Dark Matter Searches with Xe

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Andes2017 Workshop
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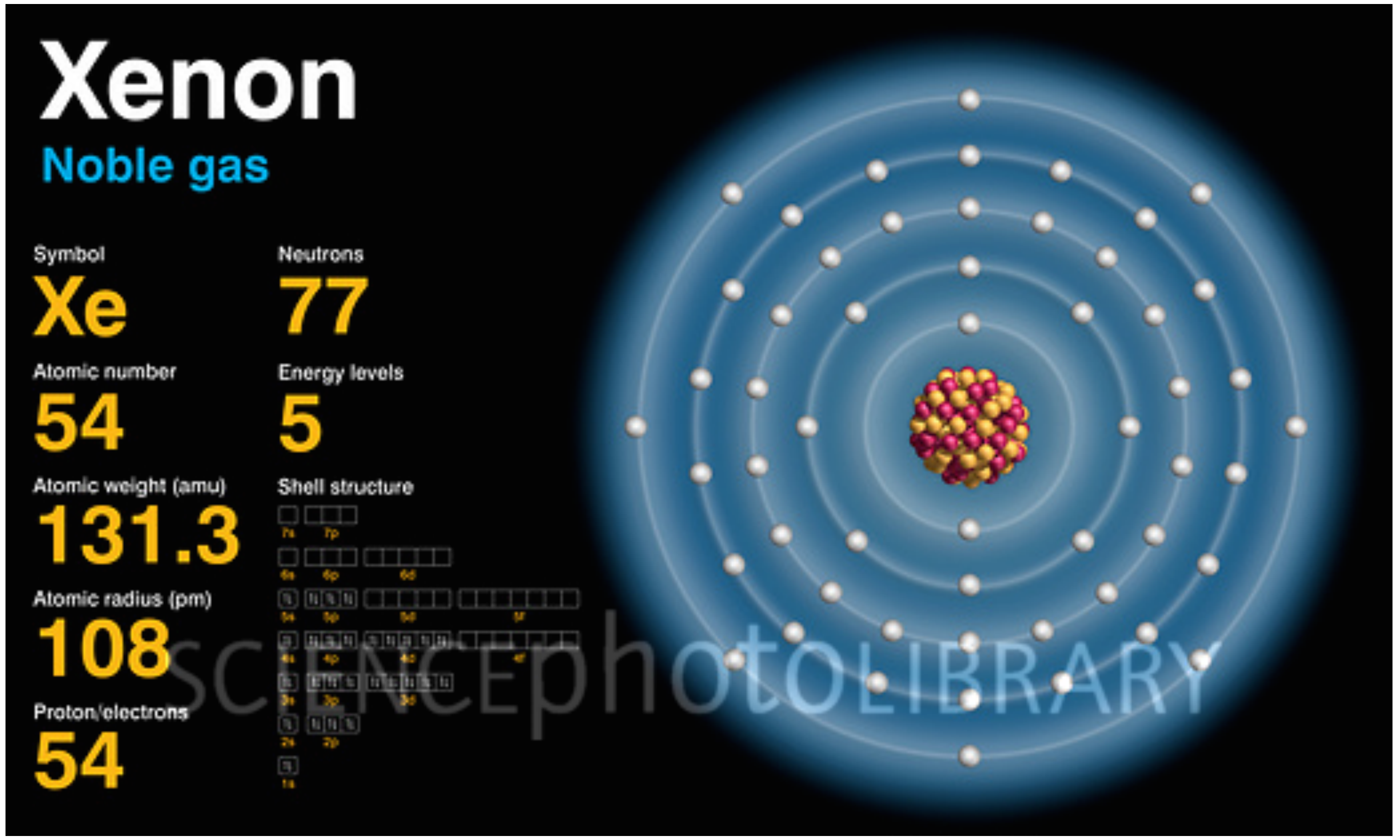
Why Liquid Xenon for a Dark Matter Detector

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

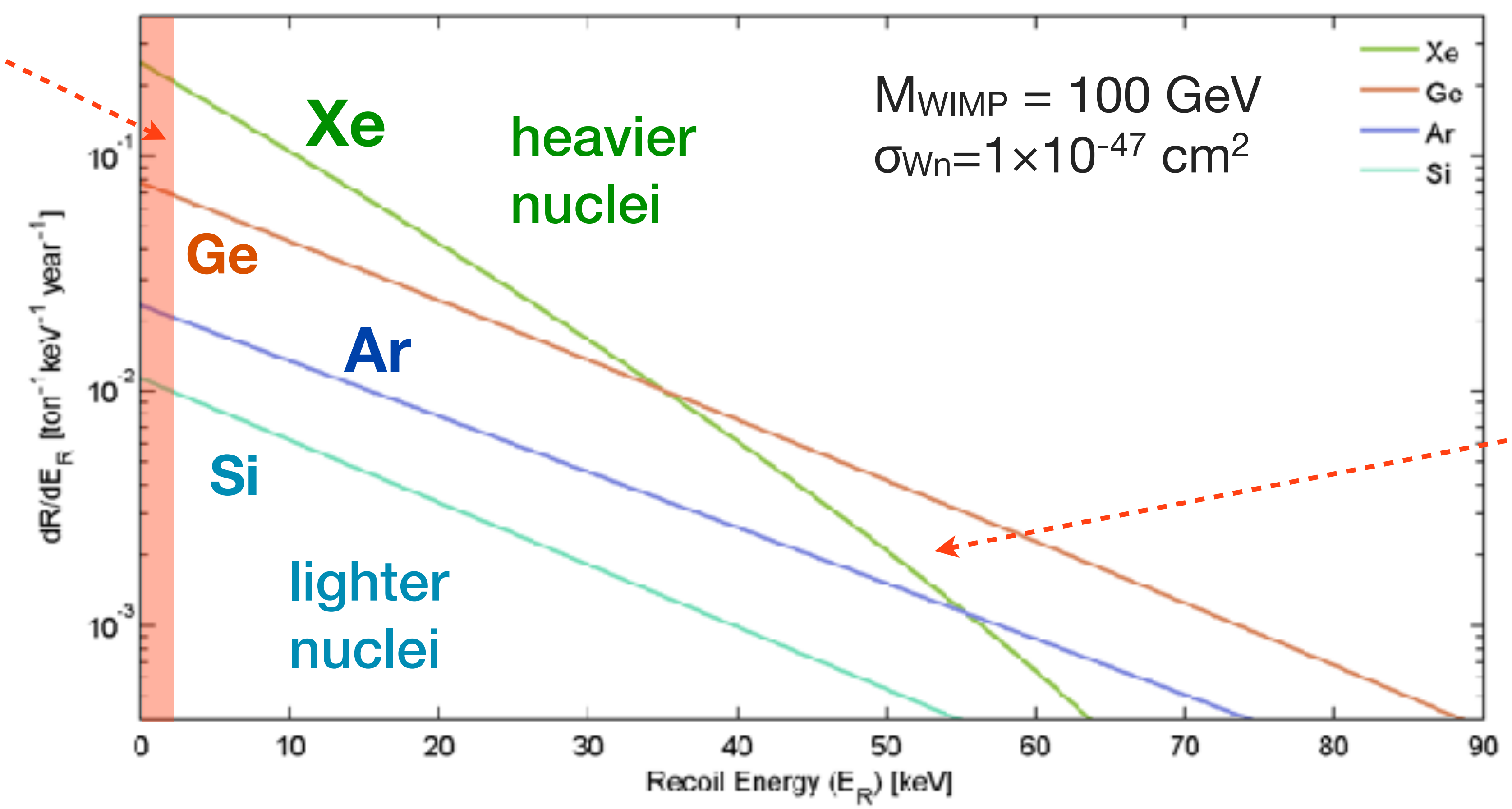


- *large nucleus and presence of isotopes with nuclear spin allow to probe SI and SD interactions with one target*
- *dense liquid for a massive WIMP target at reasonable cost (~1000$/kg)*
- *we have improved technologies to keep it cold and clean over long time*
- *no intrinsic radioactivity other than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

Expected interaction rates

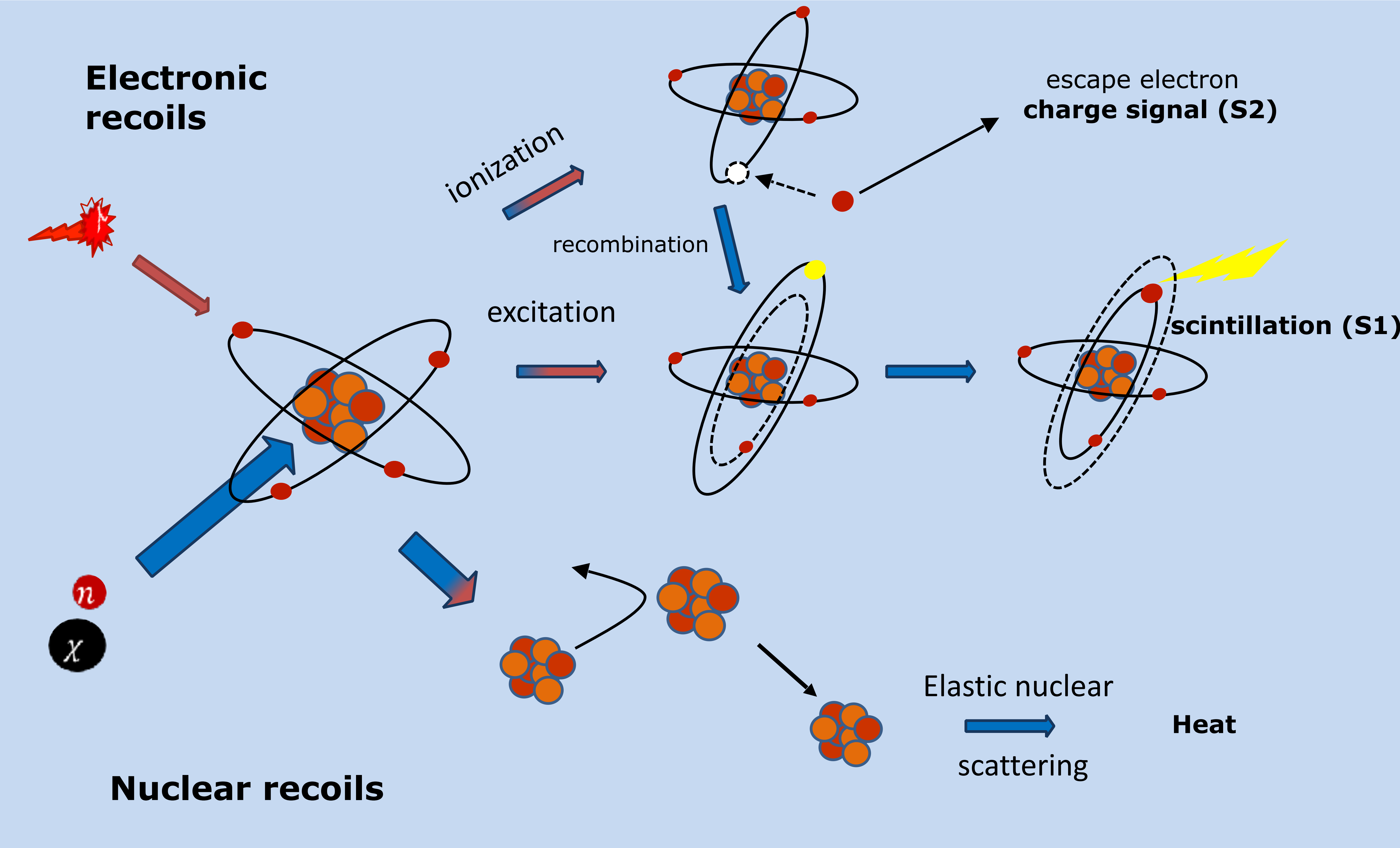
$$R \sim 0.13 \ \frac{\text{events}}{\text{kg year}} \left[\frac{A}{100} \times \frac{\sigma_{WN}}{10^{-38}\,\text{cm}^2} \times \frac{\langle v \rangle}{220\,\text{km}\,\text{s}^{-1}} \times \frac{\rho_0}{0.3\,\text{GeV}\text{cm}^{-3}} \right]$$

