The XENONnT Neutron Veto performances

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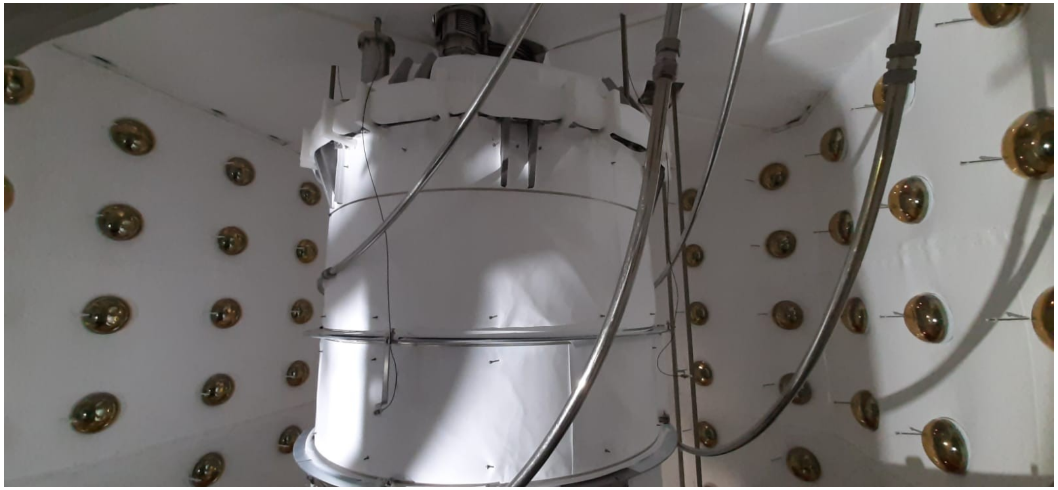
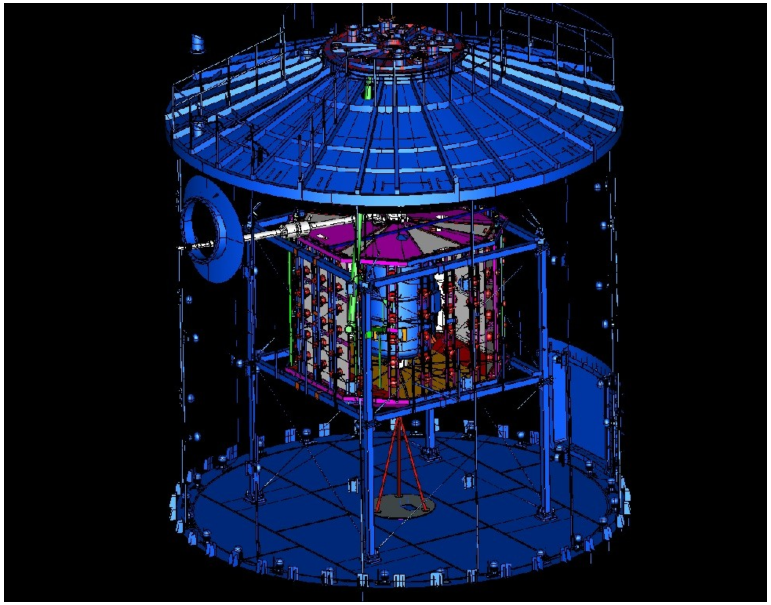
Talk by P. Di Gangi for a XENONnT introduction

