The XENONnT Neutron Veto: Performance in the Gd-doped phase

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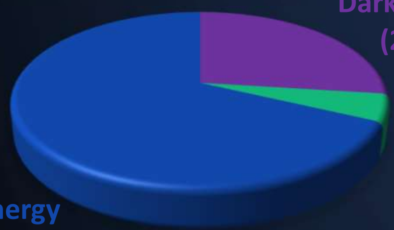
Dark Matter

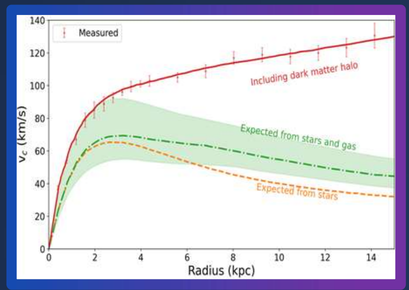
% IN UNIVERSE

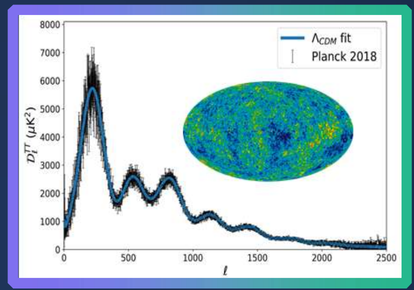


Evidences

Astronomical and Cosmological

- Galactic Rotation Curve
- Large Scale Structure
- CMB
- Gravitational Lensing
- Bullet Cluster





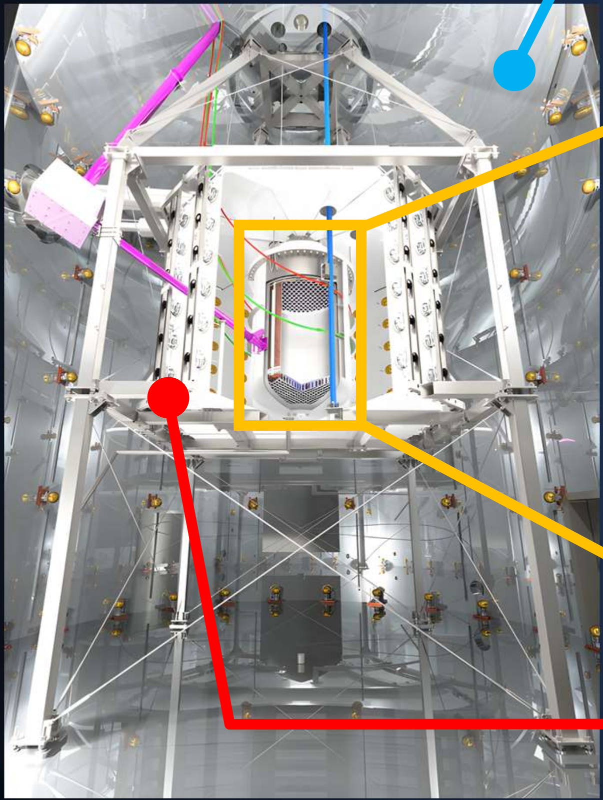
Candidates

- Sterile Neutrinos
- Axions
- Weakly Interacting Massive Particles (WIMPs)
- Light Dark Matter (SubGeV DM)
- Dark Photon

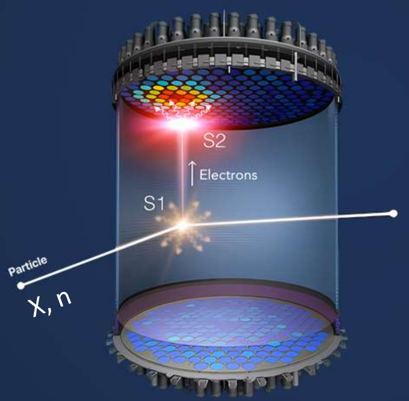
10^{-22} eV — keV — GeV — 100 TeV — M_{Planck} — 10 M_O

XENONnT experiment

The XENON Dark Matter project aims at the DIRECT DETECTION of dark matter with Liquid Xenon deep underground at the INFN Laboratori Nazionali del Gran Sasso, Italy. It is operational since 2020, with 6 t of LXe inside the TPC.



