Preliminary results of ANAIS-25

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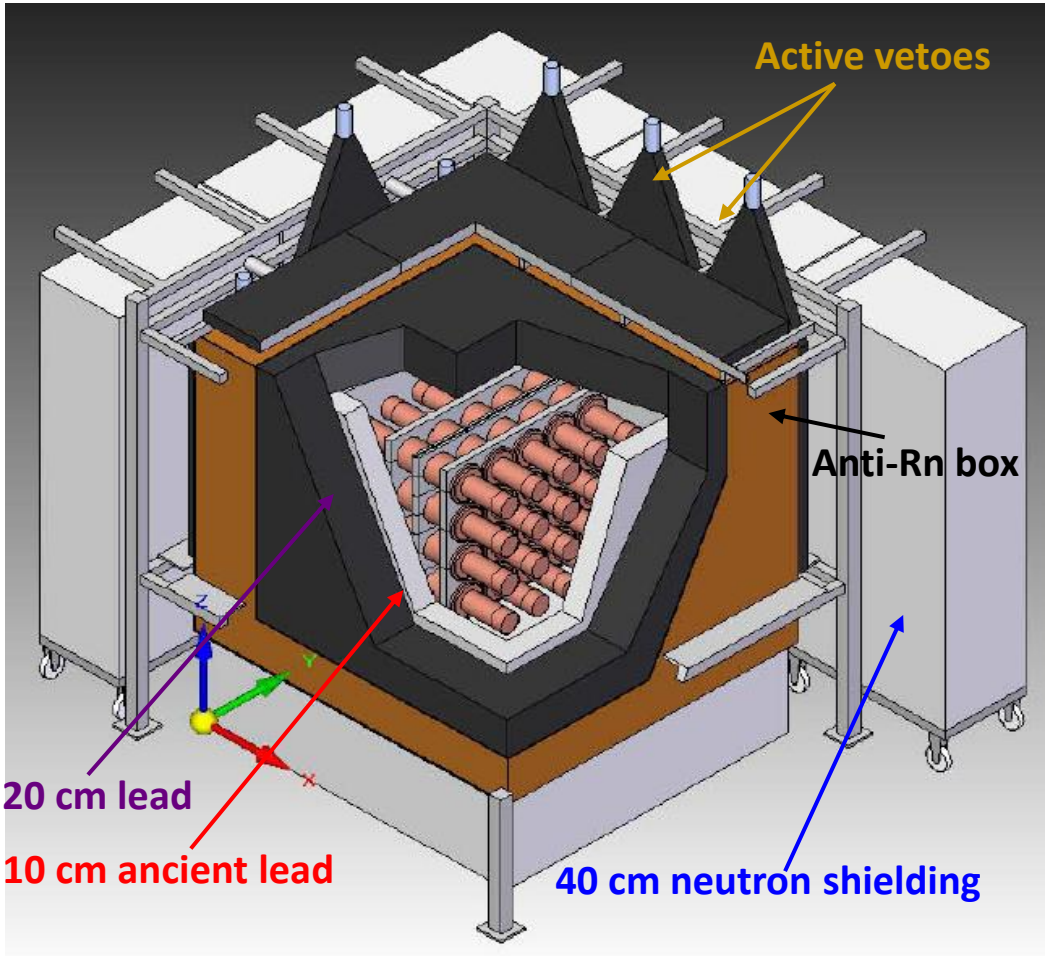
OUTLINE

1. ANAIS EXPERIMENT
2. EXPERIMENTAL SET-UP: ANAIS-0 AND ANAIS-25
3. LIGHT COLLECTION
4. BACKGROUND
5. EVENTS SELECTION
6. NaI(Tl) SCINTILLATION CONSTANTS

1. ANAIS EXPERIMENT

ANAIS is a project aiming to set up, at the new facilities of the Canfranc Underground Laboratory (Spain), a 250 kg potassium-purified NaI(Tl) experiment to look for dark matter.



Motivation

Study of the annual modulation DAMA/LIBRA positive signal. CoGeNT, CRESST, CDMS-Si results as another hint.

Technical aspects:

- 20 NaI(Tl) crystals of 12.5 kg.
- Coupled each one to 2 PMTs.
- Shielded from external radiation.

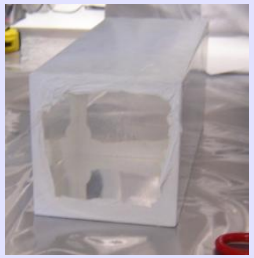
Experimental goals:

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

2. EXPERIMENTAL SET-UP: ANAIS-0 MODULE

Measurements from April 2009 to November 2012 at the Canfranc Underground Laboratory to:

- Characterize ANAIS background.
- Optimize events selection.
- Design the calibration method.
- Test the acquisition code and electronics.
- Determine the optimum configuration of photomultipliers and light guides.



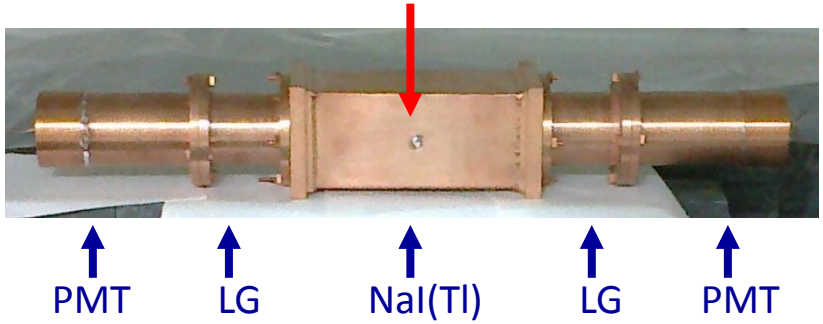
NaI(Tl) (9.6kg) old crystal made by St Gobain.

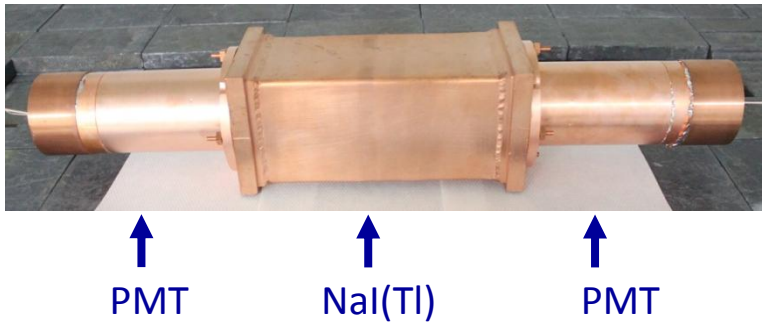
254x101.6x101.6mm^3

Copper encapsulation allowing different configurations and tests of PMTs.

Set-up	PMT	Light guides
1	ET LB	No
2	Ham LB	Yes
3	Ham ULB	Yes
4	Ham ULB	No
5	Ham VLB	No

Mylar window allowing low energy calibrations.

