LOW ENERGY EVENTS IN NaI(Tl) SCINTILLATORS. ANAIS STATUS AND PROSPECTS.

IDM 2010

Montpellier 26 July 2010

J Amaré, S Borjabad, S Cebrián, **C Cuesta**, D Fortuño, E García,
C Ginestra, H Gómez, M Martínez, M A Oliván, Y Ortigoza, A Ortiz de Solórzano,
C Pobes, J Puimedón, M L Sarsa and J A Villar.

University of Zaragoza
Canfranc Underground Laboratory

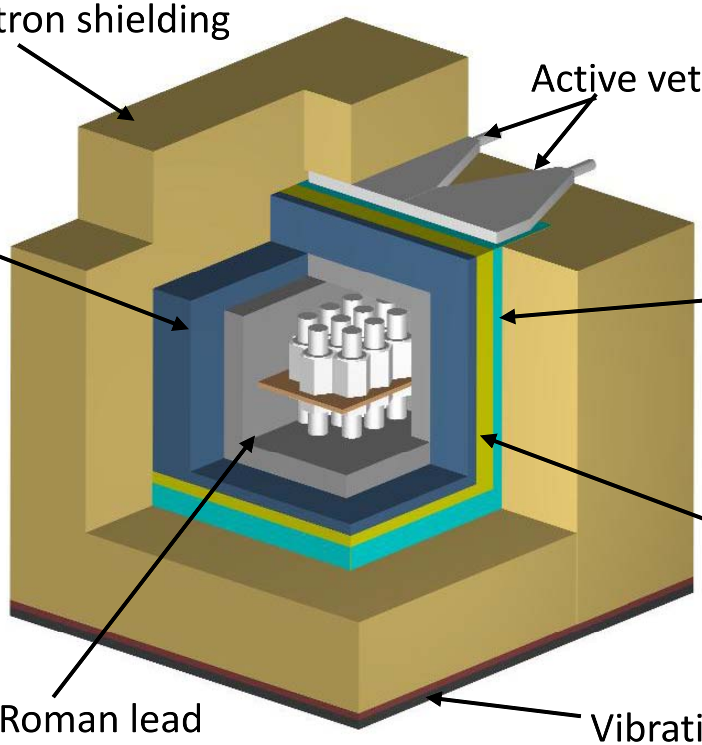
MultiDark
Multimessenger Approach for Dark Matter Detection

OUTLINE

- ANAIS experiment.
  - NaI(Tl) scintillators.
  - ANAIS-0 module.
- Low energy events.
  - Calibrations.
  - ^{40}K internal contamination.
  - Low energy estimators.
  - Noise rejection.
- Light collection vs background.
  - Resolution and efficiency.
  - Background and radiopurity.
  - Asymmetric events.
- Conclusions.

ANAIS EXPERIMENT

ANAIS is a project aiming to set up, at the new facilities of the Canfranc Underground Laboratory (SPAIN), a large scale NaI(Tl) experiment to look for dark matter.



Motivation

Study of the annual modulation DAMA/LIBRA positive signal.

Experimental goals:

- Energy threshold < 2 keV.
- Background at low energy as low as possible.
- Very stable operation conditions.

Detector mass:

100 kg funding guaranteed, possible enlargement up to 250kg.

ANAIS EXPERIMENT: NaI(Tl) SCINTILLATORS

14 Hexagonal crystals (10.7 kg each) stored underground since 1988.

Fully characterized → too much ^{40}K (15-20 mBq/kg) to be used.

R+D with Electrochemical Systems Inc. for NaI powder purification.

The goal is K < 0.1 ppm (^{40}K < 3 mBq/kg). Also low levels of ^{238}U and ^{232}Th.

Phase I: Determination of possible NaI purification methods. ***Finished***

Phase II: Test of candidate processes and production of reference sample(s). ***On-going***

- Several raw samples of the starting material have been measured at the University of Zaragoza with two methods (HP Ge and AAS): K = 1.5 - 2 ppm.
- Purified samples will also be checked and reanalyzed with the same methods.

Phase III: Production and delivery of required product (100-250kg). ***2011***

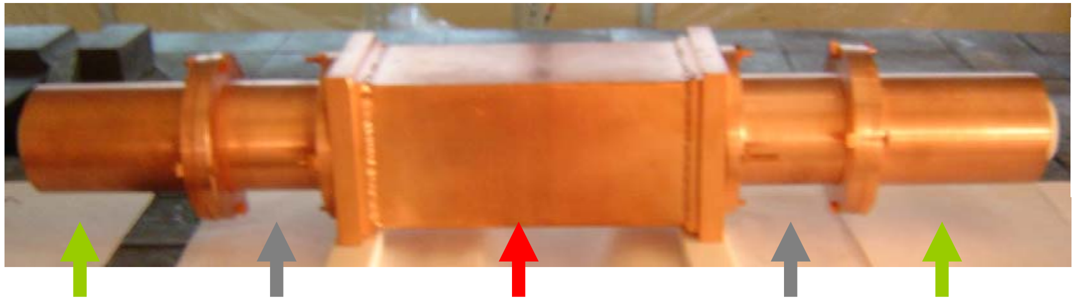
ANAIS EXPERIMENT: ANAIS-0 MODULE

On-going measurements to characterize and fully understand ANAIS background at low energy, optimize noise cuts, determine the calibration method, test the electronics and improve the light collection efficiency.

The detector was encapsulated at Zaragoza and measurements are carried out at the Canfranc Underground Laboratory.

NaI(Tl) (9.6kg) crystal made by St Gobain.

$254x101.6x101.6mm^3$



Different set-ups:

- ^{40}K coincidence measurement.
- Different photomultipliers (PMTs).
- With and without light guides (LG).

LOW ENERGY EVENTS

Expected dark matter signal at E < 6 keV.

Low energy response of the detectors is crucial, in particular noise understanding and rejection and calibration.

Populations of scintillation events, with known low energy (E<20keV) are very useful for this purpose.

