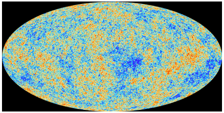
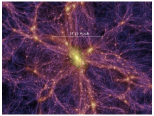
Latest XENON1T results

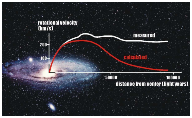
Teresa Marrodán Undagoitia
On behalf of the XENON collaboration
marrodan@mpi-hd.mpg.de

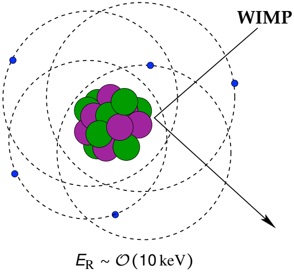
7. KAT-Strategietreffen
December 4th, 2020

Motivated by dark matter searches









Searching for the well motivated theoretical particle:

WIMP (**W**eakly **I**nteracting **M**assive **P**article)

via direct scattering off target nuclei

$$\frac{dR}{dE}(E,t) = \frac{\rho_0}{m_\chi \cdot m_A} \cdot \int v \cdot f(\mathbf{v},t) \cdot \frac{d\sigma}{dE}(E,v)\, \mathrm{d}^3 v$$

Detection of galactic dark matter via direct elastic scattering off target nuclei

Astrophysical parameters: ρ_0 and $f(\mathbf{v},t)$

Parameters of interest: m_χ and σ

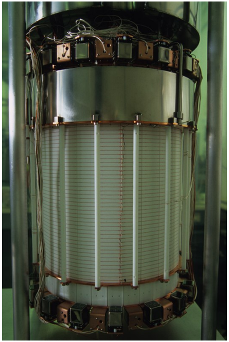
The XENON program

XENON10

(2005-2007)
Target: 25 kg

$\sigma \sim 10^{-43}\,\text{cm}^2$

XENON100



(2008-2016)
Target: 62 kg

$\sigma \sim 10^{-45}\,\text{cm}^2$

XENON1T

(2015-2018)
Target: 2 ton

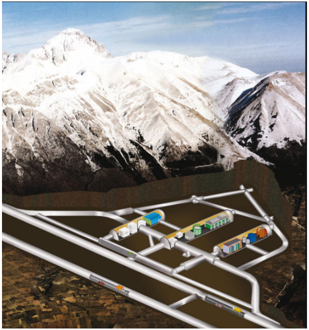
$\sigma \sim 10^{-47}\,\text{cm}^2$

XENONnT

(2019-20xx)
Target: 5.9 ton

$\sigma \sim 10^{-48}\,\text{cm}^2$

XENON1T



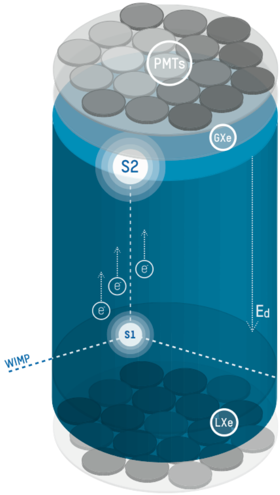
- Located at Laboratori Nazionali del Gran Sasso in Italy

  below 3 650 m.w.e. shielding ($\sim$ 1.5 km of rock)

