



Annual modulation of dark matter. AN AIS-112



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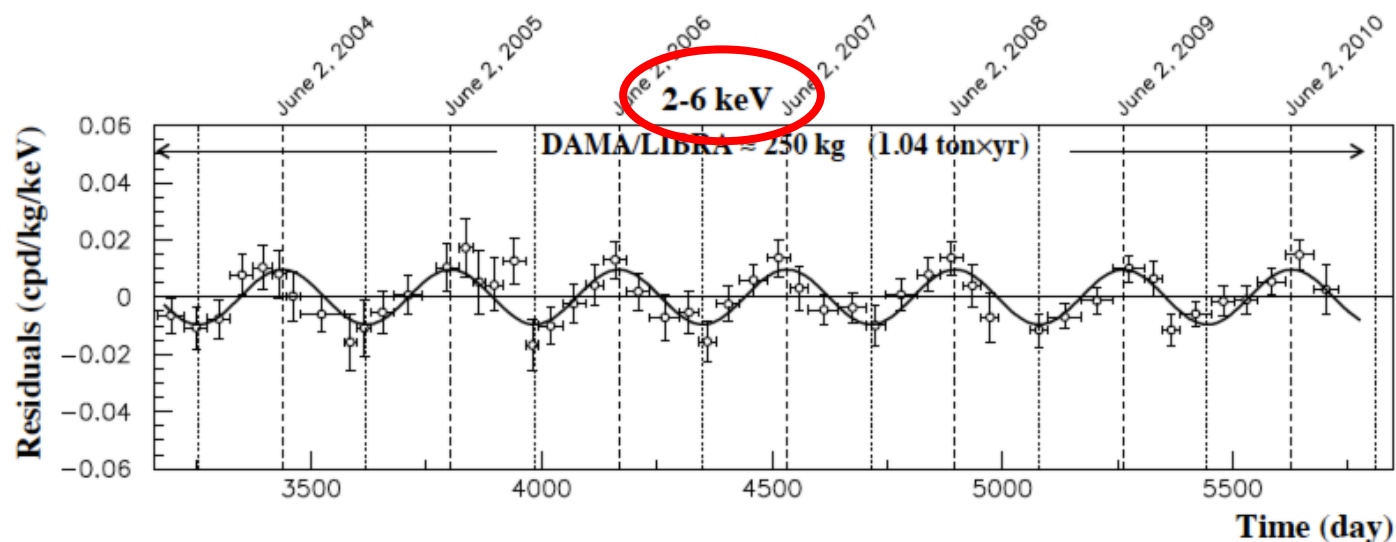
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Outline

- The DAMA/LIBRA positive signal
- The ANAIS experiment
- Searching a signal in $[2,6]$ keV_{ee}
- ANAIS-112 in $[1,6]$ keV_{ee}
- Summary and conclusions

The DAMA/LIBRA positive signal

ANAIS → Model independent confirmation DAMA/LIBRA signal



$$T = 0.998 \pm 0.002 \text{ yr}$$

$$t_0 = 144 \pm 7 \text{ days}$$

NaI(Tl)