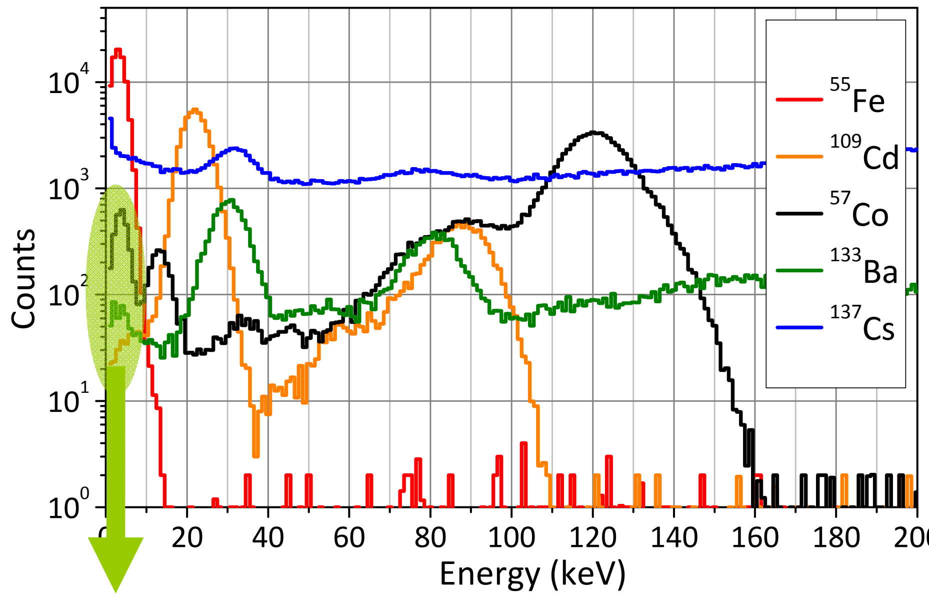
- External gamma calibration sources
- ^{40}K internal contamination (3.2 kev)

LOW ENERGY EVENTS: CALIBRATION SOURCES

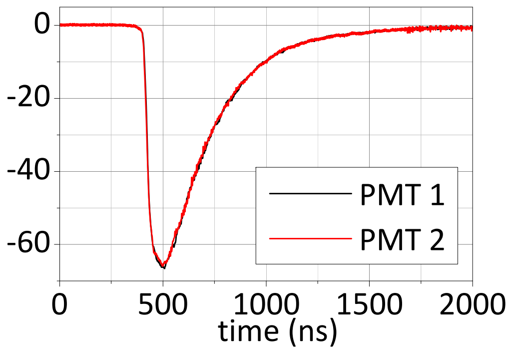
Mylar window at ANAIS-0 allows low energy calibrations

Source	Energy (keV)	I(%)
^{55}Fe	5.895	24.4
^{109}Cd	22.10 88.04	85.2 3.61
^{137}Cs	32.06	5.80
^{57}Co	6.4 14.41 122.1	32.6 9.16 85.6
^{133}Ba	30.85 81.0	99.4 34.1

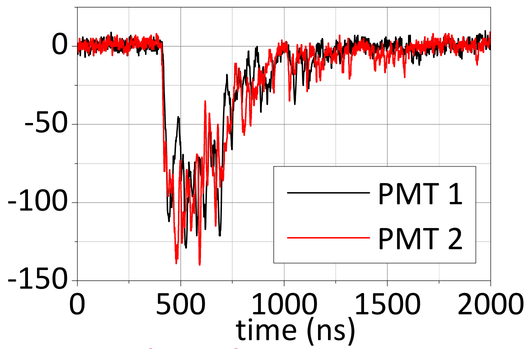
Energy is estimated from the sum of the two PMT signals.



Scintillation events, with $\tau \approx$ 230ns



Average



Single pulse

LOW ENERGY EVENTS: CALIBRATION SOURCES

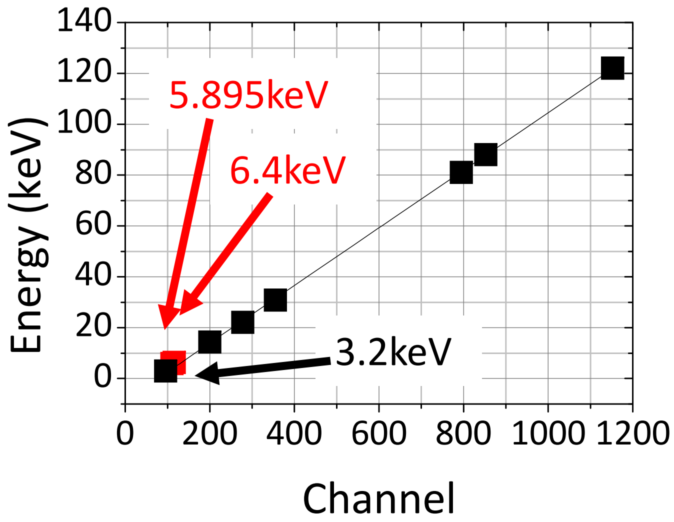
Mylar window at ANAIS-0 allows low energy calibrations

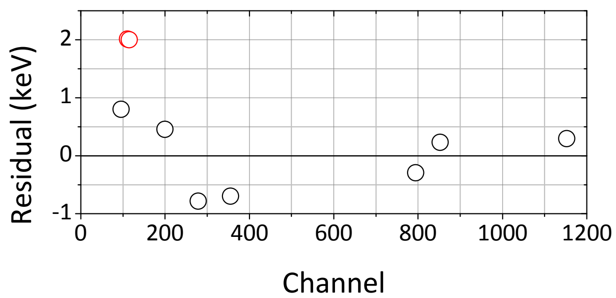
Source	Energy (keV)	I(%)
^{55}Fe	5.895	24.4
^{109}Cd	22.10 88.04	85.2 3.61
^{137}Cs	32.06	5.80
^{57}Co	6.4 14.41 122.1	32.6 9.16 85.6
^{133}Ba	30.85 81.0	99.4 34.1

^{40}K → 3.2keV

Bulk contamination, no surface effect.