- Experiment operated by $\sim$ 170 scientists worldwide

  U Mainz, U Münster, U Freiburg, MPIK Heidelberg & KIT Karlsruhe in Germany

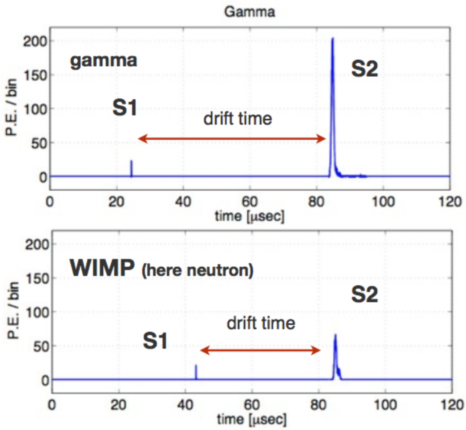
Two phase noble-gas TPC



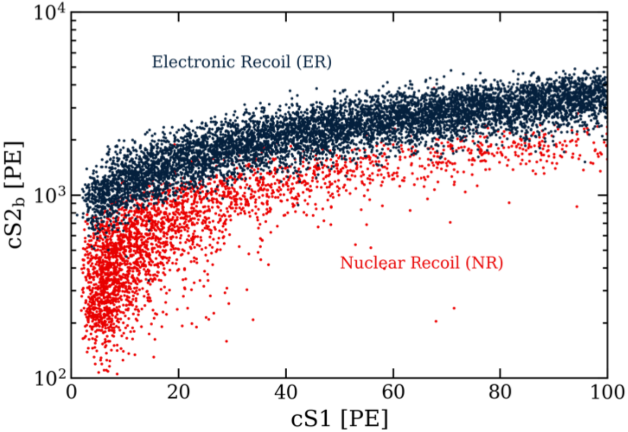
Position resolution to define the innermost radiopure volume for analysis

- Scintillation signal (S1)
- Charges drift to the liquid-gas surface
- Proportional signal (S2)

→ Electron- /nuclear recoil discrimination



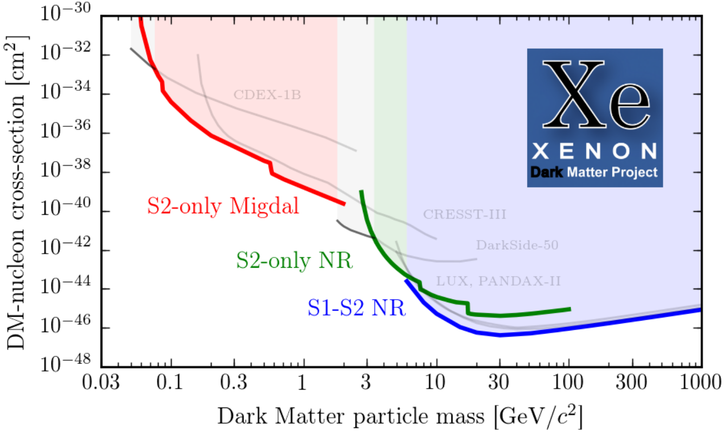
Particle identification based on S1 & S2



- ER: calibrated using a ^{220}Rn source (β-decays of ^{212}Pb)
- NR: calibrated using a neutron generator / AmBe-neutron source

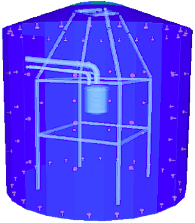
Latest dark matter results

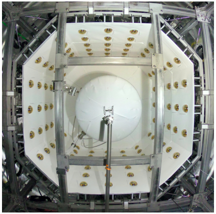
No significant signal $\rightarrow$ exclusion limit derived

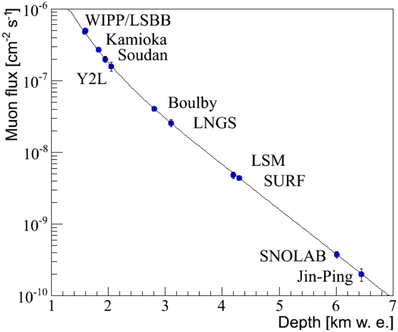


XENON1T, PRL 121 (2018) 111302, PRL 123 (2019) 251801 & PRL 123 (2019) 241803

Shielding against radiation





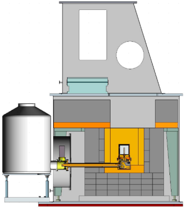


J. Phys. G: 43 (2016) 1 & arXiv:1509.08767

- Underground location to shield from cosmic particles
- Active water-Cherenkov muon shield

