Upcoming Results from XENON1T

Daniel Coderre
University of Freiburg
Moriond-EW 2018
La Thuile

For the XENON Collaboration

The XENON Collaboration

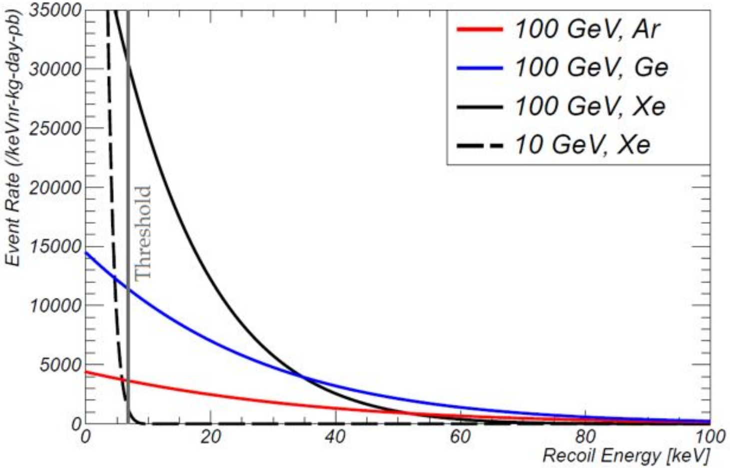
Columbia · RPI · Nikhef · Muenster · Stockholm · Mainz · MPIK · Freiburg · Zurich

Chicago · UCLA · UCSD · Rice

Tokyo · Nagoya · Kobe

Purdue · Coimbra · Subatech · LPNHE · LAL · Bologna · LNGS · Torino · Napoli · Weizmann · NYUAD

Liquid Xenon as Dark Matter Target



WIMPs neutral, S-I coupling ∝ **target atomic mass**

→ xenon: A ~131

Require a **low-background environment**

→ very high purity xenon can be obtained
- No naturally occurring radioactive isotopes (except ^{136}Xe)

→ xenon has a high stopping power
- self-shielding

LXe simultaneously **target** and **detector**

→ xenon liquid at a reasonably high temp. (-95C)
- easily accessible to modern cryogenic systems

→ scintillation light @ 178nm

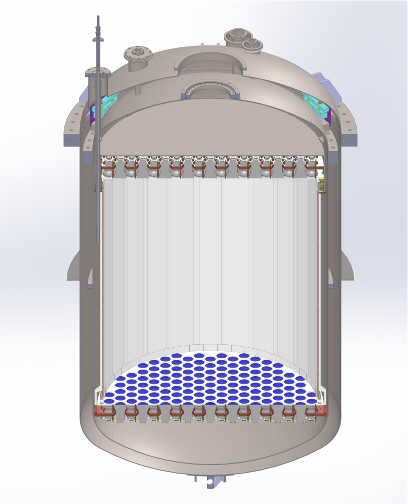
LXe TPCs are the most competitive WIMP detectors for a broad mass range

Stages of the XENON Project

XENON10
Time: Until 2007
Total: 25 kg
Target: 14 kg
Fiducial: 5.4 kg
Limit: ~10^{-43} cm^{-2}

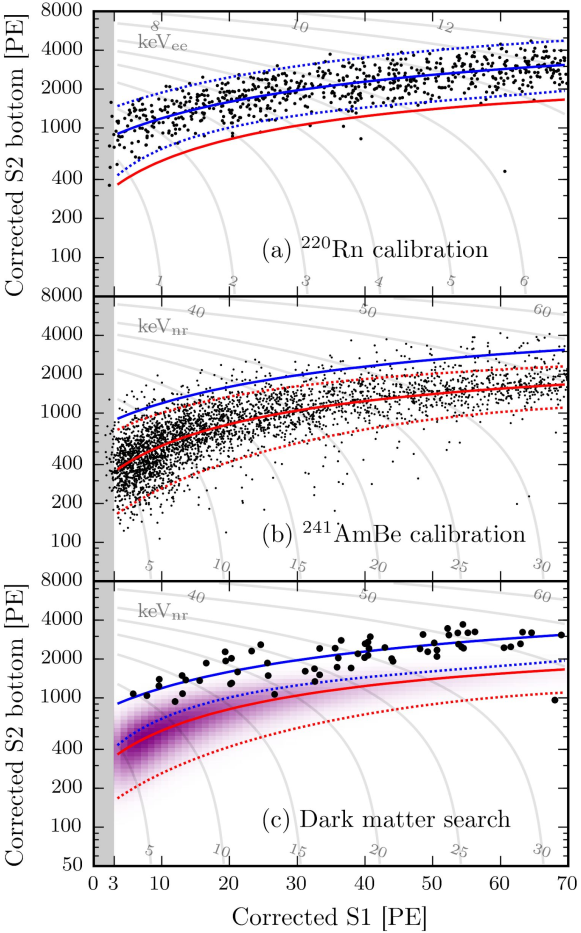
XENON100
Time: Until 2015
Total: 162 kg
Target: 62 kg
Fiducial: 48 kg
Limit: ~10^{-45} cm^{-2}

XENON1T
Time: From 2016
Total: 3500 kg
Target: 2000 kg
Fiducial: >1000 kg
Sensitivity: ~10^{-47} cm^{-2}

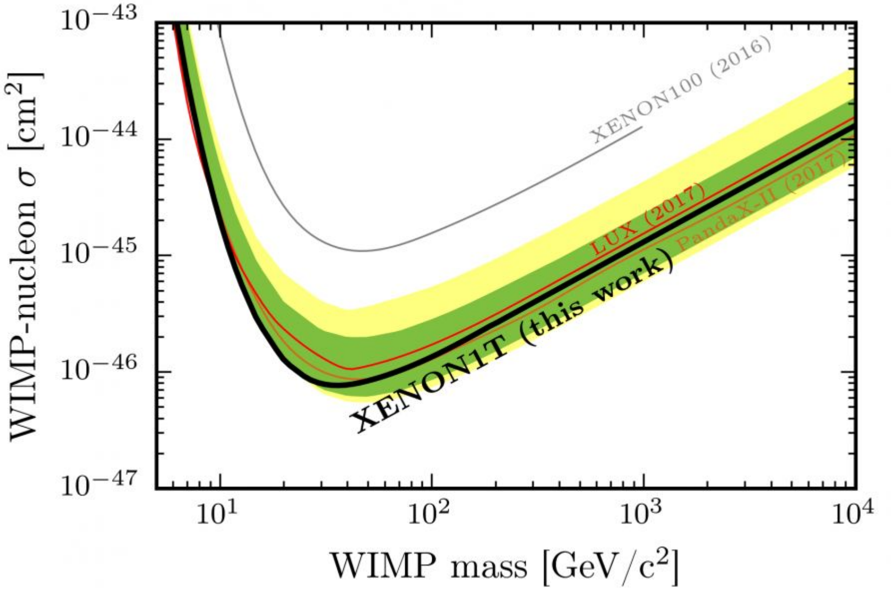


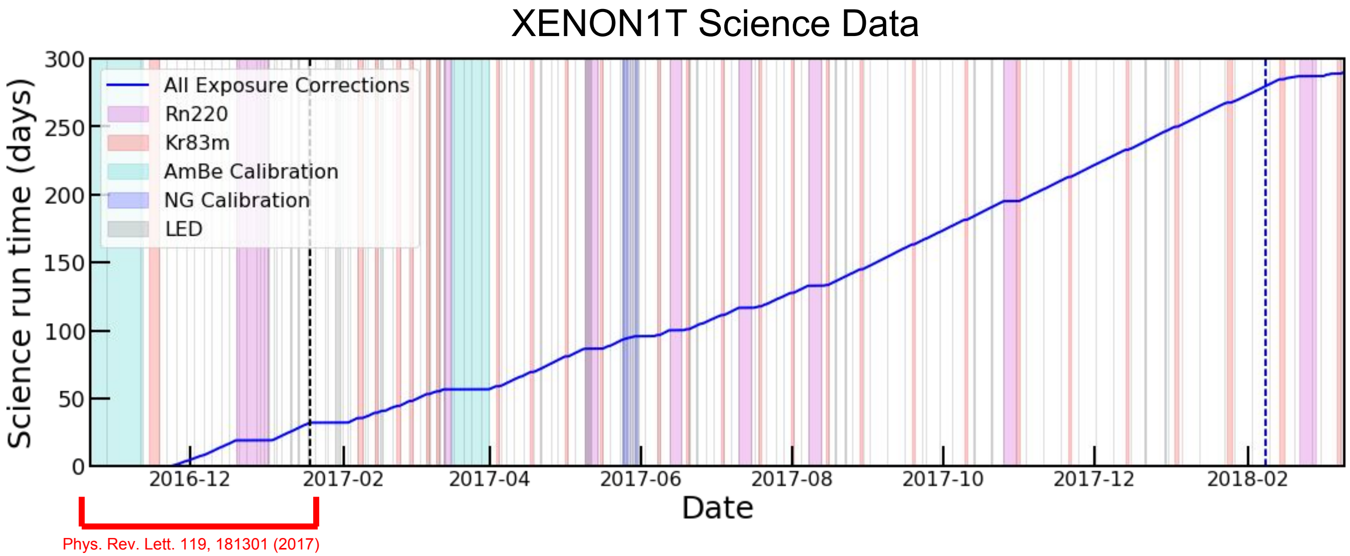
XENONnT
Time: From 2019
Total: 7500 kg
Target: 5900 kg
Fiducial: 4000 kg
Sensitivity: ~10^{-48} cm^{-2}

