Recent Results from XENON1T and Multi-messenger Future of XENONnT

XIX International Workshop on Neutrino Telescopes

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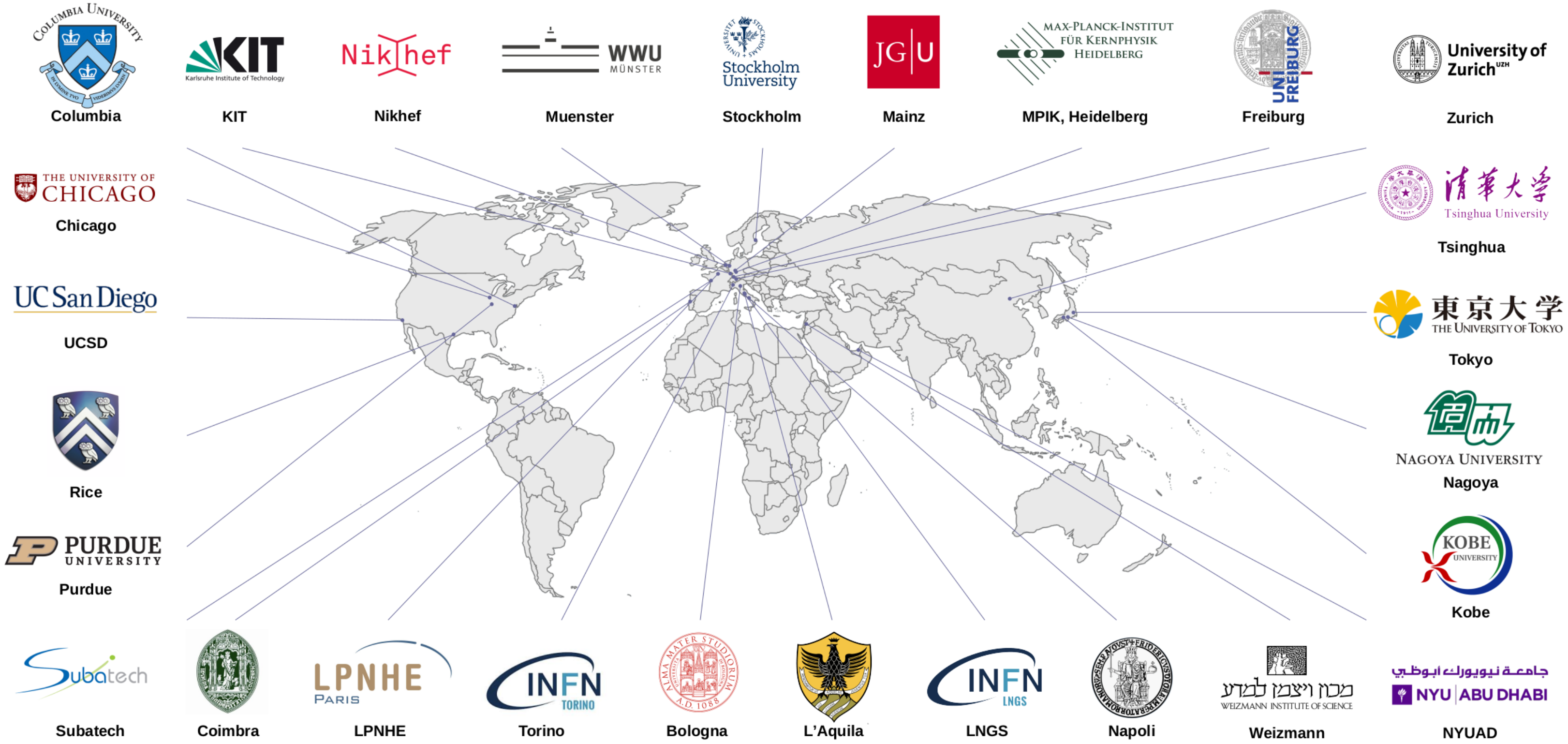
19.02.2021

XENON

XENON University of Zurich[UZH]

The XENON Collaboration

- 27 institutions worldwide
- ~170 scientists
- Main goal: look for dark matter particles with a liquid xenon TPC



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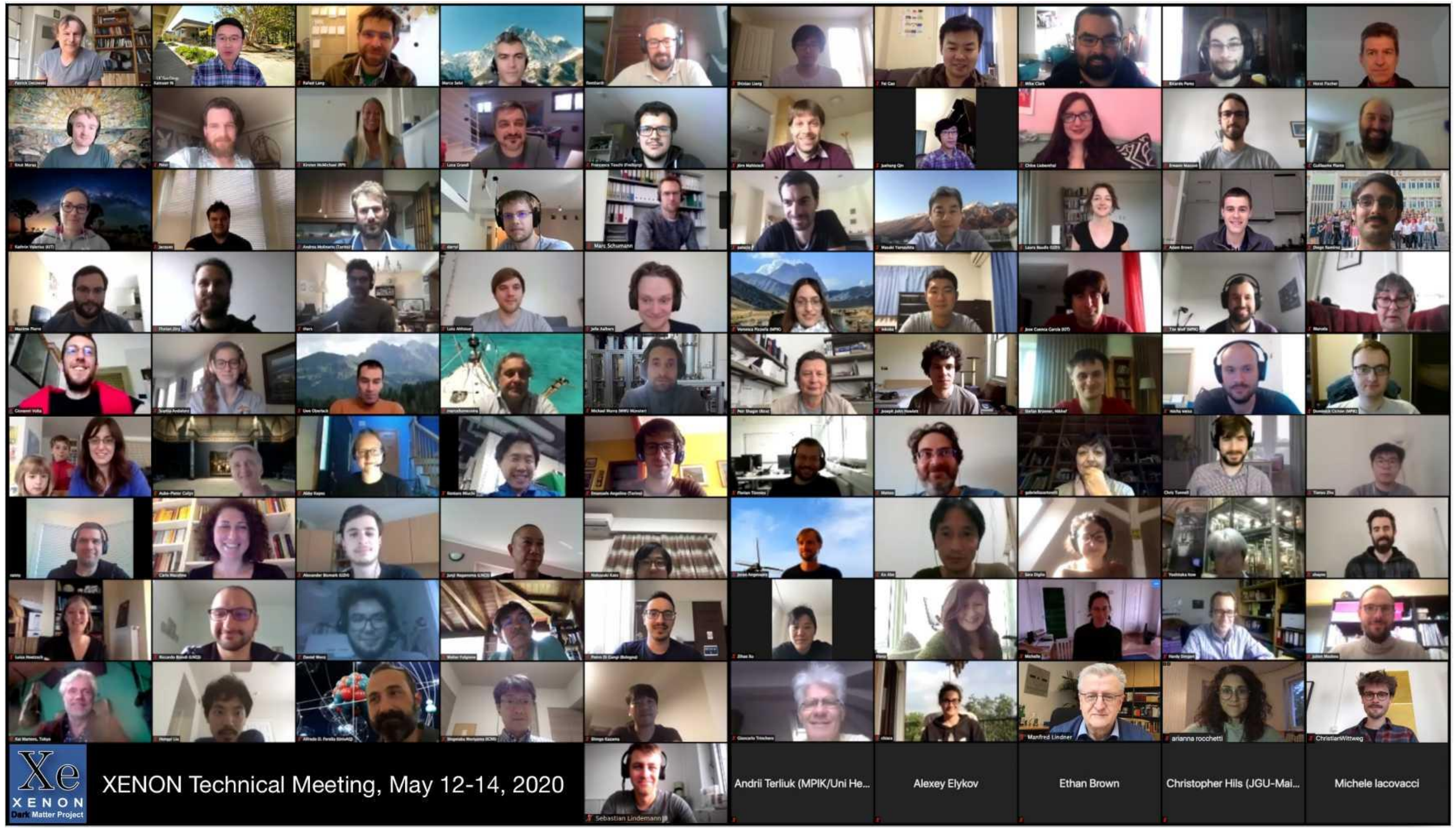


The TPC detection principle

- Dual-phase (liquid+gas)
- Energy reconstruction
- 3D event reconstruction
- Event discrimination (electronic recoil vs nuclear recoil)

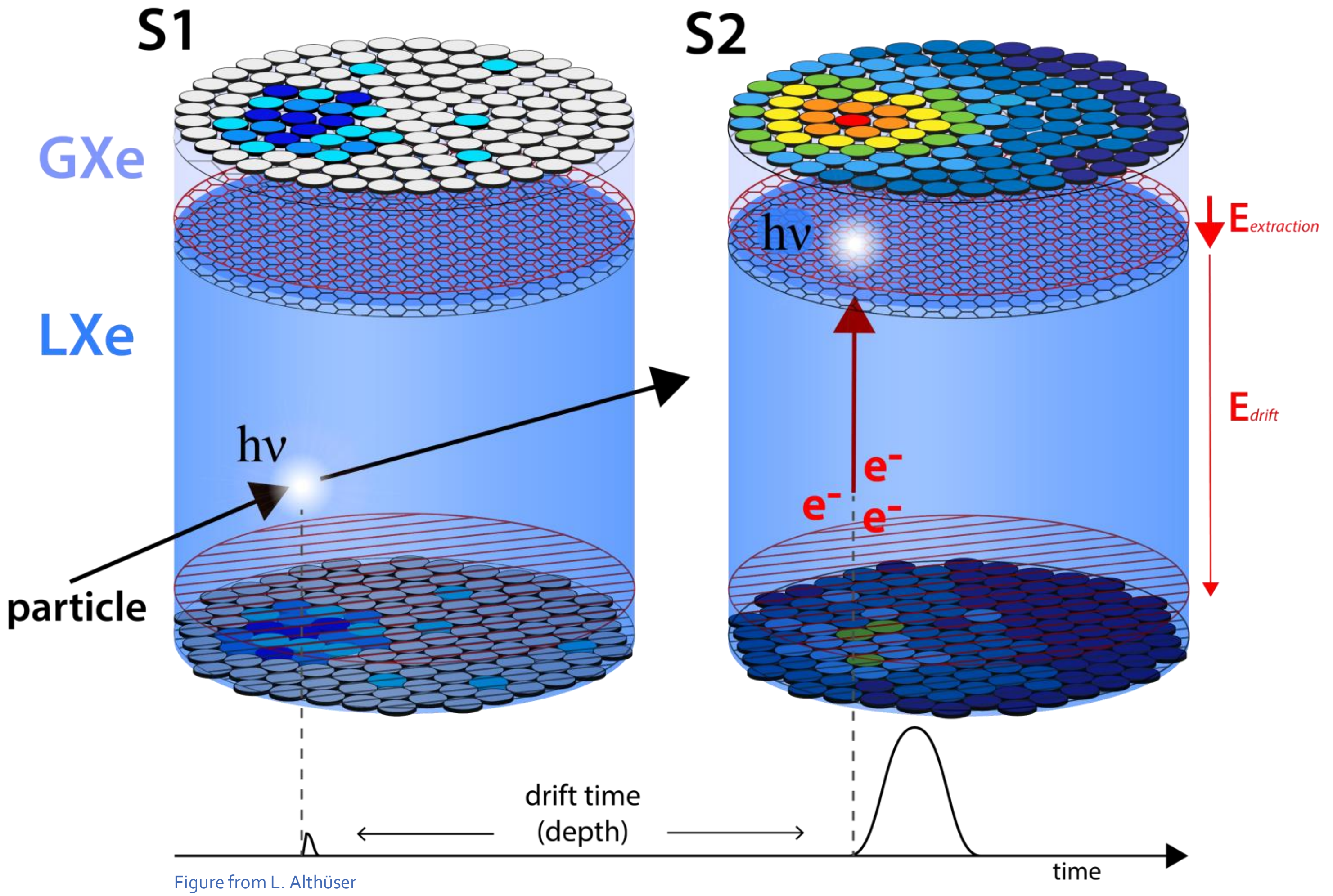
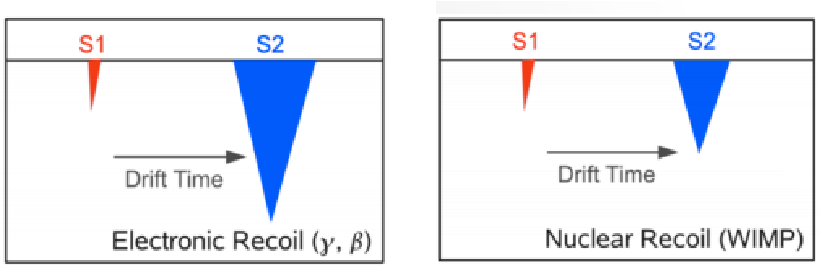


