



Measurement of Double Electron Capture of ^{124}Xe with XENON1T



nature

THE INTERNATIONAL WEEKLY JOURNAL OF SCIENCE



Ethan Brown

Rensselaer Polytechnic Institute

On behalf of the XENON

Collaboration

TRANSITIONAL
INSIGHTS

The world's largest study of
transgender people
PAGE 446

ENVIRONMENT
IN THE
DARK

How high-rise living deprives
urban centres of natural light
PAGE 452

NEUROSCIENCE
SPEECH
SYNTHESIZER

Implant gives voice to brain
signals that control movement
PAGES 406 & 410

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25 April 2019

ISSN 0028-0836



The XENON Collaboration



160 Scientists

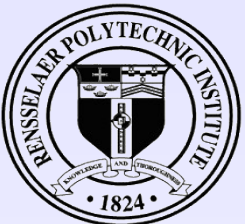
27 Institutions

11 Countries



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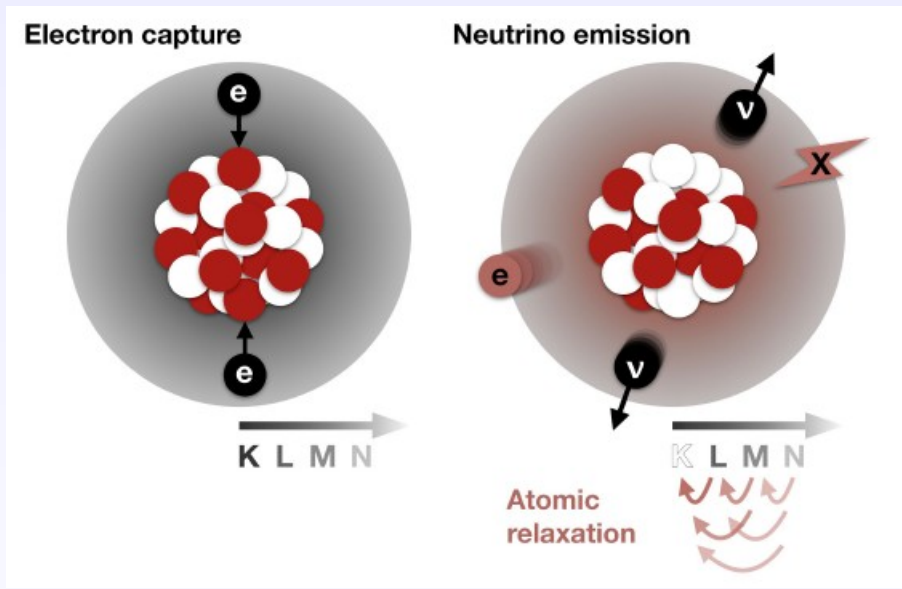
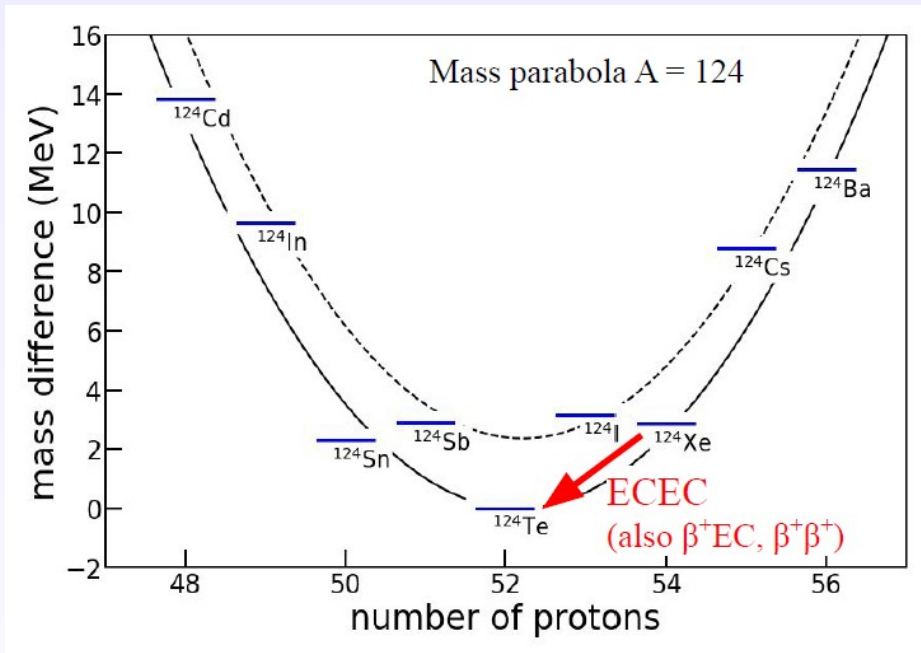
Lepton Photon, Aug 2019



