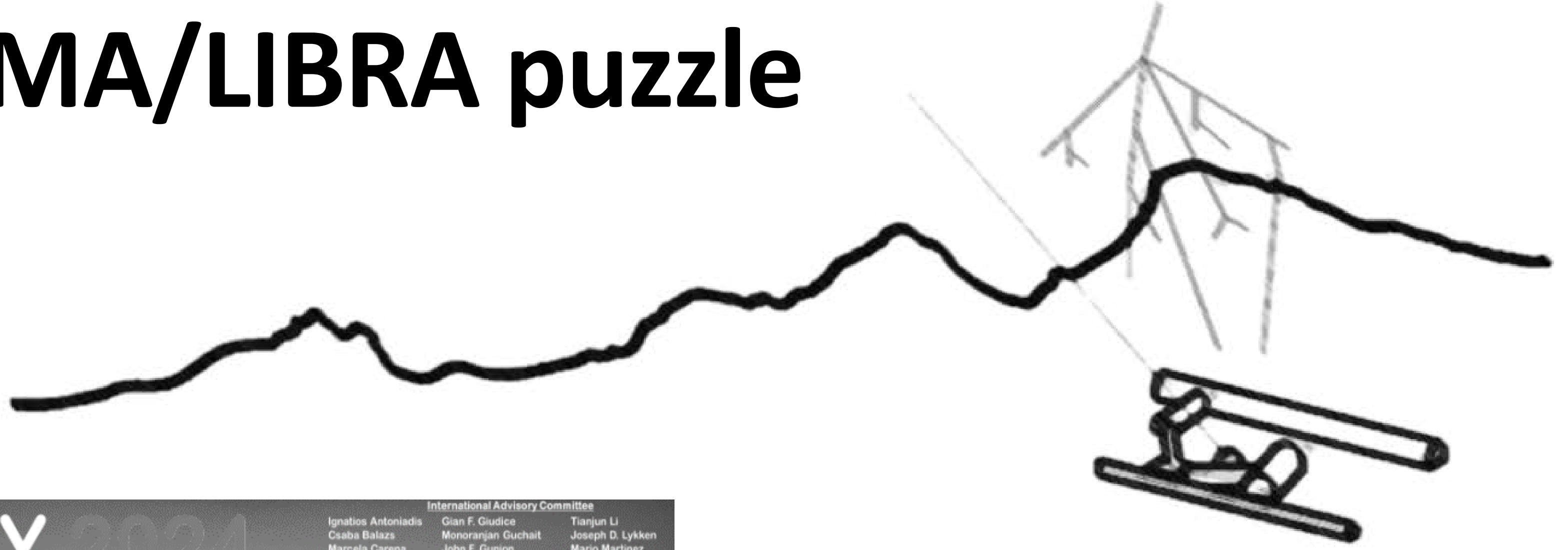
Direct Searches for Dark Matter: down to the neutrino floor while solving the DAMA/LIBRA puzzle



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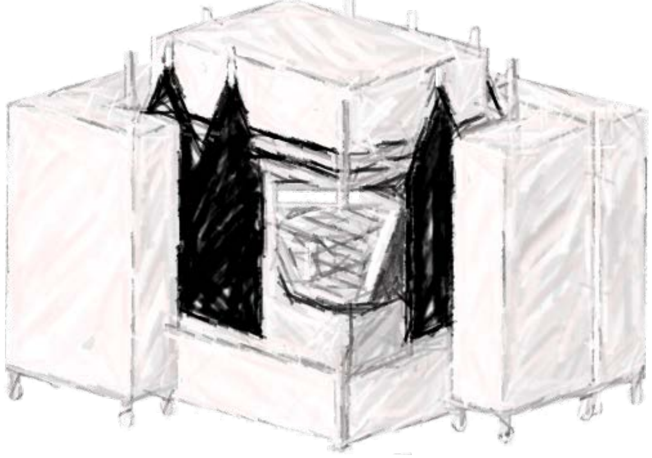
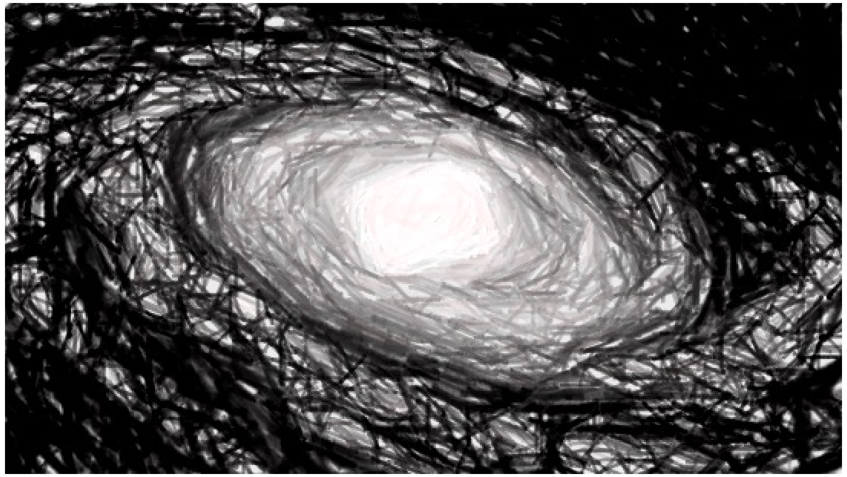
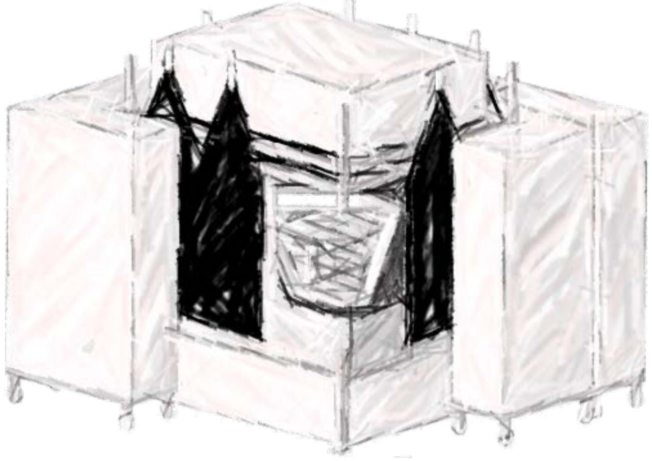
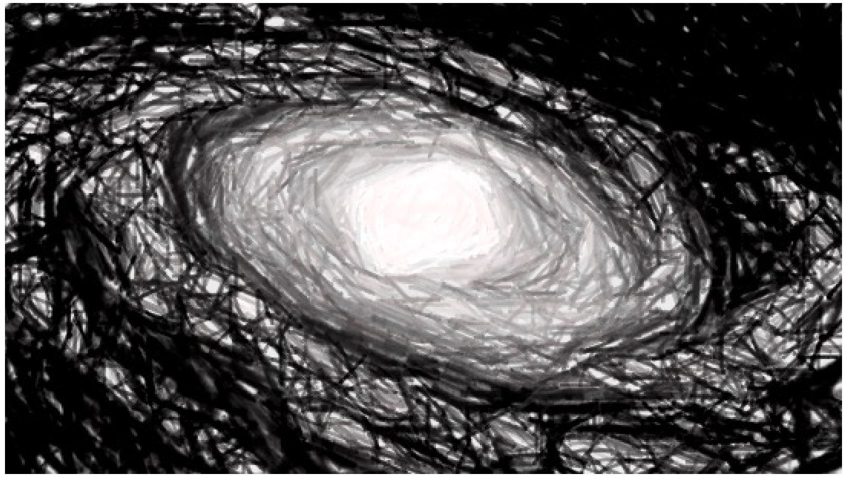




Caveat

- **This contribution is not intended as a complete review on status and prospects on Direct Dark Matter Searches. For that, please refer to the talk by W. Rau tomorrow, in plenary session**

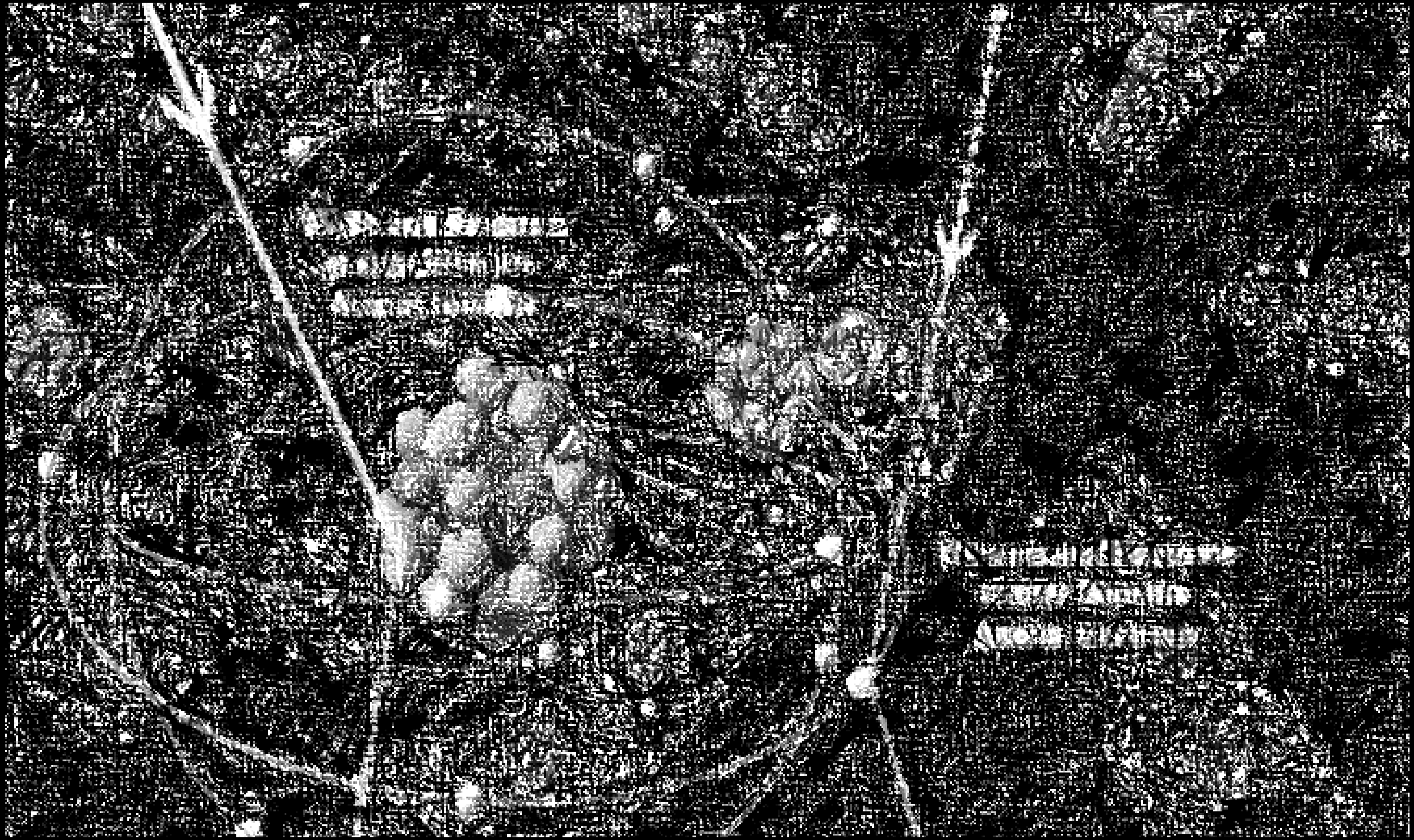
- **This contribution will refer to some of the results of the ANAIS experiment to be presented later with detail in the same session by I. Coarasa**

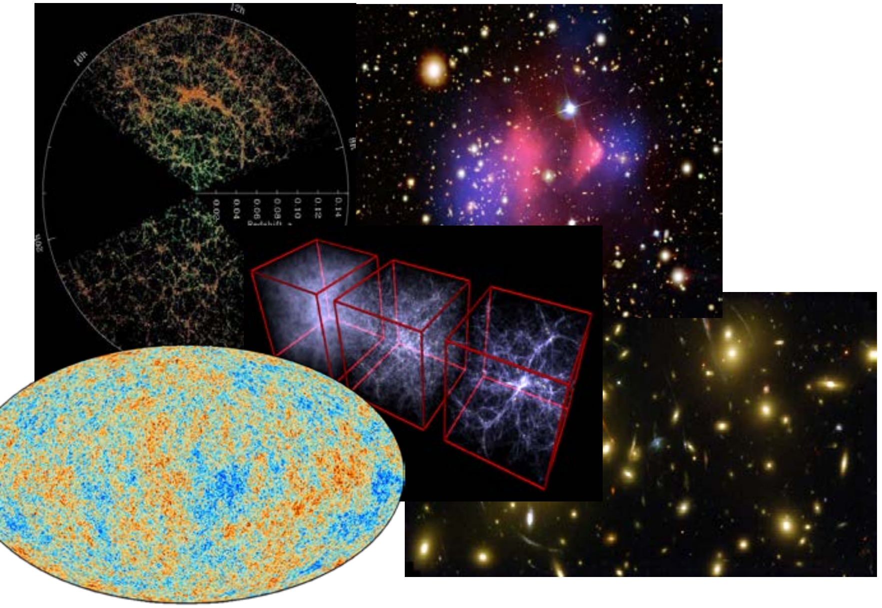
Outline


- **Dark matter direct detection**
- **The DAMA/LIBRA result among other excesses or anomalies**
- **The status of the testing of the DAMA/LIBRA result**
  - **Systematics contributing**
  - **What should we learn from DAMA/LIBRA puzzle?**
- **Open discussion on open access to data and analysis protocols, besides other good practices**
- **Summary and Outlook**

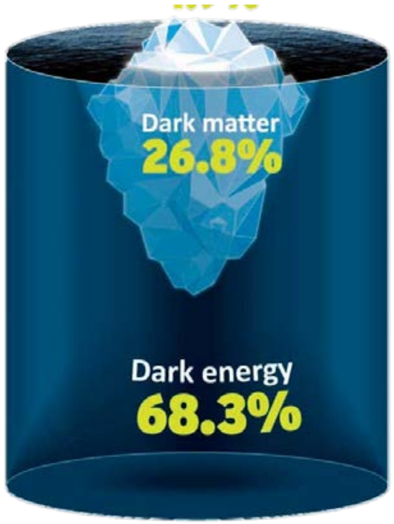
The Dark Matter Direct Detection

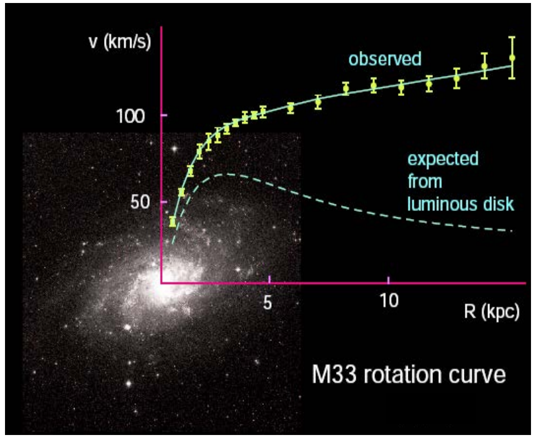




Dark Matter evidences come from very different observational techniques, from different scales and times of the Universe evolution

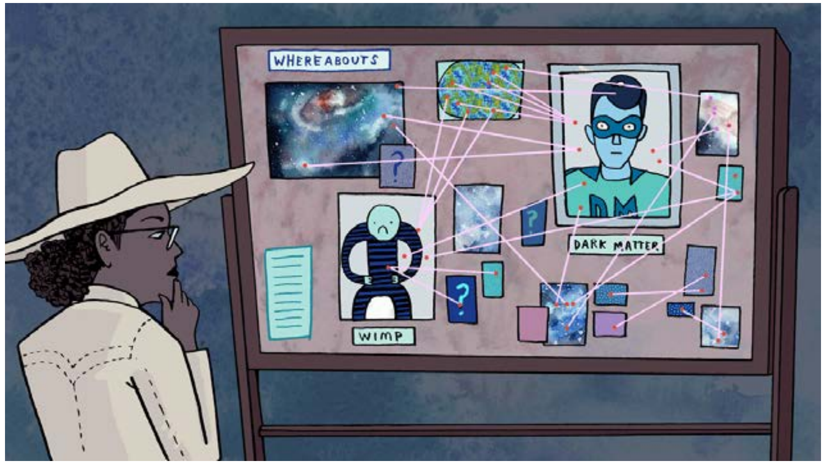
ΛCDM successfully the observations, requiring that 27% of the Universe consists of an unknown form of matter





Dark Matter is expected to be distributed in dark haloes around galaxies, in particular in the Milky Way

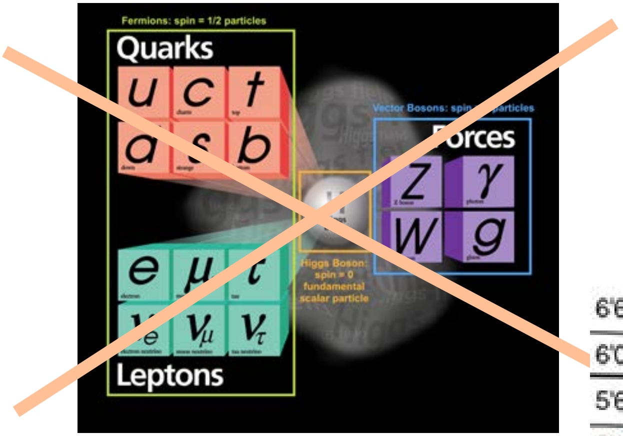
The Dark Matter nature

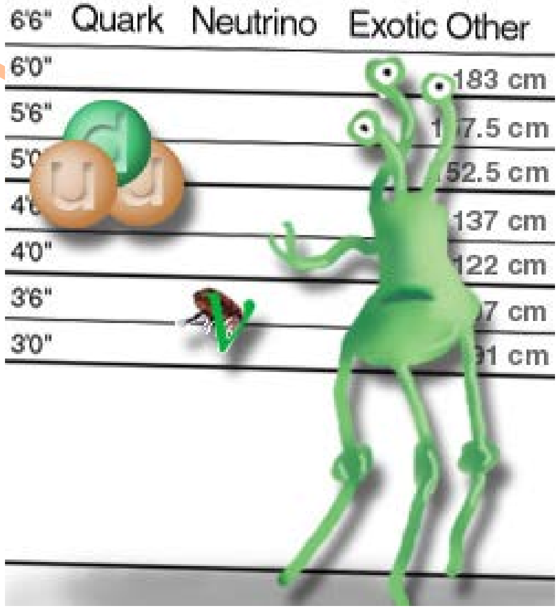


Credit:Artwork by Sandbox Studio, Chicago with Corinne Mucha

There is no unambiguous proof of the DM particle nature

Very loose bounds on mass and properties / Many DM candidates on scene



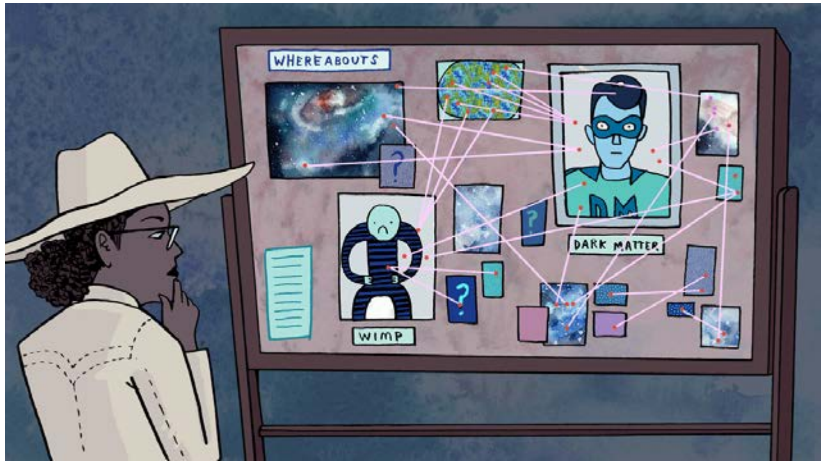


GENERIC PROPERTIES

- massive
- non-baryonic
- neutral (or milli-charged)
- stable (or very long lived)
- non relativistic when structures formed (cold/warm)
- only gravitationally interacting or very weakly interacting (non necessarily EW nature – new couplings)

Beyond the Standard Model of Particle Physics

The Dark Matter nature



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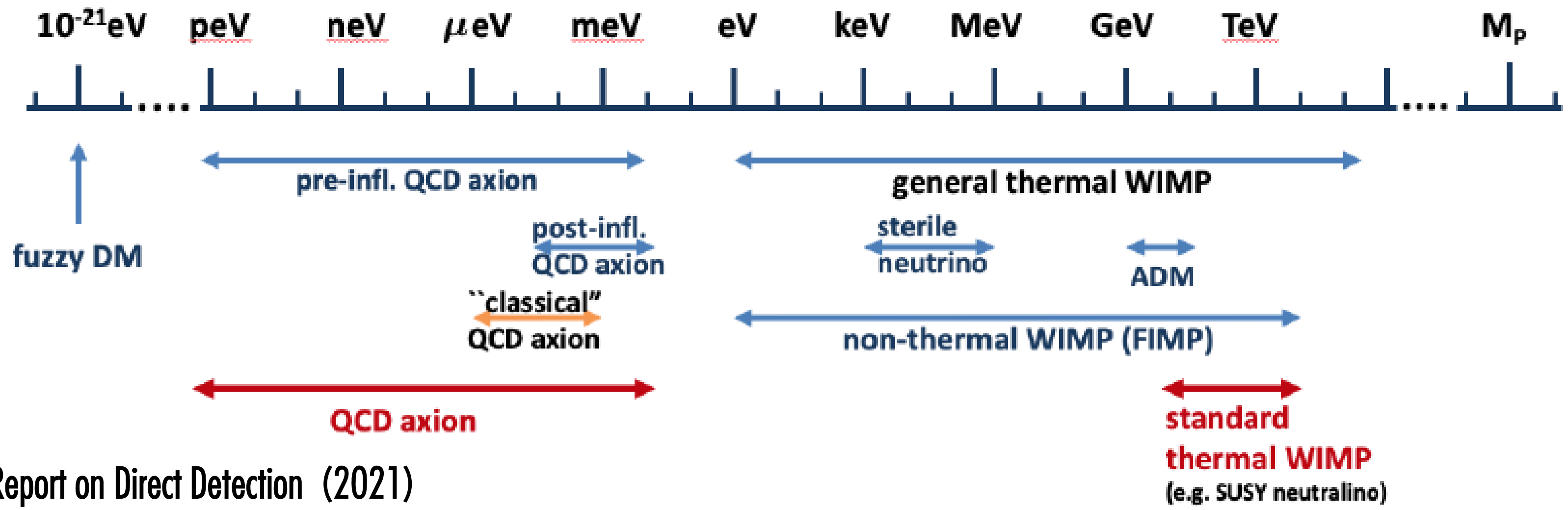
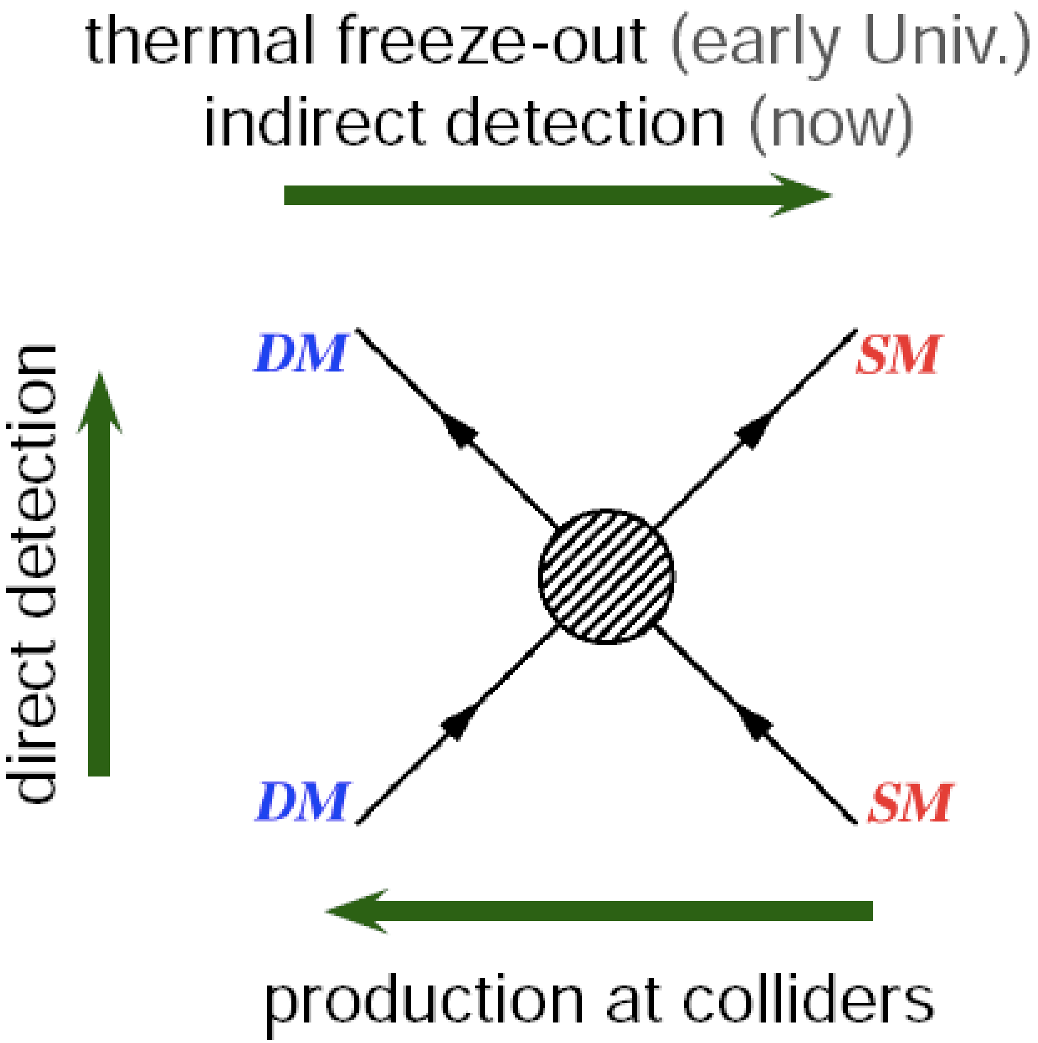


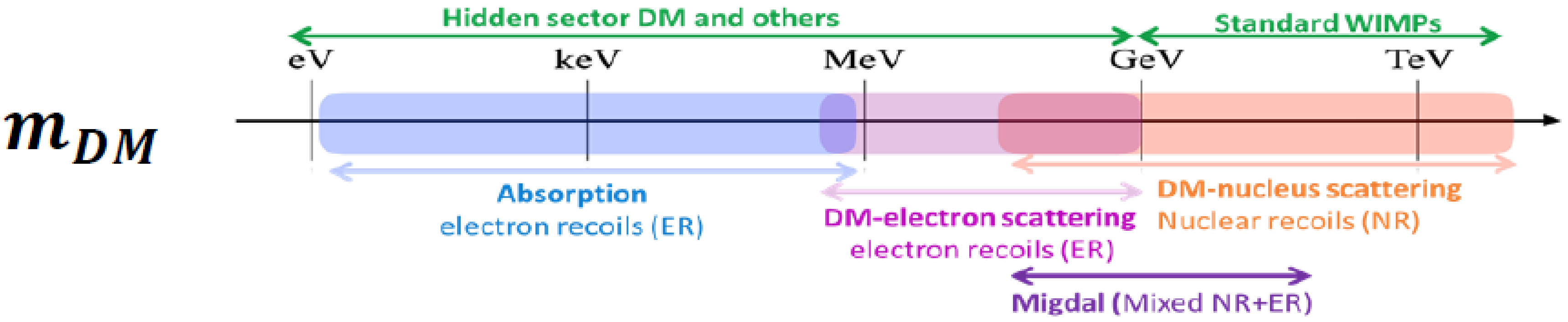
Credit: APPEC Report on Direct Detection (2021)

MACROSCOPIC DM could explain part of the DM content: primordial black holes, topological and non-topological solitons, DM clumps, etc.