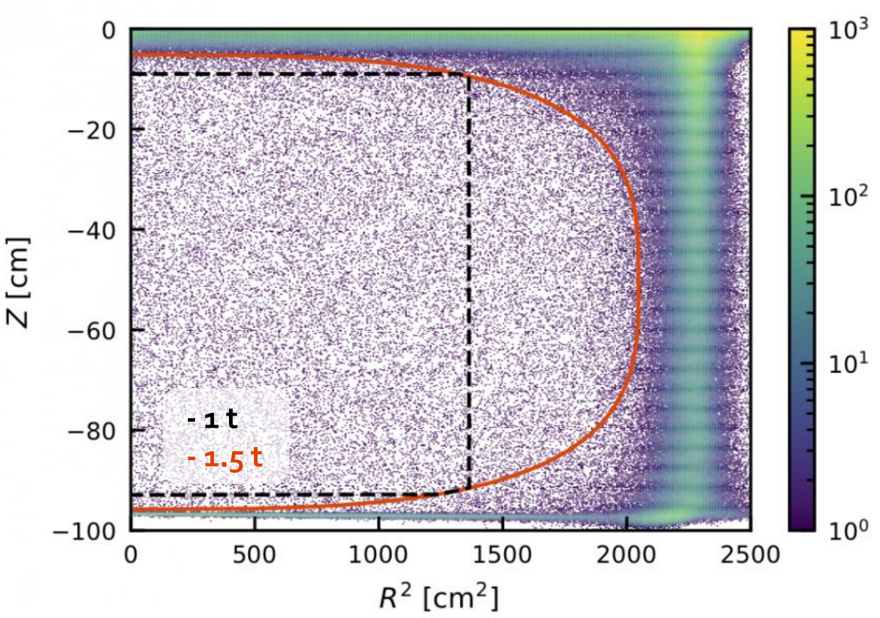
Figure from L. Althüser

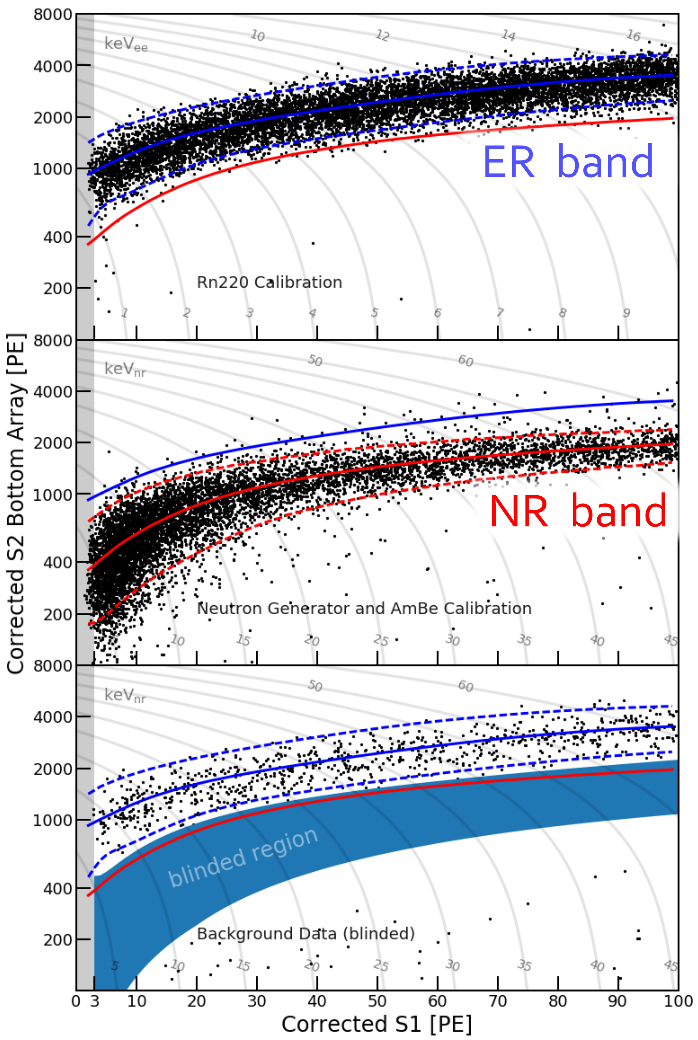
The TPC detection principle

- ER/NR events discrimination
- Particle ID (γ, α, β, n, WIMP)
- Fiducialization

Phys. Rev. Lett. **119**, 181302 (2017)







The XENON program

- Since 2005
- Dual-phase xenon TPCs
- XENONnT currently under commissioning

XENON10

Target mass: 14kg

2005-2007

XENON100

Target mass: 62kg

2008-2016

XENON1T

Target mass: 2t

2013-2018

XENONnT

Target mass: 5.9t

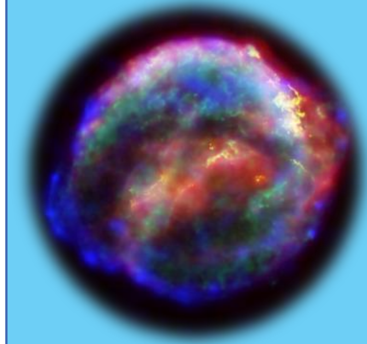
2020 - present

Analysis channels

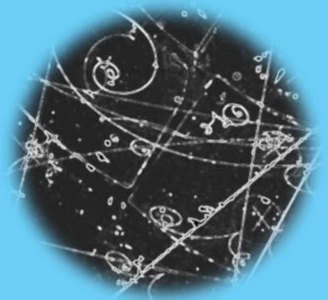
- Dark matter
- Solar neutrinos
- Supernova events
- Neutrino properties
- Atmospheric neutrinos

- WIMP-search
  - Spin-independent
  - Spin-dependent
- Sub-GeV
- Dark photons
- Axion-like particles

- Solar neutrinos
  - Boron-8
  - pp neutrinos
- Solar axions



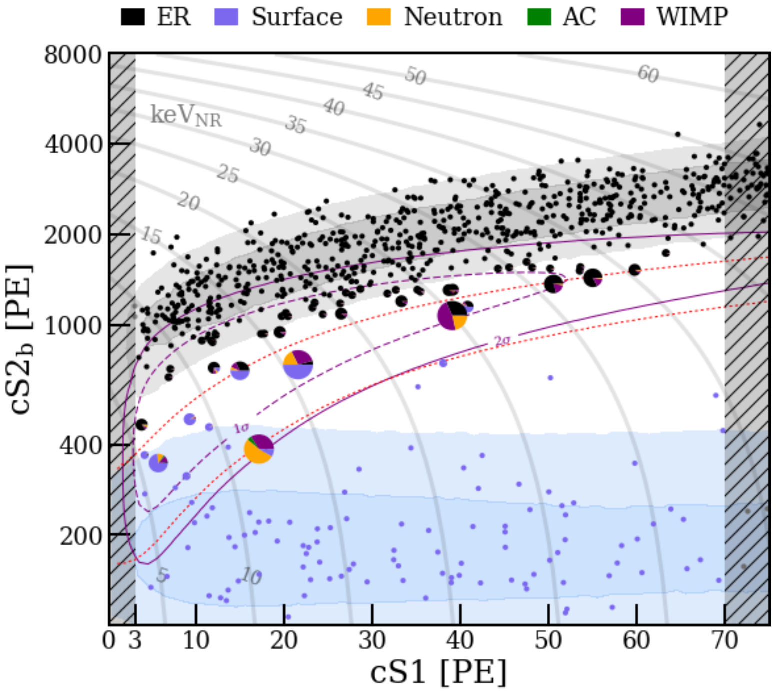
- Supernova neutrinos
- Actively communicate with SNEWS
- Multi-messenger in DM experiments



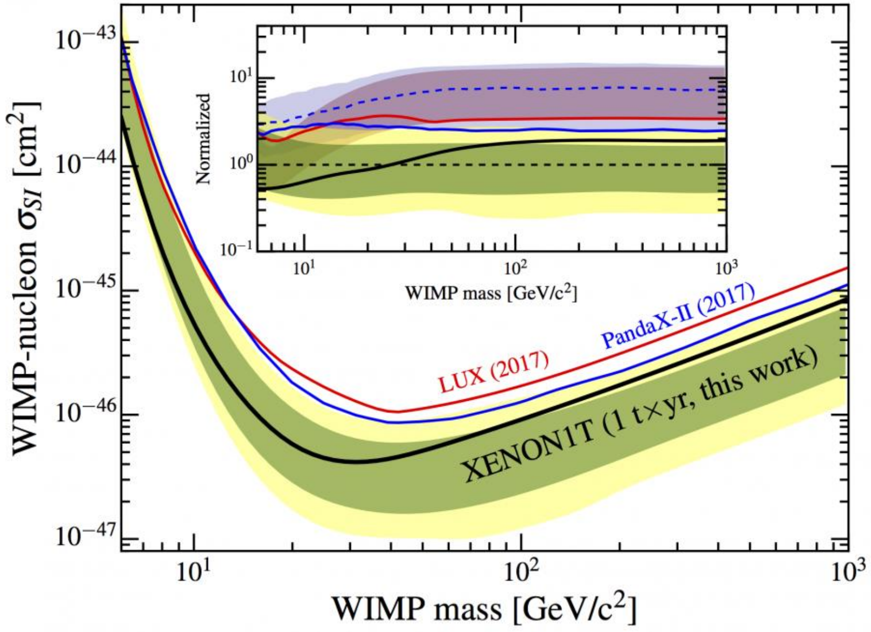
- Neutrino properties
  - Double beta decay of ^{136}Xe
  - Double-electron capture in ^{124}Xe
  - Neutrino magnetic moment

Dark Matter results

- WIMP-nucleon spin-independent elastic scatter
- 1 tonne-year exposure
- No significant excess over background
- Most stringent WIMP-nucleon cross section: 4.1×10^{-47} cm² @ 30 GeV/c², 90% CL



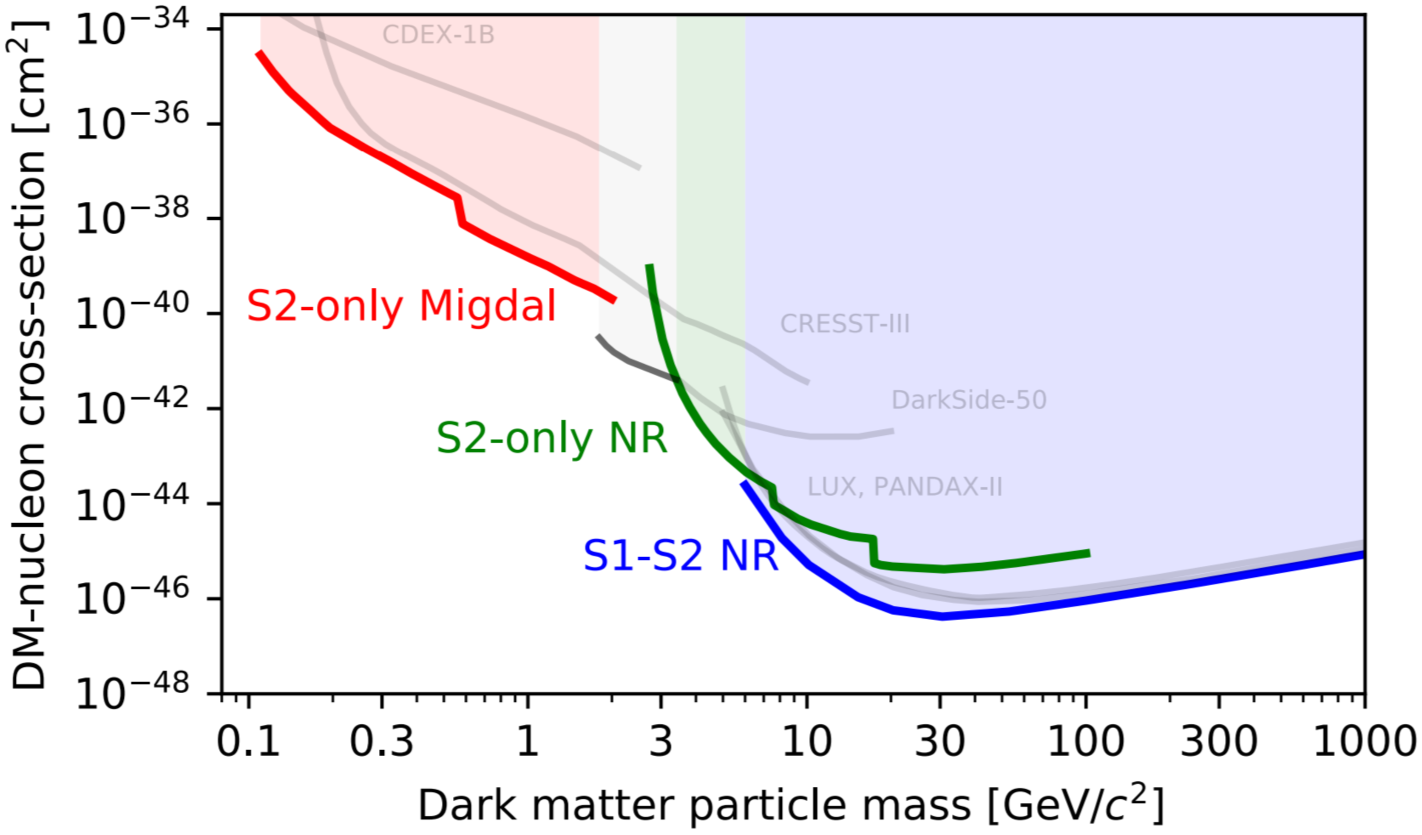
Phys. Rev. Lett. **121**, 111302 (2018)