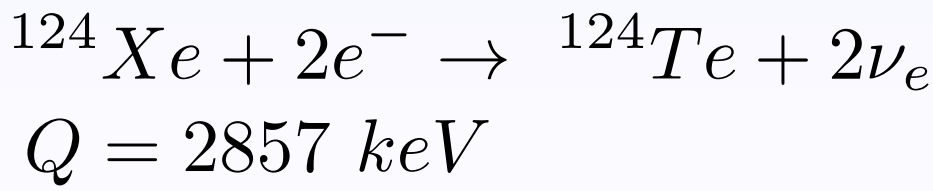
Double Electron Capture



- 2nd order standard model process
 - Emission of 2 neutrinos
- Neutrinoless version also possible for BSM Majorana neutrinos

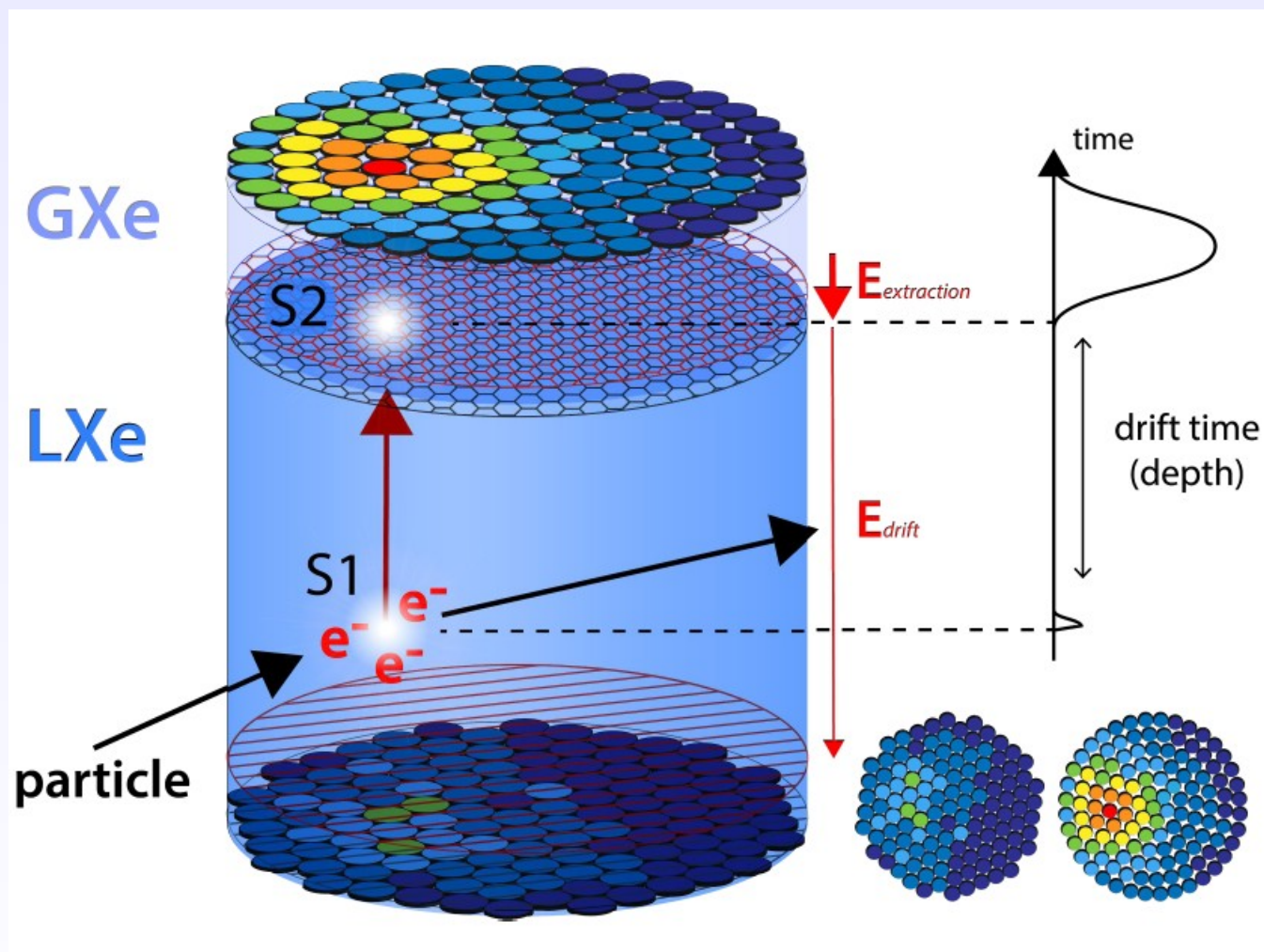


- Simultaneous capture of two shell electrons
- Nuclear recoil (~10 eV) negligible
- Observe x-rays and Auger electrons
 - Double K-shell capture (E=64.3 keV)



→ Signal

- 2 signals
 - Prompt scintillation S1
 - Ionization (via proportional scintillation) S2
- 3-D imaging
 - Time projection of z-axis
 - x-y positioning: S2 hit pattern
 - Fiducialization
 - High Z attenuates gamma backgrounds
- Recoil ID
 - Electronic vs Nuclear recoil (ratio of S2/S1)
- Multi-ton experiments
 - XENON1T: 3.5 tons Xe (1.5 ton fiducial)
 - 1.5 kg ^{124}Xe in fiducial





