XENONnT

First electronic recoil results from Science Run 0

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on behalf of XENON collaboration

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MPIK, Heidelberg, Germany
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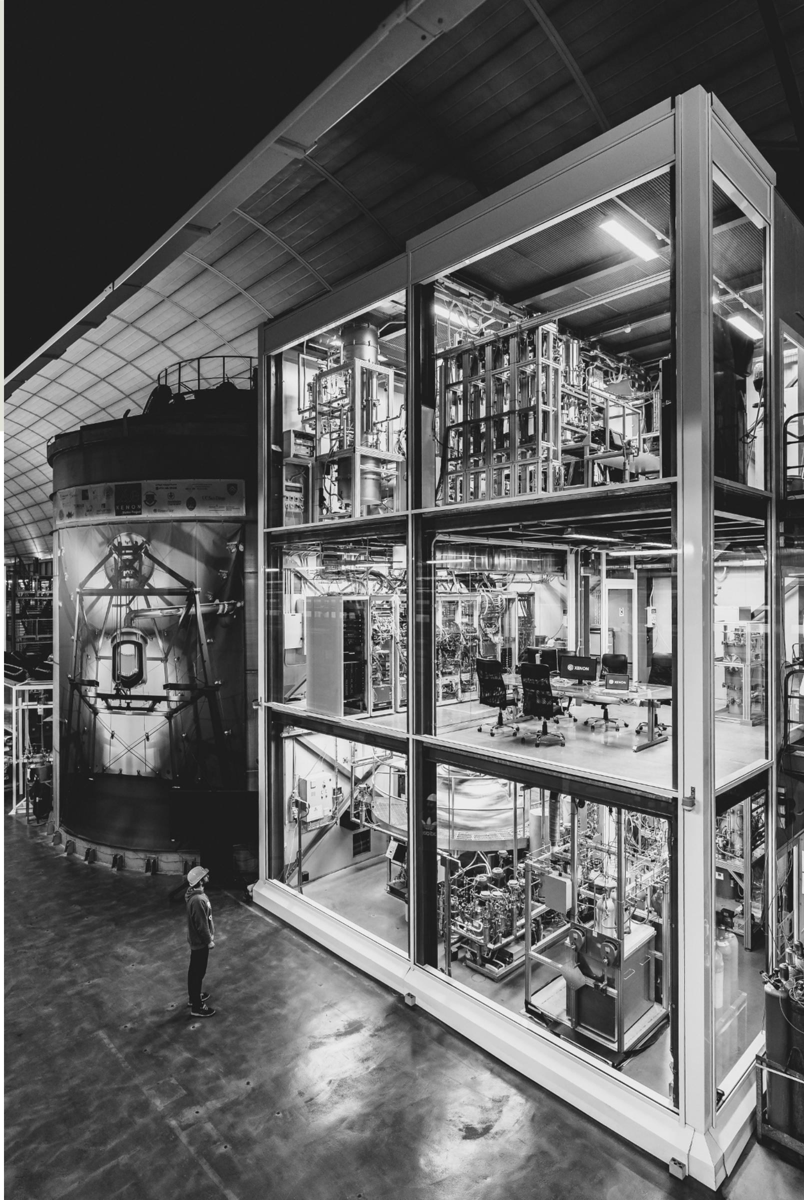
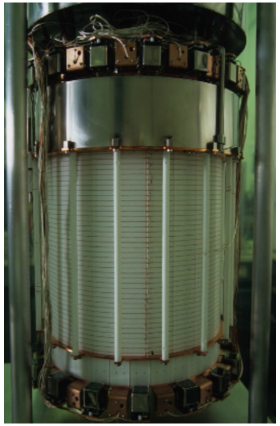
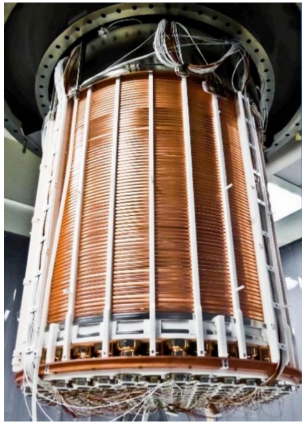


XENON program

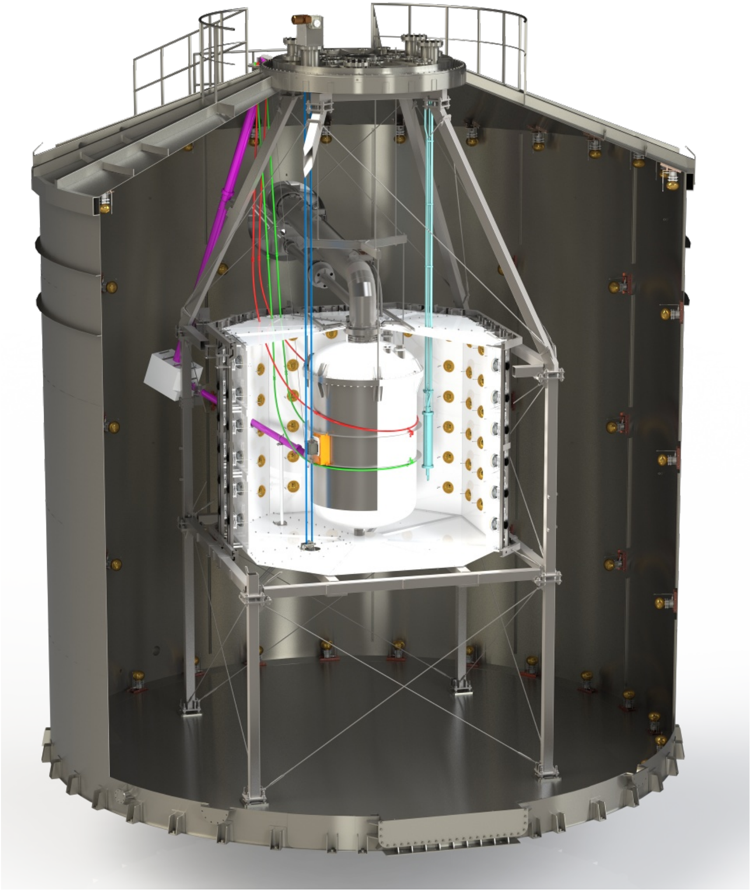

XENON10	XENON100	XENON1T	XENONnT
2005-2007	2008-2016	2012-2019	2020-2026 (data taking)
14 kg Xe target	62 kg Xe target	2 t Xe target	~6 t Xe target
$\sim 10^{-43}$ cm^2	$\sim 10^{-45}$ cm^2	$4 \cdot 10^{-45}$ cm^2	$1.4 \cdot 10^{-48}$ cm^2 (projected for 20 t·y exposure)
~2M background ER / (keV· t·y)	1800 background ER / (keV· t·y)	82 background ER / (keV· t·y)	16.1 background ER / (keV· t·y)

- Persistent improvement over the generations!

What is new in XENONnT?

- Major upgrade of XENON1T:
  - new cryostat with larger TPC and target mass
  - new xenon purification and distillation systems
  - new veto detectors for background rejection
  - improved calibration sources
  - improved cleanliness and radiopurity
  - improved analysis and triggerless data-taking

- Rich physics goals:
  - Dark Matter search
  - axions, axion-like particles, dark photons
  - coherent neutrino interactions
  - rare radioactive decay searches
  - and more



