The XENON1T Dark Matter Experiment at LNGS

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CNNP2017
Catania, October 17, 2017

The XENON collaboration

144 scientists

25 institutions

10 countries

Columbia
RPI
Nikhef
Stockholm
Muenster
Mainz
MPIK
Chicago
UCLA
UCSD
Rice
Purdue

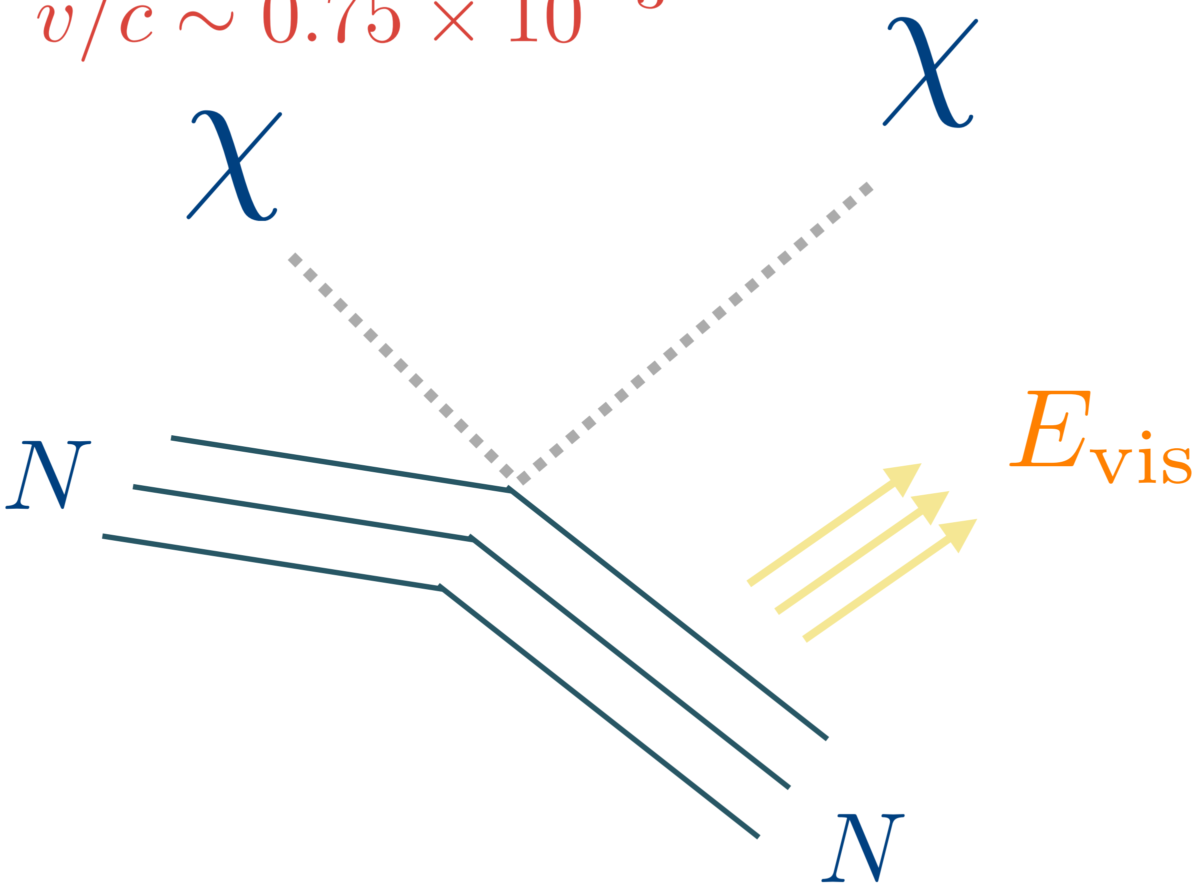
Freiburg
Zurich
NYUAD
Weizmann
Coimbra
Subatech
LPNHE
LAL
Bologna
LNGS
Torino
Napoli

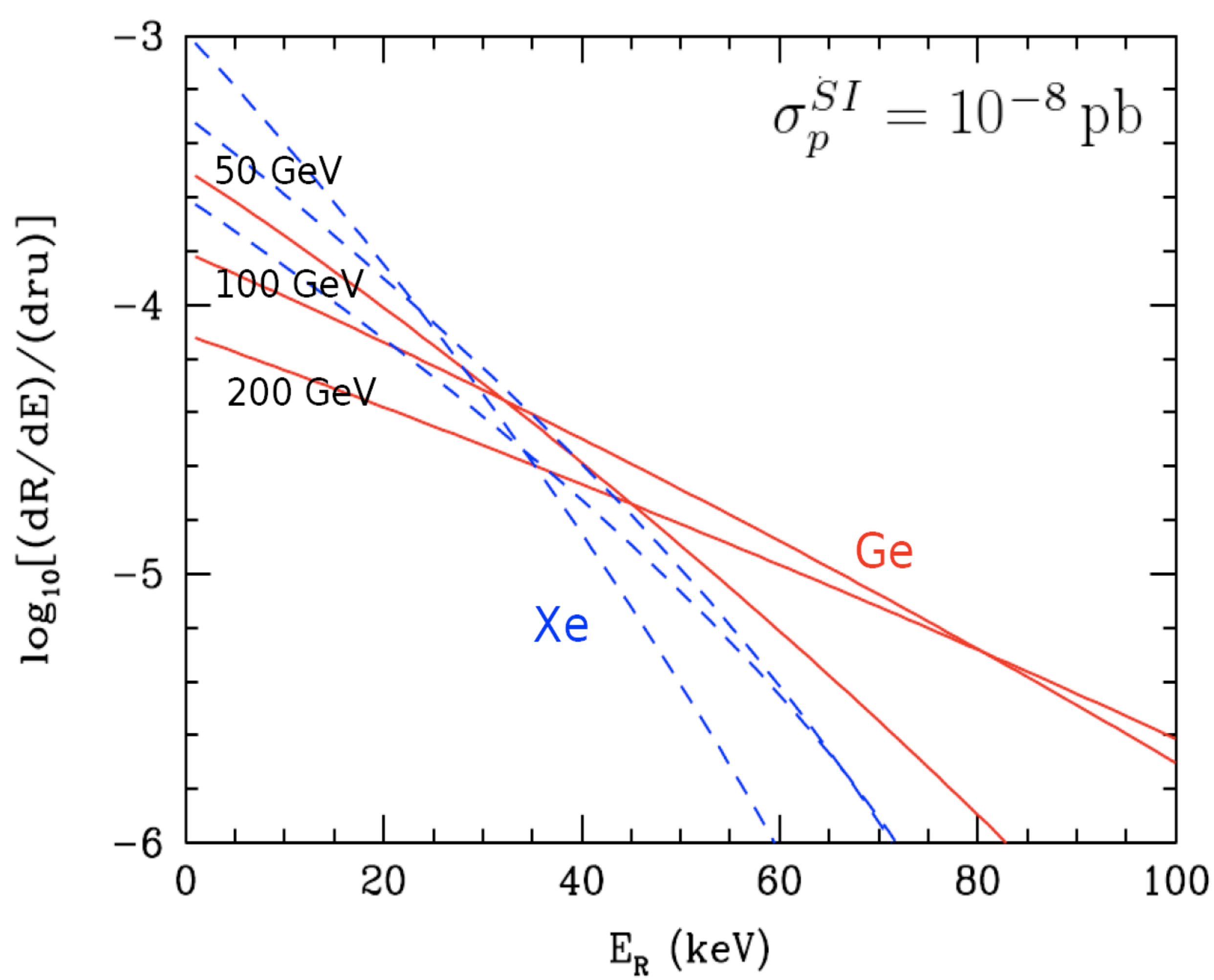
Direct detection of dark matter particles

Energy deposited in the detector ~ few keV - tens of keV

$$\frac{dR}{dE_R} \propto N_T \; \frac{\rho_0}{m_X} \; \sigma \, F^2(E_R) \int_{v_{\min}}^{v_{escape}} v \, f(v) \, dv$$

$v/c \sim 0.75 \times 10^{-3}$



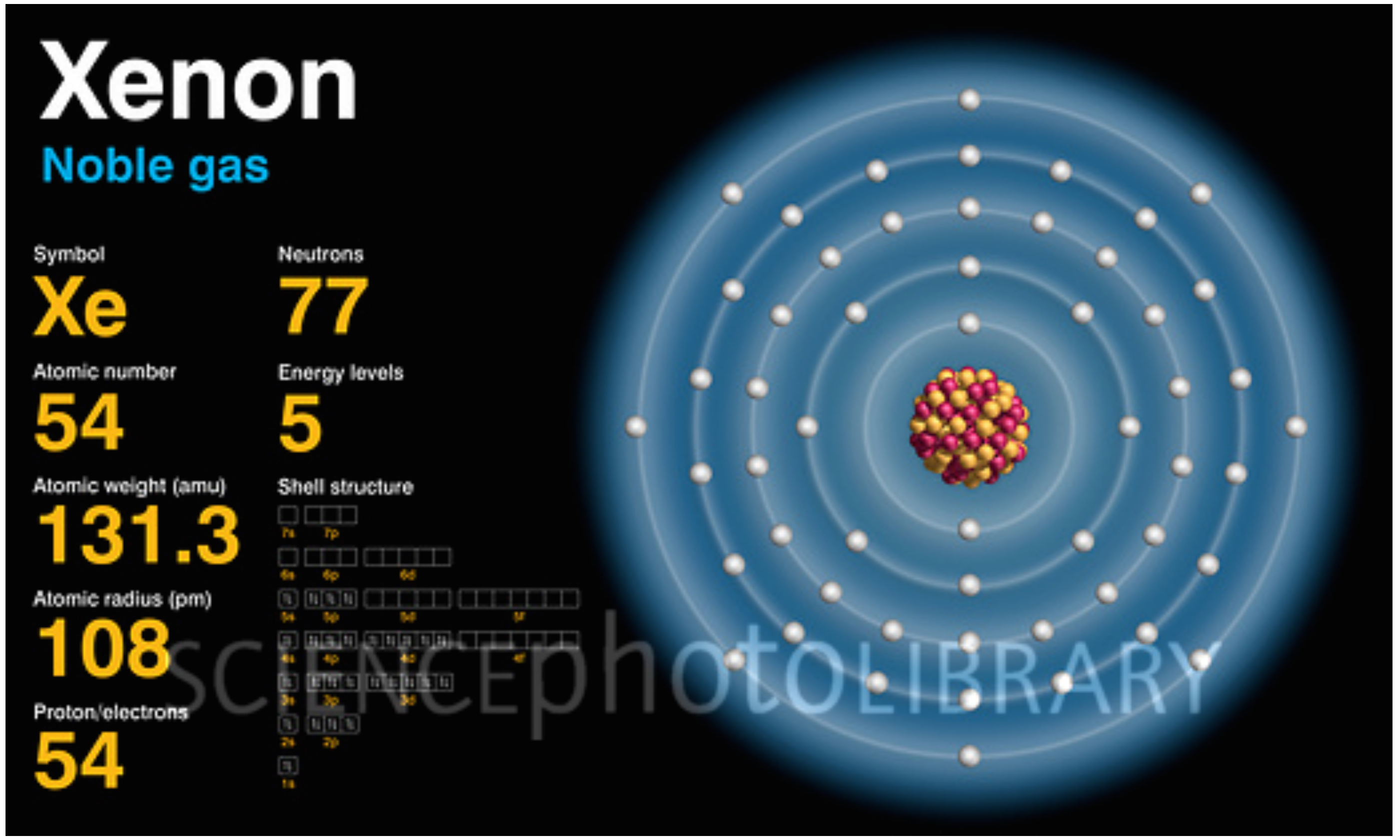


$$E_R = \frac{q^2}{2m_N} < 30\,\mathrm{keV}$$

Why Liquid Xenon for a Dark Matter Detector?

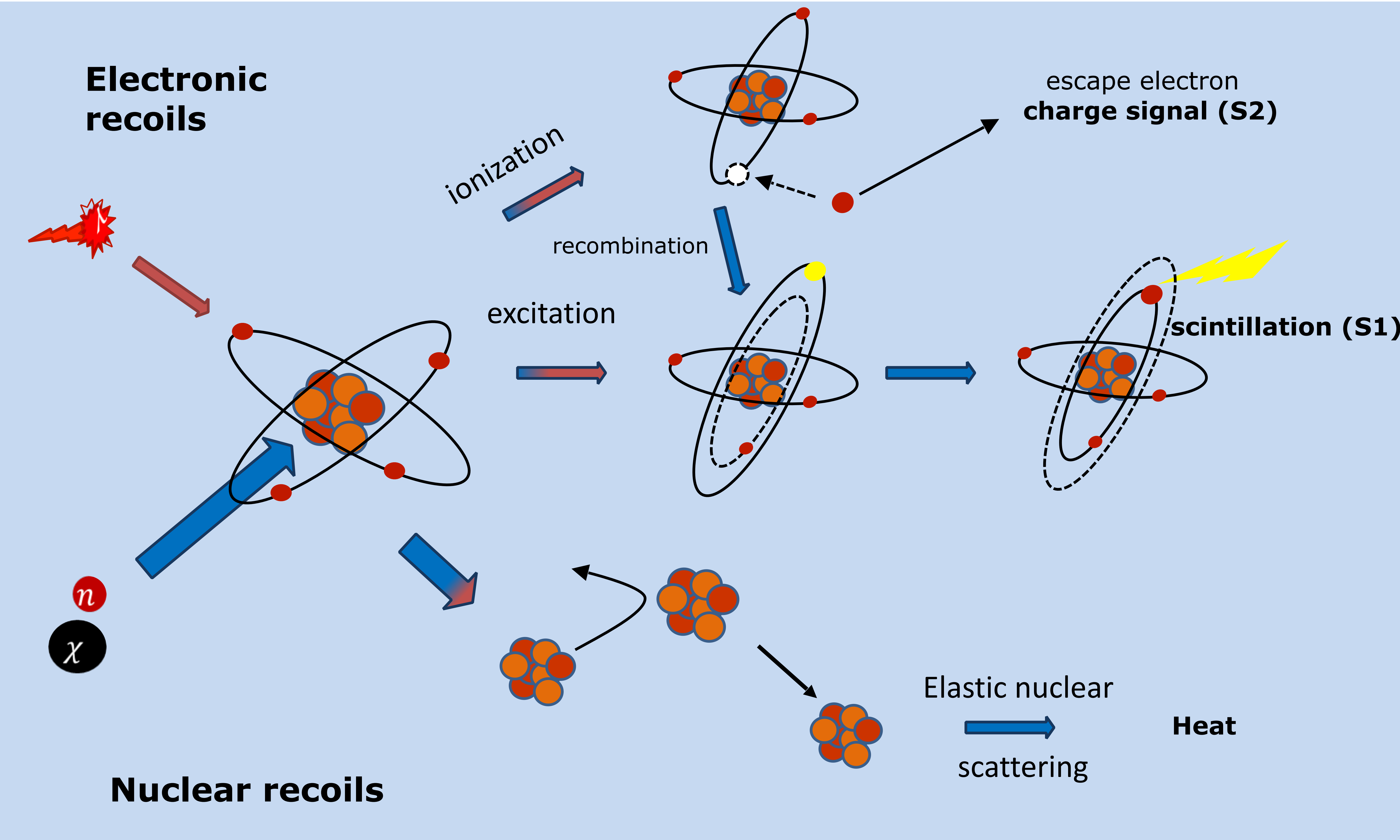
Selected Properties of Xe

Property	Value
Atomic Number (Z)	54
Atomic Weight (A)	131.30
Number of Electrons per Energy Level	2,8,18,18,8
Density (STP)	5.894 g/L
Boiling Point	−108.1 °C
Melting Point	−111.8 °C
Volume Ratio	519
Concentration in Air	0.0000087 % by volume