  XENON1T, JINST 9 (2014) P11006 & arXiv:1406.2374
- Neutron veto for XENONnT
- Veto systems instrumented with photosensors (PMTs)

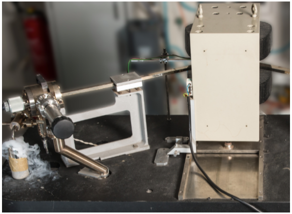
Background suppression



Scheme GeMPI detector

Gas line for Rn measurements

Kr distillation column



RGMS for Kr measurements

- γ-activity: material screening with high purity Ge detectors
  XENON1T, Eur. Phys. J. C 77 (2017) 12, 890 & arXiv:1705.01828
- Selection of low radon emanation: materials using proportional counters
  XENON1T, arXiv: 2009.13981 (2020)
- Krypton in xenon:
  - Cryogenic distillation via a separation column
    XENON1T, Eur. Phys. J. C 77 (2017) 5, 275 & arXiv:1612.04284
  - Measurement of Kr concentration with a rare-gas mass spectrometer
    Lindemann & Simgen, Eur. Phys. J. C 74 (2014) 2746 & arXiv:1308.4806

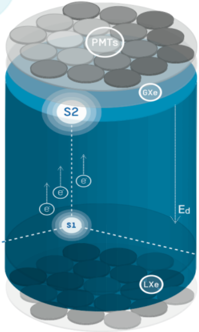
Multi-physics goals in large liquid xenon detectors

Neutrinoless double beta decay

Dark Matter

Supernova neutrinos

Rare processes e.g. DEC



LXe TPC

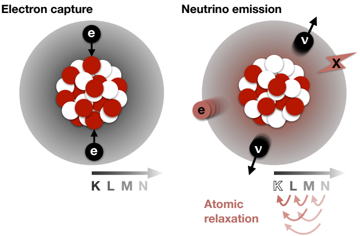
Solar neutrinos

Solar axions

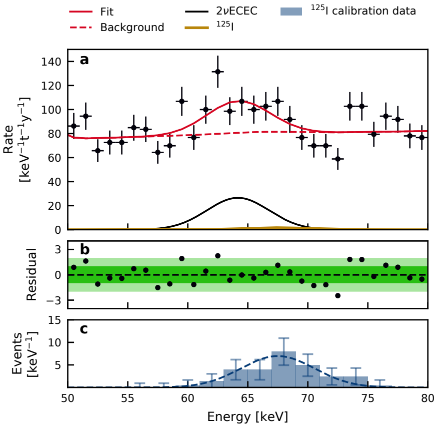
Coherent neutrino-nucleus scattering

Neutrino magnetic moment

^{124}Xe double-electron capture



From XENON1T, Nature 568 (2019) 7753, 532

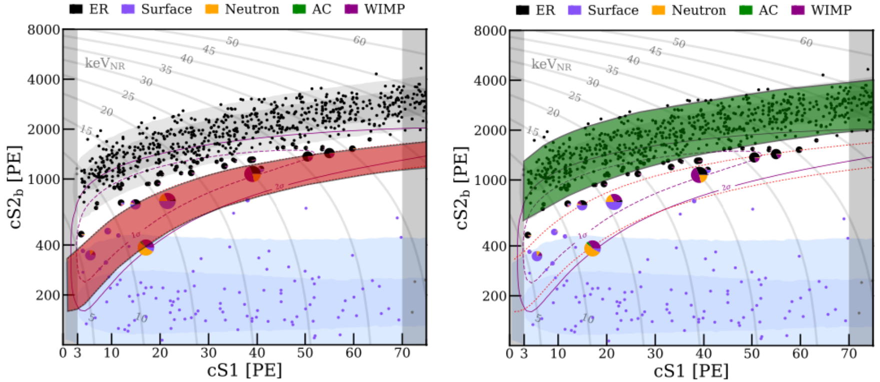


Measured half-life:

$$T^{2\nu\text{ECEC}}_{1/2} = (1.8 \pm 0.5_{\text{stat}} \pm 0.1_{\text{sys}}) \times 10^{22}\ \text{y}$$

