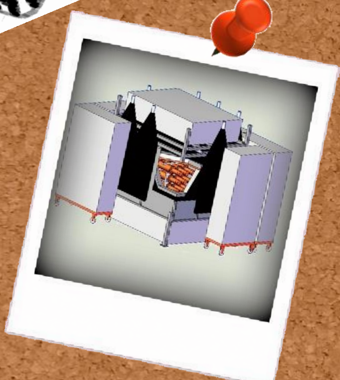
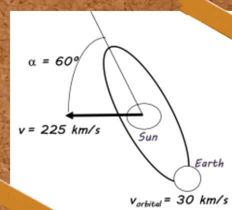
MultiDark
Multimessenger Approach for Dark Matter Detection

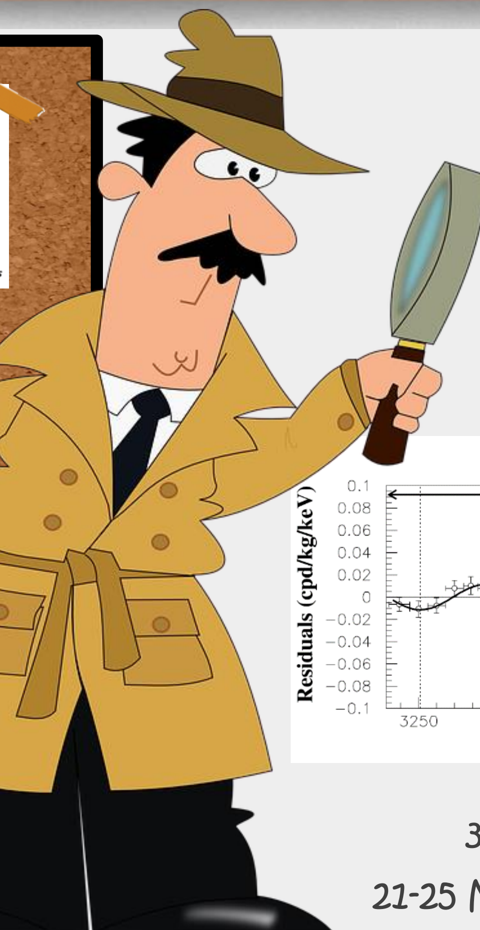
Universidad Zaragoza

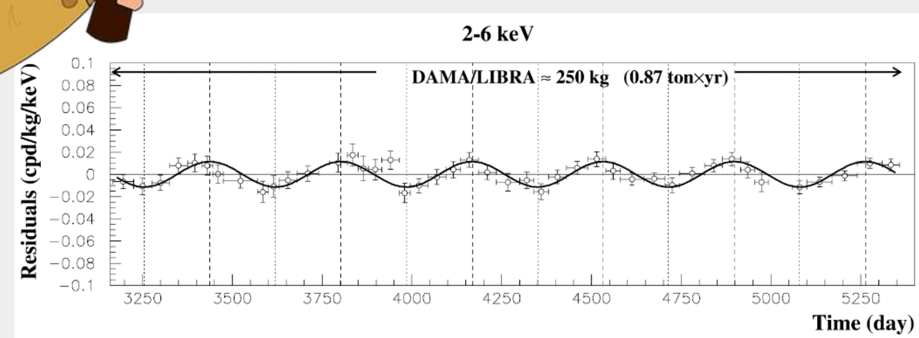
LSC
Laboratorio Subterráneo de Canfranc

Testing DAMA/LIBRA signal with ANAIS-112







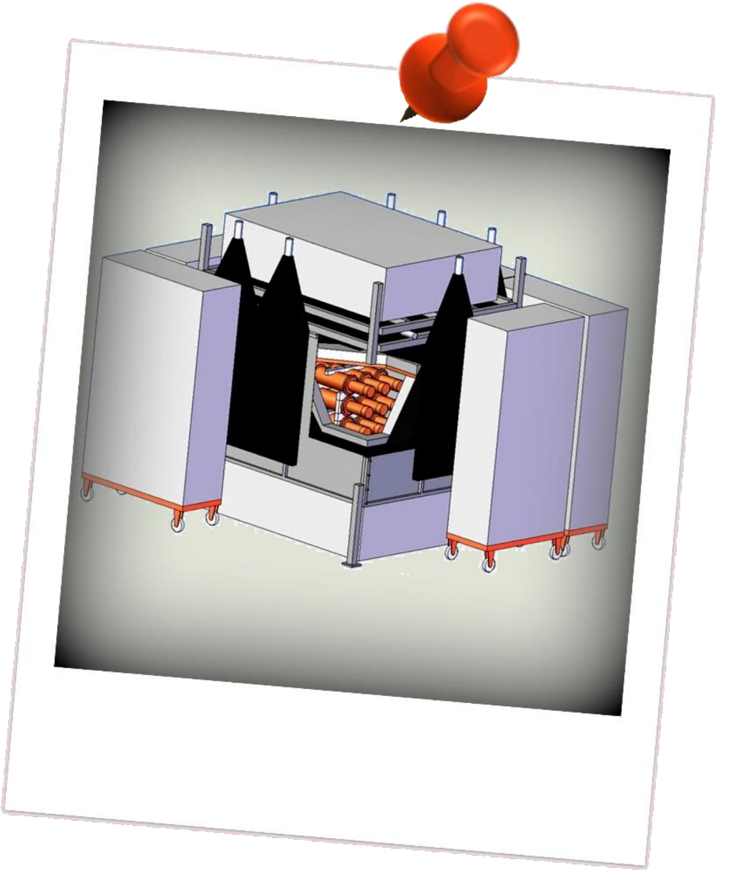


M. Martinez,
On behalf of the ANAIS coll.

3rd IBS-MultiDark-IPPP Workshop,
21-25 November 2016, Lumley Castel, Durham

OUTLINE

- The ANAIS program
- Detectors performance
- Background
- ANAIS-112 status & prospects
- Summary



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

- **The ANAIS program**
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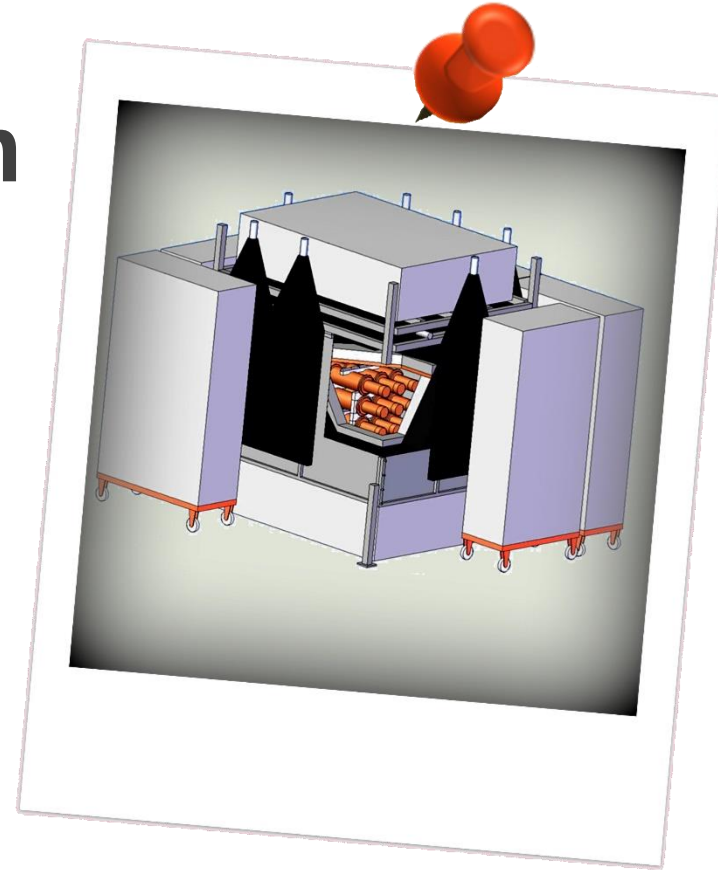
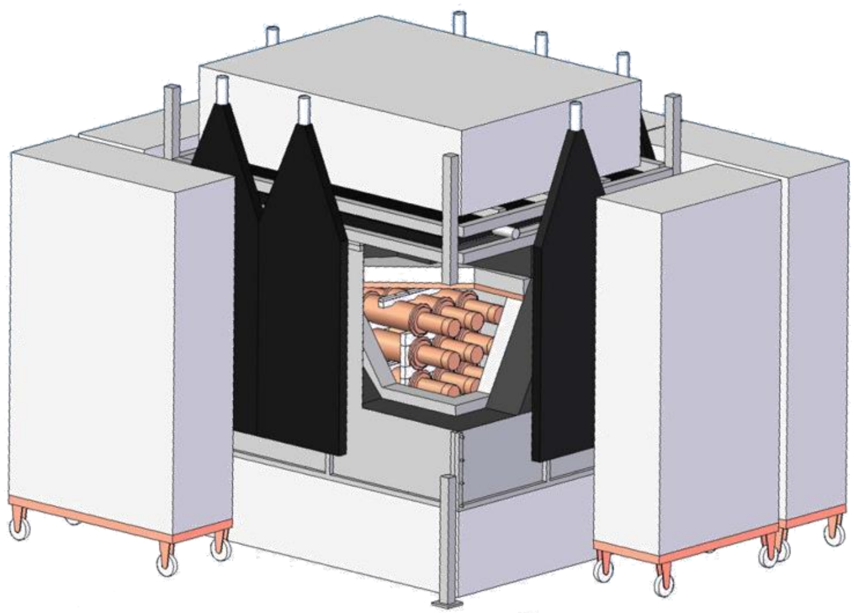


