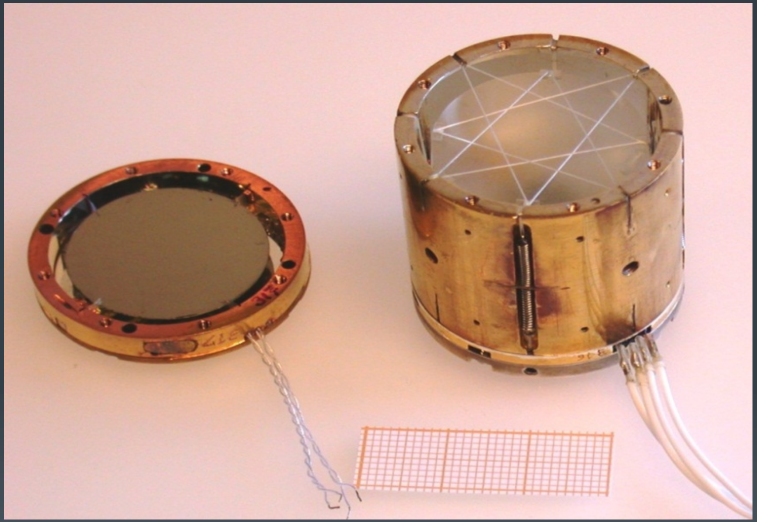
Bolometric experiments at the Canfranc Underground Laboratory



C. Ginestra, on behalf of the ROSEBUD collaboration

Reunión de la Red Nacional de Astropartículas, RENATA
Barcelona
November 2-4, 2011

CPAN
Ingenio 2010

Outline

- The ROSEBUD Collaboration
- Scintillating bolometers
- Particle discrimination
- Experimental set-up
- Main results:
    - Light & heat response to different particles
    - WIMP search prototypes
    - Neutron spectroscopy
- ROSEBUD at new LSC
- EURECA

The ROSEBUD Collaboration

Rare Object SEarch with Bolometers UndergrounD

http://www.unizar.es/lfnae/rosebud/

N. Coron, C. Cuesta, E. García, C. Ginestra, J. Gironnet, P. de Marcillac, M. Martínez, A. Ortiz de Solórzano, Y. Ortigoza, C. Pobes, J. Puimedón, T. Redon, T. Rolón, M.L. Sarsa, L. Torres and J.A. Villar.

Nuclear and Astroparticle Physics Group (GIFNA)
University of Zaragoza, Spain

Institut d'Astrophysique Spatiale (IAS)
Orsay, France

at Canfranc Underground Laboratory

The ROSEBUD Collaboration

Goals

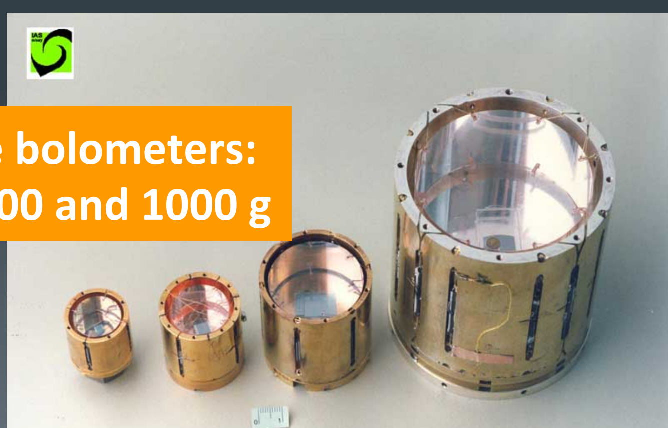
✓ Testing of particle detector prototypes in a low background environment.

✓ R&D line: characterization of scintillating materials at low temperature. All materials tested have shown scintillation at low temperature: $CaWO_4$, BGO, LiF, Al_2O_3 and SrF_2.

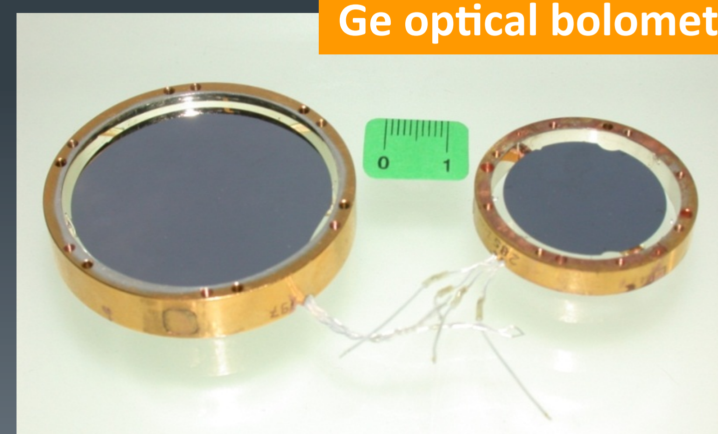
✓ Multi-target approach: use of scintillating bolometers of different materials in the same experimental set-up.

✓ Nuclear recoils discrimination against β/γ background through light + heat technique for WIMP search and nuclear physics.

✓ Scintillating bolometers for fast and slow neutron detection



Sapphire bolometers: 25, 50, 200 and 1000 g



Ge optical bolometer

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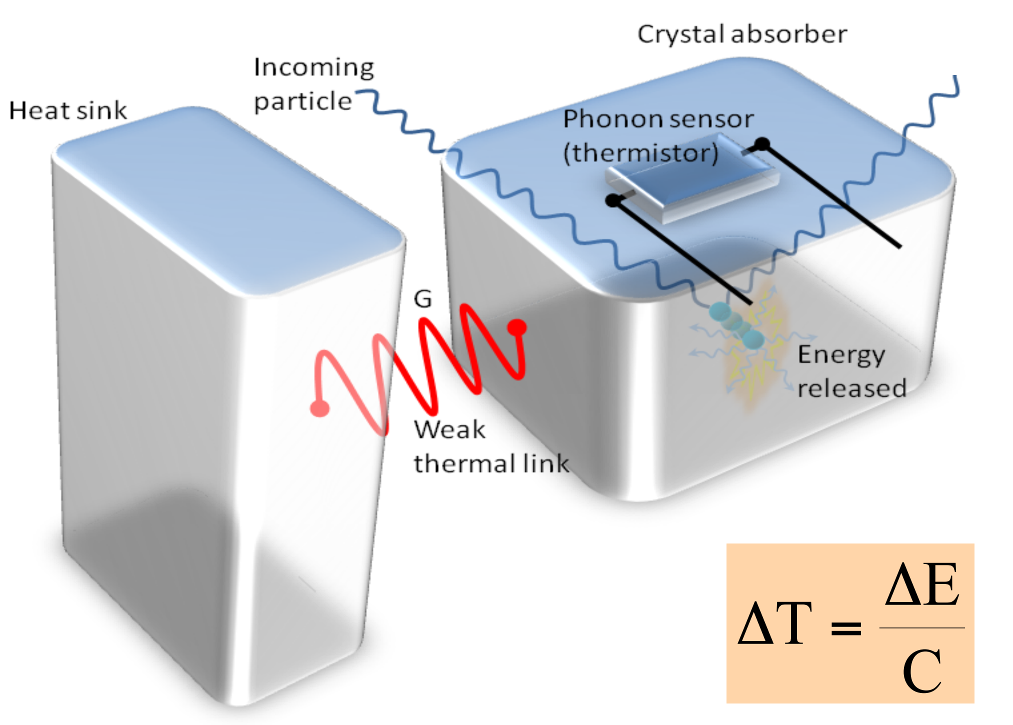
Scintillating bolometers
Simple bolometer model

Thermal model of a simple bolometer



$$\Delta T = \frac{\Delta E}{C}$$

Advantages of bolometers

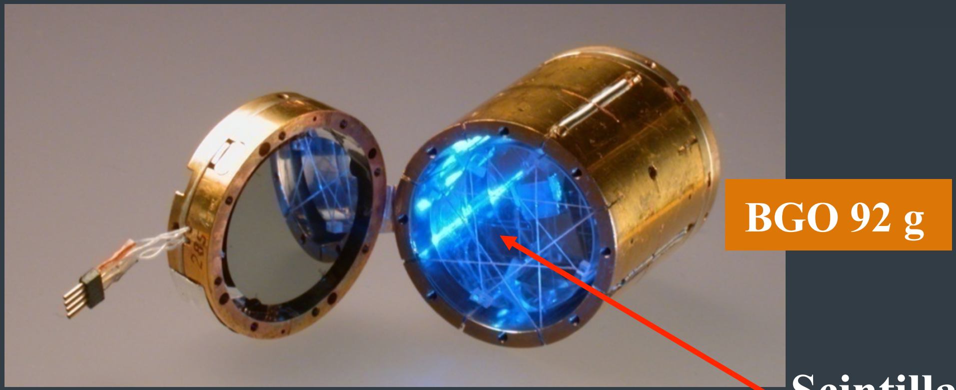
1. Wide choice of absorber materials.
2. High energy resolution.
3. Low energy threshold for particle detection.
4. Particle identification capability in hybrid measurements of heat-light or heat-charge.

$$C = \alpha \left(\frac{T}{\theta_D} \right)^3$$

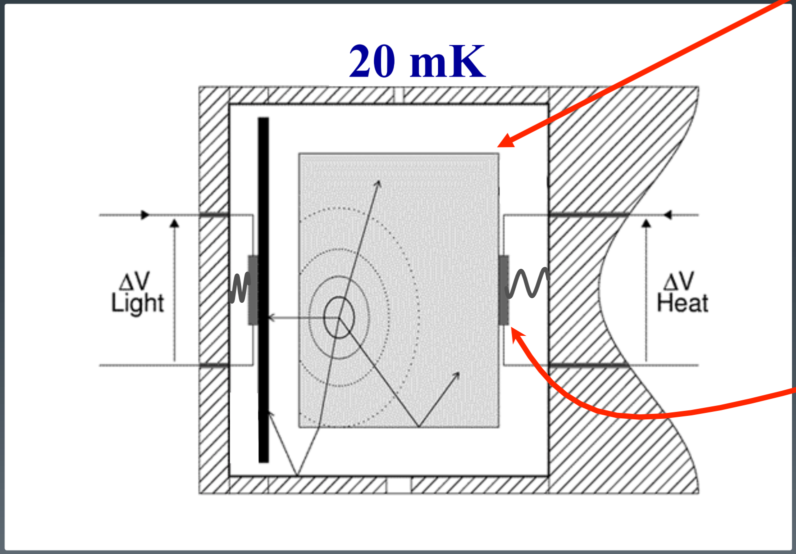
Dielectric and diamagnetic crystal

20 mK
ΔE = 1MeV ➔ $\Delta T \approx 0.1$ mK

Scintillating bolometers
Double bolometer technique

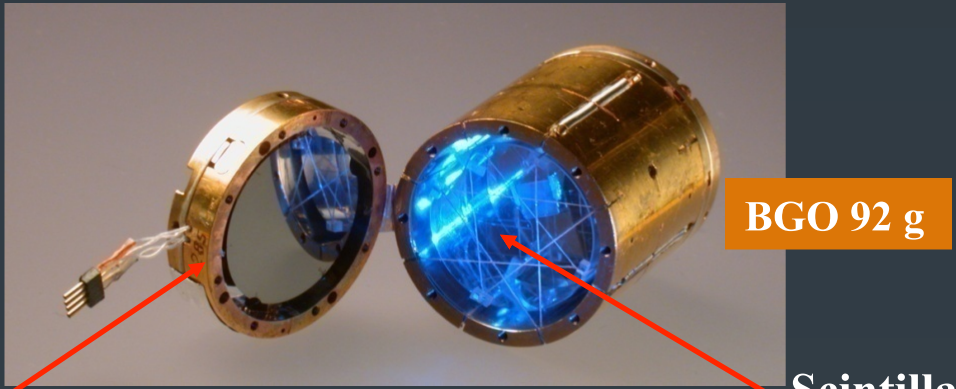


Scintillating crystal (absorber)



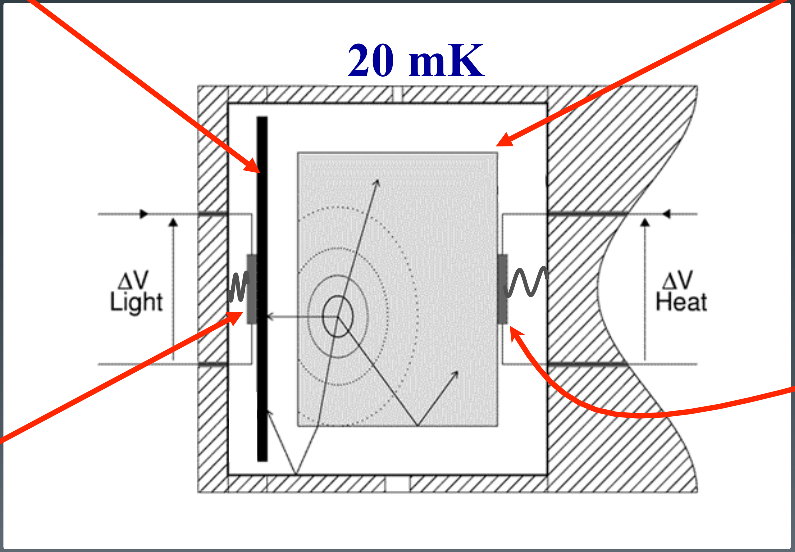
Ge-NTD thermistor

Scintillating bolometers
Double bolometer technique



Optical bolometer
(Ge disk)

