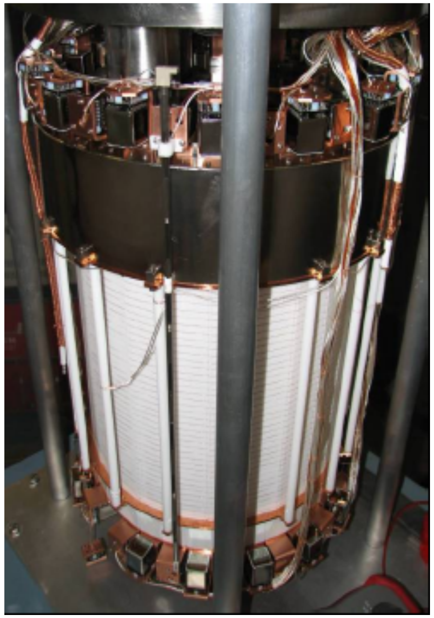
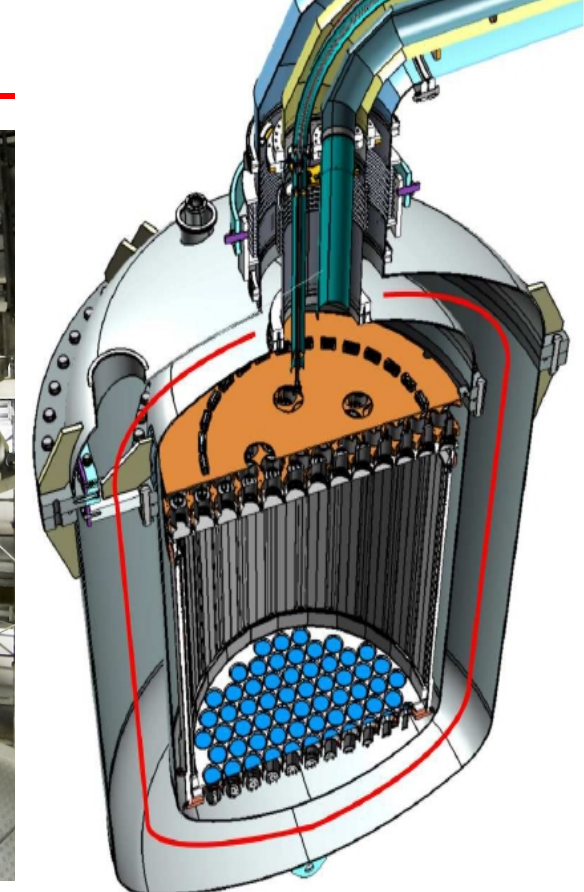
Status Report on the XENON1T experiment

J. Masbou,
on behalf of the XENON Collaboration

The XENON Dark Matter Program





XENON10
2005 – 2007
15 cm drift TPC
Total: 25 kg
Target: **14** kg
Fiducial: 5.4 kg

Achieved (2007)
$\sigma_{SI} = 8.8 \cdot 10^{-44}$ cm^2
@ 100 GeV/c^2

XENON100
2008 – 2016
30 cm drift TPC
Total: 161 kg
Target: **62** kg
Fiducial: 34/48 kg

Achieved (2015)
$\sigma_{SI} = 1.1 \cdot 10^{-45}$ cm^2
@ 55 GeV/c^2

XENON1T
2012 – 2019
100 cm drift TPC
Total: 3 200 kg
Target: **2 000** kg
Fiducial: 1 000 kg

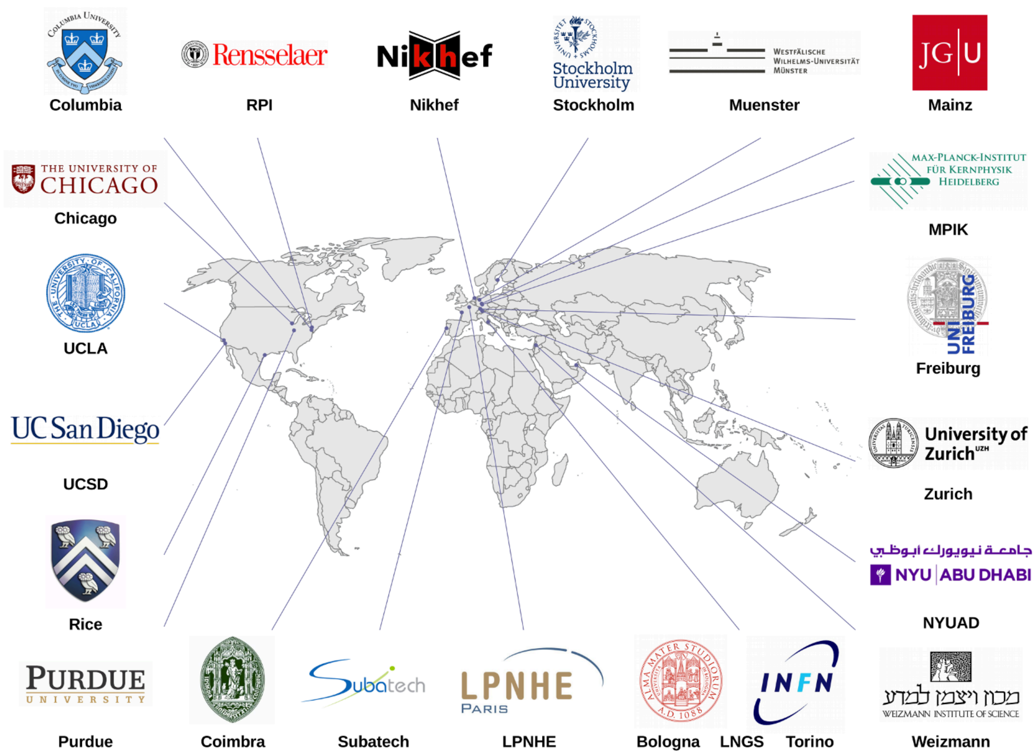
Projected (2019)
$\sigma_{SI} = 1.6 \cdot 10^{-47}$ cm^2
@ 50 GeV/c^2

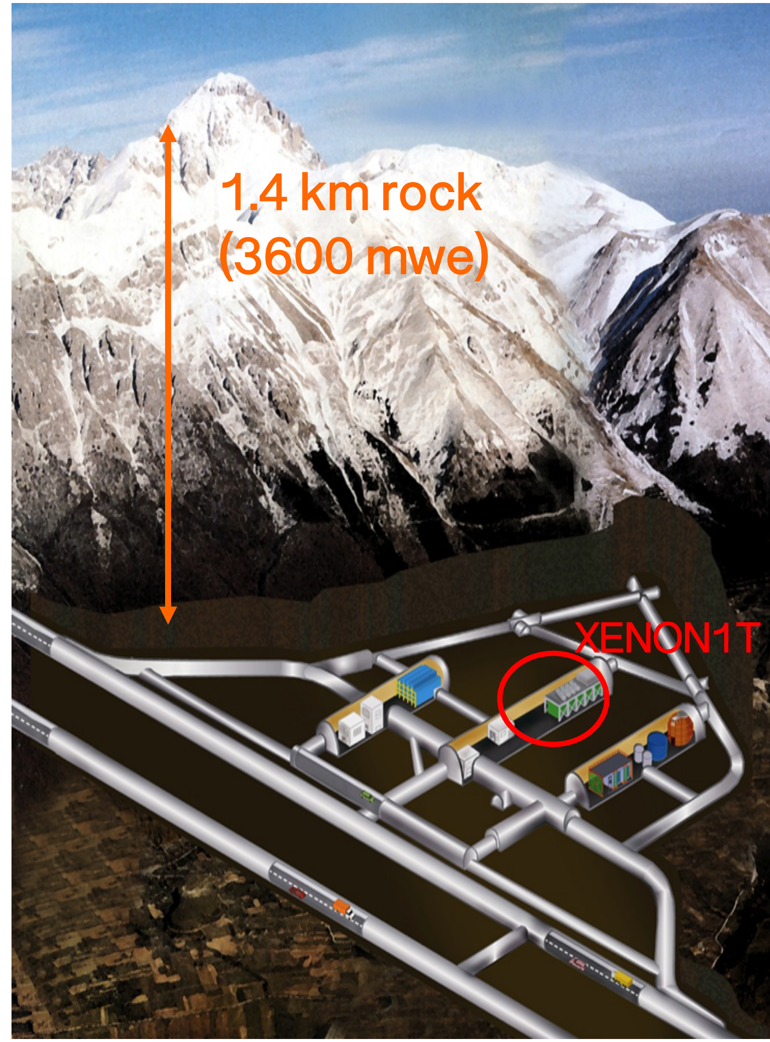
XENONnT
2017 (R&D) – 2023
144 cm drift TPC
Total: 8 000 kg
Target: **6 000** kg
Fiducial: 4 500 kg