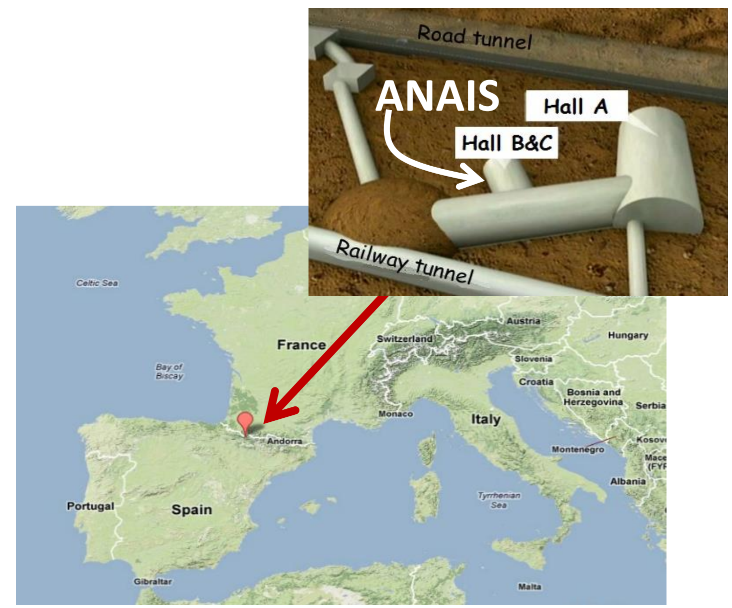
ANAIS: Annual Modulation with NaI Scintillators

Confirmation of DAMA-LIBRA modulation signal:

- **same target and technique**
- **different** experimental approach
- **different** environmental conditions affecting **systematics**



3x3 matrix of 12.5 kg cylindrical NaI(Tl) modules
(112.5 kg of active mass)



At Canfranc Underground Laboratory (SPAIN) 2450 m.w.e.

The ANAIS program

2 X 12.5 kg
Alpha Spectra Inc.

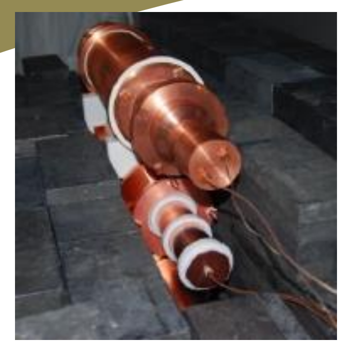
ANAIS-25

9.6 kg
Saint-Gobain

ANAIS-0

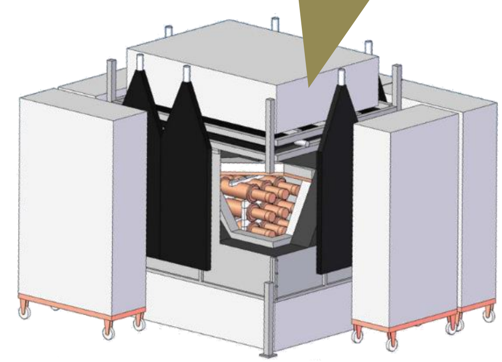
DM-32

10.7 kg
BICRON



ANAIS-37

3 X 12.5 kg
Alpha Spectra Inc.



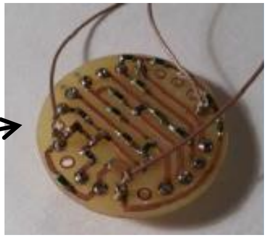
ANAIS-112

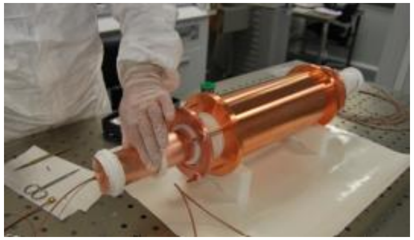
9 X 12.5 kg
Alpha Spectra Inc.

ANAIS detectors

12.5 kg NaI(Tl) modules:

- built @ AS, Co (US) from NaI selected powder
- 4.75” ϕ x 11.75” length cylindrical shape
- OFE copper encapsulation+ Teflon diffusor
- Mylar window for low energy calibration
- Two optical windows for PMT coupling
- PMTs: Ham12669SEL2 with high quantum efficiency (>33%) and low dark current





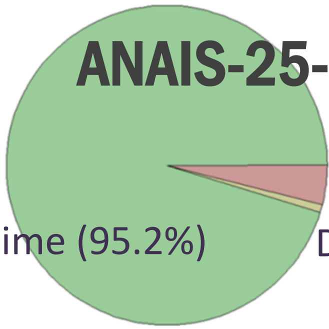
Voltage dividers made of Cuflon PCB

Electroformed copper PMT housing made at LSC facility

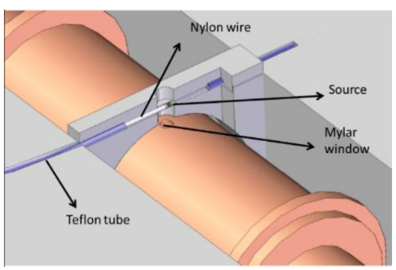
no light guides to increase light collection

Experimental features

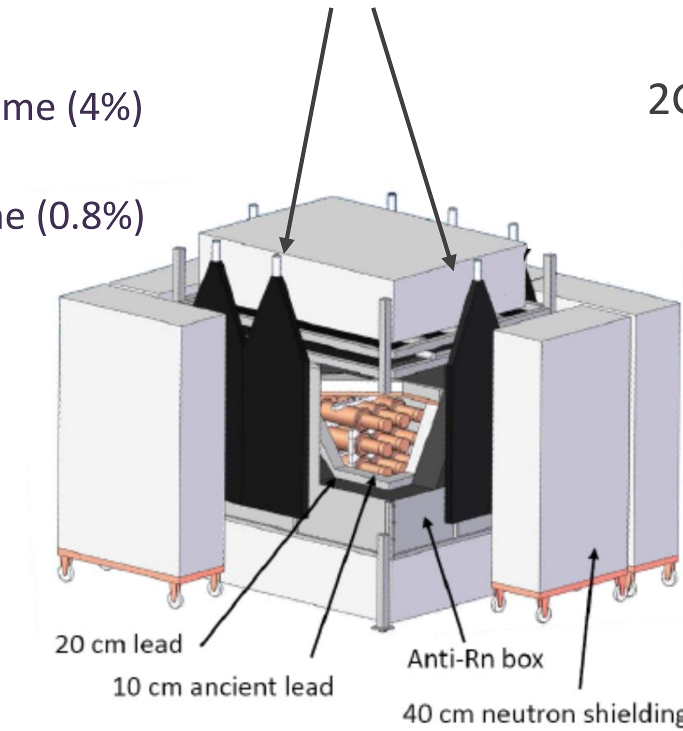
High duty cycle



Radon-free low energy calibration system

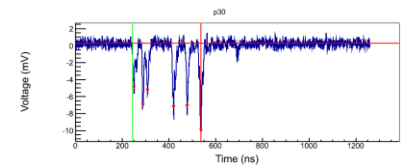


Muon-tagging system



Individual PMT signals digitized

2GS/s with high resolution (14 bits)



Robust algorithm for peak identification @ low Energy!

