Status of the XENON1T Experiment

DBD2016 Workshop, Osaka, Japan.

Alessandro Manfredini
On behalf of the XENON collaboration.

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The XENON Collaboration

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Rice NYUAD

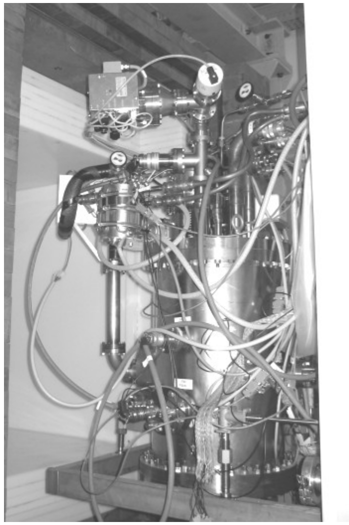
Purdue Coimbra Subatech Bologna LNGS Torino Weizmann

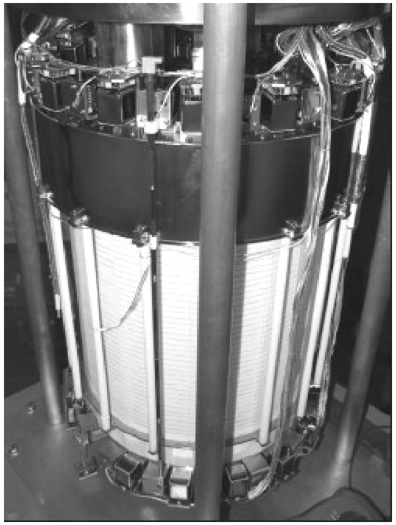
21 Institutions

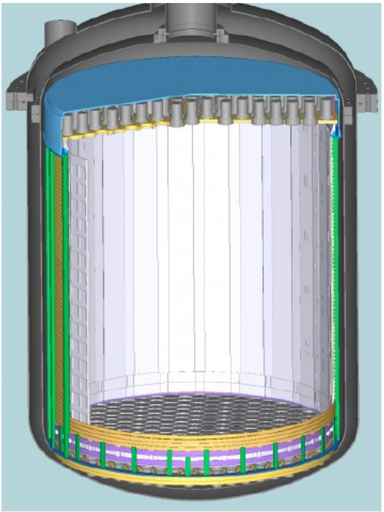
10 Countries

130 Scientists

The XENON Project







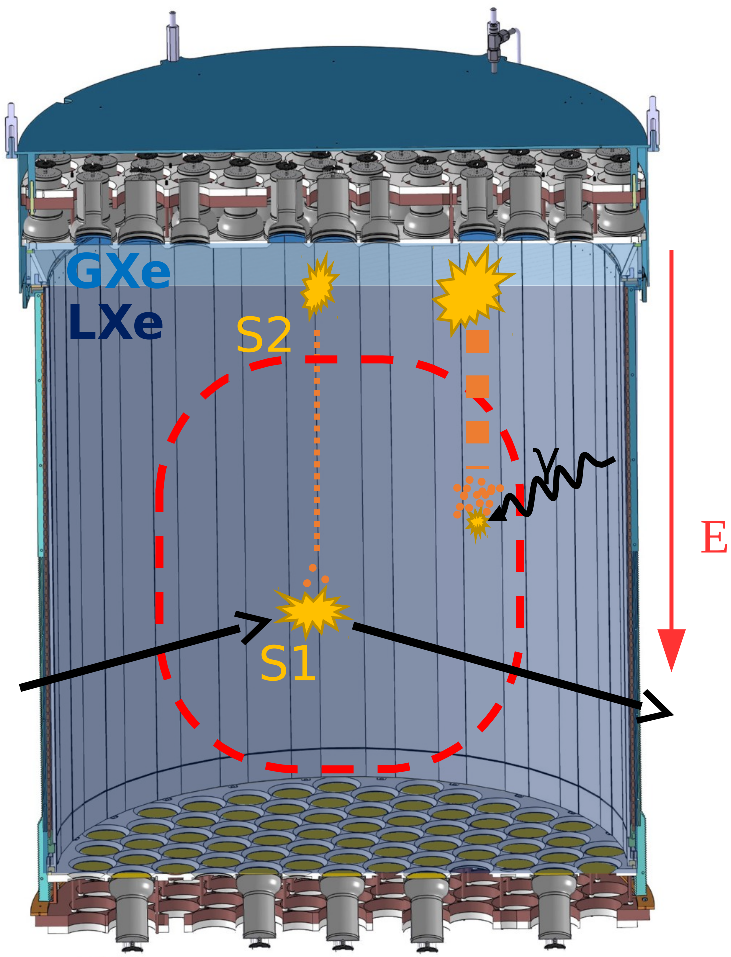
XENON10:
- 2005-2007
- 15 cm drift
- 25kg of Xe

XENON100:
- 2008-2016
- 30 cm drift
- 161 kg of Xe of which 62kg as target

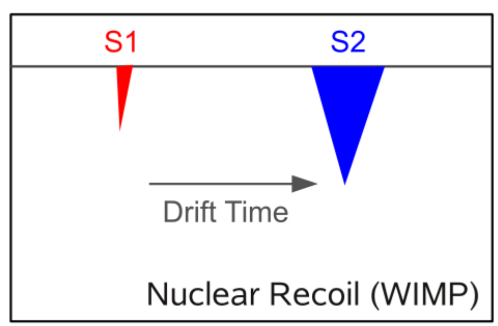
XENON1T:
- 2012-2018
- 96 cm drift
- 3200 kg of Xe of which 2 tonnes as target

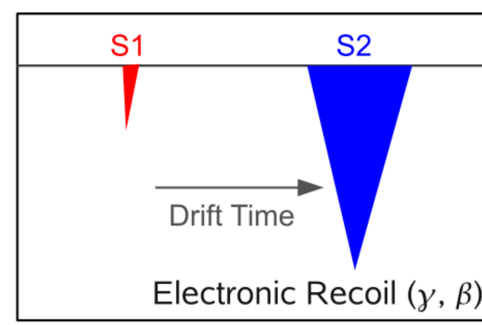
XENONnT:
- ~2019-2023
- 144 cm drift
- ~8000 kg of Xe
- 6 tonnes as target

Dark Matter Detection Principle

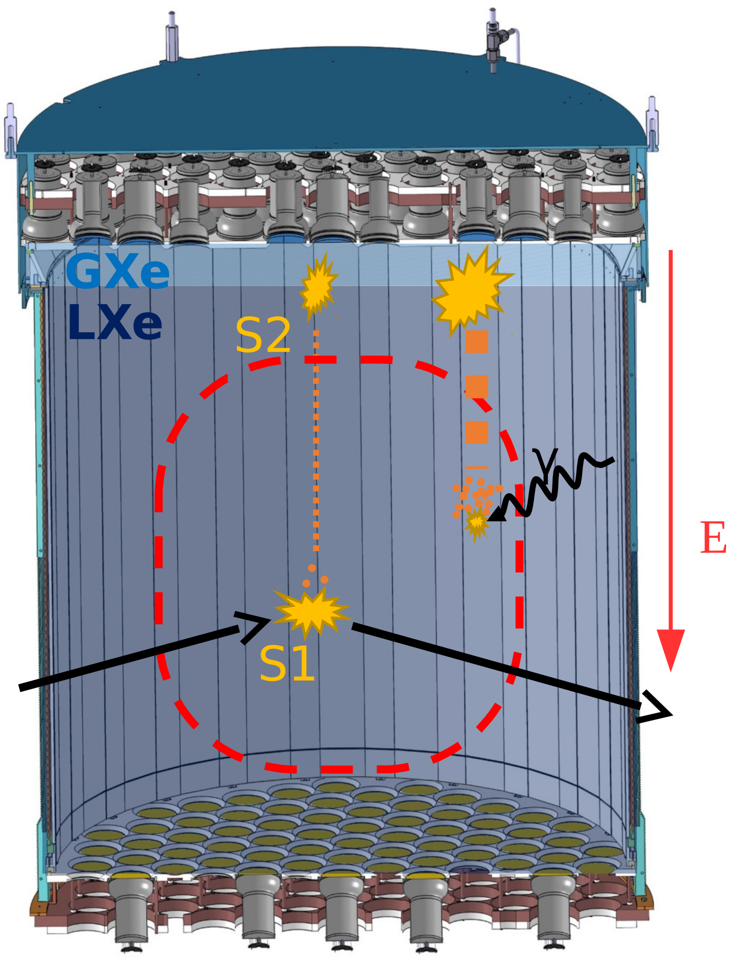


- XENON1T is dual phase Xe TPC
- Two signals (S1, S2) for each event which allows 3D positioning
- WIMPs will produce a nuclear recoil
- Separation between electronic and nuclear recoil is achieved with the ratio between charge (S2) and scintillation (S1) signals.