The Neutron Veto system

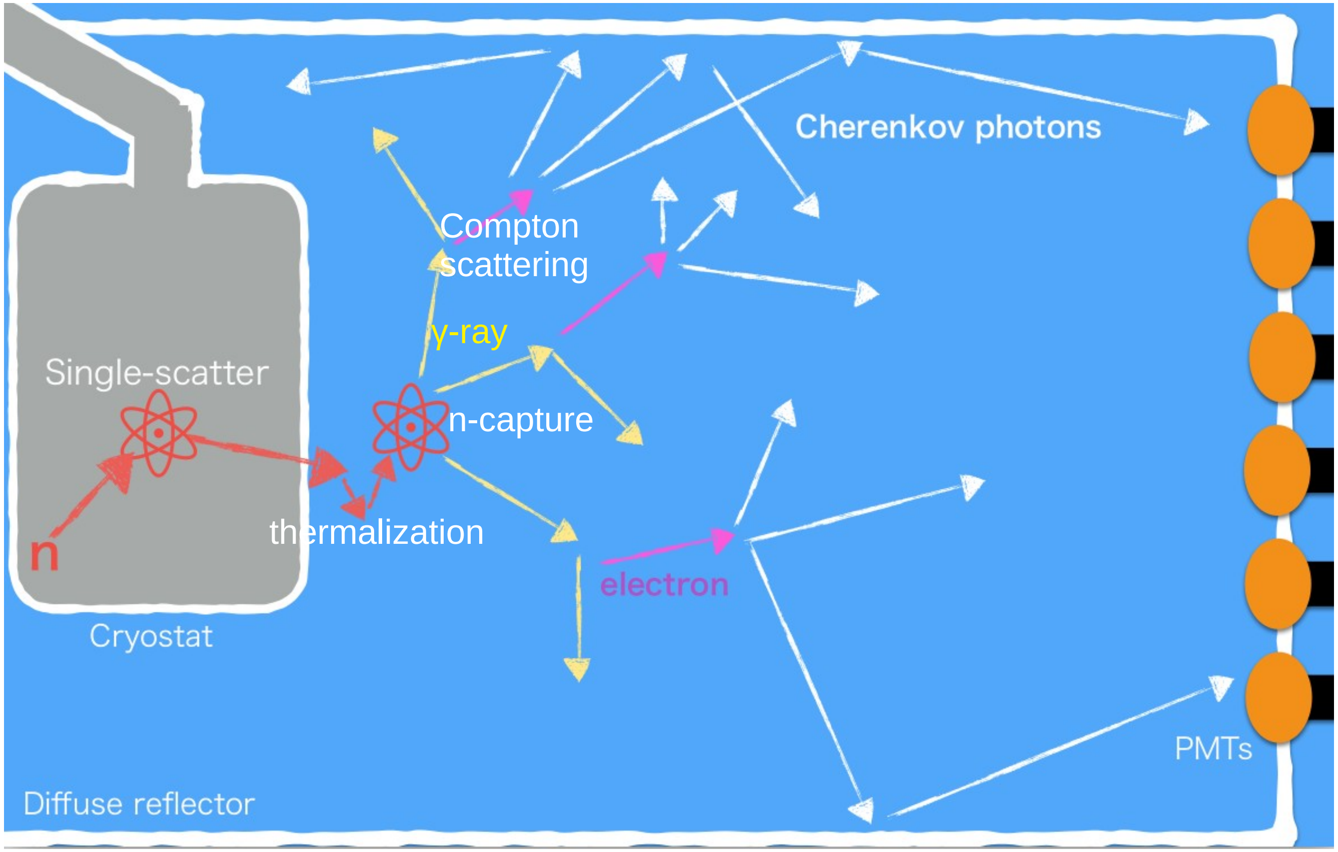
Gd-loaded water Cherenkov detector



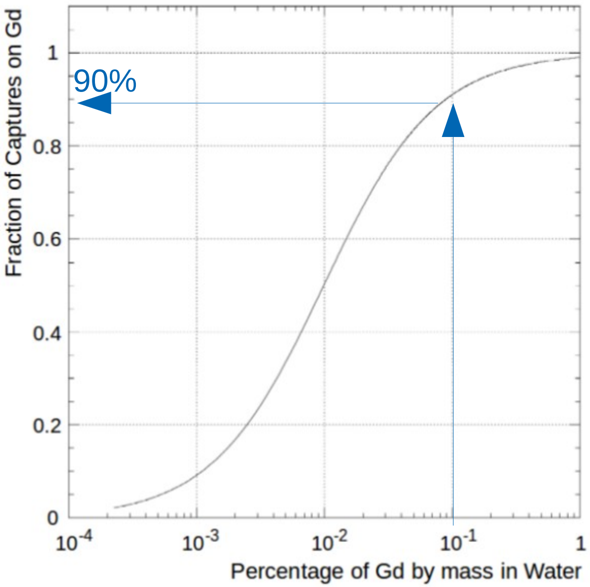


- The Neutron Veto (NV) system of XENONnT is located inside the water tank, around the cryostat to tag radiogenic neutrons from detector materials
- Gd-loaded water to increase the neutron capture rate
  - 0.2% concentration by weight of Gd-sulfate octahydrate (3.4 t)
  - Gd-sulfate is essentially transparent to Cherenkov light
- Octagonal support structure made of SS AISI304, ~700kg in total
- High reflectivity foil (ePTFE) used to confine an inner NV region with high light collection efficiency
  - ePTFE reflectivity is >99% for wavelength >300 nm
  - the outer cryostat is wrapped with reflective foils to increase light collection efficiency
  - weekly calibration on NV reflectivity foreseen
- 120 PMTs 8'' Hamamatsu R5912-100 HQE (~40%) in order to detect the Cherenkov light
- The neutron tagging efficiency stands >85%: NR background suppression of a factor 6

Neutron Veto detection principle



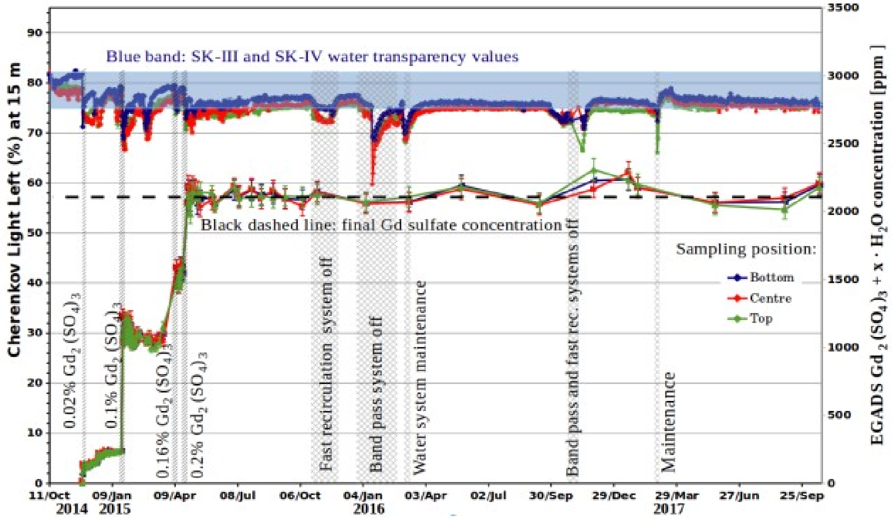
- Background events from neutrons scattering only once in the TPC
- Termalization of neutrons outside TPC
- Neutron capture → γ-ray cascades
- Compton scattering → electrons
- Cherenkov photons emitted by electrons



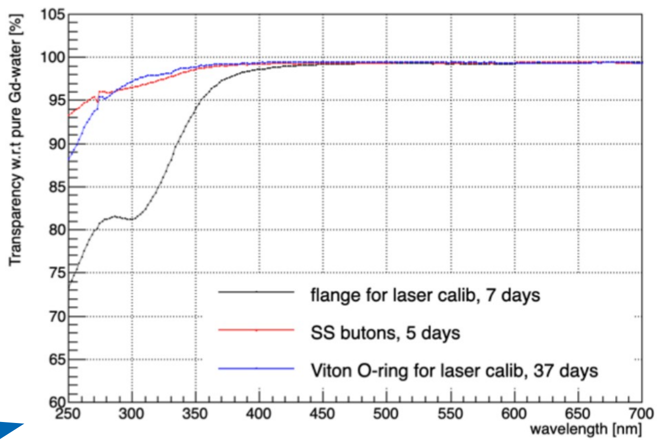
0.2% of Gd-sulphate octahydrated

- >90% of neutrons can be capture by Gd, others are captured by H
  - ^{155}Gd (14.80%): 61000 barn, 8.5 MeV γ-ray cascades
  - ^{157}Gd (15.65%): 255000 barn, 7.9 MeV γ-ray cascades
  - ^{1}H: 0.333 barn, 2.2 MeV γ-ray
- Delay time between single scatter and n-capture: ~20 μs

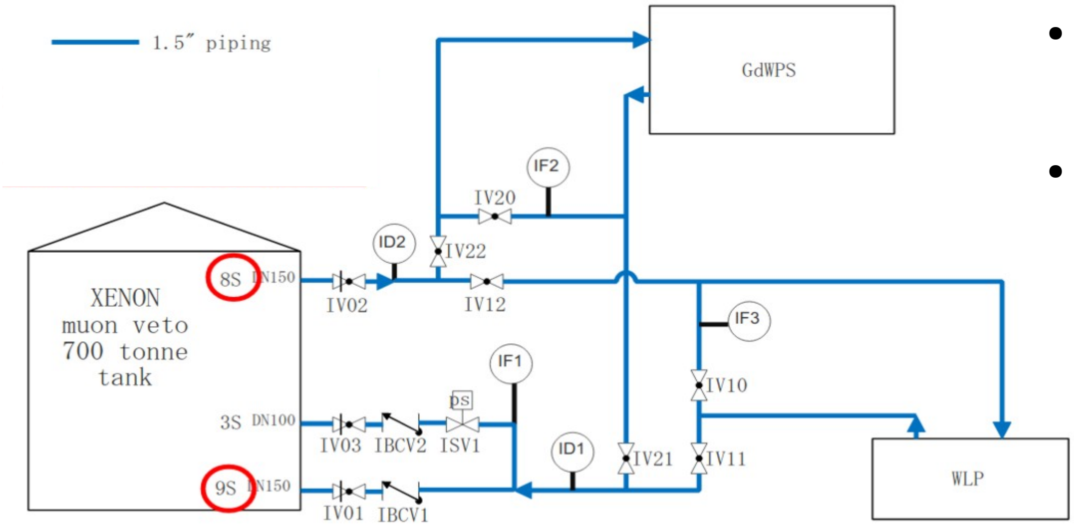
Gd-loaded technique



arXiv:1908.11532



- Gd-loaded technique from new Japanese groups in XENON, who works also in EGADS for Superkamiokande-Gd!
- Goal: maintain high transparency of Gd-loaded water
  - Careful checks of all the detector components used inside the water tank (**soak test** in Gd-loaded water)



- Similar water purification system as in EGADS
- The Gd-water plant will be ready by Autumn 2020, when the TPC commissioning with pure water around will be completed. We will then insert Gd in the water, and start the final phase of XENONnT science run

125 PMTs

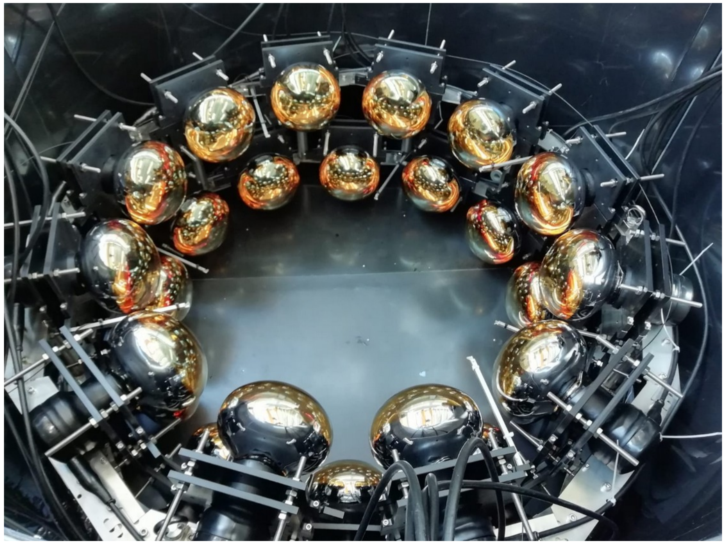
- 120 (+5 spares) Hamamatsu R5912-100-10 coaxial cable, 8'' HQE (~40%) low radioactivity glass, water-proof
- Low radioactivity measurements have been performed also at LNGS

