UZ Dark Matter searches at Canfranc

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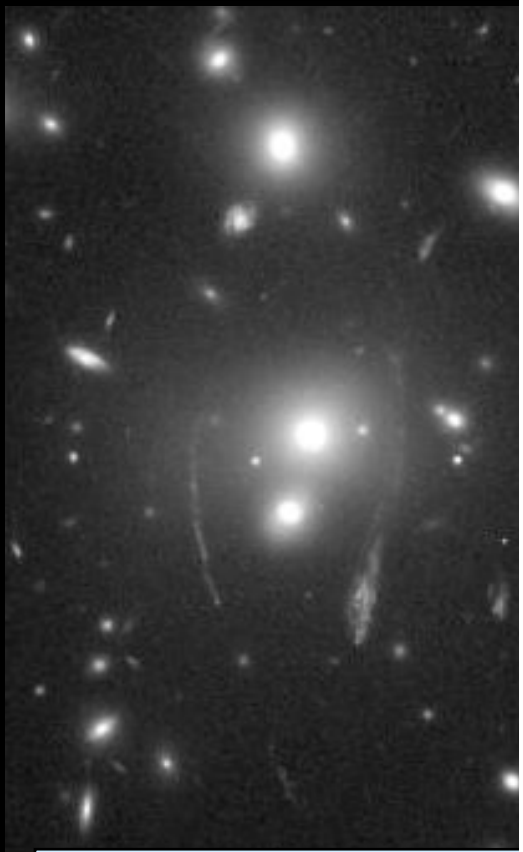
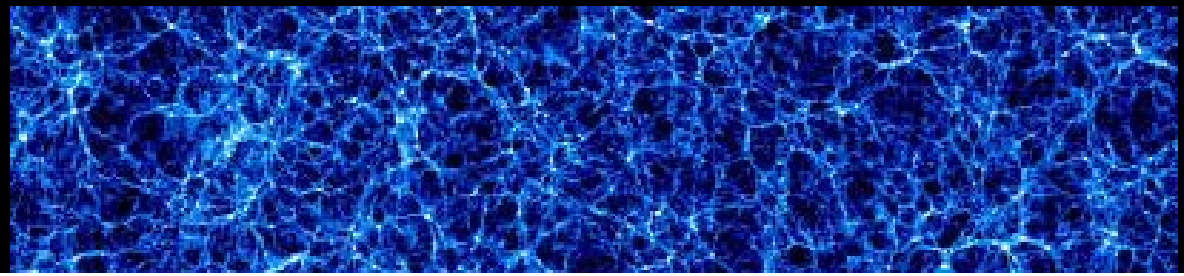
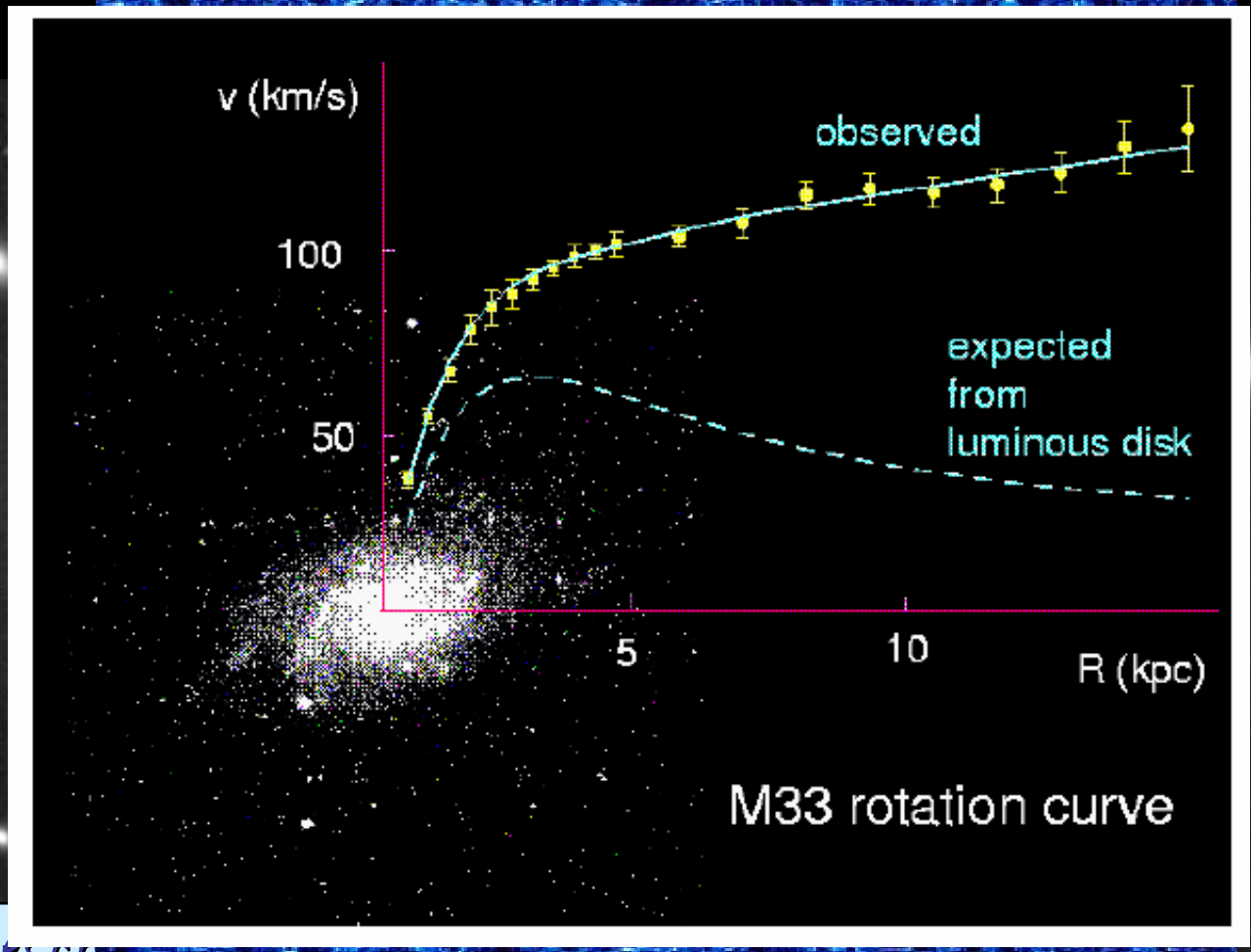
Experimental observations and well founded arguments



Hubble Space Telesc



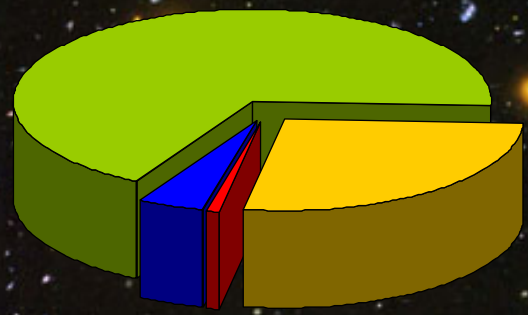


Dark Matter distribution derived from *The MareNostrum Universe*
N-body + SPH simulation with 2 billion particles

The Universe seems to be mostly DARK

$\Omega \sim 1$

Experimental observations and well founded arguments

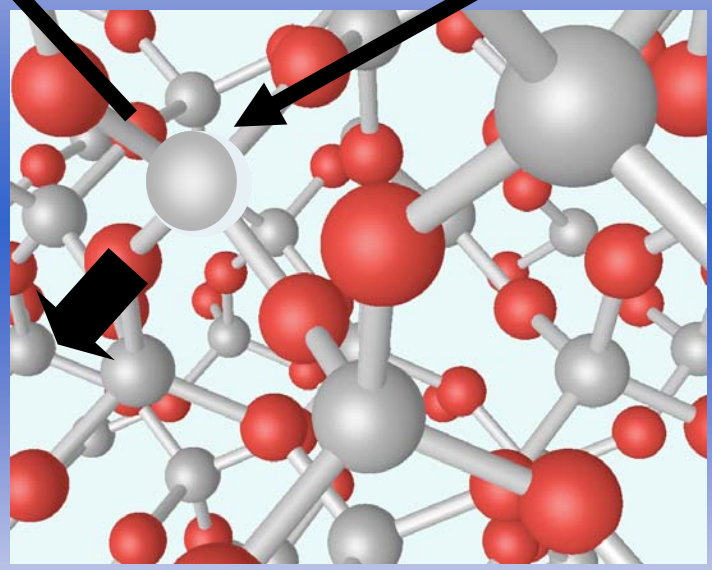


Weakly Interacting Massive Particles WIMPs

Direct Detection of WIMPs

$$\frac{dN}{dt\,dT} = N_n \frac{\rho_{\chi,local}}{m_W} \int_{v_{min}}^{v_{max}} \frac{d\sigma_{elastic}}{dT} f(v) v\, d^3v$$

scattering off target nuclei

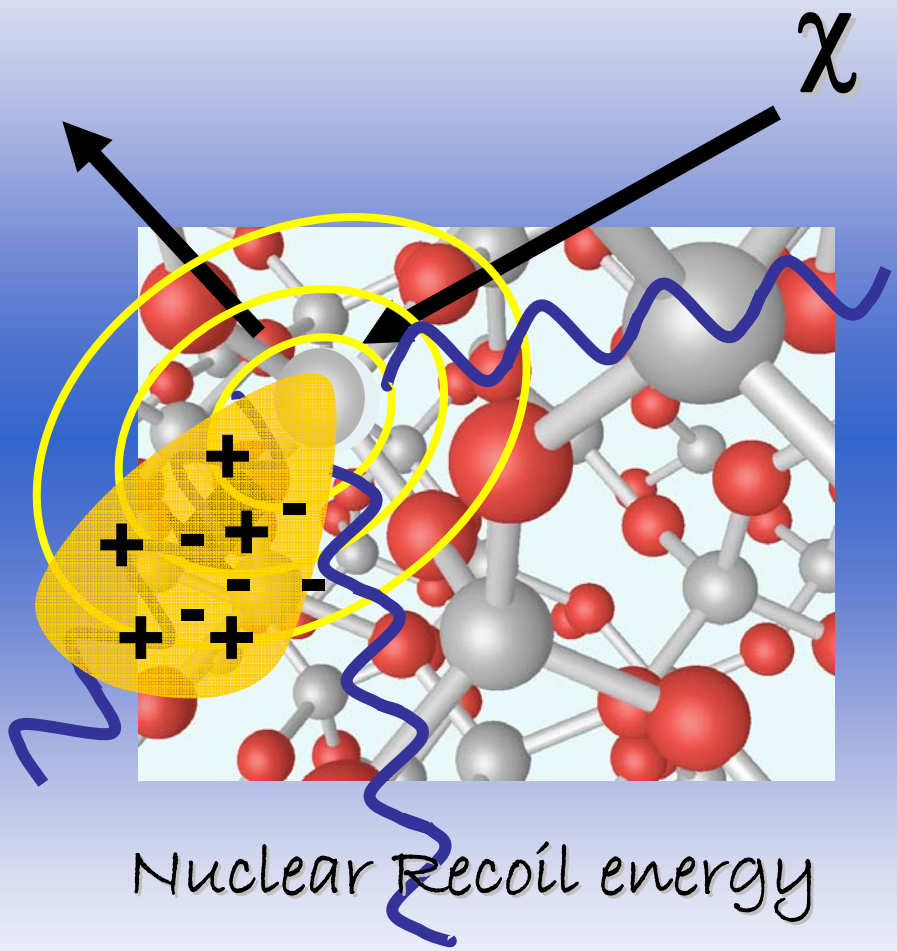


Nuclear Recoil energy

$$T = \frac{M m_W^2}{(M+m_W)^2} v^2 (1-\cos\theta)$$

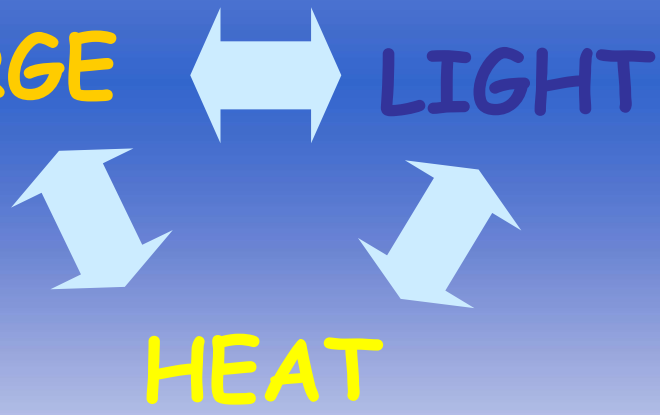
- ✓ Halo model
- ✓ WIMP model
- ✓ Detector properties

Direct Detection of WIMPs



Nuclear Recoil energy

Energy conversion into visible signal is very different depending on the detection mechanism and particle type



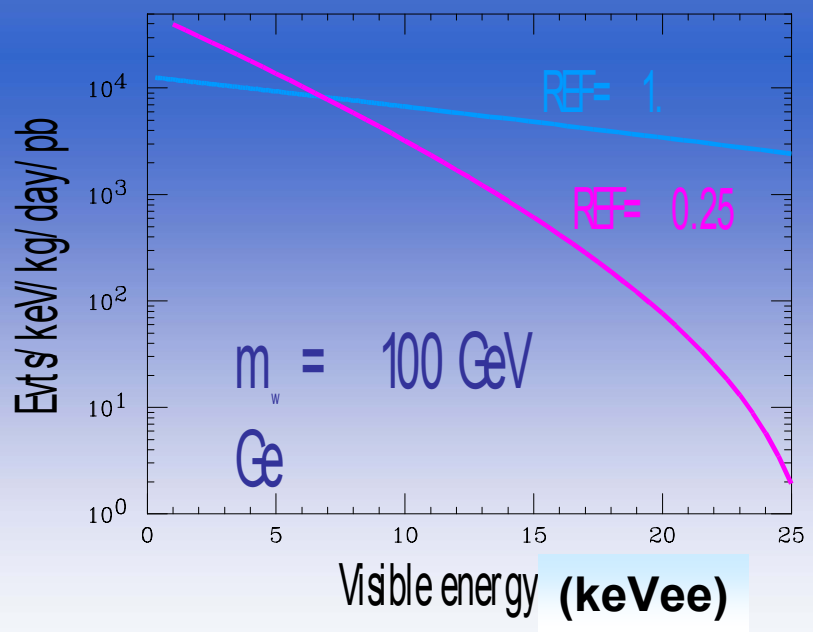
Conventional vs hybrid detection

Direct Detection of WIMPs

$$\frac{dN}{dt\,dT} = N_n \frac{\rho_{W,local}}{m_W} \int_{v_{min}}^{v_{max}} \frac{d\sigma}{dT} f(v)\, v\, d^3v$$

REF for nuclear recoils

$$T = E/REF$$



- ✓ semiconductors ~ 0.25-0.3
- ✓ scintillators ~ 0.05-0.5
- ✓ bolometers ~ 1.

General strategy for DD

- Very low energy threshold
- Very low background
  - intrinsic and induced radioactivity: very low
  - environmental: located in underground laboratories, in a radiopure environment: active / passive shieldings
  - capabilities to discriminate the signal from the background (hybrid detectors)
- Large detector mass (to increase the probability of detection)
- Good stability and control of systematics

Discriminating signal from background

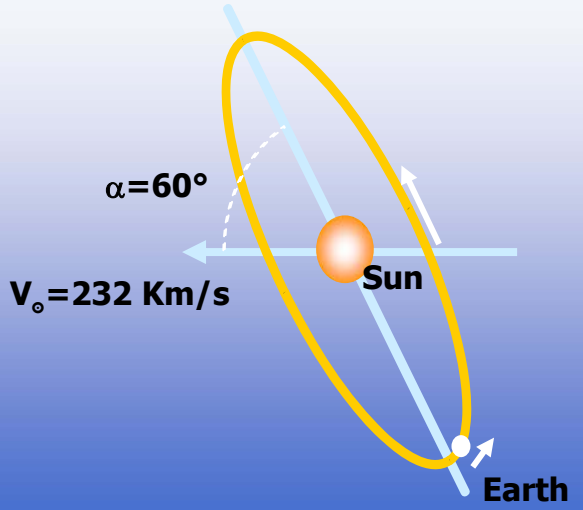
NUCLEAR VS. ELECTRONIC RECOILS DISCRIMINATION

NEUTRONS REMAIN AS THE MAIN BACKGROUND SOURCE

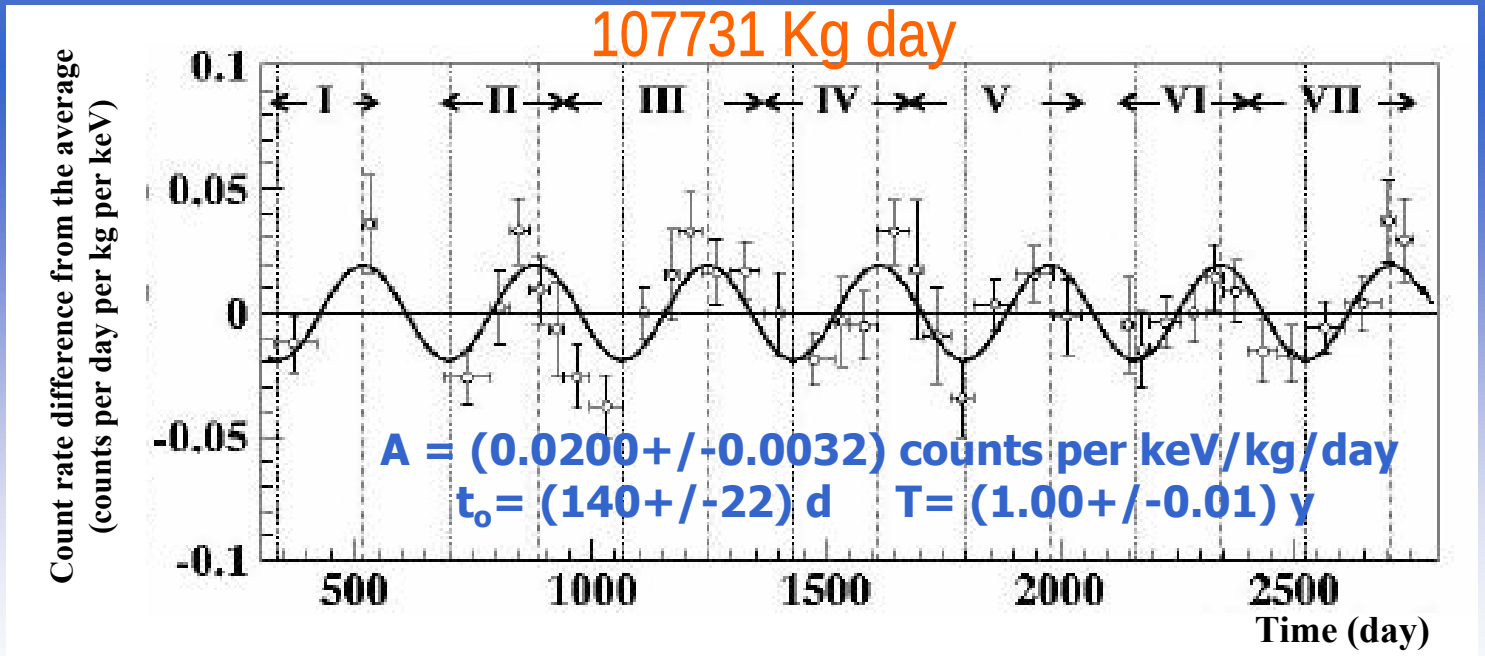
And then...

