MAX-PLANCK-INSTITUT FÜR KERNPHYSIK HEIDELBERG

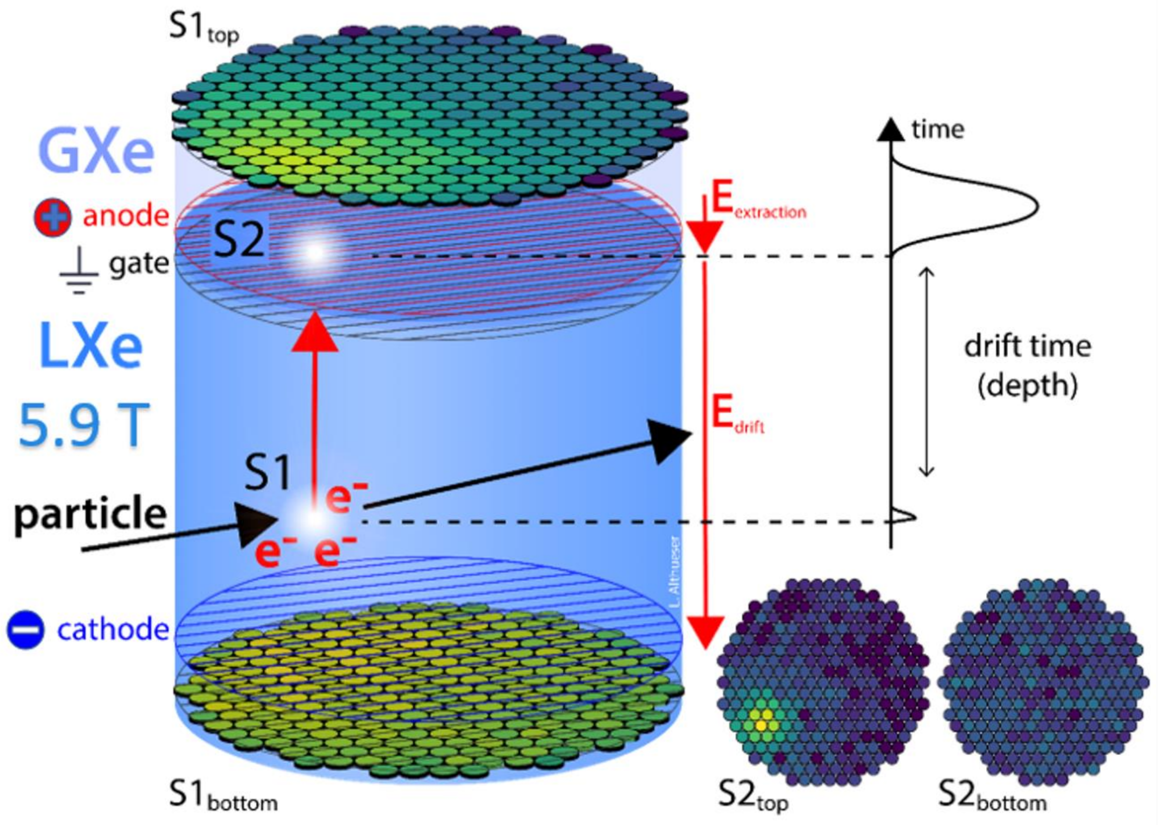
XENONnT Calibration of Low Energy Electronic Recoil Response with ^{37}Ar

Matteo Guida on behalf of the XENON Collaboration

Invisibles 22 Workshop 21.06.2022

The XENONnT Experiment

❖ Time projection chamber (TPC) operating underground in Italy at INFN's Laboratori Nazionali del Gran Sasso (LNGS).



