Latest Results from the XENON1T Dark Matter Project

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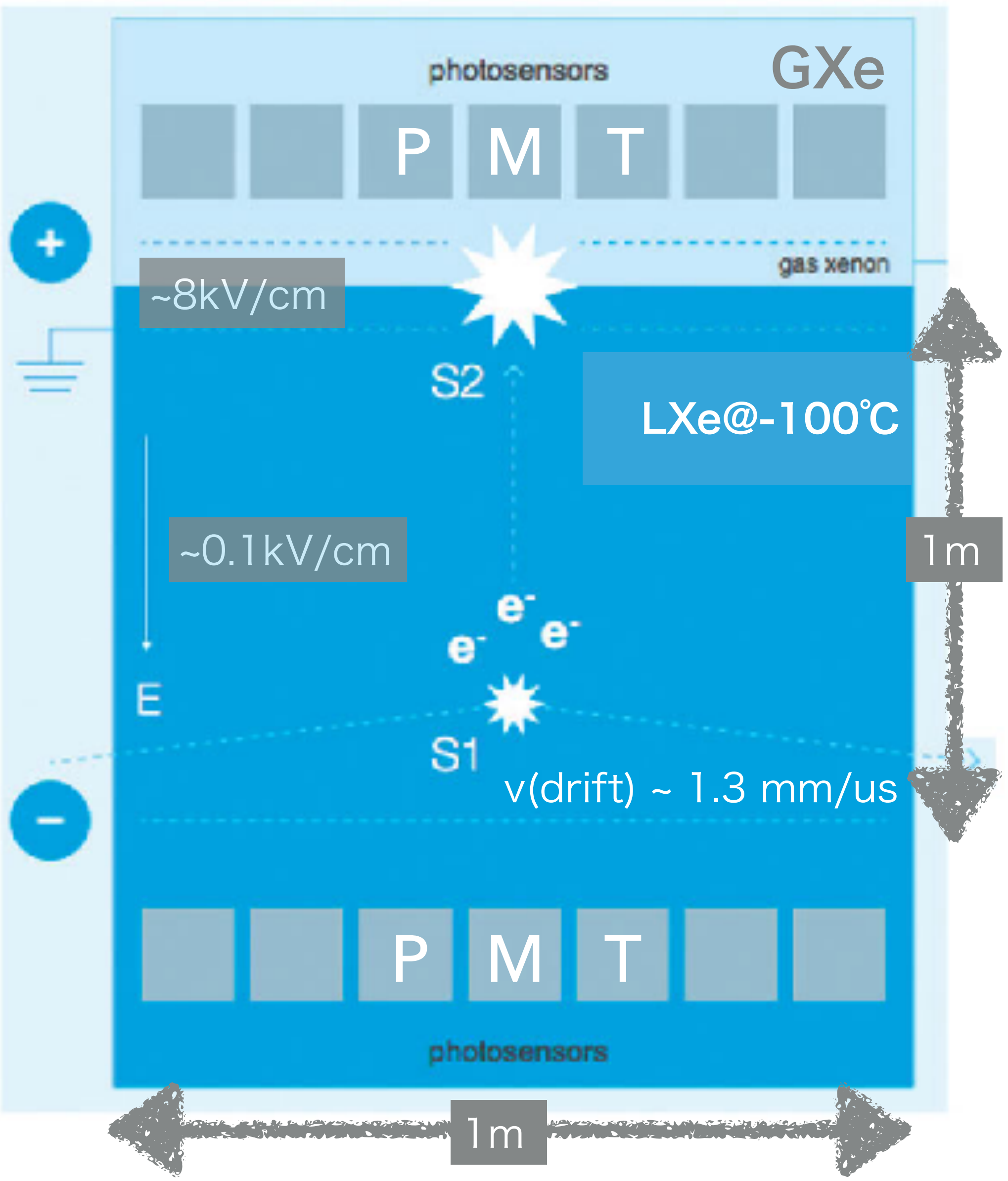
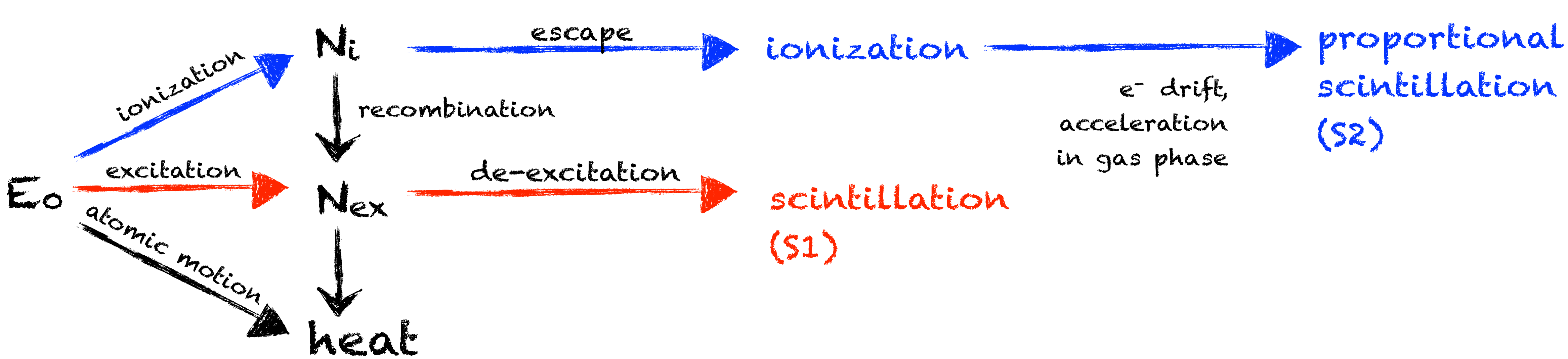
on behalf of the XENON collaboration

@43rd Johns Hopkins Workshop, June 4th 2019

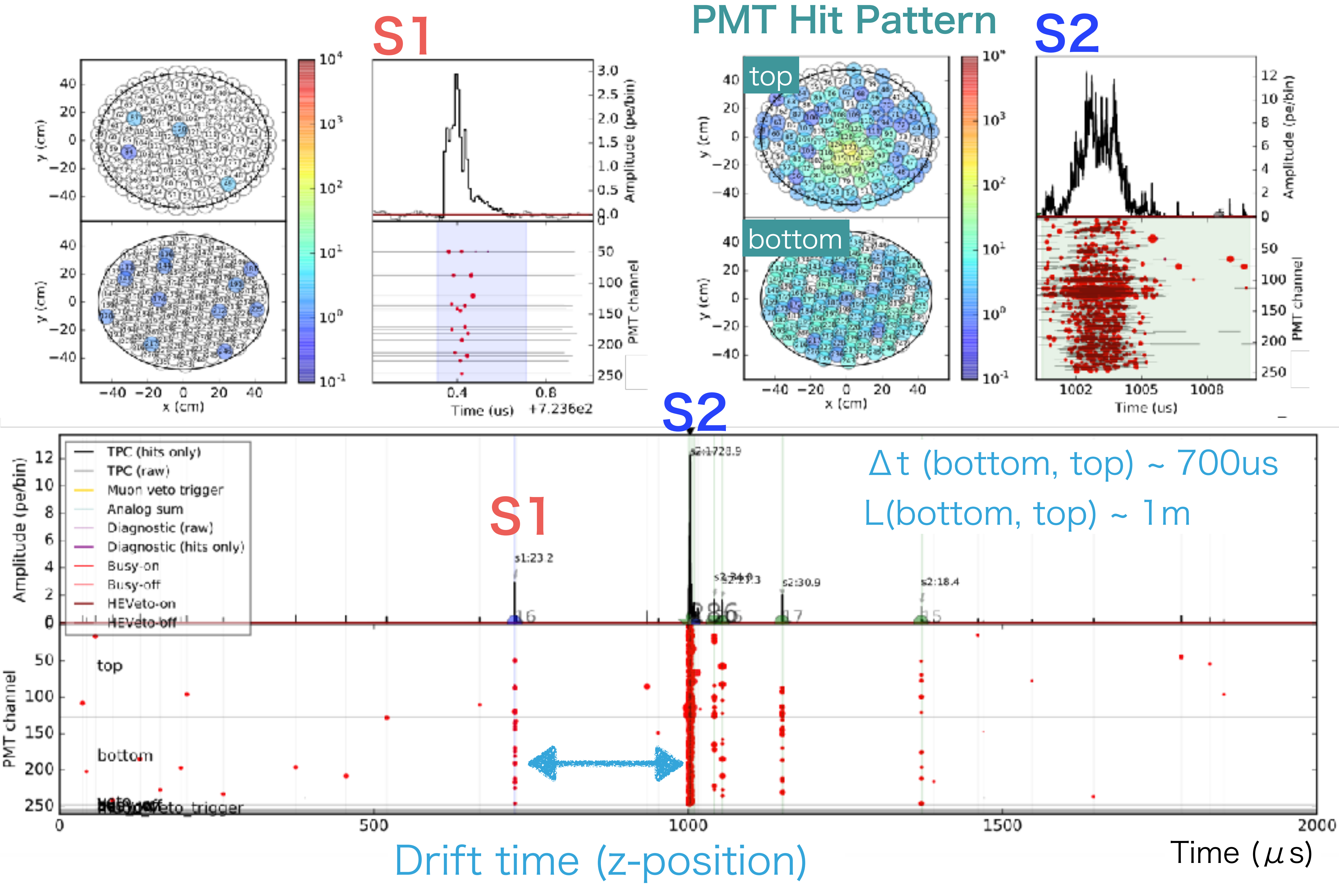
Xenon-Based Dual-Phase TPC



- Primary scintillation light (**S1**) is produced promptly at the interaction site
- Ionization electrons drift up through the LXe in the applied electric field
- Some recombine with ions, releasing more scintillation light (**S1**)
- Others are extracted above the liquid surface into gas phase region, where they form secondary proportional scintillation light (**S2**)
- Event vertex reconstruction in 3D space
  - **X,Y position: S2 hit-pattern in top PMT array**
  - **Z position: electron drift time (Δt (s1 - s2))**
- Particle type discrimination: $(S2/S1)_{\gamma,e}$ > $(S2/S1)_{\mathrm{WIMP,\ neutron}}$