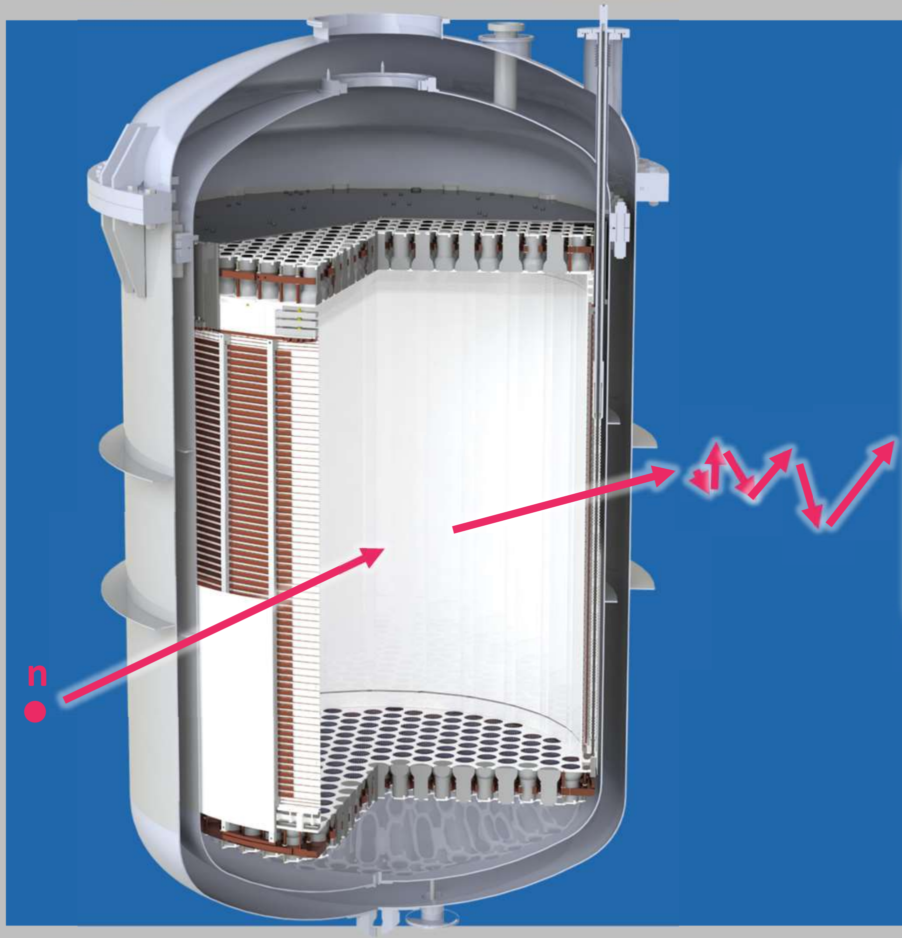
Dual Phase LXe TPC



Muon Veto

Neutron Veto

Neutron Veto

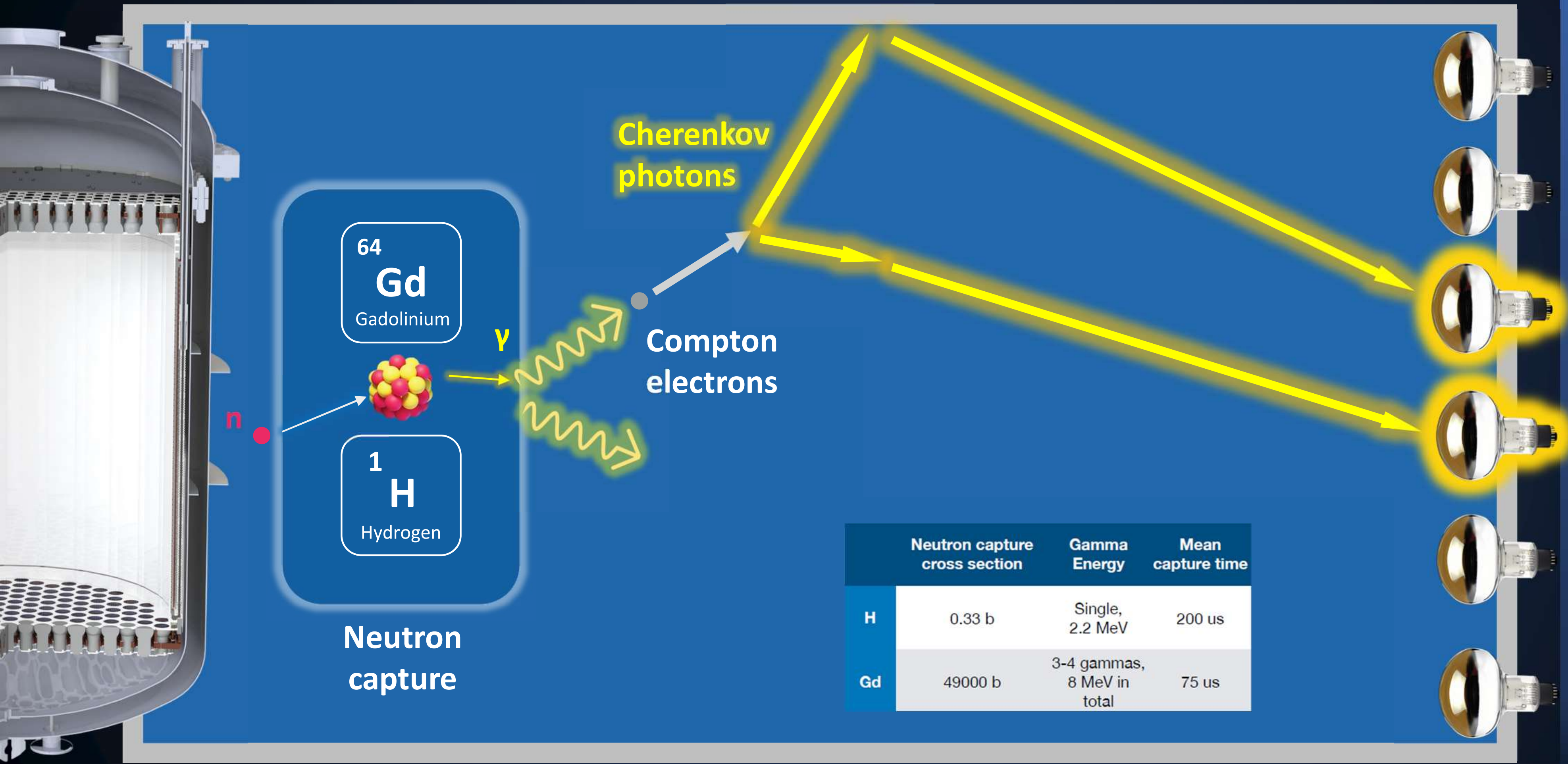


64
Gd
Gadolinium

1
H
Hydrogen

Gd-loaded water Cherenkov detector instrumented with 120 PMTs.
Optically separated from the Muon Veto with high-reflectivity ePTFE panels.