Scintillating
crystal
(absorber)



Ge-NTD
thermistor

Ge-NTD
thermistor

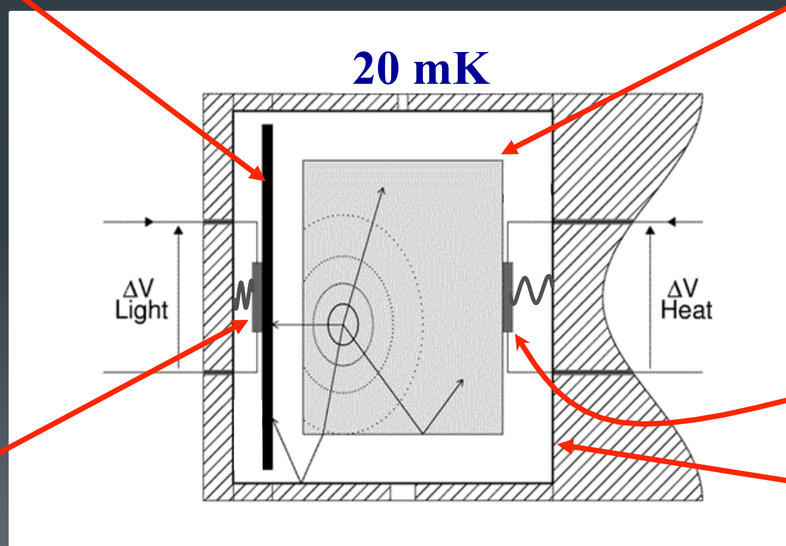
Scintillating bolometers
Double bolometer technique

BGO 92 g

Optical bolometer (Ge disk)

Cu frame

Scintillating crystal (absorber)



Ge-NTD thermistor

Ge-NTD thermistor

Internal reflecting cavity (Cu coated with Ag)

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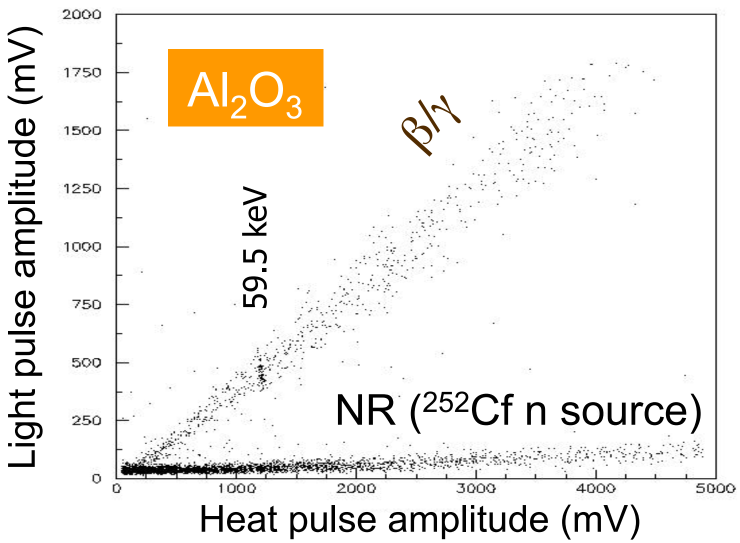
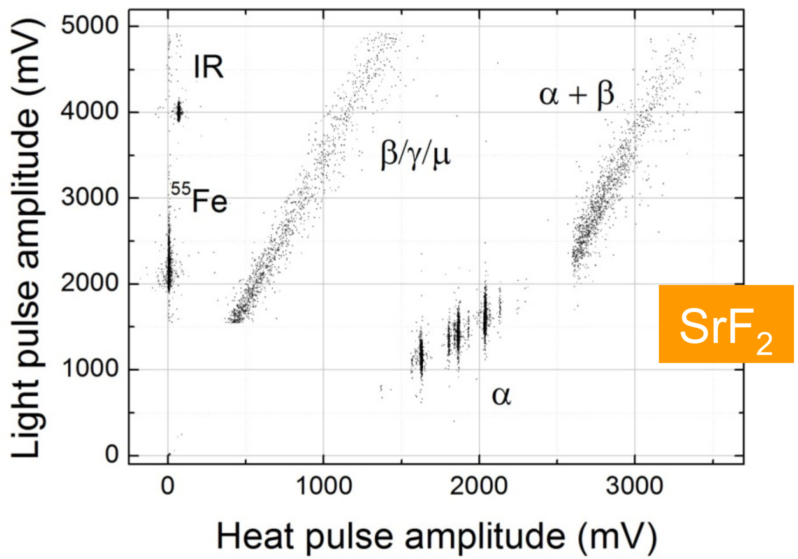
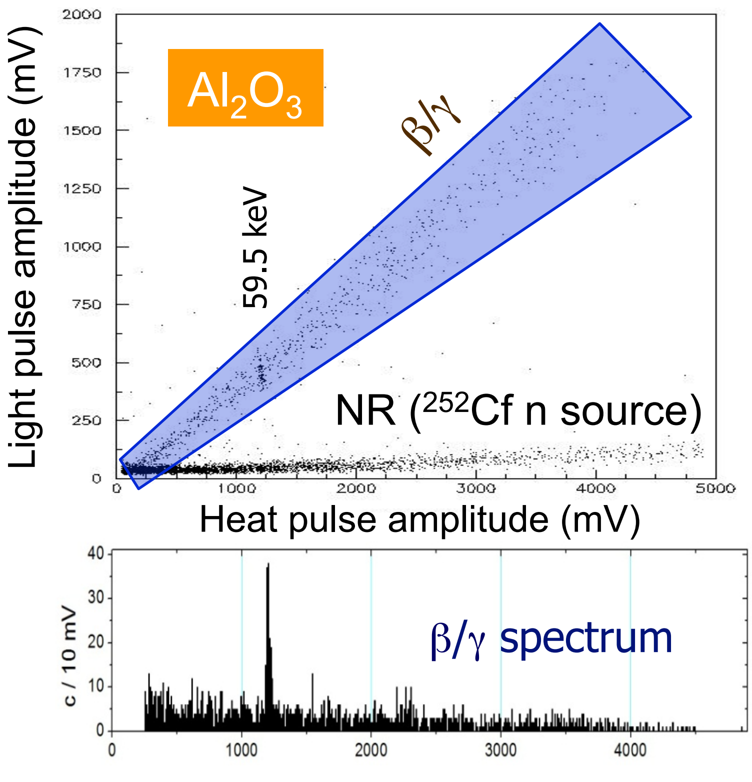
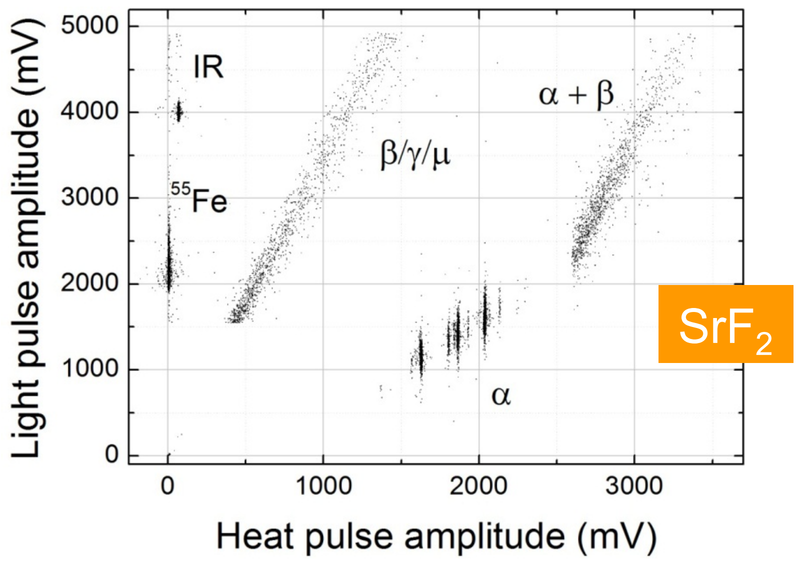
Particle discrimination