Monitor environmental parameters:

(External radon air content, humidity, temperature (inside/outside/electronics), pressure, antiradon N_2 flux, PMT HV, gain, trigger rate and level, coincidence window

Electronics:

Air conditioned room to decouple from temperature fluctuations

- The ANAIS program
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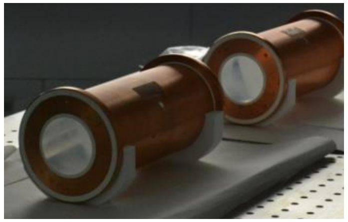
Detectors @ LSC so far

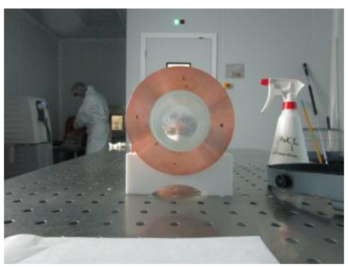


- **D0 / D1 modules**: First AS modules grown with purified NaI powder under 90ppb

  Dec 2012: **ANAIS-25 set-up**

- **D2 module**: WIMPScint-II powder, Improved protocols to reduce ^{210}Pb

  March 2015: **ANAIS-37 set-up (D0+D2+D1)**



- **D3 module**: WIMPScint-III powder, Improved powder purification to reduce potassium

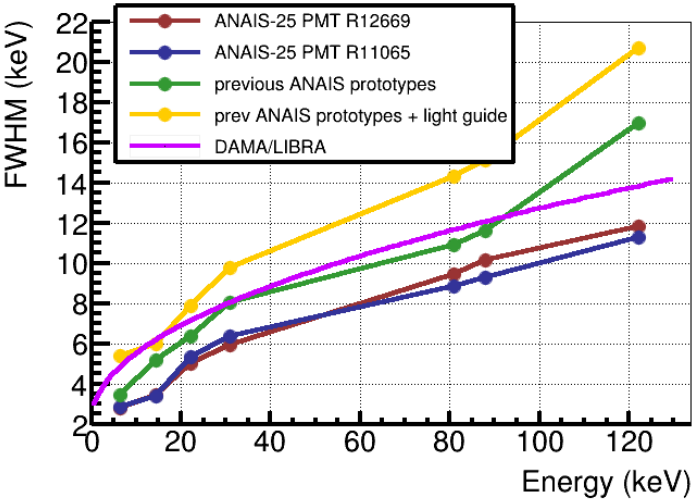
  March 2016: **ANAIS-37 set-up (D0+D3+D2)**

- **D4 / D5 modules**: WIMPScint-III powder just arrived @ LSC

Light Collection: excellent!!

Detector	setup	Light collected (phe/keV) @ 22 keV
D0	ANAIS25 ANAIS37 ANAIS37	15.6 ± 0.2 15.3 ± 0.1 15.1 ± 0.1
D1	ANAIS25 (*) ANAIS25 ANAIS37	12.6 ± 0.1 15.2 ± 0.1 14.4 ± 0.1
D2	ANAIS37	15.4 ± 0.1
D3	ANAIS37	15.2 ± 0.5

(*)PMT: Ham R11065

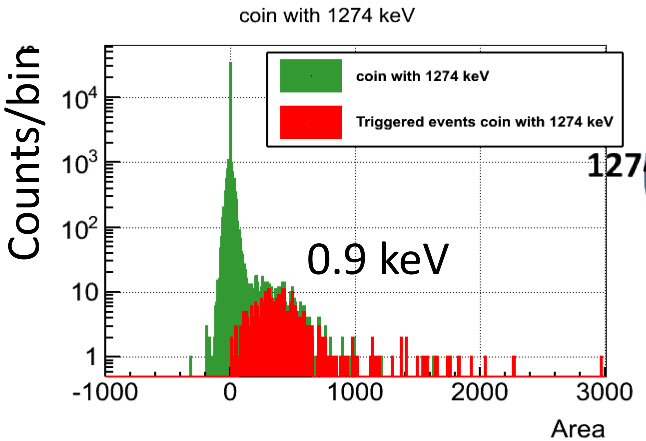


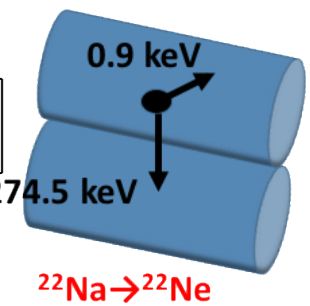
All AS Detectors in all setups: **Excellent light collection** that translates into **good energy resolution and threshold**

Energy threshold

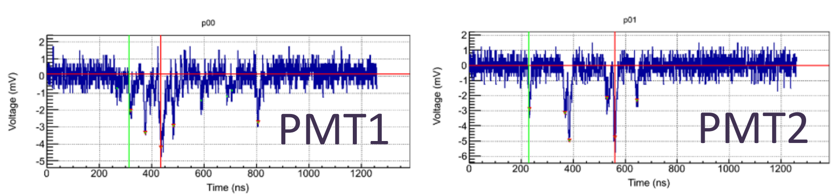
- **Trigger threshold below 1 keV with high trigger efficiency**

Trigger efficiency determined by coincidences between high energy gammas and low energy events in adjacent modules.



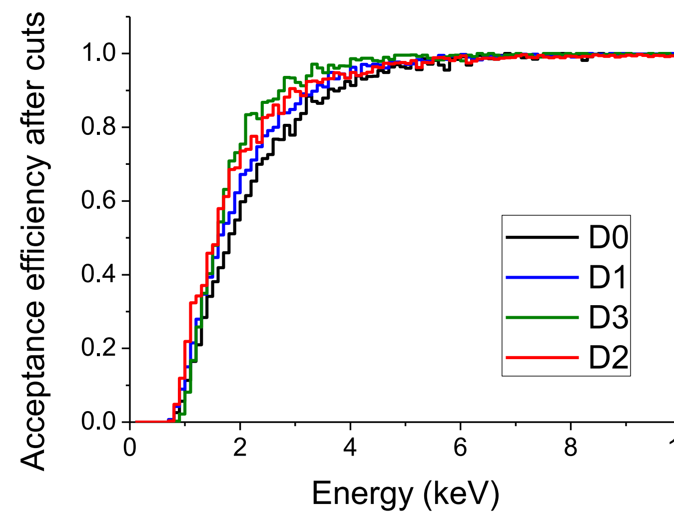


0.9 keV events:



- **Data selection at Low E: multiparametric cut**
  - Number of peaks in the pulse (>2 per PMT)
  - Temporal parameters of the total light pulse
  - Asymmetry in the light sharing

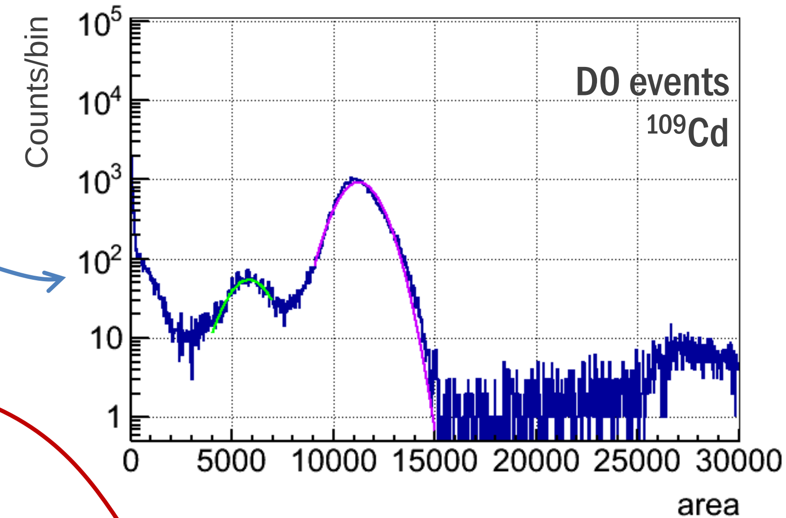
Robust acceptance efficiency Estimate (during $^{109}Cd/^{57}Co$ calibrations)

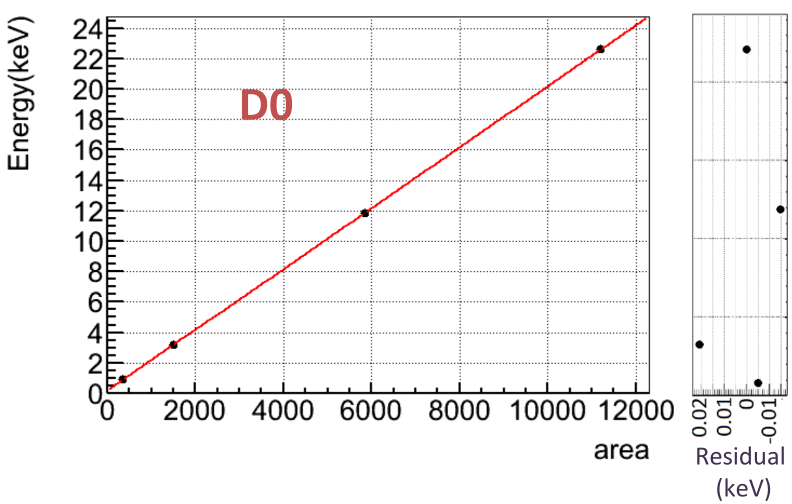


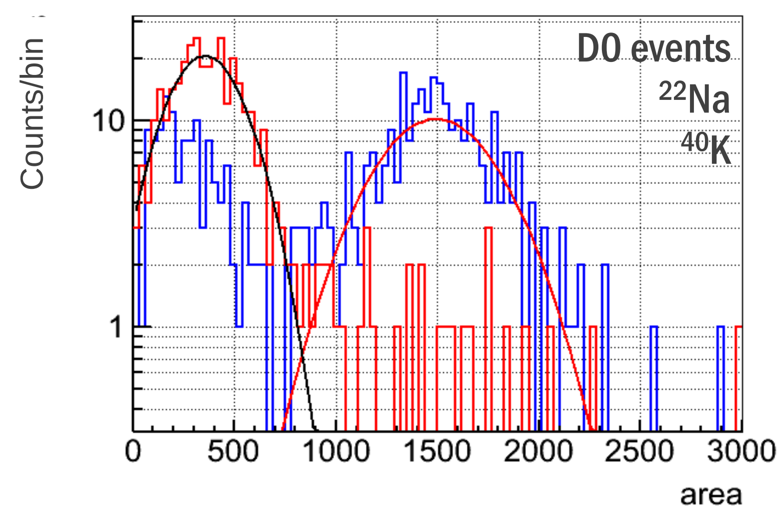
Energy calibration: linearity

Linear calibration down to 0.9 keV!

