The ANAIS-112 experiment at the Canfranc Underground Laboratory

- Goals and history
- Detectors, shielding and DAQ
- Detector response
- Radiopurity and background
- Sensitivity

J. Amaré, **S. Cebrián**, I. Coarasa, C. Cuesta, E. García, M. Martínez, M. A. Oliván, Y. Ortigoza, A. Ortiz de Solórzano, J. Puimedón, A. Salinas, M. L. Sarsa, P. Villar and J. A. Villar

Goals

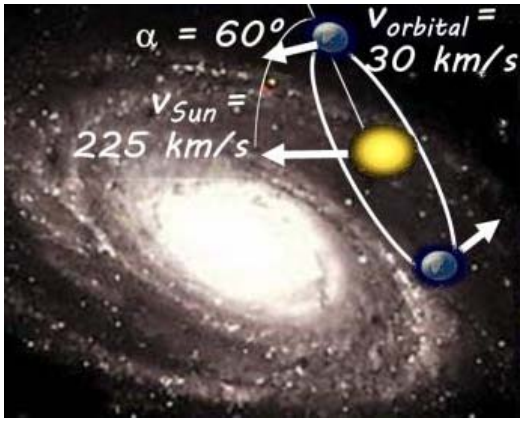
ANAIS (*Annual modulation with NAI Scintillators*) intends

to confirm the **DAMA/LIBRA** modulation signal

using the **same target and technique**

in a different environment at the **Canfranc Underground Laboratory** (Spain)

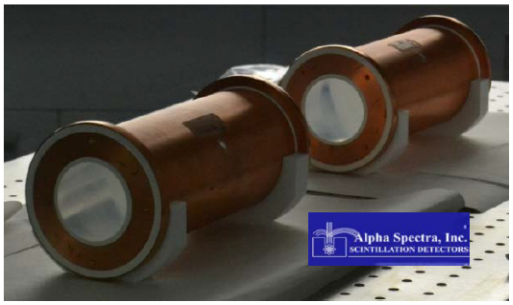
ANAIS-112: 3x3 matrix of 12.5 kg NaI(Tl) modules → **112.5 kg** active mass



Experimental requirements:

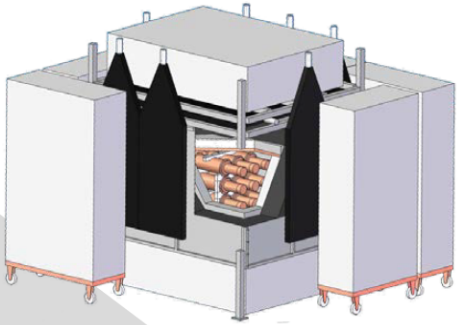
- Energy **threshold** at or below 2 keV_{ee}
- **Background** as low as possible below 10 keV_{ee} (at or below a few cpd/keV/kg)
- Very stable operation conditions

History

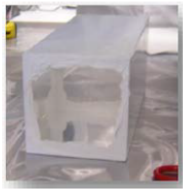


12.5 kg
Alpha Spectra Inc.

ANAIS-112



ANAIS-25



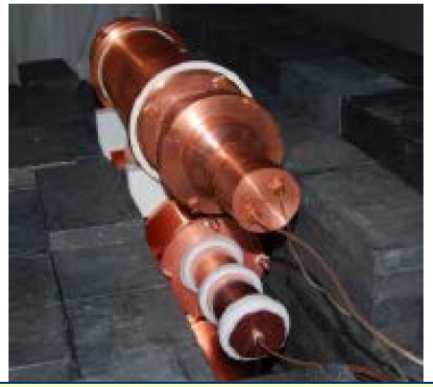
9.6 kg
Saint-Gobain

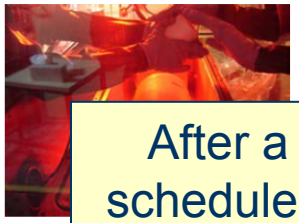
ANAIS-37

10.7 kg
BICRON

ANAIS-0

DM-32



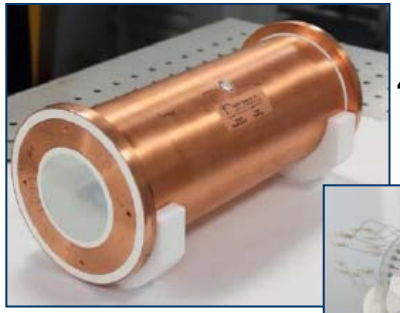


After a commissioning run, **ANAIS-112** is scheduled to start **dark matter run** this week

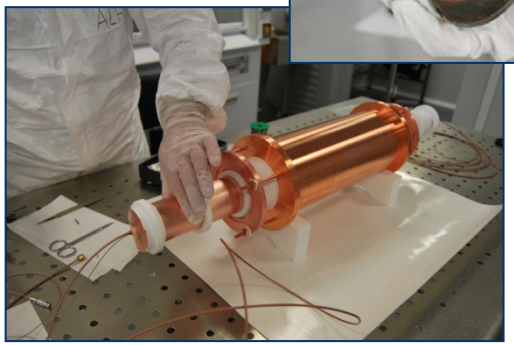
Detectors

Nine modules produced by Alpha Spectra Inc following low radioactivity protocols

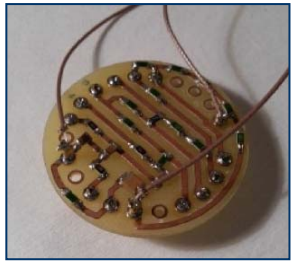
Detector	*Quality powder*	*Received at Canfranc in*
D0, D1	<90 ppb K	December 2012
D2	WIMPScint-II	March 2015
D3	WIMPScint-III	March 2016
D4, D5	WIMPScint-III	November 2016
D6, D7, D8	WIMPScint-III	March 2017



12.5 kg each
4.75'' diameter
11.75'' length



- **NaI(Tl) crystals** grown from selected ultrapure NaI powder and housed in OFE copper
- Mylar **window** allowing low energy calibration
- Two Hamamatsu R12669SEL2 **photomultipliers** coupled to each crystal at Canfranc clean room
  - Low background and high Quantum Efficiency
  - Radioactivity screening at Canfranc