$$v_{min} = \sqrt{\frac{m_N E_{th}}{2\mu^2}}$$

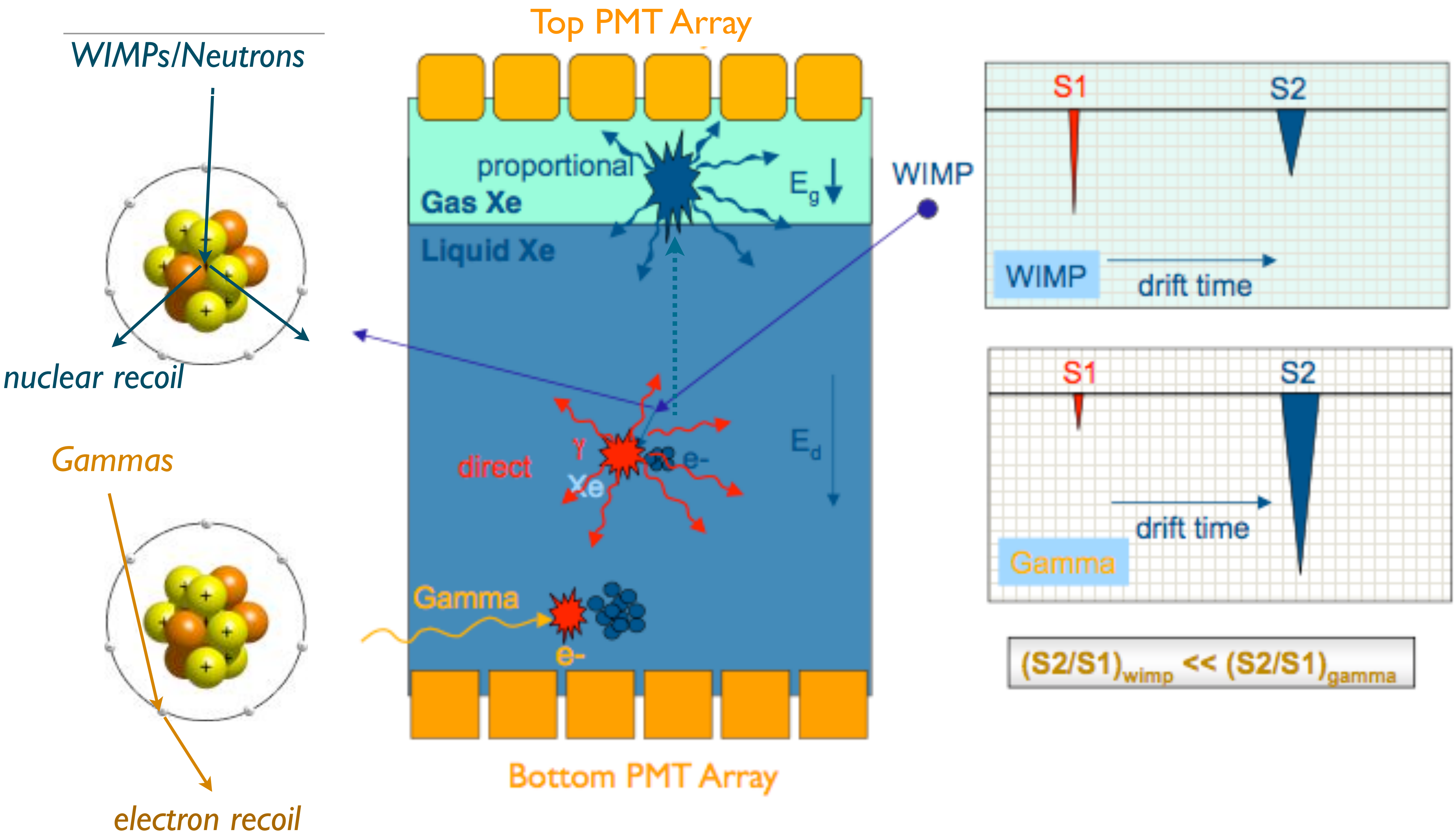


$F^2(E_R)$

Two signals produced when a WIMP hits the Xe nucleus



A Time Projection Chamber to detect these two signals



LXeTPCs: 50- 500 kg scale

XENON100 @ LNGS

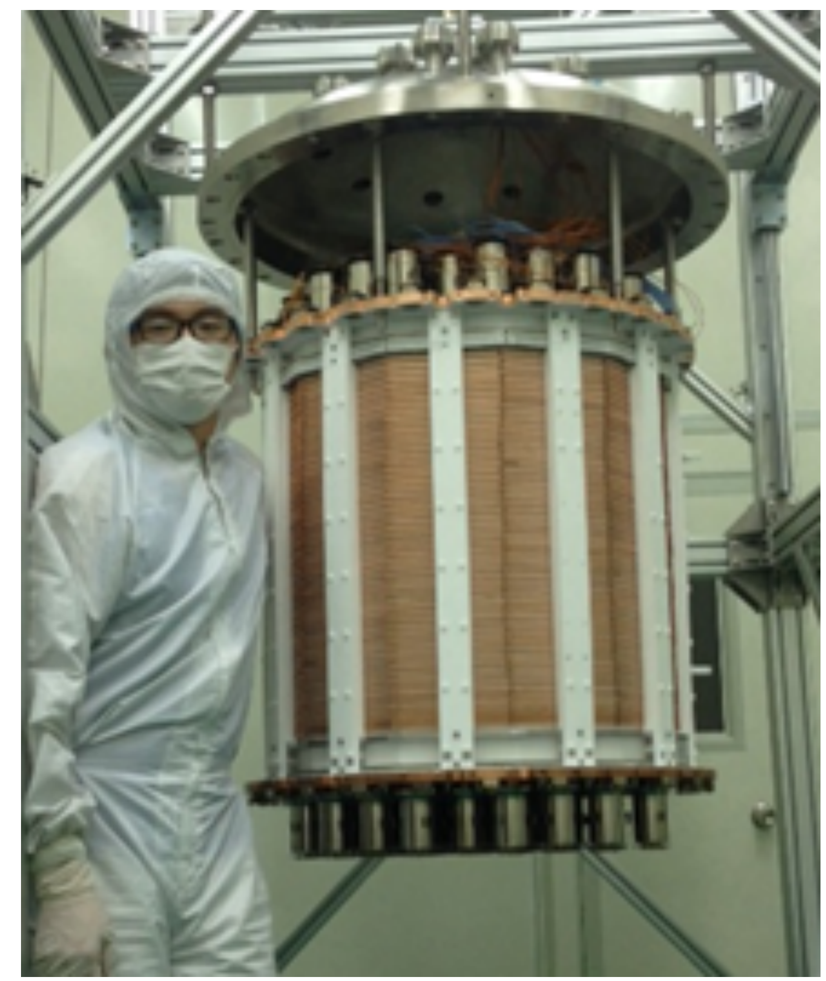
- **161 kg** LXe (62 active)

LUX @ SURF

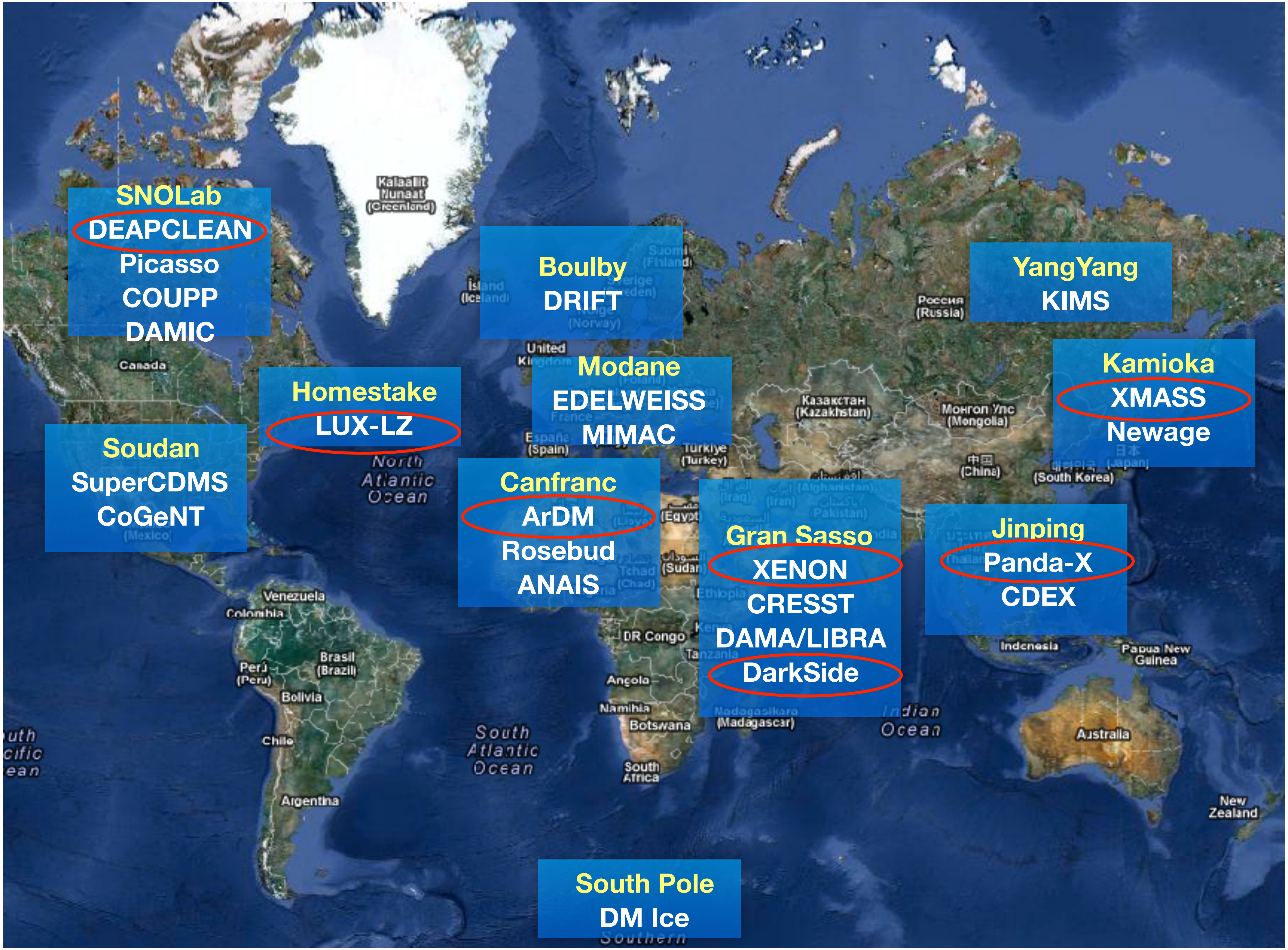
370 kg LXe (250 active)

PandaX @ CJPL

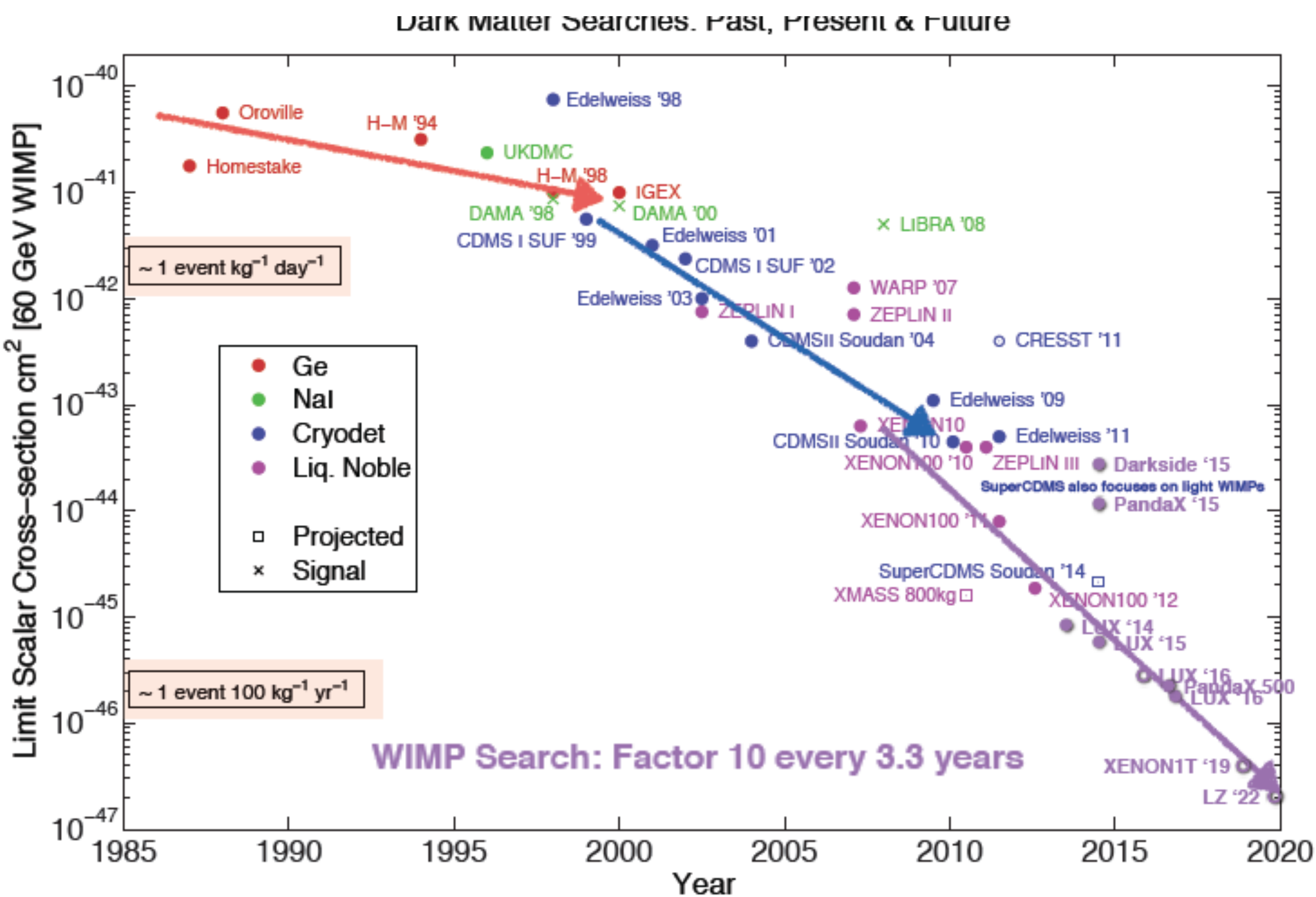
500 kg LXe (350 active)



Worldwide WIMP Searches

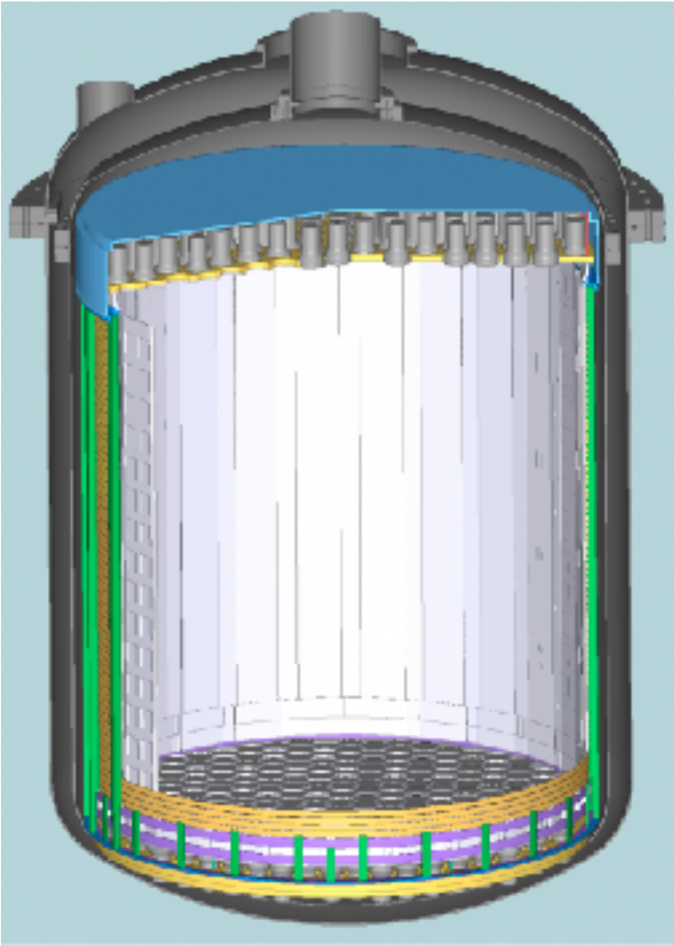


Impressive growth led by LXe



Phases of the XENON program

XENON10 | XENON100 | XENON1T / XENONnT



XENON10
2005-2007
15 cm drift TPC – 25 kg

Achieved (2007)
σ_{SI} = 8.8 x 10^{-44} cm^2

XENON100
2008-2016
30 cm drift TPC – 161 kg

Achieved (2016)
σ_{SI} = 1.1 x 10^{-45} cm^2

XENON1T / XENONnT
2013-2018 / 2019-2023
100 cm / 144 cm drift TPC - 3200 kg / ~8000 kg

Projected (2018) / Projected (2023)
σ_{SI} = 1.6 x 10^{-47} cm^2 / σ_{SI} = 1.6 x 10^{-48} cm^2