Dark Matter Detection Principle



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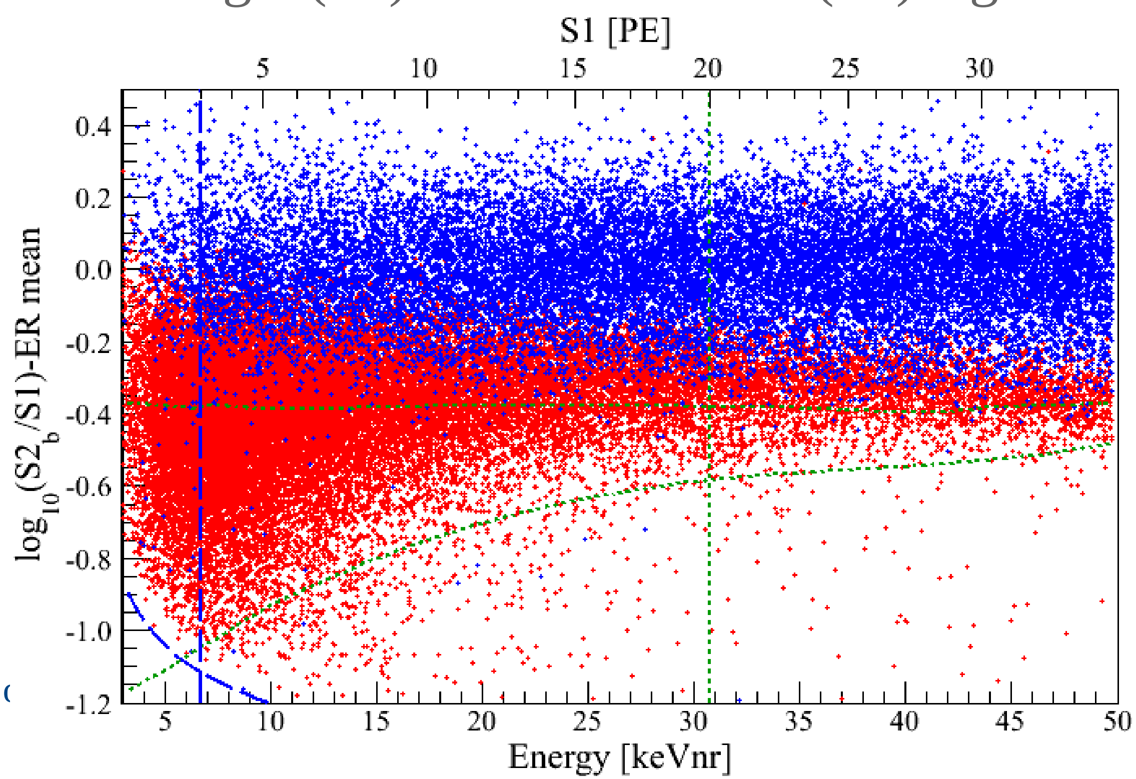


XENON1T Design Goals

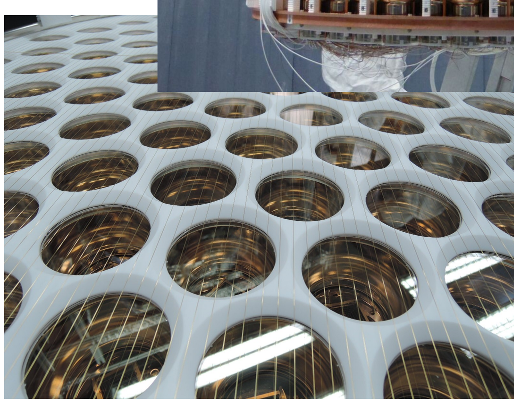
A rich science program:

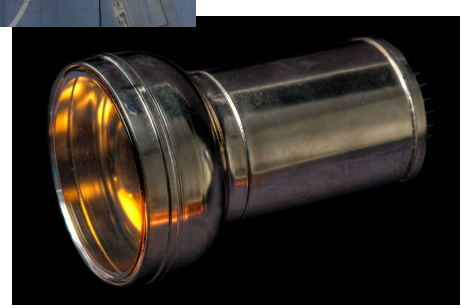
- Search for dark matter: with 2 tonne year exposure we expect to be sensitive to spin independent WIMP-nucleon scattering cross section of ~1.6 10^{-47} cm^2
- Not only dark matter:
  - measurement of coherent neutrino scattering is in principle possible
  - Search for two neutrino double electron capture on ^{124}Xe

Very low background conditions are needed:

- Overall background reduction of a factor 100 wrt XENON100
- 0.2 ppt of Kr (in 1 tonne fiducial volume)
- 10 μBq/kg of ^{222}Rn (in 1 tonne fiducial volume)
- Muon induced events < 1 in 2 tonne year

