The XENONnT Experiment

Pietro Di Gangi – Andrea Mancuso

INFN & University of Bologna

International Conference on High Energy Physics – Bologna 2022

The XENON Collaboration

~ 170 scientists – 27 institutes / 11 countries

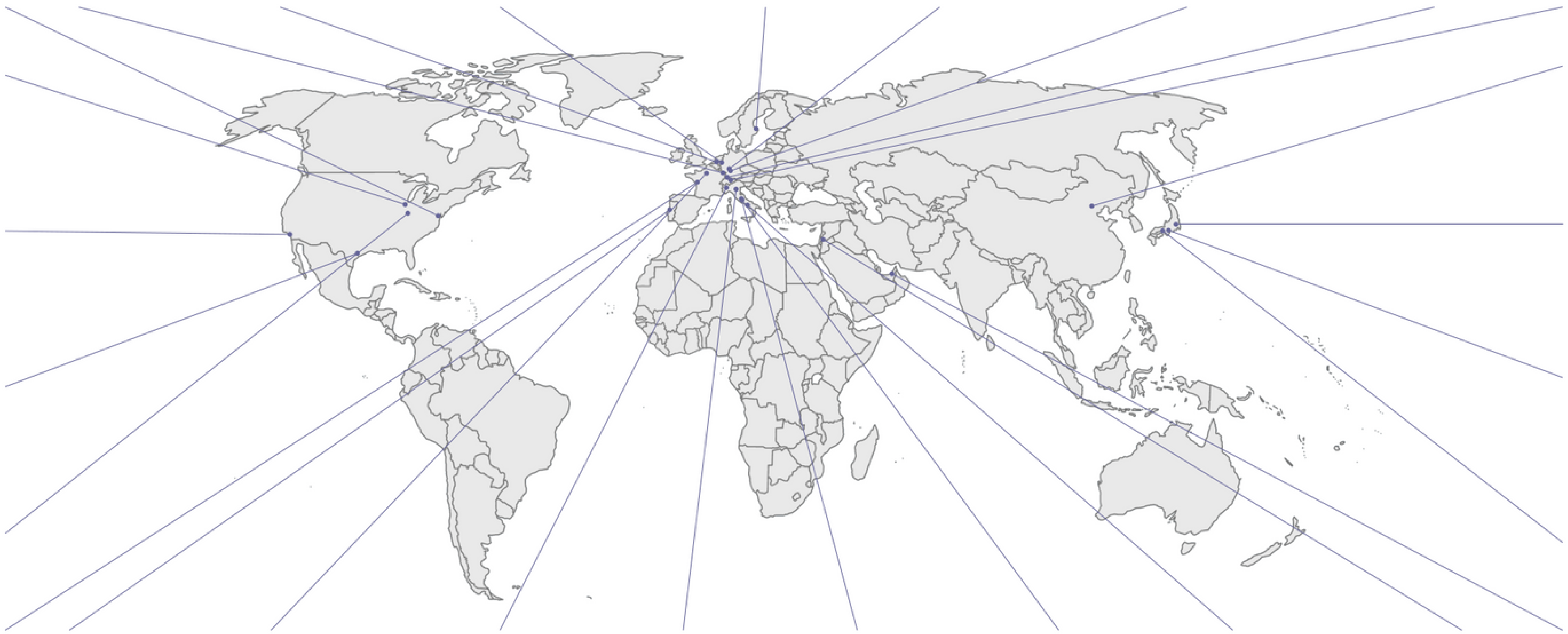
Columbia | KIT | Nikhef | Muenster | Stockholm | Mainz | MPIK, Heidelberg | Freiburg | Zurich

Chicago

UCSD

Rice

Purdue



Tsinghua

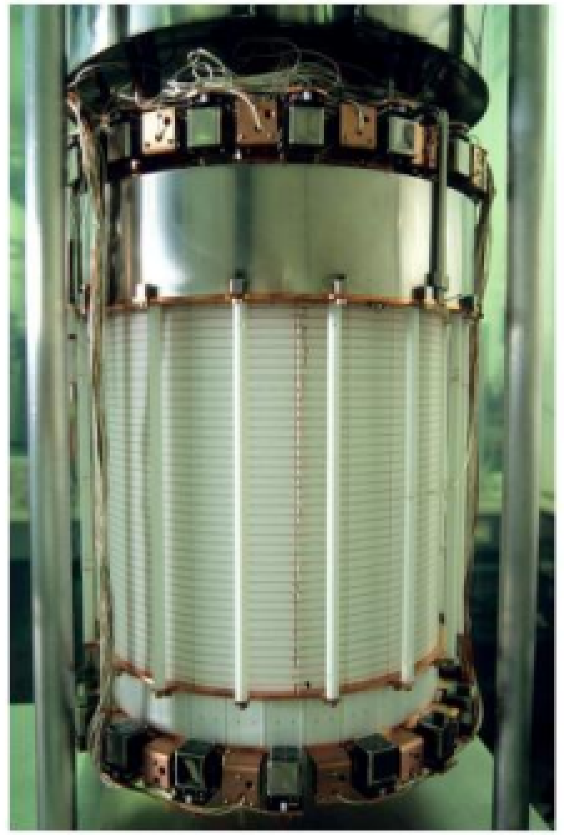
Tokyo

Nagoya

Kobe

Subatech | Coimbra | LPNHE | Torino | Bologna | L'Aquila | LNGS | Napoli | Weizmann | NYUAD

The XENON Project



XENON10

2005 - 2007

25 kg LXe

15 cm drift lenght

$\sigma_{SI} \sim 9 \times 10^{-44} \mathrm{cm}^2$ at $100 \mathrm{GeV/c}^2$

XENON100

2009 - 2016

161 kg LXe

30 cm drift lenght

$\sigma_{SI} \sim 10^{-45} \mathrm{cm}^2$ at $50 \mathrm{GeV/c}^2$

XENON1T

2016 - 2018

3.2 t LXe

1 m drift lenght

$\sigma_{SI} \sim 4 \times 10^{-47} \mathrm{cm}^2$ at $30 \ \mathrm{GeV/c}^2$

Phys. Rev. Lett. **121**

XENONnT

2020 -

8.4 t LXe

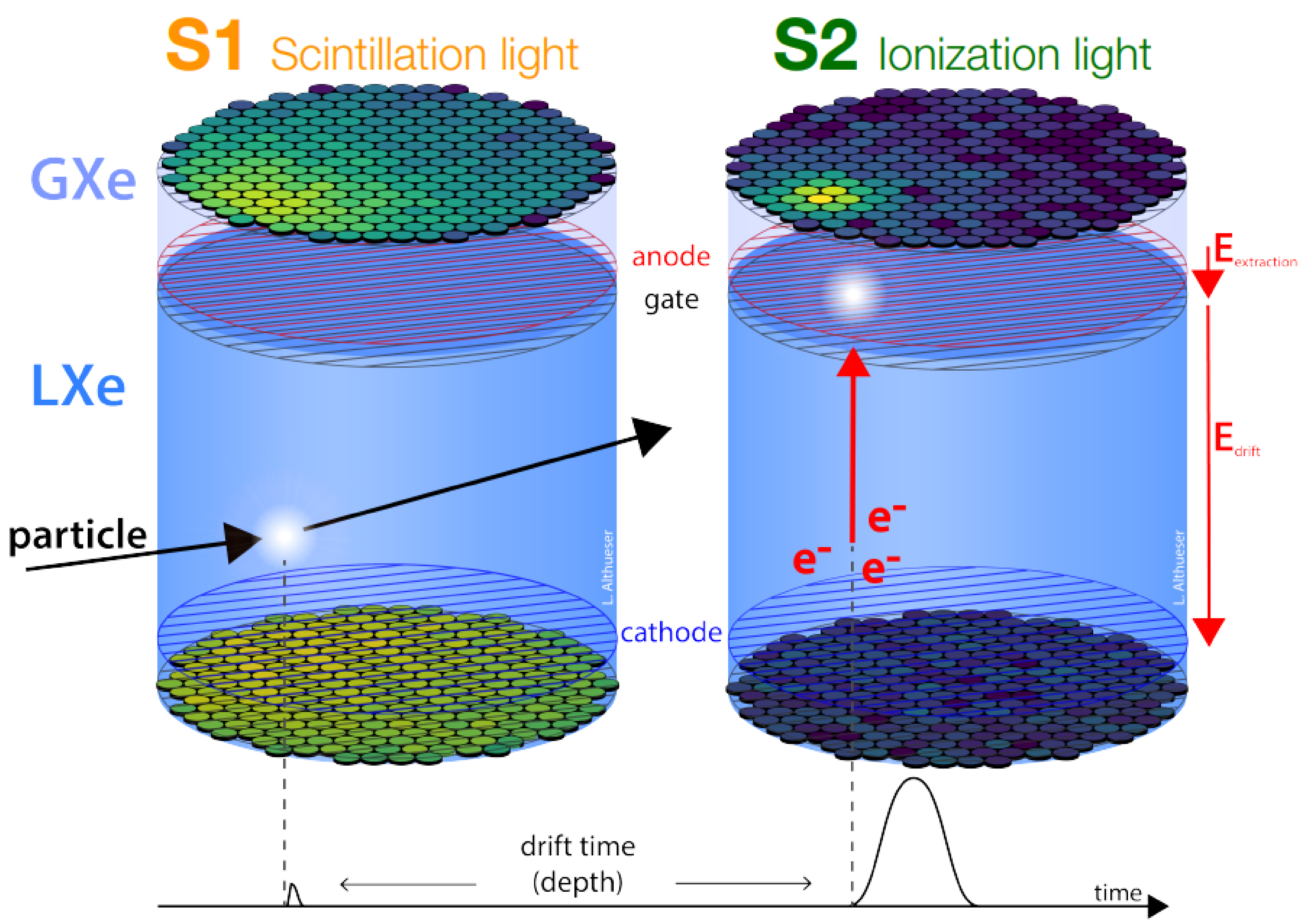
1.5 m drift lenght

$\sigma_{SI} \overset{*}{\sim} 1.4 \times 10^{-48} \mathrm{cm}^2$ at $50 \mathrm{GeV/c}^2$

JCAP 11 (2020) 031

The Xe Dual-Phase TPC

Detection Principle



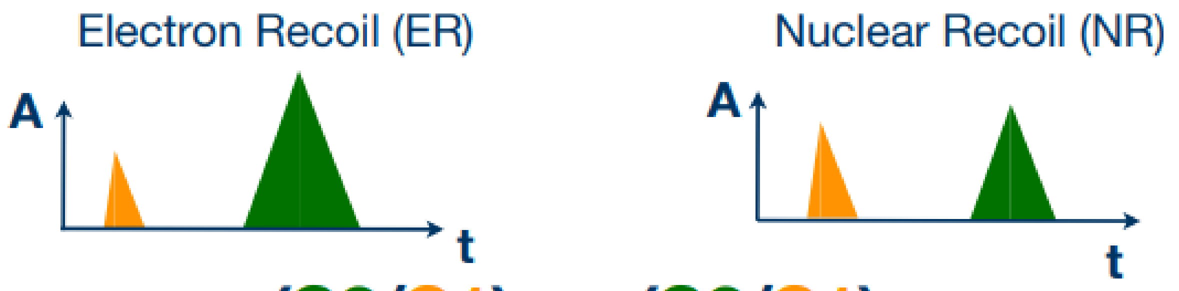
- dual-phase Xenon Time Projection Chamber (LXe + GXe)
- Energy Reconstruction $E = W\left(\frac{S_1}{g_1} + \frac{S_2}{g_2}\right)$
- 3D Event Reconstruction

  (x,y) : from S2 hit pattern / z : from drift time

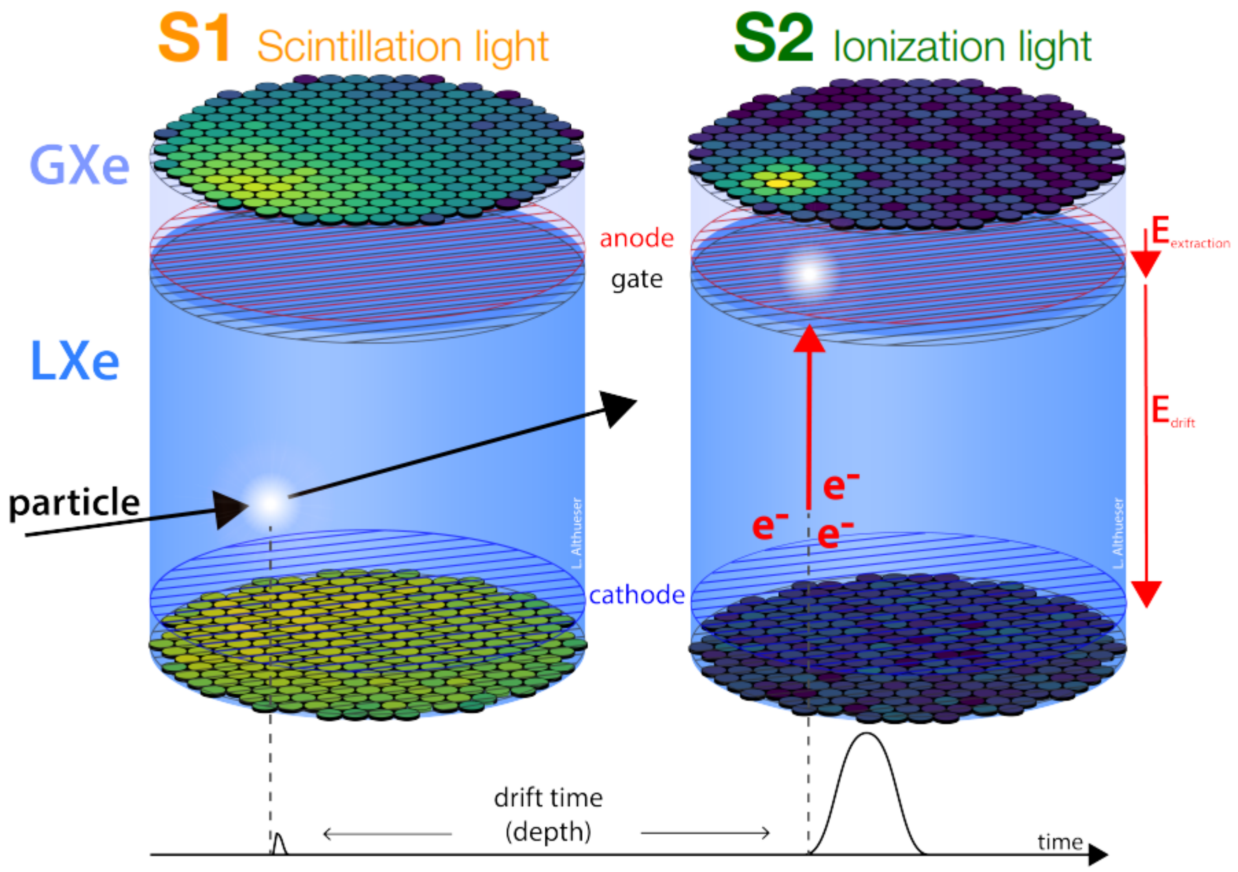
- Discrimination between Electron Recoil (ER) and Nuclear Recoil (NR)