Recap: First XENON1T Results Phys. Rev. Lett. 119, 181301 (2017)



- 34 live days dark matter exposure Oct 2016-Jan2017
- No evidence of a signal → upper limit
- Additional 247 live days of data collected to date
  - the rest of this talk





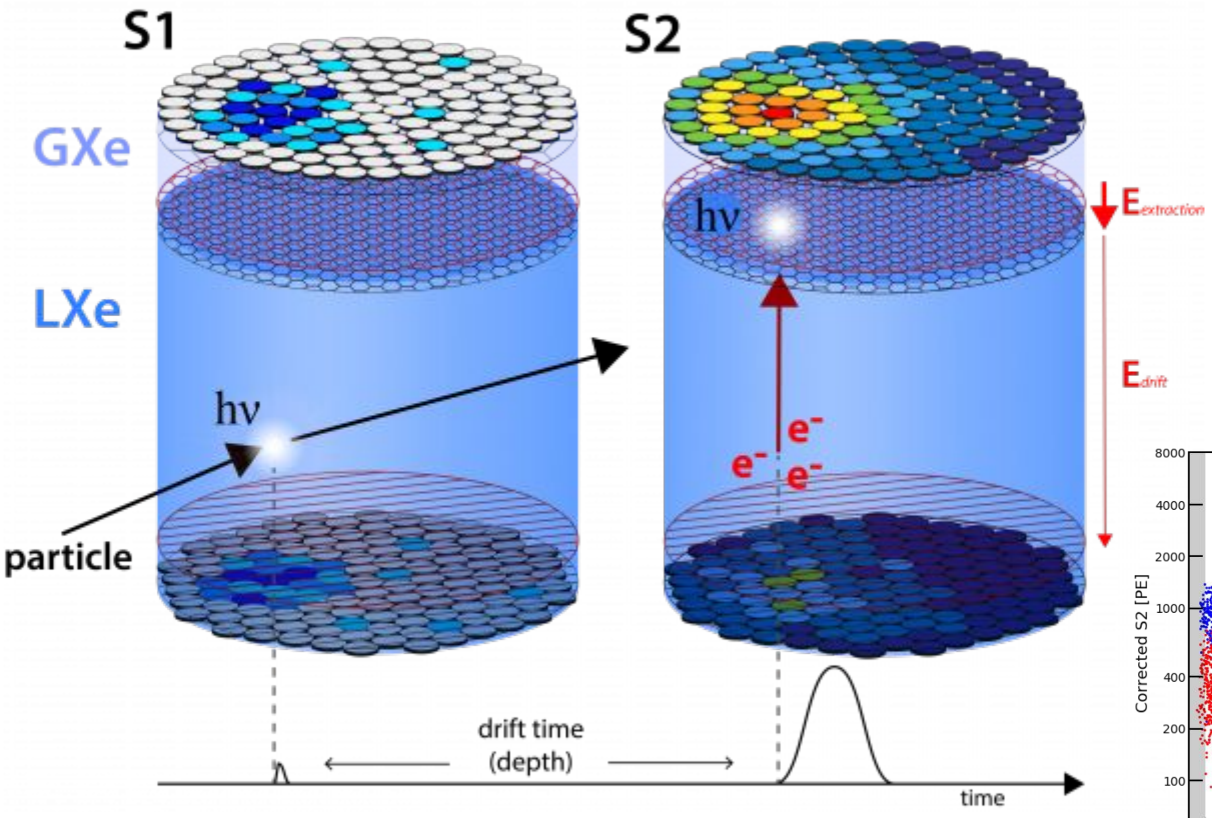
XENON1T Science Exposure

278 days high quality data (livetime-corrected)
1 ton x year at estimated 1.3t fiducial volume

Science data spans more than one calendar year of stable operation!

Detector still collecting data today.

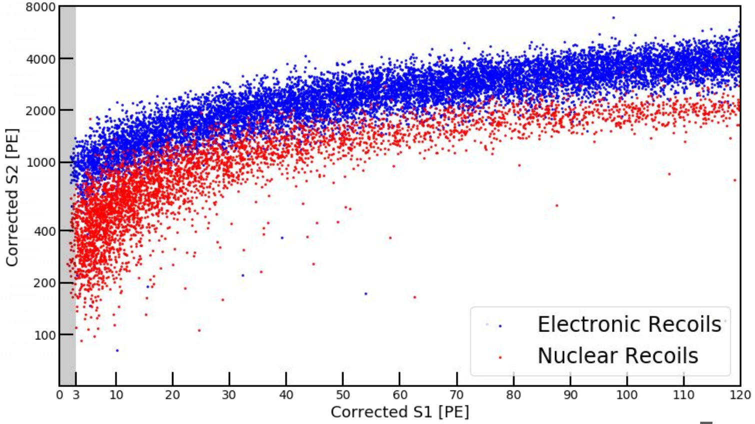
Dark Matter Detection with LXe TPCs



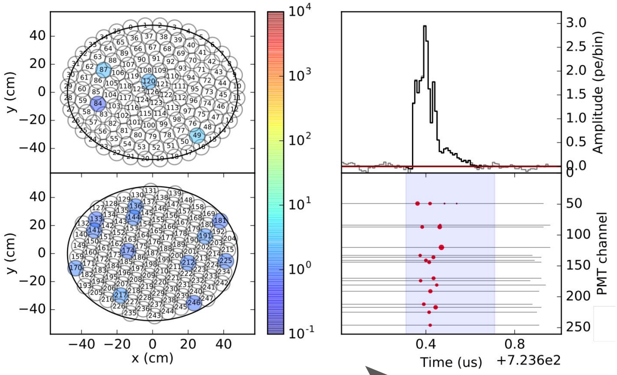
Energy
- S1 area
- S2 area

Position
- x-y (S2 signal)
- z (drift time)

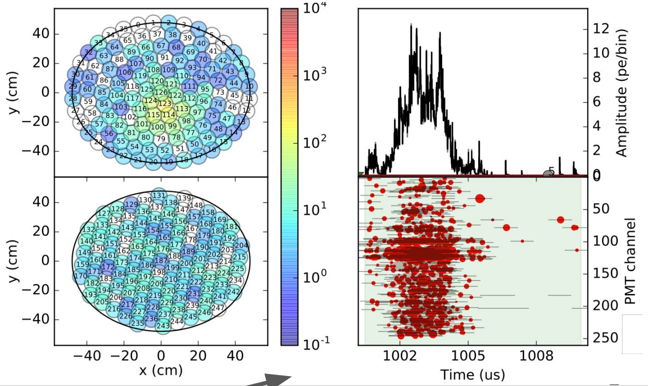
Interaction type
- S2/S1 ratio (**ER**/**NR**)