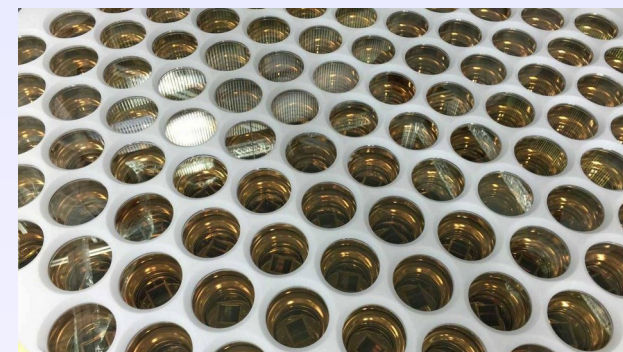
XENON1T



- Largest dark matter detector ever run
- 3.5 tons LXe (2.2 tons instrumented)
- ~1m diameter, ~1m height
- 248 VUV sensitive PMTs
 - 35% QE @178 nm
- Transparent grids and 74 copper field shaping rings for E field
- High-reflectivity PTFE support structure

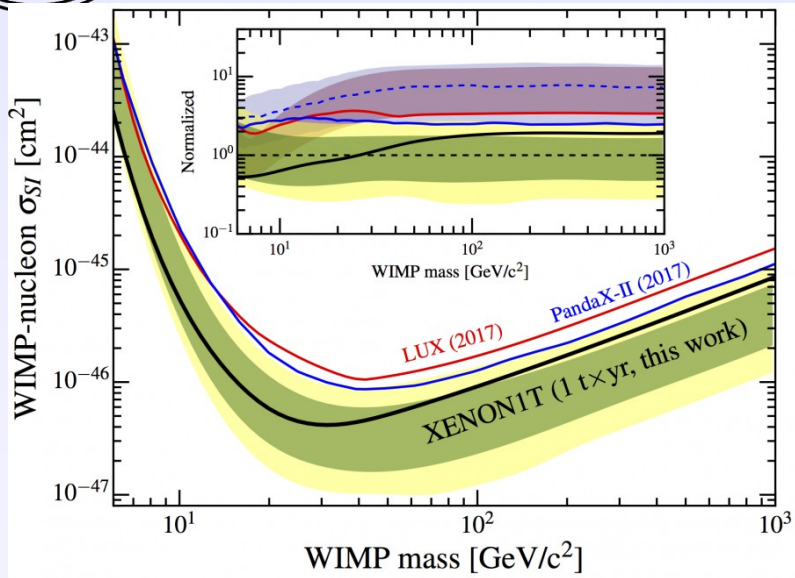
- Lowest background ever achieved in a DM experiment
- 82 ± 5 evts/keV-ton-yr below 25 keV_{ee} for 1T FV

JCAP 04:027 (2016)

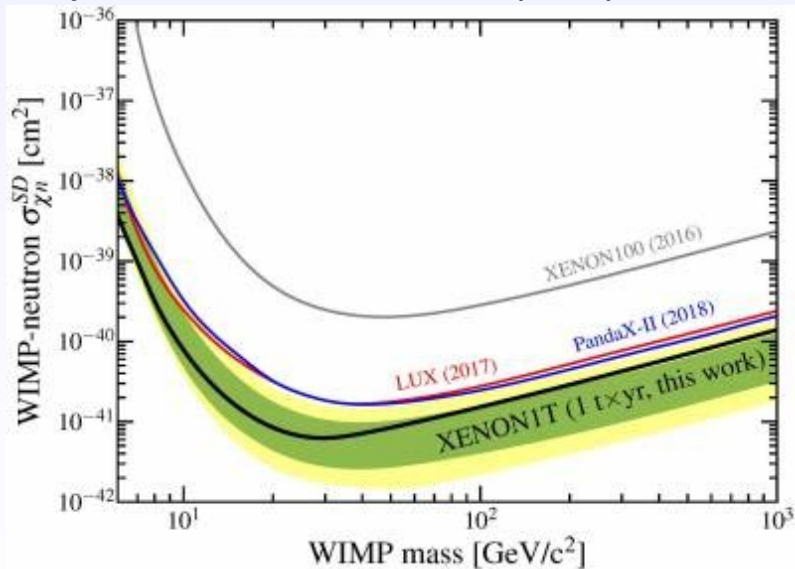




World-Leading DM Results



Phys. Rev. Lett. 121, 111302 (2018)

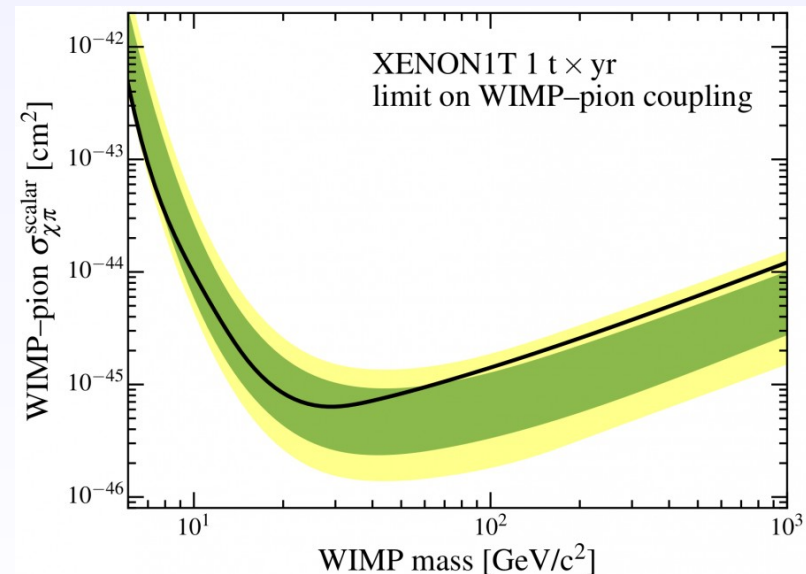


Phys. Rev. Lett. 122, 141301 (2019)

