Universidad Zaragoza 1542

LSC
Laboratorio Subterráneo de Canfranc

Status of the ANAIS experiment at the Canfranc underground laboratory

Miguel Ángel Oliván
on behalf of the ANAIS team

Universidad de Zaragoza
Laboratorio Subterráneo de Canfranc

CPAN Ingenio 2010

MultiDark
Multimessenger Approach for Dark Matter Detection

VII CPAN DAYS, Segovia 1 - 3 December2015

Outline

- ANAIS Experiment
- ANAIS-25
- ANAIS-37
- ANAIS status and prospects

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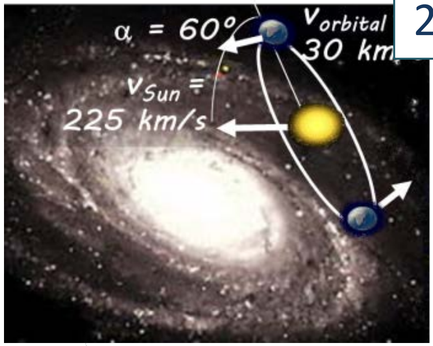
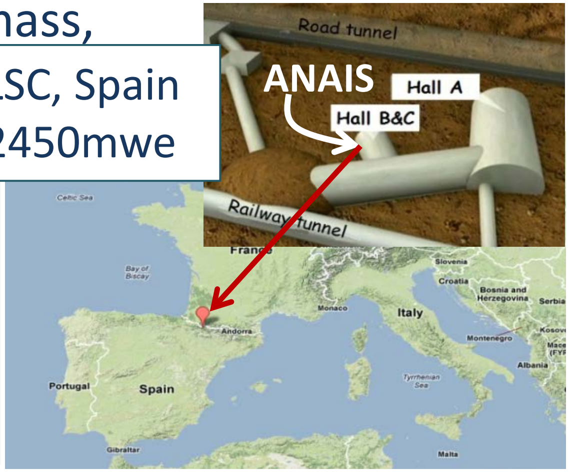
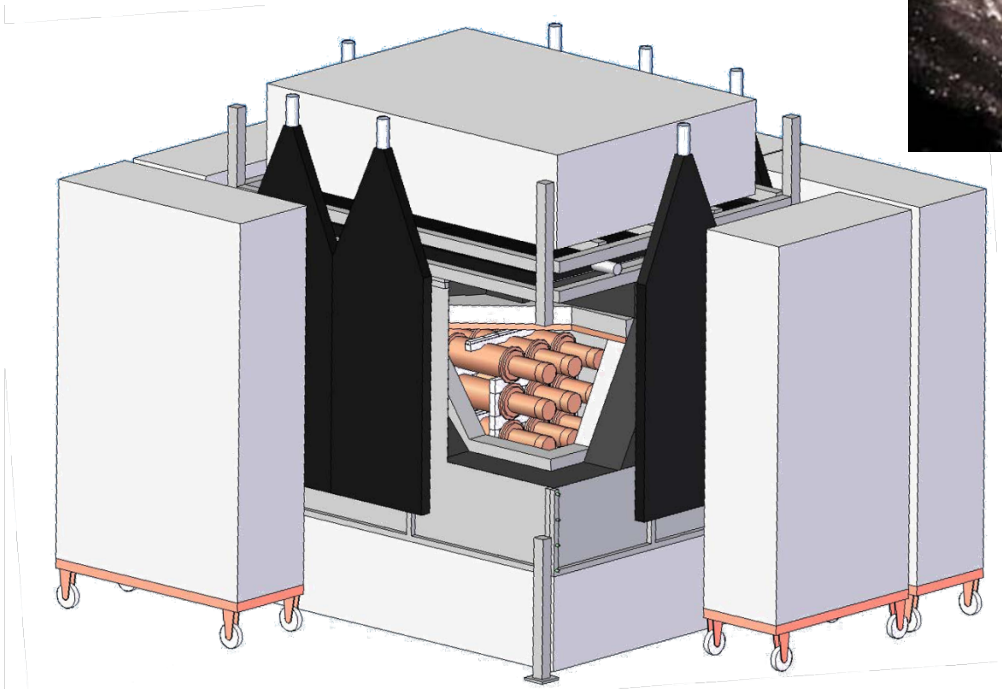
ANAIS Experiment

Project for 3×3 matrix of NaI(Tl) scintillators, 112.5 kg total mass, to look for Dark Matter (DM) annual modulation at the Canfranc Underground Laboratory (LSC)



LSC, Spain
2450mwe





Goal:
Confirmation of DAMA/LIBRA positive signal with same target and technique

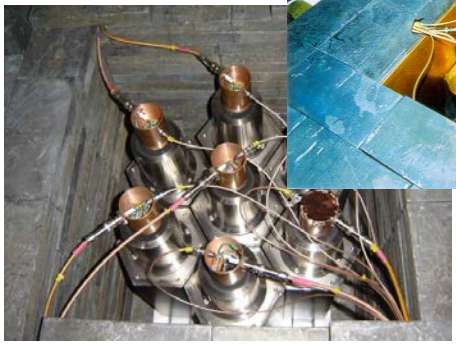
Experimental requirements:

- Energy threshold < 2 keVee
- Background few counts/(keV kg day)

ANAIS Experiment

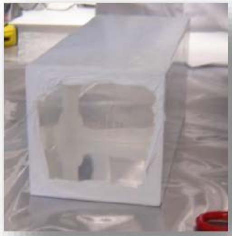
Long effort by the University of Zaragoza through the operation of different NaI detectors in Canfranc

- Using hexagonal, 10.7 kg NaI crystals from BICRON:



- Pioneer modulation analysis at **NaI32 experiment**
  - M. L. Sarsa *et al.*, *Phys. Lett. B* **386**, 458 (1996)
  - M. L. Sarsa *et al.*, *Phys. Rev. D* **56**, 185 (1997)
- First ANAIS prototypes

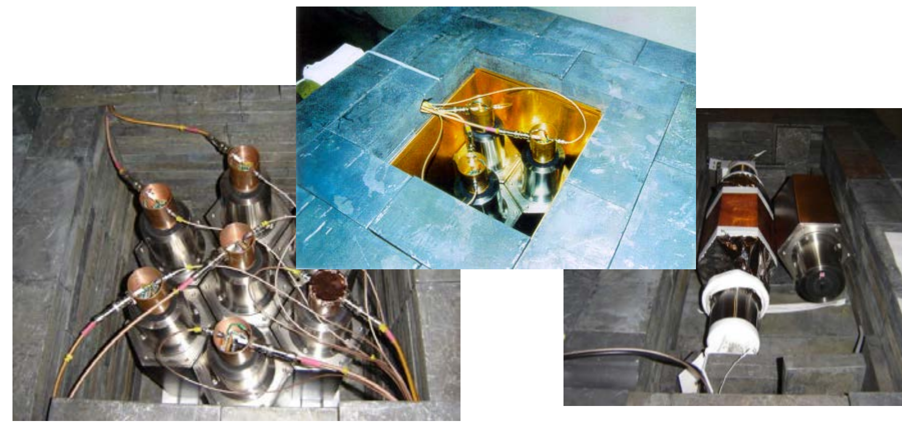
- Using a 9.6 kg NaI crystal from St. Gobain: **ANAIS-0 prototype**




- Bulk NaI(Tl) scintillation low energy events selection with the ANAIS-0 module. C. Cuesta et al., *EPJ C 74 (2014) 3150.*
- Analysis of the 40K contamination in NaI(Tl) crystals from different providers in the frame of the ANAIS project. C. Cuesta et al., *Int. J. Mod. Phys. A. 29 (2014) 1443010.*
- Slow scintillation time constants in NaI(Tl) for different interacting particles. C. Cuesta et al., *Opt. Mat. 36 (2013) 316.*
- Background model for a NaI(Tl) detector devoted to dark matter searches. S. Cebrián et al., *Astrop. Phys. (2012) 60.*

ANAIS Experiment

Long effort by the University of Zaragoza through the operation of different NaI detectors in Canfranc



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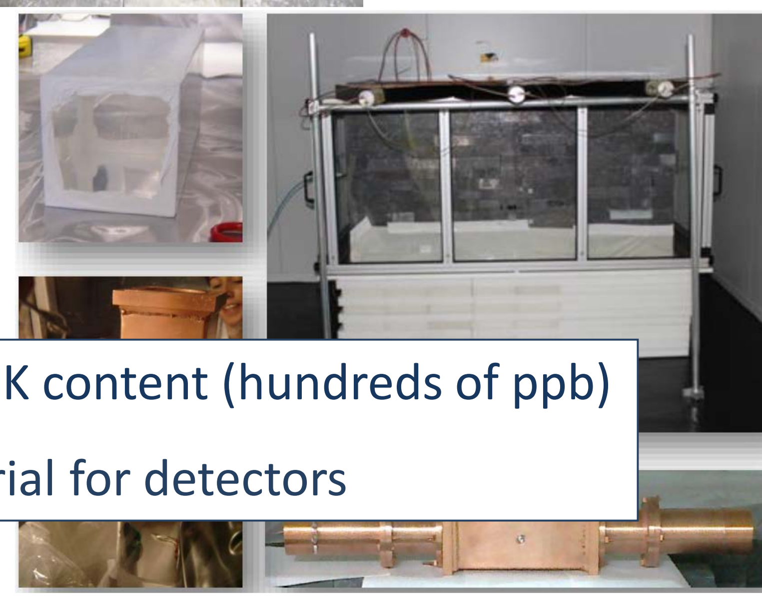


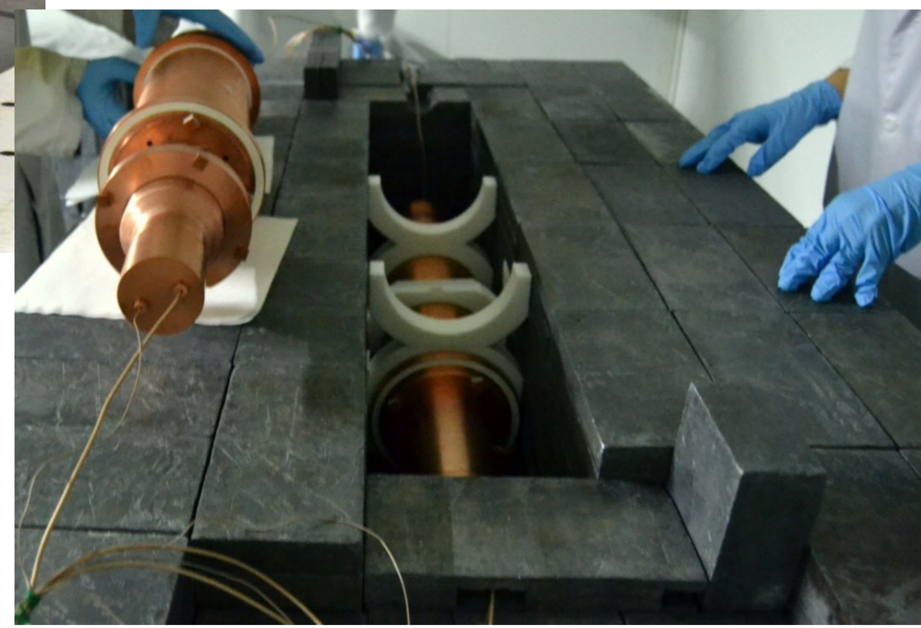
Disregarded due to an unacceptable K content (hundreds of ppb)

Search for cleaner material for detectors

ANAIS-25

Two Alpha Spectra modules:

- Clean starting NaI powder (< 90 ppb K)
- 12.5 kg, cylindrical
- Mylar window for low energy calibration
- PMT Ham (R12669SEL2 & R11065SEL)

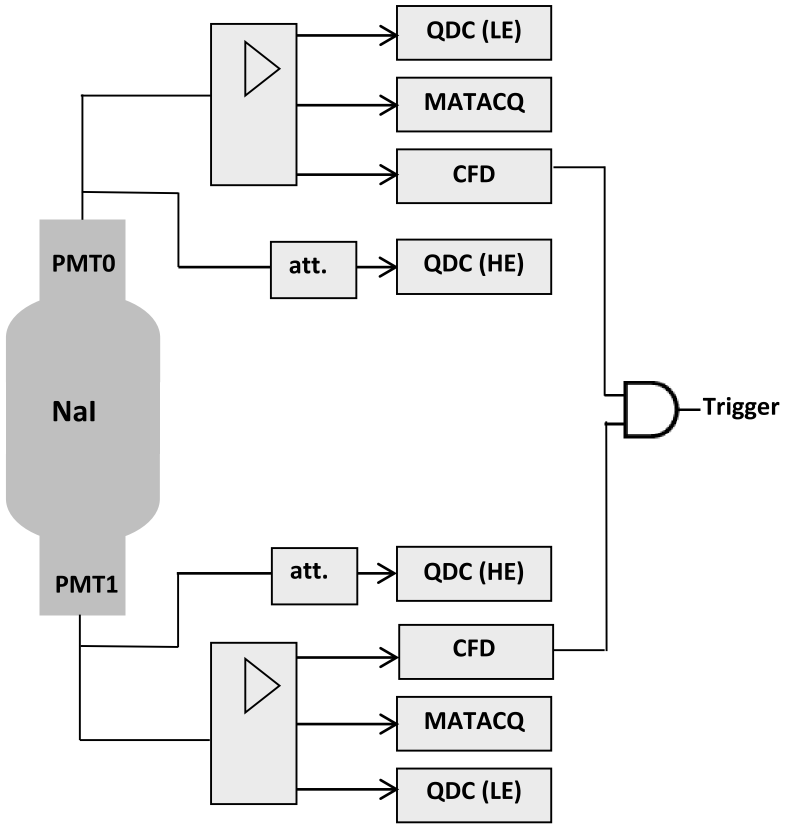


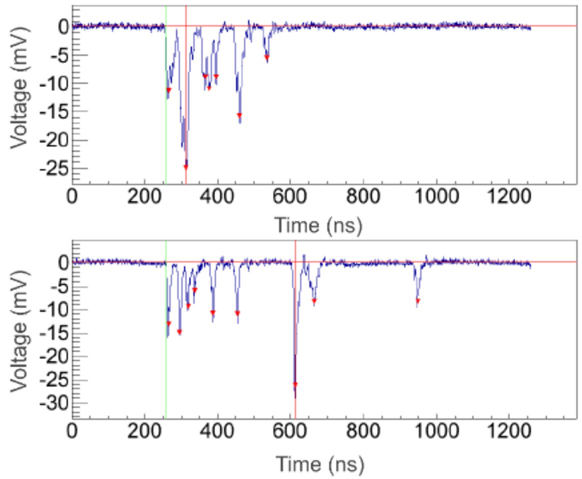
Goals:

- Measure internal contamination ^{40}K and ^{238}U and ^{232}Th chains
- Determine light collection, fine tuning of DAQ, filtering and analysis protocols, general background assessment

Taking data at LSC: Dec 2012 - Mar 2015

ANAIS Data Acquisition





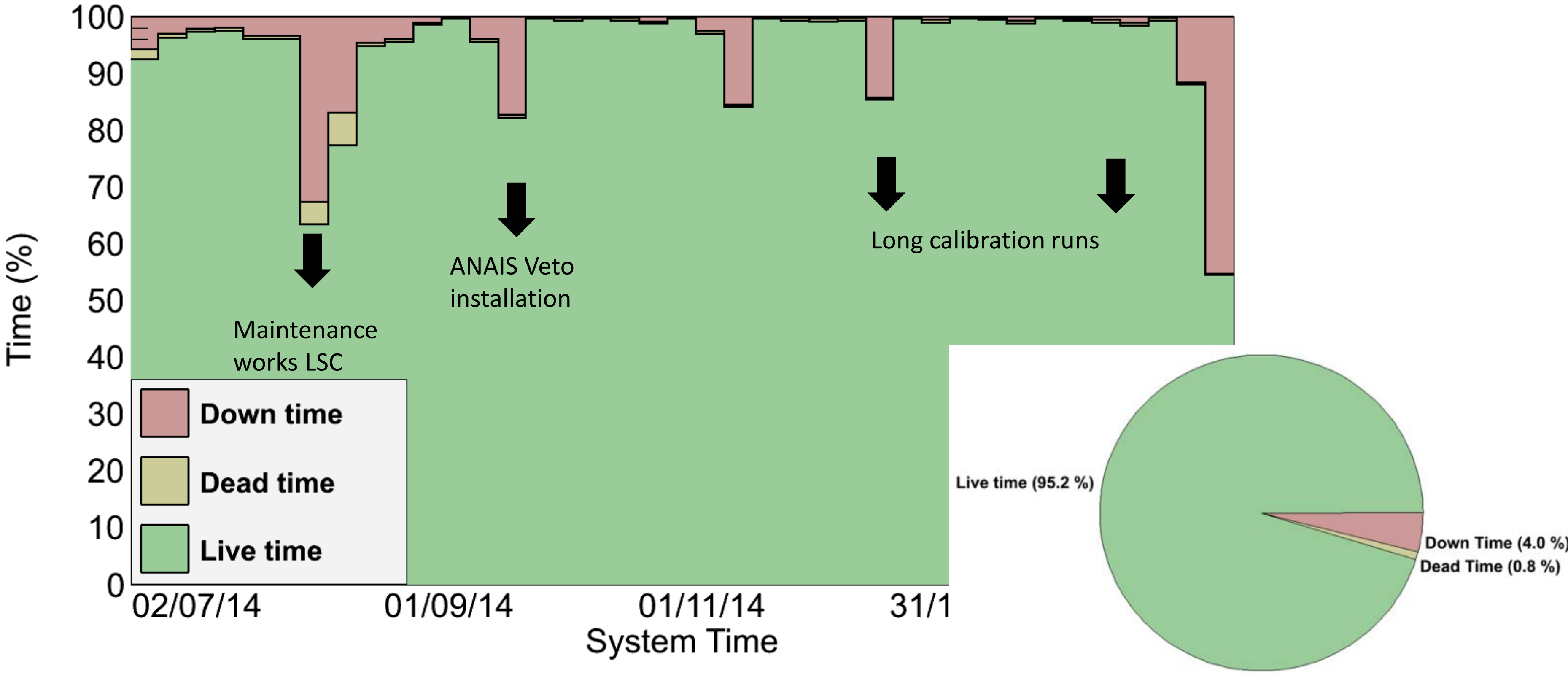
- Scalable design:
  - Both PMT digitized (Matacq Board)
  - Both PMT signals fully processed
  - Trigger at phe level @ PMTs signal
  - AND coincidence in 200ns window
  - Redundant energy conversion by QDC in HE/LE regions
- More modules →

  Global trigger in OR logical mode

ANAIS-25

ANAIS-25: phase III reached optimal operation conditions

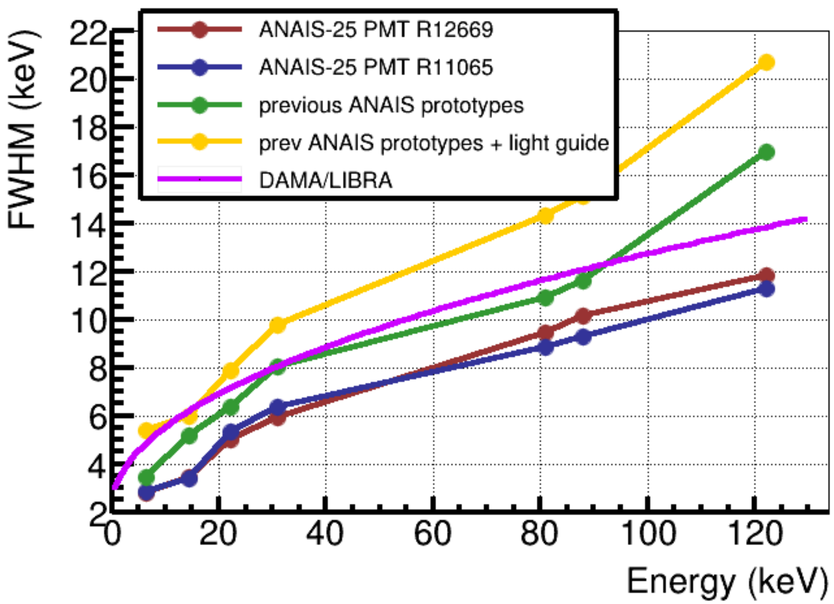
Excellent duty cycle



ANAIS-25 – Light collection

Detector	Phe-/keV
D0	15.24 ± 0.09
D1	15.19 ± 0.07

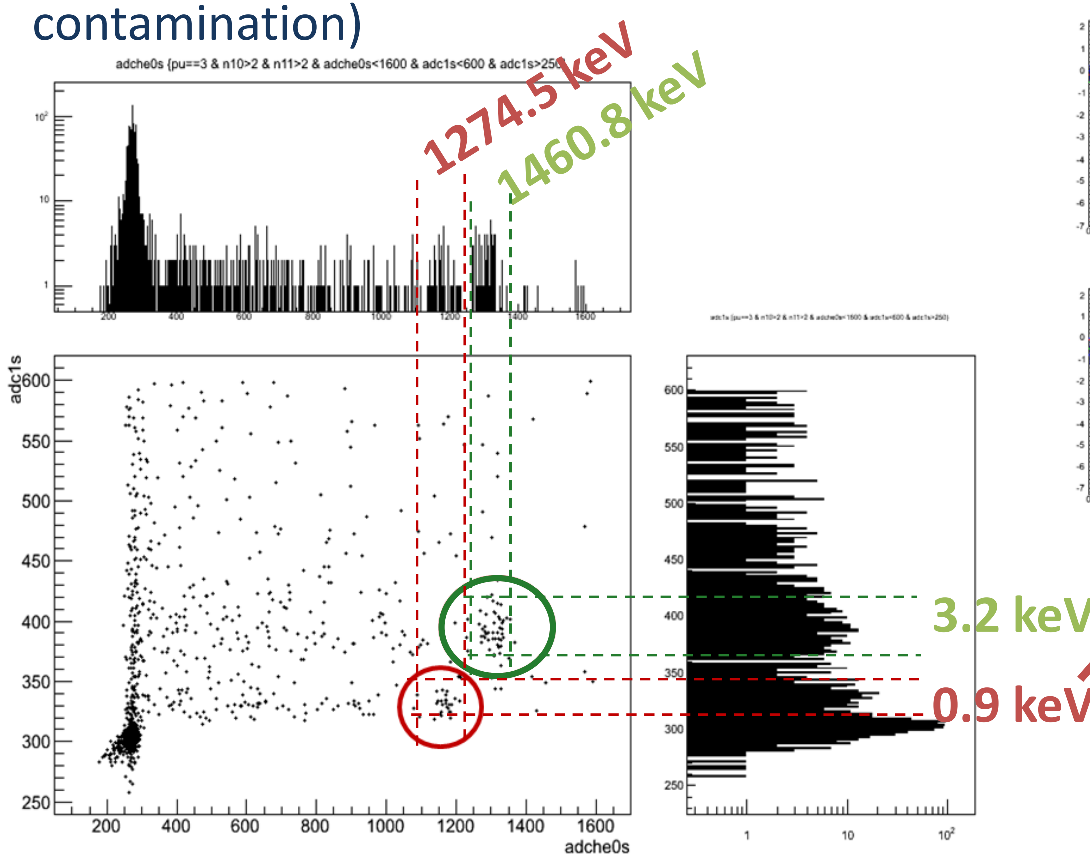
Excellent light collection (~15 phe$^-$/keV) with high quantum efficiency PMTs **R12669SEL2** (arXiv:1508.06152)

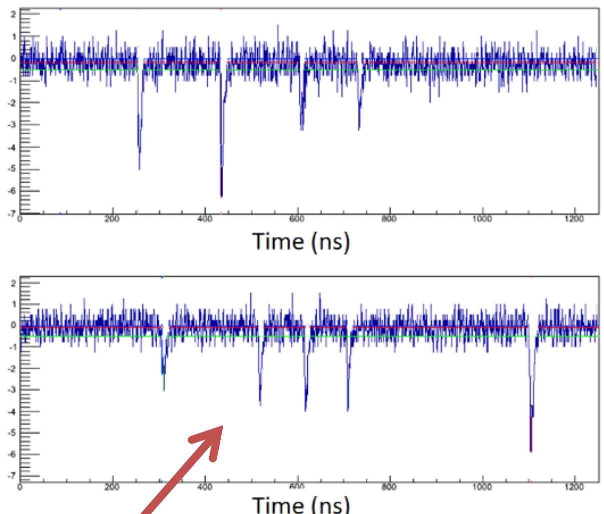


Resolution improvement in all low energy calibration lines

ANAIS-25 – Threshold

Coincident events → two energy coincident lines (^{40}K and ^{22}Na internal contamination)





