Dark matter annual modulation and ANAIS-112 results

testing the DAMA/LIBRA positive signal

María Martínez, ARAID & U. Zaragoza

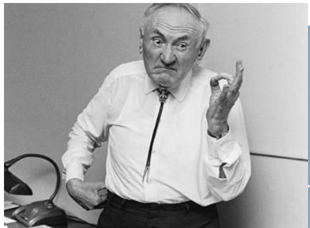
Freiburg, December 18, 2019

OUTLINE

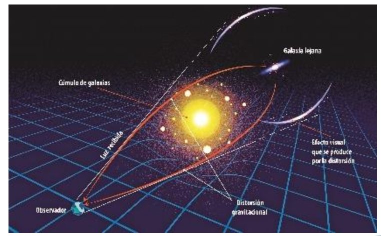
- Intro: Dark matter annual modulation
- Historical review
  - DAMA/LIBRA positive signal
- Current NaI(Tl) experiments
- ANAIS-112
  - Experimental set-up
  - Detector performance
  - Results on anual modulation
  - ANAIS-112 sensitivity
- Summary

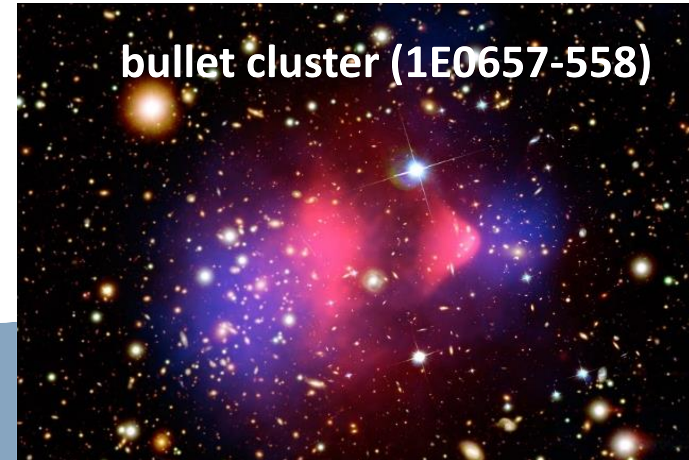
Intro: DARK MATTER ANNUAL MODULATION

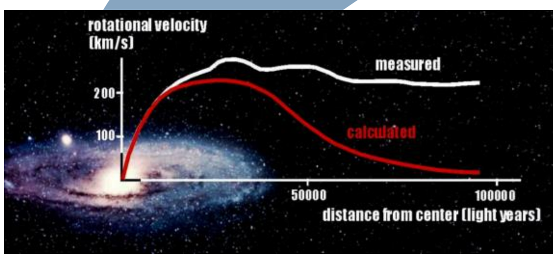
Evidence of Dark Matter

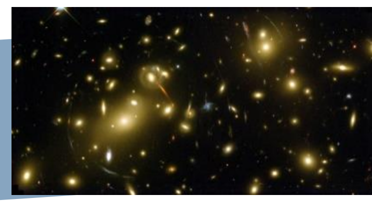


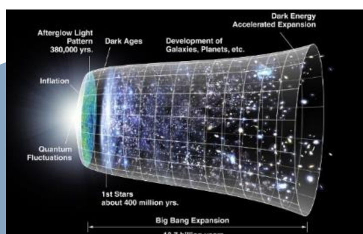
Zwicky (1933)

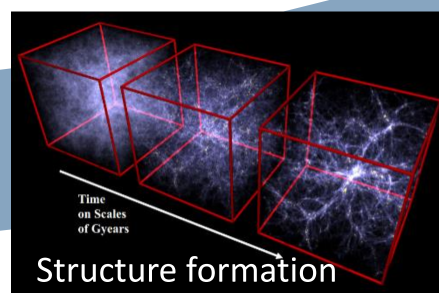




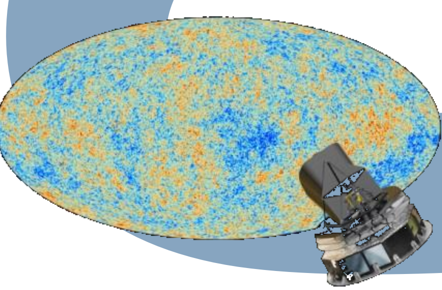


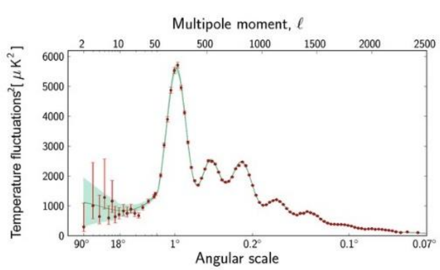


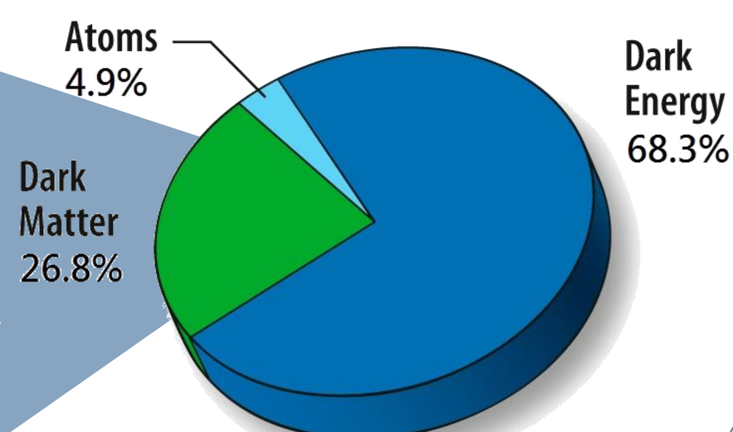




DM dominates all the structures of the Universe!







DM candidates

What we know:

- lifetime >> age of Universe
- No (or very very small) interaction with light
- Non baryonic
- Cold (or Warm) (Moving non-relativistically when galaxies started to form)
- Beyond the Standard Model

DM candidates

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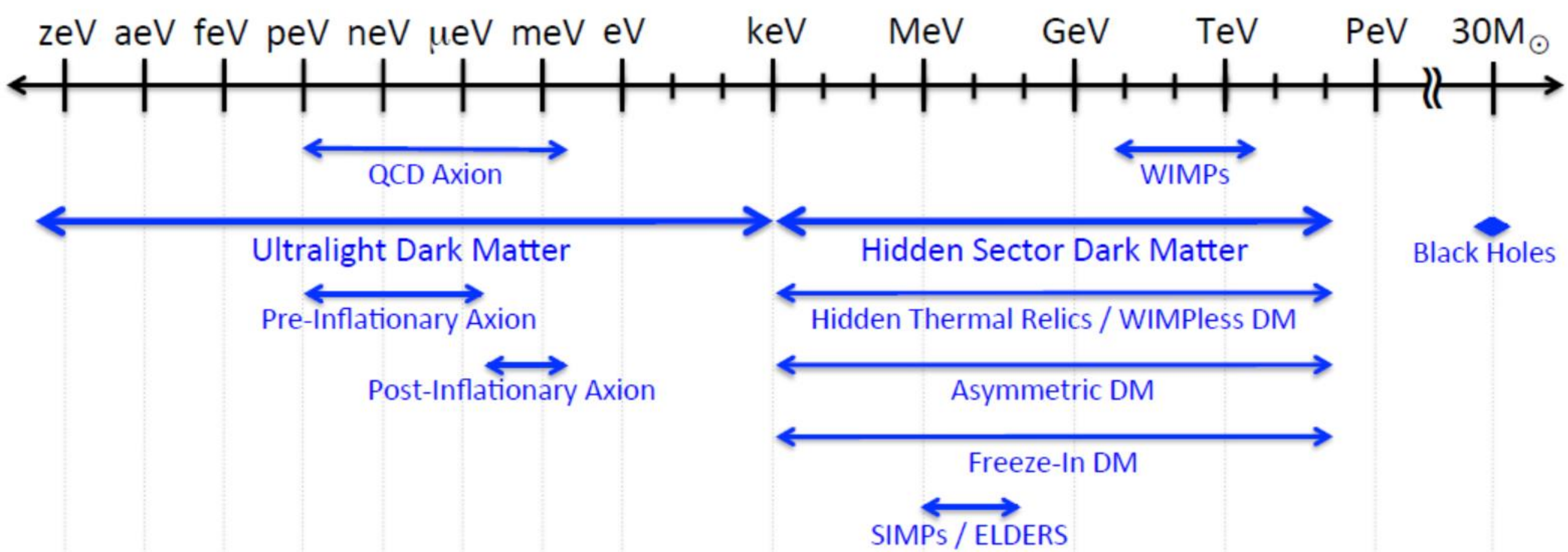
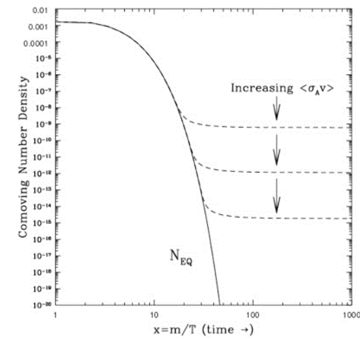


WIMPs

Weakly interacting Massive Particles (WIMPs) very well motivated

- For the observed DM density, σ corresponds to the one expected for a new weak-interacting particle
- WIMPs predicted in many extensions of the Standard Model such as SUSY

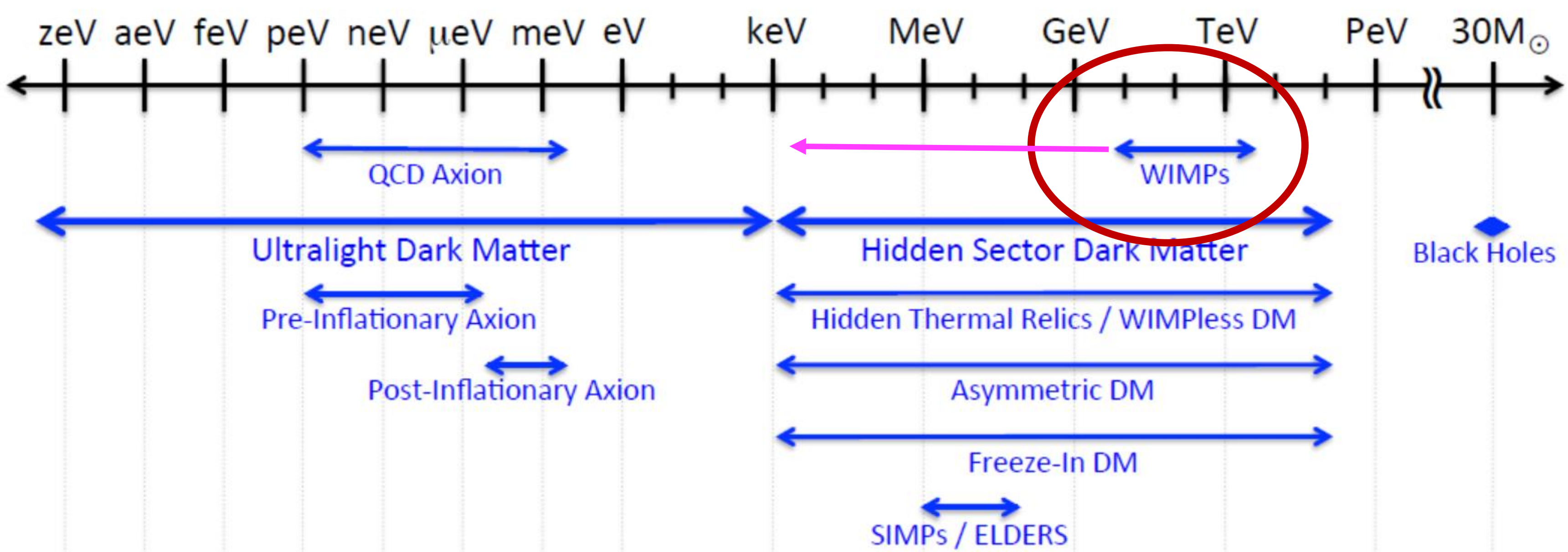


Jungman *et al* hep-ph/9506380

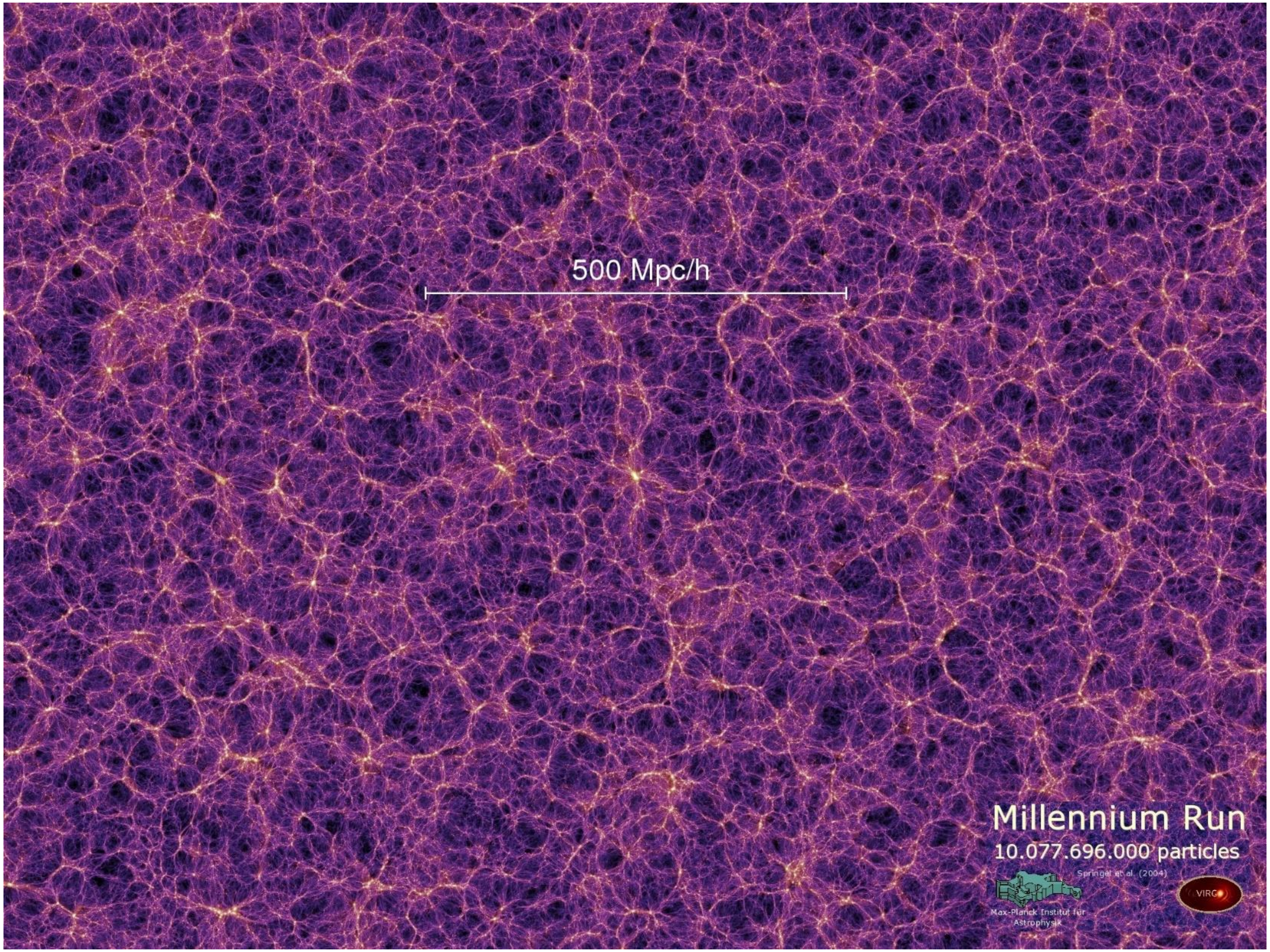
Abundance of a termal relic

$$\sim \frac{0.1\, pb}{<\sigma_A\, v/c>}$$

...but not only thermal WIMPs...



Structure of the Universe



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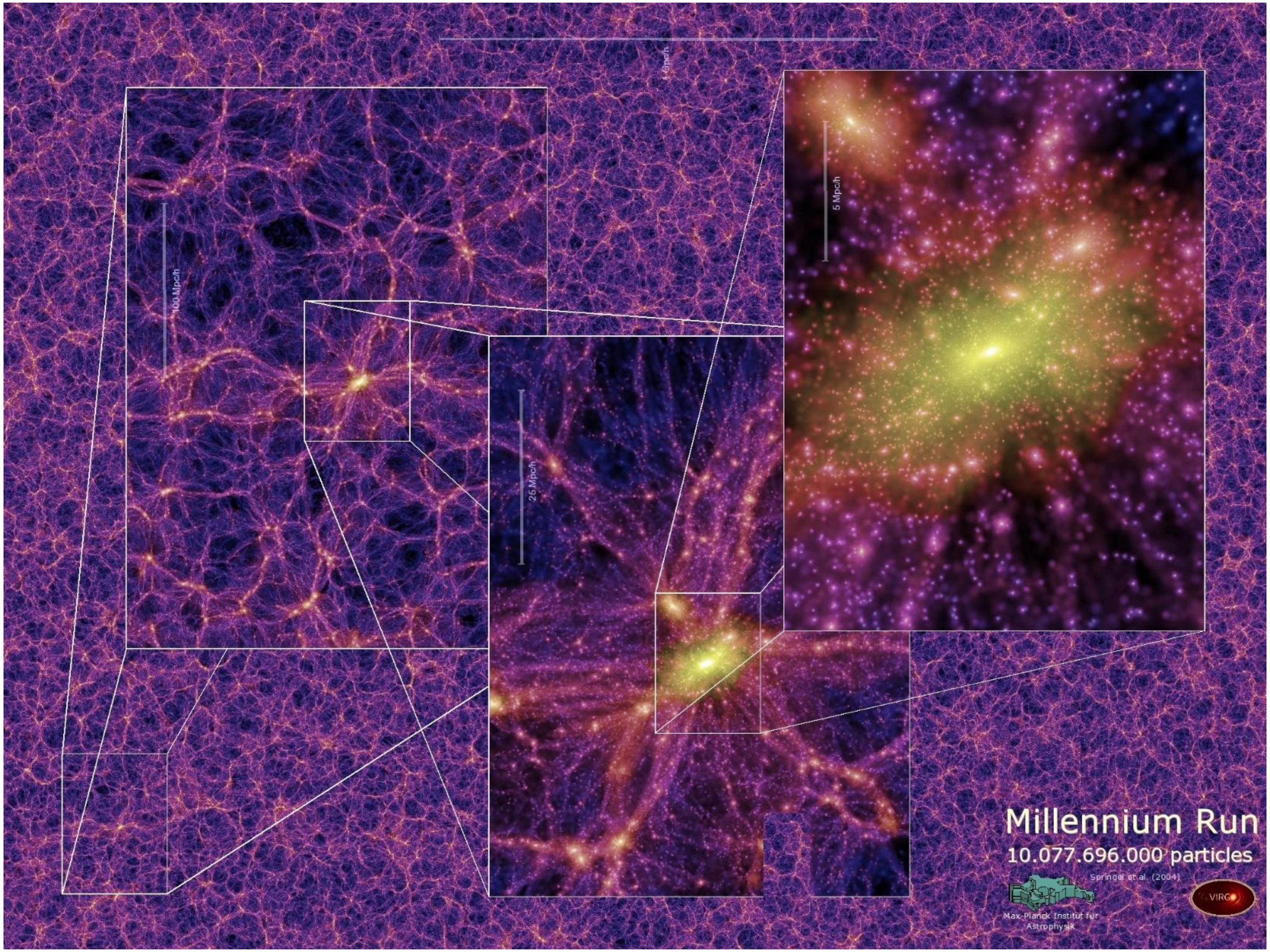
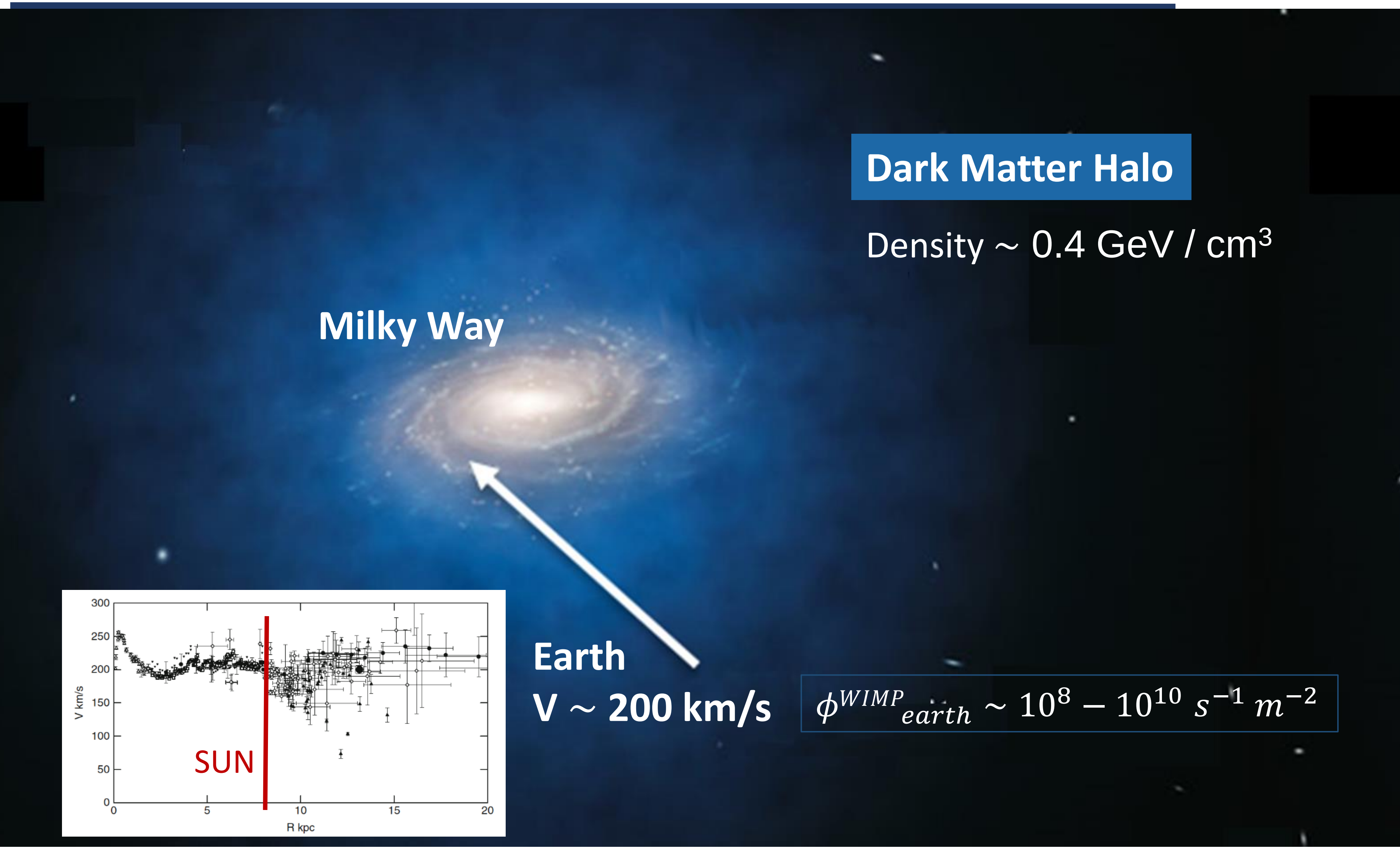
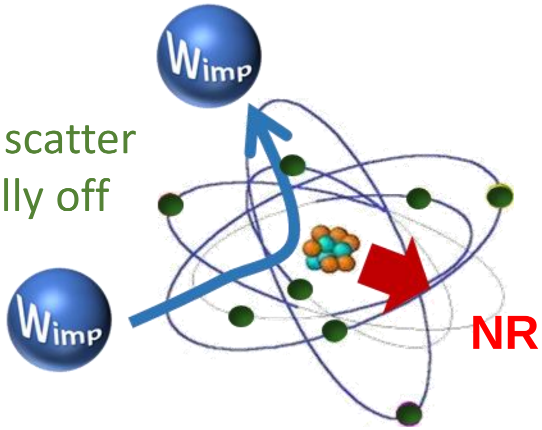