The Xe Dual-Phase TPC

Detection Principle

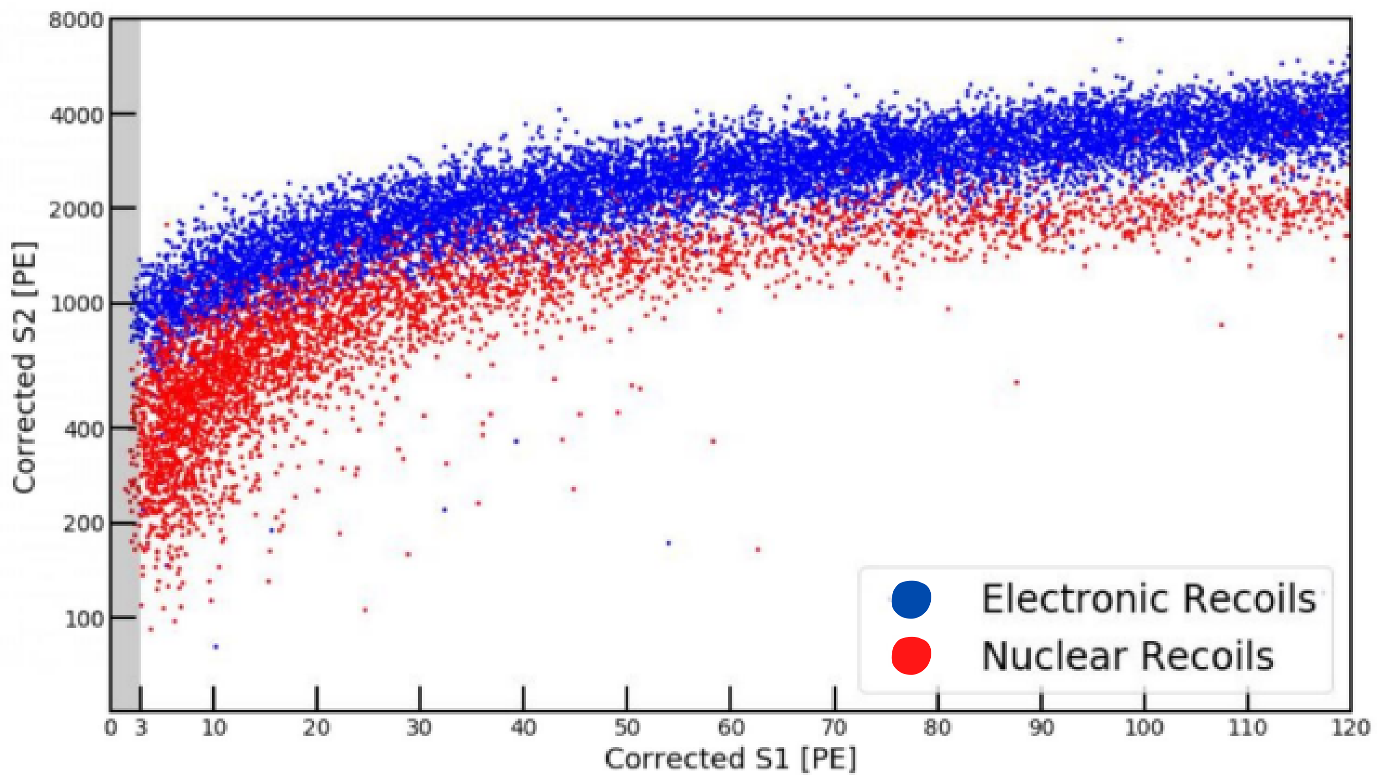


$(S2/S1)_{ER} < (S2/S1)_{NR}$

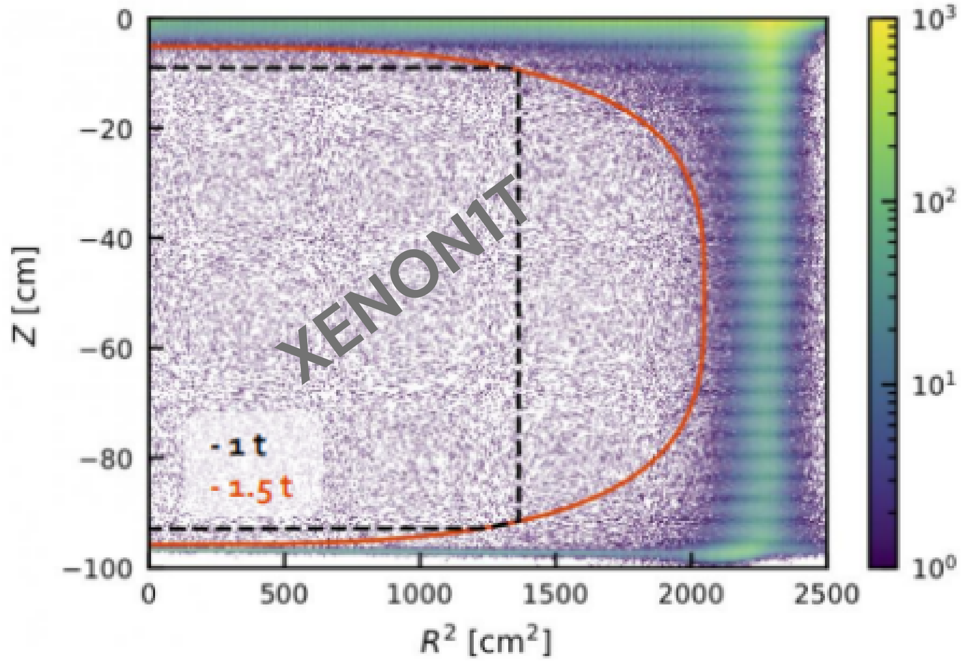


Background

ER	γ, β, ν-e interactions
NR	Neutrons, CEνNS

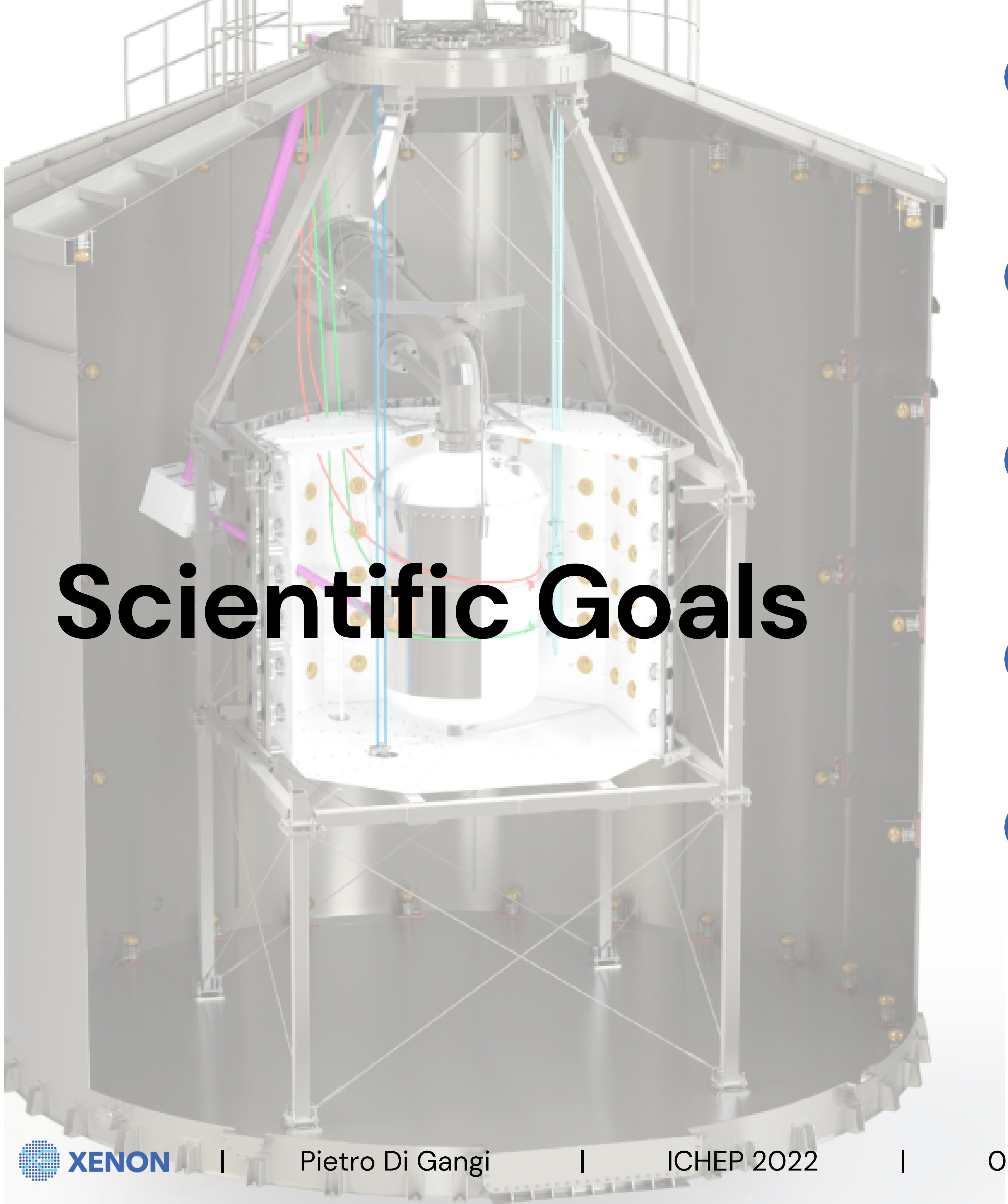


Fiducialization



Main Requirements

- Low electronegative impurities concentration
- ^{222}Rn mitigation
- High light collection efficiency



Scientific Goals

WIMP Dark Matter

best limits for WIMP masses above 6 GeV/c2
PRL 121, 111302 (2018)

Spin Independent (SI), Spin Dependent (SD) interactions

Light Dark Matter

best limits from 0.1 to 6 GeV/c2 (except 2-3 GeV/c2)
PRL 123, 241803 (2019) ,PRL 123, 251801 (2019)

Sub GeV, Dark Photons, Axion-Like Particles

Solar ^{8}B Coherent Elastic neutrino-nucleon scattering

Sub GeV, Dark Photons, Axion-Like Particles

best limits from 0.1 to 6 GeV/c2 (except 2-3 GeV/c2)
PRL 123, 241803 (2019) ,PRL 123, 251801 (2019)

Double Electron Capture in ^{124}Xe

direct observation in 124Xe
Nature 568, 532–535 (2019)
arXiv:2205.04158 (2022)

Rarest process ever OBSERVED Half-life: 1.8 x 1022 years

Neutrinoless Double Beta Decay in ^{136}Xe

Majorana neutrino and lepton number violation

probed new search method
EPJ C 80:785 (2020)

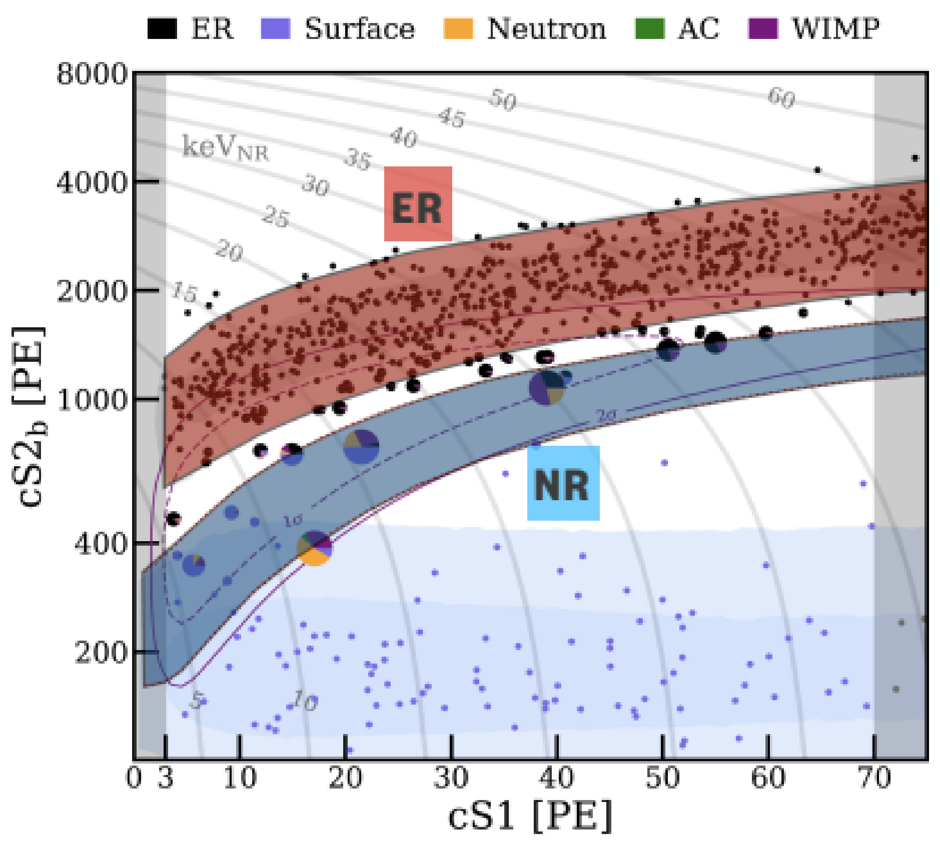
Low Energy Electronic Recoil (ER)

Solar axions, Neutrino magnetic moment

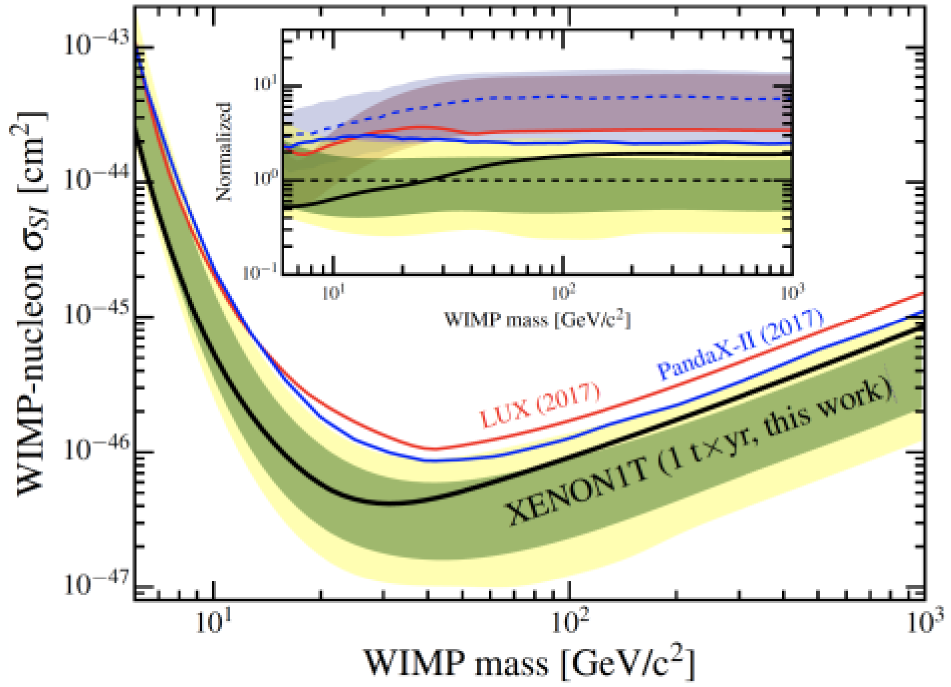
Excess observed
Phys. Rev. D 102, 072004

XENON1T main results

NR searches



PRL 121 (2018) 111302



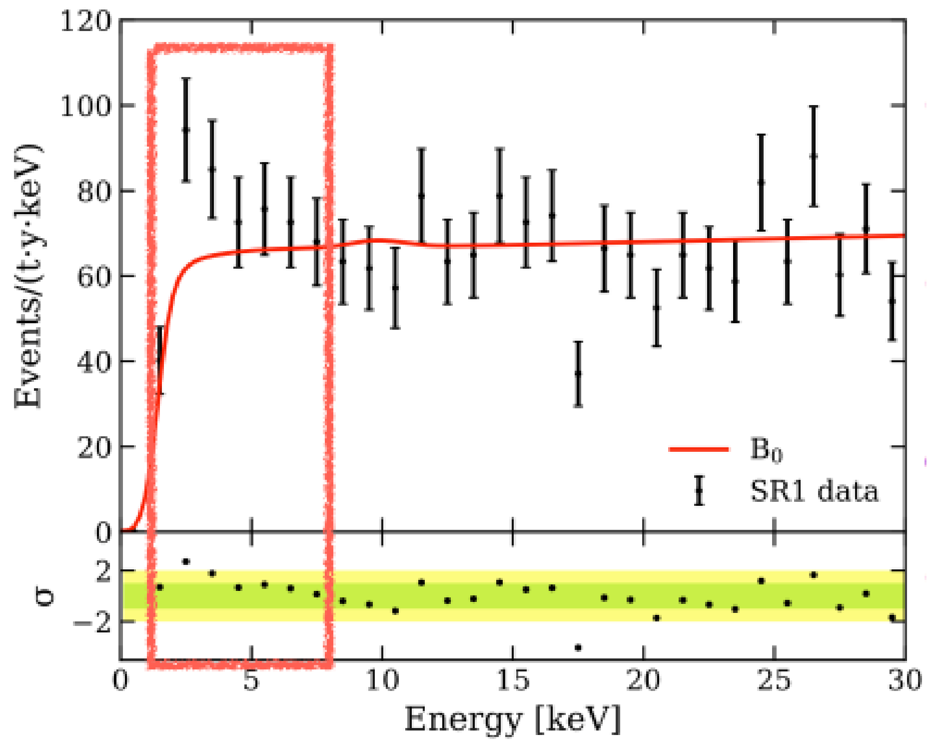
XENON1T main result:

- SI WIMP
  $\sigma_{\chi N}^{SI} = 4.1 \times 10^{-47} cm^2$ for
  $m_\chi = 30 GeV/c^2$

Other notable results

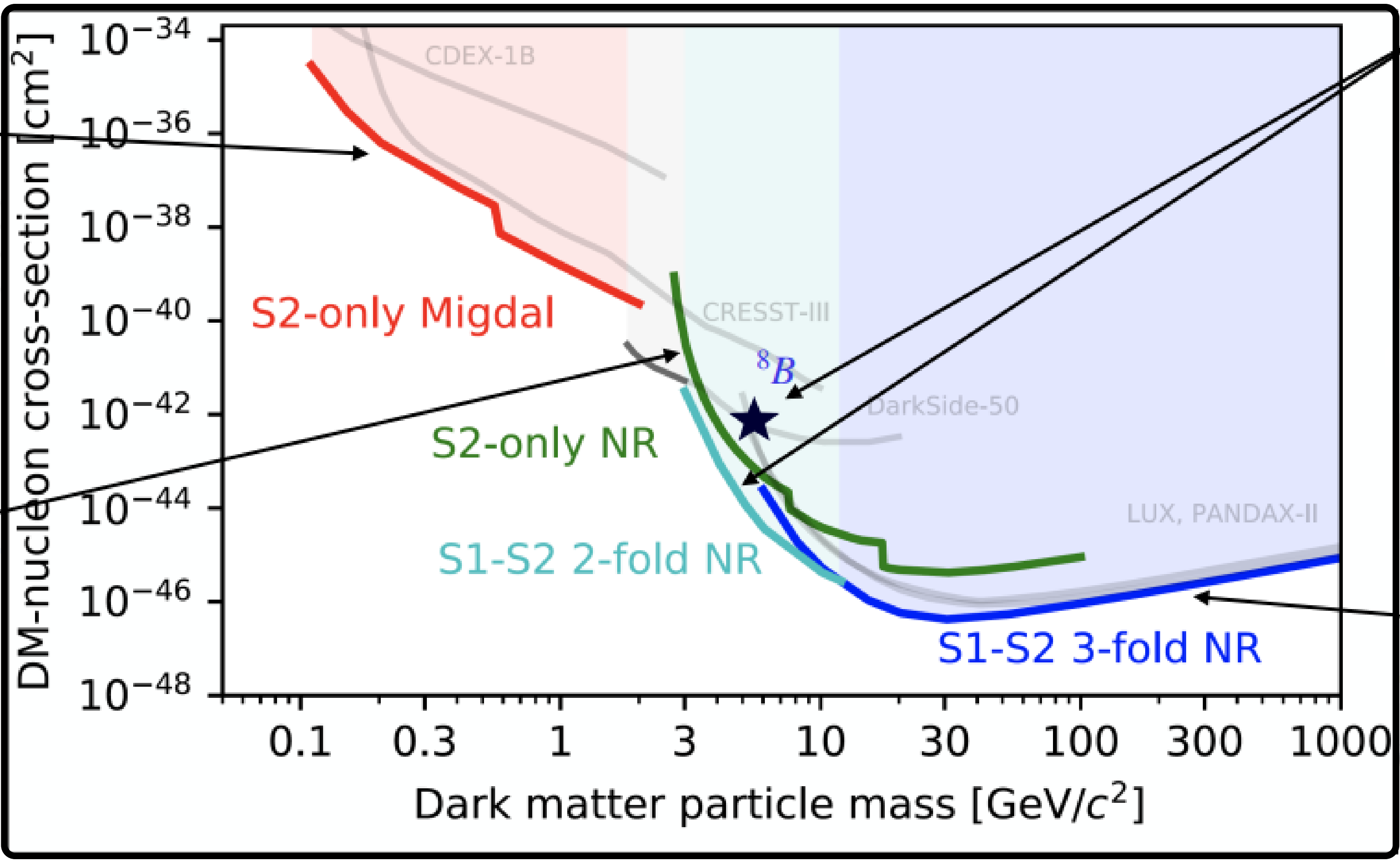
- Spin dependent analysis
  PRL 122 (2019) 141301
- First constraints on WIMP-pion interaction
  PRL 122 (2019) 071301

ER searches: Low ER excess



S2-only Migdal
PRL 123 (2019) 241803

S2-only
PRL 123 (2019) 251801

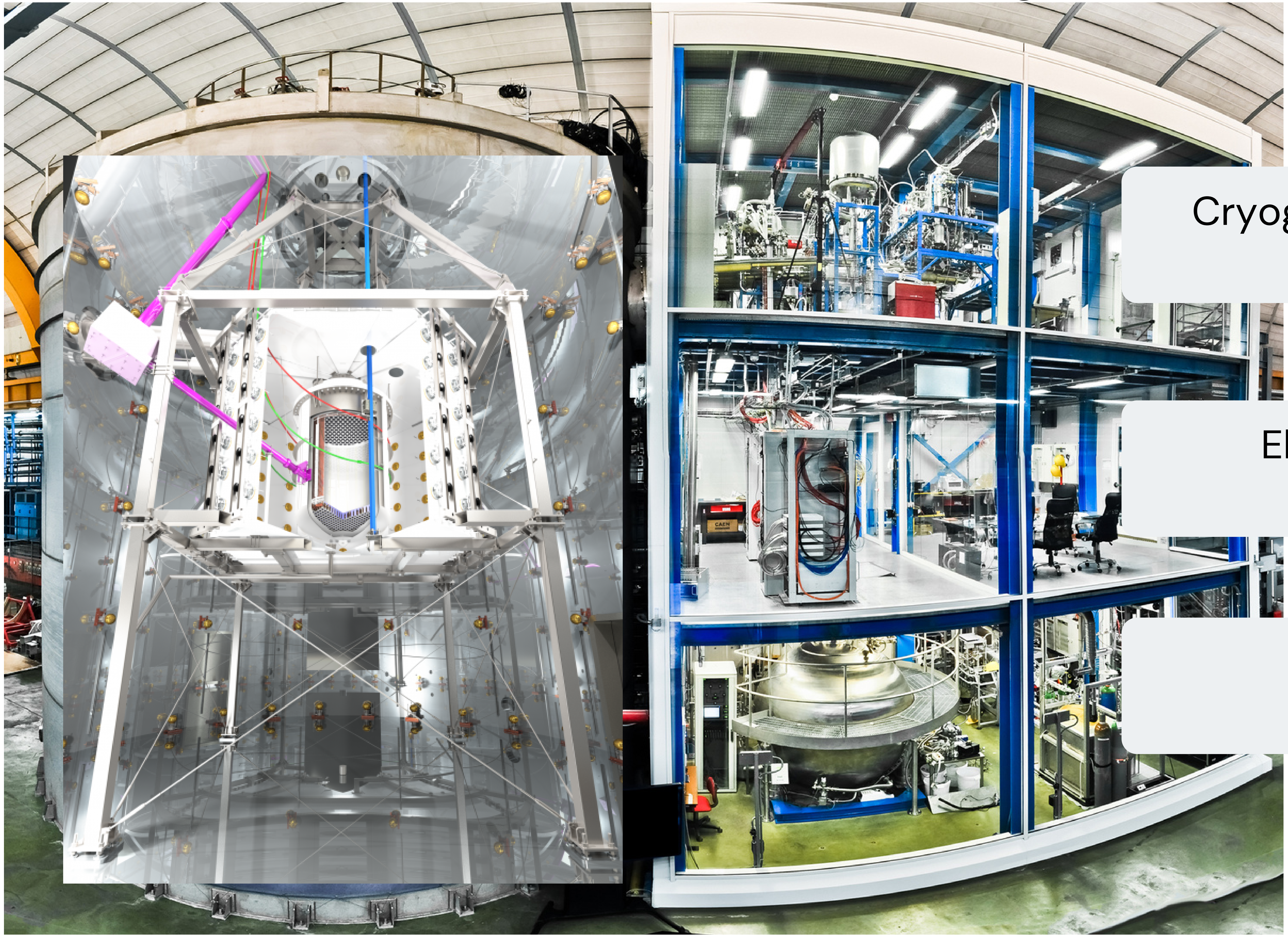


No detection of CEvNS
PRL 126 (2021) 091301

SI 1 tonneXyear result
PRL 121 (2018) 111302

The XENOnT Experiment

@ Hall B - LNGS



Cryogenics & Xenon Purification
Rn Distillation

3

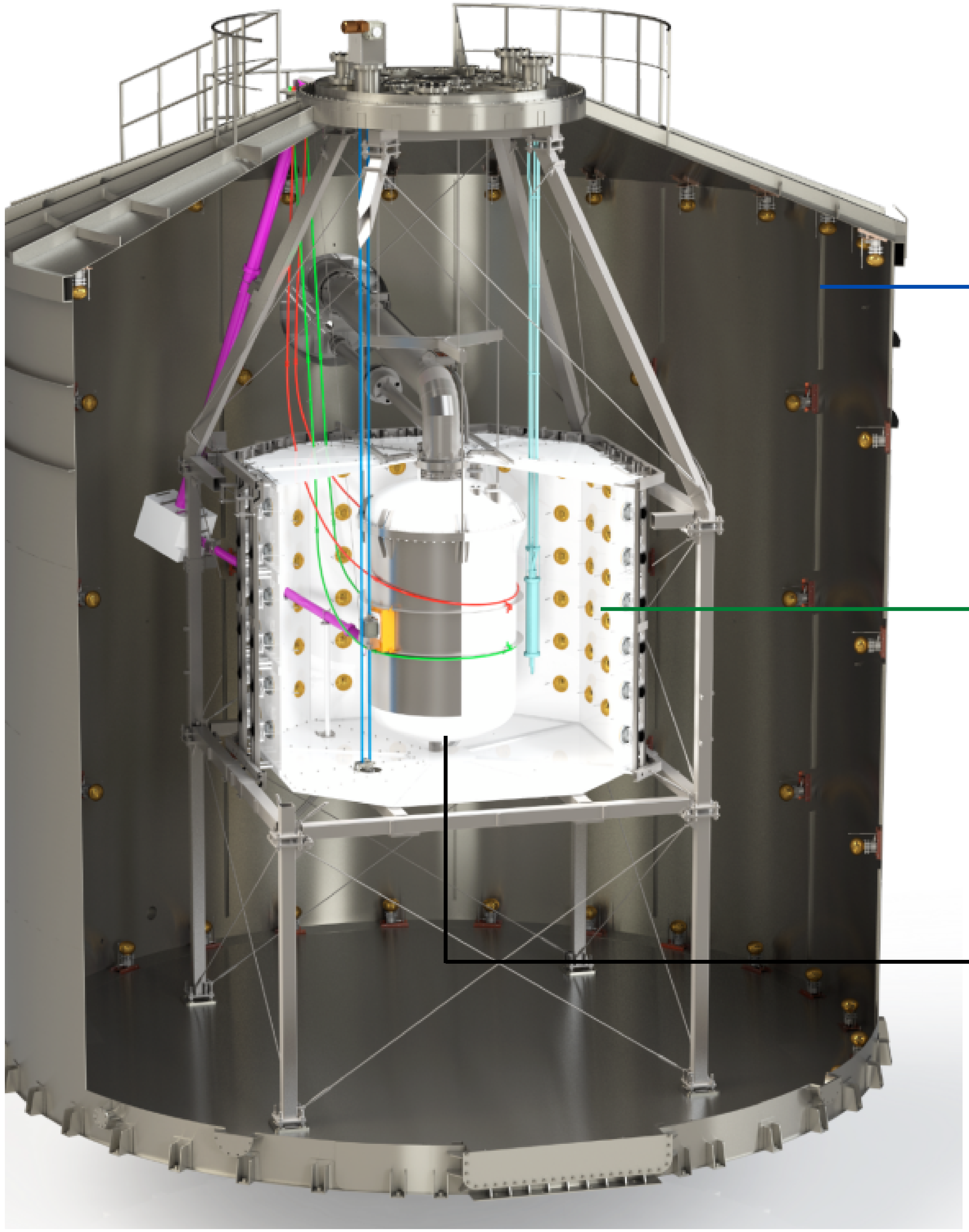
Electronics, Data Acquisition
& Slow Control

2

Xenon Storage, Recovery
& Kr Distillation

1

The Experiment



Muon Veto

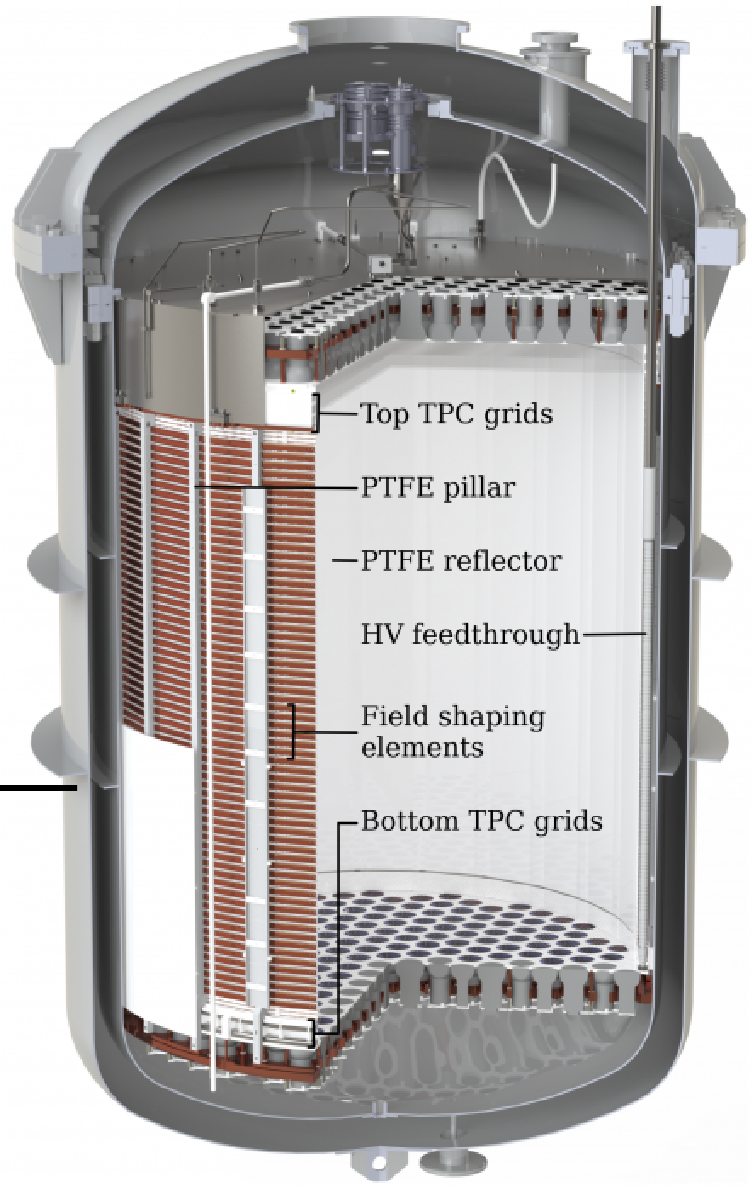
- Gd loaded Water Cherenkov detector instrumented with 84 PMTs
- Passive water shield against environmental radioactivity

Neutron Veto

- Gd loaded water Cherenkov detector
- Instrumented with 120 PMTs
- Optically separated from the MV by high reflectivity ePTFE panels