Neutron Veto working principle



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

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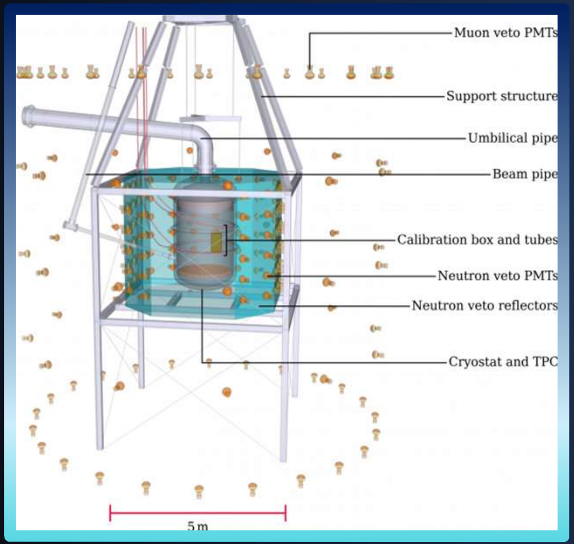
XENONnT modelization

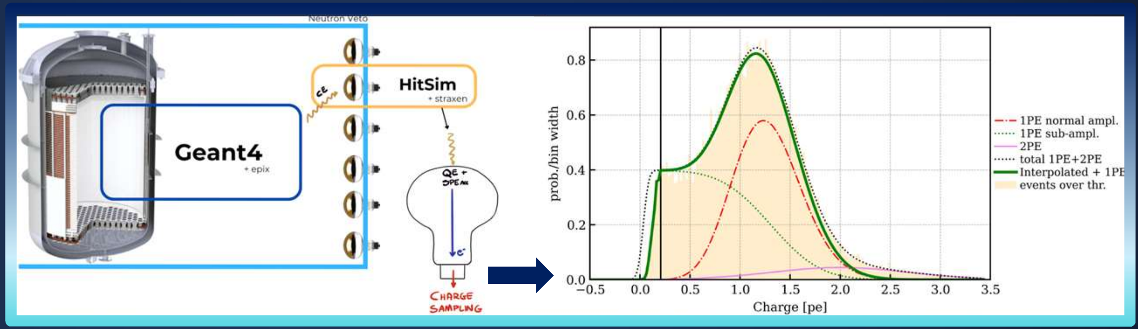
GEANT4 & HitSim

GEANT4 is a toolkit used to simulate the transportation of a particle "step-by-step", taking into account all the possible interactions with materials and fields.

Geant4 modelization



Hitlet Simulator working principle



The HitSim is designed as a fast and efficient simulator for generating NV hitlets and events. Simulated signals include charge and time information analogously to real data: charge sampling follows the SPE model developed based on PMT calibration data.

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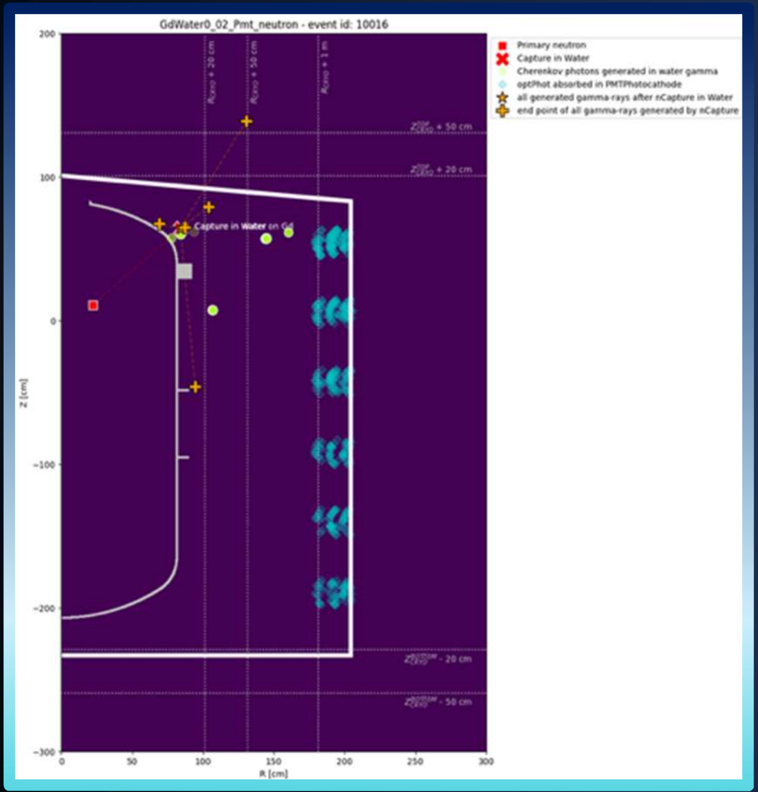
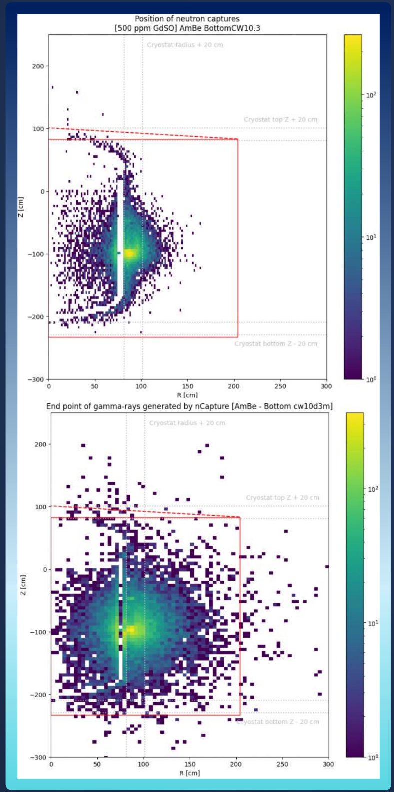
Position profiles of n-capture processes