→ longest directly measured half-life

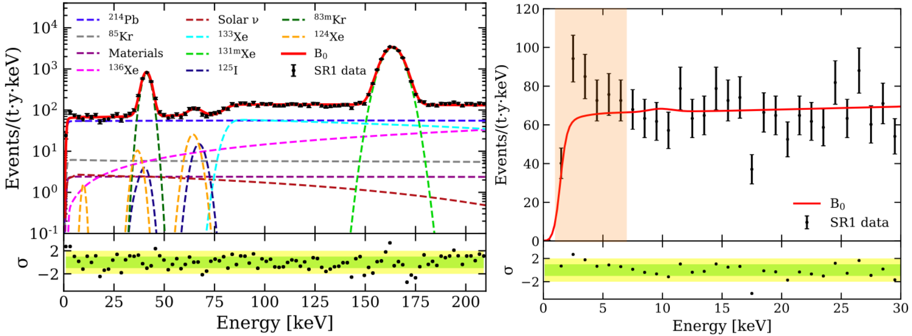
Focussing on electronic recoils



Data from XENON1T, Phys. Rev. Lett. 121 (2018) 111302 & arXiv:1805.12562

- WIMP search: in the NR region with almost zero background
- ER searches: excess events above a known background level

Low energy excess

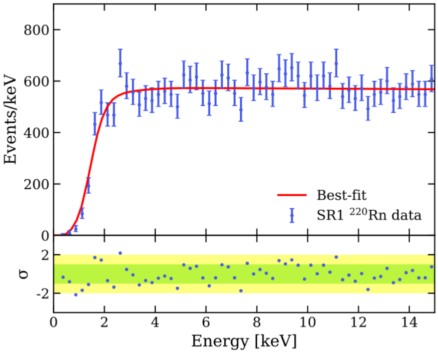


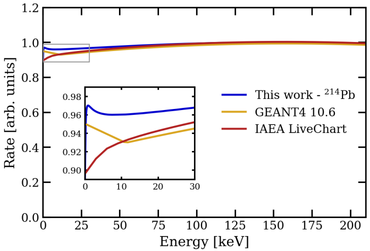
XENON1T, Phys. Rev. D 102 (2020) 072004 & arXiv: 2006.09721

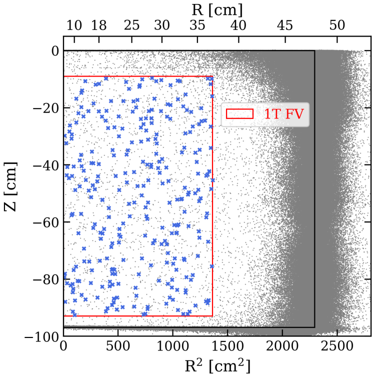
Excess between (1-7) keV

- 285 events observed vs. 232 events expected from best-fit
- 3.3 σ fluctuation → naive estimation (we actually use a likelihood)
- Great resonance in the community (> 160 citations since June)
- Data released in `https://zenodo.org/record/3924406`

Analysis checks

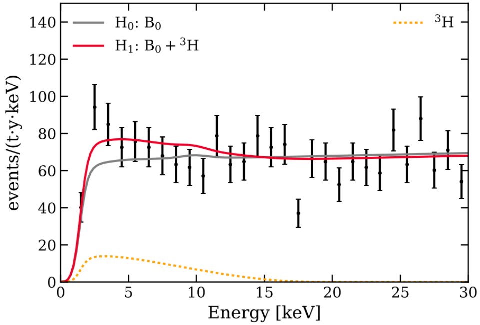




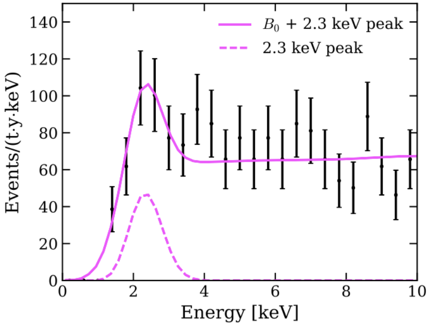


- Validation of efficiency and energy reconstruction
- Shape of the background spectrum
- Uniform distribution in the volume
- Uniform distribution in time ...