S2-only and Migdal effect results

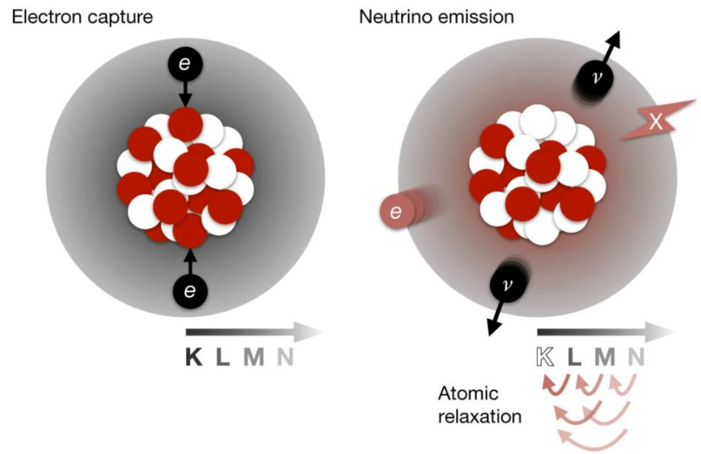
- Extended DM search with ionization-only channel
- No complete background model (only limit setting)
- O(100 eV) energy threshold

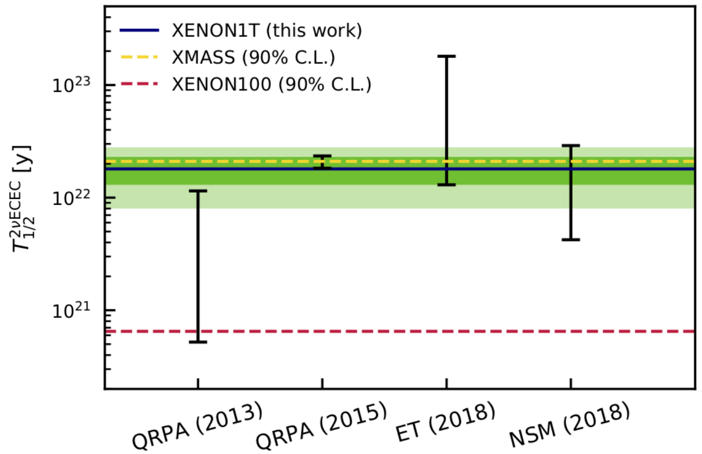
Phys. Rev. Lett. **123**, 251801 (2019)
Phys. Rev. Lett. **123**, 241803 (2019)



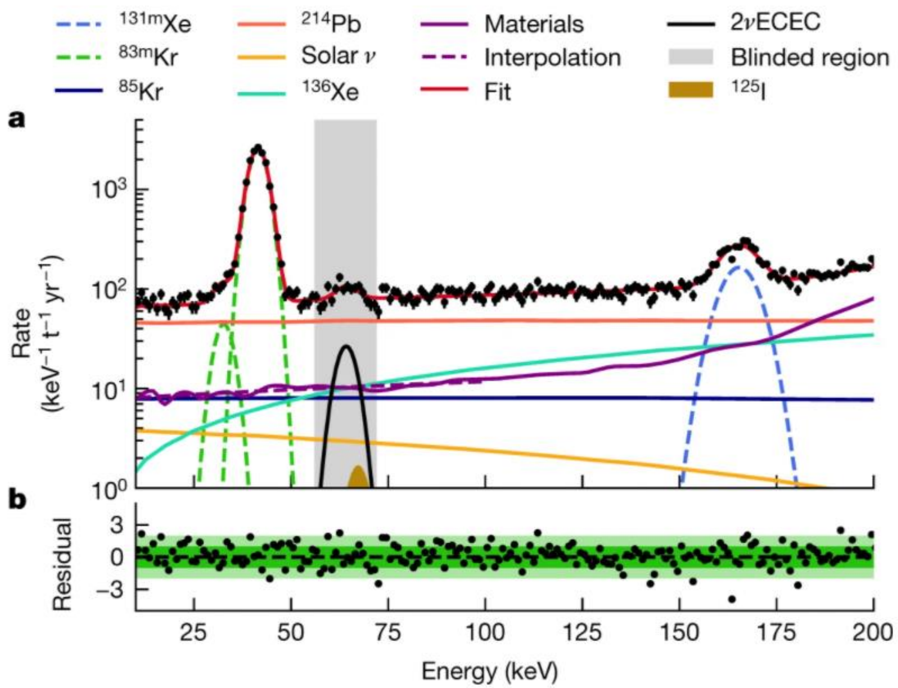
Double Electron Capture in ^{124}Xe

- Observation of X-rays and Auger electrons, Q_{value}= 64,3 keV
- Longest half-life ever observed directly: 1.8 × 10^{22} years at 4.4σ significance
- First step for neutrinoless DEC search



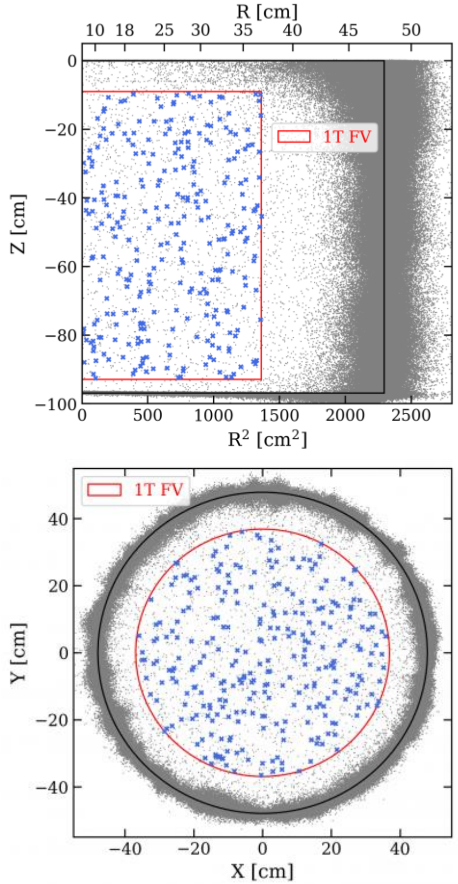


Nature volume 568, 532–535(2019)

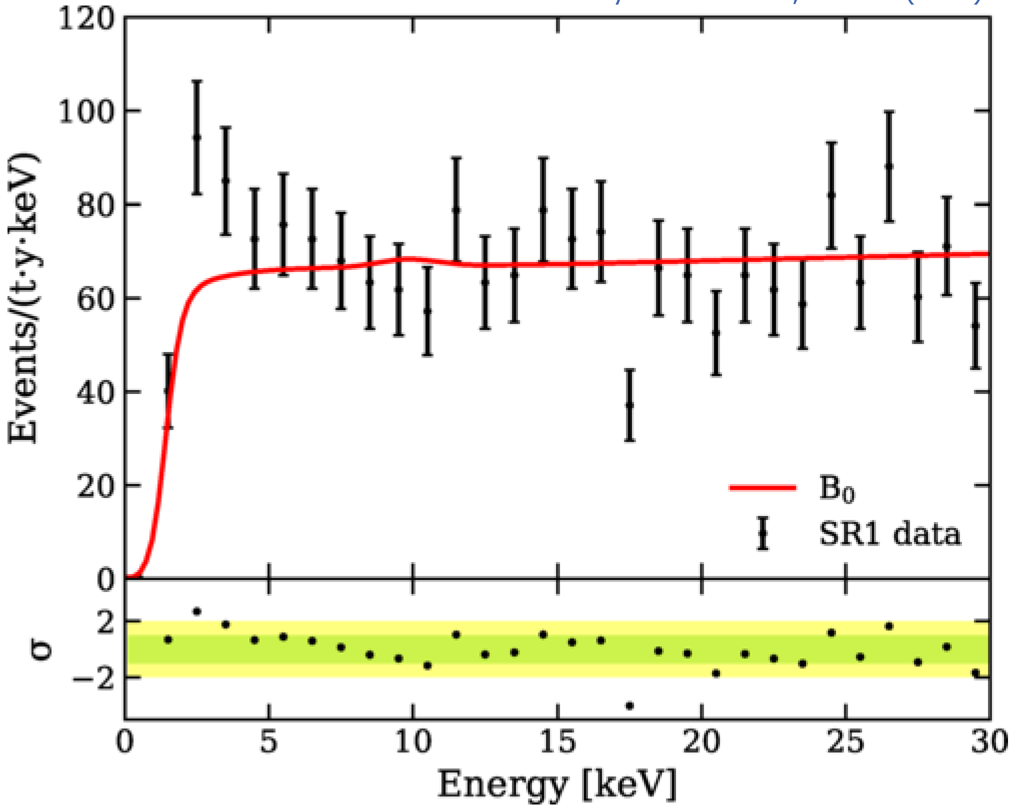


Low-ER excess

- ER search in <30 keV range
- 3.3σ fluctuation of background in 1-7 keV
- Several hypothesis:
  - Solar axions (3.4σ over bkg)
  - Neutrino magnetic moment (3.2σ over bkg)
  - Bosonic DM: ALPs and dark photons (3.0σ over bkg)
  - Tritium (3.2σ over bkg)

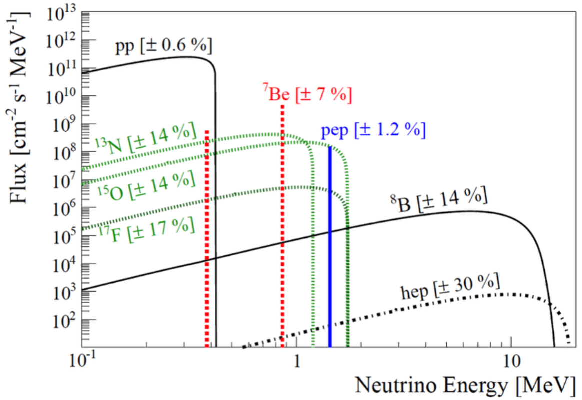


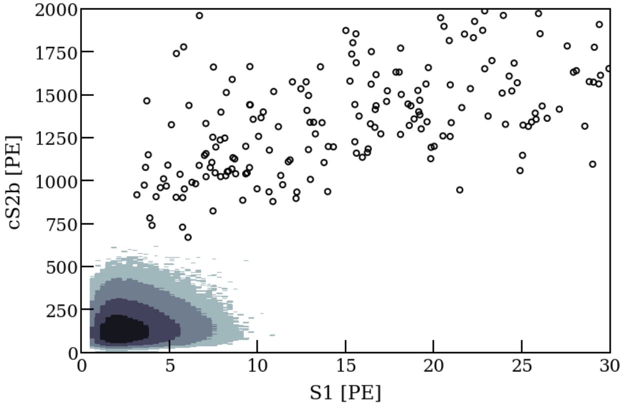
Phys. Rev. D **102**, 072004 (2020)