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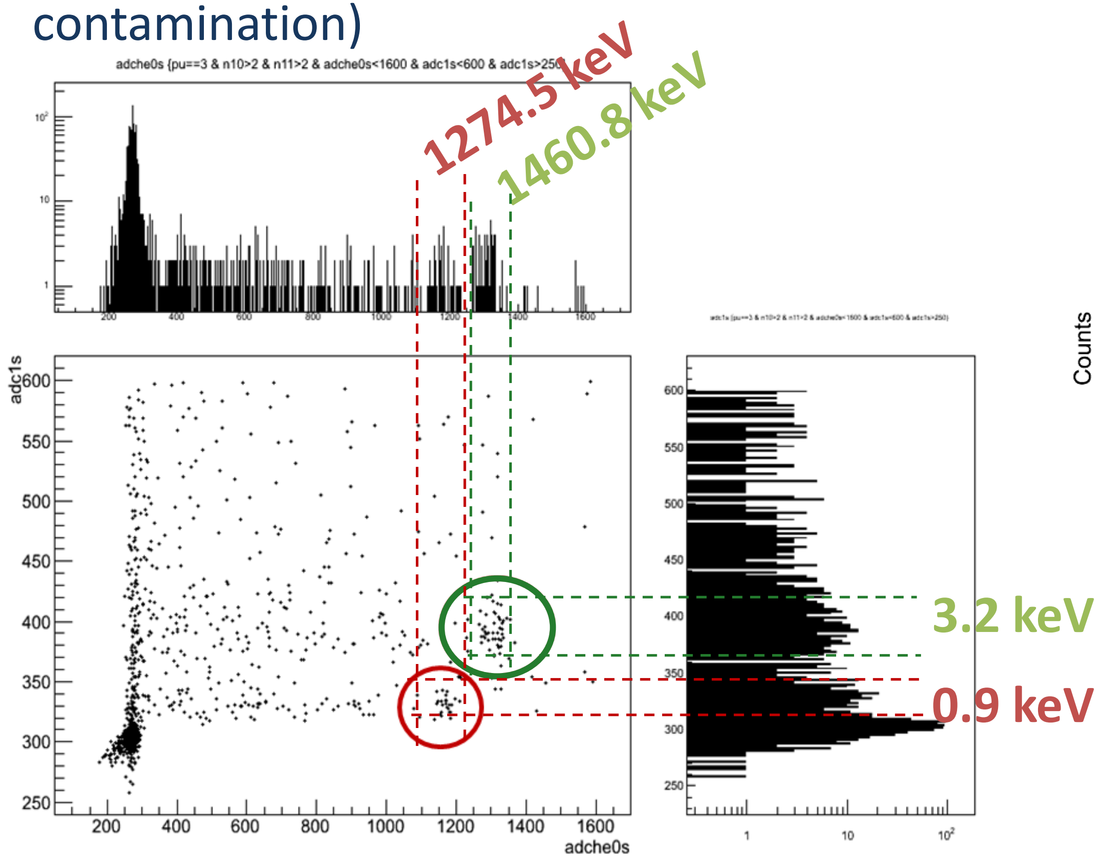
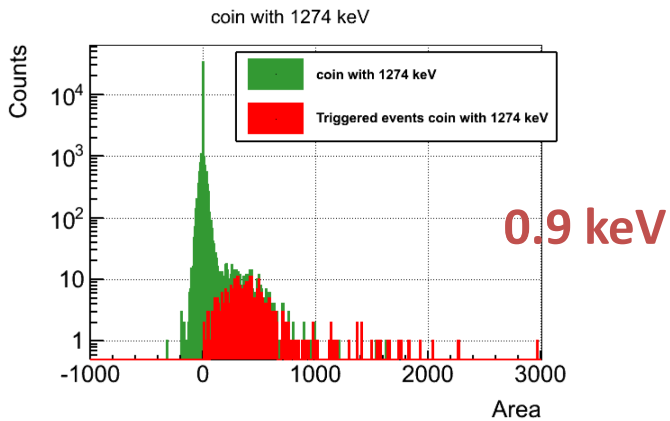
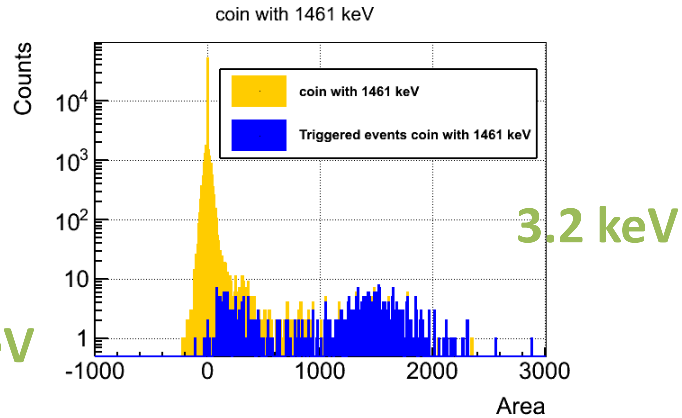






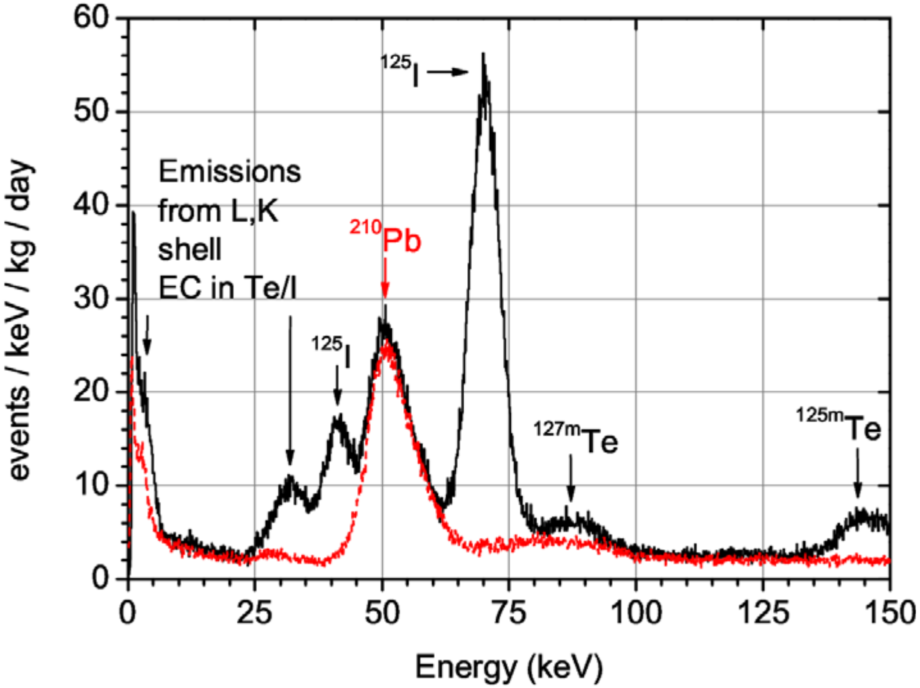
High hardware trigger efficiency down to 0.9 keV

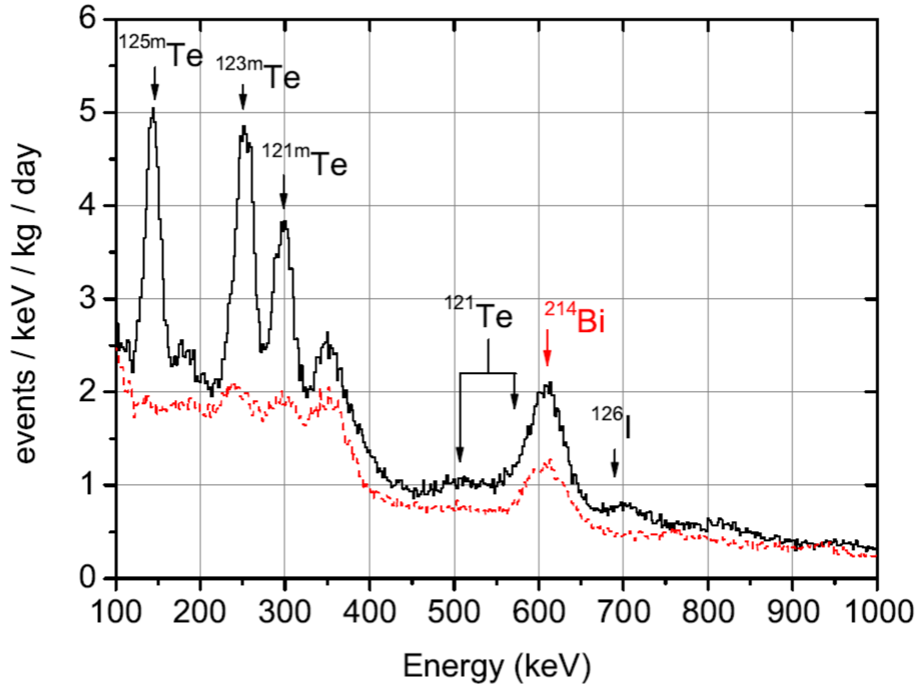
ANAIS-25 – Background

Contribution from cosmogenic isotopes induced in NaI crystals:

Determined for the first time the cosmogenic production of some isotopes in NaI (I, Te, Na)
J. Amaré et al, JCAP 02 (2015) 046

- **First month of data-taking**
- **15 months later**



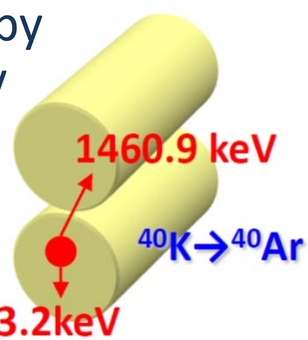


ANAIS-25 – Background

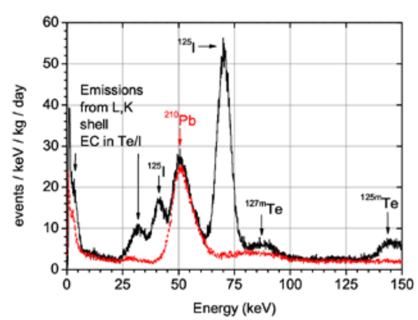
Bulk Contamination:

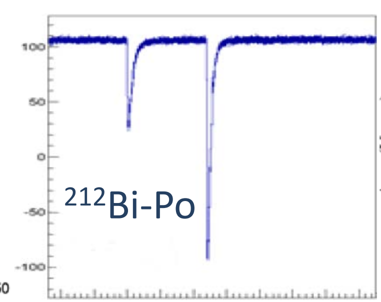
^{40}K	^{238}U	^{210}Pb	^{232}Th
1.25 mBq/kg (41 ppb K)	10 μBq/kg	**3.15 mBq/kg**	3 μBq/kg

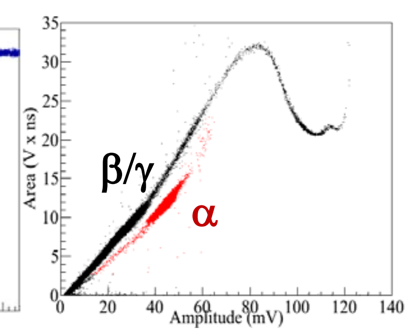
Determined by 1461/3.2 keV coincidence analysis



Determined by alpha rate and Bi/Po sequences.
Verified by simulations (see later).







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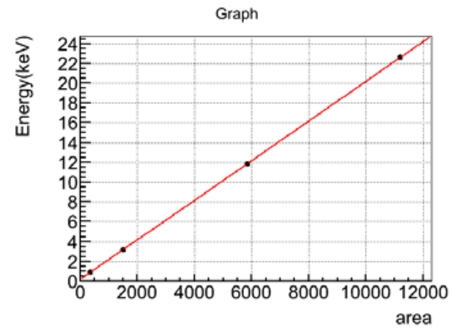
^{40}K	^{238}U	^{210}Pb	^{232}Th
1.25 mBq/kg (41 ppb K)	10 μBq/kg	**3.15 mBq/kg**	3 μBq/kg

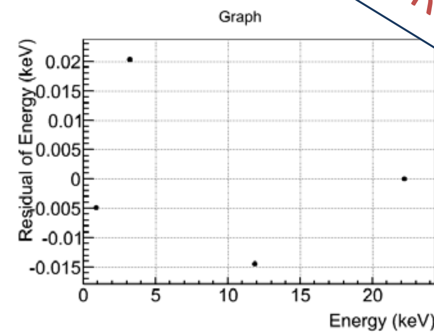
- Radiopurity goals are fulfilled for ^{40}K and ^{232}Th and ^{238}U chains, but a ^{210}Pb contamination out-of-equilibrium is present in ANAIS-25 crystals.
- Origin of the ^{210}Pb contamination identified (crystal growing) and being solved by Alpha Spectra.
- **New material prepared at Alpha Spectra using improved protocols: new detector under testing → ANAIS-37**

ANAIS-25 – Data analysis

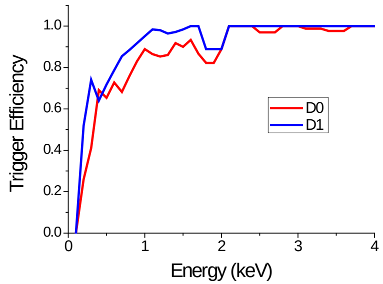
WORK IN PROGRESS

Calibration with ^{109}Cd and coincident lines (^{40}K and ^{22}Na): accurate calibration at 1keVee



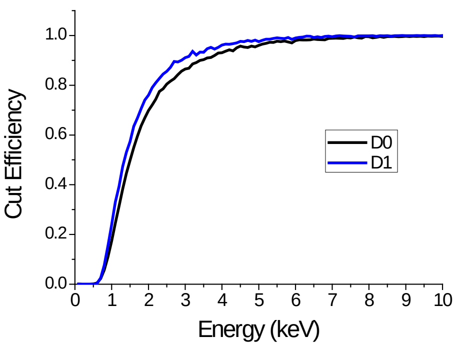


At 1 keVee the trigger efficiency is larger than 80% (estimated with coincident events, ^{22}Na and ^{40}K)



Cuts for removing PMT events:

1) Cut in the number of peaks in the pulse (n>2 in each PMT)
2) Cut in temporal parameters of the pulse
3) Cut in asymmetry in the light sharing

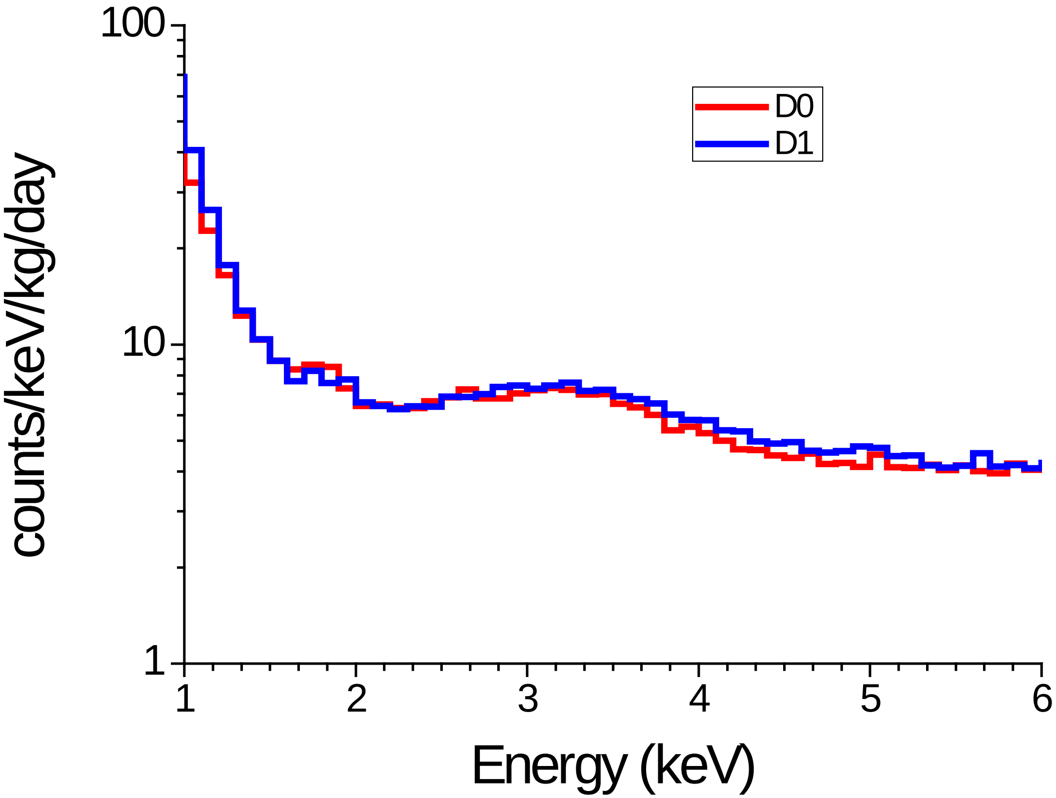


Cut efficiency at 1 keVee 20%
Very fast increasing 1-2 keVee
(calculated with ^{109}Cd events considering all events good events → underestimated)

