xenonexperiment.org

The XENON Project

XENON

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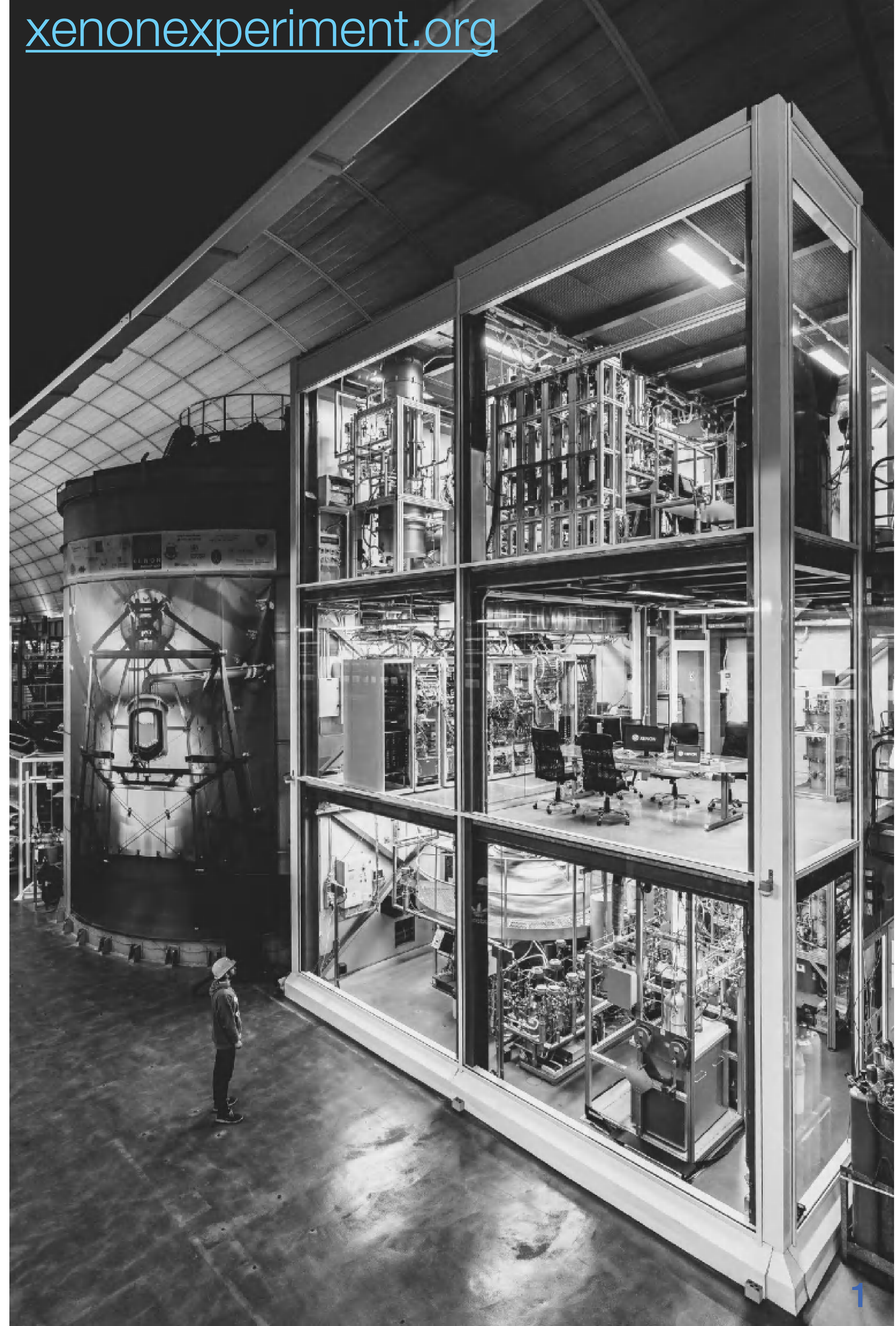
Columbia University
IN THE CITY OF NEW YORK

Neutrino Physics and Beyond
Hong Kong February 21, 2024



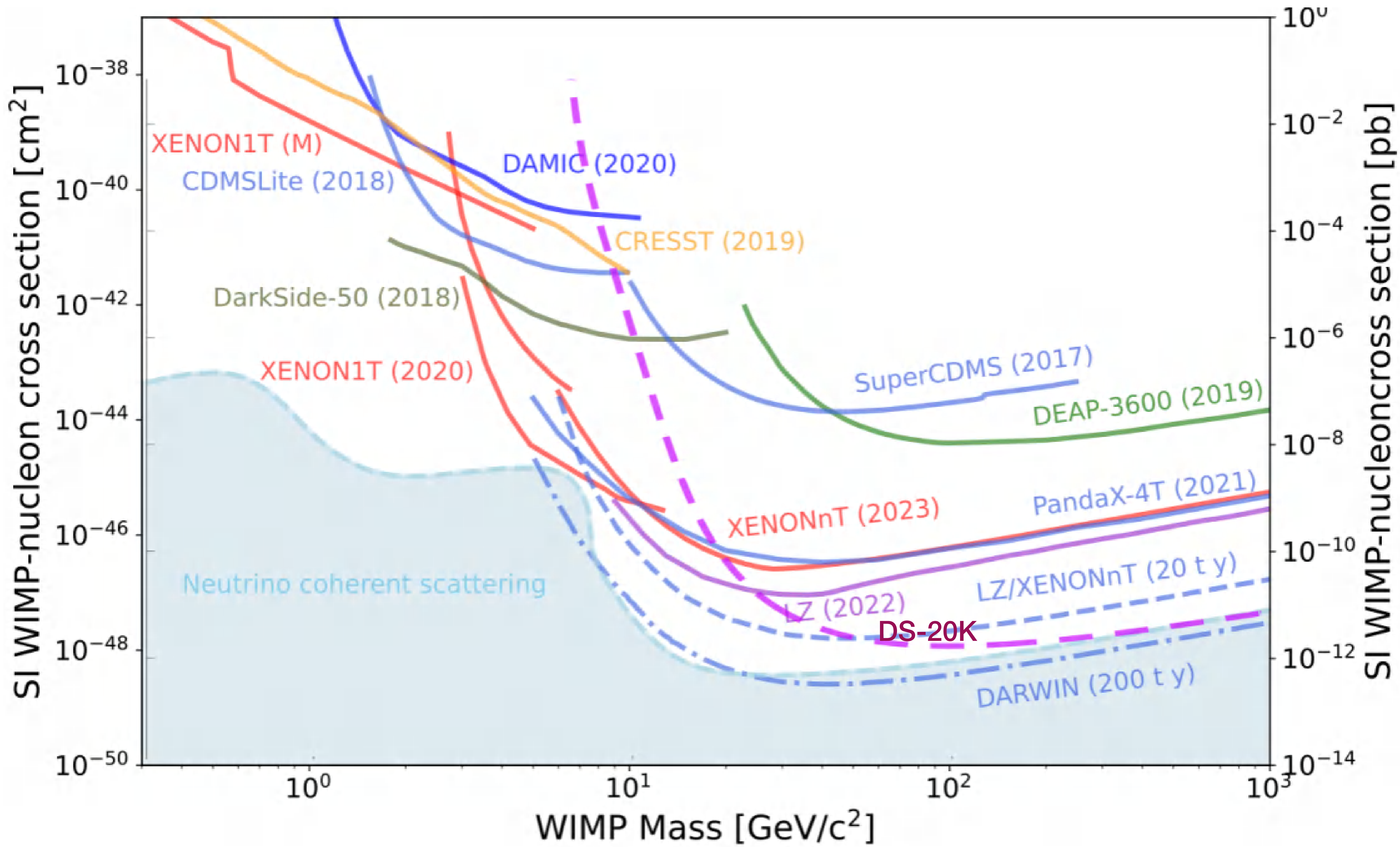
XENON

27 institutions

200 scientists

Collaboration meeting @ Paris, September 2023

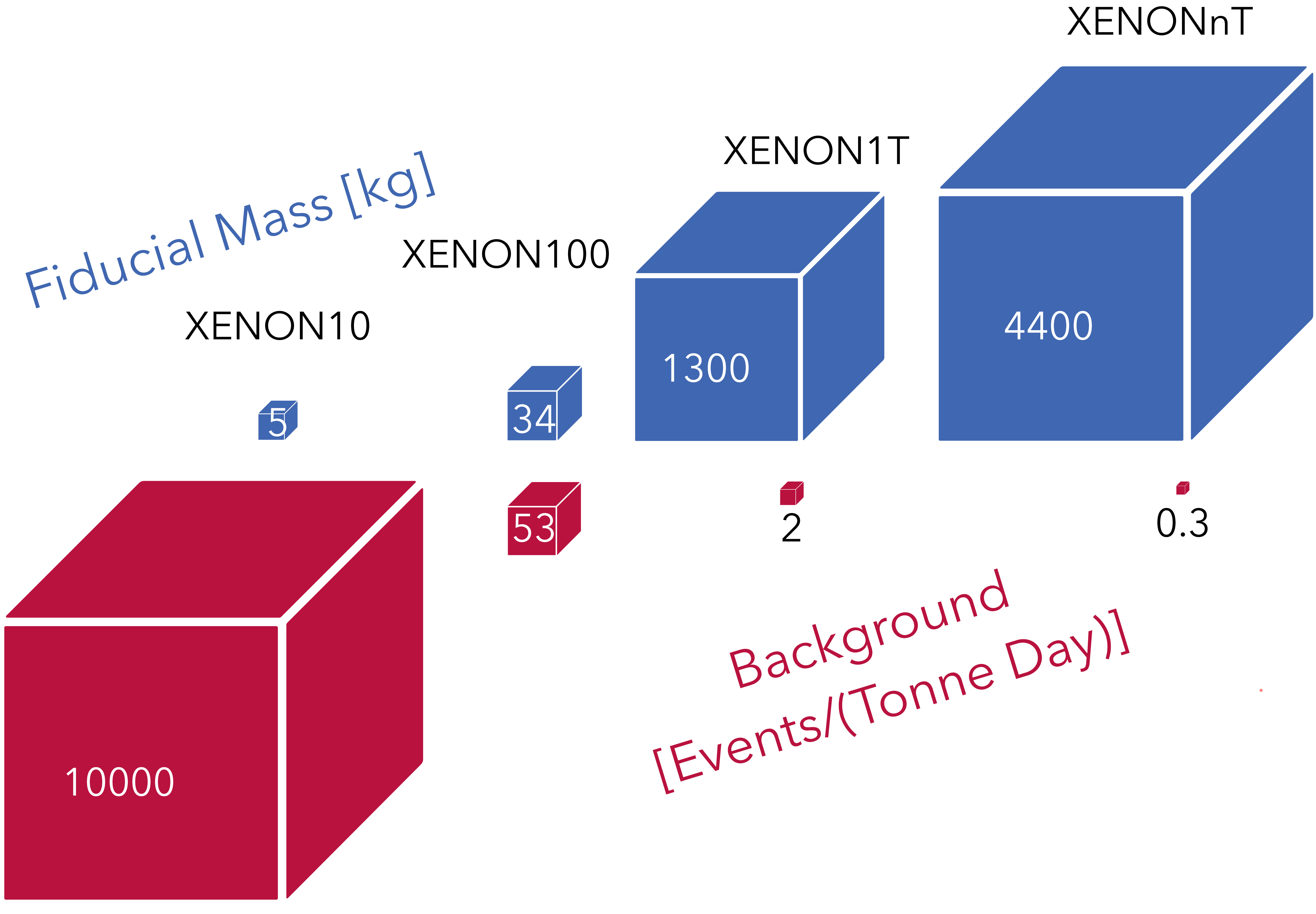
State-of-the-art and Future Projections



The XENON Phased Program of Experiments at LNGS

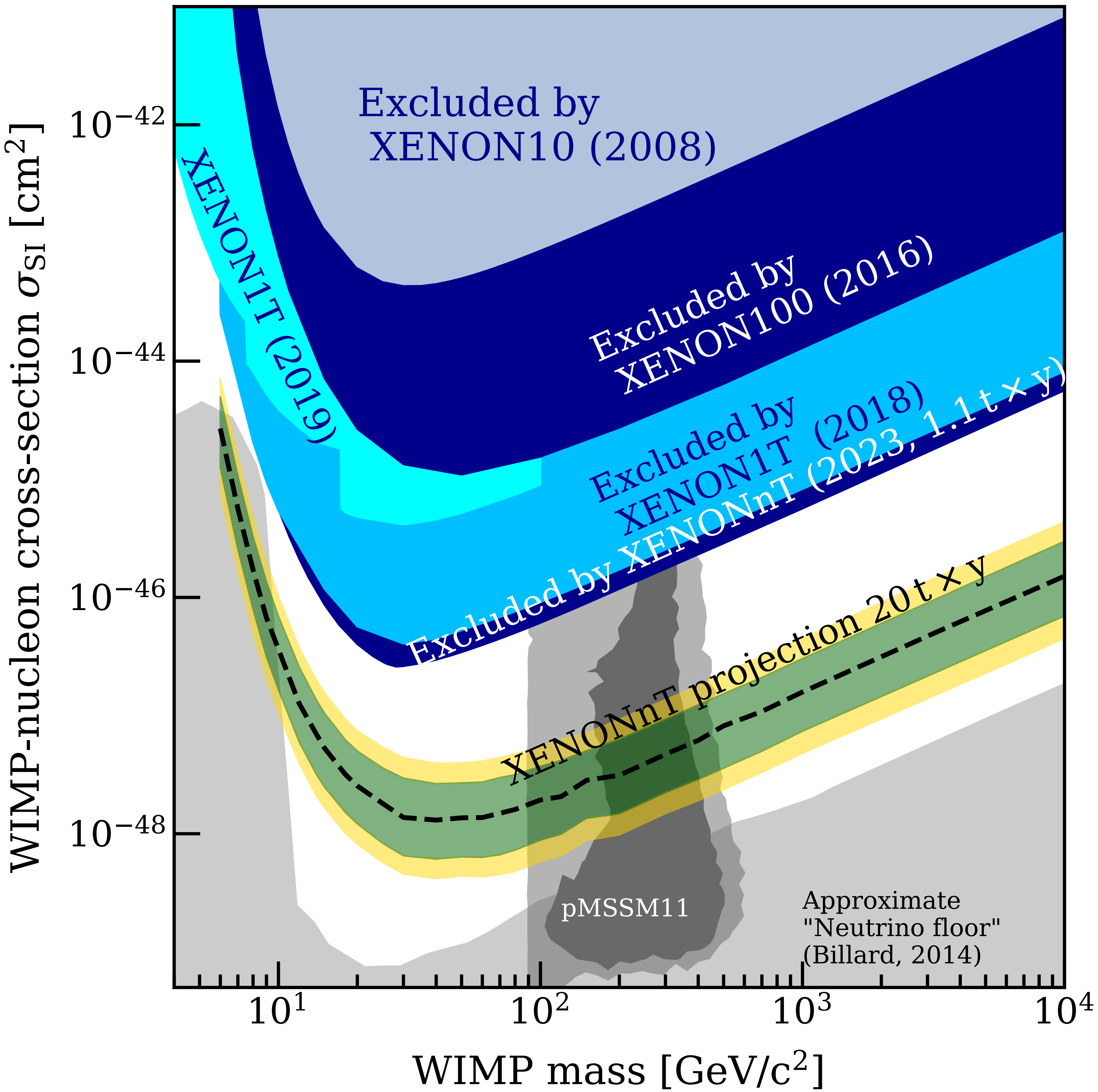



XENON10	XENON100	XENON1T	XENONnT
2005-2007	2008-2016	2012-2019	2020-2026 (taking science data)
15 kg Xe target	62 kg Xe target	2 t Xe target, 3.3t total	~6 t Xe target, 8.6t total
~10^{-43} cm^2	~10^{-45} cm^2	4 $\times 10^{-47}$ cm^2	Projection: 1.4×10^{-48} cm^2 for 20 tonne-year
~2000000 background ER events/(keV t y)	1800 background ER events/(keV t y)	82 background ER events/(keV t y)	16.1 background ER events/(keV t y)