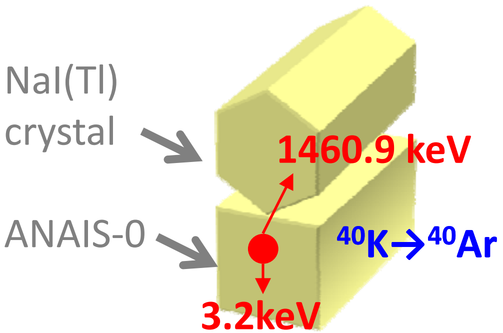
Surface effects observed at low energy.

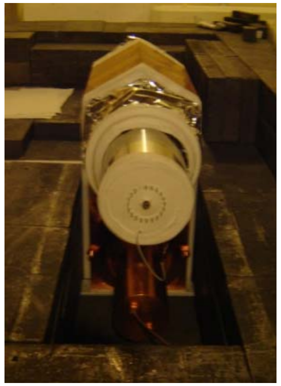




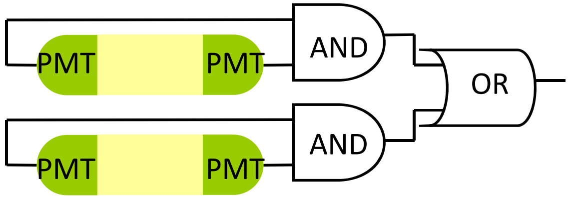
LOW ENERGY EVENTS: ^{40}K BULK CONTAMINATION

Measurement in coincidence among x-rays and Auger-e (3.2keV) in one detector and 1461 keV in another one.

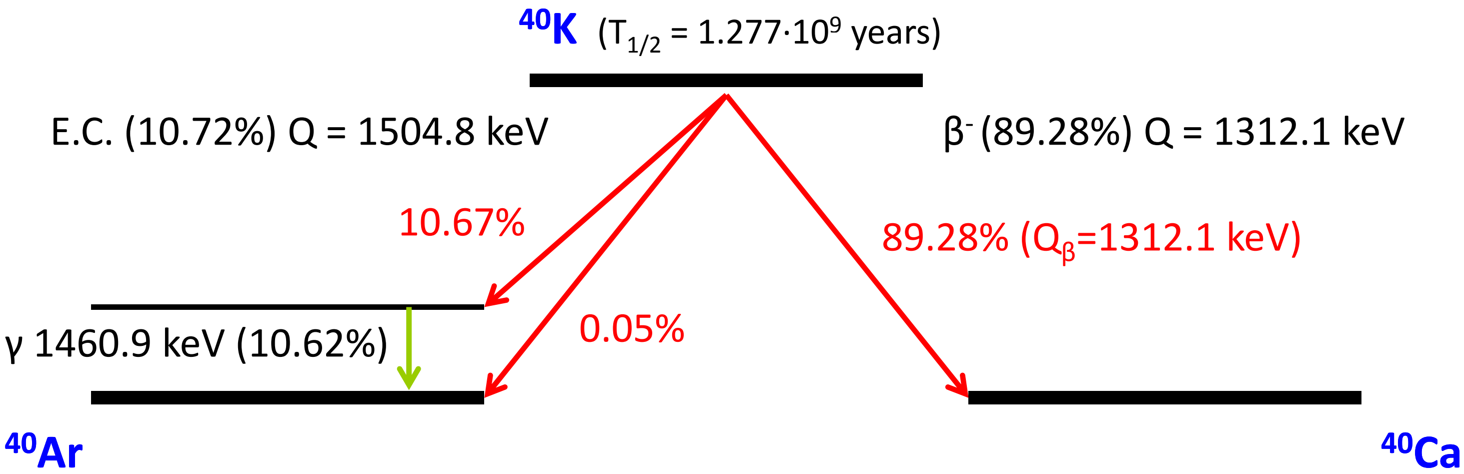




Trigger at single photoelectron in every PMT.

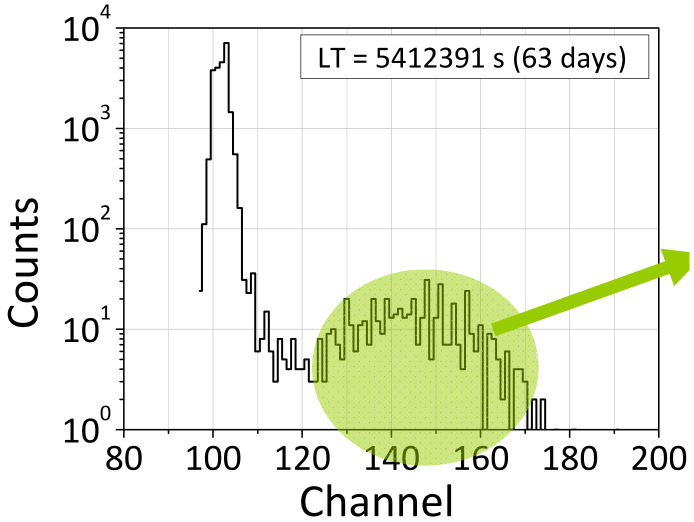


Software coincidence.

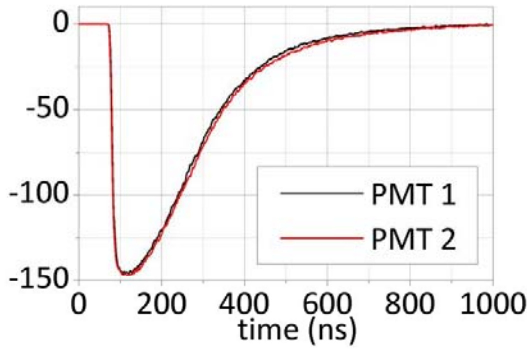


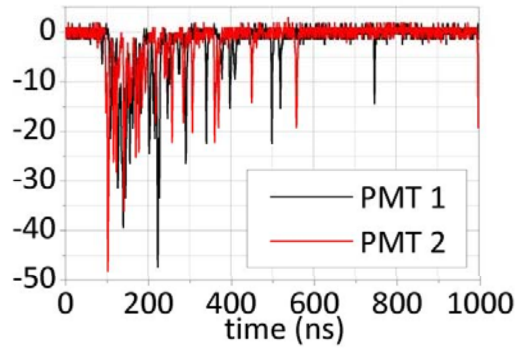
LOW ENERGY EVENTS: ^{40}K BULK CONTAMINATION

Spectrum of low energy events in ANAIS-0 in coincidence with a 1σ window at the 1460.9 keV peak in the other detector.

