The Gd-loaded Neutron Veto of XENONnT experiment

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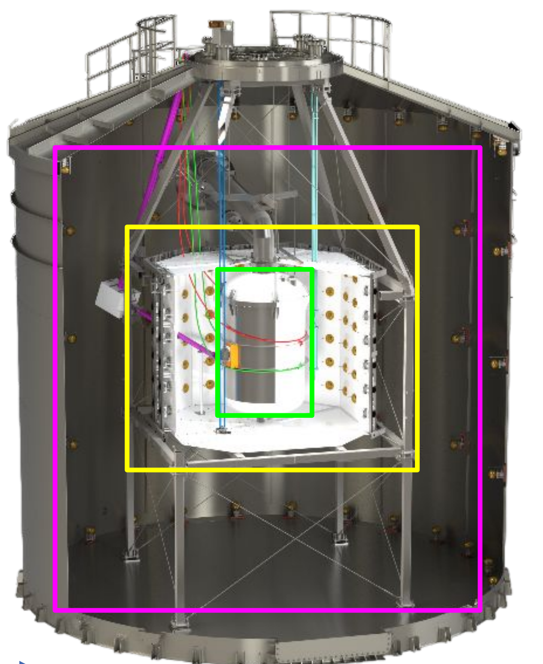
The XENON Project

XENON10	XENON100	XENON1T	XENONnT
25 kg	161 kg	3.2 t	8.5 t
2005	2008	2016	2020

Direct search for dark matter with **liquid xenon (LXe)** deep underground at **Laboratori Nazionali del Gran Sasso**, Italy.



Dual phase Xe Time Projection Chamber

5.9 t active target mass, **8.5 t total** mass

1.5 m drift length, **1.3 m** diameter

494 Hamamatsu 3'' **PMTs**

TPC

(Gd-)Water Cherenkov Neutron Veto

High reflectivity expanded **PTFE**

33 m³ volume around cryostat

120 8'' high QE **PMTs**

nVeto

(Gd-)Water Cherenkov Muon Veto

700 t water, **84** 8'' high QE **PMTs**

Active veto against **muon**-induced **neutrons** (n)

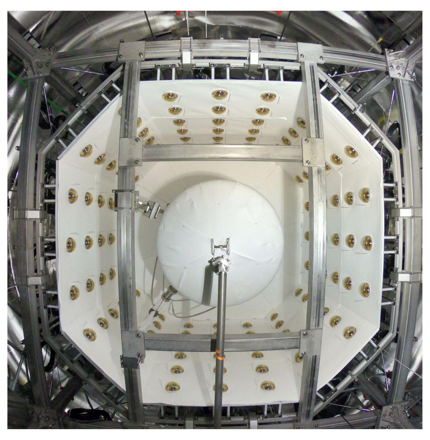
Passive veto against **γ** and **n** from **natural radioactivity**

mVeto

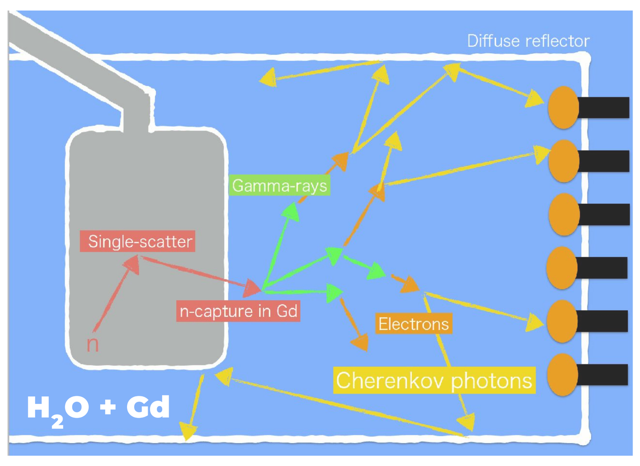
The XENONnT Neutron Veto

Neutrons emitted from **materials** (radiogenic) scatter off LXe atoms in **TPC**, inducing **Nuclear Recoils** (NR), like Weakly Interacting Massive Particle **(WIMPs).**

Neutron **capture** on **H** or **Gd** nuclei, with emission of **~ MeV photons.**



Neutron Veto (NV) designed for **otherwise irreducible background**



Photons make **Compton scattering** off **electrons**, which emit **Cherenkov** light, detected by **PhotoMultiplier Tubes** (PMTs).