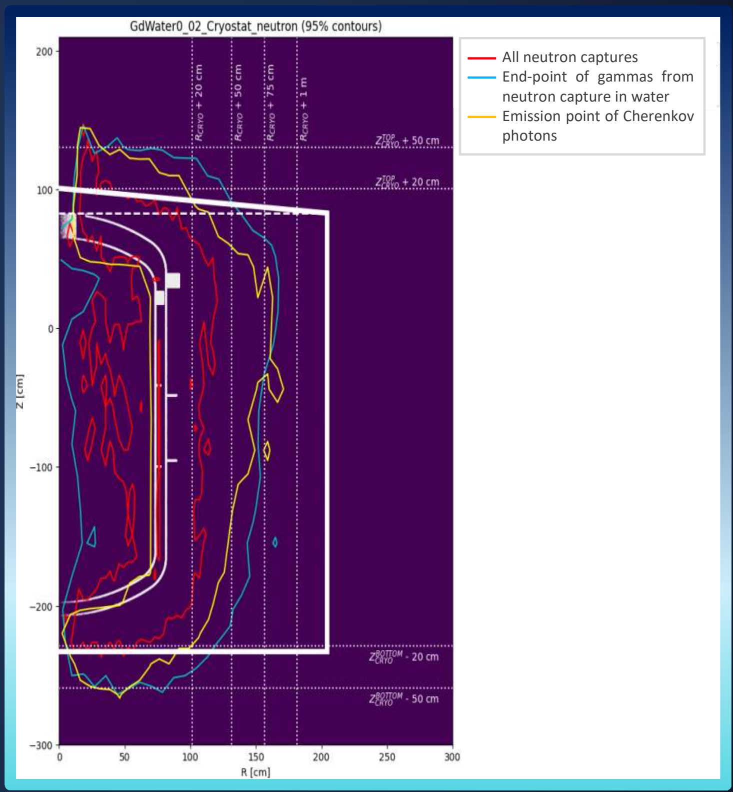
Event display in Geant4



Neutron capture position & Gamma end-point (AmBe)



Background neutrons from cryostat



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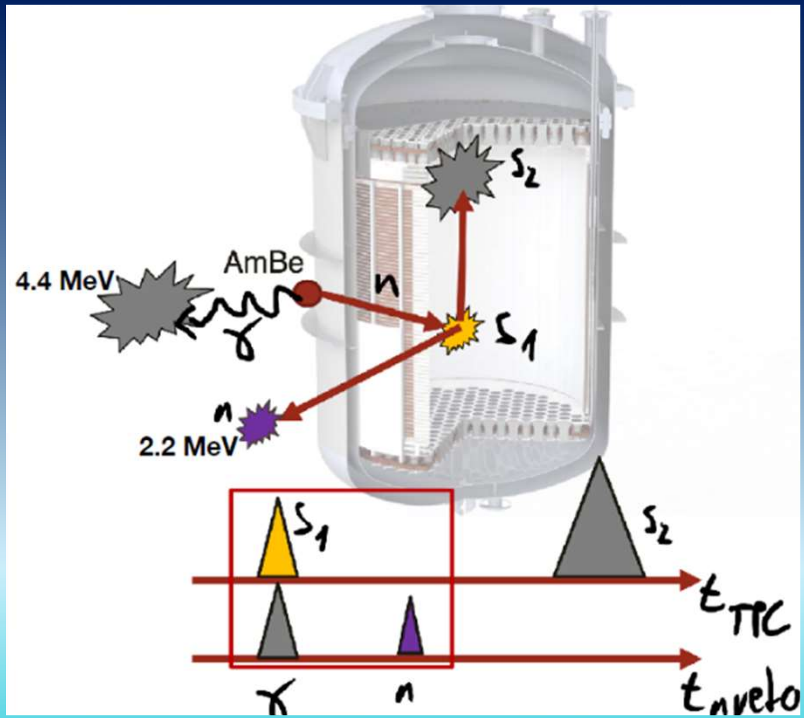
Calibration of the Neutron Veto

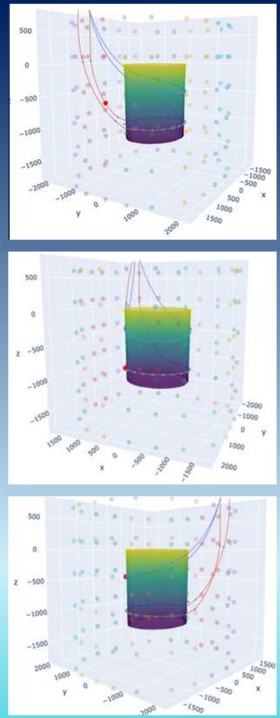
AmBe source

AmBe source emits neutrons through α-capture reaction $^{9}Be(\alpha, n)^{12}C$: its key feature is the emission of a 4.4 MeV gamma together with a neutron in about 50% of cases.