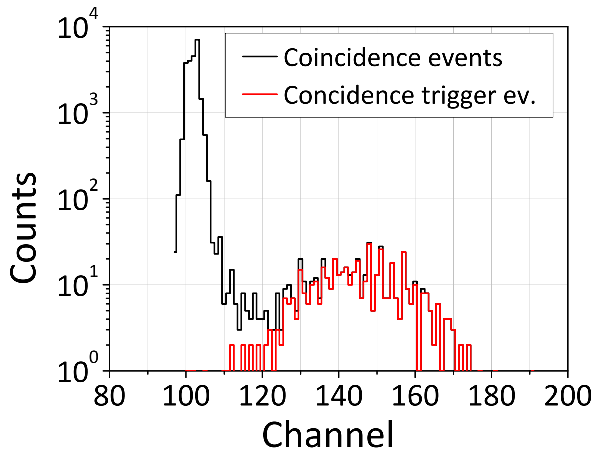


Scintillation events, with τ ≈ 230ns





Good trigger efficiency.



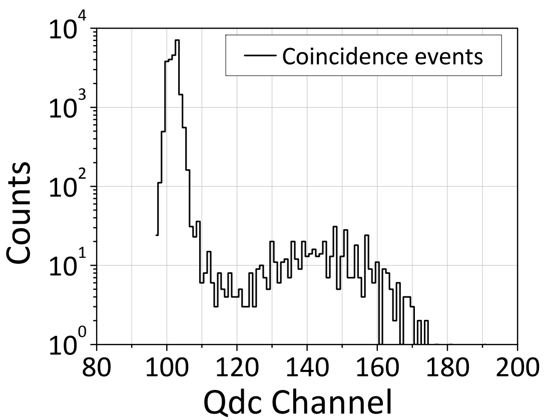
Result for ^{40}K bulk activity of the NaI(Tl) crystal (9.6kg):

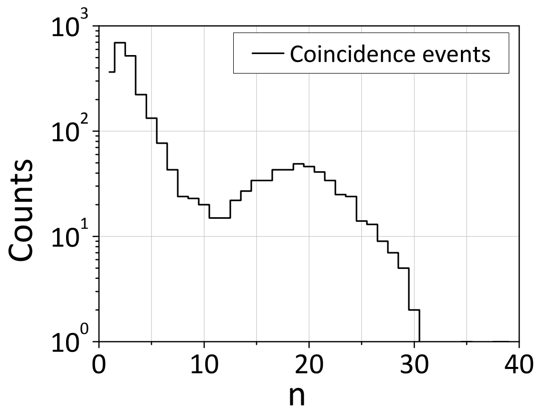
13.7 ± 0.6 mBq/kg

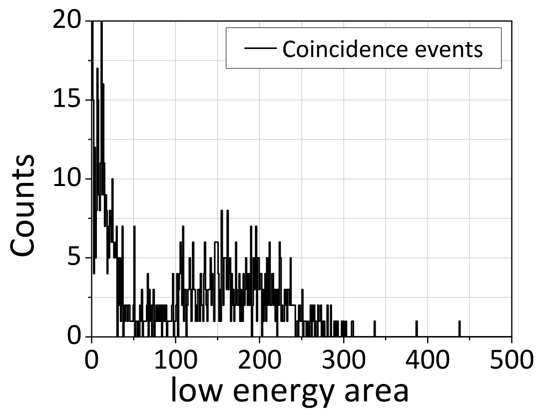
LOW ENERGY EVENTS: LOW ENERGY ESTIMATORS

Study of different low energy estimators with the **3.2keV** (^{40}K) events.

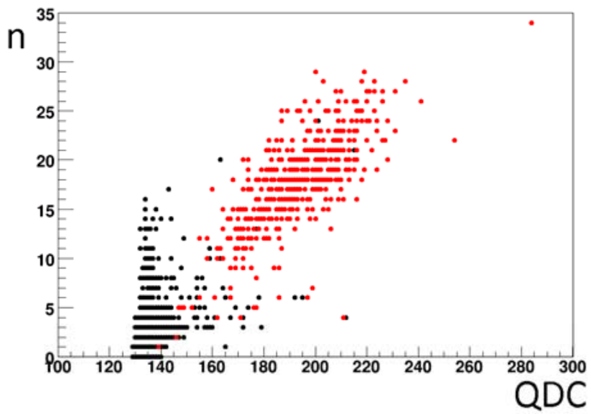
- **QDC**: charge converter.
- **n**: number of peaks in the pulse.
- **low energy area**: area of the peaks in the pulse.







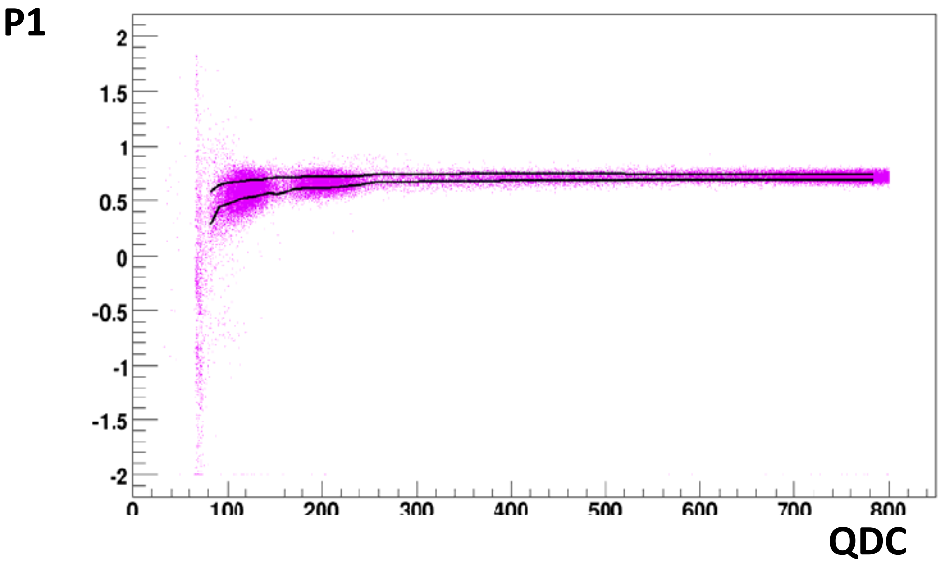
n vs adc plot distinguish noise (black) from ^{40}K events (red) → complementary information.

