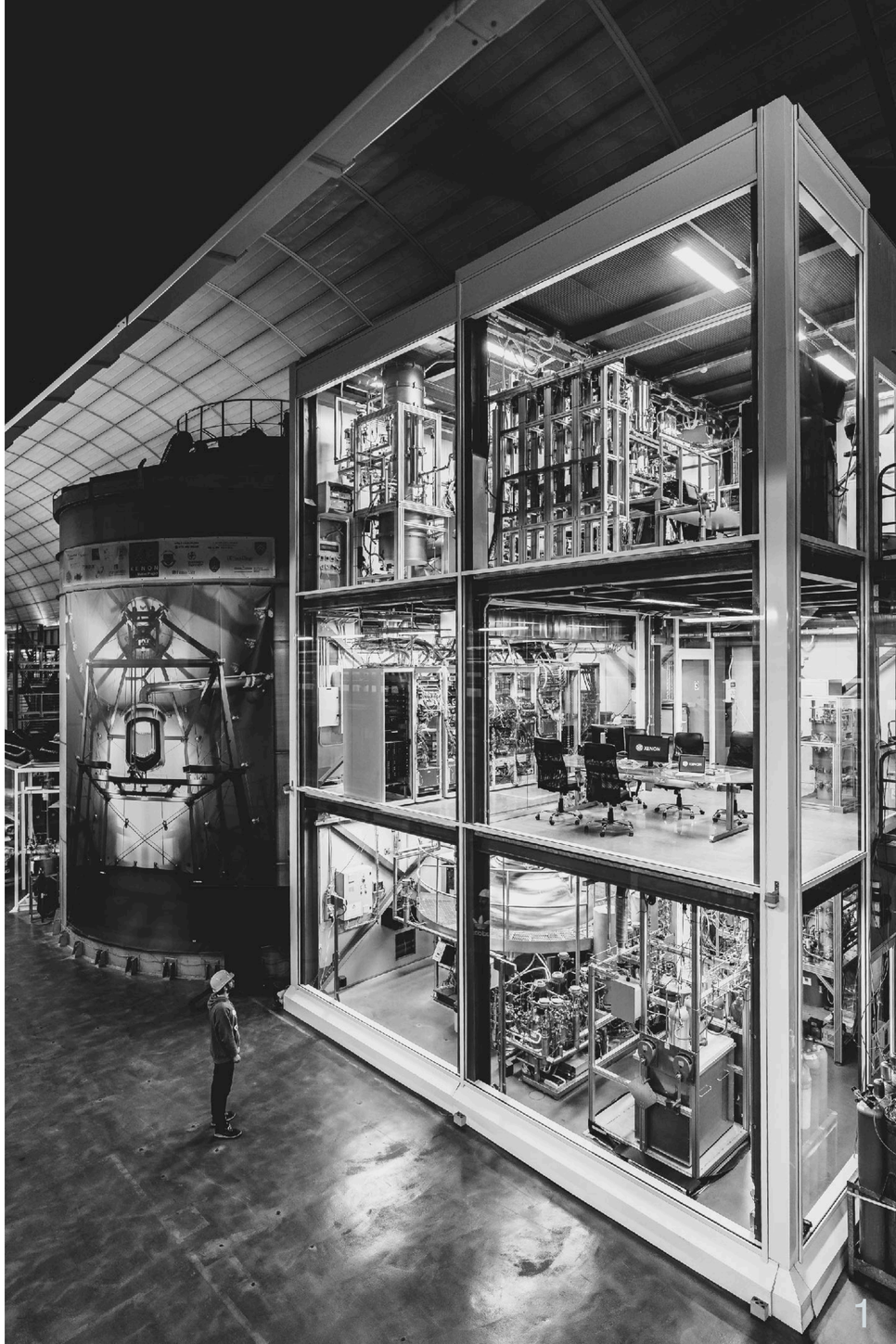
XENON

Results and Prospects for XENONnT Experiment



Masaki Yamashita

Kavli IPMU The University of Tokyo (WPI)

on behalf of the XENON collaboration

地下から解き明かす宇宙の歴史と物質の進化
Unraveling the History of the Universe and Matter Evolution with Underground Physics

科研費 KAKENHI

DMNet

ERAN

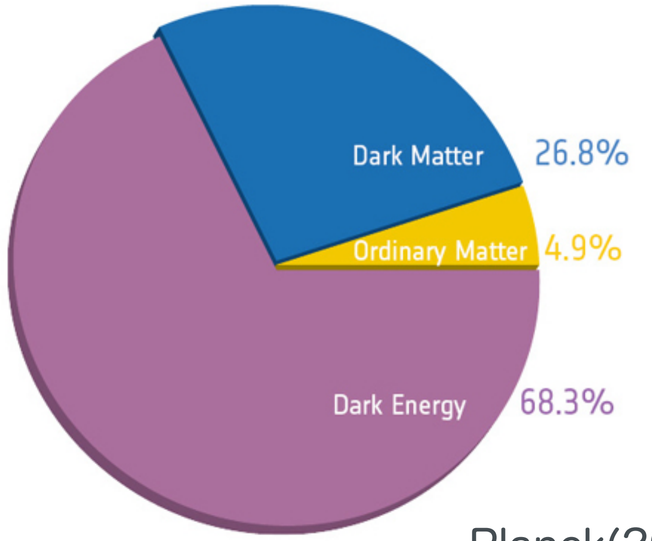
2023/12/01-03

Internal Workshop on "Double Beta Decay and Underground Science"

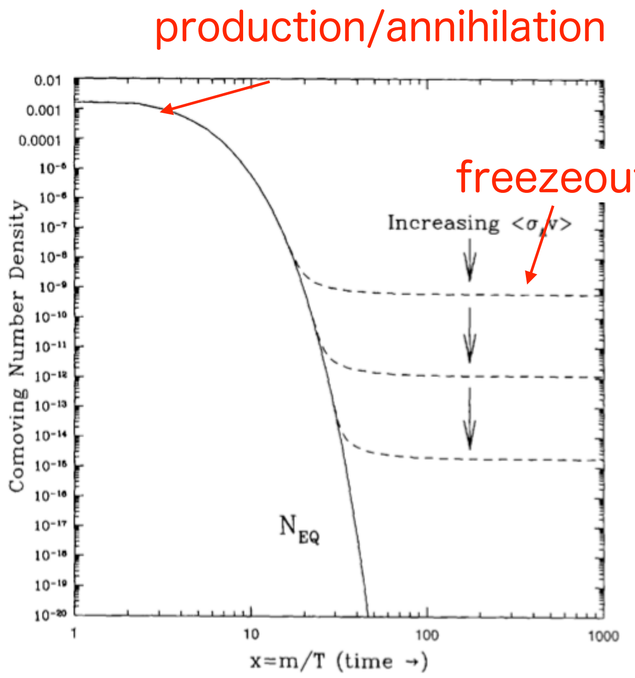
WIMP Dark Matter

XENON

- **Composition of the Universe**
  - Dark Energy/Matter　95% unknown
    - Dark Energy(68%), **Dar Matter(27%)**
- **What is Dark Matter?**
  - WIMP, Axion, Primordial Black Hole …
  - Weakly Interacting Massive Particle (WIMP)
    - **WIMP appears in beyond the standard models, such as SUSY.**
    - **WIMP is not excluded by the experiments but is detectable near future.**
    - **WIMP is a relic from the simple mechanism of the thermal freeze-out process.**
      - **successful scenario for CMB, Big Bang Nucleosynthesis (H, He, ν…)**

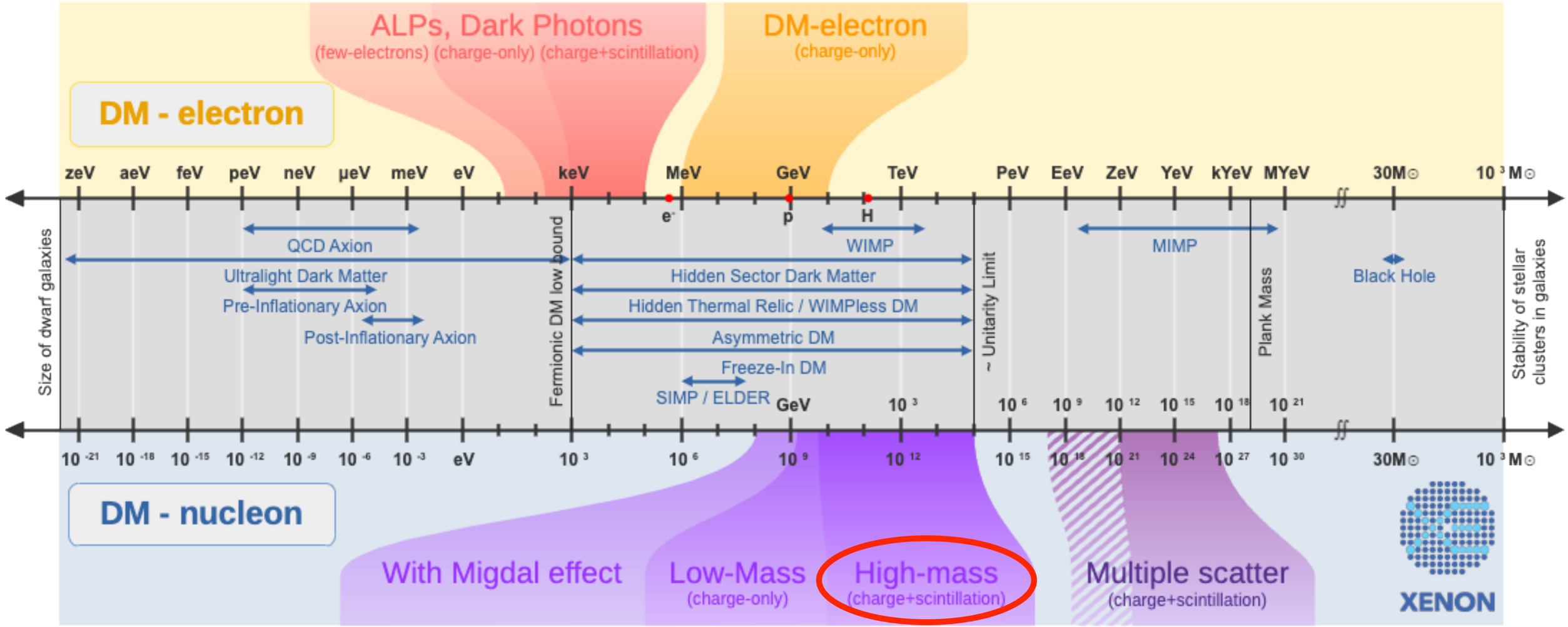


Planck(2013)



