WWU MÜNSTER

XENON

The XENONnT experiment – SR0

07.09.2022 – RICAP2022 – First results on Electronic Recoil events

Lutz Althüser, University of Münster
on behalf of the XENON collaboration

l.althueser@uni-muenster.de

XENON Collaboration

27 institutes
170 scientists

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

Chicago
UCSD
Rice
Purdue

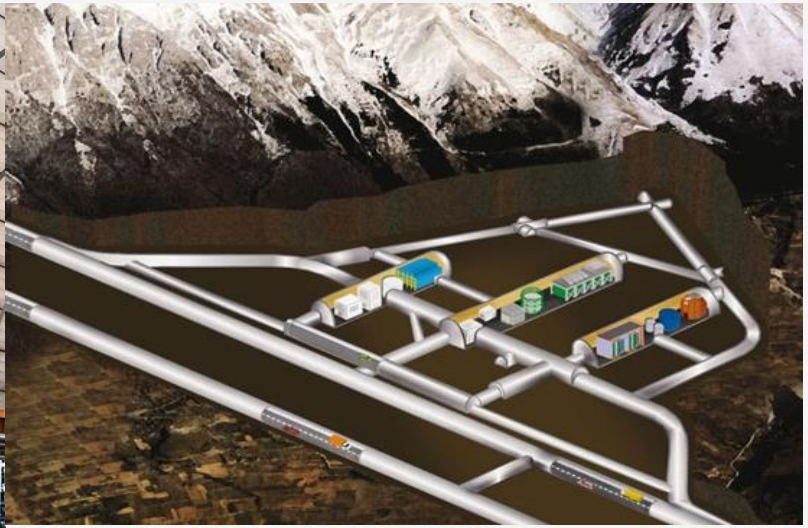
Tsinghua
Tokyo
Nagoya
Kobe

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

XENON Collaboration Meeting, July 2022, Torino

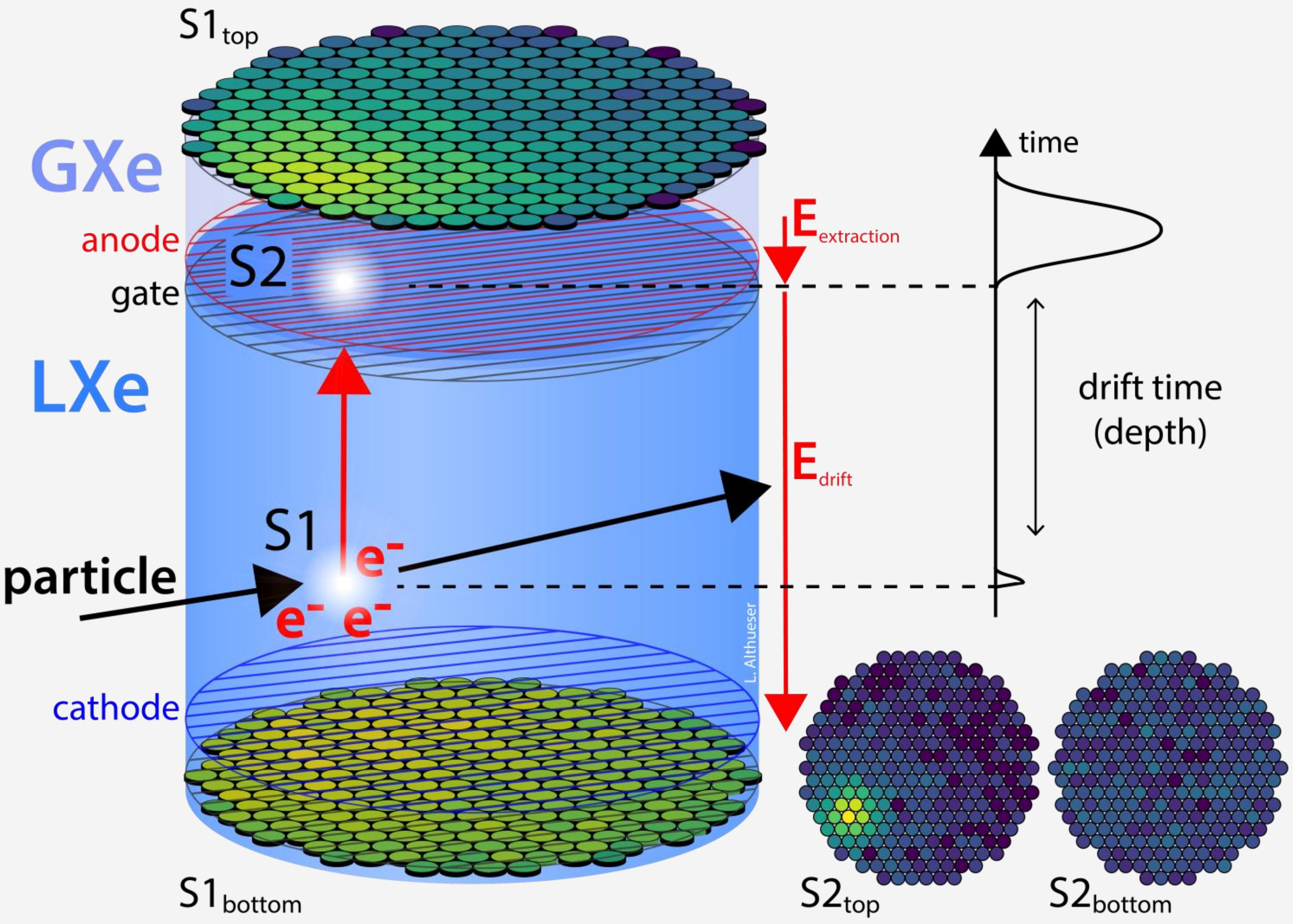
XENON Dark Matter Project

Eur. Phys. J. C. (2017) 77:881



- **XENON1T** (and **XENONnT**) detectors
- Located @LNGS in Italy
- Depth of 3600 m water equivalent
- Muon Veto (~700 t Gd-loaded water)
- (Neutron Veto for XENONnT)
- Time Projection Chamber with **2 t** (**5.9 t**) of LXe in the active region and 3.2 t (8.4 t) in total

Working Principle

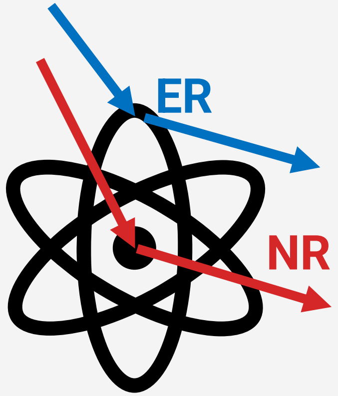


Working principle of dual-phase liquid noble gas time projection chambers (TPCs)

- Prompt light signal (**S1**)
- Secondary light in GXe from drifted charges (**S2**)
- Energy reconstruction using the combined S1 and S2 signal
- Position reconstruction
  - **z** from S1-S2-delay time
  - **x-y** from S2 hit pattern

Phys. Rev. D 100, 052014 (2019)
Phys. Rev. D 99, 112009 (2019)

Observable Signals in Liquid Xenon

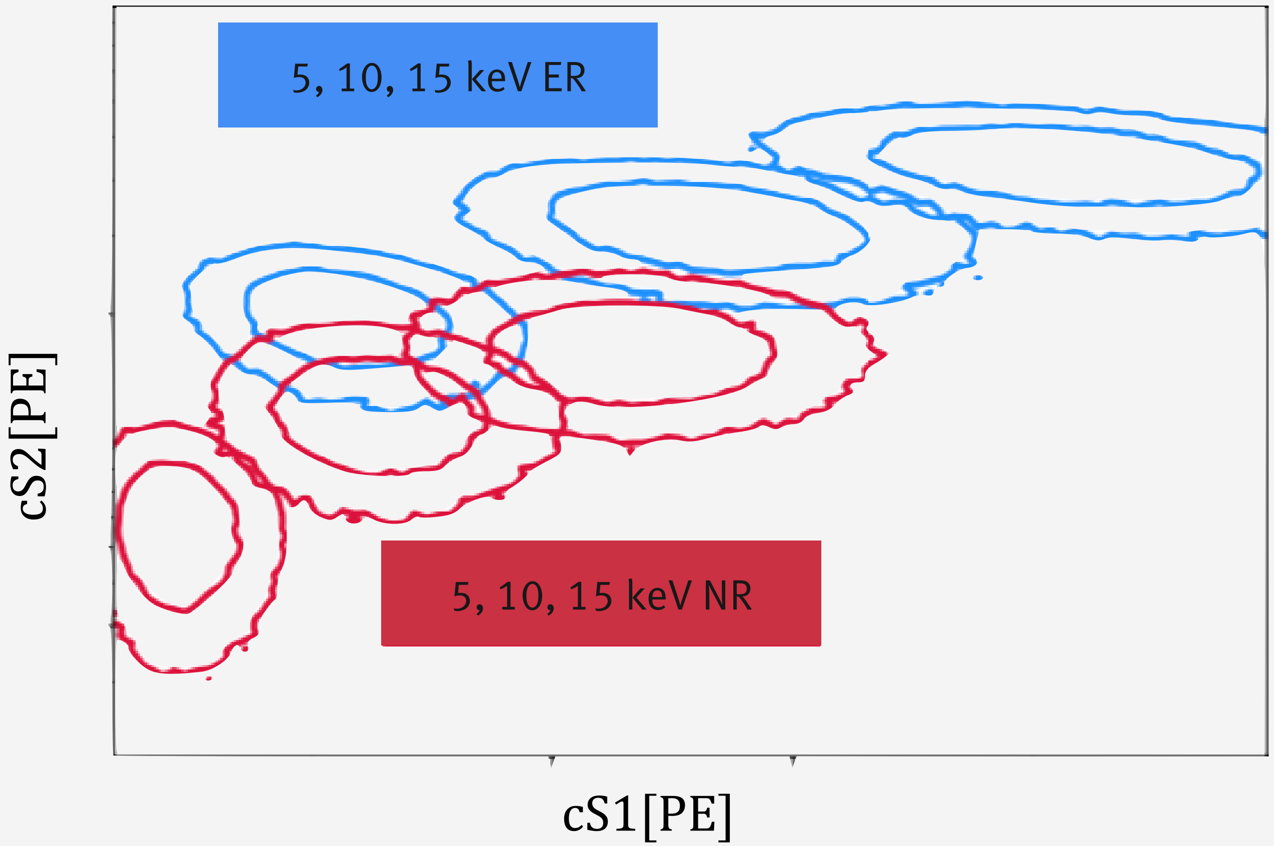


ER (Electronic Recoils)
γ, β backgrounds

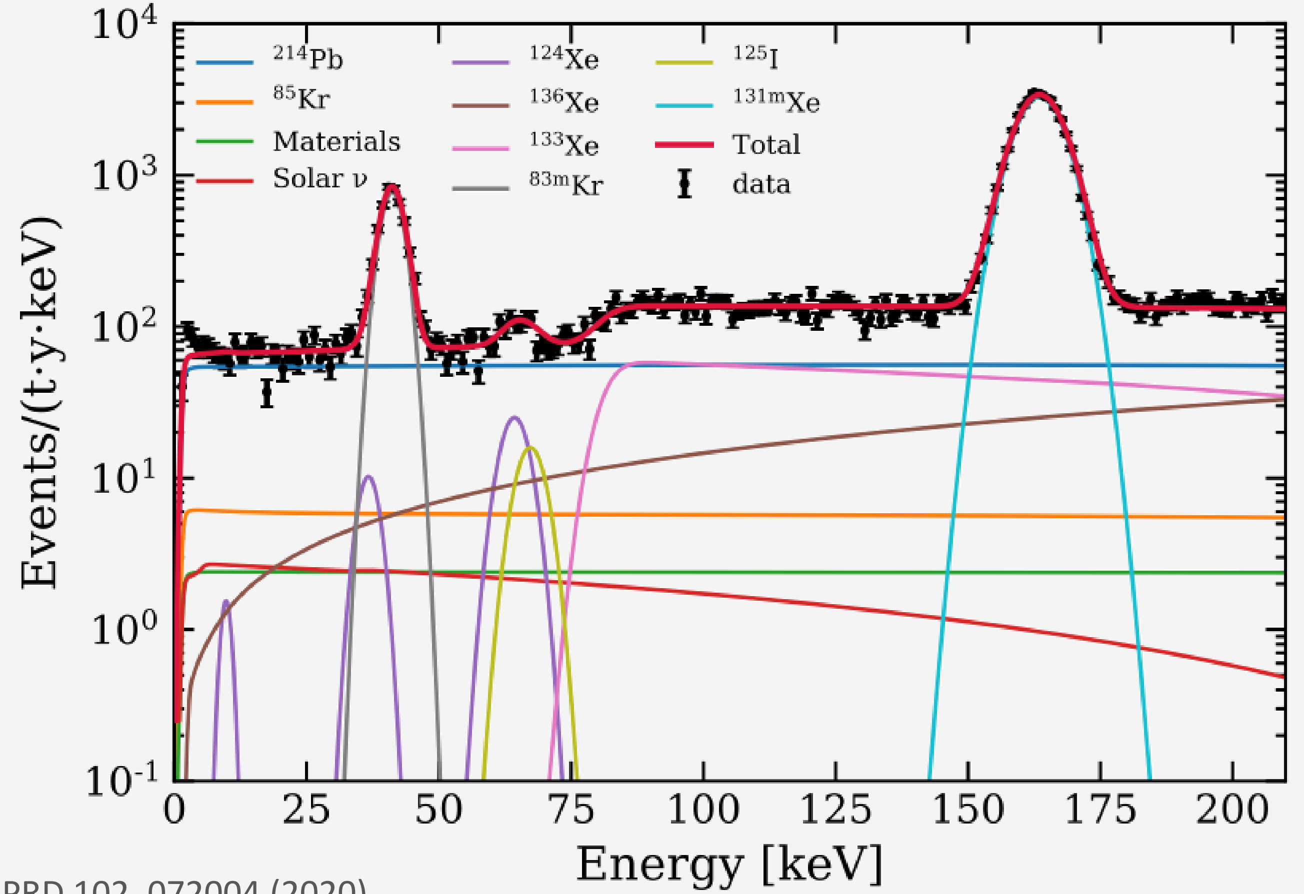
NR (Nuclear Recoils)
WIMP signal, neutrons, CNNS

