SEARCH FOR ANNUAL MODULATION WITH ANAIS-112 : TWO YEARS RESULTS

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on behalf of the ANAIS team

4th IBS-Multidark-IPPP Workshop, Daejeon (South Korea),
October 7-11 2019

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Universidad Zaragoza

LSC Laboratorio Subterráneo de Canfranc

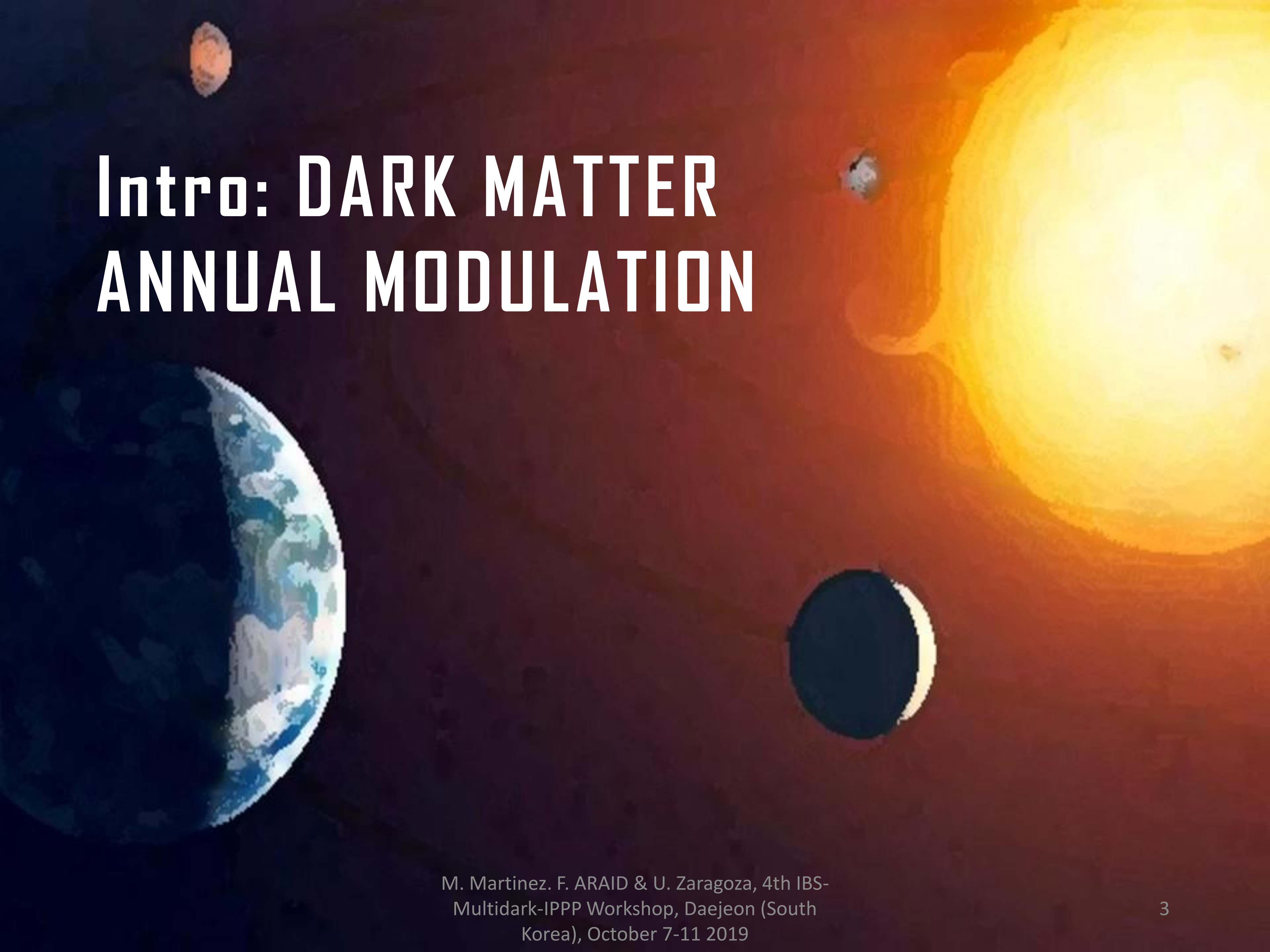
araid Fundación Agencia Aragonesa para la Investigación y el Desarrollo

MultiDark Multimessenger Approach for Dark Matter Detection

OUTLINE

- Intro
- ANAIS-112
    - Detector performance
    - Event selection & efficiency
    - Background model
- Results on annual modulation
- ANAIS sensitivity
- Summary

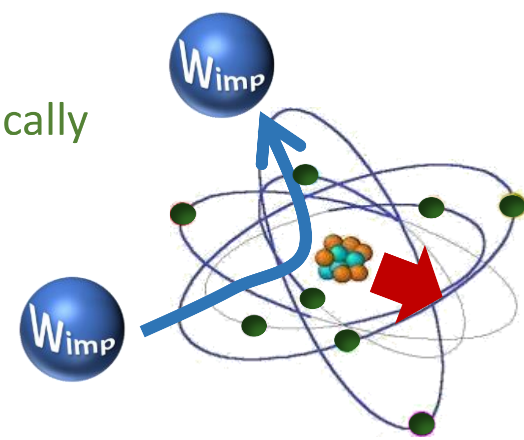
Intro: DARK MATTER ANNUAL MODULATION



Dark matter direct detection

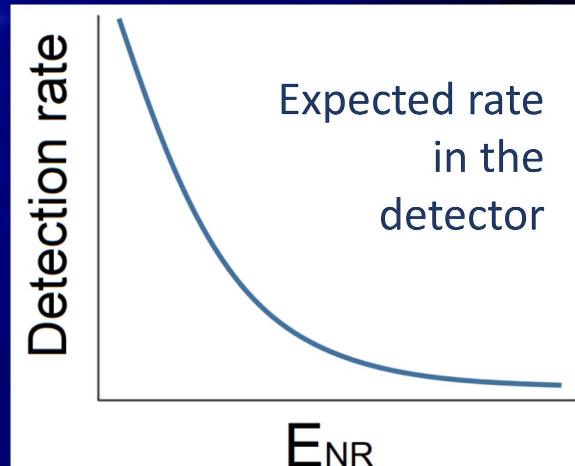
The Earth moves in the DM halo with $v \sim 220\ km/s$

WIMPs can scatter elastically off nuclei

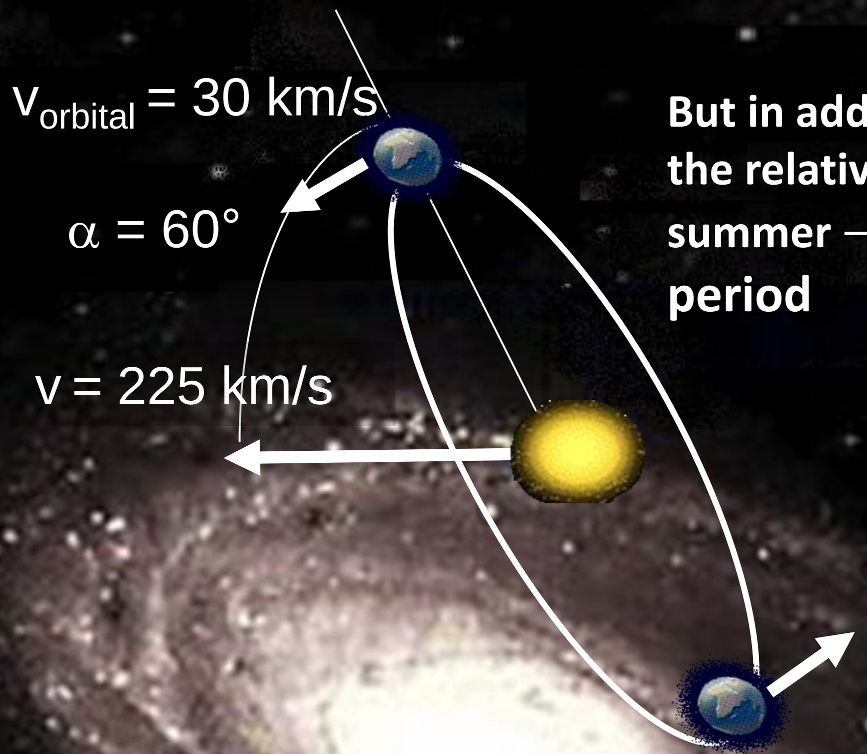


The nuclear recoil produces a signal in the detector

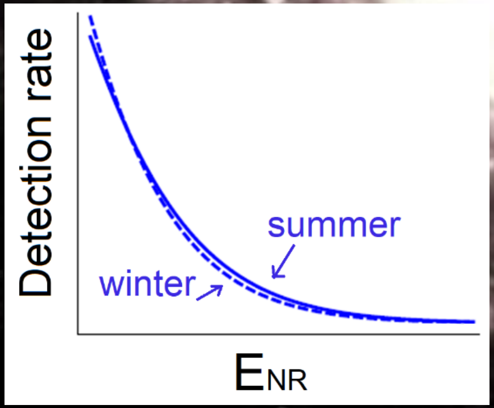
$$E_{NR} = \frac{q^2}{2m_N} \leq 30\ keV$$

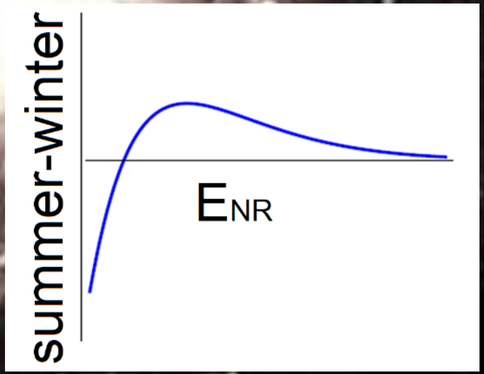


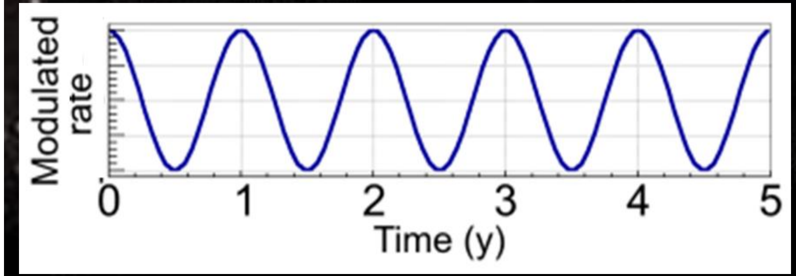
Annual modulation: a distinctive DM signal



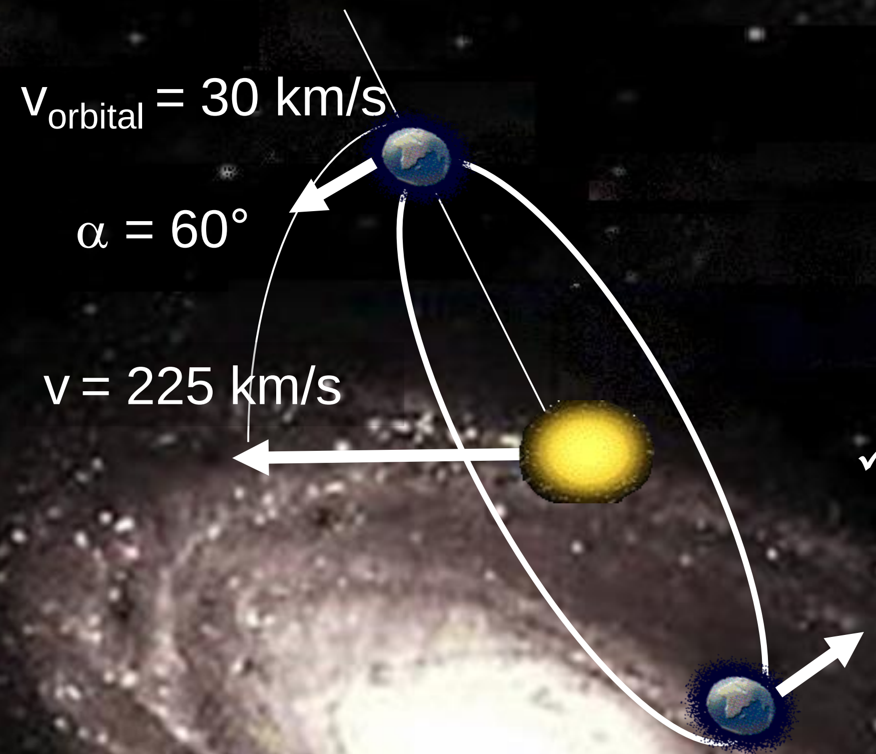
But in addition Earth moves around the Sun, so the relative velocity Earth-halo changes from winter to summer → detection rate modulated with 1 year period





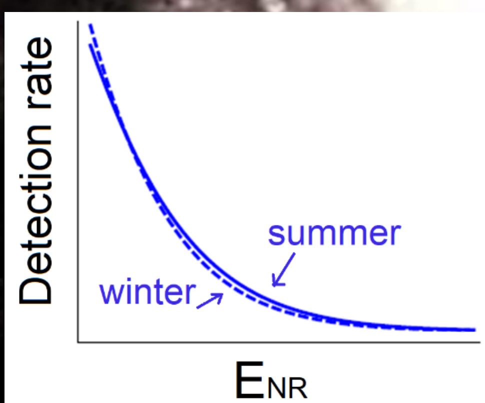


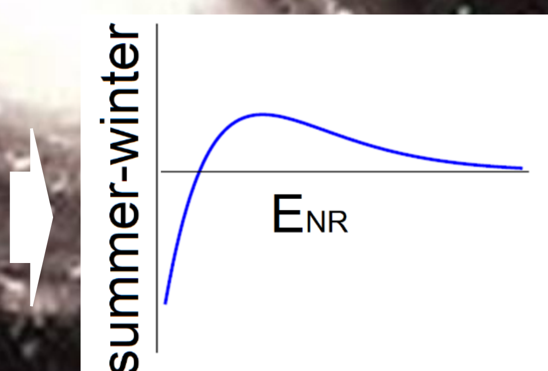
Annual modulation: a distinctive DM signal

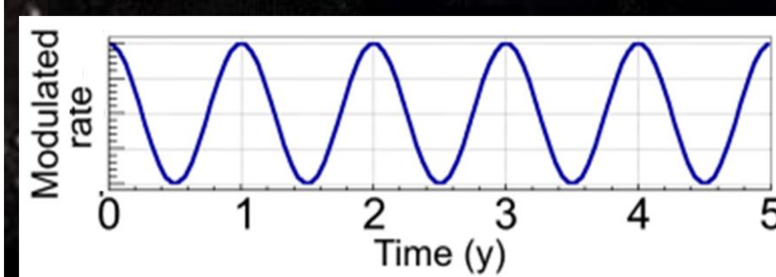


- ✓ Cosine behaviour
- ✓ 1 year period
- ✓ Maximum around June 2nd
- ✓ Weak effect (1-10%)
- ✓ Only noticeable at low energy
- ✓ Should have a phase reversal at low E

→ Very hard to mimic by bkg!!





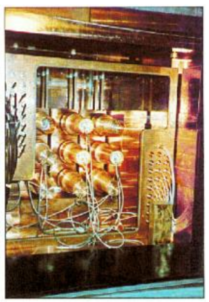


DAMA/NaI & DAMA/LIBRA

DAMA experiment

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

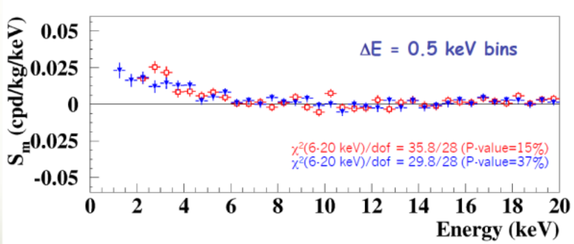
- 25 × 9.7 kg NaI(Tl) (5x5 matrix)

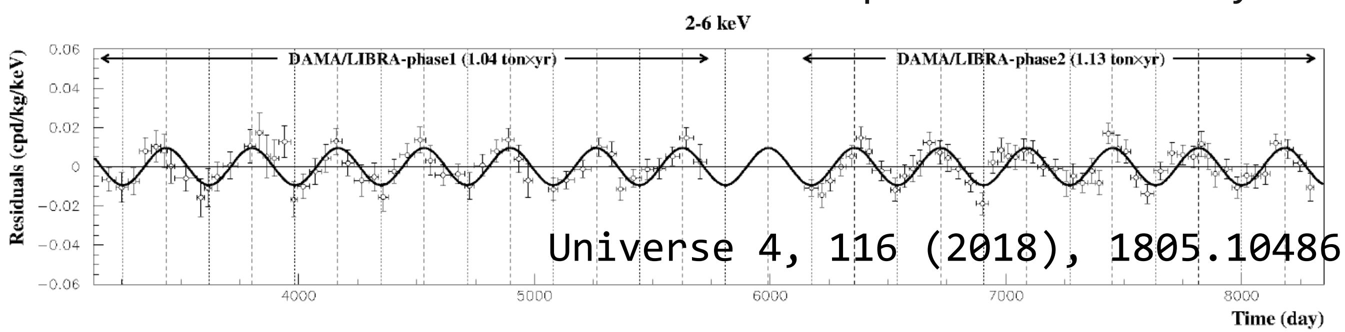
Phase 1 (2003-2010)

- 7 annual cycles
- Exposure : 1.33 ton × y

Phase 2 (2011- …)

- Higher QE PMTs
- 6 annual cycles
- Exposure : 1.13 ton × y

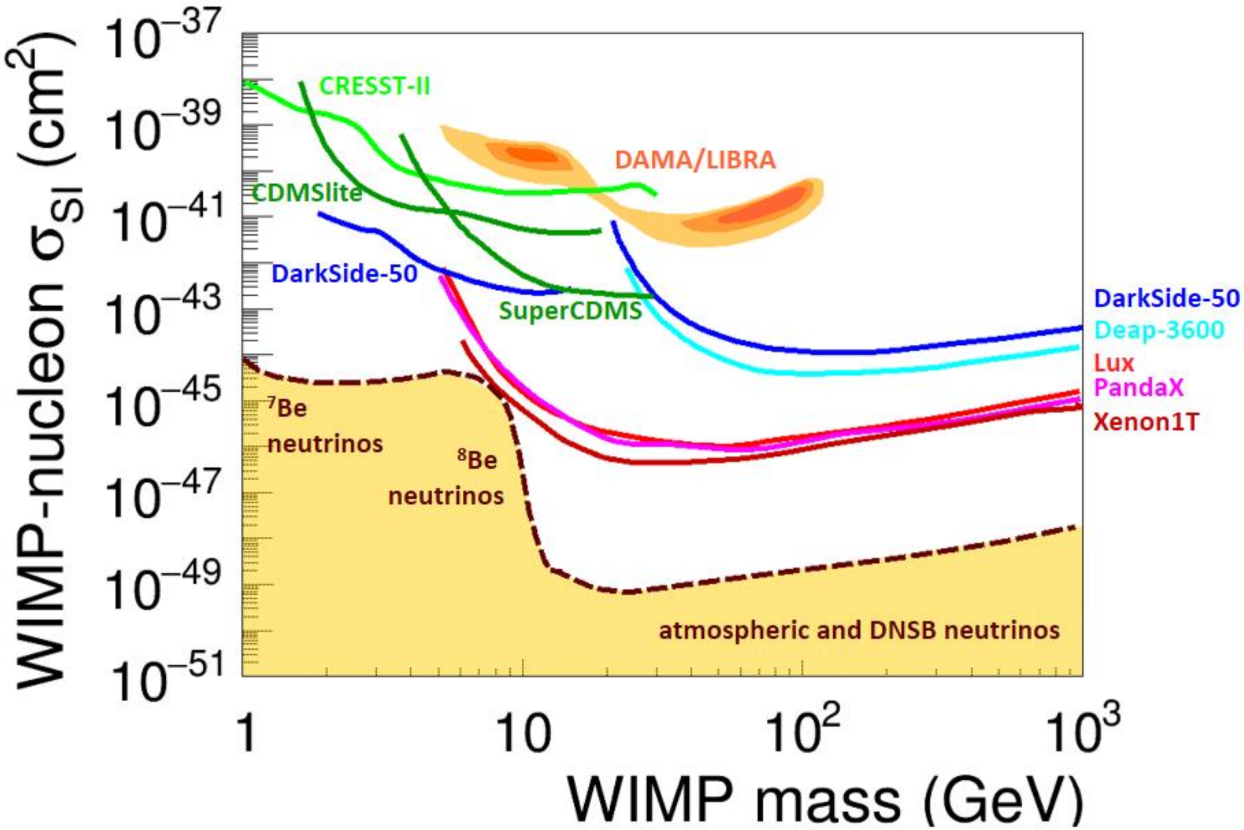




Universe 4, 116 (2018), 1805.10486

The data of DAMA/LIBRA phase1+phase2 favor the presence of a modulation with proper features at **12.9σ CL** (2.46 ton × yr)

Interpreting DAMA/LIBRA ph1 as WIMPs



Strong tension even assuming more general halo/interaction models!

