Dark matter experiment (XENONnT)

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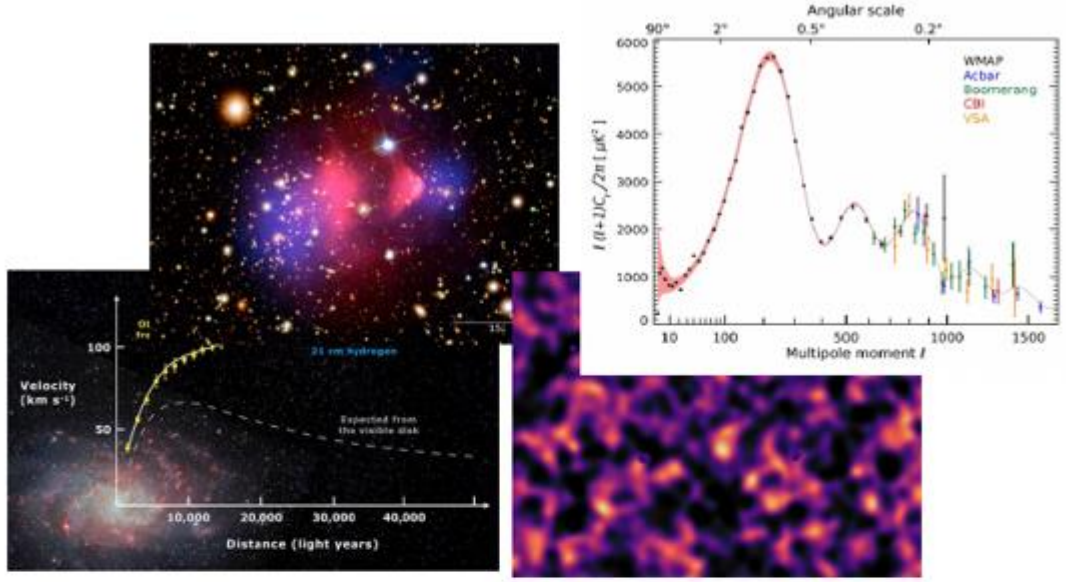
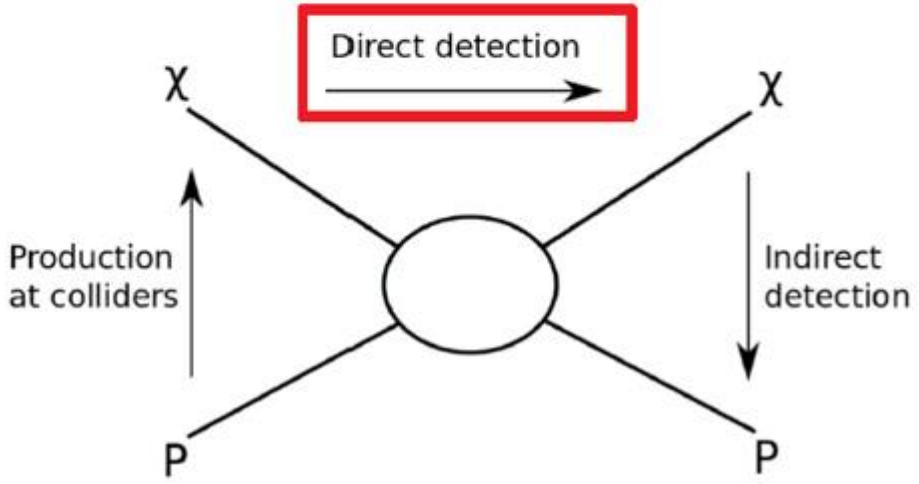
Dark matter search

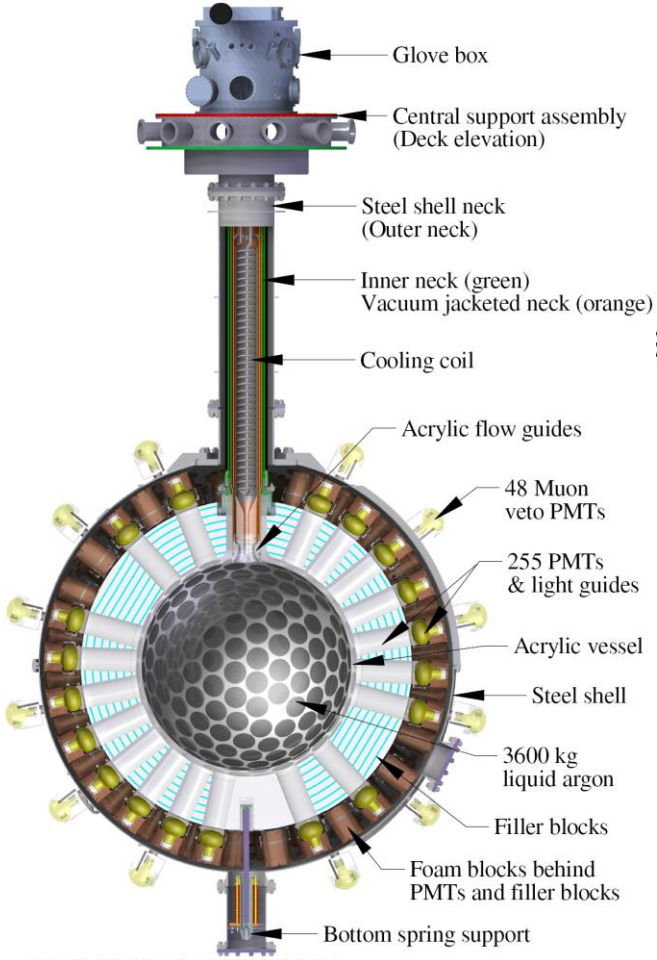
- Dark matter
  - Existence is clear from plenty of measurements related to gravitation.
    - Galaxy rotational curve, CMB, large - scale structure of the cosmos, gravitational lensing, bullet cluster, …
  - Not confirmed what it is.
- Dark matter search
  - Many candidates
    - WIMP, axion, ALPs, hidden photon, …
  - Variety of search
    - Colliders
    - Indirect detection
    - Direct detection

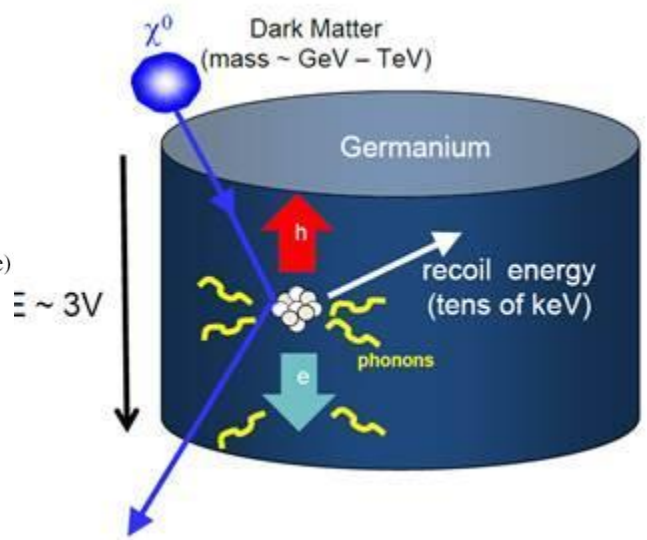


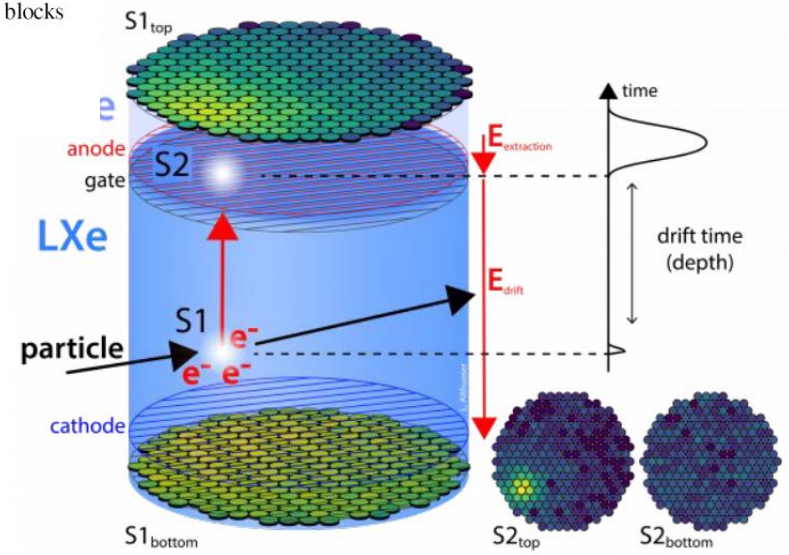


Direct DM search

- Many experiments
  - Wide energy range
    - ~eV ~ ~TeV
    - energy deposit by interaction with standard particle.
  - Variety of materials
    - Scintillator, semiconductor, cavity, …
    - gas, liquid, solid, …
  - Variety of signals
    - light, charge, heat, acoustic, babble, …
- Keys for the search
  - low BG
    - small cross section, Rare event search
    - large target volume
  - low energy threshold
    - Small energy deposit