❖ **S1 SIGNAL**
prompt scintillation photons

❖ **S2 SIGNAL**
secondary scintillation photons from electroluminescence in GXe due to drifted electrons

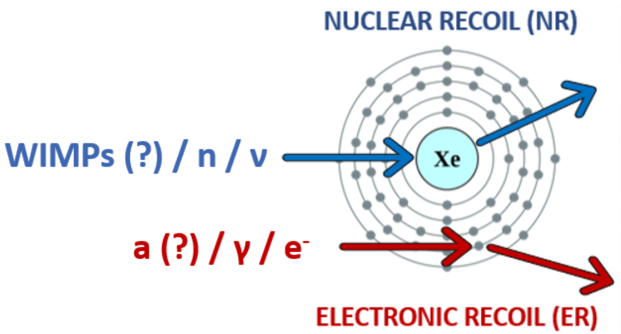
❖ **3D VERTEX RECONSTRUCTION**
X,Y: S2 hit pattern in the top PMT array
Z: drift time S2-S1

XENONnT EXPERIMENT

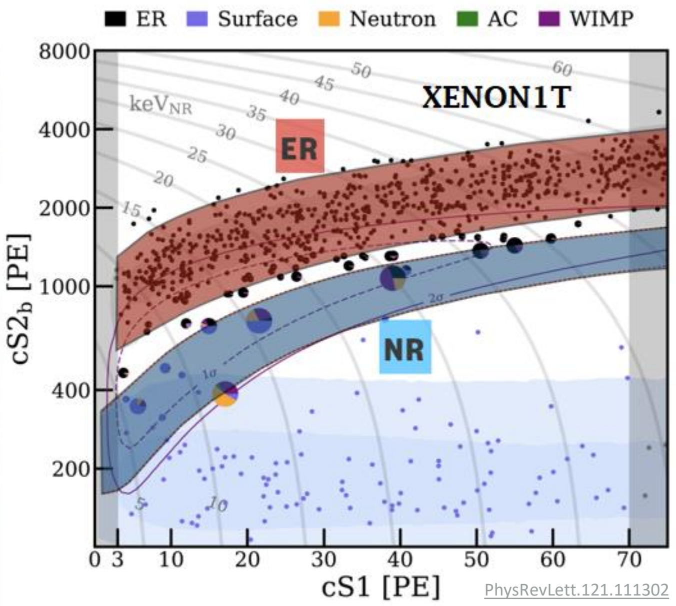
^{37}AR CALIBRATION

XENON

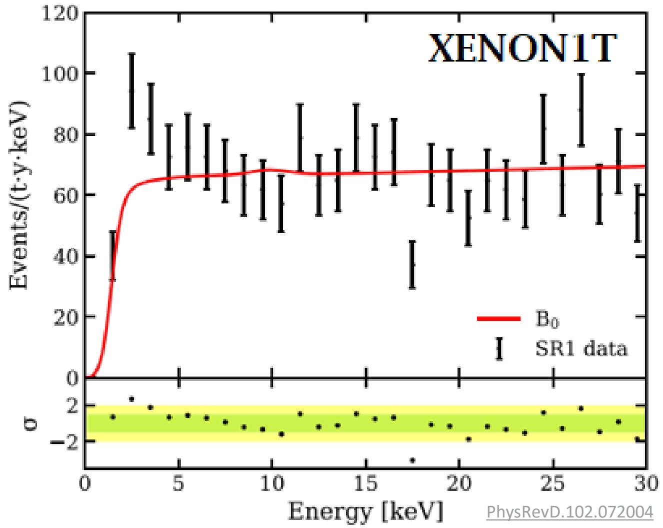
Electronic and Nuclear Recoil Interactions



ER Band	NR Band
Axion-like particles Dark photons ν magnetic moment & more	SI WIMPs SD WIMPs Sub-GeV DM & more



- Background events are well understood in the ER/NR bands so *excesses* can be searched on top of them.
- XENON1T found an unexpected 3.3σ Poissonian excess between (1-7) keV.
- Origin ***not clear***:
  - new background component
  - statistical fluctuation
  - new physics signature



XENONnT EXPERIMENT

^{37}AR CALIBRATION

XENON

^{37}Ar Low Energy ER Calibration

- ^{37}Ar calibration performed for the first time in 2018 at the end of XENON1T and repeated in XENONnT ***after the first science data taking***.

	Energy	Probability
K-shell	**2.8224 keV**	90.21%
L-shell	0.2702 keV	8.72%
M-shell	0.0175 keV	1.06%

- ^{37}Ar decays into ^{37}Cl by **electron capture** (100%)
  $T_{1/2} \simeq 35$ days (removed with online cryogenic distillation column).

- Emission of Auger electrons and X-rays producing ERs at very low energy, detected as a single monoenergetic signal.