Electronic recoil channel

XENON



XENON Collaboration

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

Chicago · Tsinghua

170 scientists, 29 Institutions, countries

UCSD · Tokyo

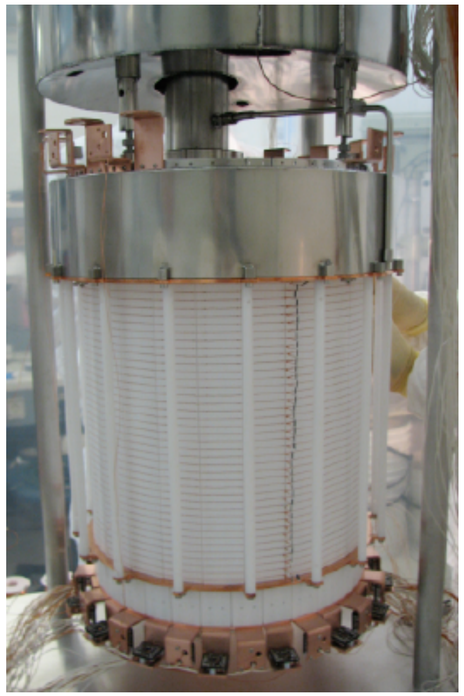
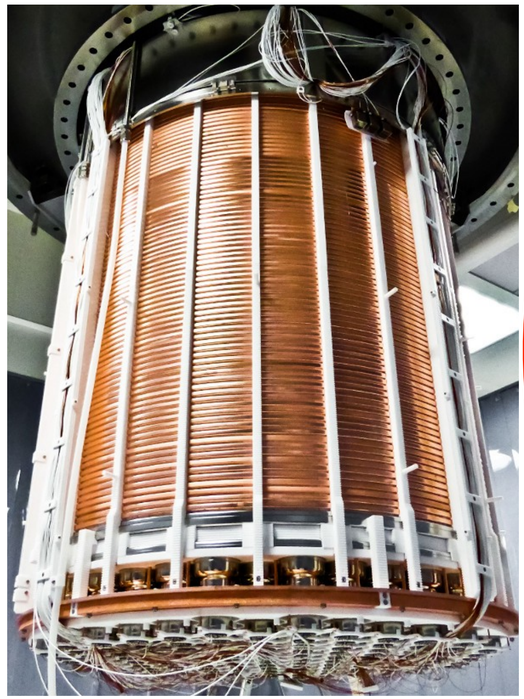
Rice · Nagoya

Purdue · Kobe

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

History of the XENON Experiment

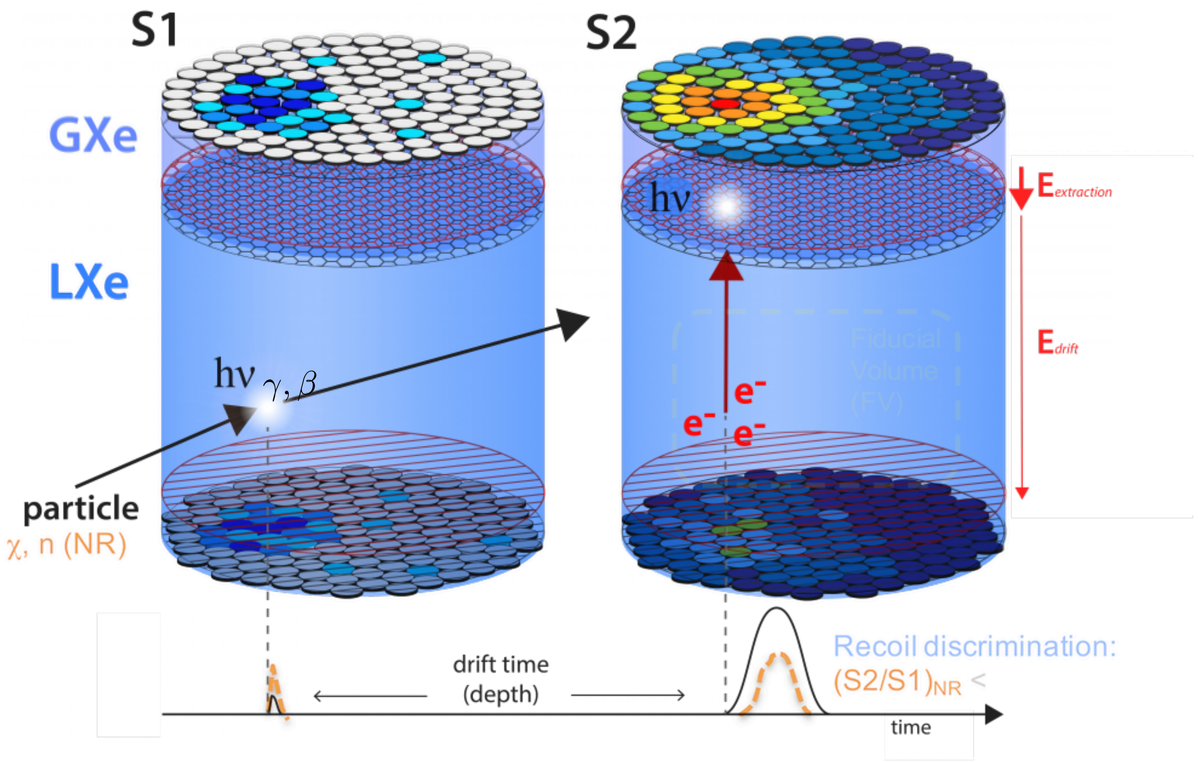
XENON

XENON10	XENON100	XENON1T	XENONnT
			
2005-2007	2008-2016	2012-2018	2019-202x
25 kg - 15cm drift	161 kg - 30 cm drift	3.2 ton - 1 m drift	8 ton - 1.5 m drift
~10^{-43} cm^2	~10^{-45} cm^2	~10^{-47} cm^2	~10^{-48} cm^2

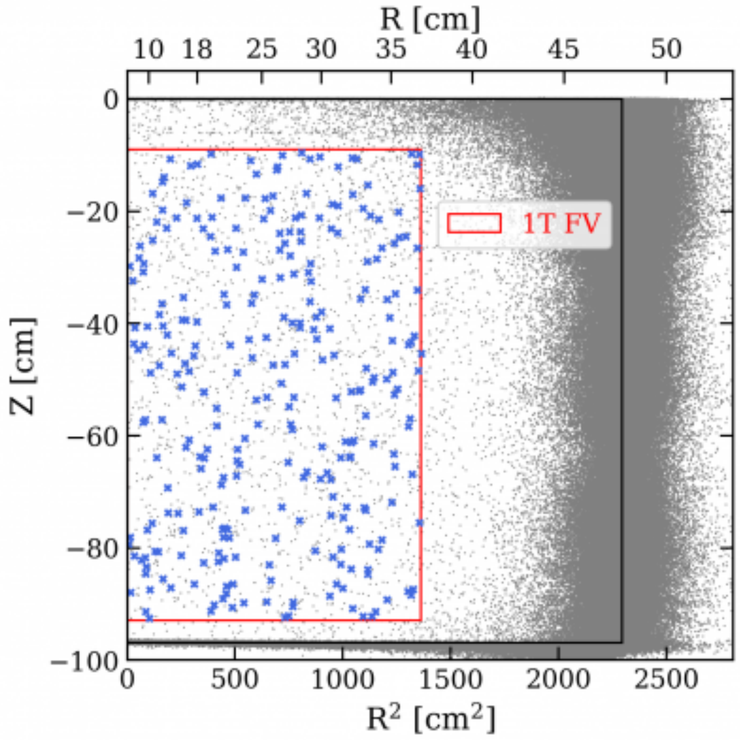
Two-phase Xe Time Projection Chamber

XENON

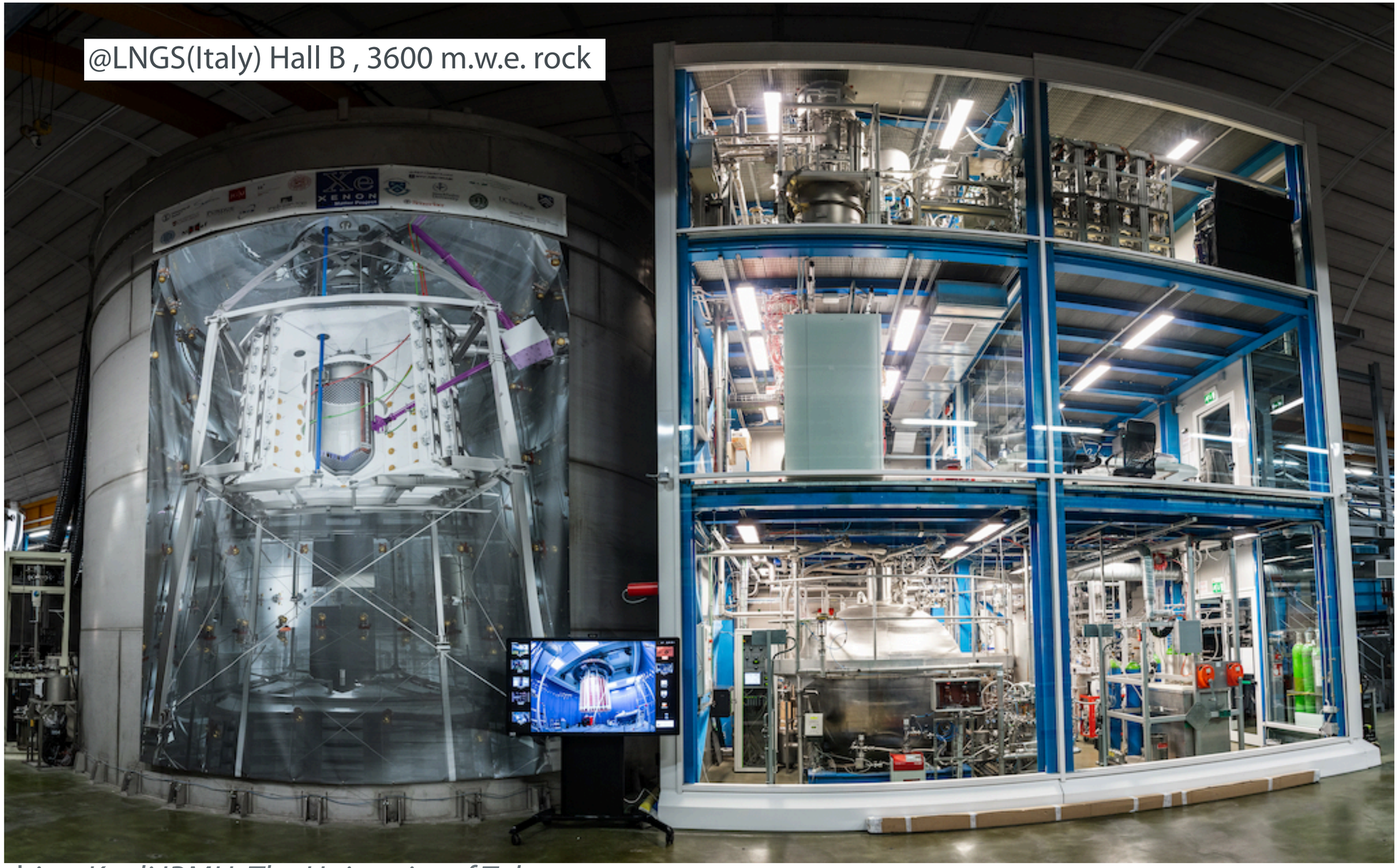
- **Scintillation light: S1**
- **Electron : S2**