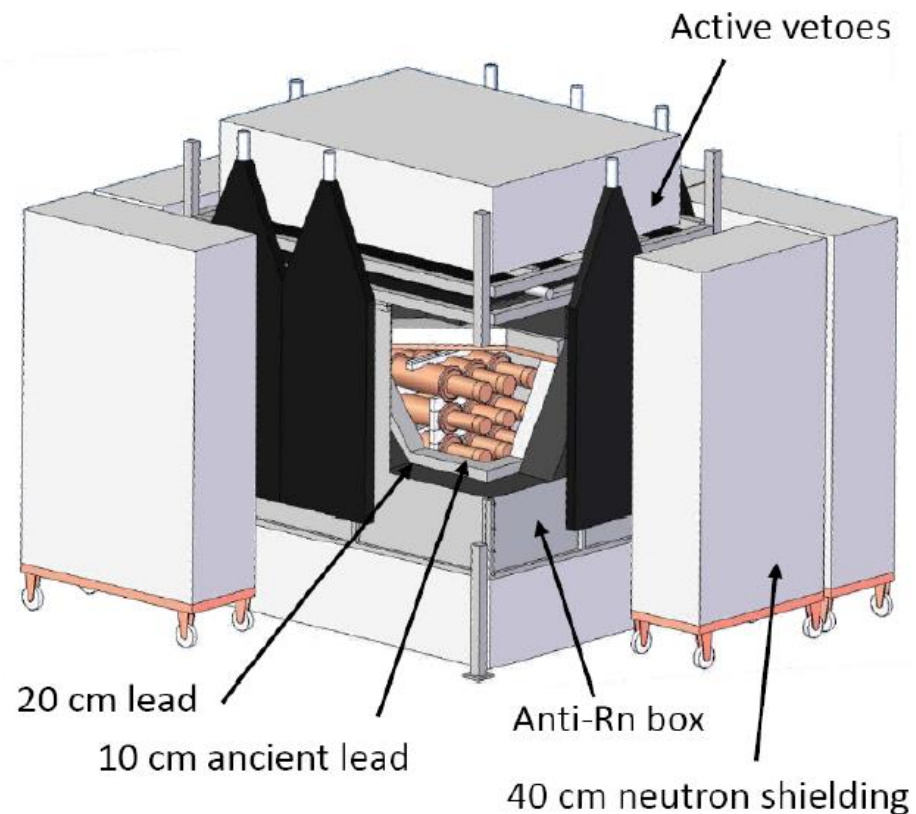
$$\frac{dR}{dE}(E, t) \approx S_0(E) + S_m(E) \cdot \cos\left(2\pi \frac{t - t_0}{T}\right)$$

0.0112 ± 0.0012 (9.3σ)
cpd/kg/keV_{ee}

[2,6] keV_{ee}

The ANAIS experiment

ANAIS-112: 3x3 matrix of 12.5 kg NaI(Tl) modules
112.5 kg active mass



I. Coarasa et al, arXiv:1704.06861v1

Module	Received	^{40}K (mBq/kg)	^{210}Pb (mBq/kg)
D0	Dec 2012	1.4 ± 0.2	3.15 ± 0.10
D1	Dec 2012	1.1 ± 0.2	3.15 ± 0.10
D2	March 2015	1.1 ± 0.2	0.7 ± 0.1
D3	March 2016	0.60 ± 0.06	1.8 ± 0.1
D4	Nov 2016	0.3 ± 0.2	1.8 ± 0.1
D5	Nov 2016	0.8 ± 0.2	0.70 ± 0.05

D6, D7 and D8 → March 2017



Searching a signal in $[2,6]$ keV_{ee}

Model independent way to check the DAMA/LIBRA result:

- ✓ Same target and technique
- ✓ In the same region $[2,6]$ keV_{ee}

$$B(\tau) = a + b \cos \tau \quad \tau = \frac{2\pi(t - t_0)}{T}$$

Modulation amplitude

Linear least-squares fit for n time bins

Only one 4 keV_{ee} bin

Estimator \hat{b} : $E(\hat{b}) = b$
 $var(\hat{b})$

Figure of merit

$$FOM = \sqrt{\frac{2 \cdot B}{\Delta E \cdot M \cdot T_M \cdot \varepsilon}} \sqrt{var(\hat{b})}$$

I. Coarasa et al, arXiv:1704.06861v1

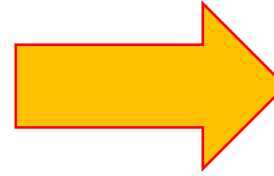
- B background
- $\Delta E = 4$ keV_{ee} energy bin width
- $M \cdot T_M$ exposure
- ε cut efficiency

To compare the different experiments looking for the annual modulation observed by DAMA/LIBRA in $[2,6]$ keV_{ee}