In addition, no annual modulation signal observed in some experiments when bkg discrimination is turned off

- CDEX-1B: arXiv: 1904.12889
- LUX: Phys. Rev. D 98, 062005 (2018)
- XMASS : Phys. Rev. D 97, 102006 (2018)
- XENON100 : PRL118, 101101 (2017)
- CDMS-II: arXiv:1203.1309

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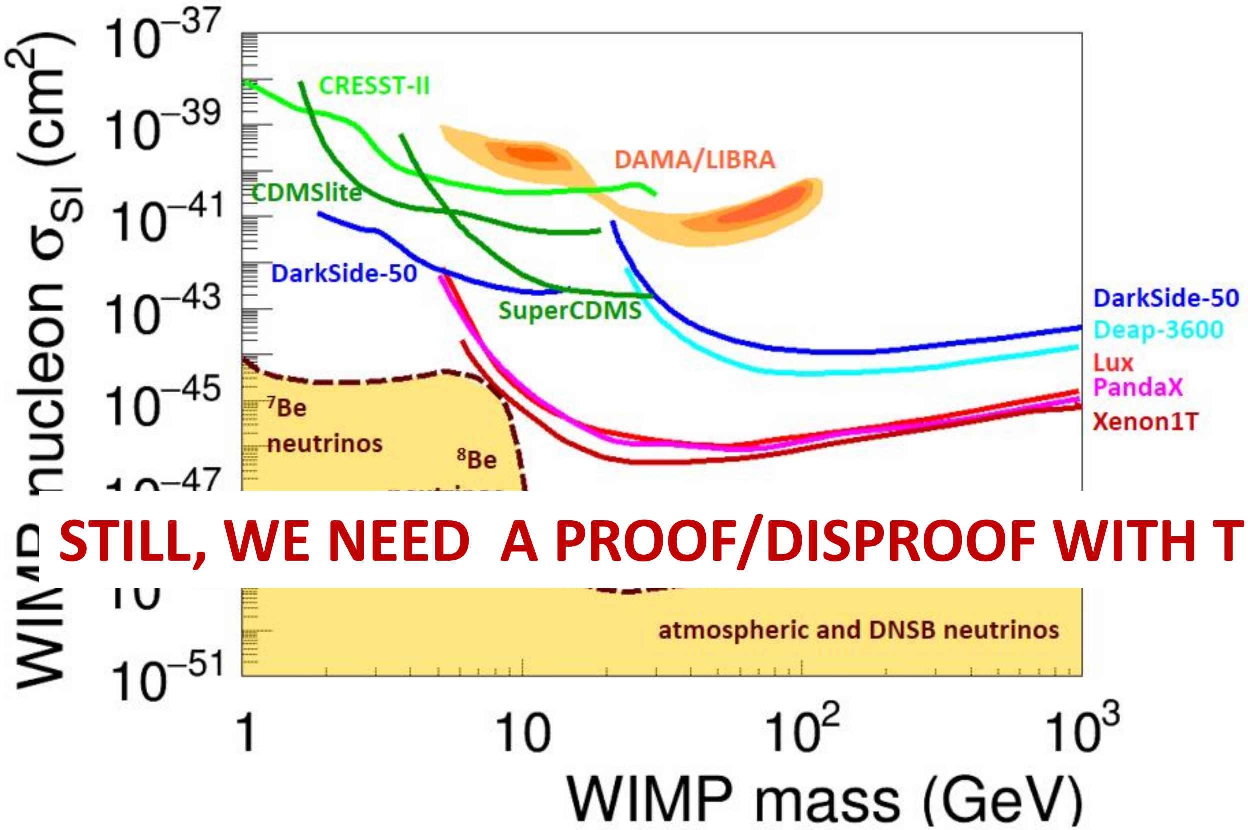

Strong tension even assuming more general halo/interaction models!

STILL, WE NEED A PROOF/DISPROOF WITH THE SAME TARGET

In addition, no annual modulation signal observed in some experiments when bkg discrimination is turned off

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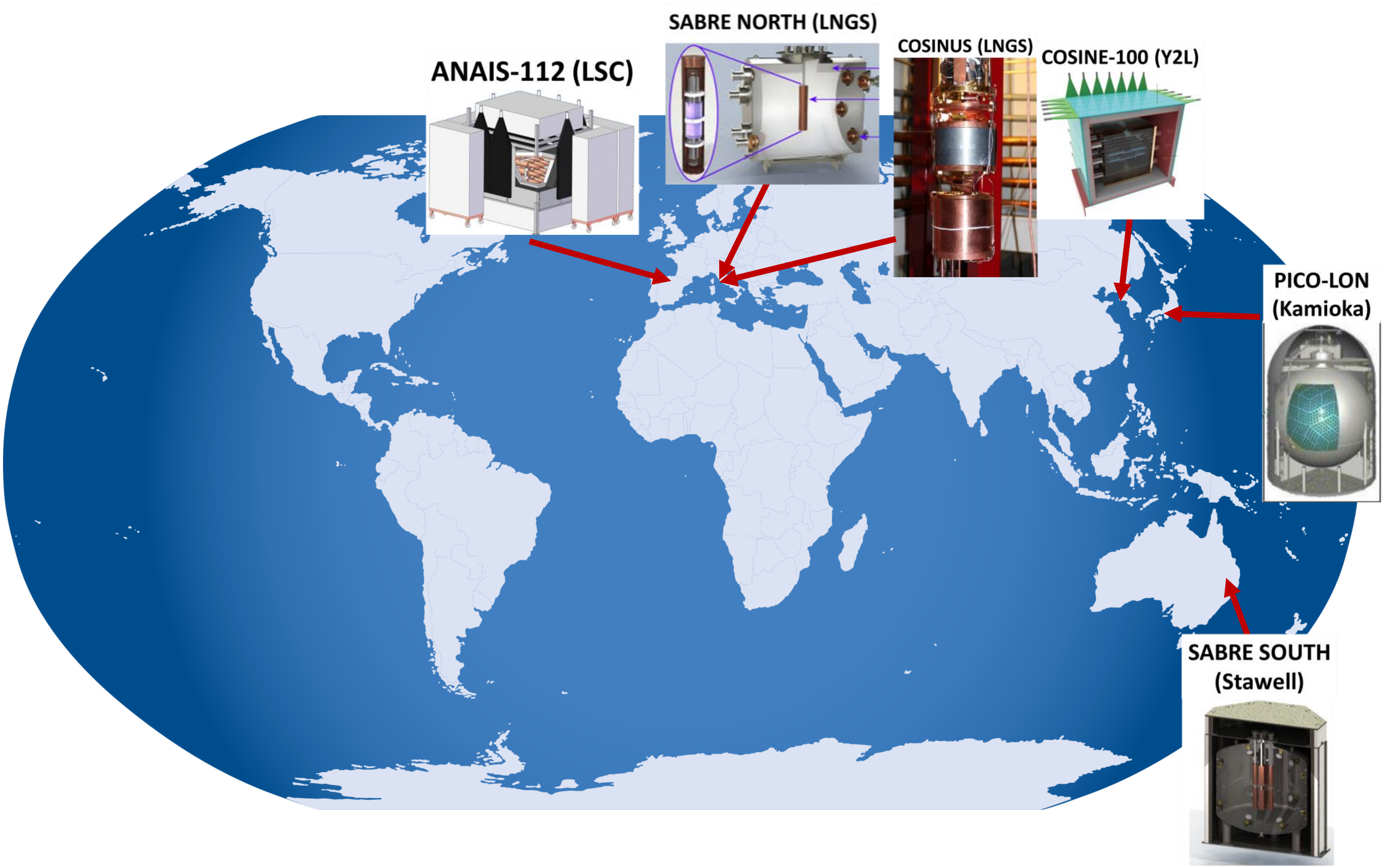
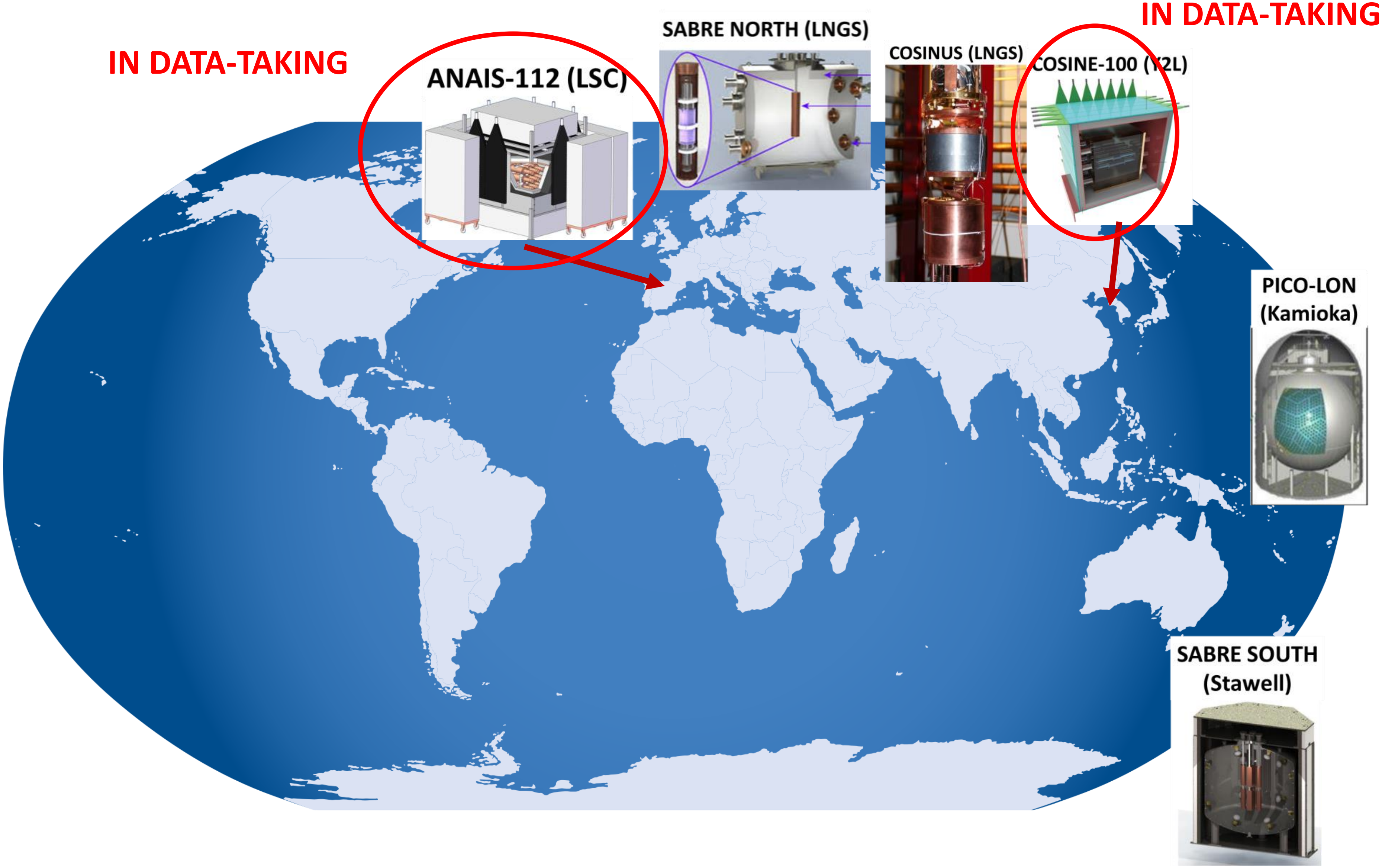
NaI experiments around the World



NaI experiments around the World



M. Martinez. F. ARAID & U. Zaragoza, 4th IBS-Multidark-IPPP Workshop, Daejeon (South Korea), October 7-11 2019

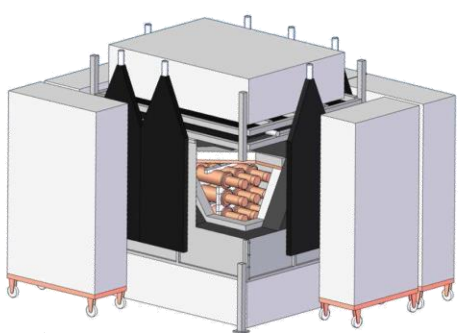

ANAIS-112 experiment

ANAIS-112

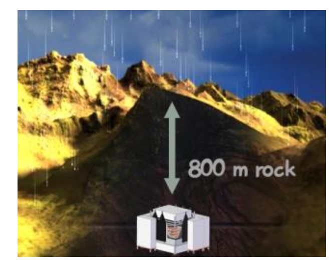
Annual Modulation with NaI Scintillators

GOAL:
Confirmation of DAMA-LIBRA modulation signal -> **same target and technique** / **different** experimental approach / **different** environmental conditions affecting **systematics**

THE DETECTOR:
3x3 matrix of 12.5 kg NaI(Tl) cylindrical modules = **112.5 kg** of active mass

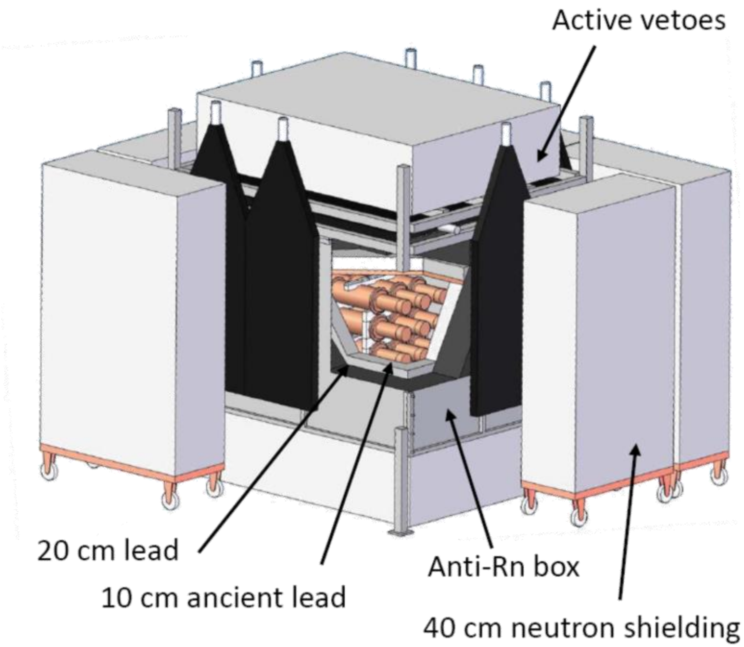


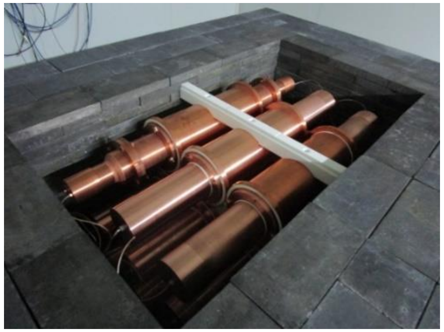
WHERE:
At Canfranc Underground Laboratory,
@ **SPAIN** (under **2450 m.w.e.**)



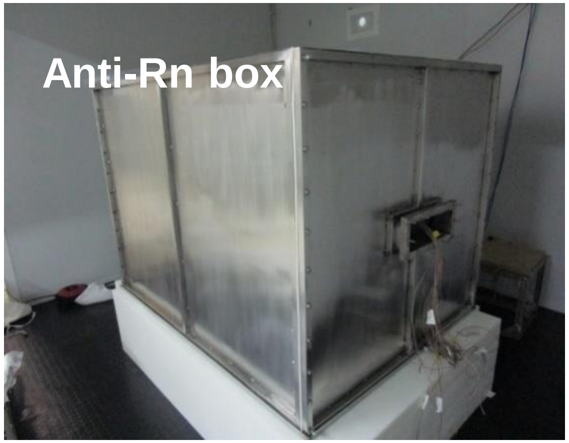
taking data since August 2017

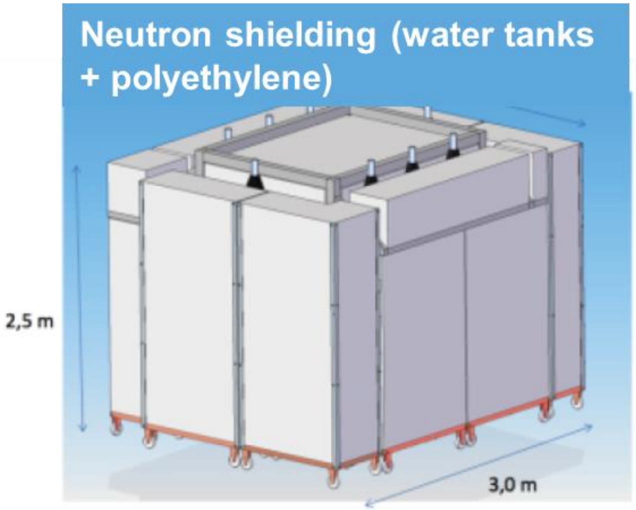
ANAIS-112: experimental setup





- 9 NaI(Tl) cylindrical crystals (12.5 kg each) in 3x3 matrix
- Ultrapure NaI powder (Alpha Spectra Inc)
- Each coupled to two Hamamatsu R12669SEL2 PMT (QE ~40%)



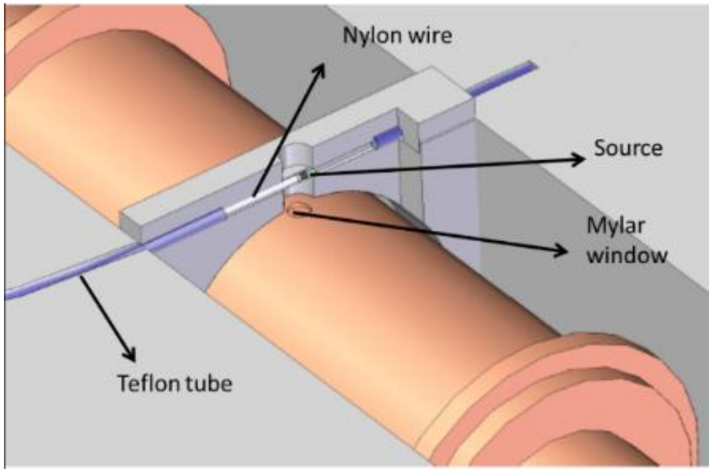


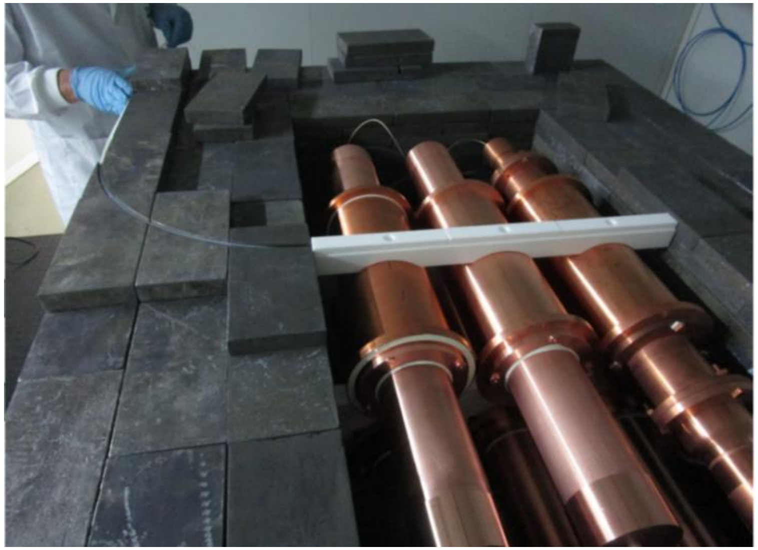
ANAIS-112: Low energy calibration

Detectors equipped with a **Mylar window**!

Radon-free system for low energy calibration:

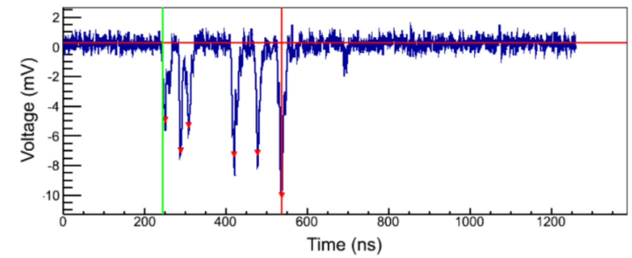
- **^{109}Cd sources** on flexible wires (radon-free)
- Energies: 11.9, 22.6 and 88.0 keV
- Simultaneous calibration of the nine modules
- Performed every two weeks

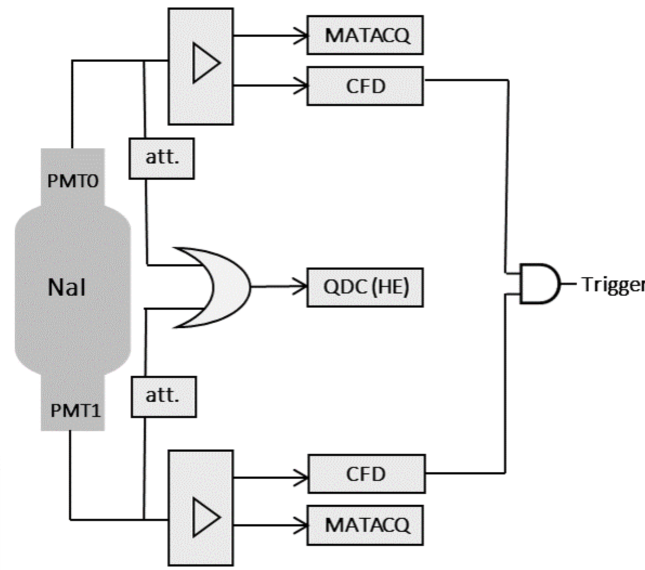


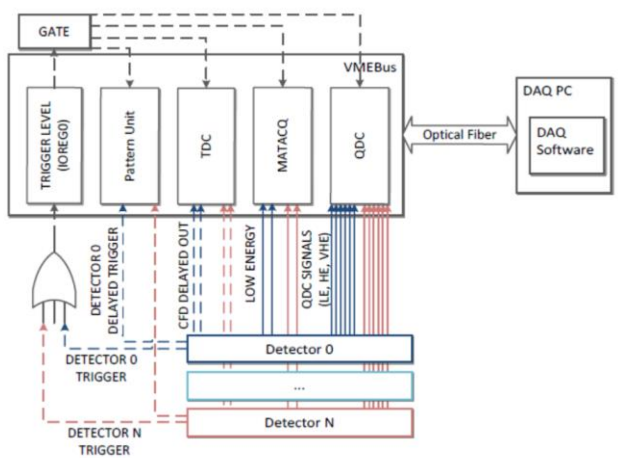


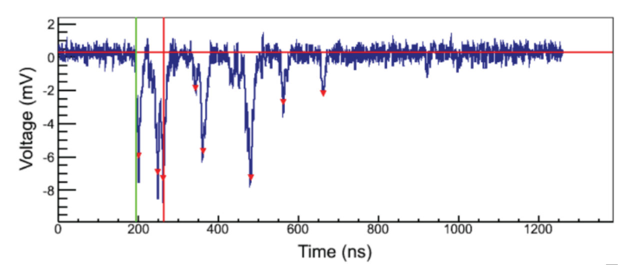
ANAIS-112: Data acquisition system

- Individual PMT signals **digitized** and fully processed **(14 bits, 2 GS/s)**
- Trigger at phe level for each PMT signal
- AND coincidence in 200 ns window
- Redundant energy conversion by QDC
- Trigger in OR mode among modules
- Electronics at air-conditioned-room to decouple from temperature fluctuations
- Muon detection system: tag every muon event to offline processing