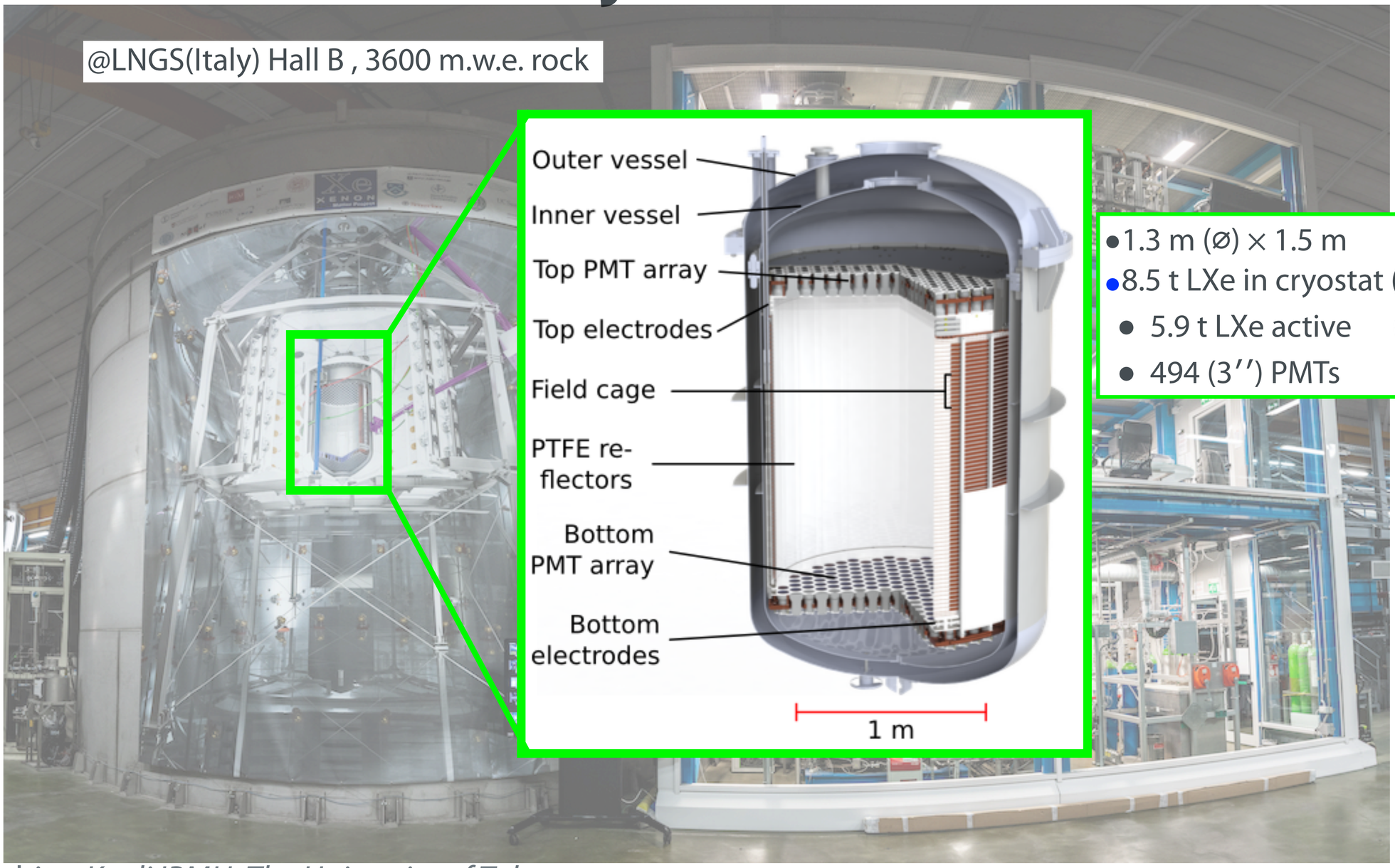
- Two signals for each event:
  - 3D event imaging: x-y (S2) and z (drift time)
  - self-shielding, surface event rejection, single vs multiple scatter events
  - Particle identification using S2/S1 ratio (nuclear recoil vs beta, gamma)



XENONnT

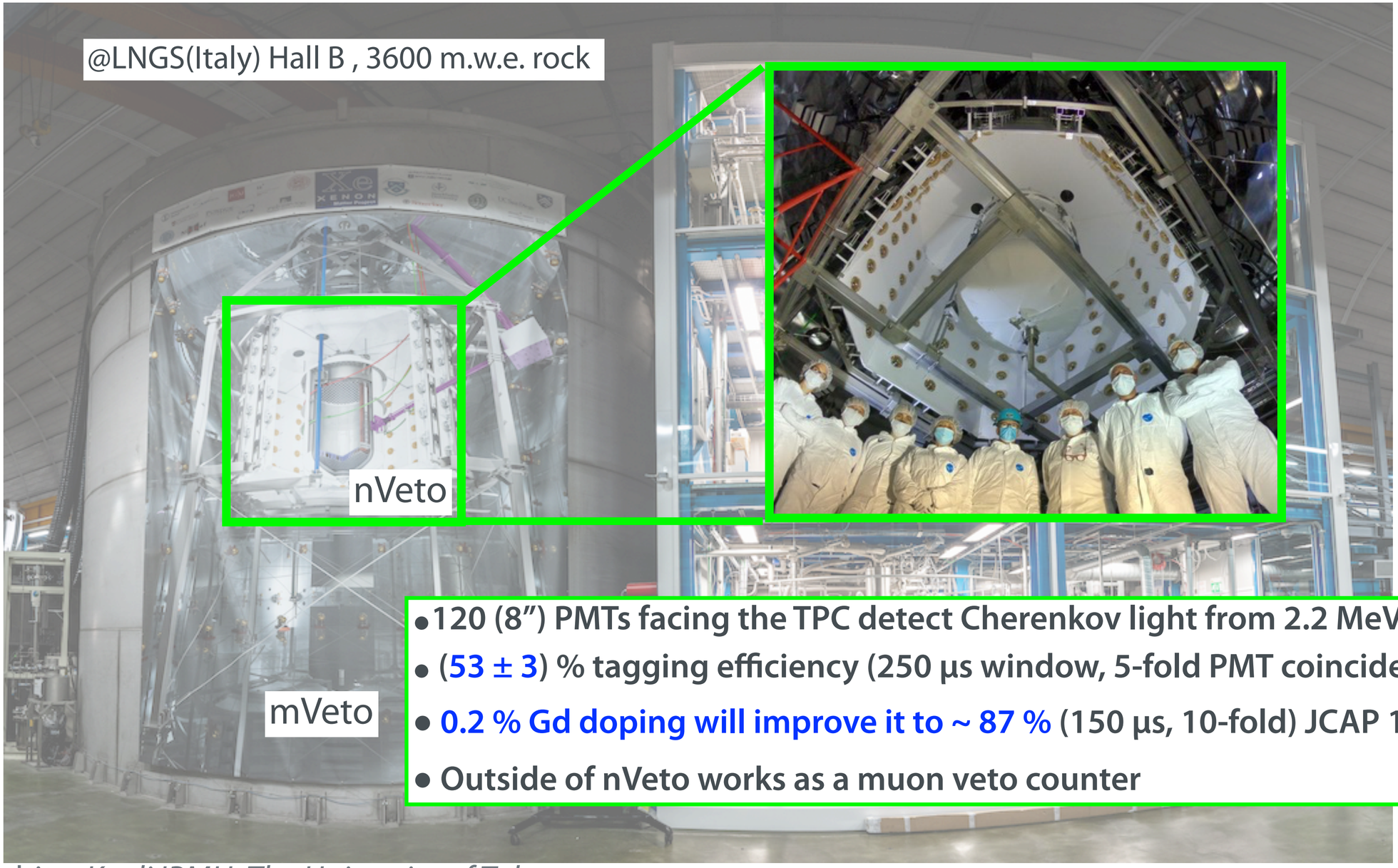


XENONnT: Time Projection Chamber



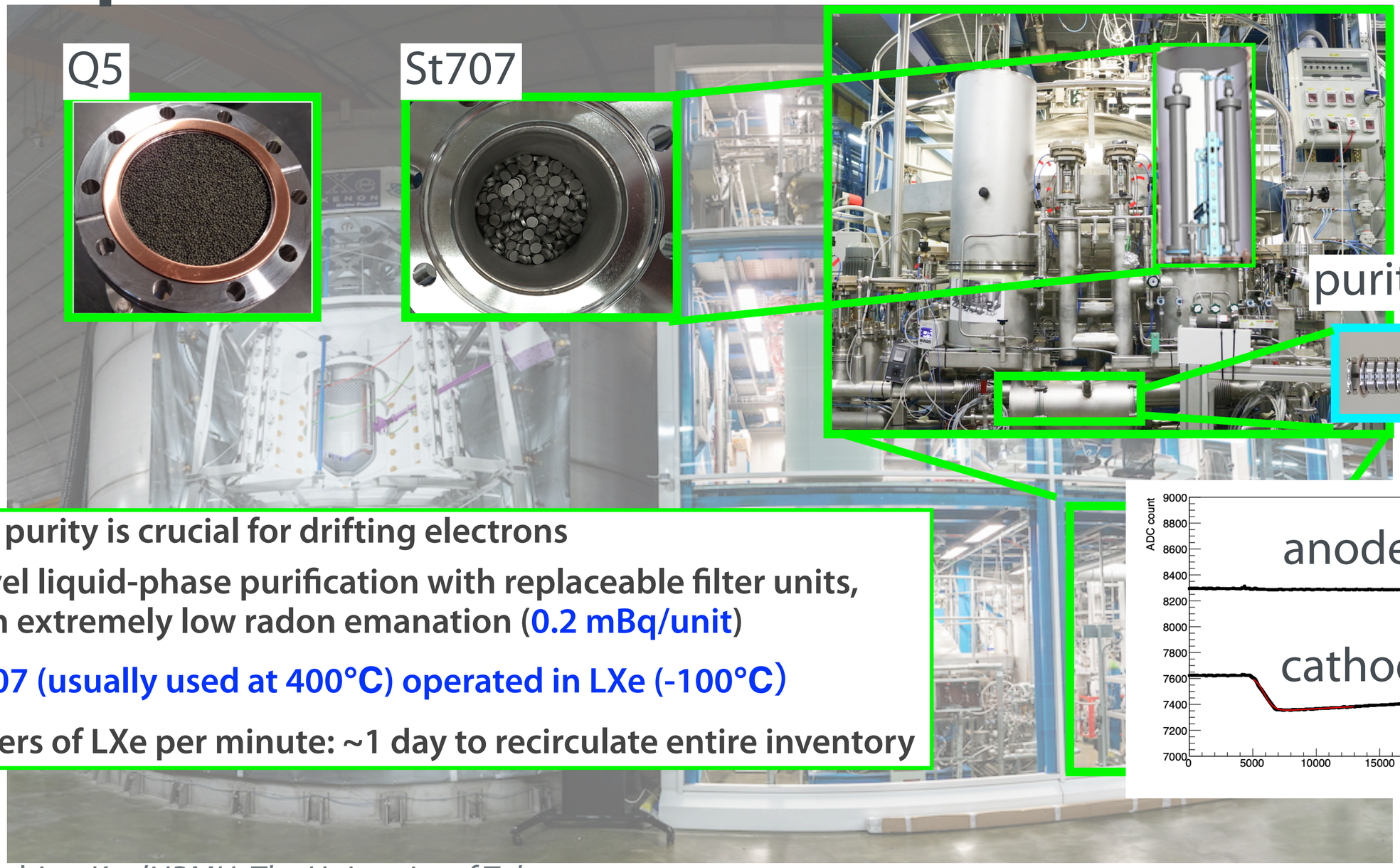
- 1.3 m (⌀) × 1.5 m
- 8.5 t LXe in cryostat (2.5x XENON1T)
  - 5.9 t LXe active (3x XENON1T)
  - 494 (3’’) PMTs (2x XENON1T)