Searching a signal in $[2,6]$ keV_{ee}

ANAIS-112 Background (B) estimate

- ✓ D0, D1 and D2: measured
- ✓ D3, D4 and D5: expected after the decay of the short-lived cosmogenic isotopes
- ✓ D6, D7 and D8: same ingot as D5



B is conservative

$$B = A(K)f(K) + A(Pb)f(Pb) + B'$$

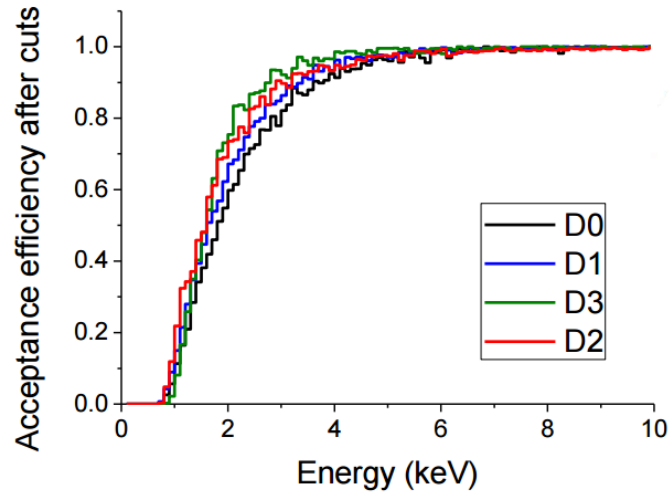
- $A(K)$ specific activity of ^{40}K inside the crystal
- $f(K)$ conversion factor from mBq to cpd/keV_{ee} in a module in anticoincidence with the other modules
- $A(Pb)$ and $f(Pb)$ for ^{210}Pb
- B' from other sources (PMTs, long-lived cosmogenic isotopes: ^{22}Na and ^3H)



