XENONnT Dark Matter Experiment

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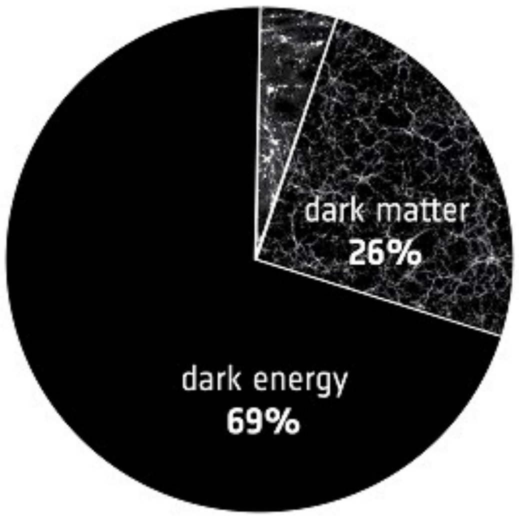
on behalf of the XENON collaboration

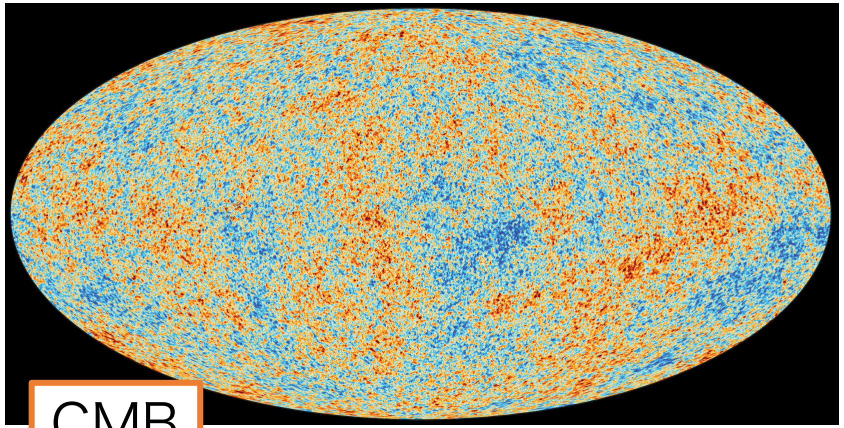
Jul. 17, 2024
ICRR young researchers' workshop

Dark Matter

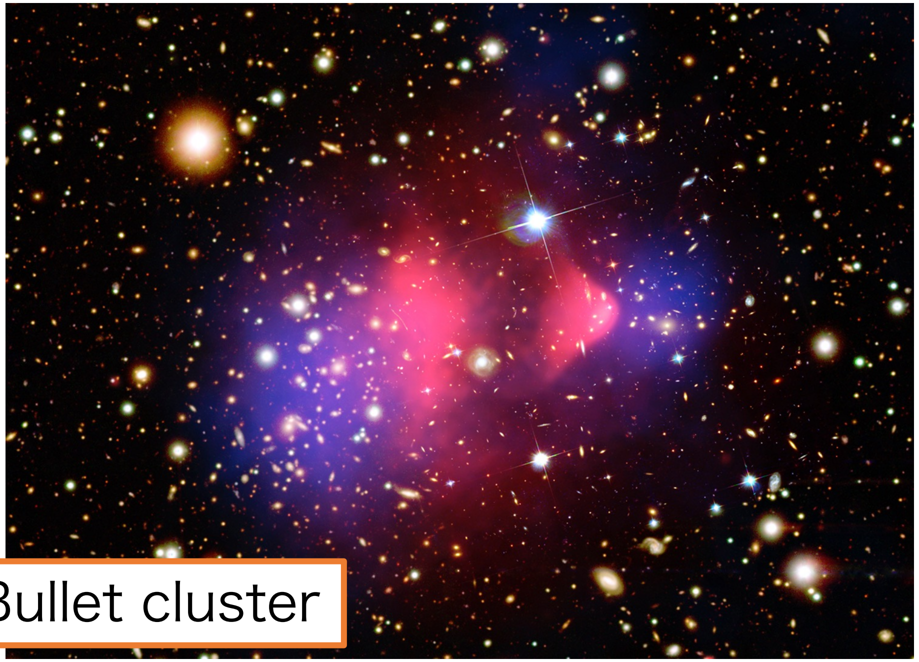
European Space Agency (https://www.esa.int)



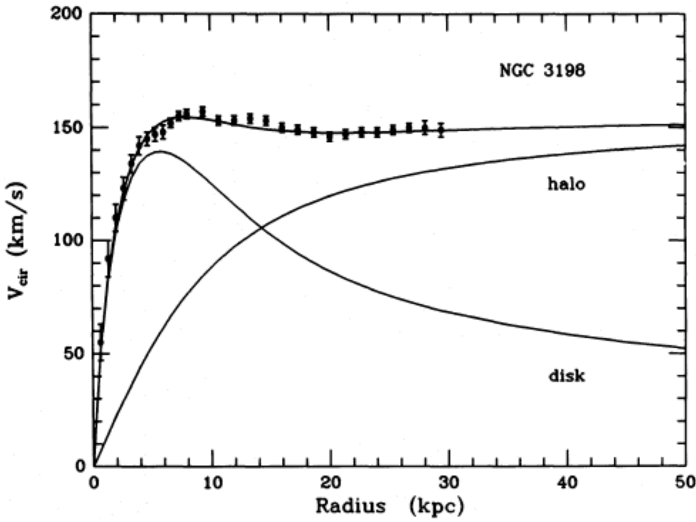
- Invisible matter accounting for 1/4 of the energy density
- multiple/multiscale evidence of existence via gravitational observation
- particle nature is unknown
  Weakly Interacting Massive Particles (WIMPS)?
  axion ?
  dark photon?



CMB



Bullet cluster

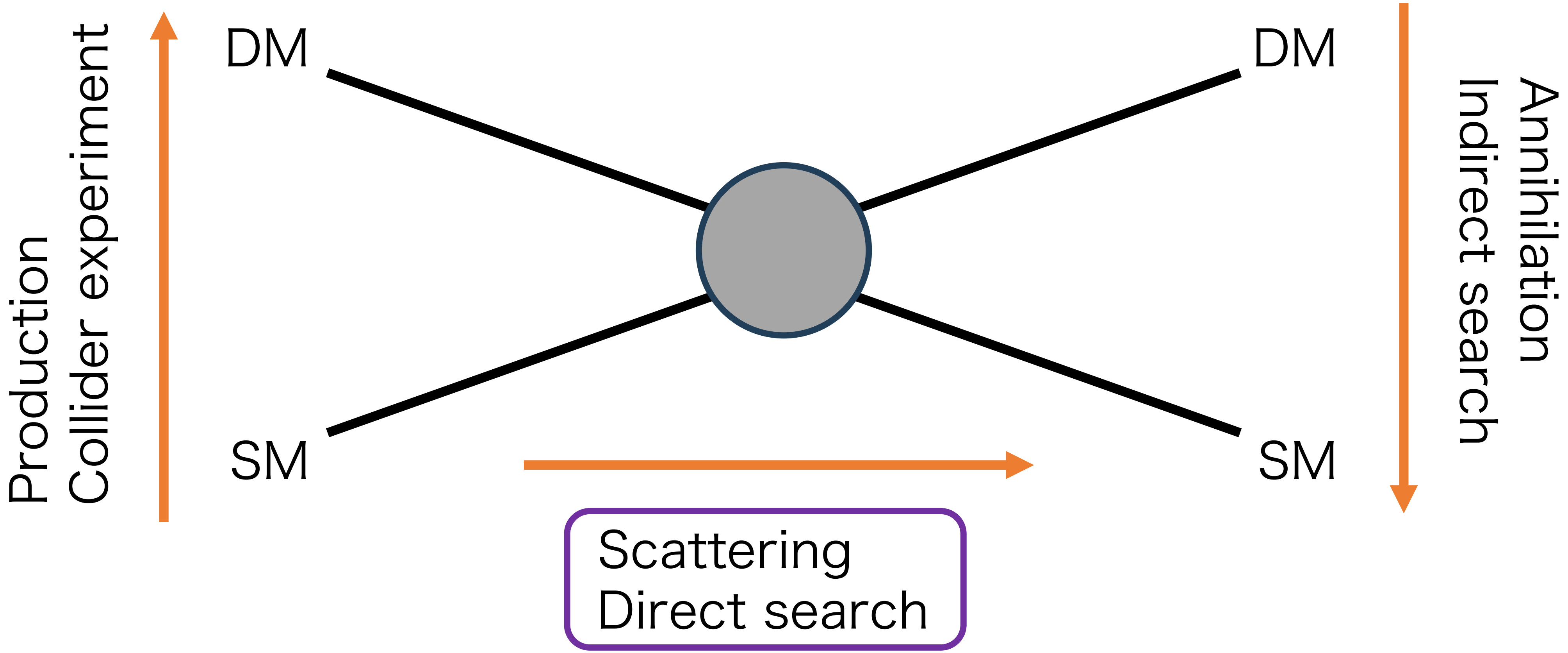


Astrophysical Journal, Vol. 295, p. 305-313 (1985)