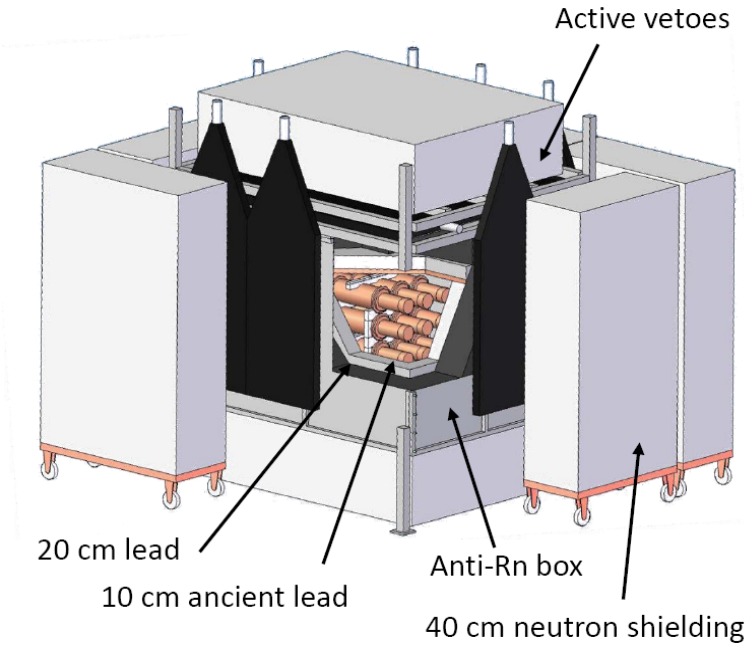


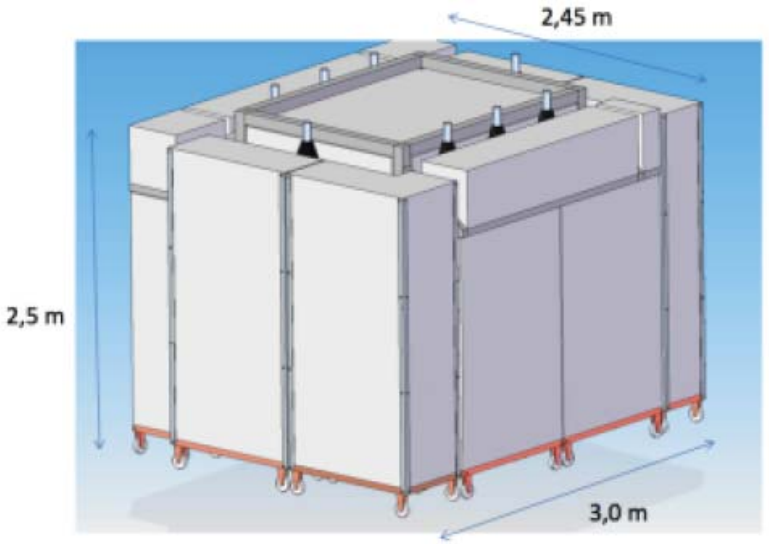
Voltage dividers in cuflon PCB

Housing made at LSC of electroformed copper

Shielding

ANAIS is located inside a hut in hall B at Canfranc laboratory under 2450 m.w.e

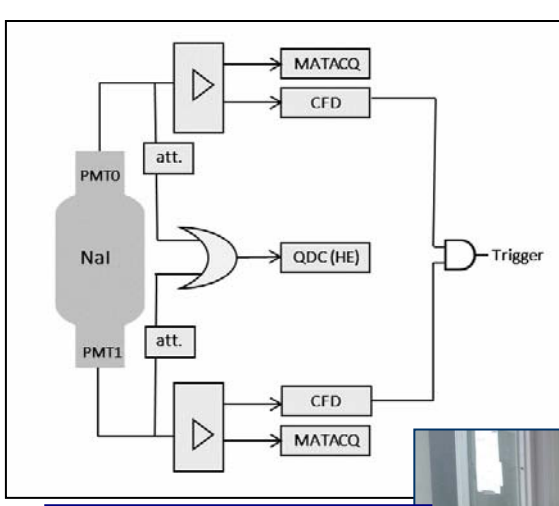


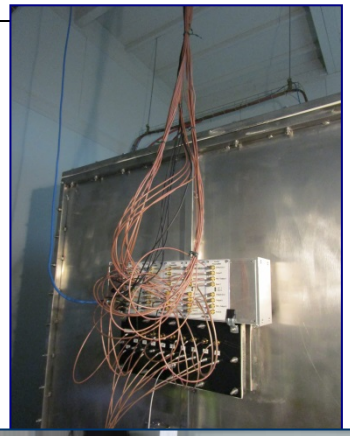


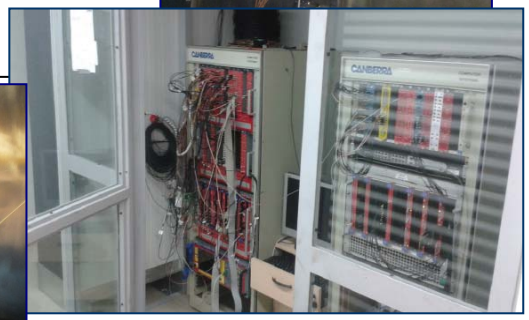
Radon-free **calibration system** for simultaneous calibration using ^{109}Cd sources