The XENON detectors were conceived and designed to search for **nuclear recoil signals from WIMPs**

- **~1keV ER** recoil energy deposited in the liquid xenon target **is enough** to yield a characteristic scintillation + charge signal
- In addition to WIMP dark matter and backgrounds, several other dark matter or new physics candidates can give a **signal**:
  - **Solar axions, axion-like particles**
  - **Solar neutrinos, SN neutrinos**
  - **Double β-decay, double EC**
  - **Other BSM**

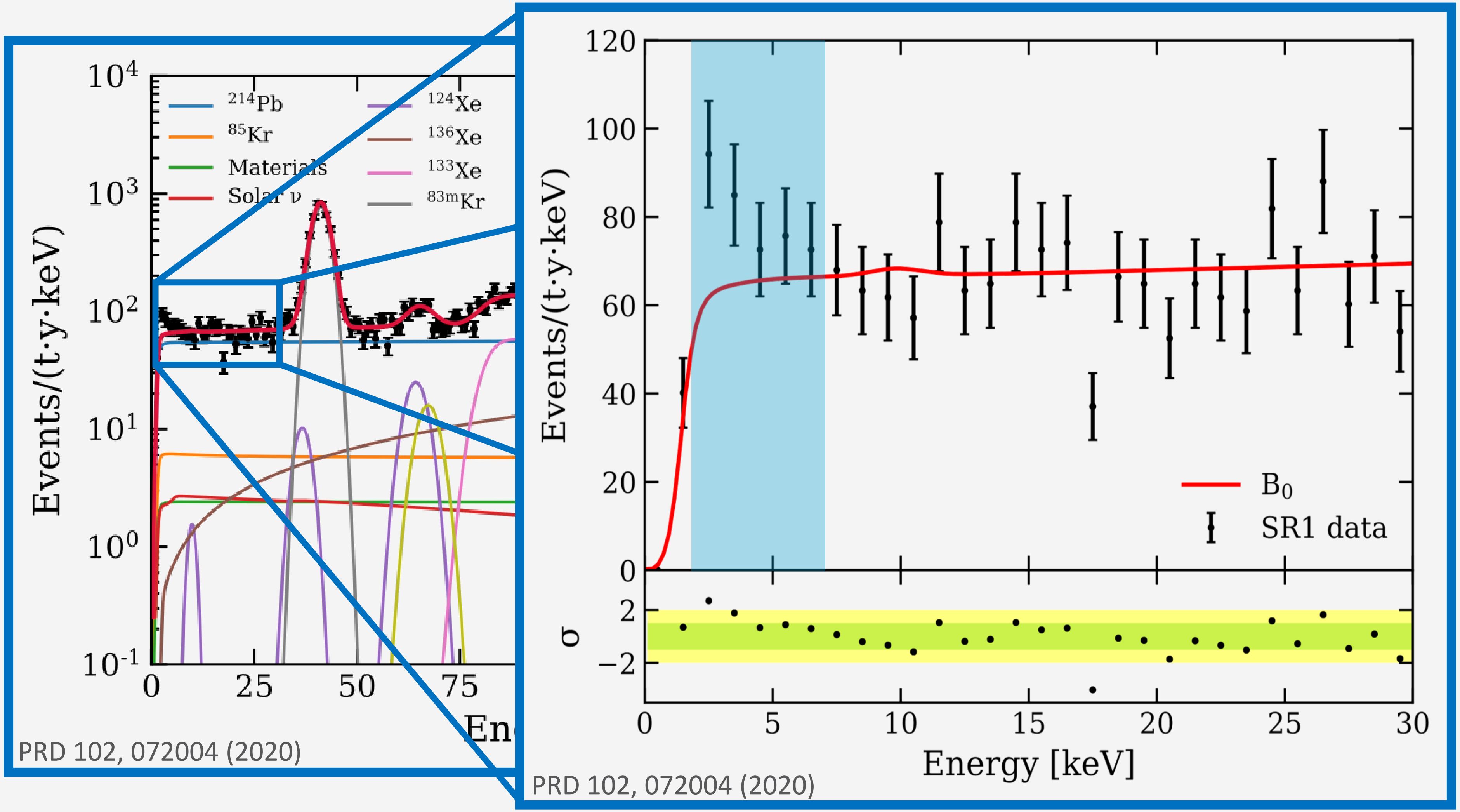


XENON1T ER Search



PRD 102, 072004 (2020)

XENON1T ER Search – Excess between 1-7 keV



285 events observed
232 (±15) events expected

3.3 σ
Poissonian fluctuation
(very naive estimate)

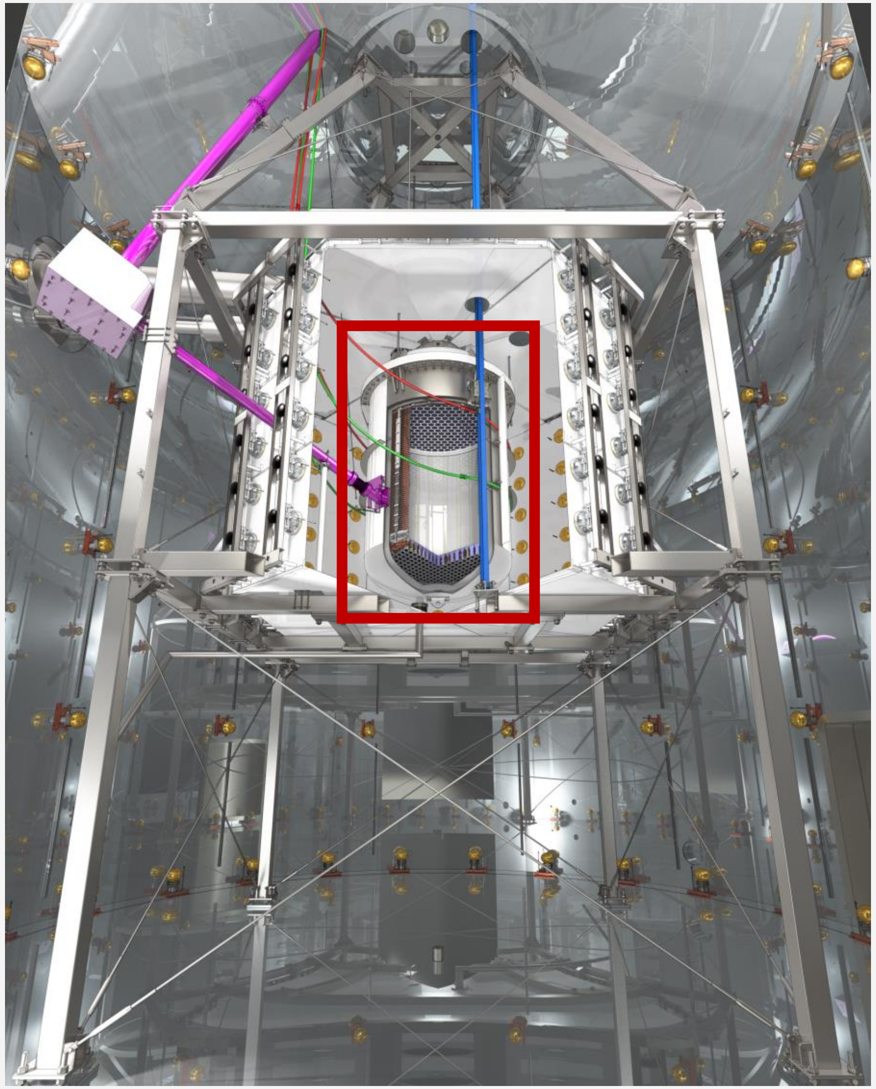
A range of **new physics** could be compatible with the excess:

- PRD 102, 072004 (2020)
- arXiv:2207.08621
- …

^{3}H is possible – not as water but as tritiated hydrogen. Required rate much greater than expected from purification

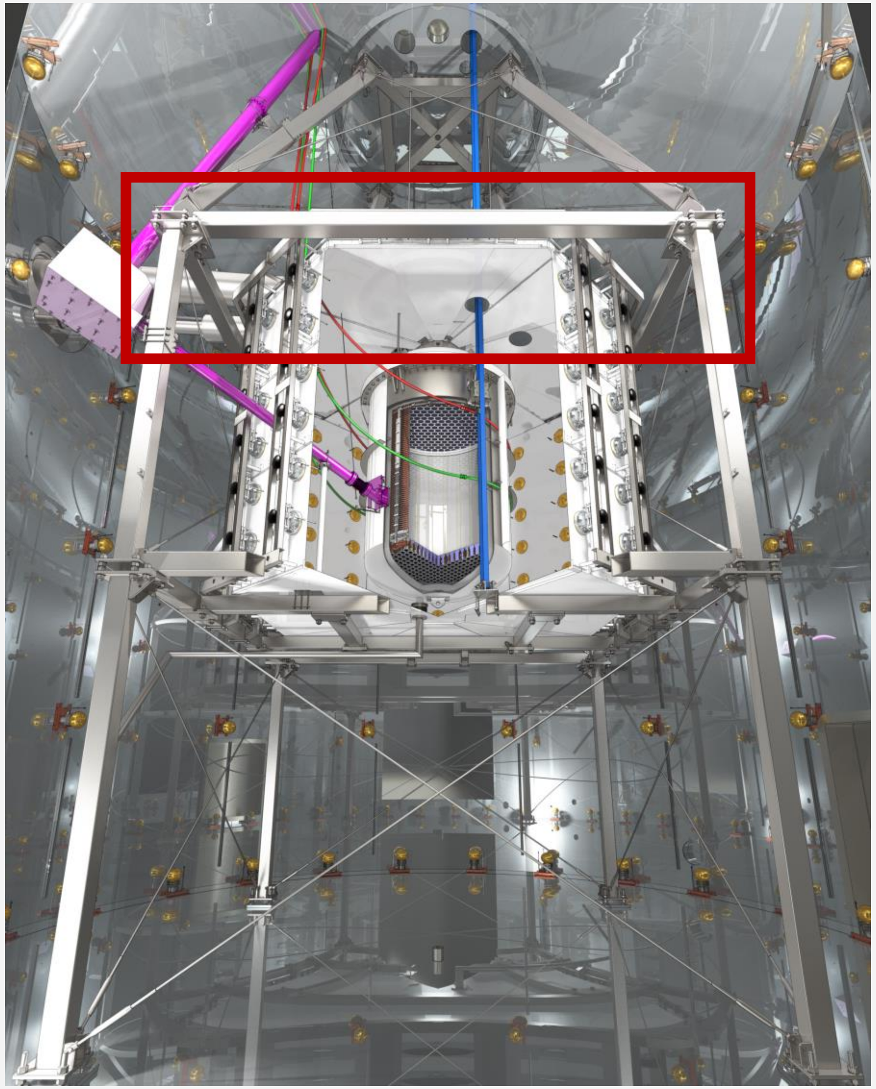
^{37}Ar would be removed by the online Kr distillation. The necessary air leak to explain the excess is > 13 l/y, upper limit is 0.9 l/y

