First results from XENONnT

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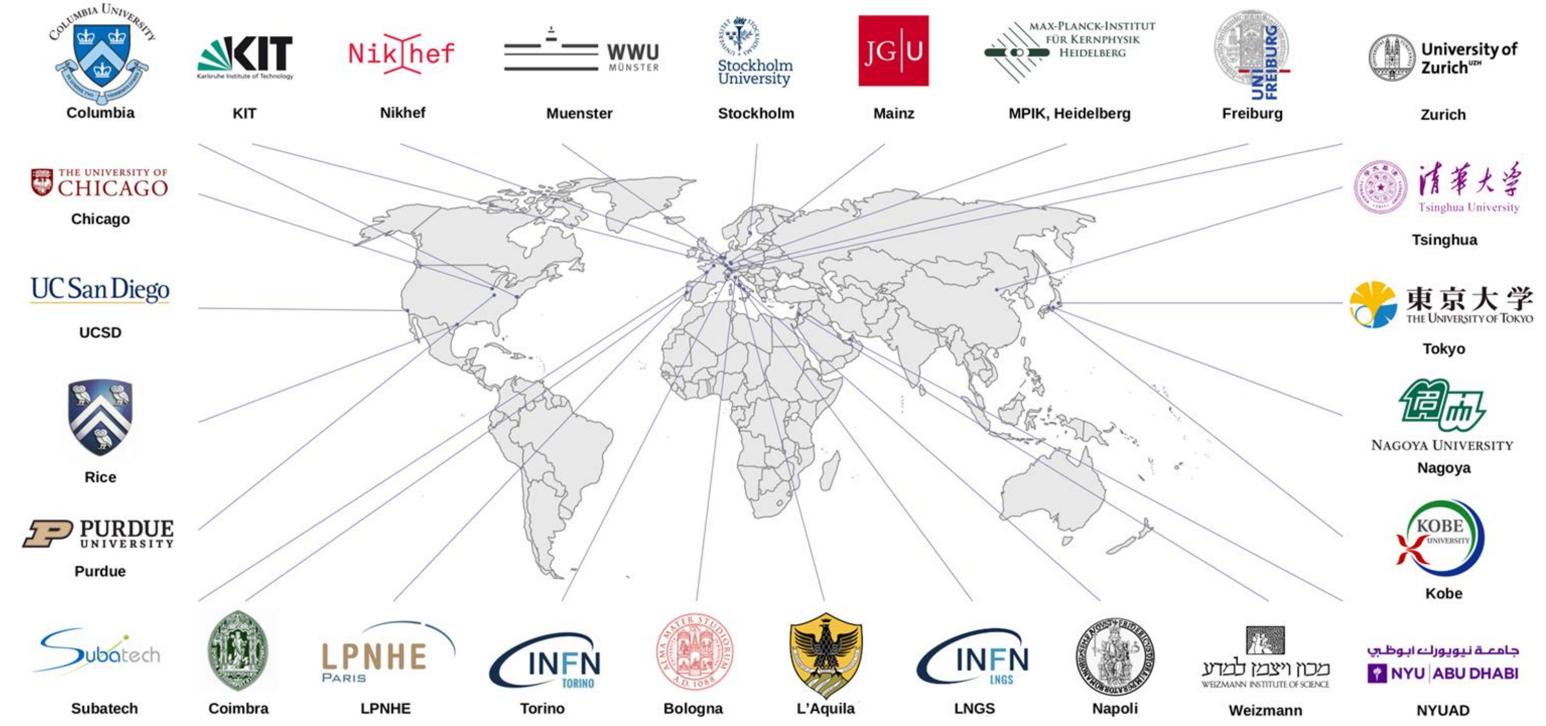
Patras Workshop 2022 JGU-Mainz

XENON Collaboration:



- 27 institutes
- 167 members

XENONnT experiment:

XENON1T → XENONnT upgrades:

- Larger TPC and inner cryostat
- New purification and distillation system
- Additional water Cherenkov neutron-veto
- New calibration systems and techniques
- New analysis software package STRAXEN and triggerless data acquisition
- Improved cleanliness and radiopurity

XENONnT experiment:

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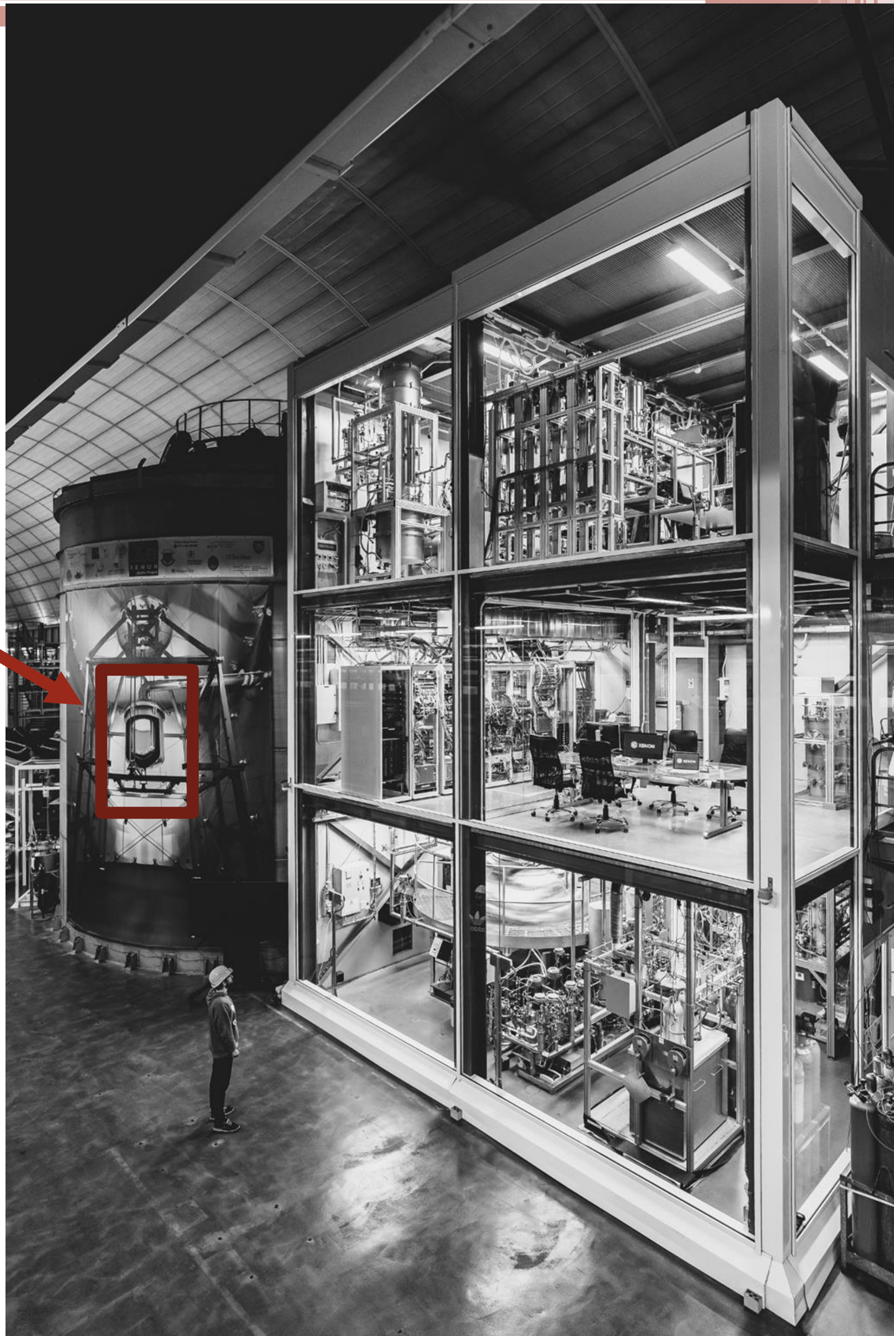
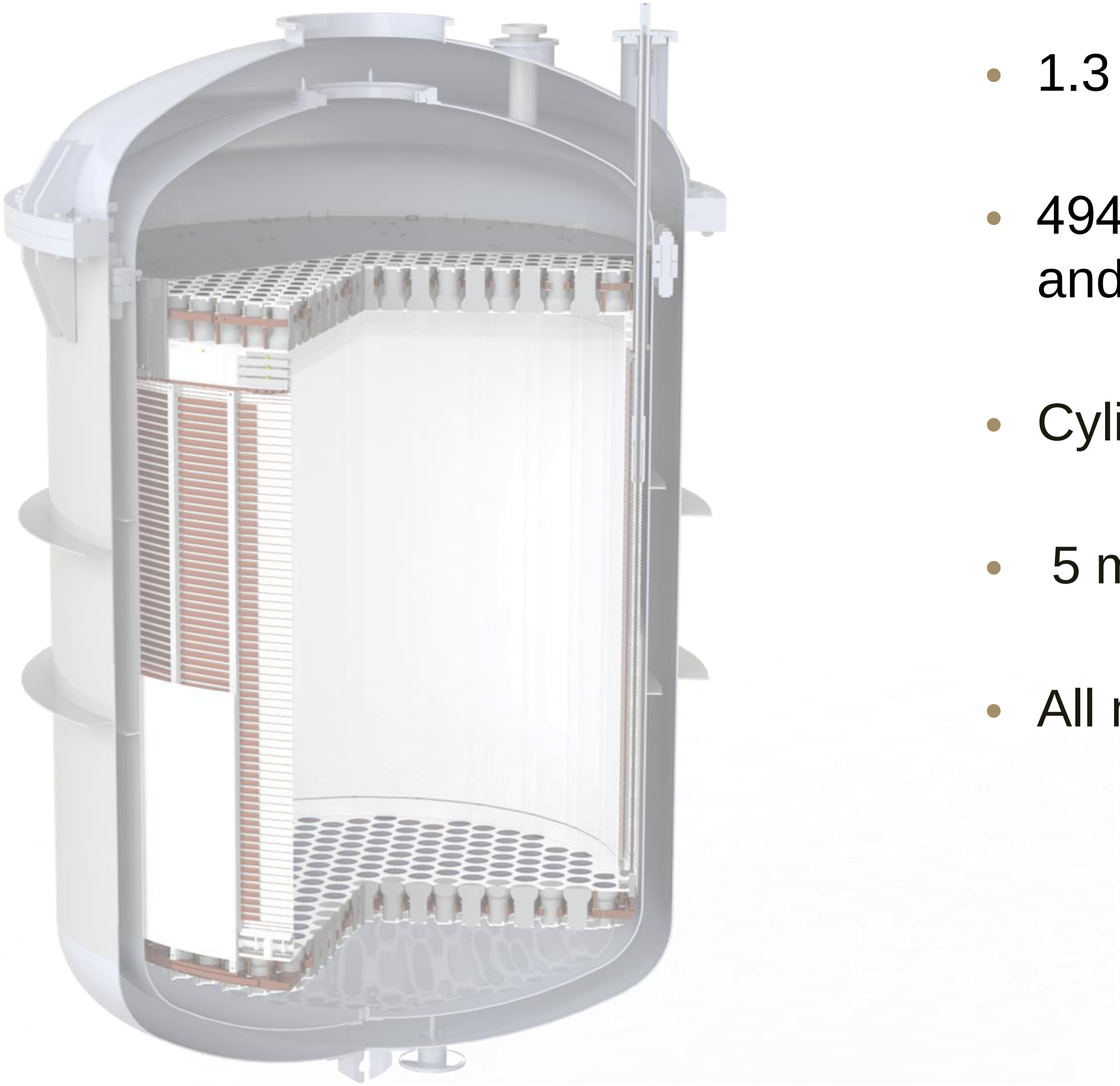
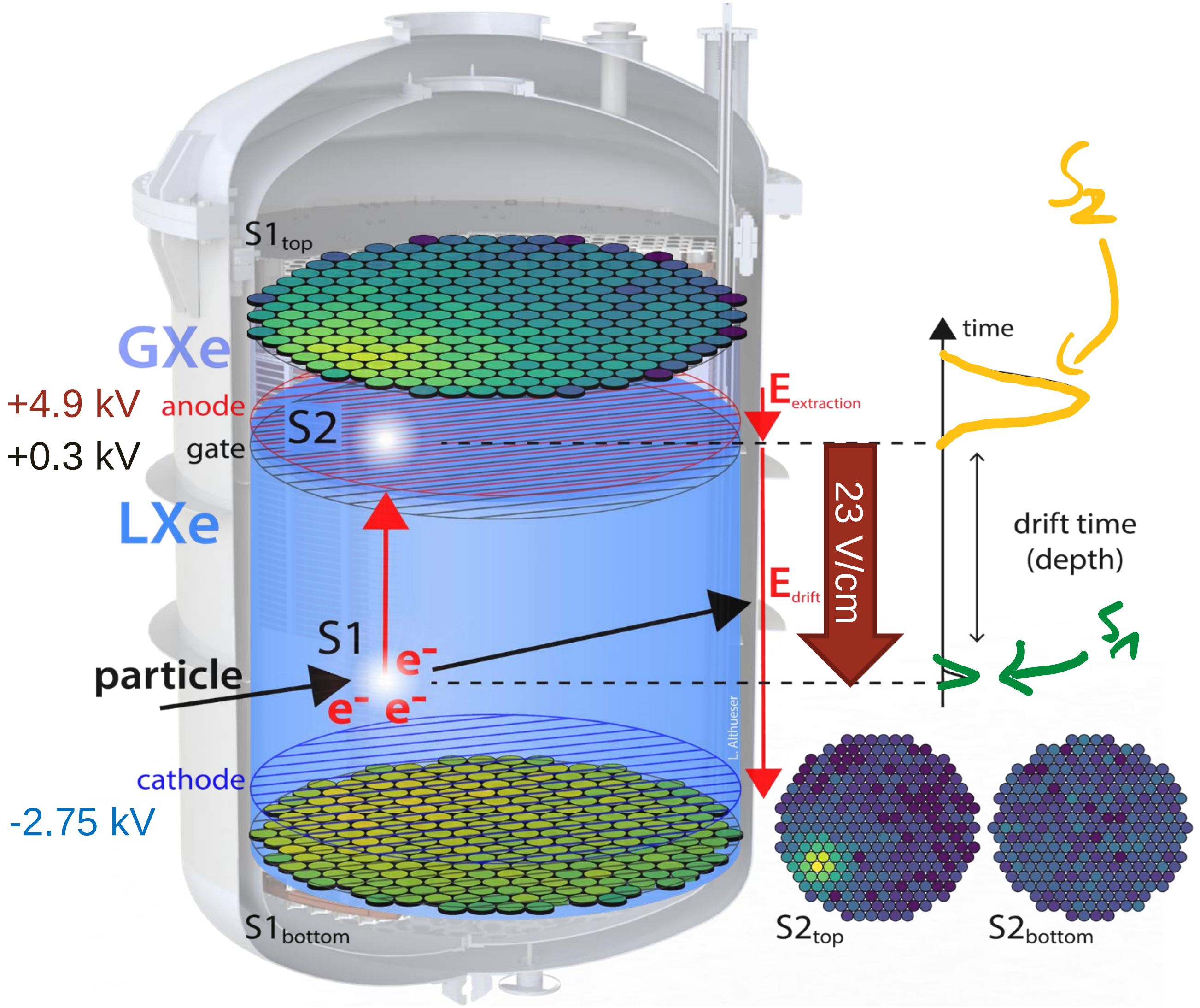


Liquid noble gas time projection chamber:



- 1.3 m x 1.5 m in height and diameter
- 494 3” PMTs (R11410-21) densely packed in a top and bottom array
- Cylinder walls made out of PTFE for high reflectivity
- 5 meshes to put electric fields and protect PMTs
- All materials carefully screened and selected

Liquid noble gas time projection chamber:



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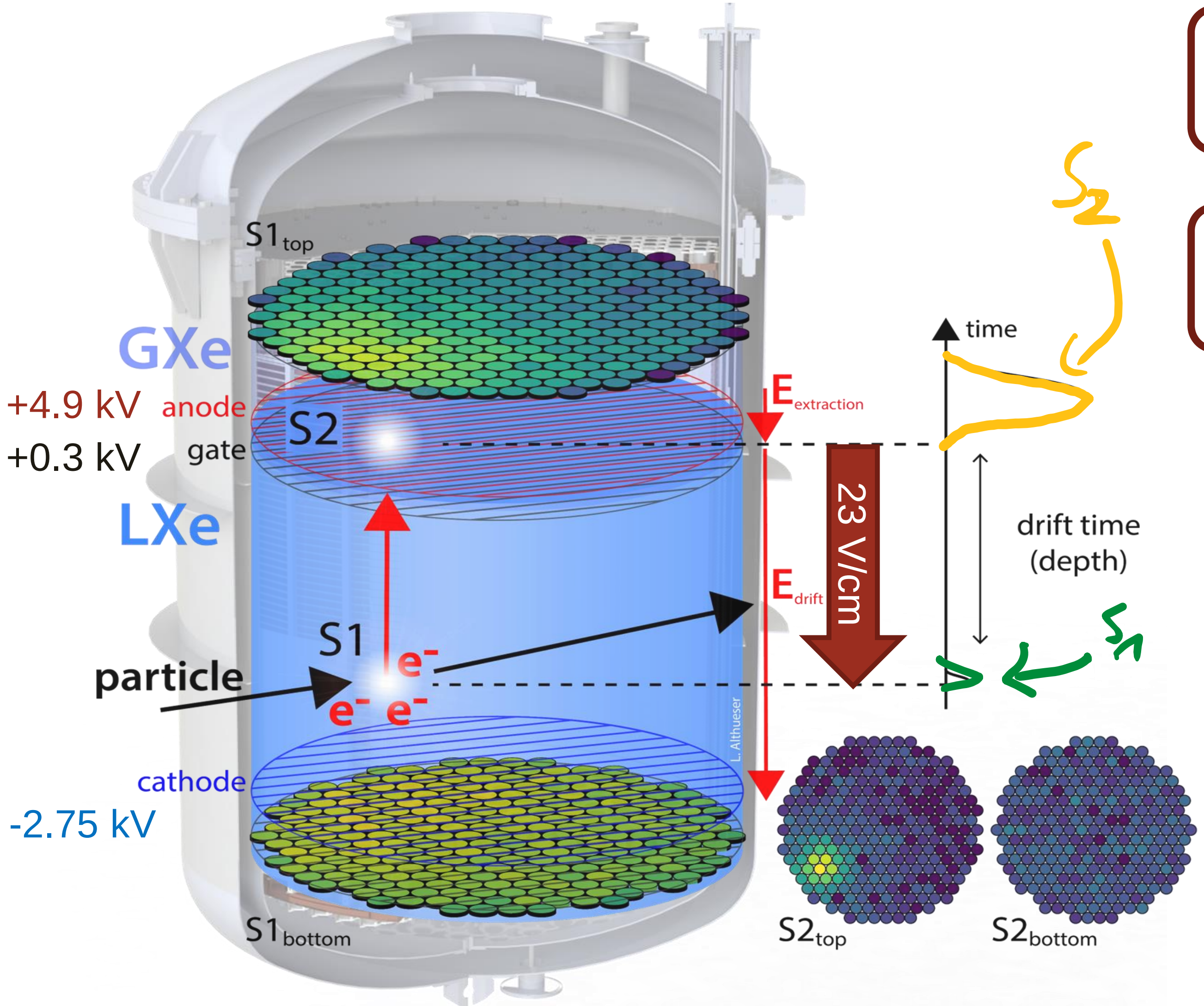
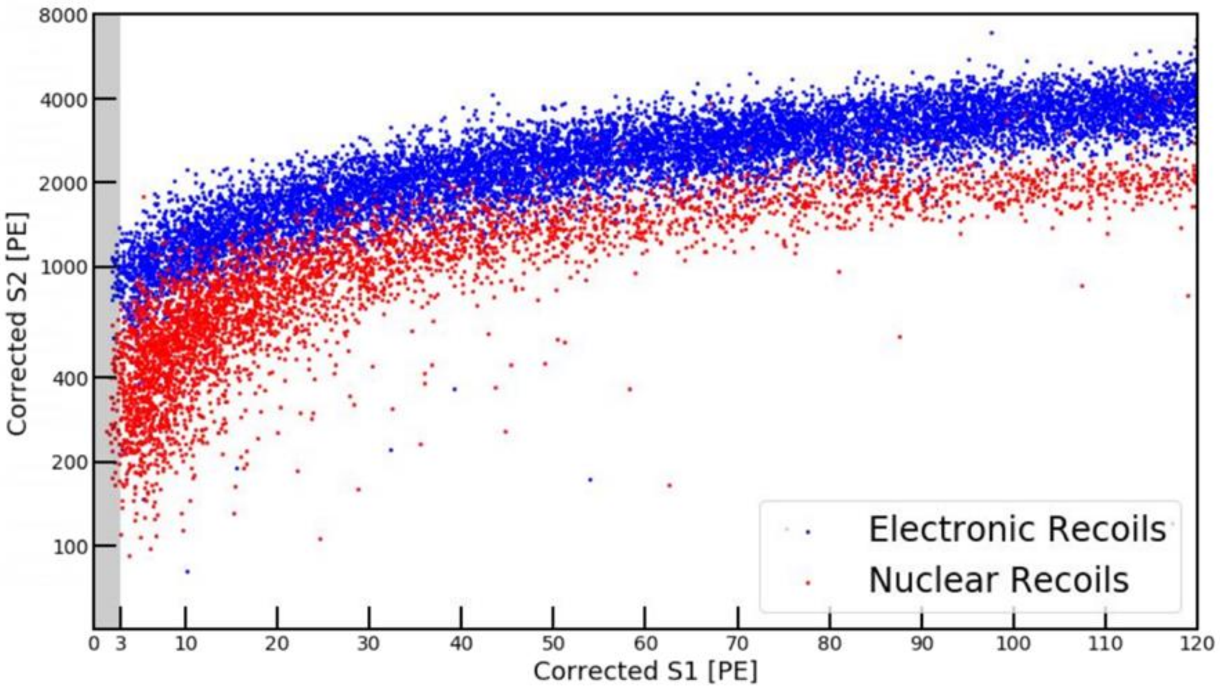


Electronic Recoils:

Nuclear Recoils:

Ratio: S2/S1 (ER) > S2/S1 (NR)



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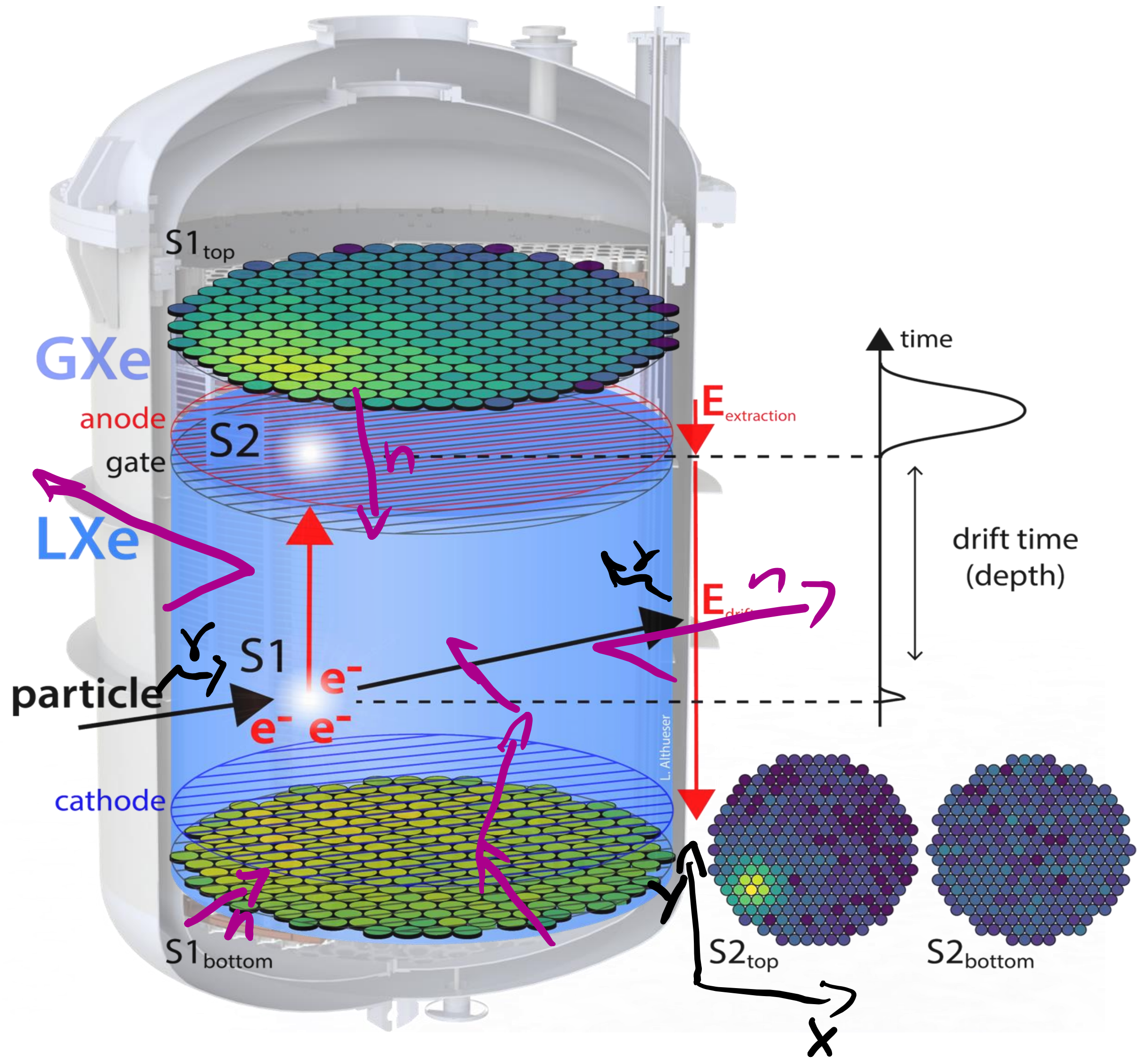
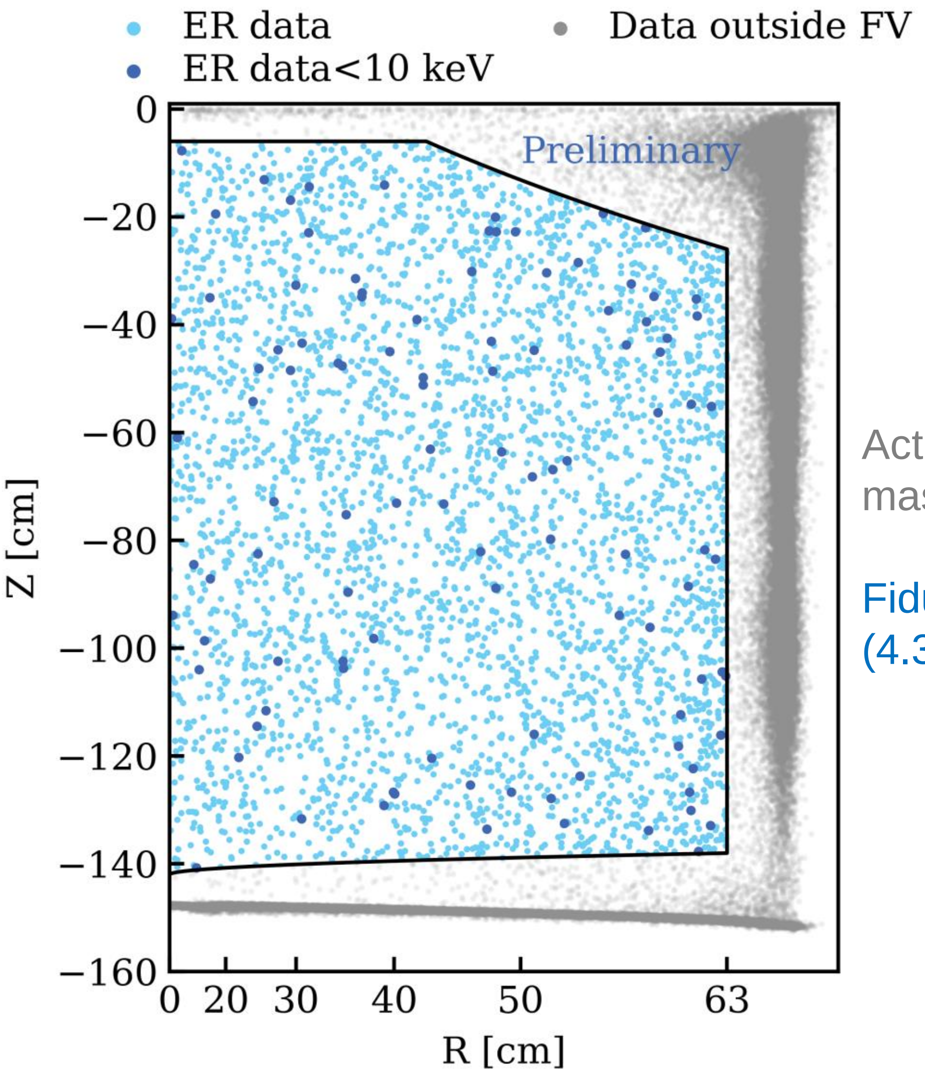
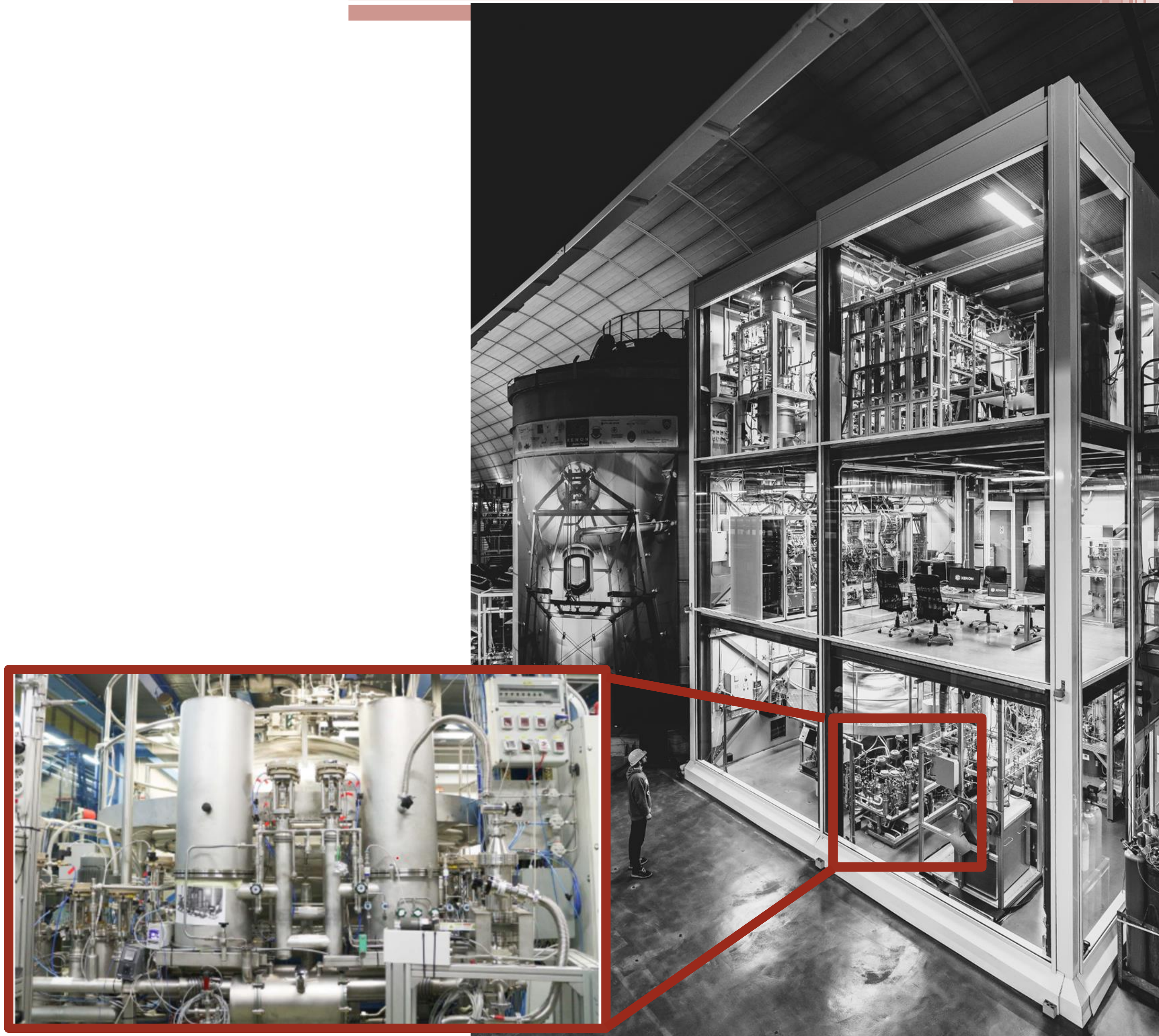