S1

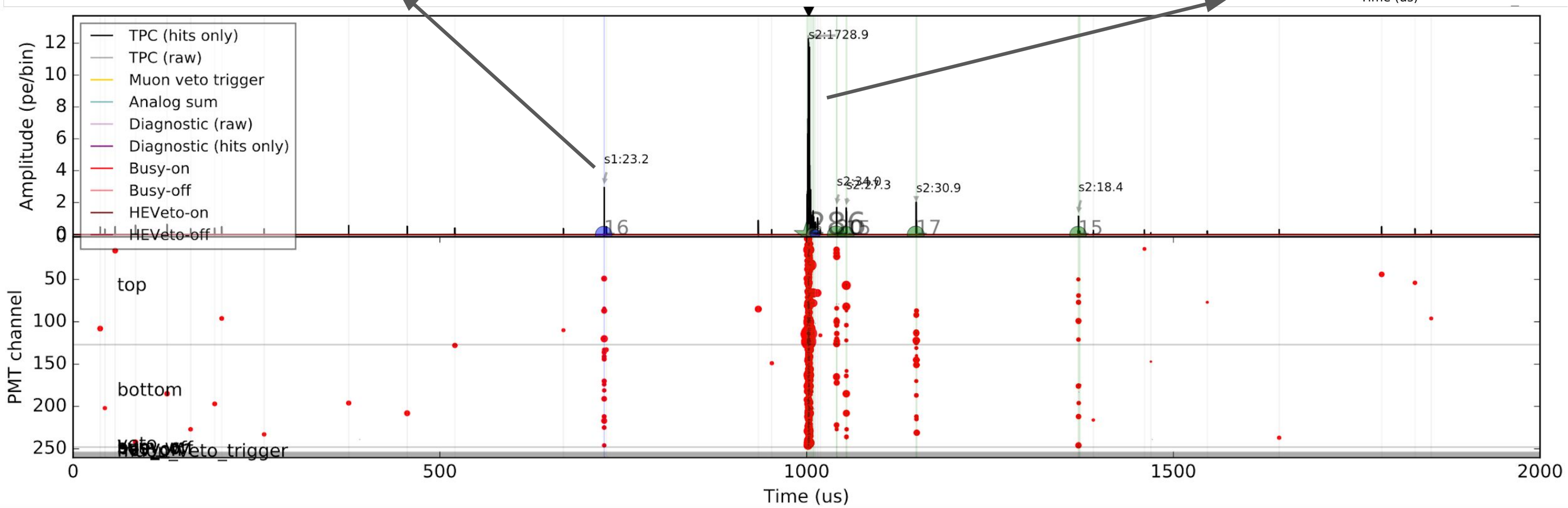


S2



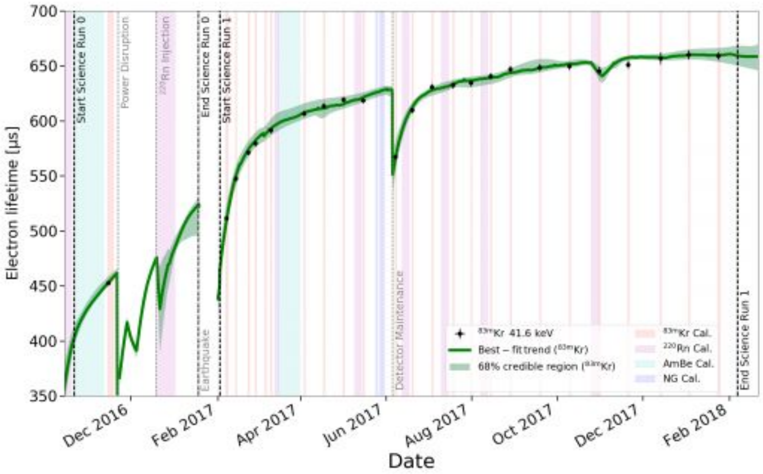
PAX
Processor for Analyzing XENON

See: github.com/XENON1T



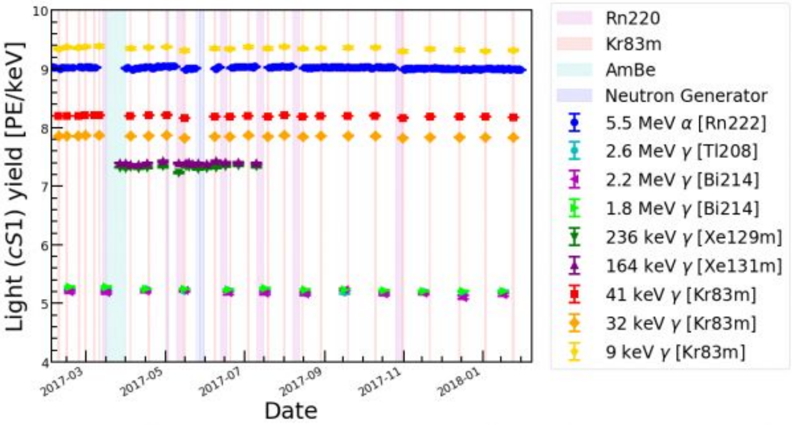
>1 Year Stable Data-Taking

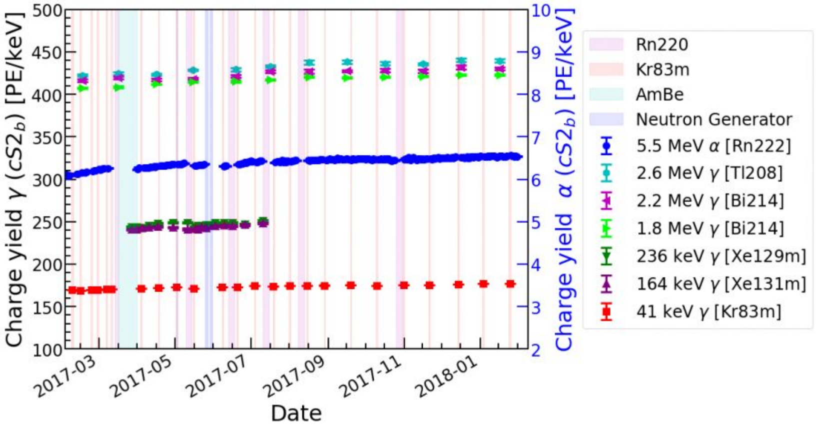
- Electronegative impurities absorb drift electrons
- Continuous purification during operation
- Monitor purity via ‘electron lifetime’
- Plateau shows stable equilibrium reached for this configuration



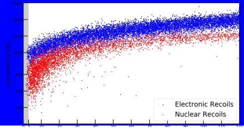
Light and **charge** yields stable throughout science run

- **Rn222** background → exploit α-decay lines
- **Kr83m** calibration → 9, 32 keV conversion e^-
- ^{129m}**Xe**, ^{131m}**Xe** → activation after n calibrations





Electronic Recoil Backgrounds

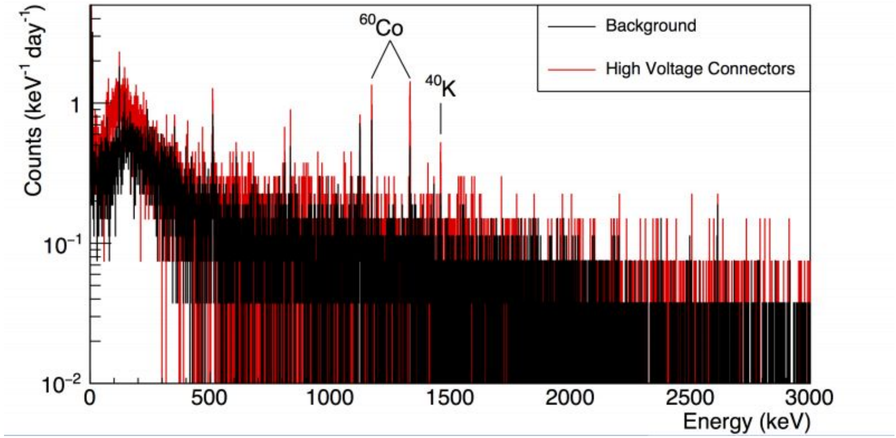


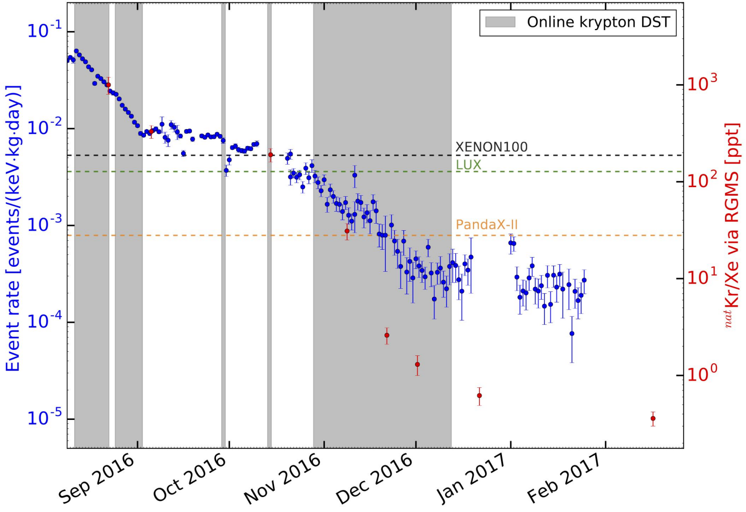
JCAP04(2016)027

Source	Count [$t^{-1}y^{-1}$]	Fraction [%]
Materials	29 ± 3	4.1
^{222}Rn	620 ± 60	85.4
^{85}Kr	31 ± 6	4.3
Solar neutrinos	36 ± 1	4.9
^{136}Xe	9 ± 4	1.4
Total	720 ± 60	

