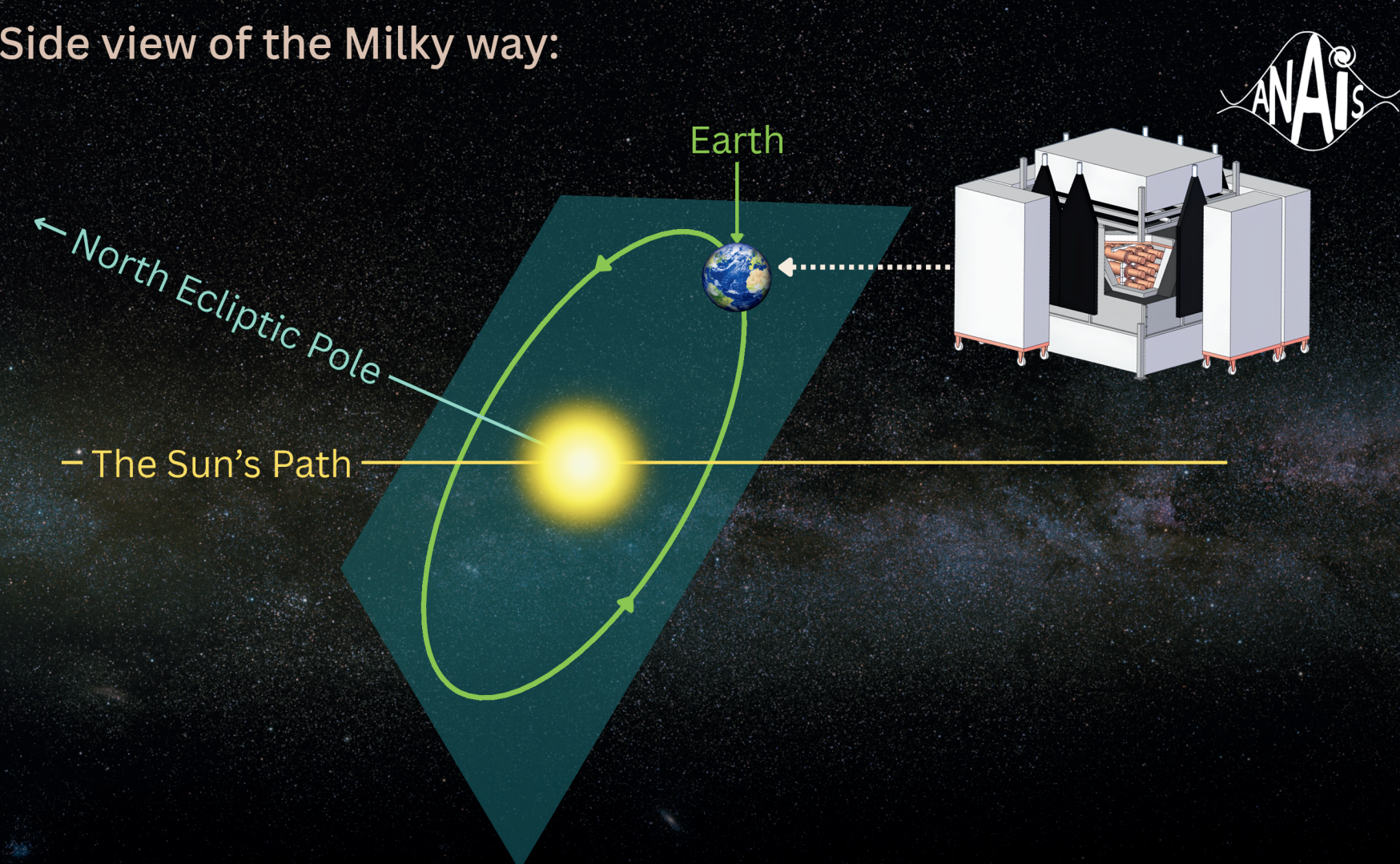


Exploring the WIMP-Nucleon Parameter Space with ANAIS-112

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Side view of the Milky way:



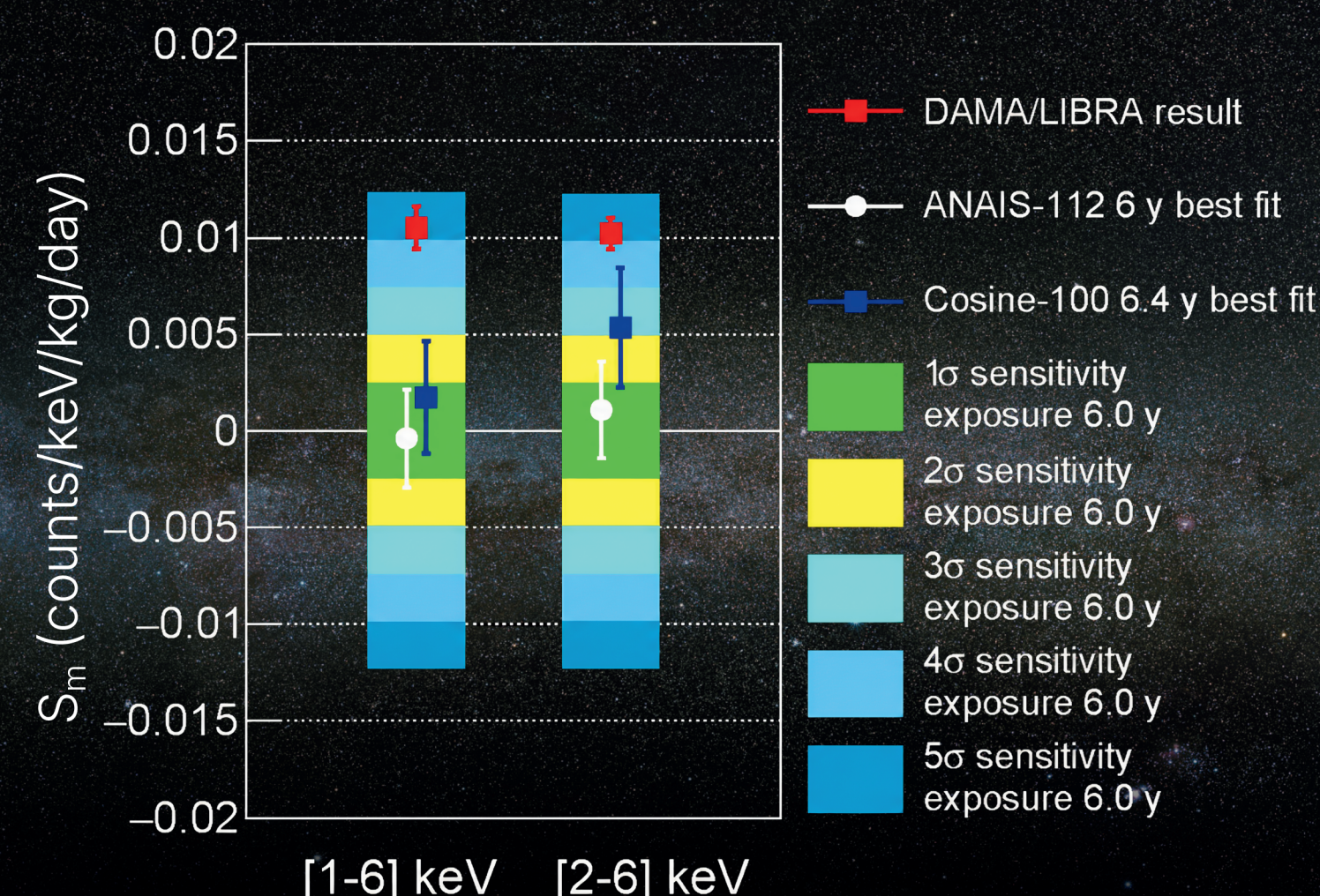
Model-independent analysis: ANAIS-112 testing the DAMA/LIBRA signal

The **Earth's motion** through the Galactic dark matter halo induces an **annual modulation in the expected interaction rate**:

$$S(t) = S_0 + S_m \cos[\omega(t - t_0)]$$

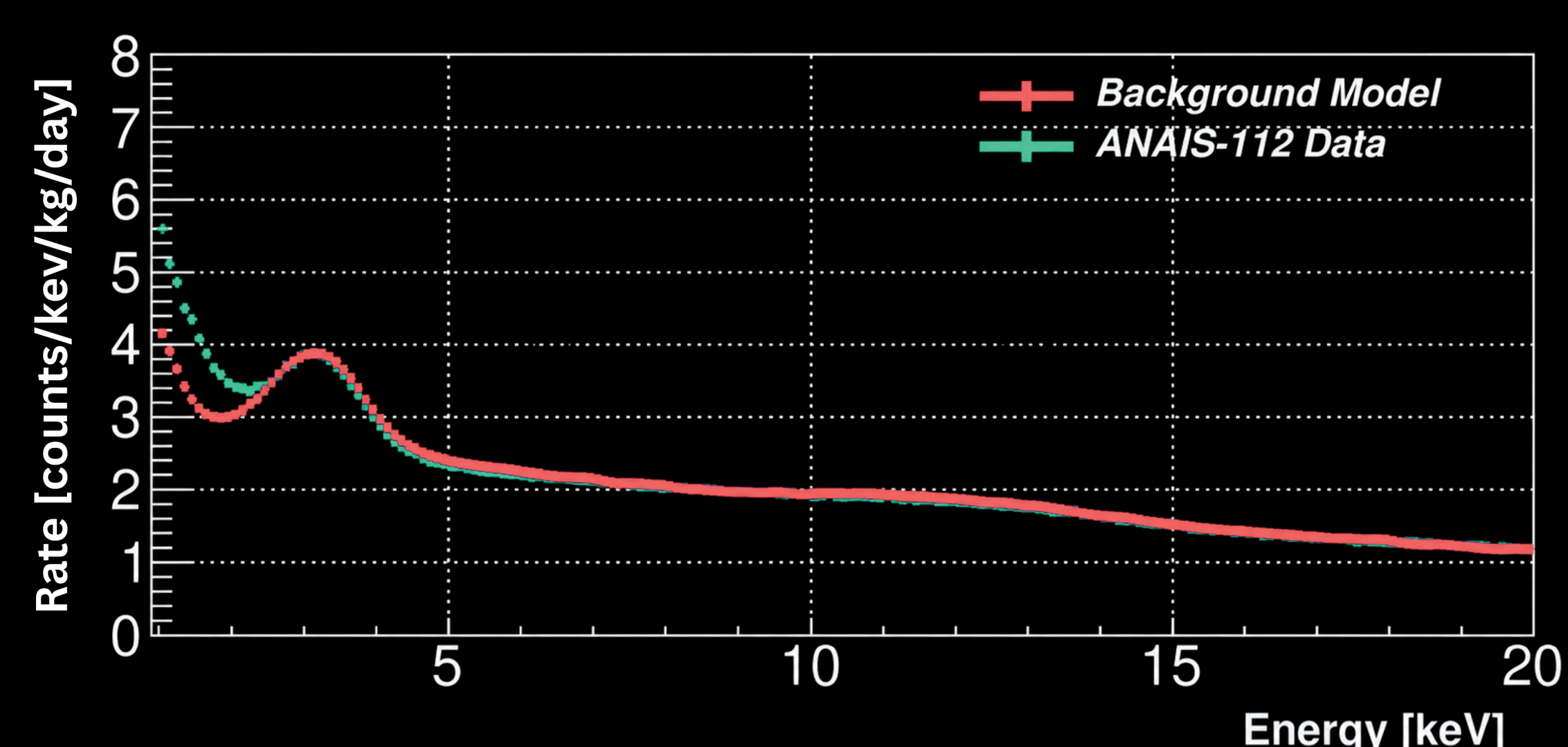
where S_m is the modulation amplitude and t_0 ($\approx$ June 2nd) is the expected phase for a dark matter signal.