- 1 tonne X year exposure
- No evidence of DM signal above background
- World's most sensitive limits on:
 - Spin independent cross section
 - Pure neutron spin-dependent cross section
 - Also competitive for pure proton coupling
 - WIMP-pion coupling
 - Brand new results for other DM coupling channels

arXiv:1907.11485

arXiv:1907.12771



Phys. Rev. Lett. 122, 071301 (2019)



Energy Calibration



- Linear combination of S1 and S2
- Exploit anti-correlation in scintillation/ionization process

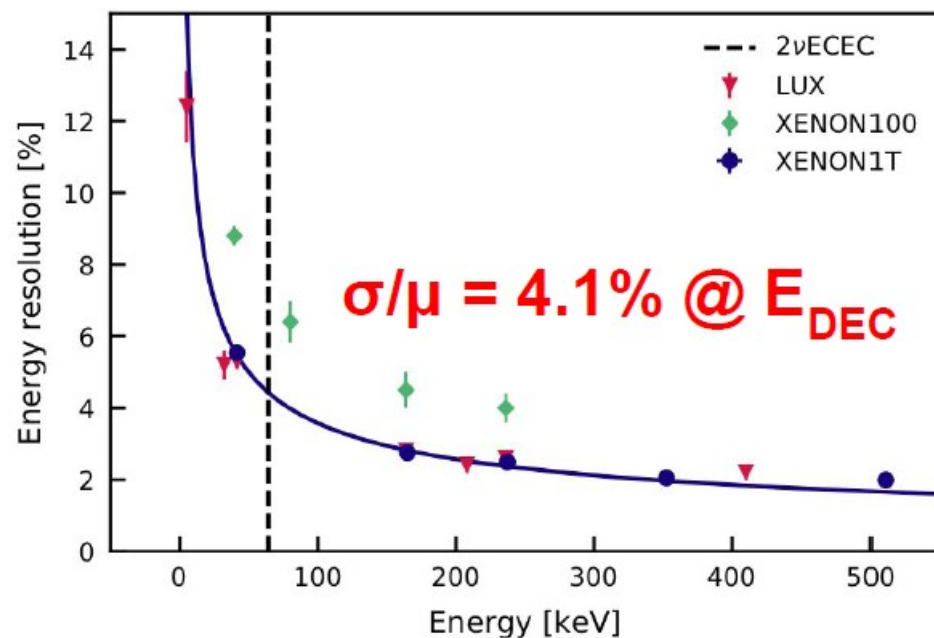
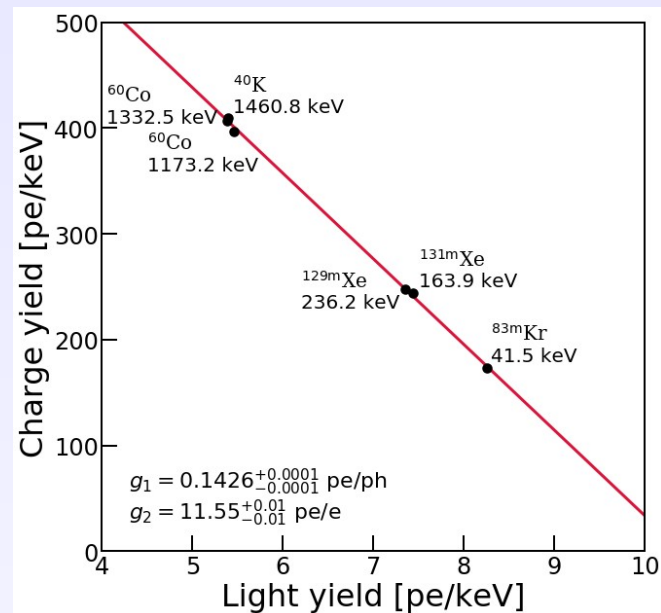
$$E = (N_{ph} + N_e) \times W$$
$$= \left(\frac{S1}{g_1} + \frac{S2}{g_2} \right) \times W$$

$$W = 13.7 \text{ eV}$$

Average energy to liberate one quantum

Eur.Phys.J. C77 (2017) no.12, 881

Nature 568, 532-535 (2019)