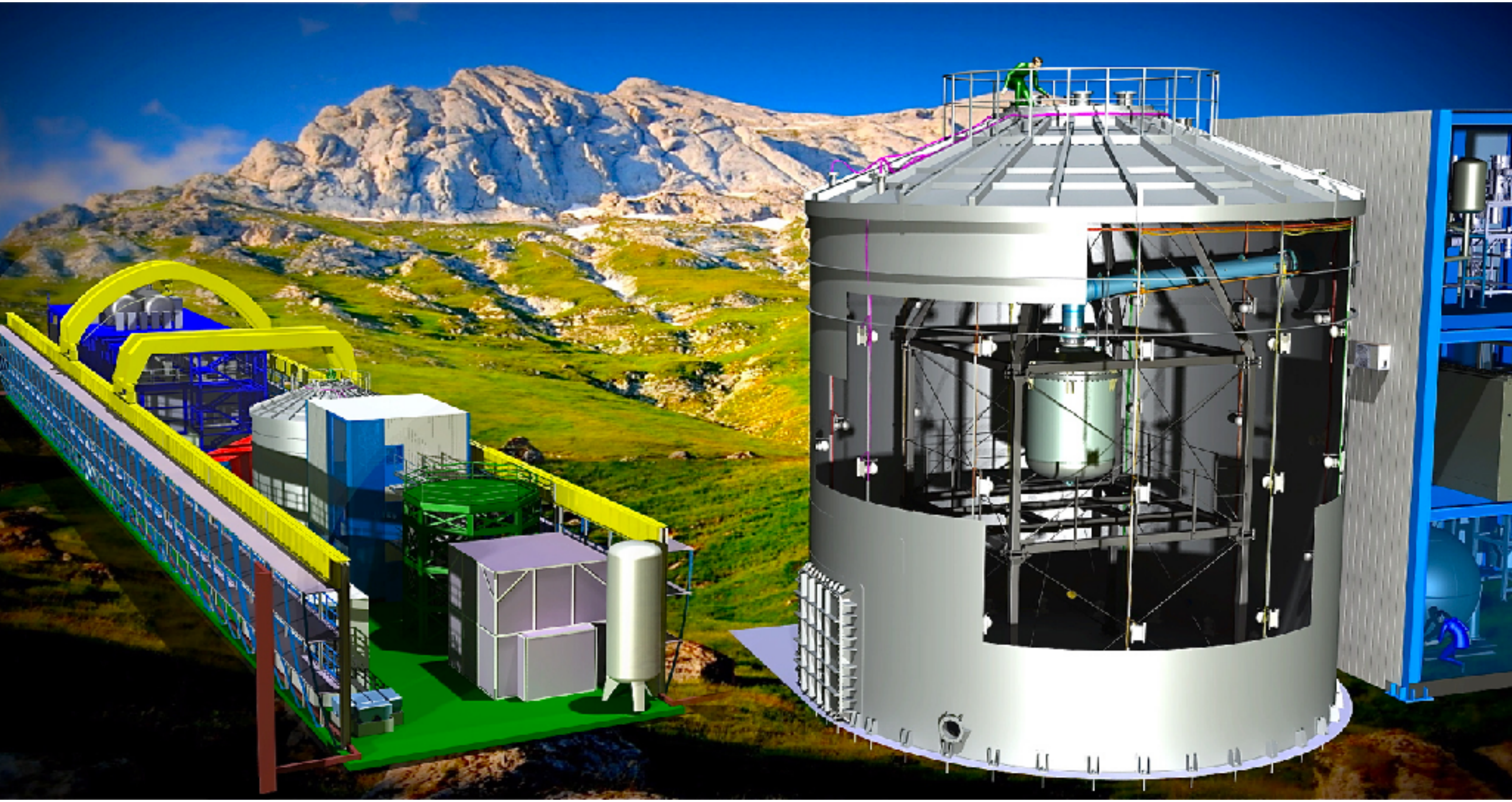
XENON World


~140 scientists from 22 institutions

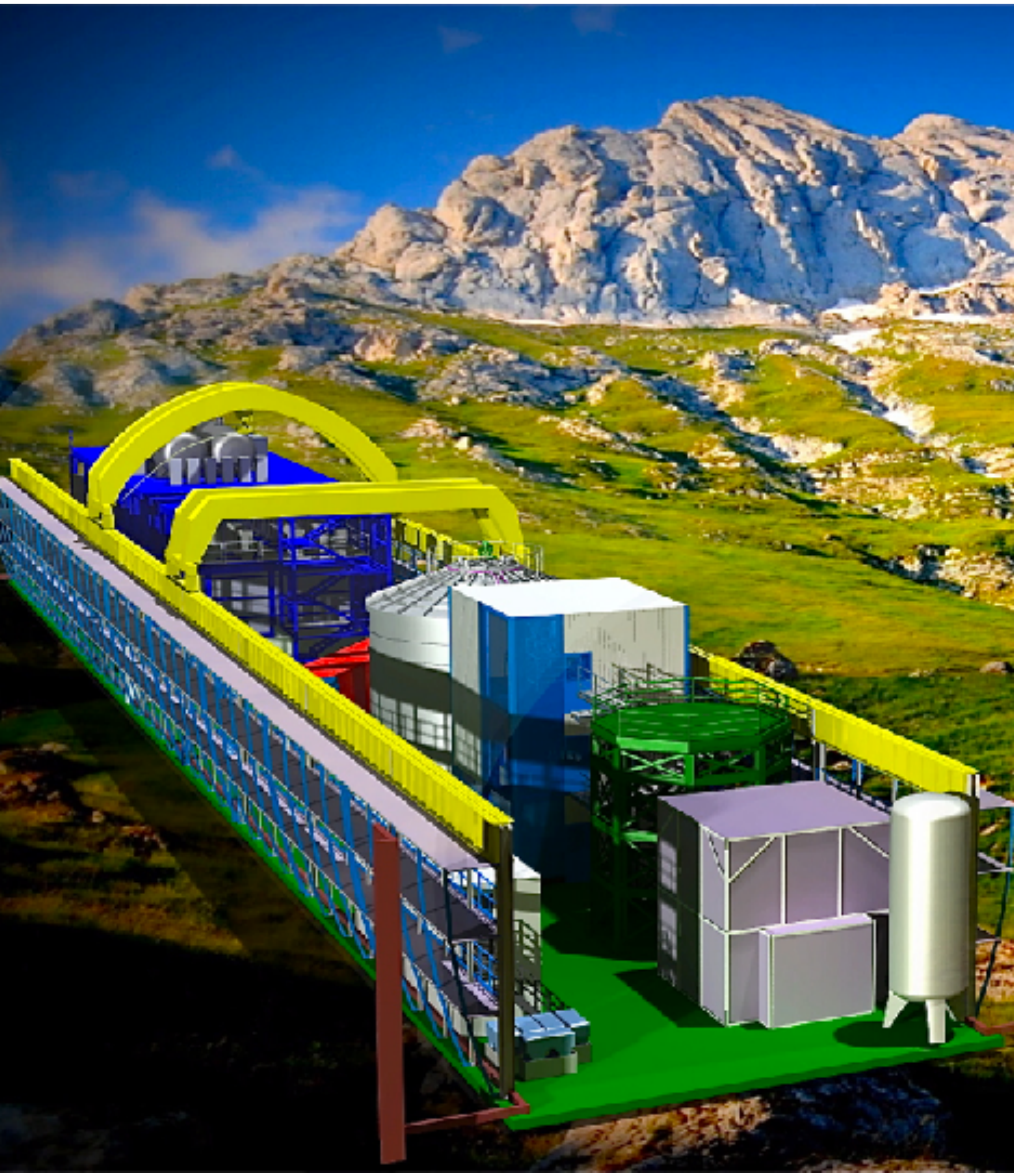

Columbia
RPI
Nikhef
Stockholm
Muenster
Mainz
MPIK
Chicago
Freiburg
UCLA
Zurich
UCSD
NYUAD
Rice
Weizmann
Purdue
Coimbra
Subatech
LPNHE
LAL
Bologna
LNGS
Torino


Laboratori Nazionali
del Gran Sasso
(LNGS), Italy
XENON1T

The XENON1T Experiment
www.xenon1t.org



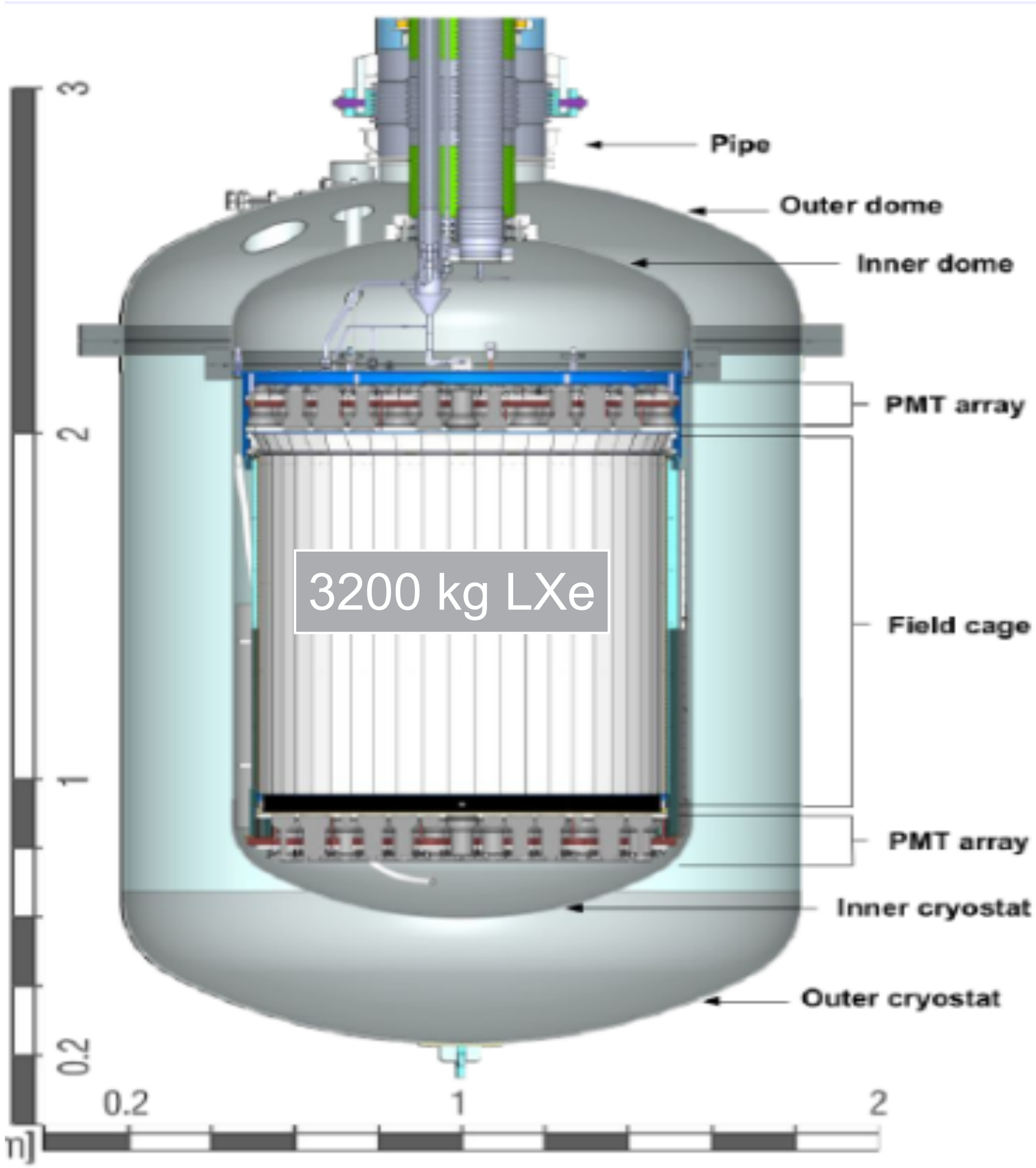
The XENON1T Experiment
www.xenon1t.org

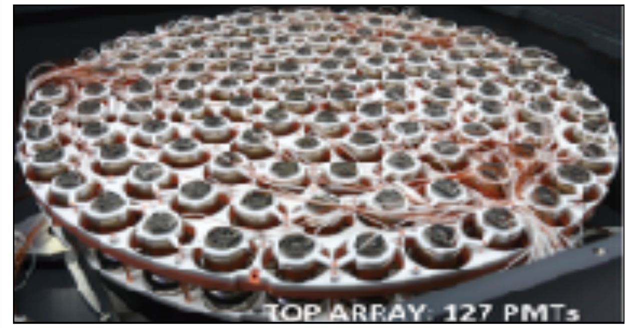


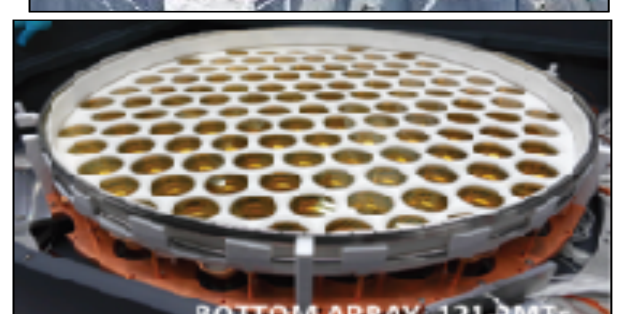
Aug. 2014

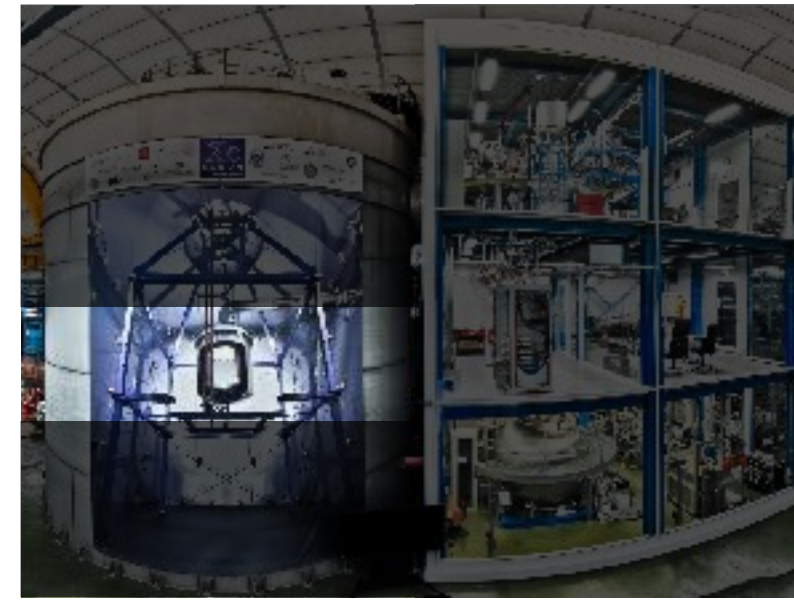

Aug. 2014

Time Projection Chamber









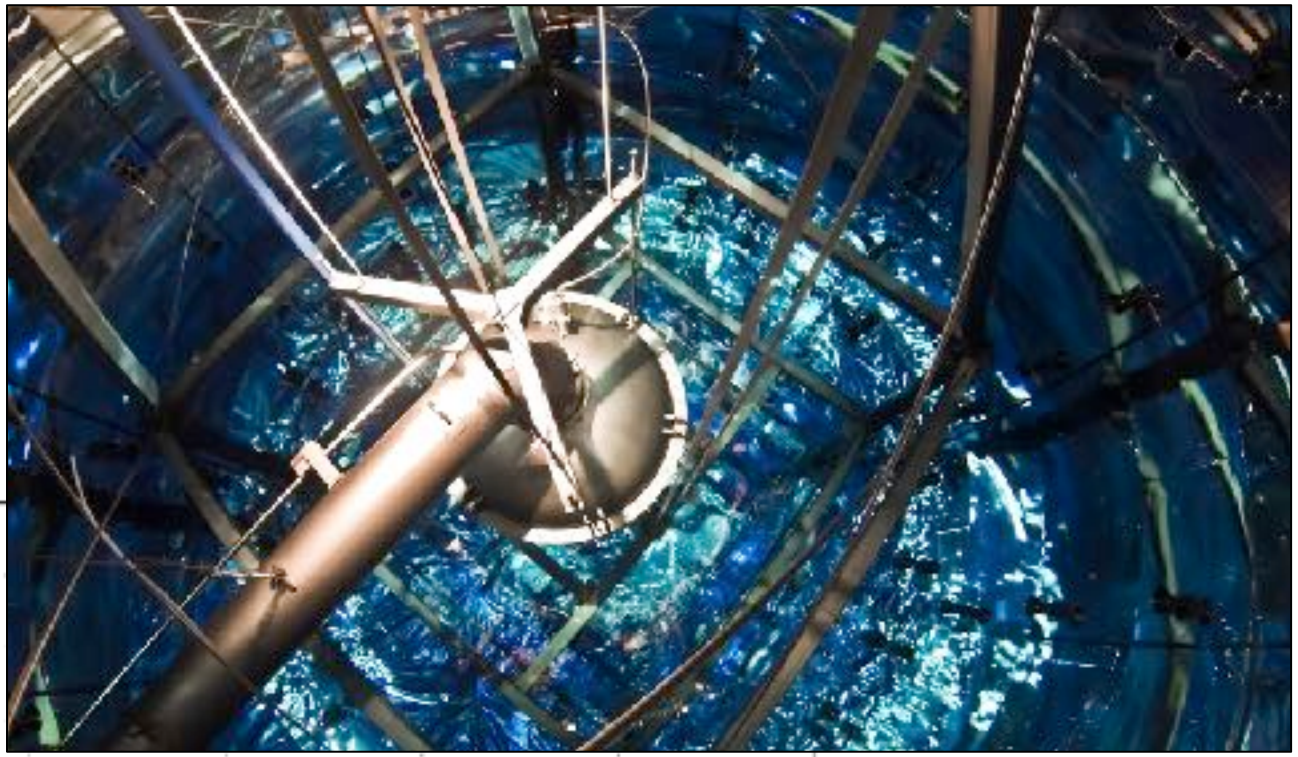
- 248 Hamamatsu R11410-21 (127 top, 121 bottom)
- QE ~34% @ 175 nm
- Average gain ~5x106 @ 1.5kV
- low radioactivity components