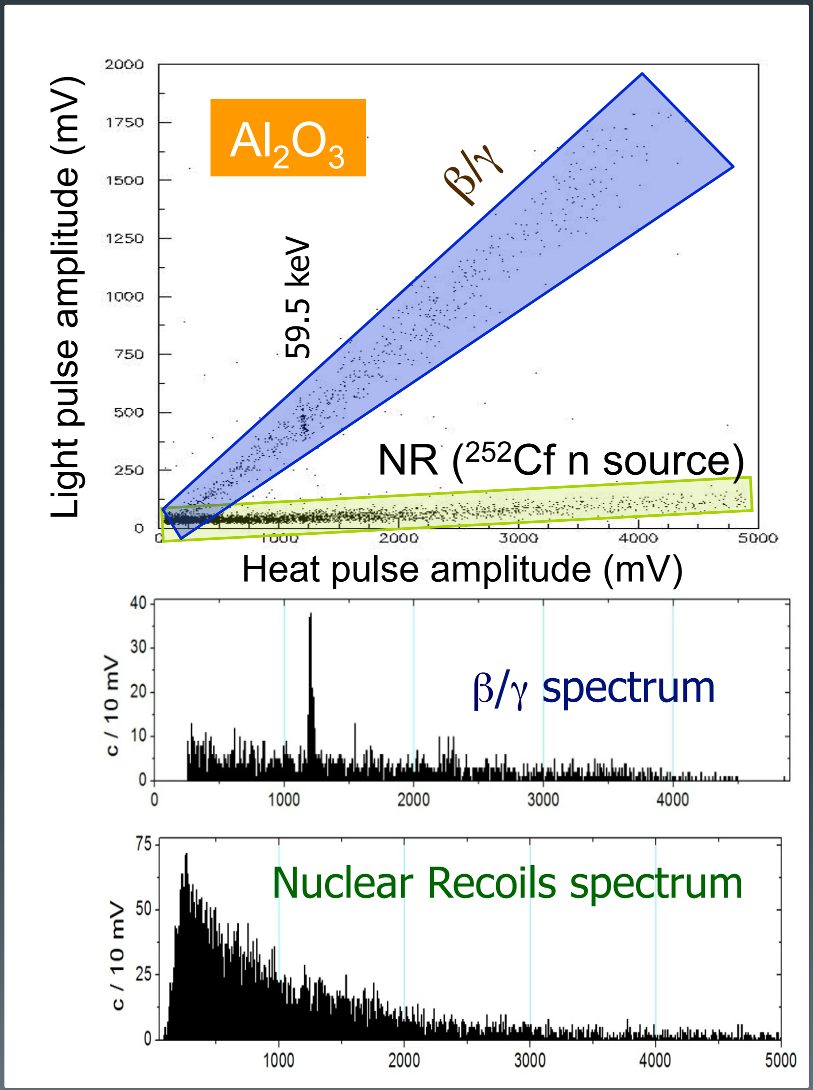


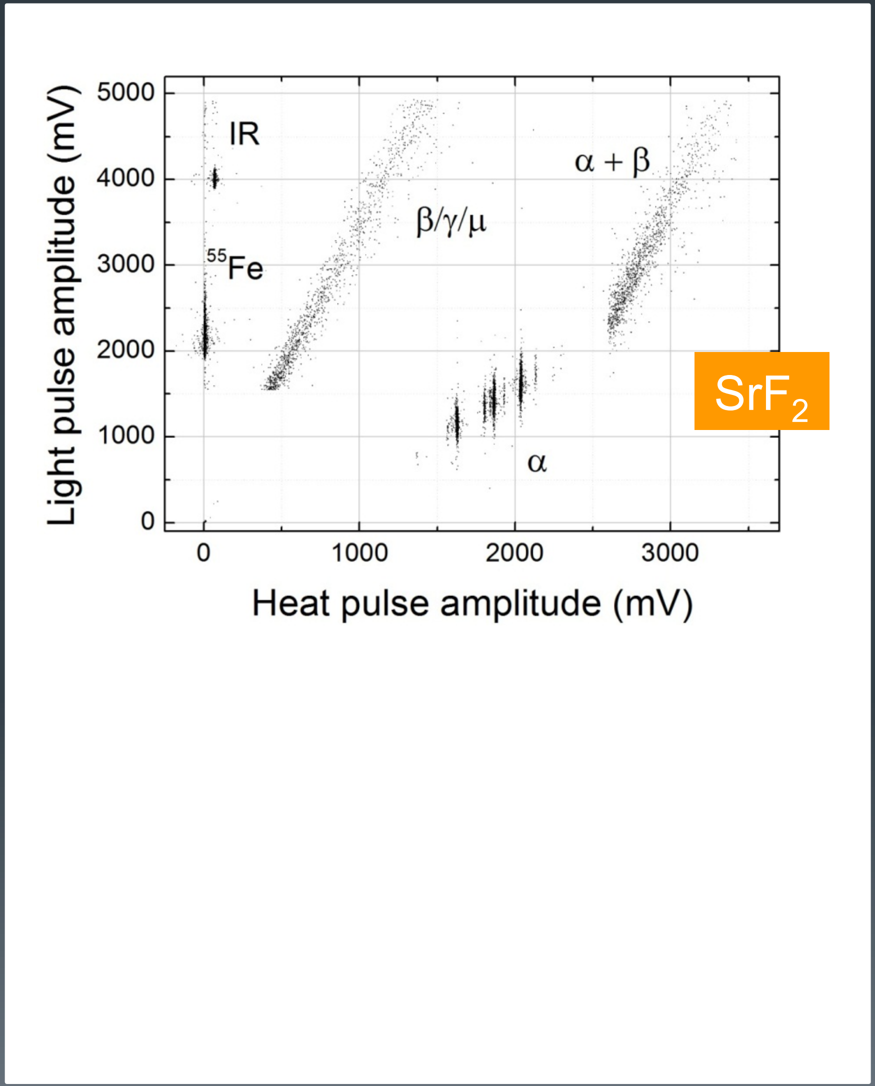
Particle discrimination



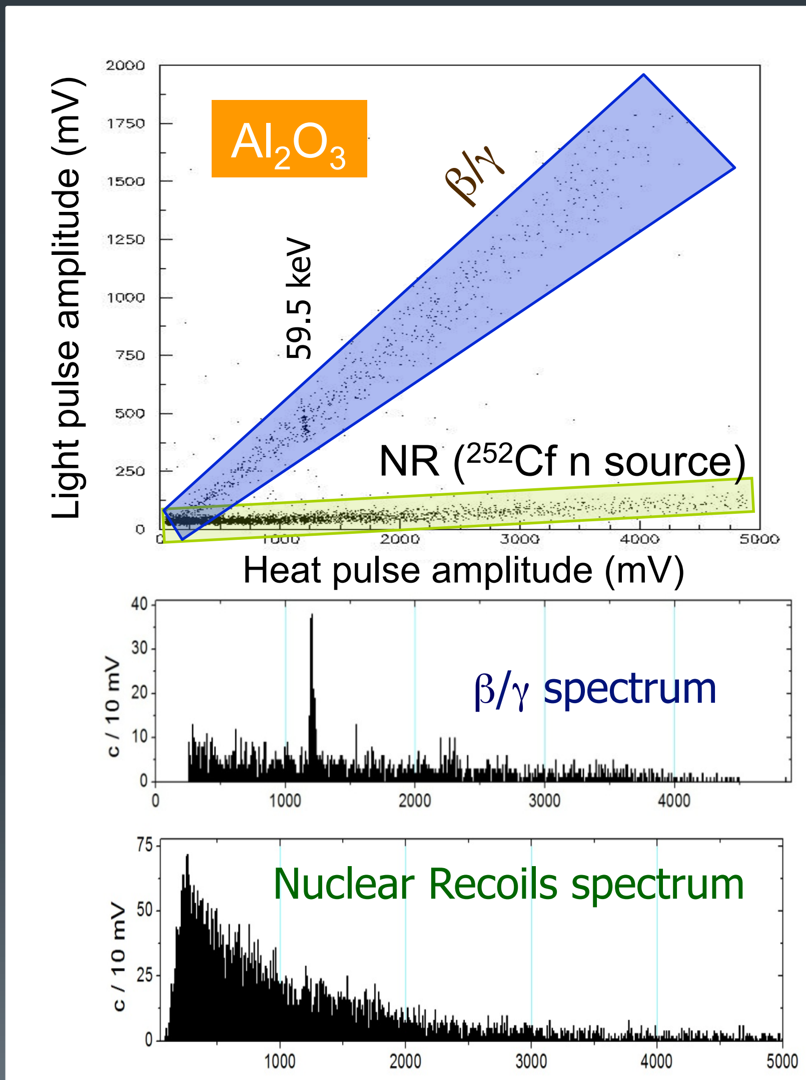


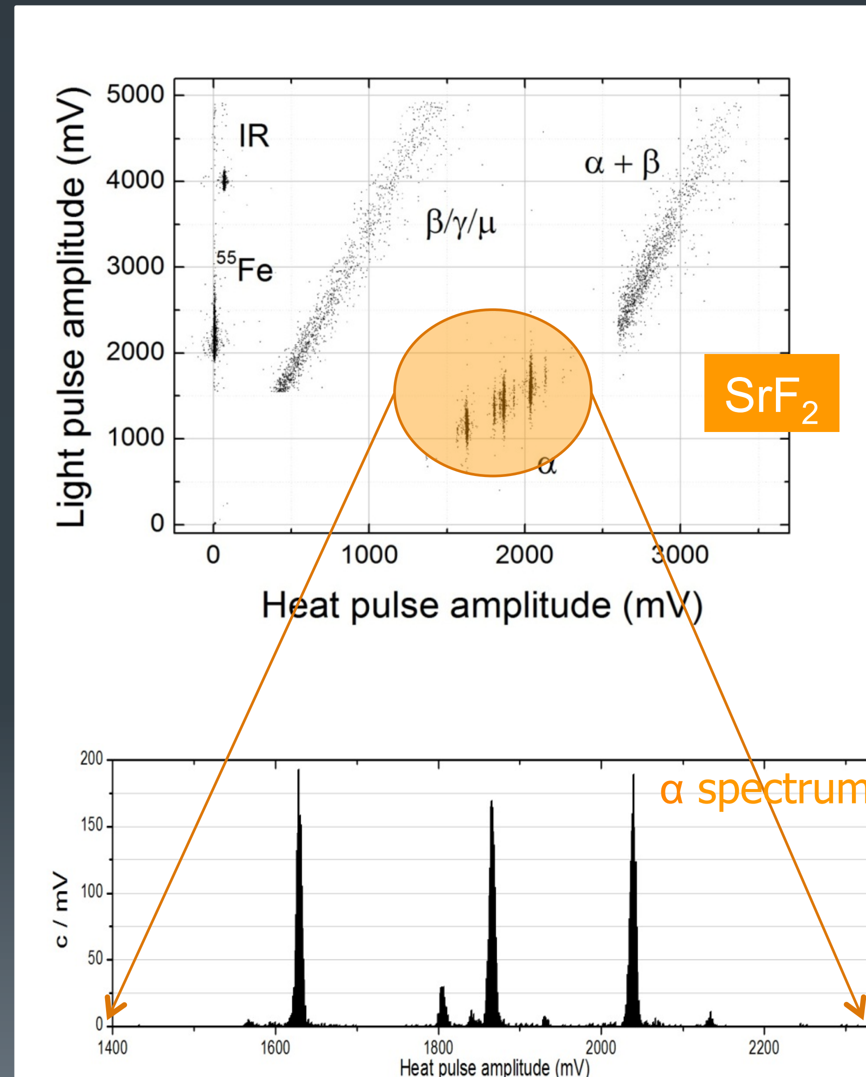
Particle discrimination





Particle discrimination





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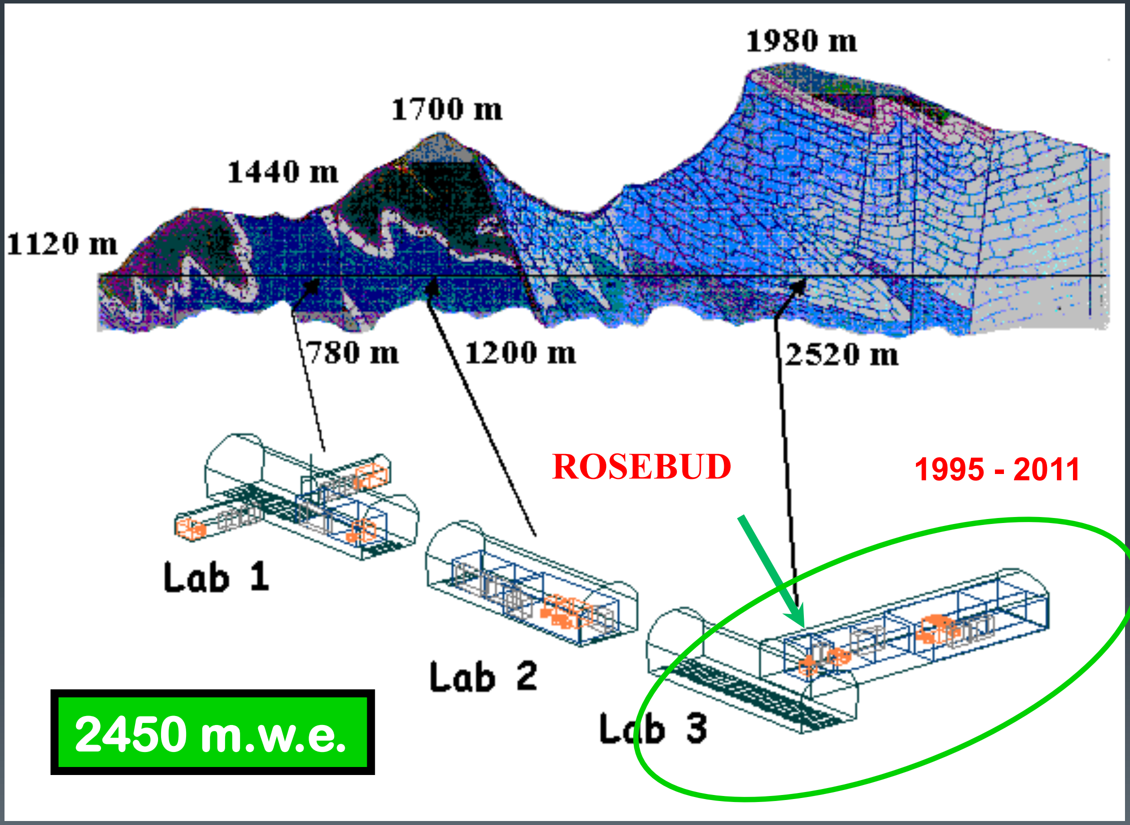
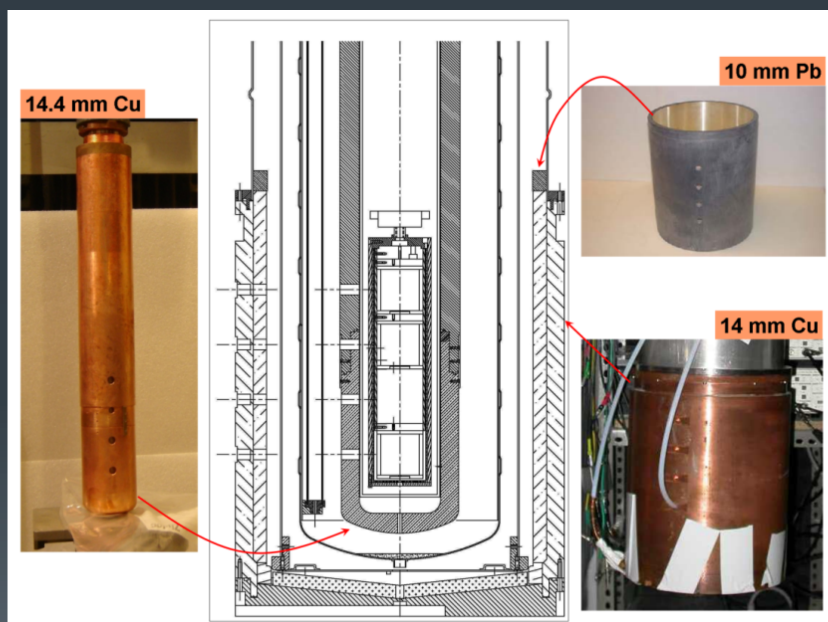
Experimental set-up
The old Canfranc Underground Laboratory