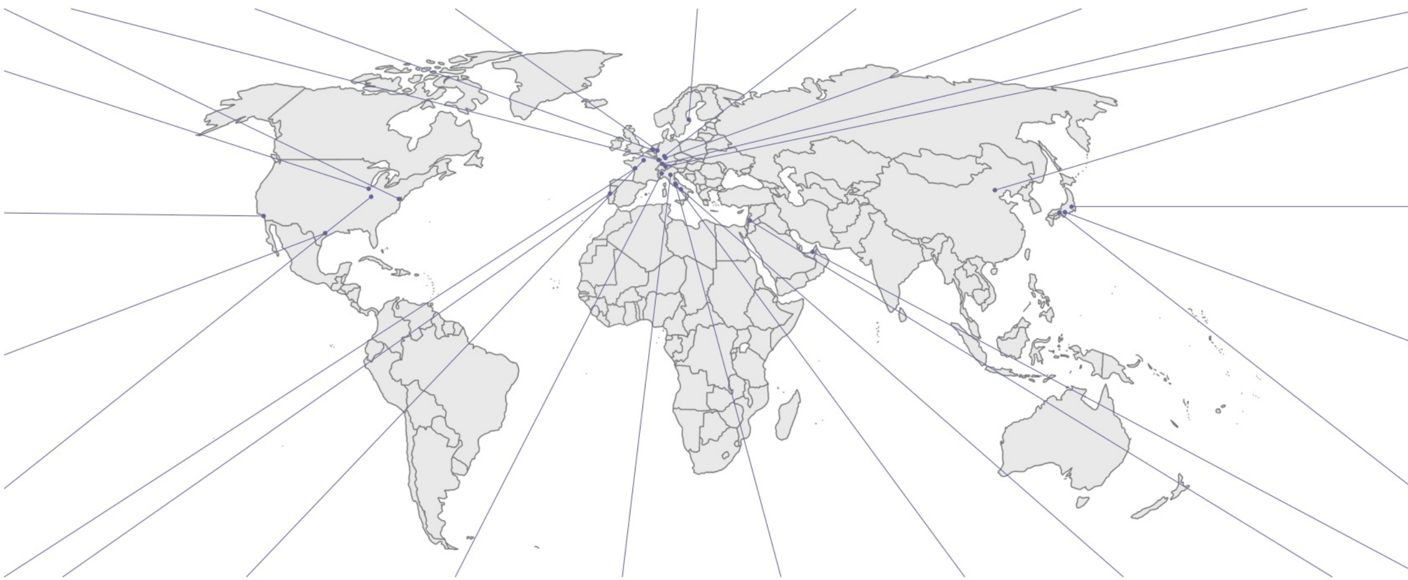
Meet the collaboration

XENON

27 institutions

Columbia
KIT
Nikhef
Muenster
Stockholm
Mainz
MPIK, Heidelberg
Freiburg
Zurich

Chicago
UCSD
Rice
Purdue



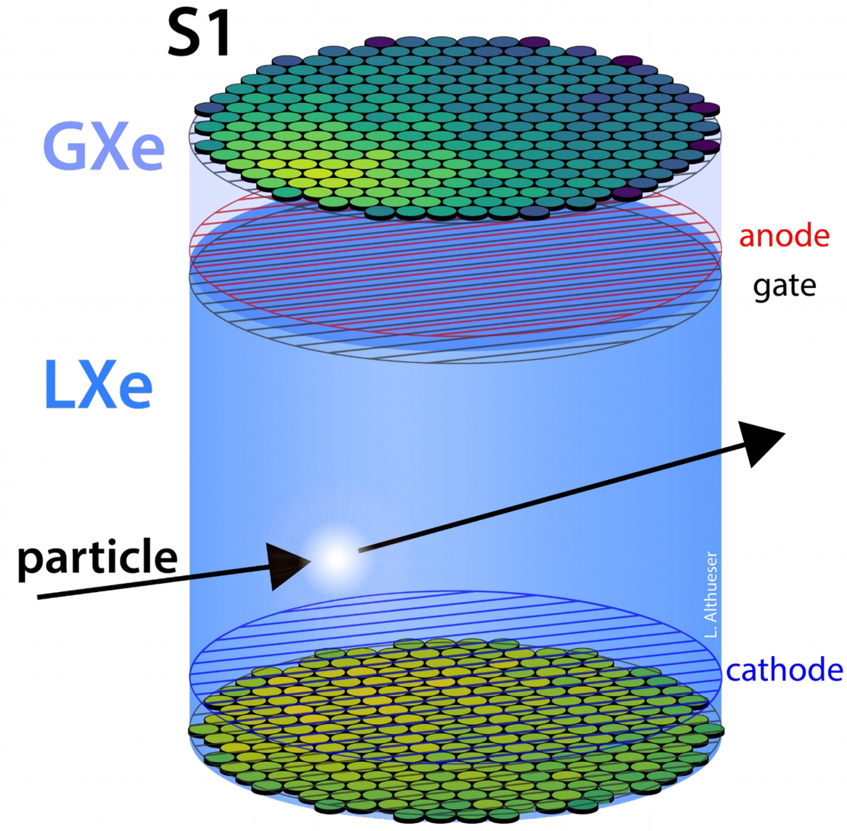
Tsinghua
Tokyo
Nagoya
Kobe

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

Meet the collaboration

Dual-phase TPC - S1 signal

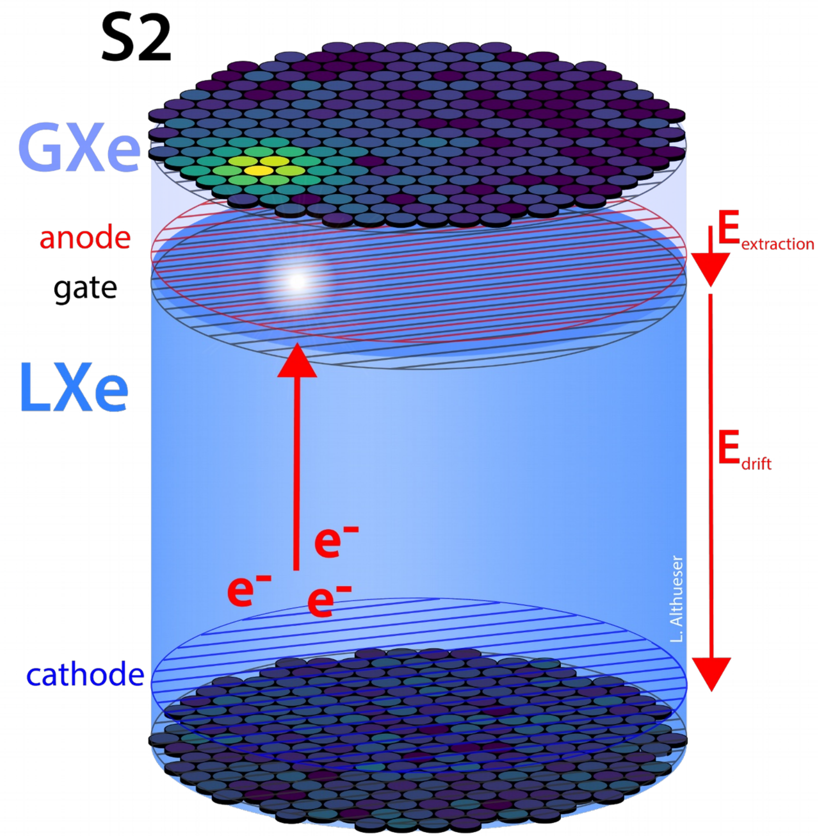
- Energy deposit:
  - atomic excitations
  - free electrons (ionization)
- Recombination + de-excitation:
  - primary scintillation emission
- **“S1 signal”**
  - light detected by top/bottom PMTs
  - (almost) instantaneous
  - provides “start time” of an event



Dual-phase TPC - S2 signal

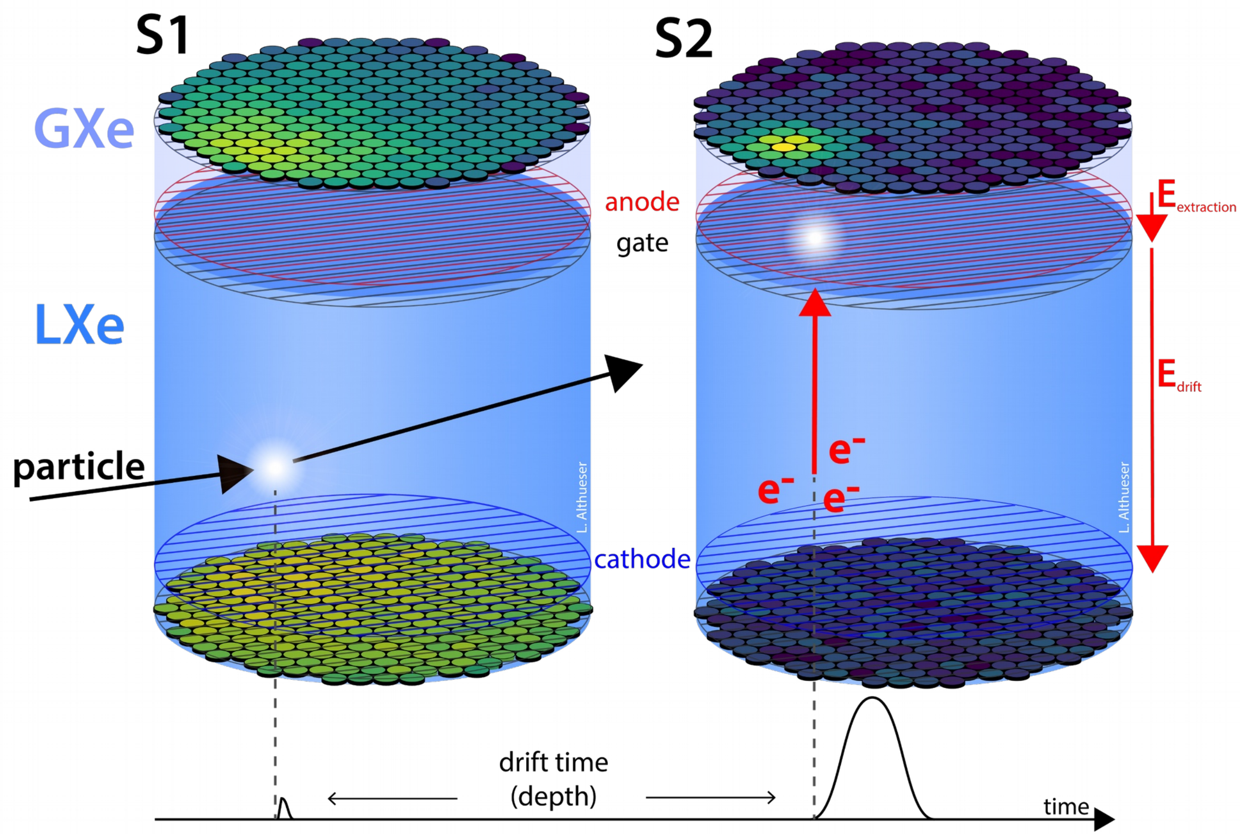
- Detector electric field:
  - electrons move in liquid phase (LXe) along drift field
  - extracted into gas phase (GXe)
  - secondary scintillation in gas gap

- **“S2 signal”**
  - most light detected by top PMTs
  - pattern of light = XY position
  - time delay to S1 = Z coordinate



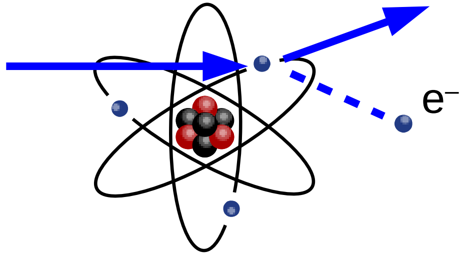
Dual-phase TPC - full event

- Full 3D interaction position reconstruction
- Interaction type identification by S2/S1 ratio
- Improved energy resolution with S1 + S2 combination



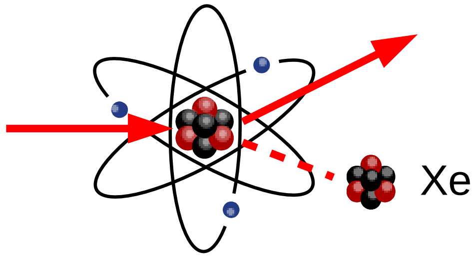
Interaction identification

- Electron recoil (**ER**)