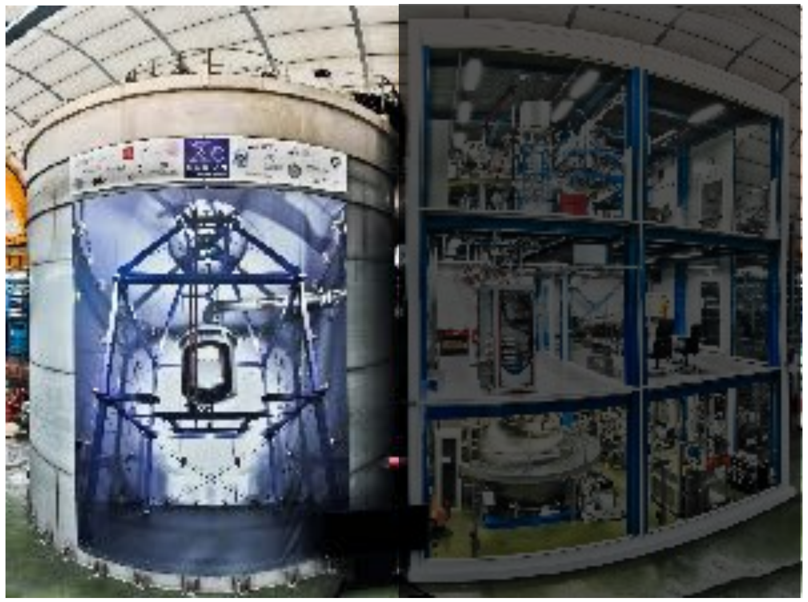
Eur. Phys. J. C75, 11, 546 (2015)
JINST 8, P04026 (2013)
JINST 12, P01024 (2017)
arXiv:1509.04055