Unit: Bq/PMT

	Other than glass		Standard glass		Low rad. glass		Assembly parts	
	Hamamatsu	LNGS	Hamamatsu	LNGS	Hamamatsu	LNGS	Hamamatsu	LNGS
K-40	0.6	0.08	4.7	2.4	0.8	0.6	1.0	–
U-series	> 0.1	<0.05	2.4	2.26	0.4	<0.6	0.8	–
Th-series	> 0.1	0.008	2.0	1.58	0.3	0.425	1.3	–

- Same PMTs as Muon Veto ones except for some improvement: low radioactivity glass, coaxial HV cable type, changing in the resistive chain (dumping resistors used: 100Ω, protective resistor used: 10kΩ)

PMTs tested both in water and in air



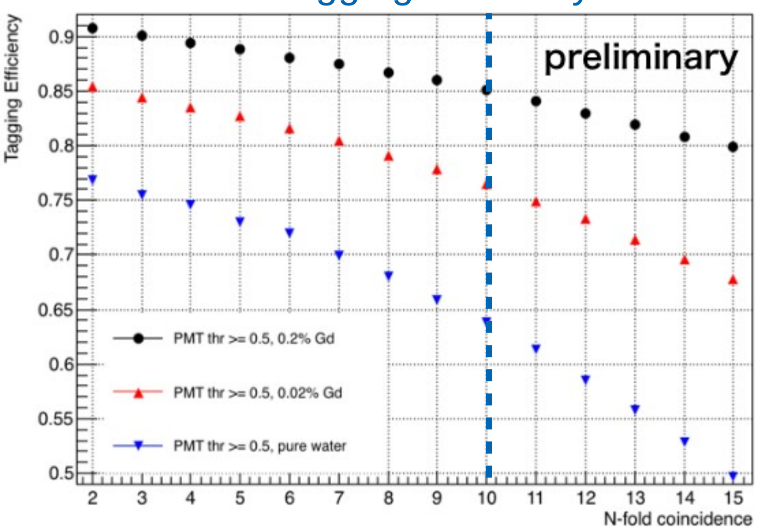
- The main PMT parameters (from measurements) are:
  - average gain: $(8.22\pm0.07)\times10^6$
  - average DR: 2.3 kHz @ 0.5 PE threshold
  - TT between PMTs (at NHV): RMS=2.7 ns
  - average TTS: <4 ns
- The performance of the PMTs resulted to be rather uniform, except for one PMT which showed high DR (~14 kHz): we have considered it as spare

Talk by A. Mancuso

Neutron Veto performances

- Obtained by MC simulations (GEANT4)
- Performed to maximize the overall NV tagging efficiency (optimization of the Gd concentration, NV geometry, reflectivity, etc.)

NV tagging efficiency



NV tagging efficiency with 10-fold coincidence

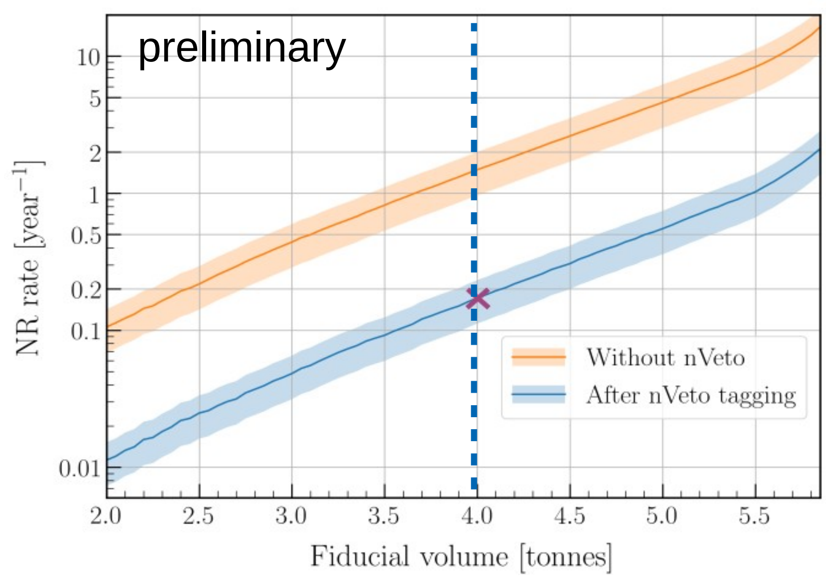
- pure water case (no Gd): >60%
- XENONnT final configuration (0.2% Gd): ~85%

Fraction of neutron background events vetoed in a given coincidence window between TPC and NV

Coincidence window	0.2%	0.02%	0%
	Fraction of the events vetoed		
100us	0.98	0.72	0.48
150us	0.99	0.85	0.62
300us	~1	0.98	0.84
500us	~1	~1	0.94

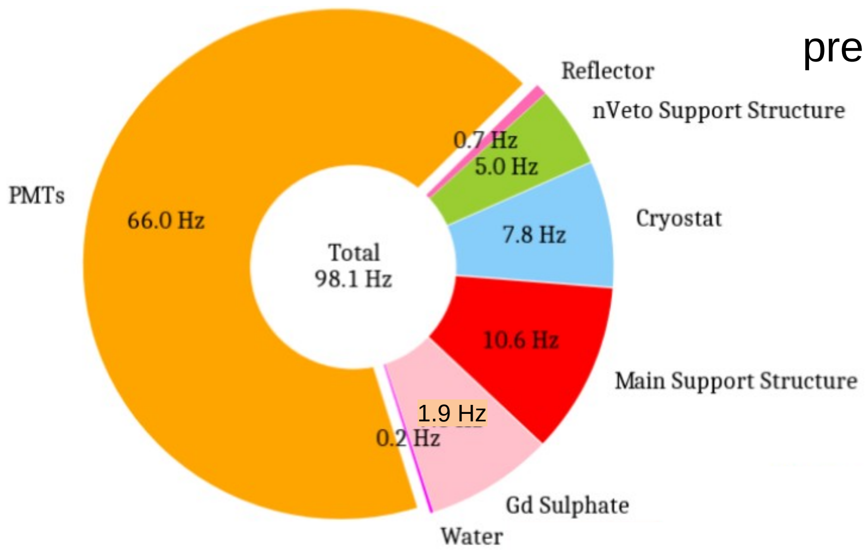
Coincidence window between TPC and NV events

- pure water case (no Gd): we should use 500 μs
- XENONnT final configuration (0.2% Gd): we can use 150 μs

