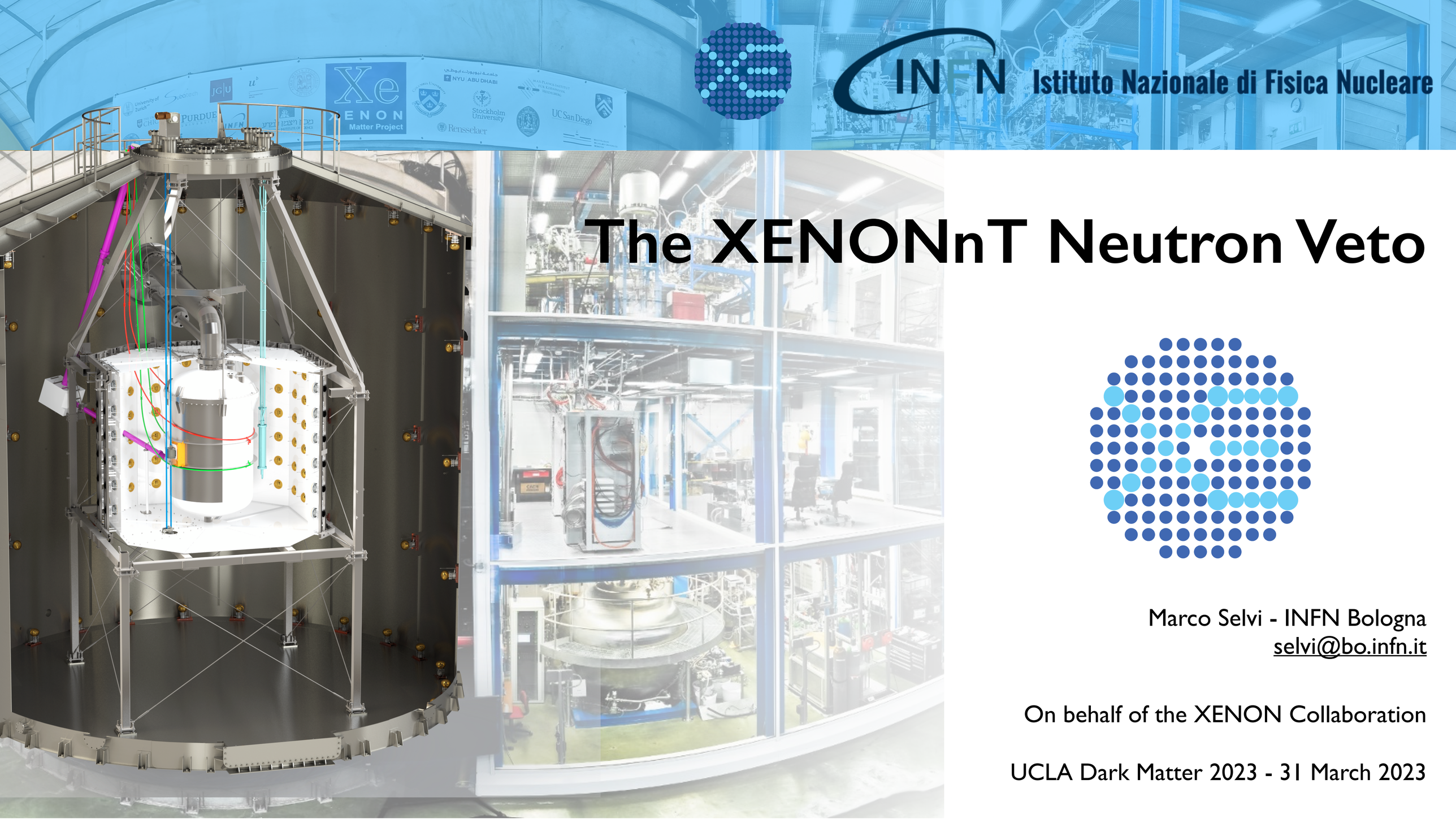


The XENONnT Neutron Veto

Marco Selvi - INFN Bologna
selvi@bo.infn.it

On behalf of the XENON Collaboration

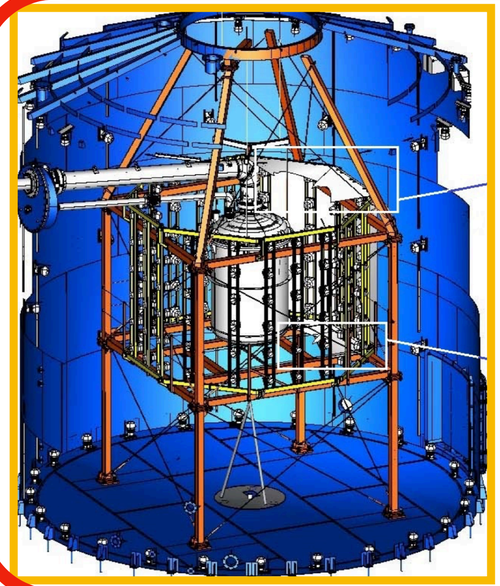
UCLA Dark Matter 2023 - 31 March 2023

XENONnT: main upgrades

Marco Selvi | selvi@bo.infn.it

Larger TPC

Total 8.5 t LXe
5.9 t in TPC
~ 4 t fiducial
248 → 494 PMTs



Neutron veto

Inner region of existing muon veto optically separated
120 additional PMTs
Gd in the water tank
0.5% $Gd_2(SO_4)_3$

^{222}Rn distillation

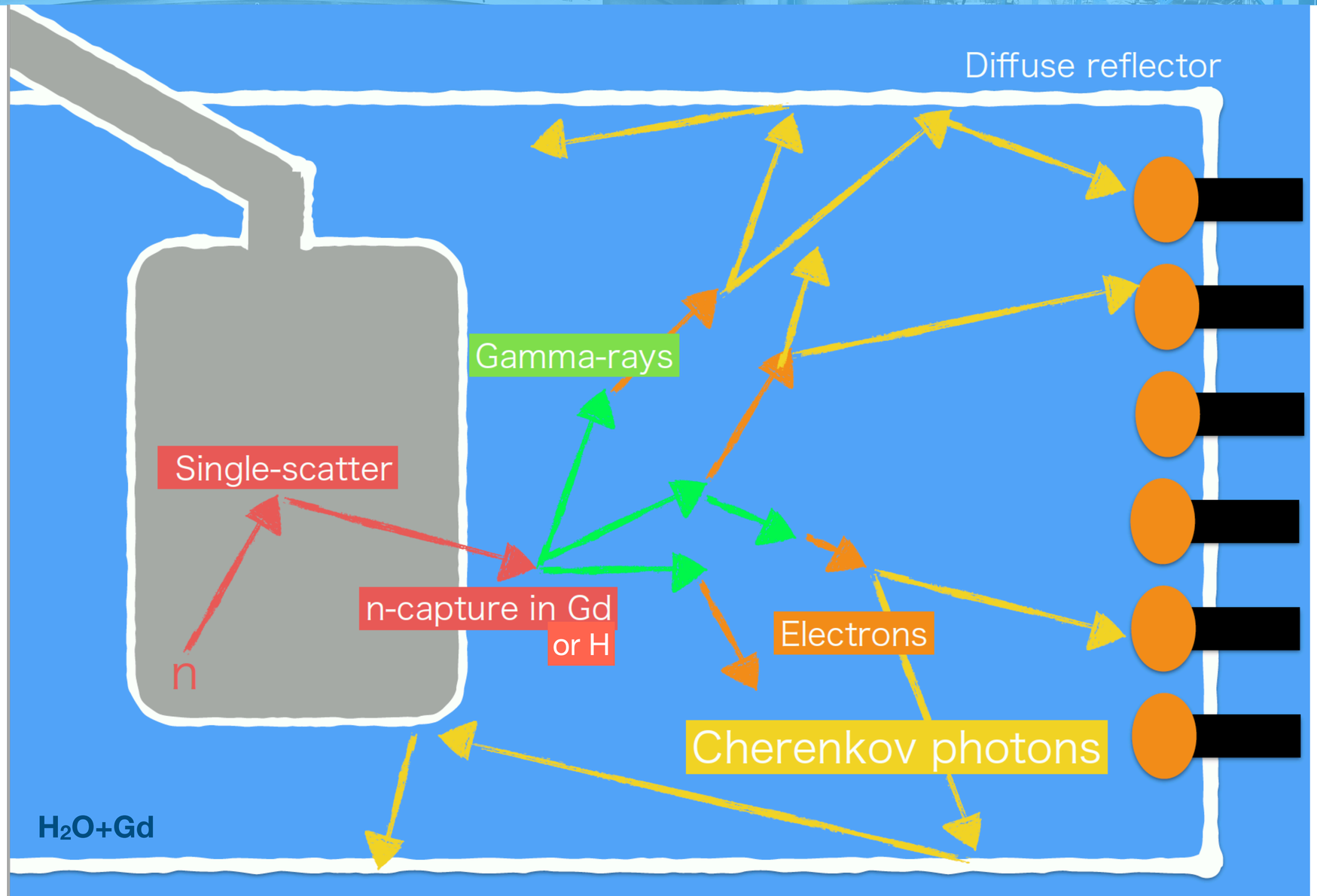
Reduce Rn (^{214}Pb) from pipes, cables, cryogenic system
New system, PoP in XENON1T

LXe purification

Faster xenon cleaning
5 L/min LXe (2500 slpm)
XENON1T ~ 100 slpm

XENONnT Neutron Veto concept

Marco Selvi | selvi@bo.infn.it



XENONnT Neutron Veto concept

Marco Selvi | selvi@bo.infn.it

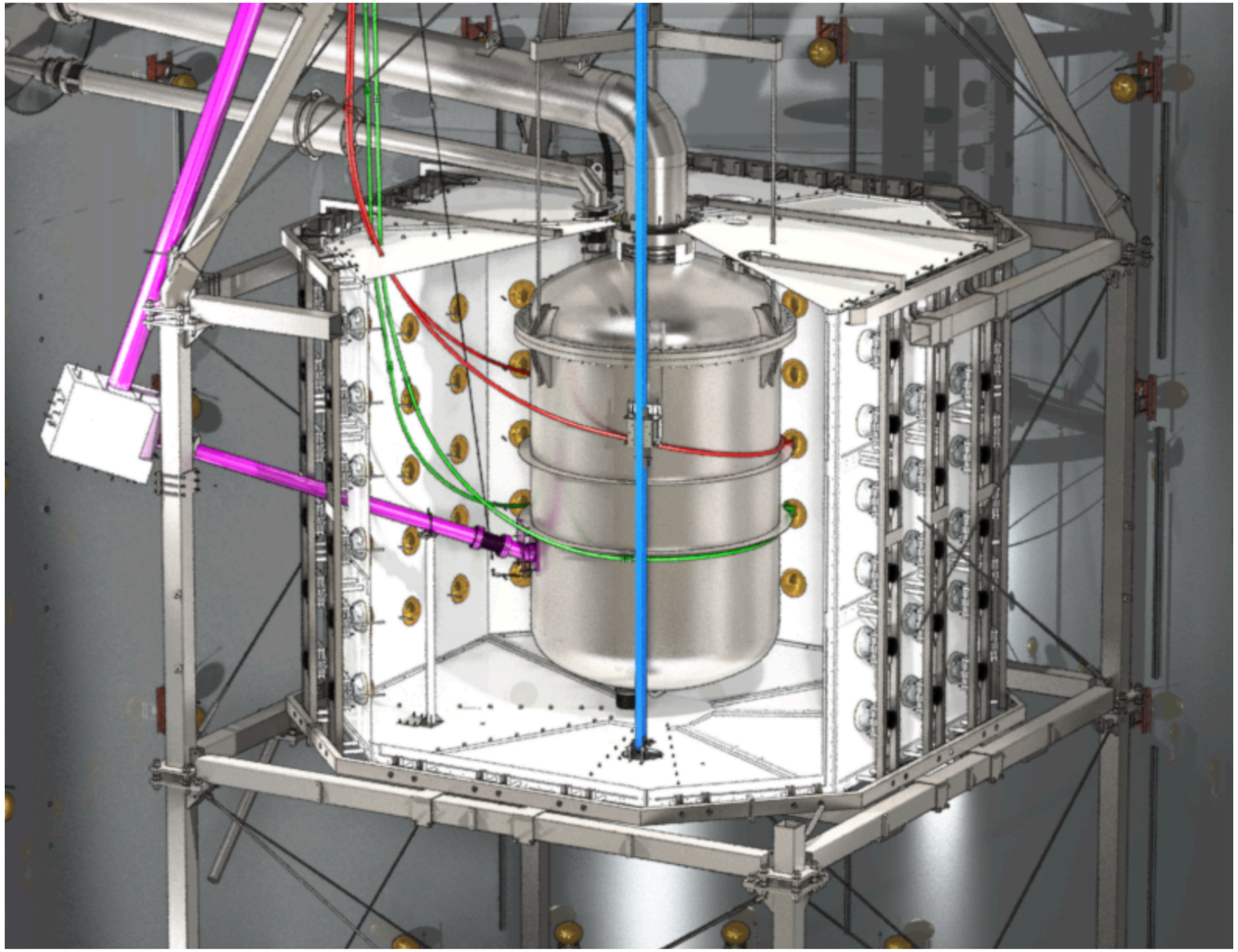
Gd-loaded Water: 0.2% of Gd in mass -> 3.4 t of Gd-sulphate-octahydrate; (technology from EGADS-SK)

Cherenkov light is detected by 120 8” high-QE low-radioactivity PMTs (Hamamatsu R5912) installed in water 1m away from the cryostat;

High-reflectivity ePTFE panels confine an inner nVeto region (33 m^3) with large light-collection efficiency;

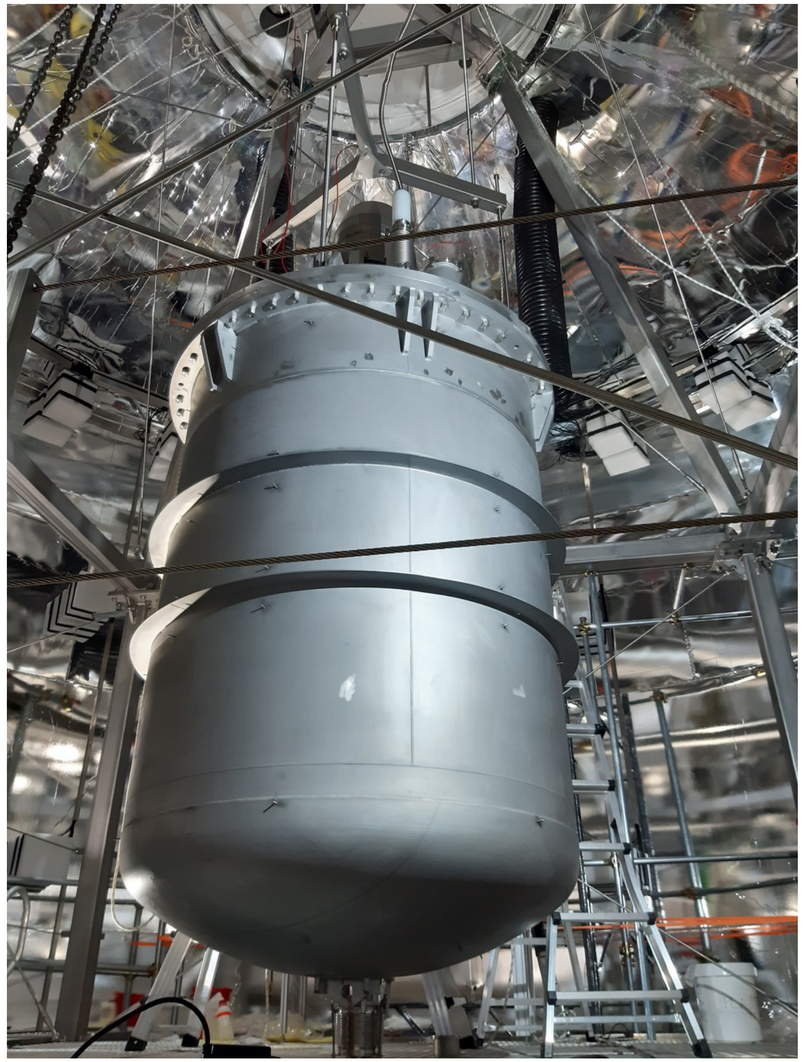
LED calibrations for PMT gain, laser calibrations for transparency monitor.