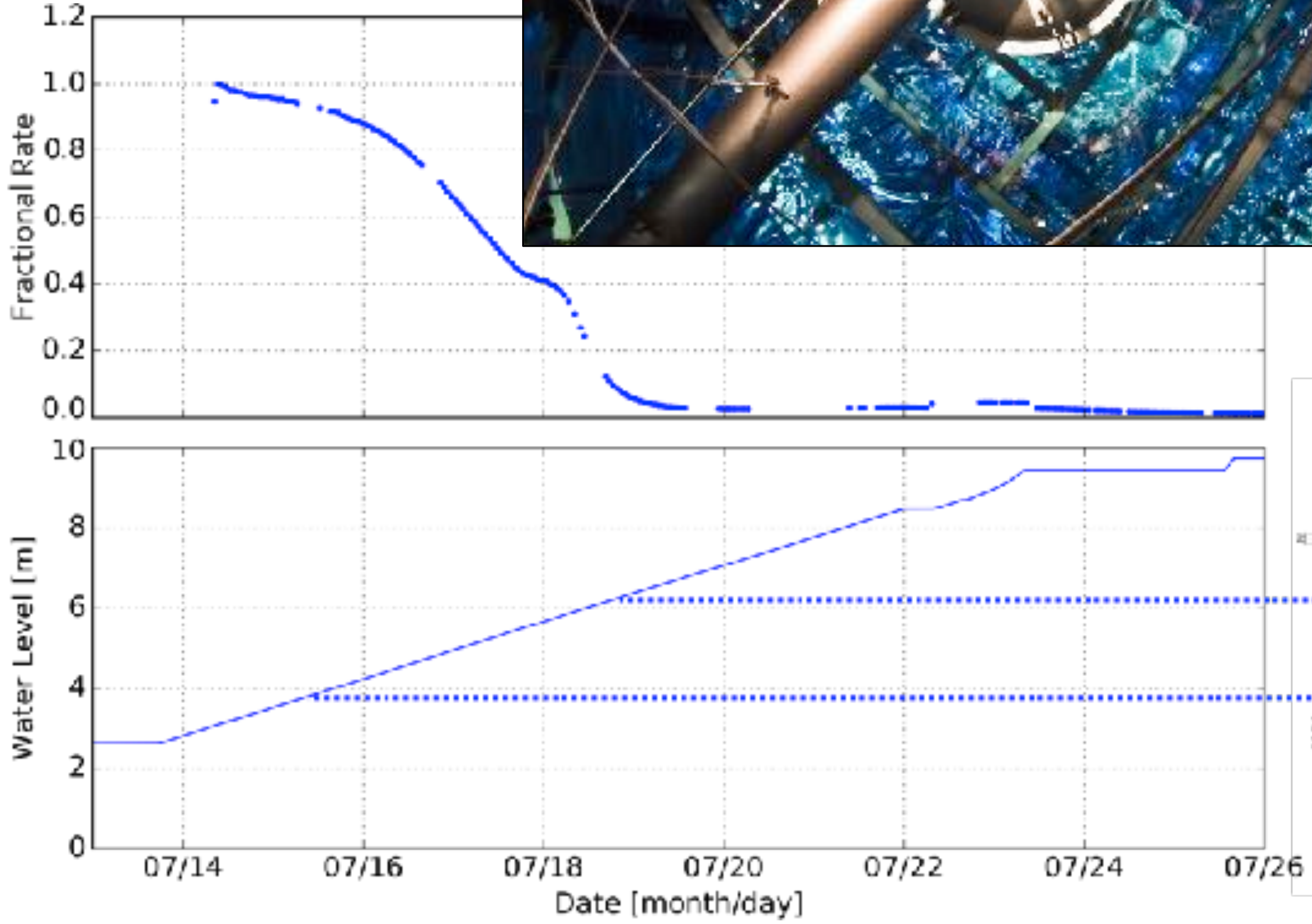

Oct 2015

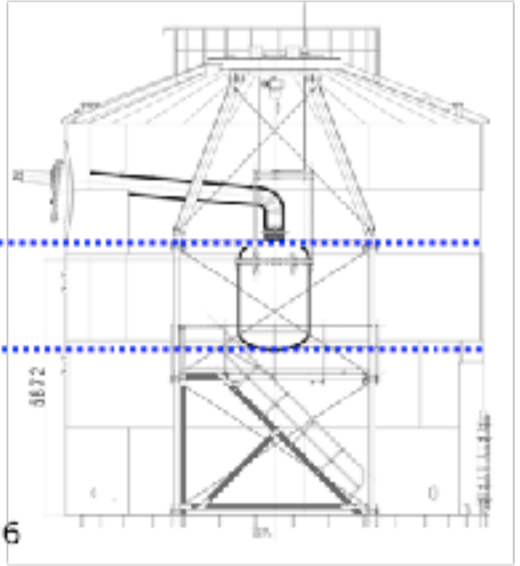
Cryostat in the Water Tank

July 2016

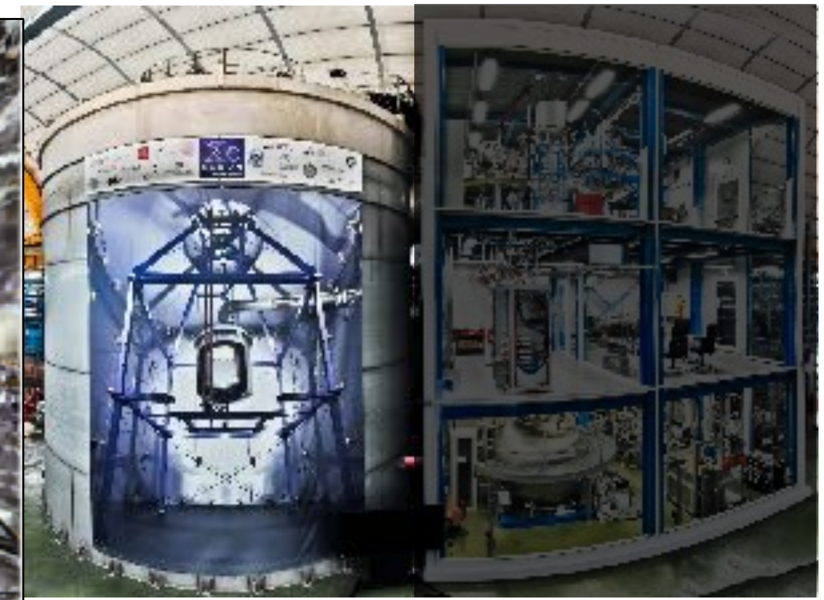




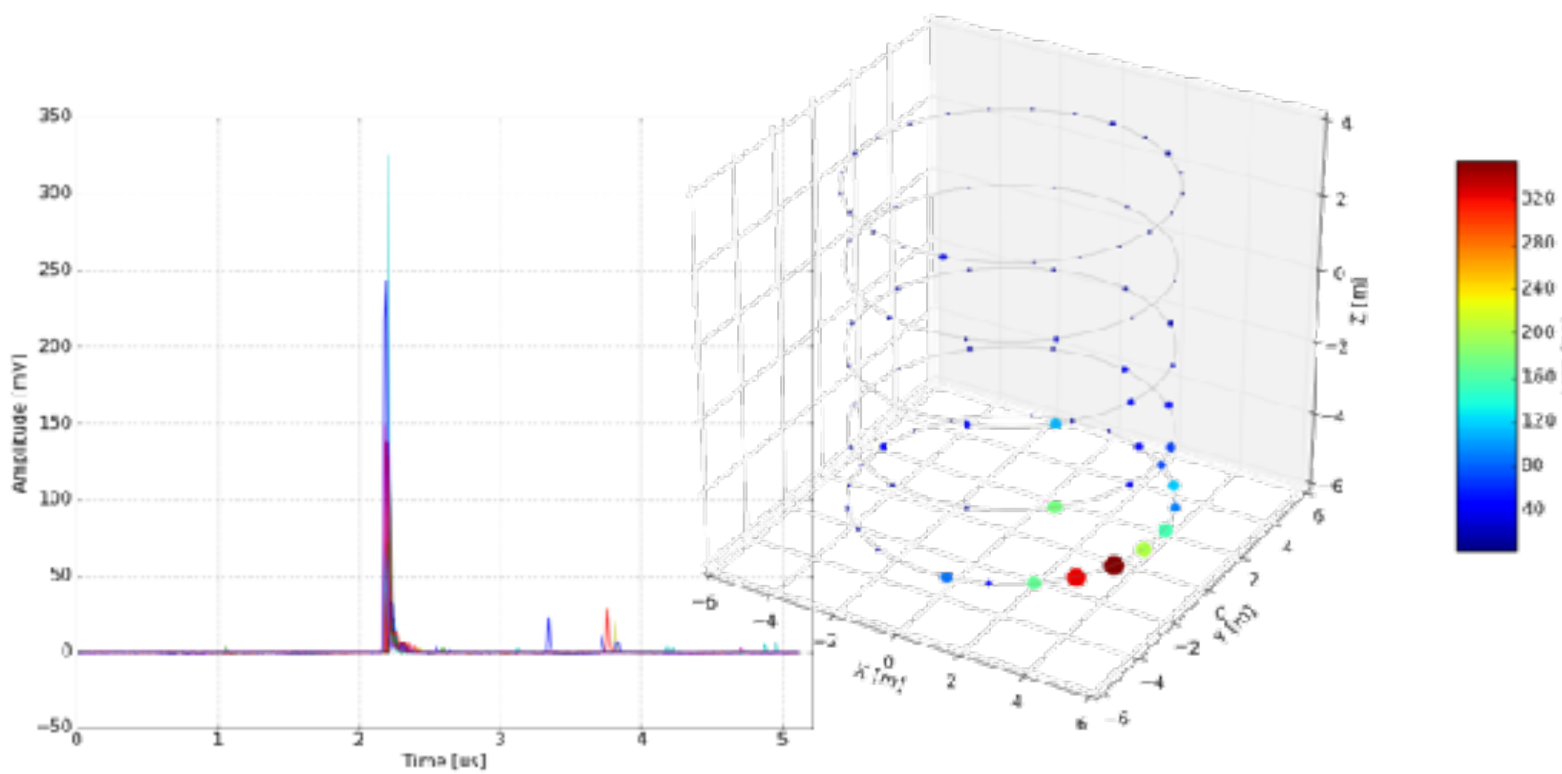




Cherenkov Muon Veto

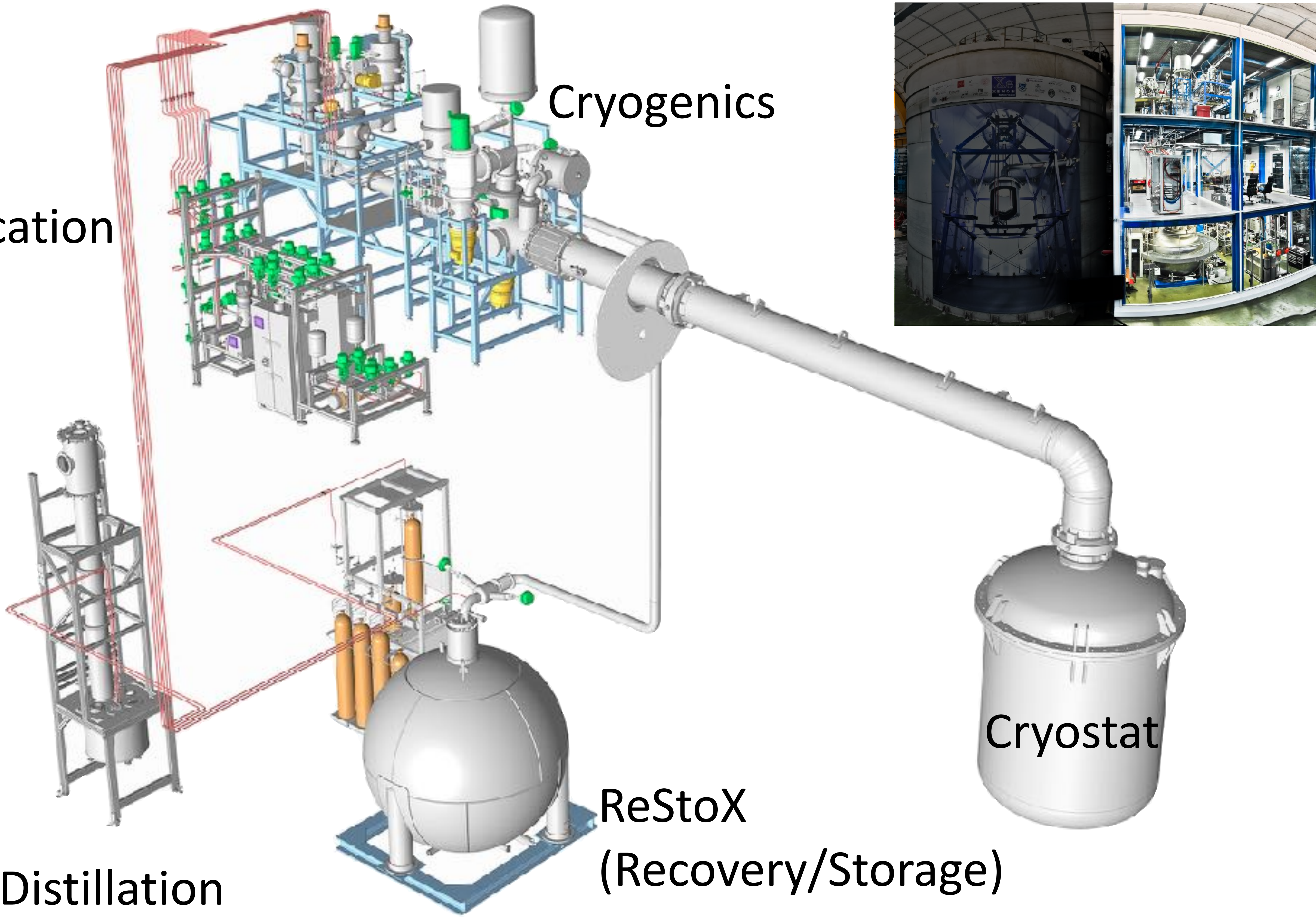


- Active shield against muons
- 84 high-QE 8'' Hamamatsu R5912 PMTs
- Trigger efficiency > 99.5% for neutrons with muons in water tank
- Can suppress cosmogenic background to < 0.01 events/ton/year
- No coincidences with TPC found in this science run



XENON1T: All Systems

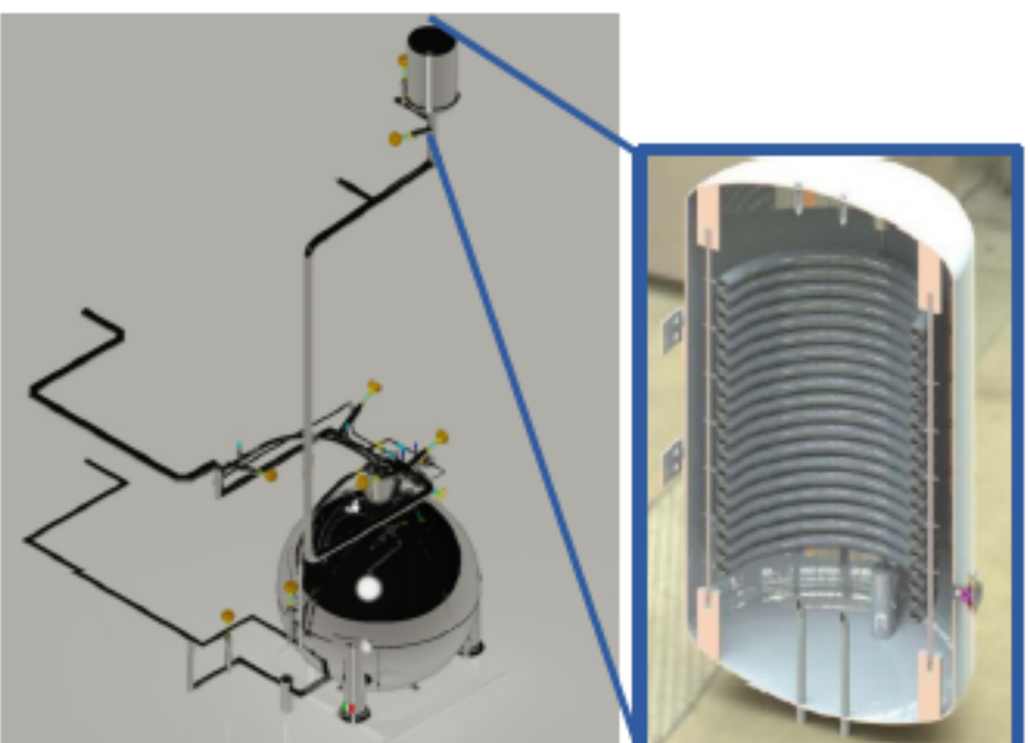
Xenon Plants

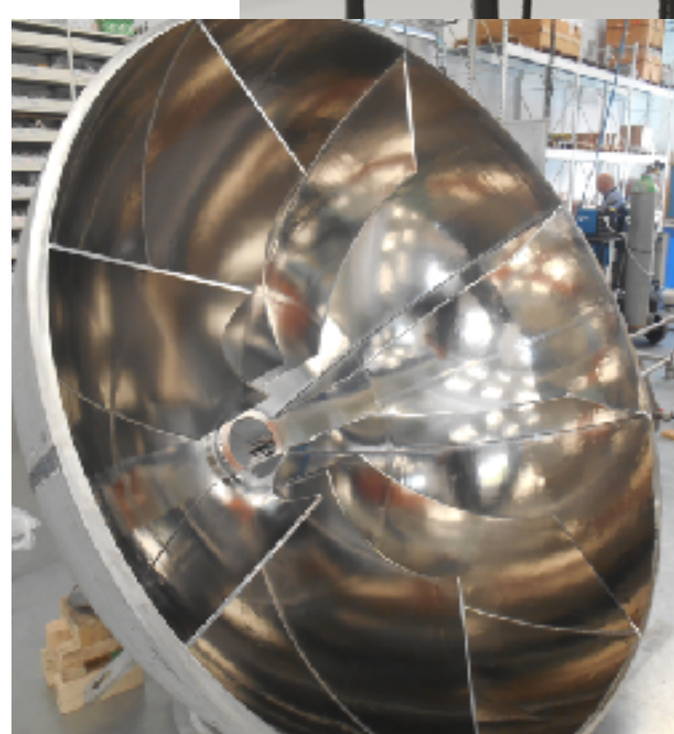


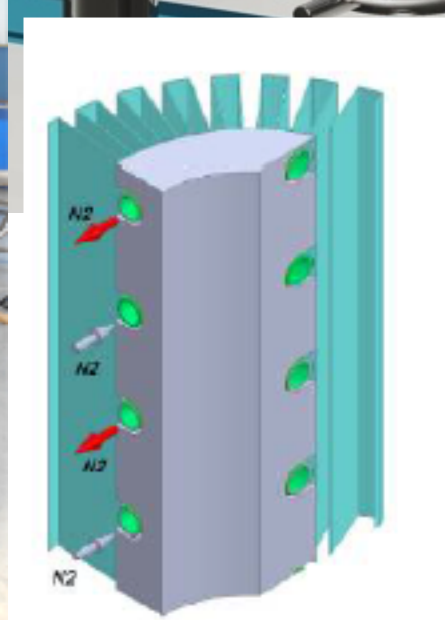
Recovery and Storage of Xe (ReStoX)

Goal:
- store up to 10 t of Xe under high purity conditions
- fill Xe in ultra-high-purity conditions into detector vessel
- recover all the Xe from the detector, within a few hours, in case of emergency

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

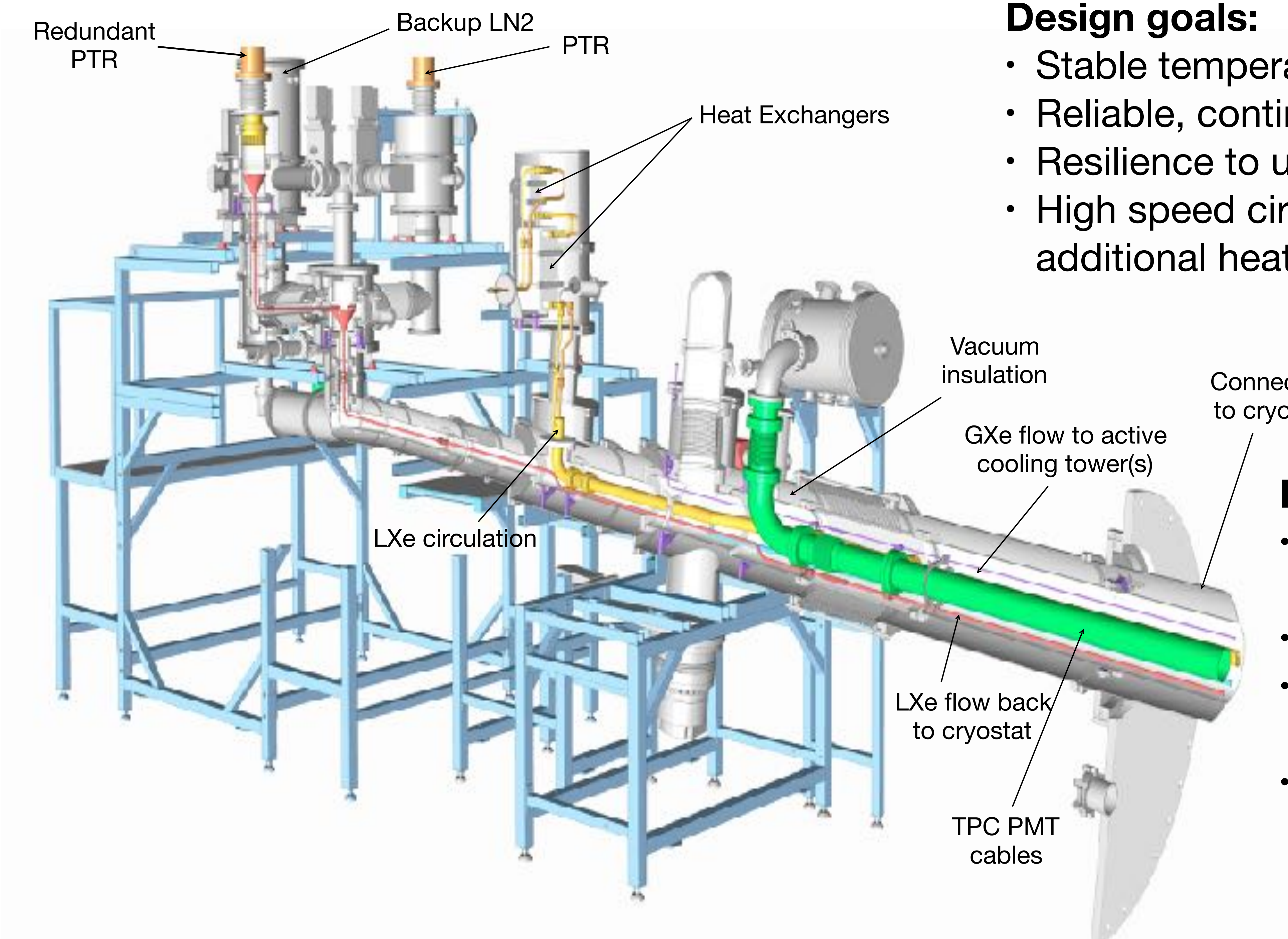






Xe Cooling System

Goal: liquefy 3300 Kg of Xe and maintain the xenon in the cryostat in liquid form, at a constant temperature and pressure, and so for years without interruption.



Design goals:

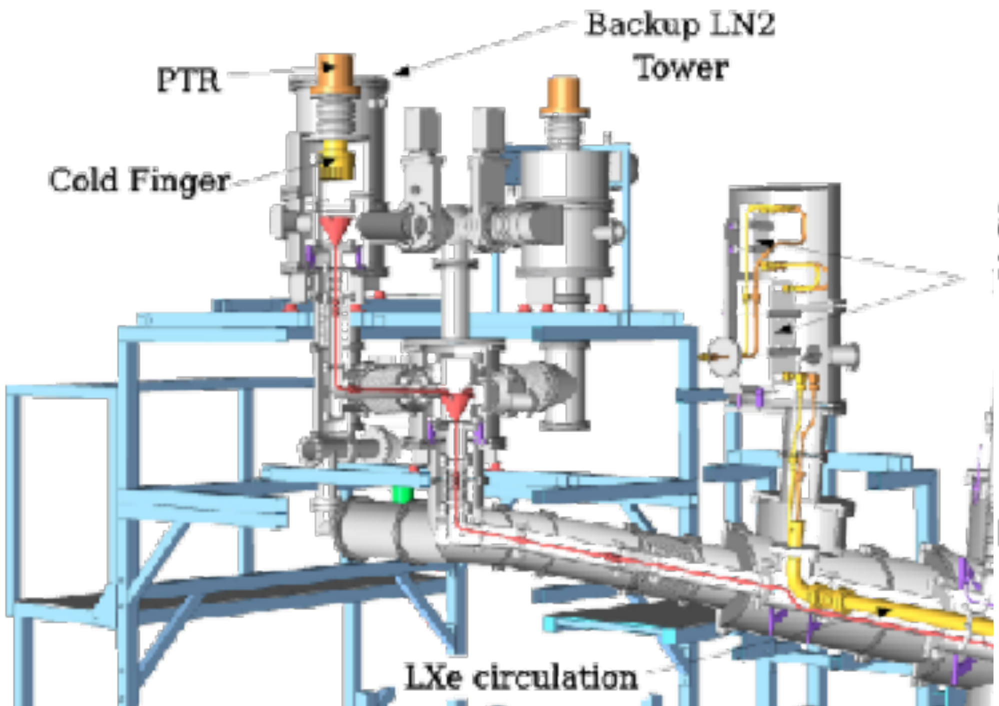
- Stable temperature and pressure control
- Reliable, continuous, long term operation
- Resilience to unexpected failures
- High speed circulation with low additional heat load

Main features:

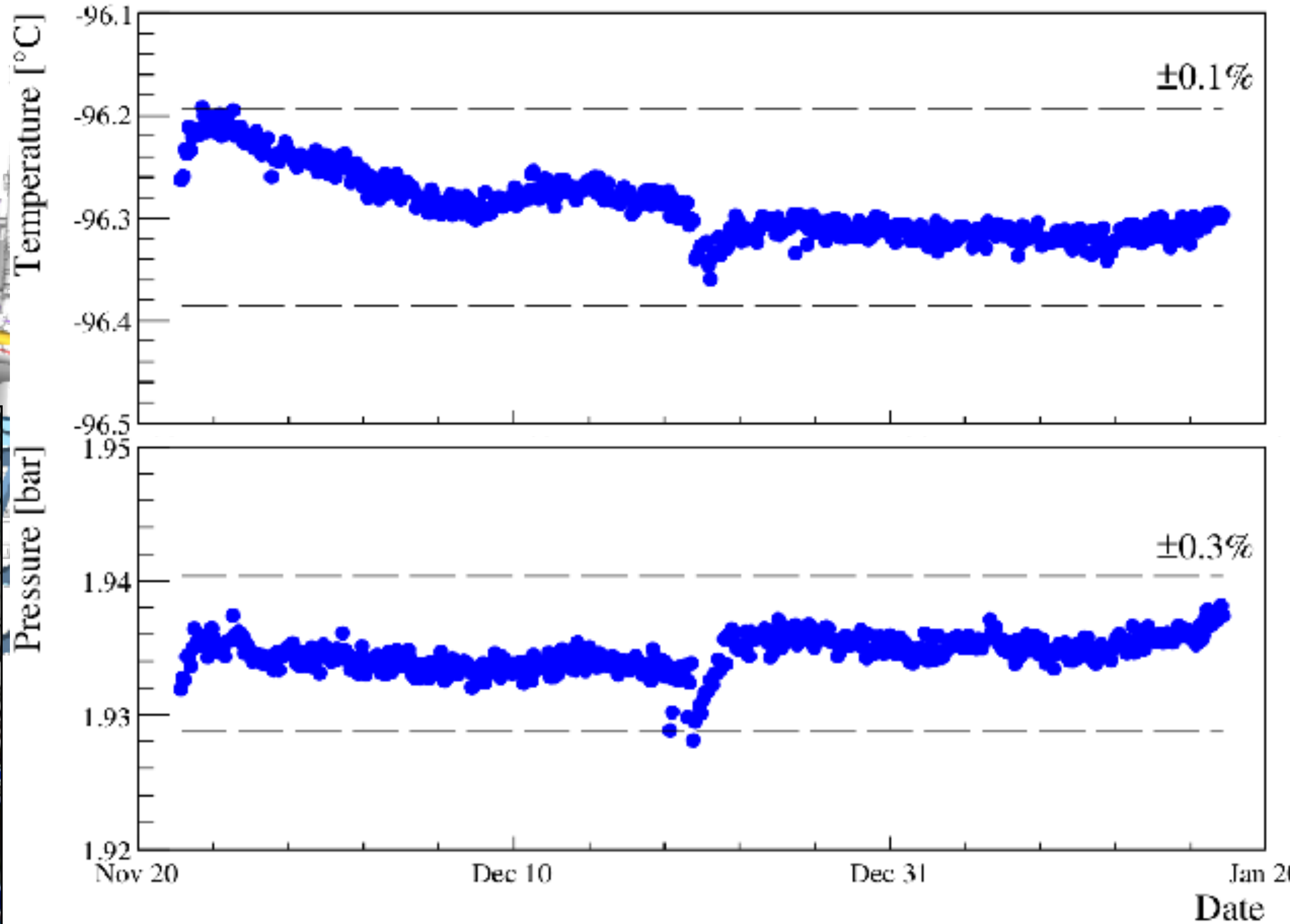
- Redundant PTR cooling systems
- Backup LN2 cooling tower
- Efficient two-phase heat exchangers
- One PTR can be serviced while the other is in operation

Detector Stability

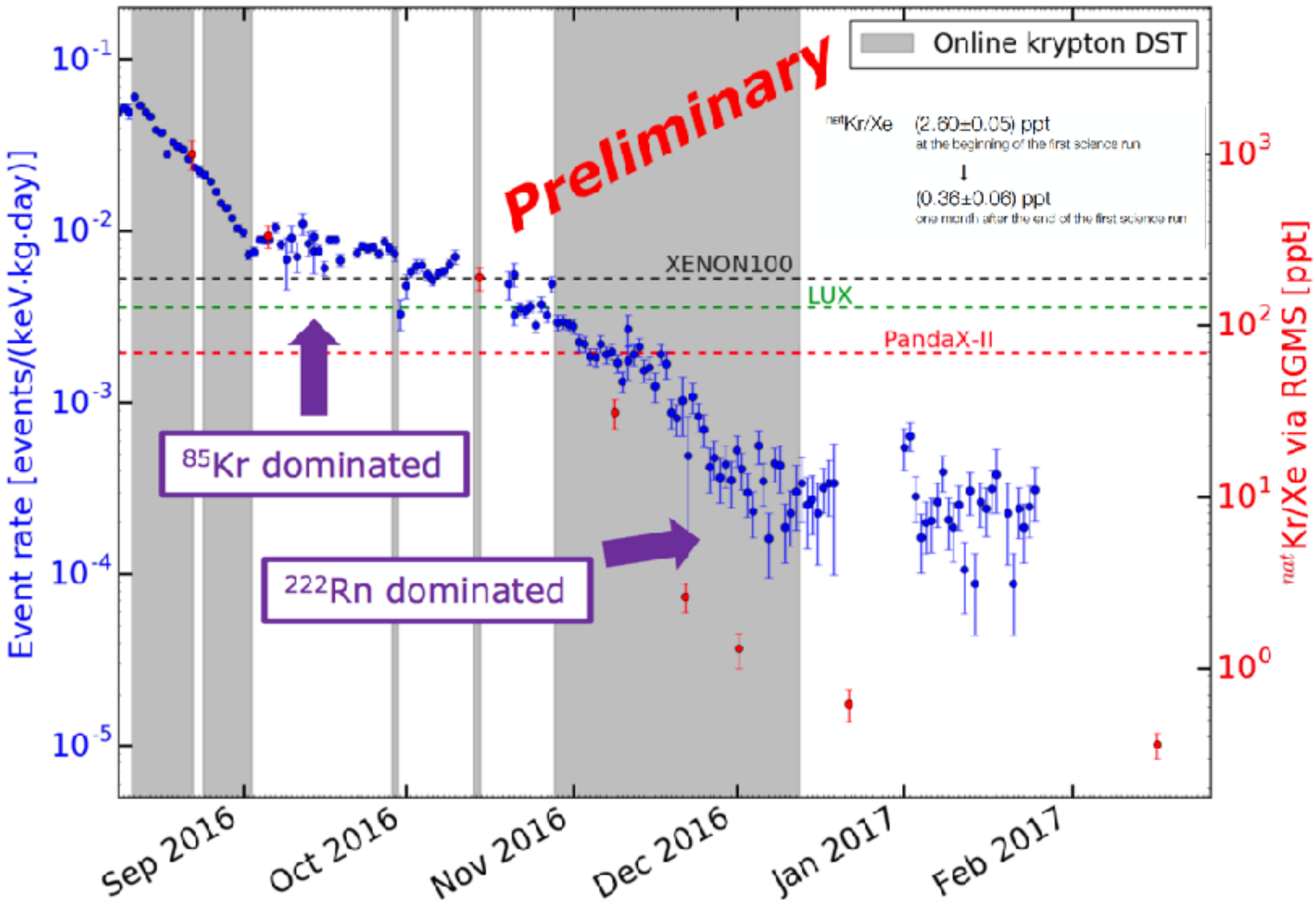
- LXe temperature stable at -96.07 °C, RMS 0.04 °C
- GXe pressure stable at 1.934 bar, RMS 0.001 bar



Slow control/Historian monitoring



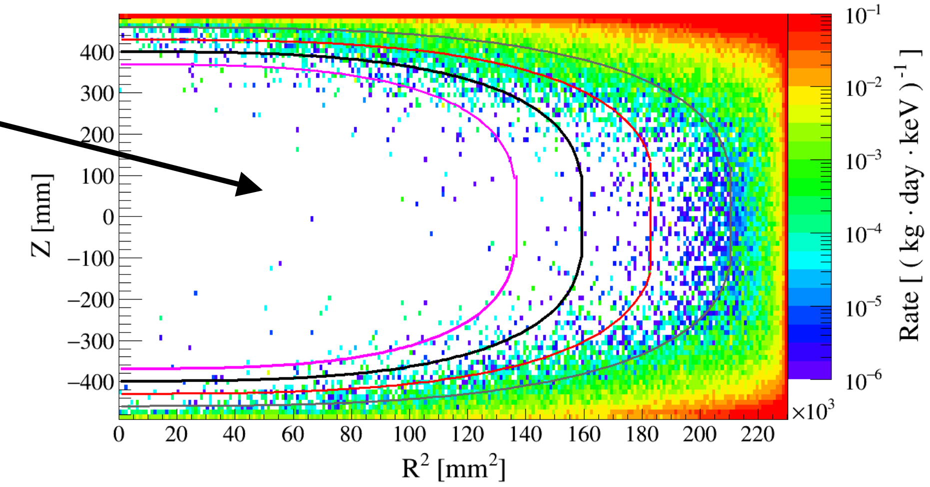
Kr Reduction



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

ER Backgrounds

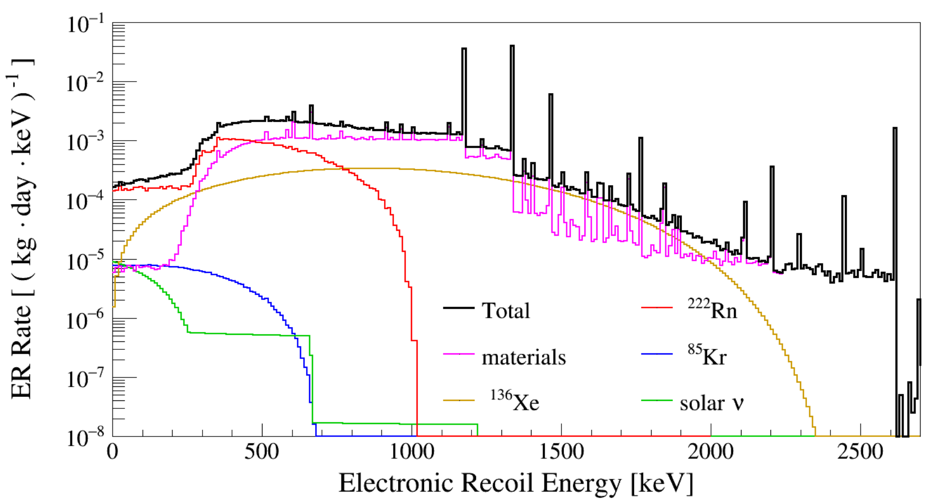
Predictions from MC simulations: ER background from materials is negligible in the 1t FV.

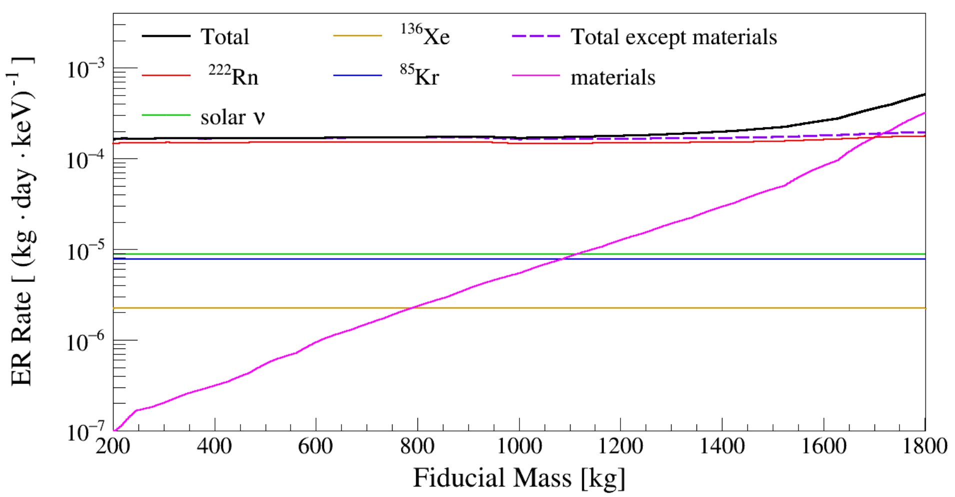


MC assumptions on the intrinsic backgrounds:

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

"Physics reach of the XENON1T dark matter experiment", JCAP 1604 (2016) 027, arXiv:1512.07501,



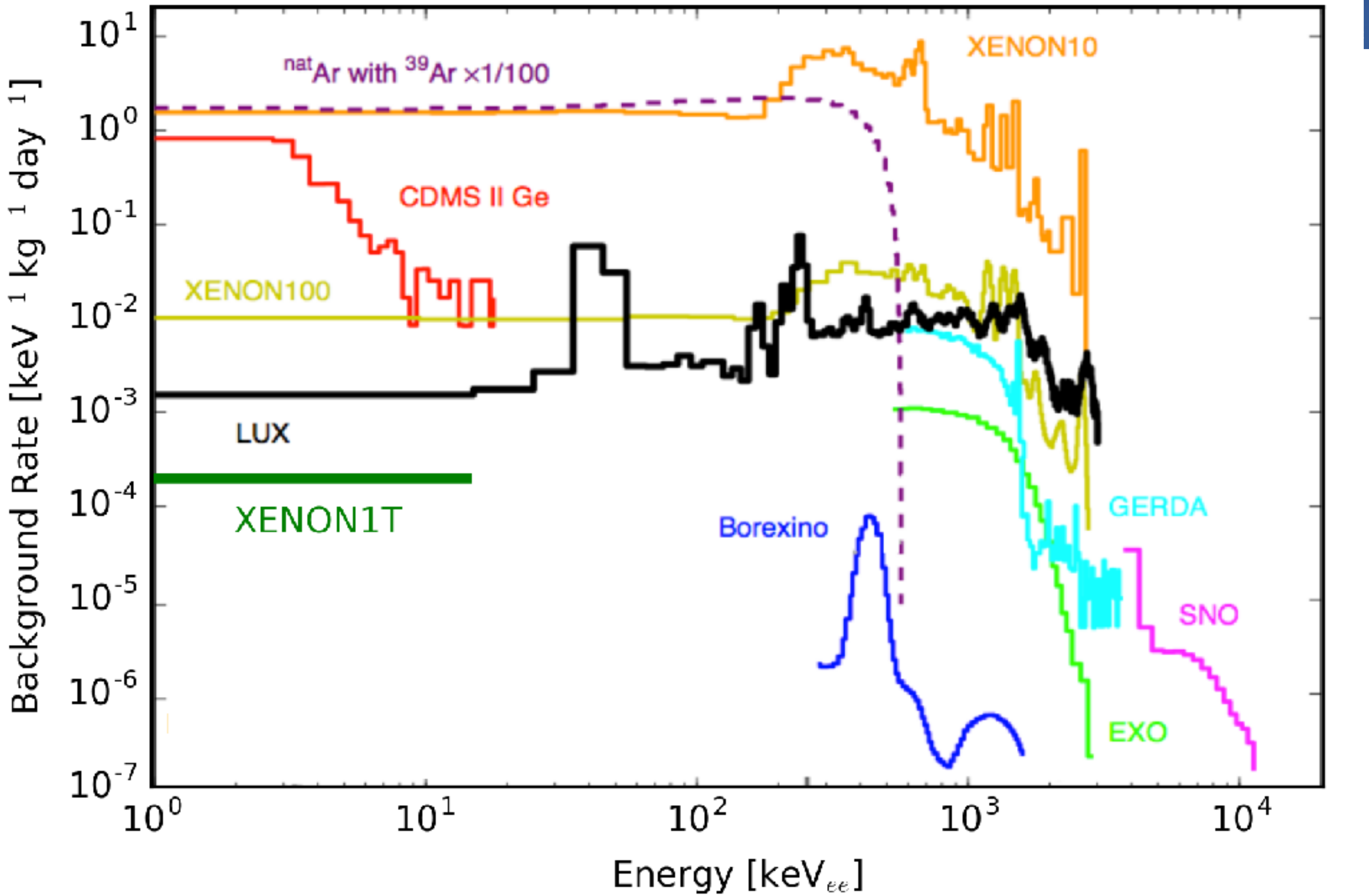


^{222}Rn (mainly from ^{214}Pb β-decay) is the most relevant source of ER background in most of the TPC.