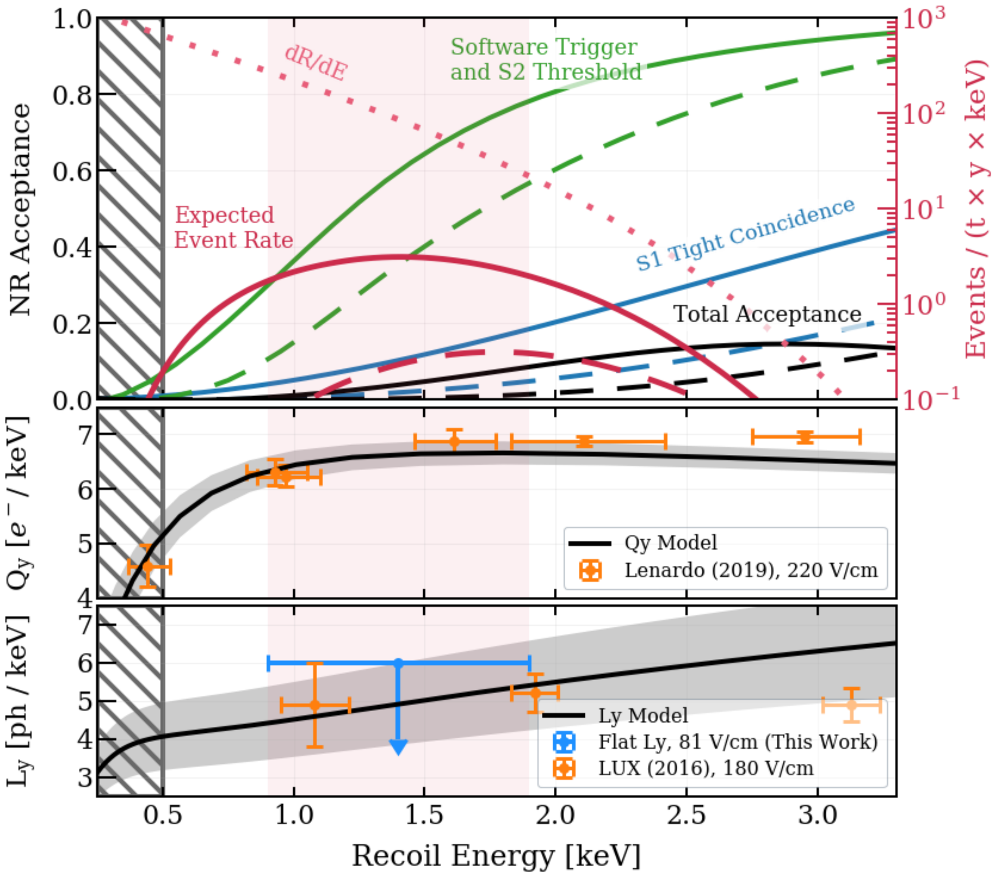
Boron- 8 solar neutrino search

- 8B neutrinos are a constant source of coherent elastic neutrino-nucleus scattering (CEvNS) events in the TPC, a background to WIMP search
- Lower detection threshold from 2-fold coincidence
- Few measurements of the charge and light yields at this energy range
- Background dominated by mispairing of S1-S2 signals (AC)



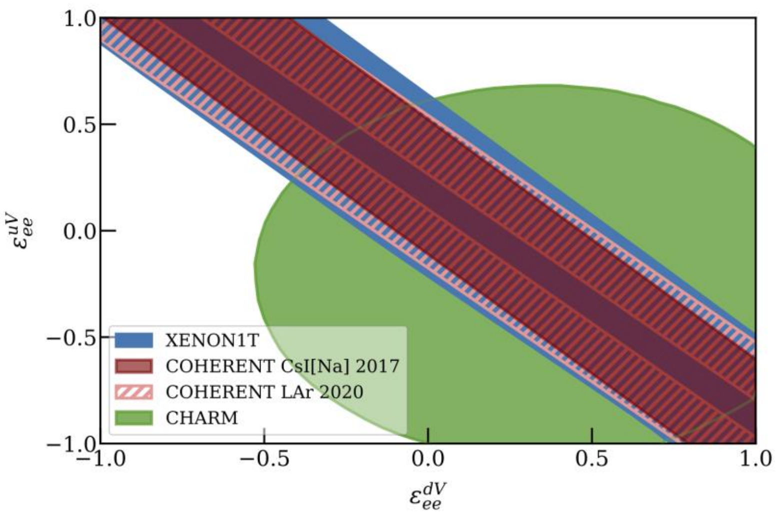


arXiv:2012.02846



Boron- 8 solar neutrino search

- No excess observed.
- Constraints on:
  - 8B neutrino flux
  - L_y and Q_y at low-E
  - Light DM (leading for DM mass 3-11 GeV/c²)



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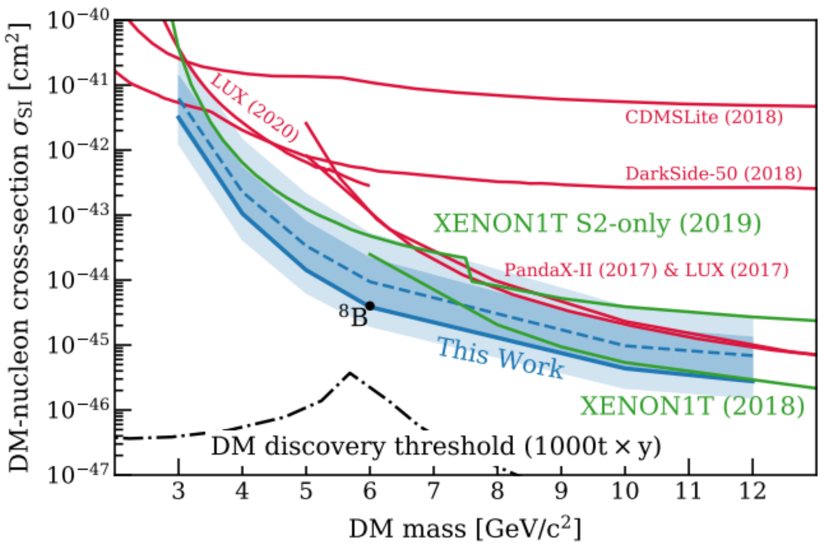


From XENON1T to XENONnT

- Larger active mass
- Lower background level
- Upgrade on 1T infrastructure
- 1.5 m tall
- 1.3 m diameter

5.9 t liquid xenon (3x XENON1t)

Liquid xenon purification system (~2500 slpm)

Active neutron veto with Gd-loaded water

494 PMTs

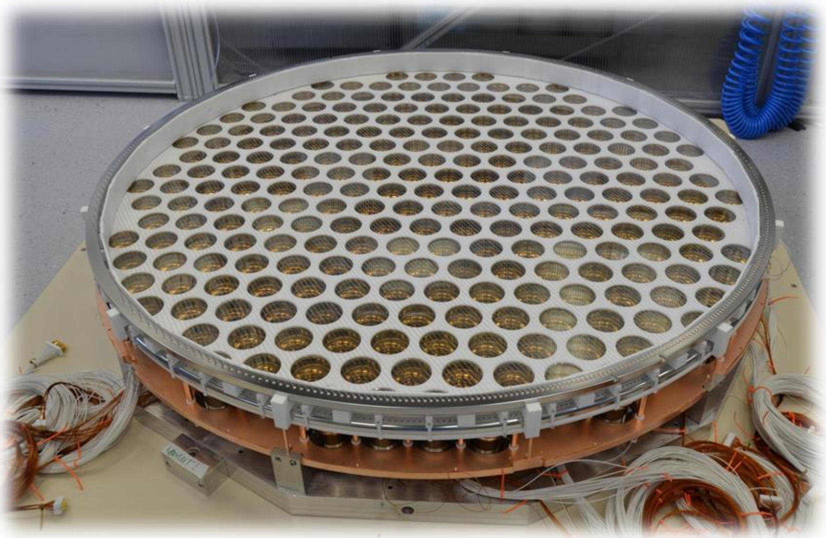
Background reduction

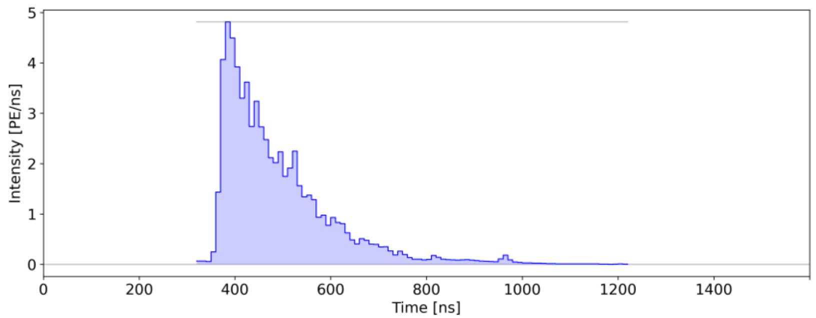
Radon distillation column
Rn-free purification pump
Material selection and cleaning

Dedicated high energy readout

From XENON1T to XENONnT

- Finished installation summer 2020
- Currently under commissioning!
- In plot: S1 signal in gas atmosphere

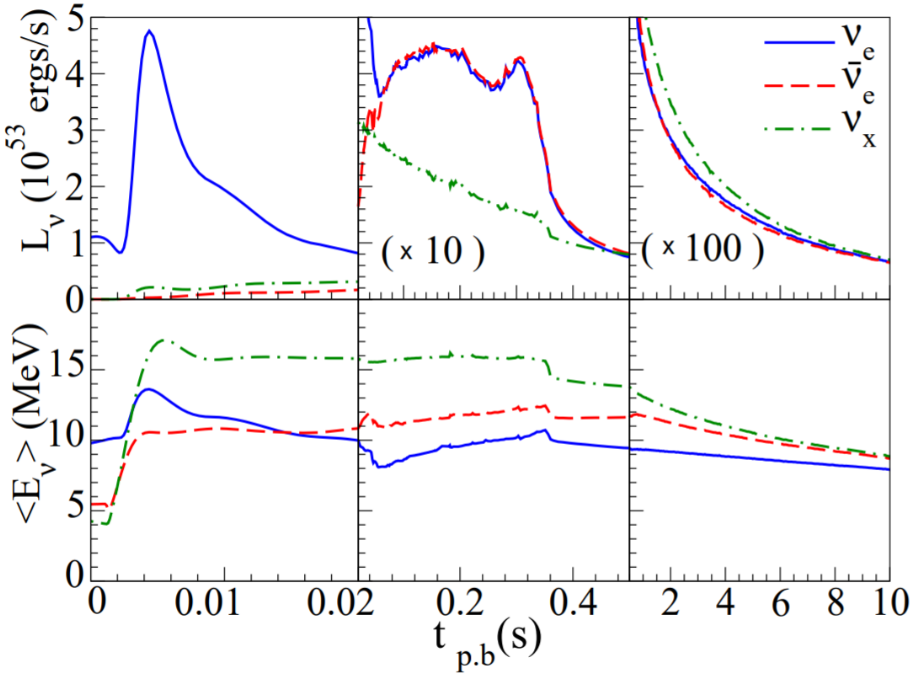




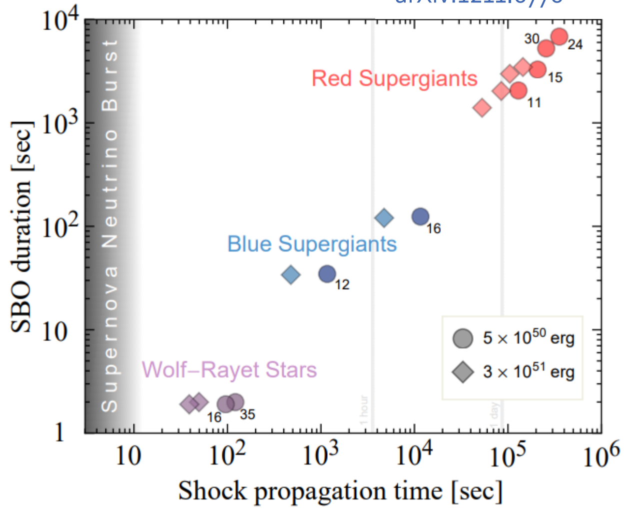
XENONnT as supernovae observatory

- Core-collapse supernovae produce an enormous amount of O(10) MeV neutrinos (2.2×10^{53} erg in SN1987a)
- SN neutrinos precede the EM radiation from minutes up to days
- Neutrino signal can be used as an early warning
- Signals from obscured SNe, in common with GW