Projected (2022)
$\sigma_{SI} = 1.6 \times 10^{-48}$ cm^2
@ 50 GeV/c^2

XENON experiment

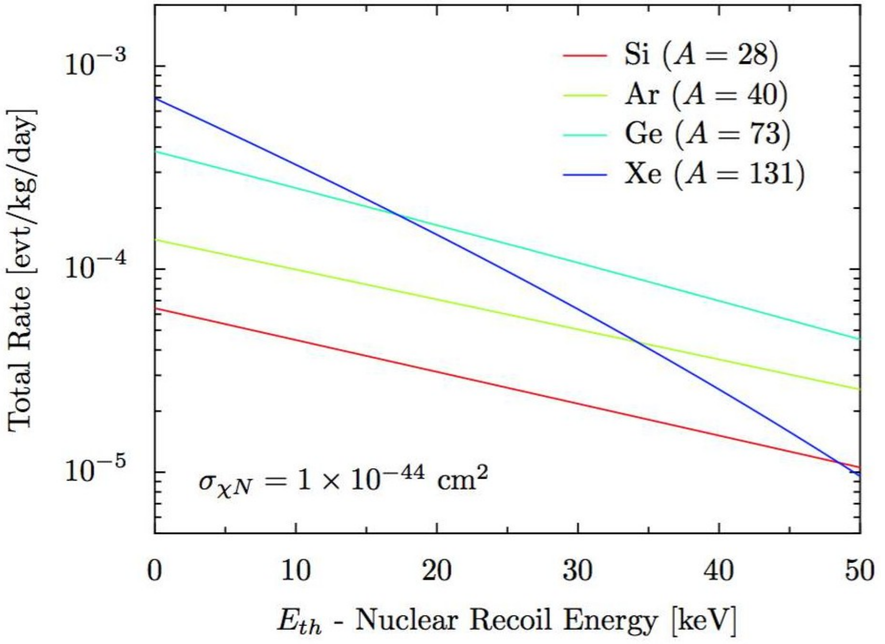
21 Institutes
~130 members



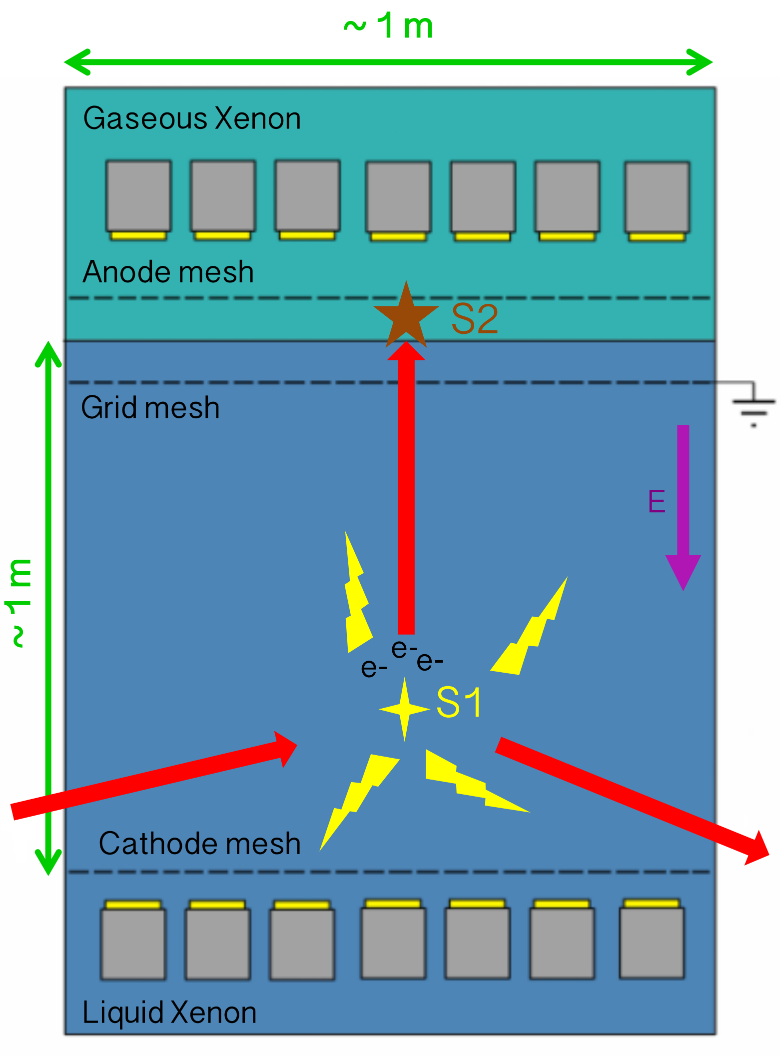


Why Xenon ?

- Large mass number A (131) (Interaction cross section $\propto A^2$)
- 50% odd isotopes (^{129}Xe, ^{131}Xe) for Spin-Dependent interactions
- High stopping power, i.e. active volume is self-shielding
- Efficient scintillator (178 nm)
- Scalable to large target masses
- Electronic recoil discrimination with simultaneous measurement of scintillation and ionization



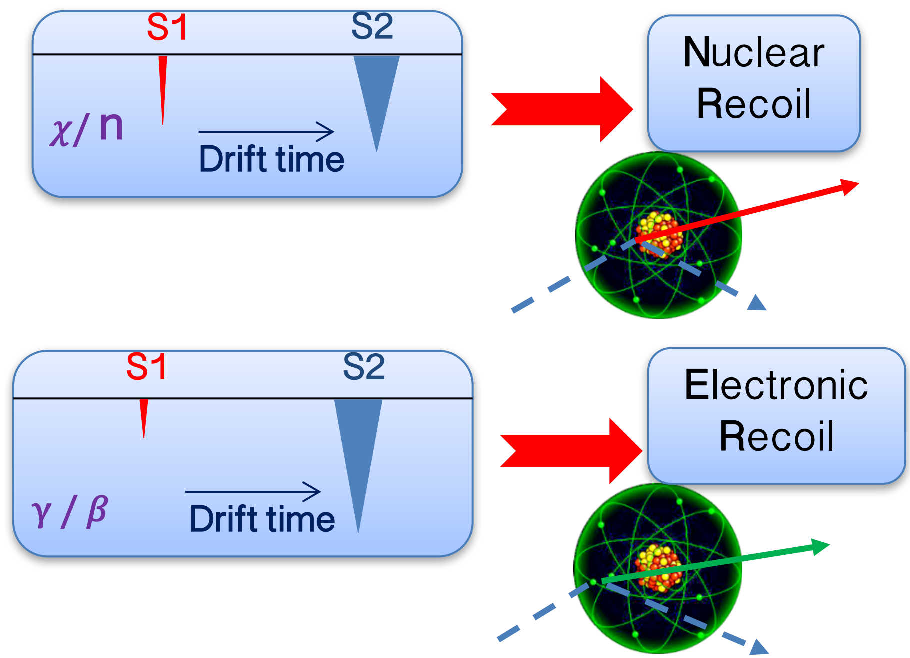
Two phase XENON TPC principle



S1:
→ Photon (λ = 178 nm) from Scintillation process → Detected by PMTs (mainly bottom array)

S2:
→ Electrons drift
→ Extraction in gaseous phase
→ Proportional scintillation light

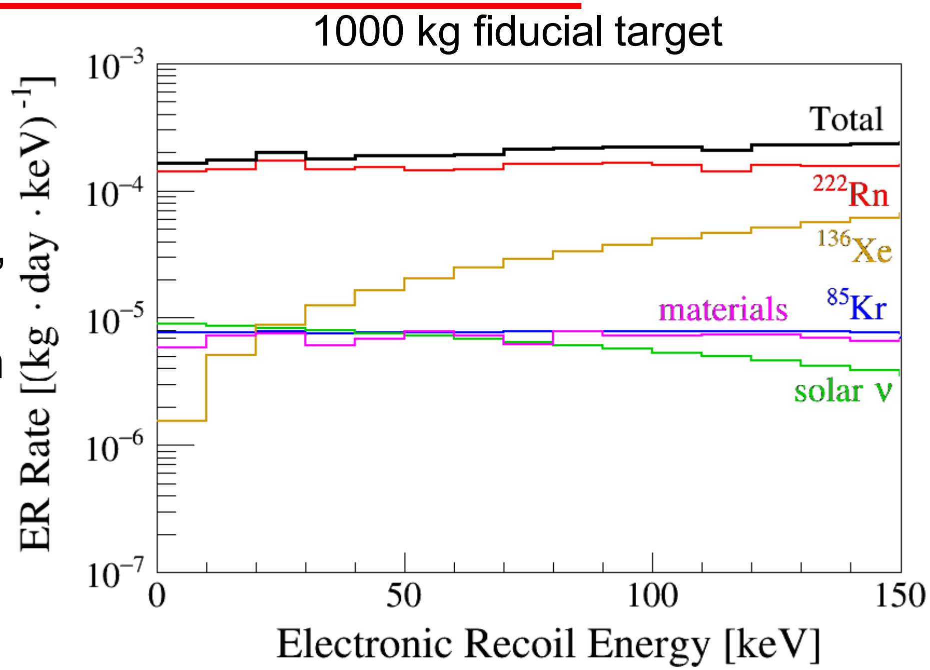
3D reconstruction :
→ X,Y from top array
→ Z from Drift time



Background in XENON1T

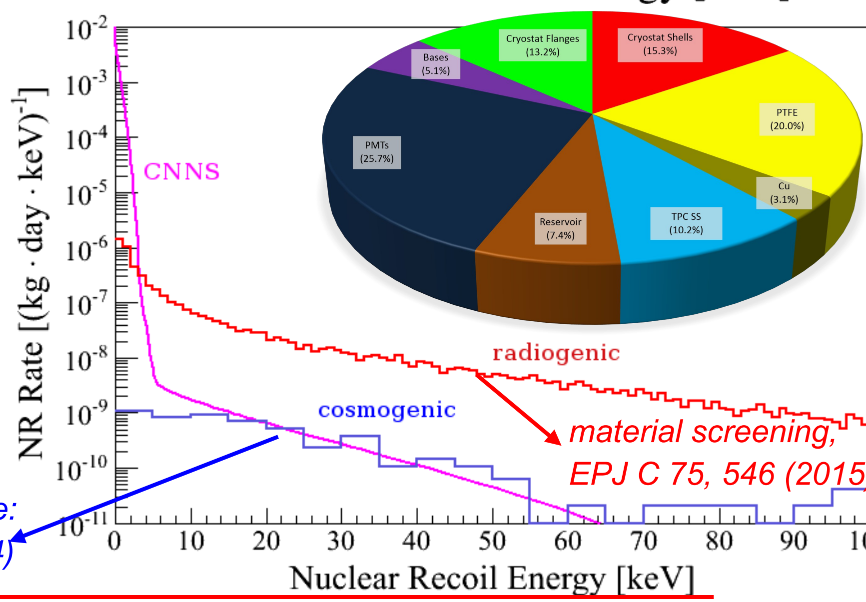
Electron recoils (ER):

- Low energy Compton scatters from the radioactive contaminants in the detector components: U and Th chains, ^{40}K, ^{60}Co, ^{137}Cs.
- Intrinsic contaminants: β decays of ^{222}Rn daughters, ^{85}Kr, ^{136}Xe.
- Elastic scattering of solar neutrinos off electrons.