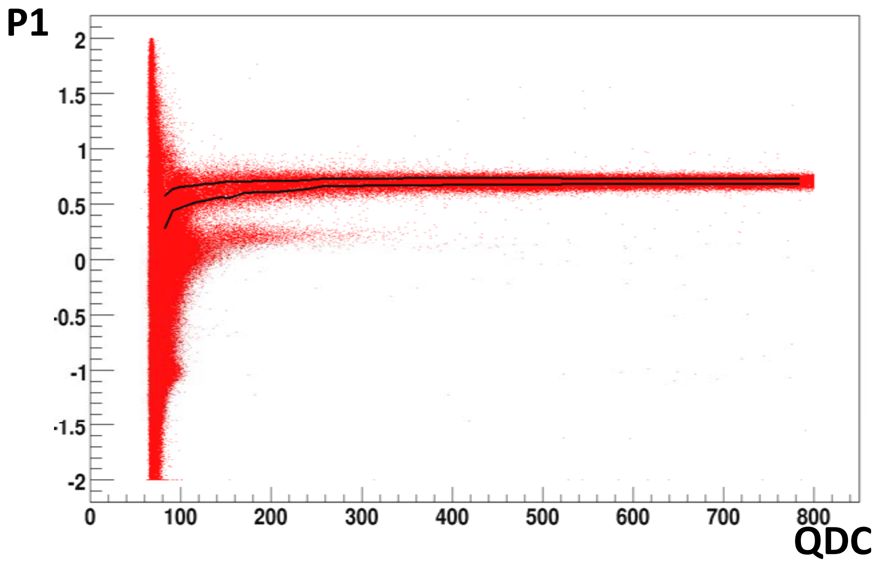


LOW ENERGY EVENTS: NOISE REJECTION

P1 is a parameter to distinguish between NaI(Tl) scintillation and noise.

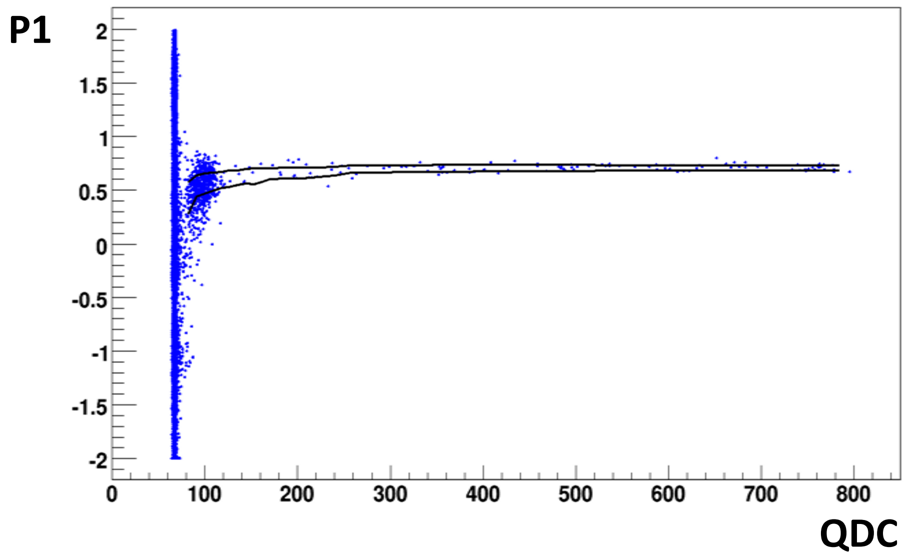
$$P1 = \frac{Area(100-600ns)}{Area(0-600ns)}$$





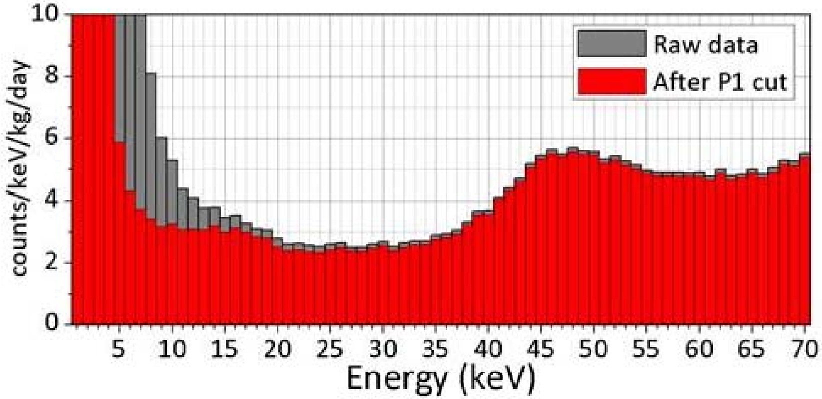
Average of the P1 values for the two PMT signals of ANAIS-0 when exposing the detector to a ^{57}Co source: population of bulk scintillation events (left) and background events (right). Solid line shows the 1σ region about the mean value of the parameter for calibration events.

LOW ENERGY EVENTS: NOISE REJECTION



3.2 keV events from ^{40}K are not rejected with this cut.

Low energy spectra with with and without noise cuts .