Upgrades towards XENONnT

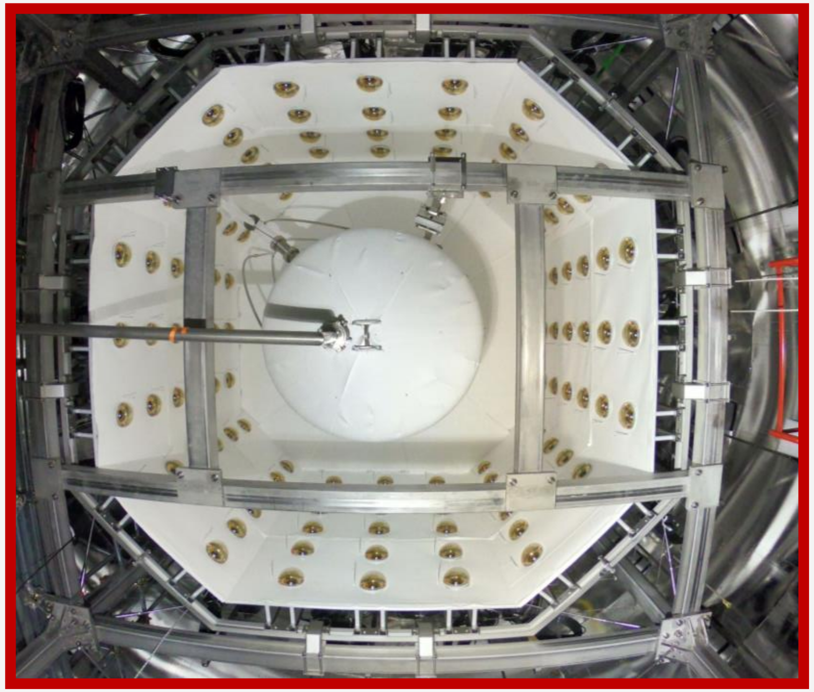


- **Increases the TPC** drift length to 1.5 m (from 1m)
- Contains a **5.9 t** active mass (from 2 t)
- Doubles the number of **PMTs to 494**, and has a larger light detection efficiency (34->36%)
- Carefully selected materials to **minimize backgrounds** (Eur. Phys. J. C (2022) 82:599)
- Field shaping rings, tuneable potential for the top one

Upgrades towards XENONnT

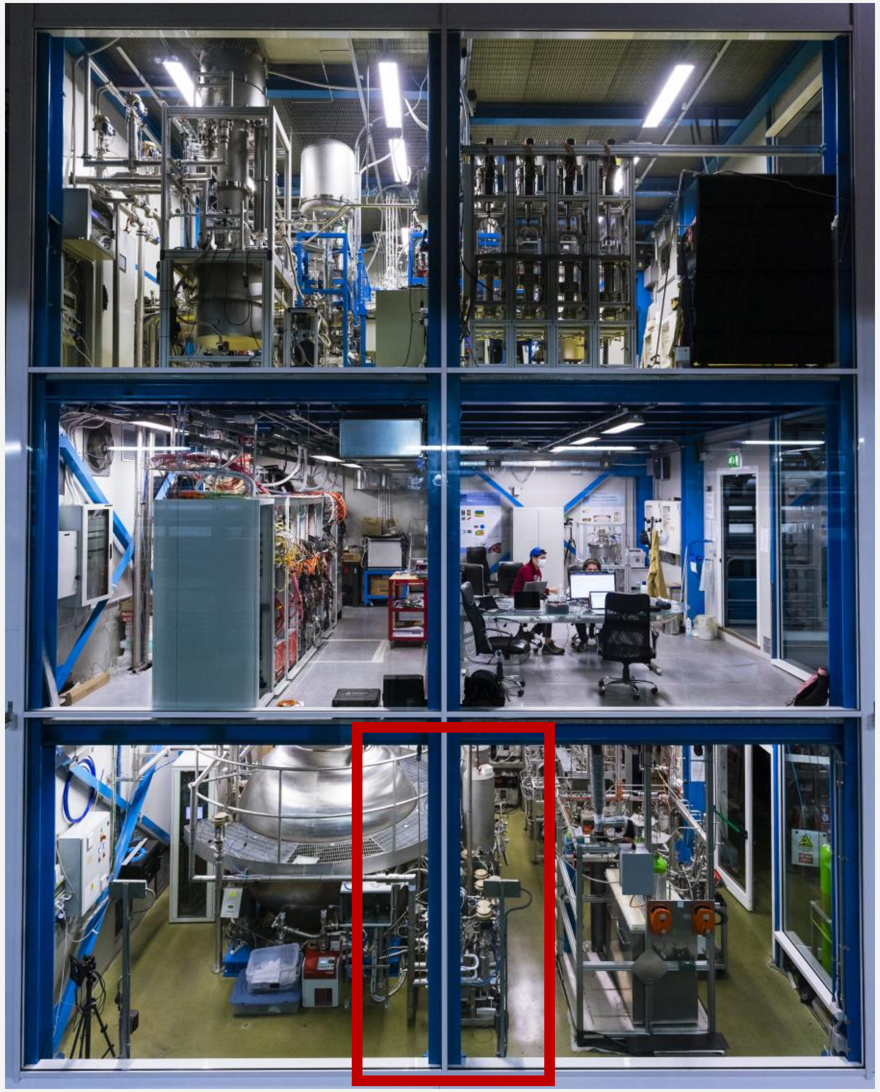


- **Cherenkov Muon veto** from 1T
- New **Neutron veto** of 4m x 3m is enclosing the TPC, with 120 PMTs placed inside an enclosure of reflective panels
- Neutron tagging efficiency projected to 87% with (planned) Gd-doping, 68% with current pure water



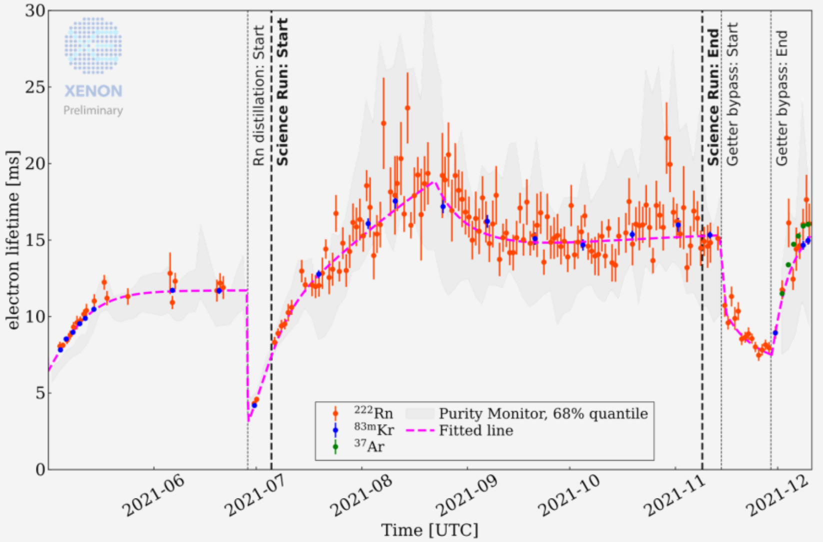
- The Neutron veto is vital for WIMP search by tagging neutrons, we **expect ~0.3 neutrons per t·y** (JCAP 11 (2020) 031)

Upgrades towards XENONnT

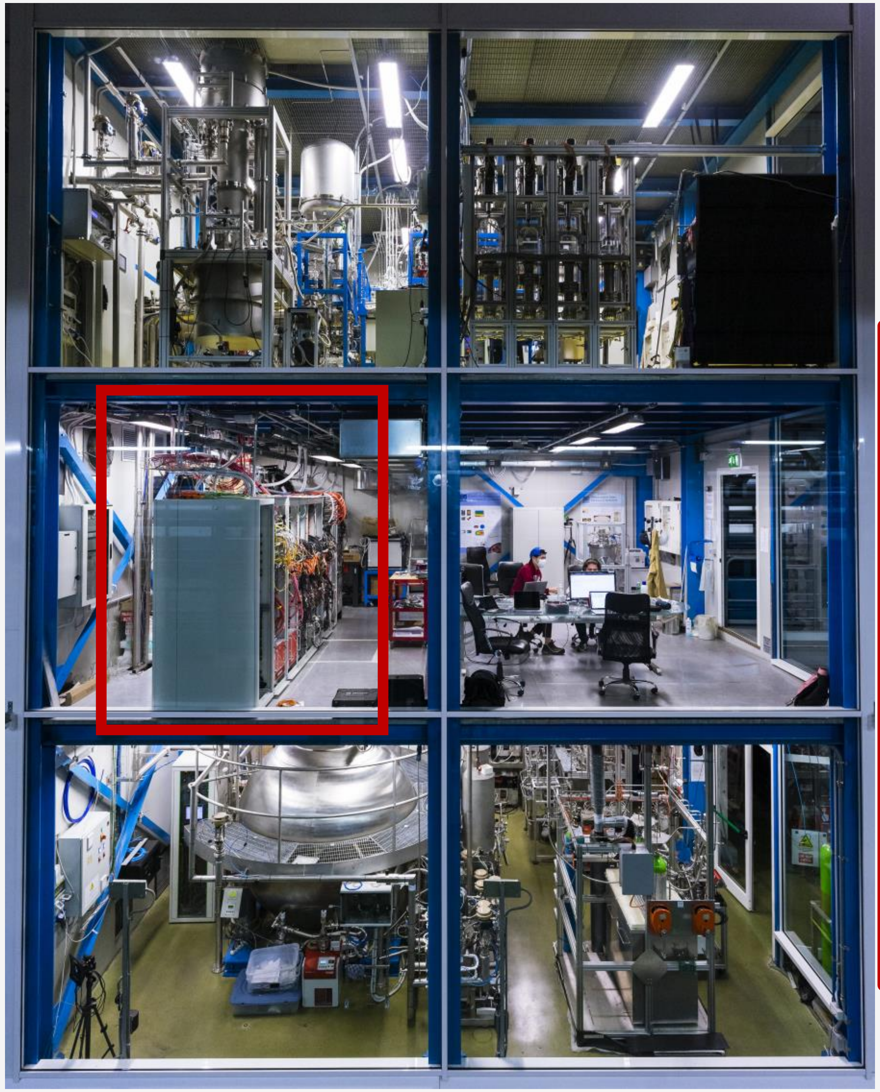


- **New liquid xenon purification technique** (arXiv:2205.07336) with replaceable filter units + extremely low radon emanation (in science run mode)
- High flow of 2 liters liquid xe/min, reach very high purity in < 1 week, 18 h to exchange the entire volume

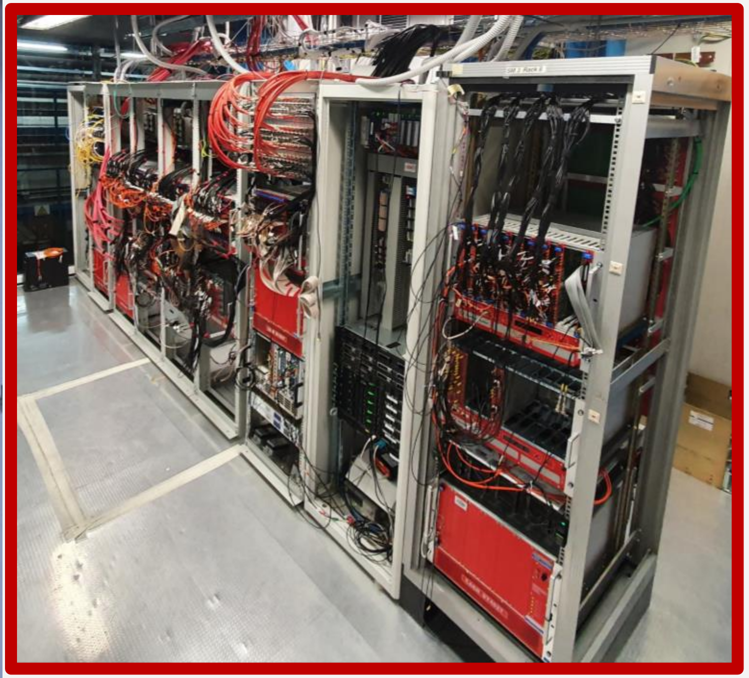
	Full TPC drift time	electron lifetime	electrons surviving a full drift length
XENON1T	0.67 ms	0.65 ms	30 %
XENONnT	2.2 ms	10+ ms	86 % @ 15 ms