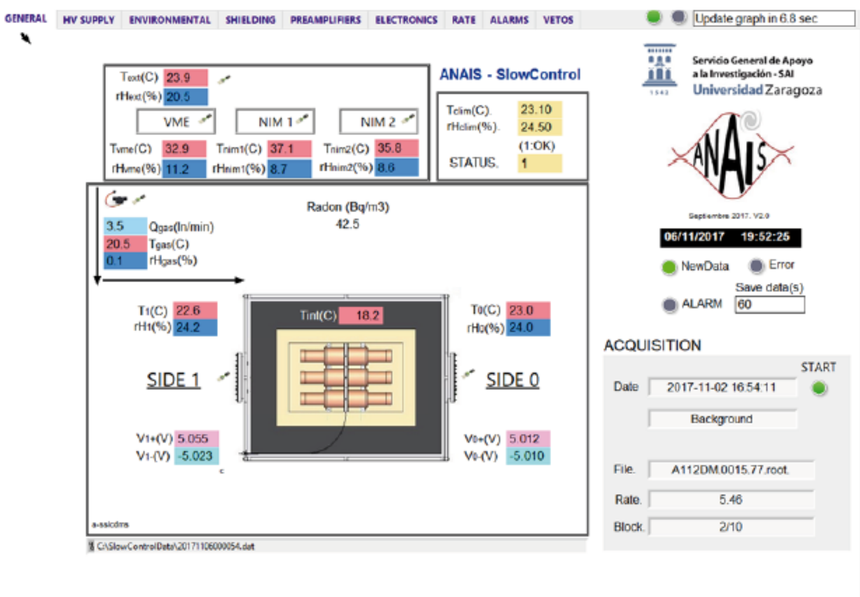
ANAIS-112: Slow control

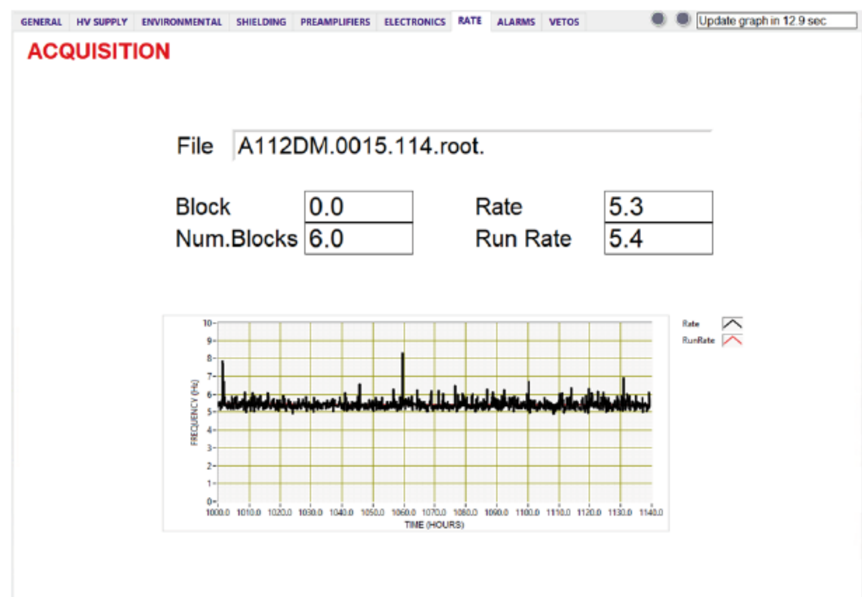
- Monitoring **environmental parameters** since the start of DM run
  - Monitoring:

    Rn content, humidity, pressure, different temperatures, N_2 flux, PMT HV, muon rate, …

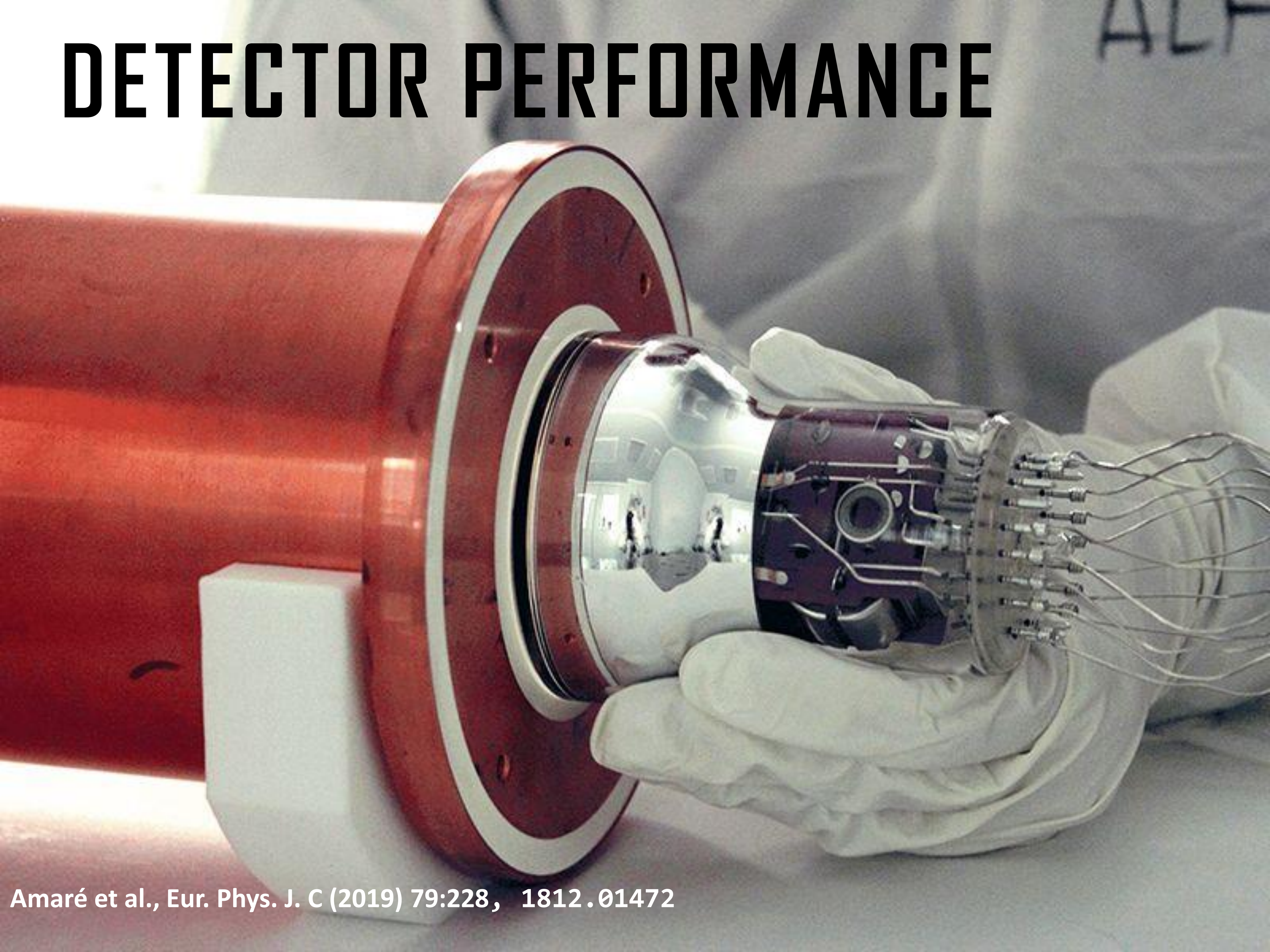
    Data saved every few minutes and alarm messages implemented
  - Stability checks:

    gain, trigger rate, …





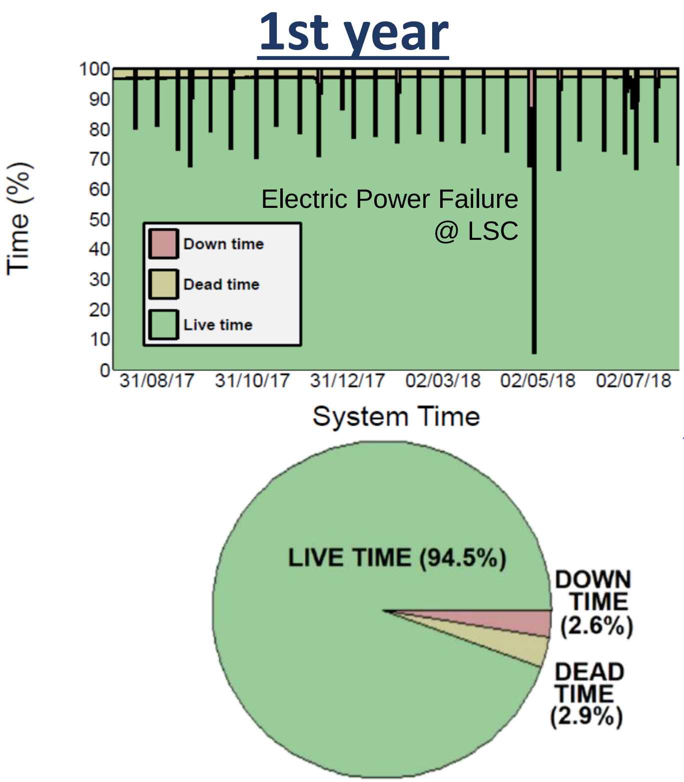
DETECTOR PERFORMANCE

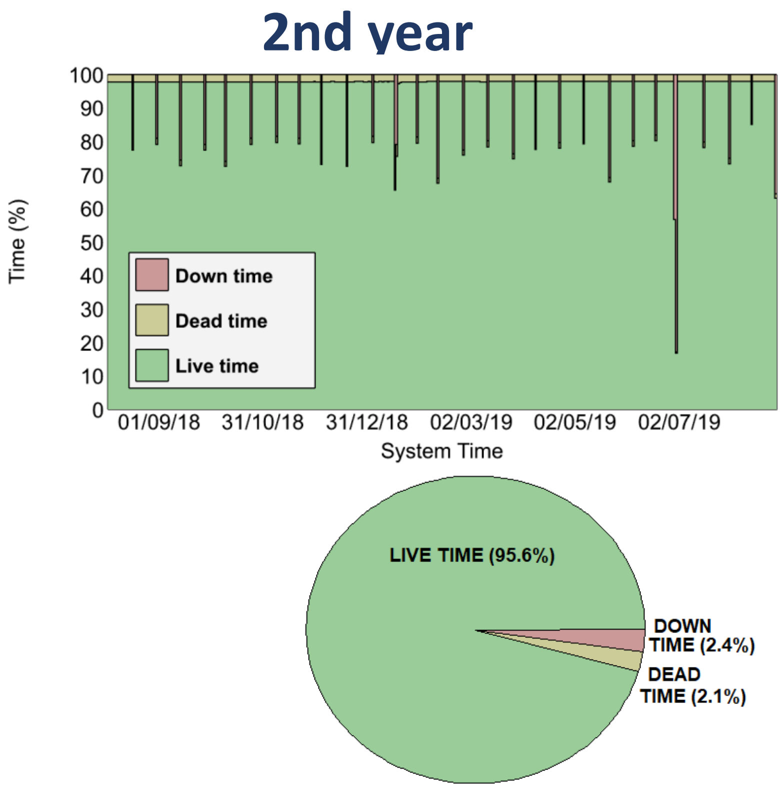


Amaré et al., Eur. Phys. J. C (2019) 79:228, 1812.01472

Duty cycle

- Excellent **duty cycle**



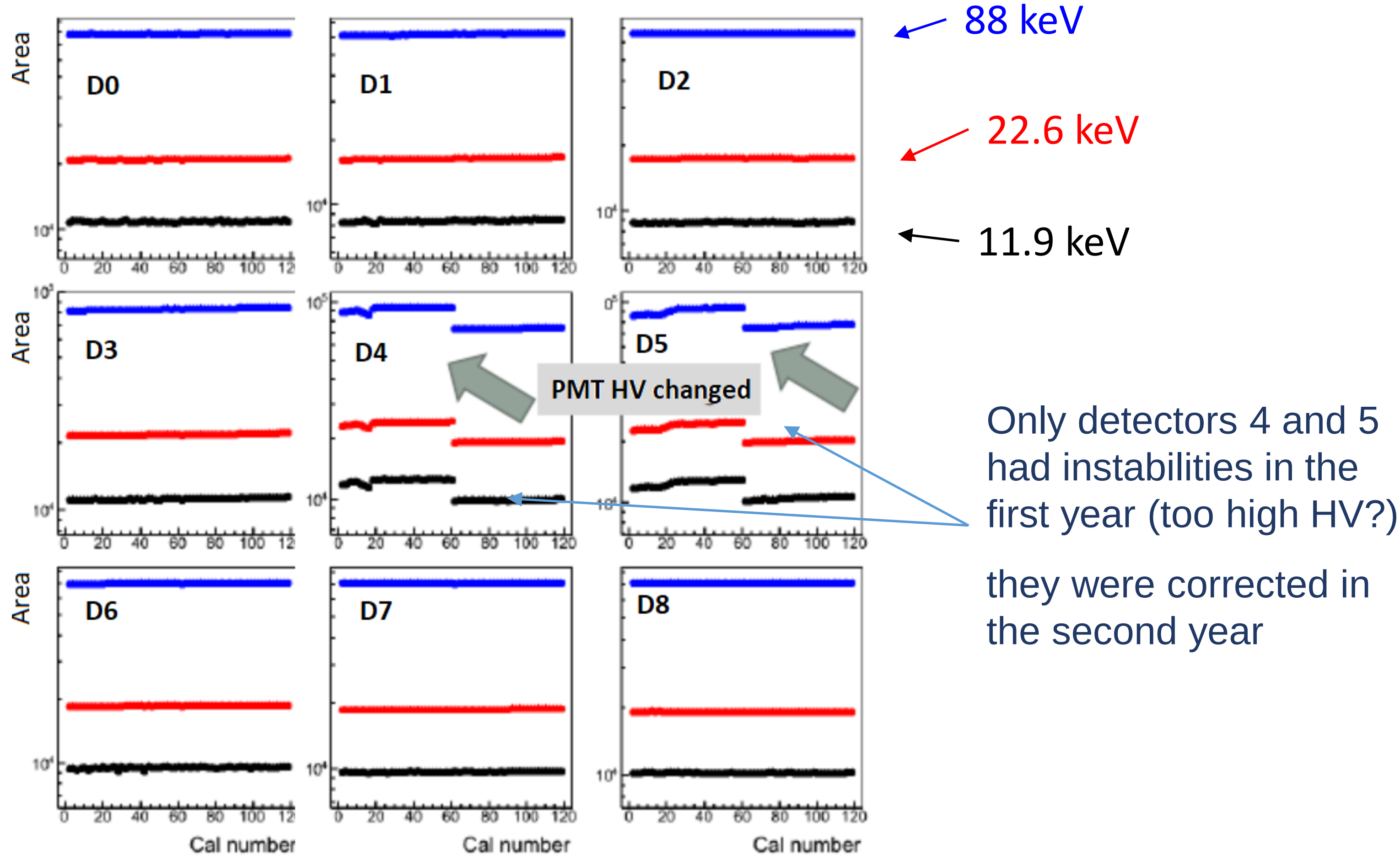


Accumulated live time in the first year: 341.72 days
in the second year: 374.30 days

total: 716.02 days

Gain stability

Evolution of ^{109}Cd lines from calibrations along the whole data-taking (~ 2 years)
→ monitor/correct posible gain drifts



Amaré et al., Eur. Phys. J. C (2019) 79:228, 1812.01472

Light collection

- Outstanding **light collection** of **~15 phe/keV**
- Stable over time

Detector	Total Light Collection (phe/keV)
D0	14.6± 0.1
D1	14.8 ± 0.1
D2	14.6 ± 0.1
D3	14.5 ± 0.1
D4	14.5 ± 0.1
D5	14.5 ± 0.1
D6	12.7 ± 0.1
D7	14.8 ± 0.1
D8	16.0 ± 0.1

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

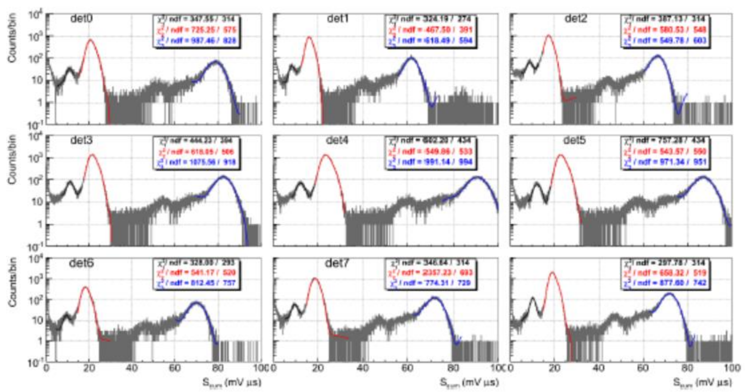
Larger and more homogeneous than the reported light collection for DAMA/LIBRA detectors:

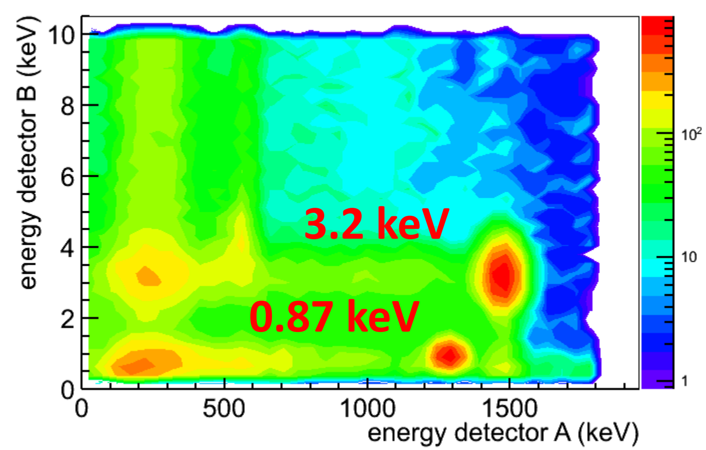
DAMA/LIBRA:
Phase 1: **5.5-7.5 phe/keV**
Phase 2: **6-10 phe/keV**
JINST 7 (2012)03009

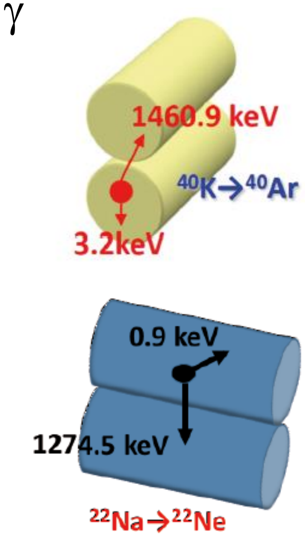
Amaré et al., Eur. Phys. J. C (2019) 79:228, 1812.01472

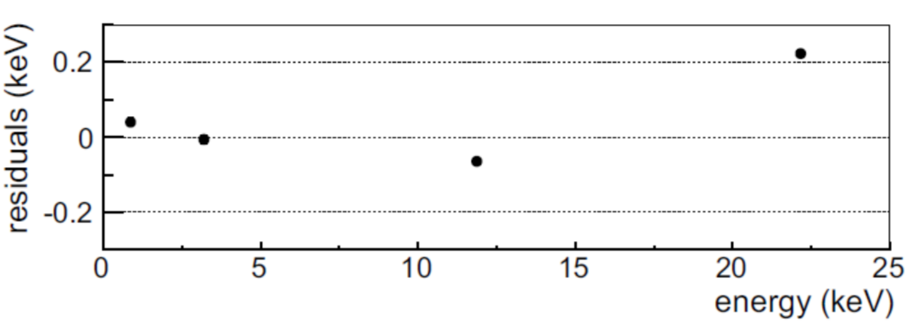
Calibration at low energy

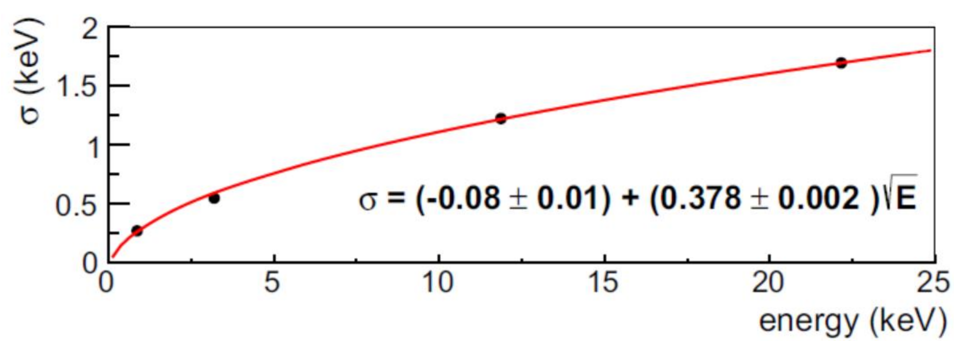
Combine ^{109}Cd calibration lines + bulk ^{22}Na and ^{40}K events identified by coincidences with high energy γ







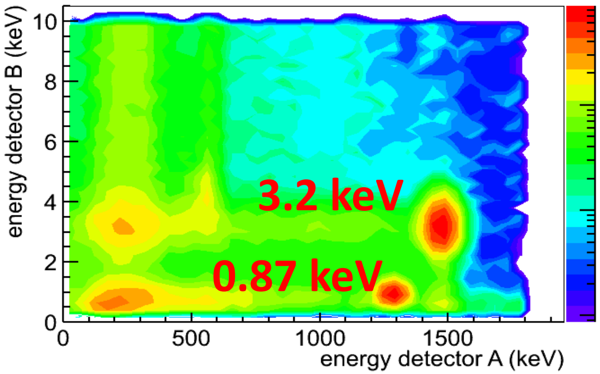


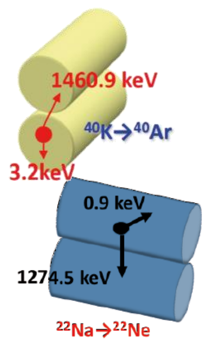


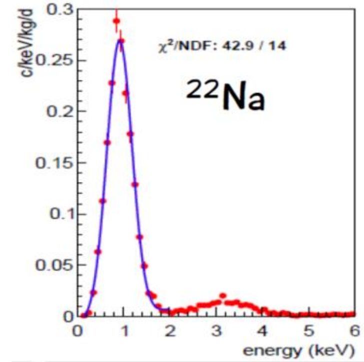
Amaré et al., Eur. Phys. J. C (2019) 79:228, 1812.01472