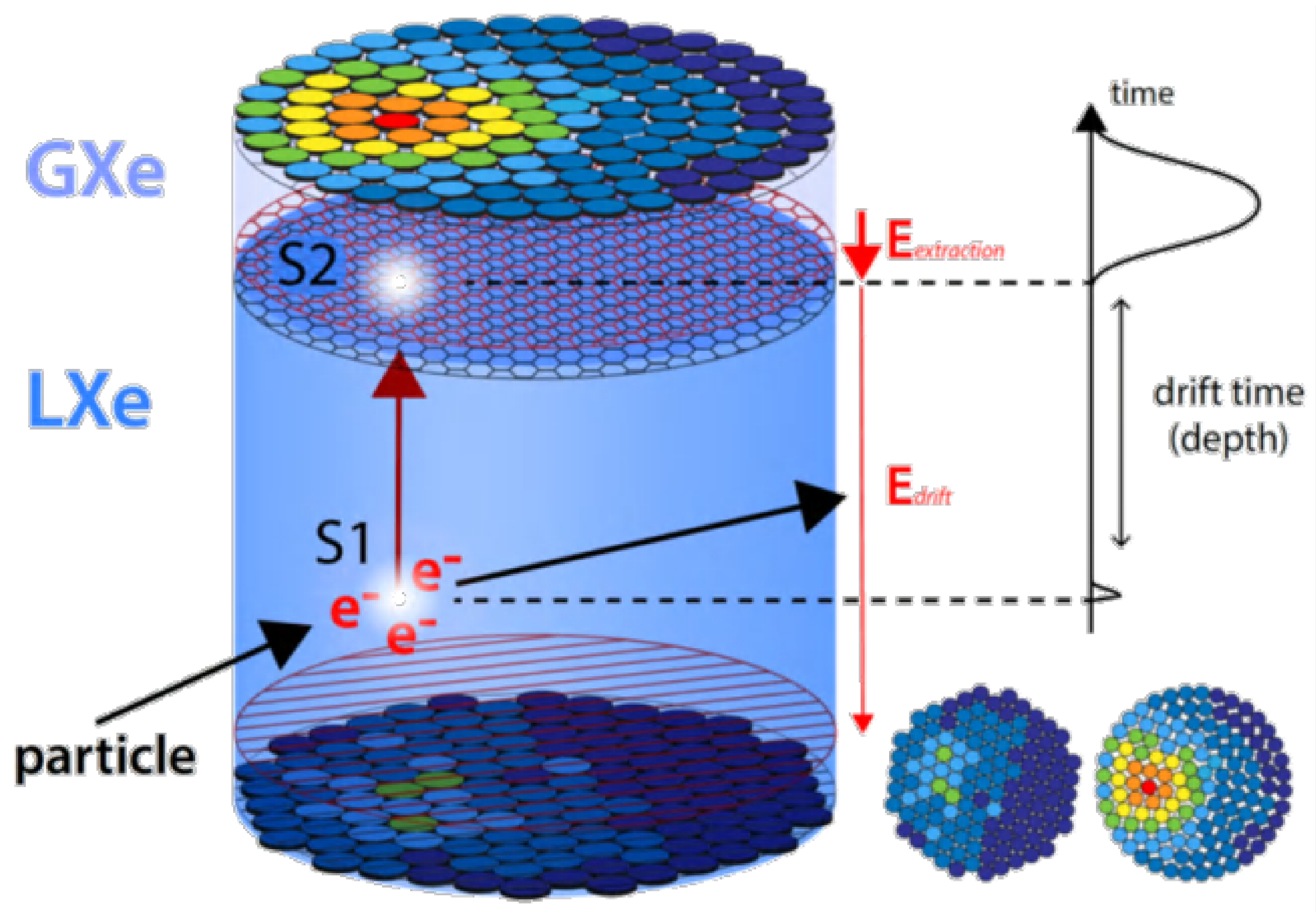
XENONnT
XENON1T
XENON100
XENON10
Fiducial Mass [kg]
5
34
1300
4400
10000
53
2
0.3
Background
[Events/(Tonne Day)]

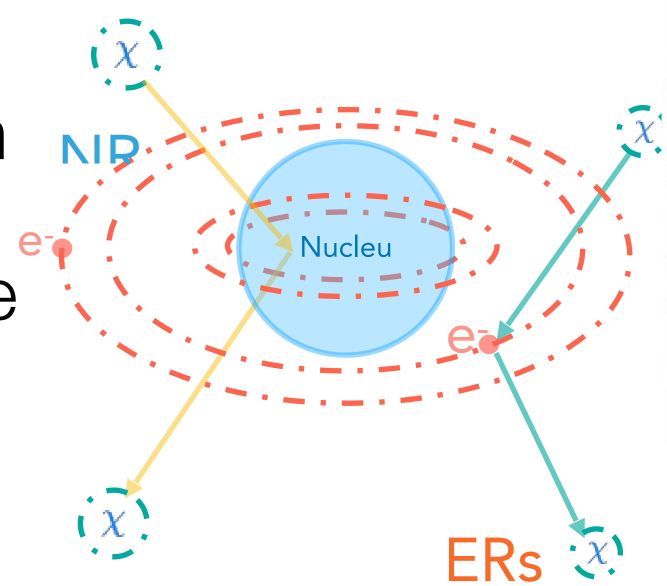
XENON limits on WIMPs

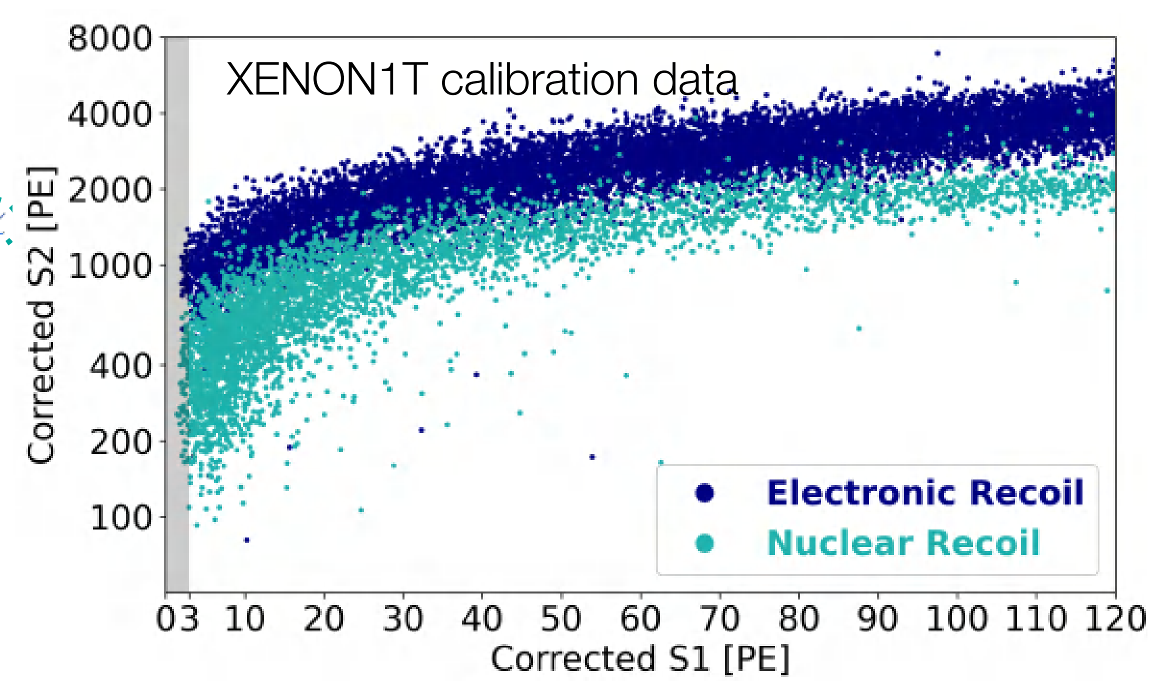


Two-Phase Liquid Xenon Time Projection Chambers

- S1: “Light signal”
  - prompt scintillation photons
- S2: “Charge signal”
  - Secondary scintillation photons from electroluminescence in GXe due to drifted electrons
- Position reconstruction:
  - X,Y: S2 hit pattern
  - Z: S1-S2 drift time