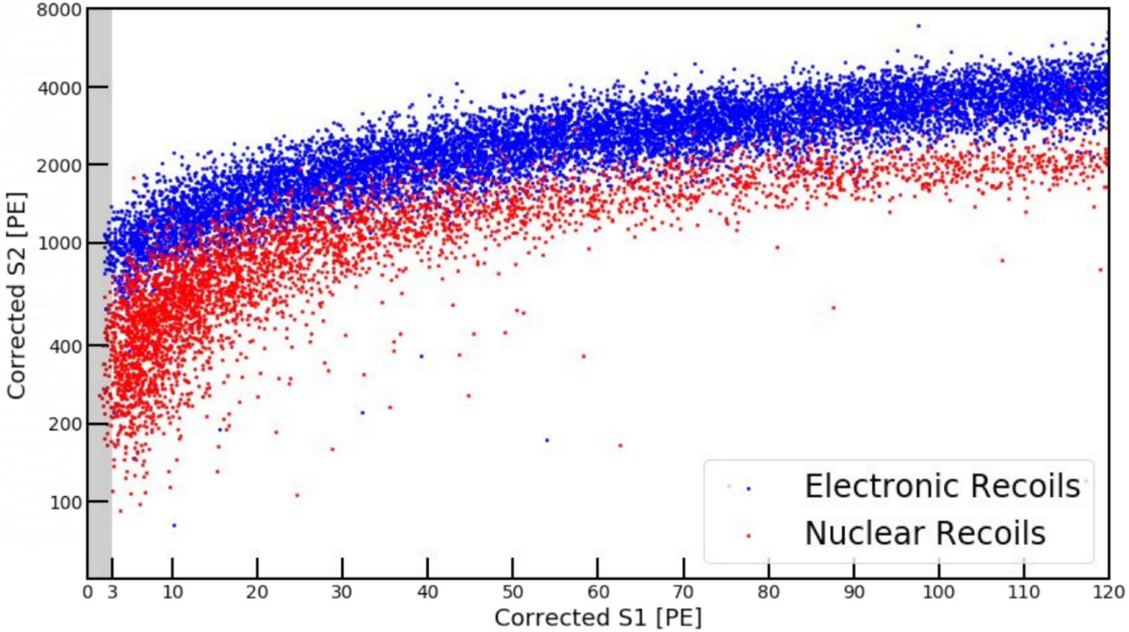


  - beta, gamma, neutrinos
  - larger S2/S1 ratio

- Nuclear recoil (**NR**)



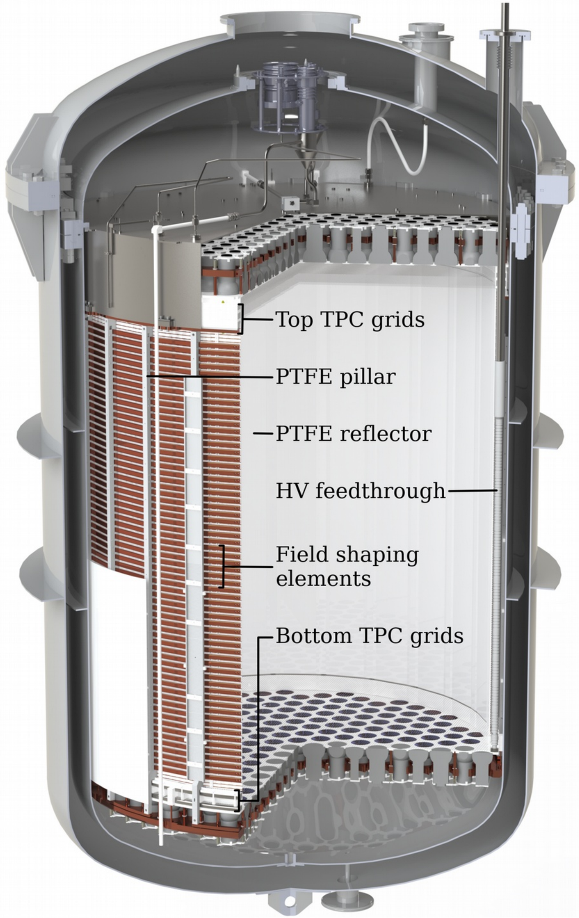
  - neutrons, CEvNS, WIMPs
  - smaller S2/S1 ratio

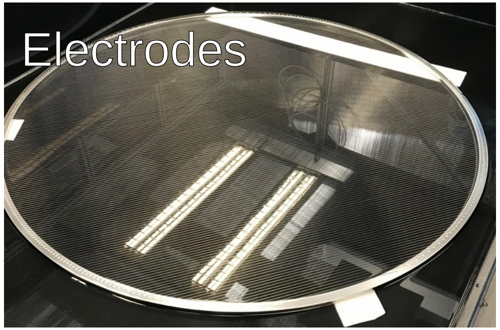


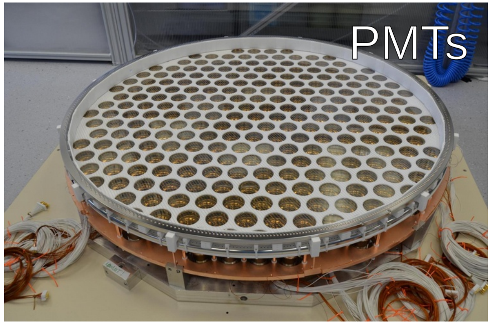
- Powerful tool to identify interaction type!
- This talk → mainly ER band

XENONnT : dual-phase TPC

- Active volume with 1.3 m diameter and 1.5 m height
- 5.9 t xenon instrumented, 8.5 t total xenon
- 5 electrodes and 2 sets of field shaping rings
- PTFE reflectors fox max light collection
- 494 3” PMTs (R11410-21) distributed over top/bottom array
- Carefully selected/screened materials to minimize background

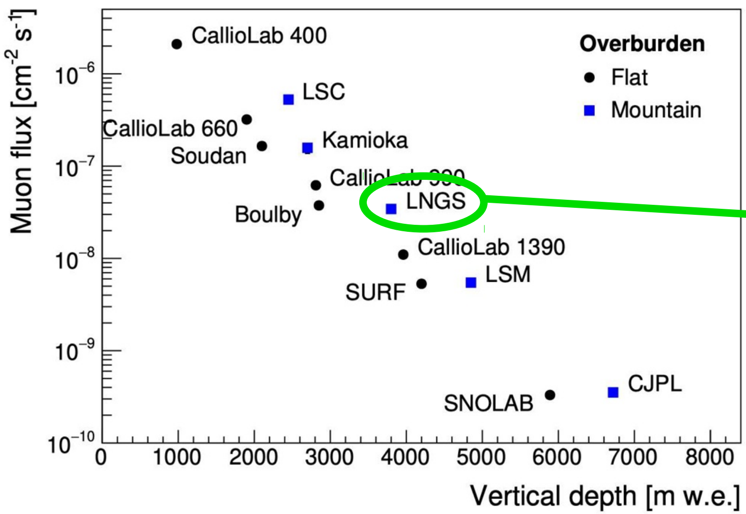


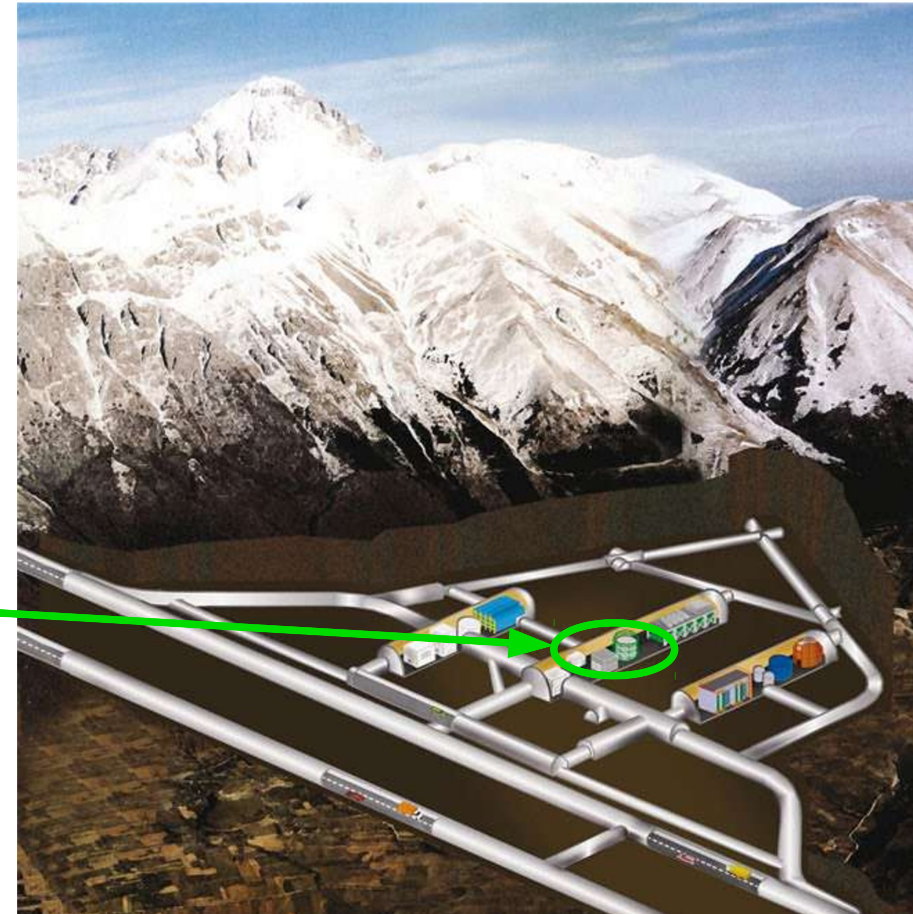




Low background is the key

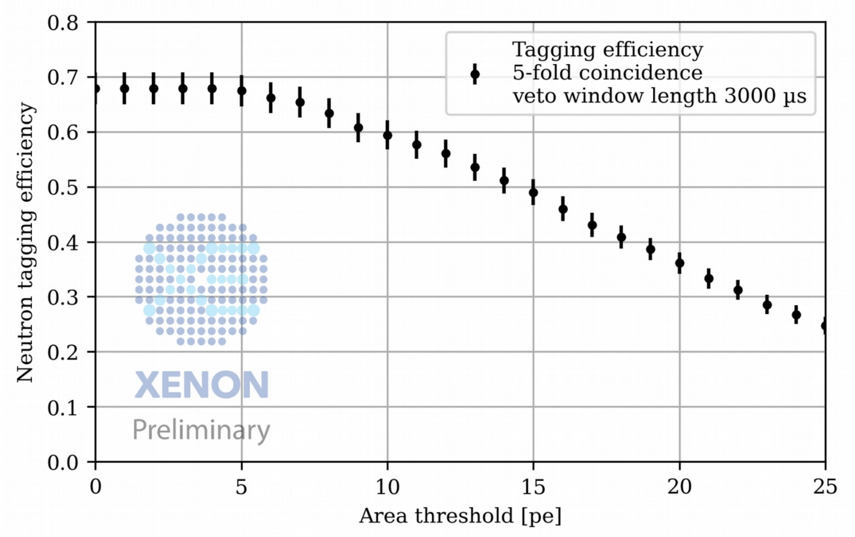
- Avoid cosmic rays → go underground
- Detector located at Laboratori Nazionali del Gran Sasso, Italy:
  - ~1500 m of rock → 3600 m.w.e.

