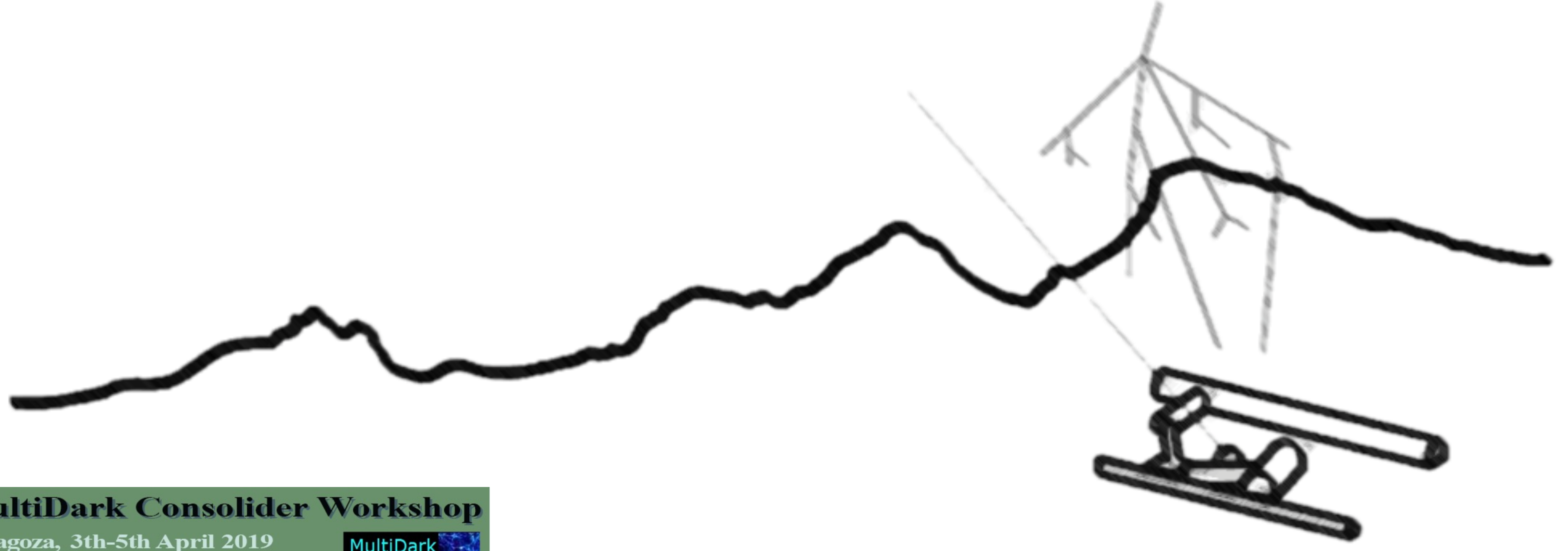
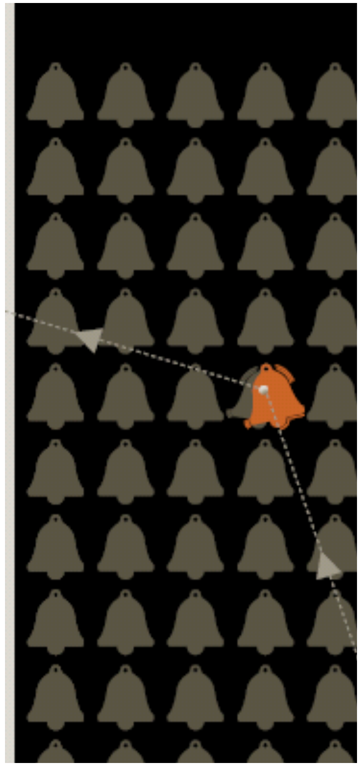
FIRST RESULTS ON ANNUAL MODULATION FROM ANAIS-112 EXPERIMENT

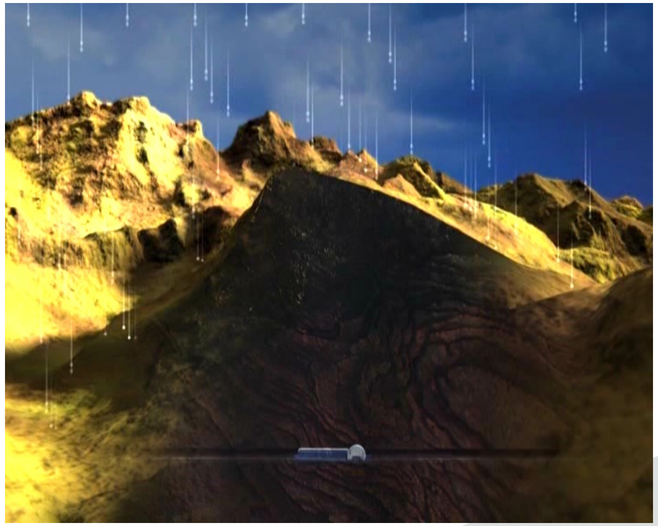


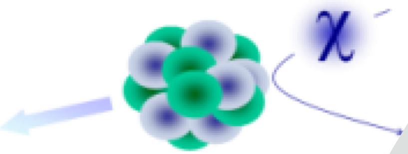
J. Amaré, I. Coarasa, S. Cebrián, E. García, M. Martínez, M.A. Oliván, Y. Ortigoza, Ortiz de Solórzano, J. Puimedón, A. Salinas, **M.L. Sarsa**, J.A. Villar †, P. Villar

4th April 2019

WIMP Direct Detection Approach





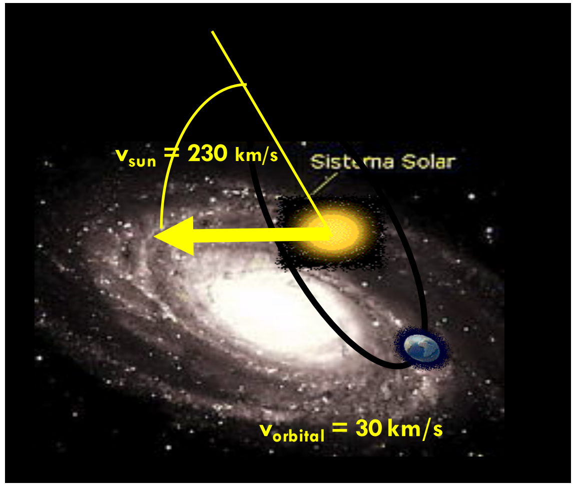


WIMPs interact (although weakly) with ordinary matter

Availability of very sensitive and radiopure particle detectors

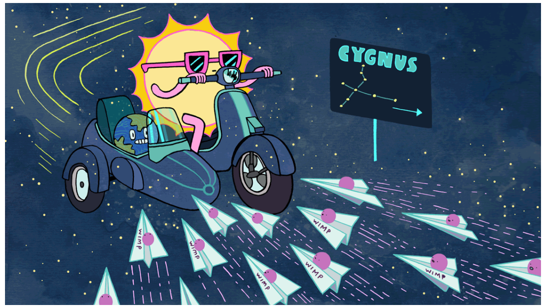
Experiments have to be shielded against all possible backgrounds and profit from active background rejection techniques

Analysis of signatures of a Dark Matter particle interaction are key for a positive result

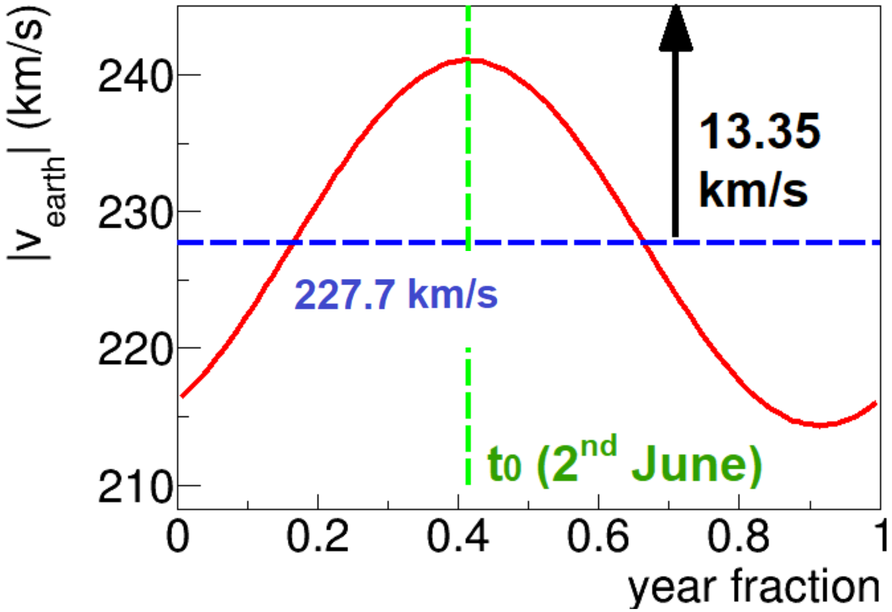


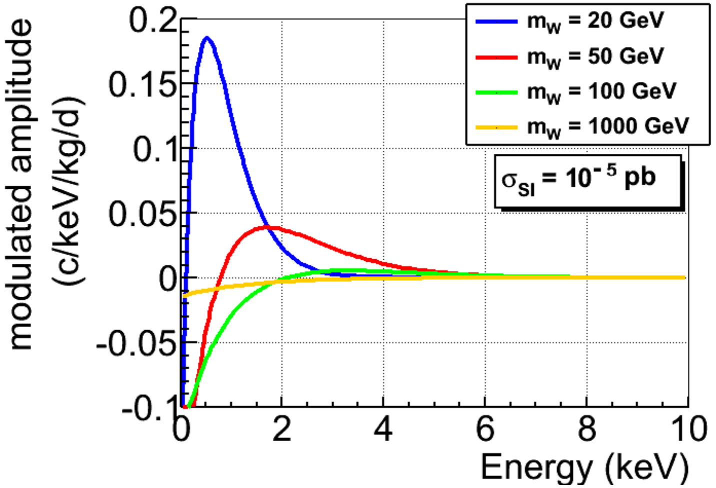
Dark Matter Annual Modulation

Positive identification of WIMP against backgrounds could be allowed by analyzing DM signatures, as annual modulation in the detection rate



The "WIMP wind"





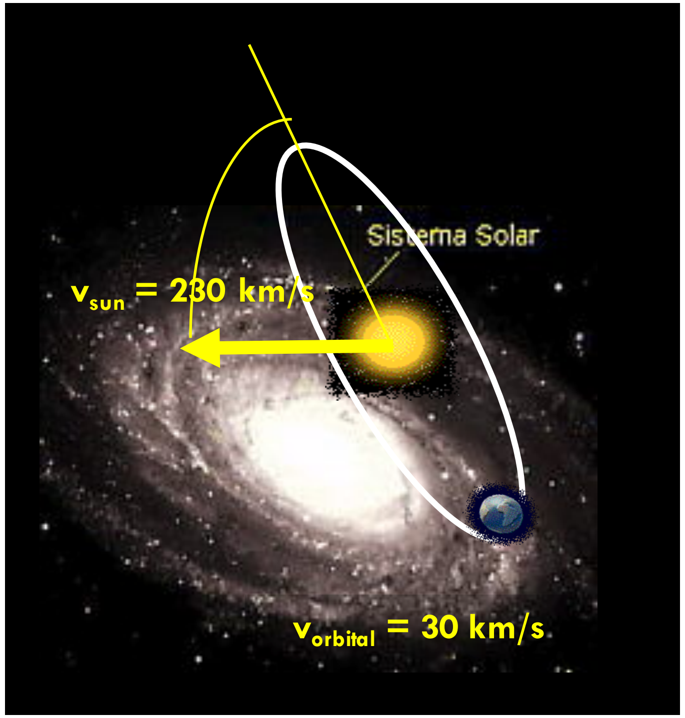
Small effect (<7% of S_0)

Inverse modulation at very low energies

It depends strongly on the halo model

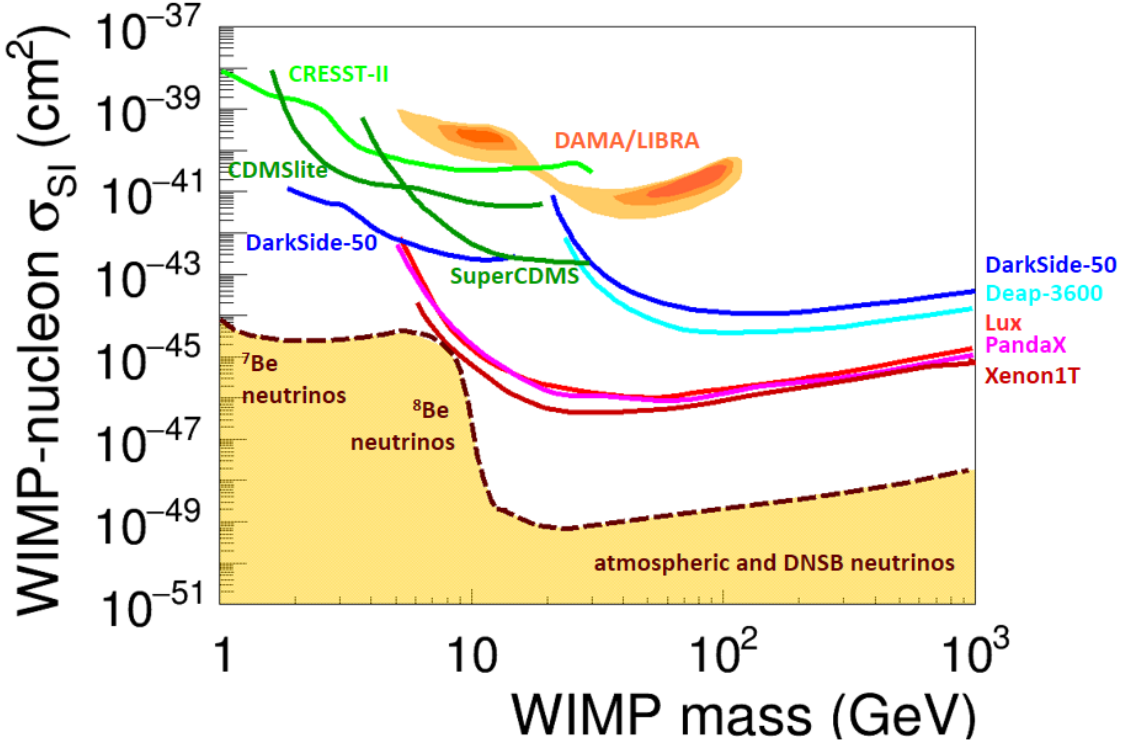
$$\eta(t) = v_{\oplus}(t)/v_0 = \eta_0 + \Delta\eta cos\omega(t - t_0)$$

$$S_k(t) = S_{0,k} + S_{m,k} cos\omega(t - t_0)$$



Experimental Situation

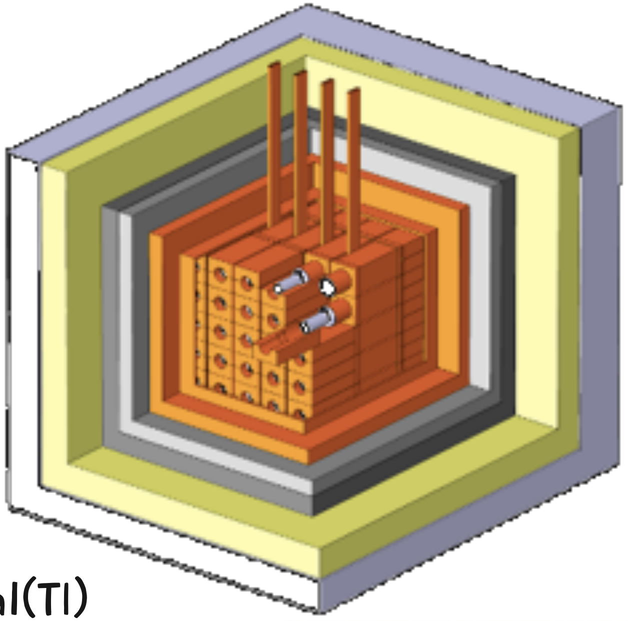
One single experiment using NaI(Tl) as target has reported evidence of a signal compatible with Dark Matter observing a model independent annual modulation
Other much sensitive experiments do not have any hint, however, comparison is model dependent



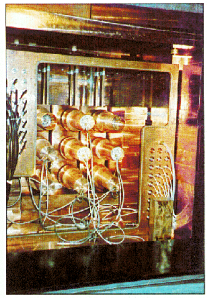
CONTROVERSIAL issue
Is possible a model independent confirmation or refutation?
NaI(Tl) as target is more interesting than ever (although not aiming at the neutrino floor)
Can DAMA/LIBRA result be a door into new Physics or just systematics?

DAMA/LIBRA experiment

@ LNGS, Laboratori Nazionali del Gran Sasso, Italy

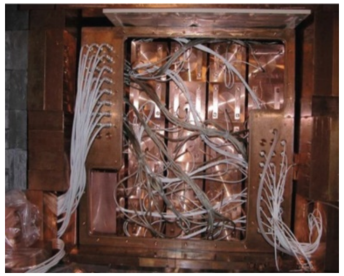


DAMA / NaI (1995-2002)

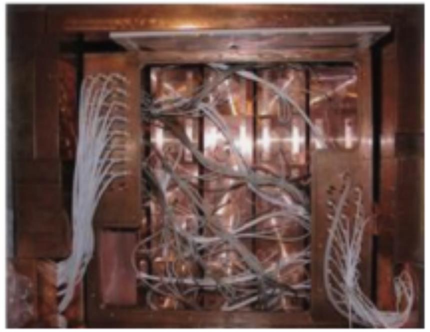


- 9 × 9.7 kg NaI(Tl) (3x3 detector matrix)
- 7 annual cycles
- Exposure : 0.29 ton × y

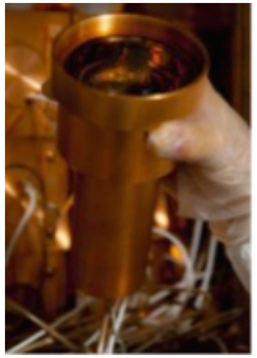
DAMA / LIBRA (2003-2010)



- 25 × 9.7 kg NaI(Tl) (5x5 matrix)
- 7 annual cycles
- Exposure : 1.17 ton × y



DAMA / LIBRA – phase2 (2011-2018)



All PMTs replaced with new ones of higher Q.E.

- 25 × 9.7 kg NaI(Tl) (5x5 matrix)
- 7 annual cycles
- Exposure : 1.13 ton × y

Data release in March 2018

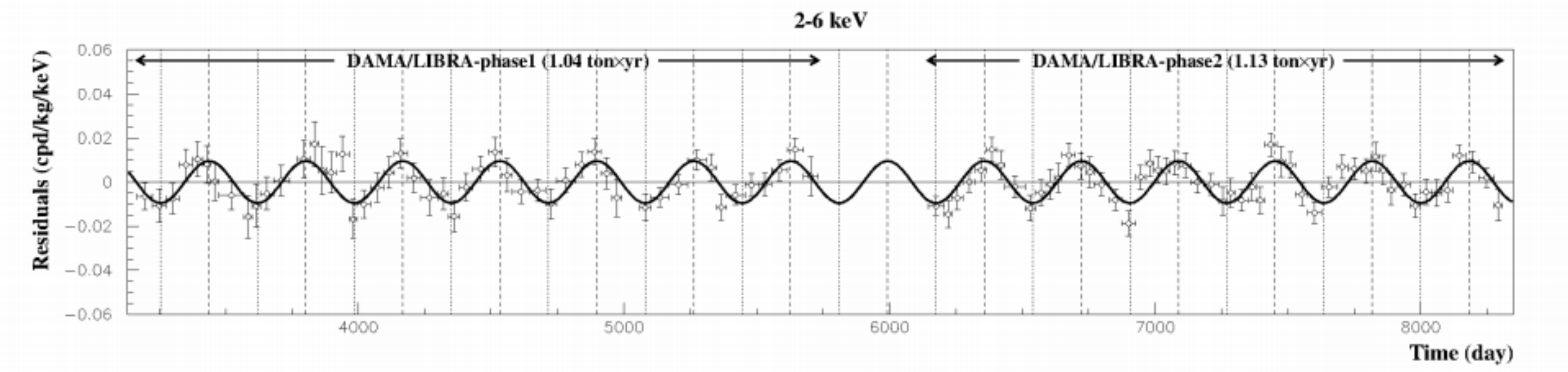
Experimental Situation

DAMA/LIBRA experiment – Phase 2

Model Independent DM Annual Modulation Result

experimental residuals of the single-hit scintillation events rate vs time and energy

DAMA/LIBRA-phase1+DAMA/LIBRA-phase2 (2.17 ton × yr)



Absence of modulation? No

- 2-6 keV: χ^2/dof=199.3/102 ⇒ P(A=0) =2.9×10^{-8}

Fit on DAMA/LIBRA-phase1+ DAMA/LIBRA-phase2

$A\cos[\omega(t-t_0)]$;
continuous lines: t_0 = 152.5 d, T = 1.00 y

2-6 keV

A=(0.0095±0.0008) cpd/kg/keV

χ^2/dof = 71.8/101 **11.9σ C.L.**

The data of DAMA/LIBRA-phase1 +DAMA/LIBRA-phase2 favor the presence of a modulated behavior with proper features at 11.9 σ C.L.

Borrowed from Rita Bernabei @ LNGS Scientific Committee Meeting
LNGS March 2018

DAMA/LIBRA experiment – Phase 2

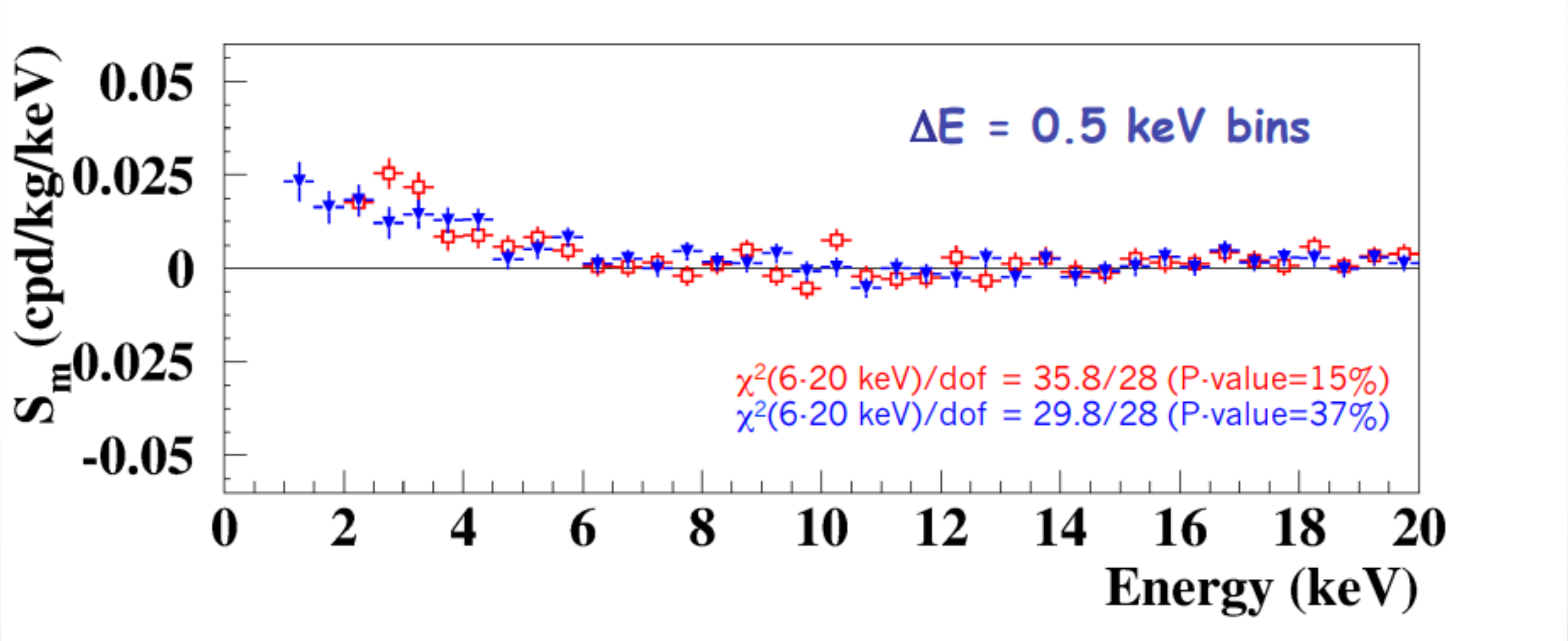
Energy distribution of the modulation amplitudes

Max-likelihod analysis

$$R(t) = S_0 + S_m \cos\left[\omega\left(t - t_0\right)\right]$$

here $T=2\pi/\omega=1$ yr and t_0= 152.5 day

DAMA/NaI + DAMA/LIBRA-phase1
vs
DAMA/LIBRA-phase2



The S_m energy distributions obtained in DAMA/NaI+DAMA/LIBRA-ph1 and in DAMA/LIBRA-ph2 are consistent in the (2-20) keV energy interval:

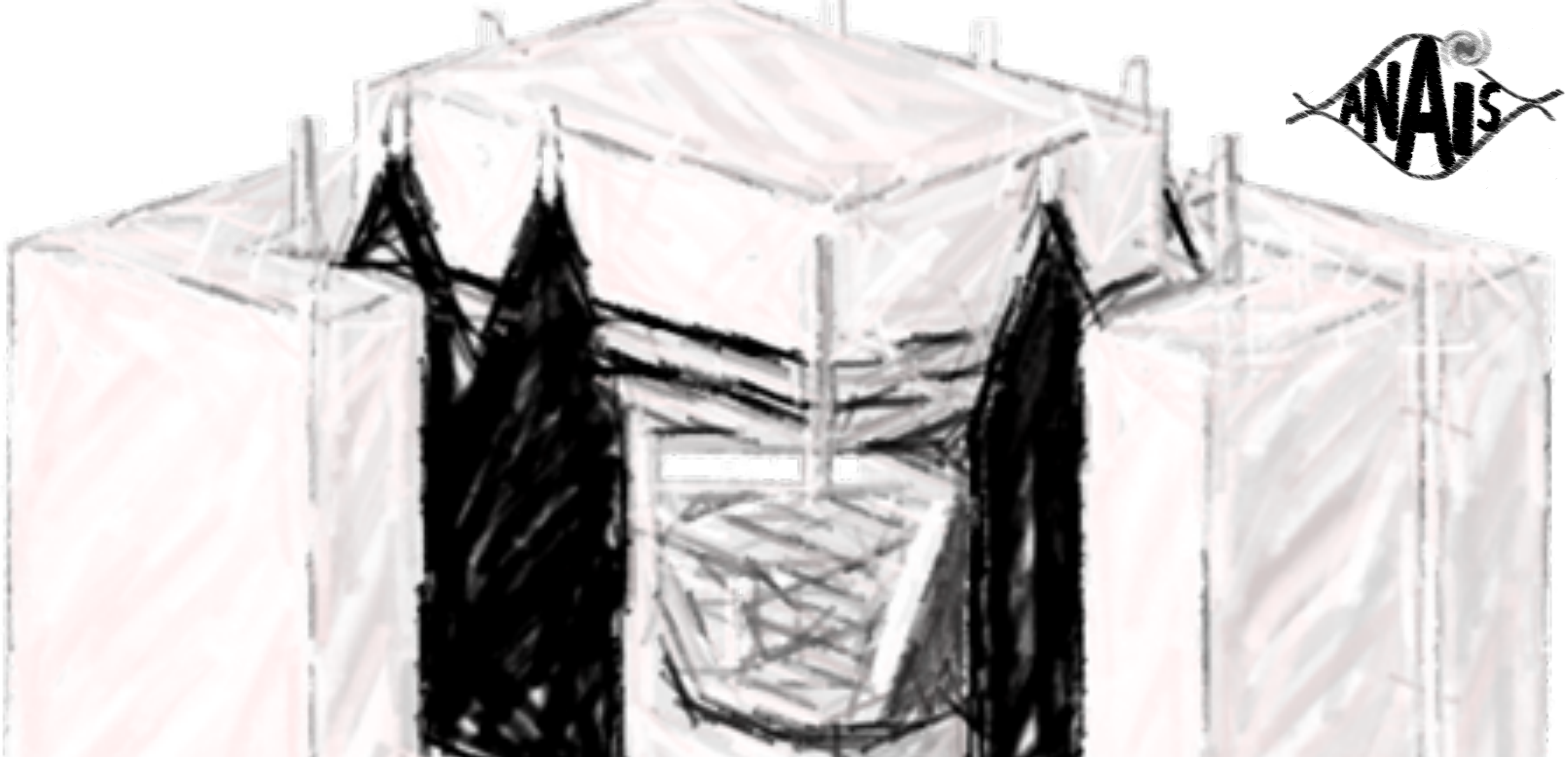
$\chi^2 = \Sigma (r_1 - r_2)^2/(\sigma_1^2+\sigma_2^2)$