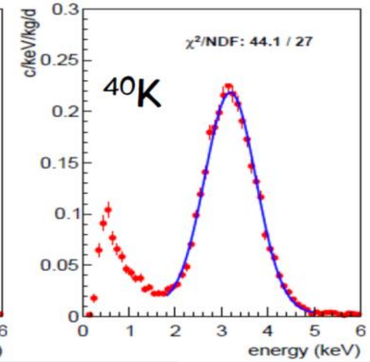
Energy threshold

- **Triggering below 1 keV$_{ee}$** very efficiently

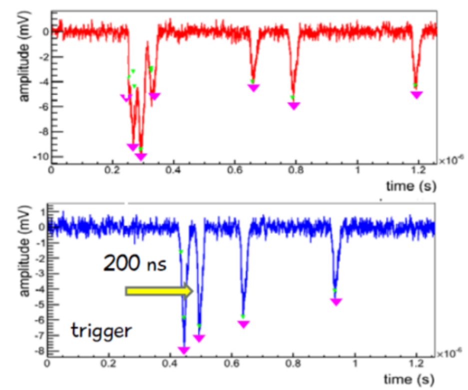


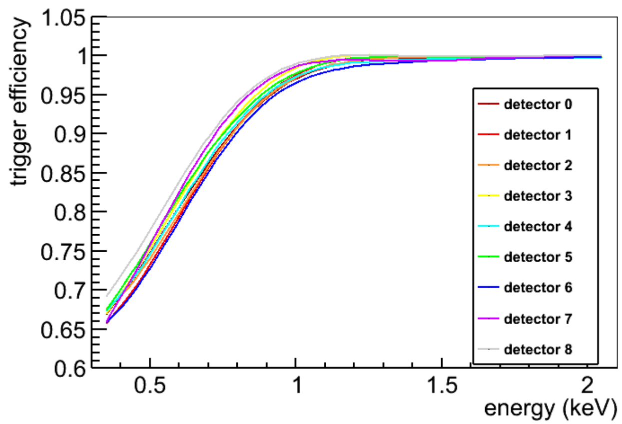






- Trigger efficiency evaluated by a MC “scintillation” simulation





But ….the energy threshold is limited by the efficiency of the PMT noise **filtering** protocols

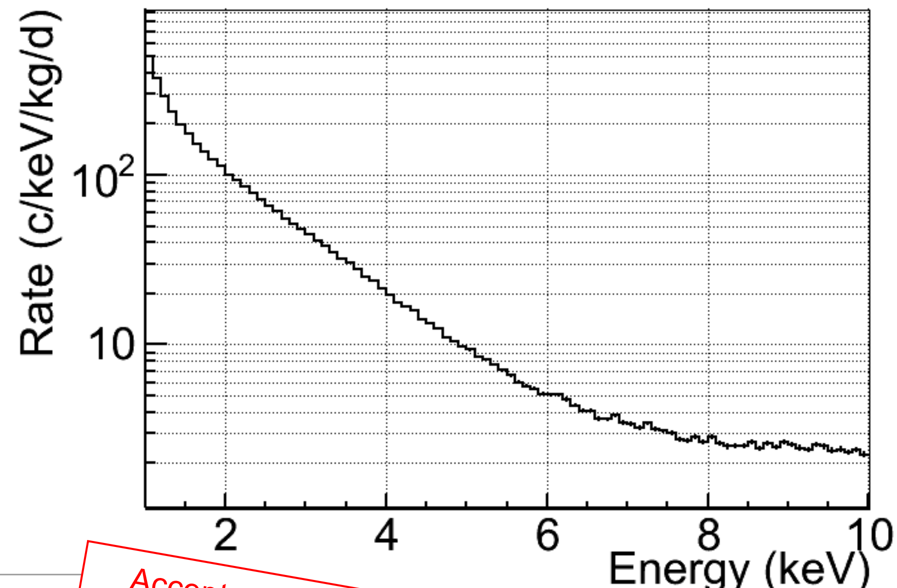
Amaré et al., Eur. Phys. J. C (2019) 79:228, 1812.01472

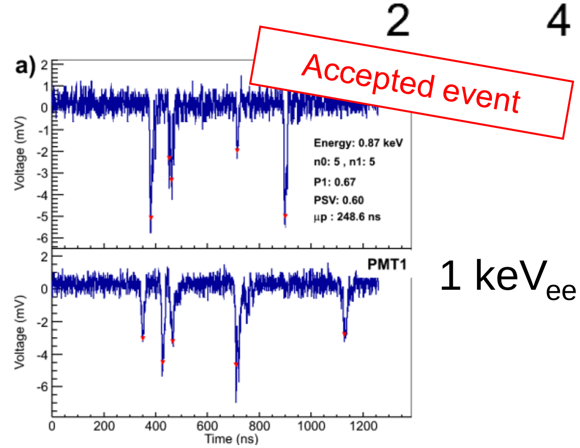
Blinded analysis

ANALYSIS STRATEGY

- Multiplicity-1 events in the RoI (1-6 keV) **blinded**
- We use multiplicity-2 events in the RoI and calibration events to tune the filtering algorithms and calculate the cut efficiencies
- We unblind 10% (~30 days randomly distributed along the first year) data for background assessment

10% unblinded data





1 keV_{ee}

Amaré et al., Eur. Phys. J. C (2019) 79:228, 1812.01472

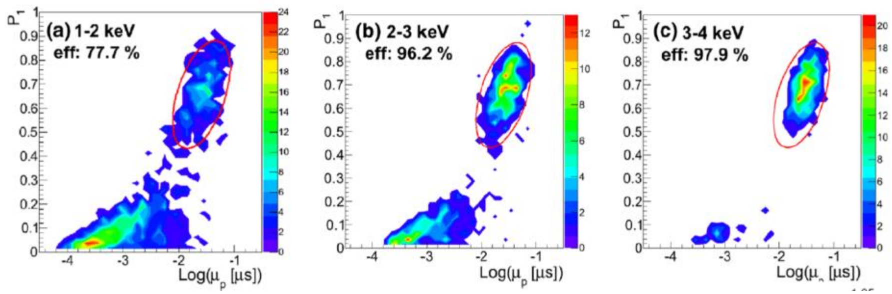
Event selection

CUTS

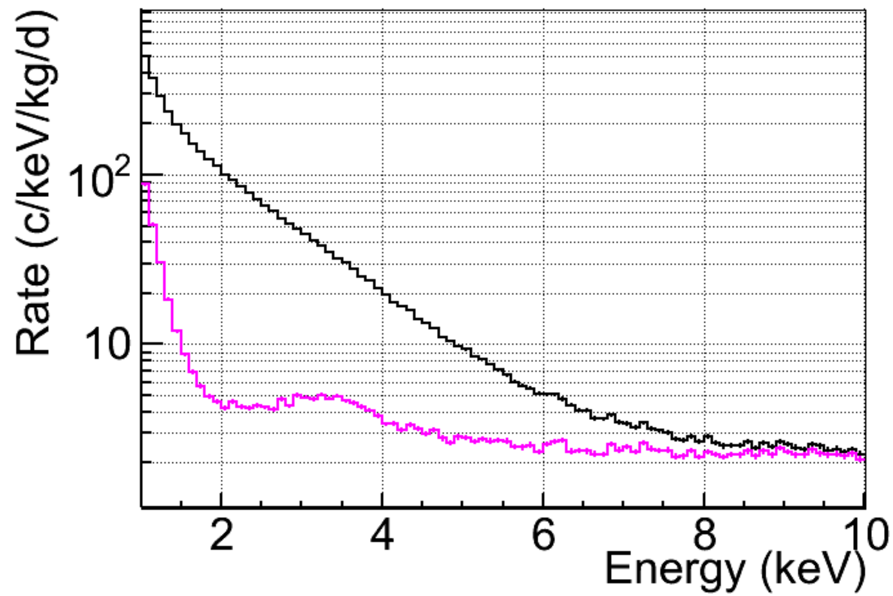
1. Pulse shape cut to select pulses with NaI(Tl) scintillation constant

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

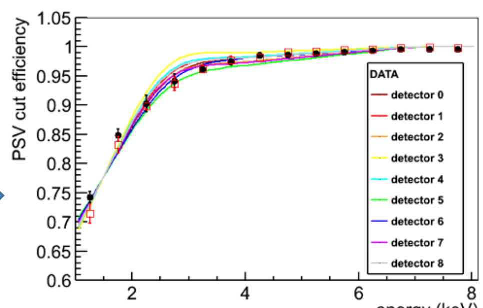
(biparametric cut)

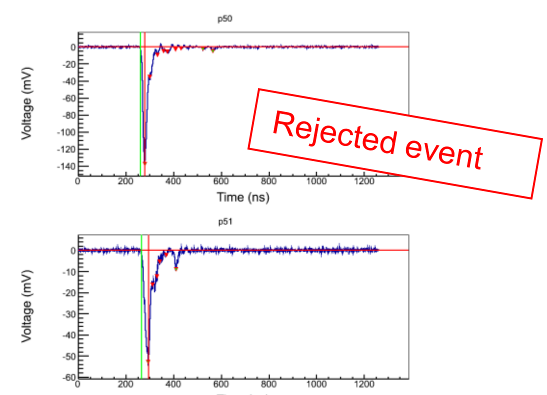


10% unblinded data



Efficiency calculated from ^{22}Na and ^{40}K events



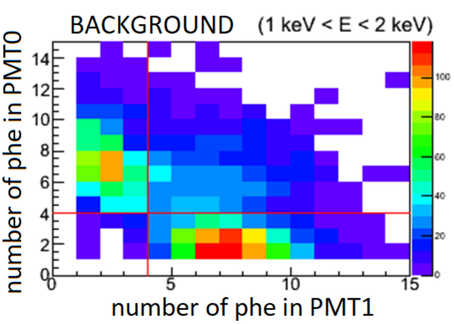


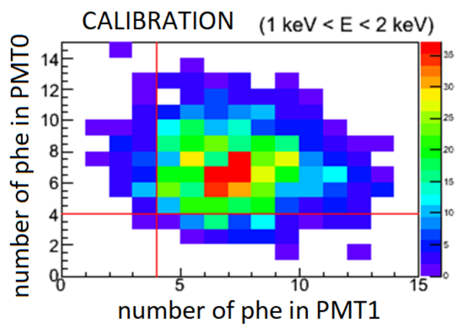
Amaré et al., Eur. Phys. J. C (2019) 79:228, 1812.01472

Event selection

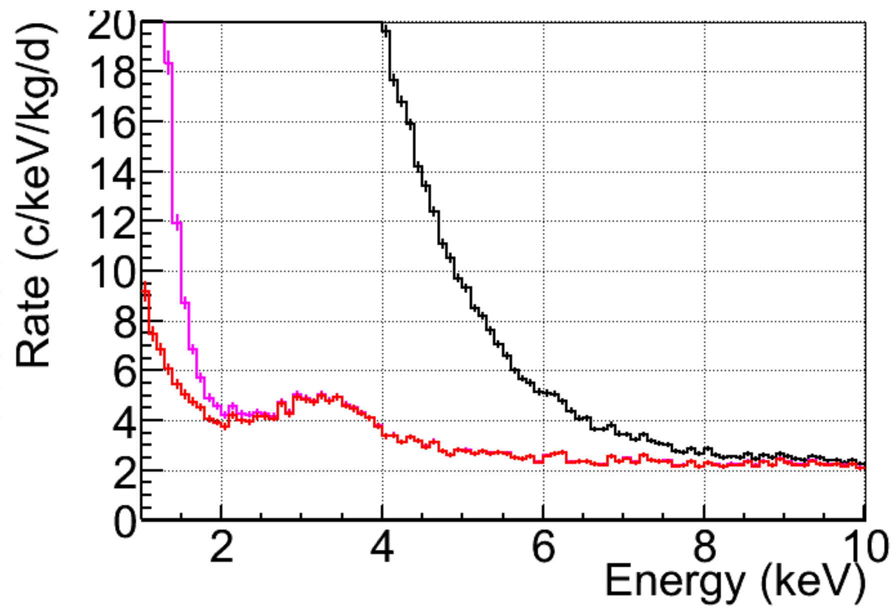
CUTS

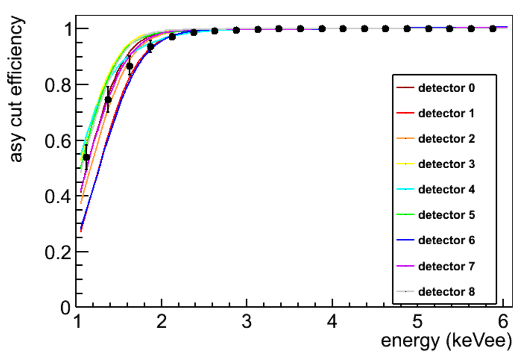
1. Pulse shape cut to select pulses with NaI(Tl) scintillation constant
2. We remove asymmetric events (<2 keVee) with origin in the PMT



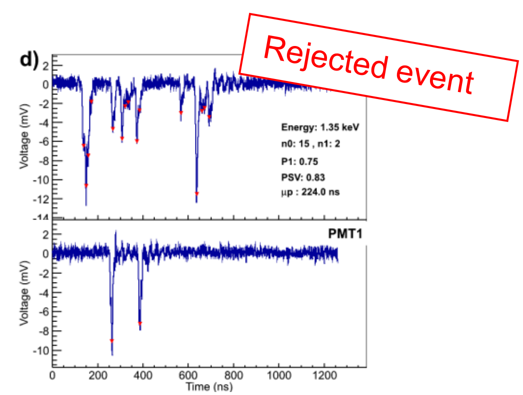


10% unblinded data





Efficiency calculated from calibration events

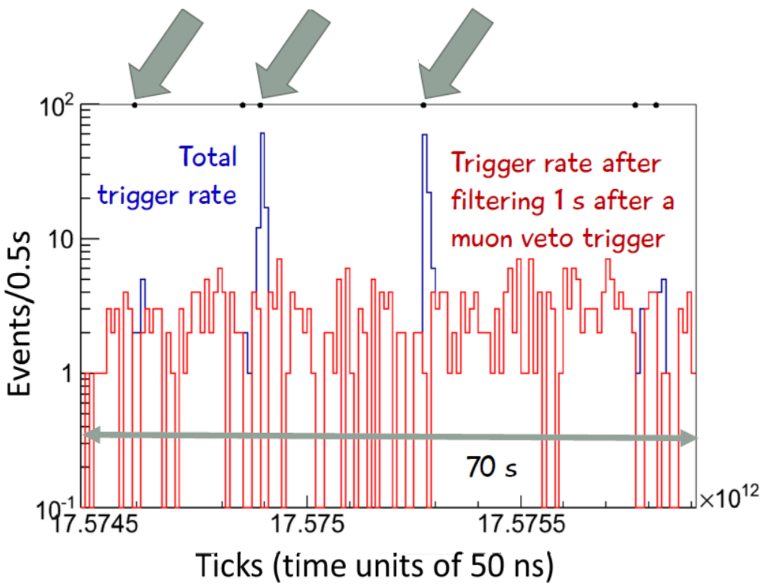


Amaré et al., Eur. Phys. J. C (2019) 79:228, 1812.01472

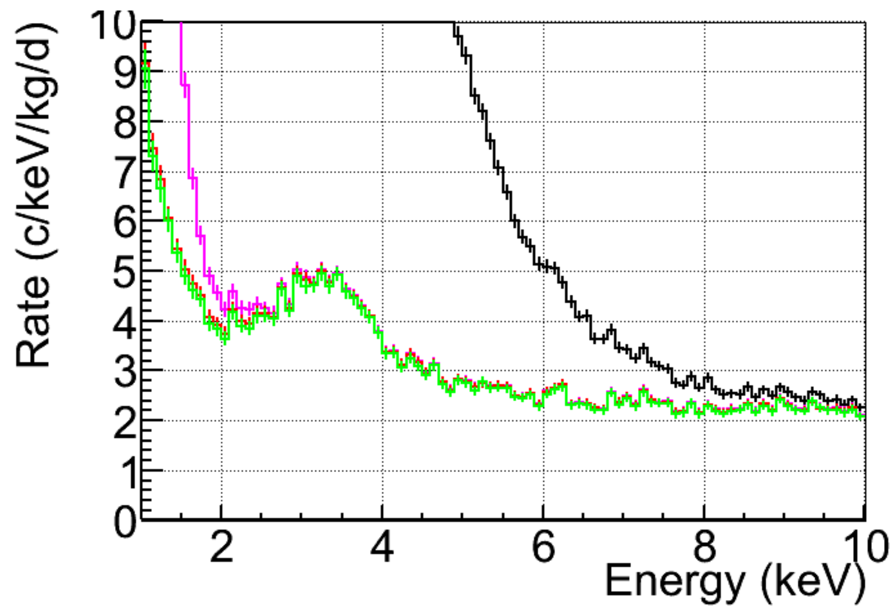
Event selection

CUTS

1. Pulse shape cut to select pulses with NaI(Tl) scintillation constant
2. We remove asymmetric events (<2 keVee) with origin in the PMT
3. Remove 1 s after a muon passage



10% unblinded data

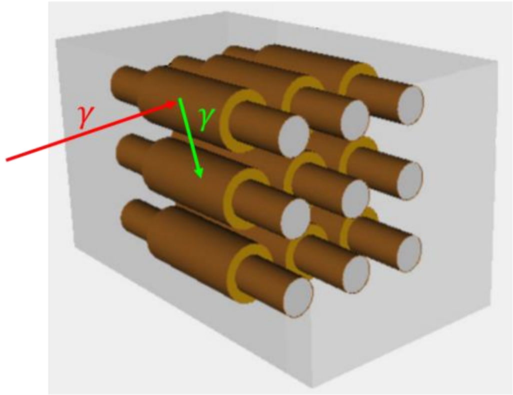


Amaré et al., Eur. Phys. J. C (2019) 79:228， 1812.01472

Event selection

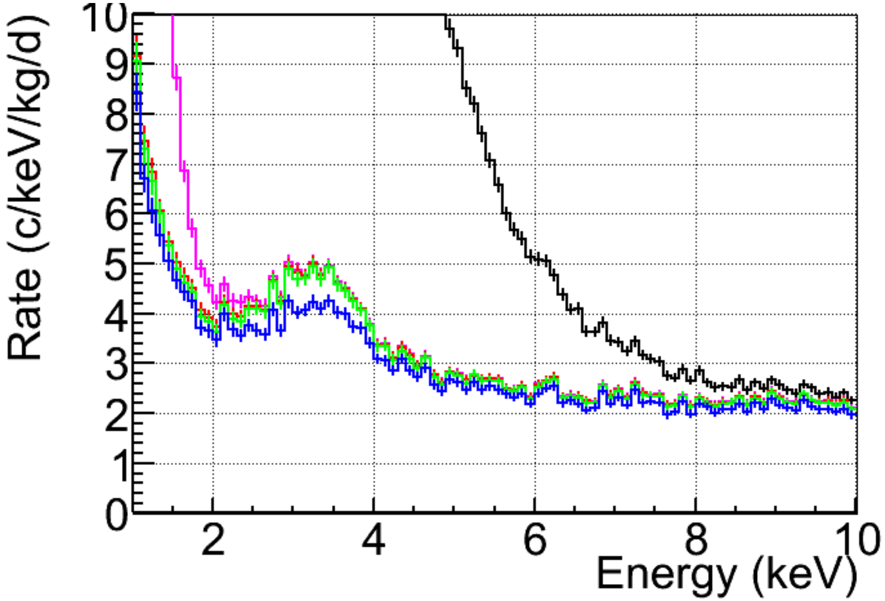
CUTS

1. Pulse shape cut to select pulses with NaI(Tl) scintillation constant
2. We remove asymmetric events (<2 keVee) with origin in the PMT
3. Remove 1 s after a muon passage
4. Multiplicity = 1



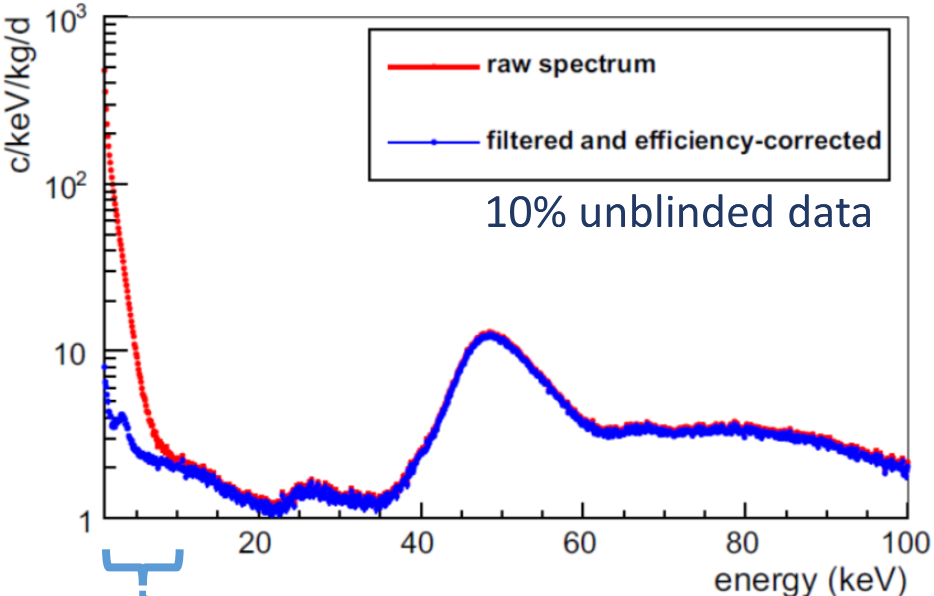
Reject events that deposit energy simultaneously in more than one crystal