Large light collection **efficiency** with **high-reflectivity ePTFE** (expanded Polytetrafluoroethylene).

First Science **Run (SR0)** with **demineralized water** in **Water Tank (WT)**

Neutron Background

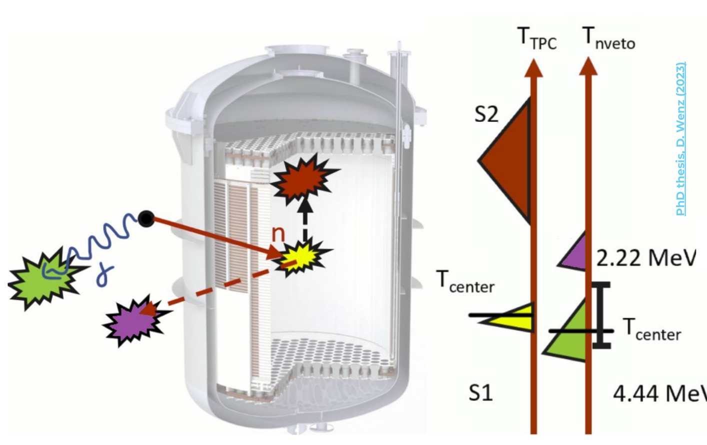
Neutrons tagged if **second interaction** observed, otherwise **indistinguishable** from **WIMPs.** With new **reduction** techniques, **electronic recoil (ER) background** comparable to **neutrons** in **signal- like** region.

SRO, NV cut applied	Nominal ROI	Best fit ROI	Best fit Signal-like
ER	134	135^{+12}_{-11}	0.92 ± 0.08
Neutrons	$1.1^{+0.6}_{-0.5}$	1.1 ± 0.4	0.42 ± 0.16
CEνNS	0.23 ± 0.06	0.23 ± 0.06	0.022 ± 0.006
AC	4.3 ± 0.9	$4.4^{+0.9}_{-0.8}$	0.32 ± 0.06
Surface	14 ± 3	12 ± 2	0.35 ± 0.07
Total background	154	152 ± 12	$2.03^{+0.17}_{-0.15}$
WIMP	…	2.6	1.3
Observed	…	152	3

Neutron calibration with AmBe

AmBe source close to cryostat (**same signature** of radiogenic **neutrons**):

- **4.4 MeV** gamma **(γ) emission** with **neutron** in about **50%** of cases



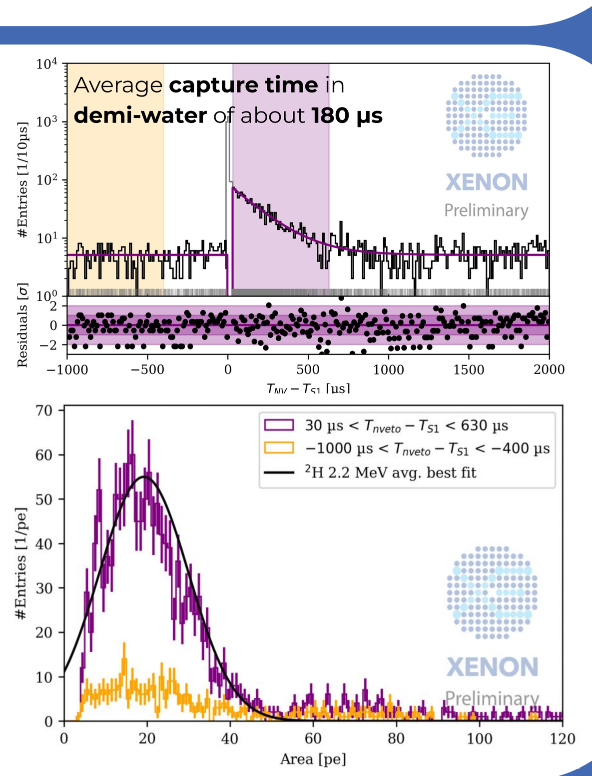
- First **4.4 MeV** γ detected in **NV**, then coincidence requirement for **NR** in **TPC**, hence search for **signals** from **neutron capture** in **NV**

Neutron tagging efficiency: (68 ± 3) % with **600 μs** window at **5-fold** coincidence, **5 PE** threshold