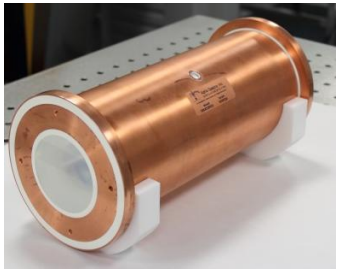




2. EXPERIMENTAL SET-UP: ANAIS-25 ULTRAPURE NaI(Tl) CRYSTALS

2 ultrapure NaI(Tl) (12.5 kg) crystals made by Alpha Spectra.

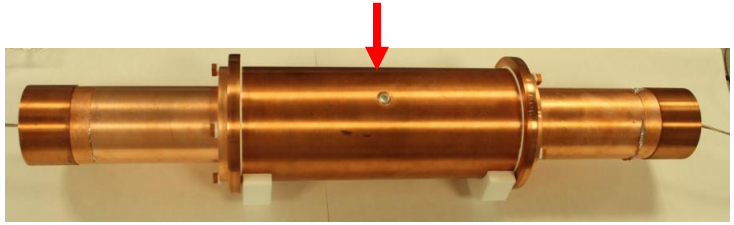
4.75“ ϕ x 11.75"



OFHC copper encapsulated.
Tightly closed with quartz windows.
PMTs coupled at the LSC clean room.

Mylar window allowing low energy calibrations.

D0 →

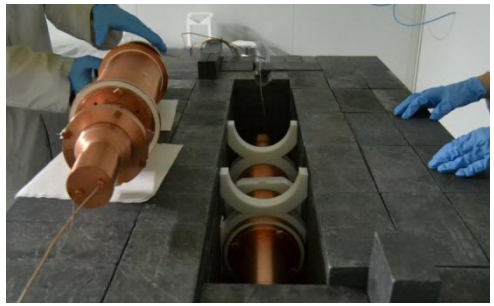


D1 →

Detector	PMT	Light guides
0	Ham VLB	No
1	Ham ULB	No

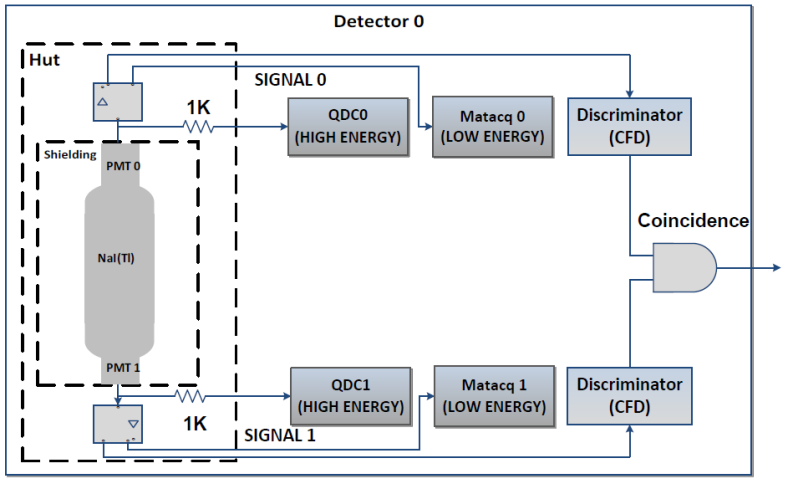
Measurements from December 2012 at the new facilities of the LSC to determine their bulk contamination:

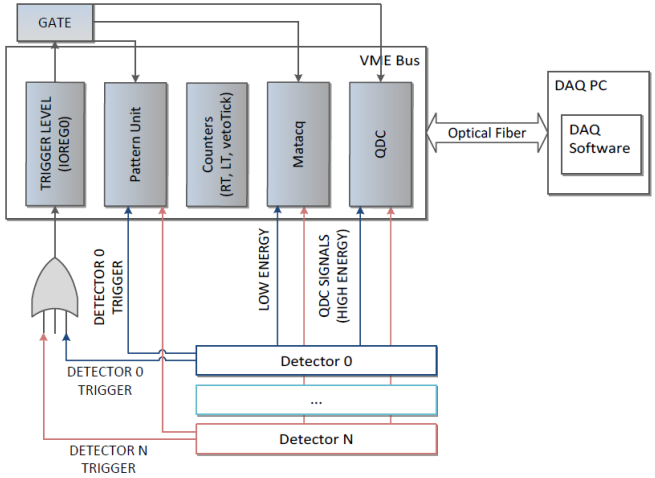
- ^{40}K coincidence measurement to quantify potassium contamination. (Ultrapure NaI powder < 100 ppb K).
- ^{232}Th and ^{238}U natural chains content.



2. EXPERIMENTAL SET-UP: HUT, SHIELDING AND ELECTRONICS

- **Hut and control room** : already constructed @ LSC Hall B.
- **ANAIS-0 and ANAIS-25 shielding:**
  - 10 cm roman lead + 20 cm lead.
  - Active vetoes anti-muons (partial coverage).
  - Anti-radon box.
  - Neutron shielding (to be accomplished).
- **VME electronics** and final acquisition software and hardware fully commissioned and tested for 2 channels. All the modules for the whole experiment purchased.





3. LIGHT COLLECTION: PHOTOMULTIPLIERS

Several models tested in ANAIS-0 to decide the model to be used in ANAIS.

QE min @420 nm: **32 %** **<30%>** **33%**

The radioactivity levels have been measured with a HP Ge detector at LSC:

	^{40}K (mBq/PMT)	^{232}Th (mBq/PMT)	^{238}U (mBq/PMT)	^{60}Co (mBq/PMT)
Low background Electron Tubes Limited 9302B	420 ± 50	24 ± 4	220 ± 12	-
Low background Hamamatsu R6233-100 MOD	678 ± 42	68 ± 3	100 ± 3	-
Ultra low background Hamamatsu R11065SEL	12 ± 7	3.6 ± 1.2	^{238}U - 47 ± 28 ^{226}Ra – 8.0 ± 1.2	4.1 ± 0.7
Very low background Hamamatsu R6956 MOD SEL	97 ± 19	20 ± 2	^{238}U - 128 ± 38 ^{226}Ra – 84 ± 3	-

3. LIGHT COLLECTION: PHOTOMULTIPLIERS

Best options to be considered are tested in ANAIS-25:
ULB: Very low background levels .
VLB: High QE and very convenient rapport radioactivity-price.