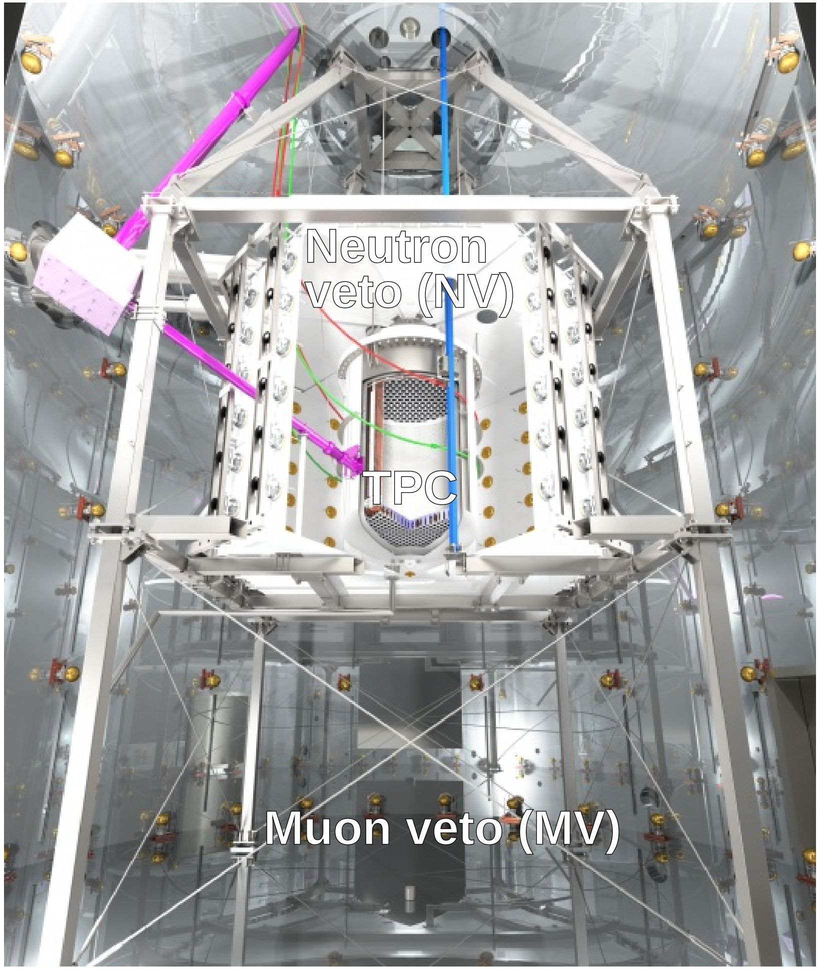




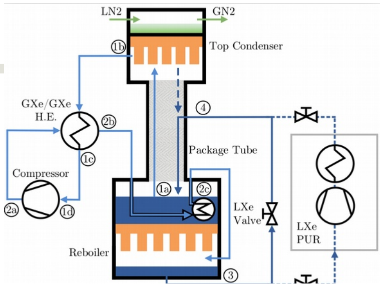
External veto systems

- Cryostat with TPC inside two external veto
  - external water Cherenkov muon veto overlooked by 84 8” PMTs
  - water neutron veto overlooked by 120 8” PMTs
- 65% neutron tagging efficiency in pure water
- 87% projected with Gd doping (planned)



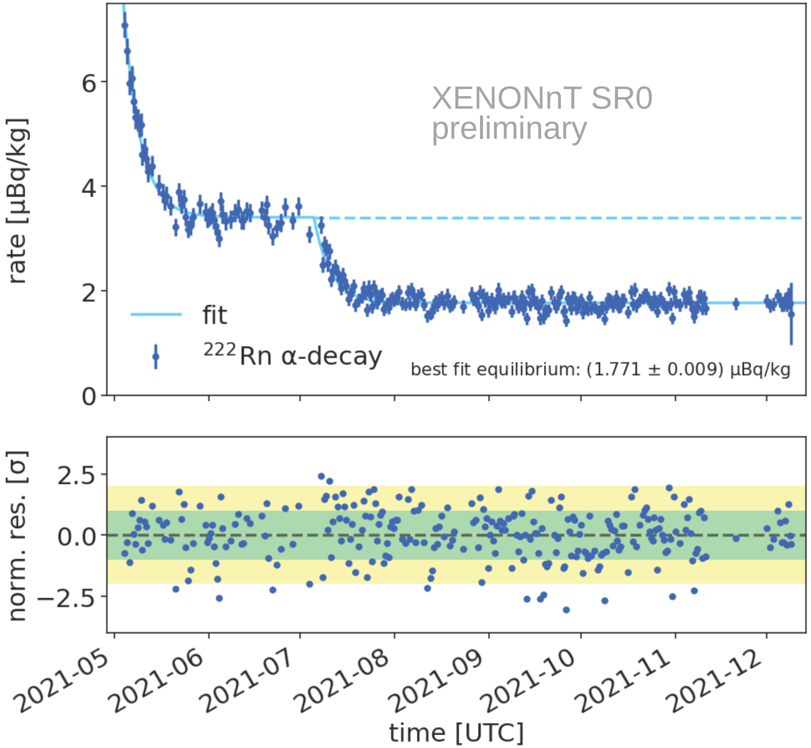


Radon distillation



- Rn-222 → primary background for XENON1T/nT
- New radon distillation column with radon-free compressors and heat exchangers
- Current mode – gas distillation
- Level in Science Run 0

1.77 ± 0.01 μBq / kg



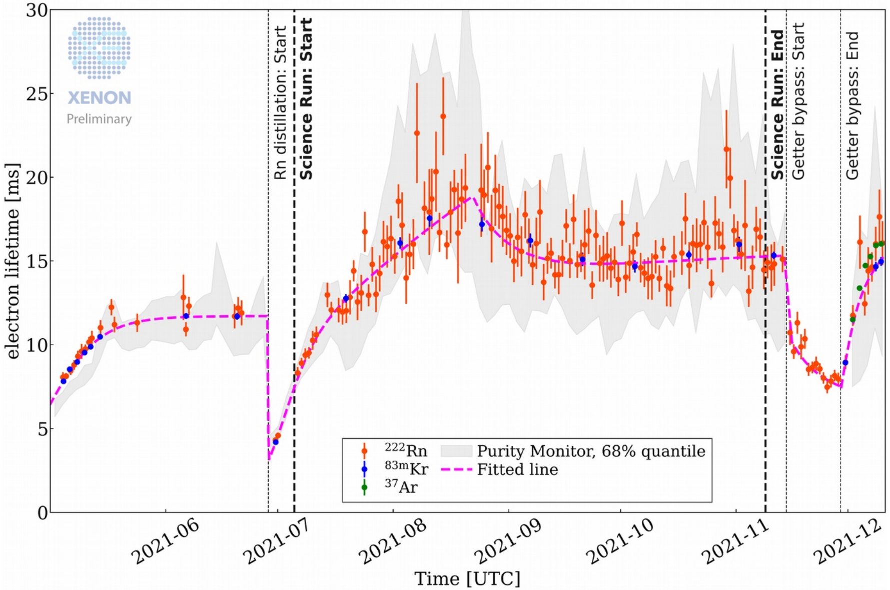
- Preliminary: already reached target of less than 1 μBq/kg in liquid mode for SR1 data taking
- More info:
  - M. Murra, D. Schulte, C. Huhmann, C. Weinheimer arXiv:2205.11492 [physics.ins-det]

Xenon purification: e-lifetime

- Longer drift time → importance of electron lifetime
- New liquid purification using filters with very low radon emanation
- Impregnated copper spheres (Q5) for fast purification and ST707 getters for science data
- Flow rate >2 litres / minute to reach high purity in less than a week
- More info:
  - G. Plante, E. Aprile, J. Howlett, Y. Zhang arXiv:2205.07336 [physics.ins-det]

	Max drift time	Electron lifetime
XENON1T	0.67 ms	0.65 ms
XENONnT	**2.2 ms**	**10+ ms**

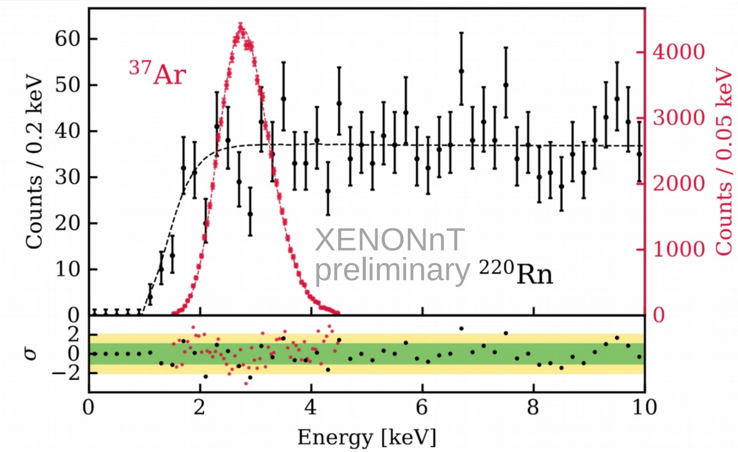
- **Electron lifetime >> maximal drift time**

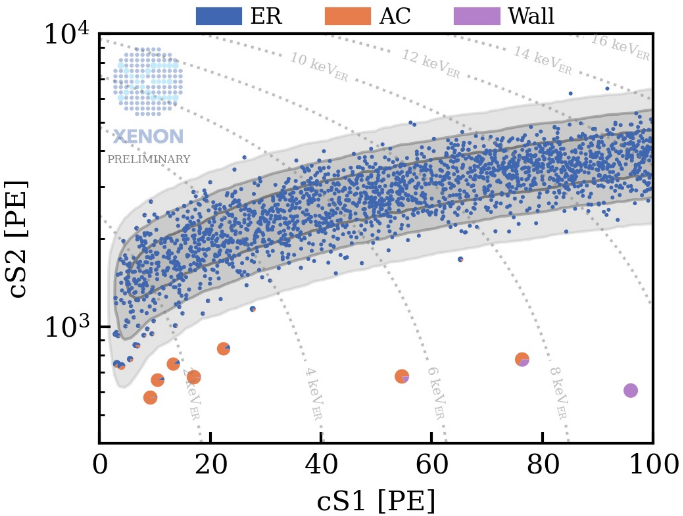


Calibration sources

- What do we calibrate:
  - detector response
  - energy resolution
  - detection and selection efficiency
  - correction of detector response non-uniformities (S1 → cS1, S2 → cS2)