(2-20) keV	χ^2 /d.o.f.=32.7/36	(P=63%)
(2-6) keV	χ^2 /d.o.f.=10.7/8	(P=22%)

Borrowed from Rita Bernabei @ LNGS Scientific Committee Meeting
LNGS March 2018

Other NaI DM experiments around the world

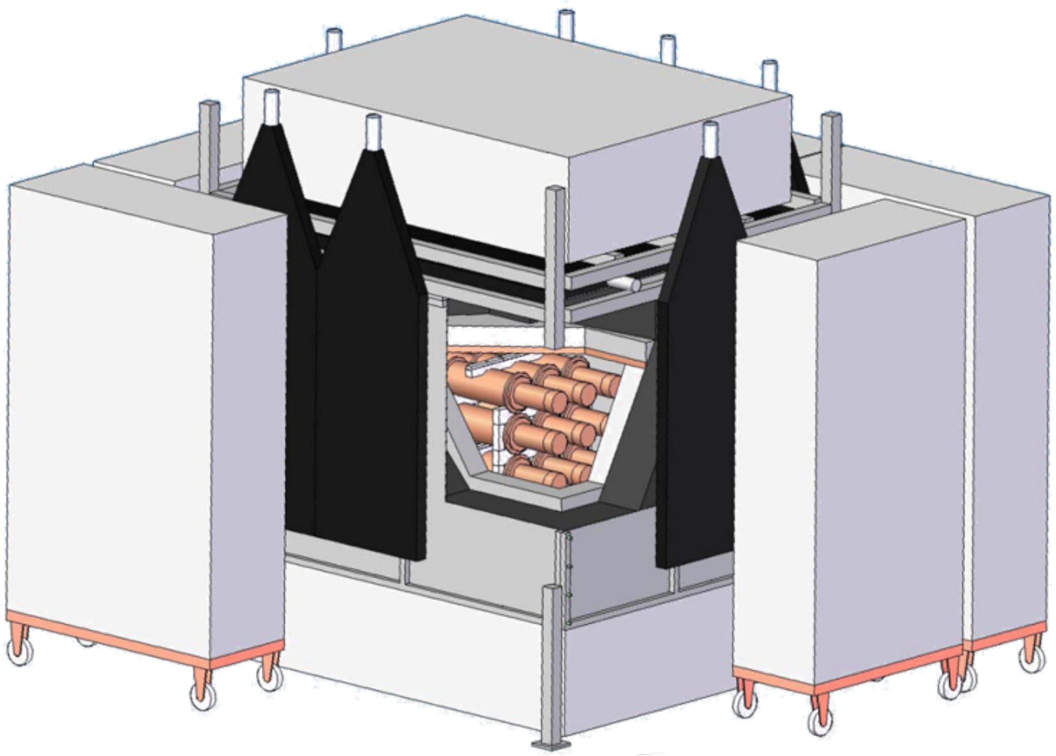
Borrowed from Yeongduk Kim @ RENATA meeting, Canfranc February 2018

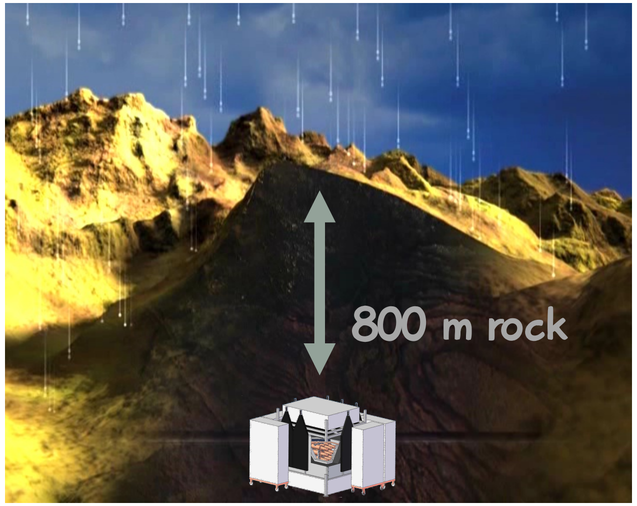


ANAIS-112 experiment at LSC

Annual modulation with NAI Scintillators

ANAIS experiment at LSC

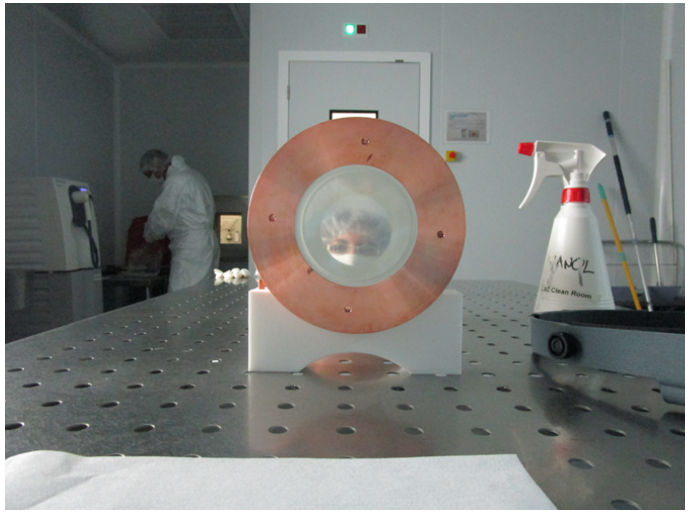


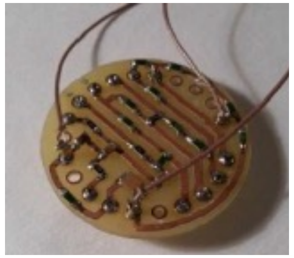


- Confirmation of DAMA-LIBRA modulation signal -> **same target and technique** / **different** experimental approach / **different** environmental conditions affecting **systematics**
- At Canfranc Underground Laboratory, @ **SPAIN** (under **2450 m.w.e.**) taking data since August 2017
- 3x3 matrix of 12.5 kg cylindrical modules = **112.5 kg** of active mass

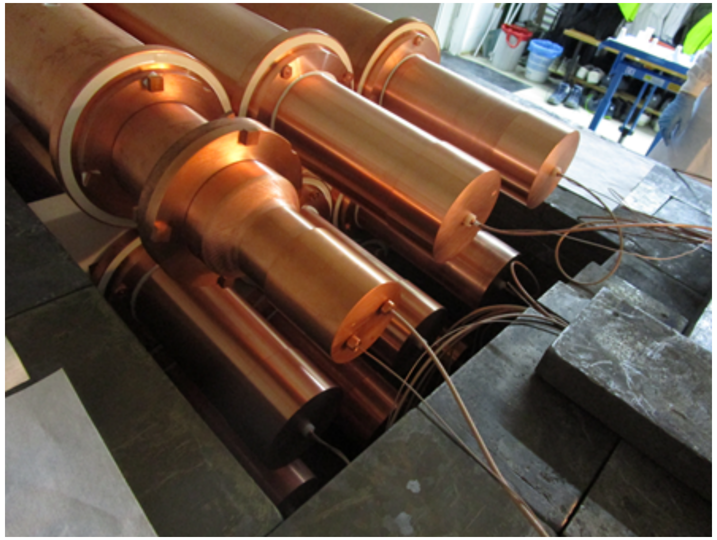
ANAIS Detectors

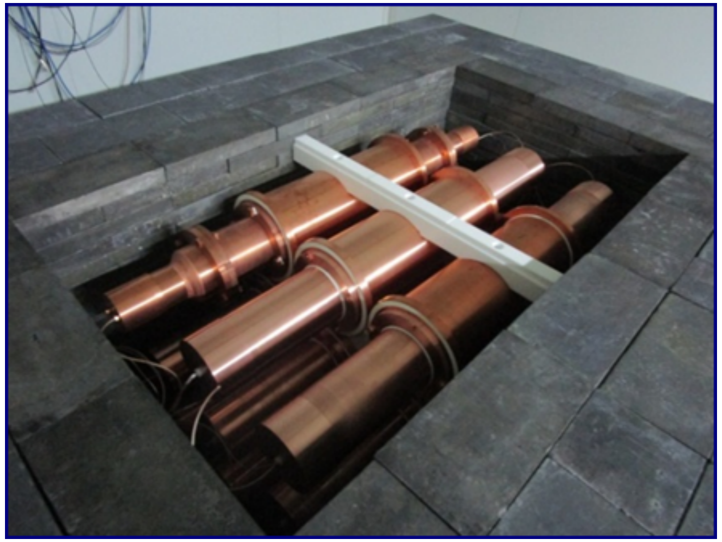
- 12.5 kg cylindrical NaI(Tl) detectors built @ Alpha Spectra, Co (US) from NaI selected powder & developing specific radiopurity protocols
- Housed in OFE copper @ AS
- Mylar windows allow for LE calibration
- 2 x HQE PMTs Ham12669SEL2 coupled at LSC clean room
- Electroformed copper PMT housing prepared at LSC facility

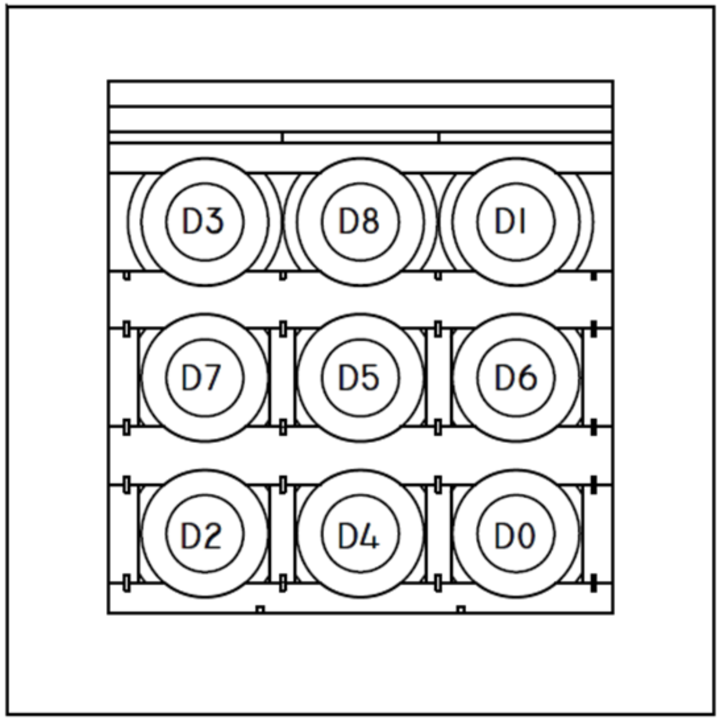




ANAIS-112 consists of a matrix of 3x3 modules of NaI(Tl)



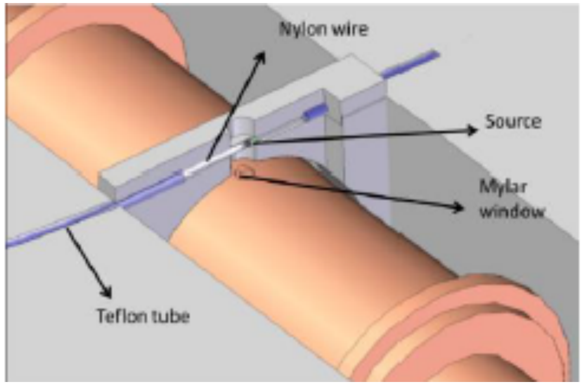




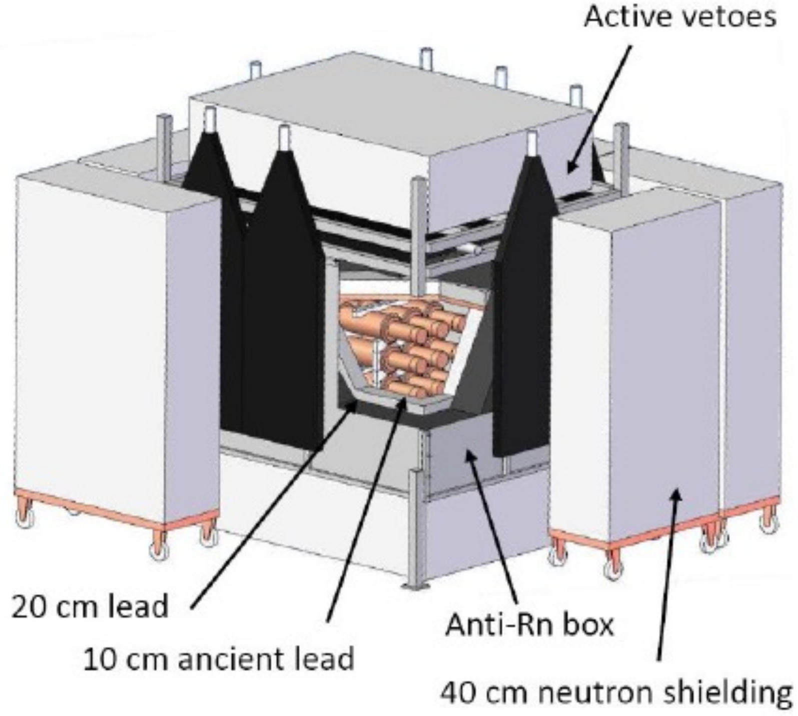
Calibration system:

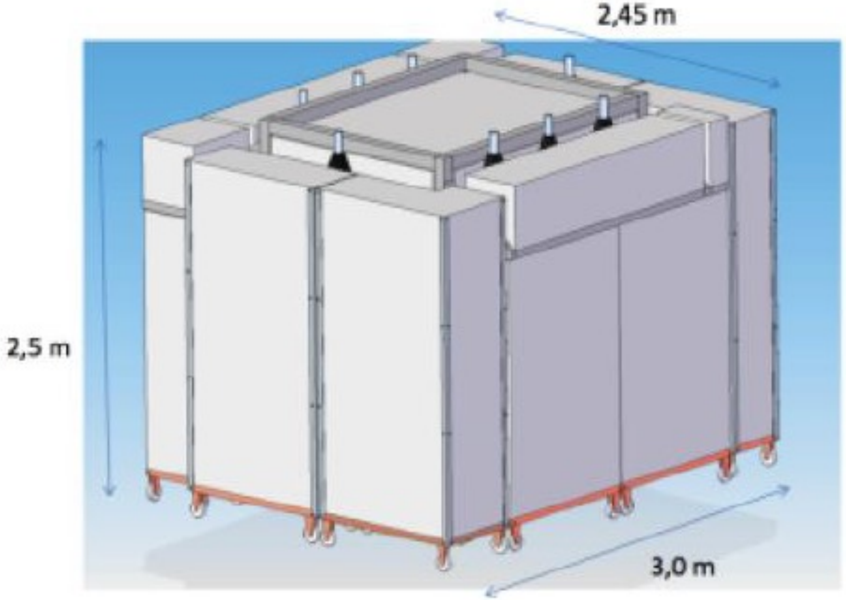
^{109}Cd sources on flexible wires in a Radon free system which allows the simultaneous calibration of the 9 modules

Energies 11.9 keV / 22.6 keV / 88.0 keV



ANAIS-112 shielding





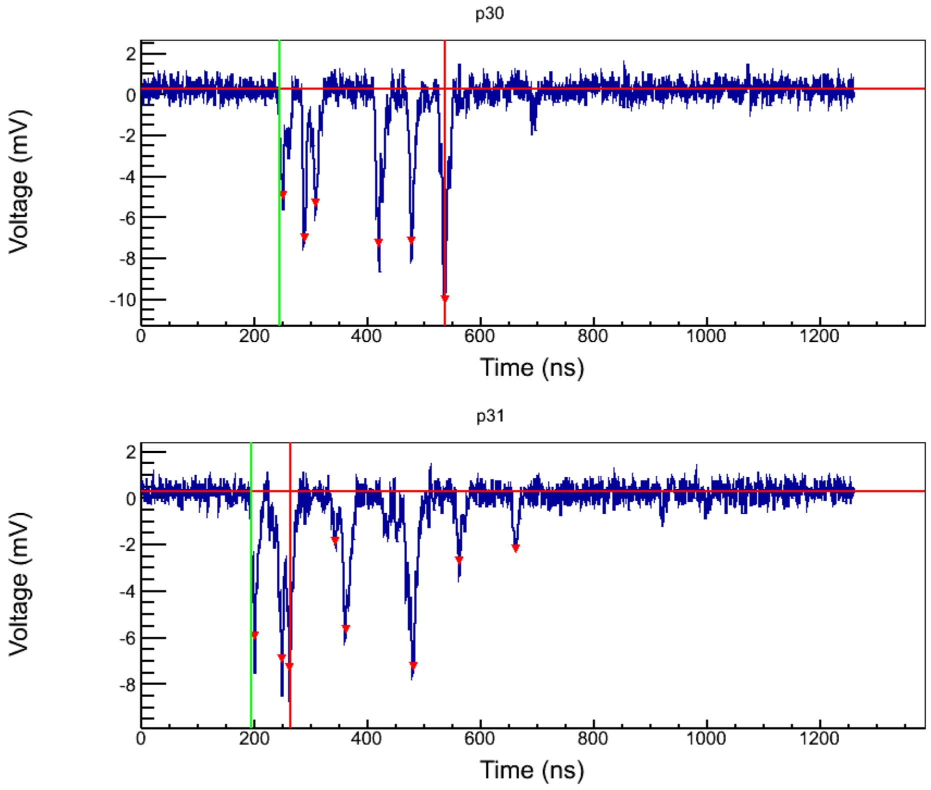
Anti-Rn box

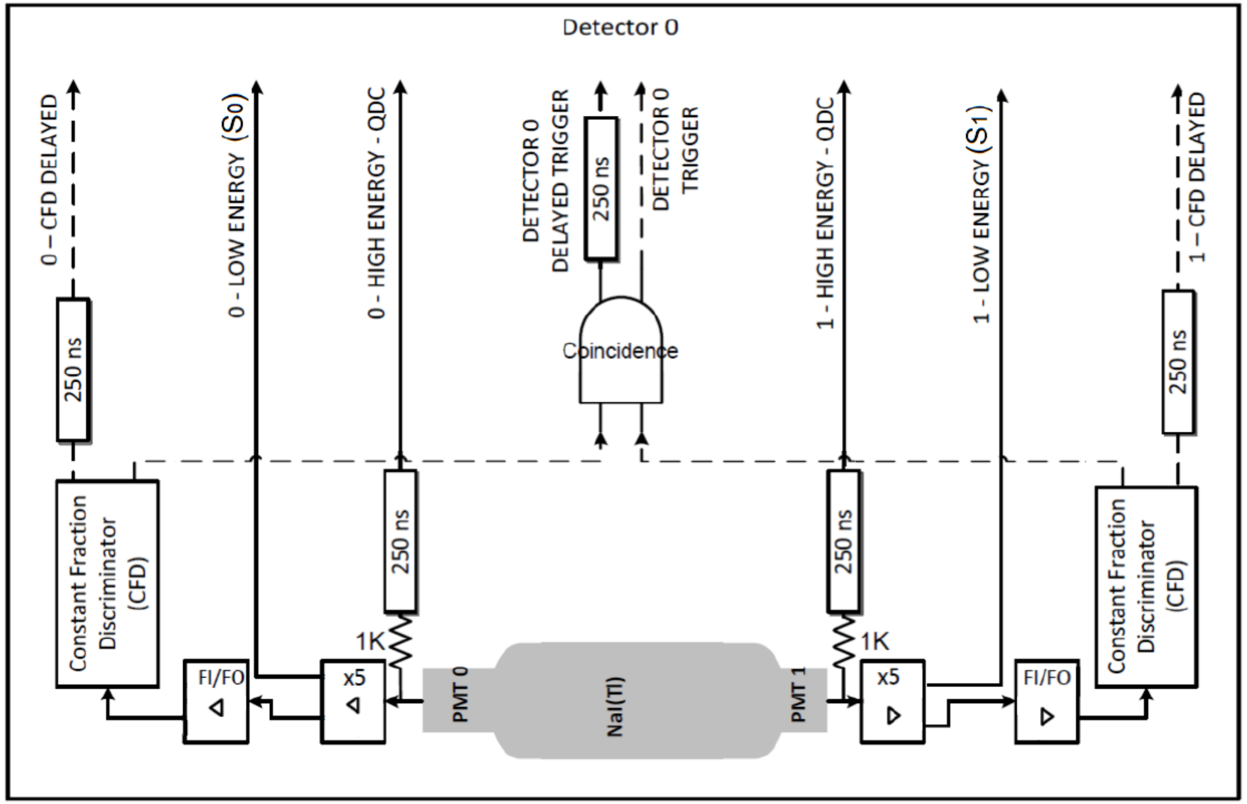
16 plastic scintillators

Neutron shielding

ANAIS-112 DAQ

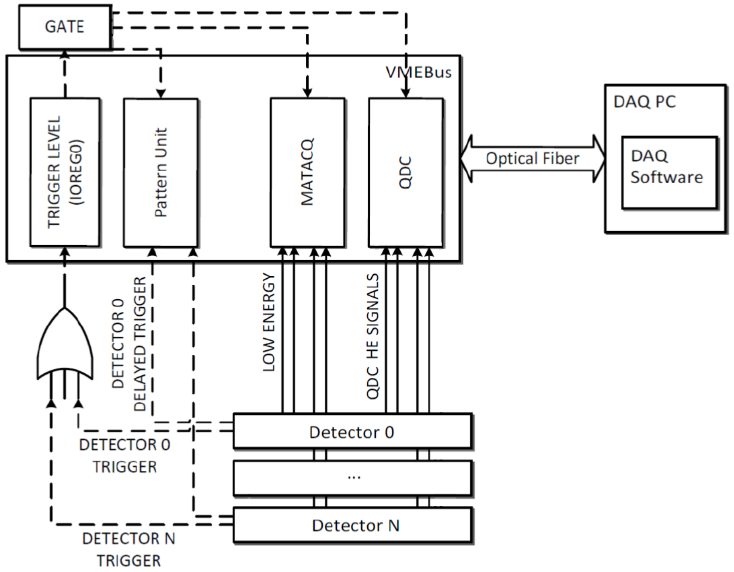
- DAQ hardware and software designed and tested with previous set-ups -> ROBUST
  - Individual PMT signals digitized and fully processed (14 bits / 2GS/s)
  - Trigger at phe level for each PMT
  - Logical AND coincidence in 200ns window for each module triggering
  - Redundant energy conversion (with QDCs for HE)
  - Preamplifiers designed at UZ

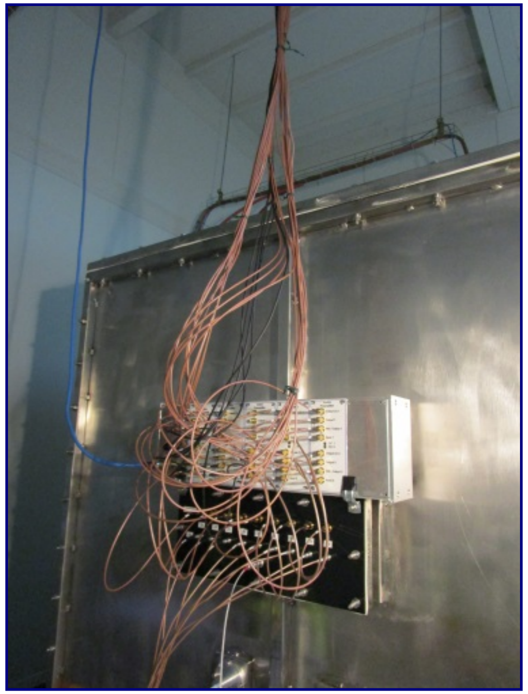




ANAIS-112 DAQ

- DAQ hardware and software designed and tested with previous set-ups -> ROBUST
  - Individual PMT signals digitized and fully processed (14 bits / 2GS/s)
  - Trigger at phe level for each PMT
  - Logical AND coincidence in 200ns window for each module triggering
  - Redundant energy conversion (with QDCs for HE)
  - Preamplifiers designed at UZ
  - Electronics at air-conditioned-room to decouple from temperature fluctuations

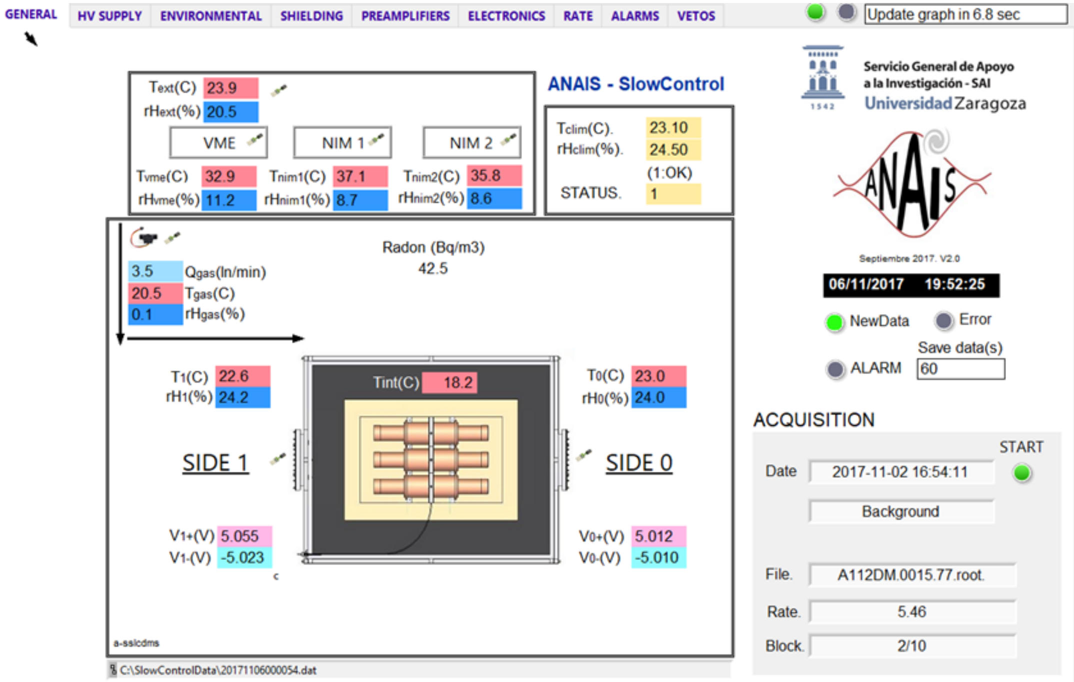


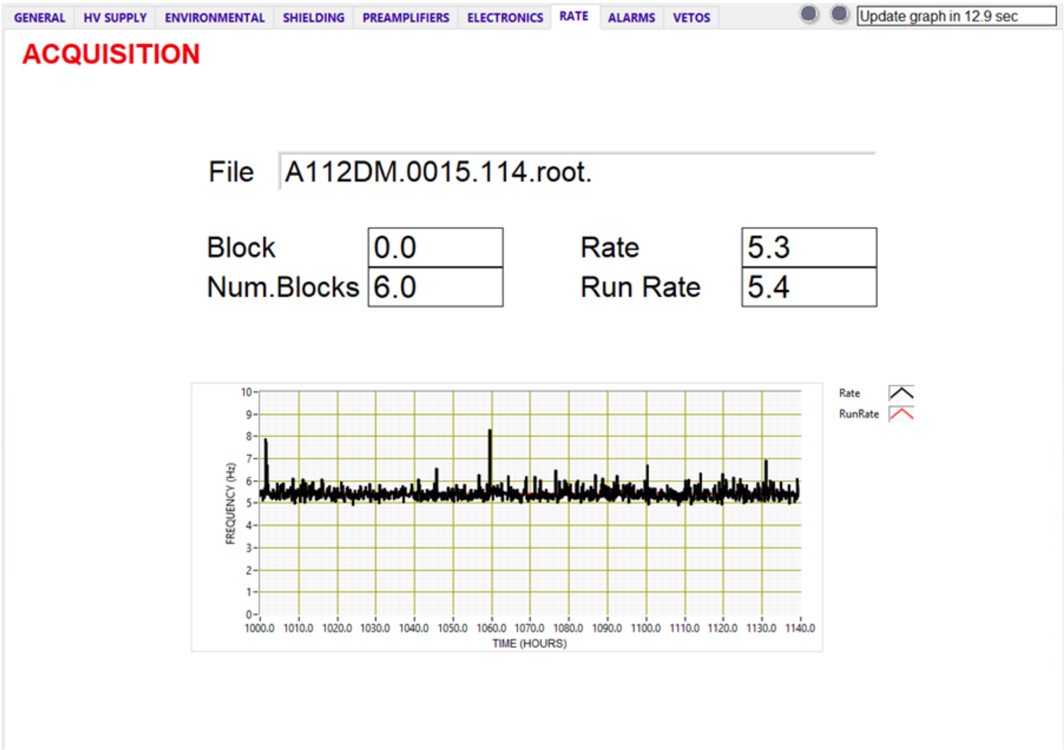


Monitoring of environmental parameters has been ongoing along ANAIS-112 DM run.