32 %

<30%>

33%

	^{40}K (mBq/PMT)	^{232}Th (mBq/PMT)	^{238}U (mBq/PMT)	^{60}Co (mBq/PMT)
Low background Electron Tubes Limited 9302B	420 ± 50	24 ± 4	220 ± 12	-
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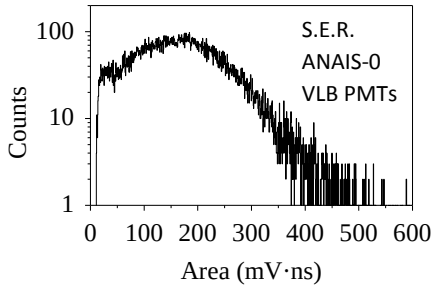
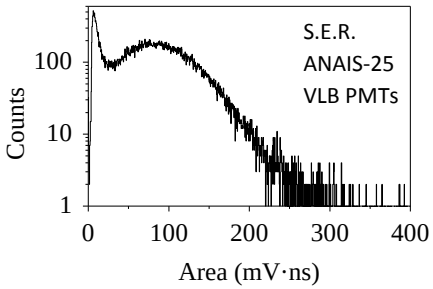
Very low background Hamamatsu R6956 MOD SEL	97 ± 19	20 ± 2	^{238}U - 128 ± 38 ^{226}Ra – 84± 3	-

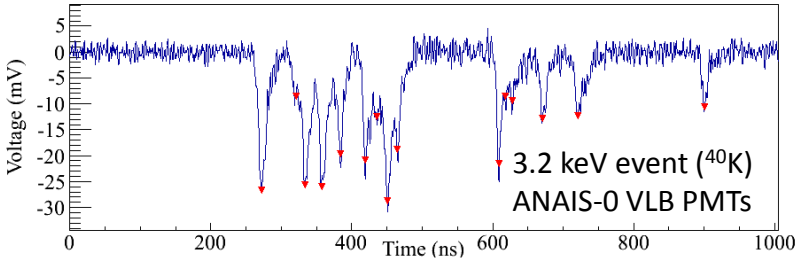
3. LIGHT COLLECTION: S.E.R. and phe./keV

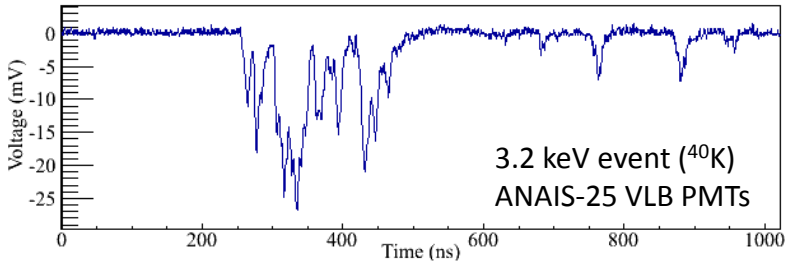
Single Electron Response:

- Algorithm to identify single peaks in the pulse.
- S.E.R.: Derived from the last peak identified in the pulse.









Phe./keV: 22.6 keV (^{109}Cd) area compared to S.E.R. area.

Set-up	PTM	Light guides	Phe$^-$/keV
ANAIS-0 set-up 4	Ham ULB	No	5.34 ± 0.05
ANAIS-0 set-up 5	Ham VLB	No	7.38 ± 0.07
ANAIS-25 detector 0	Ham VLB	No	16.13 ± 0.66
ANAIS-25 detector 1	Ham ULB	No	12.58 ± 0.13

Results:

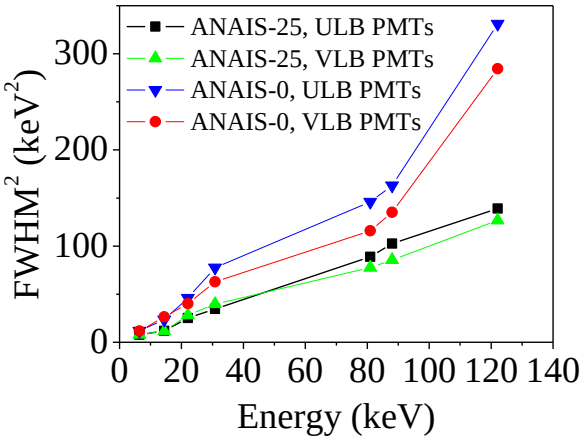
- VLB PMTs seem a good option: better Q.E. than ULB although worse bkg.
- ANAIS-25: Significant improvement in light collection.

3. LIGHT COLLECTION: RESOLUTION

Set-up	PTM	Light guides	Resolution (σ/E) (%)	
			14.4 keV	122.1 keV
ANAIS-0 set-up 3	Ham ULB	Yes	17.60	7.18
ANAIS-0 set-up 4	Ham ULB	No	14.36	6.34
ANAIS-0 set-up 5	Ham VLB	No	15.18	5.88
ANAIS-25 Detector 0	Ham VLB	No	10.20	4.11
ANAIS-25 Detector 1	Ham ULB	No	10.00	3.91

Results:

- VLB PMTs seem a good option: better Q.E. than ULB although worse bkg.
- ANAIS-25: Significant improvement in light collection.



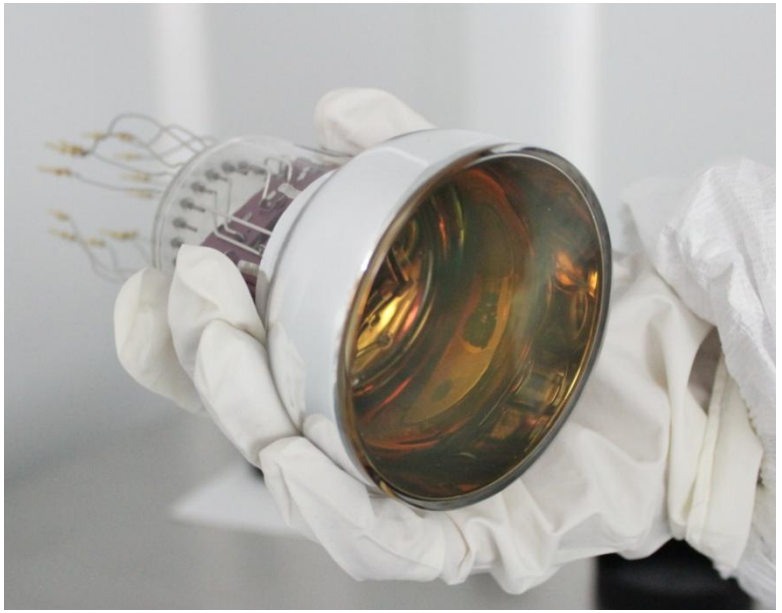
3. LIGHT COLLECTION: PHOTOMULTIPLIERS

After the light collection and background measurements, the VLB model has been chosen:

42 units of the Hamamatsu R12669-SEL2 model have been ordered.