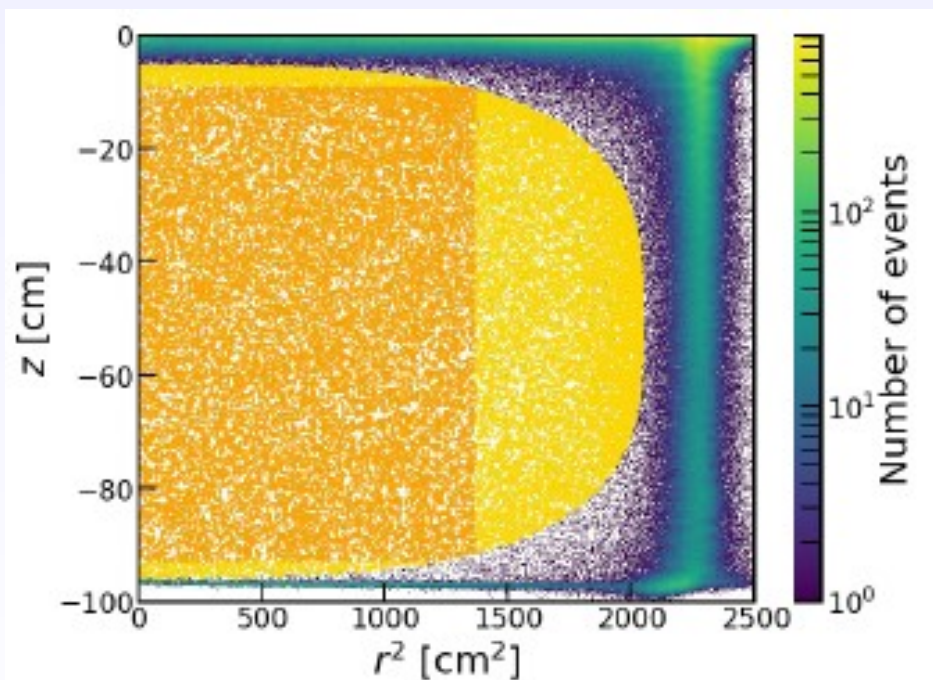




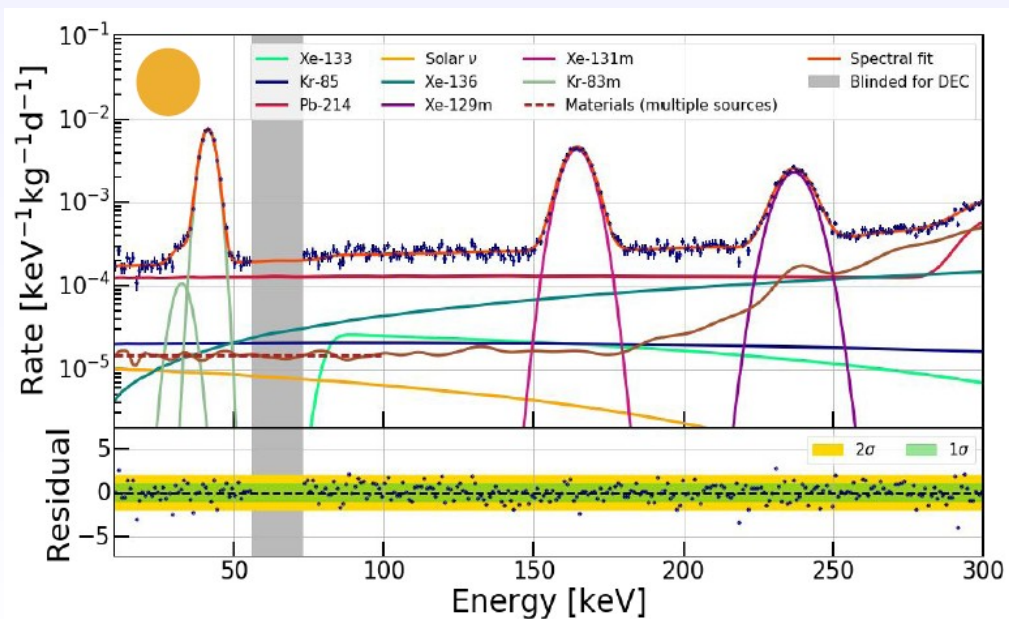
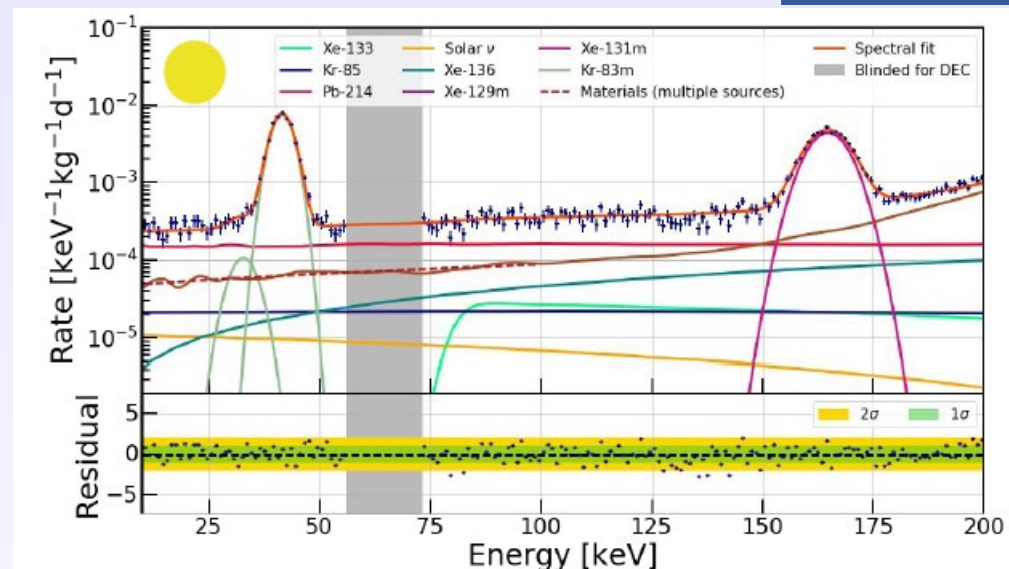
Background Model



