The XENONnT Experiment

Detector and science program

SPS/ÖPG annual meeting

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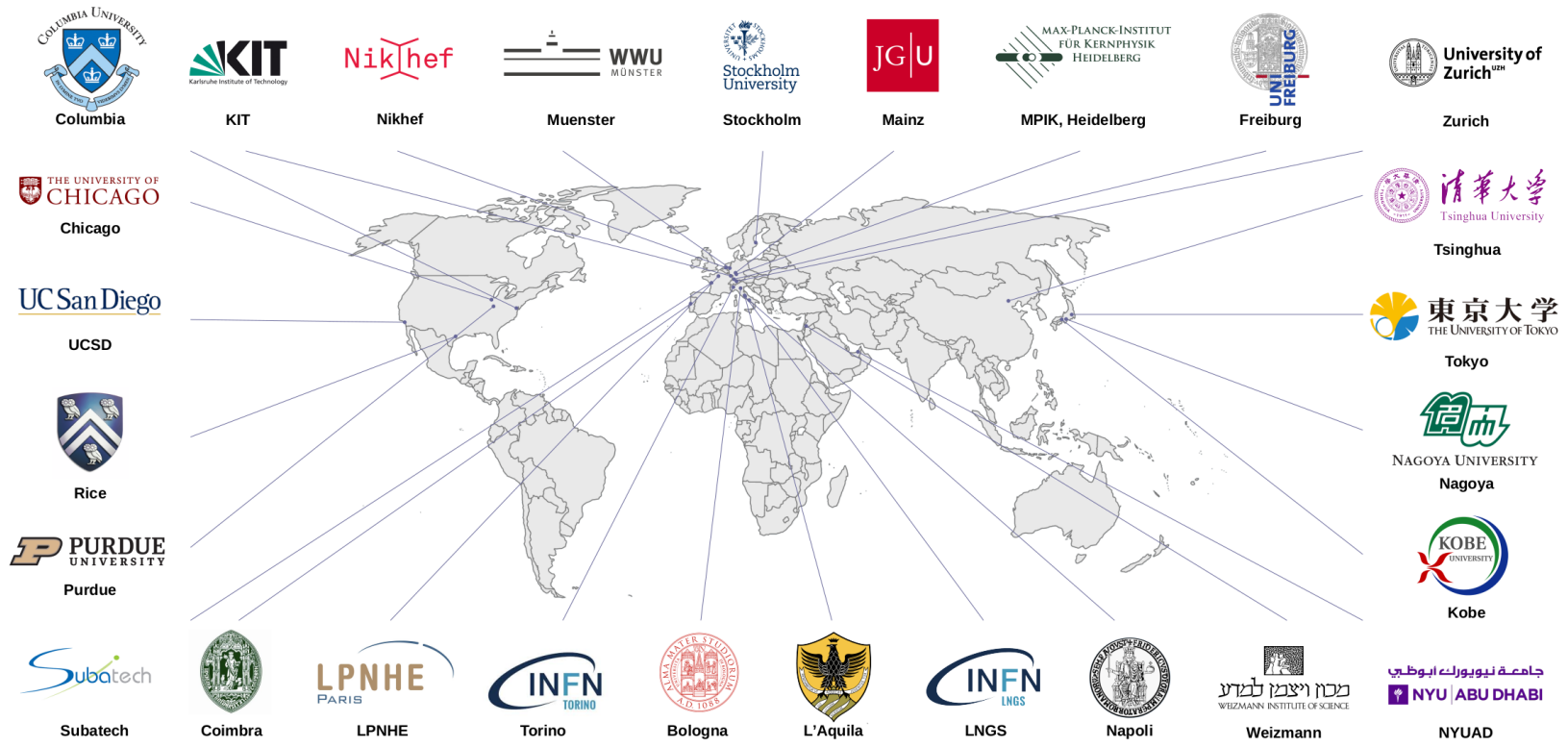
01/09/2021

The XENON Collaboration

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



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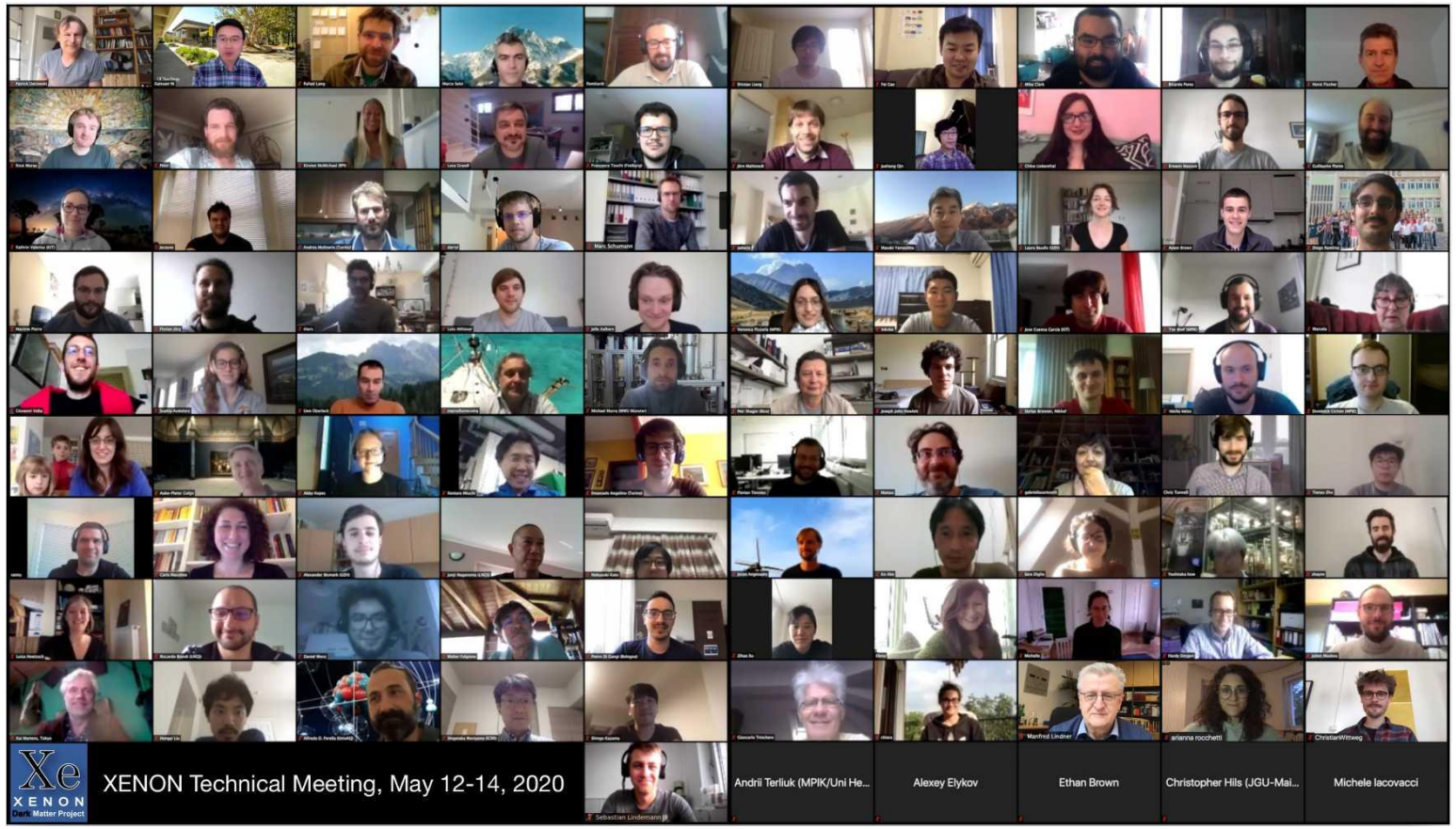


The TPC detection principle

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

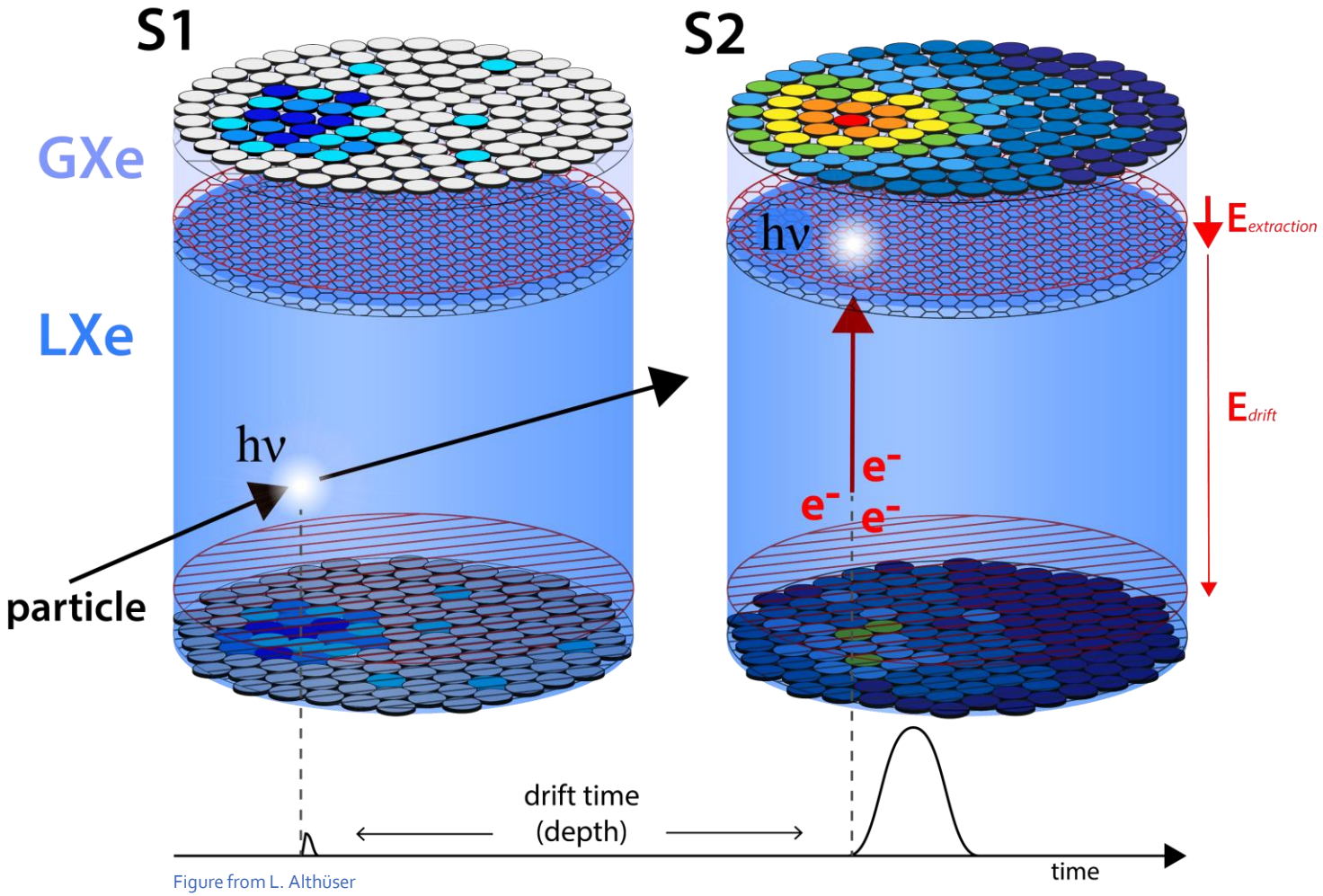
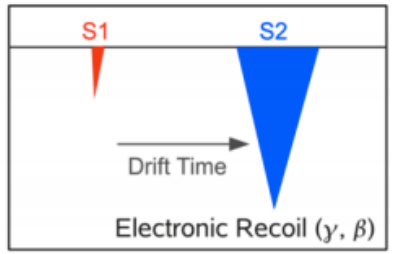
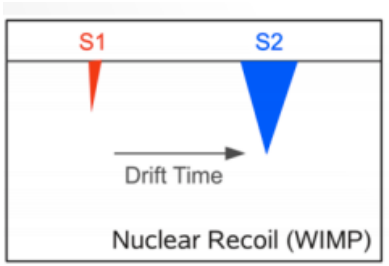