- Annual modulation in the signal
- Combination of several targets in the same experimental set-up
- Tracking the nuclear recoil energy deposition: directionality

Annual modulation of the signal



$$B + S_0 + S_m \cos[\omega(t - t_0)]$$



General Strategy for DM Direct Detection

To combine as much information as available/possible to decouple unknowns/uncertainties

- Different targets
- Different techniques of detection
- Different signatures

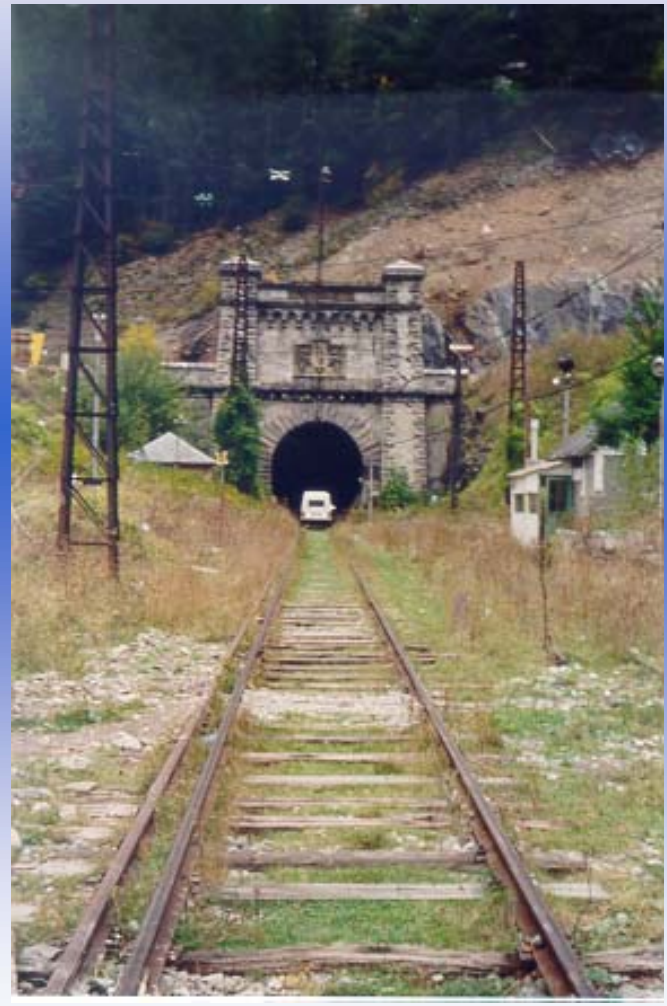
Dark Matter Search Program at CANFRANC

1990-2006

2006-

The Canfranc Underground Laboratory

Under the spanish Pyrenees



In the old railway
Somport Tunnel

The Canfranc Underground Laboratory

Since 1985, research has been carried out about:

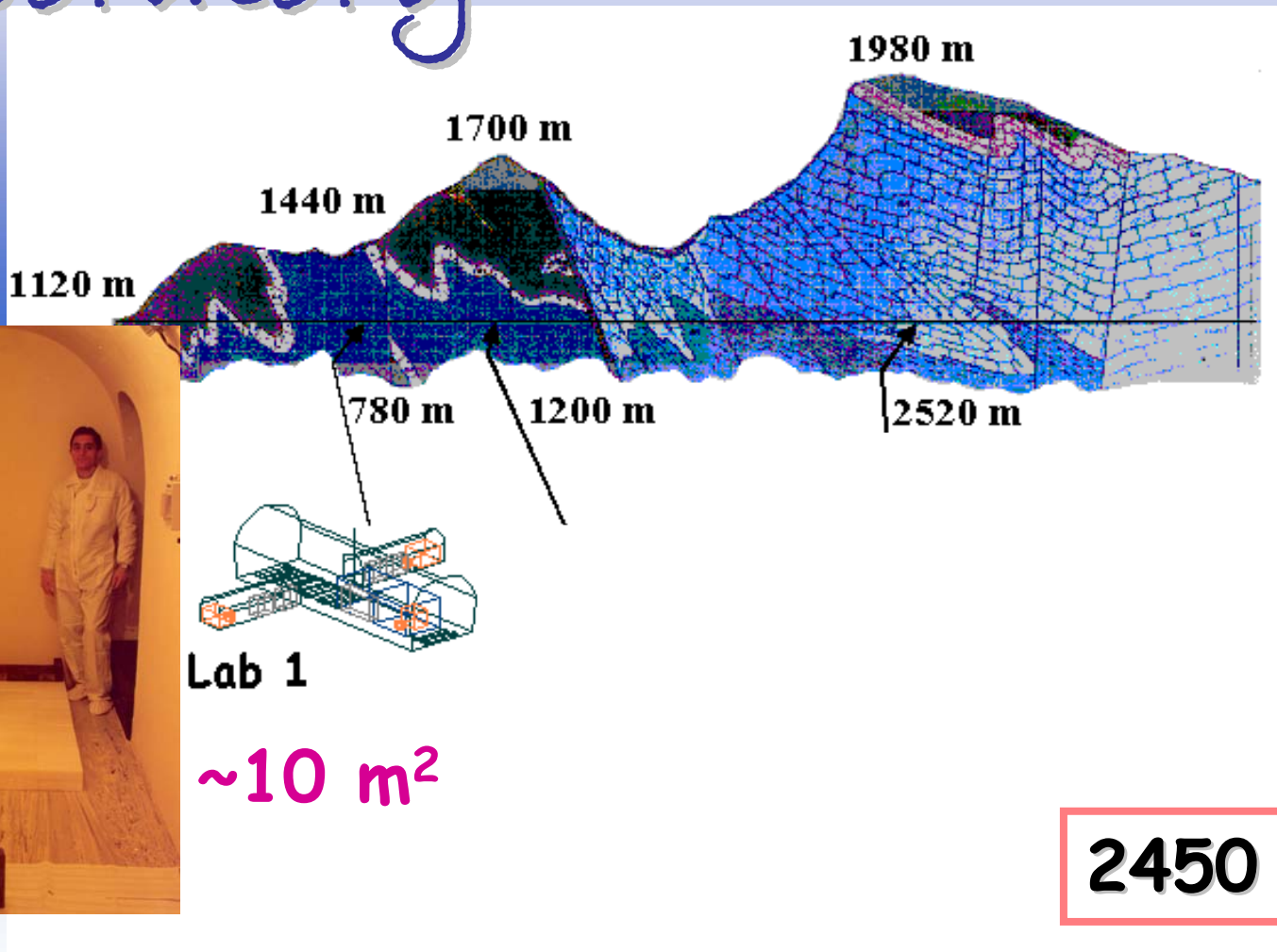
- √ Direct WIMP search
- √ Double beta decay
- √ Other "rare" processes
- √ Radiopurity measurements

The Canfranc Underground Laboratory

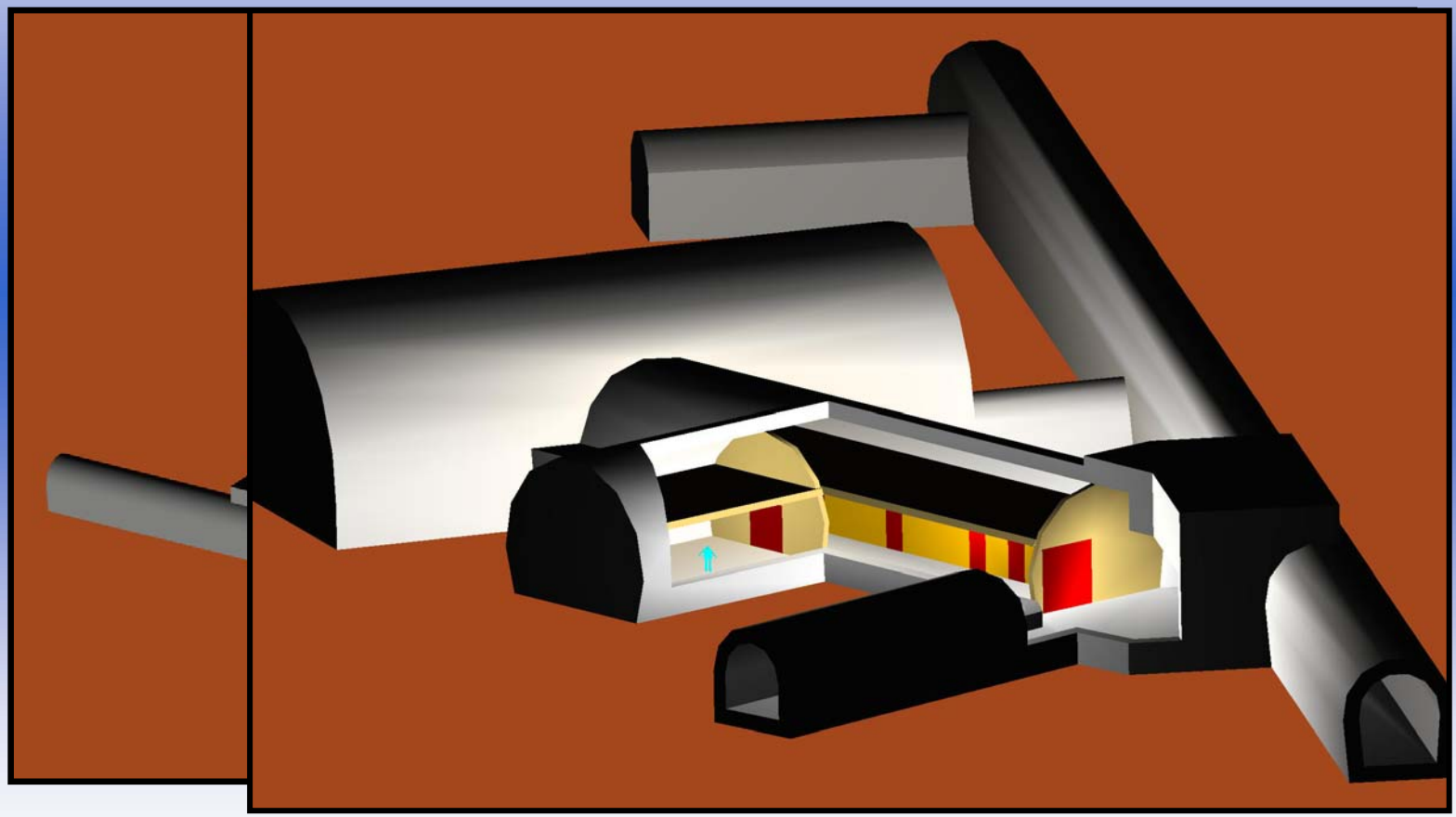
1985 first visits to the Somport Tunnel

First Canfranc Underground Facility
1989, Mounting ββ/γ

The Canfranc Underground Laboratory



The NEW Canfranc Underground Laboratory Facilities



The NEW Canfranc Underground Laboratory Facilities

Site	Experiment	Technique	Target	Status
Baksan (Russia)	IGEX	Ionisation	3kg Ge	Operational
Bern (Switzerland)	ORPHEUS	SSD	0.5kg Sn	Operational
Boulby (UK)	NaI	Scintillator	5kg NaI	Completed
	NaIAD	Scintillator	50kg NaI	Operational
	ZEPLIN I	Scintillator	5kg Lxe	Operational
	ZEPLIN II/III	Scintillator/Ionisation	30kg/7kg Xe	Construction
	ZEPLIN-MAX	Scintillator/Ionisation	1000kg Xe	Planned
	DRIFT-I	TPC	0.2kg CS_2	Operational
	DRIFT-10	TPC	2kg CS_2	Planned
Canfranc (Spain)	COSME	Ionisation	0.2kg Ge	Completed
	IGEX	Ionisation	2.1kg Ge	Operational
	ANAIS	Scintillator	107kg NaI	Constrcution
	ROSEBUD	Thermal	Al_2O_3,Ge,$CaWO_4$	Operational
Frejus (France)	Saclay-NaI	Scintillation	10kg NaI	Completed
	EDELWEISS I	Thermal/Ionisation	0.07kg Ge	Completed
	EDELWEISS II	Thermal/Ionisation	1.3 kg Ge	Operational
Gran Sasso (Italy)	Hdlberg/Mscw	Ionisation	2.7kg Ge	Completed
	HDMS	Ionisation	0.2kg Ge	Operational
	Genius	Ionisation	100kg Ge	Planned
	DAMA	Scintillation	100kg NaI	Operational
	LIBRA	Scintillation	250kg NaI	Construction
	Xenon	Scintillation	6kg Xe	Operational
	CRESST-I	Thermal	1kg Al_2O_3	Oprational
	CRESST-II	Thermal/Scintillation	10kg $CaWO_4$	Construction
	CUORICINO	Thermal	40kg TeO_2	Construction
	CUORE	Thermal	760kg TeO_2	Planned
Otto-Cosmo (Japan)	Elegants V	Scintillation	NaI	Operational
	Elegants VI	Scintillation	CaF_2	Operational
Rustrel (France)	SIMPLE	SDD	Freon	Operational
Stanford (USA)	CDMS-1	Thermal/Ionisation	0.1kg Si, 1kg Ge	Completed
Soudan (USA)	CDMS-II	Thermal/Ionisation	0.3ks Si, 0.75kg Ge	Construction
SNO (Canada)	PICASSO	SDD	1g Freon	Operational

Ionization

COSME, IGEX-DM

Ge

U. Zaragoza / South Carolina / PNNL / INR / ITEP Collaboration

CANFRANC EXPERIMENTS WIMP detection techniques

WIMP searches with Ge

- Ultrahigh purity material: very low background levels
- Low energy threshold
- Reasonable quenching factor: $E_{visible} \cong 0.25\ E_{recoil}$
- Medium size, A~70
- For spin-independent coupling no enrichment needed

COSME Experiment

E. García, A. Morales, J. Morales, A. Ortiz de Solórzano, J. Puimedón, C. Sáenz, A. Salinas, M. L. Sarsa, J. A. Villar
University of Zaragoza

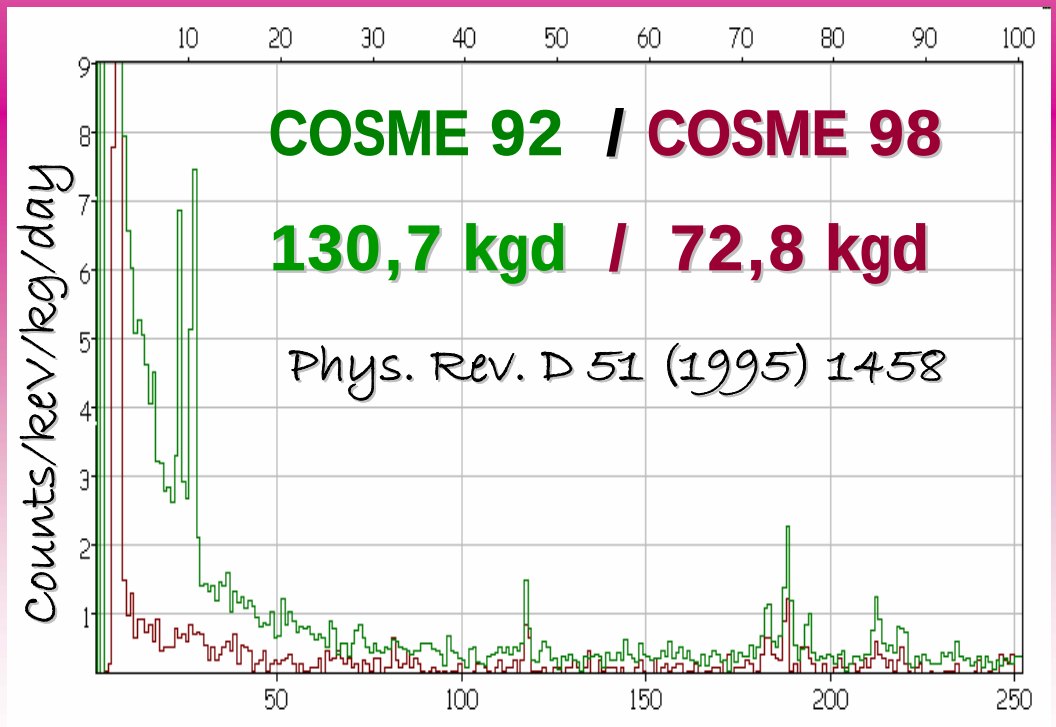
F.T. Avignone III, .I. Collar
University of South Caroline, USA

R. L. Brodzinski, W.K. Hensley, H.S. Miley, J.H. Reeves
Pacific Northwest National Laboratory, USA

COSME

PNL/USC/UZ
1990-1992

234 g natural Germanium
Search for WIMPs and solar axions
Low energy threshold 1,6 keVee



IGEX Collaboration

S. Cebrián, E. García, D. González, I. G. Irastorza, A. Morales, J. Morales, A. Ortiz de Solórzano, J. Puimedón, A. Salinas, M. L. Sarsa, J. A. Villar

University of Zaragoza

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R. L. Brodzinski, W.K. Hensley, H.S. Miley, J.H. Reeves

Pacific Northwest National Laboratory, USA

A.A. Klimenko, S.B. Osetrov, A.A. Smolnikov, A.A. Vasenko, S.I. Vasiliev

Institute for Nuclear Research, INR, Baksan

I.V. Kirpichnikov

Institute for Theoretical and Experimental Physics, ITEP, Moscow

V.S. Pogosov, A.S. Starostin, A.G. Tamanyan,

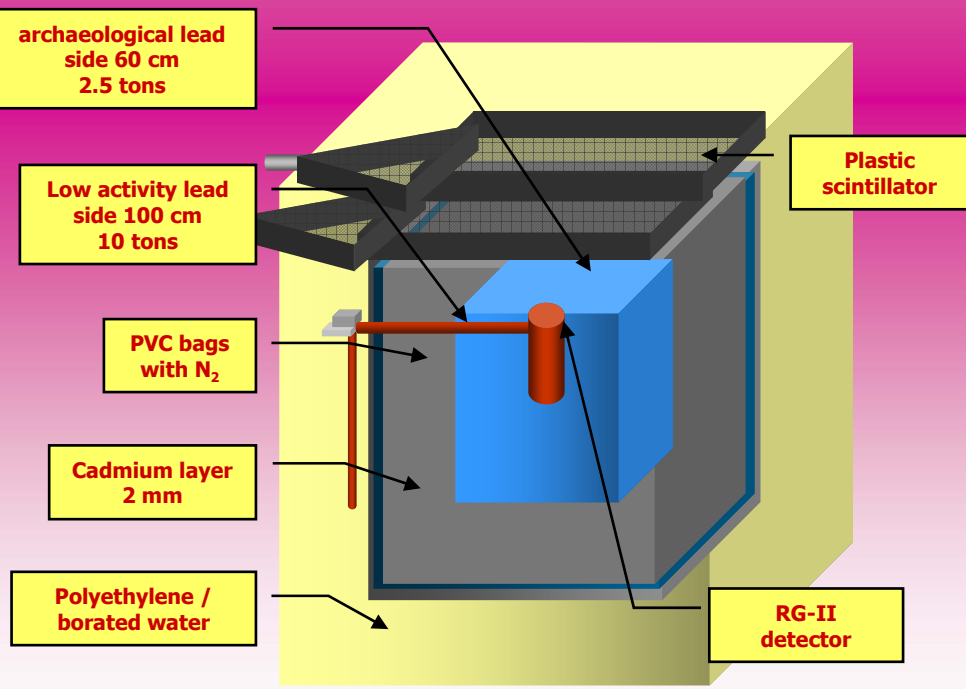
Yerevan Physics Institute

IGEX ββ

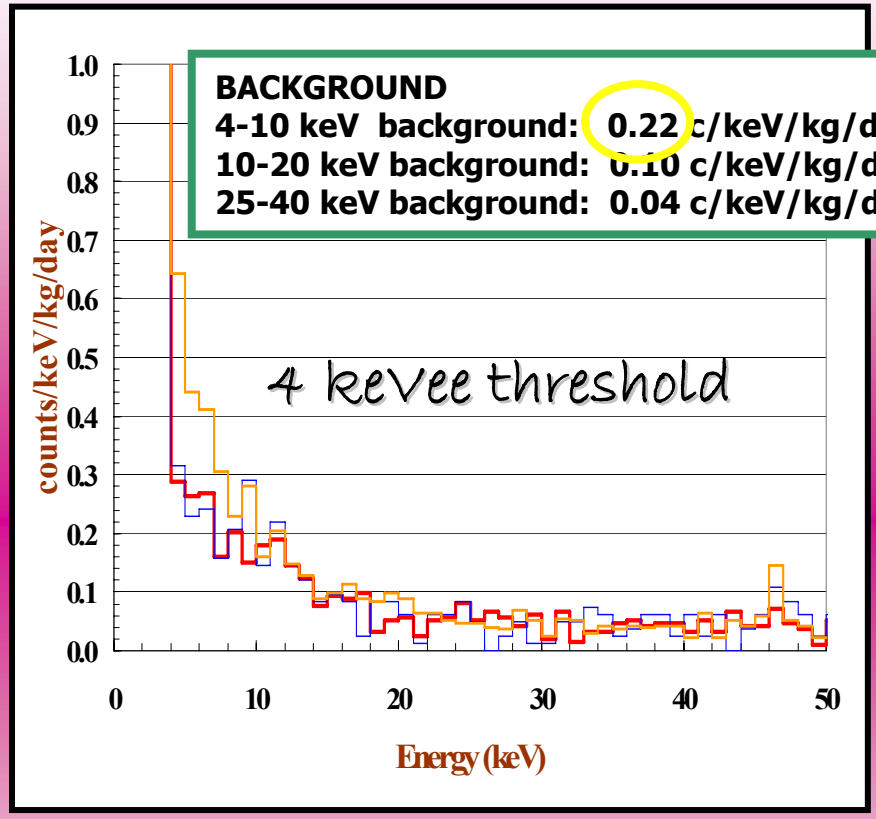
IGEX Collaboration searched for ^{76}Ge double beta decay with enriched detectors (86%)

IGEX-DM

- IGEX-DM used one detector (2.1 kg)
- An improved neutron shielding allowed a significant reduction of background at low energies

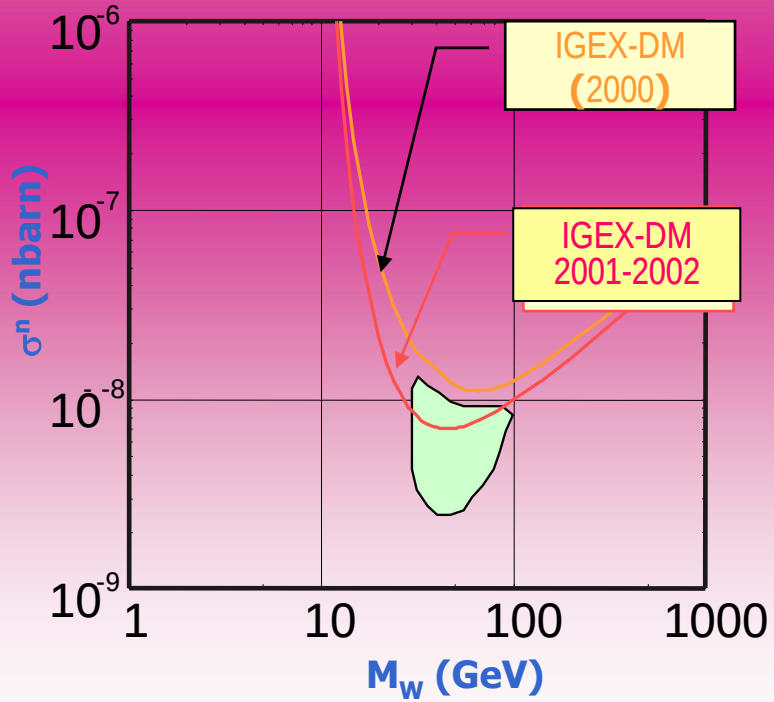


IGEX-DM



194 kg-days with 40 cm neutron shielding

82 kg-days with 80 cm neutron shielding



Astrop. Phys. 20 (2003) 247
Astrop. Phys. 21 (2004) 523
Phys. Lett. B 532 (2002) 8
Phys. Lett. B 489 (2000) 268

