEPLIN II

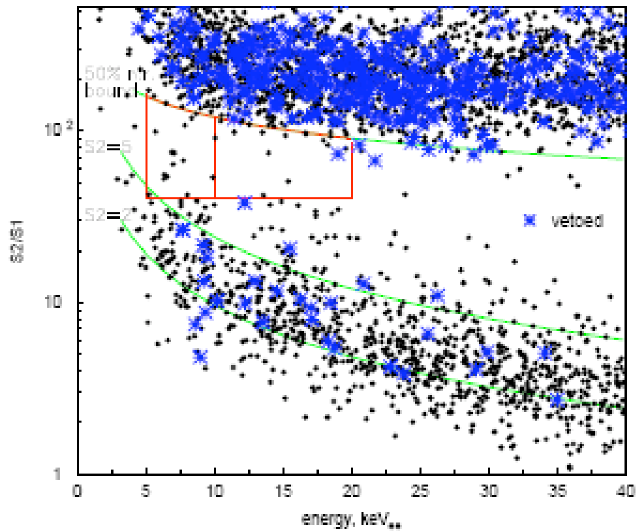
Calibration run

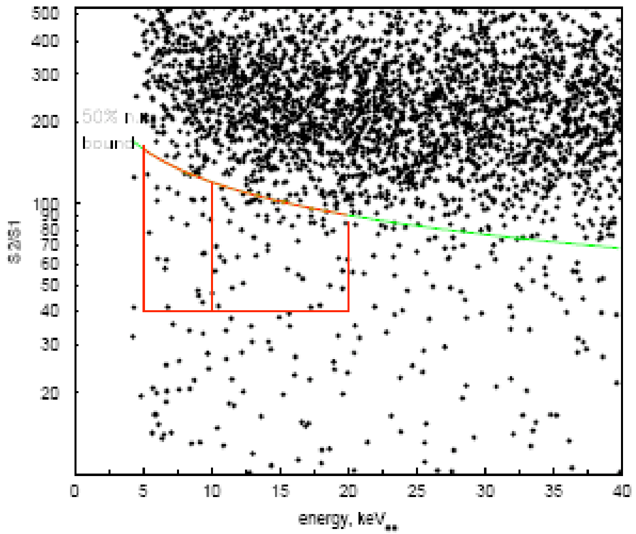
Science run



← AmBe cal

All events →

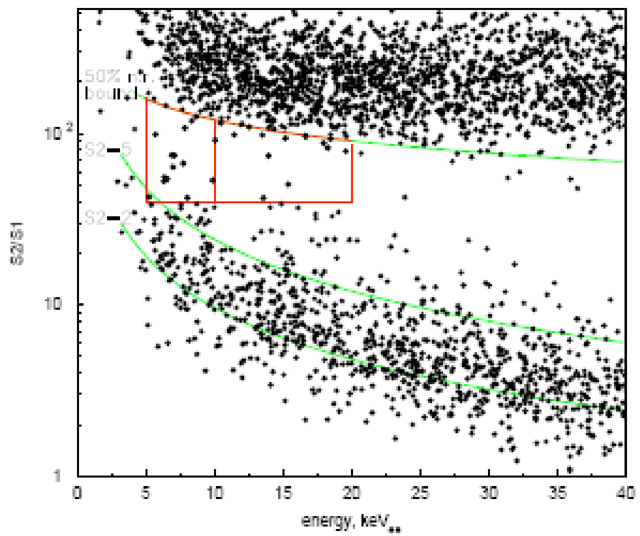




← Co-60 cal

Veto'ed events removed →

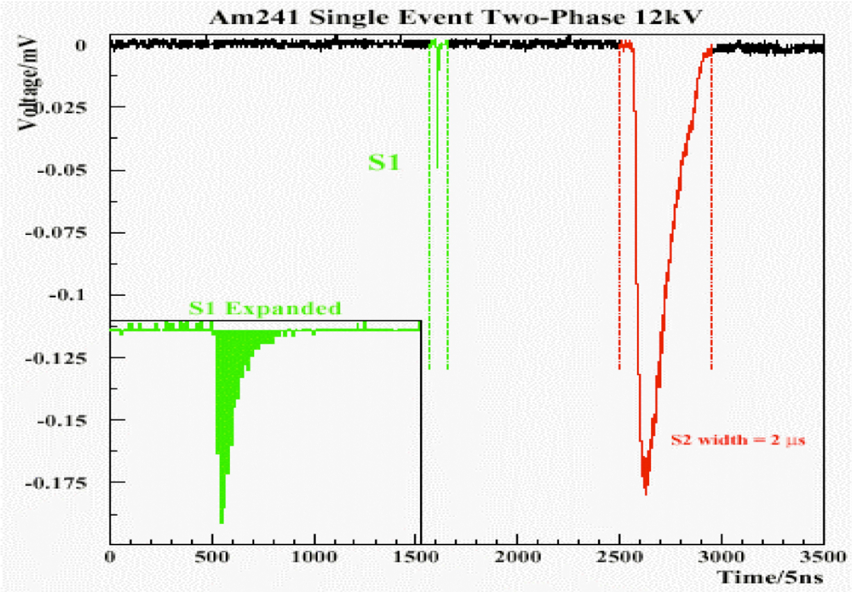
6.6 x 10^{-7}pb



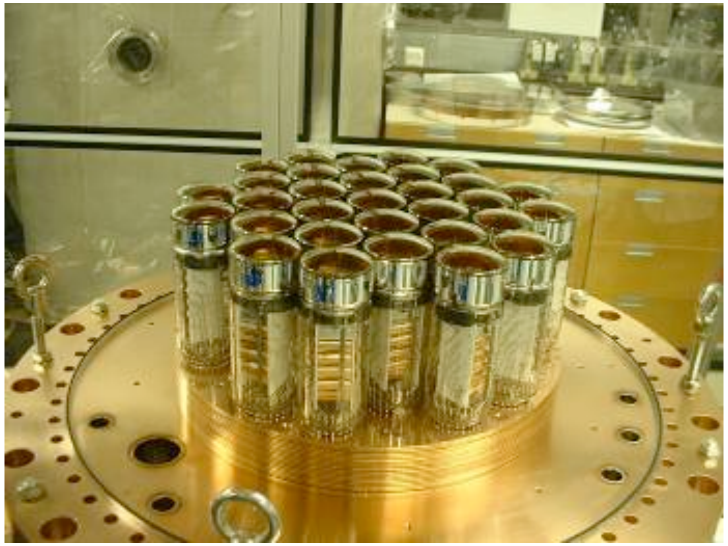
ZEPLIN III

Underground in Boulby; final assembly.

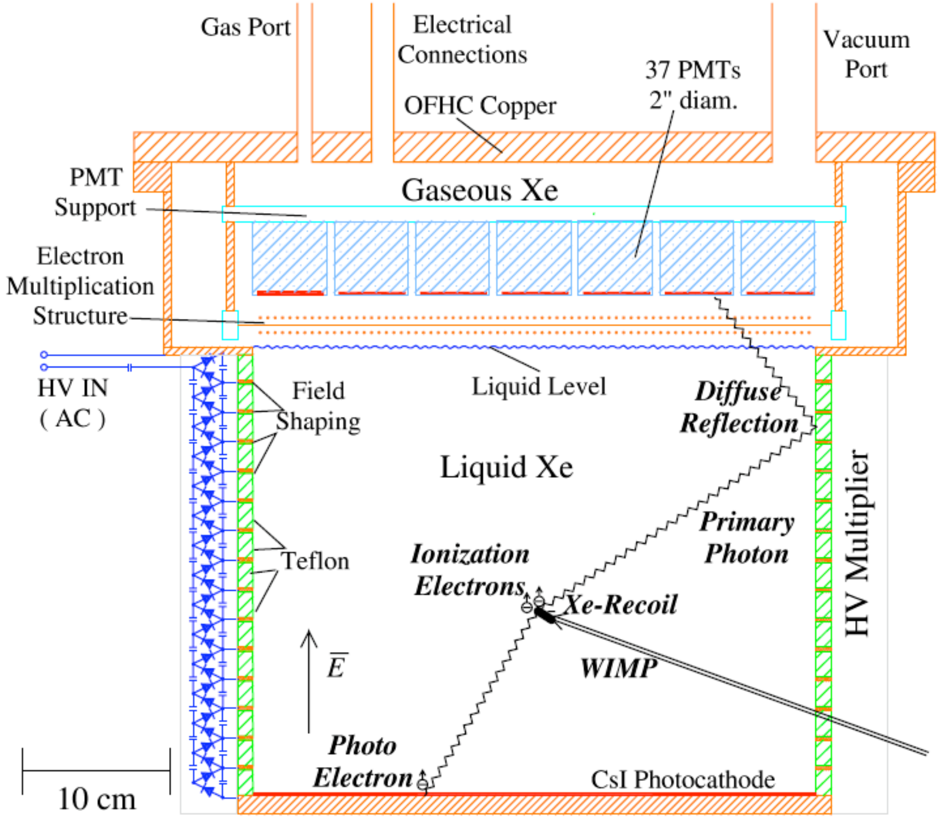
31 PMT immersed in liquid.



8 kg fid. volume



XENON (US / Gran Sasso)



Real 3-D measurement if CsI photocathode is efficient enough

- Two-phase Xe TPC
- Light/Ionization detector
- Very-low BG photomultipliers
- 10 kg prototype operating
- 100kg phase : 1 TPC

Aim: 1 ton scale (10 LXeTPC)