(2-12 keV search window, 1t FV, single scatters, before ER/NR discrimination)

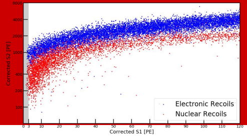
→ All detector components screened for radiopurity using HPGe detectors (shown are some cable plugs)





- **^{85}Kr**
  - ^{85}Kr/^{nat}Kr about 2x10^{-11}
  - Kr/Xe ~ 10^{-9} - 10^{-6} (commercial Xe)
  - Online distillation ^{nat}Kr/Xe = 0.62 ppt
  - Offline distillation ^{nat}Kr/Xe < 48 ppq
- **^{222}Rn**
  - Minimize leakage into cryo system (i.e., hermetically sealed pumps)
  - Low radon emanation components
  - Dedicated radon emanation measurements

Nuclear Recoil Backgrounds



JCAP04(2016)027

Muon-induced Neutrons

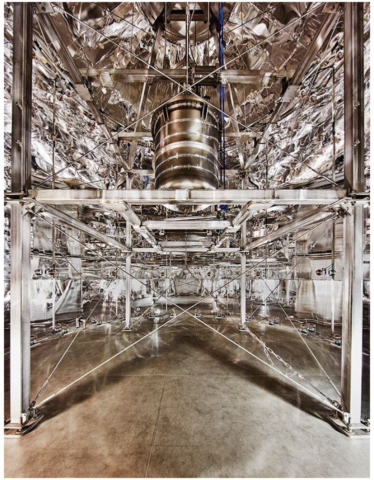
- 3,600 m.w.e. rock overburden (1x10^6 attenuation of muon rate)
- 700 m^3 demineralized water surround detector
- Water Cherenkov Muon Veto provides additional reduction
- **0.012 events/t-y expected BG**

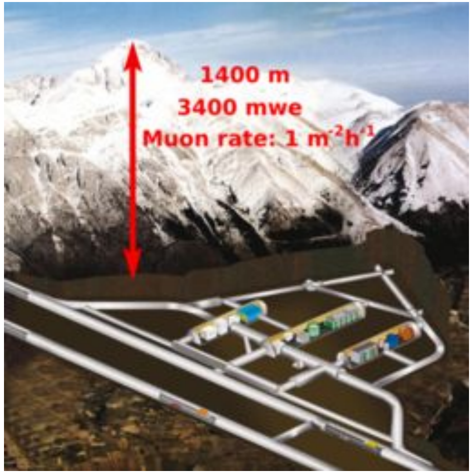
Radiogenic Neutrons

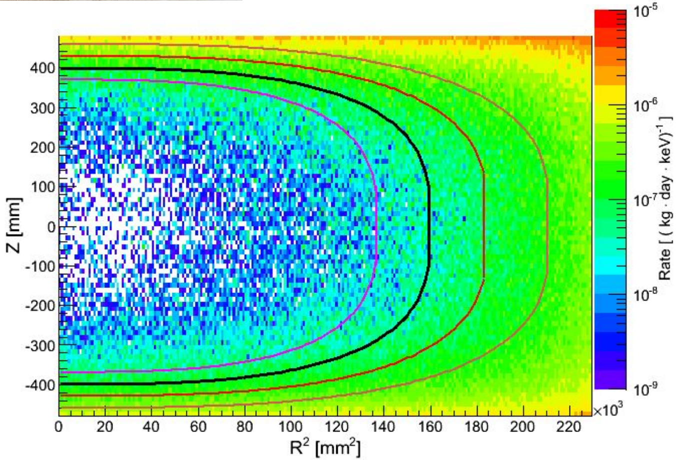
- (α, n) reactions from U- and Th- chains and spontaneous fission
- Mimic WIMP signal (many are single scatter, many penetrate into fiducial volume)
- Reduction via careful material selection and minimization of material budget
- **O(1) event/t-y expected**

Coherent Neutrino Nucleus Scattering

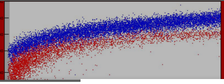
- Irreducible background
- Larger at very low energies (1keV)
- Nearly no contribution above threshold of 5 keV
- **0.01 event/t-y expected**







Nuclear Recoil Backgrounds



P04(2016)027

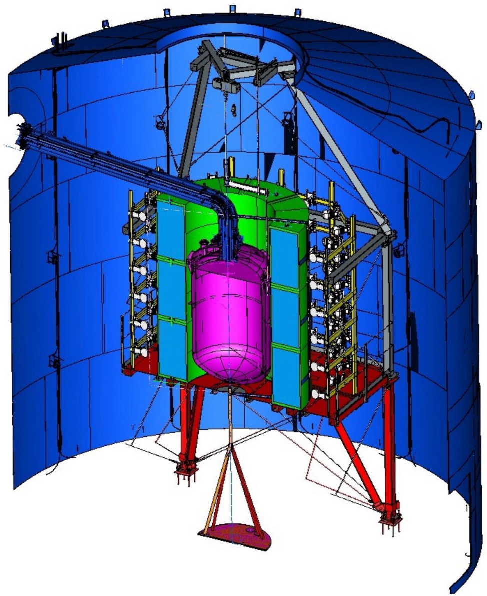
Muon-induced
- 3,600 m.w
muon rate
- 700 m^3 de
- Water Ch
reduction
- **0.012 eve**

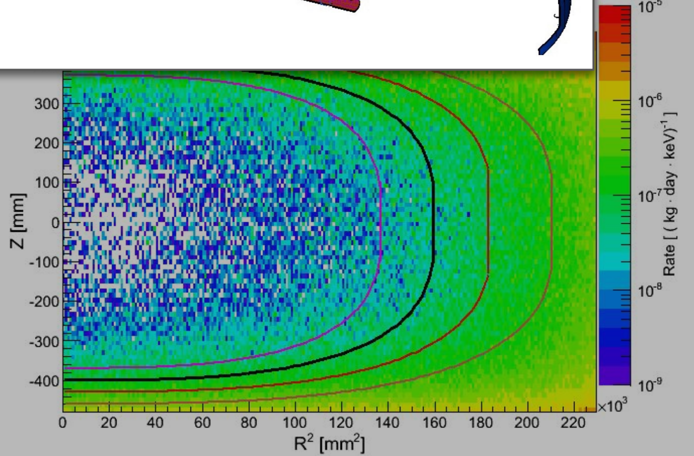
Radiogenic Neu
- (α, n) reac
spontaneo
- Mimic WIM
scatter, ma
- Reduction
minimizatio of material budget
- **O(1) event/t-y expected**

Coherent Neutrino Nucleus Scattering
- Irreducible background
- Larger at very low energies (1keV)
- Nearly no contribution above threshold of 5 keV
- **0.01 event/t-y expected**

XENONnT: Active neutron veto

- 15 tons liquid scintillator (Gd-LAB) in acrylic vessels surrounding outer cryostat
- 120 Hamamatsu R5912Assy 8” PMTs
- For 4 ton inner volume expect 0.35 events/y with 75% neutron tagging