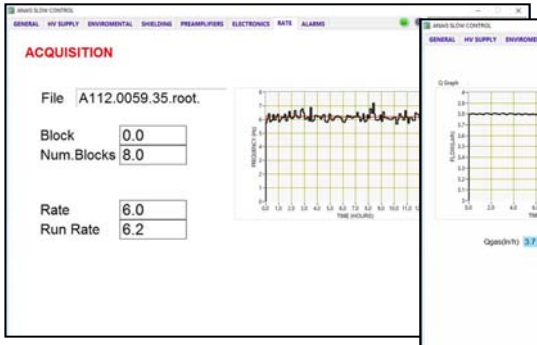
Data acquisition

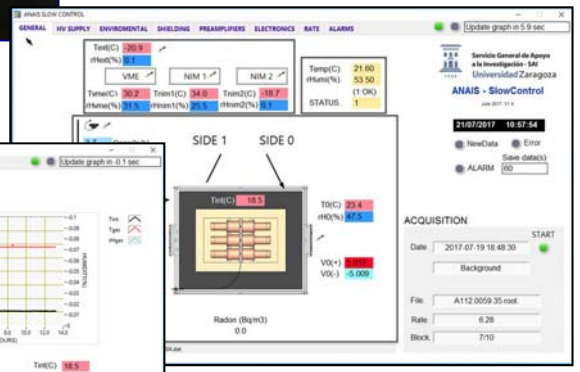
- **DAQ hardware and software** designed and tested in previous ANAIS set-ups
  - – Individual PMT signals digitized and fully processed
  - – Trigger at phe level for each PMT signal
  - – AND coincidence in 200 ns window
  - – Redundant energy conversion by QDC
  - –Trigger in OR mode among modules
- **Muon detection system** implemented to:
  - – tag muon related events
  - – monitor onsite muon flux
- **Slow control** operative:
  - – Monitoring: external Rn, humidity, P, T
    - N_2 flux
    - PMT HV
  - – Stability checks:
    - gain
    - trigger rate
    - ...





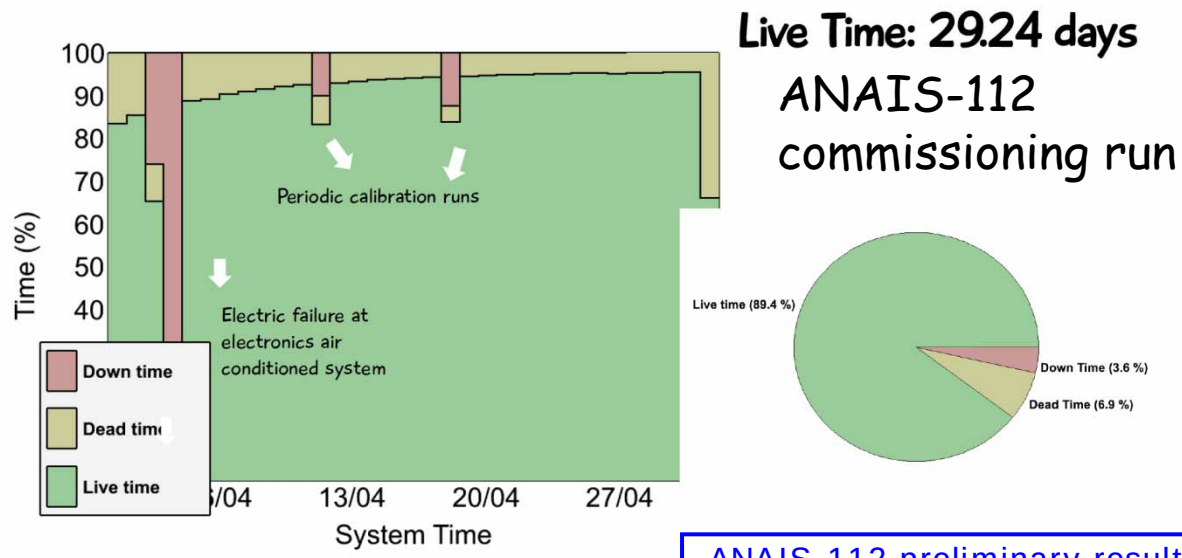






Detector response

- Excellent **duty cycle**



- Outstanding **light collection** measured in all modules at different set-ups: **~15 phe/keV**

M.A. Oliván et al, Astropart. Phys. 93 (2017) 86

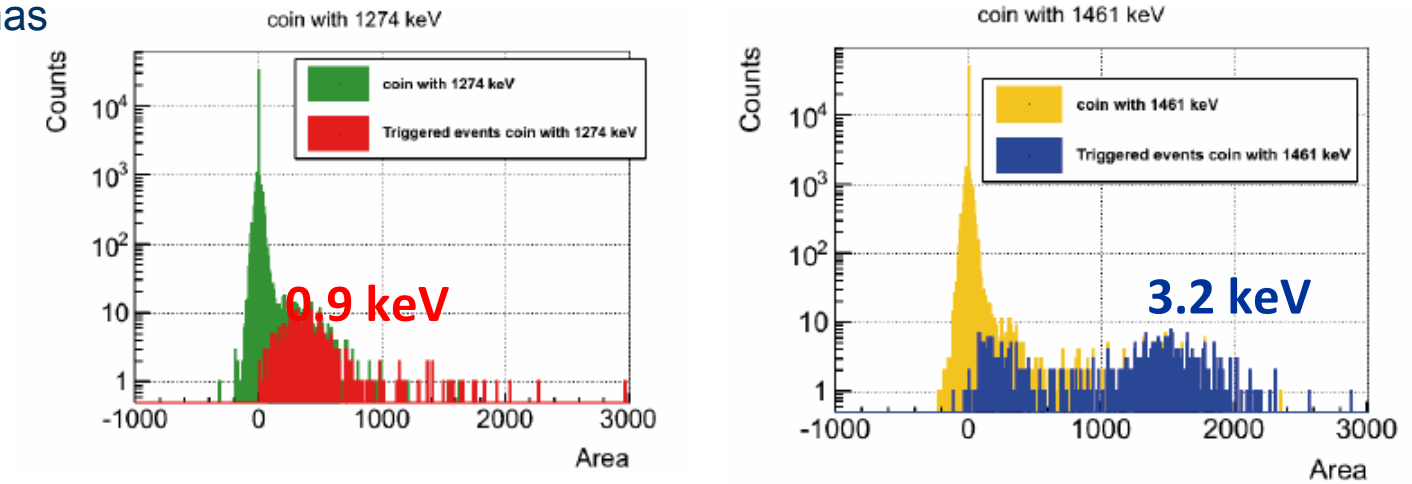
A factor of 2 larger than the published light collection for DAMA/LIBRA detectors