Galaxy rotation curve

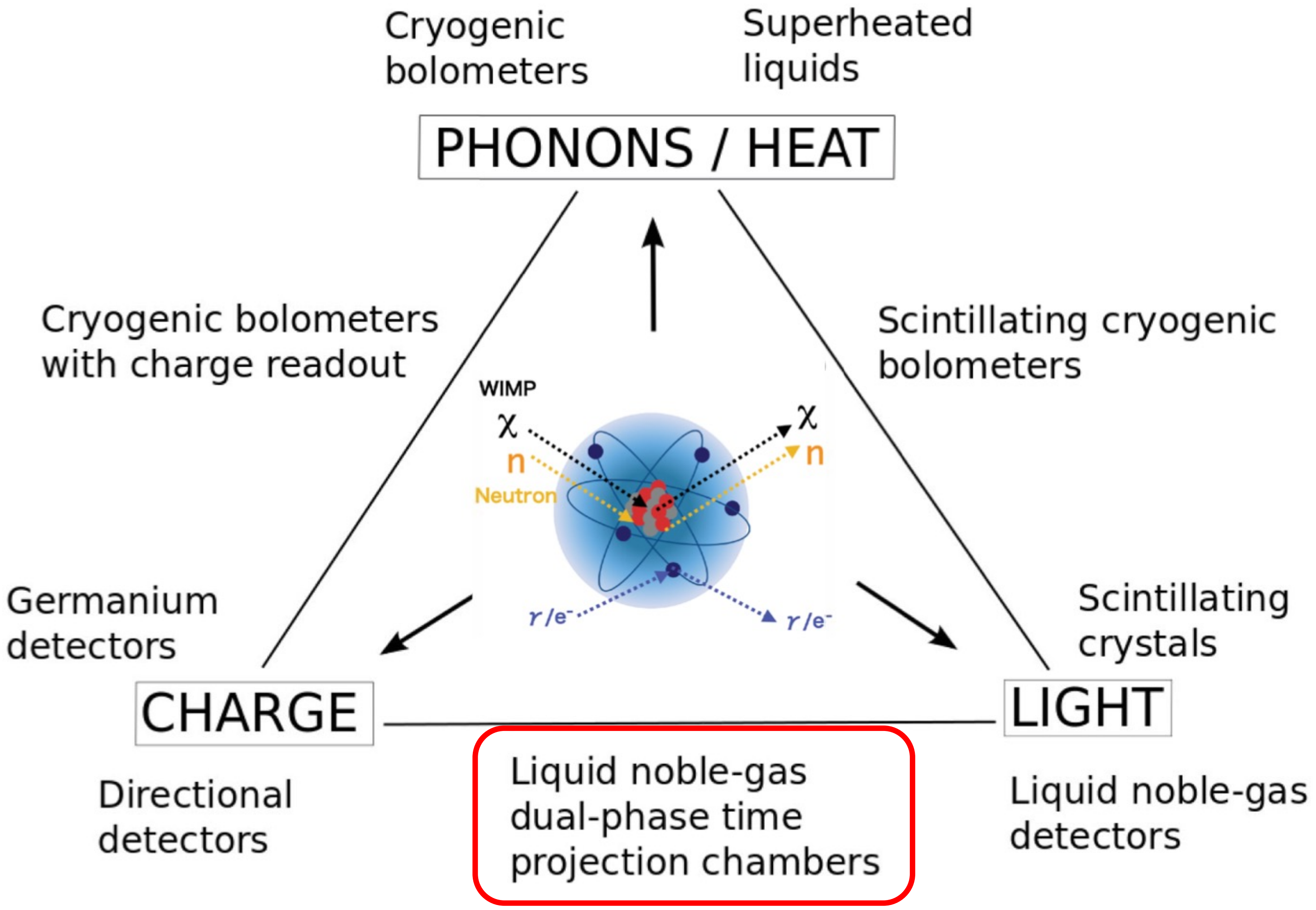
Dark Matter Search

- DM rarely interacts with standard model particles.
- Three ways of DM detection: Accelerator, Indirect, Direct



Direct search

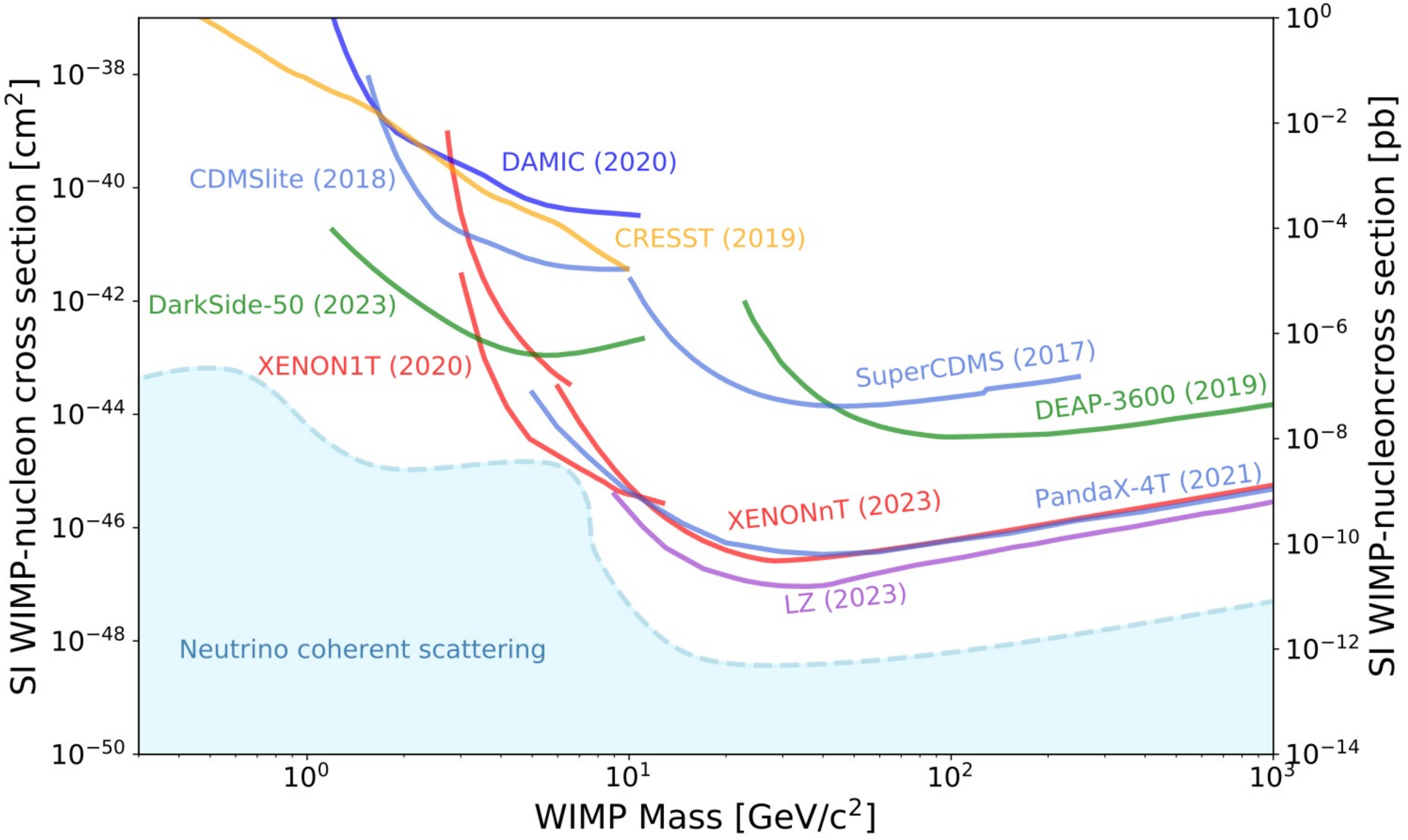
- DM local density 0.3 GeV/cm^3
- Signal
  WIMP-nucleon elastic scattering
  → **Nuclear recoil** (NR)
  axion absorption/scattering
  → **Electron recoil** (ER)
- Background
  β / γ : ER
  n : NR



J. Phys. G43 (2016) 1, 013001& arXiv:1509.08767

Current Situation

- Dual phase xenon TPC leads the field.