Estimated by Monte Carlo

Searching a signal in $[2,6]$ keV_{ee}

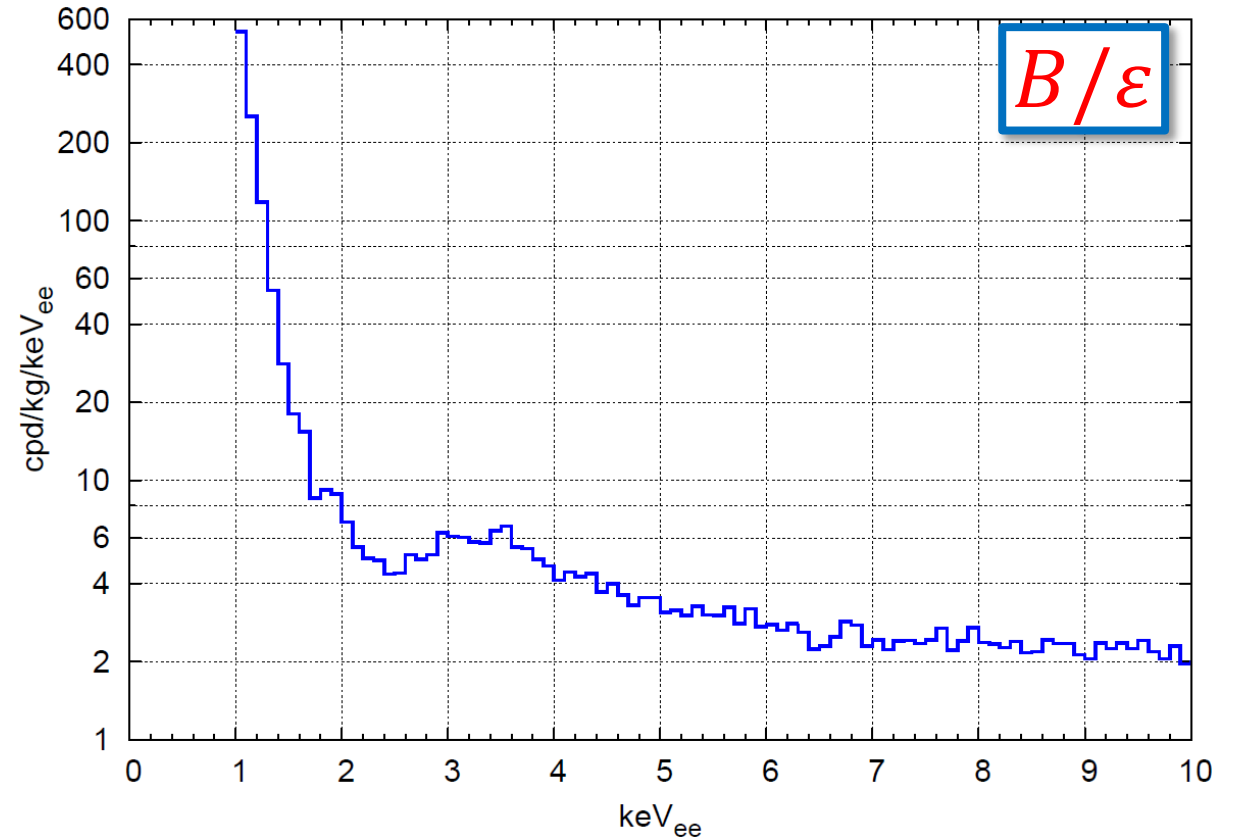
ANAIS-112 Efficiency (ε) estimate



Acceptance efficiency estimate

$$[2,6] \text{ keV}_{ee} \Rightarrow \varepsilon \simeq 0.89$$

I. Coarasa et al, arXiv:1704.06861v1

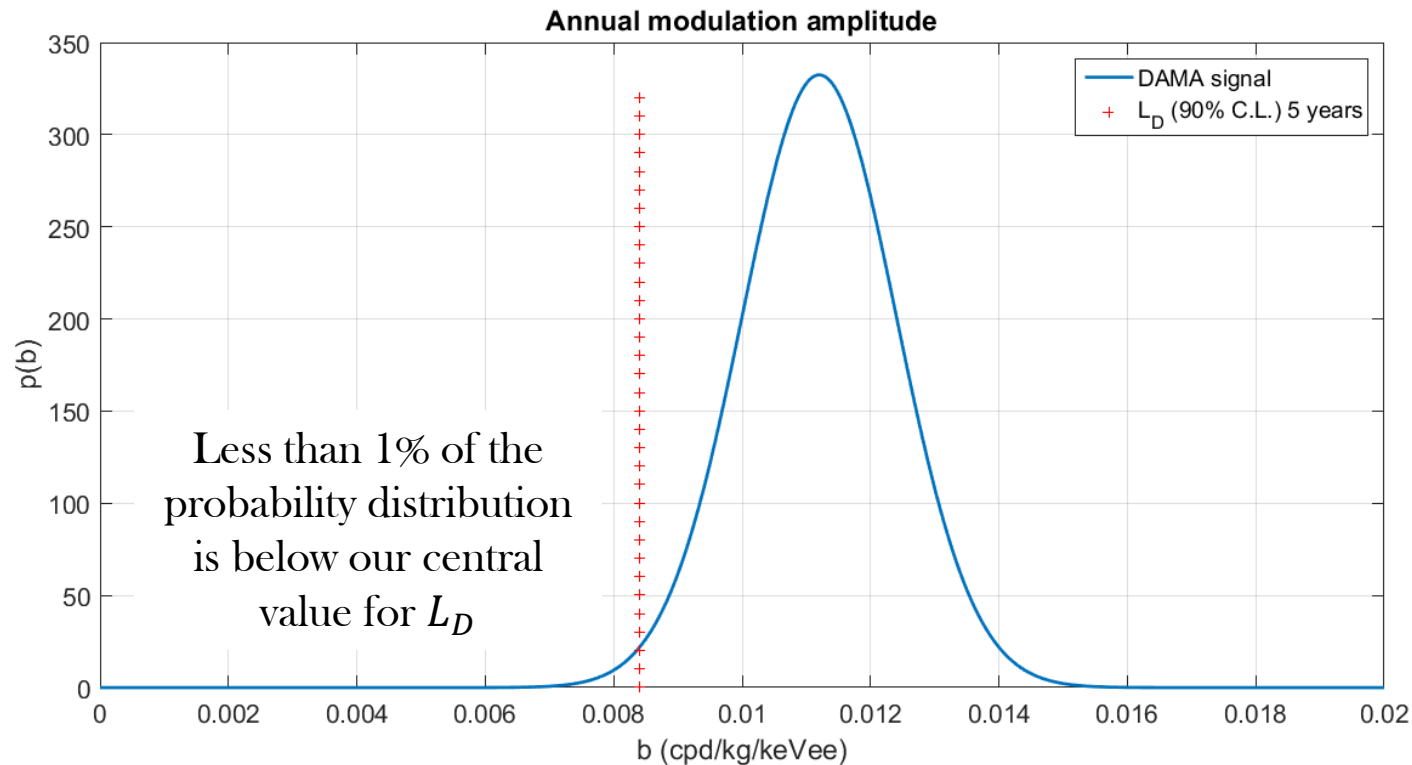


Estimated B/ε measured levels

Searching a signal in $[2,6]$ keV_{ee}

Detection limit

90% C.L. for L_C and L_D to compare properly the expectations of ANAIS-112 with other experiments



Critical and detection limits

$$P(\hat{b} \leq L_C | b = 0) = \alpha$$

$$P(\hat{b} > L_C | b = L_D) = \beta$$

112.5 kg \times 5 years

$$L_D = (8.40 \pm 0.25) \cdot 10^{-3} \text{ cpd/kg/keV}_{ee}$$

ANAIS-112 has a detection limit for annual modulation lower than the measured amplitude by DAMA/LIBRA:
 $0.0112 \pm 0.0012 \text{ cpd/kg/keV}_{ee}$