It consists of several windows for monitoring N_2 flux; temperatures at electronics, inner shielding, laboratory, preamplifiers, etc.; radon content in laboratory air; relative humidity; HV supply to every PMT; muon rates; etc.

All the data are saved every few minutes and alarms have been set on the most relevant parameters sending an alarm message to ANAIS GLIMOS through Telegram.





ANAIS-112 General Performance

Eur. Phys. J. C (2019) 79:228
https://doi.org/10.1140/epjc/s10052-019-6697-4

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

Performance of ANAIS-112 experiment after the first year of data taking

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arXiv:1812.01472

ANAIS-112 General Performance

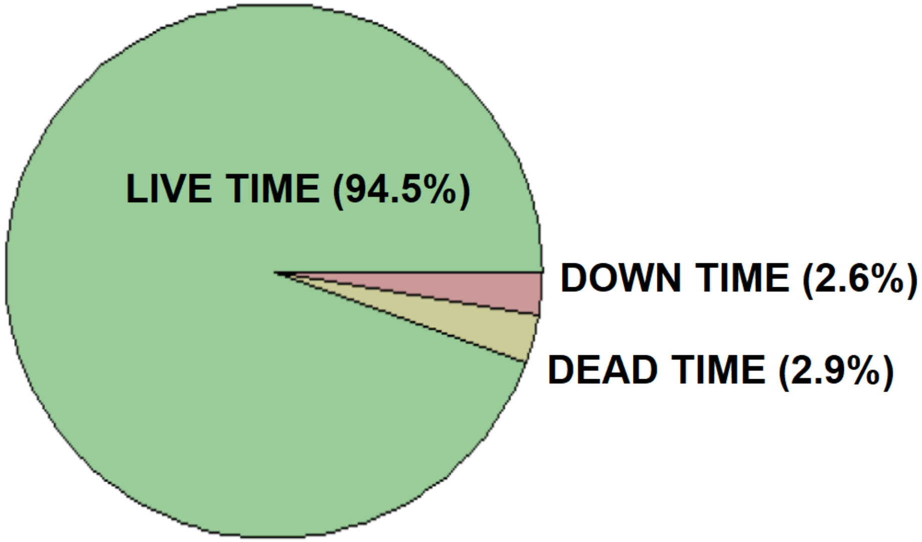
ANAIS-112 Duty Cycle

The ANAIS-112 Dark Matter Run started on August 3, 2017

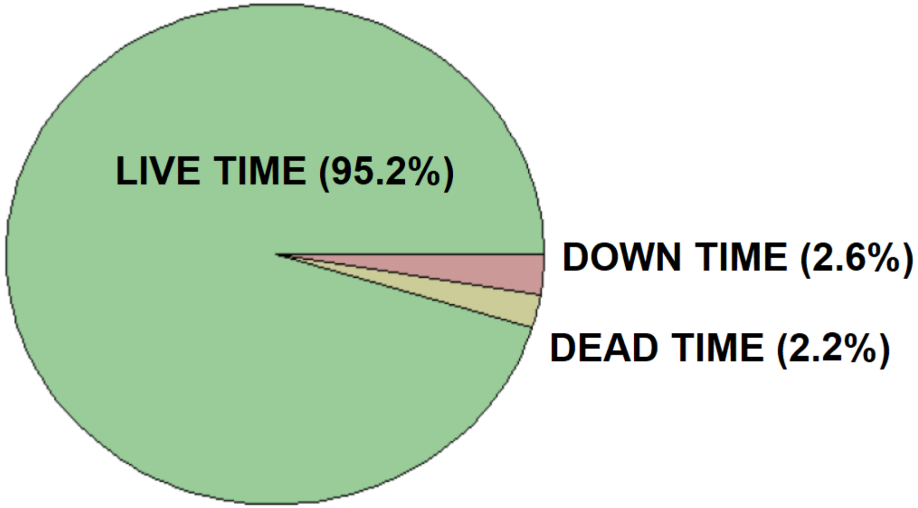
Accumulated live time in the first year: 341.72 days

in the half second year: 185.36 days

total: 527.08 days



1st year



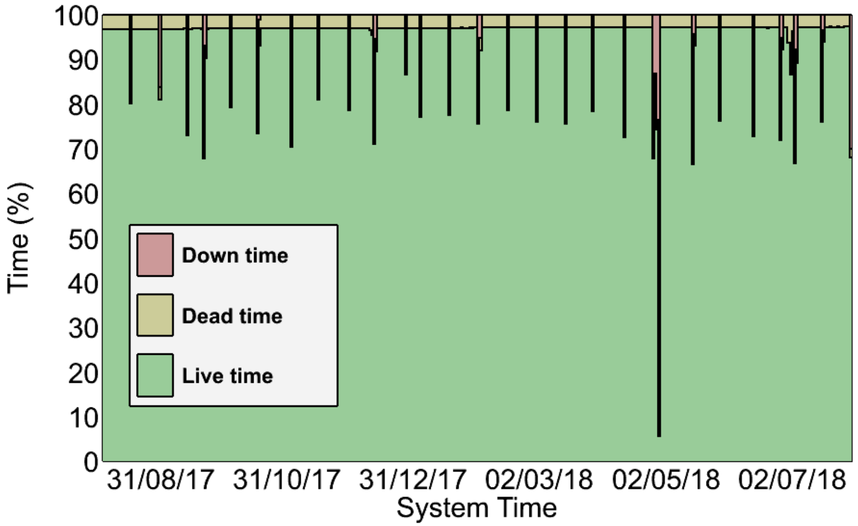
2nd year

ANAIS-112 Duty Cycle

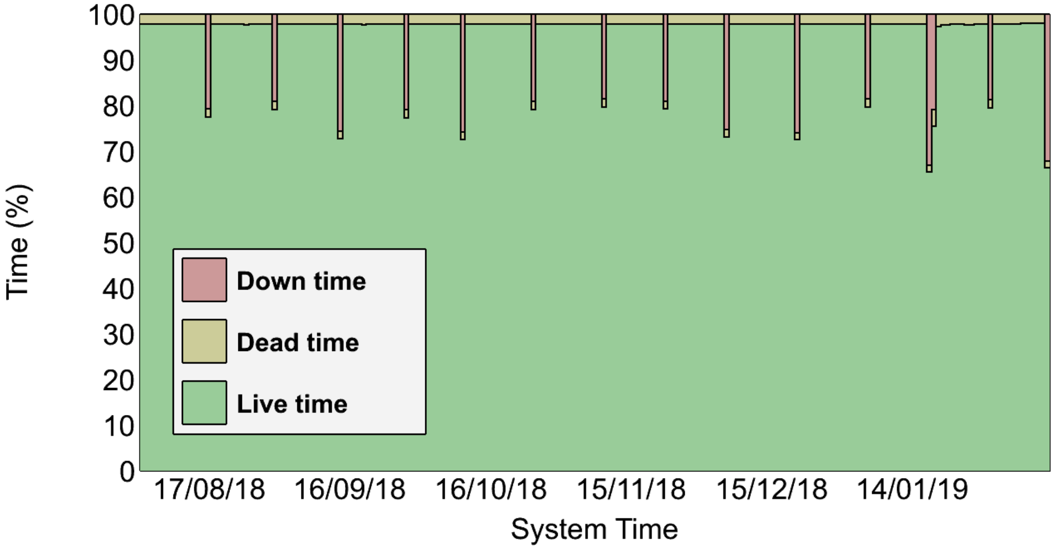
The ANAIS-112 Dark Matter Run started on August 3, 2017

Accumulated live time in the first year: 341.72 days
in the half second year: 185.36 days

total: 527.08 days



1st year

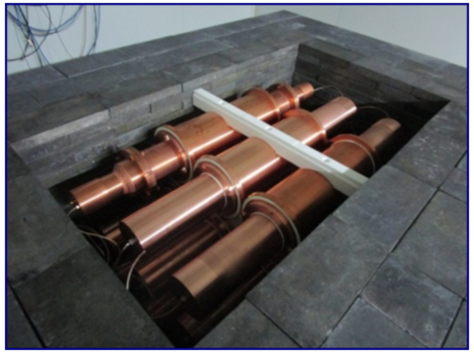


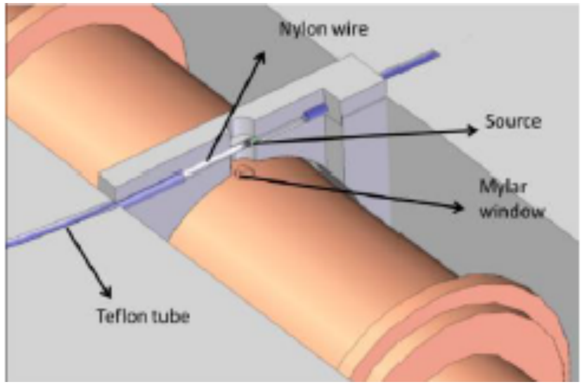
2nd year

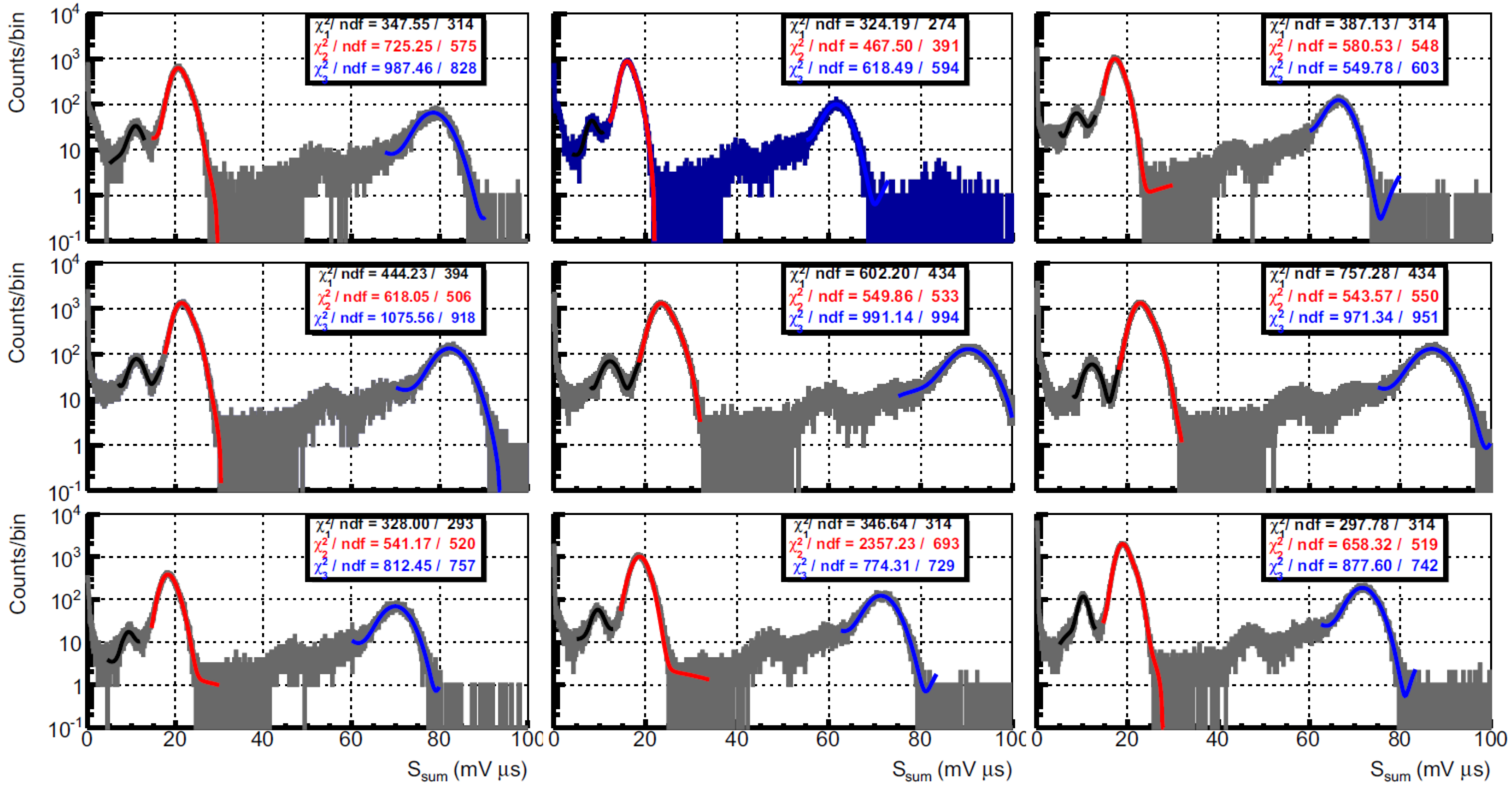
ANAIS-112 Low Energy Calibration

Periodic ^{109}Cd calibrations

They allow monitoring (and if necessary correcting) possible gain drifts in the modules.







88.0 keV
22.6 keV
11.9 keV

ANAIS-112 Low Energy Calibration

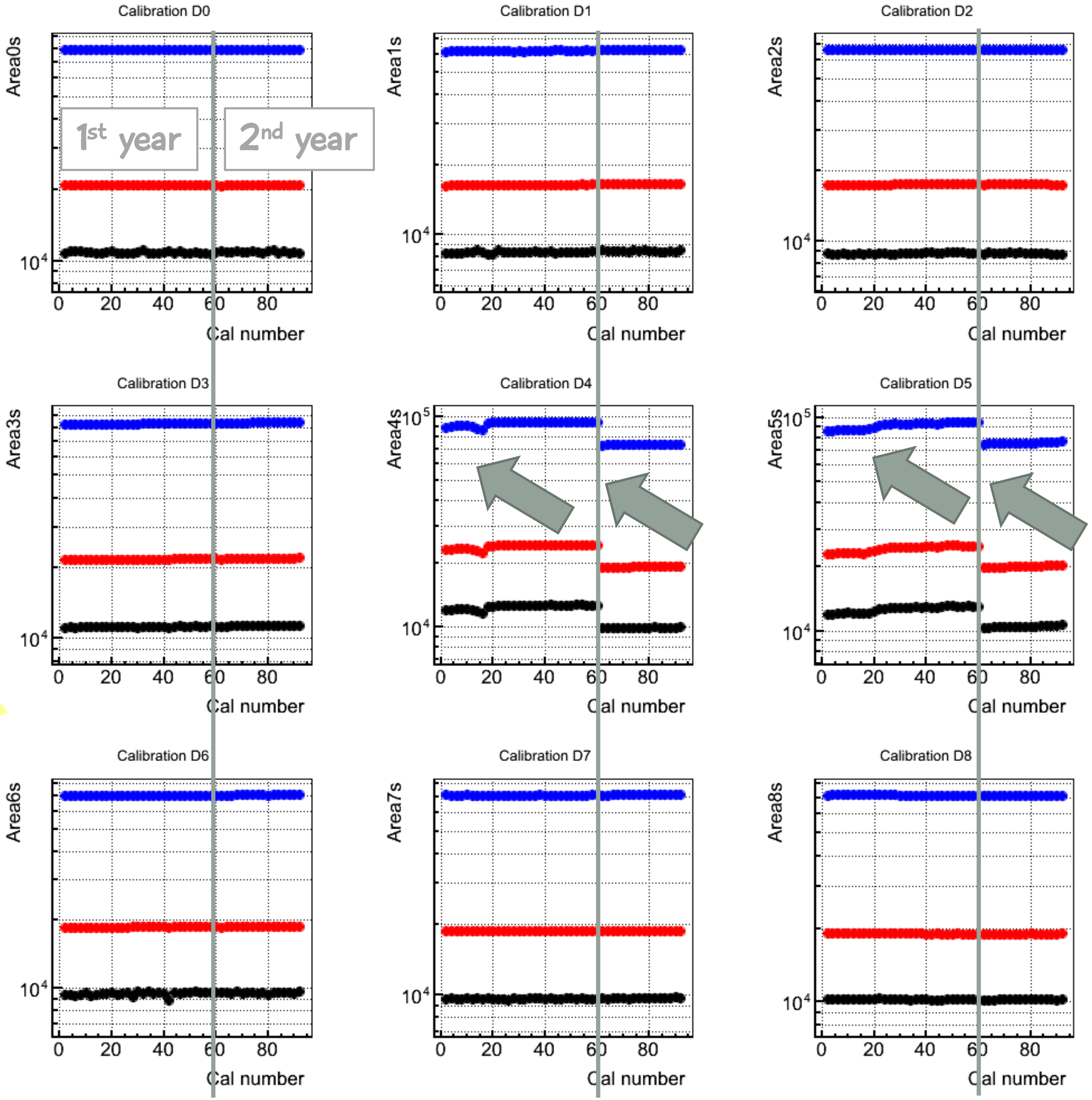
Periodic ^{109}Cd calibrations

They allow monitoring (and if necessary correcting) possible gain drifts in the modules.

Evolution of the positions of ^{109}Cd lines along ANAIS-112.

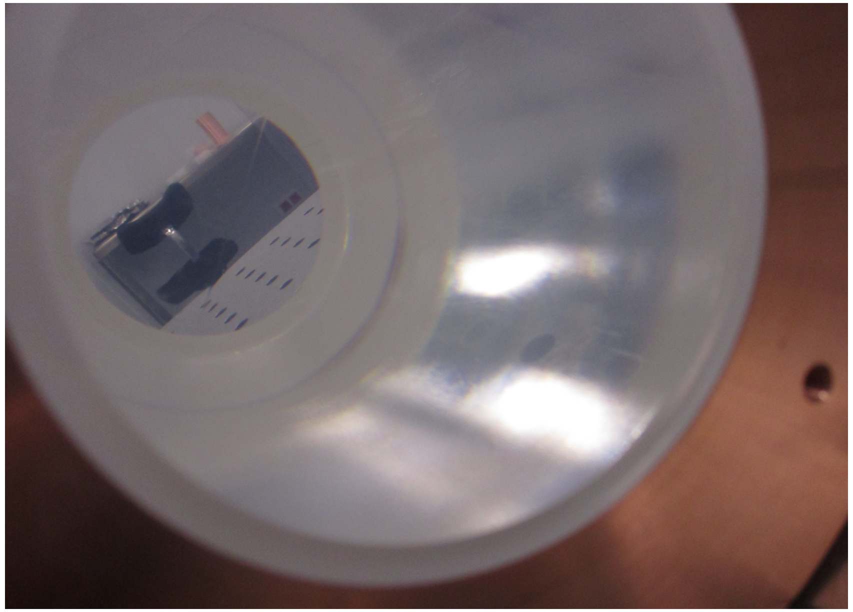
All the modules, except D4 and D5, have been very stable during this period of data taking.

88.0 keV (blue)
22.6 keV (red)
11.9 keV (black)

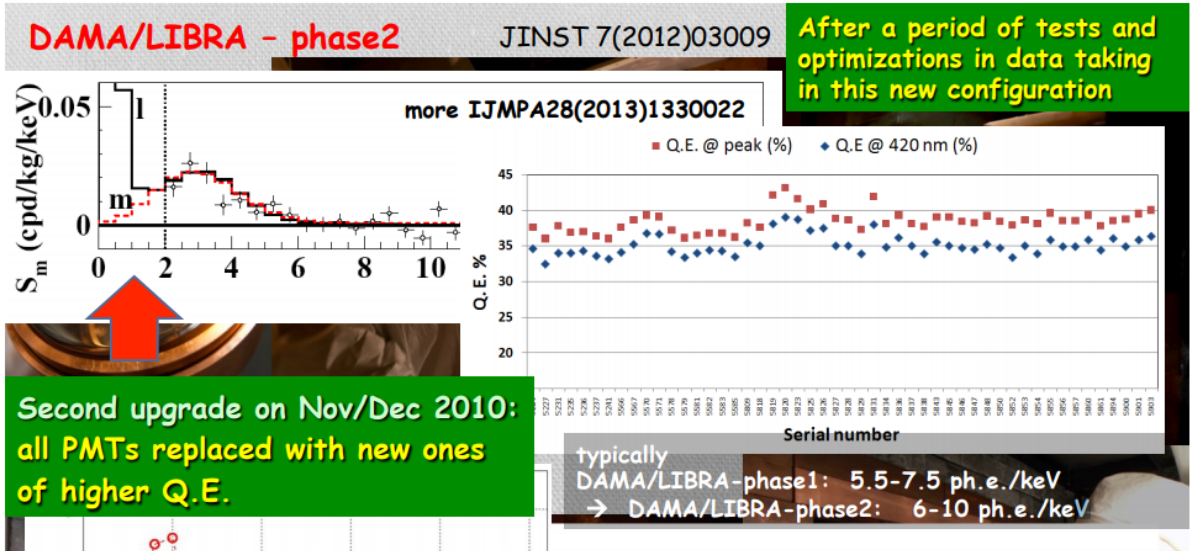


ANAIS-112 Light Collection

Excellent light collection



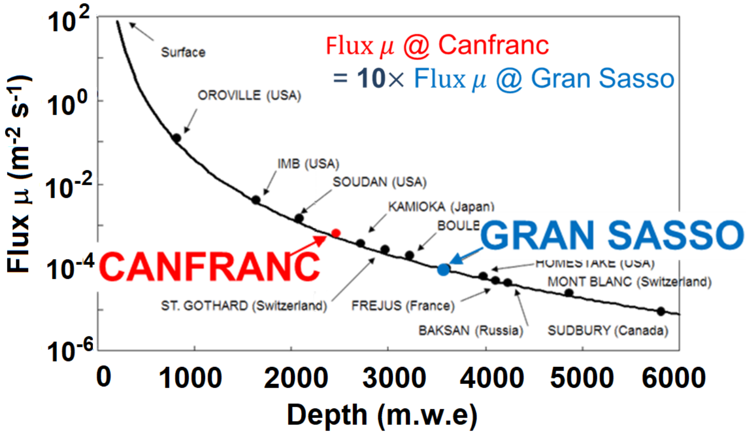
Detector	Average Light collected (phe/keV)	Standard deviation
D0	14.532	0.102
D1	14.745	0.169
D2	14.506	0.104
D3	14.453	0.109
D4	14.483	0.090
D5	14.572	0.158
D6	12.707	0.104
D7	14.743	0.137
D8	15.994	0.076

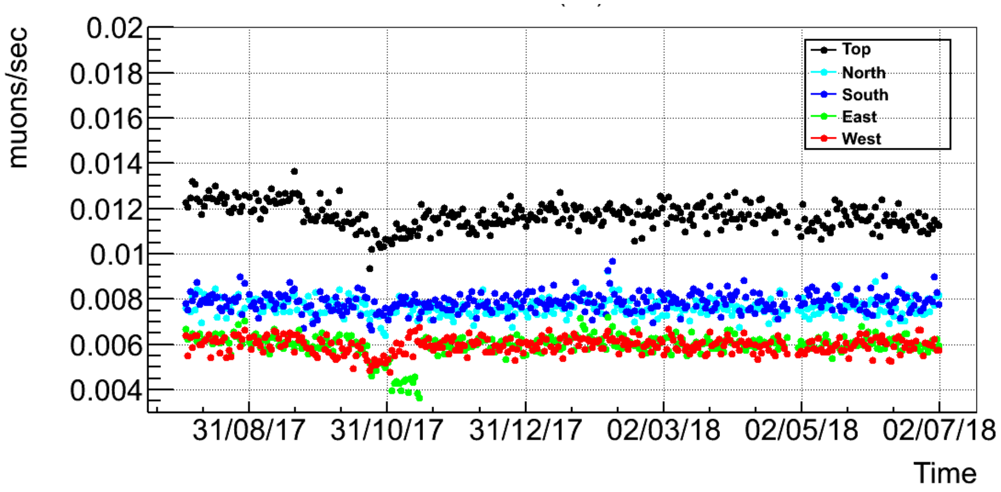


Larger and much more homogeneous than the light collection for DAMA/LIBRA –phase 2 detectors

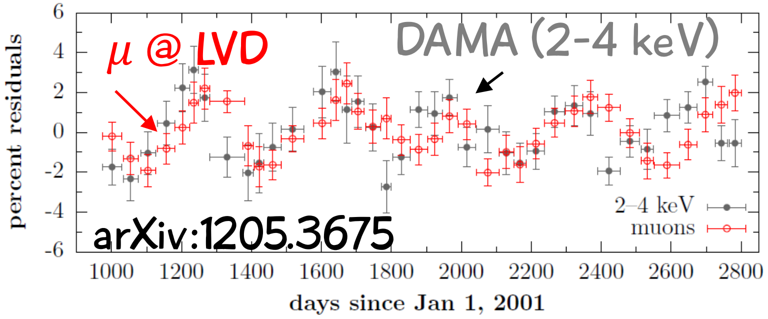
ANAIS-112 Monitoring of muons

Muon rates onsite are being monitored along the ANAIS-112 DM run.



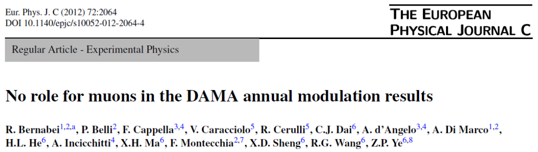


The underground muon flux is annually-modulated! -> We should care about muons



<u>DAMA reply:</u>

- Modulation phase inconsistency
- Muons interacting directly in the detectors do not fulfill the DM requisites
- Not enough muon-induced fast neutrons to account for the signal

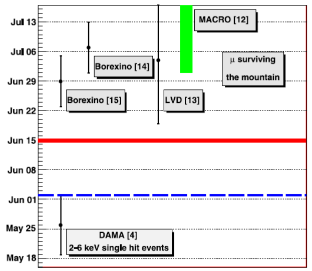

Eur. Phys. J. C (2012) 72:2064
DOI 10.1140/epjc/s10052-012-2064-4

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Experimental Physics

No role for muons in the DAMA annual modulation results

R. Bernabei, P. Belli, F. Cappella, V. Caracciolo, R. Cerulli, C.J. Dai, A. d'Angelo, A. Di Marco, H.L. He, A. Incicchitti, X.H. Ma, F. Montecchia, X.D. Sheng, R.G. Wang, Z.P. Ye



But still some open questions:

- (delayed) effect of muons in PMTs?
- slow phosphorescence in NaI?

ANAIS can test these hypotheses

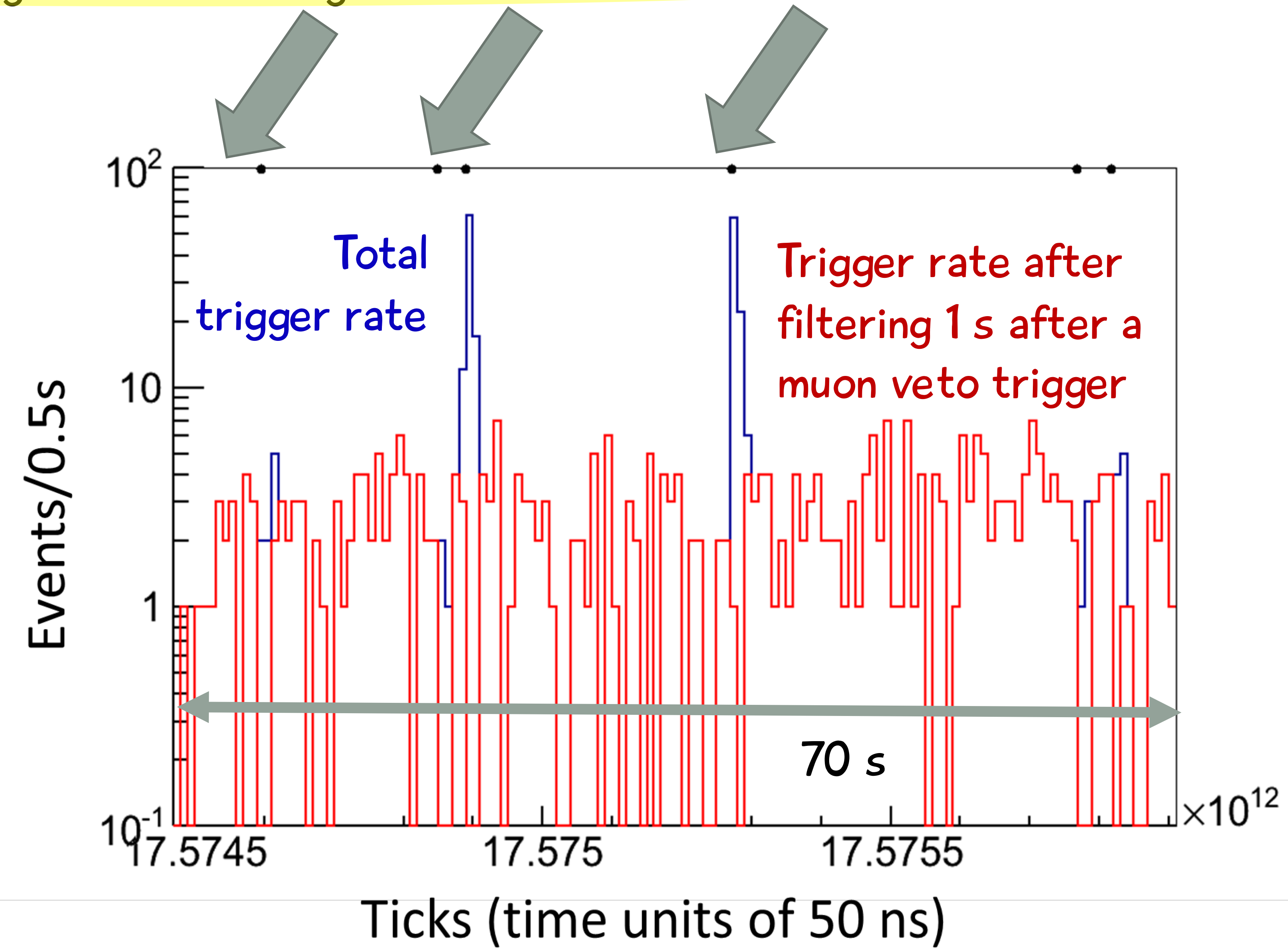
ANAIS-112 Monitoring of muons

Muon rates onsite are being monitored along the ANAIS-112 DM run.