Nuclear Recoils (NR):

- Radiogenic neutrons: spontaneous fission and (alpha, n) reaction from the U and Th chains in the detector components.
- Muon-induced neutrons (Cosmogenic)
- Coherent scattering of neutrinos off the Xe nuclei (CNNS).



Muon veto design and performance: XENON1T, JINST 9, P11006 (2014)

JCAP04(2016)027

XENON1T facility

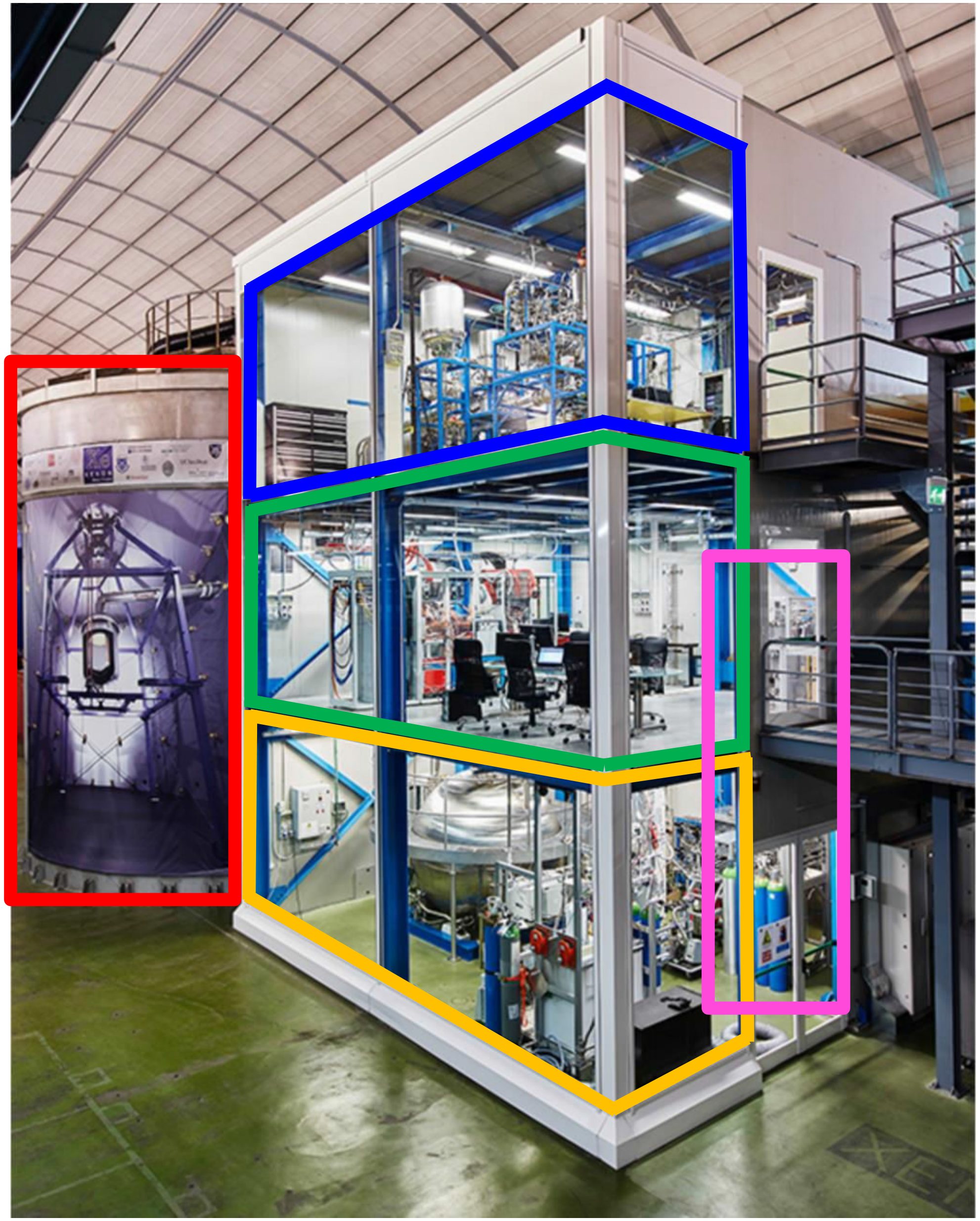
Water shield: deionized water as passive radiation shield
Muon veto: Active muon veto against muon induced neutrons (84 PMTs)

Cryogenics: Stable conditions(3.2t LXe)
Purification: LXe flow through getters, remove impurities

DAQ: Each channel has its own threshold, Flexible software algorithms
Readout: Up to 300MB/s for high rate calibrations

ReStoX: Emergency recovery up to 7.6 tons of LXe
Passive: No active cooling required to keep Xe contained

Kr Distillation: Remove Kr from system during fill or online
Rn Distillation: Initial tests show promising reduction for Rn

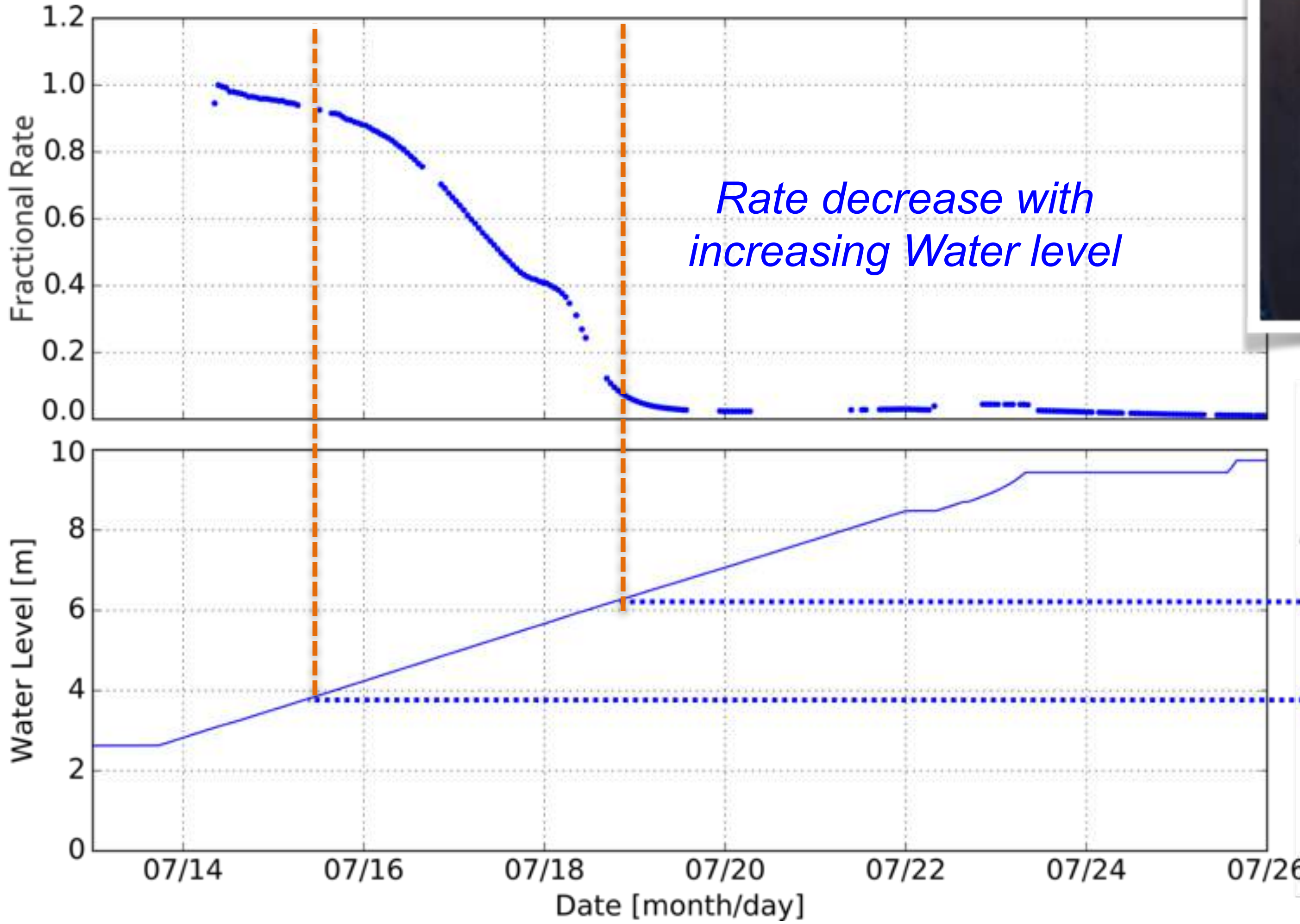


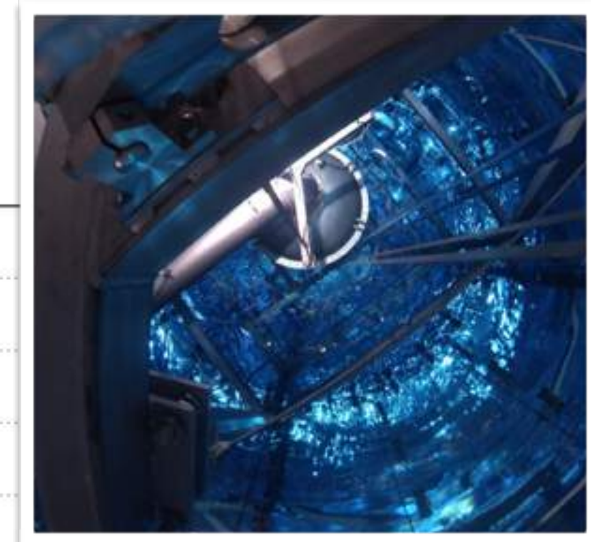
The largest Xe double-phase TPC ever built !