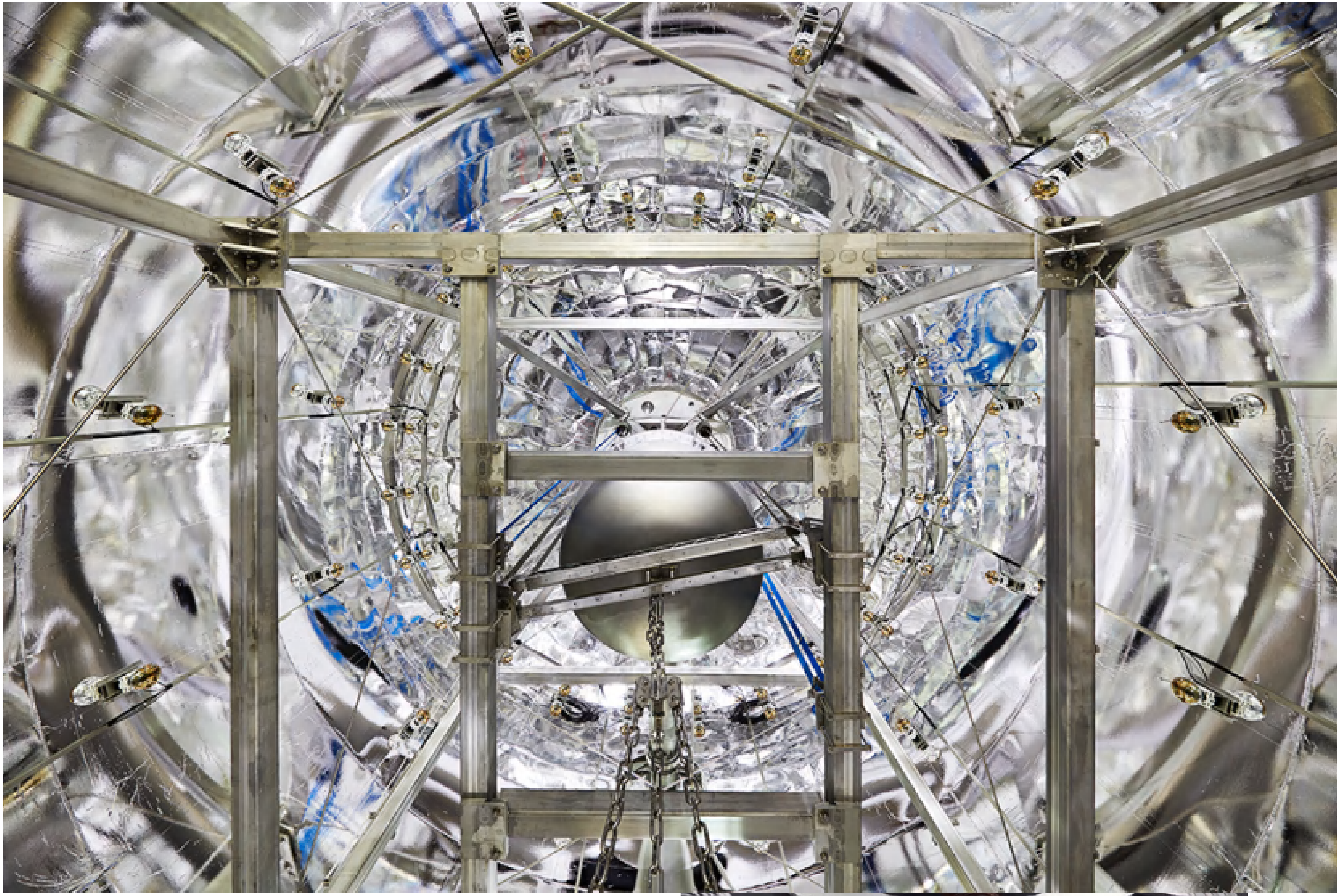




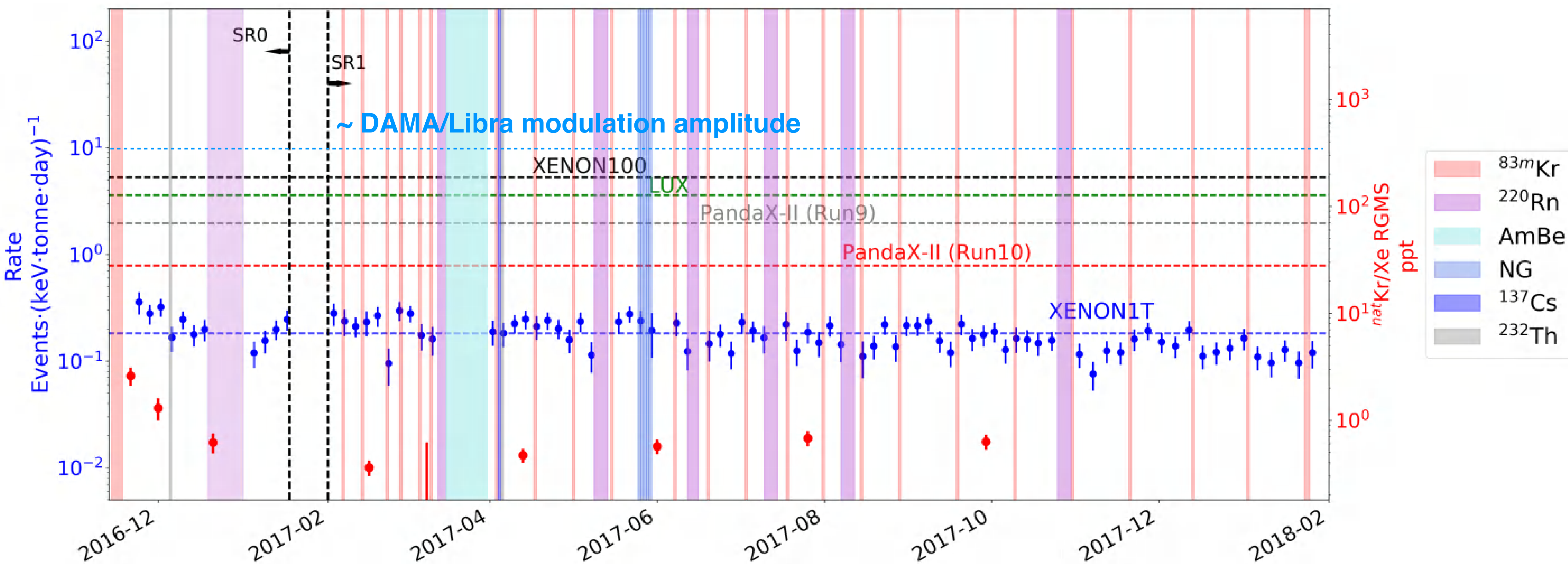
XENON1T

- The first tonne-scale LXeTPC, with a 2-tonne active mass.
- 1m diameter and height with 248 3” low-radioactivity PMTs
- TPC mounted in a cryostat suspended in center of a water Cerenkov muon veto detector

XENON1T



XENON1T Background

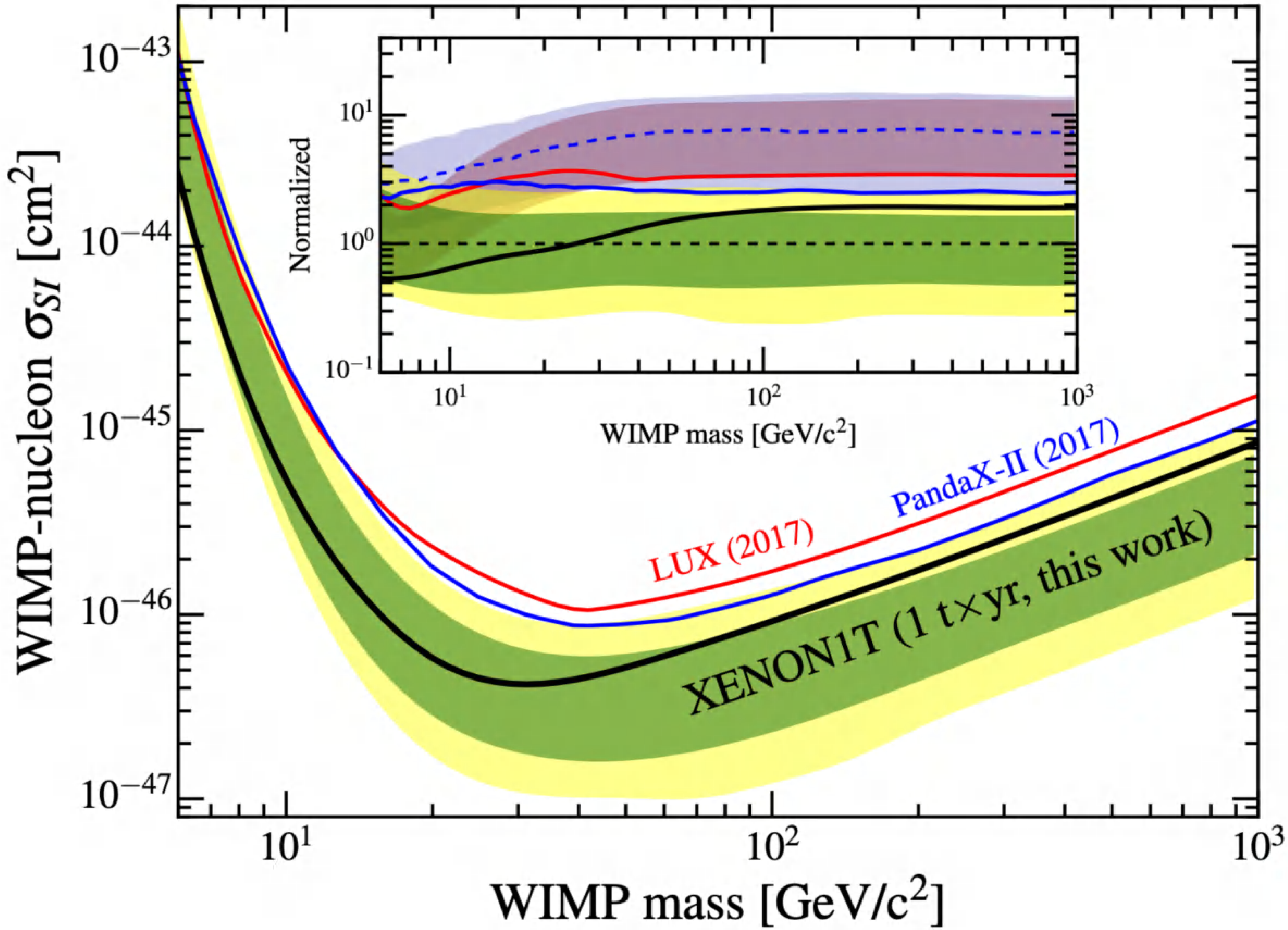


(82 ± 5) events / (t × yr × keV$_{ee}$) below 25 keVee

Lowest ER background achieved in a DM detector

Dominated by Pb214 from Rn222 (~ 10 uBq/kg)

Final WIMP result used one tonne-year of data over two science runs, with world-leading sensitivity and limits



XENON1T Science Results: much more than WIMP limits!

WIMP DARK MATTER
PRL 119, 181301
PRL 121, 111302
PRL 122, 071301
PRL 122, 141301
PRL 126, 091301
PRD 103, 063028

LIGHT
DARK MATTER
PRL 123, 241803
PRL 123, 251801

BOSONIC
DARK MATTER
PRD 102, 072004

SOLAR ^{8}B CEvNS
PRL 126, 091301

SOLAR AXION
PRD 102, 07200

DOUBLE
ELECTRON CAPTURE
Nature 568, 532

NEUTRINO
MAGNETIC MOMENT
PRD 102, 072004

0vbb DECAY
EPJ C (2020) 80:785 (analysis R&D)

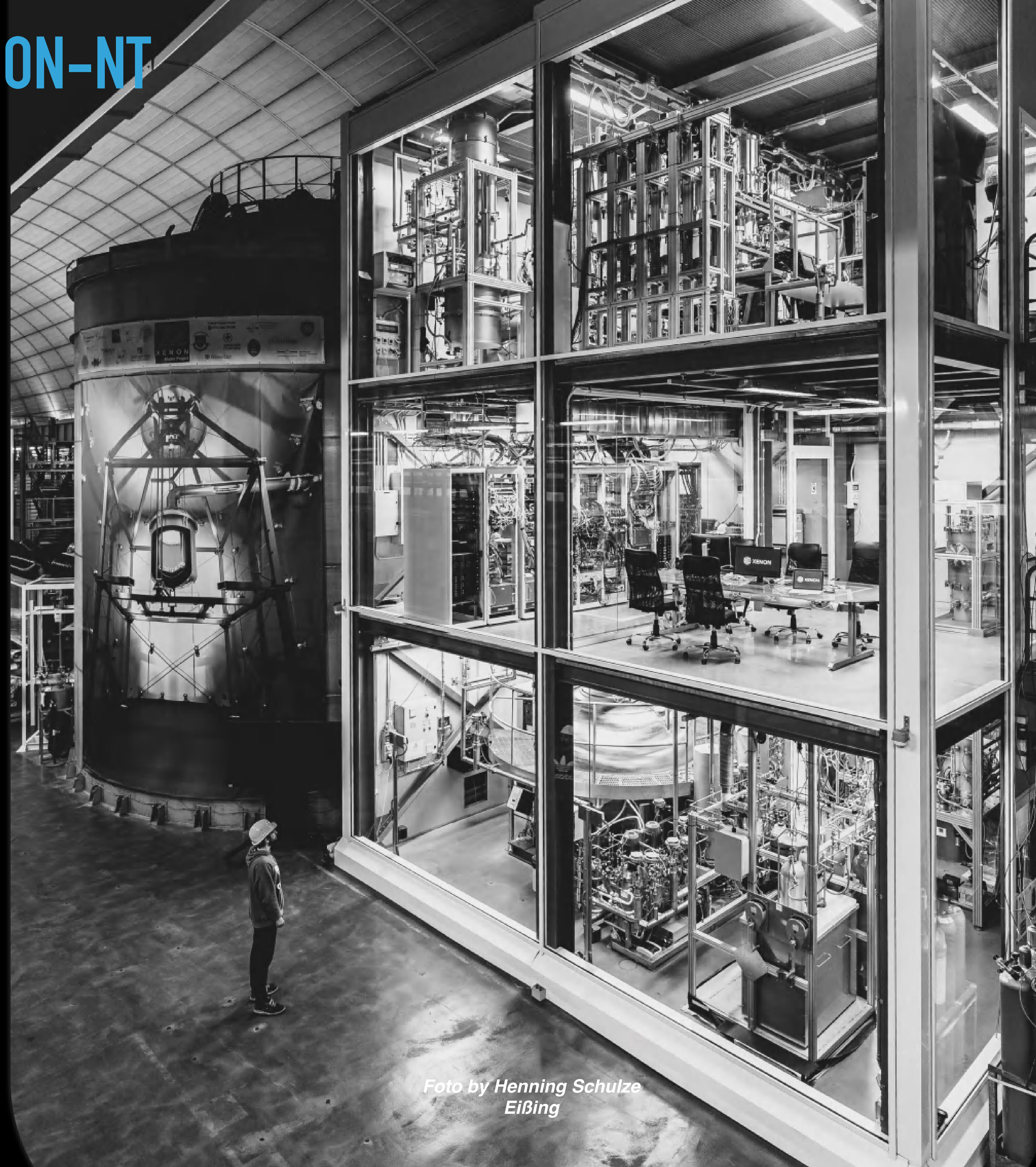
TECHNICAL ANALYSIS PAPERS
PRD 99, 112009
PRD 100, 052014

XENON1T Science Results: much more than WIMP limits!

FROM XENON1T TO XENON-NT

XENON1T infrastructure and subsystems designed to efficiently upgrade to a more sensitive experiment with

- ➢ new TPC with 8500 kg of LXe
- ➢ new liquid xenon purification
- ➢ new active neutron veto
- ➢ new radon removal system



FROM XENON1T TO XENO

XENON1T infrastructure and subsystems designed to efficiently upgrade to a more sensitive experiment with