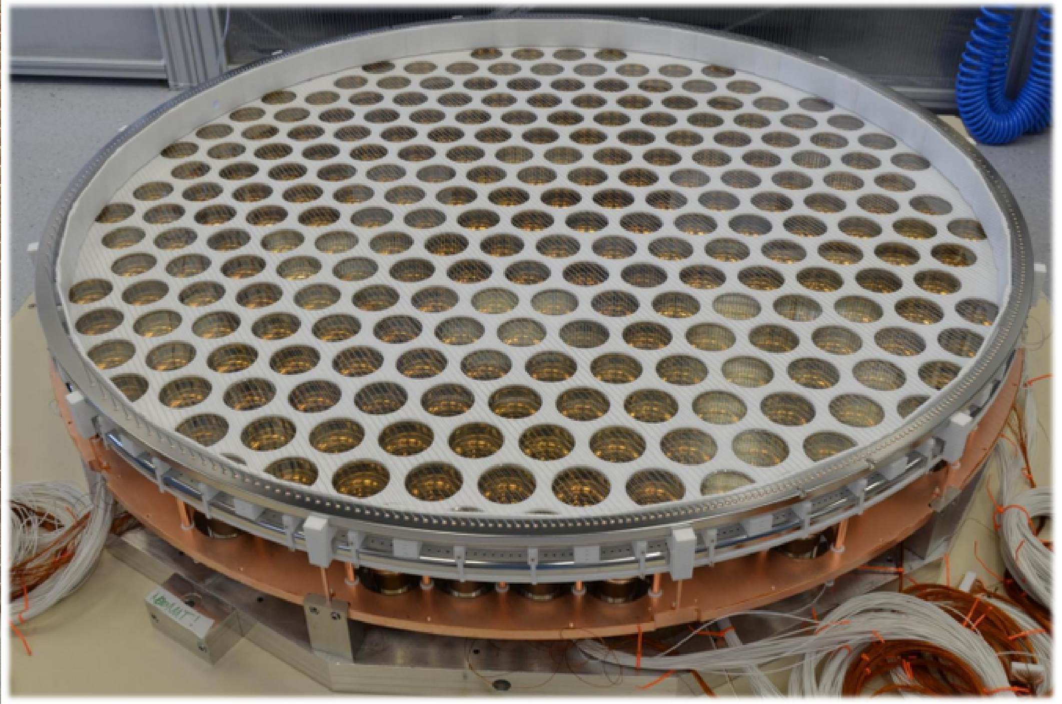
Cryostat & TPC

- 8.4 tons of Xe, 6 of which as active target mass
- Instrumented with 494 PMTs

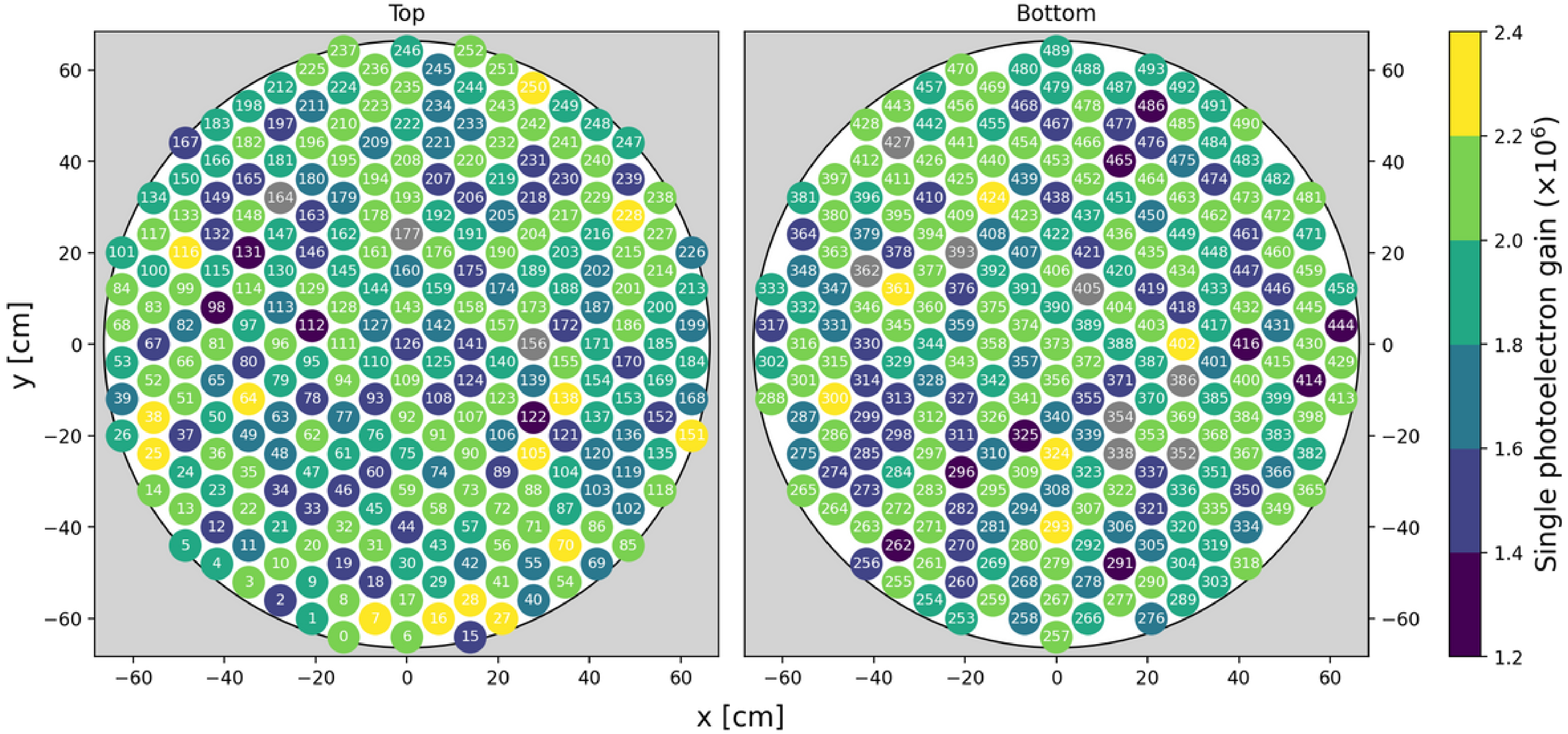


The XENONnT TPC

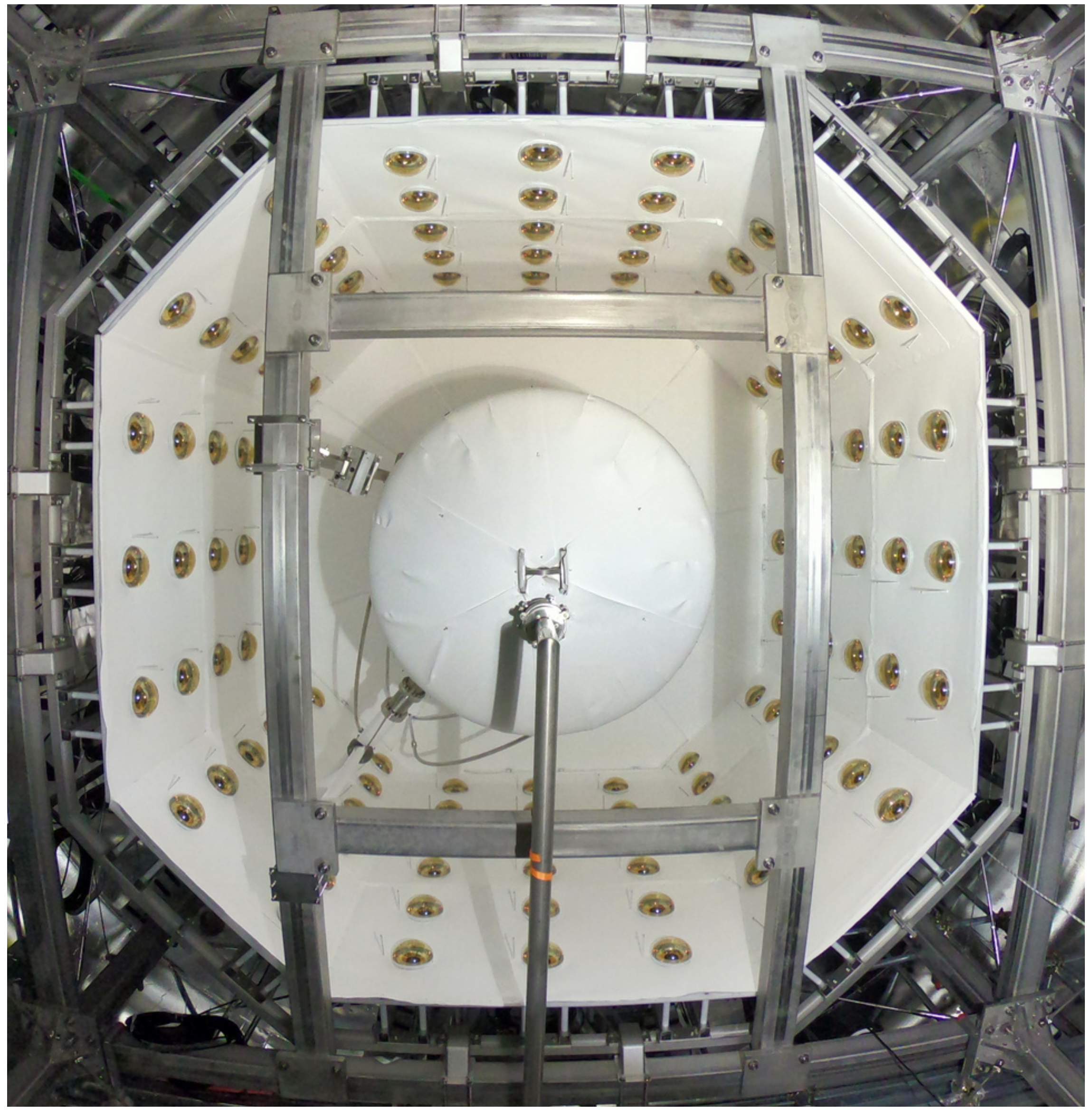
- 5.9 t active LXe (3 times XENON1T)
- 494 PMTs Hamamatsu R11410-21 3-inches
- Tunable field shaping rings chain
- 1.5 m drift length
- Materials selection based on intense screening campaing



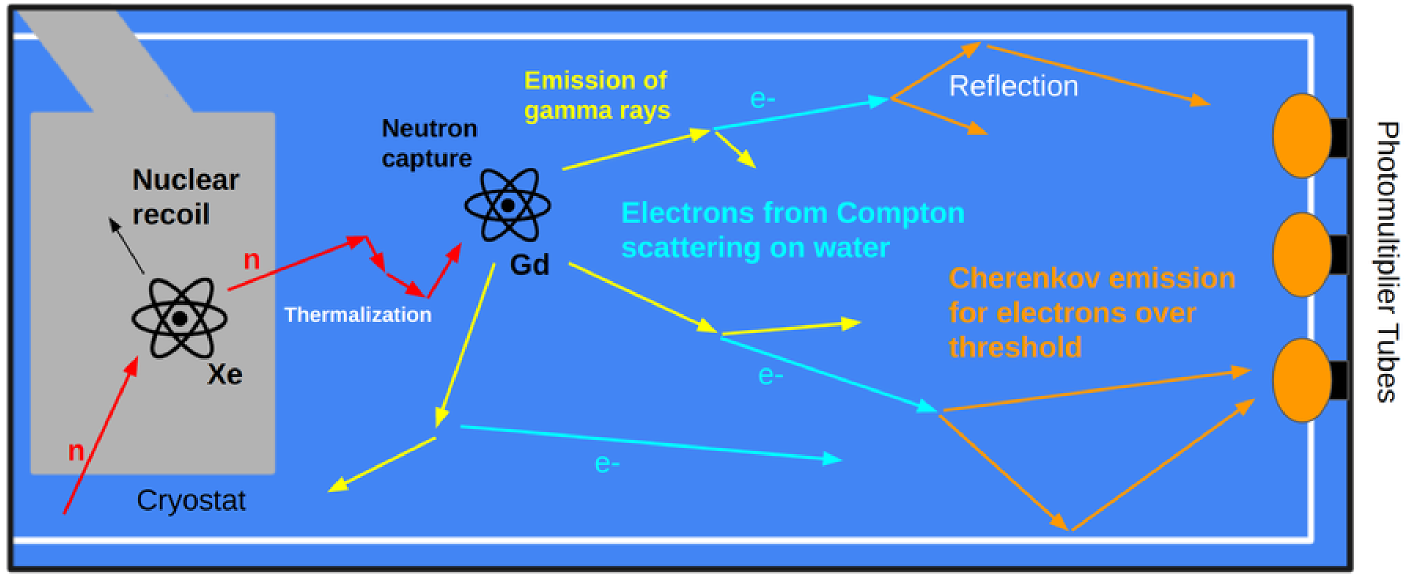
PMT Top Array



The Neutron Veto



Aims to reduce the background of radiogenic neutrons coming from the detector materials



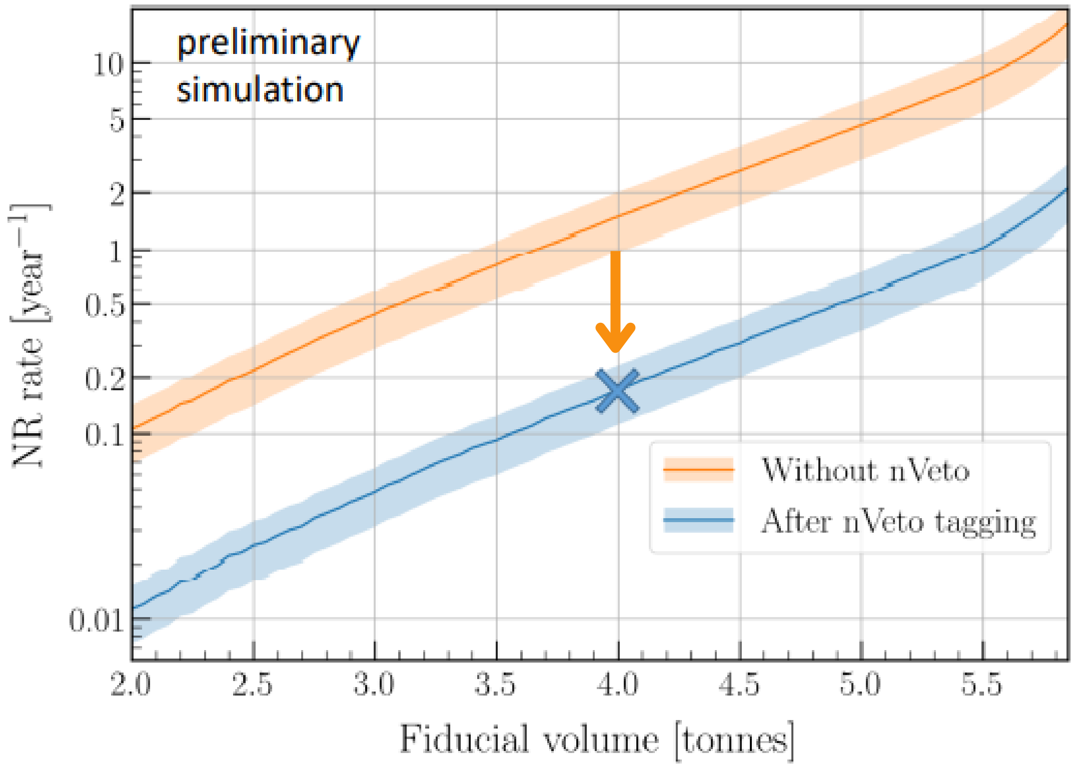
Hamamatsu R5912

featuring:

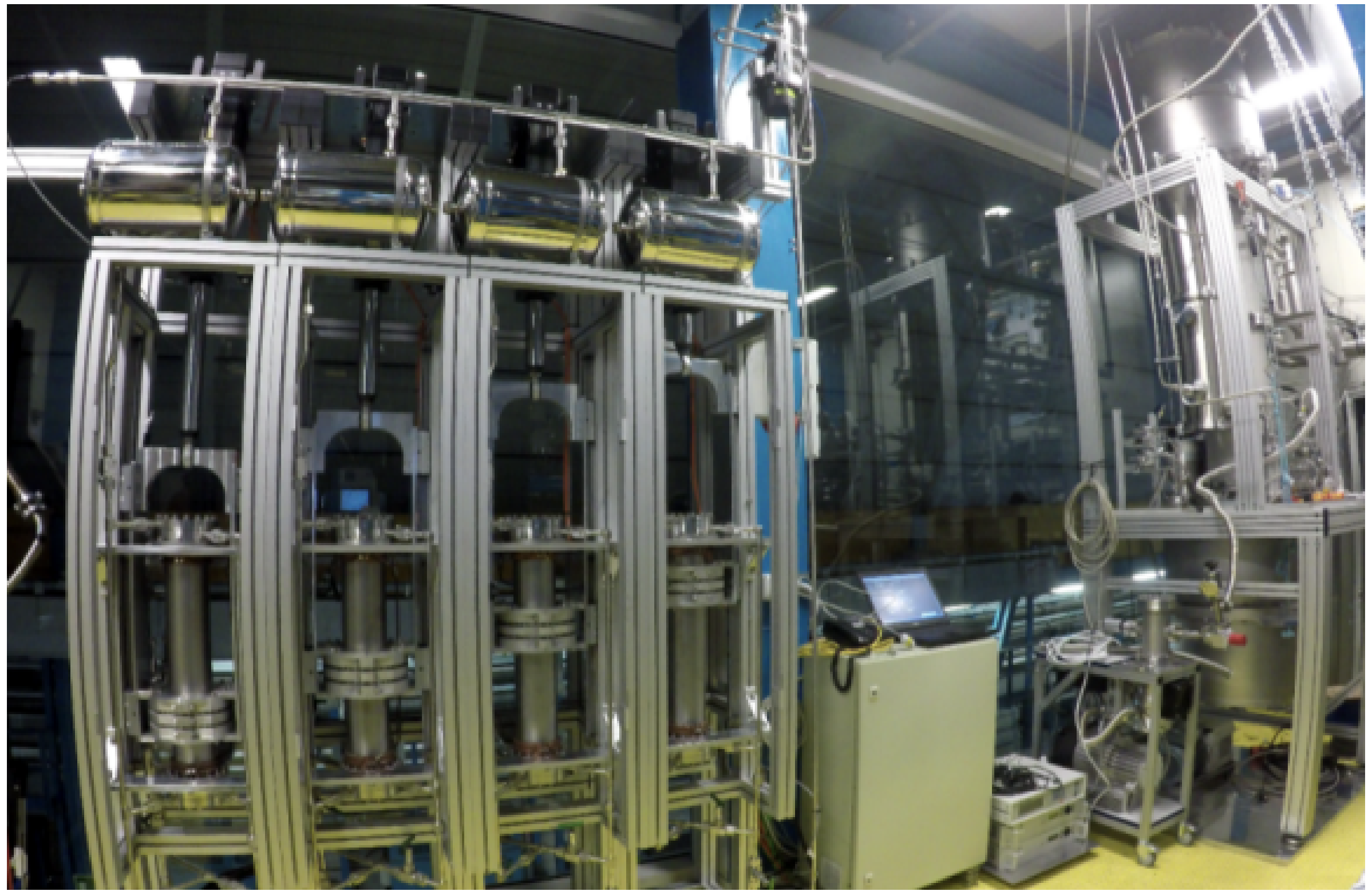
- 8-inches photocathode
- Low radioactivity
- High Quantum Efficiency (40%)

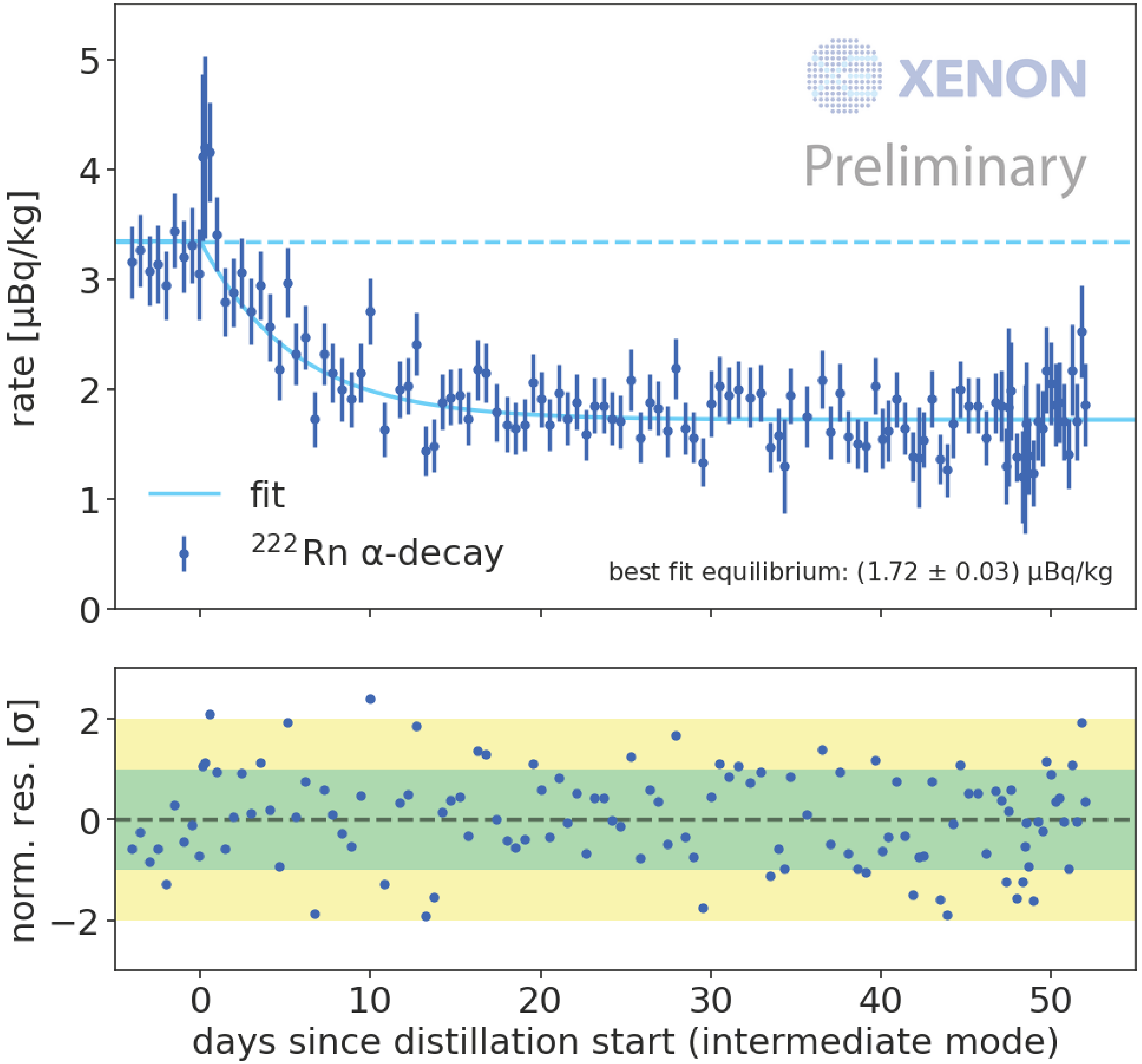
- Water Cherenkov detector, currently operated with demi-water; in the next phase we will dope with 0.5% Gd-sulphate (Gd-Water purification system currently under commissioning).
- Inner region optically separated from the Muon Veto through high reflectivity ePTFE panels
- Instrumented with 120 low-radioactivity, high-QE PMTs

- Expected tagging efficiency with Gd: 87 % - with water: 65%
- Goal: <1 neutron events / (20 t x year)



The Rn distillation system

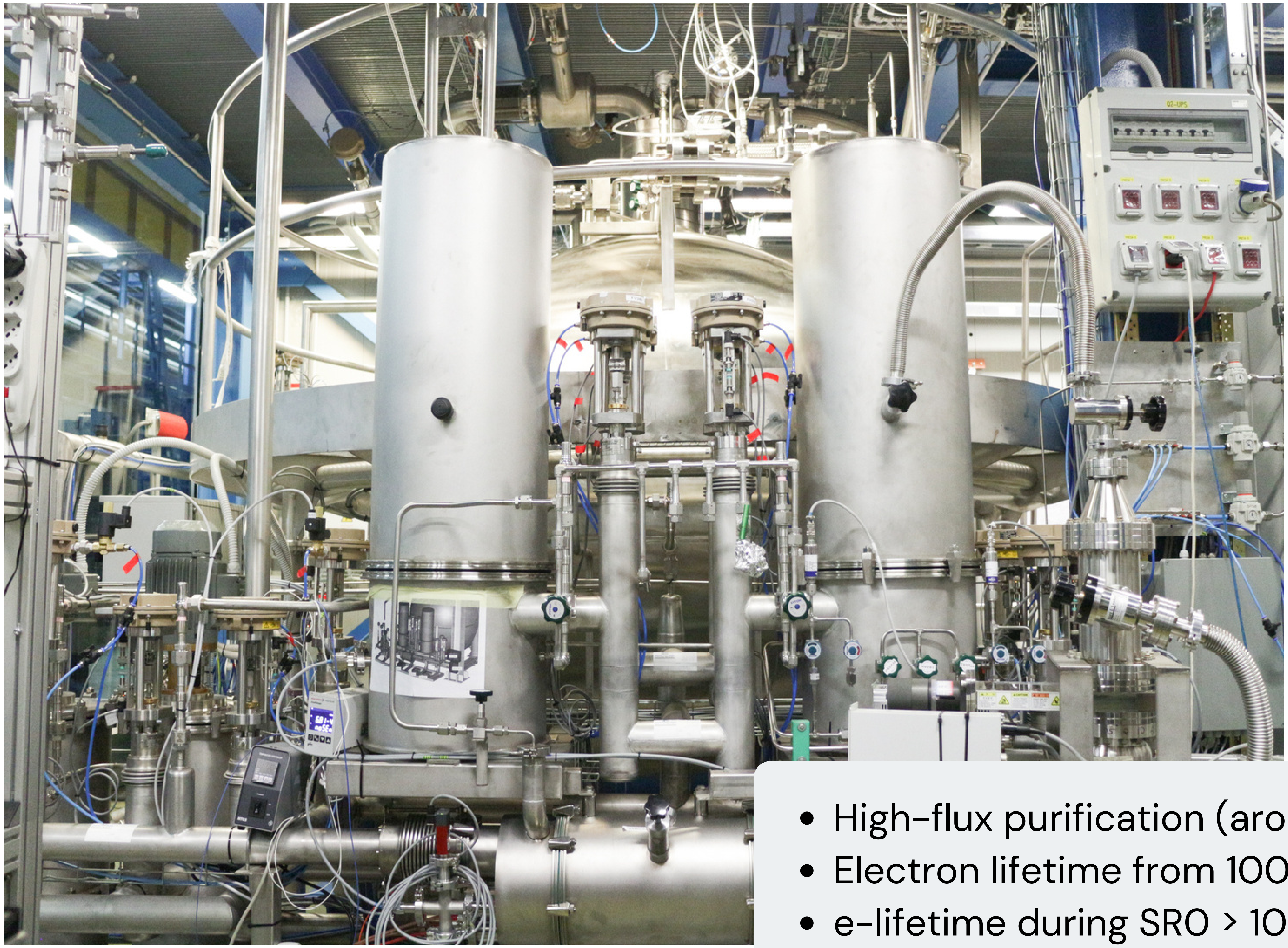


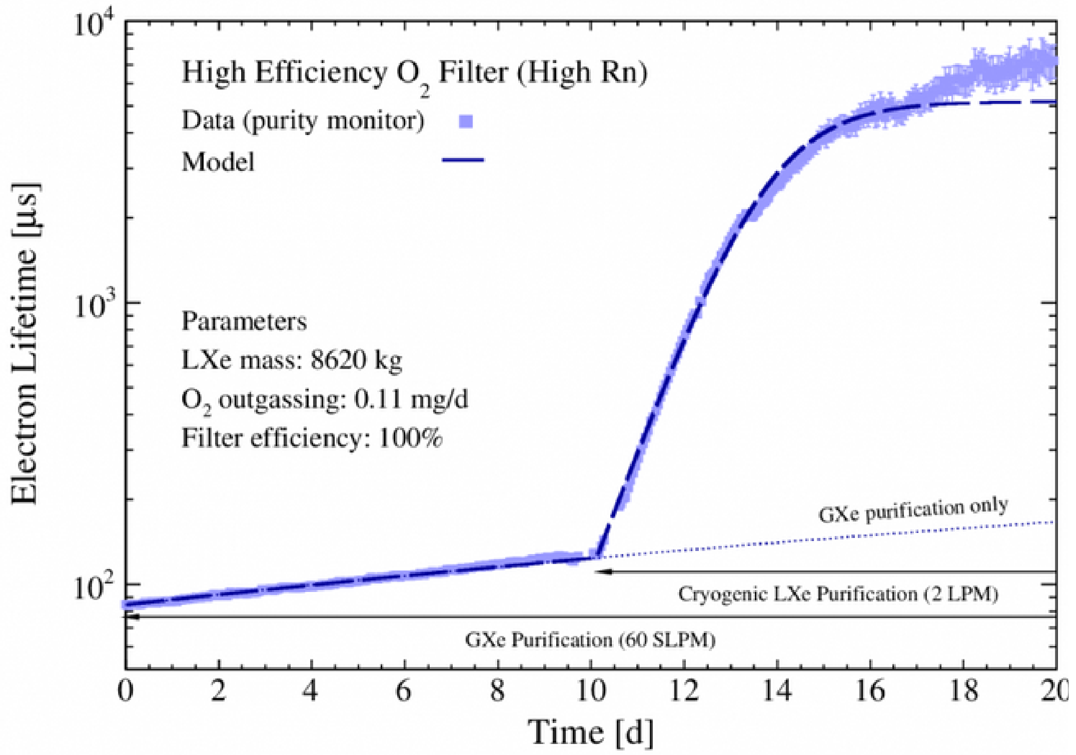


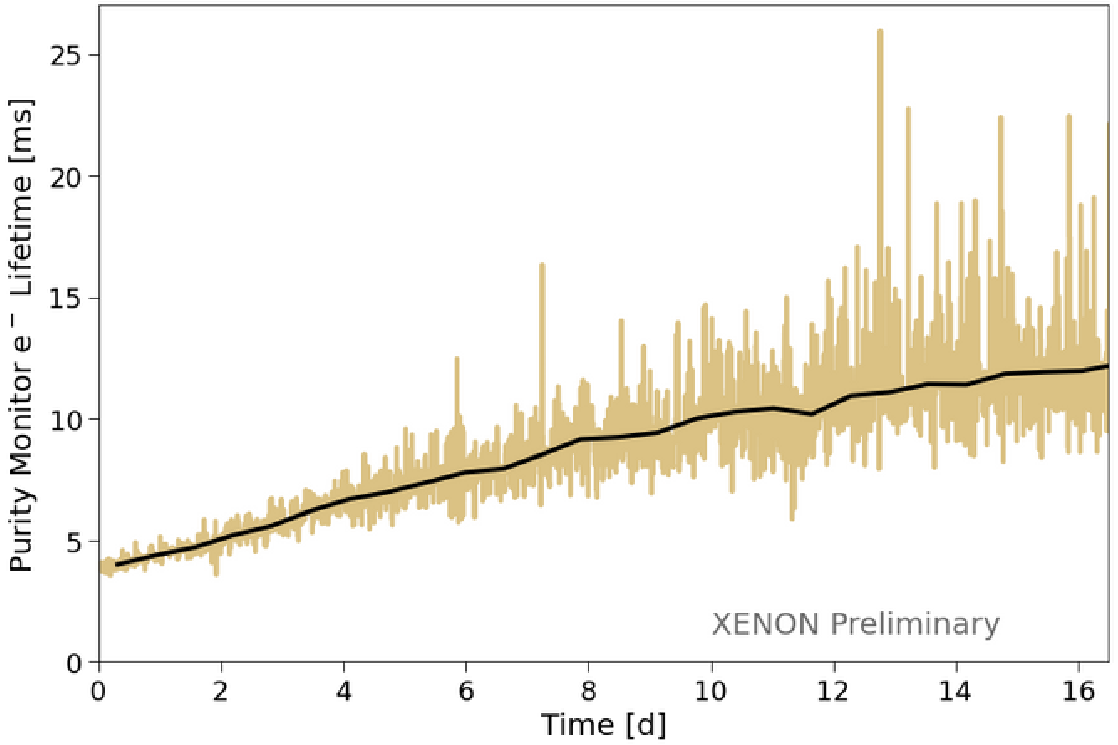
Radon intrinsic background from materials