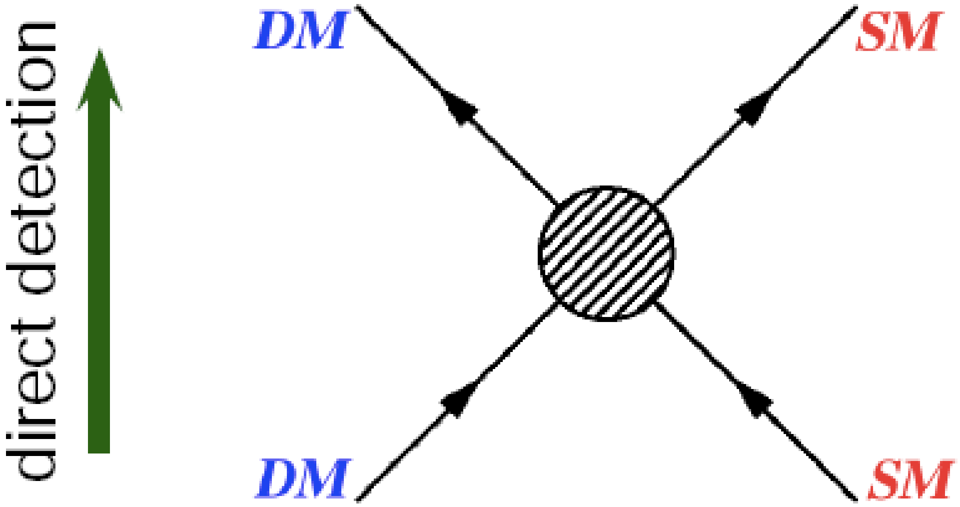


DM particles are expected to couple with ordinary matter with some weak coupling

- Allows production in the Universe (with the right relic density - WIMPs)
- Enables the detection of these particles by different strategies
- They appear naturally within extensions of the SM of the particle Physics



Credit:M. Martínez



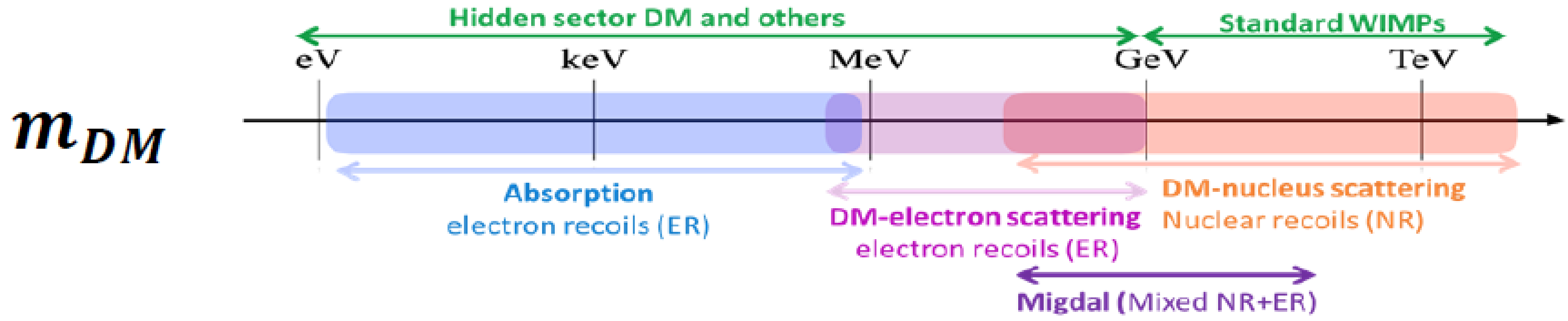
Standard thermal WIMPs and other lighter particles from DM sector can release energy in a convenient detector resulting either in NR or ER signals

standard WIMP scenarios ($\mathbf{m_W = 10 - 10^3}$ **GeV**) : Look for NR, preferred targets with high A

standard WIMP scenarios ($\mathbf{m_W = 1 - 10}$ **GeV**) : Look for NR, **very low energy threshold!**

dark sector couplings ($\mathbf{m_W = 1 - 1000}$ **MeV**) : Inelastic scattering off bound electrons

dark sector & ALPS ($\mathbf{m_W = 1 - 10^6}$ **eV**) : DM absorption



Credit:M. Martínez

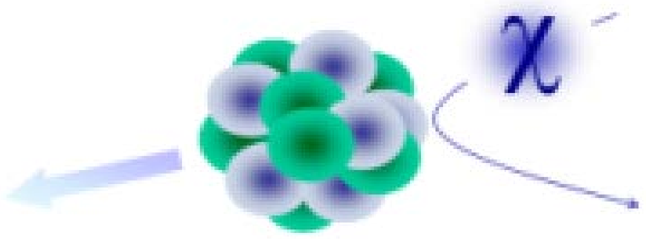
The signal searched for is the energy transferred (NR or ER) by the DM particle

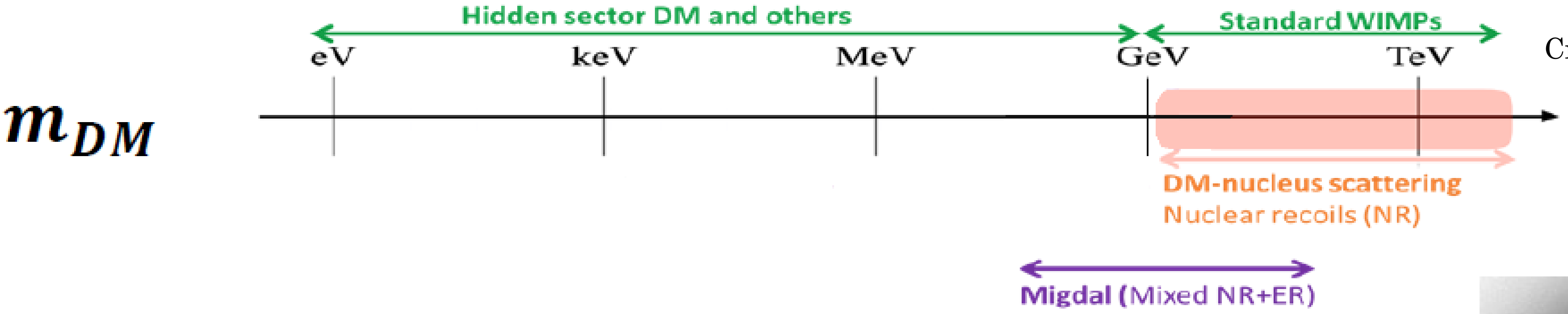
The interpretation of any detection (or lack of it) is model dependent !!

DM-Particle model and nuclear effects

Dark Matter Halo model

$$\frac{dR}{dE} = n_{DM} N_N \int f_{Lab}(\vec{v}) v \frac{d\sigma_{DM-N}}{dE} d\vec{v}$$



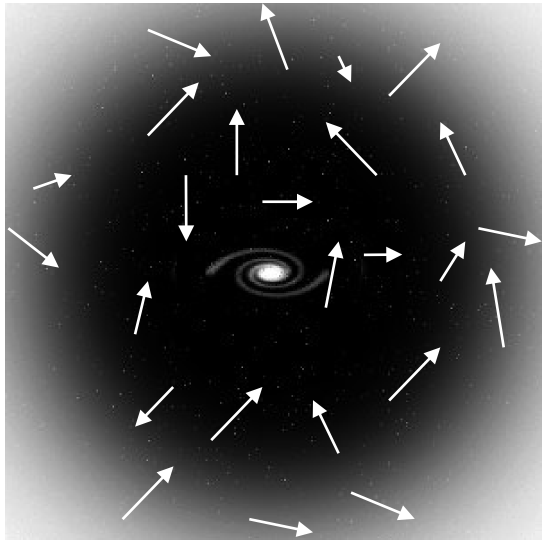


Credit:M. Martínez

About the DM halo model

SHM: isotropic and spherical thermal distribution of non relativistic WIMPs

$$f(\vec{v}_{gal})d^3\vec{v}_{gal} = \frac{1}{v_0^3\pi^{3/2}}e^{-\frac{|\vec{v}_{gal}|^2}{v_0^2}}d^3\vec{v}_{gal}$$



$v_{rms} \approx$ 270km/s–300km/s

$v_{esc} \approx$ 544 km/s

$$n_W = \frac{\rho_0}{m_W}$$

$\rho_0 \approx$ 0.2-0.4 GeV/cm^3

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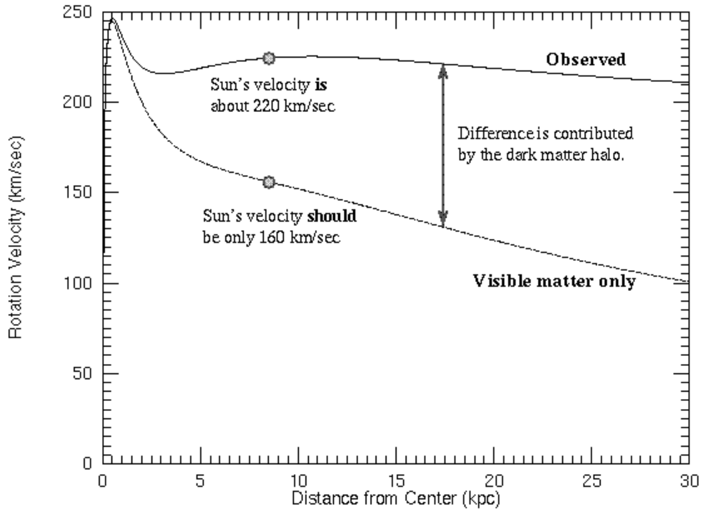

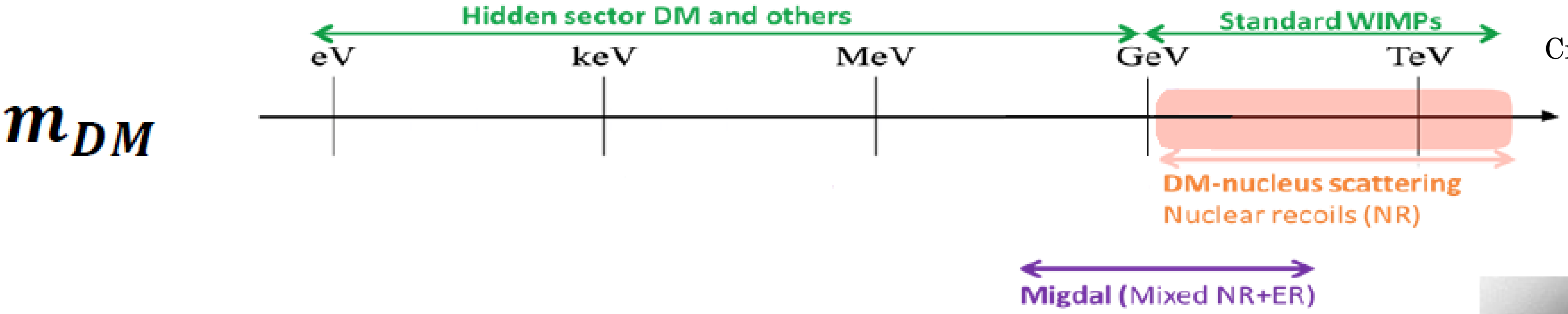

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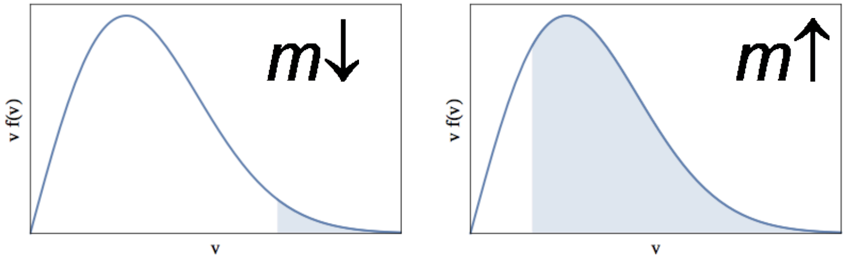
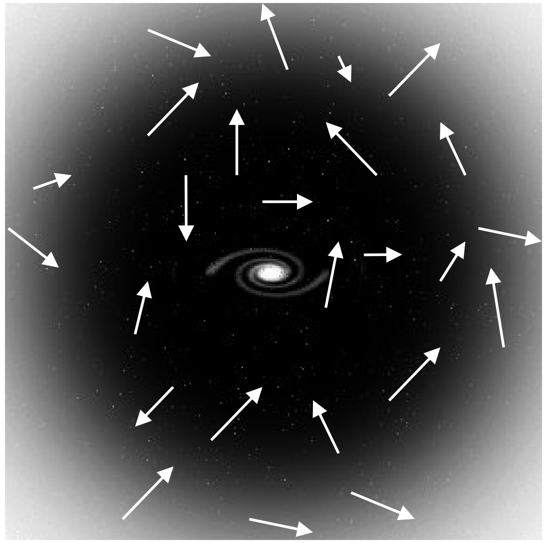
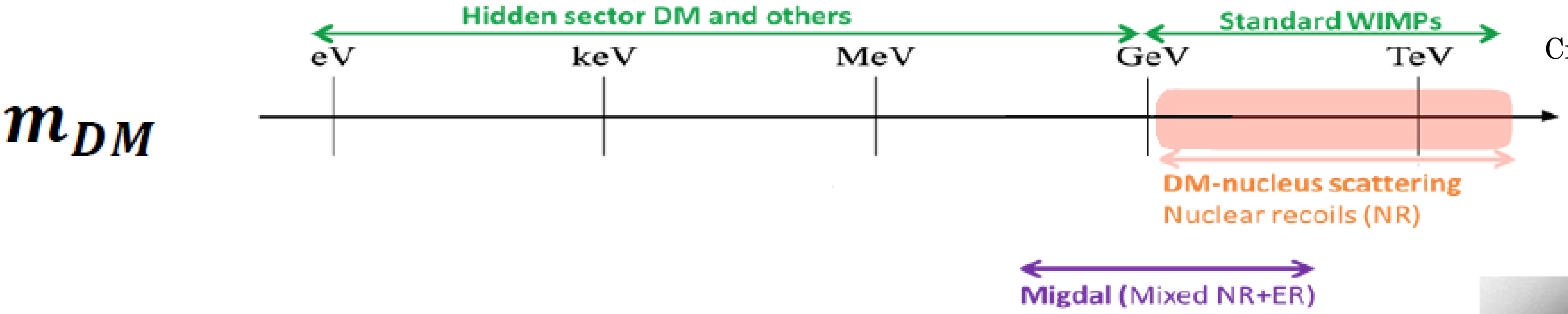




Dark Matter Halo model

$$\frac{dR}{dE} = n_{DM} N_N \int f_{Lab}(\vec{v})v \frac{d\sigma_{DM-N}}{dE} d\vec{v}$$

The whole WIMP phase space is not accesible -> strongly dependent on E threshold for low mass WIMPs



Credit:M. Martínez

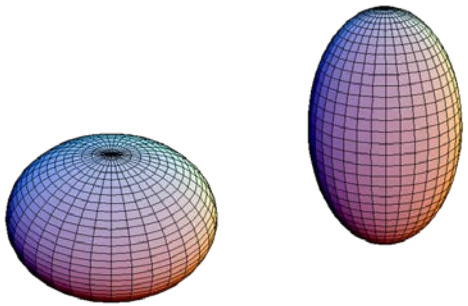
About the DM halo model

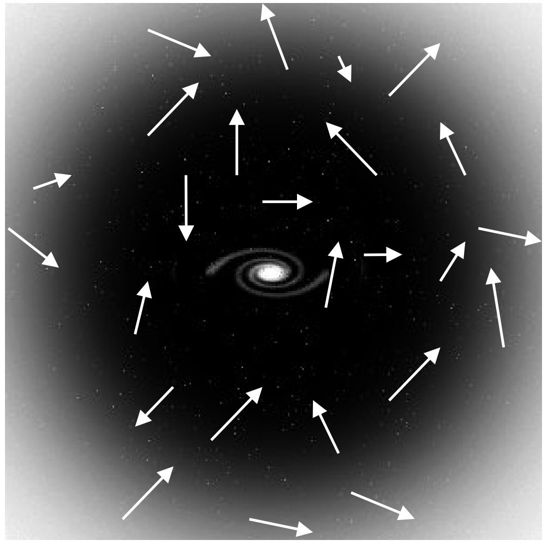
Haloes can be quite different from SHM

-non-spherical

-can have sub-structures:

- **-Sub-haloes**
- **-Dark Disk**
- **-Satellites producing directional fluxes**





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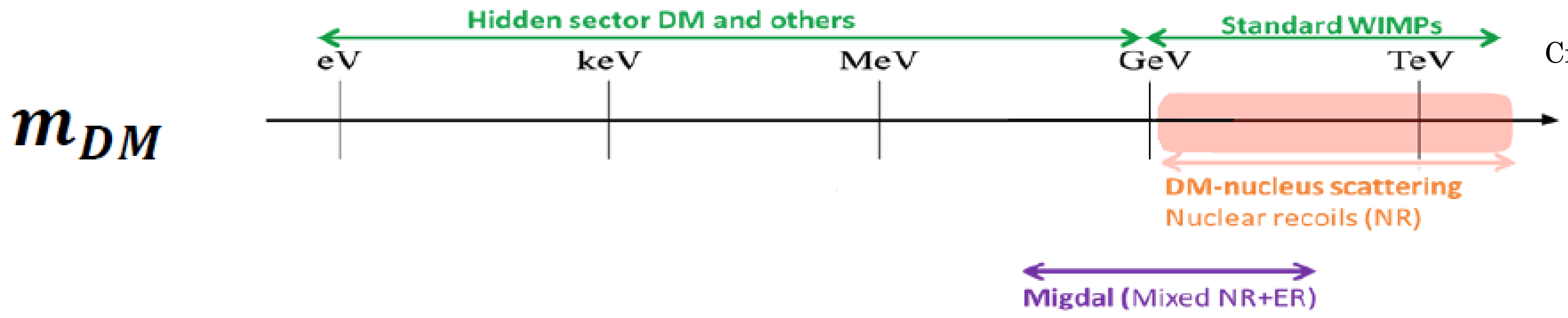


Credit:M. Martínez

About the microscopic DM particle model

The scattering cross section σ_{WN} is completely unknown and contains details from DM particle model and target nuclear structure

Effective operators considering all the posible interaction mechanisms can contribute to the lagrangian with arbitrary weights

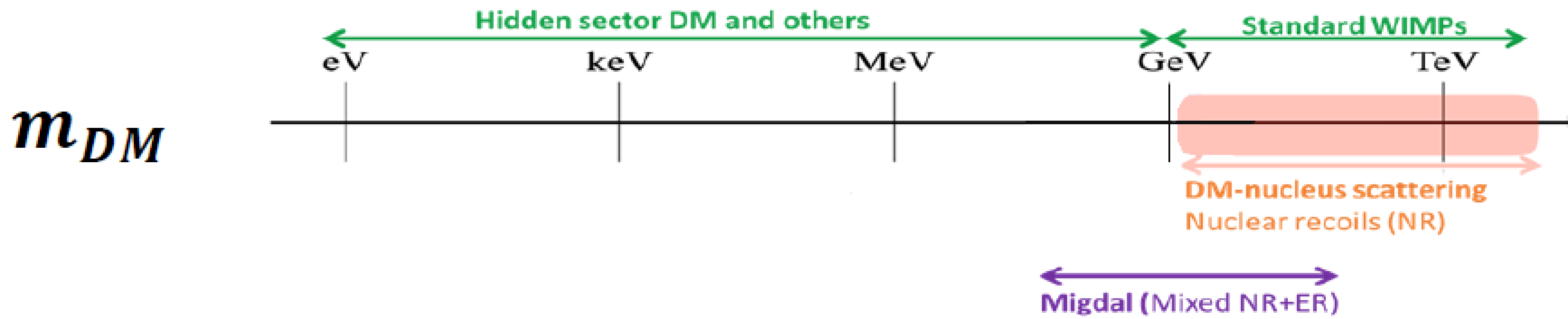
$$\mathcal{O}_1 = 1_\chi 1_N$$
$$\mathcal{O}_3 = i\vec{S}_N \cdot \left[\frac{\vec{q}}{m_N} \times \vec{v}^\perp\right]$$
$$\mathcal{O}_4 = \vec{S}_\chi \cdot \vec{S}_N$$
$$\mathcal{O}_5 = i\vec{S}_\chi \cdot \left[\frac{\vec{q}}{m_N} \times \vec{v}^\perp\right]$$
$$\mathcal{O}_6 = \left[\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right]\left[\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right]$$
$$\mathcal{O}_7 = \vec{S}_N \cdot \vec{v}^\perp$$
$$\mathcal{O}_8 = \vec{S}_\chi \cdot \vec{v}^\perp$$
$$\mathcal{O}_9 = i\vec{S}_\chi \cdot \left[\vec{S}_N \times \frac{\vec{q}}{m_N}\right]$$
$$\mathcal{O}_{10} = i\vec{S}_N \cdot \frac{\vec{q}}{m_N}$$
$$\mathcal{O}_{11} = i\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}$$
$$\mathcal{O}_{12} = \vec{S}_\chi \cdot \left[\vec{S}_N \times \vec{v}^\perp\right]$$
$$\mathcal{O}_{13} = i\left[\vec{S}_\chi \cdot \vec{v}^\perp\right]\left[\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right]$$
$$\mathcal{O}_{14} = i\left[\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right]\left[\vec{S}_N \cdot \vec{v}^\perp\right]$$
$$\mathcal{O}_{15} = -\left[\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right]\left[\left(\vec{S}_N \times \vec{v}^\perp\right) \cdot \frac{\vec{q}}{m_N}\right]$$

DM-Particle model

nuclear effects

$$\frac{dR}{dE} = n_{DM} N_N \int f_{Lab}(\vec{v})\, v \frac{d\sigma_{DM-N}}{dE}\, d\vec{v}$$

$$\mathcal{L}_{\text{int}} = \sum_{i=1,15} c_i \chi^* \mathcal{O}_\chi \chi \Psi_N^* \mathcal{O}_i \Psi_N$$