- Various calibration sources:
  - **^{37}Ar** – 2.82 keV mono-energetic line
  - **^{212}Pb** of **^{220}Rn** – almost flat β at low energies
  - **^{83m}Kr** – 32.1 + 9.4 keV gamma lines
  - **AmBe** – neutron calibration source

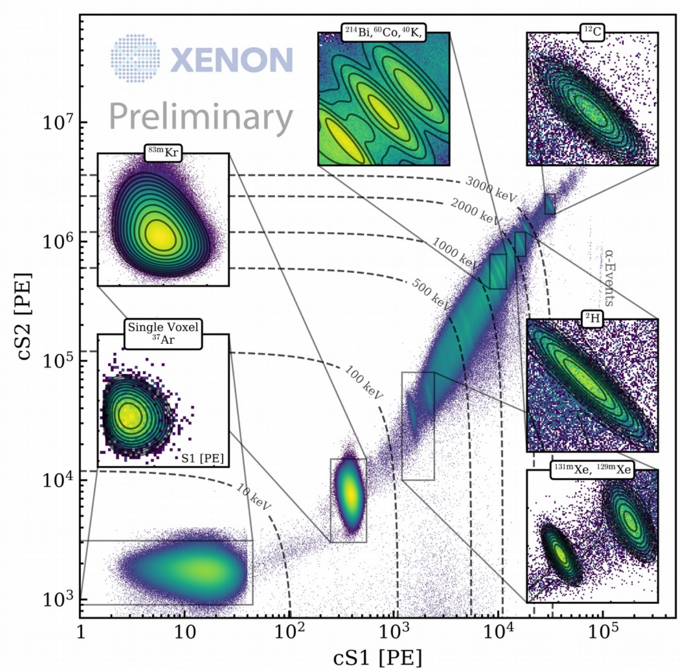


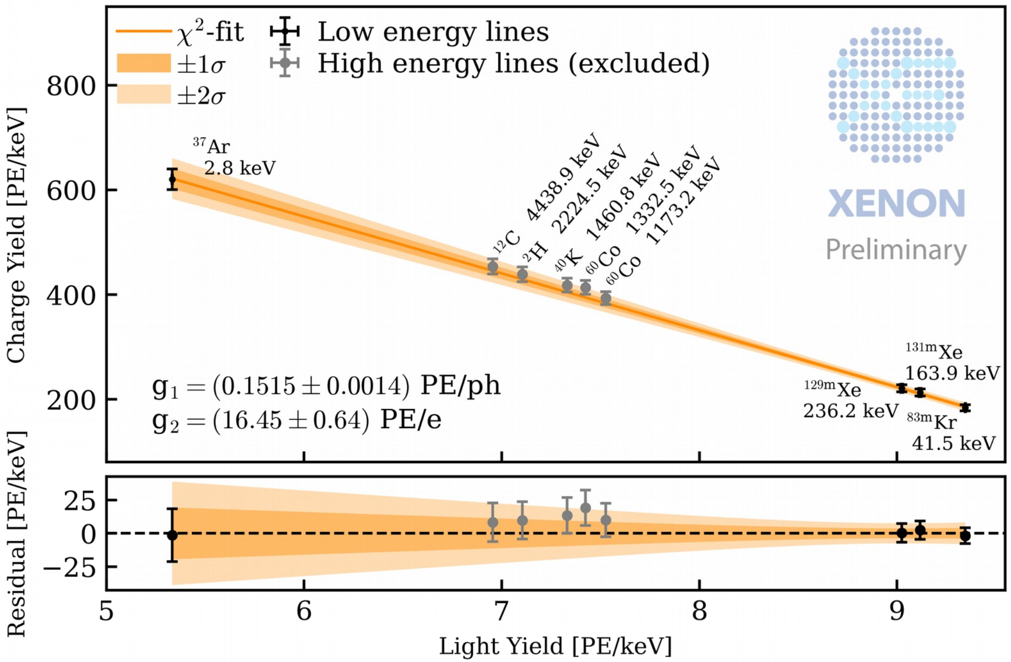


Energy and response calibration

- Based on peaks of ^{37}Ar, ^{83m}Kr, ^{129m}Xe, ^{131m}Xe
- Bias of 1-2% used as systematic uncertainty in modelling

$$E = 13.7\text{eV}\left(\frac{cS1}{g_1} + \frac{cS2}{g_2}\right)$$



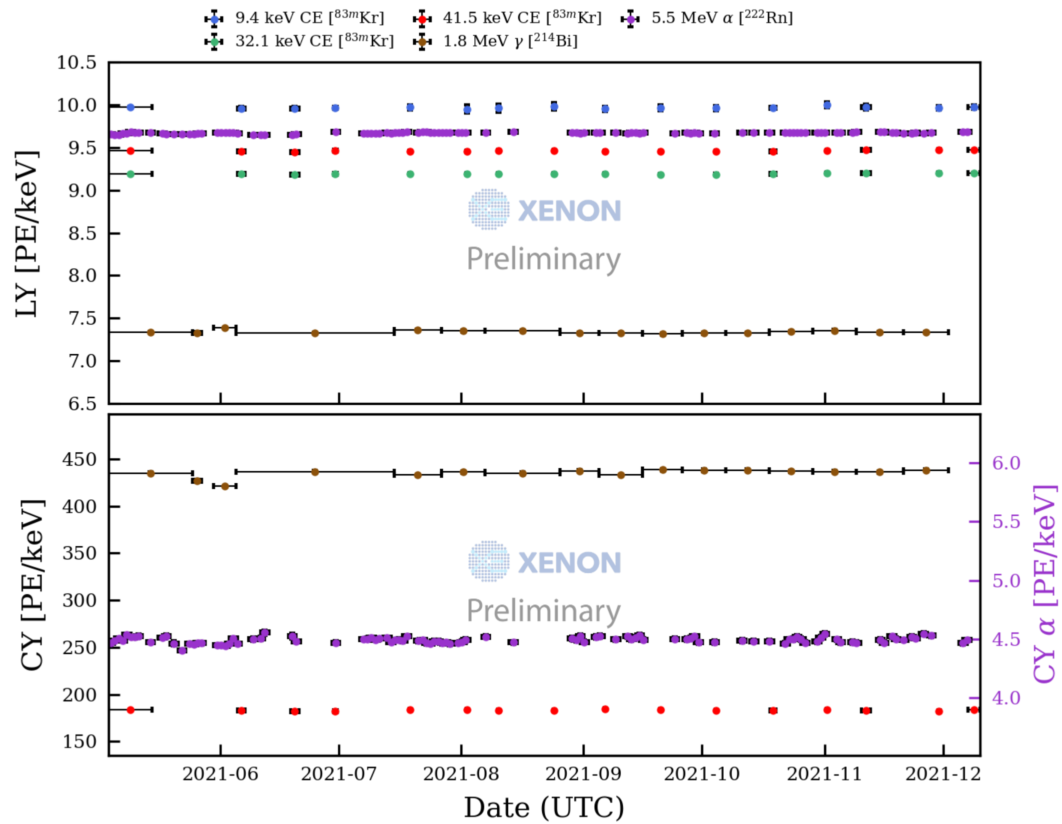


Detector response stability

- Continuous monitoring of detector stability:
  - regular bi-weekly ^{83m}Kr calibration
  - background sources

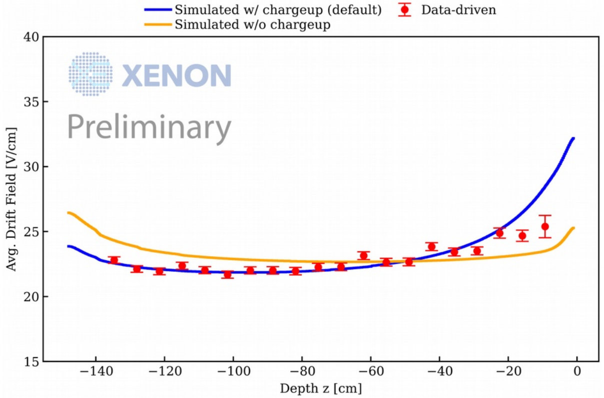
- Light yield stability ~1%

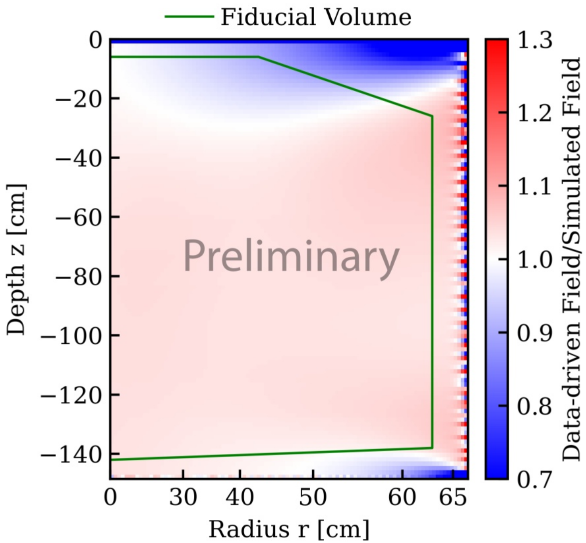
- Charge yield stability ~1.9%



Drift field calibration

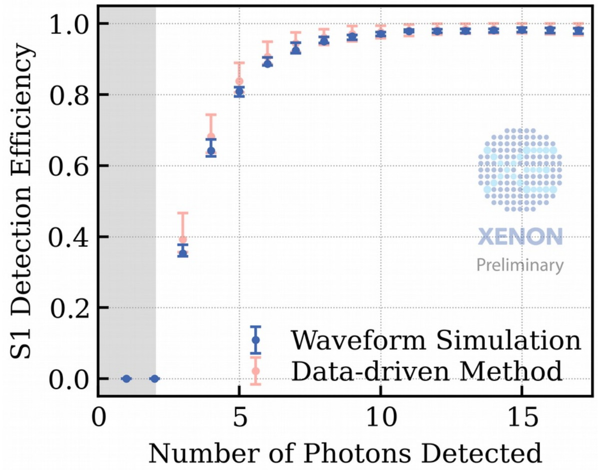
- Current drift field at ~23 V/cm
- Important to control field non-uniformities
- Calibration with ^{83m}Kr
  - two consecutive lines 32.1 and 9.4 keV
  - ratio of observed amplitudes → drift field sensitivity
  - tuning of COMSOL-based field simulation to current detector conditions
- Better than 10% match in fiducial volume for SR0