Checked with **calibration lines** & **internal lowE depositions**







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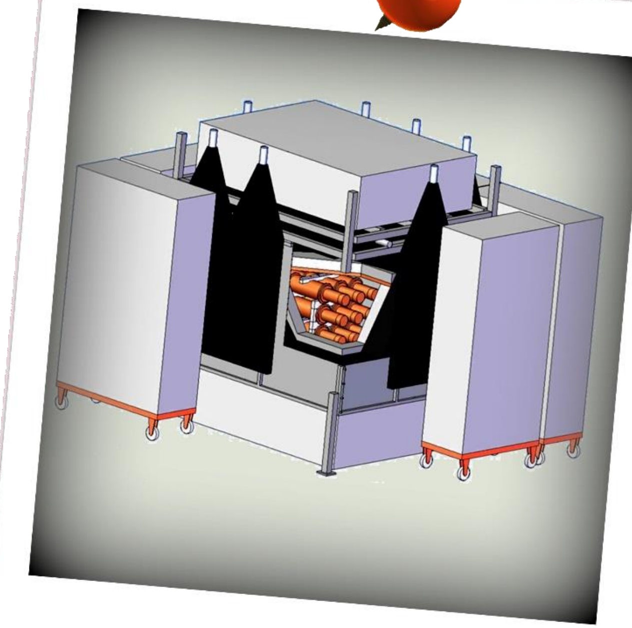


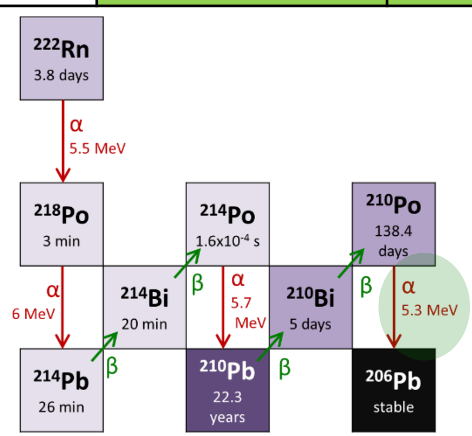
Detector internal contaminants

	^{40}K	^{238}U	^{210}Pb	^{232}Th
D0	1.4 mBq/kg (45 ppb K)	9 μBq/kg	3.15 mBq/kg	5 μBq/kg (^{220}Rn-^{216}Po) 3 μBq/kg (^{212}Bi-Po)
D1	1.1 mBq/kg (34 ppb K)	9 μBq/kg	3.15 mBq/kg	4 μBq/kg (^{220}Rn-^{216}Po)
D2	1.1 mBq/kg (34 ppb K)	2.7 μBq/kg	0.70 mBq/kg	$\approx$1 μBq/kg (^{220}Rn-^{216}Po) $\approx$1 μBq/kg (^{212}Bi-Po)
D3	0.6 mBq/kg (19 ppb K)	$\sim$4 μBq/kg	$\sim$1.8 mBq/kg	$\approx$0,6 μBq/kg (^{220}Rn-^{216}Po) $\approx$0,6 μBq/kg (^{212}Bi-Po)

- Very good levels of ^{238}U & ^{232}Th
- Acceptable levels of ^{40}K (improved in last module to the DAMA upper limit)
- ^{210}Pb out-of-equilibrium contamination, improved in D2, but increased again in D3

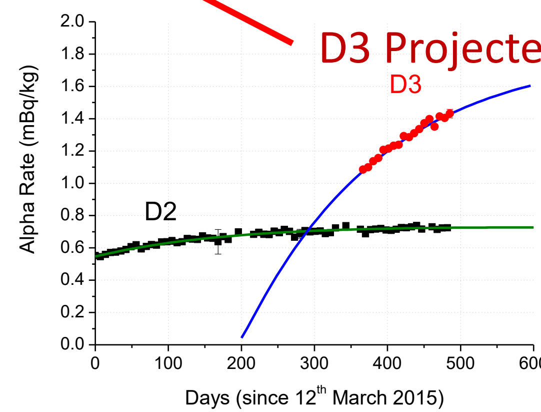
Detector internal contaminants

	^{40}K	^{238}U	^{210}Pb	^{232}Th
D0	1.4 mBq/kg (45 ppb K)	9 μBq/kg	3.15 mBq/kg	5 μBq/kg (^{220}Rn-^{216}Po) 3 μBq/kg (^{212}Bi-Po)
D1	1.1 mBq/kg (34 ppb K)	9 μBq/kg	3.15 mBq/kg	4 μBq/kg (^{220}Rn-^{216}Po)
D2	1.1 mBq/kg (34 ppb K)	2.7 μBq/kg	0.70 mBq/kg	≈1 μBq/kg (^{220}Rn-^{216}Po) ≈1 μBq/kg (^{212}Bi-Po)
D3	0.6 mBq/kg (19 ppb K)	~4 μBq/kg	~1.8 mBq/kg	≈0,6 μBq/kg (^{220}Rn-^{216}Po) ≈0,6 μBq/kg (^{212}Bi-Po)



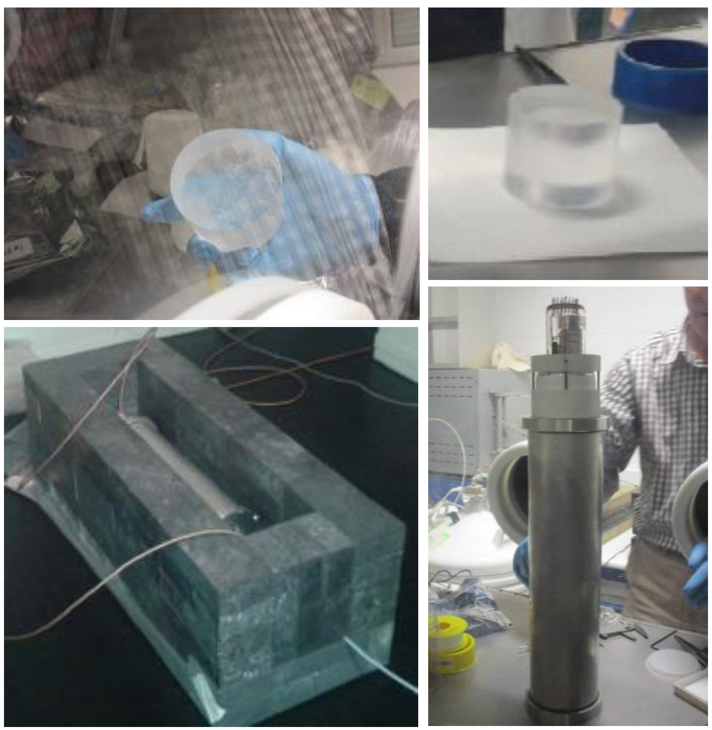
^{210}Po activity is being built

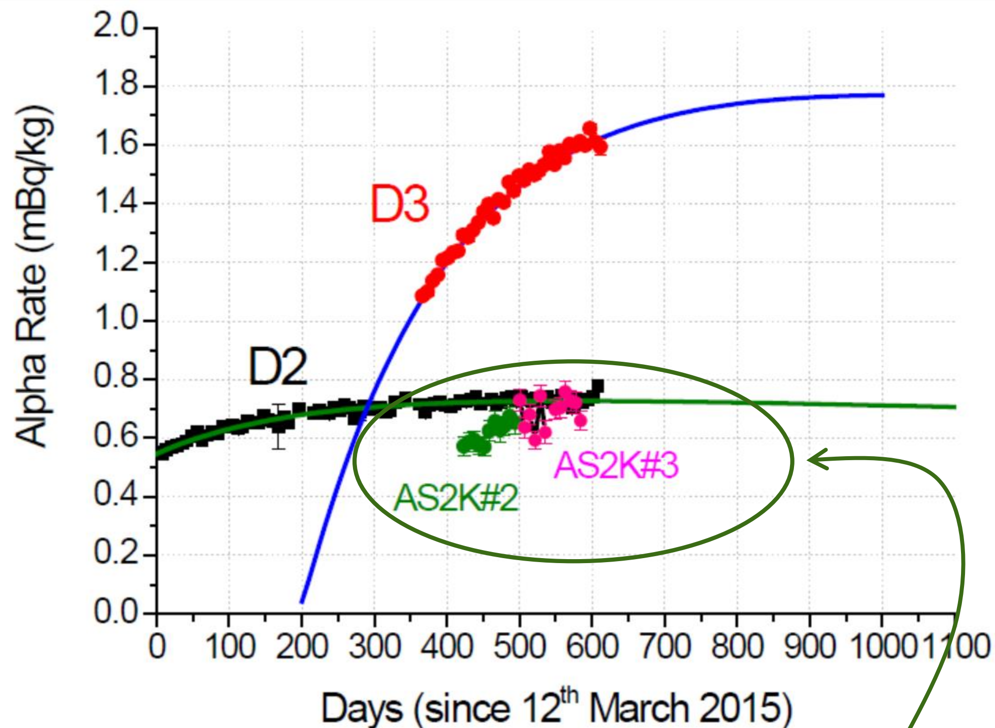
D3 Projected value



Studying ^{210}Pb contamination

Origin of the ^{210}Pb contamination is under study in collaboration with AS → 1 kg crystals tests at LSC