Active LXe mass: 5.9 t

Fiducial mass: (4.37 ± 0.14) t

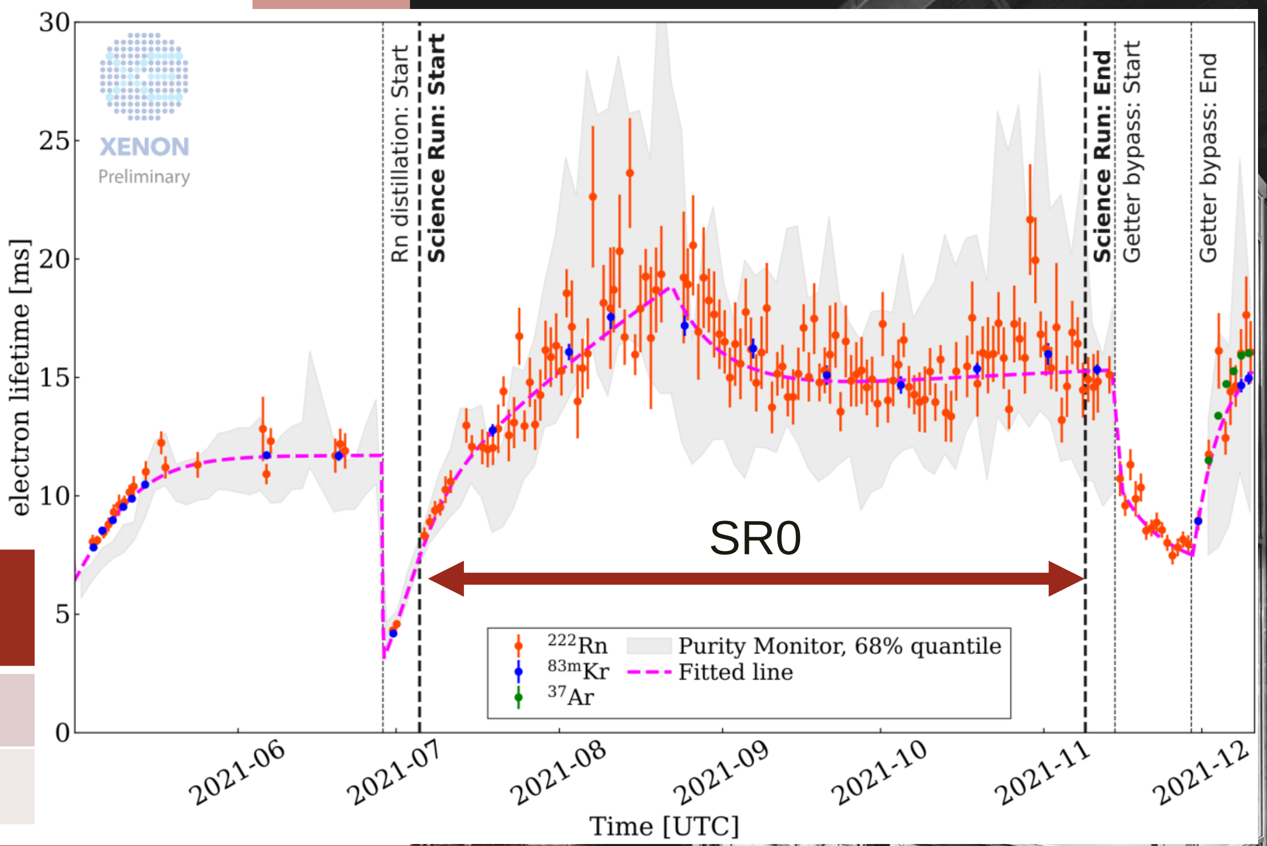
Liquid xenon purification

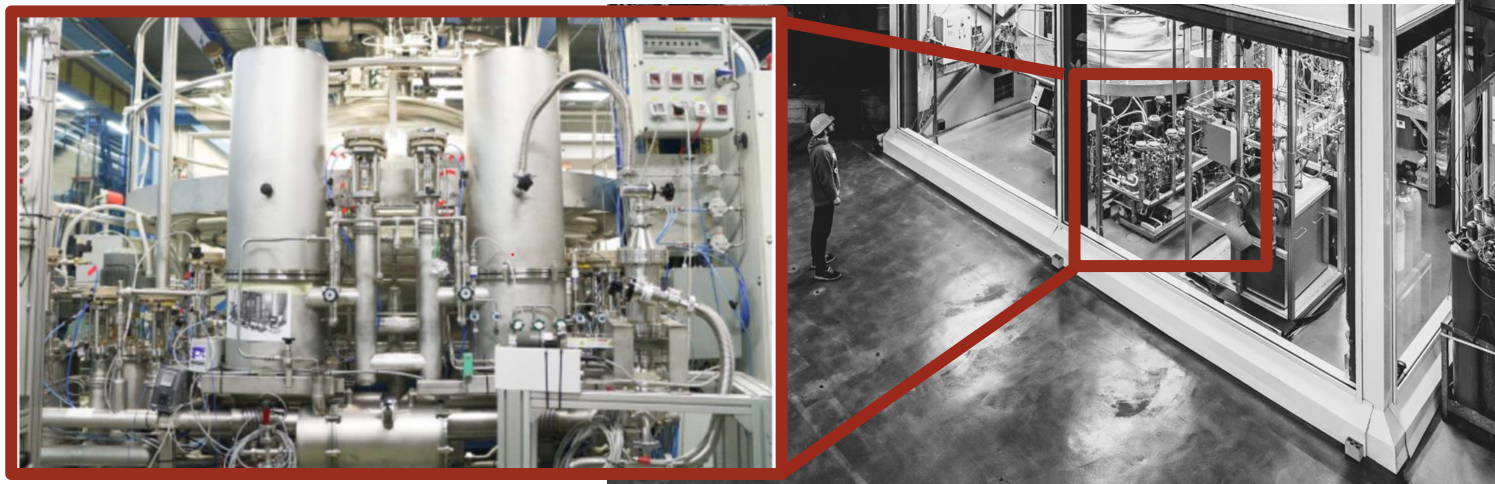


Liquid xenon purification

- Xenon purity important to drift electrons
- New liquid purification technique:
  - Replaceable filter units
  - Low radon emanation
  - 2 liters **liquid /** minute → 18 h for entire volume

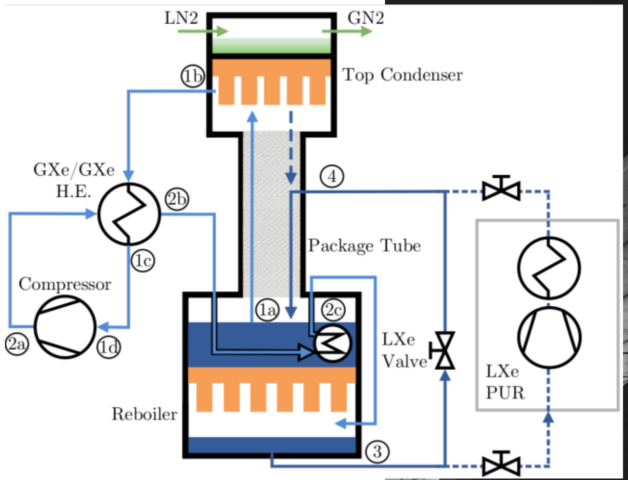
	Full drift time:	Electron lifetime:	Electron survival (@full drift length):
1T	0.67 ms	0.65 ms	30 %
nT	2.2 ms	>10 ms	86 % @ 15 ms

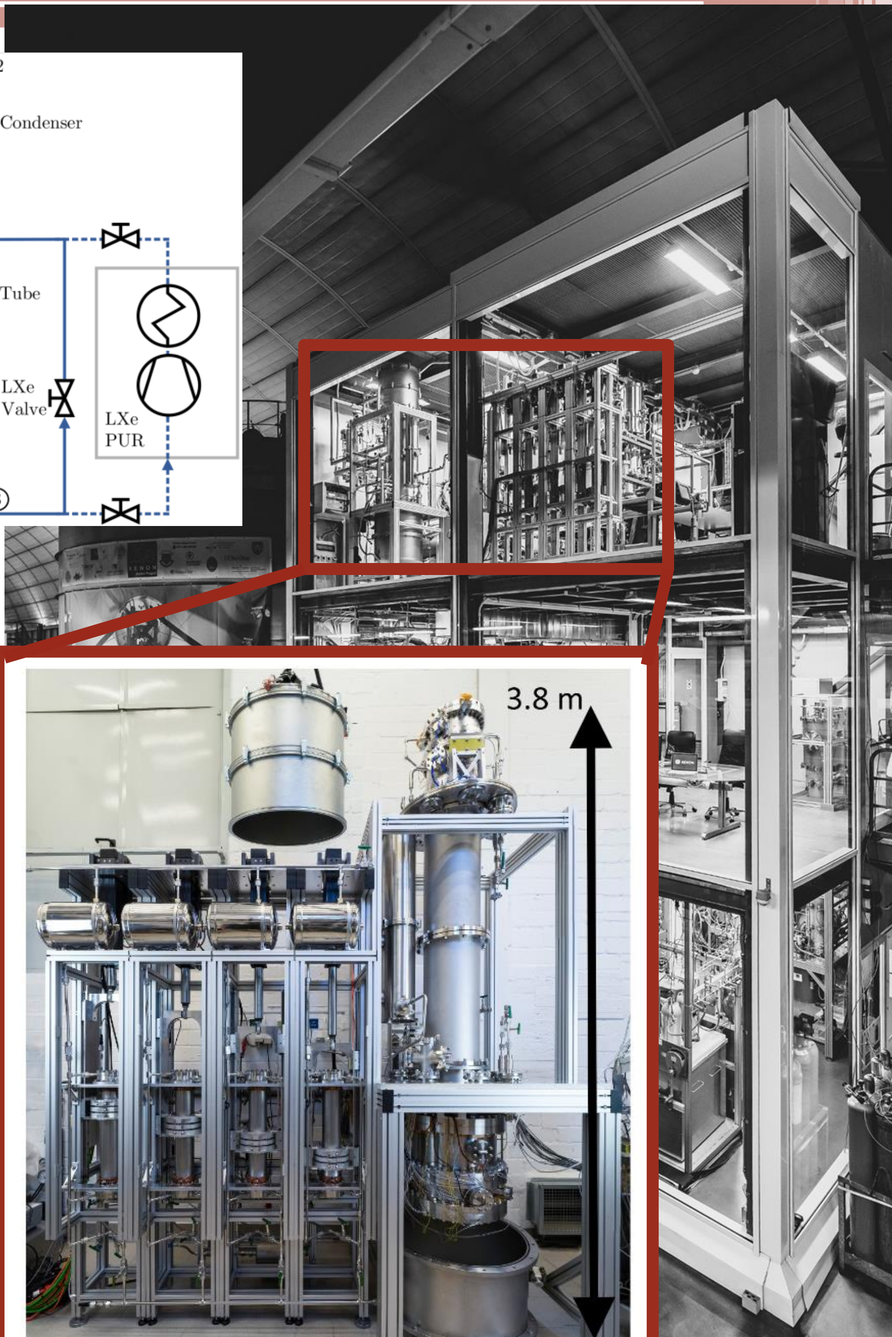




G. Plante, E. Aprile, J. Howlett, Y. Zhang
arXiv:2205.07336 [physics.ins-det]

Radon distillation:

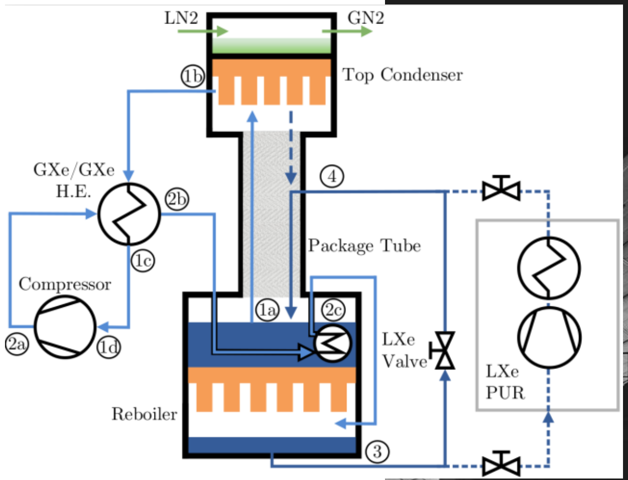


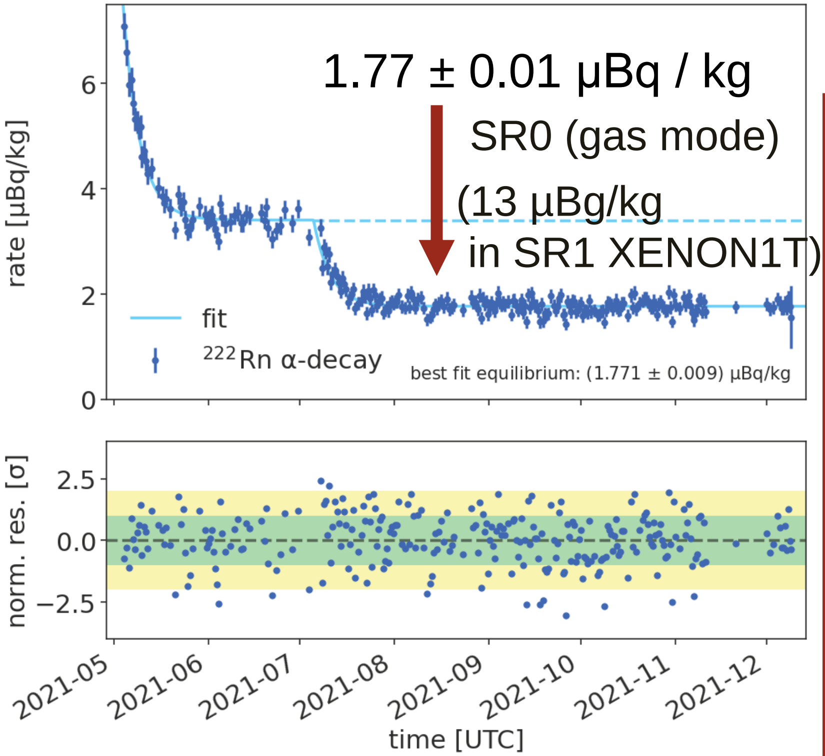


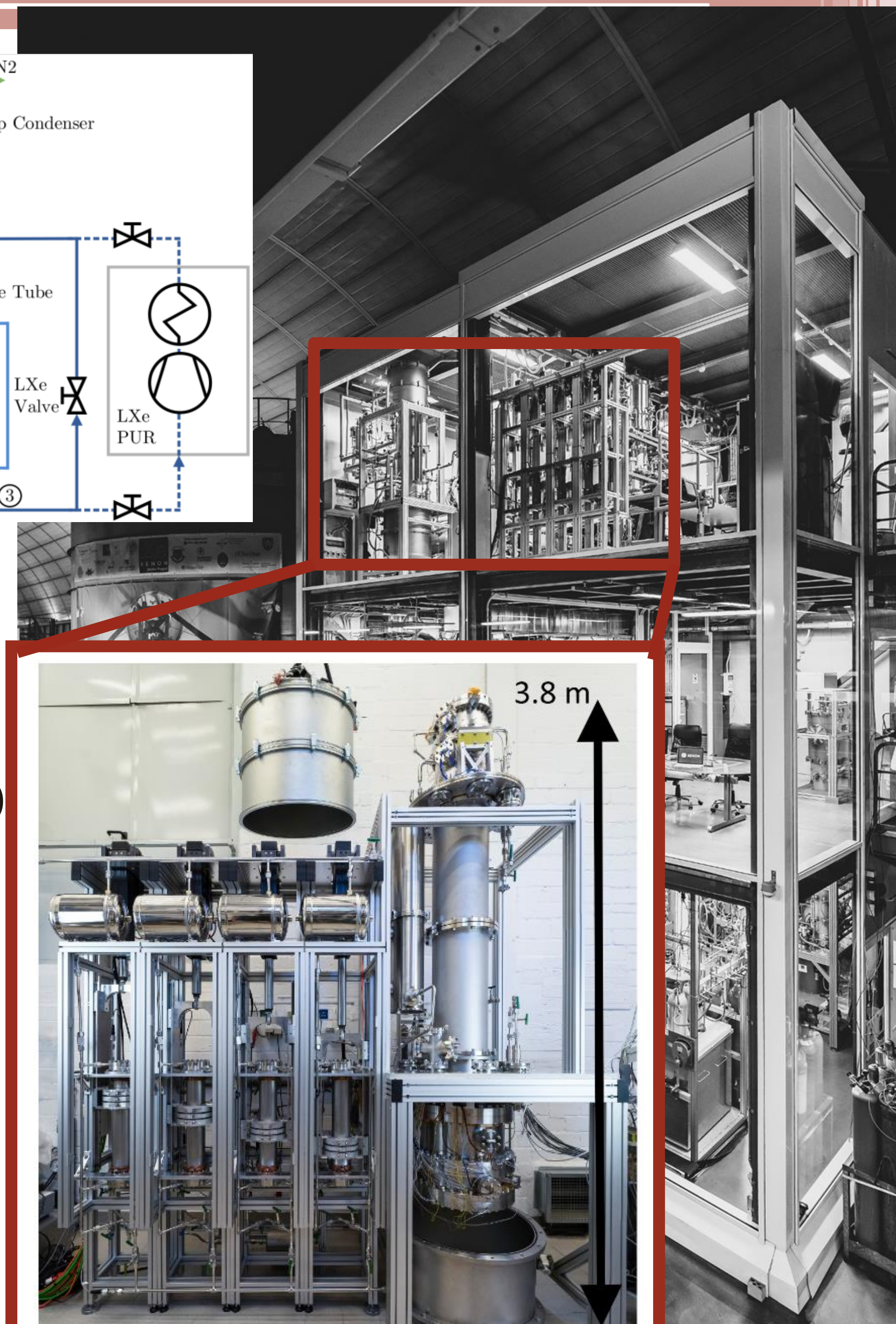
Radon distillation:

- Rn222 dominant background in 1T/nT
- Added radon distillation together with radon free magnetic-piston pumps
- In SR0 operated in gas-mode
- Preliminary:

  We are able to reach values < 1 µBq/kg for SR1 in liquid + gas mode



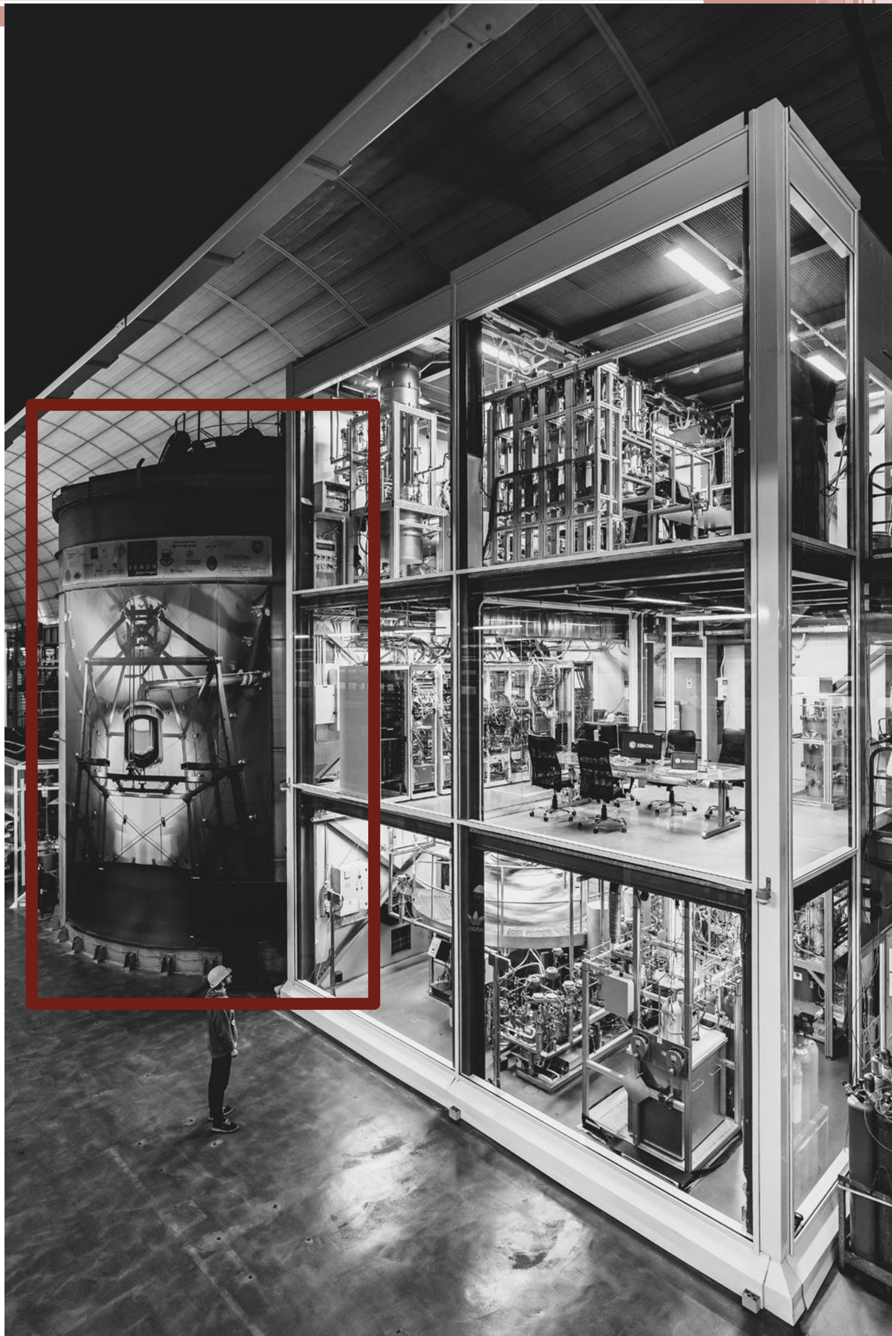




M. Murra, D. Schulte, C. Huhmann, C. Weinheimer

arXiv:2205.11492 [physics.ins-det]

XENONnT neutron-veto:



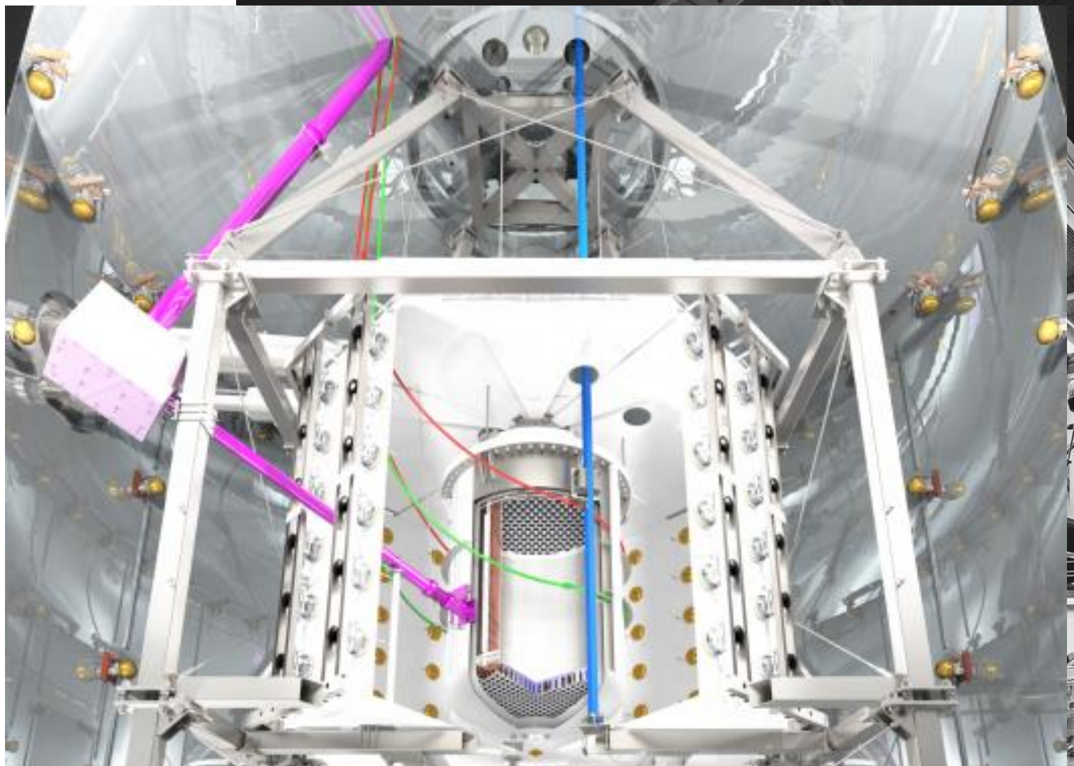
XENONnT neutron-veto:

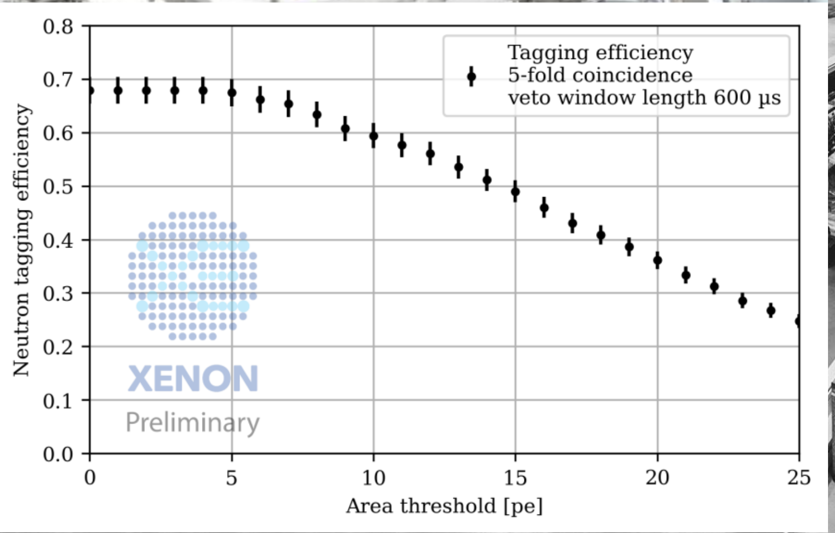
- Added new water Cherenkov neutron-veto into muon-veto water tank
- 120 8” PMTs are watching the TPC cryostat
- Highly reflective ePTFE and ultra-pure water to maximize light collection efficiency
- Using tagged neutrons to calibrate the NR response as well as the neutron-veto tagging efficiency.

→ Preliminary tagging efficiency of $(67.5 \pm 2.9)\%$

- After SR0 loading with 0.2 % of $(Gd_2(SO_4)_3 \times 8(H_2O))$

→ Expected tagging efficiency ~87 %



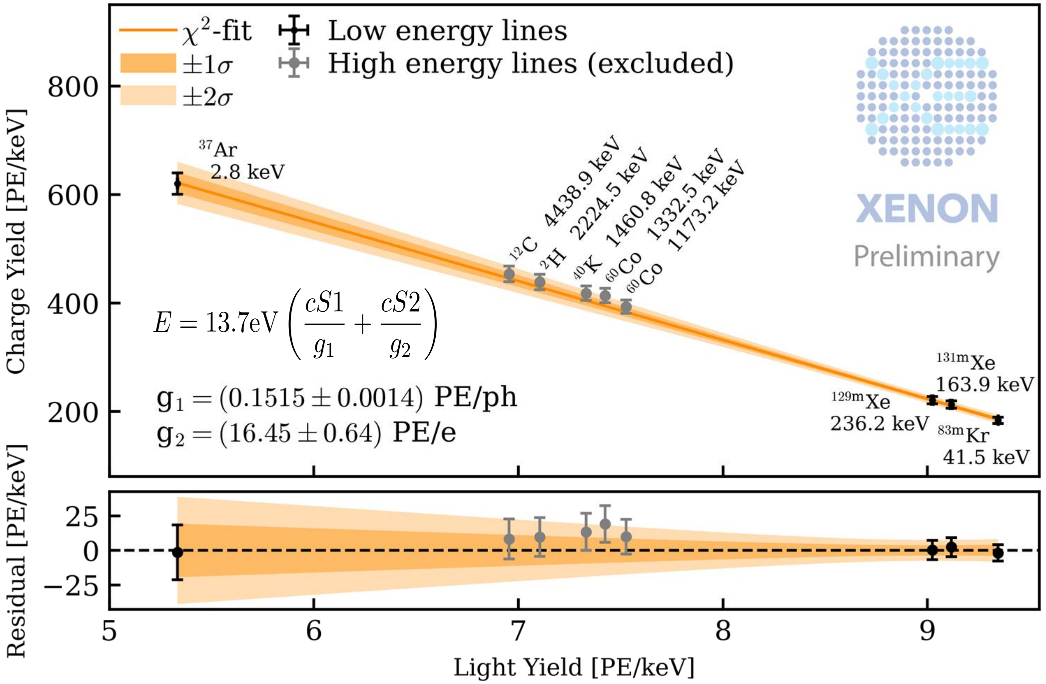


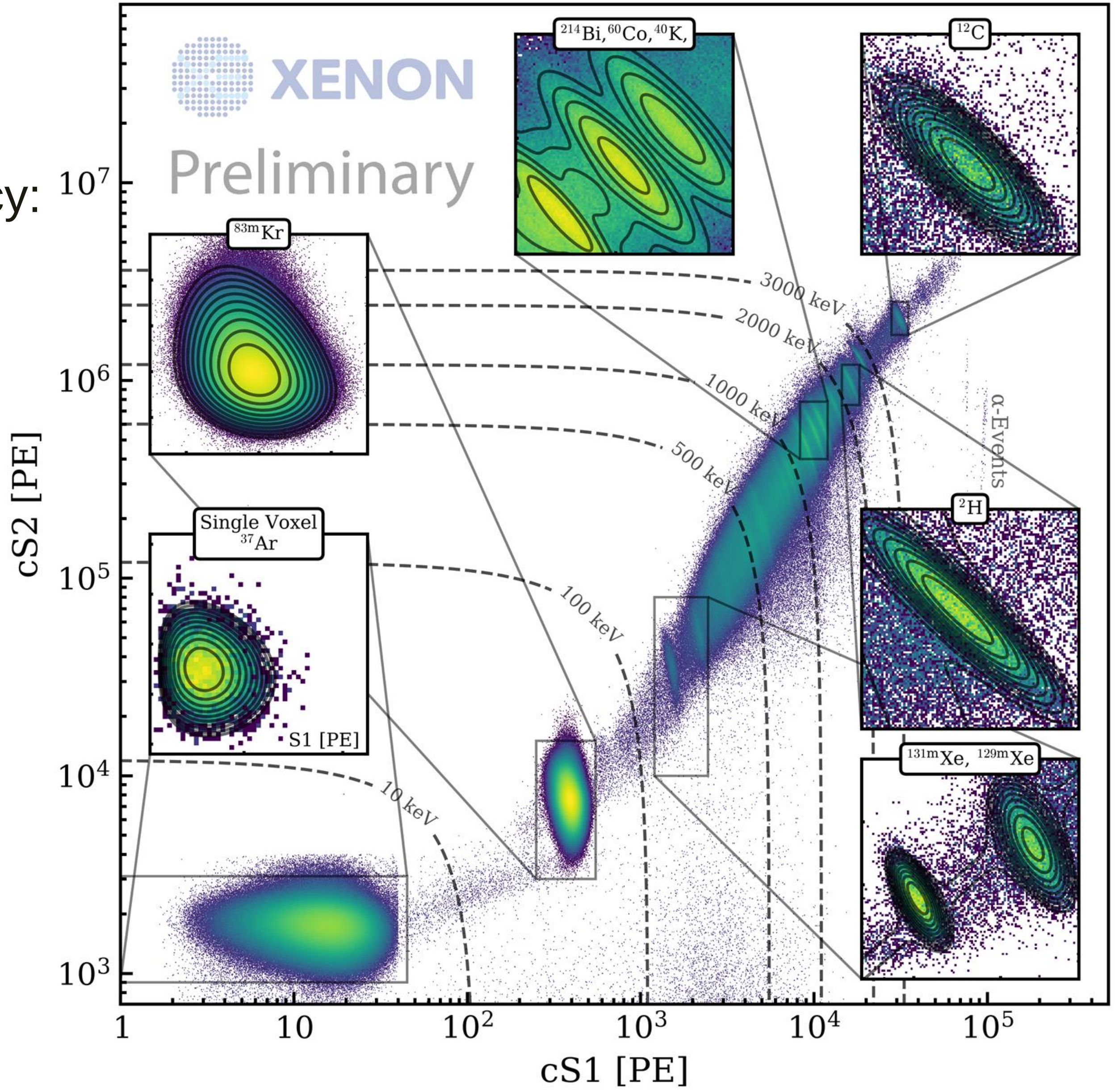
E. Aprile *et al*
arXiv:2007.08796
JCAP11(2020)031

Calibration of XENONnT:

Calibration of XENONnT:

- Weekly PMT calibrations via LEDs
- Calibration of detector response and efficiency:
  - Use internal source: ^{37}Ar, ^{83m}Kr, ^{129m}Xe, ^{131m}Xe
  - Bias is used as systematic uncertainties
- Bi-weekly ^{83m}Kr and materials background **α** and **γ** are used for stability monitoring
- ^{83m}Kr used to validate drift field