→ **highest** neutron **detection efficiency measured** in a **water Cherenkov** detector

In Science Run 0, **time window** of **250 μs** to **reduce** induced **dead-time:**

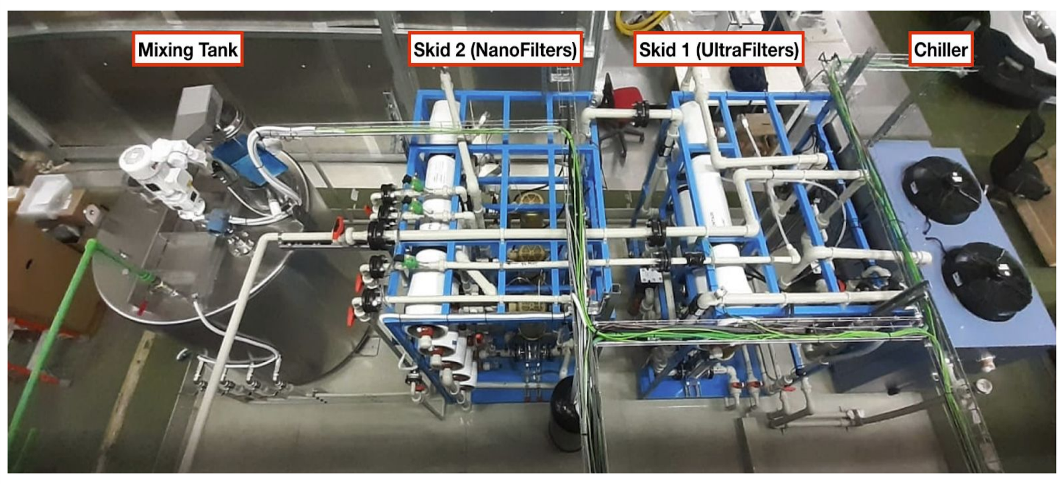
→ **(53 ± 3) %** tagging efficiency with **1.6% livetime loss**



Gadolinium-water Purification System

	Neutron capture cross-section	γ energy	Mean capture time
H	0.33 b	Single γ, 2.2 MeV	200 us
Gd	49000 b	3-4 γ, 8 MeV in total	75 us

Novel **Gd-Water Purification System (GdWPS)** to keep good water conditions **developed** (**EGADS technology**) and **procedure** for **insertion** of **Gd-sulfate (GdSO) tested** in Science Run 2



Gadolinium Sulfate Octahydrate ($Gd_2(SO_4)_3 \cdot 8H_2O$) **injected** into **WT** through GdWPS in various steps

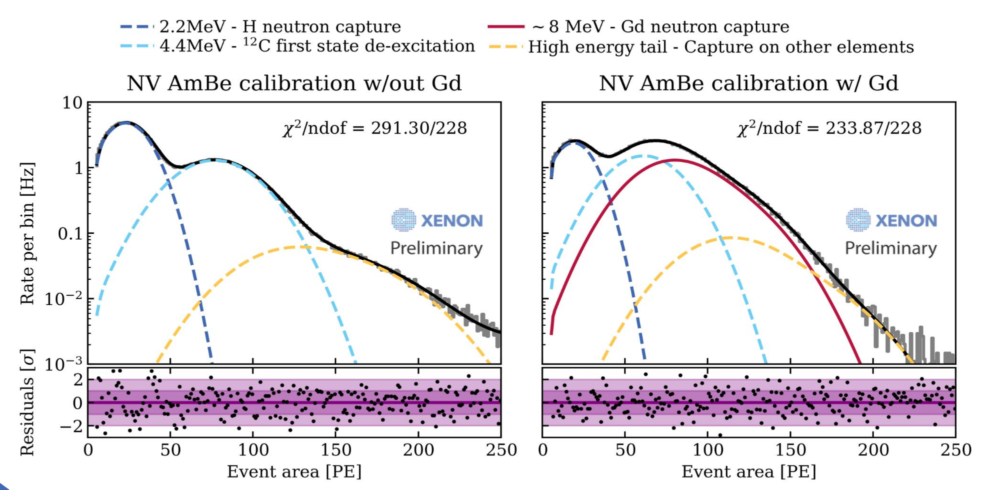
Reached **0.02% Gd mass concentration** with to **350 kg** of GdSO (**500 ppm GdSO**)