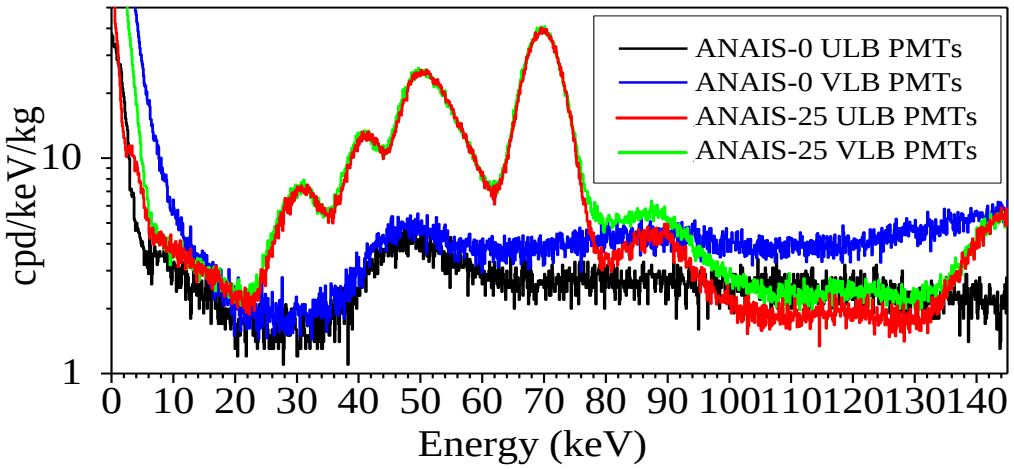
- Dark current <500 Hz.
- Quantum efficiency >33 % at 420 nm.
- Radioactivity of each unit will be screened at the LSC HP Ge spectrometers.
  Radioactivity results for one unit:

^{40}K	^{232}Th	^{238}U
mBq/PMT		
97 ± 19	20 ± 2	^{238}U - 128 ± 38 ^{226}Ra – 84 ± 3



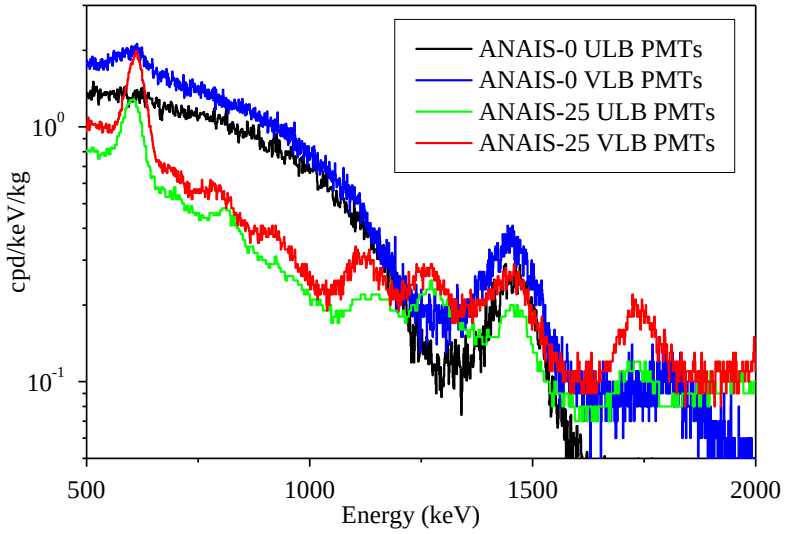
If possible light guides will be avoided (~30 % more light).

4. BACKGROUND: RAW BACKGROUND



Cosmogenic lines and ^{222}Rn in air present in first weeks of ANAIS-25 data.

No filtering applied.



Results:

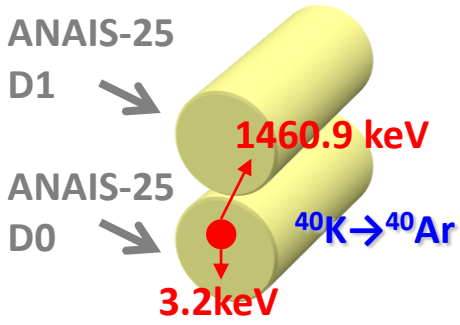
- PMT background contribution can be seen at medium and high energy, but the effect of VLB PMTs without light guides seems to be minor in the LE region .
- Lower background in ANAIS-25 data above 100 keV. Below 100 keV background is dominated by cosmogenic contributions.

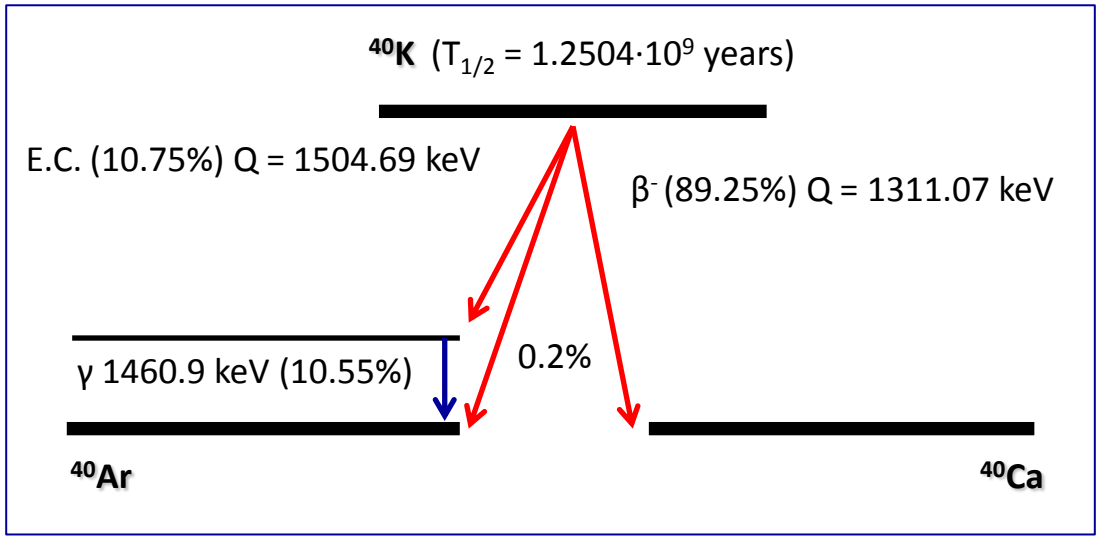
4. BACKGROUND: ^{40}K BULK CONTENT

Measurement in coincidence

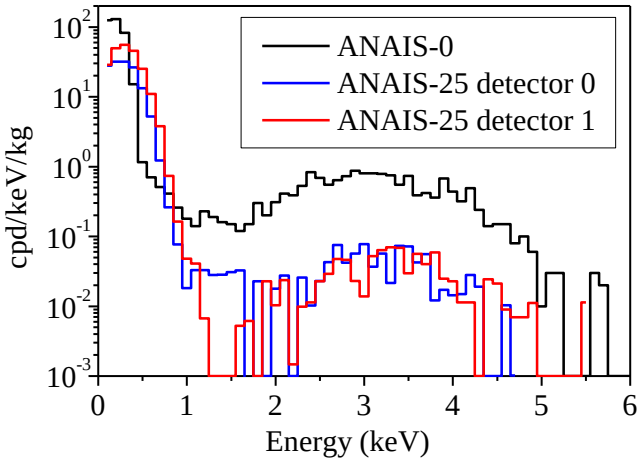
We search for 3.2 keV in one detector and 1460.9 keV in the other.