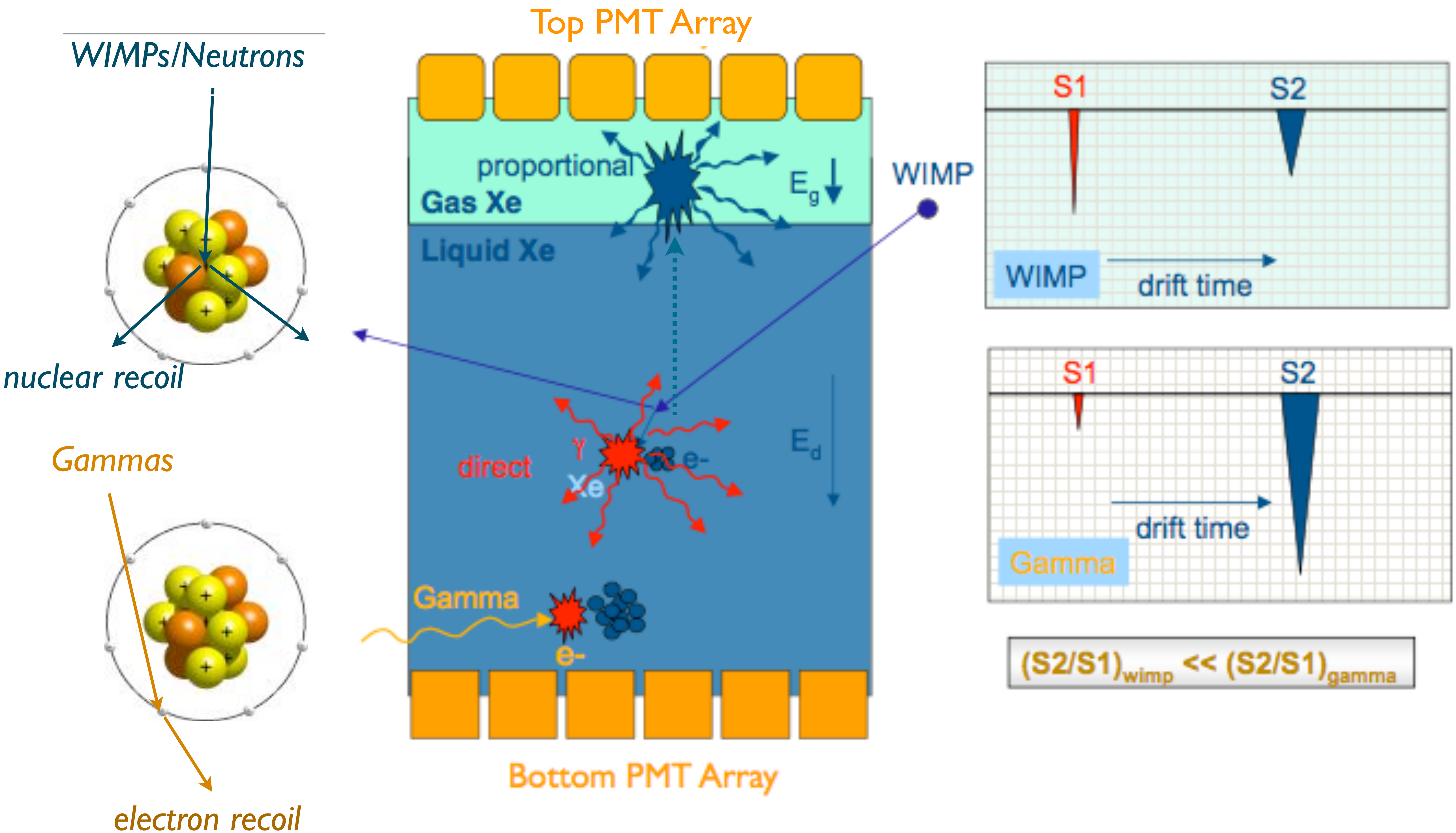


- ✦ *dense liquid for a massive WIMP target at reasonable cost (~1000$/kg)*
- ✦ *large nucleus and presence of isotopes with nuclear spin allow to probe SI and SD interactions with one target*
- ✦ *we have improved technologies to keep it cold and clean over long time*
- ✦ *no intrinsic radioactivity other than Kr85 which we know how to remove*
- ✦ *two signals (ionization and scintillation) in response to radiation*

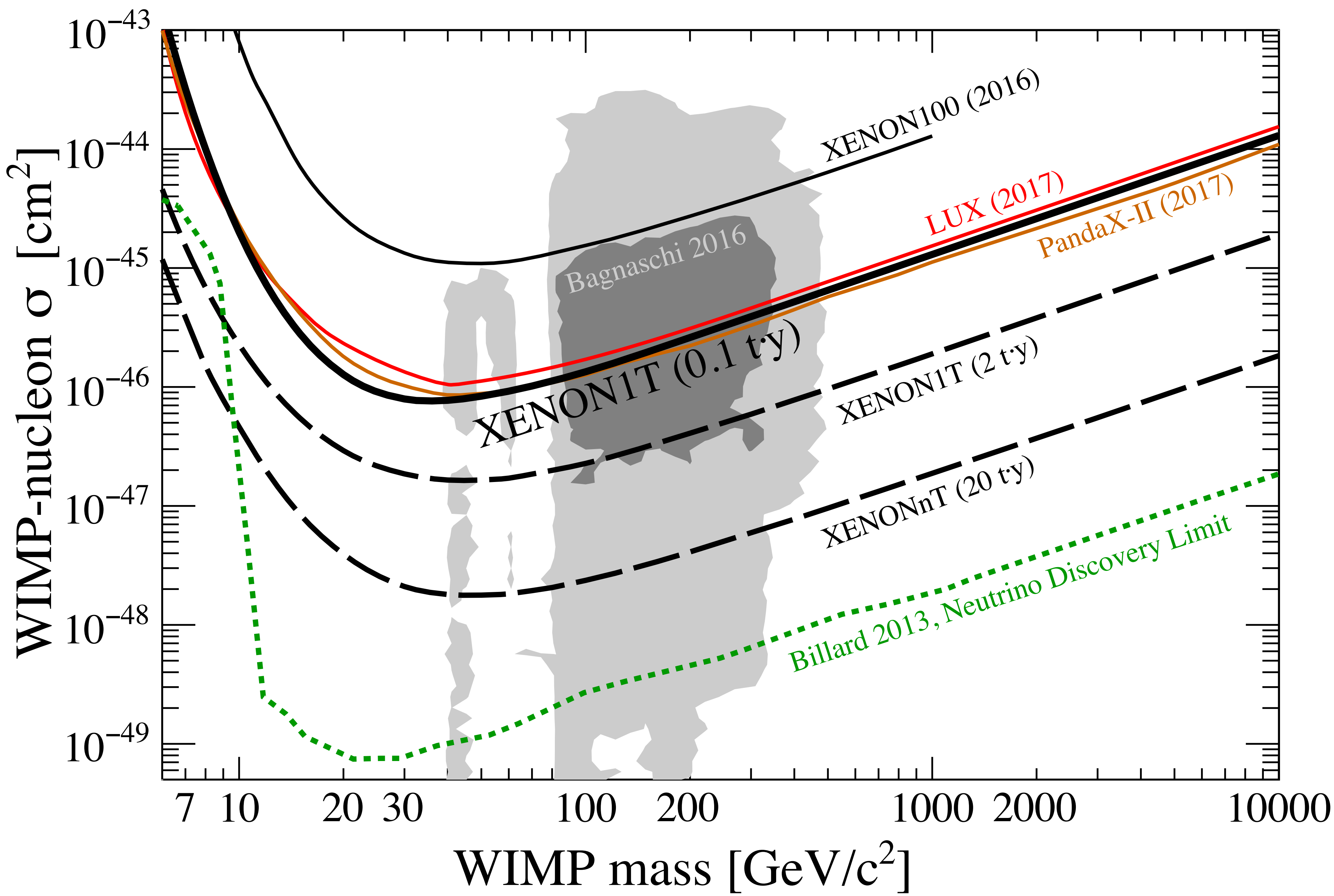
Two signals produced when a WIMP hits the Xe nucleus



A Time Projection Chamber to detect these two signals

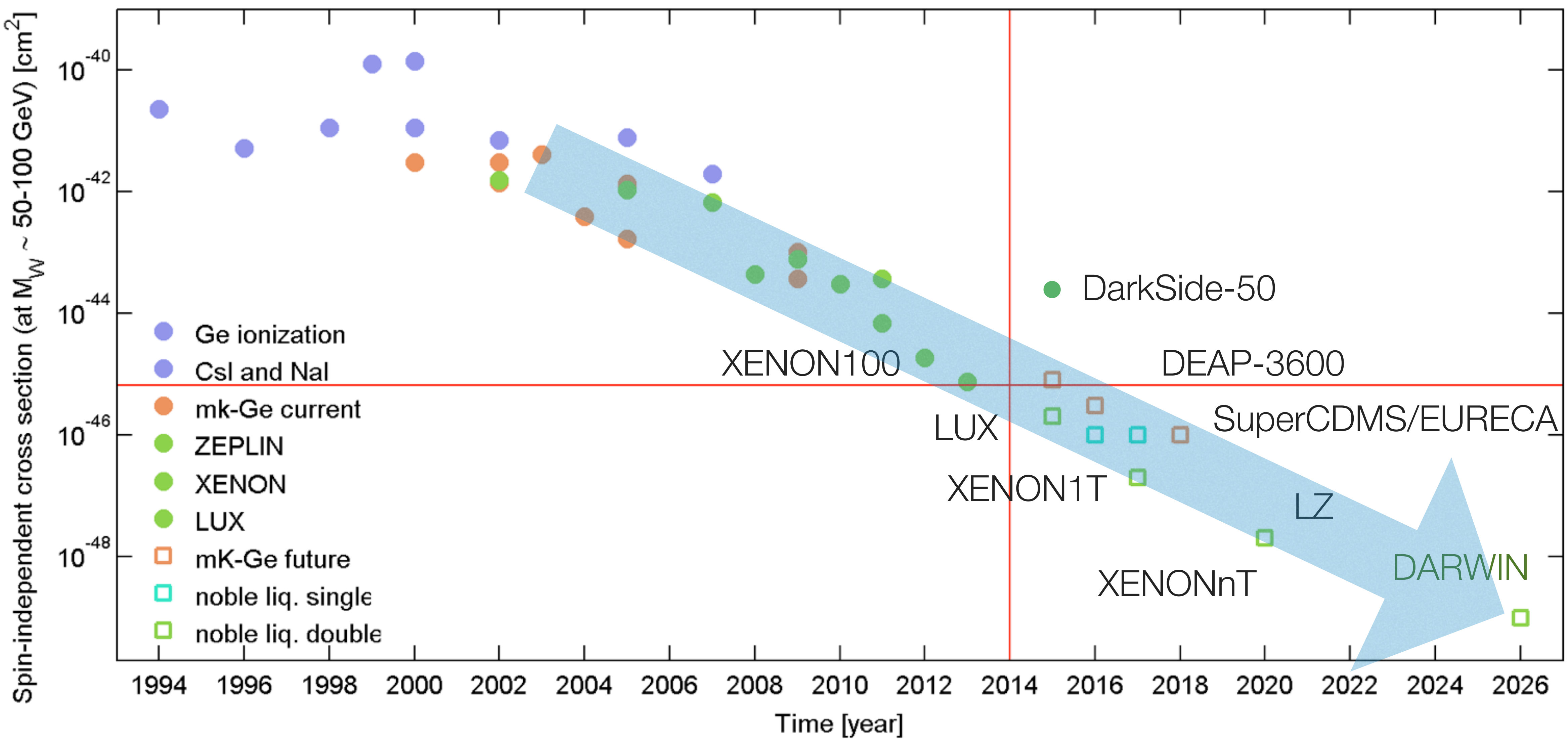


the state-of-the-art: driven by LXeTPC experiments



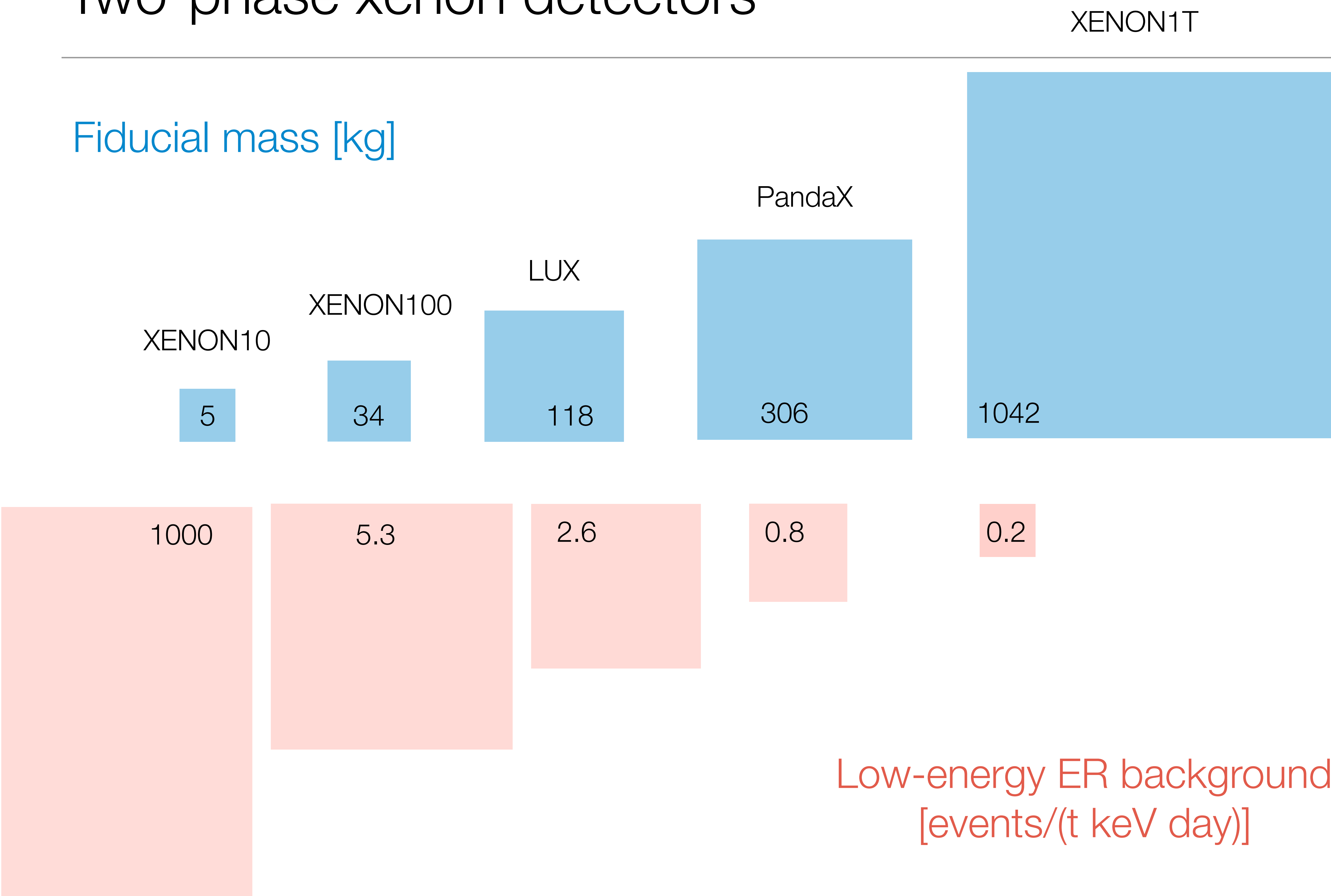
WIMP-nucleon cross section versus time

- About a factor of 10 increase every ~ 2 years
- Progress led by searches using LXe