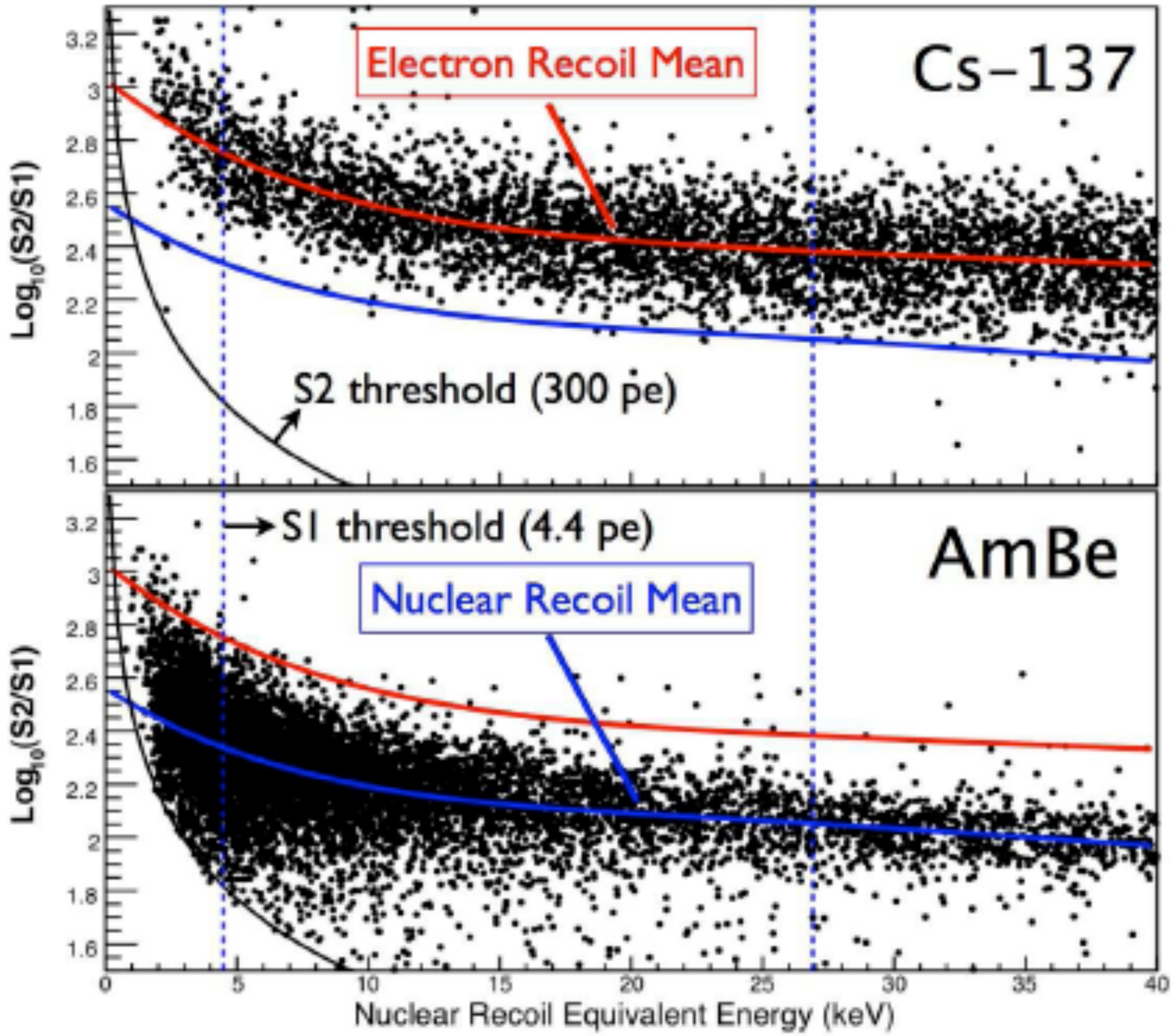
2.2 pe / keV$_{ee}$

99.5% discrimination at 50%

Reach 10^{-10} pb within 3 years

XENON Neutron / Gamma Calibration

J Angle et al., astro-ph:0706.0039



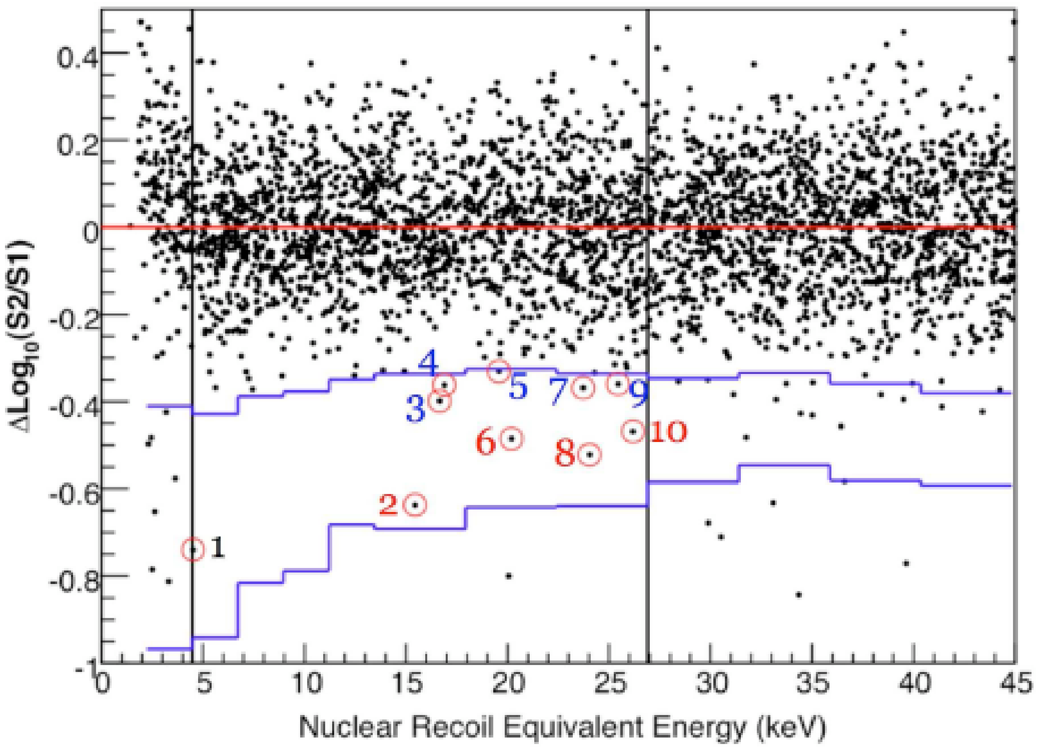
Gamma Calibration

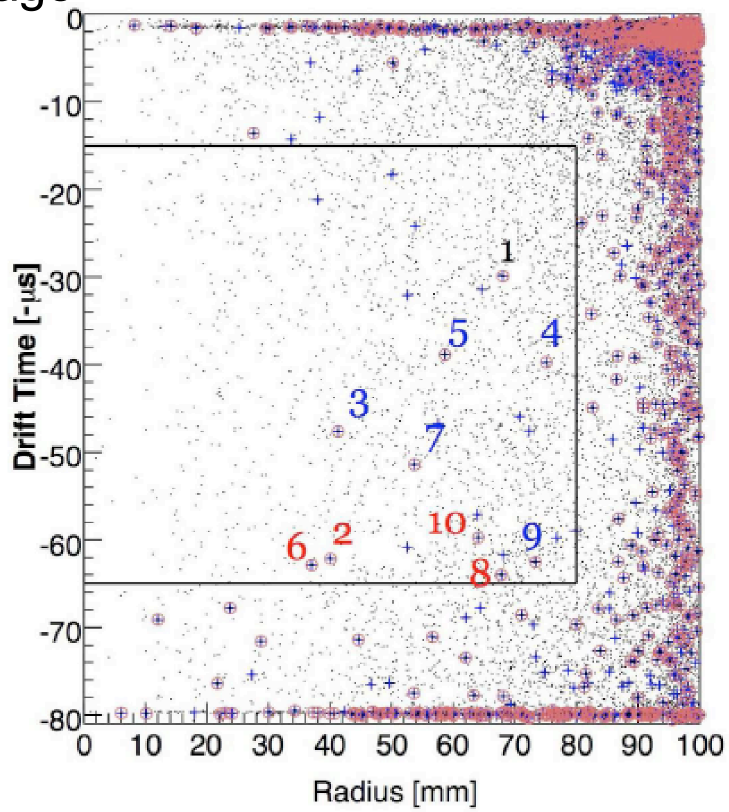
Neutrons from AmBe Source

XENON Results

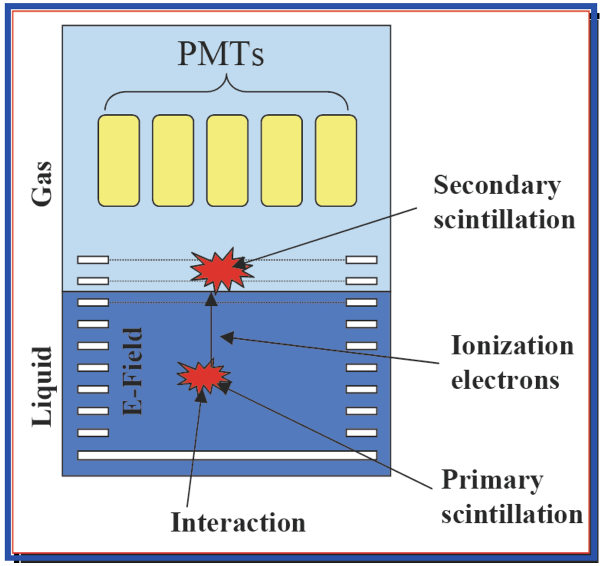
Most experiments (ZEPLIN, XENON, WArP) are already recording background and look at ways to remove it.

