The Neutron Veto DAQ system for XENONnT experiment

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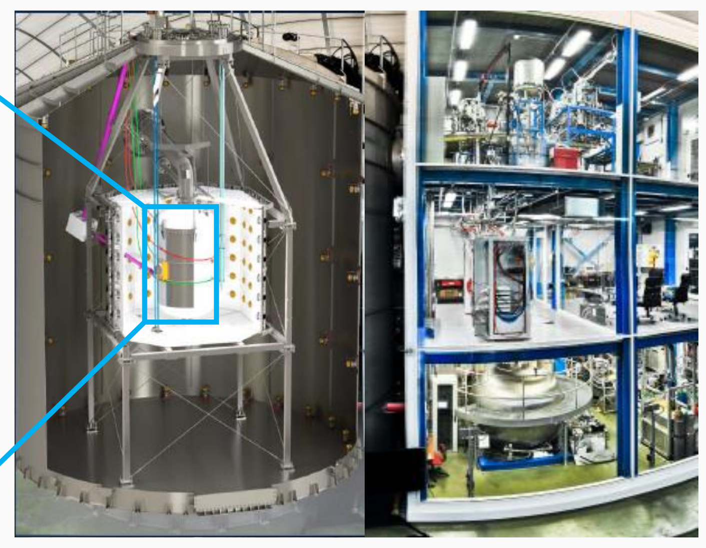
Abstract

The aim of the **XENONnT upgrade** (at the INFN Laboratori Nazionali del Gran Sasso) is to increase the experimental sensitivity to Dark Matter detection by an order of magnitude with respect to the previous XENON1T.
This goal can be achieved by means of some important improvements on detector and other systems: a three times larger target mass (5.9 t LXe with respect to 2.0 t in XENON1T) and the~ enhanced background suppression. The latter relies on an upgraded purification system, a new online cryogenic Radon distillation column and, finally, the **development of Neutron Veto (NV)** sub-detector to tag the radiogenic neutrons especially those interacting once in the TPC which exactly mimic the WIMP signal.
NV sub-detector is made of an octagonal structure (3 m-high and 4 m-wide) inside the water tank around the cryostat. In order to improve the neutron detection efficiency, the water will be loaded with gadolinium. A total of 120 Hamamatsu 8" high-QE PMTs with low-radioactivity windows are placed along the lateral walls to detect the Cherenkov photons.
A new generation **Waveform Digitizer boards** developed by CAEN are responsible for digitizing the 120 PMT signals. The NV DAQ is designed around a **triggerless data collection scheme**. The possibility to provide the pulse shape and the time stamp of each PMT signal allows to run without a hardware event trigger. In fact, the **event building is completely implemented via software** processes running on the online server. This architecture allows us to lower the energy threshold and to have for each channel an independent data readout by means of an individual trigger threshold (self-trigger).
This paper describes the implementation and the performance of the NV DAQ system

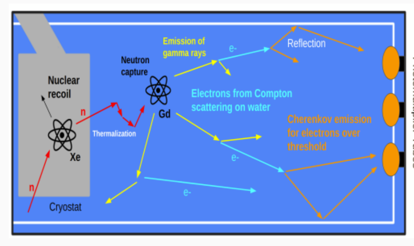
Fast upgrade to XENONnT

NEW LARGER TPC	NEUTRON VETO DETECTOR
× 3 LXe target mass: 2.0 t -> 5.9 t 8.6 t total LXe in the system × 2 PMTs: 248 -> 494	Gd-doped water Cherenkov detector 120 PMTs, highly reflective 87% neutron tagging efficiency (exp.)