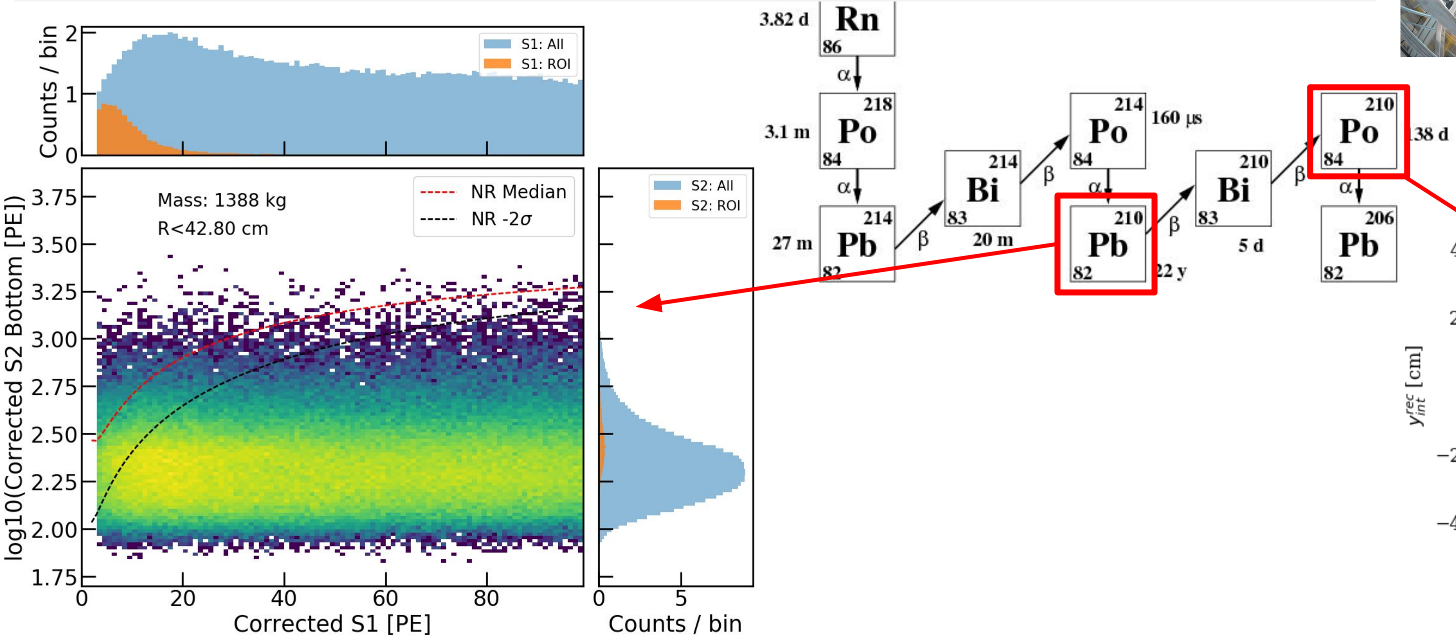




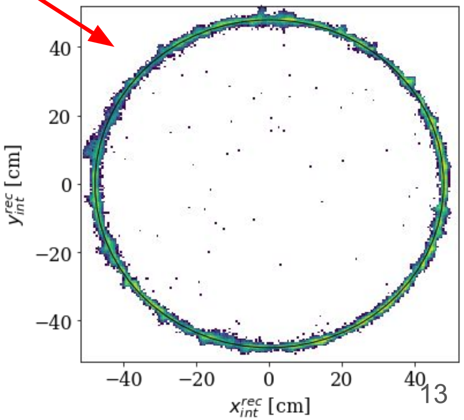
PTFE Surface Background

PTFE Surface Background

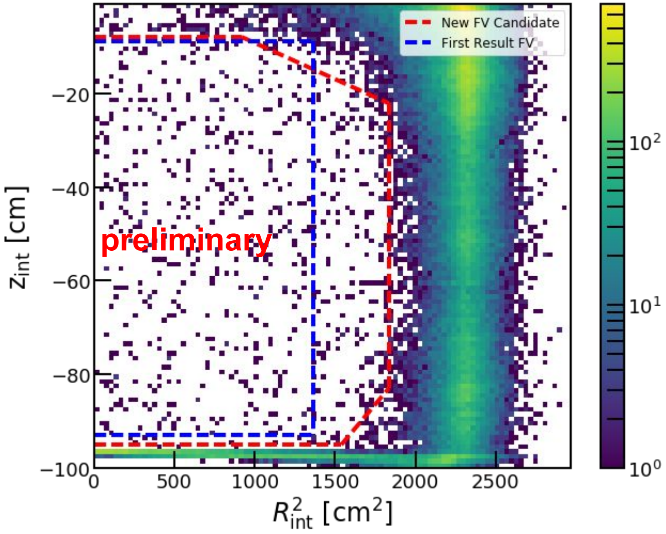
- S2 loses charge on the PTFE wall → ER events misreconstructed in signal region
- Suppressed via fiducial volume
- Data-driven model based on selected samples of surface events



^{210}Po PTFE surface contamination



Increasing the active volume

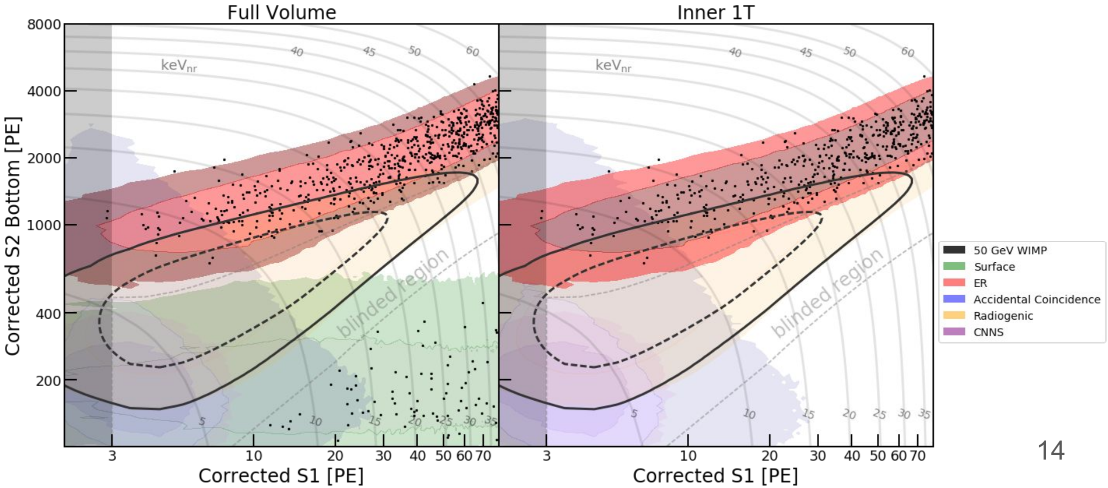


Fiducial volume: exploit LXe self-shielding by selecting only a low-activity inner volume to use for the WIMP search. Optimized on combined background models

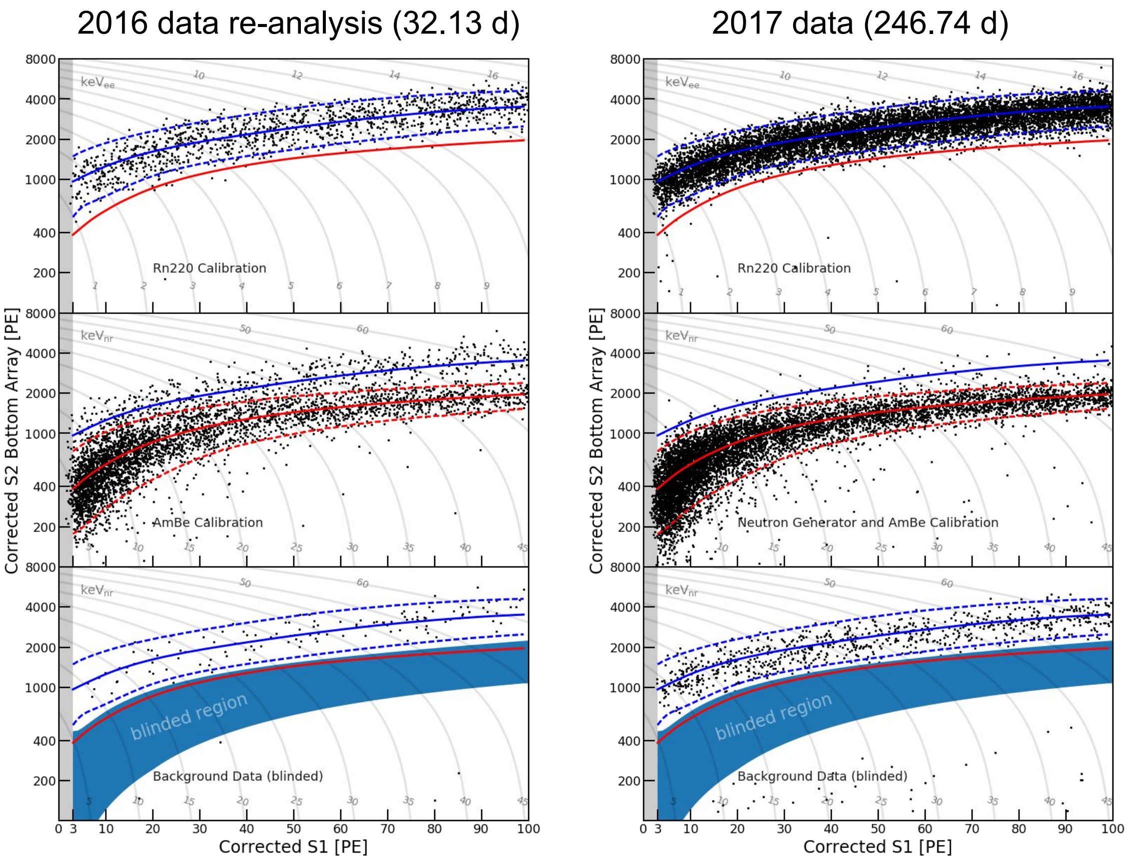
- **First result:** 1-ton fiducial
- **This result:** expanded by several hundred kg!
    - Improvements to position reconstruction and field and teflon charge-up corrections
    - Additional spatial dimension in statistical interpretation