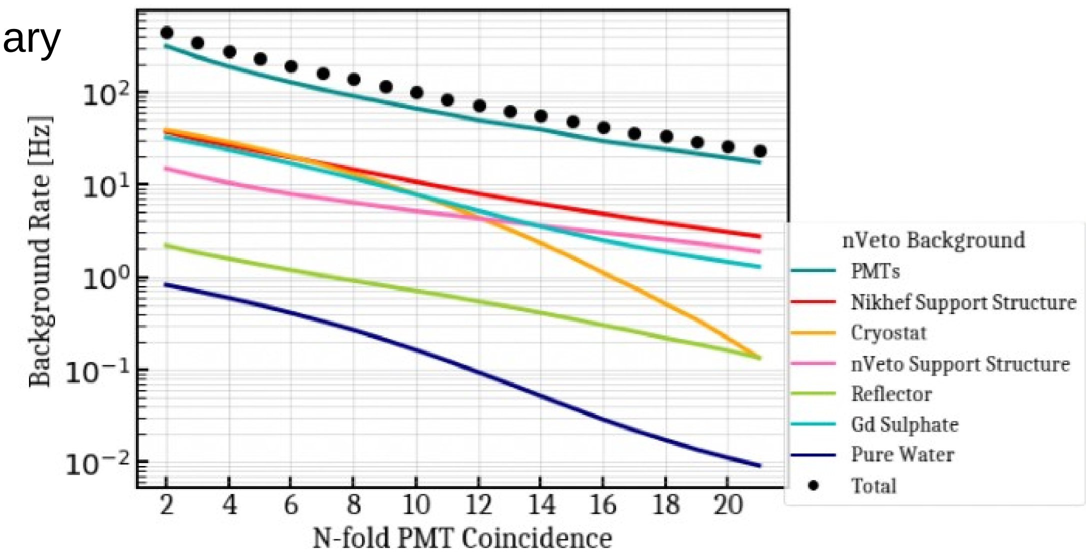


- **NV tagging efficiency: ~85%** if we use 0.2% of Gd with 10-fold coincidence and 150 μs coincidence window between TPC and NV event
- NR background reduction in XENONnT: from 1.2±0.2 evt/yr without NV, to 0.17±0.05 evt/yr (with NV) in [4,50] keVr and 4 t FV with 100% NR acceptance

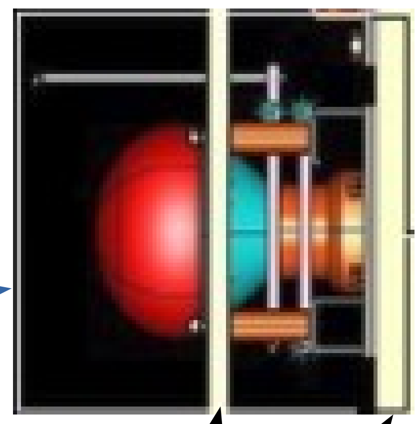
Neutron Veto background



preliminary



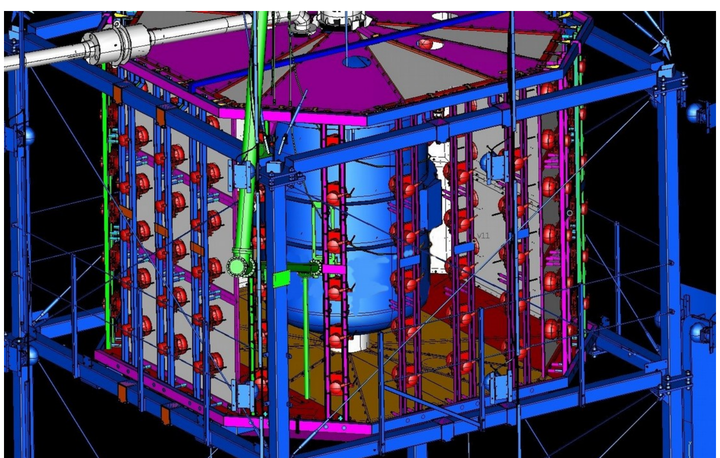
- Background budget in NV from detector components (mainly NV itself and cryostat) is obtained by MC simulations
  - We screened all the detector materials
  - We want to reduce the rate of fake events in order to keep as much TPC data as possible
- Background dominated by the radioactive impurities in the PMTs
  - reduction by ~70% if the reflector is placed just behind the PMT photocathode
- With 10-fold coincidence, the rate of fake events is ~100 Hz
  - Loss of TPC events: ~1.5% with 150 μs coincidence window



Neutron Veto: state of the art

- Installation of the mechanical structure is just been completed. It includeed:
  – SS support structure
  – Lateral reflector panels, TOP and BOTTOM reflectors
  – 120 PMTs and optical fibers
  – 4 diffuser balls
  – reflectivity monitor system
  – wrapping of the detector pieces located inside the NV, *i.e.* cryostat, Neutron Genetrator Beam pipe, holder, etc.
- PMT cables and optical fibers have been guided into the control room
- PMT cables are going to be connectorized soon and the optical fibers are available for connection to light source

From the theory… to the reality



Neutron Veto: state of the art

Installing the NV lateral panels

Interference between NV roof and calibration parts (U-tubes)

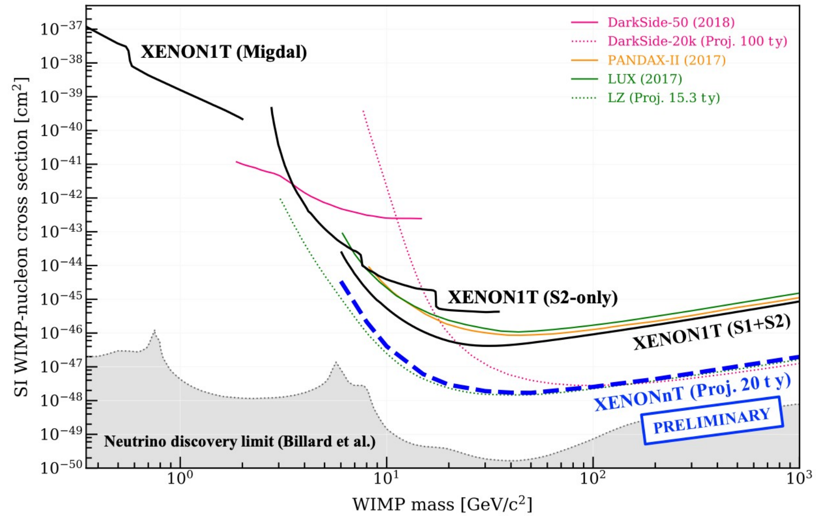
Wrapping of Neutron Generator beam holder and pipe

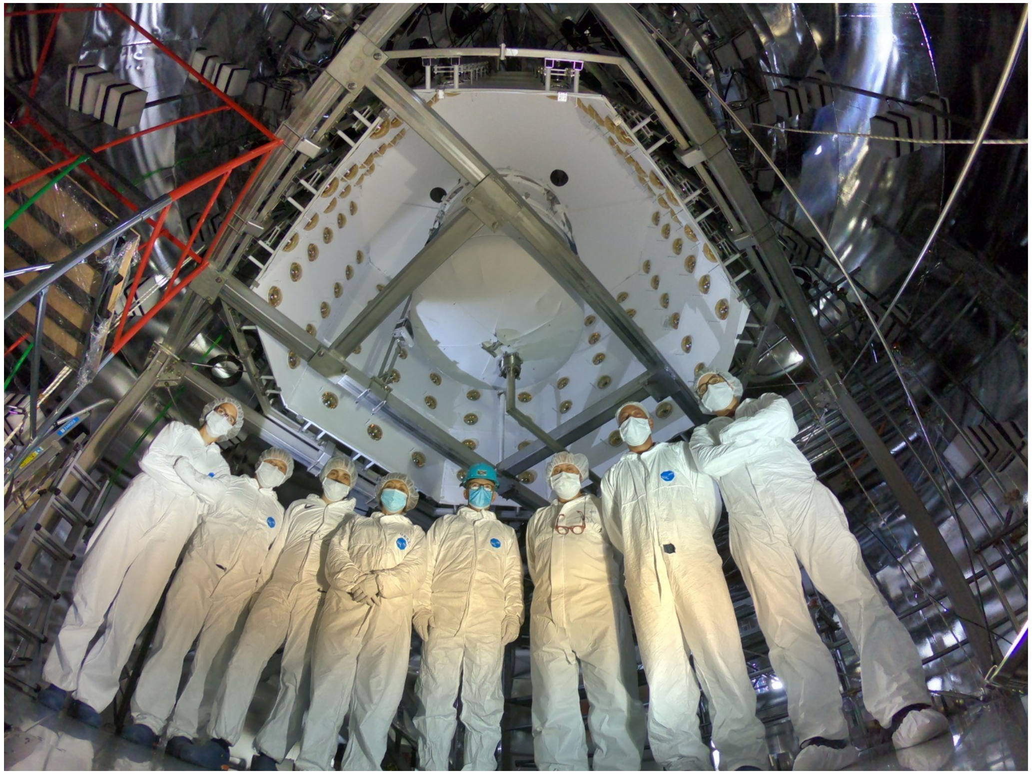
Additional material: YouTube videos by **P. Di Gangi**, **The Making of XENONnT Neutron Veto**