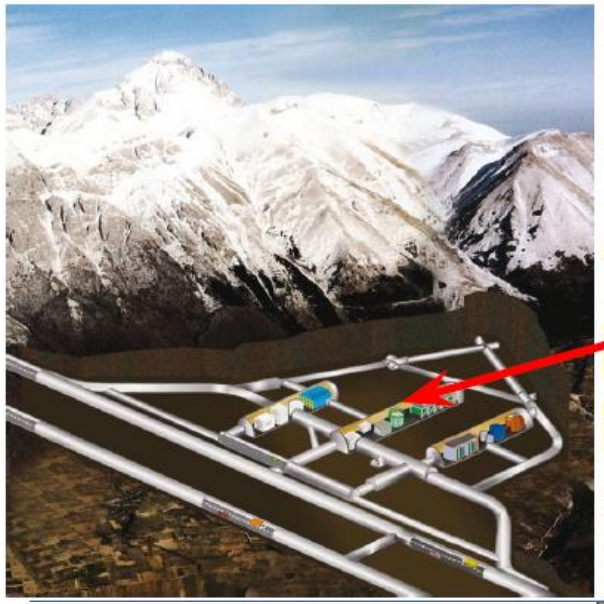


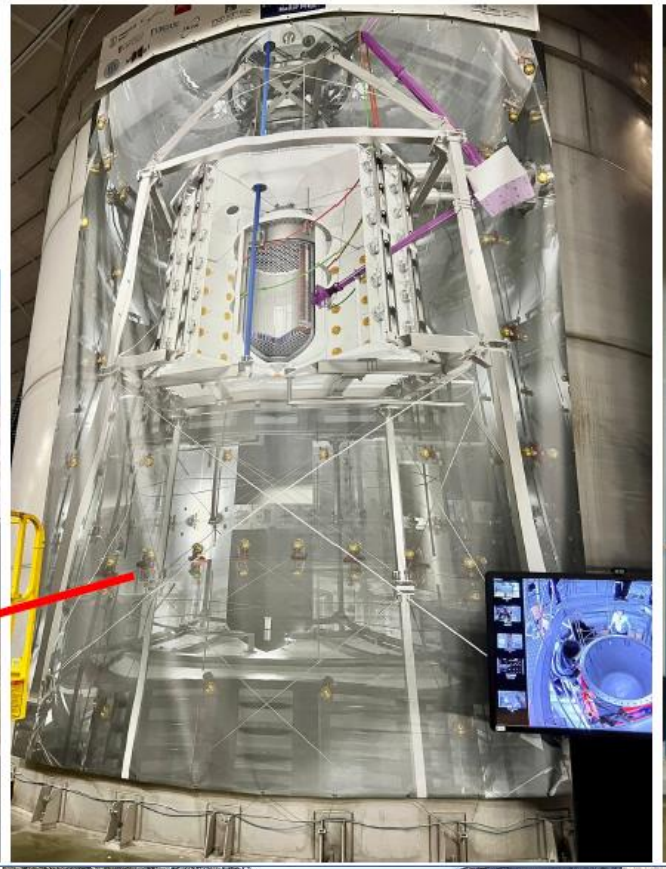




XENON experiment

- INFN Laboratori Nazionali del Gran Sasso, L'Aquila, Italy
- 1300m rock, 3600m.w.e
- Dual phase Xe TPC
  - 5.9t active volume
- XENON collaboration
  - 12 countries
  - 28 institutions
  - ~170 scientists



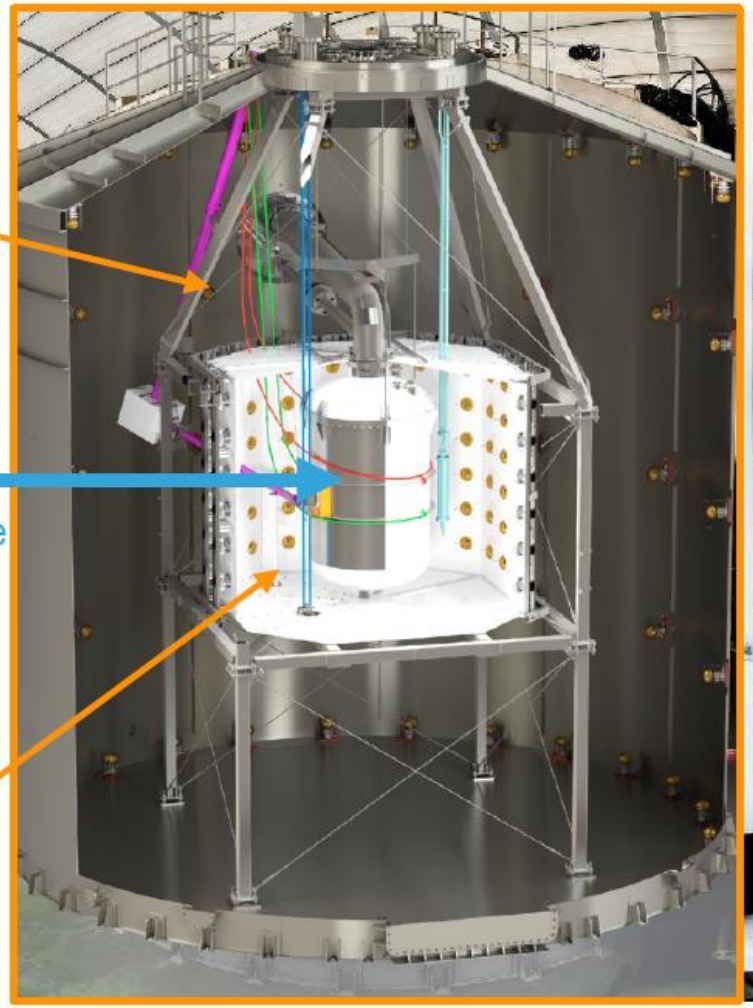


XENONnT detector

New ER and NR calibration systems

Larger TPC with 3x active volume

Gd-loaded water Cherenkov neutron veto



Radon distillation column

Upgraded DAQ with dedicated high-energy readout

Liquid xenon purification

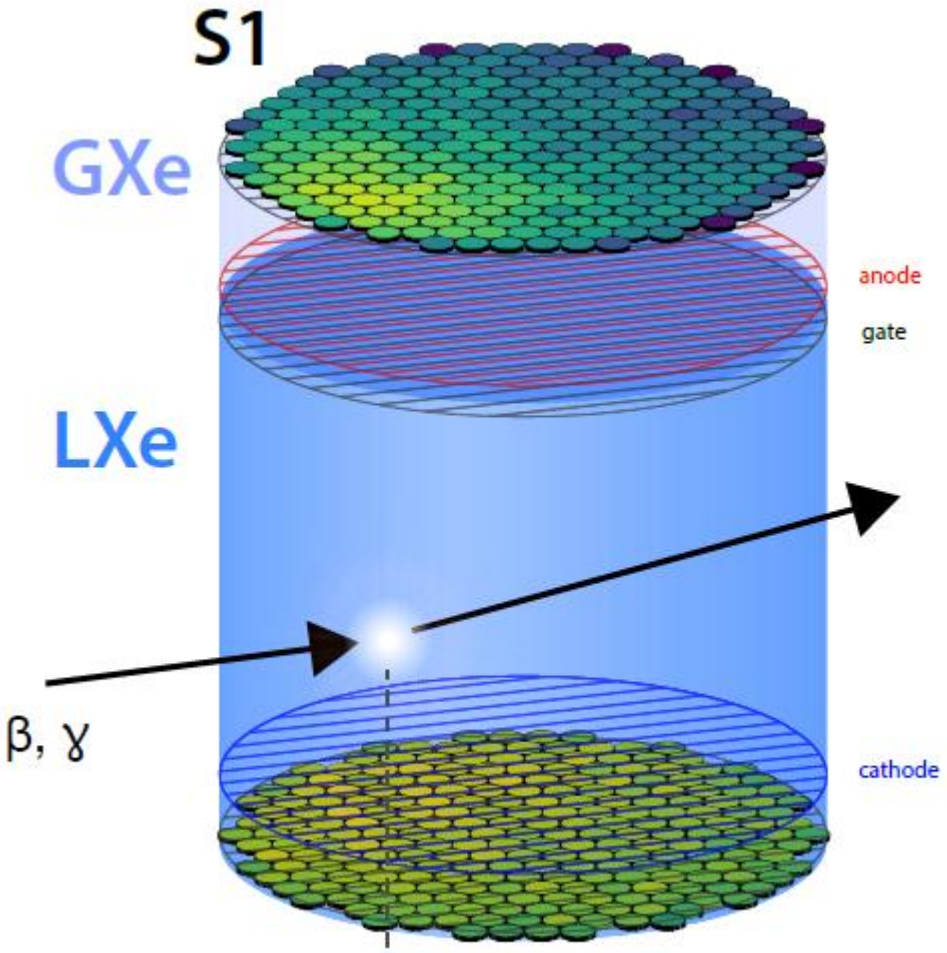
XENON nT

- Larger TPC
  - Active LXe mass 5.9t (x3 from XENON1T)
  - Drift length 1.5m (x1.5 from XENON1T)
  - 494 PMTs (x2 from XENON1T)