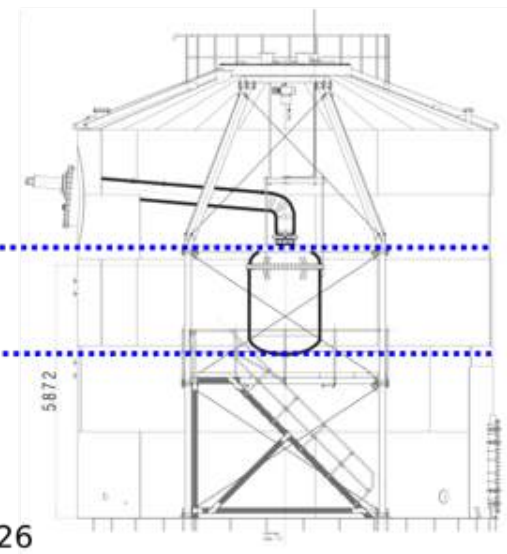
- Deployed inside the inner cryostat in November 2015.
- Active Xe mass: 2 tons.
- Light sensors:
  127+121 low-background 3” PMTs with average QE = 35% (R11410-21).
  JINST 8 P04026 (2013)
  Eur. Phys. J. C75 (2015) 11, 546
- Fully covered with high reflectivity PTFE to maximize light collection.
- Drift region: 1m height, 1m diameter.
- Highly transparent electrodes (meshes, wires).
- Cathode feedthrough tested to 100kV.

Water Shield filling

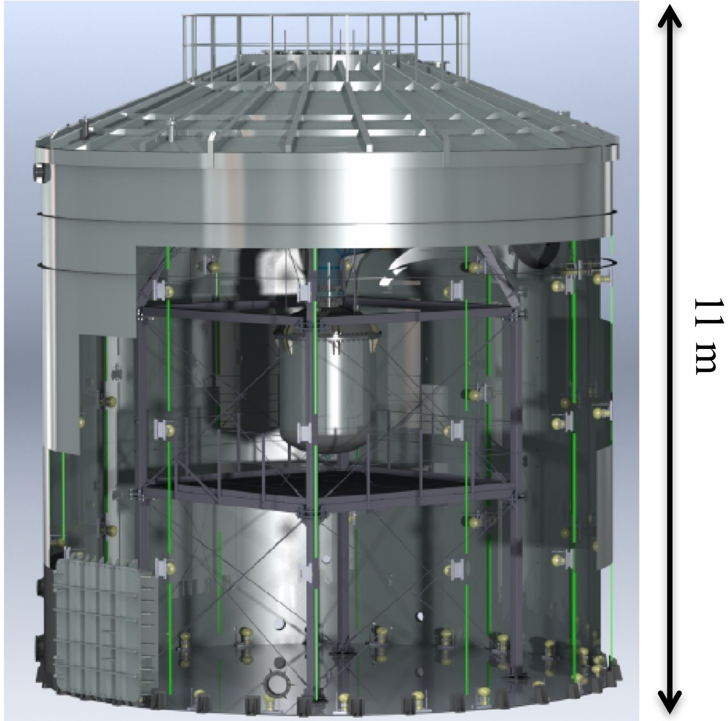
- TPC fully immersed in water since July 2016
- Background studies and calibration runs started



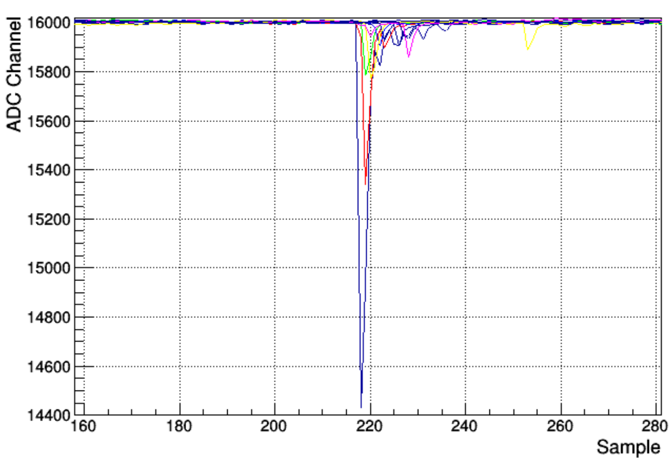


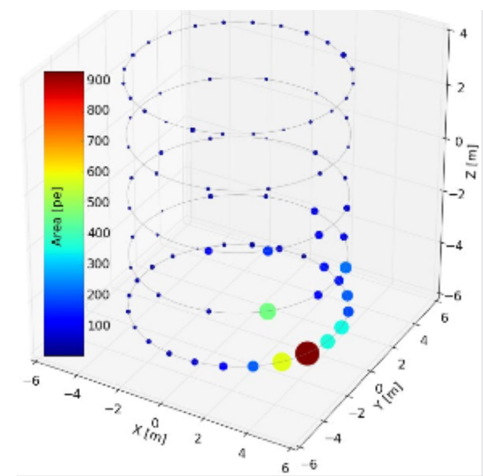


Muon Veto Cherenkov Detector

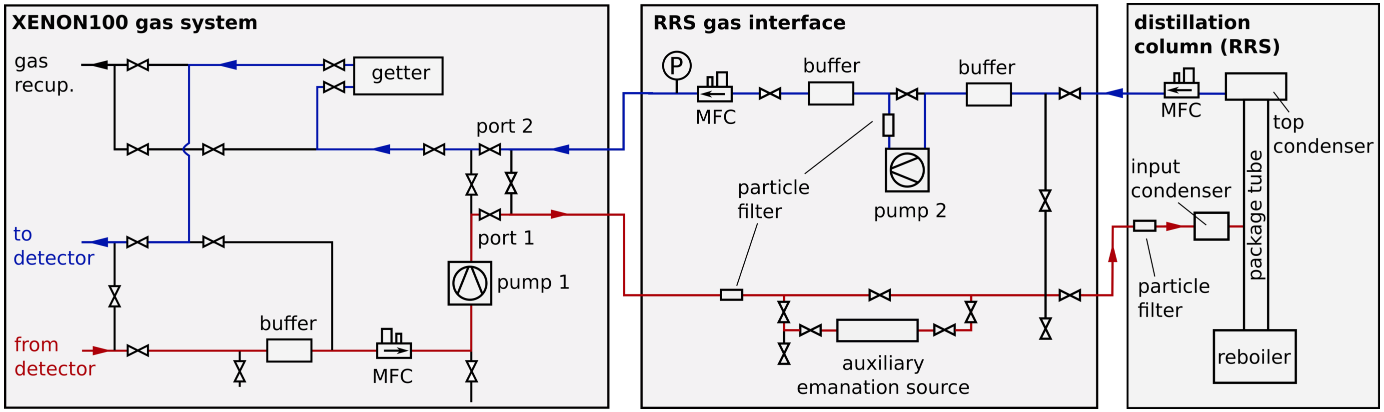


- The cryostat is immersed in a water shield filled with 700 tons of water
- Deionized water is used as passive shield from environmental radiation
- Water is constantly purified
- Equipped with 84 high-QE, 8" PMTs
- All walls are covered with reflective foil Detects Cherenkov light to tag muons.
- Expected muon flux underground is 1.2 $/m^2h^{-1}$ → muon-induced neutron background is reduced to less than 0.01 ev/y thanks to muon tagging
  JINST 9 P11006 (2014)
- Fully commissioned in March 2015





Background Reduction: ^{222}Rn

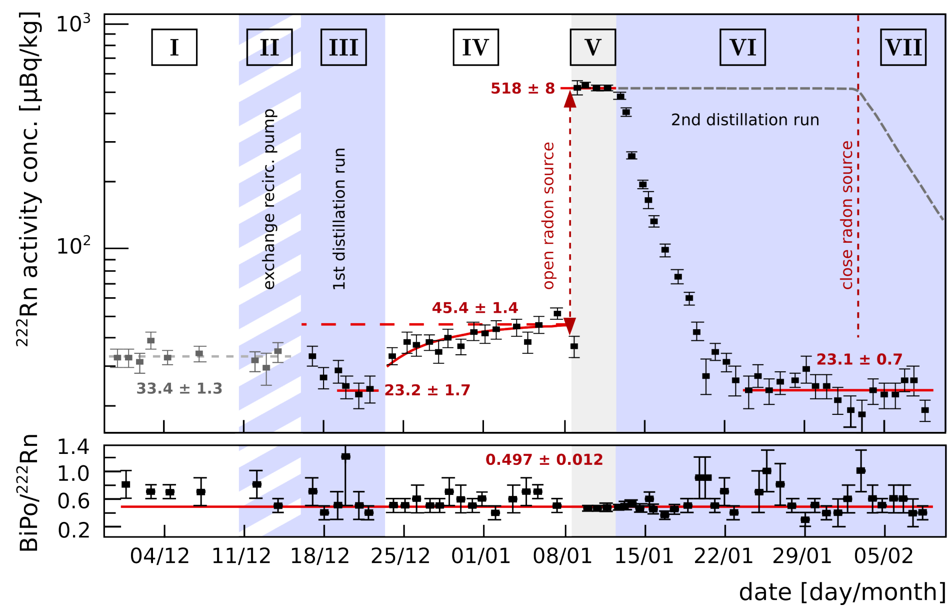


- Successful demonstration of radon removal by cryogenic distillation at XENON100
- Reduction factor of R > 27 (95% C.L.)