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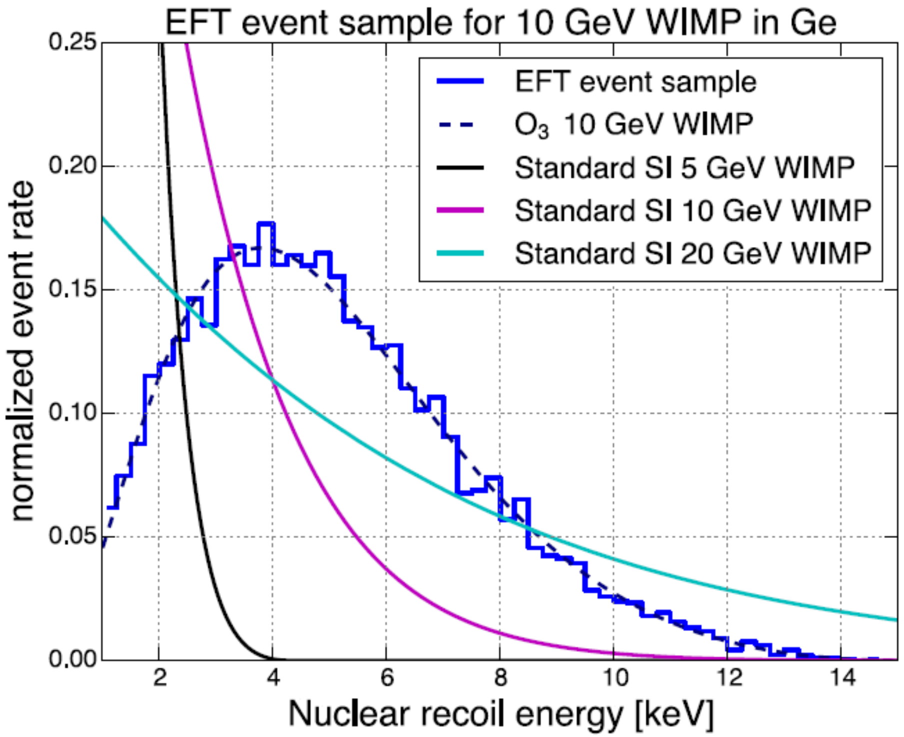

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effects

$$\mathcal{O}_1 = 1_\chi 1_N \qquad \mathcal{O}_{10} = i\vec{S}_N \cdot \frac{\vec{q}}{m_N}$$
$$\mathcal{O}_3 = i\vec{S}_N \cdot \left[\frac{\vec{q}}{m_N} \times \vec{v}^\perp\right] \qquad \mathcal{O}_{11} = i\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}$$
$$\mathcal{O}_4 = \vec{S}_\chi \cdot \vec{S}_N \qquad \mathcal{O}_{12} = \vec{S}_\chi \cdot \left[\vec{S}_N \times \vec{v}^\perp\right]$$
$$\mathcal{O}_5 = i\vec{S}_\chi \cdot \left[\frac{\vec{q}}{m_N} \times \vec{v}^\perp\right] \qquad \mathcal{O}_{13} = i\left[\vec{S}_\chi \cdot \vec{v}^\perp\right]\left[\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right]$$
$$\mathcal{O}_6 = \left[\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right]\left[\vec{S}_N \cdot \frac{\vec{q}}{m_N}\right] \qquad \mathcal{O}_{14} = i\left[\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right]\left[\vec{S}_N \cdot \vec{v}^\perp\right]$$
$$\mathcal{O}_7 = \vec{S}_N \cdot \vec{v}^\perp$$
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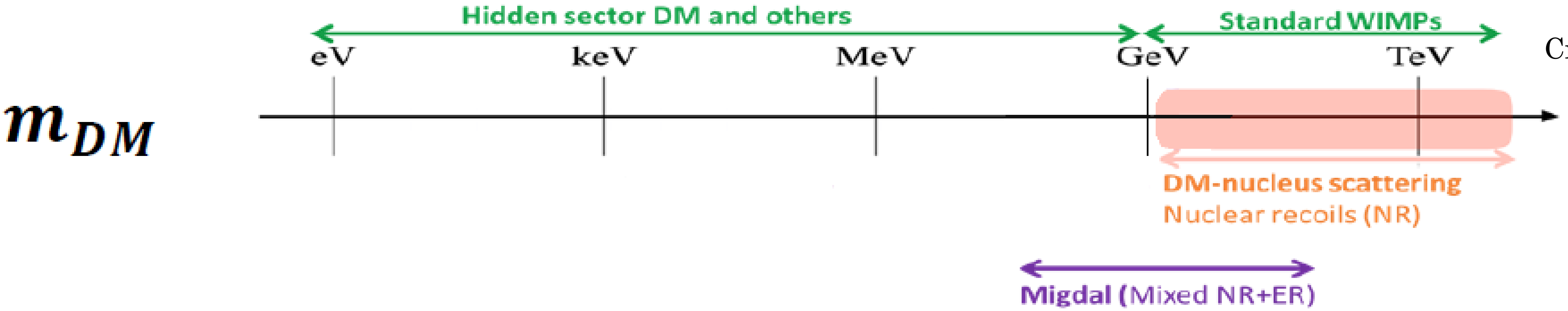
$$\mathcal{O}_9 = i\vec{S}_\chi \cdot \left[\vec{S}_N \times \frac{\vec{q}}{m_N}\right]$$

$$v \frac{d\sigma_{DM-N}}{dE} d\vec{v}$$

Different spectral features for different operators

Nuclear effects relevant



Credit:M. Martínez

About the microscopic DM particle model

The DM mass is unknown and it strongly affects to the kinematics of the elastic scattering

Kinematical mass matching in the response to WIMPs and relevance of the threshold in Energy

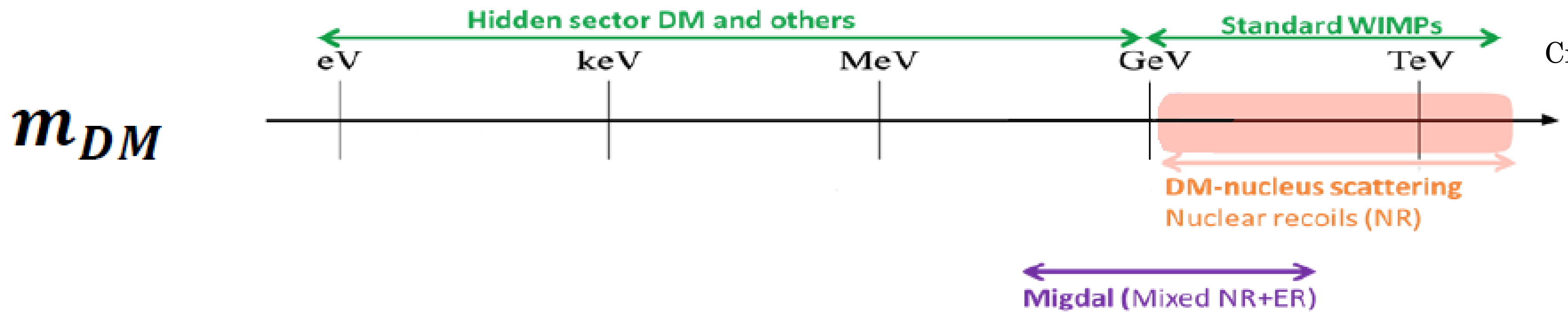
$$T_{recoil} = E_0 - E_{WIMP}^{f} = \frac{m_W{}^2 M_N}{(m_W + M_N)^2} v^2 (1 - \cos\theta)$$

$$T_{\max} = \frac{2 m_W{}^2 M_N}{(m_W + M_N)^2} v^2$$

$$v_{\min}{}^2 = \frac{(m_W + M_N)^2}{2 m_W{}^2 M_N} T_{threshold}$$

DM-Particle model and nuclear effects

$$\frac{dR}{dE} = n_{DM} N_N \int f_{Lab}(\vec{v}) v \frac{d\sigma_{DM-N}}{dE} d\vec{v}$$



Credit:M. Martínez

How to compare results from different experiments?

Experiments provide limits on σ_{WN}
Comparison should be done in some parameter independent of the target
-> at lagrangian level or at some intermediate level, σ_{Wn}

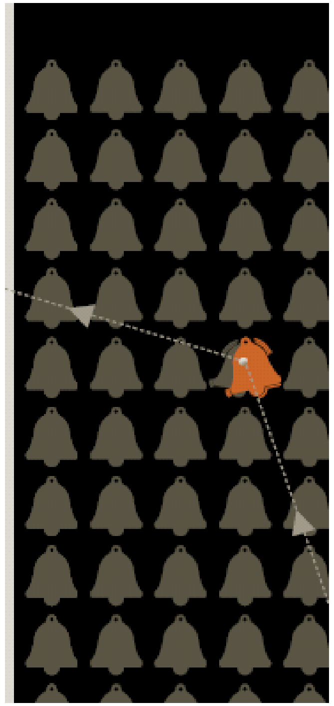
$$\sigma_{WN,SI} \propto \frac{m_{WN}^2}{m_{Wn}^2} A^2 F^2 \sigma_{Wn,SI}^0$$

$$\mathcal{O}_1 = 1_\chi 1_N$$

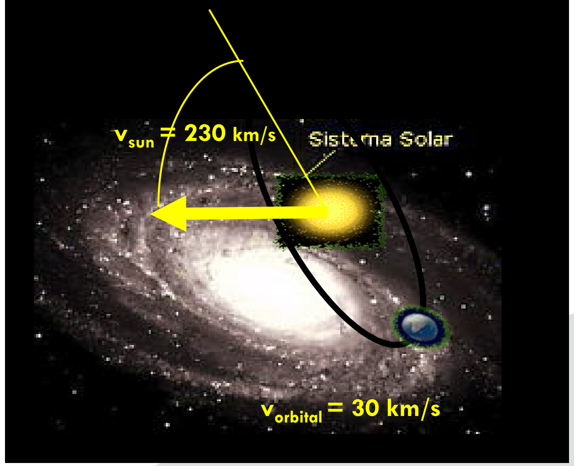
For SI interacting WIMPs, rate scales with A^2
Usually adopted to compare experiments using different targets
But, any comparison will be MODEL-DEPENDENT

$$\frac{dR}{dE} = n_{DM} N_N \int f_{Lab}(\vec{v}) v \frac{d\sigma_{DM-N}}{dE} d\vec{v}$$

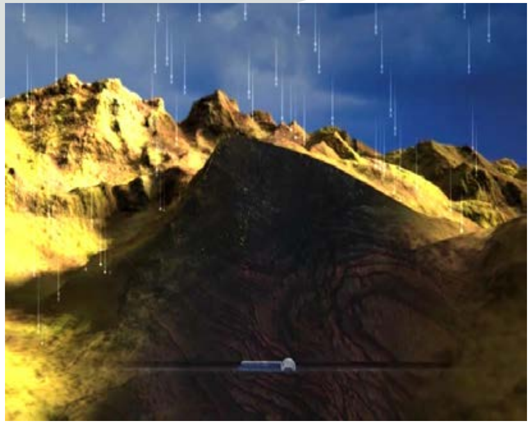
The Dark Matter Direct Detection



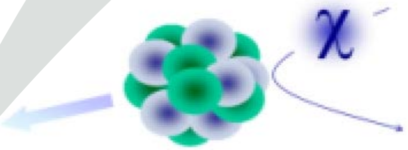
Availability of very sensitive and radiopure particle detectors



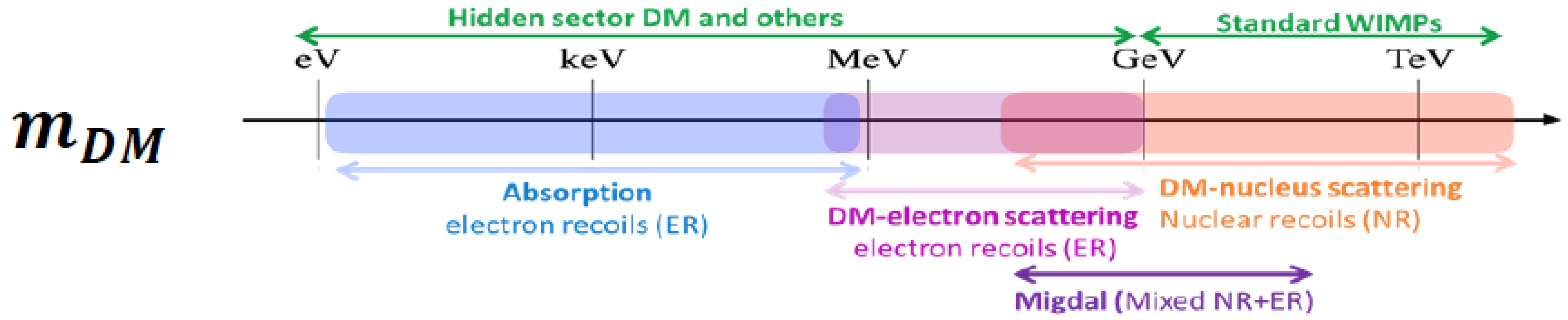
Signatures of a Dark Matter interaction are very convenient for a positive result



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



WIMPs interact (although weakly) with ordinary matter



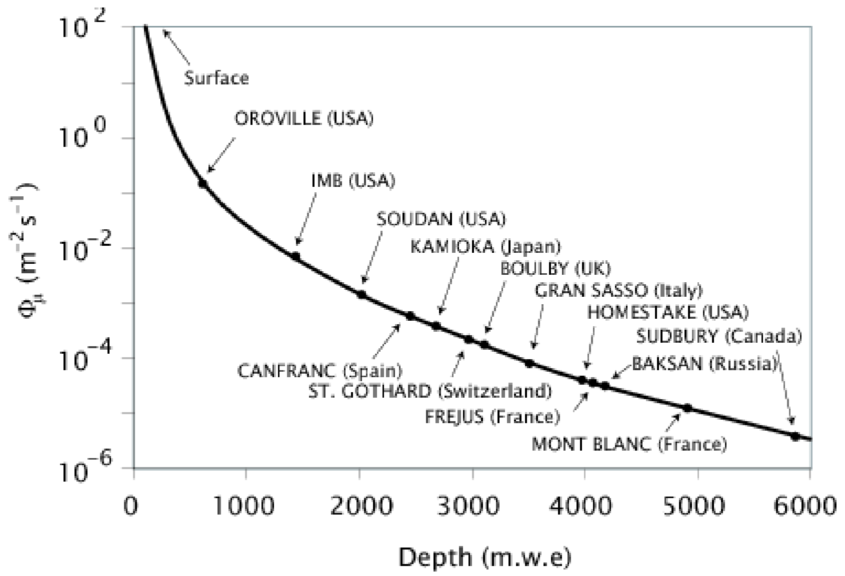
Credit:M. Martínez

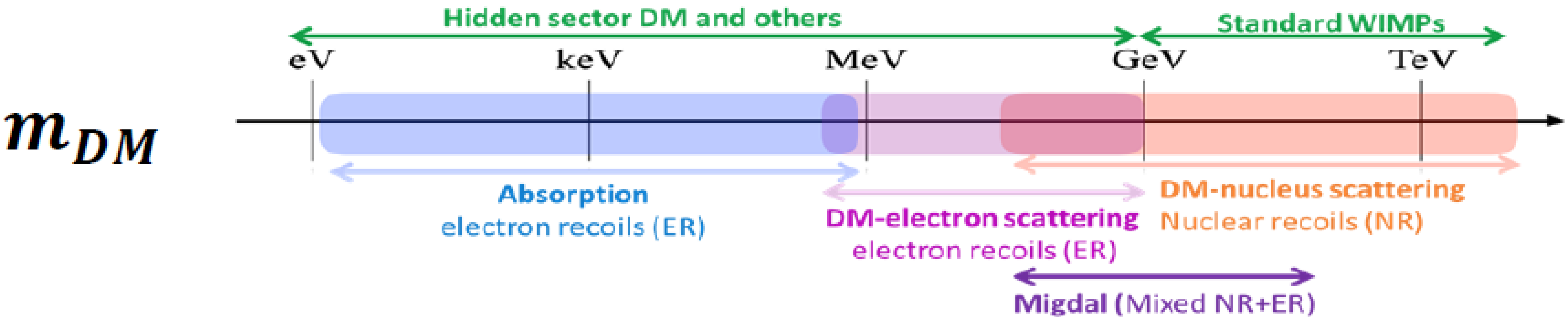
Background signals interferring with WIMP detection

How to fight them

Cosmic Rays (μ)

Operation of the experiments at Underground Laboratories





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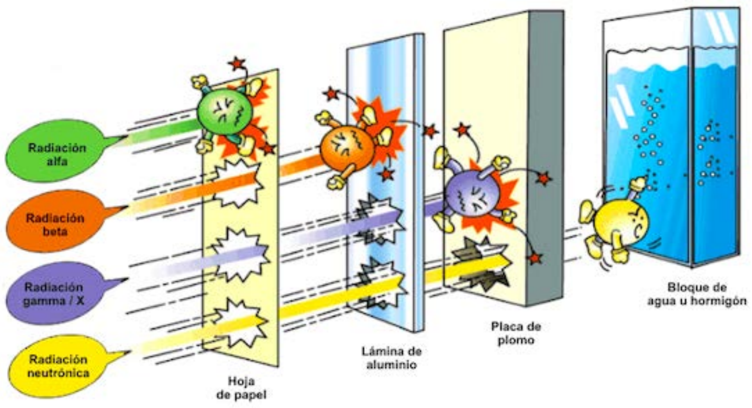
Background signals interferring with WIMP detection

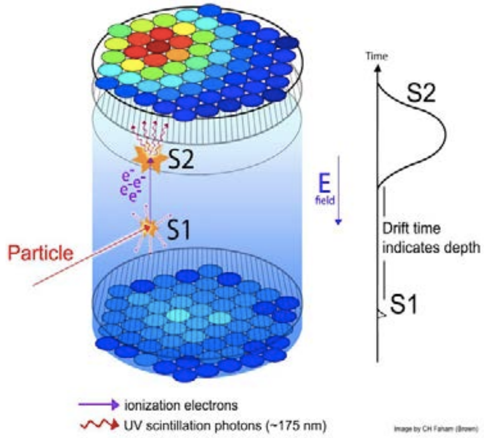
How to fight them

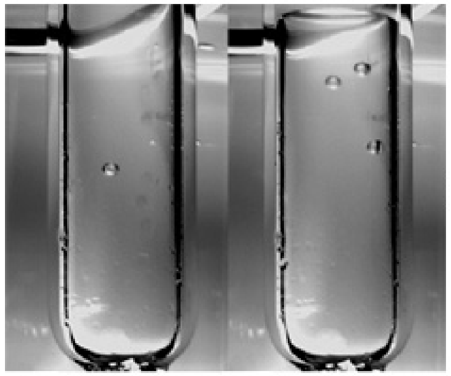
Cosmic Rays (μ)
Radioactive Isotopes (n, α, β, γ)

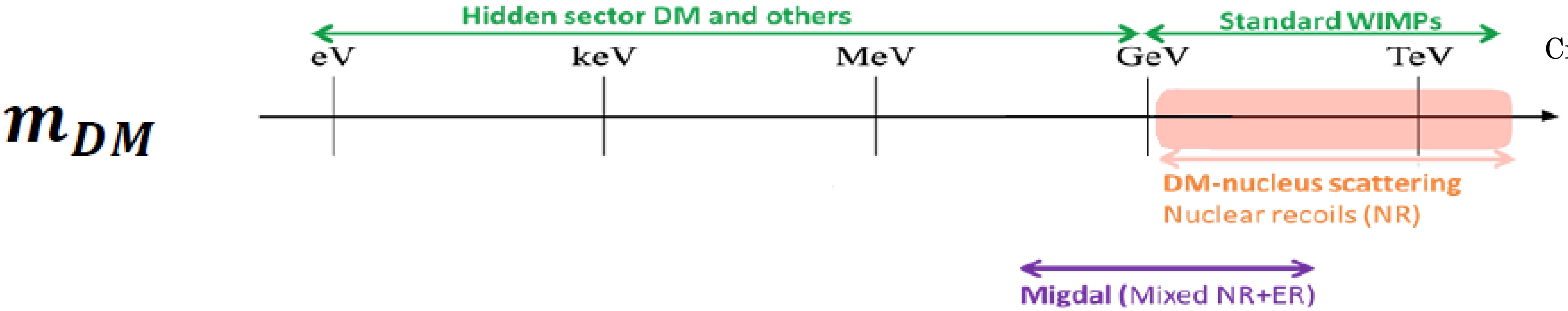
Operation of the experiments at Underground Laboratories

Low background techniques, purification and radiopure materials selection, shielding and veto techniques, NR-ER discrimination, etc…









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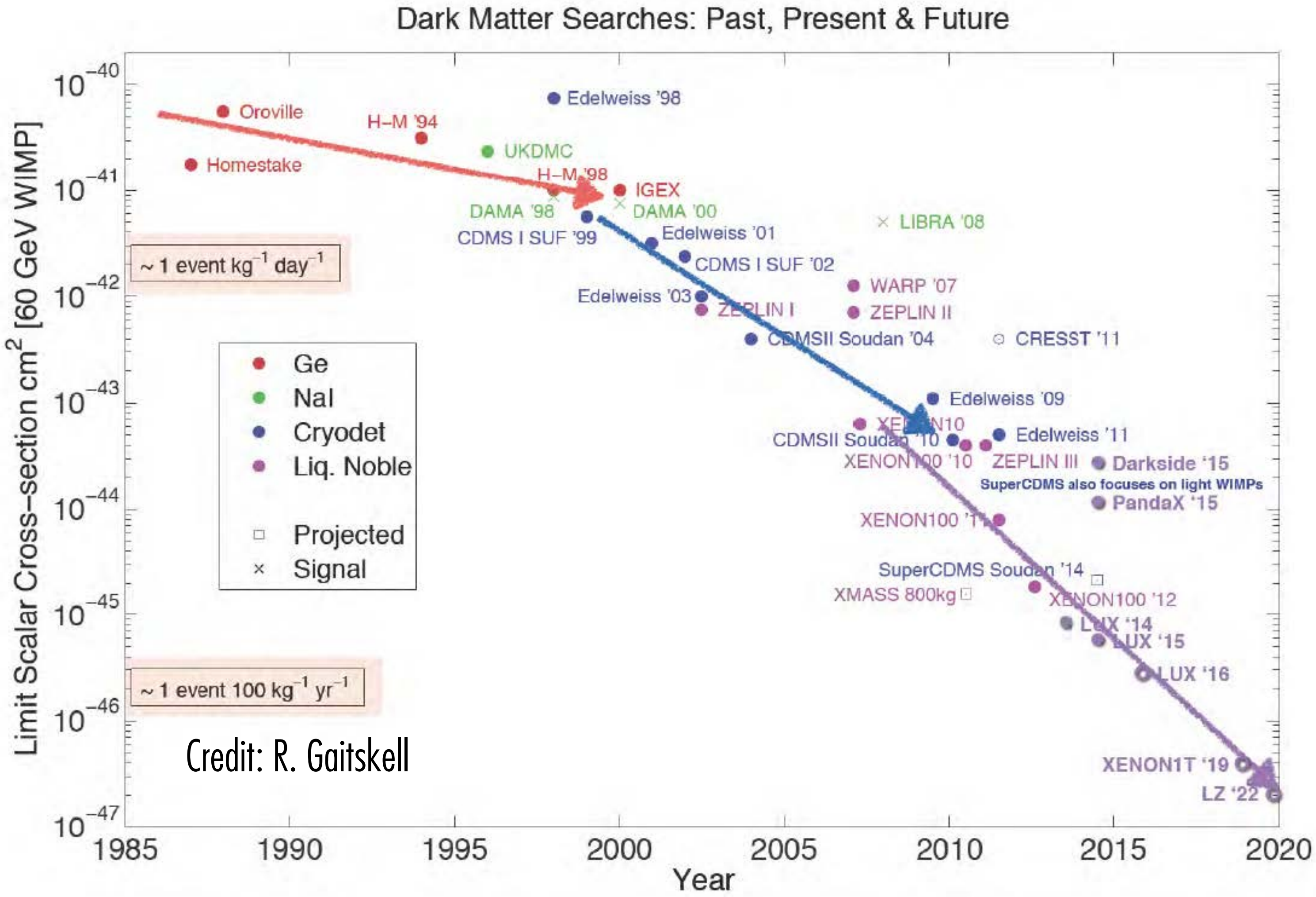
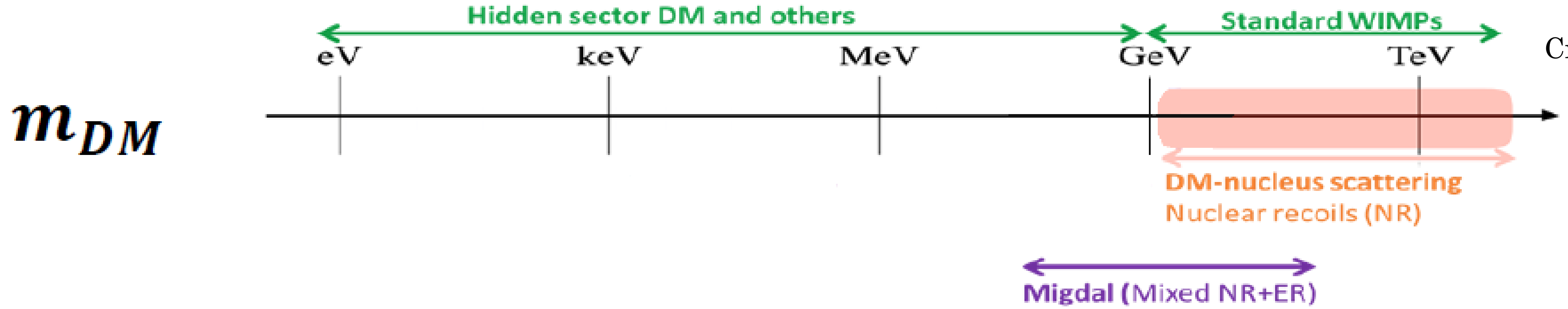
Background signals inte with WIMP detection

Cosmic Rays (μ)
Radioactive Isotopes (n, α, β, γ)