Gd-loaded Water Cherenkov Counter for Neutron



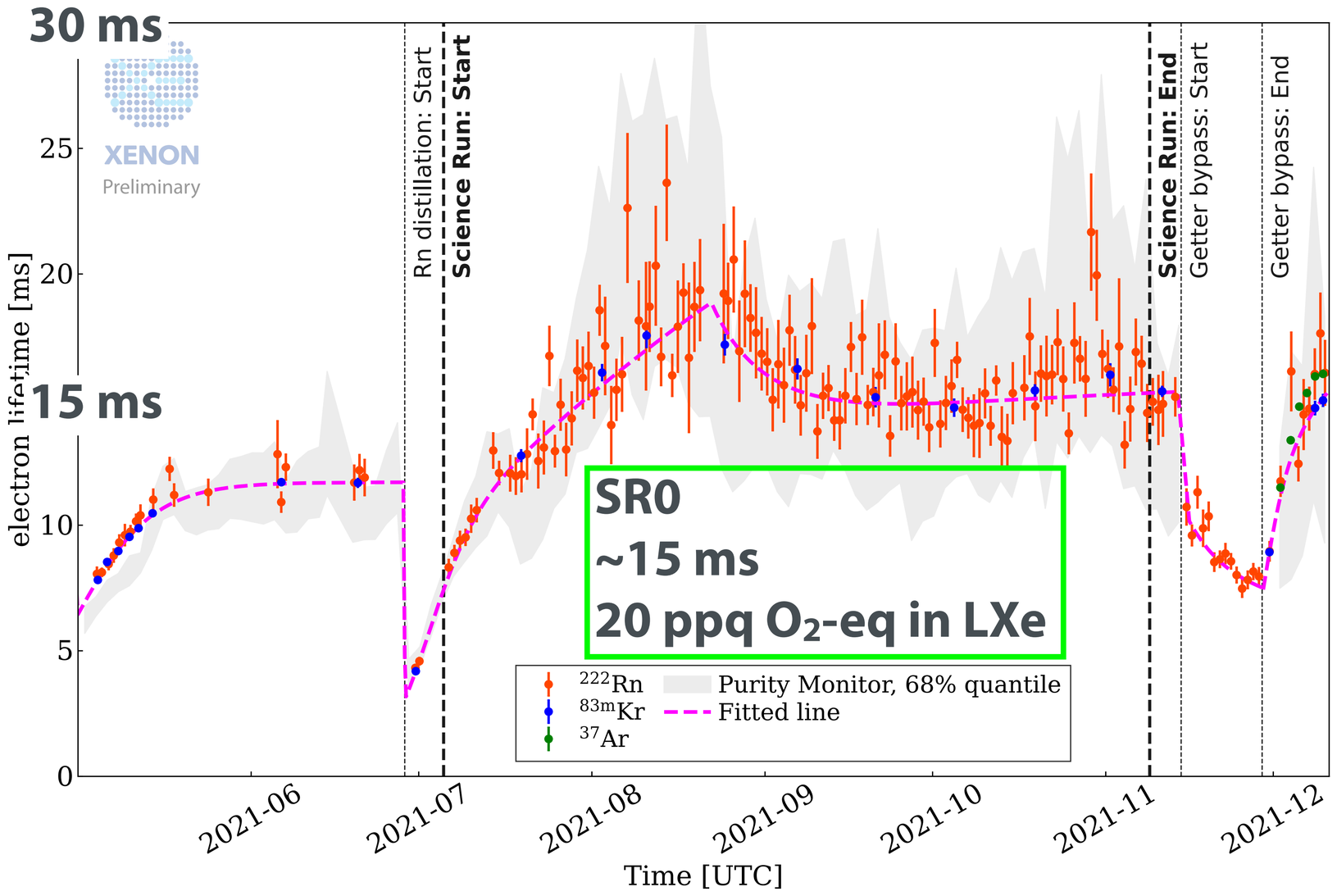
- 120 (8”) PMTs facing the TPC detect Cherenkov light from 2.2 MeV gamma
- (53 ± 3) % tagging efficiency (250 μs window, 5-fold PMT coincidence)
- 0.2 % Gd doping will improve it to ~ 87 % (150 μs, 10-fold) JCAP 11 031 (2020)
- Outside of nVeto works as a muon veto counter

Liquid Phase Purification

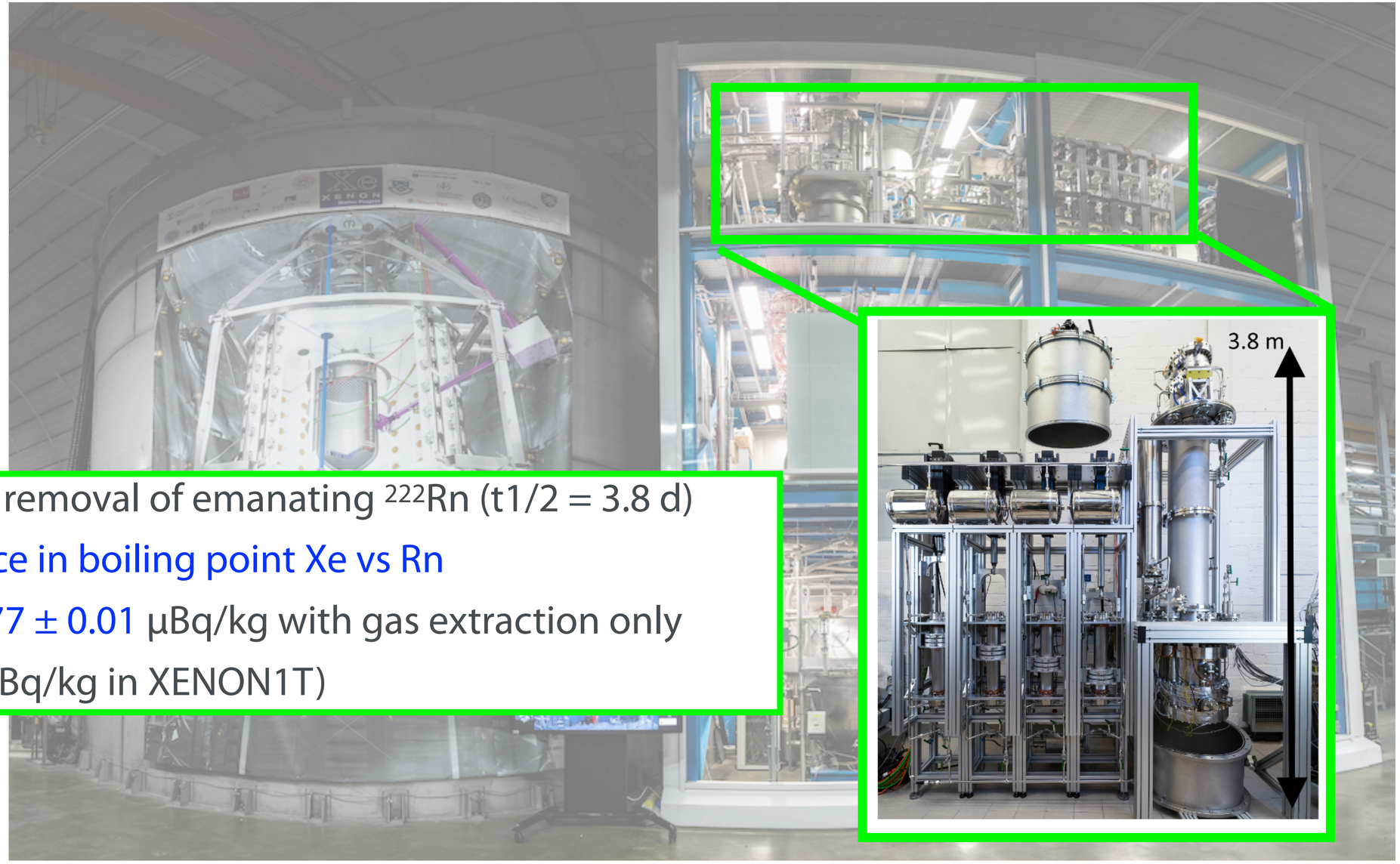


- LXe purity is crucial for drifting electrons
- Novel liquid-phase purification with replaceable filter units, with extremely low radon emanation (0.2 mBq/unit)
- St707 (usually used at 400℃) operated in LXe (-100℃)
- 2 liters of LXe per minute: ~1 day to recirculate entire inventory

Electron lifetime



Radon distillation column

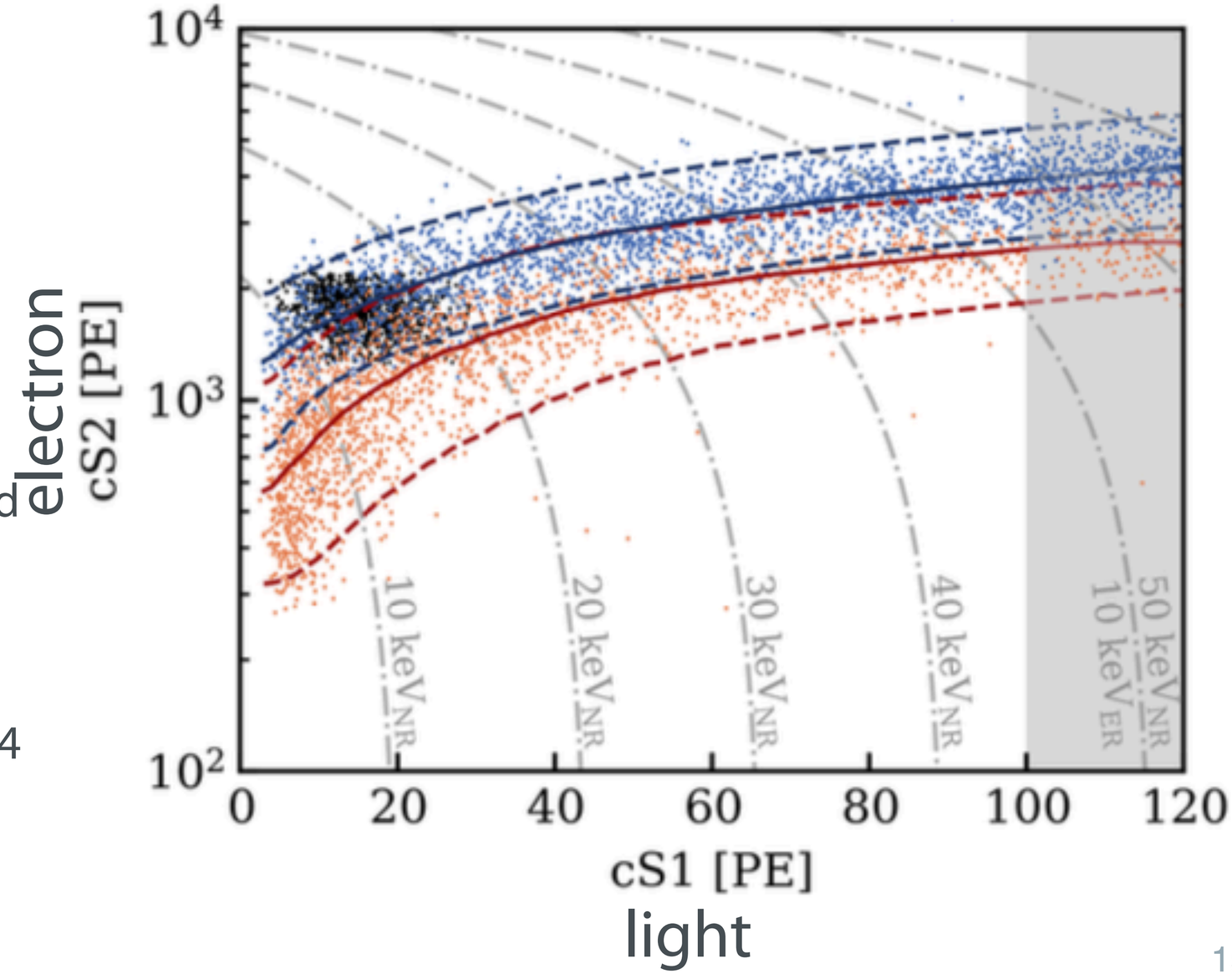


- "Online" removal of emanating ^{222}Rn (t1/2 = 3.8 d)
  difference in boiling point Xe vs Rn
- ^{222}Rn 1.77 ± 0.01 μBq/kg with gas extraction only
  - (~ 13 μBq/kg in XENON1T)