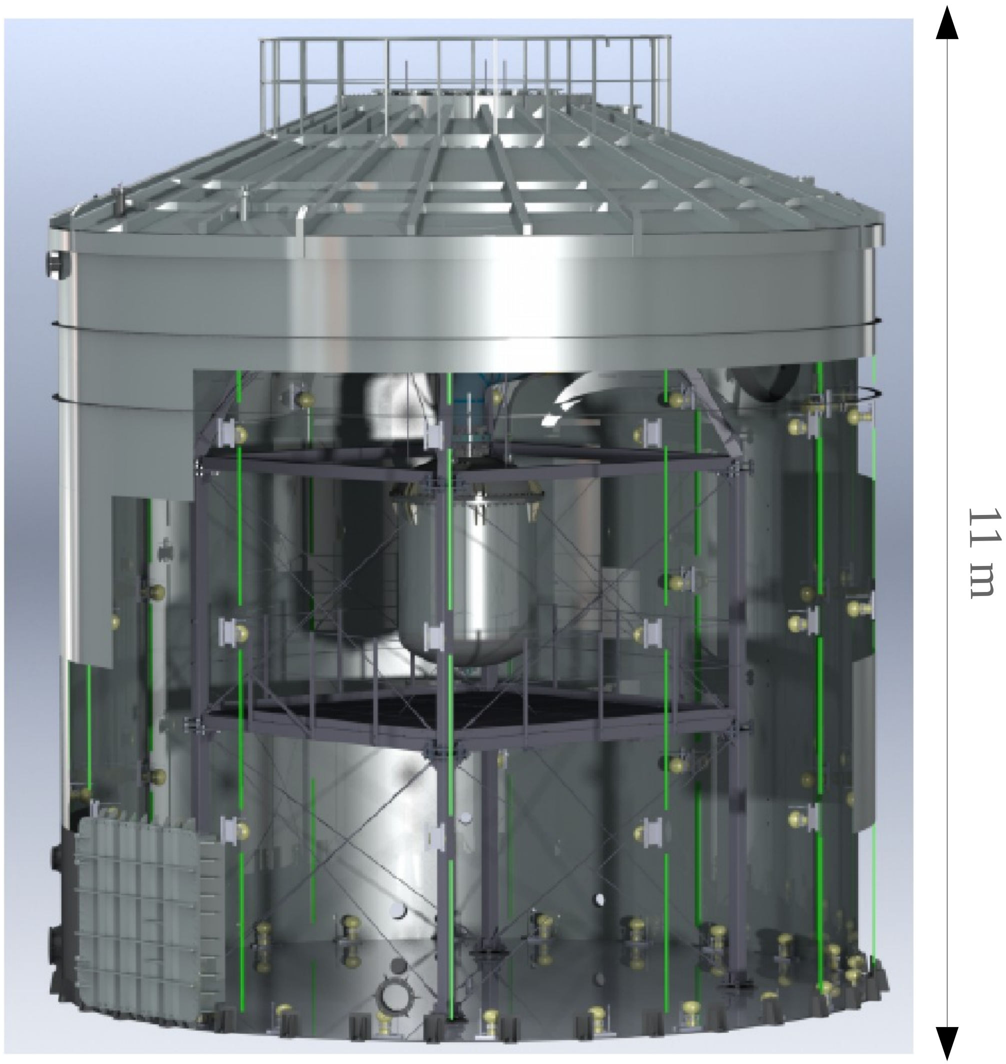
XENON1T: TPC





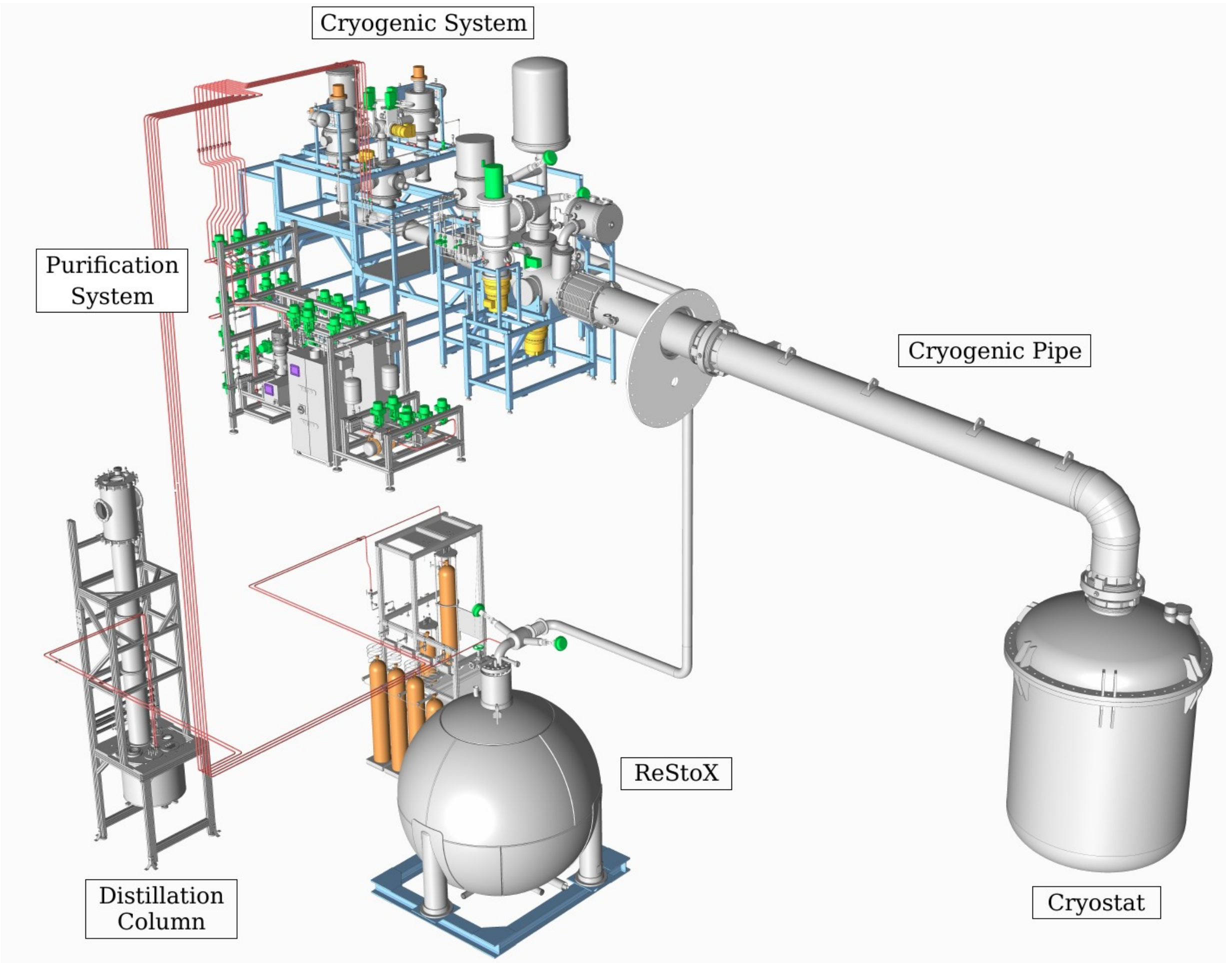
- 96 cm drift x 96 cm diameter TPC has been installed at LNGS (Italy)
- Material have been chosen after an extensive radioactivity screening campaign
- 248 low radioactivity 3" PMTs
- high QE (~35%) R11410-21 (arXiv:1503.07698)
- Covered with high reflectivity PTFE → maximize light collection efficiency

XENON1T: Water Shield



- The cryostat is immersed in a water shield filled with 700 tonnes of water
- Deionized water is used as passive shield from environmental radiation
- Water is constantly purified
- Equipped with 84 high-QE, 8" PMTs
- All walls are covered with reflective foil
- Detects Cherenkov light to tag muons.
- Expected muon flux underground is 10^{-2} /m^2h → reduced to an expected background of 0.01 ev/year with muon tagging (arXiv:1406.2374)
- Fully commissioned in March 2016

XENON1T: Xe Handling Systems

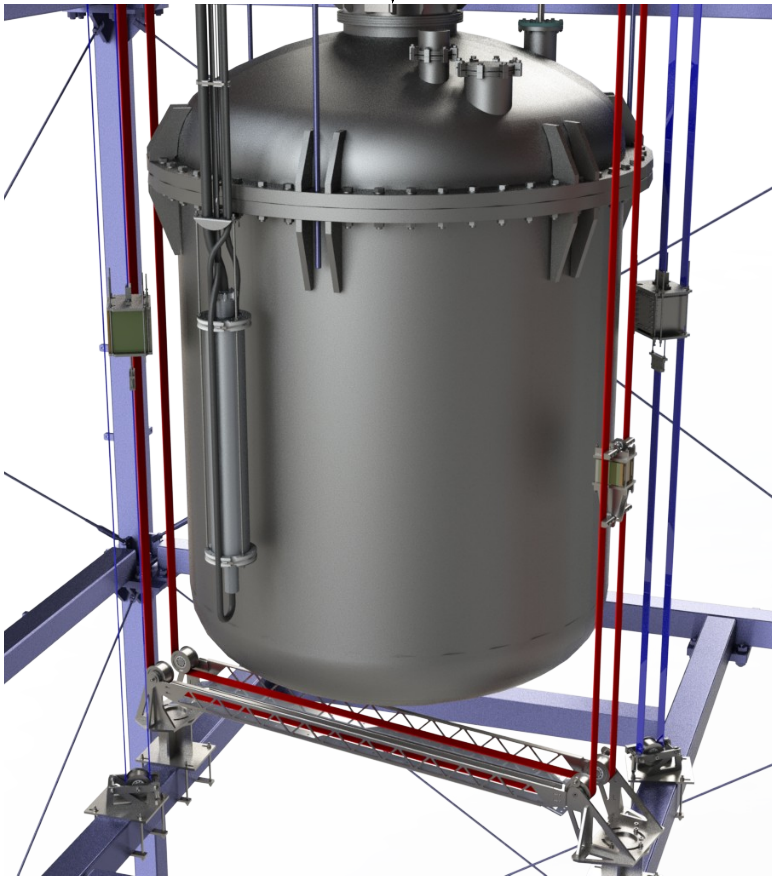


- The same system will be shared between XENON1T and nT
- Safety system for Recuperation and Storage of Xenon (ReStoX)
- Constant Xe purification with two getters working in parallel
- Online Kr distillation, no need to empty detector.
- Status: the Xe handling system is commissioned and fully operational.