Neutron Veto

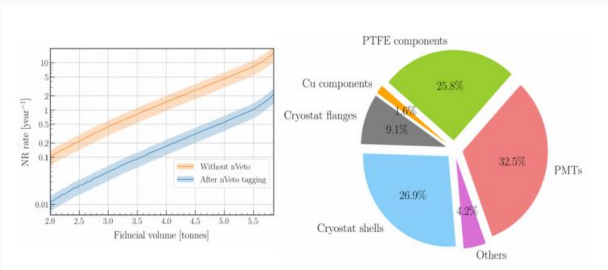
Neutron events become the one of main backgrounds once Rn is removed (~1 μBq/kg):



- ➢from neutrons scattering only once in the TPC
- ➢thermalisation of neutrons in the water outside the cryostat
- Neutron capture → γ-ray cascades
- Compton scattering → electrons
- Cherenkov photons emitted by electrons.
- ✓The Neutron Veto (NV) system located inside the water tank, around the cryostat
- ✓Octagonal support structure made of SS AISI304, ~700 kg in total
- ✓Gd-loaded water Cherenkov detector technology from EGADS/SK-Gd experiment in Kamioka
- ✓Build an inner neutron veto detector with higher PMT coverage & light collection efficiency with highly reflective foil
- ✓120 PMTs 8'' Hamamatsu R5912-100 HQE (~40%) in order to detect the Cherenkov light
- ✓The neutron tagging efficiency stands ~87%: NR background suppression of a factor 6

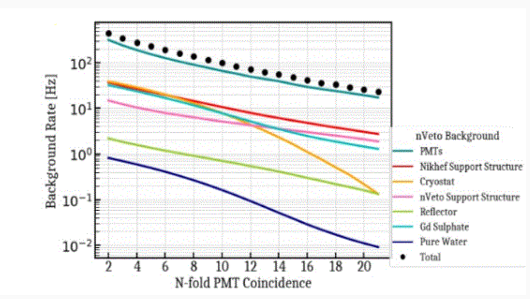
Background signal

Background in NV from detector components obtained by MC
- mimic a WIMP-like signal inside the TPC



The materials of which the NV system is built contribute to the background of the neutron tagging
- main contribution from radioactive impurities in PMTs

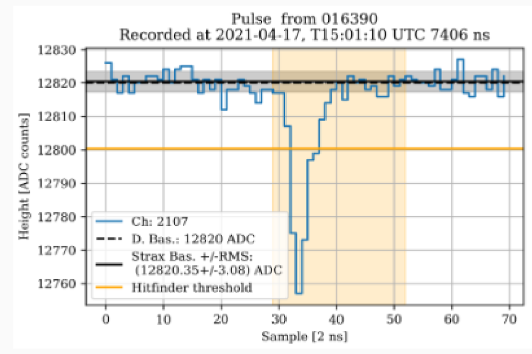
From MC, the total background rate due to NV system with respect to the N-fold coincidence



Nuclear recoil background reduction achieved in XENONnT with the NV operational
- 1.3±0.3 neutron events / yr in 4t fiducial volume without NV to 0.17±0.05 evt/yr (with NV) with 100% NR acceptance➔ for 20 t-year exposure, ~ 6.5 events!

Data Acquisition requirements

To efficiently tag the neutron events (> 87%) the signals ranging 0.5 PE – 100 PE
- **small signals** last about 100−200 ns (mostly from dark rate) => bottom level for the NV data throughput
- **high energy events** induced by radiogenic neutrons with long duration (up to tens of μs) on many channels requiring to sustain higher peak of data rate.
- **fast response** (few ns) of PMTs requires fast waveform digitizer for signal sampling.



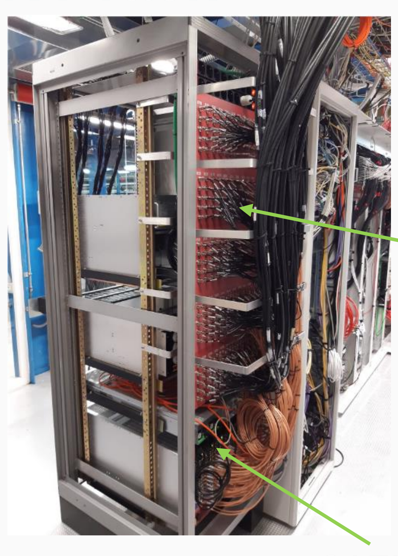
PMT characteristics (dark rate, afterpulsing, timing resolution) essential for the correct design of front-end electronics and online processing
- dark rate puts a limit on the detection of very low energy radiation => estimation on the accidental coincidence;
- operating with a threshold set to 0.5 PE, the measured PMT dark rate is about 2.7 kHz with an accidental rate > 10 kHz for a 2-fold PMT coincidence (within Δt = 300 ns)