58.6 live days, 10 events, expected 6.8 from leakage

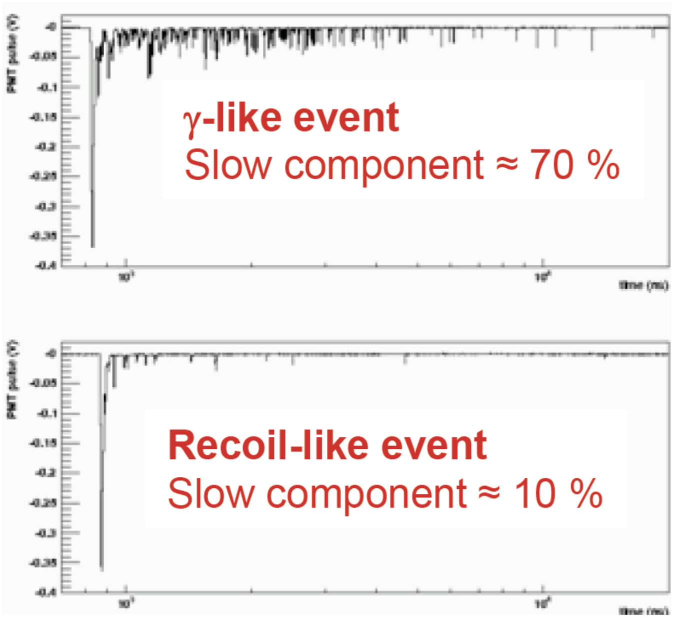


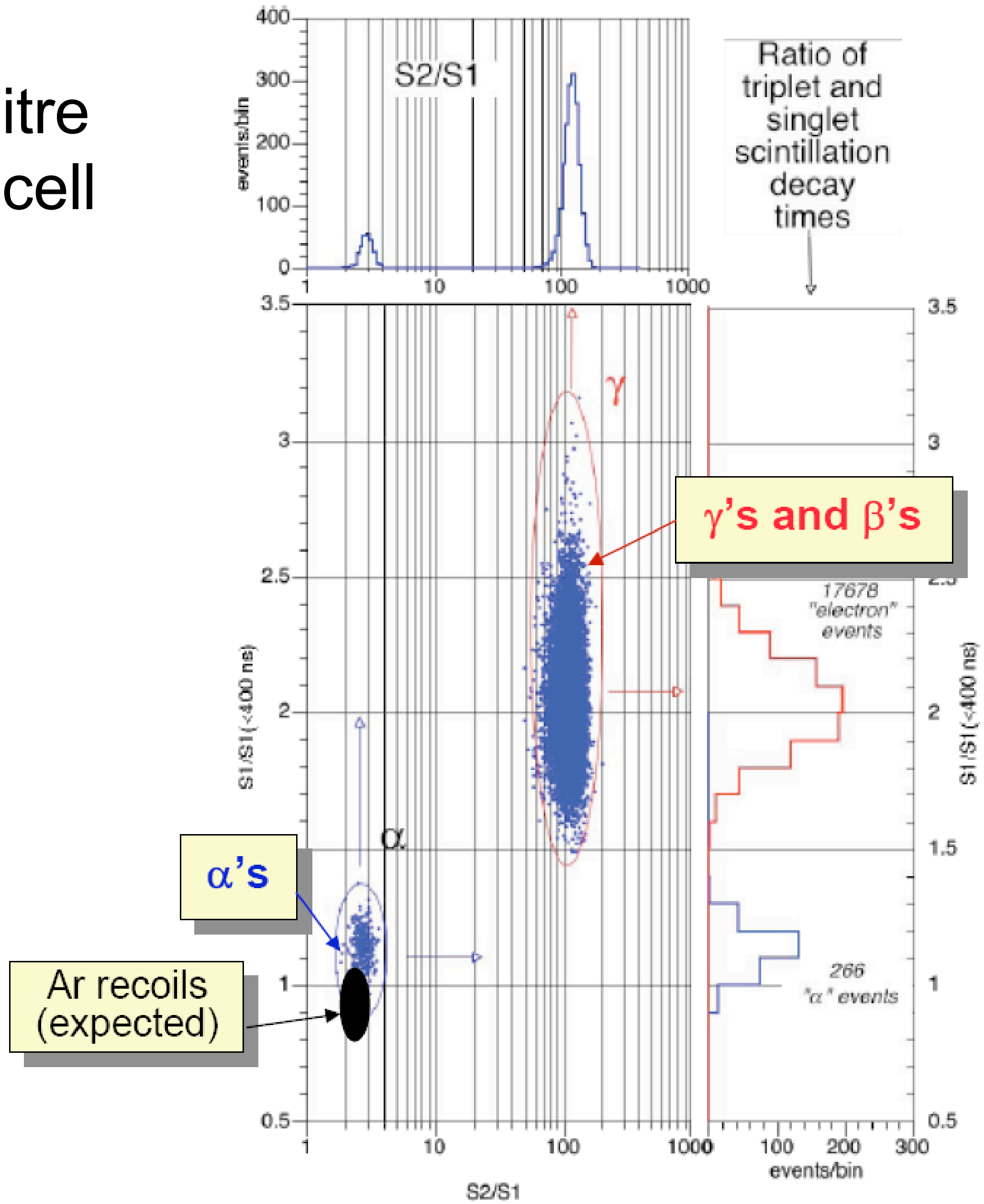


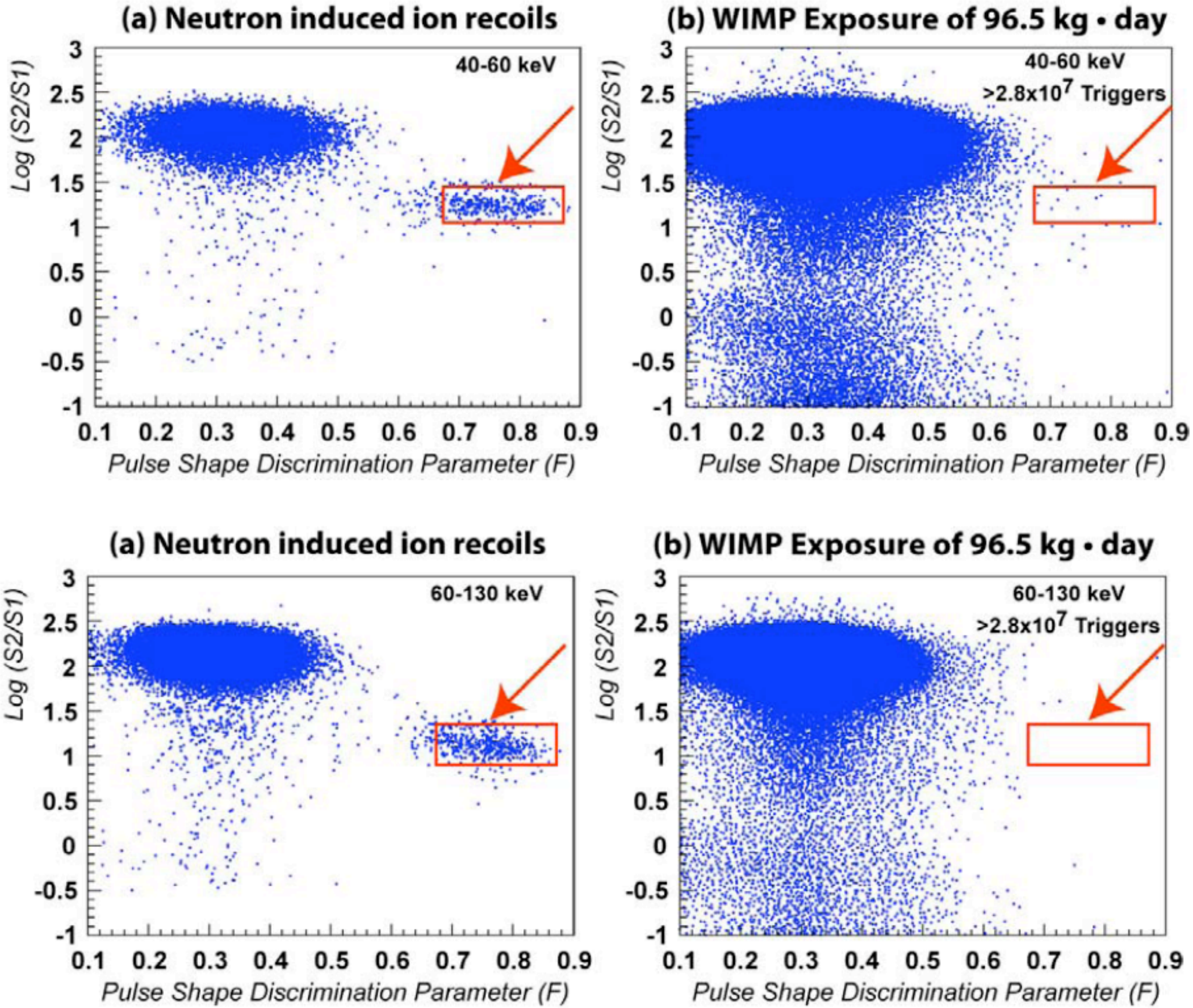
WARP – WIMP Argon Programme



2.3 litre
test cell

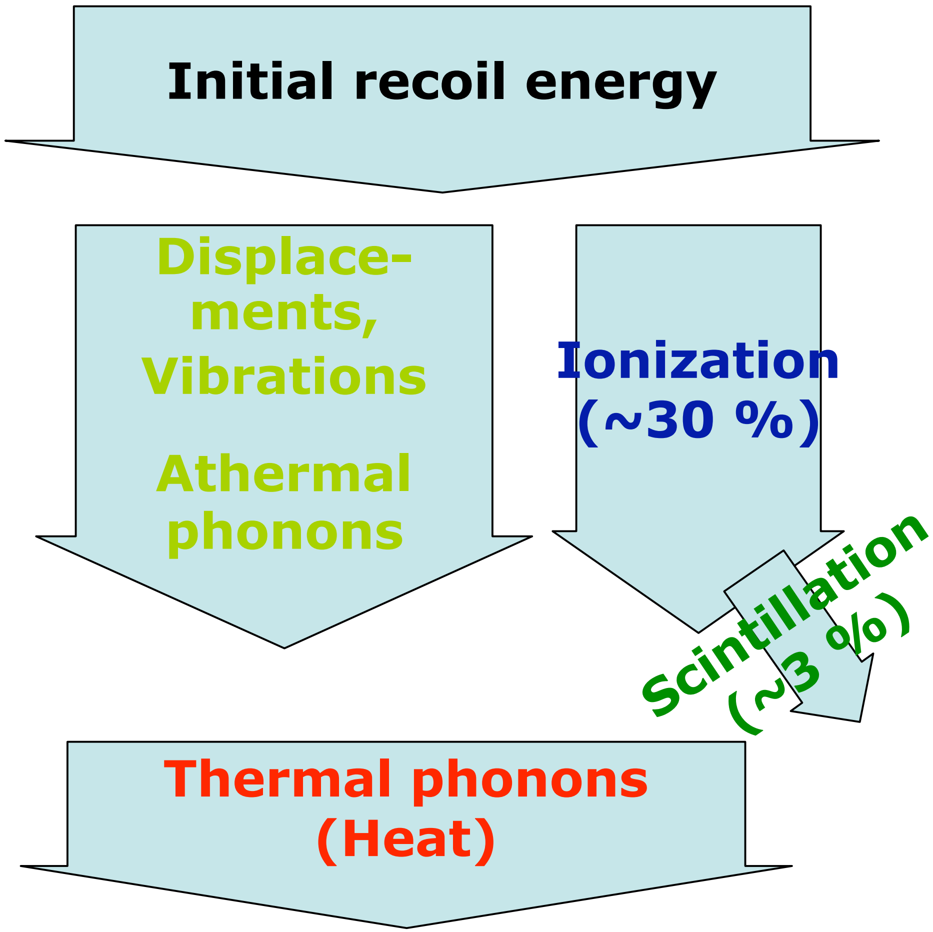





(a) Neutron induced ion recoils
40-60 keV
Log (S2/S1)
Pulse Shape Discrimination Parameter (F)
(b) WIMP Exposure of 96.5 kg • day
40-60 keV
>2.8x10^7 Triggers
Log (S2/S1)
Pulse Shape Discrimination Parameter (F)
(a) Neutron induced ion recoils
60-130 keV
Log (S2/S1)
Pulse Shape Discrimination Parameter (F)
(b) WIMP Exposure of 96.5 kg • day
60-130 keV
>2.8x10^7 Triggers
Log (S2/S1)
Pulse Shape Discrimination Parameter (F)

Cryogenic Techniques

Combination of phonon measurement with measurement of ionization or scintillation

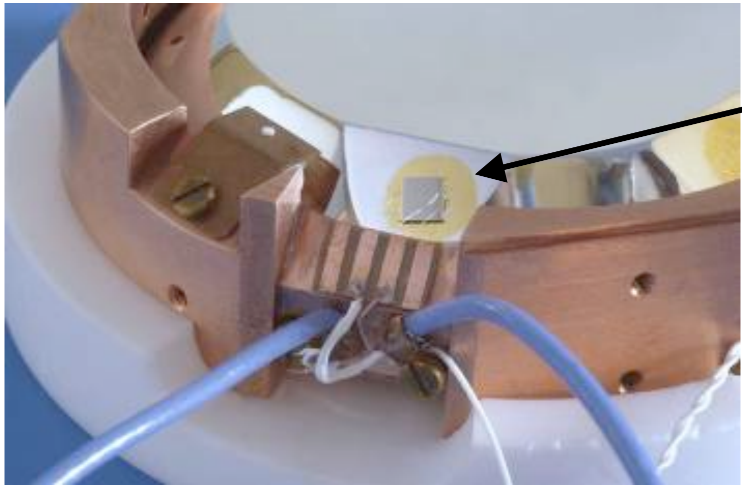


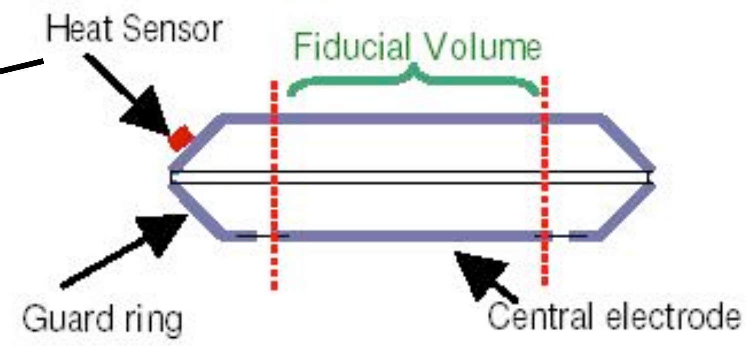
Phonon: most precise total energy measurement

