The XENON Dark Matter Project: Status of XENON1T & XENONnT

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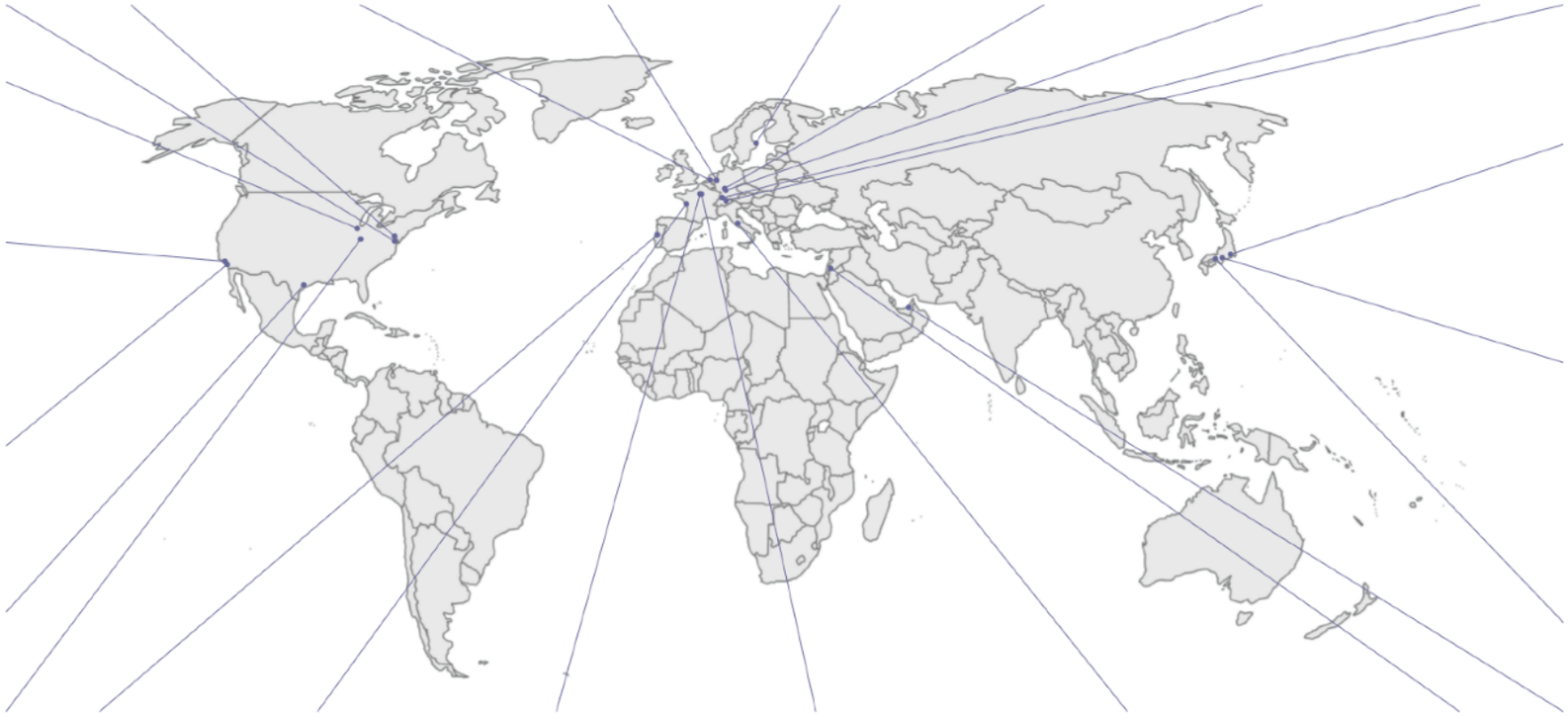
LNGS Scientific Committee
LNGS, March 26, 2018

The XENON Collaboration: ~170 scientists

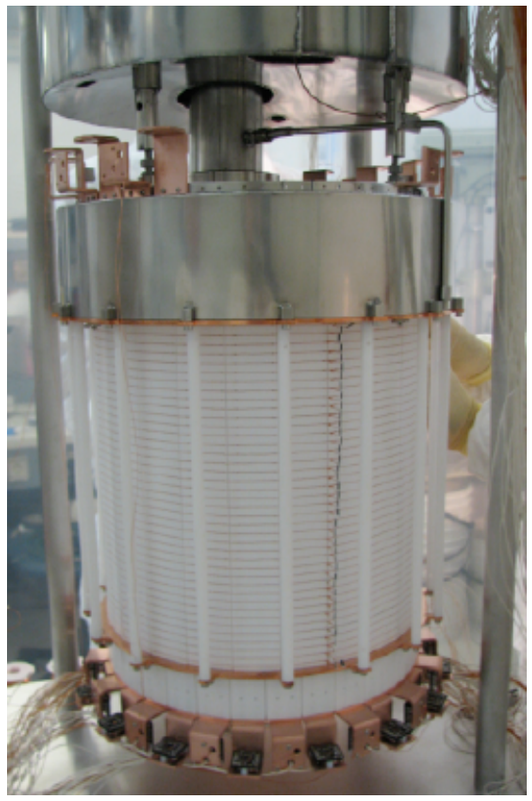
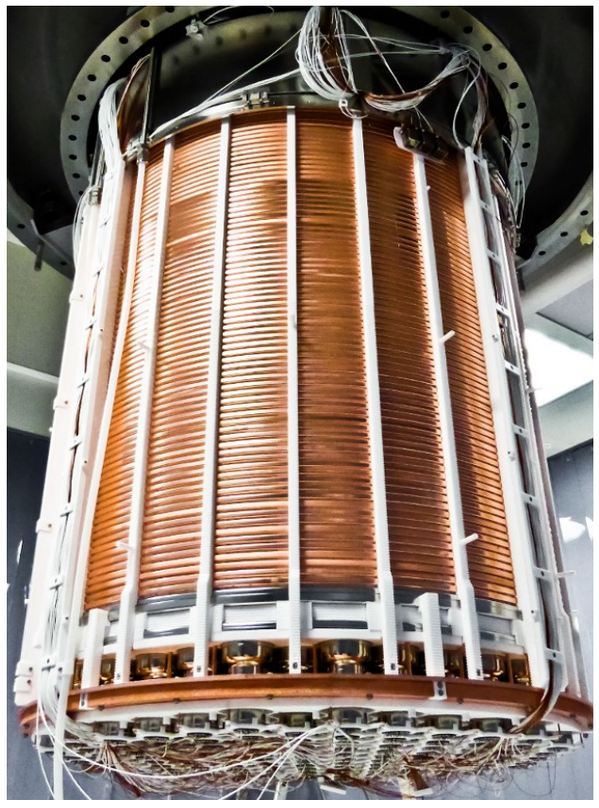
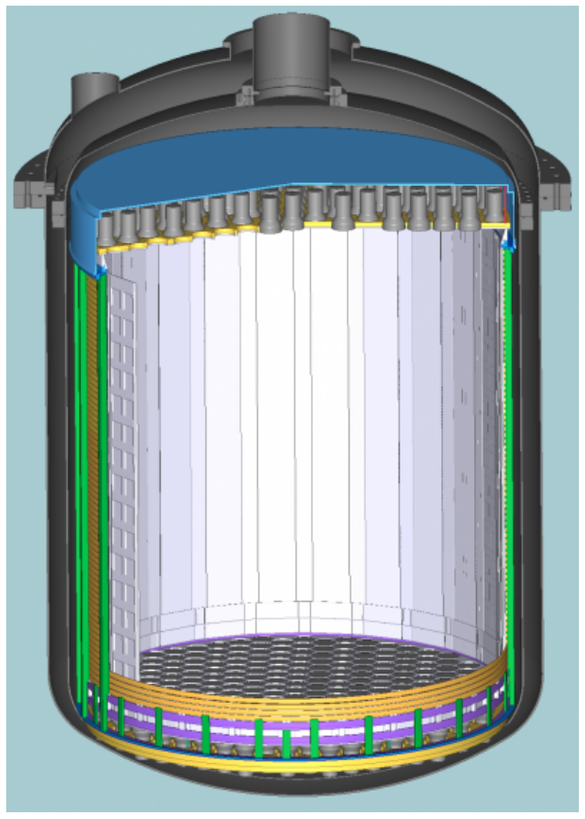
Columbia · RPI · Nikhef · Muenster · Stockholm · Mainz · MPIK · Freiburg · Zurich



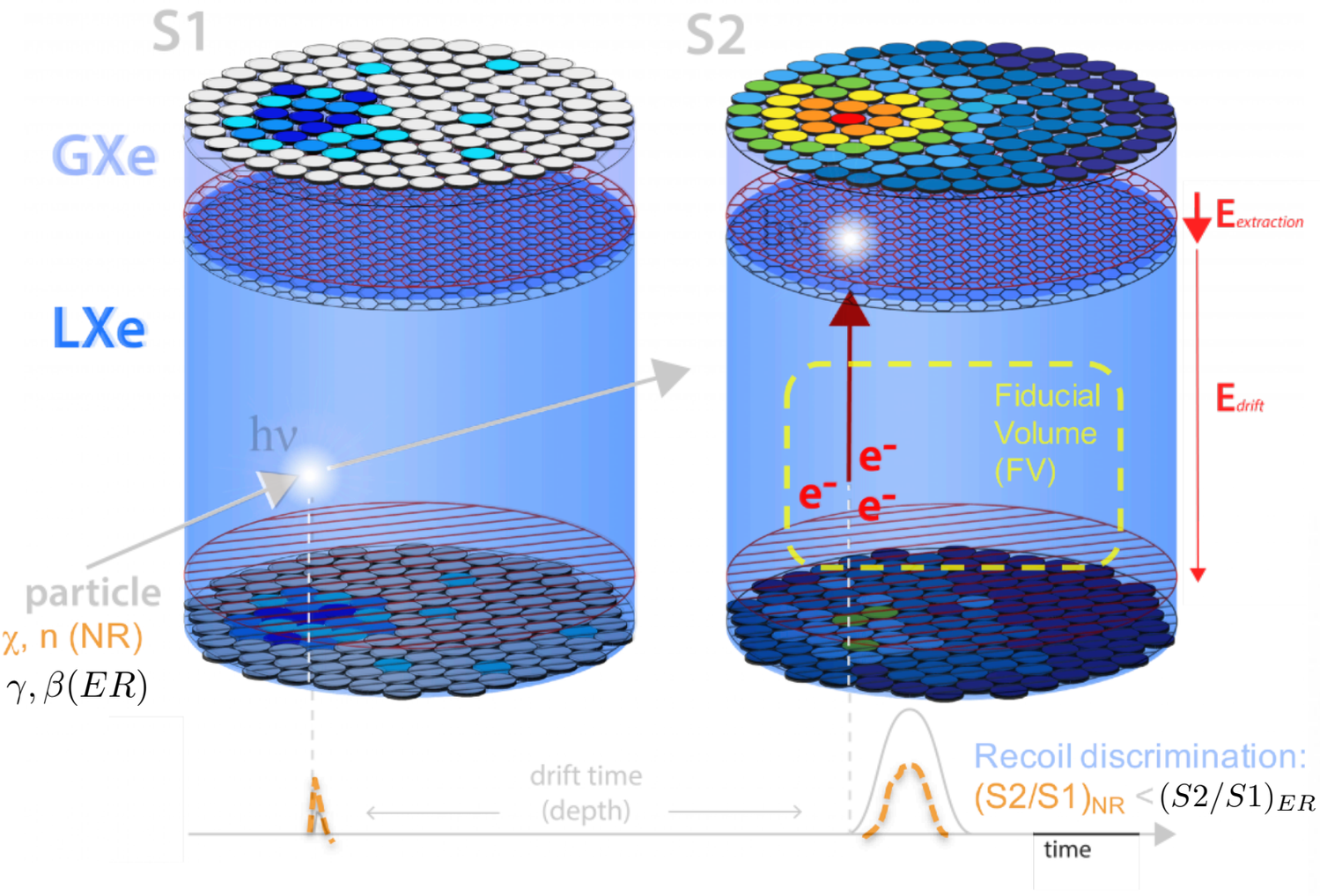
Chicago · Tokyo · UCLA · Nagoya · UCSD · Kobe · Rice

Purdue · Subatech · LPNHE Paris · LAL · INFN · Weizmann Institute of Science · NYU Abu Dhabi

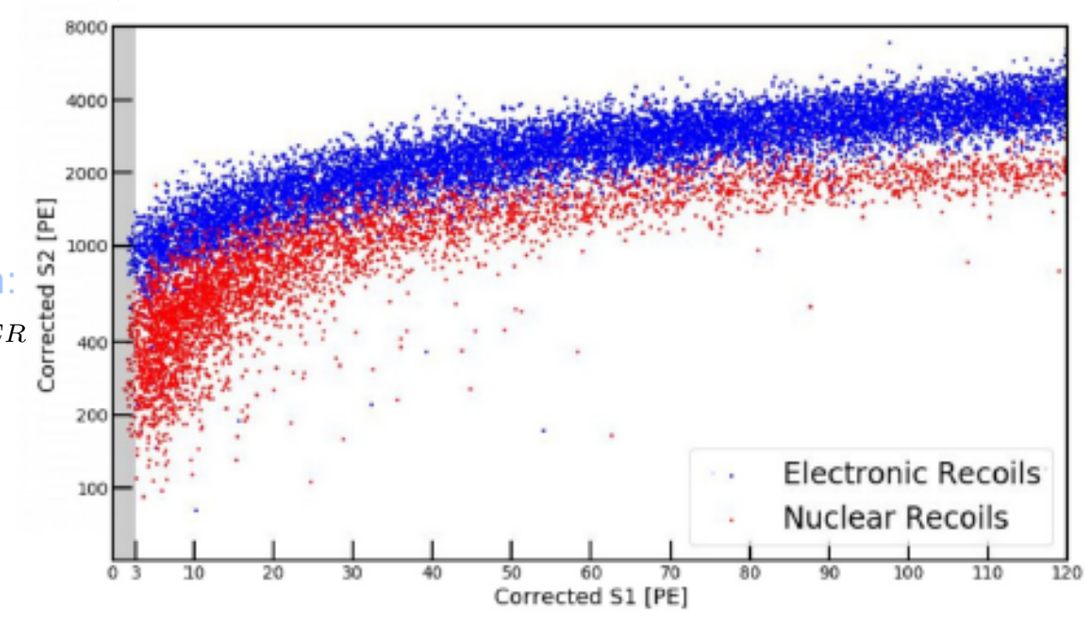
The phases of XENON

XENON10	XENON100	XENON1T	XENONnT
			
2005-2007	2008-2016	2012-2018	2019-2023
25 kg - 15cm drift	161 kg - 30 cm drift	3.2 ton - 1 m drift	8 ton - 1.5 m drift
~10^{-43} cm^2	~10^{-45} cm^2	~10^{-47} cm^2	~10^{-48} cm^2

Two-phase Xe Time Projection Chamber as WIMP detector



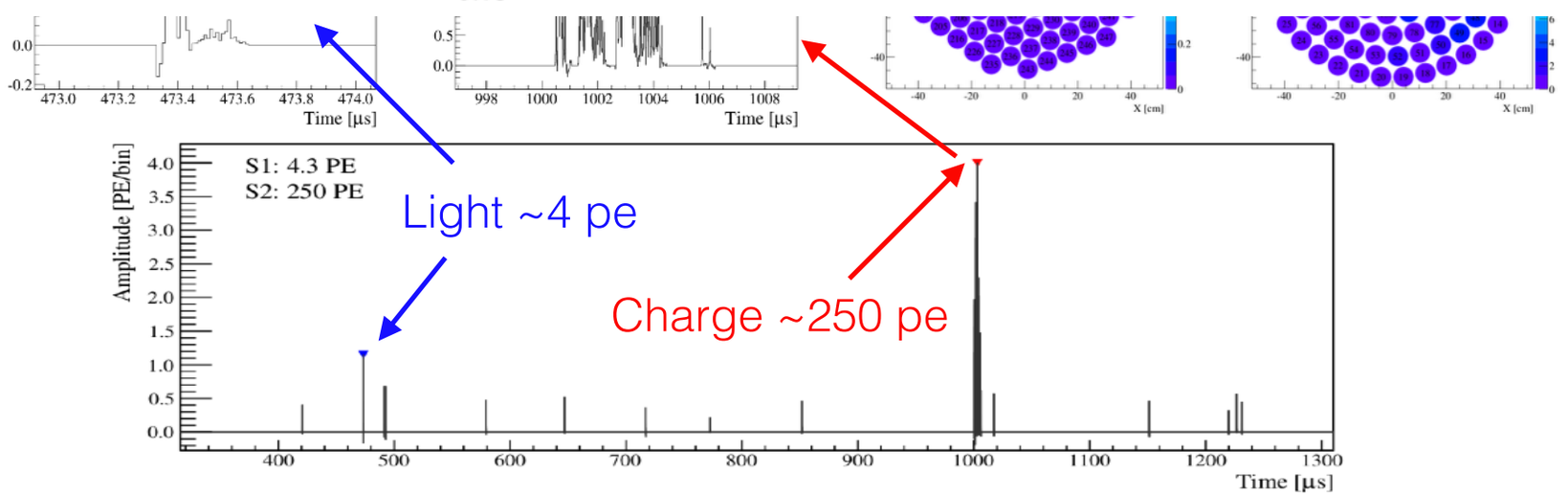
- *two signals for each event:*
  - *Energy from S1 and S2 area*
  - *3D event imaging: x-y (S2) and z (drift time)*
  - *self-shielding, surface event rejection, single vs multiple scatter events*
- *Recoil type discrimination form ratio of charge (S2) to light (S1)*



The XENON1T Time Projection Chamber

XENON1T Photomultipliers

EPJC 75 (2015) 11, 546



XENON1T Overview

EPJ C 77, 881 (2017)