- New components
  - Liquid purification system
  - Rn distillation
  - Neutron veto system

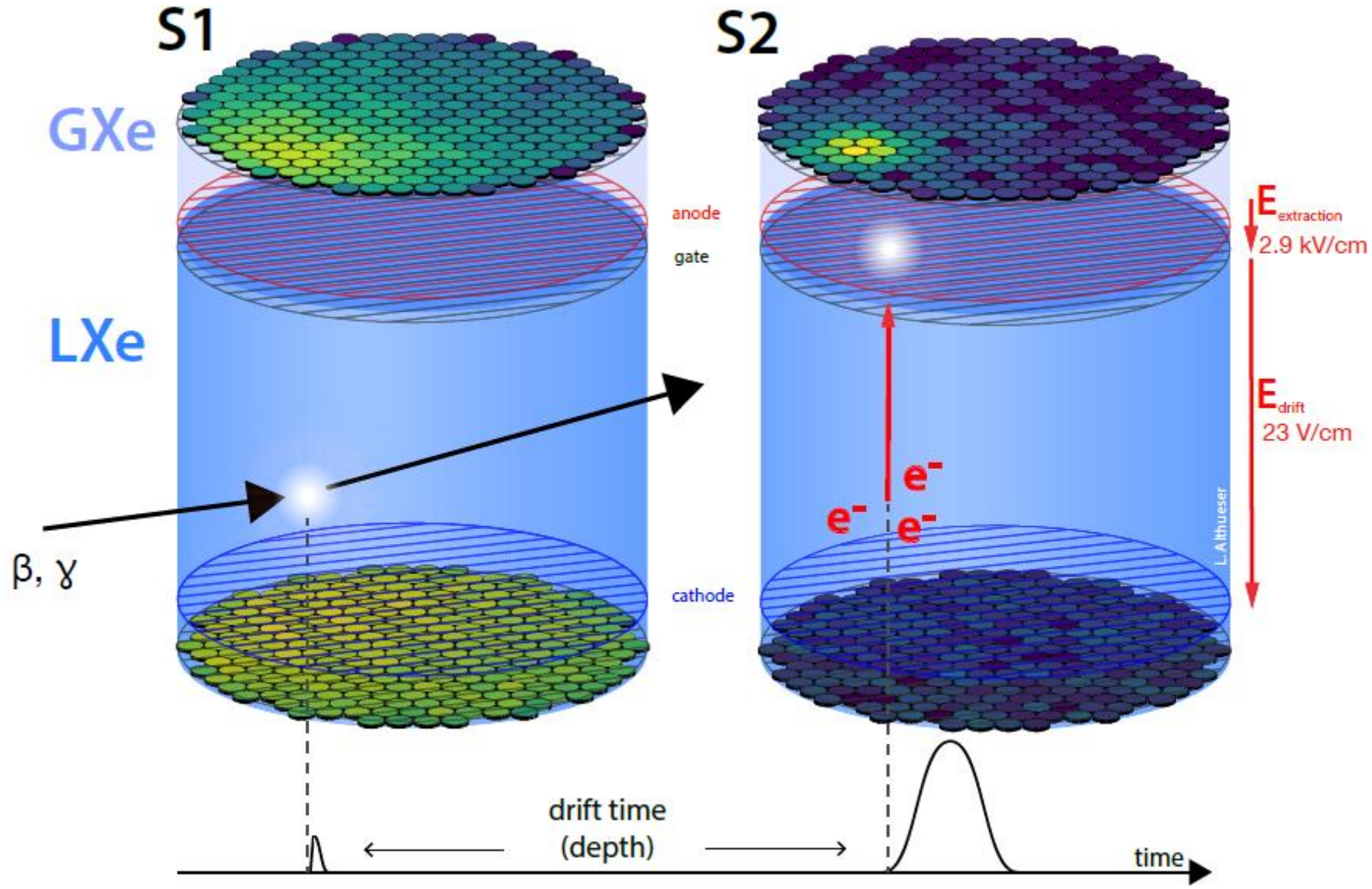
	XENON10	XENON100	XENON1T	XENONnT
Period	2005 - 2007	2008 - 2016	2012 - 2018	**2019 - 2025**
Dimensions	15 x 20 cm	30 x 30 cm	1 x 1 m	**1.5 x 1.3 m**
Active mass	14 kg	62 kg	2 tons	**5.9 tons**
Sensitivity	~10^{-43} cm^2	~10^{-45} cm^2	~10^{-47} cm^2	**~10^{-48} cm^2**

two-phase TPC



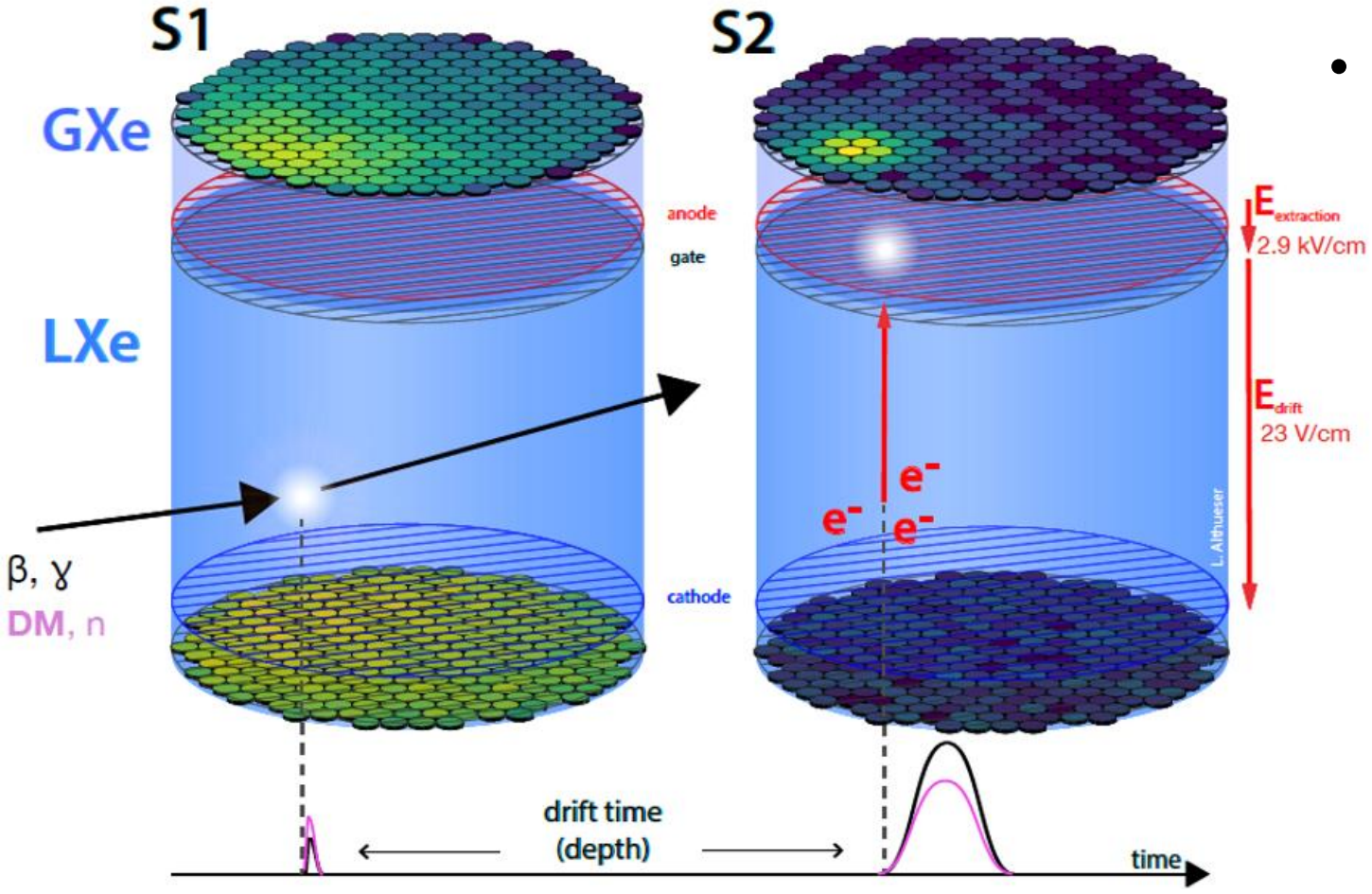
- Main component of the experiment.
- Xe two phase time projection chamber
- Xe
  - Large scintillation yield
  - strong stopping power
  - No long-life radioisotope
  - easy to handle (relatively)
- Two phase TPC
  - liquid layer, gas layer
  - Electric field
    - Electrodes
      - cathode, gate, anode
  - PMTs at top and bottom
- Two signal
  - Interaction generate two signals
  - Scintillation photon and charge from ionization.