Further parameterize inner volume as function of r to increase useful exposure volume:

- **Left**: largest fiducial volume, visible surface background
- **Right:** inner 1T volume, no surface background



Calibration and Background Data in the Search Region



A blind analysis is the only way to perform this type of rare event search

- Signal region inaccessible to analysts until analysis fixed
- Prevents human bias

The data is also 'salted'

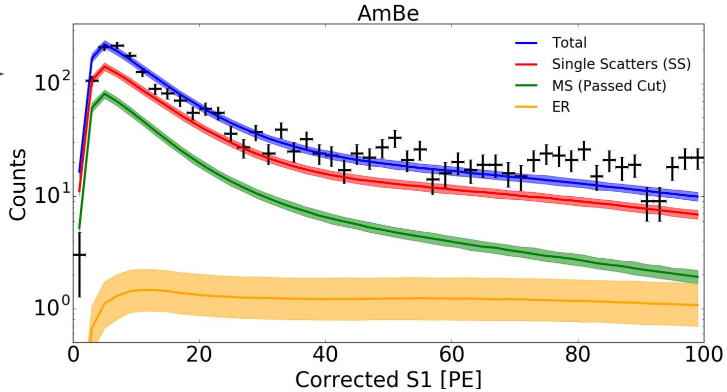
- Fake signal events may or may not inhabit signal region
- Additional protection against bias in post-unblinding scrutinization of events

We're unblinding this data very soon!

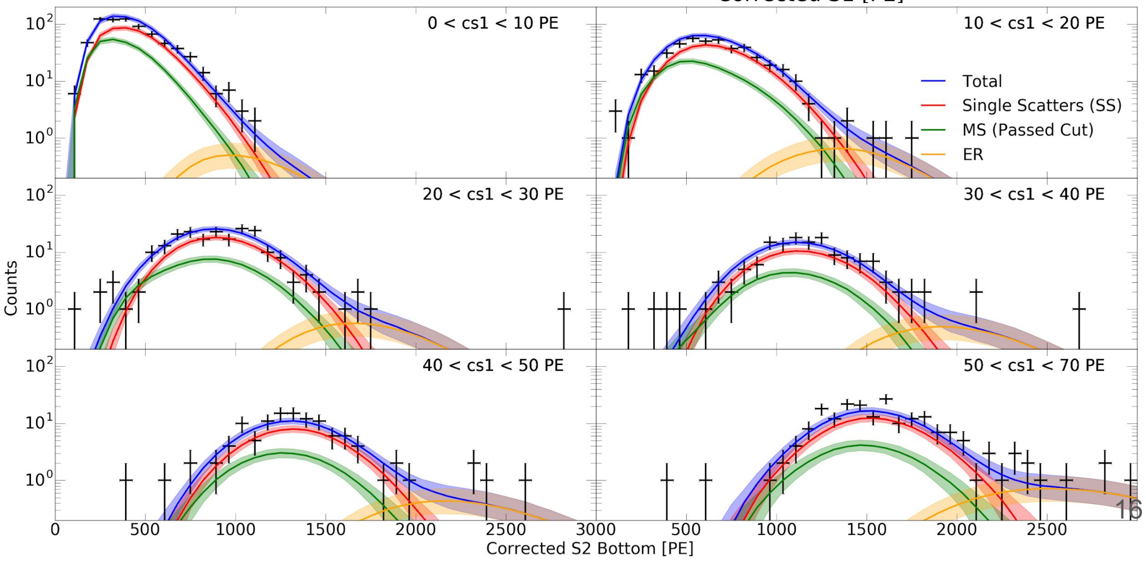
Parameterizing Signal and Background

- **WIMP signal**, **ER background,** and **NR background** models derived by fitting Monte Carlo simulations to calibration data
- **Surface background**, **accidental coincidences** described by empirical models derived from data
- All models derived in 3-dimensional space: **(cs1, cs2, radius)**

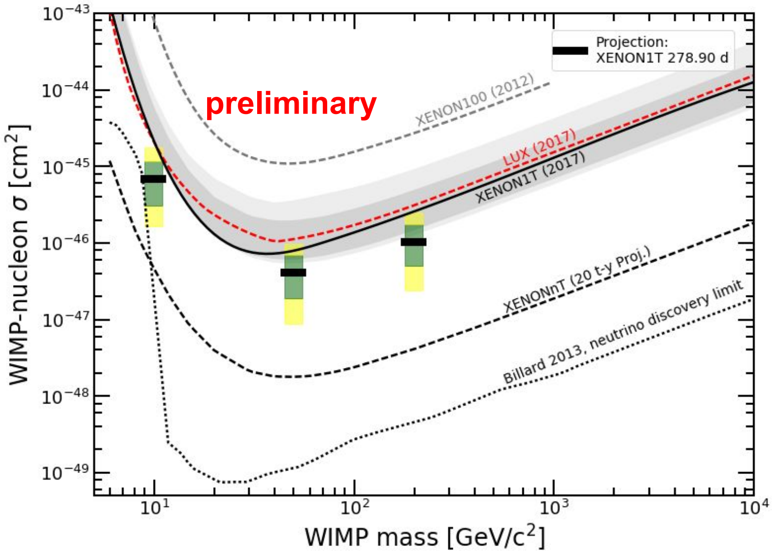
S1 space



Projections in S2 space



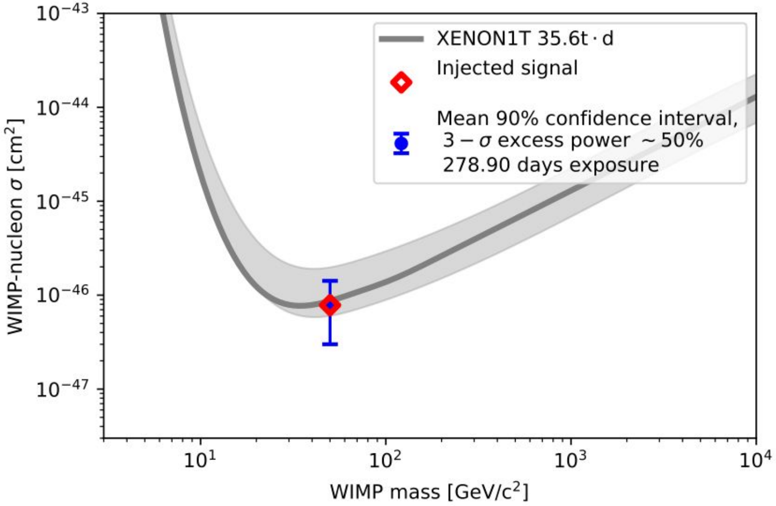
Upcoming Results



- Results interpreted with unbinned profile likelihood analysis in cs1, cs2, r space

- XENONnT to provide another order of magnitude boost to sensitivity

- For a WIMP-nucleon cross-section at the current best limit, this exposure has >50% chance at a 3-sigma excess



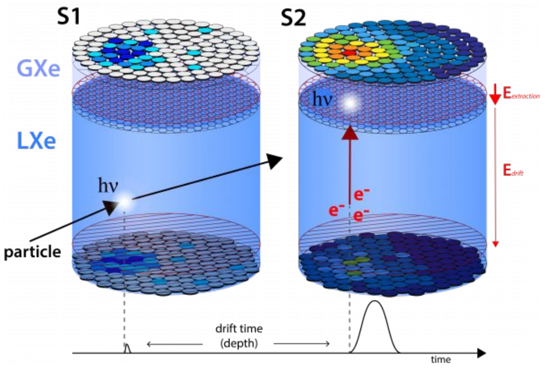
Conclusion/Outlook

- New results coming soon!
  - Twitter: https://twitter.com/xenon1t
  - Blog: https://www.xenon1t.org

- Our one ton-year exposure allows us to do rare event searches in other channels as well:
  - Low-mass WIMPs (S2-only)
  - ER searches (e.g. axions)
  - Annual modulation of ER rate
  - And more, stay tuned

- **Our next upgrade, XENONnT is under construction and planned to start operation in 1.5 years**