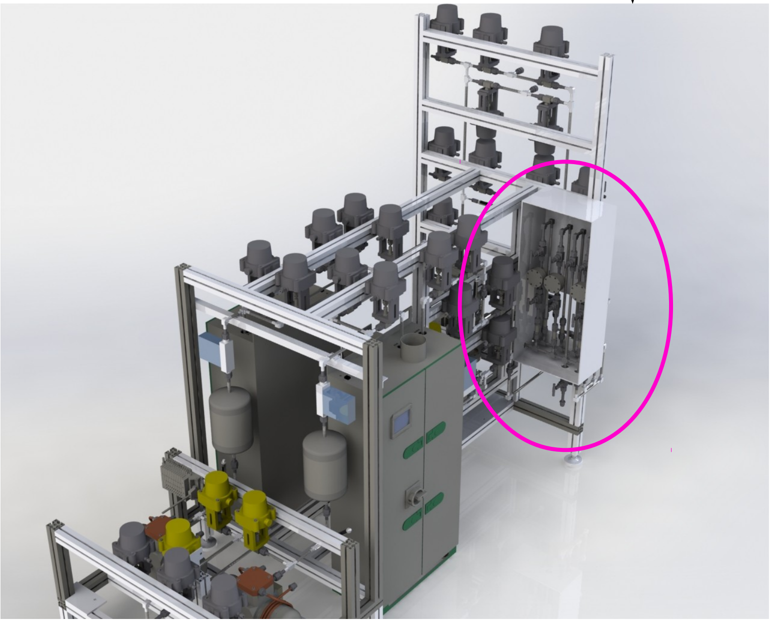
XENON1T: calibration system

Two possible calibration methods:

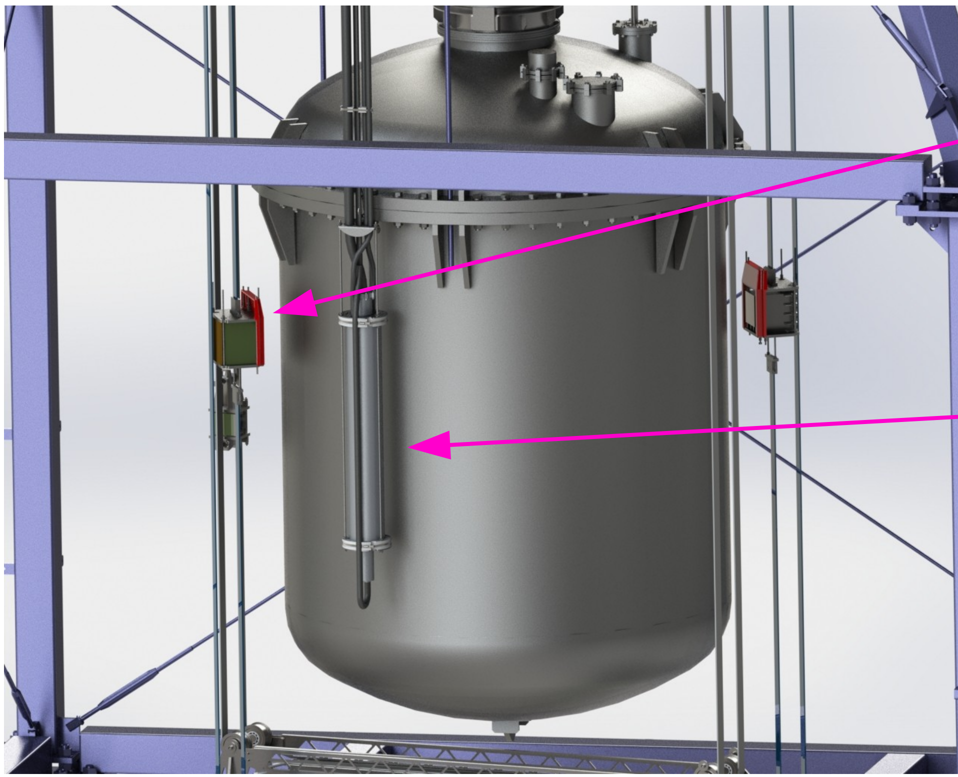
Via external sources moved on a system of belts and winches.



Via “internal” sources, i.e. injected as gas after the purification system



External Calibration System

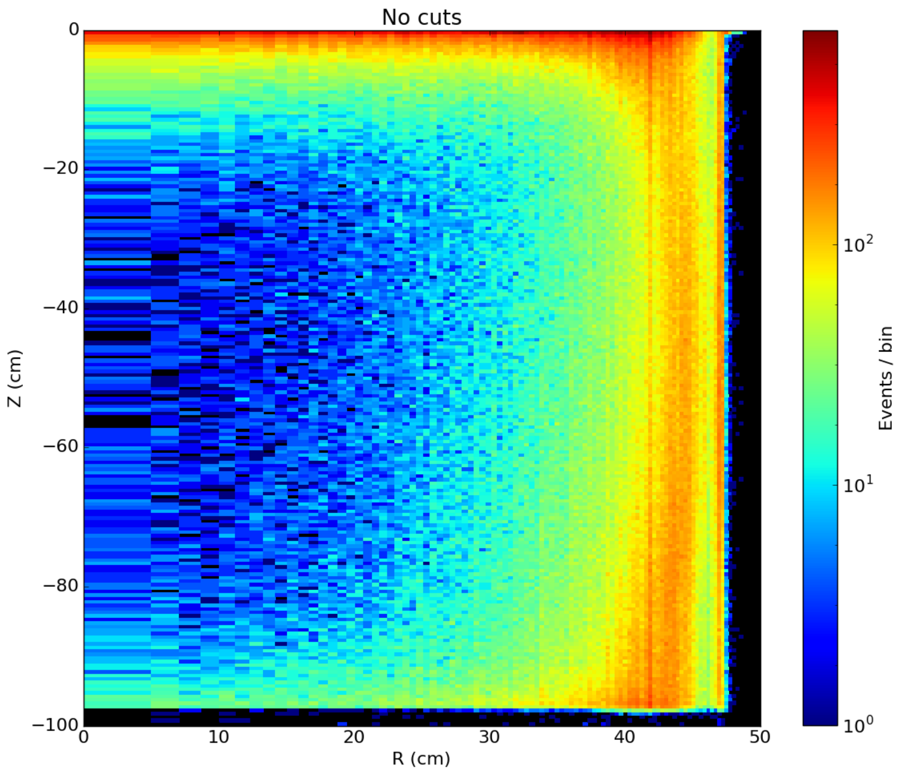


- Two tungsten collimator can house exchangeable sources.
- Possibility for a third collimator to satisfy future requirements.
- A deuterium fusion neutron generator which produces 2.5 MeV neutrons can be immersed in water.
- XENON1T is expected to be able to identify neutron double scatter → measure of Leff, Qy. As done already by LUX (arXiv:1608.05381)
- Data taken with following sources: Cs^{137} and AmBe, expected Th^{232}

Internal Calibration System

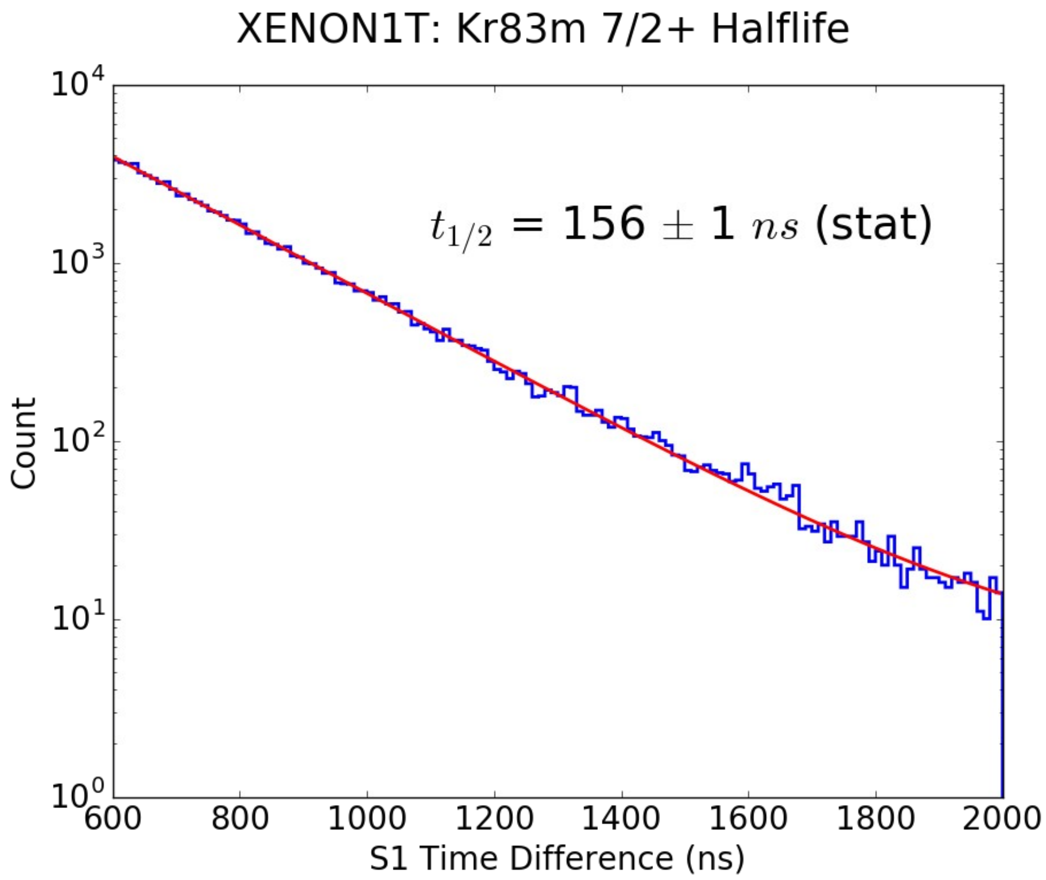
- Radioactive isotopes are mixed directly into the xenon recirculation system
- Three different sources have been selected:
  - ^{83m}Kr for energy scale calibration
  - ^{220}Rn as a probe of Rn emanation background and to low energy electronic recoil.
  - Tritiated methane for low energy ER. Long lifetime, need to be removed by purification system afterwards
  - XENON1T data already taken with ^{83m}Kr and ^{220}Rn