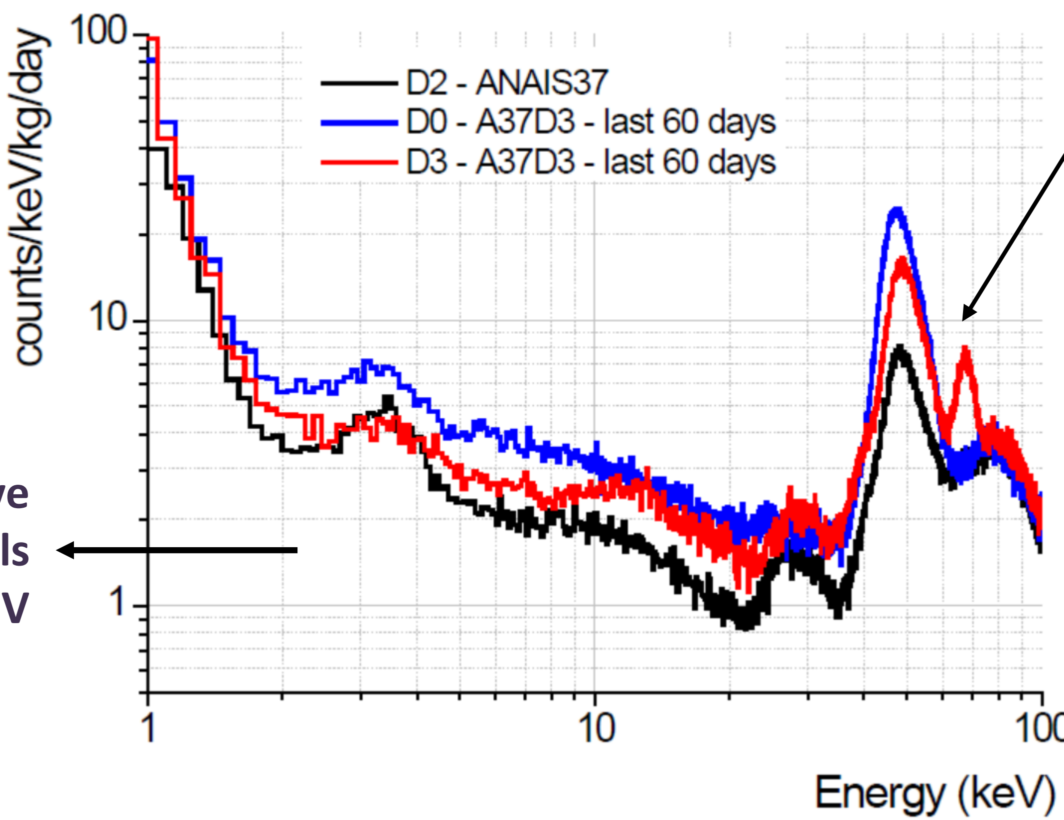




Two of the samples measured by now are below 0.7 mBq/kg (D2 level)

Background @ low E

Dominated by ^{210}Pb (continuum) & ^{40}K (peak) contaminations in the crystal

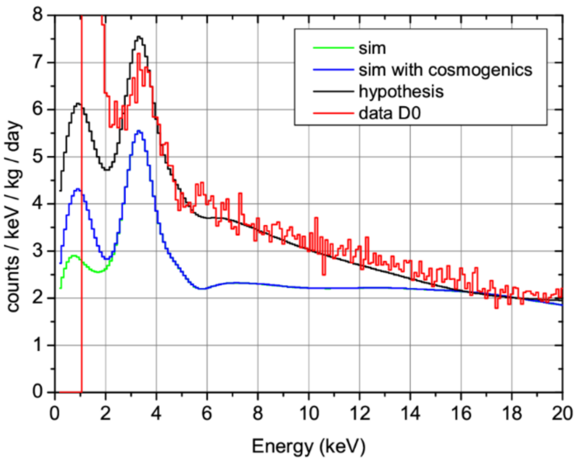


Cosmogenics still decaying in D3

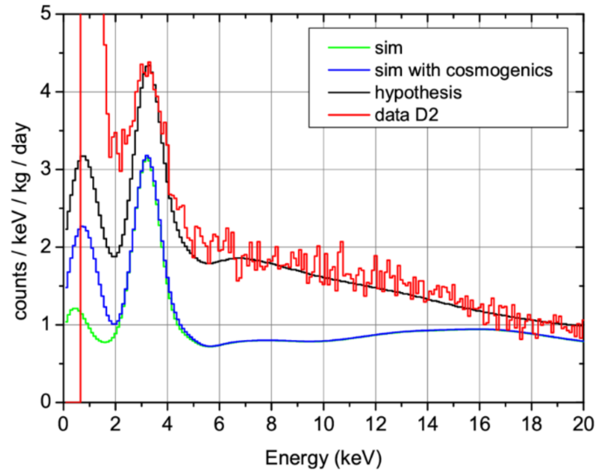
Working to improve filtering protocols below 2 keV

Background budget

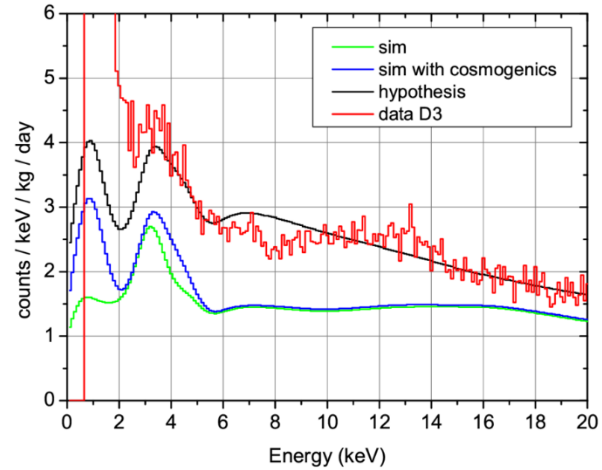
D0 module



D2 module

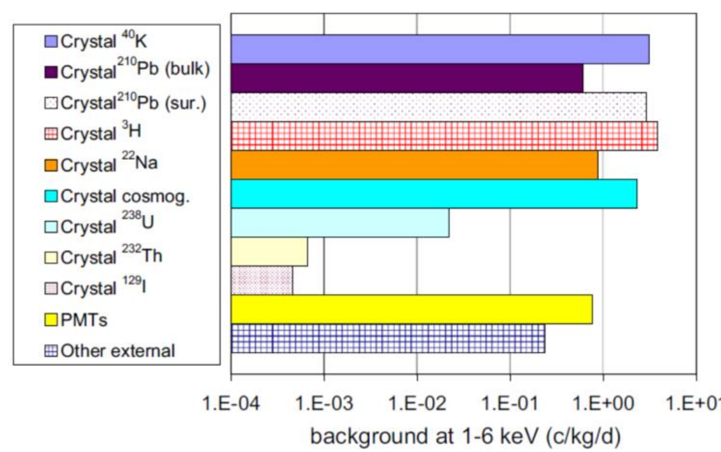


D3 module



In all detectors: continuum excess at low energy can be explained by including ^{3}H and ^{210}Pb at a surface depth from 10-100 μm

D2 module



Eur. Phys. J. C (2016) 76:429

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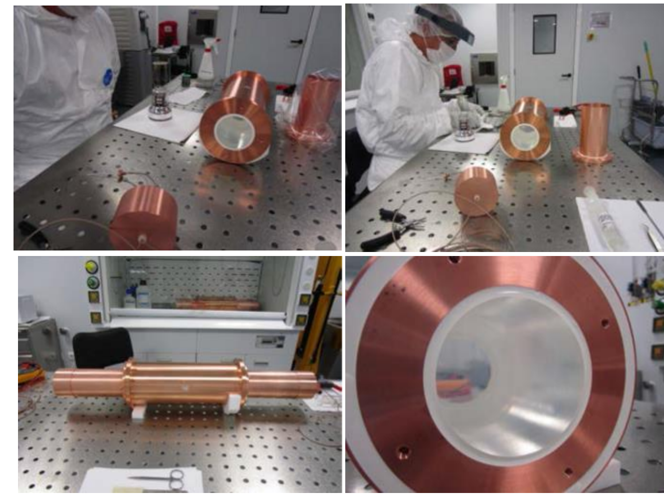
ANAIS-112 Status



D4 & D5 arrived at LSC !