LB, Physics of the Dark Universe 4, 2014

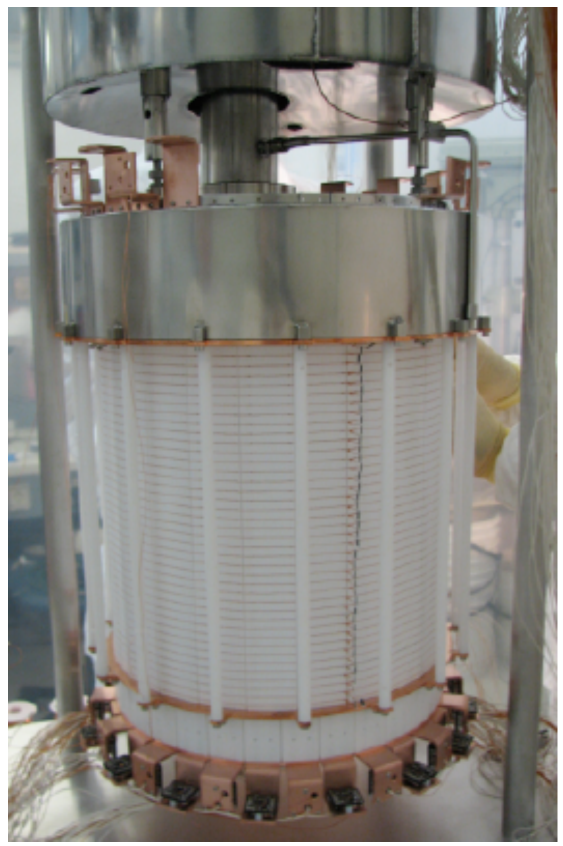
Two-phase xenon detectors



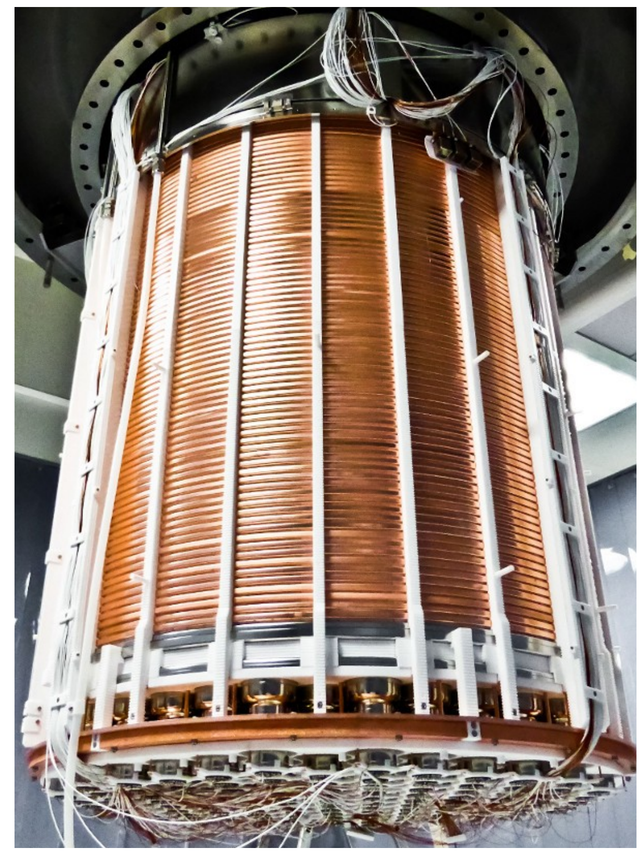
The phases of the XENON Program

XENON10

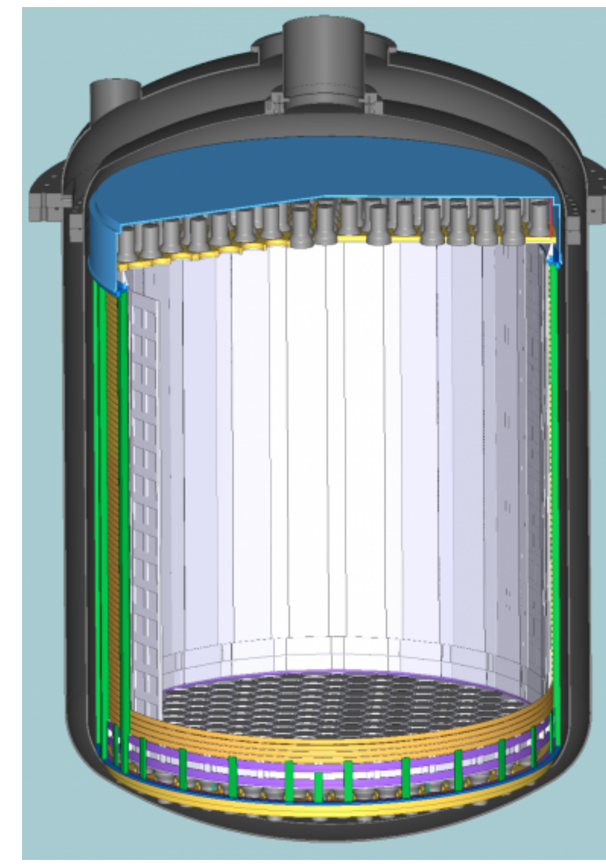
XENON100



XENON1T



XENONnT



2005-2007	2008-2016	2012-2018	2019-2023
25 kg- 15cm drift	161 kg- 30 cm drift	3200 kg- 100 cm	8000 kg-150 cm
~10^{-43} cm^2	~10^{-45} cm^2	~10^{-47} cm^2	~10^{-48} cm^2

The XENON1T Experiment

www.xenon1t.org

XENON1T Overview

Water tank and Cherenkov muon veto

Cryostat and support structure for TPC

Time projection chamber

Umbilical pipe (cables, xenon)

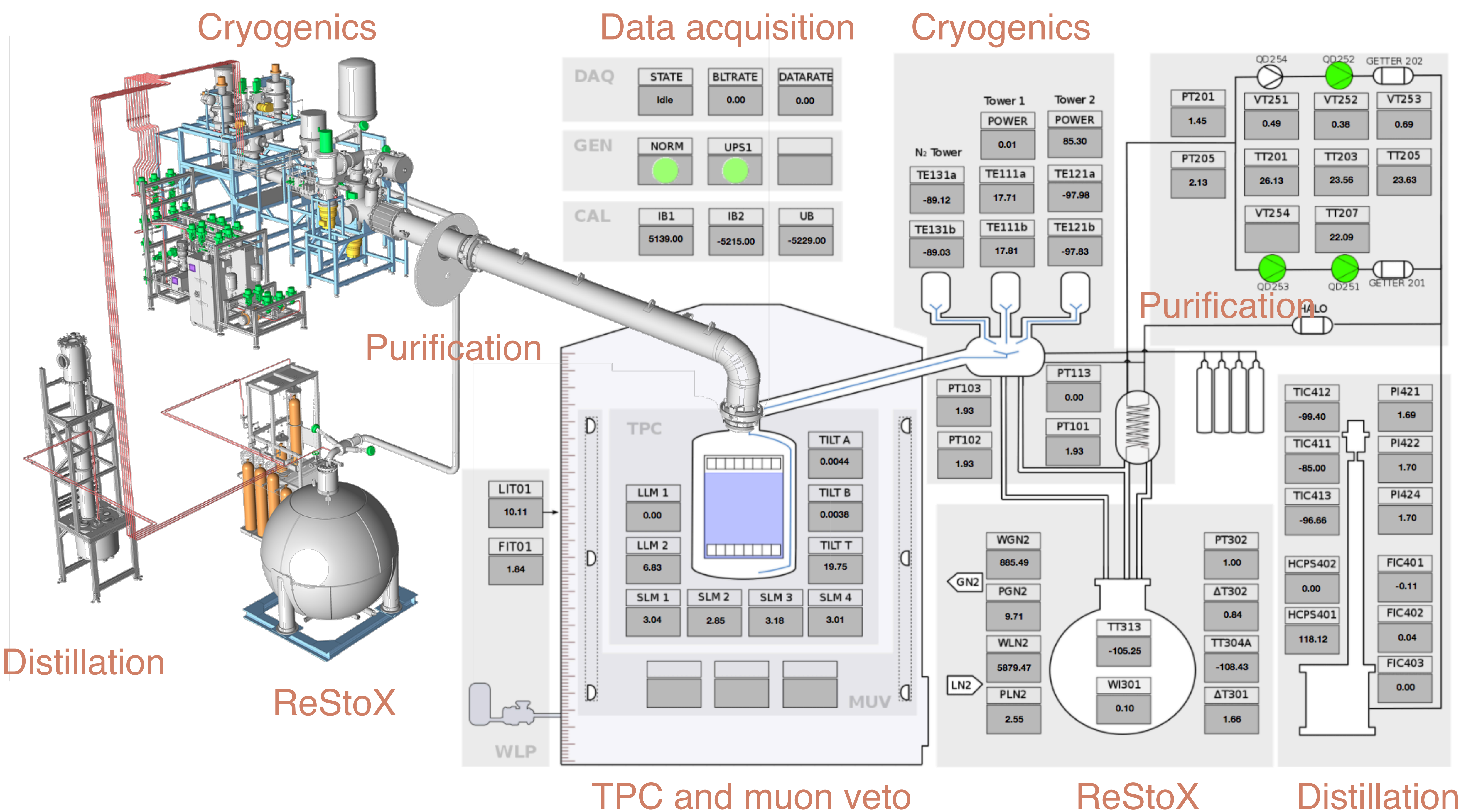
Cryogenics and purification

Data acquisition and slow control

Xenon storage, handling and distillation column

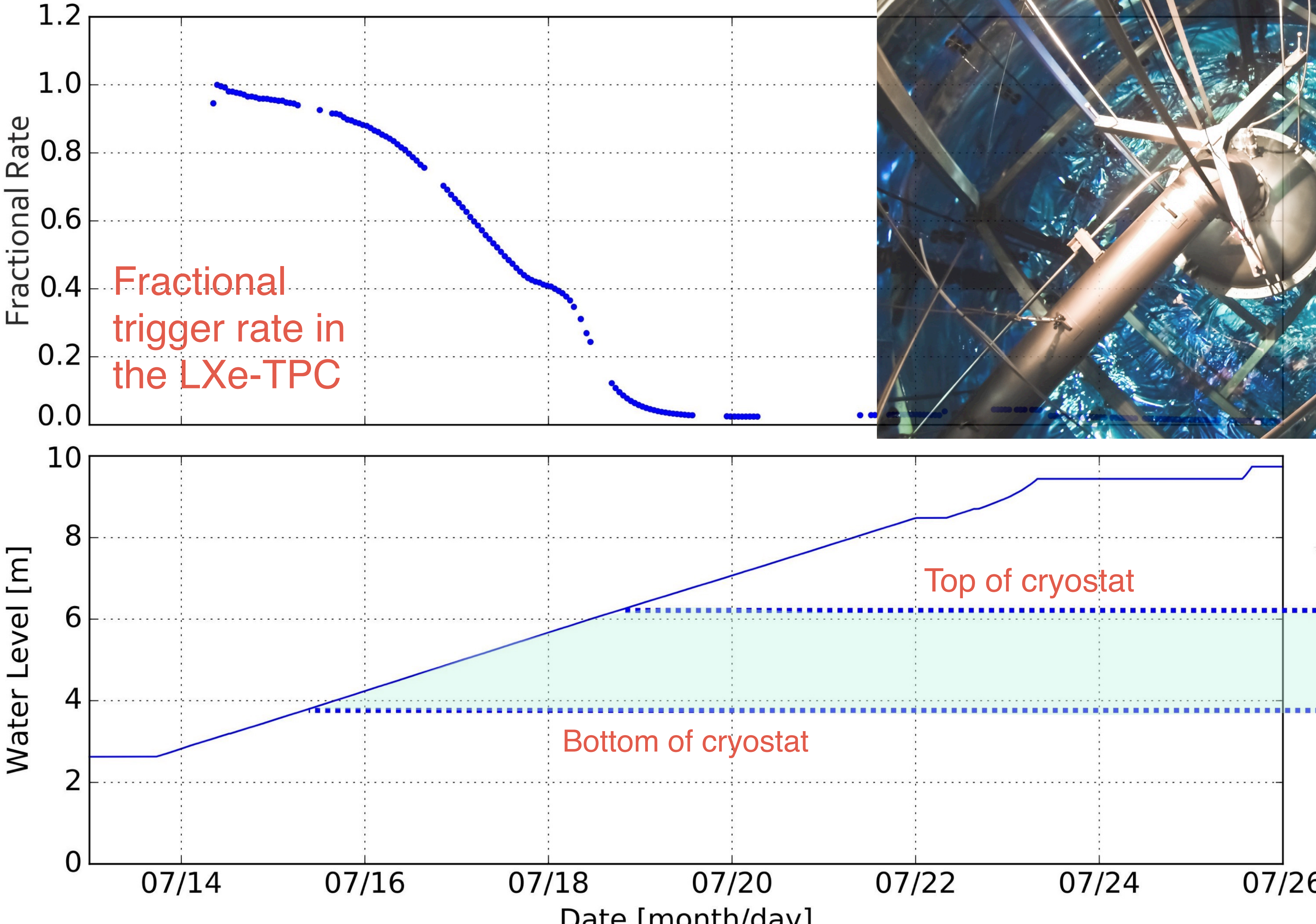
XENON1T Overview

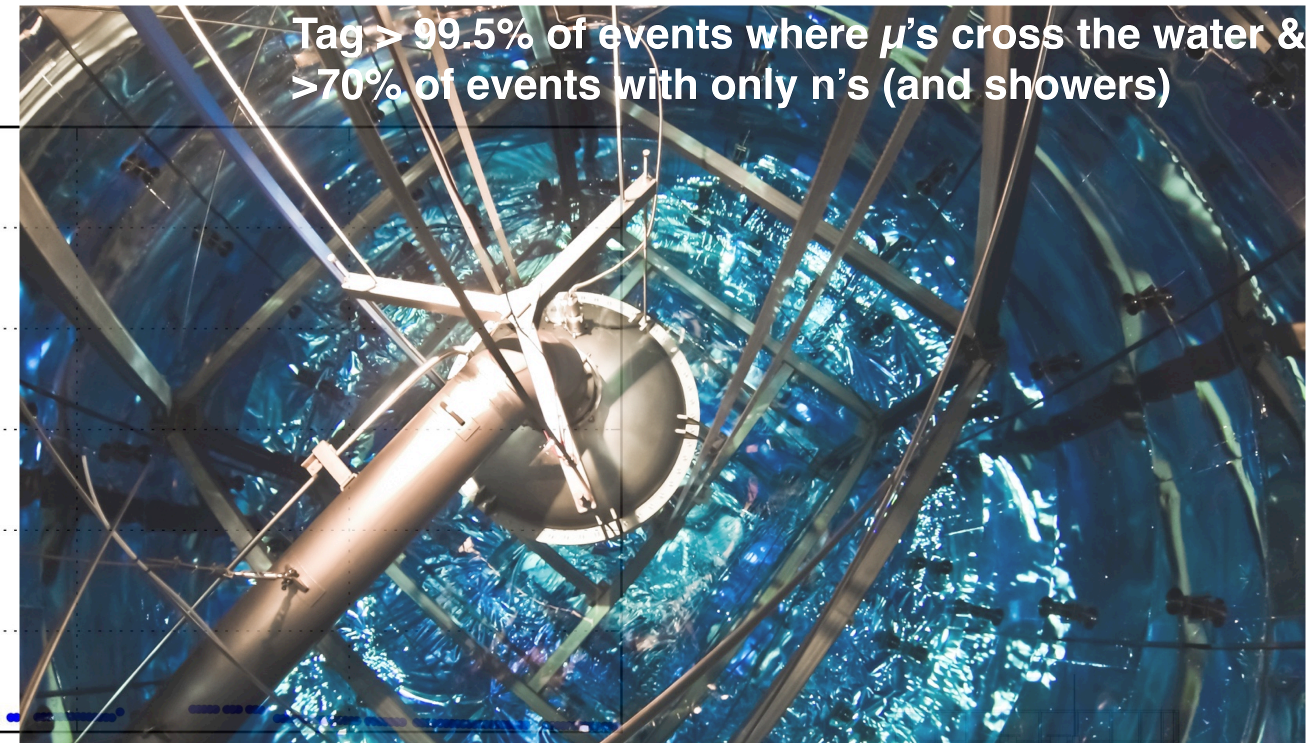
- Slow control system: functional screens for remote monitoring and controlling