ANAIS-112 preliminary results

Detector	PMT/set-up	Total Light Collection (phe/keV)
D0	Ham R12669 / ANAIS25	15.6 ± 0.2
	Ham R12669 / ANAIS37	15.3 ± 0.1
	Ham R12669 / A37D3	15.1 ± 0.1
	Ham R12669 /ANAIS112	15.3 ± 1.1
D1	Ham R11065 / ANAIS25	12.6 ± 0.1
	Ham R12669 / ANAIS25-III	15.2 ± 0.1
	Ham R12669 / ANAIS37	14.4 ± 0.1
D2	Ham R12669 / ANAIS37	15.4 ± 0.1
	Ham R12669 /ANAIS112	15.3 ± 1.4
D3	Ham R12669 / A37D3	15.2 ± 0.5
	Ham R12669 /ANAIS112	14.6 ± 0.8
D4	Ham R12669 / A37D5	14 ± 1
	Ham R12669 /ANAIS112	14.0 ± 0.8
D5	Ham R12669 / A37D5	15 ± 1
	Ham R12669 /ANAIS112	14.0 ± 0.8
D6	Ham R12669 /ANAIS112	12.6 ± 0.8
D7	Ham R12669 /ANAIS112	17.0 ± 2.0
D8	Ham R12669 /ANAIS112	14.6 ± 0.9

Detector response

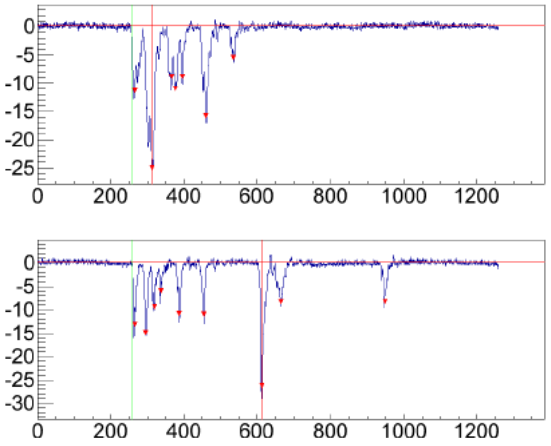
• **Triggering** below 1 keV_{ee}: bulk ^{22}Na and ^{40}K events identified by coincidences with high energy gammas



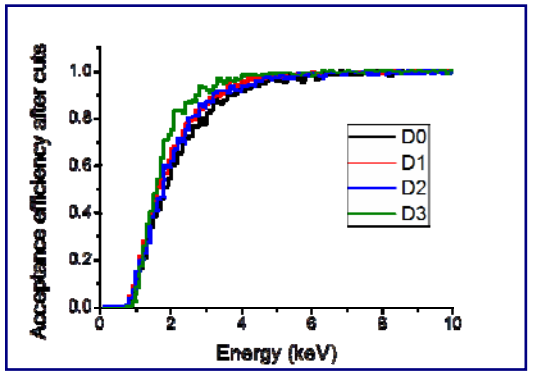
• Effective **filtering** protocols for PMT noise C. Cuesta et al., EPJ C 74 (2014) 3150

Multiparametric cuts on:

- Number of peaks in the pulse (n>2 in each PMT)
- Temporal parameters of the pulse
- Asymmetry in light sharing



Acceptance efficiency curves from external calibration data



A **blank module** will be set-up to monitor non NaI(Tl) scintillation events and build a "blank" population for the study of annual modulation systematics

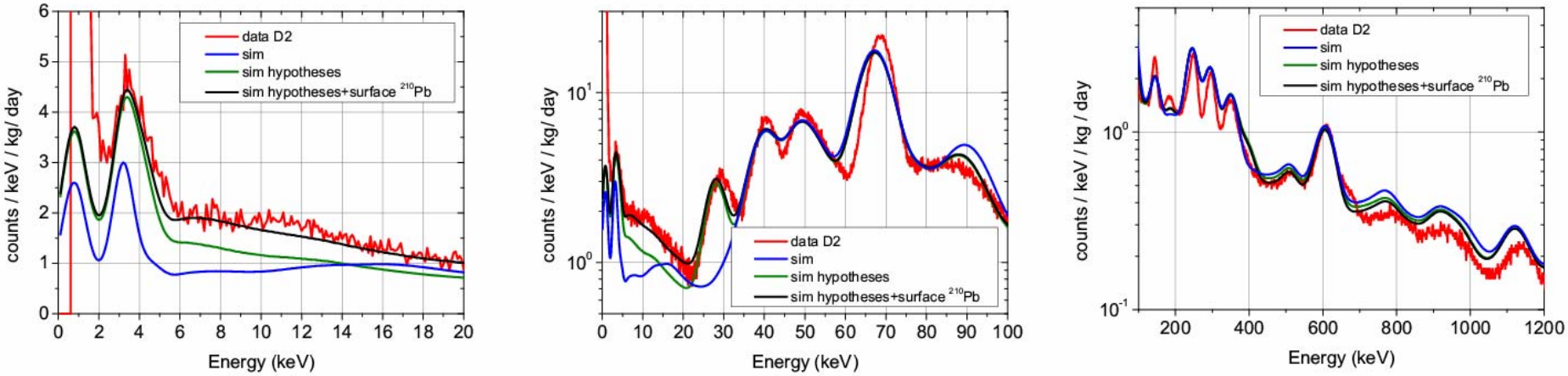
Radiopurity and background

Detailed **background models** for first modules operated in Canfranc, based on Geant4 Monte Carlo simulation and accurate quantification of **background sources**

- **Internal activity** directly assessed (mainly ^{40}K, ^{210}Pb)
- **Cosmogenic activity** in crystals quantified from ANAIS-25 data
- **Activity from external components** measured with HPGe detectors at Canfranc

J. Amaré et al, Eur. Phys. J. C 76 (2016) 429; JCAP 02 (2015) 046

D2: simulated contributions vs data (89.5 d, data from 2015)