First Science Run has been performed with demineralzed-water



XENONnT timeline

Marco Selvi | selvi@bo.infn.it



March 2020

- installation of the TPC underground at LNGS, a few days before the first COVID19 lock-down

July-December 2020

Installation of the nVeto

Filling of the cryostat with LXe

Water Tank closed and filled with demi-water

January-June 2021

Commissioning, commissioning, commissioning…

July-November 2021

Science Run 0

in 2022

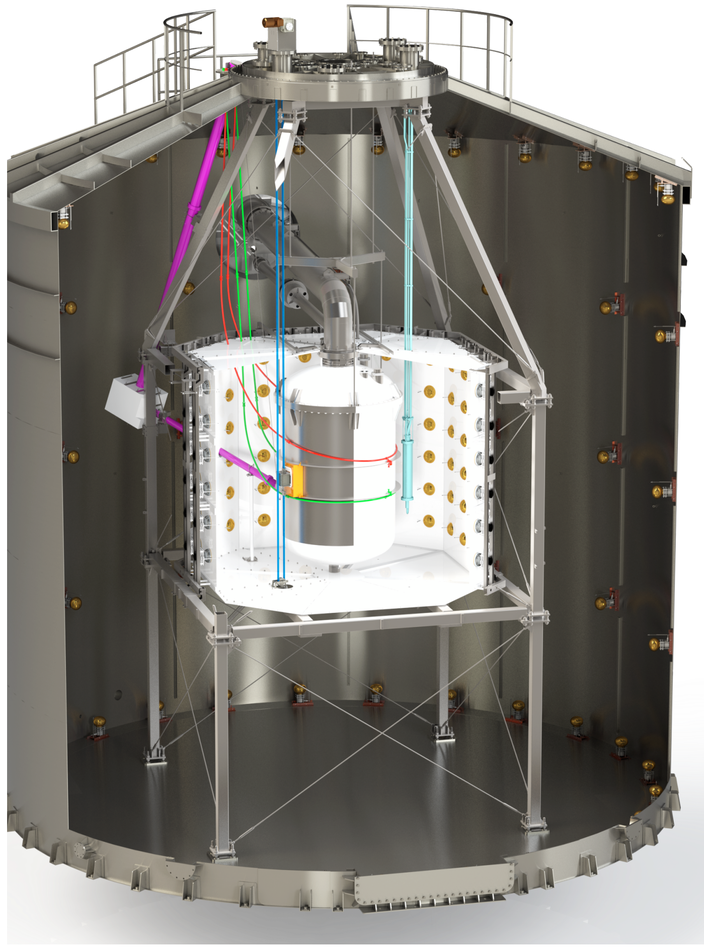
Refurbishment of Rn Distillation Column

Start of Science Run 1, ongoing …

Commissioning of the GdWater Purification Plant with demi-water

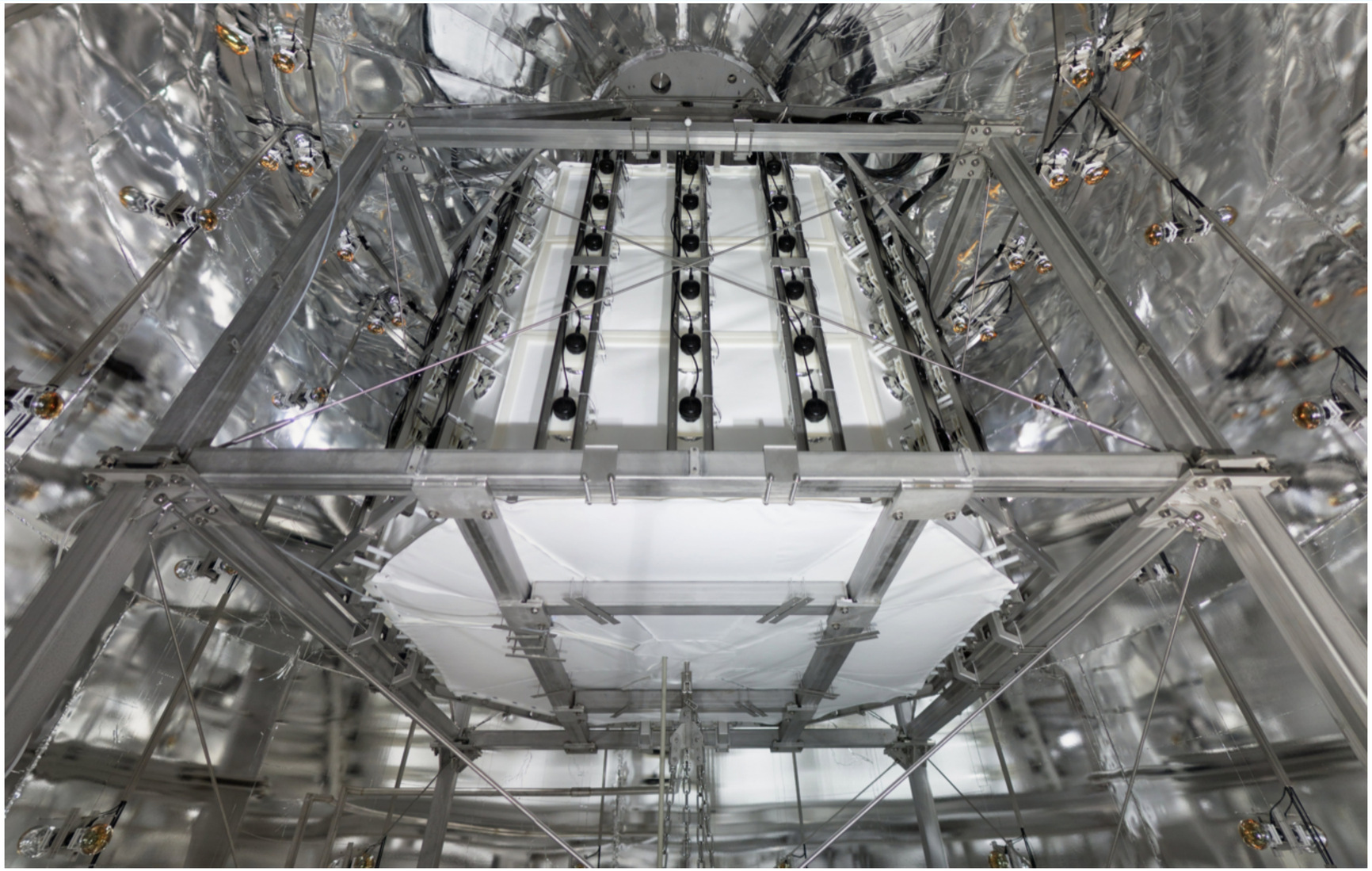
in 2023

First insertion of Gd-Sulphate in the GdPlant



XENONnT Neutron Veto: some pictures

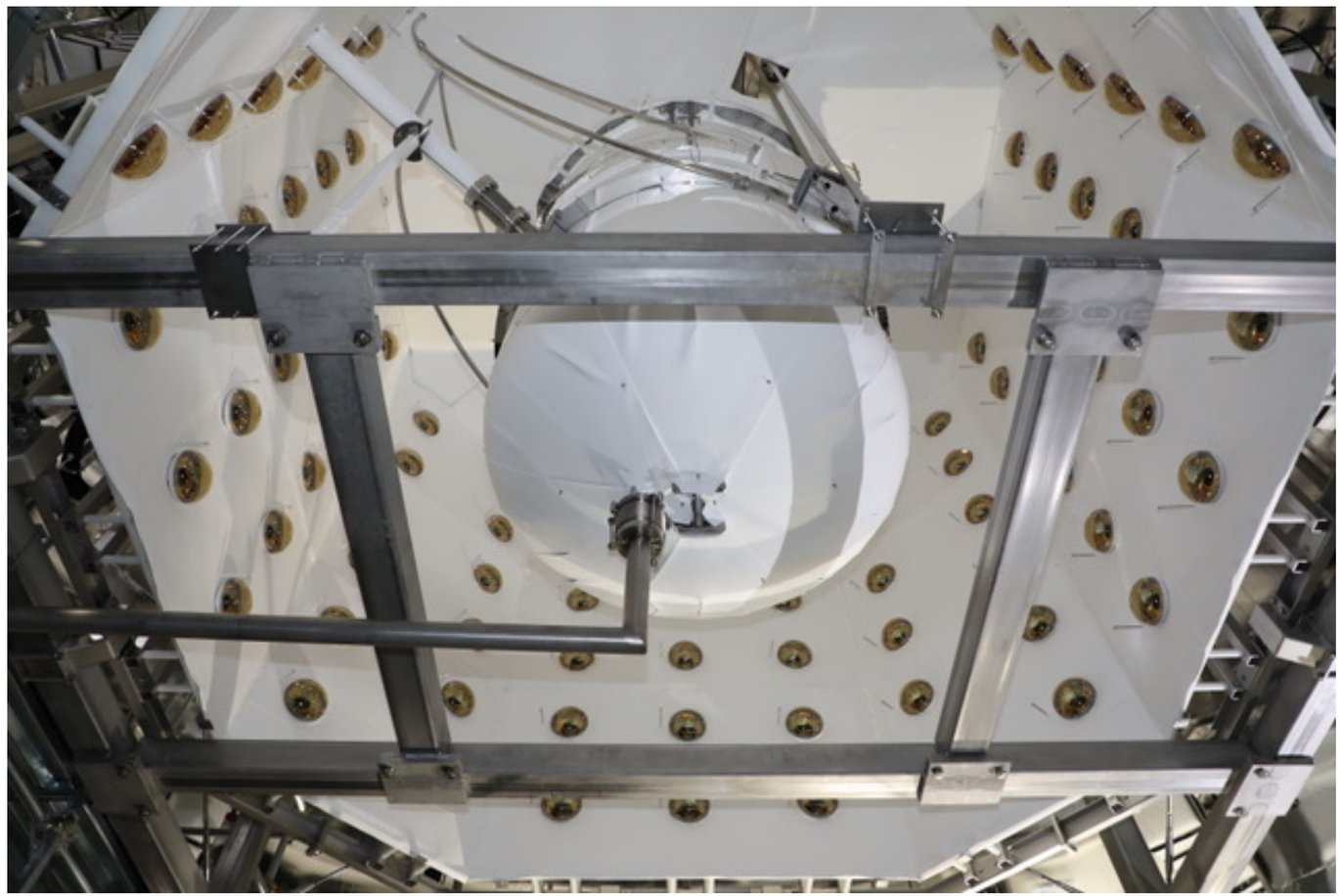
Marco Selvi | selvi@bo.infn.it



…a Baptistery inside the Cathedral

XENONnT Neutron Veto: some pictures

Marco Selvi | selvi@bo.infn.it



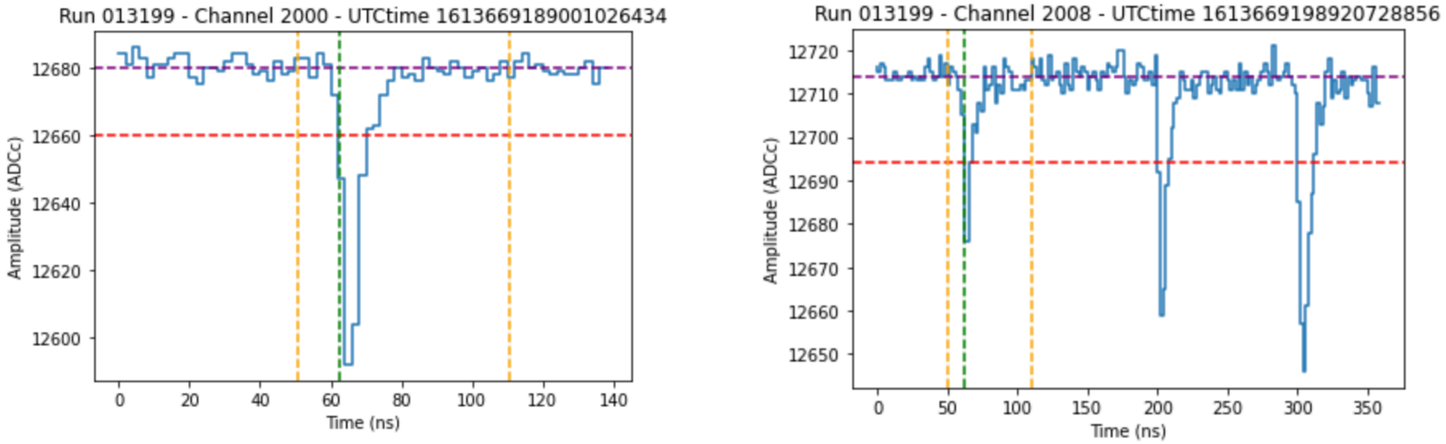
https://www.nature.com/articles/d41586-020-02741-3