Ionization

COSME, IGEX-DM

Ge

U. Zaragoza / South Carolina / PNNL / INR / ITEP Collaboration

Light

DM32, ANAIS

NaI

U. Zaragoza

CANFRANC EXPERIMENTS
WIMP
detection techniques

WIMP searches with NaI scintillators

- 100% nuclei with non-zero spin: ^{23}Na (J=3/2)
  ^{127}I (J=5/2)
- Heavy+light nuclei, A=127 & 23
- Easy scale up to large mass
- Pulse shape discrimination (PSD) capability
- Small quenching factor (Q<10%) for I, and medium for Na (Q~30-40%)

NaI Scintillators at Canfranc

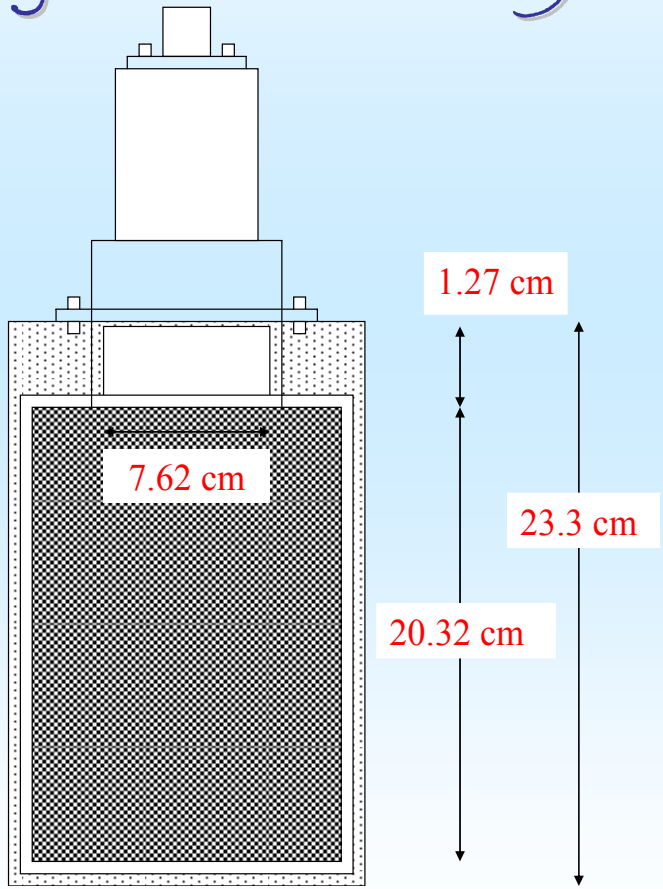
14 detectors, used in previous experiments, underground since 1988

PMT EMI9765

quartz window

stainless steel vessel 0.5 mm

crystal 10.7 kg NaI (Tl)



NaI32 Experiment

E. García, A. Morales, J. Morales, A. Ortiz de Solórzano, J. Puimedón, C. Sáenz, A. Salinas, M. L. Sarsa, J. A. Villar

University of Zaragoza

NaI32 (3x10,7 kg NaI, LSC)

looking for the annual modulation effect

carried out in the Canfranc Underground Laboratory from 1993 to 1995

Mt=4614 kg.day

Phys. Lett. B 386 (1996) 458
Phys. Rev. D 56 (1997) 1856

ANAIS

ANAIS experiment

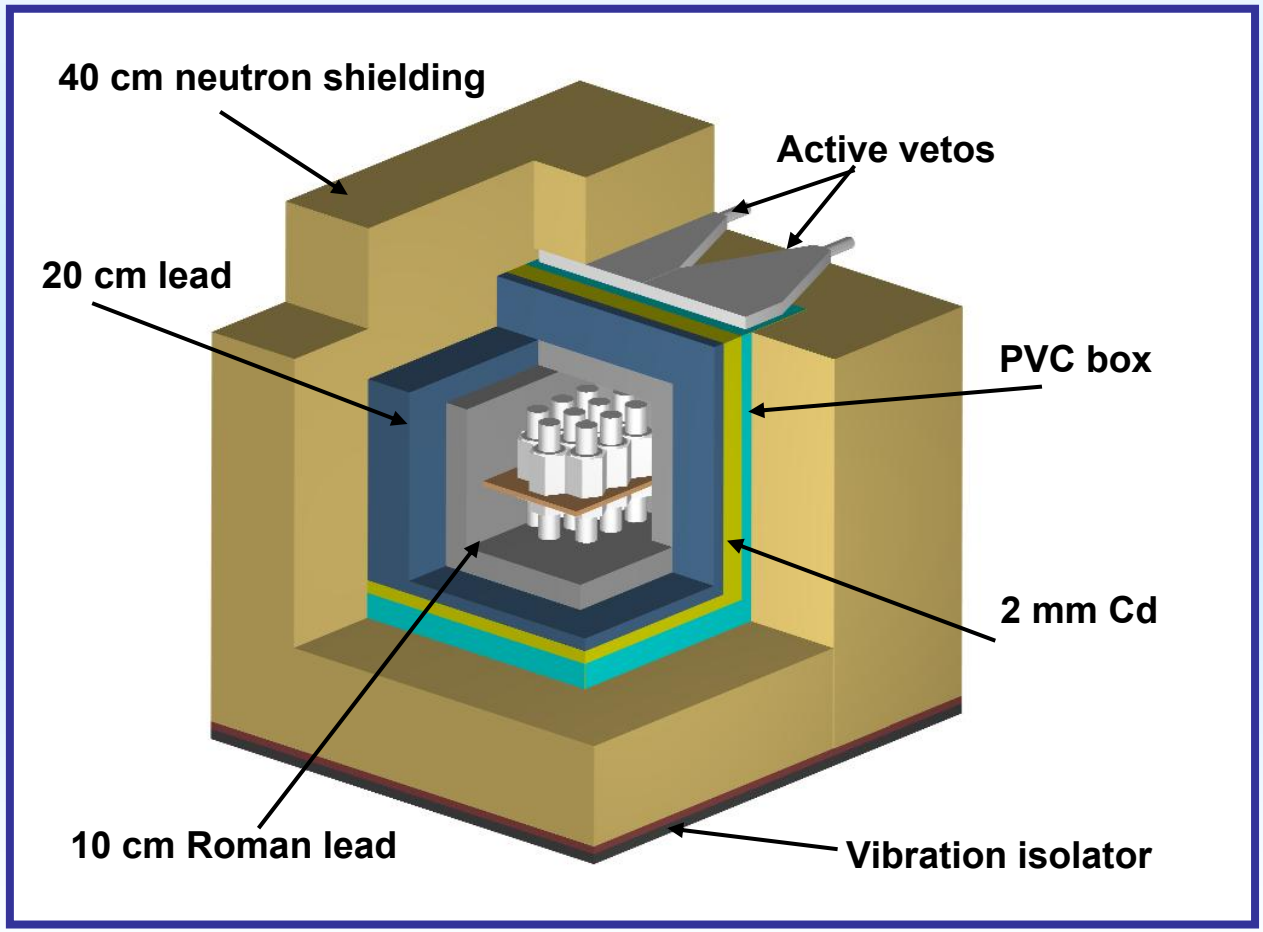
J. Amaré, B. Beltrán, J. M. Carmona, S. Cebrián, E. García,
H. Gómez, I. G. Irastorza, G. Luzón, M. Martínez, J. Morales,
A. Ortiz de Solórzano, C. Pobes, J. Puimedón, A. Rodríguez, J. Ruz,
M. L. Sarsa, L. Torres, J. A. Villar

University of Zaragoza

ANAIS PROJECT

10 x 10.7 kg NaI dark matter search experiment looking for annual modulation

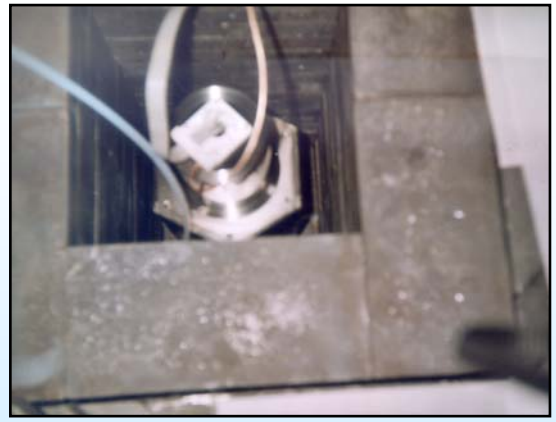
To be installed at the new Canfranc Underground Laboratory



PROTOTYPE I

10.7 kg NaI

PSD discrimination to reject PMT noise: lowering threshold



2069.85 kg day

Nucl. Phys. B (PS) 114 (2003) 111

IMPROVED PROTOTYPE I

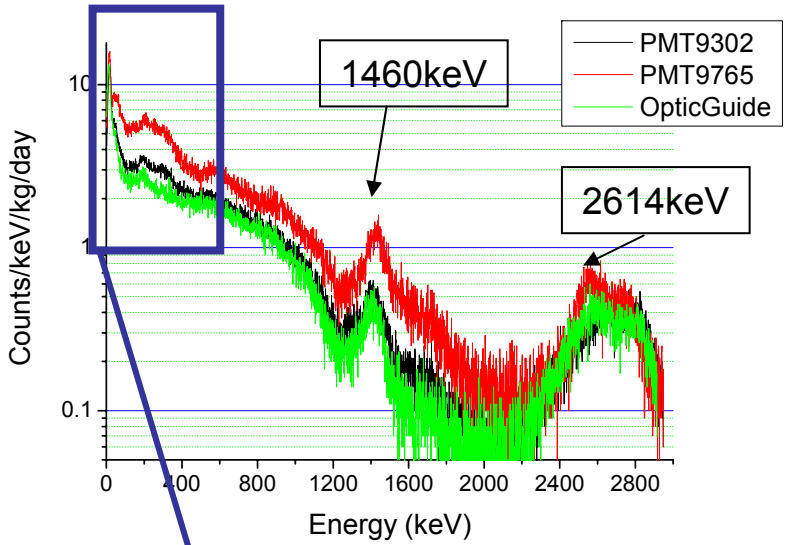
Understanding and improvement of background

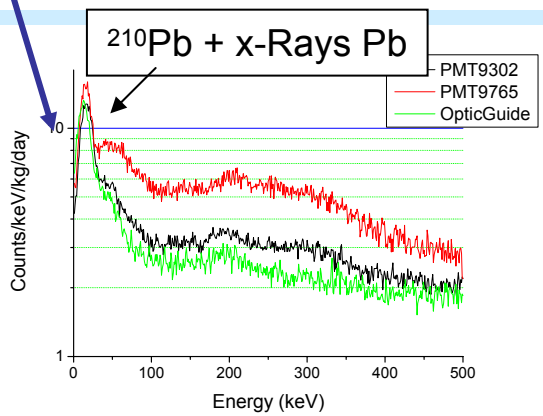
IMPROVED PROTOTYPE I

Background from PMT

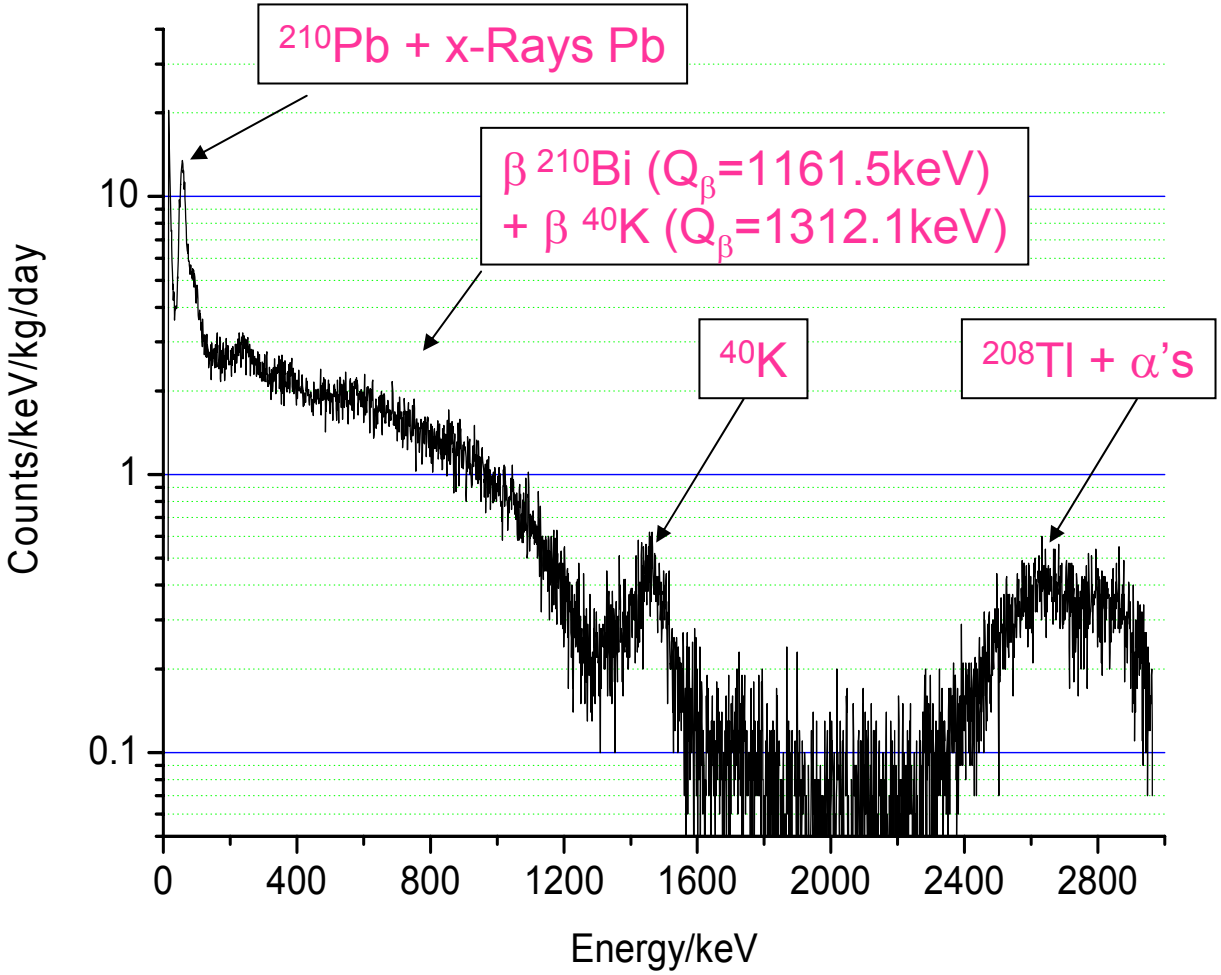
EMI9765

EMI9302



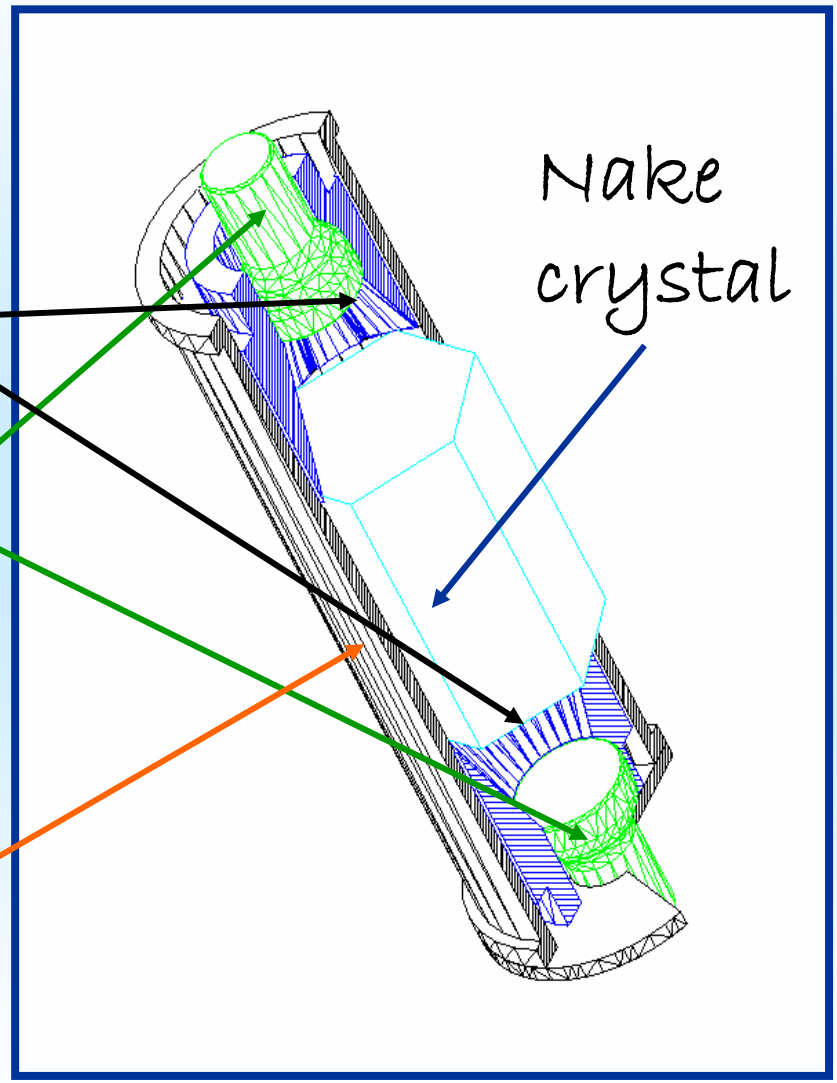


IMPROVED PROTOTYPE I



PROTOTYPE II (2003-)

- Removal of the old PMT and steel vessel
- Coupling to 2 ultra-low background PMT + light guides
  - Anticoincidence
  - Light collection efficiency
  - Background improvement
- Selection of high purity materials in Canfranc using a Ge detector
  - Background improvement



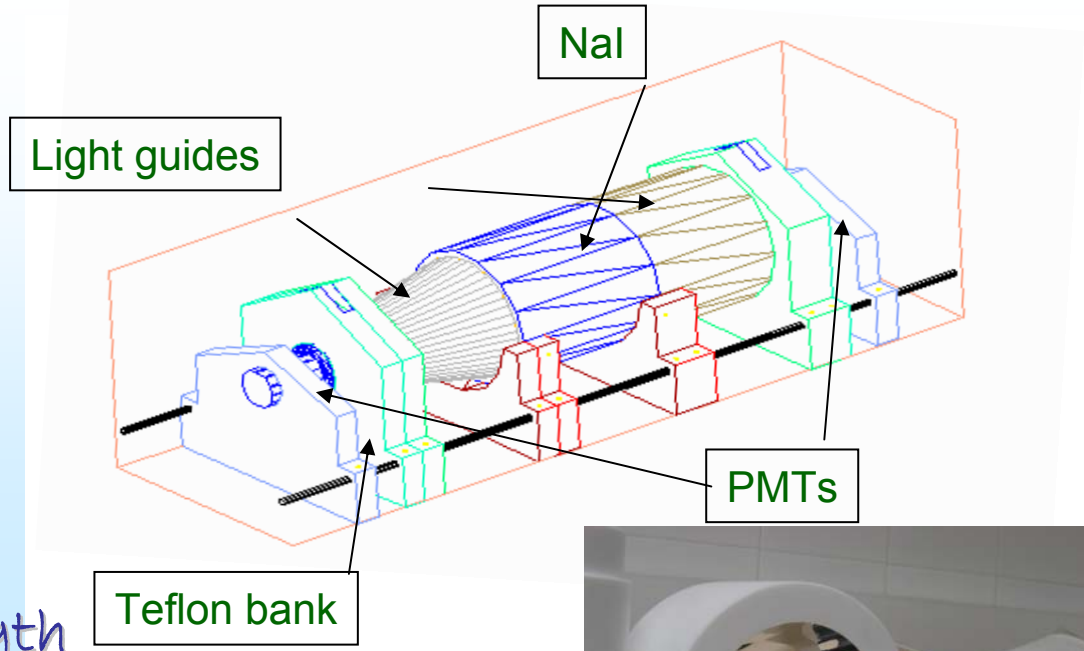
PROTOTYPE II

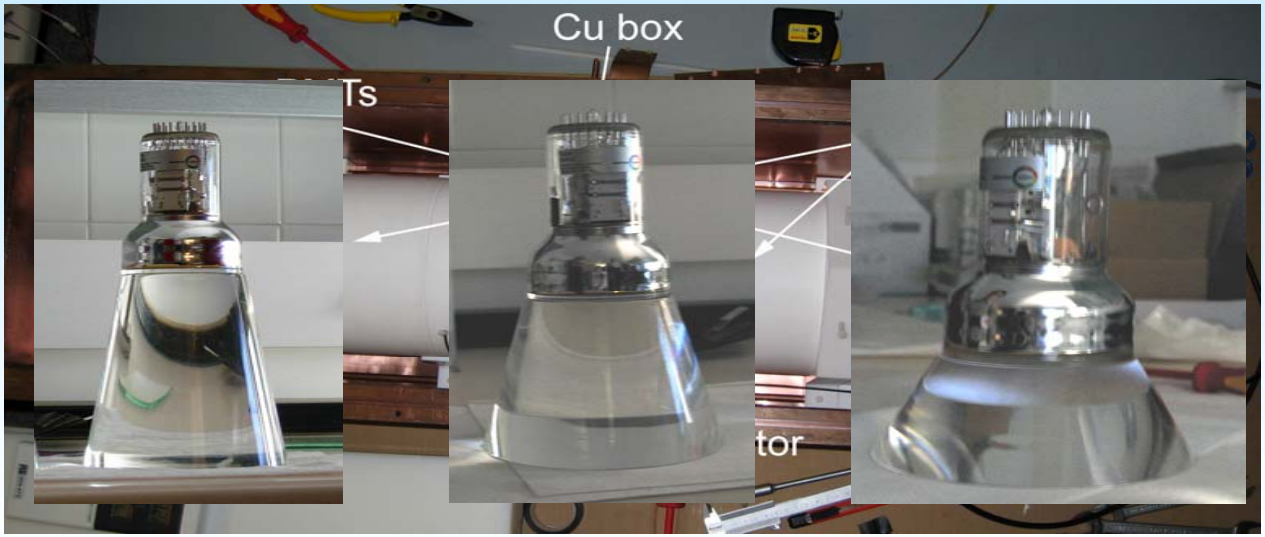
10.7 kg NaI

Flexible set-up

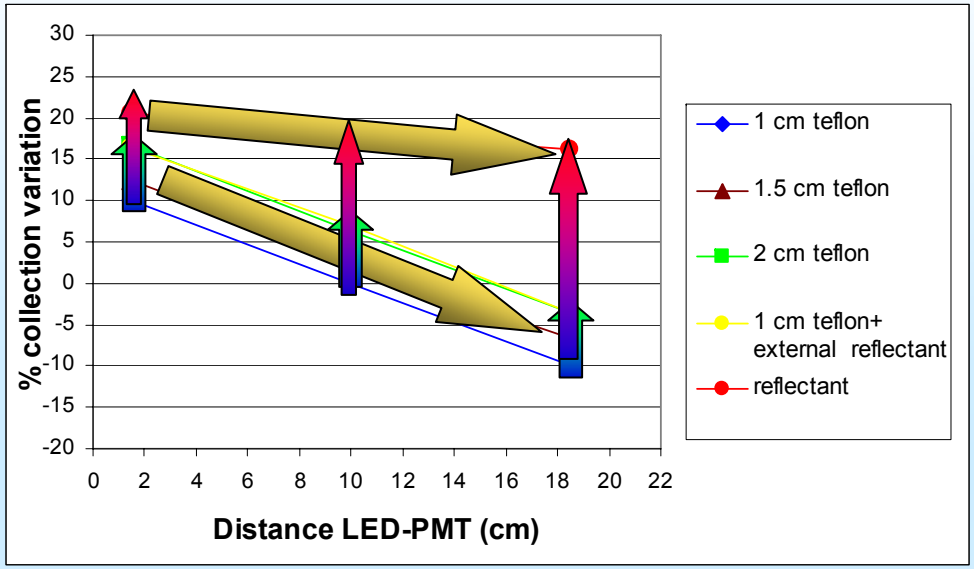
Test reflector/diffusor materials and thickness