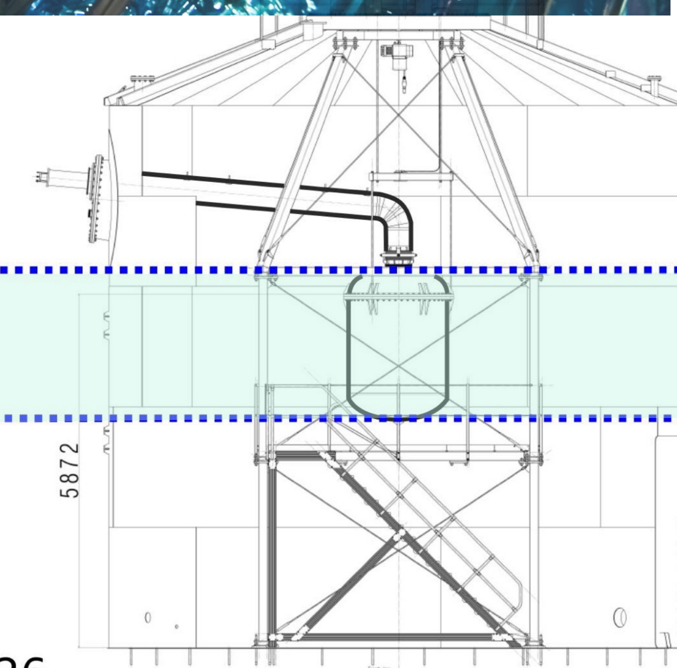


The Water Cherenkov Muon Veto

Water tank instrumented with 84 8-inch PMTs*







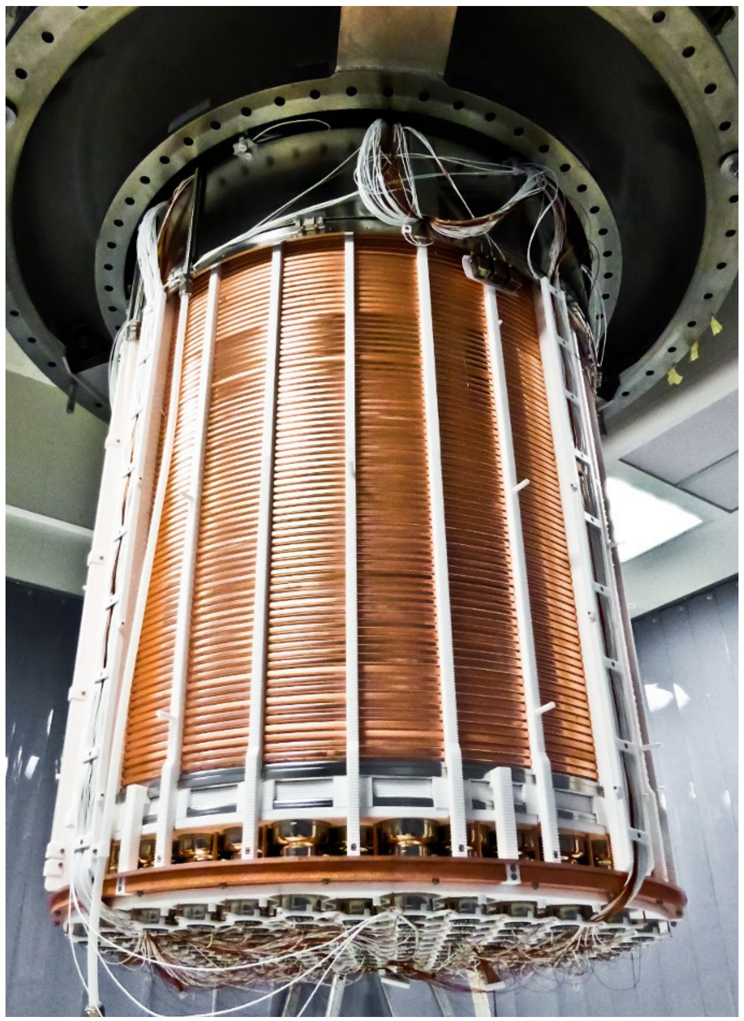
=> < 0.01 events/(t y) (muon-induced NRs)

* XENON collaboration, JINST 9, 2014

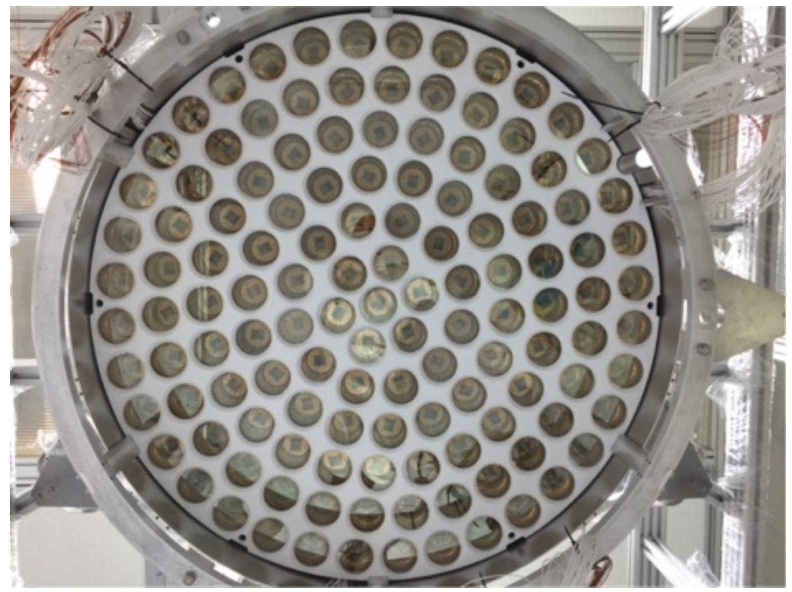
The XENON1T Time Projection Chamber

The XENON1T Time Projection Chamber

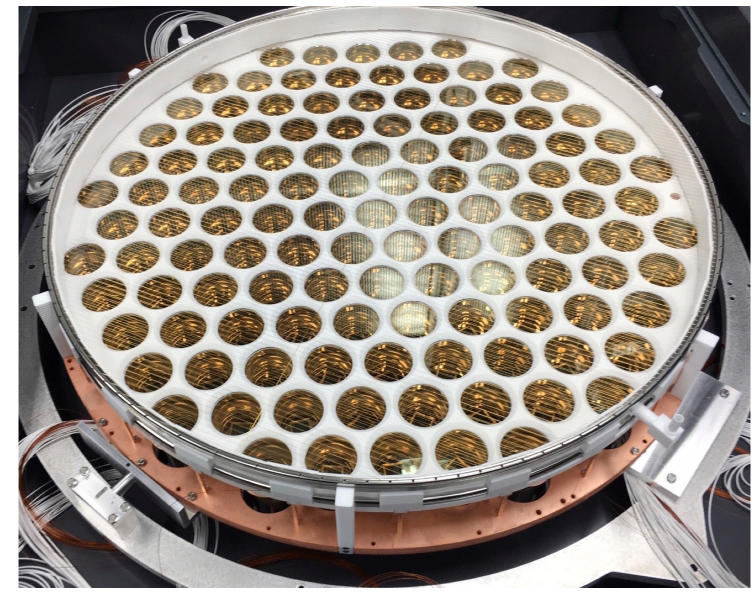
- 248 3-inch, low-radioactivity PMTs arranged in two arrays EPJC 75 (2015) 11, 546



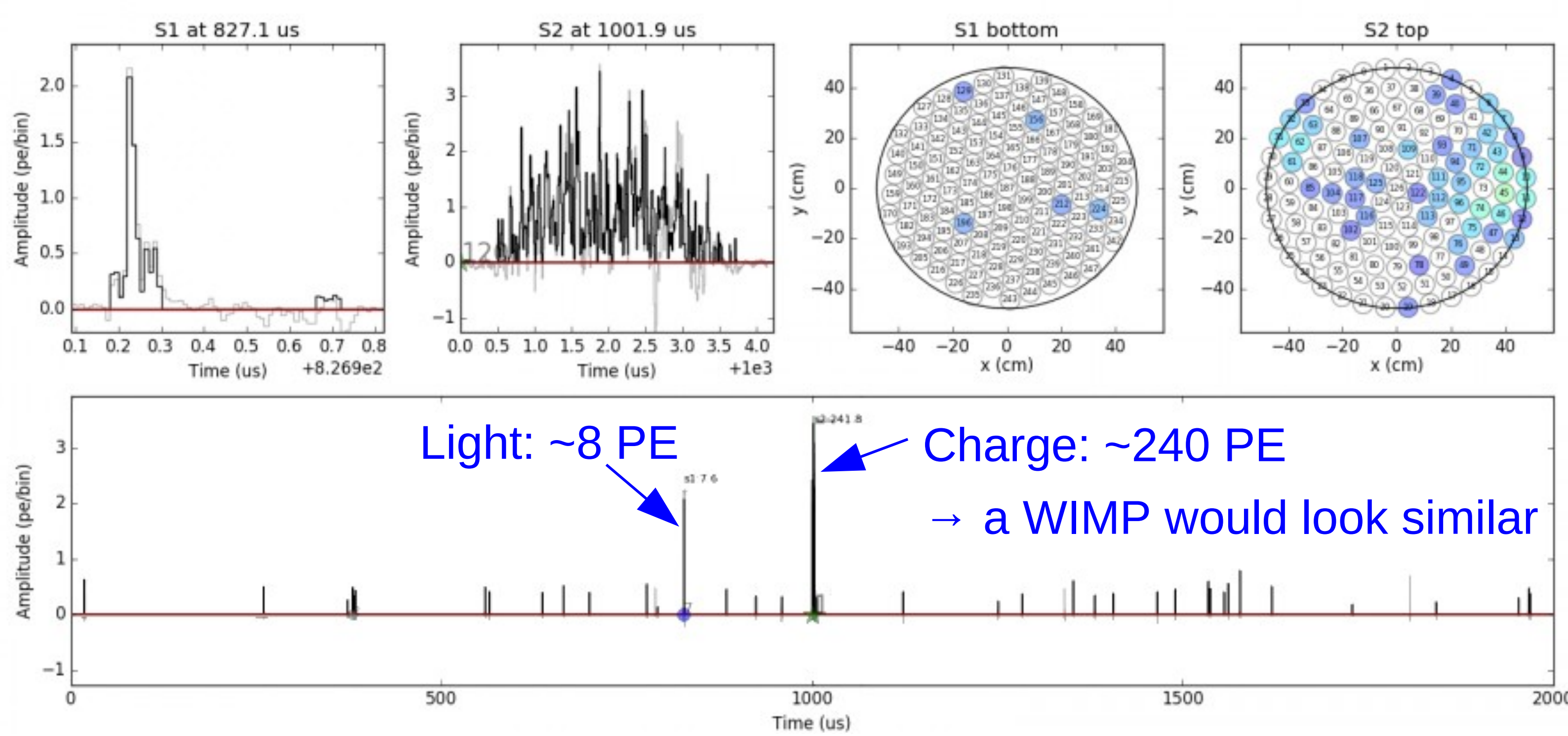
3.2 t LXe @180 K
~1 meter drift length
~1 meter diameter



127 PMTs in the top array

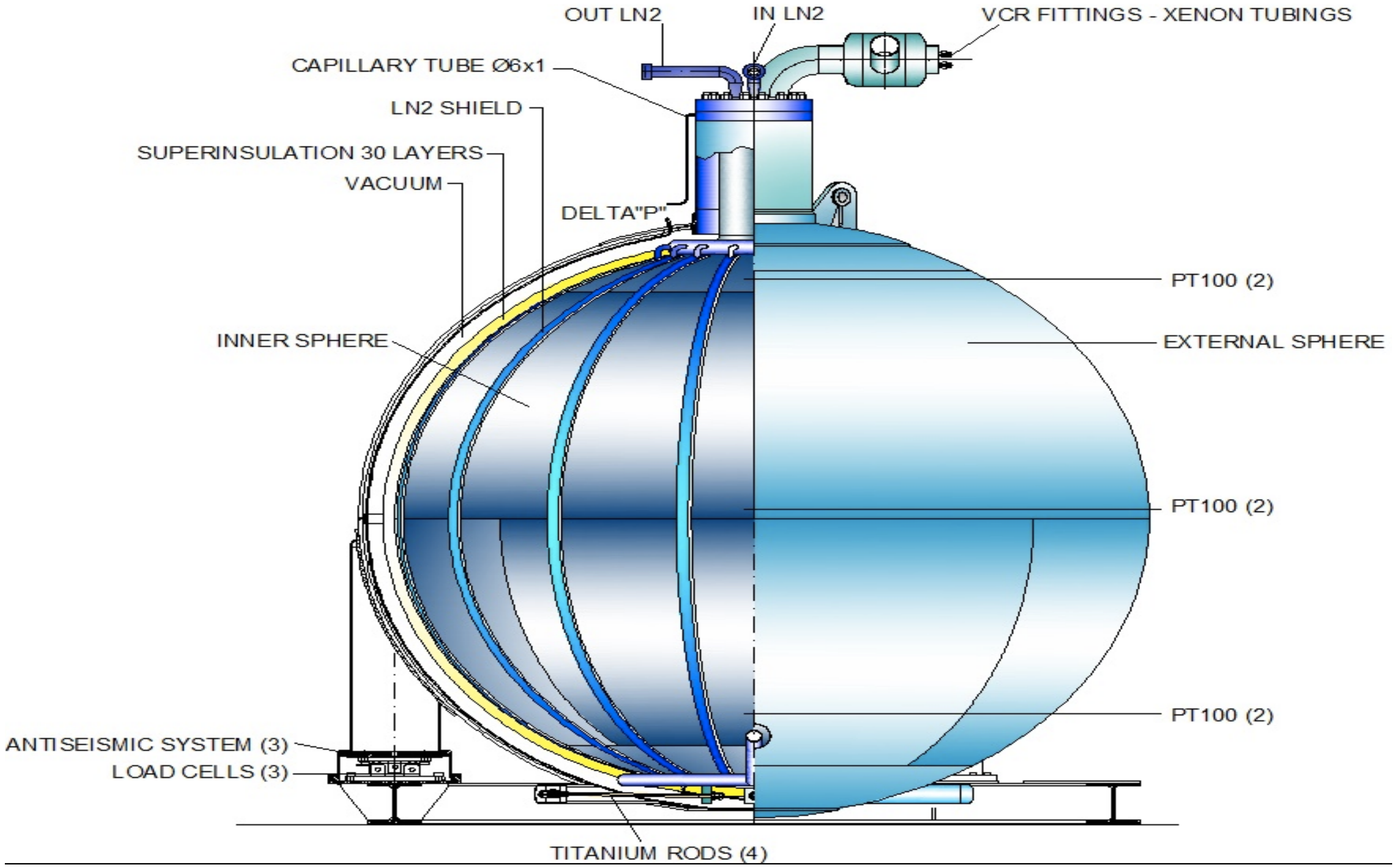


121 PMTs in the bottom array



The Xe Recovery & Storage System

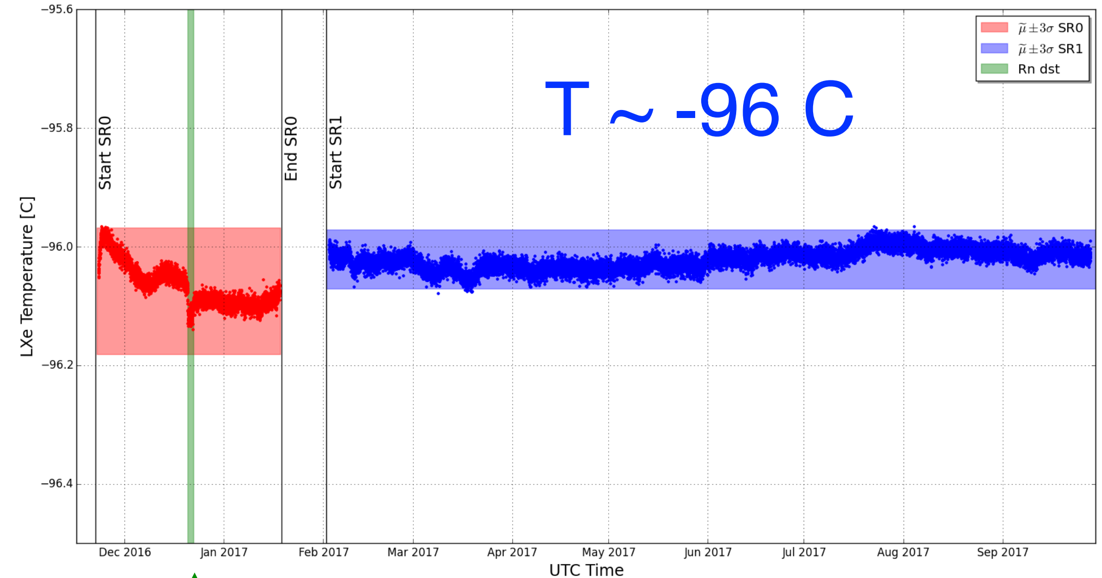
- Double-walled, high pressure (70 atm), vacuum-insulated, LN_2 cooled
- Can store up to 10t of xenon in gas or liquid/solid phase in high-purity conditions
- Fast recovery (few hours) in case of emergency