^{40}K and **^{22}Na** peaks and **^{210}Pb** (bulk+surface) and **^{3}H** continua are the most significant contributions in the very low energy region

Radiopurity and background

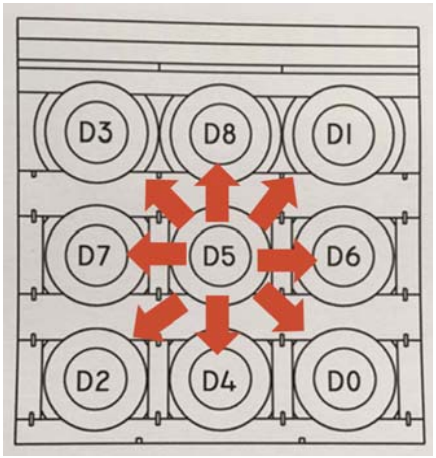
- Determination of **potassium content** in NaI(Tl) crystals

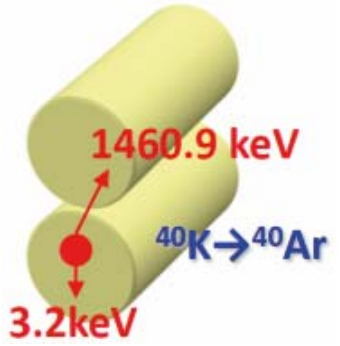
^{40}K: measured by identifying coincidences C. Cuesta et al., Int. J. Mod. Phys. A. 29 (2014) 1443010

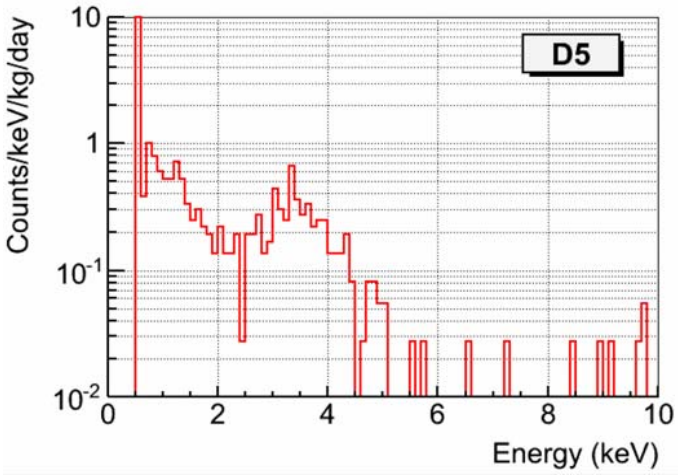
Estimate from last 30.1 days (June-July) in ANAIS-112

(statistical uncertainty ~10%)

Detector	^{40}K (mBq/kg)
D0	1.1
D1	1.4
D2	0.9
D3	0.7
D4	1.0
D5	1.0
D6	1.1
D7	1.0
D8	0.6





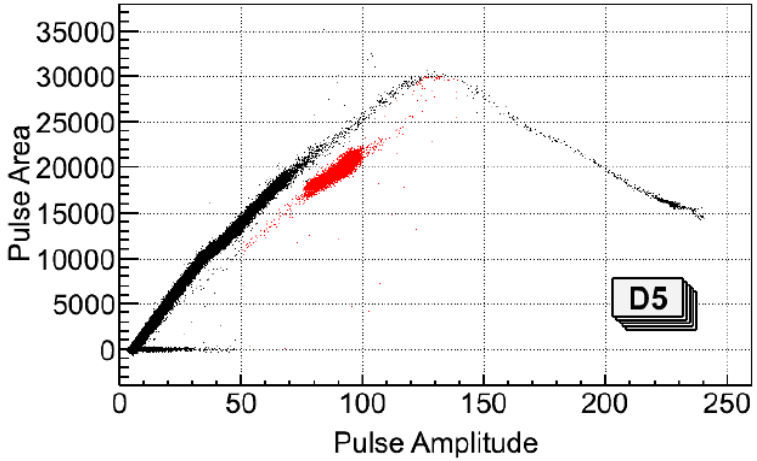


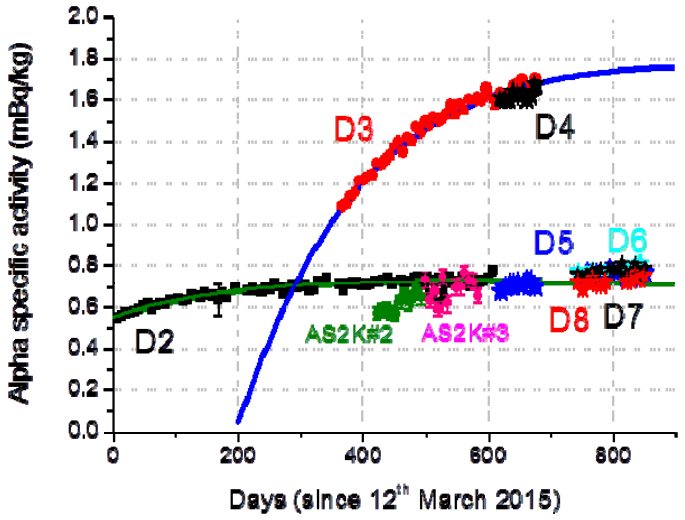
DAMA/LIBRA crystals: ~20 ppb K = 0.6 mBq/kg ^{40}K

Radiopurity and background

- **Activity of ^{232}Th, ^{238}U** determined by alpha rate following PSA and analysis of BiPo sequences at a level of a few μBq/kg, but **^{210}Pb out of equilibrium**

The origin of **^{210}Pb** contamination has been under study in collaboration with Alpha Spectra





Module	Average alpha specific activity
D5	0.75 ± 0.01 mBq/kg
D6	0.76 ± 0.01 mBq/kg
D7	0.75 ± 0.01 mBq/kg
D8	0.72 ± 0.01 mBq/kg