Extra: Combined S1+S2 Energy Reconstruction

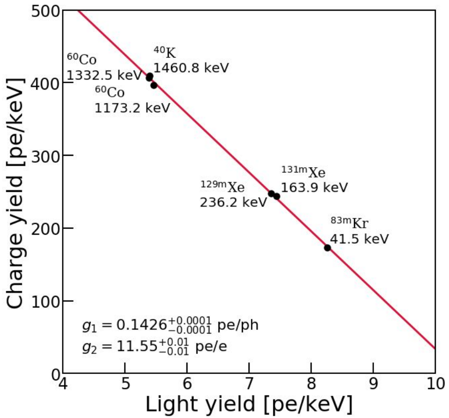


Energy loss to *either* light or charge channel
→ S1/S2 anticorrelation

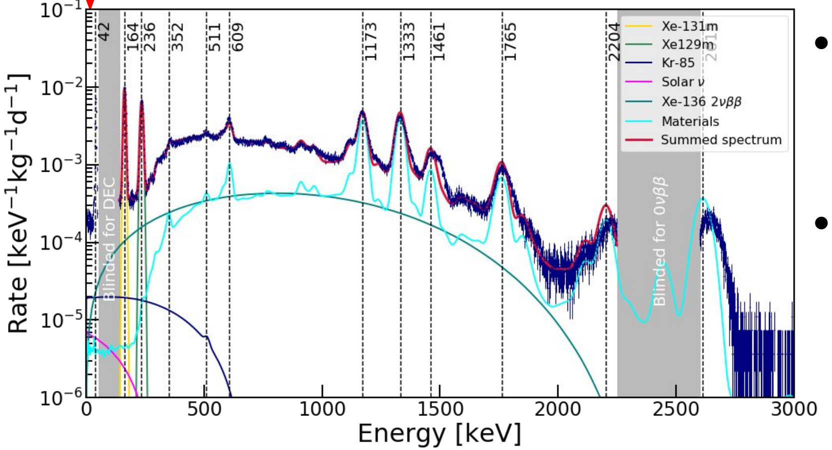
$$\frac{S1}{E} = \frac{n_\gamma}{n_e + n_\gamma} \times \frac{g1}{W}$$

$$\frac{S2}{E} = \frac{n_e}{n_e + n_\gamma} \times \frac{g2}{W}$$

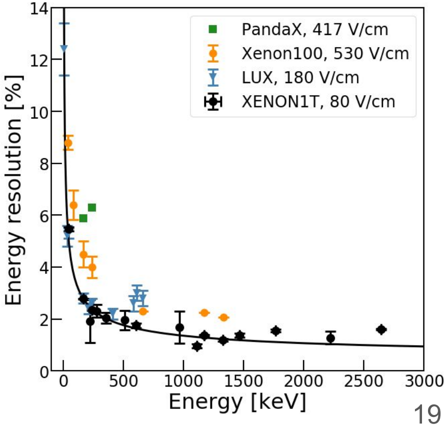
"Doke plot" → linear fit to calibration isotopes



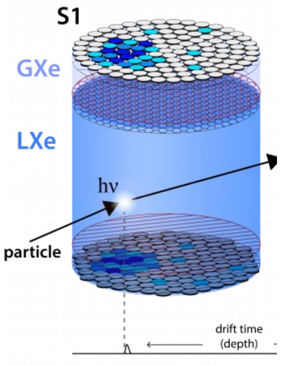
ROI for WIMP search up to ~30 keV

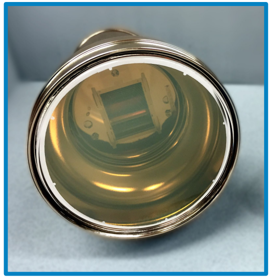


- Solve the above for E for combined energy reconstruction
- Excellent resolution across a broad energy range



Extra: S1 Light Collection





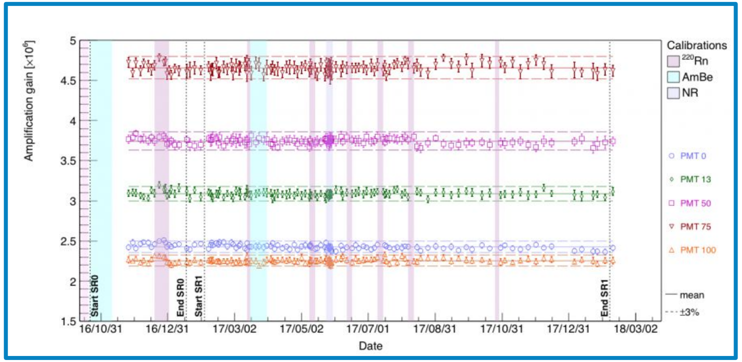
PTFE Lining

- High reflectivity
- Low radioactive background
- Covers entire inner volume

Highly sensitive light detection

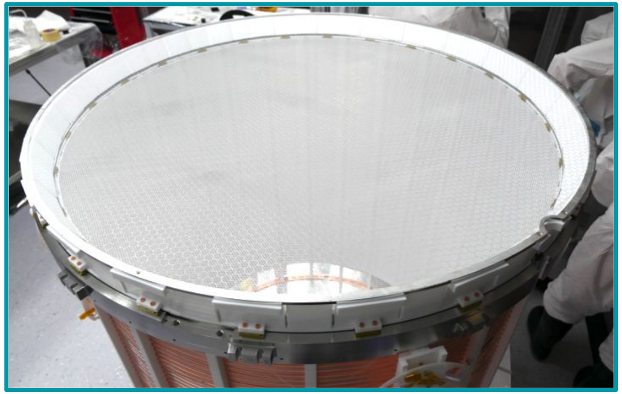
- 248 Hamamatsu R11410-21 PMTs
- Quantum efficiency: 35% @178nm
- Operating gain 5x10^6 @ 1.5kV
- Single photoelectron acceptances ~94%
- Gains stable within 1-2%
- Low background design

JINST 12 (2017) no.01, P01024 2017-01-30)

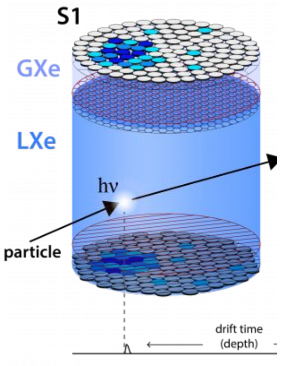


Near-transparent field grids

- Transparencies >90%



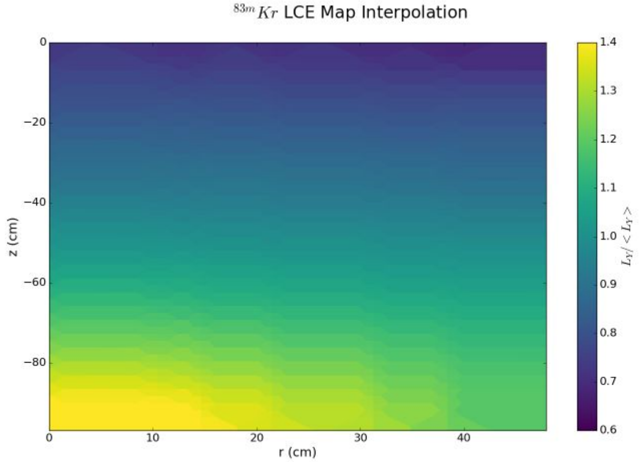
Extra: S1 Light Collection

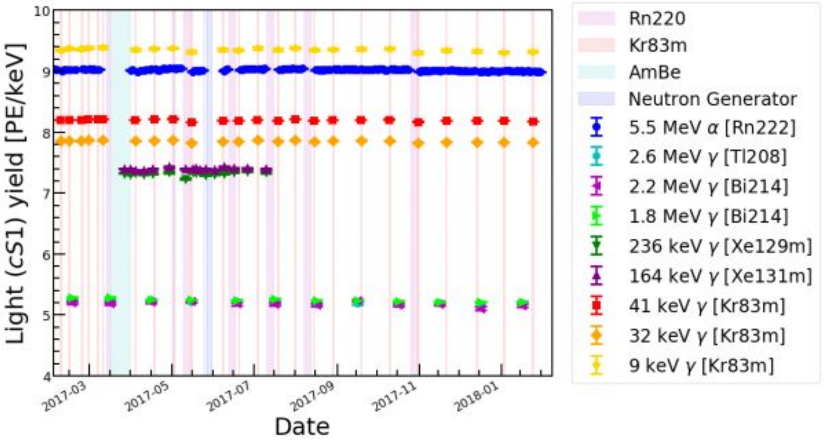


Light collection position dependent (solid angle)

However very well understood:

- Direct measurement with ^{83m}Kr calibrations
- Agreement with optical Monte Carlo simulation