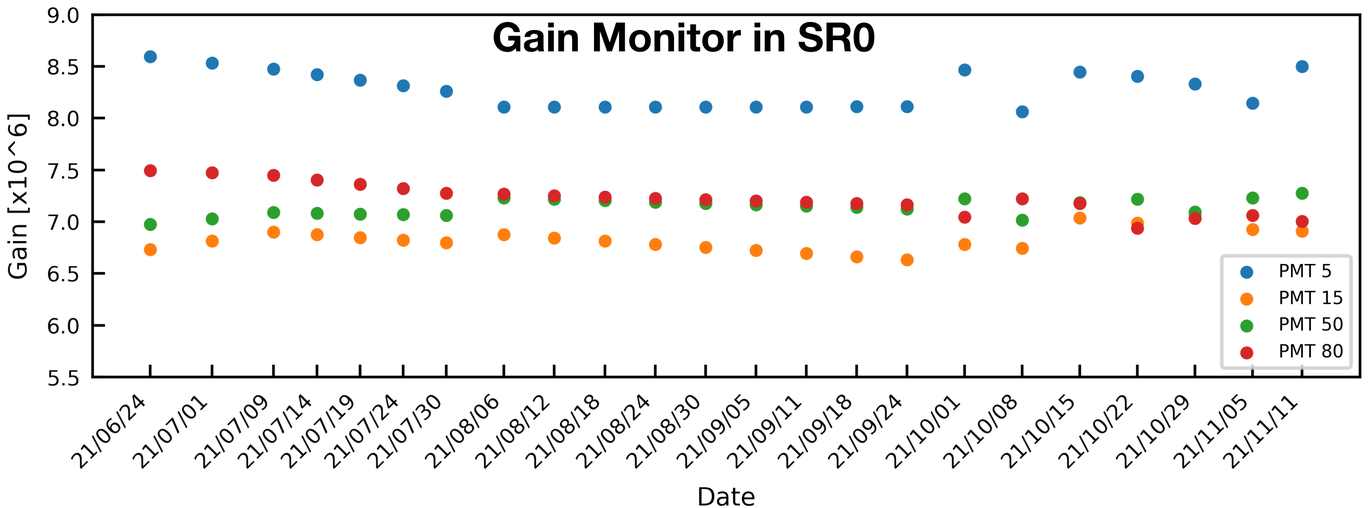
XENONnT Neutron Veto: PMTs and DAQ

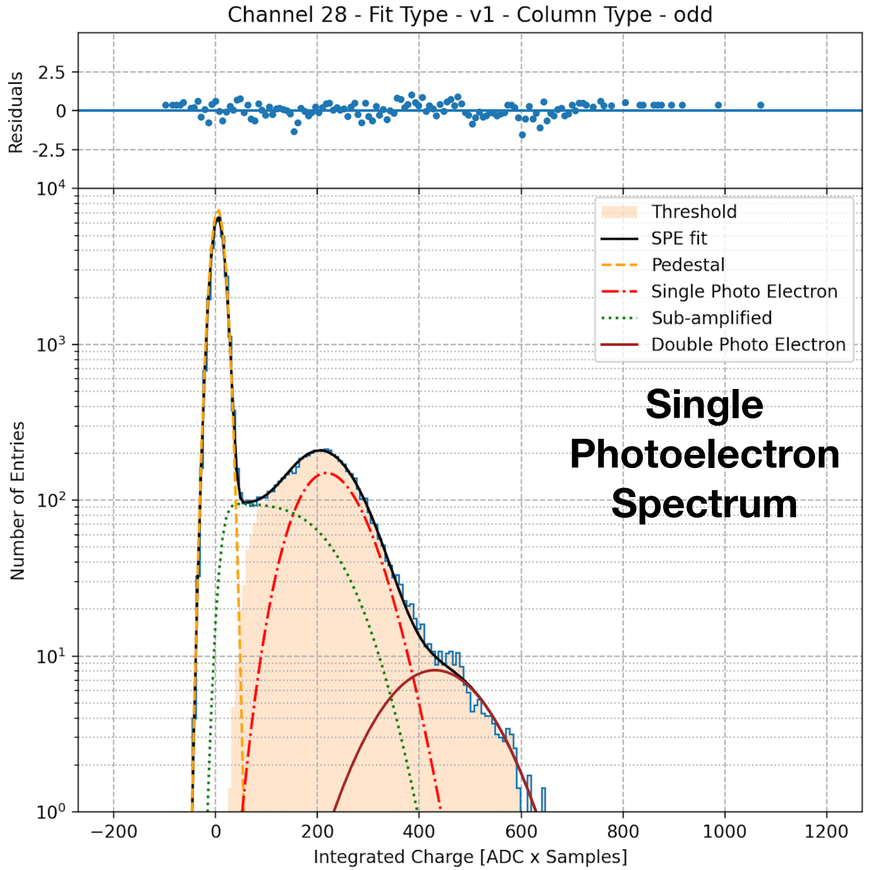
Marco Selvi | selvi@bo.infn.it

- Digitizers CAEN V1730: 2 ns sampling, 14 bit resolution.
- Data Acquisition in Self-Trigger mode, Threshold 15 ADC counts.
- All 120 PMTs and channels are working very well, with RMS of baseline <3.

Example Waveforms





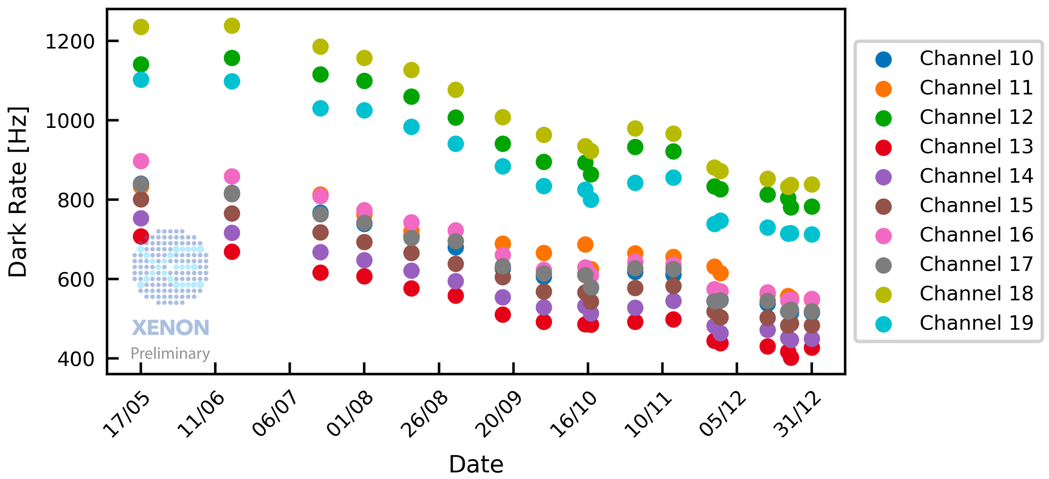


- PMT gains are monitored via weekly LED calibrations.
- Gains were stable within 5% for the whole Science Run 0

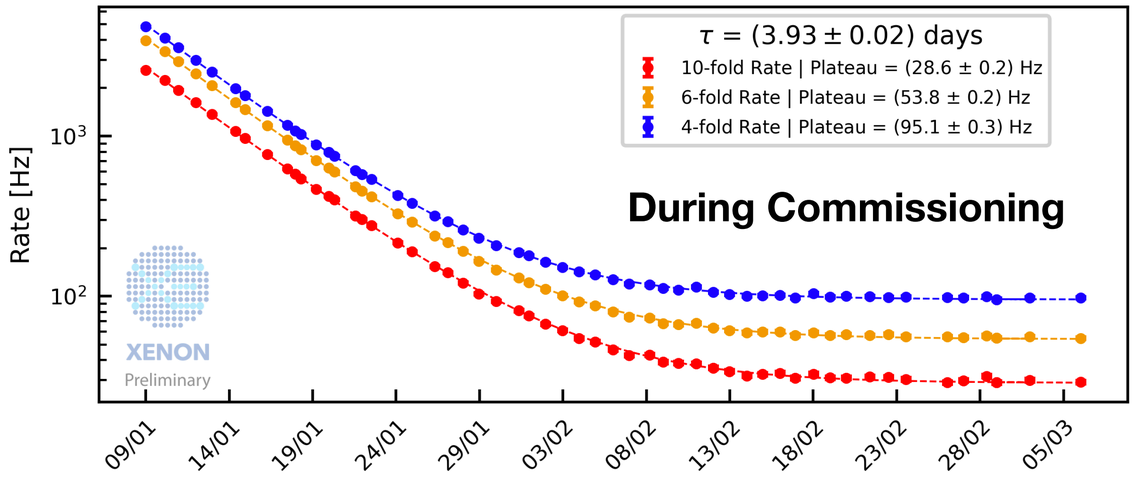
XENONnT Neutron Veto: background rate

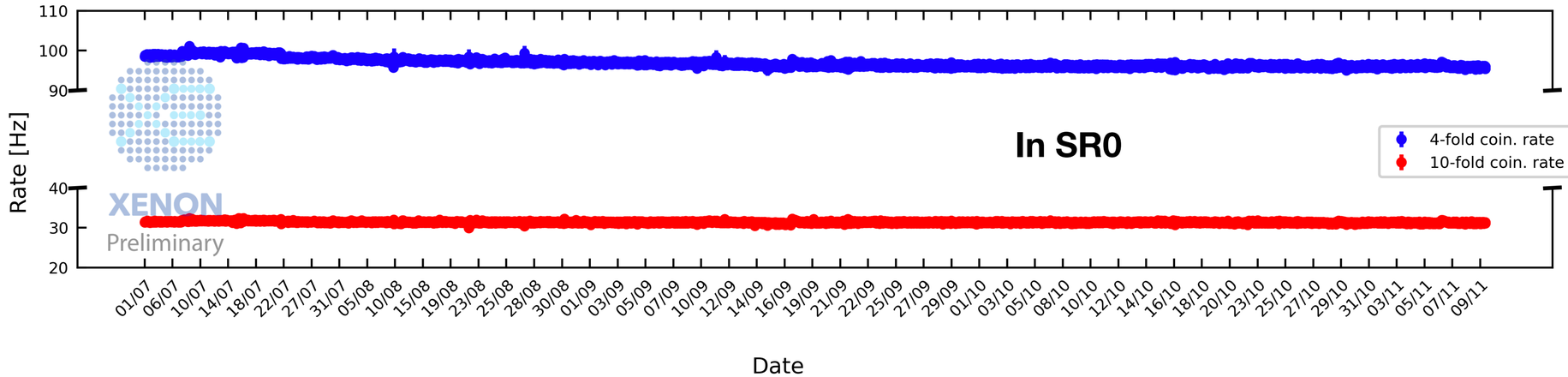
Marco Selvi | selvi@bo.infn.it

PMT dark rate during SR0



nVeto coincidence rate (inside 300 ns)





- Low dark rate in each PMT: O(1kHz)
- Initial decrease of coincidence rate due to Rn-decay in water
- Plateau at <100 Hz with a 4-fold requirement (due to gammas from the radioactivity of the materials close to the nVeto)
- Deadtime induced in the TPC due to accidental coincidences with the nVeto = 100 Hz x 500 us -> 5%

Neutron calibration with AmBe

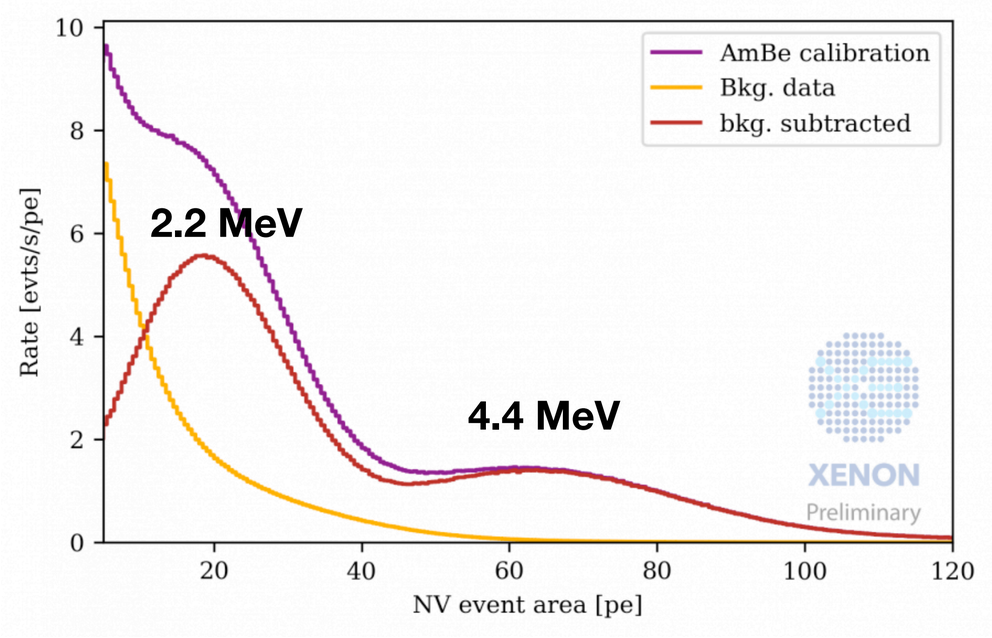
Marco Selvi | selvi@bo.infn.it

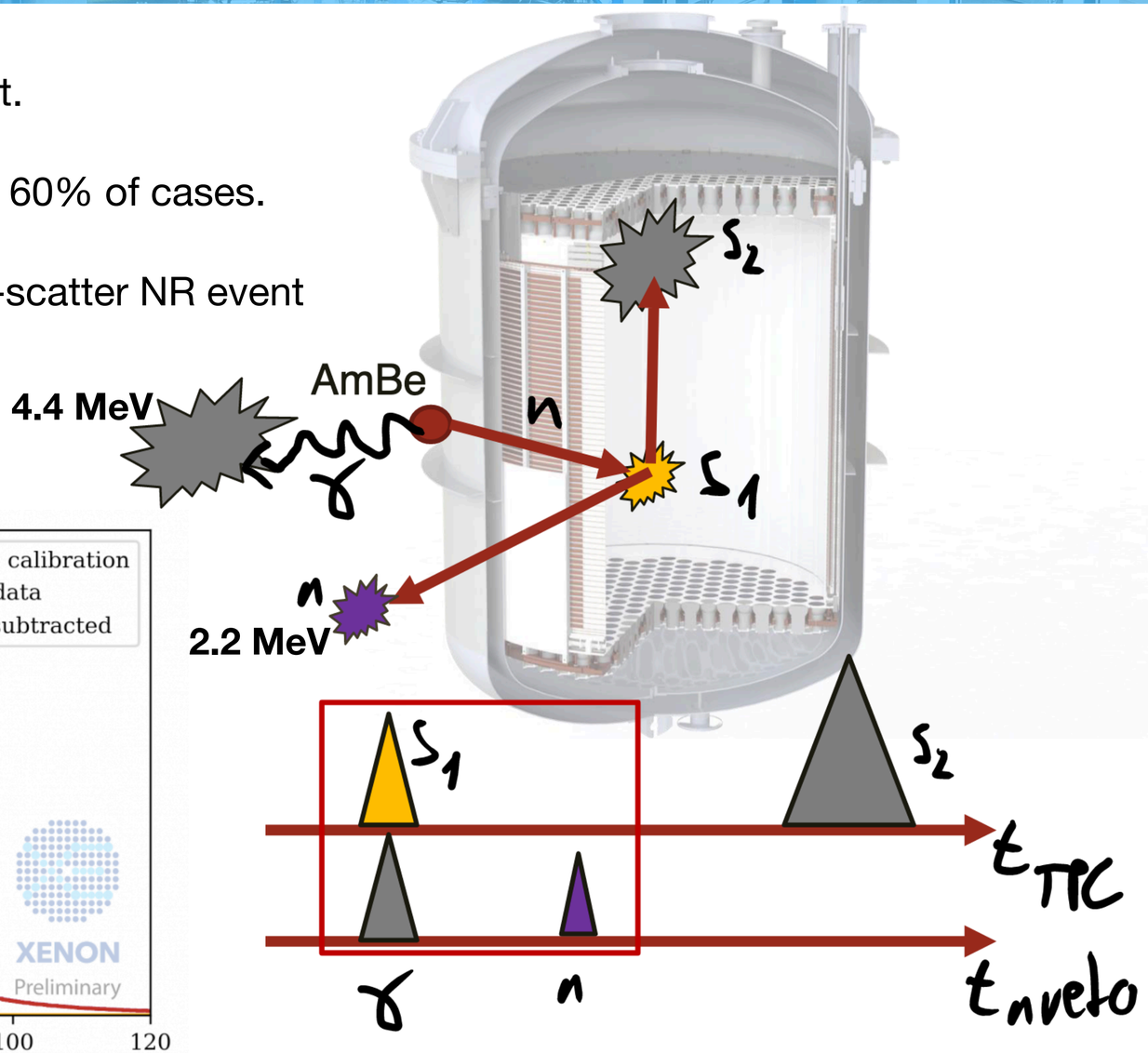
- Neutron calibration with AmBe source placed close to the cryostat.

- AmBe emits a 4.4 MeV gamma together with the neutron in about 60% of cases.