Milky way dark matter halo



WIMP direct detection

WIMPs scatter elastically off nuclei



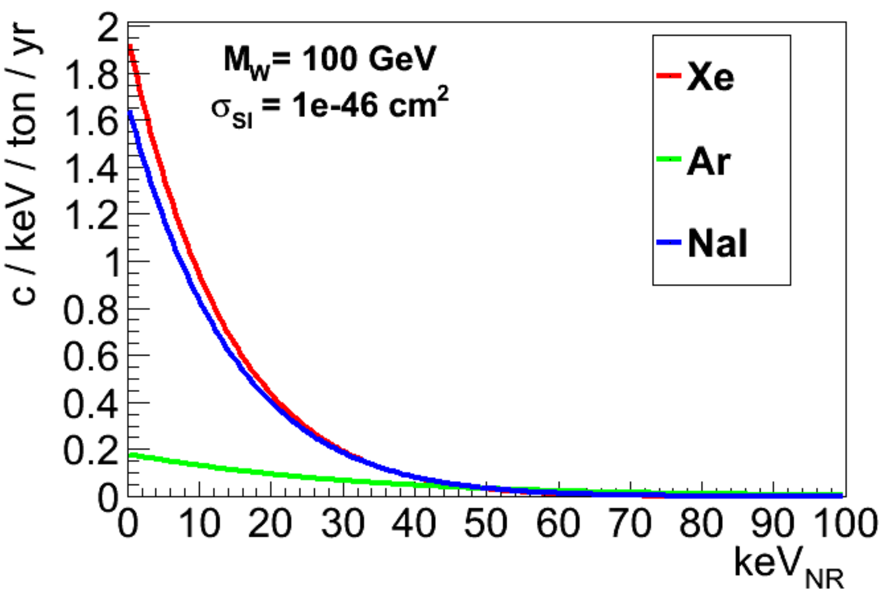
Expected rate @ Earth:

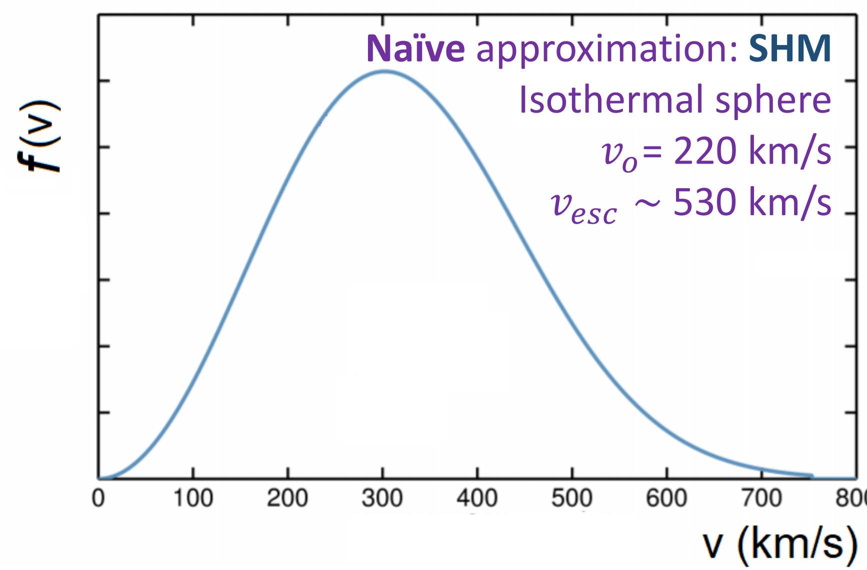
Wimp model

Halo model

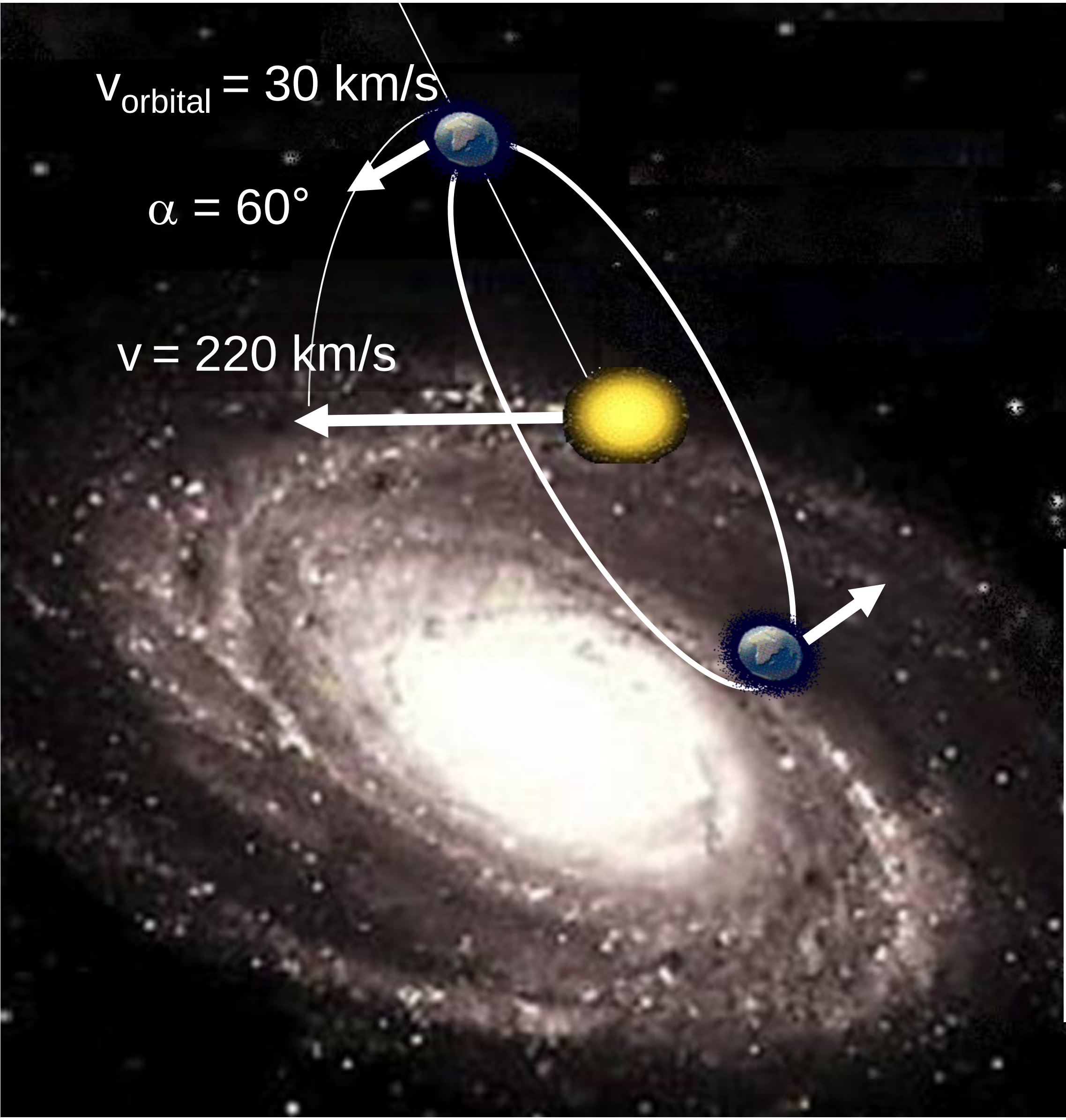
$$\frac{dR}{dE_R} = \frac{\rho_0 M_{Det}}{2 m_W m_{WN}^2} \sigma_{WN} \int_{vmin}^{vmax} \frac{f(v)}{v} dv^3$$

TARGET DEPENDENT!

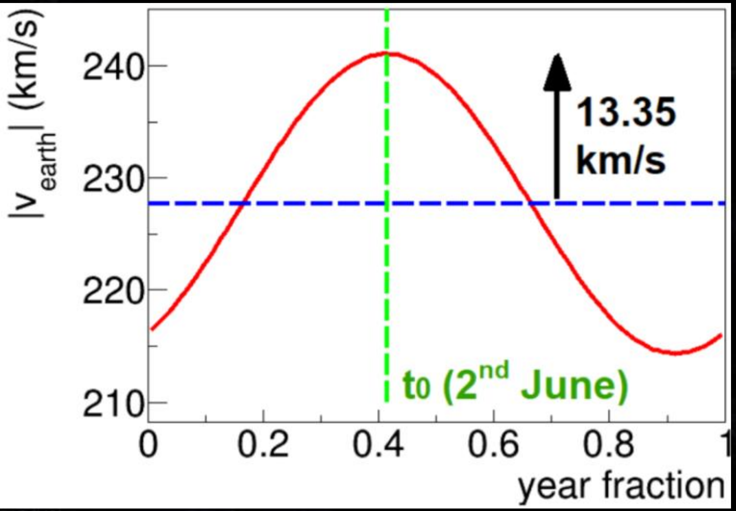




Annual modulation



Due to the Earth revolution around the Sun, the relative speed Eath-halo present a cosine-like behavior with 1 year periodicity and small amplitude (~ 7%)



Annual modulation

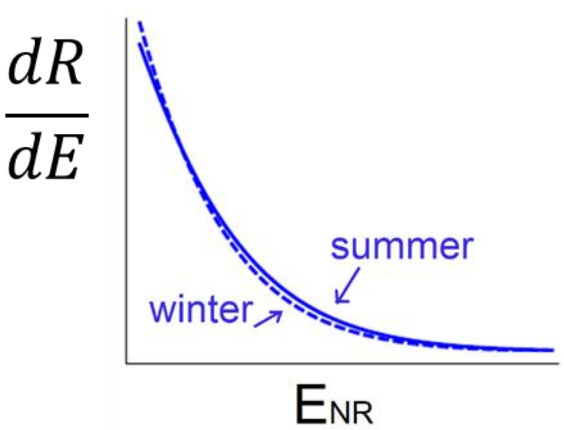
$$\frac{dR}{dE}(E,t) \approx S_0(E) + S_m(E)\cos\omega(t - t_0)$$

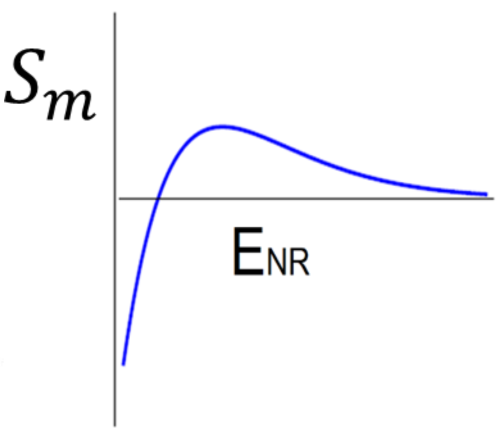
Where

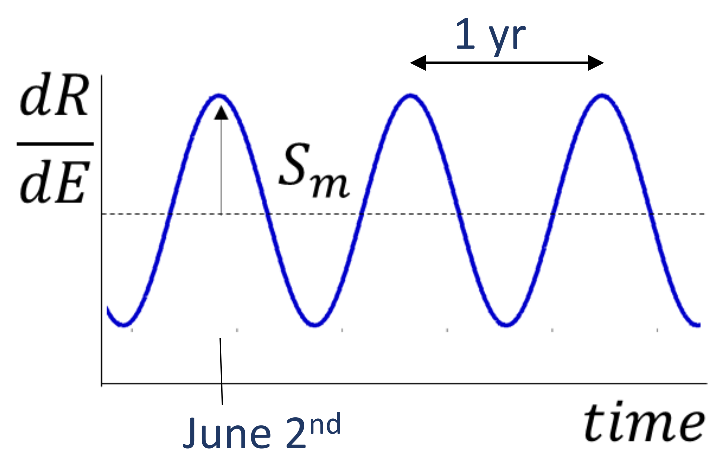
$$S_m(E) = \frac{1}{2}\left(\frac{dR}{dE}(E,t_0) - \frac{dR}{dE}(E,t_0+182)\right)$$

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

Hard to mimic by background!

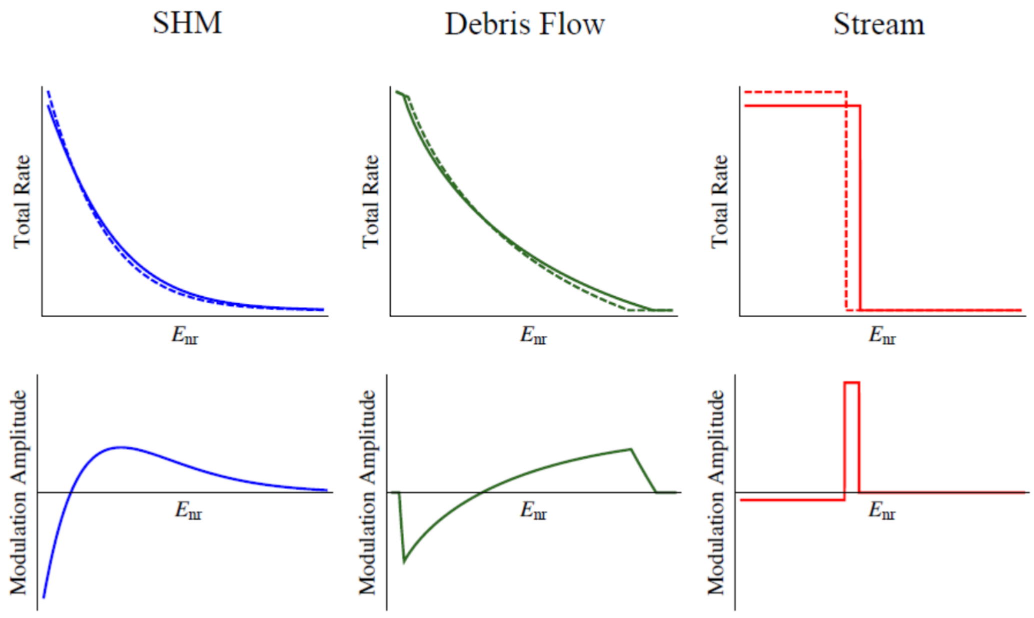


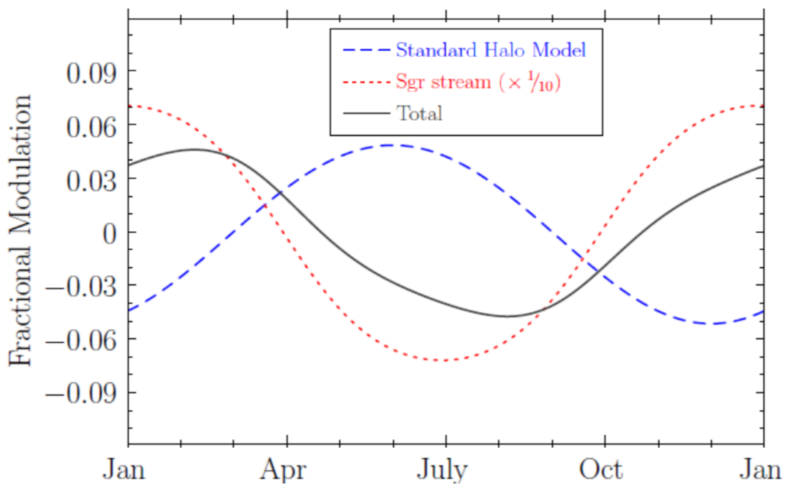




Annual modulation

Caveat: the modulation (phase and amplitude) depends on the halo model, in particular of the presence of substrucutre





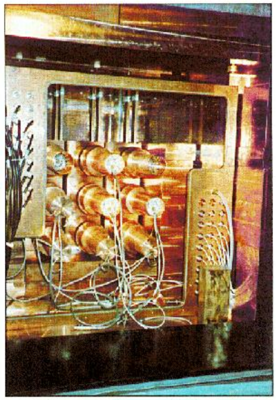
Freese, Lisanti, Savage, Rev. Mod. Phys 85 (2013)

DAMA: an observatory for rare processes @LNGS

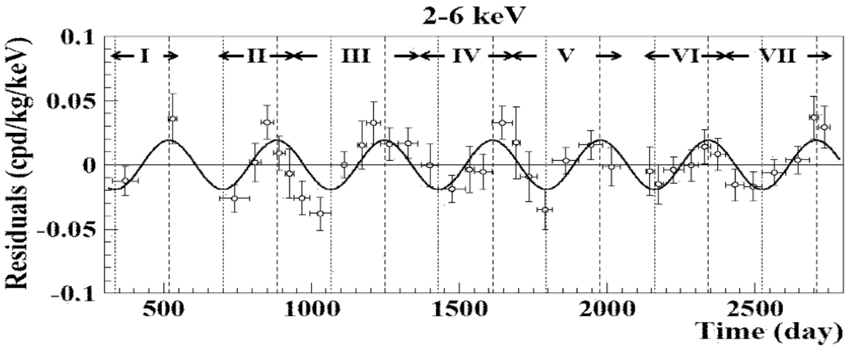
http://people.roma2.infn.it/dama

DAMA/NaI & DAMA/LIBRA (phase 1)

DAMA / NaI (1995-2002)



- 10 × 9.7 kg NaI(Tl) (3x3 matrix)
- 7 anual cycles
- Expusure : 0.29 ton × y



Riv. Nuov. Cim., 26 (2003) 1

The data support the presence of a modulation (1 y period, phase on May 20th) at **6.3σ CL**

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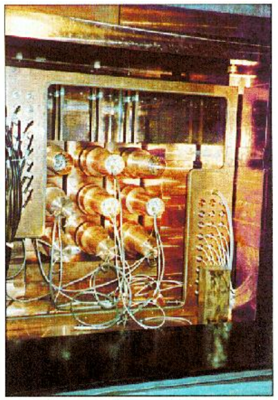

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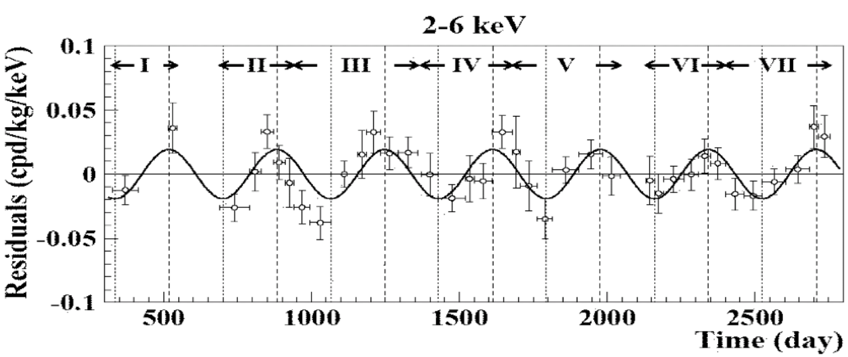
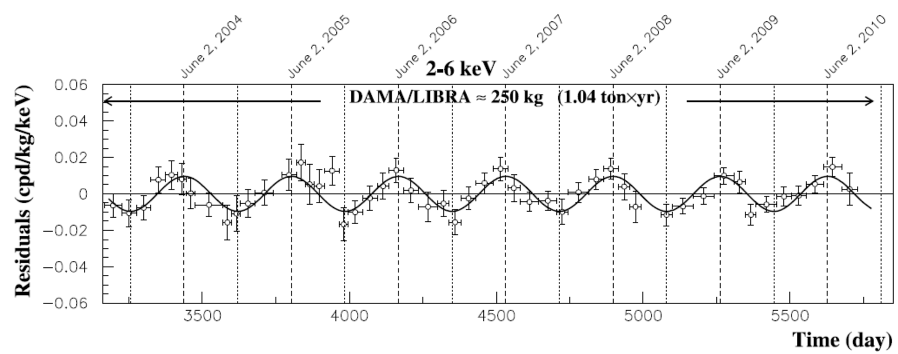


Riv. Nuov. Cim., 26 (2003) 1

The data support the presence of a modulation (1 y period, phase on May 20th) at **6.3σ CL**

DAMA / LIBRA (2003-2010)

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

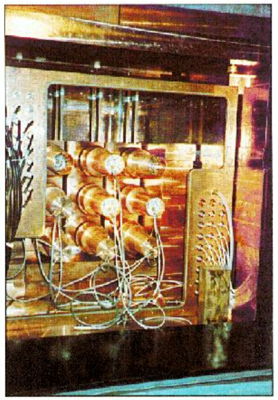


Eur. Phys. J. C (2013) 73:2648

The data support the presence of a modulation (1 y period, phase on May 20th) at **9.2σ CL**

DAMA/NaI & DAMA/LIBRA (phase 1)

DAMA / NaI (1995-2002)