Muon related events are triggering ANAIS DAQ

Most of them are removed by rejecting 1 second after a veto trigger

The fraction of live time rejected after the application of this filtering amounts only to a 3%.



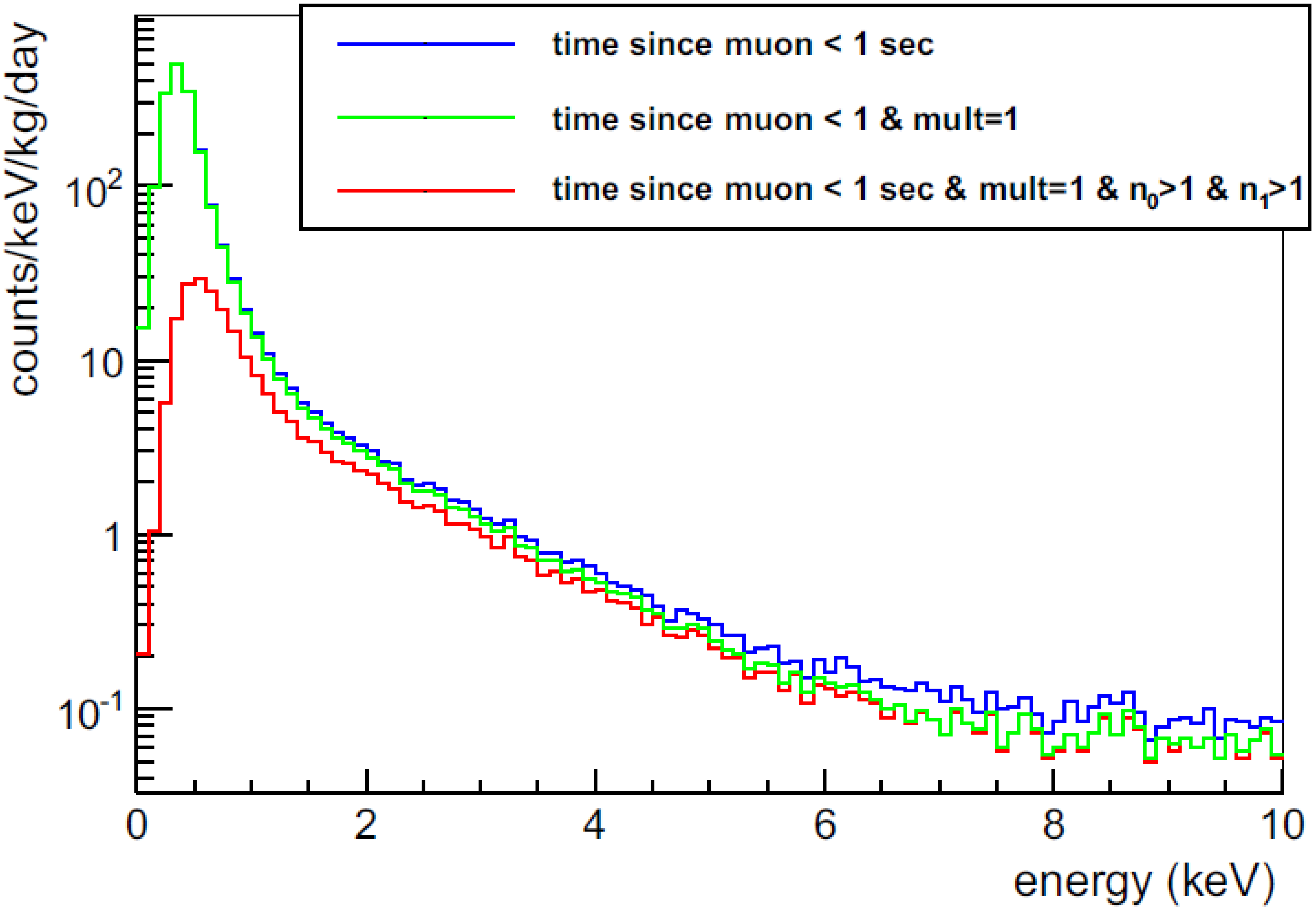
Muon rates onsite are being monitored along the ANAIS-112 DM run.

Muon related events are triggering ANAIS DAQ

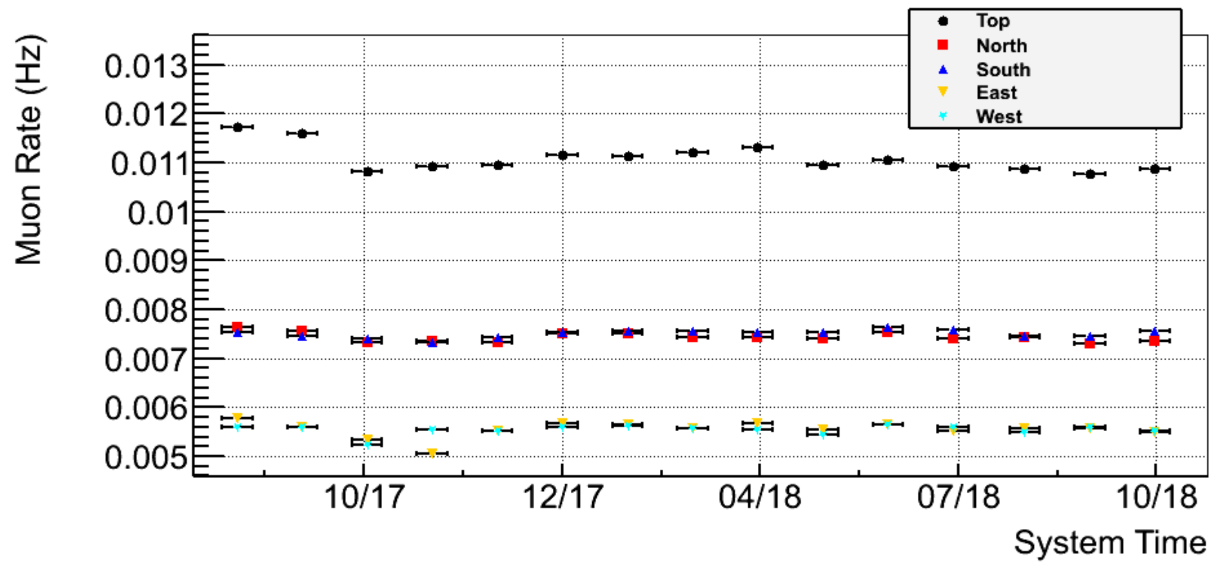
Most of them are removed by rejecting 1 second after a veto trigger

The fraction of live time rejected after the application of this filtering amounts only to a 3%.

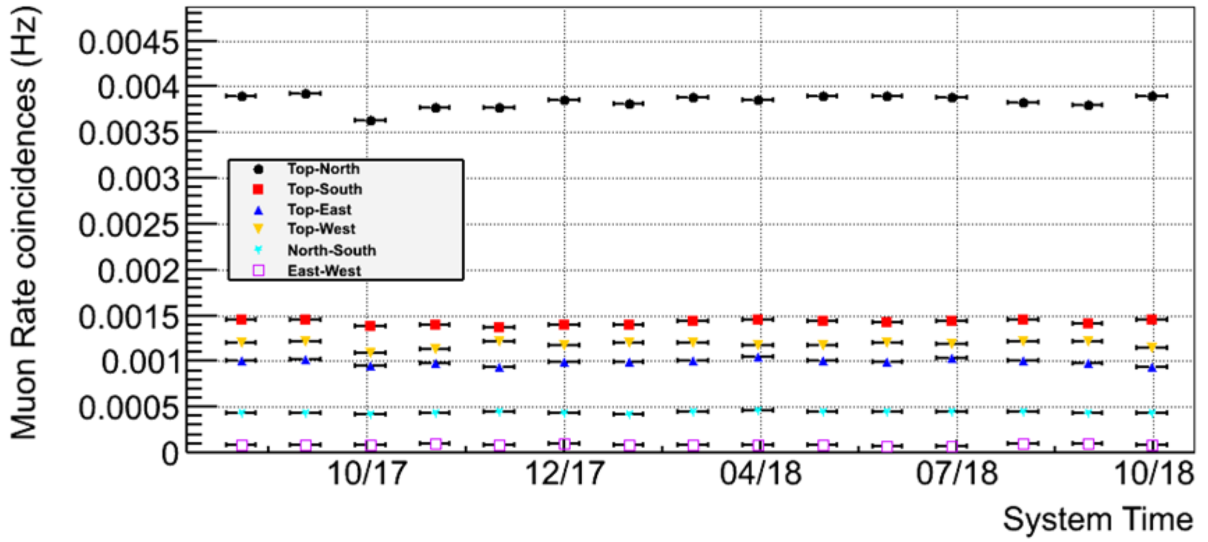
Most of the removed events fall in the RoI



Muon rates onsite are being monitored along the ANAIS-112 DM run.



Rates at each side of the veto system on a monthly basis.



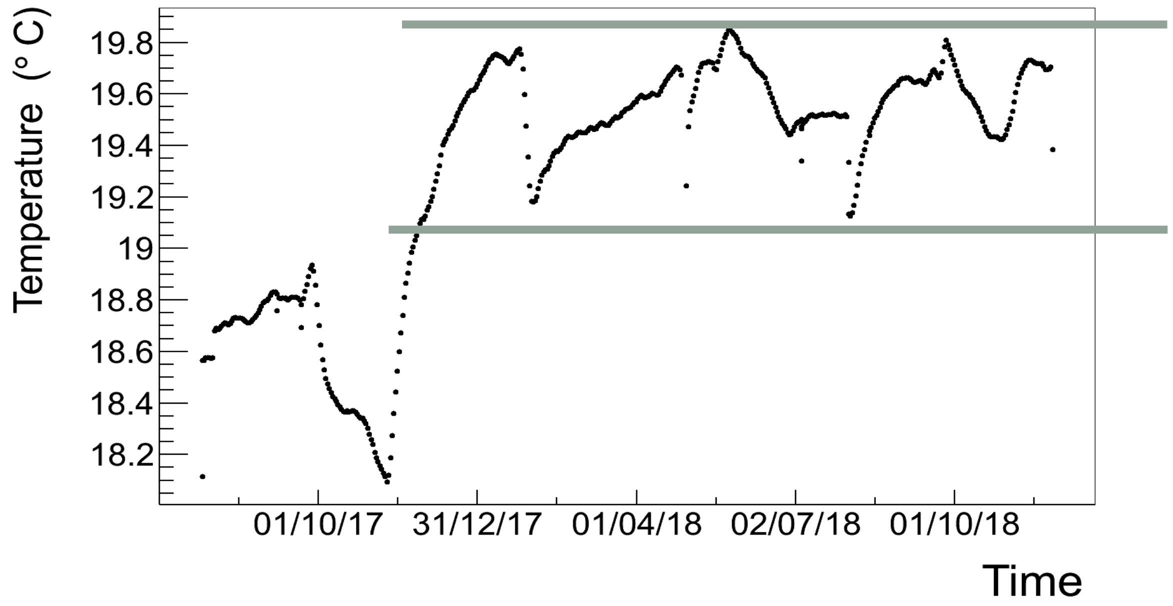
Rates of coincidences between two sides of the veto system on a monthly basis

ANAIS-112 Monitoring of muons

ANAIS-112 Monitoring of environmental parameters

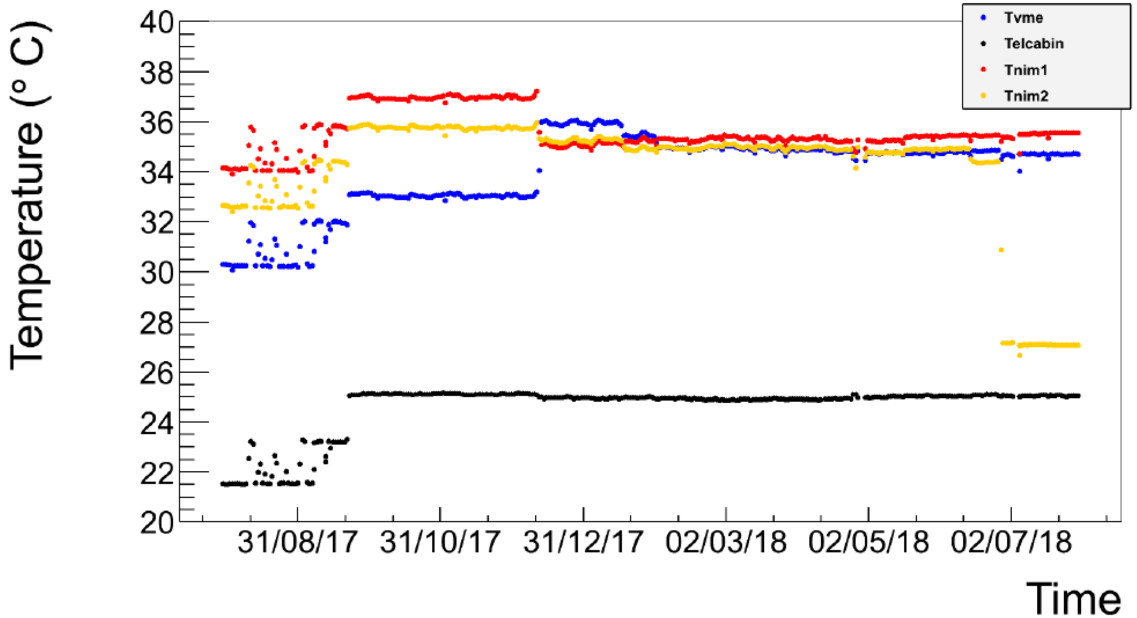
Monitoring of environmental parameters has been ongoing along ANAIS-112 DM run.

Temperature inside ANAIS-112 shielding ->
It has stabilized after the first six months of data taking



For the first year:
Mean value: 19.24ºC
Standard deviation: 0.48ºC

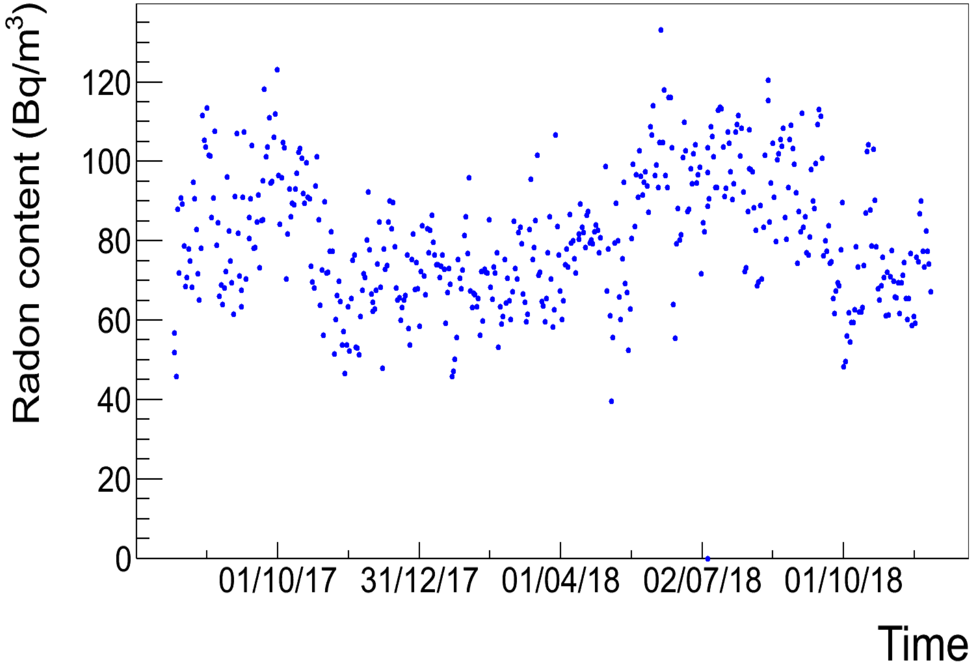
Temperatures at the electronics -> Fully decoupled from Hall B temperature

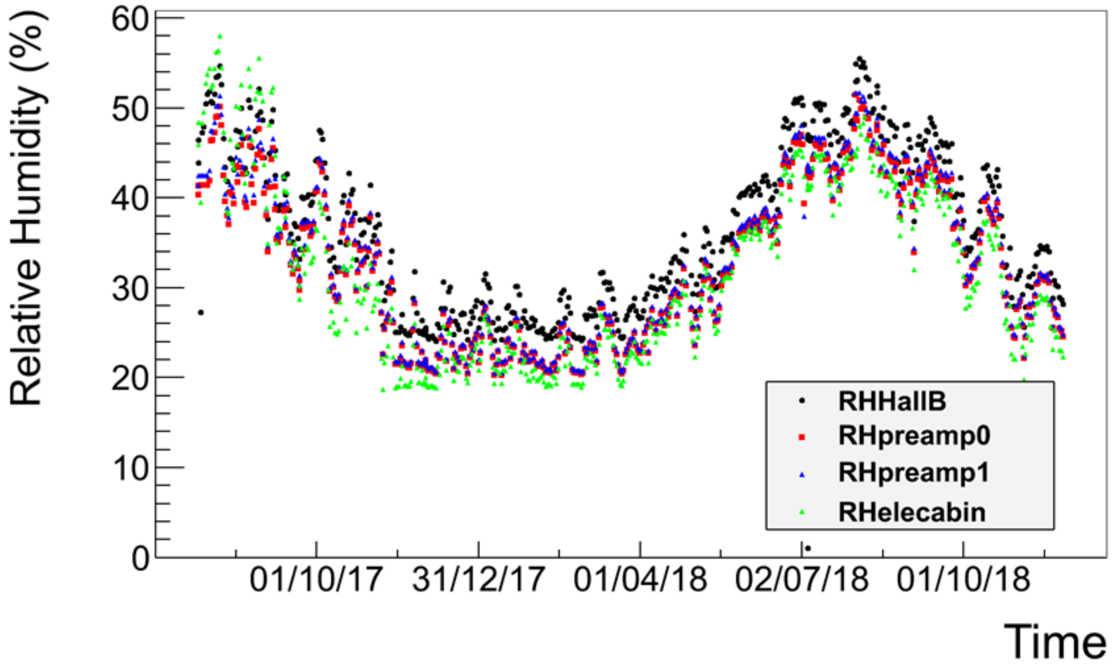


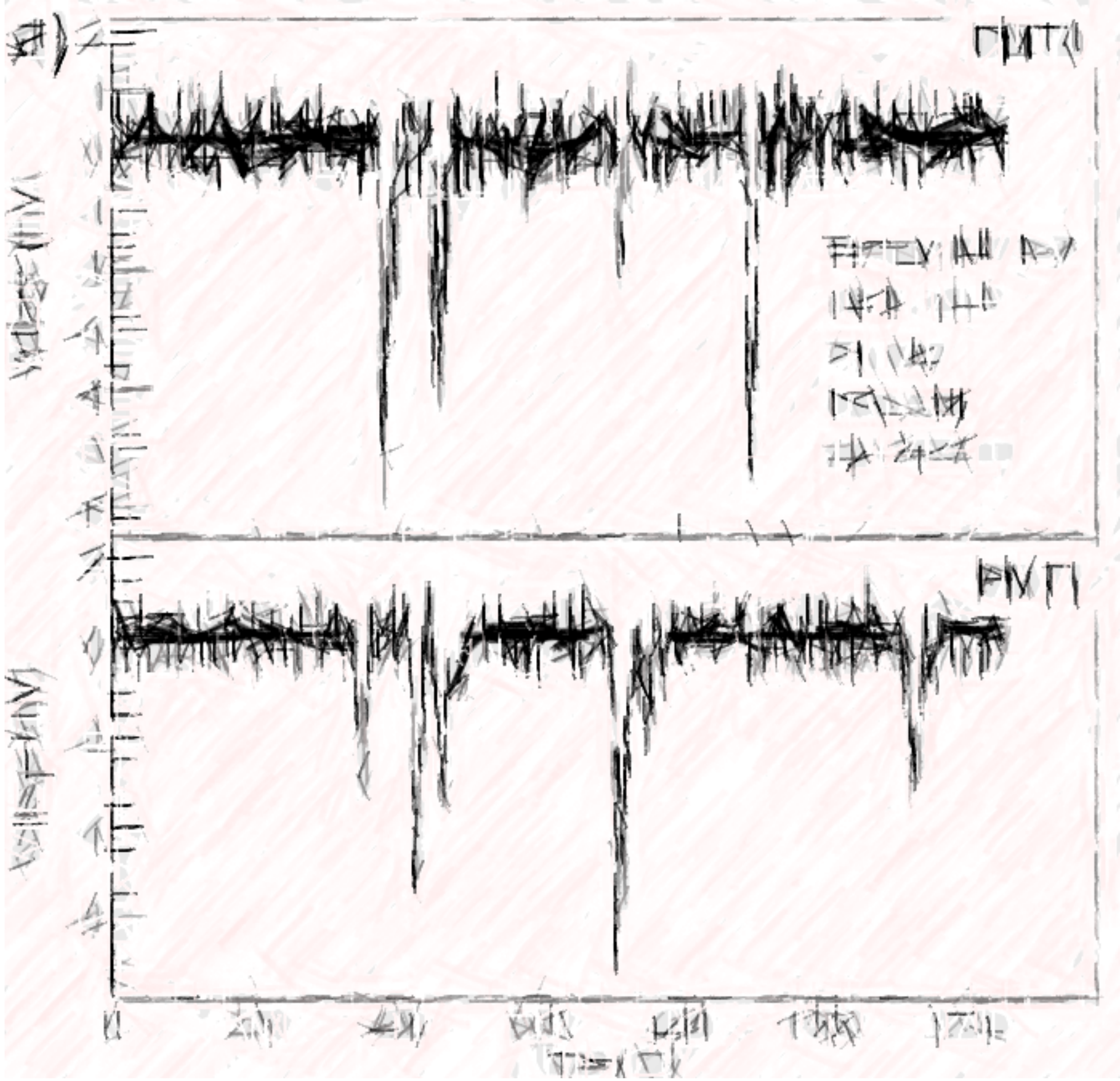
ANAIS-112 Monitoring of environmental parameters

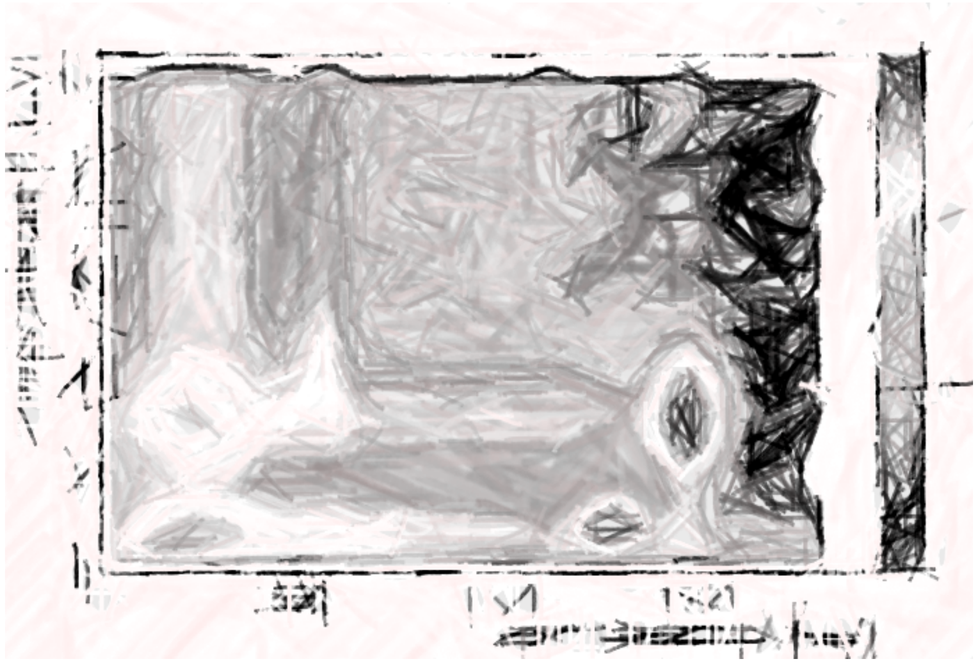
Monitoring of environmental parameters has been ongoing along ANAIS-112 DM run.

Radon content and Relative Humidity in different positions but outside the ANAIS-112 shielding







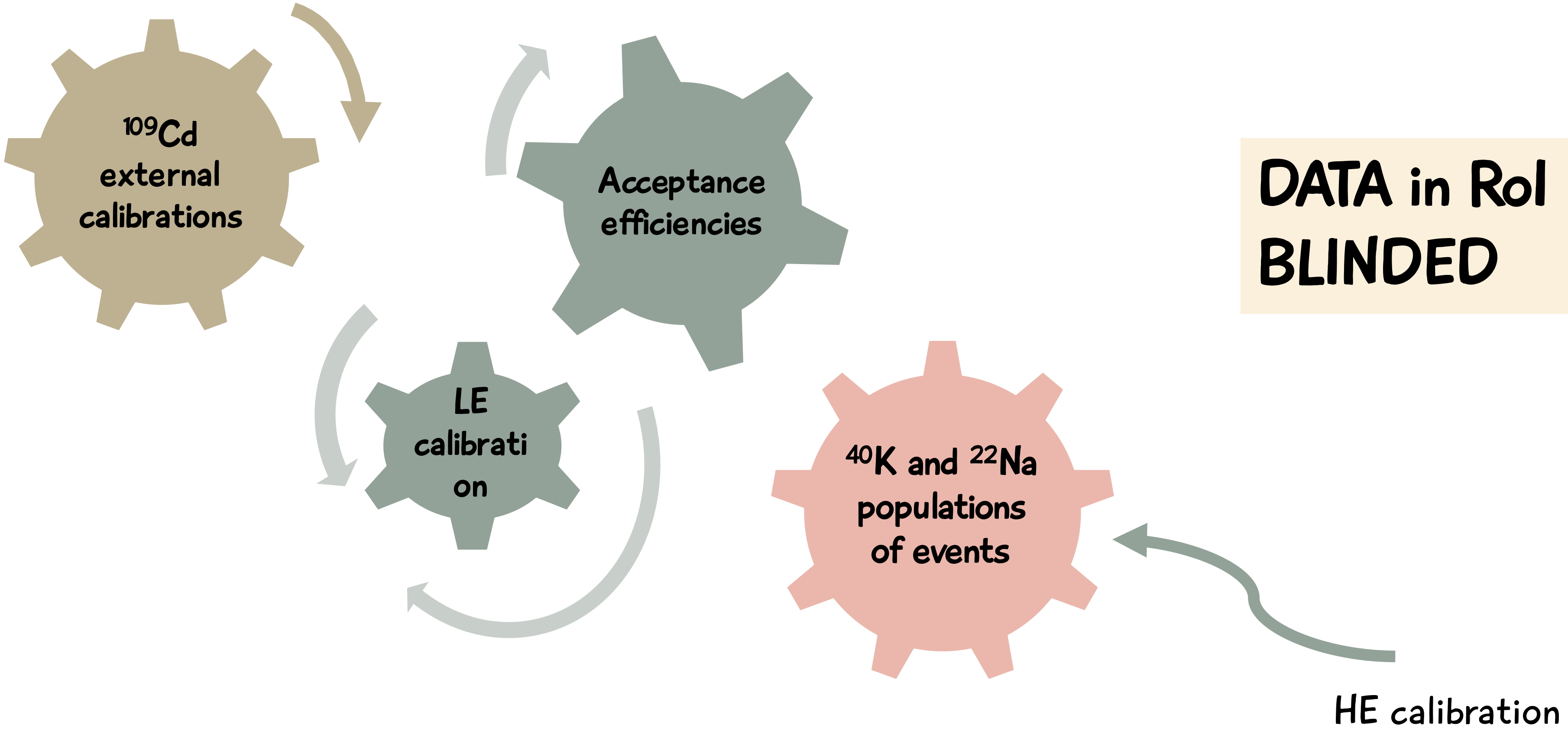


ANAIS-112 Data Analysis

ANAIS-112 Data Analysis

We have refined and tuned event selection procedures developed from previous ANAIS set-ups.