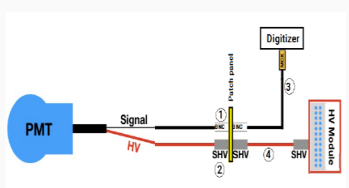
- ➢In a typical trigger-based DAQ architecture, lower the number of coincident PMTs is mandatory ➔ increasing of data rate
- ➢Architecture based on a readout system of independent channels allows the acquisition of all the self-triggered PMT signals and the lowering of the energy threshold

DAQ implementation

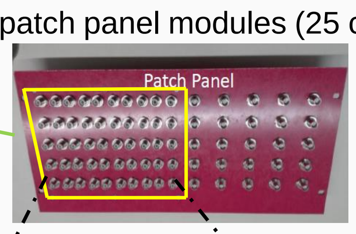
PMTs are connected to the readout electronics and HV system located in the counting room by means of 30 m coaxial cables with separate grounding for signal and high voltage cable lines.

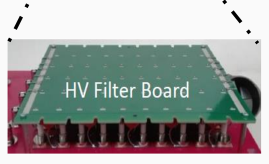
NV rack





5 patch panel modules (25 ch)





CAEN HV

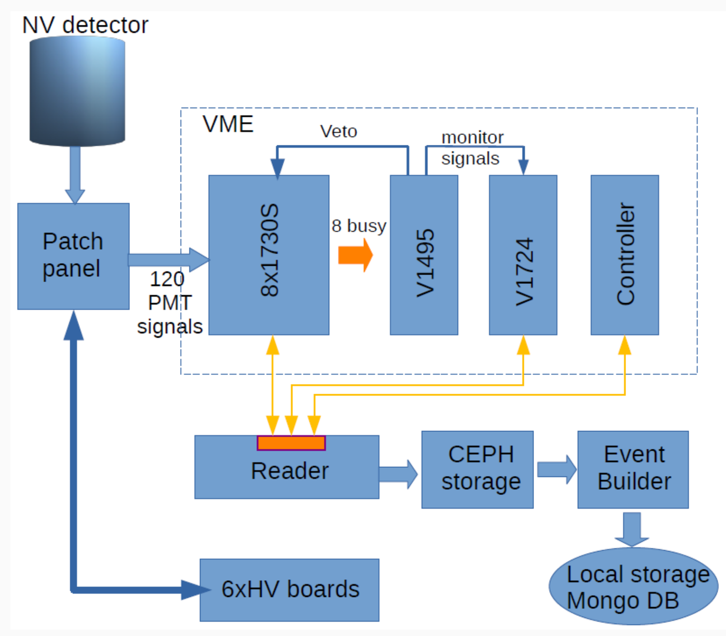
HV lines are low-pass filtered to reduce high frequency noise (> MHz) and connected to the HV system (CAEN SY4527/A7435SP)

Triggerless architecture

NV DAQ is designed around a triggerless data collection scheme:
- pulse shape and timestamp for PMT signals allows the data collection with fully independent channels without the use of a global trigger
- event building, implemented in software on dedicated servers, is based on timestamps and coincidences between PMTs to define events.

VME crate

- ➢8 CAEN **V1730S** boards
  - 6U VME 16-ch, 14-bit 500 MHz flash ADC
  - input dynamic range 2 V or 0.5 V with 16-bit DAC to set DC offset
  - accessed via an optical link based on CONET interface
- ➢1 CAEN **V1724** board
  - acquisition monitor channels
- ➢1 CAEN **V2718** board
  - generates and distributes several control signals to the digitizers
- ➢1 CAEN **V1495** board
  - manages the V1730S busy signals and the veto logic