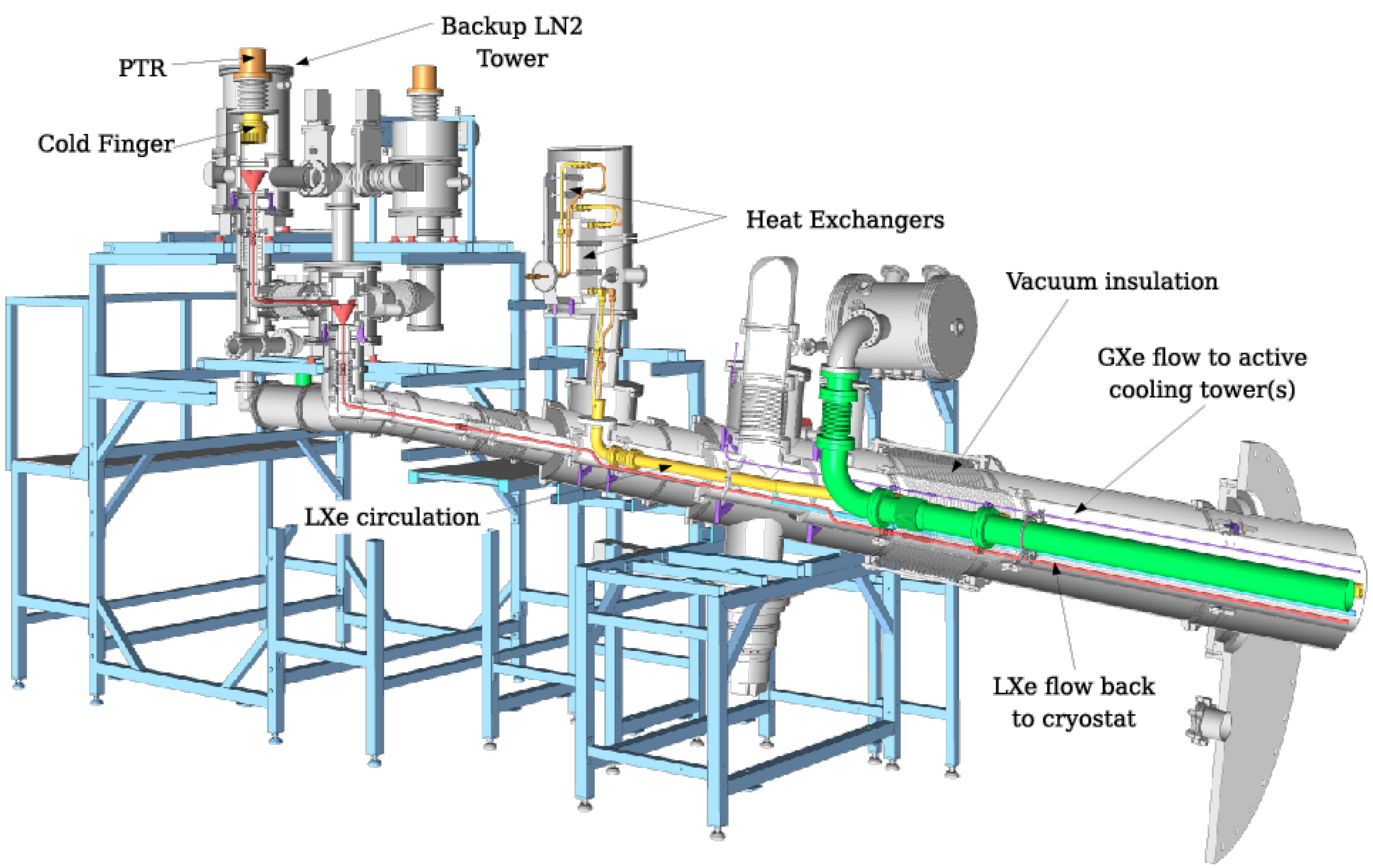
The Cryogenic System

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

Two redundant PTR cooling systems and one LN_2 cooling tower backup-
Efficient two-phase heat exchangers



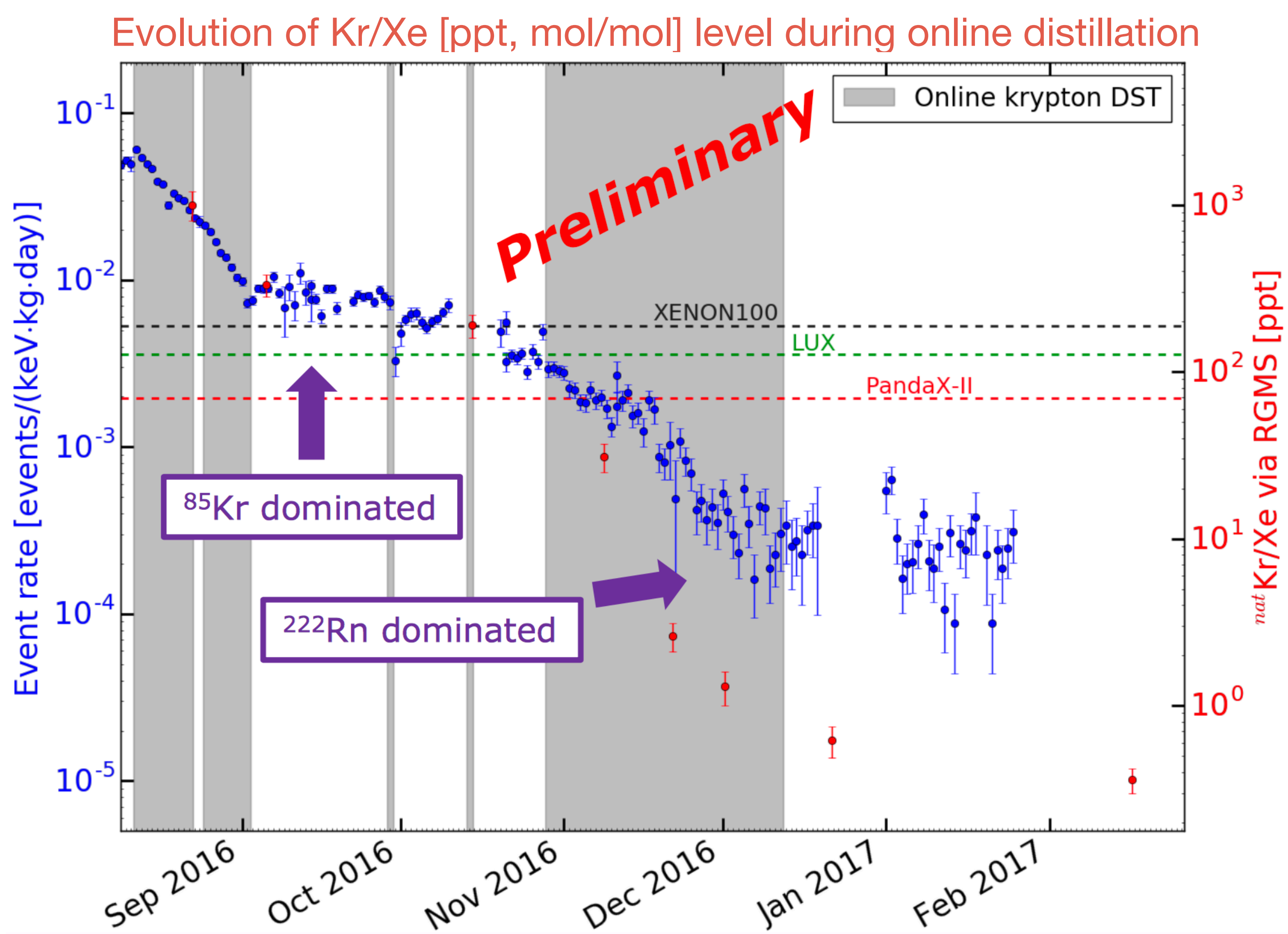
Rn distillation, Rn level reduced by ~20%



The Distillation Column

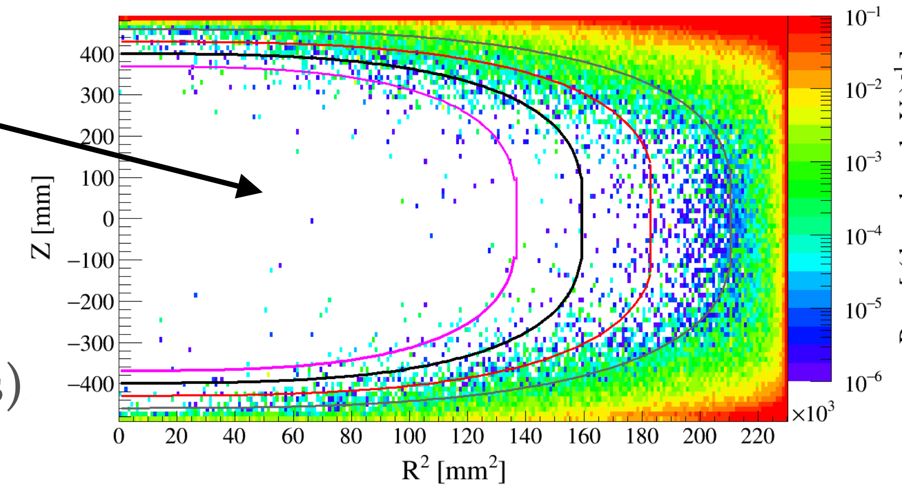
- Commercial Xe: 1 ppm - 10 ppb of Kr
- XENON1T sensitivity demands: 0.2 ppt
- Solution: 5.5 m distillation column, 6.5 kg/h throughput $>6.4\times10^5$ separation, output concentration < 48 ppq (RGMS)

XENON collaboration arXiv:1612.0428, & EPJ-C74, 2014



ER Backgrounds: Prediction vs Data

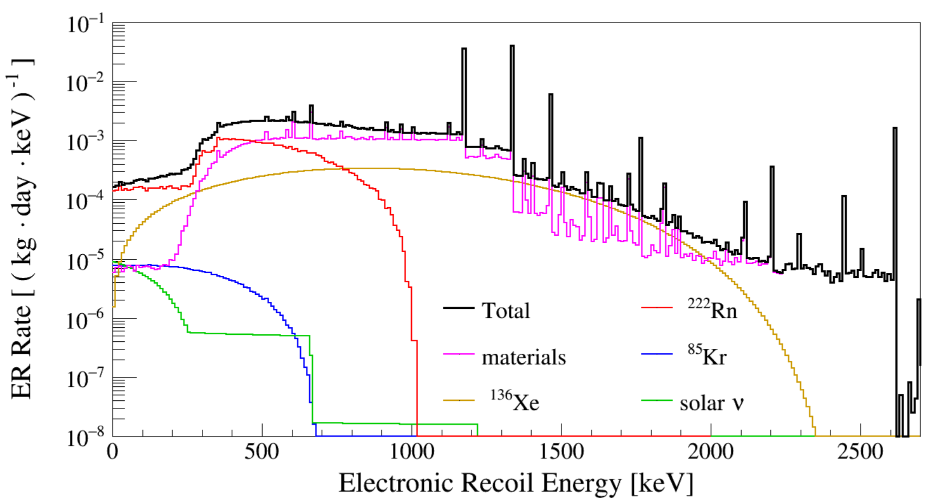
Predictions from MC simulations: ER background from materials is negligible in the 1t FV.

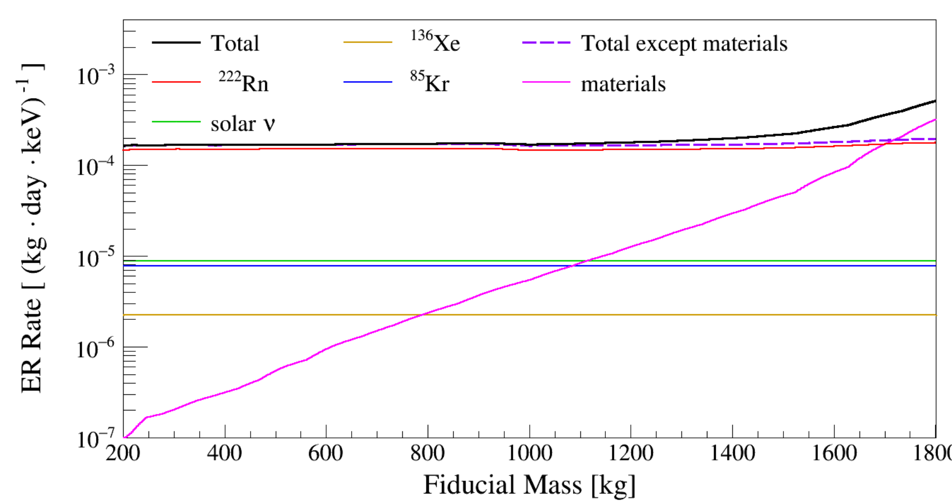


Eur. Phys. J. C77 (2017) no.5, 275 & arXiv:1702.06942

MC assumptions on the intrinsic backgrounds:

- 0.2 ppt of ^{nat}Kr (achieved in XENON1T distillation column tests),
- 10 µBq/kg of ^{222}Rn (estimation based on Rn emanation measurements)





^{222}Rn (mainly from ^{214}Pb β-decay) is the most relevant source of ER background in most of the TPC.

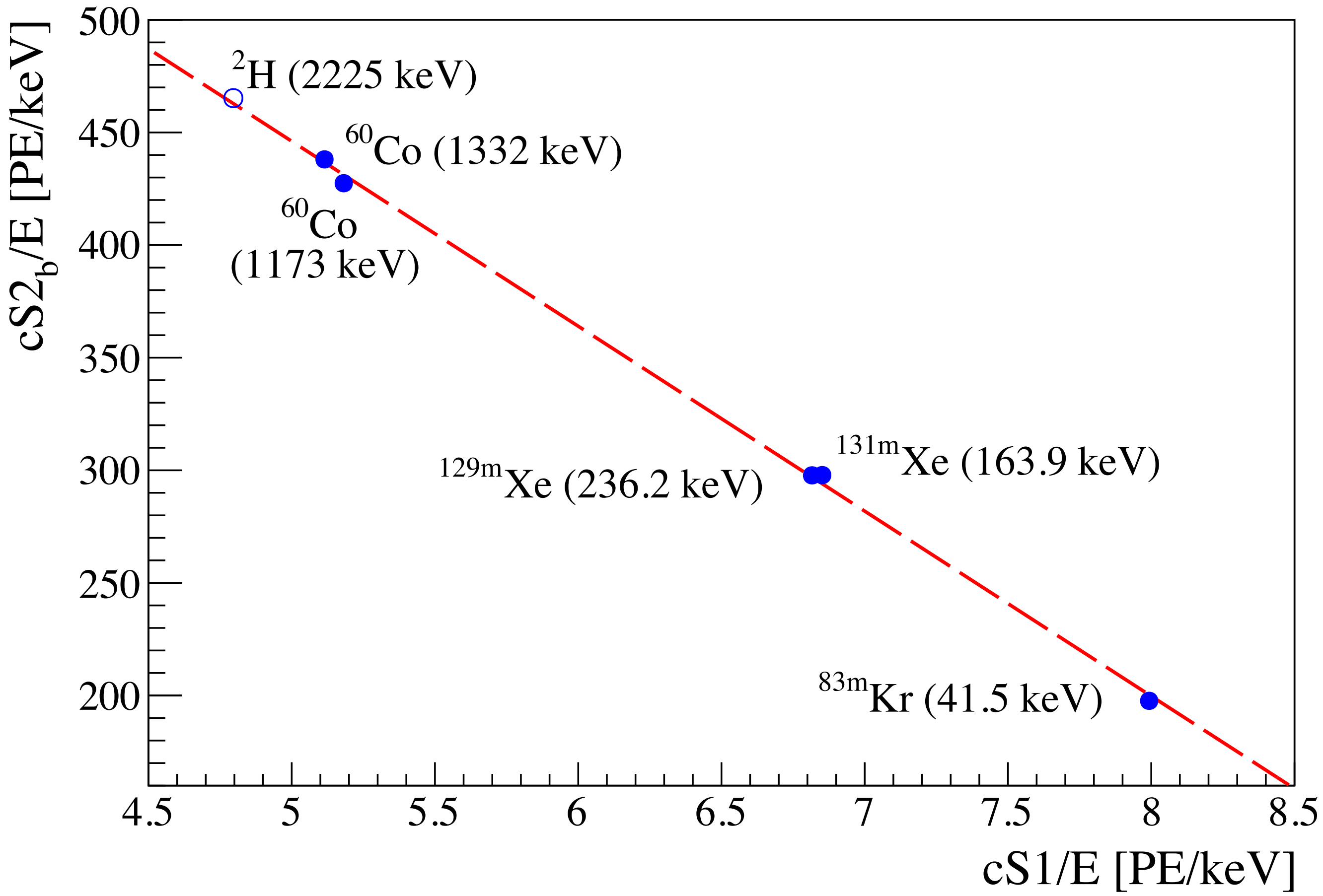
Measured: (1.93 +/- 0.25) 10^{-4} events / (kg day keV) in 1042 kg FV and 5-40 keVnr ROI
Predicted (considering the average 1.5 ppt of Kr in first run): (2.3 +/- 0.2) 10^{-4} events / (kg day keV)

Lowest ER background ever achieved in a DM detector !