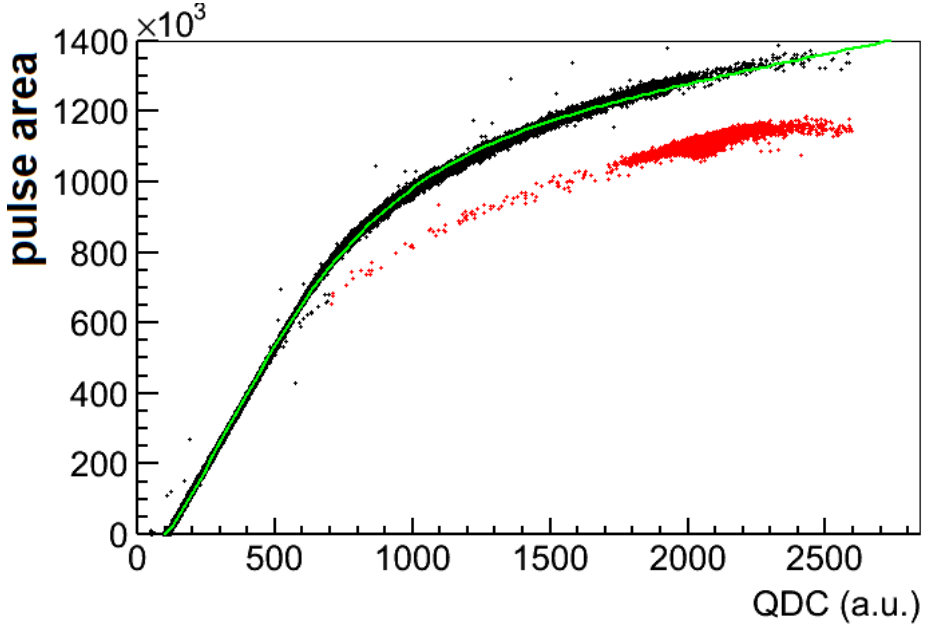
-> using preferably non-blinded event populations (outside the region of interest, coincident events, etc.), although finally, we have unblinded about 10% of the total statistics from the first year (34 days selected randomly, amounting 32.9 days live time) for background assessment and final tuning of some of the procedures.

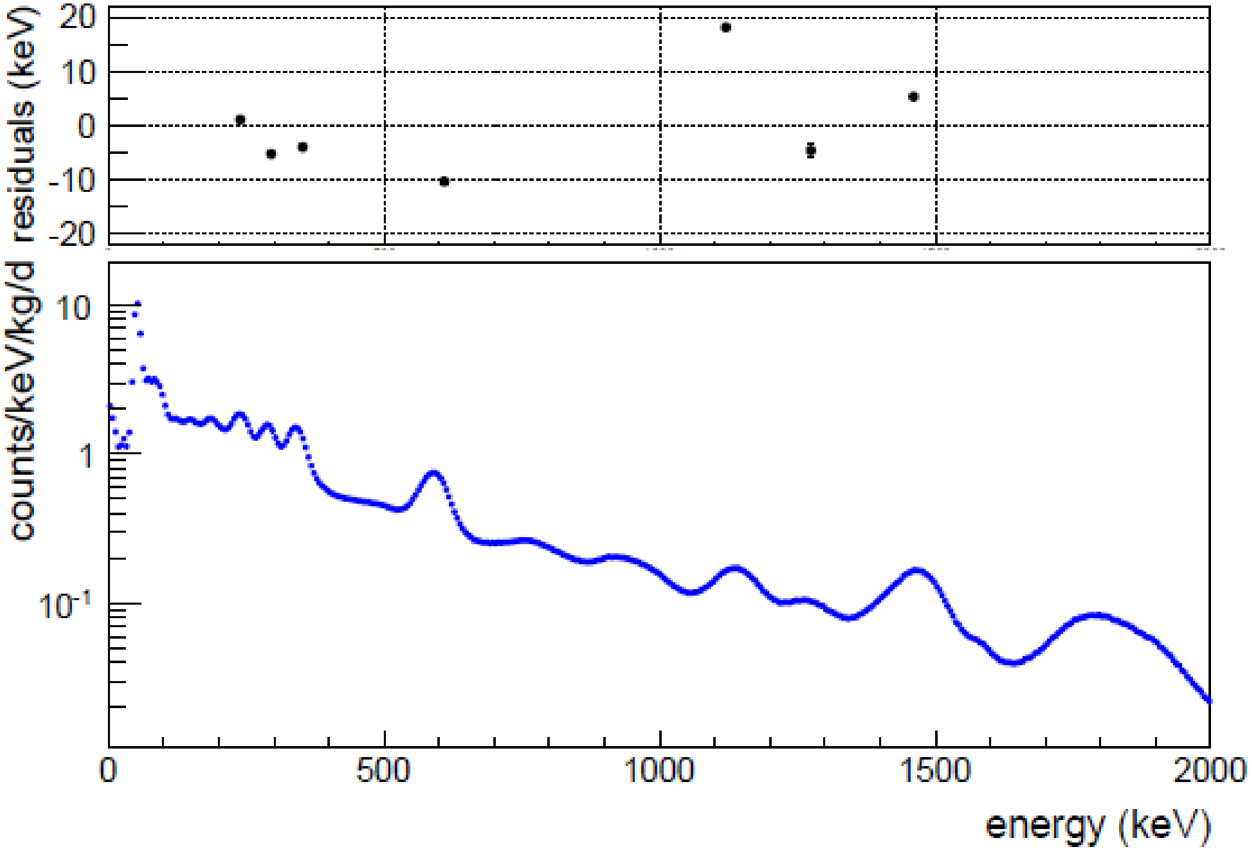


DATA in RoI BLINDED

Calibration @ HE (above 50 keV)

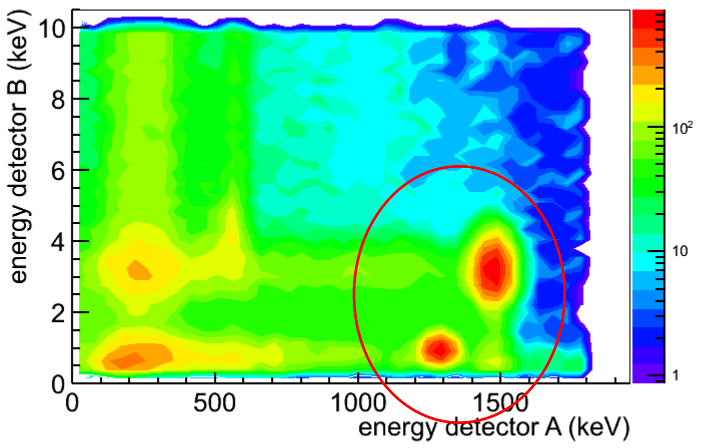
we estimate energy by linearizing the pulse area – QDC relation for each module and calibrating with background lines (every two weeks)





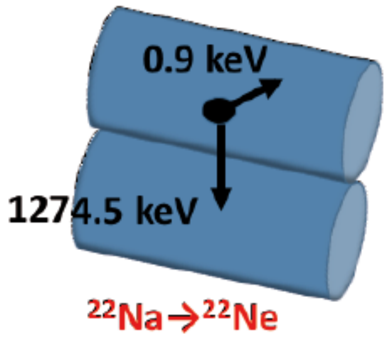
ANAIS-112 Effective Triggering

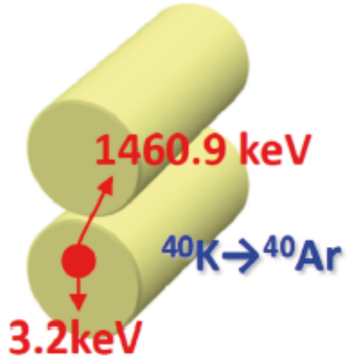
Effectively triggering below 1 keV



bulk ^{22}Na and ^{40}K events identified by coincidences with high energy gammas

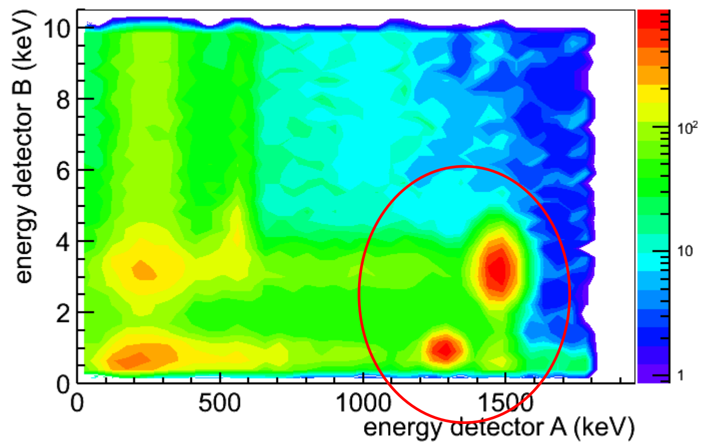
Populations at very LE well tagged by the coincidence



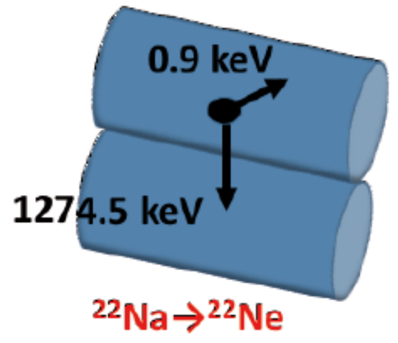


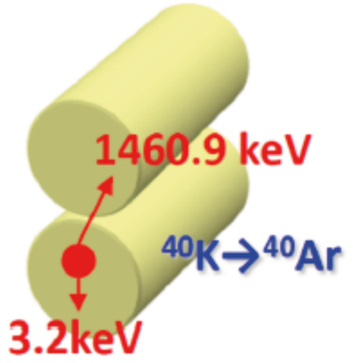
0.87 keV from ^{22}Na is actually below our analysis threshold, but clearly above our trigger threshold
Selection by the coincidence allows to use these events (almost free from noise/background)

Effectively triggering below 1 keV

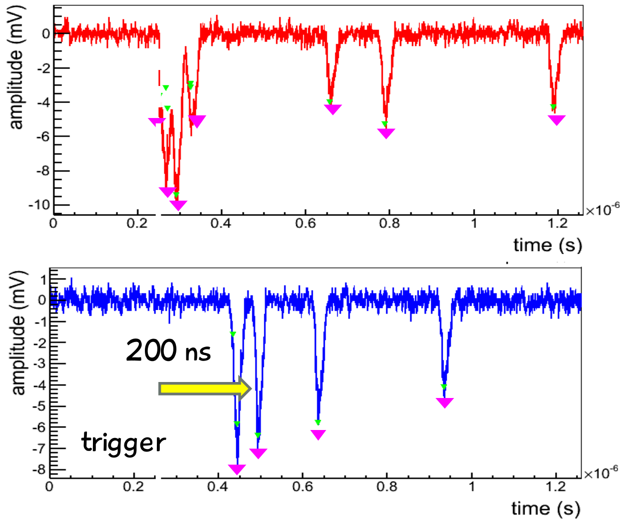


bulk ^{22}Na and ^{40}K events identified by coincidences with high energy gammas

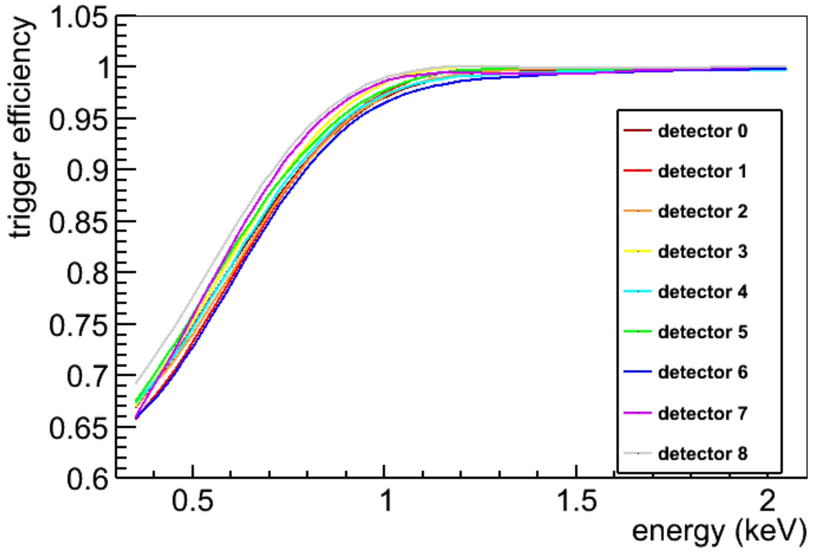




Trigger efficiency evaluated with a MC "scintillation" simulation based on experimental SER and light collection determined per each module



MC event (energy ~1 keV)



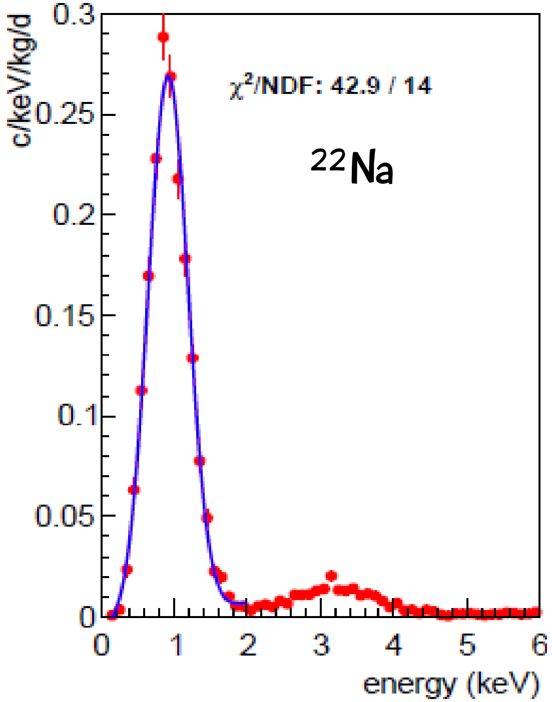
ANAIS-112 Effective Triggering

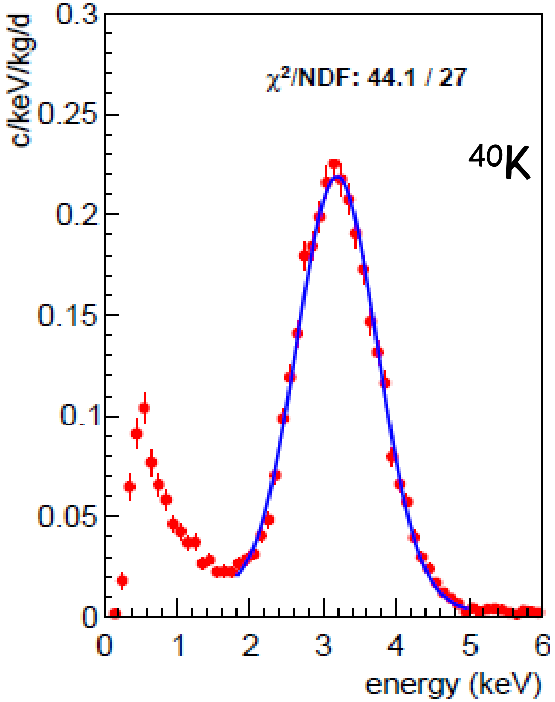
Calibration @ LE (below 50 keV)

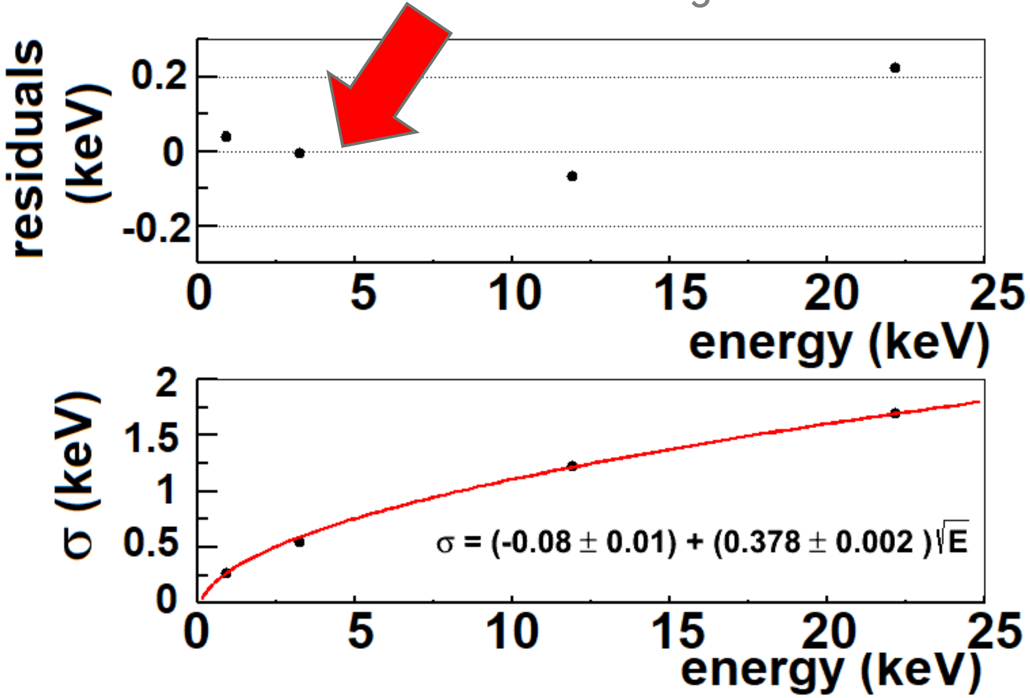
- Periodic Cd calibrations every two weeks provide peaks very close to RoI -> first calibration step to correct for any gain drift
- Known background lines from contaminants in the bulk in the RoI allow to increase the accuracy of our calibration procedure -> adding one and a half months of bckg to recalibrate energy using the median of the ^{40}K and ^{22}Na lines selected by the coincidence

Full First Year Data selected by coincidence with a HE gamma

Fitted to a Gaussian + linear bckg







ANAIS-112 Event Selection

-**Single Hit events**

-**Events arriving more than 1 second after a muon**

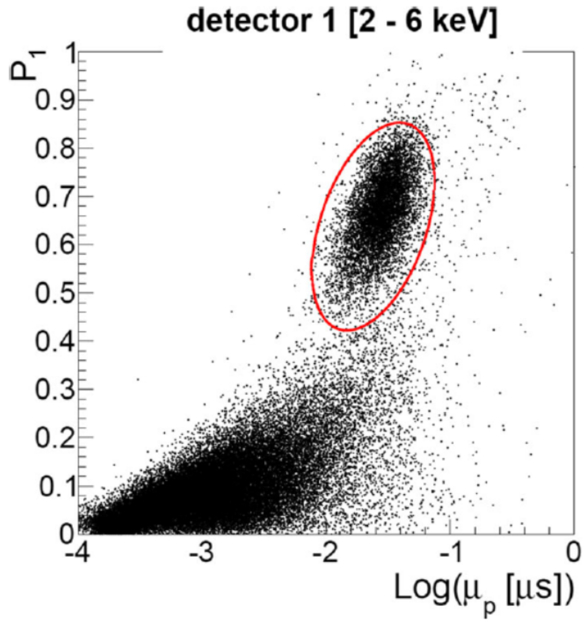
Live Time (after cut) = 511.16 days

PMT noise filtering protocols are mandatory to reach 1 keV energy threshold

-**Biparametric cut** to properly select events with pulse shapes from NaI(Tl) scintillation

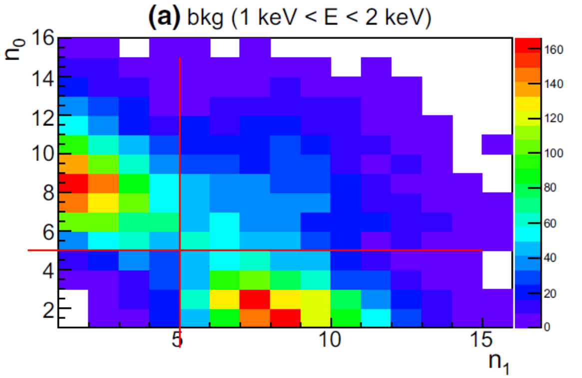
$$P_1 = \frac{\int_{100\,ns}^{600\,ns} A(t)dt}{\int_{0}^{600\,ns} A(t)dt}$$

$$\mu_p = \frac{\sum A_p t_p}{\sum A_p}$$

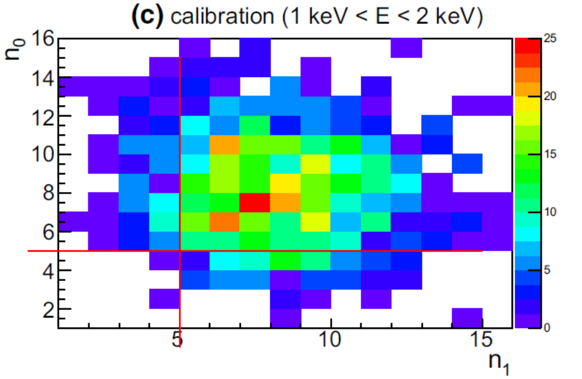


10 % data unblinded background @ RoI (random distribution)

-**Asymmetric events rejection** (E<2keV), number of peaks >4 at each PMT



BKG

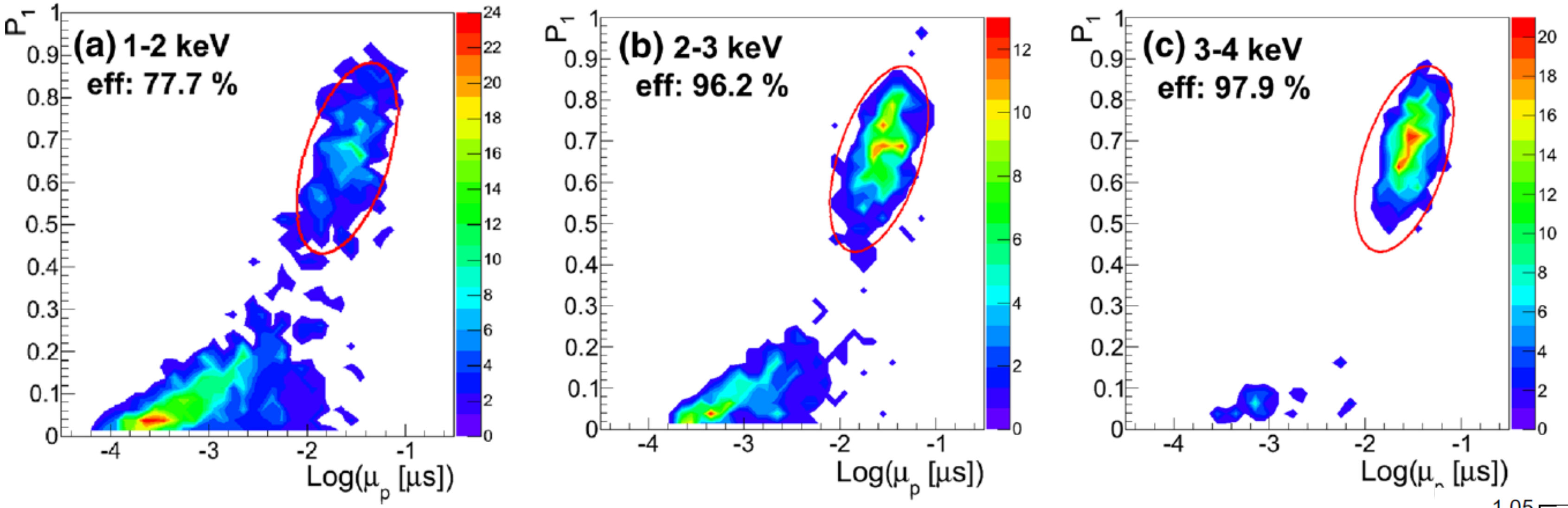


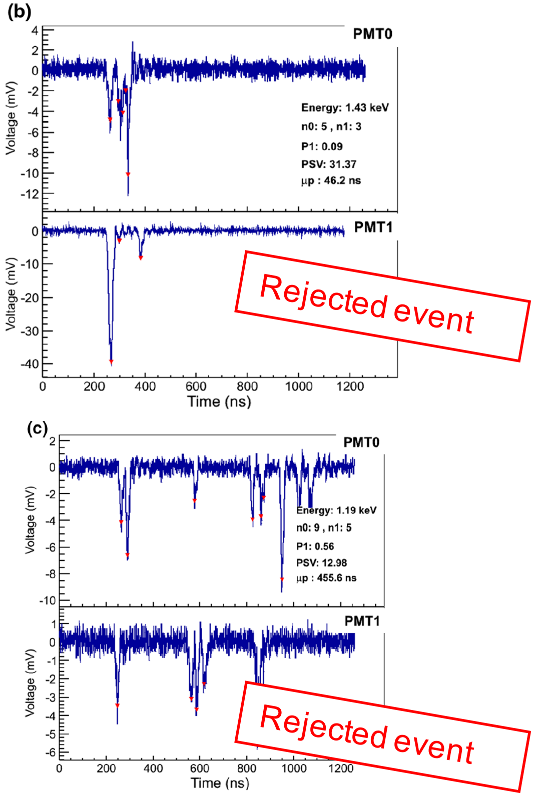
CAL

ANAIS-112 Event Selection efficiency

1.- **Biparametric cut** to properly select events with pulse shapes from NaI(Tl) scintillation

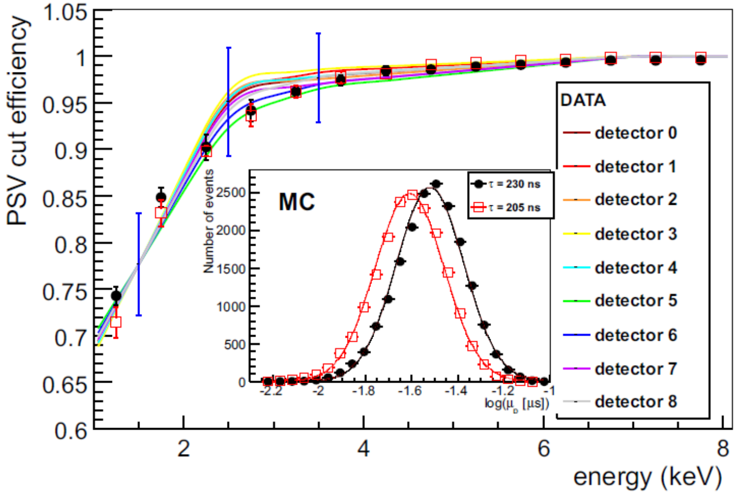
$$P_1 = \frac{\int_{100\,ns}^{600\,ns} A(t)dt}{\int_{0}^{600\,ns} A(t)dt} \qquad \mu_p = \frac{\sum A_p t_p}{\sum A_p}$$