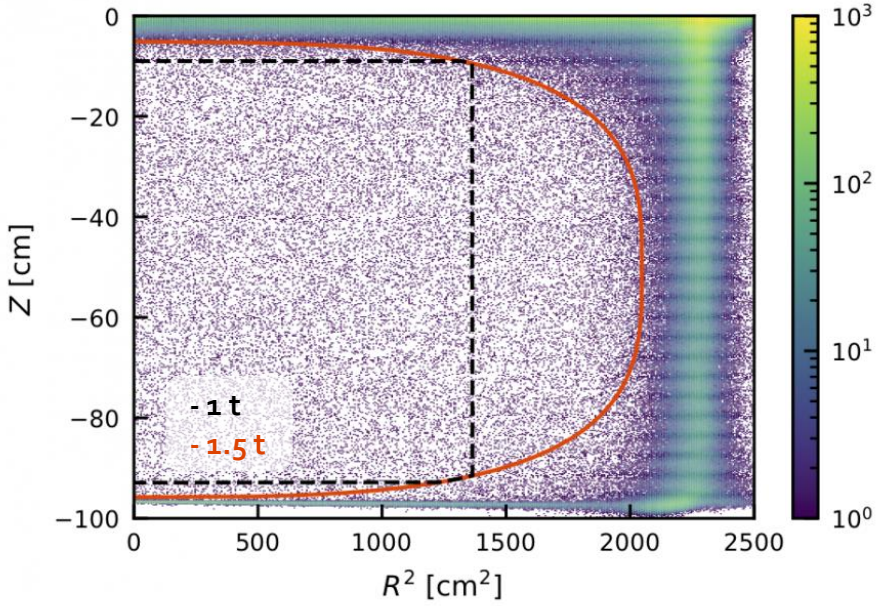
Figure from L. Althüser

The TPC detection principle

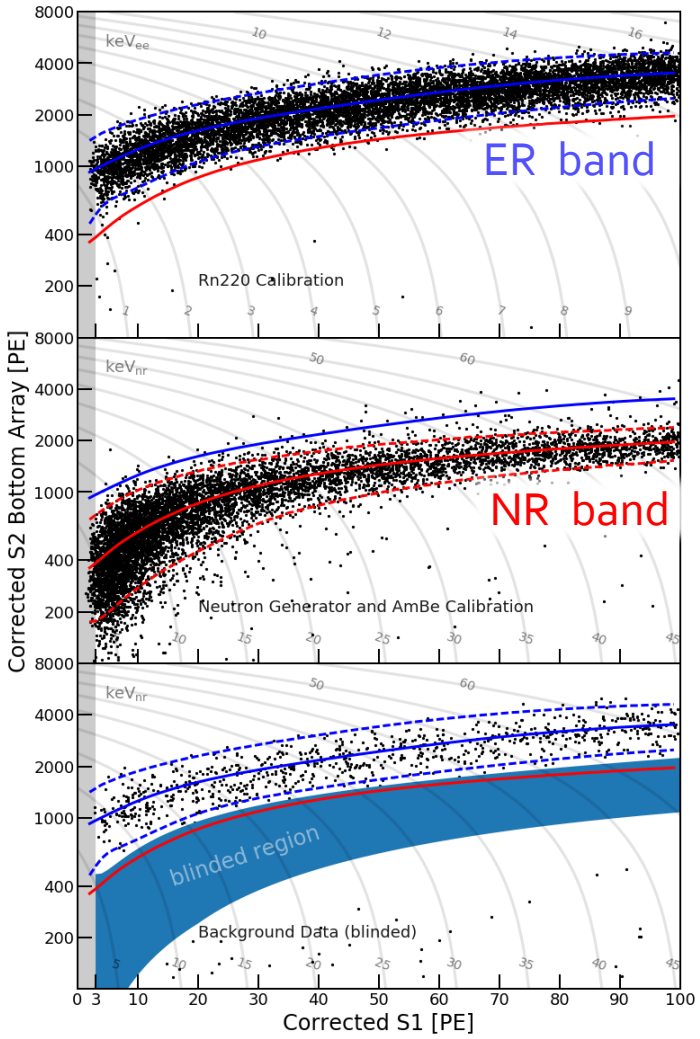
- Energy reconstruction
- ER/NR events discrimination
- Particle ID (γ, α, β, n, WIMP)
- Fiducialization







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



The XENON program

- Since 2005
- Dual-phase xenon TPCs
- XENONnT currently taking science data

XENON10

Target mass: 14kg

2005-2007

XENON100

Target mass: 62kg

2008-2016

XENON1T

Target mass: 2t

2013-2018

XENONnT

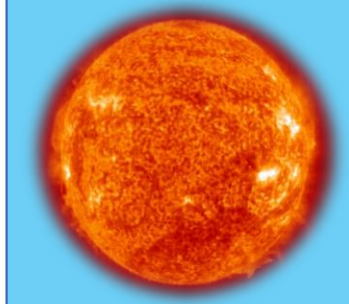
Target mass: 5.9t

2020 - present

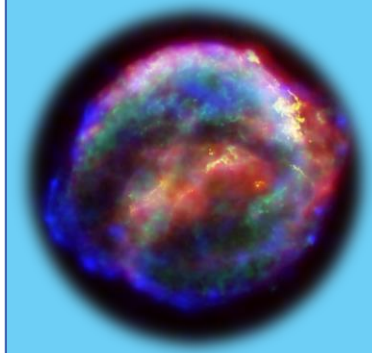
Physics channels

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

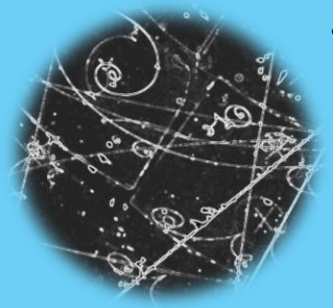
- WIMP-search
  - Spin-independent
  - Spin-dependent
- Sub-GeV
- Dark photons
- Axion-like particles



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



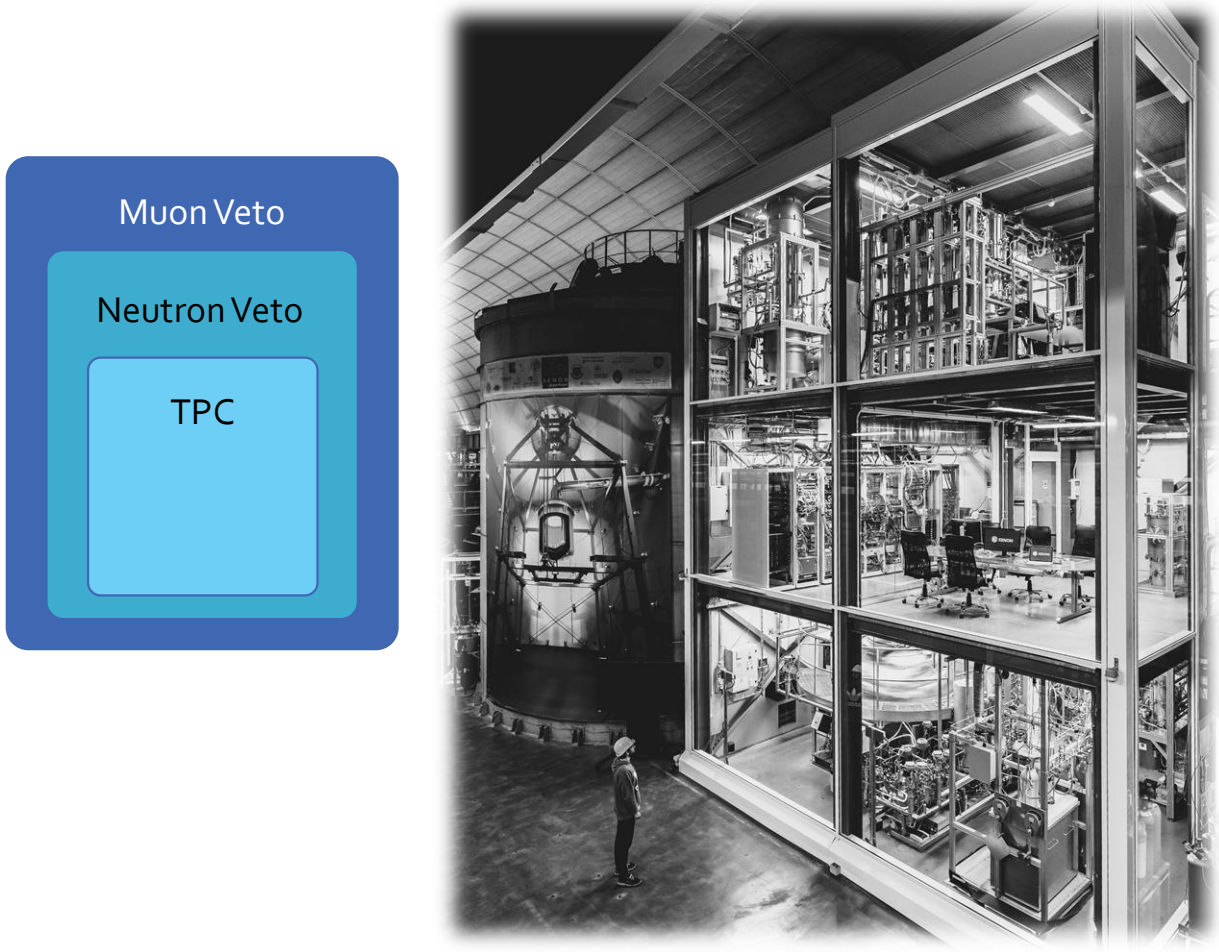
- Supernova neutrinos
- Actively communicate with SNEWS
- Multi-messenger in DM experiments



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

XENONnT experiment

- 3 complementary detectors:
  - TPC
  - Muon Veto
  - Neutron Veto
- Several auxiliary systems
- Fast upgrade on 1T infrastructure



- Cryogenics and purification
- DAQ and SC
- Calibration lines
- Kr and Rn distillation
- Xenon storage

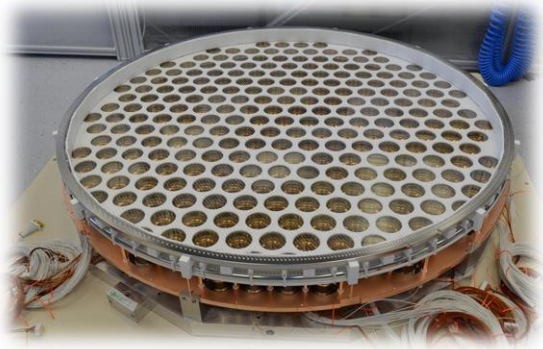
TPC

- Larger active mass
- 1.5 m height
- 1.3 m diameter
- Finished installation summer 2020

5.9 t active liquid xenon (3x XENON1t)