LIGHT COLLECTION VS BKG: PHOTOMULTIPLIERS

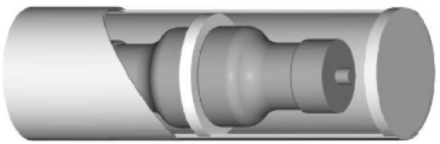
Test of different PMTs:

- Electron Tubes
  - 9302B → low background (**ET**)
- Hamamatsu
  - R6233-100 → High Quantum Efficiency (**Ham HQE**).
  - R6233-100 → low background (**Ham LB**).
  - R11065SEL → ultra low background (**Ham ULB**).

ANAIS-0.

HP Ge.

Test bench at Zaragoza.



ET

Ham HQE

Ham LB

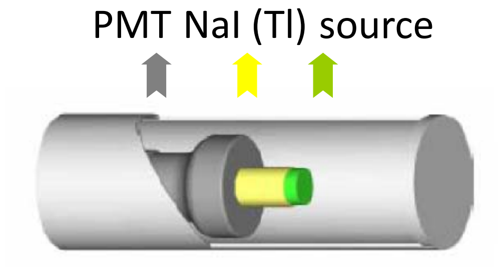
Ham ULB

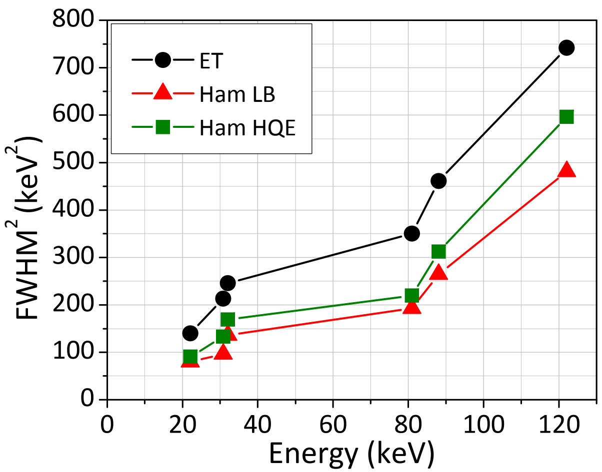
LIGHT COLLECTION VS BKG: RESOLUTION

Nominal quantum efficiency:

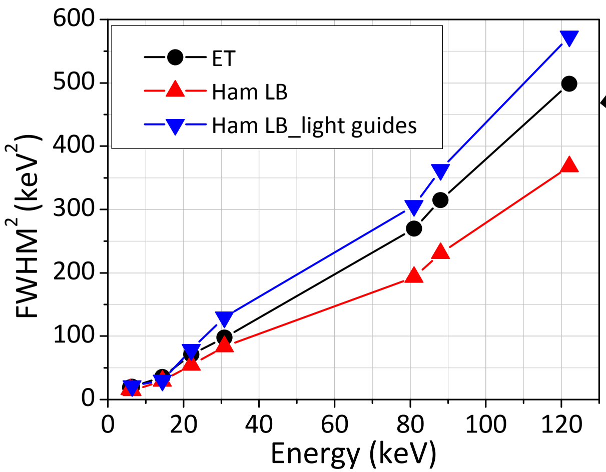
ET	Ham HQE	Ham LB	Ham ULB
30%	≥40%	≥35%	≥32%

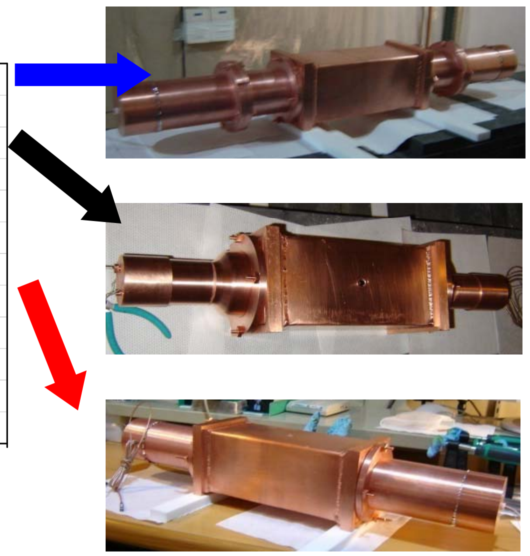
- **Test-bench at Zaragoza**





- **ANAIS-0 Measurements**





- Hamamatsu PMTs have better resolution than ET ones.
- Light guides worsen considerably resolution.

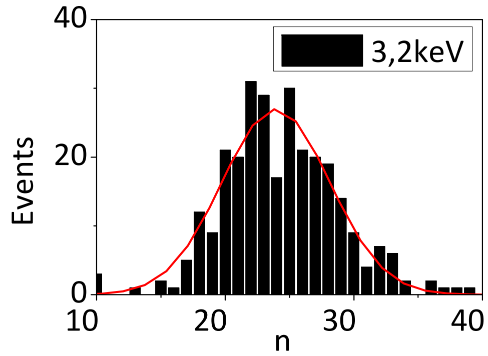
LIGHT COLLECTION VS BKG: EFFICIENCY

Photoelectrons / keV

n: number of peaks in the pulse

~ number of photoelectrons

Calculation of **n** for 3.2keV(^{40}K), selecting 1σ QDC



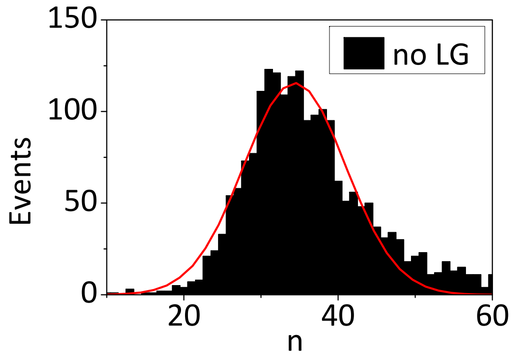
As a preliminary result (without LG):
7.5±2.5 phe$^-$/keV

n = 24 ± 8

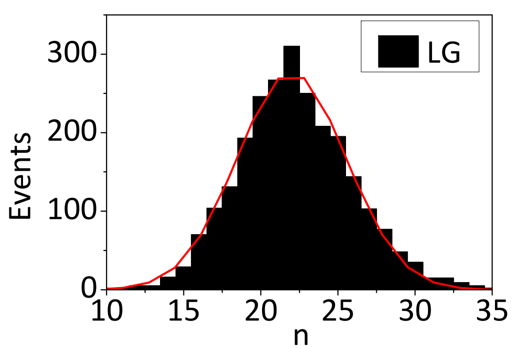
Effect of light guides in the light collection

Comparison of **n** with and without light guides .