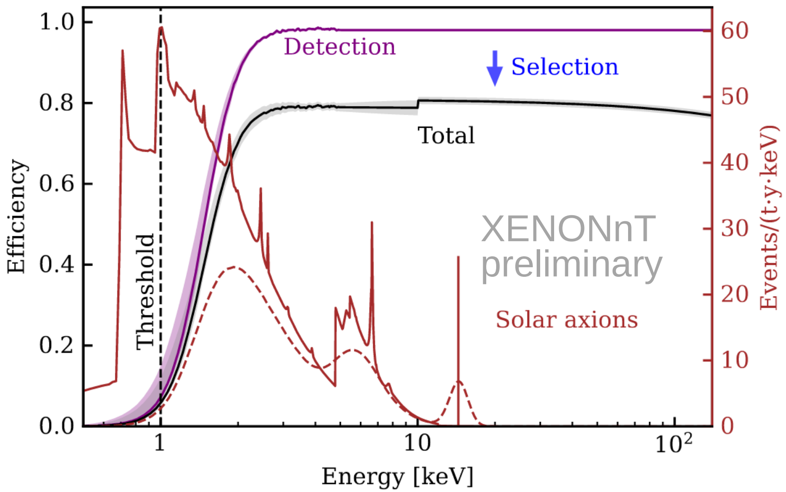




Threshold and efficiency estimate

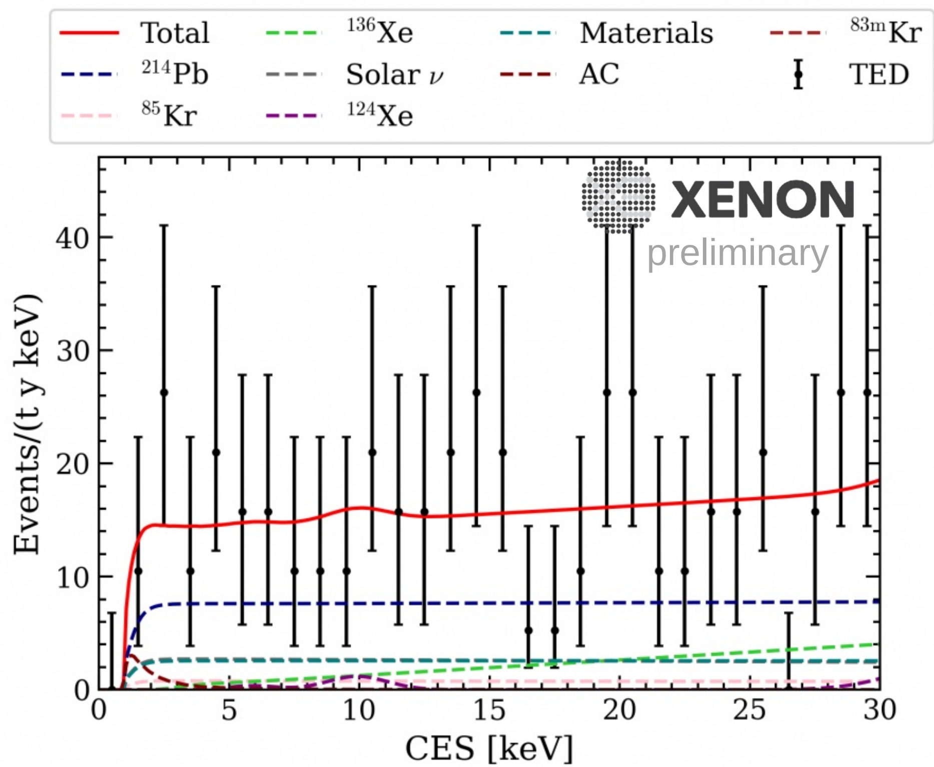
- Require 3 PMT hits to identify S1
- Efficiency estimation:
  - simulations: full waveform modelling of PMT signals
  - data-driven approach: sample from higher energy events
  - good agreement between two approaches
- ~86% average total cut acceptance





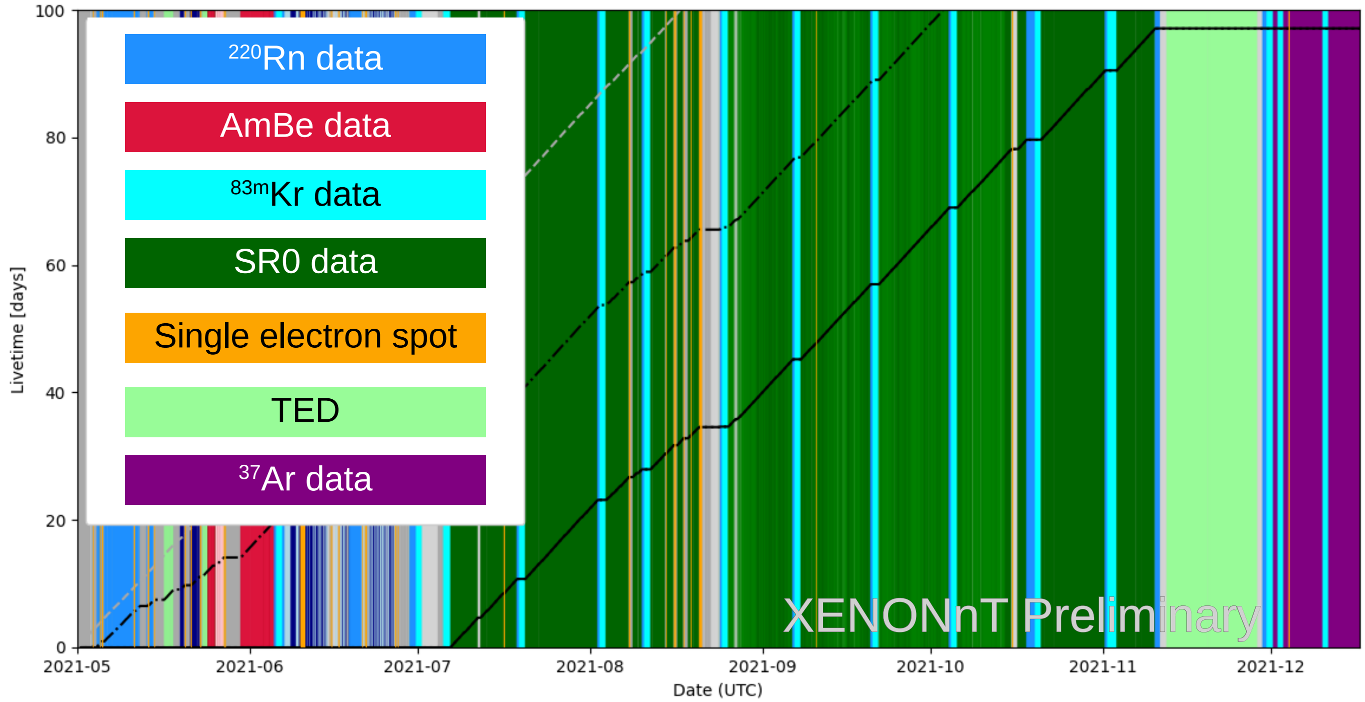
Control of tritium

- Tritium – potential explanation of XENON1T excess
- Control of hydrogen contamination:
  - detector outgassing
  - purification of GXe with Zr getters
  - 3 weeks of GXe cleaning
- Special mode:
  - “tritium enhanced data” bypassing getters
  - orders of magnitude in hydrogen level increase (conservative – at least 10x)
  - 14.3 days of ^{3}H enhanced data



- Result of blind TED analysis → no significant levels expected in SR0

XENON Science Run 0

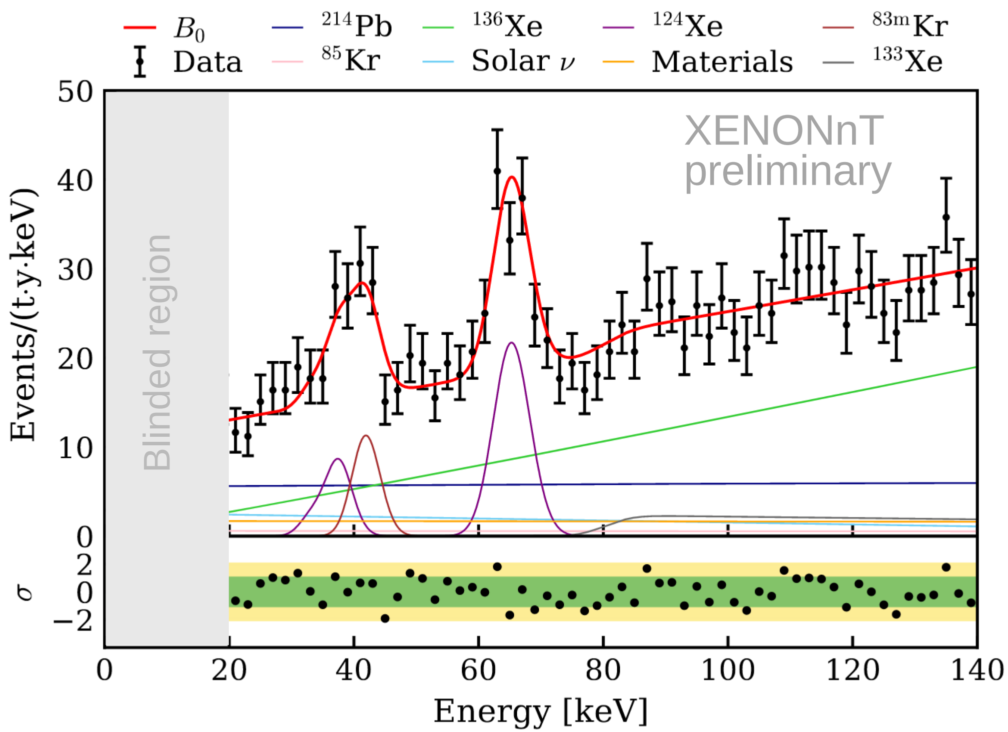


- Science data exposure of **97.1** days between July 6 – Nov 11 2021
- Drift field ~23 V/cm, extraction field ~2.9 kV/cm
- Radon distillation in gas mode