- Detect the 4.4 MeV gamma, require the coincidence with a single-scatter NR event in the TPC, and look for the 2.2 MeV gamma of neutron capture in the nVeto.

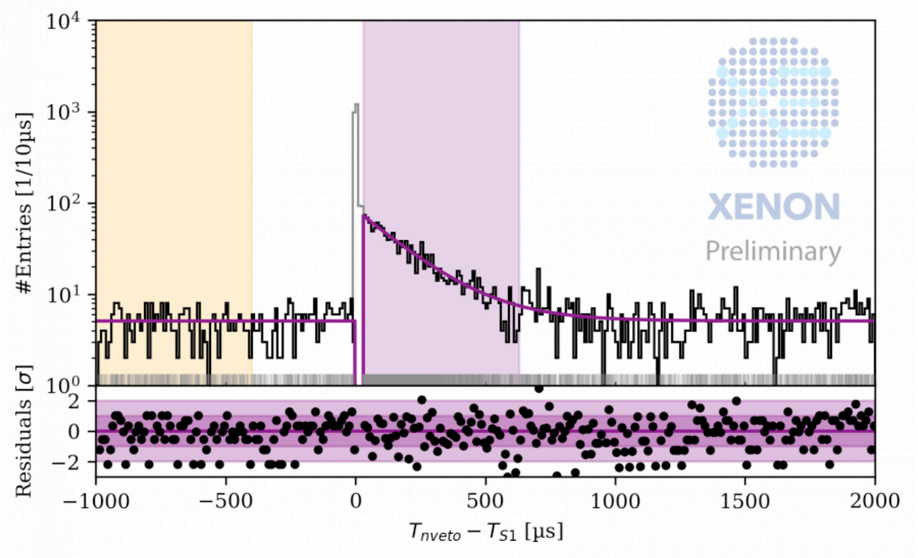
- Direct measurement of the neutron tagging efficiency of the nVeto (the event pattern is the same of dangerous neutrons produces by detector's materials)

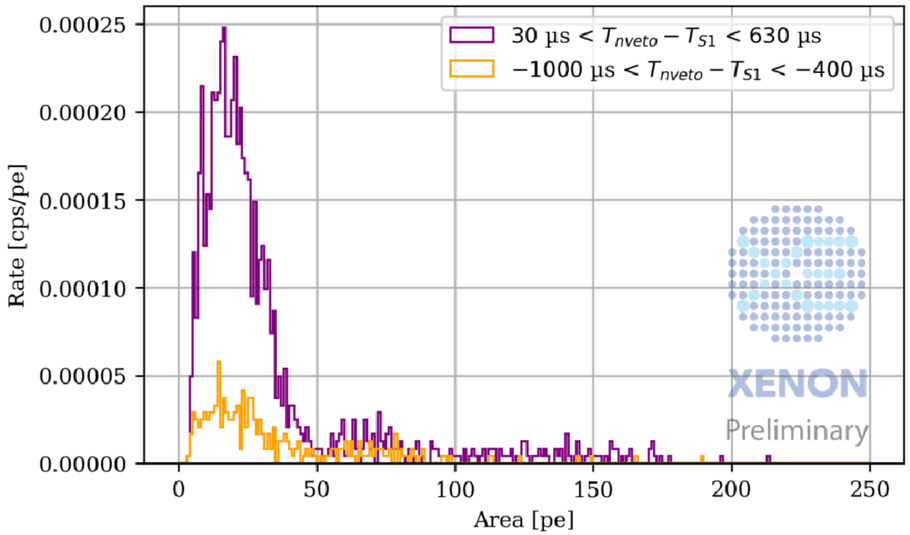




Neutron calibration with AmBe

Marco Selvi | selvi@bo.infn.it



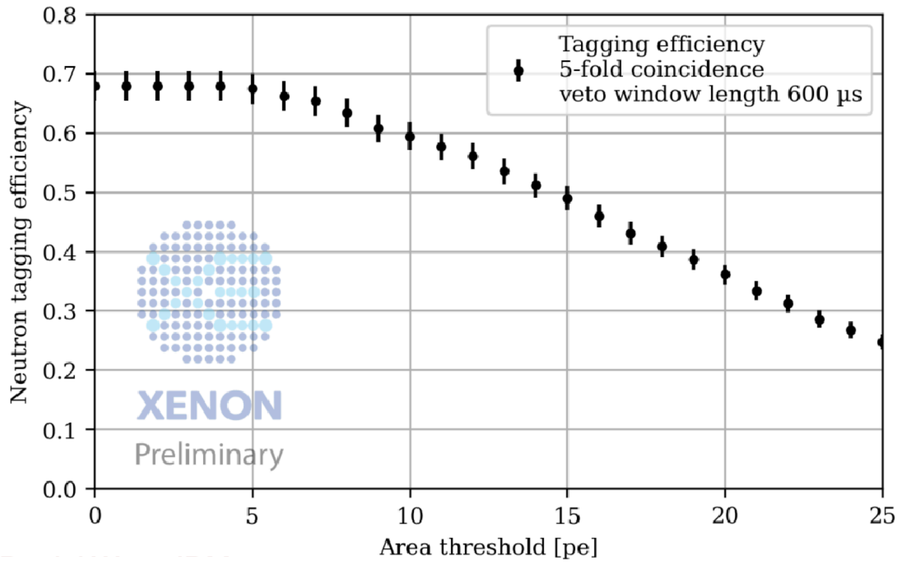


- Average capture time in demi-water: $(180 \pm 8)\mu s$

- The 2.2 MeV gamma peak corresponds to about 20 detected pe.

- Neutron Tagging efficiency (after background subtraction): $(68 \pm 3)\,\%$
(at 5-fold coincidence, 5 pe threshold, 600 us time window)

To our knowledge, this corresponds to the highest neutron detection efficiency ever obtained in a water Cherenkov detector (paper in preparation).



In Science Run 0 we decided to shorten the time window to 250 us, to reduce the induced dead time.
The efficiency becomes $(53 \pm 3)\,\%$, and the live-time lost is 1.6%.

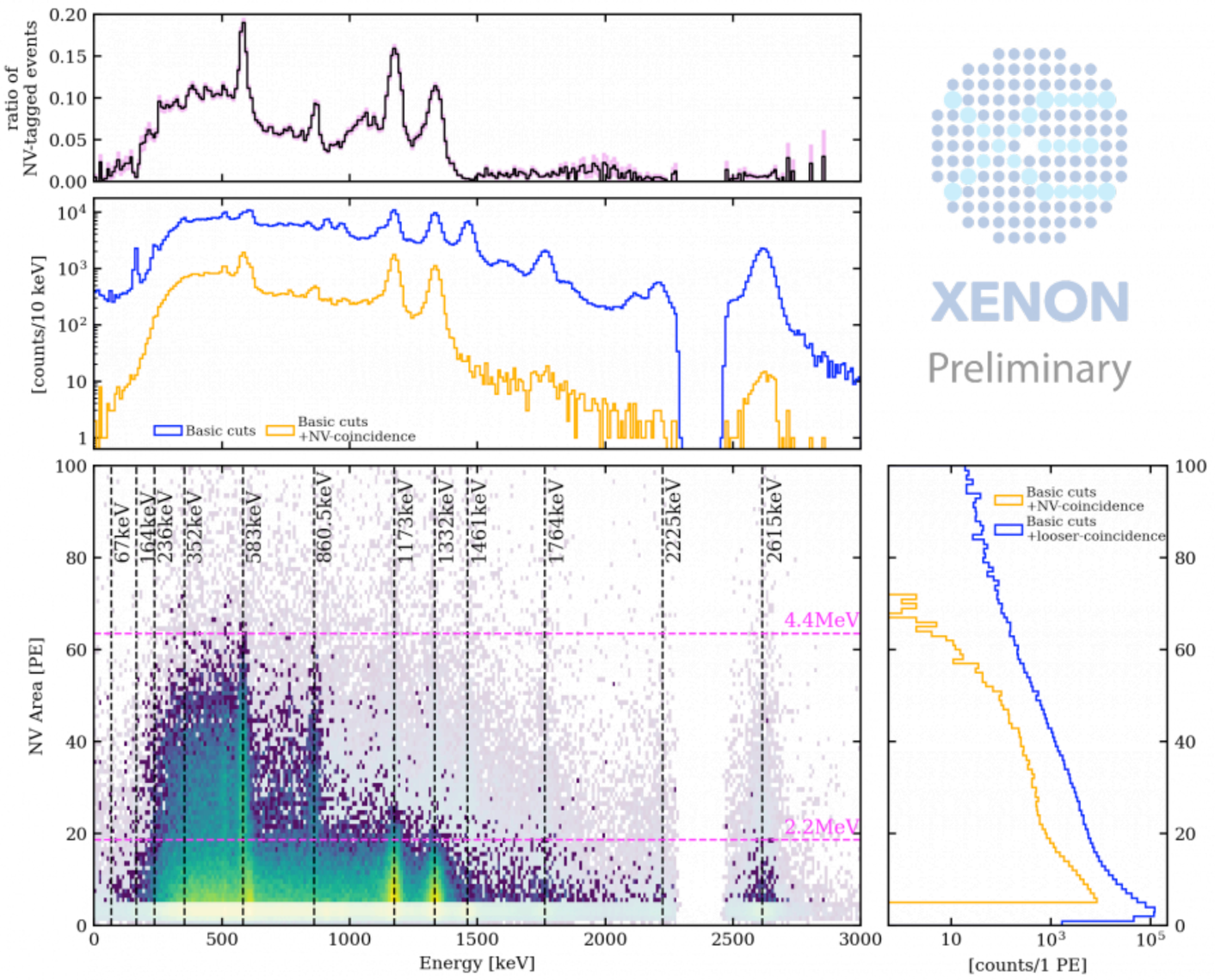
Neutron Veto in Science Run 0

Marco Selvi | selvi@bo.infn.it

In the search for **Electronic Recoil** events, the nVeto has been used to tag part of the gammas from material radioactivity, as ^{60}Co and ^{208}Tl, that present some energy deposit in the nVeto together with the one in the TPC.

- Reduction about 10% for ER background from materials.

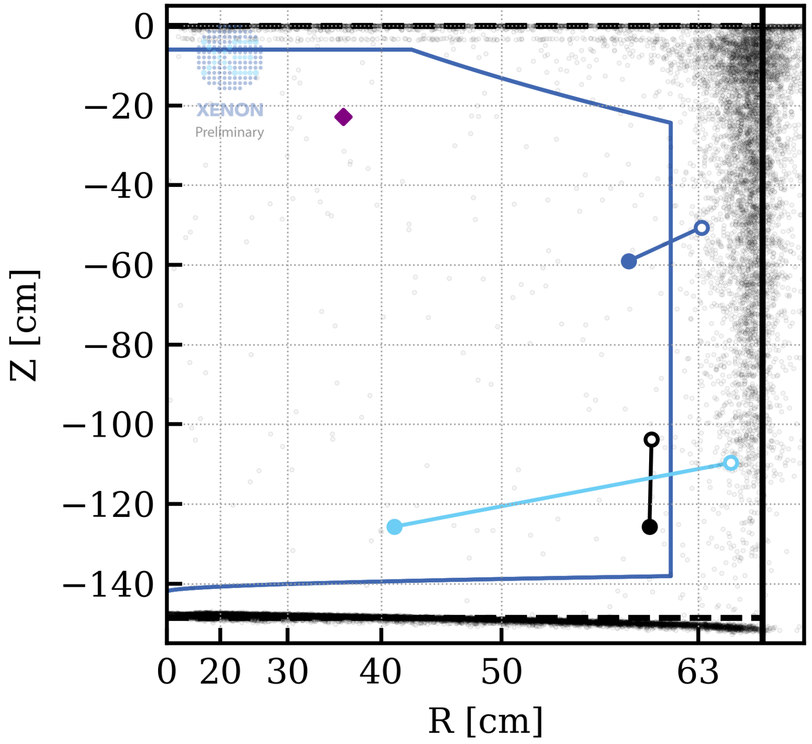
- Clear and effective demonstration of the low energy threshold of the neutron veto.

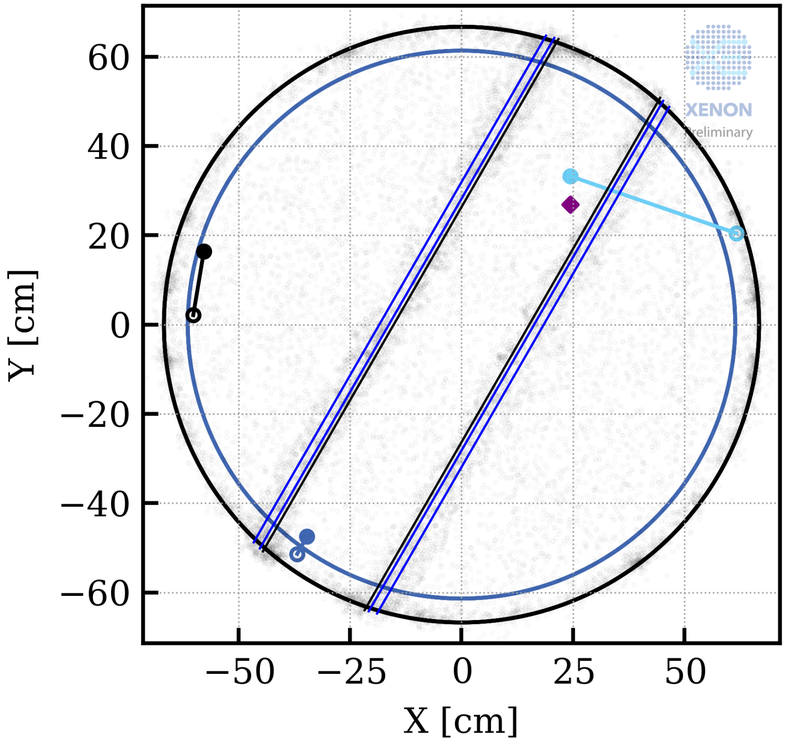


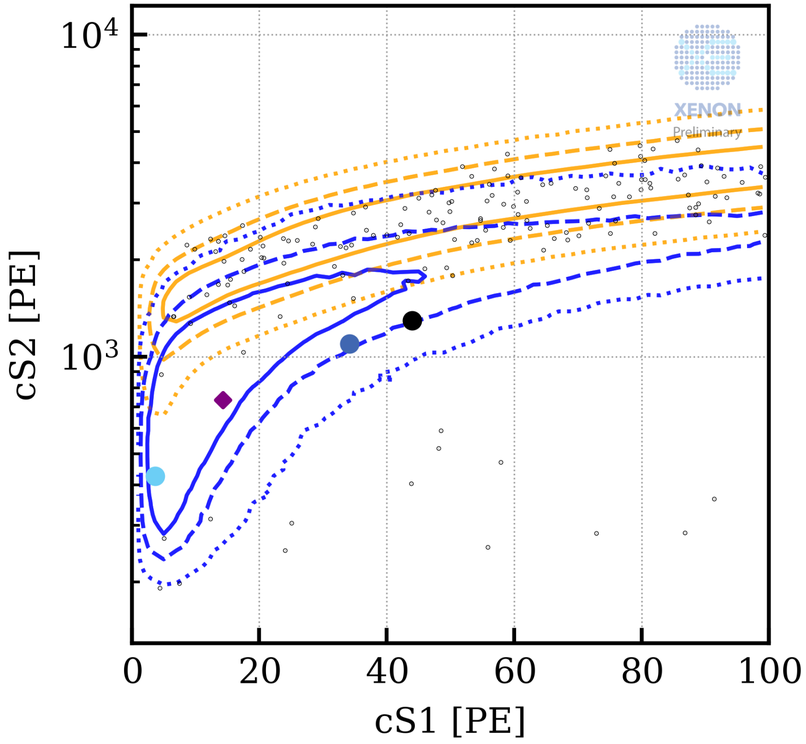
Neutron Veto in Science Run 0

Marco Selvi | selvi@bo.infn.it

In the search for **Nuclear Recoil** events, the nVeto has been used to tag multiple and single scatter NR events in the TPC, to obtain a data-driven estimation of the neutron background.