Efficiency of the coincidence determined by MC.





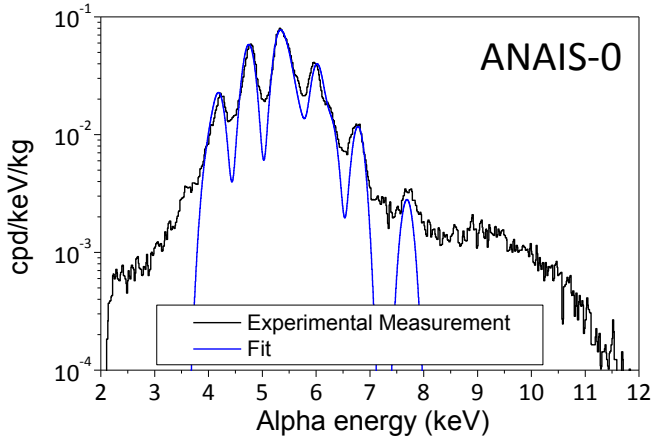
Detector	K content (ppb)
ANAIS-0	420 ± 20
ANAIS-25	41.7 ± 3.7



4. BACKGROUND: ^{232}Th and ^{238}U CHAINS

ANAIS-0

1) α events can be discriminated from β/γ by PSA.
2) α - α events from Bi-Po sequences have been identified and used for calibration of the spectrum.
3) α spectrum has been fitted allowing broken equilibrium in natural chains.

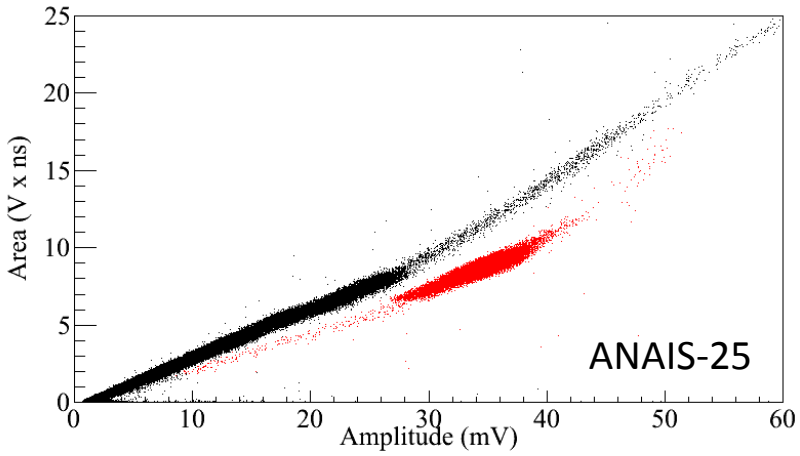


ANAIS-0	
Parent Isotope	**Activity** (mBq/kg)
^{232}Th	0.013 ± 0.005
^{228}Th	0.035 ± 0.003
^{238}U / ^{234}U	0.075 ± 0.005
^{230}Th	0.023 ± 0.007
^{226}Ra	0.098 ± 0.004
^{210}Pb	0.188 ± 0.005

ANAIS-25

High α rate → 3.15 mBq/kg.

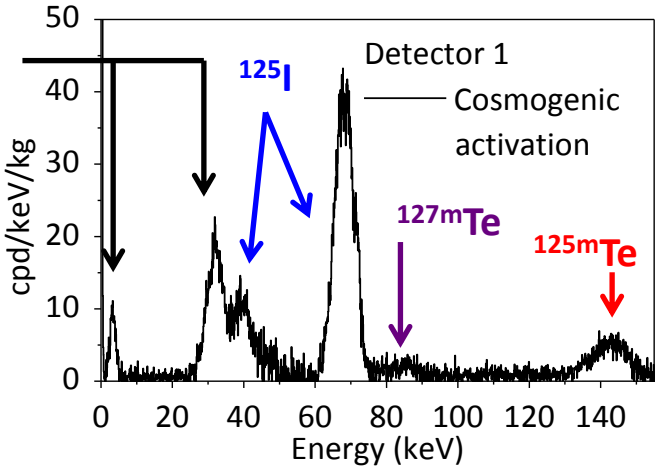
- Thorium chain seems very suppressed.
- Measurements on-going to better calibrate and determine activities in the ^{238}U chain.



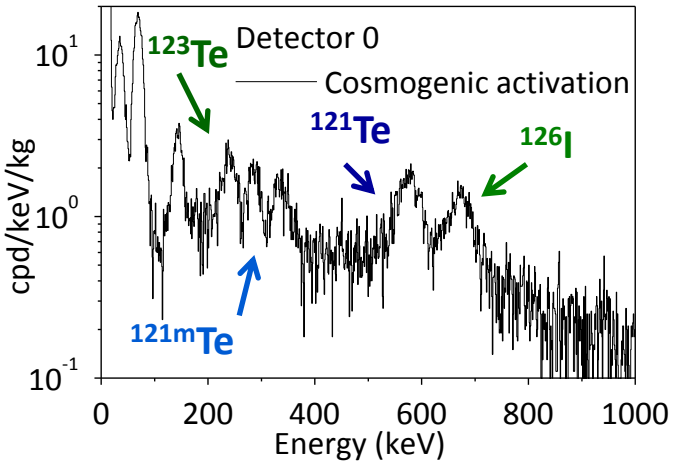
4. BACKGROUND: ANAIS-25 COSMOGENIC ACTIVATION

Fast commissioning and good resolution.

L/K shell binding energies from Sb/Te following EC in Te/I.



^{222}Rn in air present in in the first week of data.