- In XENON1T ^{222}Rn was the dominant bkg (~ 13 μBq/kg)
- Dedicated system (in addition to Kr column)
- Lowest level in LXeTPC (<2 μBq/kg ^{222}Rn)
- **Goal: 1 μBq/Kg**, with further improvement

The LXe purification system



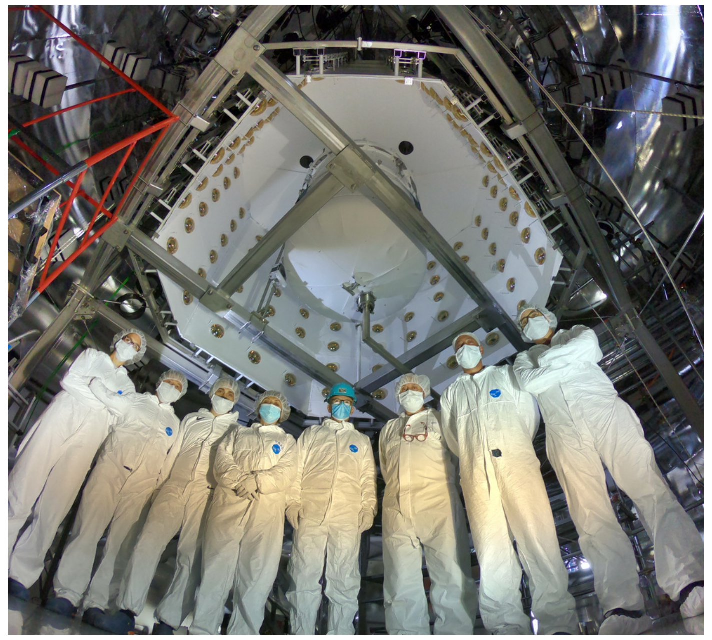




- High-flux purification (around 350 kg/h)
- Electron lifetime from 100 µs to 5 ms within 5 days (0.65 ms in XENON1T)
- e-lifetime during SR0 > 10 ms

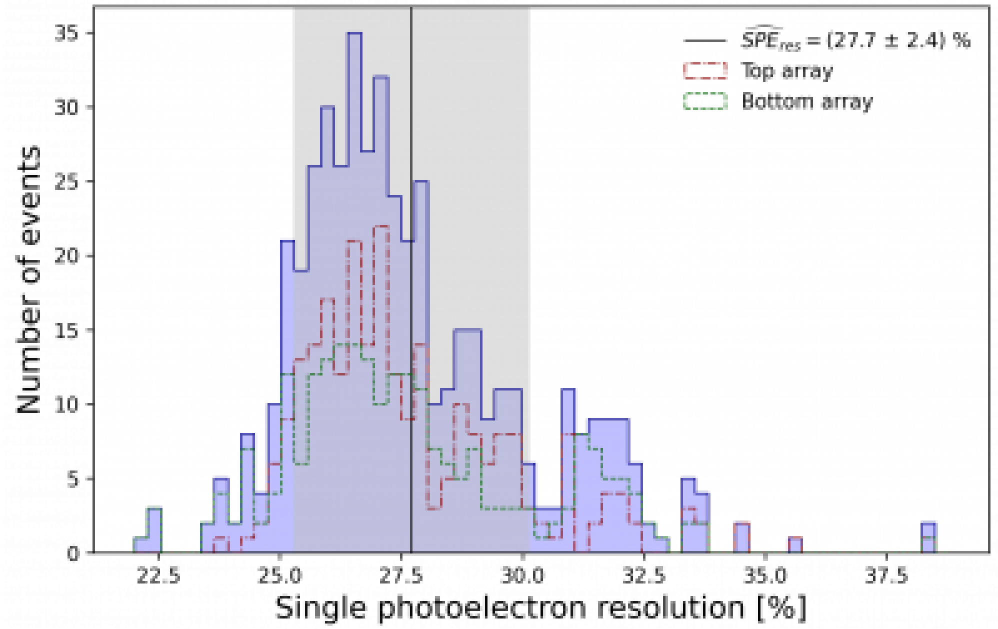
Status and Performances

- Commissioning completed in the first half of 2021
- Science Run 0 completed in the end of 2021

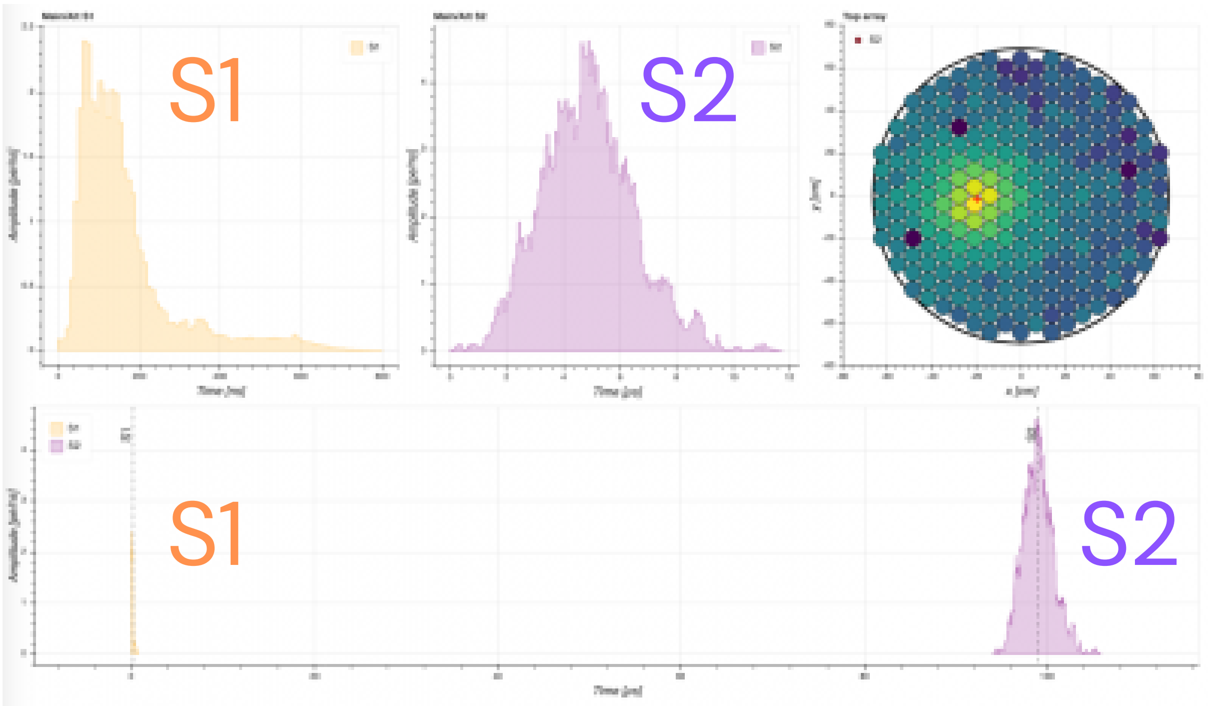


Science Run ongoing

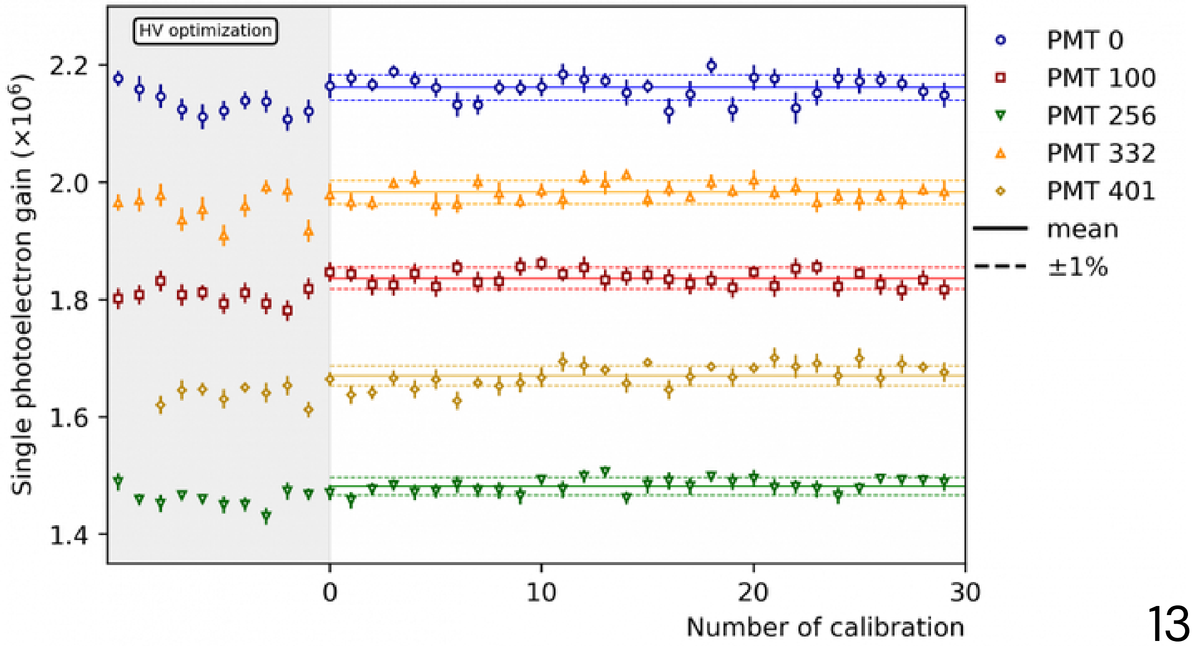
- Focused on WIMP search
- Investigation of the low-energy ER events



Initial XENONnT Performances



- Steady conditions: PMT showing excellent gain stability
- Light Collection : ~17%
- SPE Resolution : ~27%



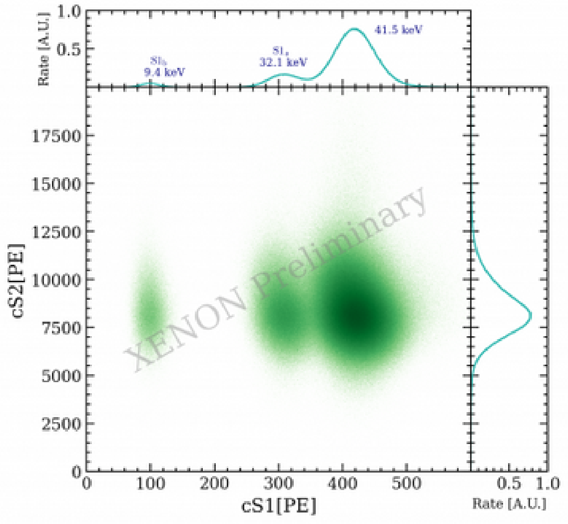
First Science Run

Calibrations

^{83m}Kr

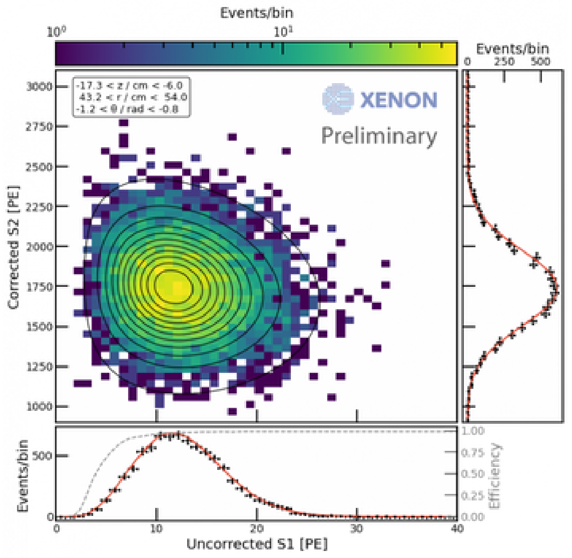
Detector effect & Energy Resolution

7.6% energy resolution at 41.5 keV

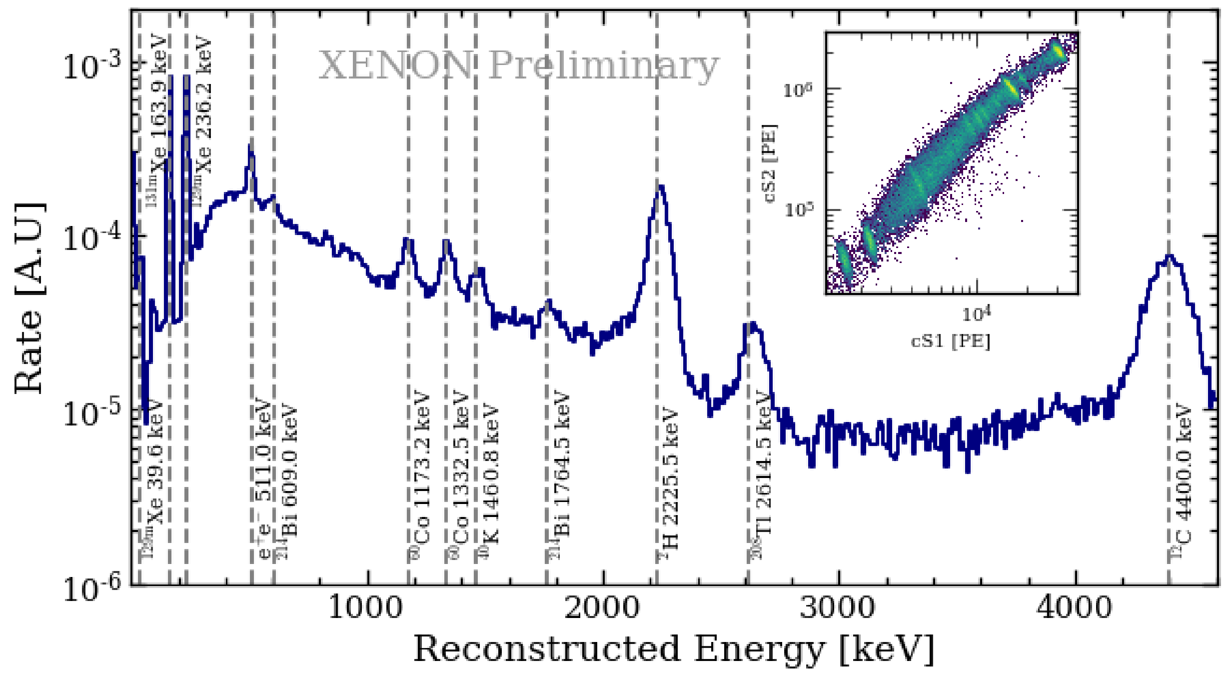


^{37}Ar

provides an additional (very) low energy calibration source for TPC response characterization