ANAIS-25 – Data analysis

WORK IN PROGRESS

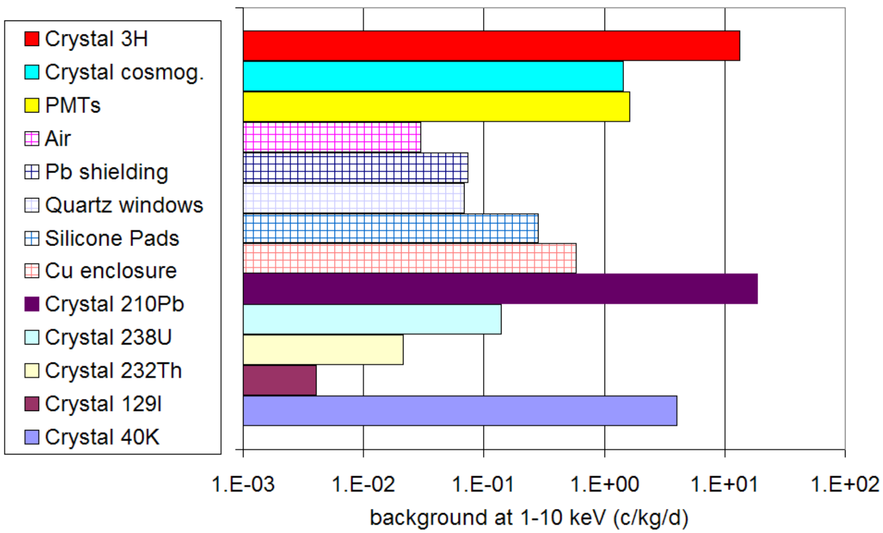
Background after applying the cuts, efficiency corrected:

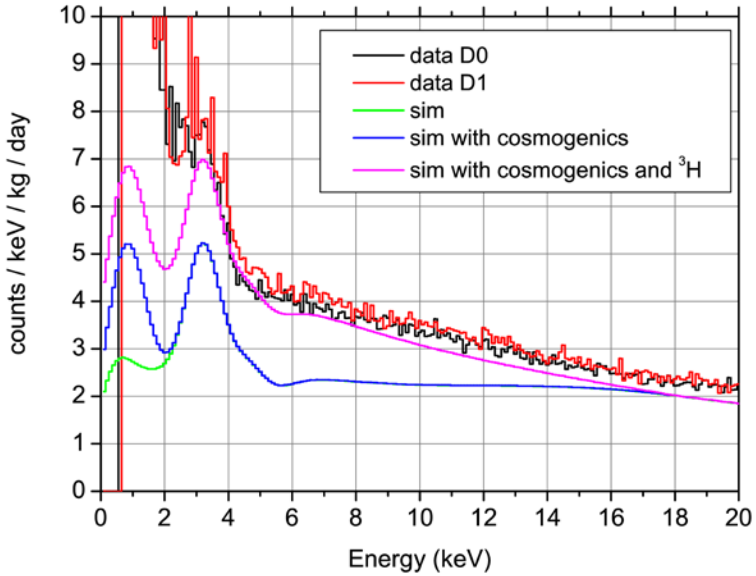


- Working on more aggressive cuts to reduce background below 2 keVee
- Working on a *blank module* (without crystal) to study the PMT coincident events

ANAIS-25 – Background model

- Measured activity of external components (PMTs, copper, …)
- Measured activity in NaI crystals
  (^{40}K, ^{238}U, ^{232}Th, ^{210}Pb)
- Cosmogenics
  J. Amaré et al, JCAP 02 (2015) 046
- ^{3}H activity





Good agreement with filtered background, coincident and anticoincident spectra down to 3 keVee. (arXiv:1508.07907)

Outline

- ANAIS Experiment
- ANAIS-25
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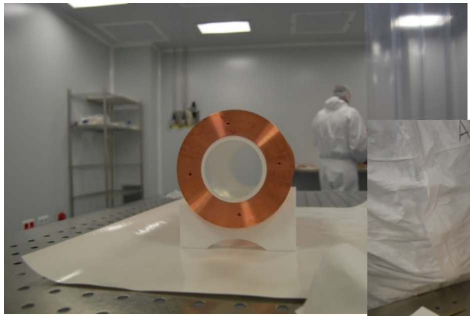
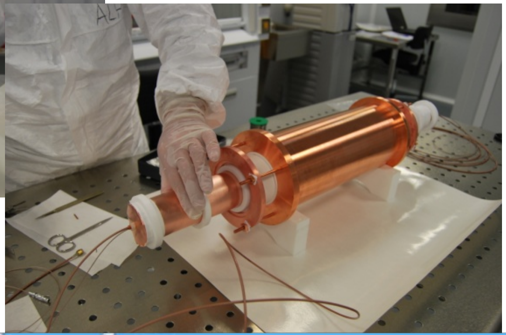
ANAIS-37

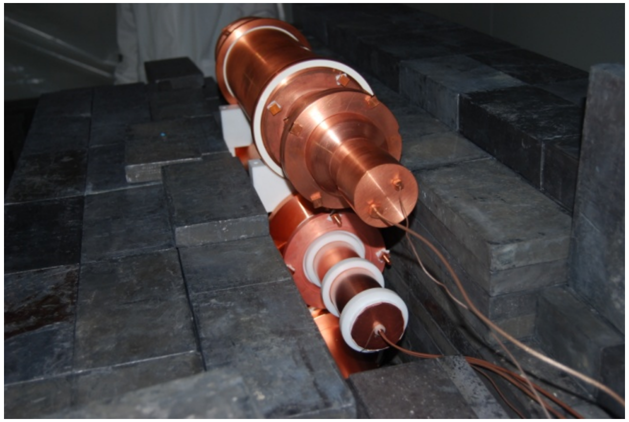
New module by Alpha Spectra (D2)
Goals, check:

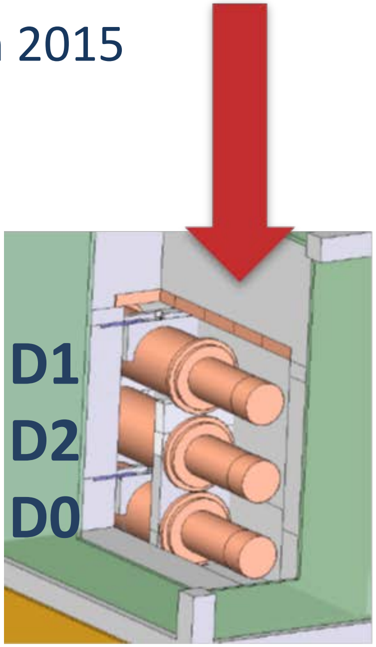
- ^{210}Pb reduction
- ^{40}K and ^{238}U and ^{232}Th chains
- Light collection

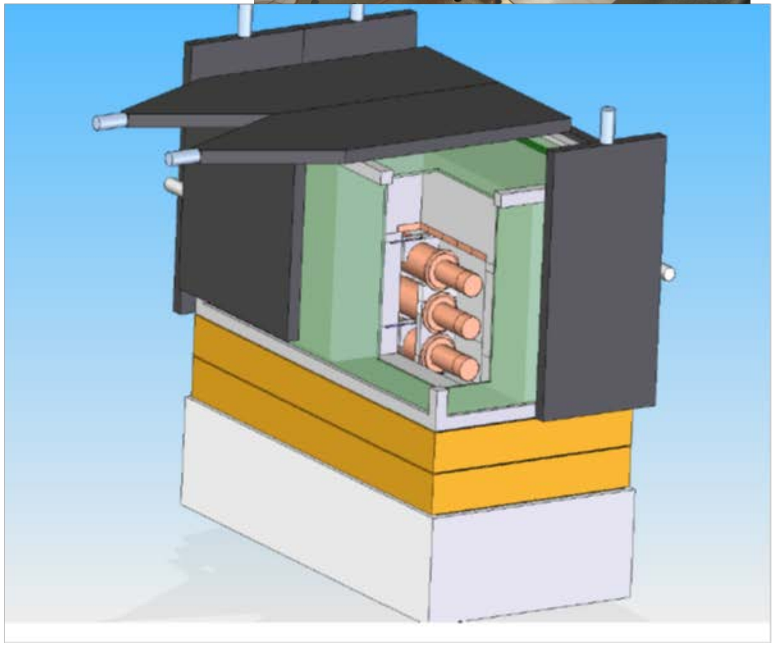
Taking data at LSC since March 2015







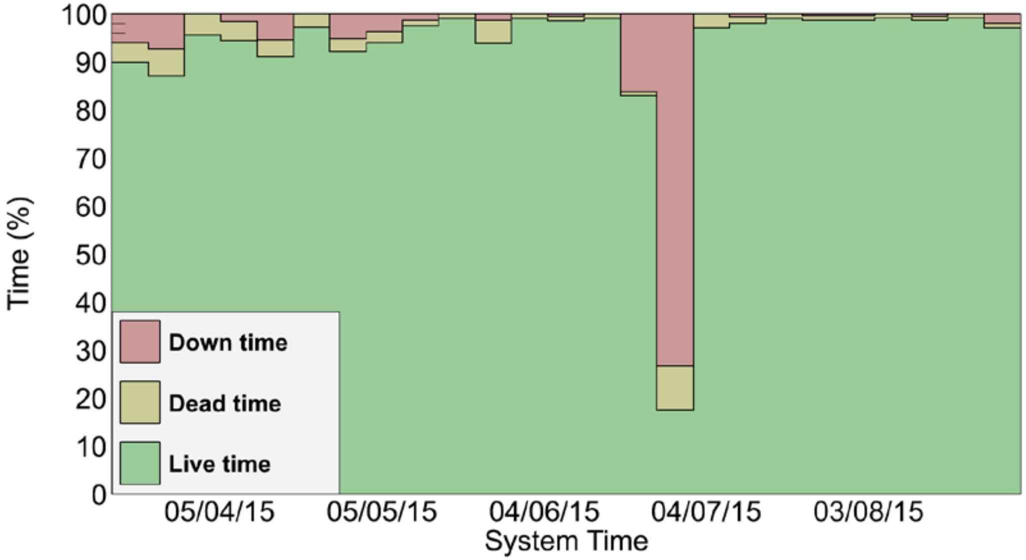




ANAIS-37

Data taking since March 2015

- Optimal operation conditions
- Excellent duty cycle



Excellent light collection:

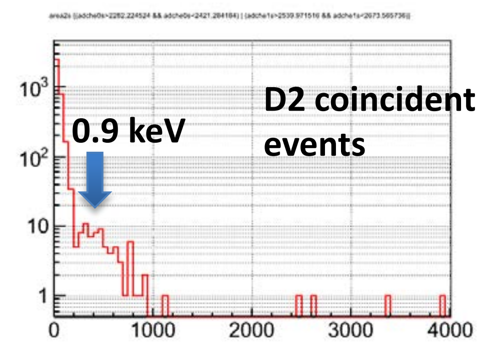
arXiv:1508.06152

Detector	Phe-/keV
D0	15.26 ± 0.10
D1	14.44 ± 0.09
D2	**16.31 ± 0.56**

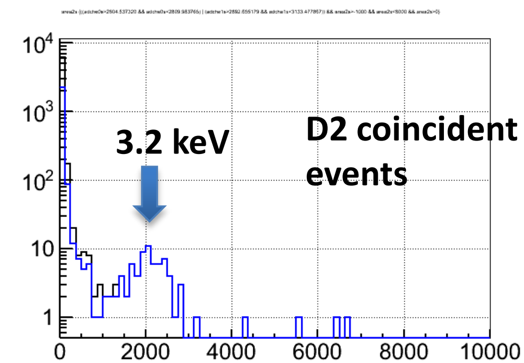
ANAIS-37 – Background

New detector (D2) background:

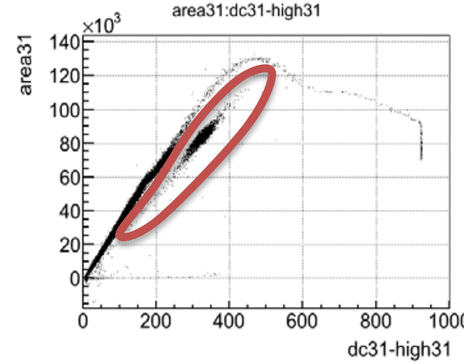
- Coincidence window at 1274 keV in D0 | D1 ^{22}Na coincident events **as cross-check of the threshold**