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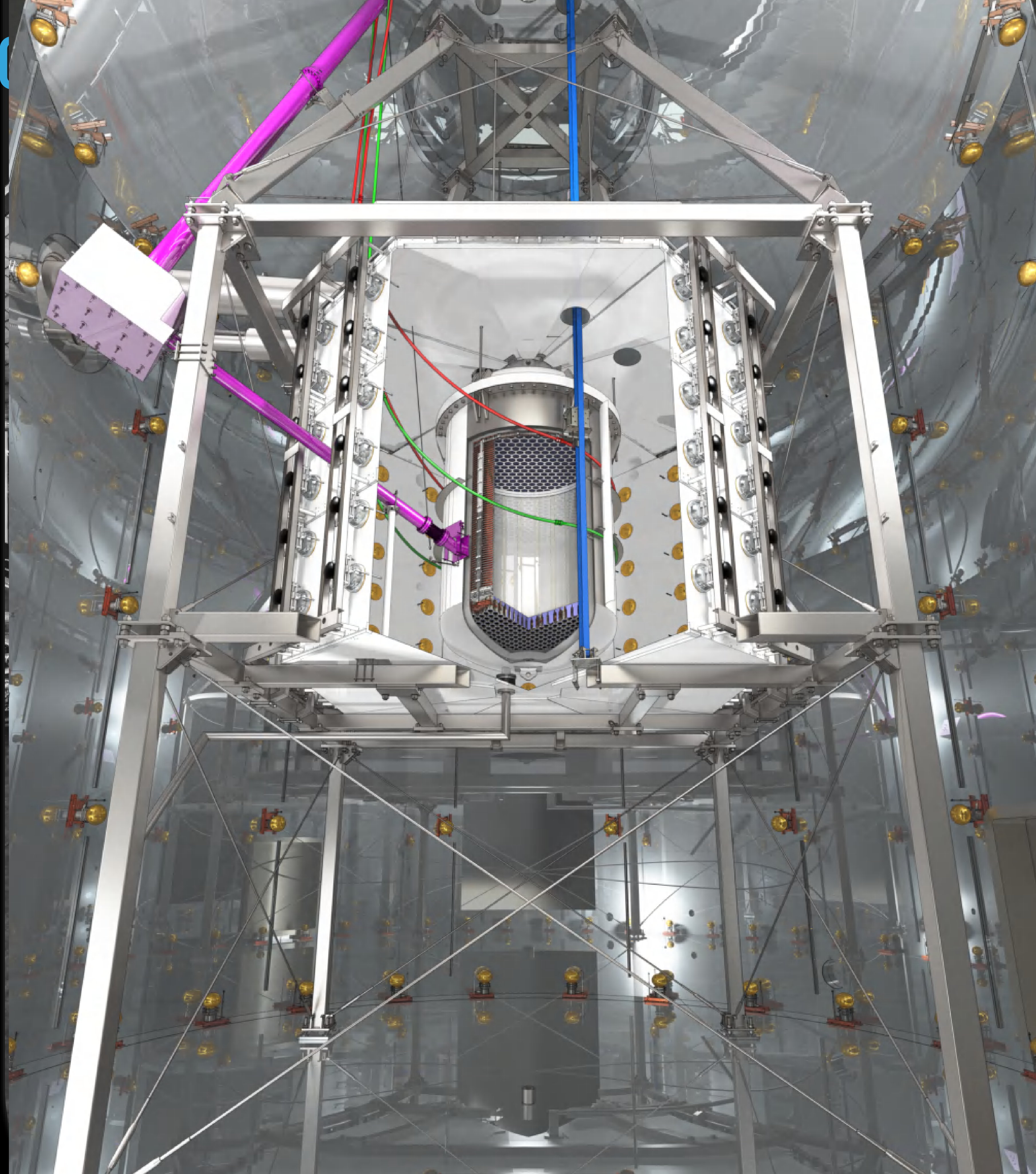
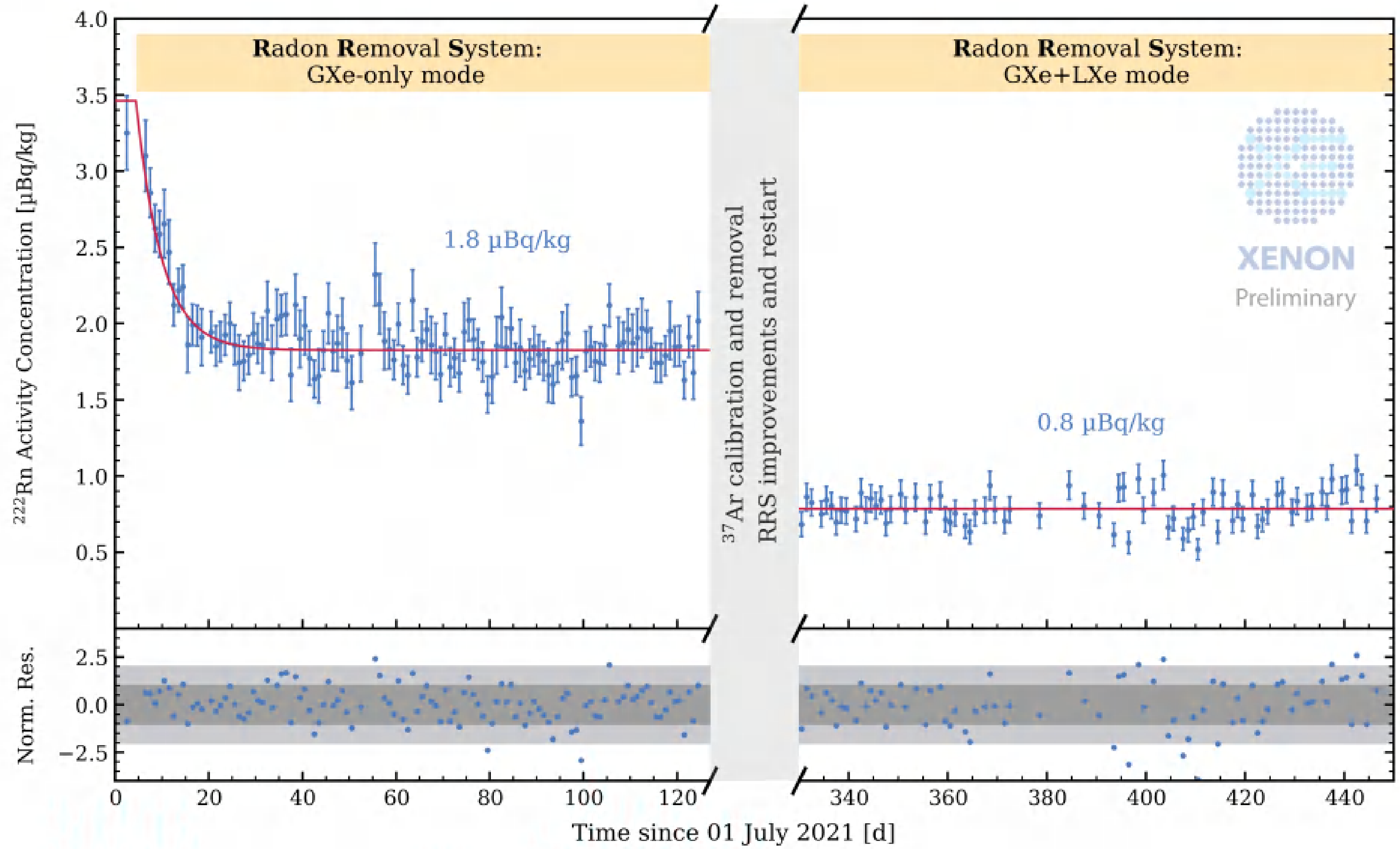
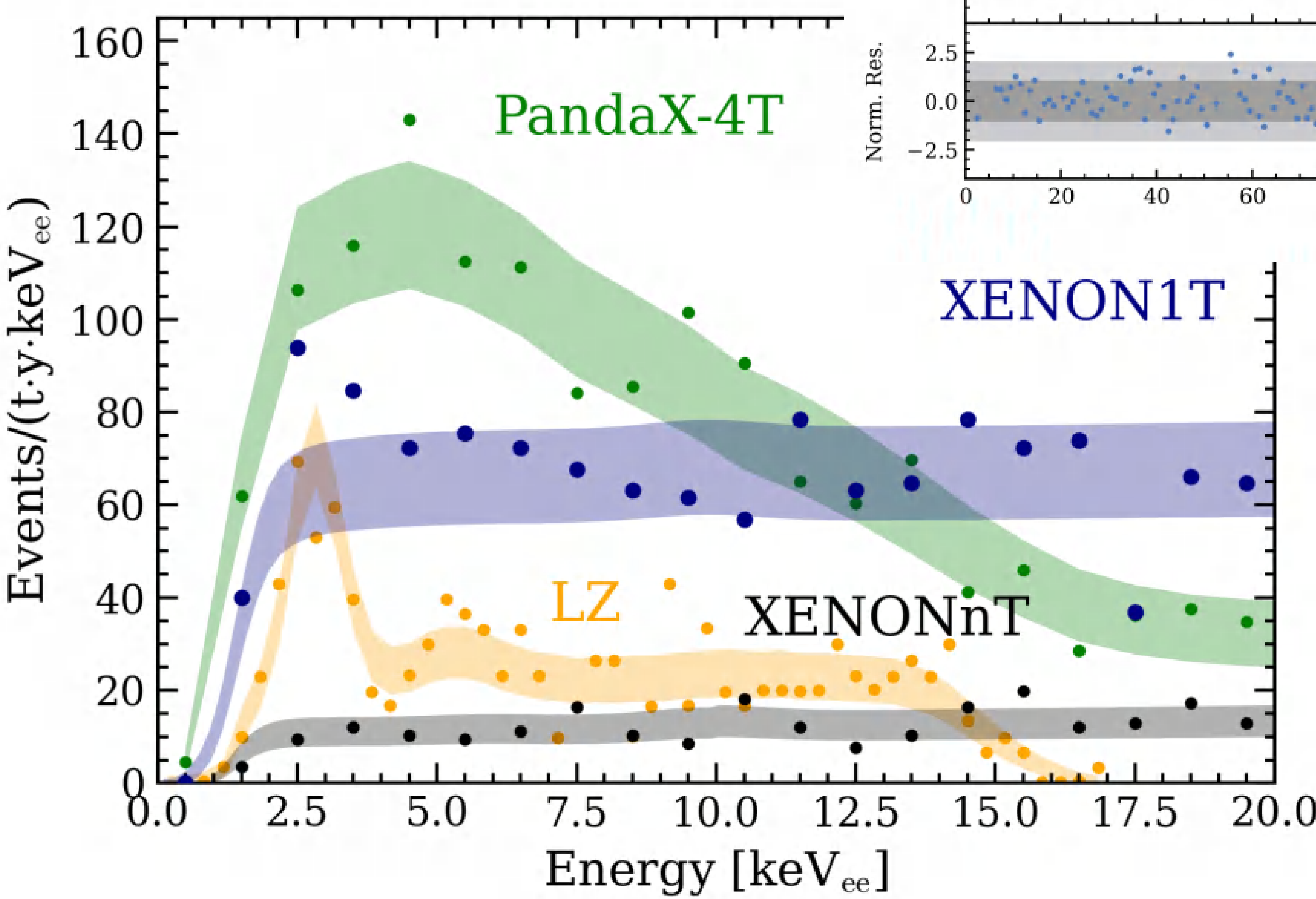


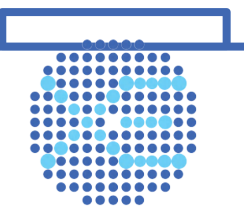
XENONnT Background





PRL 129, 161804 (2022)
PRD 102, 072004 (2020)
arXiv:2207.03764
PRL 129, 161805 (2022)

Neutrinos Searches with XENON



Neutrinoless Double β decay ($0\nu\beta\beta$) in ^{136}Xe	ER	2458 keV	Beyond Standard Model
2 Neutrinos Double Electron Capture (2νDEC) in ^{124}Xe	ER	64.3 keV	Standard Model
Solar pp Neutrinos with Enhanced Magnetic Moment	ER	O(1) keV - O(100) keV	Beyond Standard Model
Solar pp Neutrinos Elastic Scattering	ER	O(1) keV - O(100) keV	Standard Model
Supernova (SN) Neutrinos	NR	< 10 keV	Standard Model
Solar ^{8}B Neutrinos CEvNS	NR	< 3 kev	Standard Model

Nature 568, 532–535, 2019

First observed in XENON1T

Longest half-life ever measured!