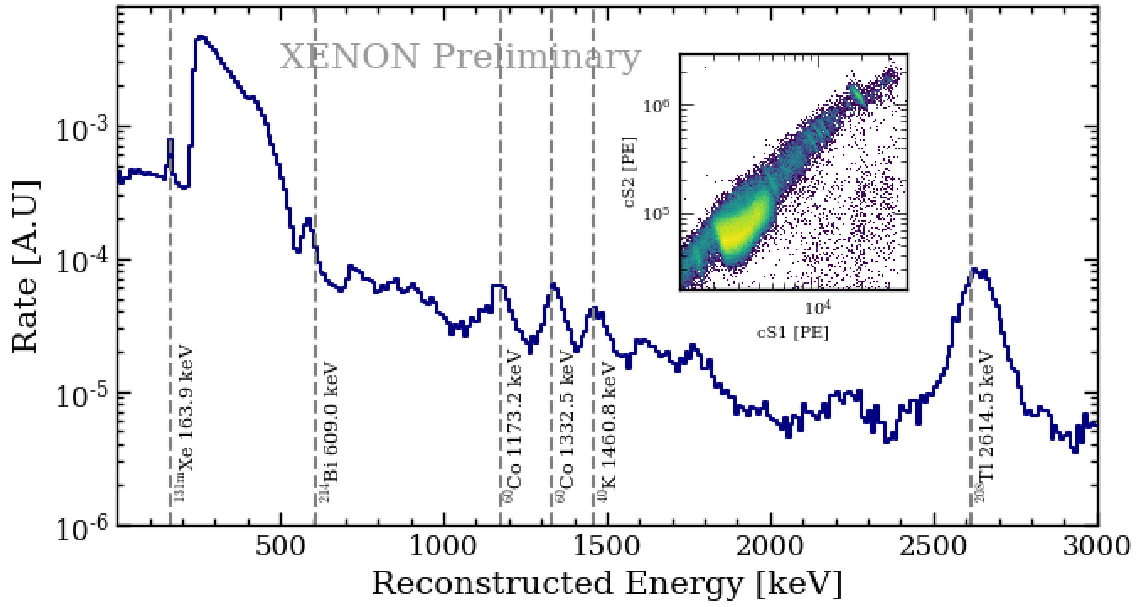


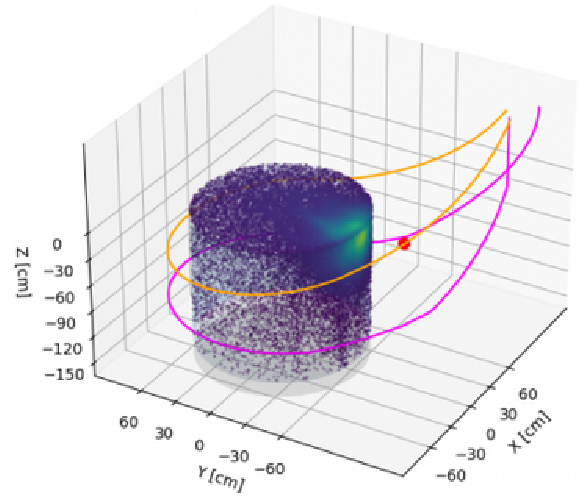
^{220}Rn ER Band & CES

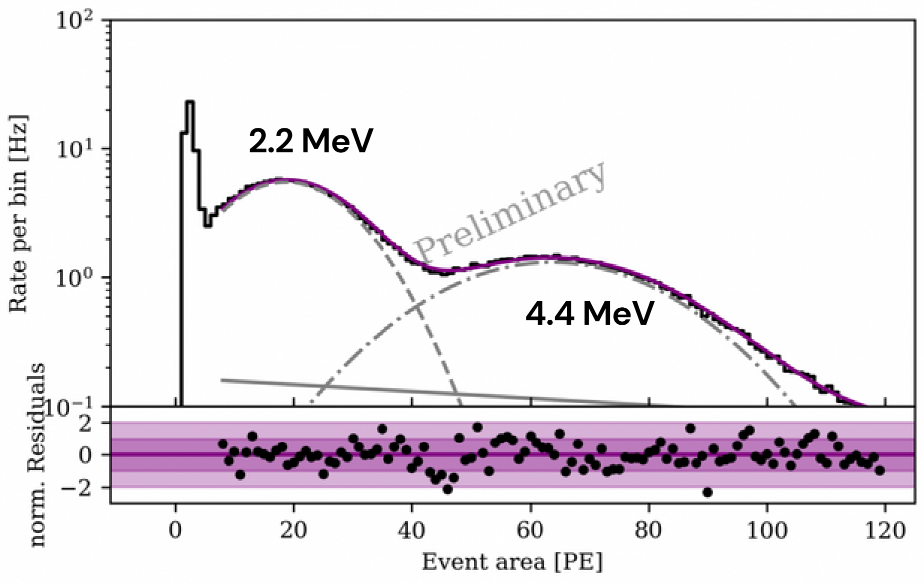


AmBe

NR Band (&CES) & Neutron Veto tagging efficiency







Tagging efficiency (Preliminary)

$\varepsilon = (0.69 \pm 0.02)$

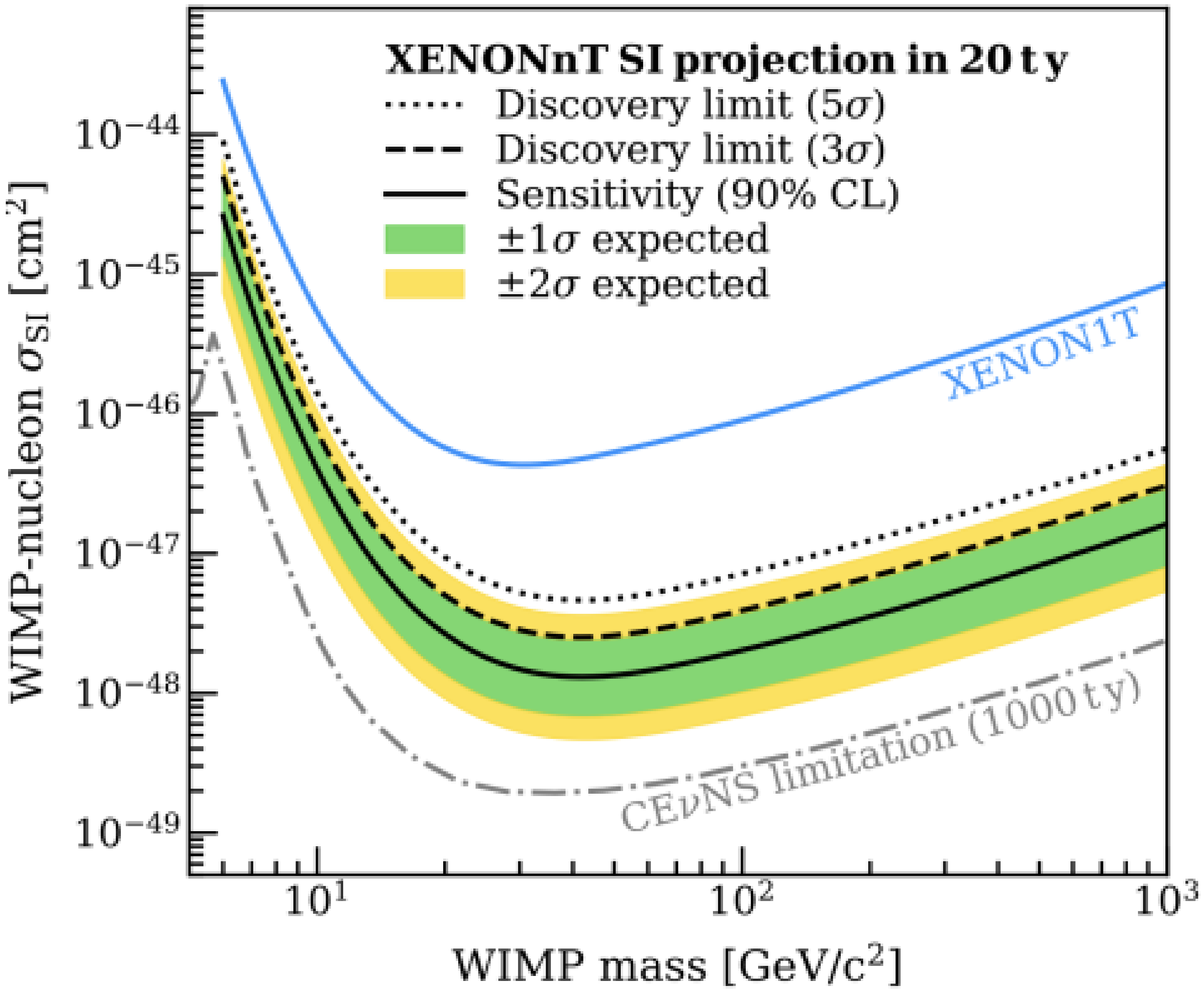
(with demi water)

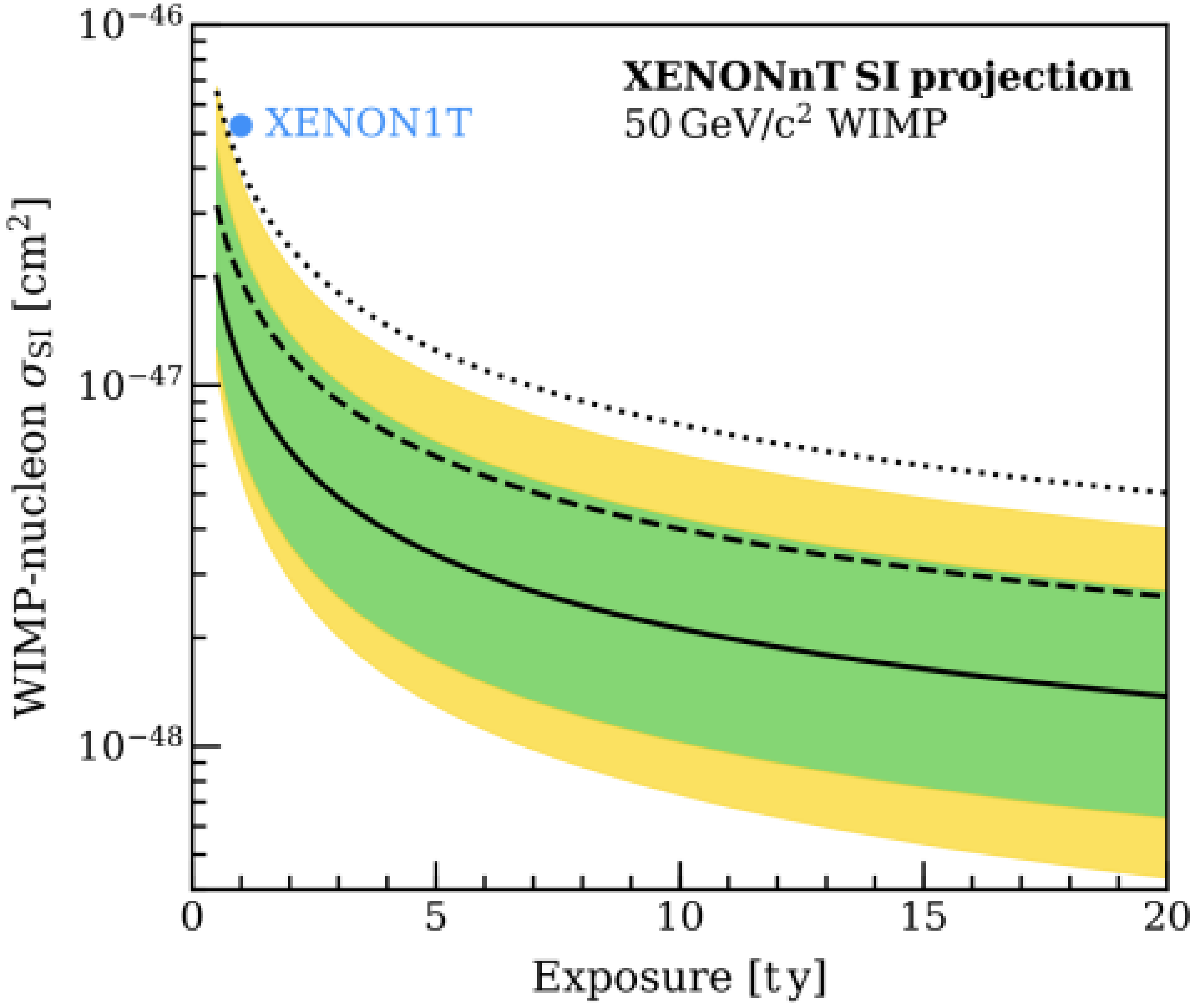
Projections

JCAP 11 (2020) 031 WIMP

- Exposure goal : 20 t x yr

$$\sigma_{SI} \sim 1.4 \times 10^{-48} \mathrm{cm}^2 \text{ at } 50 \mathrm{GeV/c}^2$$