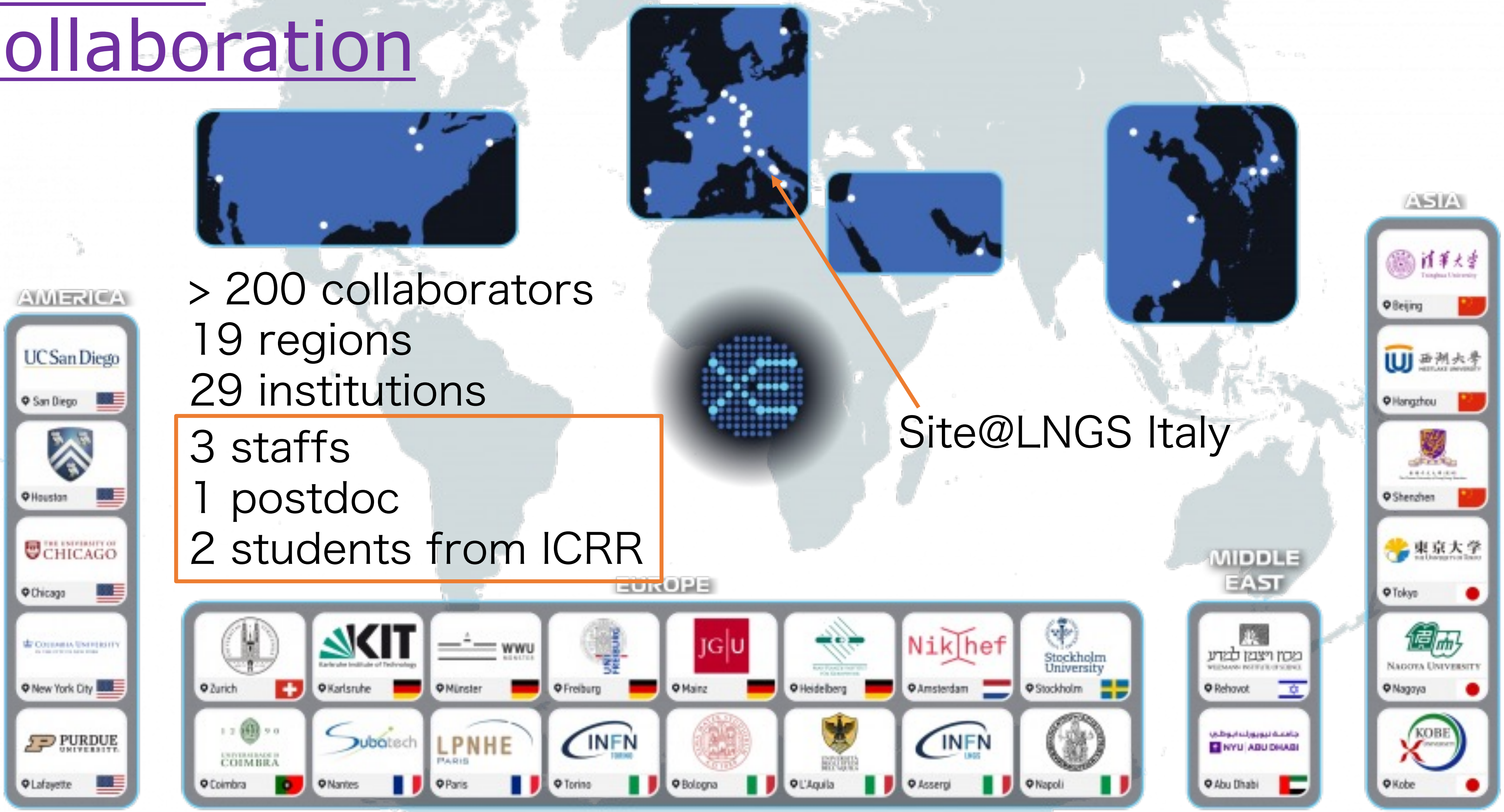
LZ
PandaX-4T
XENONnT

XENON Collaboration

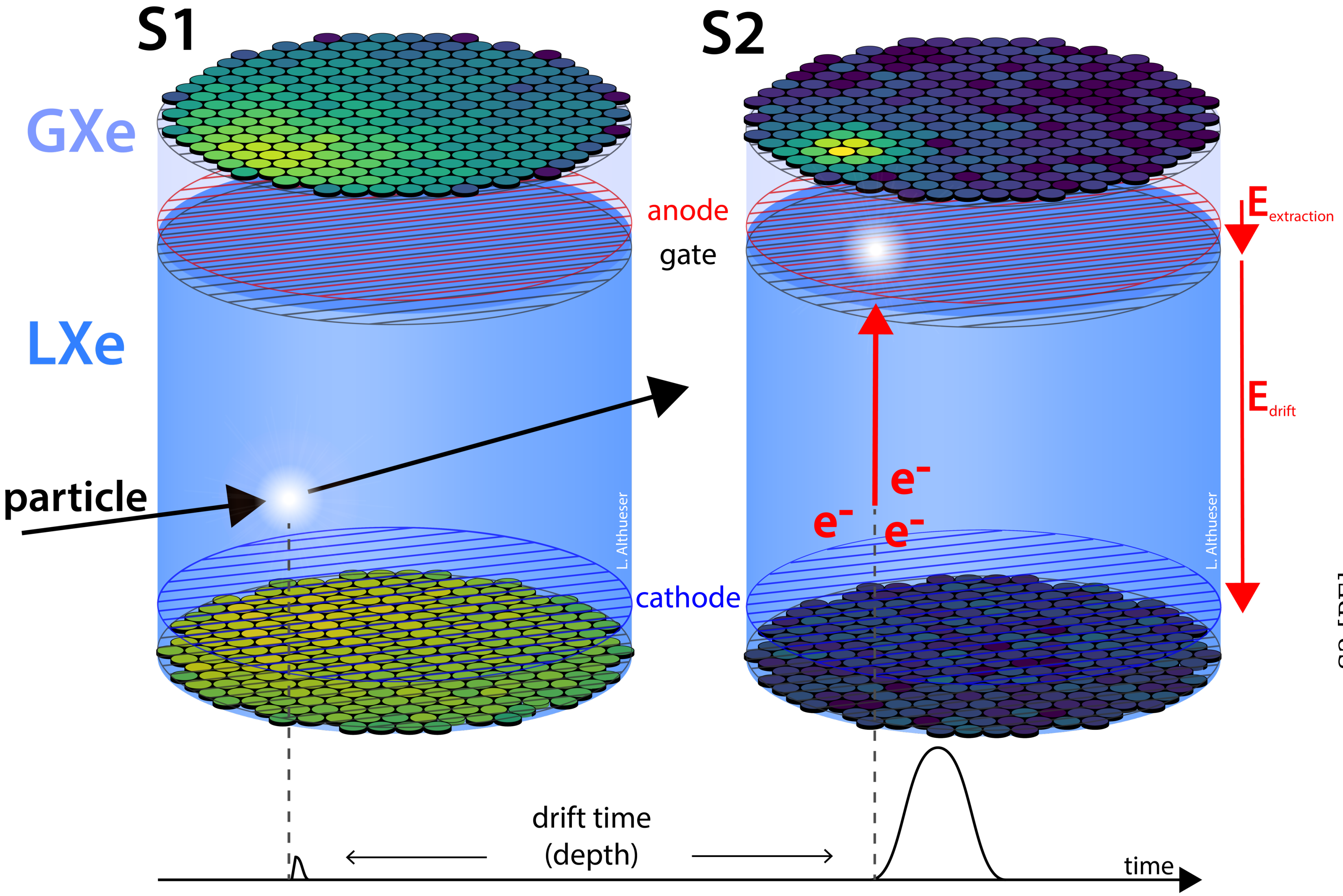
> 200 collaborators
19 regions
29 institutions