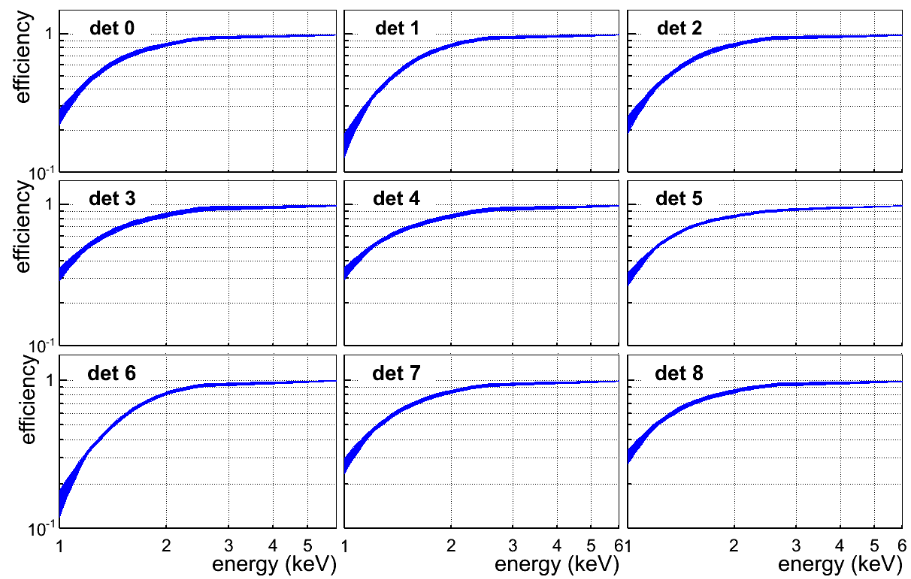
10% unblinded data

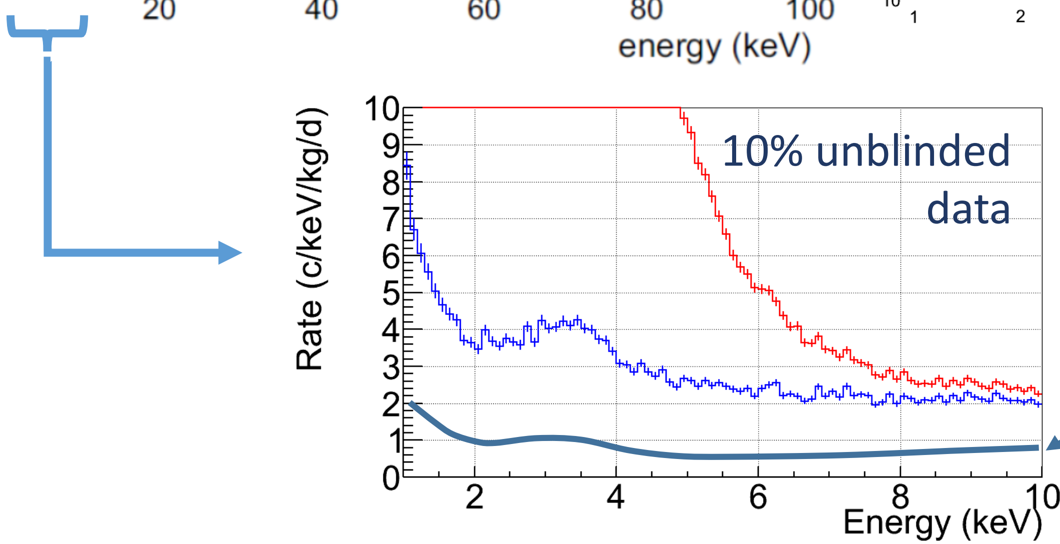


Amaré et al., Eur. Phys. J. C (2019) 79:228, 1812.01472

Background & efficiency





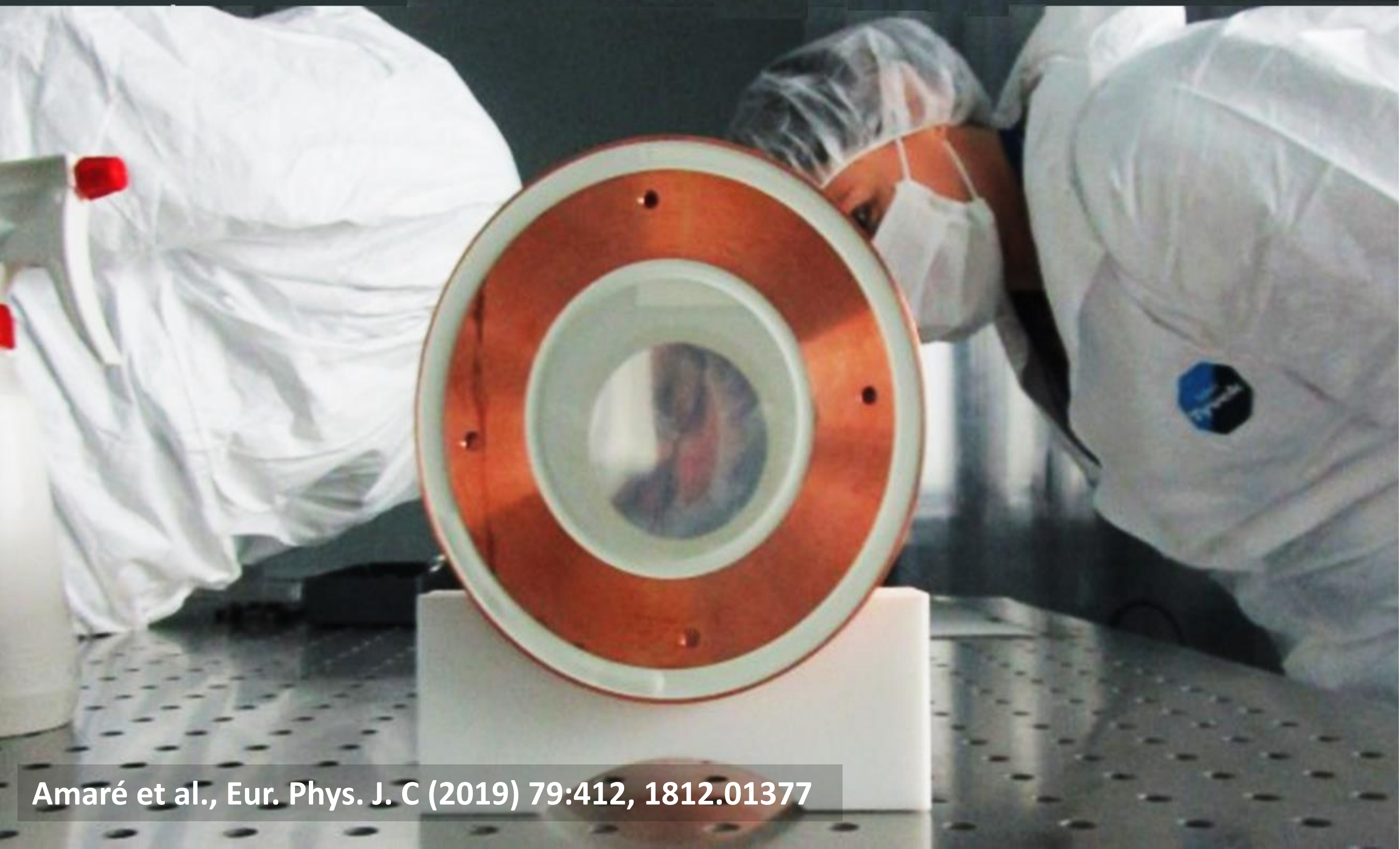


DAMA/LIBRA

`Universe 4, 116 (2018), 1805.10486`

Amaré et al., Eur. Phys. J. C (2019) 79:228, 1812.01472

BACKGROUND MODEL



Amaré et al., Eur. Phys. J. C (2019) 79:412, 1812.01377

Background sources

- Detailed **background models** for each detector
  - Geant4 Monte Carlo simulation
  - accurate quantification of **background sources**
    - **Activity from external components** measured with HPGe detectors at Canfranc

Component	Unit	^{40}K	^{232}Th	^{238}U	^{226}Ra	Others
PMTs D0	mBq/PMT	97±19	20±2	128±38	84±3	
		133±13	20±2	150±34	88±3	
PMTs D1	mBq/PMT	105±15	18±2	159±29	79±3	
		105±21	22±2	259±59	59±3	
PMTs D2	mBq/PMT	155±36	20±3	144±33	89±5	
		136±26	18±2	187±58	59±3	
PMTs D3	mBq/PMT	108±29	21±3	161±58	79±5	
		95±24	22±2	145±29	88±4	
PMTs D4	mBq/PMT	98±24	21±2	162±31	87±4	
		137±19	26±2	241±46	64±2	
PMTs D5	mBq/PMT	90±15	21±1	244±49	60±2	
		128±16	21±1	198±39	65±2	
PMTs D6	mBq/PMT	83±26	23±2	238±70	53±3	
		139±21	24±2	228±52	67±3	
PMTs D7	mBq/PMT	104±25	19±2	300±70	59±3	
		103±19	26±2	243±57	63±3	
PMTs D8	mBq/PMT	127±19	23±1	207±47	63±2	
		124±18	21±2	199±44	61±2	
weighted mean	mBq/PMT	114.9±4.6	21.6±0.4	180.2±9.8	66.7±0.6	
Copper encapsulation	mBq/kg	<4.9	<1.8	<62	<0.9	^{60}Co: <0.4
Quartz windows	mBq/kg	<12	<2.2	<100	<1.9	
Silicone pads	mBq/kg	<181	<34		51±7	
Archaelogical lead	mBq/kg		<0.3	<0.2		^{210}Pb: <20
Inner volume atmosphere	Bq/m^3					^{222}Rn: 0.6

Amaré et al., Eur. Phys. J. C (2019) 79:412, 1812.01377

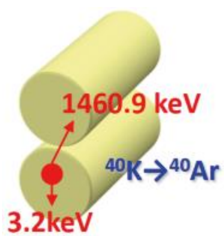
Background sources

- Detailed **background models** for each detector
  - Geant4 Monte Carlo simulation
  - accurate quantification of **background sources**
    - **Activity from external components** measured with HPGe detectors at Canfranc
    - **Internal activity** directly assessed: mainly ^{40}K, ^{210}Pb

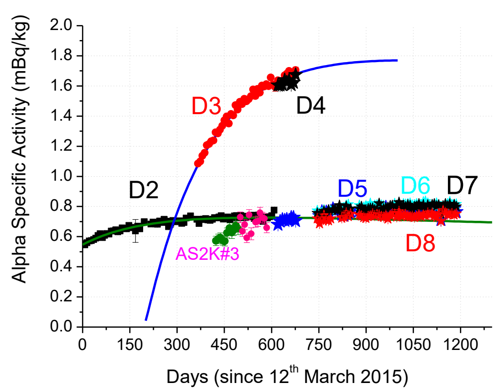
C. Cuesta et al., Int. J. Mod. Phys. A. 29 (2014) 1443010

J. Amaré et al, Eur. Phys. J. C 76 (2016) 429

Module	^{40}K (mBq/kg)	^{210}Pb (mBq/kg)
D0	1.4 ± 0.2	3.15 ± 0.10
D1	1.1 ± 0.2	3.15 ± 0.10
D2	1.1 ± 0.2	0.7 ± 0.1
D3	0.60 ± 0.06	1.8 ± 0.1
D4	0.5 ± 0.2	1.8 ± 0.1
D5	0.8 ± 0.2	0.78 ± 0.01
D6	0.8 ± 0.2	0.81 ± 0.01
D7	0.9 ± 0.2	0.80 ± 0.01
D8	0.6 ± 0.2	0.74 ± 0.01



^{40}K: by identifying coincidences



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

Amaré et al., Eur. Phys. J. C (2019) 79:412, 1812.01377

Background sources

- Detailed **background models** for each detector
  - Geant4 Monte Carlo simulation
  - accurate quantification of **background sources**
    - **Activity from external components** measured with HPGe detectors at Canfranc
    - **Internal activity** directly assessed: mainly ^{40}K, ^{210}Pb
    - **Cosmogenic activity:** short-lived Te and I isotopes, ^{3}H, ^{22}Na, ^{109}Cd, ^{113}Sn

^{22}Na: from analysis of coincidences

Same order of specific activity measured using HPGe by SABRE on AstroGrade powder: 0.48 mB/kg

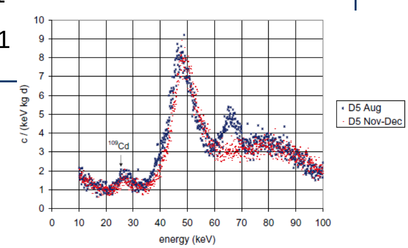
SABRE Colaboration, Astroparticle Physics 106 (2019) 1–9

^{109}Cd, ^{113}Sn: from peaks at binding energies of K-shell electrons (after EC)

Preliminary estimate of production rates:

^{109}Cd (2.38±0.20) kg^{-1}d^{-1}

^{113}Sn (4.53±0.40) kg^{-1}d^{-1}



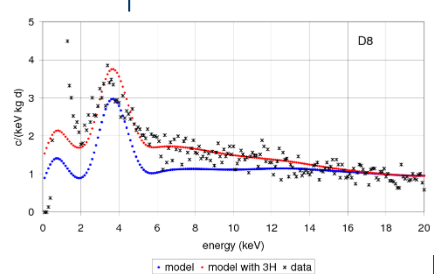
^{3}H: additional background source contributing only in the very low energy region required, which could be tritium

D0-D1: 0.20 mBq/kg

D2-D8: 0.09 mBq/kg (upper limit DAMA/LIBRA)

Same order of ^{3}H activity fitted by COSINE-100

P. Adhikari et al, Eur. Phys. J. C (2018) 78:490



JCAP 02 (2015) 046

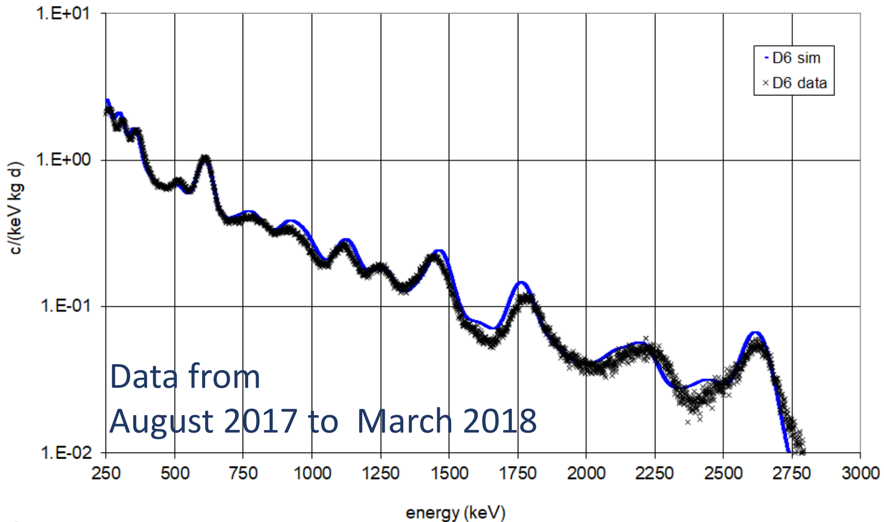
Astropart. Phys.97 (2018) 96

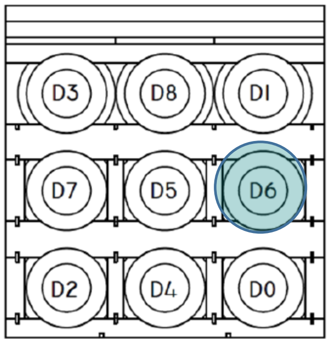
Int. J. Mod. Phys. A 33 (2018) 1843006

Amaré et al., Eur. Phys. J. C (2019) 79:412, 1812.01377

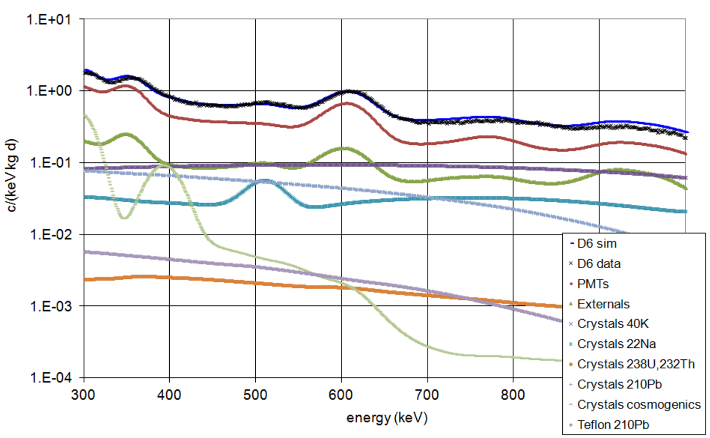
Comparison with data

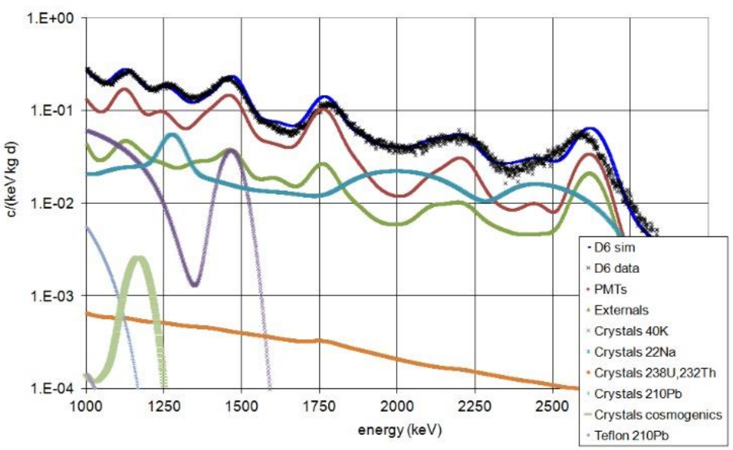
Good agreement at high energy (>250 keV)





Individual contributions:

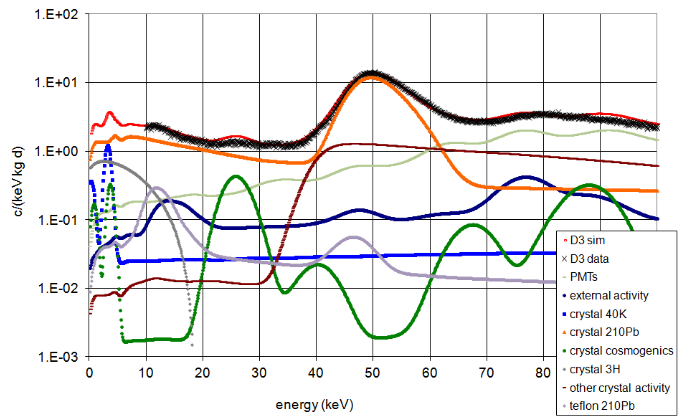


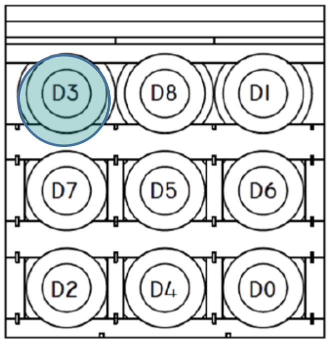


Amaré et al., Eur. Phys. J. C (2019) 79:412, 1812.01377

Comparison with data

- Good agreement at low energy (<100 keV)



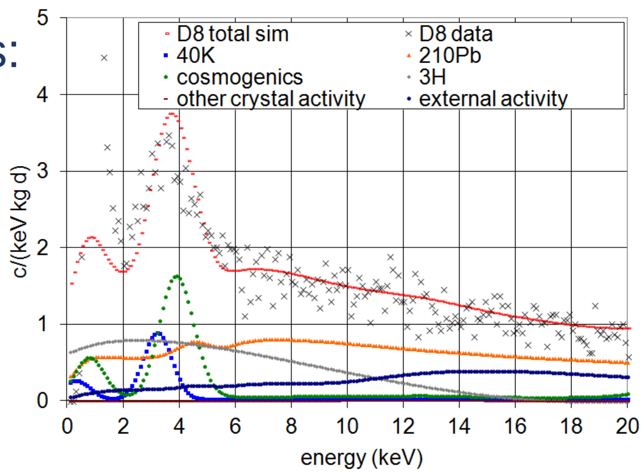


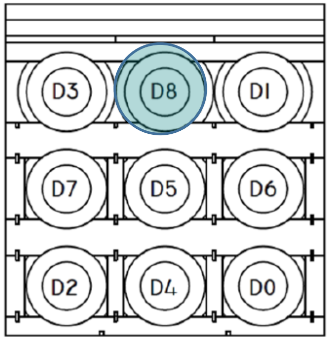
- At very low energy (<20 keV) (Commissioning run, July 2017)

Most significant contributions:

- ^{40}**K** and ^{22}**Na** peaks
- ^{210}**Pb** (bulk+surface)
- ^{3}**H**

Very good agreement except between 1-2 keV

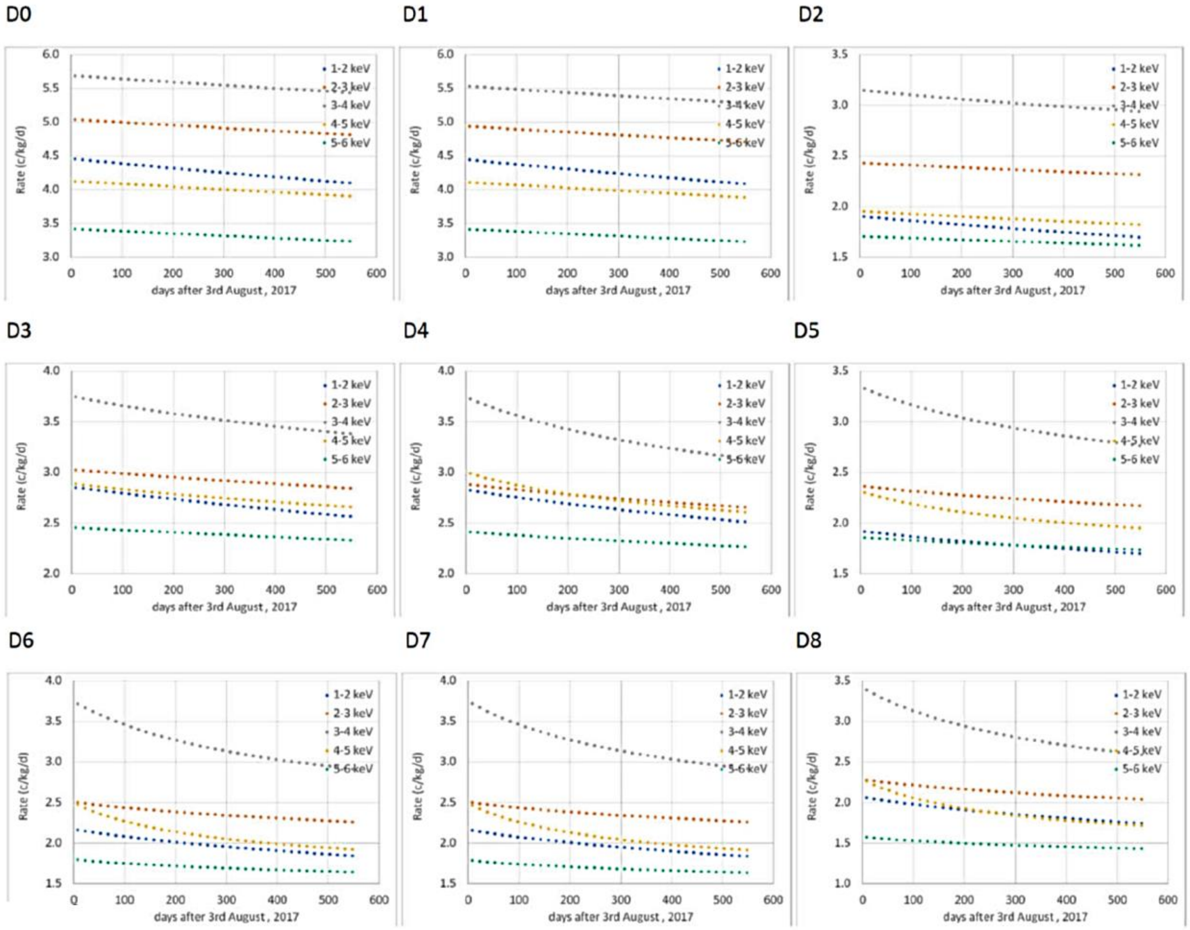




Amaré et al., Eur. Phys. J. C (2019) 79:412, 1812.01377

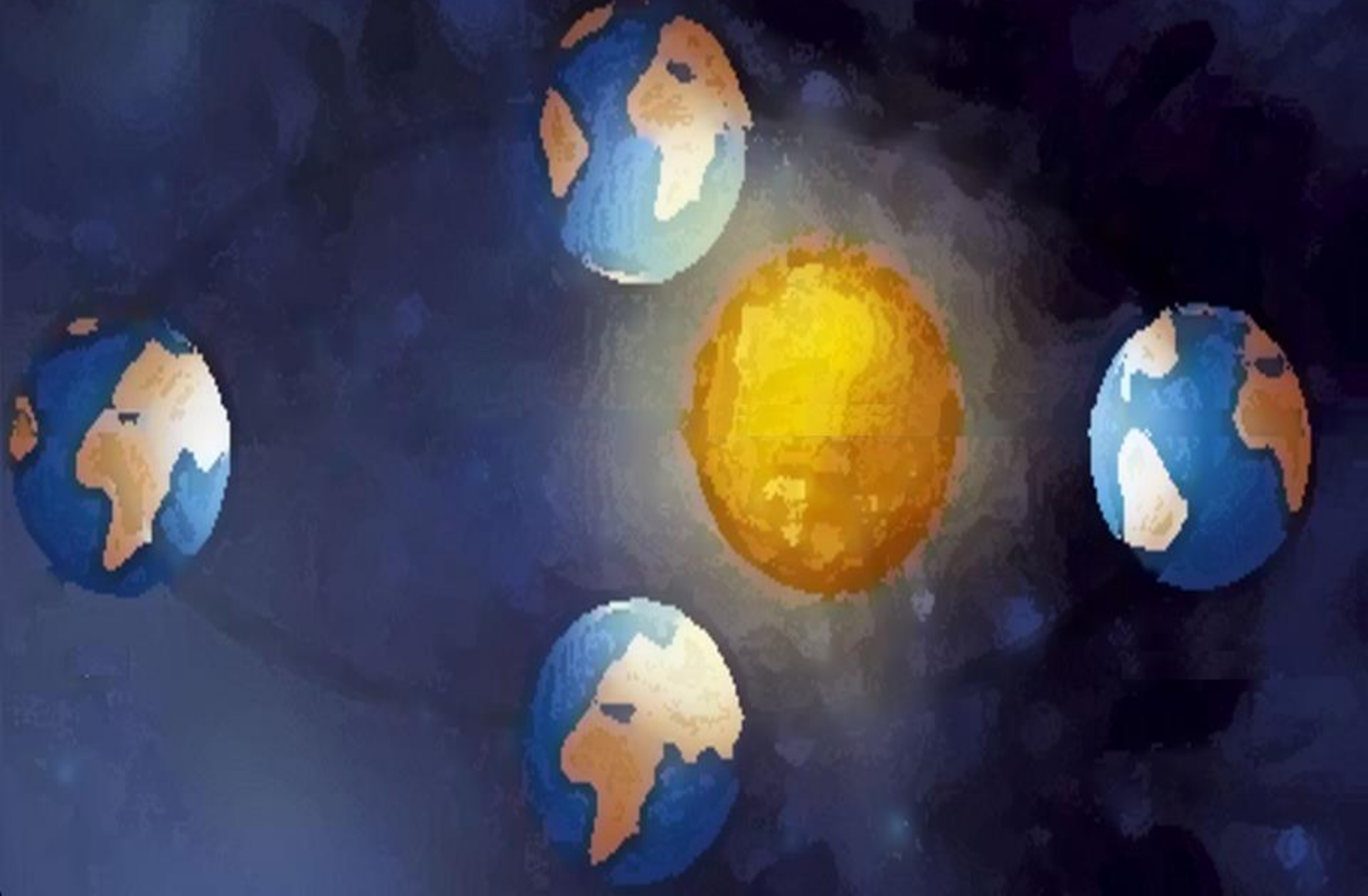
Time evolution

Prediction of the time evolution of rates from the model: cosmogenic isotopes (^{3}H, ^{22}Na, …) and ^{210}Pb

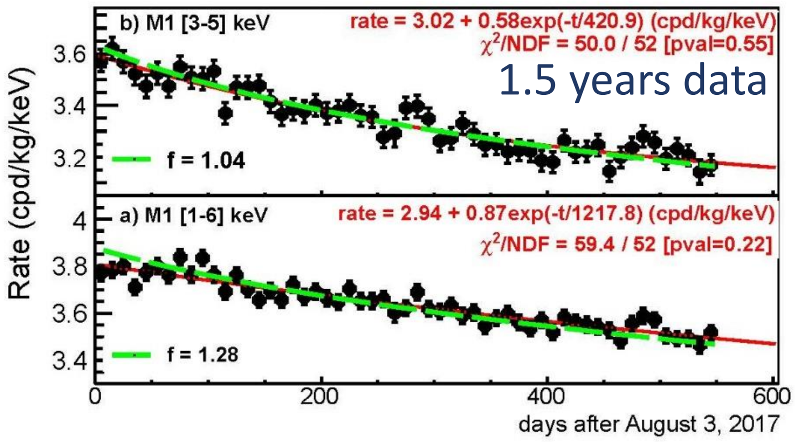


Amaré et al., Eur. Phys. J. C (2019) 79:412, 1812.01377

RESULTS ON ANNUAL MODULATION



Analysis strategy



Background decay rate in the RoI consistent with our background model (in green)

$$R(t) = R_0 + R_1 \exp(-t/\tau) + \boldsymbol{S_m} \cos(\omega(t+\phi))$$

<u>ANALYSIS STRATEGY</u>

- Focus on model independent analysis searching from modulation
- In order to better compare with DAMA/LIBRA results, we use the **same energy regions ([1-6] keV, [2-6] keV) and fit parameters**

<u>Fixed parameters:</u>

τ (background model)

ω (freq. corresponding to a period of 1 year)

ϕ (maximum in June, 2nd)

1st results: Multidark Zaragoza 04/19

1st Annual modulation results

157.55
kg x yr

Least squared fit to : $R(t) = R_0 + R_1 \exp(-t/\tau) + \boldsymbol{S_m} \cos(\omega(t+\phi))$

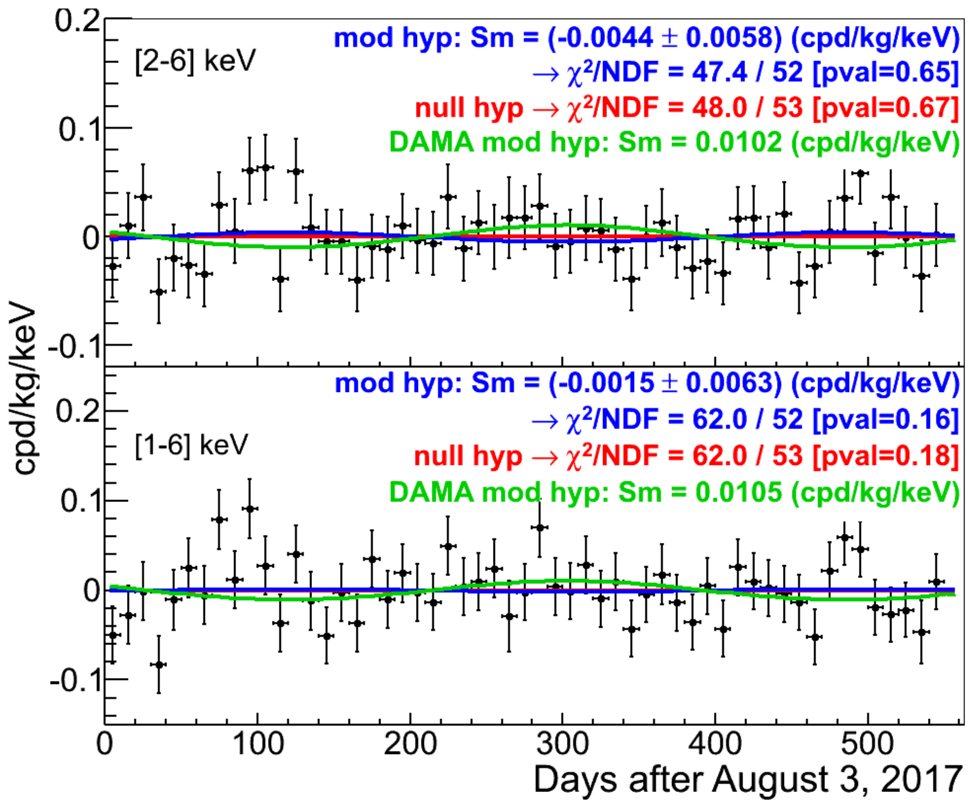
Fixed parameters:

τ (background model)

ω (freq. corresponding to a period of 1 year)

ϕ (maximum in June, 2nd)

$\boldsymbol{S_m}$ fixed to 0 in the null hypothesis and left unconstrained for the modulation hypothesis



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

arXiv:1903.03973

Phys. Rev. Lett., 123, 031301 (2019)

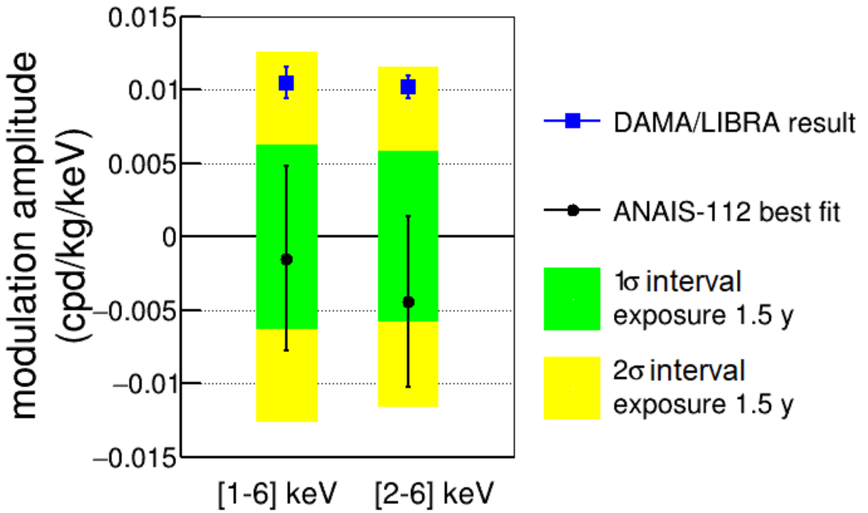
1st Annual modulation results

157.55 kg x yr

[2-6] keV → S_m = −0.0044 ± 0.0058 c/keV/kg/d (S_m^{DAMA} = 0.0102 cpd/kg/keV)

[1-6] keV → S_m = −0.0015 ± 0.0063 c/keV/kg/d (S_m^{DAMA} = 0.0105 cpd/kg/keV)

- Null hypothesis is well supported by the χ^2test (p-values=0.18, 0.67)
- Best fits for the modulation hypothesis have p-values slightly lower than for the null hypothesis
- Best fits are incompatible at 2.5σ (2-6 keV) and 1.9σ (1-6 keV) with DAMA/LIBRA results. Sensitivity (1.5 y) 1.8σ



The statistical significance of our result is determined by the standard deviation of the modulation amplitude distribution, $\sigma(S_m)$

arXiv:1903.03973

Phys. Rev. Lett., 123, 031301 (2019)

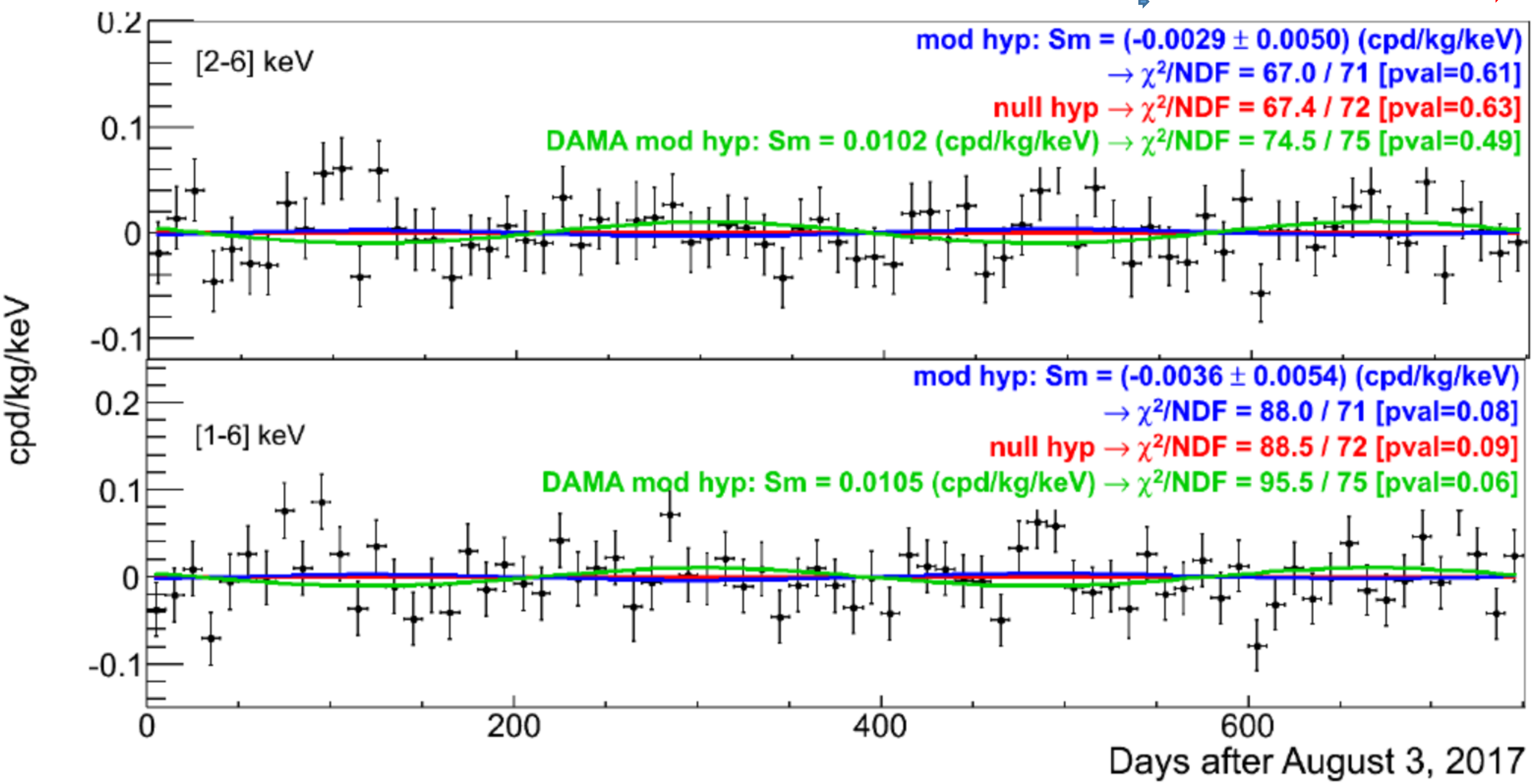
2 years results

M. L. Sarsa @ TAUP2019

PRELIMINARY

213.6 kg x yr

NEW!



2 years results

213.6 kg x yr

M. L. Sarsa @ TAUP2019

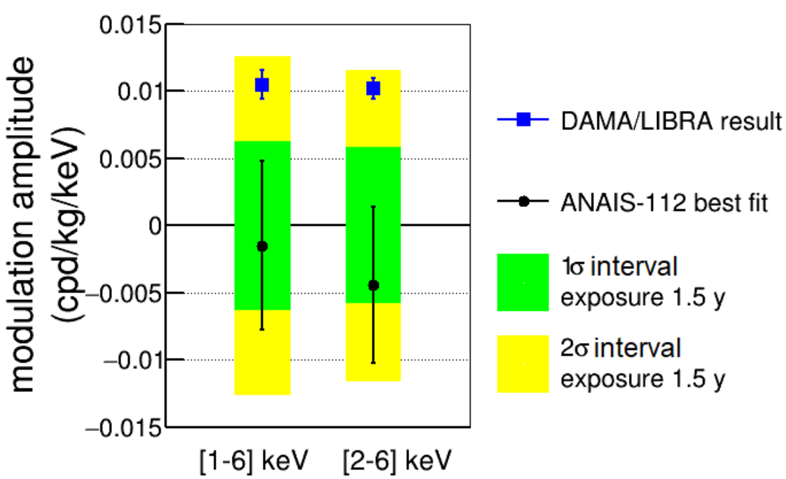
PRELIMINARY

[2-6] keV → $S_m = -0.0029 \pm 0.0050$ c/keV/kg/d (S_m^{DAMA} = 0.0102 cpd/kg/keV)

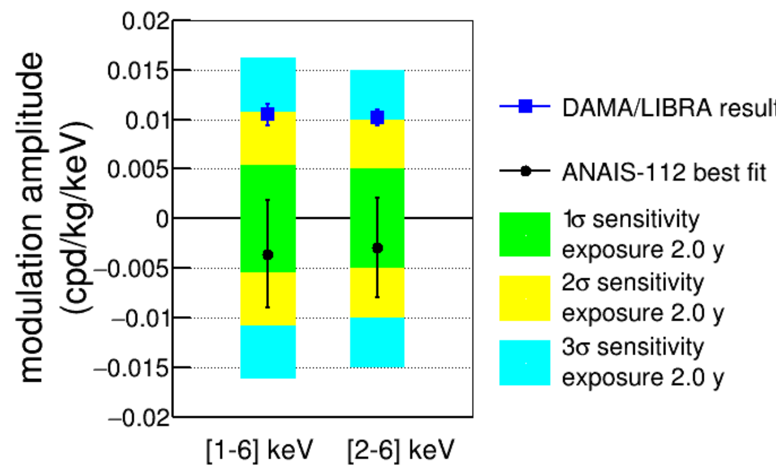
[1-6] keV → $S_m = -0.0036 \pm 0.0054$ c/keV/kg/d (S_m^{DAMA} = 0.0105 cpd/kg/keV)

- Null hypothesis is well supported by the χ^2test (p-values=0.09, 0.63)
- Best fits for the mod. hypothesis p-values slightly lower than for the null hypothesis
- Best fits incompatible at 2.6σ with DAMA/LIBRA results. Present sensitivity 2σ

1.5 years (PRL 123 (2019) 031301)



2 years (TAUP 2019)



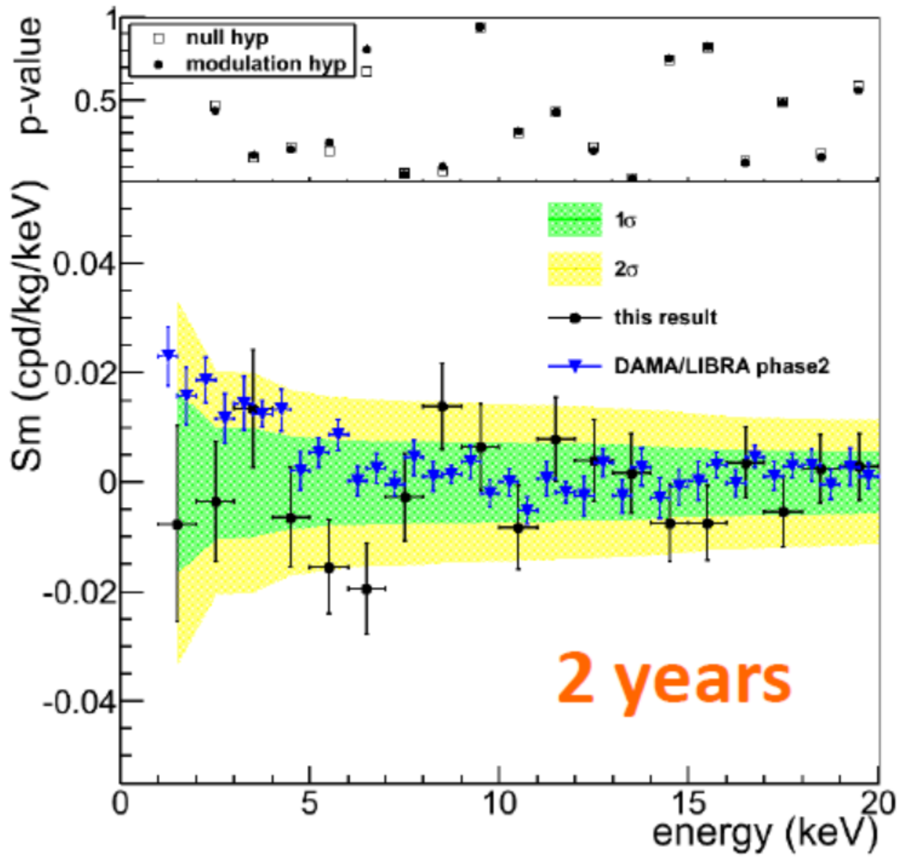
2 years results

M. L. Sarsa @ TAUP2019

PRELIMINARY

213.6 kg x yr

The absence of modulation is well supported also when we consider 1 keV bins in the RoI