~ 10^{22} y

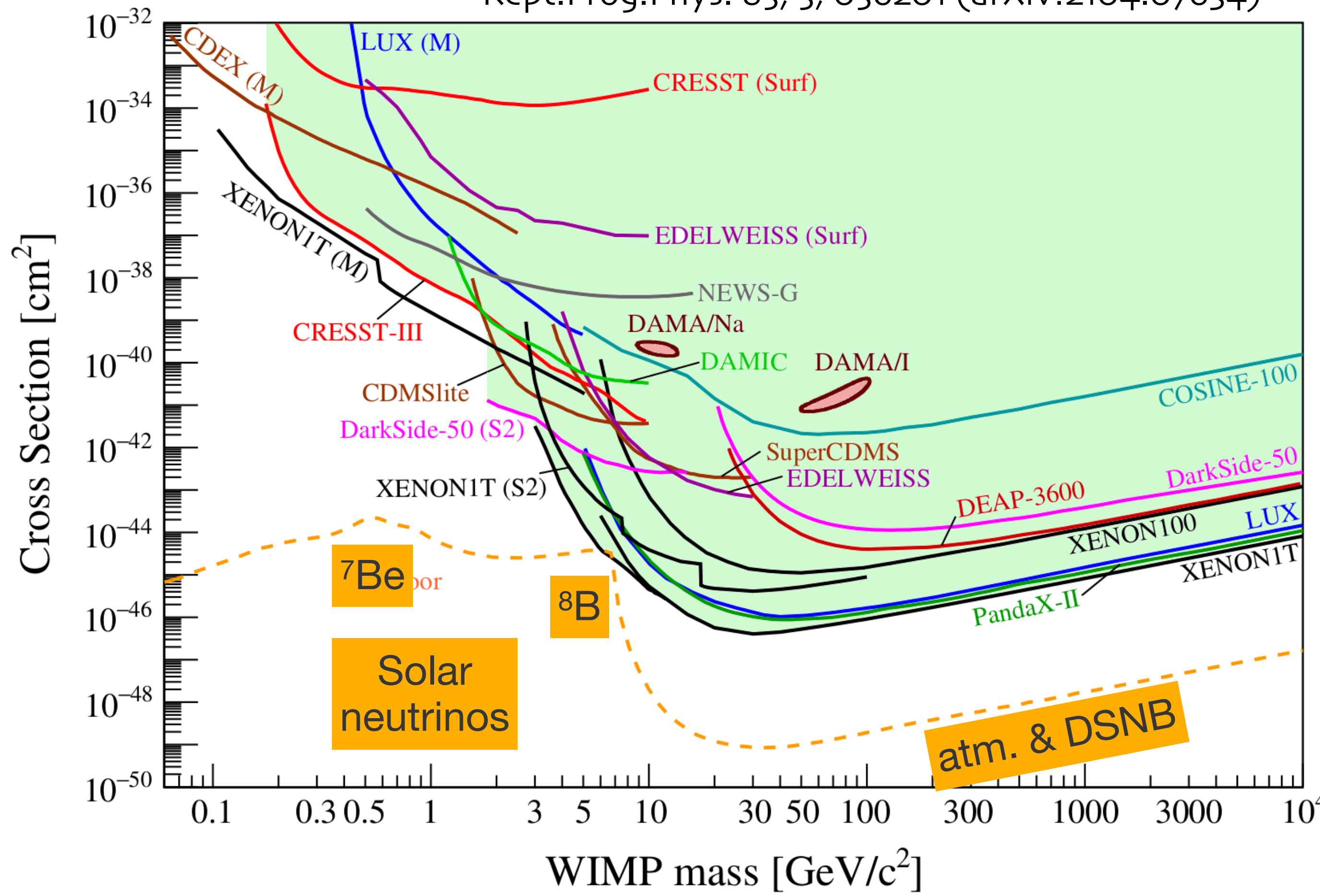
Nuclear Recoil Searches: CEνNS

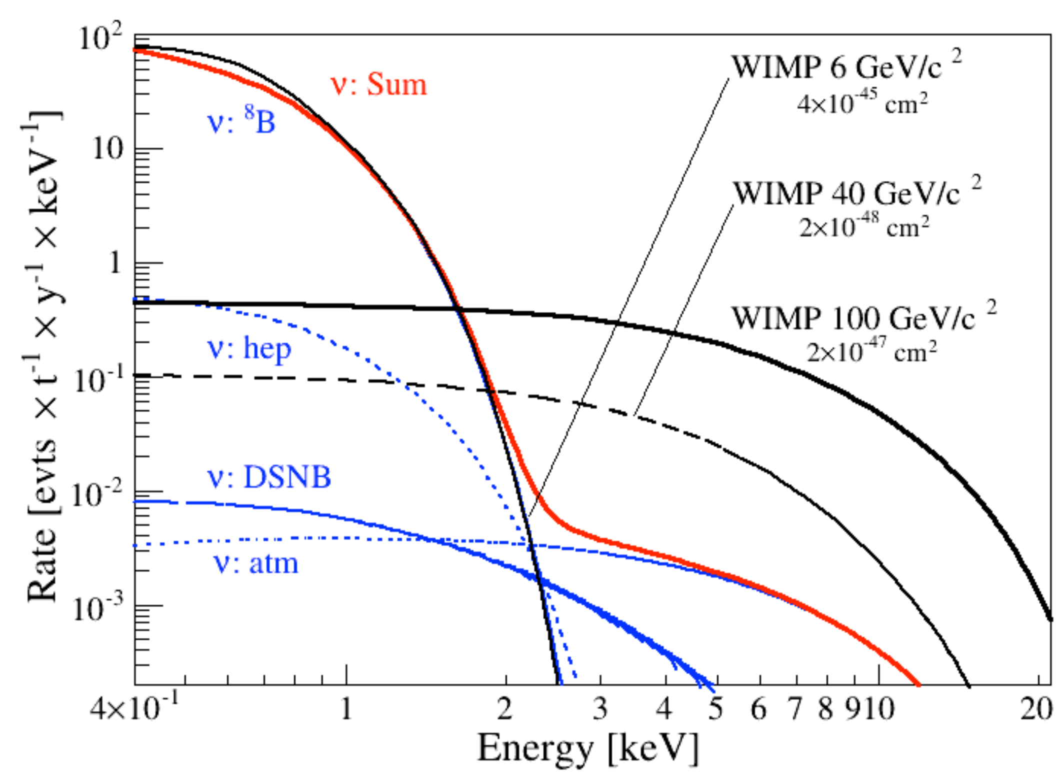
- **C**oherent **E**lastic **n**eutrino **N**ucleus **S**cattering:

$$\nu + N \rightarrow \nu + N$$

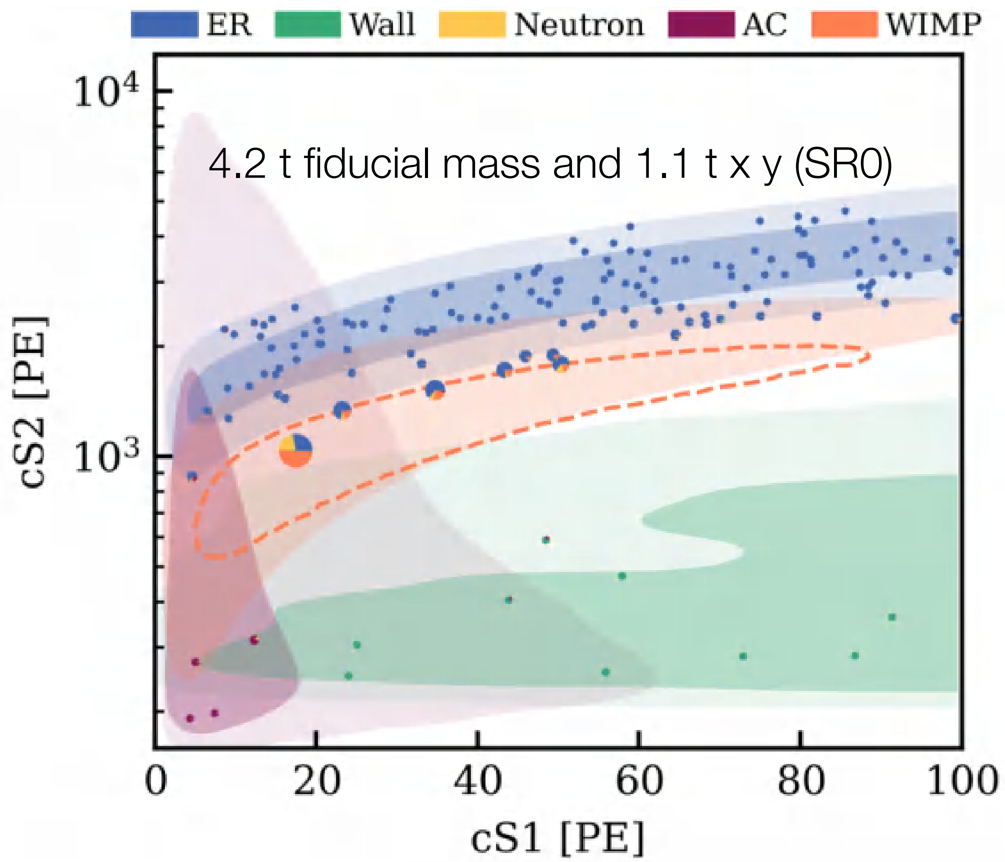
  - A neutrino hits a nucleus via Z-exchange and the nucleus recoils as a single particle; coherent for $E_\nu \lesssim 50$ MeV
  - SM interaction, flavor blind, no energy threshold
  - first detected in 2017 by COHERENT experiment
- Nuclear recoil signature, same as expected for DM-nucleus interactions ➞ "Neutrino floor/fog": Irreducible background for DM Searches
- Treated as a signal:
  - could be the first detection of CEvNS from solar neutrinos
  - **^{8}B solar neutrinos** expected to contribute most in LXe DM experiments
  - Similar rate as 6 GeV WIMPs with x-section of 4×10^{-45} cm^2

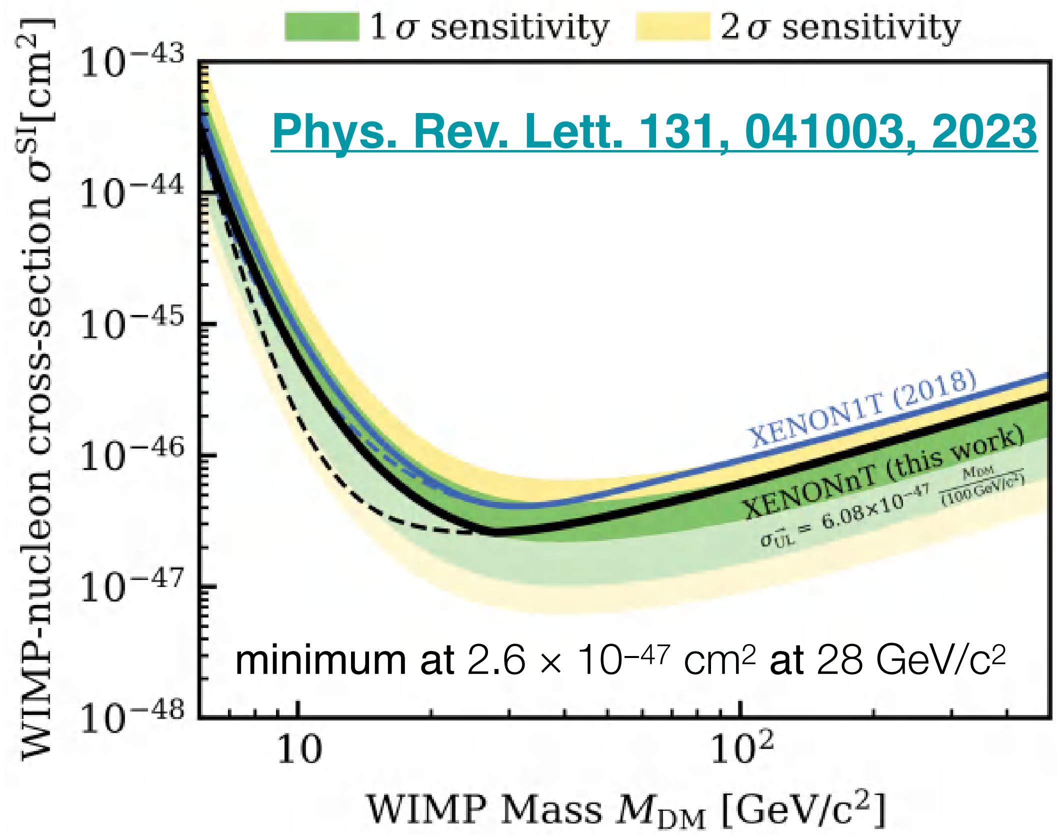
Rept.Prog.Phys. 85, 5, 056201 (arXiv:2104.07634)





Nuclear Recoils Search in XENONnT (Blind Analysis)

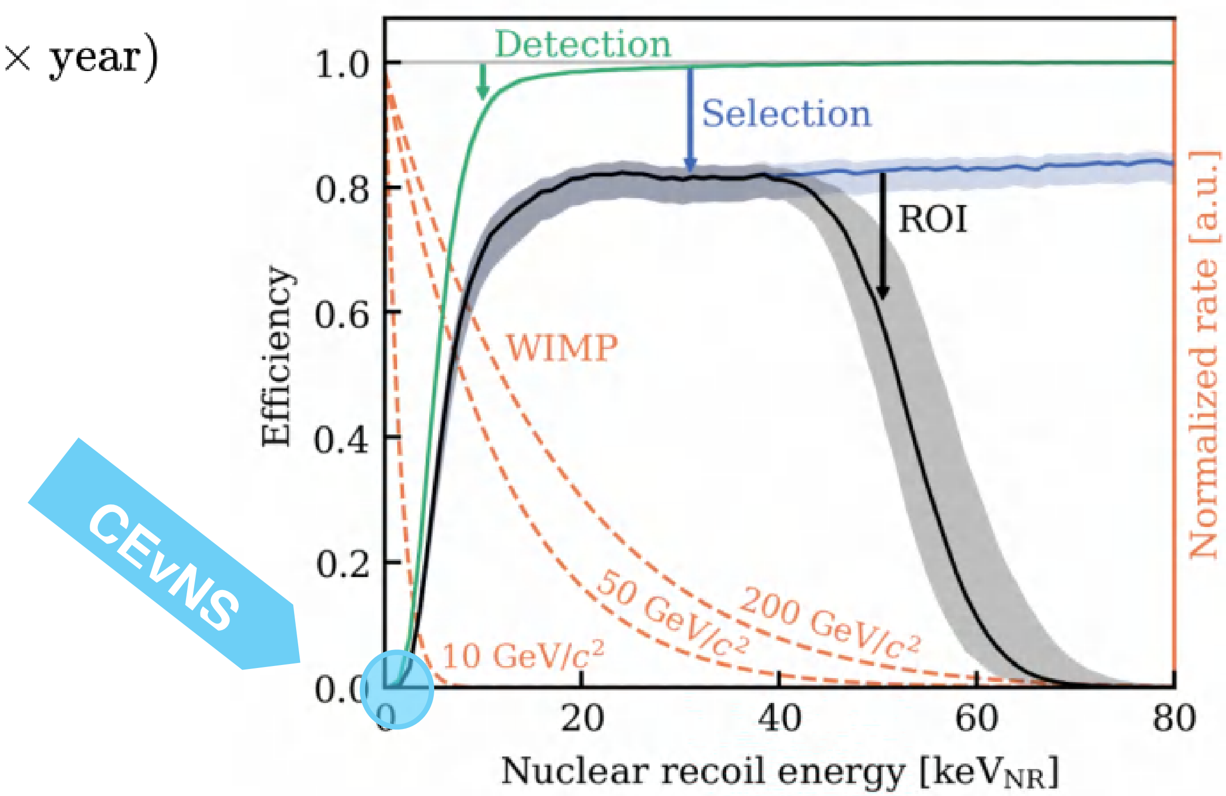




hundreds of events from **CEvNS** but at extremely low energies where detection **efficiency** is around 0.04%

$$R = \phi(\nu) \times \sigma_\nu \times \text{exposure} \simeq 600\,\text{events}/(\text{tonne} \times \text{year})$$

	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	$4.4^{+0.5}_{-0.8}$	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



Solar ^8B Neutrinos CEvNS search

INCREASE DETECTION EFFICIENCY

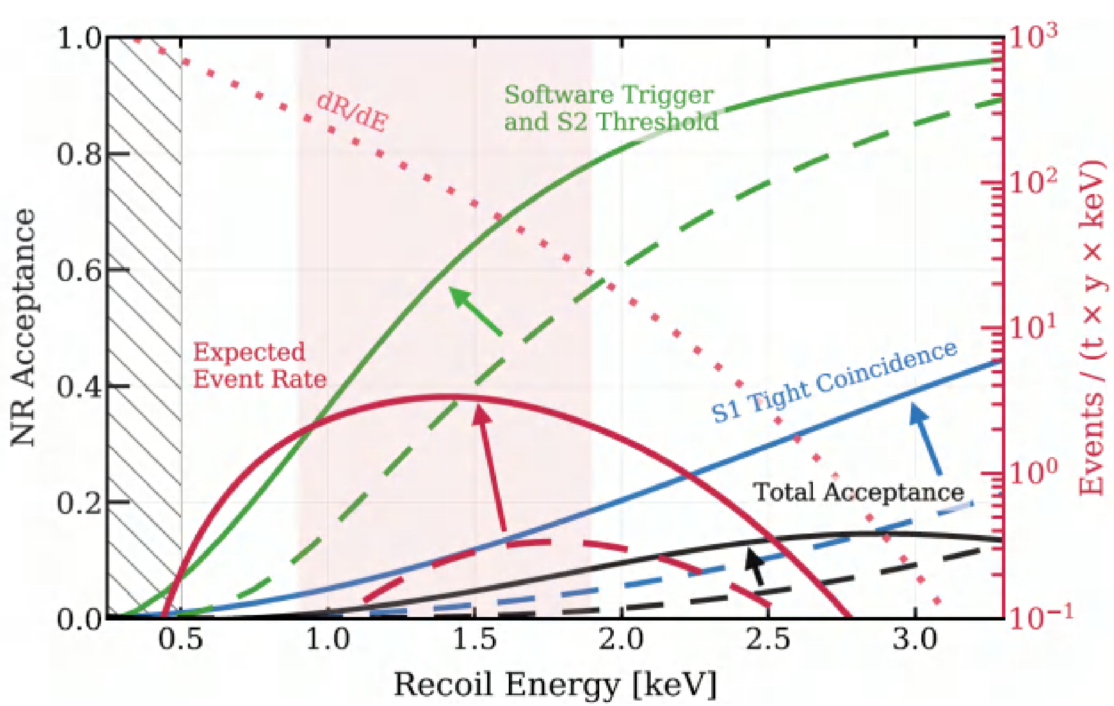
S1 threshold: 3 → 2 PMTs coincidence

S2 threshold: 200 → 100 PE

With XENON1T the NR threshold was lowered to 1.6 keV

No CEvNS excess , new WIP limit down to 3GeV

Lower energy **threshold** → **Background rate** increased by **two orders** of magnitude



Phys. Rev. Lett. 126, 091301, 2021

REDUCE BACKGROUND AT LOW ENERGY

Main background for **CEvNS** given by **Accidental Coincidences** (AC), resulting from random **pairing** of **isolated S1s** and **S2s**.