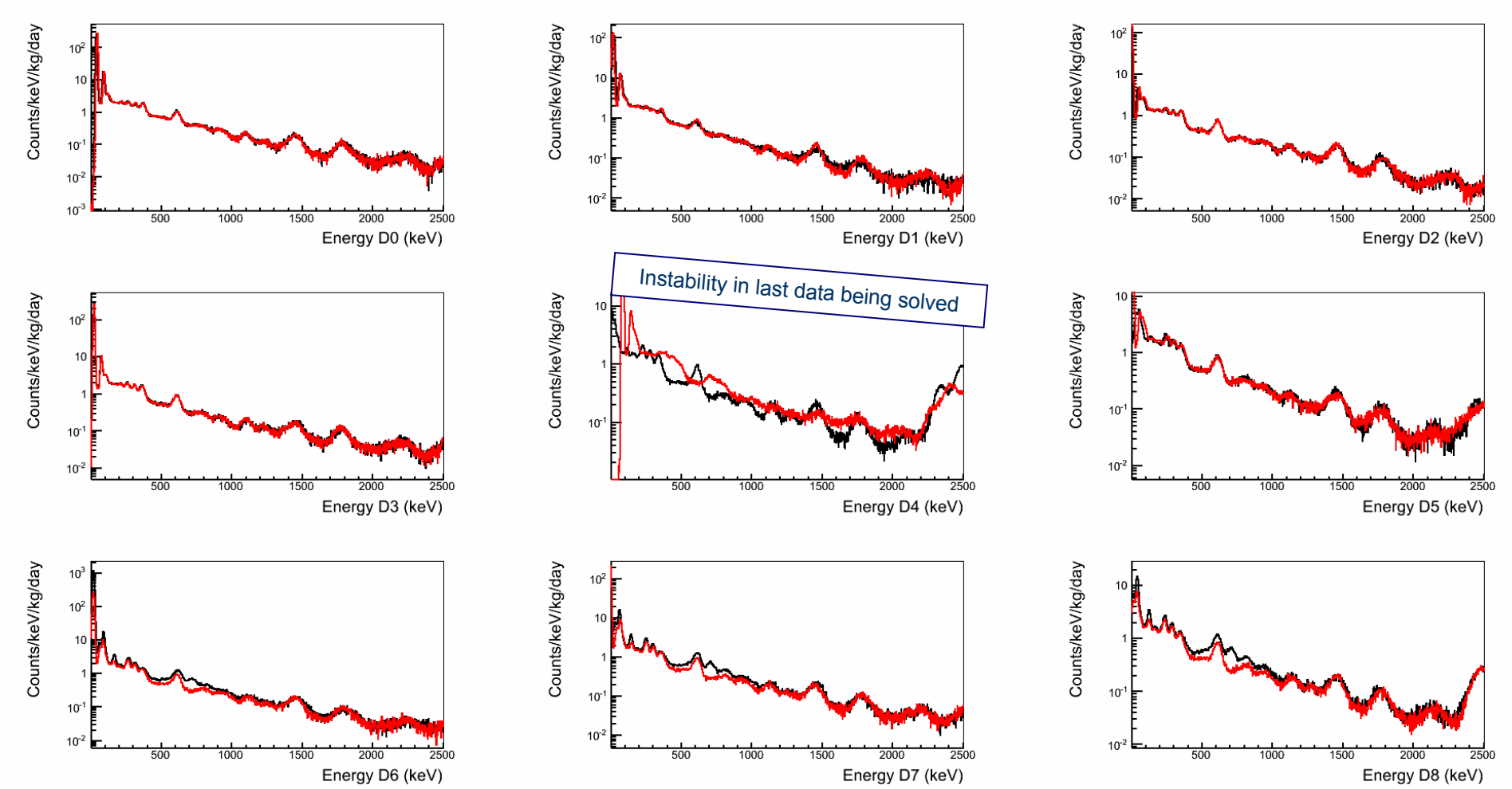
Very similar alpha rate in the latest produced crystals, lower than in the previous ones

Radiopurity and background

- **Background at high energy** from ANAIS-112 data

First 29.2 days (March-April)

Last 30.1 days (June-July)