XENON1T:

- Minimize leakage into purification system at Xe1T (i.e., hermetically sealed pumps)
- Low radon emanation components
- Dedicated radon emanation measurements

arXiv:1702.06942



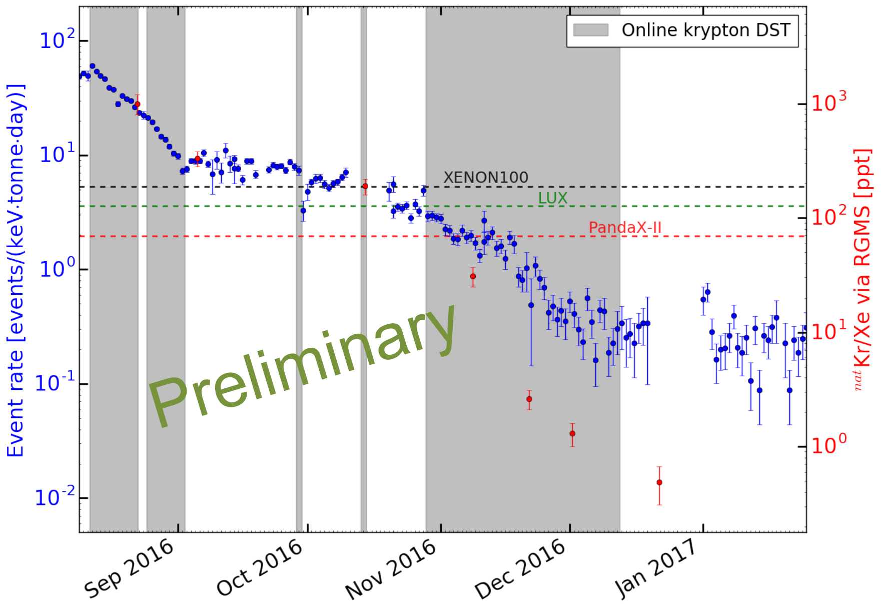
Background Reduction: ^{85}Kr

- Commercial Xe contains ~ ppb of Kr
- Column principle : remove Kr from Xe by means of cryogenic distillation (gases have different boiling points)
- >6.4 × 10^5 separation, output concentration < 0.048 ppt
- 5.5 m column, 6.5 kg/hr,

- New approach: Online Distillation
- Successfully reduced Kr to (0.62 +- 0.13) ppt measured by RGMS

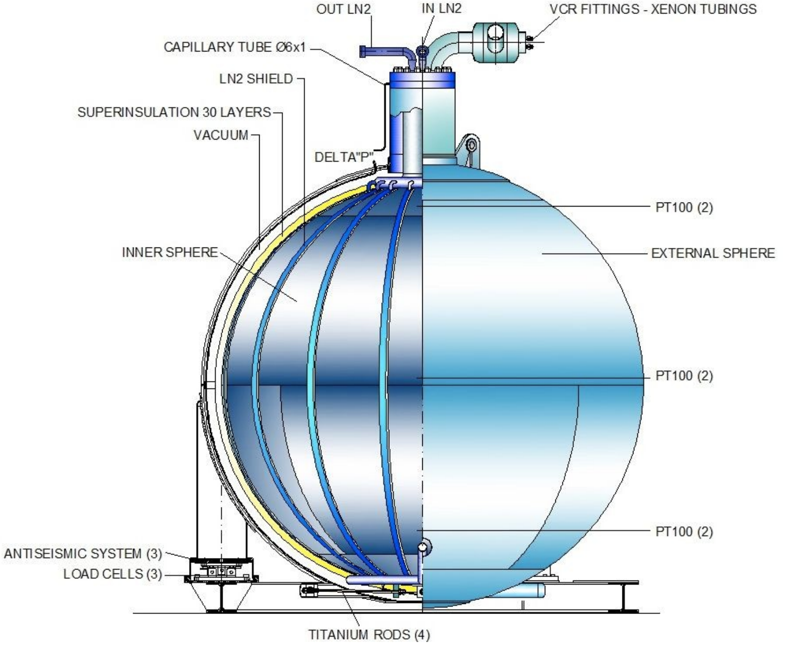
- Background is now radon dominated

arXiv:1612.04284
EPJC 74, 2746 (2014)



Recovery and Storage System: ReStoX

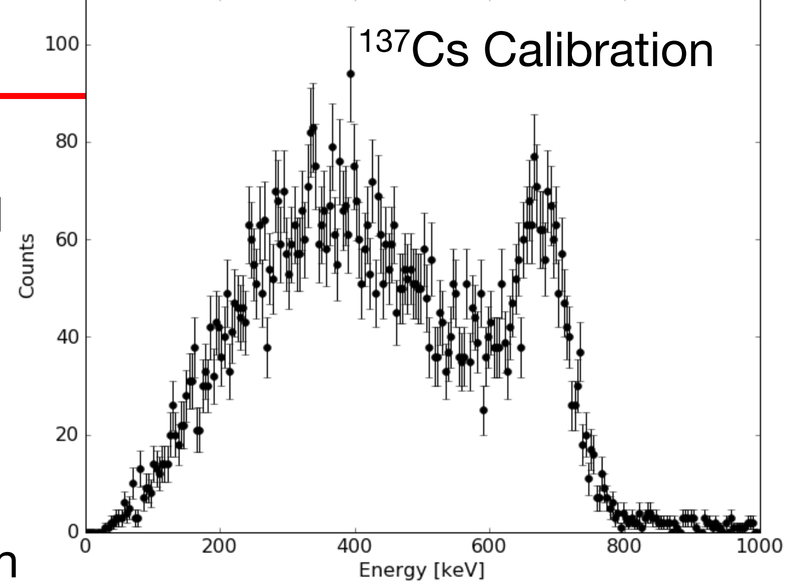
Goals:
- Store up to 7600 kg of Xe in gaseous or liquid/solid phase under high purity conditions
- Fill Xe in ultra-high-purity conditions into detector vessel
- Recover all the Xe from the detector. In case of emergency all Xe can be safely recovered in a few hours

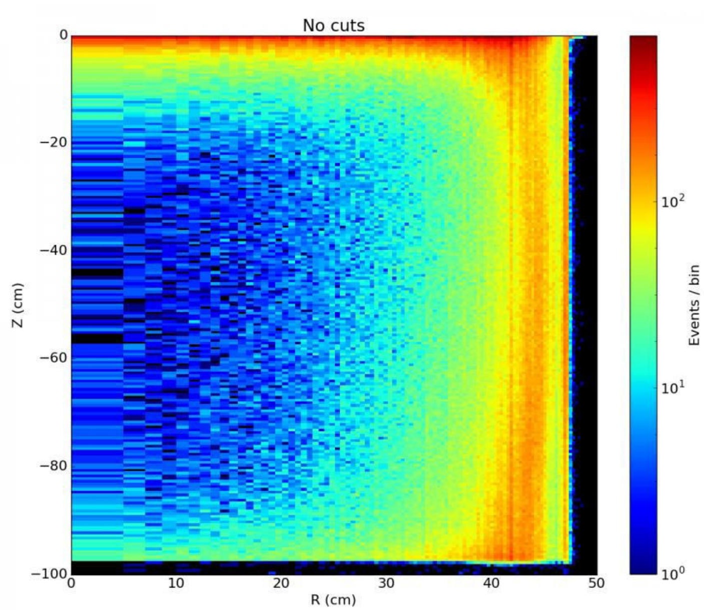


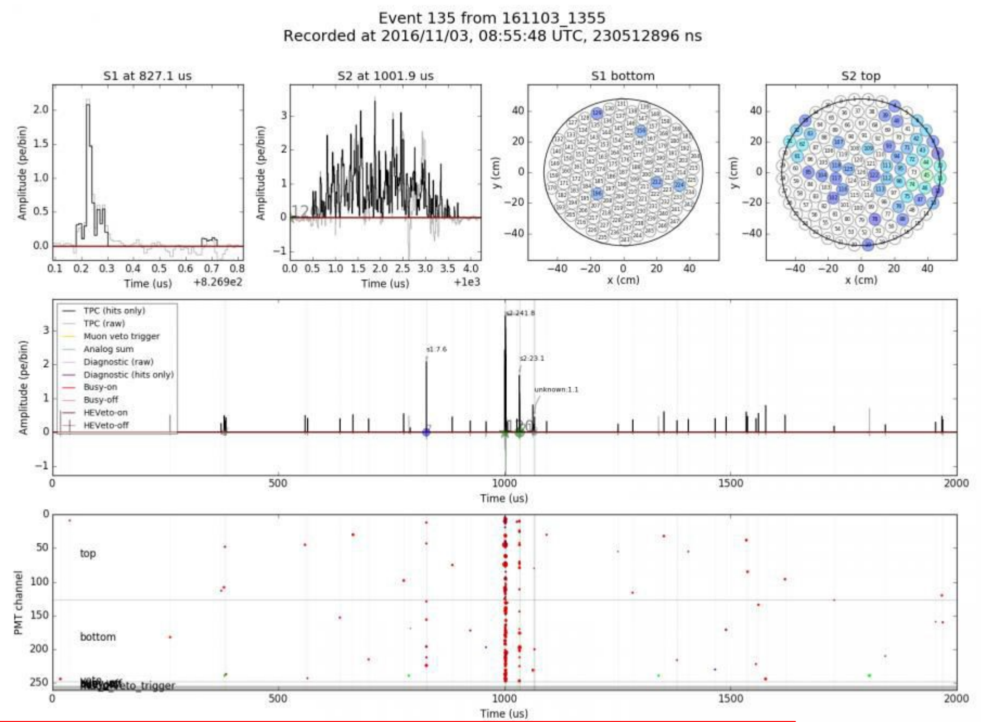
Double walled, high pressure (72 bar) vacuum insulated sphere of 2.1 meter diameter, cooled by LN2 and by an internal LN-based condenser.