The **ANAIS-112 experiment** was designed to perform an **independent test** of the DAMA/LIBRA result using 112.5 kg of NaI(Tl). The data taking started in 2017 and ended in 2026. With the first 6y exposure, ANAIS-112 results are **incompatible with the DAMA/LIBRA signal** (Ref. [1]).



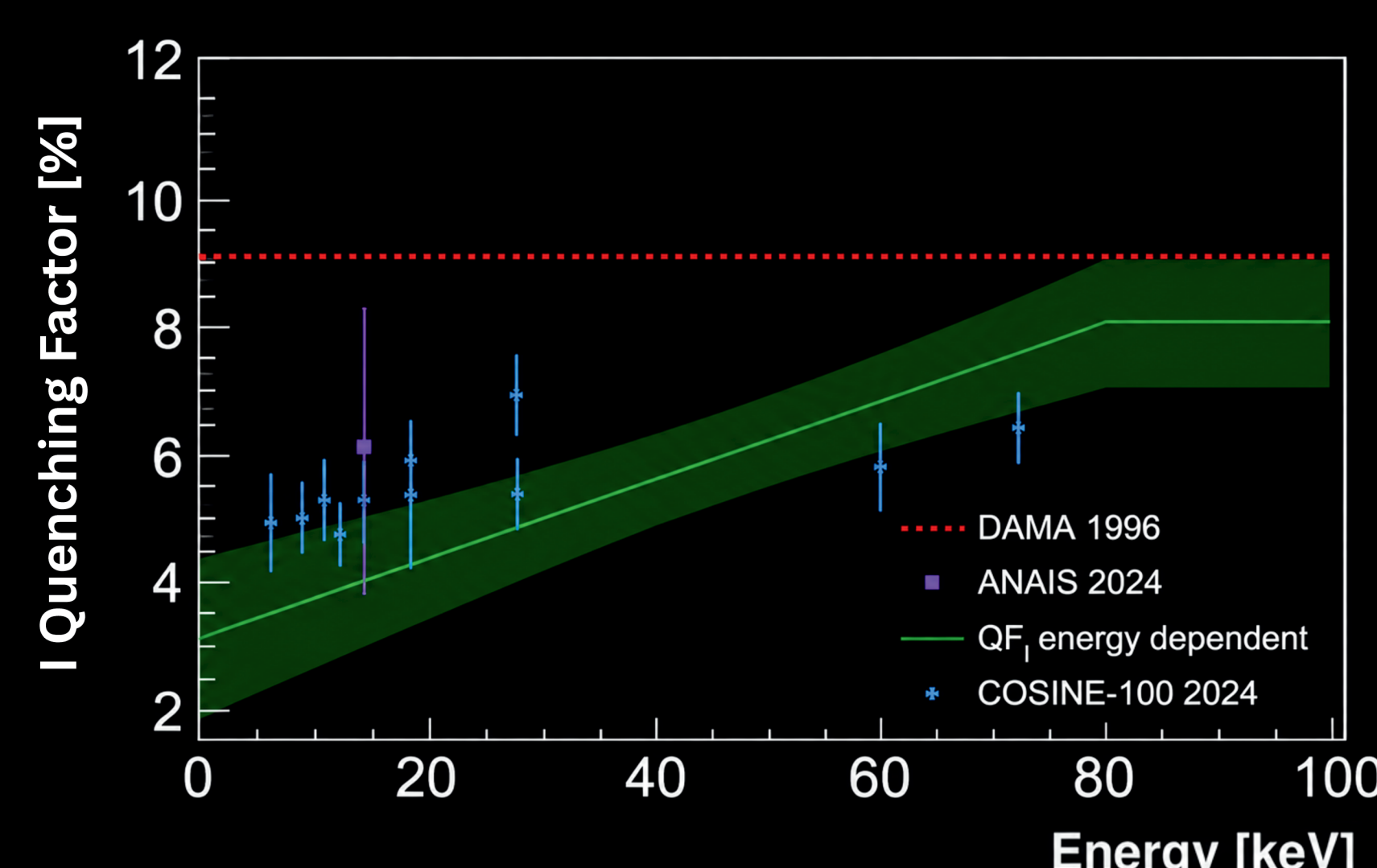
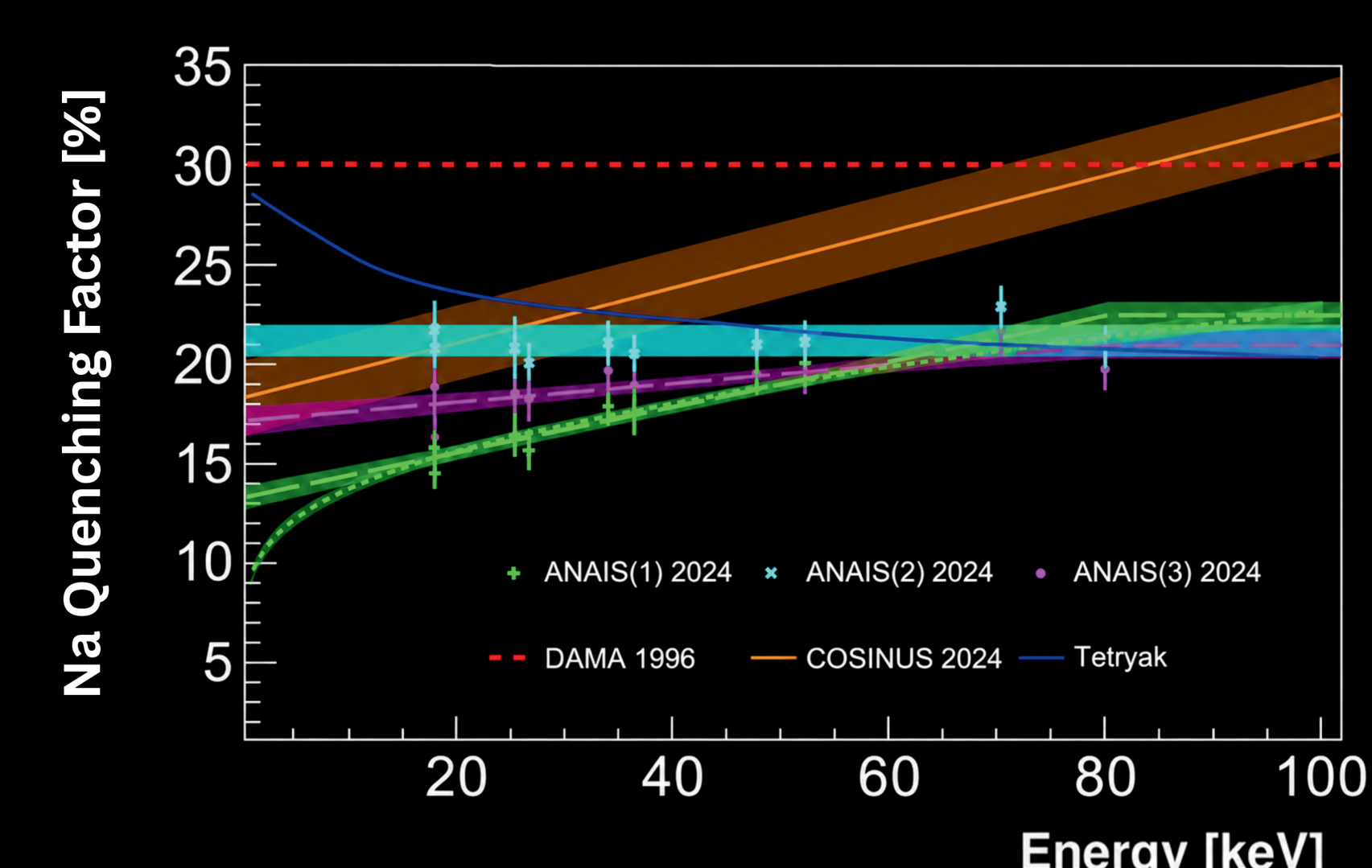
ANAIS-112 Background model vs data:

The background model **reproduces well the data above 2.5 keV**. Below, there is an excess not yet understood, but mainly associated with **anomalous light events** that come from the **PMTs** (Ref [2]).



The impact on the nuclear recoil quenching factor (QF):

The QF relates the electron equivalent **observed energy** to the **true nuclear recoil energy** in scintillators. An accurate determination of this quantity is essential for the interpretation of signals and exclusion limits. For this purpose, **dedicated onsite neutron calibrations** were carried out in ANAIS-112 (Ref [2]).



Model-dependent WIMP interpretation: Spin Independent (SI) coupling

For **SI interactions**, the WIMP **couples coherently to the whole nucleus** following:

$$\sigma_{SI} \propto (Zf_p + Nf_n)^2 F^2(q) \approx A^2 F^2(q)$$

Where Z and N are the numbers of protons and neutrons in the nucleus, A is the nuclear mass number, f_p and f_n are the effective WIMP couplings to p and n and $F(q)$ is the nuclear form factor as a function of the momentum transfer q .