Calculation of **n** for 6.4kev (^{57}Co), selecting 1σ QDC



n = 34 ± 13

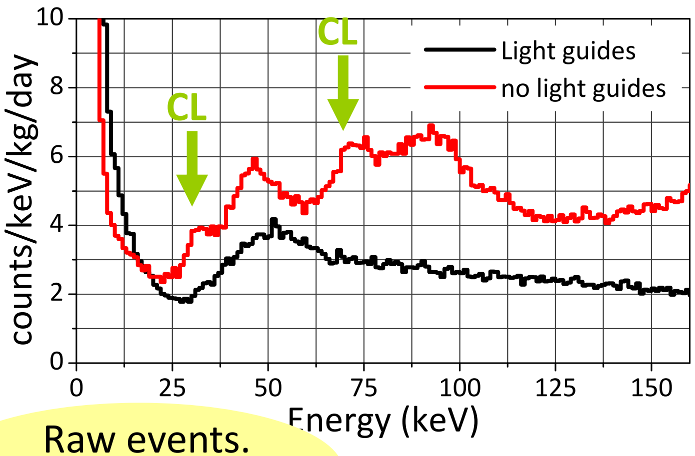


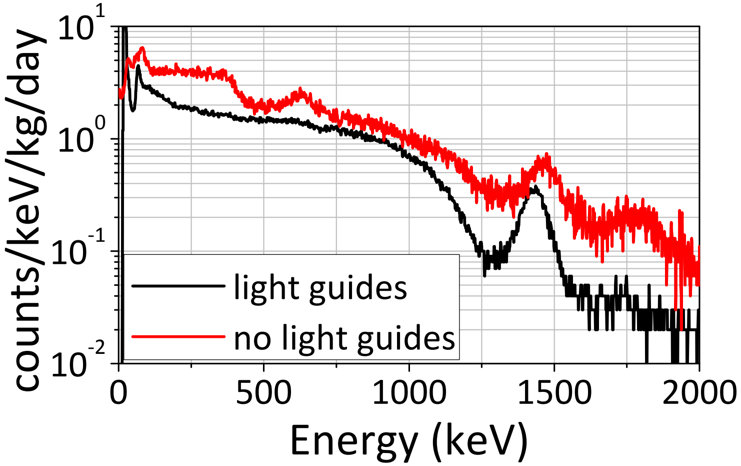
n = 22 ± 8

With light guides,
31% light collection less

LIGHT COLLECTION VS BKG: BACKGROUND

However, light guides improve background at low and high energy:





Raw events.
No noise cuts applied

Spectrum without light guides was obtained just after taking the crystal underground and cosmogenic lines (CL) can be seen.

With LG, background is dominated by crystal contamination.

Hamamatsu R11065SEL

- Ultra Low Background -> no light guides will be needed
- 2PMTs will be tested soon in ANAIS-0

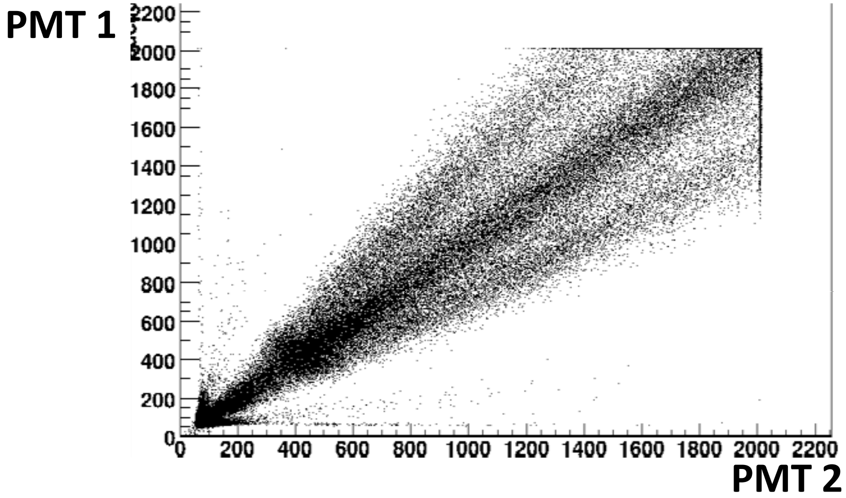
LIGHT COLLECTION VS BKG: RADIOPURITY

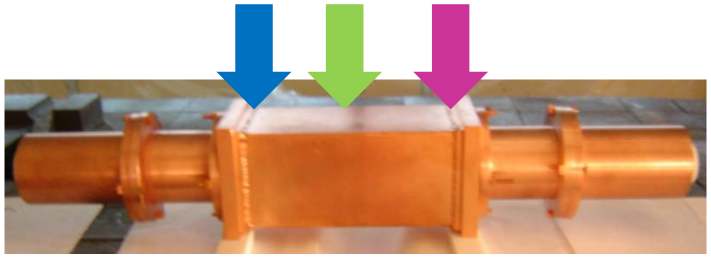
Radiopurity levels of the different PMTs tested at the low background HP Ge test bench in Canfranc.