Energy response

at 125 V/cm drift field

- L_y = (8.02±0.06) pe/keV at 41.5 keV
- Q_y = (198.3±2.3) pe/keV at 41.5 keV



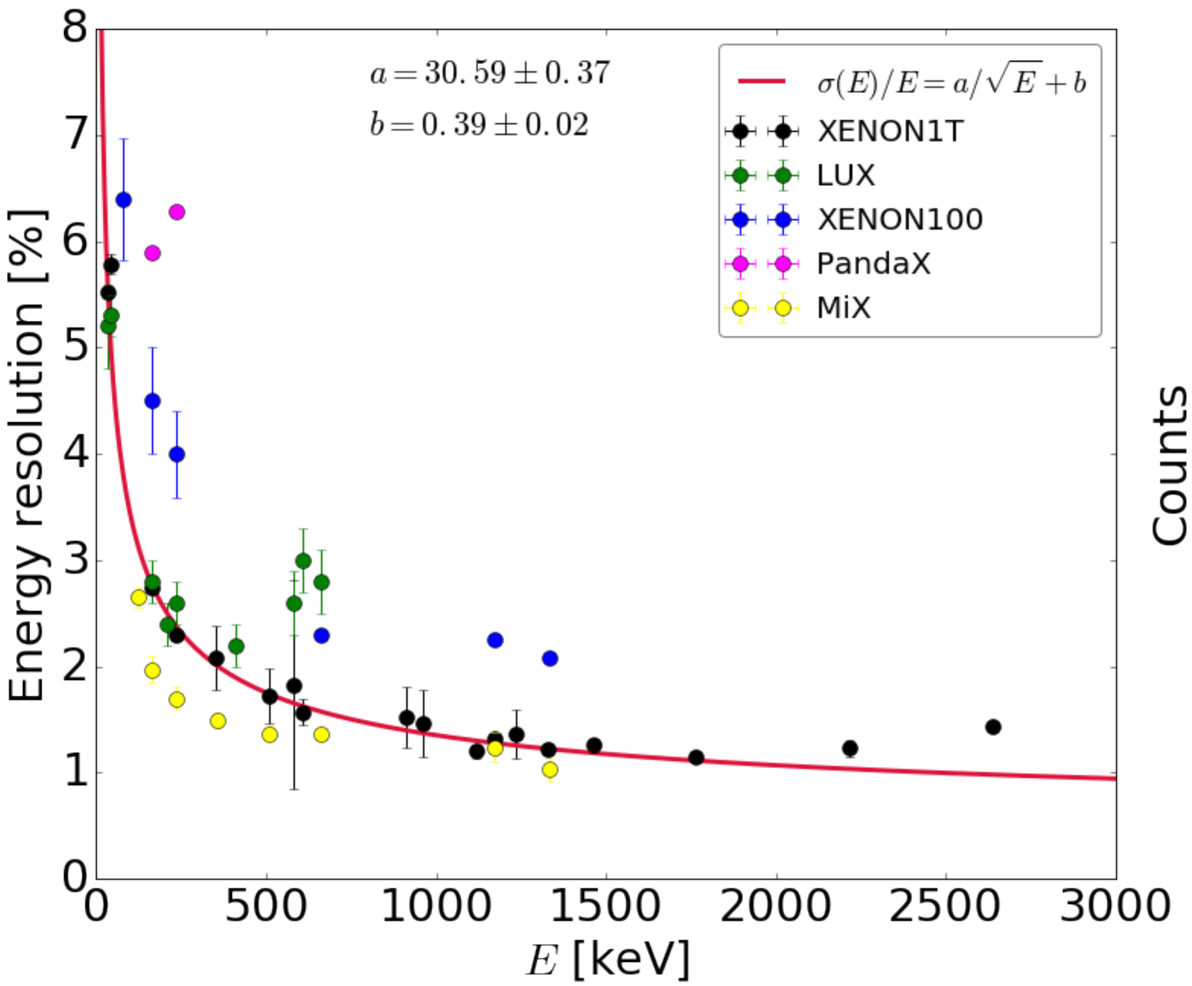
$$E = (n_{ph} + n_e) \cdot W = \left(\frac{S_1}{g_1} + \frac{S_2}{g_2} \right) \cdot W$$

- Excellent linearity with electronic recoil energy from 40 keV to 2.2 MeV
  - g_1 = photon gain
  - g_2 = electron gain
  - W-value = 13.7 eV

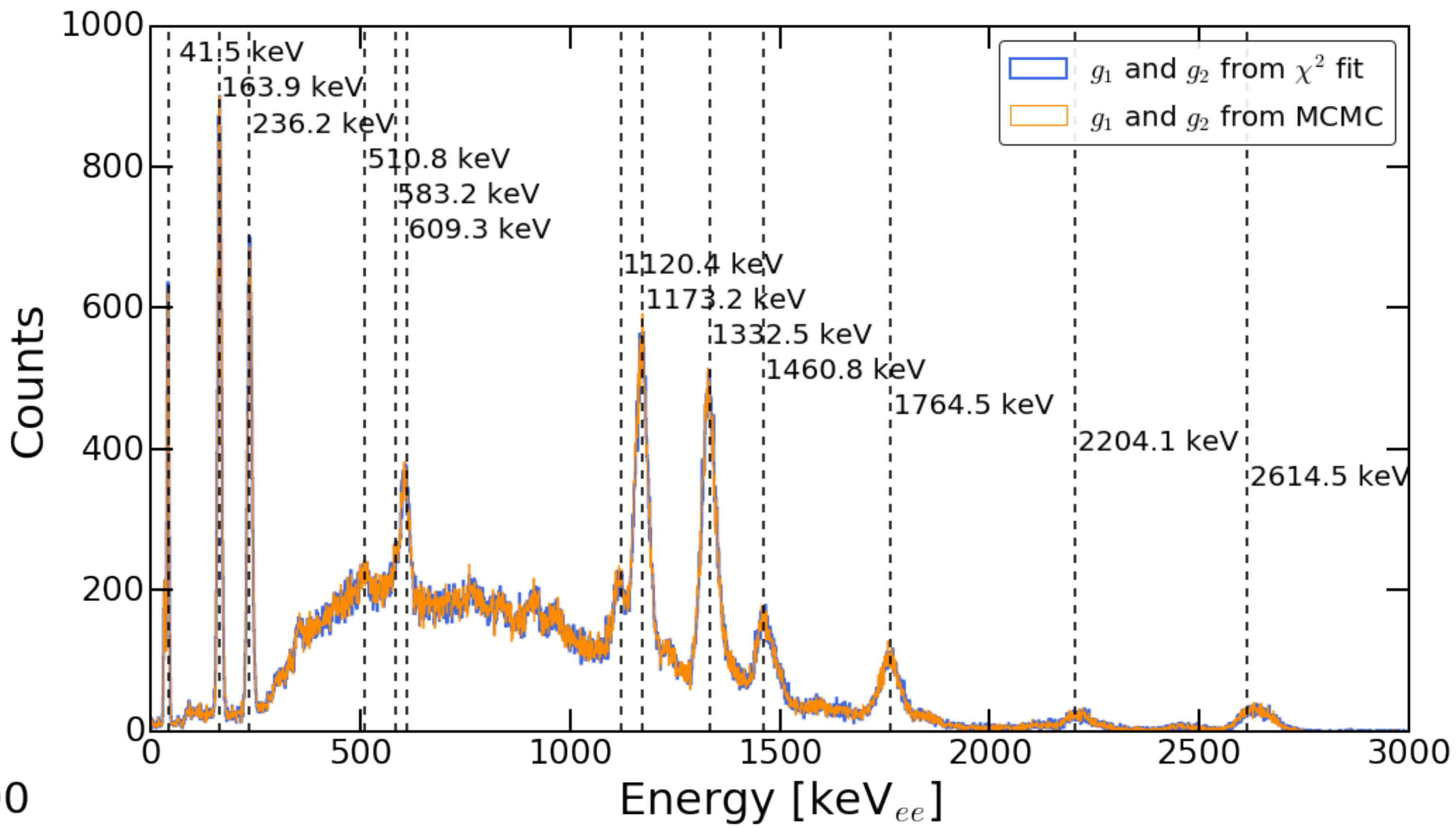
- g_1 = (0.144 ± 0.007) pe/photon
- g_2 = (11.5 ± 0.8) pe/electron

Energy resolution

- One of the best energy resolutions among all liquid xenon TPCs
- Covers large energy range



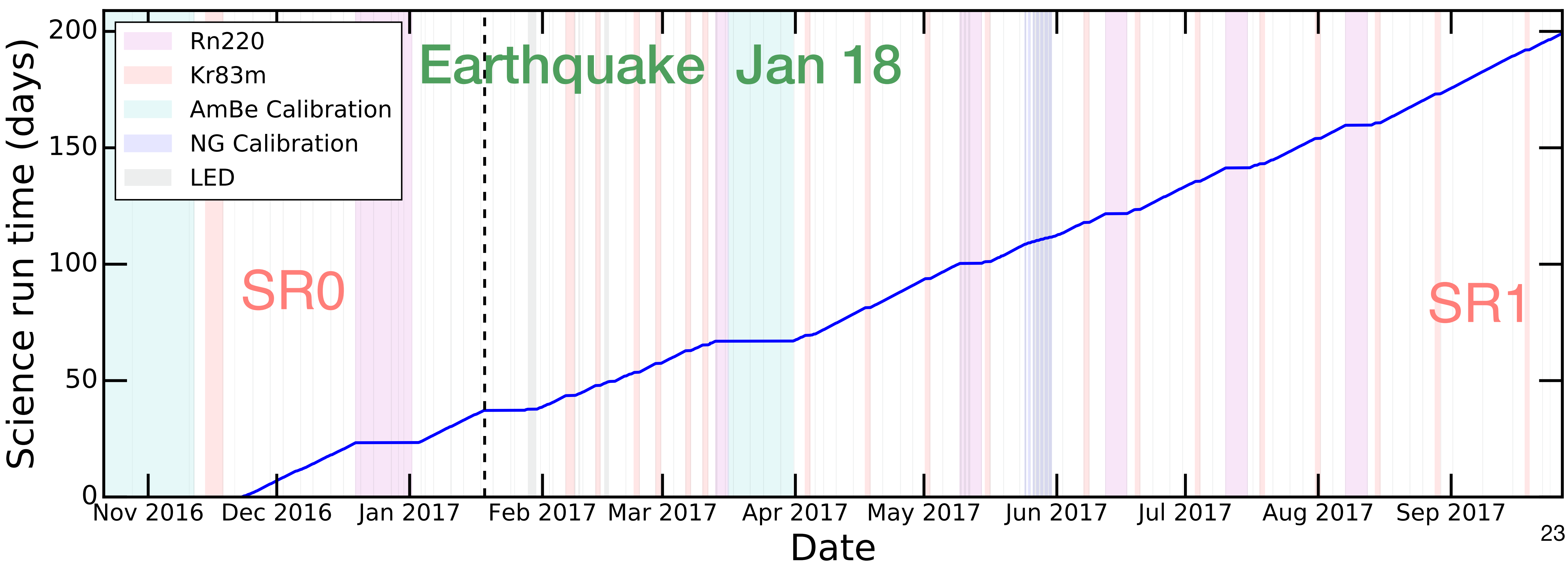
Relative energy resolution (σ(E)/E) versus energy



Energy spectrum of electronic recoils

Data overview: science and calibration

- Detector running smoothly
- **DAQ efficiency: ~ 99%**
- Accumulated live days: SR0 (34.2 d), SR1 (~165 d of blinded dark matter data)
- SR0: published; SR1: analysis ongoing, expect new results by early 2018



SR0 results

Accepted Paper

First dark matter search results from the XENON1T experiment

Phys. Rev. Lett.