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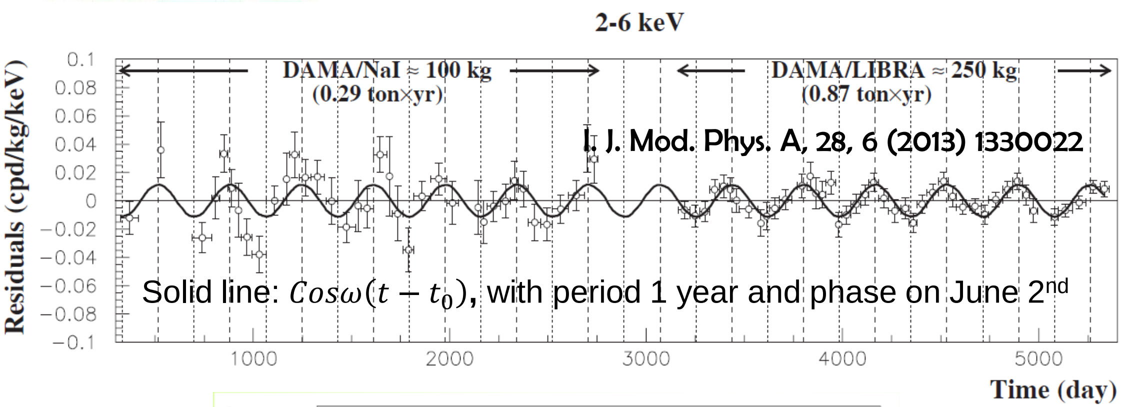
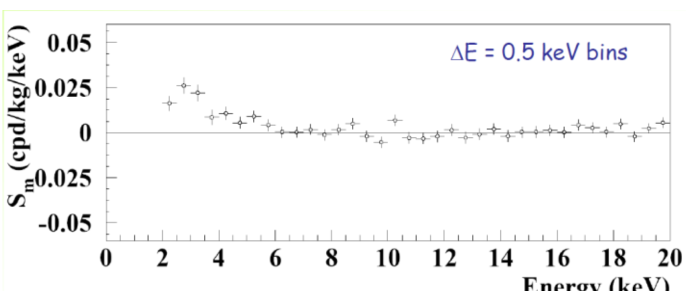
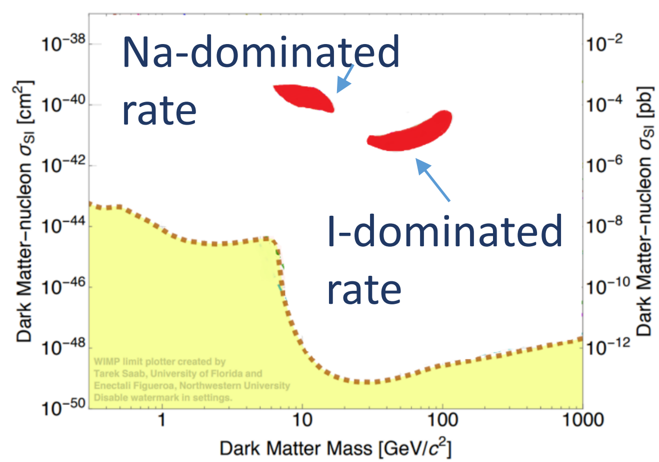
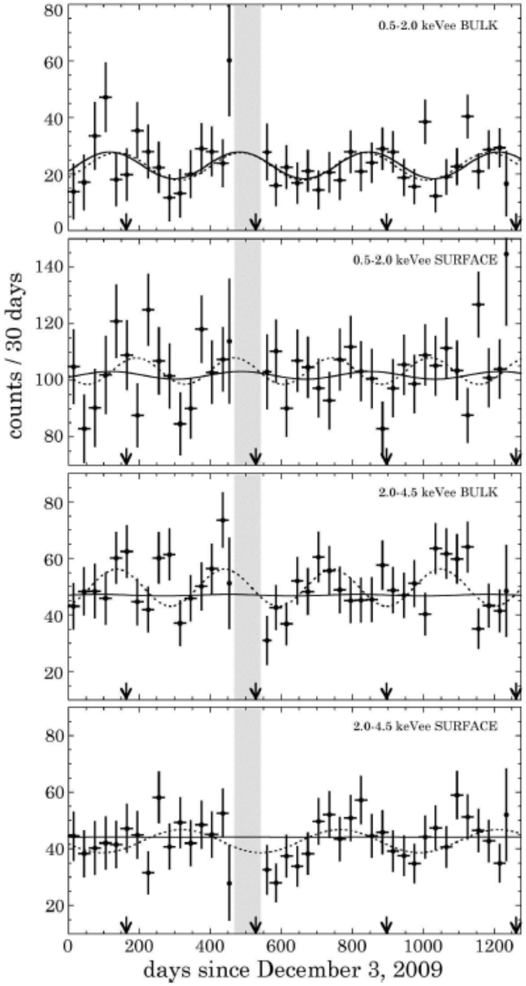




The signal satisfies all requirements for DM and can be interpreted as a std WIMP in the SHM

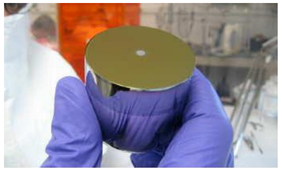


2011-2013 exciting times



Hint of annual modulation in one experiment

CoGeNT (2011-2014)



One PPC HPGe @ SOUDAN

330 g Ge, 3.4 years
No β/γ discrimination

(Sm 4-7 times larger than predicted in SHM)

ArXiv:1401.3295

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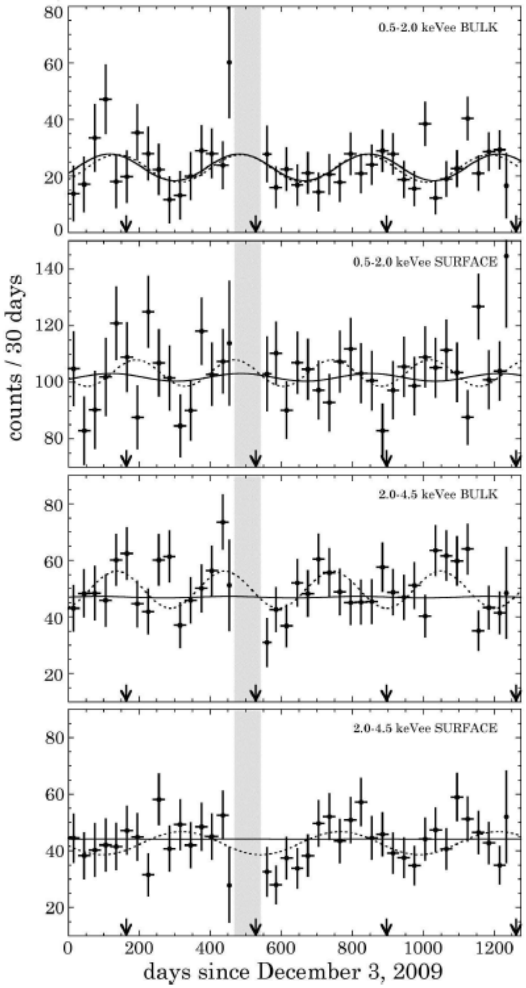

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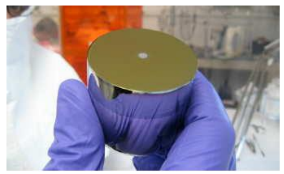

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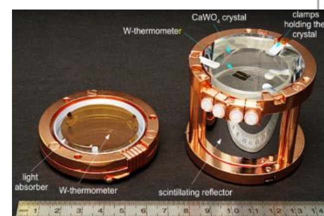
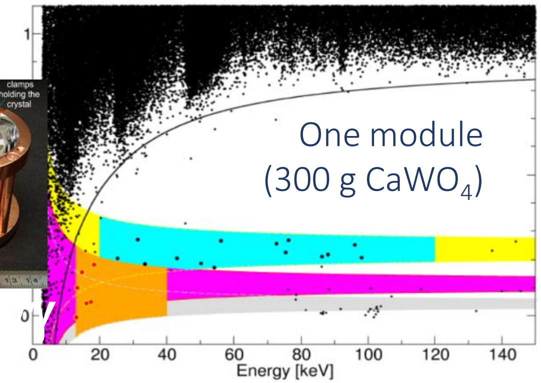
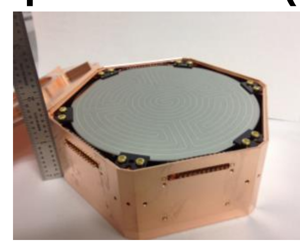
Excess of events in WIMP region in two experiments:

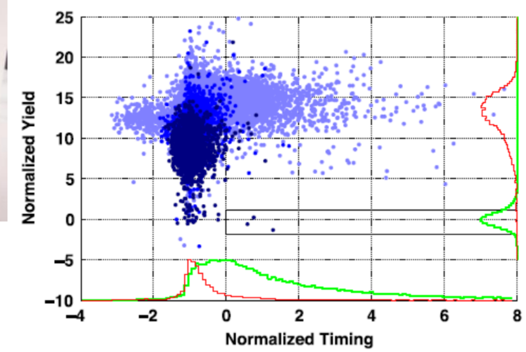
CRESST (2011)





SuperCDMS-Si (2013)





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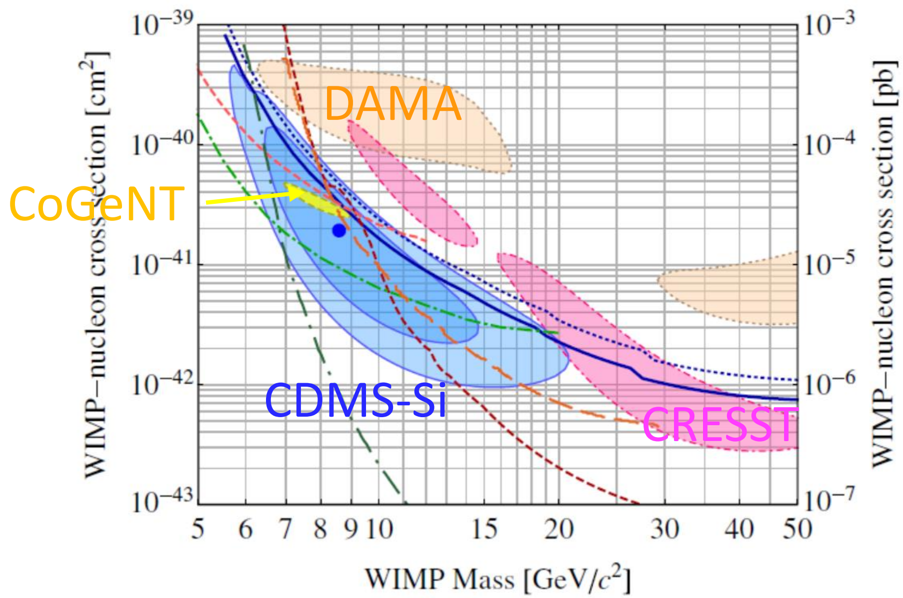
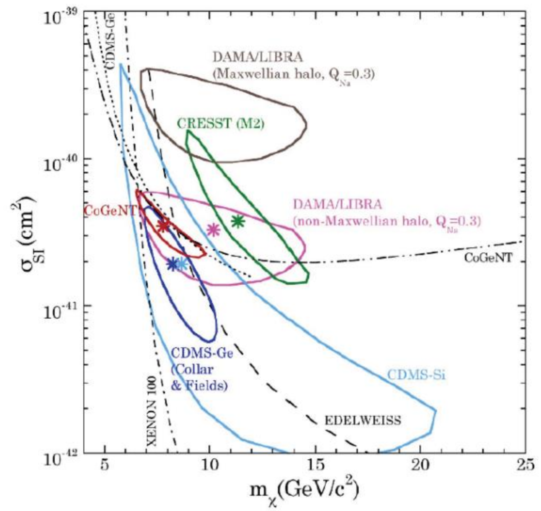


CoGeNT modulation too large, but can be in agreement with DAMA/LIBRA for some non-SHM haloes



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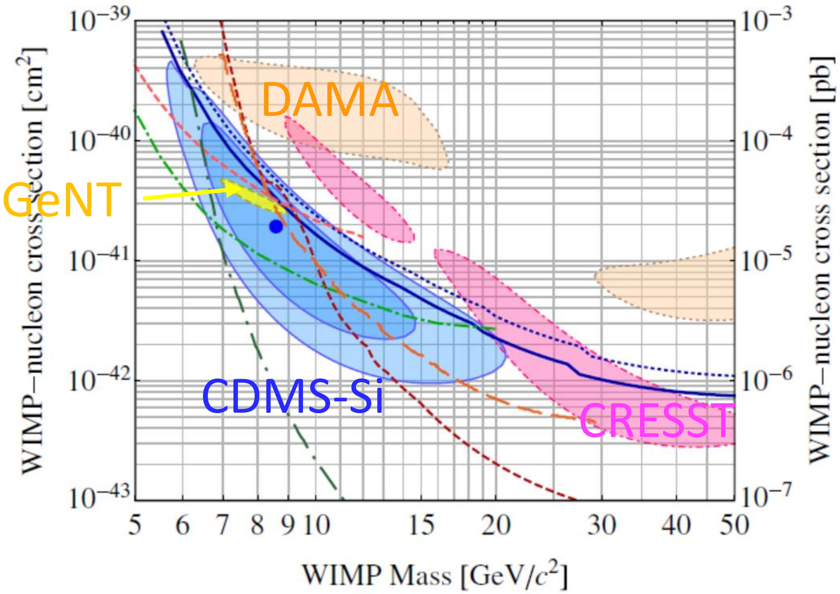

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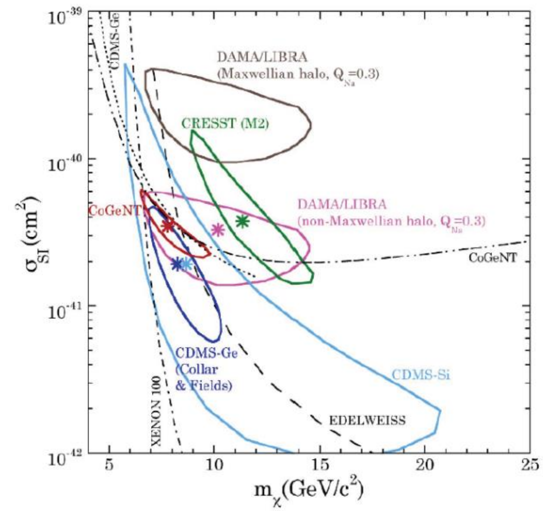
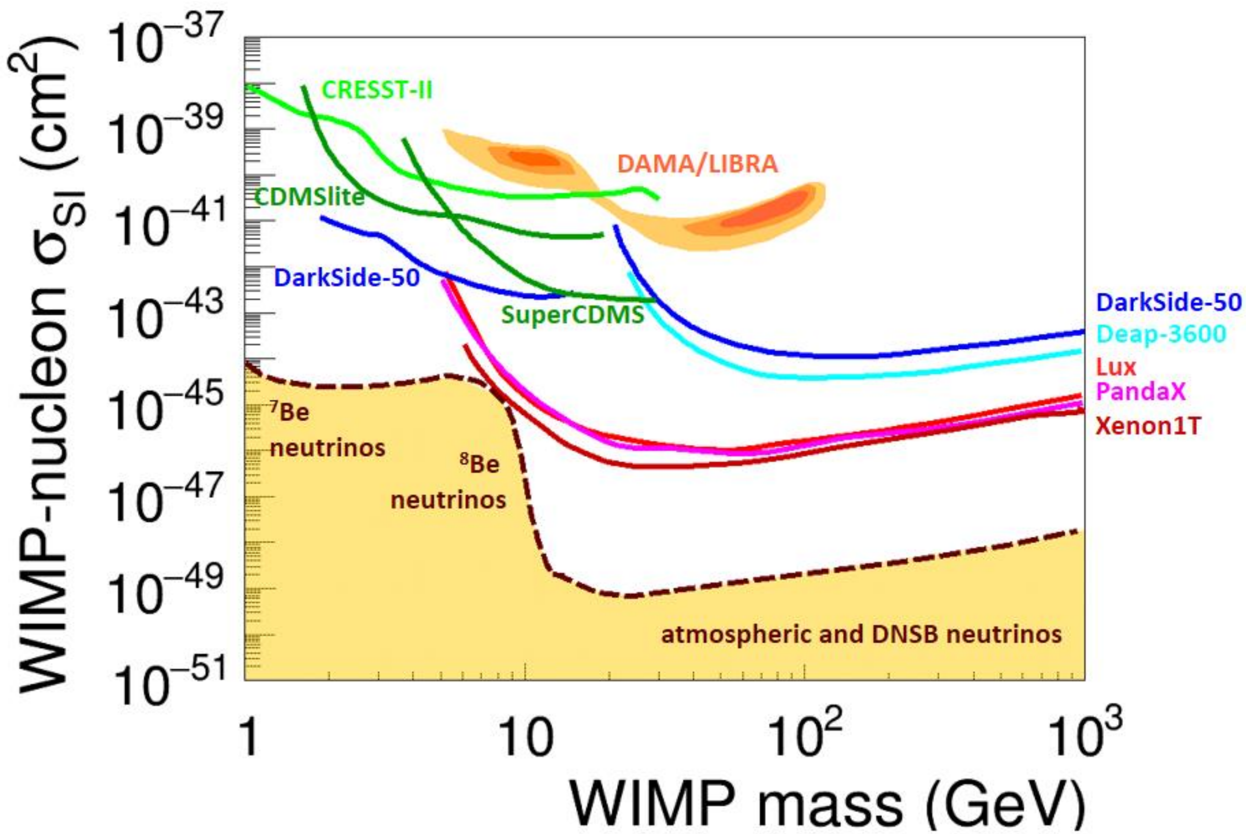


But since 2013 … ☹

- CRESST-II (2014-2015) with an upgraded detector did not confirm the excess
- CoGeNT's signal significance decreased with time (3.4y by 2014) to below 2σ. Different interpretations among the collaboration.
- CDMS-II-Si signal very small. No more data

Interpreting DAMA/LIBRA ph1 as WIMPs

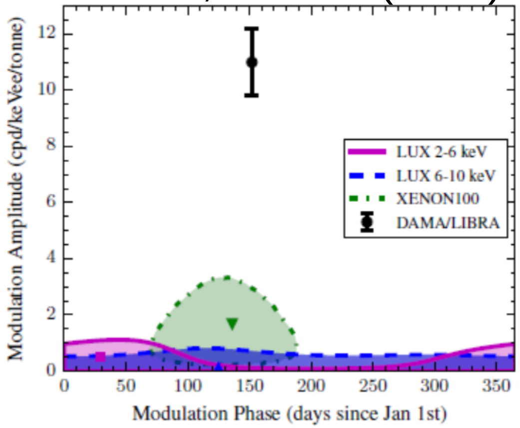
DAMA clearly sees an annual modulation at 12.9σ



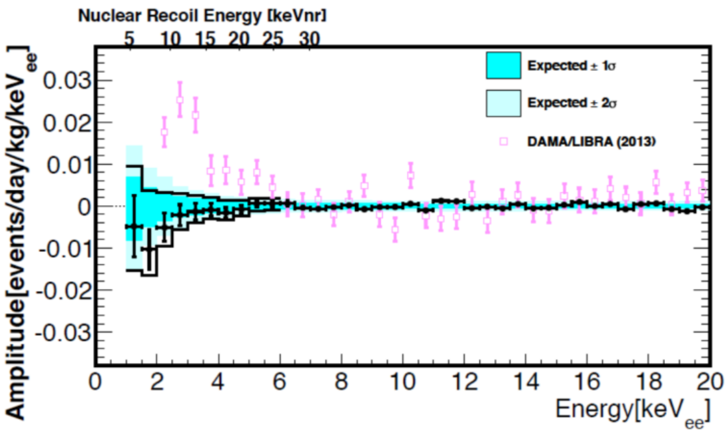
But the signal is in strong tension with the most sensitive experiments, even assuming more general halo/interaction models!

Other annual modulation searches

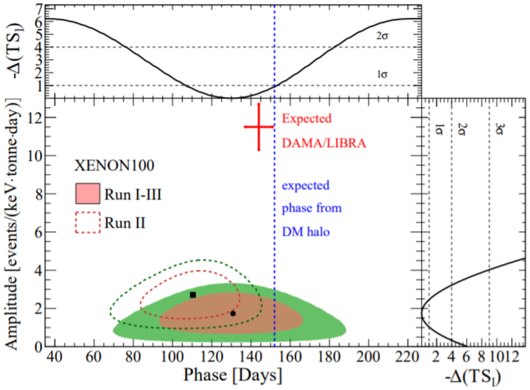
"A search for annual and diurnal rate modulations in the LUX experiment", Phys. Rev. D 98, 062005 (2018)



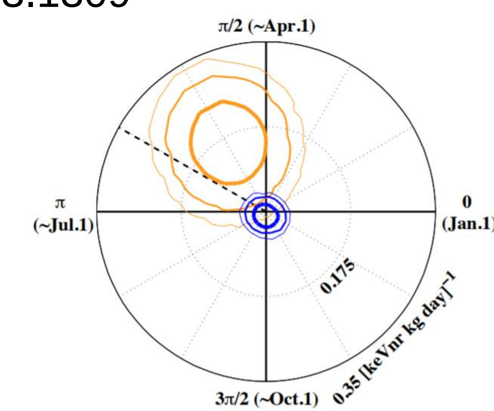
"Direct dark matter search by annual modulation with 2.7 years of XMASS-I data", Phys. Rev. D 97, 102006 (2018)



"Search for Electronic Recoil Event Rate Modulation with 4 Years of XENON100 Data"
PRL118, 101101 (2017)



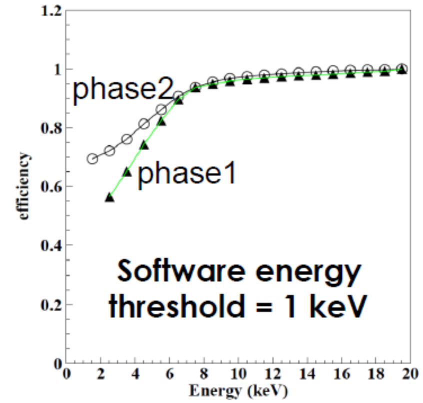
"Search for annual modulation in low-energy CDMS-II data", 1203.1309



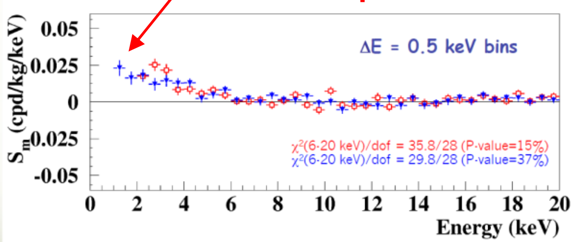
DAMA/LIBRA phase2 (2011-2018)

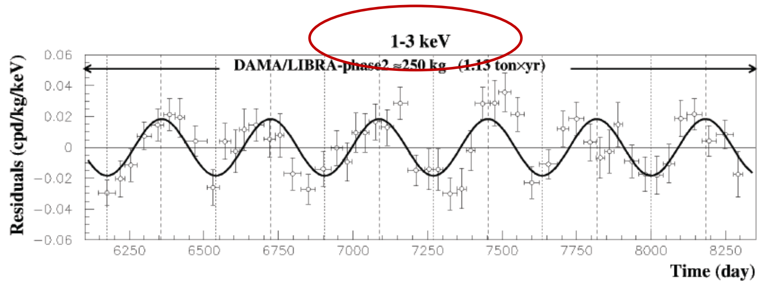
1805.10486, Nucl. Phys. At. Energy 19, 307 (2018)