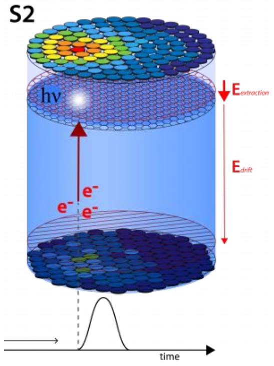




Light yield stability monitored throughout the science run with several sources:

- ^{222}Rn daughters
- Activated Xe after neutron calibrations
- ^{83m}Kr calibrations

Extra: S2 Energy Reconstruction

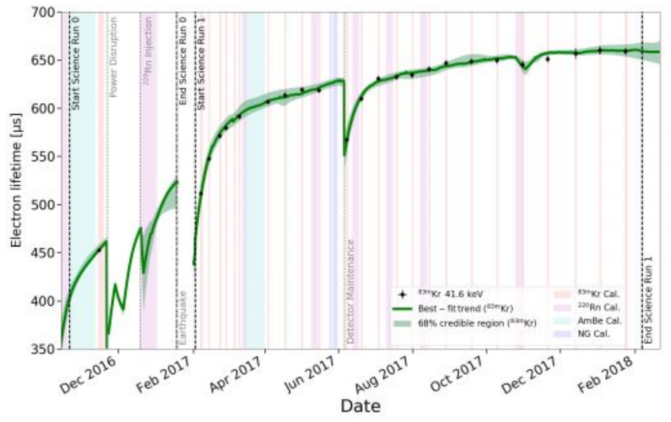


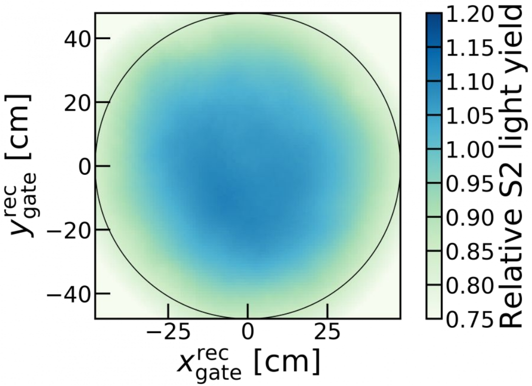
Electron Lifetime

- Ionization e- absorbed by impurities
- Exponential loss w.r.t. drift time
- Monitoring with ^{222}Rn alpha decays and ^{83m}Kr calibrations

Amplification correction

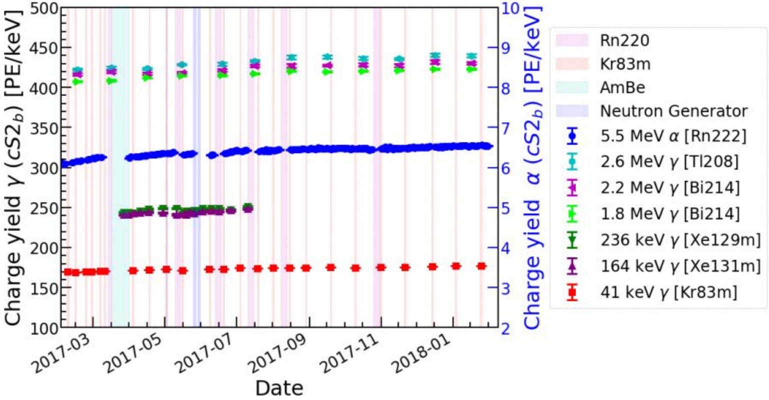
- x-y dependent amplification correction
- Driven by anode 'sagging' w.r.t. gate





Charge yield

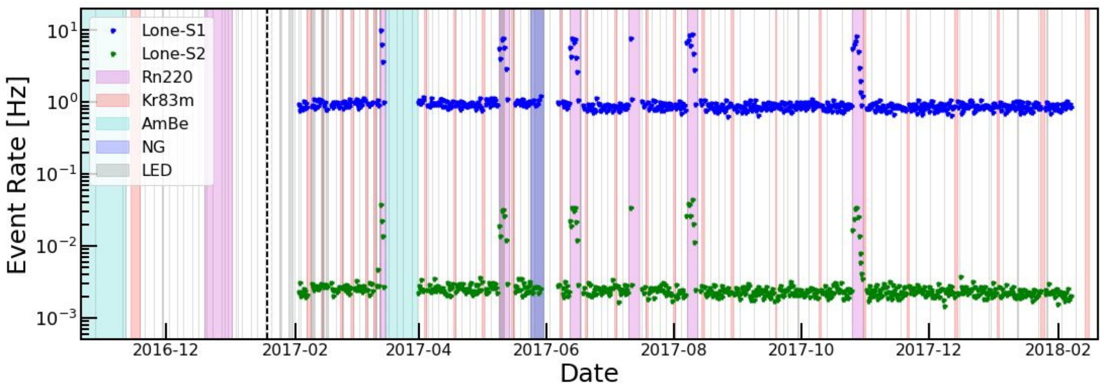
- Monitored with ^{222}Rn progeny, activated Xe, ^{83m}Kr
- Stable within a few percent
- Slight rise during science run probably driven by improving purity

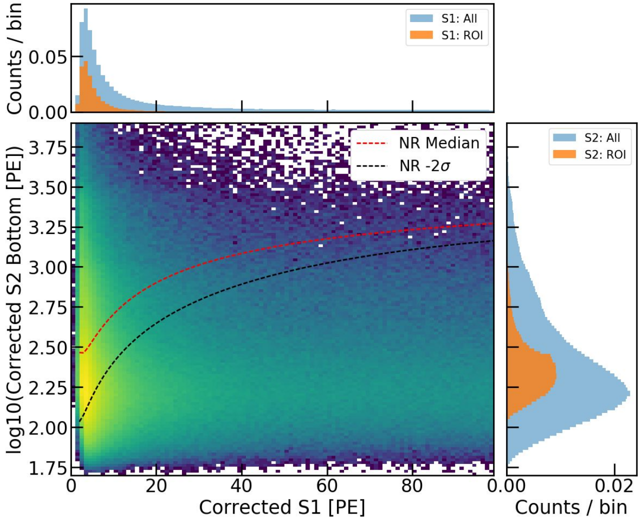


Extra: Accidental Coincidence Background

“Lone” s1/s2 coincidences

- S1 from eg. below cathode
- S2 from eg. near field grids
- Can get fake events that populate signal region

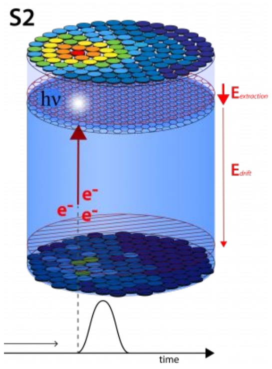




Empirical model

- Select unpaired S1/S2 from data
- Randomly pair to form events
- Apply selection conditions from analysis
- Performance verified in ^{220}Rn data and background sidebands

Extra: S2 Position Reconstruction



x-y reconstruction via **neural network**:

- **Input:** charge/channel top array
- **Training:** Monte Carlo simulation

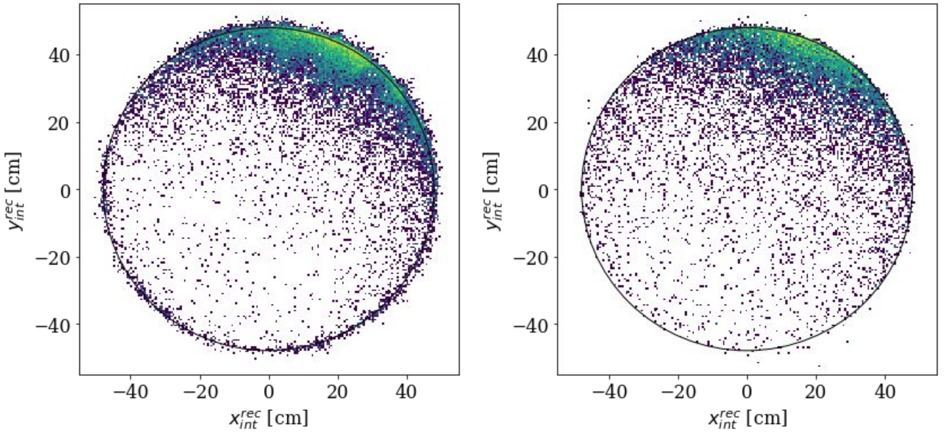
Position resolution using ^{83m}Kr

- Two interactions (9, 31 keV), same x-y
- Position resolution (1-2 cm)
- PMT diameter (7.62 cm)

Position corrections using ^{83m}Kr

- **Drift field distortion**
- Localized inhomogeneities from inactive PMTs
- Data-derived correction verified by comparison to MC with several event sources

Neutron Generator Source



(blinded) background data