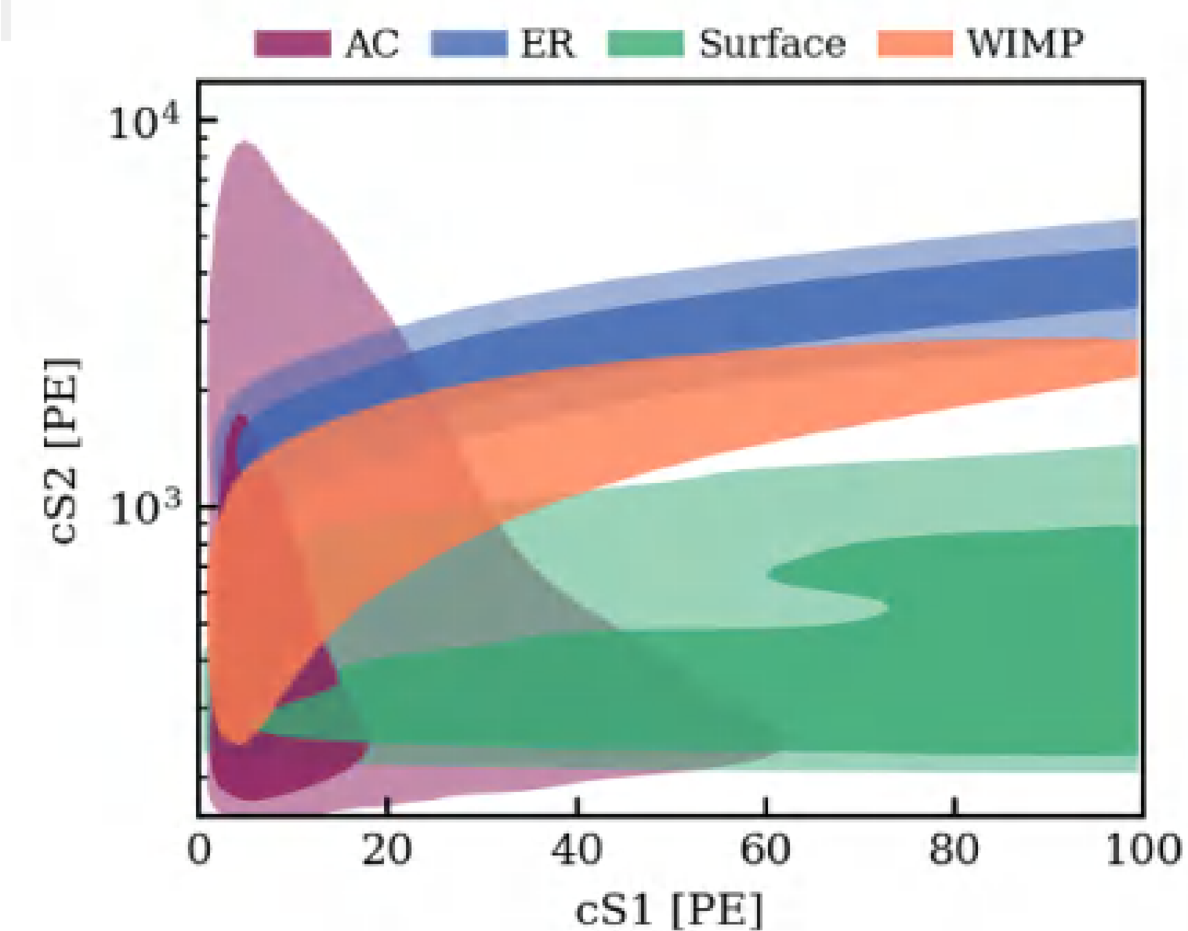
Various **mitigation** strategies: dedicated **selection** in **specific observables**, **ML techniques** and AC background **modeling**

Isolated **S1s**

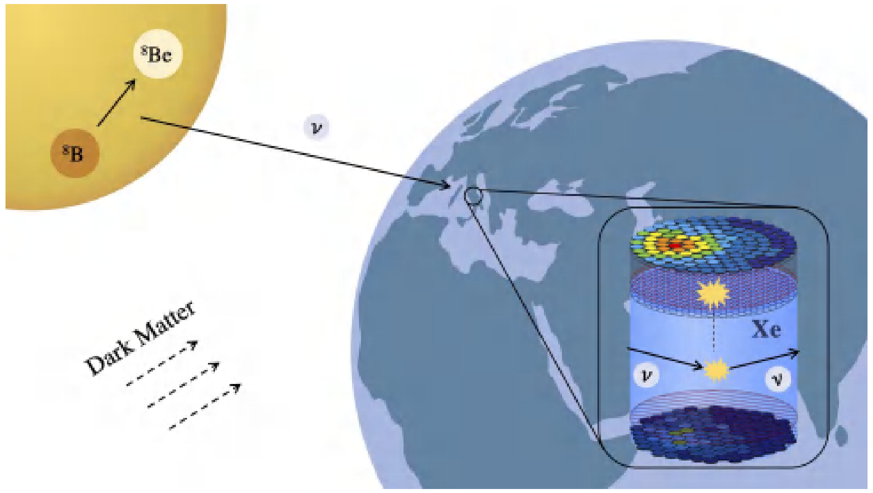
→ PMT **dark counts**
→ Misidentified **single electron**
→ Below-**cathode** and **surface**

Isolated **S2s**

→ **Single electrons** from **delayed** extraction or **photo-ionization**
→ Misidentified PMT **afterpulses**



Higher Discovery Potential for ^{8}B Neutrinos with XENONnT

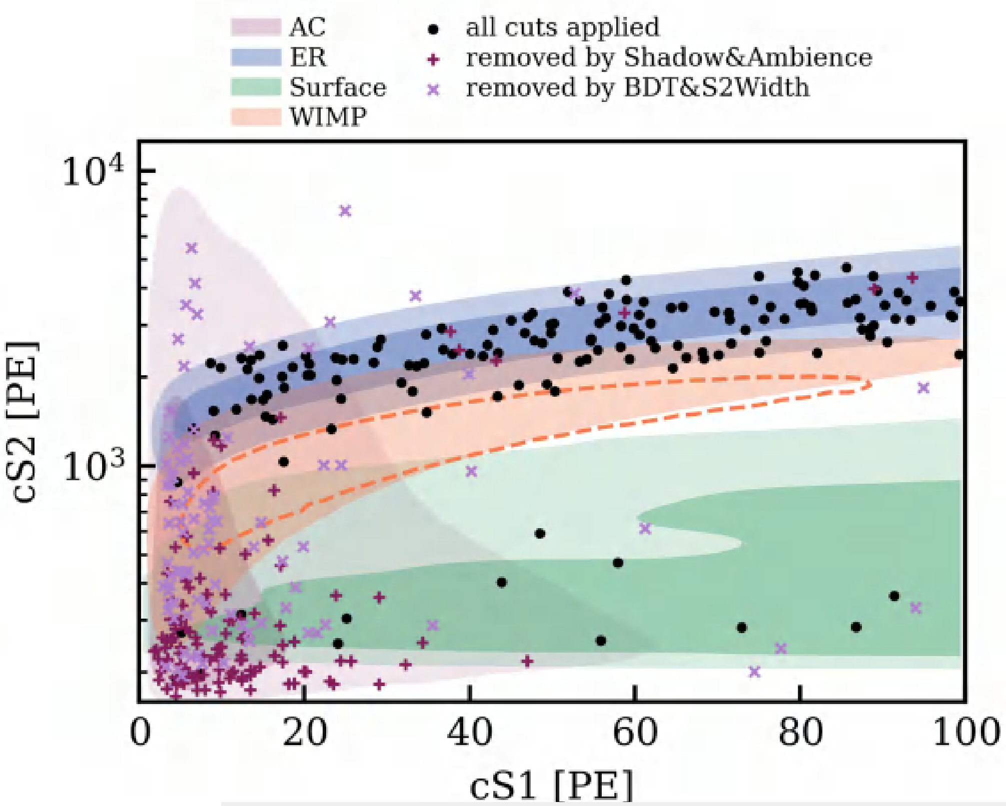


Lower drift **field** results in:

- **larger** isolated **S2** rate
- **longer drift** time
- **worst** NR-ER **discrimination**, but negligible for CEvNS

Higher exposure in XENONnT

Larger AC rate but improved **AC suppression** with new techniques, mostly due to S1S2 correlations



Accidental coincidence background **reduced** and modeling **validated** in the **XENONnT WIMP** analysis (Science Run 0)

Ongoing **low-threshold 2-fold** coincidence analysis!

Expectation	AC / (t x yr)	CEvNS / (t x yr)	Exposure / (t x yr)
XENON1T	8.6	3.6	0.6
XENONnT	~3.2	~5	> 0.6