- Coincidence window at 1461 keV in D0 | D1 ^{40}K Potassium Content: 34 ppb



- Total alpha rate at the level of **0.70 mBq/kg** ANAIS-25 alpha rate: 3.15 mBq/kg (**factor 0.22**)

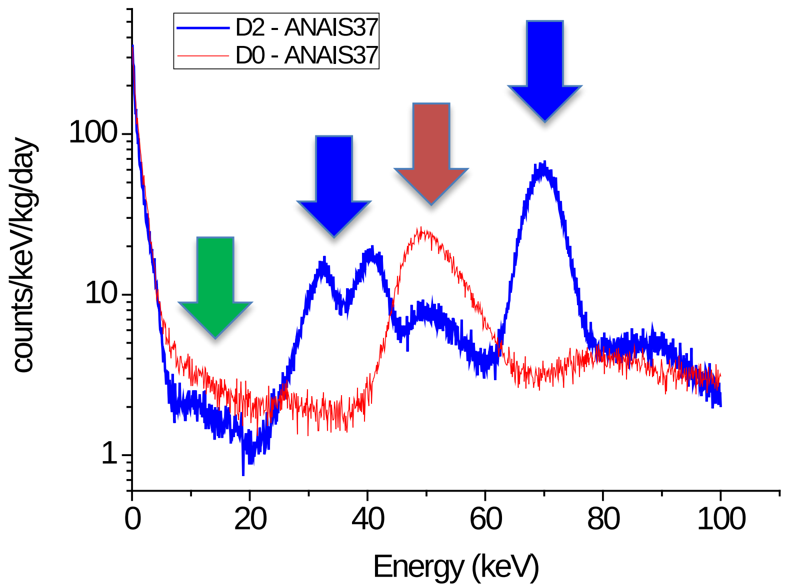


ANAIS-37 – Background

Raw D2 background without filtering:

Very promising reduction under 20 keV
and cosmogenics still decaying

^{210}Pb clear reduction with respect to ANAIS-25 modules (further reduction expected for new WIMPScint-III powder)



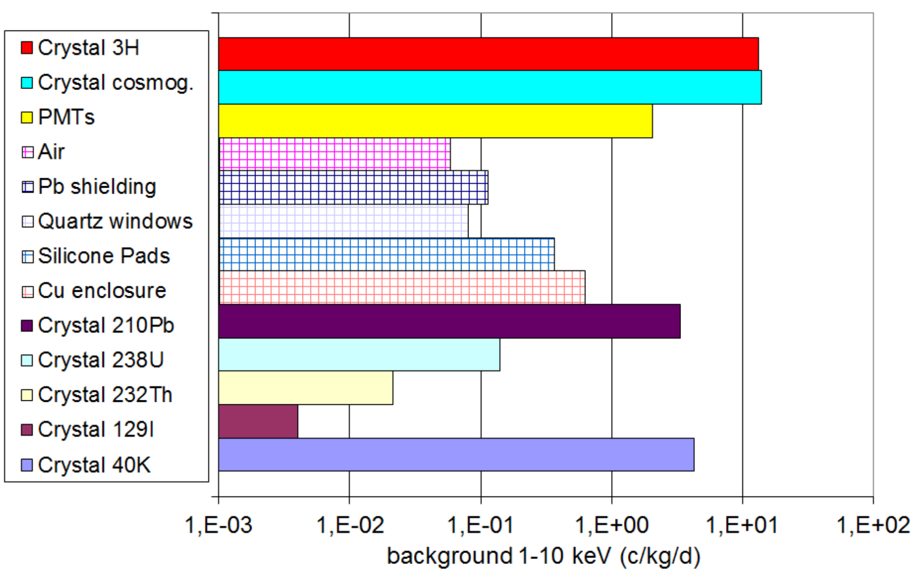
ANAIS-37 – Background model

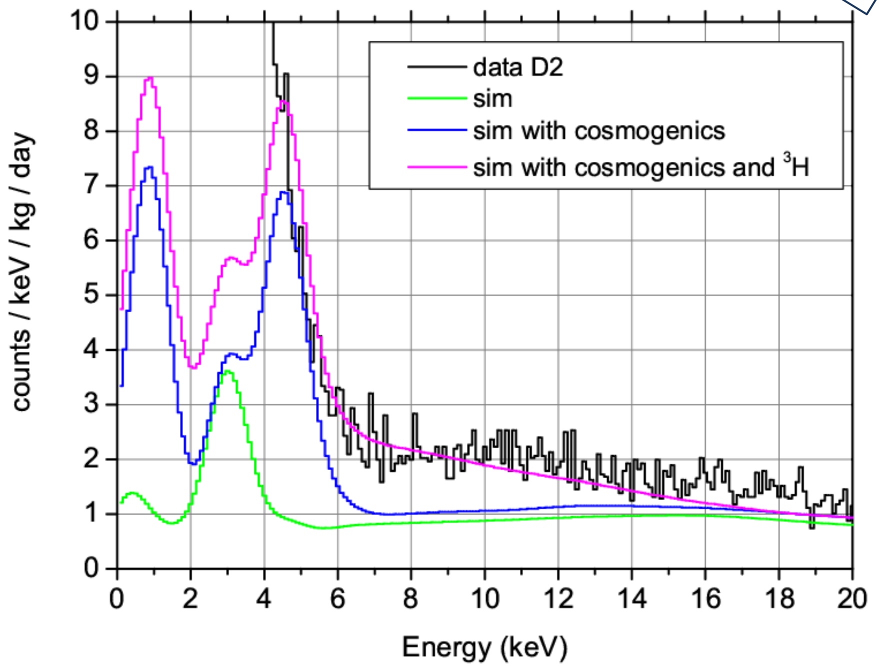
WORK IN PROGRESS

Same ANAIS-25 contributions except:

- Less ^{210}Pb
- new detector →

Cosmogenic isotopes still decaying





Good agreement with **raw** background down to 4 keVee

arXiv:1508.07907

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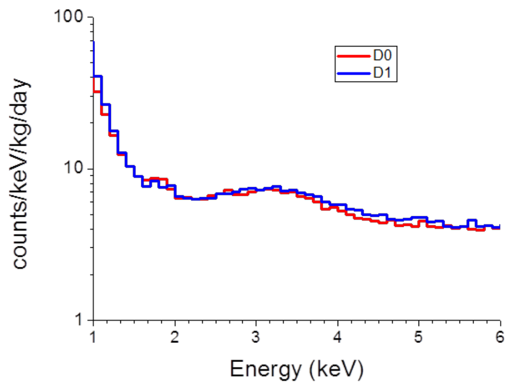
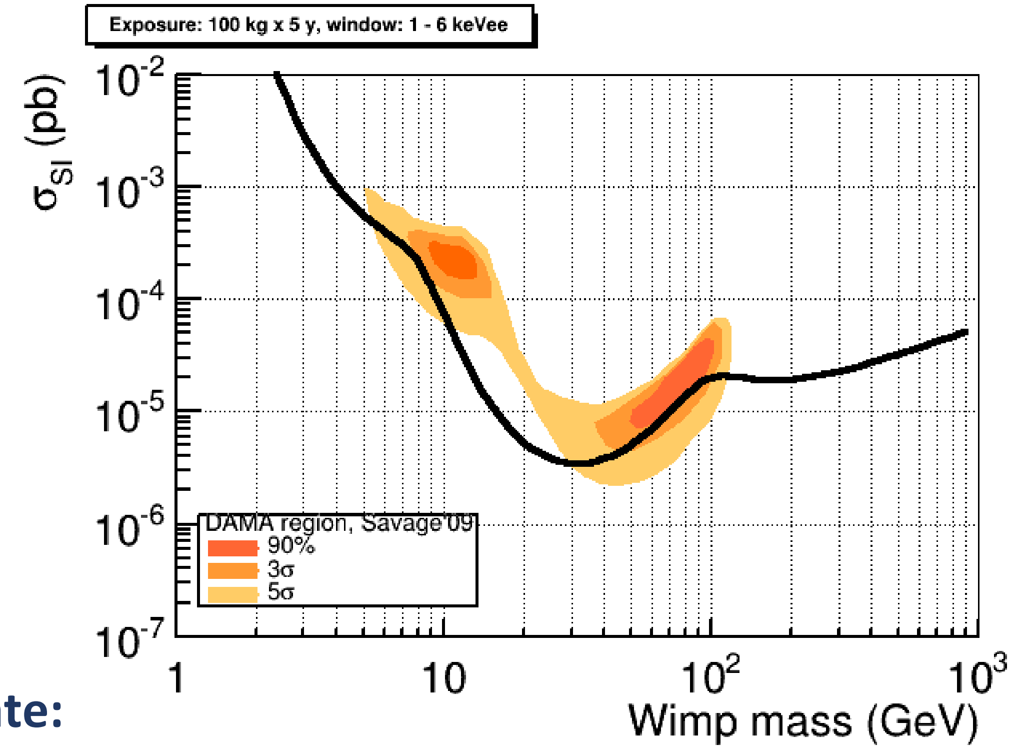
ANAIS – Sensitivity prospects

Detection at 90% C.L in 90% of the carried out experiments



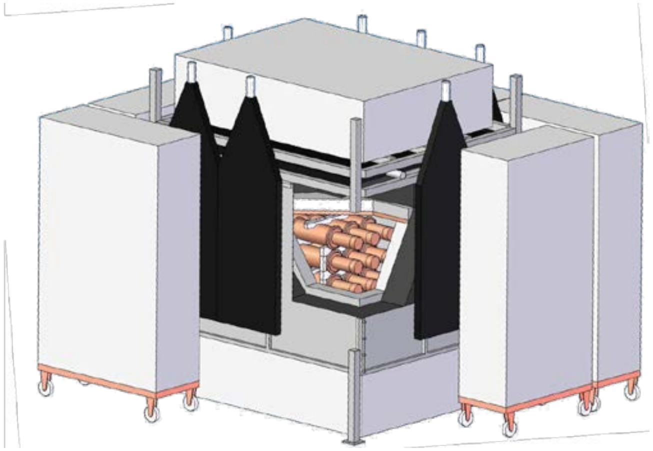


Conservative background estimate:

Contribution of 2.57 mBq/kg of ^{210}Pb subtracted to the background measured at ANAIS-25. Further improvement is expected in next modules, coincident background rejection not included (arXiv:1508.07213)

ANAIS – Status and Schedule

- Acquisition of new 6 modules:
  - 4th module testing at the beginning of 2016
  - **Start data taking with 9 modules (3×3 matrix, 112.5 kg) along 2016**
- Ready to run:
  - Shielding available
  - Muon tagging system
  - Slow Control
    (temperatures, external Rn activity, N_2 flux, PMT voltage …)
  - PMTs Ham R12669SEL2 under testing
  - Front-end modules available
  - DAQ software and
    analysis algorithms tested



- Improvement of filtering and selection protocols and efficiency estimation at low energy ongoing
- Simulation of 3×3 matrix and coincidence rejection factor
- Simulation of liquid scintillator veto

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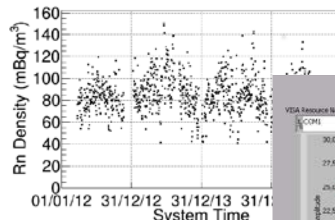

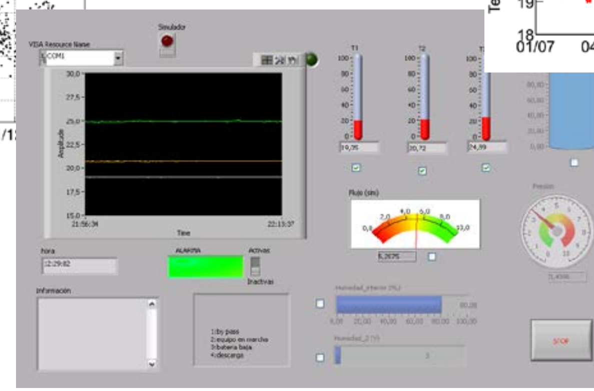

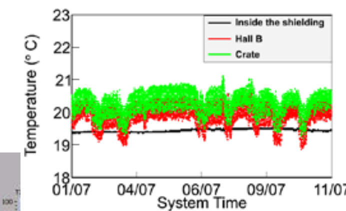

ANAIS – Status and Schedule

- Acquisition of new 6 modules
  - 4^{th} module testing at the beginning of 2016
  - Start data taking with 9 modules (3×3 matrix, 112.5 kg) along 2016
- Ready to run:
  - Shielding available
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  - Slow Control
    (temperatures, external Rn activity, N_2 flux, PMT voltage …)
  - **PMTs Ham R12669SEL2 under testing**
  - Front-end modules available
  - DAQ software and
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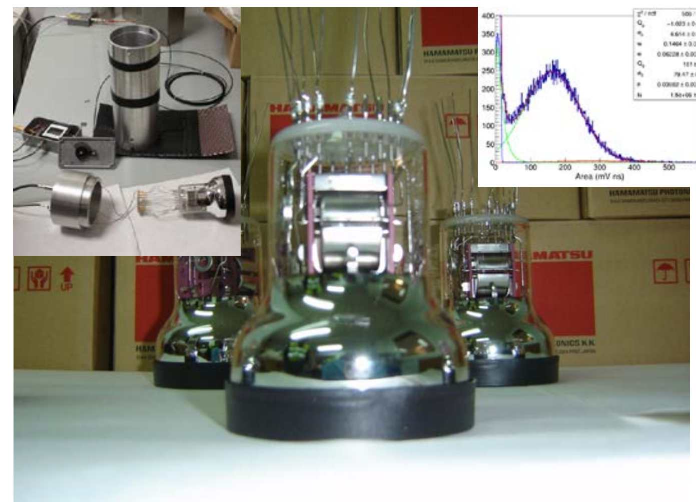