- Link play list: https://www.youtube.com/playlist?list=PLL-hbOWYH4jJ1SRuSb4xnjfTqiI50ddFm

Conclusions

- XENON1T currently leads the field of dark matter direct search
- The quick upgrade XENONnT will improve the sensitivity by a factor ~10 thanks to a larger fiducial mass and further background suppression
- The Neutron Veto, a Gd-loaded water Cherenkov detector, will be used in XENONnT to further reduce the neutron background from the detector materials
- It will suppress the neutron background by a factor 6
- NV tagging efficiency: ~85% if we use 0.2% of Gd with 10-fold coincidence and 150 μs coincidence window between TPC and NV event
- The NV mechanics has just been installed at LNGS. PMT cabling is ongoing
- We are almost ready to start the commissioning!

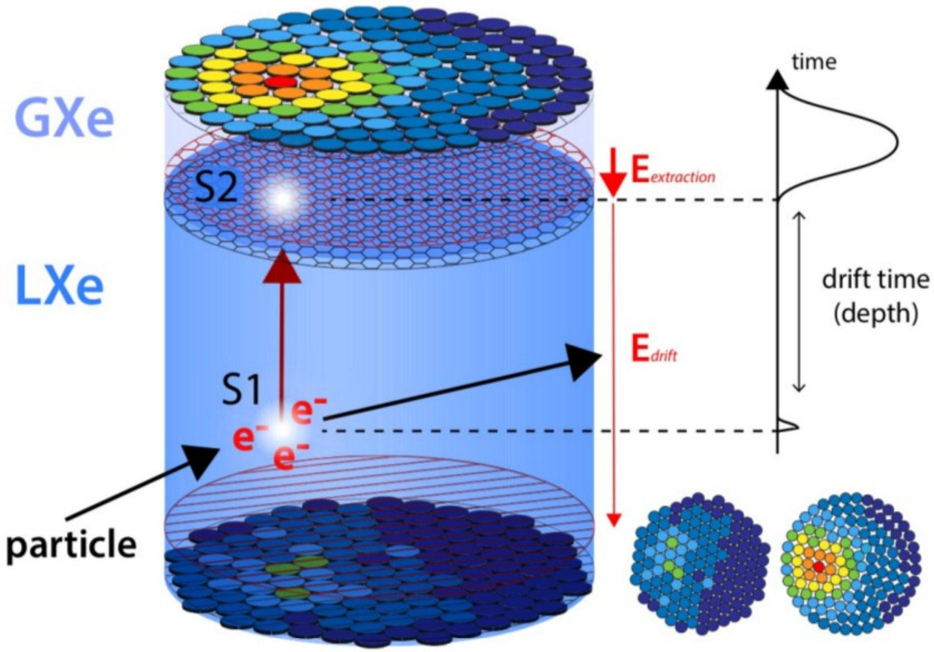





Back-up
slides

The XENON detection technique

Dual-phase Xenon Time Projection Chamber (TPC)

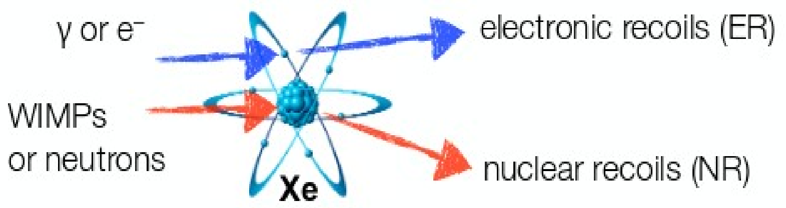


- **S1**: light signal in LXe
  → prompt scintillation photons
- **S2**: charge signal in GXe
  → secondary scintillation from drifted e^-

Reconstruction of energy using both S1 and S2 (*Combined Energy Scale)*

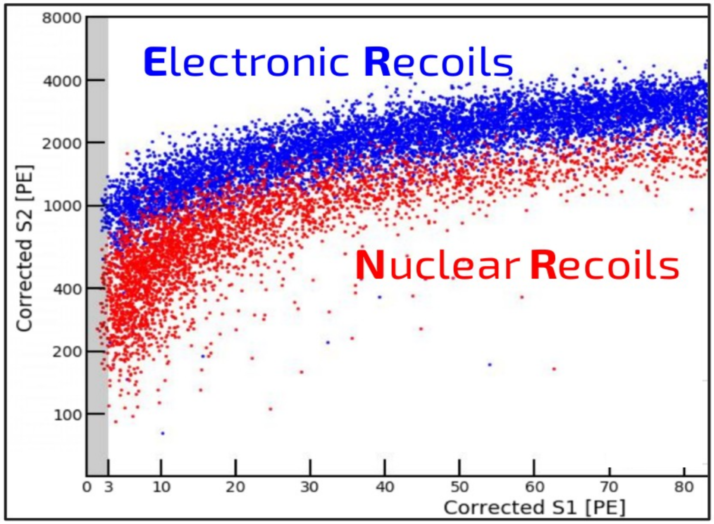
- 3D position reconstruction:
  x,y from S2 pattern in top PMT array and **z** using drift time

- WIMPs (or n) scattering off Xe nucleus → Nuclear Recoils, **NR**
- e^-, γ backgrounds scattering off Xe electrons → Electronic Recoils, **ER**



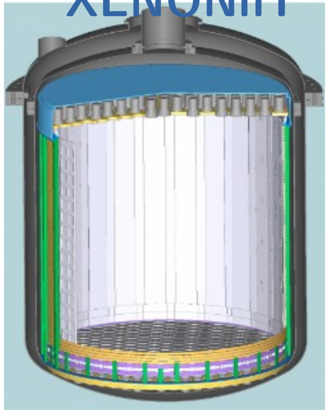
Particle-type discrimination from S2/S1 ratio:

$$S2/S1_{NR} << S2/S1_{ER}$$



The XENON project



XENON10	XENON100	XENON1T	XENONnT
25 kg	161 kg	3.2 ton	8 ton
15cm drift	30 cm drift	1 m drift	1.5 m drift
~10^{-43} cm^2	~10^{-45} cm^2	~10^{-47} cm^2	~10^{-48} cm^2
BG~1000 (keV t y)$^{-1}$	BG~5 (keV t y)$^{-1}$	BG~0.2 (keV t y)$^{-1}$	BG~0.02 (keV t y)$^{-1}$