Xenon-Based Dual-Phase TPC



XENON1T at LNGS

EPJ-C 77 (2017) 12

Water tank

- 700 t of pure water

Cherenkov Muon Veto

- 84 8-inch PMTs (R5912)

External calibration

- ^{241}AmBe
- Neutron generator

Cryostat and support structure for TPC

TPC

- 248 3-inch PMTs (R11410-21,QE34%@178nm)
- Diameter ~1m, height ~1m
- Fully covered by high reflective PTFE
- **LXe mass: 3.2 t(total), 2.0t (active)**

Cryogenics, and purification

Internal calibration

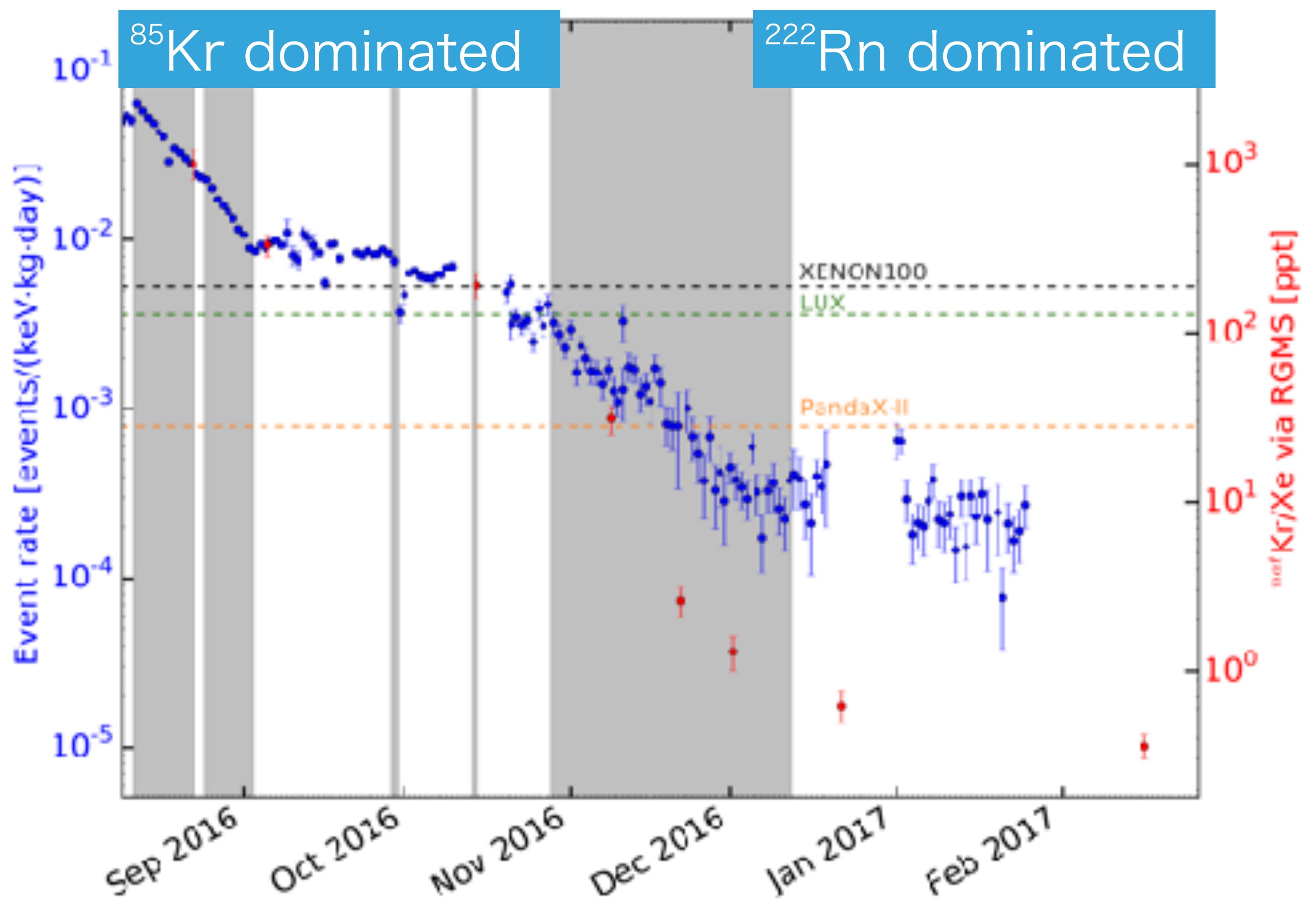
- ^{83m}Kr, ^{220}Rn

DAQ and slow control

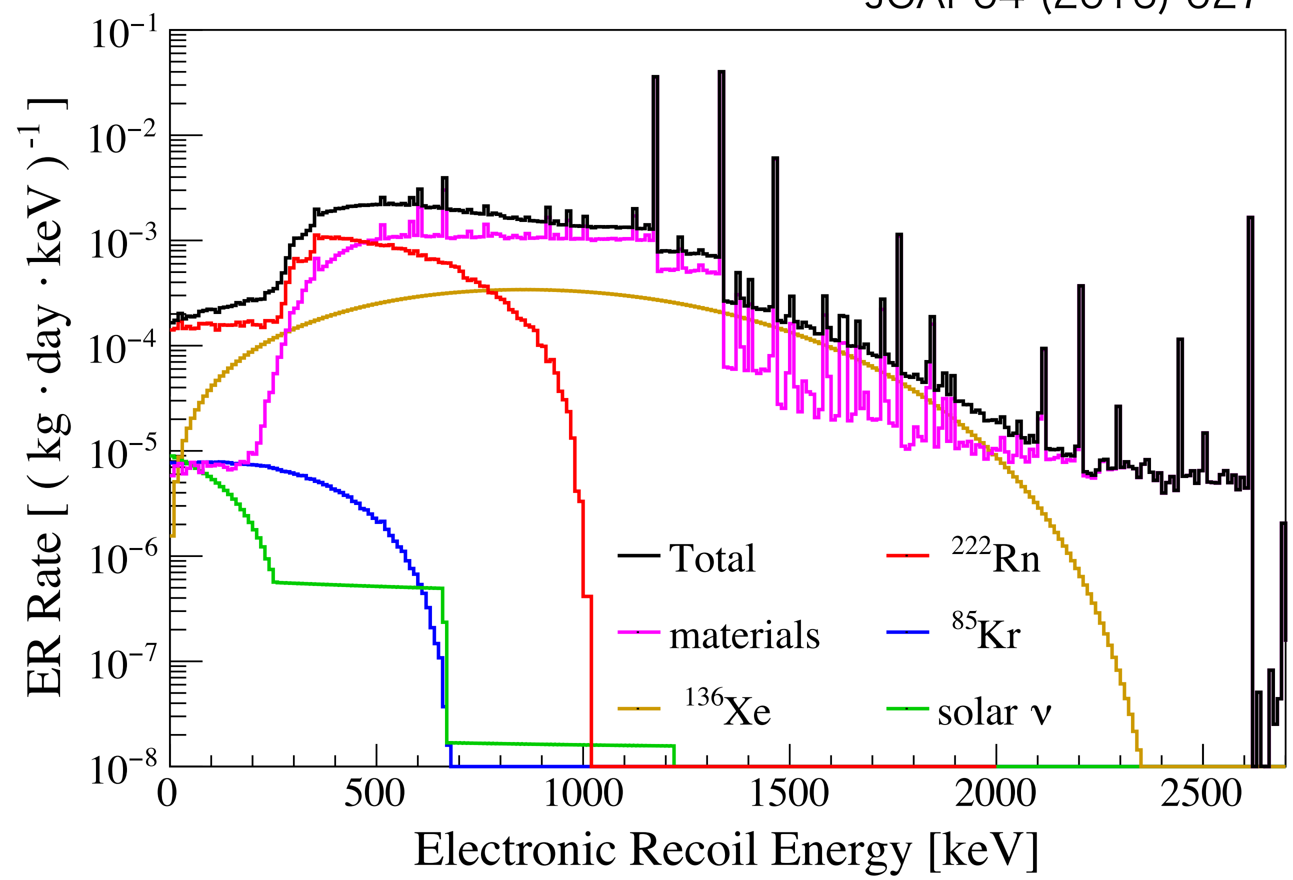
Xenon storage, handling and Kr distillation

Electronic Recoil Backgrounds

- Material background
  - Suppressed by careful material selections and fiducialization.
- $^{nat}Kr/Xe$: (0.66 ± 0.11) ppt
  - Initially BG was ^{85}Kr dominated —> negligible due to online distillation column
- ^{222}Rn: ~10 μBq/kg (—> reduced to ~4 μBq/kg due to purification upgrade & online distillation)
  - Careful surface emanation control and further reduction by online distillation column