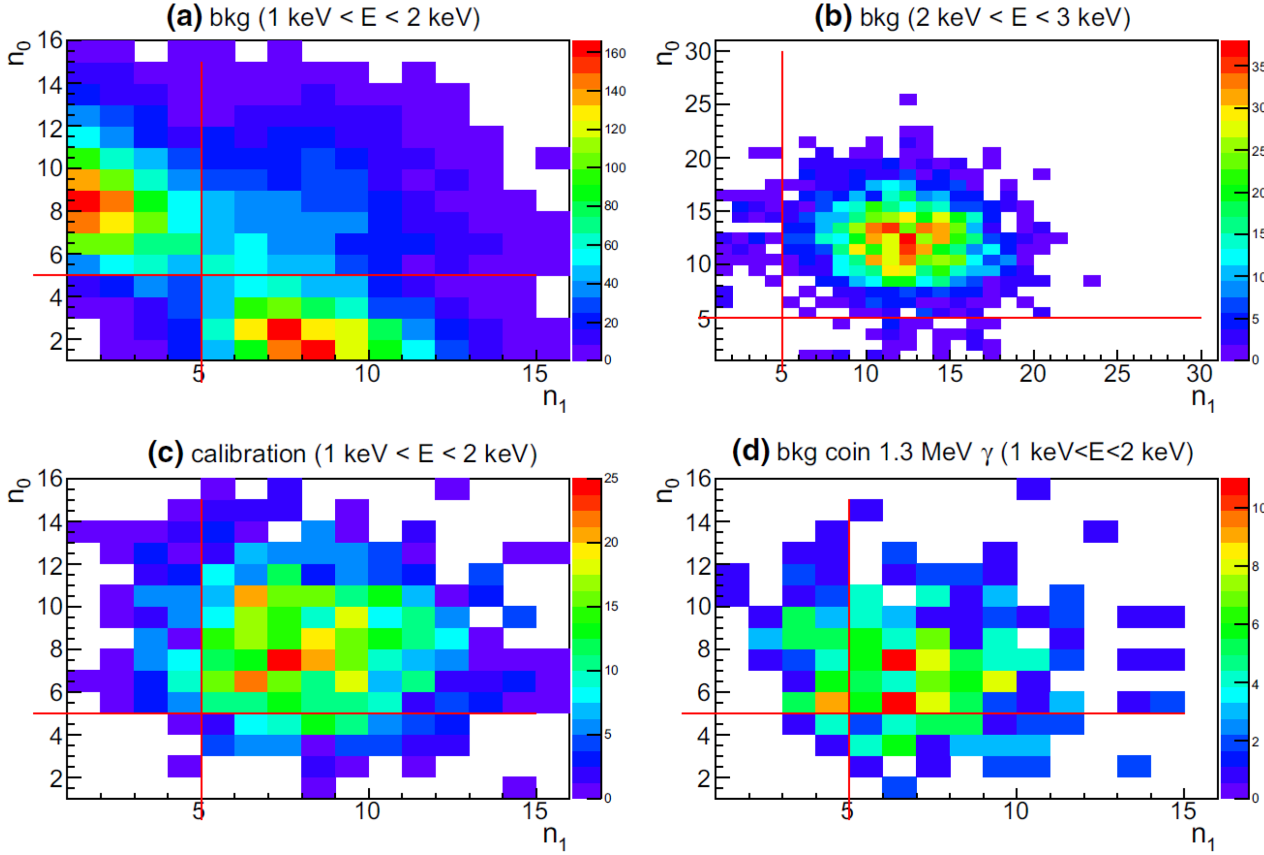
- Cut in (P_1, μ_p) plane selected by fixing a 78% acceptance @ [1-2] keV for ^{22}Na and ^{40}K populations

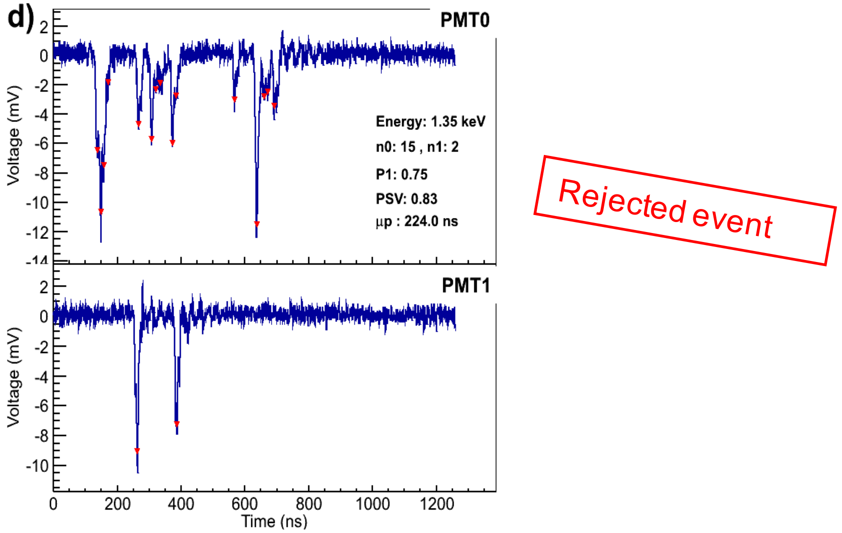
- Efficiency between [2-4] keV determined from ^{22}Na and ^{40}K populations and checked with MC "scintillation" simulation

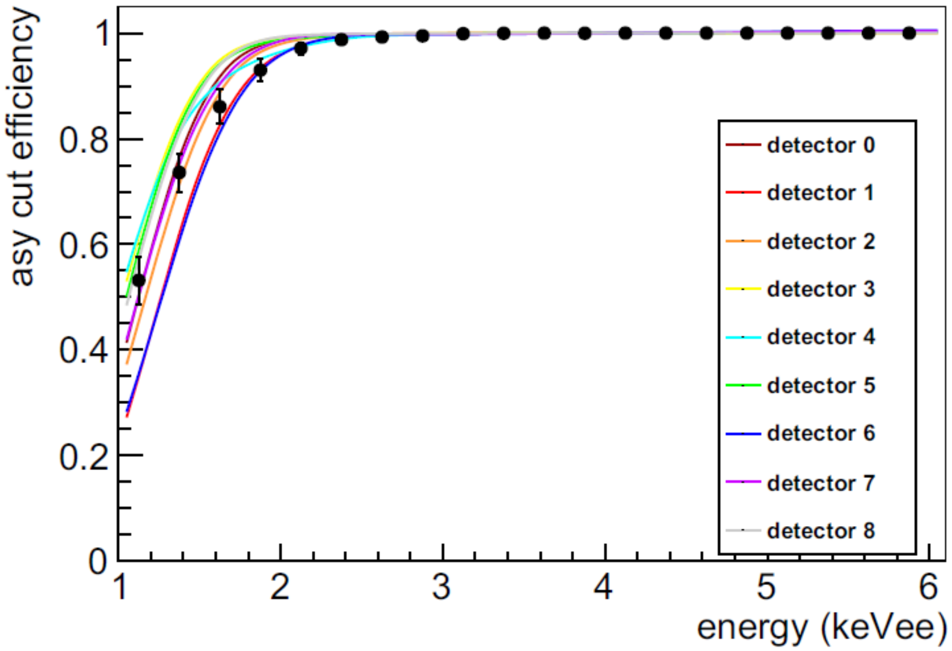


ANAIS-112 Event Selection efficiency

2.- Asymmetric events (<2 keV): accept events with number_of_peaks identified > 4 @ every PMT

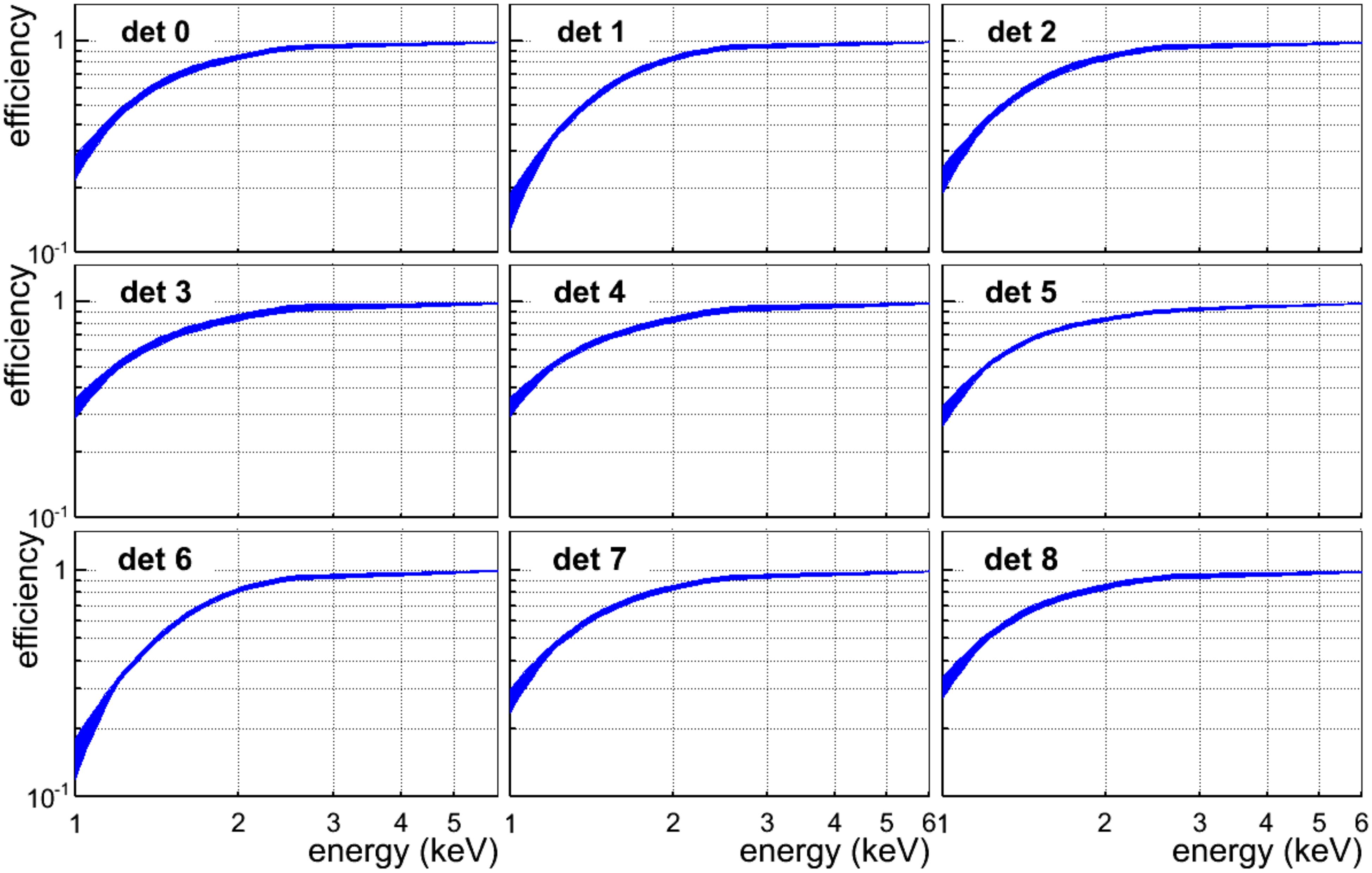






Acceptance efficiency calculated from calibration runs and checked with MC "scintillation" simulation

ANAIS-112 Event Selection efficiency

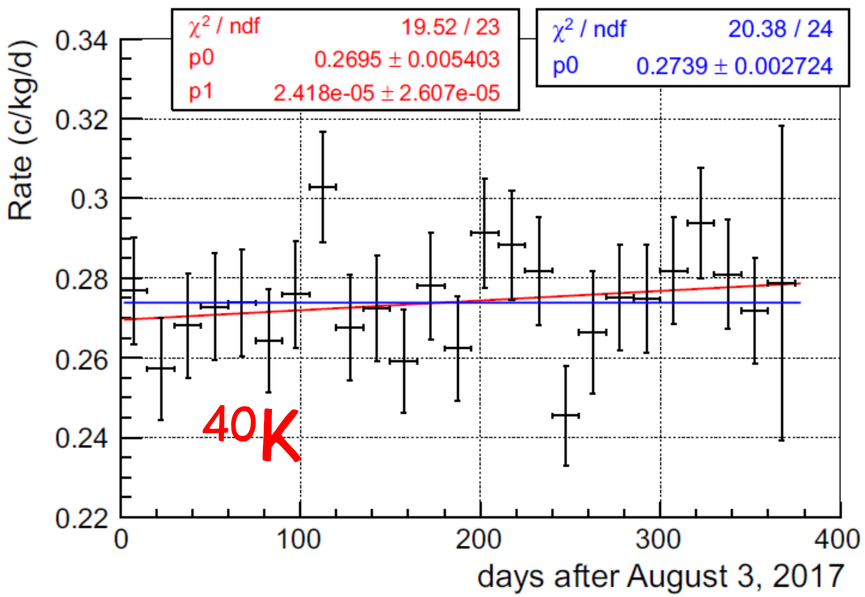


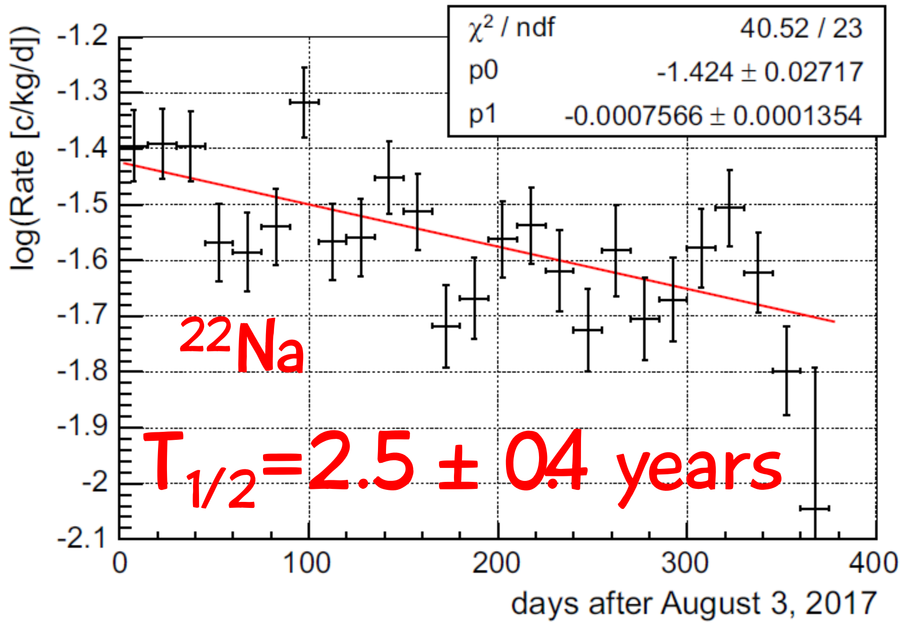
Line width shows the statistical + systematic errors

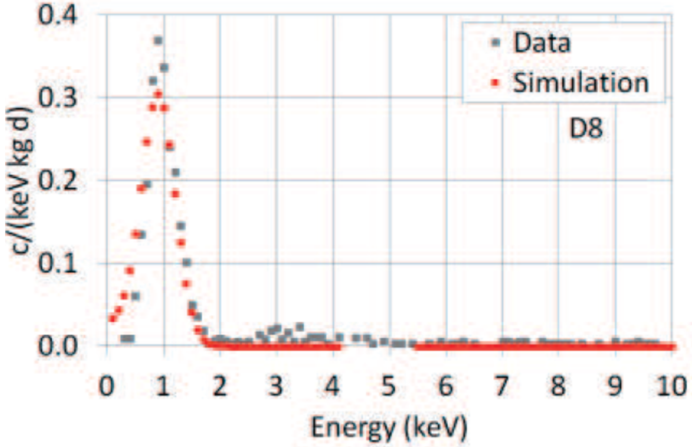
ANAIS-112 Event Selection efficiency

Checking the filtering protocols with ^{40}K and ^{22}Na populations

Time evolution of the rate compatible with decay constants



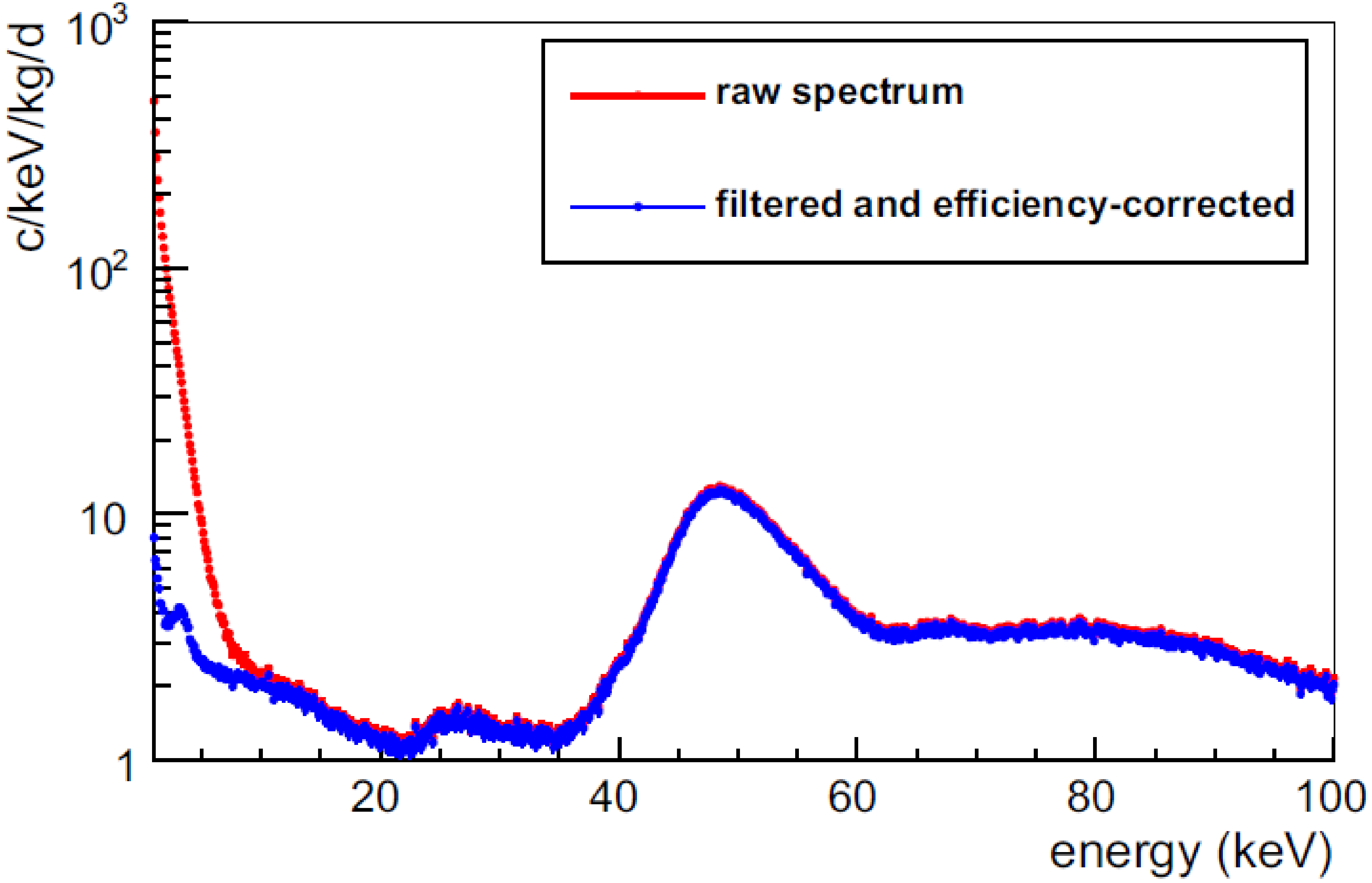


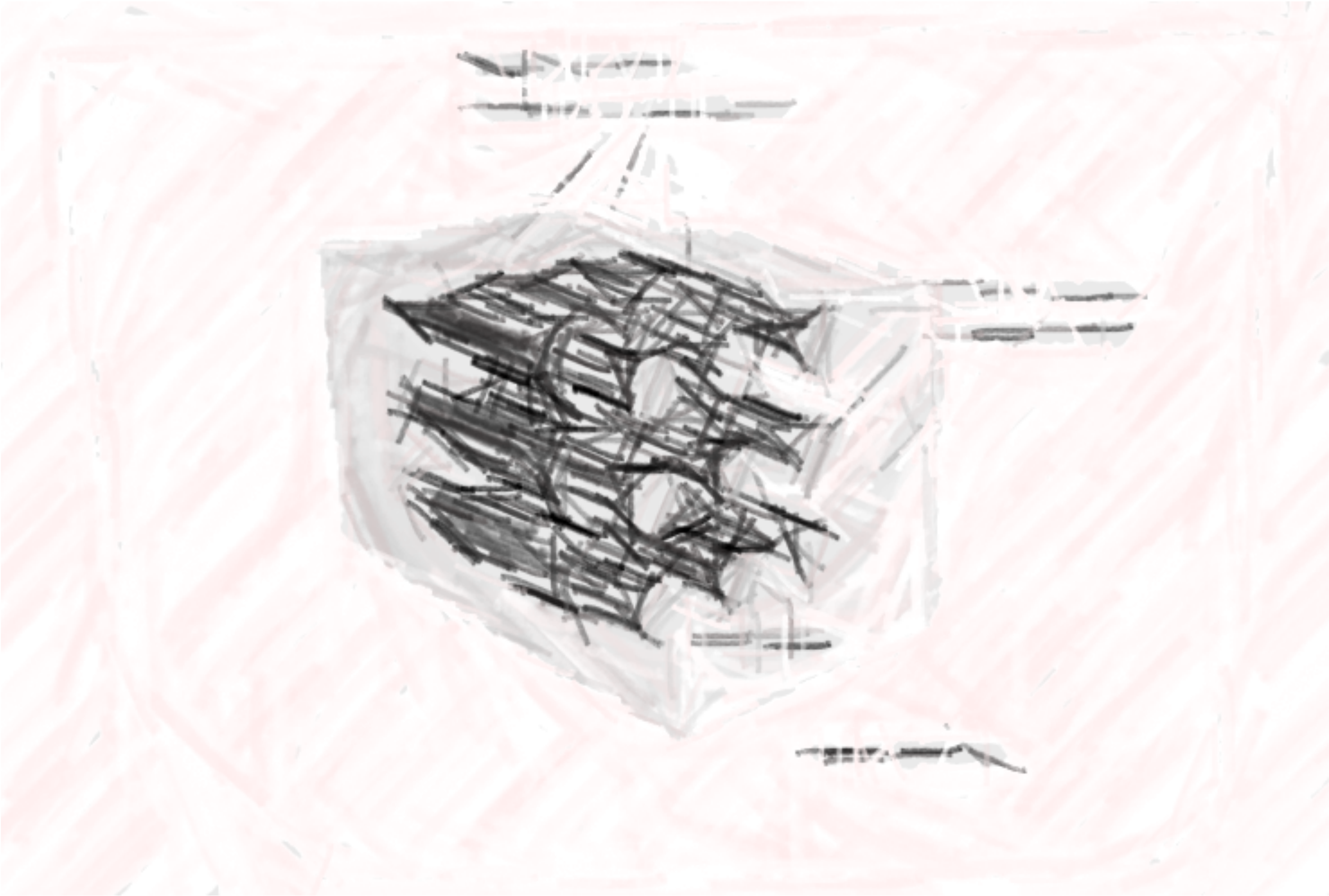


Measured rate (after filtering and efficiency corrrection) at 0.9 keV well reproduced by simulation using the ^{22}Na activity quantified independently

→ **ANALYSIS THRESHOLD @ 1 keV**

10 % data unblinded background @ RoI (random distribution)





ANAIS-112 Background Model

Eur. Phys. J. C manuscript No.
(will be inserted by the editor)

Analysis of backgrounds for the ANAIS-112 dark matter experiment

arXiv:1812.01377

J. Amaré[1,2], S. Cebrián[a,1,2], I. Coarasa[1,2], C. Cuesta[1,4], E. García[1,2], M. Martínez[1,2,3], M.A. Oliván[1,5], Y. Ortigoza[1,2], A. Ortiz de Solórzano[1,2], J. Puimedón[1,2], A. Salinas[1,2], M.L. Sarsa[1,2], J.A. Villar[b,1,2], P. Villar[1,2]

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Received: date / Accepted: date

ANAIS-112 Background Model

ANAIS112 background model

Detailed **background models** based on Geant4 Monte Carlo simulation and accurate quantification of **background sources**

- **Internal activity** directly assessed by different techniques: ^{40}K, ^{210}Pb, natural Chains
- **Activity from external components** measured with HPGe detectors at Canfranc

Detector	^{40}K (mBq/kg)	^{232}Th (mBq/kg)	^{238}U (mBq/kg)	^{210}Pb (mBq/kg)
D0	1.33±0.04	(4±1) 10^{-3}	(10±2) 10^{-3}	3.15±0.10
D1	1.21±0.04			3.15±0.10
D2	1.07±0.03	(0.7±0.1) 10^{-3}	(2.7±0.2) 10^{-3}	0.7±0.1
D3	0.70±0.03			1.8±0.1
D4	0.54±0.04			1.8±0.1
D5	1.11±0.02			0.78±0.01
D6	0.95±0.03	(1.3±0.1) 10^{-3}		0.81±0.01
D7	0.96±0.03	(1.0±0.1) 10^{-3}		0.80±0.01
D8	0.76±0.02	(0.4±0.1) 10^{-3}		0.74±0.01

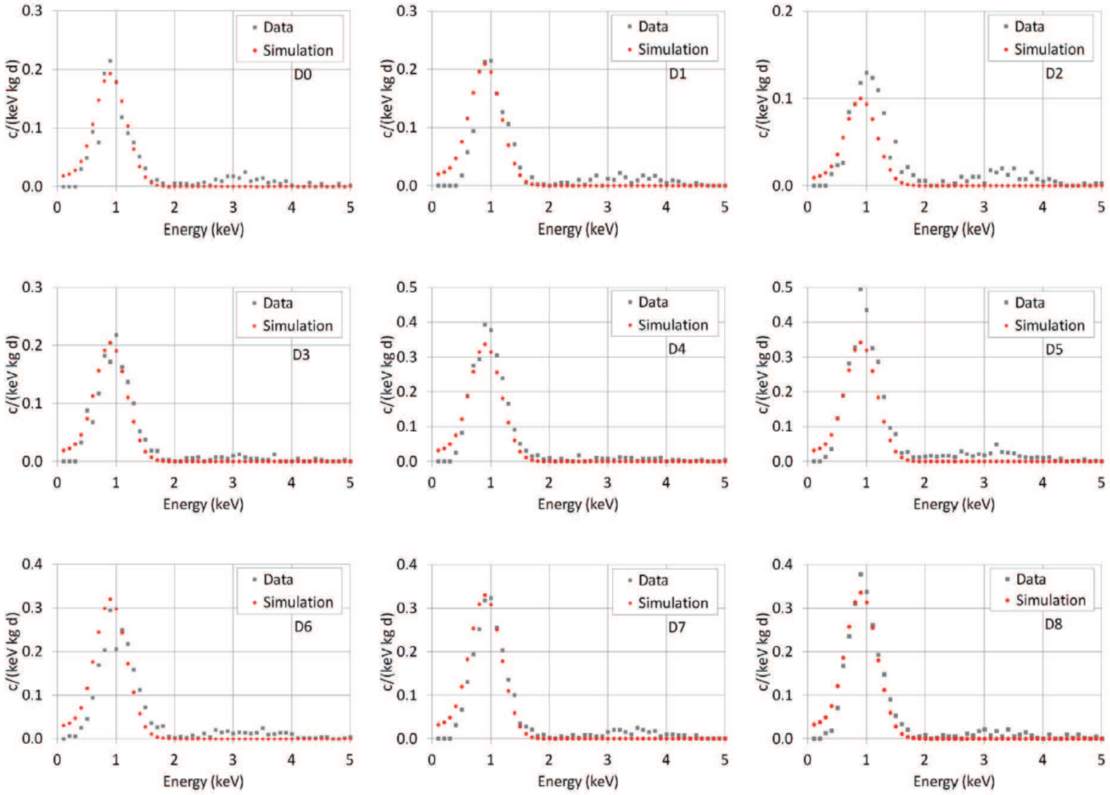
- **Cosmogenic activity** in crystals (^{22}Na, short life I and Te isotopes, Tritium, ^{109}Cd, ^{113}Sn, etc.)