Commissioning and First Run

- Started commissioning in April 2016 with first fill
- Other subsystems came online
- Science run began in Fall 2016:
  - Internal source calibration with ^{83m}Kr, ^{220}Rn
  - External source calibration with AmBe, ^{228}Th
  - Science data-taking still ongoing

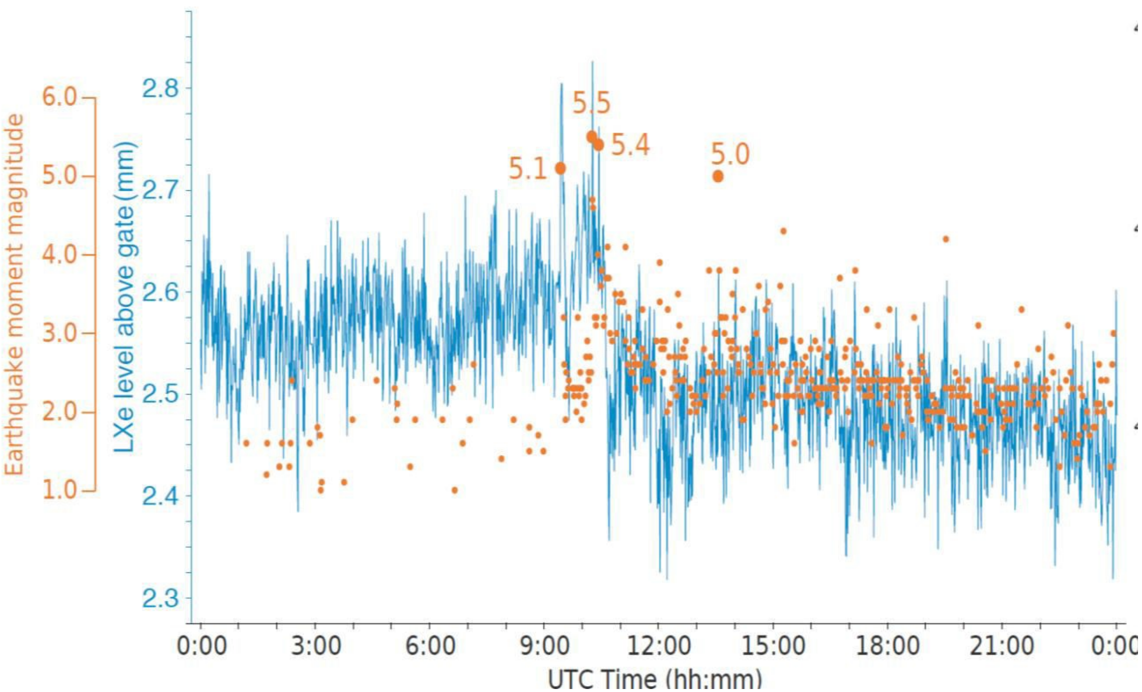


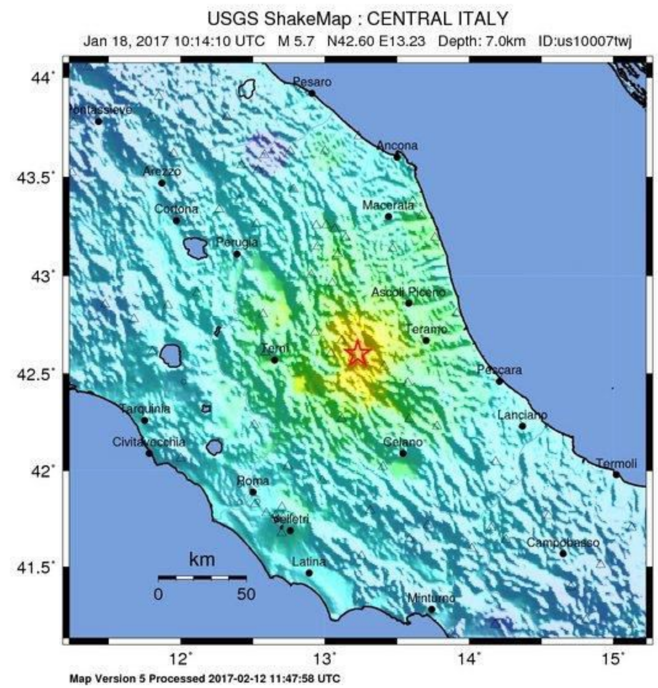




Earthquake of 18th January 2017

- Magnitude 5.5 earthquake ~20 km away detected
- Detector still operating and taking data





PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.06	0.2	0.8	2.0	4.8	12	29	70	>171
PEAK VEL.(cm/s)	*<0.02*	*0.08*	*0.3*	*0.9*	*2.4*	*6.4*	*17*	*45*	*>120*
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Faenza and Michelini, 2010, 2011

Sensitivity

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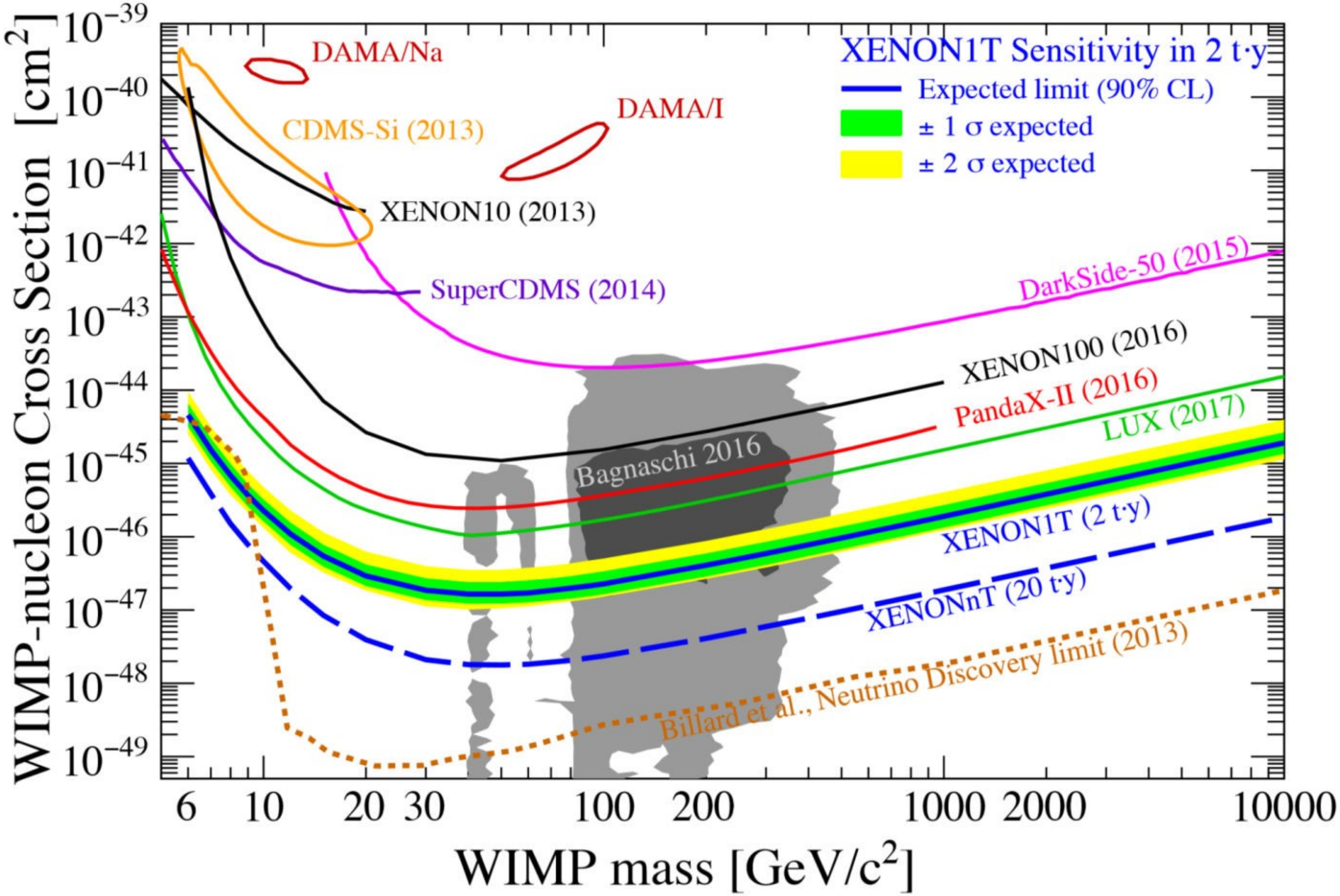
based on background predictions shown before, 2 t × y exposure:



assumptions: S1 interval: 3 – 70 PE

ER rejection 99.5% @ 50% NR acceptance
→ measured LY is ~2x higher than in XENON100!