Impressive improvement in sensitivity from 1985

- **Much larger detector masses**
- **Better background**





Credit:M. Martínez

Background signals interferring with WIMP detection

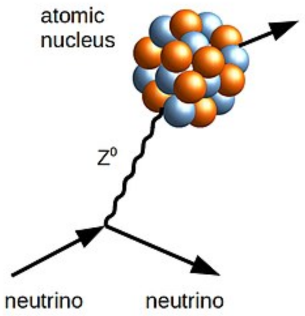
How to fight them

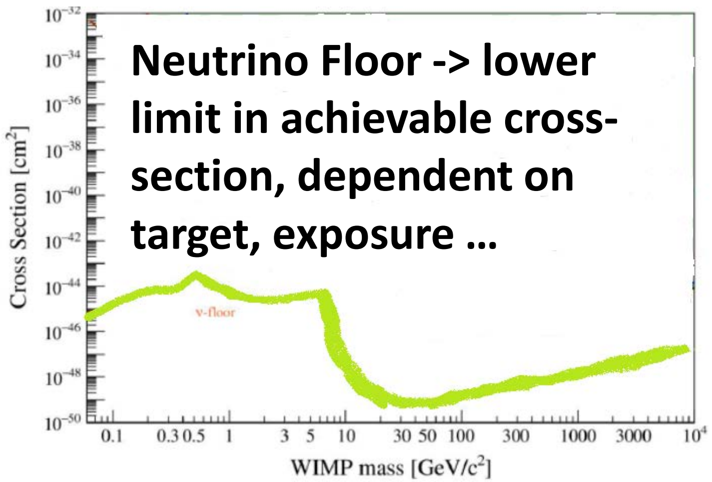
Cosmic Rays (μ) — **Operation of the experiments at Underground Laboratories**

Radioactive Isotopes (n, α, β, γ) — **Low back… radiopur… techniqu… o**

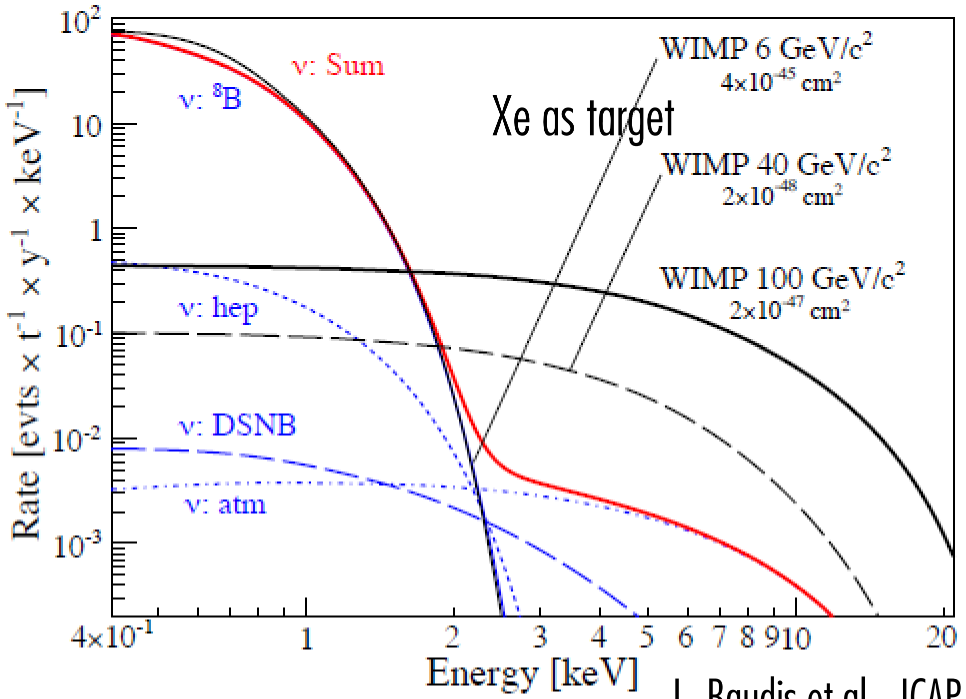
Neutrinos

$\nu N \rightarrow \nu N$ **CENνS**



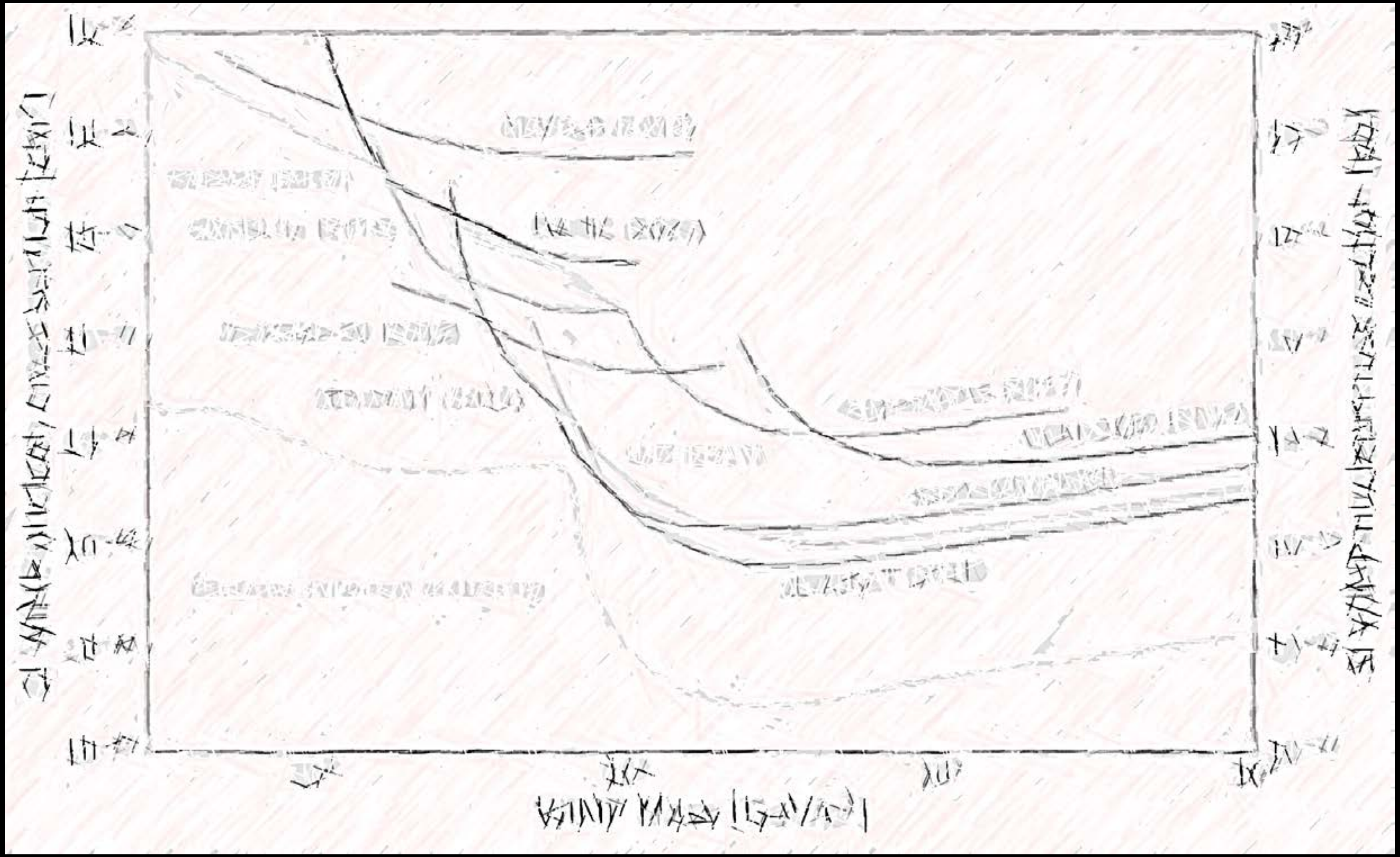


Neutrino Floor -> lower limit in achievable cross-section, dependent on target, exposure …



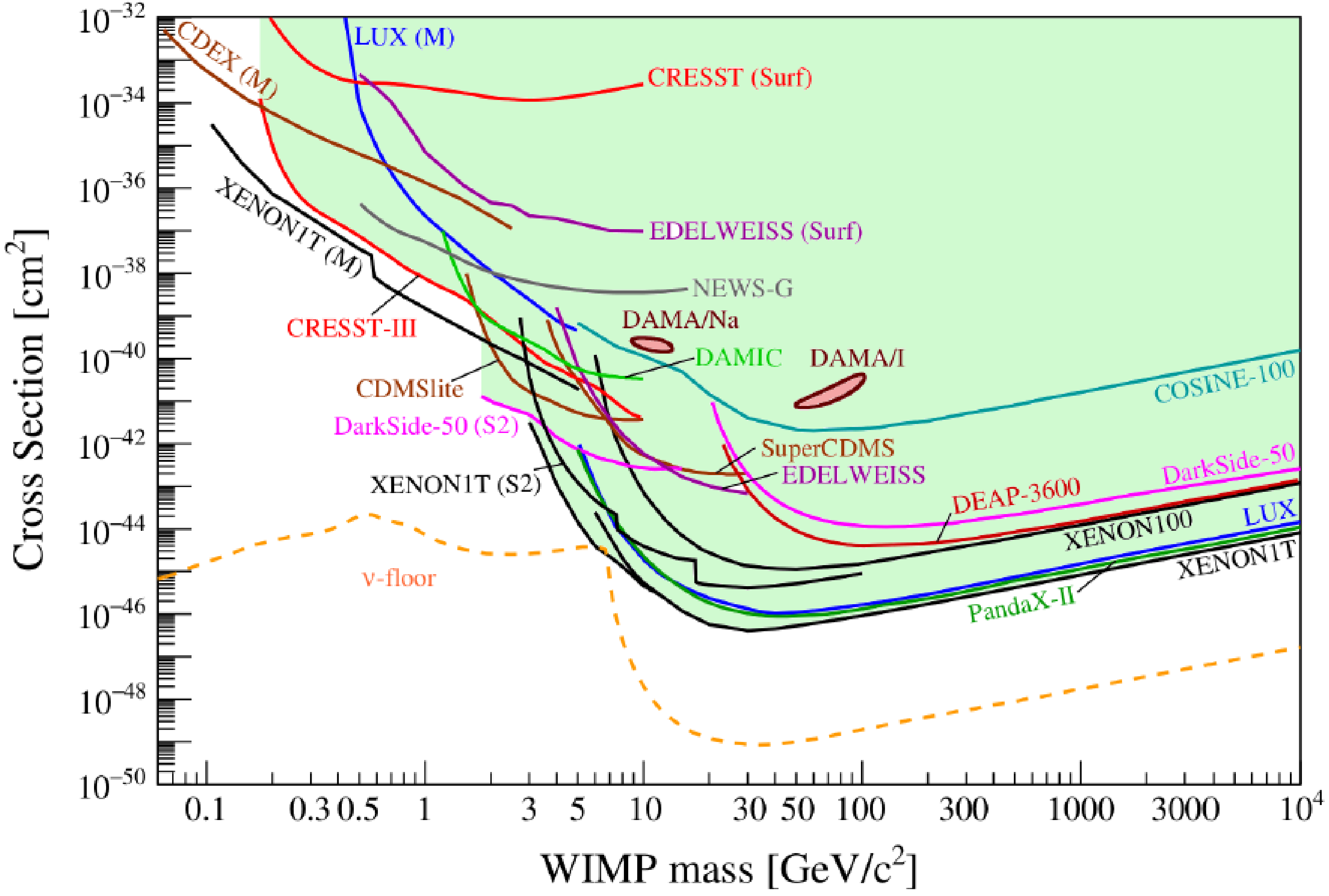
L. Baudis et al., JCAP 2014

The Dark Matter Direct Detection: experimental status and prospects

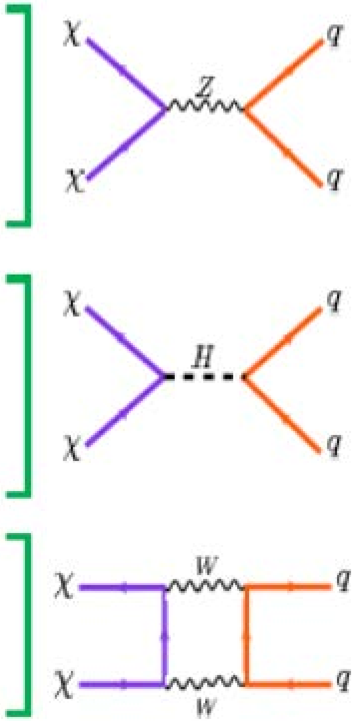


Current status of searches for SI elastic WIMP-nucleus scattering for SHM parameters – APPEC report

Direct Detection of Dark Matter – APPEC Committee Report, arXiv:2104.07634

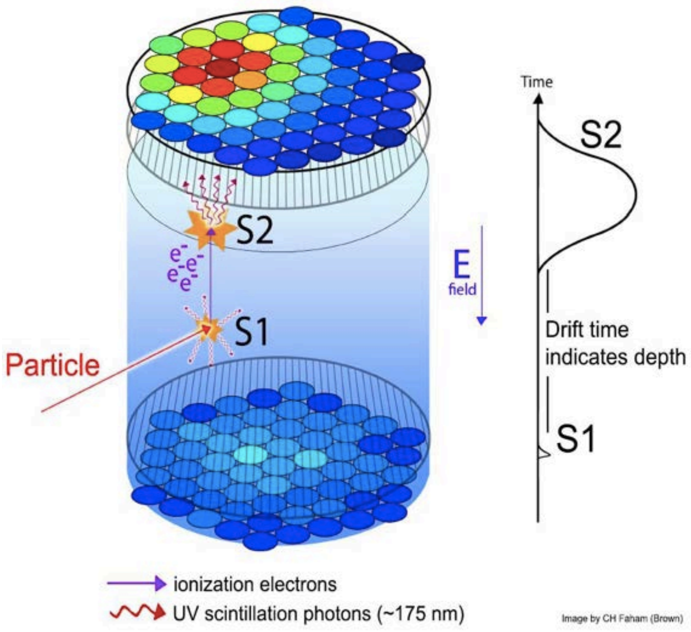


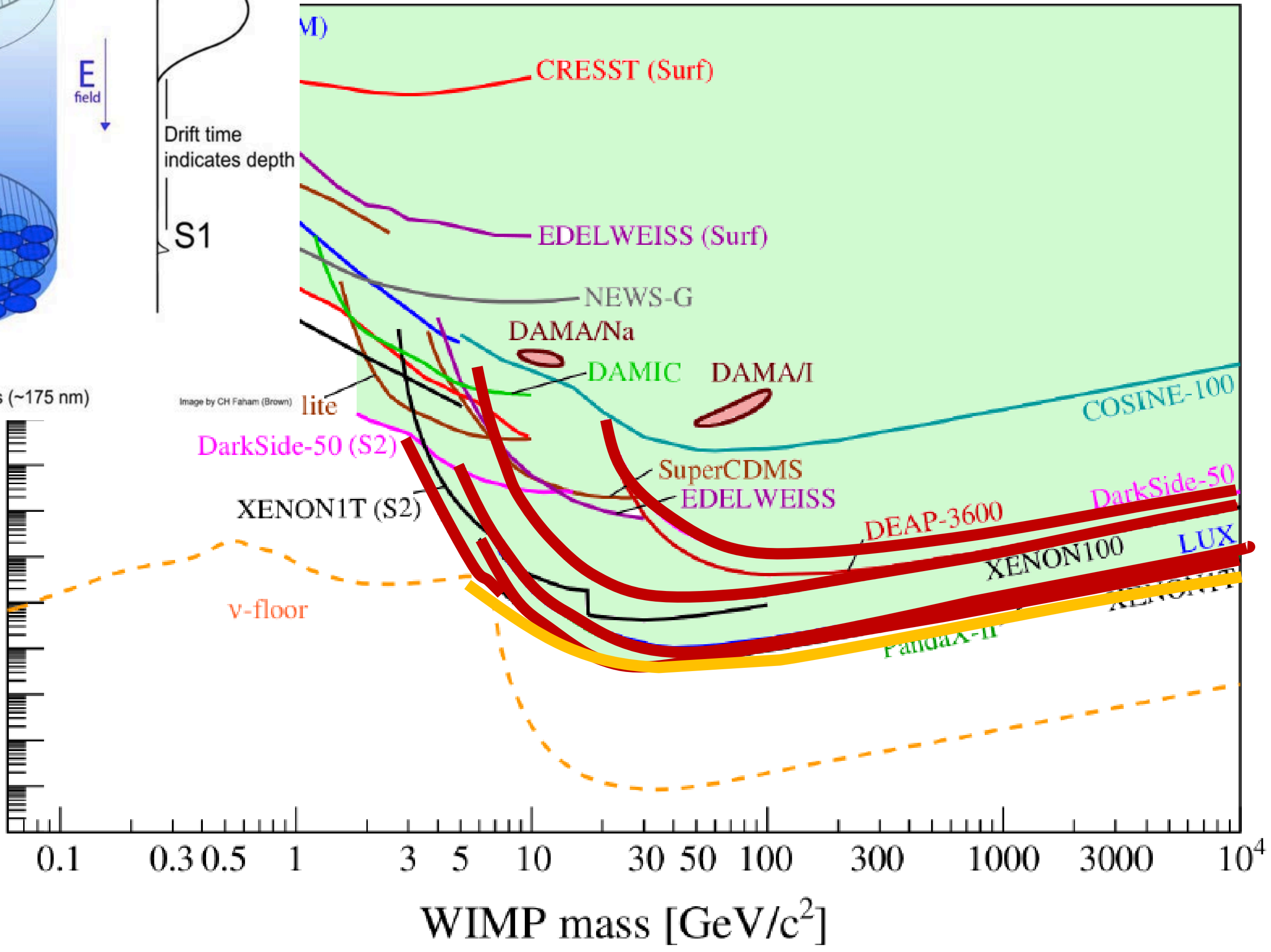
$$\mathcal{O}_1 = 1_\chi 1_N$$



DOUBLE-PHASE NOBLE LIQUID TPCs lead DM searches

XENON PANDAX
LUX DarkSide-50
LZ





Xe and Ar are good scintillators and easily ionized

Scalability to large mass

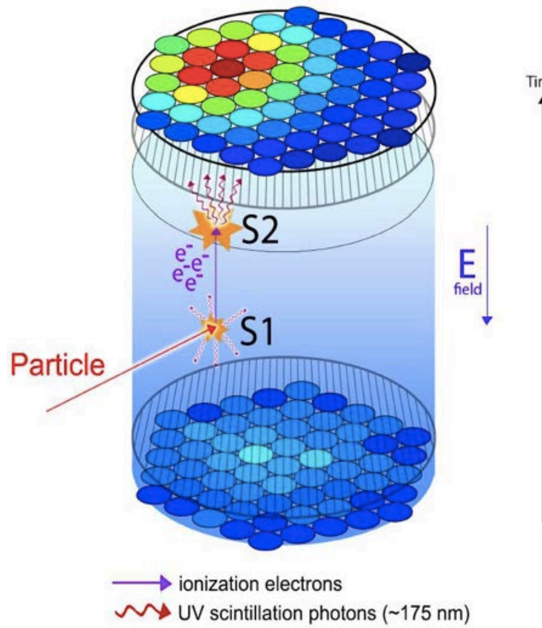
Fiducialization

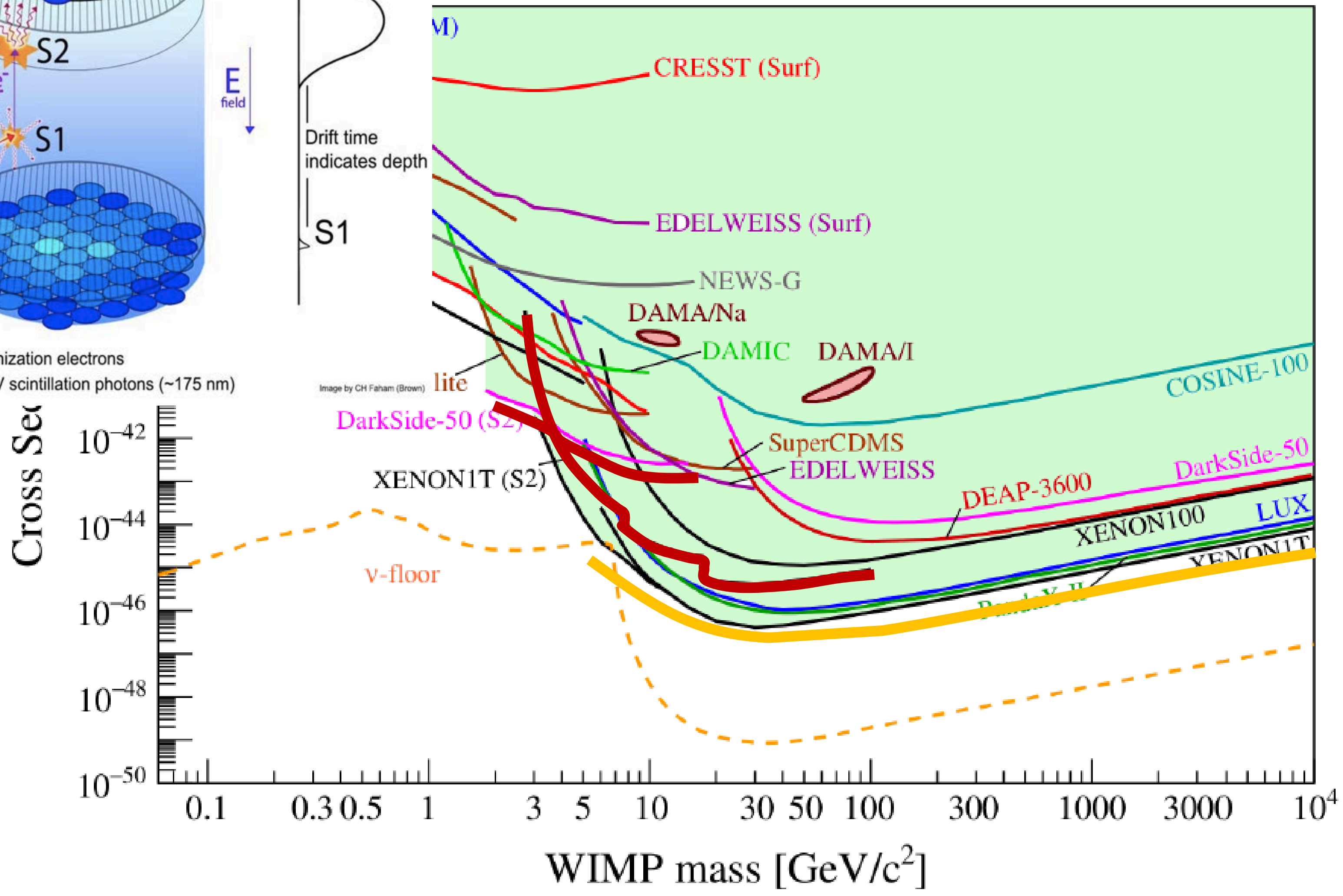
NR/ER discrimination

The DM Direct Detection limits

DOUBLE-PHASE NOBLE LIQUID TPCs with only S2 signal

DarkSide-50
XENON





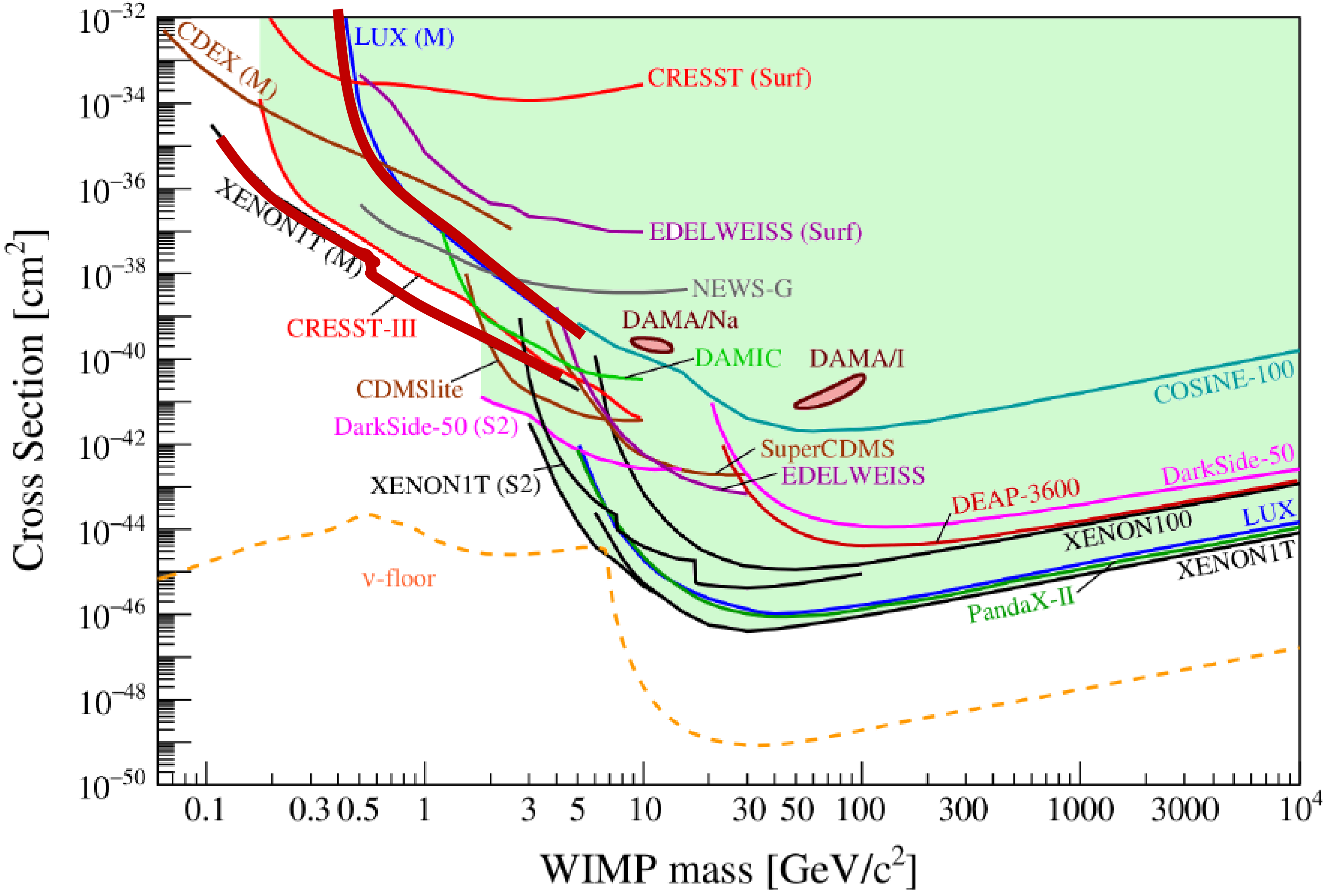
Xe and Ar are good scintillators and easily ionized