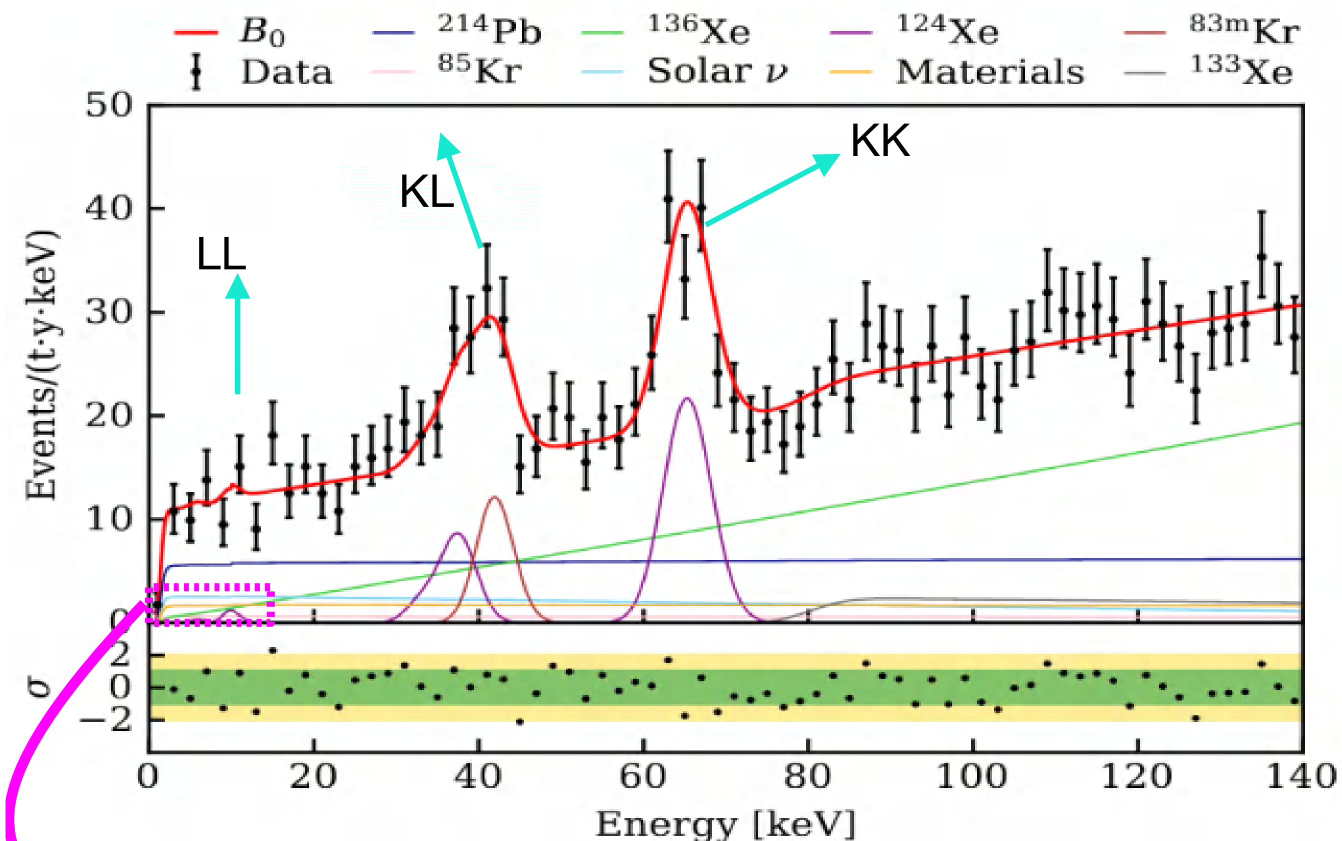
PRELIMINARY

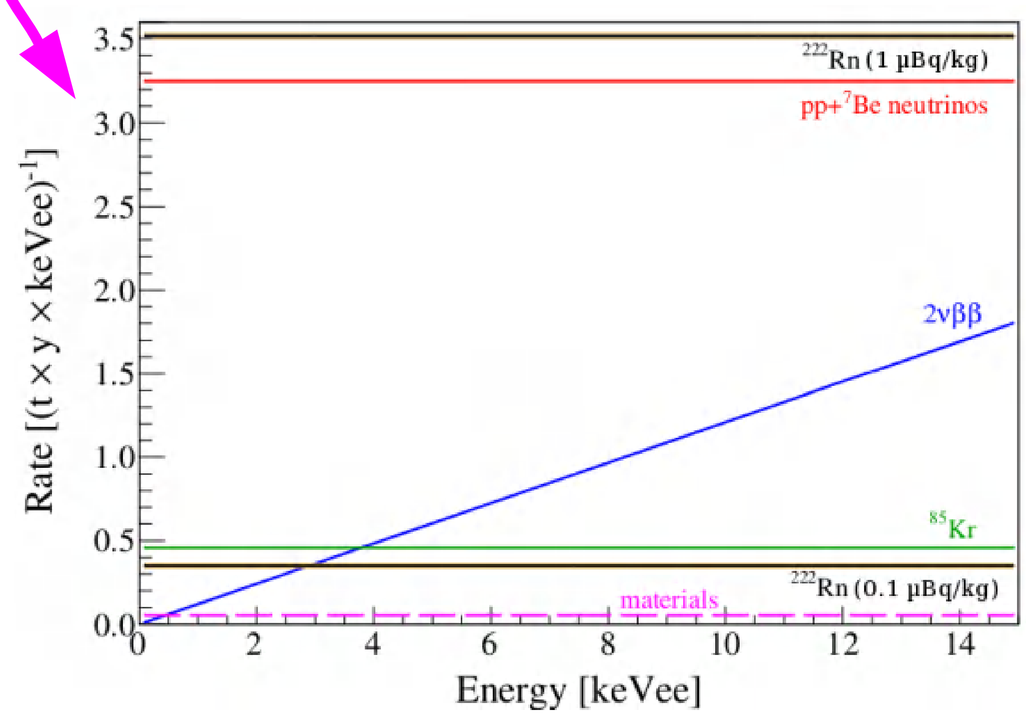
Electronic Recoils Search in XENONnT(Blind Analysis)

- Spectral shape dominated by two double-weak decays: ^{136}Xe $2\nu\beta\beta$, ^{124}Xe 2νECEC
- Total ER background below 30 keV: 16 events/(t y keV) dominated by Pb214
- Solar neutrinos: second largest background below 10 keV
- No excess observed in XENONnT
- Better constraints on BSM physics, for instance on neutrino magnetic moment $\mu_\nu < 6.4 \times 10^{-12} \mu_B$

	(1, 10) keV	(1, 140) keV
^{214}Pb	56 ± 7	980 ± 120
^{85}Kr	6 ± 4	90 ± 60
Materials	16 ± 3	270 ± 50
^{136}Xe	8.7 ± 0.3	1520 ± 50
Solar ν	25 ± 2	300 ± 30
^{124}Xe	2.6 ± 0.3	260 ± 30
AC	0.70 ± 0.03	0.71 ± 0.03
^{133}Xe	-	160 ± 60
^{83m}Kr	-	80 ± 16

Phys. Rev. Lett. 131, 041003, 2023





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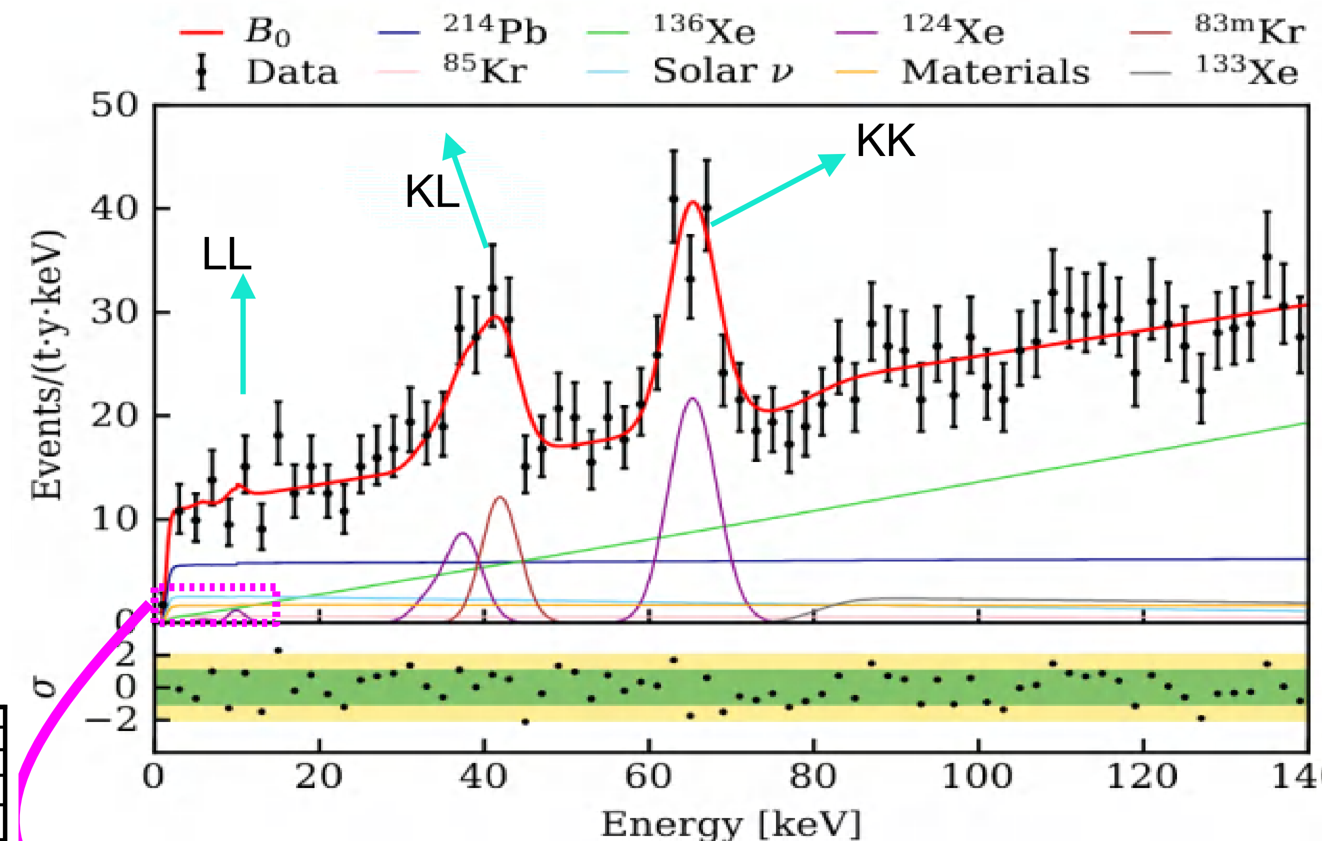
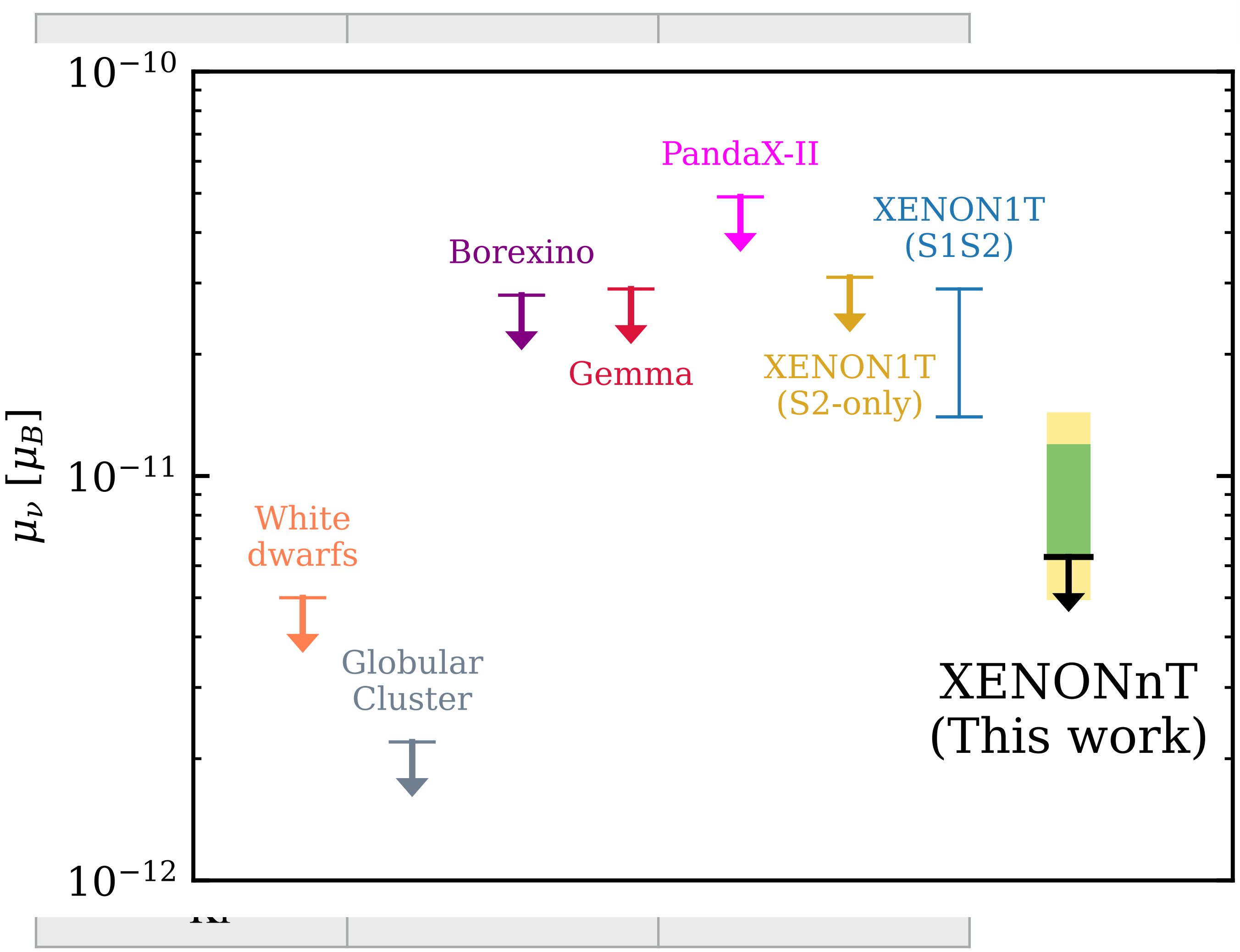
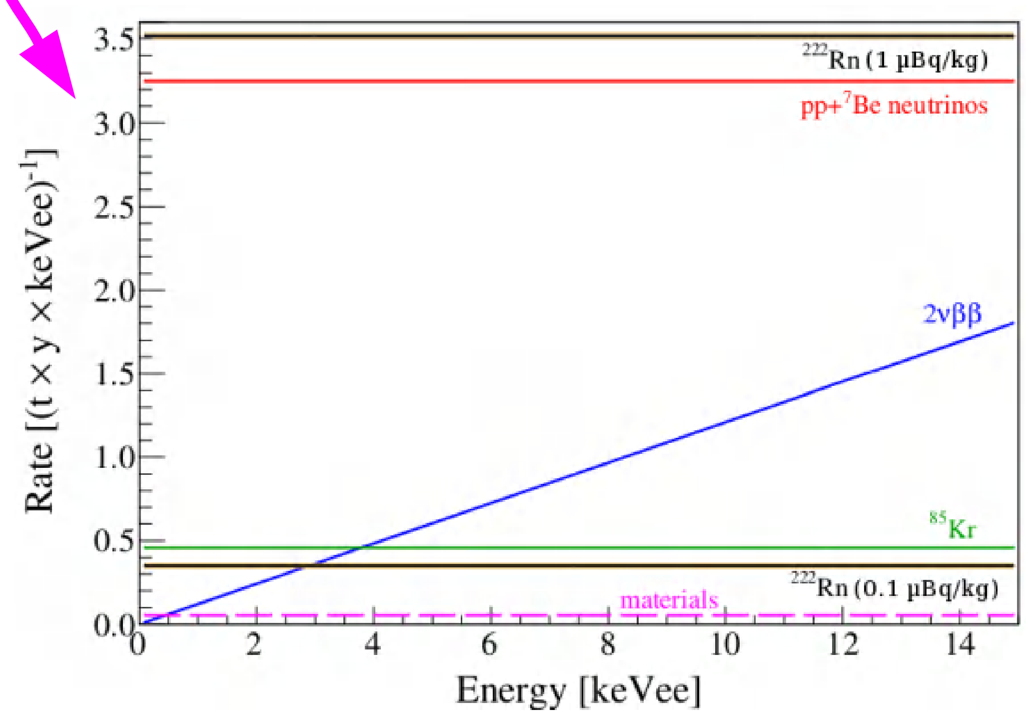
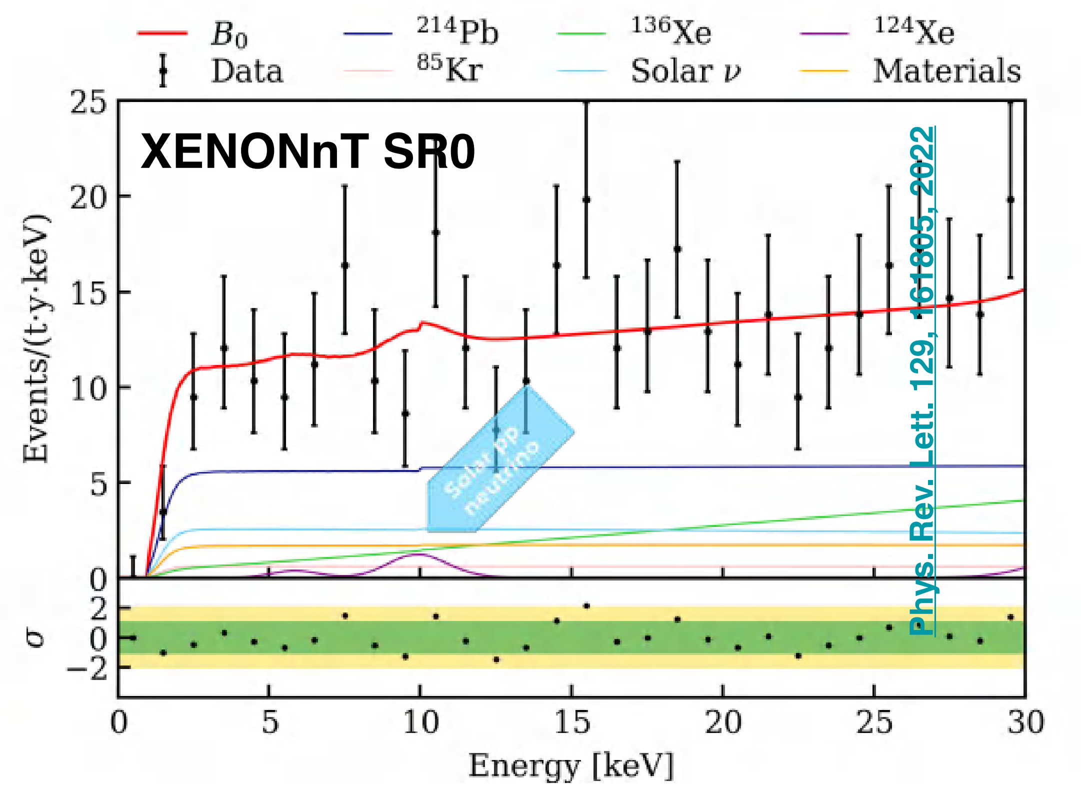