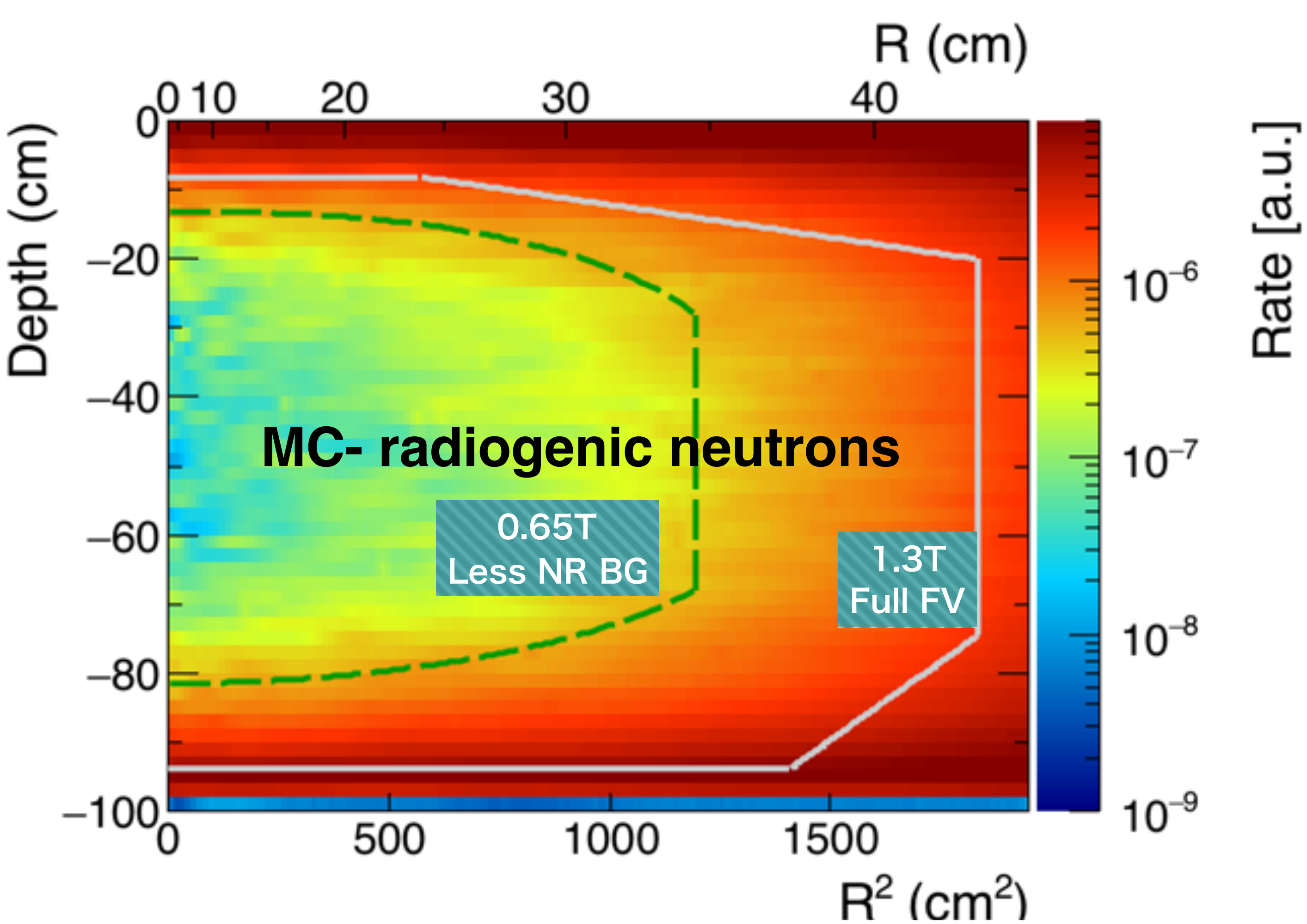
JCAP04 (2016) 027



- ER rate: (82±5) events/(keV t y), in 1.3 t and below 25 keV_{ee}
  - In the dark matter search region, ~0.2 events/(keV t y)
- Lowest background ever achieved in a dark matter detector

Nuclear Recoil Backgrounds

- Muon-induced neutrons: reduced by overburden and veto
- CEνNS from ^{8}B neutrinos: irreducible background < 1 keV
- Radiogenic neutrons from (α,n) and spontaneous fission from ^{238}U and ^{232}Th: reduced via material selection, multiplicity and fiducialization (+ a dedicated neutron veto for XENONnT)
- MC-based predictions from measured contaminations, validated with multi-scatter events.



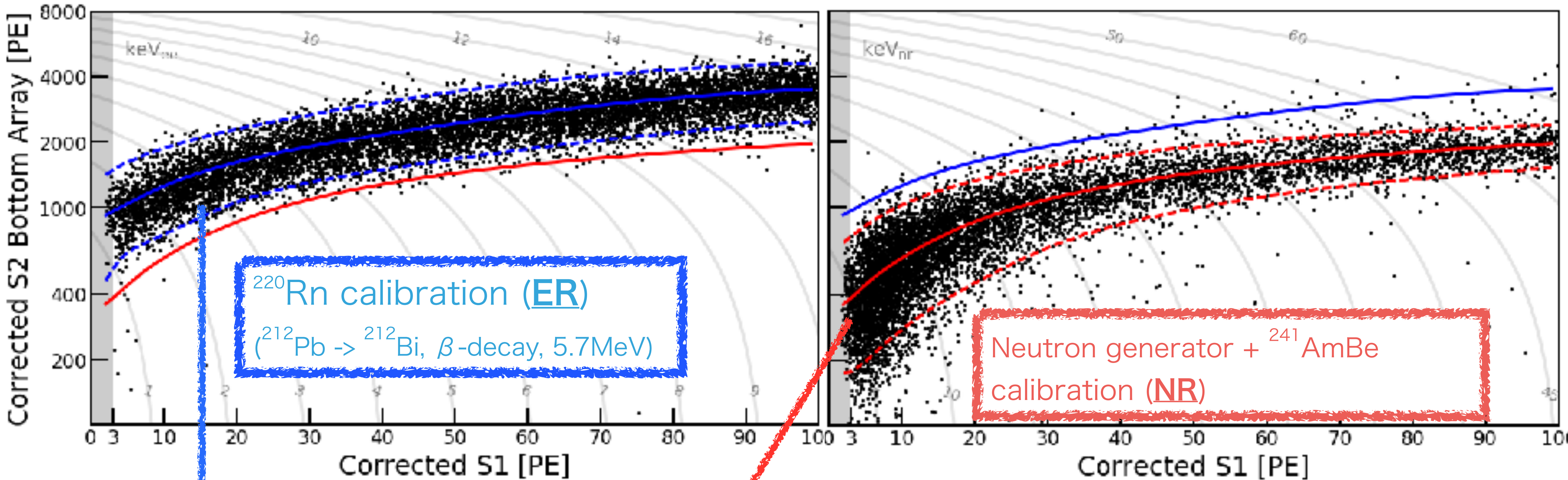
Expectation in 1ton FV, 4-50 keV$_{nr}$ window

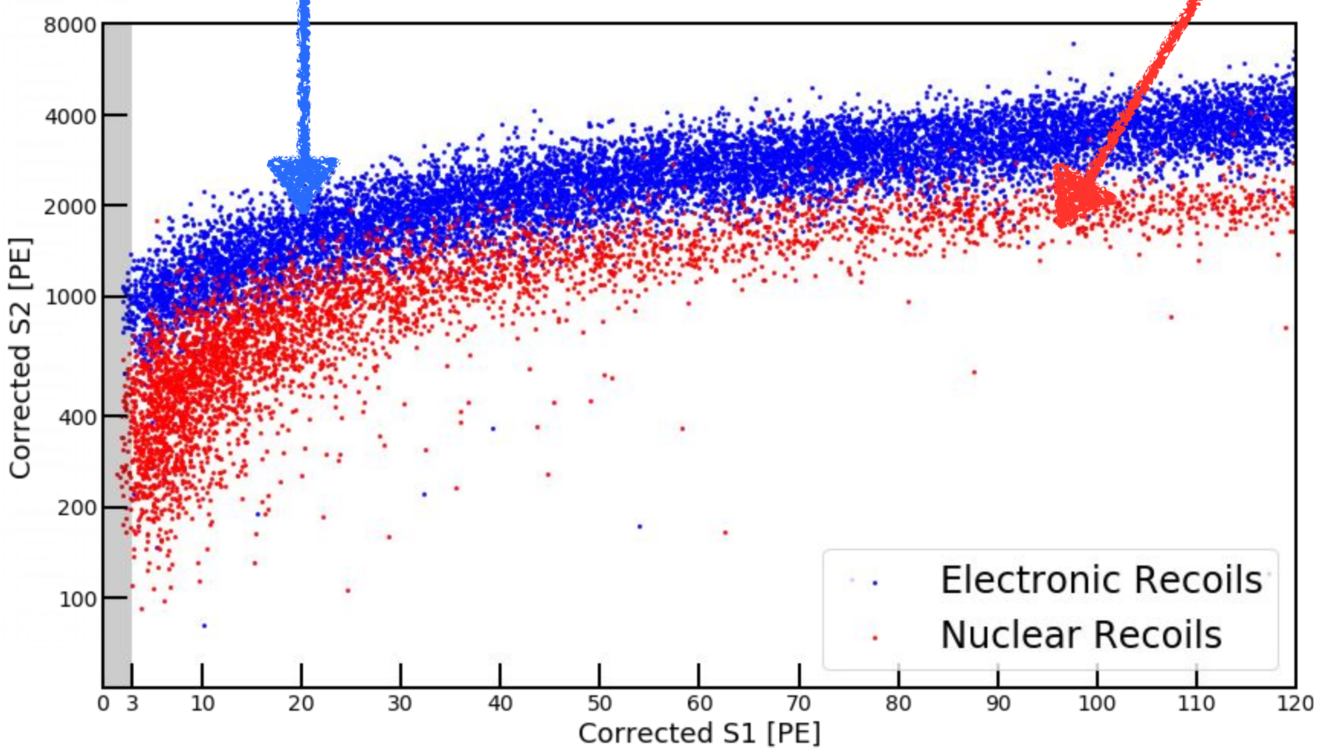
Source	Rate [t^{-1} y^{-1}]	Fraction [%]
Radiogenic	0.6±0.1	96.5
CEνNS	0.012	2.0
Cosmogenic	<0.01	<2.0