Muon flux decreased by a factor $\sim 10^5$

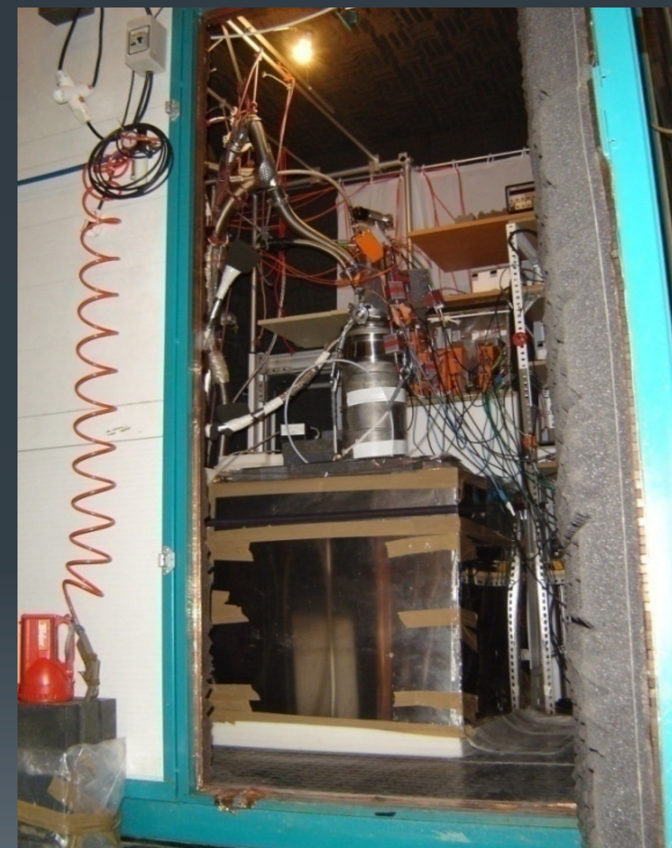
Experimental set-up
Cryogenics and shielding

Dilution unit



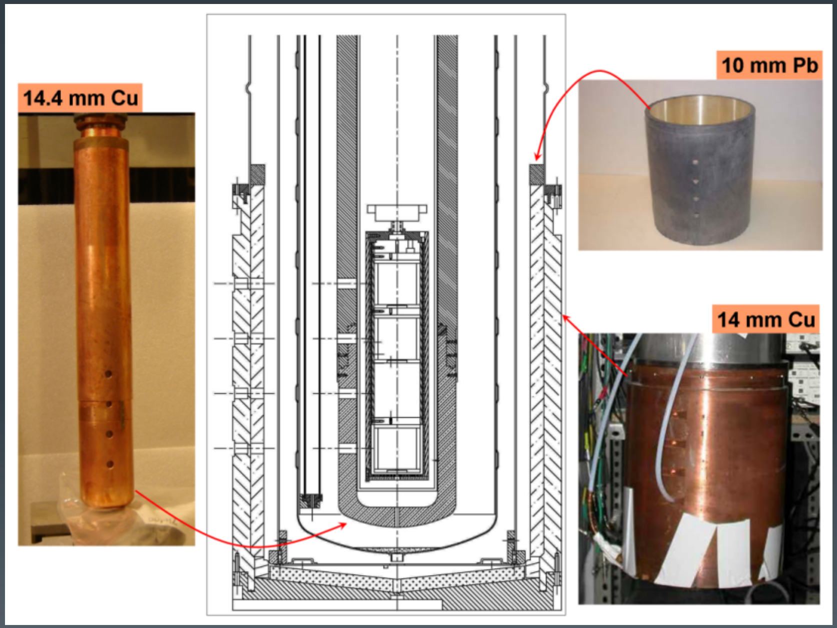
Shielded cryostat

Faraday cage

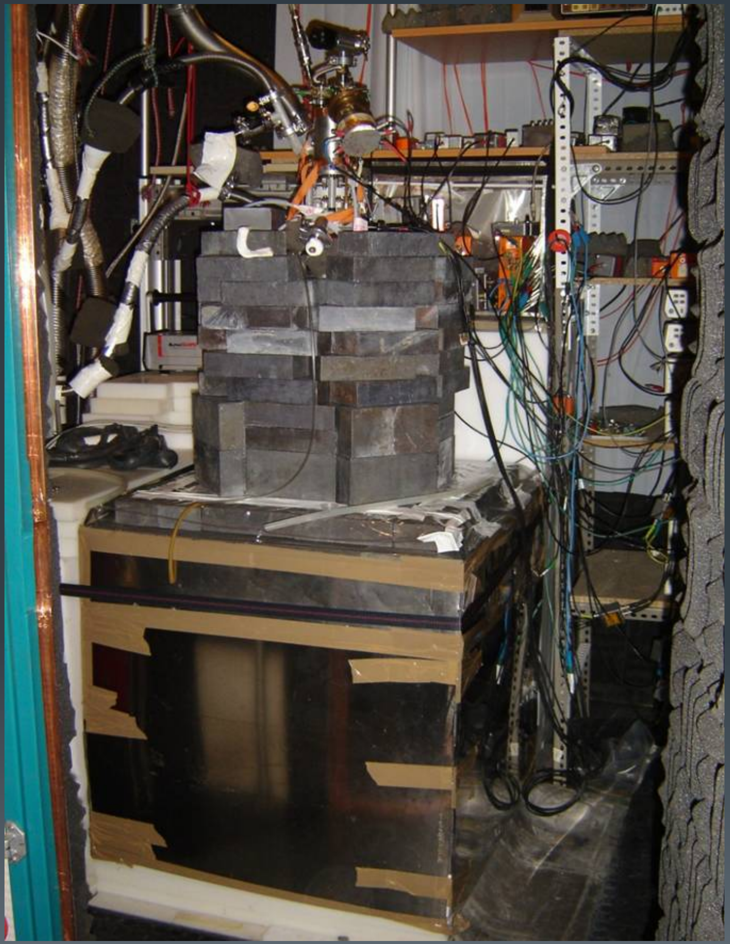


Experimental set-up
Cryogenics and shielding

Dilution unit

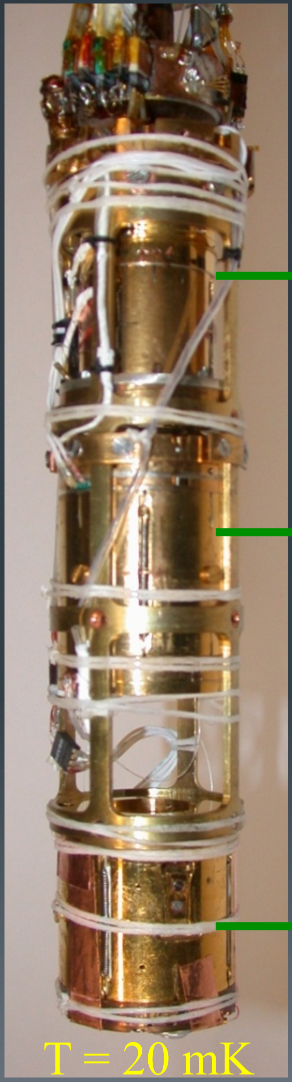


Shielded cryostat



External shielding

Experimental set-up
Scintillating bolometers



BGO ($Bi_4Ge_3O_{12}$)

- Mass 46 g
- ^{209}Bi sensitive to σ_{SI} (↑A) and σ_{SD} (J=9/2)
- β/γ spectrometer ↑Z

LiF

- Mass 33 g
- Monitoring of neutrons through ^{6}Li(n,t)α

Sapphire (Al_2O_3)

- Mass 50 g
- Sensitive to light WIMPs (↓A) and ^{27}Al to σ_{SD} (J=5/2)

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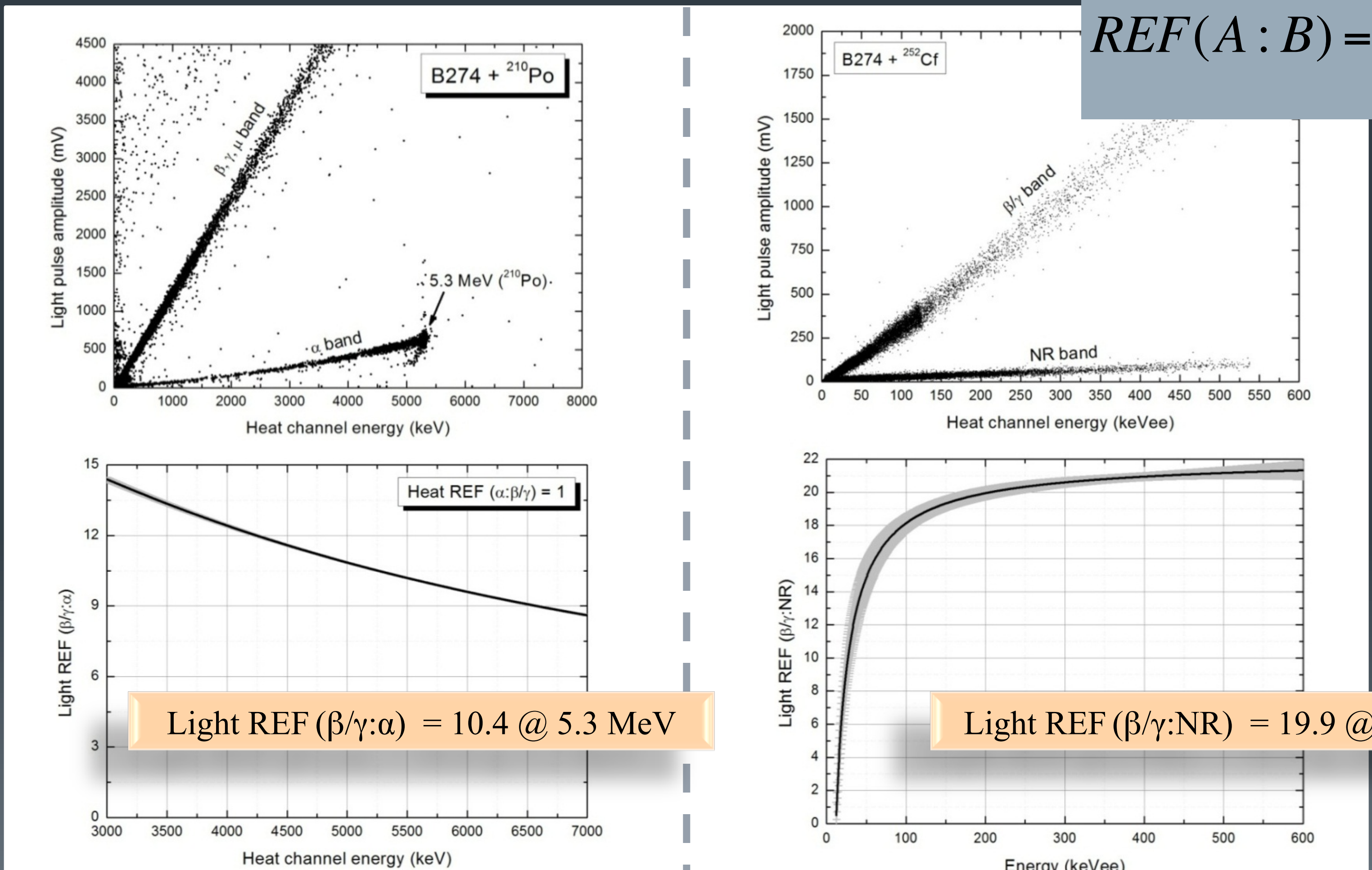
Light Relative Efficiency Factor (REF_ℓ)

(β/γ:α) and (β/γ:NR) in Al_2O_3

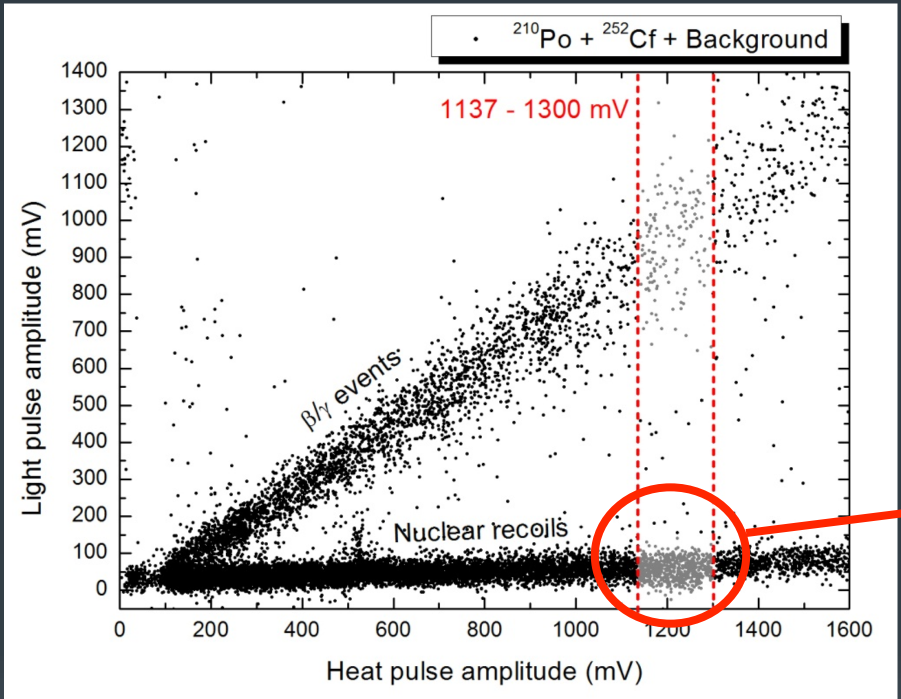
$$REF(A:B) = \frac{signal\ A}{signal\ B}$$