Sm & phase free

213.6 kg x yr

M. L. Sarsa @ TAUP2019

PRELIMINARY

$$R(t) = R_0 + R_1 \exp(-t/\tau) + \boldsymbol{S_m} \cos(\omega(t + \phi))$$

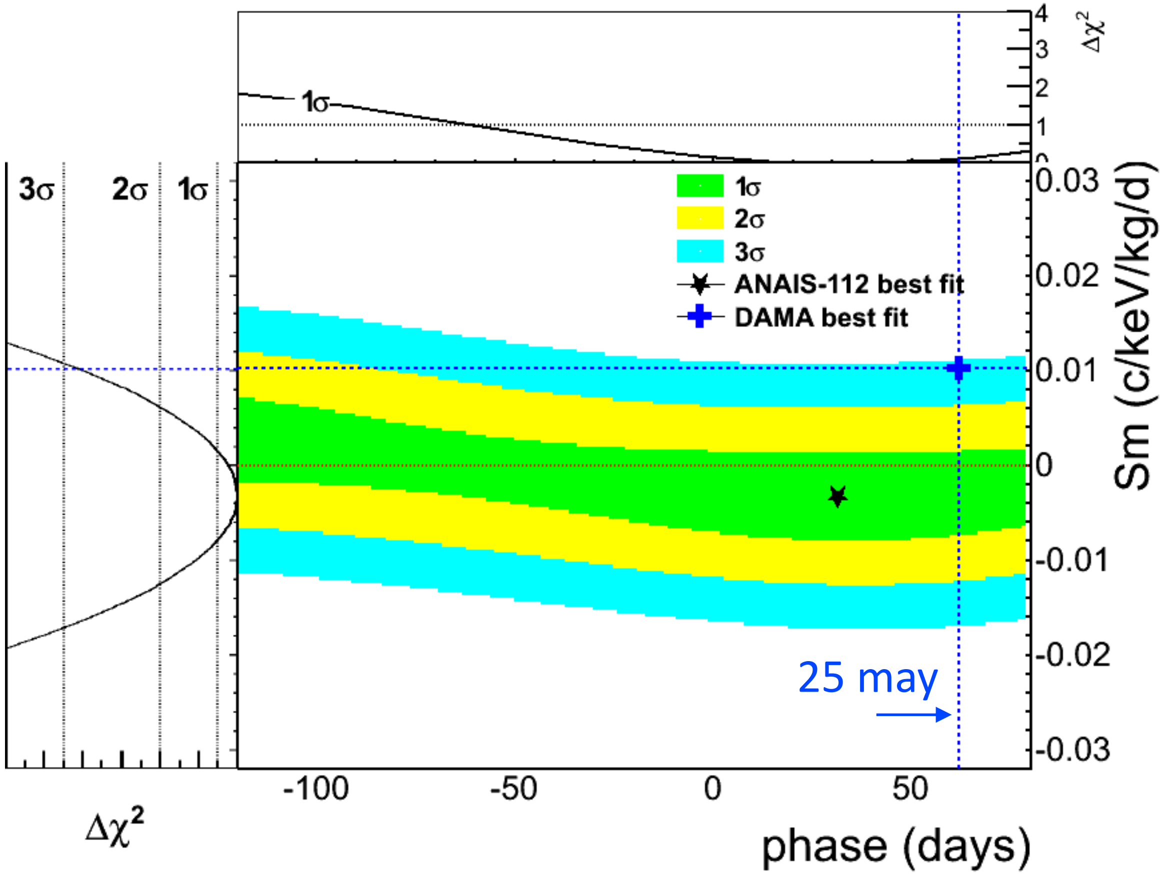
Fixed parameters:

τ (background model)

ω (freq. corresponding to a period of 1 year)

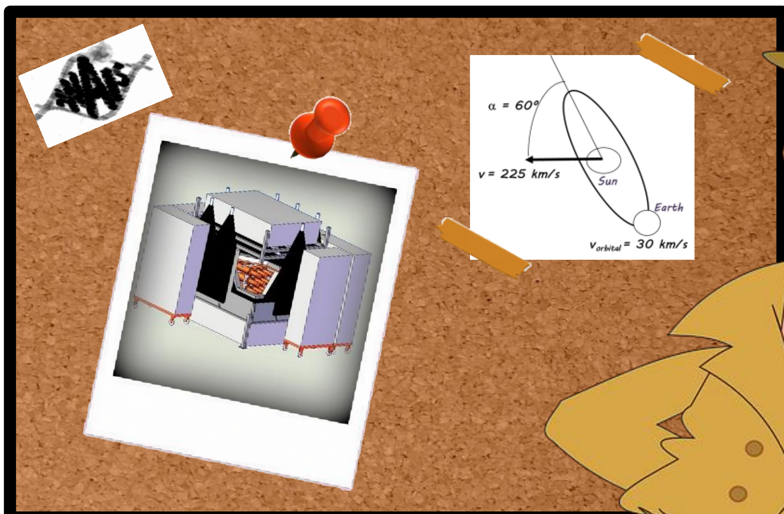
Free parameters:

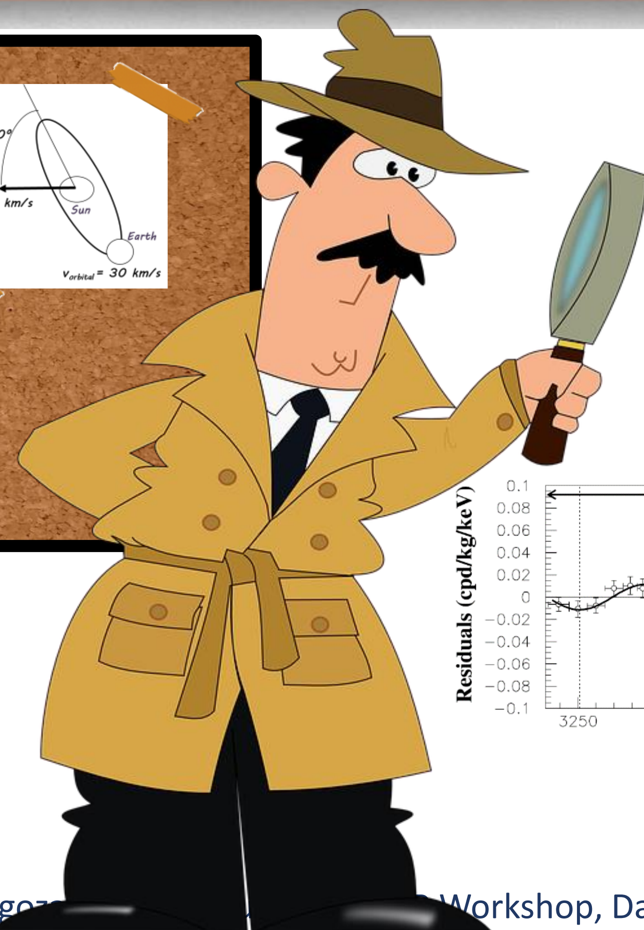
R_0, R_1, S_m, ϕ

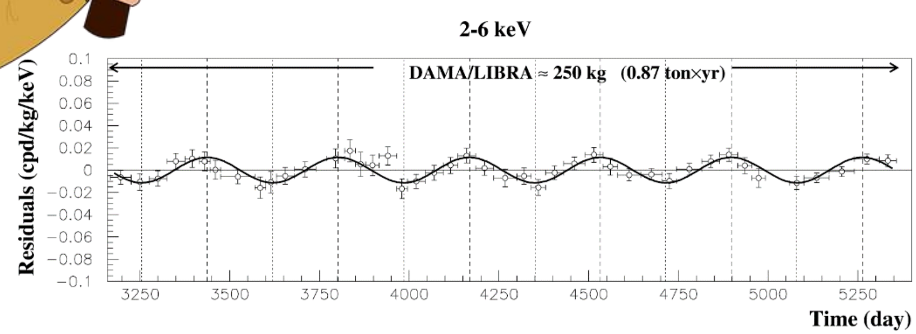


M. Martinez. F. ARAID & U. Zaragoza, 4th IBS-Multidark-IPPP Workshop, Daejeon (South Korea), October 7-11 2019

ANAIS-112 SENSITIVITY



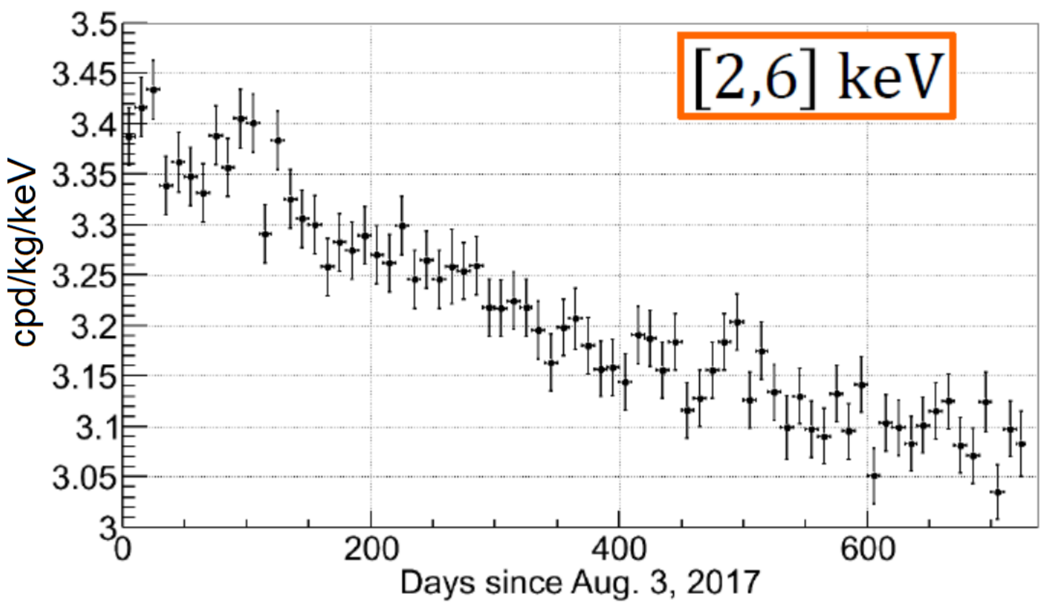




Calculating the sensitivity

Least squared fit to : $R(t) = R_0 + R_1 \exp(-t/\tau) + \boldsymbol{S_m} \cos(\omega(t+\phi))$

Three free parameters (R_0, R_1, S_m)



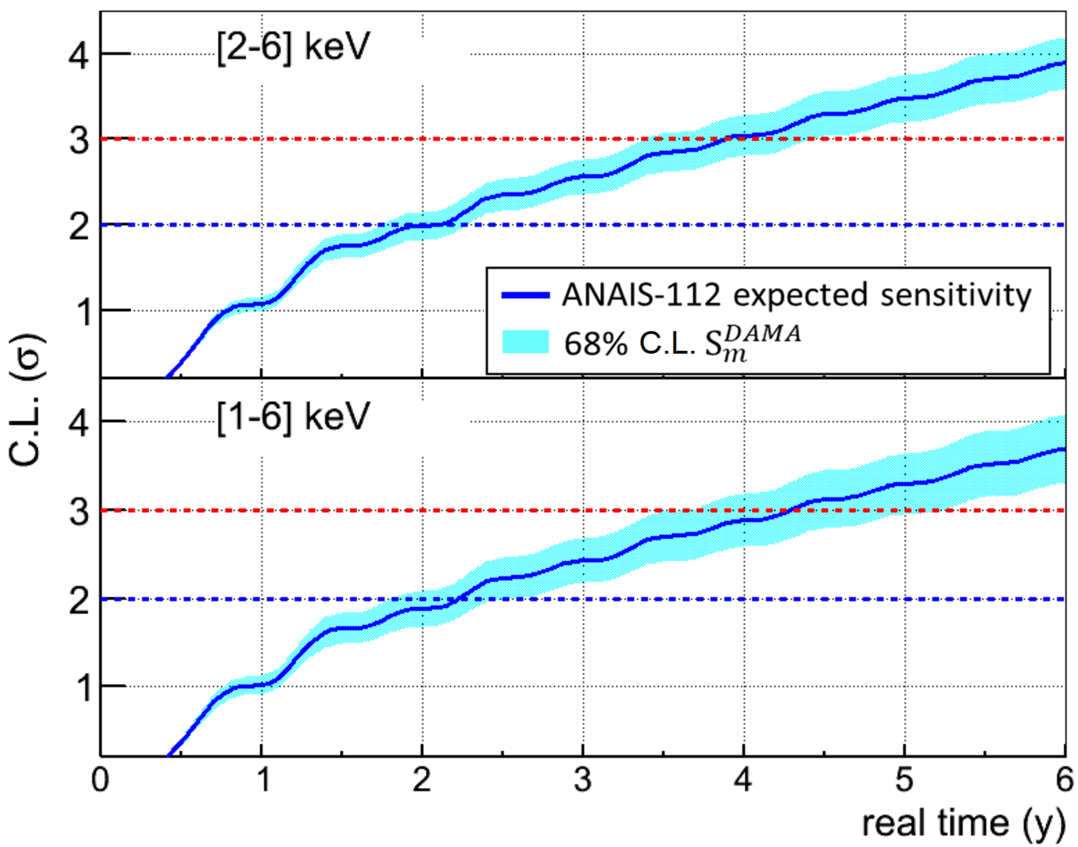
The experimental sensitivity is given by the standard deviation of the modulation amplitude $\boldsymbol{\sigma(S_m)}$, that can be calculated analytically from :

- Updated background
- Efficiency estimate and its error
- Live time distribution

See details in **Coarasa et al., Eur. Phys. J. C (2019) 79:233, 1812.02000**

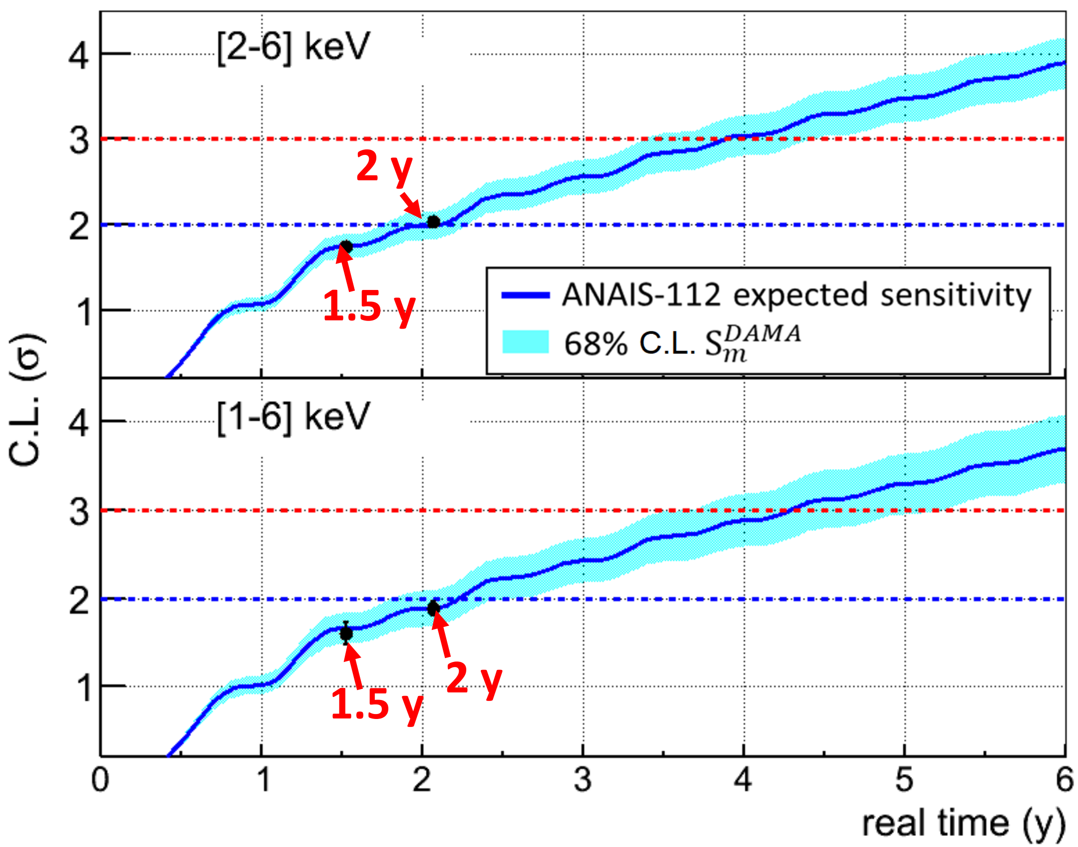
Expected sensitivity

We quote our sensitivity to DAMA/LIBRA result as the ratio $S_m^{DAMA}/\sigma(S_m)$



Expected sensitivity

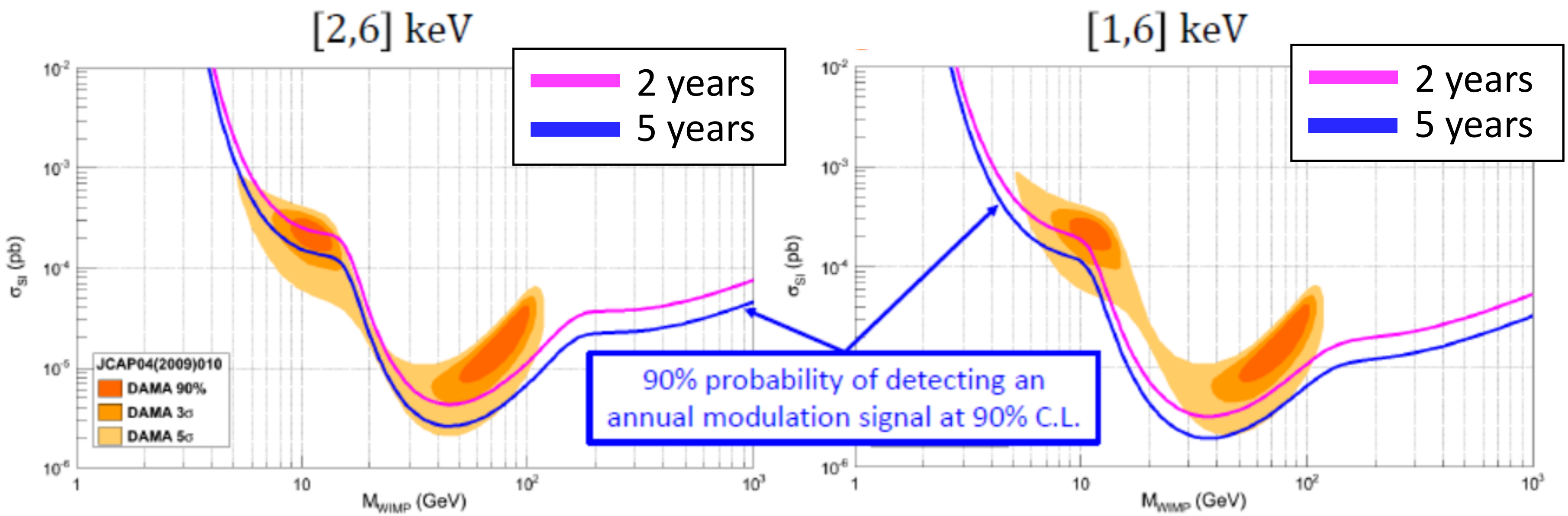
We quote our sensitivity to DAMA/LIBRA result as the ratio $S_m^{DAMA}/\sigma(S_m)$



- **1.5 and 2 y data confirm our sensitivity projection to DAMA/LIBRA result**
- **Present sensitivity: 2σ**
- **3σ at reach in 2.5 years from now**

Model dependent (SI interaction)

Likelihood 90% - 90%



- Standard halo model
- Spin-independent interaction
- $\rho_0 = 0.3\ \mathrm{GeV/cm^3}$
- $v_0 = 220\ \mathrm{km/s}$
- $v_{esc} = 650\ \mathrm{km/s}$
- $Q_{Na} = 0.30, Q_I = 0.09$

DAMA regions from:

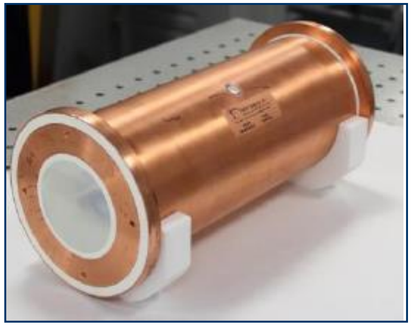
C. Savage et al., JCAP04 (2009) 010

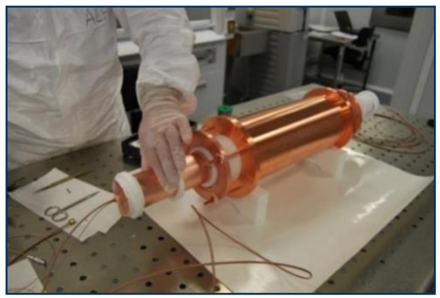
Summary and outlook

- ANAIS-112 is taking data at LSC with 112.5 kg NaI(Tl) with >2 years of data by now
  - Excellent duty cycle: >95% live time
  - low energy calibrations in the RoI every 15 days
  - excellent light collection (15 phe/keV), threshold at 1 keV
  - Good background understanding
- Model-independent annual modulation analysis with 2 years (213.6 kg×y)
  - Null hypothesis well supported by χ^2 test
  - best fits for modulation hypothesis incompatible with DAMA/LIBRA at 2.6σ. Present sensitivity: 2σ
  - 3σ sensitivity at reach in about 2.5 years from now
- Near future:
  - Improve event selection near threshold. Blank module taking data in LSC will provide a pure "noise population"
  - Preliminary conversations to combine ANAIS-112 and COSINE-100 data to reach 3σ sensitivity sooner
  - Plan to make ANAIS data public after use to allow independent analysis