Calibration

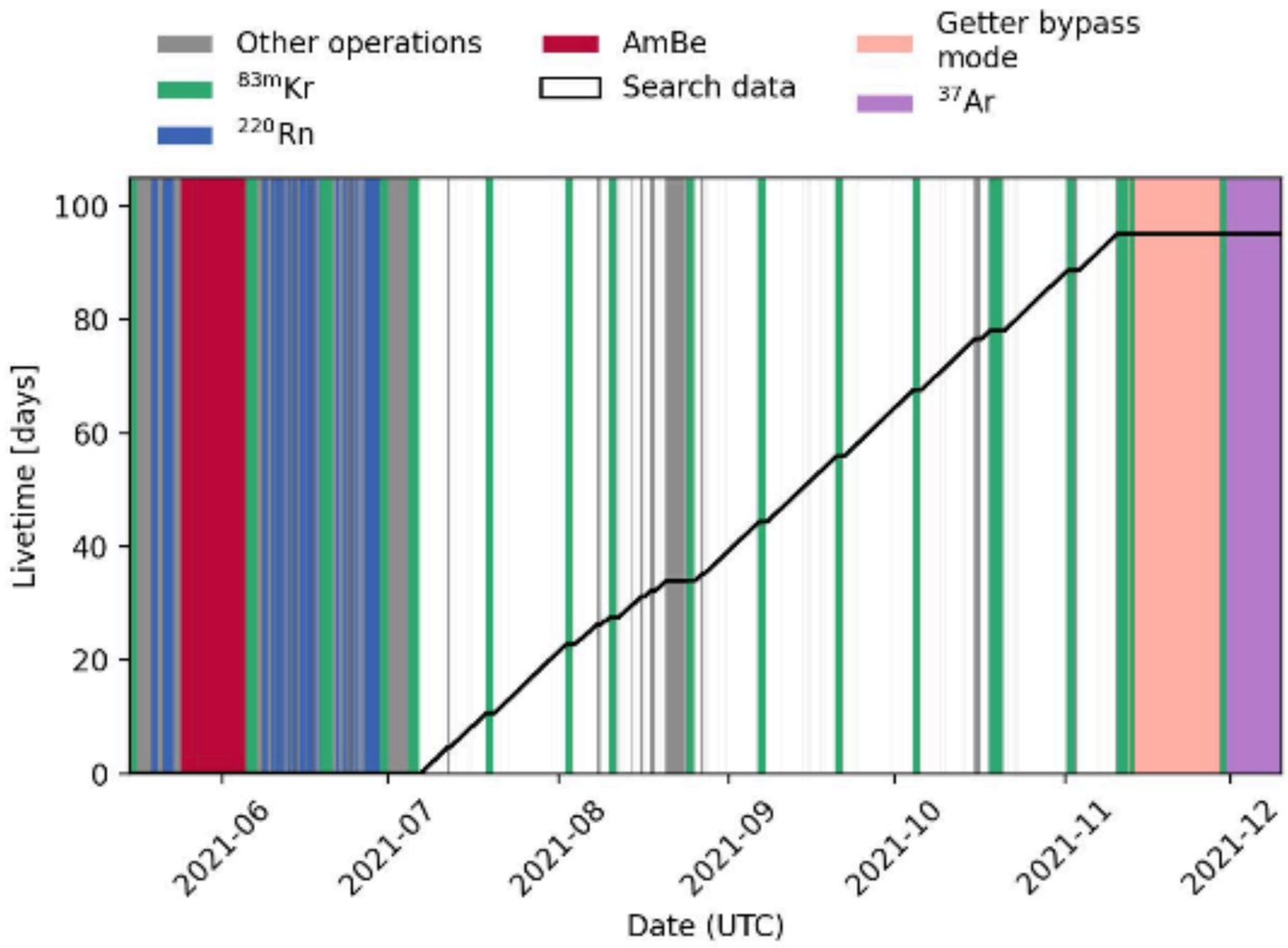
XENON

- **ER response model**
  - ^{212}Pb from ^{220}Rn gives a roughly flat β-spectrum to estimate cut acceptances and energy threshold
  - ^{37}Ar gives a mono-energetic 2.82 keV peak, to model low-energy response and resolution near detector energy threshold
- **NR response model**
  - ^{241}AmBe external source emits neutrons, which are tagged using the coincident 4.4 MeV γ-ray observed in the neutron veto



First XENONnT science run (SR0) Bind analysis

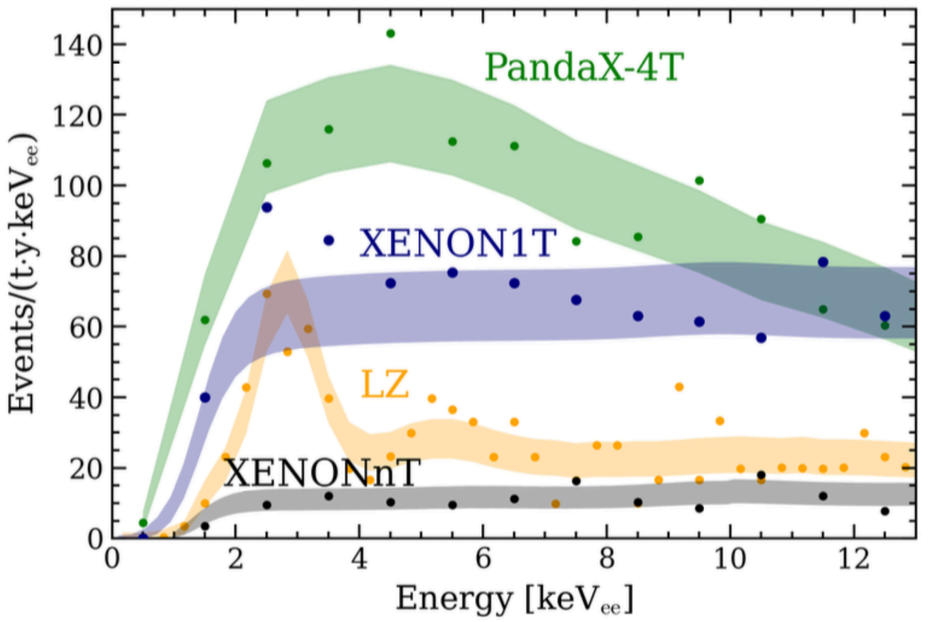
- 97.1 days of exposure from July 6th - Nov 11th 2021
- 23 V/cm drift field
- Light and charge yield: stable within 2%

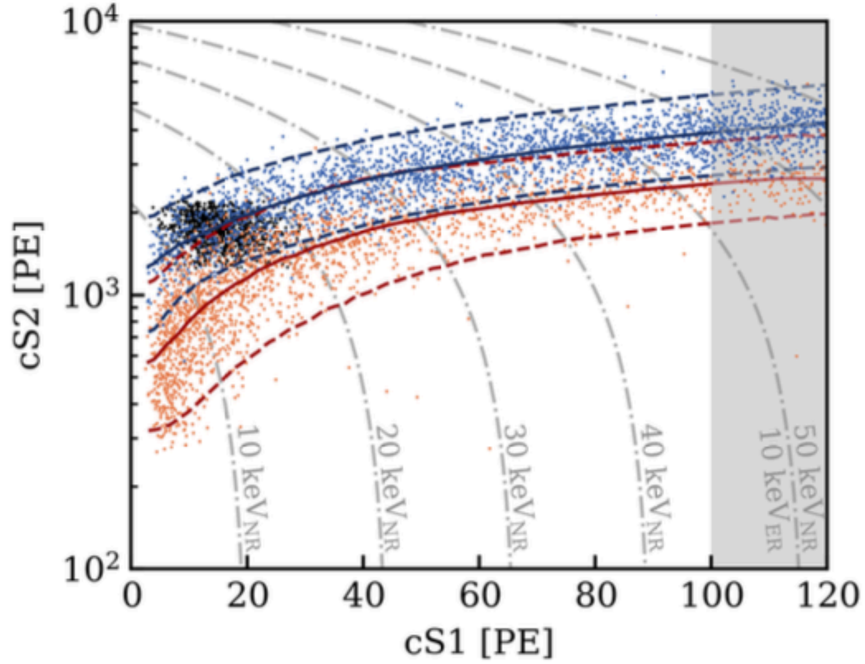


New Physics Search

XENON

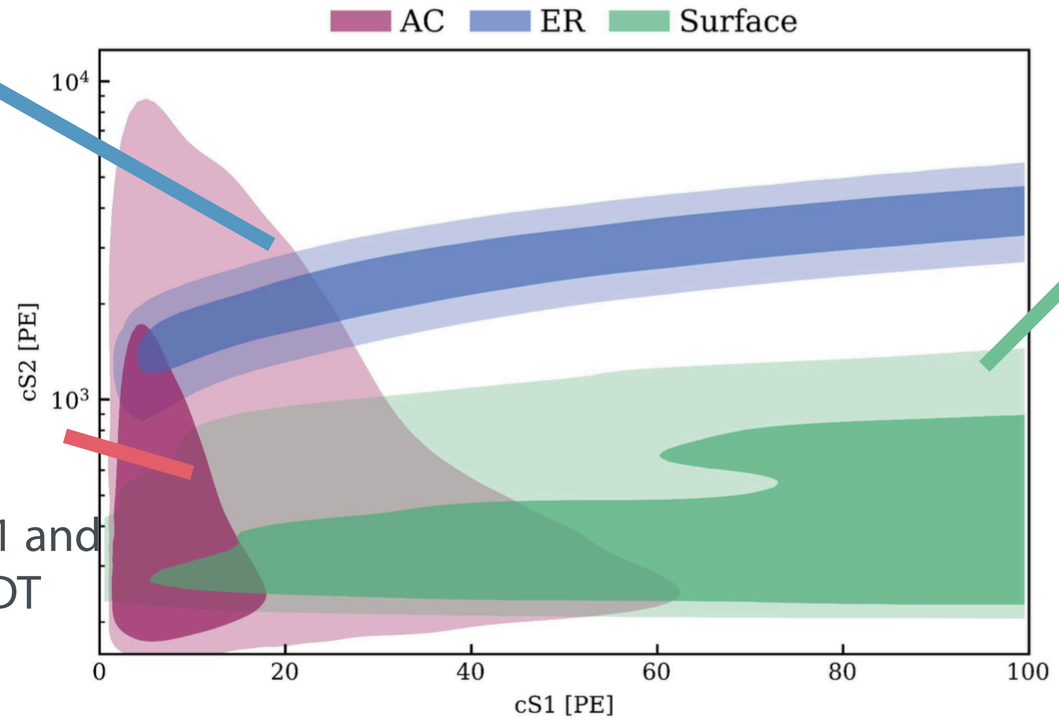
- **Electronic recoils** ***PRL 129, 161805 (2022)***
  - Combine S1 and S2 signals for search in reconstructed energy
  - Lowest ever ER background in the field: (15.8 ± 1.3) (t yr keV)$^{-1}$
  - No low-energy ER excess found (beyond-SM explanation for XENON1T excess excluded)
- **Nuclear recoils (this talk)** ***PRL 131, 041003 (2023)***
- Suppress ER background by to ER/NR discrimination
- Search in S1, S2 and radius
- 4.18 t fiducial mass (out of 5.9 t), total exposure of 1.1 t yr





WIMP Search: Background model

- Electronic recoil (ER)
  - Mainly β-decay of 214Pb + pp Solar neutrino
- Accidental coincidence (AC)
  - Random pairing of isolated S1 and S2 signals; suppressed by GBDT cut based on S2 shape