System Commissioning



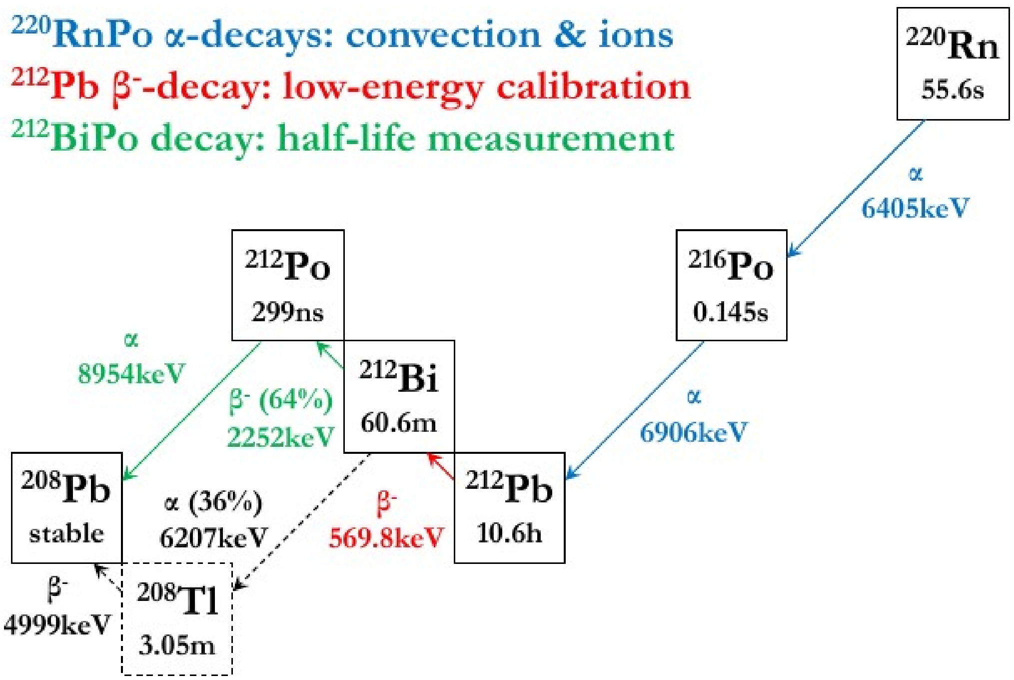
- Detector filled with 3.2 tonnes since April
- The TPC is fully active
- Water shield filled in July
- Factor 2 improved light yield wrt XENON100 (from Kr calibration data)
- Electron lifetime monotonically increasing!
- Current status: detector calibration with neutrons, data taking.

Operation Summary: Internal Calibration ^{83m}Kr



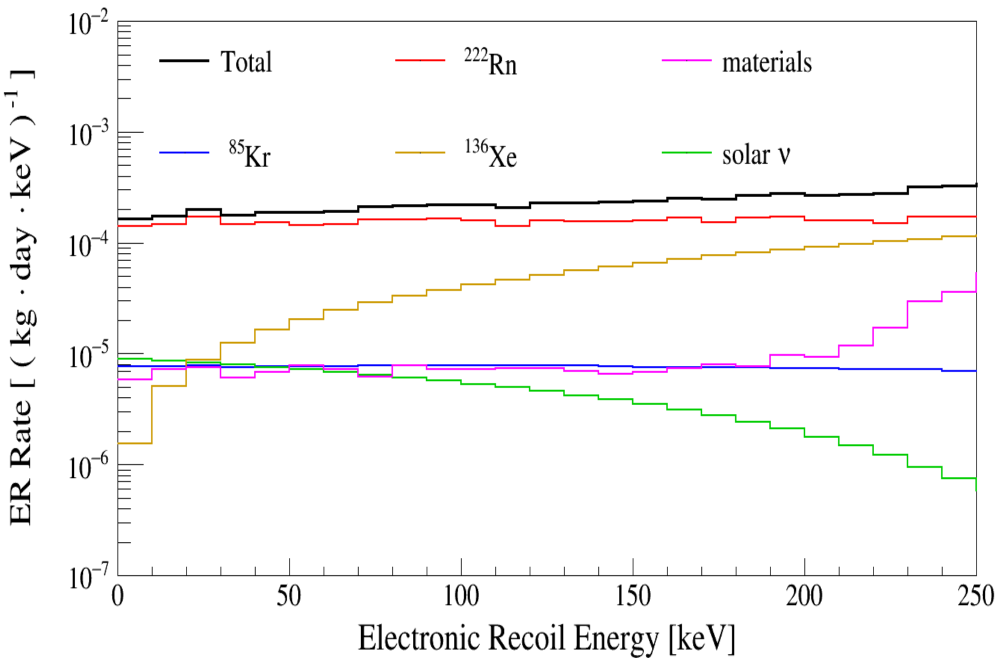
- In August performed the first ^{83m}Kr calibration
- ^{83m}Kr undergoes two subsequent decays via electron conversion.
- Emits electrons with energies of 32 and 9 KeV
- The halflife of the second decay is 154ns.
- Useful for low energy calibration and light collection efficiency maps.
- Plan to get regular ^{83m}Kr calibration data.

Operation Summary: Internal Calibration ^{220}Rn

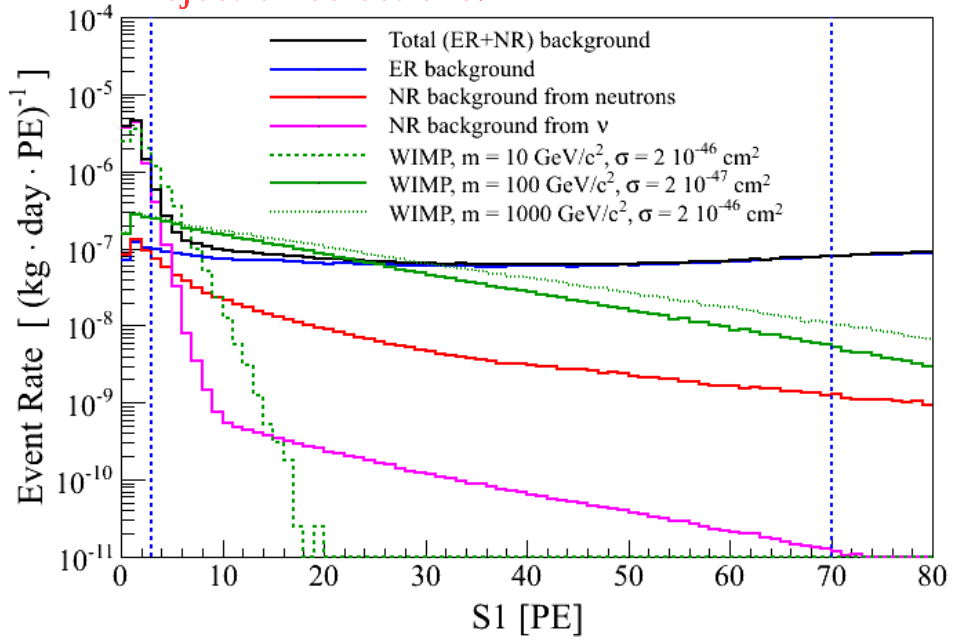


- Proof of concept on XENON100 (arXiv:1602.01138)
- XENON1T data were taken recently in October.
- ^{220}Rn emanated from a ^{228}Th source
- No long lived isotopes → cleaning achievable in a week
- Probe for ^{222}Rn, ER spectrum with β from ^{212}Po
- Measure of convection possible with Rn-Po decay.