Sensitivity Vs Time

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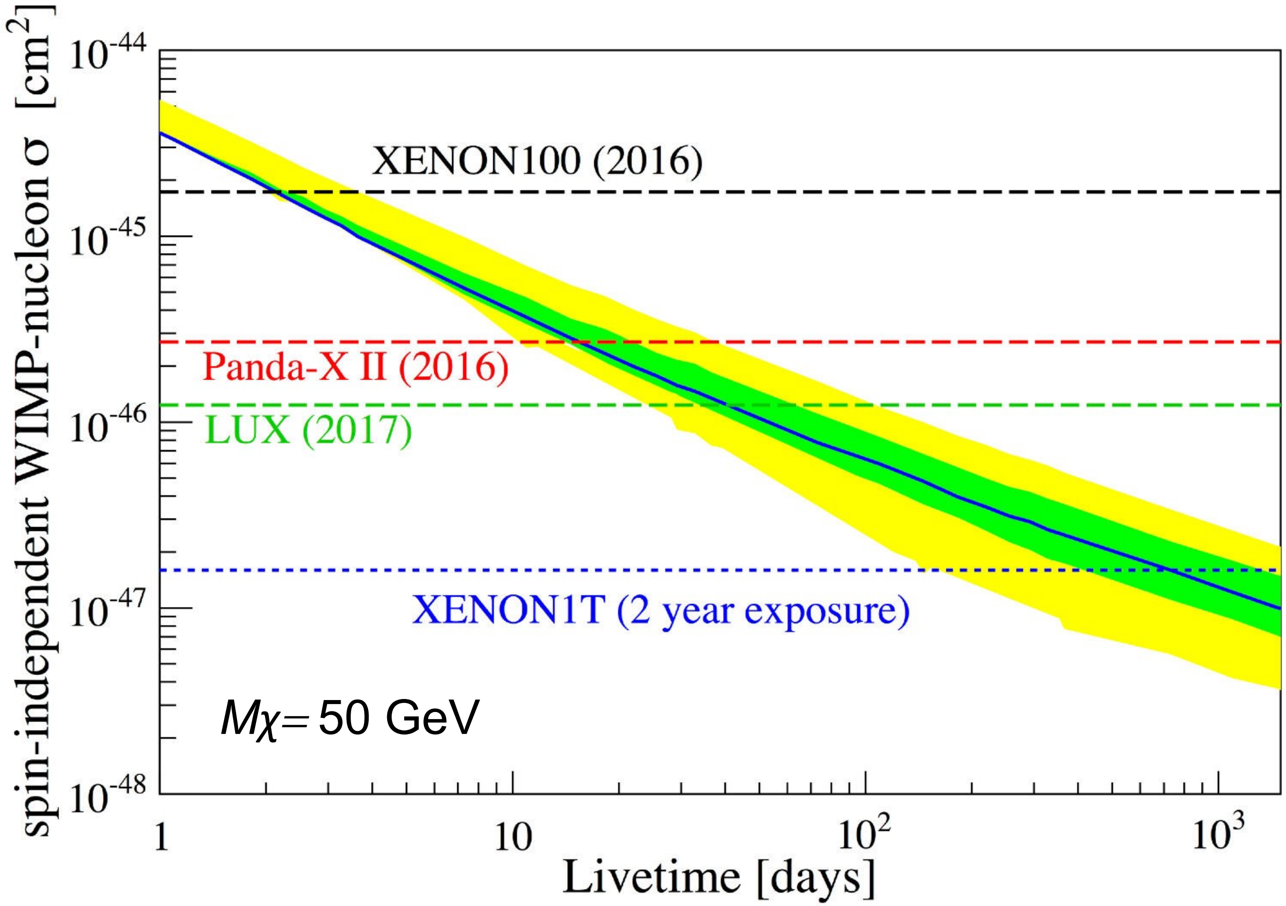
based on background predictions shown before, 2 t × y exposure:

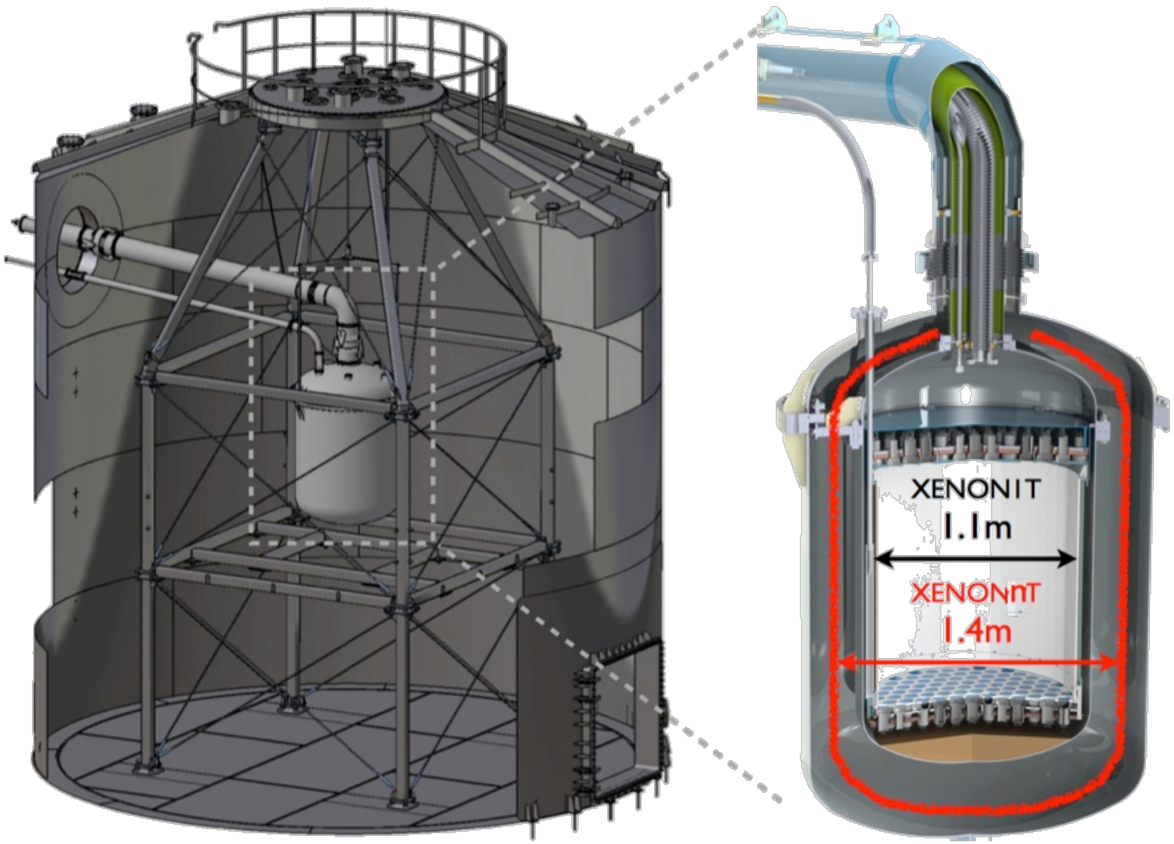


assumptions: S1 interval: 3 – 70 PE

ER rejection 99.5% @ 50% NR acceptance
→ measured LY is ~2x higher than in XENON100!

Upgrade: XENONnT

- Quick upgrade of TPC and inner cryostat
- All major systems remain unchanged
- Construct TPC in parallel to XENON1T operation
- Upgrade starting 2018



From XENON1T to XENONnT

All major systems remain unchanged, XENON1T infrastructure designed for the rapid deployment of an upgraded detector

- Muon veto efficiency essentially the same for XENONnT
- Cryostat support and levelling systems designed for an enlarged detector
- Cryostat outer vessel can accommodate new larger inner vessel
- Cryogenic system designed to handle additional heat load
- Modular and scalable GXe purification system
- Kr distillation column can fulfill XENONnT ^{85}Kr requirement
- Modular, parallelized DAQ system ready for XENONnT

Upgrades required for XENONnT

+ Larger cryostat inner vessel

+ New TPC

+ Additional ~200 PMTs, with lower radioactivity already ordered

+ Additional minor DAQ electronics

+ LXe (~ 8t in our hands)

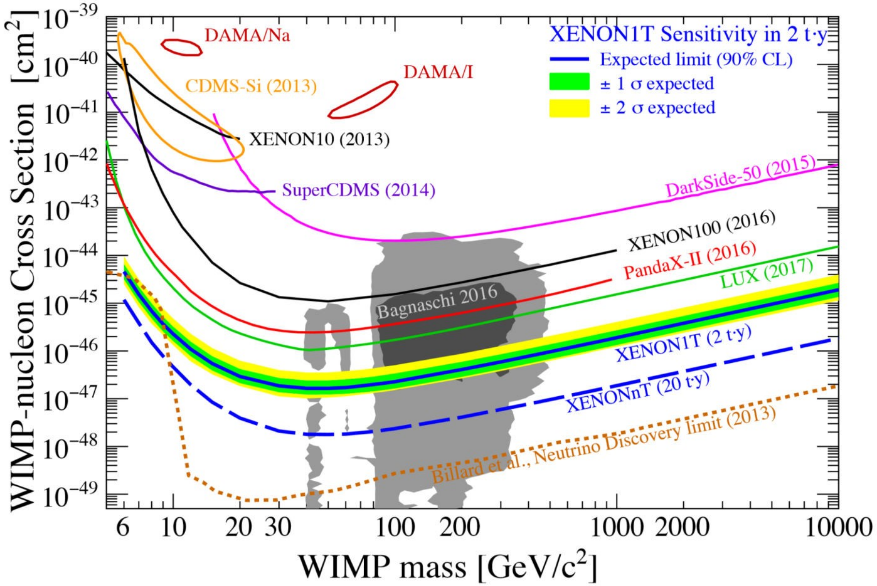
+ New Storage System

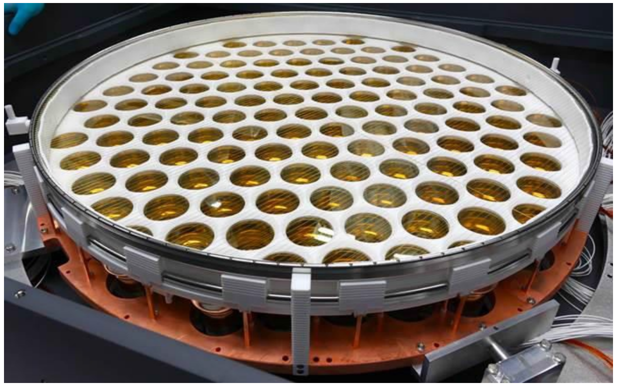
+ Rn material selection (screening, treatment) and new Rn distillation column