A new background?



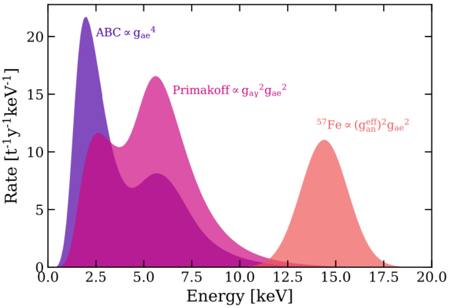
Test of the tritium hypothesis



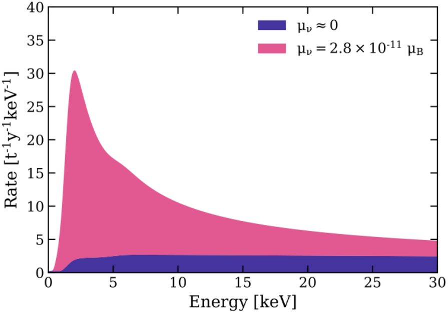
Test of monoenergetic signal hypothesis

- Tritium favoured over background-only at **3.2** σ
  - Tiny concentration ($<$ 3 atoms per kg of xenon)
  - Unclear origin → cosmogenic activation and from natural abundance unlikely
- ^{37}Ar: argon in xenon is strongly reduced by cryogenic distillation
  - Leak hypothesis or in-situ production ruled out

A signal of new physics?



Solar axion signal



Neutrino magnetic moment signature

- Solar axion hypothesis favoured over background-only at **3.4** σ
  - In strong tension with astrophysical constrains from stellar cooling (see for instance arXiv:2003.01100)
- Neutrino magnetic moment favoured at **3.2** σ
  - Magnetic moment: $\mu_\nu \in (1.4, 2.9) \times 10^{-11} \mu_B$ at 90% CL
  - In tension with astrophysical constraints (arXiv:1910.10568 & arXiv:1907.00115)

XENONnT

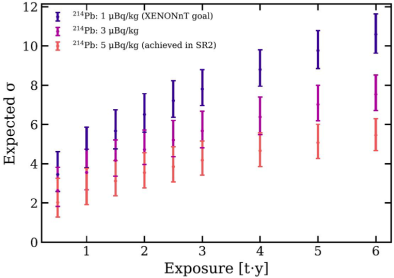
TPC installed underground

x3 — Active volume

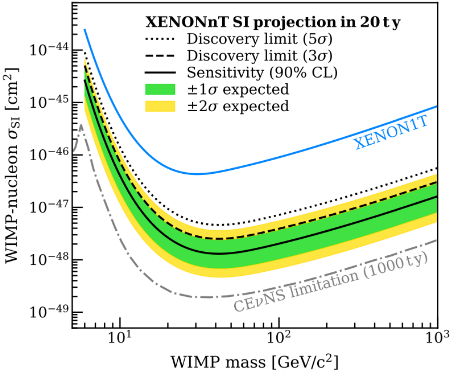
1/6 — Background

Under commissioning

- XENONnT is coming soon!!!
- Able to discriminate axions from tritium with ~ few months of data



XENONnT

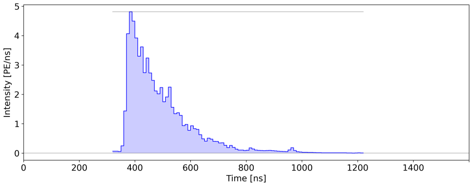


- Aim to measure WIMPs soon ☺

  → Figure from XENON1T JCAP11 (2020) 031 & arXiv:2007.08796

- Commissioning of subsystems being finalized

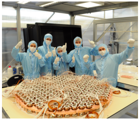
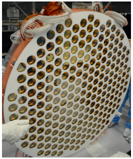
- TPC commissioning on-going