JCAP04 (2016) 027

ER/NR Calibrations

Blue: ER, Red: NR; ——: median, ·····:±2σ



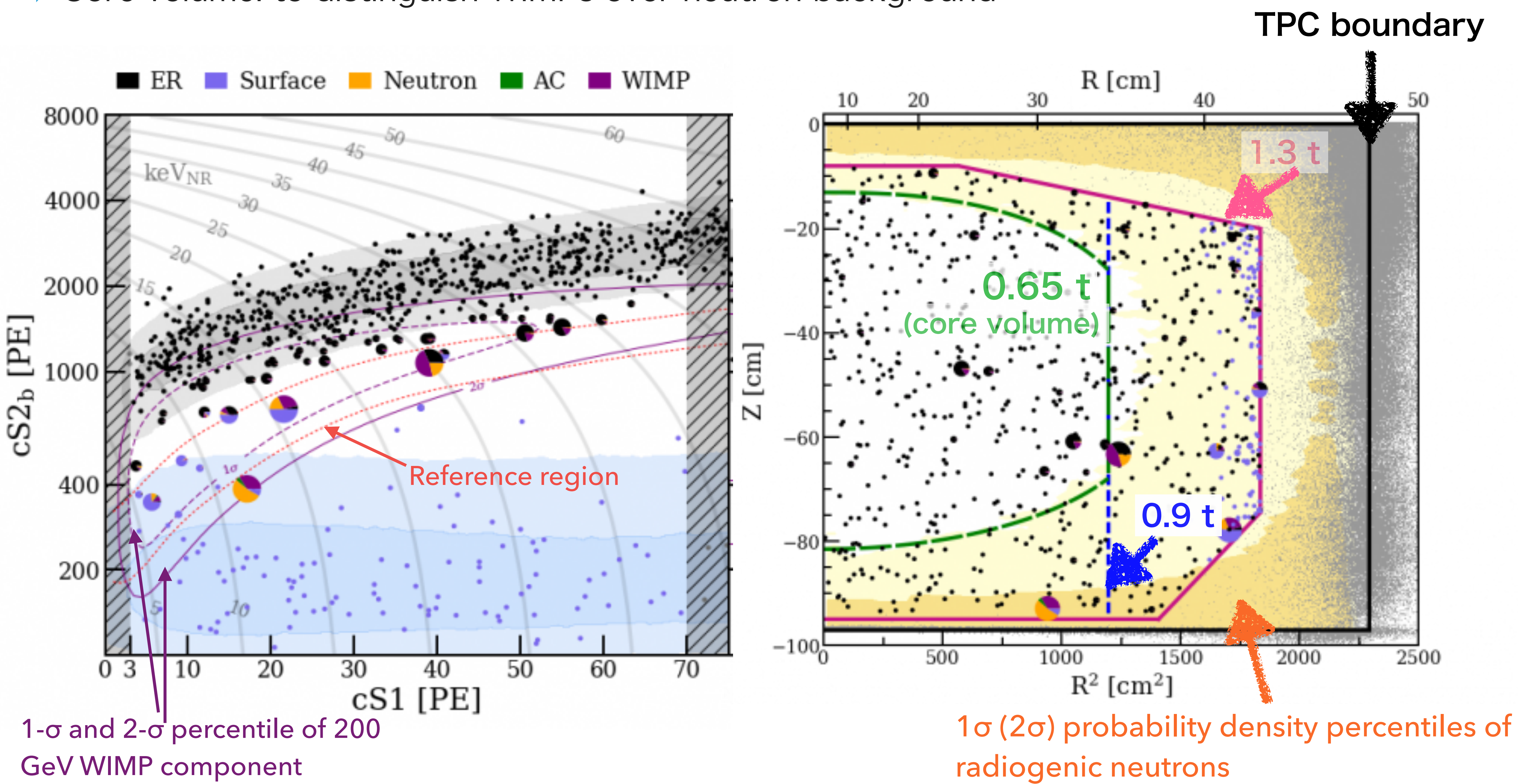


- ER and NR are well separated with each other, but separation is not perfect
- The region below NR-mean and above NR -2σ region -> reference region
- ER-leakage fraction below NR mean is ~ (1-3)×10^{-3}, which is similar discrimination power as for XENON100, LUX and Panda-X

Interpreting DM Search Data

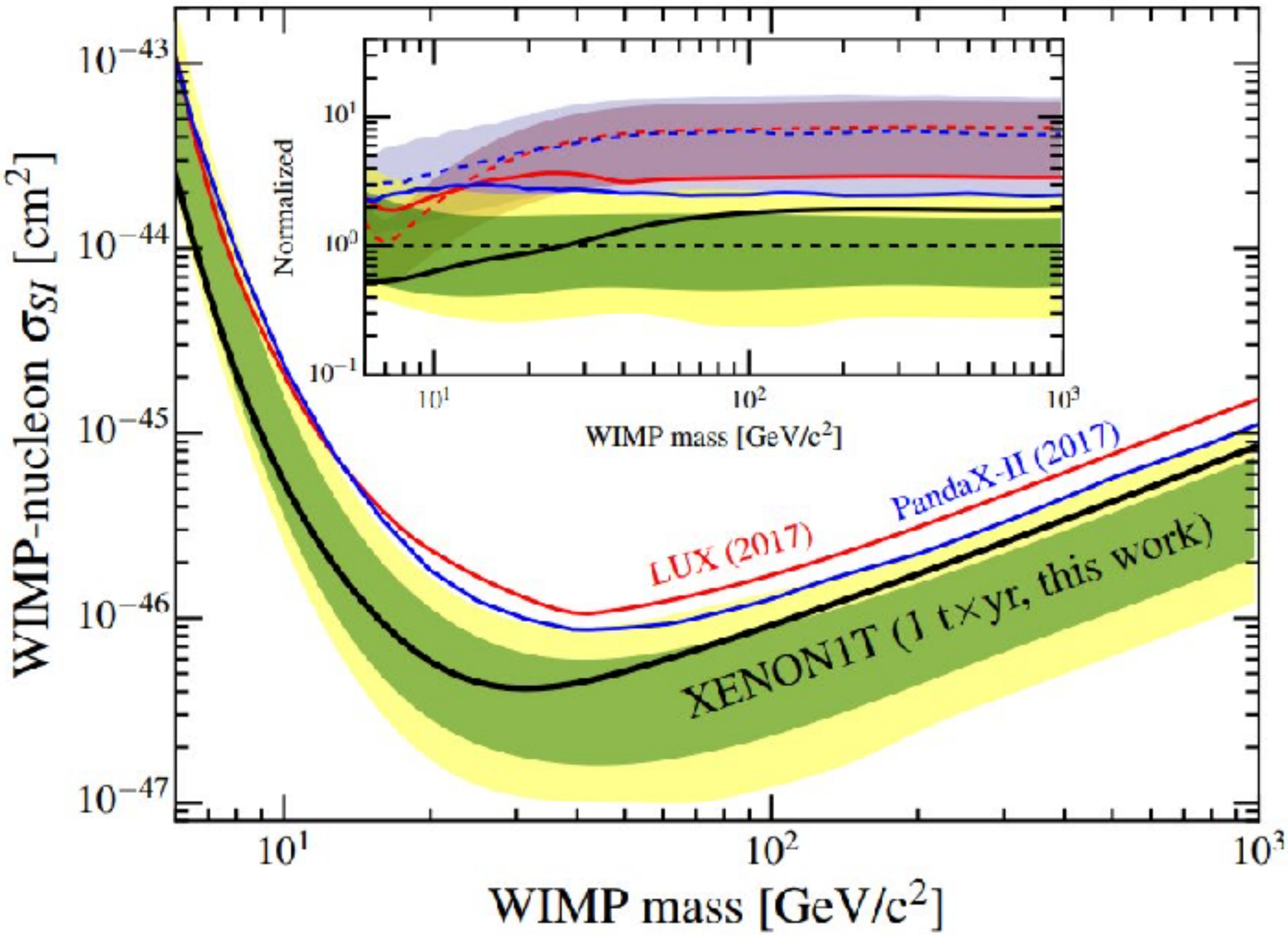
Phys. Rev. Lett. 121, 111302

- Results interpreted with unbinned profile likelihood analysis in s1, s2, R, z (all model uncertainties included in the likelihood as nuisance parameters)
- Piecharts: relative PDF from the best fit of 200 GeV WIMPs with 4.7×10^{-47} cm^2
- Core volume: to distinguish WIMPs over neutron background