Water tank and
Cherenkov muon veto

Cryostat and support
structure for TPC

Time Projection
Chamber / Feed
Pipe

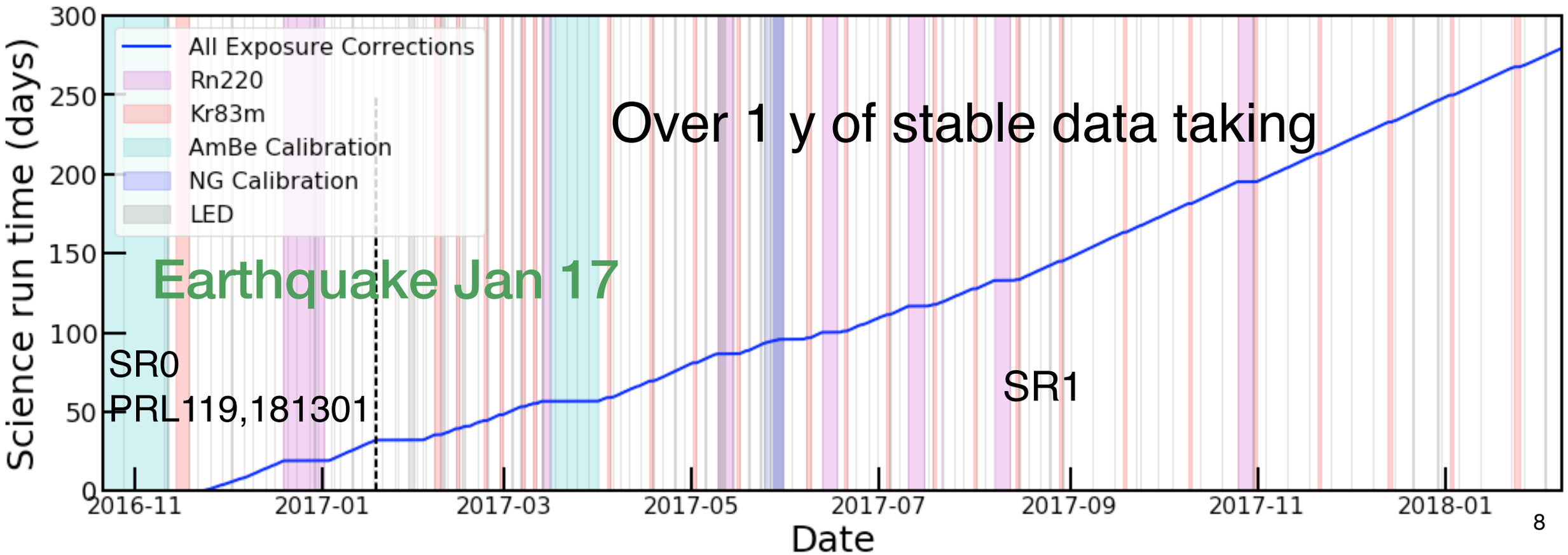
Cryogenics/
Purification/
Calibration sources

Electronics/
Data acquisition/
Slow Control

Xenon Storage/
Recovery
Kr-distillation column
Gas handling/
analytics

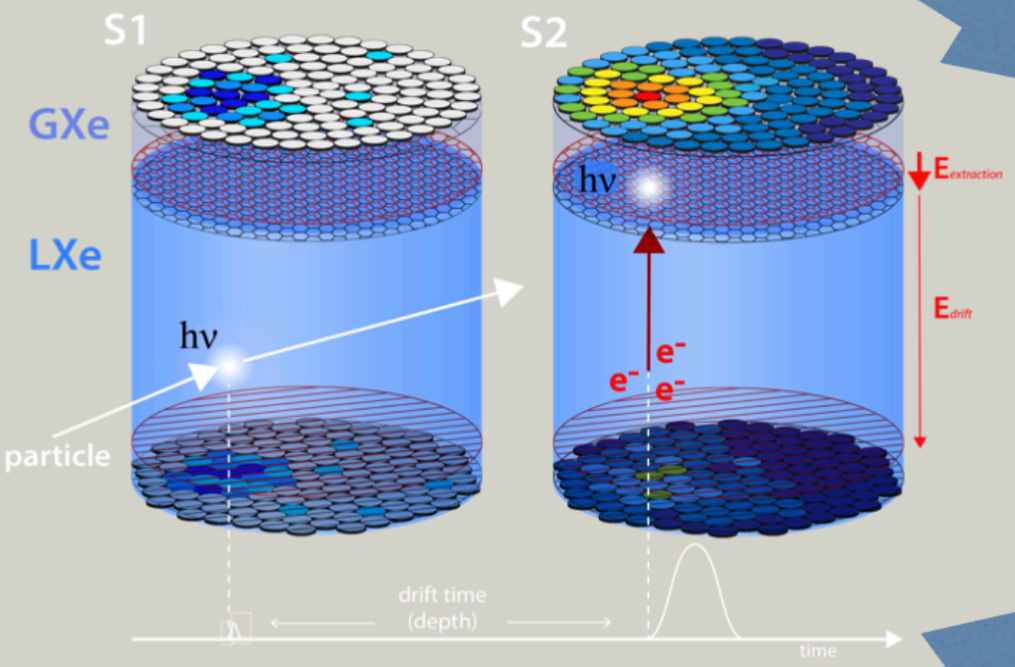
XENON1T Data overview: science and calibration

- Detector still running smoothly and taking data with high efficiency
- SR0 (34 days): best SI limit 7.7 x 10^{-47} cm^2 at 35 GeV/cm^2 (PRL 119, 2017)
- SR1 (247 days): improved detector stability - calibration statistics - refined analysis
- Blind analysis of SR0+SR1. Data still blinded. Final stage of checking.



XENON1T data analysis

XENON1T
(real waveforms)



Geant4
+waveform
simulation

Raw data
Processor (PAX)

- pulse-finding
- pos reconstruction
- S1, S2
- etc.

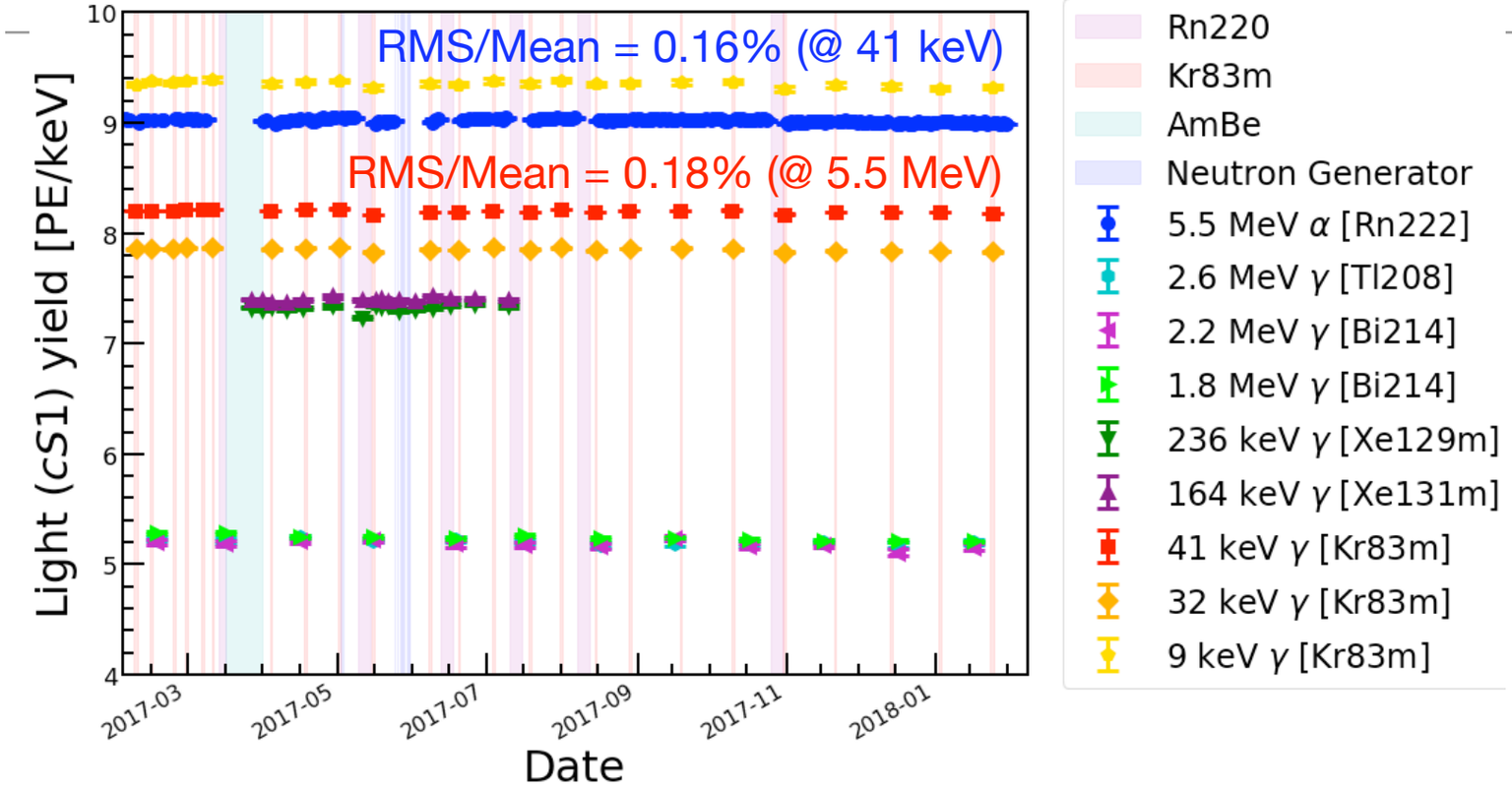
Calibration analysis

Background analysis

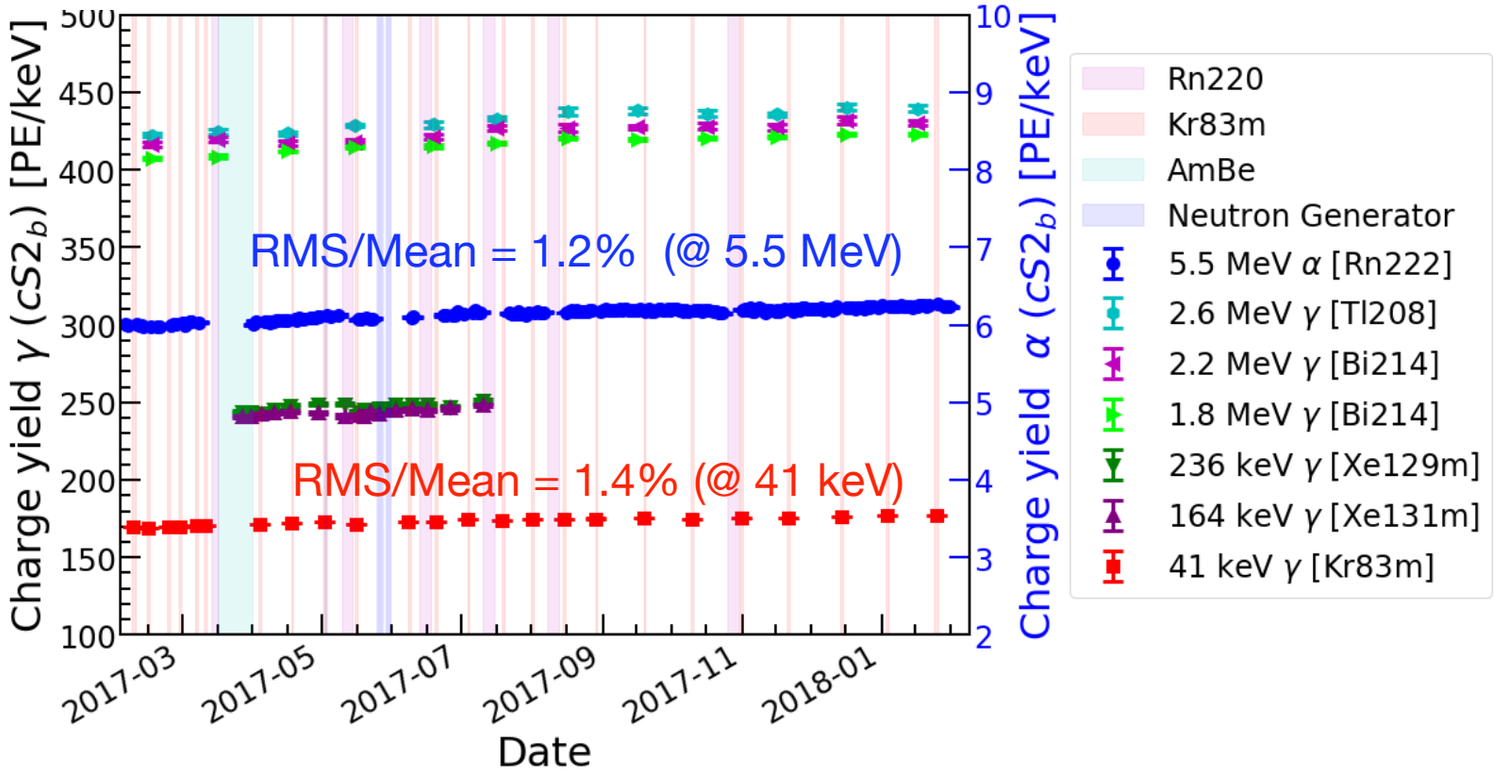
Statistical interpretation

Physics Results

Light and Charge Yields Stability



- L_y = (8.02±0.06) pe/keV @ 41.5 keV
- Q_y = (17.2± 0.2) e/keV @ 41.5 keV



Nuclear Recoil Background

Cosmogenic μ-induced neutrons significantly reduced by rock overburden and passive/active shielding

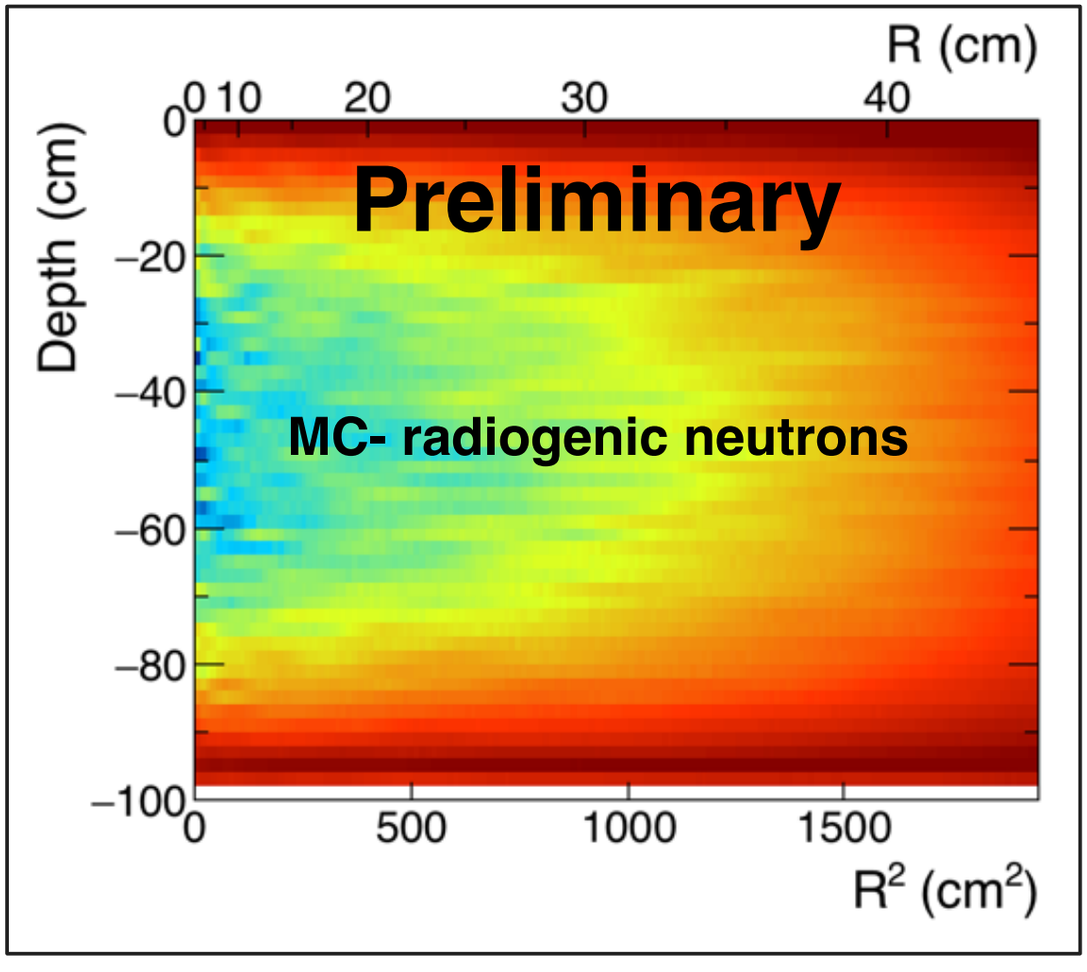
Coherent elastic ν-nucleus scattering irreducible background at very low energy (1 keV)

Radiogenic neutrons from (α, n) reactions and fission from ^{238}U and ^{232}Th: reduced via careful materials selection, event multiplicity and fiducialization.