Gd-water in Neutron Veto

AmBe source **far** from **cryostat** (**50 cm**) to monitor NV **response** along time, **area spectrum** given by:

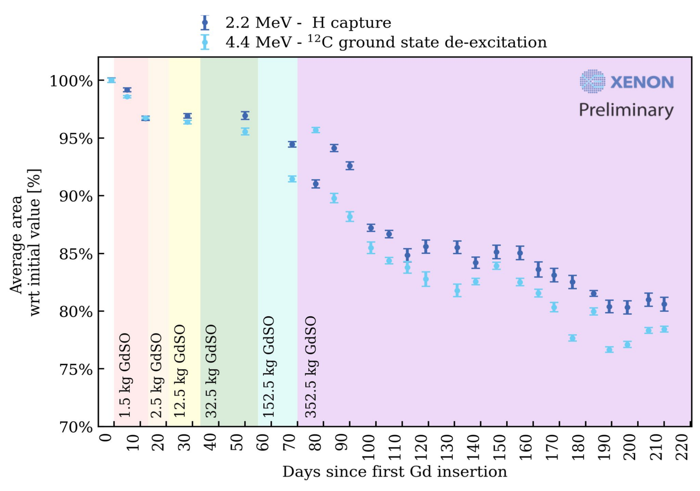
- **2.2 MeV peak** (**H** capture) → **1 Gaussian** with threshold
- **4.4 MeV** peak (**^{12}C de-excitation**) → **1 Gaussian** with threshold
- About **8 MeV** peak (**Gd** capture) → **2 Gaussians** with threshold
- High energy tail (higher level ^{12}C de-excitations or n captures on ^{56}Fe) → 2 Gaussians

Mean area and **amplitude** correspond to **mean collected light** (→ NV **optical properties**) and **neutron captures**.

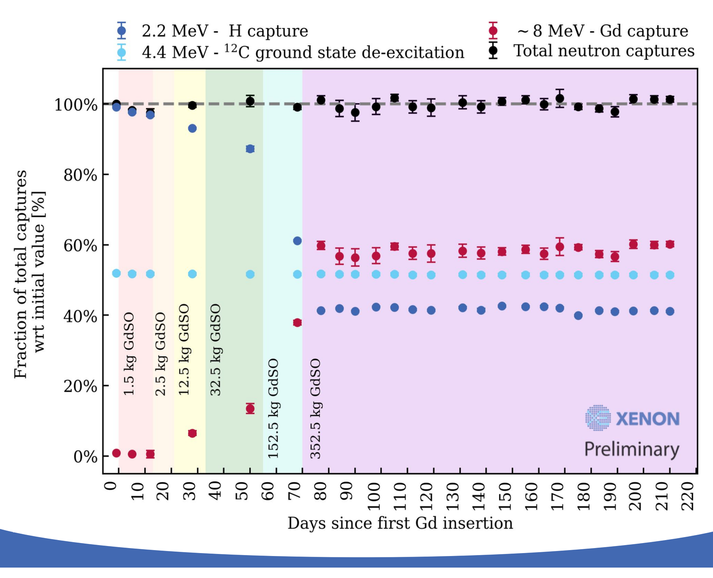


Gd-water in Neutron Veto

Mean collected light, monitored with **periodic** calibrations, reduced by **20%** (→ **4% less H** captures)



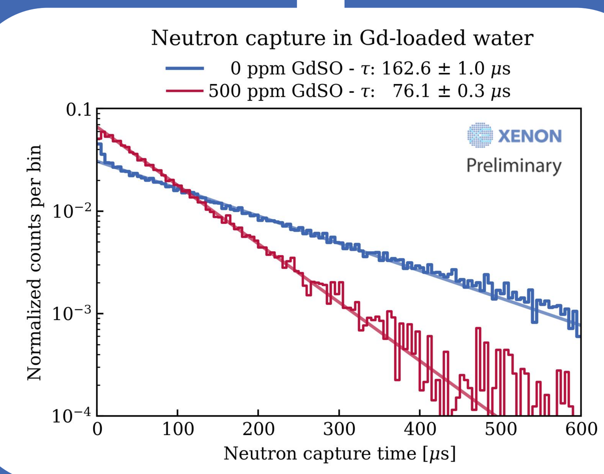
About **60%** of captures **on Gd.** Given the **large** water buffer in this source position, **total number** of **n-capture** does **not change** with Gd