- **Internal source** diluted in liquid xenon, all the active volume is *probed uniformly*.

- An additional calibration line in the energy range of interest complementary to continuous β spectra.

^{37}Ar Charge Yield and Light Analysis

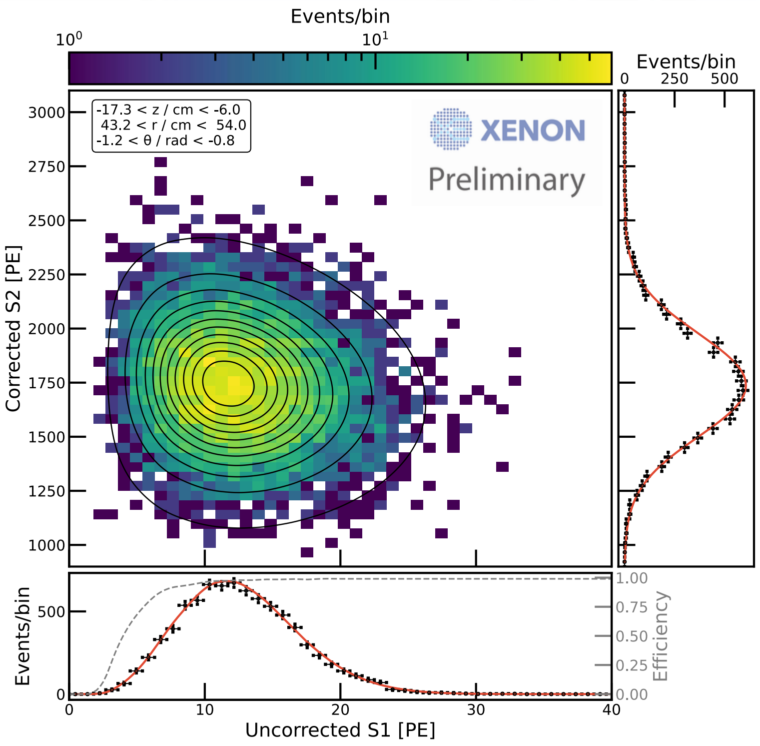
^{37}Ar K-shell peak
charge yield and *light yield*