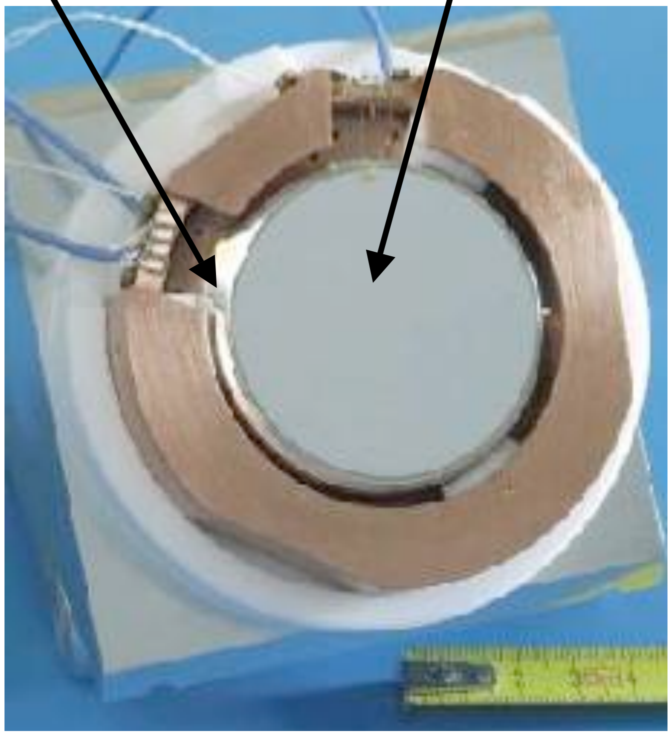
Ionization / Scintillation: yield depends on recoiling particle

Nuclear / electron recoil discrimination.

EDELWEISS – Detectors

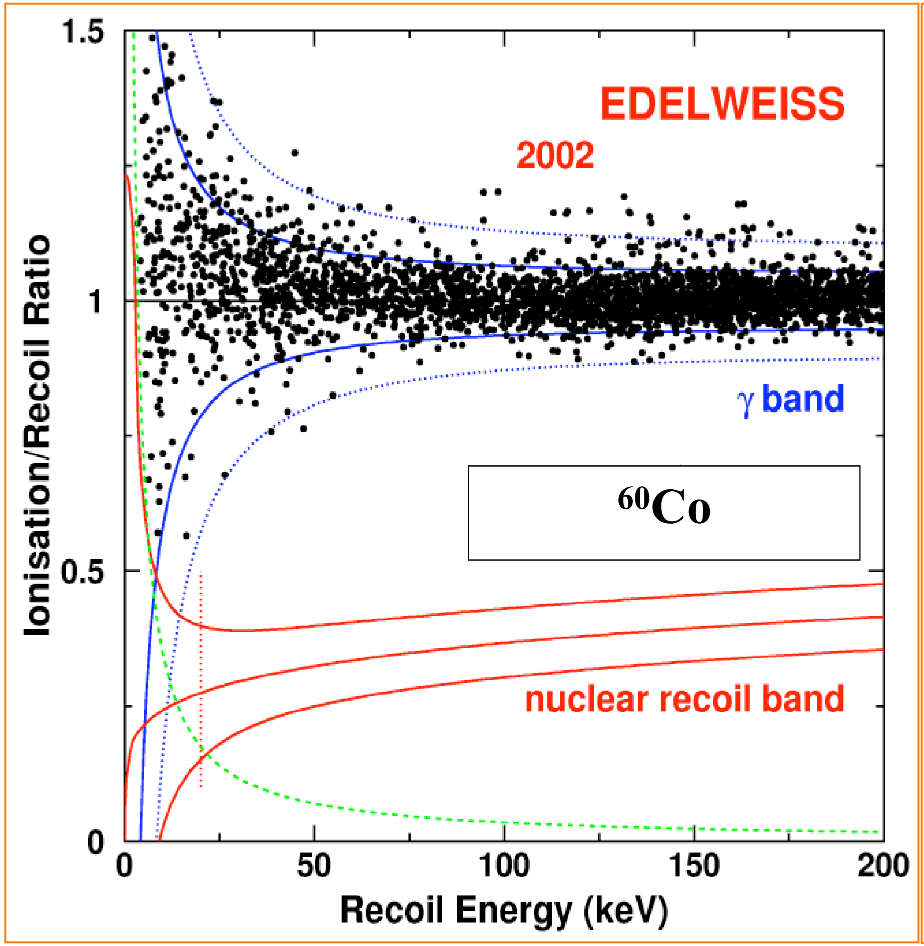


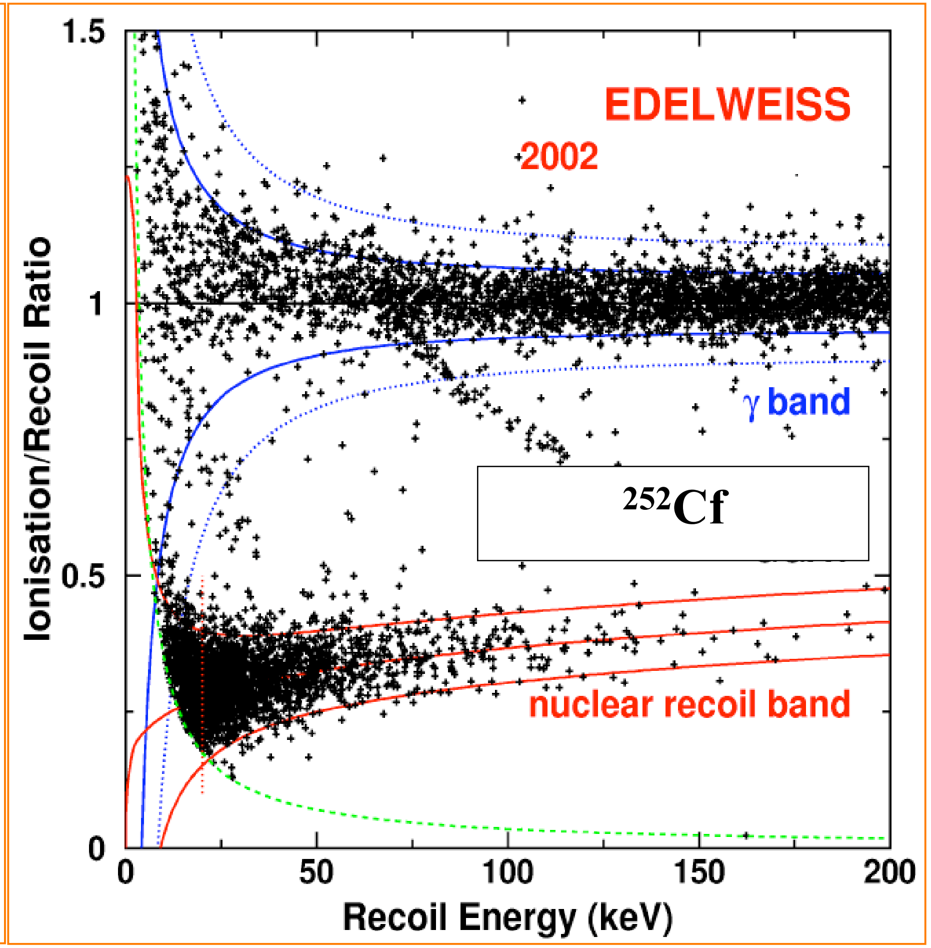




Target:
Cyl. Ge crystal, 320 g
Ø 70 mm, h = 20 mm
Phonon - signal:
NTD-Ge (~ 20 mK)
Ionisation - signal:
Inner disc / outer guard ring

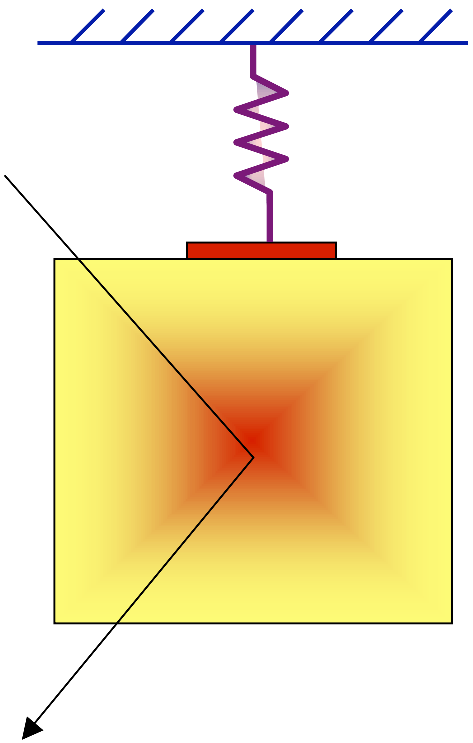
Phonon – Ionisation

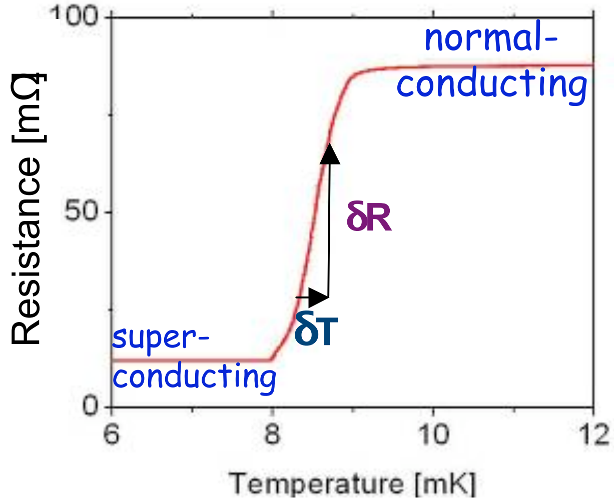




Excellent resolution in ionisation and phonon signals.
Clean γ-calibration data: no event below Q = 0.7.