494 3" PMTs

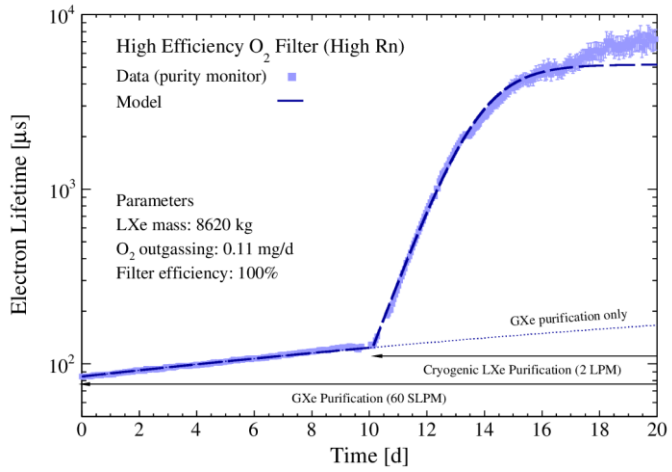
Tunable field shaping rings chains



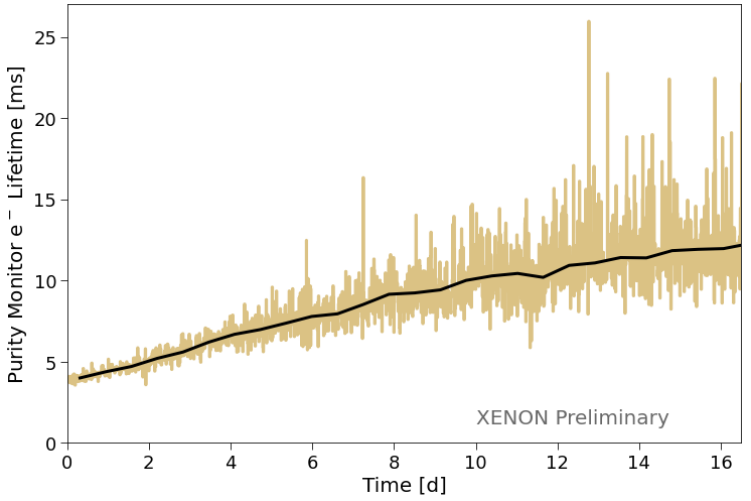
Thoroughly selected and screened materials

Liquid Xenon Purification

- Purification directly in liquid
- ~1000 slpm purification speed
- Electron lifetime of >10 ms achieved
- Very low Rn emanation

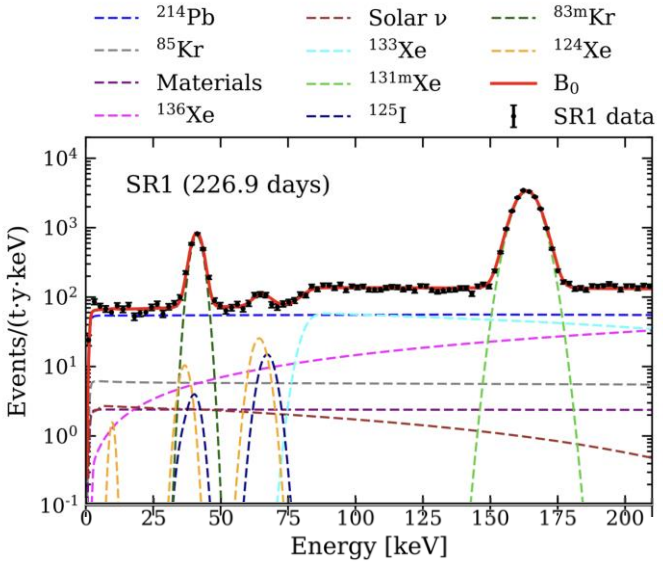


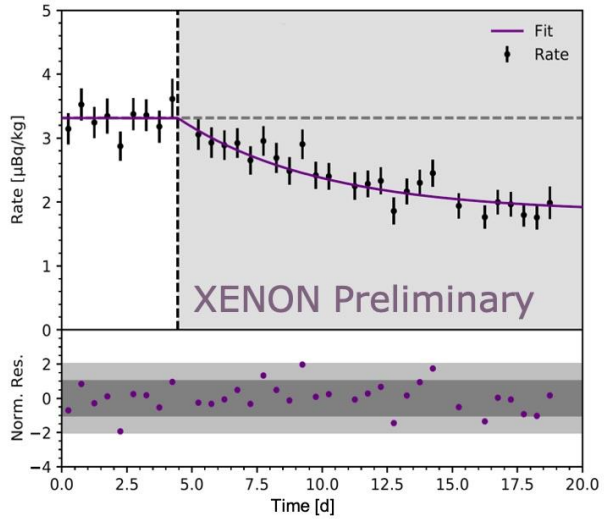
> 90% electron survival probability, improving S2-only and neutrino searches



Radon Distillation Column

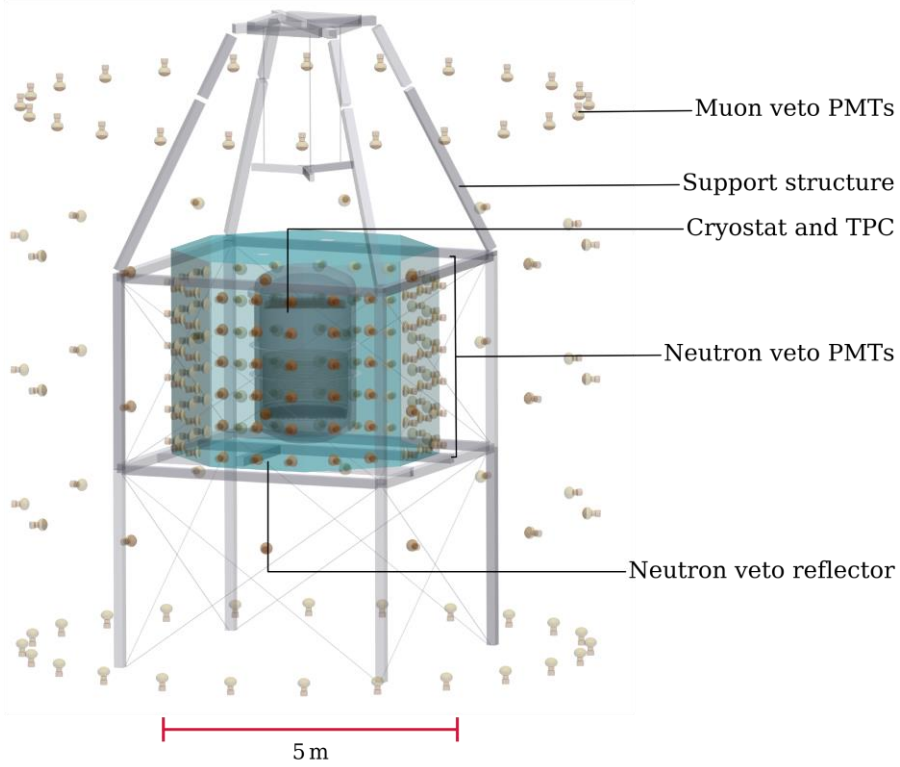
- Main internal ER background in XENON1T
- Developed and installed a Rn distillation column
- Goal of 1 µBq/kg (13 µBq/kg in XENON1T)
- 2 µBq/kg achieved and extra factor of 2 reduction possible

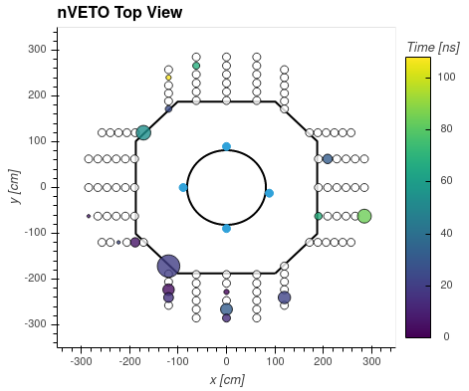


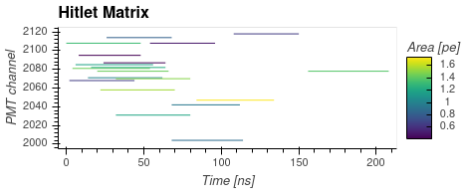


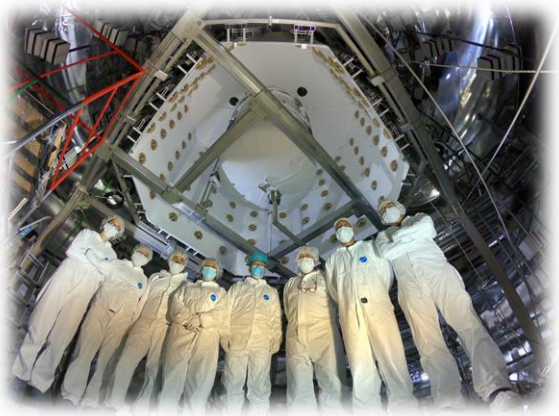
Neutron and Muon Veto

- Neutron Veto:
  - Gd loaded water Cherenkov detector (soon)
  - Optically separated from the MV
  - 120 dedicated PMTs
  - 87% neutron tagging efficiency by design
- Muon Veto:
  - Passive water shield
  - Cherenkov detector