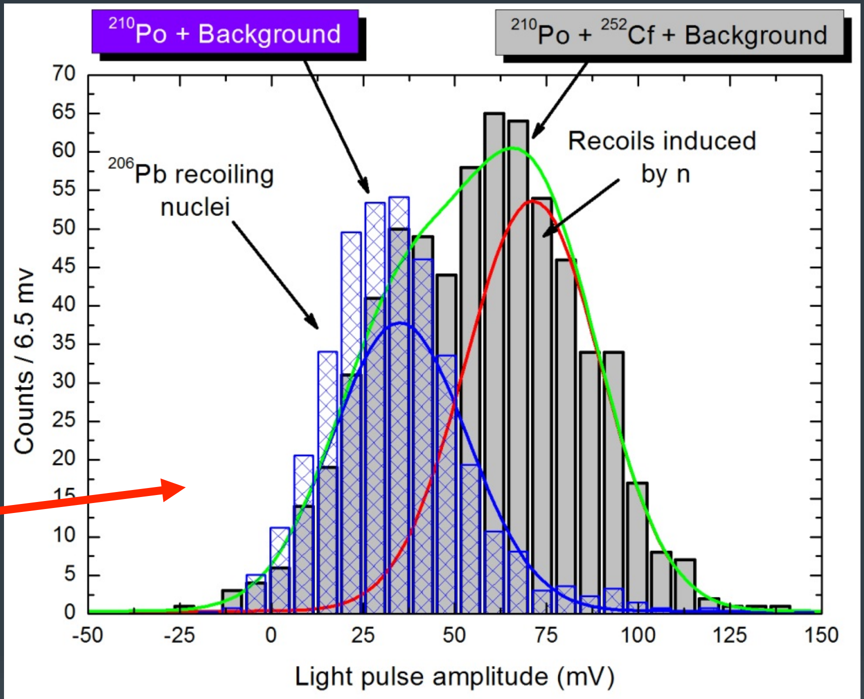


Light REF (β/γ:α) = 10.4 @ 5.3 MeV

Light REF (β/γ:NR) = 19.9 @ 200 keVee

Light Relative Efficiency Factor (REF$_\ell$) (β/γ:NR) in Al_2O_3



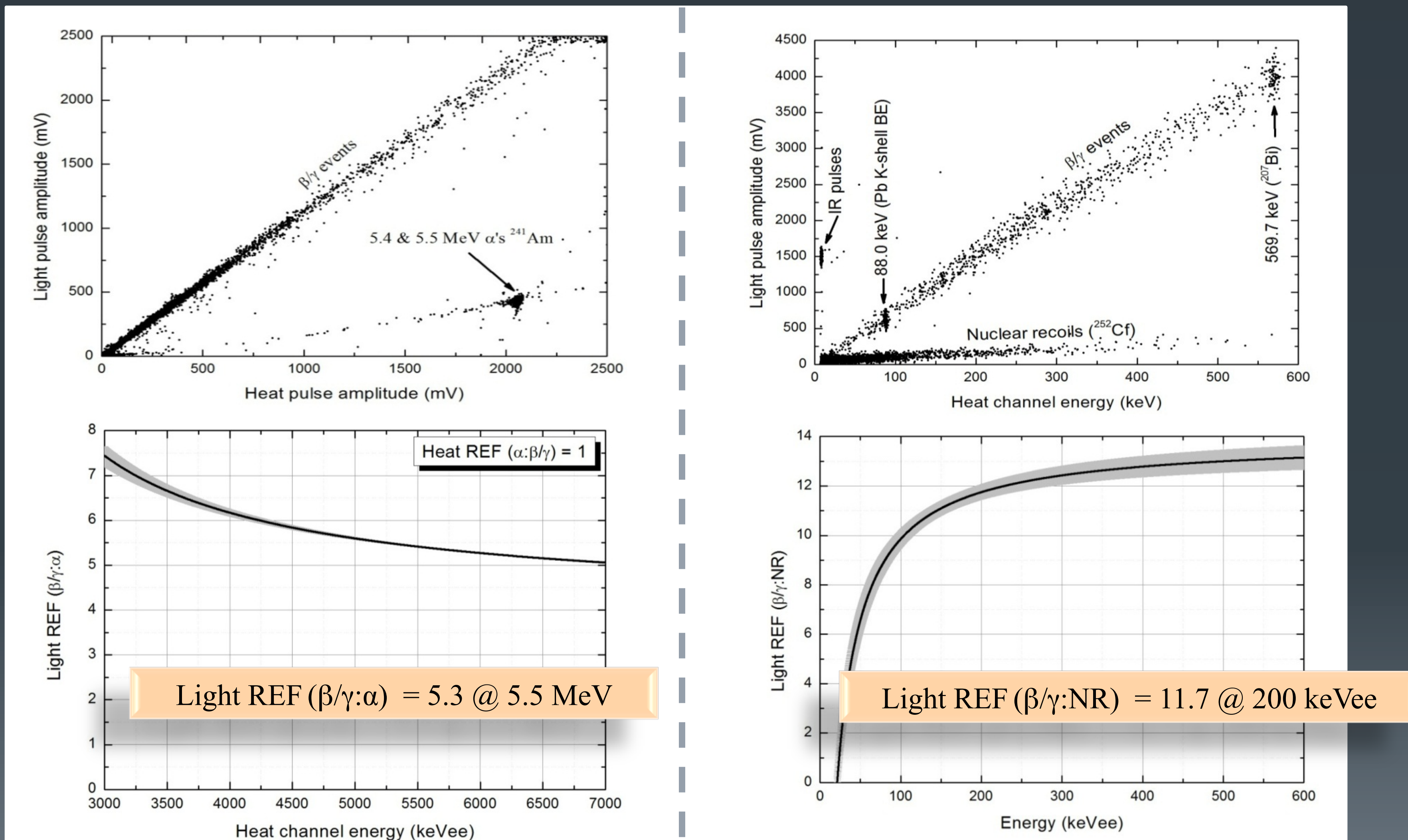


Recoils induced by neutrons:	**Light REF (β/γ:NR) = $18.6 \pm 0.8_{stat} \pm 2.9_{syst}$**
^{206}Pb recoiling nuclei:	**Light REF (β/γ:Pb) = $66.8 \pm 4.1_{stat} \pm 27.0_{syst}$**

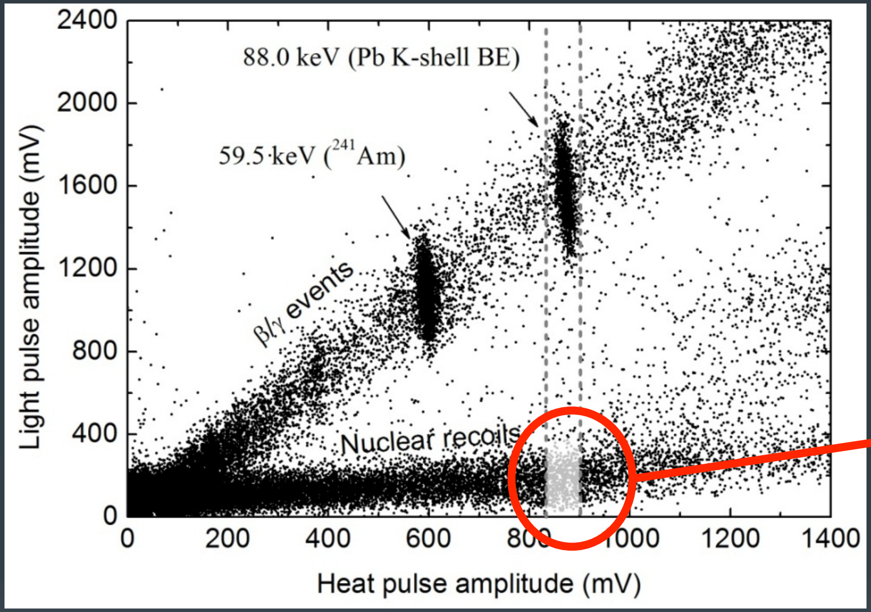
@ 103 keV

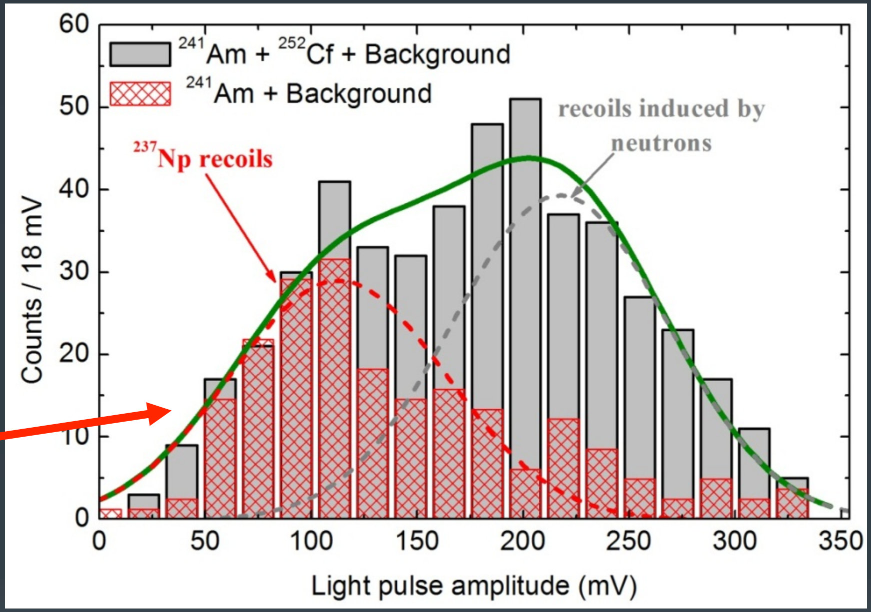
Light Relative Efficiency Factor (REF_{ℓ})

(β/γ:α) and (β/γ:NR) in BGO



Light Relative Efficiency Factor (REF_ℓ) (β/γ:NR) in BGO



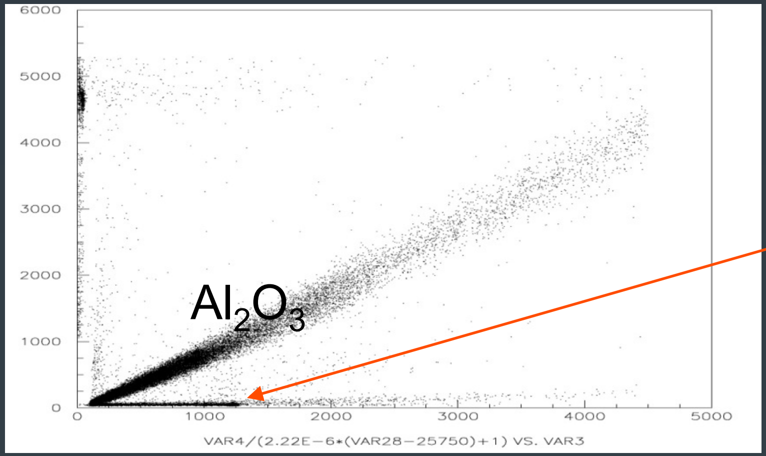


O recoils induced by neutrons:	**Light REF (β/γ:O) = $10.5 \pm 0.4_{stat} \pm 0.8_{syst}$**
^{237}Np recoiling nuclei:	**Light REF (β/γ:Np) = $39.5 \pm 7.2_{stat} \pm 13.7_{syst}$**