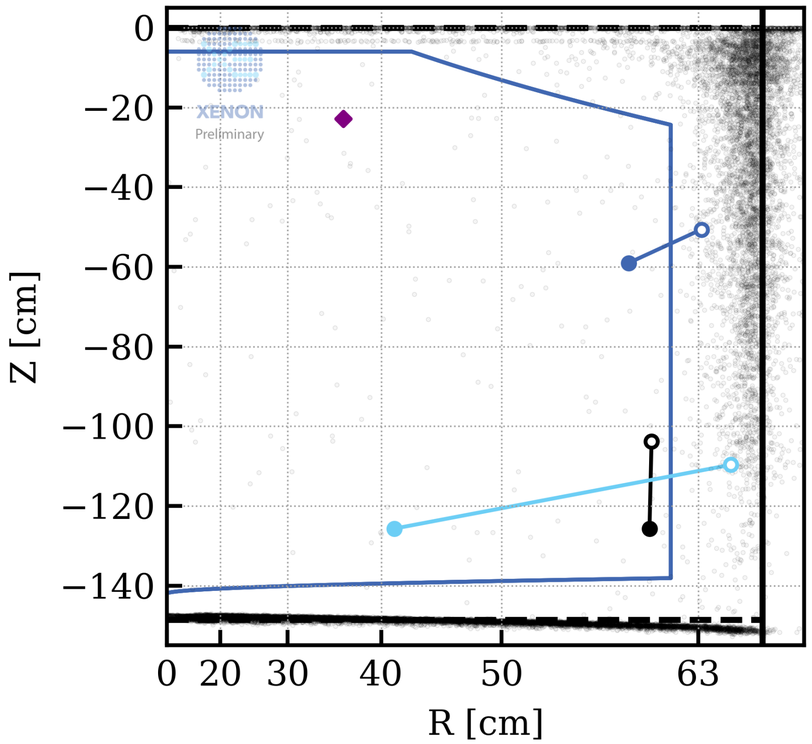


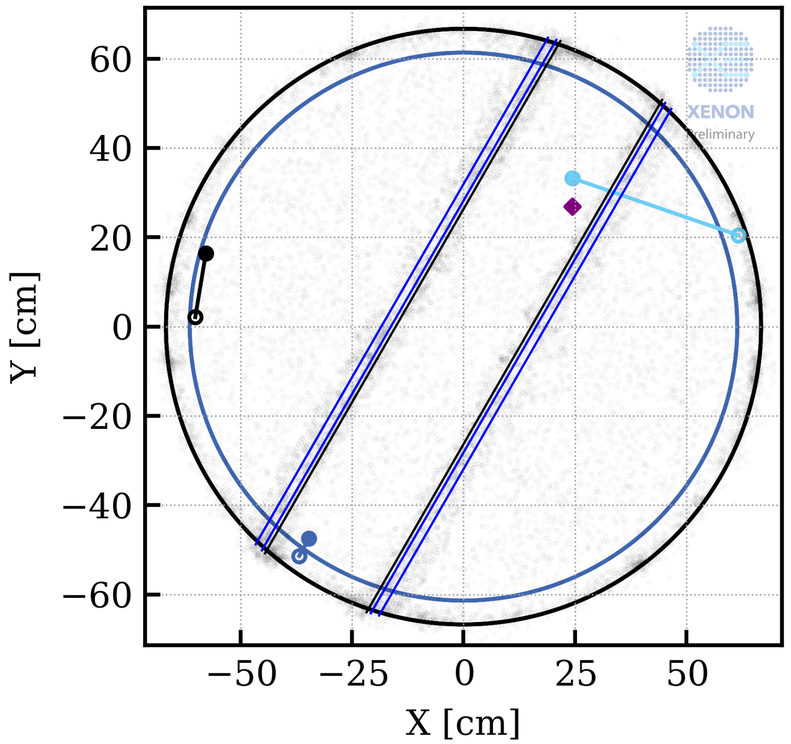


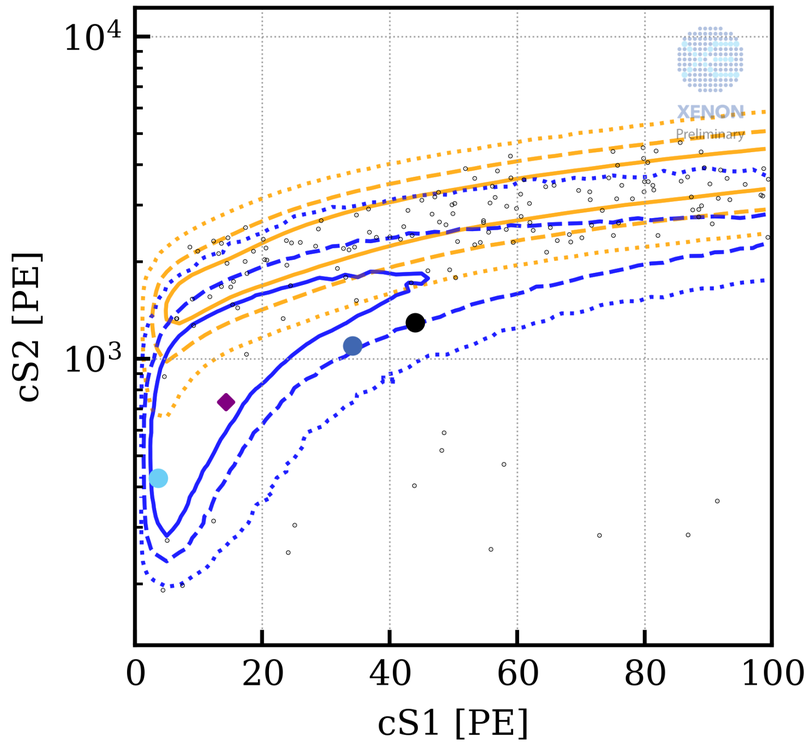
Neutron Veto in Science Run 0

Marco Selvi | selvi@bo.infn.it

In the search for **Nuclear Recoil** events, the nVeto has been used to tag multiple and single scatter NR events in the TPC, to obtain a data-driven estimation of the neutron background.







Considering the 3 multiple scatter + 1 single scatter events, **nVeto-tagged,** with the primary S2 inside the fiducial volume, and the MS/SS ratio of ~ 2.5, obtained from MC and validated with AmBe data + the 53% nVeto tagging efficiency, **we obtained the neutron background prediction of** (1.1 ± 0.5) **neutron-induced events in SR0**.

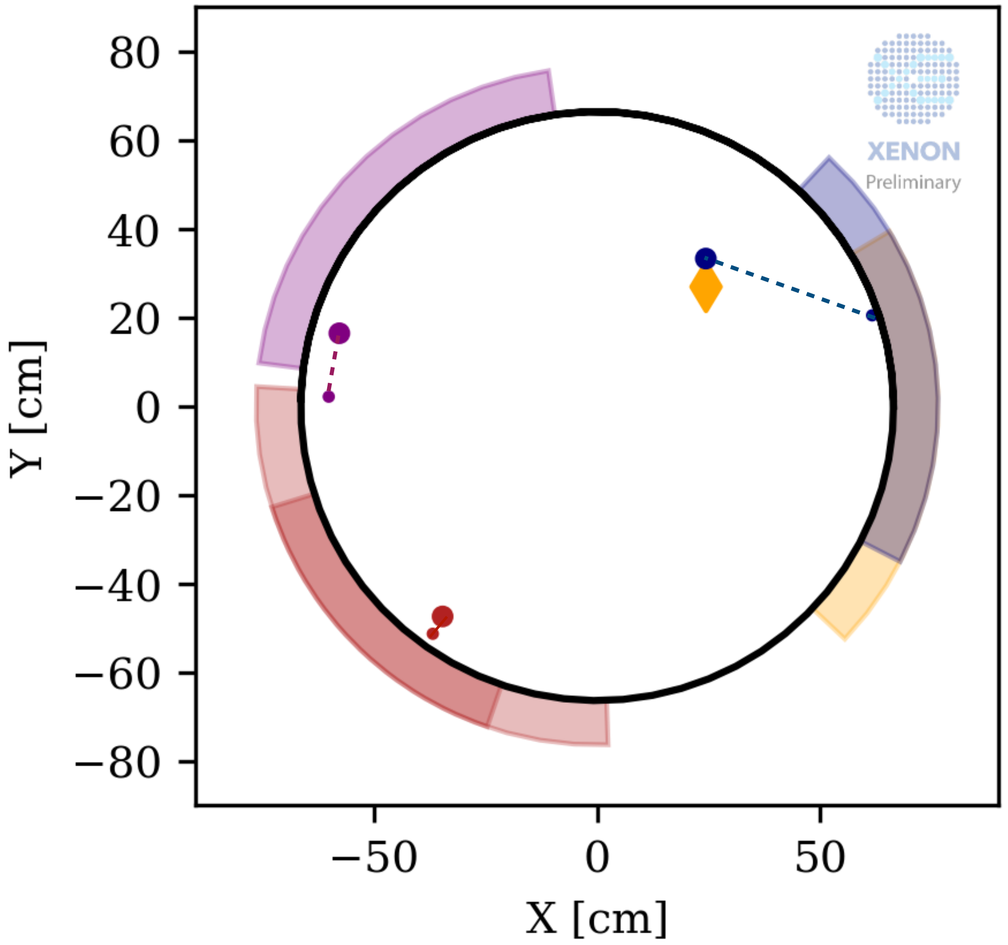
This measurement is x6 larger than MonteCarlo predictions, based on material screening: checks are ongoing to explain the discrepancy.

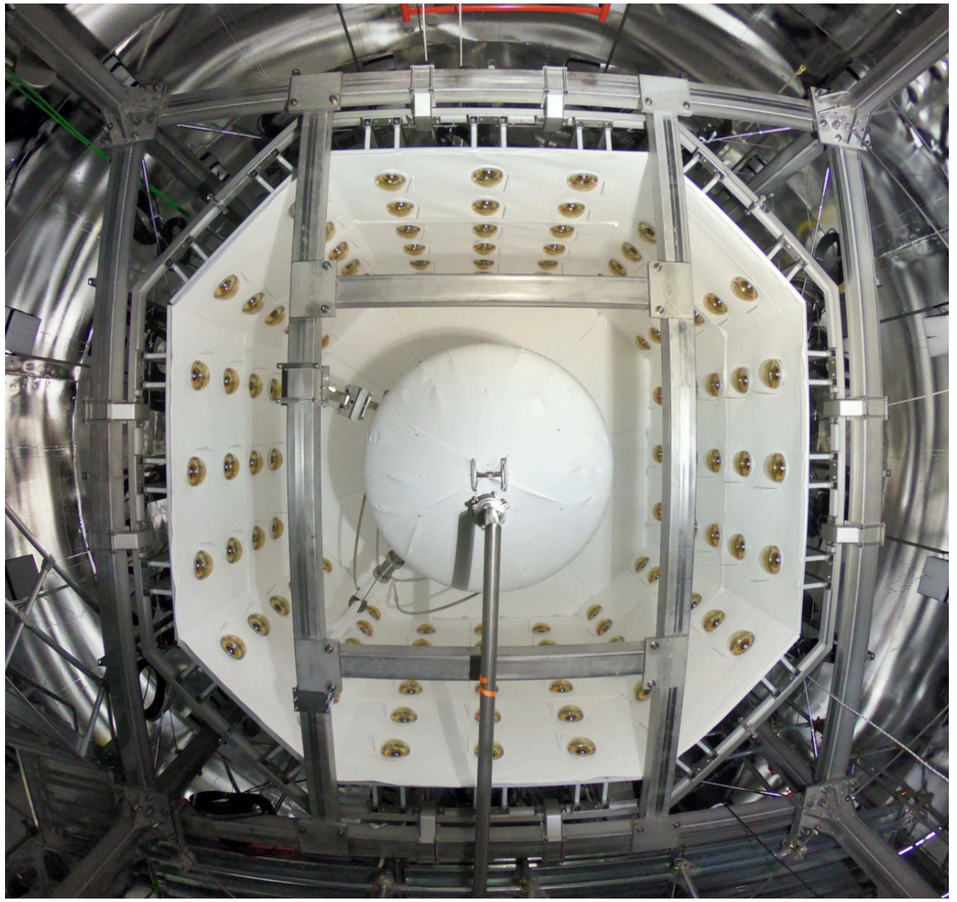
Neutron Veto in Science Run 0

Marco Selvi | selvi@bo.infn.it

- The angular position of events in the Neutron Veto can be obtained by the first hits in the PMTs