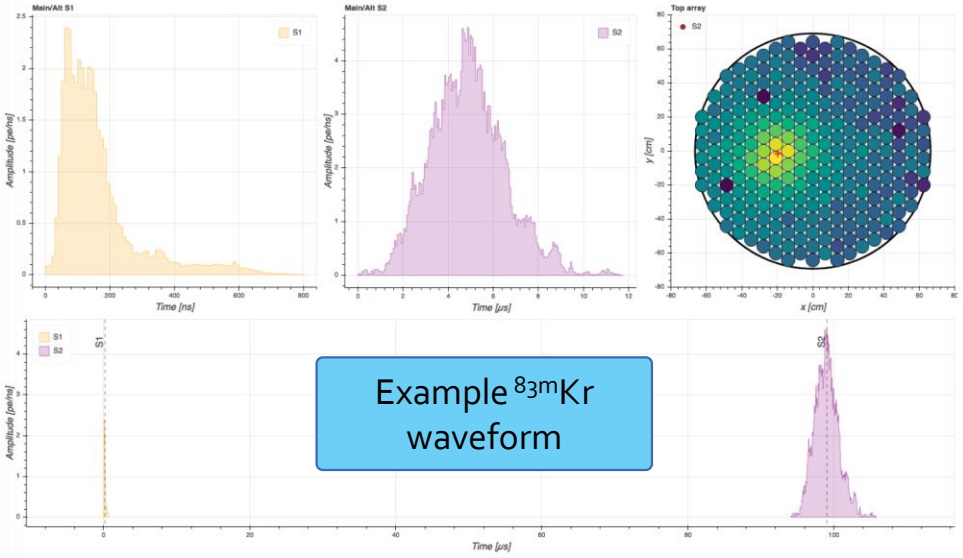




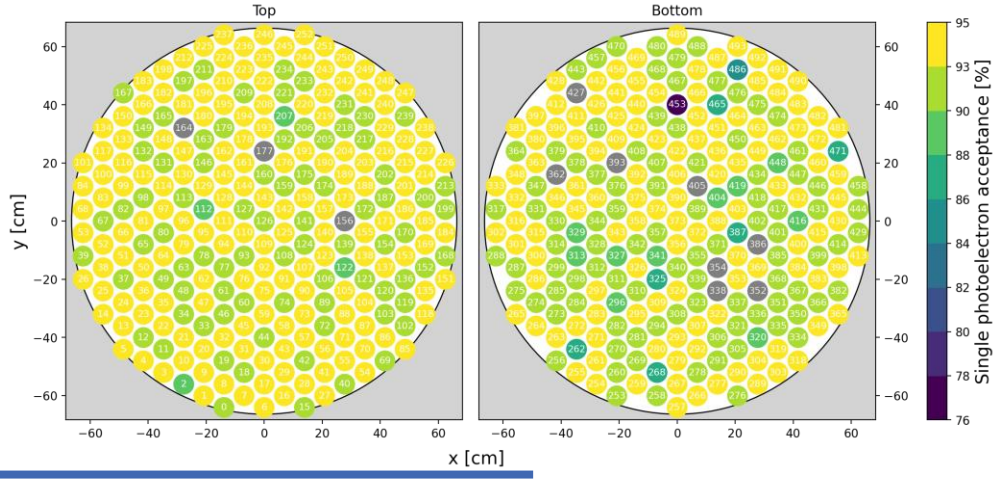


Data in science run configuration

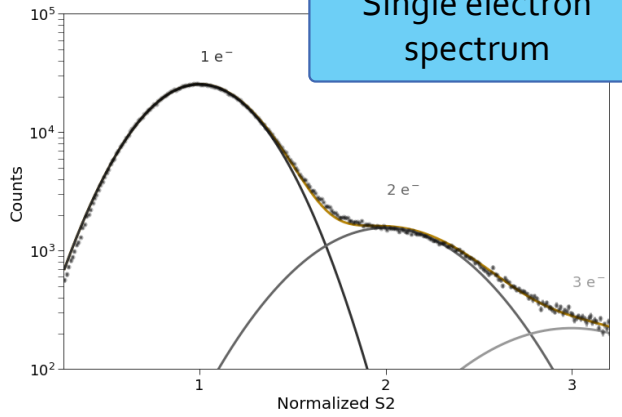
- PMT arrays performing well
- Single electron resolution with triggerless DAQ
- PDE: ~0.17 PE/photon



Example ^{83m}Kr waveform



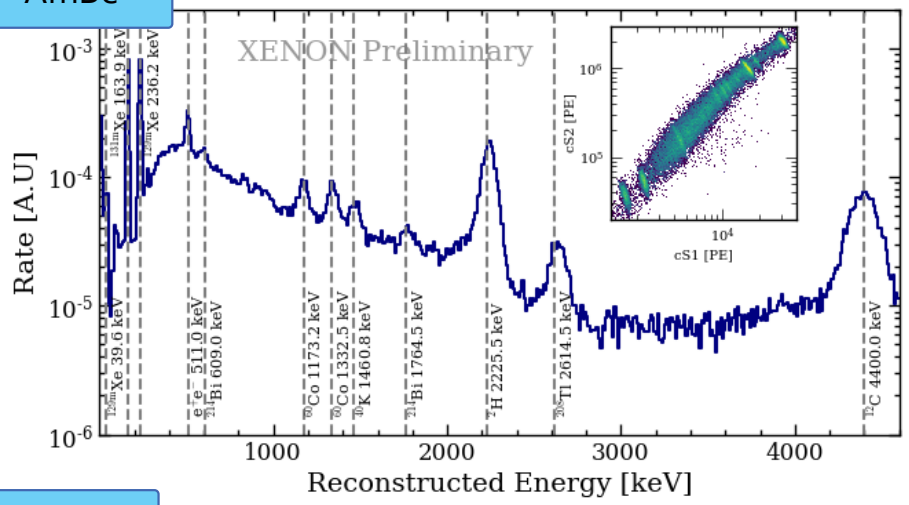
Single electron spectrum



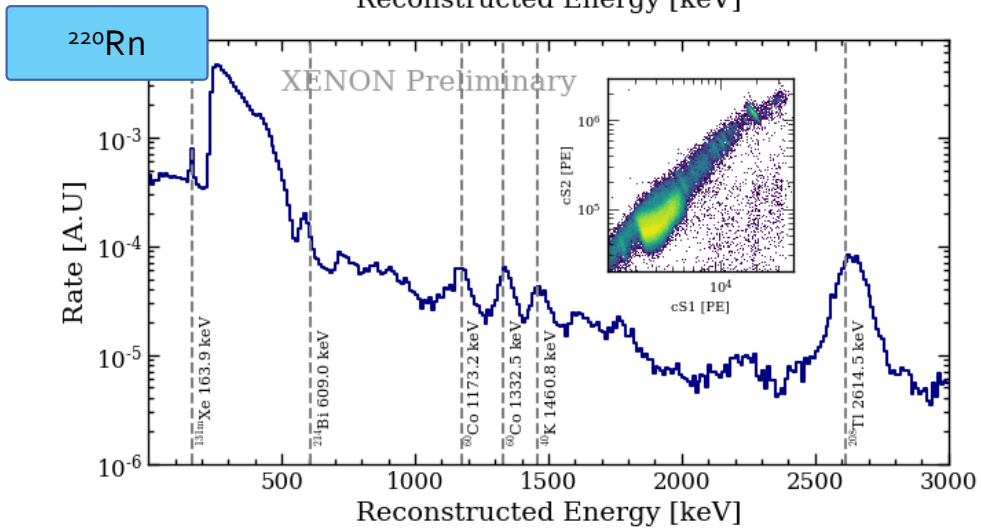
Data in science run configuration

- Successful calibration runs:
  - NR – AmBe
  - ER – ^{220}Rn
  - Detector effects and energy resolution – ^{83m}KR
- 7.6% energy resolution at 41.5 keV

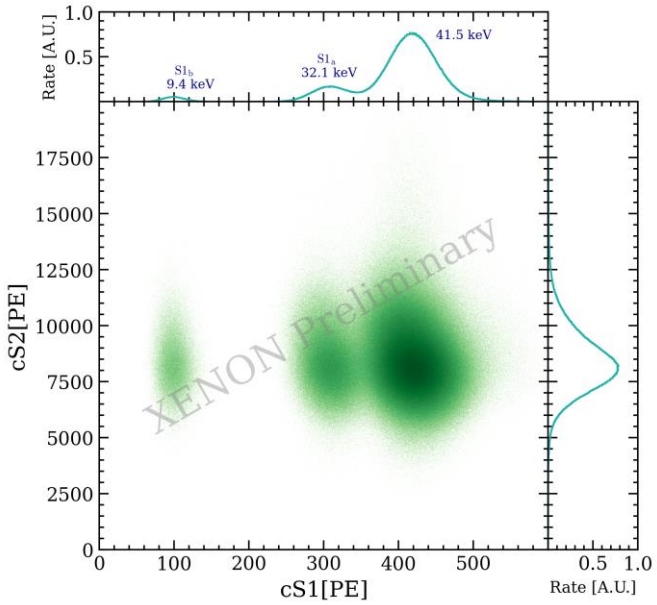
AmBe



^{220}Rn



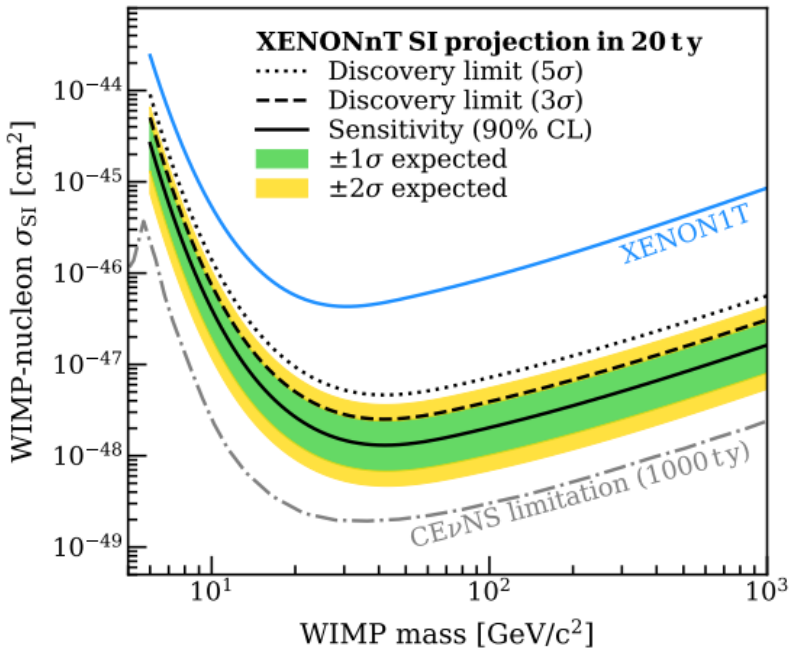
^{83m}Kr



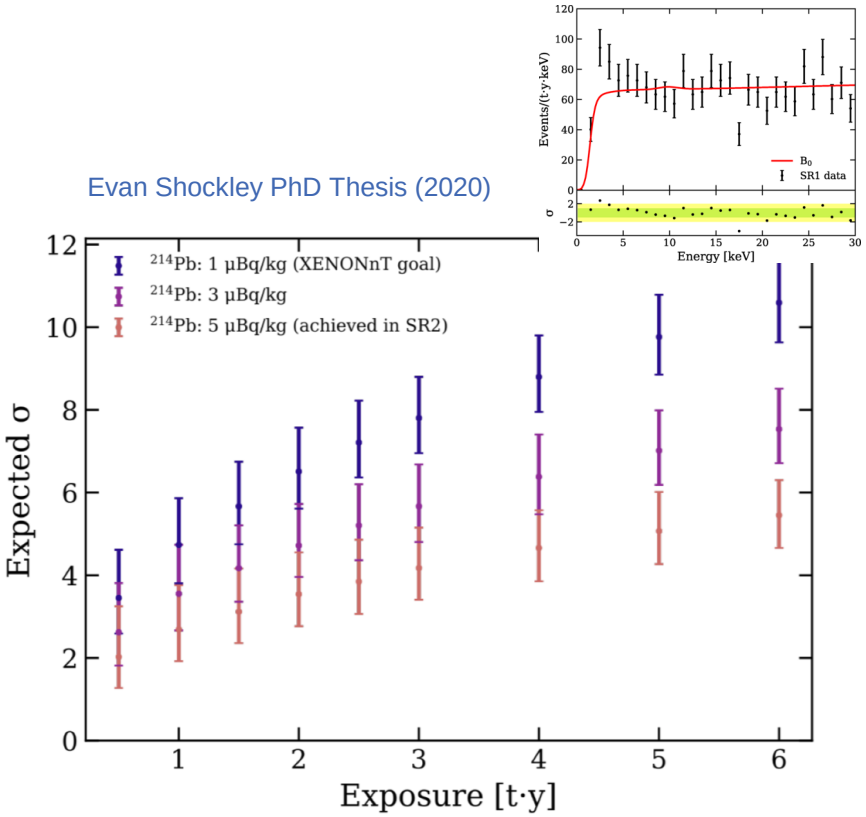
First science results on the horizon

- Two main physics analysis:
  - WIMP search (1.4×10^{-48} cm^2@50 GeV/c^2 for 20 t.y)
  - Low-energy ER excess seen in XENON1T
- Most conditions on goal value (e-lifetime, ^{222}Rn level)
- First science run ongoing!

JCAP11(2020)031



Evan Shockley PhD Thesis (2020)



Summary and Outlook

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@XENONexperiment

fb.com/XENONexperiment

@xenon_experiment

- LXe TPCs exceptional to 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 taking science data with major improvements over XENON1T configuration:
  - target mass: 5.9 t
  - e-lifetime: > 10 ms (liquid purification)
  - Rn level: < 2 μBq/kg (Rn distilation column)
  - Neutron veto in place
- First results from XENONnT are on the horizon, shedding light on the XENON1T Low-energy ER excess and leading limits on the SI WIMP-nucleon interaction cross section.