Firmware and digitizer operation

Digitizers are operated with DPP-DAW firmware ➔ **self-trigger mode** with independent data acquisition on each channel
- Trigger threshold: 15 LSB →amplitude ~1.8 mV (~0.3 PE th.)
- Pre-Trigger: 32 samples (@ 2ns)
- Minimum Record Length : 70 samples

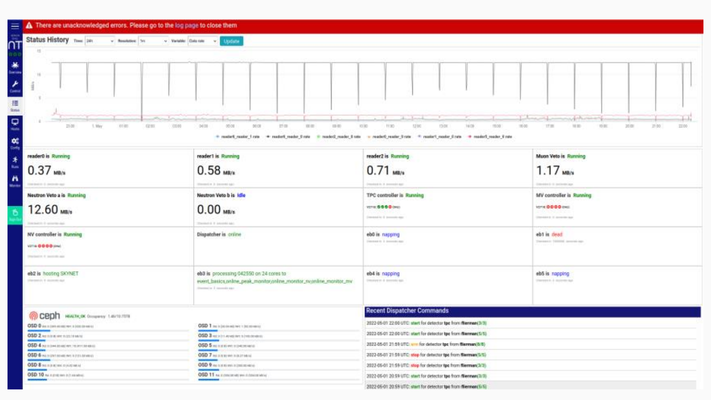
Readout server

- ➢equipped with CAEN A3818 PCIe interface card (4 optical links)
  - manage data collection and control (each link up to 90 MB/s)
- ➢custom software to read data in block transfers via the CAENVMElib
  - processing thread compresses the digitizer-native format data and writes it to the Ceph buffer for online processing (event building and event definition)

Linked mode

NV DAQ has been fully integrated with TPC and Muon Veto DAQ systems. These are operated as a unique system and share the same 50 MHz clock reference and two common signals (start-of-run and synchronization signals)

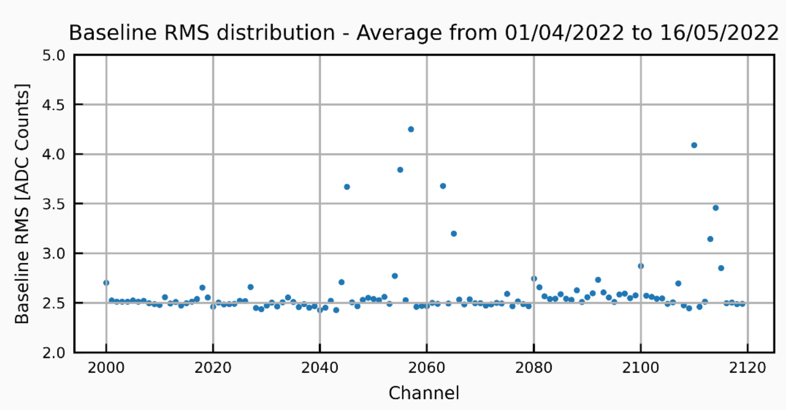
Commissioning and Science Runs (SR)



A web interface allows the control and monitoring of data taking and of all the live processing in the DAQ system.

- ➢During 2020 and early 2021 NV DAQ system was successfully commissioned together with the other sub-systems (TPC and Muon Veto) as designed.
- ➢The DAQ system collected more than 6 months of data during the first Science Run (SR0, 2021).
- ➢NV DAQ system has also been operated to collect calibration data.

Tuning and optimization



- ➢Noise levels in all the NV channels have been measured and monitored
- ➢Most of the channels (apart 10/120) have an RMS of the baseline below 3 ADCcounts

Conclusions

The DAQ of the Neutron Veto system for XENONnT experiment at LNGS has been designed around a triggerless data collection scheme allowing a continuous data stream of independent channels. The event building is then implemented in software. This design also gives the possibility to use the full dataset to monitor the performance of the detector.
A good time resolution, that is required to properly identify each SPE, is achieved by means of CAEN V1730S fast digitizers with a sampling rate of 500 MHz.
Neutron Veto DAQ system has been successfully commissioned at LNGS and integrated within the overall DAQ environment and is now in a stable data taking in preparation for SR1.

References:

www.xenonnt.org
www.caen.it

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