^{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

ANAIS112 background model

The comparison of measured rate for coincident events attributable to ^{22}Na decaying in the bulk with the simulated rate (using as input the ^{22}Na initial activity determined according to a different signature, coming from high energy events) allows us to conclude that PMTs events rejection procedure and calculated efficiencies work fine down to 1 keV and even below

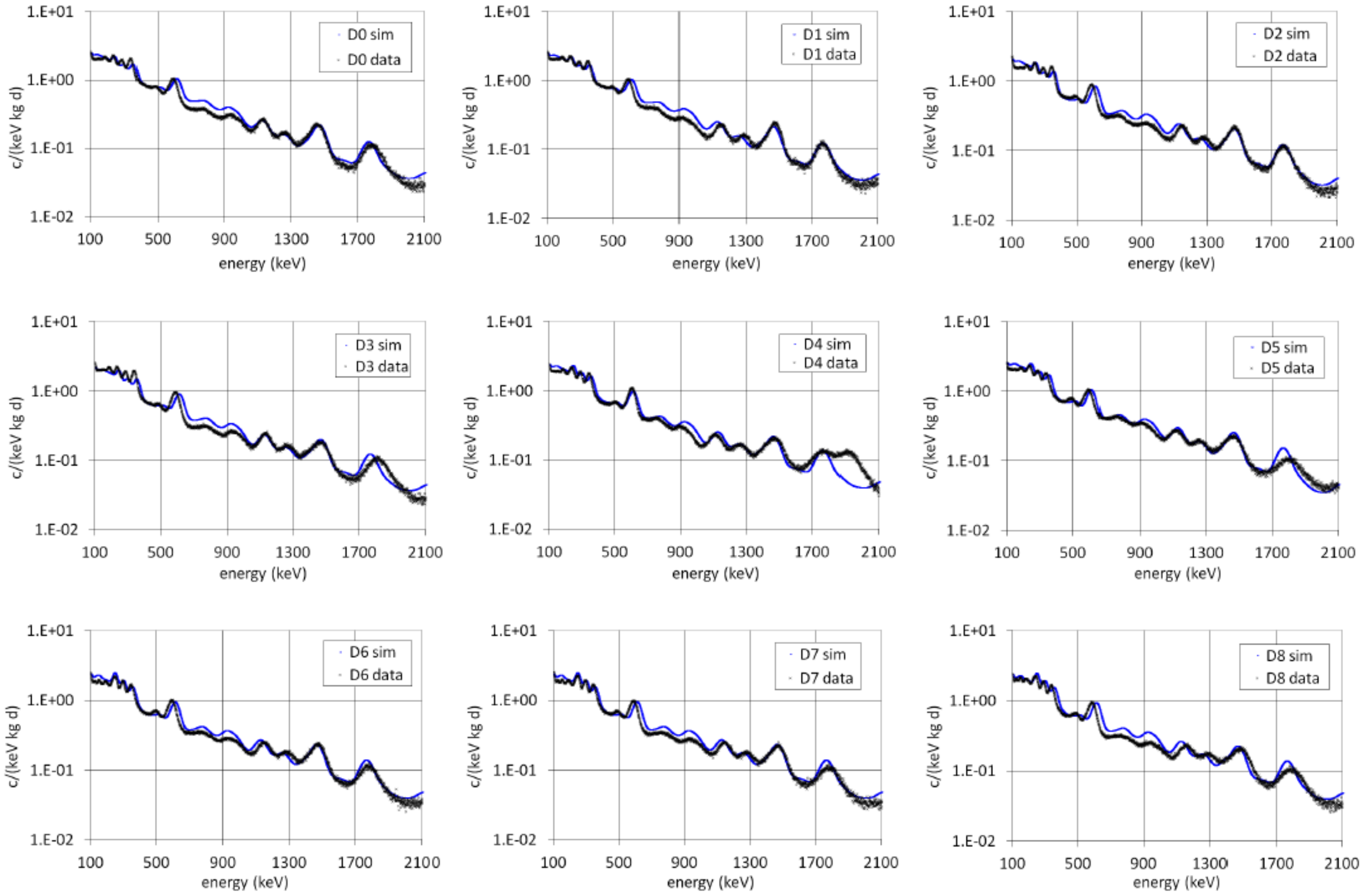
Detector	Measurement ($kg^{-1}\ d^{-1}$)	Simulation ($kg^{-1}\ d^{-1}$)	Deviation (%)
D0	0.124±0.005	0.136	10.2
D1	0.132±0.006	0.148	12.4
D2	0.095±0.005	0.071	-25.1
D3	0.141±0.006	0.145	2.5
D4	0.256±0.008	0.238	-7.0
D5	0.296±0.008	0.242	-18.2
D6	0.197±0.007	0.226	14.9
D7	0.211±0.007	0.234	11.0
D8	0.235±0.007	0.237	1.1
ANAIS-112	0.187±0.007	0.186	-0.5



ANAIS112 background model

Overall description of measured data at all energy ranges above 2 keV in coincidence and anticoincidence is good

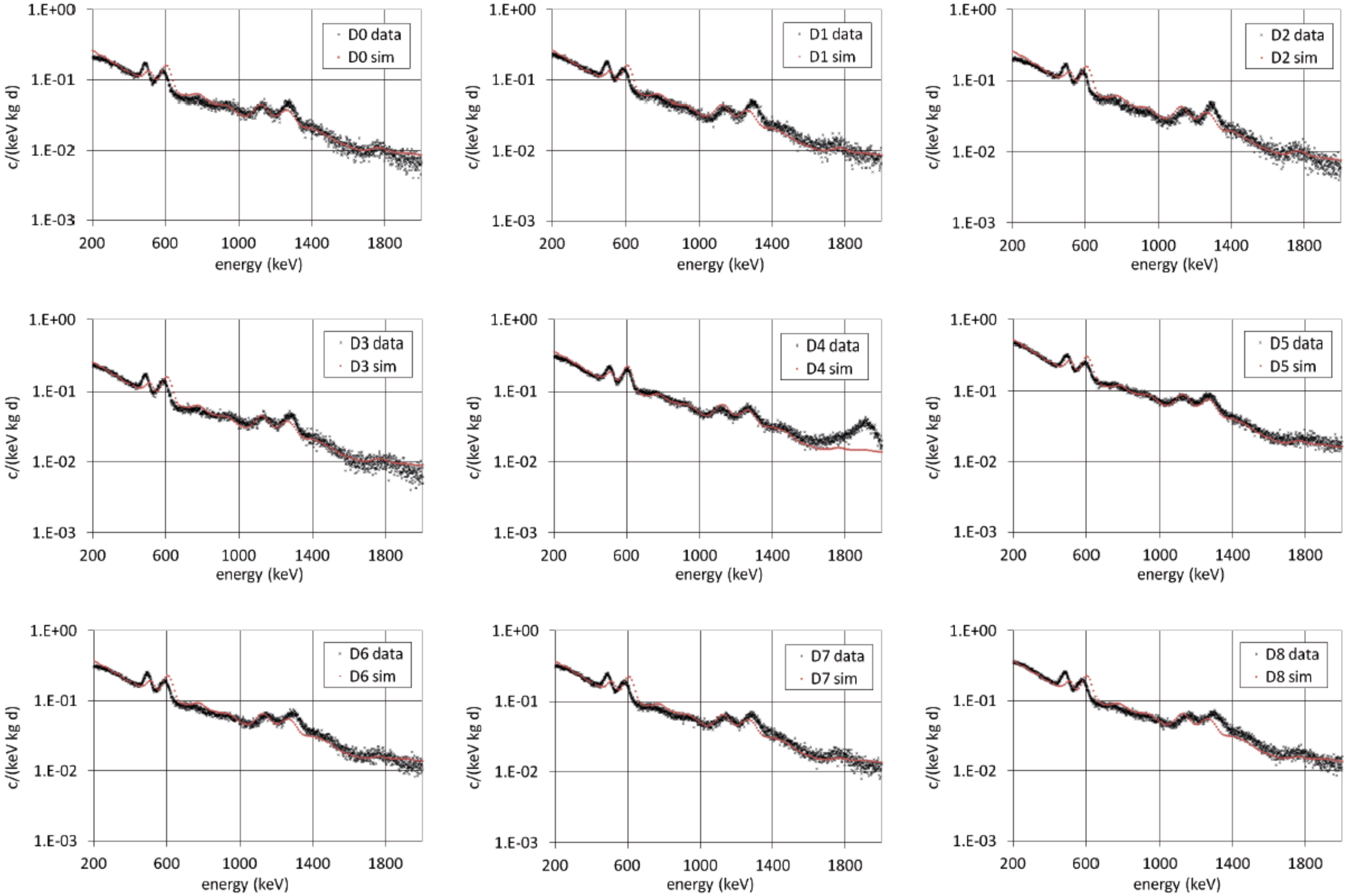
HE total spectra



ANAIS112 background model

Overall description of measured data at all energy ranges above 2 keV in coincidence and anticoincidence is good

HE concidence spectra



ANAIS112 background model

Overall description of measured data at all energy ranges above 2 keV in coincidence and anticoincidence is good

HE total and coincidence rates

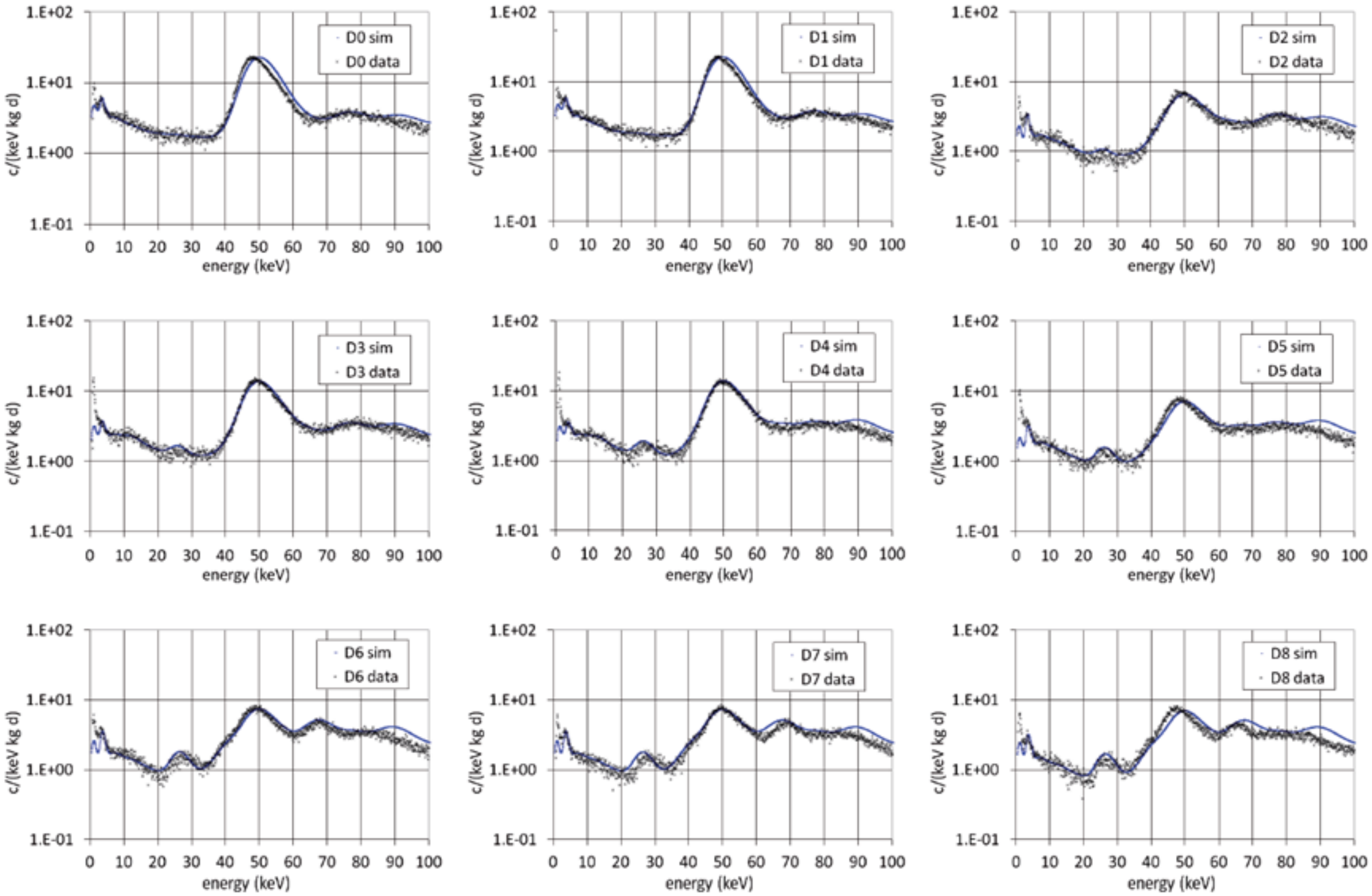
	total rate, 0.1-2 MeV			coincidences, 0.2-2 MeV		
Detector	Measurement (kg^{-1} d^{-1})	Simulation (kg^{-1} d^{-1})	Deviation (%)	Measurement (kg^{-1} d^{-1})	Simulation (kg^{-1} d^{-1})	Deviation (%)
D0	992.6±0.5	1048.0	5.6	102.3±0.2	108.9	6.5
D1	1000.4±0.5	1038.6	3.8	107.0±0.2	108.9	1.7
D2	798.8±0.4	842.8	5.5	99.1±0.2	106.9	7.8
D3	920.2±0.5	910.9	-1.0	107.3±0.2	109.1	1.6
D4	956.9±0.5	1012.5	5.8	156.7±0.2	158.4	1.1
D5	1010.2±0.5	1082.8	7.2	215.9±0.2	216.9	0.5
D6	929.1±0.5	989.7	6.5	154.5±0.2	158.3	2.4
D7	909.7±0.5	990.8	8.9	152.2±0.2	159.0	4.5
D8	904.8±0.5	976.8	8.0	159.3±0.2	158.9	-0.3
ANAIS-112	935.8±0.1	988.1	5.6	139.4±0.1	142.8	2.9

ANAIS112 background model

Overall description of measured data at all energy ranges above 2 keV in coincidence and anticoincidence is good

LE anticoincidence spectra

For the 10% unblinded data

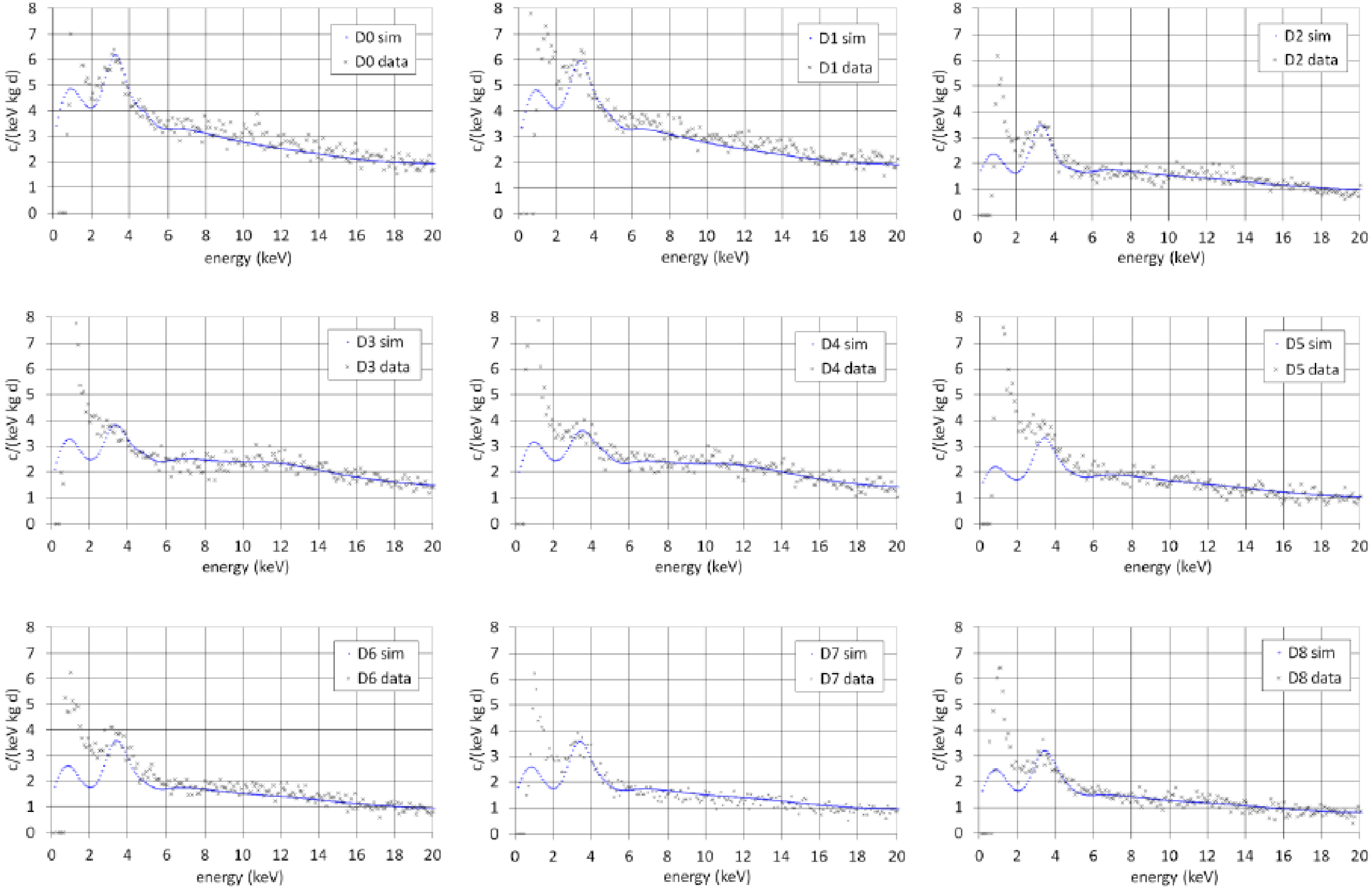


ANAIS112 background model

Overall description of measured data at all energy ranges above 2 keV in coincidence and anticoincidence is good

LE anticoincidence spectra

For the 10% unblinded data

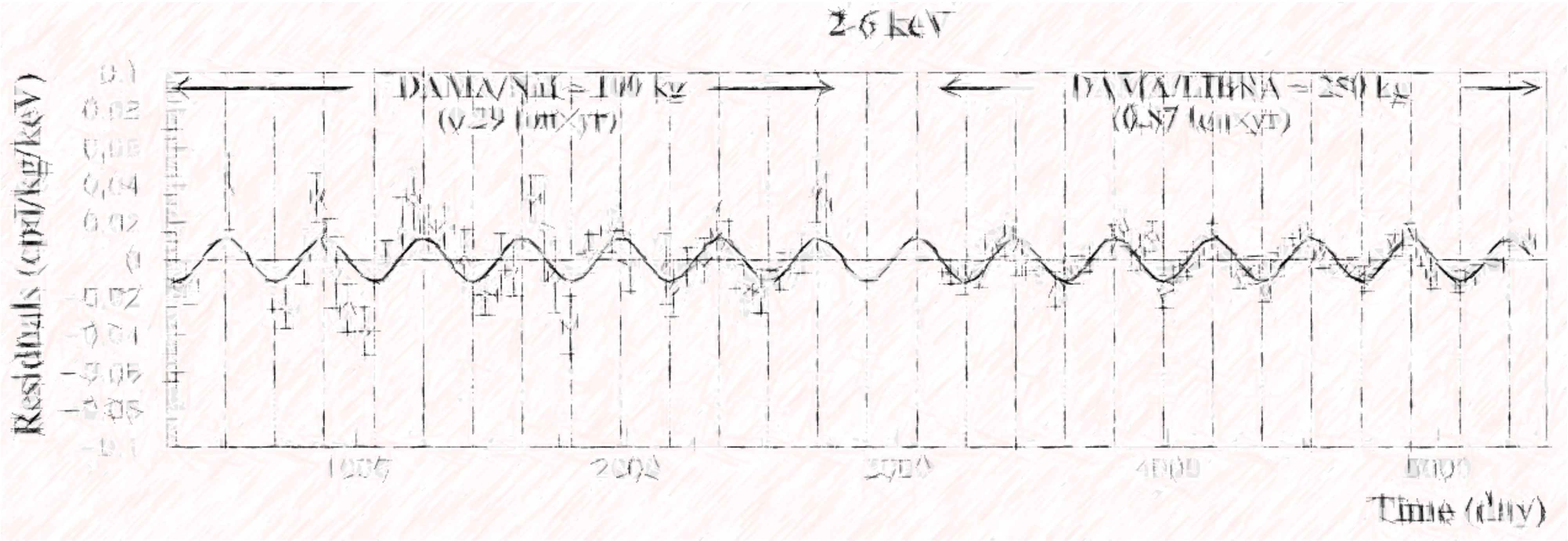


ANAIS112 background model

Overall description of measured data at all energy ranges above 2 keV in coincidence and anticoincidence is good

	1 to 2 keV			2 to 6 keV		
Detector	Measurement (keV^{-1} kg^{-1} d^{-1})	Simulation (keV^{-1} kg^{-1} d^{-1})	Deviation (%)	Measurement (keV^{-1} kg^{-1} d^{-1})	Simulation (keV^{-1} kg^{-1} d^{-1})	Deviation (%)
D0	6.62±0.12	4.37	-34	4.58±0.05	4.53	-1.0
D1	6.55±0.12	4.36	-33	4.66±0.05	4.46	-4.4
D2	3.62±0.09	1.84	-49	2.44±0.04	2.27	-7.0
D3	6.40±0.12	2.77	-57	3.16±0.04	2.97	-6.2
D4	5.54±0.11	2.73	-51	3.12±0.04	2.88	-7.6
D5	5.84±0.12	1.84	-68	2.96±0.04	2.34	-20.9
D6	4.16±0.10	2.04	-51	2.90±0.04	2.42	-16.3
D7	3.78±0.09	2.03	-46	2.61±0.04	2.42	-7.4
D8	3.74±0.09	1.94	-48	2.29±0.04	2.18	-5.1
ANAIS-112	5.14±0.03	2.66	-48	3.19±0.01	2.94	-7.9

Below 2 keV the background model is not able to explain the rate increase in about a 50%. The unexplained events below 2 keV could be due to non-bulk scintillation events leaking in the RoI or some unknown background source not considered in our model. Further work in these directions is ongoing.



ANAIS-112 First Results on Annual modulation

First results on dark matter annual modulation from ANAIS-112 experiment

J. Amaré,[1,2] S. Cebrián,[1,2] I. Coarasa,[1,2] C. Cuesta,[1,3] E. García,[1,2] M. Martínez,[1,2,4] M.A. Oliván,[1,5] Y. Ortigoza,[1,2] A. Ortiz de Solórzano,[1,2] J. Puimedón,[1,2] A. Salinas,[1,2] M.L. Sarsa*,[1,2] P. Villar,[1,2] and J.A. Villar†[1,2]

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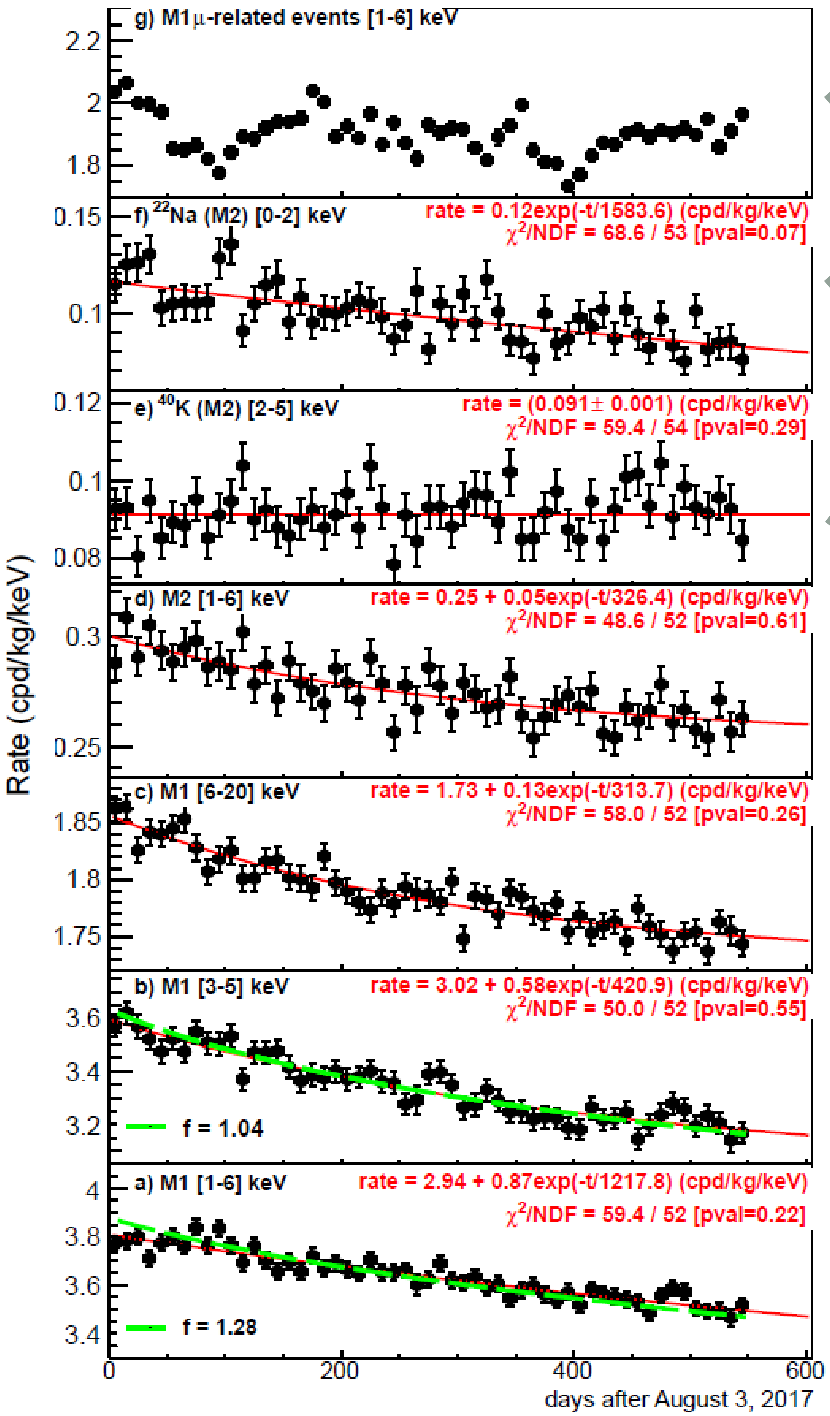
arXiv:1903.03973

ANAIS is a direct detection dark matter experiment aiming at the testing of the DAMA/LIBRA annual modulation result, which standing for about two decades has neither been confirmed nor ruled out by any other experiment in a model independent way. ANAIS-112, consisting of 112.5 kg of sodium iodide crystals, is taking data at the Canfranc Underground Laboratory, Spain, since August 2017. This letter presents the annual modulation analysis of 1.5 years of data, amounting to 157.55 kg×y. We focus on the model independent analysis searching for modulation and the validation of our sensitivity prospects. ANAIS-112 data are consistent with the null hypothesis (p-values of 0.65 and 0.16 for [2-6] and [1-6] keV energy regions, respectively). The best fits for the modulation hypothesis are consistent with the absence of modulation ($S_m = -0.0044 \pm 0.0058$ cpd/kg/keV and -0.0015 ± 0.0063 cpd/kg/keV, respectively). They are in agreement with our estimated sensitivity for the accumulated exposure, supporting our projected goal of reaching a 3σ sensitivity to the DAMA/LIBRA result in 5 years of data taking.