The sudden motion of the recoiling nucleus can induce excitation or ionization of atomic electrons via the **Migdal Effect** (Ref. [6]) and therefore, an **additional electromagnetic signal** is produced (E_{EM}). Then, the **experimentally observed energy** is given by: $E_{ee} = E_{EM} + Q(E_{NR})E_{NR}$

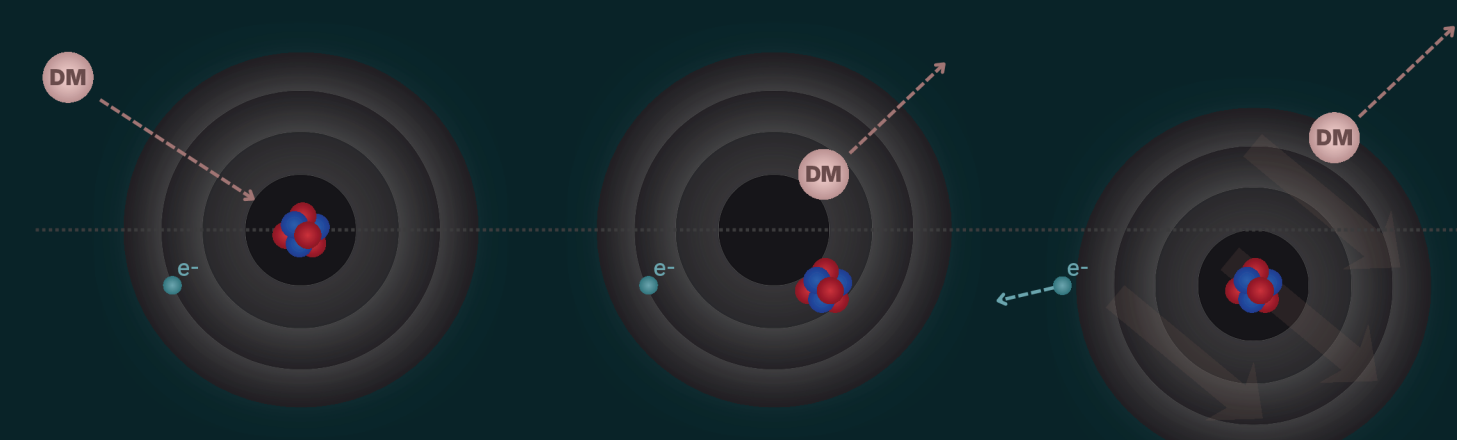
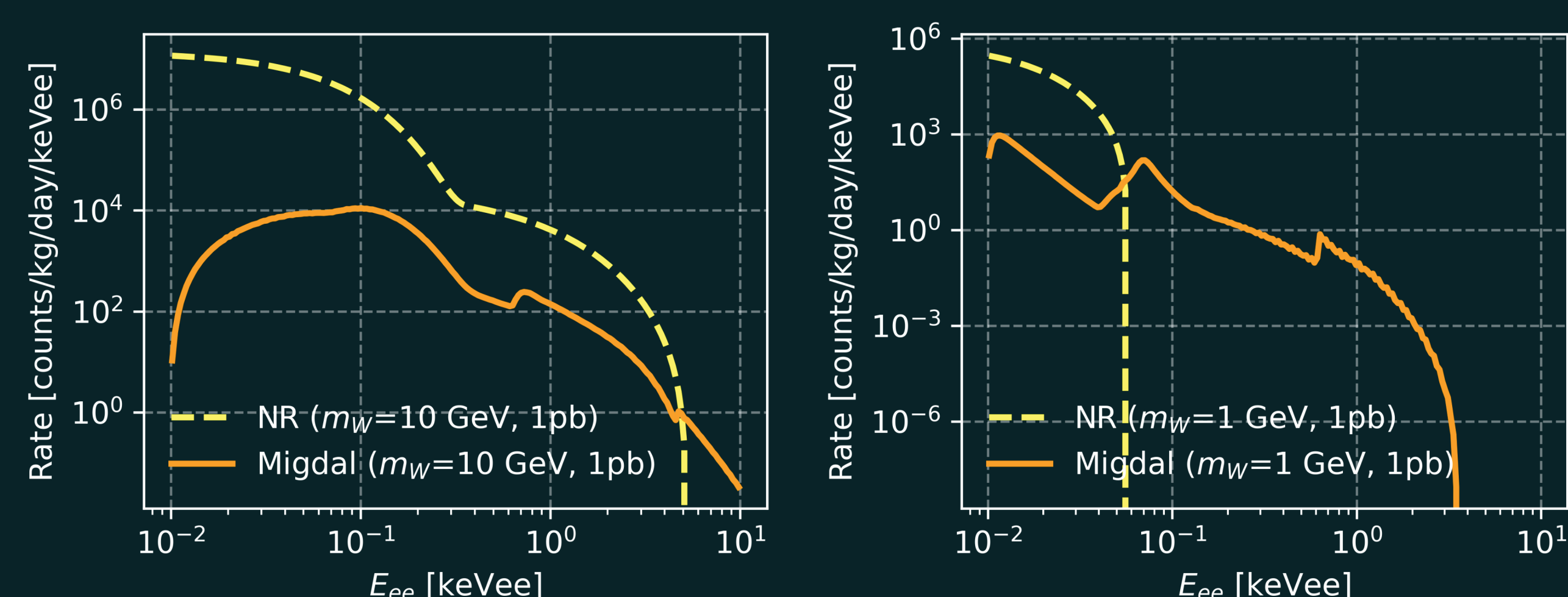
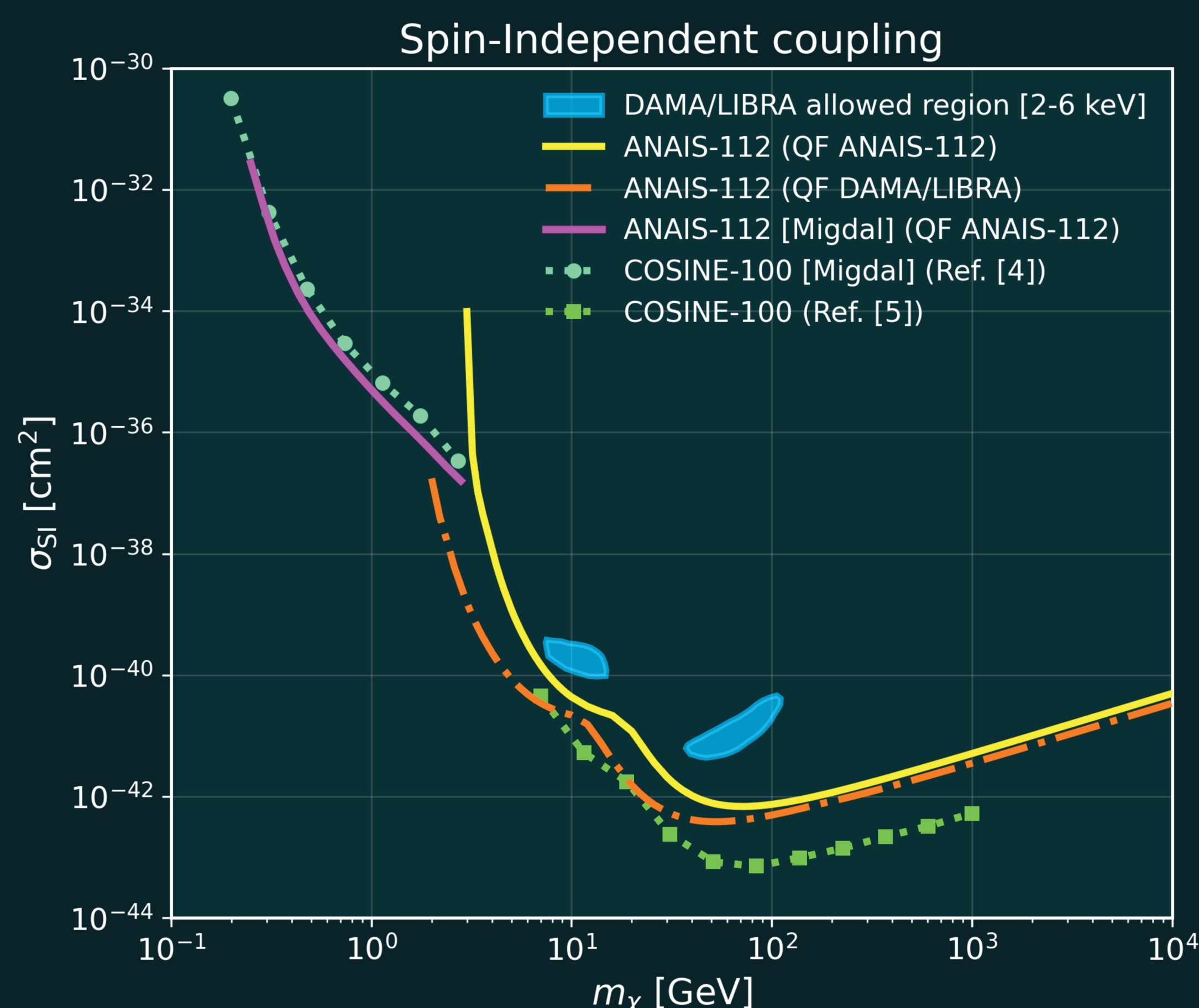