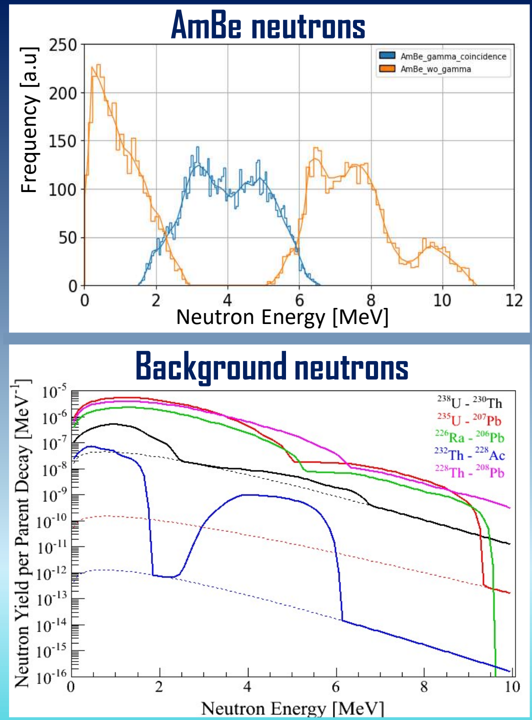
Calibration method



Calibration positions



Emission energy spectra



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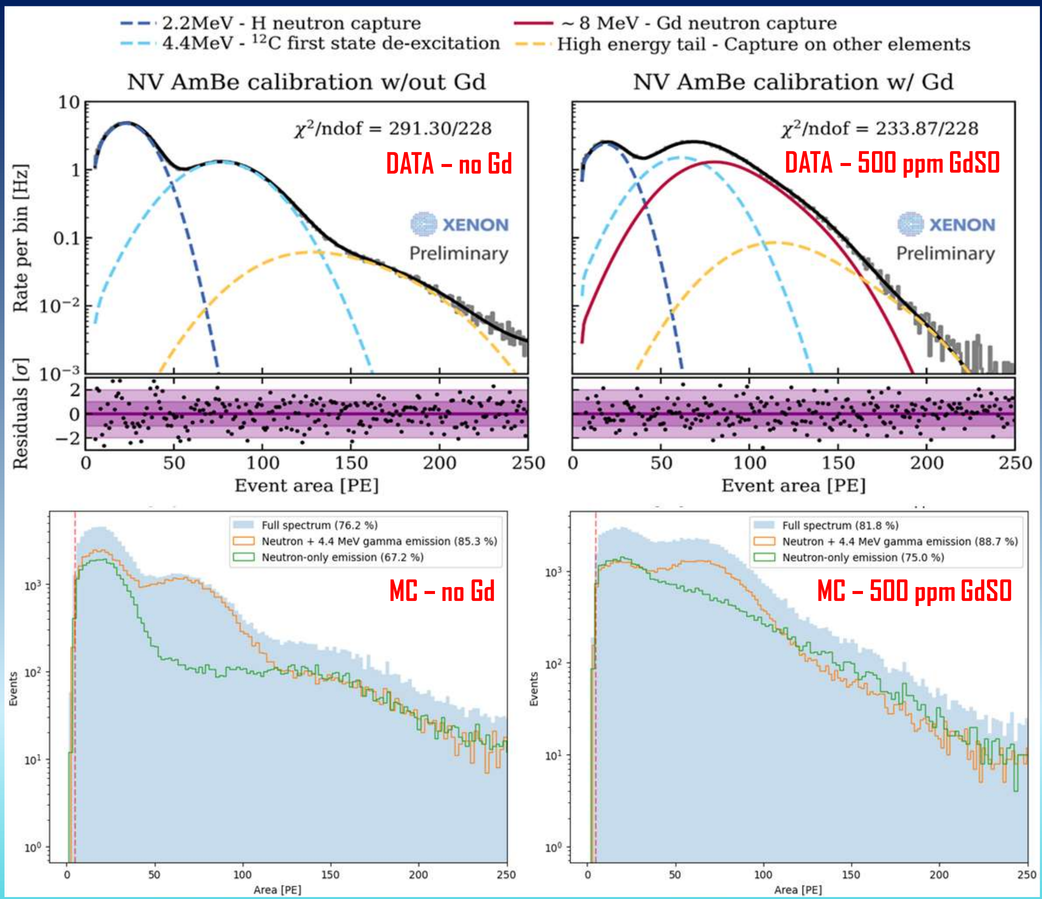
MC – DATA matching