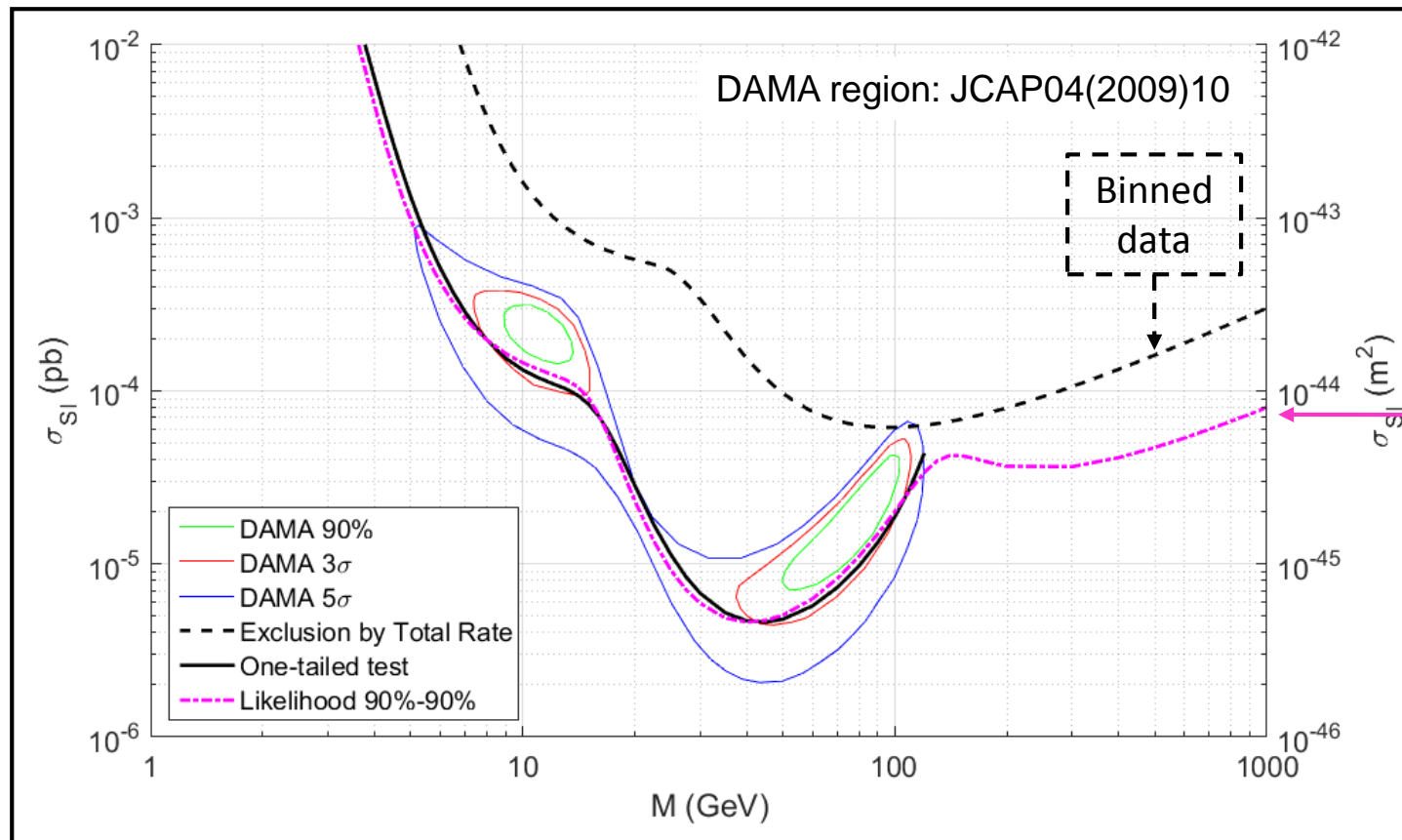
✓ Considering the energy binning and the segmented detector in nine modules: $L_D = 8.27 \cdot 10^{-3} \text{ cpd/kg/keV}_{ee}$

Searching a signal in $[2,6]$ keV_{ee}

Dark matter hypothesis

The possible modulation has to be compatible with the energy dependence of the modulation amplitude, $b(E; \sigma, M_W)$

The test statistic is *the maximum likelihood ratio* of the *no DM* and *DM* hypotheses



- Estimated average background
- 2 – 6 keV_{ee} region
- 112.5 kg × 5 years

L_D : 90% probability of detecting an annual modulation signal at 90% C.L.

(Equivalent to solid black line)