Expected Backgrounds



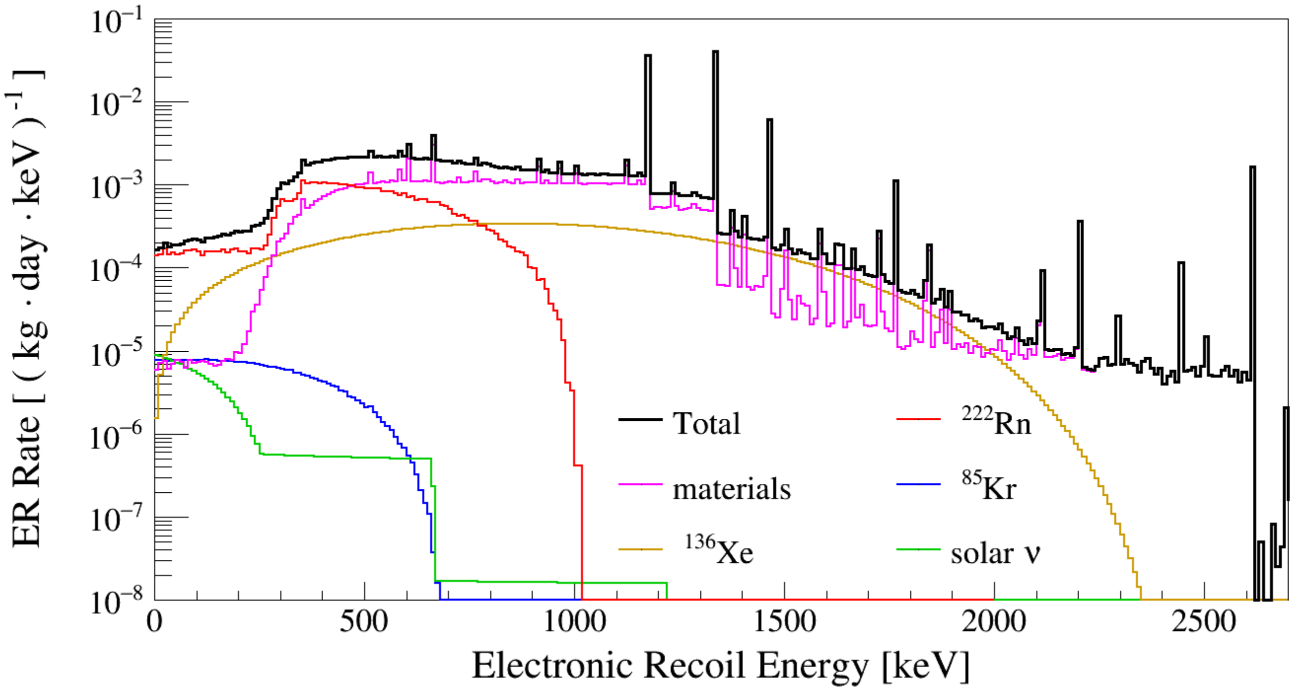
Expected spectrum after 99.75% ER rejection selections.



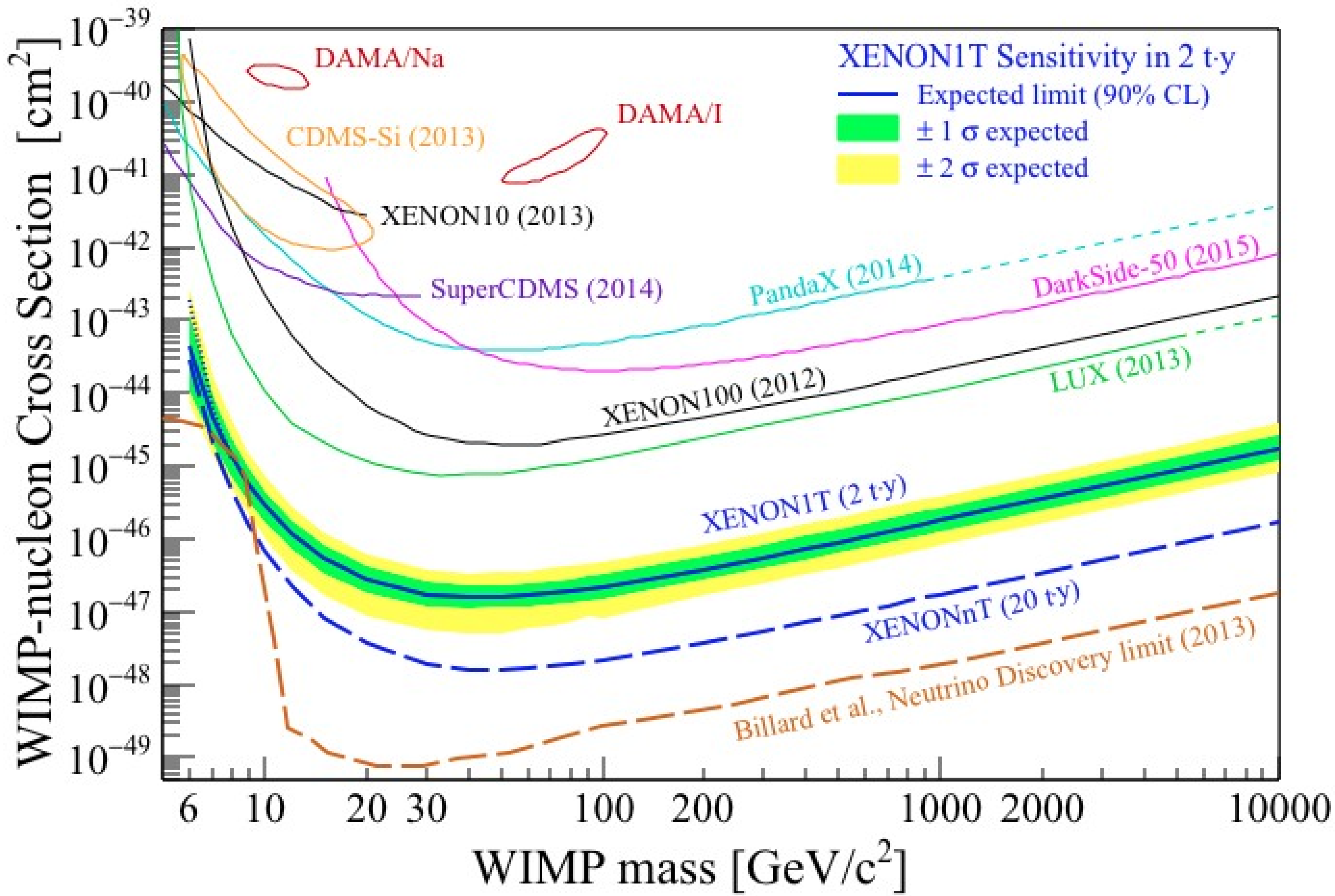
- Total Electronic Recoil (ER) background expected for 1T fiducial volume is $1.8\cdot10^{-4}$ $(\text{kg}\cdot\text{day}\cdot\text{KeV})^{-1}$ (*JCAP04(2016)027)*
- Total Nuclear Recoil background in the region of interest is 0.6 $(\text{tonne}\cdot\text{year})^{-1}$
- ^{222}Rn is the dominant contribution for ER, while is radiogenic neutrons for NR.
- It assumes: 10 μBq/kg of ^{222}Rn and 0.2 ppt of ^{nat}Kr

Background Analysis: ^{222}Rn

- ^{222}Rn is expected to be the dominant ER background.
- A preliminary analysis that identifies α decays reports a concentration compatible with what expected from MC prediction using material screening data.