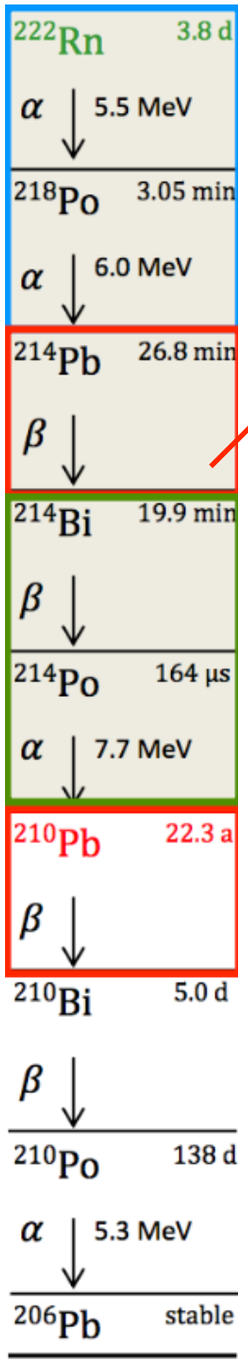
From JCAP 04 (2016) 027

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

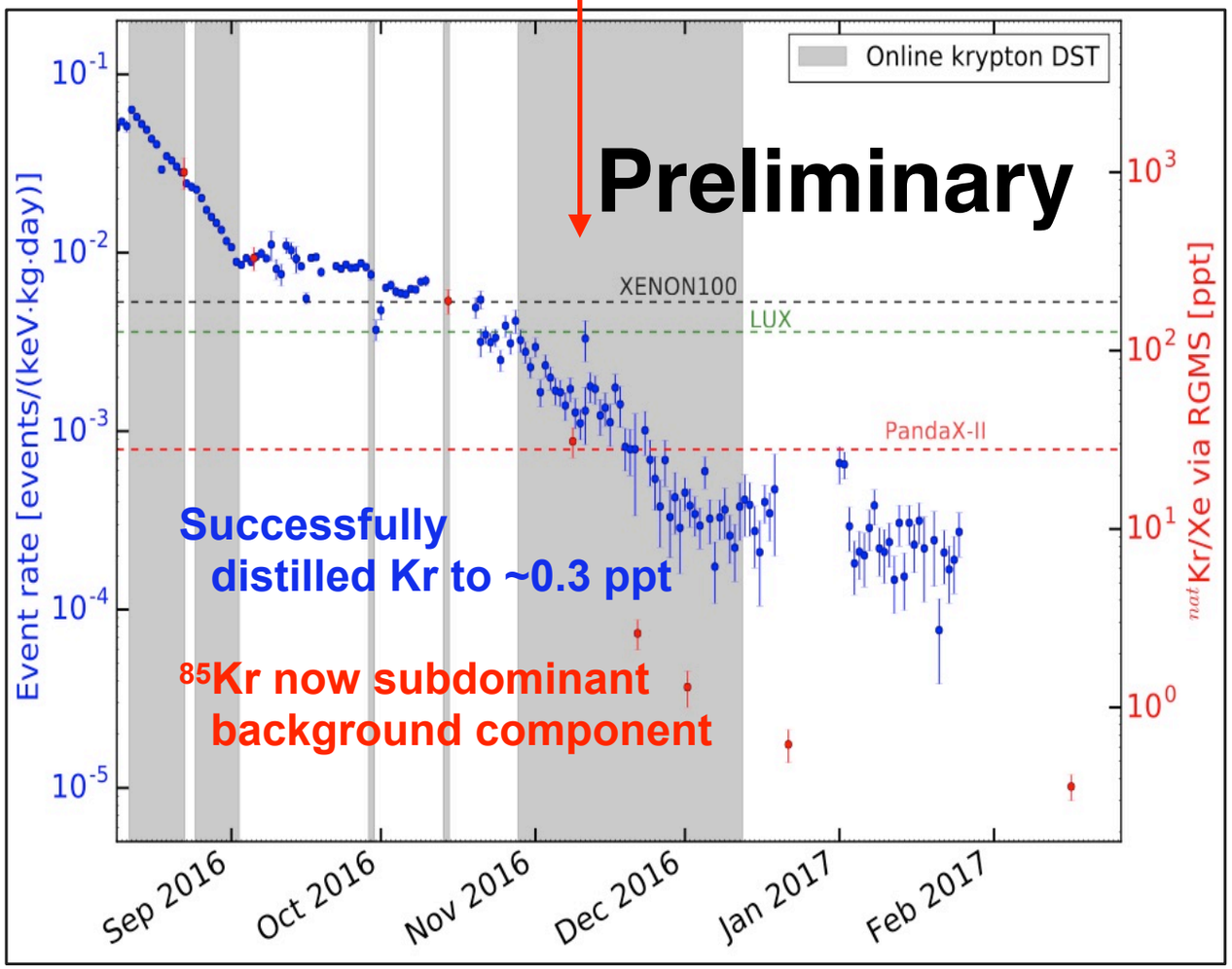
(Expectations in 4-50 keV search window, 1t FV, single scatters)



Electronic Recoil Background



- Rn222 Budget : 10 uBq/kg
  - Achieved with careful surface emanation control and measurements
  - Further reduction with online cryogenic distillation
- Kr85 Budget : sub-ppt Kr/Xe
  - Achieved with online cryogenic distillation
- ER background from materials subdominant

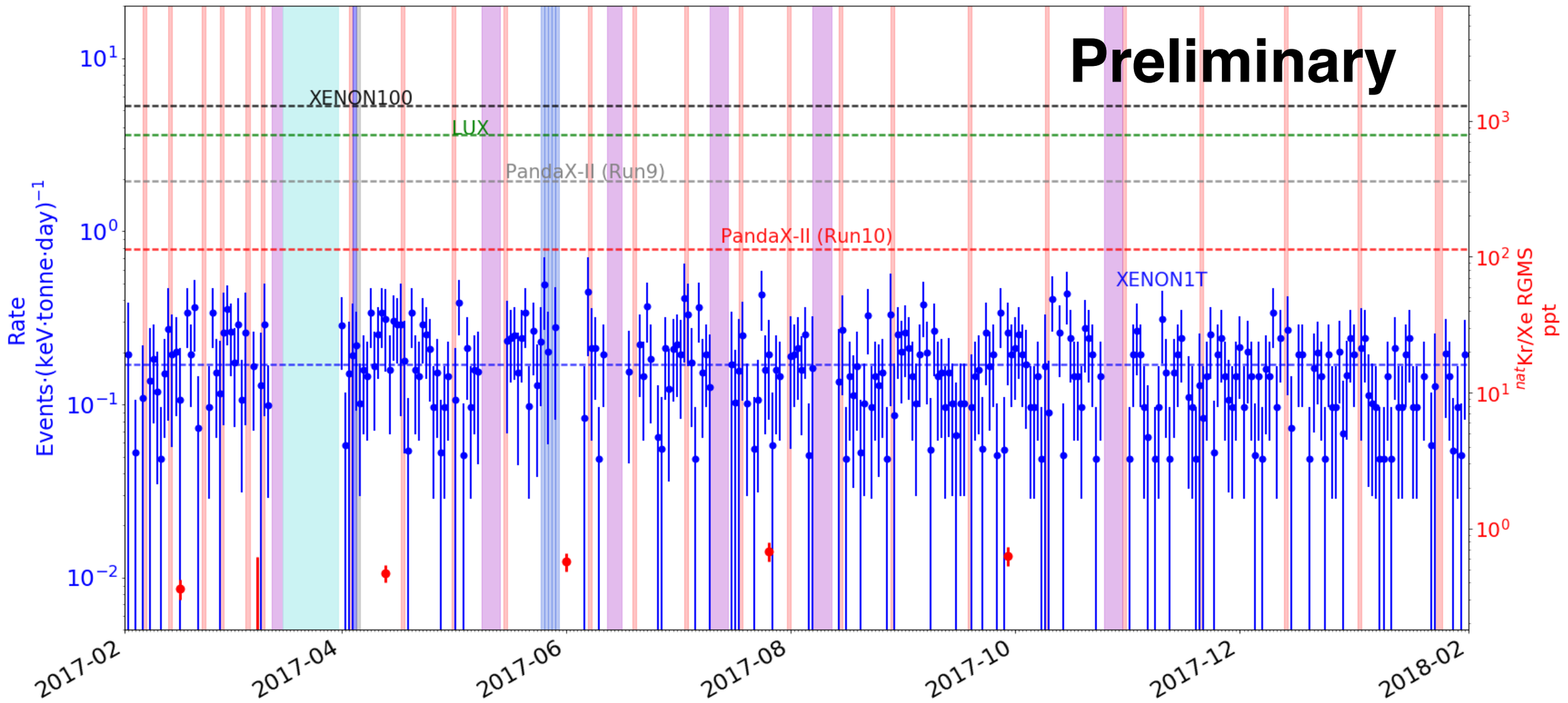


Source	Rate [t^{-1} y^{-1}]	Fraction [%]
222Rn	620 ± 60	85.4
85Kr	31 ± 6	4.3
Solar ν	36 ± 1	4.9
Materials	30 ± 3	4.1
136Xe	9 ± 1	1.4
Total	720 ± 60	

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

Lowest ER background ever measured in a DM detector:
(62 ± 11) events / (ton·year·keV)

ER Background: Data

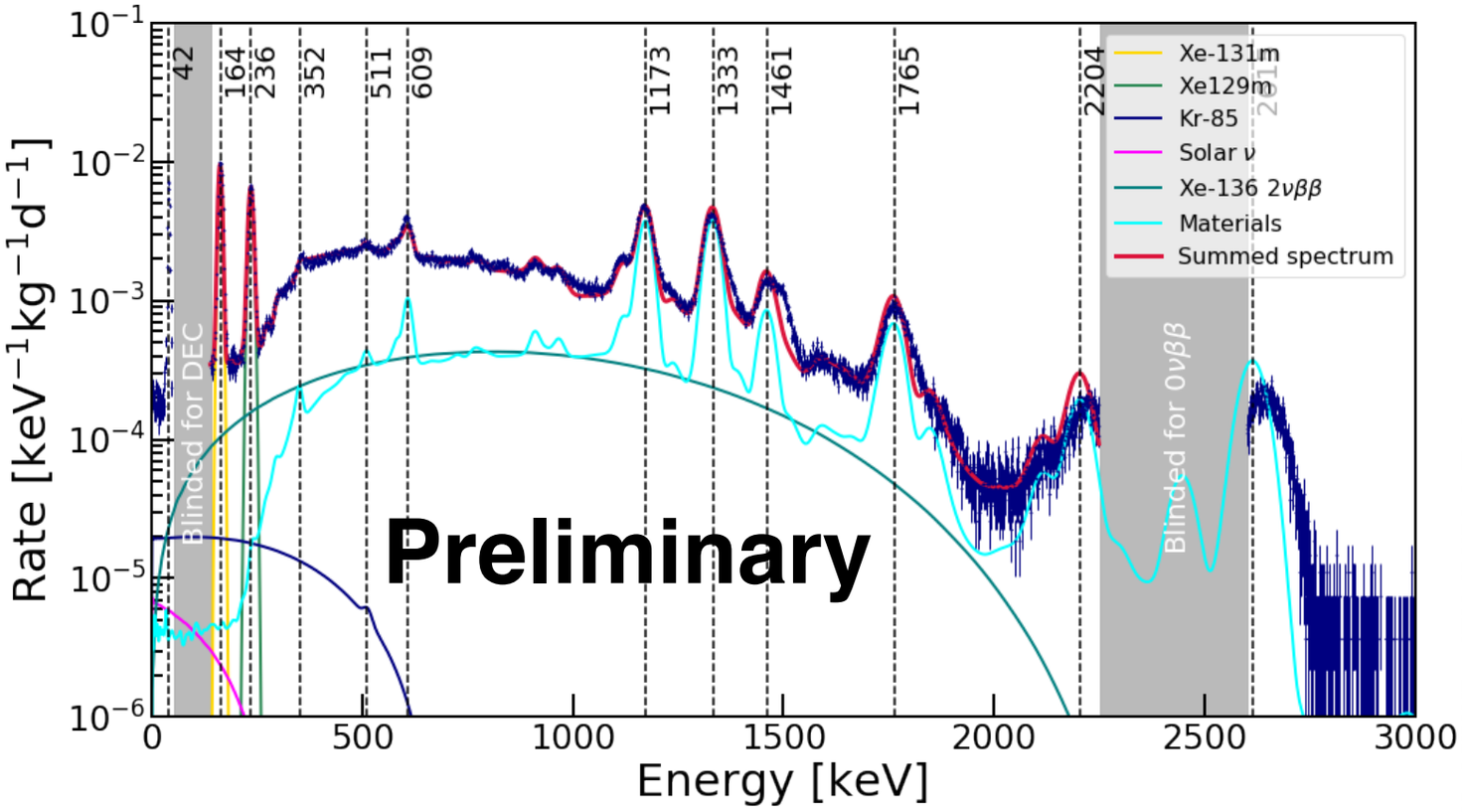


Measured in SR1: (1.7 +/- 0.25) 10^{-4} events / (kg day keV) in 1300 kg FV and 5-40 keVnr)
Predicted for SR1 (considering the average 0.45 ppt of Kr): (1.9 +/- 0.2) 10^{-4} events / (kg day keV)

Lowest ER background ever achieved in a DM detector !

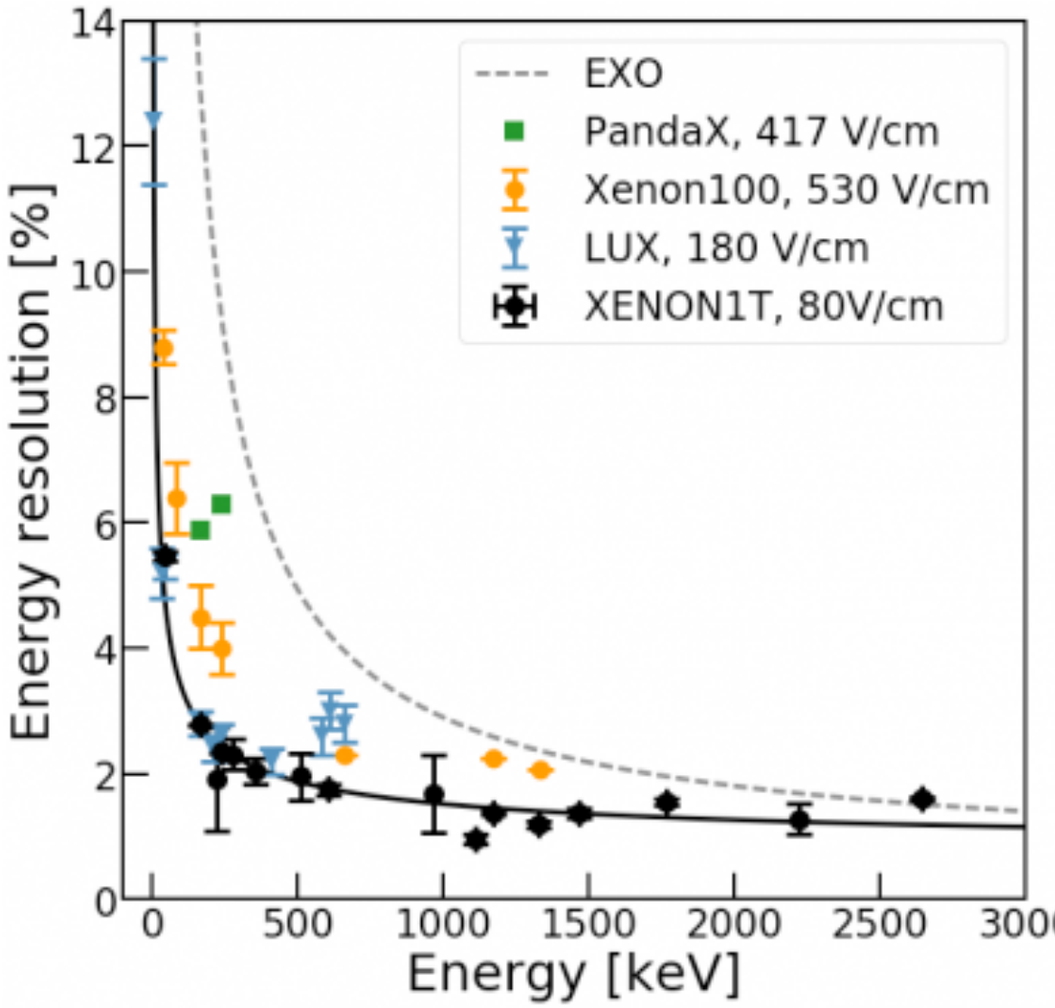
Dominated by Pb214 from Rn222.

Background Data: Energy Spectrum and Energy Resolution

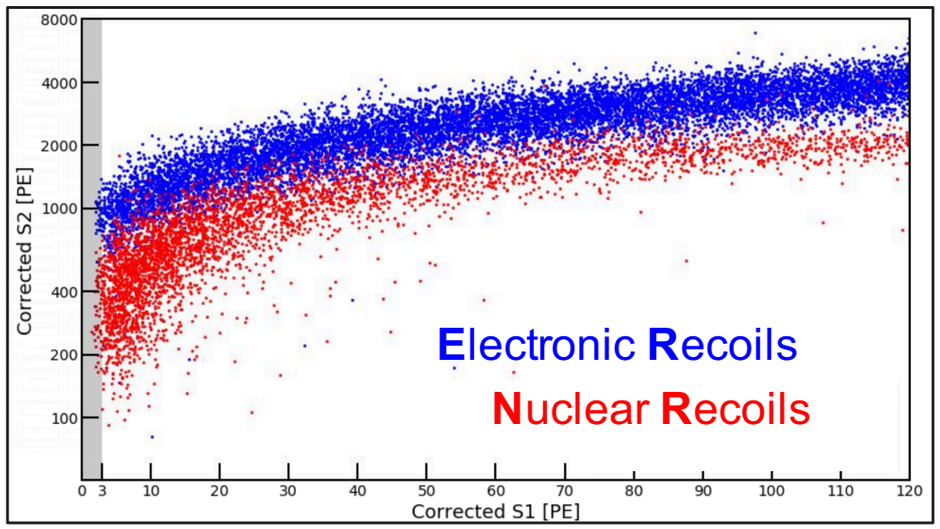


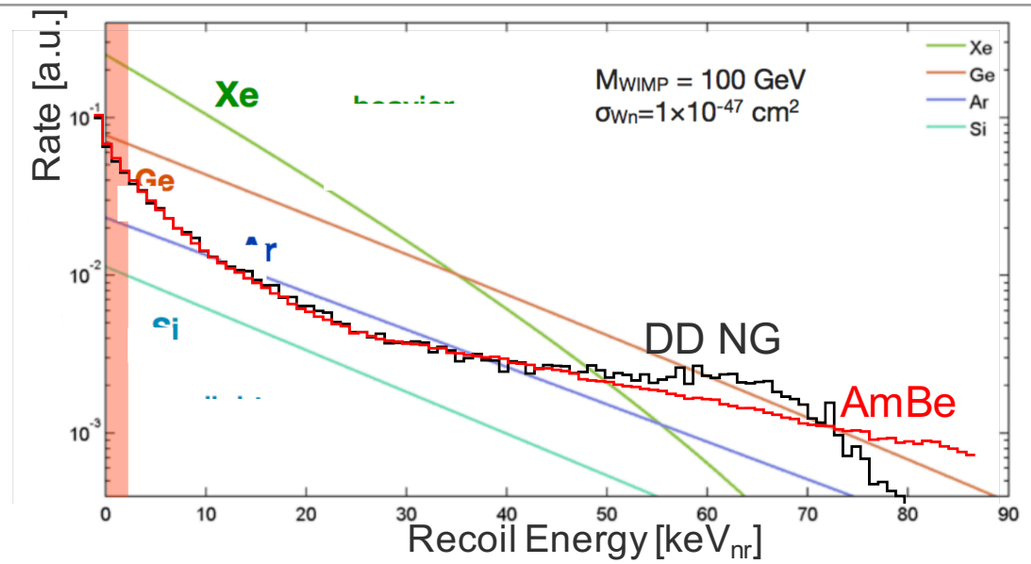
- Good agreement between predicted and measured background spectrum
- Kr: ~0.45 ppt; Pb214: ~ 10 uBq/kg
- Gammas based on screening measurements