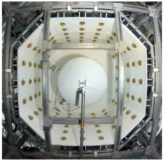
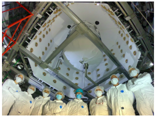


PRELIMINARY: XENONnT S1 waveform in xenon gas

Summary

- XENON1T: largest detector with lowest background rate to date
- Best sensitivities for WIMP searches reached
- Excess of ER events at lowest energies
- New background sources being investigated
- Eventually first sign of new physics
- XENONnT is being commissioned!

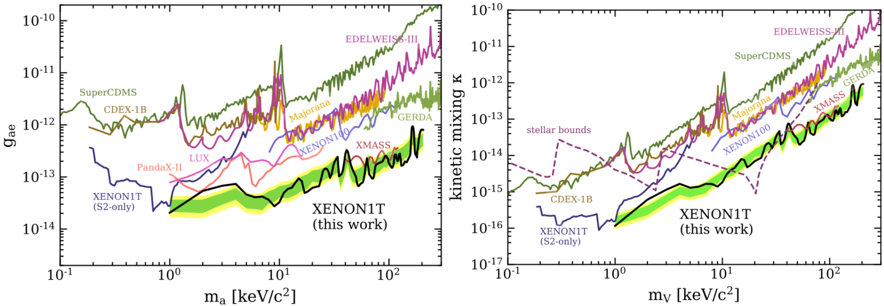



Peak-like searches

No global significance over 3 σ under the BG model B_0

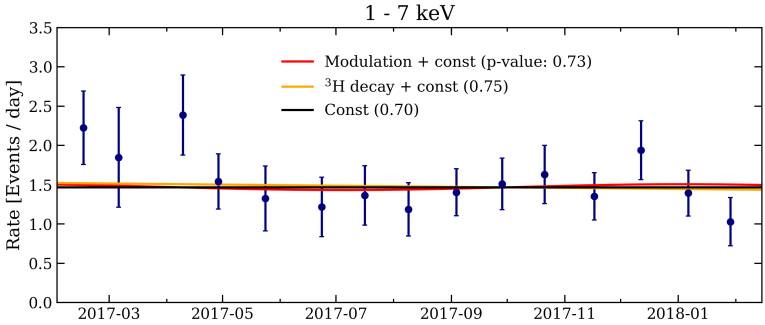
- Axion-like particles (ALPs) are viable DM candidates
- ALPs would be absorbed in XENON1T via axio-electric effect
- Best exclusion limits for bosonic dark matter



Axion-like particles

Dark photons

Time evolution of the excess



PRELIMINARY

Three statistical tests applied to the $(1 - 7)$ keV data points:

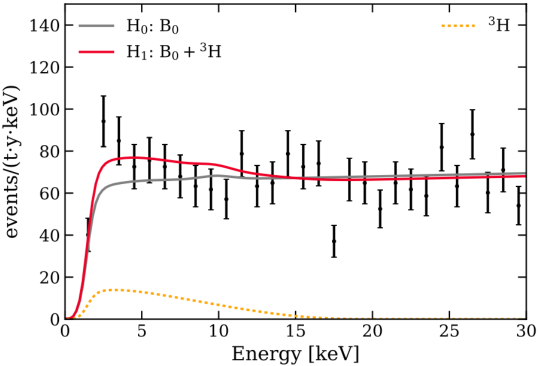
- Modulation due to Earth-Sun distance to test solar axion and magnetic moment hypotheses (7% peak to peak with fixed phase)
- An exponential decay with the tritium decay time
- A **constant** background rate.

→ All three tests agree with the data

Tritium hypothesis

Can the signal originate from tritium decays in the LXe?