Spin-Independent WIMP Search

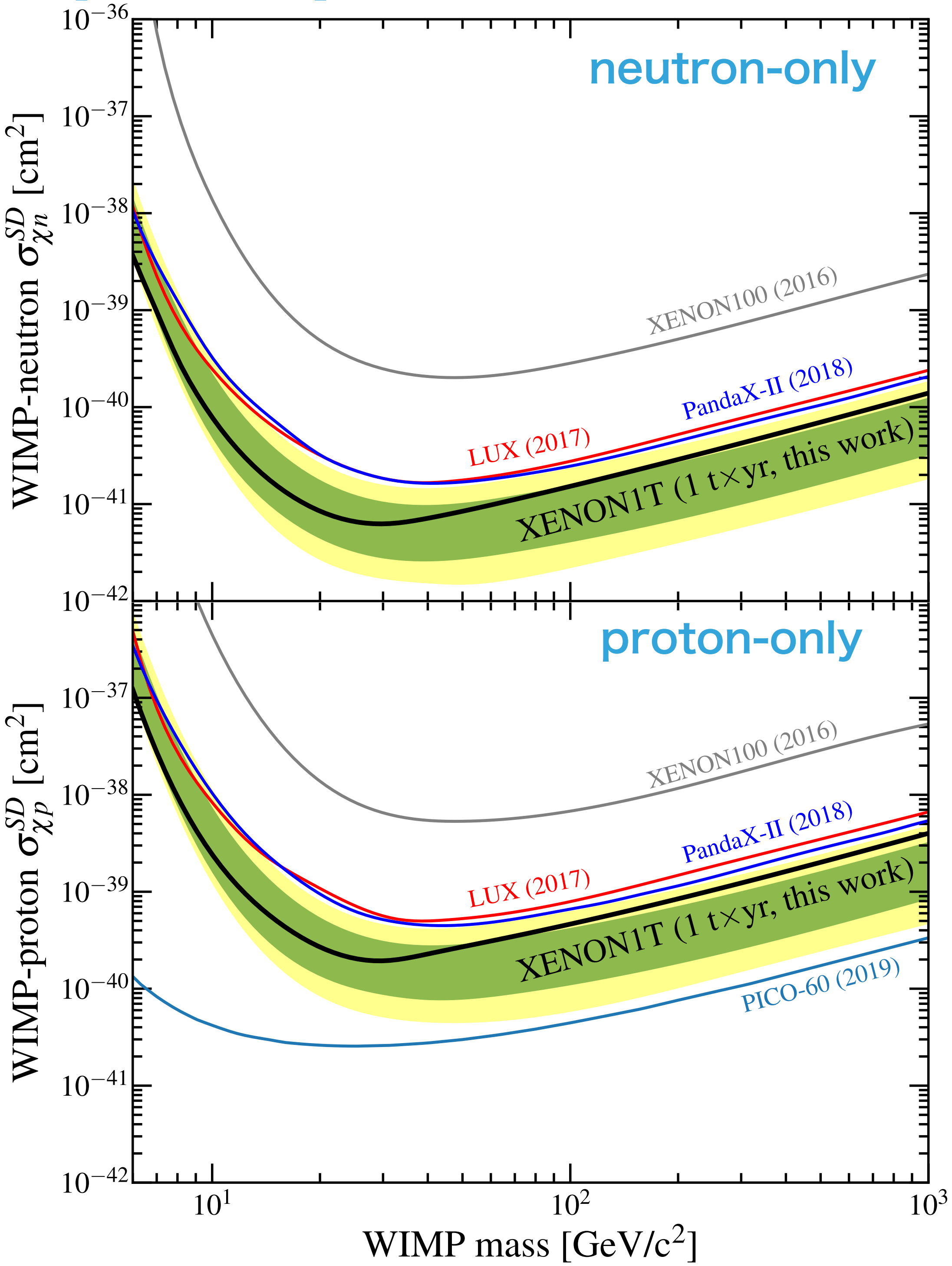
Phys. Rev. Lett. 121, 111302



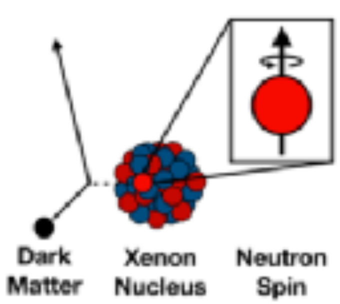
- **Strongest upper limit (at 90% CL) on SI WIMP-nucleon cross sections > 6 GeV**
- Median sensitivity: factor 7 higher than for previous experiments (LUX, PandaX-II)
- 1-σ fluctuation at higher WIMP masses could be due to background or signal

Spin-Dependent WIMP Search

Phys. Rev. Lett. 122, 141301



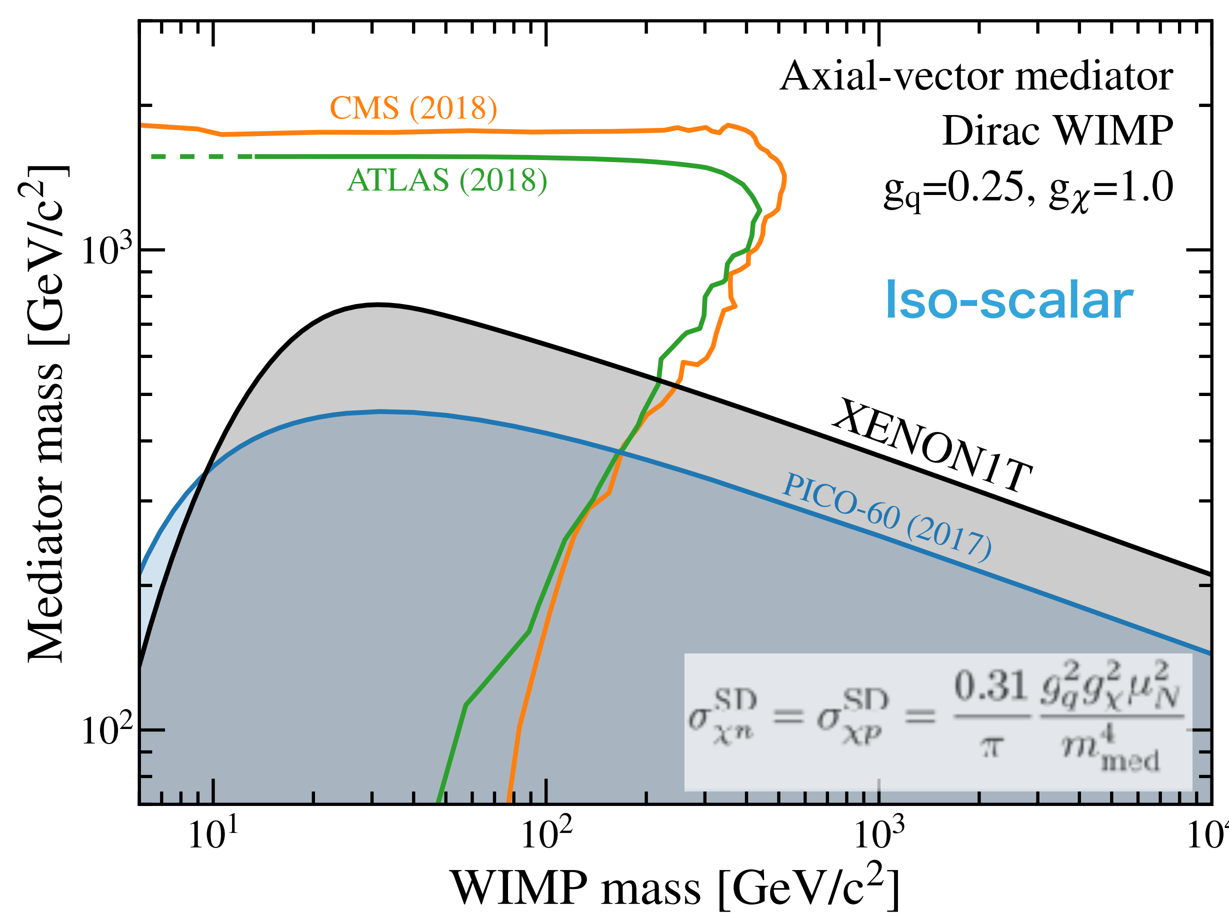
- Limits on WIMP interactions with ^{129}Xe (1/2) and ^{131}Xe (3/2) (isotopes of xenon with nonzero nuclear spin)
- Most of the spin in xenon is carried by neutrons, so WIMP-neutron scattering dominates.
- Constrain a new region in WIMP mass-mediator mass space
  - Assumption: Dirac fermion and an s-channel interaction with quarks, mediated by a spin-1 particle of mass m_{med} with an axial-vector coupling to both the WIMP and the quarks (mediator couples equally to all quark flavors)