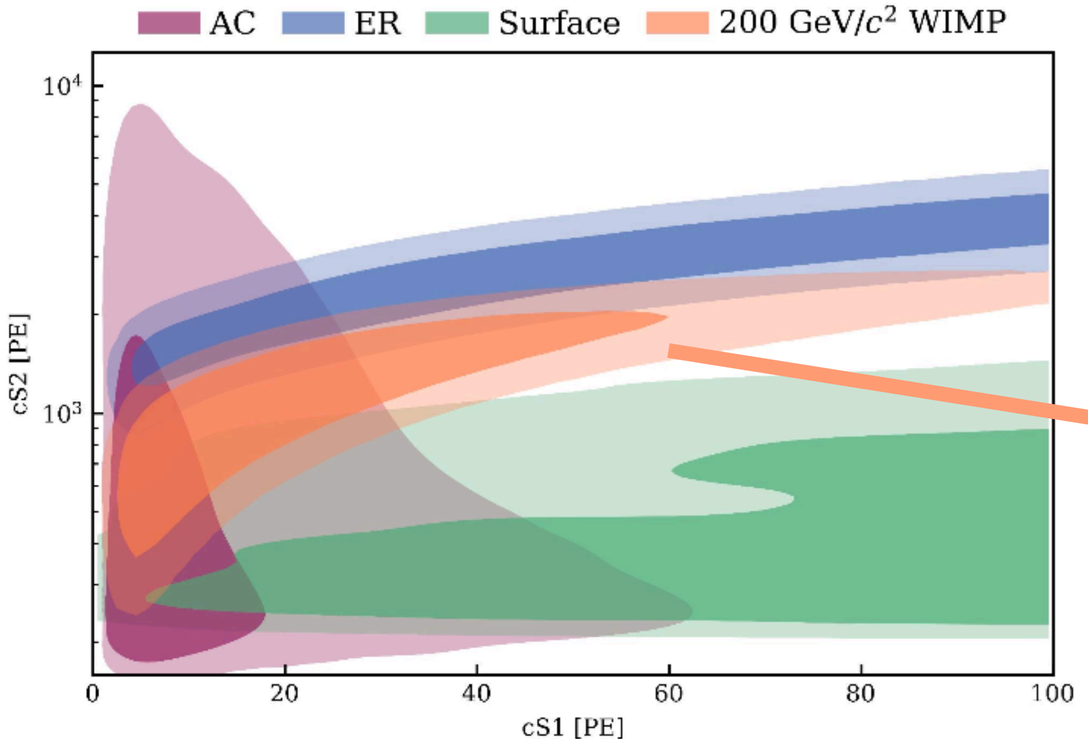


- Surface background
  - 210Pb plate-out on TPC walls, leading to 210Po α-decays with electron loss; suppressed by volume financialization
- Nuclear recoil (NR)
  - Radiogenic neutrons constrained by neutron veto tagging (~1.1 events),
  - CEvNS less than 0.2 events due to decreased efficiency at low energies

WIMP Search: Background model

- Electronic recoil (ER)
  - Mainly β-decay of 214Pb

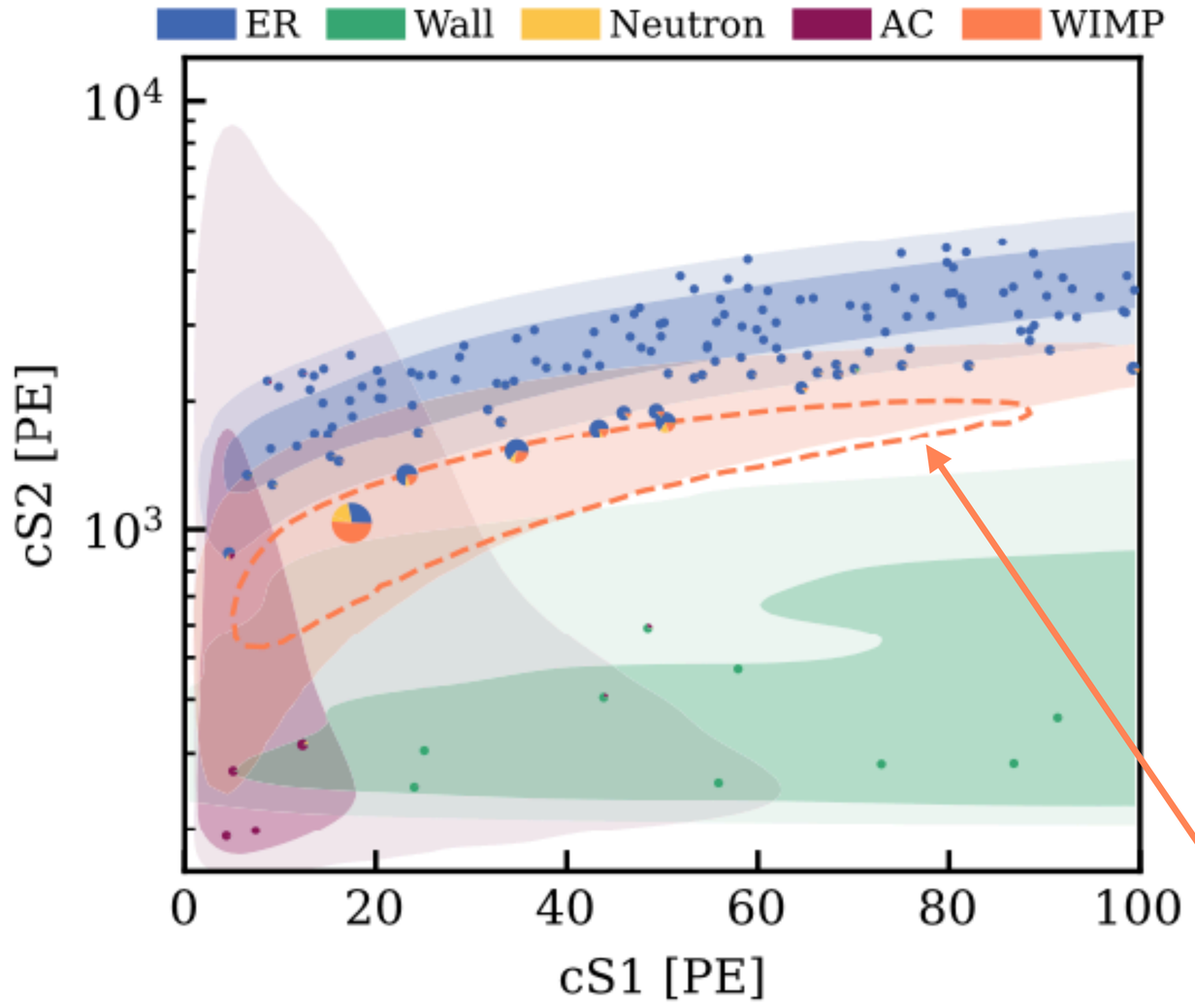
- Accidental coincidence (AC)
  - Random pairing of isolated S1 and S2 signals; suppressed by GBDT cut based on S2 shape



- Surface background
  - ^{210}Pb plate-out on TPC walls, leading to ^{210}Po α-decays with electron loss;
  - suppressed by volume fiducialization

- Nuclear recoil (NR)
  - Radiogenic neutrons constrained by neutron veto tagging (~1.1 events),
  - CEvNS less than 0.2 events due to decreased efficiency at low energies

XENONnT NR Search Result



	Nominal	Best fit	
	ROI		Signal-like
ER	134	135^{+12}_{-11}	0.92 ± 0.08
Neutrons	$1.1^{+0.6}_{-0.5}$	1.1 ± 0.4	0.42 ± 0.16
CEνNS	0.23 ± 0.06	0.23 ± 0.06	0.022 ± 0.006
AC	4.3 ± 0.9	$4.4^{+0.9}_{-0.8}$	0.32 ± 0.06
Surface	14 ± 3	12 ± 2	0.35 ± 0.07
Total background	154	152 ± 12	$2.03^{+0.17}_{-0.15}$
WIMP	…	2.6	1.3
Observed	…	152	3

A pie chart showing the fraction of the best-fit model evaluated at the position of the event.

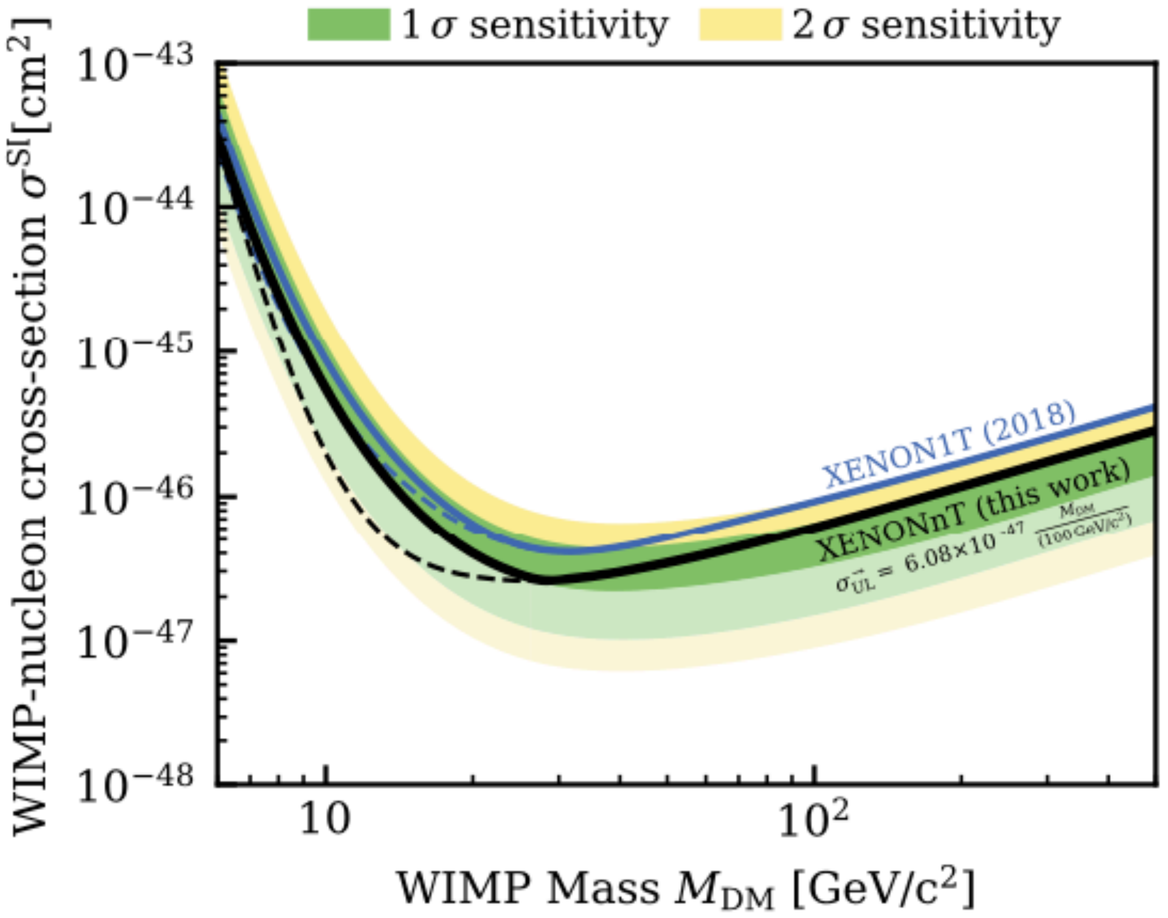
The signal-like region containing 50% of the 200 GeV WIMP signal

WIMP Search limit (blind analysis)

XENON

Limit setting

- Un-binned maximum likelihood
- Power-constrained limits (PCL) based on rejection power in order to not place limits on models for which an experiment has low sensitivity
- Factor 1.6 improvement w.r.t. XENON1T (with considerably shorter livetime)
- Strongest limit: $2.6 \cdot 10^{-47}$ cm^2 at WIMP mass of 28 GeV/c^2