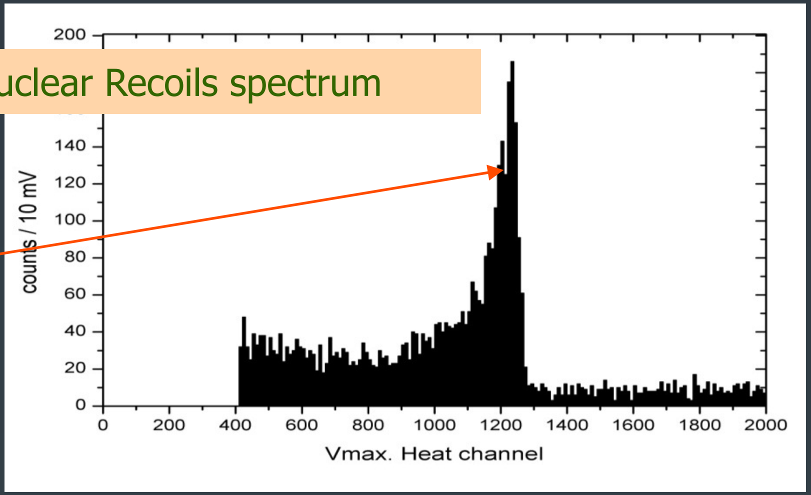
@ 88 keV

Thermal REF
Al_2O_3 and BGO

^{206}Pb recoils at 103.08 ± 0.10 keV from ^{210}Po α source in Al_2O_3



^{206}Pb recoils



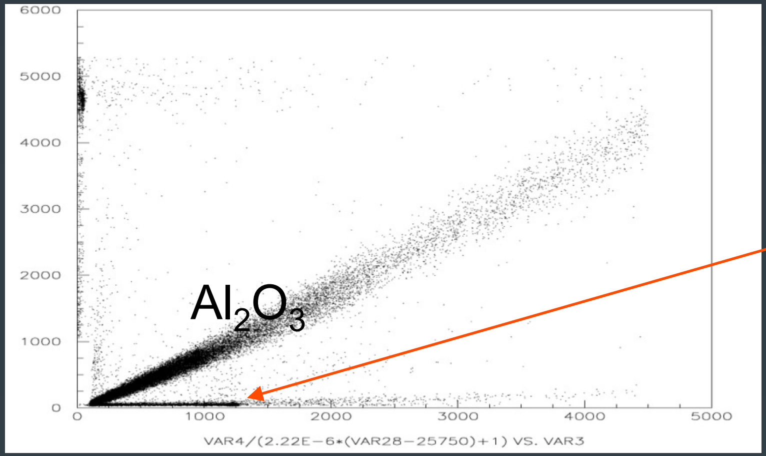
$$REF(nuclear\ recoils : \beta / \gamma) = 1.044 \pm 0.008_{stat} \, {}^{+0.056}_{-0.008}{}_{syst}$$

^{237}Np recoils at 92.40 ± 0.12 keV from ^{241}Am α source in BGO

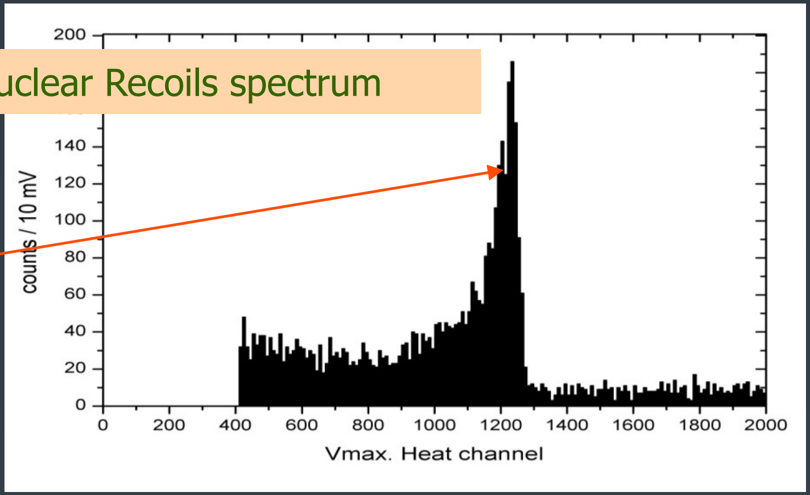
$$REF(nuclear\ recoils : \beta / \gamma) = 0.937 \pm 0.015_{stat} \, {}^{+0.302}_{-0.004}{}_{syst}$$

Thermal REF
Al_2O_3 and BGO

^{206}Pb recoils at 103.08 ± 0.10 keV from ^{210}Po α source in Al_2O_3



^{206}Pb recoils



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^{237}Np recoils at 92.40 ± 0.12 keV from ^{241}Am α sour

$$REF(nuclear\ recoils : \beta/\gamma) = 0.937 \pm 0.015_{stat}\ {}^{+0.302}_{-0.004}{}_{syst}$$

Both compatible with 1

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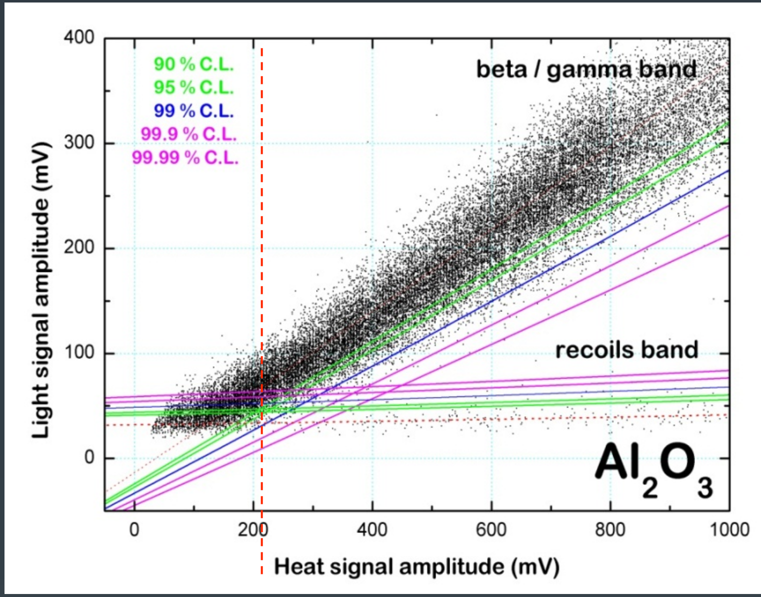
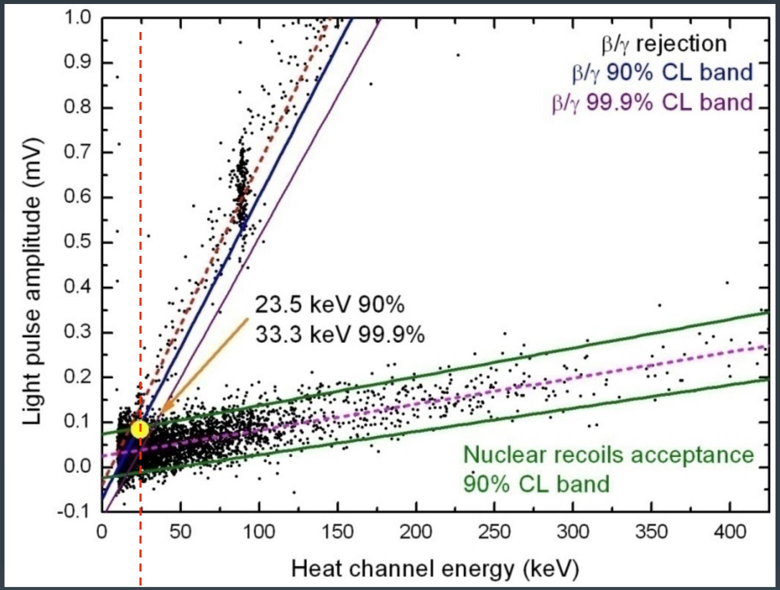
WIMP searches
Particle discrimination capability

Sapphire	BGO



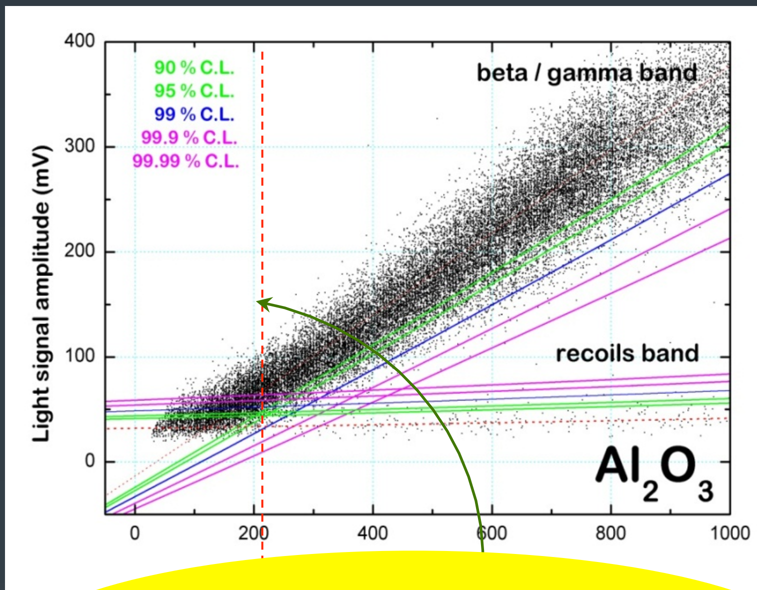
C.L (1 tailed)	E (keV)
90 %	8.7
95 %	10.0
99 %	13.0
99.9 %	17.1
99.99 %	21.3

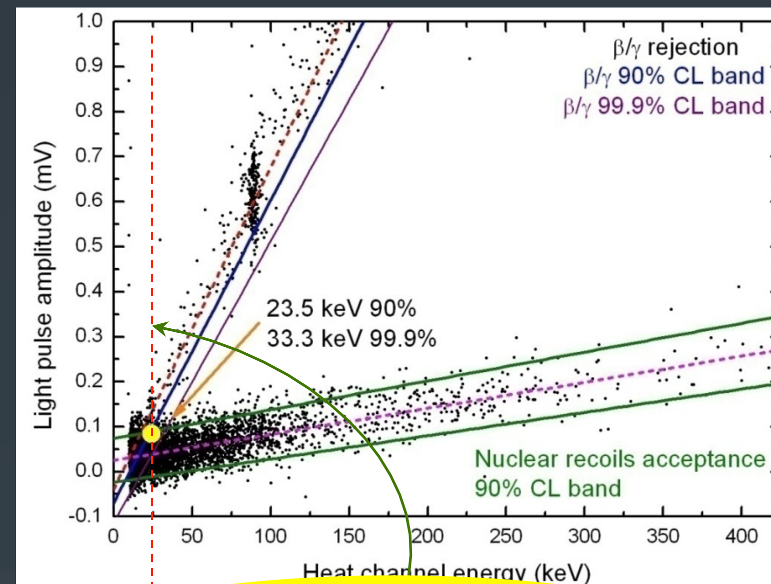


C.L (1 tailed)	E (keV)
90%	23.5
99.9%	33.3

WIMP searches
Particle discrimination capability

Sapphire	BGO





Discrimination of NR down to ≈10 keV

95 %	10.0
99 %	13.0
99.9 %	17.1
99.99 %	21.3

Discrimination of NR down to ≈25 keV

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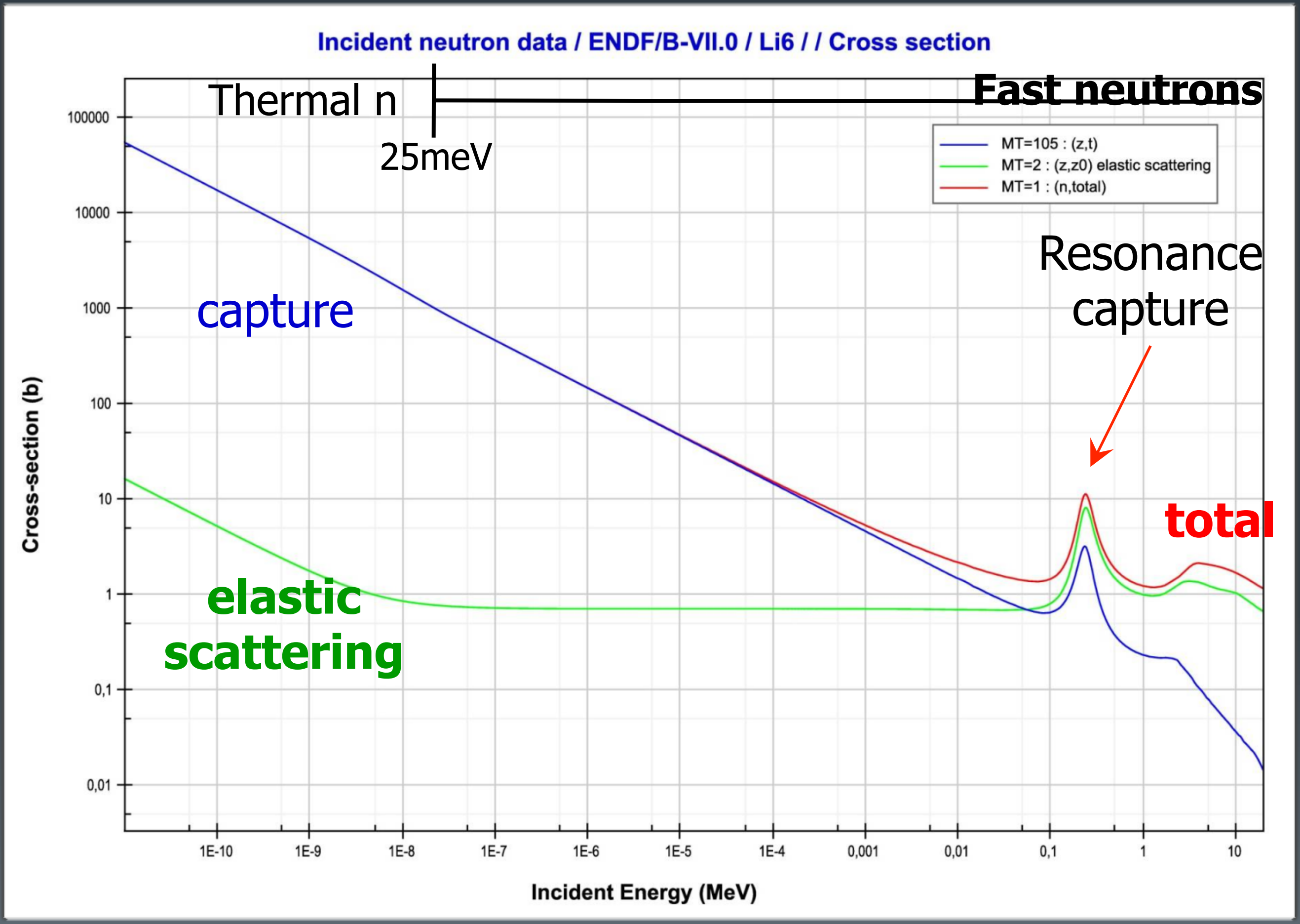
Fast neutron spectroscopy
LiF scintillating bolometer