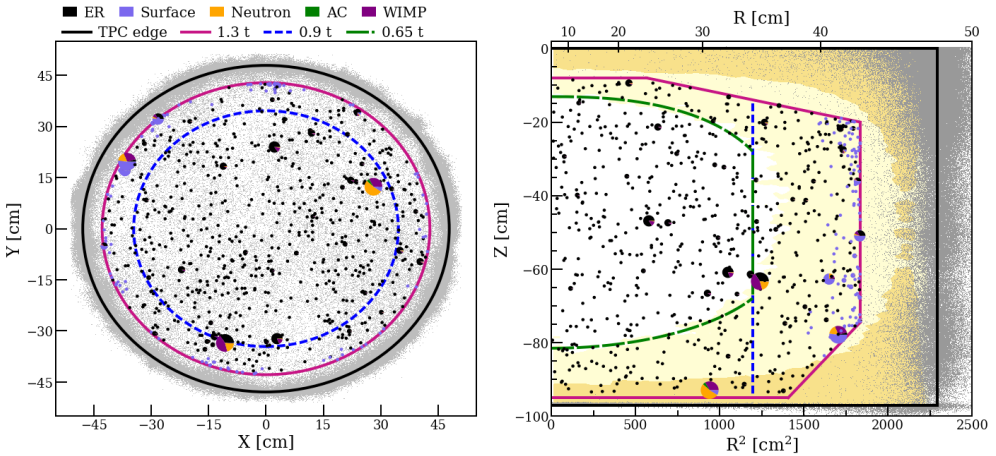
Backup Slides

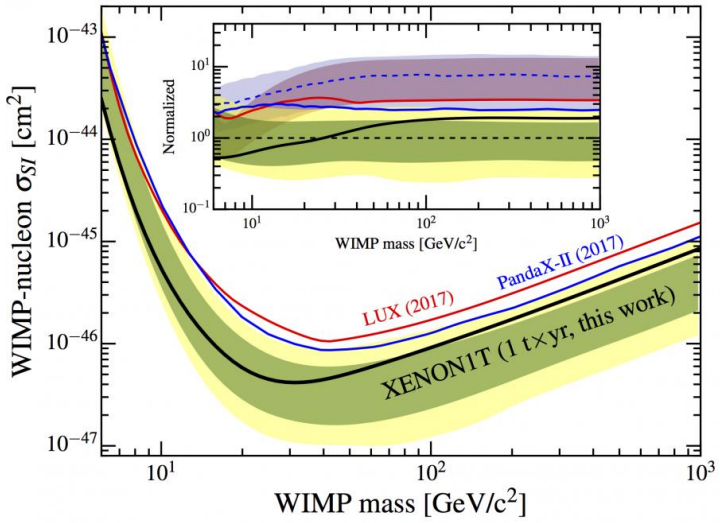
XENON1T/nT detectors

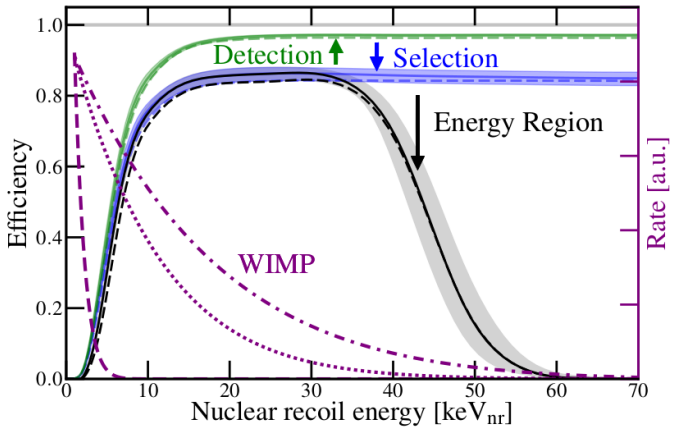
- Dual-phase XENON TPC in a water passive and active muon veto
- Service building:
  - Xenon storage and recuperation
  - DAQ
  - Kr distillation column
  - Cryogenics and calibration system

Dark matter search

- Phys. Rev. Lett. 121, 111302 (2018)
- No significant excess over background
- Most stringent WIMP-nucleon cross section: 4.1×10^{-47} cm² @ 30 GeV/c², 90% CL

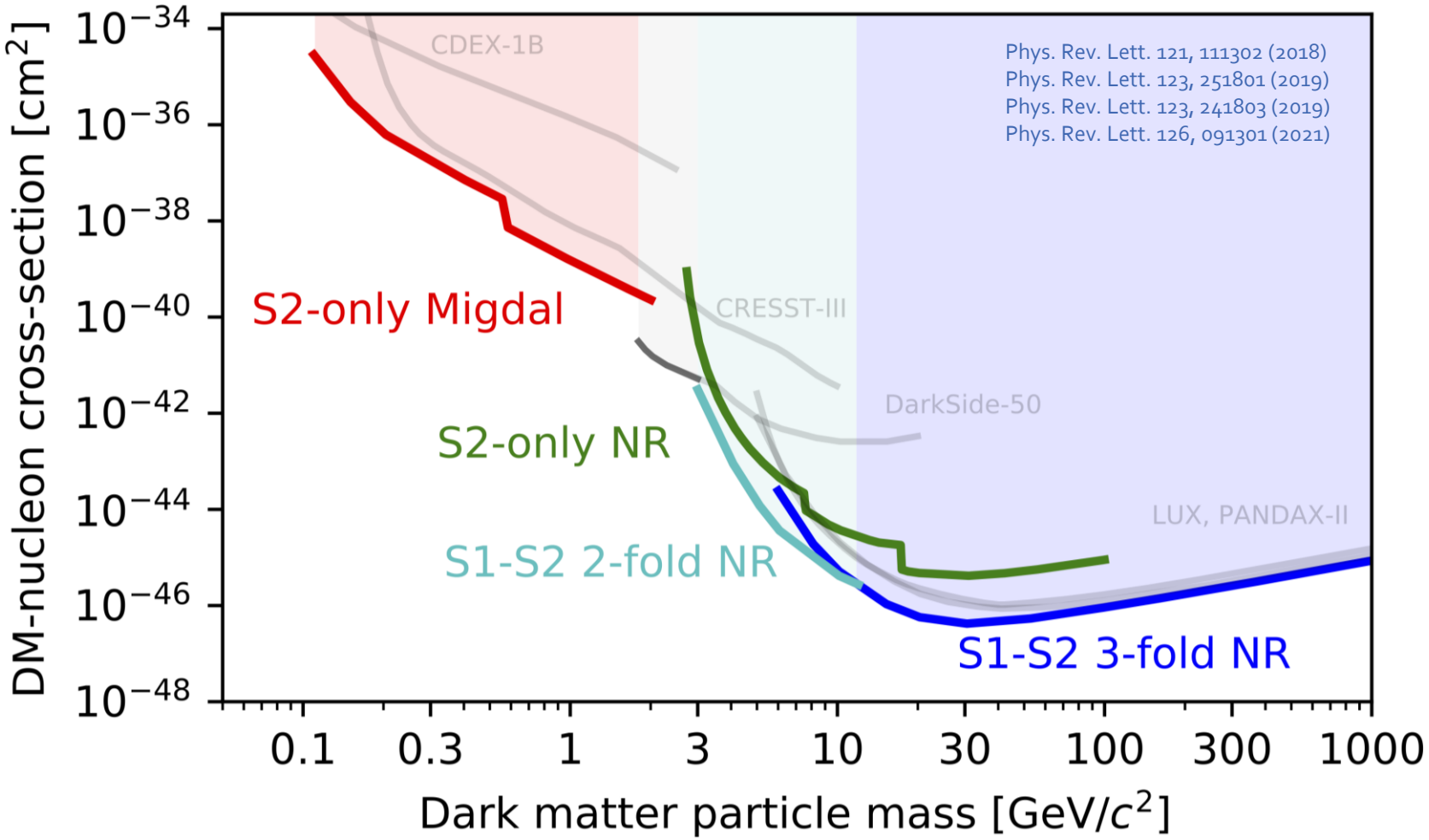






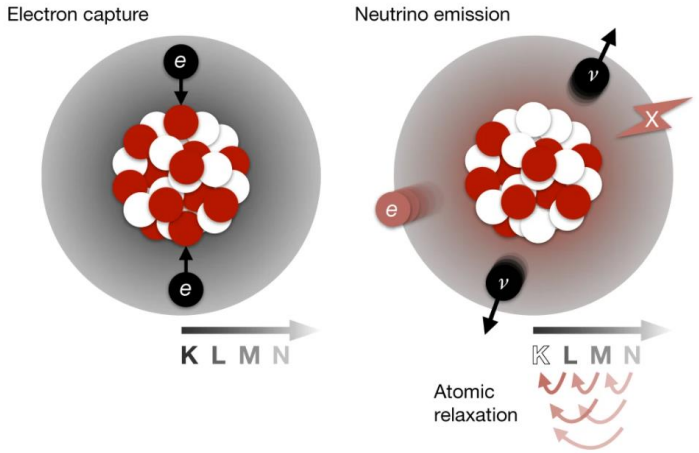
XENON1T SI WIMP results

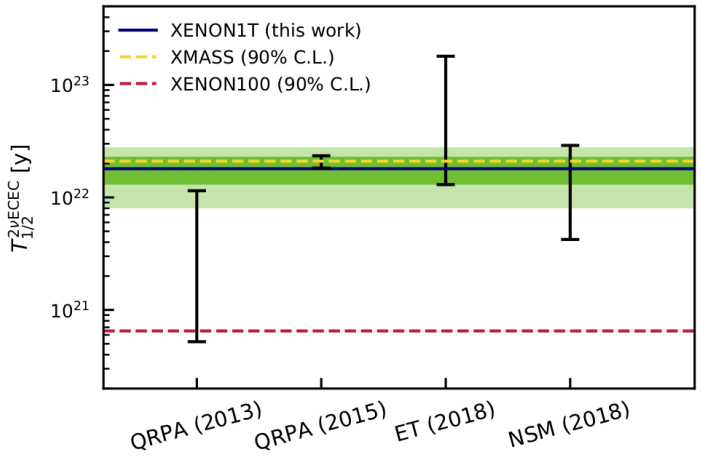
- Extended DM search with ionization-only channel
- No complete background model (only limit setting)
- O(100 eV) energy threshold