- Q-value at 18.6 keV and long half life of 12.3 years

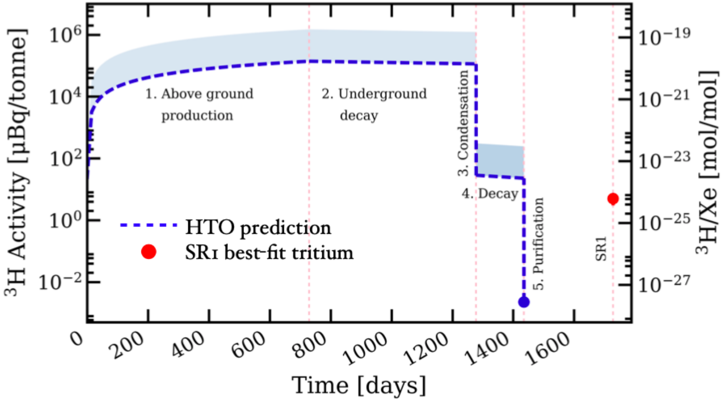


Tritium favored over background-only hypothesis at 3.2 σ

- Fitted tritium rate: (159 ± 51) events/(t·y·keV)
- Tritium/Xe concentration: $(6.2 \pm 2.0) \times 10^{-25}$ mol/mol

  → fewer than 3 tritium atoms per kg of xenon!

Tritium from cosmogenic activation in xenon



Tritiated water (HTO) formed in the xenon bottles

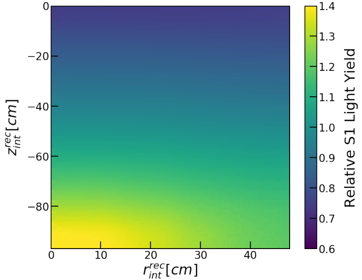
- Activation above ground: ~ 32 tritium atoms/kg/day (Zhang 2016)
- 1 ppm water in the bottles but 99.99% removal (SAES getter)
  → dedicated hydrogen removal unit in the purification system

Predicted rate **100x lower** than observation → unlikely explanation

Tritium from natural abundance

Question: Excess from natural abundance of tritium in H_2O and/or H_2?

Assumed tritium abundance in H_2 and H_2O: $(5 - 10) \times 10^{-18}$ mol/mol



- H_2O absorb UV-photons
- Amount of H_2O based on light yield measurement: $O(ppb)$
- $(30 - 60)$ *ppb* to explain the excess

  → **HTO** emanation seems unlikely

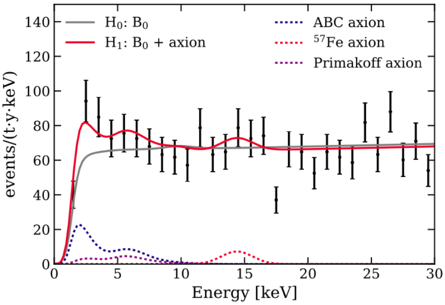
- Good electron lifetime indicates $O(0.1\,ppb)$ O_2-equivalent impurities
- Excess would require 100× more H_2 than other molecules

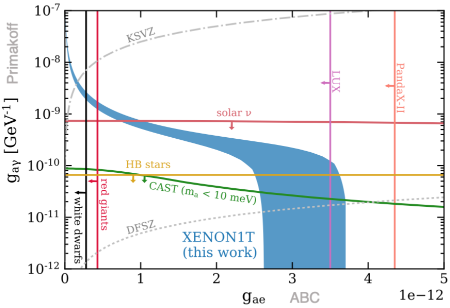
  → **HT** emanation can not be confirmed or excluded: unclear

Many unknowns around tritium in LXe

→ considered as a hypothesis, not in background model

Solar axion hypothesis





Axion hypothesis favoured at 3.4 σ

- Search for ABC, Primakoff and ^{57}Fe axions simultaneously
- Fit of ABC alone increases the significance slightly