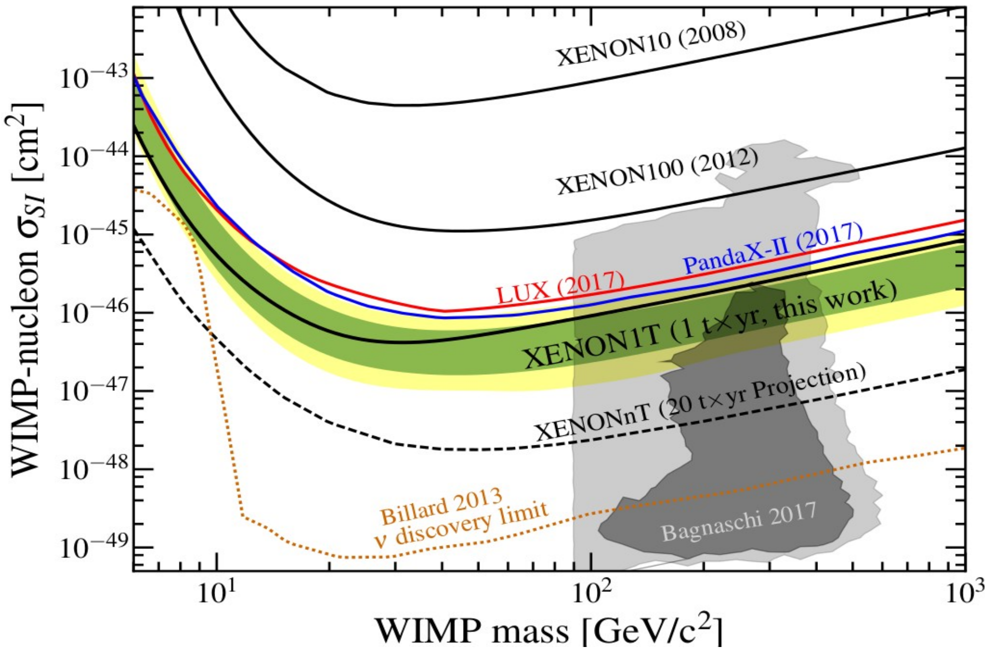
XENON1T performances

- Lowest ER background in a DM search experiment (1.3 t FV and below 25 keVee):
  82 $^{+5}_{-3}$ (sys) ± 2(stat) events/(t·y·keV)
- 7 times better sensitivity compared to previous experiments:
  minimum at 4.1·10^{-47} cm^2 for a WIMP of 30 GeV/c^2

Phys. Rev. Lett. 121, 111302 (2018)

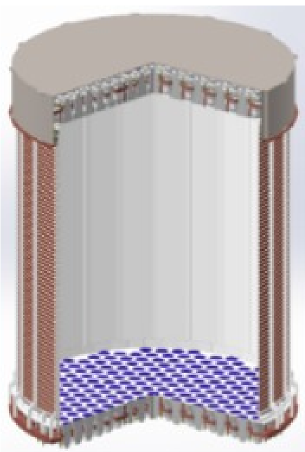
XENONnT expectations

- x10 higher sensitivity compared to XENON1T in 20 ton-year exposure



From XENON1T to XENONnT

- Most of the XENON1T subsystems have been designed in order to accommodate also a larger dark matter detector: XENONnT
- Commissioning of XENONnT and first data taking scheduled in 2020

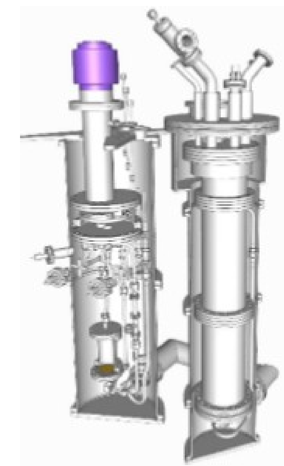


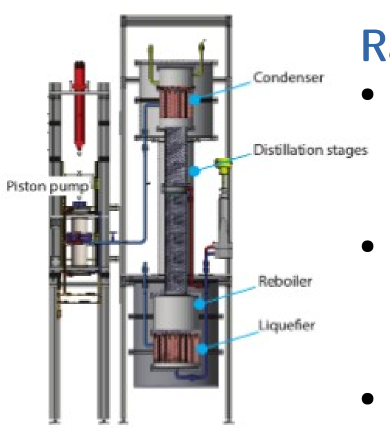
Larger TPC

- 494 PMTs
- 8 t total Xenon
- 6 t target LXe in TPC
- 1.48 m height
- 1.33 m diameter

Liquid Xenon purification

- Faster purification speed in order to purify the 8 t of Xe in reasonable time
  - LXe: 5L/min LXe, 2500 SLPM
  - GXe: 120 SLPM



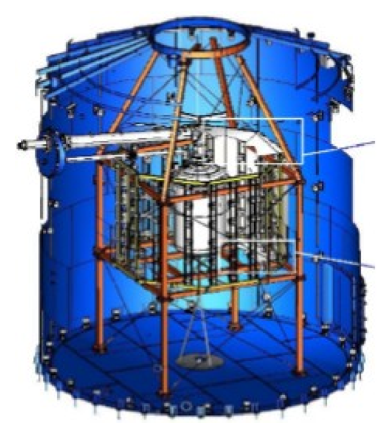


Radon Distillation Column

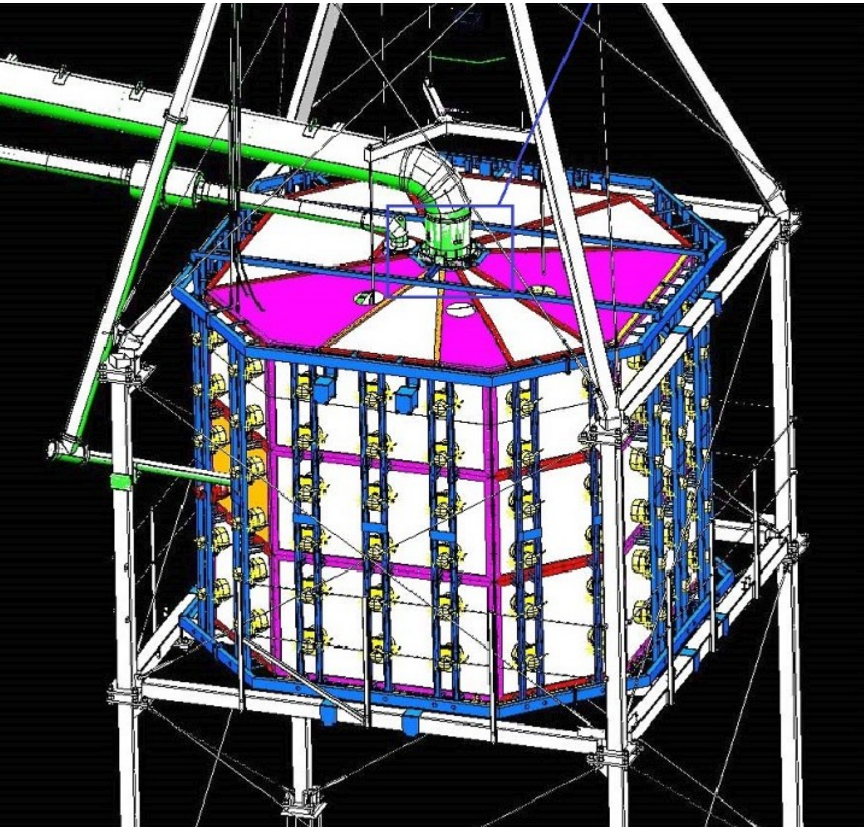
- To online remove ^{222}Rn emanated inside the detector
- Goal: ~1 µBq/kg Rn contamination, 10x lower than in XENON1T
- Rn distillation already tested in XENON1T

Neutron Veto

- if Rn can be reduced as aimed for, NR becomes dominant background
- 1.3±0.2 neutron events/yr in [4-50] keVr in 4 t FV without neutron veto
- NR background reduced by a factor 6