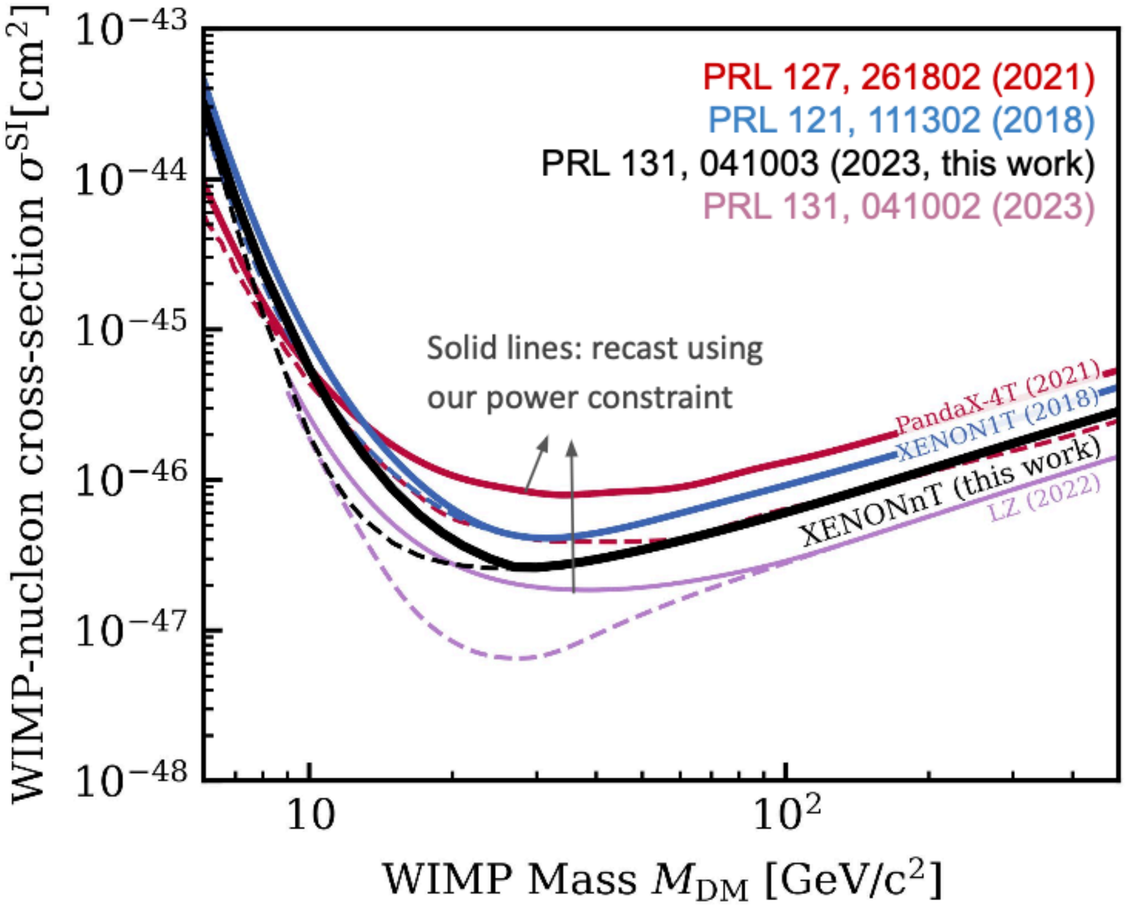
- w/o power constraint

Comparison with Other LXe experiments (no-blinded)

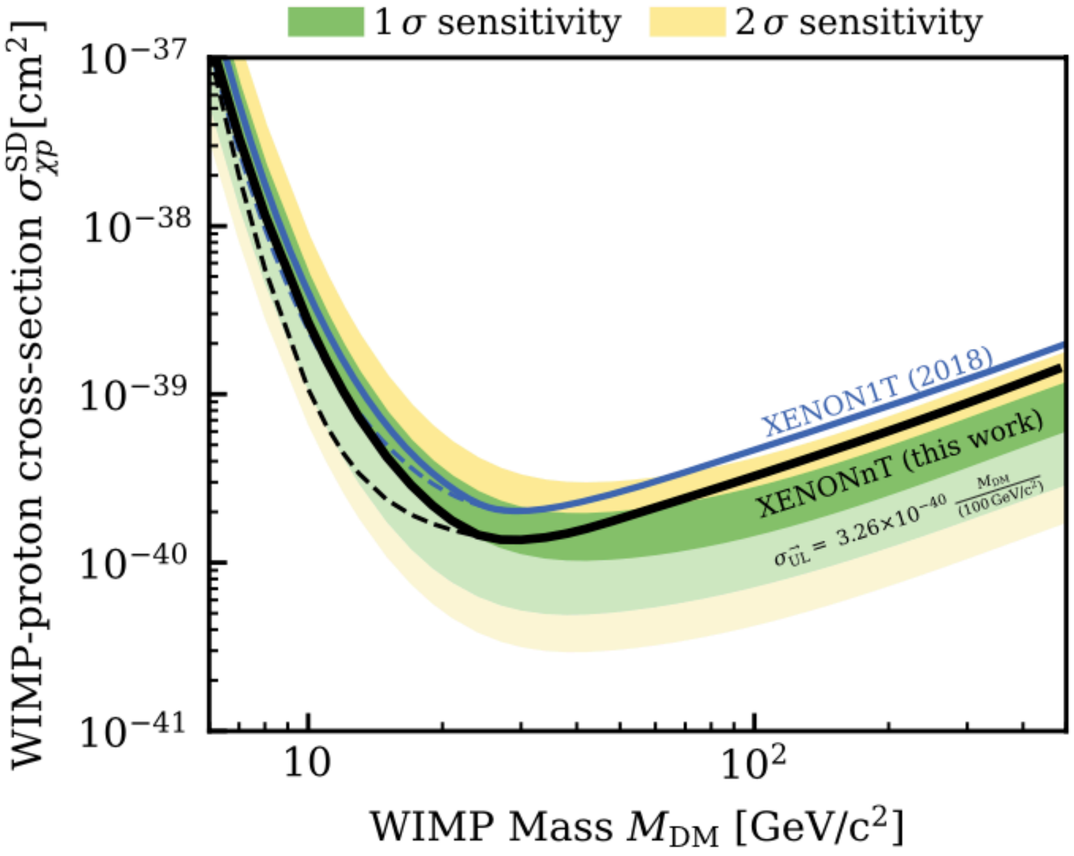
XENON

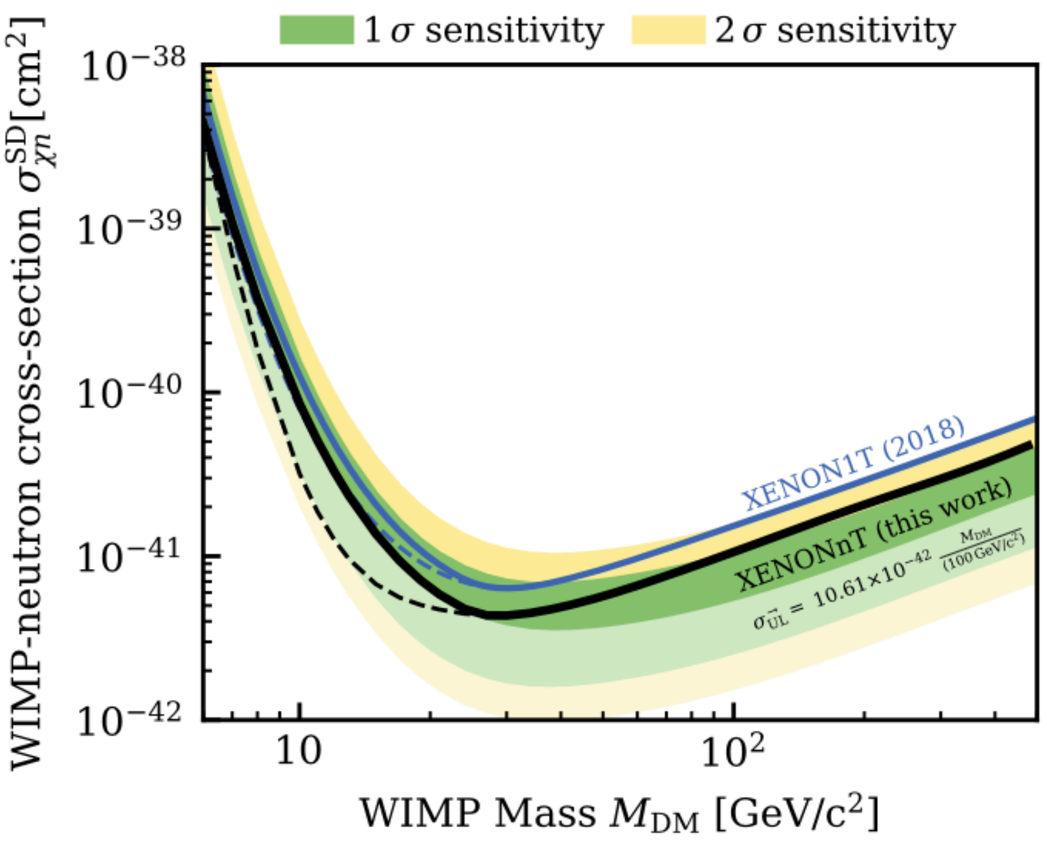
Limit setting

- Un-binned maximum likelihood
- Power-constrained limits (PCL) based on rejection power in order to not place limits on models for which an experiment has low sensitivity
- Factor 1.6 improvement w.r.t. XENON1T (with considerably shorter lifetime)
- Strongest limit: $2.6 \cdot 10^{-47}$ cm^2 at WIMP mass of 28 GeV/c^2
- Conservative choice at a median of sensitivity band (need agreement with the community)