CRESST – Detectors

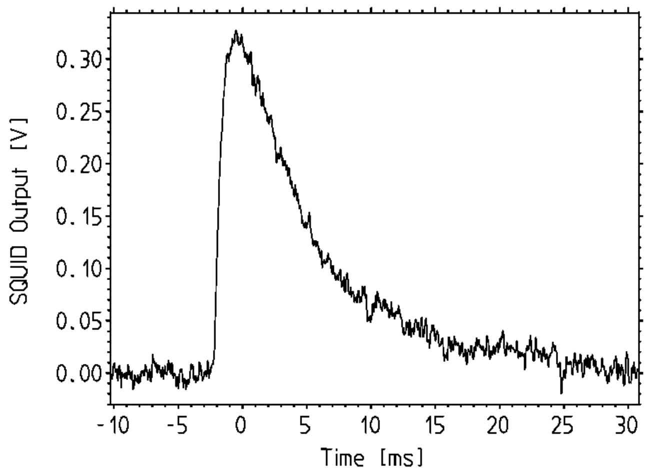




Width of transition: ~1mK
Signals: few μ K
Stablity: ~ μ K

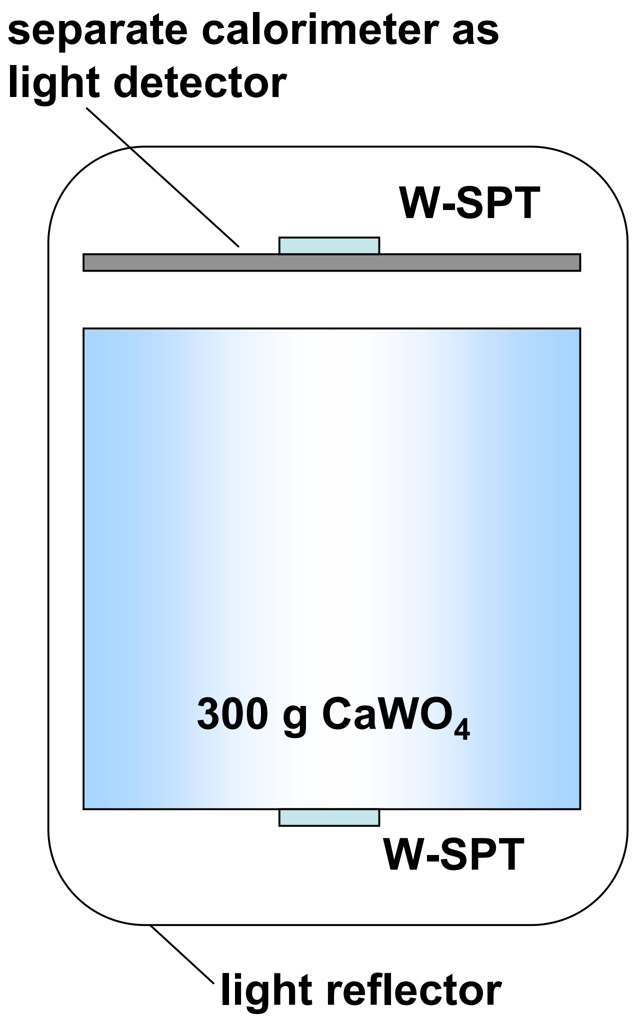
Particle interaction in absorber creates a temperature rise in thermometer which is proportional to energy deposition in absorber

Temperature pulse (~6keV)

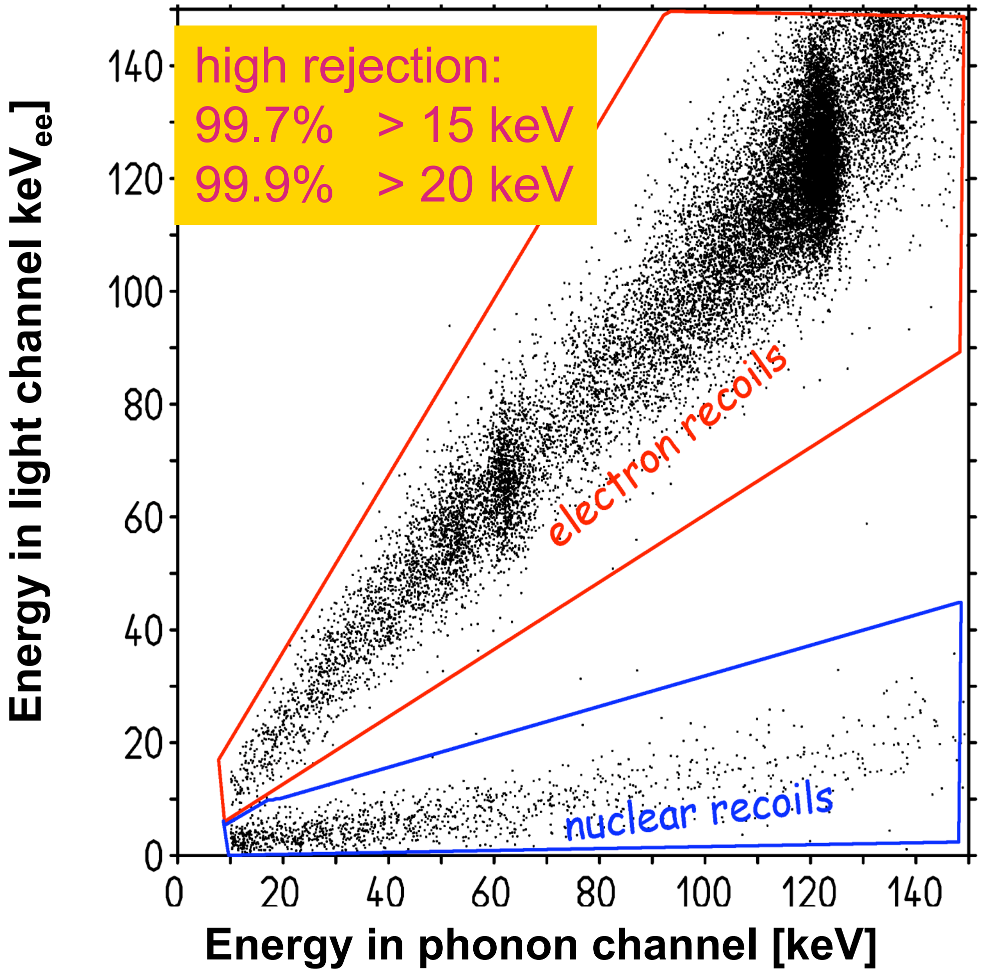


Phonon – Scintillation

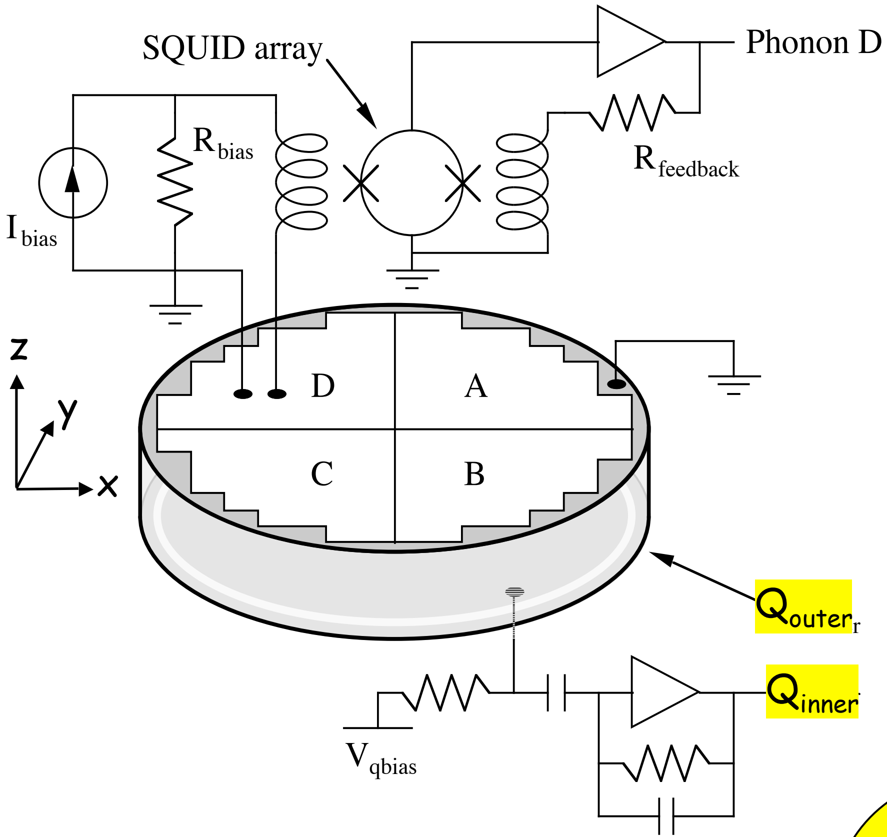
Discrimination of nuclear recoils from radioactive backgrounds (electron recoils) by simultaneous measurement of phonons and scintillation light



proof of principle

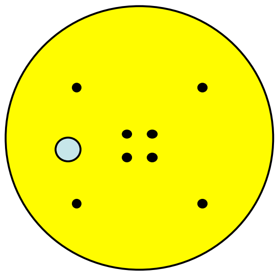


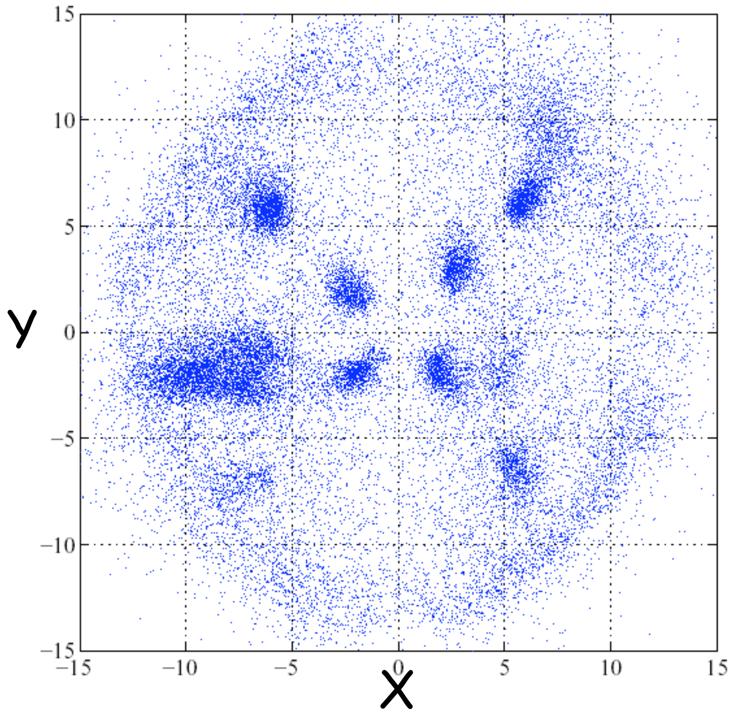
CDMS II (US)



Z-sensitive
Ionization and
Phonon-mediated©

Measure ionization in low-field (~volts/cm) with segmented contacts to allow rejection of events near outer edge