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

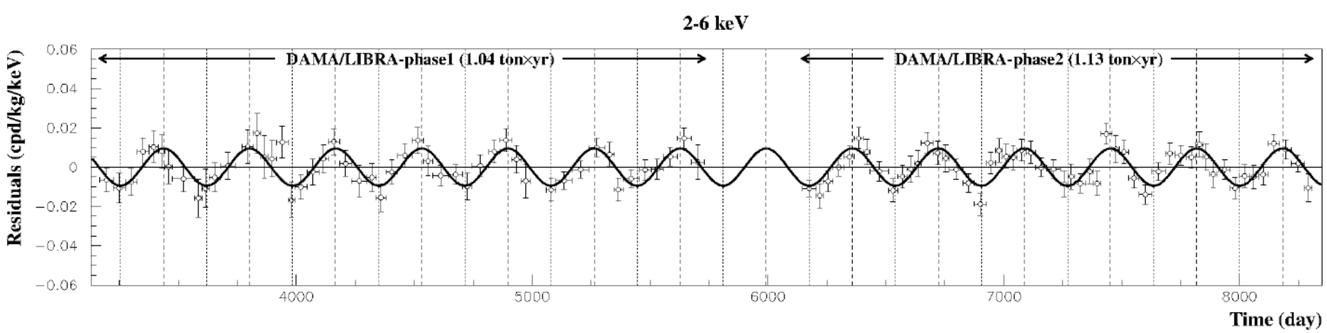


2 more points



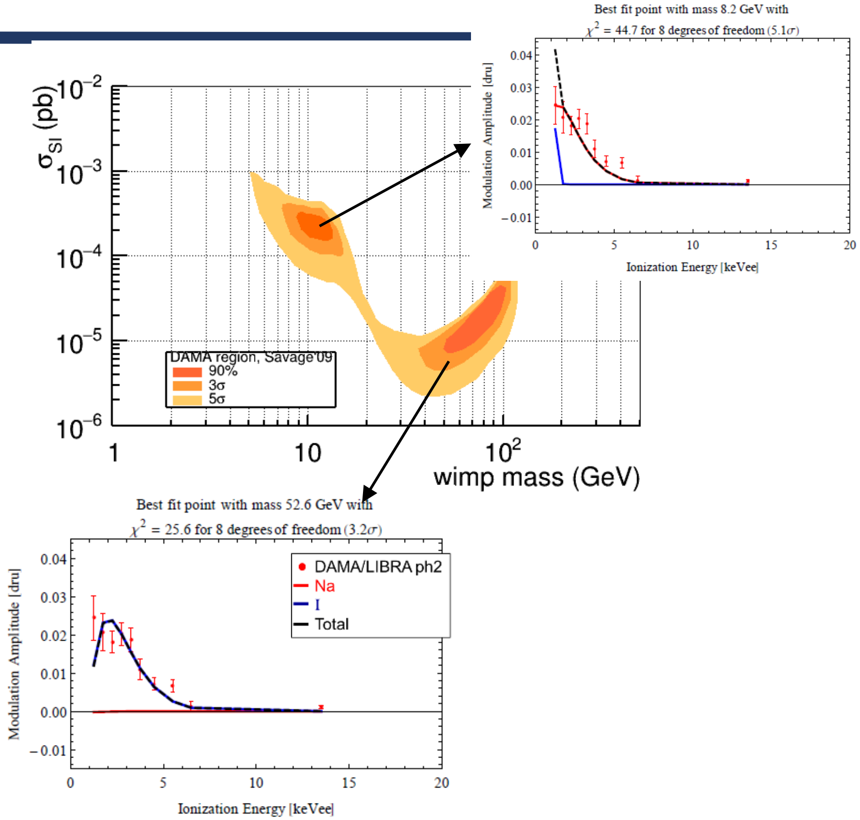


- 6 anual cycles
- Exposure: 1.13 ton × y



The data of DAMA/LIBRA phase1+phase2 favor the presence of a modulation with proper features at **11.9σ CL** (2.17 ton × yr)

Interpretation of the 1 keV point



1804.01231, Baum, Freese, Kelso "Dark Matter implications of DAMA/LIBRA-phase2 results"

"the observed annual modulation signal is no longer well fitted by canonical (isospin conserving) spin-independent WIMP nucleon couplings"

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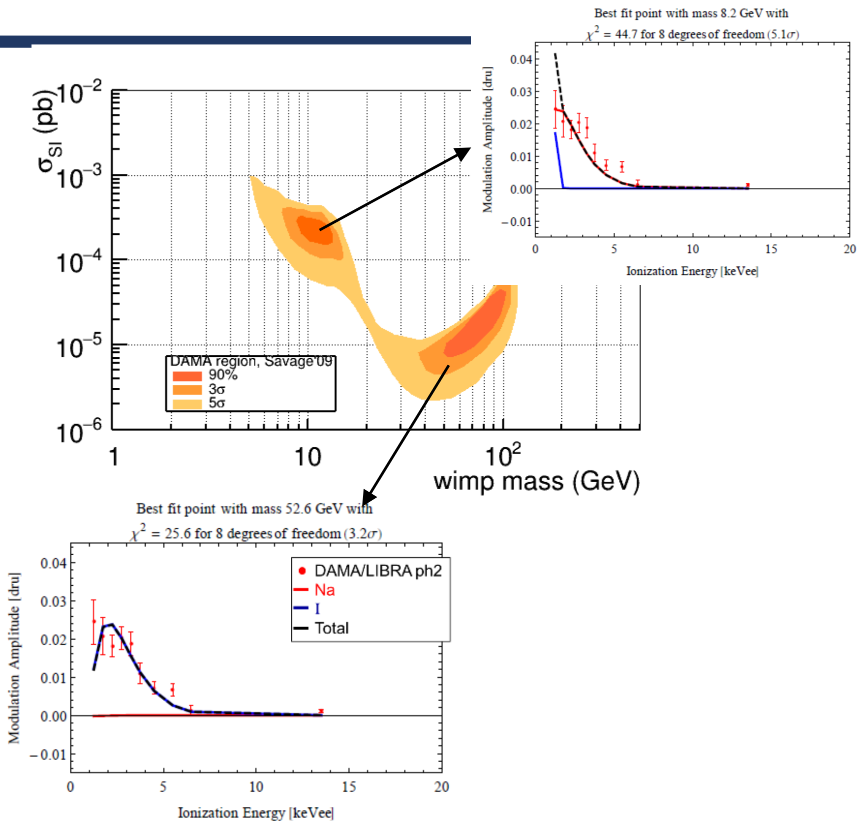
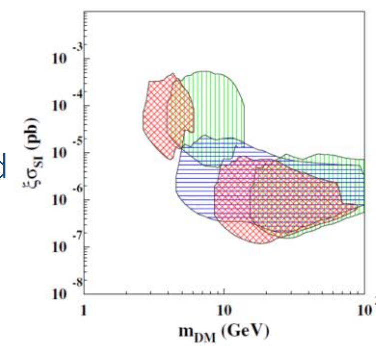


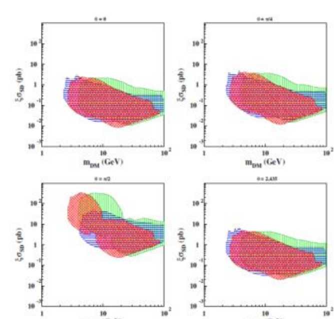
1907.06405 , Bernabei et al. "Improved model-dependent corollary analyses after the first six annual cycles of DAMA/LIBRA-phase2"

"at present level of uncertainties the DAMA data, if interpreted in terms of DM particle inducing nuclear recoils through SI interaction, can account either for low and large DM particle mass and for a wide range of the ratio fn=fp, even including the "standard" case fn=fp = 1."



1804.01231, Baum, Freese, Kelso "Dark Matter implications of DAMA/LIBRA-phase2 results"

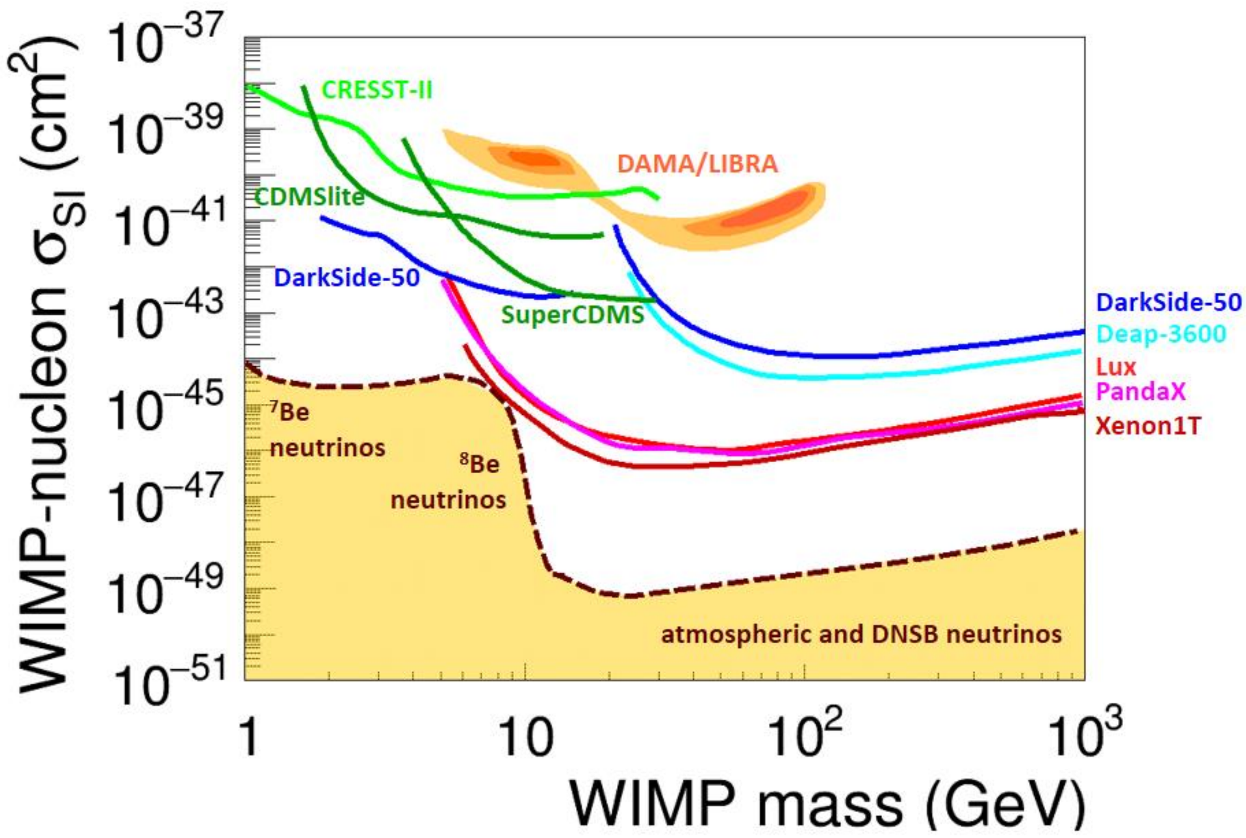
"the observed annual modulation signal is no longer well fitted by canonical (isospin conserving) spin-independent WIMP nucleon couplings"



"the purely SD scenarios are in good agreement with the DAMA results and can explain the dierent capability of detection among targets with dierent unpaired nucleon."

Interpreting DAMA/LIBRA ph1 as WIMPs

DAMA clearly sees an annual modulation at 12.9σ

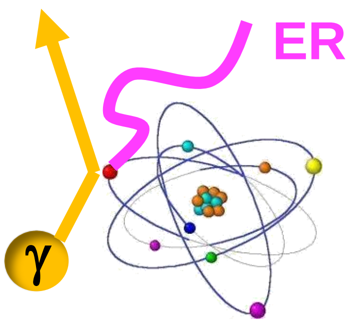


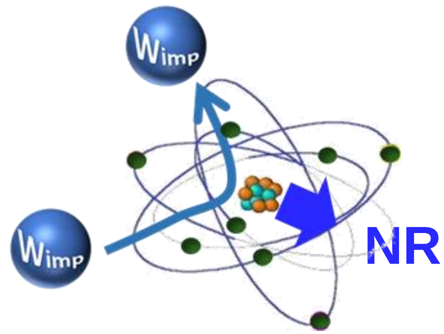
Dark matter or systematics?

TO AVOID ANY MODEL DEPENDENCE, WE NEED A PROOF/DISPROOF WITH THE SAME TARGET

Nuclear recoil quenching factor

An **ER** produces much more light than a **NR** of the same energy!





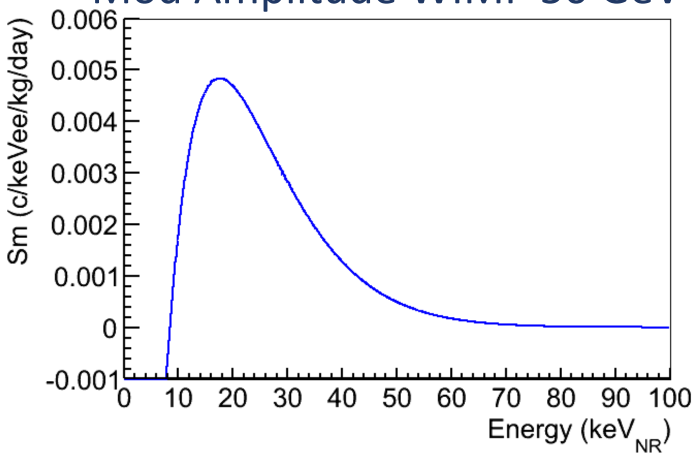
The spectra are calibrated with X/γ sources, so it is given in keVee(*). In order to be interpreted as NR, $\boldsymbol{Q}$ has to be measured to correct the energy scale:

$$\boldsymbol{Q} = \frac{signal_{NR}/keV}{signal_{ER}/keV}$$

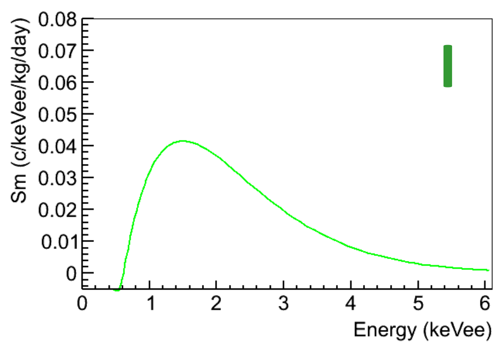
(*) keVee: electron-equivalent keV

First NaI quenching factor measurements (Spooner'94) : $\boldsymbol{Q_{Na} = 0.3}$ $\boldsymbol{Q_I = 0.09}$

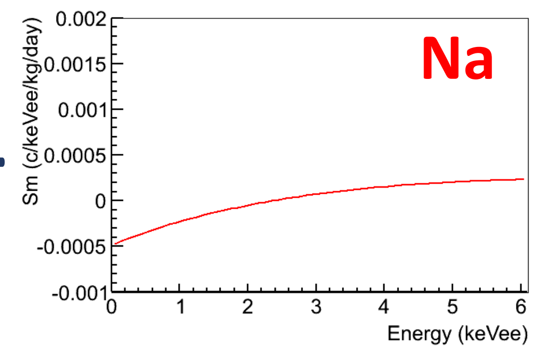
Mod Amplitude WIMP 50 GeV



WHAT I WOULD MEASURE:

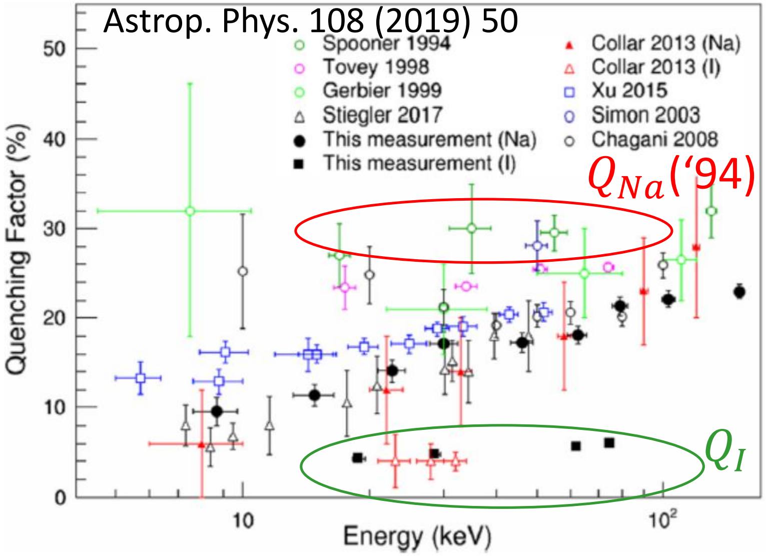


+

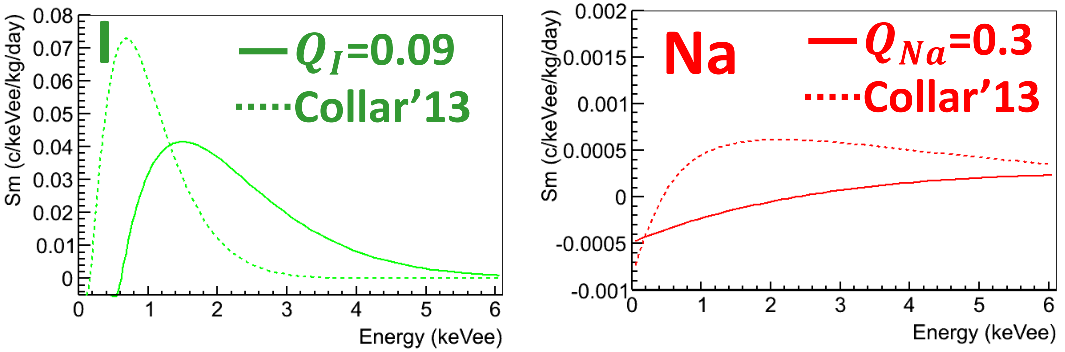


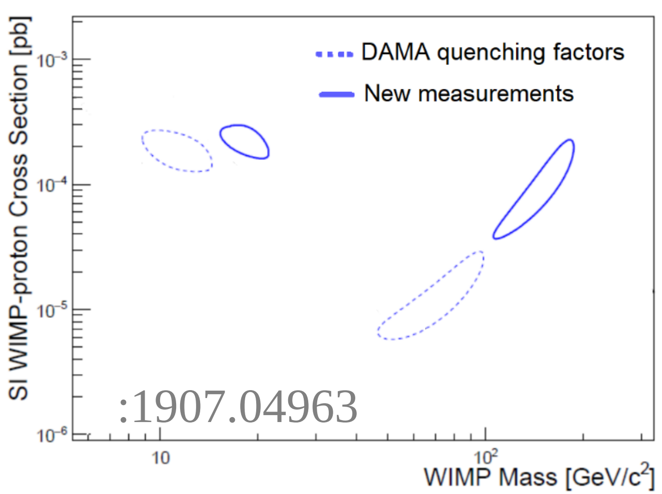
Nuclear recoil quenching factor

Recent measurements give lower values. Na quenching decreses when decresing the energy.



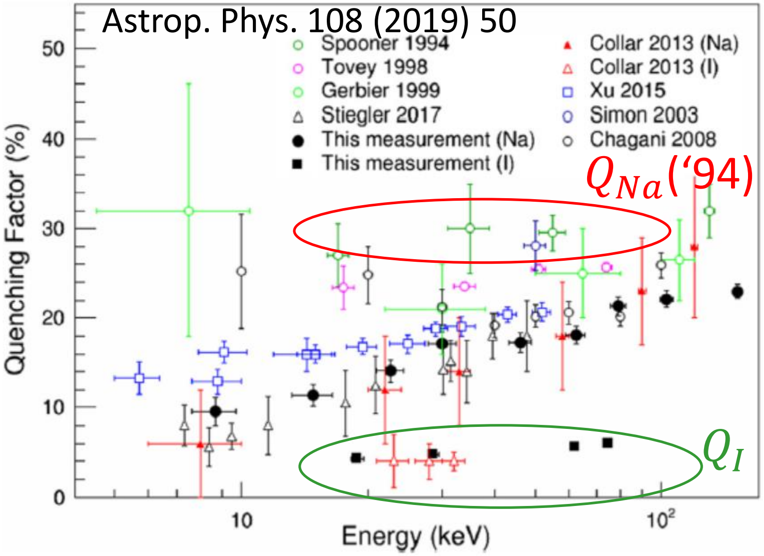
Mod Amplitude in keVee WIMP 50 GeV





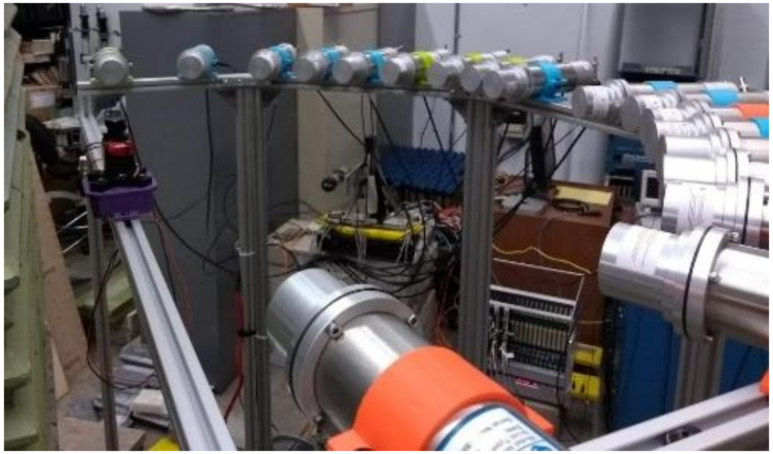
Nuclear recoil quenching factor

Recent measurements give lower values. Na quenching decreses when decresing the energy.



Is there a (large)dependence of the quenching factor with the crystal?