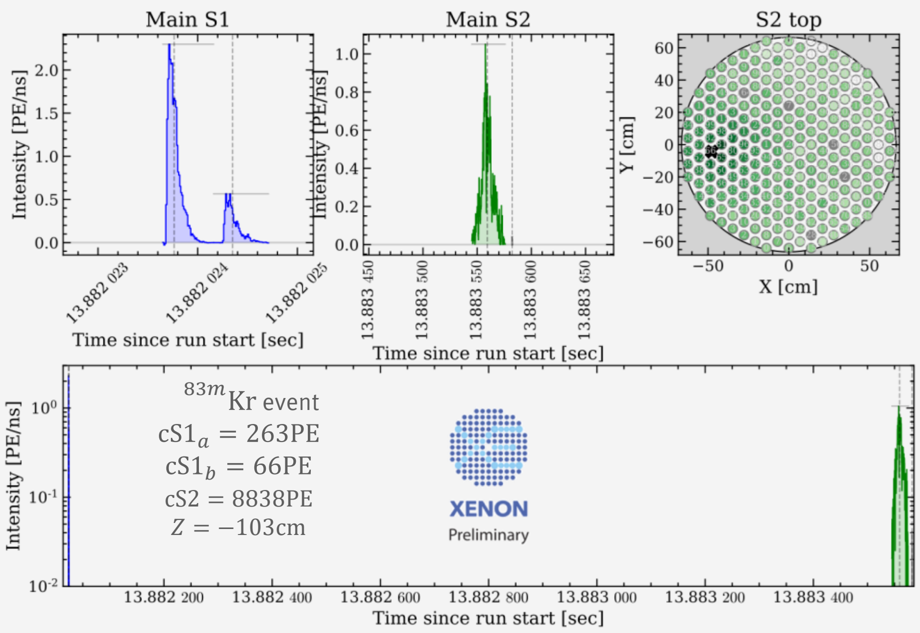


Upgrades towards XENONnT

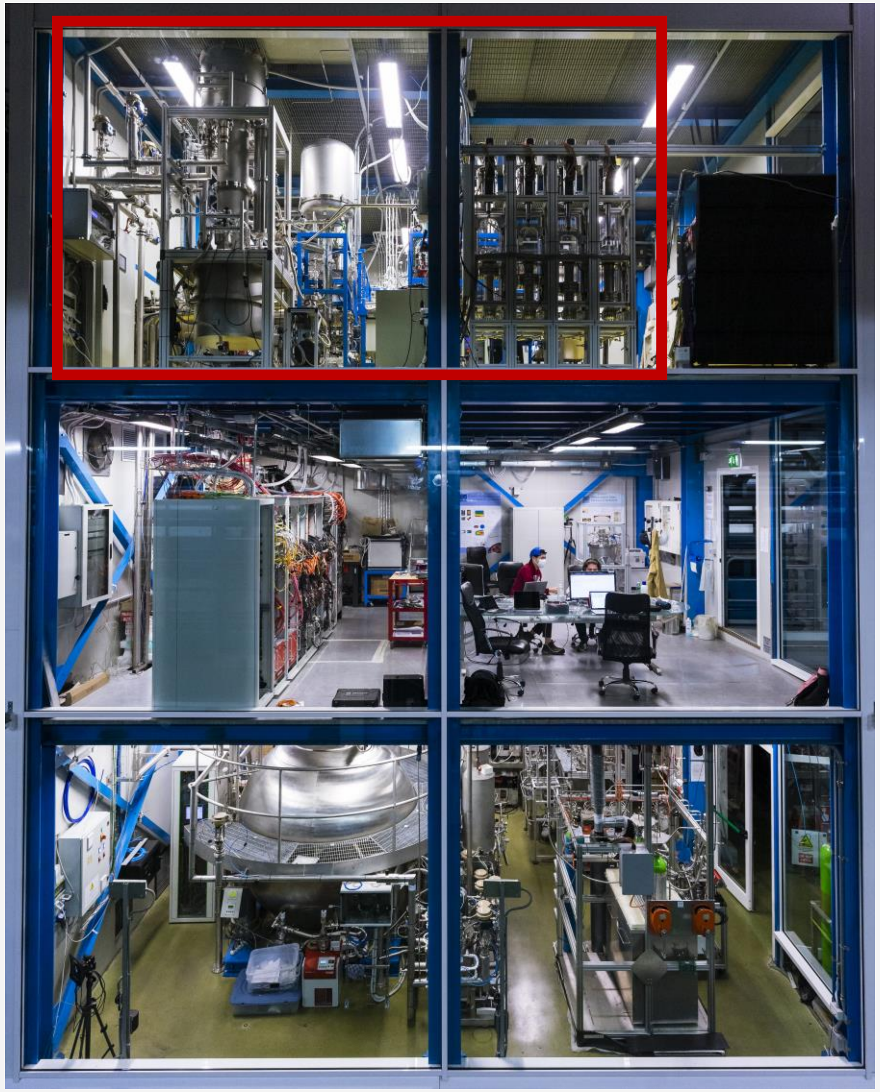


- **Triggerless**: all data above per channel threshold stored long term
- Fully **live processing**
- Open-source software: straxen (straxen@github)

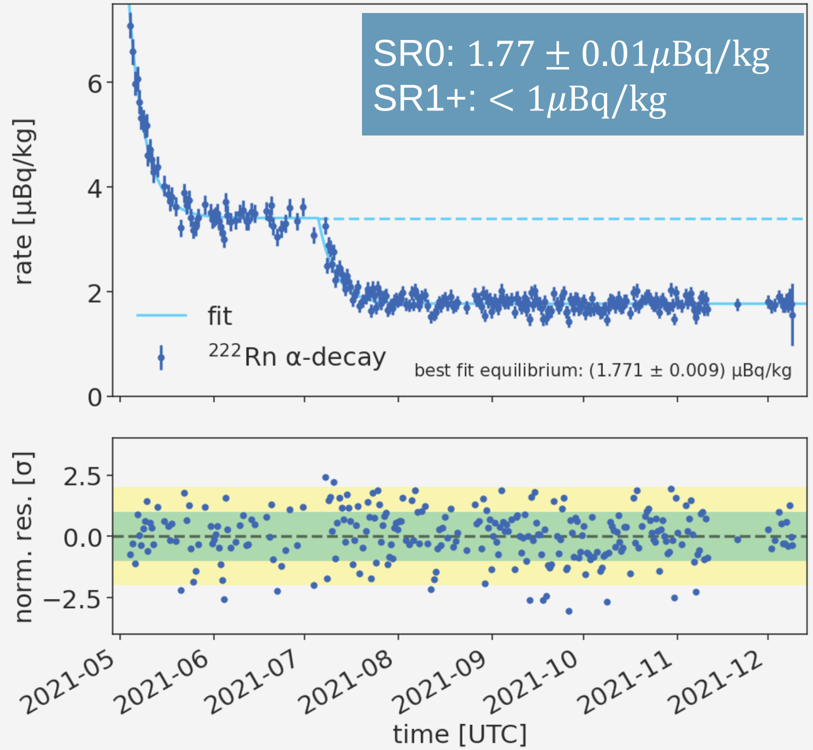




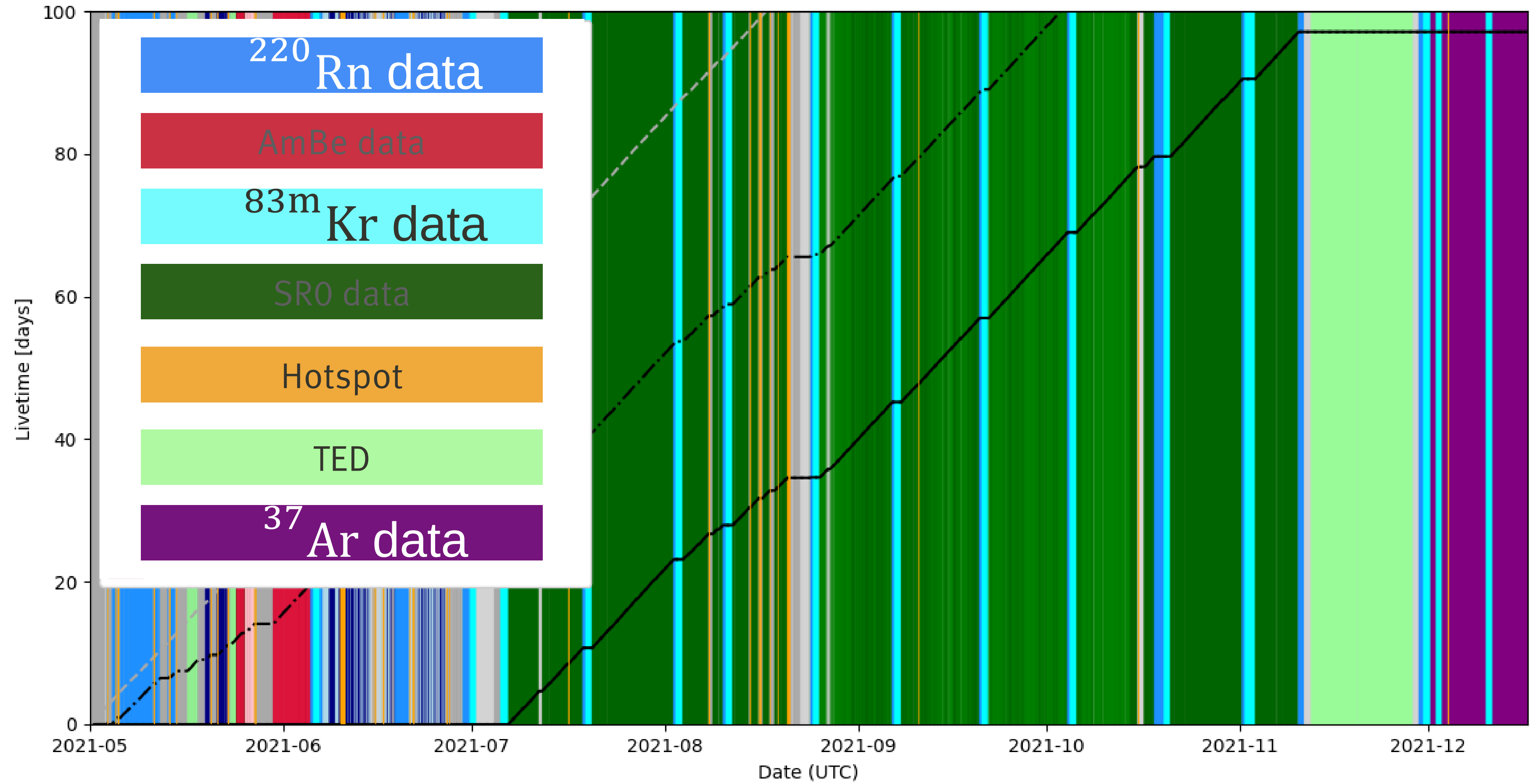
Upgrades towards XENONnT



- ^{222}Rn is primary source of backgrounds
- **Newly developed Rn column** (arXiv:2205.11492) handles large xenon flows using radon-free compressors and heat exchangers
- Gas-only mode during SR0 leading to 1.77 μBq/kg
- **Reaching <1 μBq/kg** in following science runs