3 staffs
1 postdoc
2 students from ICRR

Site@LNGS Italy



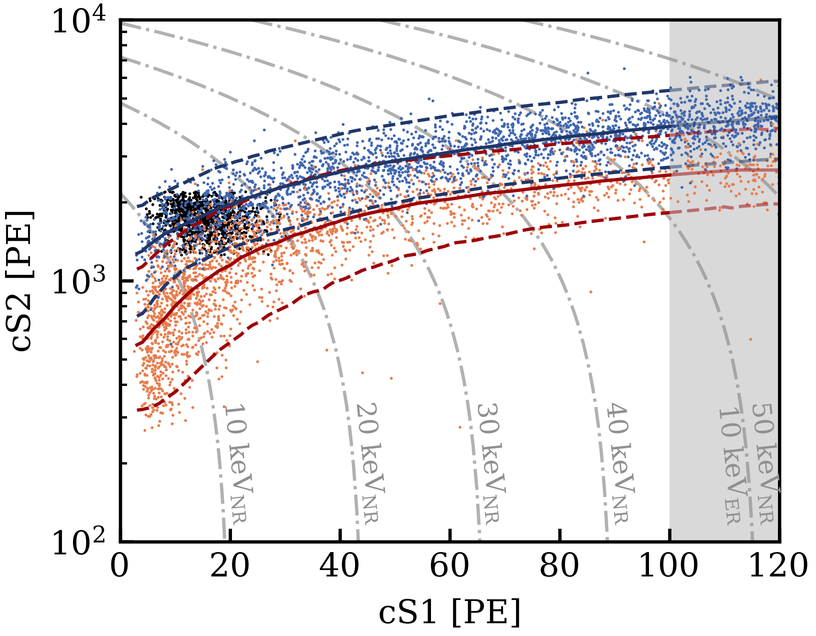
TPC Detection Principle



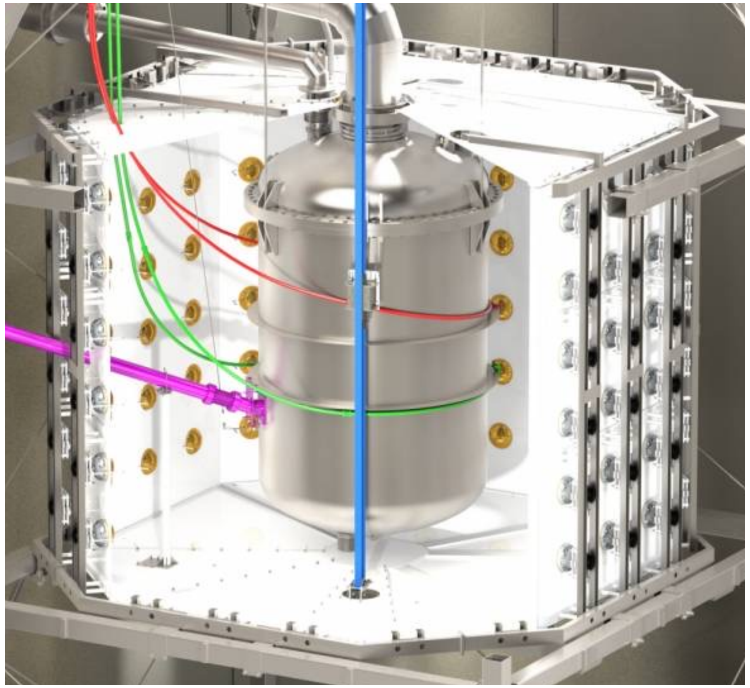
S1: Scintillation
S2: Ionization

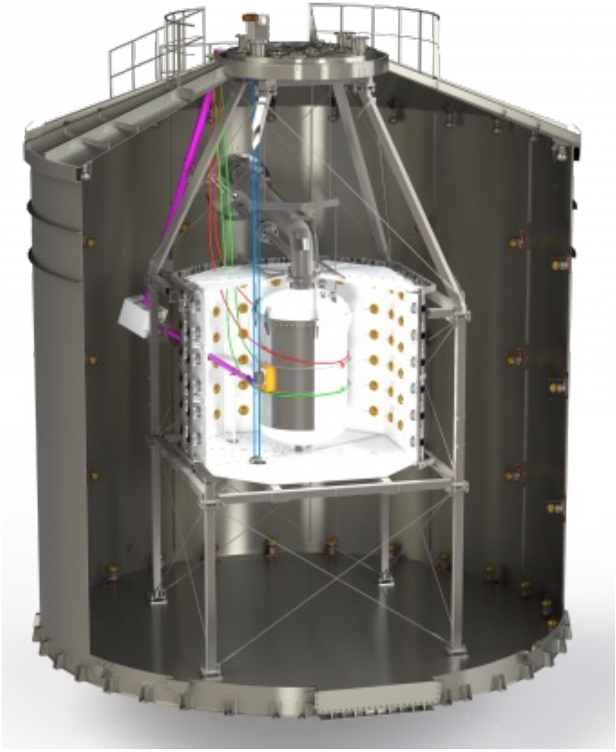
3D position reconstruction
xy: PMT hit pattern
z: drift time
→ Fiducialization

NR/ER discrimination
S1:S2 ratio



Three nested detectors



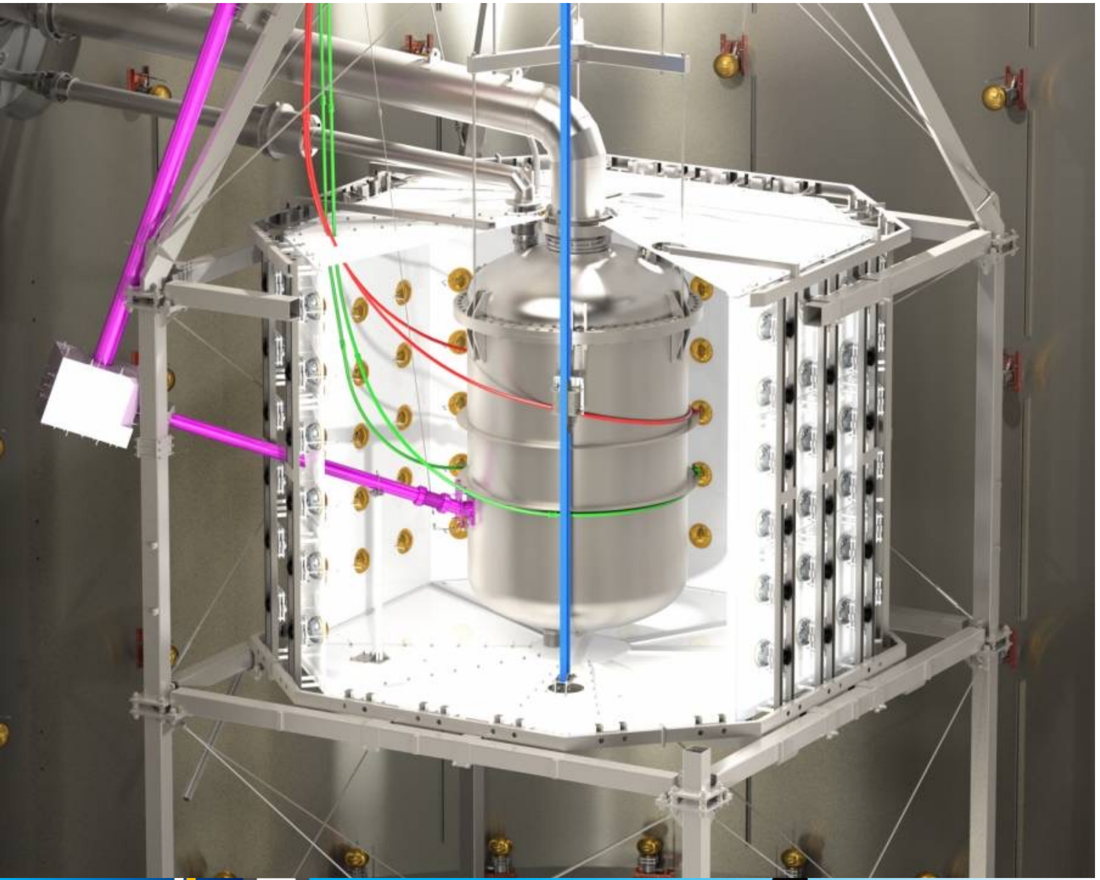


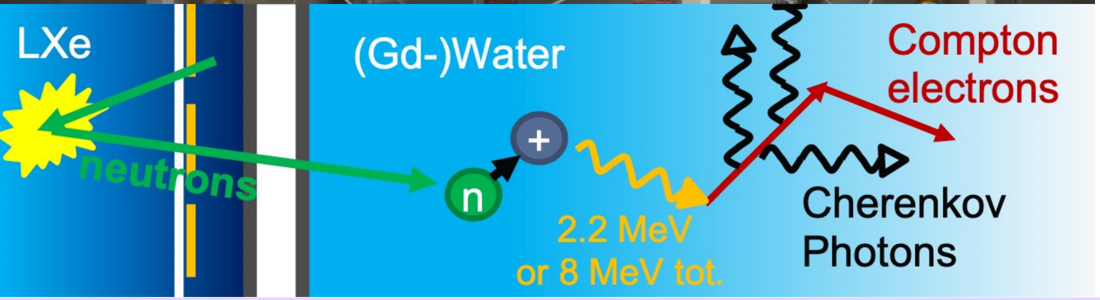
TPC
5.9 t LXe active target
1.3 m x 1.5 m diameter x height
494 PMTs
23 V/cm drift field
2.9 kV/cm extraction field