Solar pp Neutrinos Detection with XENONnT



SR0 best-fit	(1, 10) keV	(1, 140) keV
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ELECTRONIC RECOILS SEARCH

Solar neutrinos (mostly from **pp** chain) can be detected due to **elastic scattering** off **e$^-$** in LXe (charged and neutral current)

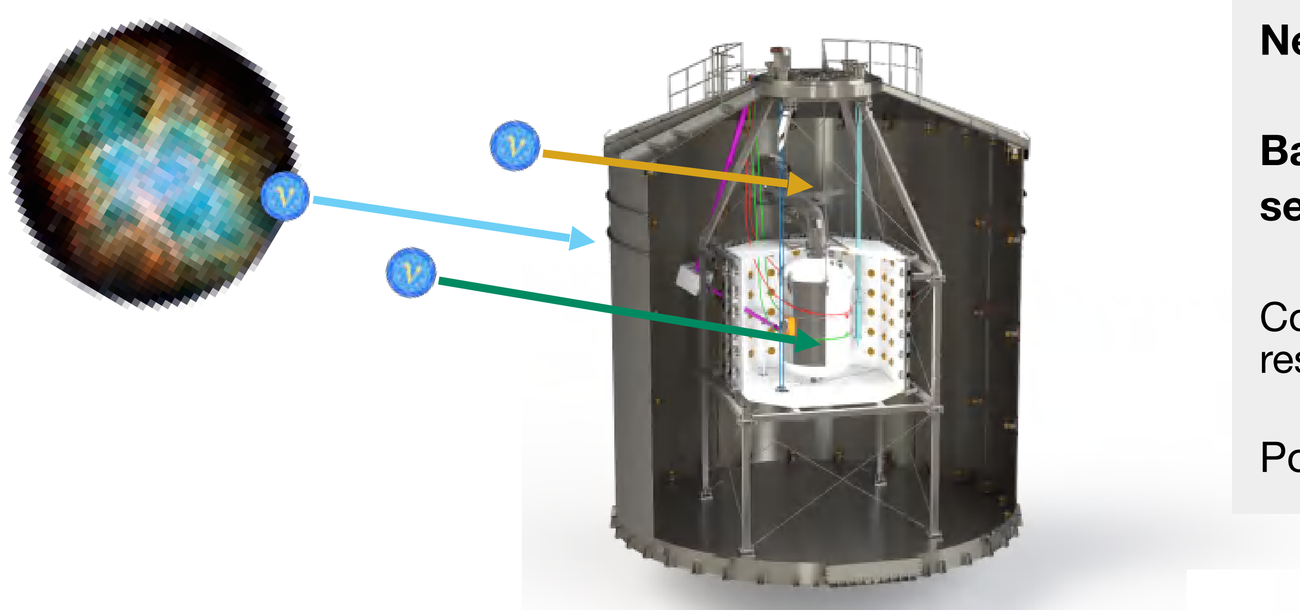
^{214}Pb (from **^{222}Rn**) is one **major background** in this region but improvements to **Radon Removal System** reduced it **below 1 uBq/kg** for science runs after SR0

Search for solar pp neutrinos in SR1

Measurement starts to be possible in XENONnT as the **^{214}Pb** in SR1 is less than half of that in SR0

For the **first** time, elastic scattering off e- from **solar neutrinos** has a **similar ER contribution** as **^{214}Pb** in (1, 10) keV

Supernova Neutrinos Detection with XENONnT



PREDICTIONS

Neutrinos deposit around **O(1) keV** in LXe

Background stable in time, can be reduced with **specific selection** (similar to ^{8}B search)

Considering signal evolution, time **window** can be **optimized**, resulting in ~8σ significance (10 kpc)

Possible improvements using **coincident** signals from **vetoes**

SUPERNOVA NEUTRINO CHANNELS IN XENONnT

→ **TPC**, **6 t** of LXe

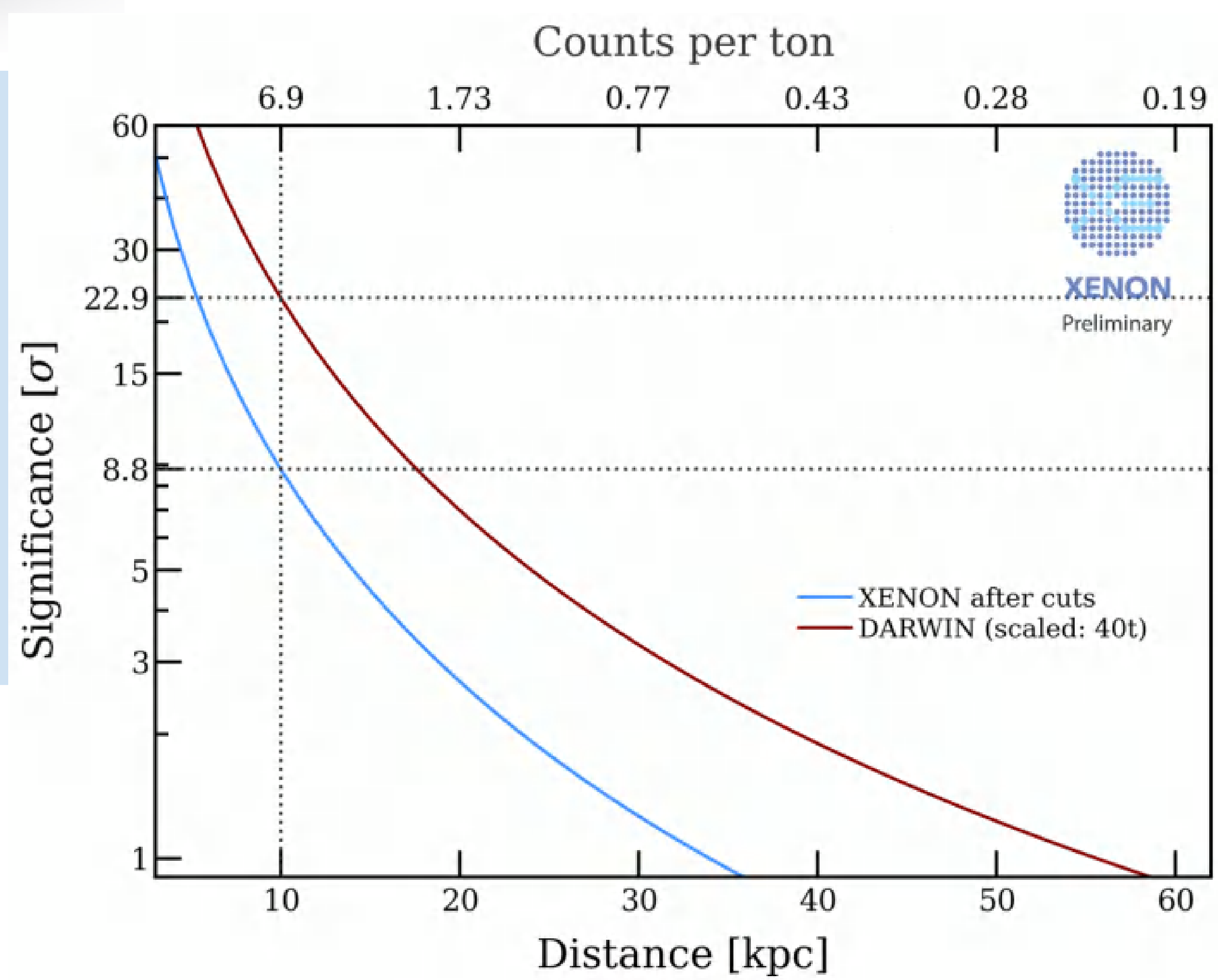
$\nu_{e,\,\mu,\,\tau}\,,\,\bar{\nu}_{e,\,\mu,\,\tau}$ via **CEvNS** (charged and other neutral current are subdominant)

~ **100 expected** events from supernova at 10 kpc

→ **MUON & NEUTRON VETO**, **700 t** ultra-pure water

$\bar{\nu}_e$ via **inverse beta** decay with H

~ **70 - 200 expected** events from supernova at 10 kpc

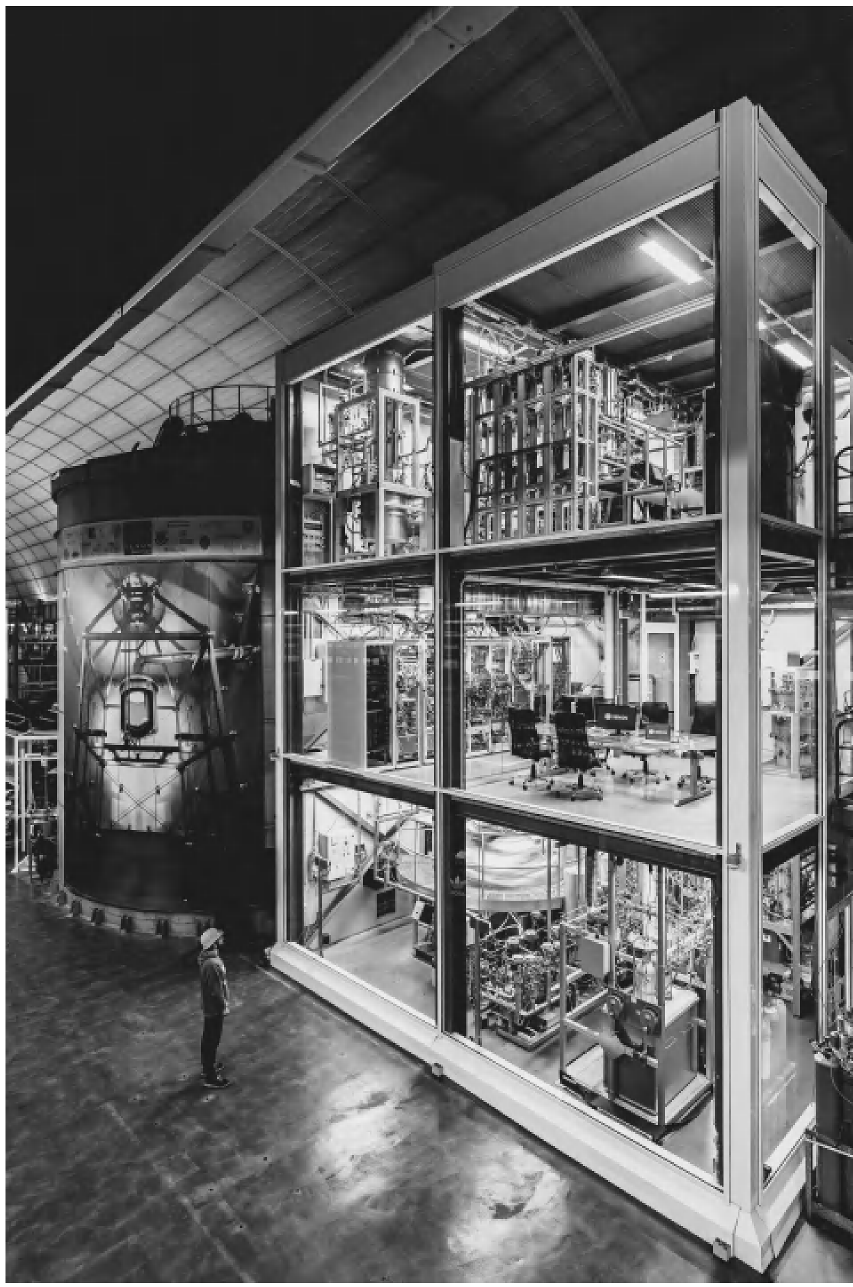


SNEWS INTEGRATION

XENONnT is **ready** to join the **Supernova Early Warning System (SNEWS)**

It will **receive** incoming **alerts** to check data and **send** possible **supernova observations**

Summary



- Current generation WIMP detectors based on LXe can contribute to neutrino physics already.
- With the lowest ER background among all DM experiments, XENONnT has already placed the strongest experimental limit on **neutrino magnetic moment.**
- XENONnT (and other LXeTPCs) will likely measure **CEvNS from 8B solar neutrinos. It** is also sensitive to **supernova neutrinos** for up to 50kpc
- Future multi-ten-ton scale xenon detectors will be able to probe an even larger range of neutrino physics in both
    - ER: Solar Neutrinos (^{7}Be, pp) second highest background after ^{214}Pb from ^{222}Rn
    - NR via CEvNS: DSN, atmospheric neutrinos, precision measurements of solar neutrinos (8B and hep)