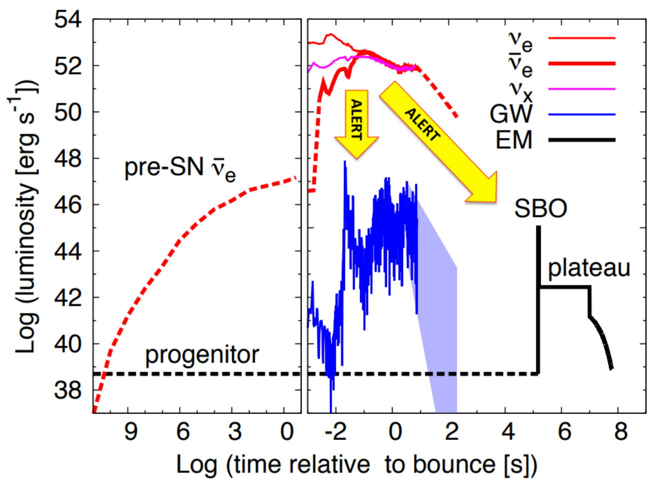
Phys. Rev. D 94, 103009 (2016)



arXiv:1211.6770



arXiv:2011.00035

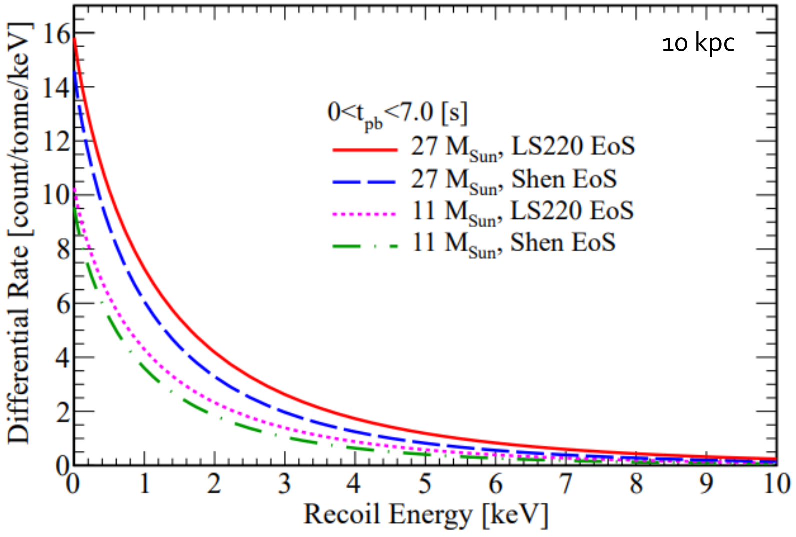


XENONnT as a SN observatory

- In XENONnT, SN neutrinos mostly interact through CEvNS, a flavour independent channel
- Low-NR, O(1 keV), enhanced by ionization-only channel
- Constrained by mass, energy threshold and single-electron background
- Expecting ~80 events in the TPC for a 27Mo@10kpc

$$\frac{d\sigma}{dE_r} = \frac{G_F^2}{4\pi} Q_w^2 M \left(1 - \frac{M E_r}{2E_\nu^2}\right) F(E_r)^2$$

$$Q_w^2 = \left[\left(\frac{1}{2} - 2\sin^2(\theta_w)\right) Z - \frac{1}{2} N\right]$$



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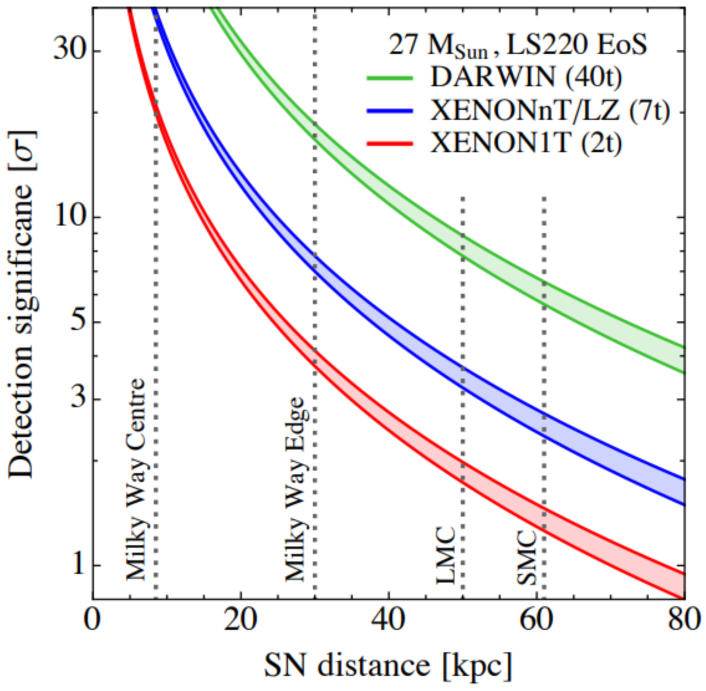
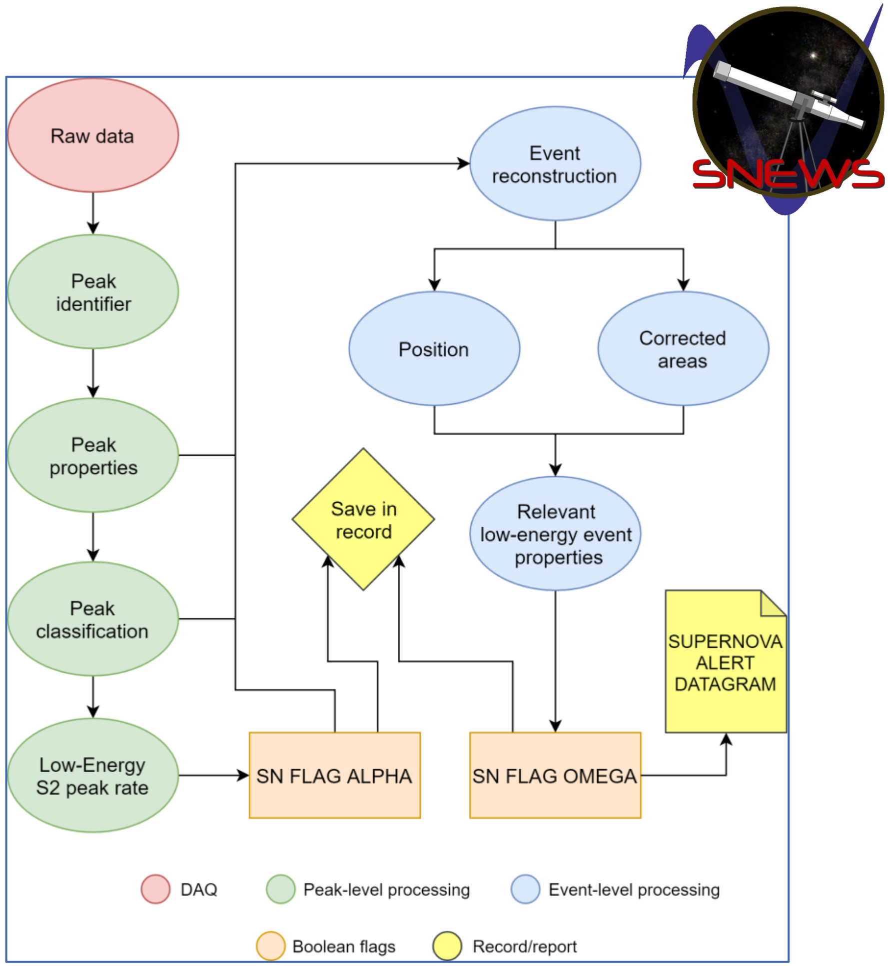


A collaborative effort

- XENONnT will receive alerts from the SNEWS network and act on its data accordingly
- No pointing available, only timing
- Prompt response to SNe signals under study
- Actively contributing to SNEWS 2.0 (arXiv:2011.00035) under consideration



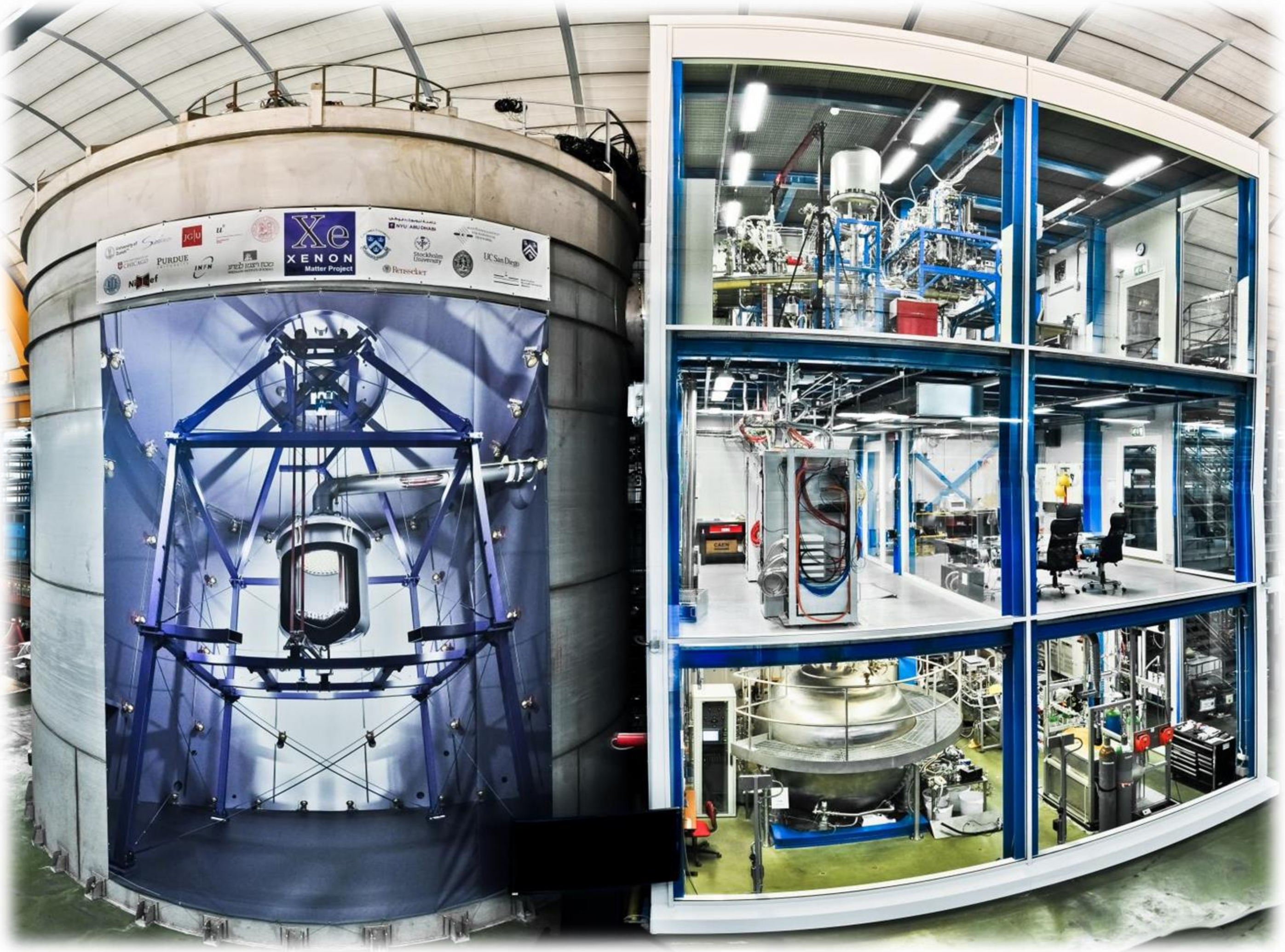
Summary and Outlook

- LXe TPCs can probe several rare-event processes.
- XENON1T made considerable improvements to the field throughout the years, both in dark matter, neutrino physics and technical design for low-background experiments
- XENONnT is now under commissioning and aims to improve upon XENON1T results in just a few months time
- XENONnT will prototype the use of DM experiments as multimessenger observatories, aiming to actively contribute to SNEWS and online SN neutrino detection
- DARWIN, as successor of XENON, will improve even further on these objectives (see Andrii Terliuk's talk, "Potential of neutrino physics with DARWIN", 25.02, 17:30.)