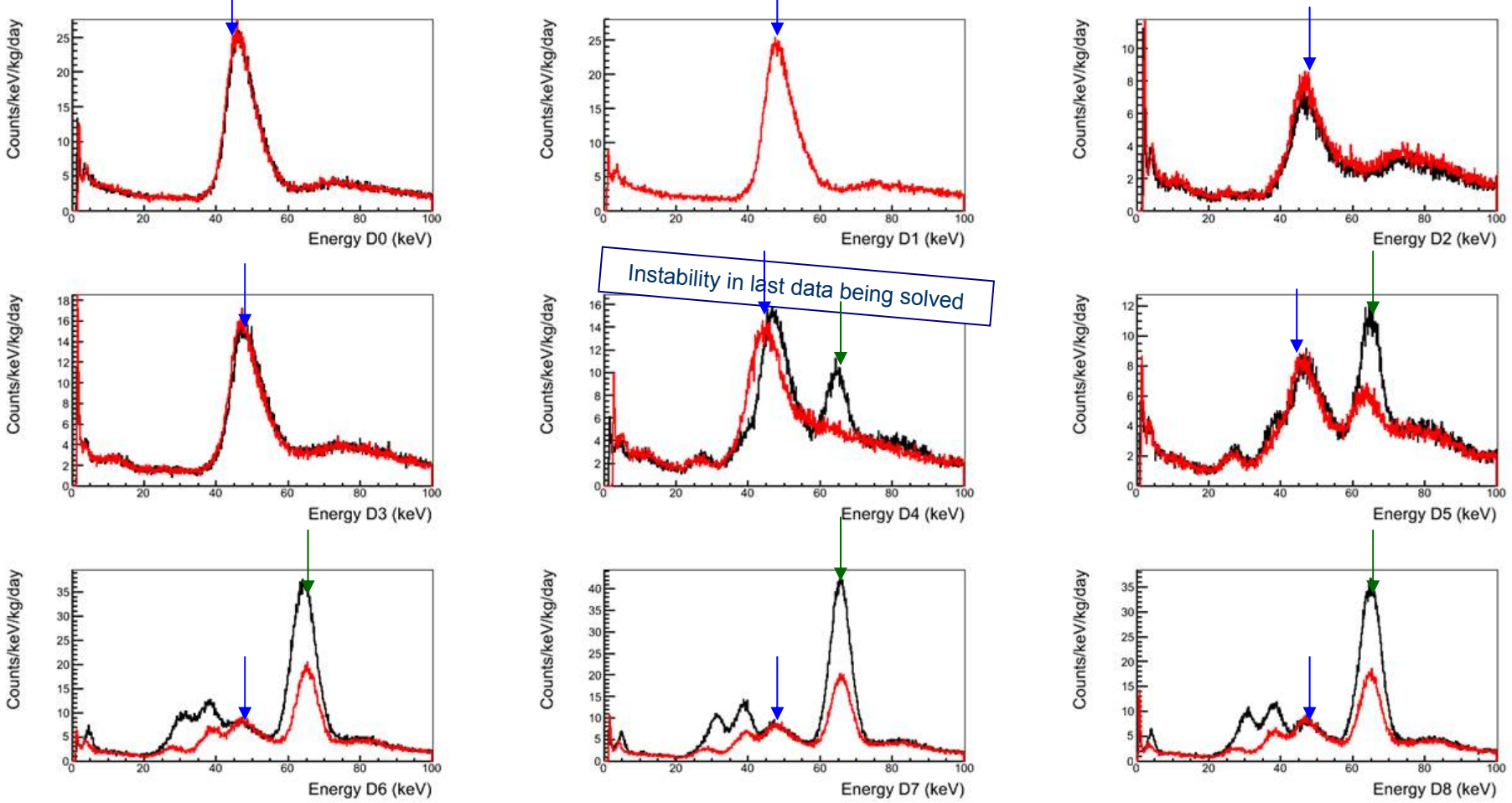


Radiopurity and background

- **Background at low energy** from ANAIS-112 data
  (Filtered spectra but with no cut efficiency correction yet)

First 29.2 days (March-April)

Last 30.1 days (June-July)



Instability in last data being solved

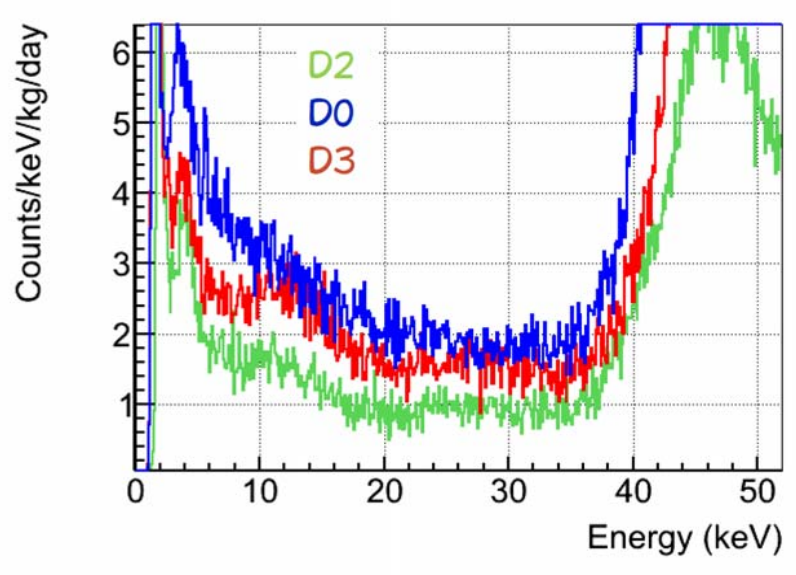
Cosmogenics still decaying for **D4-D8**

^{210}Pb contribution at **~50 keV** region, consistent with the measured alpha specific activity

Radiopurity and background

- **Summary of crystal activity** (from last 30.1 days in ANAIS-112)

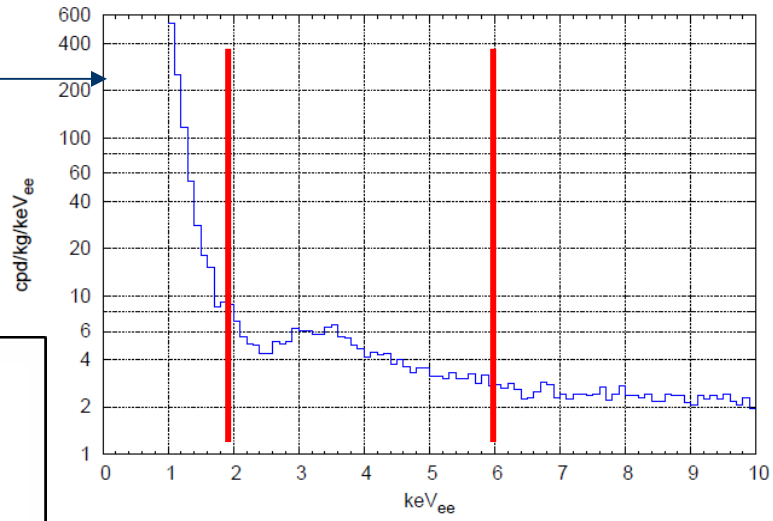
Detector	^{40}K (mBq/kg)	^{210}Pb (mBq/kg)
D0	1.1	3.15
D1	1.4	3.15
D2	0.9	0.70
D3	0.7	1.8
D4	1.0	1.8
D5	1.0	0.75
D6	1.1	0.76
D7	1.0	0.75
D8	0.6	0.72
average	**1.0**	**1.5**