Optimal light guides length

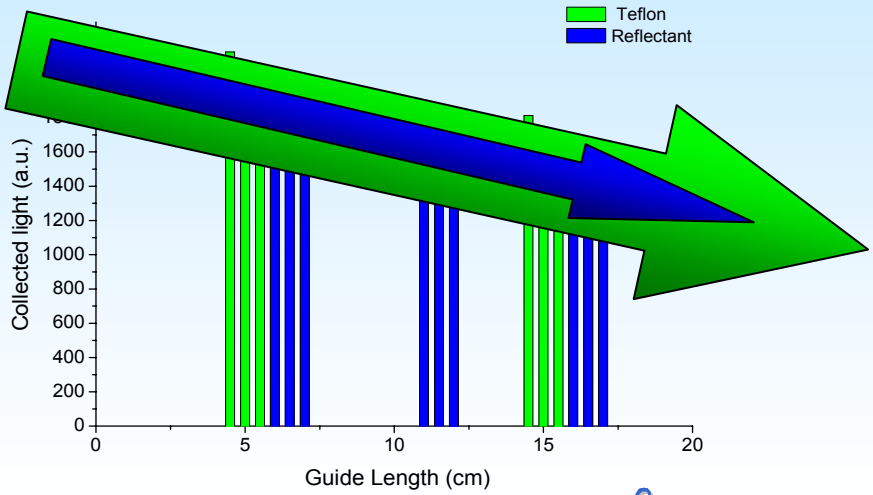




Light collection results

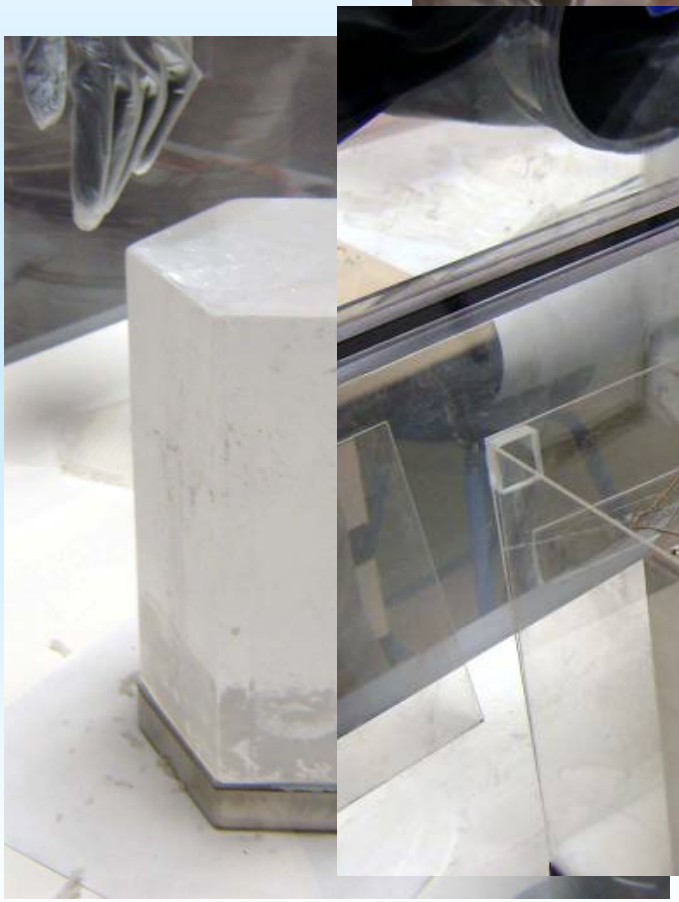


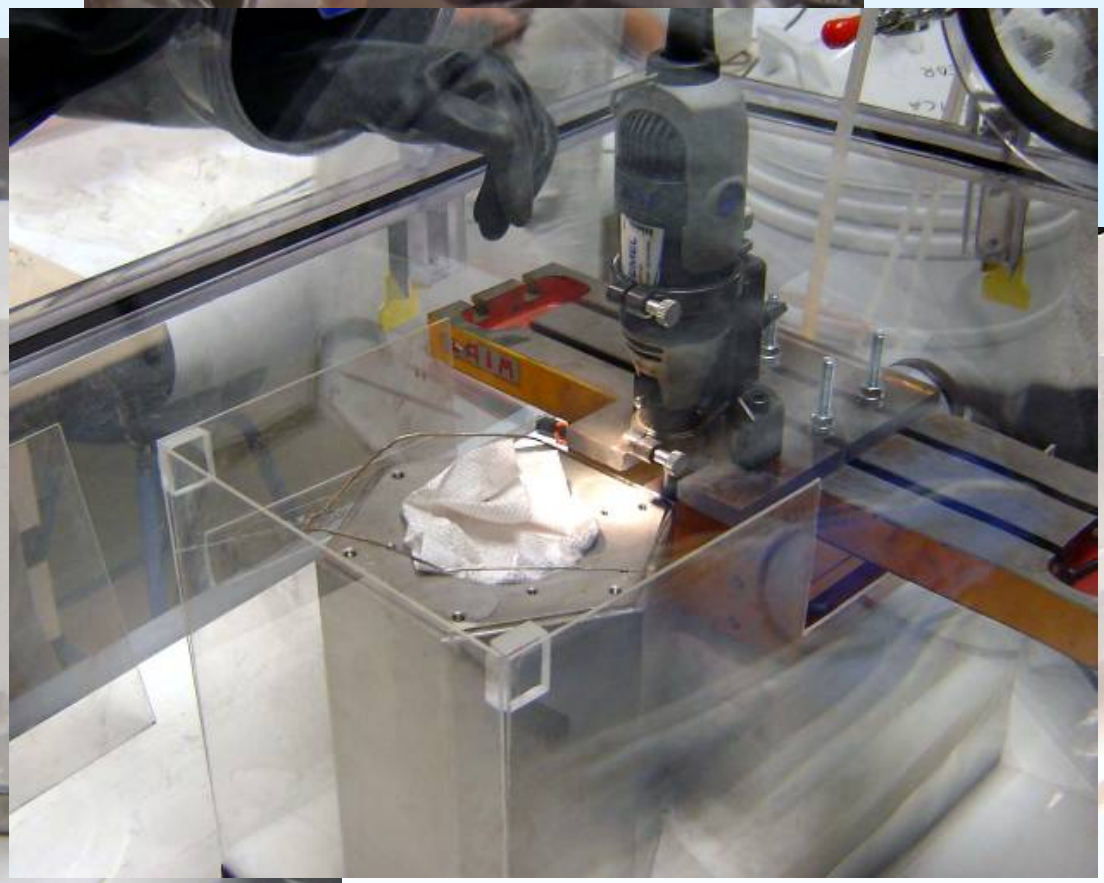
- ✓ Teflon thickness slightly increases light collection
- ✓ Reflectant improves light collection ~20%
- ✓ Reflectant decreases positional dependency of light collection



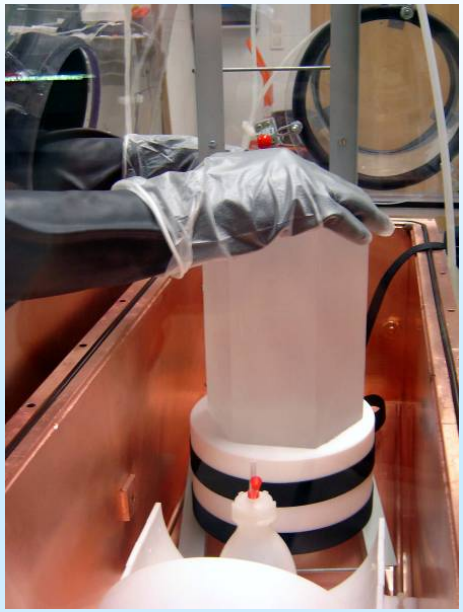
- ✓ We lose ~10% light every 5 cm optical guide

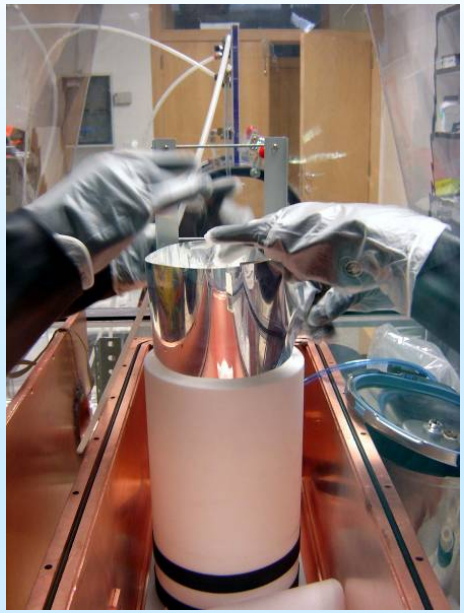
STRIPPING THE CRYSTAL

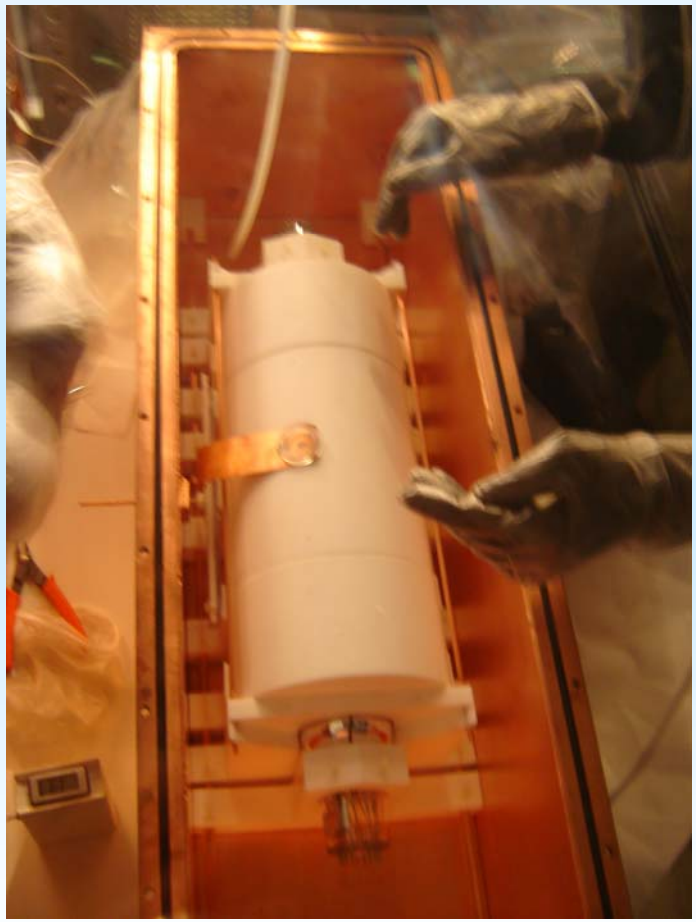


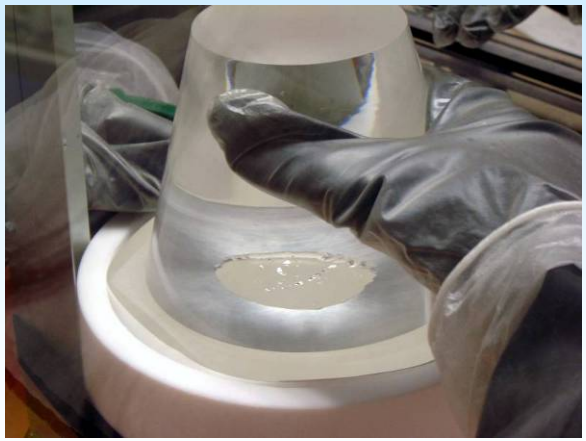


COUPLING PROTOTYPE II





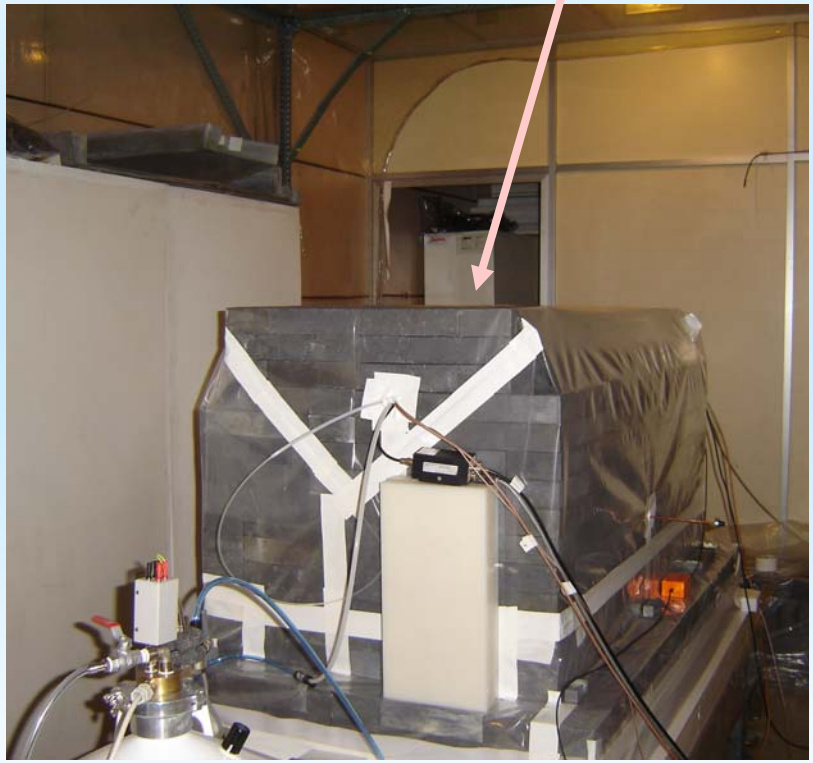




PROTOTYPE II: Canfranc measurements

10 cm archeological lead

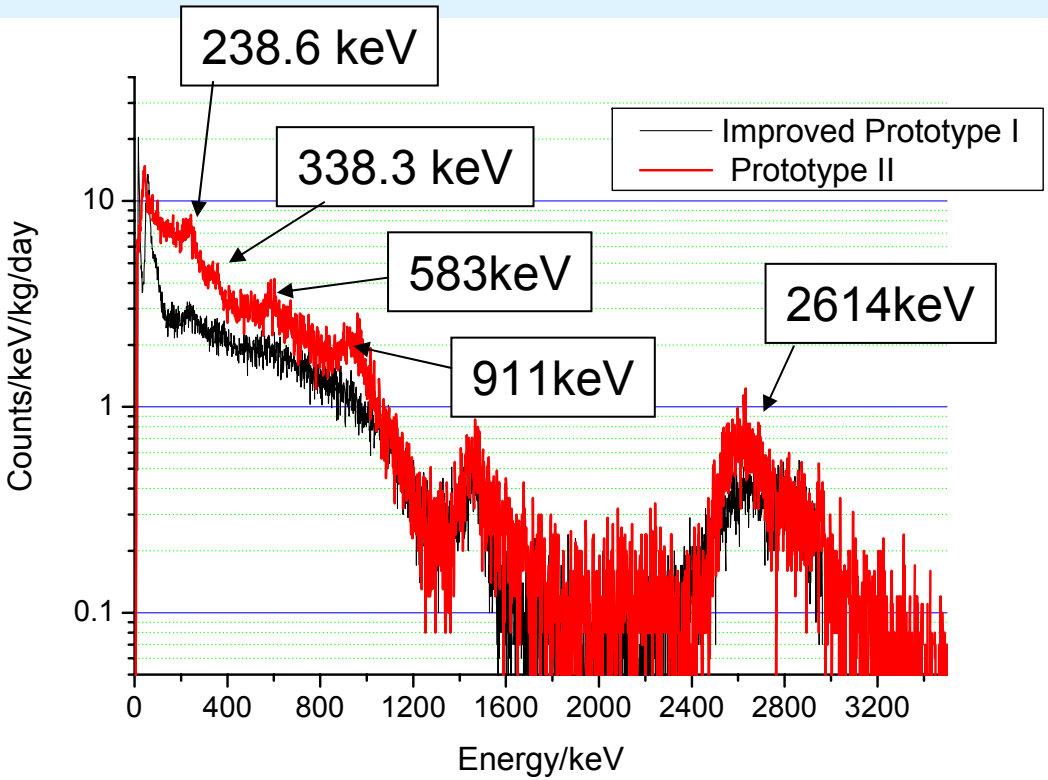
Anti-radon PVC box



10 cm lead

PROTOTYPE II: Canfranc measurements

^{232}Th contamination!