XENON1T Expected Sensitivity

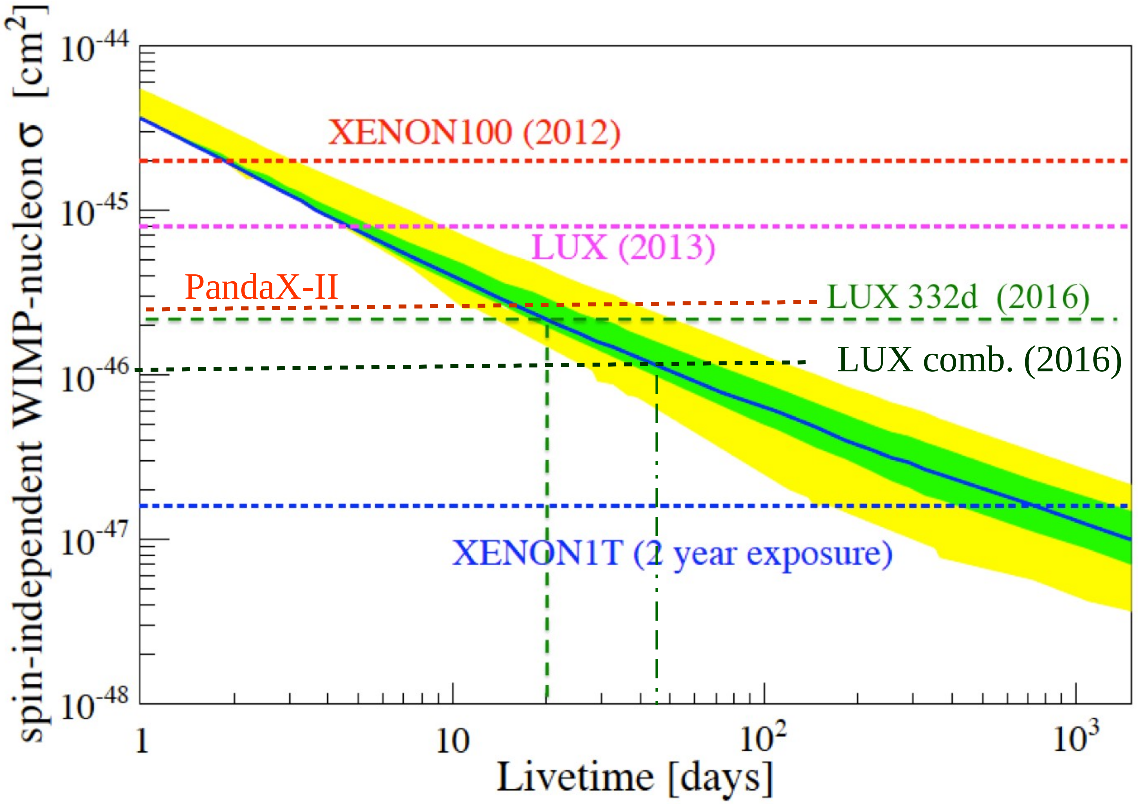


Assuming the LUX (arXiv:1608.05381) LXe emission model and a 2T·year exposure, the expected sensitivity for spin-independent WIMP-nucleon scattering of a 50 GeV WIMP mass is $1.6\ 10^{-47}$ cm^2.

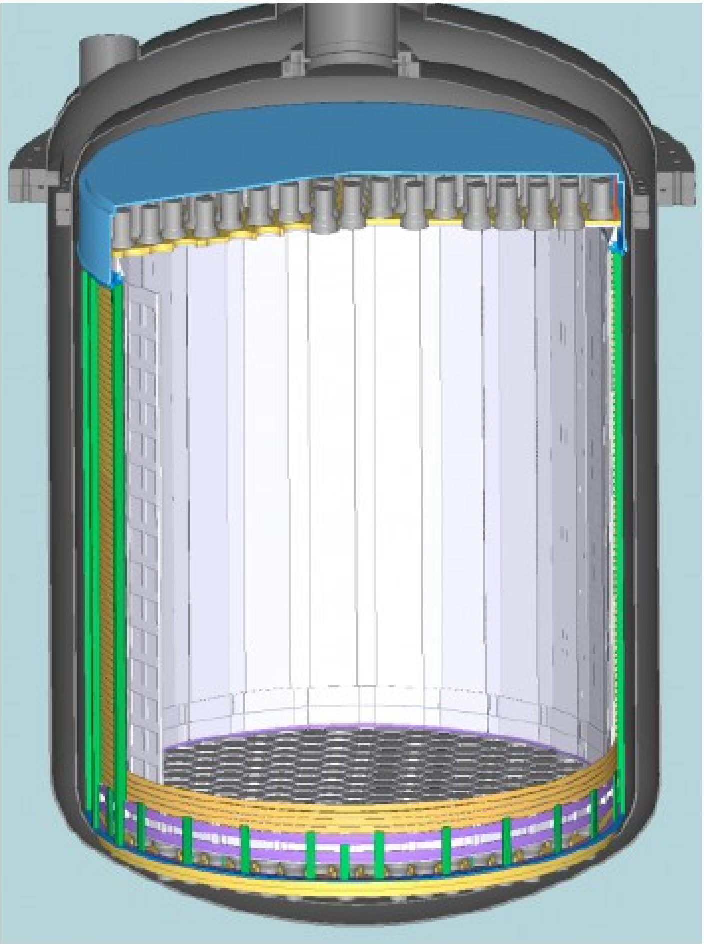
Summary of Current Status and Next Steps

- Detector and all system in regular operation phase, all performing well
- Light yield and charge yield keep improving with purification

- Background estimation compatible with design goals.
- Detector under calibration with neutrons.
- Kr removal via distillation is expected to start soon.
- Dark matter science run after Kr removal.
- Will reach the current best experimental sensitivity to WIMP in about ~30 days



Prospects for XENONnT



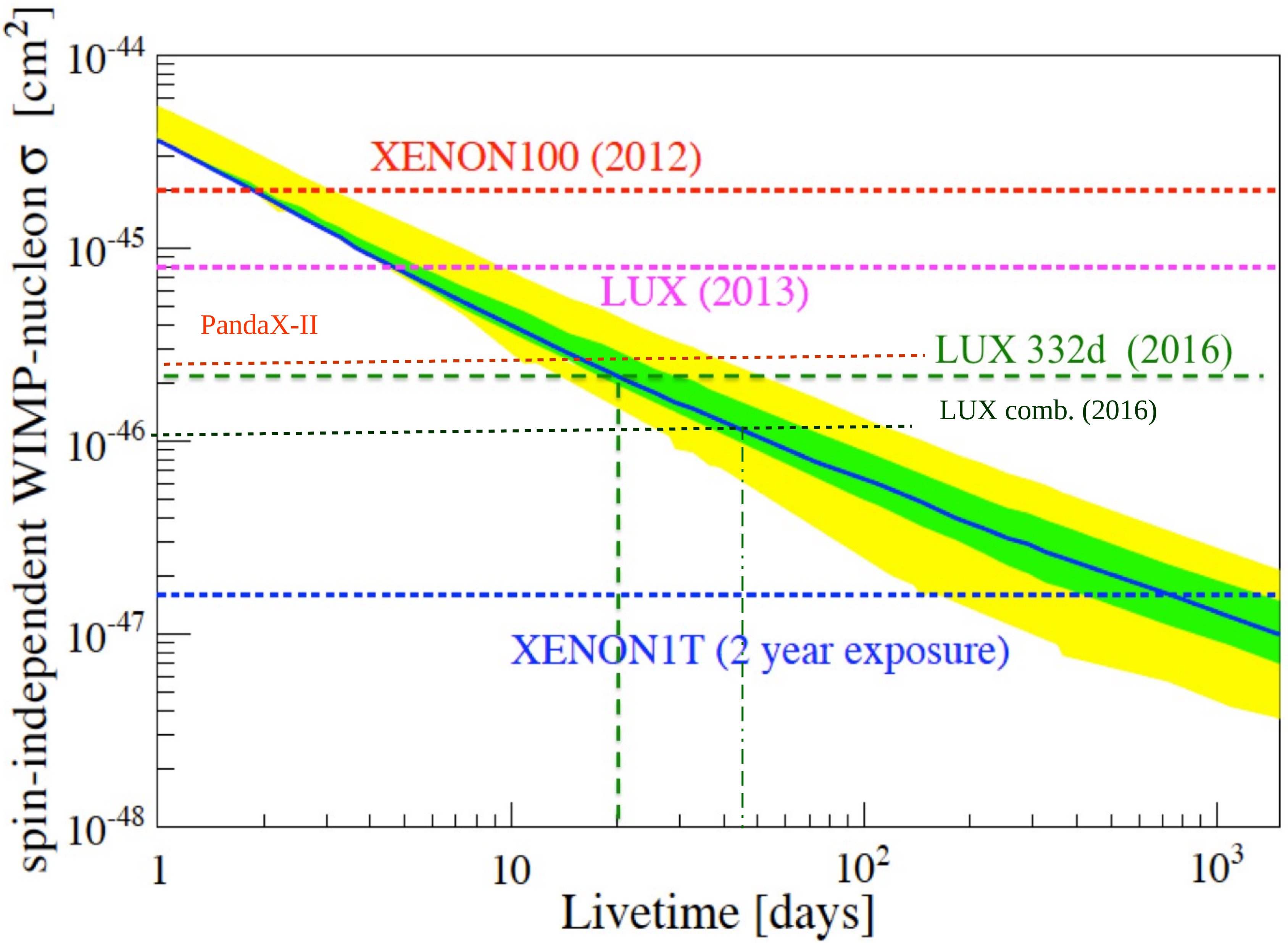
- XENON1T is envisioned to be upgraded to XENONnT with minimal interventions
- A new TPC and new cryostat vessel will be necessary, all other systems will receive minor upgrades.
- Additional PMTs: 248 → 476
- A larger total LXe mass of ~8 tonnes
- 6 tonne target, an increase of a factor x3!
- Installation late 2018.