  Axion + tritium hypothesis favoured over tritium-only at 2.0 σ

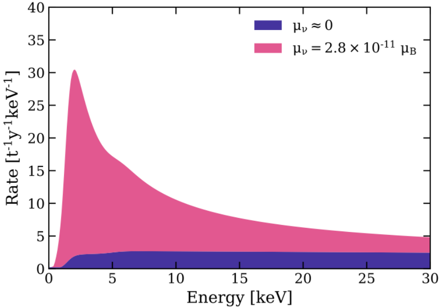
- In strong tension with astrophysical constraints from stellar cooling

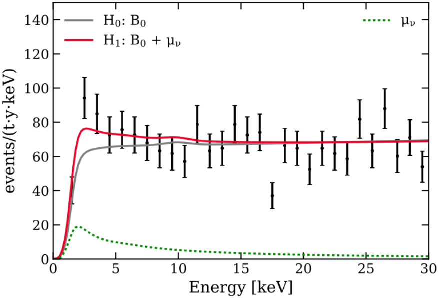
  (see for instance arXiv:2003.01100)

Neutrino magnetic moment

Neutrinos acquire magnetic moment in extensions of the SM

- Source: neutrinos from the Sun (mostly from pp-reactions)
- Reaction: elastic scattering off electrons



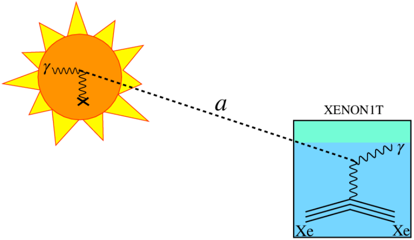


Neutrino magnetic moment hypothesis favored at 3.2 σ

- Significance down to 0.9 σ if tritium is included in the BG model

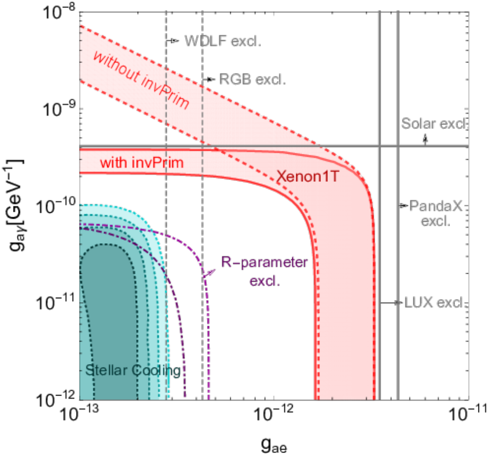
Inverse Primakoff effect

Inverse Primakoff effect: additional detection channel



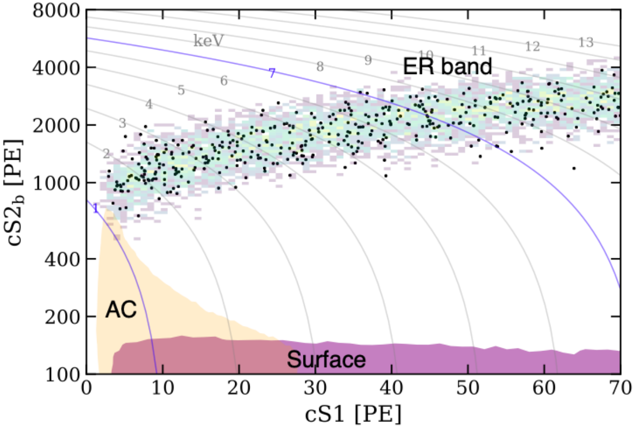
Schematics from C. Gao et al, arXiv:2006.14598

- Tension with astrophysical constrains is somewhat alleviated



Result from C. Gao et al, arXiv:2006.14598
Similar conclusion in Dent et al., arXiv:2006.15118

Instrumental backgrounds?



Verification of other background populations to the R.O.I.

- Negligible amount of accidental coincidences (AC)
- No surface background in the 1T analysis volume