two-phase TPC



- Scintillation
  - S1 signal
- Charge
  - Drifts to gas layer by electric field
  - Proportional scintillation by strong field around anode wire.
    - S2 signal
- 3D position reconstruction
  - X,Y
    - S1, S2 signal photon distribution in PMT array.
  - Z
    - Drift time
    - between S2 and S1

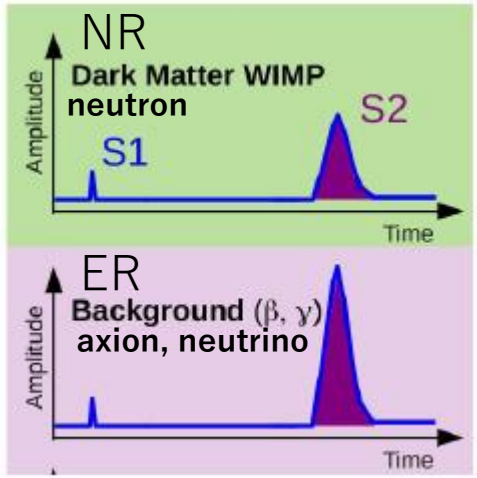
two-phase TPC

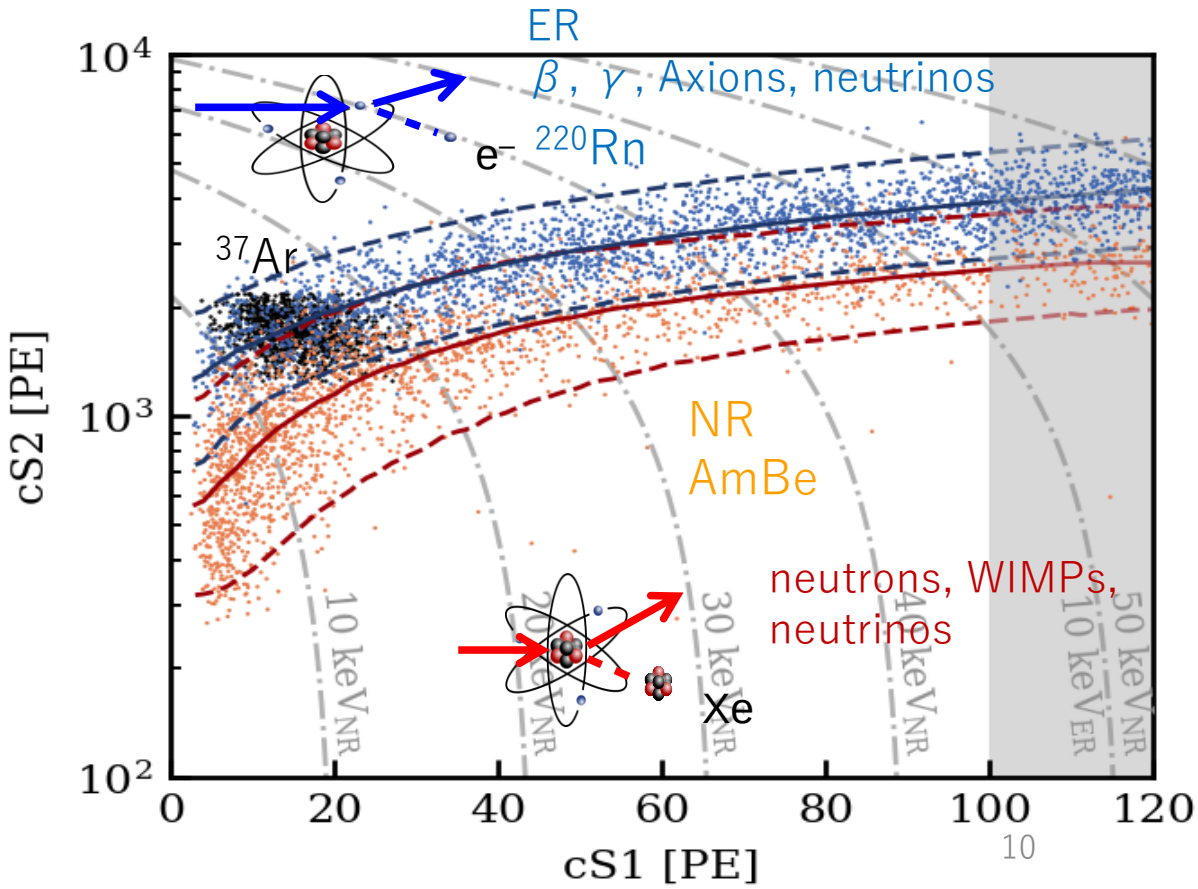


- 3D position reconstruction
  - BG reduction by fiducialization
    - reject events around wall
    - BG from detector material
- Electron recoil and nuclear recoil
  - ER: interact with electron
  - NR: interact with nulceous
  - Different S2/S1 ratio
    - Depend on ~dE/dX
    - ER
      - smaller dE/dX
      - Larger number of charges can escape “recombination” by thinner density.
      - Larger S2, smaller S1
    - NR
      - larger dE/dX
      - More charges converted to photon by recombination.
      - Smaller S2, larger S1

ER and NR

- ER
  - larger S2/S1
  - Electron, gamma, axion, neutrino
  - Calibration source
    - 220Rn
      - flat beta spectrum
    - 37Ar
      - 2.82keV peak
      - for the region close to the threshold energy
- NR
  - smaller S2/S1
  - neutron, neutrino, WIMP
  - calibration source
    - 241AmBe
      - 4.4MeV gamma and neutron