Backup

Screening campaign

ID	Component	Material	Quantity	Unit	Contamination [mBq/unit]							
					^{238}U	^{235}U	^{226}Ra	^{232}Th	^{228}Th	^{60}Co	^{40}K	^{137}Cs
1	**Cryostat Shells**	SS	870	kg	2.4 ± 0.7	$(1.1 \pm 0.3) \cdot 10^{-1}$	$< 6.4 \cdot 10^{-1}$	$(2.1 \pm 0.6) \cdot 10^{-1}$	$< 3.6 \cdot 10^{-1}$	9.7 ± 0.8	< 2.7	$< 6.4 \cdot 10^{-1}$
2	**Cryostat Flanges**	SS	560	kg	1.4 ± 0.4	$(6 \pm 2) \cdot 10^{-2}$	< 4.0	$(2.1 \pm 0.6) \cdot 10^{-1}$	4.5 ± 0.6	37.3 ± 0.9	< 5.6	< 1.5
3	**Reservoir**	SS	90	kg	11 ± 3	$(5 \pm 2) \cdot 10^{-1}$	1.2 ± 0.3	1.2 ± 0.4	2.0 ± 0.4	5.5 ± 0.5	< 1.3	$< 5.8 \cdot 10^{-1}$
4	**TPC Panels** (1)	PTFE	92	kg	$< 2.5 \cdot 10^{-1}$	$< 1.1 \cdot 10^{-2}$	$< 1.2 \cdot 10^{-1}$	$< 4.1 \cdot 10^{-2}$	$< 6.5 \cdot 10^{-2}$	$< 2.7 \cdot 10^{-2}$	$< 3.4 \cdot 10^{-1}$	$(1.7 \pm 0.3) \cdot 10^{-1}$
5	**TPC Plates** (2)	Cu	184	kg	< 1.2	$< 5.5 \cdot 10^{-1}$	$< 3.3 \cdot 10^{-2}$	$< 4.3 \cdot 10^{-2}$	$< 3.4 \cdot 10^{-2}$	0.10 ± 0.01	$< 2.8 \cdot 10^{-1}$	$< 1.6 \cdot 10^{-2}$
6	**Bell and Rings** (3)	SS	80	kg	2.4 ± 0.7	$(1.1 \pm 0.3) \cdot 10^{-1}$	$< 6.4 \cdot 10^{-1}$	$(2.1 \pm 0.6) \cdot 10^{-1}$	$< 3.6 \cdot 10^{-1}$	9.7 ± 0.8	< 2.7	$< 6.4 \cdot 10^{-1}$
7	**PMT Stem**	Al_2O_3	248	PMT	2.4 ± 0.4	$(1.1 \pm 0.2) \cdot 10^{-1}$	$(2.6 \pm 0.2) \cdot 10^{-1}$	$(2.3 \pm 0.3) \cdot 10^{-1}$	$(1.1 \pm 0.2) \cdot 10^{-1}$	$< 1.8 \cdot 10^{-2}$	1.1 ± 0.2	$< 2.2 \cdot 10^{-2}$
8	**PMT Window**	Quartz	248	PMT	< 1.2	$< 2.4 \cdot 10^{-2}$	$(6.5 \pm 0.7) \cdot 10^{-2}$	$< 2.9 \cdot 10^{-2}$	$< 2.5 \cdot 10^{-2}$	$< 6.7 \cdot 10^{-3}$	$< 1.5 \cdot 10^{-2}$	$< 6.8 \cdot 10^{-3}$
9	**PMT SS**	SS	248	PMT	$(2.6 \pm 0.8) \cdot 10^{-1}$	$(1.1 \pm 0.4) \cdot 10^{-2}$	$< 6.5 \cdot 10^{-2}$	$< 3.9 \cdot 10^{-2}$	$< 5.0 \cdot 10^{-2}$	$(8.0 \pm 0.7) \cdot 10^{-2}$	$< 1.6 \cdot 10^{-1}$	$< 1.9 \cdot 10^{-2}$
10	**PMT Body**	Kovar	248	PMT	$< 1.4 \cdot 10^{-1}$	$< 6.4 \cdot 10^{-3}$	$< 3.1 \cdot 10^{-1}$	$< 4.9 \cdot 10^{-2}$	$< 3.7 \cdot 10^{-1}$	$(3.2 \pm 0.3) \cdot 10^{-1}$	< 1.1	$< 1.2 \cdot 10^{-1}$
11	**PMT Bases**	Cirlex	248	PMT	$(8.2 \pm 0.3) \cdot 10^{-1}$	$(7.1 \pm 1.6) \cdot 10^{-2}$	$(3.2 \pm 0.2) \cdot 10^{-1}$	$(2.0 \pm 0.3) \cdot 10^{-1}$	$(1.53 \pm 0.13) \cdot 10^{-1}$	$< 5.2 \cdot 10^{-3}$	$(3.6 \pm 0.8) \cdot 10^{-1}$	$< 9.8 \cdot 10^{-3}$
12	**Whole PMT**	-	248	PMT	8 ± 2	$(3.6 \pm 0.8) \cdot 10^{-1}$	$(5 \pm 1) \cdot 10^{-1}$	$(5 \pm 1) \cdot 10^{-1}$	$(5.0 \pm 0.6) \cdot 10^{-1}$	$(7.1 \pm 0.3) \cdot 10^{-1}$	13 ± 2	$< 1.8 \cdot 10^{-1}$

Table 1. Summary of the contaminations of the materials considered in the XENON1T Monte Carlo simulation.
(1) includes all the PTFE components present in the TPC walls, rings and pillars, the plates of the two support structures of the PMTs, and a trapezoidal section ring on top of the TPC;
(2) field shaping rings and support structure of the two PMT arrays;
(3) top and lateral part of the bell; support rings of the five electrodes.



spin-independent WIMP-nucleon σ [cm²]
10-44
10-45
10-46
10-47
10-48
XENON100 (2012)
LUX (2013)
PandaX-II
LUX 332d (2016)
LUX comb. (2016)
XENON1T (2 year exposure)
1
10
10²
10³
Livetime [days]

Calibrating XENON1T

- XENON1T is designed to reduce external background → difficult to calibrate with external source. However external sources are more versatile.
- Using known sources one can combine S1 and S2 obtaining a “combined energy scale” probe for energy deposition.
- Calibration sources are used to evaluate detector response to WIMP: the light yield (Ly), charge yield (Y), light collection efficiency, Leff and Qy (to translate response to nuclear recoil).
- Electronic recoil and nuclear recoil spectrum can be obtained with sources.