- Fit background in both 1T and 1.5T fiducial volumes
- Match MC to data
 - MC includes physics (Geant4) and detector response
- Includes all known backgrounds

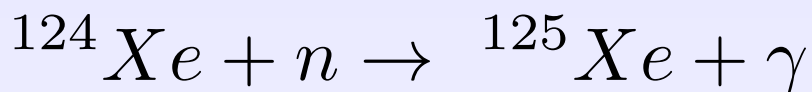


Nature 568, 532-535 (2019)

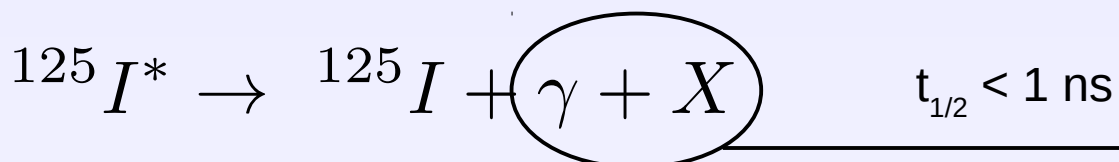
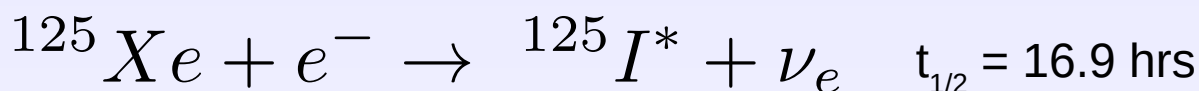




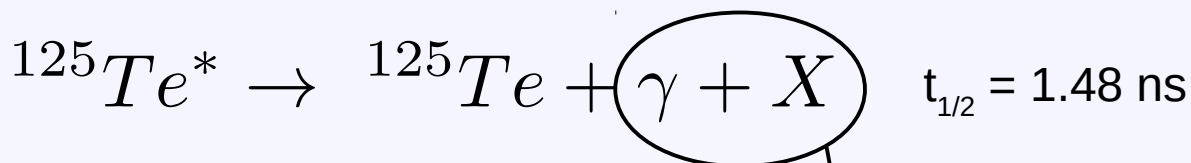
^{125}I Background



Thermal neutron capture (calibration plus radiogenic, 5kg outside of water shield)



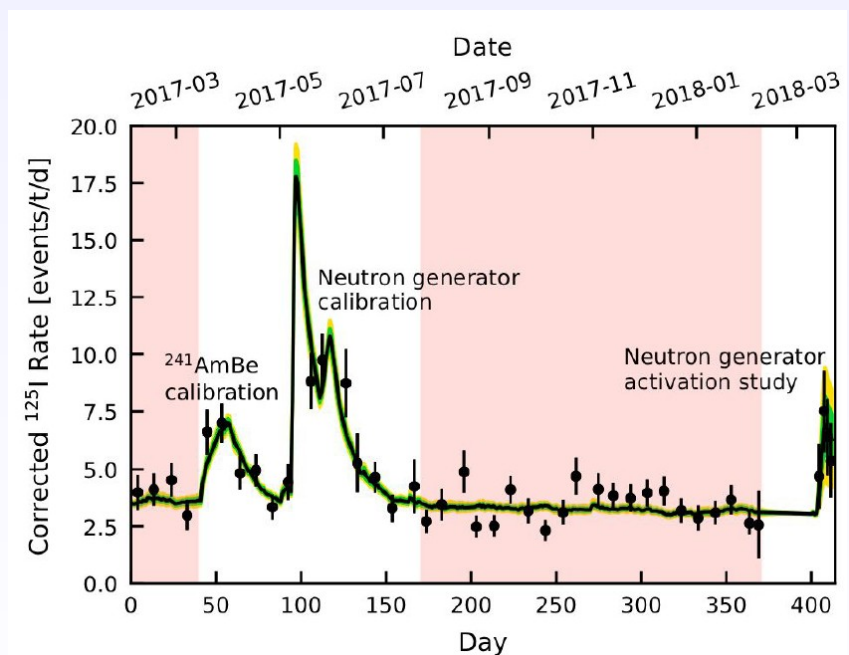
Lines at 222 and 277 keV
(during/after n calibrations)