- Agreement between position in the TPC and the Neutron Veto



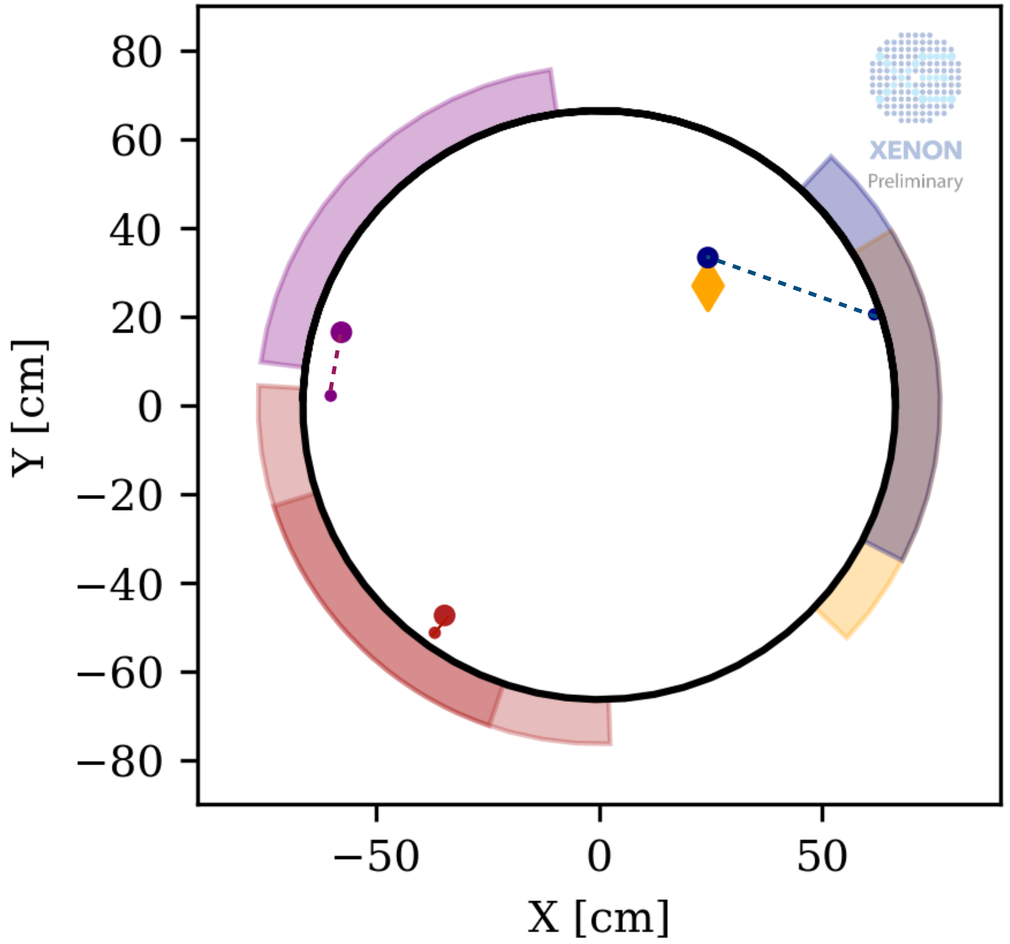


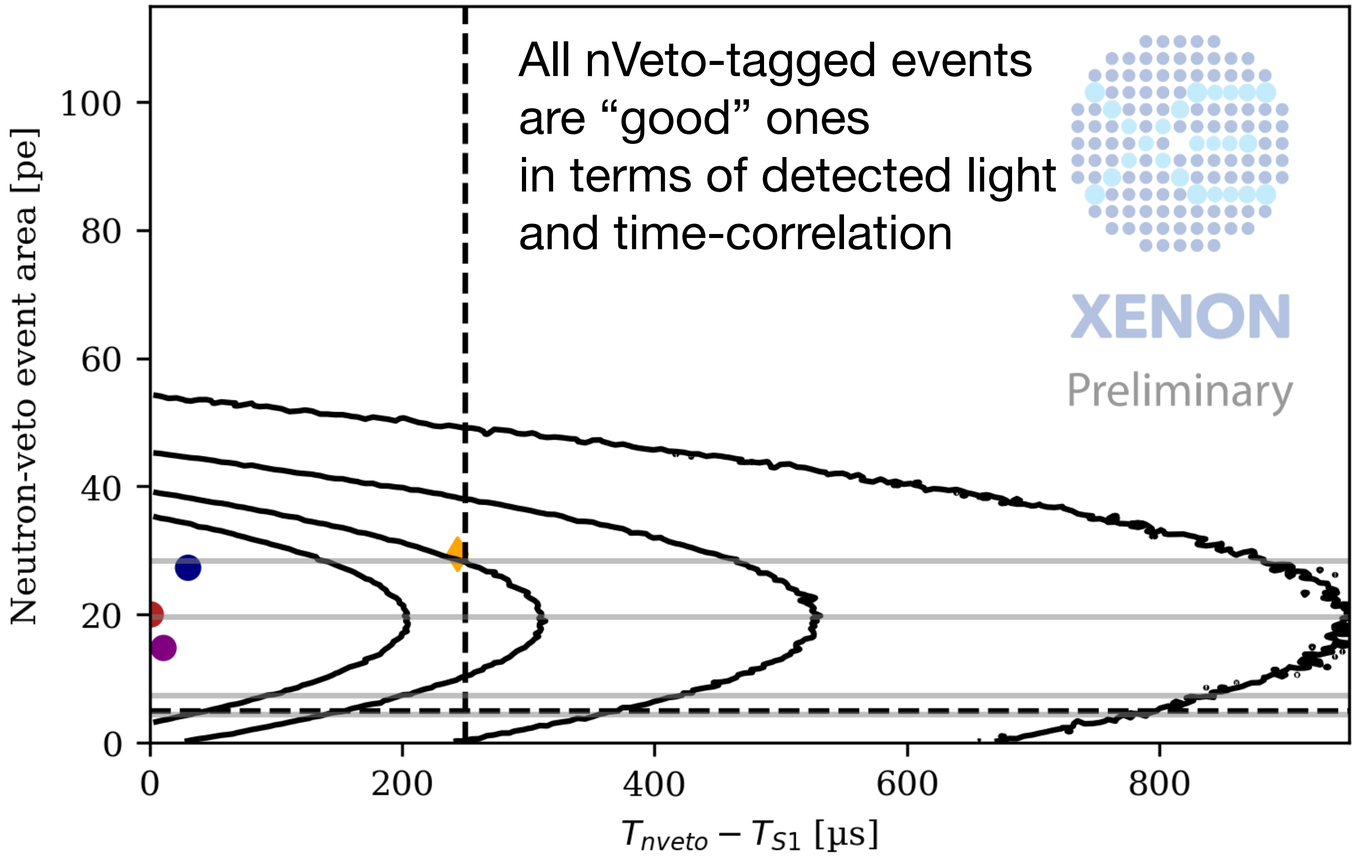
Neutron Veto in Science Run 0

Marco Selvi | selvi@bo.infn.it

- The angular position of events in the Neutron Veto can be obtained by the first hits in the PMTs

- Agreement between position in the TPC and the Neutron Veto





Future steps with Gd-doped water

Marco Selvi | selvi@bo.infn.it

To further improve the neutron veto performances, we plan to dope water with Gd-Sulphate-Octahydrate salt, with a concentration of 0.2% of Gd in mass (corresponding to 0.5% of salt).

	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	30 us

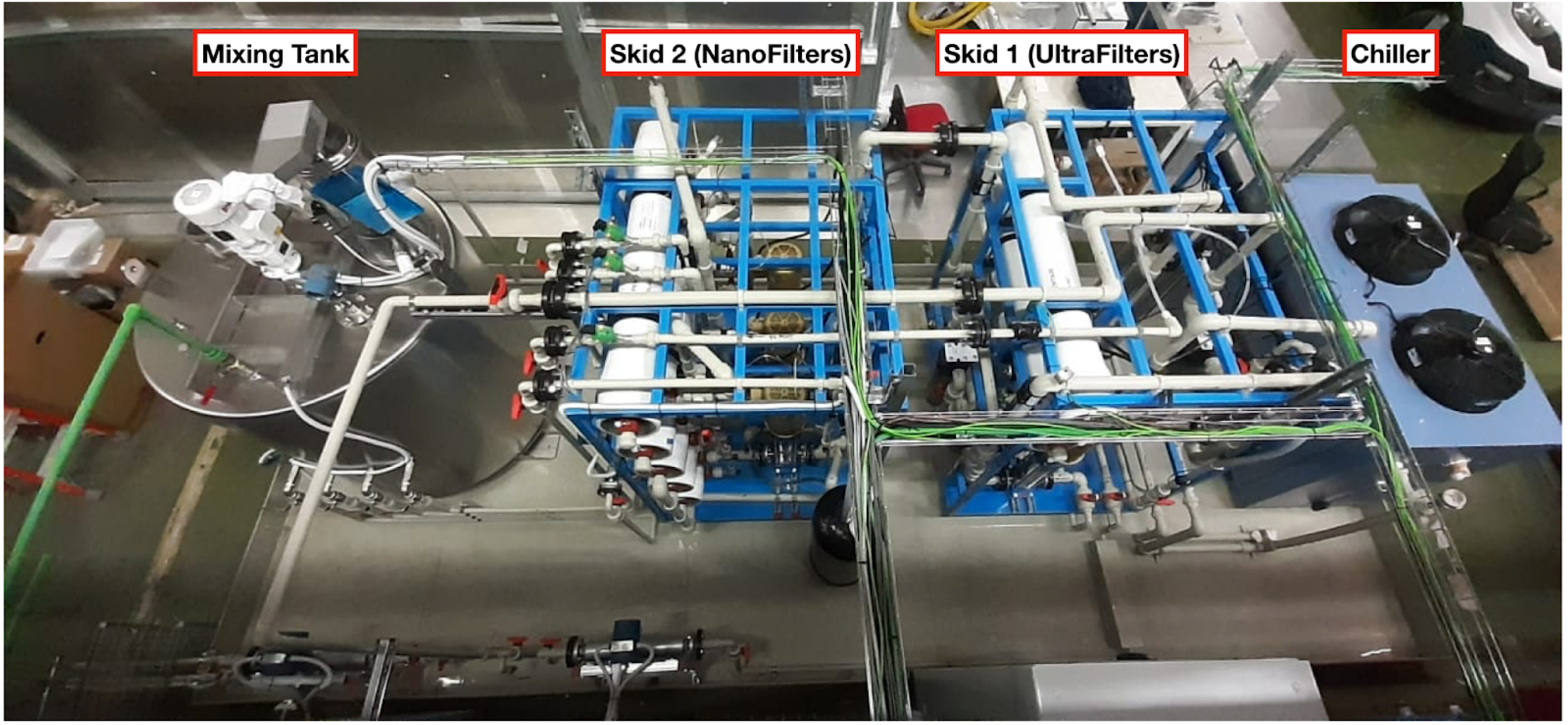
Monte Carlo prediction for neutron tagging efficiency with Gd is 87%, improving the neutron background by a factor 3 with respect to Science Run 0.

A novel purification plant for Gd-Water is needed, with technology mutuated from the EGADS project.