Constraining the spin-dependent WIMP-nucleon cross sections with XENON1T

E. Aprile *et al.* (XENON Collaboration)
Phys. Rev. Lett. **122**, 141301 (2019)

Published 8 April 2019

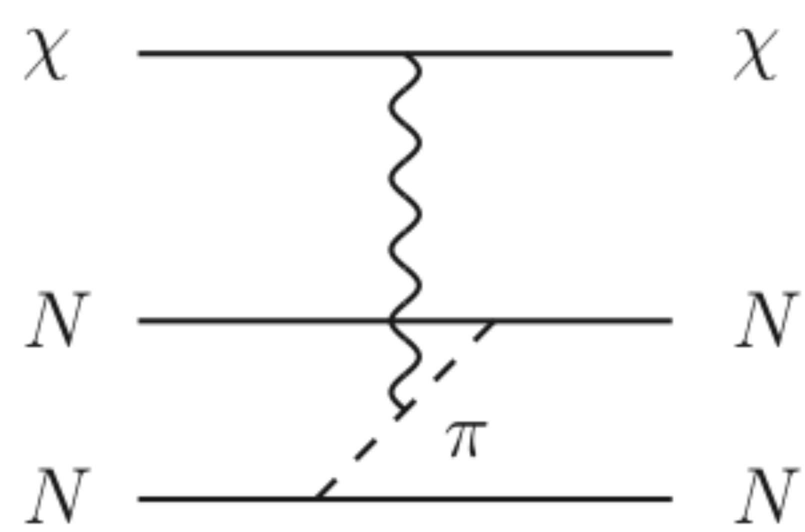


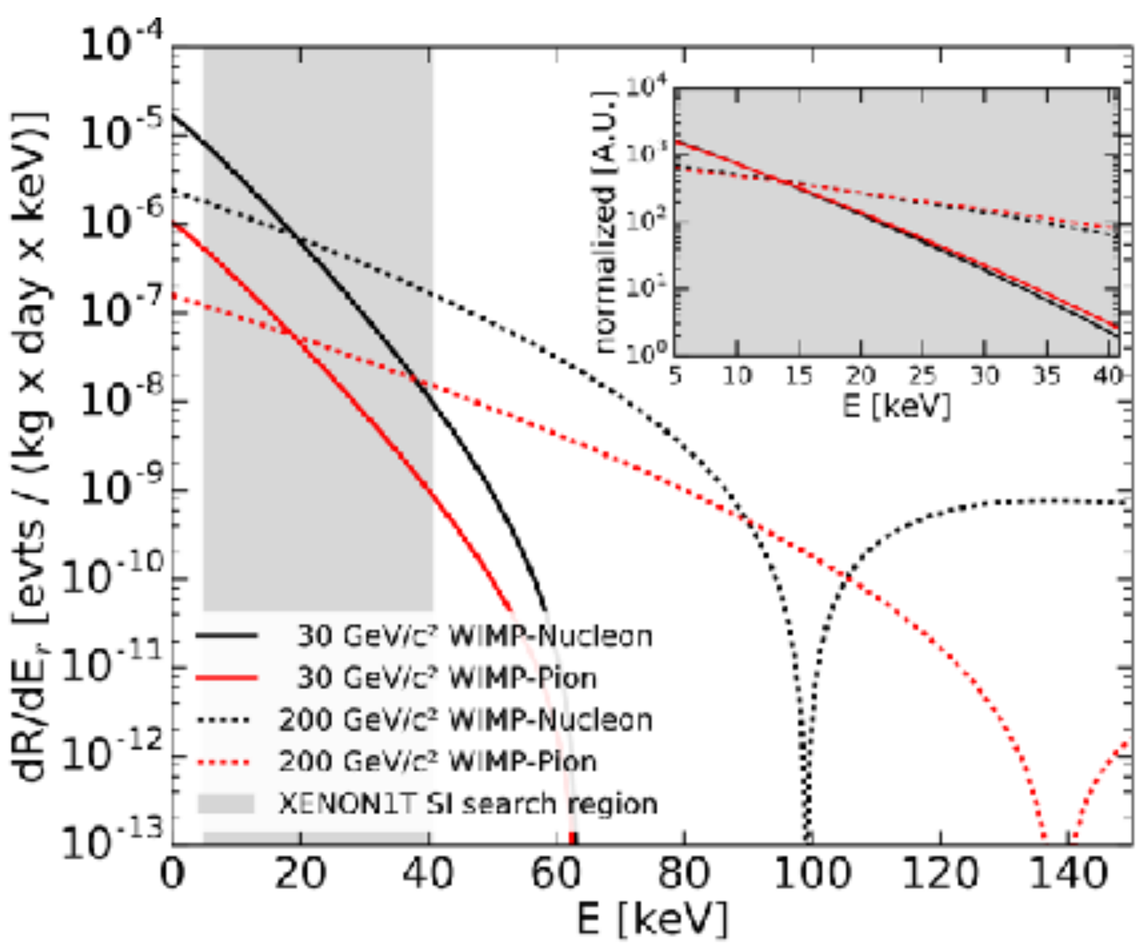
WIMP-Pion Interaction Search

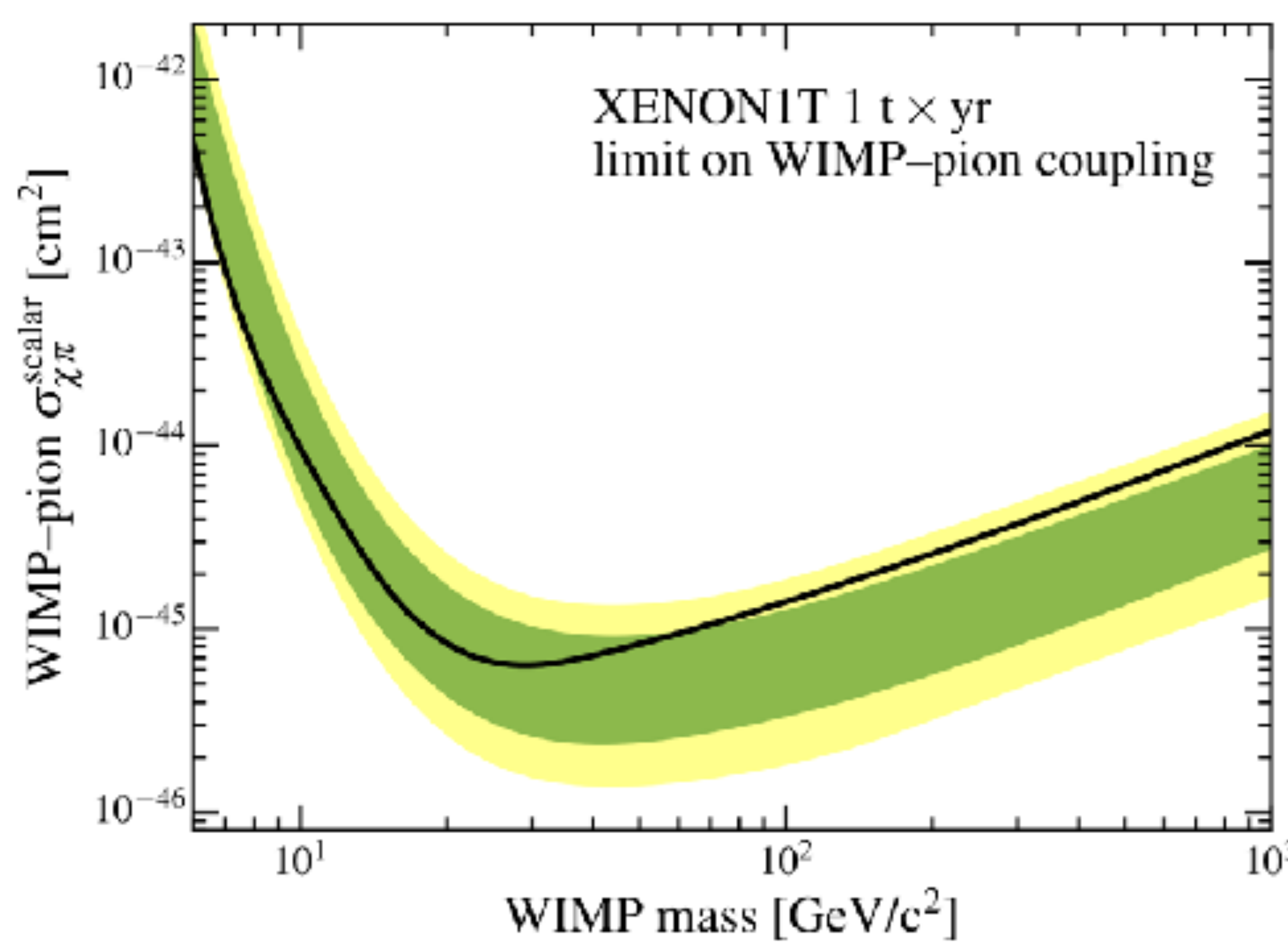
Phys. Rev. Lett. 122, 071301

- WIMP could couple to a virtual pion exchanged between the nucleons in a nucleus
- These pion-exchange currents can be coherently enhanced by the total number of nucleons.

  may dominate in scenarios where spin-independent WIMP–nucleon interactions are suppressed