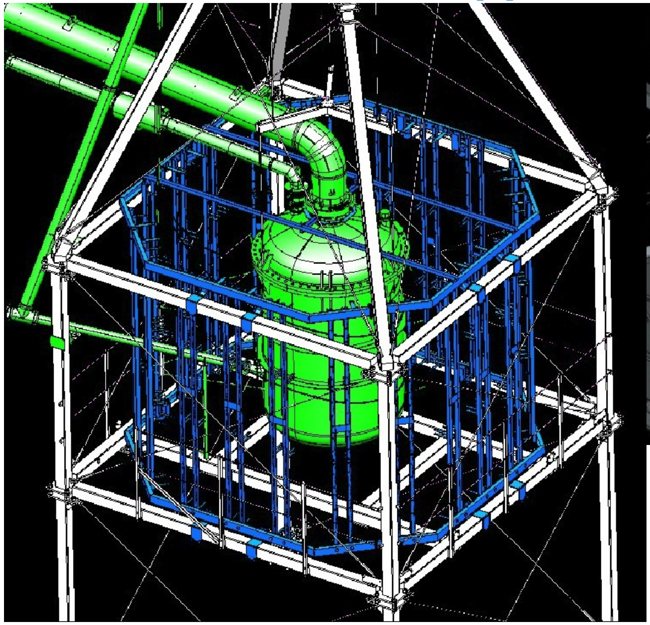


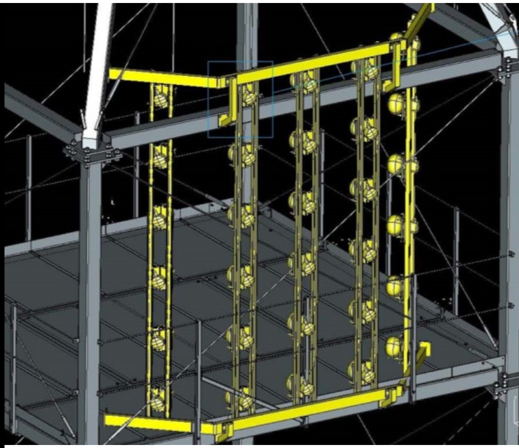
Mechanical structure: overview



- Designed by the Bologna group together with the INFN technical design office

SS NV support structure





Non-regular octagonal structure

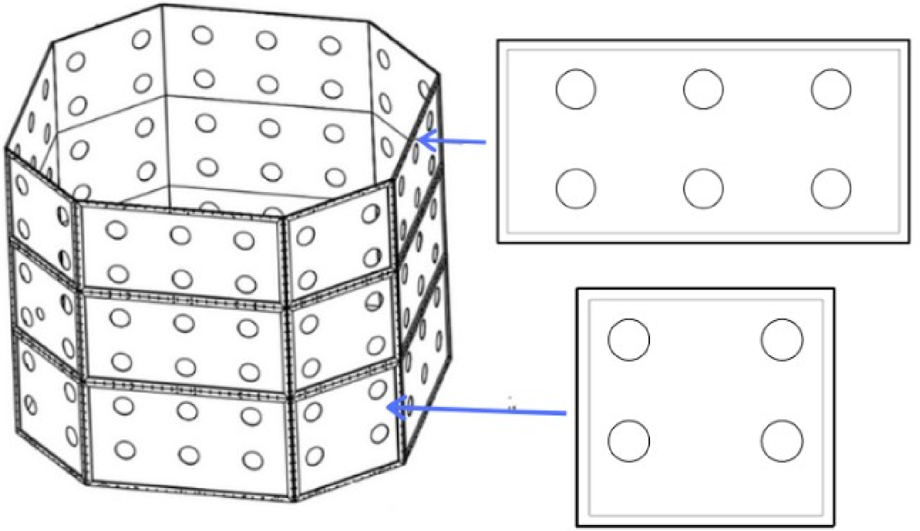
- Height: 3.3 m
- Longer edge: 2.3 m
- Shorter edge: 1.3 m
- ~2 m lateral distance from TPC center

- The ePTFE reflectors are mounted on PE frames

- The SS structure supports both the PE frames and the PMTs (fixed through dedicated PE holders)

- PE lateral frames are located behind the PMTs photocathode

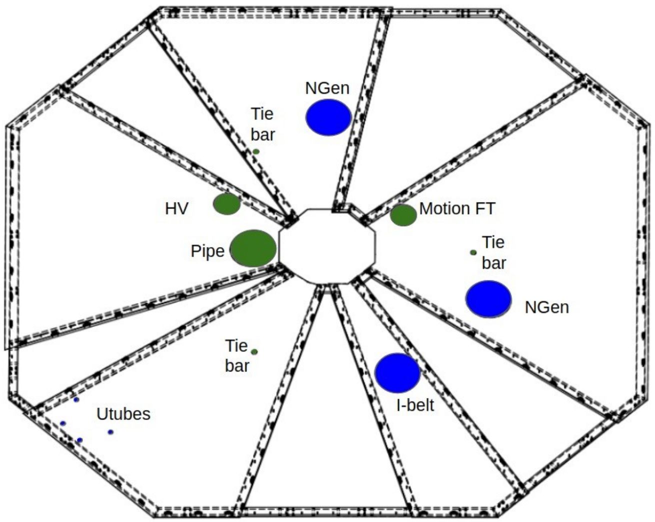
Polyethylene frames with ePTFE reflectors



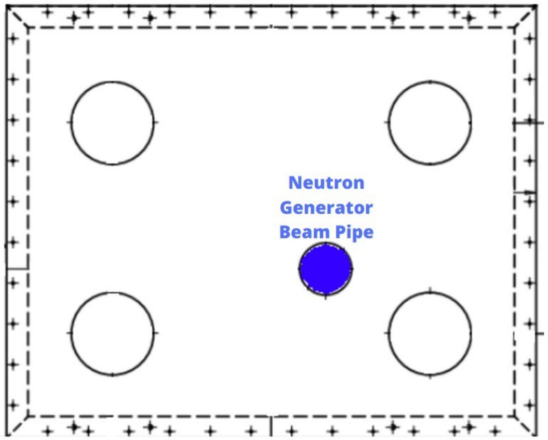
Mechanical structure: interference

In order to fit in the already existing XENON mechanical structure, we had to solve several interferences, basically due to Calibration and Cryostat pipes