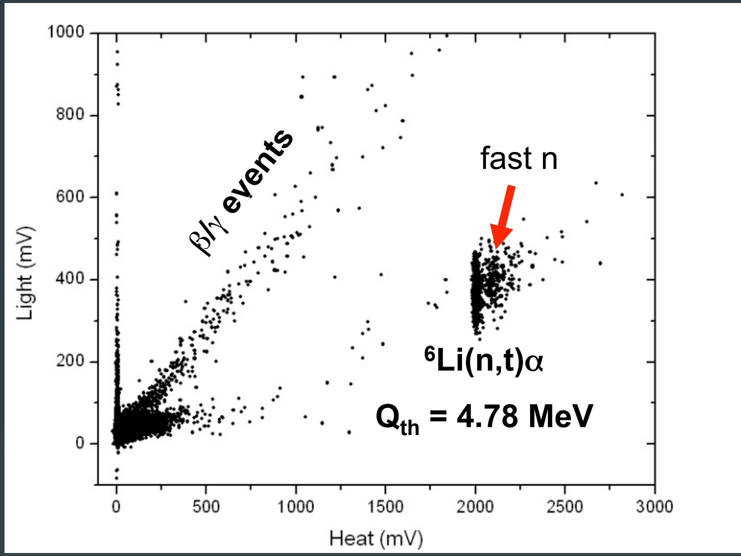
^{6}Li (7.5% i. a.)

$^{6}Li(n,t)\alpha$

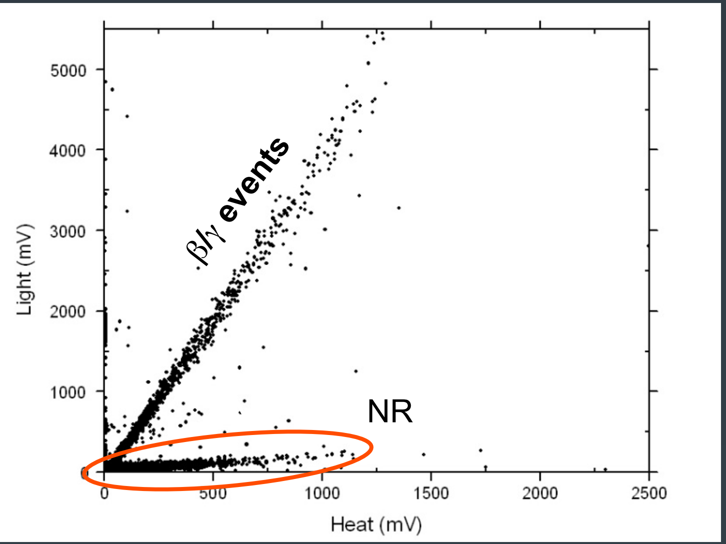
Q_{th} = 4.78 MeV

Neutron spectroscopy
Fast neutron flux inside the shielding

Irradiation of a 33 g LiF and a 50 g Al_2O_3 scintillating bolometers with ^{252}Cf



LiF & Al_2O_3



Hypothesis: fast neutron flux inside the lead shielding

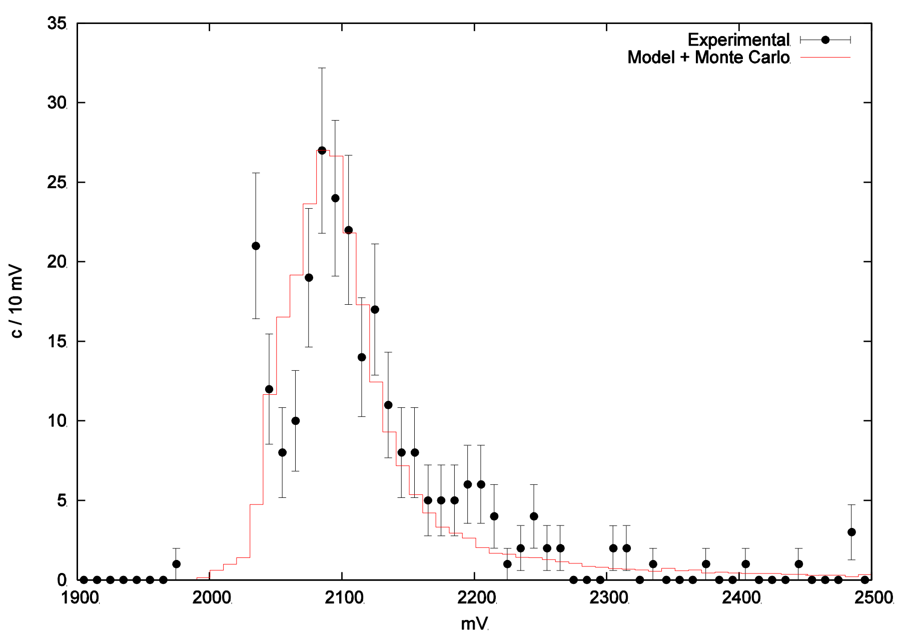
$$\frac{\Phi_0}{\Gamma(\alpha+1)}\left(\frac{E}{T}\right)^{\alpha} e^{-\left(E/T\right)}\frac{dE}{T}$$

We estimated the region of three parameters (Φ_0,α,T) compatible with experimental data

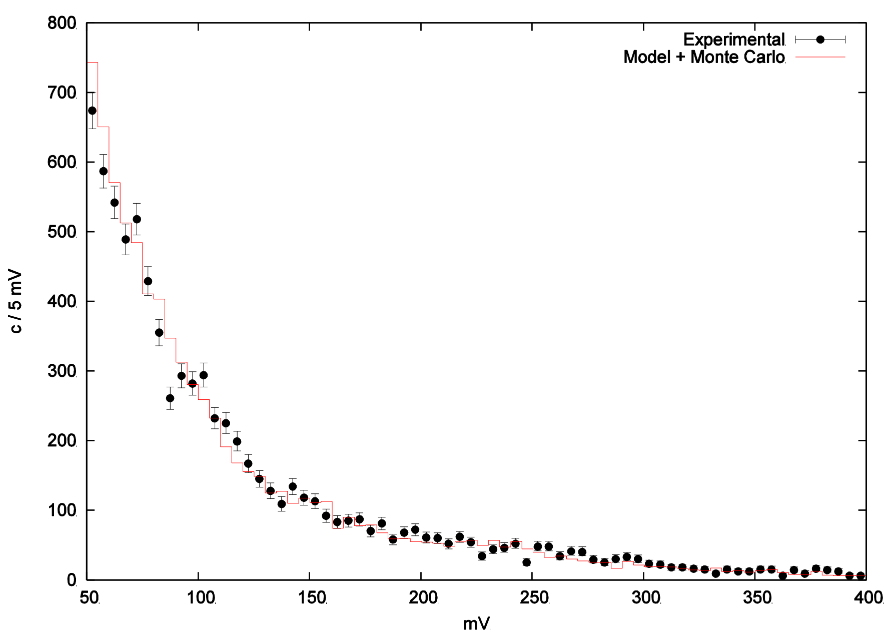
Neutron spectroscopy

MC simulation (MCNP-poliMI) of the neutron flux

captures in the ^{6}Li resonance



Al_2O_3 heat NR spectra



0.218 ± 0.016 n s^{-1} cm^{-2}

Incident flux
(E > 0.1 MeV)

0.204 ± 0.025 n s^{-1} cm^{-2}

Spectra shape and flux estimates in good agreement

We can monitor the fast neutron differential flux

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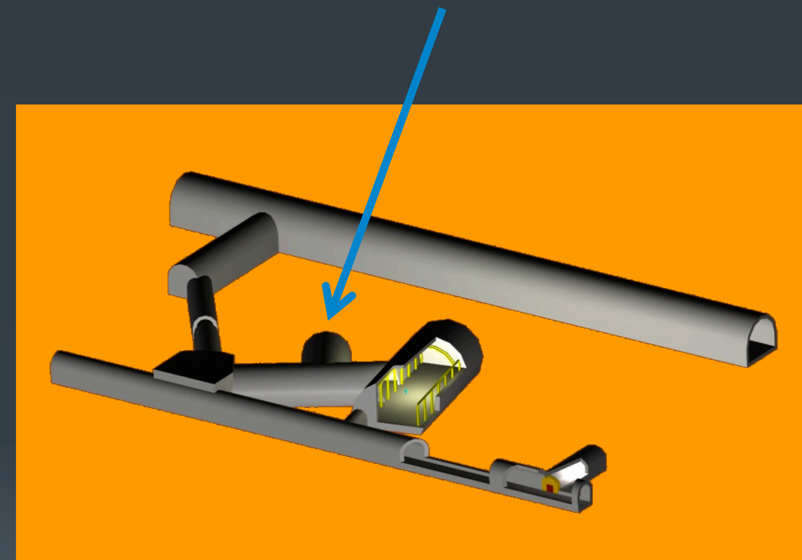
ROSEBUD at new LSC

ROSEBUD is moving to the new facilities of the Canfranc Underground Laboratory (LSC):

- New Faraday cage and acoustic isolation.
- Moving of the cryogenic system.



Cryogenic tests and first runs with scintillating bolometers in 2012

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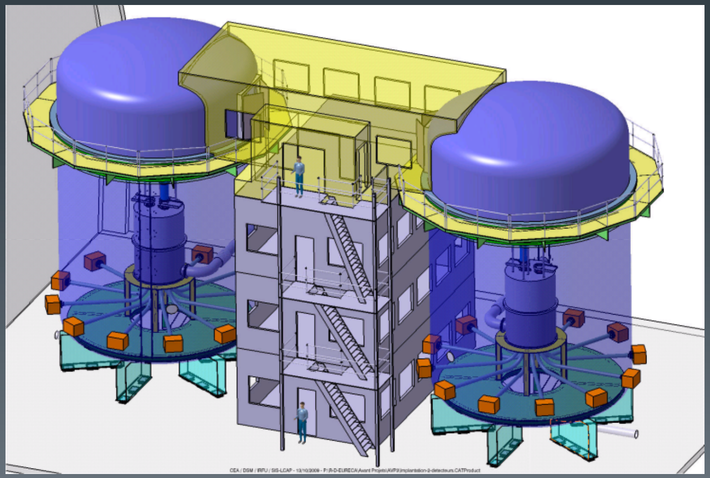
EURECA project

Institut d' Astrophysique Spatiale IAS

Universidad de Zaragoza

http://www.eureca.ox.ac.uk/

- ✓ Target mass 1 ton.
- ✓ Semiconductor bolometers built with the technology of EDELWEISS (LSM).
- ✓ Scintillating bolometers built with the technology of CRESST (LNGS) and ROSEBUD (LSC).
- ✓ To be carried out at the Modane Underground Laboratory (LSM) in France.



Conclusions

- ROSEBUD is a collaborative effort dedicated to the development of scintillating bolometers for nuclear and particle physics experiments, focusing on rare event search experiments.