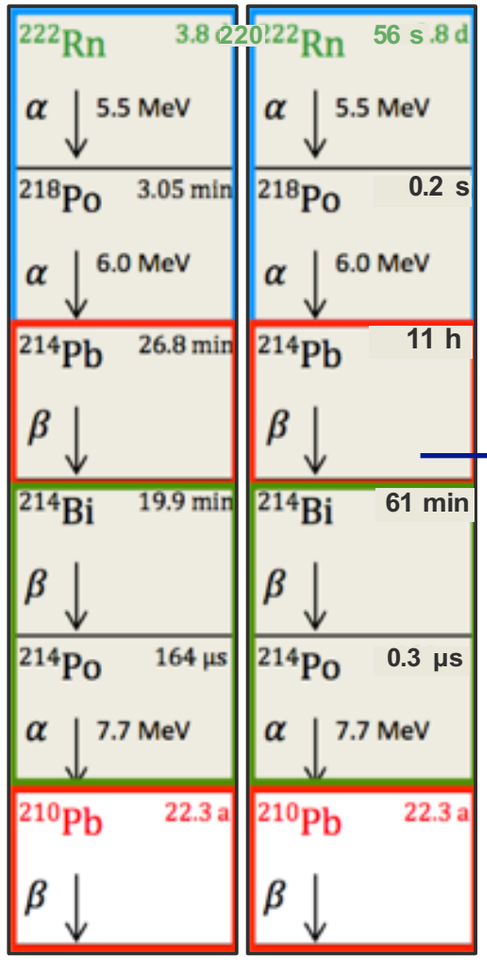
- Excellent energy resolution measured with a large LXeTPC

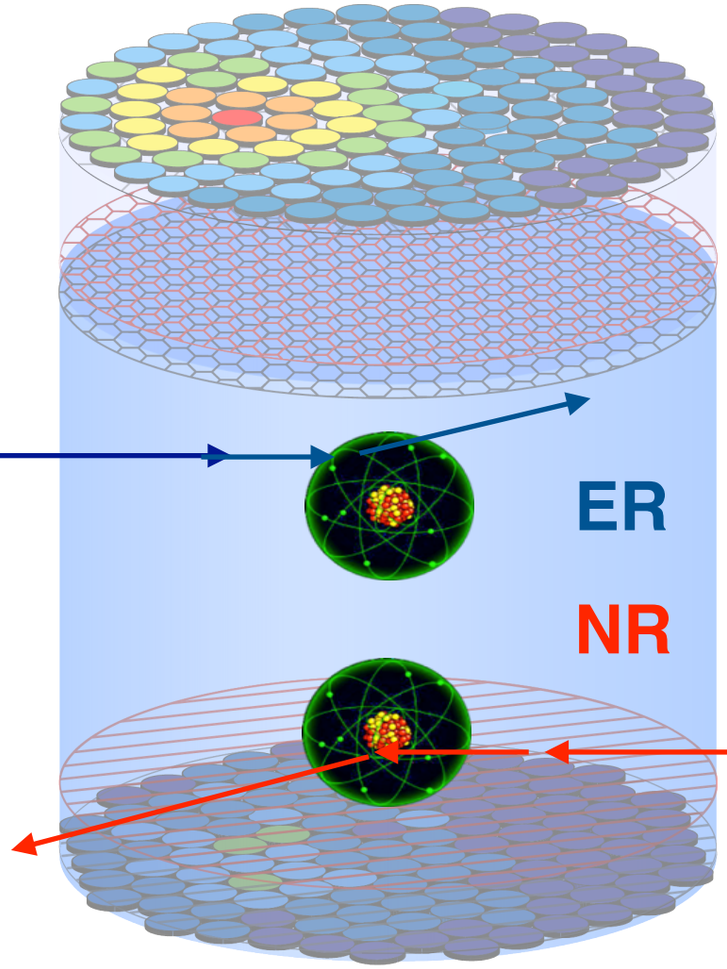


Calibrating ERs and NRs

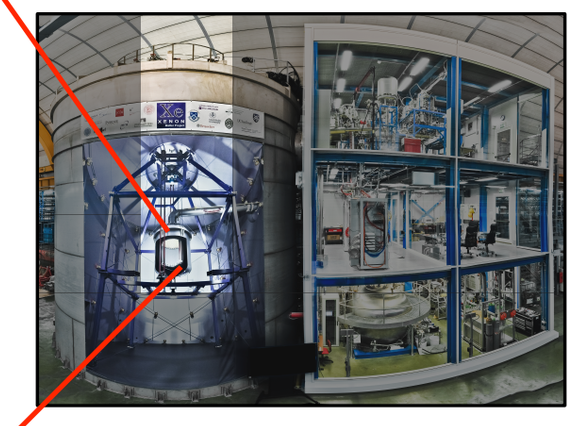








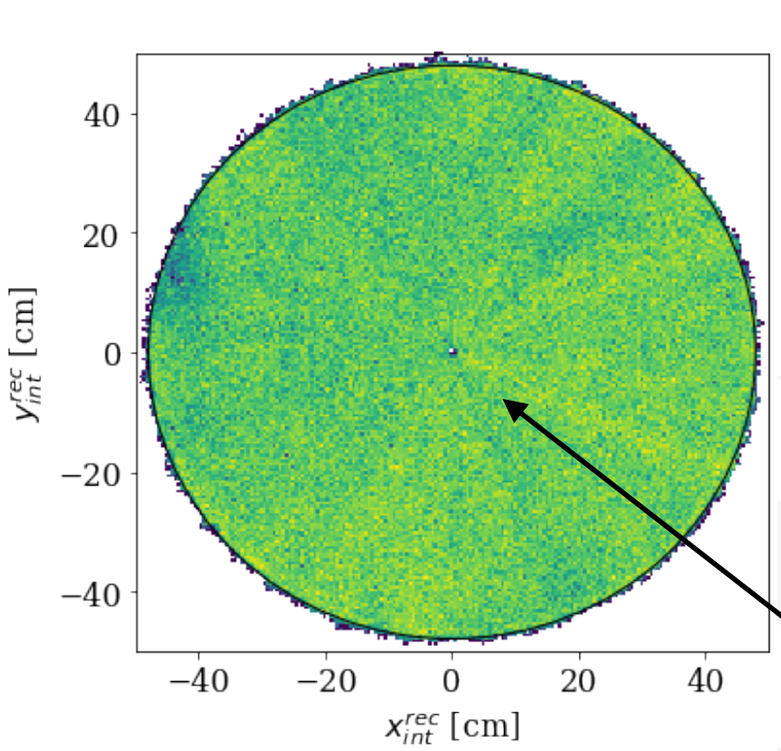
1), DD fusion neutron generator



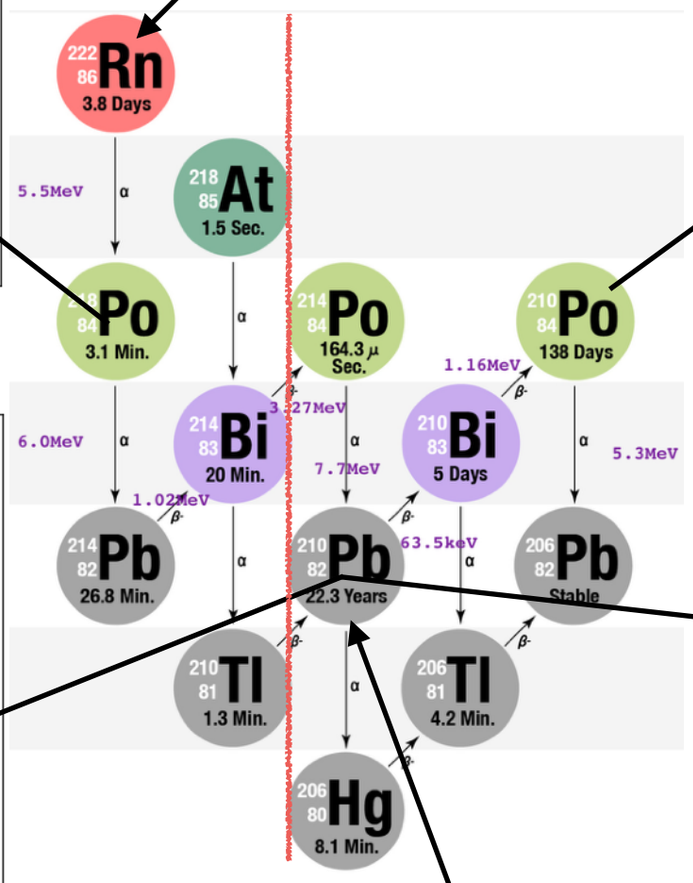
n, WIMPs

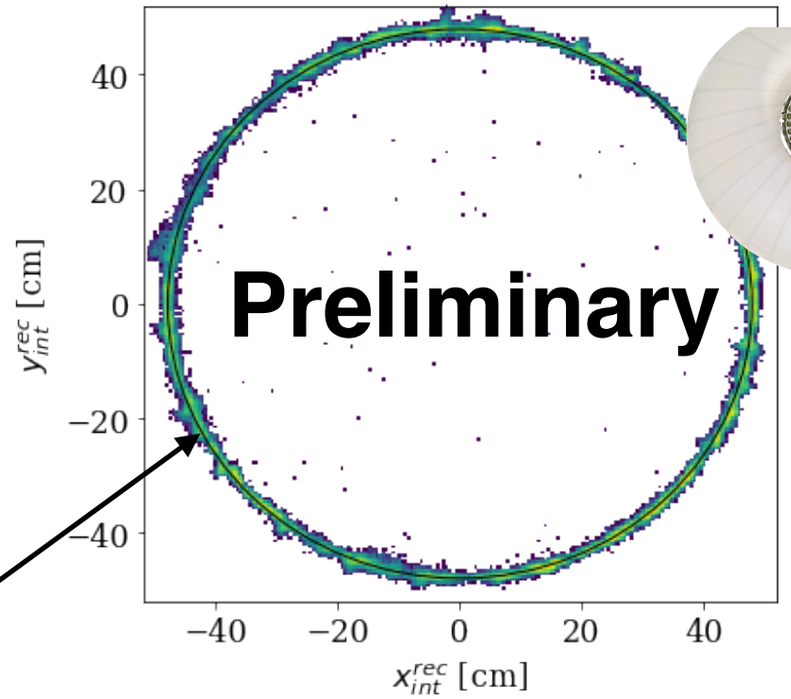
2), AmBe radioactive source

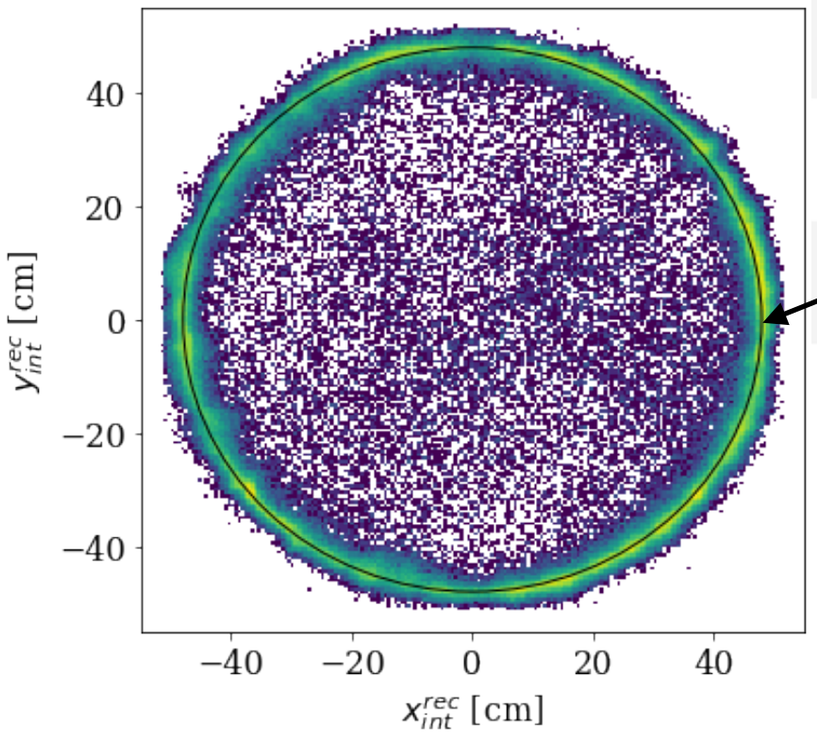
Seeing Rn-222 decay chain in the XENON1T TPC

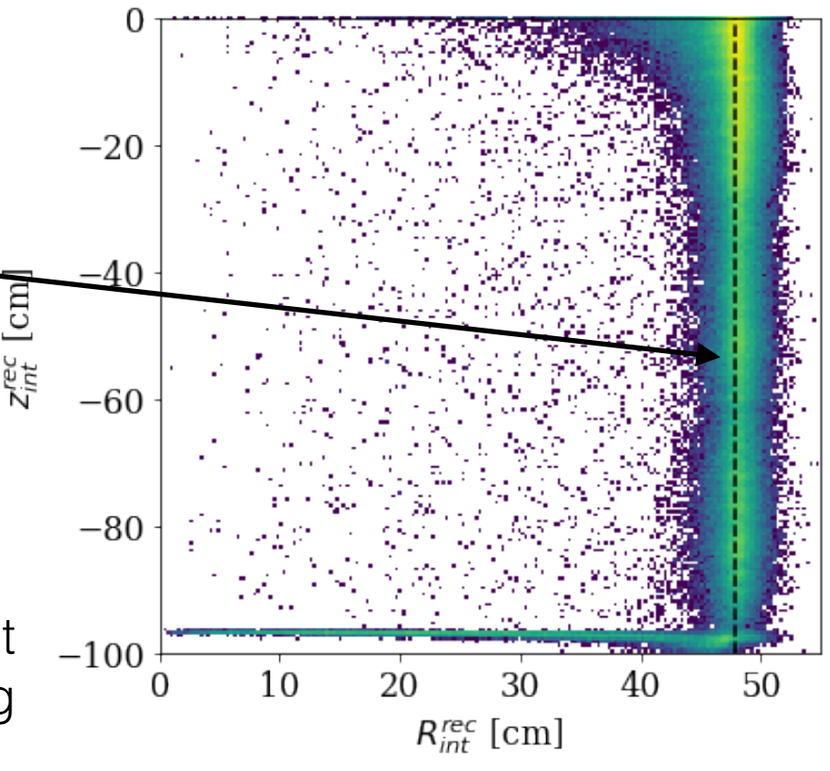


Radon-222 concentration in LXe









Pb210 and Po210 plated-out on TPC surfaces during construction/assembly

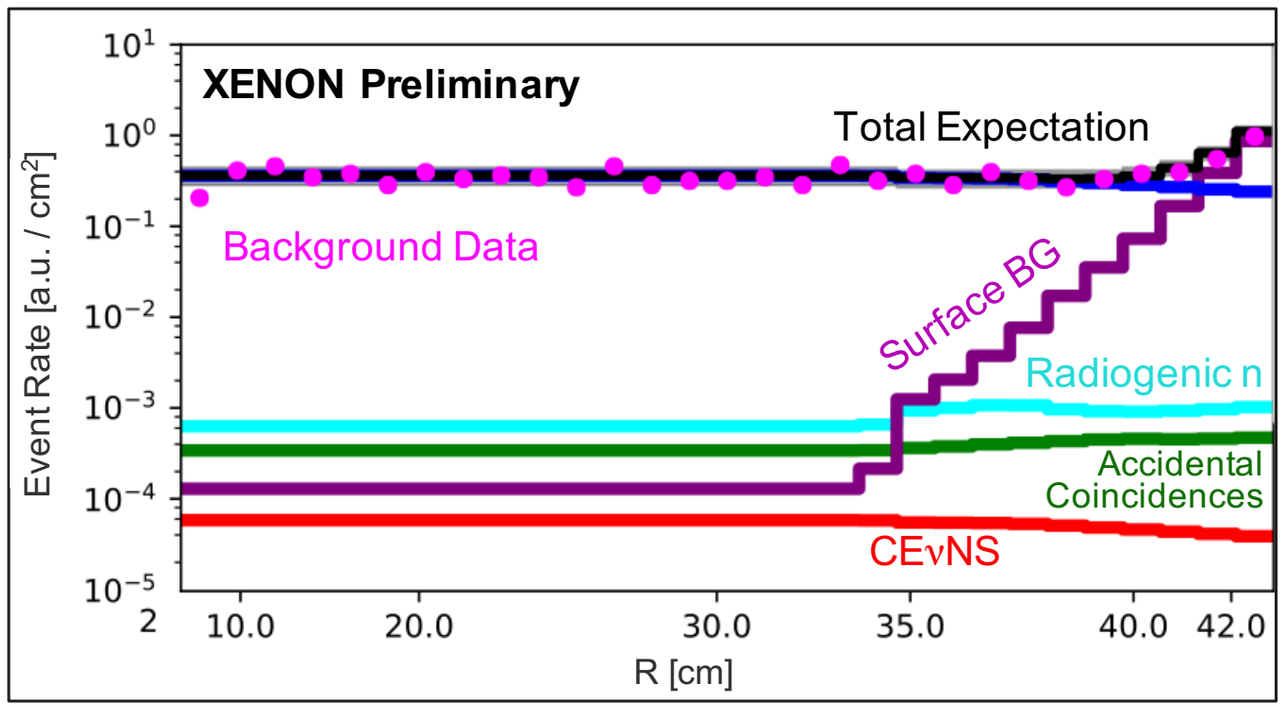
Fiducial volume and R dependence

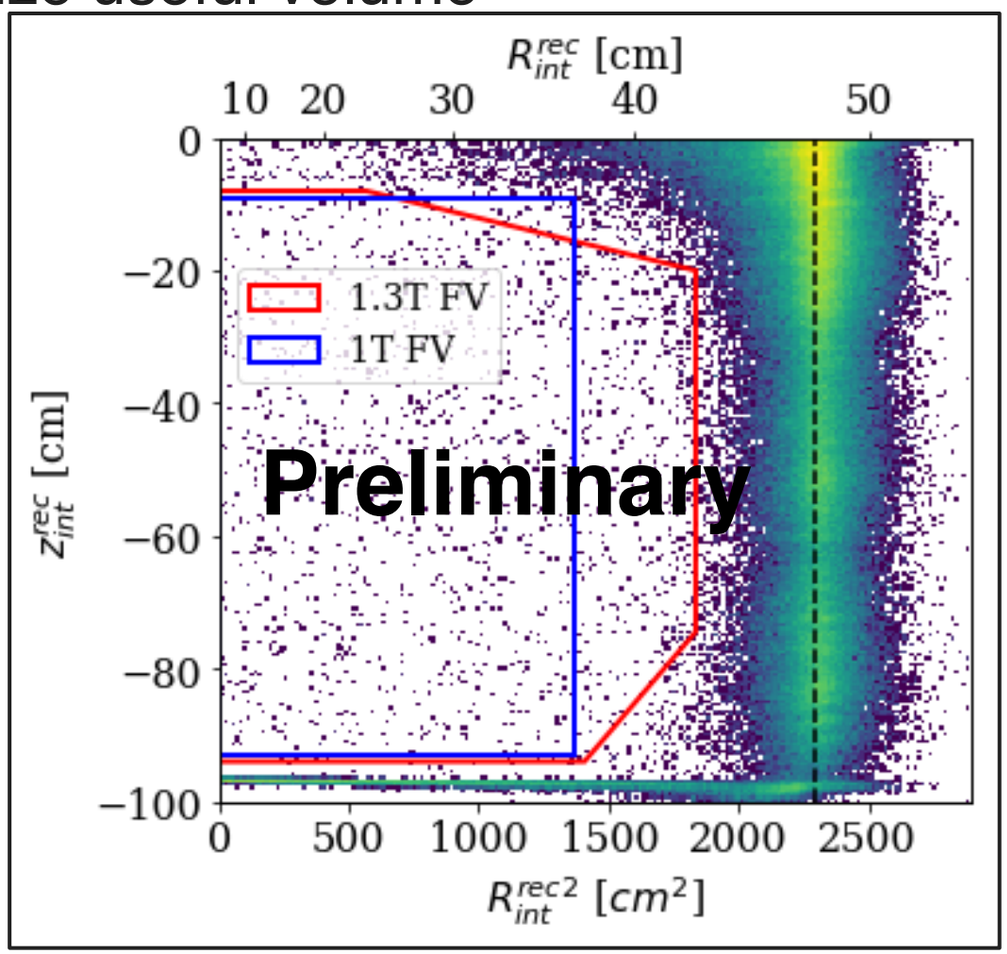
- ***Select FV to reduce materials and surface background***