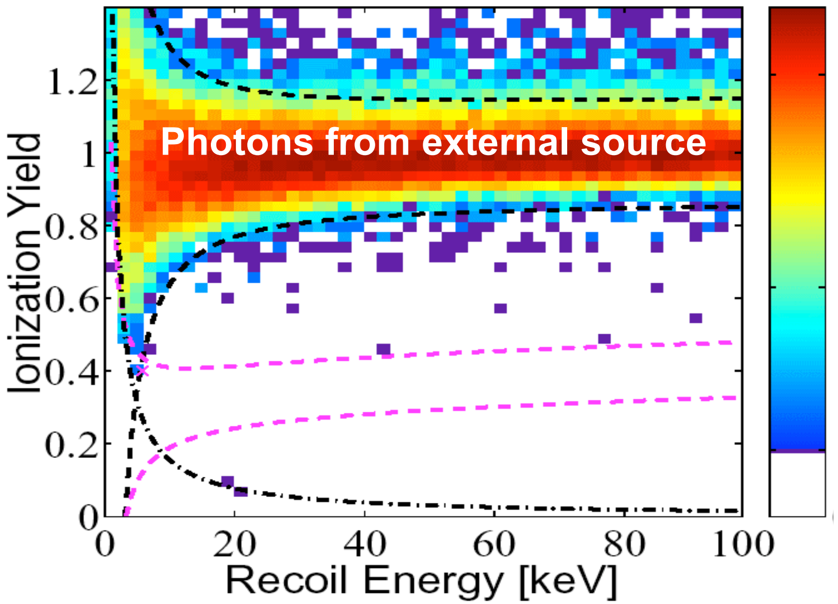


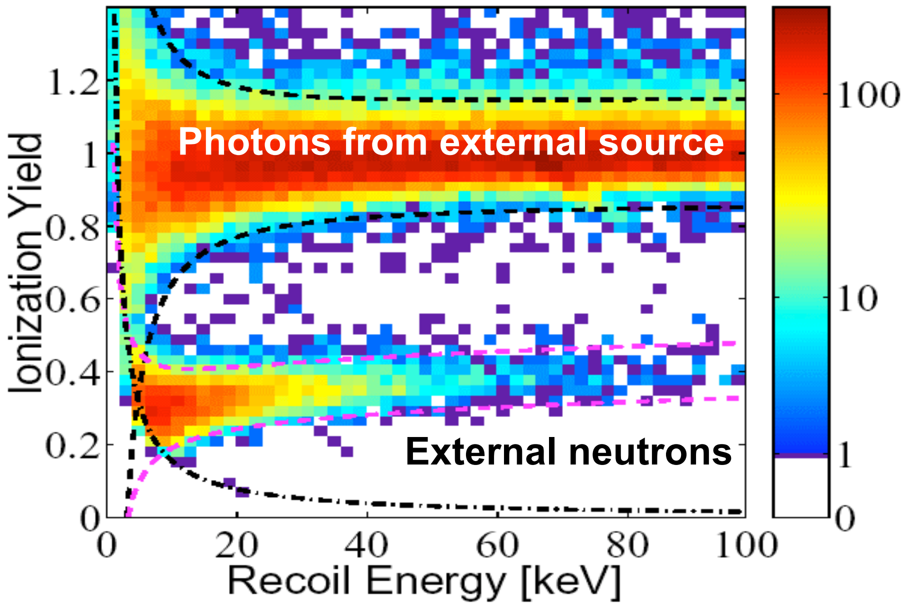


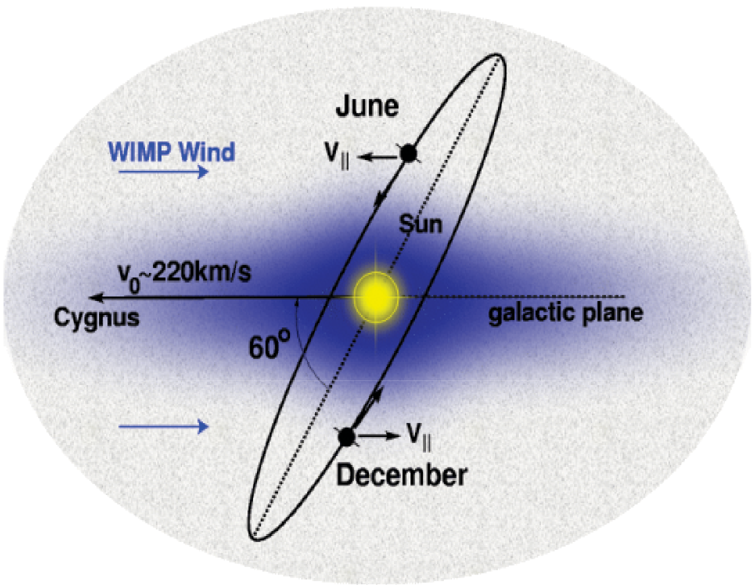
250 g Ge or 100 g Si crystal
10 mm thick x 75 mm diameter

Collect athermal phonons:
XY position imaging;surface (Z) event veto based on pulse shape risetime

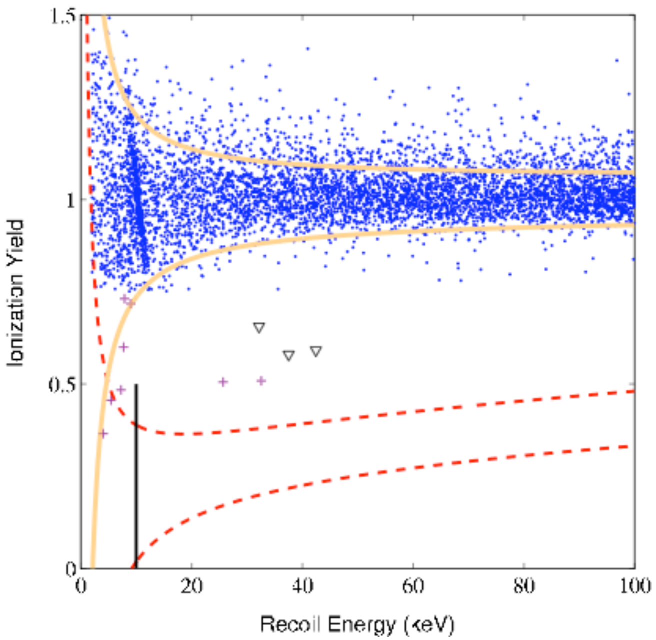
CDMS II: Discrimination







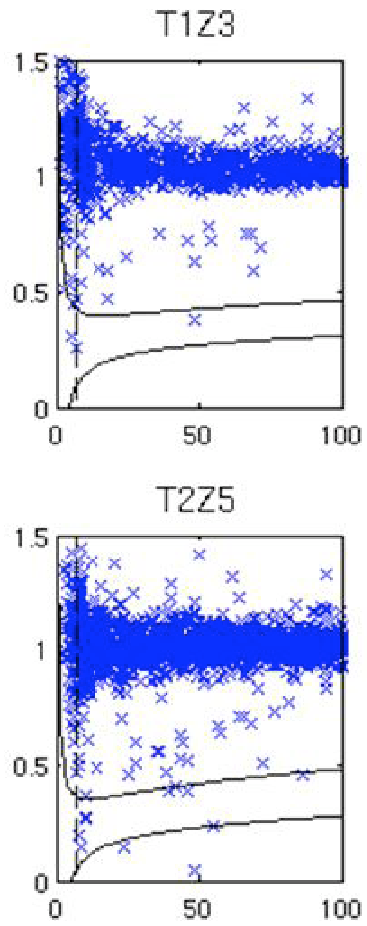
Underground run in Soudan astro-ph/0405033 (with 2 towers, now 5 towers installed)

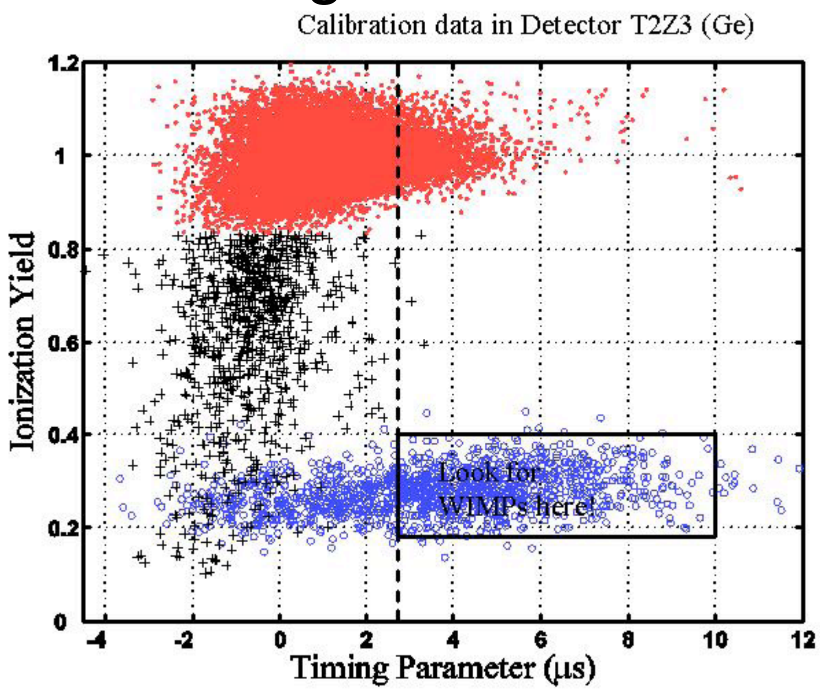


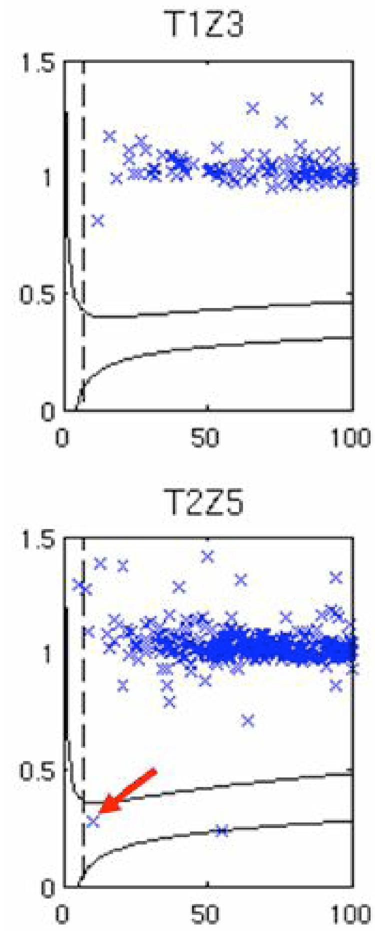
CDMS II: Results

An example on background rejection and detector physics:

Germanium before | Timing Cut | … Germanium after



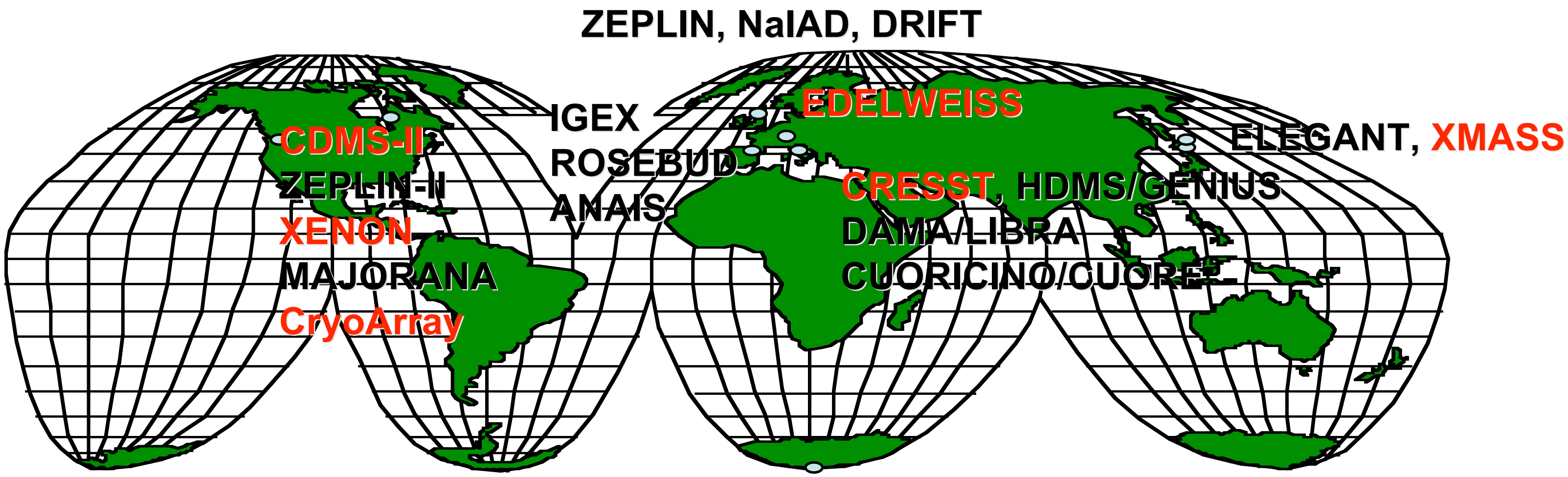




WIMP Direct Detection Experiments

- CDMS-II @ Soudan Mine (US project) → SuperCDMS
- EDELWEISS (cryo Ge @ Fréjus) → EURECA
- CRESST (cryo $CaWO_4$, $ZnWO_4$) @ Gran Sasso → EURECA
- XENON-10 @ Gran Sasso, ZEPLIN-II and -III @ Boulby Mine) → ELIXIR
- LIBRA (NaI @ Gran Sasso), NaIAD (Boulby), ANAIS (Canfranc)
- ArDM @ Canfranc, WARP @ Gran Sasso → common project
- DRIFT + MIMAC → CYGNUS
- IGEX @ Canfranc, HDMS/GENIUS-TF (Ge) @ Gran Sasso
- CUORICINO / CUORE ($Te0_2$) @ Gran Sasso
- SIMPLE, MACHe3, ORPHEUS (Bern)
- XMASS, ELEGANT, LiF @Japan

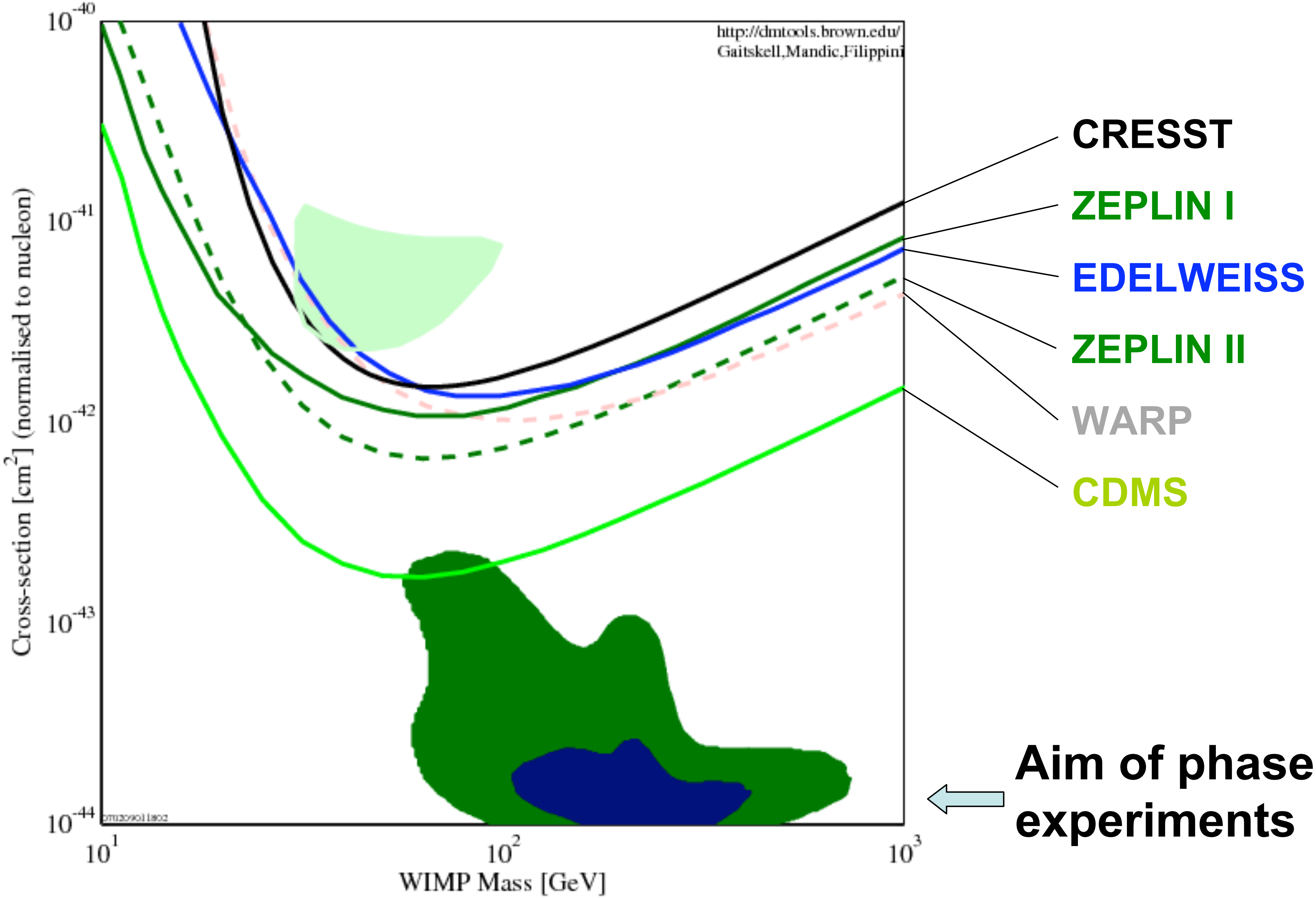
(Future experiments: SuperCDMS, EURECA , XENON-100, GERDA, LUX…)



A Couple of Current Experiments

Discrim.	Name	Location	Technique	Target	Status
None	CUORICINO	Gran Sasso	Heat	41 kg TeO_2	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	CS2	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 $CaWO_4$	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

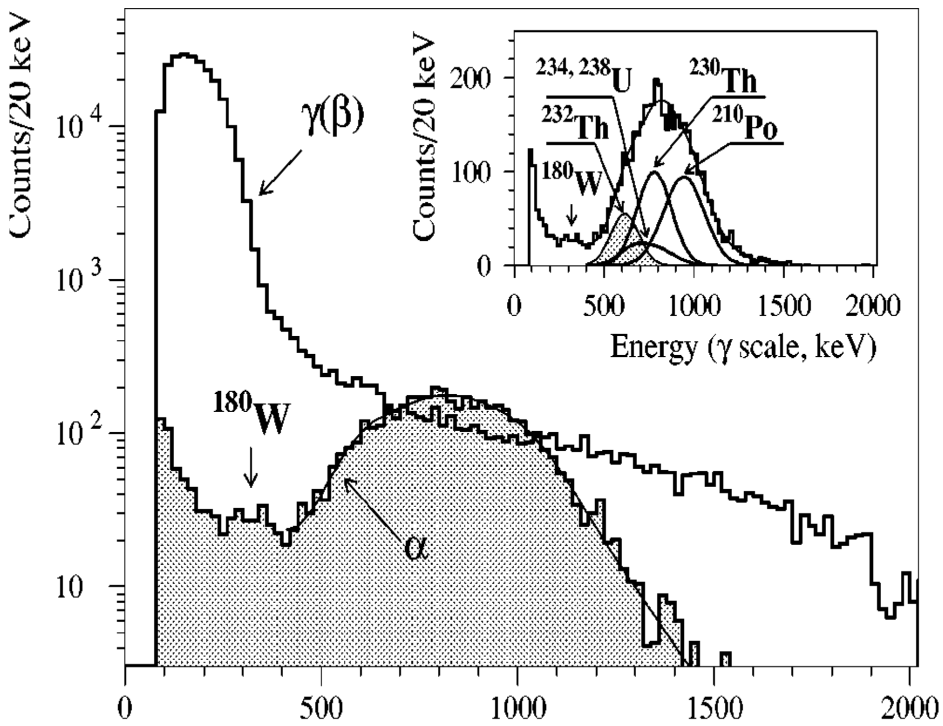
Exlusion Limits (Feb 07)



Aim of phase II experiments

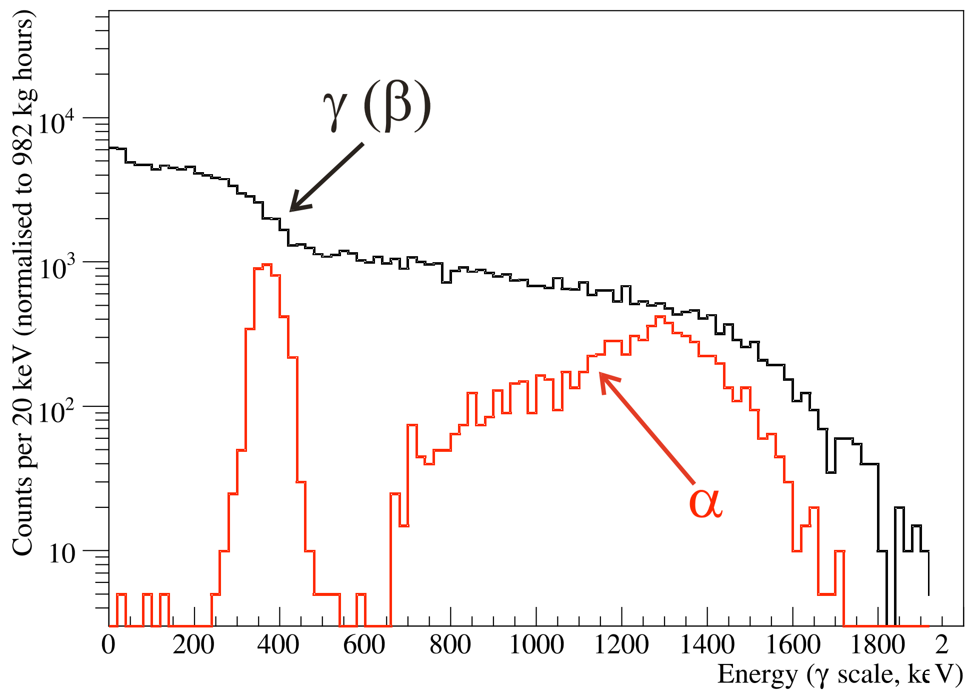
α – β/γ Discrimination

A 'standard' scintillator (pulse shape discrim.)