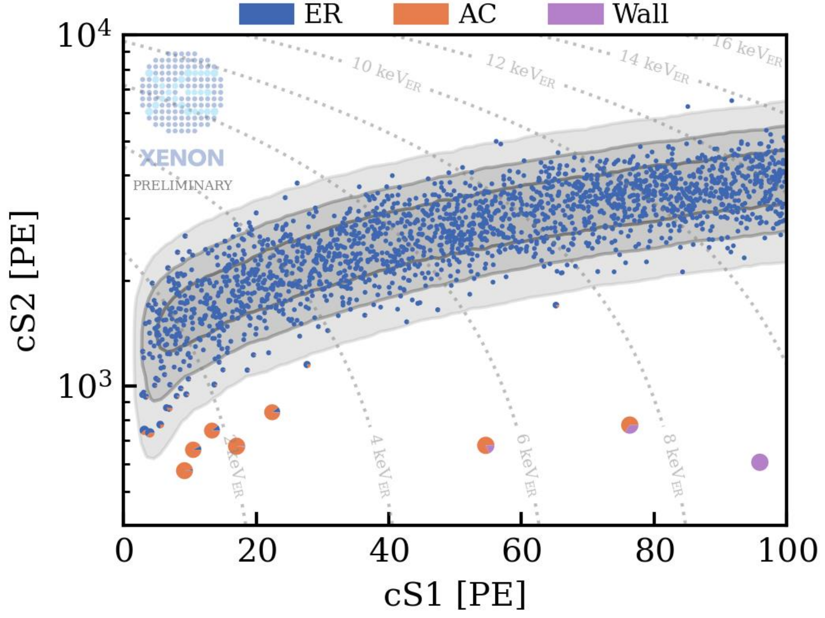


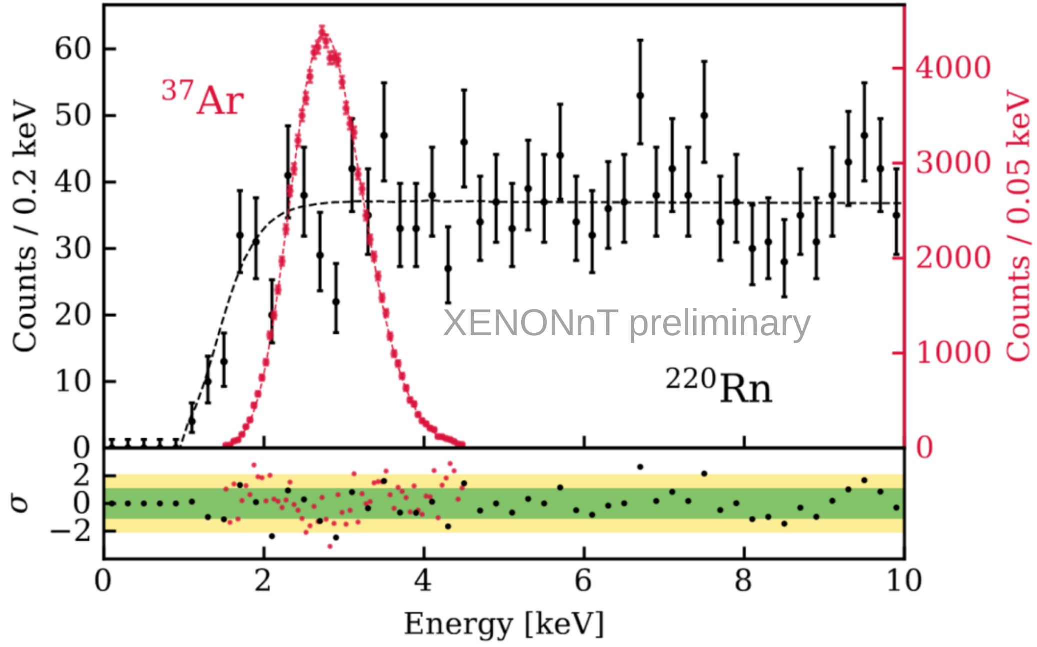
Calibration of XENONnT:

- Calibration of ER response using ^{220}Rn
  - Gives approximately flat spectrum
  - Used to validate cut acceptances and detector threshold
- Detector performance at low energies using ^{37}Ar
  - Mono-energetic line @2.8 keV
  - Allows to study performance with high resolution, due to high statistics
  - Source was produced @TRIGA Mainz

See also the poster by C. Hils

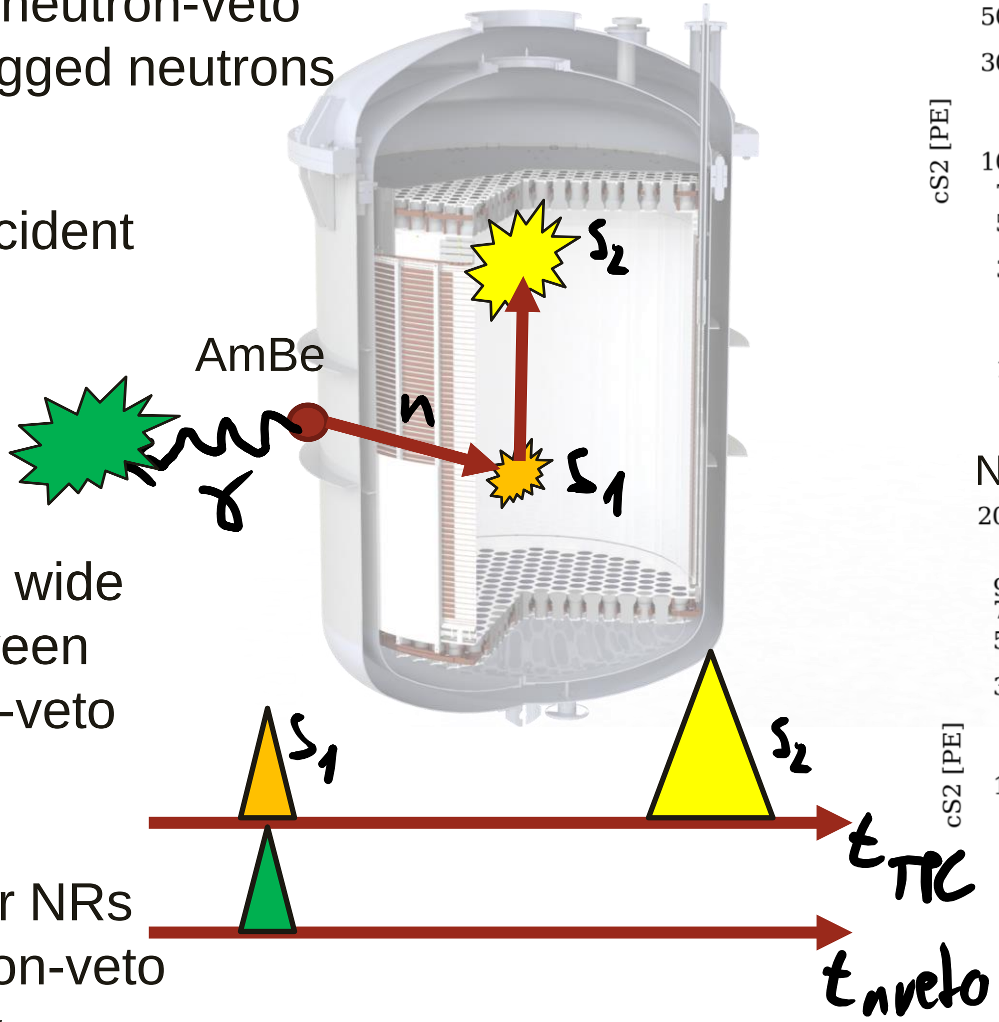
- ER response model based on a combined fit

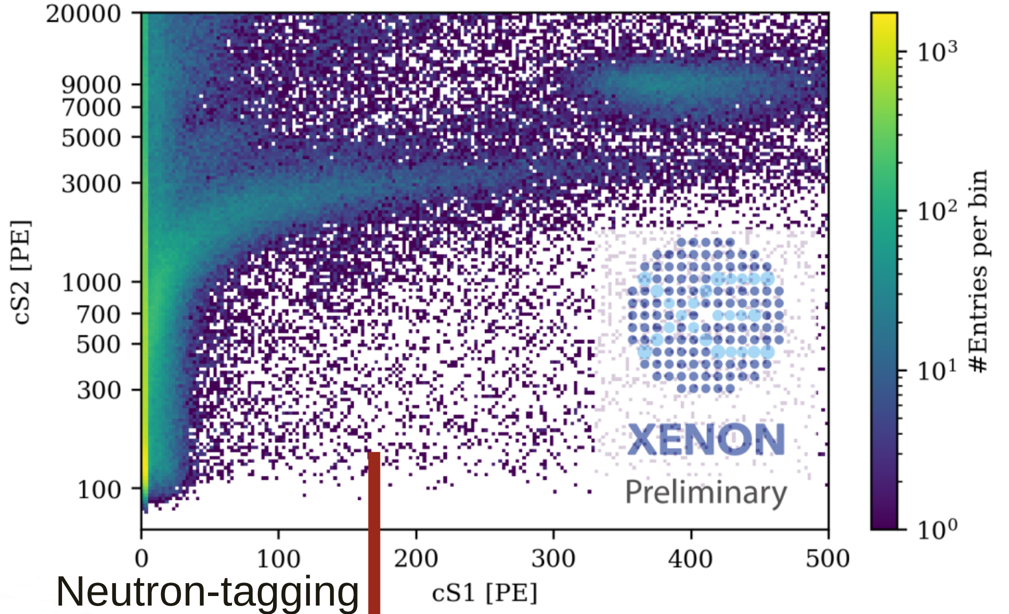




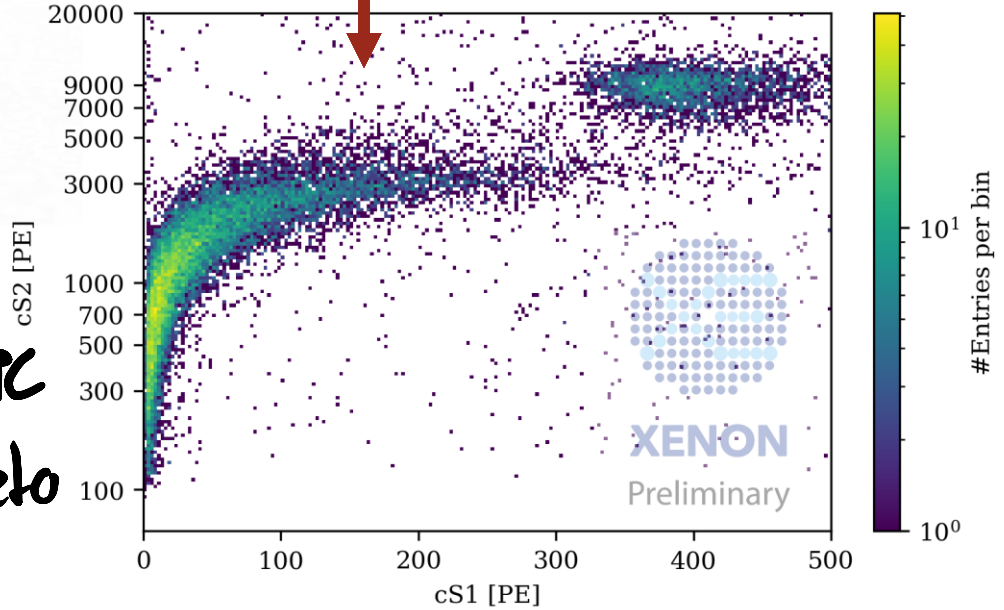
Calibration of NR response:

- Calibration of the neutron-veto and TPC using tagged neutrons
- AmBe emits coincident 4.4 MeV gamma
- Build tight 400 ns wide coincidence between TPC and neutron-veto
- Use single scatter NRs to calibrate neutron-veto tagging efficiency



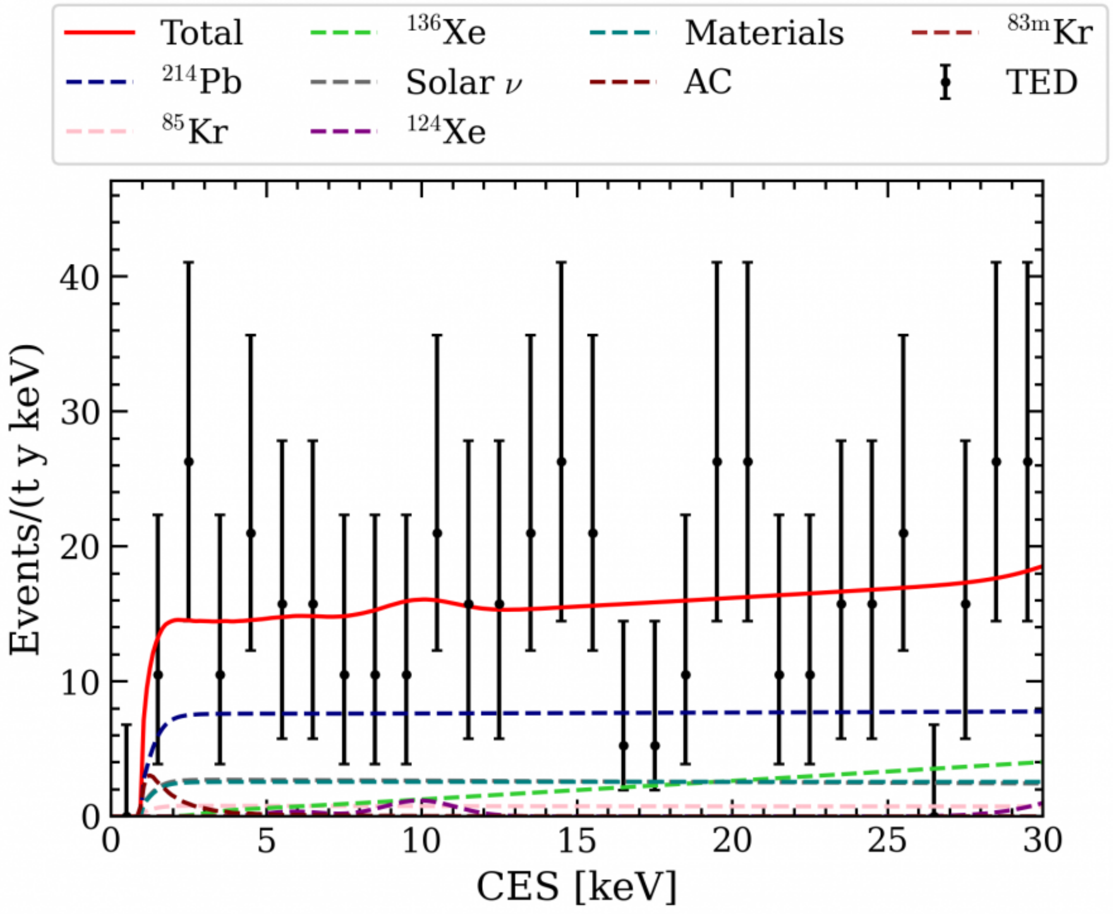


Neutron-tagging

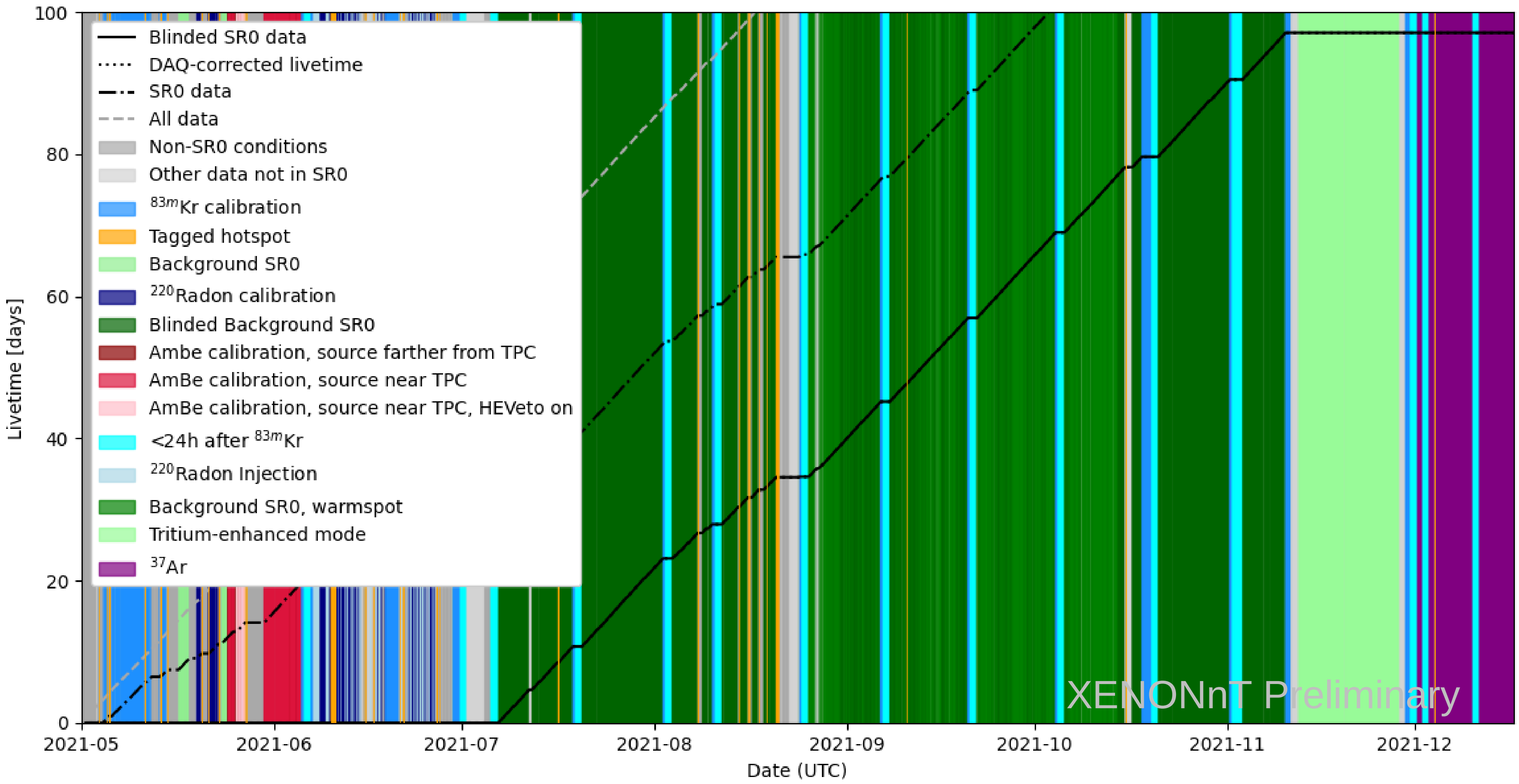


Tritium-enhanced data:

- Tritium as possible explanation for 1T excess.
- Therefore, additional measures in nT:
  - 3 months of outgassing and cleaning procedure
  - All xenon processed through Kr-removal system
  - 3 weeks of GXe circulation
- 14.3 days of operation in tritium-enhanced mode:
  - Bypassing the getter
  - Conservative estimate for tritium enhancement of at least x10 (but could also be a factor x100)
  - No ^3H excess found



SR0 data taking:



97.1 days of exposure between July 6 – Nov 11 2021

Backgrounds:

- NR and ER data below 20 keV blinded
- Initial constraints on backgrounds by external measurements and a data-driven coincidence model
- Verification of the background model on side band before unblinding

Component	Constraint	Fit
^{214}Pb	(584, 1273)	
^{85}Kr	90 ± 59	
Materials	266 ± 51	
^{136}Xe	1537 ± 56	
Solar neutrinos	297 ± 30	
^{124}Xe	$-$	
AC	0.70 ± 0.04	
^{133}Xe	$-$	
^{83m}Kr	$-$	

Backgrounds:

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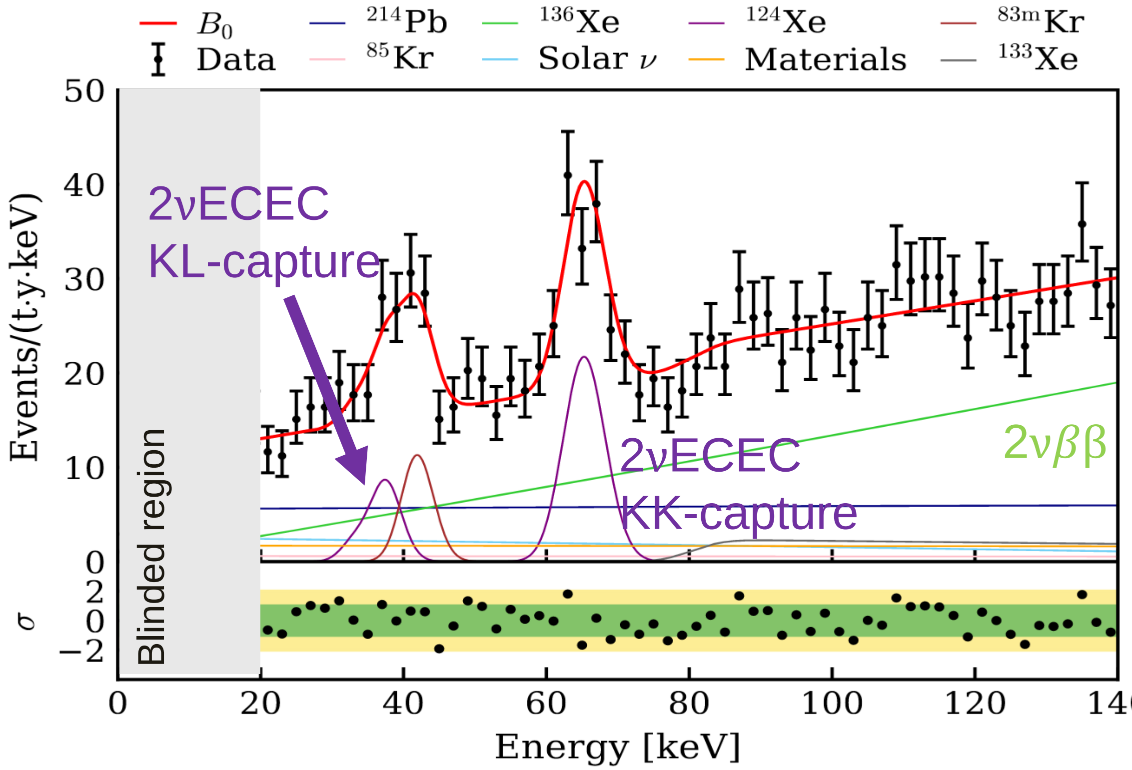
Component	Constraint	Fit
^{214}Pb	(584, 1273)	980 ± 120
^{85}Kr	90 ± 59	91 ± 58
Materials	266 ± 51	267 ± 51
^{136}Xe	1537 ± 56	1523 ± 54
Solar neutrinos	297 ± 30	298 ± 29
^{124}Xe	–	256 ± 28
AC	0.70 ± 0.04	0.71 ± 0.03
^{133}Xe	–	163 ± 63
^{83m}Kr	–	80 ± 16



2nd order weak processes dominating spectral shape!

$$T_{1/2}^{2\nu ECEC} = (1.15 \pm 0.13_{stat} \pm 0.14_{sys}) \cdot 10^{22}\ yr$$

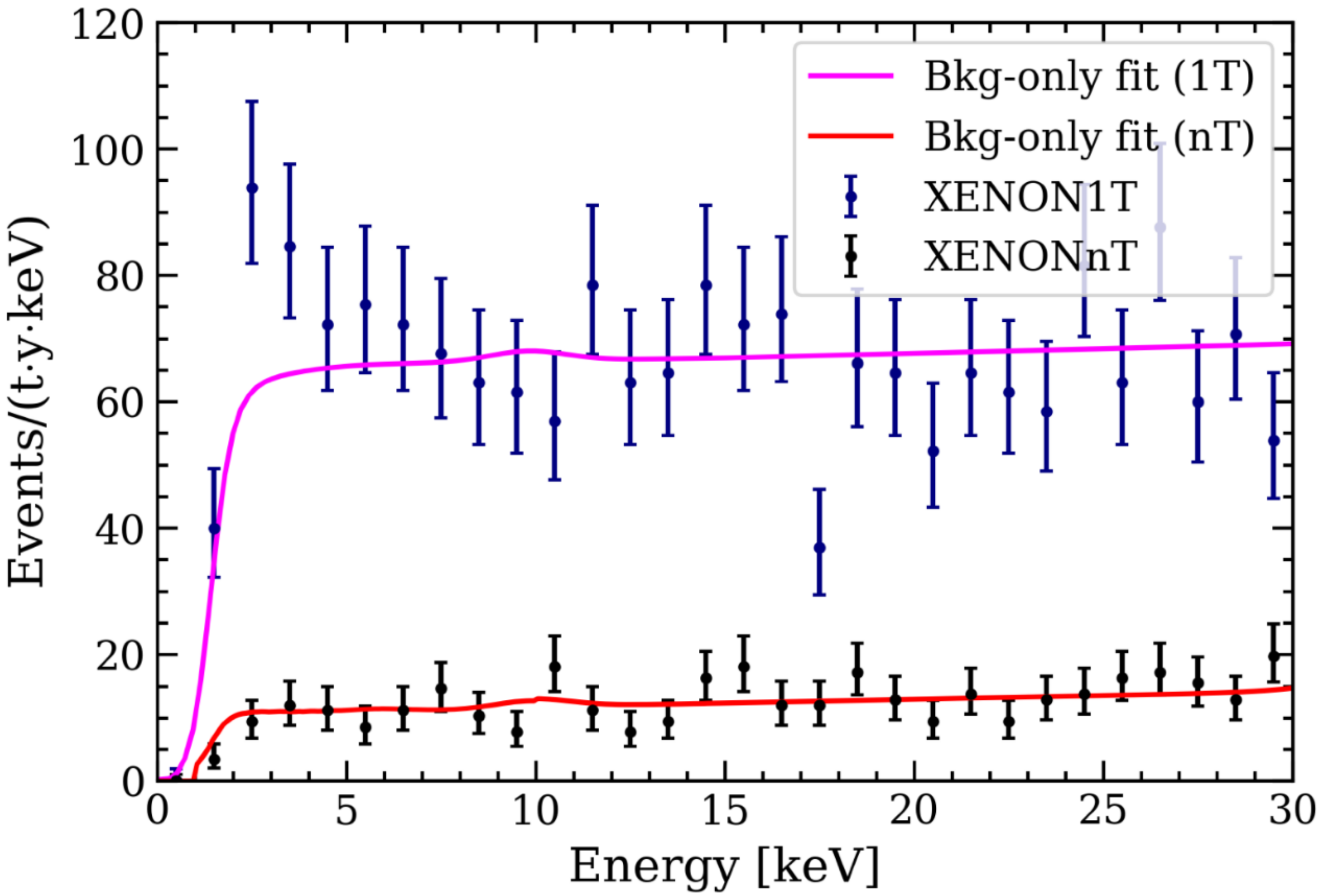
(significance of ~10 sigma)

Discovery in XENON1T, now calibration source in nT!

ER results XENONnT:

- Factor x5 improved background compared to XENON1T
- No excess below 5 keV found
  - 8.6σ exclusion of XENON1T-size peak

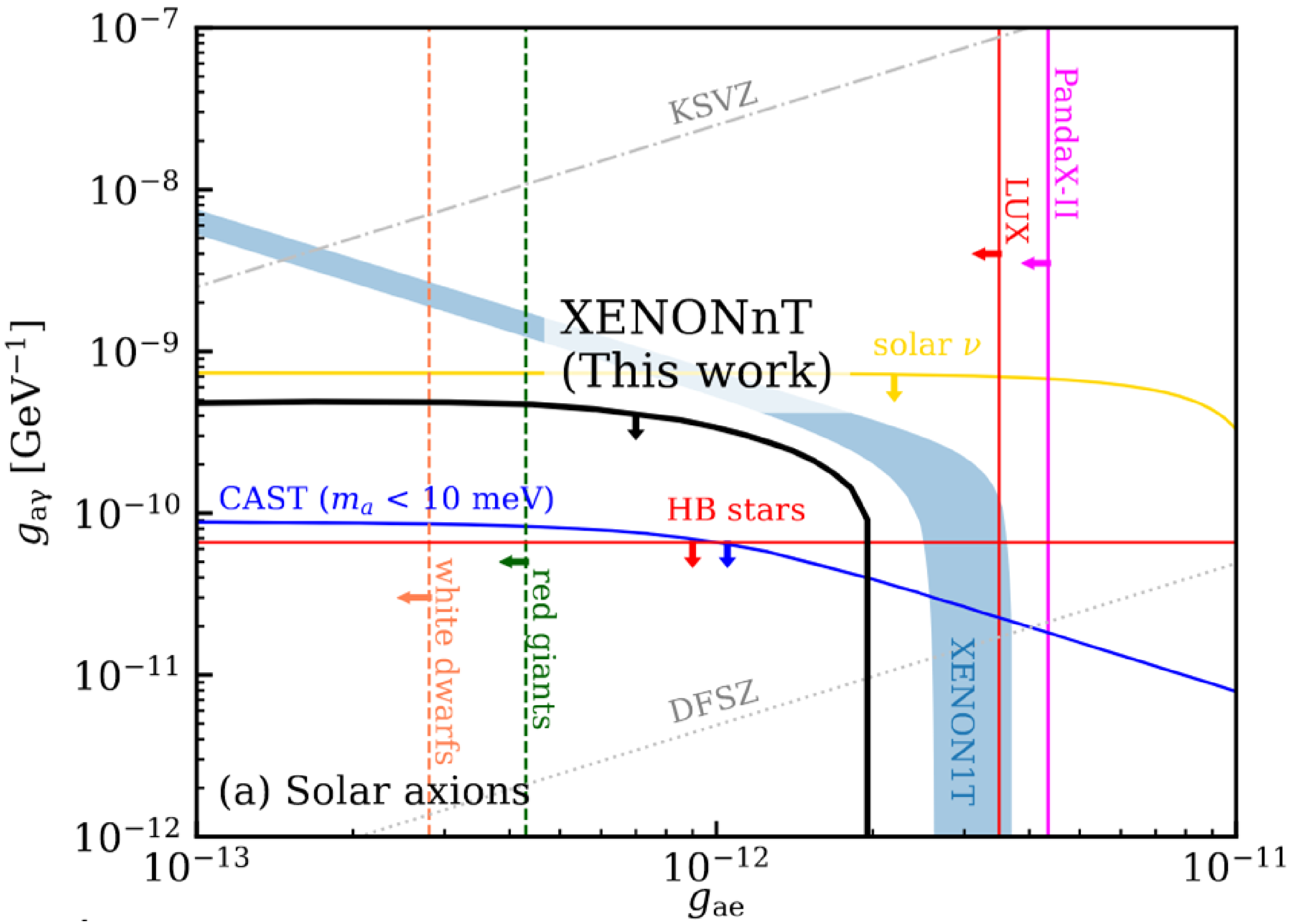
E. Aprile *et al*
Search for New Physics in Electronic Recoil Data from XENONnT
arXiv:2207.11330



ER results XENONnT:

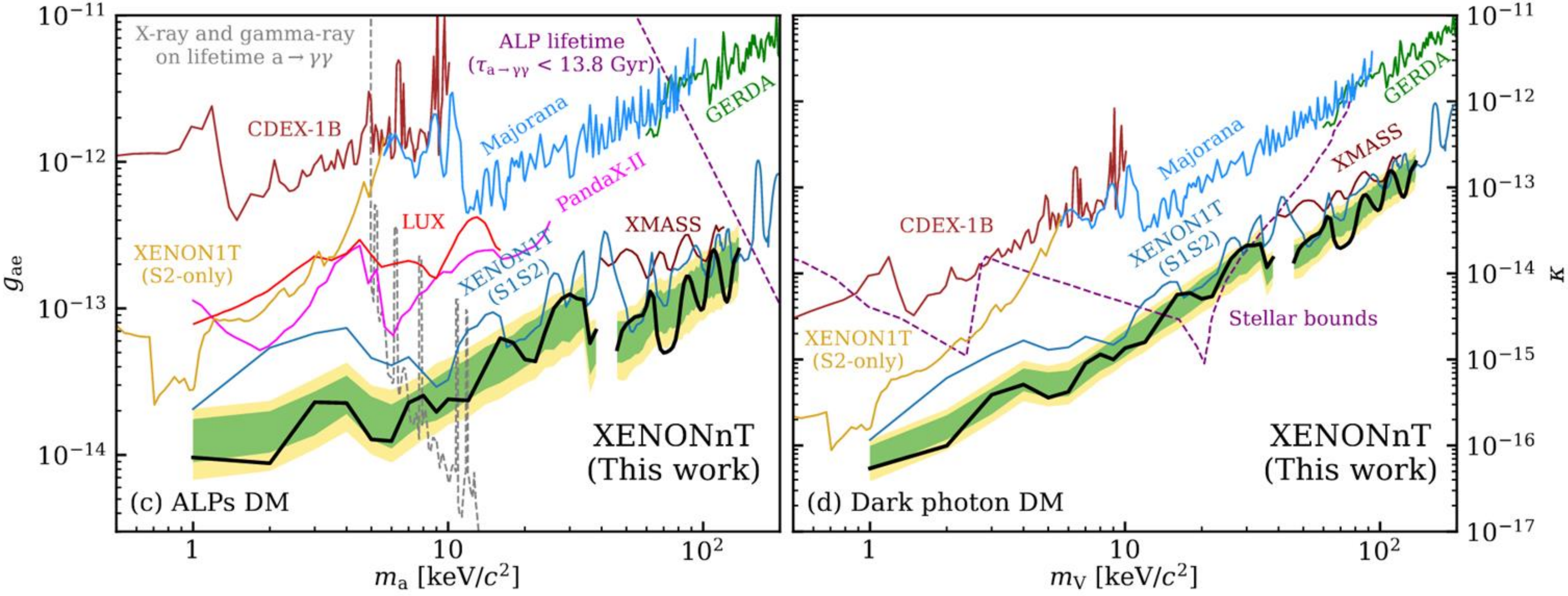
- Axion signal includes axio-electric and reverse Primakoff effect
- Improved constraints on the axion-gamma, axion-electron and axion-nucleon couplings
- Upper limit on the ^{57}Fe solar axion rate

➡ < 20.4 ev/(t·y) (90% C.L.)