Neutron Veto
33 t water Cherenkov detector
~1 around TPC
120 8” PMTs

Muon Veto
700 t water
10 m x 10 m
84 8” PMTs
sharing same water w/ nVeto

Neutron Veto



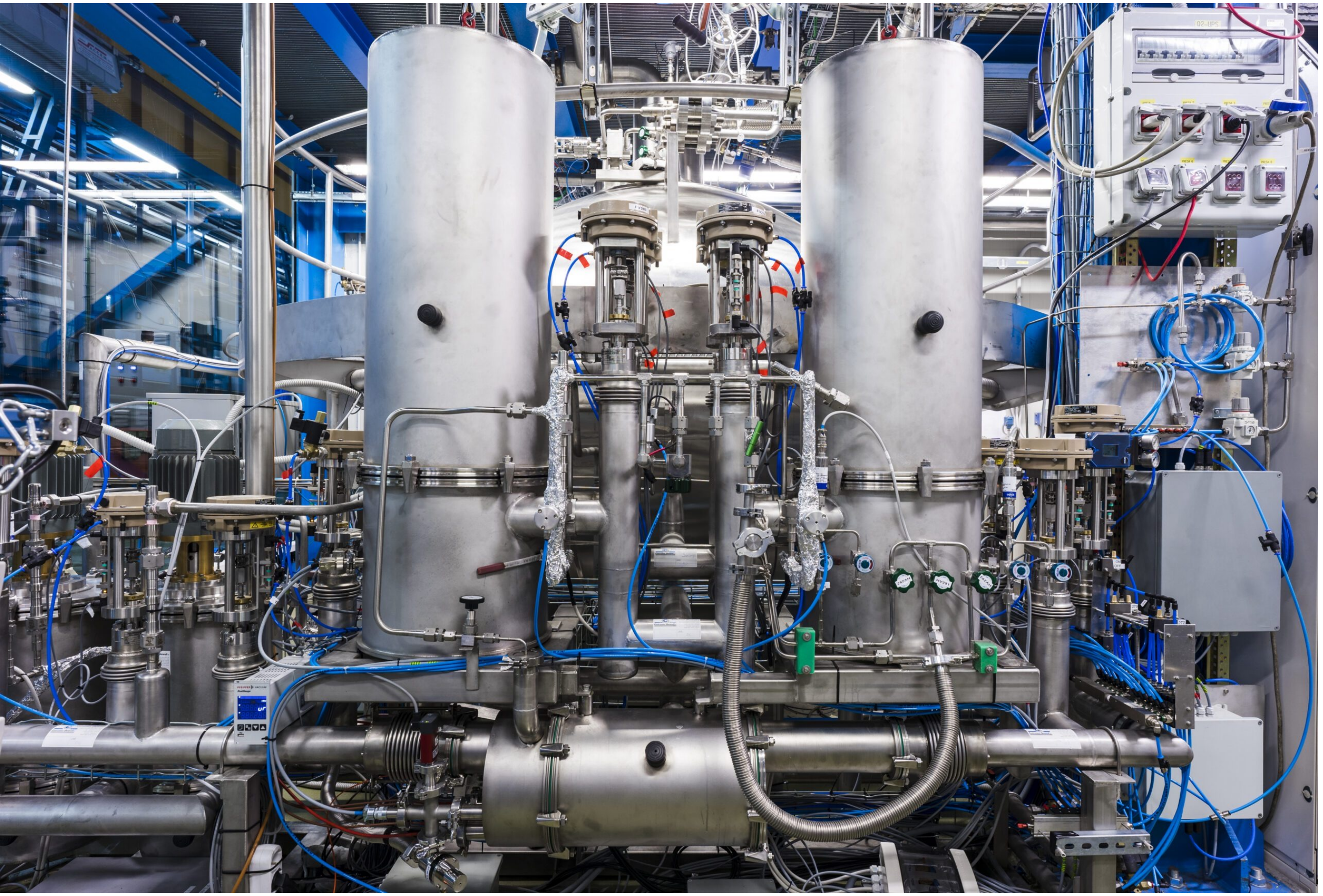


- neutrons → NR background source resembling WIMPs
- Tagging neutrons by (n, γ) on H (or Gd)
- Started w/ pure water
- Gd load from 2023 Oct.
  techniques from EGADS/Super-K!

Stage	$Gd_2(SO_4)_3 \cdot 8H_2O$ concentration	n-tag eff.
SR0	0	53%
Current	500 ppm	77%

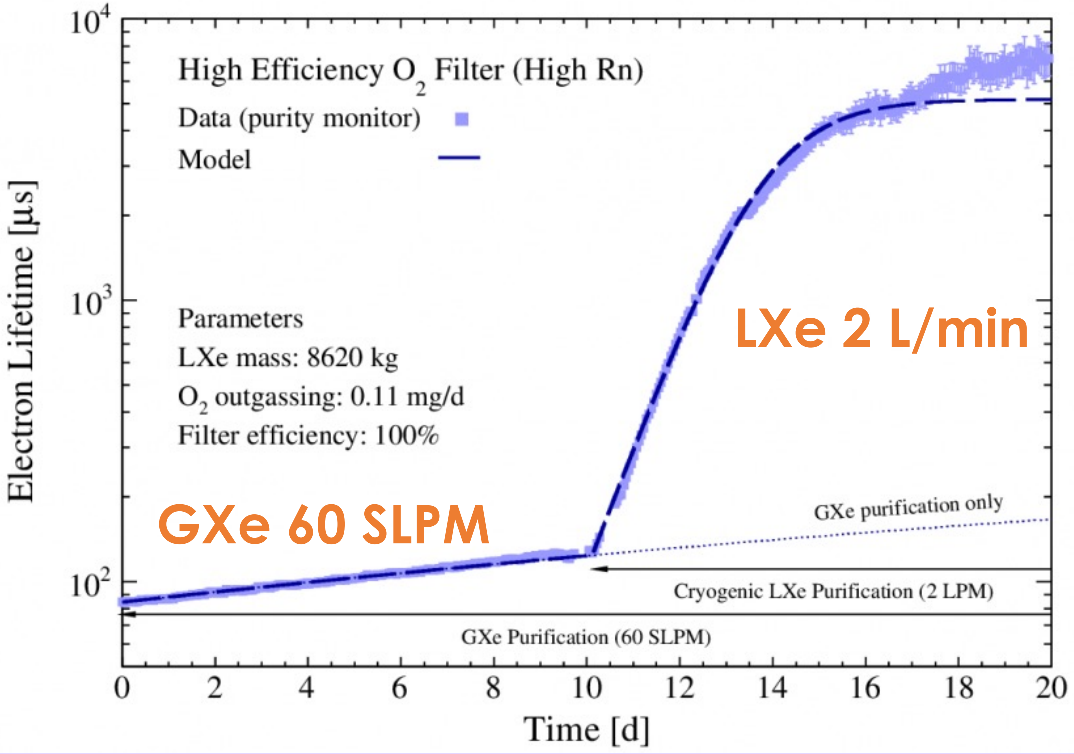
Liquid phase purification

ICRR contribution w/ Kavli IPMU



- Remove electronegative impurities
- Improve survival probability of drift electrons
  → > 90% even at the bottom of TPC

- One of the major update from Xenon1T



Estimation of ^{85}Kr BG using delayed coincidence count

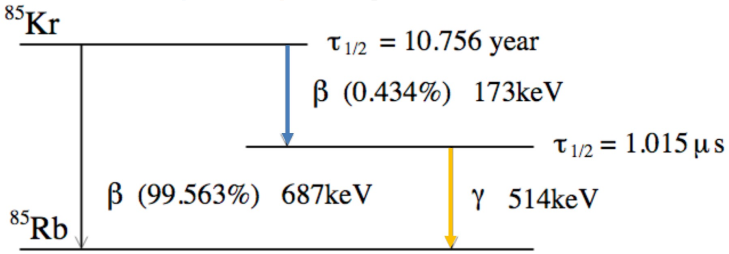
- **^{85}Kr**, Background Source in Low Energy Region:
  - an electric-recoil BG source, contaminates Xe.
  - Reduction technique: Distillation (ppb → ppt level)
- New Abundance Estimation Method:
  - Goal: Reduce measurement uncertainty.
  - Method: Detects ^{85}Kr rare decay events with β & γ -rays.
  - Pros:
    Independent of ^{85}Kr/^{nat}Kr ratio.
    Serves as an effective Krypton monitor.
  - Cons:
    Time-intensive due to low branching ratio.
  - Performance:
    Signal acceptance: $30.0 \pm 3.2_{stat} \pm 1.1_{sys}$%. & Remaining AC BG: 0.2 events/100d.
- Results:
  - Giving an upper limit of 290 ppq Kr concentration (90%CL) for SR0.
  - Consistency confirmed with existing methods for SR0,1,2.
  - Utilized for monitoring air leakage.

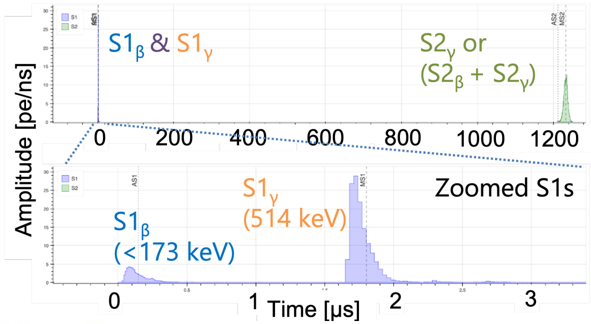
Background model B0 with fit constraints

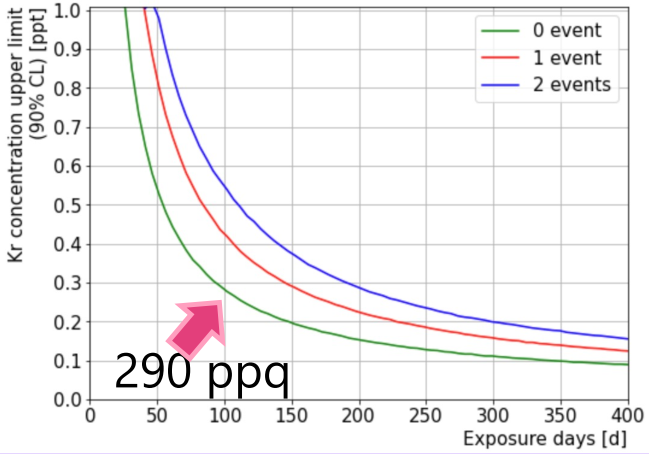
Component	Constraint [Events/t · y · (1~140)keV]
^{214}Pb	(570, 1200)
Materials	270 ± 50
^{85}Kr	**90 ± 60**

From "Search for New Physics in Electronic Recoil Data from XENONnT", PRL, 129, 161805 (2022)