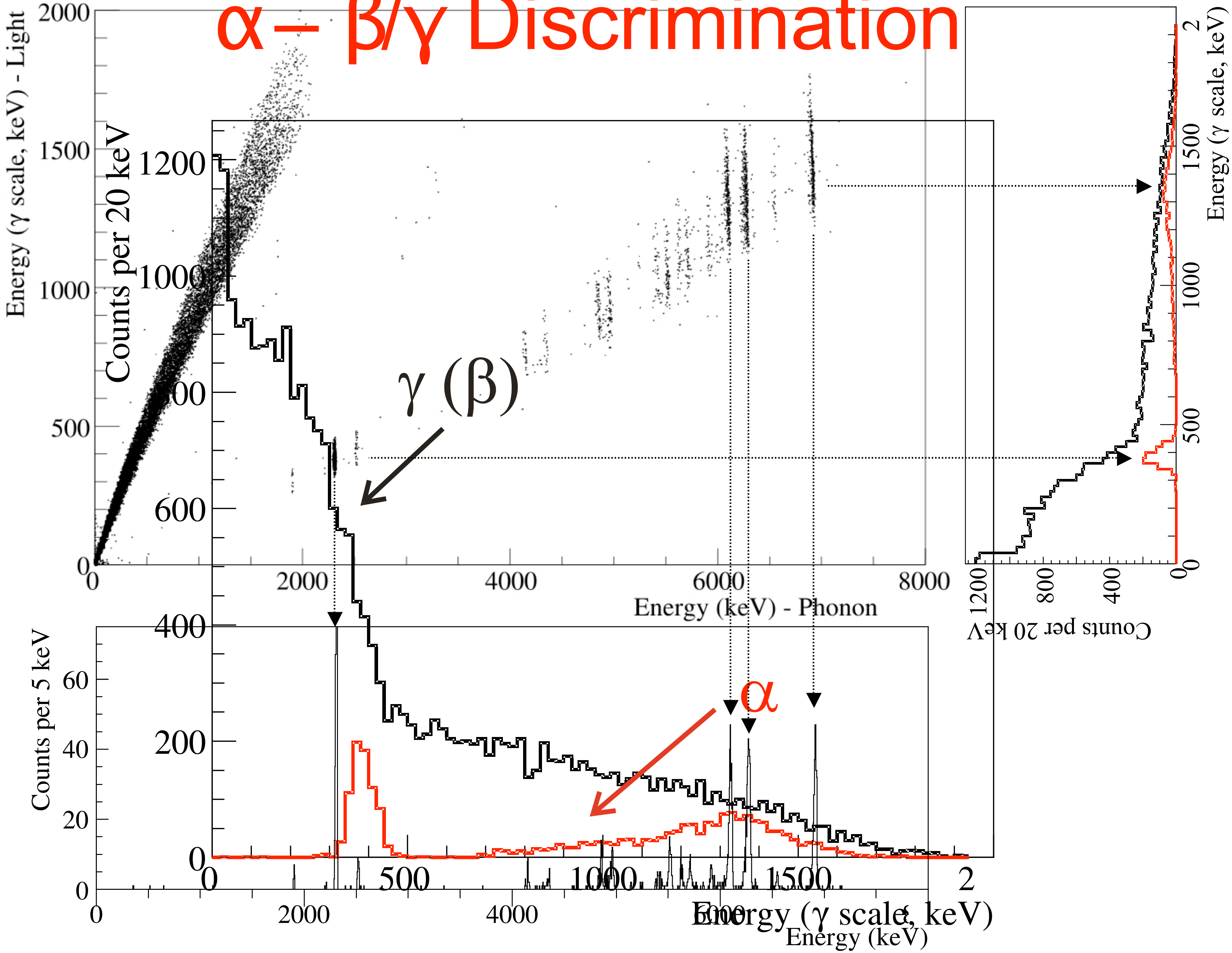
Danewich et al – Kiev
($^{116}CdWO_4$ – 330 g, 2975 hrs)

Scintillation part of a phonon – scintillation detector (CRESST)

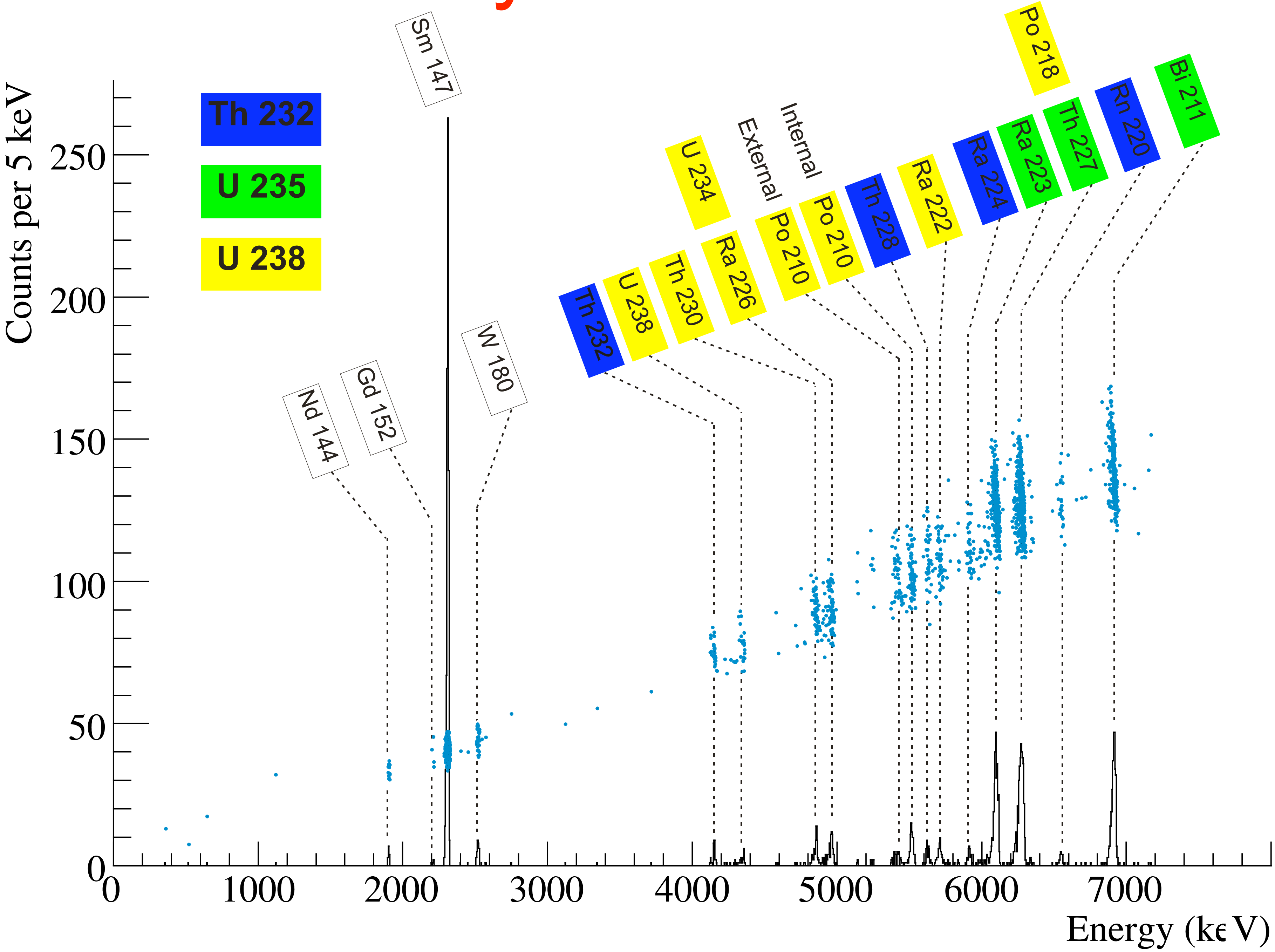


CRESST – LNGS
($CaWO_4$ – 300 g, 633 hrs)

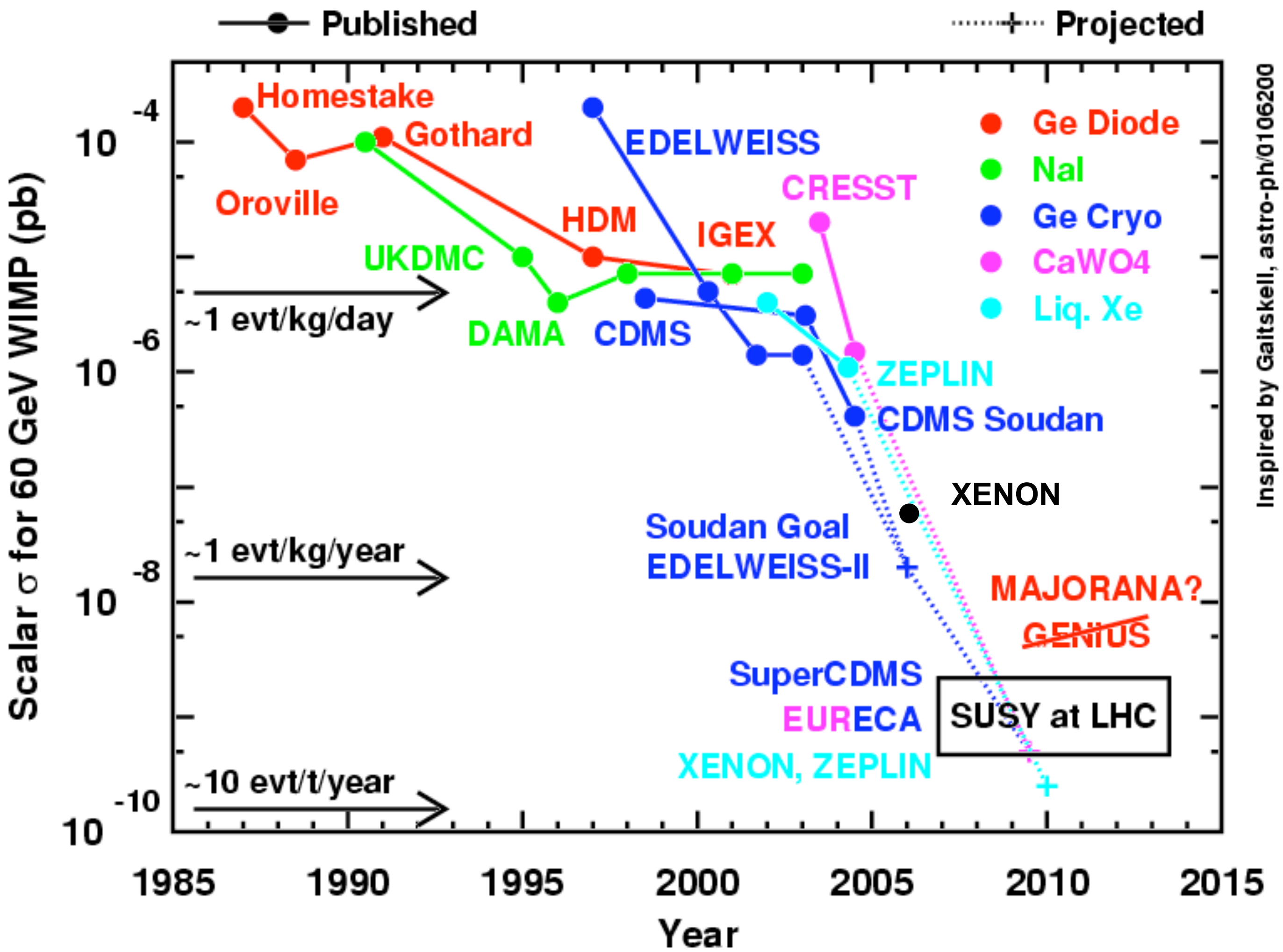
α – β/γ Discrimination



Decay Identification



Status and Long-term Future



Status and Long-term Future

Europe:

- Portfolio of well-performing / promising techniques
- Mastering the future (example for two groups joining)
- EDELWEISS / CRESST merging → EURECA
- Similar Convergence for Noble Gas? ELIXIR?

US:

CDMS → SuperCDMS

XENON / LUX collaborations