Identified at the weldings of the copper box

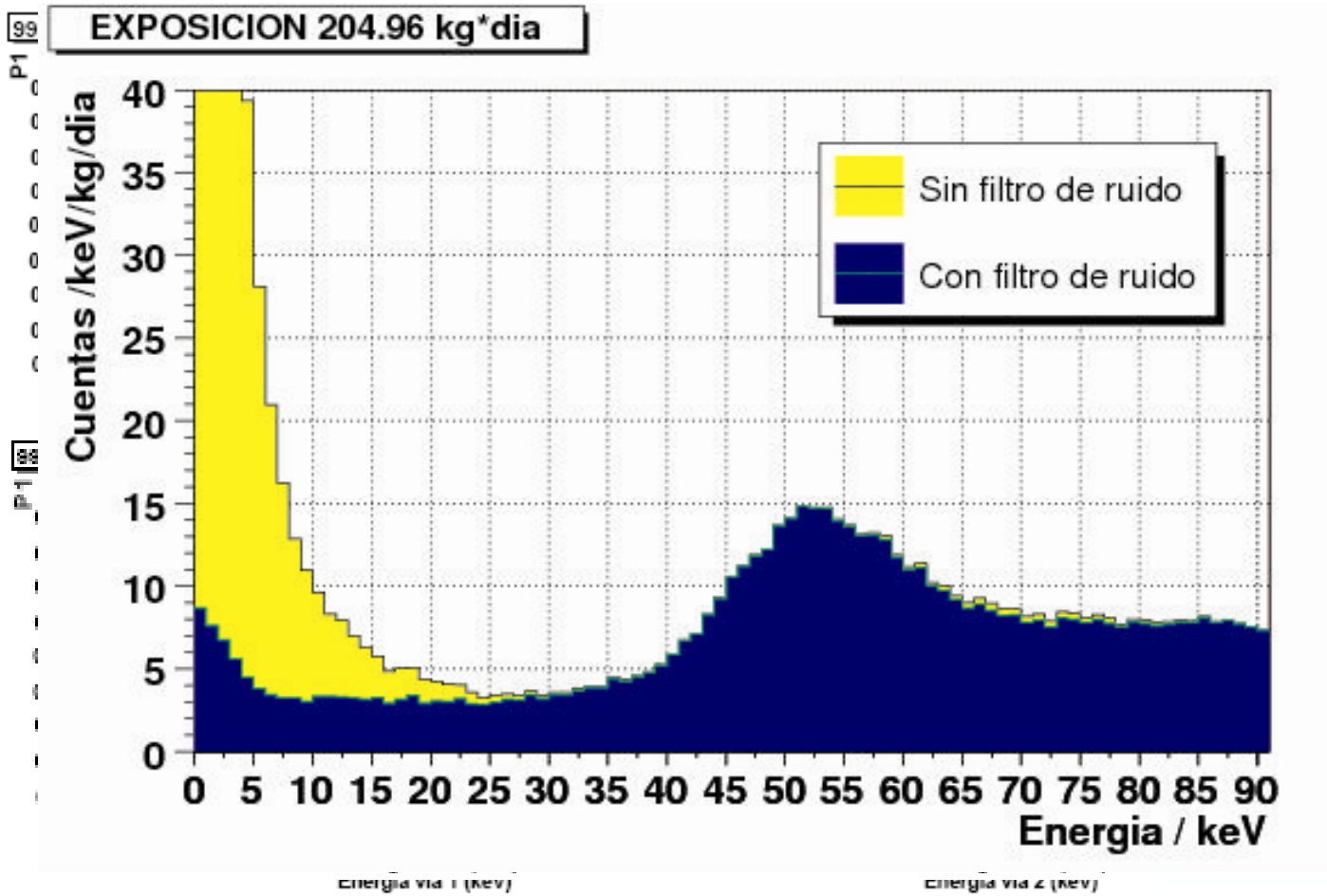
GTAW

PROTOTYPE II: Noise rejection

Trigger at photoelectron level implies noise in coincidence

Cuts applied down to 2 keV

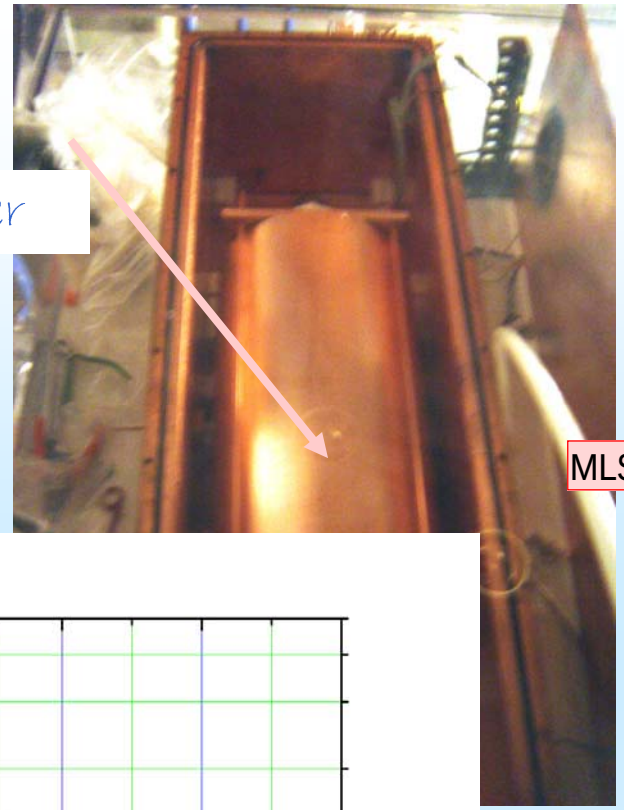
$$P1 = \frac{area(100-600\ ns)}{area(0-600\ ns)} \qquad P2 = \frac{area(0-50\ ns)}{area(0-100\ ns)}$$



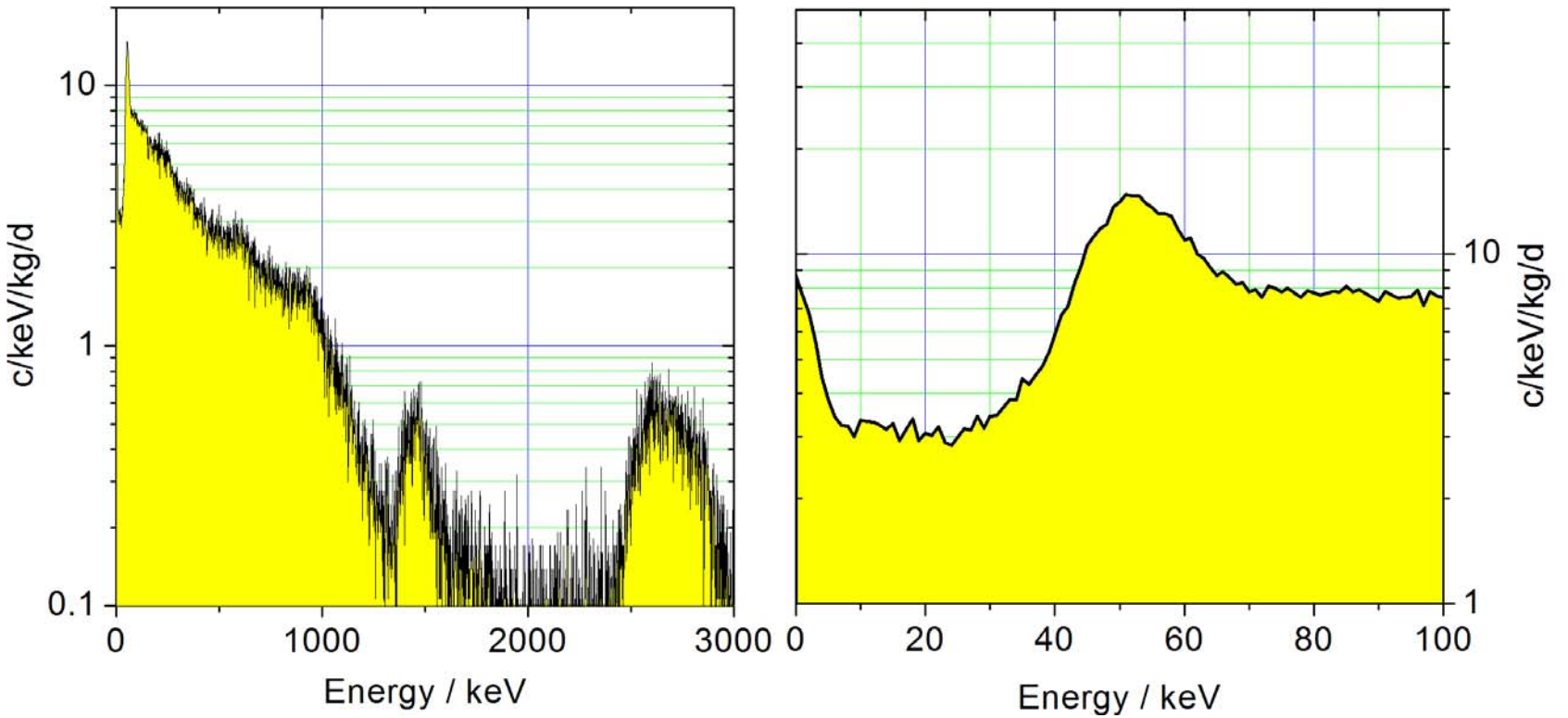
oration

kground

PROTOTYPE II: Canfranc measurements



Inner Cu shielding
Noise rejection

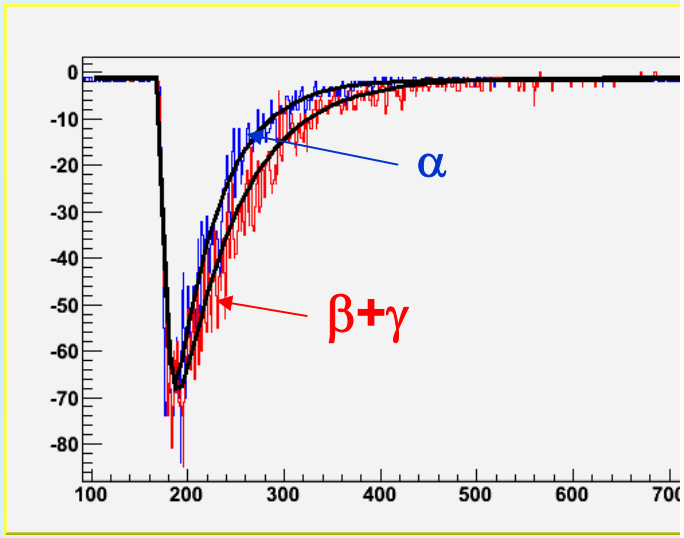


Diapositiva 45

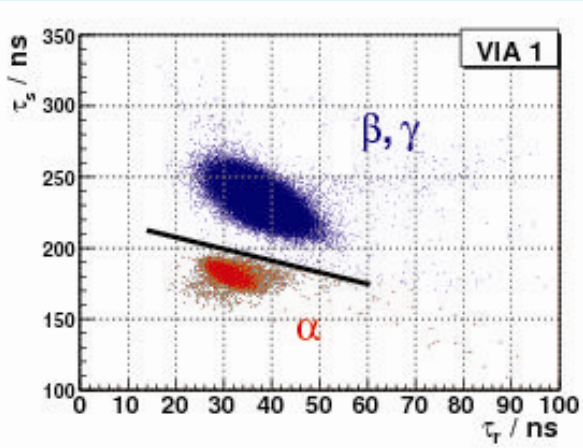
MLS7 Comparar el fondo con Cobre con el fondo antes de colocar el cobre

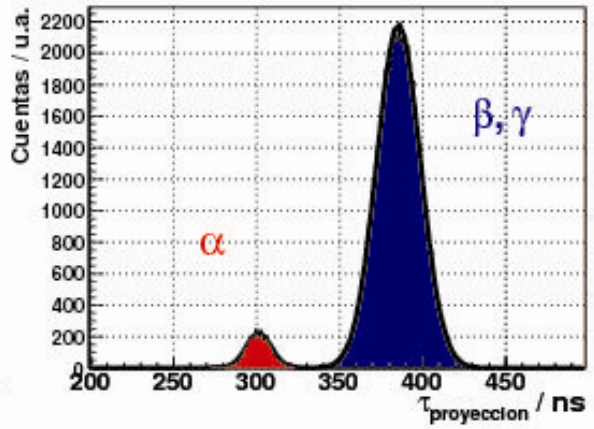
María Luisa Sarsa; 08/06/2006

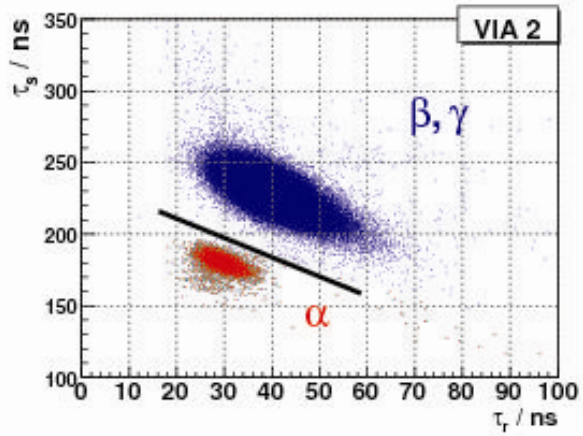
PROTOTYPE II: PSD for α discrimination

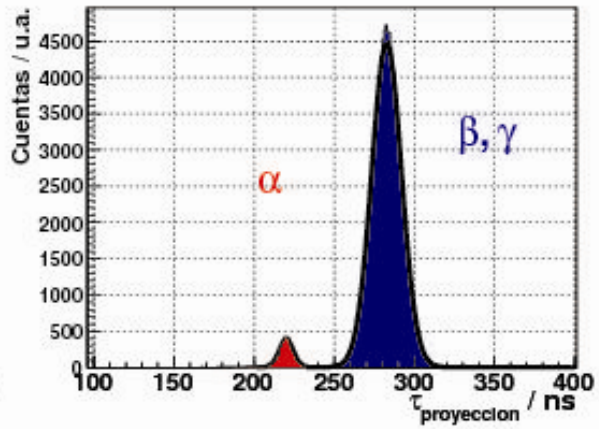


$$V(t) = \frac{-QR}{\tau_r - \tau_s}\left(e^{-t/\tau_s} - e^{-t/\tau_r}\right)$$

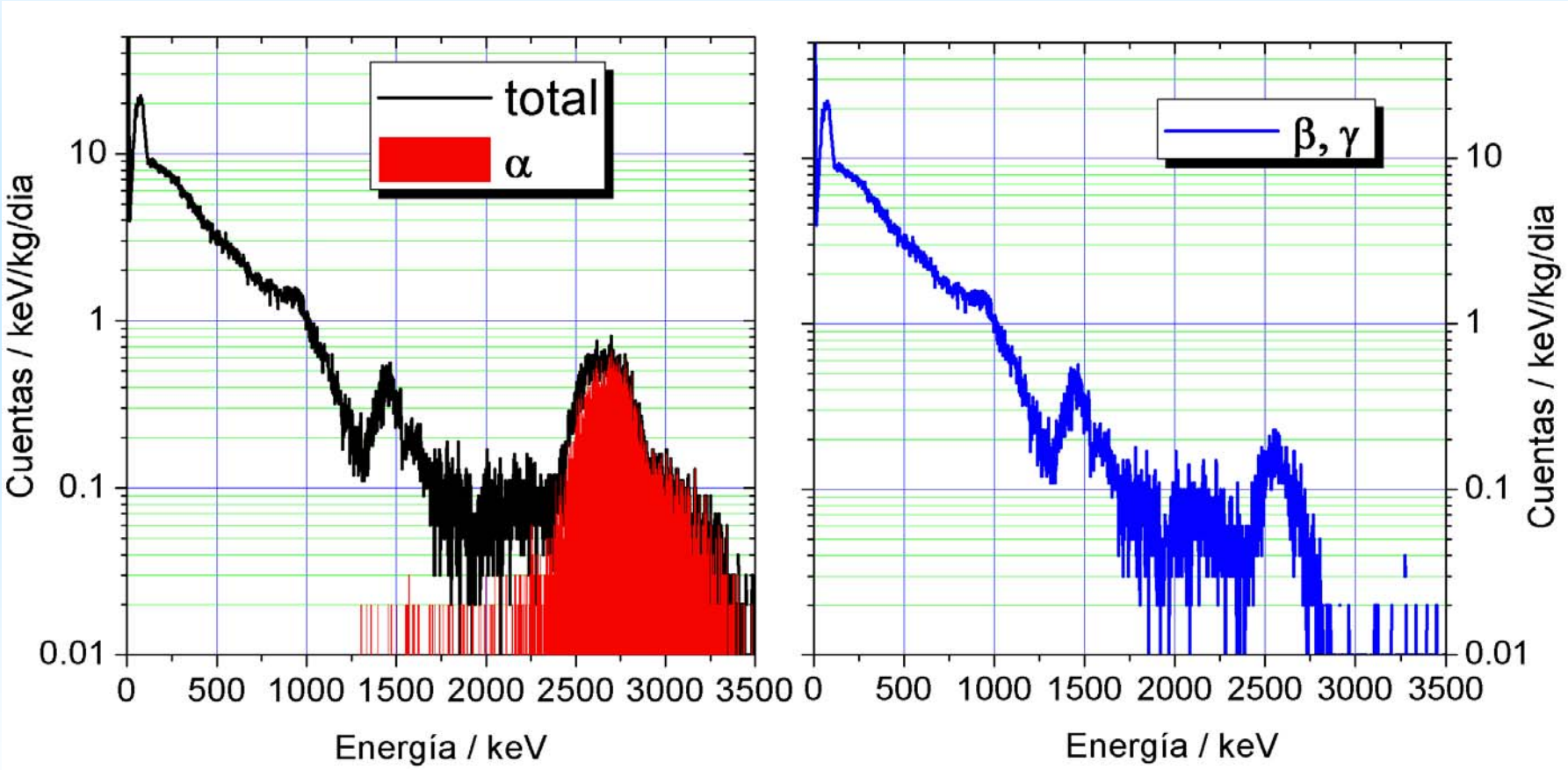








PROTOTYPE II: PSD for α discrimination

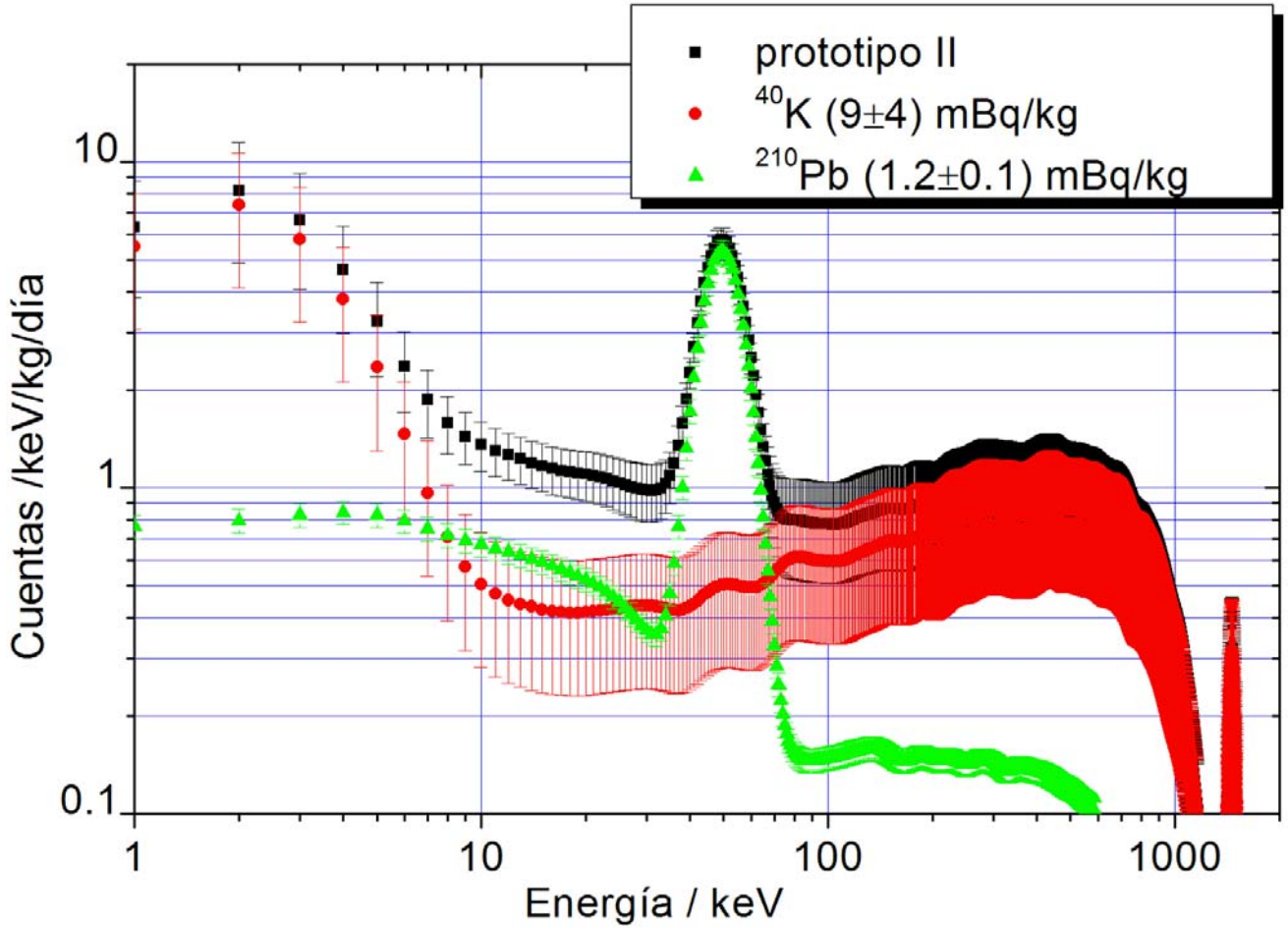


PROTOTYPE II: PSD for α discrimination

	Contamination (mBq/kg)	
Parent Isotope	PII	EP-058
^{238}U	0,017 ± 0,007	-
^{226}Ra	0,14 ± 0,01	0,22 ± 0,05
^{210}Pb	1,2 ± 0,1	0,54 ± 0,12
^{232}Th	0,027 ± 0,007	-
^{228}Ra	0,07 ± 0,02	0,021 ± 0,006