  SR0 result: 1T FV (PRL 119, 181301 (2017))

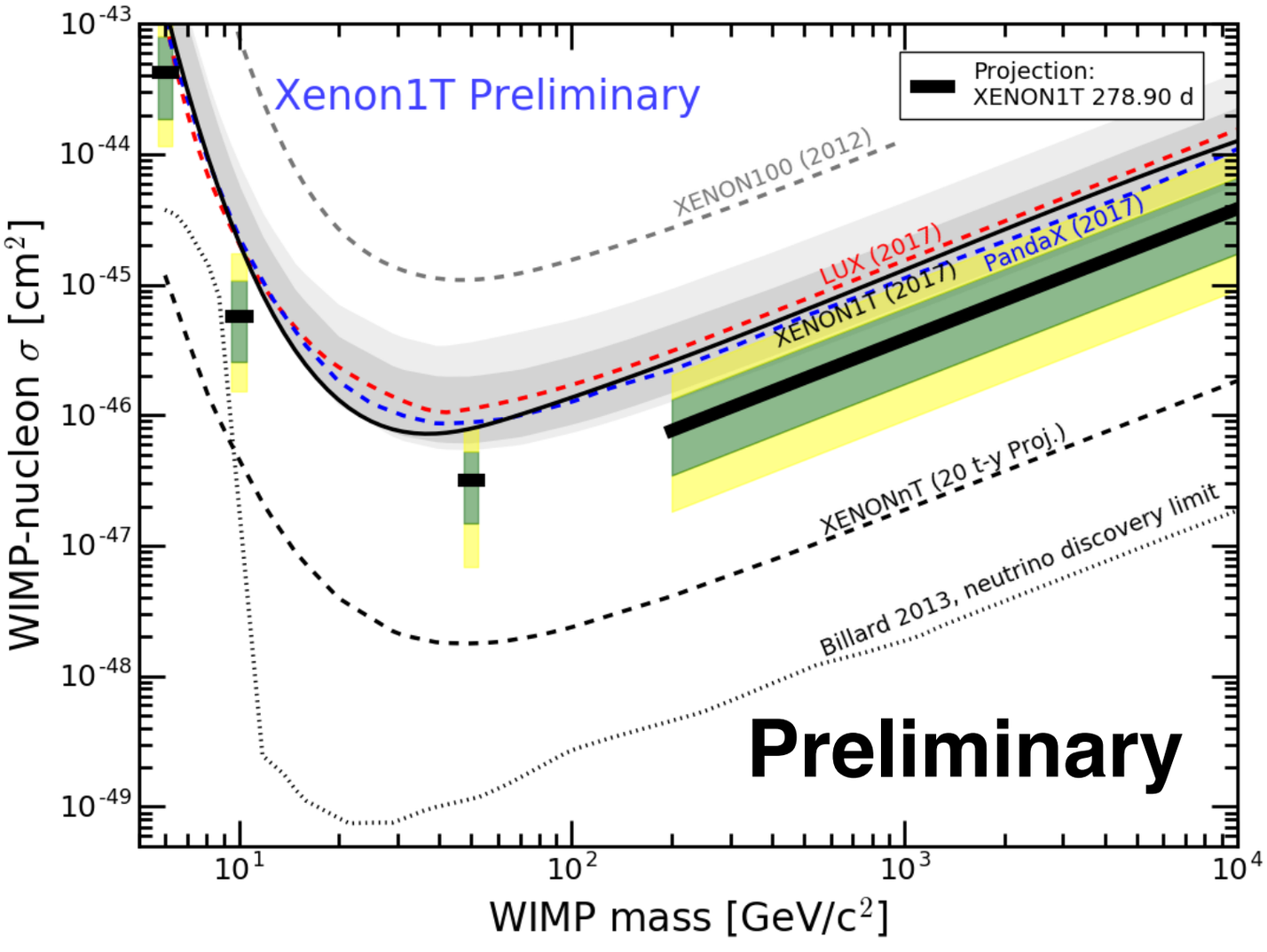
  This work: FV increased by ~30% due to improvements in position reconstruction, including PTFE charge-up and field corrections

- Furthermore, new surface background model allows inclusion of radius, R, in statistical inference to maximize useful volume





XENON1T Sensitivity



- Expected sensitivity generated from toy MC at 4 typical WIMPs masses: 6, 10, 50, 200 GeV
- For a 50 GeV WIMP a factor of 3 sensitivity increase compared to SR0
- If WIMP cross-section close to our SR0 limit we expect a signal with 3-sigma significance

Our next step: XENONnT

XENONnT in a nutshell

Aprile et al., Eur. Phys. J. C (2017) 77: 881. *XENON1T sub-systems*

Aprile et al., JCAP 77 (2016), 358. *online Rn-removal*

Aprile et al., Eur. Phys. J. C (2017) 77: 275. *online Kr-removal*

Aprile et al., JCAP 4 (2016), 27. *sensitivity*

Minimal Upgrade

The XENON1T infrastructure and sub-systems were originally designed to ***accommodate a larger LXe TPC***.

Active Xe Target

XENONnT TPC features:

total Xe mass = 8 t

target mass = 5.9 t

fiducial mass = ~4 t

Background

Record low-back levels in XENON1T dominated by ^{222}Rn-daughters.

Identified strategies to effectively ***reduce ^{222}Rn by ~ a factor 10***.

Fast Turnaround

Use ***XENON1T sub-systems,*** already tested

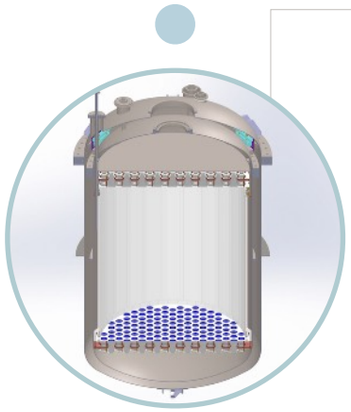
Fast pace:

Installation within 2018

start data-taking in 2019

XENON1T Infrastructure and sub-Systems (already operative)

Aprile et al., Eur. Phys. J. C (2017) 77: 881

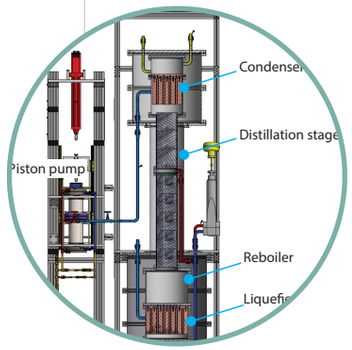


New TPC

5.9-ton Time Projection Chamber

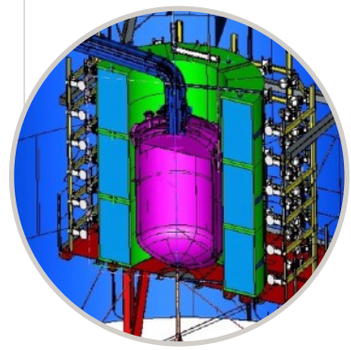
LXe Purification

To achieve fast cleaning of the large LXe volume (5000 SLPM)



Radon Distillation

To online remove the ^{222}Rn emanated inside the detector

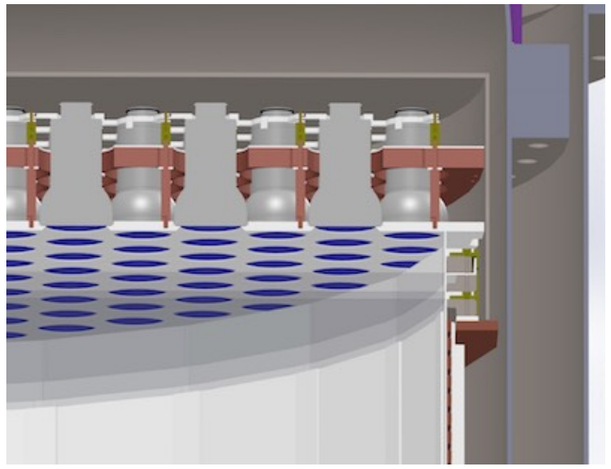


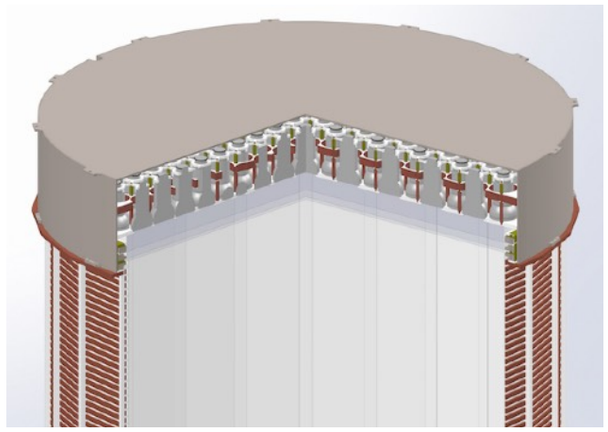
Neutron Veto

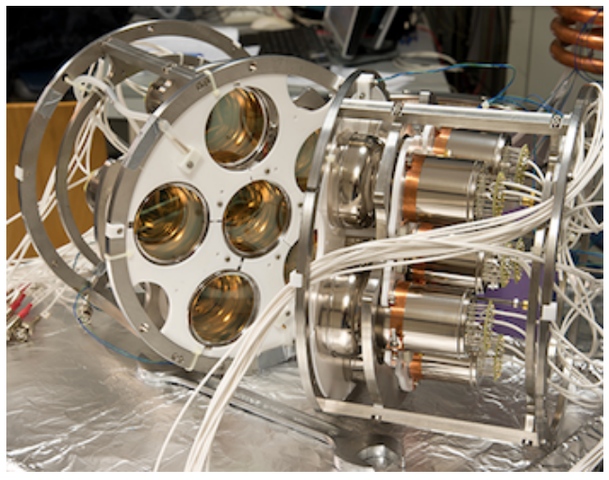
To tag and measure in situ neutron-induced background

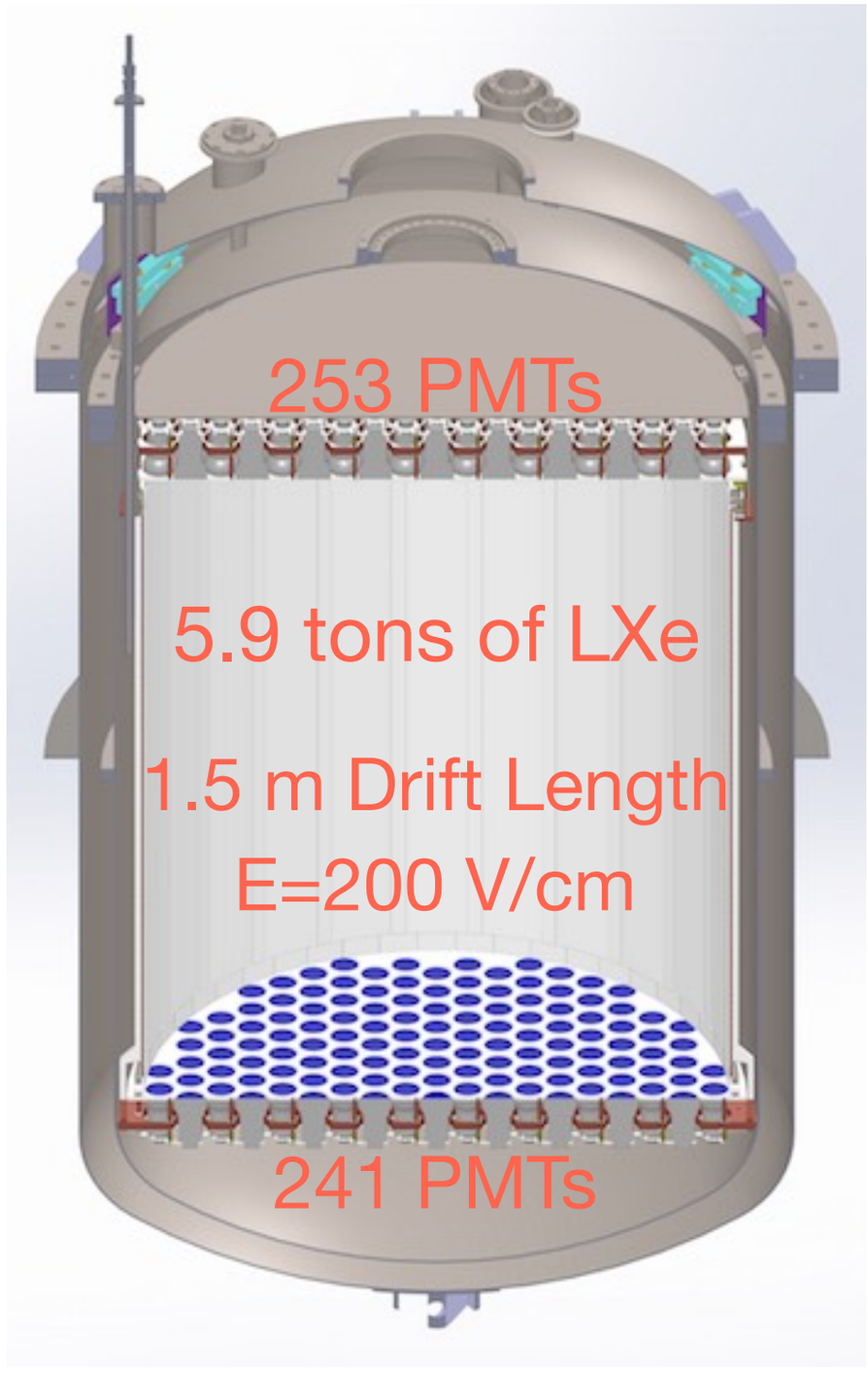
The XENONnT Time Projection Chamber

- ***Largest*** TPC ***fitting*** in the XENON1T ***outer vessel:***
  - ➡ *Identified **new clean material for inner vessel and new electrodes-** order placed-awaiting offers to place order for construction*
  - ➡ *Use **same holding structure** and **leveling** mechanism.*
- ***Concept design finalized:***
  - ➡ *Raw **materials** under **procurement** and **screening** ongoing.*
- ***Technical design and FEM*** in advanced stage:
  - ➡ ***mockup components under production*** to freeze the design.
- ***PMTs procured*** and under ***test*** in LXe in facilities @ZURICH, STOCKHOLM and MPIK.