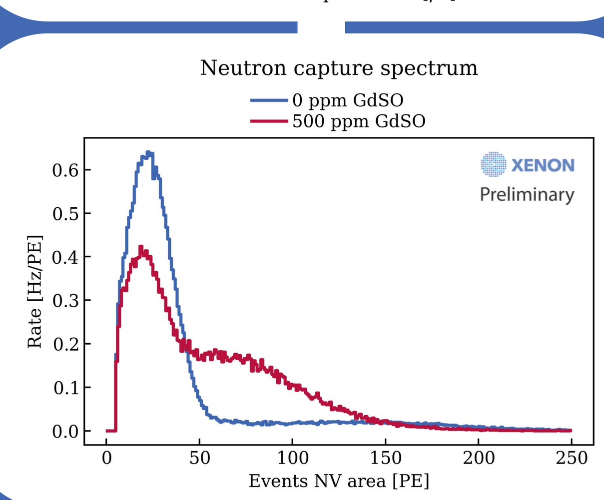


Neutron tagging efficiency with Gd-water

AmBe source **close** to **cryostat** (**~ 1 cm**):

- Neutron **capture time** and **area spectrum estimated** by using **NV** events **following 4.4 MeV** signals from AmBe.
- At 500 ppm GdSO, average **capture time** at **76 μs** (2x **shorter** than **demi-water**) and **larger** average **area**, with **10% increase** in **captures**.

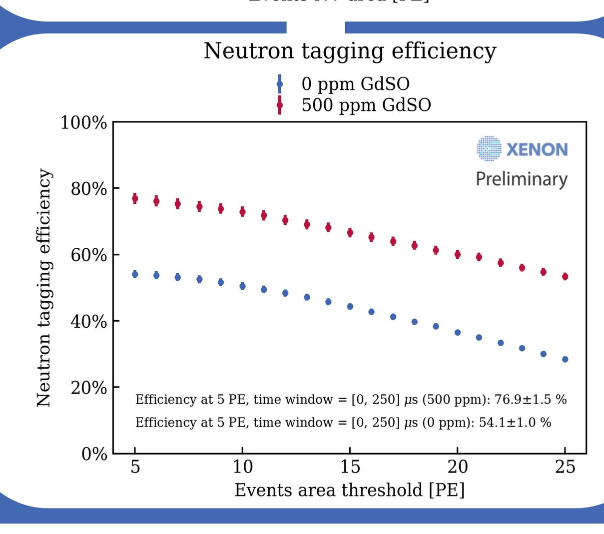




Neutron tagging efficiency estimated by requiring **coincidence** with **NR** in the **TPC:**

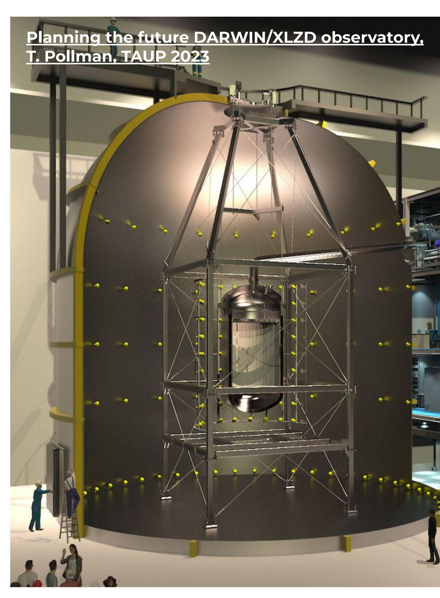
→ About **77%**, with **500 ppm** of GdSO and **250 us** time-window

→ **2x** neutron **background reduction** wrt SR0 with demi water



Future perspective

- Planned **XENONnT** nVeto with **3.5 t** of **GdSO** (**0.2 % Gd mass concentration**), with **tagging efficiency** at **87%**
- **Neutron background** will be **further reduced** by **factor 3** wrt to SR0
- **Gd-loaded water** technology can be effectively **employed** for **next-generation** LXe detector



Dual-phase Xe TPC with **~60** t of active **LXe**, from the **joint** efforts of **XENON**, LZ and **DARWIN** into **XLZD consortium**.

Neutron background **reduction** crucial for a **multi-purpose observatory** for **dark matter, neutrino** and **rare events**.