Background estimates

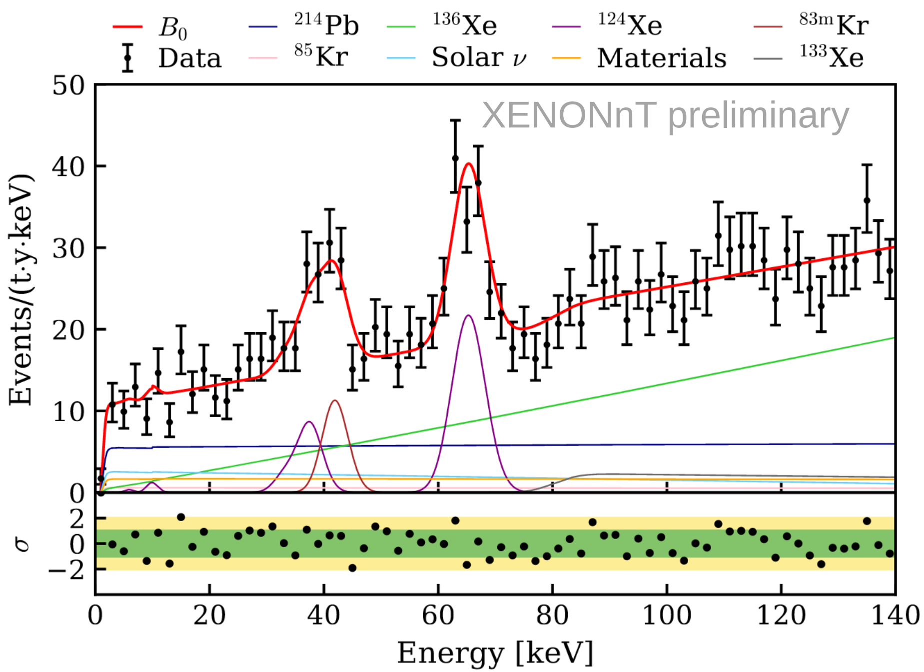
- Initial estimates of background:
  - external measurement
  - data-driven accidental coincidence model
  - verification in side-band
- Total background estimate:

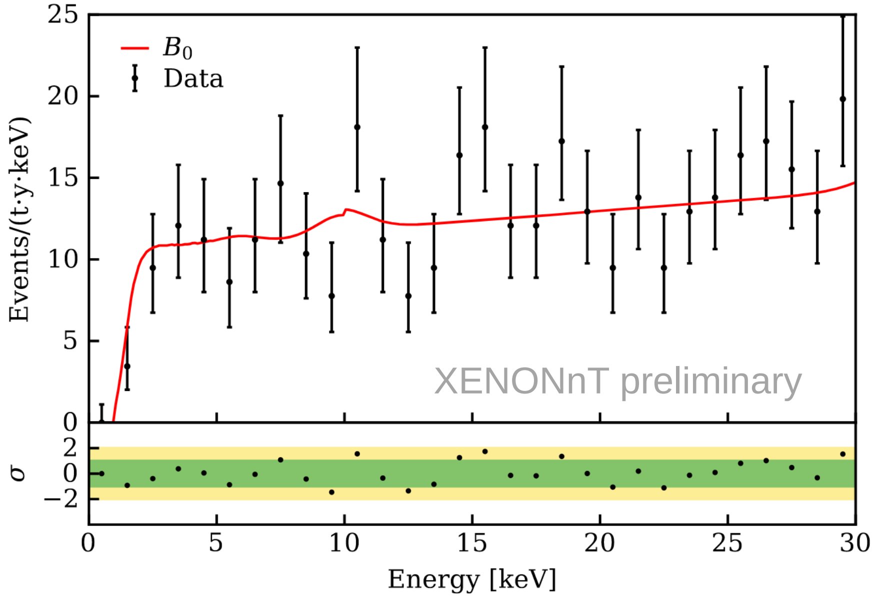
Component	events < 140 keV	events < 10 keV
^{214}Pb	980 ± 120	56 ± 7
^{85}Kr	91 ± 58	5.8 ± 3.7
Materials	267 ± 51	16.2 ± 3.1
^{136}Xe	1523 ± 54	8.7 ± 0.3
Solar neutrino	298 ± 29	24.5 ± 2.4
^{124}Xe	256 ± 28	2.6 ± 0.3
Accidental	0.71 ± 0.03	0.71 ± 0.03
^{133}Xe	163 ± 63	0
^{83m}Kr	80 ± 16	0



Unblinding of energy spectrum

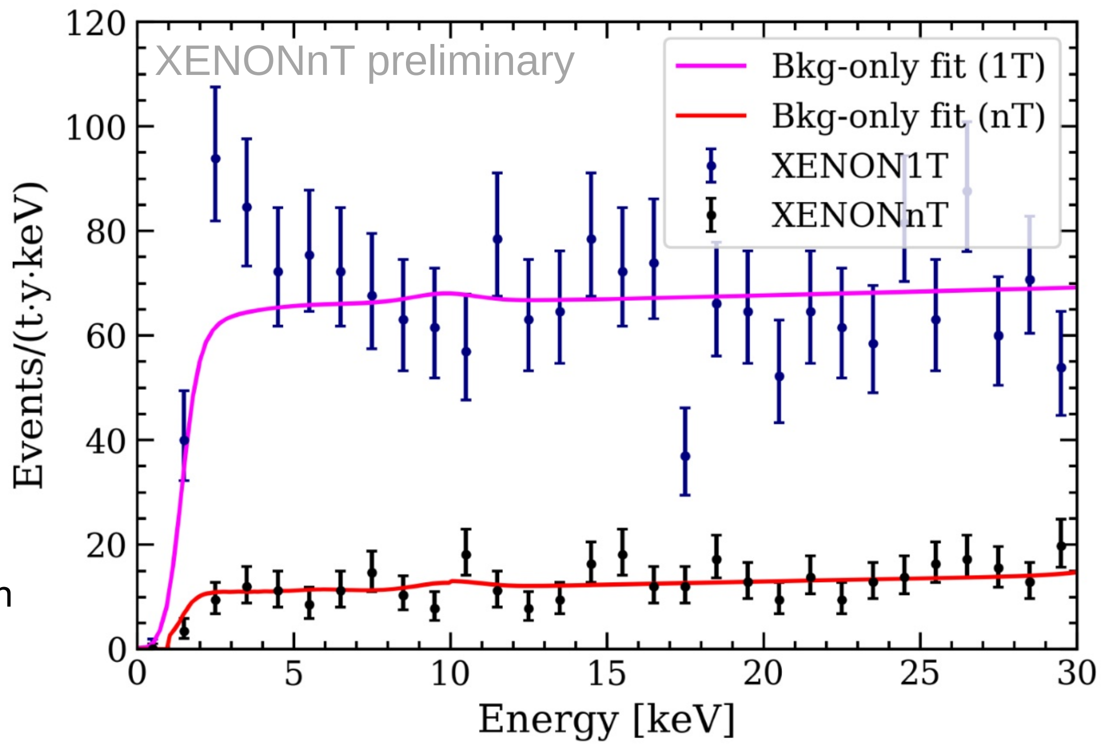
- Fully blind analysis with various stages of unblinding:
  - 10-20 keV side band, accidental coincidence, wall sample, full range
- Final energy range in fiducial mass of (4.37 ± 0.14) tonnes





XENONnT vs XENON1T

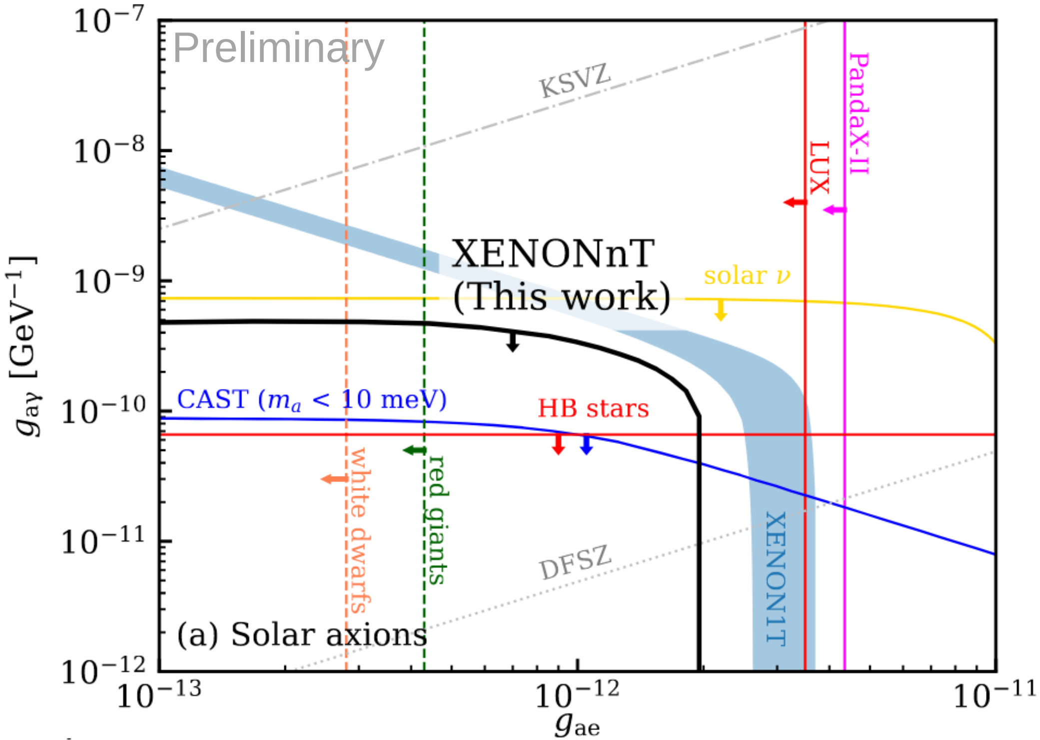
- In XENON1T data:
  - low energy excess below 5 keV
  - unknown nature:
    - tritium?
    - detector artefact?
    - new physics?
- **No comparable excess observed in XENONnT SR0**
  - 8.6σ exclusion of XENON1T-size peak → likely small ^3H contamination
  - tight constraints on new physics



Solar axion constraints

- Significantly improved constraints on axion-gamma, axion-electron and axion-nucleon coupling
- Axion signal assumes axio-electric effect and reverse Primakoff effect
- Limit for signal from ^{57}Fe axions

< 20.4 ev/(t·y) (90% C.L.)