Line at 67.3 keV

Total ^{125}I background:

$$N_{I-125} = 10 \pm 7$$

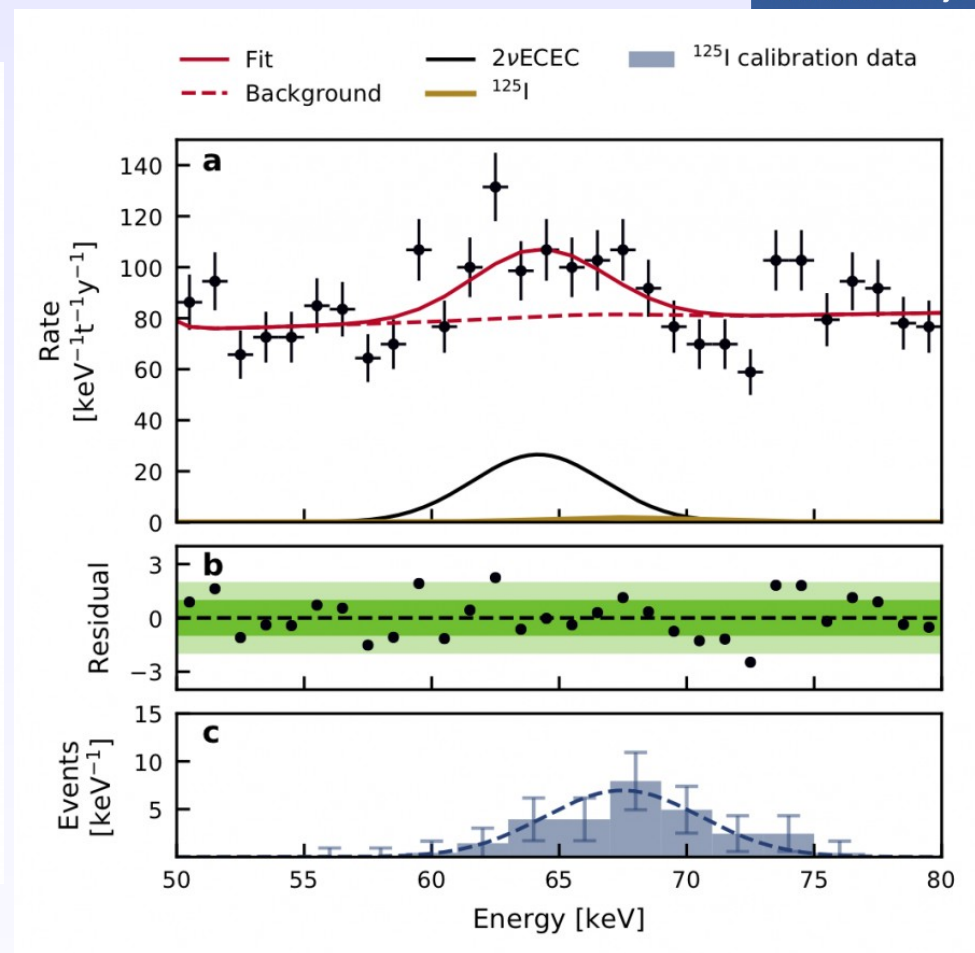
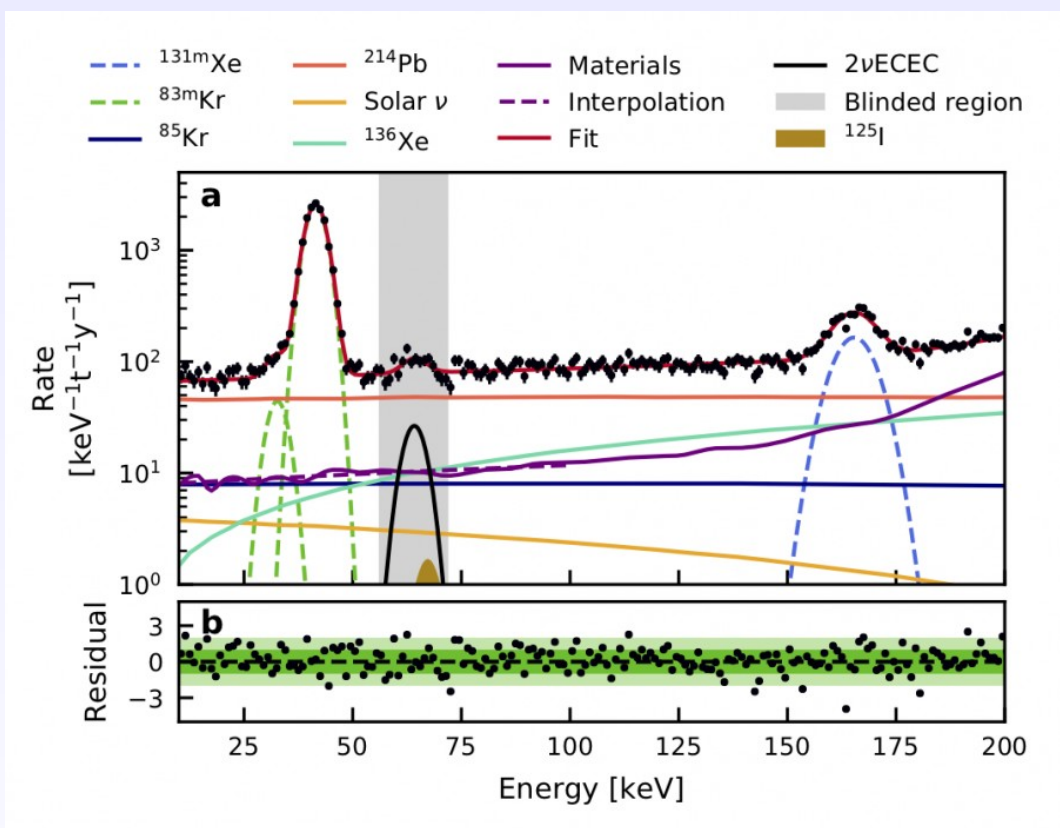