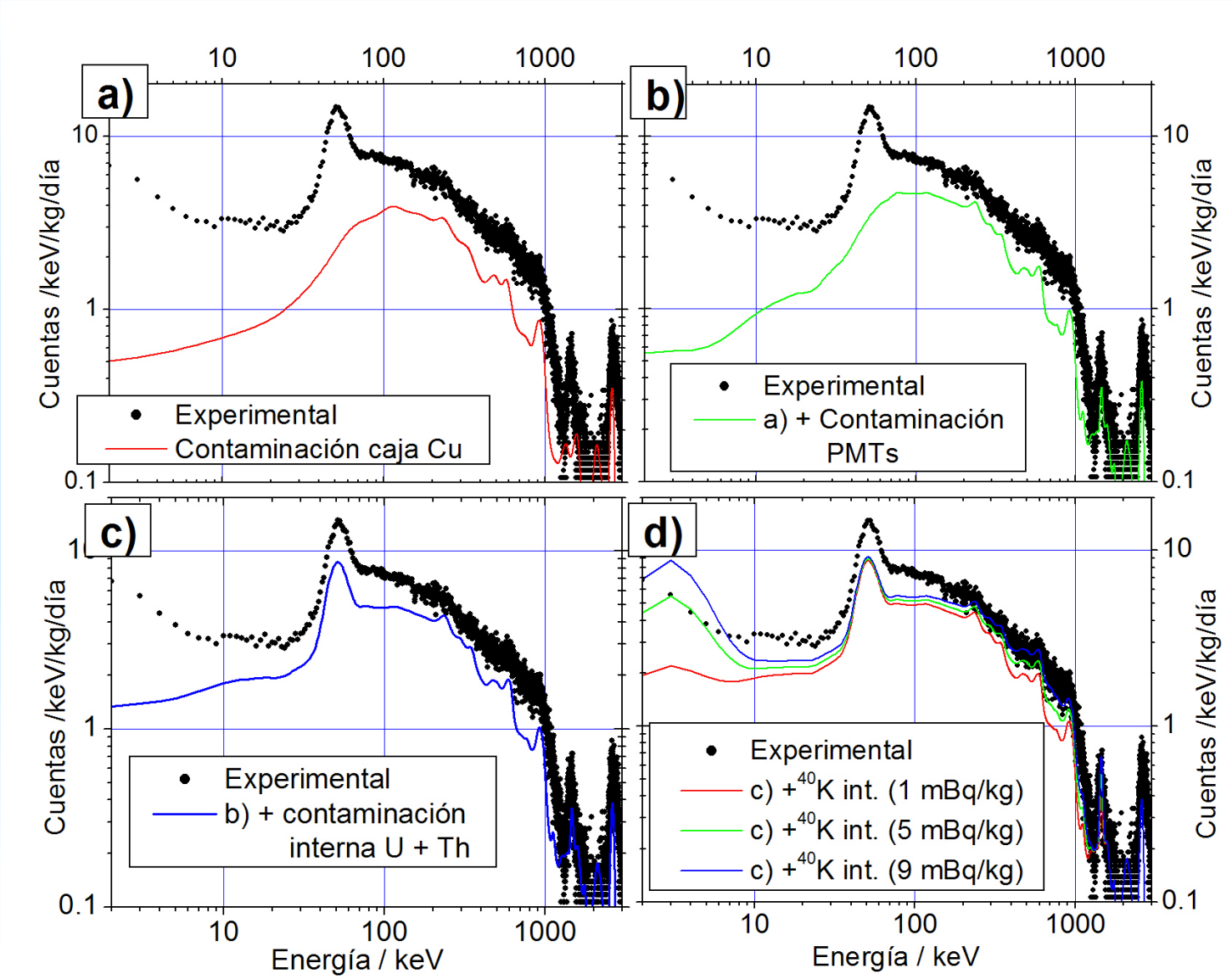
PROTOTYPE II: PSD for α discrimination

GEANT-4 Simulation of internal U-Th-Pb-K

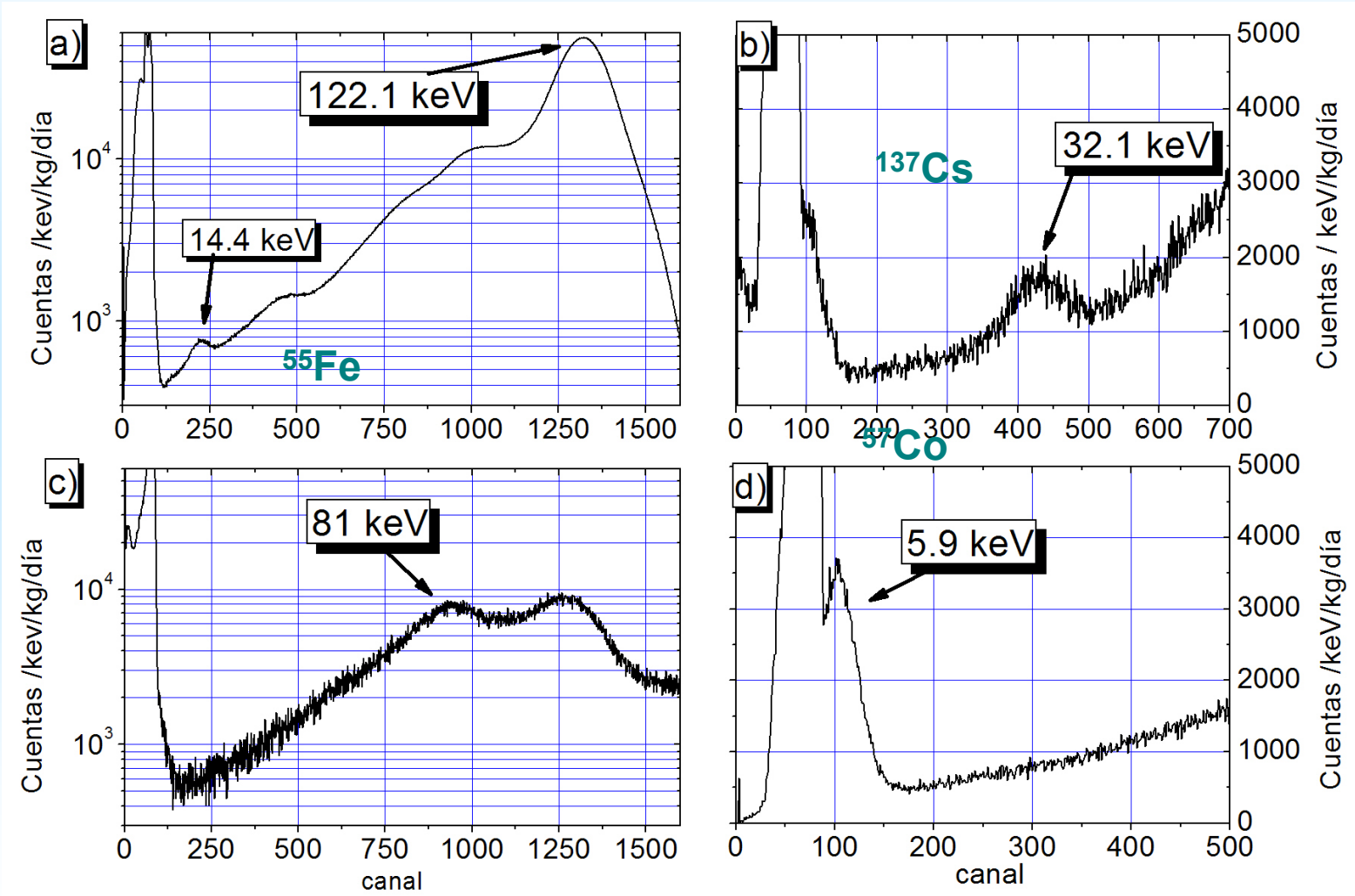


^{40}K has been assumed to be completely of internal origin

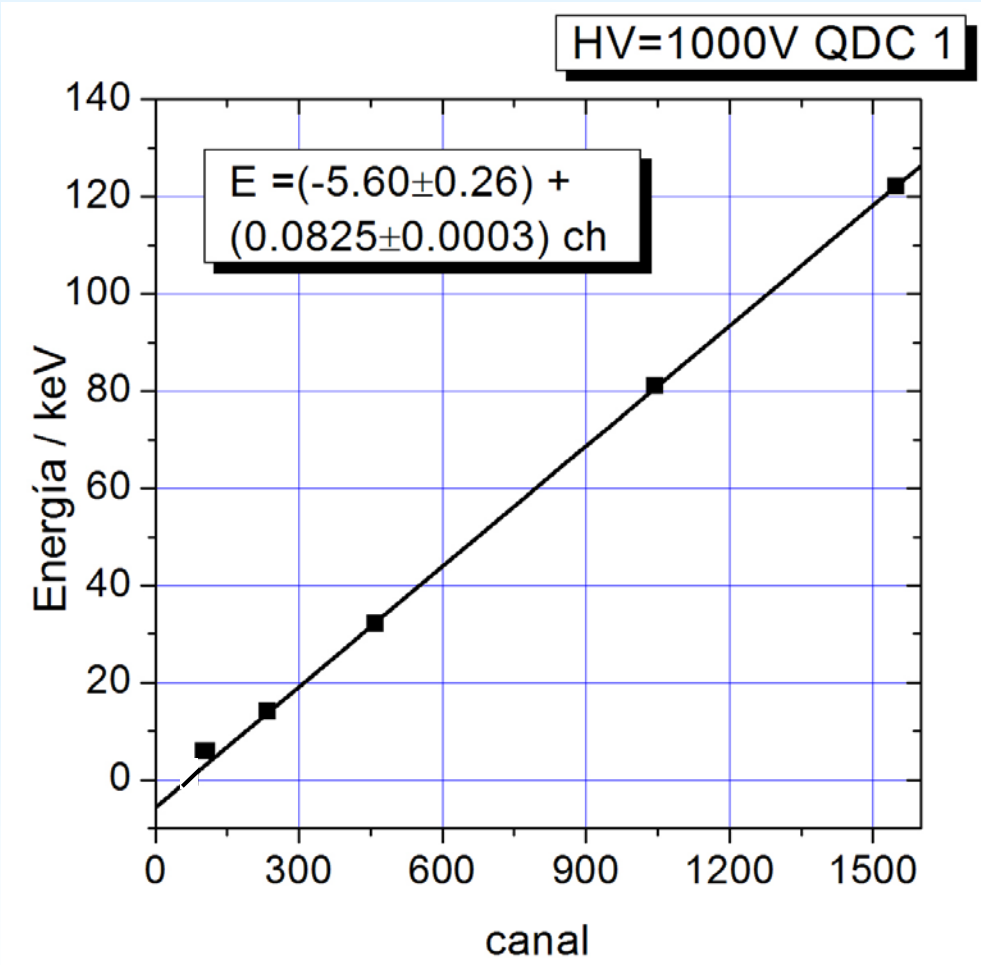
Background understanding



Low Energy calibration



Low Energy calibration

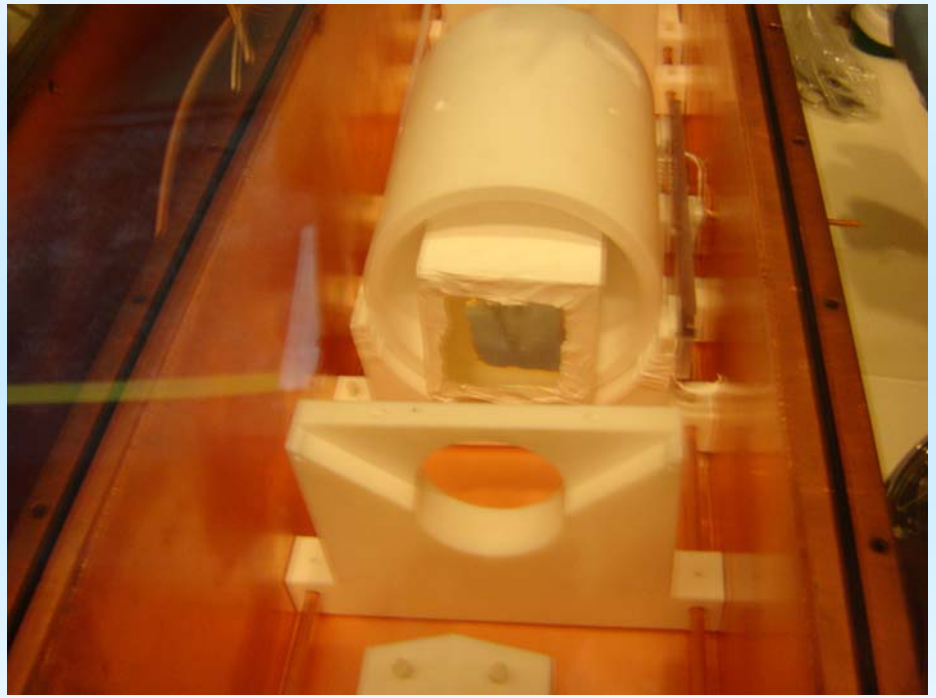


Aprox. linear behaviour down to 14.4 kev

6 kev line from ^{55}Fe at lower energies than extrapolation

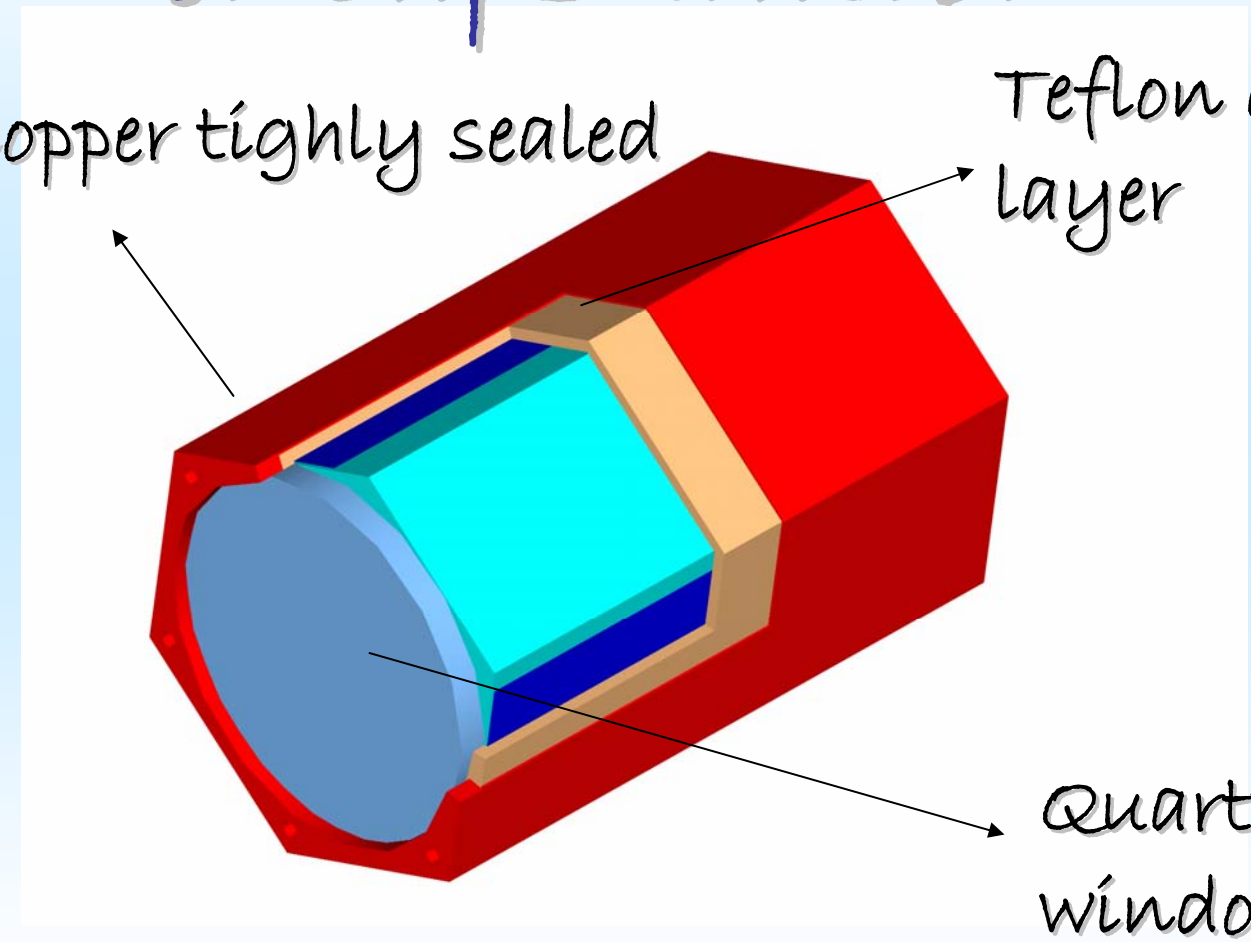
Superficial effects can be responsible

New NaI(Tl) 9,6 kg crystal

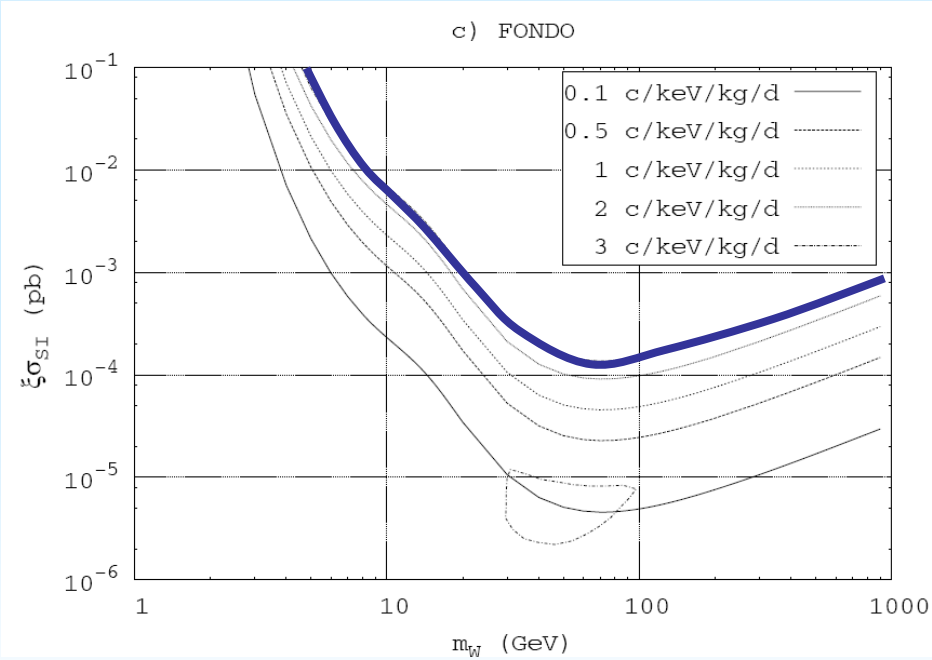


Last week mounting in Canfra

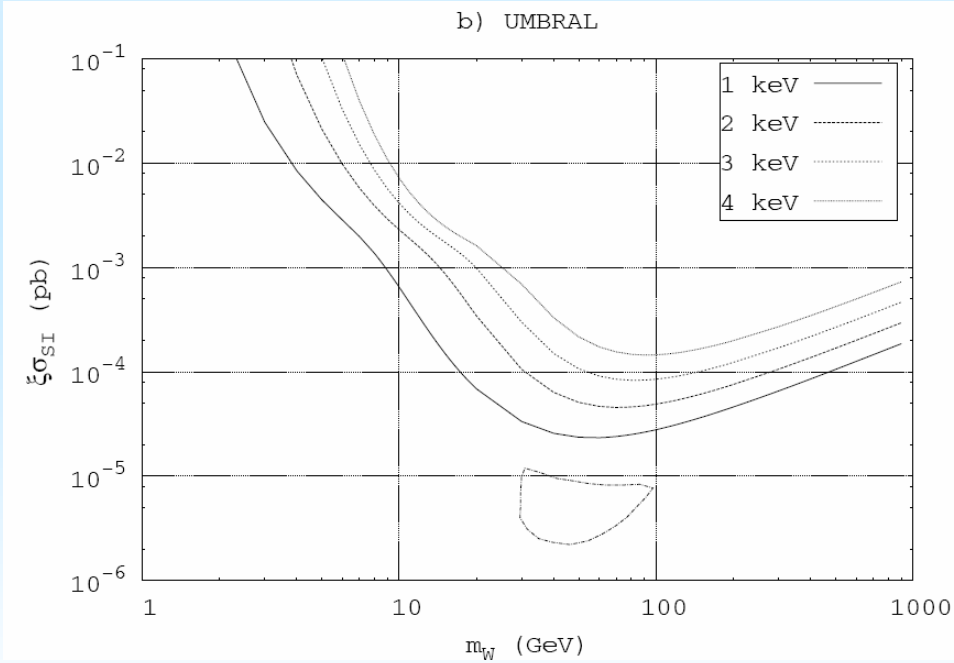
Design of a new encapsulation



Exclusion plots in different scenarios without modulation search (90%CL)