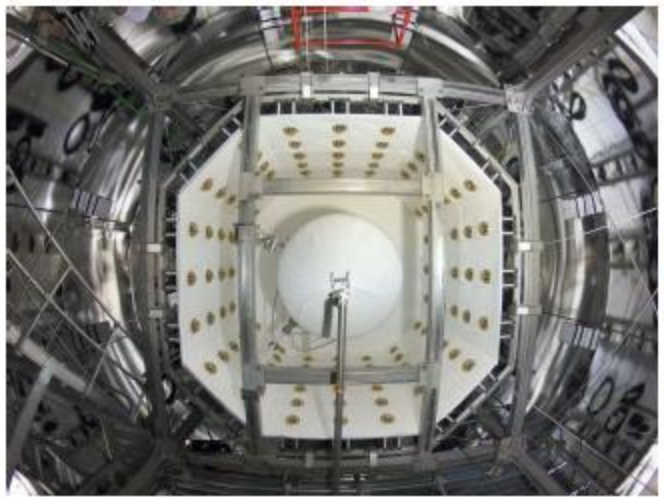
For lower BG, larger volume

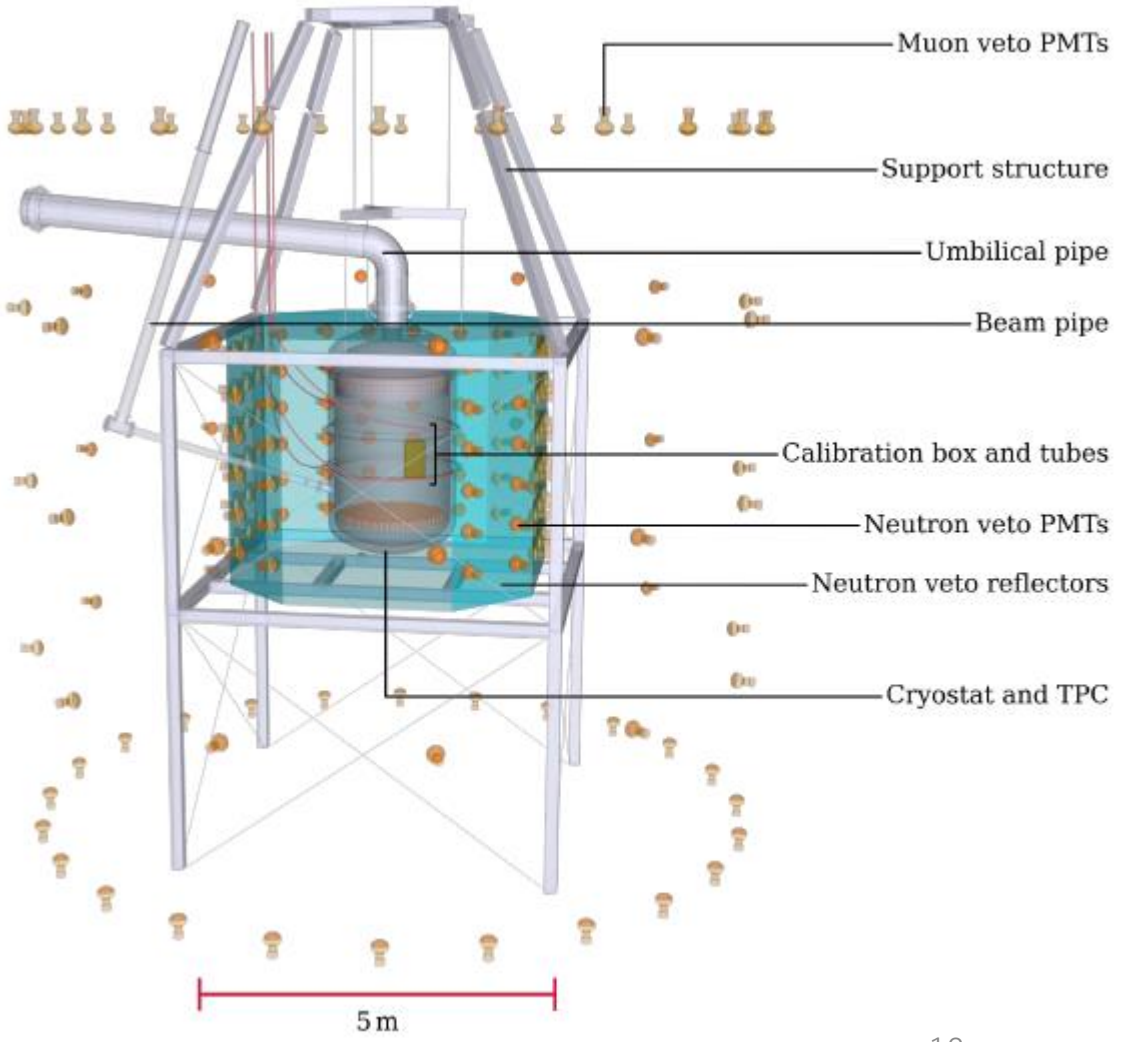
- Target ~event/t/year
  - Larger volume detector + larger reduction of BG
- BG reduction
  - Detector material RI
    - Material screening
    - Radon
    - Neutron
      - Nuclear recoil, difficult to separate from WIMP signal
      - Difficult to reduce
- Larger volume
  - Longer drift time
    - electronegative impurities

- New components in XENONnT
  - Online Rn distillation
    - Constantly emanate from detector materials
    - Still main BG component
  - neutron veto
    - difficult to reduce
  - Liquid purification system
    - Impurity removal
    - Old system had only gas purification.
    - Need to increase speed for larger amount

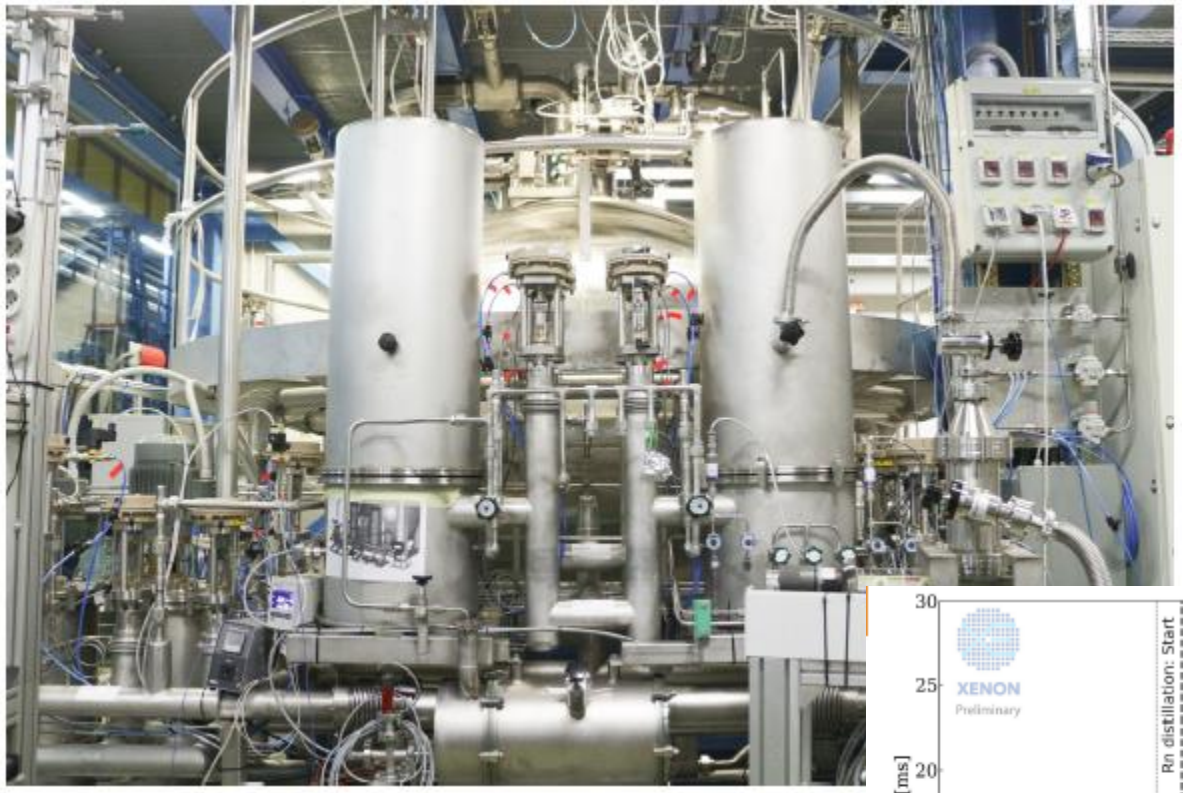
neutron veto

- Smaller water Cherenkov detector inside muon veto water tank, around the TPC.
- Octagonal 3x4m, 120 8-inch PMTs
- ePTFE wall for reflector
- Current, pure water
  - neutron tagging efficiency 68%
- Planning to load Gd
  - ~87% tagging efficiency