Scalability to large mass

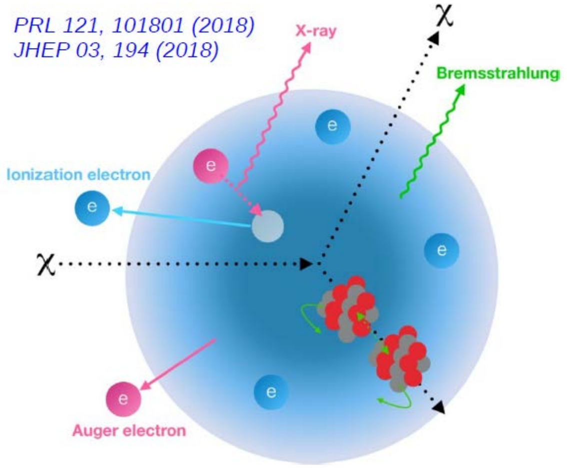
Fiducialization

Better threshold
Sensitivity to low mass WIMPs

MIGDAL EFFECT: The nucleus recoiling inside the electron cloud can transfer energy to the electrons // Robust prediction bot not yet observed It will naturally extend down to lower energies the reach of DM searches



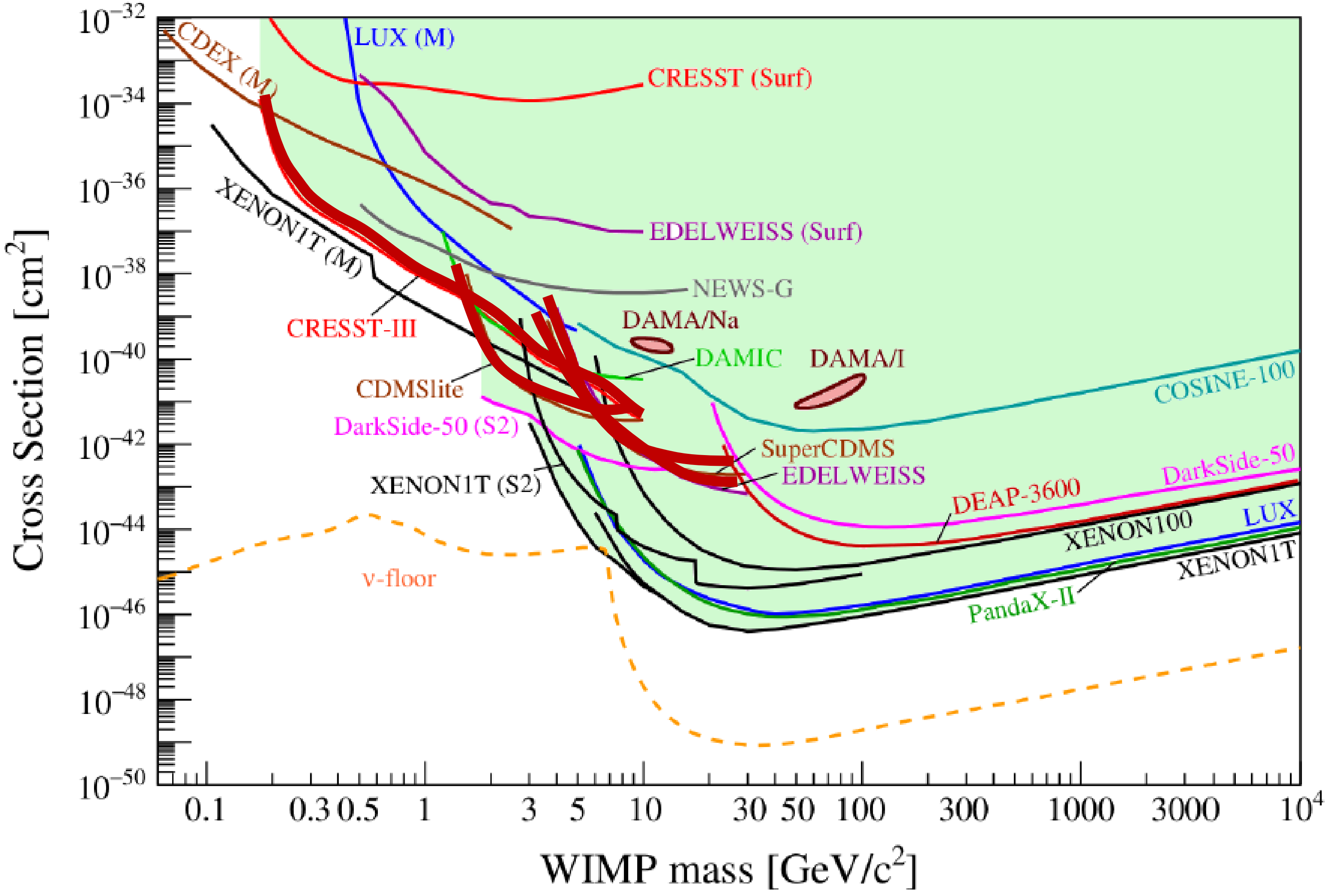
XENON
LUX

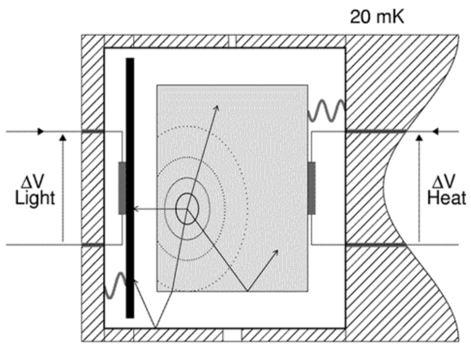


Credit: M. Schumann

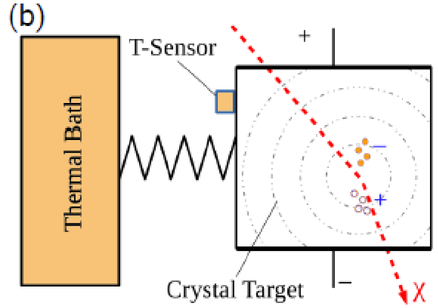
SCINTILLATING/IONIZATION BOLOMETERS

Very good energy threshold and NR/ER discrimination
→ leading low mass range





CRESST-III



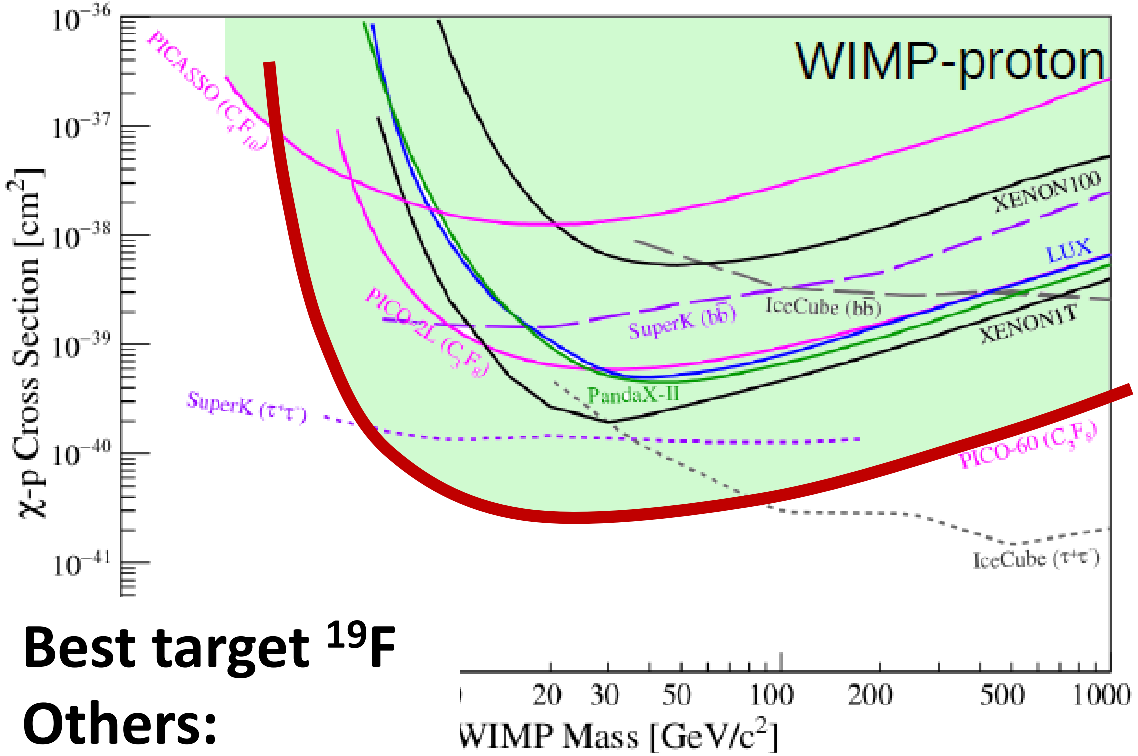
EDELWEISS
SuperCDMS
CDMSlite

Current status of searches for SD elastic WIMP-nucleus scattering for SHM parameters – APPEC report

Strongly dependent on the nuclear spin and unpaired-nucleon -> Limits are shown separately for coupling to proton / neutron

Sensitivity in cross-section worse than for SI coupling (x1000)

$$\mathcal{O}_4 = \vec{S}_\chi \cdot \vec{S}_N$$

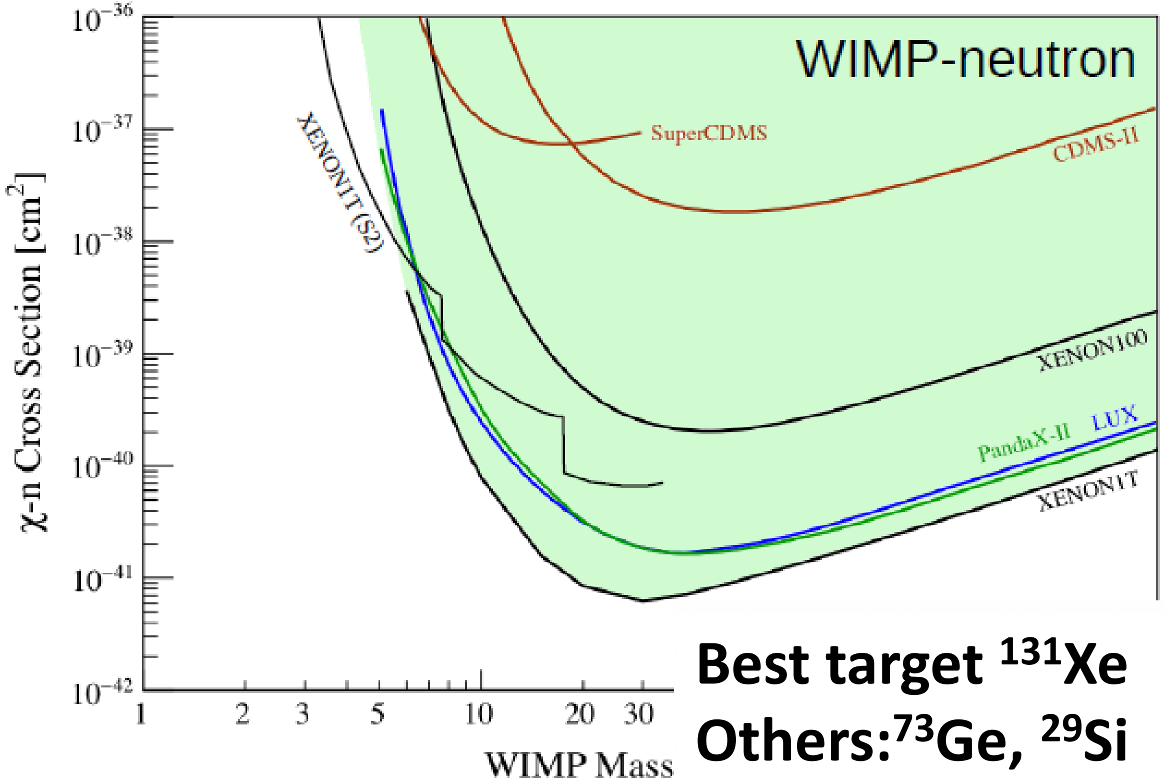


Best target ^{19}F

Others:

^{23}Na, ^{127}I, ^{7}Li

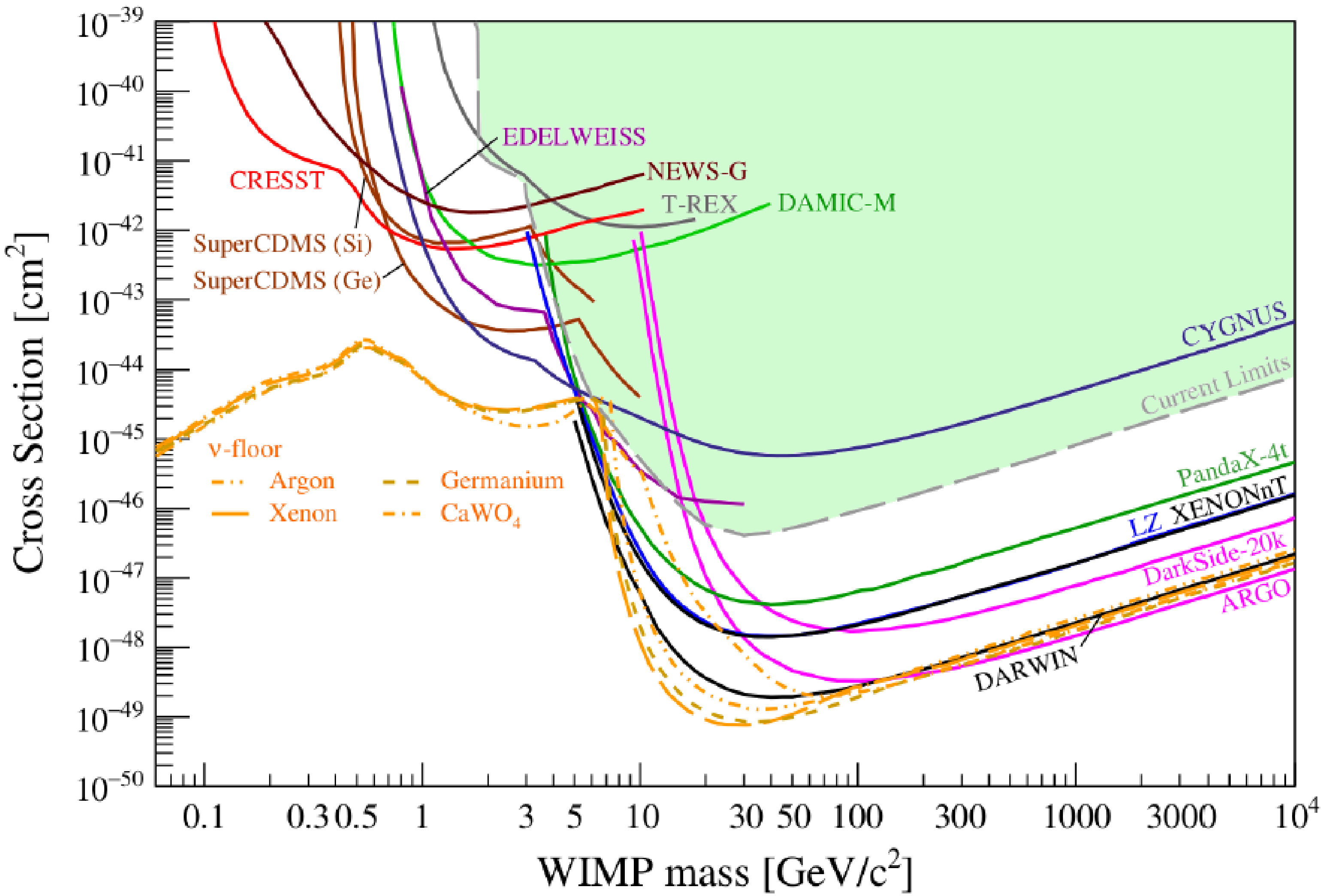
PICO



Best target ^{131}Xe

Others: ^{73}Ge, ^{29}Si

Sensitivity projections 90%C.L. for SI interacting WIMP-nucleon scattering – APPEC report



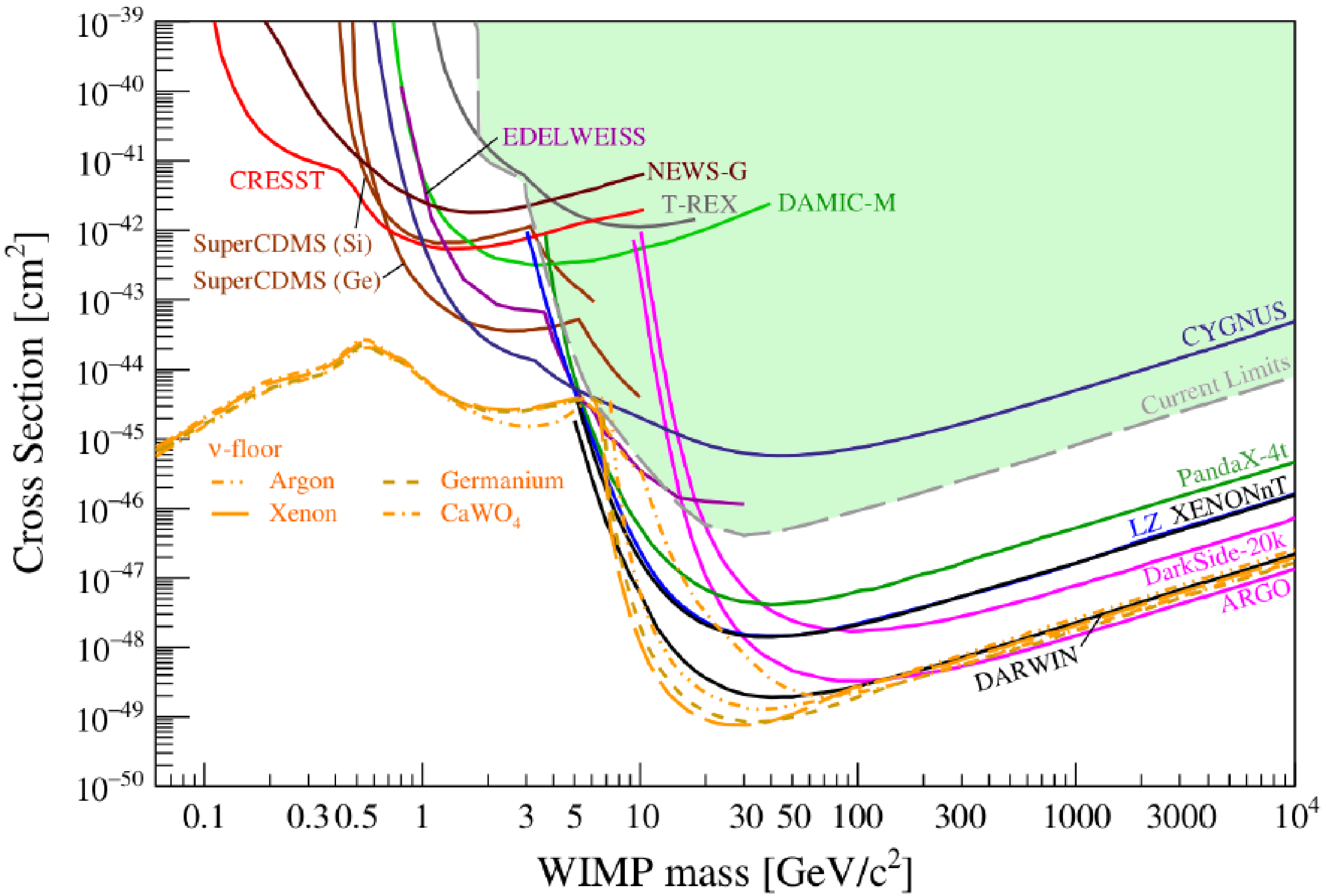
Approaching the neutrino floor in the range above 10 GeV

Much space still to be explored in the low mass region (SI / SD)

SENSEI
DAMIC-M
SUPERCDMS
ARGO
DARWIN

CRESST
T-REX
(ANAIS+)

Sensitivity projections 90%C.L. for SI interacting WIMP-nucleon scattering – APPEC report

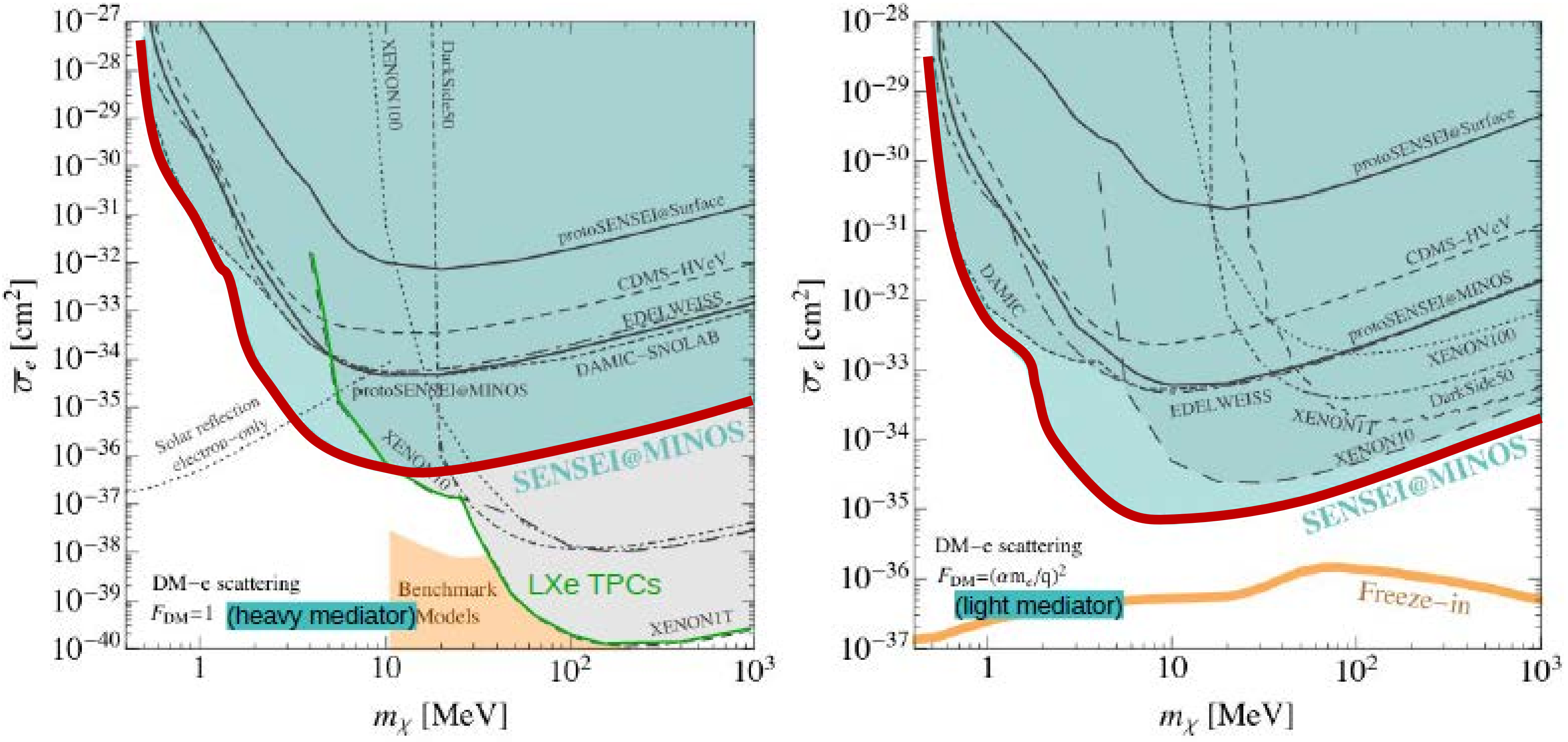


MULTITARGET and MULTITECHNIQUE strategy is mandatory to cope with the many unknowns and uncertainties