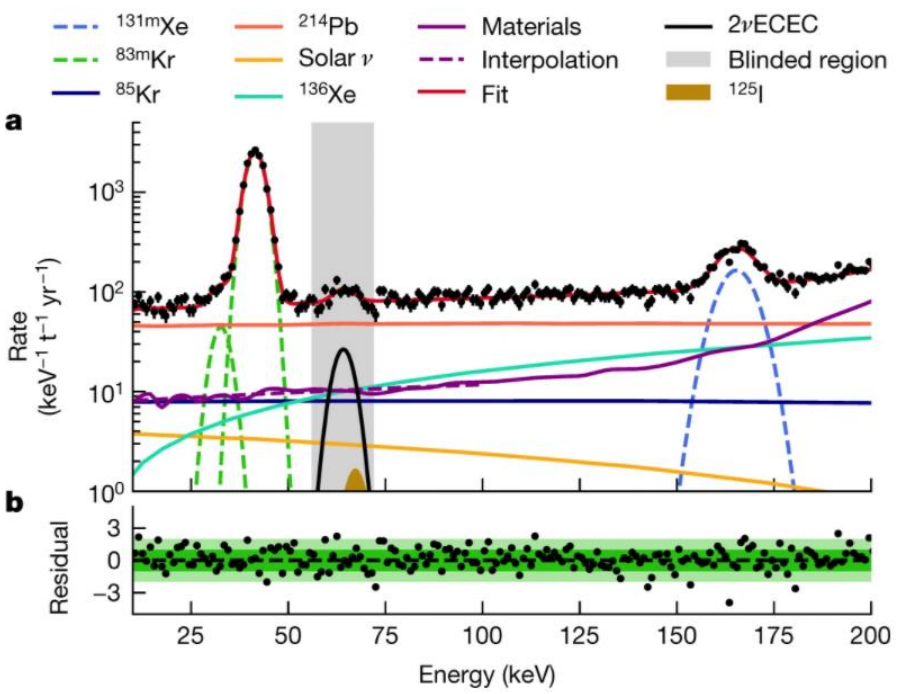
Double Electron Capture in ^{124}Xe

- 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



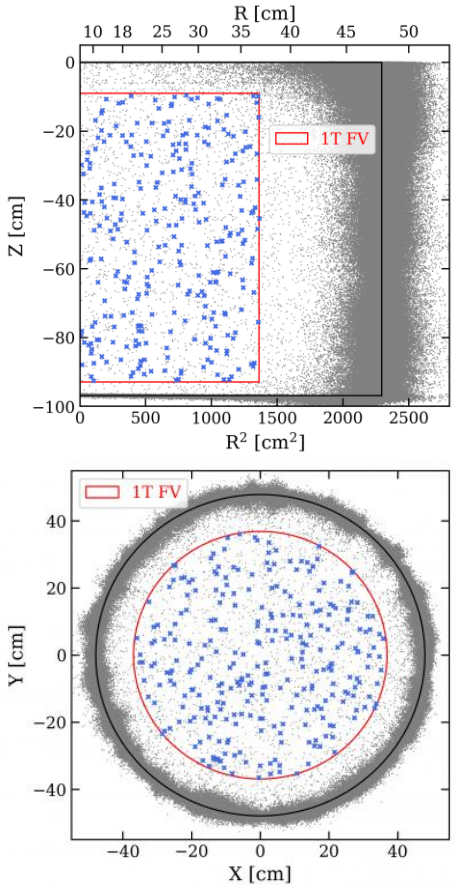


Nature volume 568, 532–535(2019)

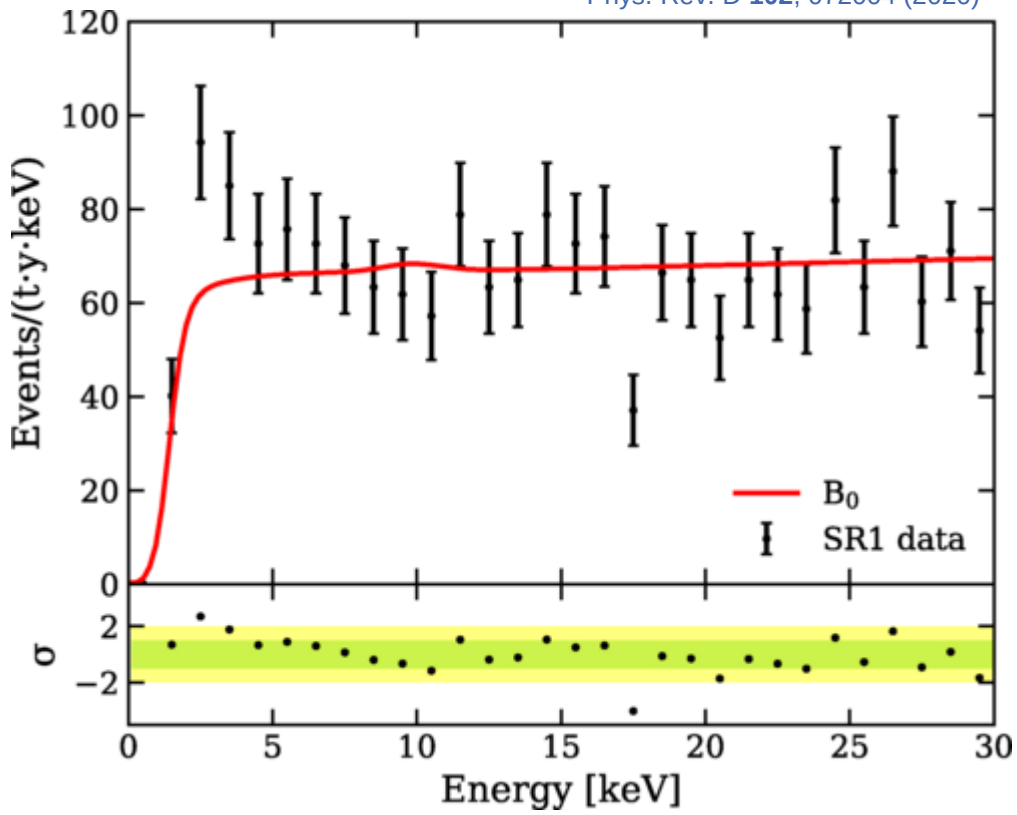


Low-ER excess

- 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)



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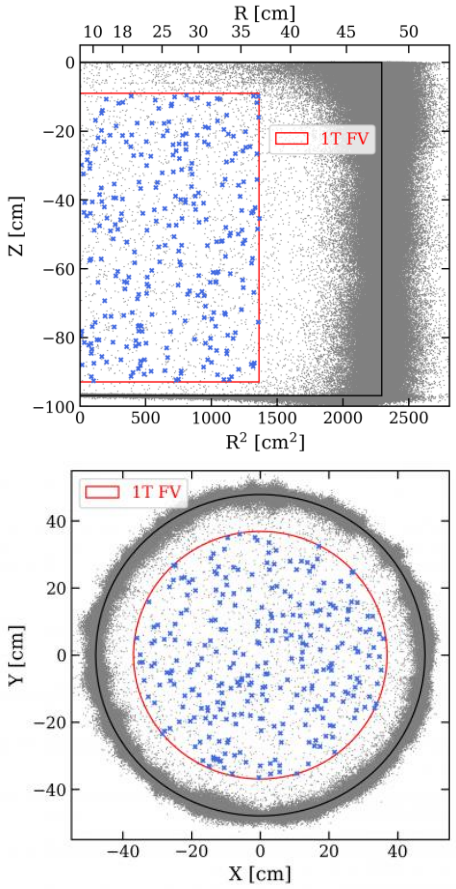
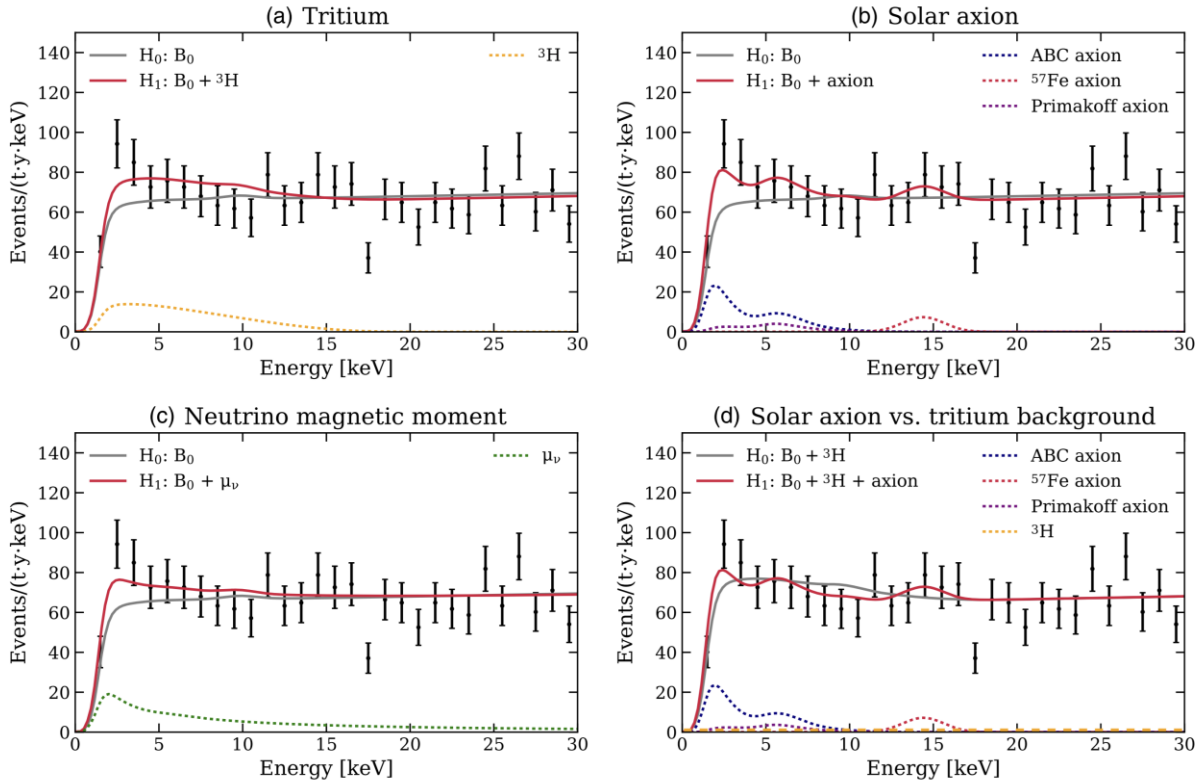
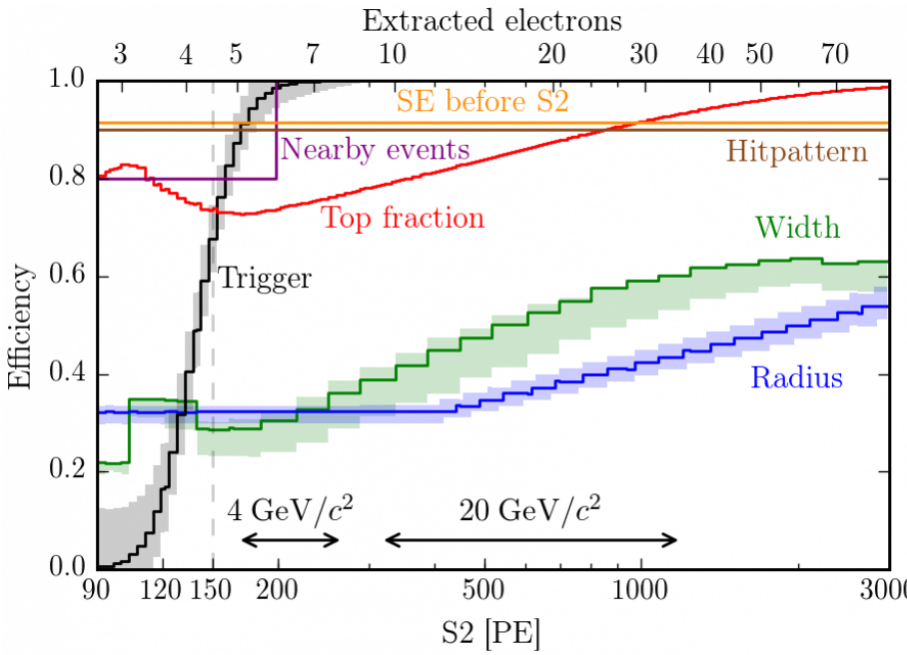
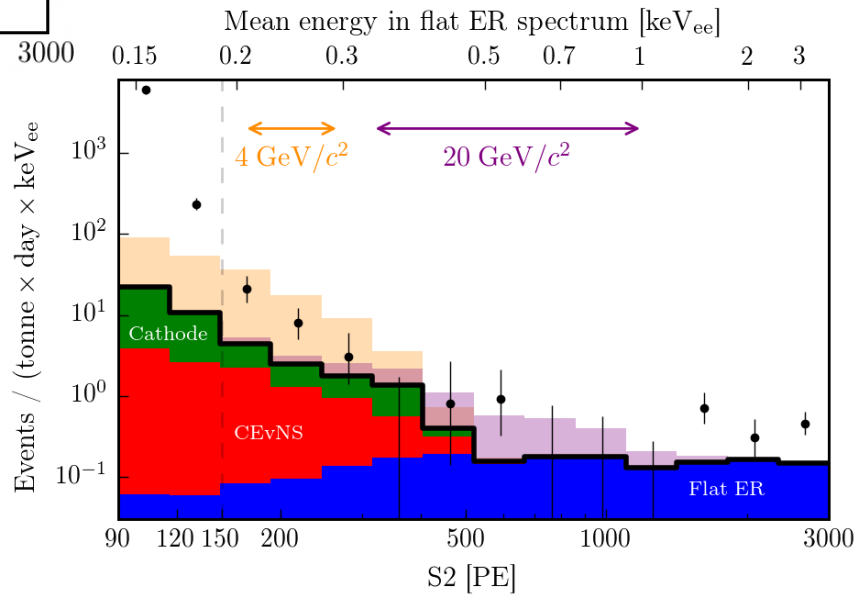