E. Aprile et al.

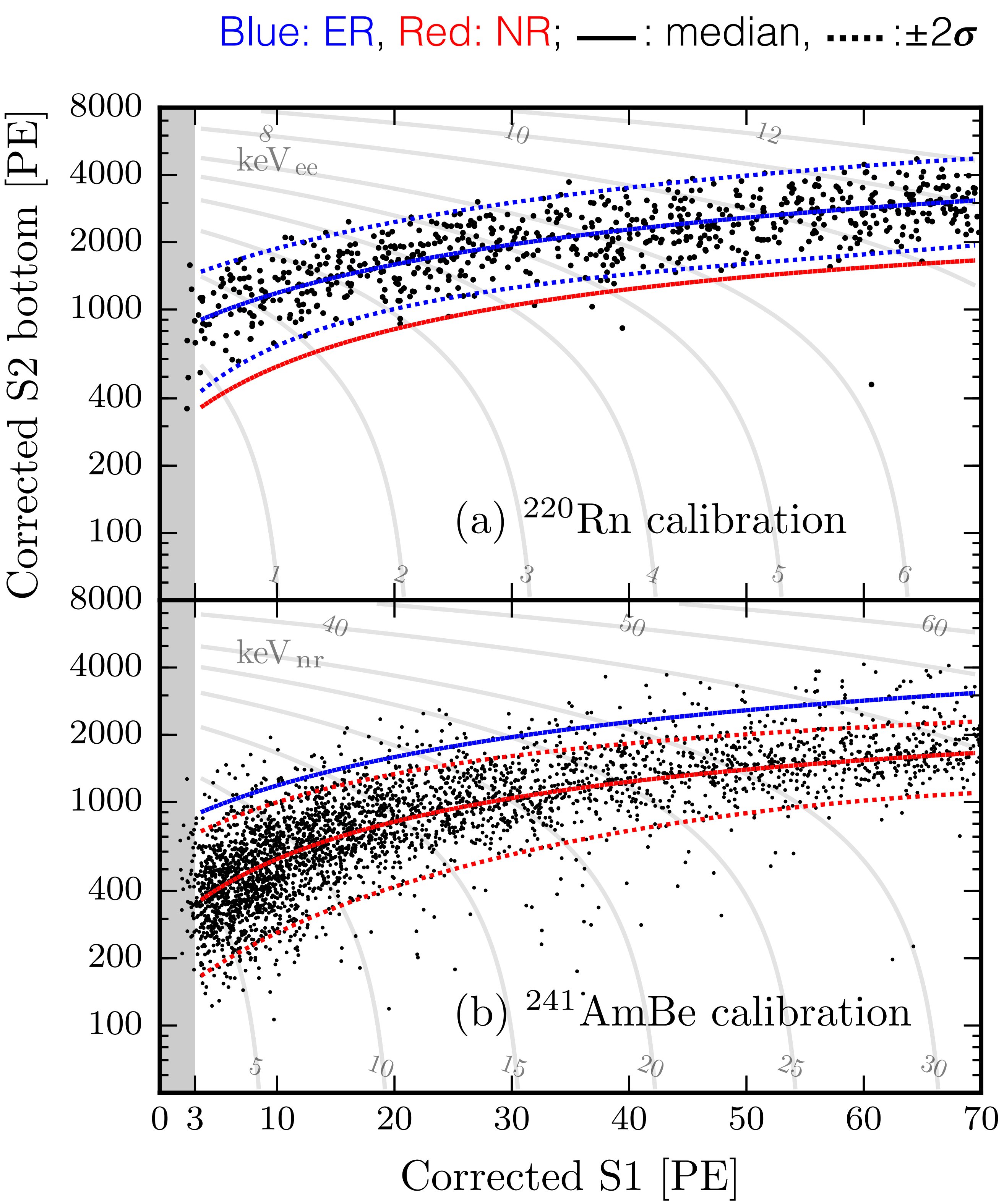
Accepted 15 September 2017

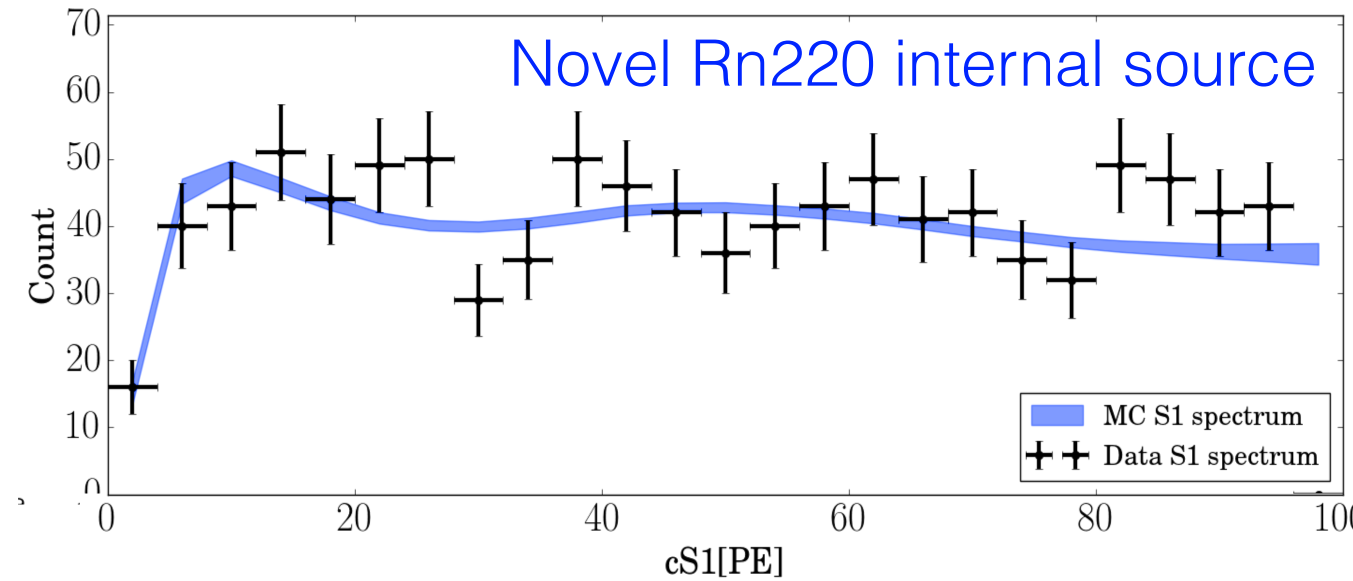
ABSTRACT

ABSTRACT

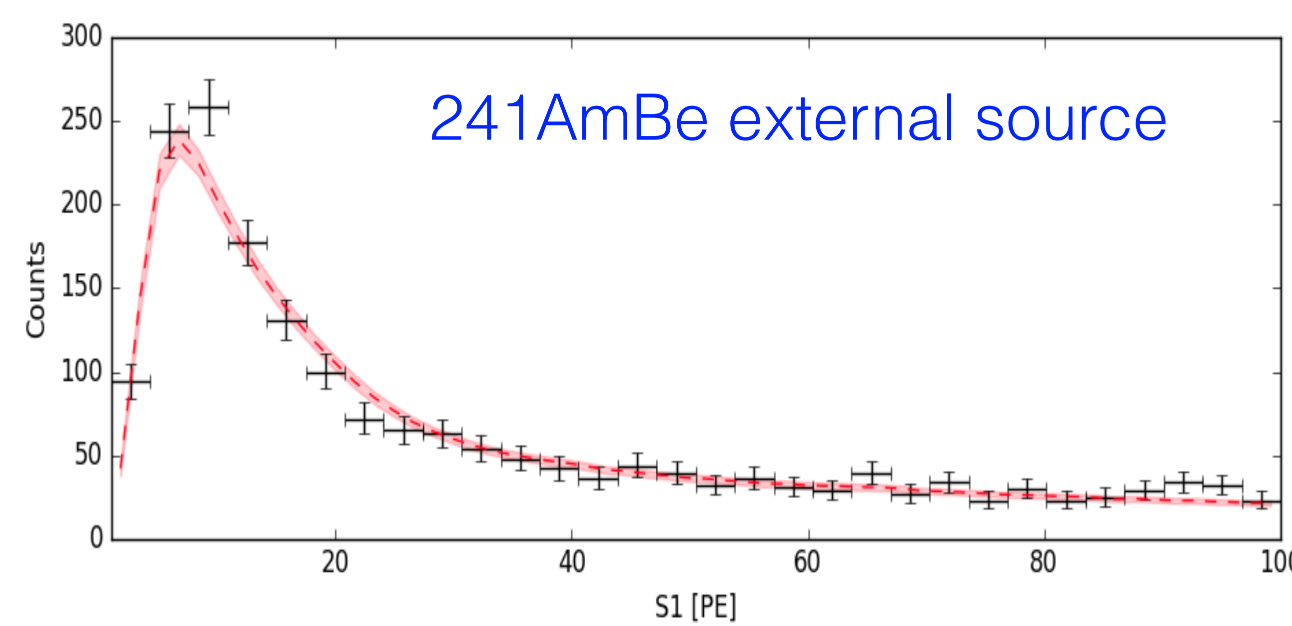
We report the first dark matter search results from XENON1T, a \sim2000-kg-target-mass dual-phase (liquid-gas) xenon time projection chamber in operation at the Laboratori Nazionali del Gran Sasso in Italy and the first ton-scale detector of this kind. The blinded search used \num{34.2} live days of data acquired between November 2016 and January 2017. Inside the \num{(1042\pm12)}~kg fiducial mass and in the [5, 40] keV_{nr} energy range of interest for WIMP dark matter searches, the electronic recoil background was (1.93 \pm 0.25) \times 10^{-4} \dru, the lowest ever achieved in such a dark matter detector. A profile likelihood analysis shows that the data is consistent with the background-only hypothesis. We derive the most stringent exclusion limits on the spin-independent WIMP-nucleon interaction cross section for WIMP masses above 10~\gevcsq, with a minimum of 7.7~\num{\times 10^{-47}}~cm^2 for 35-\gevcsq~WIMPs at 90\% confidence level.

ER and NR Response in SR0





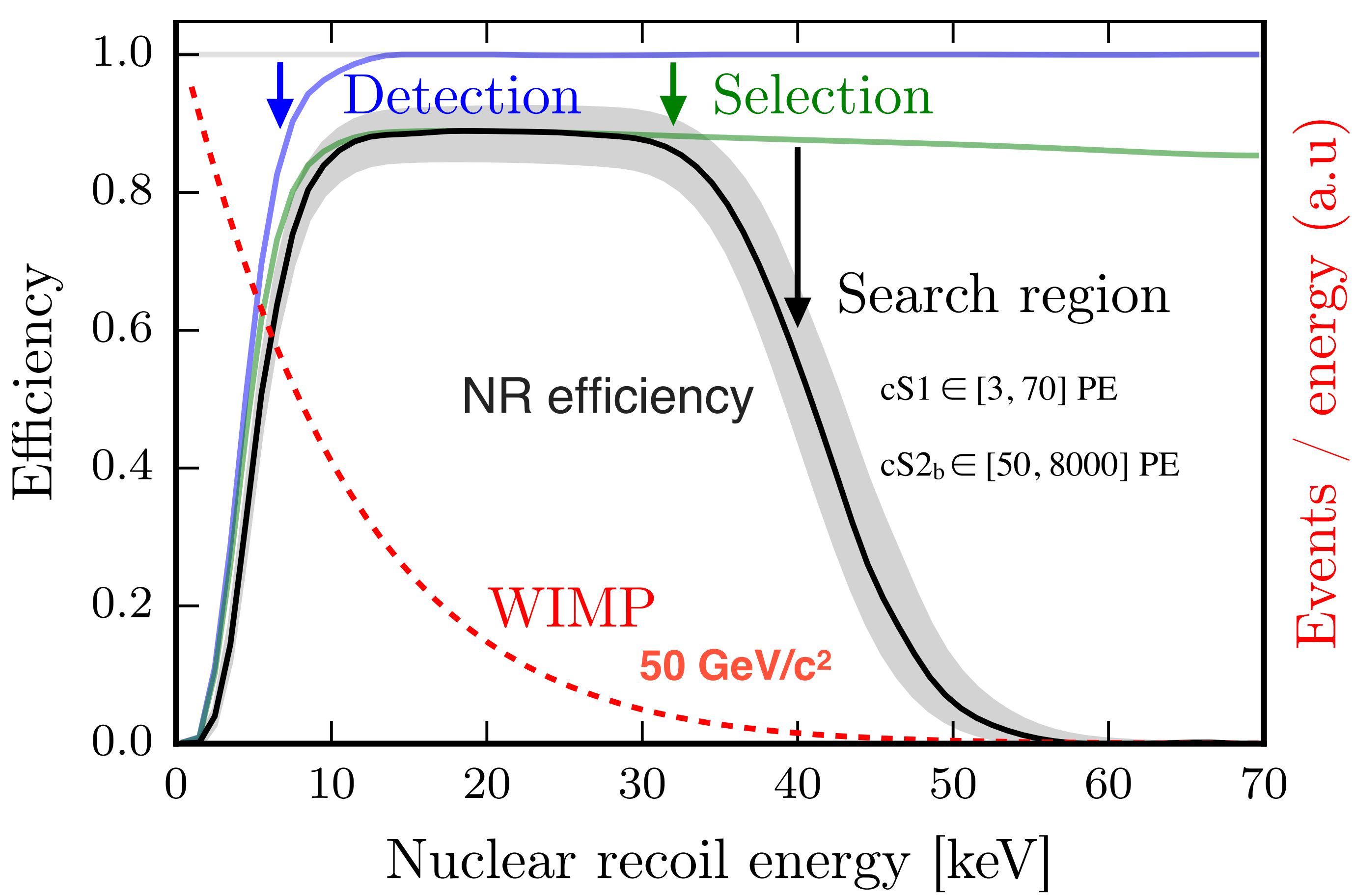
- Full modeling of LXe and detector response in $cS2_b$ vs cS1 space
- All parameters fitted with no significant deviation from priors

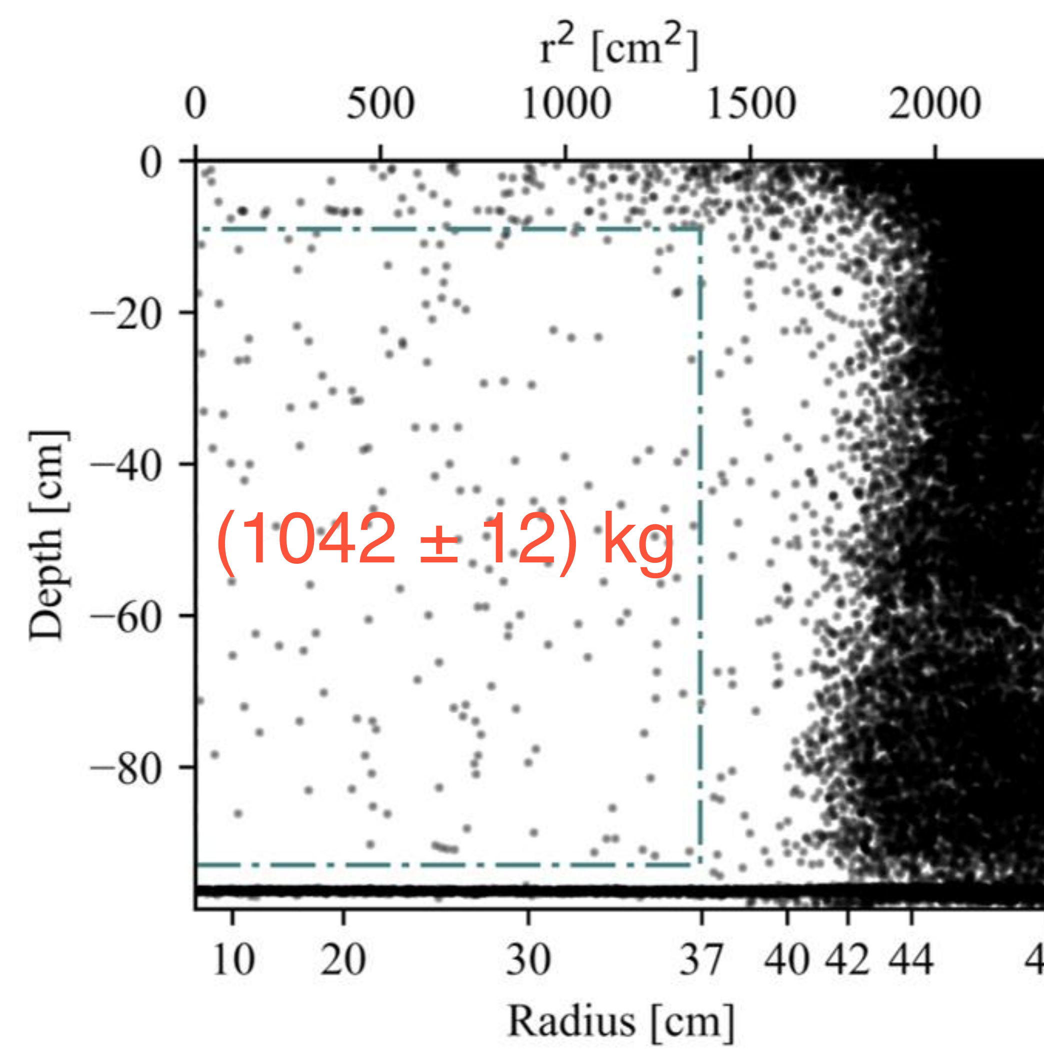


Data selection

- Signal region blinded until selection fixed
- Single-scatter, event quality, peak quality, fiducial volume

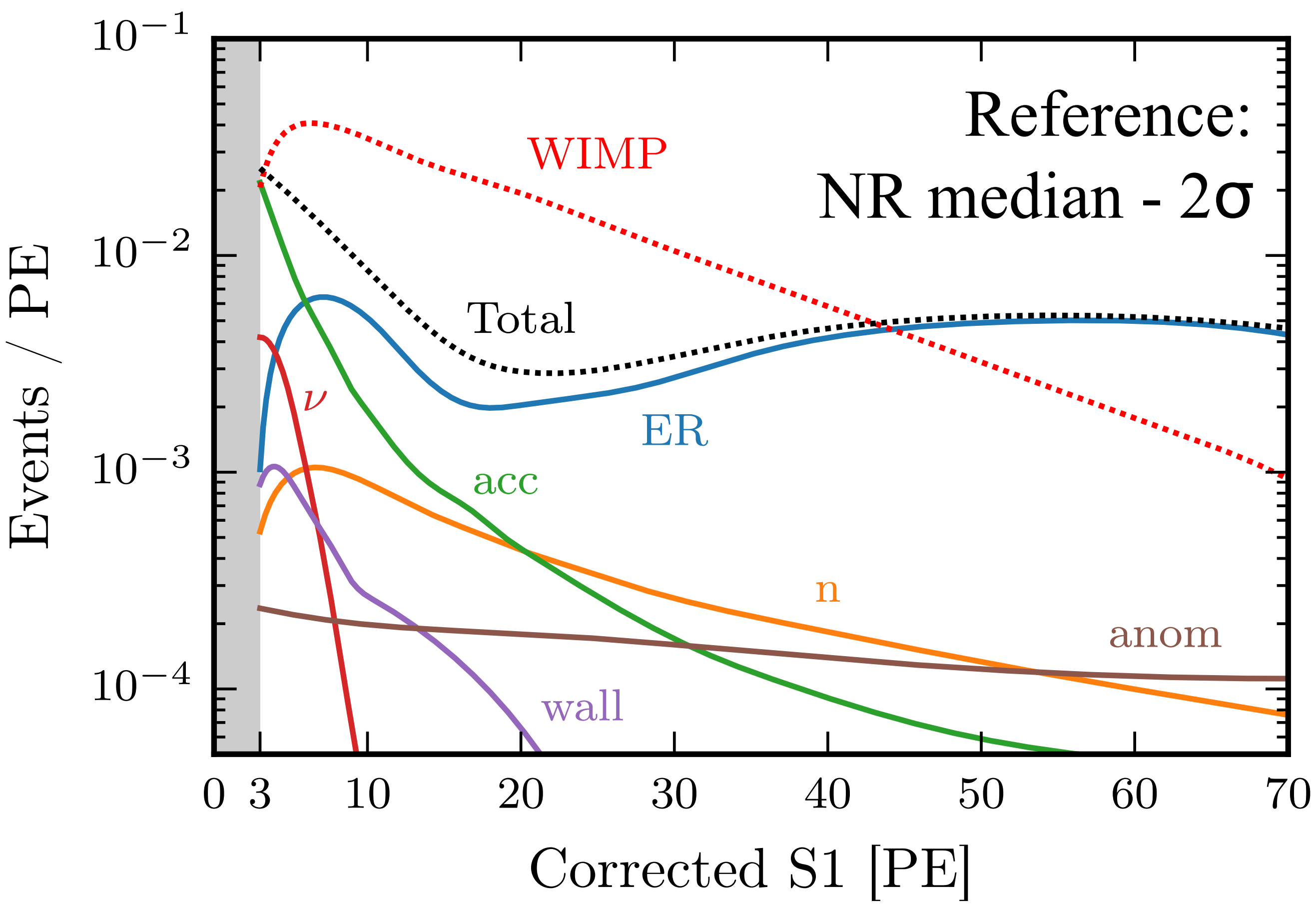
Selection criterium	Events remaining
All events (cS1<200 PE)	128144
Data quality, selection	48955
Fiducial volume	180
S1 range (3-70) PE	63





Total background

- ER rate is dominated by radon (emanation from detector materials)
- Target concentration of 10 µBq/kg reached
- Further reduction by Rn distillation (see EPJ C (2017) 77:358, arXiv:1702.06942)