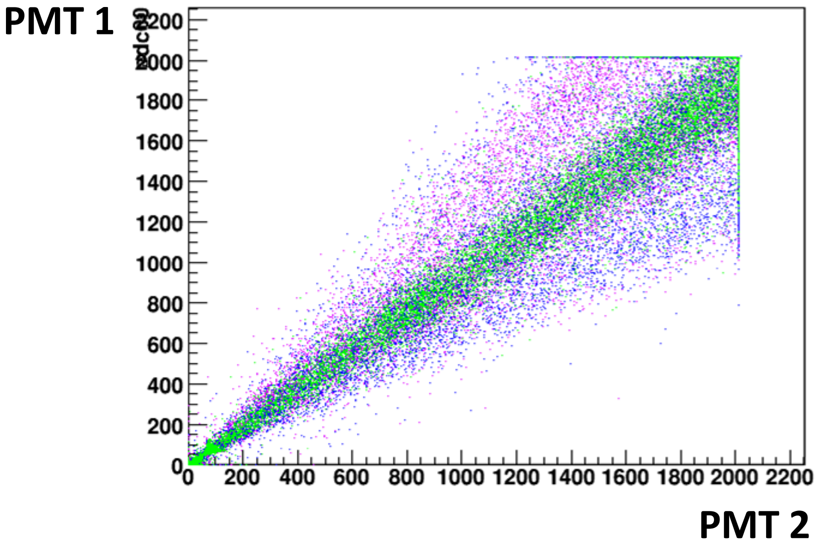
	^{40}K (mBq/PMT)	^{232}Th (mBq/PMT)	^{238}U (mBq/PMT)	^{60}Co (mBq/PMT)
ET	420 ± 50	24 ± 4	220 ± 12	-
Ham HQE (1066DA)	$(184.5 \pm 0.9) \cdot 10^3$	$(0.42 \pm 0.04) \cdot 10^3$	$(0.51 \pm 0.03) \cdot 10^3$	-
Ham LB (ZE5331)	678 ± 42	67.8 ± 2.8	100 ± 2.8	-
Ham ULB (ZK5171)	32 ± 9	1.9 ± 0.7	^{238}U - 33 ± 7 ^{226}Ra - 6.7 ± 0.9	3.7 ± 0.5

LIGHT COLLECTION VS BKG: ASYMMETRY EFFECTS

- Asymmetry in the sharing of the energy is observed in ANAIS-0.
- According to calibrations, lateral bands reflect background events coming from the sides.



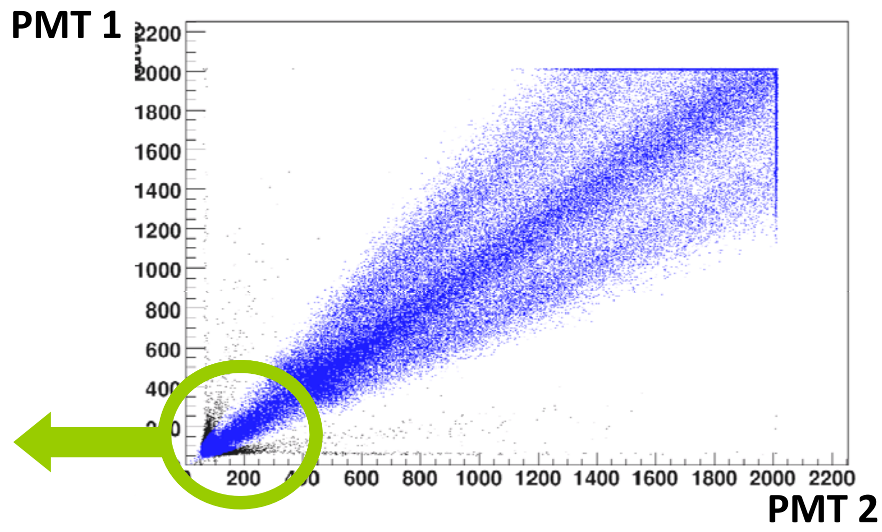


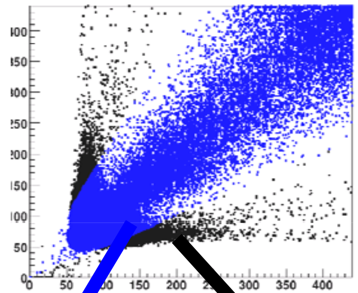


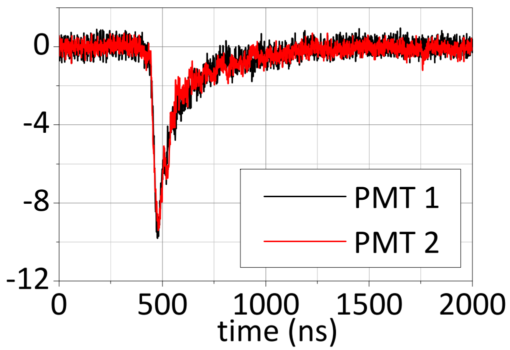
- Lateral events are not a huge amount. (~10% with LG and ~15% without LG).
- Contribution to the background from the LB PMTs used is suggested.

LIGHT COLLECTION VS BKG: ASYMMETRY EFFECTS

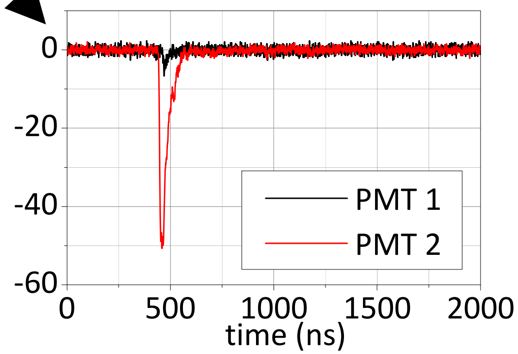
- Lateral events present normal scintillation shape, must not be rejected.
- However, the strongly asymmetric events can be rejected because they are non-bulk scintillation.







NaI(Tl) scintillation, τ = 230ns



Non-bulk scintillation, $\tau \neq$ 230ns

CONCLUSIONS

- A contract with Electrochemical Systems Inc. to purify NaI powder has been signed. If purification method is successful, 100kg -250kg will be purified. Two different methods (HP Ge and AAS) will be able to check this purity.
- On-going measurements in Canfranc with ANAIS-0 to characterize and fully understand ANAIS background at low energy, optimize noise cuts, determine the calibration method, test the electronics and improve the light collection efficiency.
- We have controlled populations of scincillation events (calibration sources and internal ^{40}K) at very low energy. They are very useful to calibrate and reject noise in the region where we will look for dark matter.
- Light guides worsen considerably the collection of the light but they are necessary to reduce the contribution of the PMTs to the background. Ultra low background photomultipliers from Hamamatsu (R11065) could solve this problem.