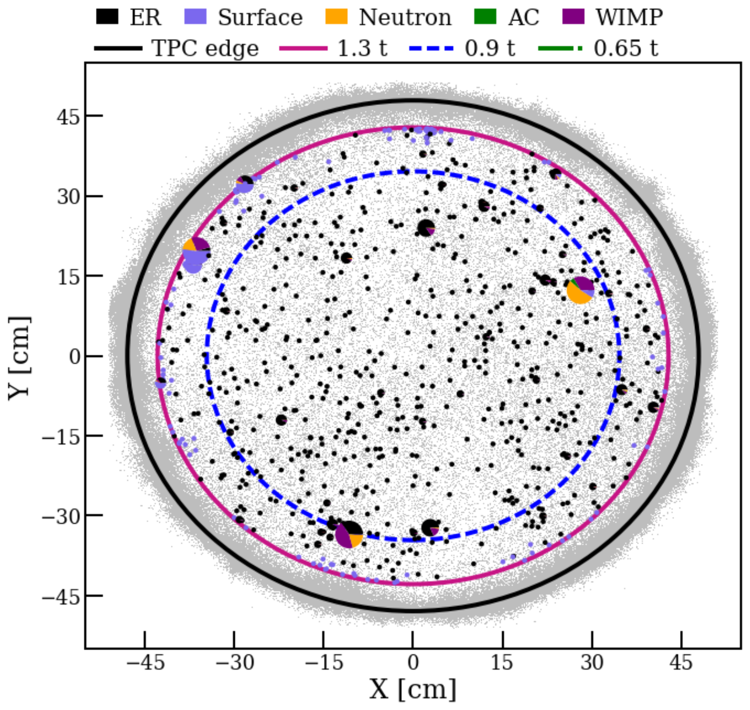
Backup Slides

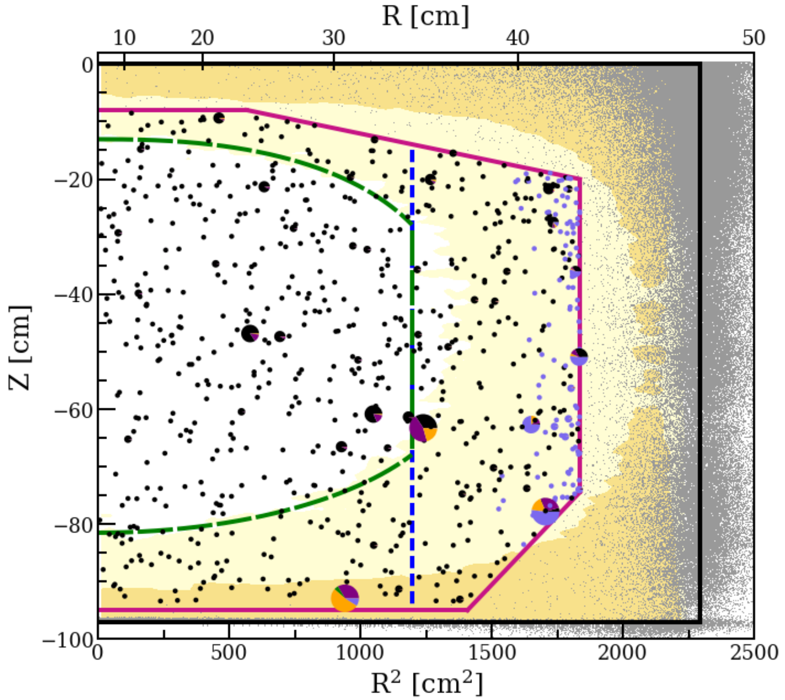
XENON1T/nT detectors

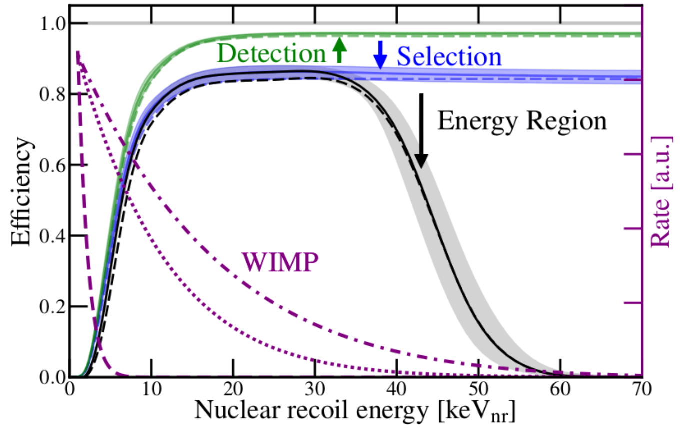
- Dual-phase XENON TPC in a water passive and active muon veto
- Service building:
  - Xenon storage and recuperation
  - DAQ
  - Kr distillation column
  - Cryogenics and calibration system