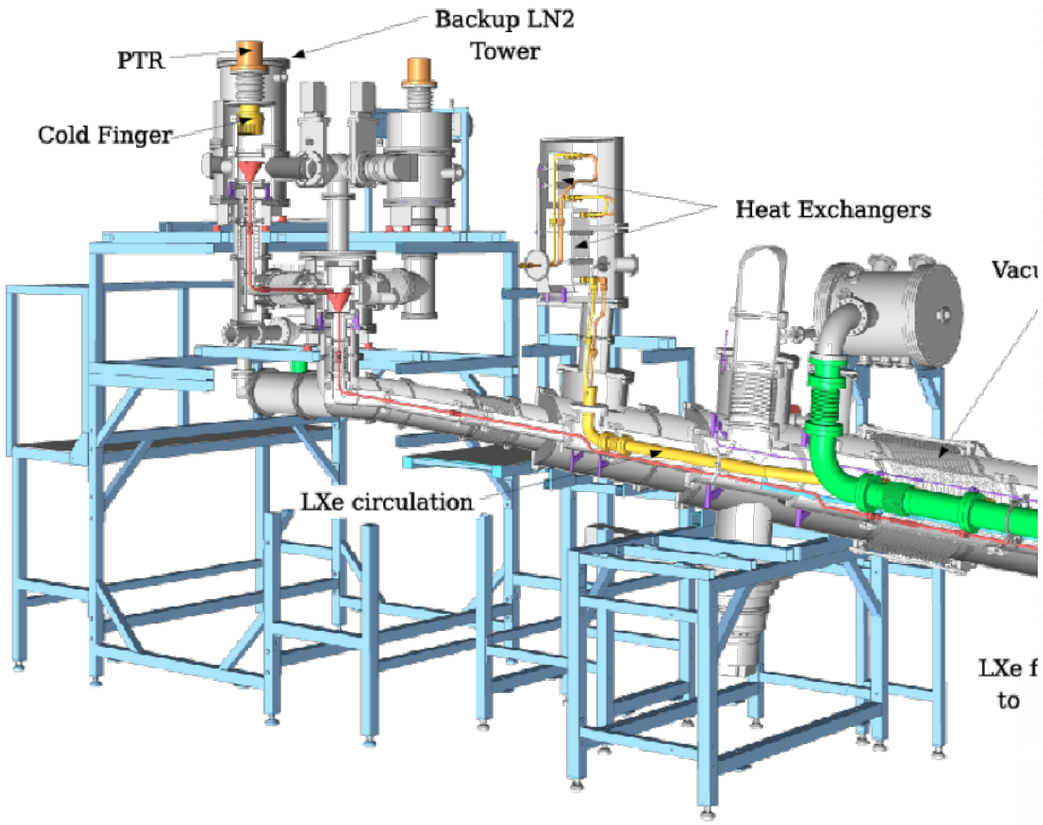


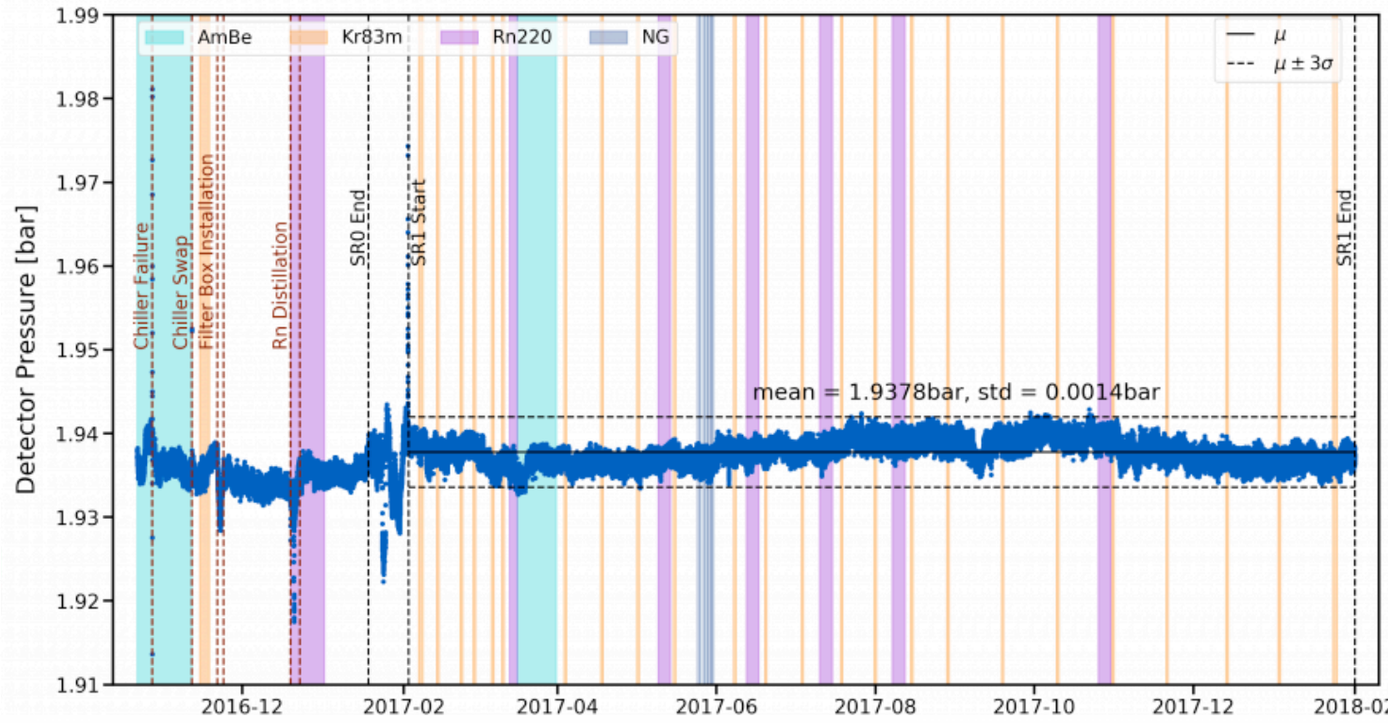


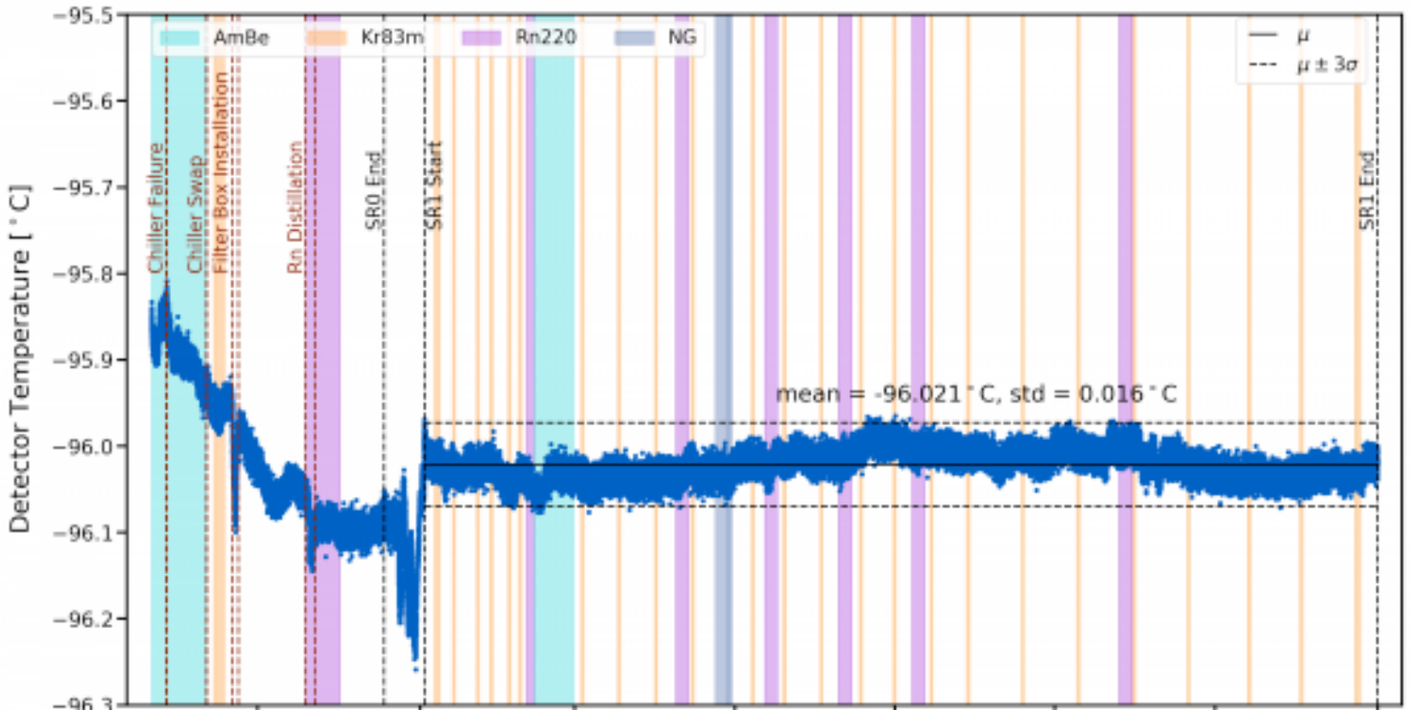


The XENON1T/nT Cryogenic System

- Liquefies and maintains xenon in liquid state, provides stable conditions for data taking

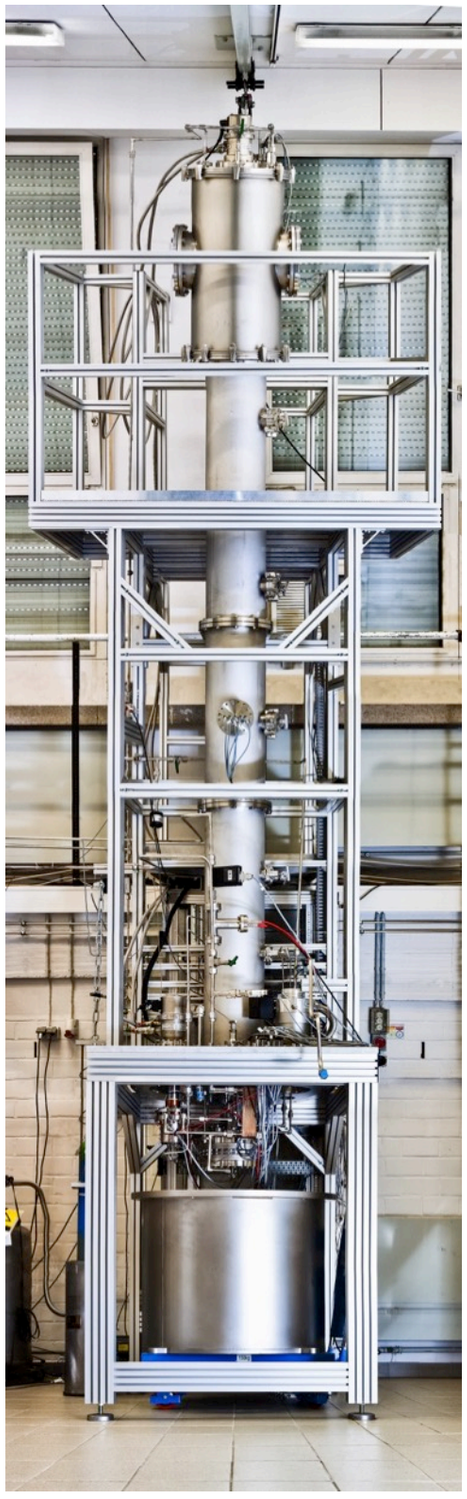






- Two redundant Pulse Tube Refrigerato and plus a LN_2 cooling tower backup
- Efficient two-phase heat exchangers
- XENON1T cold with stable pressure/ temperature since Fall 2016!
- For XENONnT total heat load similar ~245W -> same system.

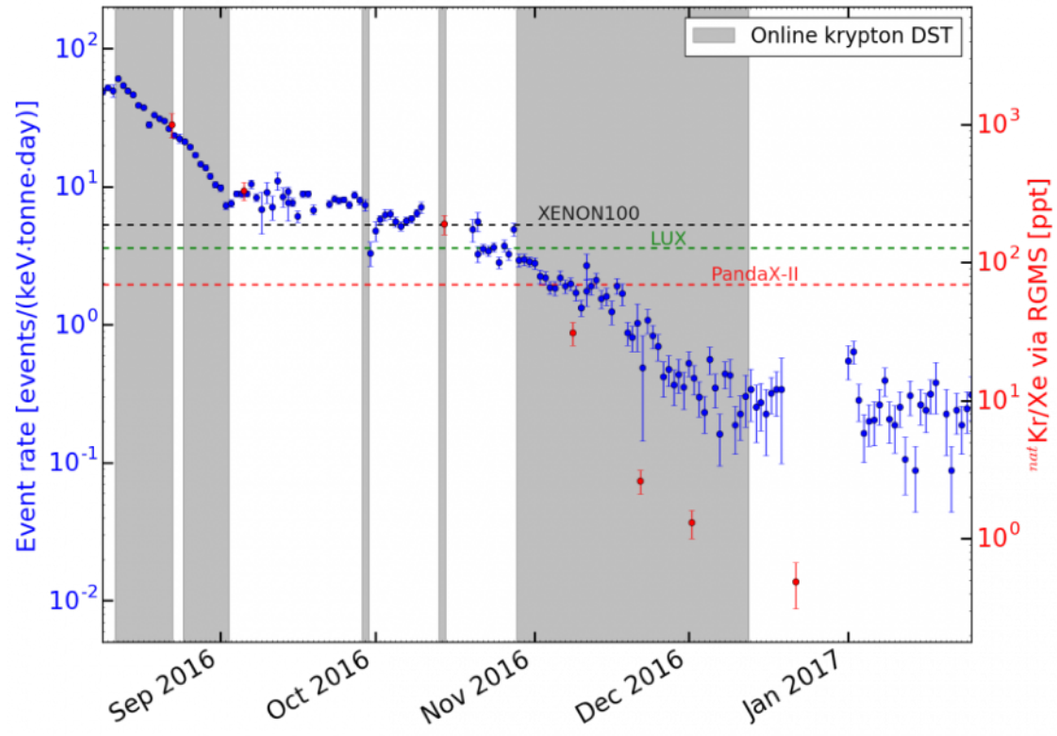
The XENON1T/nT Kr-Distillation Column



- ^{nat}Kr/Xe in commercial gas is at ppm - ppb level
- XENON1T/nT sensitivity demands Kr/Xe << 1ppt
- Solution: 5.5 m distillation column, 6.5 kg/h throughput >6.4×10^5 separation
- Aprile et al., EPJ (2017) 77

In ***XENON1T:***

- ***operated Kr-distillation column online*** for *~70 days*
  - ➡ *reduced ^{nat}Kr/Xe concentration from ppm to **0.3ppt** (~1/3300th!)*

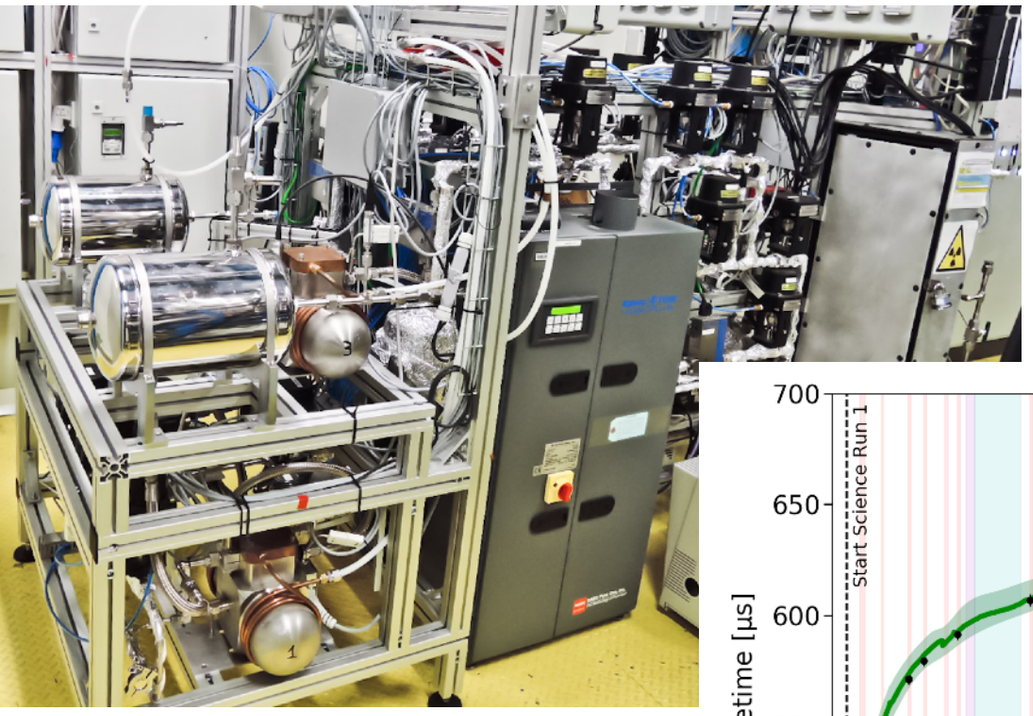


For ***XENONnT use the SAME column:***

- ***pre-distilled 8t of gas**. **Start** run with about **0.2ppt**;*
- *operate the column **online** at the start of the run*
  - ➡ *improve only by a factor 10 (small!), down to **20ppq**.*

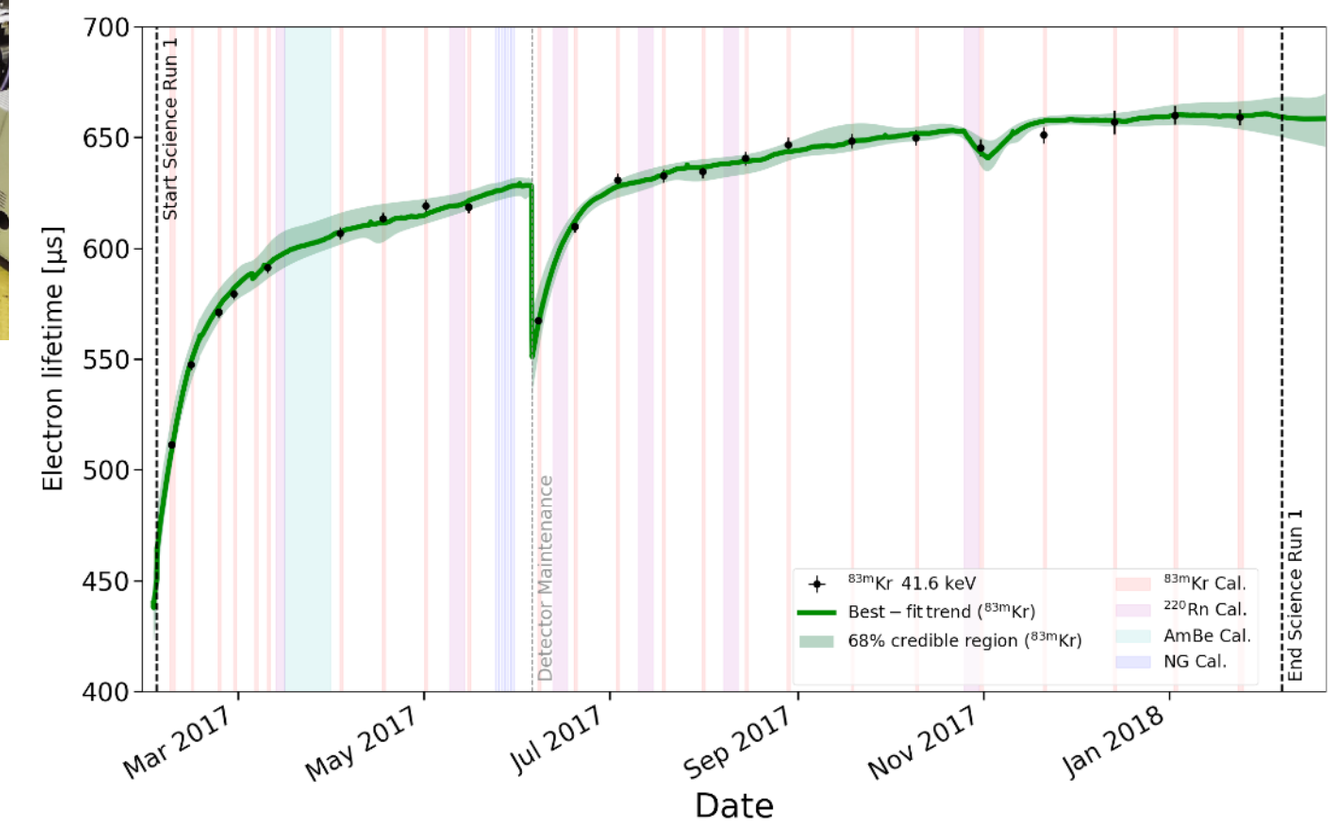
The column was shown to reach ^{nat}*Kr/Xe <26ppq from RGMS measurement*.