SENSEI
DAMIC-M
SUPERCDMS
ARGO
DARWIN

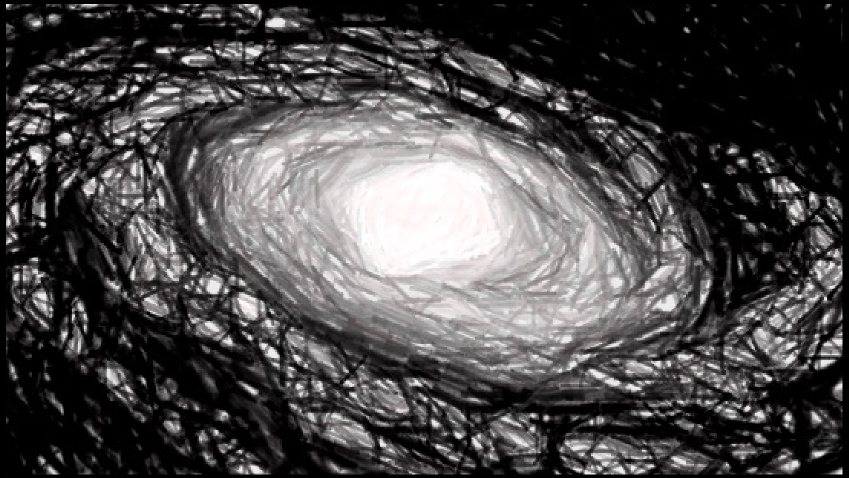
CRESST
T-REX
(ANAIS+)

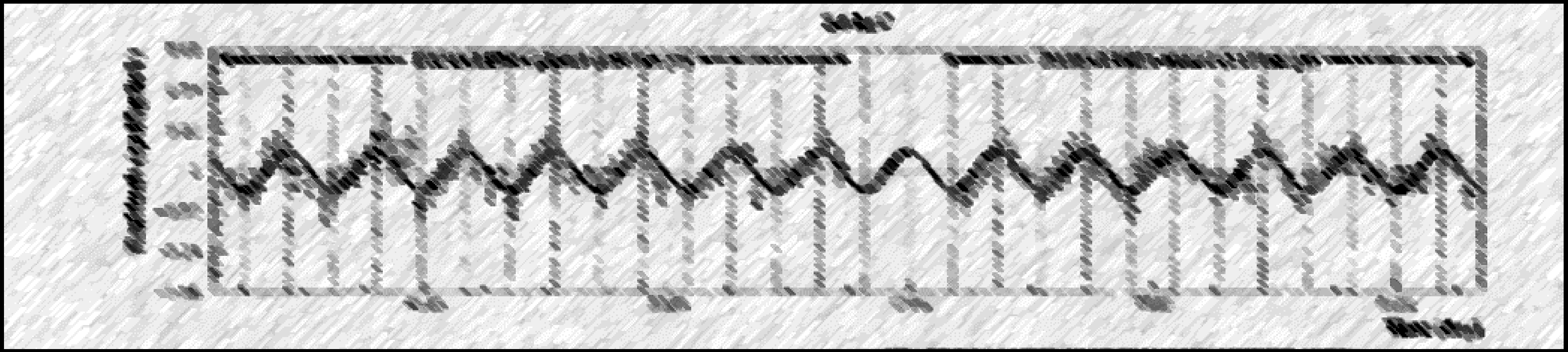
Current status of searches for WIMP-electron scattering for SHM parameters



SENSEI

The DAMA/LIBRA anomaly and other excesses



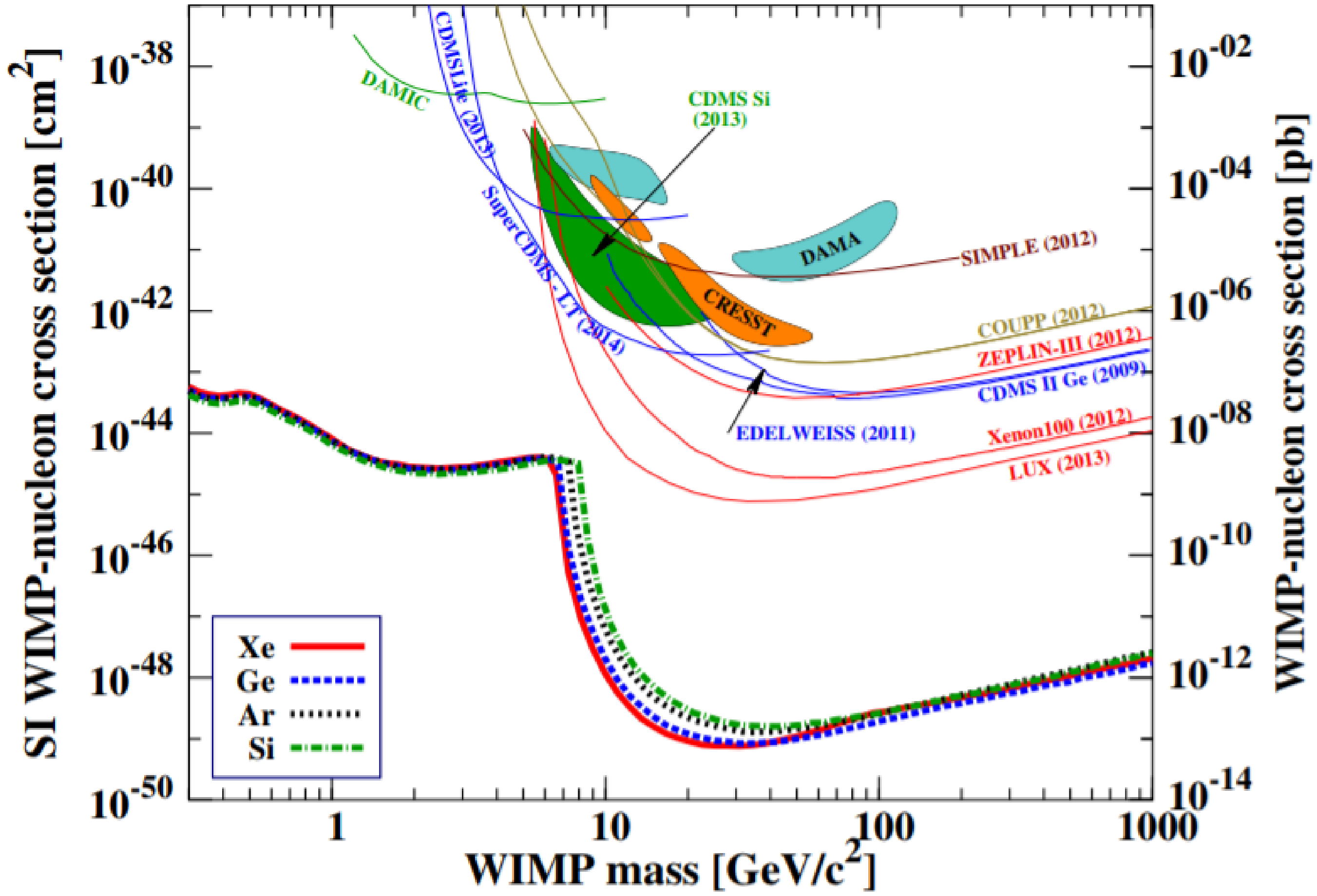


The discovery of new particles interactions should appear as an excess of events above the expected backgrounds

Some anomalies have appeared along the years -> islands in (m,σ) plot

CRESST
CDMS – Si
DAMA/LIBRA (annual mod.)
COGeNT (annual mod.)

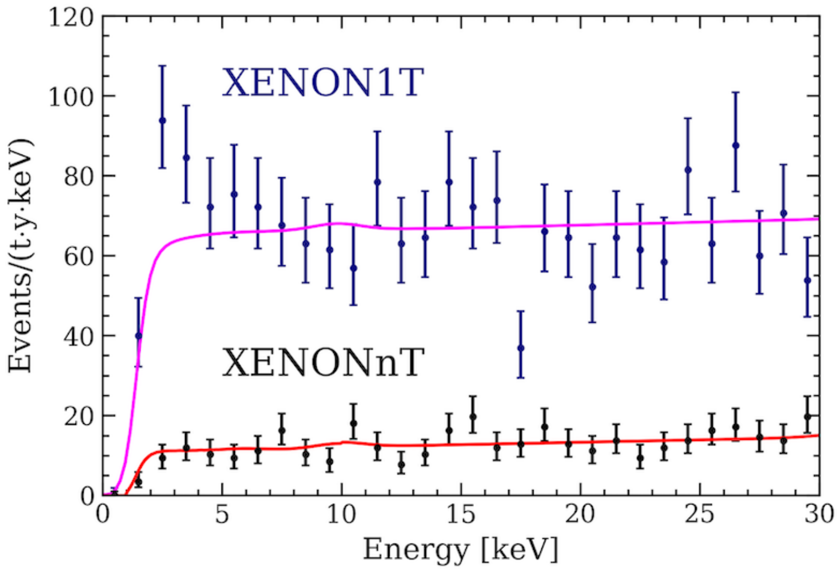
Some disappeared with more statistics or reanalysis or by finding a new background origin.

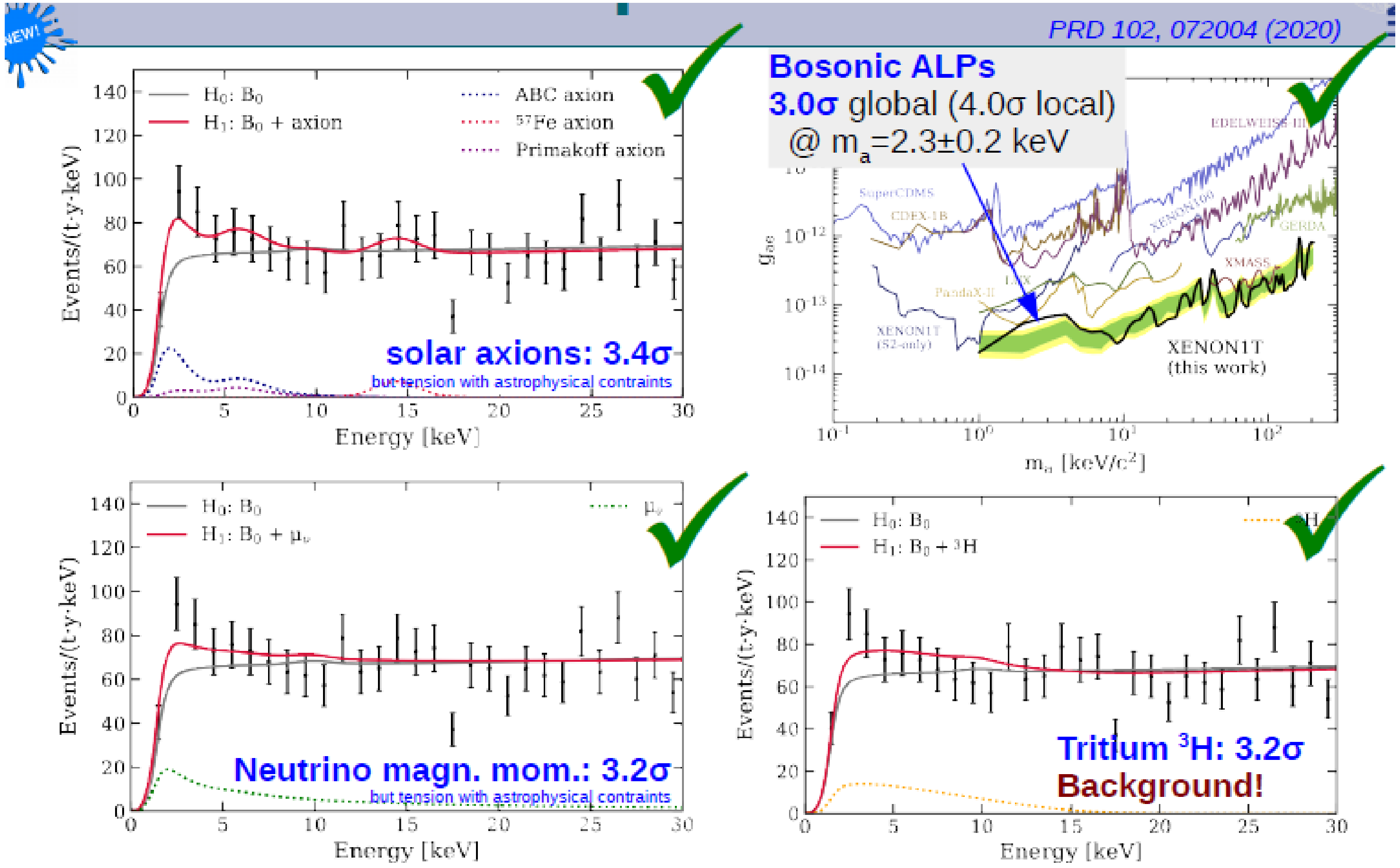


The discovery of new particles interactions should appear as an excess of events above the expected backgrounds

Some anomalies have appeared along the years -> islands in (m,σ) plot

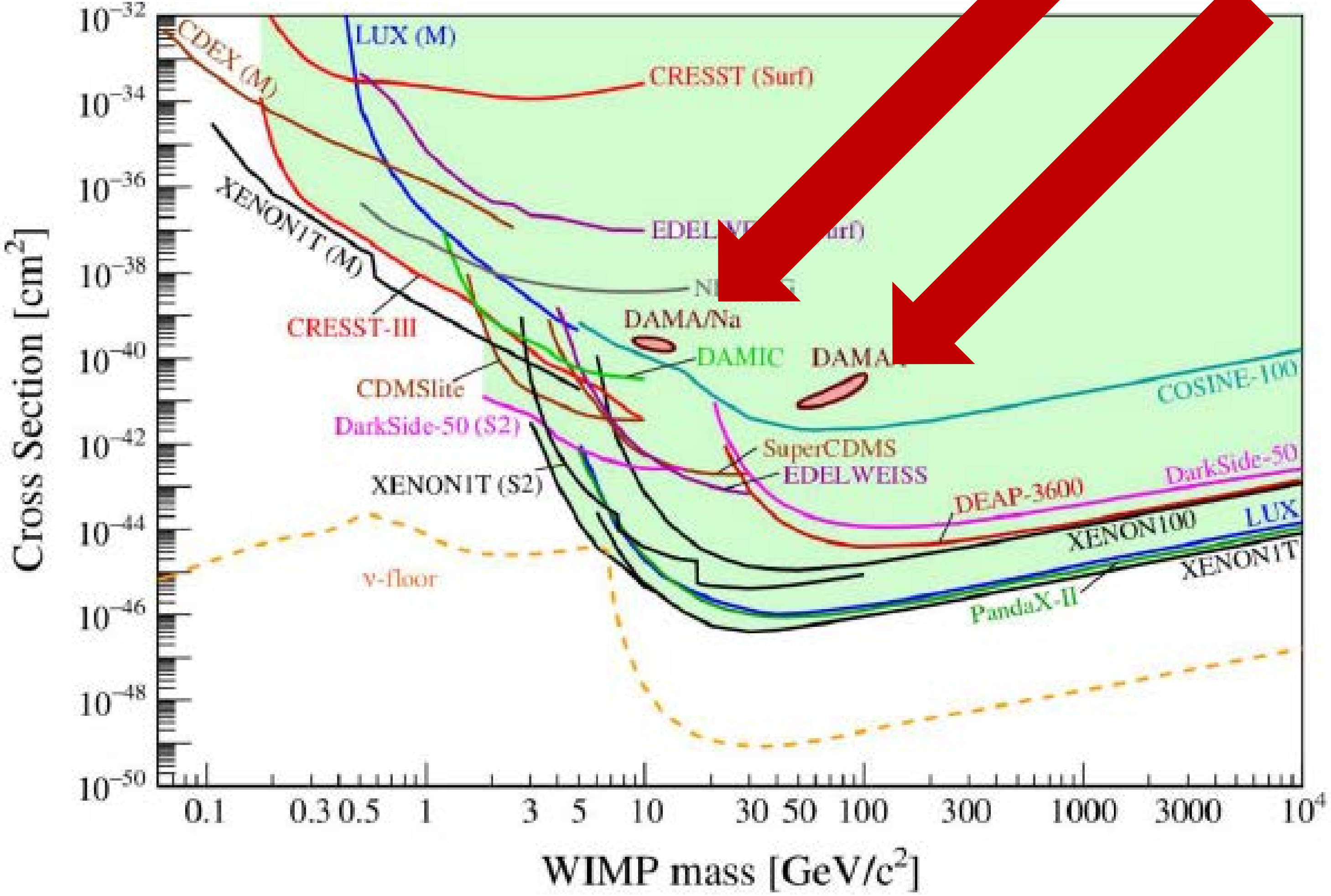
The most recent one is the XENON1T excess -> compatible with new Physics in different sectors and finally solved by XENONnT data



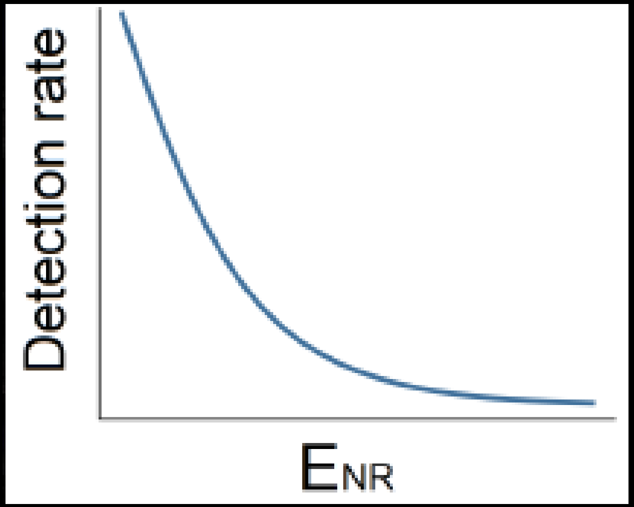


The DAMA/LIBRA anomaly

For more than twenty years DAMA/LIBRA reports a signal compatible with galactic DM searching for the annual modulation in the interaction rate incompatible in most of the scenarios considered with all of the other experiments

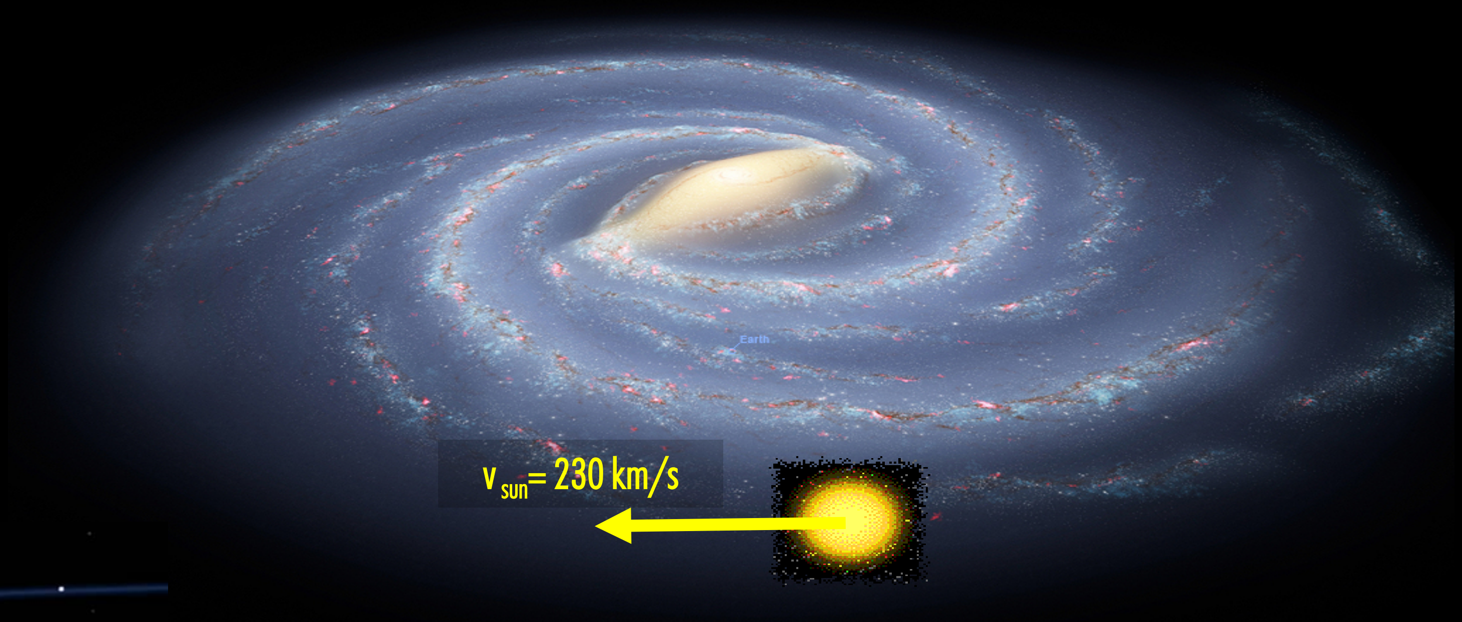


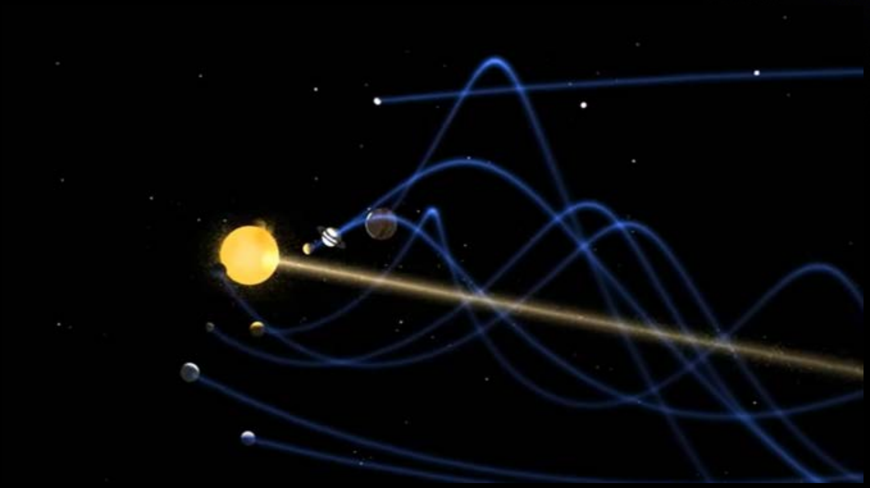
ANNUAL MODULATION SIGNAL



Dark Matter Halo

Density $\rho_0 \sim 0.4$ GeV / cm^3

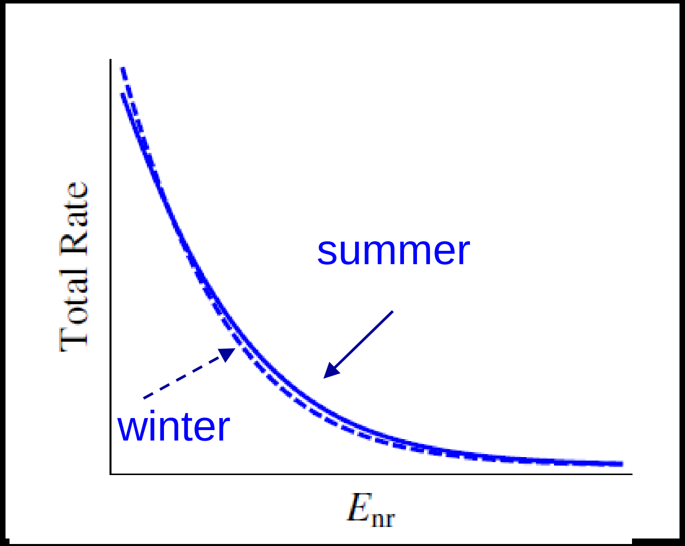




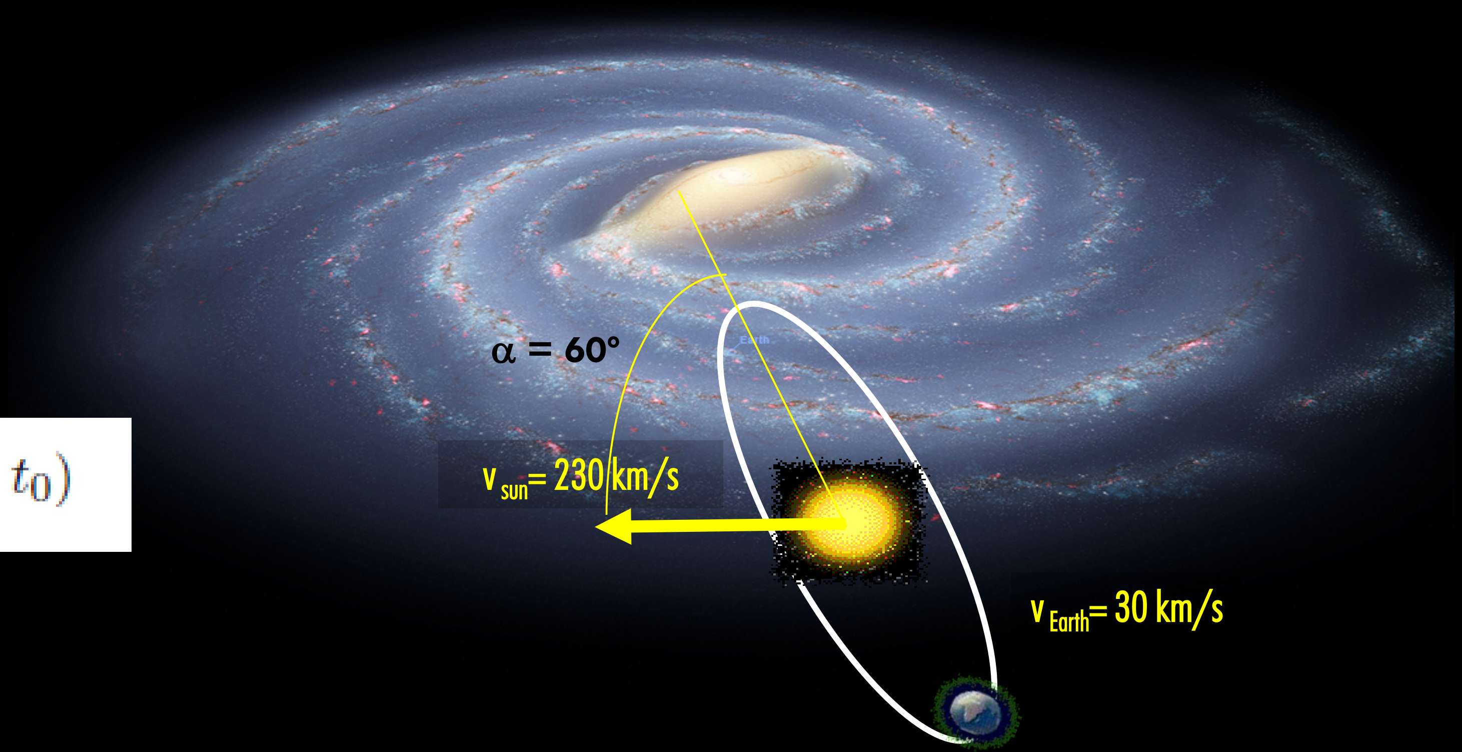
$$S(E_{NR}) = \frac{dR}{dE_{NR}} = \frac{\rho\, M_{det}}{2 m_W m_{WN}^2} \int_{v_{min}}^{v_{max}} \frac{\boldsymbol{f(v)}}{v}\, \sigma_{WN}\, dv^3$$