Measured: (1.93 +/- 0.25) 10^{-4} events / (kg day keV)

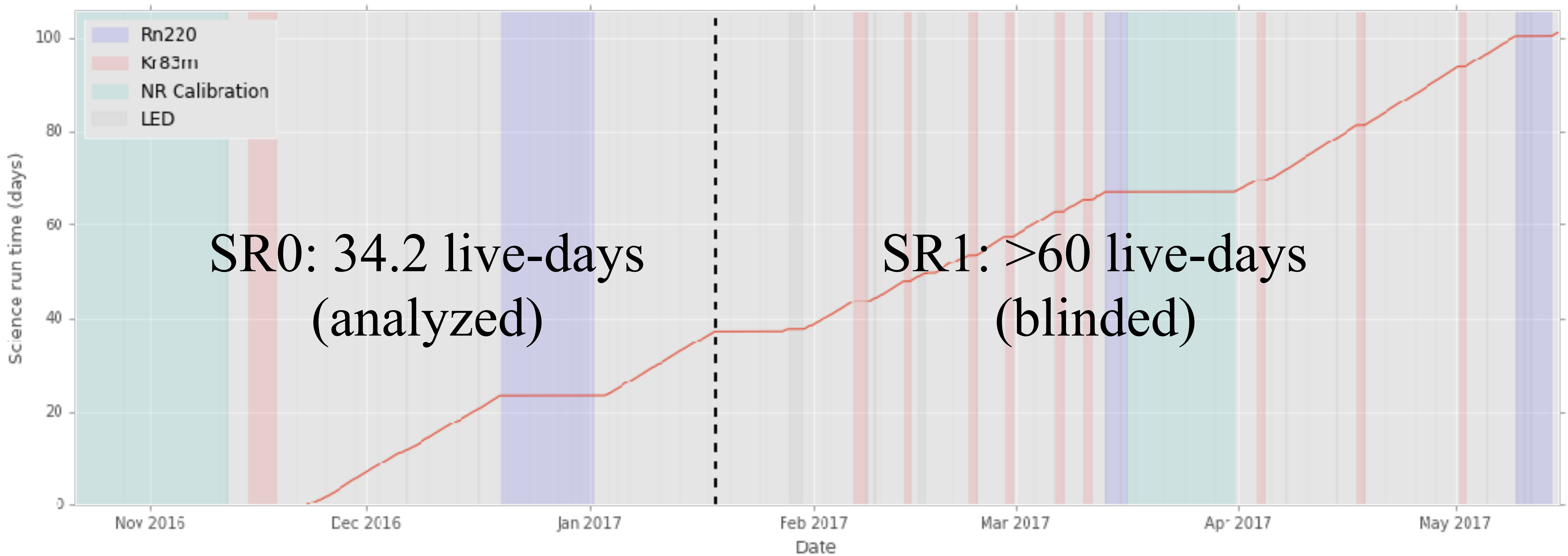
Predicted (considering the average 1.5 ppt of Kr in first run): (2.3 +/- 0.2) 10^{-4} events / (kg day keV)

Lowest ER background ever achieved in a DM detector !



XENON10
natAr with 39Ar ×1/100
CDMS II Ge
XENON100
LUX
XENON1T
Borexino
GERDA
SNO
EXO
Background Rate [keV⁻¹ kg⁻¹ day⁻¹]
Energy [keV_ee]

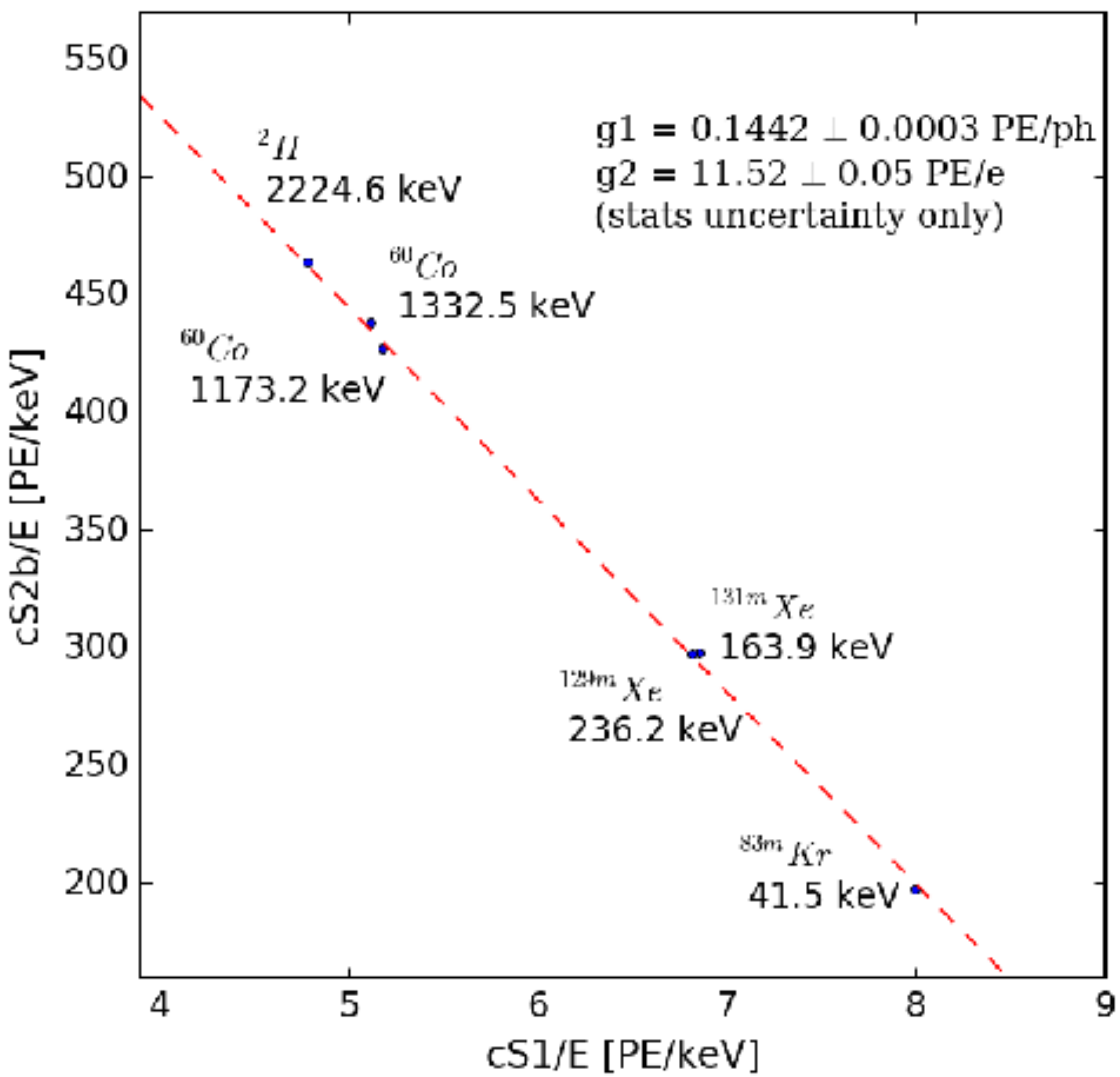
Science Run: Exposure



- This talk highlights the analysis of the first science run (SR0)
- We continue to take data after the earthquake and analyzing SR1 now

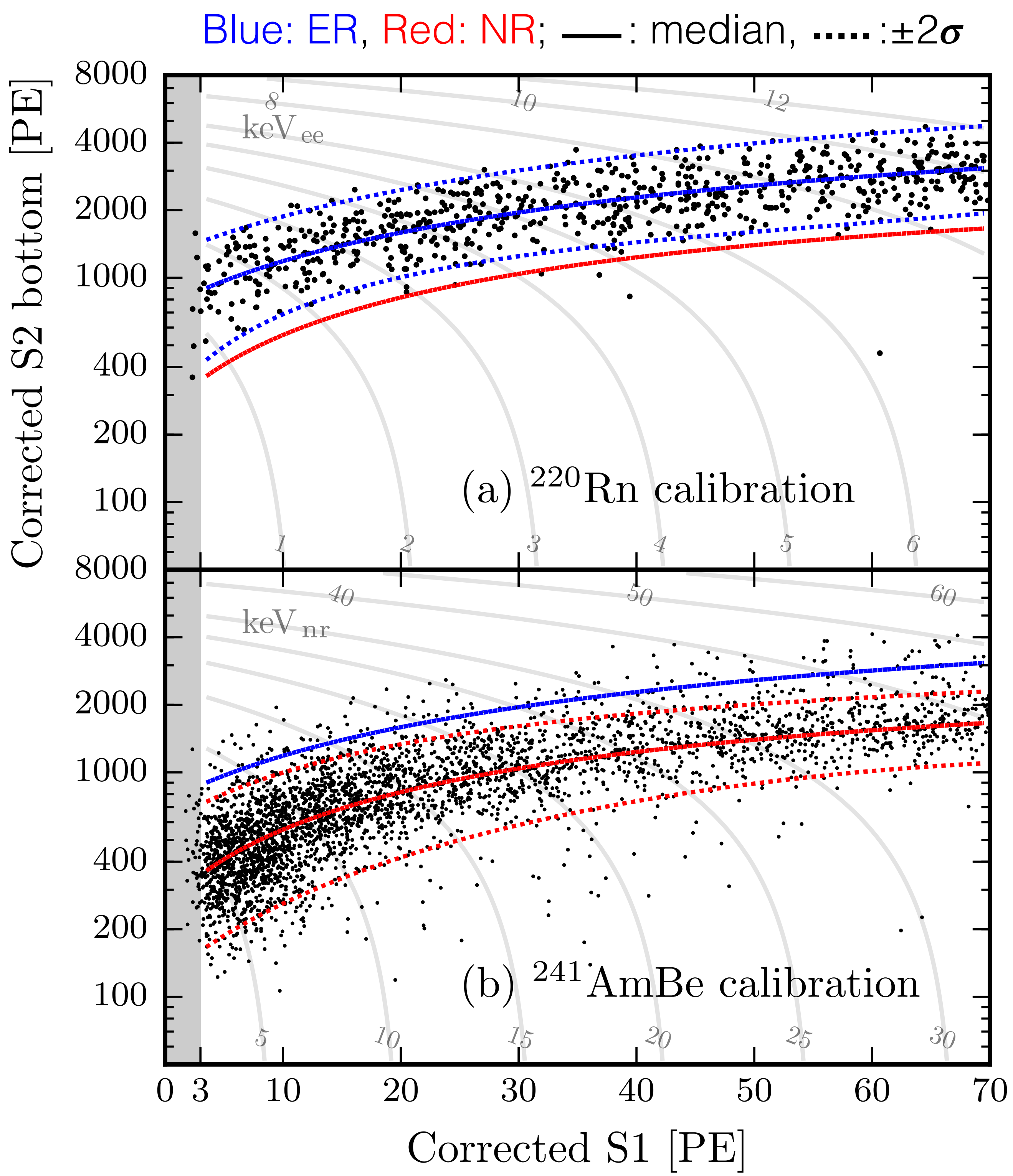
Energy response

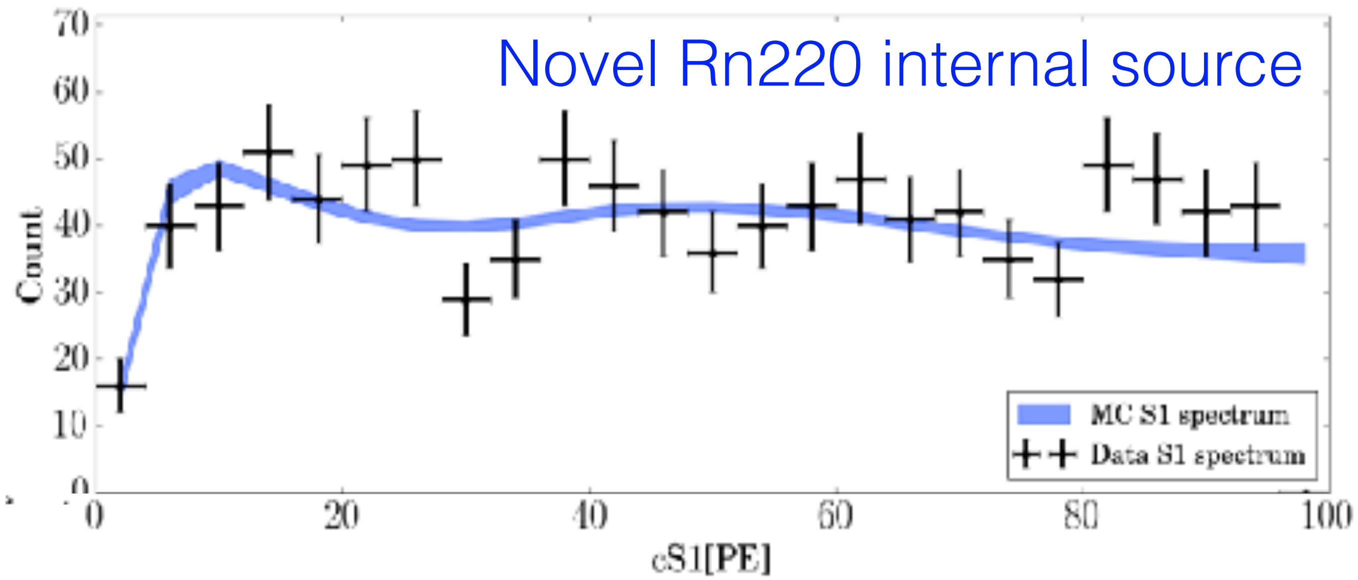
$$E = (n_{ph} + n_e) \cdot W = (\frac{S1}{g1} + \frac{S2}{g2}) \cdot W$$



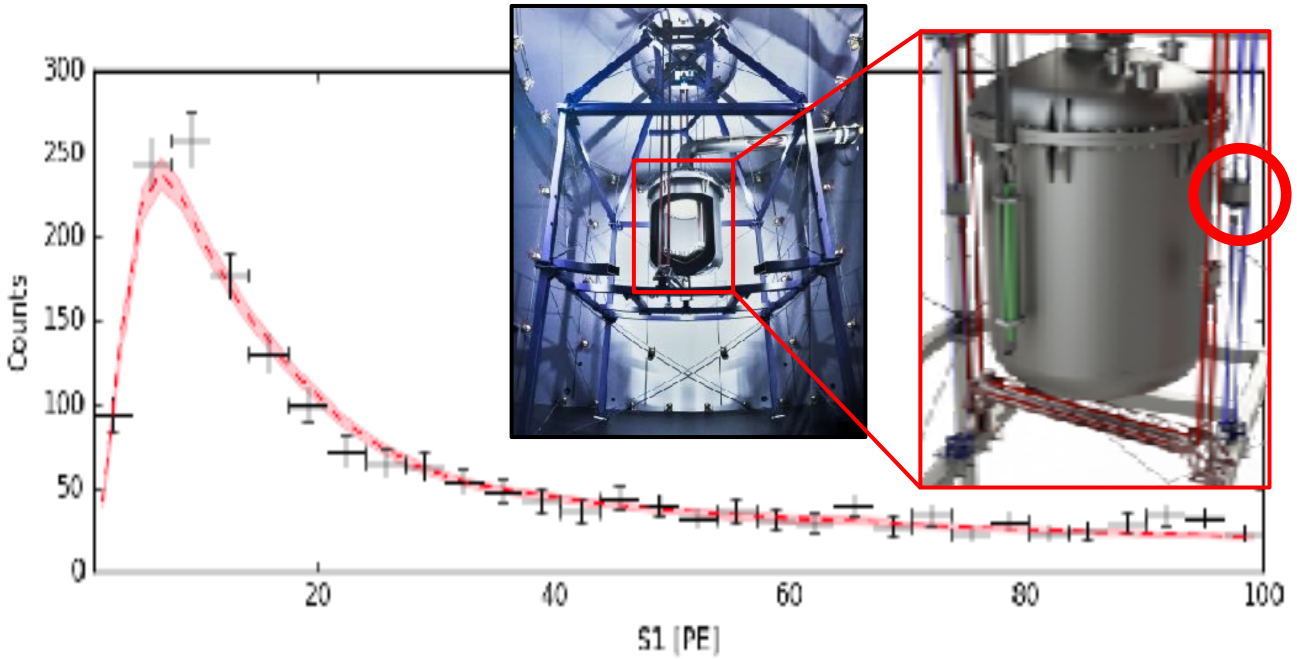
- Excellent linearity with electronic recoil energy from 40 keV to 2.2 MeV
- g1 = 0.1442 ± 0.0068 (sys) PE/photon corresponds to a light detection efficiency of 12.5 ± 0.6%, consistent with MC prediction of 12.1%.
- The amplification in gas (g2) corresponds to ~100% extraction of charges from the liquid.