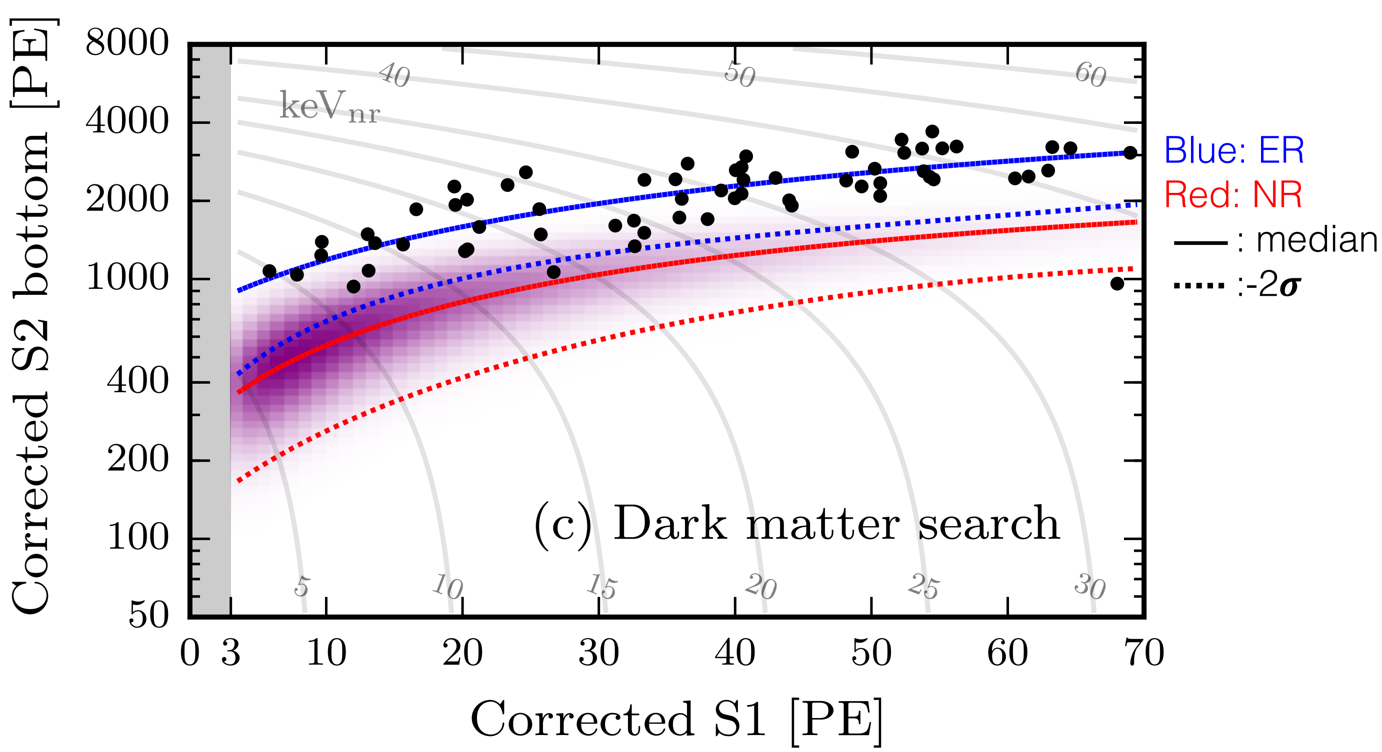


	Full	Reference
Electronic recoils (*ER*)	(62 ± 8)	$(0.26^{+0.11}_{-0.07})$
Radiogenic neutrons (*n*)	0.05 ± 0.01	0.02
CNNS (ν)	0.02	0.01
Accidental coincidences (*acc*)	0.22 ± 0.01	0.06
Wall leakage (*wall*)	0.5 ± 0.3	0.01
Anomalous (*anom*)	$0.10^{+0.10}_{-0.07}$	0.01 ± 0.01
Total background	63 ± 8	$0.36^{+0.11}_{-0.07}$

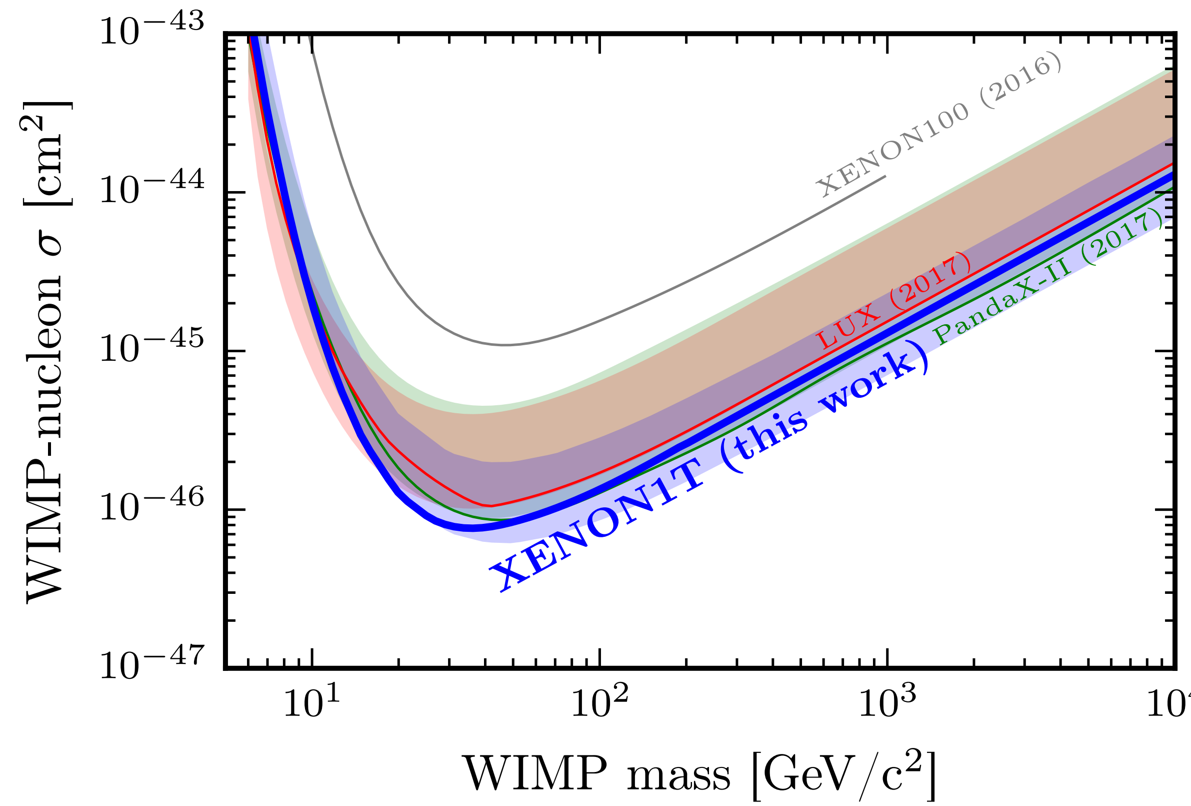
Observed ER rate: $(1.93 \pm 0.25) \times 10^{-4}$ events/(kg $\times$ d $\times$ keV)

Dark matter search results

- No post-unblinding changes to event selection
- Unbinned profile likelihood analysis, data consistent with background-only hypothesis
- ER/NR shape largely determined from calibration fits



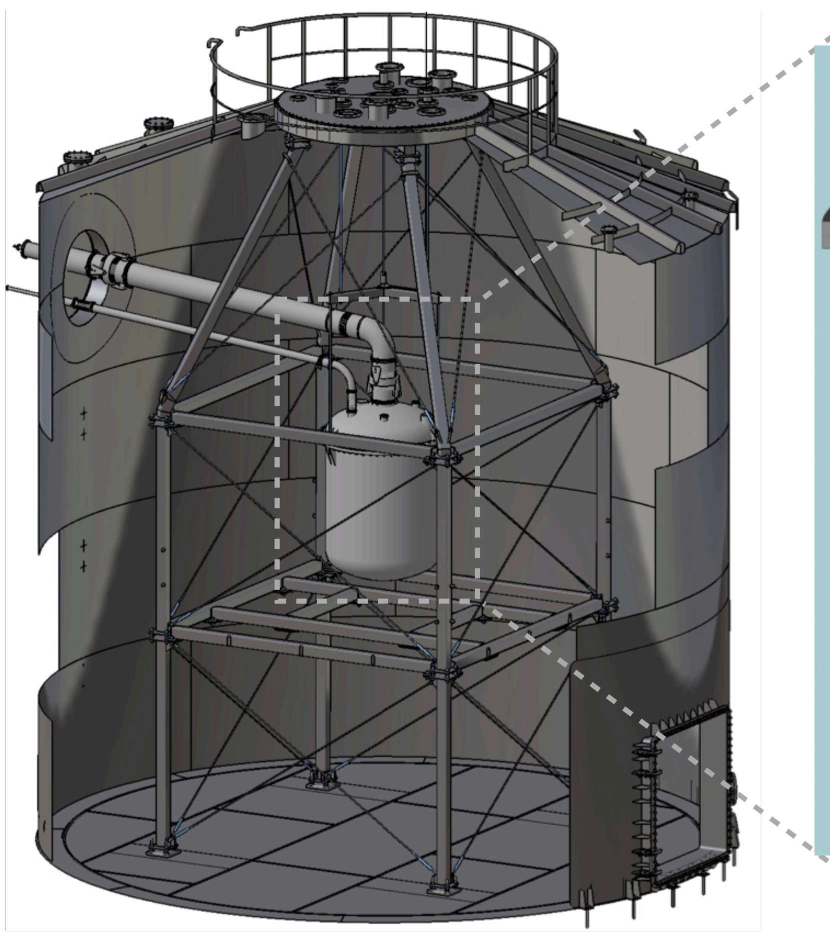
v_0 = 220 km/s, ρ_{DM} = 0.3 GeV/cm^3, v_{esc} = 544 km/s

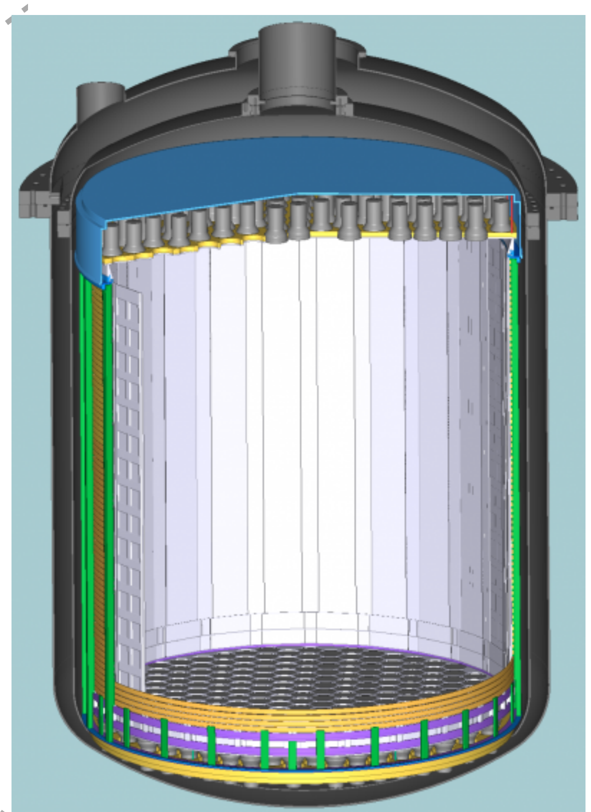


$$\sigma_{\min} = 7.7 \times 10^{-47}\,\mathrm{cm}^2 \text{ at } 35\,\mathrm{GeV/c^2}$$

Next step: XENONnT to start in 2019

- A rapid upgrade to XENON1T, with: 8 t total LXe mass, 6 t active (x3 compared to 1T)
- Most sub-systems can handle a larger detector with up to 10 t of LXe:



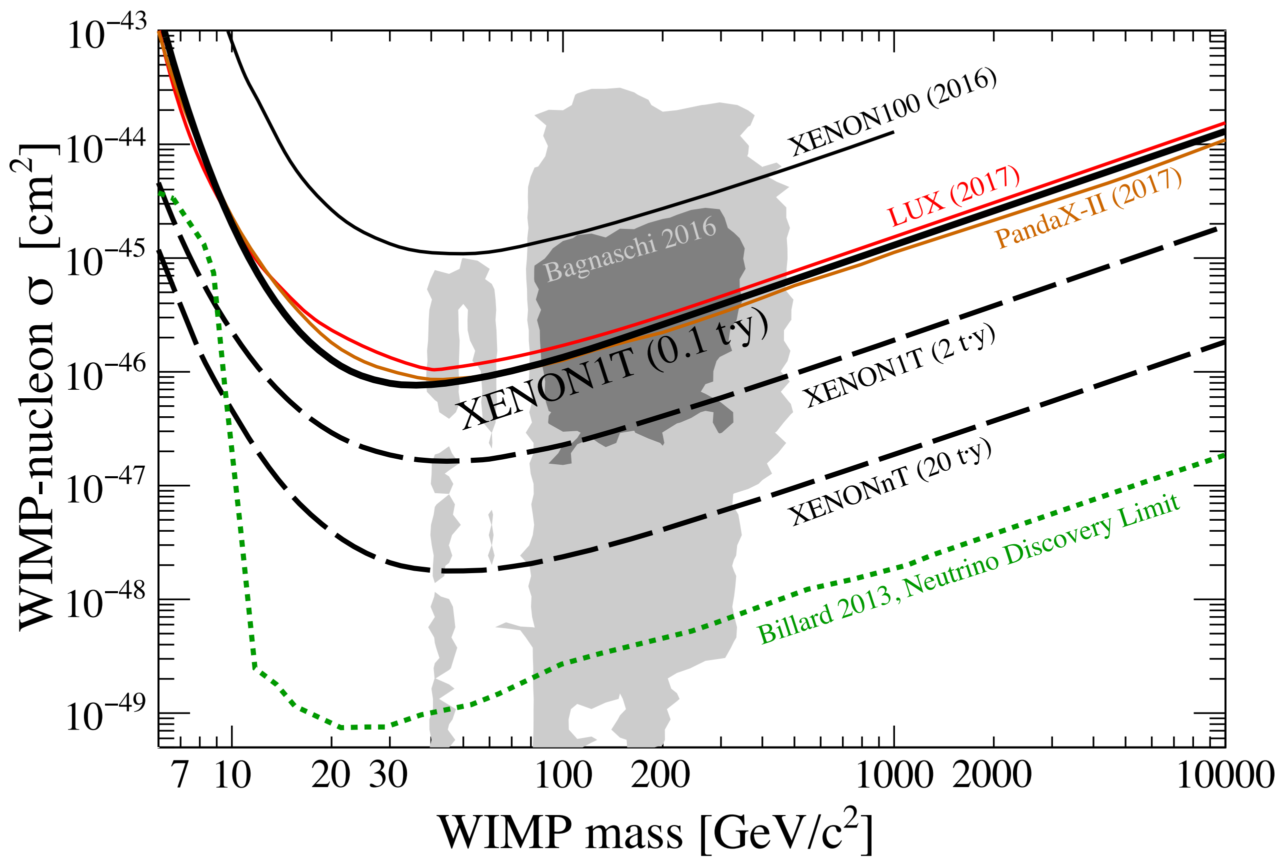


- Water tank + muon veto
- Outer cryostat and support structure
- Cryogenics and purification system
- LXe storage system
- Cables installed for XENONnT as well
- New inner cryostat, new TPC, 476 PMTs
- Neutron veto, Rn removal tower, additional LXe purification and storage system
- Work on new systems progressing

XENON1T and XENONnT science reach

- XENON1T: 1.6 x 10^{-47} cm^2 with an exposure of 2 tonnes x year
- XENONnT: to start in mid 2019, aiming for 20 tonnes x year exposure

	XENON1T	XENONnT	LZ
Fiducial Volume [tons]	1	4	5.6
Livetime Fraction	80%	80%	80%
WIMP Energy Range [keV_{nr}]	4-50	4-50	6-30
NR Acceptance	40%	40%	50%
ER Rejection	99.75%	99.75%	99.5%
Bkg rate [evt/year]	2.08	1.15	2.35



Summary

- The XENON1T experiment operates the largest LXeTPC (ton-scale)
- First physics results accepted in PRL, from 34.2 live days of data
- Lowest background in a dark matter detector (~0.2 events/(t d keV))
- Data-taking continues in stable conditions and with very good performance
- More than 165 additional live days of (blinded) science data. New results expected for early next year—> exciting time ahead!
- Work toward the upgrade to the XENONnT phase well underway. Installation of new detector planned for late 2018.