ER results XENONnT:

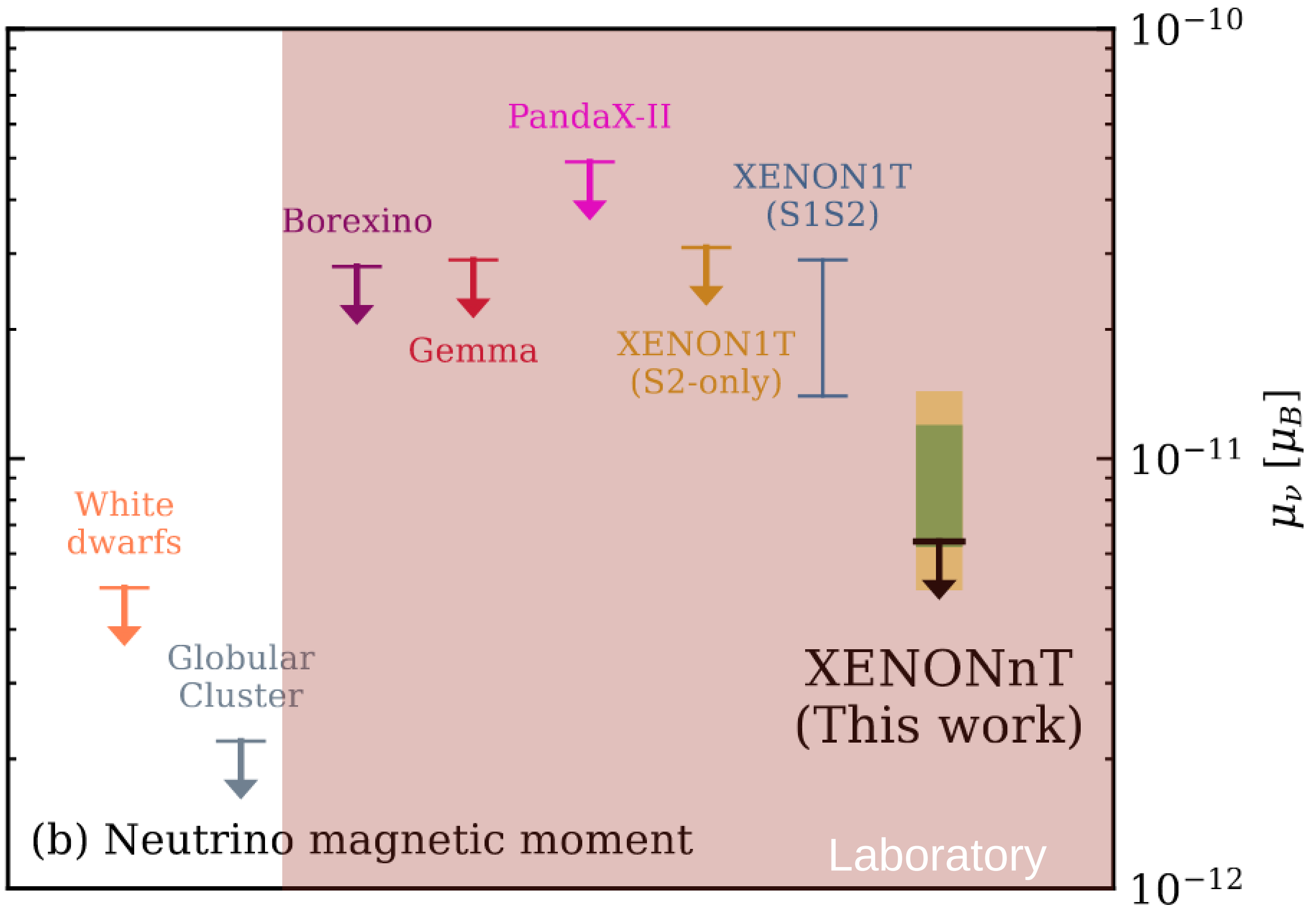
- Put constraints on new physics
- No peak-like signals as expected from axion like particles or dark photons



ER results XENONnT:

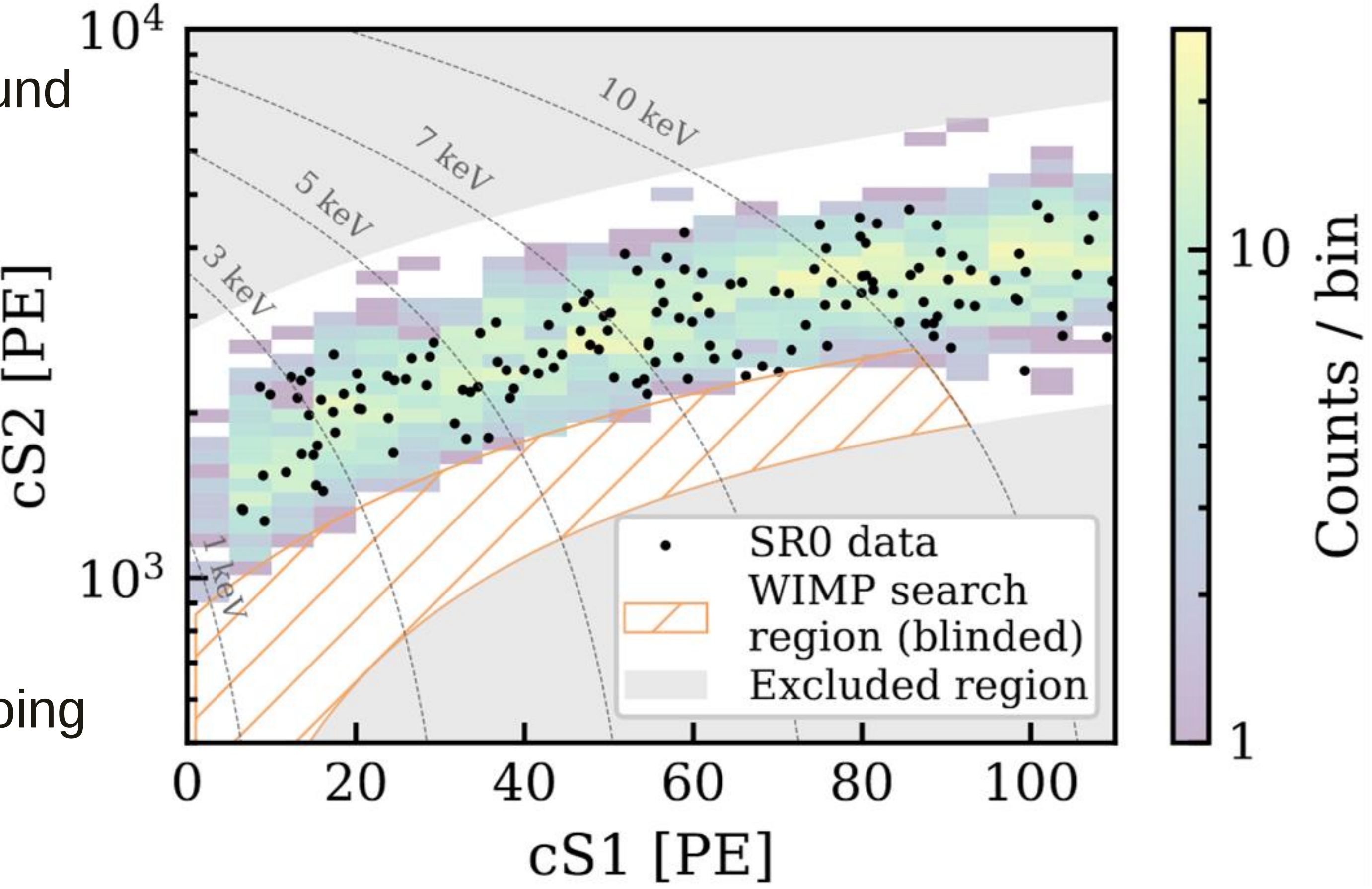
- New constraints on neutrino-magnetic moment:

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



Outlook and conclusion:

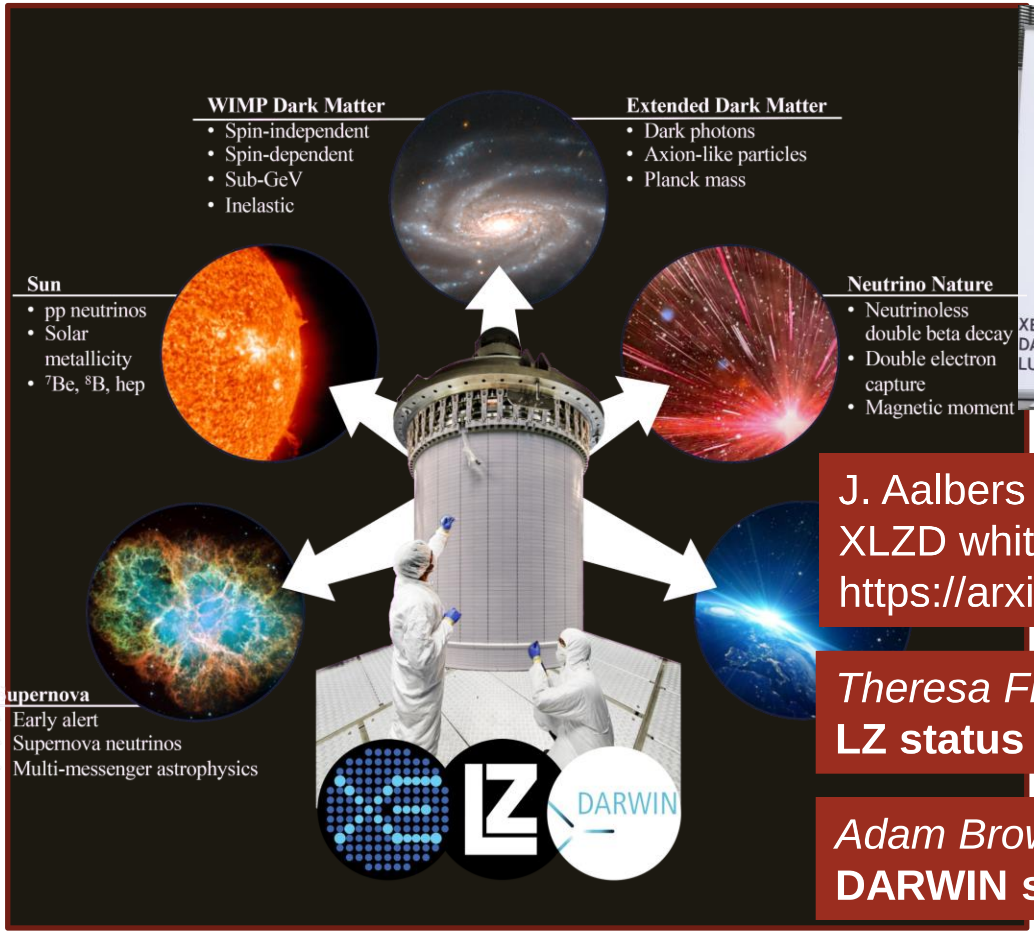
- XENONnT achieves excellent background levels and xenon purity!
- New subsystems work as expected
- ER analysis disfavors a XENON1T like excess, but puts new constraints on different dark matter models
- NR unblinding and WIMP analysis ongoing expect also here new results soon!



Is it a Bird?… Is it a Plane? No it‘s

- Joining effort and expertise between XENON, LZ and DARWIN
- See **xlzd.org**

XLZD meeting at Karlsruhe

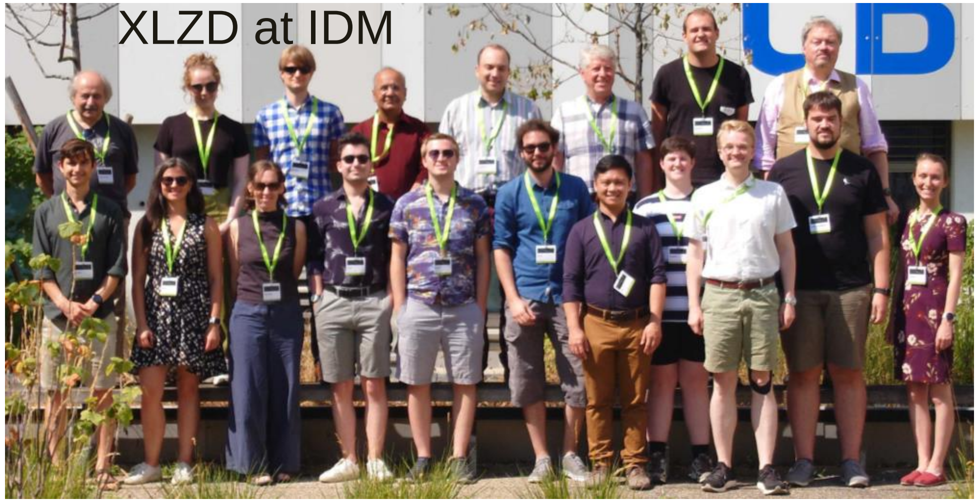


J. Aalbers *et al*
XLZD white paper
https://arxiv.org/abs/2203.02309

Theresa Fruth
LZ status *Wednesday 11:10*

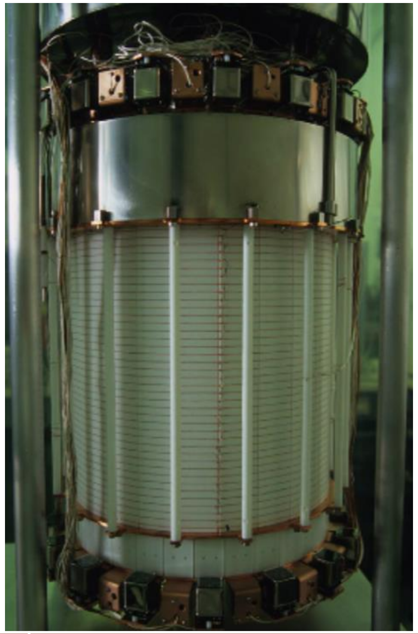
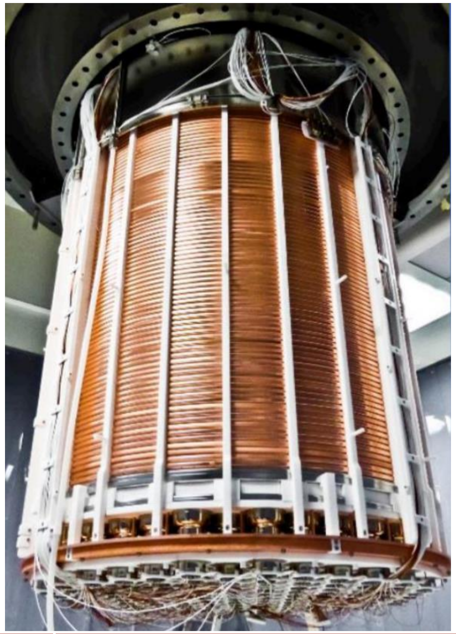
Adam Brown
DARWIN status *Friday 11:10*