ANNUAL MODULATION SIGNAL

The DAMA/LIBRA anomaly



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

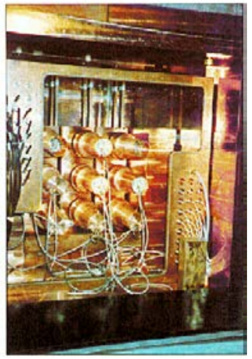


Relative velocity Earth – halo changes along the year

$$S(E_{NR}) = \frac{dR}{dE_{NR}} = \frac{\rho\, M_{det}}{2 m_W m_{WN}^2} \int_{v_{min}}^{v_{max}} \frac{\boldsymbol{f(v,t)}}{v}\, \sigma_{WN}\, dv^3$$

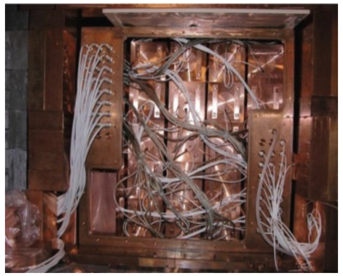
The DAMA/LIBRA experiment @ LNGS

DAMA / NaI (1995-2002)



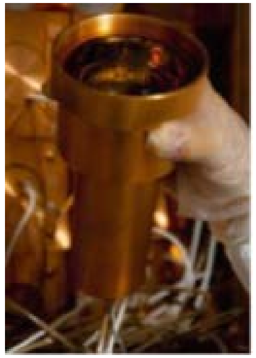
- 9 × 9.7 kg NaI(Tl) (3x3 matrix)
- 7 annual cycles
- Exposure : 0.29 ton × y

DAMA / LIBRA (2003-2010)



- 25 × 9.7 kg NaI(Tl) (5x5 matrix)
- 7 annual cycles
- Exposure : 1.04 ton × y

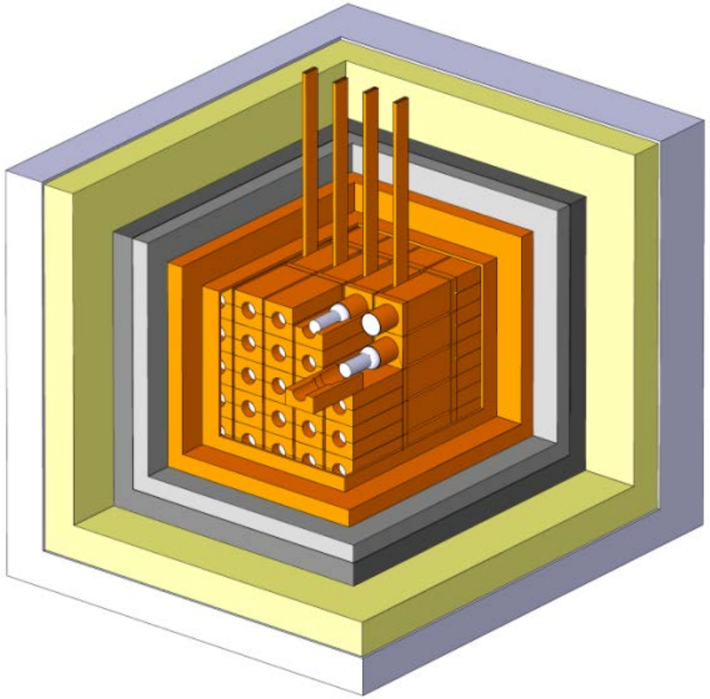
DAMA / LIBRA – phase2 (2011-2021)



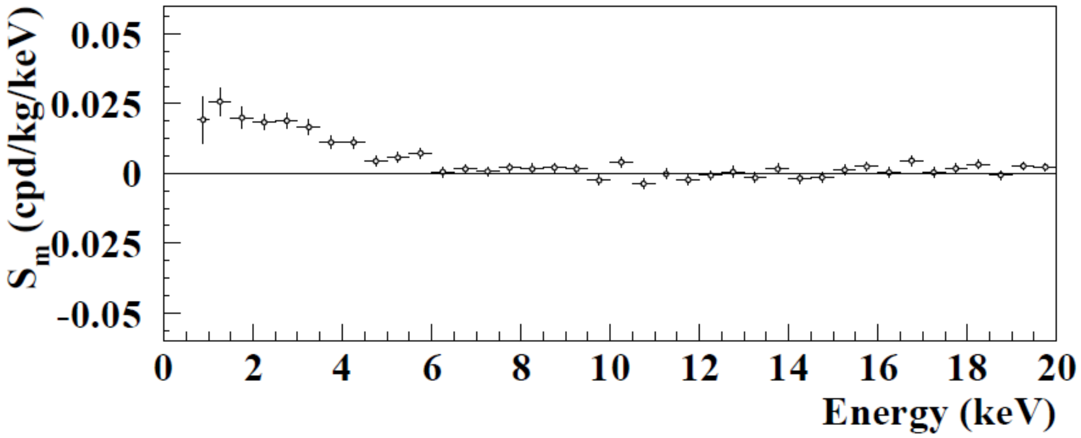
- 25 × 9.7 kg NaI(Tl) (5x5 matrix)
- 8 annual cycles
- Exposure : 1.53 ton × y

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

Threshold lowered down to 1 keV first, to 0.75 keV



The DAMA/LIBRA signal



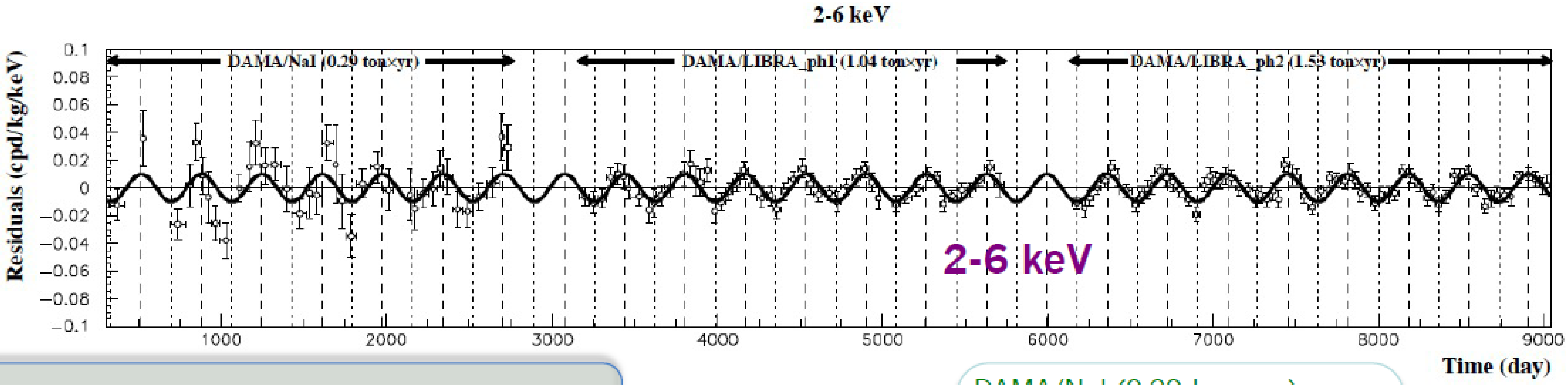
Sinusoidal behaviour

Annual periodicity

Maximum at around 2 June

Small effect (Sm<7%So)

Only relevant at very low energy single hit events (for NaI, E<6 keVee)



The DAMA/LIBRA signal

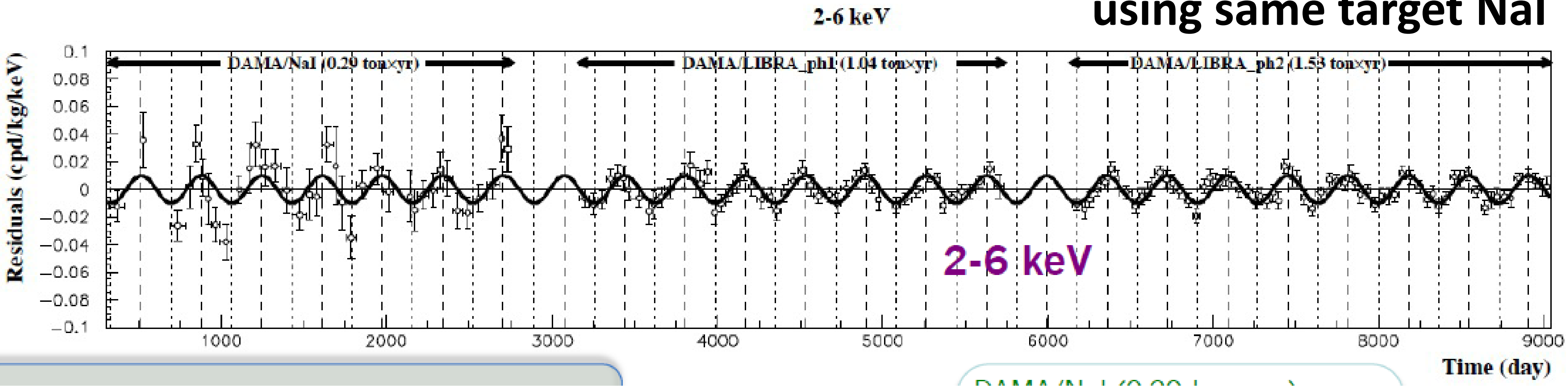
	ΔE	A(cpd/kg/keV)	T=2π/ω (yr)	t_0 (day)	C.L.
DAMA/LIBRA-ph2	(1-3) keV	0.0191±0.0020	0.99952±0.00080	149.6±5.9	9.6σ
	(1-6) keV	0.01058±0.00090	0.99882±0.00065	144.5±5.1	11.8σ
	(2-6) keV	0.00954±0.00076	0.99836±0.00075	141.1±5.9	12.6σ
DAMA/LIBRA-ph1 + DAMA/LIBRA-ph2	(2-6) keV	0.00959±0.00076	0.99835±0.00069	142.0±4.5	12.6σ
DAMA/NaI + DAMA/LIBRA-ph1 + DAMA/LIBRA-ph2	(2-6) keV	0.01014±0.00074	0.99834±0.00067	142.4±4.2	13.7σ

More than twenty years of data

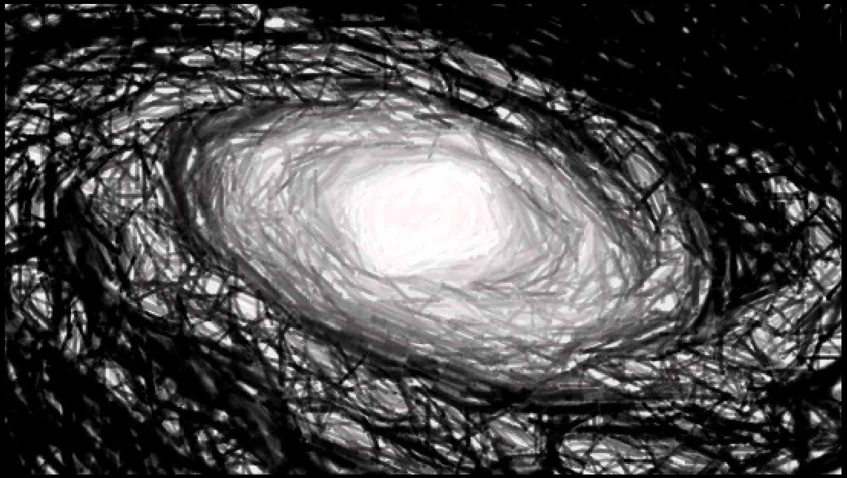
Stop taking data in 2024

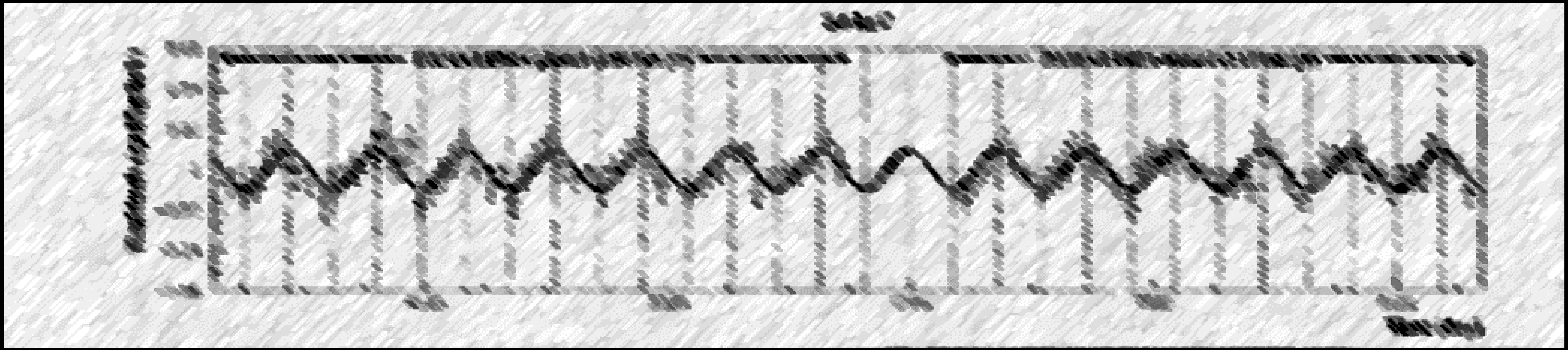
Requires confirmation or refutation in a model-independent way:

using same target NaI



The status of the testing of the DAMA/LIBRA signal





The testing of the DAMA/LIBRA signal

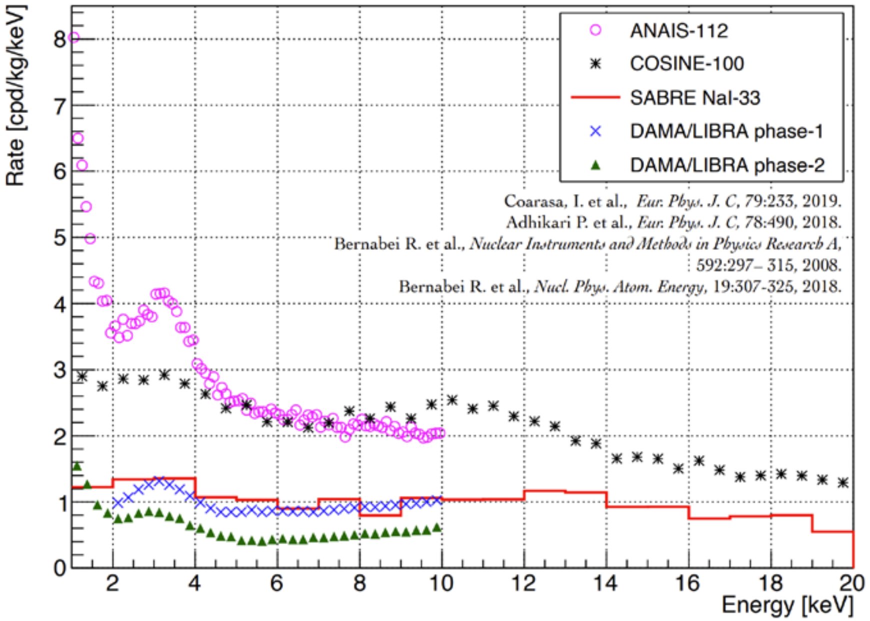
IN DATA-TAKING
112,5 kg
Since Aug 17

DATA-TAKING
61,3 kg (effective mass)
Since Sept 16 to Nov 23
COSINE-100U
COSINE-200

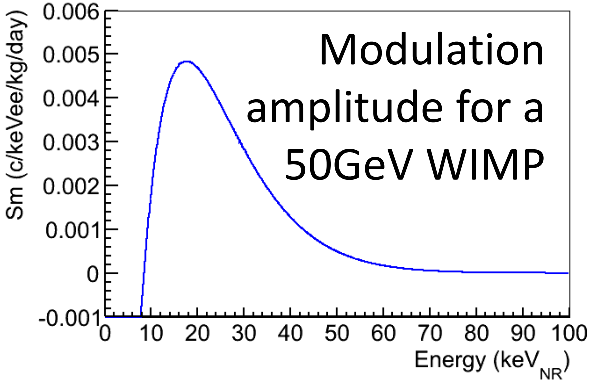
IN DATA-TAKING
~250 kg
Since Sept 2003 phase -1 / since Dec 2010 phase-2

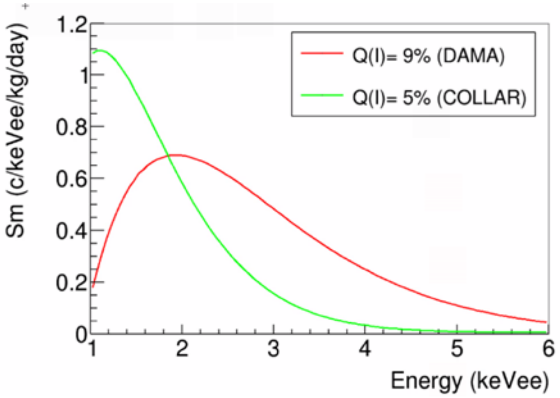
Experimental requirements

- **Target: NaI / NaI(Tl)**
- Large exposure ✓
- Very stable operation conditions ✓
- Energy threshold: 1 keVee or below ✓
- Background level as low as possible (DAMA: 1 cpd/kg/keV @ 2 keVee) ✓
- Good knowledge of the detector response, in particular to nuclear recoils ✗

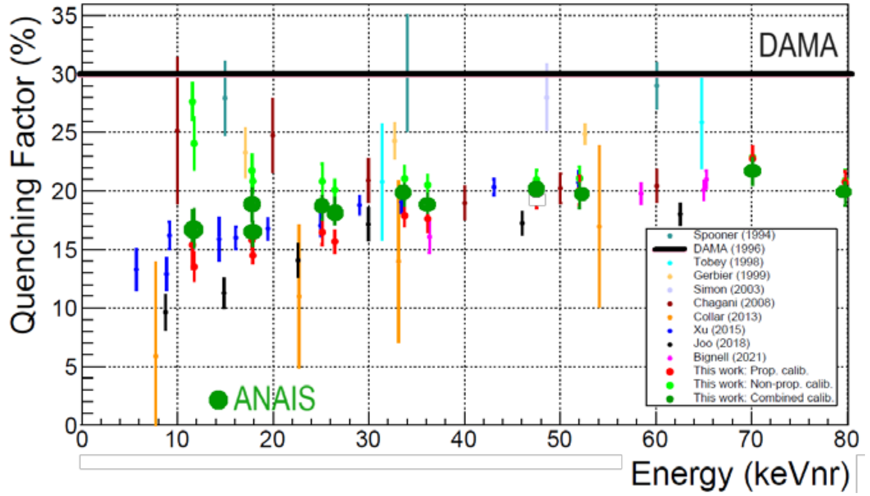


$$QF = \frac{signal_{NR}/keV}{signal_{ER}/keV}$$





Visible energy for two different QF_Na



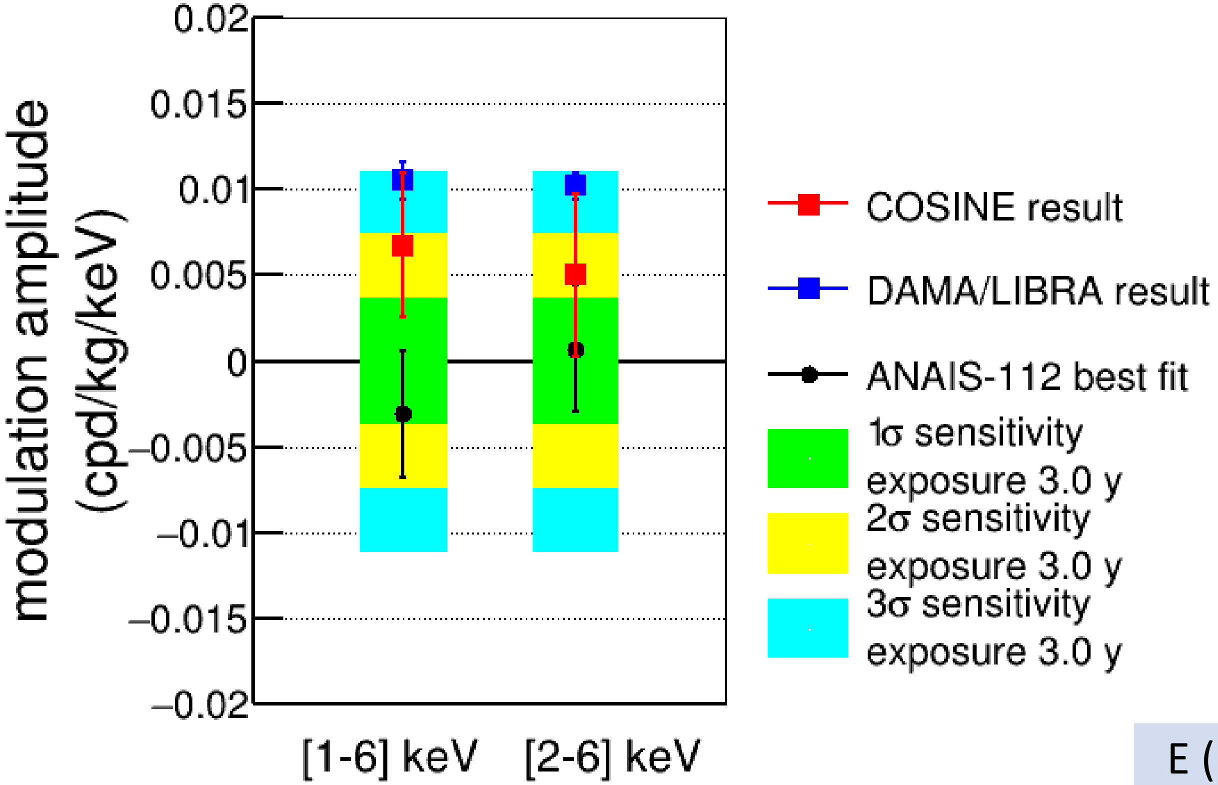
Experimental requirements

- **Target: NaI / NaI(Tl)**
- Large exposure ✓
- Very stable operation conditions ✓
- Energy threshold: 1 keVee or below ✓
- Background level as low as possible (DAMA: 1 cpd/kg/keV @ 2 keVee) ✓
- Good knowledge of the detector response, in particular to nuclear recoils ✗

But, we should think beyond this…

- How to guarantee the reproducibility of the experimental results? Which results are reliable?
- Necessity of implementing new policies: open access to all the data and fully transparent analysis procedures.
- Collaboration among the different experimental approaches: data sharing, but also technological developments

Assuming QF for NR are the same for all the experiments or scattering with the electrons in the material → MODEL INDEPENDENT TESTING OF DAMA/LIBRA

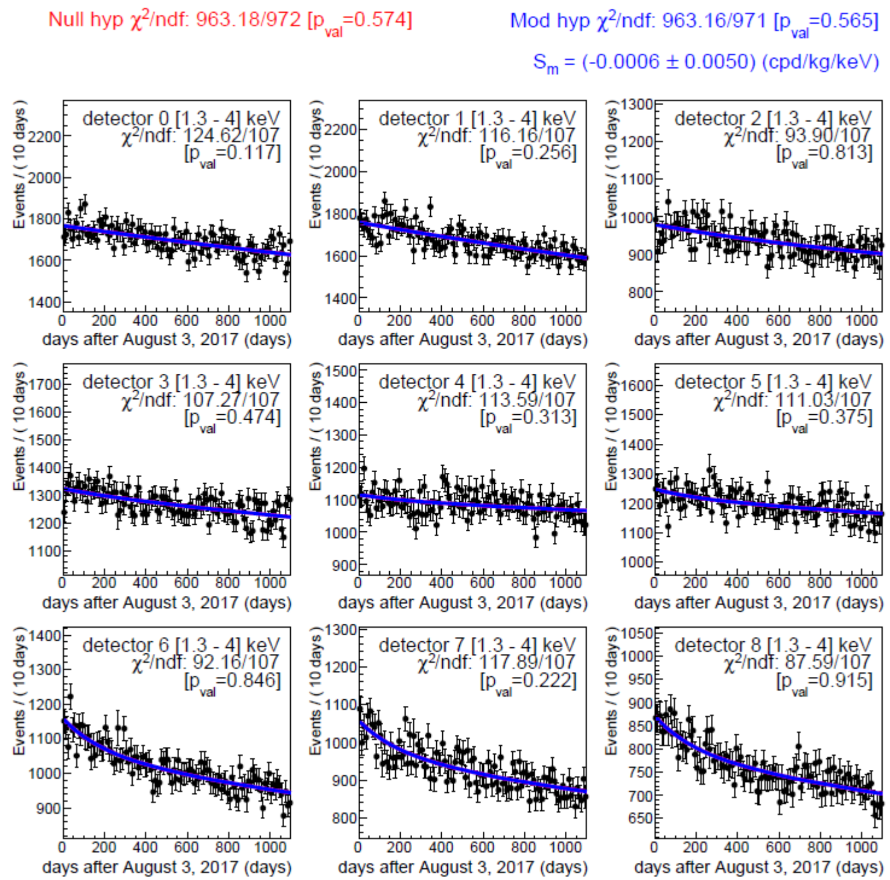


- Best fits are incompatible with DAMA/LIBRA result at 3.9 and 2.8 σ in [1-6] and [2-6] keV energy regions
- Sensitivity is at 2.8 and 2.8 σ in [1-6] and [2-6] keV energy regions