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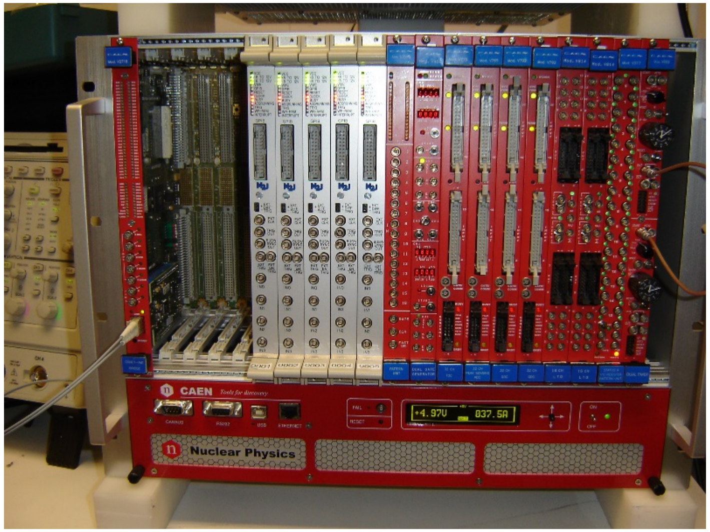

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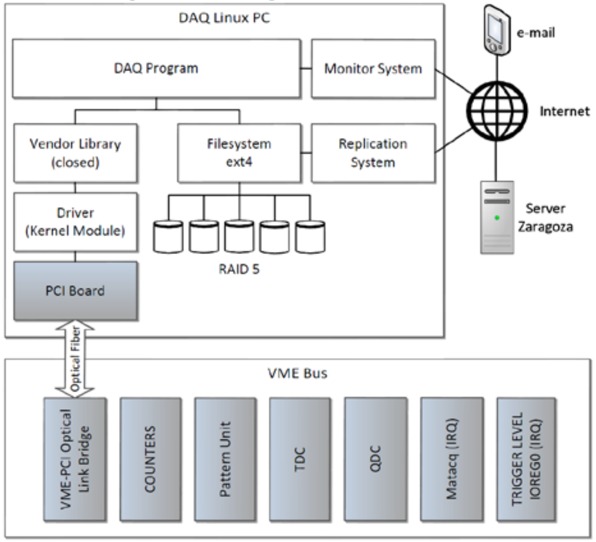

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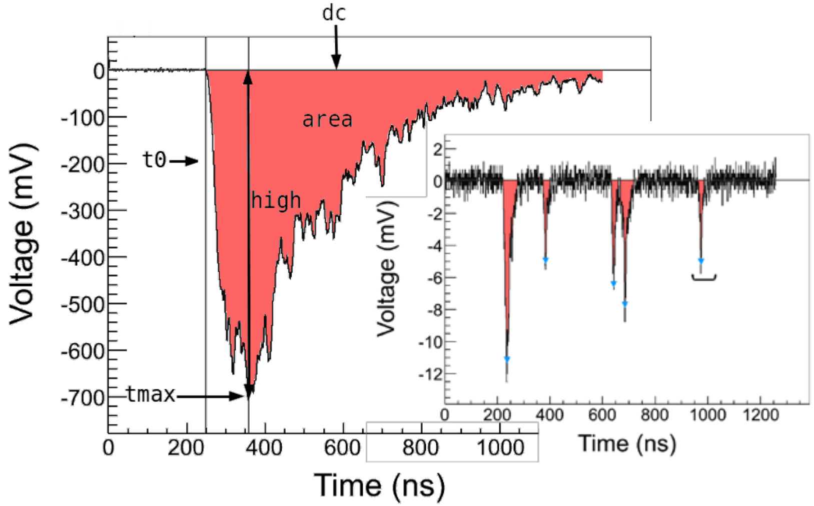

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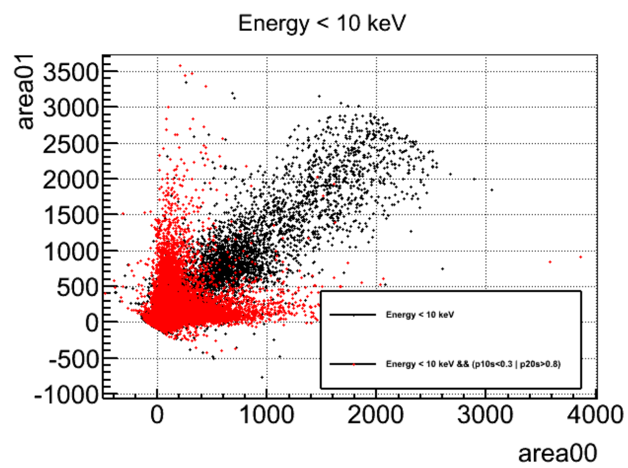

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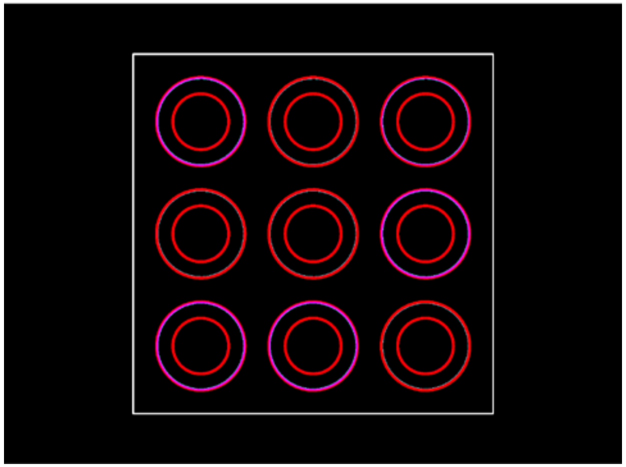

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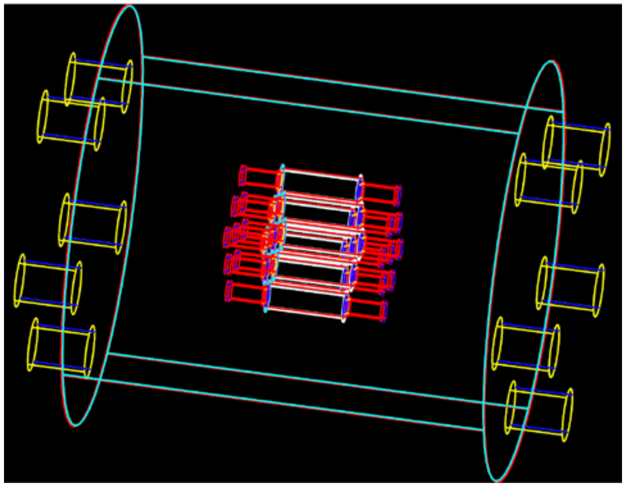

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Summary

- The ANAIS experiment, intended to confirm the DAMA/LIBRA annual modulation positive signal, is under development at the Canfranc Underground Laboratory
  - 112.5 kg (3×3 crystal matrix) of NaI could be taking data along 2016
  - Shielding, electronic front-end, DAQ and software, slow control ready for the full experiment
- Good quality NaI detectors from Alpha Spectra have been fully characterized:
  - Outstanding light collection improving energy resolution and with 1 keVee energy threshold at reach
  - K content at the level of 35-40 ppb, ^{210}Pb reduction 0.7 mBq/kg (reduced by a factor 5, further improvement is expected)
- Background measured in ANAIS-25 and ANAIS-37 set-ups is well understood down to 3 keVee. Further improvement in new modules is expected.
- Good sensitivity prospects for exploring the DAMA/LIBRA signal (even under very conservative assumptions) already achieved

LSC

Laboratorio Subterráneo de Canfranc

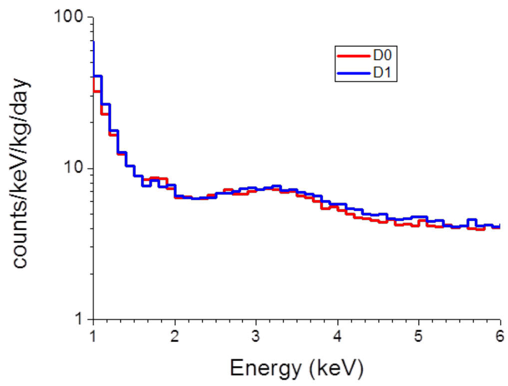
Status of the ANAIS dark matter project at the Canfranc underground laboratory

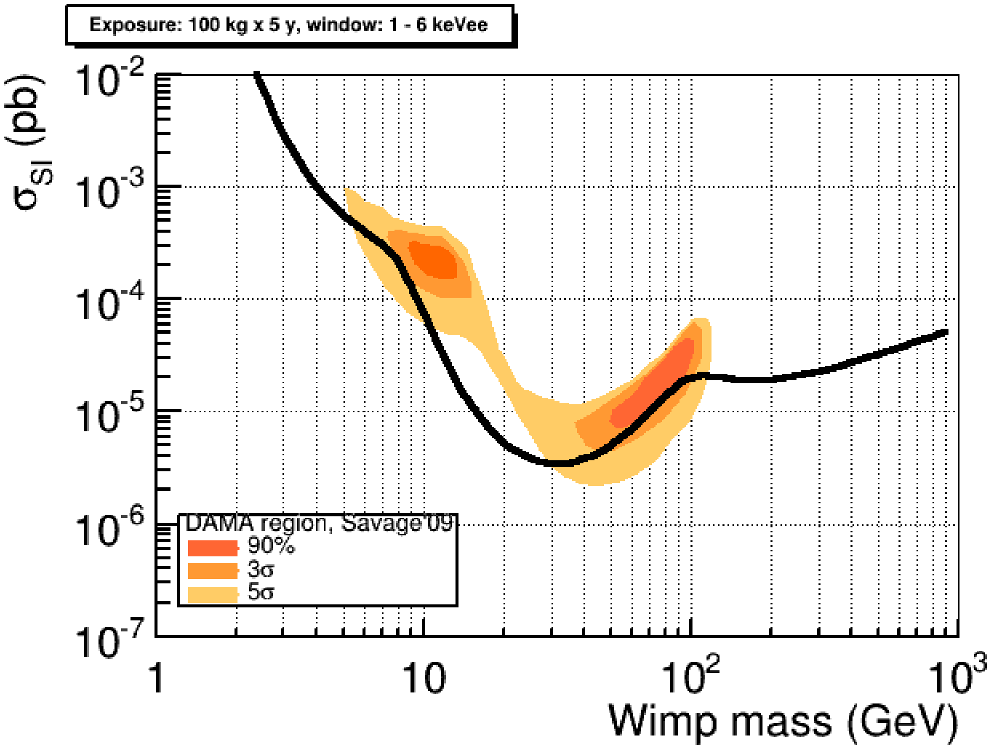
Miguel Ángel Oliván
on behalf of the ANAIS team

Universidad de Zaragoza
Laboratorio subterráneo de Canfranc

ANAIS – Prospects

Detection at 90% C.L in 90% of the carried out experiments



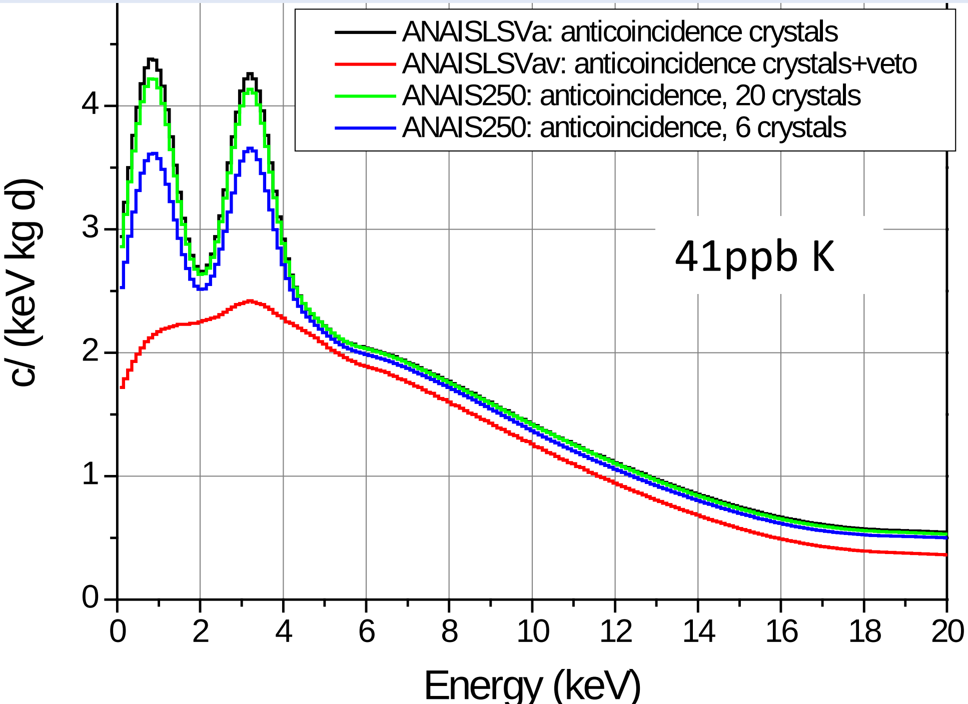


Computed using Cebrian, S., et al. "Sensitivity plots for WIMP direct detection using the annual modulation signature." Astroparticle Physics 14.4 (2001): 339-350.