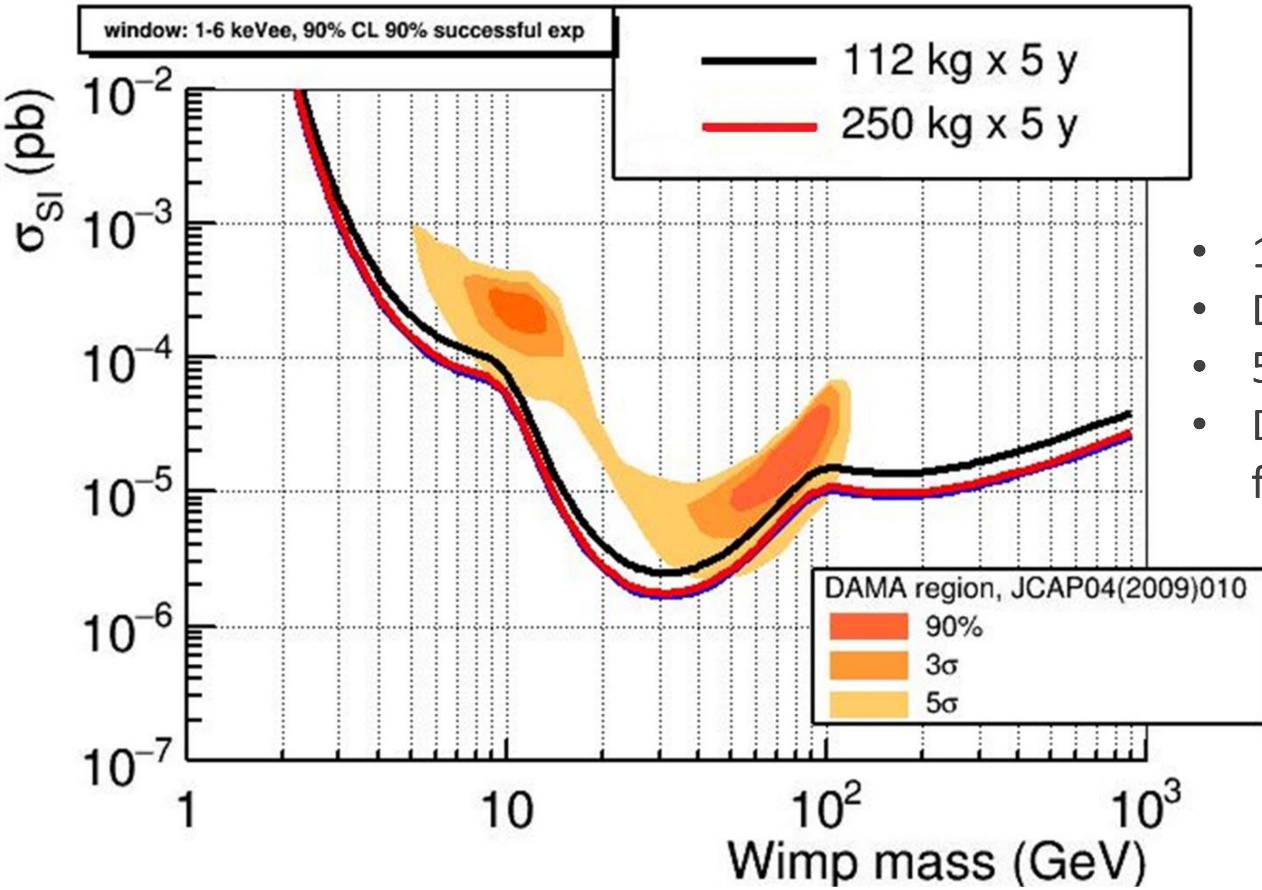
- D4 -> same ingot as D3
- D5 -> same ingot as AS2K2/3

Nov 14th : Start data-taking for bkg assesment

SCHEDULE (if required ^{210}Pb & ^{40}K levels confirmed)

- Start D6, D7, D8 (ASK2/3 ingot) purchasing immediately (MD funding)
  - production: 6/8 weeks
  - transport: 4 weeks
- February: Mounting ANAIS-112
- End February/ beginning March: **START DATA-TAKING**

ANAIS-112 sensitivity

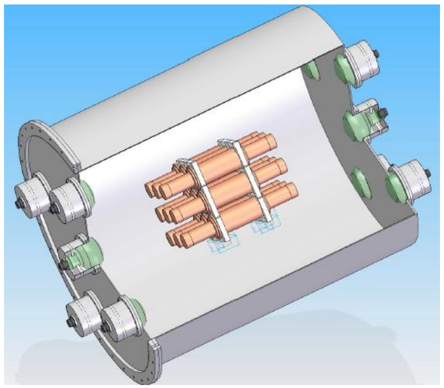


- 1-6 keVee region
- D2 background level
- 5 years data taking
- Detection limit at 90% C.L. for a critical limit at 90% C.L.

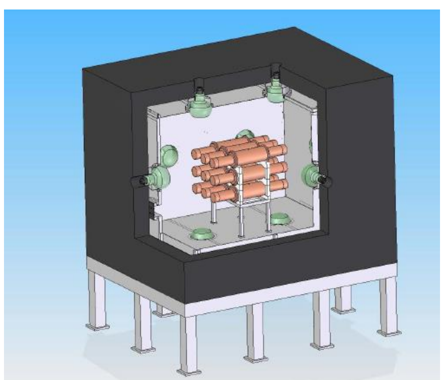
(Following S. Cebrián et al., Astroparticle Physics 14, 2001, 339)

Liquid Scintillator Veto Simulation

It could be incorporated to ANAIS-112 in a second phase of the experiment



LSVc
3.8 t LAB
scintillator



LSVb
1.7 t LAB
scintillator
(fits in present experimental setup)

	R.F. (%) ^{40}K from crystals	R.F. (%) ^{22}Na from crystals	R.F. (%) PMTs	R.F. (%) All
3x3 modules	69.0	62.4	62.3	83.7
3x3 modules + LSVb (500 keV threshold)	20.5	11.0	31.1	61.3
3x3 modules + LSVb	14.5	3.7	7.3	56.6
3x3 modules + LSVc (500 keV threshold)	15.5	5.7	29.3	59.1
3x3 modules + LSVc	11.9	1.2	7.3	55.6

Summary

- ANAIS experimental proposal:
  - 112.5 kg (3x3 crystals matrix) of NaI(Tl) at LSC:
  - 6 modules available at LSC (75 kg) /waiting for 3 more with improved radiopurity
  - Blind Analysis Strategy
- Good quality NaI(Tl) detectors from Alpha Spectra:
  - Outstanding light collection
  - Triggering at 1 keVee
  - Potassium content at 20ppb level
  - ^{210}Pb required level to be confirmed with D5
- Shielding, DAQ system and software ready at LSC – Hall B
- **Expected to start data-taking by the beginning of March 2017**
- Neutron calibrations and REF measurements pending

Good sensitivity prospects for exploring the DAMA/LIBRA signal in a model independent way: **DISCOVERY POTENTIAL**


THANKS!!!