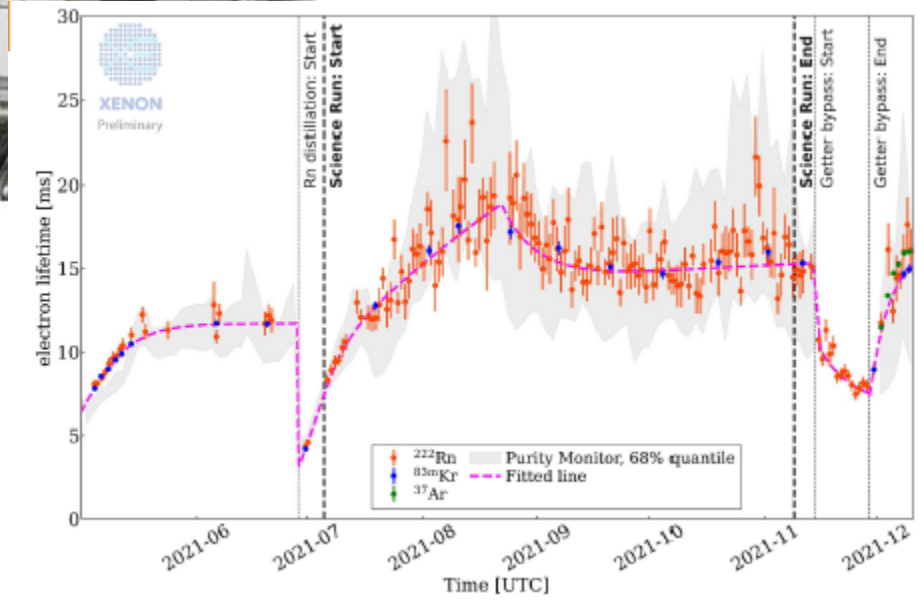




Liquid purification system



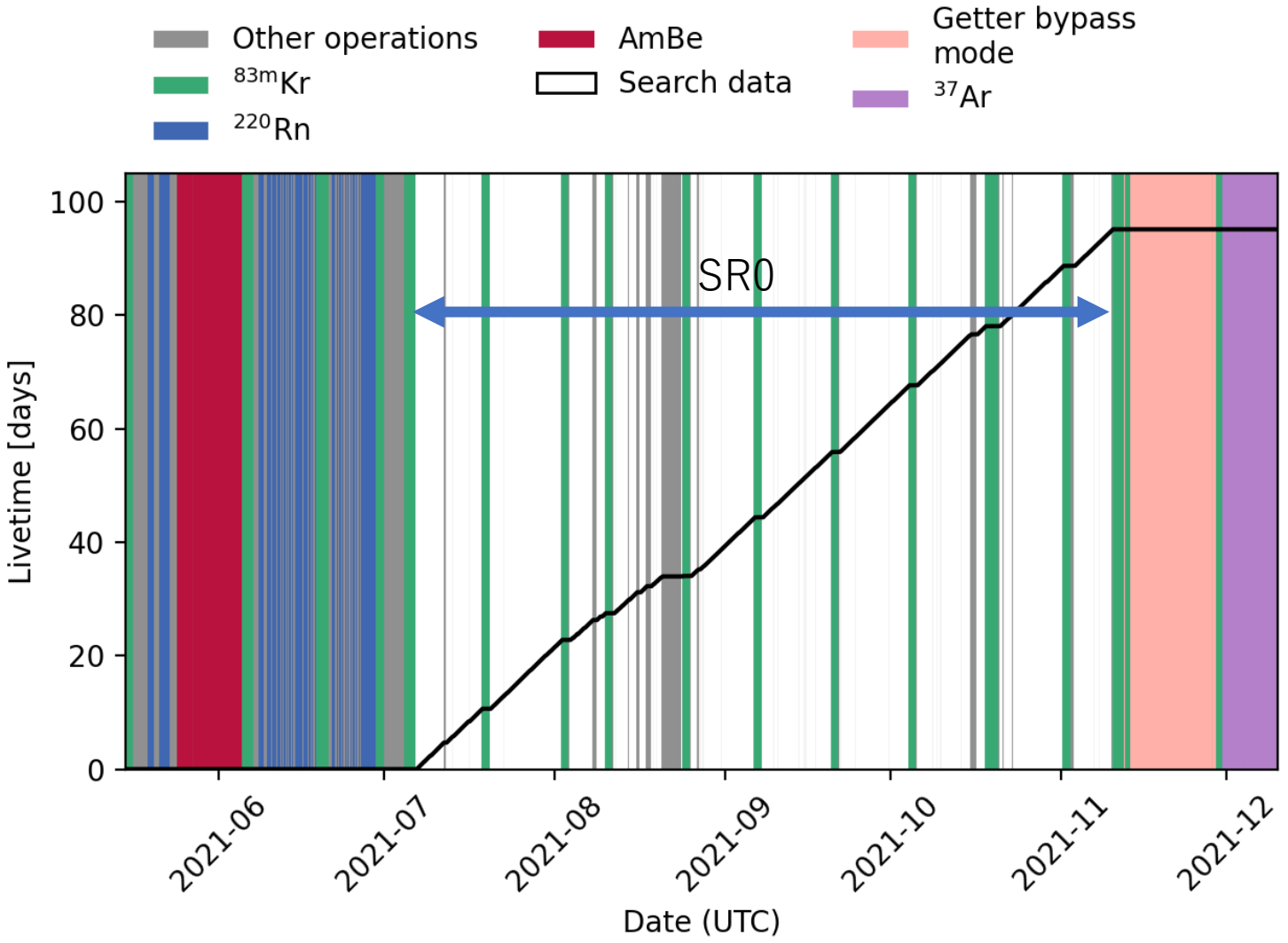
- Electronegative impurities in LXe cause loss of drift electron and reduce S2 signal.
  - Need faster purification for larger amount of LXe
- Liquid purification system
  - Liquid circulation by cryogenic pumps
  - 2L/min flow speed
    - 18h to exchange the entire volume
  - Low Rn emanation filter units
  - Online purity monitor
    - Electron lifetime exceeds 10ms in < 1 week



	Max. TPC drift time	Electron lifetime	e^- survival @ max. drift length
1T	0.67 ms	0.65 ms	30%
nT	**2.2 ms**	**> 10 ms**	**> 90%**

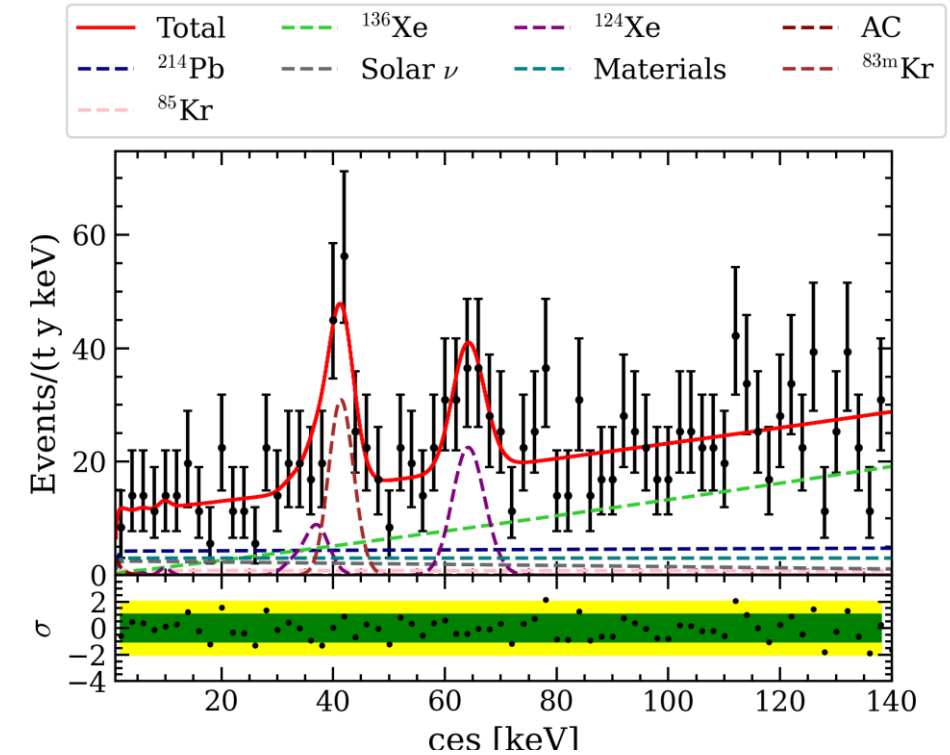
First science run, SR0

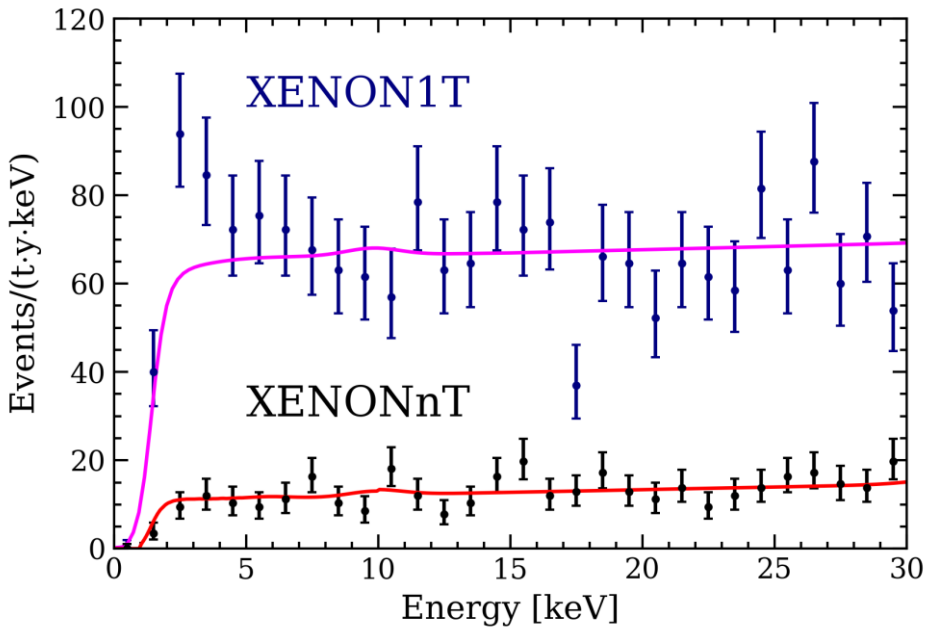
- July 6 – Nov 10, 2021
- 97.1 days livetime
- ER and NR search
  - blind analysis
- Fiducial volume
  - (4.37 ± 0.14) t for ER
  - (4.18 ± 0.13) t for NR
- Exposure after deadtime correction
  - 1.16 tonne-yr for ER
  - 1.1 tonne-yr for NR