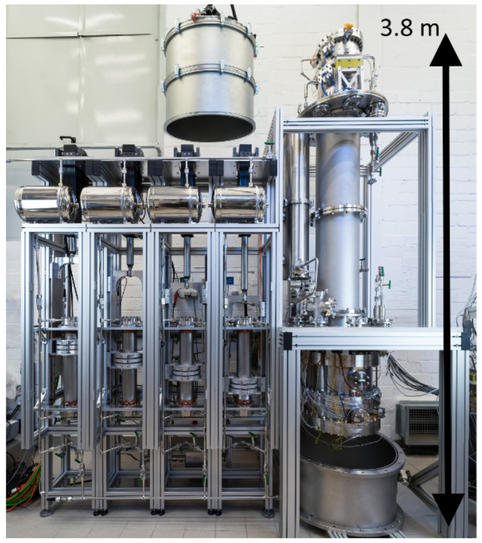


Spin-dependent case





Summary and Future Prospects

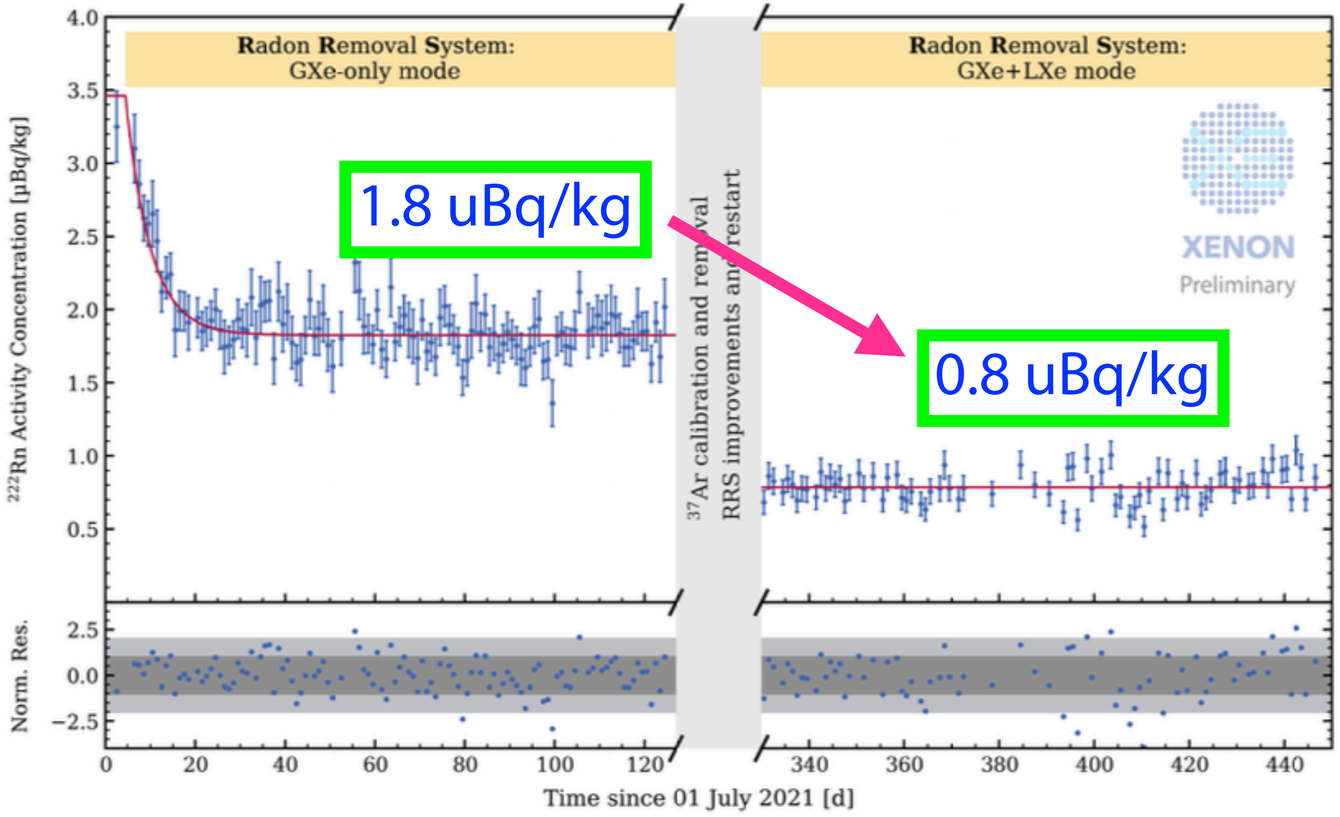


XENONnT SR0:

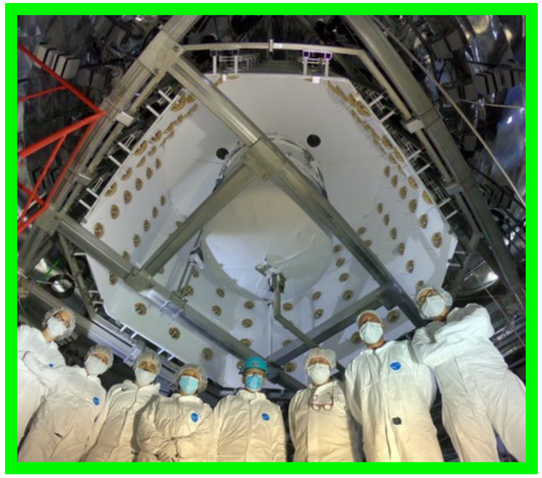
- Ultrapure target, with an electron lifetime stably at ~ 15 ms.
- Lowest ER background in the field: (15.8 ± 1.3) (t yr keV)-1
(~ 5x background reduction w.r.t. XENON1T)
- First blinded searches for electronic and nuclear recoil signals yielded no significant excess over background

Taking more data with:

- 50 % lower ^{222}Rn level by changing flow path



Summary and Future Prospects



XENONnT SR0:

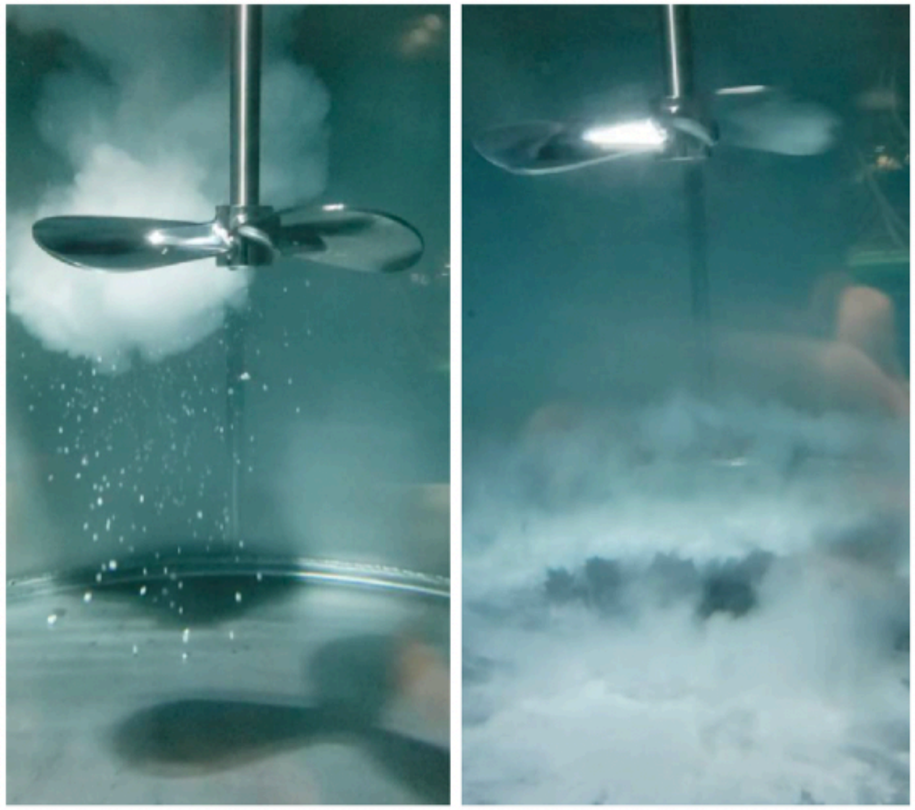
- Ultrapure target, with an electron lifetime stably at ~ 15 ms.
- Lowest ER background in the field: (15.8 ± 1.3) (t yr keV)-1
(~ 5x background reduction w.r.t. XENON1T)
- First blinded searches for electronic and nuclear recoil signals
yielded no significant excess over background

Taking more data with:

- 50 % lower ^{222}Rn level by changing flow path
- Planned Gd-loaded neutron veto with ~ 87 % neutron
background tagging efficiency

- Improving WIMP search,
- new analysis for solar neutrinos, double beta decays, and more...

Gd Salt insertion

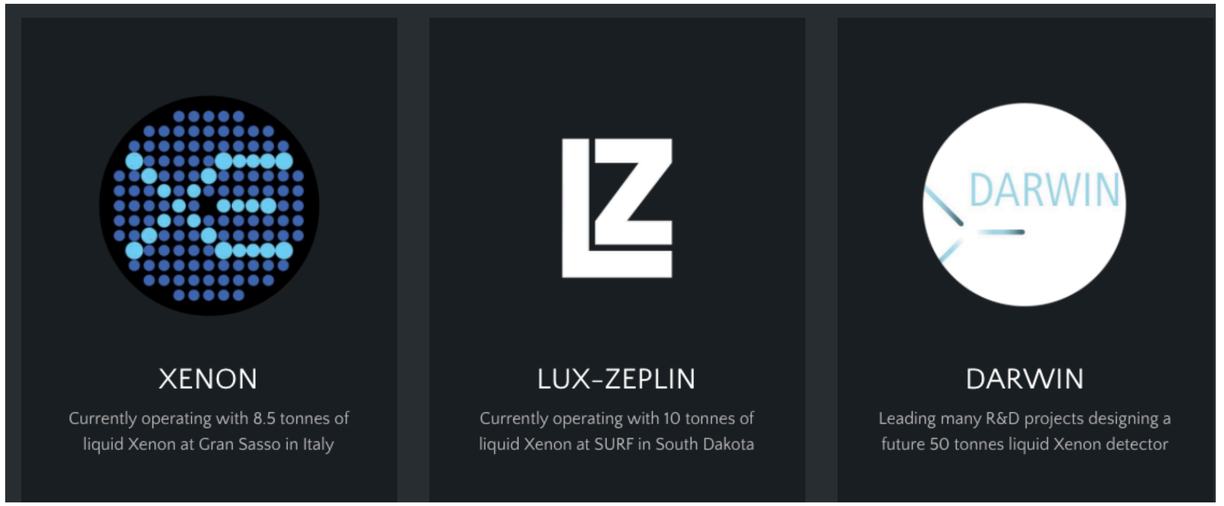


Summary and Future Prospects

XENON

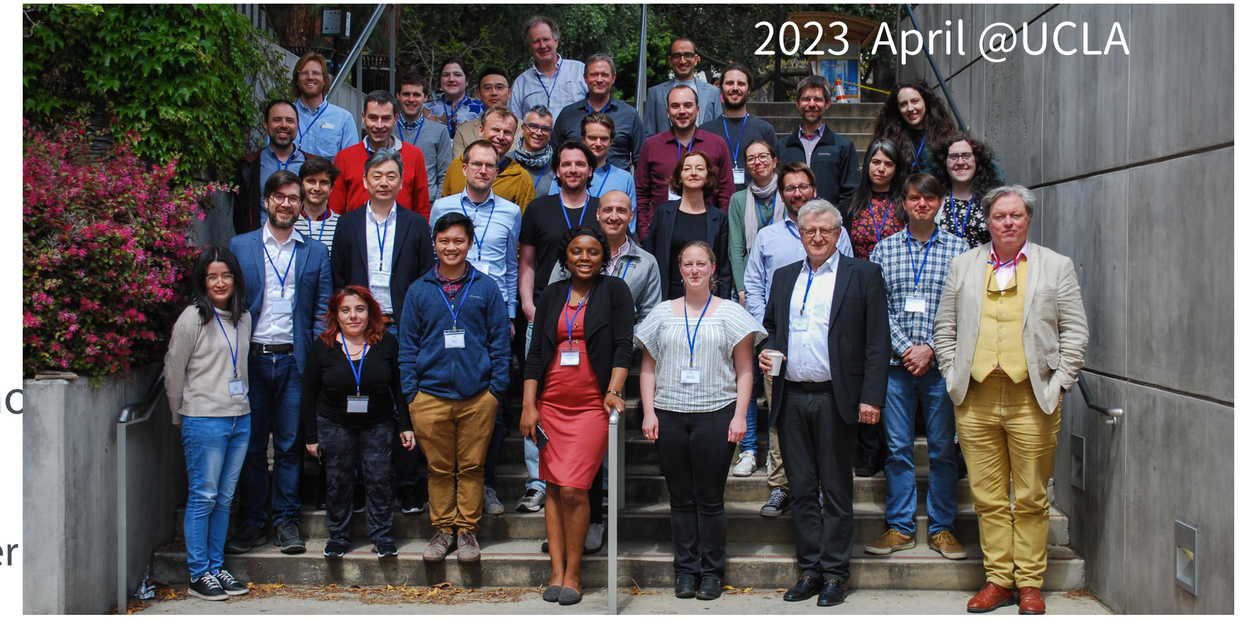
XENONnT SR0:

- Ultrapure target, with an electron lifetime stably at ~ 15 ms.
- Lowest ER background in the field: (15.8 ± 1.3) (t yr keV)-1
(~ 5x background reduction w.r.t. XENON1T)
- First blinded searches for electronic and nuclear recoil signals
yielded no significant excess over background



Taking more data with:

- 50 % lower ^{222}Rn level by changing flow path
- Planned Gd-loaded neutron veto with ~ 87 % neutron
background tagging efficiency



- Improving WIMP limits,
- new analysis for solar neutrinos, double beta decays and mo

Beyond XENONnT:

XLZD consortium: Joining forces toward a next-generation dark matter
experiment. (my talk on Sunday)