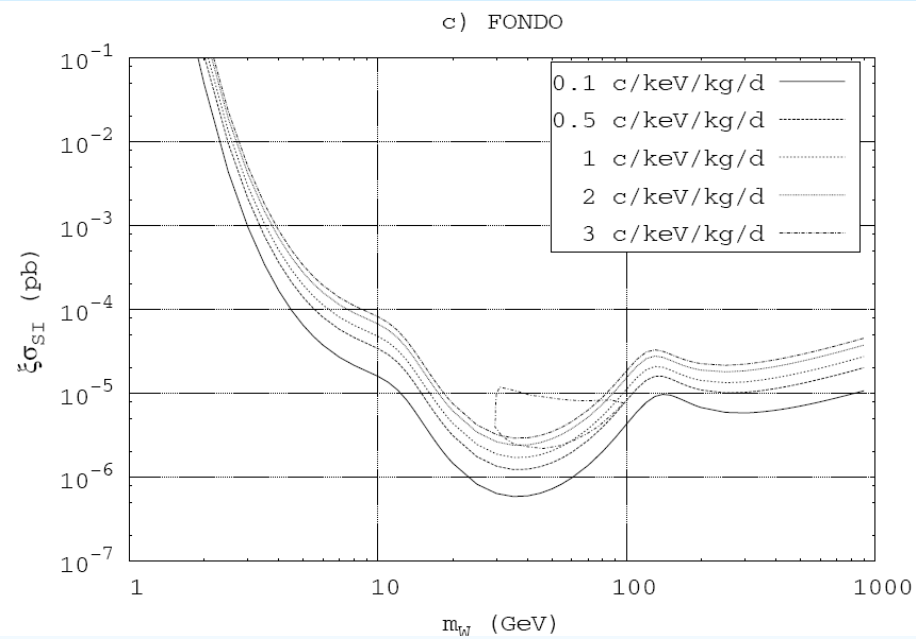


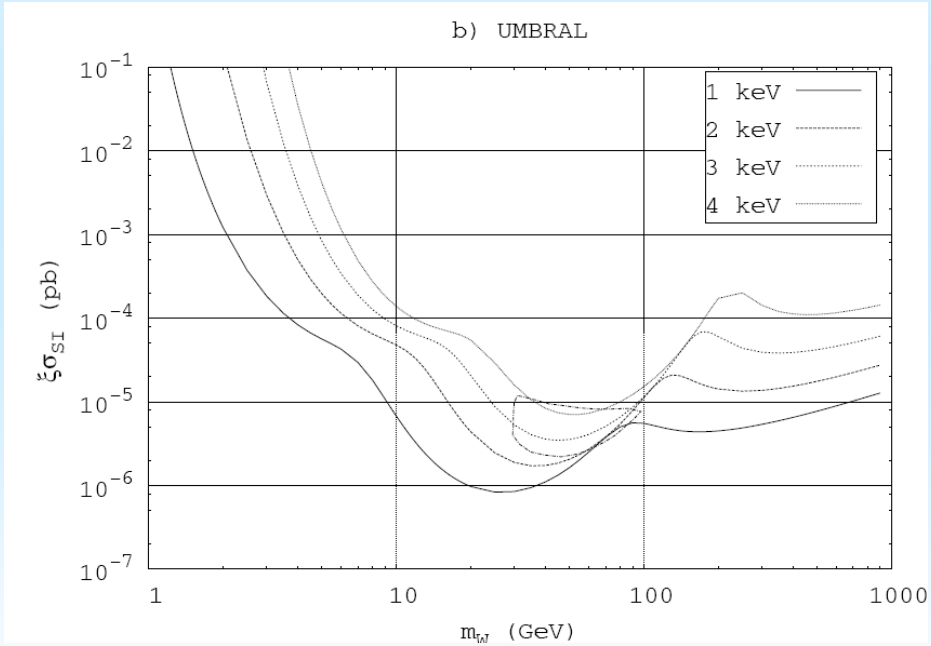
2-8 keV energy window
5x107 kg.yr exposure



1 c/keV/kg/d
5x107 kg.yr exposure

Expected sensitivity for a dark matter modulated signal in different scenarios (δ^2=5.6, Astrop. Phys. 14 (2001) 339)





2-8 keV energy window
5x107 kg.yr

1 c/keV/kg/d
5x107 kg.yr

ANAIS PROSPECTS

-New copper encapsulation in preparation

- 9,6 kg radiopure crystal to be tested in the PROTOTYPE II set up (taking data)

- PMT tests (background and response)

-Alpha PSD measurements to select the best crystals among available

-Main limitation seem to come from internal contaminants: ^{40}K requires more study

-2 keVee threshold achieved (further calibration)

- Optimized shielding conditions in the new LSC for Prototype III

Ionization

COSME, IGEX-DM

Ge

U. Zaragoza / South Carolina / PNNL / INR / ITEP Collaboration

Light

DM32, ANAIS

NaI

U. Zaragoza

CANFRANC EXPERIMENTS WIMP detection techniques

TPC MICROMEGAS

Heat

ROSEBUD-I / II

Al_2O_3 Ge

U. Zaragoza / IAS Orsay Collaboration

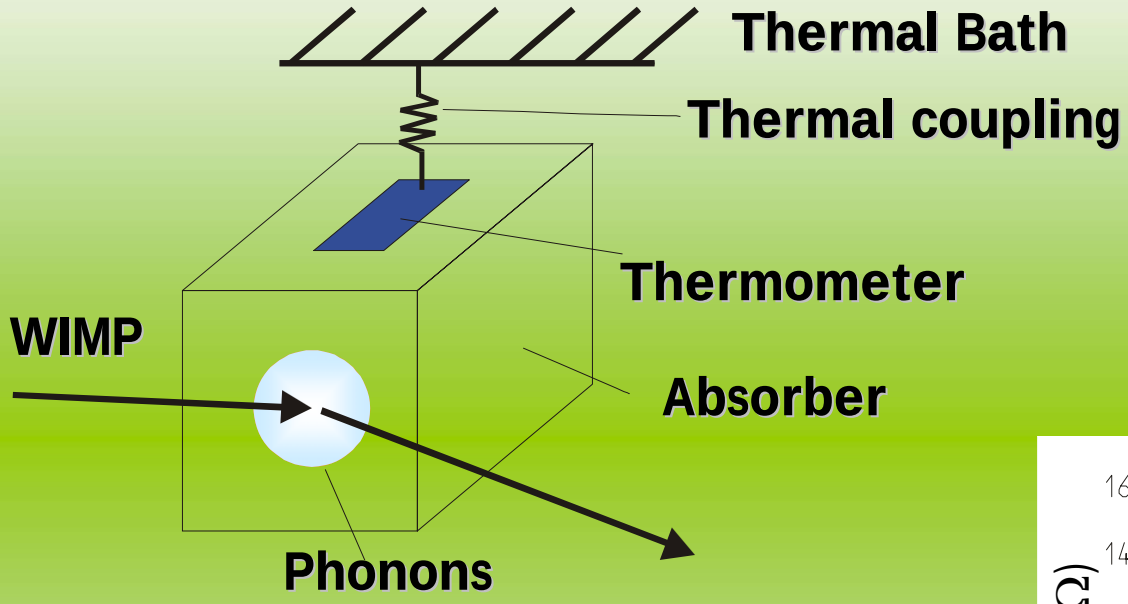
Light+Heat

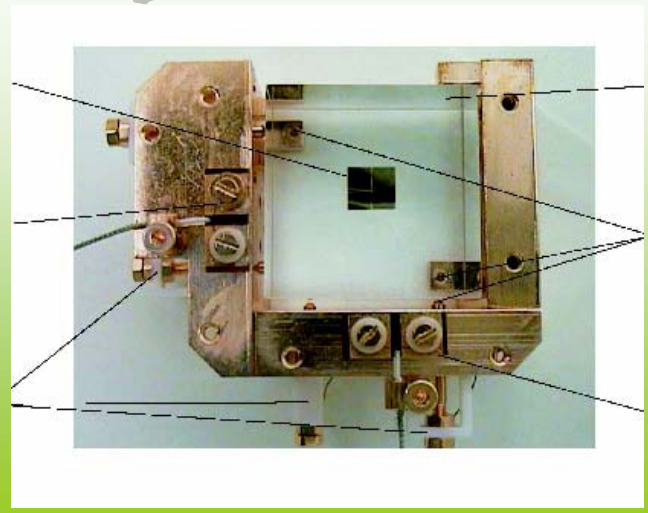
ROSEBUD-II / III

$CaWO_4$ BGO **Al_2O_3**

U. Zaragoza / IAS Orsay Collaboration

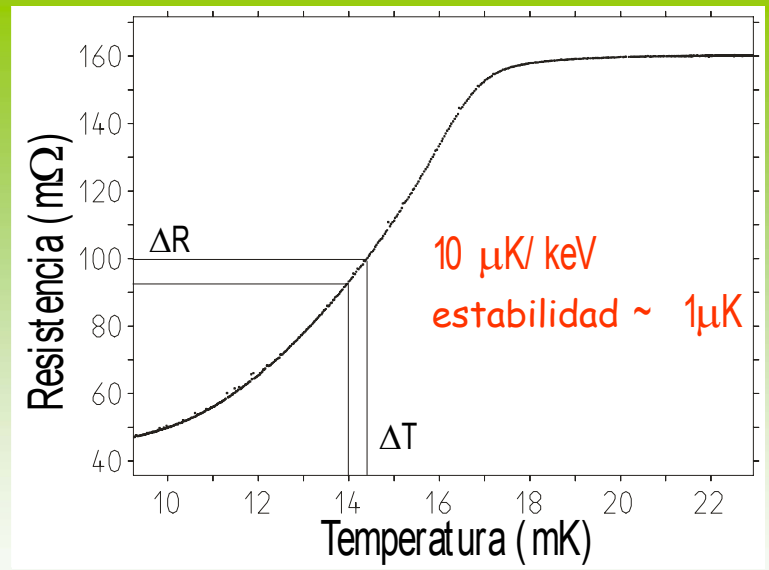
Bolometric detection





$$\Delta E = T_{recoil}$$

$$\Delta T \cong \frac{\Delta E}{C} \quad \begin{cases} C = \alpha T^3 \\ C = \alpha T^3 + \beta T \end{cases}$$



WIMP searches with bolometers

- Wide absorber choice
- Quenching factors seem to be compatible with 1
- Very low energy thresholds
- Discrimination capabilities event by event increase dramatically sensitivity:
  - CHARGE VS HEAT / LIGHT VS HEAT
- Large mass experiments in preparation: feasible

ROSEBUD Collaboration

Rare Objects SEarch with Bolometers UnDerground

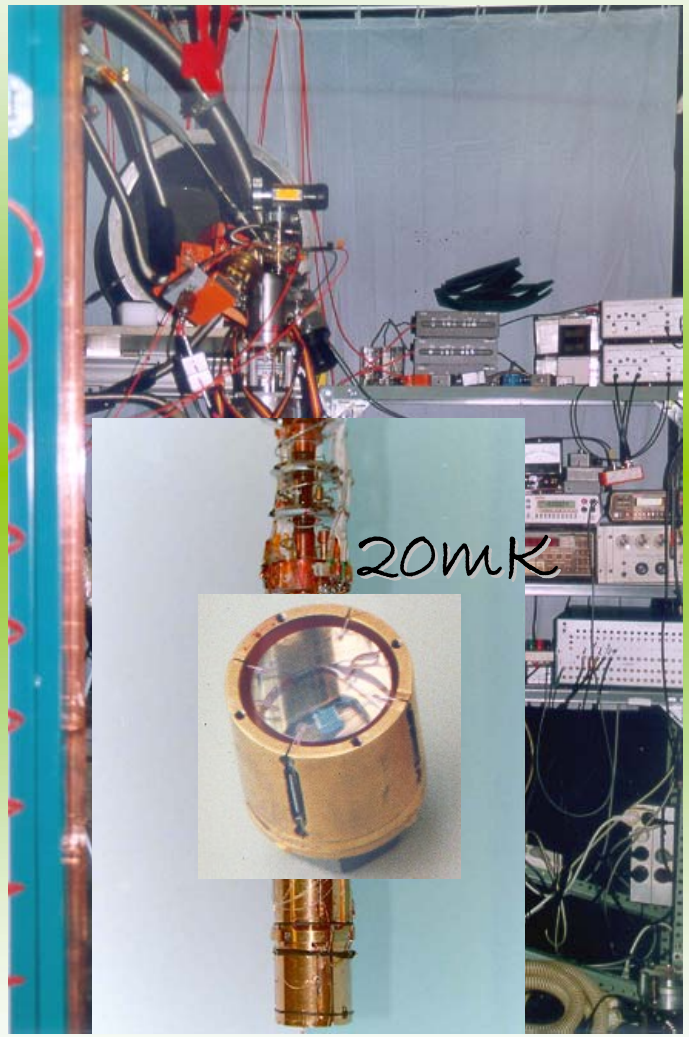
J. Amaré, B. Beltrán, J. M. Carmona, S. Cebrián, E. García, H. Gómez, I. G. Irastorza, G. Luzón, M. Martínez, J. Morales, A. Ortiz de Solórzano, C. Pobes, J. Puimedón, A. Rodríguez, J. Ruz, M. L. Sarsa, L. Torres, J. A. Villar

University of Zaragoza

N. Coron, G. Dambier, J. Leblanc, P. de Marcillac, T. Redon

Institute d'Astrophysique Spatiale, ORSAY

ROSEBUD



Since 1997

Devoted to the search for galactic halo WIMPs at LSC with bolometric techniques

- Phase I (1999-2000): Al_2O_3 (25 g and 50g)
  - ✓ Understanding and reduction of the background

Astrop. Phys. 15 (2001) 79

ROSEBUD

Phase II (since 2000):

Al_2O_3 (50 g), Ge (67 g), $CaWO_4$ (54 g) + Ge (optical bolometer) in the same experimental set-up

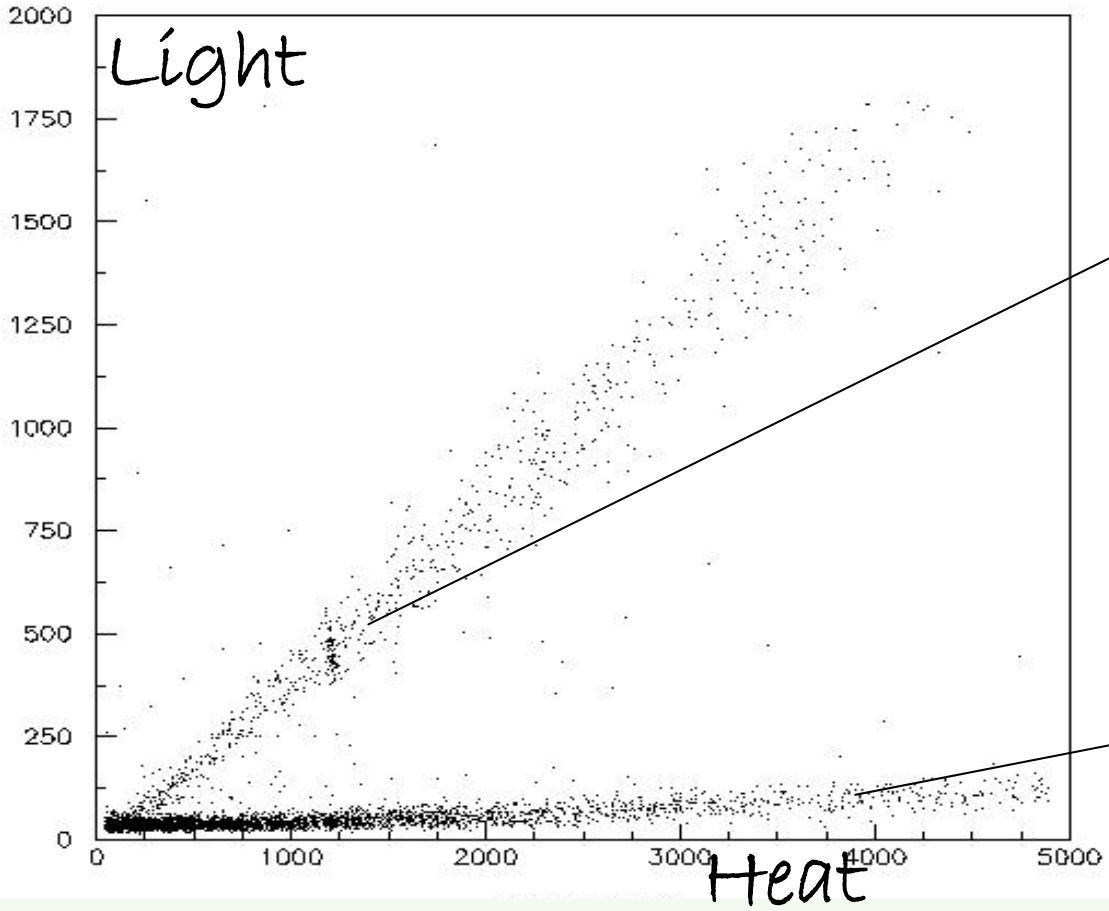
- ✓ First light vs heat discrimination technique implemented deep underground

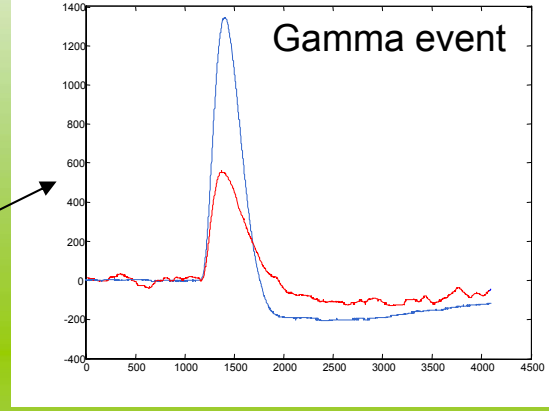
  Phys. Lett. B 563 (2003) 48

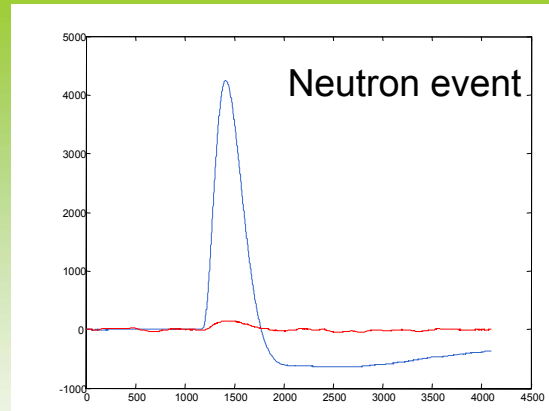
- ✓ First low background experiment using 3 different absorbers in the same set-up (to explore target dependence of the DM signal)

  Astrop. Phys. 21 (2004) 23

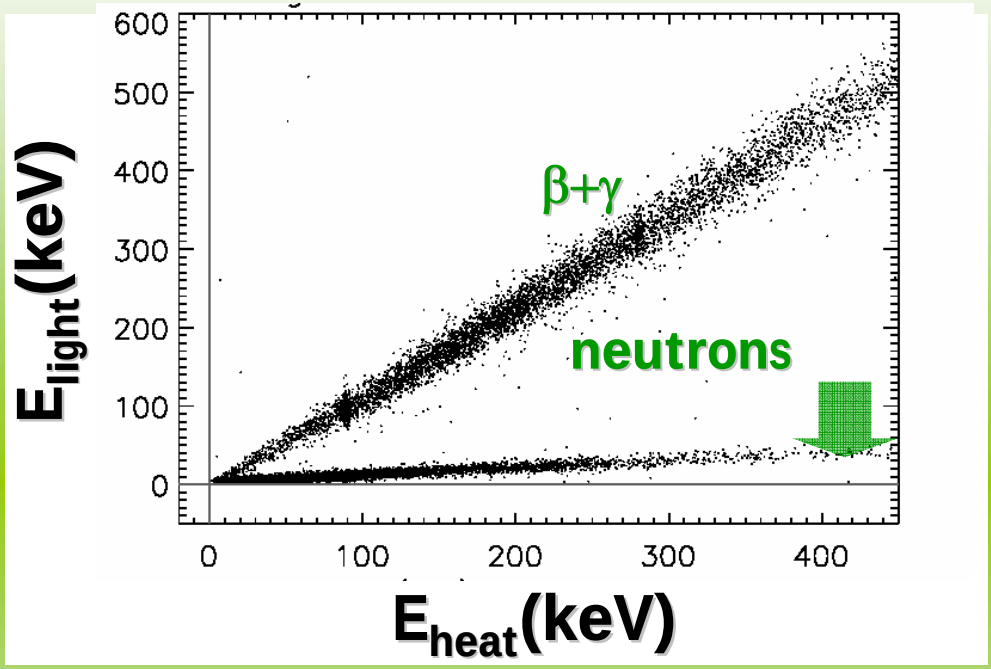
Background discrimination: light vs heat