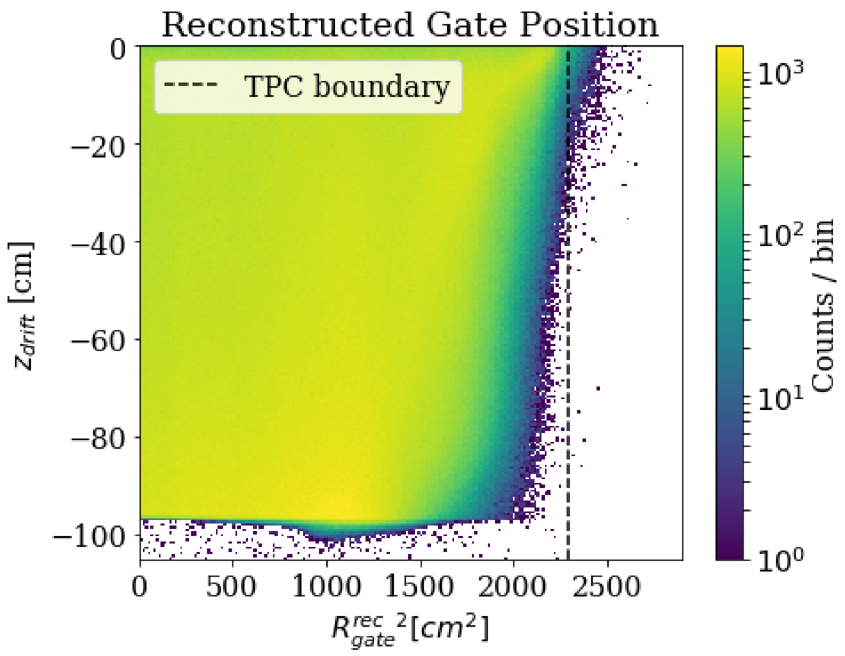
Dark matter search

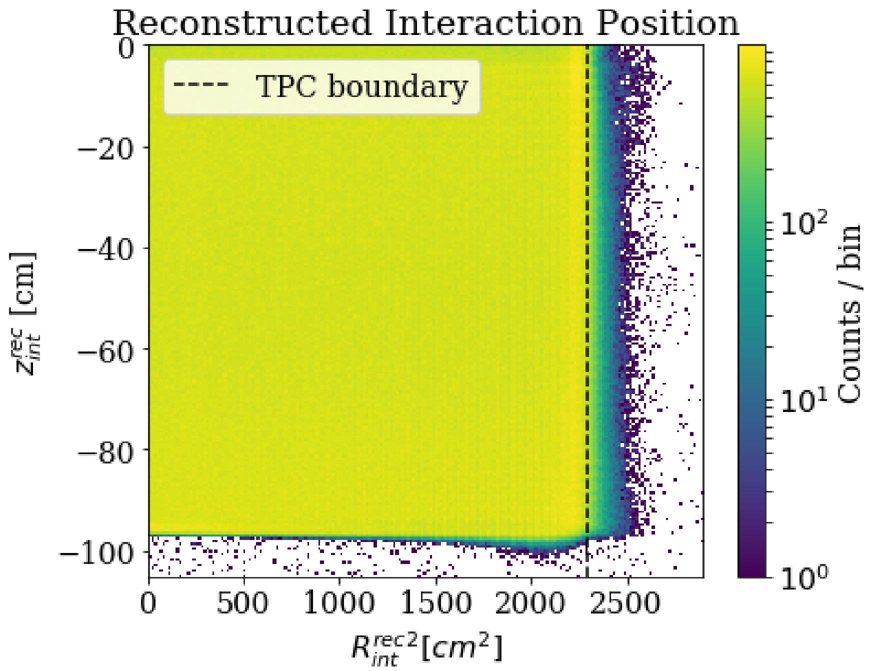




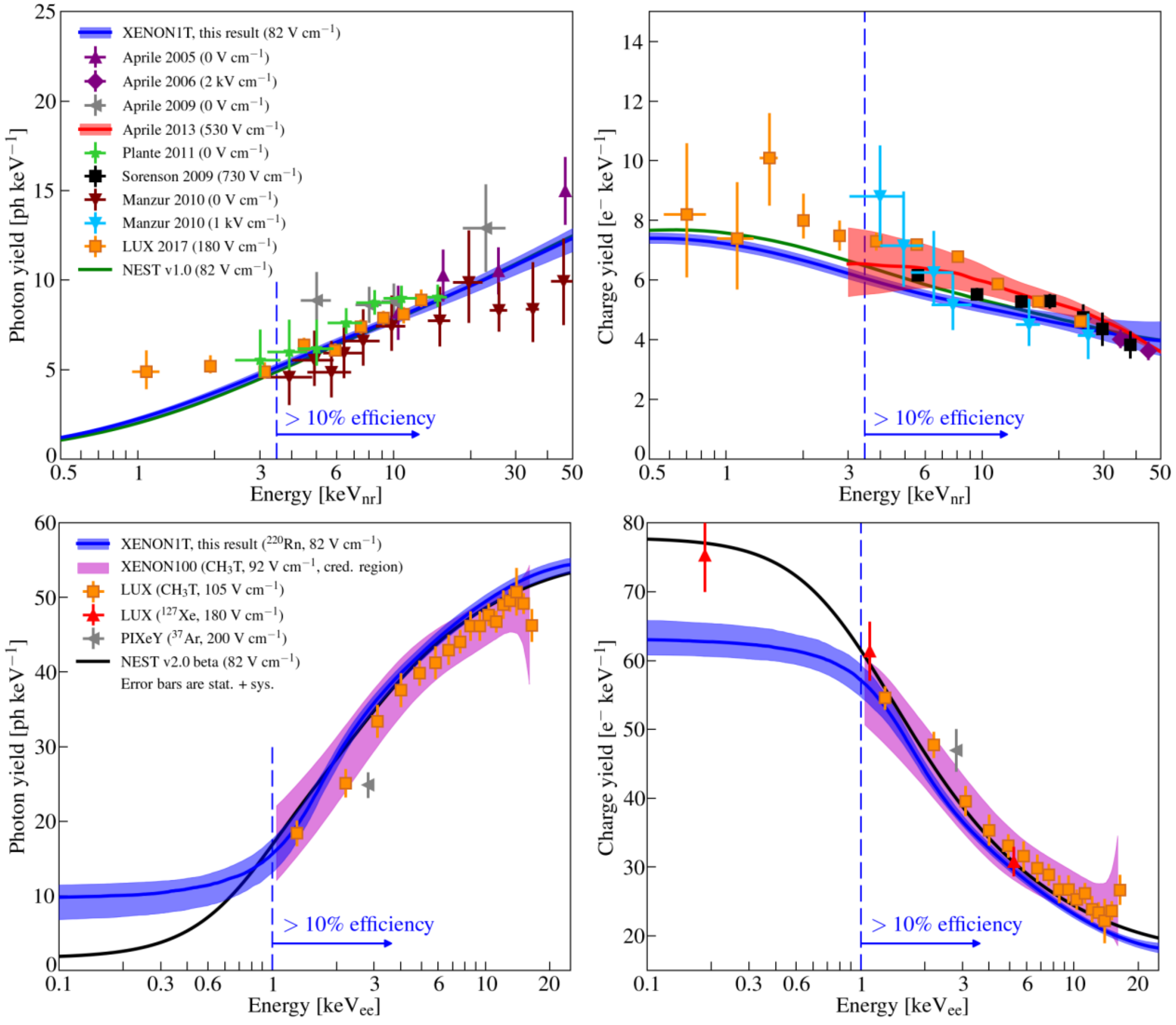


Corrections

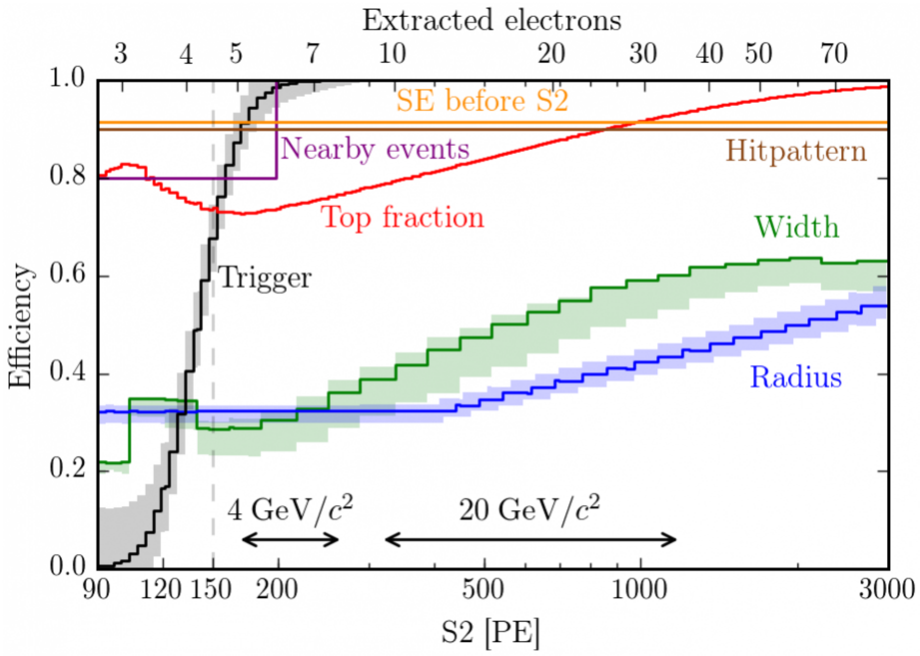




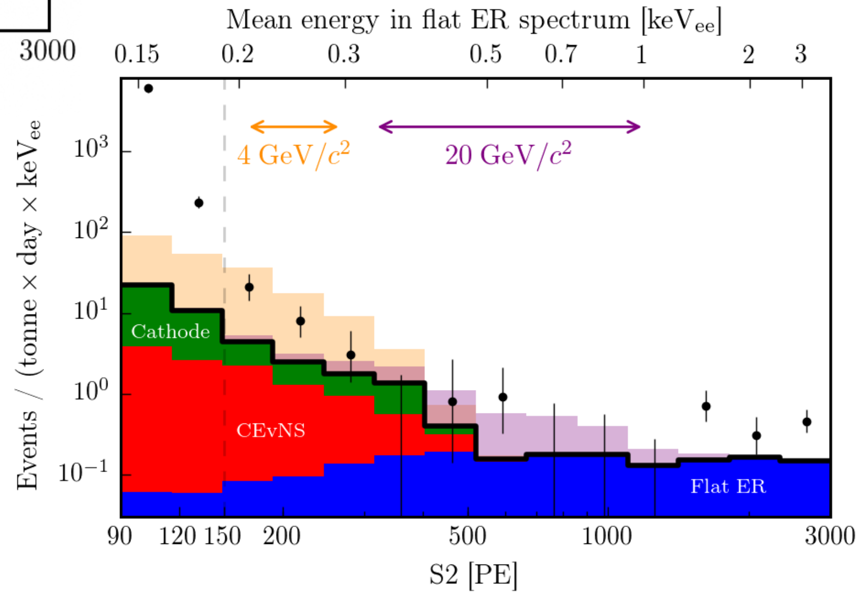
Light and Charge yields



S2-only

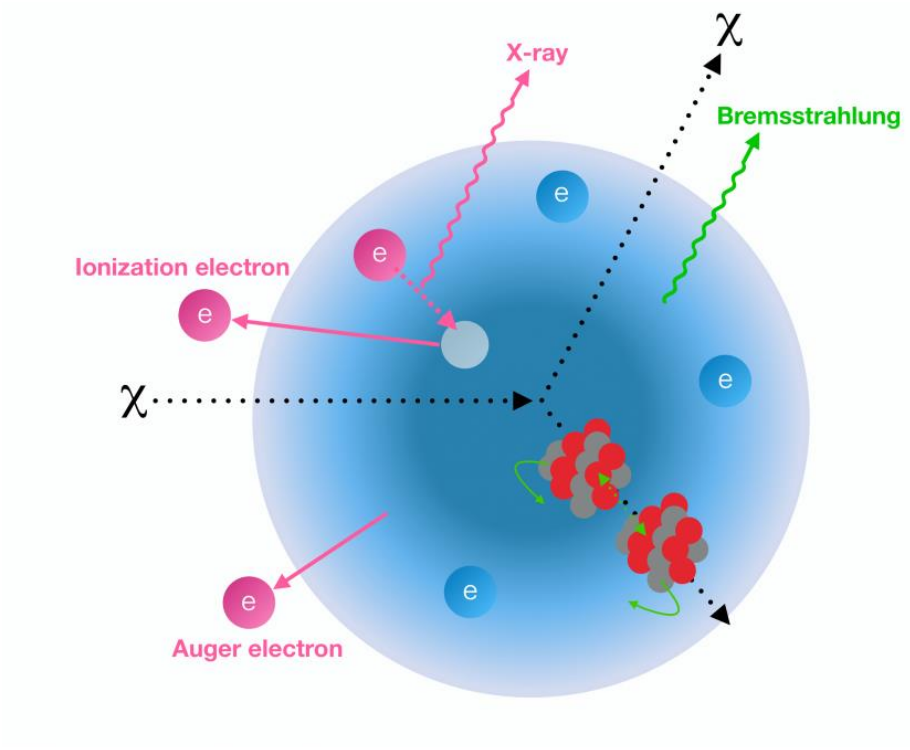


Extracted electrons
3
4
5
7
10
20
30
40
50
70
1.0
0.8
0.6
0.4
0.2
0.0
Efficiency
SE before S2
Nearby events
Hitpattern
Top fraction
Width
Trigger
Radius
4 GeV/c^2
20 GeV/c^2
90
120 150
200
500
1000
3000
S2 [PE]



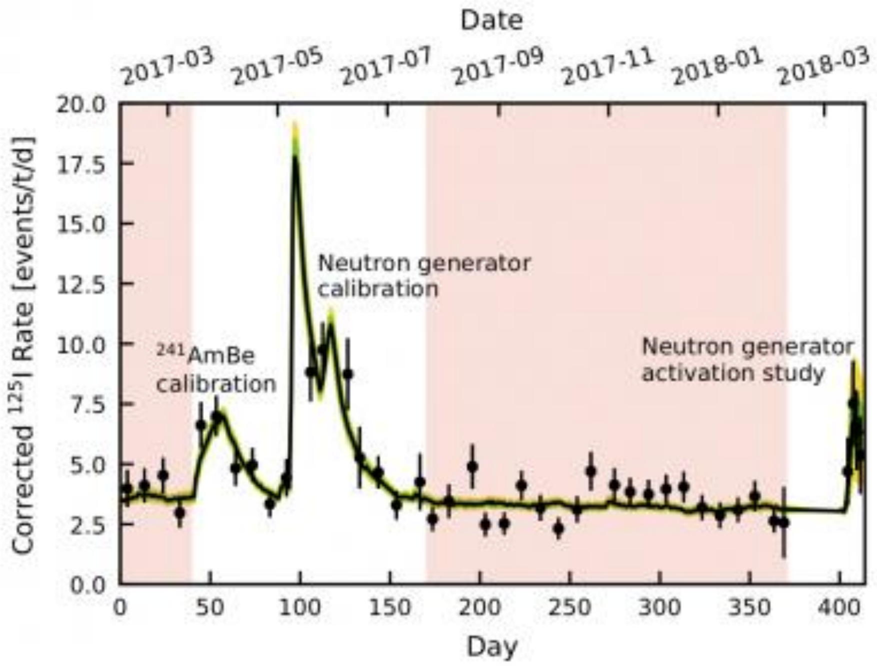
Mean energy in flat ER spectrum [keV_{ee}]
0.15
0.2
0.3
0.5
0.7
1
2
3
Events / (tonne × day × keV_{ee})
10^3
10^2
10^1
10^0
10^{-1}
4 GeV/c^2
20 GeV/c^2
Cathode
CEvNS
Flat ER
90
120 150
200
500
1000
3000
S2 [PE]

Migdal and b

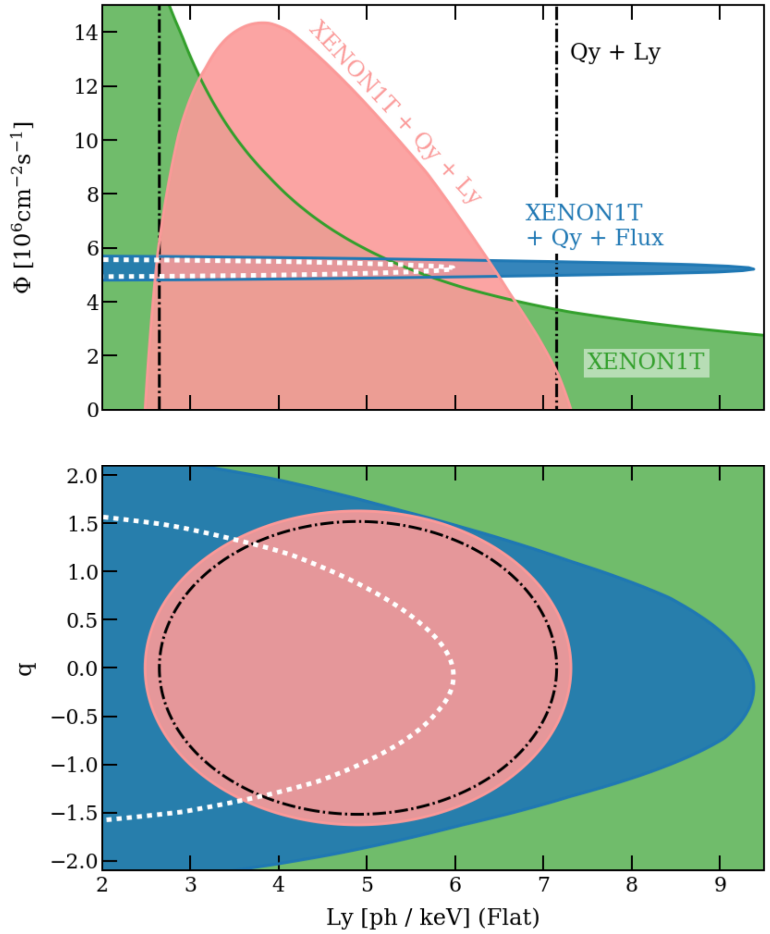

X-ray
χ
Bremsstrahlung
Ionization electron
e
χ
e
e
e
e
Auger electron

DEC search

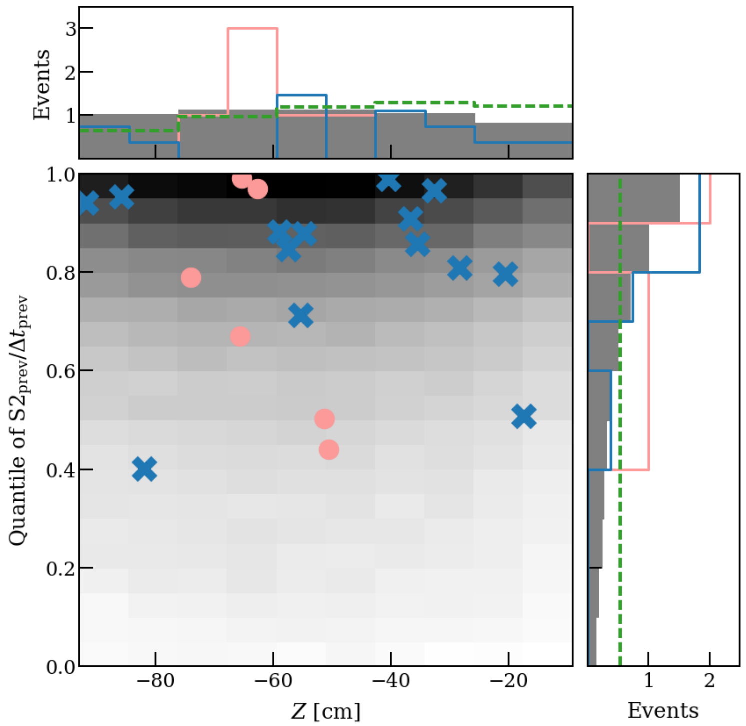
- Iodine activation modelling



Boron-8



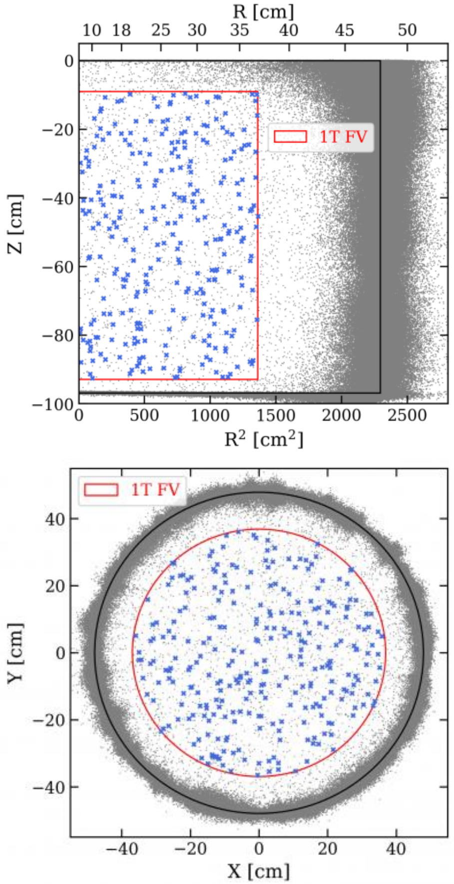
Qy + Ly
XENON1T + Qy + Ly
XENON1T
+ Qy + Flux
XENON1T
Φ [10^6cm^−2s^−1]
q
Ly [ph / keV] (Flat)