Illustration of the Migdal Effect: an electron from the electronic cloud has a certain probability of being emitted when a DM particle scatters off a nucleus.



Expected rates without energy resolution for SI interactions. The plot show the comparison from standard nuclear recoils and Migdal-induced signals. The latest becomes especially relevant for low-mass WIMPs, where the Migdal contribution can generate signals above threshold (1 keV). QF derived from neutron calibrations.



ANAIS-112 exclusion limits (90% C.L.) with an exposure of 358 kg x y, under the Standard Halo Model hypothesis. The study is performed using **quenching factors** derived from **dedicated neutron calibrations** and also those **adopted by DAMA/LIBRA**. The DAMA/LIBRA allowed regions are shown for comparison (Ref. [3]).

Model-dependent WIMP interpretation: Spin Dependent (SD) coupling

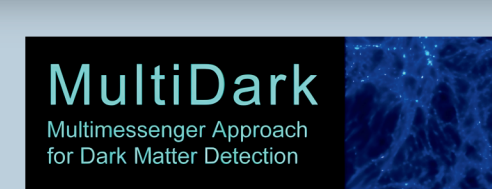
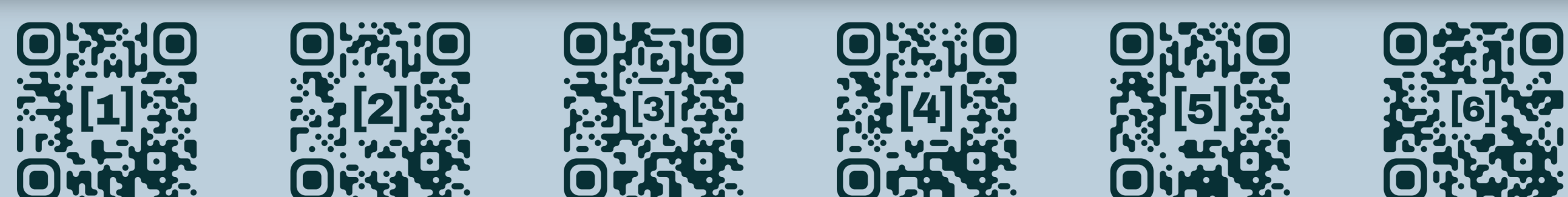
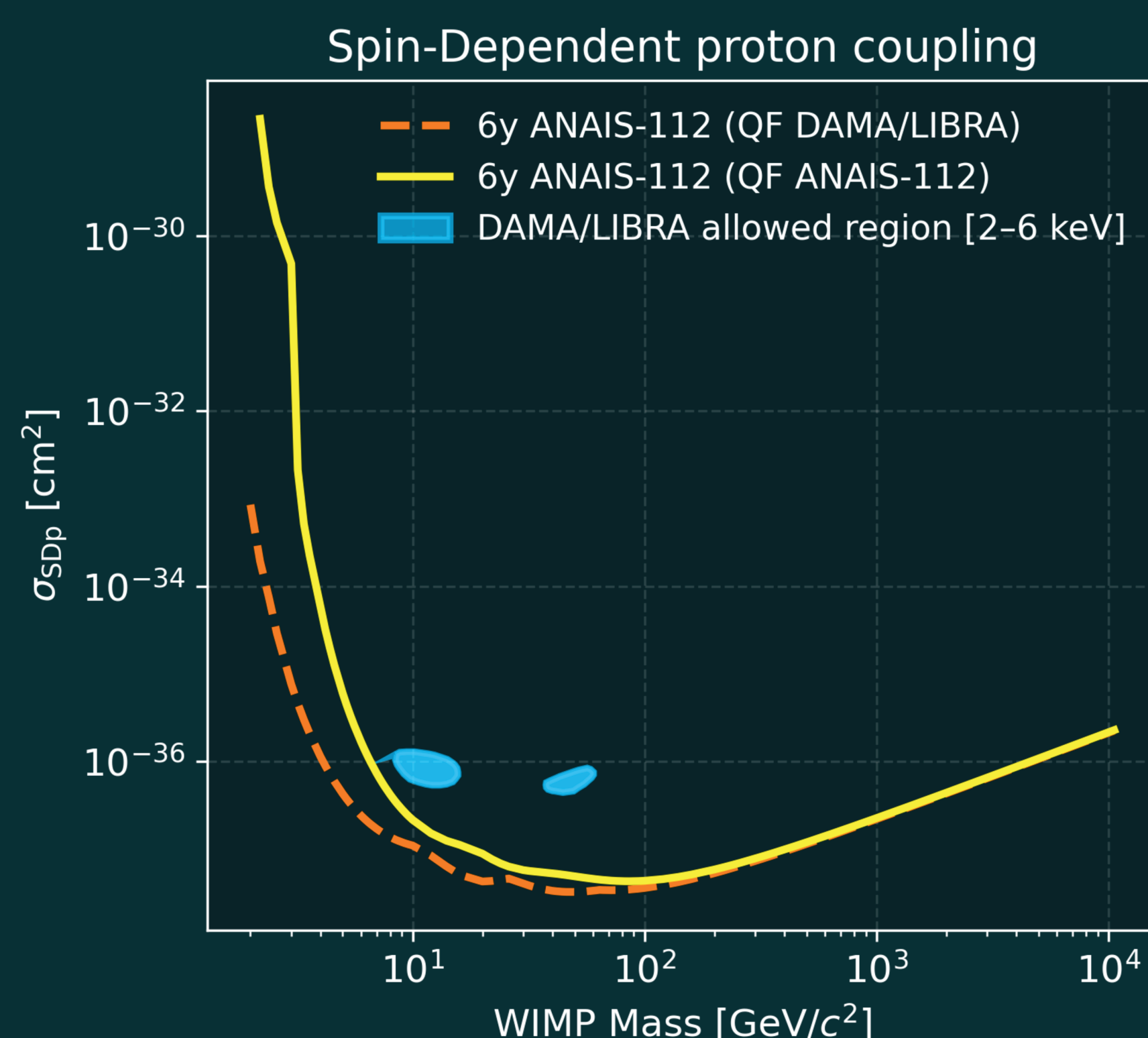
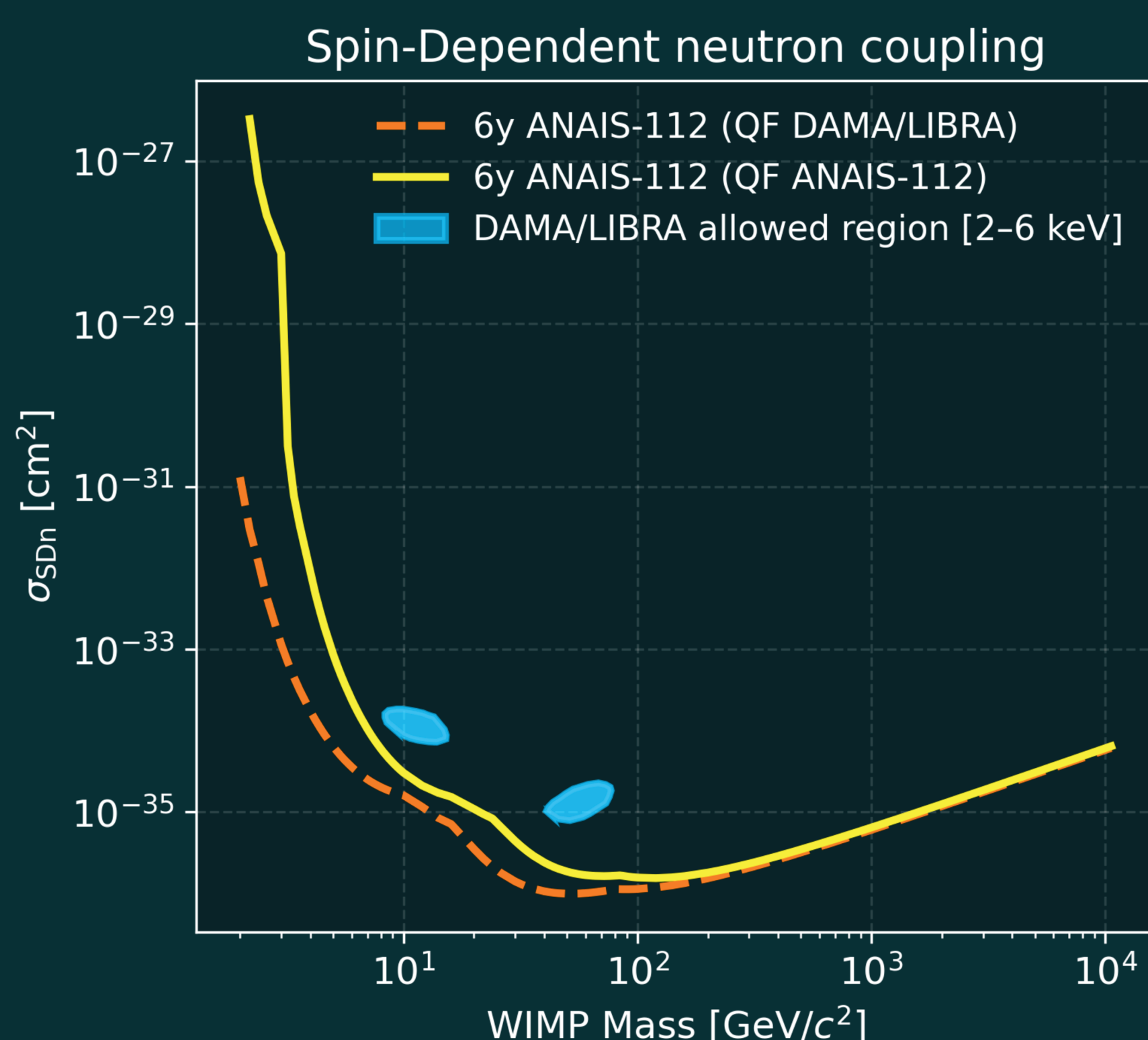
For **SD interactions**, the WIMP **couples to the spin content** of the nucleus, making the sensitivity strongly dependent on the nuclear spin structure:

$$\sigma_{SD} \propto \frac{J+1}{J} (a_p \langle S_p \rangle + a_n \langle S_n \rangle)^2$$

Where J is the total nuclear angular momentum (nuclear spin), a_p and a_n are the effective WIMP couplings to protons and neutrons and $\langle S_p \rangle$ and $\langle S_n \rangle$ are the proton and neutron spin expectation values of the target nucleus.

NaI(Tl) detectors are particularly sensitive to SD interactions since **both ^{23}Na and ^{127}I have non-zero nuclear spin**.

The **ANAIS-112 exclusion limits** for both neutron (left) and proton (right) **Spin-Dependent couplings** are shown on the right panel. Migdal calculations for the SD coupling are currently under development.



This work has been financially supported by MCIN/AEI (P10.13039/501100011033 under Grants No. PID2022-13835/NB-C21 and No. PID2019-104374 GB-I00, the Consolidar-Ingenio 2010 Programme under Grants MultiDark CSD2009-00064 and CPAN CSD2007-00042, the LSC Consortium, the Gobierno de Aragón and the European Social Fund (Group in Nuclear and Astroparticle Physics) and funds from European Union NextGenerationEU/PRTR (Planes complementarios, Programa de Astrofísica y Física de Altas Energías).