L. Marti et al., NIMA 959, 163549 (2020)

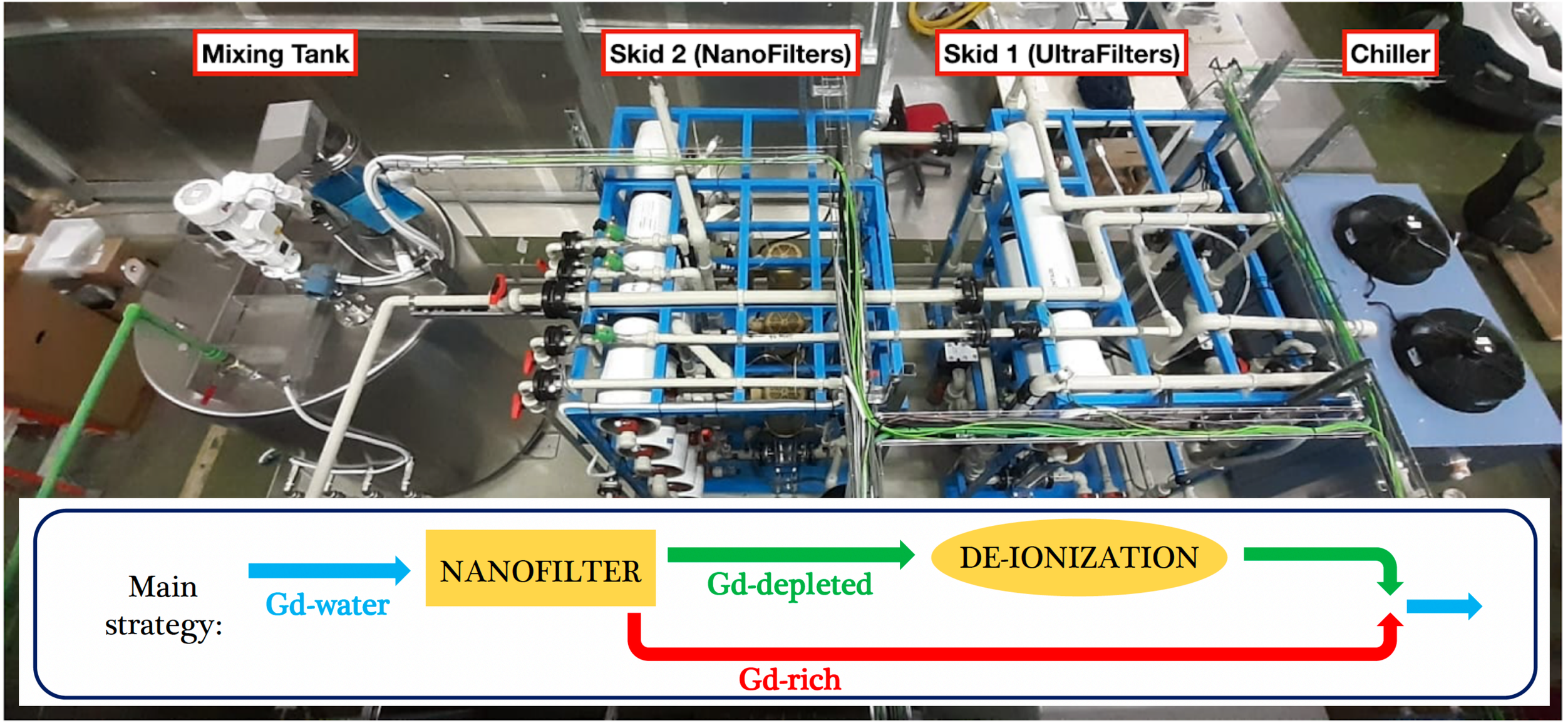
The Gd-Water Purification Plant

Marco Selvi | selvi@bo.infn.it



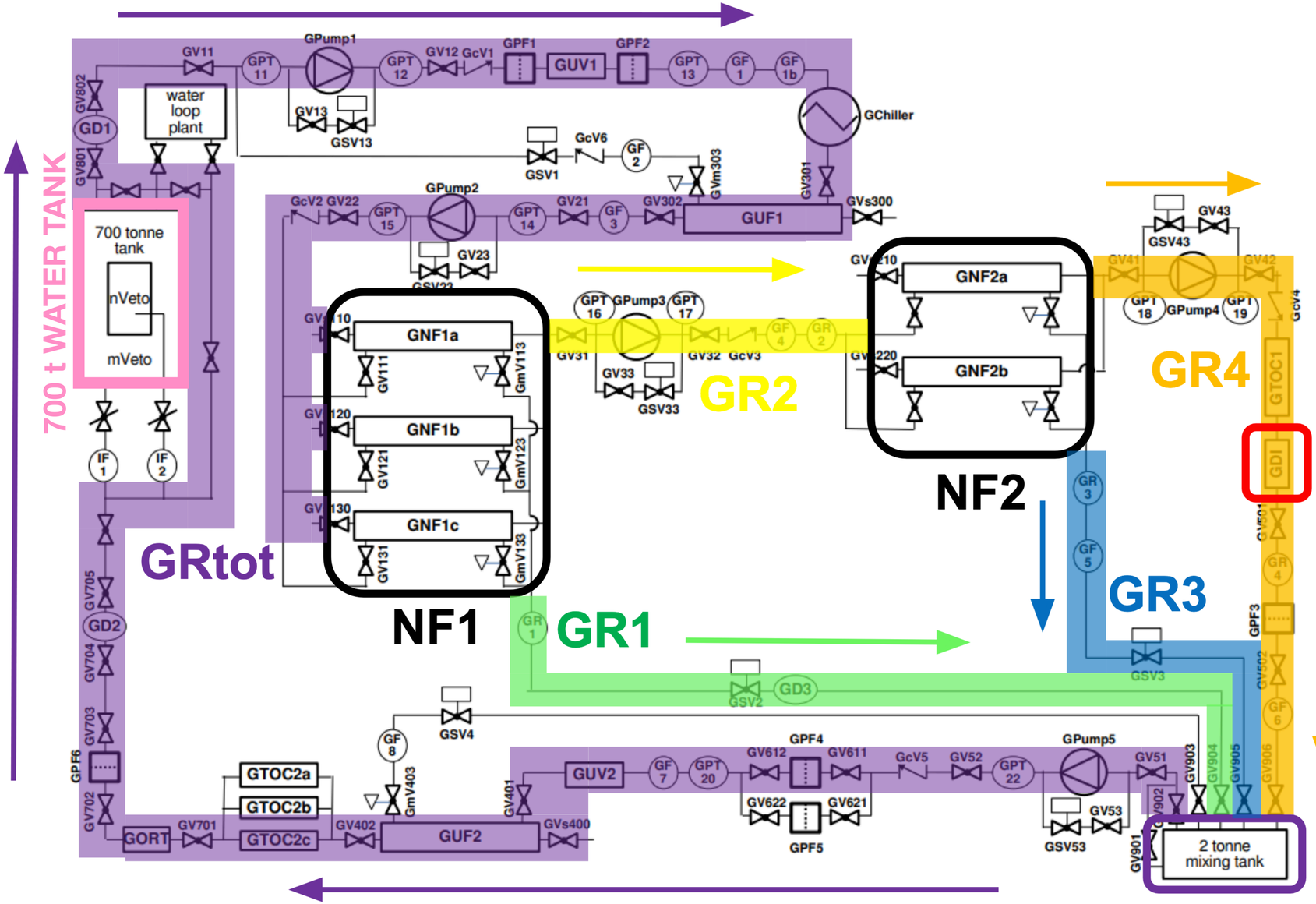
The Gd-Water Purification Plant

Marco Selvi | selvi@bo.infn.it



XENONnT: GdPlant P&ID

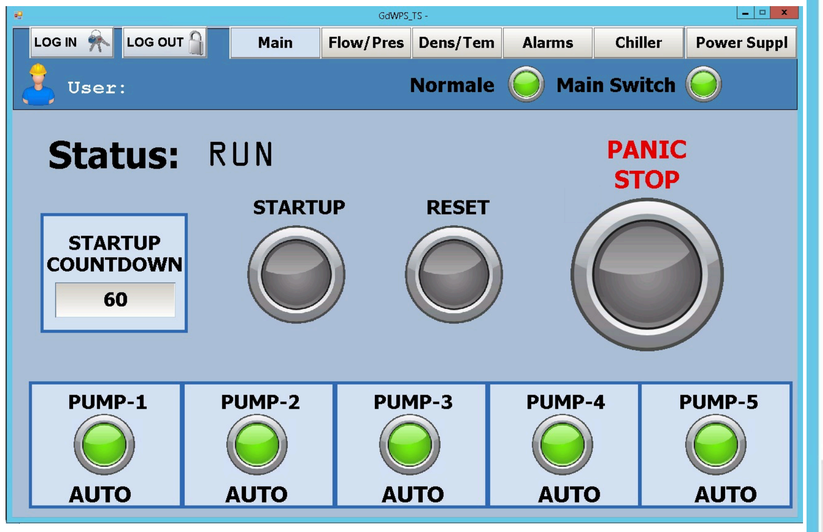
Marco Selvi | selvi@bo.infn.it

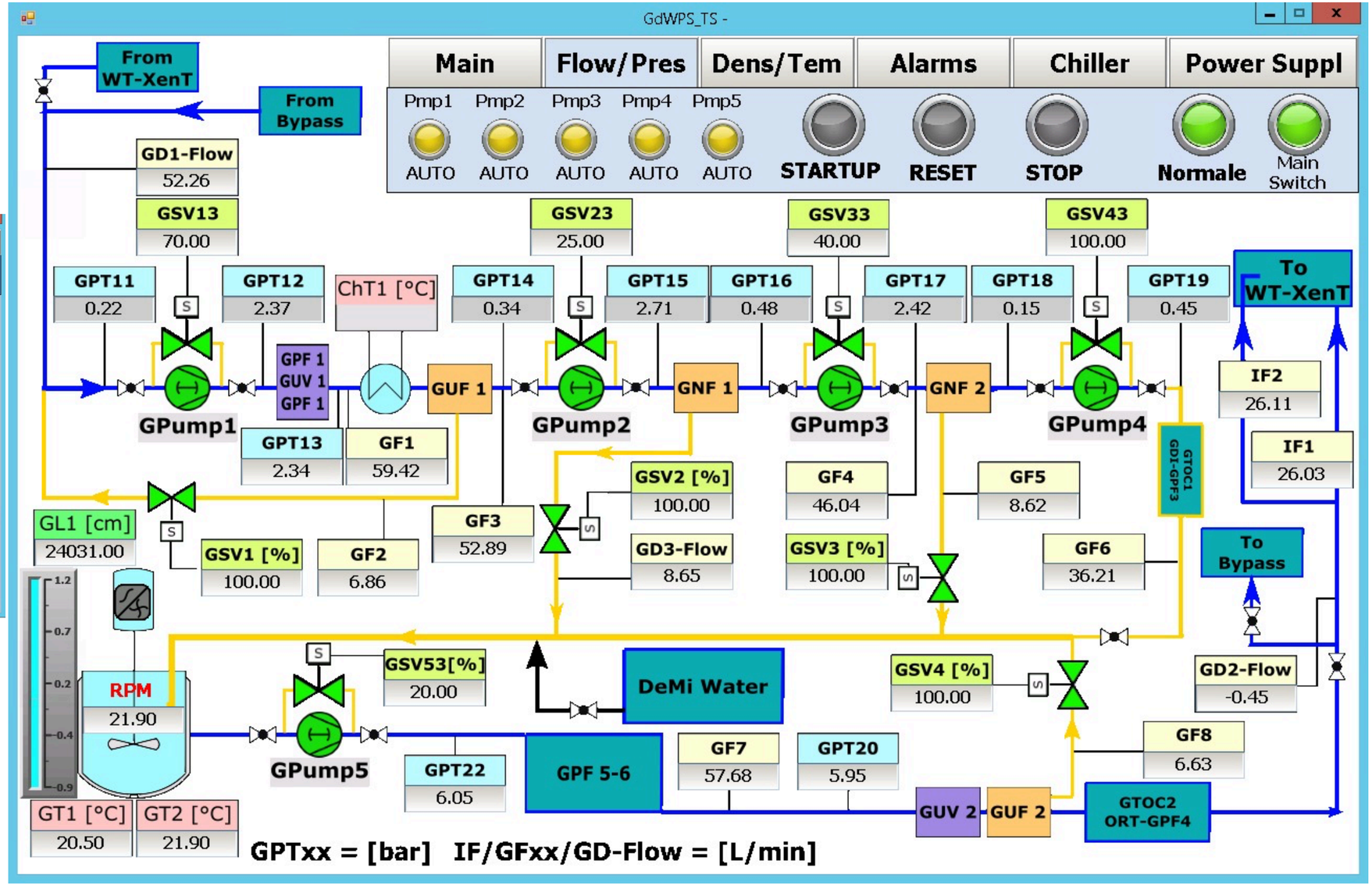


The Gd-Water solution, after some preliminary treatment, is separated via NanoFiltration (**NF1** and **NF2**) into a Gd-rich part (green and blue) sent directly to a Mixing Tank, and a Gd-depleted part which is first purified via a standard water treatment as Delonization, then mixed again with the other branches, before returning to the main 700 t water tank.

XENONnT: GdPlant Slow Control

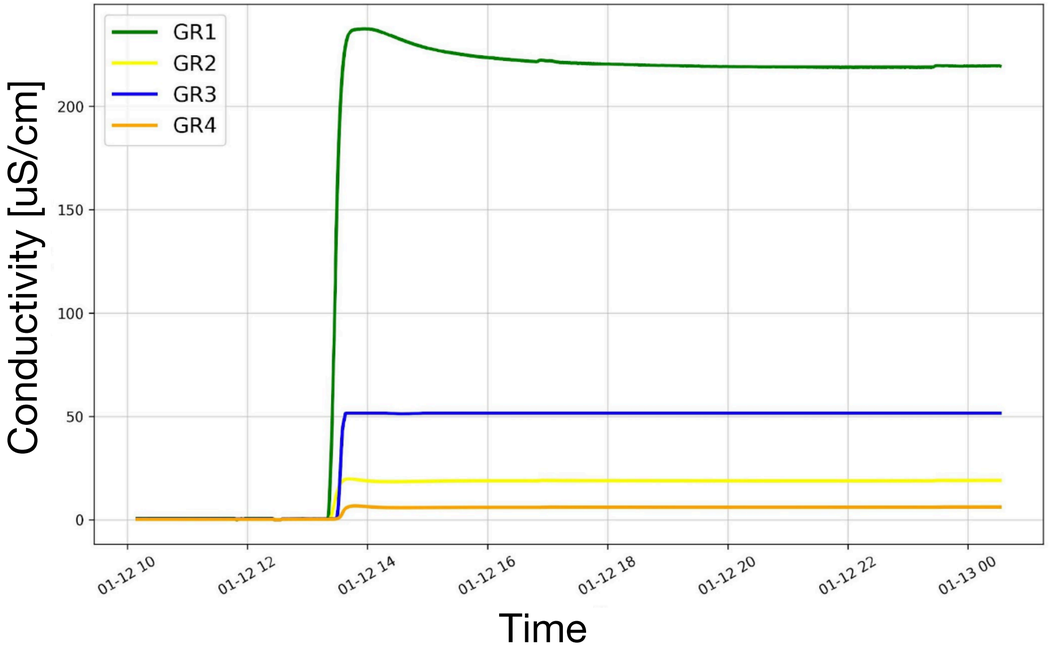
Marco Selvi | selvi@bo.infn.it





GdSalt first insertion

Marco Selvi | selvi@bo.infn.it



We recently inserted a first batch of 15 kg of Gd-Salt in closed loop inside the GdPlant, to test the transport, insertion and dissolution procedure, testing various concentrations and reaching the nominal one (0.5% of Gd-salt in mass).

Commissioning of the plant, in particular the nano-filtration performances, water purification and transparency of the solution are ongoing.

Transport system connection → Salt insertion → Stirrer activation

XENONnT neutron veto: Conclusions

Marco Selvi | selvi@bo.infn.it

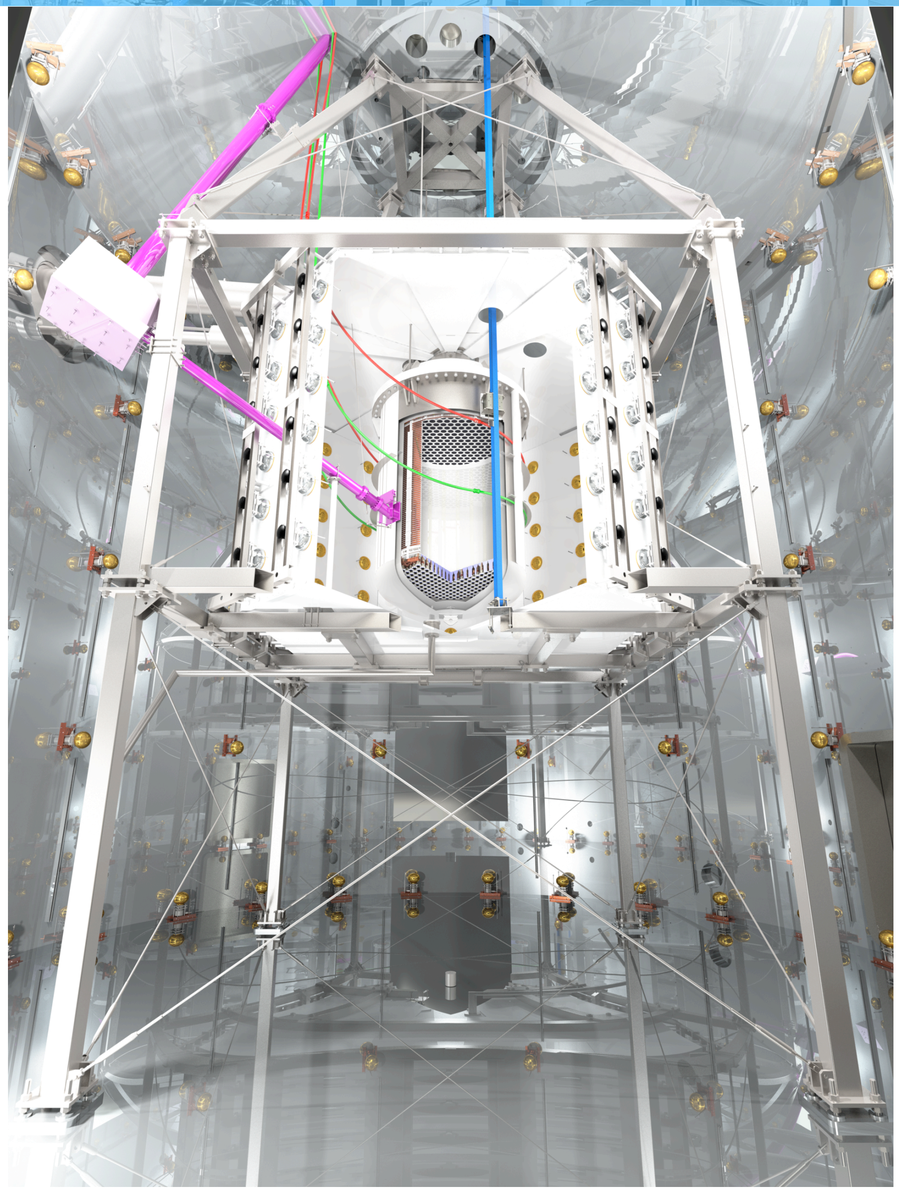
The XENONnT Neutron Veto was built in 2020, commissioned in 2021 and used in the first Science Run with demi-water.

The calibration with AmBe neutron showed a very good **neutron tagging efficiency of 68%**, the highest ever measured in a water Cherenkov detector.

The system allowed to constrain in a data-driven way the neutron background in Science Run 0.

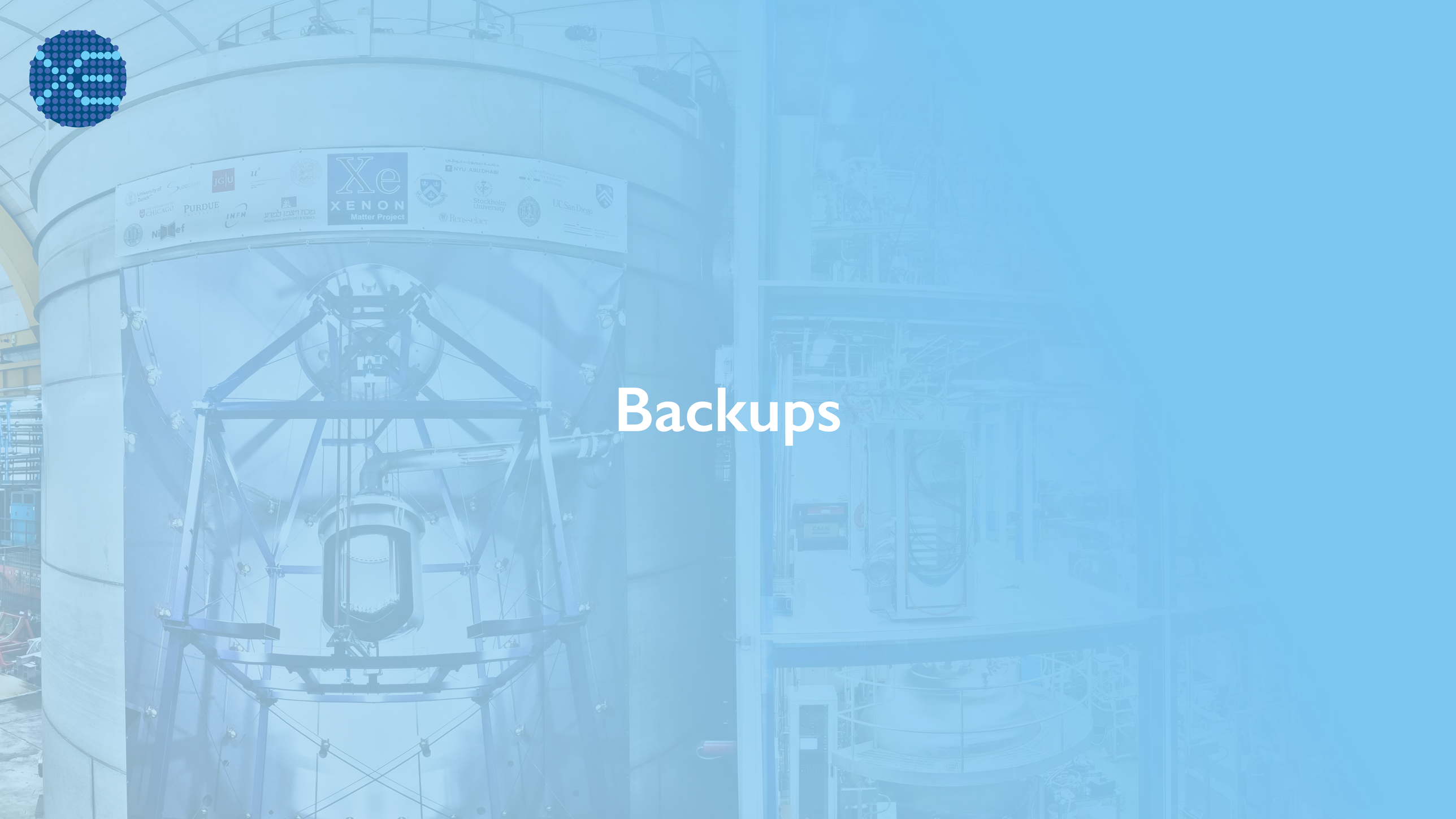
In the next phase, we will dope the water with Gd, improving the **efficiency up to 87%**, reducing the neutron background by a factor 3.