SPARE

PMTs

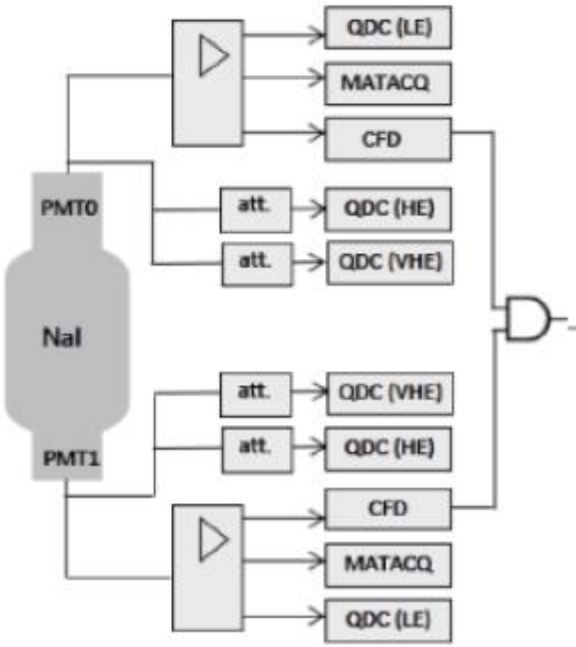
2xHE PMT Ham12669SEL2 model coupled to each module at LSC clean room

- High Quantum Efficiency / Low dark current
- Electroformed copper housing made at LSC facility
- Voltage dividers made of Cuflon PCB
- PMT Radioactivity screening at LSC

Component	Unit	^{40}K	^{232}Th	^{238}U	^{226}Ra
PMTs (R12669SEL2)	mBq/PMT	97±19	20±2	128±38	84±3
		133±13	20±2	150±34	88±3
		108±29	21±3	161±58	79±56
		95±24	22±2	145±29	88±4
		136±26	18±2	187±58	59±3
		155±36	20±3	144±33	89±5
mean activity all units	mBq/PMT	111±5	20.7±0.5	157±8	82.5±0.8

DAQ

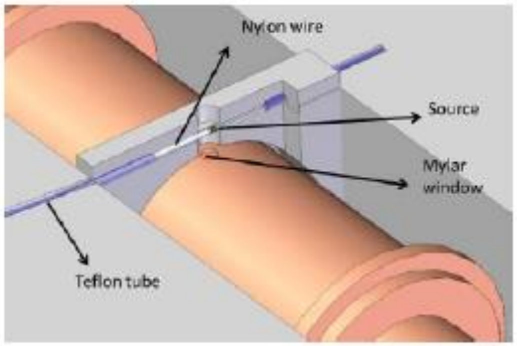
- DAQ hardware and software designed and tested with ANAIS-25 and ANAIS-37 set-ups
  - Individual PMT signals digitized (*) and fully processed
  - Trigger at phe level for each PMT
  - Logical AND coincidence in 200ns window for each module triggering
  - Redundant energy conversion in different ranges (digitized signal + QDCs)
  - (Logical XOR trigger among different modules)



* CAEN V1729A – VME 6U board – MATACQ chip

- * 14 bits / 2 GS/s
- * 300 MHz bandwidth
- * ±1V
- * 4 channels

Data analysis strategy



External calibration source data (^{109}Cd / ^{57}Co)

- Energy calibration
- Determination of cut efficiency

Background data

- Coincidences with HE γ
  - Energy Calibration
  - Determination of trigger efficiency
  - Checking cut efficiency

- Application of cuts
- Efficiency correction

Building filtered background

Background understanding

Simulations of the different modules using Geant-4 package
Input contamination determined by HPGe spectrometry for external components and PMTs, and taking internal contaminations values derived as shown before

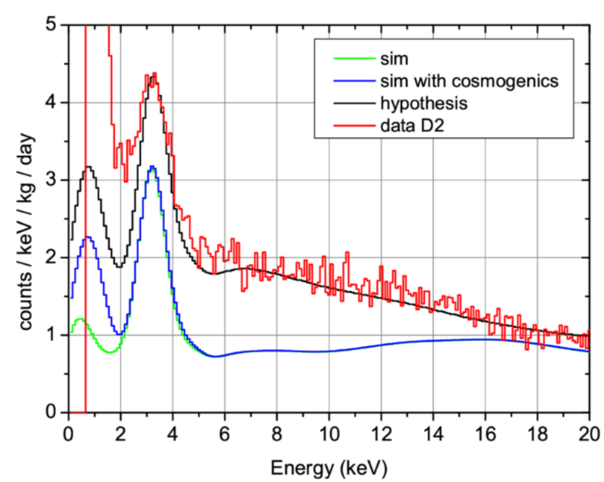
- **CRYSTAL**

3.2 - 0.6 mBq/kg ^{210}Pb
1.0 – 0.6 mBq/kg ^{40}K (34 - 19 ppb K)
0.94 mBq/kg ^{129}I
U/Th chains in the NaI bulk
Cosmogenic backgrounds (all isotopes but ^{22}Na in saturation)

- **PMTs**

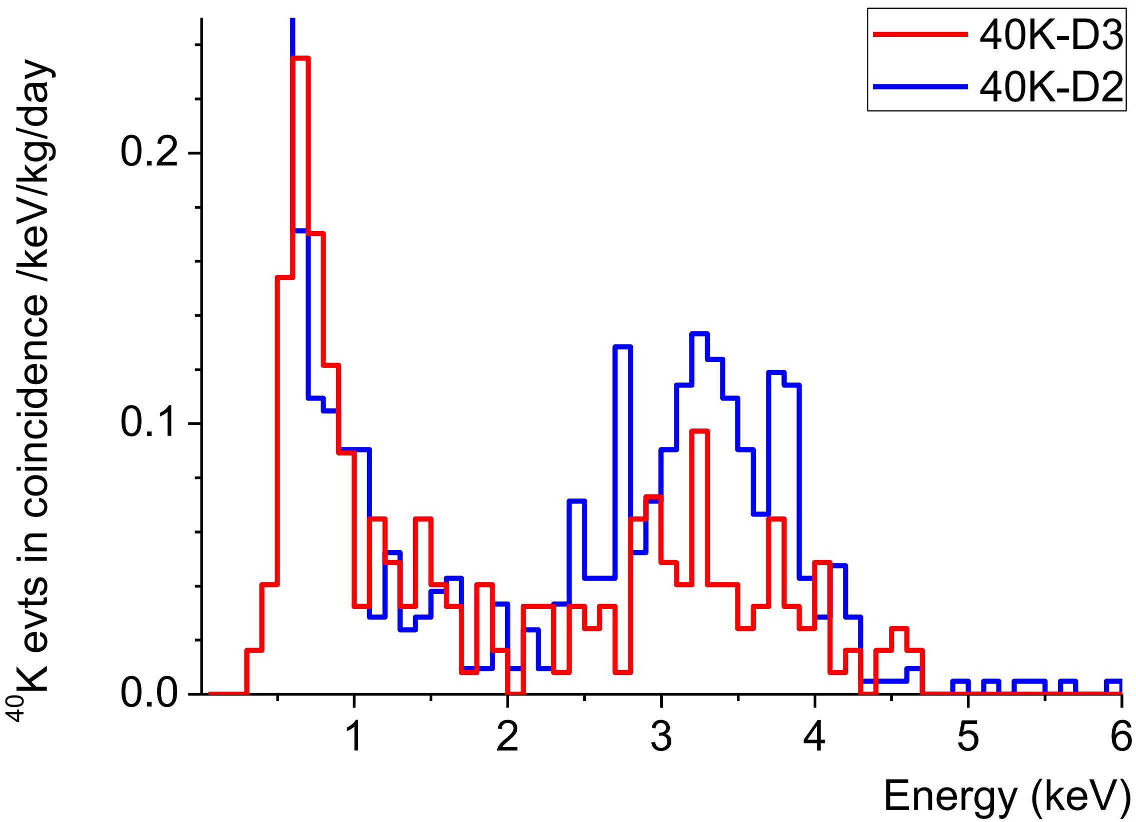
Upper bounds on:
Quartz window
Silicone pads
Copper housing
Residual Radon
Lead shielding