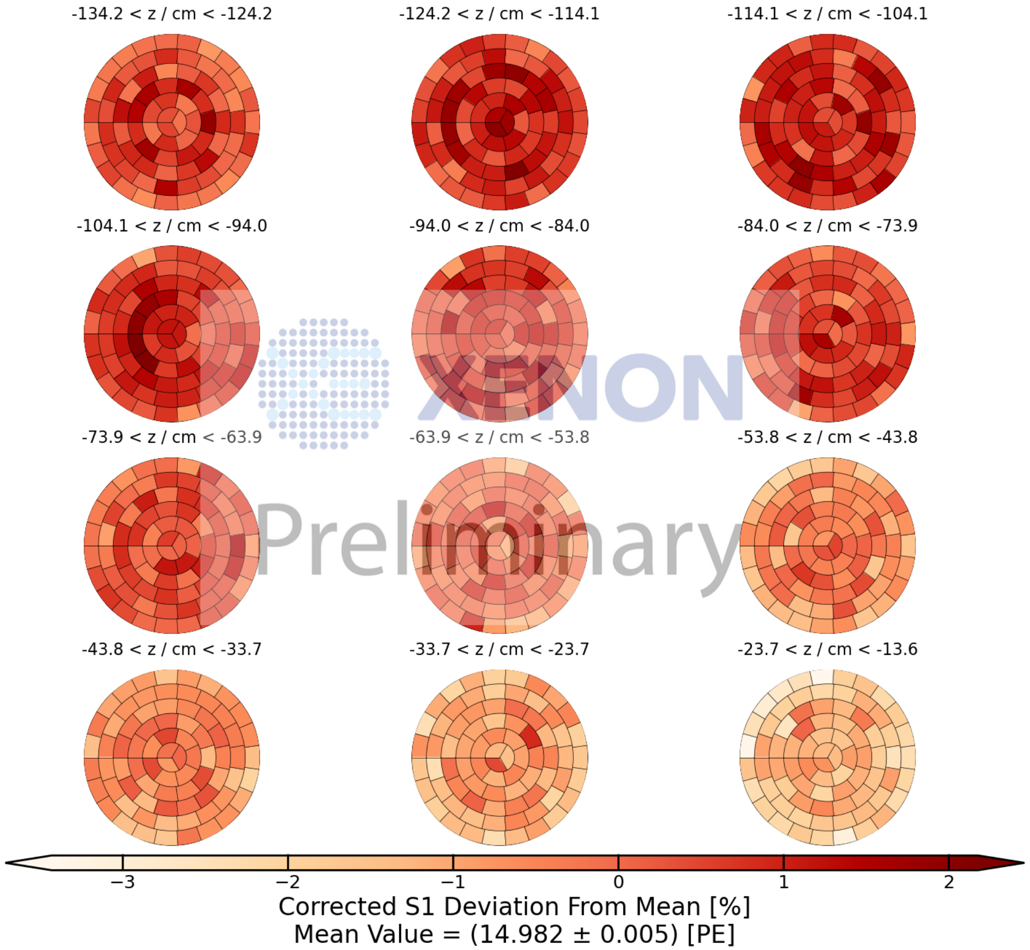
→

dedicated spatial dependent analysis:
TPC volume divided in equivolume bins (voxels)