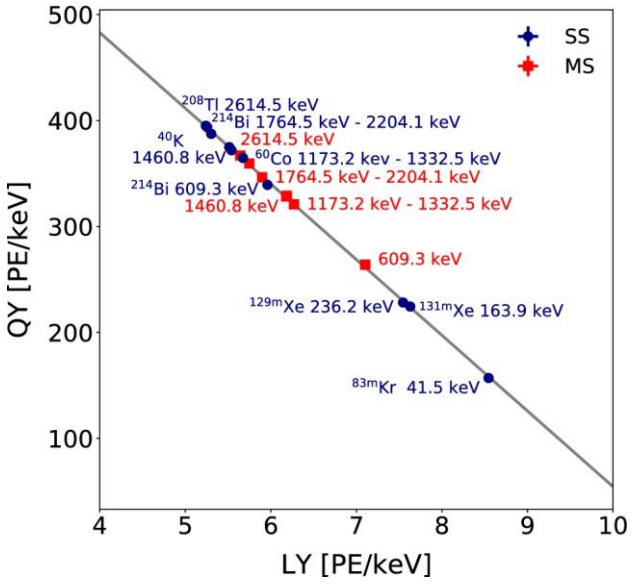
S2-only


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]

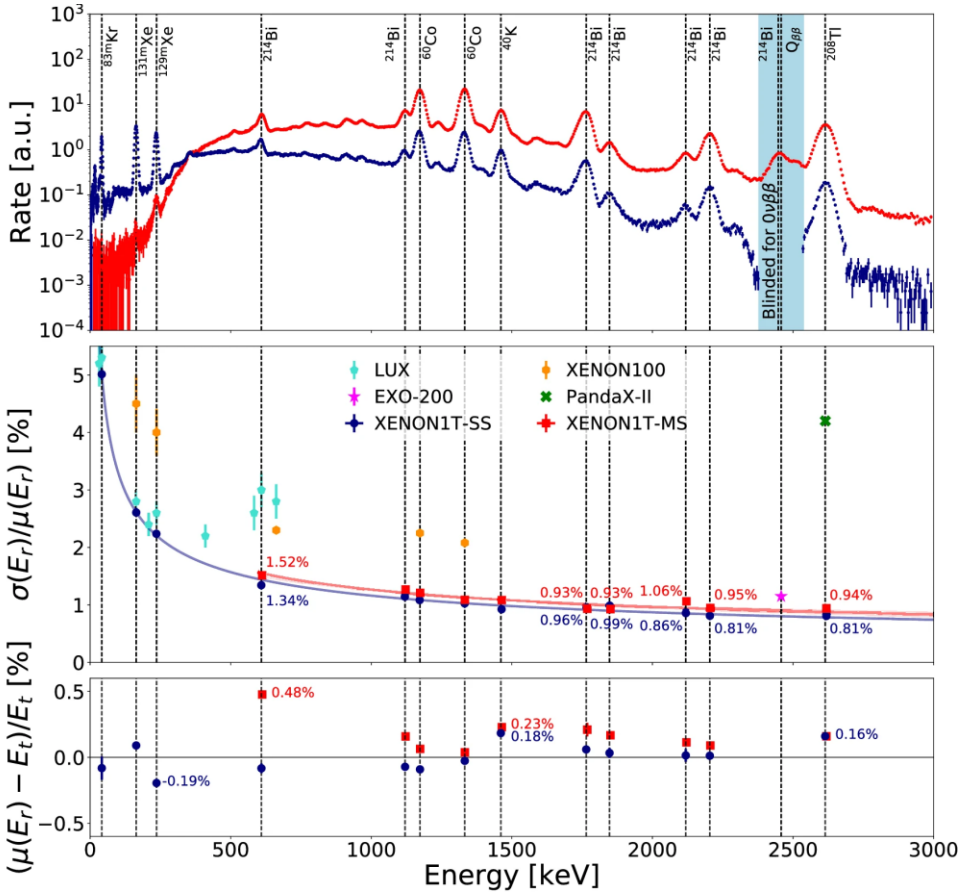
ER Energy Scale

- 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!



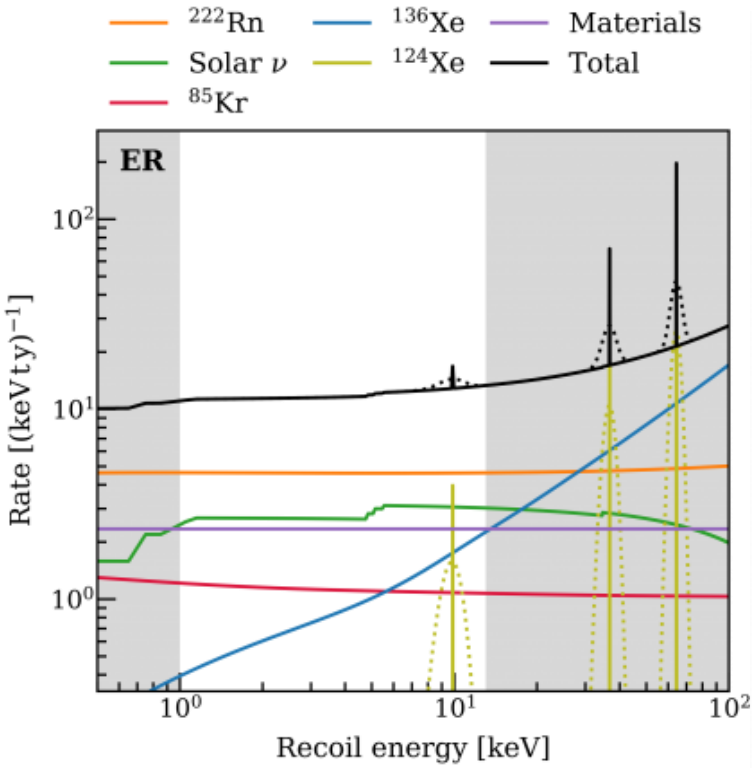
$$E = (n_{ph} + n_e) \cdot W$$
$$= \left(\frac{S1}{g1} + \frac{S2}{g2}\right) \cdot W$$