XLZD at IDM



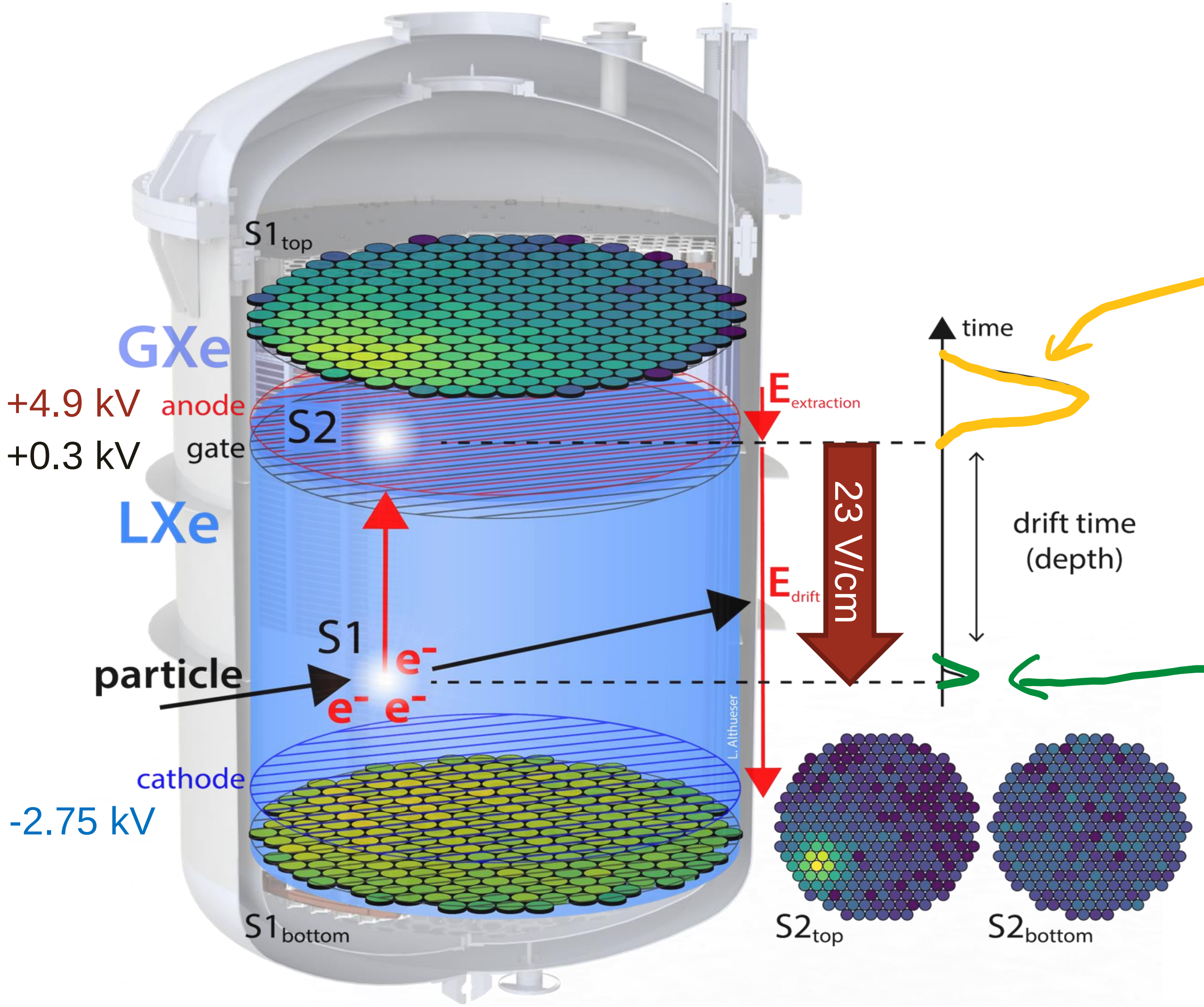
Back-up:

The XENON evolution:


XENON10	XENON100	XENON1T	XENONnT
2005-2007	2008-2016	2012-2019	2020-2026
14 kg Xe target	62 kg Xe target	2 t Xe target	~6 t Xe target, 8.6 t total mass
~10^{-43} cm^2	~10^{-45} cm^2	$4 \cdot 10^{-47}$ cm^2	$1.4 \cdot 10^{-48}$ cm^2 (projected for 20 t·y exposure) (Flea)
~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)

Liquid noble gas time projection chamber:



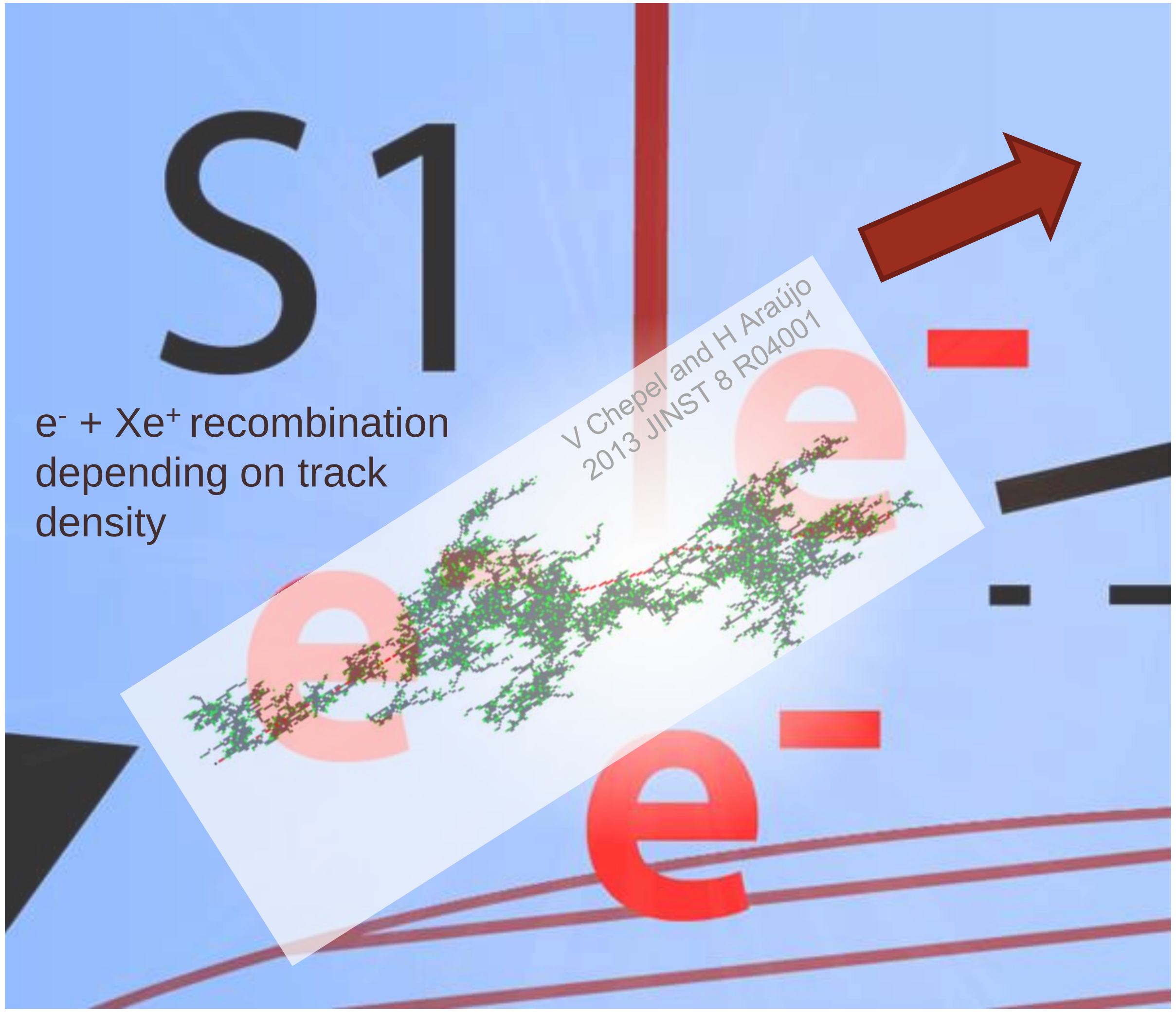
Scintillation #2 signal (S2)

- Electrons from ionized Xe^+ drift upwards between anode and gate
- Extraction from LXe into GXe by higher field
- Electroluminescence yields S2 which is prop. to number of e^-
- Signals O(100 pe – 100000 pe)

Scintillation #1 signal (S1)

- Excited Xe atoms form excimers Xe_2^*
- Excimers deexcite via emission of VUV-photons (178 nm)
- Signals O(3 pe – 1000 pe)

Liquid noble gas time projection chamber:



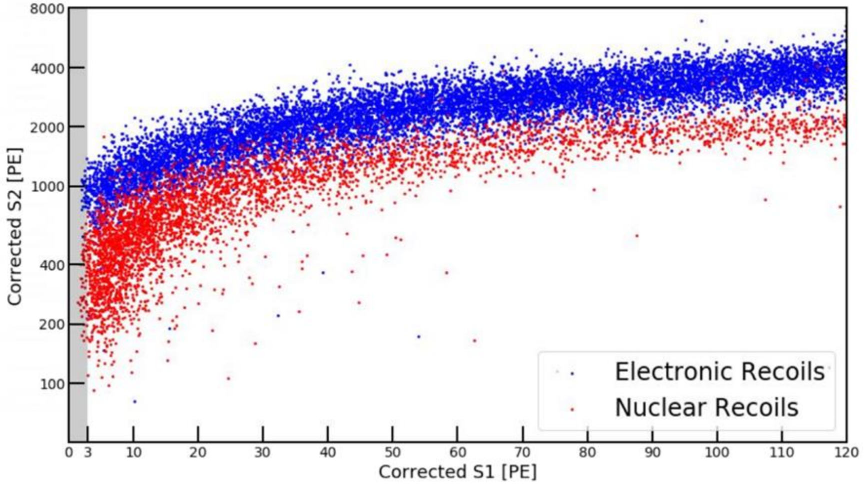
e^- + Xe^+ recombination depending on track density

Electronic Recoils:

Nuclear Recoils:

Ratio: S2/S1 (ER) > S2/S1 (NR)

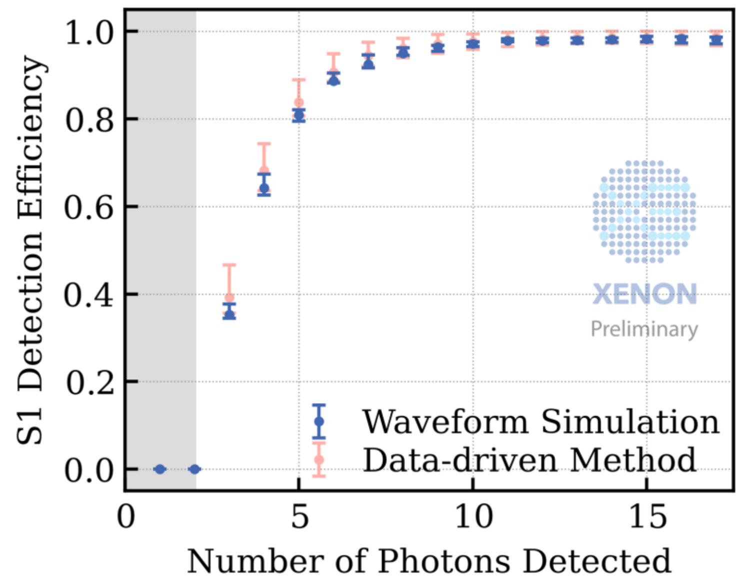
recombination leads to S2 quenching for NR

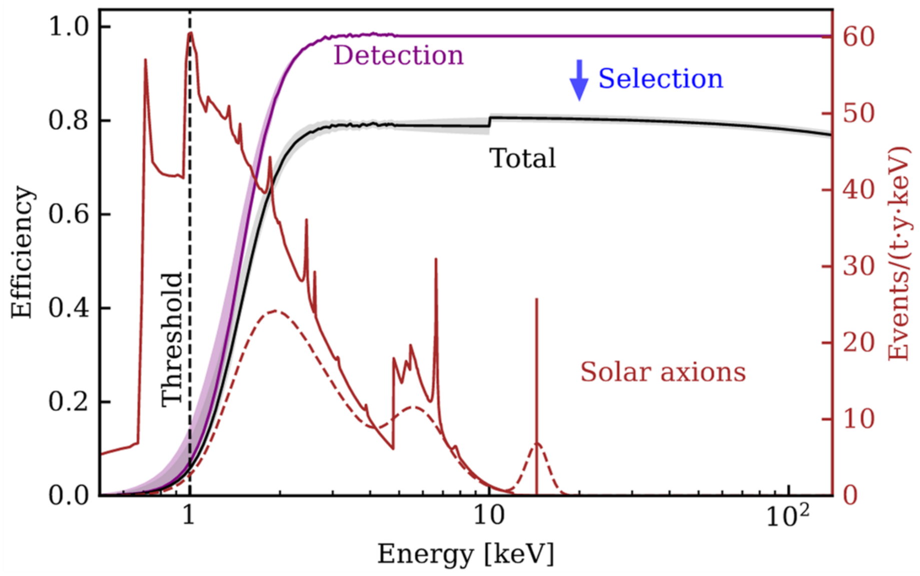


Calibration of detector threshold and acceptance:

- Detector threshold estimate using a data and a simulation driven method
  - Threshold driven by a 3-fold PMT coincidence requirement for S1 signals
  - Simulation of full waveforms which are analyzed with the same processing framework
  - Data-driven uses higher energetic peaks to sample toy peaks.

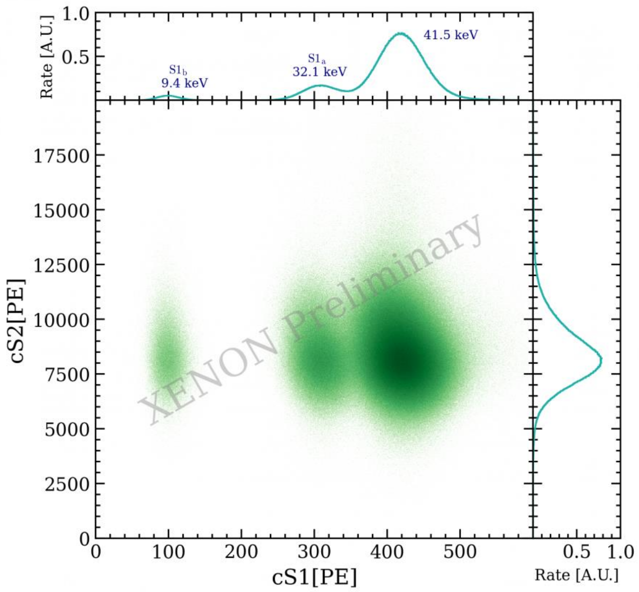
- Average data-quality cut acceptance ~86 %

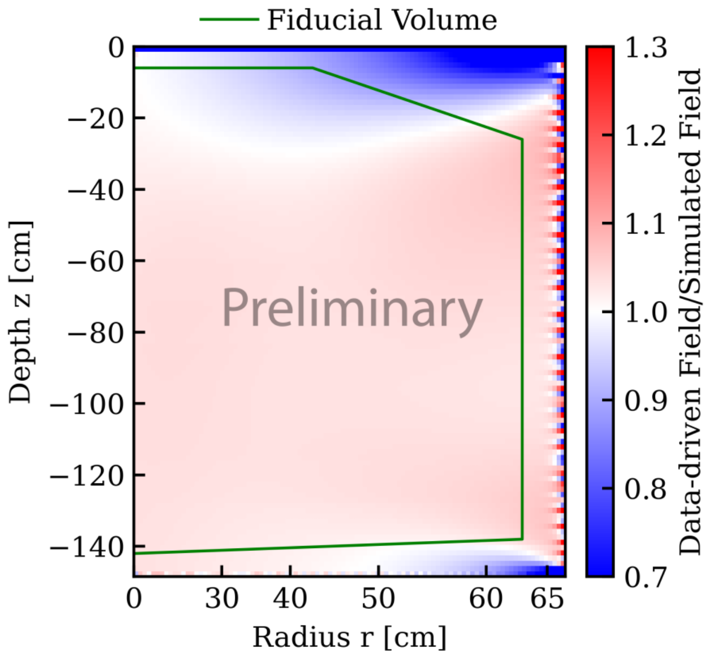


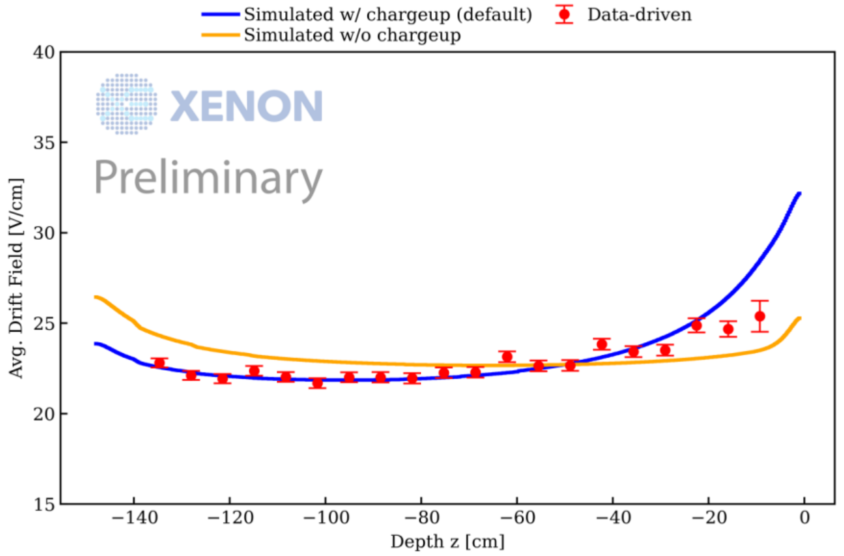


Detector uniformity and electric field validation:

- ^{83m}Kr, decays slow enough to be diffused uniformly over the LXe volume.
  - Used to calibrate position dependent light collection efficiencies for S1/S2
  - To calibrate for field distortions in the position reconstruction
  - Validate COMSOL field simulation by comparing its 32.1 keV and 9.4 keV signal







Detector stability:

- Light and charge yield monitoring using background source and bi-weekly ^{83m}Kr calibrations
  - Light yield stability ~1 %
  - Charge yield stability ~1.9 %