SR0 Low ER results

- Data agree with BG only model
- Dominated by beta decays from ^{214}Pb a daughter of ^{222}Rn
- No excess was found
  - Most likely the explanation of XENON1T excess is a small tritium contamination.
- Factor x5 improved background compared to XENON1T
  - Unprecedented low ER BG rate (15.8 ± 1.3) events/(t·yr·keV)

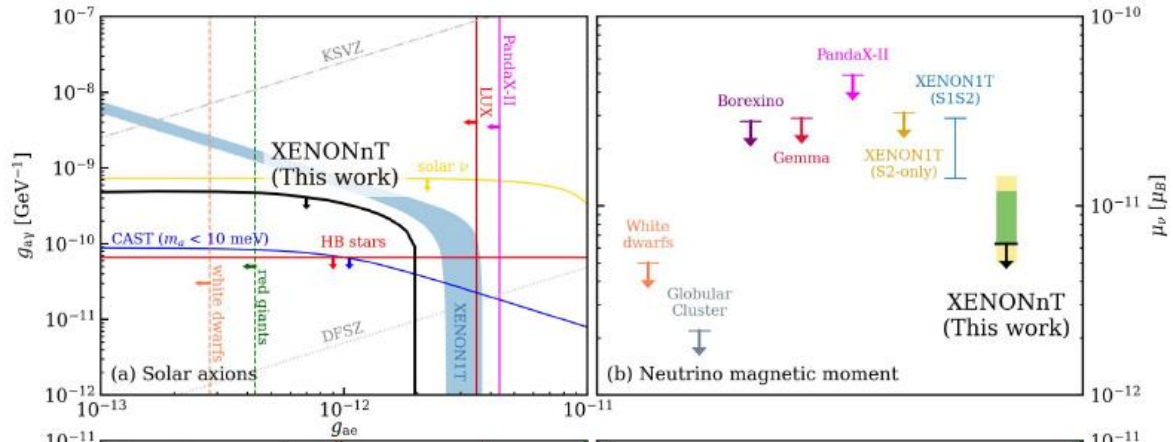




SR0 Low ER results

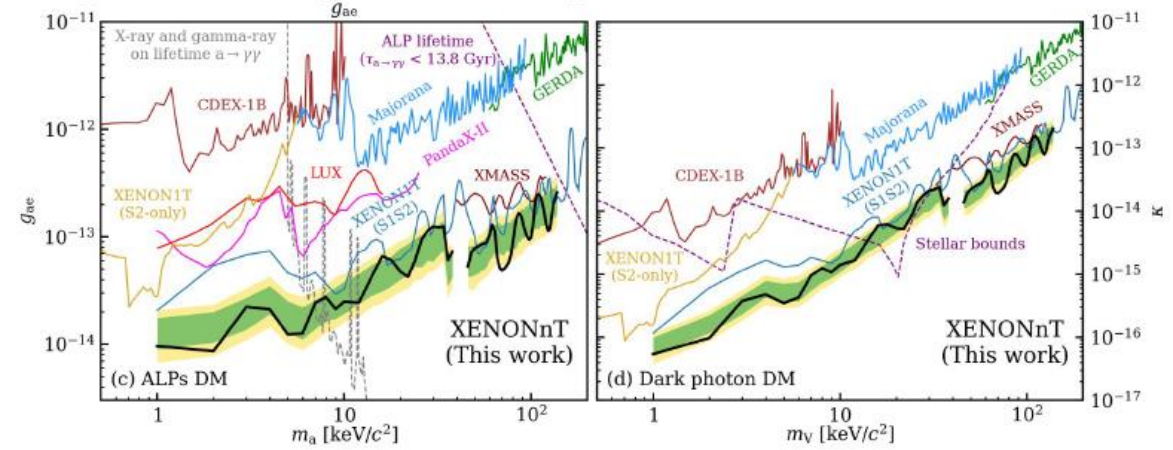
- Stringent new limits
  - Solar axions
  - Enhances neutrino magnetic moment
  - Axion-like particles
  - Dark photons

Solar Axions

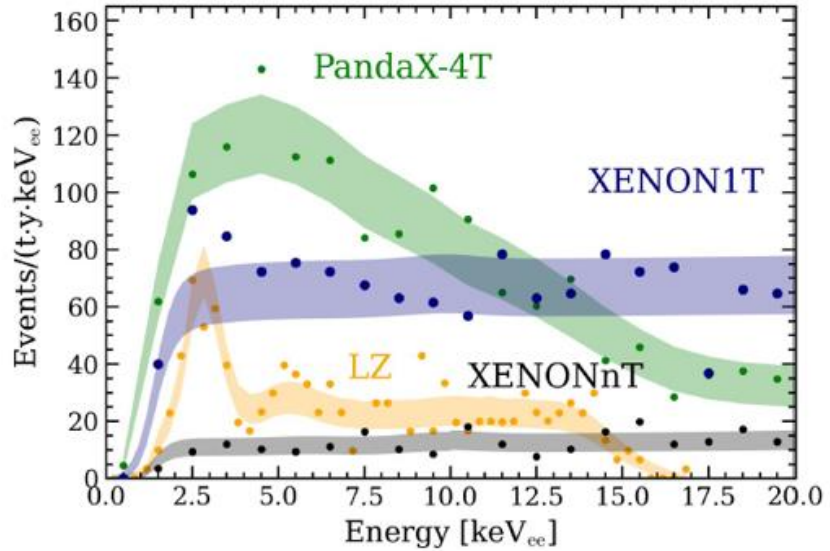


Neutrino Magnetic Moment

Axion-like particles



Dark Photons

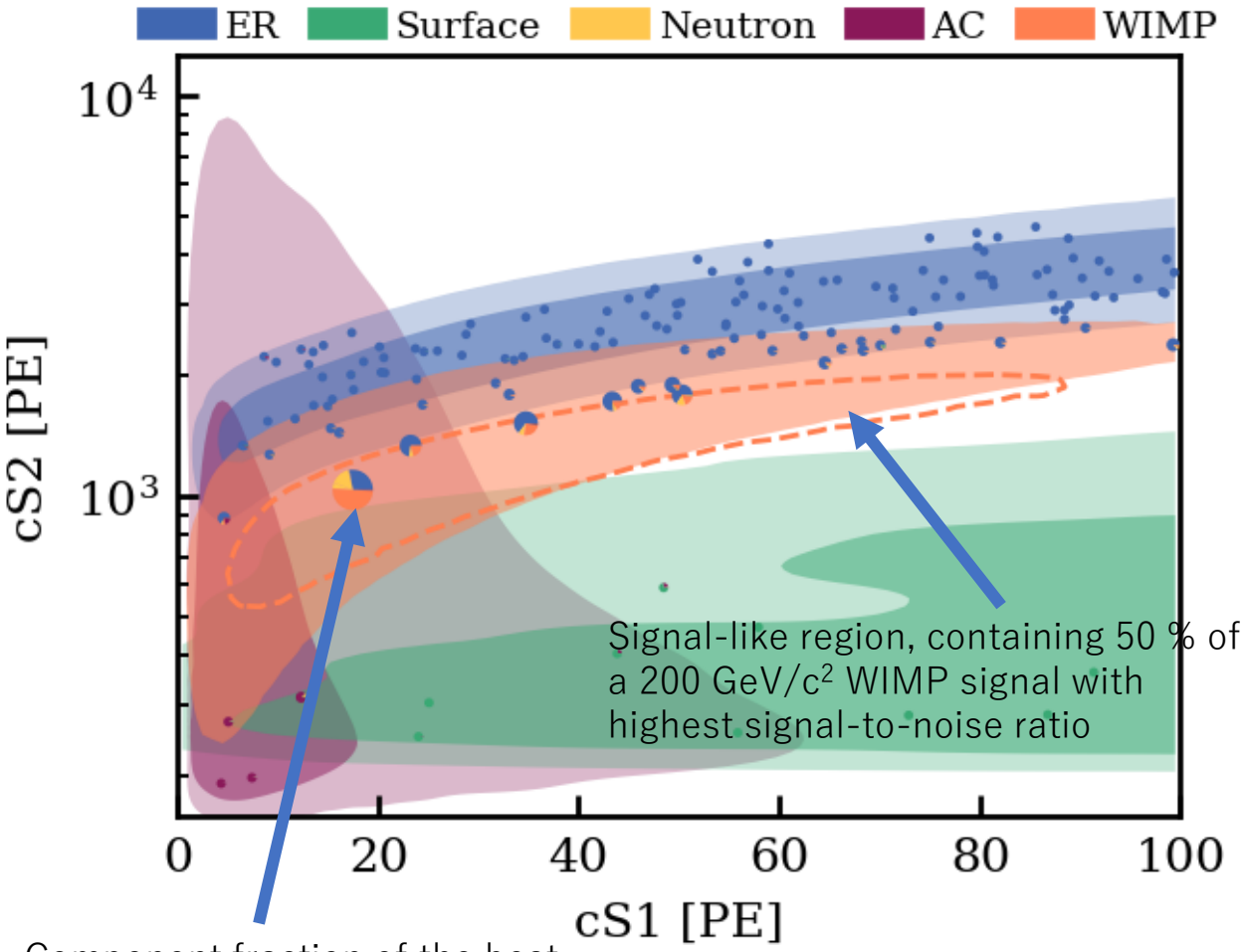


PandaX-4T PRL 129, 161804 (2022)
XENON1T PRD 102, 072004 (2020)
LZ arXiv:2207.03764
XENONnT PRL 129, 161805 (2022)