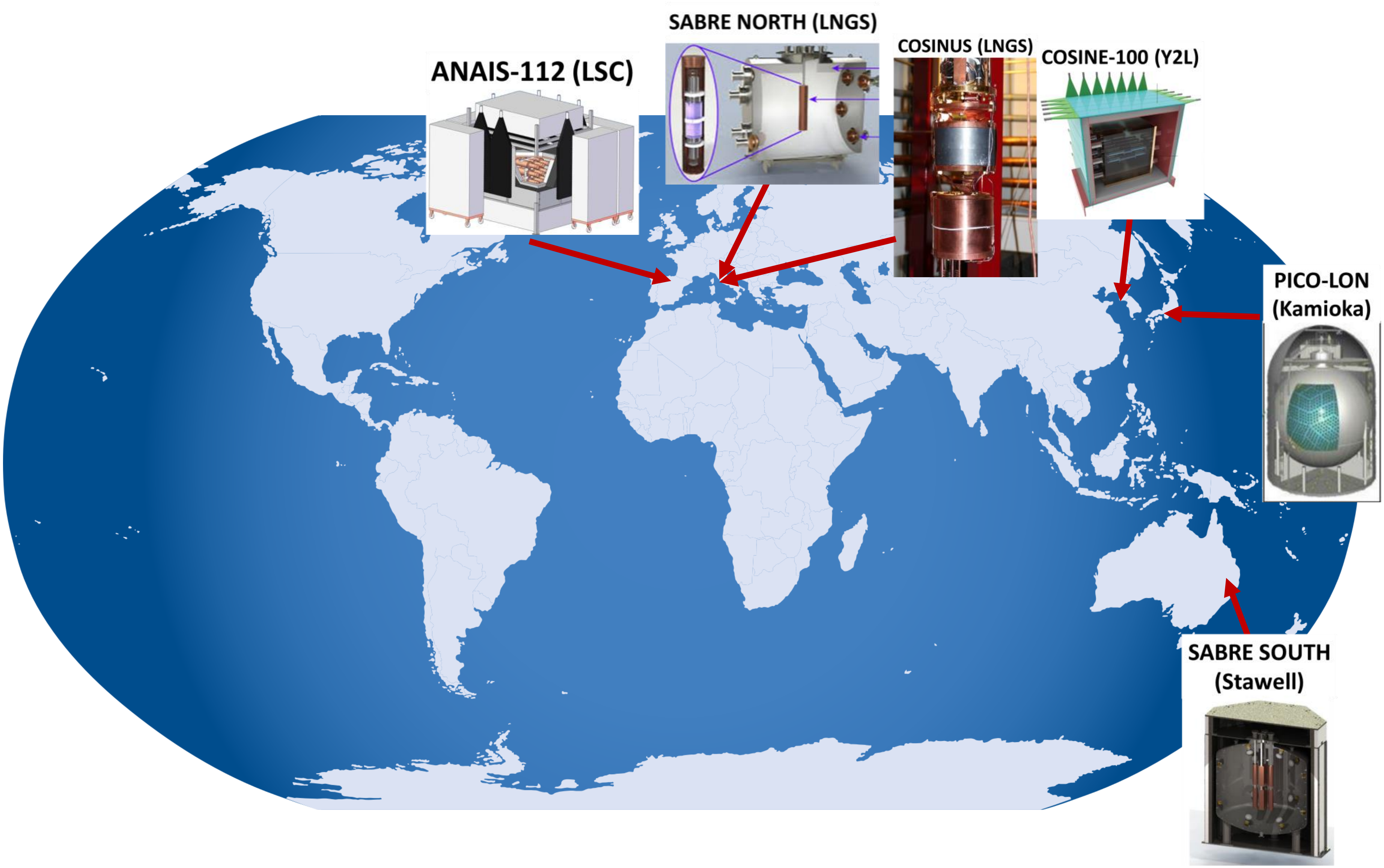
- Impurities
- Tl level
- Crystal quality
- …



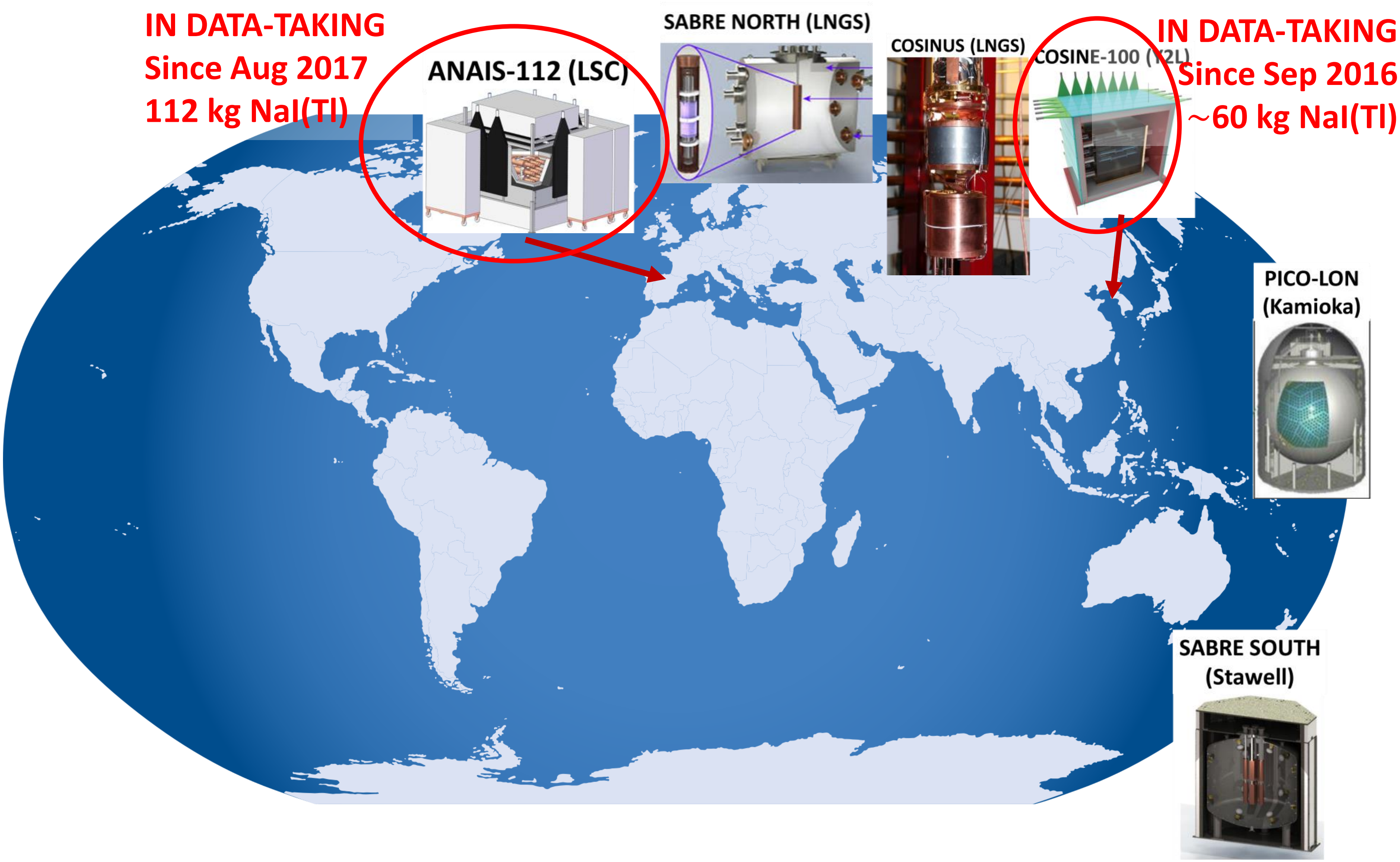
Cosine+Anais combined measurements @ TUNL (Duke Univ.)
different NaI(Tl) crystals in the same setup
Results soon!

CURRENT NaI(Tl) experiments

NaI experiments around the World



NaI experiments around the World



Why took so long?

Large mass

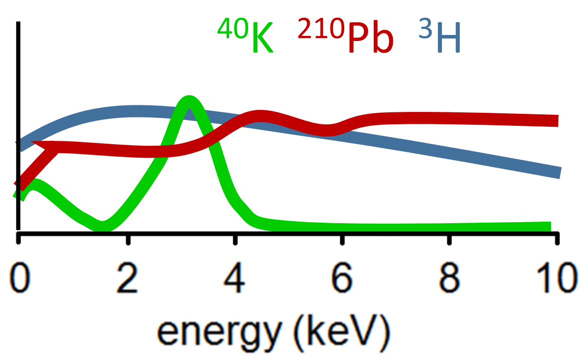
$$\text{Sensitivity} \propto \sqrt{\frac{MT\epsilon}{B}}$$

Stable conditions over years

High efficiency at very low energy

Very low radioactive background!!

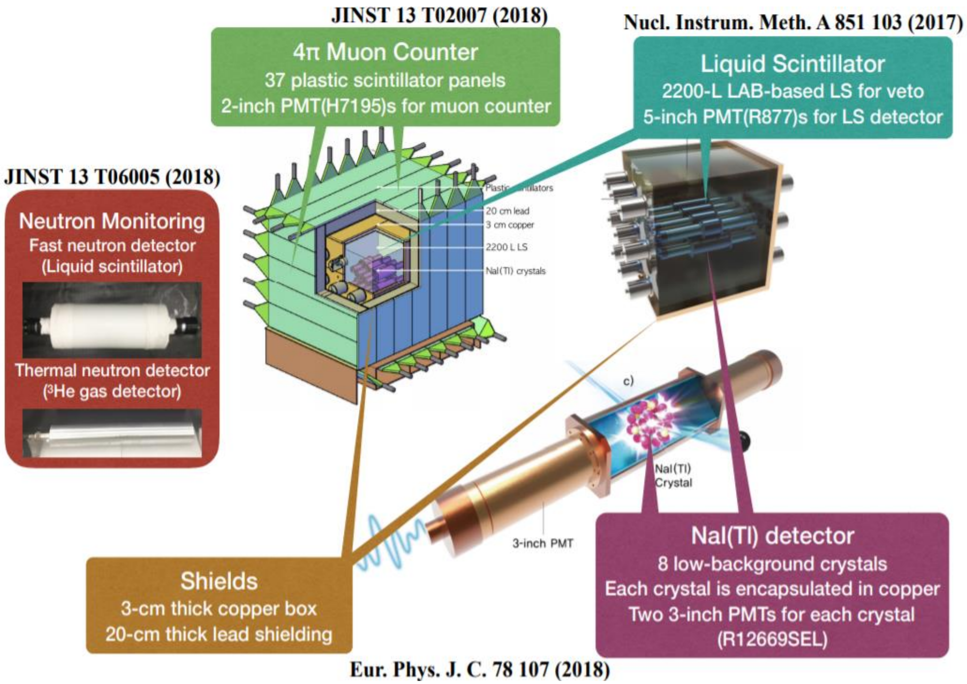
- **The main contribution to the background comes from the crystal itself**
- Long effort of ANAIS team looking for ultra pure NaI(Tl), R&D with Alpha Spectra → crystals now used by ANAIS-112 and COSINE-100
- However, **up to the date, the quality of the DAMA crystals has not been reached by any group**



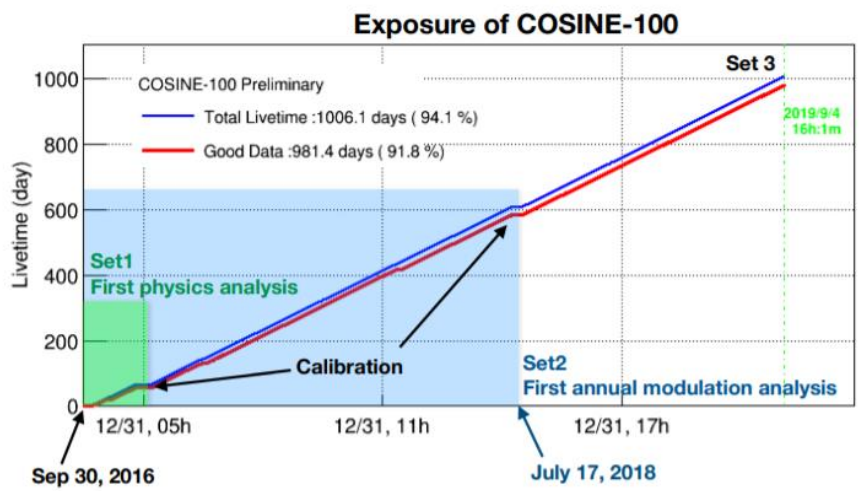
	K (ppb)	^{210}Pb (mBq/kg)
DAMA (Saint Gobain)	13	0.01-0.03
ANAIS/COSINE (Alpha Spectra)	18-44	0.7-3

COSINE-100

From Y. J. Ko @ TAUP2019



- Data-taking started in Sep 2016, Y2L (South Korea)
- 8 ultra low-background NaI(Tl) crystals with 106 kg in total (**but only ~60 kg usable for DM search**)
- Inside lead shielding and Liquid Scintillator tank to reject coincident events (^{40}K!)
- Muon veto & neutron monitoring



<u>NEXT STEP: COSINE-200 (2020?)</u>

Goal: Run 200 kg NaI(Tl) in the same set-up, with improved background (lower than DAMA/LIBRA)

Status: Power purification, crystal growing and handling facilities established, buy a factor 2 or more improvement in bkg is needed.

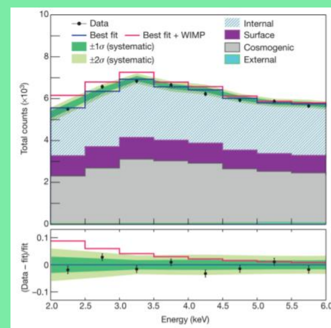
From G. Adhikari @ TAUP2019

COSINE-100 results

From Y. J. Ko @ TAUP2019

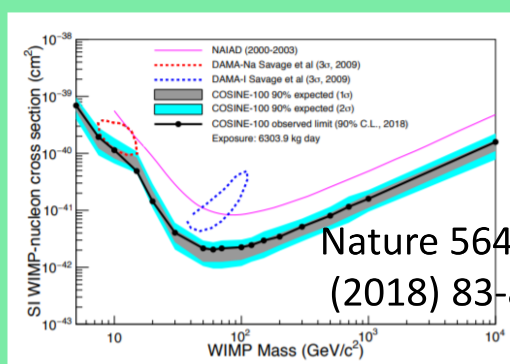
SET1 (59.5 days)

Background + WIMP signal is fit to data:



→ Model dependent exclusion of DAMA/LIBRA-phase1 (*)

- Spin Independent interaction
- Maxwellian velocity distribution

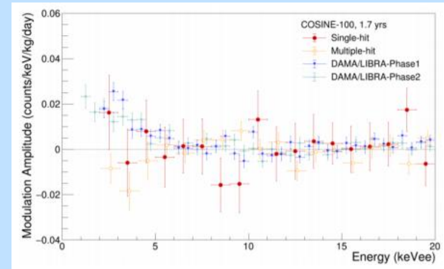


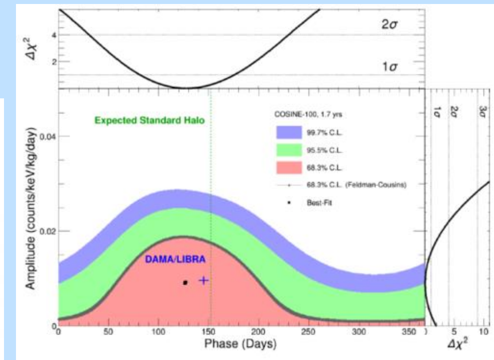
Nature 564 (2018) 83-86

(*) But not excluded in effective models (COSINE coll. & S. Scopel, JCAP 1906 (2019) 06, 048)

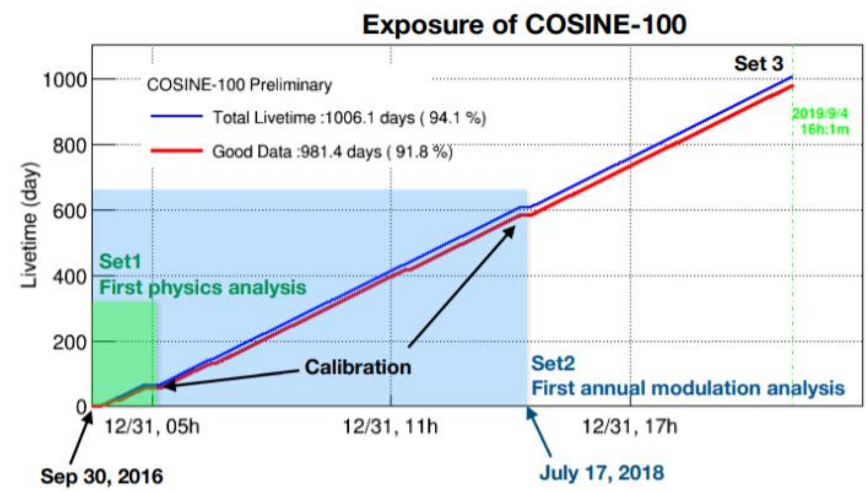
SET2 (1.7 y, 97.7 kg·year exposure)

Phys.Rev.Lett. 123 (2019) 031301



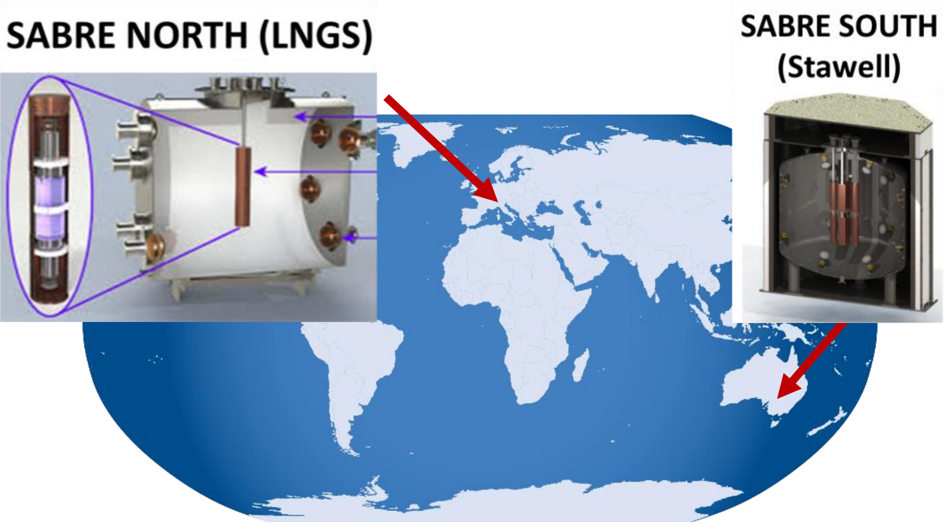


At 68.3% C.L., result is consistent with both a null hypothesis and DAMA/LIBRA's best fit value.



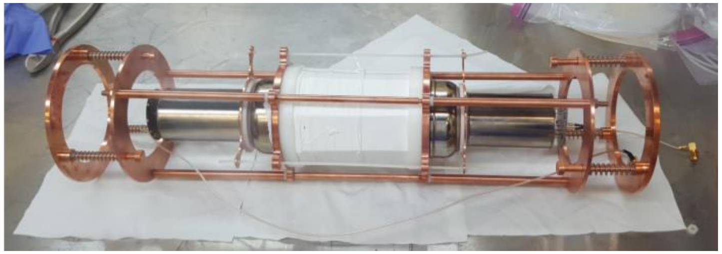
SABRE

From S. Copello @ TAUP2019



- Ultra-clean NaI(Tl) (Princeton)
- Two sites (LNGS/ Stawell)

Proof of Principle: one NaI crystal in LS vessel



LS Vessel ready at LNGS

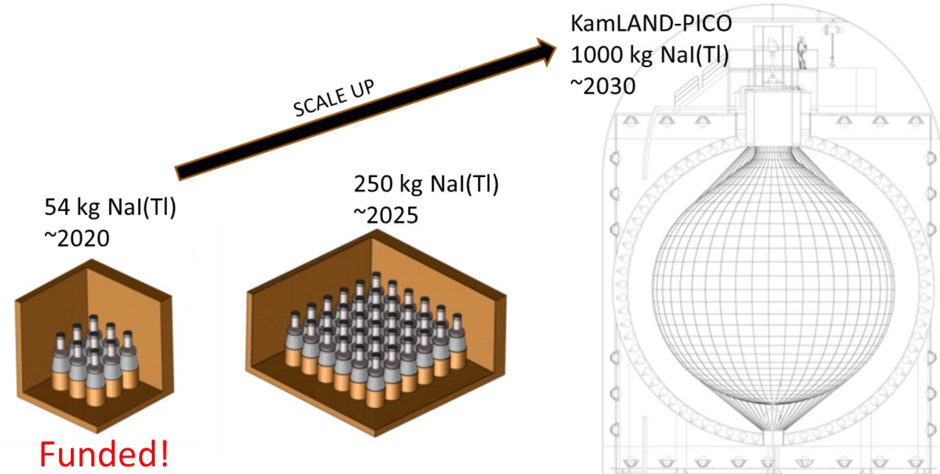
First crystal (3.5 kg)
arrived @ LNGS on August 2019

	K (ppb)	^{210}Pb (mBq/kg)
SABRE	4	0.4
DAMA	13	0.01-0.03
ANAIS	18-44	0.7-3

PICOLON

From K.Fushimi @ TAUP2019

GOAL: Development of highly radiopure NaI(Tl) scintillator



Funded!
35 MJPY

Status of NaI(Tl) purification
(~April 2019)

RI	Ingot26 (2015)	Ingot37 (2016)	Ingot71 (2018)	Ingot76 (2019)	Goal
Size	3”ϕX3”	4”ϕX3#	3”ϕX3”	5”ϕX4”(*)	5”ϕX5”
^{40}K (ppb)	2630	120	<20	<20	<20
^{232}Th (ppt)	0.4±0.5	3.7±0.5	1.7±0.2	--	<4
^{238}U (ppt)	4.7±0.3	5.9±0.3	9.7±0.8	4.4±0.2	<10
^{210}Pb (μBq/kg)	30±7	2300	1076	~560	<50
Method	Resin for Pb	I26+cation resin	double re-crystallization	Pb resin + double re-crystallization	

DAMA

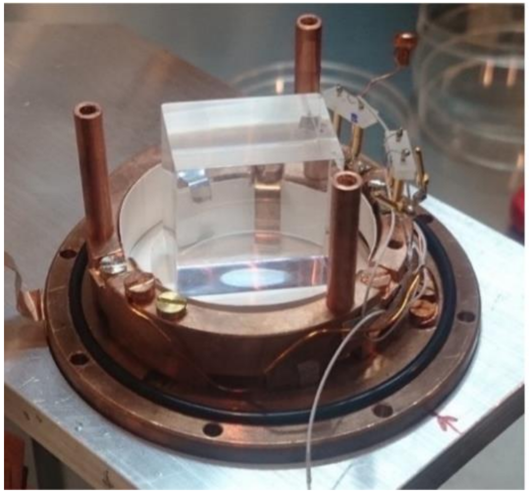
13

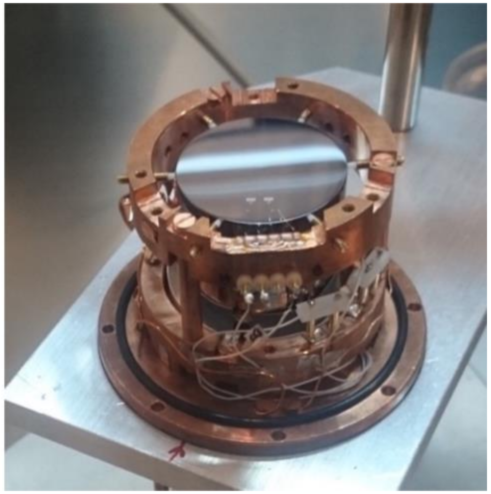
10-33

COSINUS

First NaI detector with particle discrimination

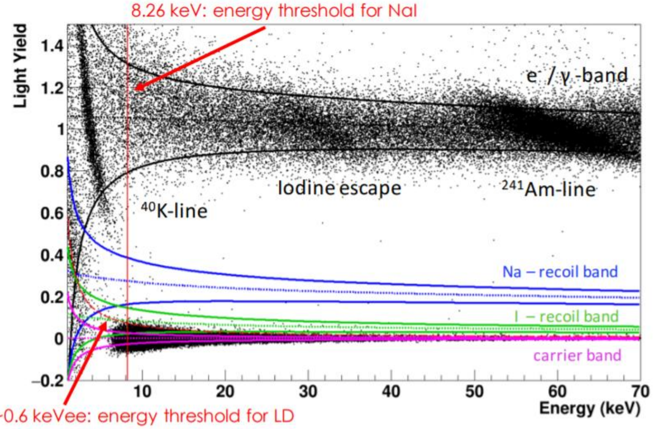
(Two channel approach: HEAT and LIGHT)





With a moderate exposure of few O(100) kg-days , can confirm or rule-out a **nuclear recoil origin** of the DAMA/LIBRA dark matter claim

Schäffner, K. et al. J Low Temp Phys (2018). https://doi.org/10.1007/s10909-018-1967-3



Present threshold: 8.26 keV_{NR}

(Goal: 1 keV_{NR})


ANAIS-112 experiment

ANAIS-112

Annual Modulation with NaI Scintillators

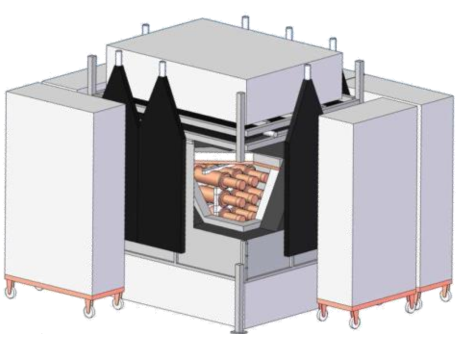
J. Amaré, I. Coarasa, S. Cebrián, E. García, M. Martínez, M.A. Oliván, Y. Ortigoza, A. Ortiz de Solórzano, J. Puimedón, A. Salinas, M.L. Sarsa, J.A. Villar†, P. Villar

GOAL:

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

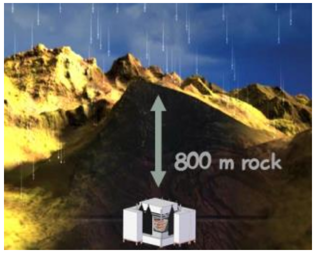
THE DETECTOR:

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



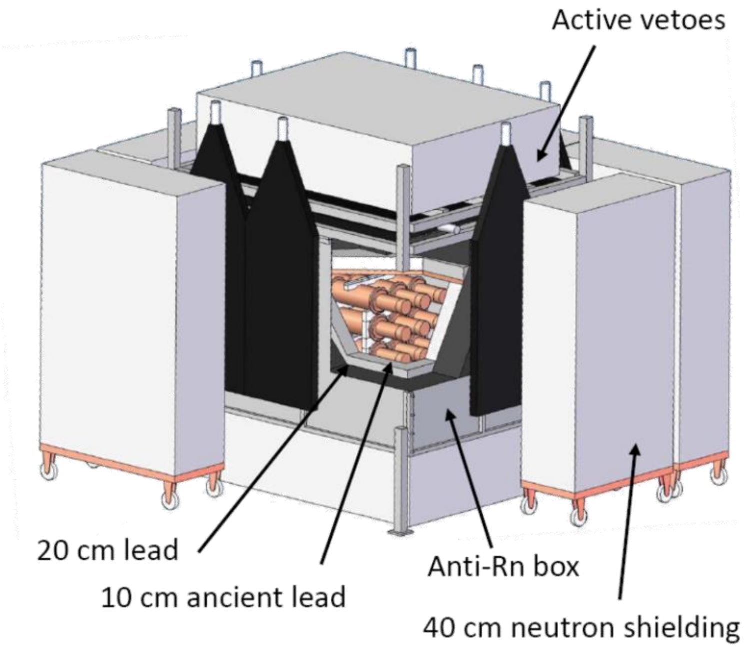
WHERE:

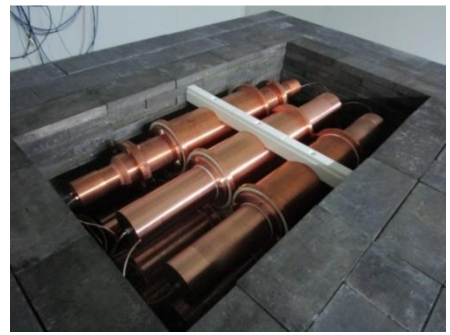
At Canfranc Underground Laboratory, @ **SPAIN** (under **2450 m.w.e.**)



taking data since August 2017

ANAIS-112: experimental setup





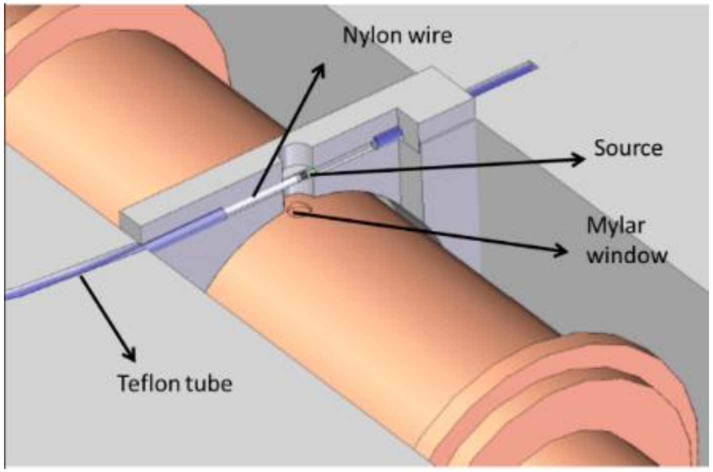
- 9 NaI(Tl) cylindrical crystals (12.5 kg each) in 3x3 matrix
- Ultrapure NaI powder (Alpha Spectra Inc)
- Each coupled to two Hamamatsu R12669SEL2 PMT (QE ~40%)

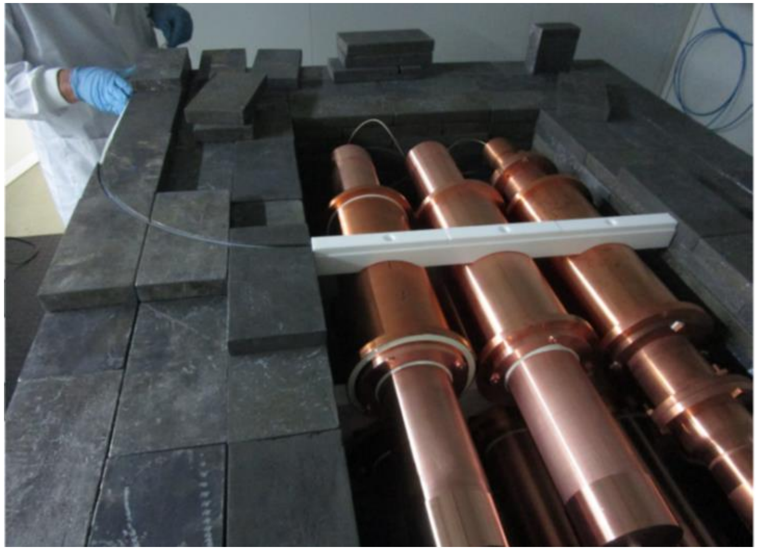
ANAIS-112: Low energy calibration

Detectors equipped with a **Mylar window**!

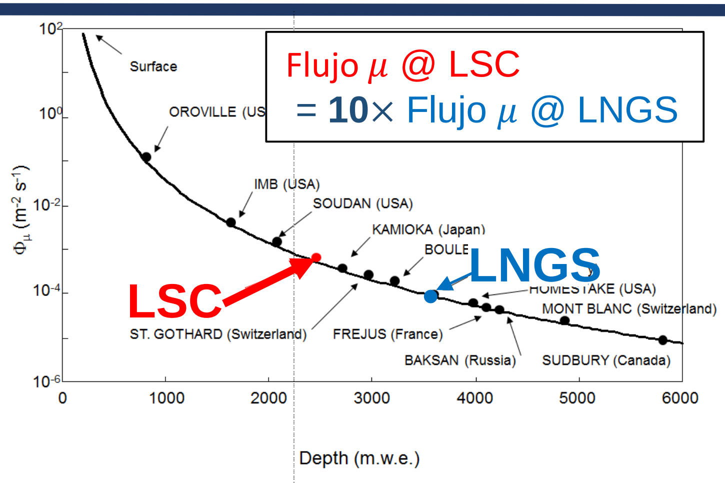
Radon-free system for low energy calibration:

- **^{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



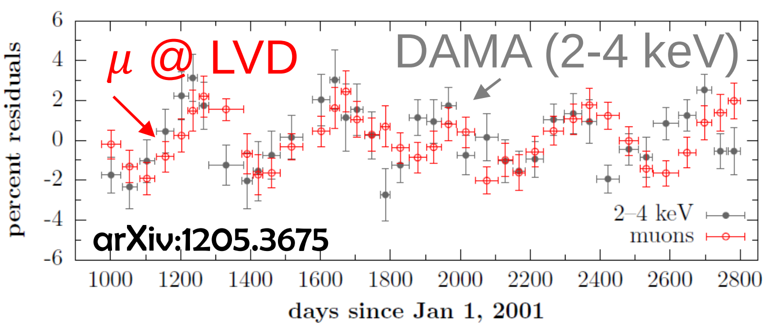


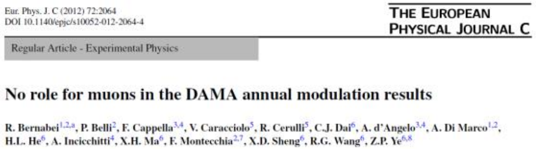
ANAIS-112: Muon Veto



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!





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

THE EUROPEAN PHYSICAL JOURNAL C

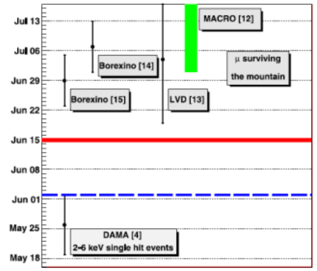
Regular Article - Experimental Physics

No role for muons in the DAMA annual modulation results

R. Bernabei[1,2,a], P. Belli[2], F. Cappella[3,4], V. Caracciolo[5], R. Cerulli[5], C.J. Dai[6], A. d'Angelo[3,4], A. Di Marco[1,2], H.L. He[6], A. Incicchitti[4], X.H. Ma[6], F. Montecchia[2,7], X.D. Sheng[6], R.G. Wang[6], Z.P. Ye[6,8]

DAMA reply:

- 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



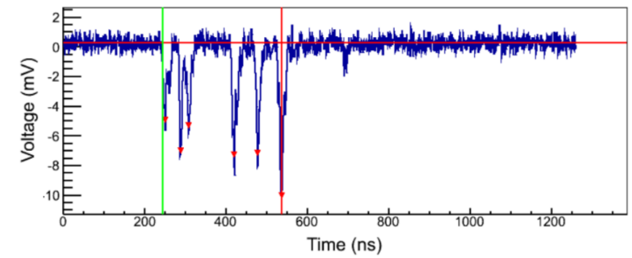
But still some open questions:

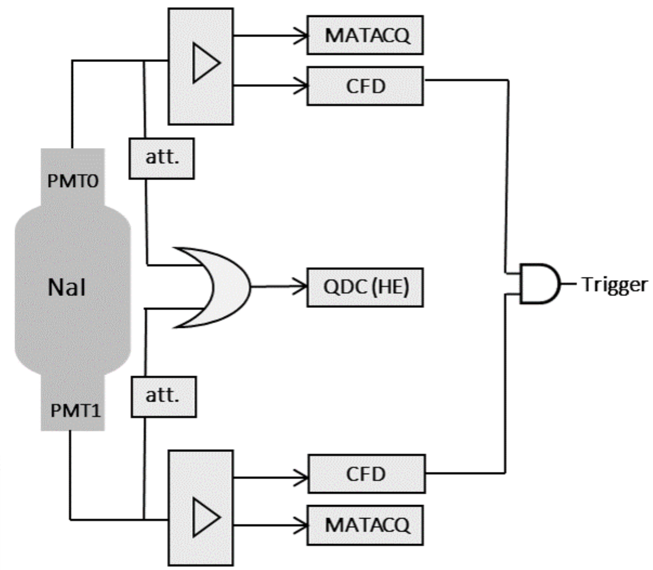
- (delayed) effect of muons in PMTs?
- slow phosphorescence in NaI?

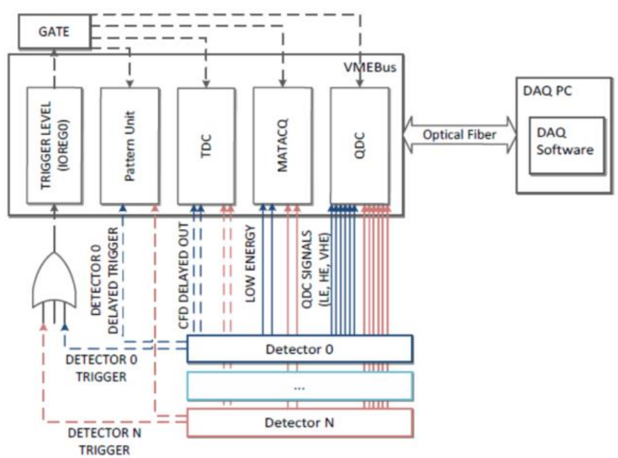
ANAIS can test these hypotheses

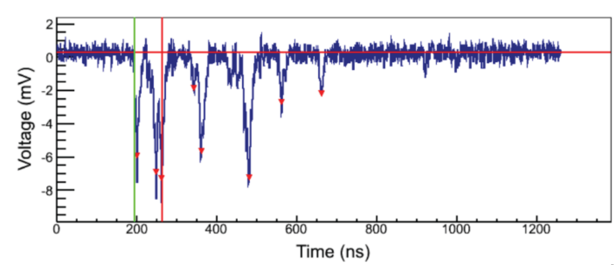
ANAIS-112: Data acquisition system

- 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



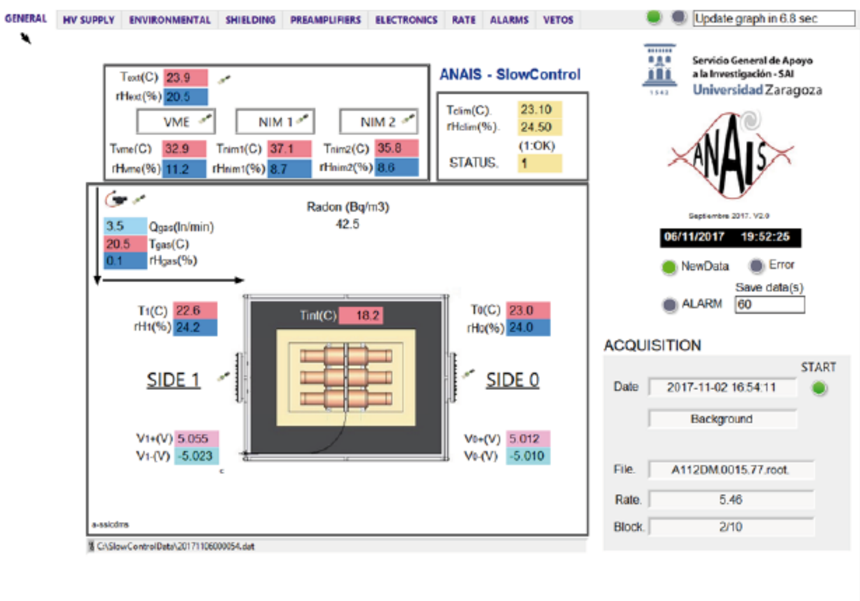


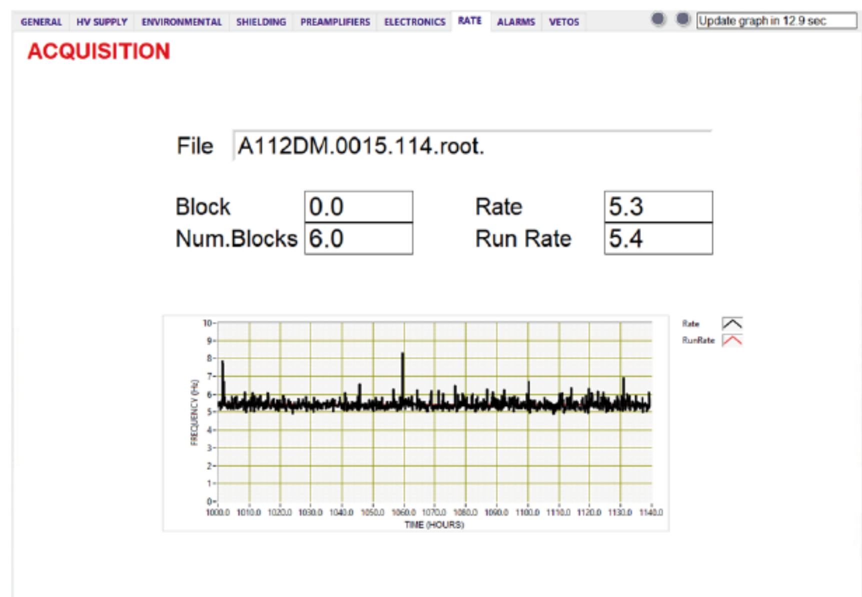




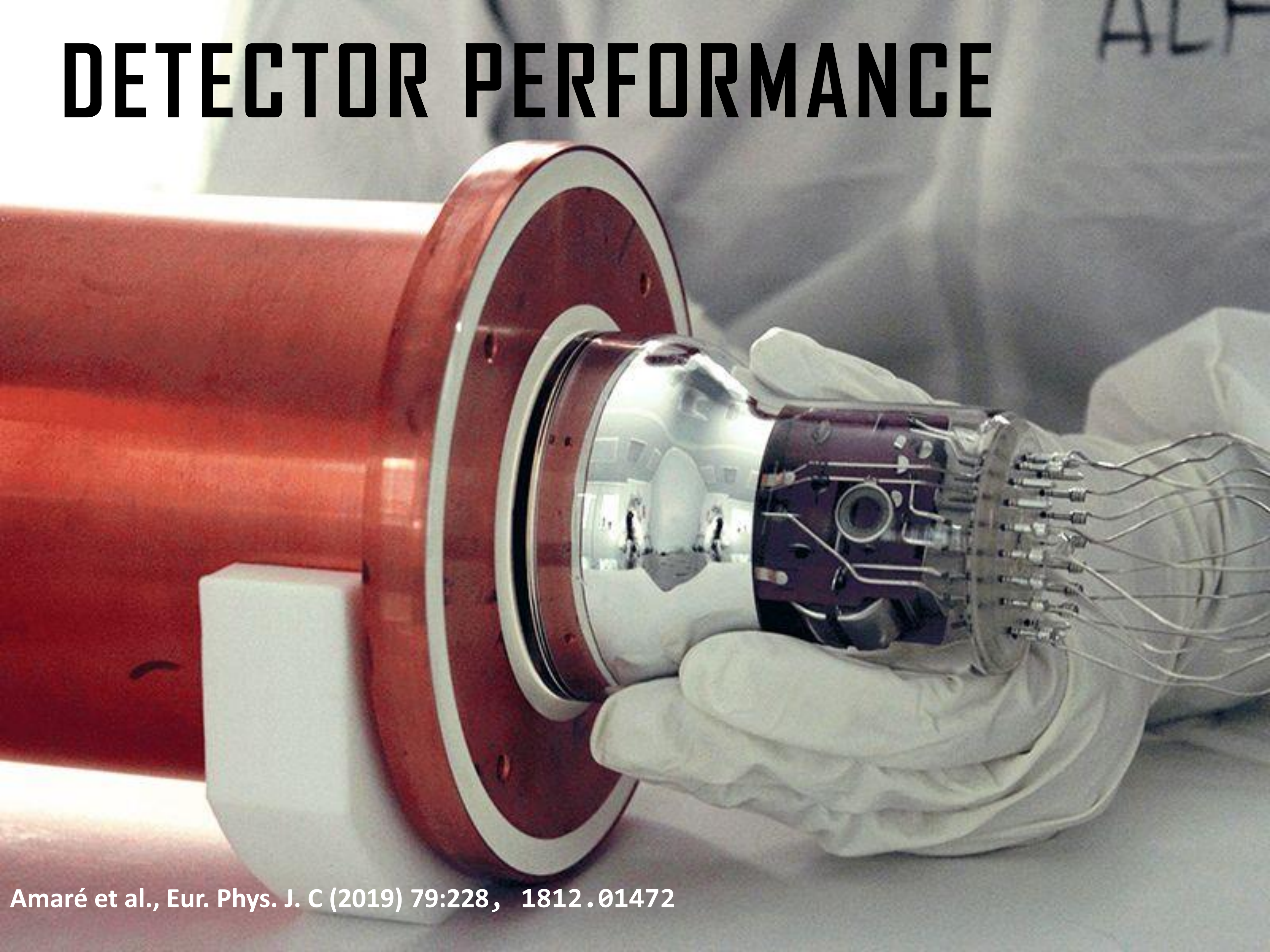
ANAIS-112: Slow control

- 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

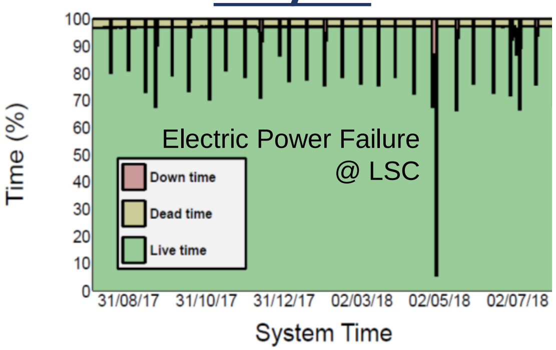


Amaré et al., Eur. Phys. J. C (2019) 79:228, 1812.01472

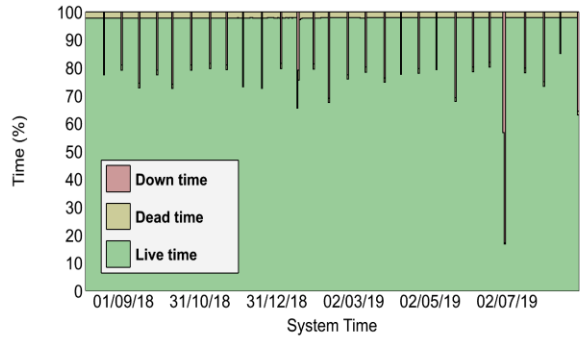
Detector Response: duty cycle & stability

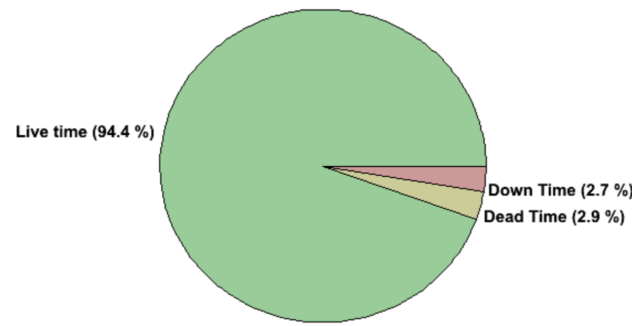
- Excellent **duty cycle**

1st year

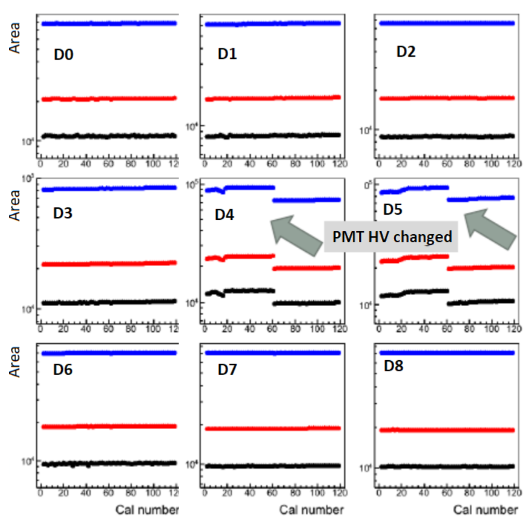


2nd year





- Good **total rate and gain stability**

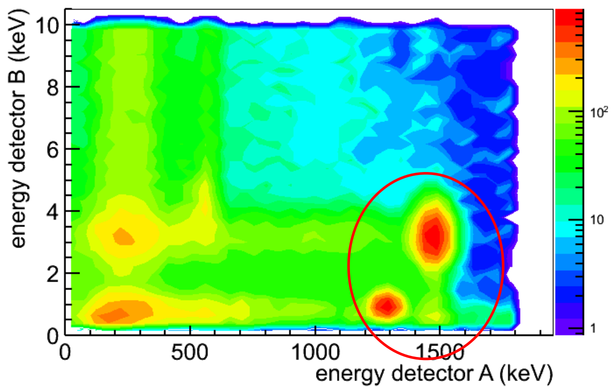


Evolution of ^{109}Cd lines from calibrations along the whole data-taking (~ 2 year)

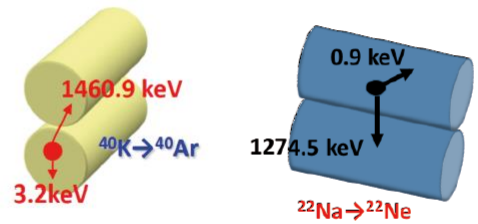
Detector respose: threshold

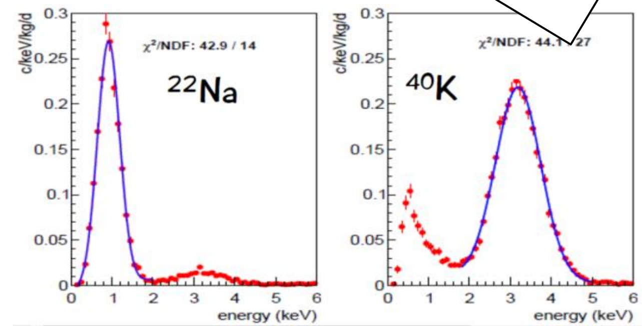
Outstanding **light collection** of **~15 phe/keV**