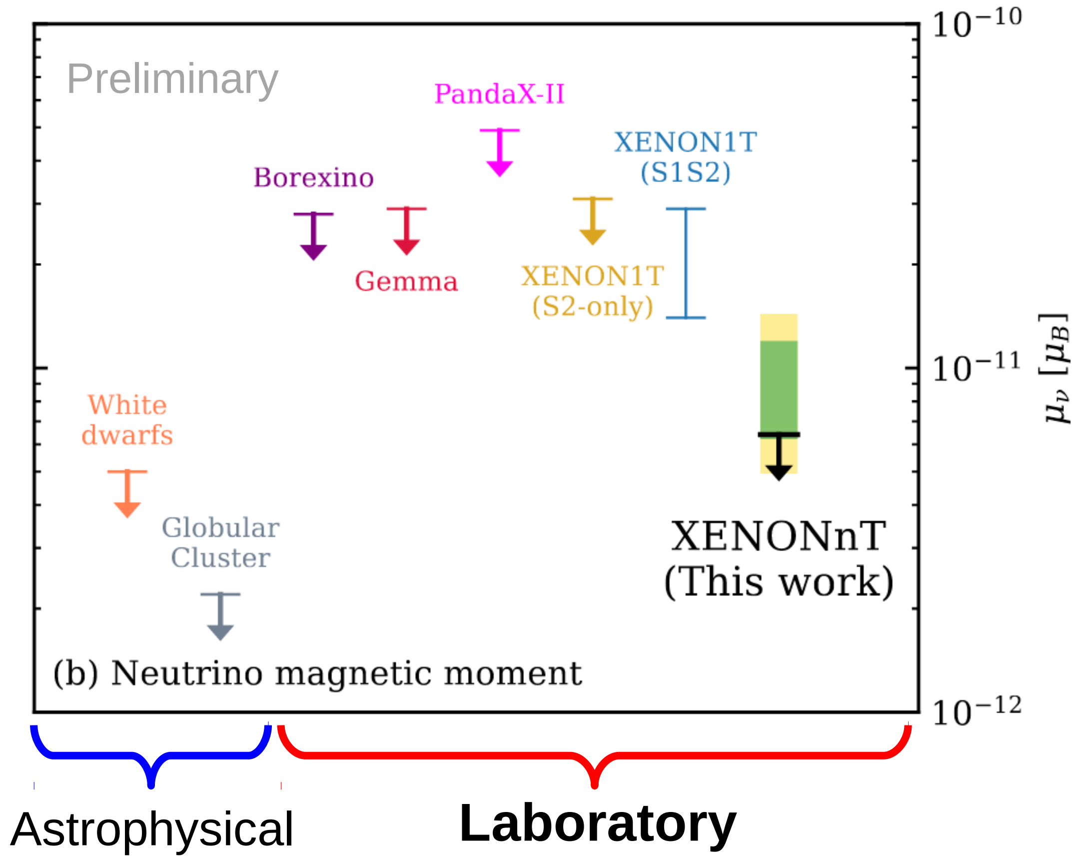


Neutrino magnetic moment

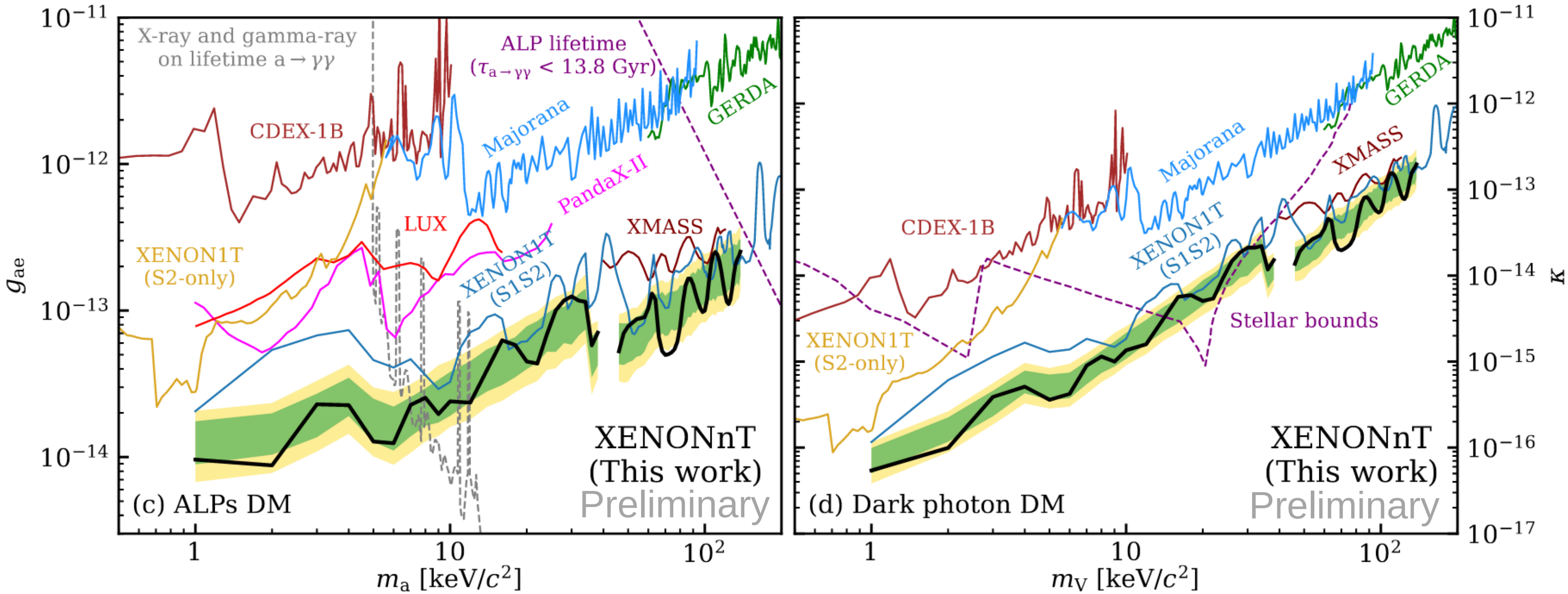
- Constraint on neutrino magnetic moment

$$\mu_\nu < 6.3 \times 10^{-12} \mu_B$$

- The most stringent limit in direct detection experiment!



ALP DM and dark photon



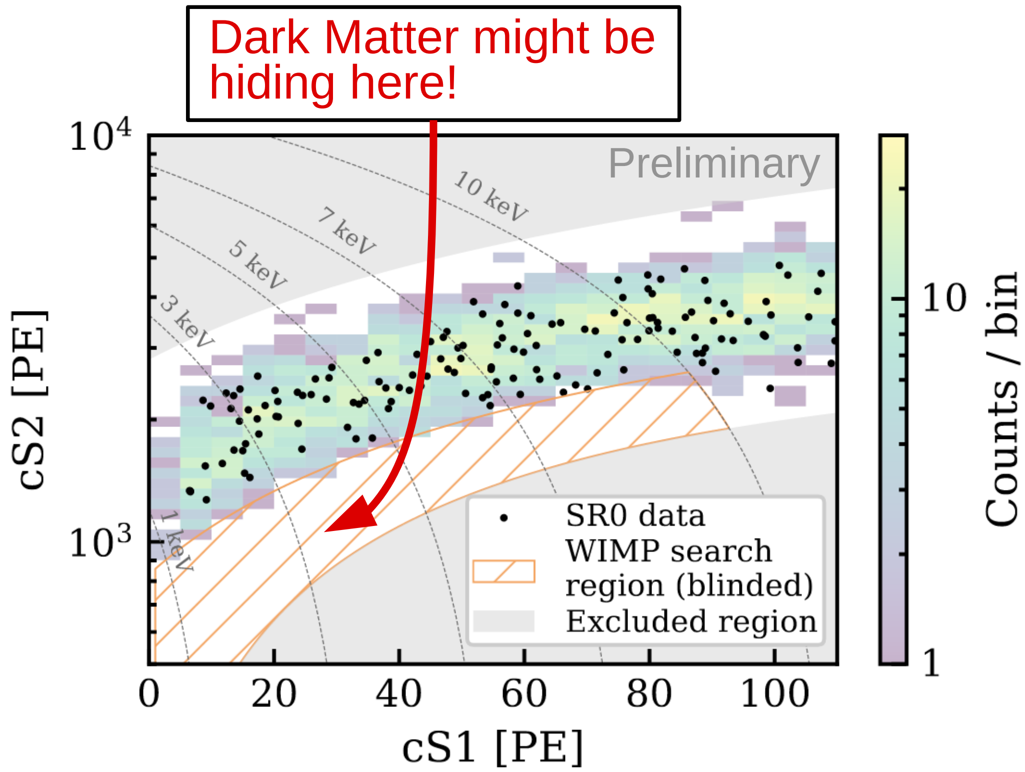
- No peak-like signature expected from axion-like particles or dark photons
- Unconstrained normalization of ^{83m}Kr→ no limit around 41.5 keV

What is next?

- Now:
  - unblinded electron recoil band
  - limits on new physics in ER band

- Coming up next:
  - WIMP NR search
  - CEvNS
  - and more

- **NR WIMP unblinding is in progress!**



Summary

- Successful construction and commissioning of XENONnT:
- New techniques to achieve:
  - electron lifetime of > 10 ms
  - ~5x background reduction of XENON1T level
- Science run 0:
  - drift field of ~23 V/cm
  - 97.1 days with total exposure of ~1.16 t·y
- First results:
  - fully blinded analysis of electron recoil (ER) band
  - no excess observed → stringent limits on new physics
  - XENON1T result was likely due to small ^{3}H contamination
- Stay tuned for more results in near future!

Backup slides