SPARE

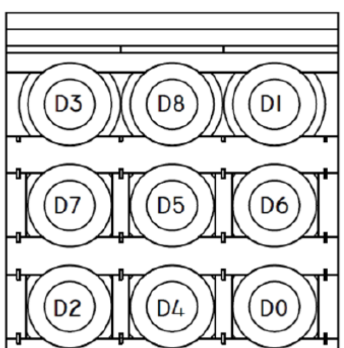
ANAIS-112: Detectors





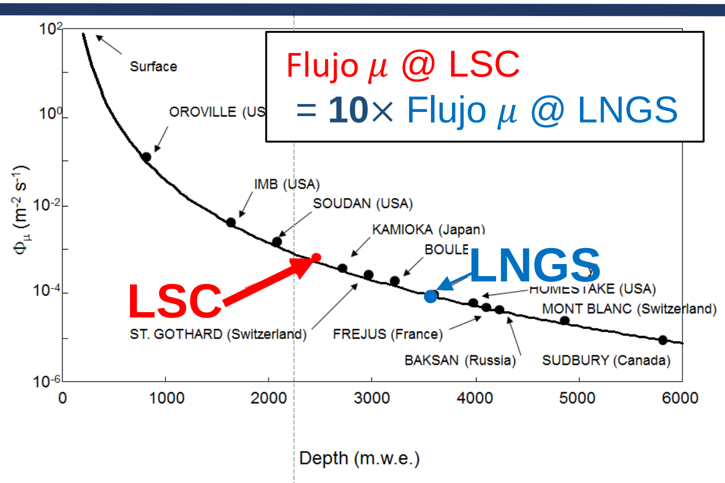
Housing made at LSC of electroformed copper

- **9 NaI(Tl) crystals** grown from selected ultrapure NaI powder (Alpha Spectra Inc)
- Housed in OFE copper
- Two Hamamatsu R12669SEL2 PMT
  - coupled at LSC clean room
  - low background
  - high QE (~40%)



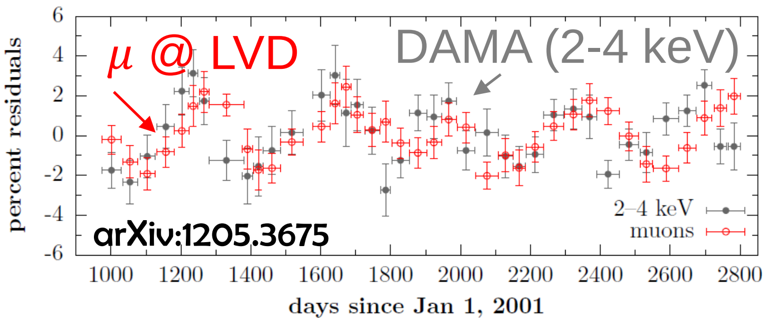
Detector	*Quality powder*	*Received at LSC:*
D0, D1	<90 ppb K	December 2012
D2	WIMPScint-II	March 2015
D3	WIMPScint-III	March 2016
D4, D5	WIMPScint-III	November 2016
D6, D7, D8	WIMPScint-III	March 2017

ANAIS-112: Muon Veto

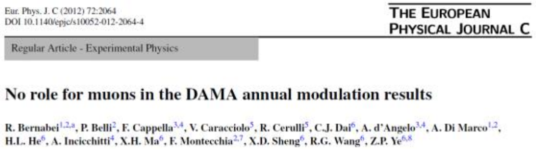


In ANAIS we flag every muon that cross the shielding and set a (configurable) dead-time after every passage (DAMA/LIBRA has no muon veto)

The underground muon flux is annual-modulated!



DAMA reply:


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

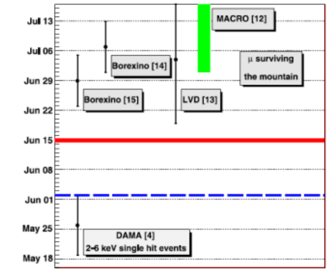
THE EUROPEAN PHYSICAL JOURNAL C

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

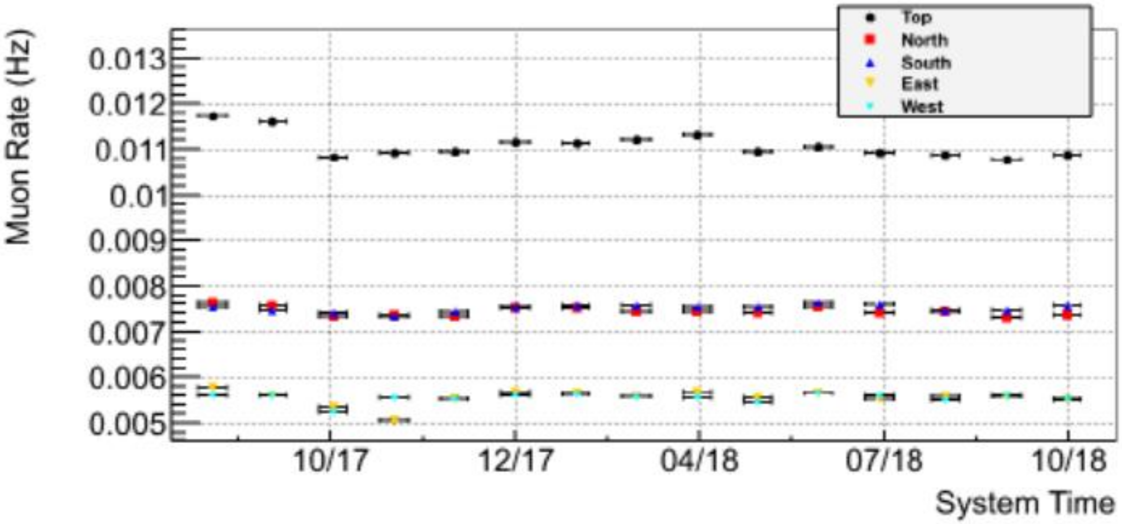
- Modulation phase inconsistency
- Muons interacting directly in the detectors do not fulfill the DM requisites
- Not enough muon-induced fast neutrons to account for the signal



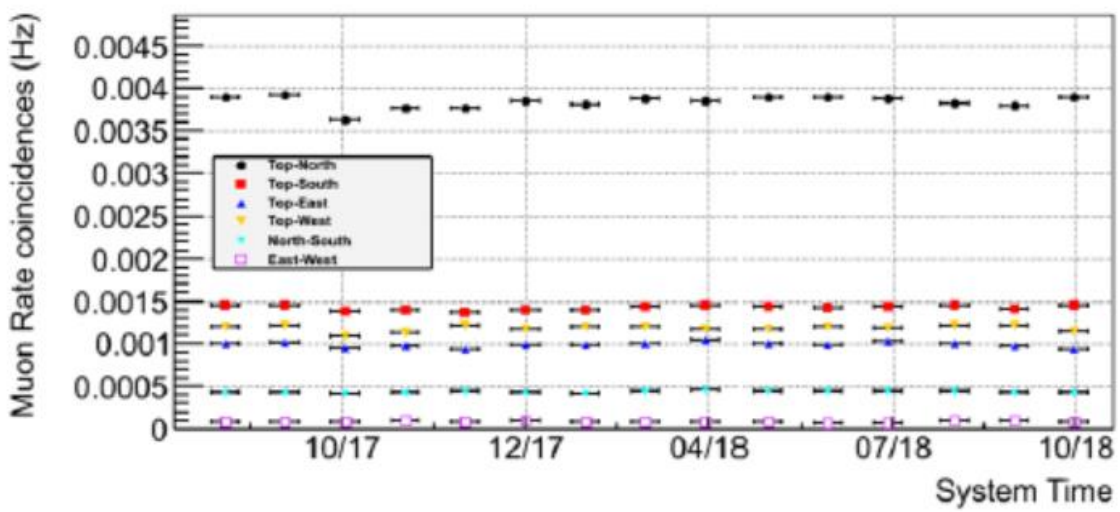
But still some open questions:
- (delayed) effect of muons in PMTs?
- slow phosphorescence in NaI?

ANAIS can test these hypotheses

Muon rate

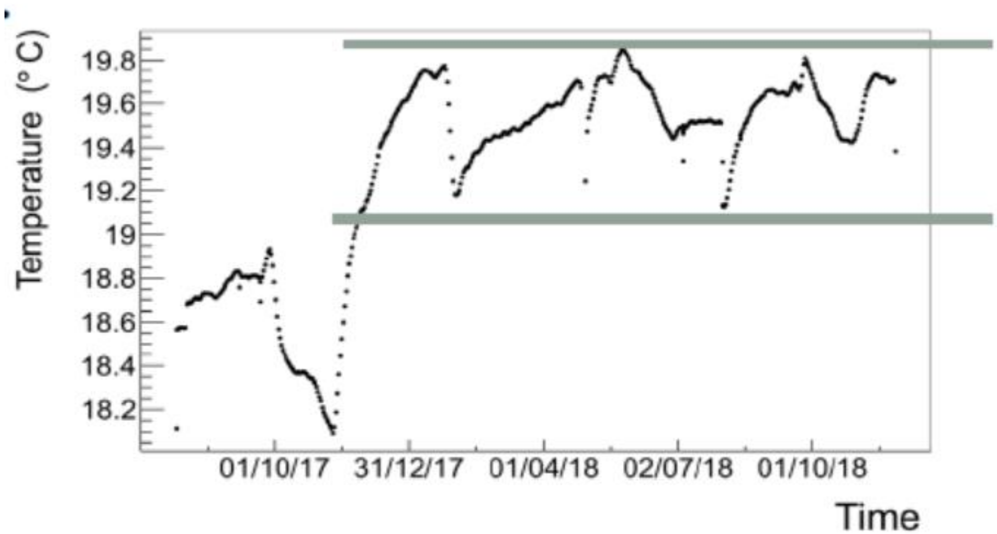


Rates at each side of the veto system on a monthly basis.



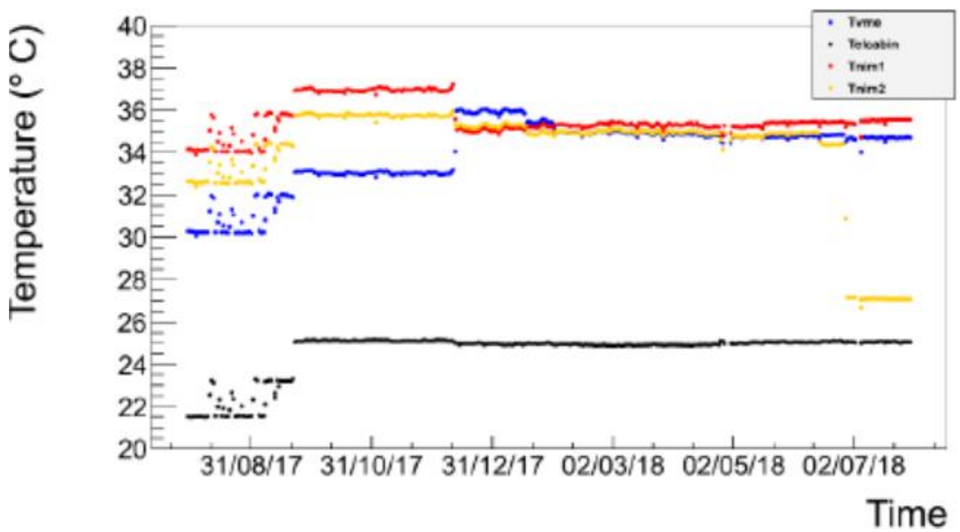
Rates of coincidences between two sides of the veto system on a monthly basis

Temperature evolution



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

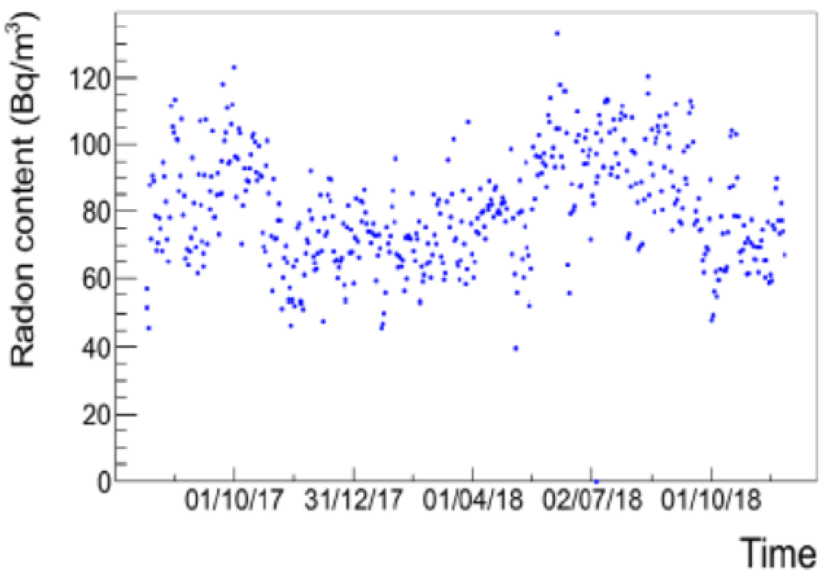
Mean value: 19.24ºC
Standard deviation: 0.48ºC

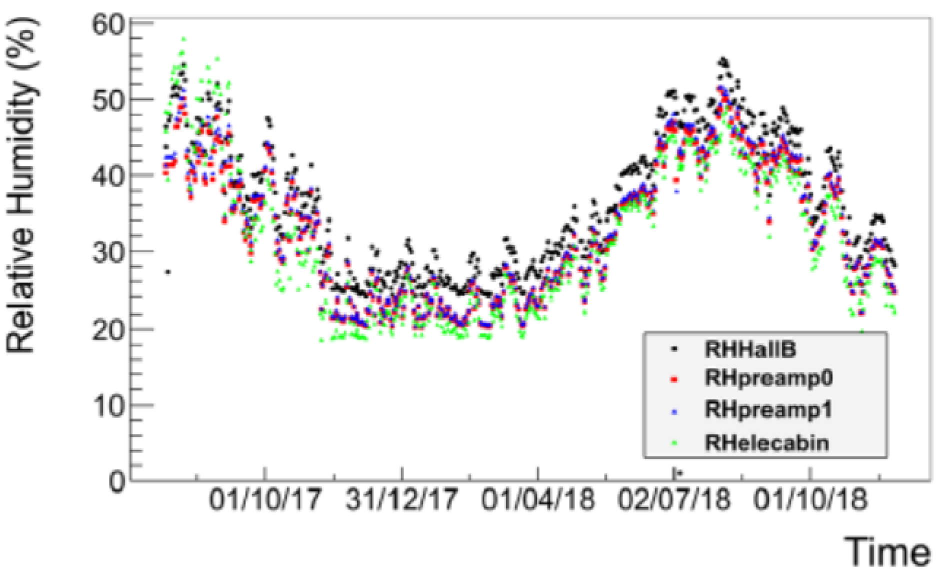


Temperatures at the electronics -> Fully decoupled from Hall B temperature

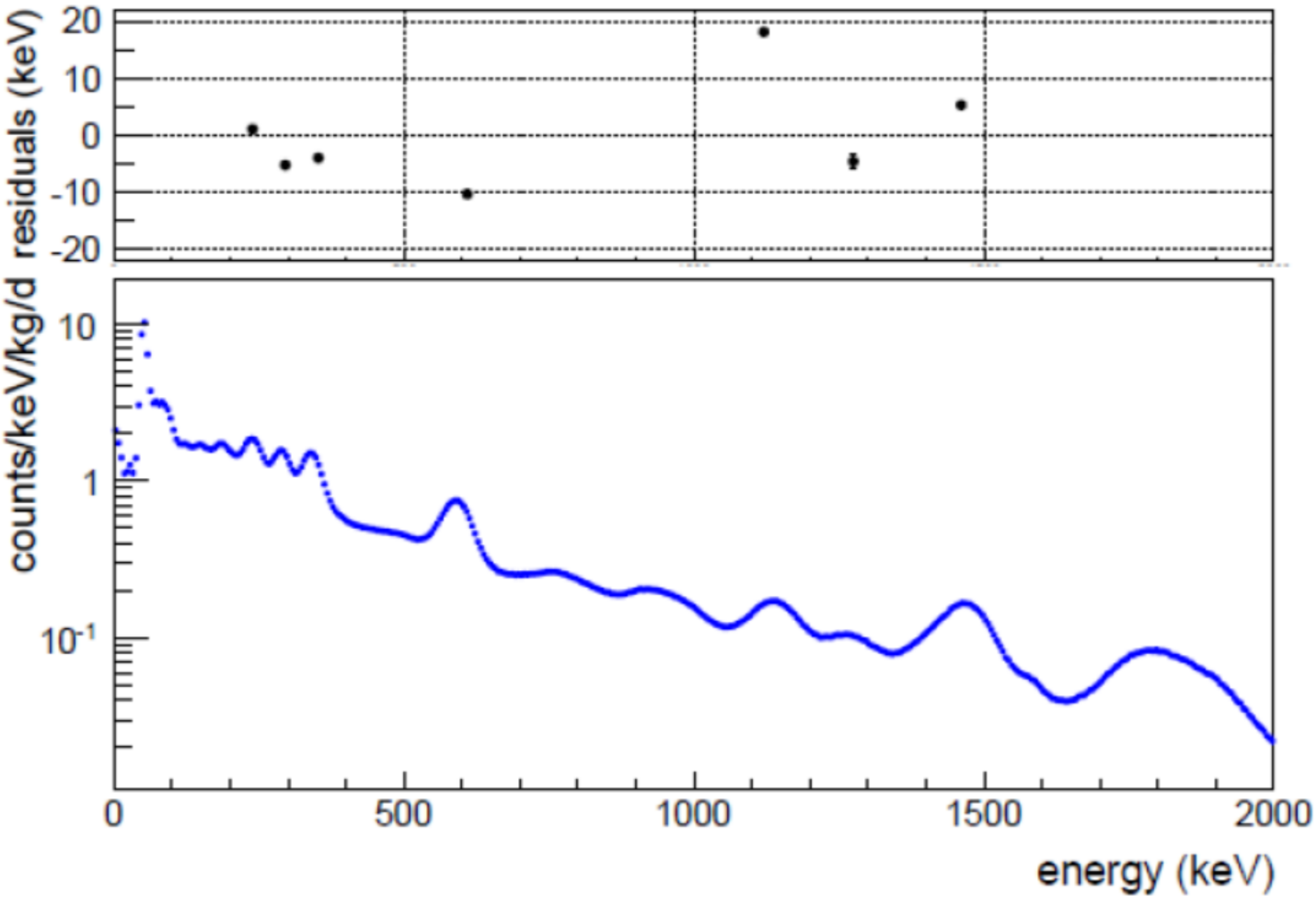
Monitoring environmental parameters

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

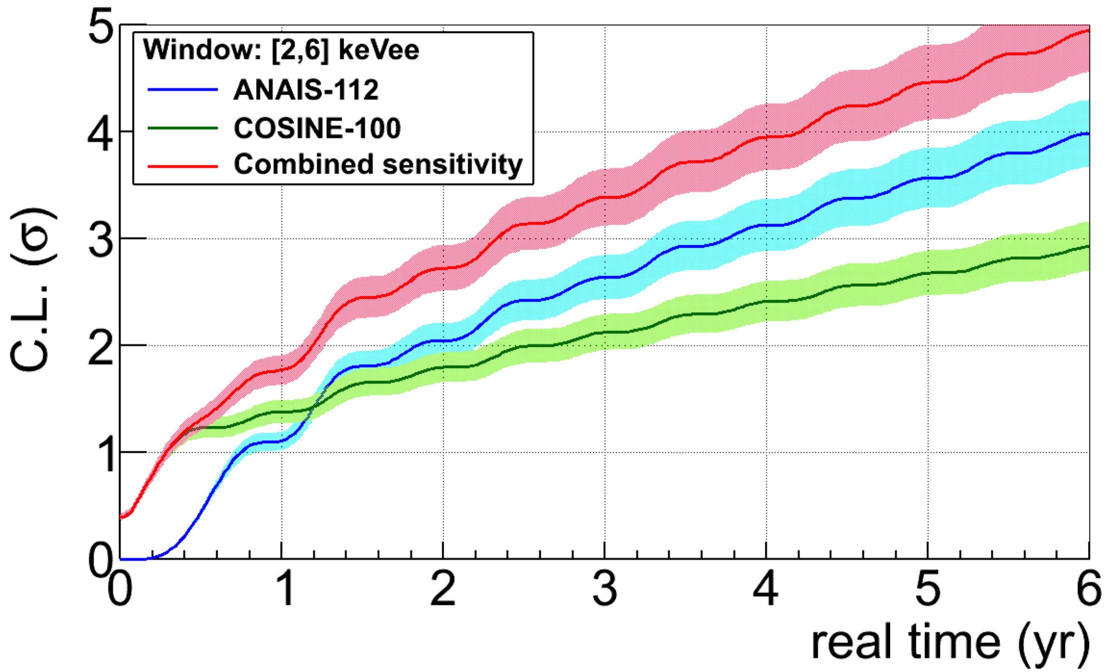




High energy calibration



Projected combined sensitivity



ANAIS-112 mass: 112.5 kg
COSINE-100 mass: 61.4 kg

COSINE background & efficiencies taken from

Nature 564 (2018) 83-86
Phys.Rev.Lett. 123 (2019) 031301

- **3σ sensitivity** can be reached in **4 months from now**
- **4σ sensitivity** can be reached in **2 years from now**