Liquid Scintillator Veto Simulation

We compare:
ANAIS250 (4x5 modules anticoinc)
ANAISLSVa (3x3 modules anticoinc)
ANAISLSVav (3x3 modules anticoinc+LS veto without threshold)

Assuming the background level of the ANAIS25 modules

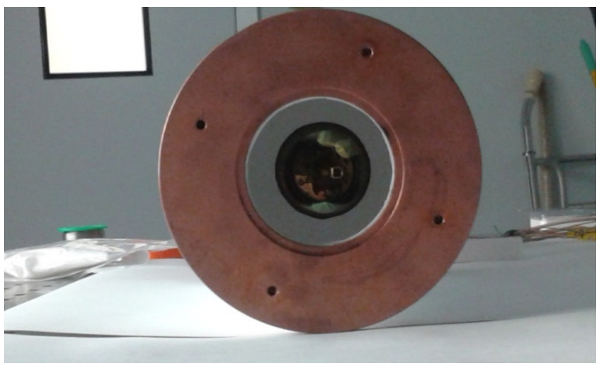


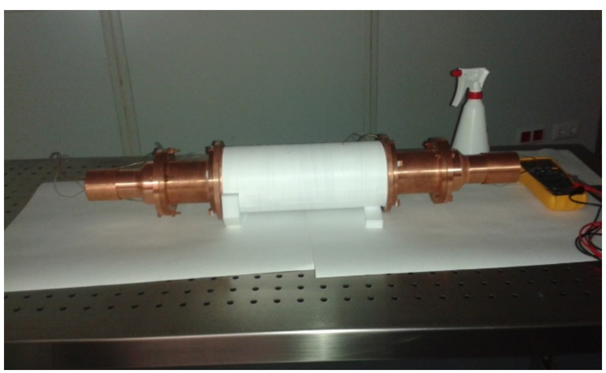
Background reduction factors in the 1-10 keV region for the LSV system and for ANAIS250

	40K from crystals	22Na from crystals	PMTs	all
ANAISLSV a (%)	70.3	60.2	64.2	89.1
ANAISLSV av (%)	15.5	1.1	9.1	71.0
ANAISLSV av500 (%)	19.1	5.5	31.3	73.9
ANAIS250 a (%)	50.6	37.9	35.5	79.6

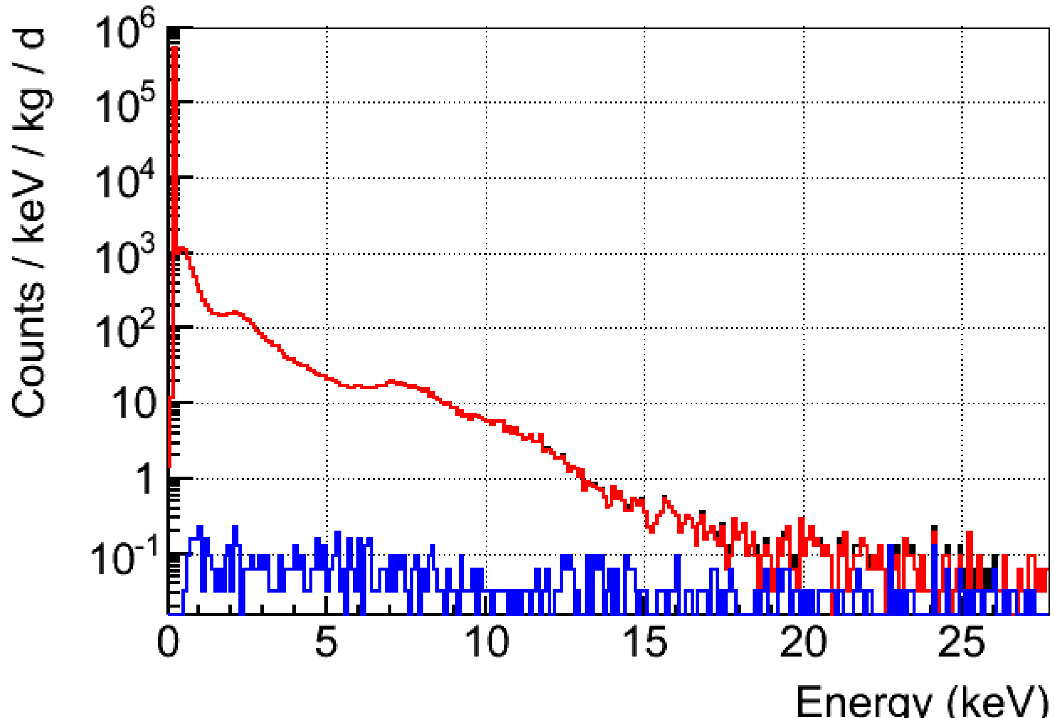
ANAIS – Blank module

- A “detector” without crystal in order to characterize PMT events





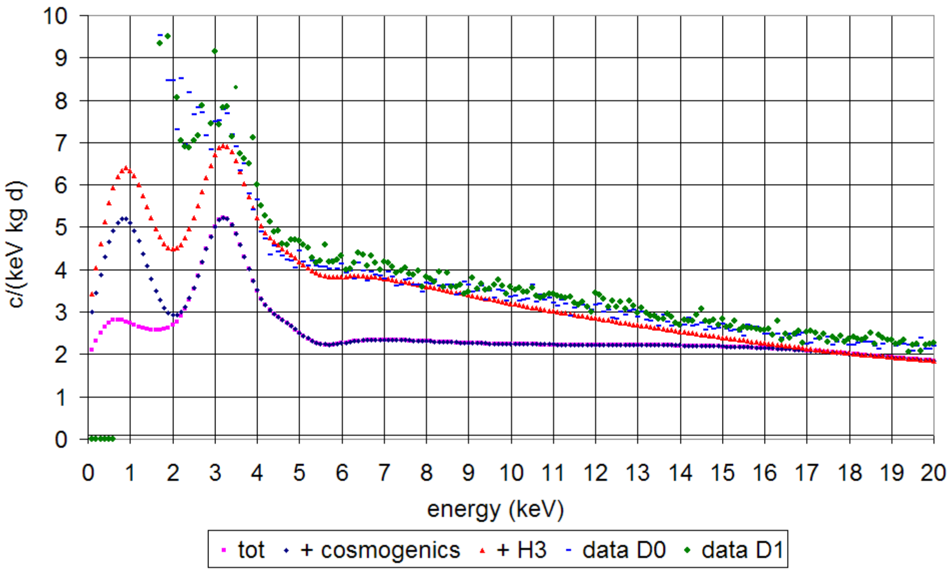
Analysis is ongoing: Filtering protocols seem to be OK and reject most of the PMT events



ANAIS-25 – Background model

PRELIMINARY

✓ Hypothesis: ^{3}H contribution



An activity of 0.2 mBq/kg of ^{3}H in the NaI crystals significantly improves the agreement with data

Data for ^{3}H in NaI:

•DAMA/LIBRA: A<0.09 mBq/kg

R. Bernabei et al., NIMA 592 (2008) 297

•Calculated production rate: R=31.1 kg^{-1} d^{-1}

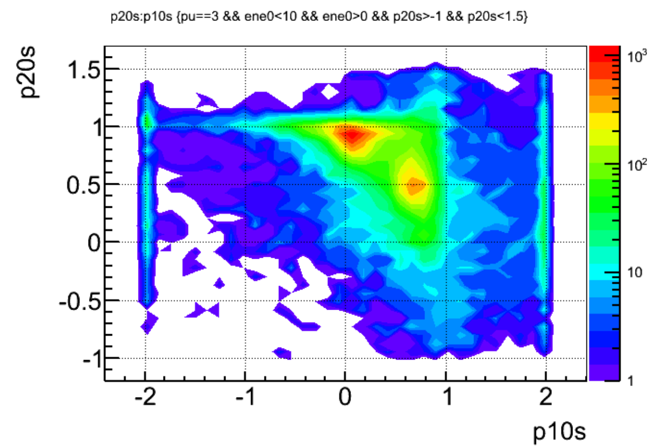
D. M. Mei et al, Astropart. Phys. **31**, 417–420 (2009).

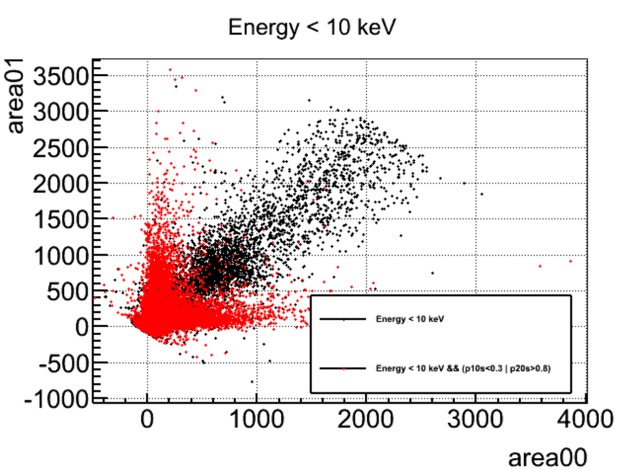
For a production rate of 50 $kg^{-1}d^{-}1$ an exposure of 1.9 y to the neutron flux at Grand Junction, Colorado, would produce the required ^{3}H activity in ANAIS-25 crystals

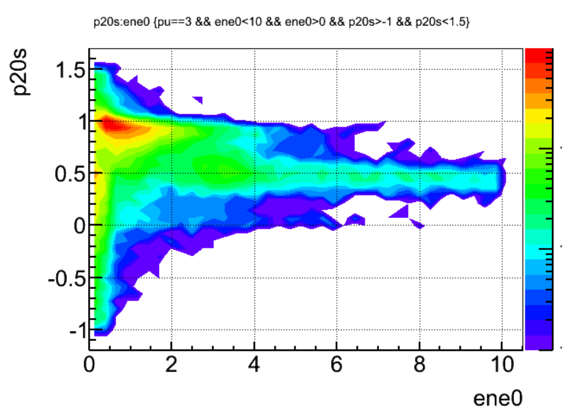
ANAIS-25 – Data analysis

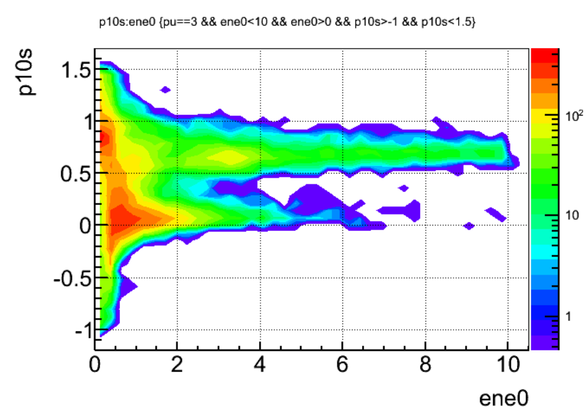
Description of the cuts used to remove PMT events

1) Cut in the number of peaks in the pulse (n>2 in each PMT)
2) Cut in temporal parameters of the pulse: p1s, p2s
3) Cut in asymmetry in the light sharing

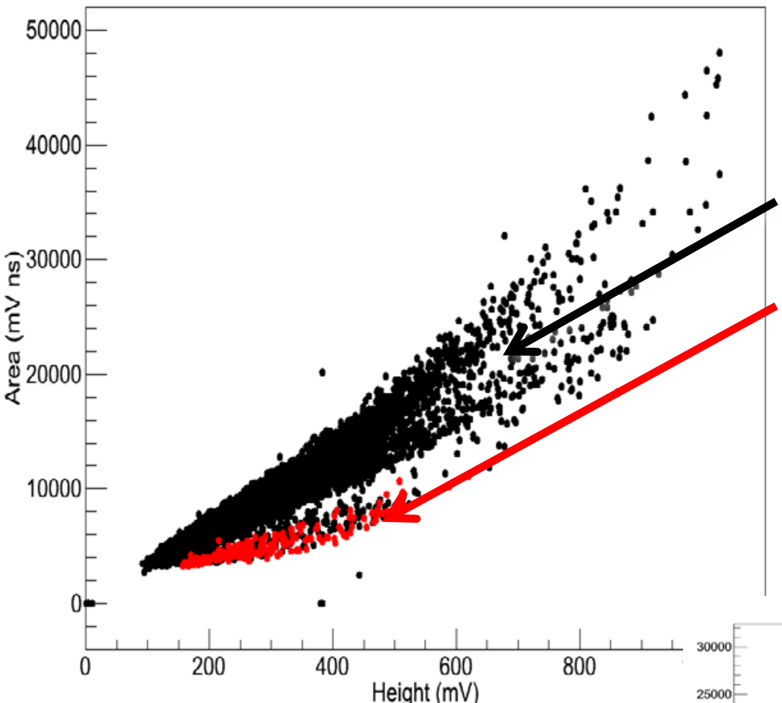






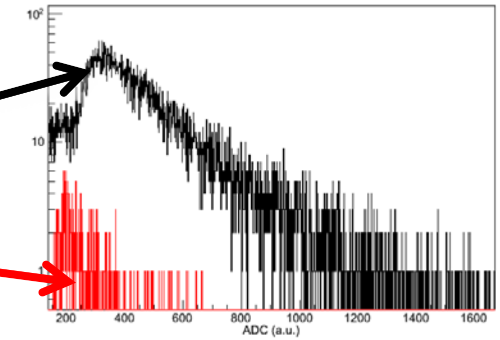


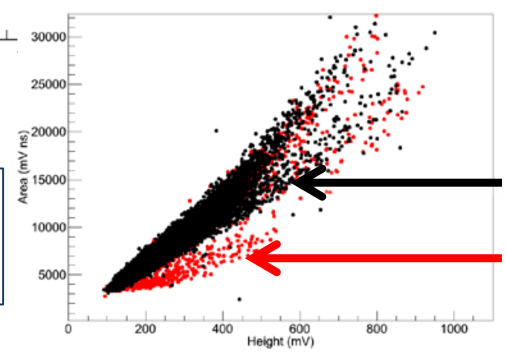
ANAIS – Muon vs. Fast events



Surface

Underground





Surface test with two piled vetoes:

Coincident events → μ

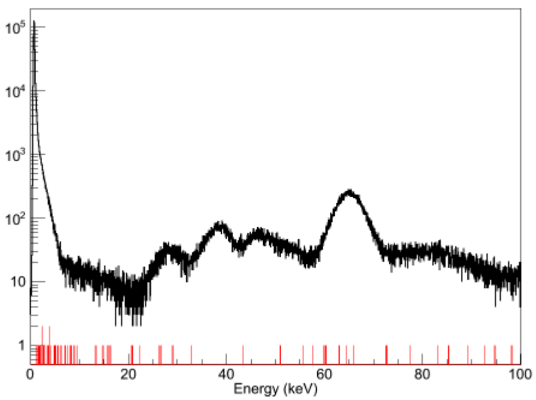
Anticoincident events

Fast events, no muons → Discriminate

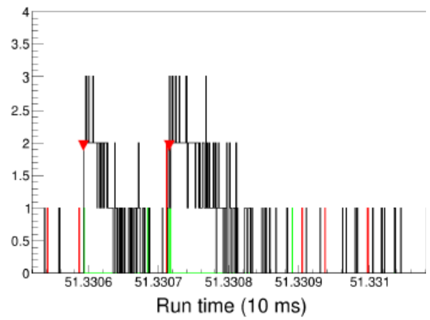
ANAIS – Muon tagging

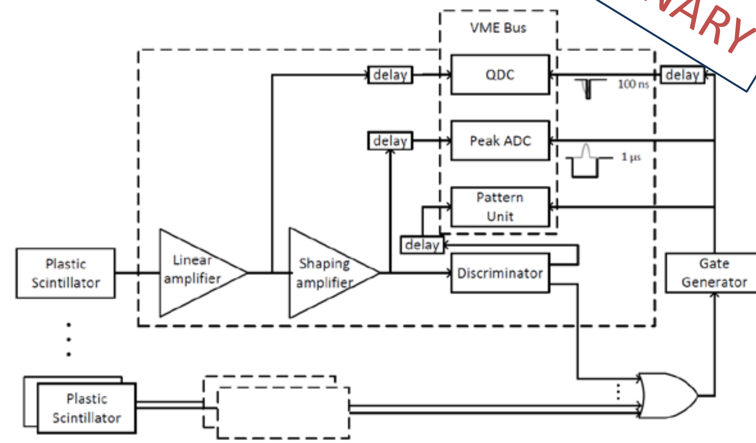
PRELIMINARY

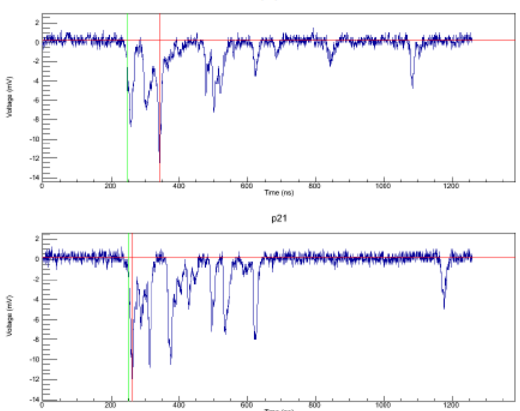
Muon event tagging by threshold and shape based on ADC values (fully compatible with digitized waveform)



(a)







(b)

Face	Plastic	Measured rate $(\mu \times m^{-2} \times s^{-1}) \times 10^{-3}$	Measured rate $(\mu \times m^{-2} \times s^{-1}) \times 10^{-3}$
South	#1	5.27 ± 0.10	5.43 ± 0.07
	#2	5.53 ± 0.10	
West	#3	4.88 ± 0.10	4.75 ± 0.07
	#4	4.61 ± 0.10	
East	#5	4.53 ± 0.10	4.54 ± 0.07
	#6	4.54 ± 0.10	
North	#7	5.05 ± 0.10	4.91 ± 0.07
	#8	4.77 ± 0.10	
Top	#9	7.23 ± 0.12	7.36 ± 0.07
	#10	7.54 ± 0.12	
	#11	7.32 ± 0.12	

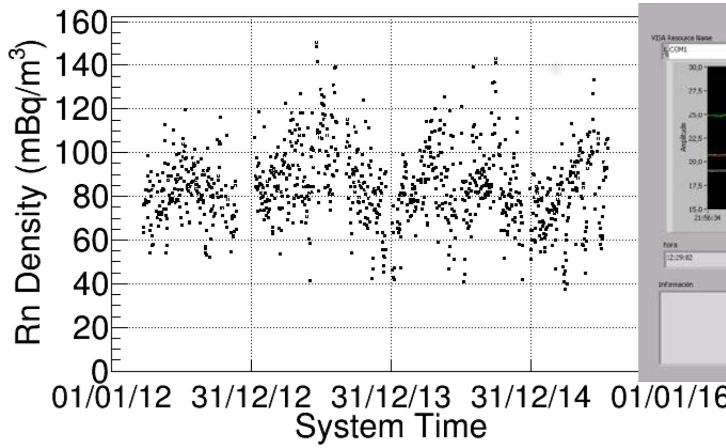
Table 4.3: Muon detection rate

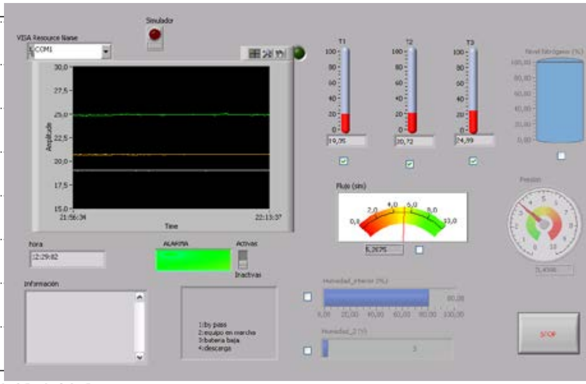
Faces	Coincident rate (mHz)
Top-North	3.26 ± 0.07
Top-South	1.05 ± 0.04
Top-East	0.87 ± 0.04
Top-West	0.95 ± 0.04
North-South	0.37 ± 0.02
East-West	0.14 ± 0.01
North-East	0.48 ± 0.03
North-West	0.34 ± 0.02
South-East	0.45 ± 0.03
South-West	0.47 ± 0.03

Table 4.4: Faces coincident rate

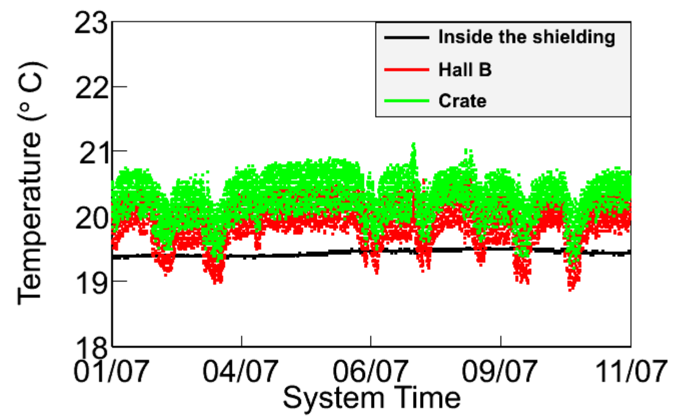
ANAIS – Slow Control

- Slow control:
  - External Rn





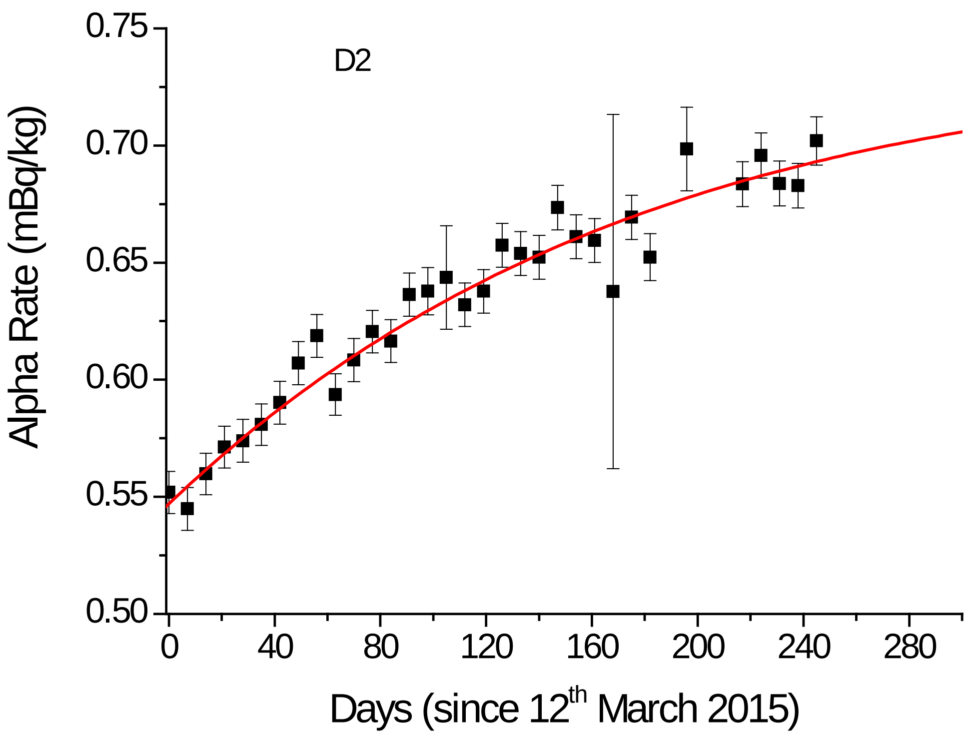
  - Temperatures
    - Inside the shielding
    - Environment
    - Frontend



  - N_2 flux
  - HV Power supply voltage & current

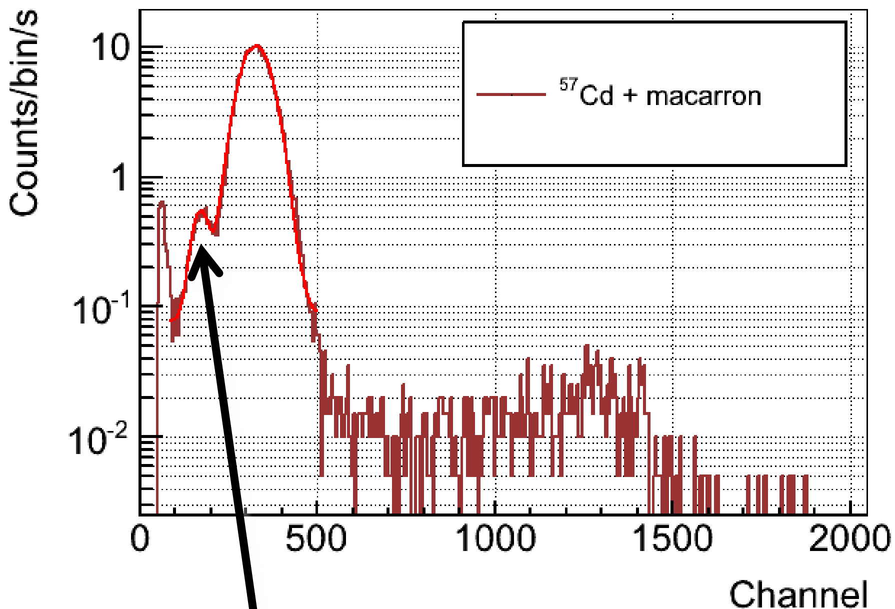
Alpha contamination

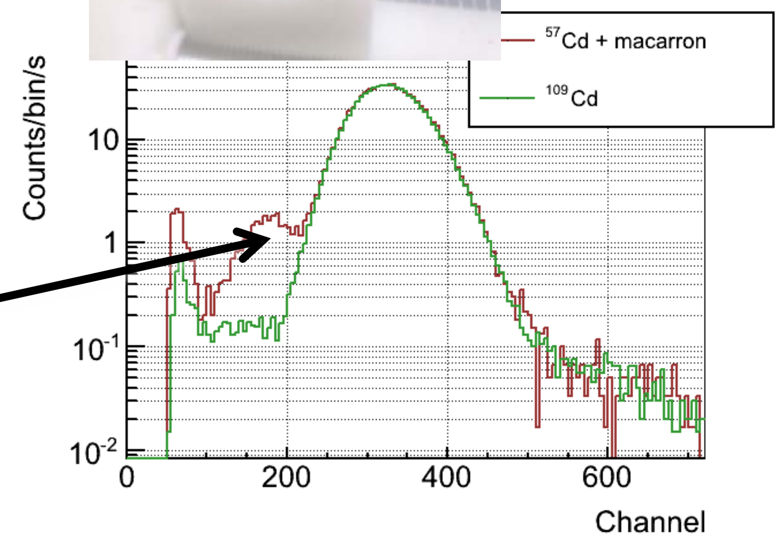
- **Total Alpha Rate in D2**



- Still building ^{210}Po activity
- ^{210}Pb crystal content at the level of **0.70 mBq/kg** compatible with D2 HE-LE data
- effective reduction of Rn entrance achieved @ AS in **WIMPScint-II** production
- further improvement expected for **WIMPScint-III** powder

ANAIS – Low energy calibration
12 keV line





Energy: 11.59 keV