AmBe source



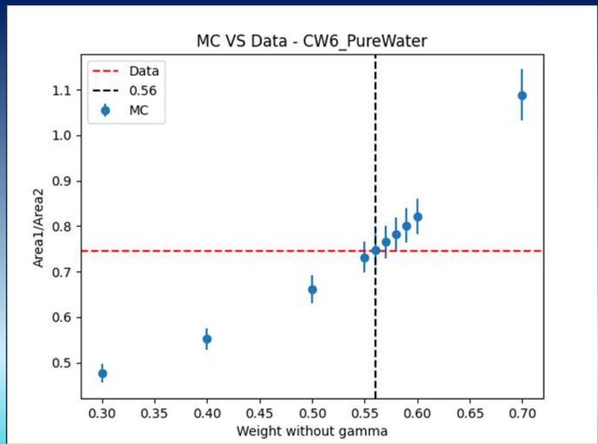
From the light collected in the nVeto with the AmBe source, we obtain **data** to build the energy spectrum with various peaks:

- H-capture at 2.2 MeV (20 PE),
- AmBe gamma at 4.4 MeV (65 PE),
- Gd-capture at about 8 MeV (broad region at 80 PE).

MC data are produced separately for:

- neutron-only emission
- (neutron + γ) emission

Afterwards combined assuming various weights.



Best MC-data match for a (n+γ) emission in 44% of cases.

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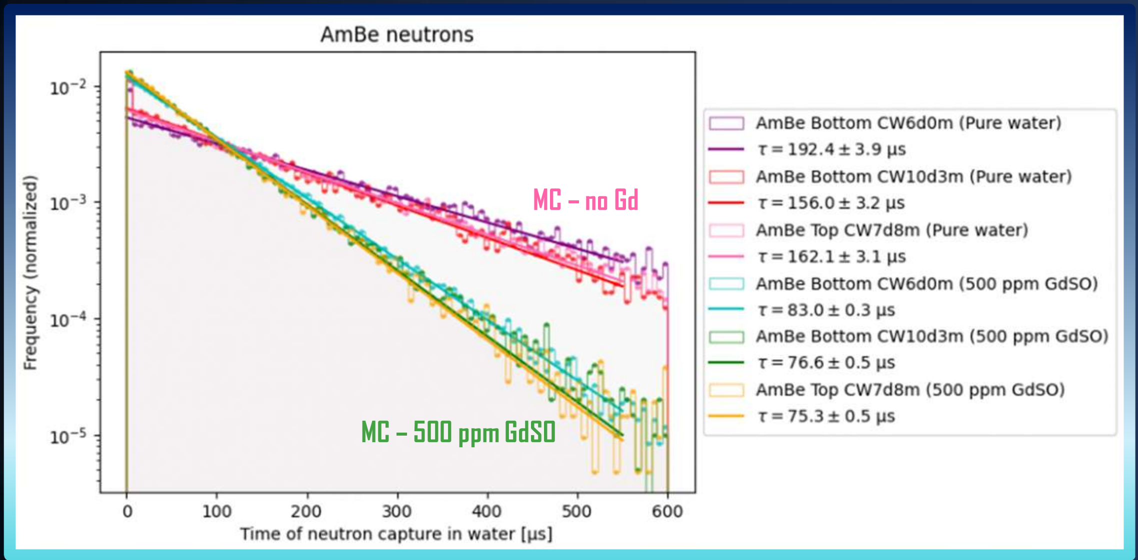
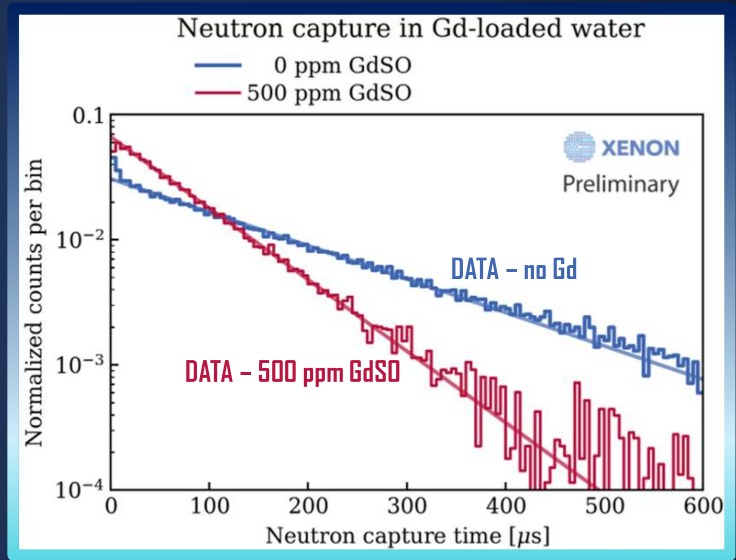
Neutron capture time

The **neutron capture time** is the average time from the neutron emission to its capture. It is obtained by fitting the time distribution of the neutron capture events.



AmBe neutron capture time for different positions and in different conditions (pure water and 500 ppm GdSO concentration).



Neutron capture time decreased from (163 ± 3) μs in SR1 (0 ppm GdSO) to (75 ± 2) μs in SR2 (500 ppm GdSO).