	S_m(cpd/keV/ton)		
E (keV)	ANAIS-112	COSINE-100	DAMA/LIBRA
[1-6]	-3.7±3.7	6.7±4.2	10.5±1.1
[2-6]	0.7±3.7	5.0±4.7	10.2±0.8

Coarasa et al. 2404.17348 **PRD 106, 052005 (2022)** **PPNP 114, 103810 (2020)**

Coarasa et al, 2404.17348



Considering different QF (but constant with energy) for DAMA/LIBRA and ANAIS

- ANAIS: QFNa 0.2 / QFI 0.06
- DAMA/LIBRA: QFNa 0.3 / QFI 0.09

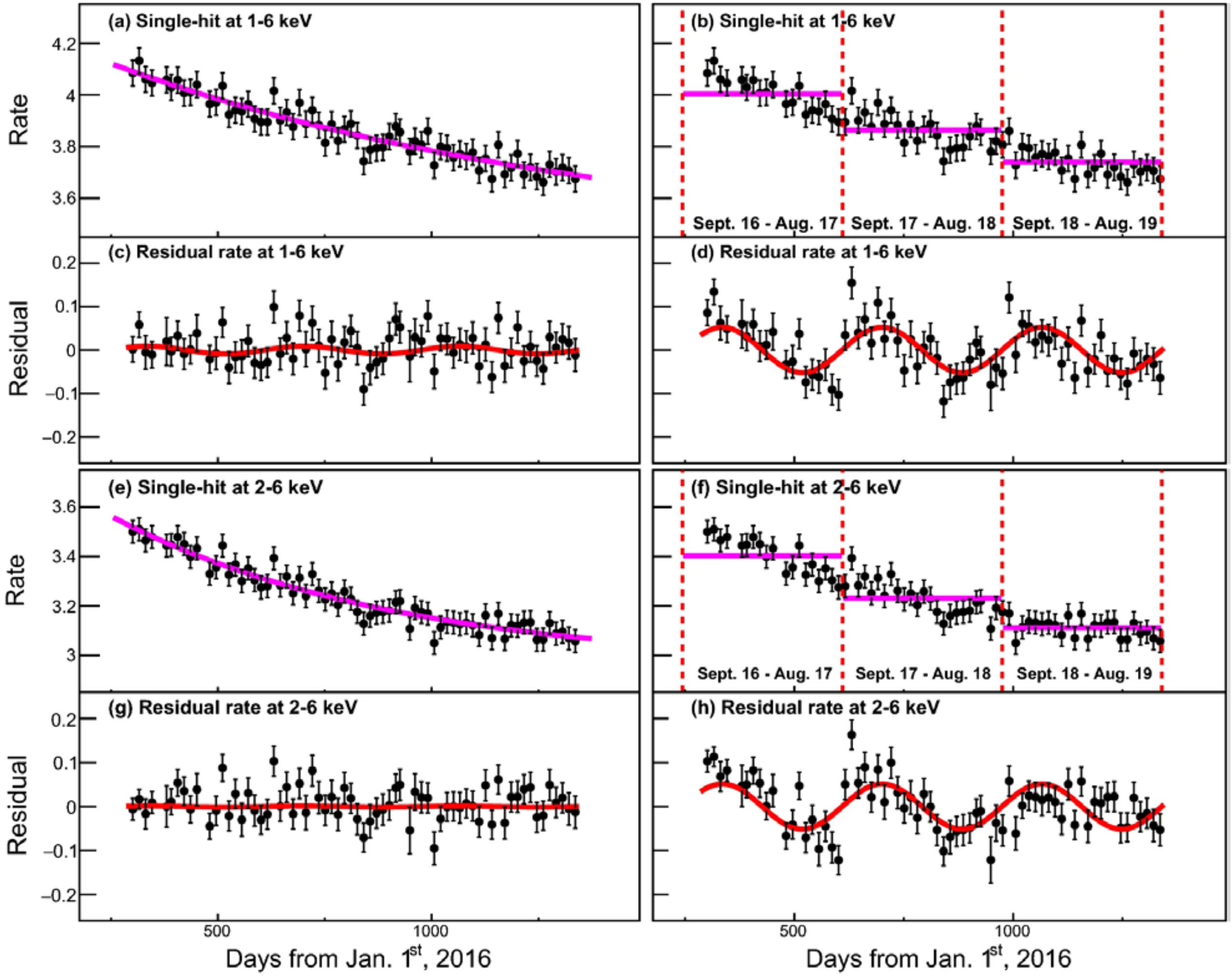
The DAMA/LIBRA [2-6] keV energy region will convert into [1.3-4] keV in ANAIS for NR

	S_m(cpd/keV/ton)	
E (keV)	**ANAIS-112**	**DAMA/LIBRA**
[1.3-4]	-0.6$\pm$5.0	
[2-6]	0.7$\pm$3.7	10.2$\pm$0.8

Result compatible with no modulation and incompatible with DAMA/LIBRA with $\sim 2\sigma$

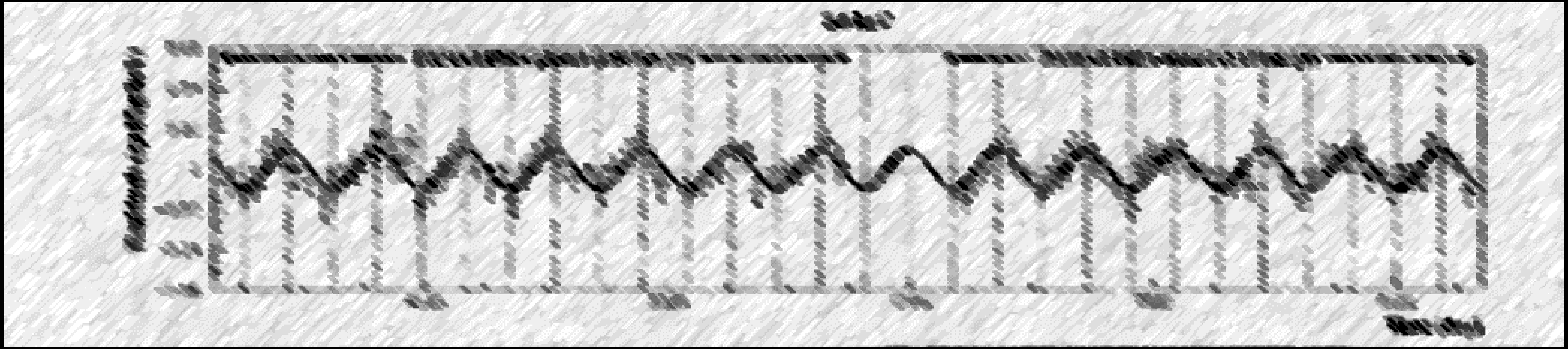
Some analysis systematics could explain the signal

COSINE-100 collaboration, Sci.Rep. 13 (2023) 4676



- DAMA/LIBRA subtract the average background year by year and it has never shown the experiment total rates
- COSINE-100 recovers a modulation in his data by applying a similar analysis

However, the phase is not compatible with that obtained by DAMA/LIBRA
Difficult to reconcile, but similar modulation amplitude is recovered

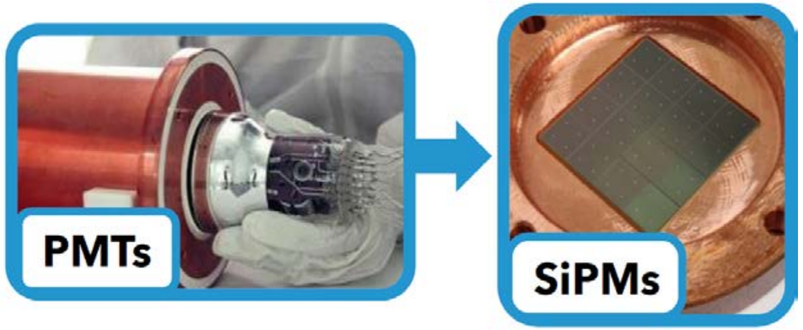


How to go beyond this testing and understanding DAMA/LIBRA signal?

- ANAIS-112 has accumulated already 7 years of data, results for 6 years will be released soon. Sensitivity at 5 σ level by the end of 2025.
- SABRE, COSINE-200 and PICOLON are working to develop more radiopure crystals of NaI(Tl) in order to reduce the background in the ROI
- COSINUS is developing a new detection technology: scintillating bolometers using NaI(Tl) as target. This will have strong background rejection power and it can identify NR from ER. Moreover, it will reduce the dependence on the QF systematics and it will allow for very low Energy threshold.

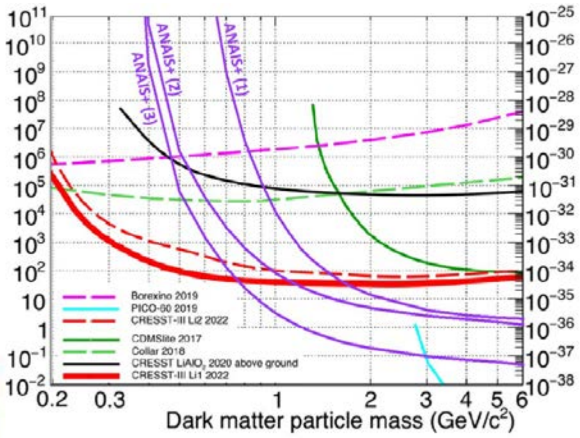
New inputs could help to better understand the backgrounds in the ROI, the light generation mechanism in NaI(Tl) and possible related systematics

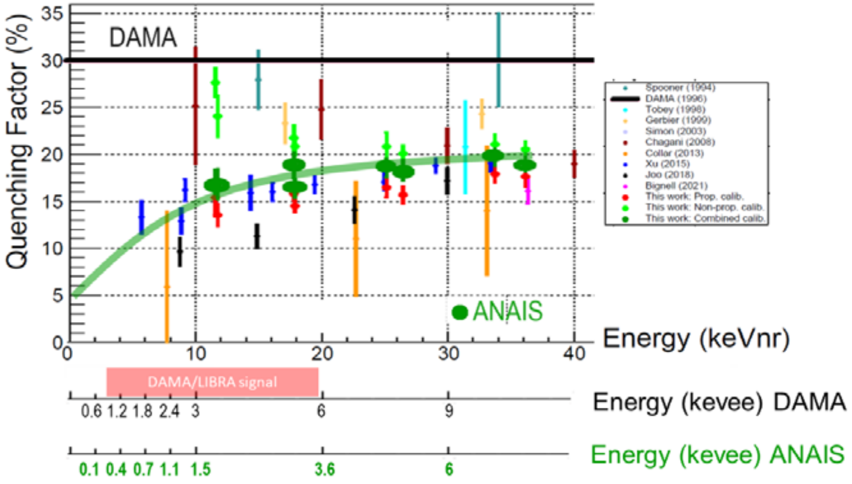
We are moving forward R&D on a new technological approach ANAIS+

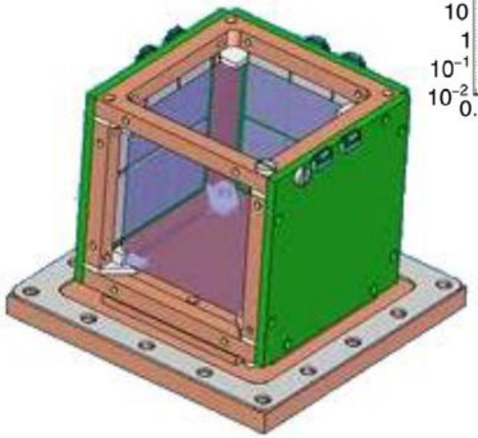


Replace PMTs by SiPM and operation at low T (~100K)

- Reduce "light noise" coming from the PMT
- Increase light collection and then, reduced threshold
- Allow the operation inside a LAr active veto to fight backgrounds







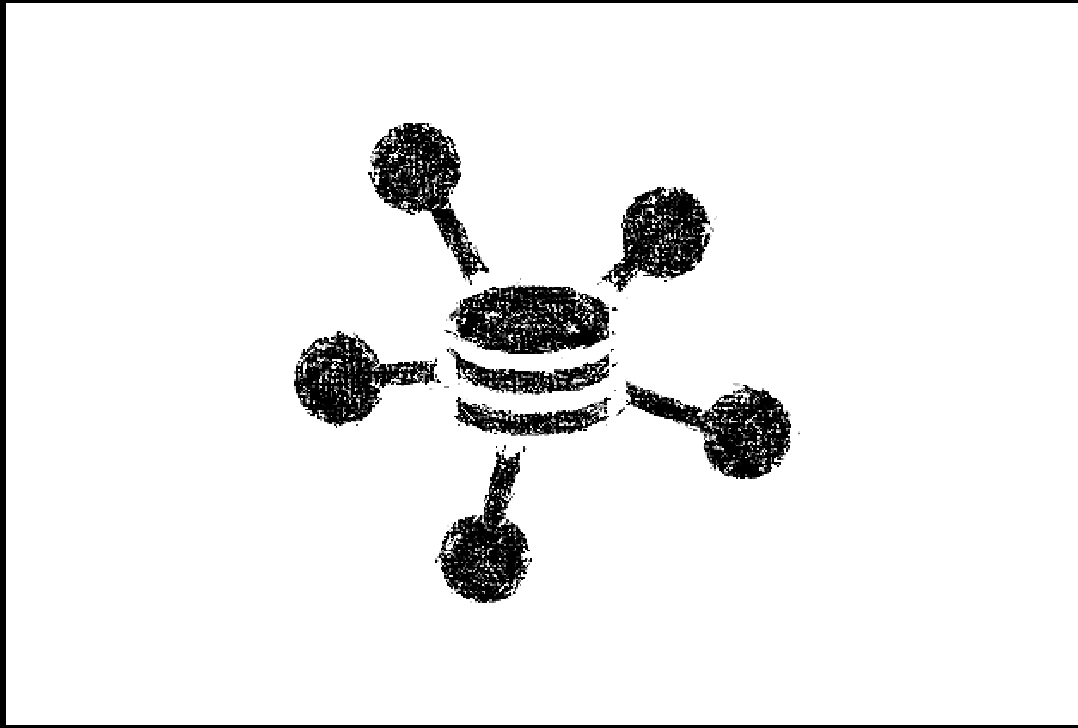
First prototype in construction

Centro de Astropartículas y Física de Altas Energías
Universidad Zaragoza

INFN LNGS

Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

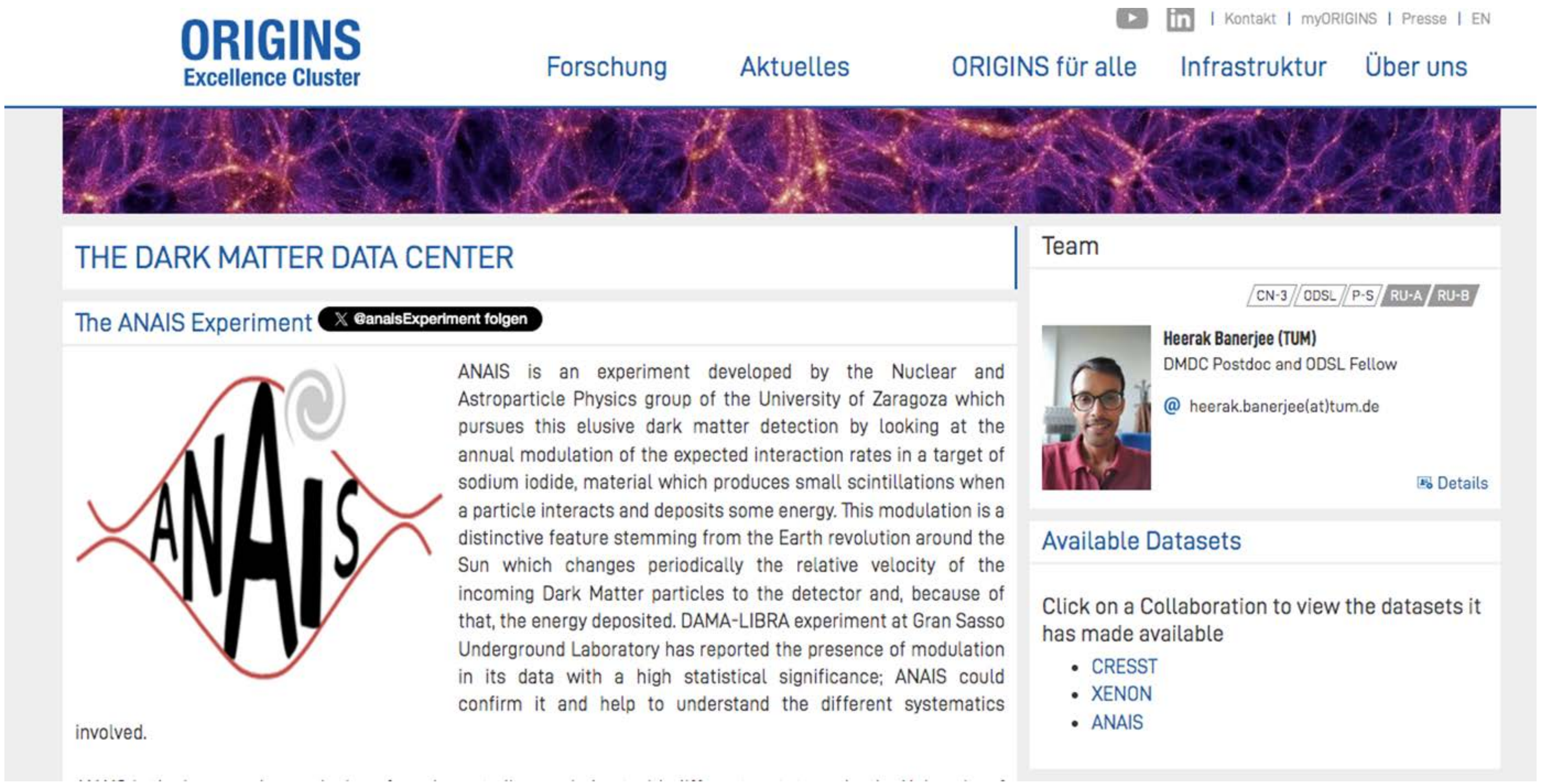
The testing of the DAMA/LIBRA signal



Open discussion on data and analysis sharing protocols, other good practices

We are collaborating with The Dark Matter Data Center for providing open access to our data

https://www.origins-cluster.de/odsl/dark-matter-data-center/available-datasets/anais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THE DARK MATTER DATA CENTER

The ANAIS Experiment @anaisExperiment folgen

ANAIS is an experiment developed by the Nuclear and Astroparticle Physics group of the University of Zaragoza which pursues this elusive dark matter detection by looking at the annual modulation of the expected interaction rates in a target of sodium iodide, material which produces small scintillations when a particle interacts and deposits some energy. This modulation is a distinctive feature stemming from the Earth revolution around the Sun which changes periodically the relative velocity of the incoming Dark Matter particles to the detector and, because of that, the energy deposited. DAMA-LIBRA experiment at Gran Sasso Underground Laboratory has reported the presence of modulation in its data with a high statistical significance; ANAIS could confirm it and help to understand the different systematics involved.

Team

CN-3 ODSL P-S RU-A RU-B

Heerak Banerjee (TUM)
DMDC Postdoc and ODSL Fellow
@ heerak.banerjee(at)tum.de
Details

Available Datasets

Click on a Collaboration to view the datasets it has made available

- CRESST
- XENON
- ANAIS

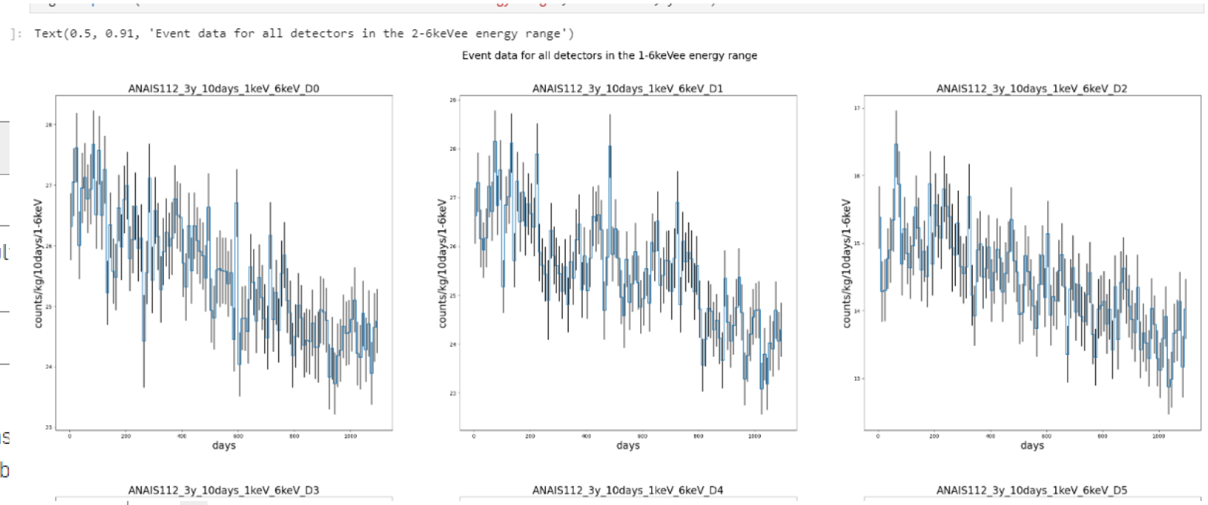
- We have released data associated to our three-year data analysis and reanalysis: temporal evolution in the two energy regions analysed in 10-day bins after filtering procedures and calibration

- This is not the full data structure and it does not enable complete re-analysis, which will be our final goal, but reproduce the fitting and modelling of our publications

ANAIS-112 Three Year

Detector Module	ANAIS-112
Material	NaI(Tl)
Technology	3 × 3 Array of NaI(Tl) scintillating crystals D0-D8 using two Photo Mul Tubes (PMTs) each to detect scintillation light signal.
Fiducial Mass	12.5 Kg each. Total 112.5 Kg
Total Live Time	1013.83 days **Sec III of PhysRevD.103.102005 misquotes this as 1018.6 days. The las 111, live time: 4.74 days, was not considered for the analysis in this pub
Threshold	1 keV (Electron equivalent energy. All energies are in keVee, aliased by keV)
Acceptance Region	1-6 keV and 2-6 keV
Average Resolution	$\sigma = (-0.008 \pm 0.001) + (0.378 \pm 0.002) \times \sqrt{E(keV)}$

ANAIS provides a JuPyter Notebook with examples of how to plot the data in these datasets and to run the RooFit macro for fitting the data.
Launch a Binder session with the notebook preloaded: launch binder



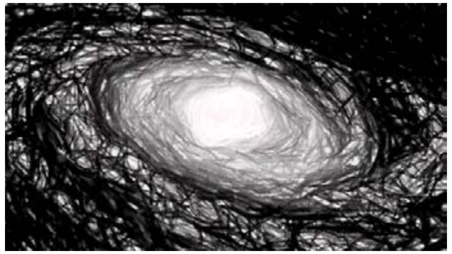
Data and analysis open release

- Before releasing less processed data, we need to take some decisions on format and analysis tools and we would like to receive feedback about which data could be more interesting and useful for the community
- RAW DATA can be quite difficult to manage and to interpret requiring the design of more complex analysis tools while filtered data could be biased, which is something we would like to avoid

Very soon we will release our results for 6 years analysis, with sensitivity beyond 4 sigma to DAMA/LIBRA result, so stay tuned!

- We are collaborating with COSINE-100 experiment, sharing information on data and analysis, aiming at combining our results in order to identify possible systematics and increase the statistical significance of the testing to DAMA/LIBRA signal

Summary and Outlook



Summary and Outook

Testing at 5 sigma the DAMA/LIBRA result is at hand by 2025 by ANAIS experiment and we are working on sensitivity improvements -> new DAQ is under commissioning and R&D on ANAIS+
Other experiments are also progressing towards testing DAMA/LIBRA with different strategies

However, there is still a relevant systematics in this testing: the response of the NaI(Tl) detector to NR is not yet well known.

Neutron calibration “onsite” and QF measurements are relevant for understanding systematics -> more coordinated work from the community would be required → if QF is dependent on the crystal properties, we will not be able to test DAMA/LIBRA results without carrying out more specific QF measurements of their crystals

We are approaching to close the DAMA/LIBRA anomaly. We should have learnt to develop more transparent protocols for data analysis and make a common practice of providing open access to data

Thank you for your attention

ANAIS

MultiDark
Multimessenger Approach
for Dark Matter Detection

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Universidad Zaragoza