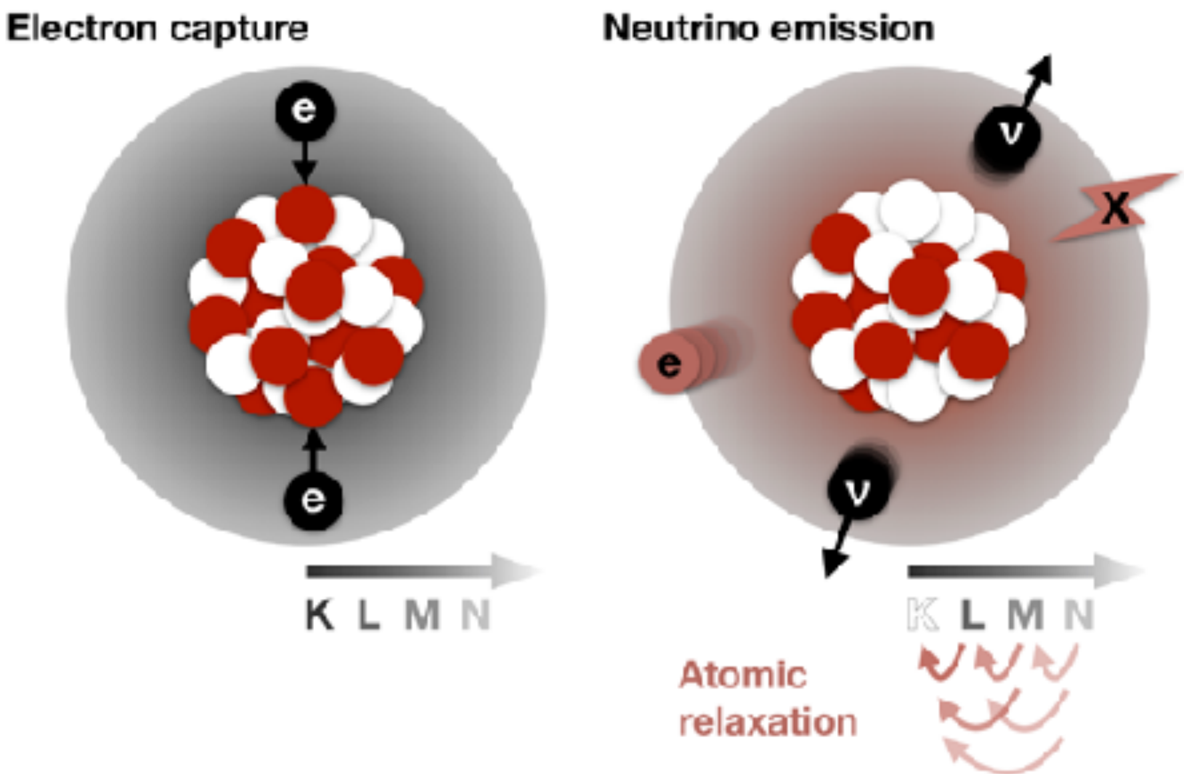


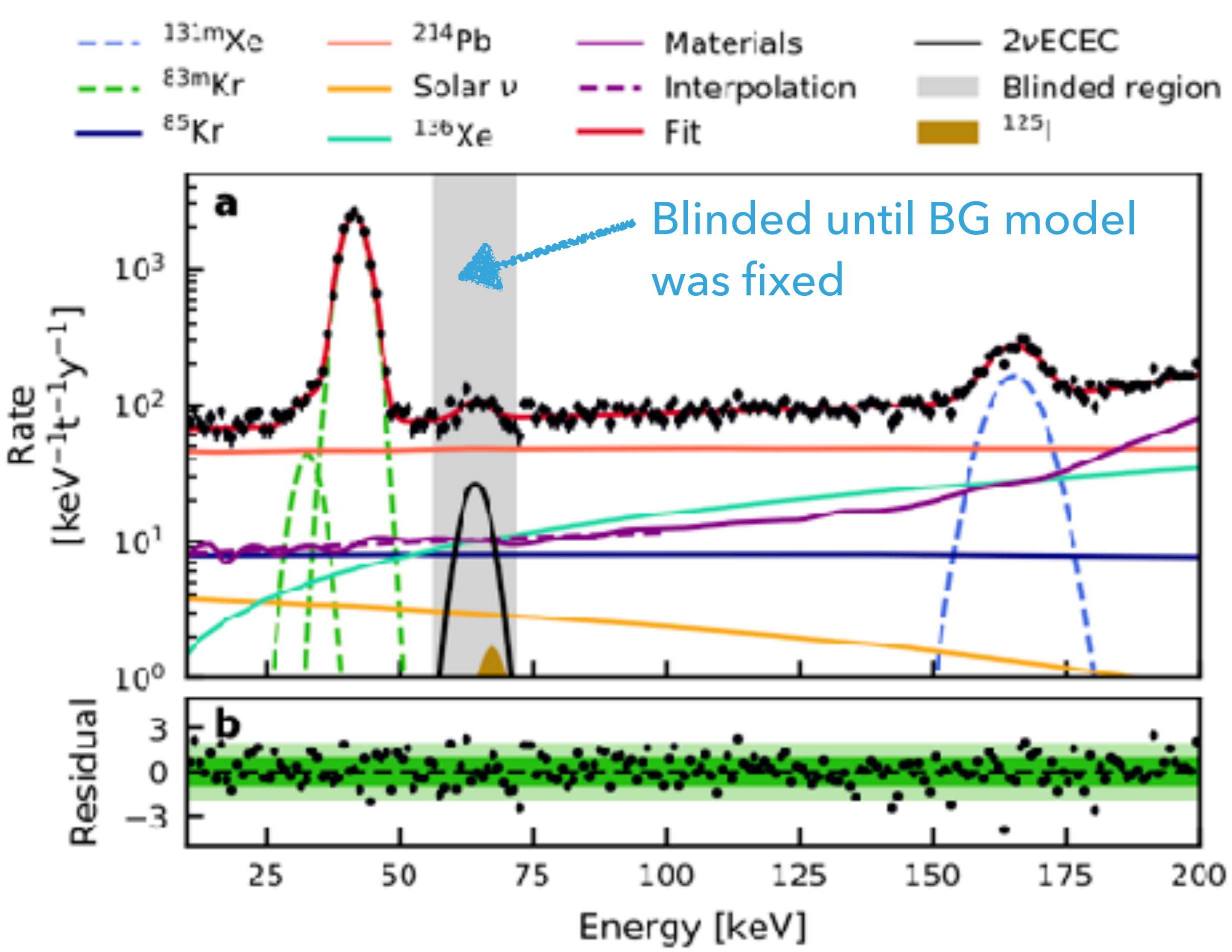




Double Electron Capture in ^{124}Xe

Nature 568, p.532-535, 2019





- Two-neutrino double electron capture (2νECEC)
  - second-order weak-interaction process
  - half-life >> the age of the Universe (~10^{12} times larger)
- Two protons are converted into neutrons by the absorption of two electrons and the emission of two ν_e
  - filling of vacancies generate X-rays and Auger electrons
- A good reference for nuclear matrix element calculation, and meaningful step in the search for neutrinoless double electron capture, a lepton number violation process

$$^{124}\mathbf{Xe} \longrightarrow {}^{124}\mathrm{Te} + \nu_e + \nu_e$$

- 1 kg ^{124}Xe per tonne of liquid Xe
- ^{124}Xe undergoes 2νECEC to ^{124}Te with Q = 2857 keV
- Observable: peaks at 64.3±0.6 keV (double K-shell electron-capture)
- Total fiducial mass (1502 ± 9_{stat}) kg