- Effectively **triggering below 1 keV$_{ee}$**



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

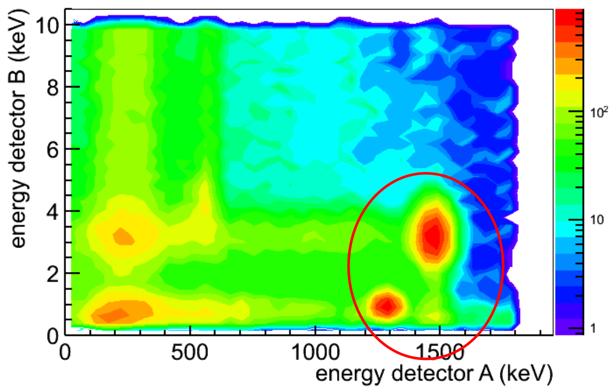




Detector respose: threshold

Outstanding **light collection** of **~15 phe/keV**

- Effectively **triggering below 1 keV$_{ee}$**



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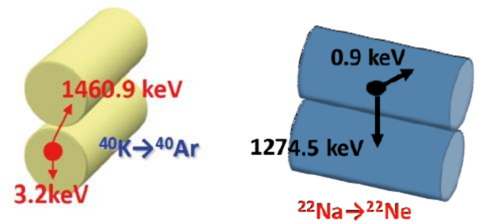
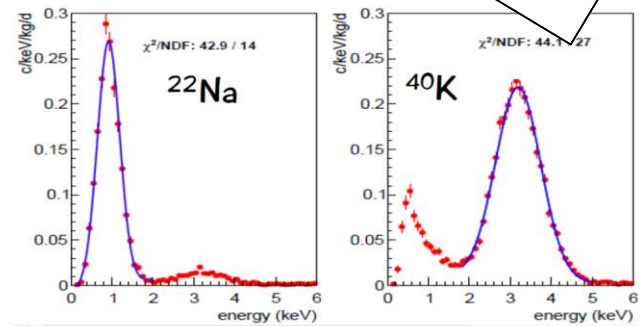
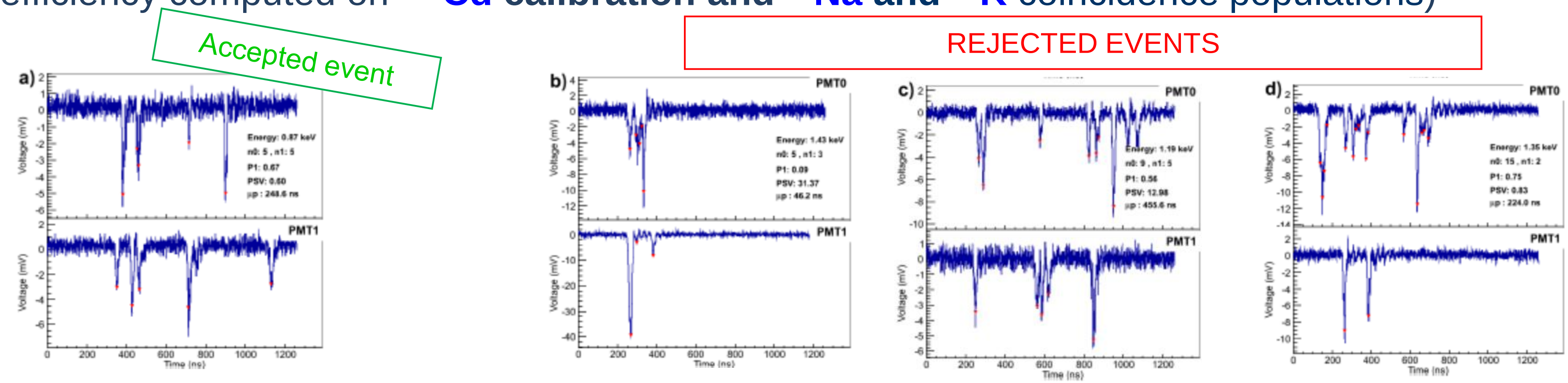


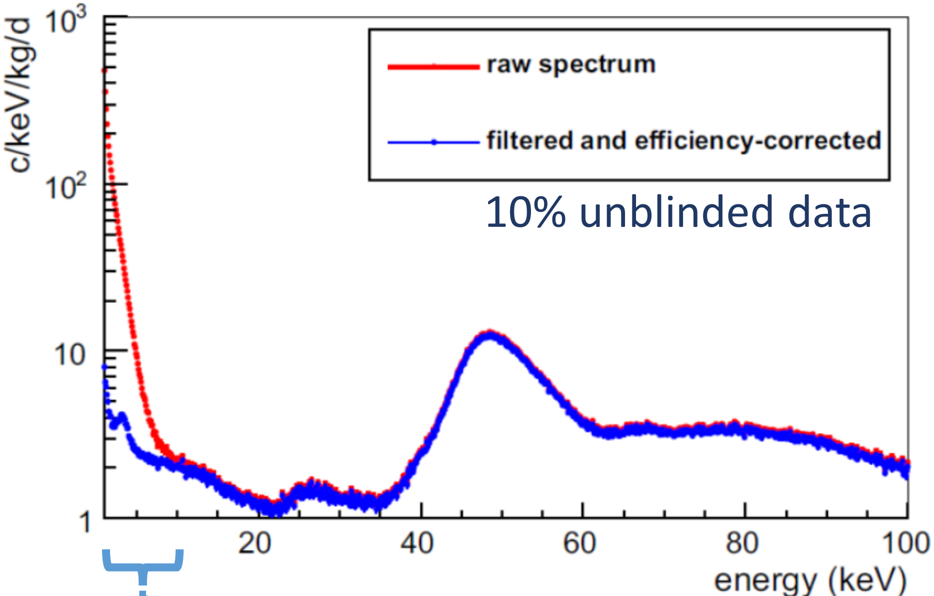


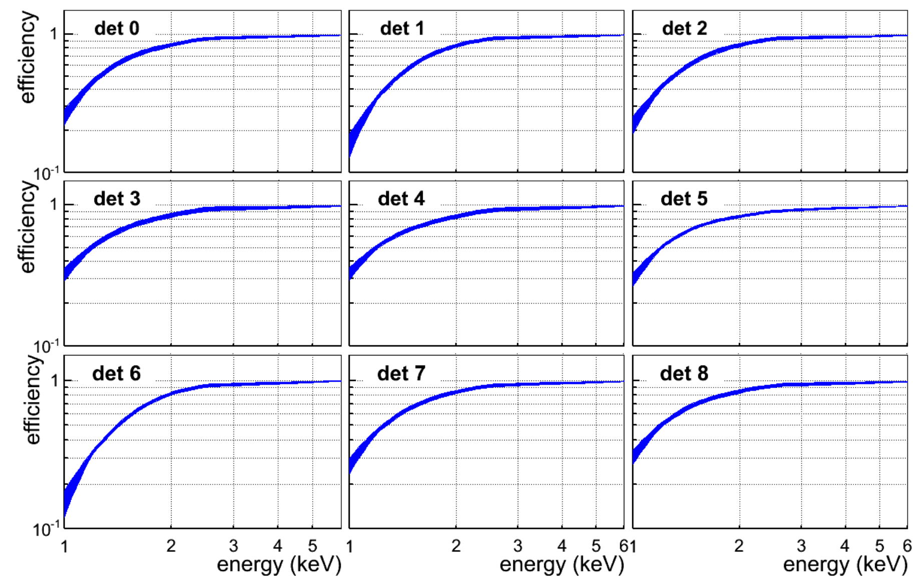
- Energy threshold limited by PMT noise **filtering** protocols efficiency

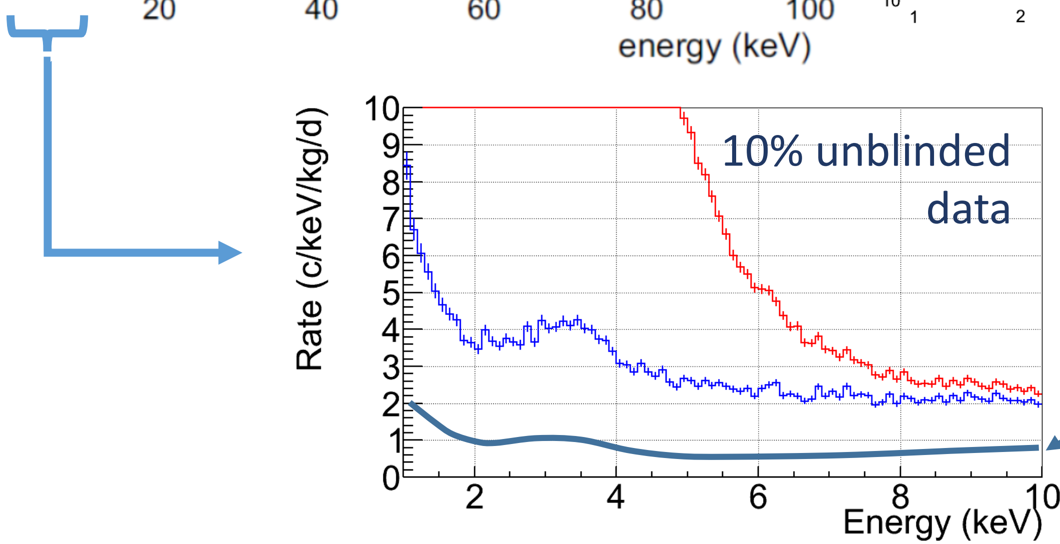
- **Multiparametric cuts** to properly select events with pulse shapes from NaI(Tl) scintillation (efficiency computed on **^{109}Cd calibration and ^{22}Na and ^{40}K** coincidence populations)



Background & efficiency







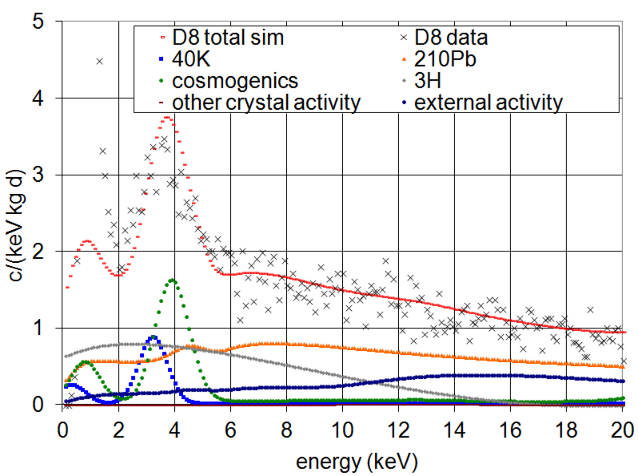
DAMA/LIBRA
Universe 4, 116 (2018),
1805.10486

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

Background model

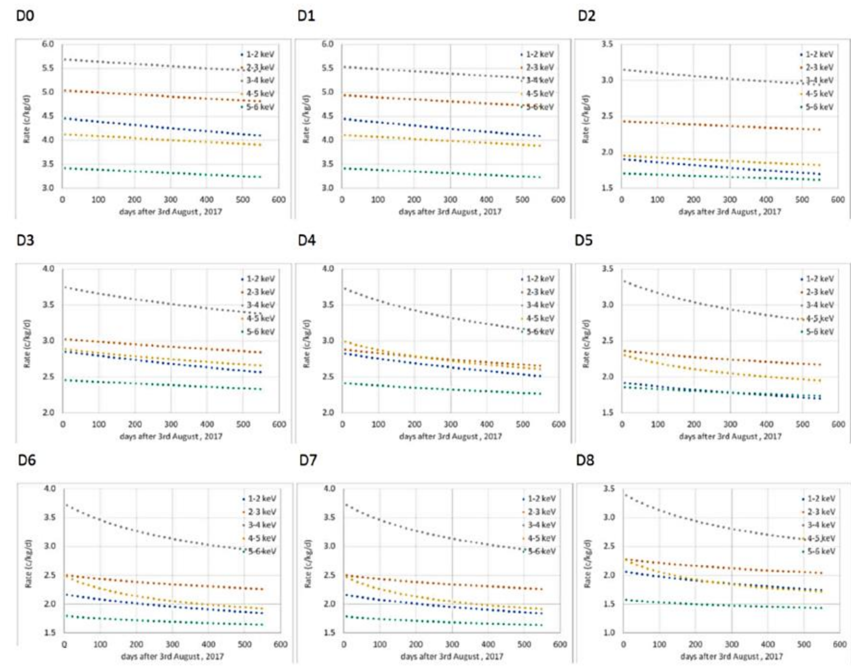
At very low energy (<20 keV), most significant contributions come from the crystal itself

- ^{40}**K** and ^{22}**Na** ($T_{1/2}$ = 2.6 y) peaks
- ^{210}**Pb** (bulk+surface) ($T_{1/2}$ = 22.3 y)
- ^{3}**H** ($T_{1/2}$ = 12.3 y)



Very good agreement with data except between 1-2 keV

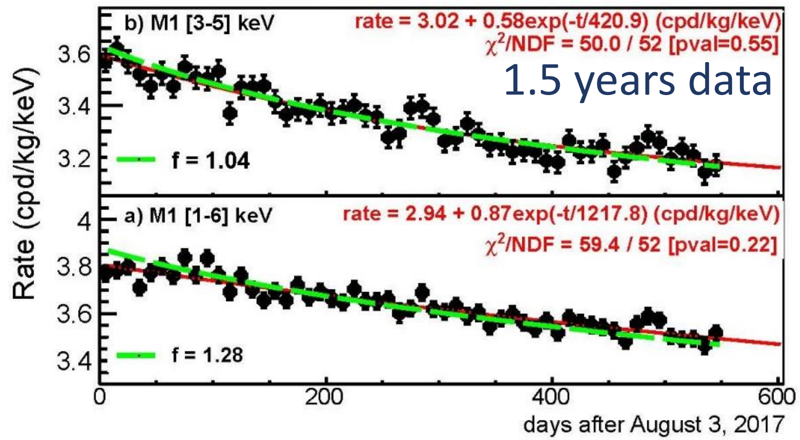
Prediction of the time evolution of rates from the model: cosmogenic isotopes (^{3}H, ^{22}Na, …) and ^{210}Pb:



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)

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

ANALYSIS STRATEGY

- 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**

Fixed parameters:

τ (background model)
ω (freq. corresponding to a period of 1 year)
ϕ (maximum in June, 2^{nd})

1st Annual modulation results

157.55 kg x yr

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

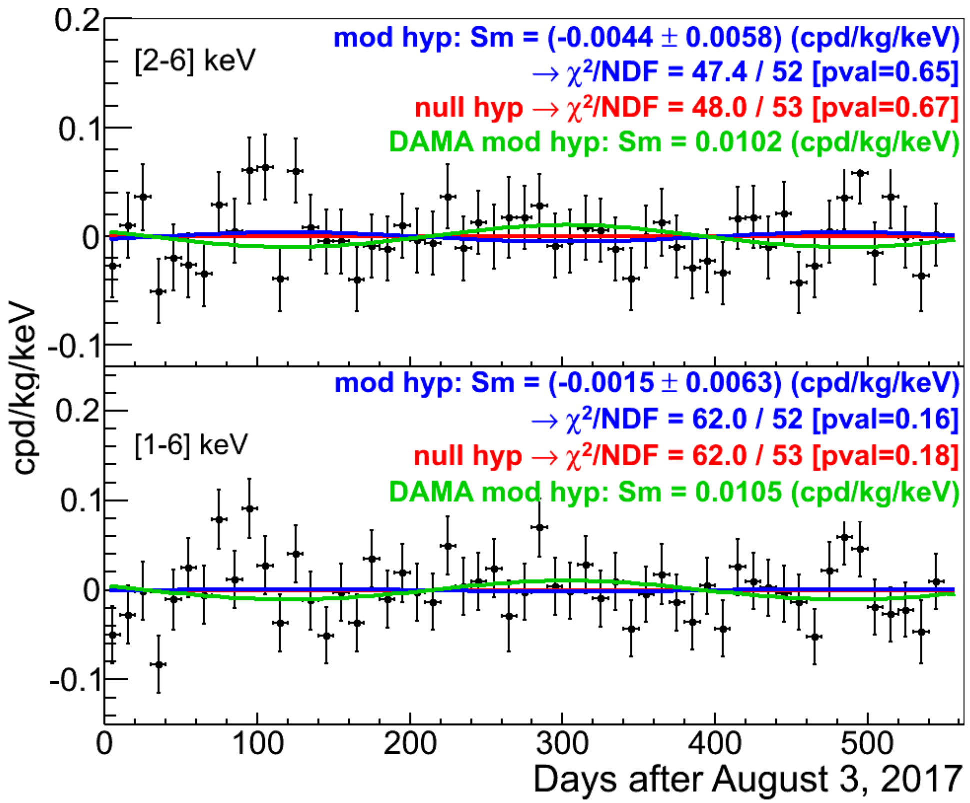
Fixed parameters:

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



arXiv:1903.03973

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

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

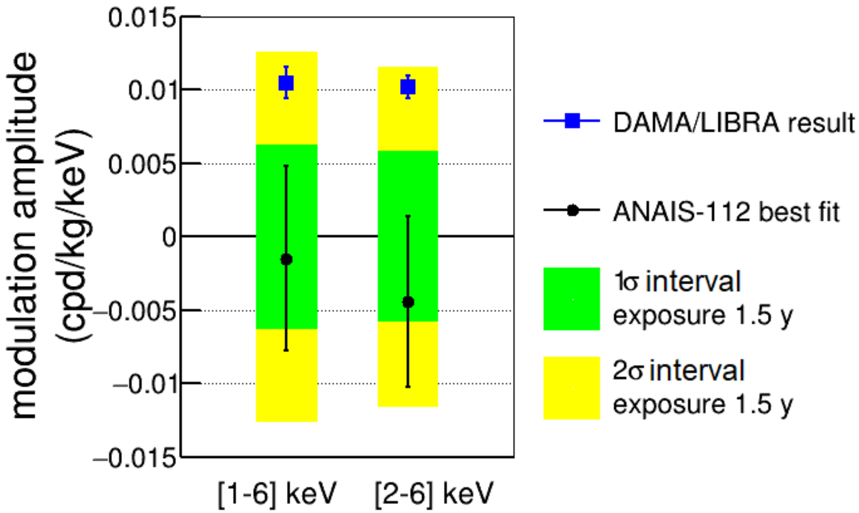
1st Annual modulation results

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 compatible with no modulation and 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)

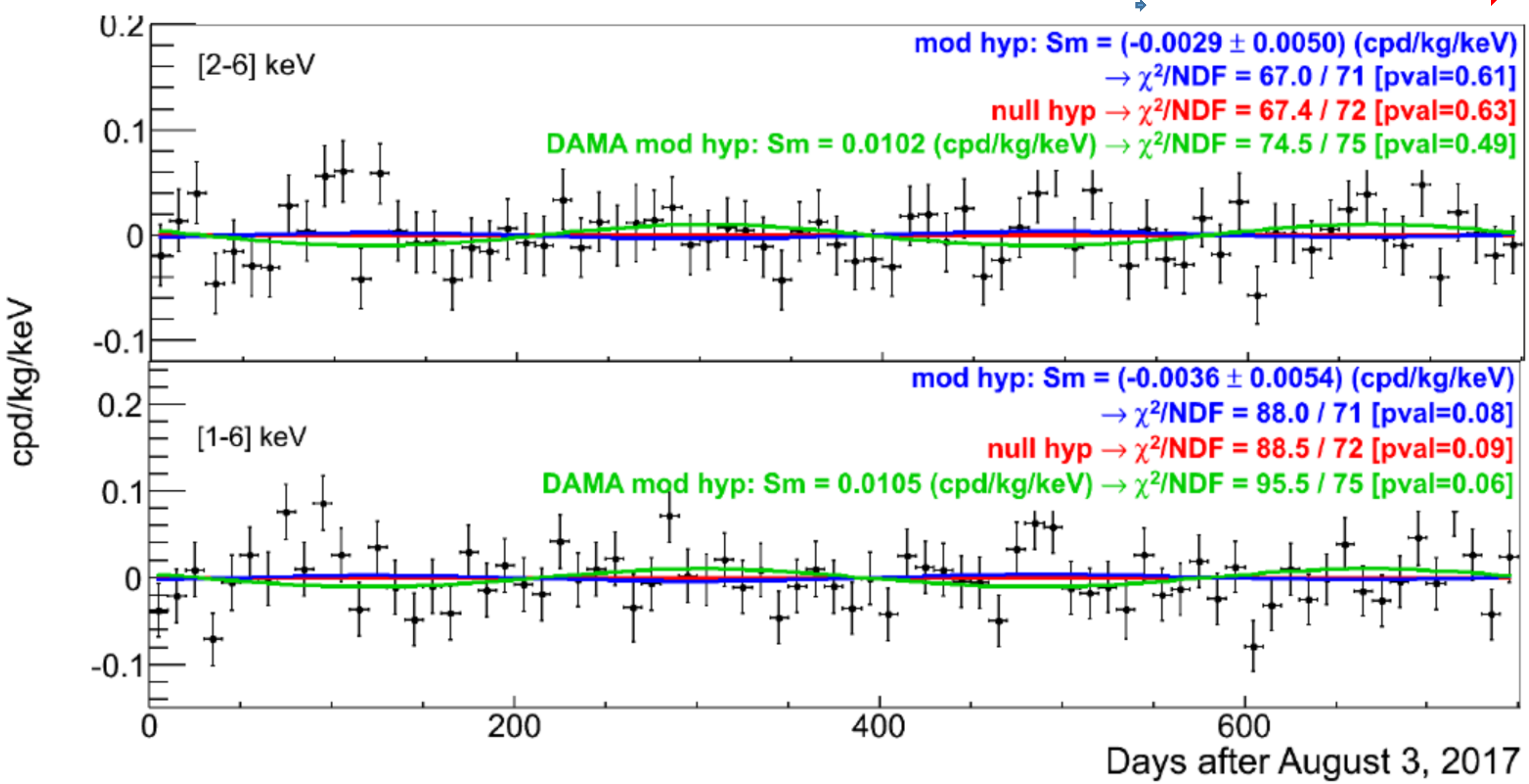
2 years results

213.6 kg x yr

M. L. Sarsa @ TAUP2019

PRELIMINARY

NEW!