Nature 568, 532-535 (2019)



Results

Nature 568, 532-535 (2019)



- Blind analysis
- 177.7 live days
- 1.5 ton fiducial
- 1.49 kg of ^{124}Xe

Best fit result:

$N_{\text{DEC}} = 126$ (black)

$N_{\text{I-125}} = 9$ (gold)

Exclude null hypothesis at 4.4σ



^{124}Xe Half Life Measurement



$$T_{1/2} = (1.8 \pm 0.5_{stat} \pm 0.1_{sys}) \times 10^{22} \text{ yr}$$

$$T_{1/2} = \ln 2 \frac{\epsilon \eta N_A m t}{M_{Xe} N_{DEC}}$$

- ^{124}Xe target mass:

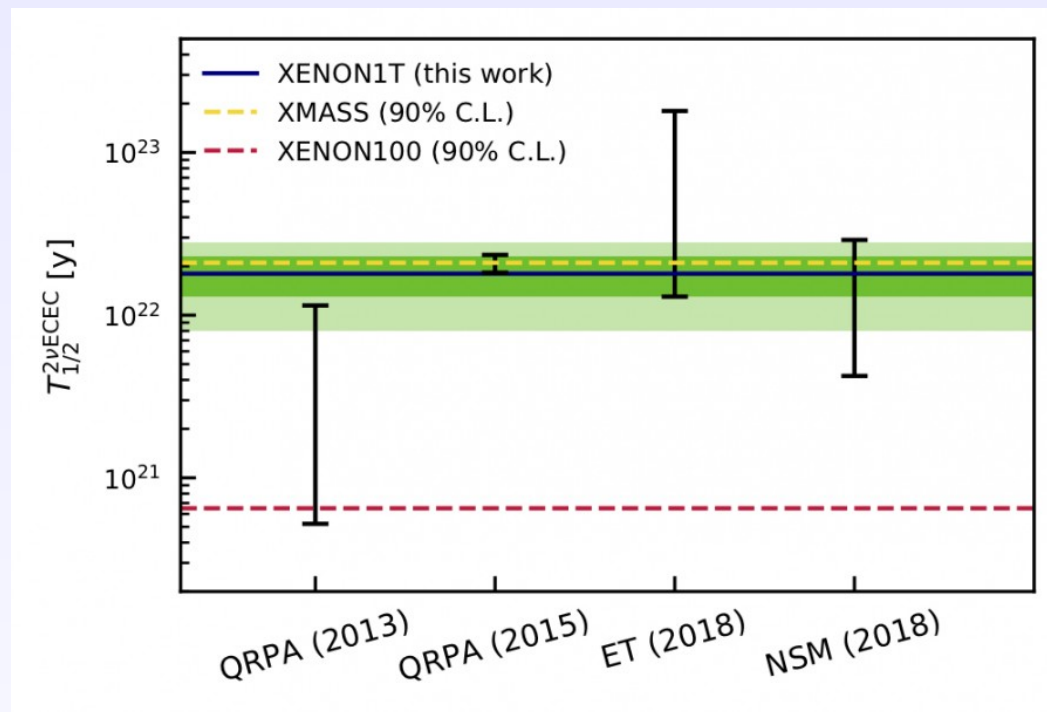
$$m = (1502 \pm 9_{sys}) \text{ kg}$$

- Cut acceptance:

$$\epsilon = 0.967 \pm 0.007_{stat} \pm 0.033_{sys}$$

- ^{124}Xe abundance:

$$\eta = (9.94 \pm 0.14_{stat} \pm 0.15_{sys}) \times 10^{-4}$$



Nature 568, 532-535 (2019)

Longest process ever directly observed



Summary and Outlook



Summary

- XENON1T
 - World's most successful DM experiment to date
 - Leading DM limits in multiple channels
- Unprecedented ER sensitivity
 - First observation of double electron capture of ^{124}Xe
 - Half life of 1.8×10^{22} yr
 - Longest process ever directly observed

Outlook

- XENON1T complete (shut down end of 2018)
- Upgrade underway to XENONnT
 - Re-use all major systems from XENON1T
 - Designed with nT in mind
- Increase detector to 6.9 ton LXe
 - Larger TPC, more PMTs
- Construction underway
- Commissioning to begin Jan 2020
- Reach $\sim 10^{-48}$ cm² SI cross section
- High stats measurement of DEC

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<http://xenon1t.org/>