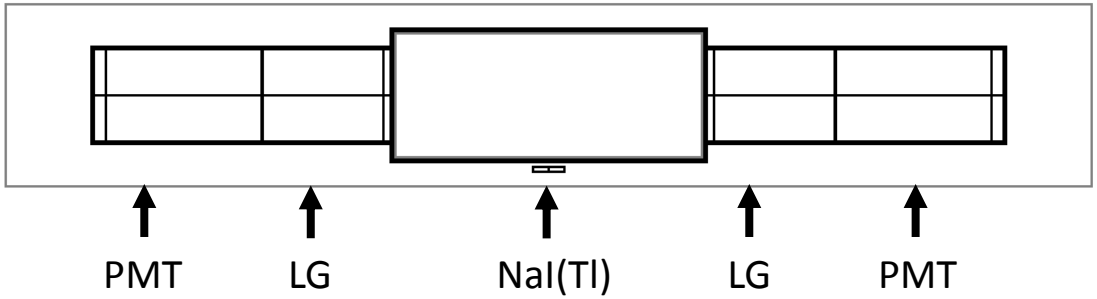
With the difference from the first week of measurements and a week 70 days after, several isotopes identified:

Isotope	Lifetime	Decay	Main γ emissions
^{125}I	59.4 d	EC	35.5
^{126}I	13.11 d	EC, β^-	666.0
^{121m}Te	154 d	IT, EC	294.0
^{121}Te	16.8 d	EC	507.6, 573.1
^{123}Te	119.7 d	IT	247.6
^{125m}Te	57.4 d	IT	144.8
^{127m}Te	109 d	IT, β^-	88.3

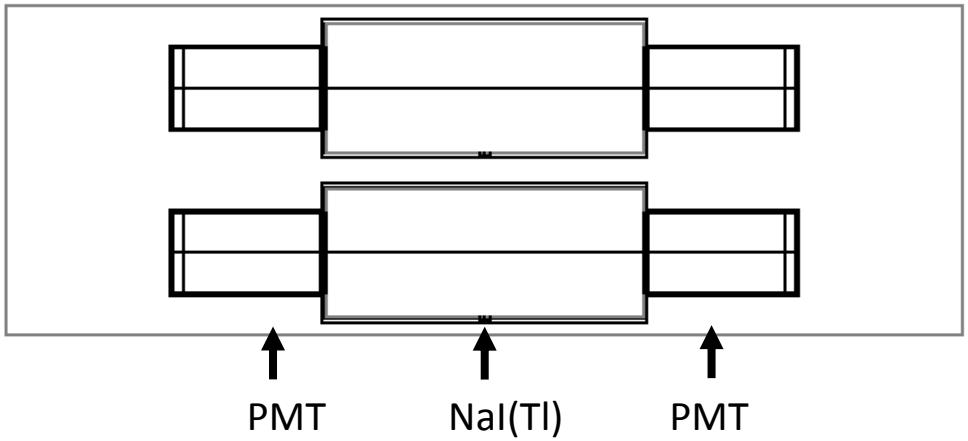
4. BACKGROUND: BACKGROUND MODEL

- **Geant4.9.4.p01:** Energy conservation in the decays has been checked.
  Some improvements in the code with respect to previous versions.

- **ANAIS-0 geometry**



- **ANAIS-25 geometry**



Quartz windows
Optional light guides
Copper encapsulation
Shielding:
- 10 cm roman lead
- 20 cm lead

Optional calibration source

4. BACKGROUND: ANAIS-0 BACKGROUND MODEL

Complete background model developed.

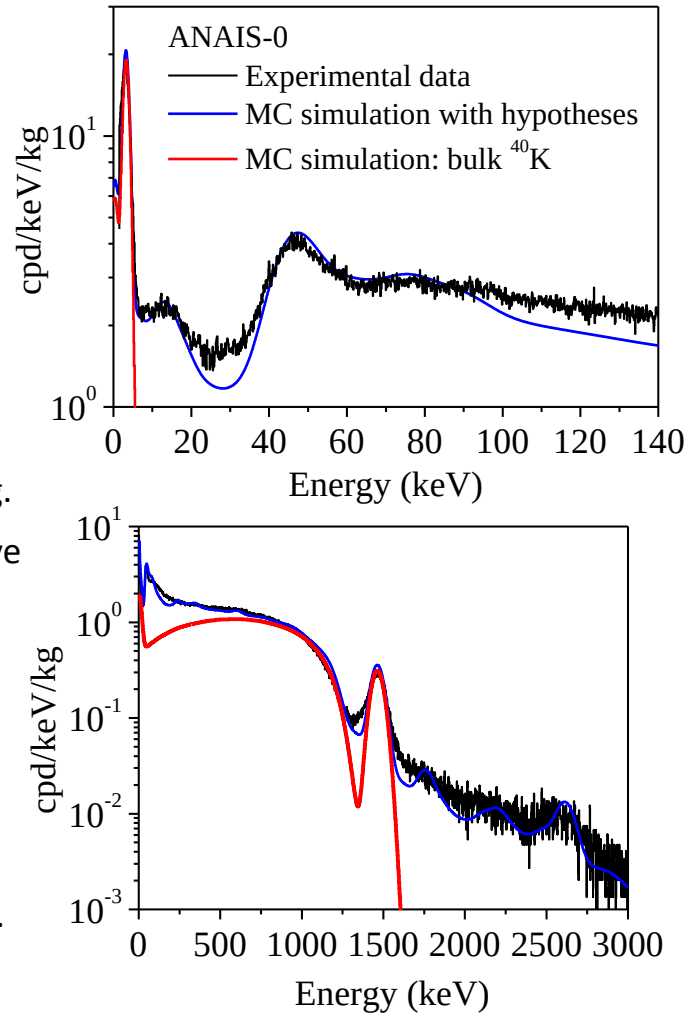
- Bulk contaminations in NaI(Tl) crystal of:

  $^{40}K \rightarrow$ Coincidence measurement

  ^{232}Th, ^{228}Th, ^{238}U, ^{234}U, ^{226}Ra and $^{210}Pb \rightarrow$ PSA

  $^{129}I \rightarrow$ 9.01 mBq/crystal, *NIM A 592 (2008) 297*

- Photomultipliers contaminations (HPGe).
- Upper limits for contamination in quartz windows, light guides, copper, roman lead and optical grease (HPGe).
- Radon content in the air filling the inner volume of the shielding.
- At low energy we find some non-explained components: we have considered some hypotheses to explain those events but no "fitting" has been tried.
  - Addition of ^{210}Pb contamination at the surfaces of NaI(Tl) crystal and copper encapsulation.
  - Addition of ^{210}Pb contamination at shielding.
  - Addition of ^{3}H contamination in the bulk of the NaI(Tl).
  - Increase in the ^{129}I at NaI(Tl) activity previously assumed .
  - Some upper limits (^{238}U and ^{232}Th) have been reduced.