2 years results

213.6
kg x yr

M. L. Sarsa @ TAUP2019

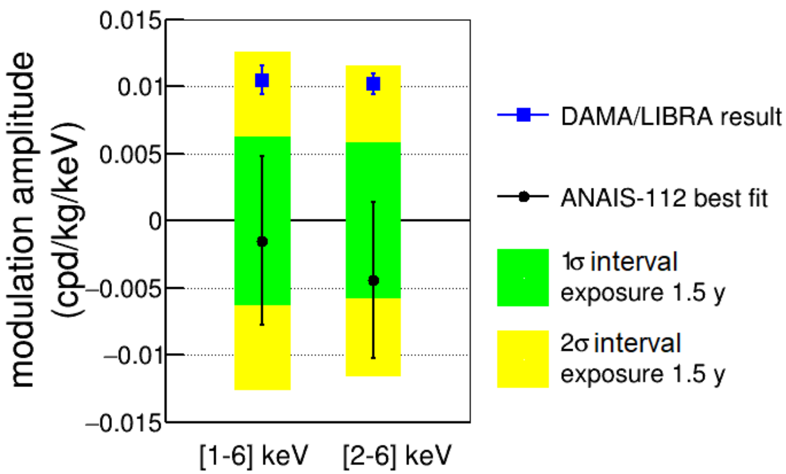
PRELIMINARY

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

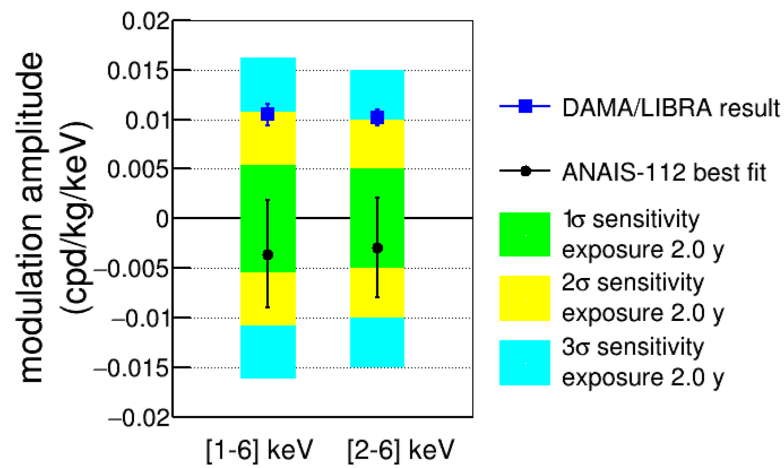
[1-6] keV → $S_m = -0.0036 \pm 0.0054$ c/keV/kg/d (S_m^{DAMA} = 0.0105 cpd/kg/keV)

- 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 are compatible with no modulation and incompatible at 2.6σ with DAMA/LIBRA results. Present sensitivity 2σ

1.5 years (PRL 123 (2019) 031301)



2 years (TAUP 2019)



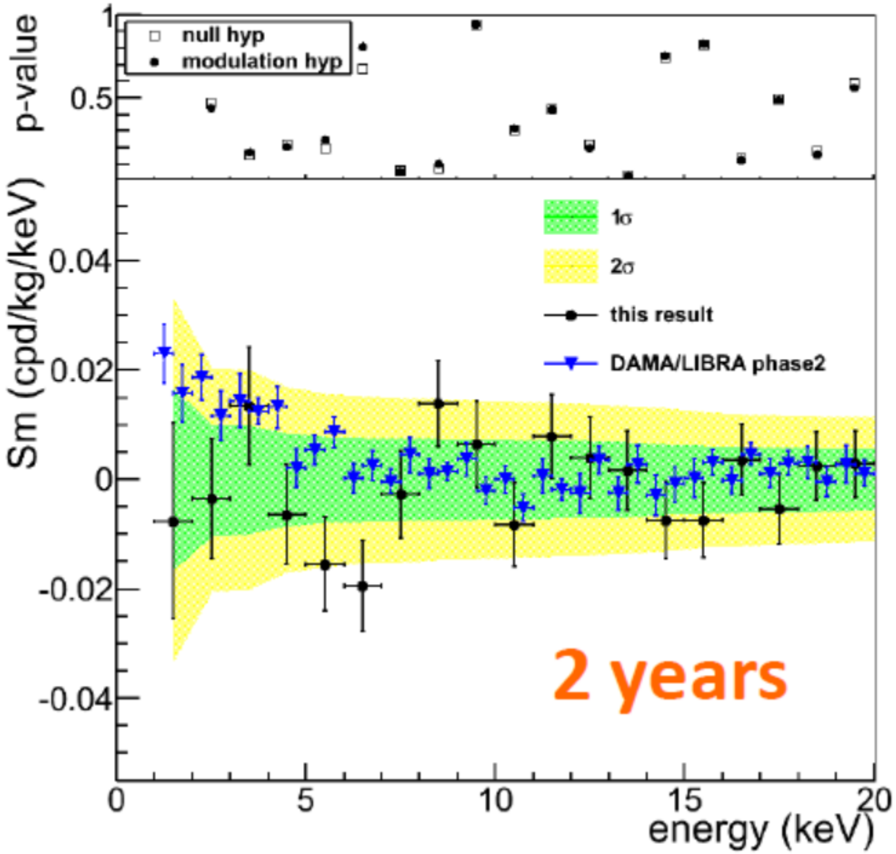
2 years results

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

M. L. Sarsa @ TAUP2019

PRELIMINARY

213.6 kg x yr

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

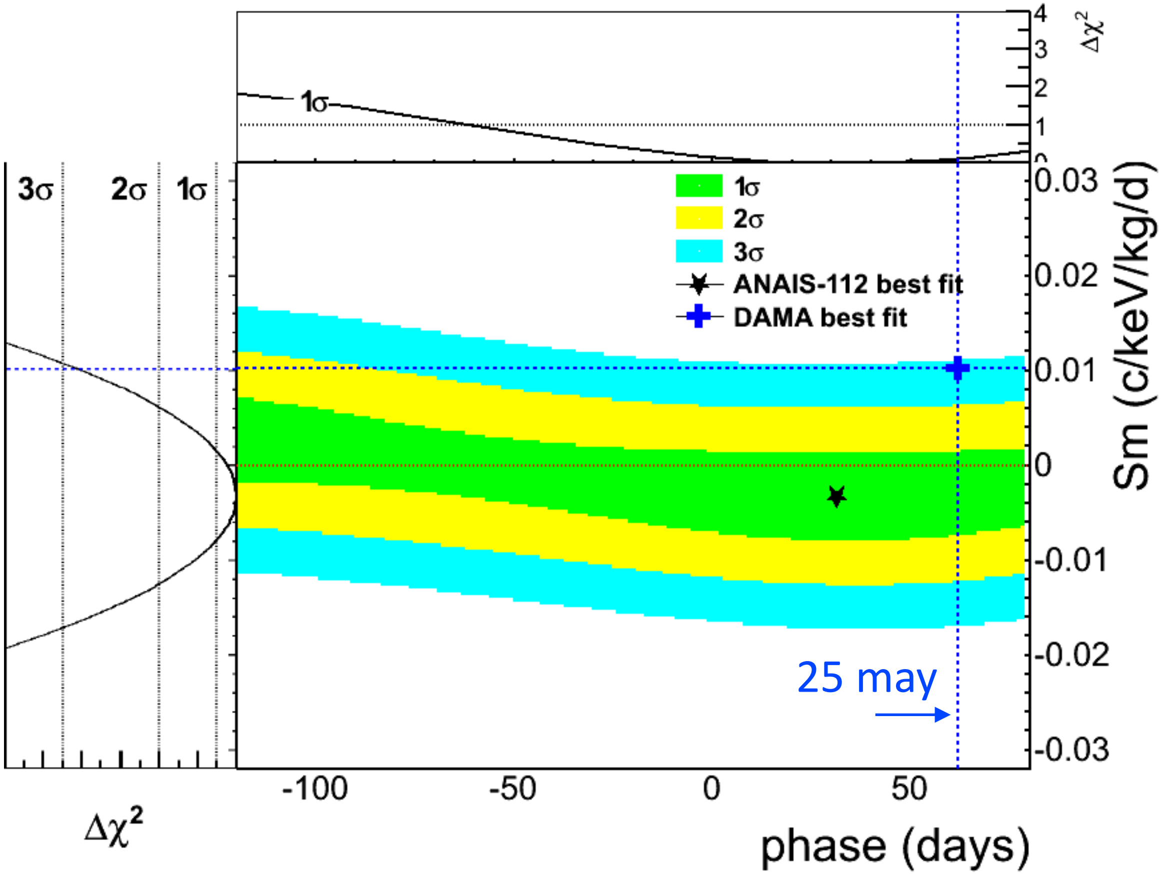
Fixed parameters:

τ (background model)

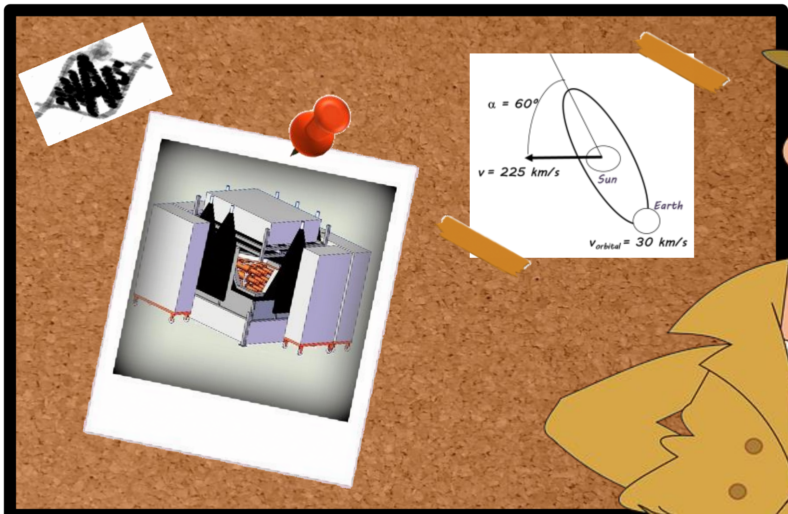
ω (freq. corresponding to a period of 1 year)

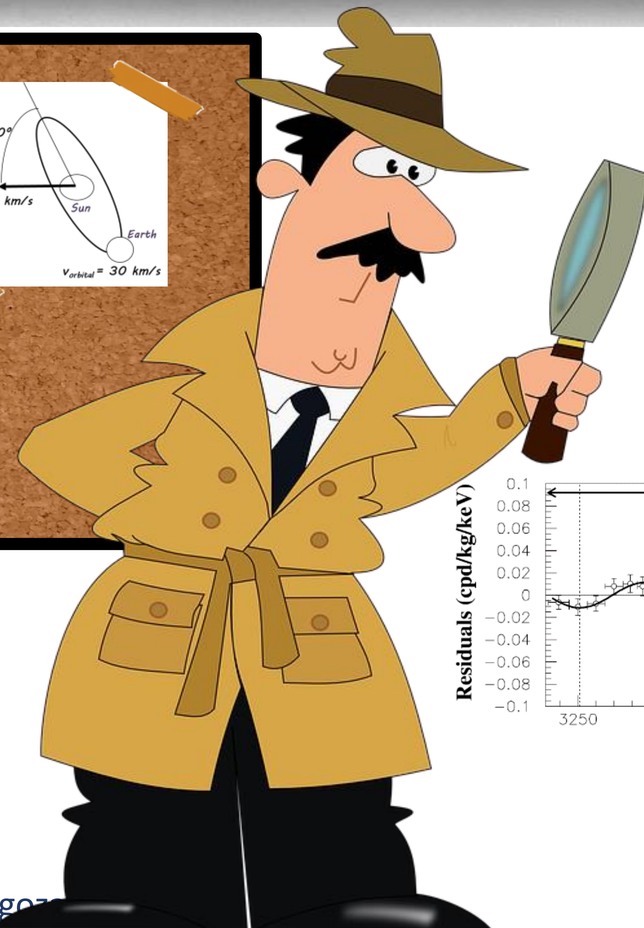
Free parameters:

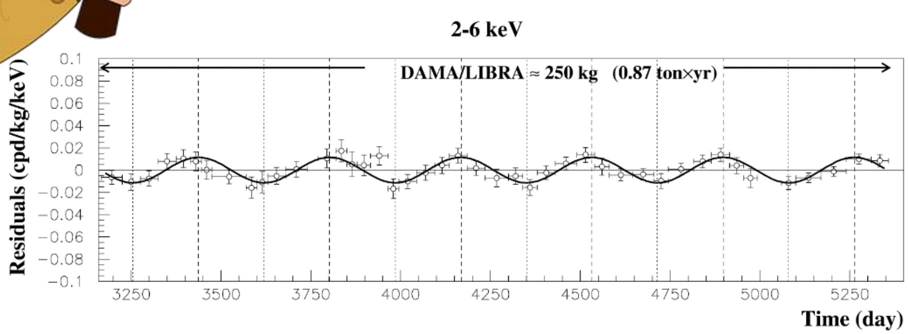
R_0, R_1, S_m, ϕ



ANAIS-112 SENSITIVITY



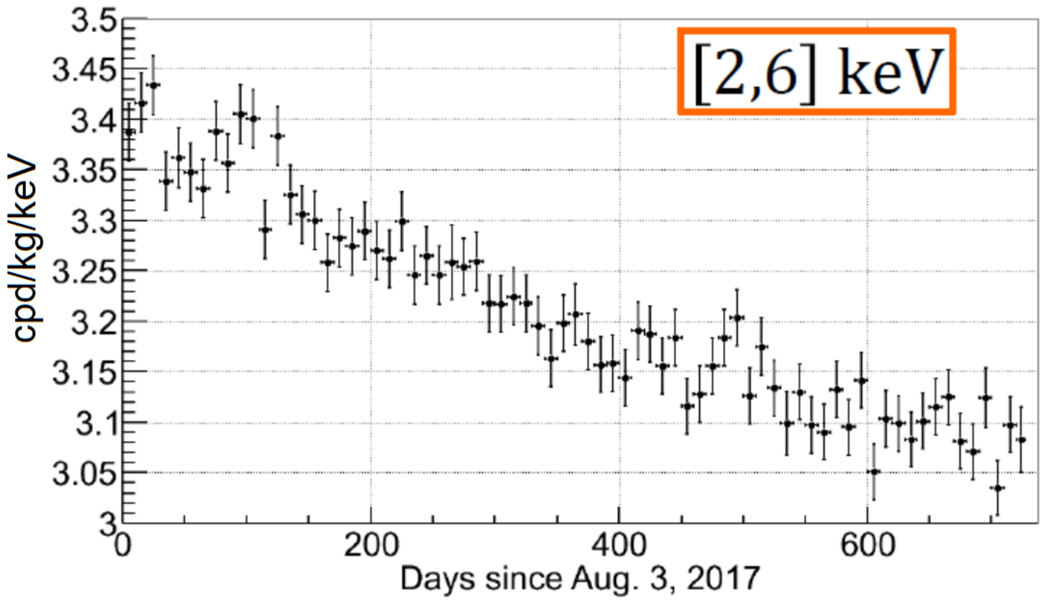




Calculating the sensitivity

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)



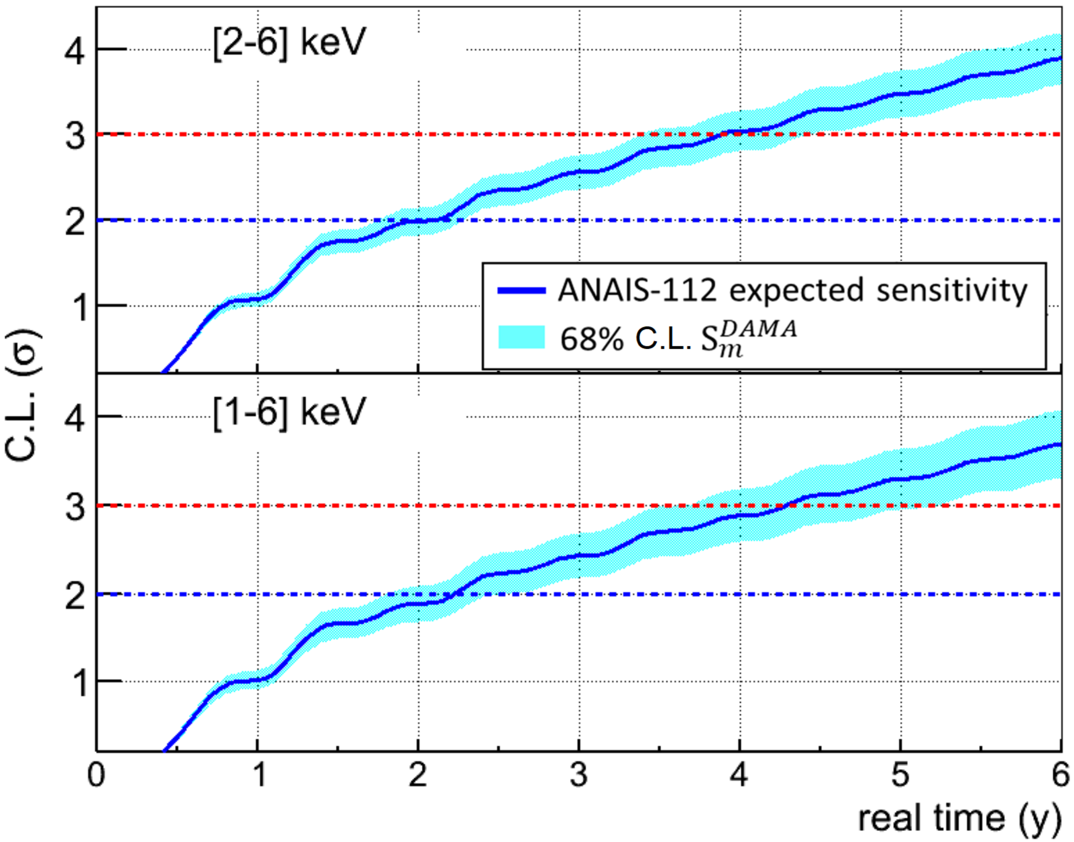
The experimental sensitivity is given by the standard deviation of the modulation amplitude $\boldsymbol{\sigma(S_m)}$, that can be calculated analytically from :

- 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

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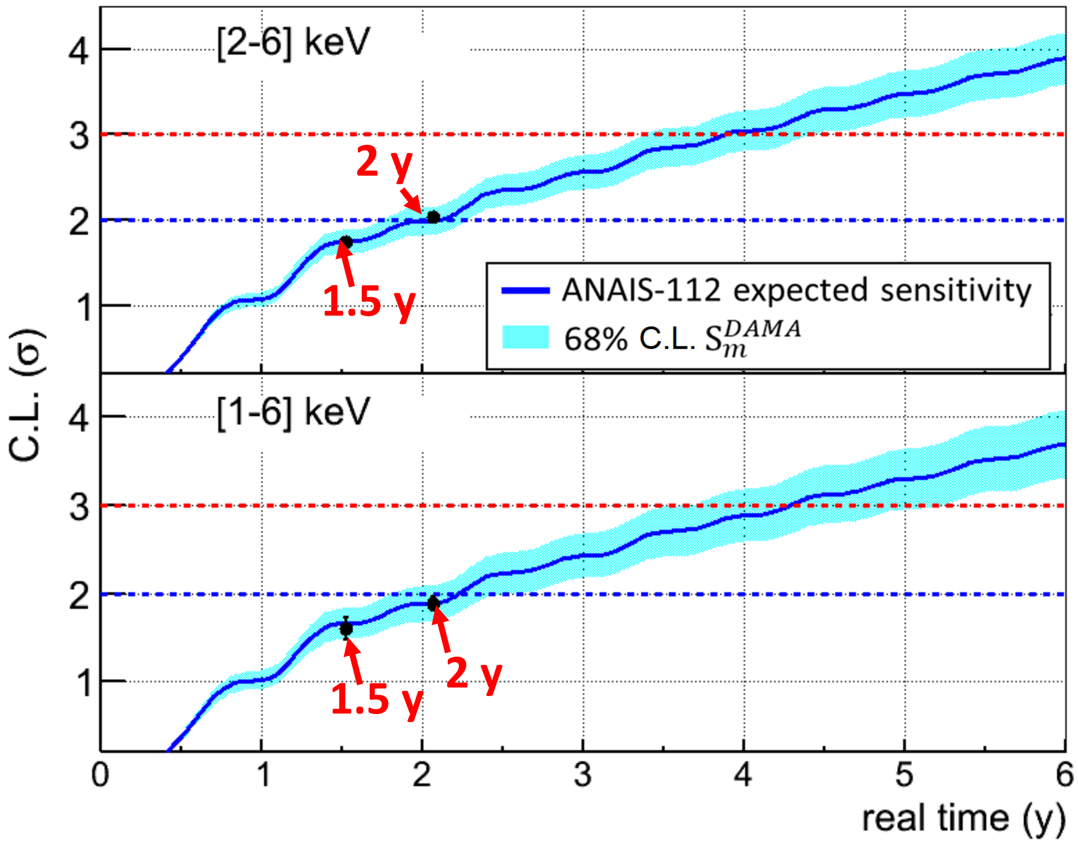
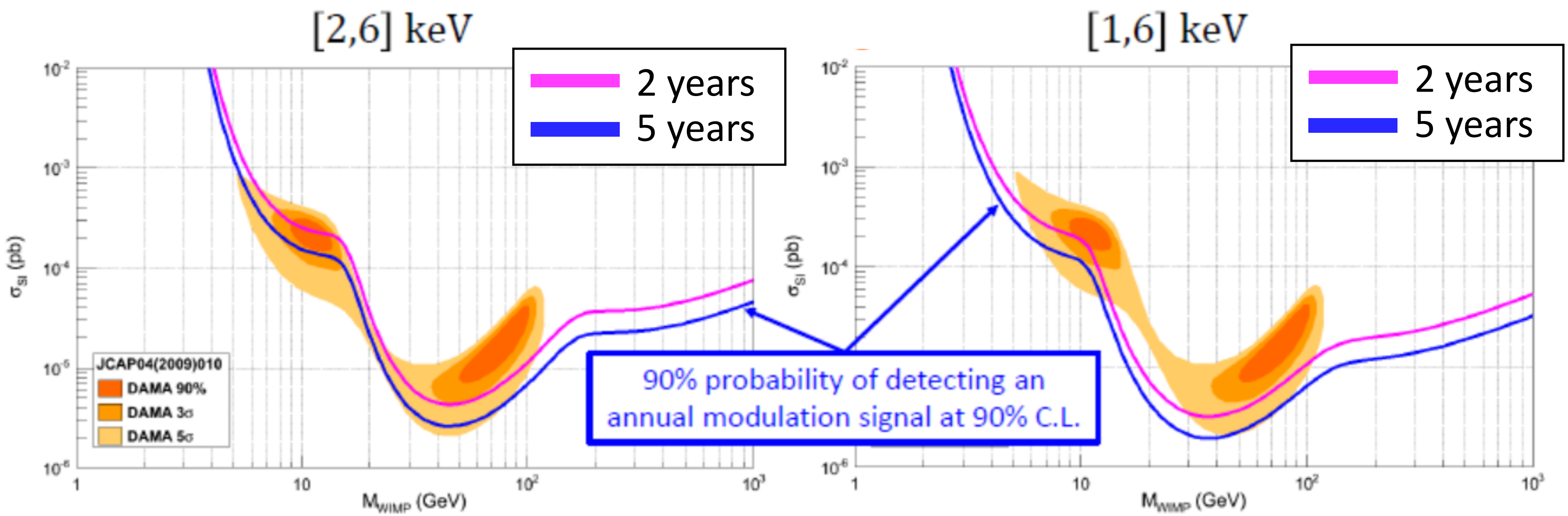


- **1.5 and 2 y data confirm our sensitivity projection to DAMA/LIBRA result**
- **Present sensitivity: 2σ**
- **3σ at reach in 2.5 years from now**

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

- Annual modulation is a distinctive signature of Dark Matter
- One positive signal (DAMA/LIBRA) for more than 20 years, in strong tension with other experiments
- Currently, many efforts trying to confirm / rule out DAMA/LIBRA signal with the same target. COSINE-100 and ANAIS-112 in data-taking
- ANAIS results compatible with absence of modulation and incompatible with DAMA/LIBRA at 2σ after 2 years of data-taking. 3σ sensitivity at reach in about 2.5 years from now.

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DANKE!!