→

to properly take into account S1 detection efficiency





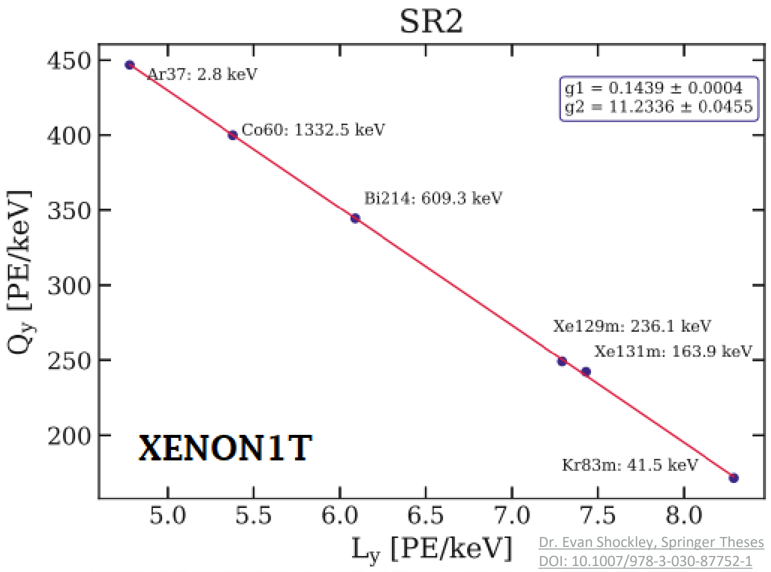
XENONnT EXPERIMENT

^{37}AR CALIBRATION

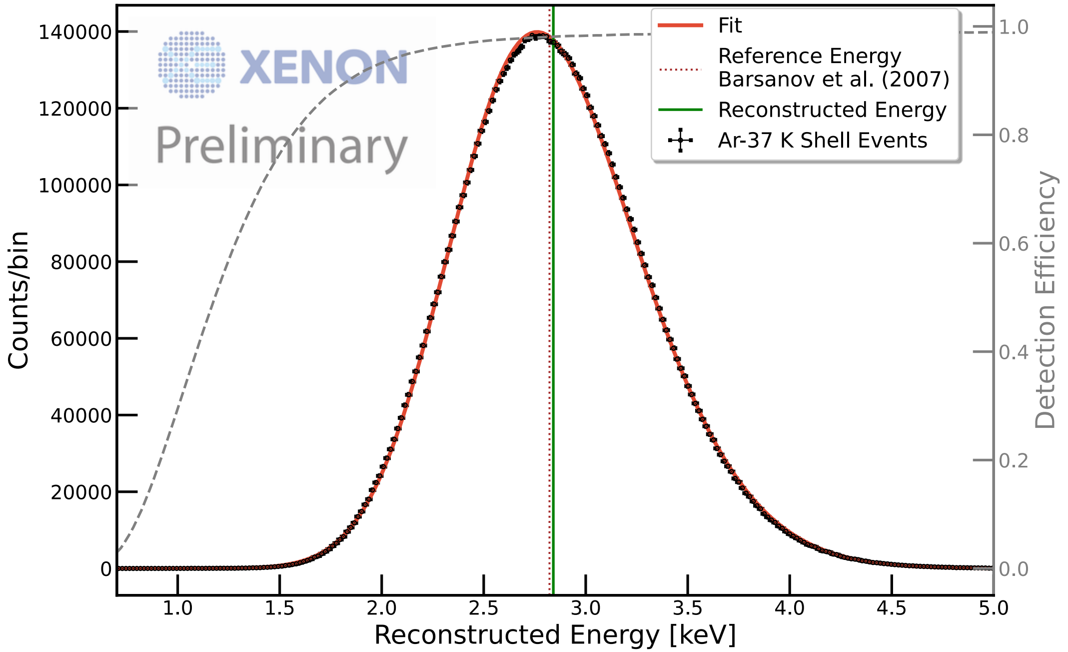
XENON

Low Energy Reconstruction with ^{37}Ar

- To reconstruct the energy of each event corrected $S1 \propto n_{ph}$ and corrected $S2 \propto n_e$ are combined.
- Check anti-correlation between light and charge with different calibration data.
- Powerful check to exclude an energy dependent response of the detector.



Dr. Evan Shockley, Springer Theses
DOI: 10.1007/978-3-030-87752-1



✔ Noteworthy energy reconstruction of the ^{37}Ar K-shell peak with energy resolution ~ 17 %.

↓

Analysis framework almost ready to ***unblind*** low energy ER band.

XENONnT EXPERIMENT

^{37}AR CALIBRATION

XENON

FIRST XENONnT RESULTS COMING VERY SOON
STAY TUNED!

Photo credit: **Luigi Di Carlo for the XENON Collaboration**

BACKUP SLIDES

Energy Scale Calibration

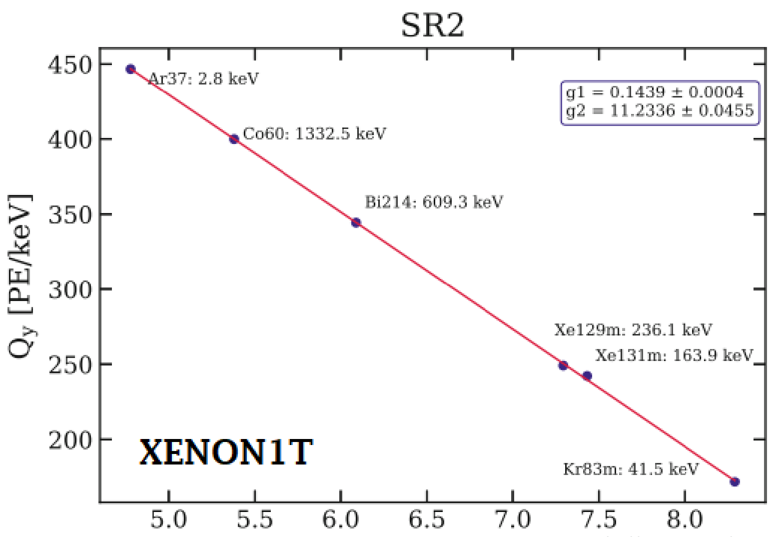
- To reconstruct the energy of each event $S1 \propto n_{ph}$ and $S2 \propto n_e$ are combined.

$$E = W \cdot \left(\frac{S1}{g_1} + \frac{S2}{g_2}\right)$$

$W \simeq 11.5$ eV/quanta, average energy required to create one “quantum” (photon or electron).