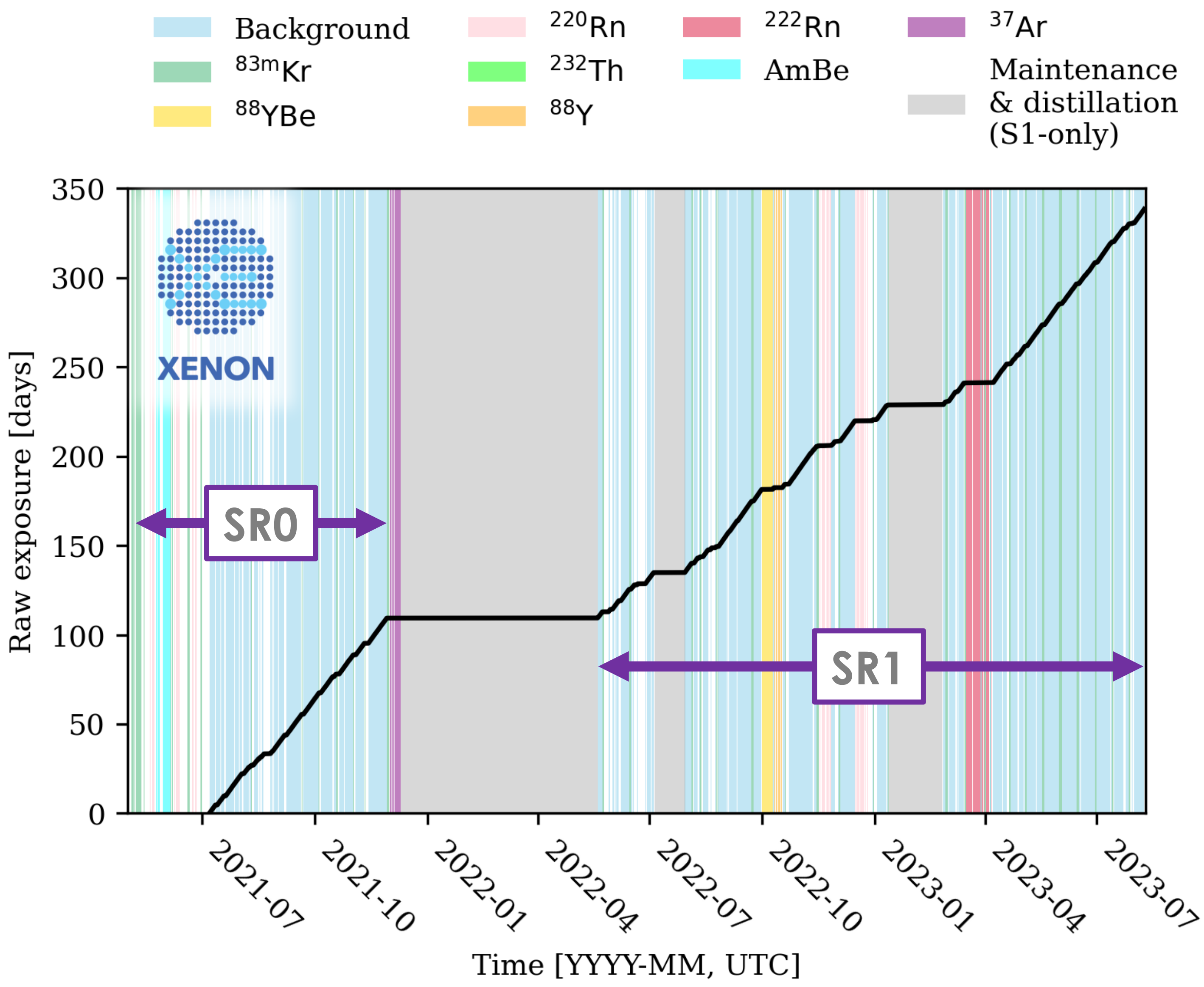
Kr concentration:
56 ± 36 ppq
~60% uncertainty







Science Run 0 & 1

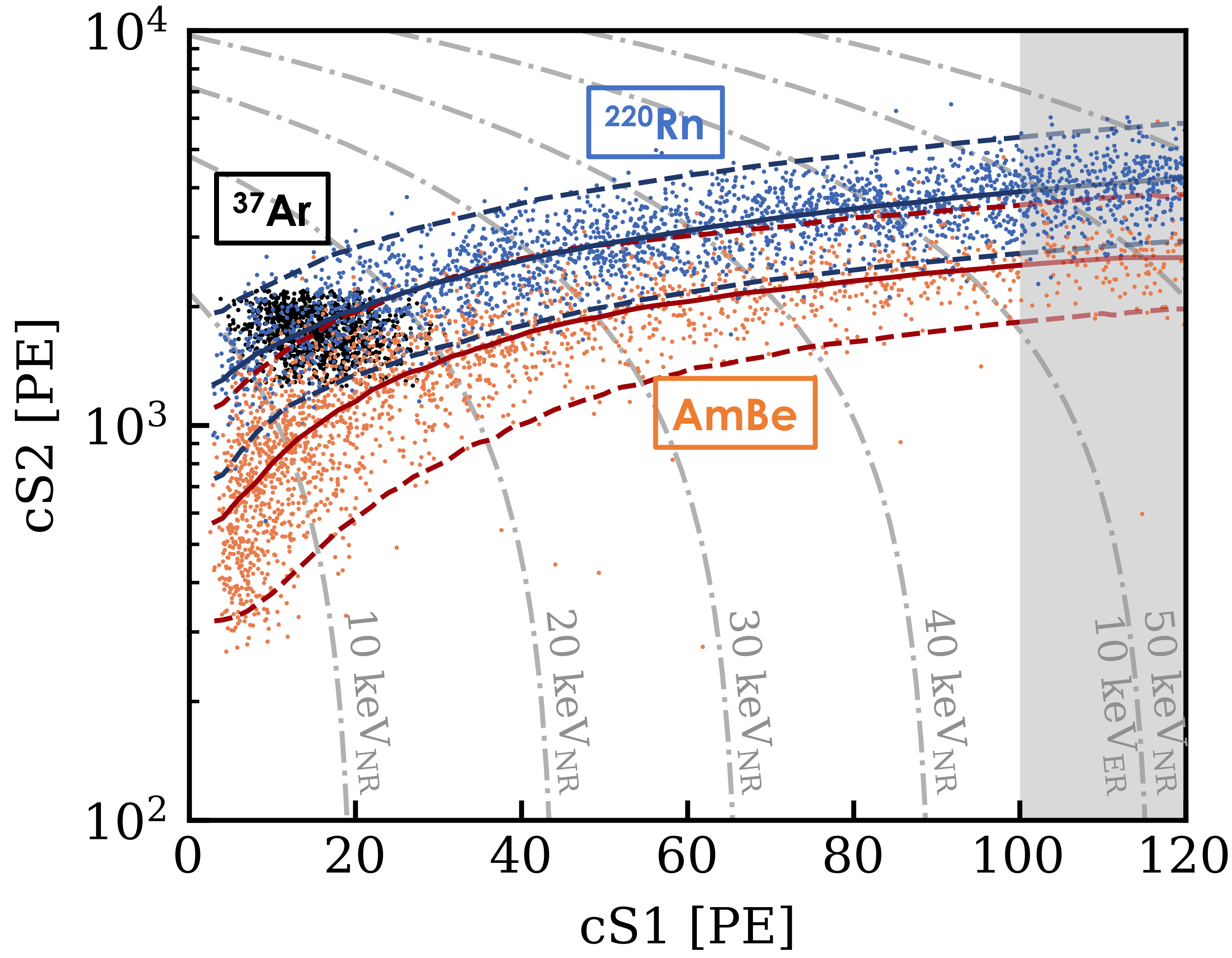


- SR0: 2021 Jul. – 2021 Nov.
- SR1: 2022 May. – 2023 Aug.

- w/ source calibrations seeing detector stabiity

- SR2 is ongoing

Calibration



^{220}Rn

- ER response
- ER bandshape

^{37}Ar

- LowE ER
- Energy reconstruction

AmBe

- NR response

(YBe)