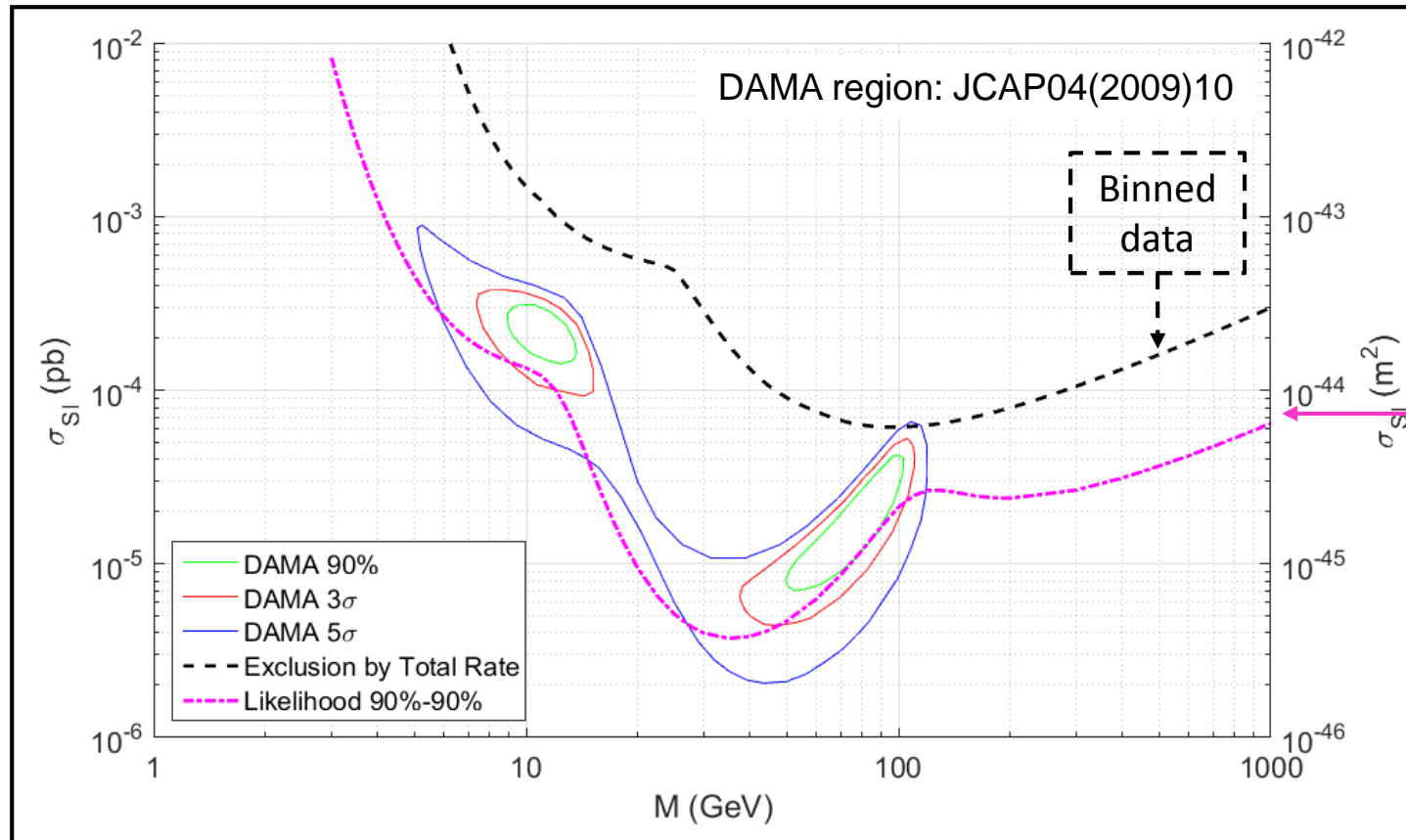
ANAIS-112 can detect the annual modulation in the 3σ region compatible with the DAMA/LIBRA result

ANAIS-112 in $[1,6] \text{ keV}_{ee}$

Dark matter hypothesis

ANAIS-112 is able to use more information from the background spectrum up to 1 keV_{ee}

The region of detection is now bigger for $M_W < 50 \text{ GeV}$ ($\uparrow B$, but \uparrow signal below 2 keV_{ee})



- Estimated average background
- $1 - 6 \text{ keV}_{ee}$ region
- $112.5 \text{ kg} \times 5 \text{ years}$

L_D : 90% probability of detecting an annual modulation signal at 90% C.L.

ANAIS-112 can detect the annual modulation in the 3σ region compatible with the DAMA/LIBRA result

Summary and conclusions

- ✓ ANAIS-112 background estimated from measured background of the six modules D0 to D5
- ✓ Detection limit at 90% C.L. (for a critical limit at 90% C.L.) of ANAIS-112 for the annual modulation observed by DAMA/LIBRA has been estimated
- ✓ Good sensitivity prospects for exploring the DAMA/LIBRA signal (5 years, 3σ region)
- ✓ Simple figure of merit to compare different experiments looking for the annual modulation observed by DAMA/LIBRA

Acknowledgments

Thank you for your attention!