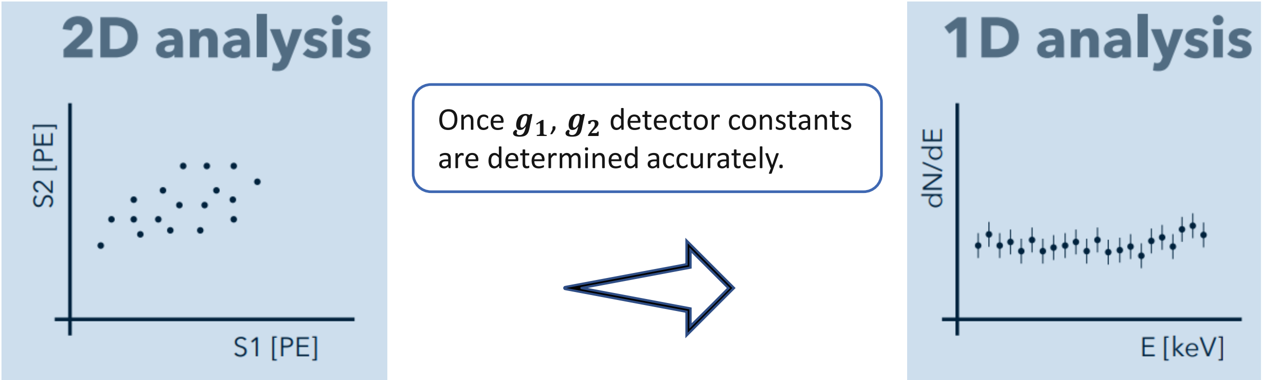
g_1: *photon detection efficiency*: number of observed photoelectrons [PE] per scintillation photon produced.

g_2: *electron detection efficiency* : number of observed photoelectrons per electron produced.



Dr. Evan Shockley, Springer Theses
DOI: 10.1007/978-3-030-87752-1

- Powerful check to exclude an energy dependent response of the detector.



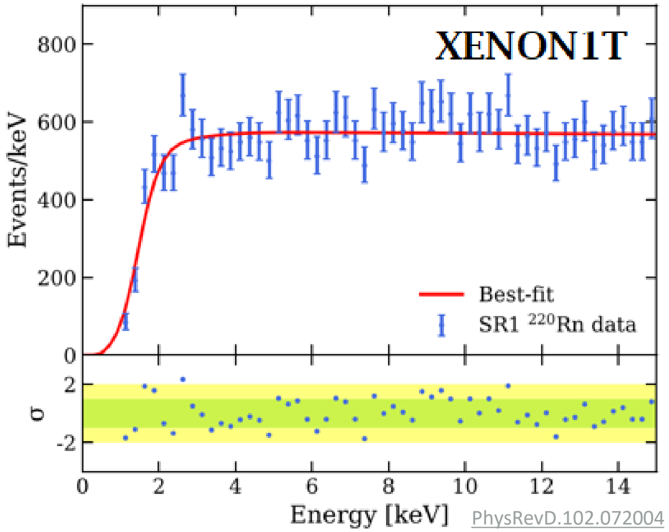
XENONnT EXPERIMENT

XENON

The Origin of the Excess

- ❖ The origin of the excess is **UNCLEAR**.

✓ Energy reconstruction and efficiency is properly working looking at β-decay spectrum from ^{220}Rn calibration data.



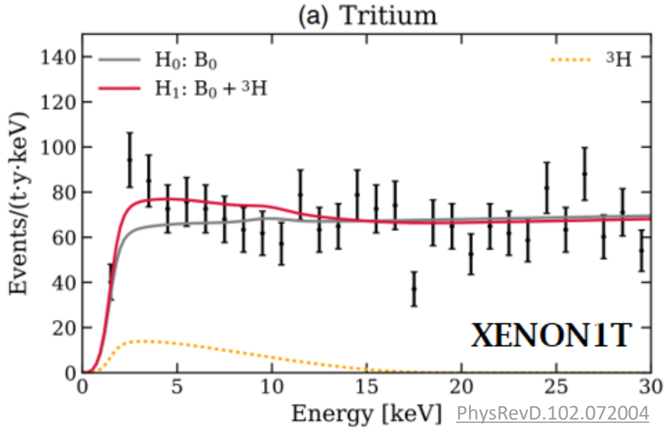
- ❖ One background option: β-decay from **TRITIUM ^{3}H** ($T_{1/2} \simeq 12.3$ y | Q-value = 18.6 keV).

- ❖ Tritium was never considered in the background model of a LXe-TPC analyses before.