- LowE NR
- from SR1

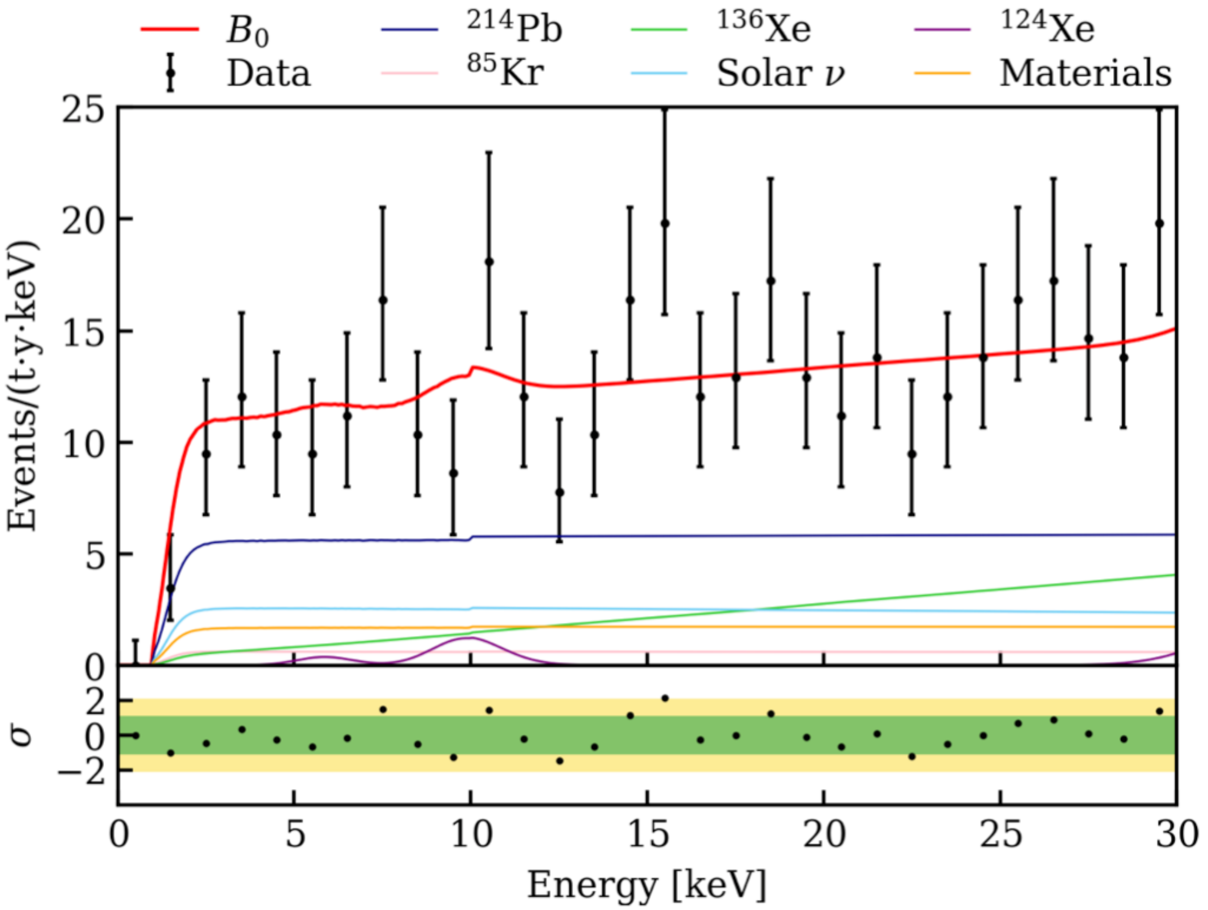
^{83m}Kr

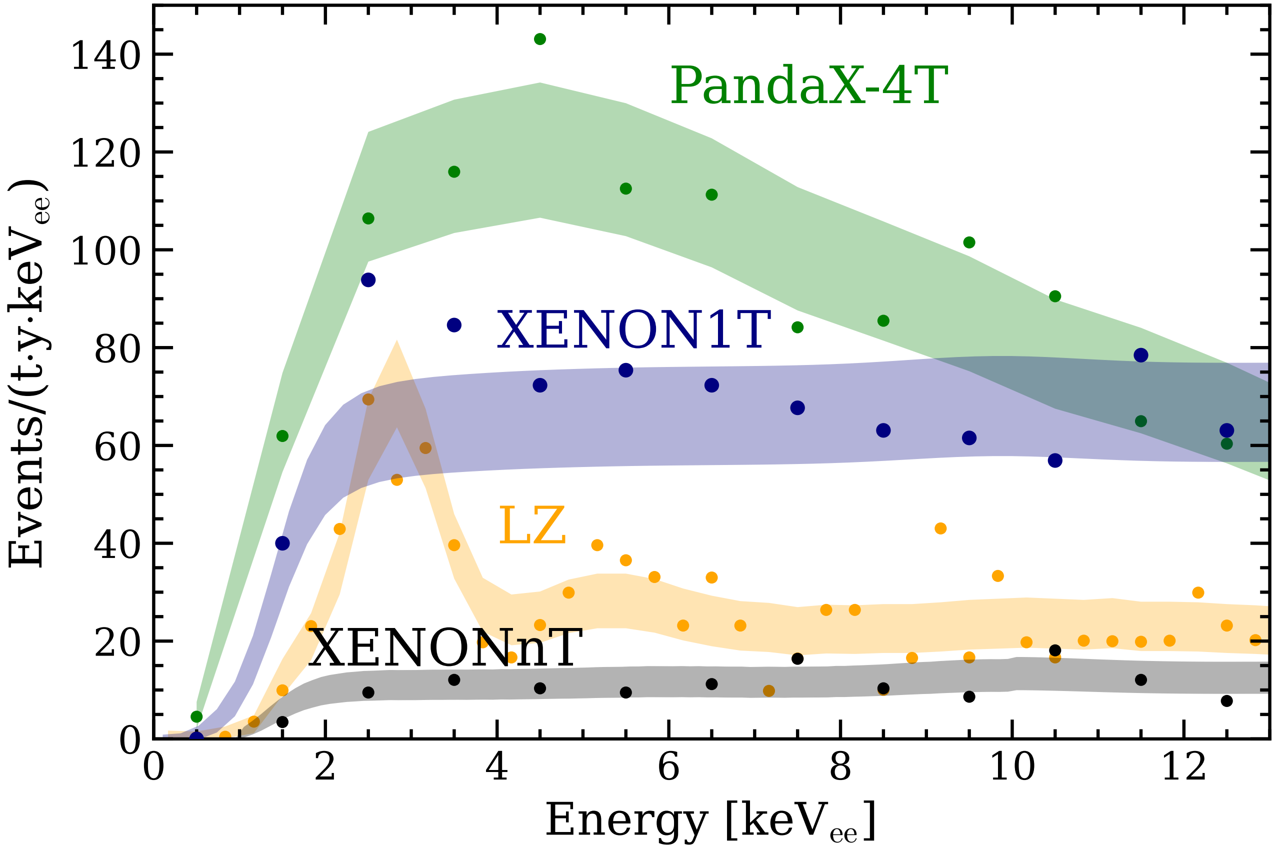
- Position reconstruction
- Energy reconstruction

+ other monoenergetic peaks

SR0 ER result

XENONnT: PRL 129, 161805 (2022) XENON1T: PRD 102, 072004 (2020)
LZ: PRL 131, 041002 (2023) PandaX-4T: PRL 129, 161804 (2022)

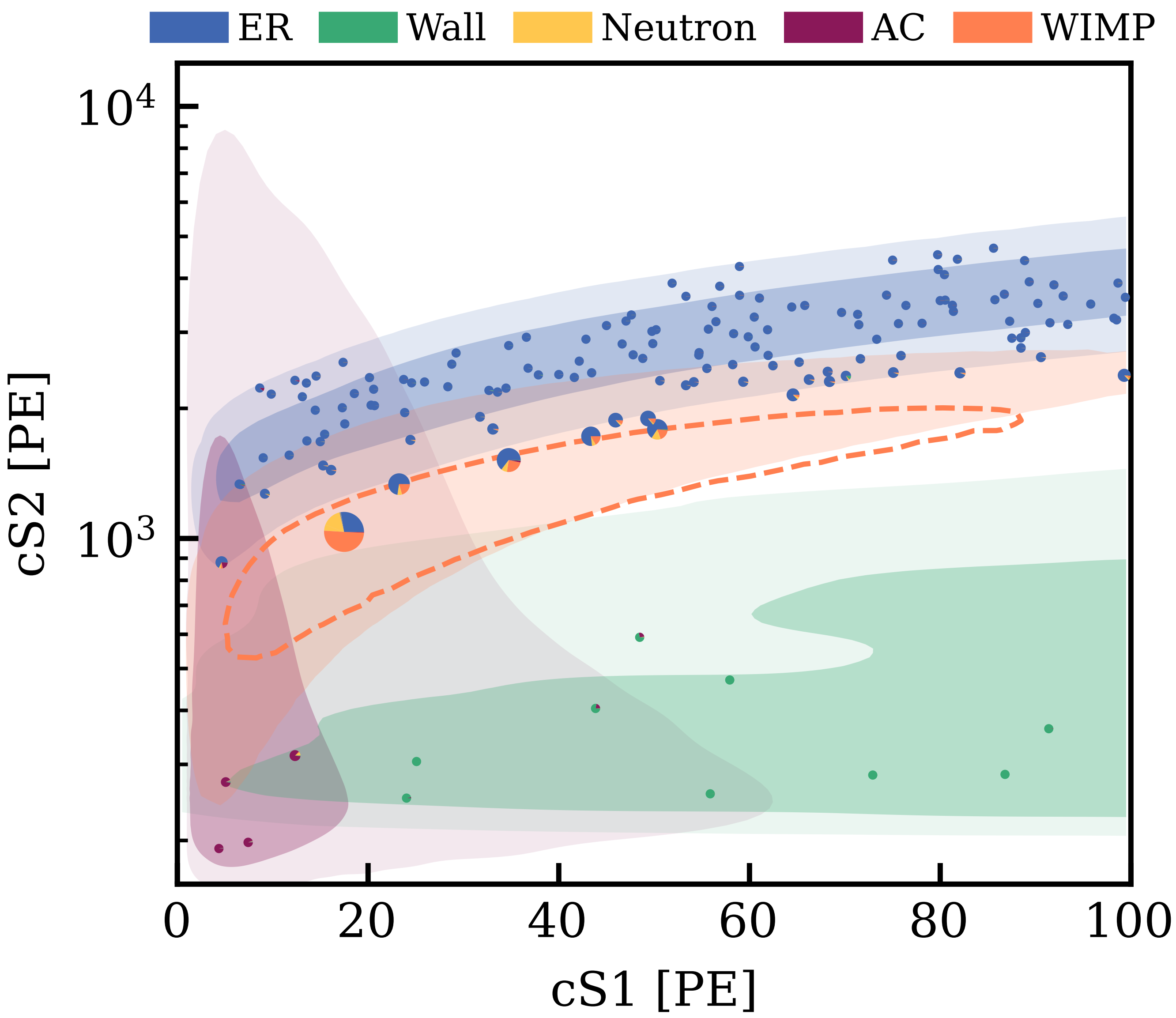




- 1.16 t·y exposure / 97.1 days livetime
- Consistent with the background model → no sign of axions, dark photons, etc.
- Denied so called “Xenon1T Low ER Excess” with the world lowest BG index

PRL 131, 041003 (2023)