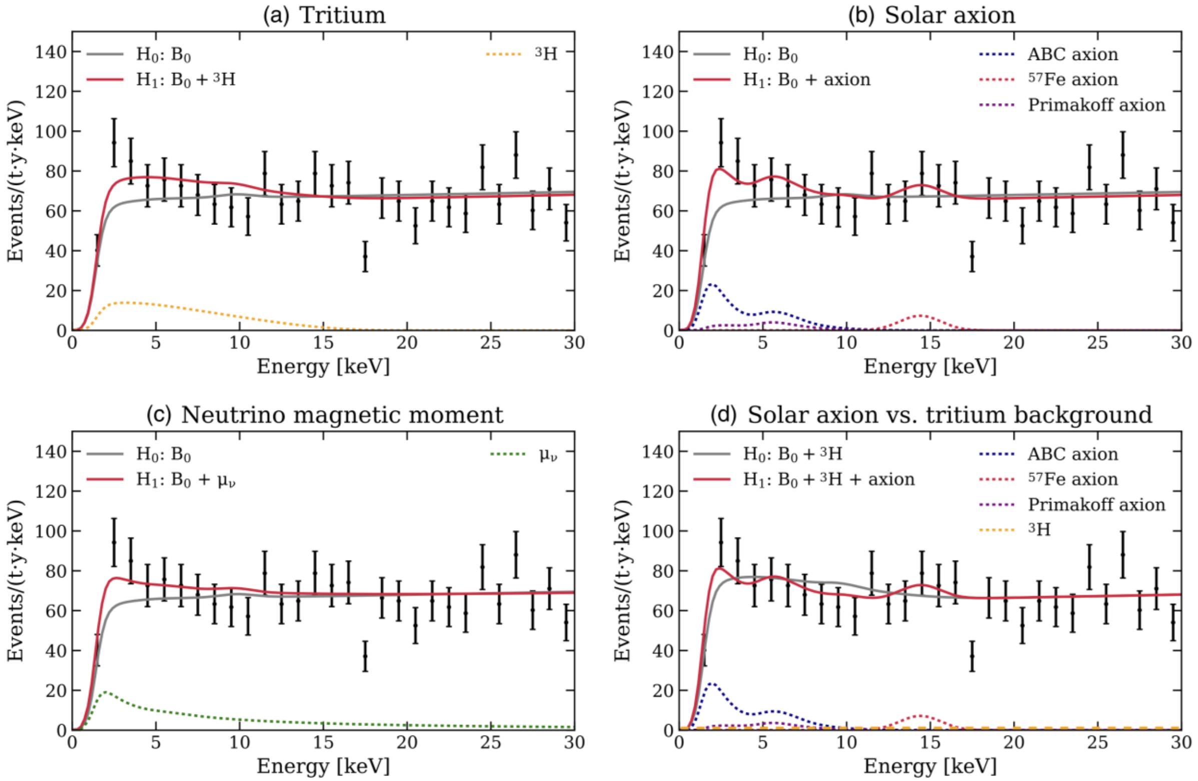


Events
Quantile of S2prev/Δtprev
Z [cm]
Events

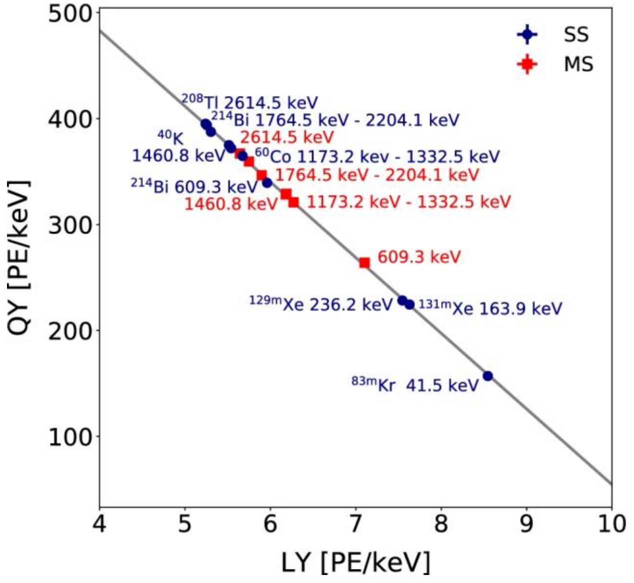
Low-ER excess

- Solar axions (3.4σ over bkg)
- Neutrino magnetic moment (3.2σ over bkg)
- Bosonic DM: ALPs and dark photons (3.0σ over bkg)
- Tritium (3.2σ over bkg)

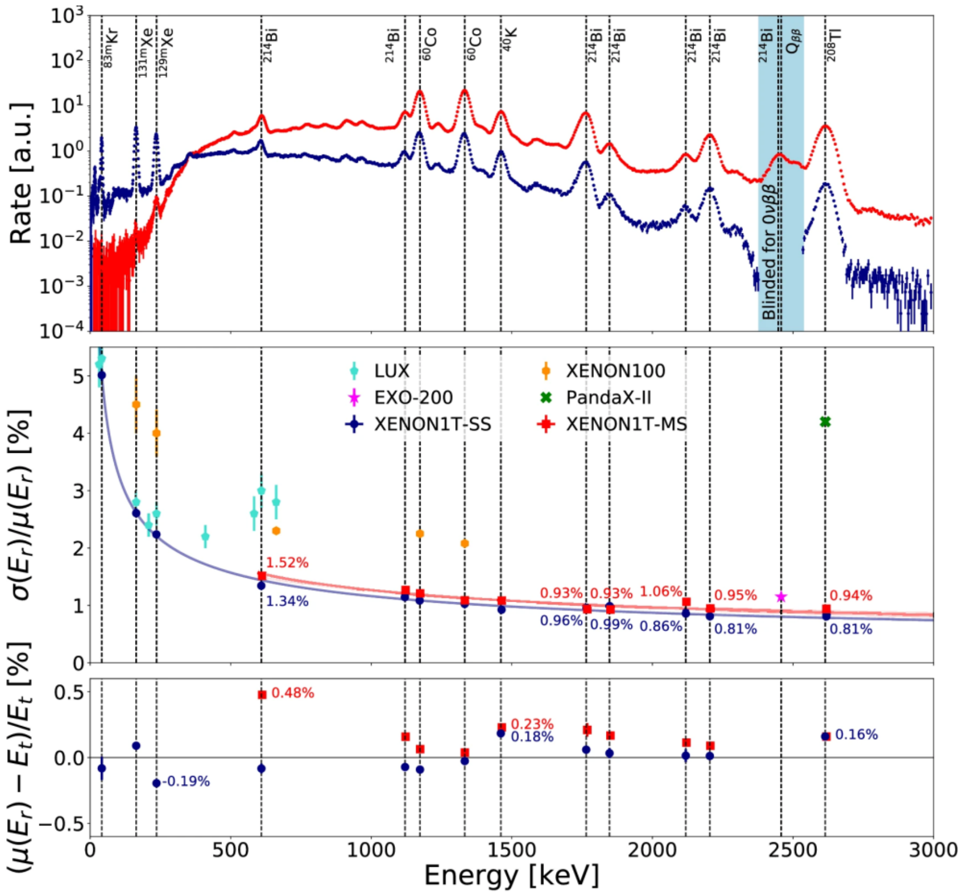




ER Energy Scale



Eur. Phys. J. C (2020) 80:785



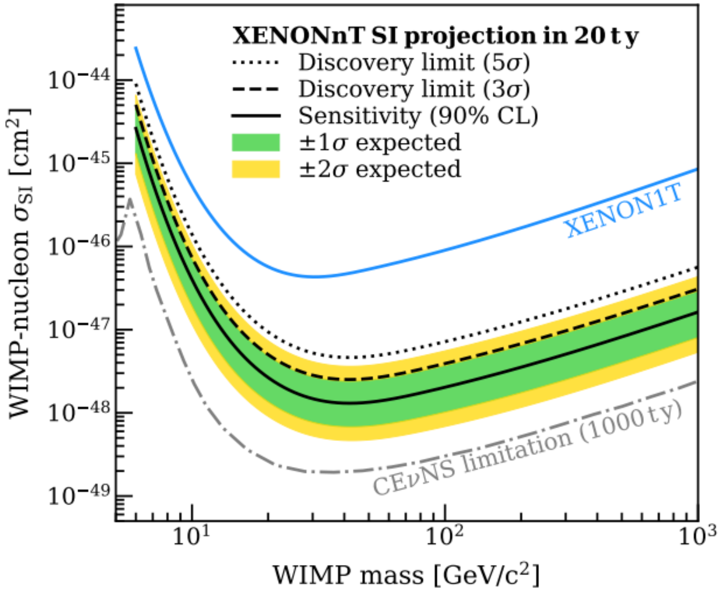
$$E = (n_{ph} + n_e) \cdot W$$
$$= \left(\frac{S1}{g1} + \frac{S2}{g2}\right) \cdot W$$

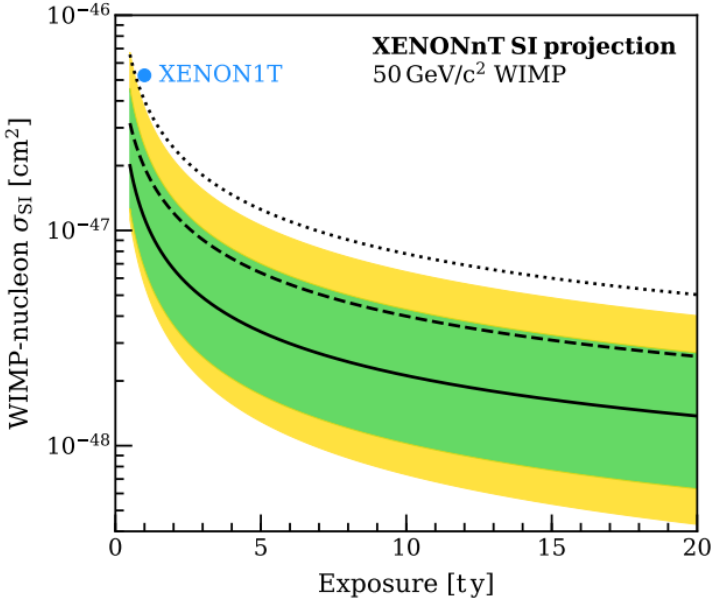
- ER background MC-data matching validates framework
- Very low energy resolution at ^{136}Xe $Q_{\beta\beta}$=2.46MeV: (0.80±0.02)%
- Promising for near future neutrinoless double-beta decay results!

WIMP sensitivity projections

- A 4 t fiducial volume is considered
- After 20 t y, the expected sensitivity is 1.4×10^{-48} cm² @ 50 GeV/c², 90% CL
- In 5 years, one more order of magnitude probed!

JCAP11, 031 (2020)





SNEWS 2.0

- Real-time algorithms
- Lower threshold
- Multimessenger follow-up
- Pointing with neutrinos

SNEWS

SNEWS 2.0: A Next-Generation SuperNova Early Warning System for Multi-messenger Astronomy

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Absolute timing in XENONnT