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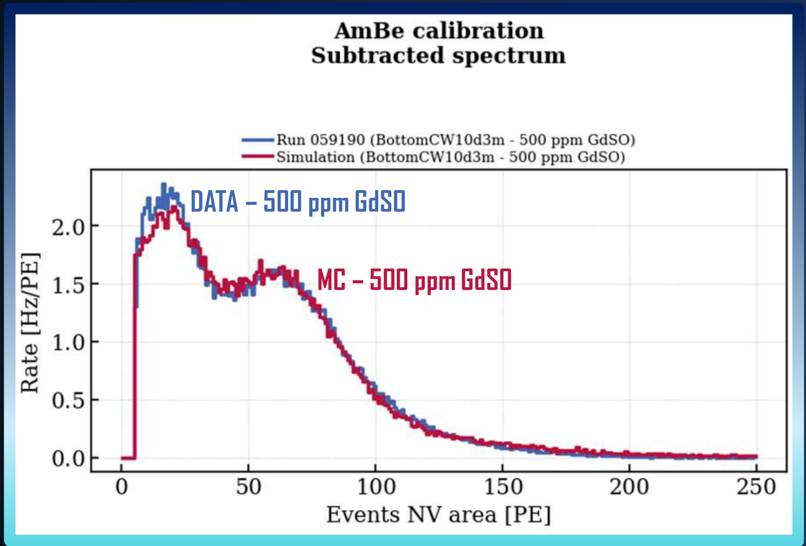
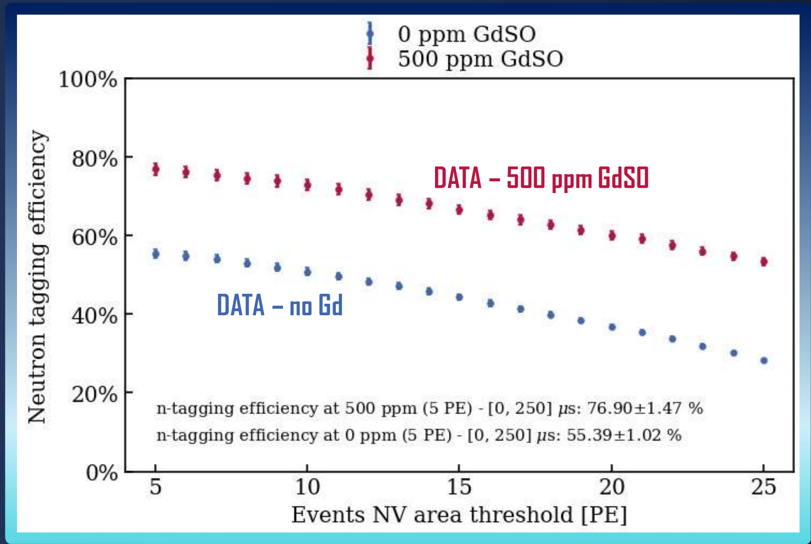
Neutron tagging efficiency

The **neutron tagging efficiency** quantifies the fraction of dangerous neutron signals in the TPC that are tagged by the nVeto.



Comparison between data and MC energy spectra in the NV for the position BottomCW10d3. Only the NV selection cuts are applied (area ≥ 5 PE & multiplicity ≥ 5).



Neutron tagging efficiency measured with an AmBe calibration in position Top CW7d8 for a time window of [0, 250] μs, the one used in Science Run 0 analysis.

After Gd-doping (500 ppm of GdSO) the **neutron background** is **reduced by a factor 2**.

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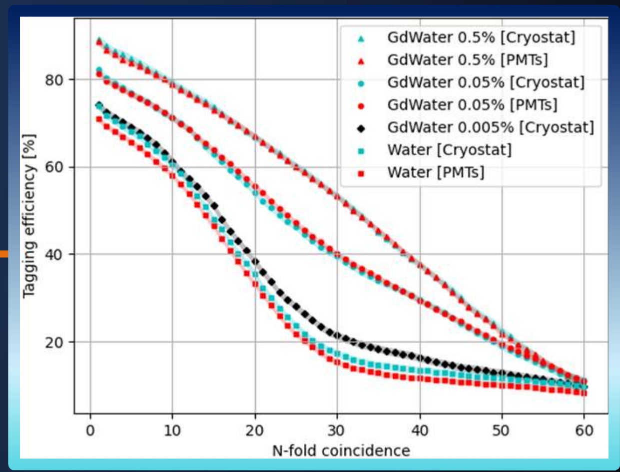
SUMMARY AND CONCLUSIONS

- **AmBe source characterization**: best MC-data match for a n+γ emission in 44% of cases.
- **MC-DATA**: good agreement.
- **Neutron capture time**: reduced from (163 ± 3) μs in SR1 (0 ppm GdSO) to (75 ± 2) μs in SR2 (500 ppm GdSO).
- **Neutron tagging efficiency**: improvement with the current 500 ppm concentration of Gd-salt and background reduced by a factor 2.
- **FUTURE**: with the goal concentration of 5000 ppm of Gd-salt in XENONnT or with the new XLZD experiment, we can reach an 85% neutron tagging efficiency, reducing further the neutron background.