SR0 WIMP search result

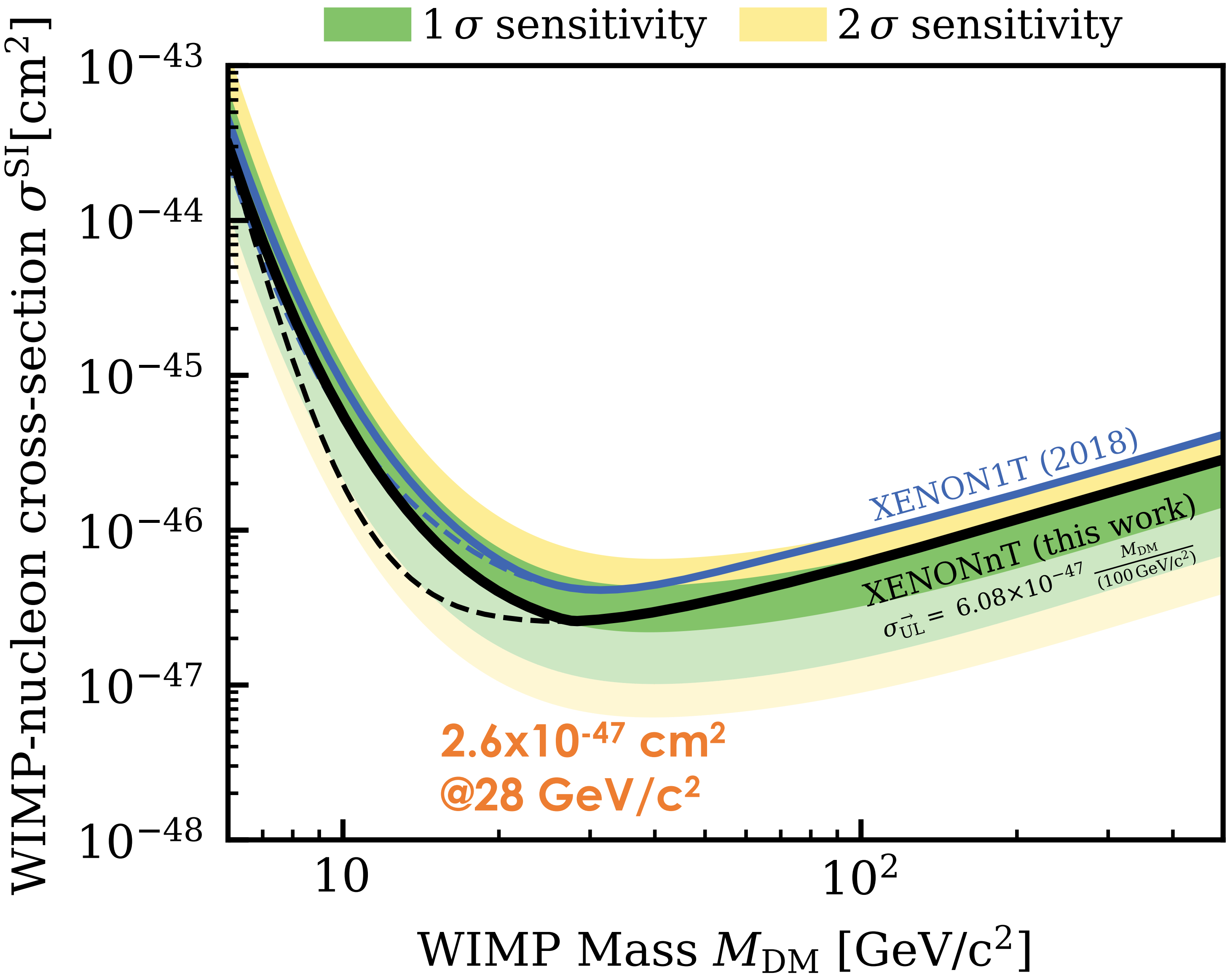


	Nominal	Best Fit	
	ROI		Signal-like
ER	134	135^{+12}_{-11}	0.92 ± 0.08
Neutrons	$1.1^{+0.6}_{-0.5}$	1.1 ± 0.4	0.42 ± 0.16
CEνNS	0.23 ± 0.06	0.23 ± 0.06	0.022 ± 0.006
AC	4.3 ± 0.9	$4.4^{+0.9}_{-0.8}$	0.32 ± 0.06
Surface	14 ± 3	12 ± 2	0.35 ± 0.07
Total Background	154	152 ± 12	$2.03^{+0.17}_{-0.15}$
WIMP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

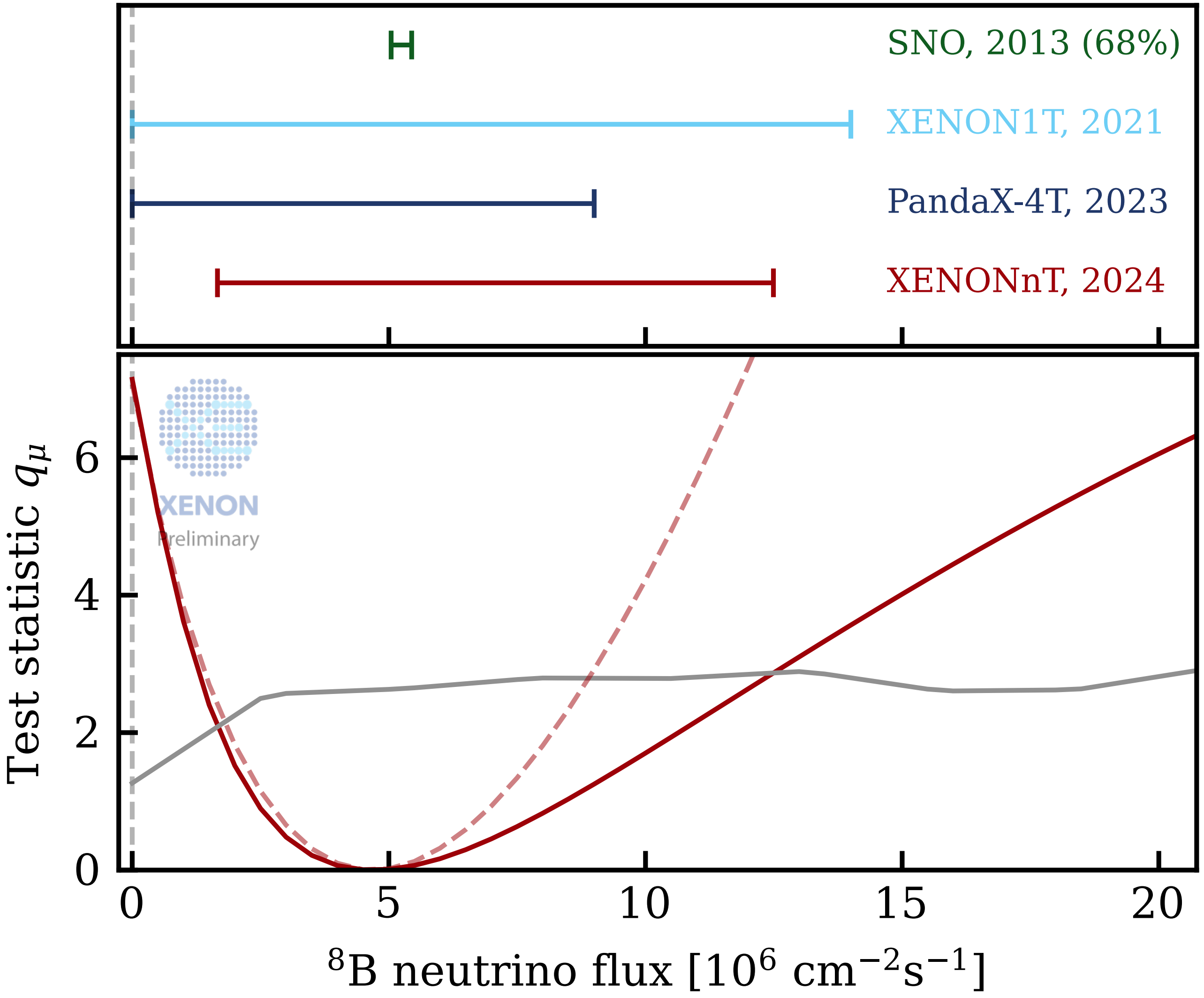
- 1.1 t·y exposure / 95.1 days livetime
- Consistent with the background model → no sign of WIMPs

PRL 131, 041003 (2023)

SR0 WIMP Limit



First Measurement of CEvNS of Solar ^{8}B Neutrinos



Component	Background only fit	Background + ^{8}B fit	Nominal Expectation
AC - SR0	7.55	7.36	7.48 ± 0.52
AC - SR1	18.26	17.90	17.77 ± 1.23
ER	0.74	0.54	0.68 ± 0.68
NR	0.50	0.45	0.47 ± 0.32
Total Background	27.05	26.24	26.4 ± 1.5
^{8}B	-	10.71	11.9 ± 3.1
Observed		37	

- SR0+SR1
- 2.73σ significance
- reached neutrino fog!

Summary

- ✓ XENONnT: dark matter direct detection experiment
  - Dual-phase xenon TPC → fiducialization + NR/ER discrimination
  - Neutron Veto / Muon Veto

- ✓ Contribution from ICRR
  - Gd-water Cherenkov neutron veto: SK/EGADS technology
  - Liquid phase purification / purity monitor
  - ^{85}Kr background estimation

- ✓ SR0 results
  - BG modeling, Lowest ER BG, No excess in ER channel
  - $O(10^{-47})$ cm^2 upper limit for 10 – 100 GeV/c^2 WIMPs

- ✓ SR0+SR1 result
  - First measurement of ^{8}B solar neutrino CEvNS