First Science Run – XENONnT SR0

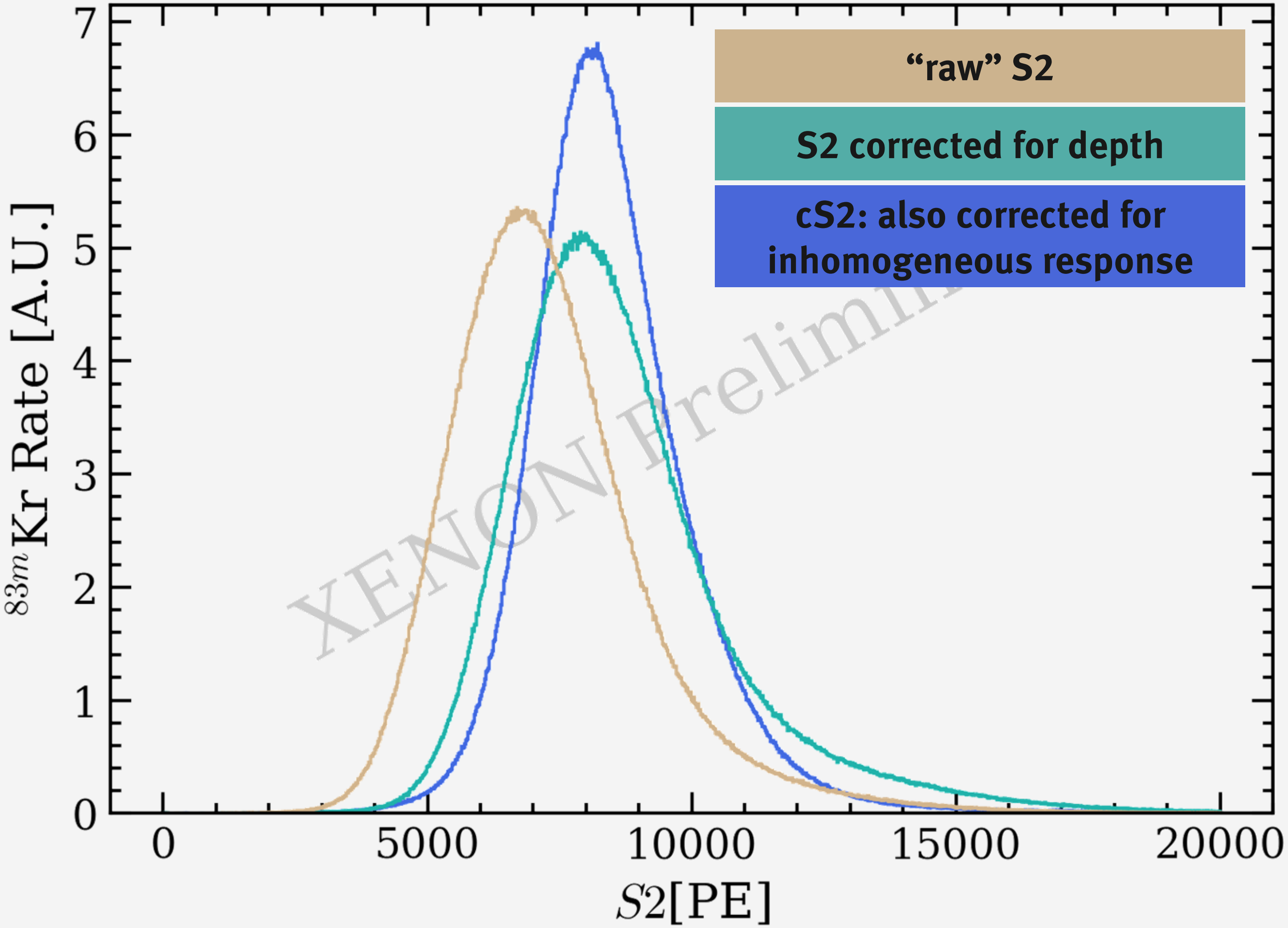


- **97.1 days exposure** from July 6th-Nov 11th 2021
- Rn column in gas-only mode
- All but 17 PMTs working, gain stable at 3%
- 23 V/cm drift field, Extraction Field in LXe 2.9 kV/cm
- Localized high single-electron emission occurring seemingly at random, anode ramped down

Calibration and Analysis

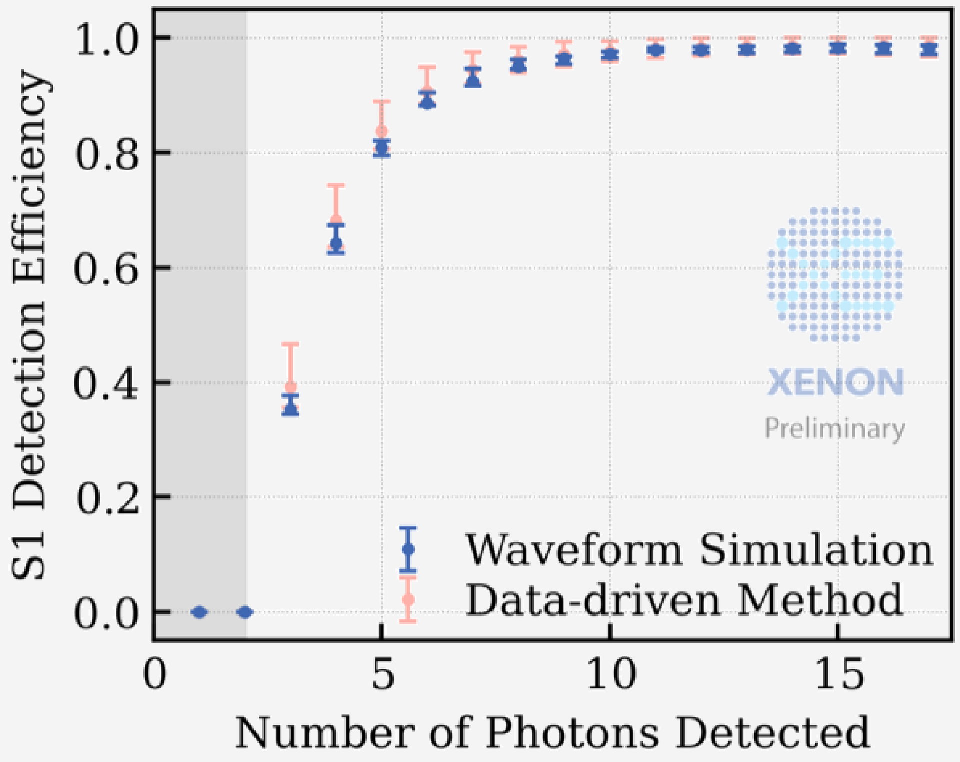
The **SR0 analysis effort** covers:

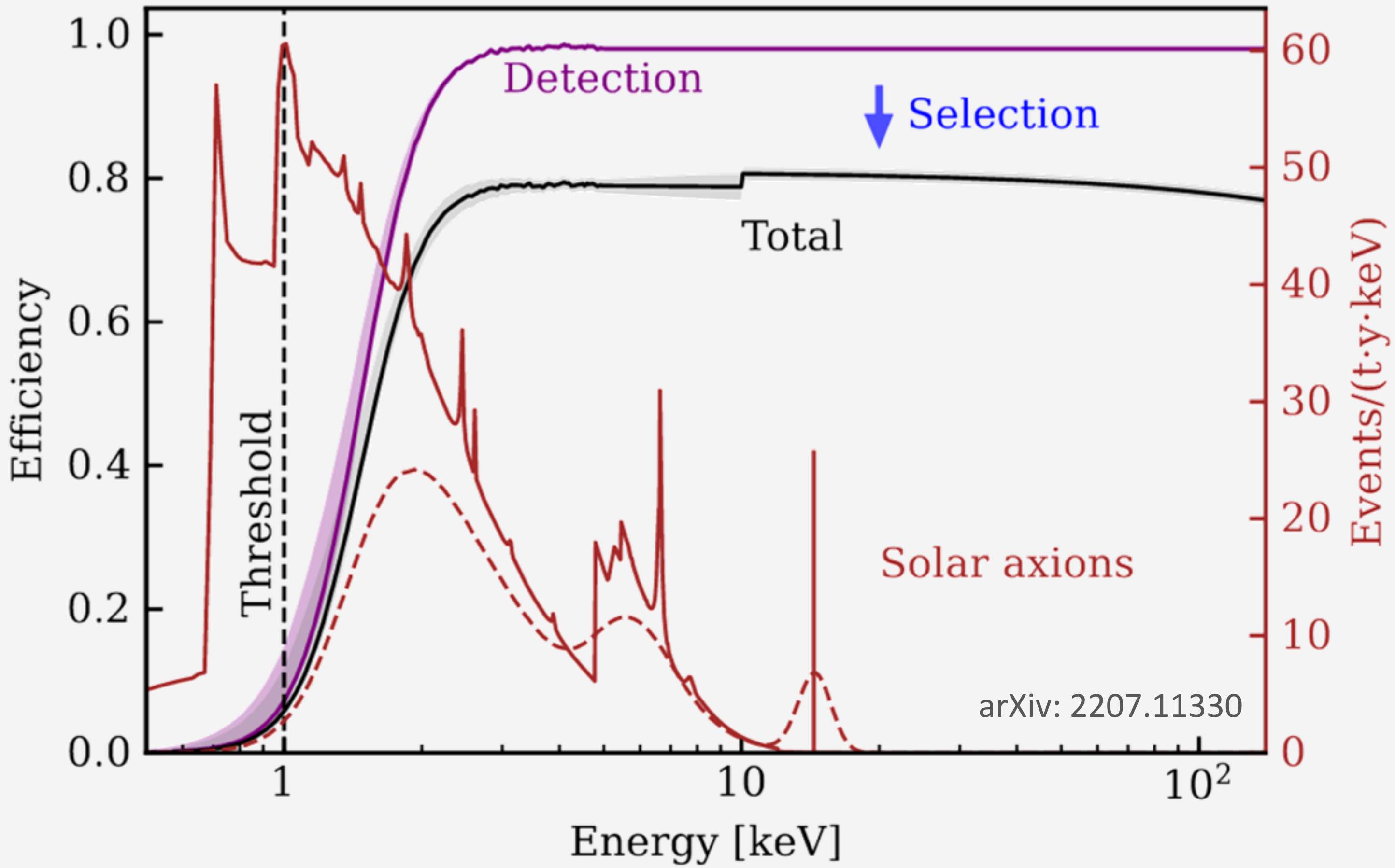
- Peak and event reconstruction
- “corrections”— compensating for detector responses to give good estimators
- Data quality validation, cuts against backgrounds
- Backgrounds models
- Detector response modelling
- Inference



Efficiencies

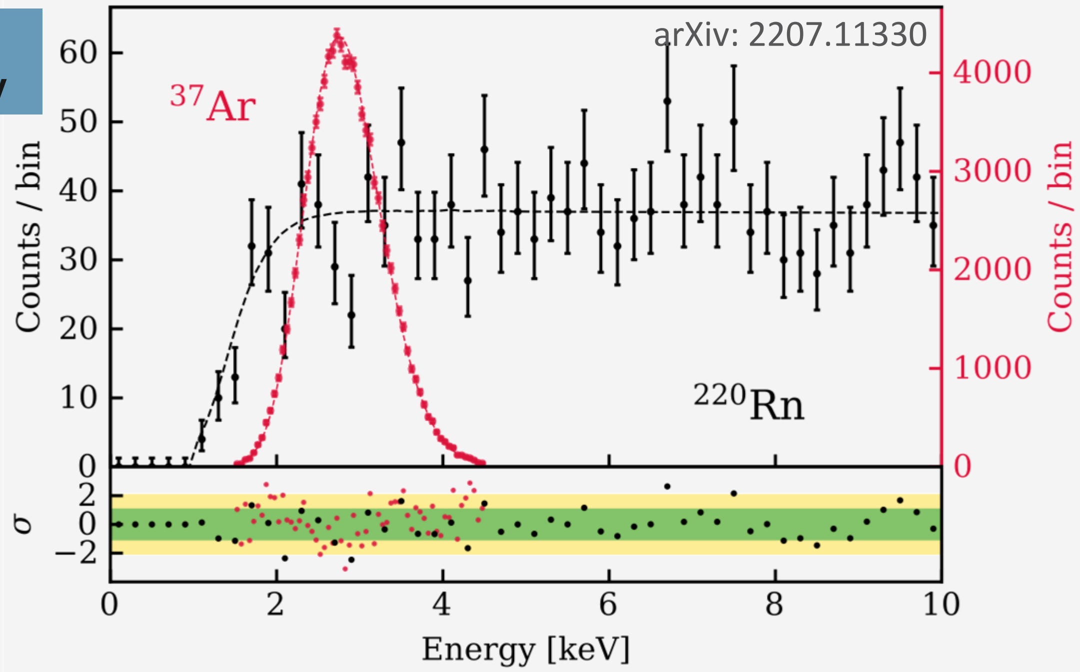
- **Detection efficiency** validated using simulation & data driven methods
- Using reconstruction chain to characterize efficiency: probability to reconstruct a peak
- Good agreement between two approaches





Calibration Sources

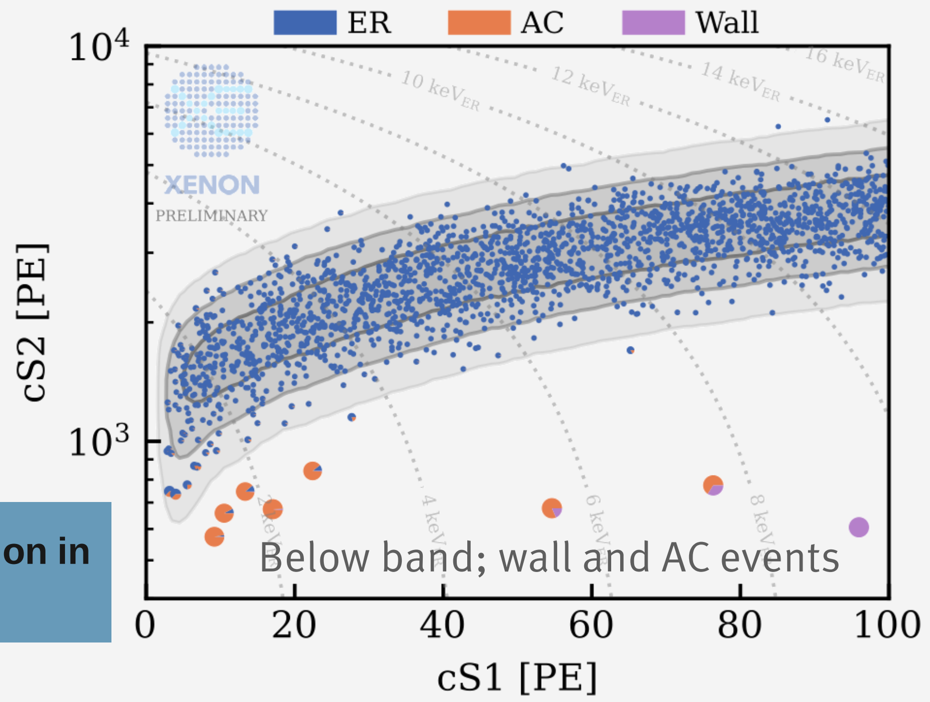
Rn and Ar calibration in reconstructed energy