- Scintillating bolometers characterized by ROSEBUD (Al_2O_3, BGO and LiF) have shown excellent capabilities for particle discrimination and background rejection.

- Relative Efficiency Factors have been estimated for several particles and targets.

- ROSEBUD is currently moving to the Hall B in the new LSC facilities planning to restart measurements in 2012. New materials are being characterized in IAS.

- UNIZAR and IAS also participate in EURECA.

UNIZAR and IAS participation in EURECA

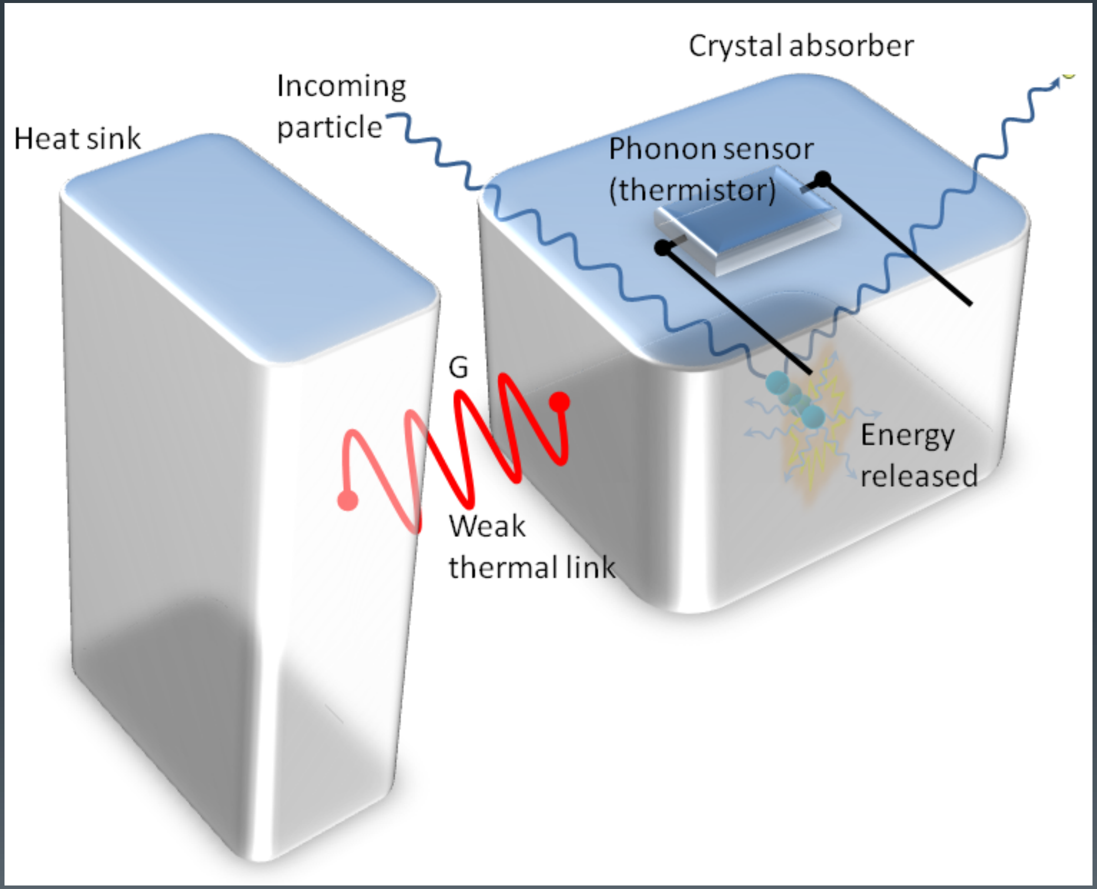
- Radiopurity measurements of materials (crystals, cryogenic resins, shieldings, detector components, dilution unit pieces) at LSC using ultra-low background germanium detectors.
- Development of new scintillating bolometers.
- Test of scintillating bolometers at the Canfranc Underground Laboratory (LSC) in order to characterize and optimize scintillators in a low background environment , evaluating these for use as potential dark matter targets in EURECA.

EURECA time line

Project	09	10	11	12	13	14	15	16	17	18	19
CDR/ASPERA D. Study											
TDR											
Decision											
Construction I (150 kg)											
Exploitation I											
Construction II (1 ton)											
Exploitation II											

Scintillating bolometers
Simple bolometer model

Thermal model of a simple bolometer



$$\Delta T = \frac{\Delta E}{C}$$

E/C (300K) =1 MeV/R=10^{-14}K

E/C (0.02K) =
=1 MeV/5 GeVK^{-1}=0.0001K

C of SrF2 at 0.02K

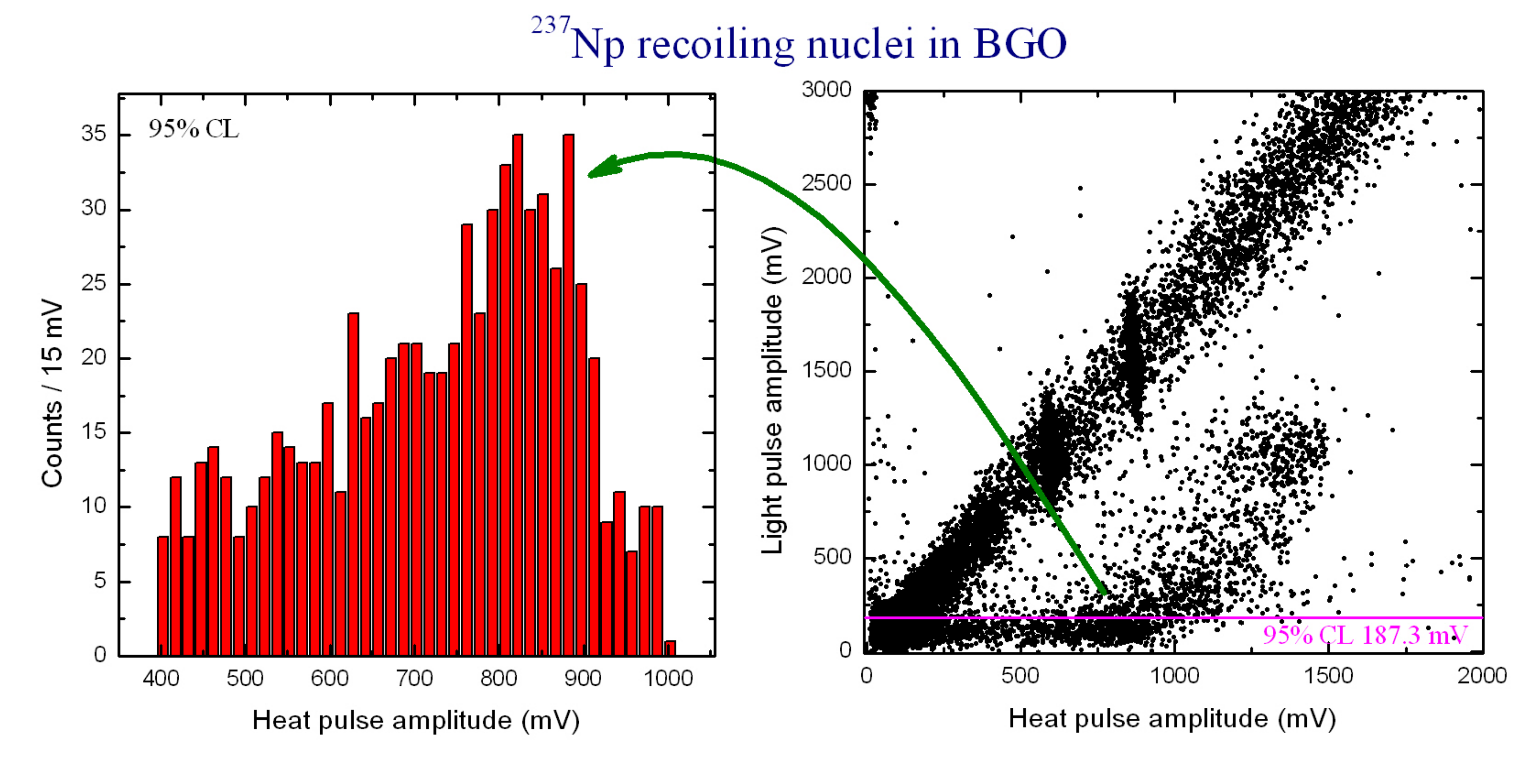
$$C = \alpha\left(\frac{T}{\theta_D}\right)^3$$

BGO Thermal REF (^{237}Np nuclear recoils:β/γ)

BGO irradiation with ^{241}Am α source

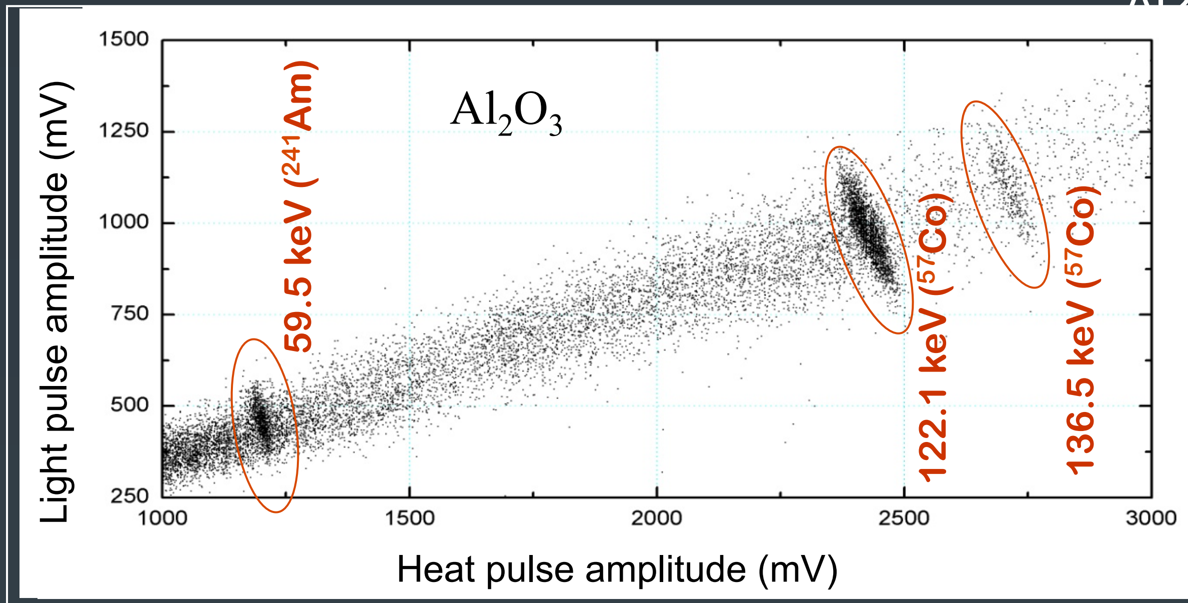
^{237}Np recoiling nuclei at 92.40 ± 0.12 keV from ^{241}Am α source

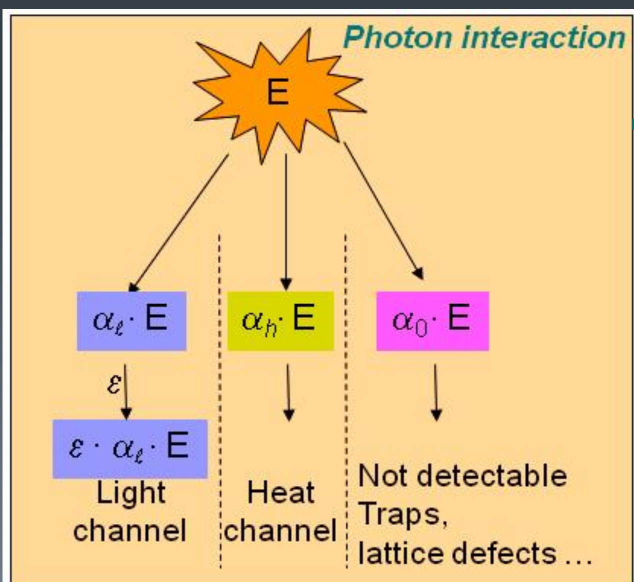
$$REF(nuclear\ recoils:\beta/\gamma) = 0.937 \pm 0.015_{stat}\ {}^{+0.302}_{-0.004}{}_{syst}$$



Energy partition in Sapphire and BGO scintillating bolometers

Al2O3





$$\alpha_\ell + \alpha_h + \alpha_0 = 1$$

Al_2O_3

α_ℓ = 0.112 ± 0.013	α_h = 0.778 ± 0.103	α_0 = 0.110 ± 0.104

BGO

α_ℓ = 0.058 ± 0.006	α_h = 0.464 ± 0.093	α_0 = 0.478 ± 0.093

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