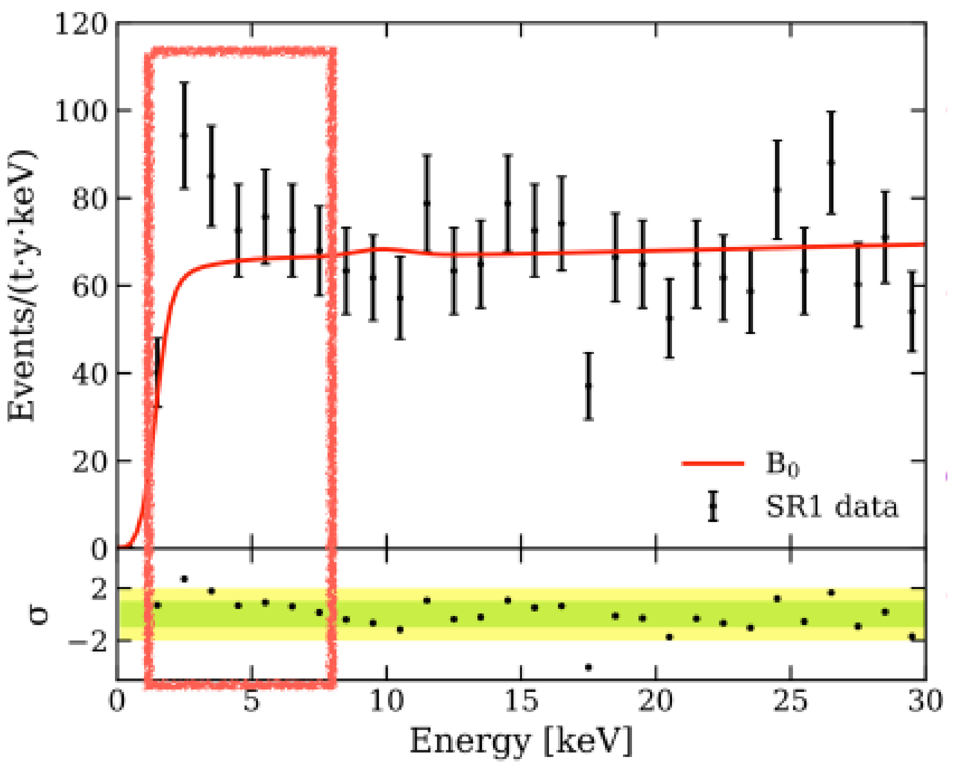


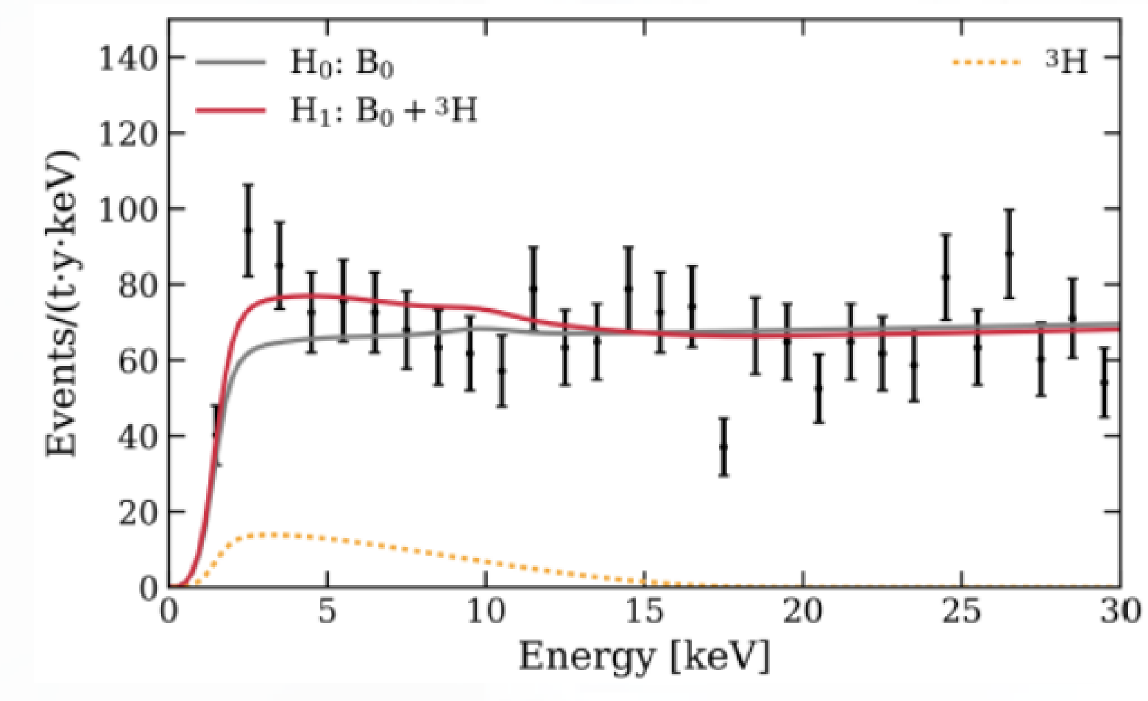


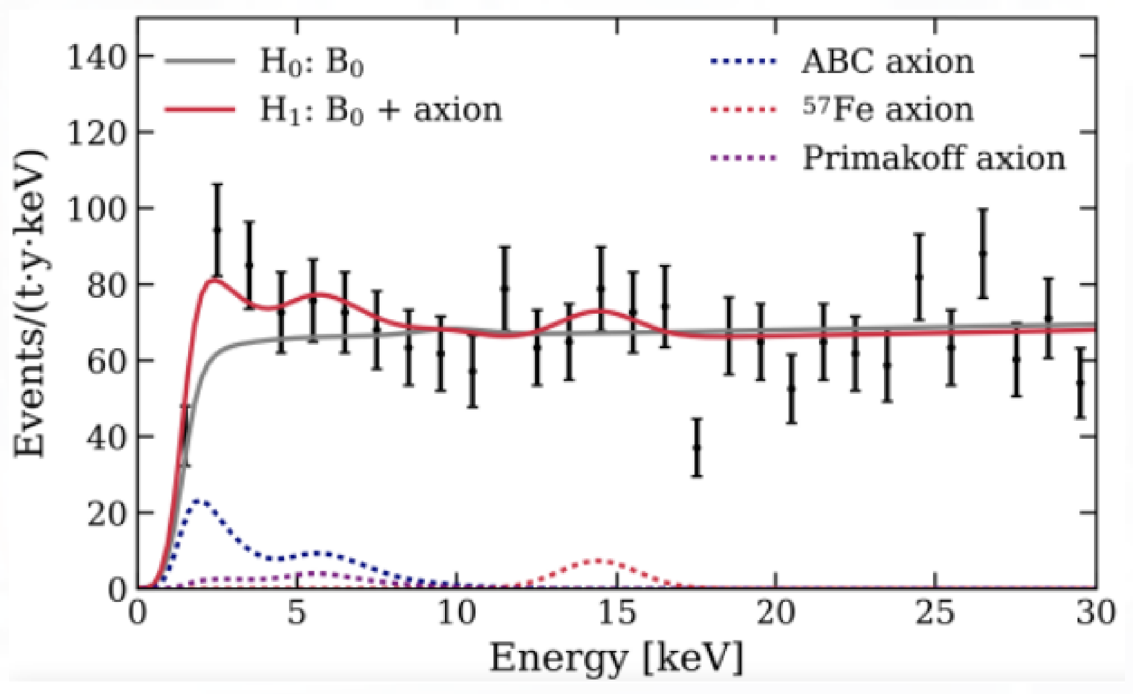
The XENON1T Low-ER excess

Phys. Rev. D 102, 072004 (2020)

XENON1T observed an excess of events in the low-ER region [1-7] keV





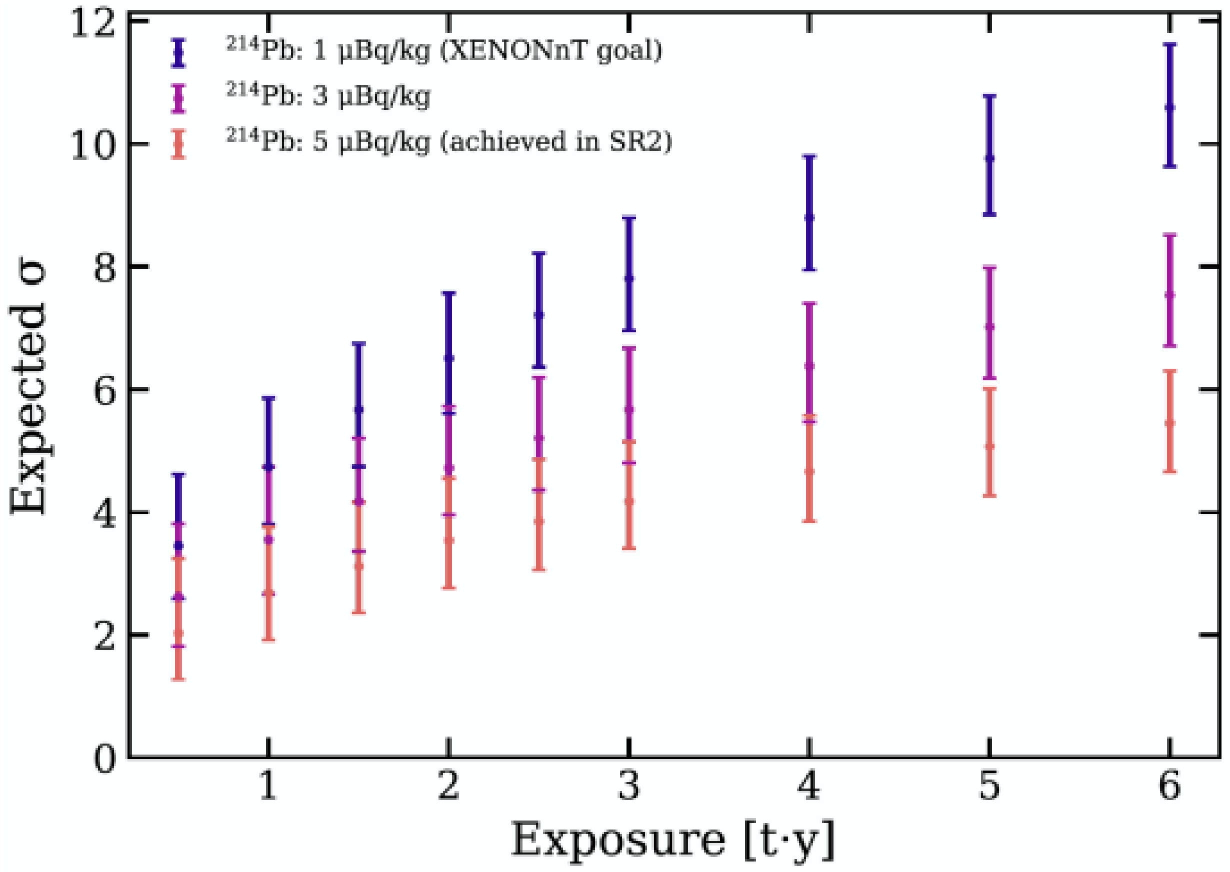


Observed 285 events in 1-7 keV
Expected (232 ± 15) events
→ ~ 3.3σ Poissonian fluctuation!

Signal compatible with solar axion spectrum:

- (3.4 σ) without tritium BG assumption
- (2.0 σ) with tritium BG assumption

XENONnT will reveal the true nature of the XENON1T excess with the results of the first science run



Summary & Outlook

The XENONnT Experiment, located at Laboratori Nazionali del Gran Sasso, has been commissioned in 2020/21 and is currently taking science data :

- with a Dual-phase Xe TPC with 5.9 t target mass
- achieving an e-lifetime >10 ms
- with a low Rn level (< 2 μBq/kg)
- with a reduced n-background thanks to the novel nVeto system

The first Science Run has been completed at the end of 2021. After some maintenance and refurbishment we are again taking Science Data.

The analysis of the first months of data will be focused on the WIMP search and on the low-ER events, shedding light into the excess of event in the low ER region, seen by its predecessor, XENON1T

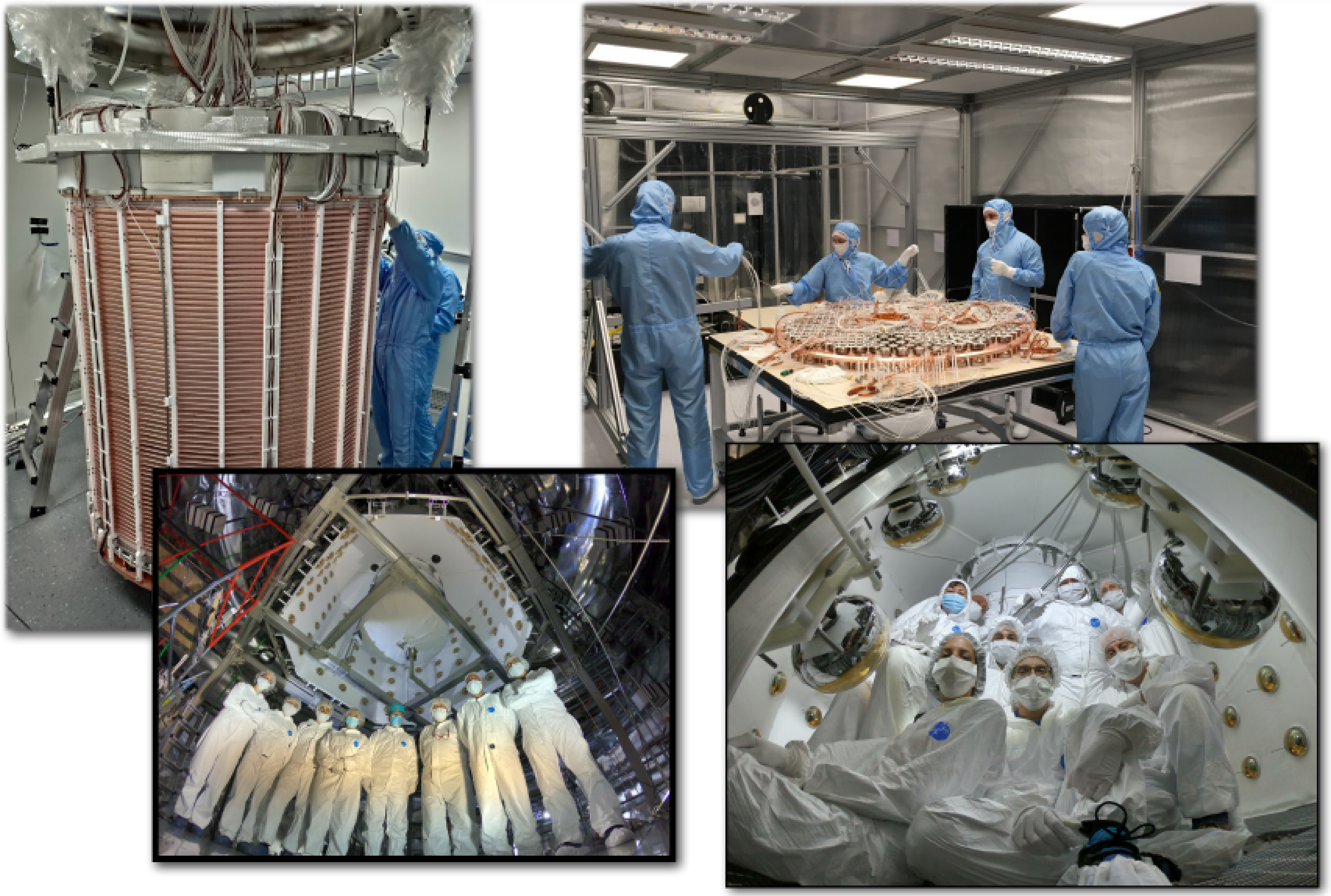
Thanks for your attention

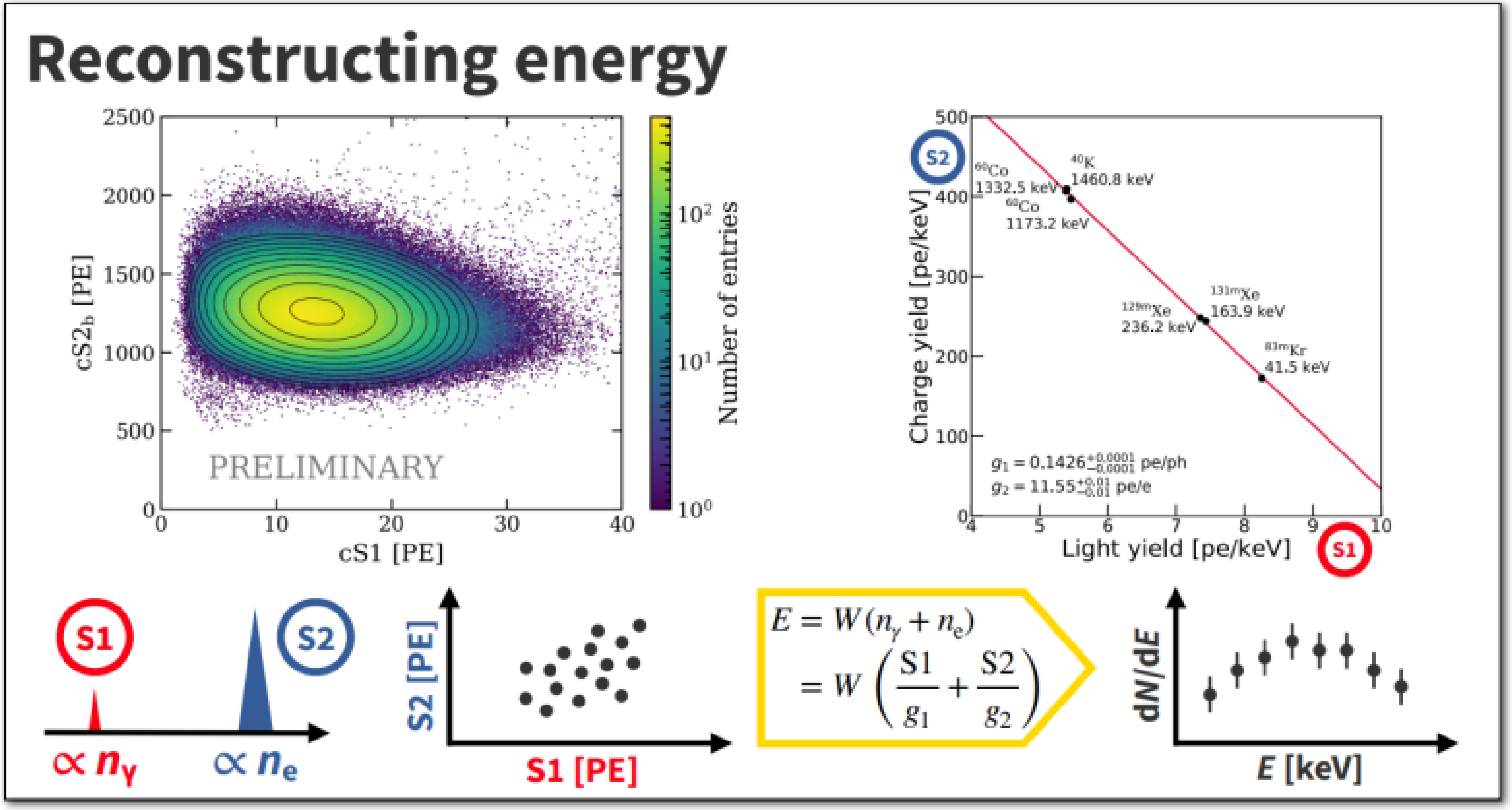
Backup

XENONnT Commissioning

XENON

- Spring 2020 — TPC Installation
- Summer 2020 — NV Installation
- December 2020 — Water Tank filled
- First months 2021 — Test of all the subsystems and TPC commissioning
- Now — Science Run





Erwann Masson, "From XENON1T to XENONnT: Latest Results and First Light", 32e Rencontres de Blois, 17-22 October