XENONnT
(2020)
6 t Xe target

XLZD
60 t Xe target



Thank you for your attention

XENON

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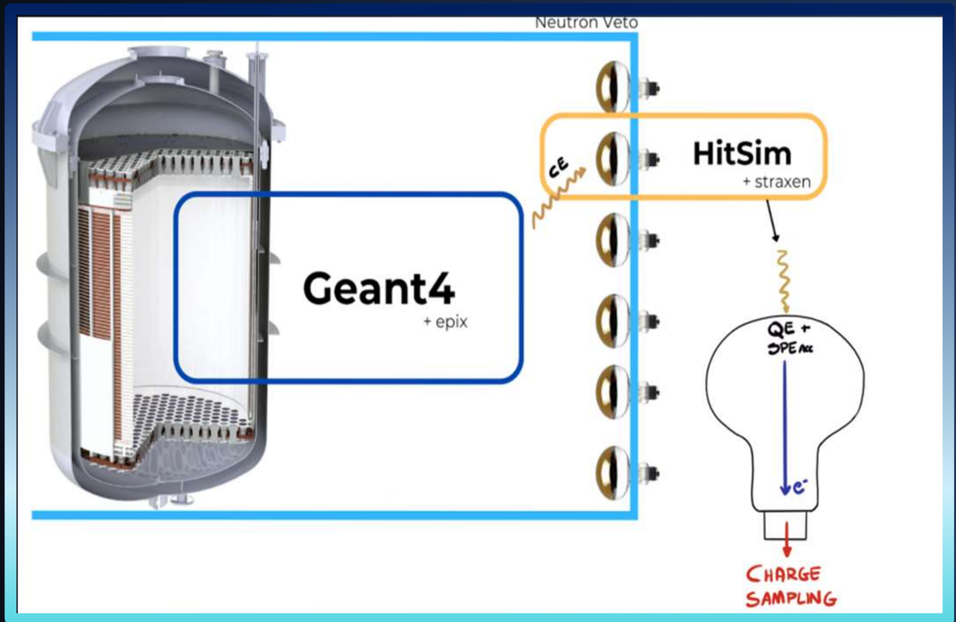
Photo credit: **Luigi Di Carlo for the XENON Collaboration**

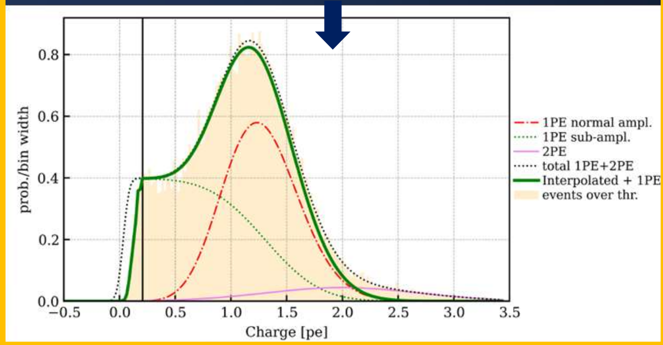
Hitlet Simulator

The HitSim is designed as a fast and efficient simulator for generating NV hitlets and events, based on the principle of delta pulse PMT signals.



Simulated hits undergo a series of steps akin to those experienced by real γ in the detector:

1. In PMT conversion of γ into PE happens at the photocathode (**QE(λ)**)
2. PE should be collected at the first dynode of the amplification stage (**CE**)
3. If PE is collected, sampling of the charge for each hits (**SPE model**)



Geant4

Physics processes simulated

γ

HitSim

Determine if γ converted into a PE and detected

?

Simulated signal with charge and timing fully analogous to real data

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MC – DATA matching

Neutron event rate

The **neutron event rate** consists in the number of observed events in the nVeto: in Table below, we compare the rate of observed events in the nVeto with the AmBe source at three positions: Top CW7d8, Bottom CW10d3, and Bottom CW6d0.

Source	Relative increase of neutron capture rate (0 VS 500 ppm GdSO)	
	Data	**MC**
Top CW7.8	+11.2%	+12.5%
Bottom CW10.3	+9.7%*	+11.5%
Bottom CW6.0	+1.5%	+3.6%

*(50 ppm GdSO)

There is a consistent agreement in the rate improvement after Gd insertion for all the positions.

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Neutron captured on H and Gd

We investigated the **fraction of neutrons captured on H, Gd, and other detector** materials. In Table below are reported values concerning three positions in two different concentrations (0 ppm and 500 ppm) of Gd-salt: Bottom CW6d0, Bottom CW10d3, and Top CW7d8.

Source	Pure water	500 ppm GdSO	Relative increase
AmBe - Bottom CW6d0	98.1%	98.9%	+0.8%
AmBe - Bottom CW10d3	56.3%	66.7%	+18%
AmBe - Top CW7d8	59.3%	68.9%	+16%

A significant increase is observed with Gd, particularly in the Bottom CW10d3 and Top CW7d8 positions (closer to the cryostat).

Furthermore, an analysis was conducted to determine how many **neutron captures** occurring in water were **on Gd or H** in the presence of 500 ppm GdSO. In Table below are reported values concerning three positions: Bottom CW6d0, Bottom CW10d3, and Top CW7d8.

Source	Relative fraction captured on Gd	Relative fraction captured on H
AmBe - Bottom CW6d0 [500 ppm]	62.4%	35.0%
AmBe - Bottom CW10d3 [500 ppm]	63.3%	34.3%
AmBe - Top CW7d8 [500 ppm]	63.1%	34.4%

Of the total neutron captures: ~ 63% occur on Gd, ~ 34% on H, and the rest mainly on O.
These values agree with the predicted rate of ~ 60% of captures happening on Gd.

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