Two **ER calibration sources at low energy**:

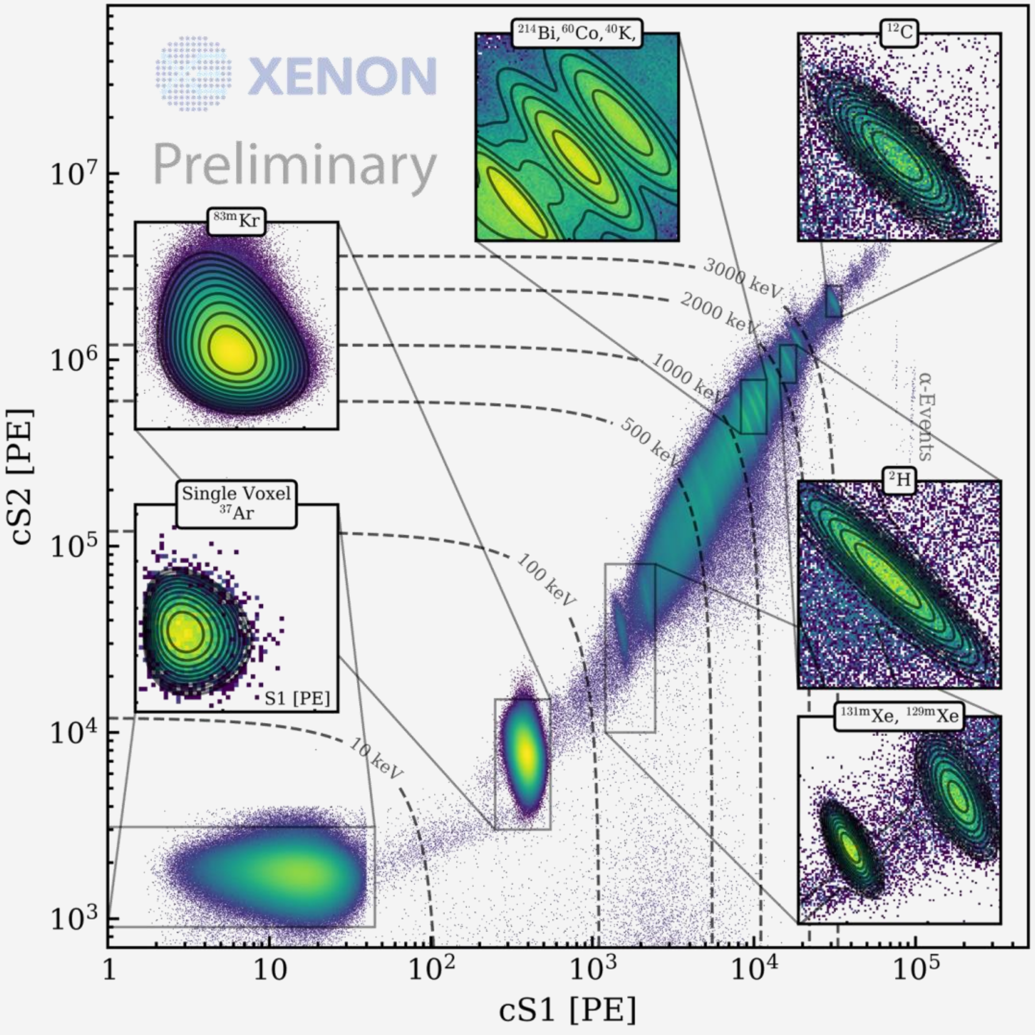
- **^{37}Ar**, which gives mono-energetic 2.82keV peak used to anchor the low-energy response and resolution models with high statistics
- **^{212}Pb** from ^{220}Rn gives a roughly flat β-spectrum to estimate cut acceptances and validates our threshold

Also used to define our blinding region, check detector response



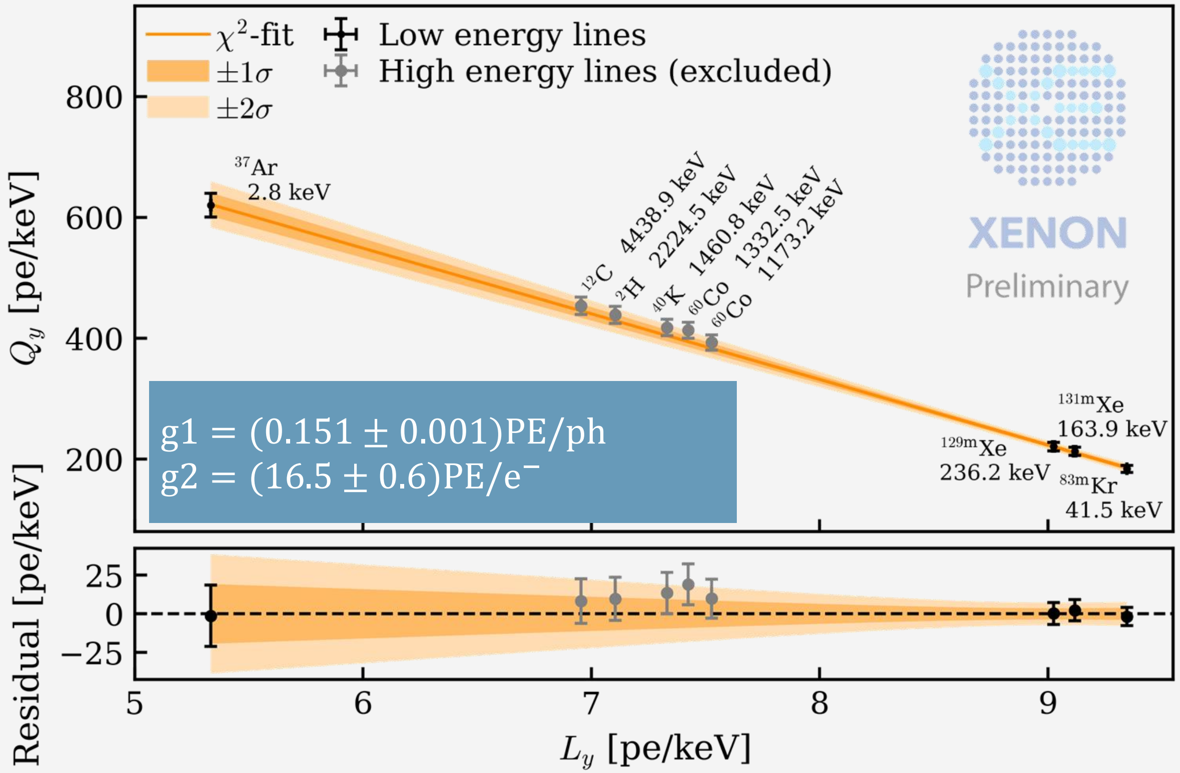
^{220}Rn calibration in cS1, cS2

Energy Reconstruction



- 4 low-energy calibration points: ^{37}Ar, ^{83m}Kr, ^{129m}Xe, ^{131m}Xe
- Observed and corrected bias from reconstruction between 1-2%
- Stability of the light and charge yield monitored over SR0 using the calibration sources, ^{222}Rn αs and material γs

$$E = W \times \left(\frac{\mathrm{cS1}}{\mathrm{g1}} + \frac{\mathrm{cS2}}{\mathrm{g2}} \right)$$



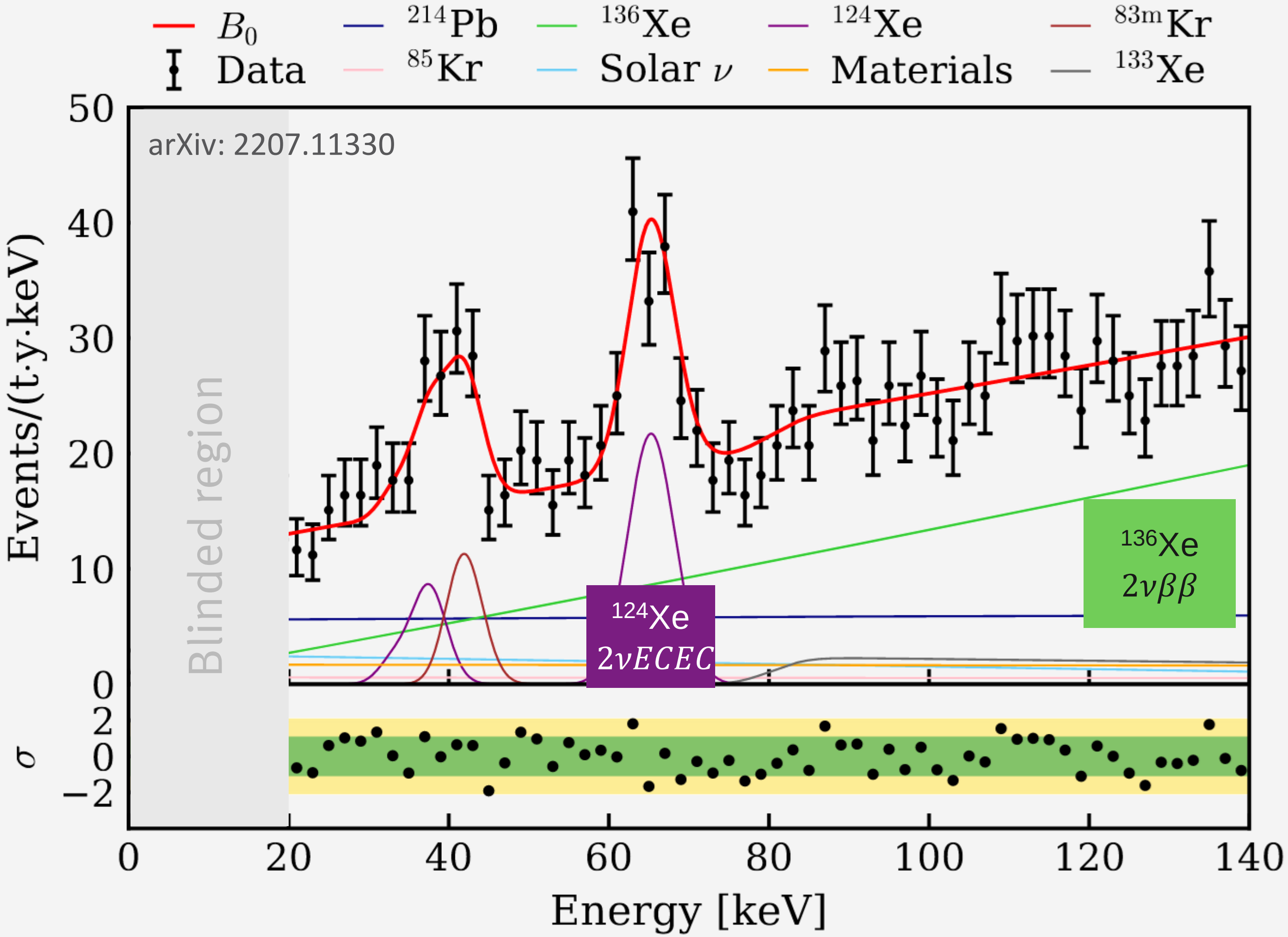
Electronic Recoil Spectrum

Initial estimates of background:

- External measurement
- Data-driven accidental coincidence model
- Verification in side-band