The Gd-Salt insertion has been successfully proven, and the commissioning of the Gd-Water purification plant is ongoing.



Thank you for the attention!

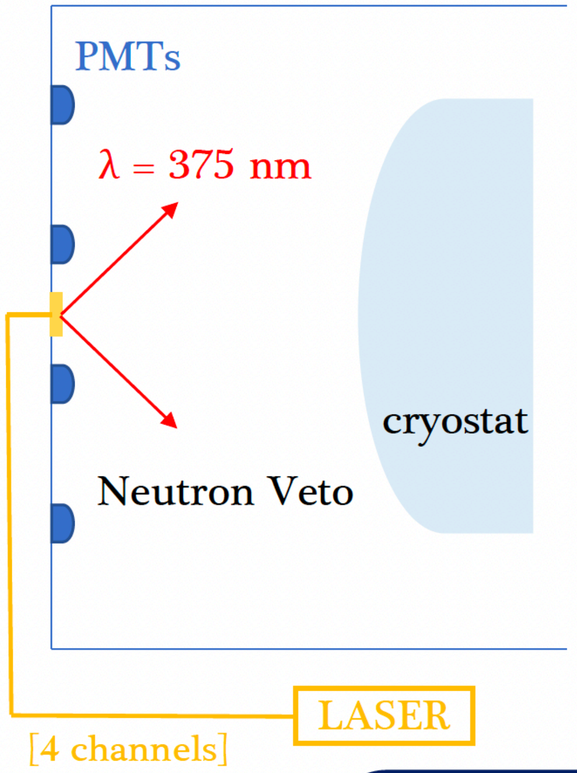
Marco Selvi - INFN Bologna
The XENONnT Neutron Veto
UCLA Dark Matter - 31 March 2023


Xe
XENON
Matter Project
NYU ABU DHABI
PURDUE
Stockholm University
Rensselaer
UC San Diego
Nikhef
INFN

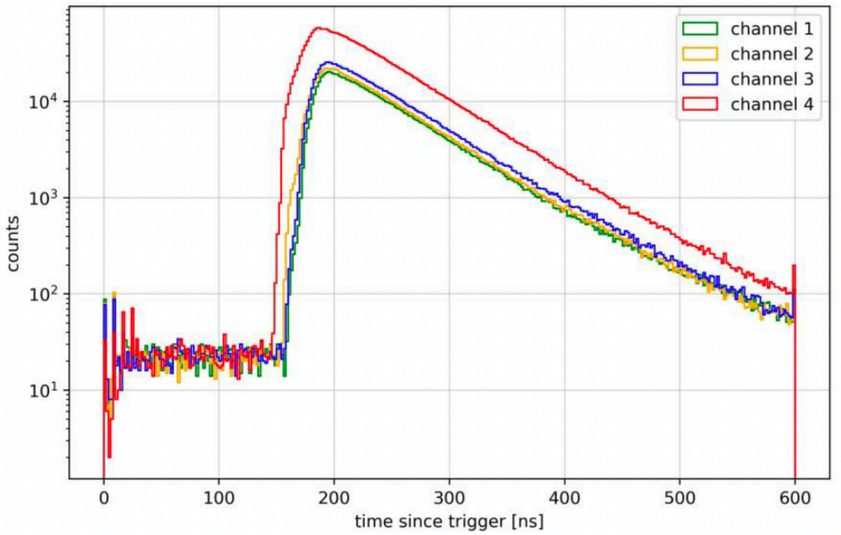
Backups

Neutron Veto performances: transparency monitor

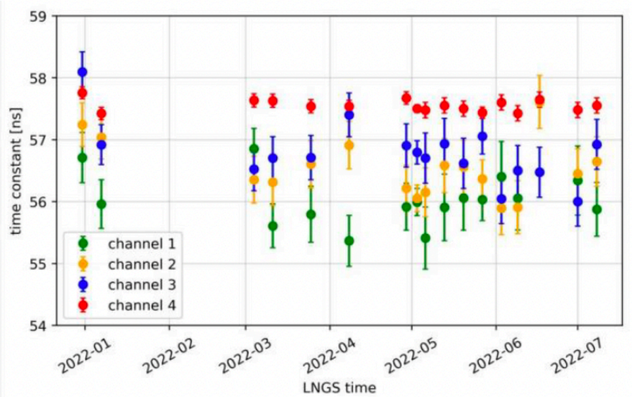
Marco Selvi | selvi@bo.infn.it



PMT hits timings are recorded; the distribution is **exponential:**



Time constant τ stable over time: (57 ± 1) ns



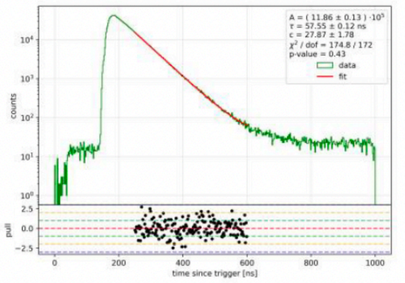
- measure of the **optical properties**
- depends on water **transparency** and wall **reflectivity**

Selection cuts in:

- number of PMTs
- hits area in photoelectrons

3-parameter **fit**:

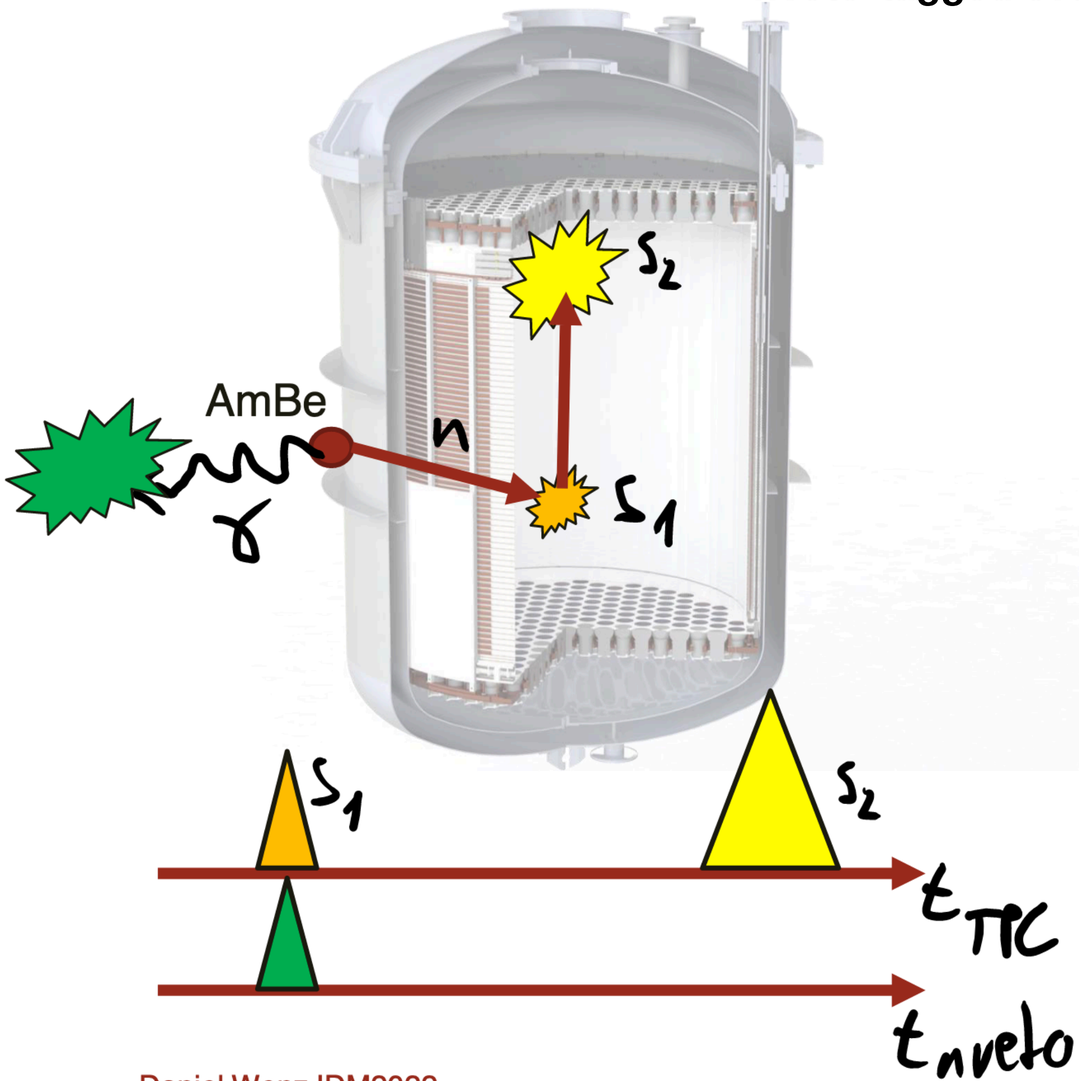
$$f(t) = Ae^{-t/\tau} + c$$



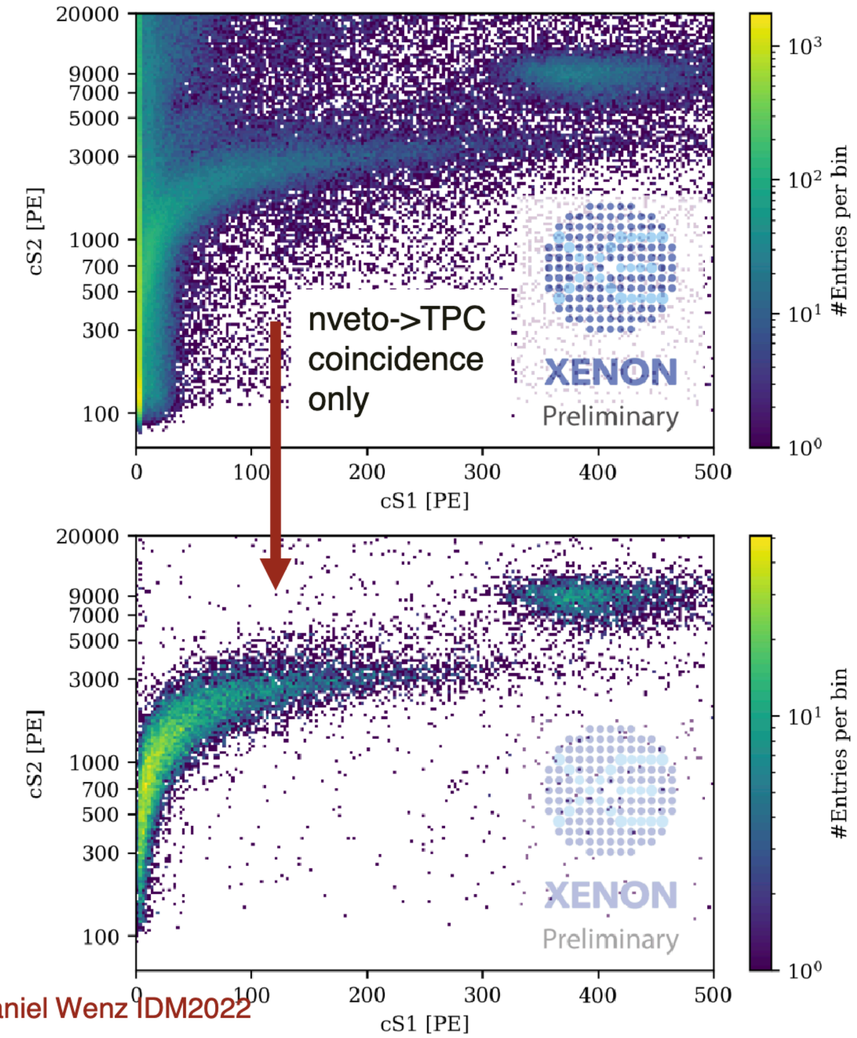
Neutron calibration with AmBe

Marco Selvi | selvi@bo.infn.it

nVeto-tagged events clean-up the NR band



Daniel Wenz IDM2022



Daniel Wenz IDM2022

Marco Selvi | selvi@bo.infn.it

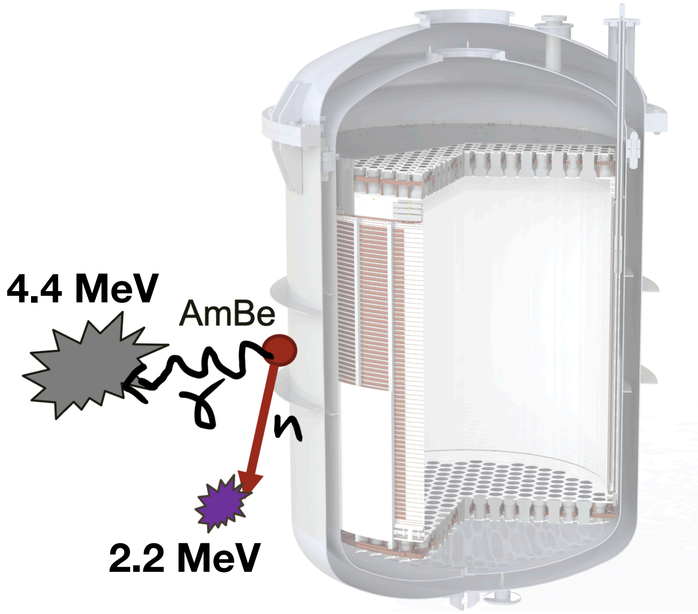
Neutron detection efficiency

- Neutron calibration with AmBe source placed close to the cryostat.

- AmBe emits a 4.4 MeV gamma together with the neutron in about 60% of cases.

- Detect the 4.4 MeV gamma in the TPC or nVeto,
and look for the 2.2 MeV gamma of neutron capture in the nVeto.

- Direct measurement of the neutron detection efficiency of the nVeto



"Number of neutrons detected | selection"
"Number of 4.4 MeV gamma detected in the TPC"

➡ $(80.2 \pm 1.3)\ \%$ @ 5-fold coincidence, 5 pe threshold and 600 μs window

➡ To our knowledge highest detection efficiency ever measured in a water Cherenkov detector.