Xe- Purification (gas phase)



In ***XENON1T***:

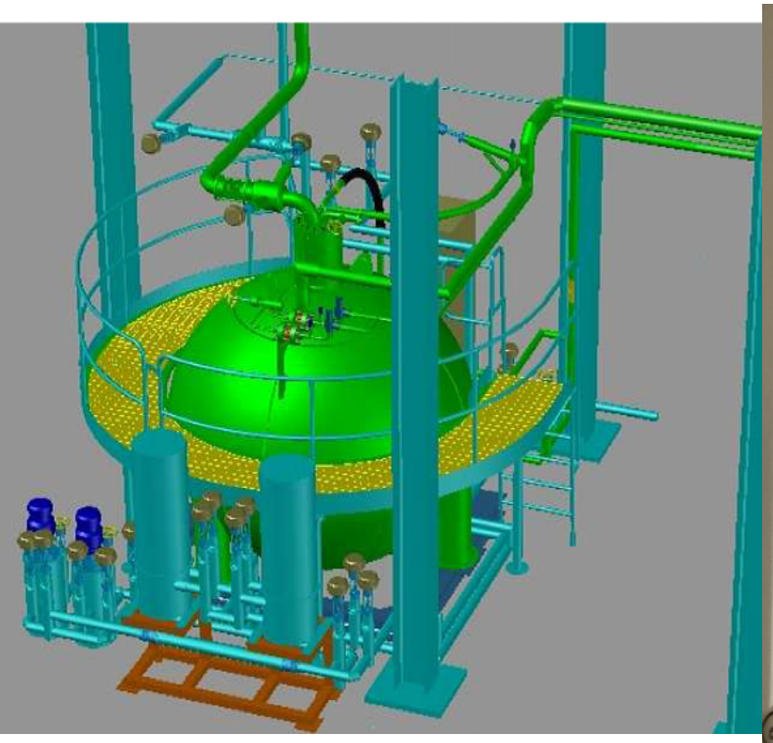
- ***Gaseous recirculation/purification*** through a hot getter;
- Recirculation flow limited mostly by QDrive ~ ***55 SLPM***
- ***Drifting electron lifetime ~ 650us*** to be compared with maximum drift time of ~760us

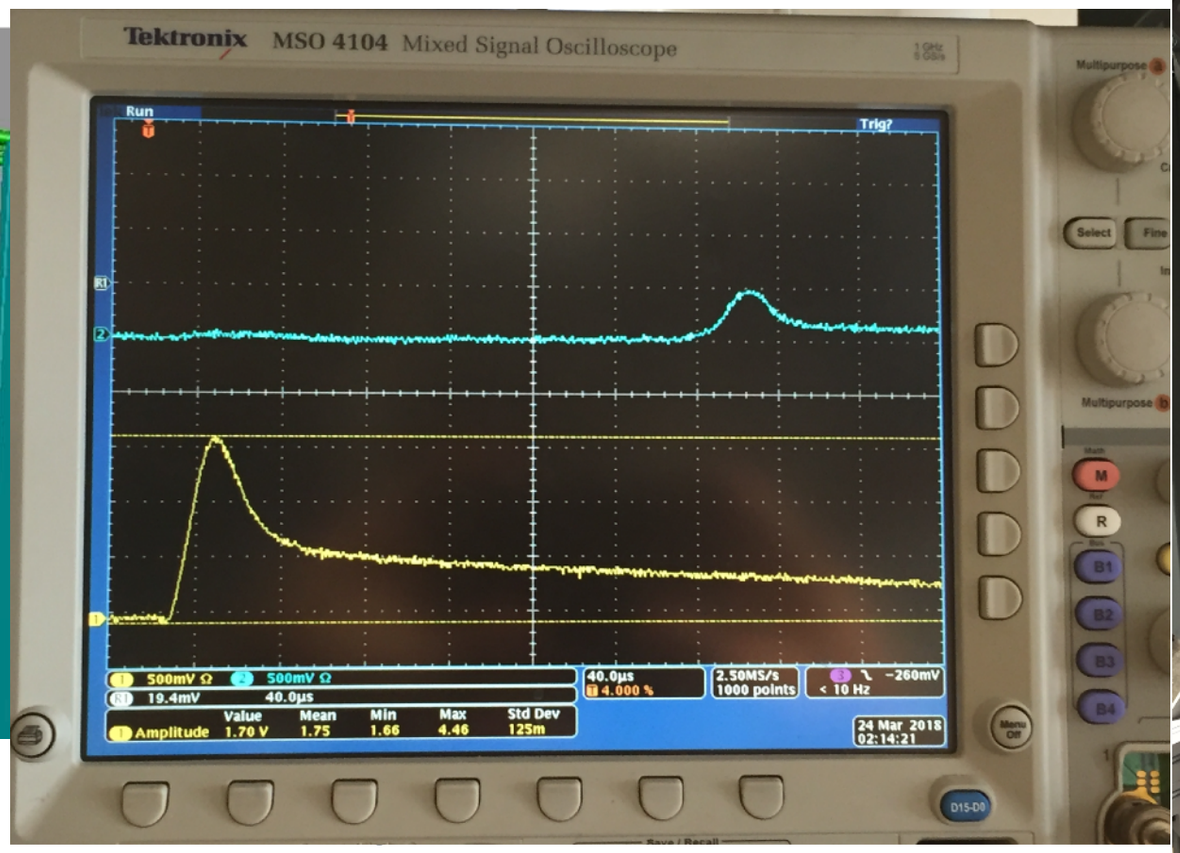


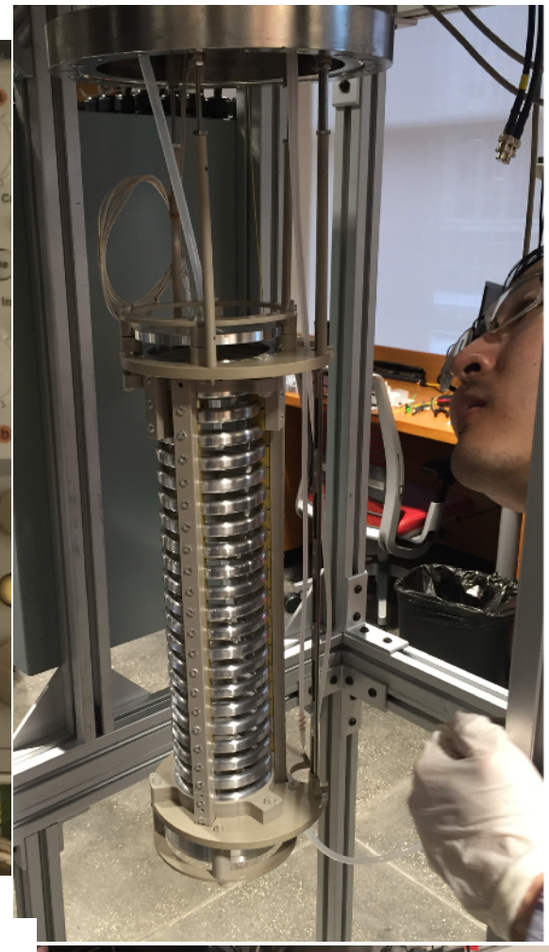
For ***XENONnT***:

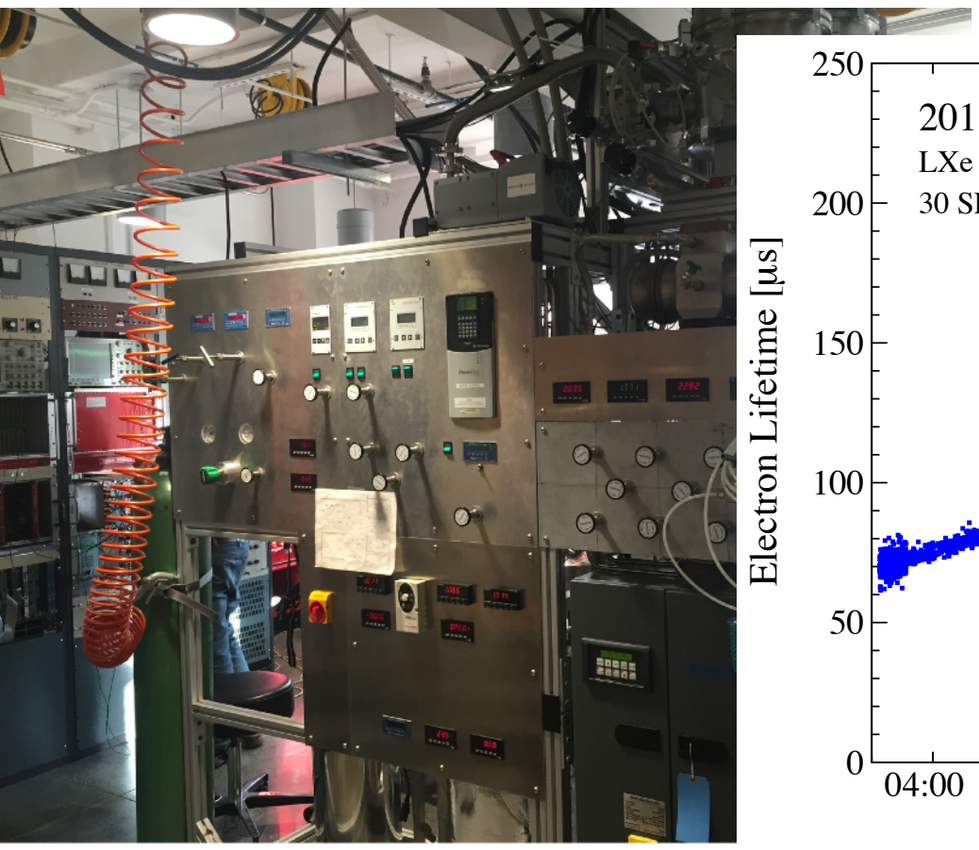
- ***upgraded (higher flow)*** gas recirculation/purification system with ***larger tubing, higher throughout valves, and new magnetically- coupled piston pump*** (100 SLPM) custom developed by Munster/RPI groups

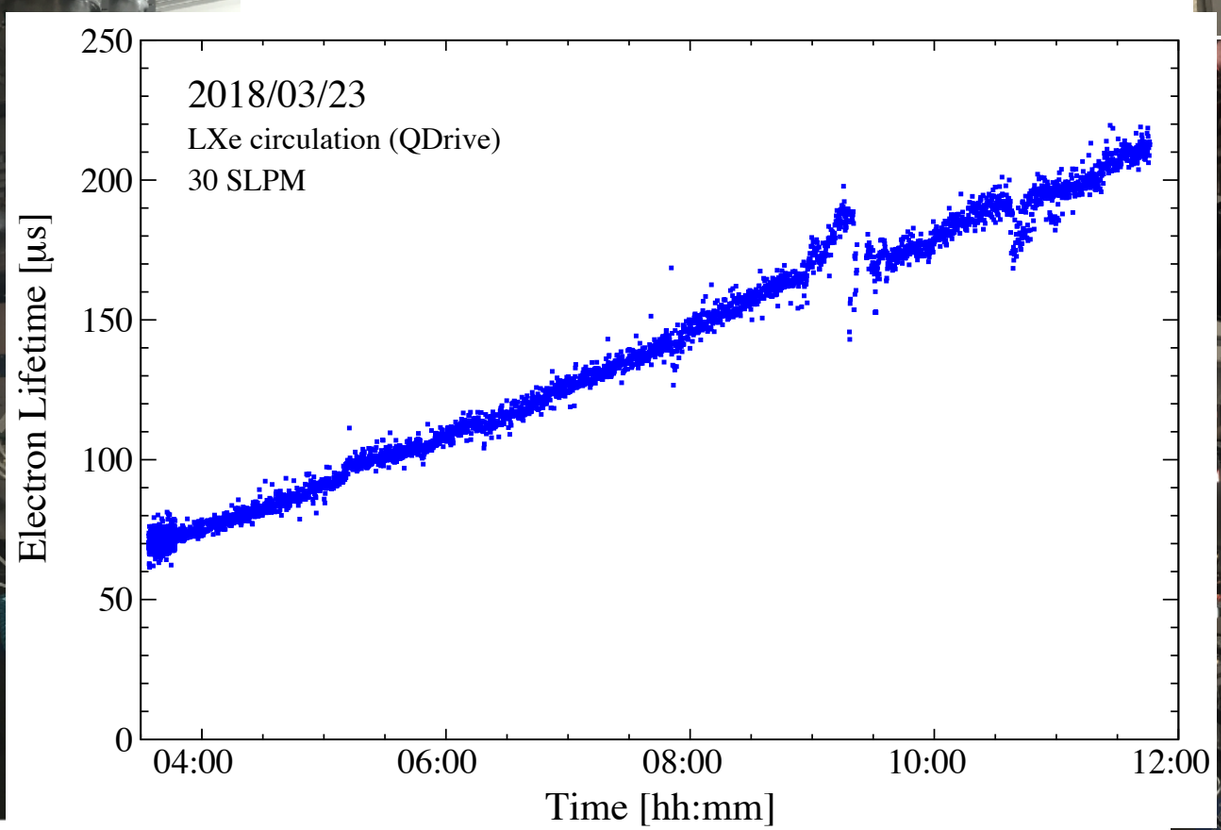
Xe- Purification (liquid phase)

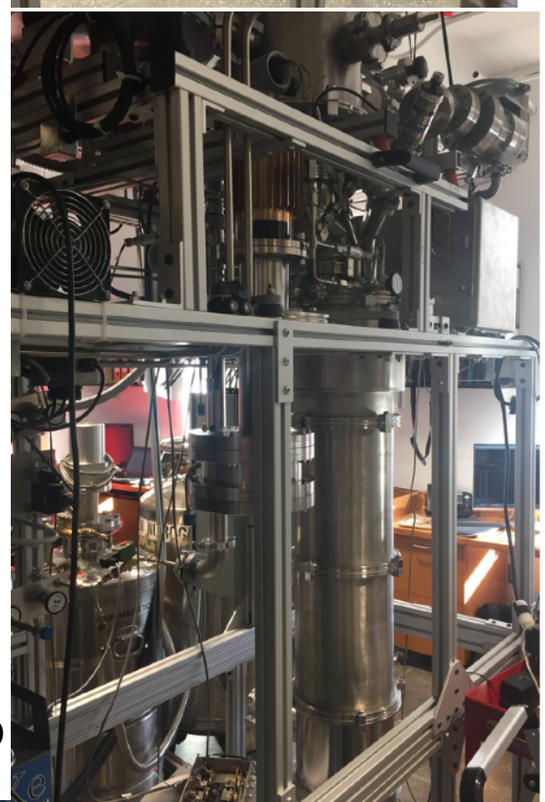




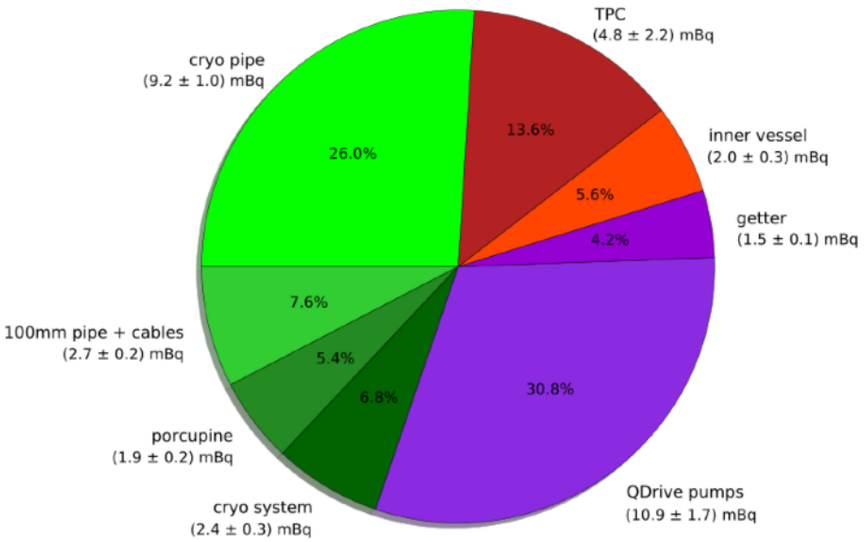








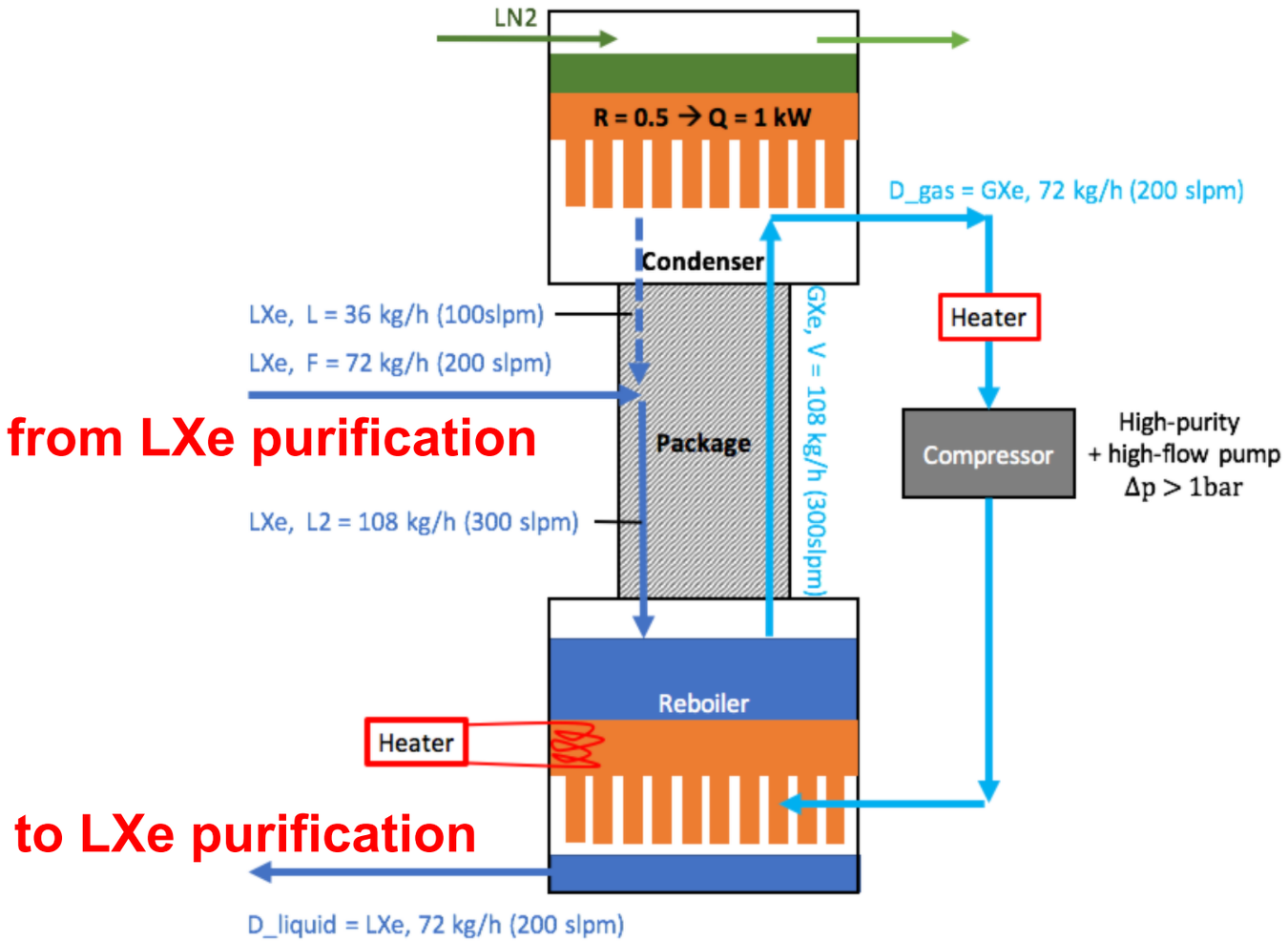
Rn-distillation column

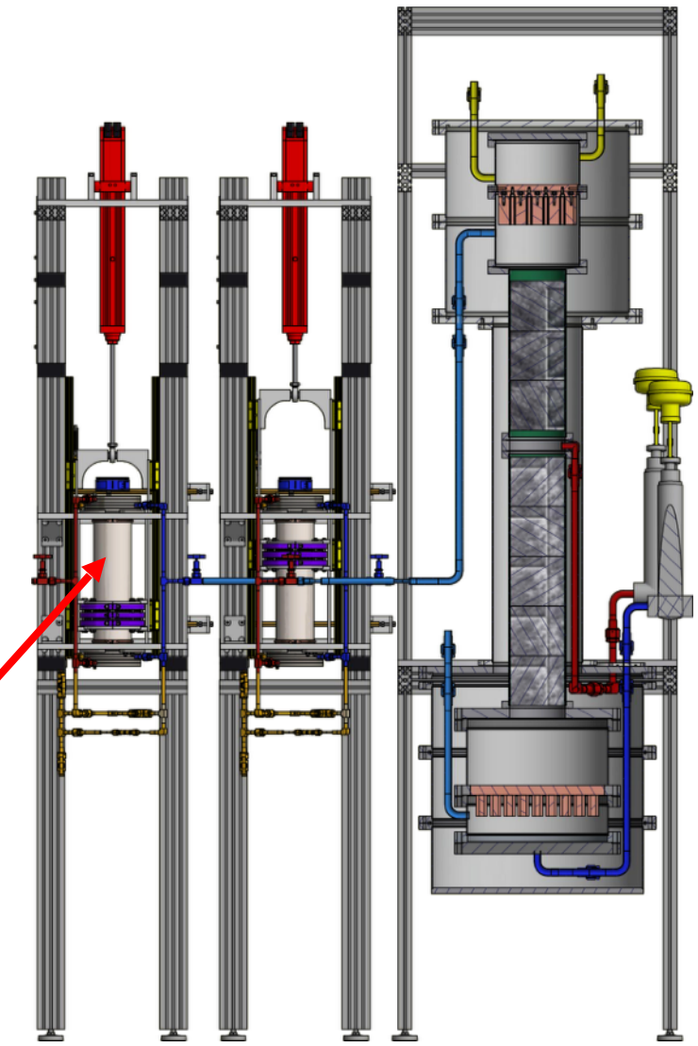


dedicated column for online removal of Rn type II sources (green components).Integrated with LXe Purification system.