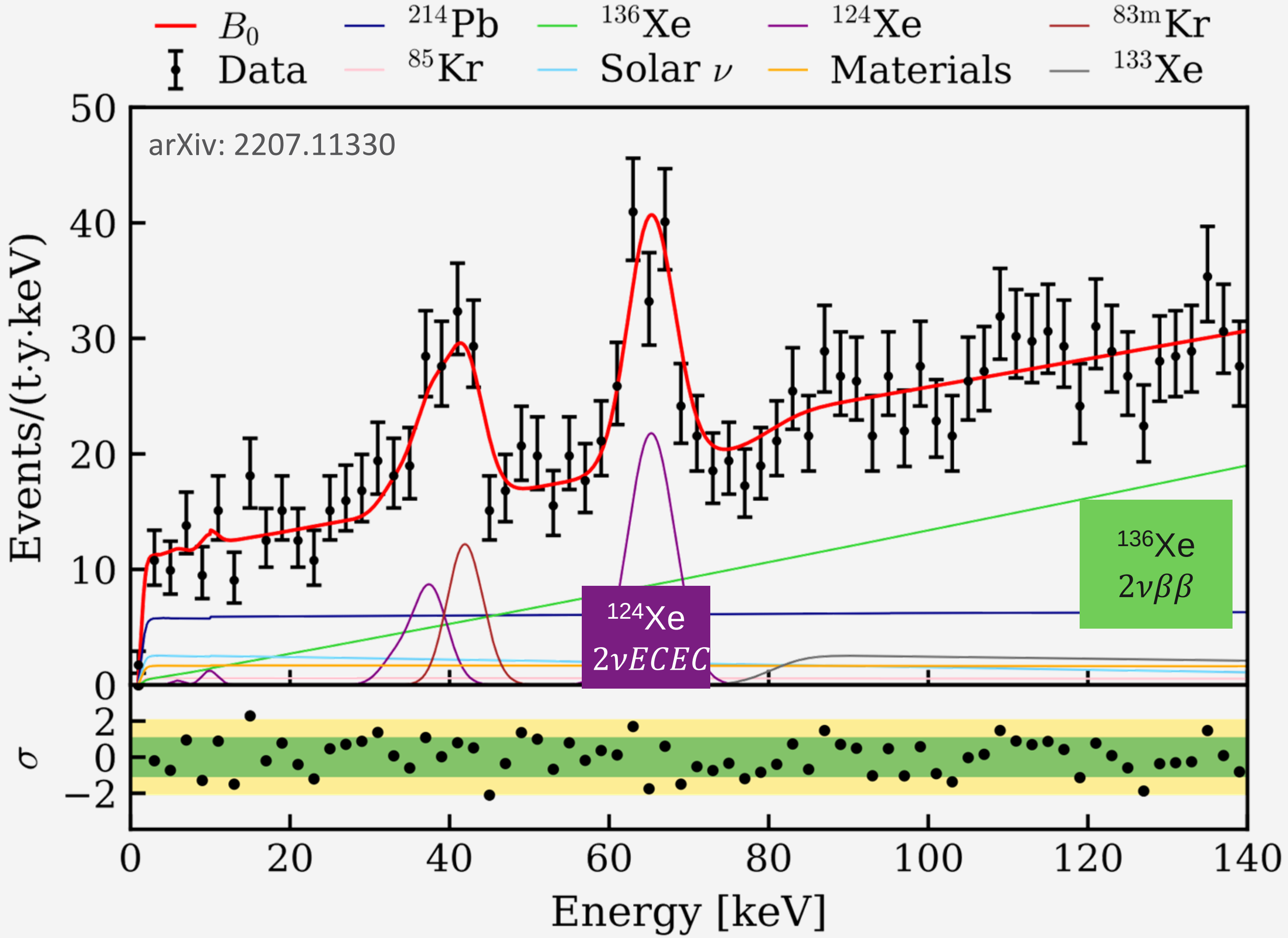
Double weak processes dominating the backgrounds

- $2\nu ECEC$ from ^{124}Xe
- $2\nu\beta\beta$ from ^{136}Xe



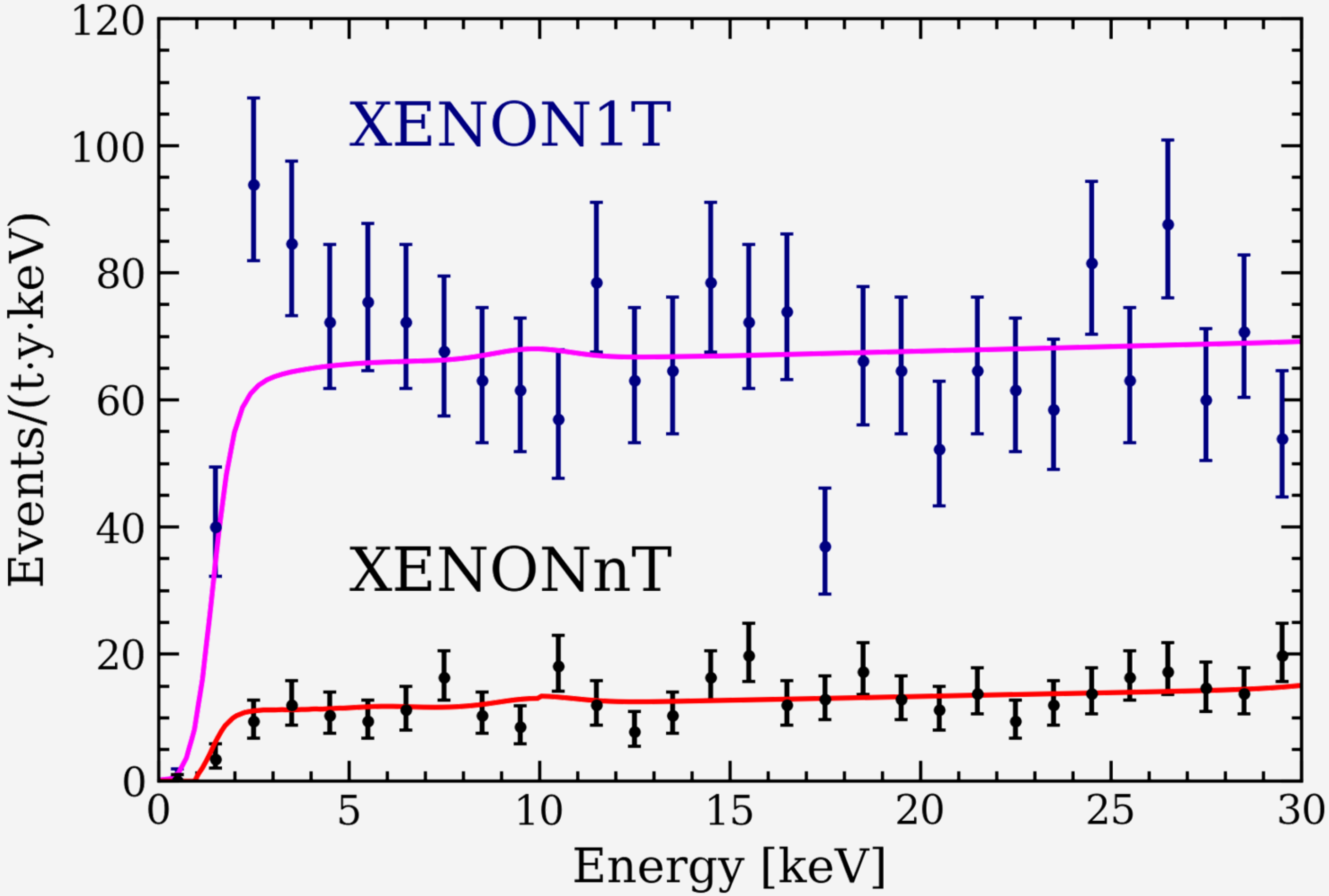
Electronic Recoil Spectrum

- **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) t
- **No excess observed** (arXiv:2207.11330)
- ^{3}**H** was likely observed **in XENON1T** and not BSM physics. Further time stability investigations of XENON1T in preparation.



XENON1T vs XENONnT

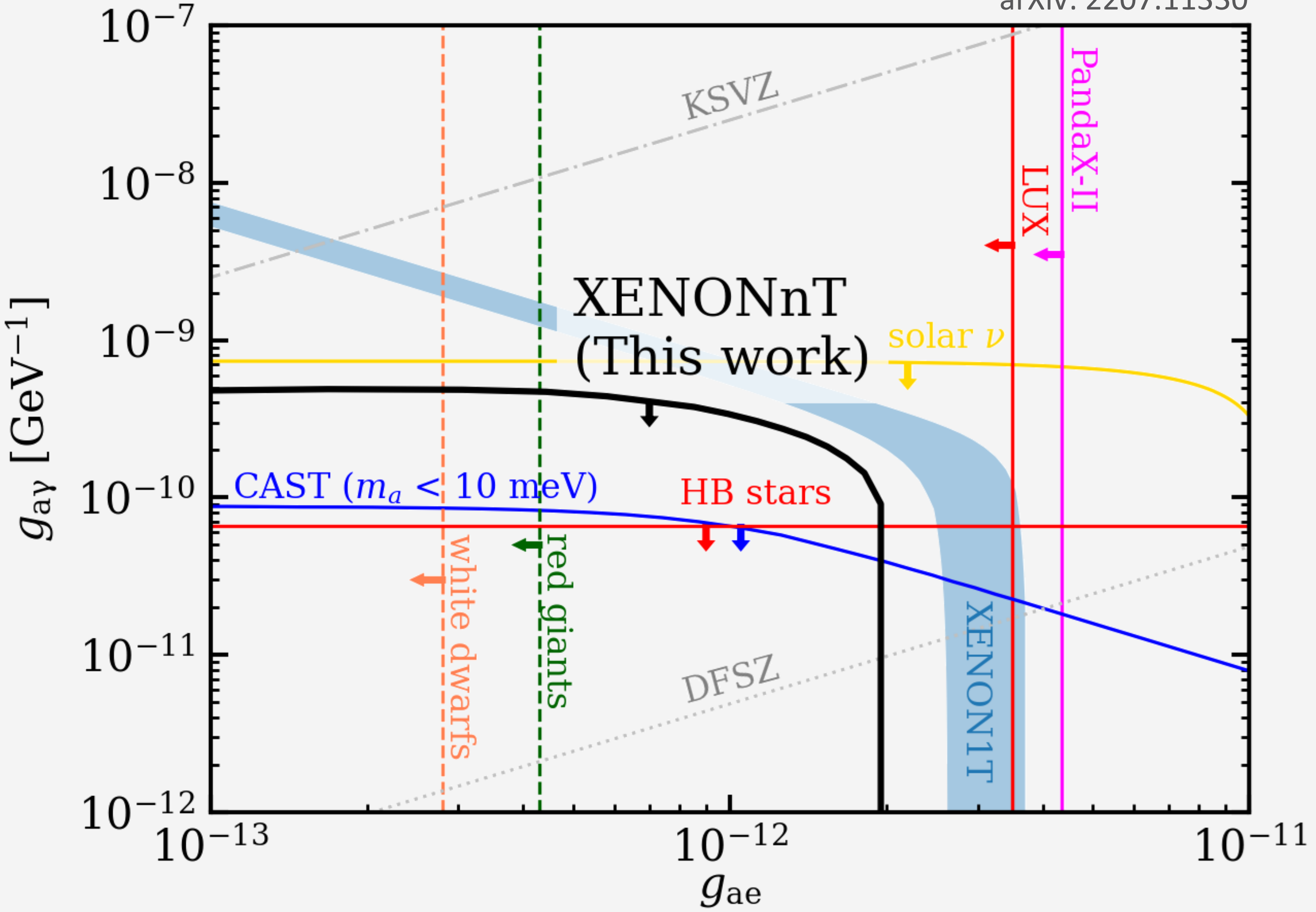
- **Extraordinary reduction of backgrounds**
- An **excess** of the XENON1T magnitude is **excluded** at 8.6 σ



Solar Axion Couplings

- Axion signal assumes axio-electric- and reverse Primakoff effect
- **Significantly improved constraints** on axion-gamma, axion-electron and axion-nucleon coupling
- Limit for signal from ^{57}Fe axions ‹ 20.4 ev/(t·y) (90% C.L.)