ANAIS-112 First Results on Annual modulation

ANAIS-112 annual modulation



Time evolution of the rate of different event populations in 1.5 years of ANAIS-112 data

-single hit muon related events in 1-6 keV region

-^{22}Na events (coincidence selected)

-^{40}K events (coincidence selected)

-Multiple hit (M=2) events in 1-6 keV region

-single hit events in 6-20 keV region

-single hit events in 3-5 keV region

Background estimated evolution   Exponential + constant fit

-single hit events in 1-6 keV region

Background estimated evolution   Exponential + constant fit

ANAIS-112 annual modulation

We fit the ANAIS-112 time-binned data in 1-6 / 2-6 keV energy regions to:

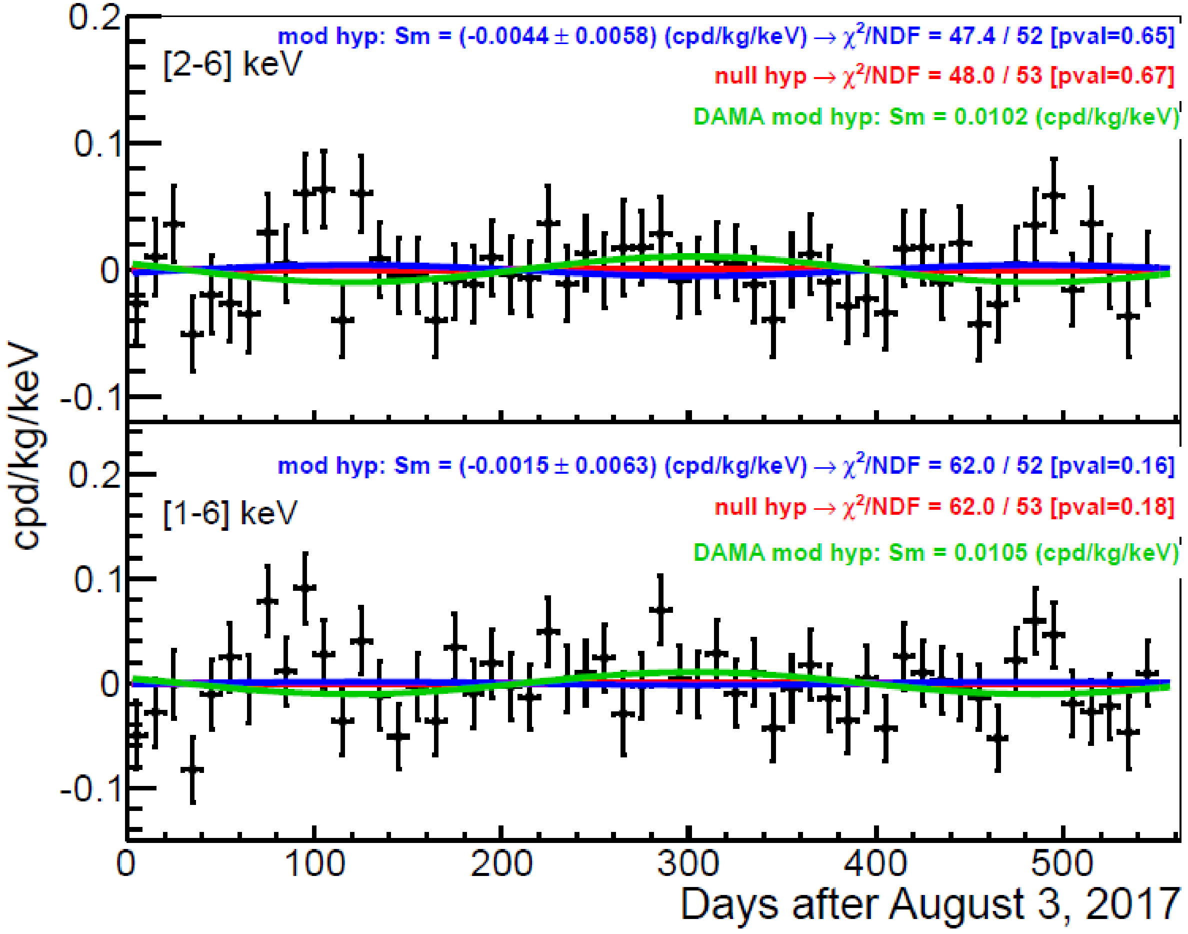
$$R(t) = R_0 + R_1 \cdot exp(-t/\tau) + S_m \cdot cos(\omega \cdot (t + \phi)),$$

τ is fixed to the value obtained from our background model

ω is fixed (corresponding to 1 year period)

ϕ is fixed to have the maximum of the cosine function in June, 2nd

S_m is fixed to 0 to analyze the null hypothesis and left unconstrained for the modulation hypothesis



DAMA/LIBRA result with 1 –free parameter is shown for comparison

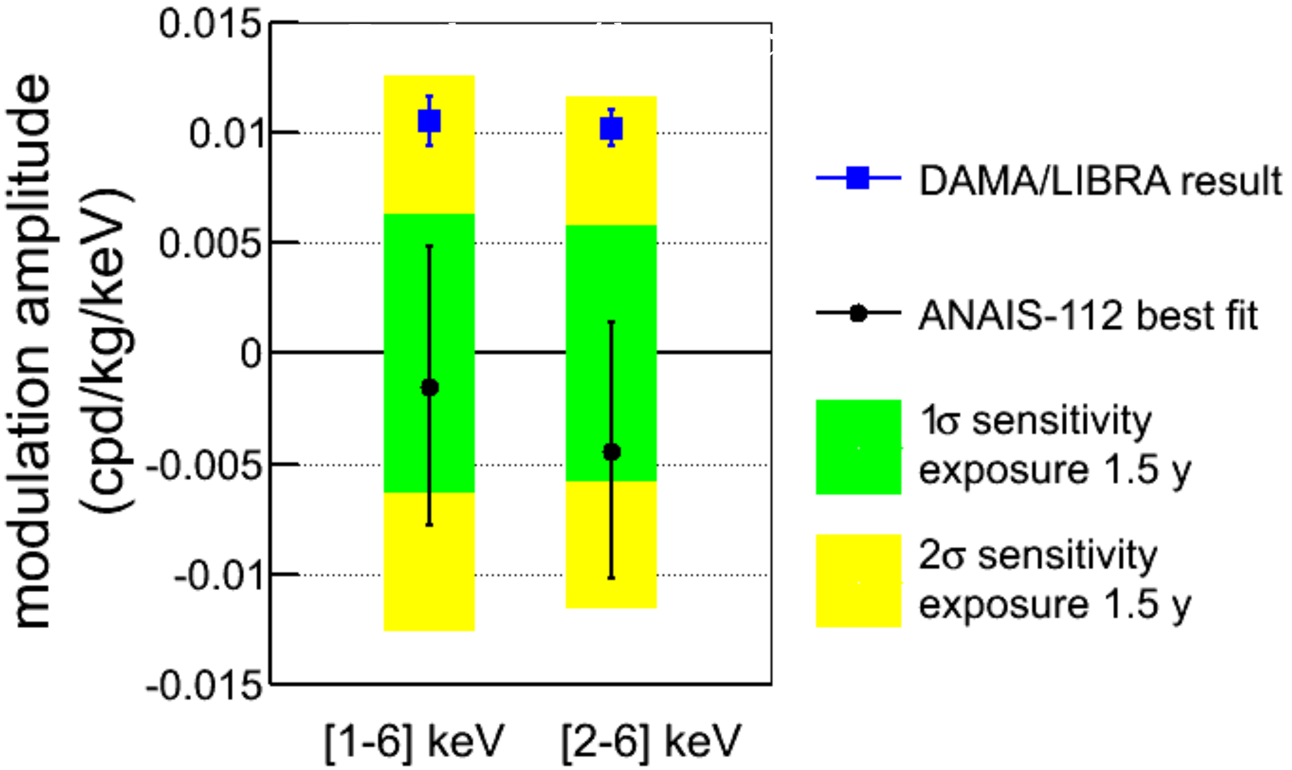
Null hypothesis is well supported by the χ^2 test (p-values of 0.67 and 0.18 for 2-6 and 1-6 keV energy regions)

Best fits for the modulation hypothesis have p-values slightly lower than for the null hypothesis

$$S_m = -0.0044 \pm 0.0058\ cpd/kg/keV$$ (2-6 keV energy region)

$$S_m = -0.0015 \pm 0.0063\ cpd/kg/keV$$ (1-6 keV energy region)

Best fits are incompatible at 2.5σ (2-6 keV energy region) and 1.9σ (1-6 keV energy region) with DAMA/LIBRA results

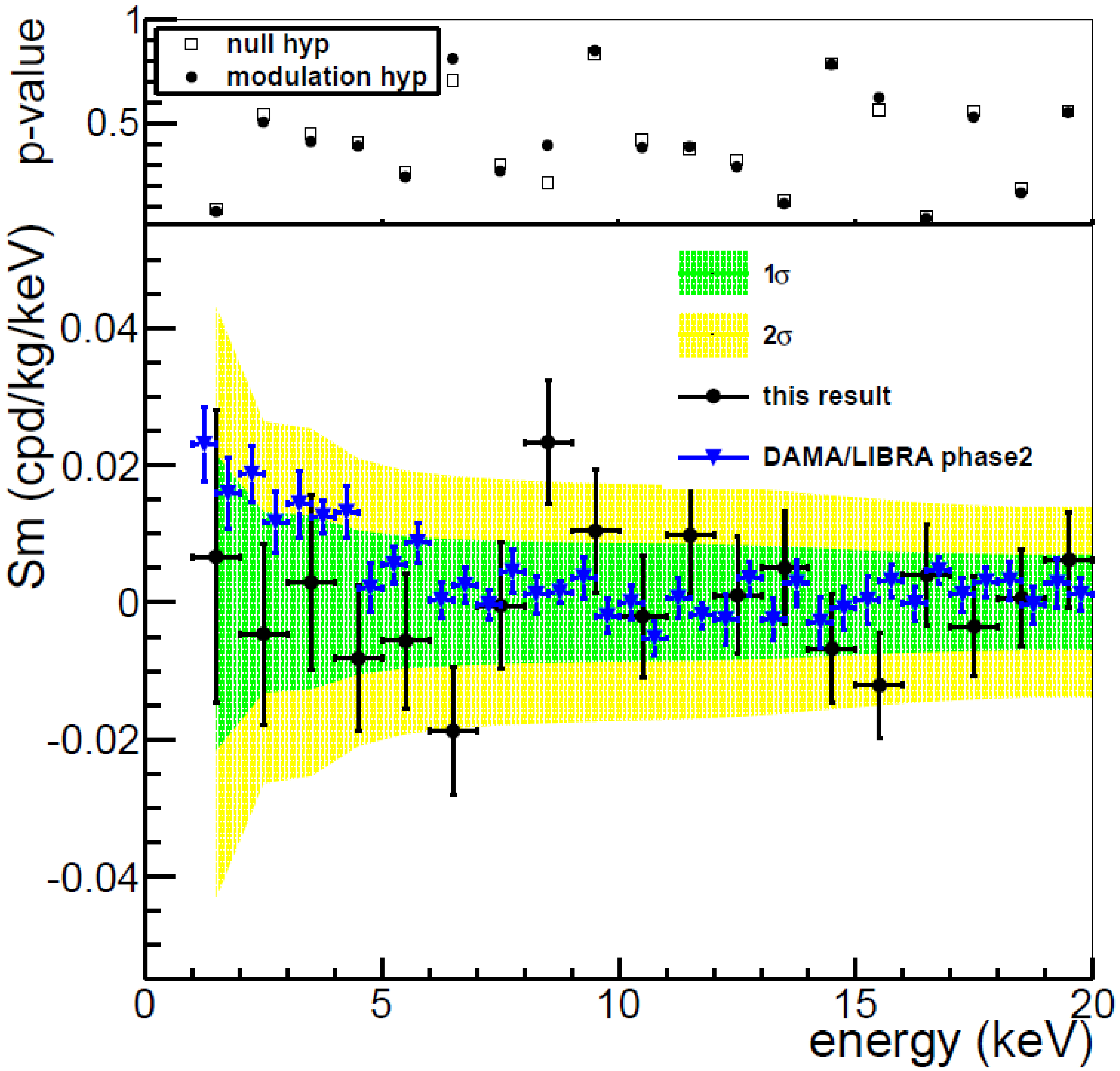


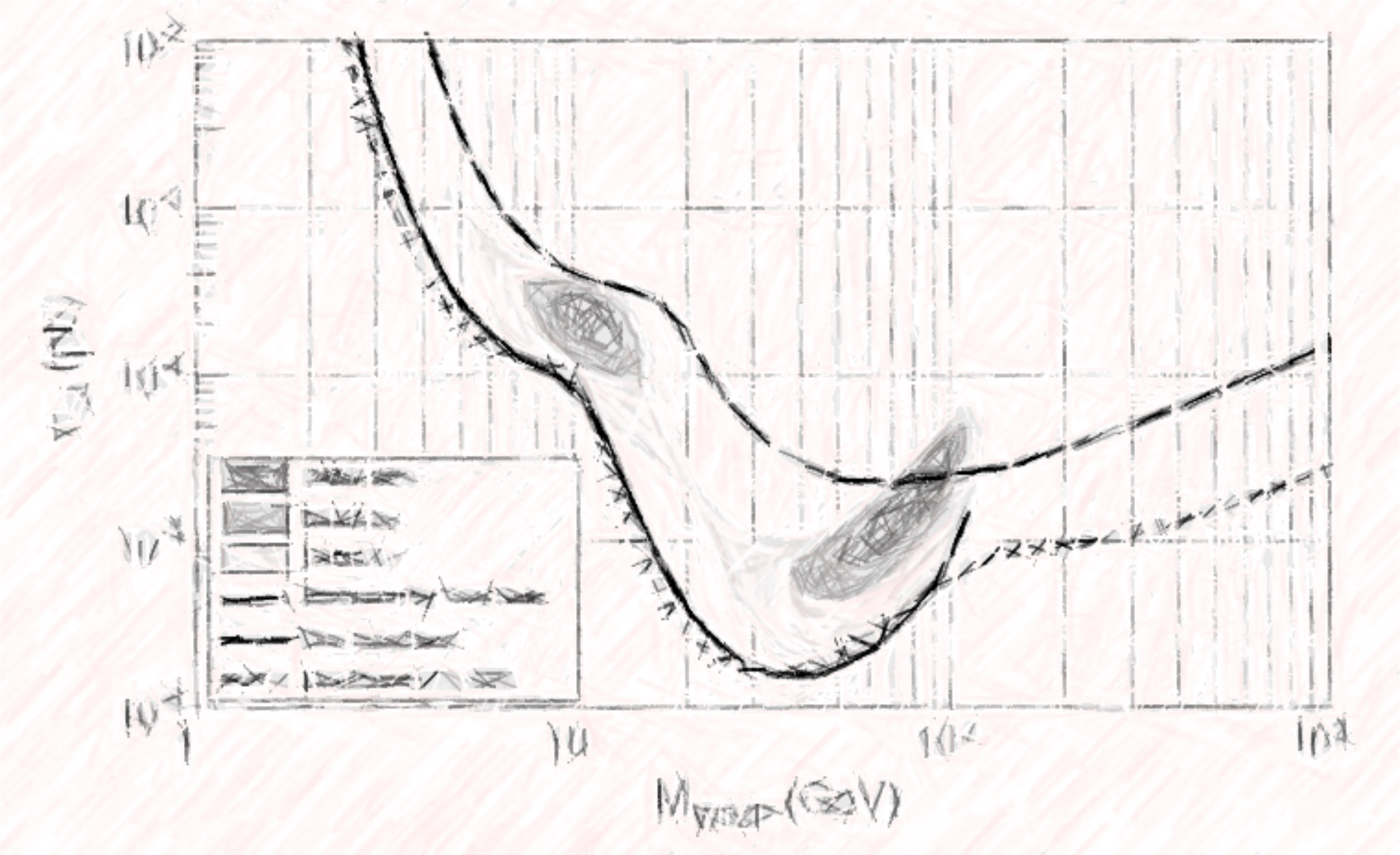
ANAIS-112 annual modulation

Modulation amplitudes in 1keV energy bins have been calculated from 1 to 20 keV

All the amplitudes in the RoI are compatible with 0 and in general p-values are larger for the null hyp. than for the modulation hyp.

Green and yellow bands show our estimated sensitivity at 1σ and 2σ for the present ANAIS-112 exposure





ANAIS-112 Sensitivity

Eur. Phys. J. C (2019) 79:233
https://doi.org/10.1140/epjc/s10052-019-6733-4

THE EUROPEAN PHYSICAL JOURNAL C

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Regular Article - Experimental Physics

ANAIS-112 sensitivity in the search for dark matter annual modulation

arXiv:1812.02000

I. Coarasa[1,2,a], **J. Amaré**[1,2], **S. Cebrián**[1,2], **C. Cuesta**[1,2,4], **E. García**[1,2], **M. Martínez**[1,2,3], **M. A. Oliván**[1,5], **Y. Ortigoza**[1,2], **A. Ortiz de Solórzano**[1,2], **J. Puimedón**[1,2], **A. Salinas**[1,2], **M. L. Sarsa**[1,2], **P. Villar**[1,2], **J. A. Villar**[1,2]

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Received: 5 December 2018 / Accepted: 28 February 2019

ANAIS-112 Sensitivity

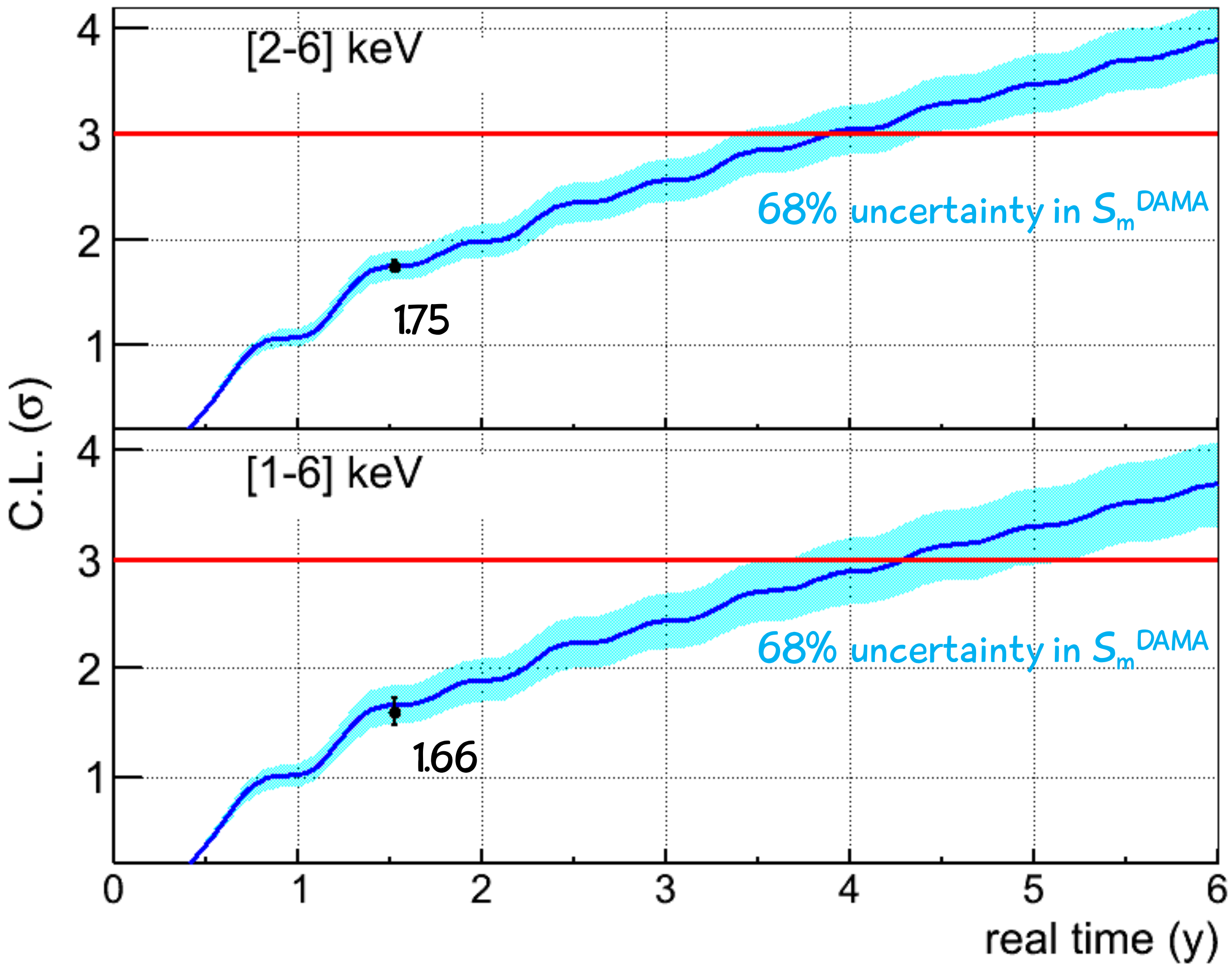
ANAIS-112 sensitivity

Statistical significance of our result is determined by the standard deviation of the modulation amplitude distribution, σ(Sm)

We quote our sensitivity to DAMA/LIBRA result as the ratio S_m^{DAMA} / σ(Sm)

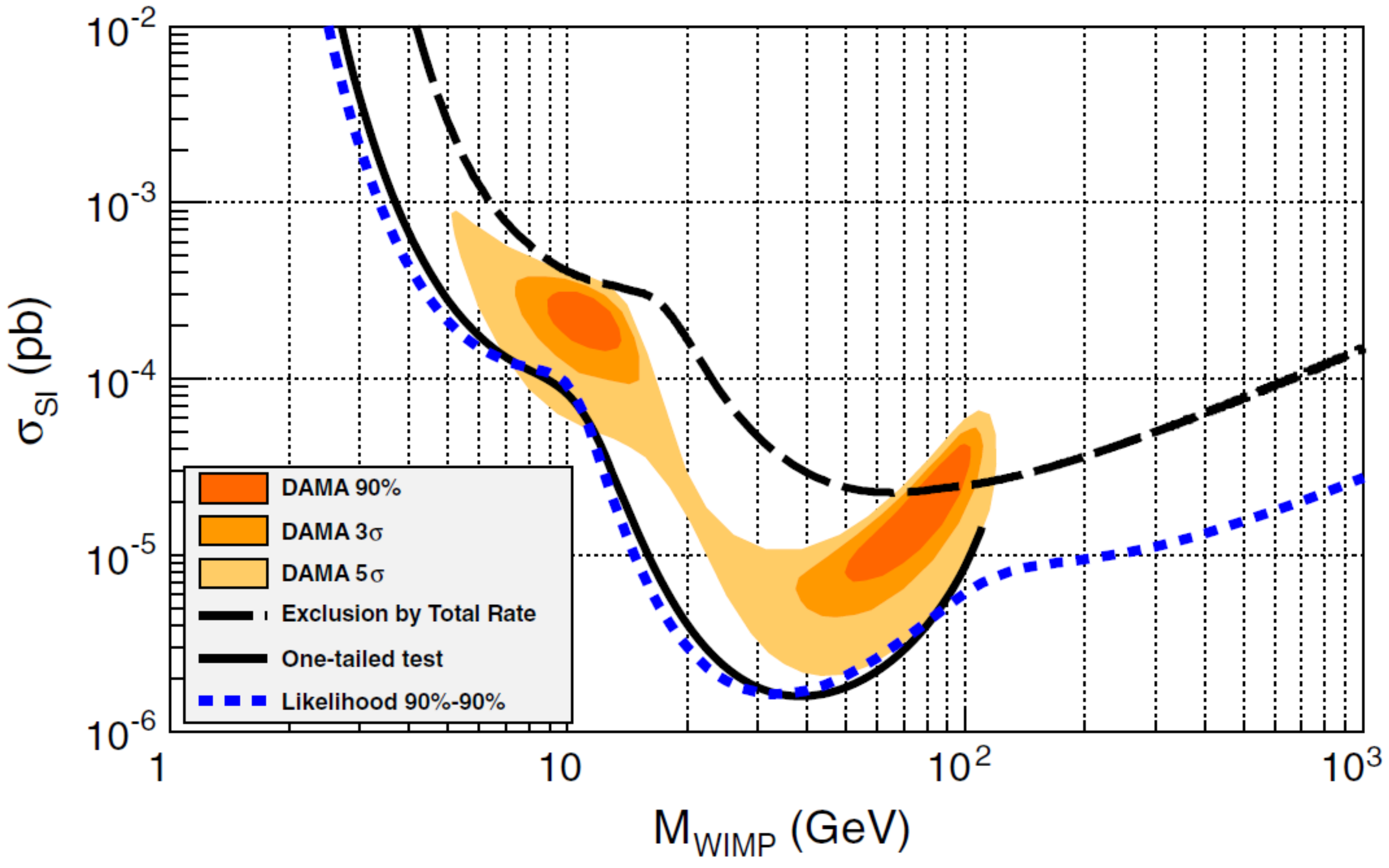
$$\sigma(S_m) = \sqrt{\frac{2}{\Delta E\ m\ T_m}} \left(\sum_{k=1}^{9} \frac{1}{\langle B/\epsilon \rangle^k} \right)^{-1/2}$$

We project our sensitivity with our updated background, efficiency estimates and its errors and live time distribution



3σ sensitivity model independent is at reach in 4-5 years (total) of data taking

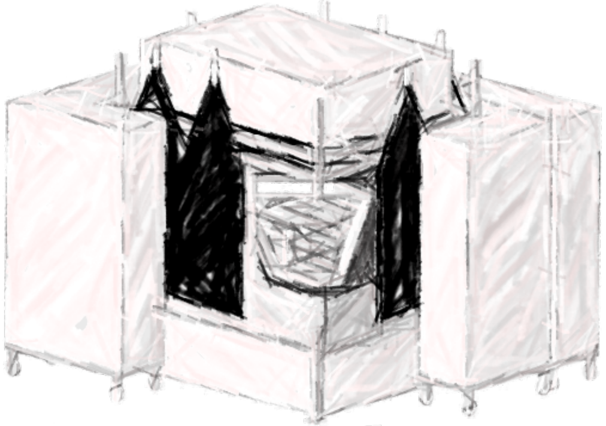
Model dependent exclusion at reach in five years using 1-6 keV data

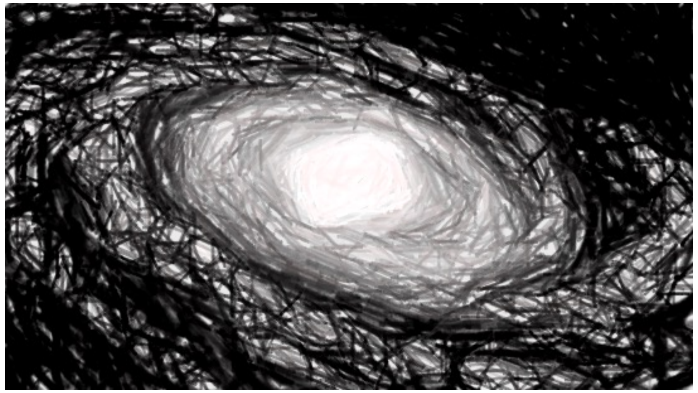


arXiv:1812.02000

ANAIS-112 sensitivity

Summary





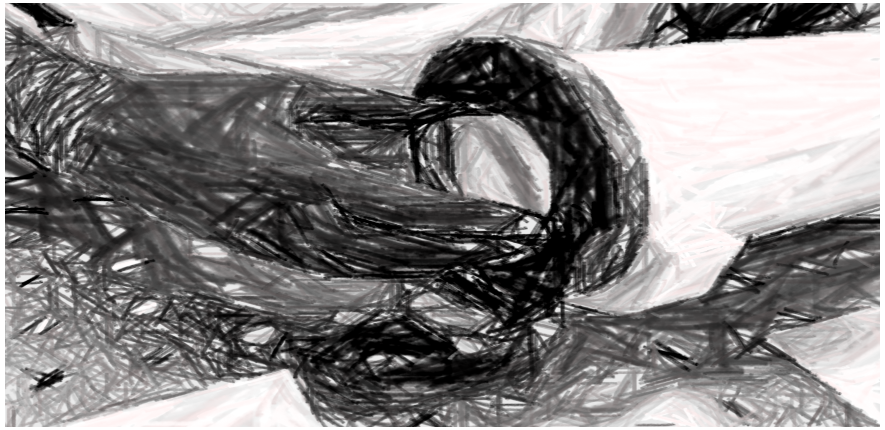
✓ **ANAIS-112 is** taking data using **112.5 kg of sodium iodide** and is running smoothly

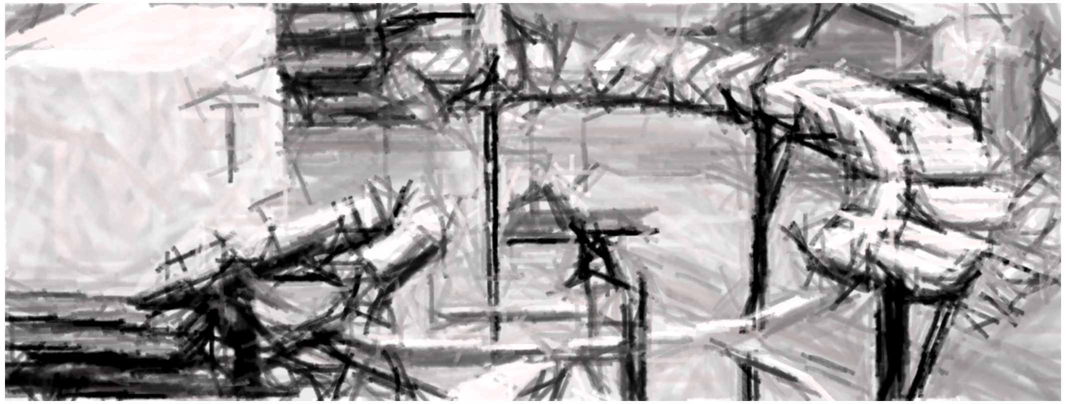
- **1 year and a half of data-taking completed** by last February blind - analysed **for model indpendent annual modulation** and sent for publication
  - We confirm our sensitivity projections to DAMA/LIBRA result -> 3σ at reach in about three years from now
  - Null hypothesis is well supported by the χ^2 test
  - Best fits are incompatible at 2.5σ (2-6 keV energy region) and 1.9σ (1-6 keV energy region) with DAMA/LIBRA results
- Careful **low energy calibration** (from external gamma sources and bulk emissions)
- Excellent **light collection** of **~15 phe/keV** and **triggering** below **1 keV$_{ee}$** in all modules
- **1 keV$_{ee}$ analysis threshold**
- Good **background understanding but in 1-2 keV energy region**, dominated by crystal activity (^{210}Pb, ^{40}K, ^{22}Na, ^{3}H)

Outlook

✓ **Next future…**

- Data taking will continue in the same conditions, together with a **blank module** to monitor non-NaI(Tl)-scintillation events, BUT… ANAIS is only funded until December'19. ASKING FOR FUNDING in the next national call.
- Excess of events in 1-2 keV energy region has to be understood
- Measurement of Scintillation **Quenching Factor** for nuclear recoils already performed at TUNL laboratories (Duke University, US) in collaboration with Yale / Duke Univ., investigating possible dependence on crystal quality, WORKING ON DATA ANALYSIS
- Combining data between **COSINE-100 and ANAIS-112** would allow to reach 3σ sensitivity to DAMA/LIBRA result sooner
- Plan to make ANAIS **data public** after use to allow independent analysis





Thank you for your attention

ANAIS

MultiDark
Multimessenger Approach
for Dark Matter Detection

LSC
Laboratorio Subterráneo de Canfranc

Universidad Zaragoza