Double Electron Capture in ^{124}Xe

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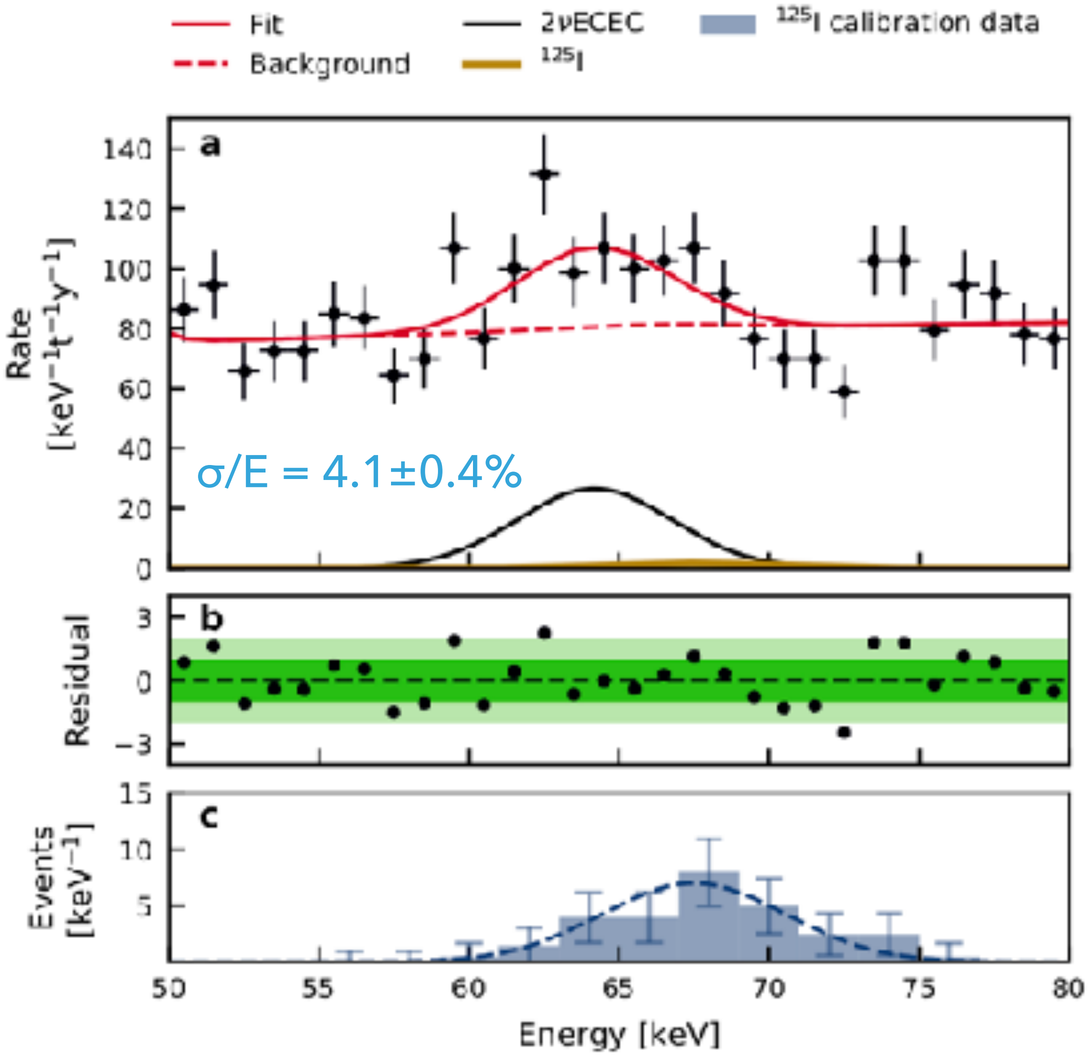
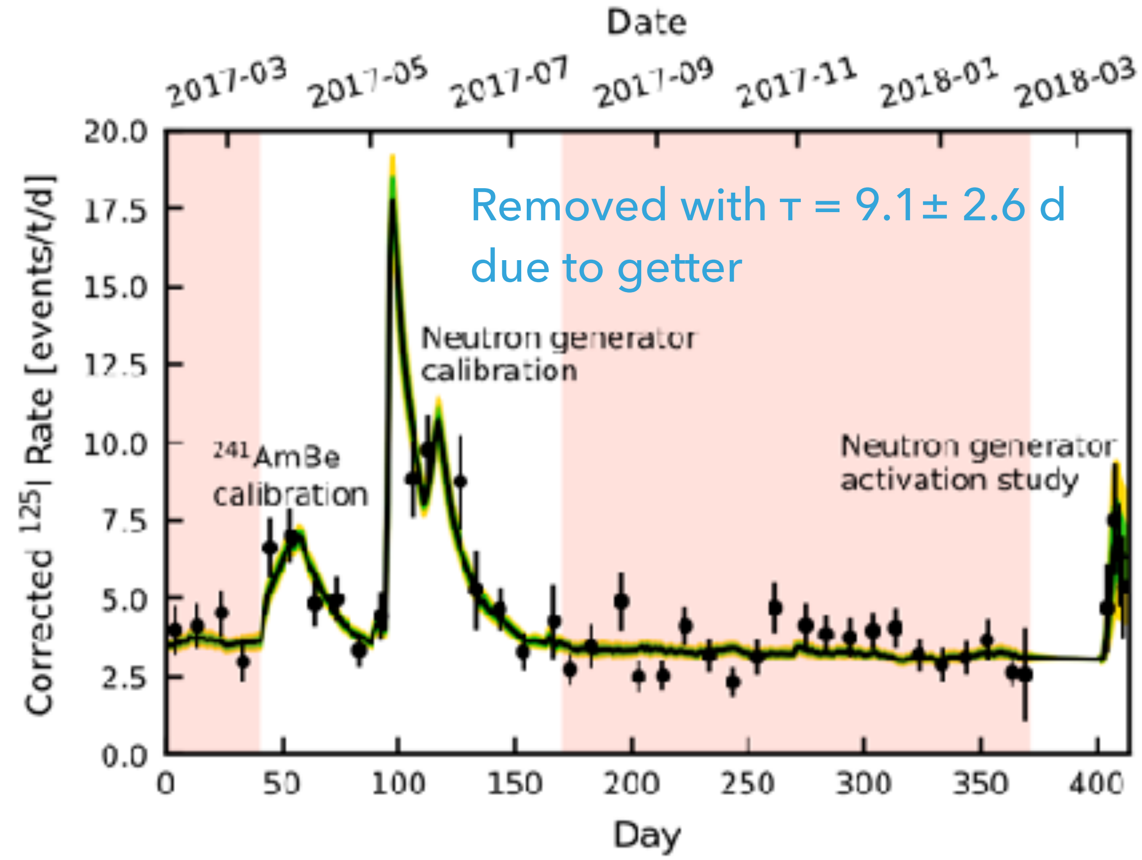
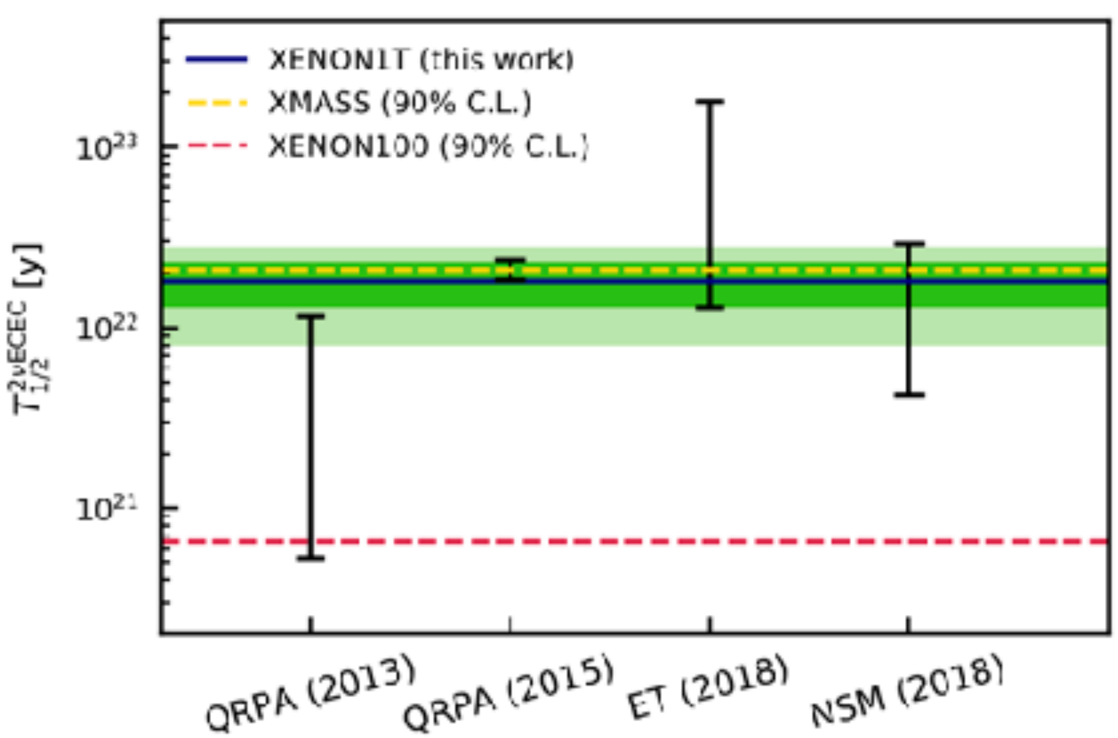


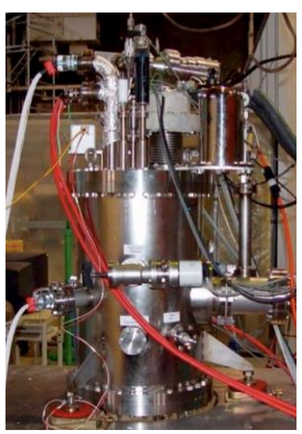




- Modeled nearby background ^{125}I (at 67.3 keV) from activation from neutron calibration
- Fit results: μ=(64.2±0.5)keV , σ=(2.6±0.3)keV
- Half-life of $(1.8 \pm 0.5_{stat} \pm 0.1_{sys}) \times 10^{22}$ years, longest directly measured half-life to date
- significance 4.4σ! (N_{signal} = 126 ± 29)

Summary and Outlook

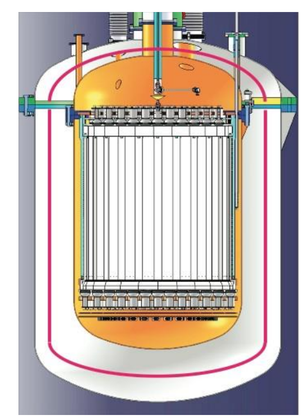
- The first multi-ton scale LXe-TPC was operated > 1 y
- Achieved the lowest background in a dark matter detector
- Result from an analysis of 1 tonne year exposure: the strongest upper limit on SI WIMP-nucleon cross sections for masses > 6 GeV, with 4.1×10^{-47} cm^2 at 30 GeV
- First detection of two neutrino double electron capture in ^{124}Xe
- Many analyses in the pipeline (Migdal effect, S2-only, $0\nu\beta\beta$-decay of ^{136}Xe, annual modulation, ALPs, Dark-Photons, etc)



XENON10
Total Xe: 25 kg
Target:14 kg
Fiducial: 5.4 kg
Limit: ~10^{-43}

XENON100
Total Xe: 162 kg
Target: 62 kg
Fiducial: 34/48 kg
Limit: ~10^{-45}

XENON1T
Total Xe: 3.2 ton
Target: 2 ton
Fiducial: 1 ton
Limit: ~10^{-47}



XENONnT
Total Xe: ~8.4ton
Target: 5.9ton
Fiducial: ~4ton
Limit: ~10^{-48}

DARWIN
Total Xe: 50 ton
Target: 40 ton
Fiducial: 30 ton
Limit: ~10^{-49}