[Astrop. 37 (2012) 60-69]

4. BACKGROUND: ANAIS-25 BACKGROUND MODEL

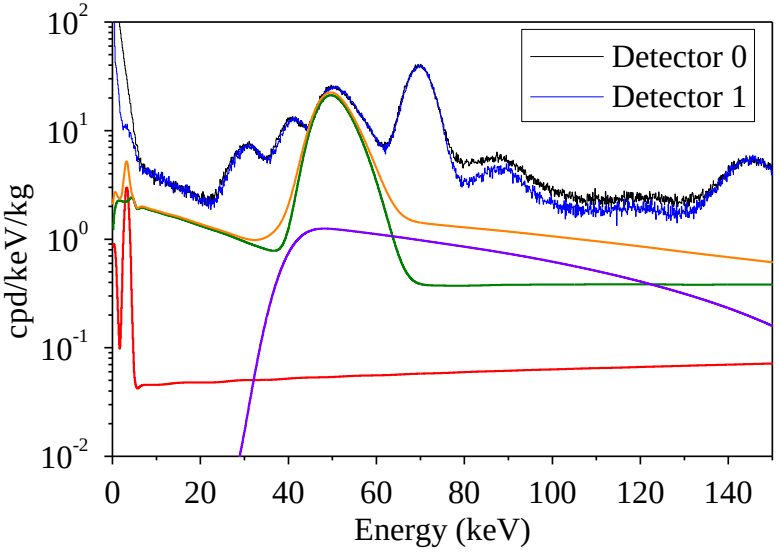
Preliminary results:

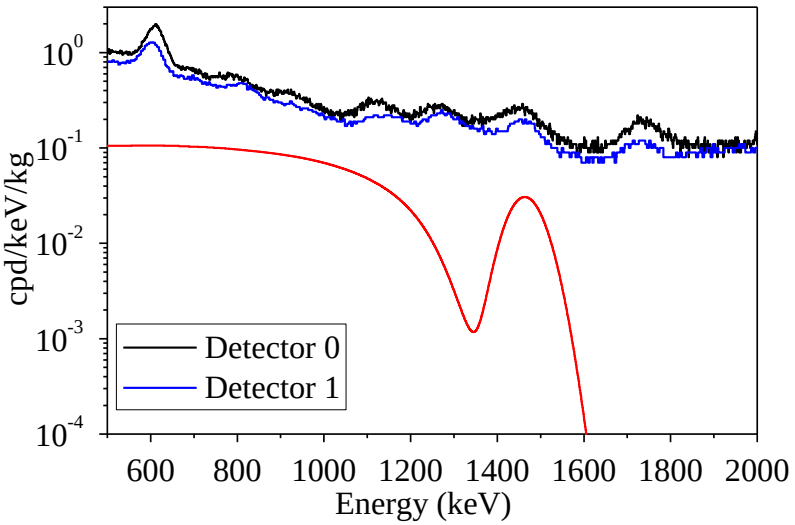
- Bulk contaminations in NaI(Tl) crystal of:

  ^{40}K → 1.25 mBq/kg, coincidence measurement.

  ^{210}Pb → 3.15 mBq/kg, total alpha activity assumption.

  ^{129}I → 0.94 mBq/kg, *NIM A 592 (2008) 297.*





On-going simulations for the rest of components.

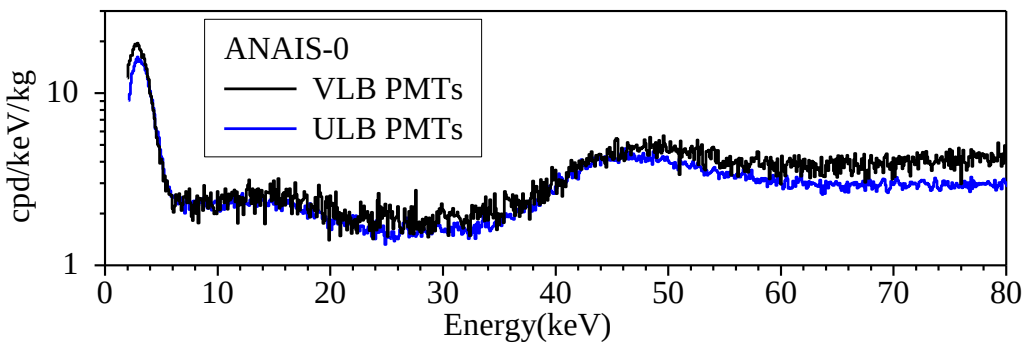
5. EVENTS SELECTION: ANAIS-0

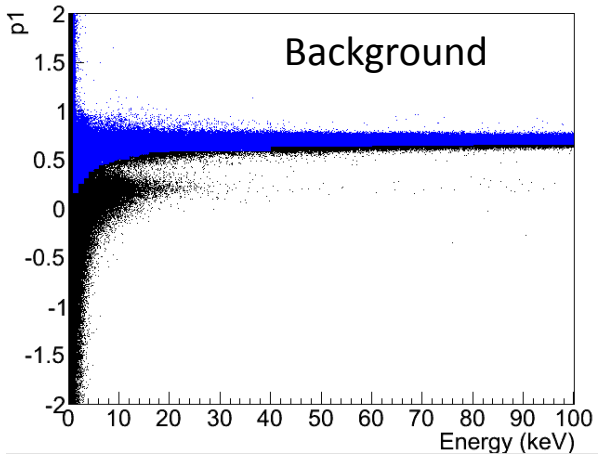
A protocol to reject non NaI(Tl) scintillation events developed:

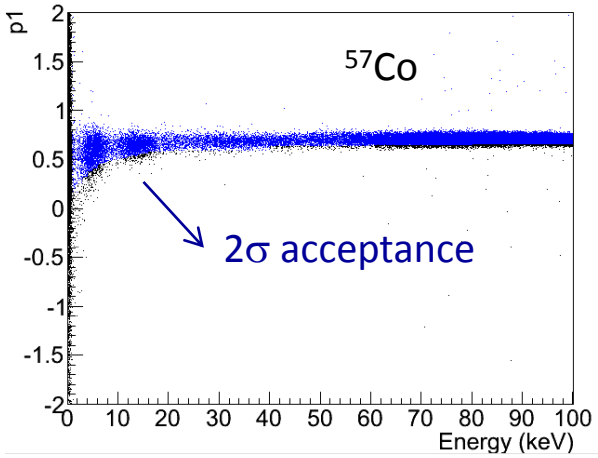
- Periods of anomalous high rate are not considered.
- Muon related events are rejected.
- NaI(Tl) scintillation events selected through:
  - number of photoelectrons (n > 3).
  - p1 parameter.

$$p1 = \frac{Area1(100-600ns) + Area2(100-600ns)}{Area1(0-600ns) + Area2(0-600ns)}$$

Efficiency checked with calibrations down to 2 keVee.