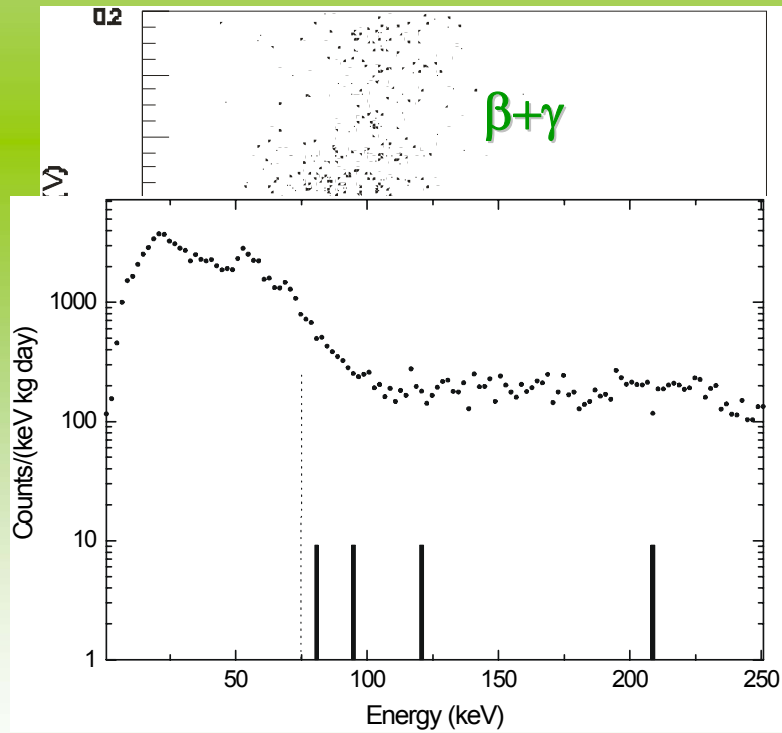




ROSEBUD phase II: $CaWO_4$



^{252}Cf calibration @ IAS Orsay



Background @ Canfranc

T=24,2h

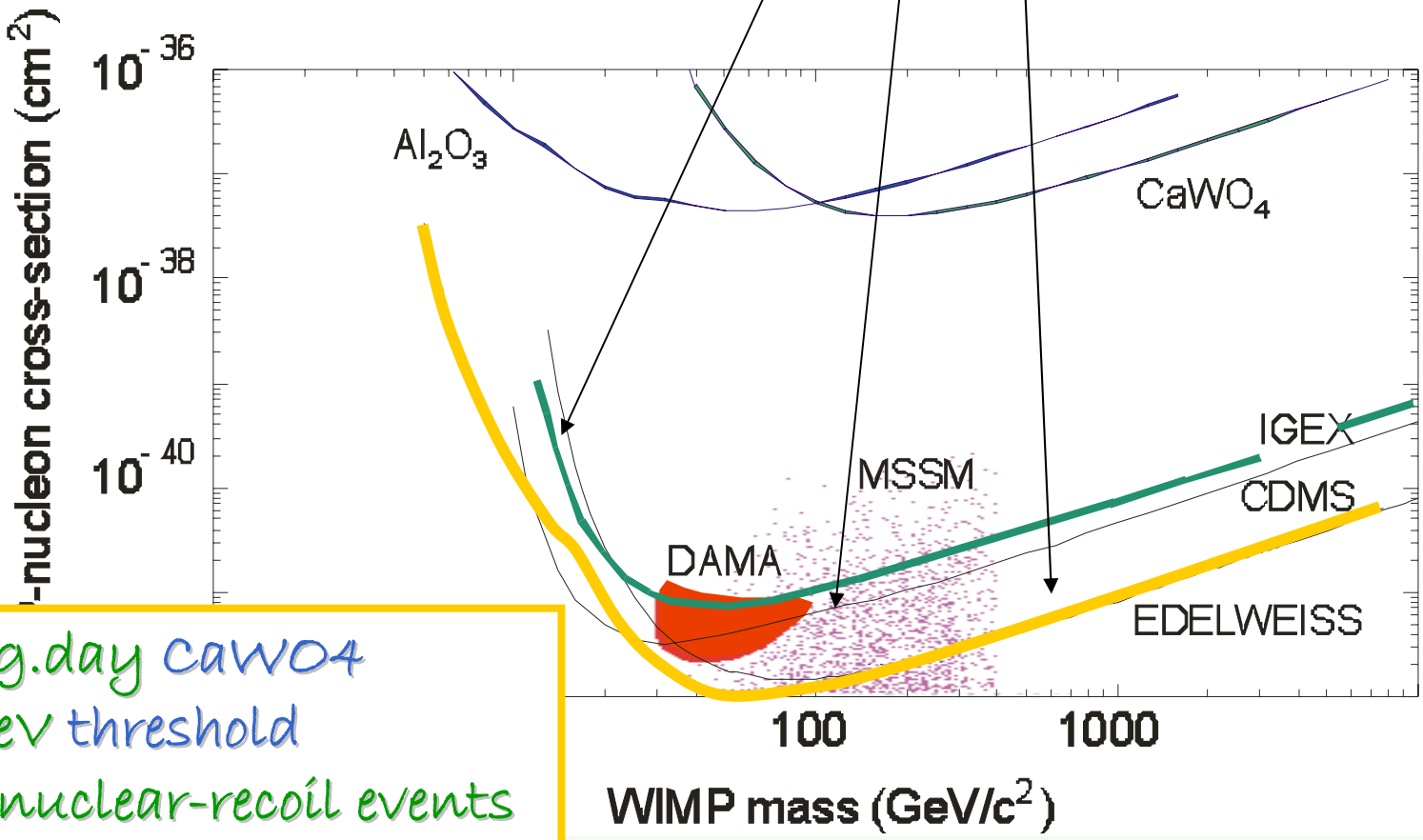
M=54g

Results and Prospects

A. Morales et al., Phys. Lett. B 556 (2003) 14

D. Abrams, et al., Phys. Rev. D 66 (2002) 122003

A.Benoit et al., Phys. Lett. B 545 (2002) 43



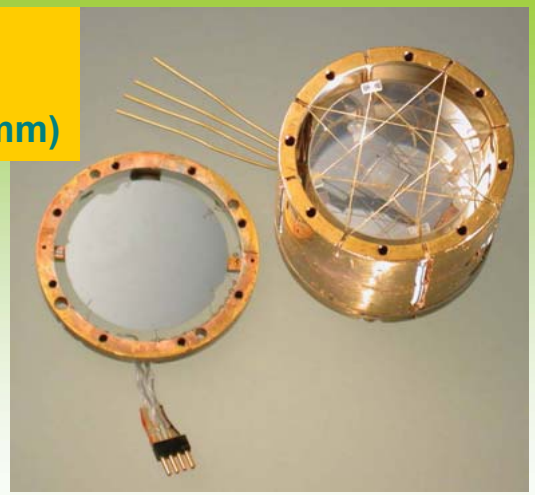
10 kg.day CaWO4
10 keV threshold
zero nuclear-recoil events

On the search for new scintillating materials (IAS)

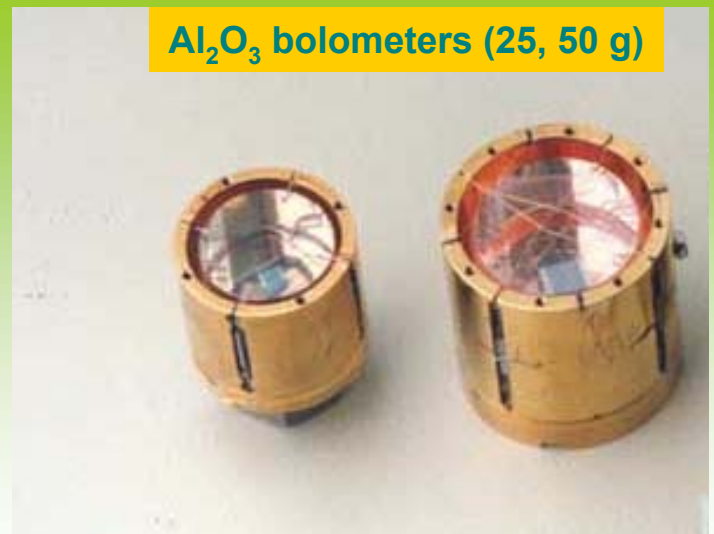
Scintillation at 20 mK detected for:

- Crystals: YAP:Ce, GSO:Ce, CaF_2:Eu, Al_2O_3:Ti
- Bolometers: $CaWO_4$, BGO, LiF, TeO_2, Al_2O_3, SrF_2, SiO_2

BGO (91 g) and Ge light detector (Ø= 25 mm)



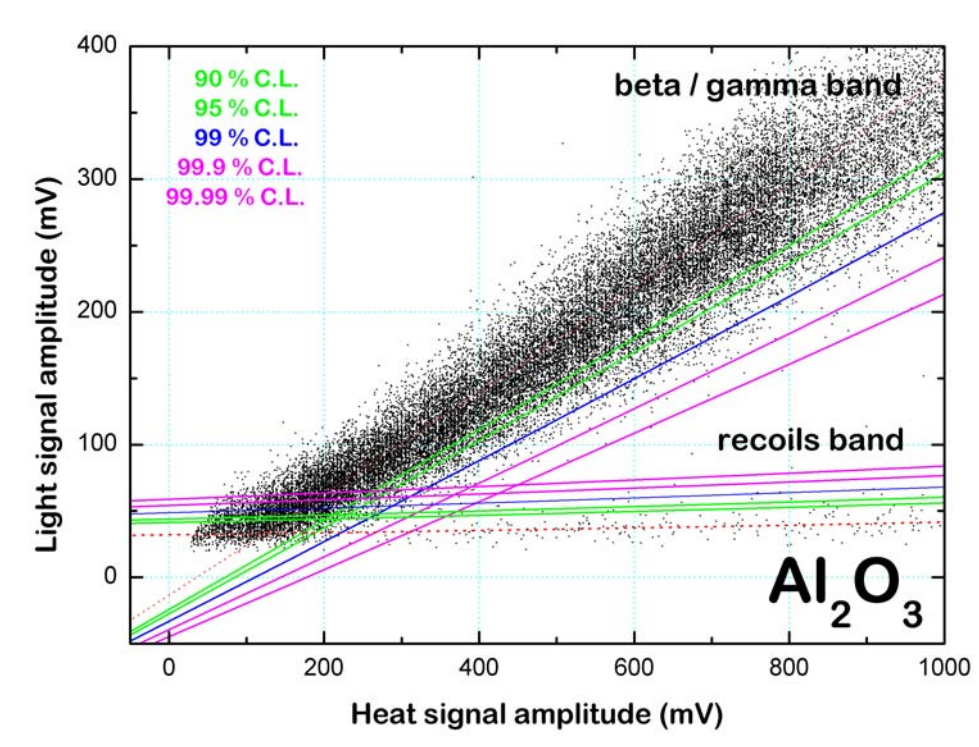
Al_2O_3 bolometers (25, 50 g)



Next DM run at LSC: BGO and Al_2O_3

Sapphire (Al_3O_2)

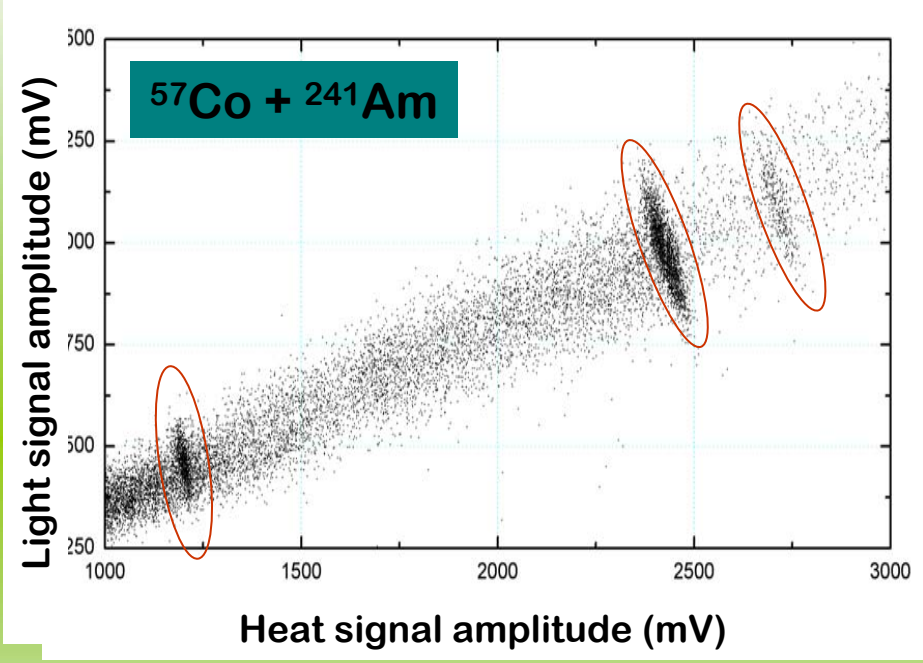
promising candidate to explore low WIMP masses



E_{th} for particle discrimination

C.L (1 tailed)	E (keV)
90 %	8.7
95 %	10.0
99 %	13.0
99.9 %	17.1
99.99 %	21.3

Light yield of undoped sapphire at 20 mK

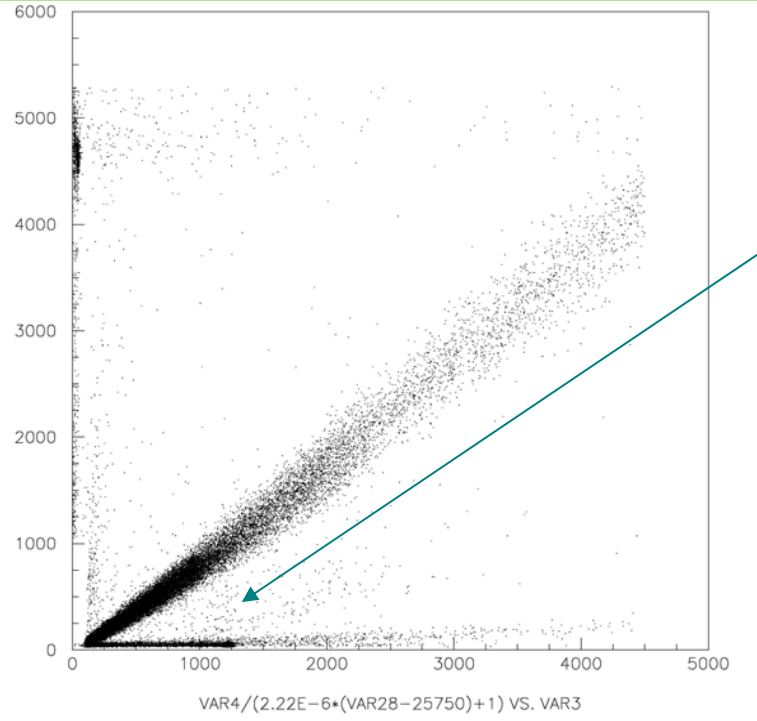


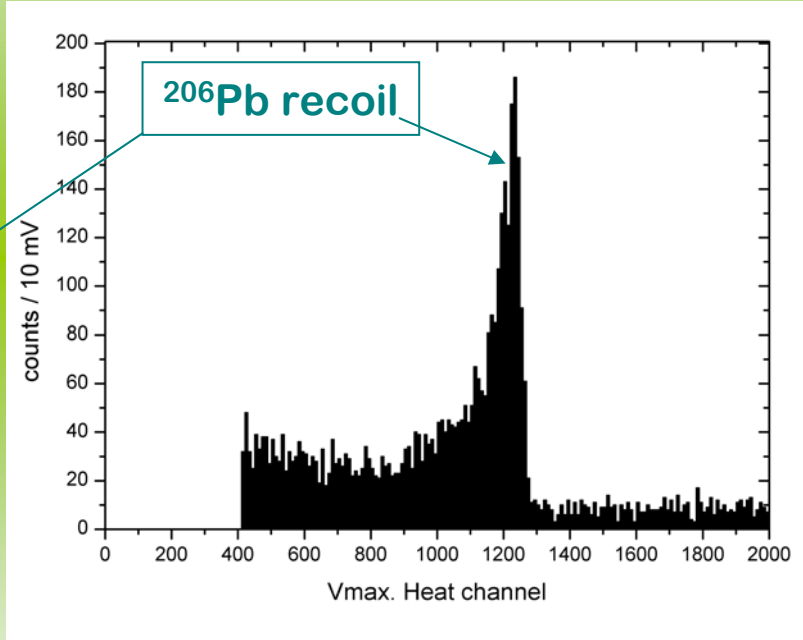
Applied Physics Letters 87 (2005)

Absolute mean light yield estimate of sapphire	
β / γ	0.127 ± 0.010
α	0.012 ± 0.005
n	0.0073 ± 0.0010

Heat signal REF in sapphire

External ^{210}Po source emitting α particles and ^{206}Pb recoils

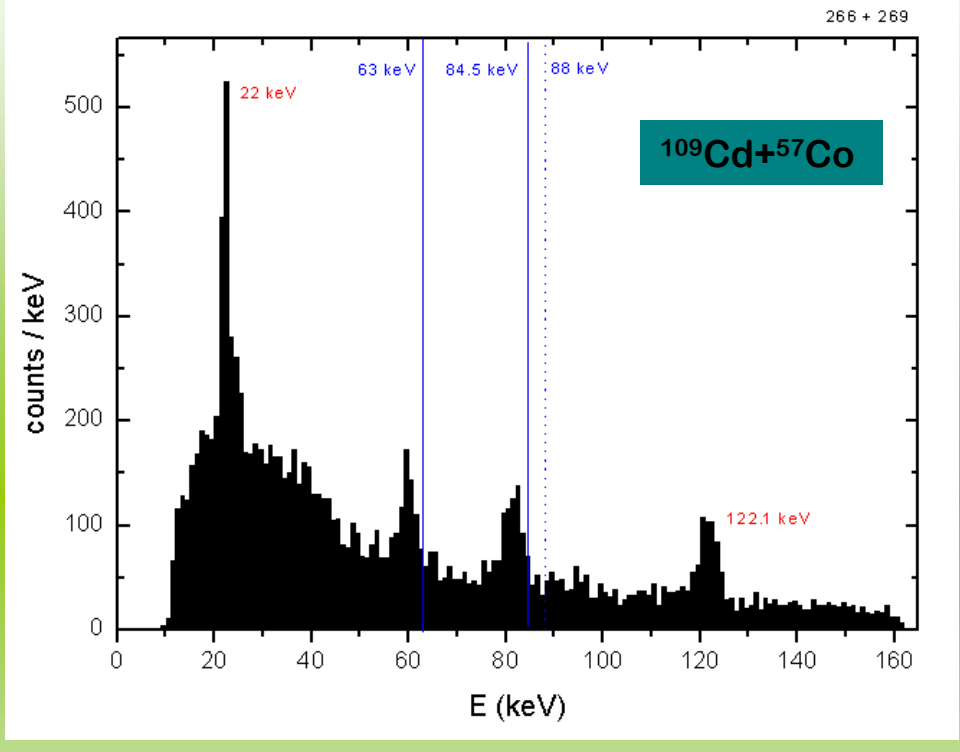




PRELIMINARY

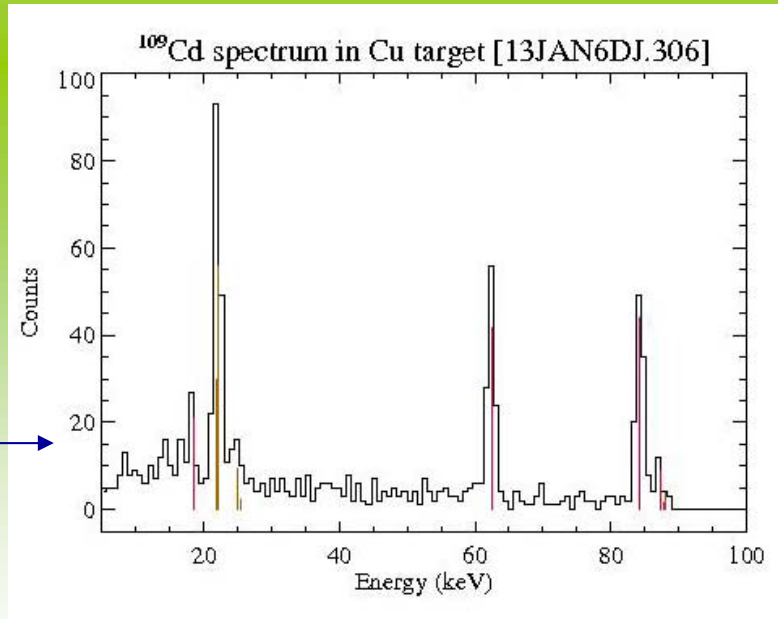
REF (γ : ^{206}Pb recoils) 1.0

Superficial effects in sapphire



E_e = 62.5 keV → 60 keV

E_e = 84 keV, E_e = 87 keV → 81.7 keV

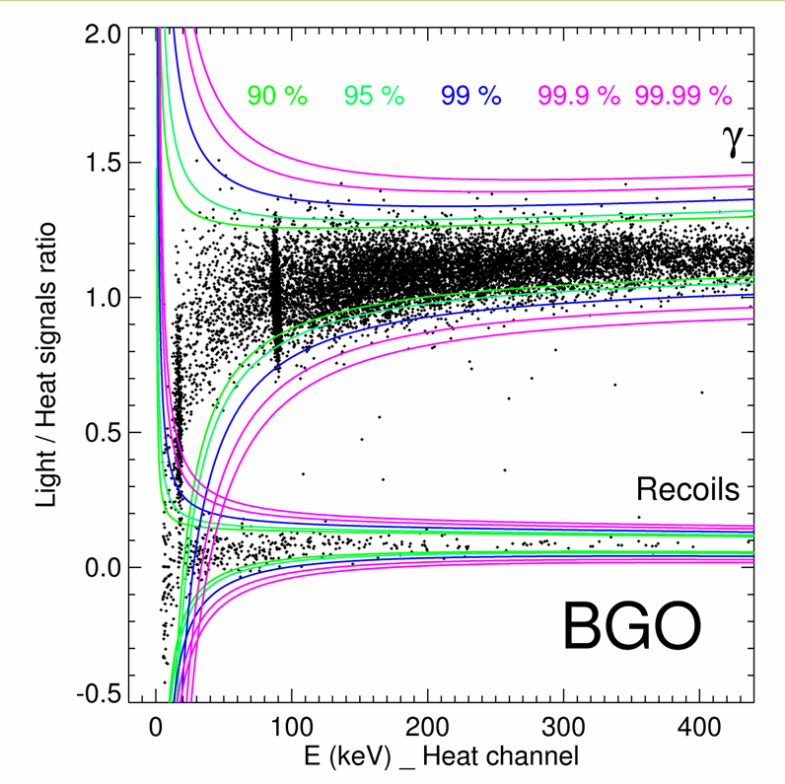


Self-degradation in the source (unclean) is discarded by calibration on Cu bolometer

Next DM run at LSC: BGO and Al_2O_3

BGO ($Bi_4Ge_3O_{12}$):

Interest for WIMP searches: ^{209}Bi $\uparrow A \Rightarrow \uparrow\sigma_{SI}$; $J = 9/2 \Rightarrow \uparrow\sigma_{SD}$



- Relative light output factor :

  Q (recoils : α : γ / β) = 1 : 2.6 : 15

- Particle discrimination threshold:
  - 90% CL at E > 23 keV
  - 99.99% CL at E > 51 keV

Prospects

- Dark matter run at LSC using BGO and sapphire bolometers as absorbers. Goal 15 keV for BGO and 10 keV for sapphire recoil discrimination energy threshold.
- Collaboration with the University of Lisbon for using a dilution unit able to house larger mass bolometers (terms being discussed)
- Incorporation to the Cryogenic Dark Matter Search European Project EURECA (application under study)

Summary

- Searches for Dark Matter at the Canfranc Underground Laboratory are going on since 1990
  - Different techniques and targets
- ANAIS and ROSEBUD experiments will be installed at the new Canfranc facilites