Target mass of 6 tons, sensitivity to spin-independent WIMP-nucleon elastic scattering cross sections of 1.6×10^{-48} cm^2

Summary

- XENON1T fully commissioned and taking Science Data
- Largest LXe TPC
- Online Physics data taking started last year and ongoing
- After 2 years of exposure, design sensitivity reached
  → upgrade under development : XENONnT





Monte Carlo Simulation

Reproduce via software the performance of the XENON1T detector, and predict the sensitivity of the experiment

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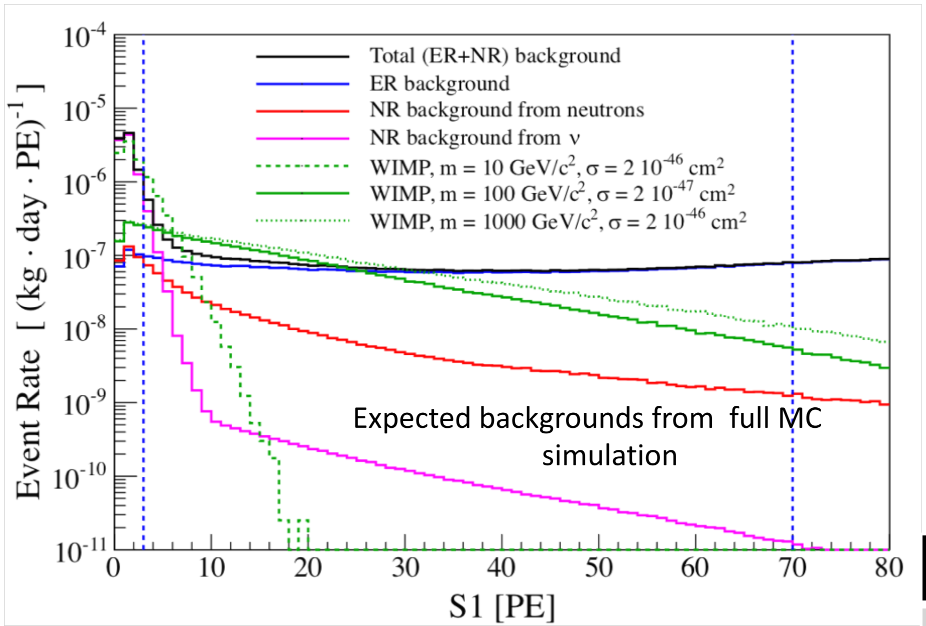
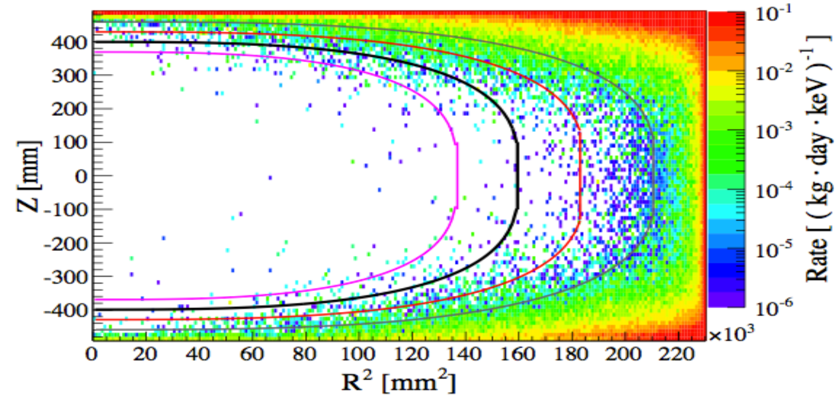


1 ton fiducial volume S1 in [3,70] PE
ER discrimination 99.75%
NR acceptance 40%

Position of the ER background from the materials, negligible inside the 1 ton fiducial volume



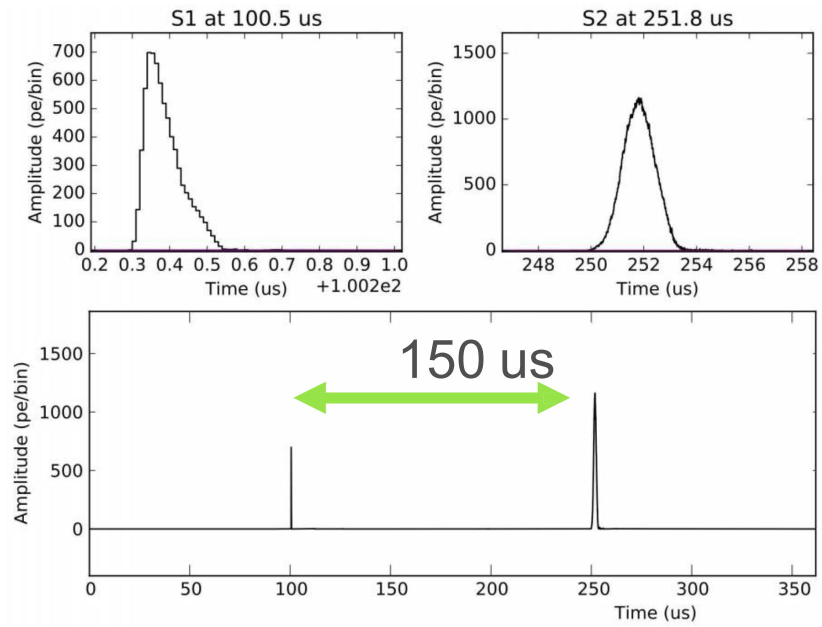
Method:

- Input from screening campaign by all detector components
- Monte Carlo simulation with GEANT4
- Statistical treatment

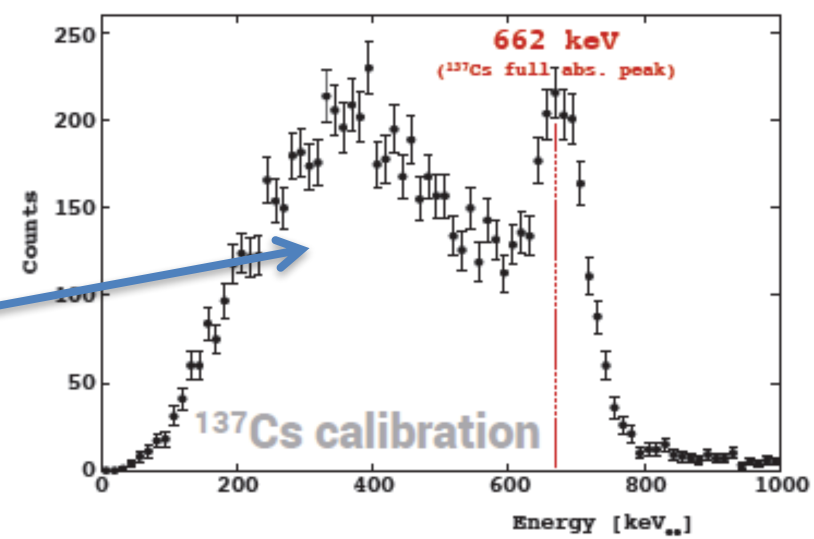
Source	Bkg (evts/ton/year)
ER (materials + intrinsic + solar ν)	1.6
NR from radiogenic neutrons	0.22
NR from ν coherent scattering	0.23
Total	2.05

XENON1T: TPC Commissioning

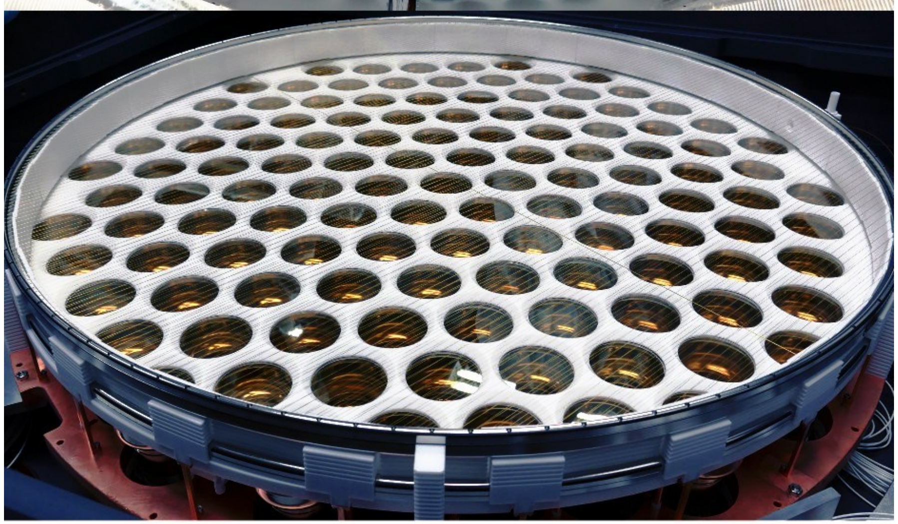
- Cryogenics: well behaved, stable pressure and temperature
- Both charge and light are detected throughout the whole TPC
- Electron lifetime (« purity ») at a few 100 mμs and improving exponentially.
- Detector is responding to radiation as expected



Taken without muon veto,
Not final performance



XENON1T: PMT, DAQ, Electronics



- all 254 PMTs operational
- DAQ electronics for TPC and muon veto installed in T-stabilized DAQ room
- detectors can be operated simultaneously (and time-synced) or independently
- PMT/DAQ commissioning ongoing