NR search, SR0 WIMP results

	Nominal	Best Fit	
	ROI		Signal-like
ER	134	135^{+12}_{-11}	0.81 ± 0.07
Neutrons	$1.1^{+0.6}_{-0.5}$	1.1 ± 0.2	0.42 ± 0.10
CEvNS	0.23 ± 0.06	0.23 ± 0.06	0.022 ± 0.011
AC	4.3 ± 0.2	4.32 ± 0.15	0.363 ± 0.013
Surface	14 ± 3	12^{+0}_{-4}	$0.34^{+0.01}_{-0.11}$
Total	154	152 ± 12	$1.95^{+0.12}_{-0.16}$
WIMP	-	2.4	1.2
Observed:	-	152	3

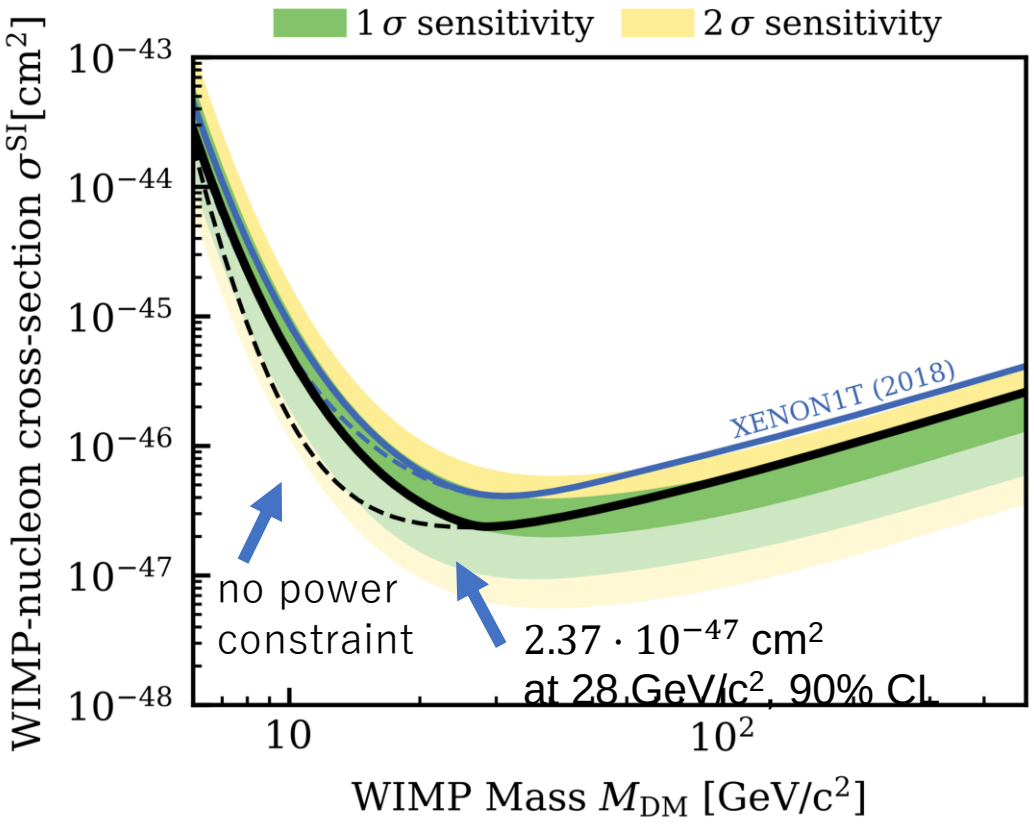
- 152 events in ROI, 16 in blinded region
- Best fit indicates no significant excess

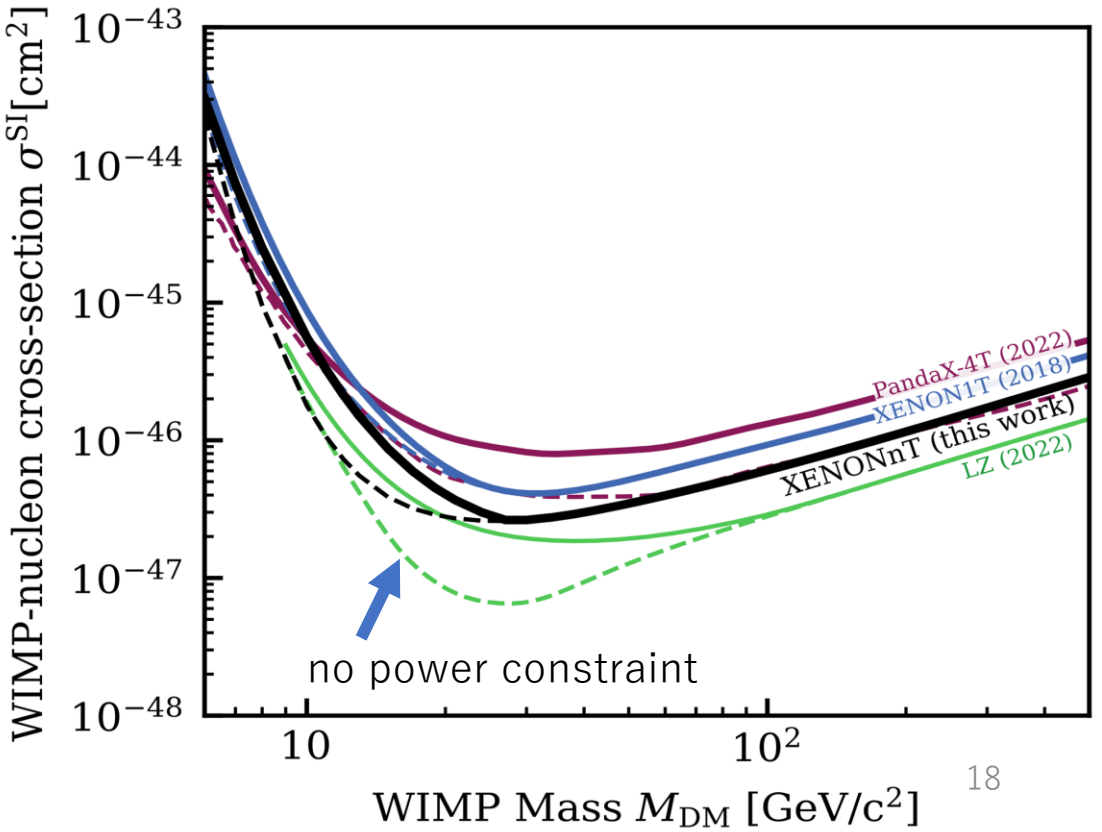


Component fraction of the best fit model including a 200 GeV/c² WIMP evaluated at event position

WIMP results

- Spin independent, $2.37 \times 10^{-47} cm^2$ @$28 GeV/c^2$
- Power constraint limit based on “rejection power” .
  - median of sensitivity





Summary

- Dark matter search
  - Existence is clear
  - many experiment with variety of methods
- Direct detection
  - low BG and low E threshold
- XENONnT
  - Dual phase Xe TPC with active LXe mass 5.9t
  - New
    - Liquid purification system
    - Rn distillation
    - Neutron veto system
- Science run0
  - July 6 – Nov 10, 2021, 97.1 days livetime
  - Exposure ~1.1 tonne-yr
- ER search results
  - Unprecedented low ER BG rate of (15.8 ± 1.3) events/(t·yr·keV)
  - new stringent limits, Solar axions, neutrino magnetic moment, Axion-like particles, Dark photons
- WIMP search results
  - Spin-independent limit of 2.4×10^{-47} cm^2 at 28 GeV/c^2
- Data taking ongoing with improved ER background