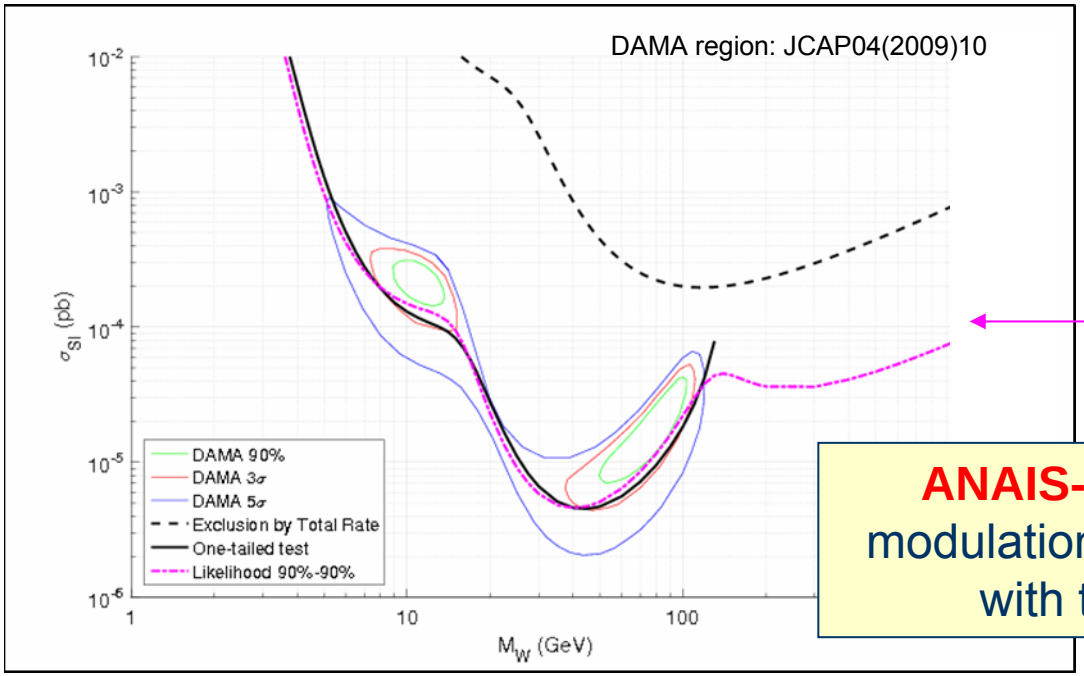
Sensitivity

Detection limit at 90% C.L. for a critical limit at 90% C.L. for ANAIS-112

- Estimated **average background** from **D0-D5 measured levels (**corrected for cut efficiency)
- 2-6 keV_{ee} region
- 5 years



Dark matter hypothesis



90% probability of detecting an annual modulation signal at 90% C.L.

ANAIS-112 can detect the annual modulation in the 3σ region compatible with the DAMA/LIBRA result

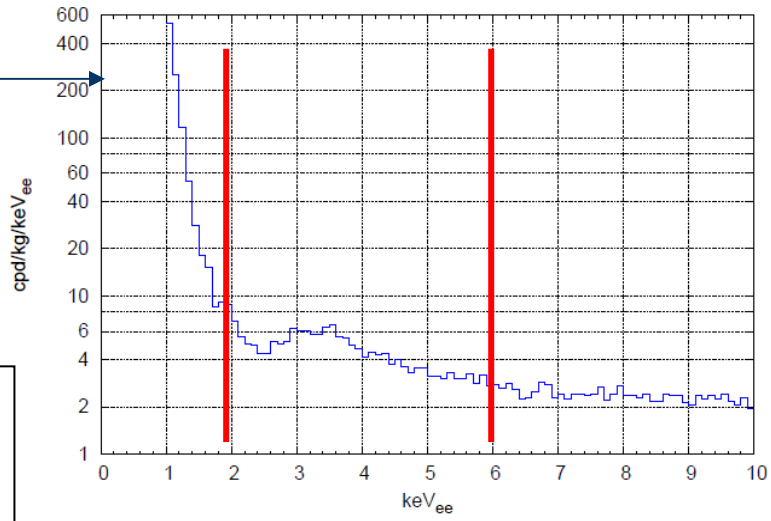
I. Coarasa et al, arXiv:1704.06861v1

Sensitivity

Detection limit at 90% C.L. for a critical limit at 90% C.L. for ANAIS-112

- Estimated **average background** from **D0-D5 measured levels (**corrected for cut efficiency)
- 2-6 keV_{ee} region
- 5 years

Model-independent annual modulation



Factor of Merit: from the variance of the estimator of the modulated amplitude

$$FOM = \left(\frac{2 \cdot B}{\Delta E \cdot M \cdot T_M \cdot \varepsilon} \right)^{\frac{1}{2}}$$

Detection Limit for annual modulation amplitude: for ANAIS-112 parameters

$$L_D = (8.40 \pm 0.25) \cdot 10^{-3} \text{ cpd/kg/keV}_{ee} \quad (90\% \text{ C.L.})$$

ANAIS-112 has a detection limit for annual modulation lower than the measured amplitude by DAMA/LIBRA: 0.0112 ± 0.0012 cpd/kg/keV_{ee}

I. Coarasa et al, arXiv:1704.06861v1

Summary and outlook

- ✓ **ANAIS detectors:** modules from Alpha Spectra characterized at Canfranc
  - Outstanding **light collection** of **~15 phe/keV** and **triggering** at **1 keV$_{ee}$**
  - **Background models** provide a good description of measured data at all energy ranges: crystal contamination is the dominant background source giving ^{210}Pb, ^{40}K, ^{22}Na and maybe ^{3}H the most relevant contributions
    - Acceptable **K content** reached
    - **^{210}Pb problem** addressed by means of dedicated tests with Alpha Spectra

- ✓ **ANAIS-112:** data taking using **112.5 kg (3x3 crystal matrix)** ongoing
  - Shielding, electronics, DAQ, slow control installed in the first months of 2017
  - Successful commissioning run to assess response and background of new modules
  - Analysis protocols ready following the experience from first modules
  - Data taking expected to go on in these conditions during the next two years
    - Control populations (muon-related events, blank module…) available
    - Blind annual modulation analysis foreseen
  - Plan to make ANAIS data public after use to allow independent analysis

The **ANAIS-112 dark matter run** underway at **Canfranc** with good prospects to test the DAMA/LIBRA modulation signal using same target and technique