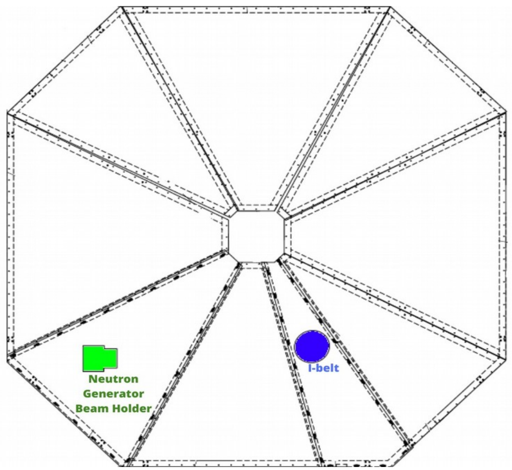
Top reflectors



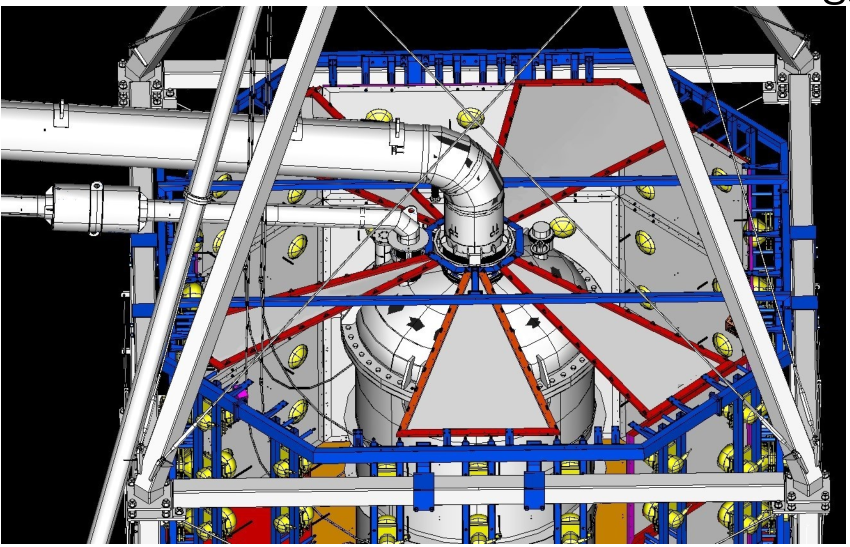
Lateral reflector



Bottom reflectors

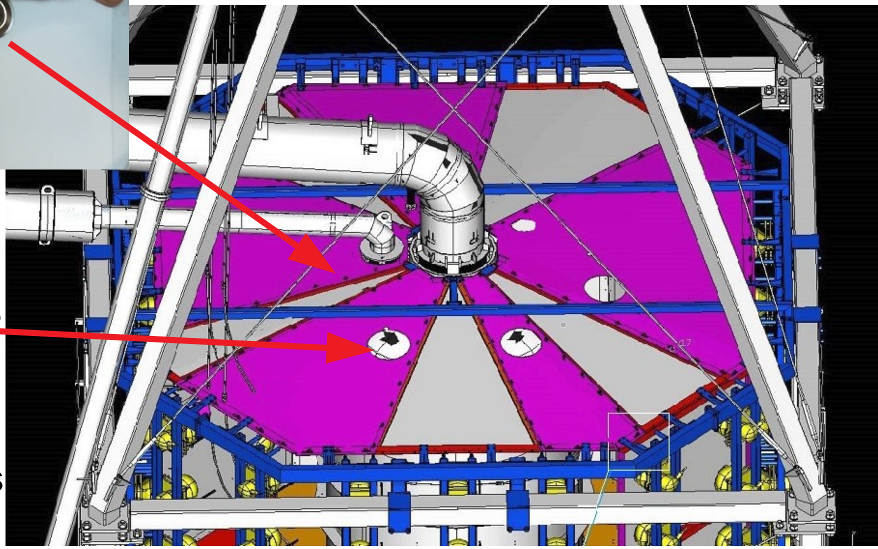


Top reflectors: how do we solve the interference



SS tourniquet to fix ePTFE reflectors to the PE frames

Zipper to close the ePTFE reflectors around the pipes



Same for the lateral reflector and the bottom slices

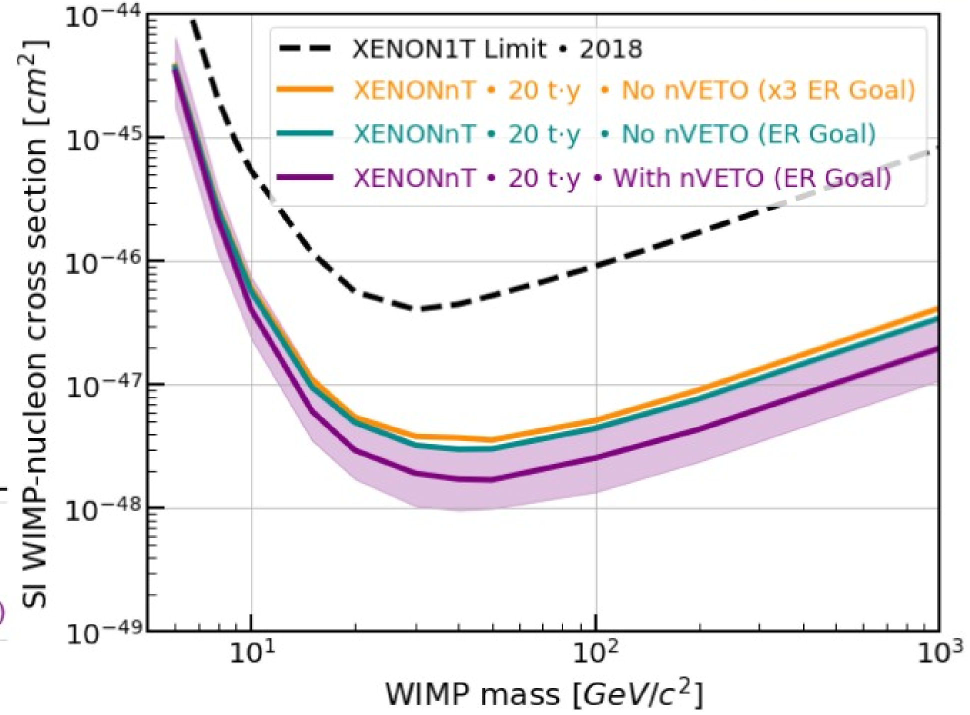
Prototype

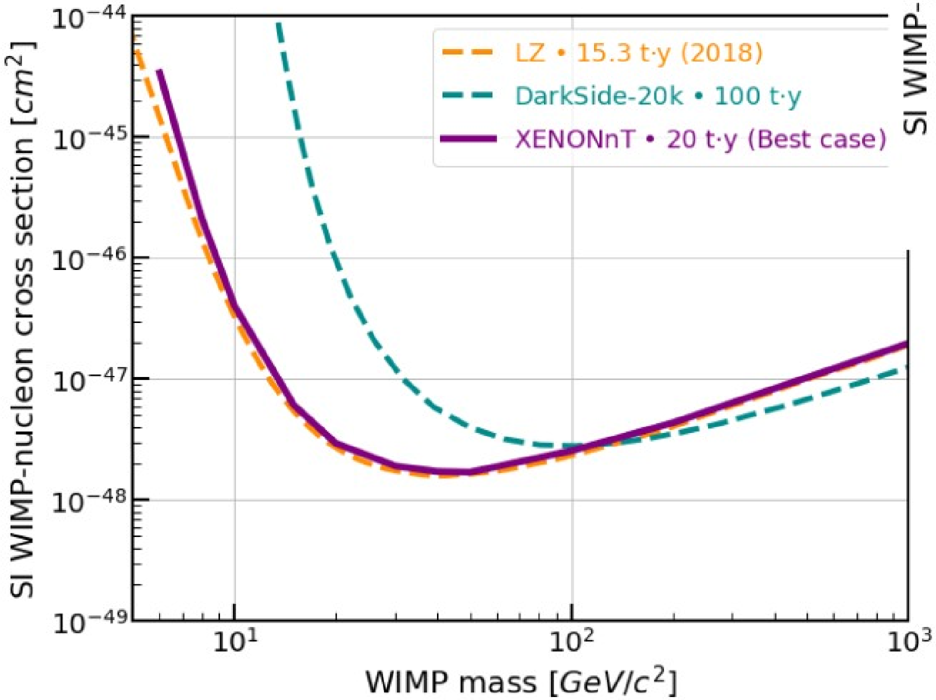
- Prototype of the PMT support structure and reflective panel assembled in Bologna
- It was useful to verify the NV mechanics and to establish a mounting procedure for the final installation

XENONnT sensitivity

Background assumptions in XENONnT

- **ER Goal:** reduced by a factor 10 with respect to XENON1T (or ~3 in a worst case scenario)
- **Radiogenic neutrons:** 0.6 events in 20 t*y exposure (4t fiducial volume), in the WIMP search region, using the nVeto
- **nVeto** efficiency: 85%
- **CNNS** included





- **Improvement** by a factor 2 thanks to the nVeto
- **Minimum** at 30 GeV/c^2: 2x10^{-48} cm^2 in 20 t*y exposure
- **Sensitivity** very similar to LZ projection (arXiv:1802.06039)