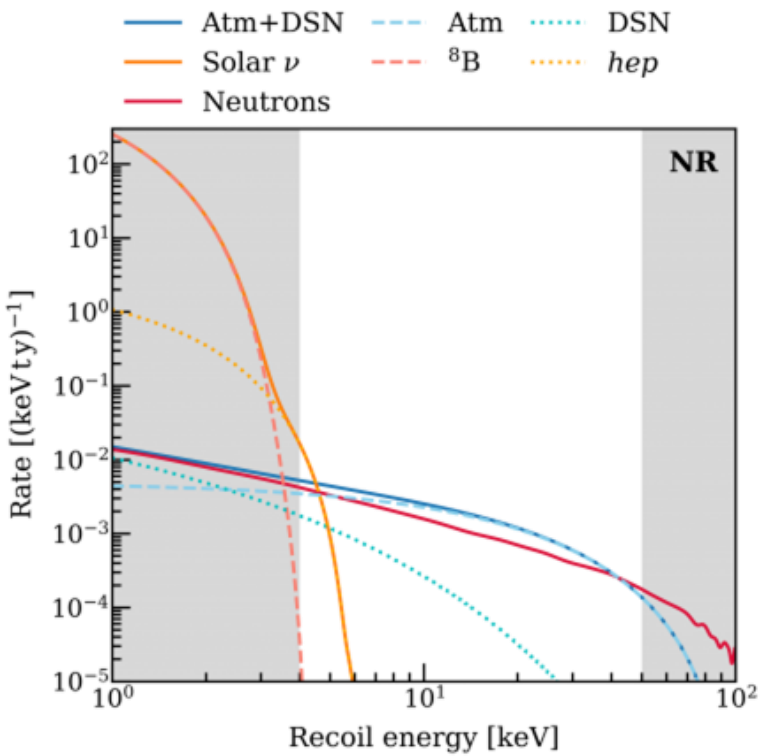
Eur. Phys. J. C (2020) 80:785



ER and NR background

- MC projections for XENONnT
- JCAP11(2020)031

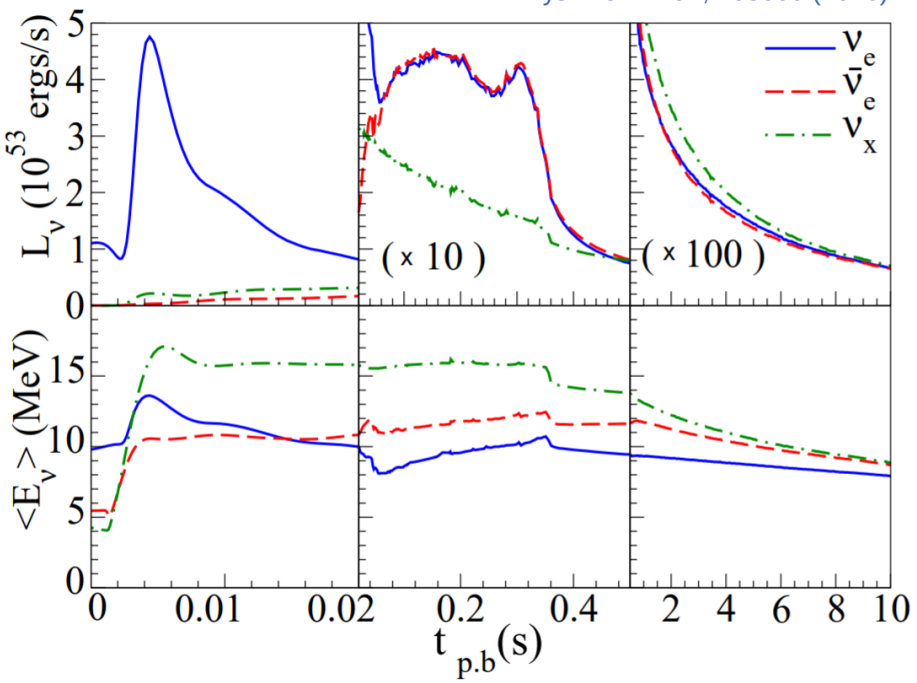




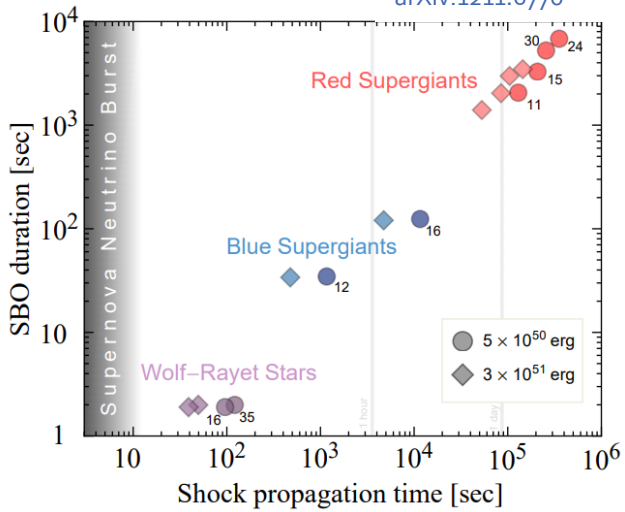
XENONnT as supernovae observatory

- 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

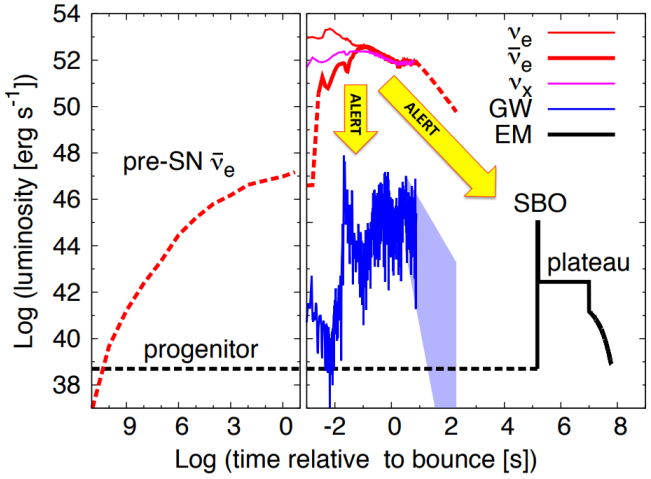
Phys. Rev. D 94, 103009 (2016)



arXiv:1211.6770



arXiv:2011.00035

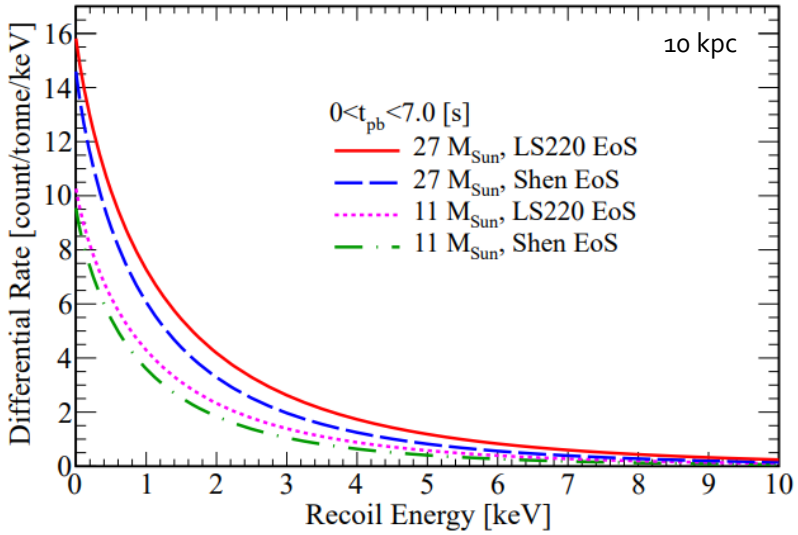


XENONNnT as a SN observatory

- 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 27M⊙@10kpc

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

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



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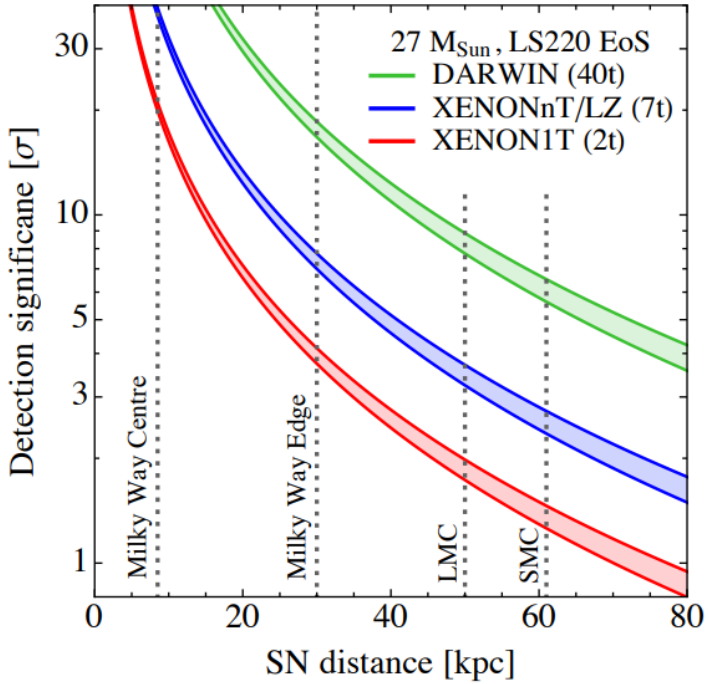
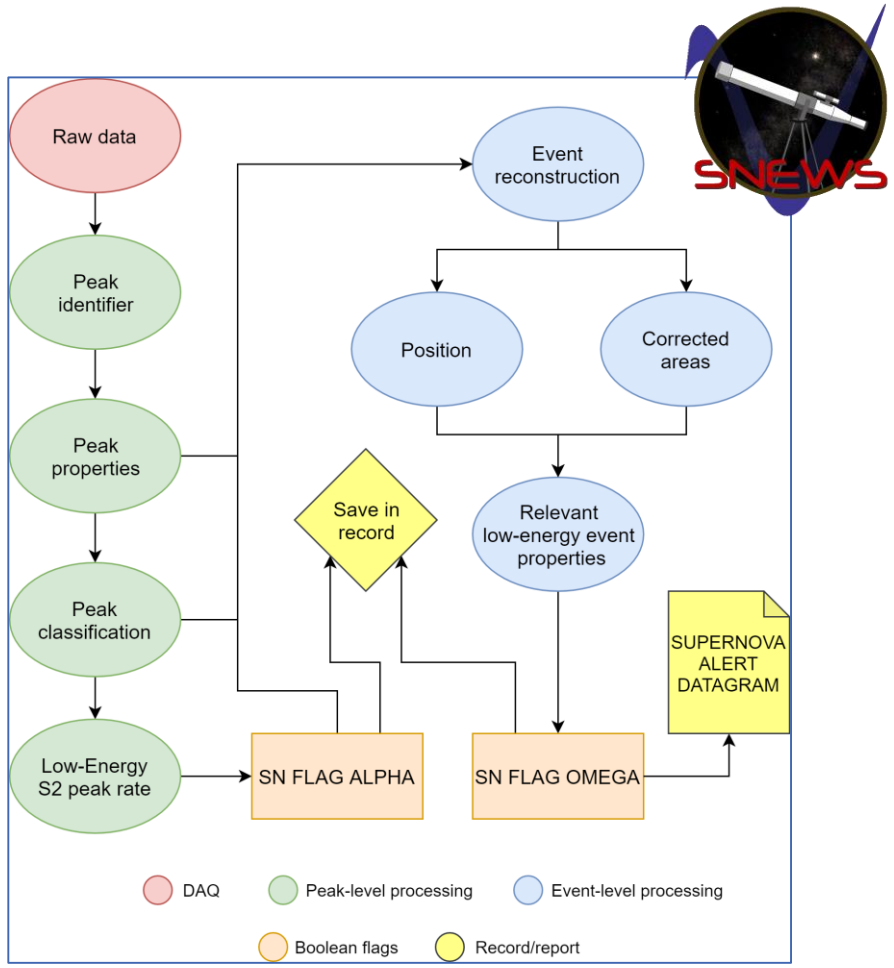
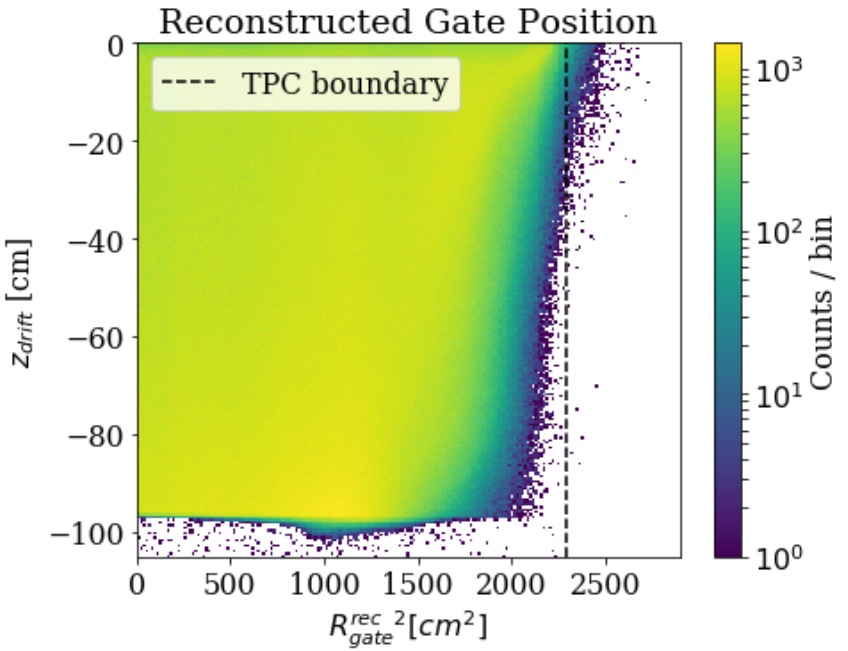


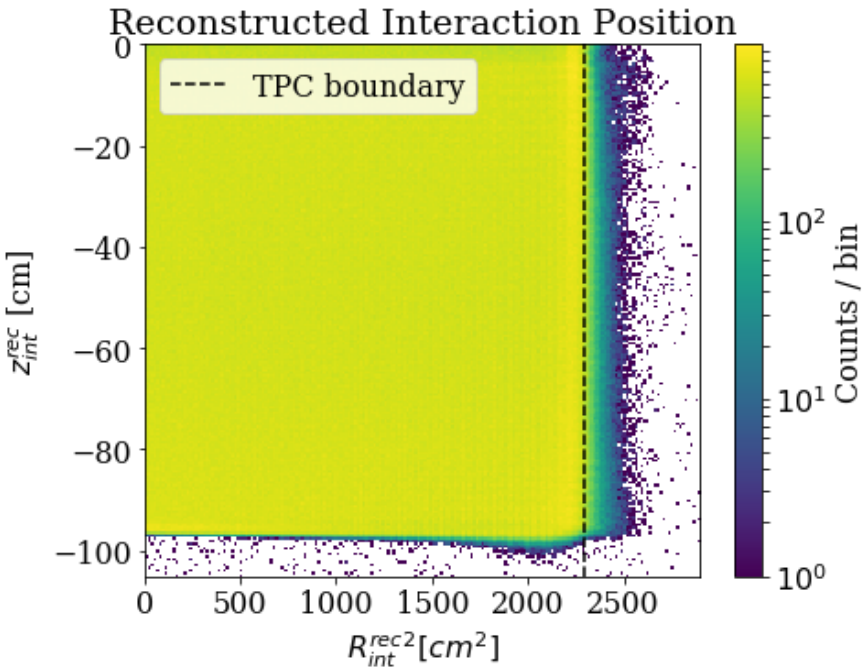
A collaborative effort

- 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



Field Corrections





Light and Charge yields