Concept tested in *XENON100 and* applied in *XENON1T* -> operated Kr-column in reverse mode to mimic a Rn-column (@ 3 SLPM, non-optimized) -> Measured 20% reduction of the background.

Under development at Munster





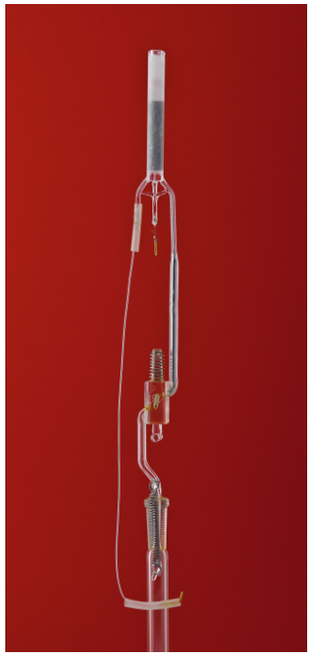
radon-free magnetically coupled double piston compressor

E. Brown et al., submitted to arXiv

Additional Rn-mitigation strategy

Working group led by MPIK to certify materials (HPGe, ICPMS, Rn emanation) and cleaning procedures. Overall Rn-reduction goal is factor of 10 to 1 uBq/kg

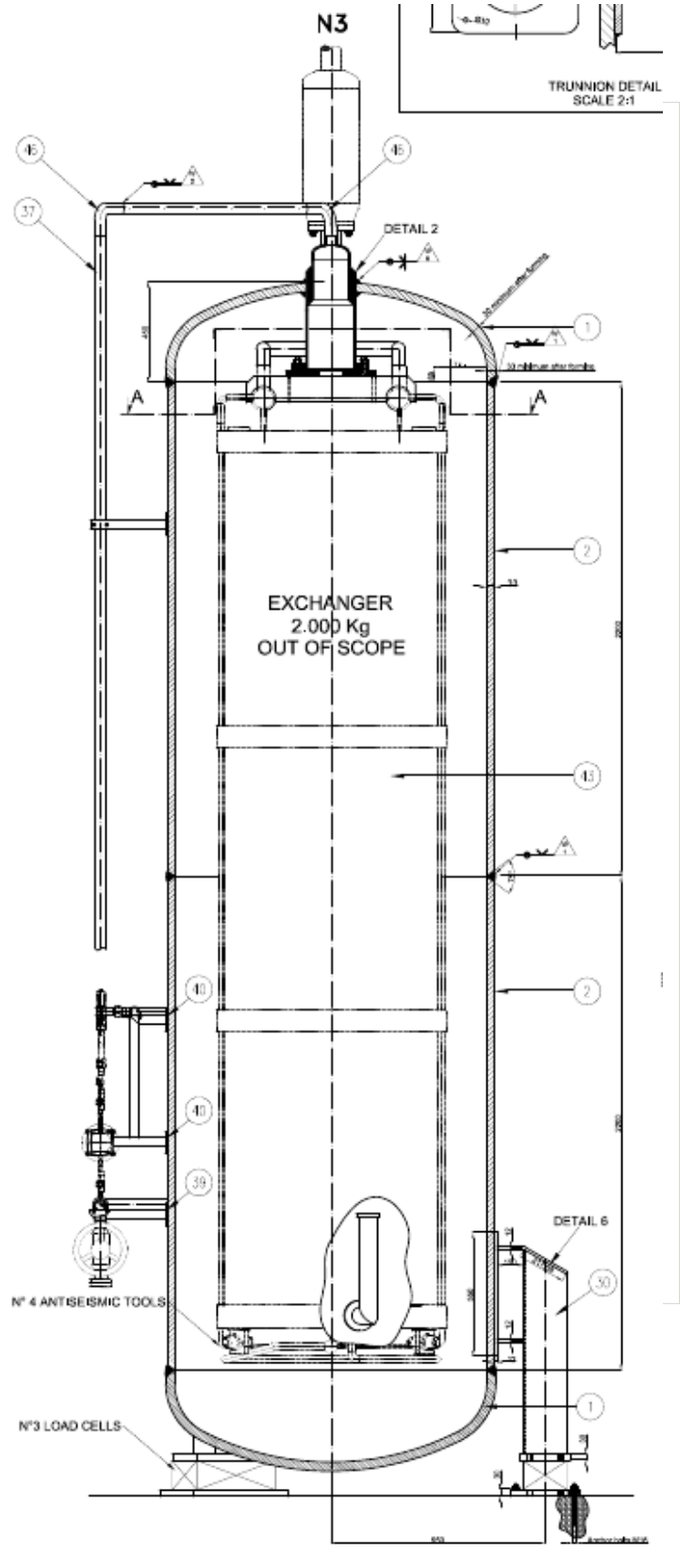
- Proportional counters for sensitive radon emanation measurement
- Electrostatic radon monitors
- Parallel measurements available for high sample throughput
- Automatized emanation measurements with Auto-Ema setup for reproducibility



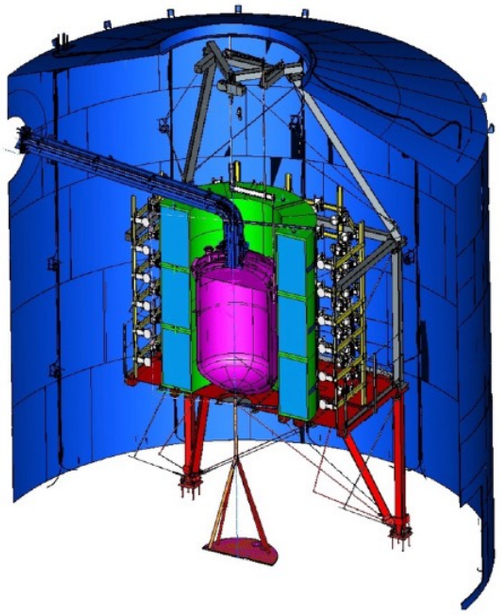
Xe Storage and Recovery

for ***XENONnT***:

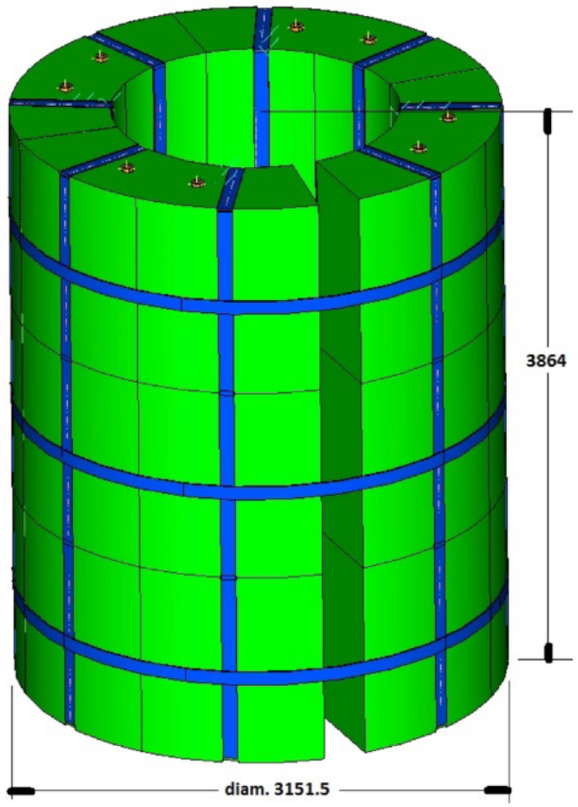
- use ReStoX + ***ReStoX2*** :
- new storage device with ***10 tons*** capacity (gas, liquid or solid)
- Very fast recovering with xenon crystallization (1 ton/hour expected)
- ***Design completed and presently in fabrication at the manufacturer site. Expected delivery by June 2018 for installation in Hall B.***



Liquid Scintillator Neutron Veto



- ~***15t*** of ***Gd-loaded LAB Scintillator***
- contained in 12 transparent ***Acrylic Vessels***
- readout by ***120*** Hamamatsu R5912Assy ***8" PMTs***
- radiogenic neutrons down to ***less than 1 in the total fiducial exposure*** (~75% tagging)



Mixture samples presently under study @ Mainz to ***certify the production procedure***.

Expertise available @ MPIK where the DOUBLE CHOOZ scintillator was produced.

Acrylic Module (1.2t) ***pre-filled at the production plant***, sealed and transported to LNGS.

Vessel ***engineering*** study under ***final review*** with Reynolds Polymer Technology, Inc.

Ongoing Risk Analysis of the LS veto, to be submitted to LNGS in Spring 2018.

Production plant and transportation system for large quantities is coming together.

It leverages on ***infrastructure built and operative*** @ MPIK

Calibration/DAQ/Slow Control/Computing

SAME *source deployment system* as ***XENON1T***.

+

pulsed-neutron generator

SAME *DAQ* as ***XENON1T*** (reached *96% up-time* fraction*)*.

Digitizers/CPUs for extra channels (+246) already procured.

Double Gain Amplifiers under production (0v2b)

SAME computing/ processing framework as ***XENON1T.***

Scalable since based on *OSG/EGI* resources and ***LHC***-developed ***data management***.

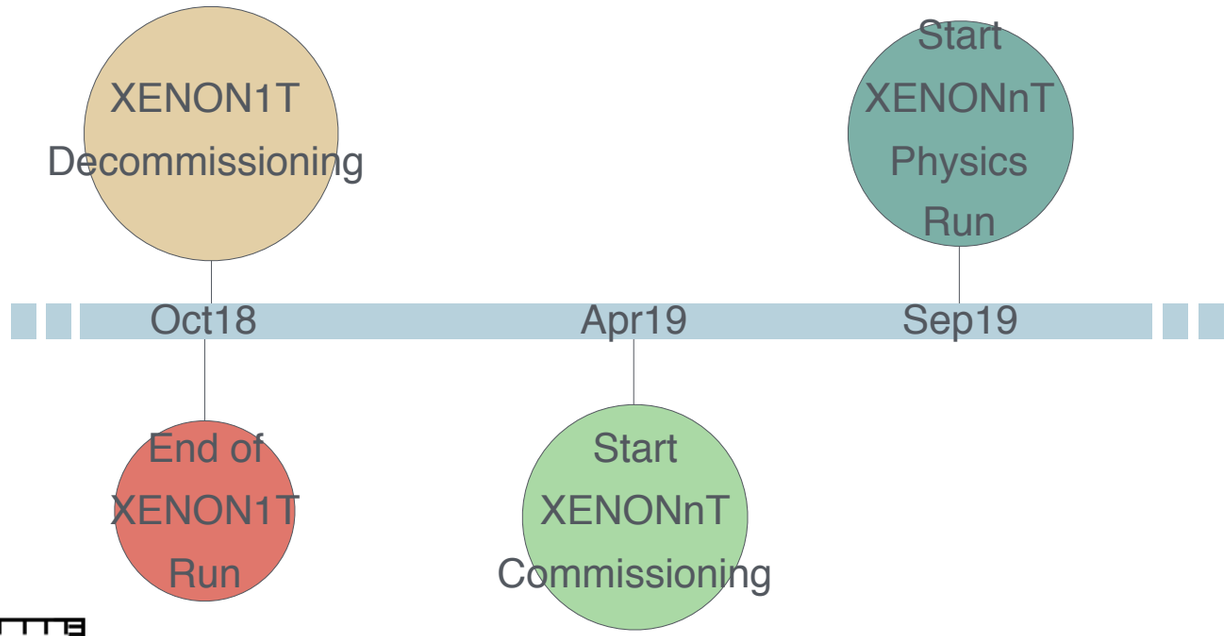
Extra storage under procurement.

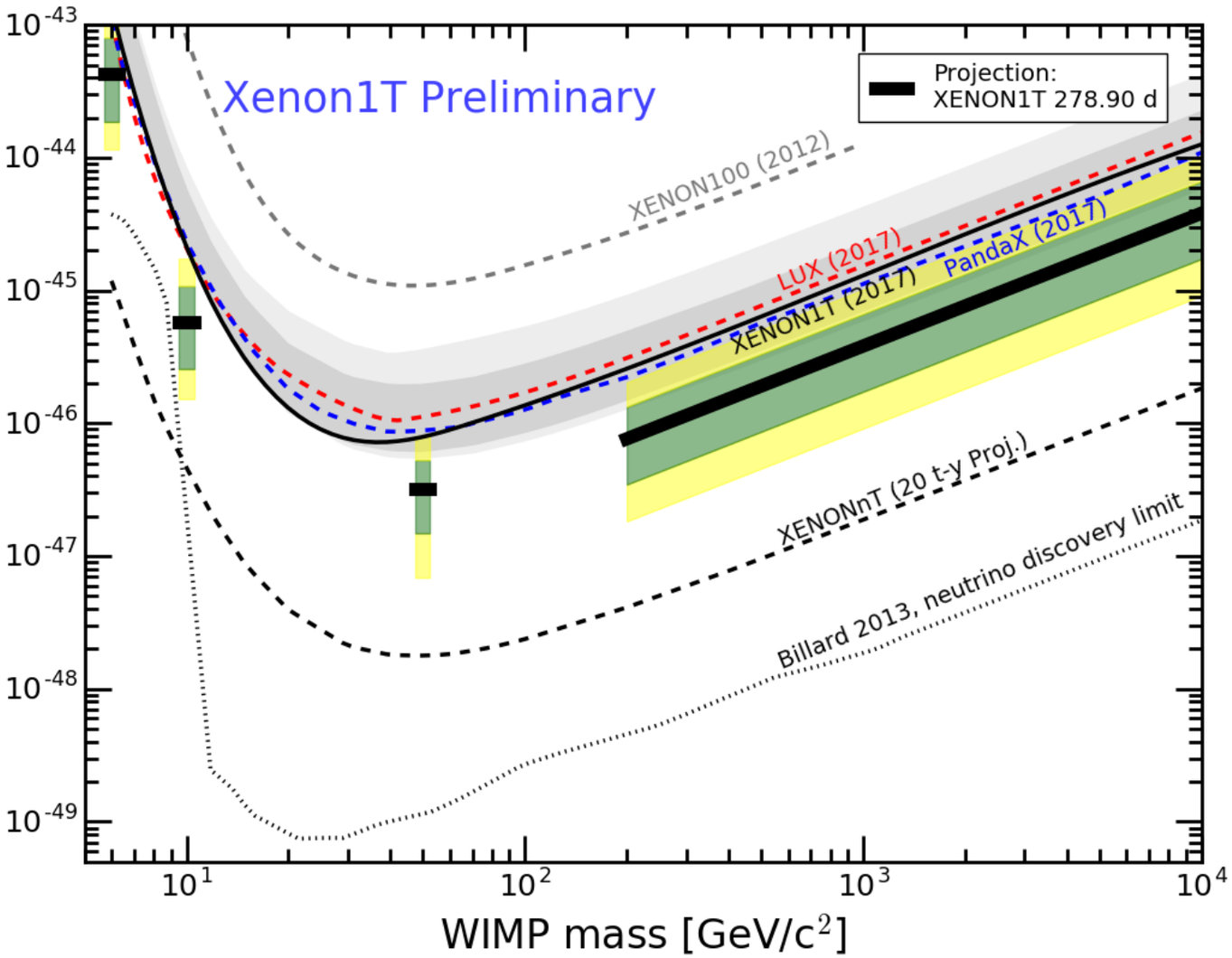
SAME Slow Control as ***XENON1T***

Thoroughly tested and certified during the last 2 years- update for new equipment

XENONnT on the Horizon

SENSITIVITY & SCHEDULE





Summary

- First result from XENON1T, the world's most sensitive dark matter search, yielded the most stringent limit on SI WIMP cross section with only 34 live days.
- New SI result from an exposure of 1 ton-year to be released within weeks.
- Demonstrated > 1 year operation with 3.2 t of LXe: a milestone for this technology.
- Achieved the lowest background ever measured in a DM detector: 0.2 events/ (t keV d).
- With 1 ton-year exposure we will search for many more rare events: SD, inelastic scattering, low-mass WIMPs(S2 only), ER searches (axions, etc.), annual modulation of ER rate, bb-decay of Xe136, and more..
- XENON1T continues to take data until we upgrade it to XENONnT.
- XENONnT funded and on track. First science data by late 2019.