+ HYPOTHESIS:
- Some ^{210}Pb at surface
- 0.09 – 0.18 mBq/kg ^{3}H in the bulk



Eur. Phys. J. C (2016) 76:429

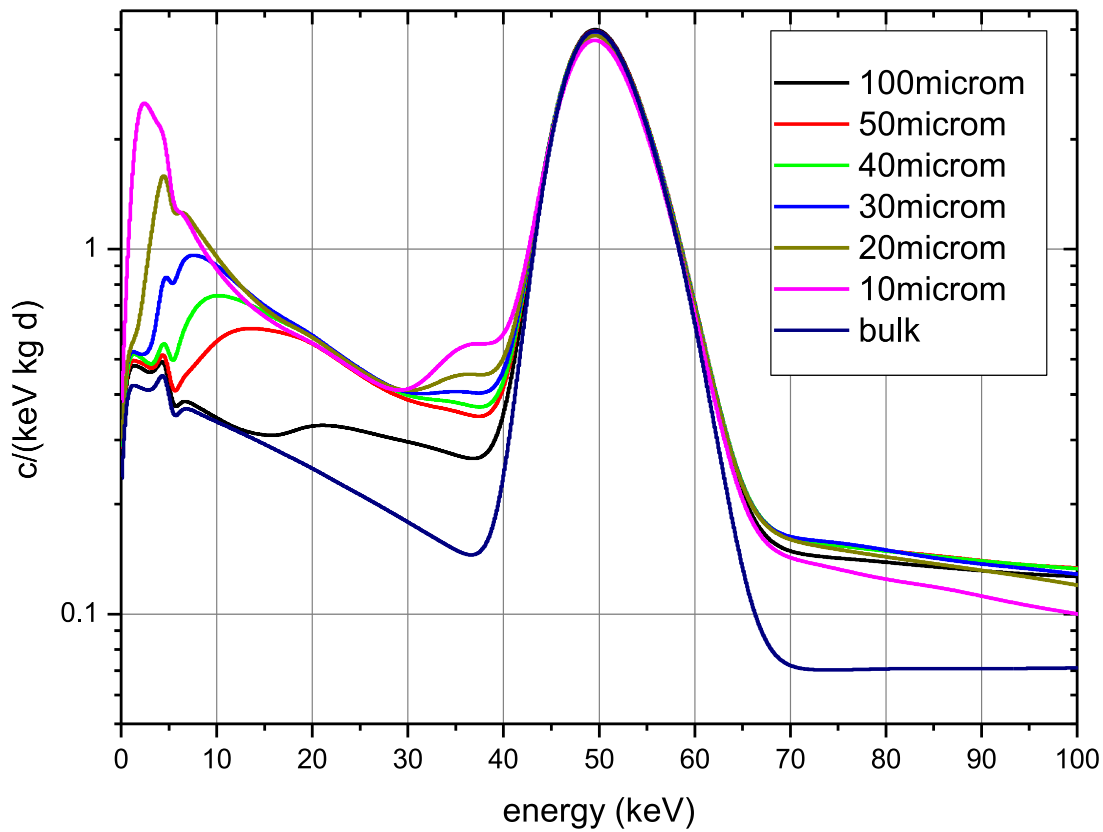
^{40}K D3 Vs D2



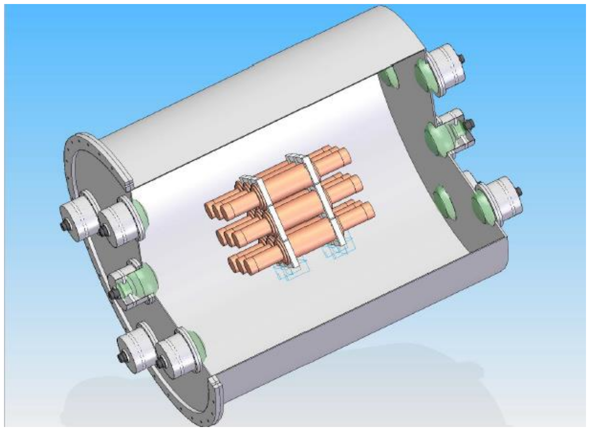
40K-D3
40K-D2
0.2
0.1
0.0
1
2
3
4
5
6
Energy (keV)
40K evts in coincidence /keV/kg/day

Surface ^{210}Pb

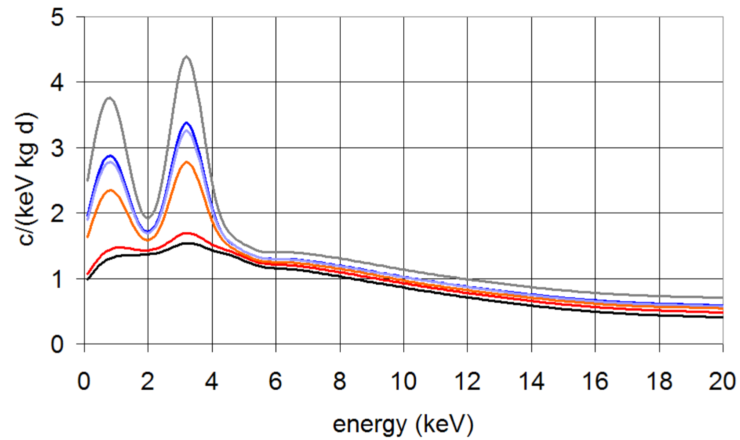
^{210}Pb in the crysal surface could provide an explanation for the low energy background features

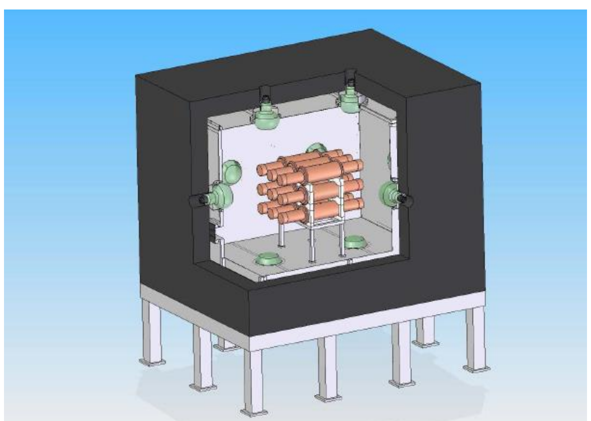


Liquid scintillator veto simulation

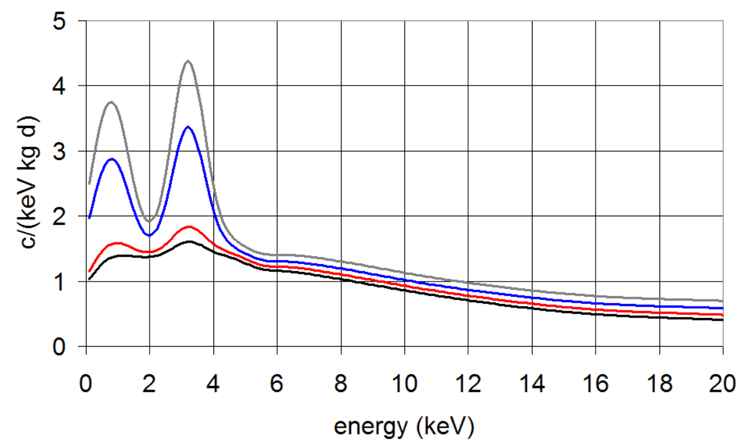


LSVc
3.8 t LAB scintillator

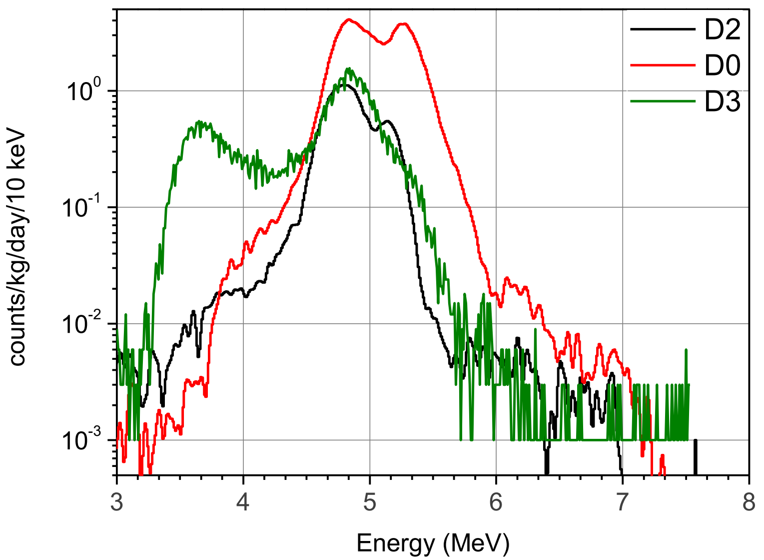


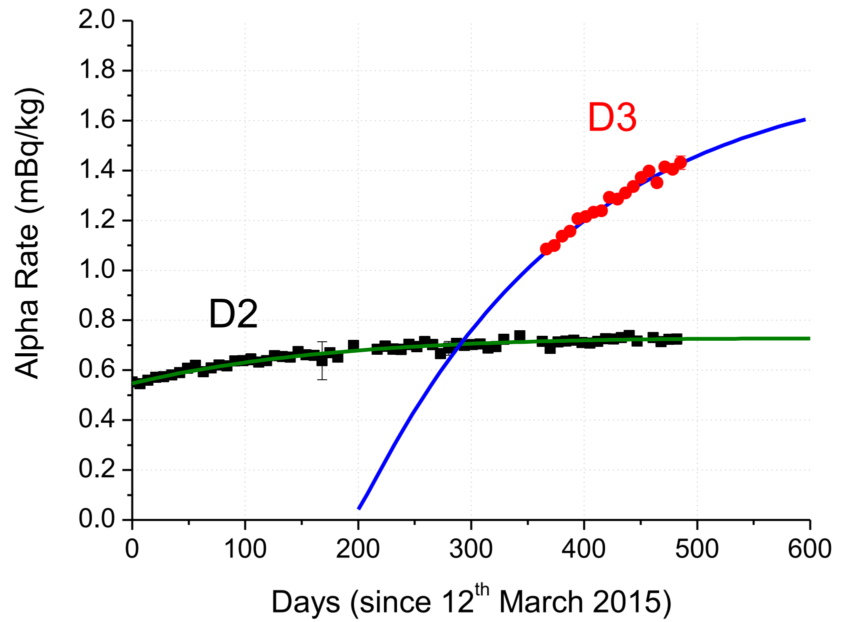


LSVb
1.7 t LAB scintillator
It fits in present experimental configuration



Alpha spectrum





Very different alpha spectrum in D3 with respect to that of D2
Surface contaminations?