- ❖ To fit the data required a concentration ^{3}H/Xe of:

$(6.2 \pm 2.0) \times 10^{-25}$ mol/mol < 3 ^{3}H atoms per kg of LXe.

- ❖ This tiny quantity **cannot** be measured from a sample.



Tritium favoured over background-only at 3.2 σ.

1T RESULTS

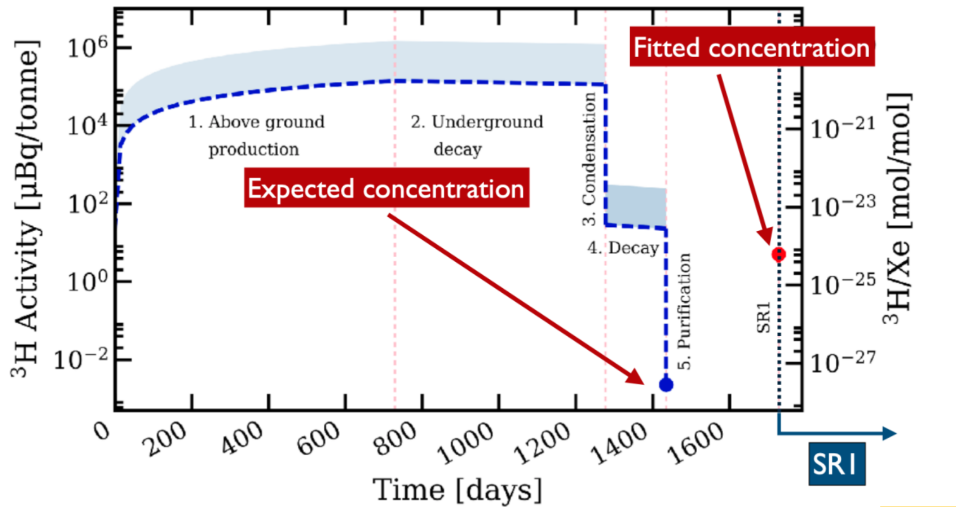
XENON

The Tritium Hypothesis

UNLIKELY

Cosmogenic activation of Xe

- Production of radioactive isotopes due to exposure to cosmic rays mainly above surface and marginally underground.
- Primarily HTO vapour which should condense on the walls of the cold storage vessel.
- Efficiently removed by the getters.



MAYBE ?

Natural abundance in materials

- HTO concentration in H_2O (assumed the same for HT) :

$$(5-10)\times 10^{-18}\ \text{mol/mol}$$

- To explain the excess would be necessary a concentration:

$$(H_2O + H_2) : (60-120)\ \text{ppb}$$

- Possible presence inside materials such as TPC reflectors and the stainless steel of the cryostat.
- HTO affects optical transparency as water impurities:

$$\text{from light yield} < O(1)\ \text{ppb}$$

- H_2 emanation rate cannot be excluded: **but** it should be $\times$ 100 higher than electronegative impurities in the detector.

1T RESULTS

XENON

Why is ^{37}Ar not the Explanation for Excess?

- Based on the fit, to account for the excess, the required ^{37}Ar rate is ~ 65 events/(t · y).
- Origins of eventual traces of ^{37}Ar:
  - initial amount in the xenon gas
  - air leak during operation of the detector.

EXCLUDED

Initial amount in the xenon gas

- From the measured concentration in the xenon inventory and the time of data taking beginning: rate is ~ 0.6 events/(t · y).
- Higher volatility of argon compared to xenon allows removal via online and offline **cryogenic distillation**, *difference with LZ*.
- It constantly removes ^{37}Ar from the gaseous phase.
  - Reduction of an order of magnitude every ~ 4 days
  - X 25 faster than natural decay
- More than 90 days of online distillation occurring in the early days of XENON1T, any initial ^{37}Ar activity **was further suppressed** by a factor of ~ 10^{-20}.

EXCLUDED

Air leak during operation of the detector.

- From routinely measurement of krypton concentration using rare gas mass spectrometry (RGMS) an hypothetical air leak can be constrained.
- Measured a tiny increase in the concentration of krypton of ~ 1 ppt/year over the course of XENON1T SR1, conservatively assumed entirely due to air leak.
- Conservative upper limit on the ^{37}Ar rate of 5 events/(t · y).

XENON