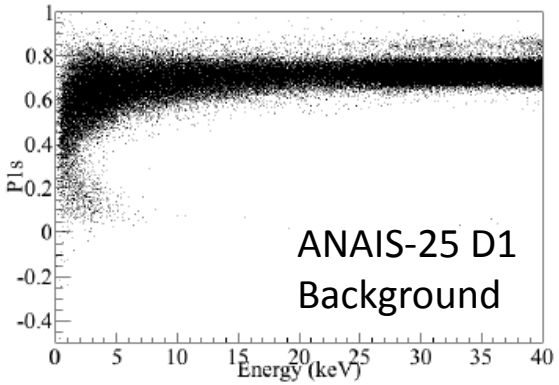


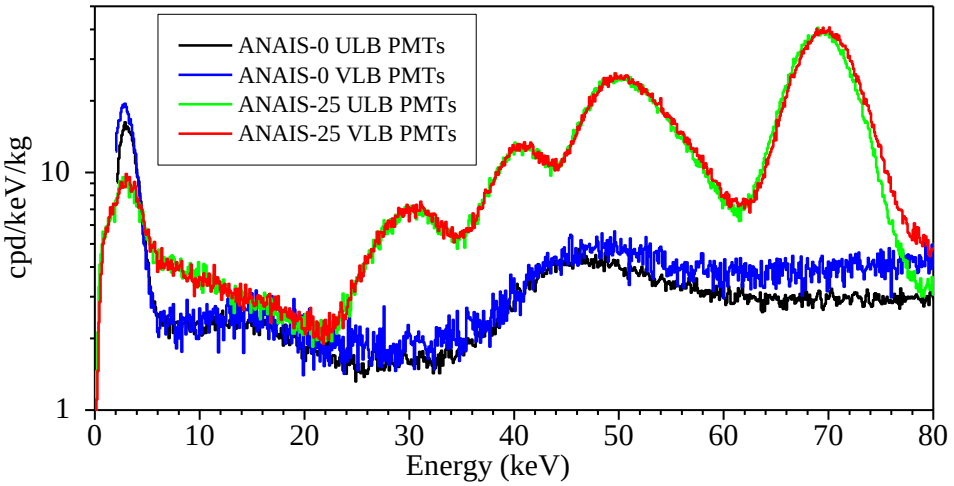
5. EVENTS SELECTION: ANAIS-25

A protocol to reject non NaI(Tl) scintillation events is being developed:

- Periods of anomalous high rate are not considered
- Rejection of muon related events. *Not yet applied.*
- NaI(Tl) scintillation events selected through:
  - number of photoelectrons (n_{ULV} > 3 & n_{VLB}>5).
  - p1 parameter. *Not yet applied.*

Further efforts to determine the effective experimental threshold. Threshold below 2 keVee could be achieved.





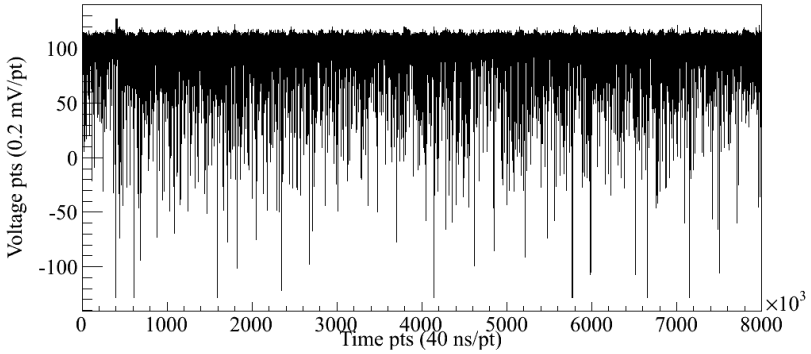
Cosmogenic lines present in ANAIS-25 data.

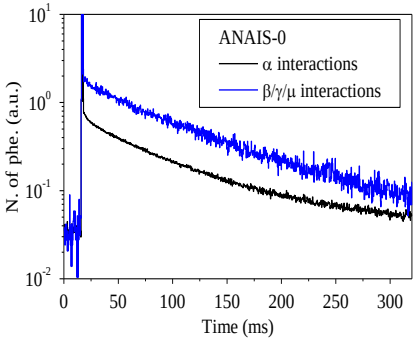
Low energy response carefully studied for ANAIS-0 and and in progress for ANAIS-25 data:

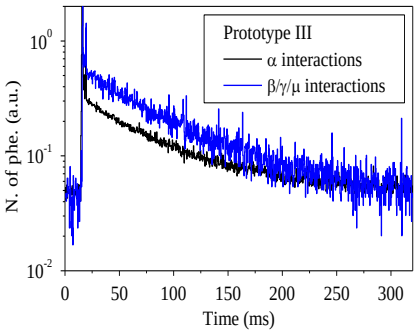
- Trigger efficiency at phe. level.
- Low energy calibrations (including a neutron calibration).
- Asymmetry in the sharing of the energy between the two PMT signals.
- Muon related events identification.

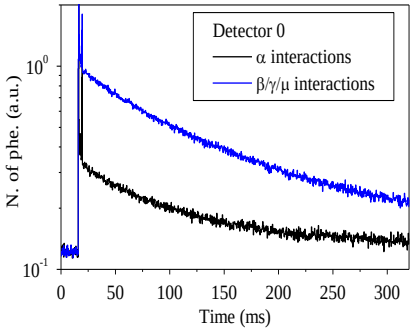
6. NaI(Tl) SCINTILLATION CONSTANTS

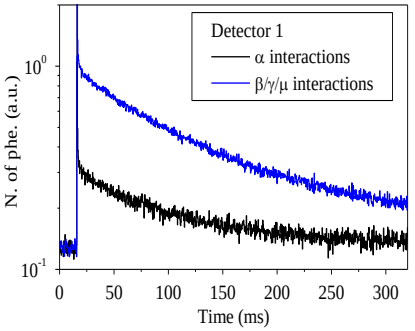
- We have determined in a precise way the time constants of the NaI(Tl) phosphorescence.
- A long-life scintillation component in NaI put in evidence after muon energy deposition in ANAIS-0, Prototype III, ANAIS-25 detector 0 and detector 1 (but with different amplitude).











- Differences observed between α and β/γ/μ interactions (especially in amplitude).

Detector	τ_1(ms)		τ_2(ms)	
	α	β/γ/μ	α	β/γ/μ
ANAIS-0	10.7 ± 0.3	22.7 ± 2.3	79.0 ± 0.3	92.3 ± 1.6
PIII	34.2 ± 4.7	19.8 ± 10.3	81.7 ± 4.1	75.77 ± 2.7
Detector 0	54.1 ± 3.8	52.5 ± 2.4	174.4 ± 17.5	171.5 ± 4.2
Detector 1	42.2 ± 7.2	59.6 ± 3.1	128.6 ± 12.8	186.7 ± 9.7

CONCLUSIONS

- **ANAIS-0 results.**

  ANAIS-0 (old NaI crystal) has been taking data at the LSC to test new PMTs, optimize electronic chain and acquisition protocols, characterize ANAIS background, optimize events selection and design the calibration method.

  Best configurations: Ultra low background PMTs and VLB PMTs.

  Low energy events selection procedure has been carefully studied and efficiency of the cuts have been estimated.

  Background model explains satisfactorily background measurements.

- **ANAIS-25 preliminary results.**

  2 ultrapure NaI(Tl) crystals from Alpha spectra (12.5 kg each) being tested at the LSC.

  Outstanding light collection.

  Potassium content of 41.7 ± 3.7 ppb.

  Alphas rate too high, possible ^{210}Pb bulk contamination under investigation.

  On-going discussion with Alpha Spectra trying to improve the ^{40}K and ^{210}Pb contamination contents of the crystals before deciding to buy the 250kg. Next months will be crucial.