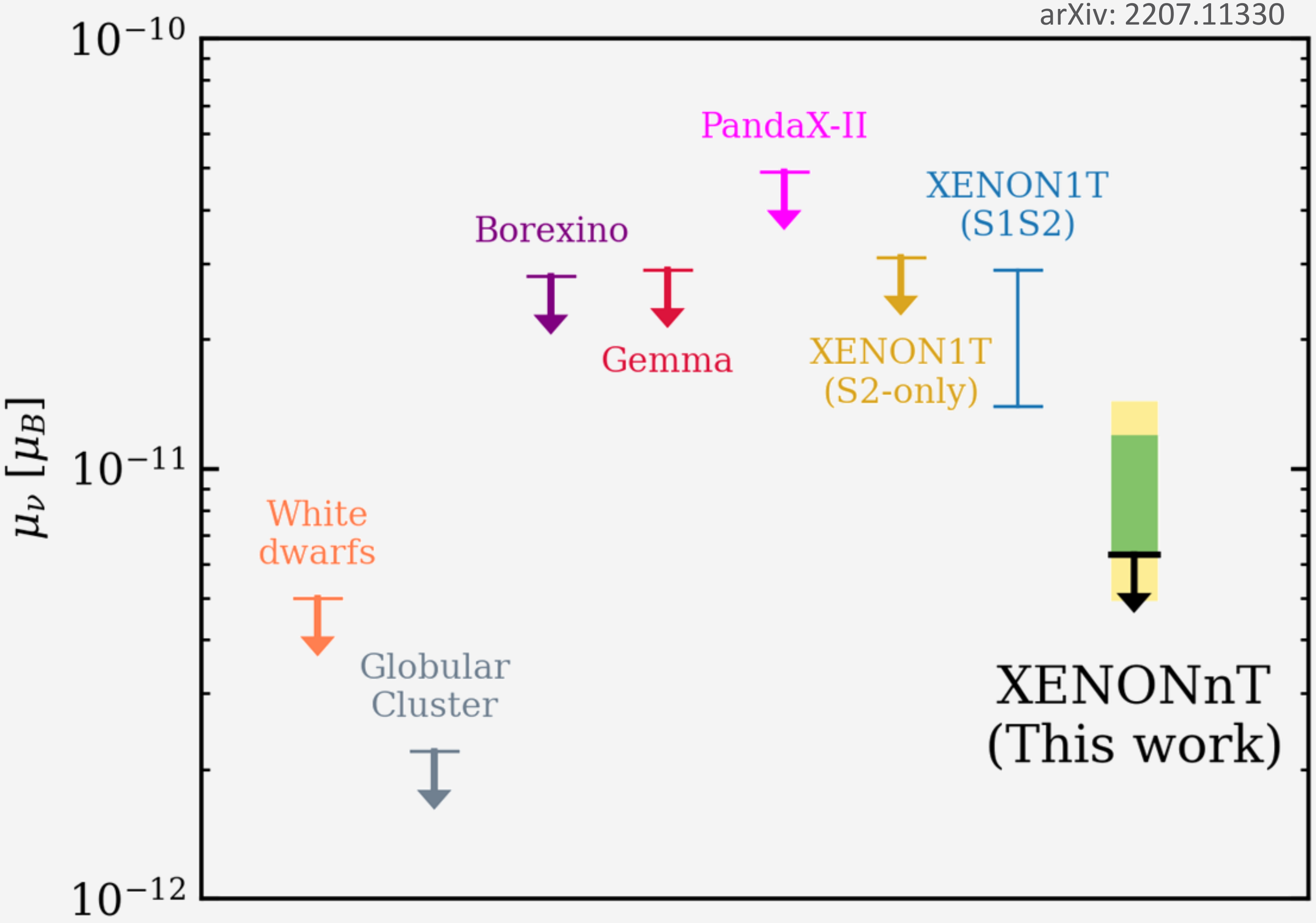
arXiv: 2207.11330



Solar Neutrino Magnetic Moment

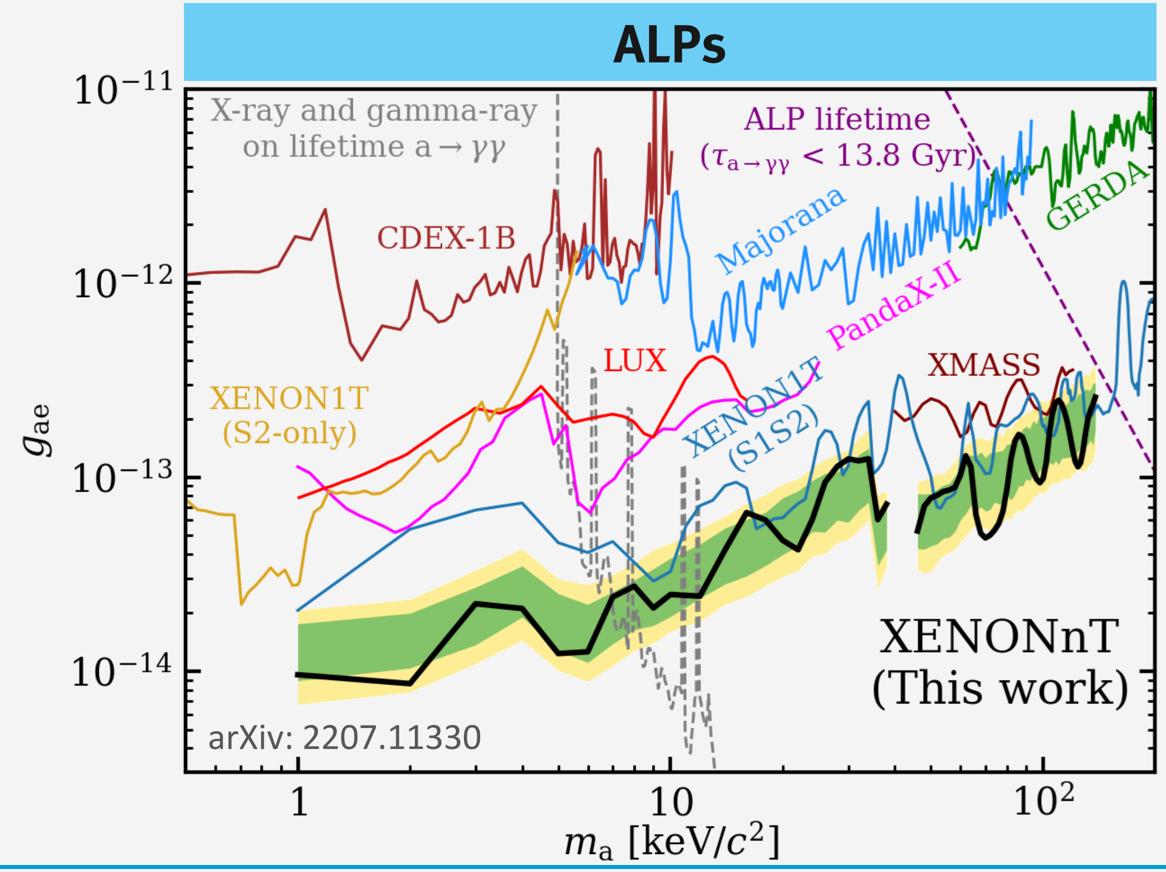
- Constraint on neutrino magnetic moment $\mu_\nu < 6.3 \times 10^{-12} \mu_B$
- **The most stringent limit in any direct detection experiment!**

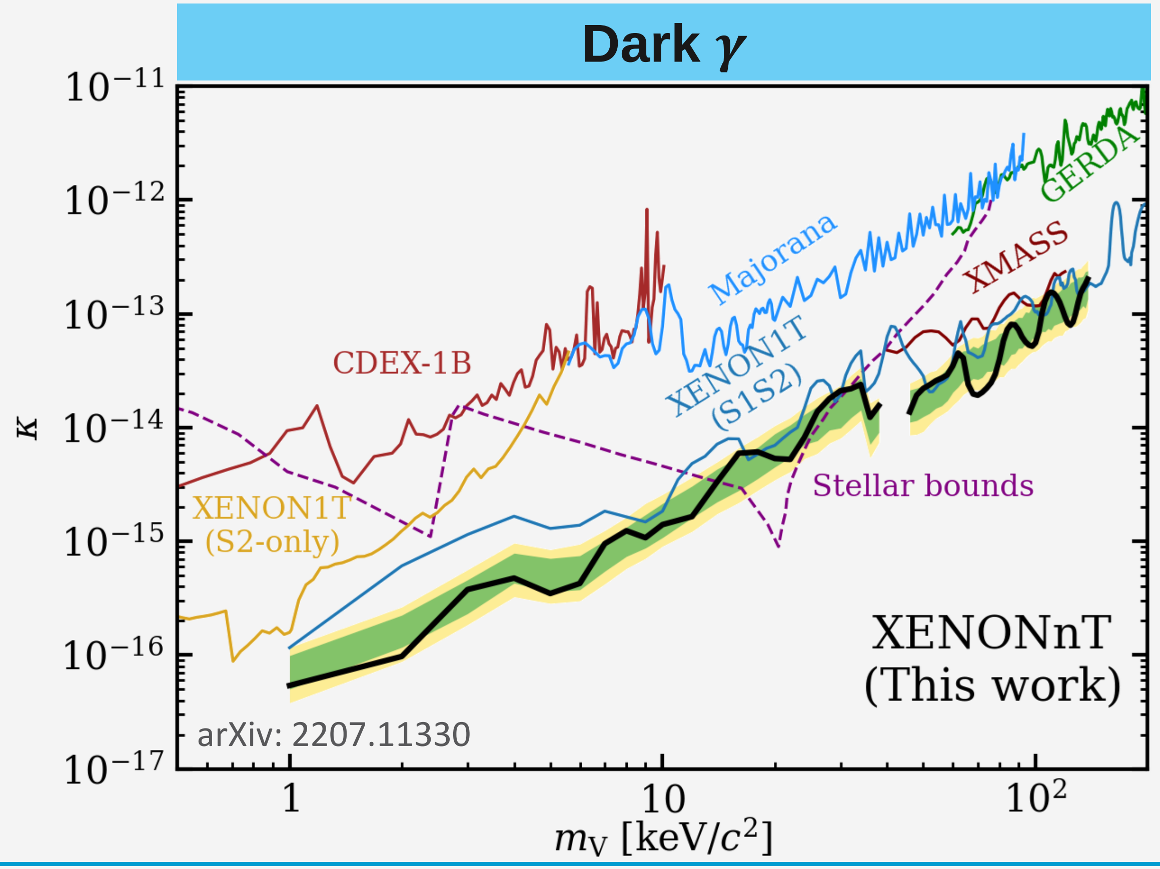
arXiv: 2207.11330



Bosonic Dark Matter

- Search for a peak from **axion-like particles or dark photons sees no significant excess**
- New stringent limits between 1-140 keV
- Since the ^{83m}Kr rate is left unconstrained, we do not place limits at 41.5 keV





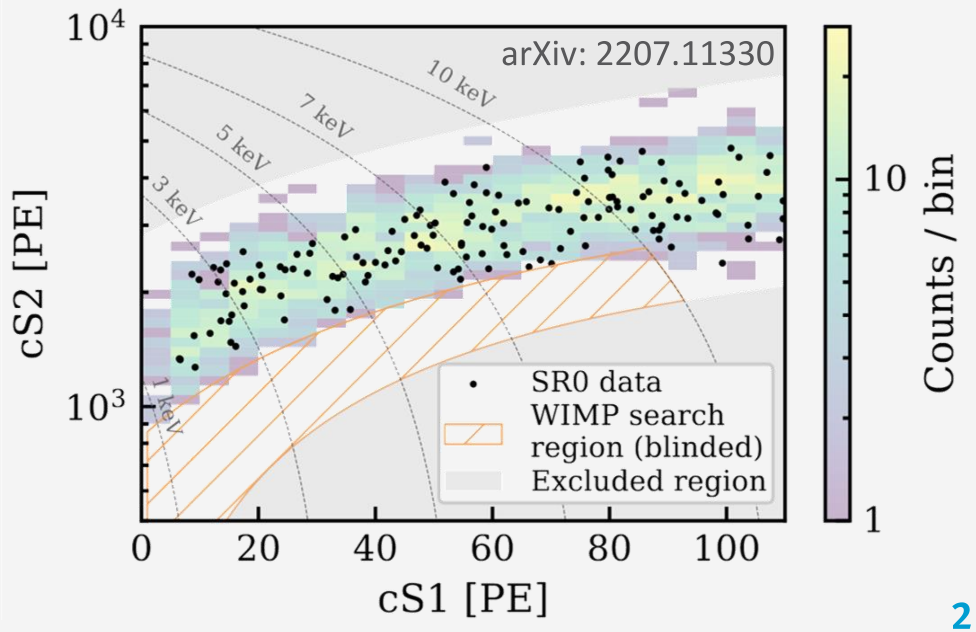
Summary

xenonexperiment.org
xenon_experiment
xenonexperiment

XENONnT SR0
- Electron lifetime of › 10 ms
- ~5× lower background w.r.t. 1T

First results
- Blinded electronic recoil (ER) search
- No excess observed -› limits on new physics (2207.11330)

Next step
- Unblind NR and WIMP analysis
- SR1 with factor 2× lower radon



Summary

XLZD

World leading researchers with more than twenty years of successfully building liquid xenon Dark Matter detectors unite forces in the XLZD Consortium
(white paper 2203.02309)

xenonexperiment.org
xenon_experiment
xenonexperiment

xlzd.org

XENON
Currently operating with 8.5 tonnes of liquid Xenon at Gran Sasso in Italy

LUX-ZEPLIN
Currently operating with 10 tonnes of liquid Xenon at SURF in South Dakota

DARWIN
Leading many R&D projects designing a future 50 tonnes liquid Xenon detector