Fitting Models to Calibration



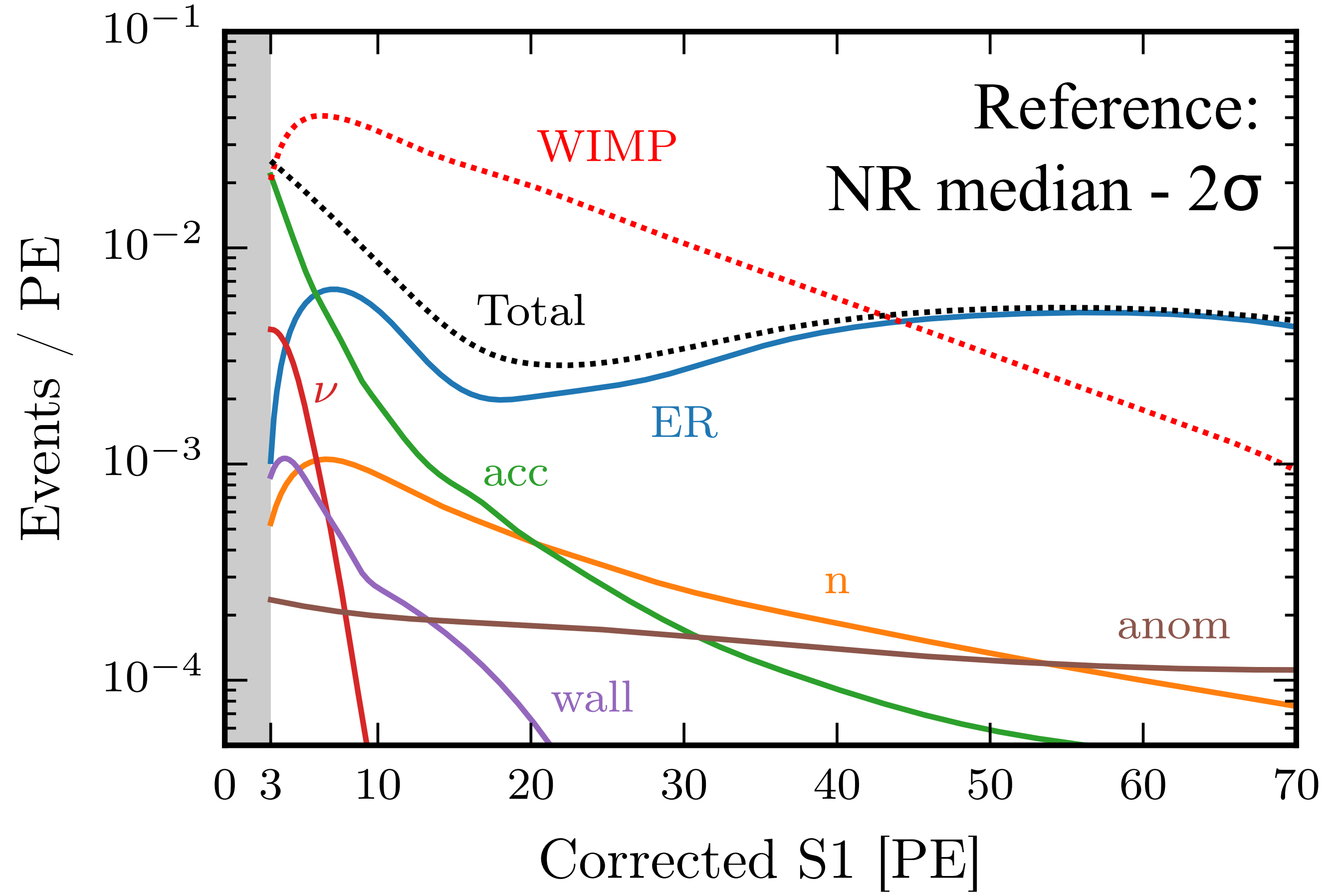


- Full modeling of LXe and detector response in $cS2_b$ vs cS1 space
- All parameters fitted with no significant deviation from priors



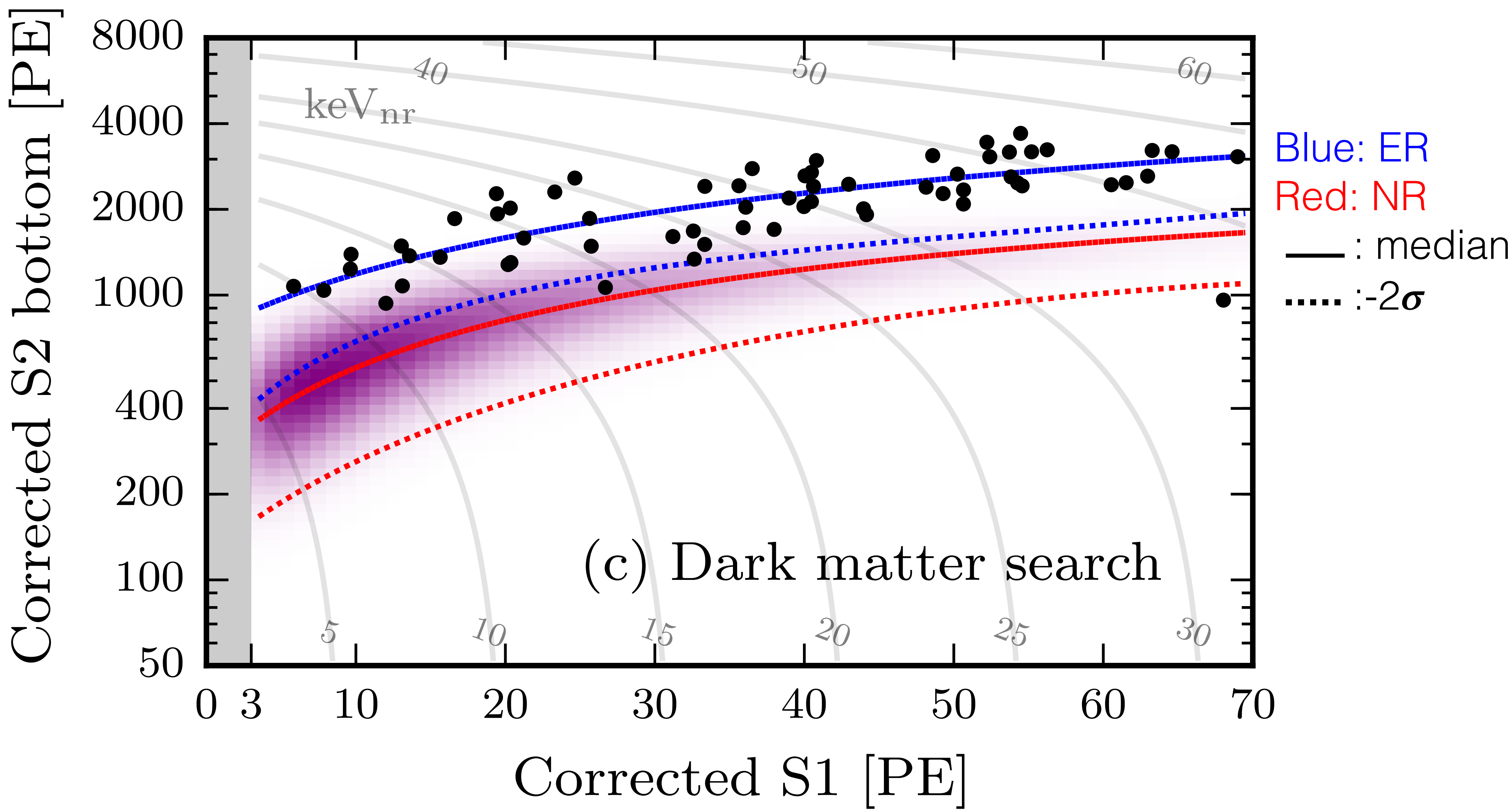
Background model

- ER and NR spectral shapes derived from models fitted to calibration data
- Other background expectations are data-driven, derived from control samples



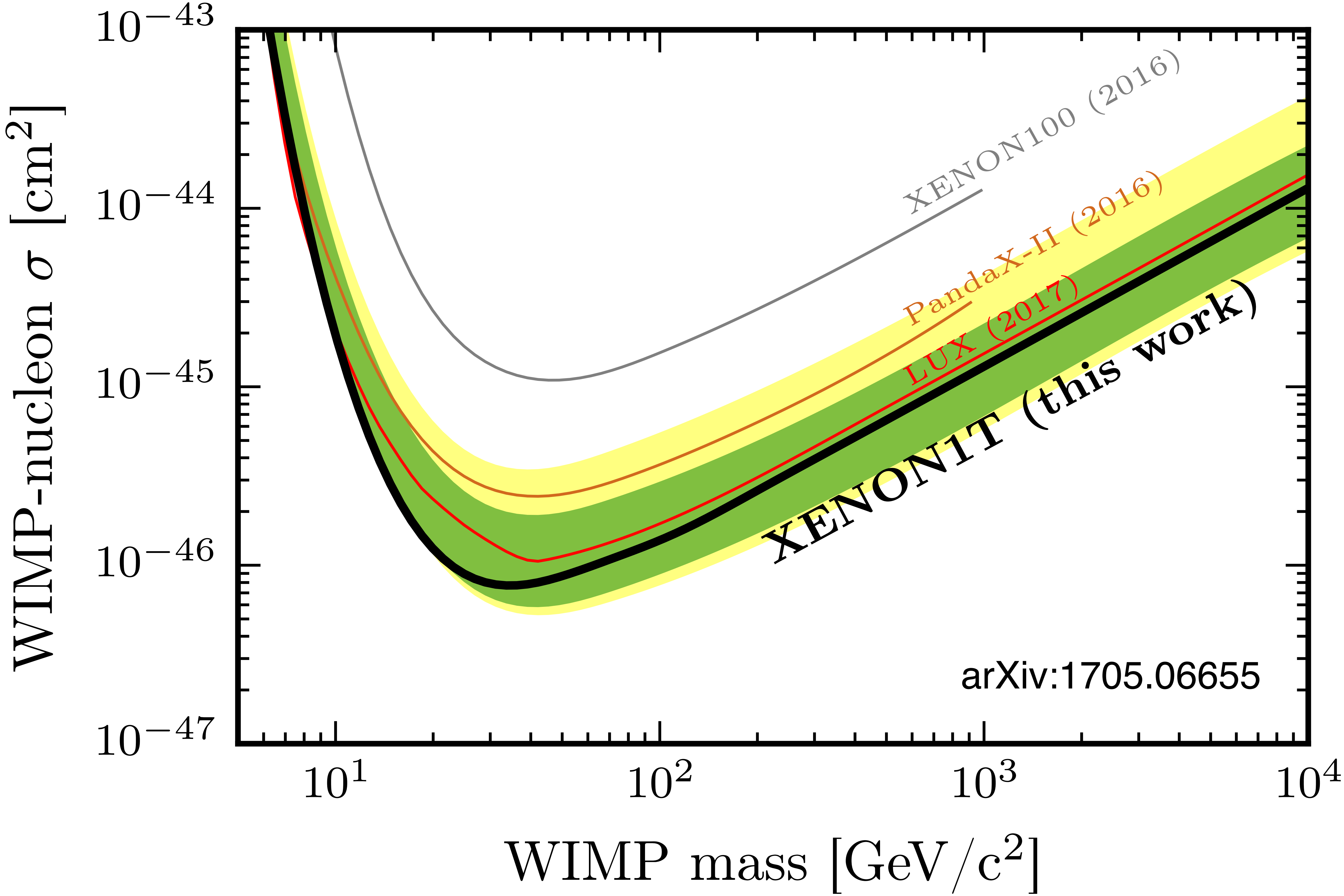
Background & Signal Rates	Total	Reference
Electronic recoils *(ER)*	62 ± 8	0.26 (+0.11)(-0.07)
Radiogenic neutrons *(n)*	0.05 ± 0.01	0.02
CNNS (ν)	0.02	0.01
Accidental coincidences (*acc*)	0.22 ± 0.01	0.06
Wall leakage (*wall*)	0.52 ± 0.32	0.01
Anomalous (*anom*)	0.09 (+0.12)(-0.06)	0.01 ± 0.01
Total background	**63 ± 8**	**0.36 (+0.11)(-0.07)**
50 GeV/c², 10^{-46} cm² WIMP *(NR)*	1.66 ± 0.01	0.82 ± 0.06

Dark Matter Search



- Extended unbinned profile likelihood analysis
- ER & NR shape parameters included from calibration fits
- Normalization uncertainties for all components
- Safeguard to protect against spurious mis-modeling of background

XENON1T Results



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From XENON1T to XENONnT

XENONnT is a rapid upgrade of the XENON1T detector:

- New inner cryostat vessel inside the same outer vessel
- Total LXe mass will be ~8 t with 6 t active- x3 more than XENON1T
- New TPC structure with modest increase in diameter and length: additional PMTs (and electronics): 248 -> 476
- All other systems can handle a larger detector with a target mass of up to 10t: Cryogenics, Purification, Recovery, Support structure, DAQ, Slow Control, Muon veto. Their established performance will enable the operation of XENONnT on a fast timescale.
- Current schedule: start XENONnT in early 2019

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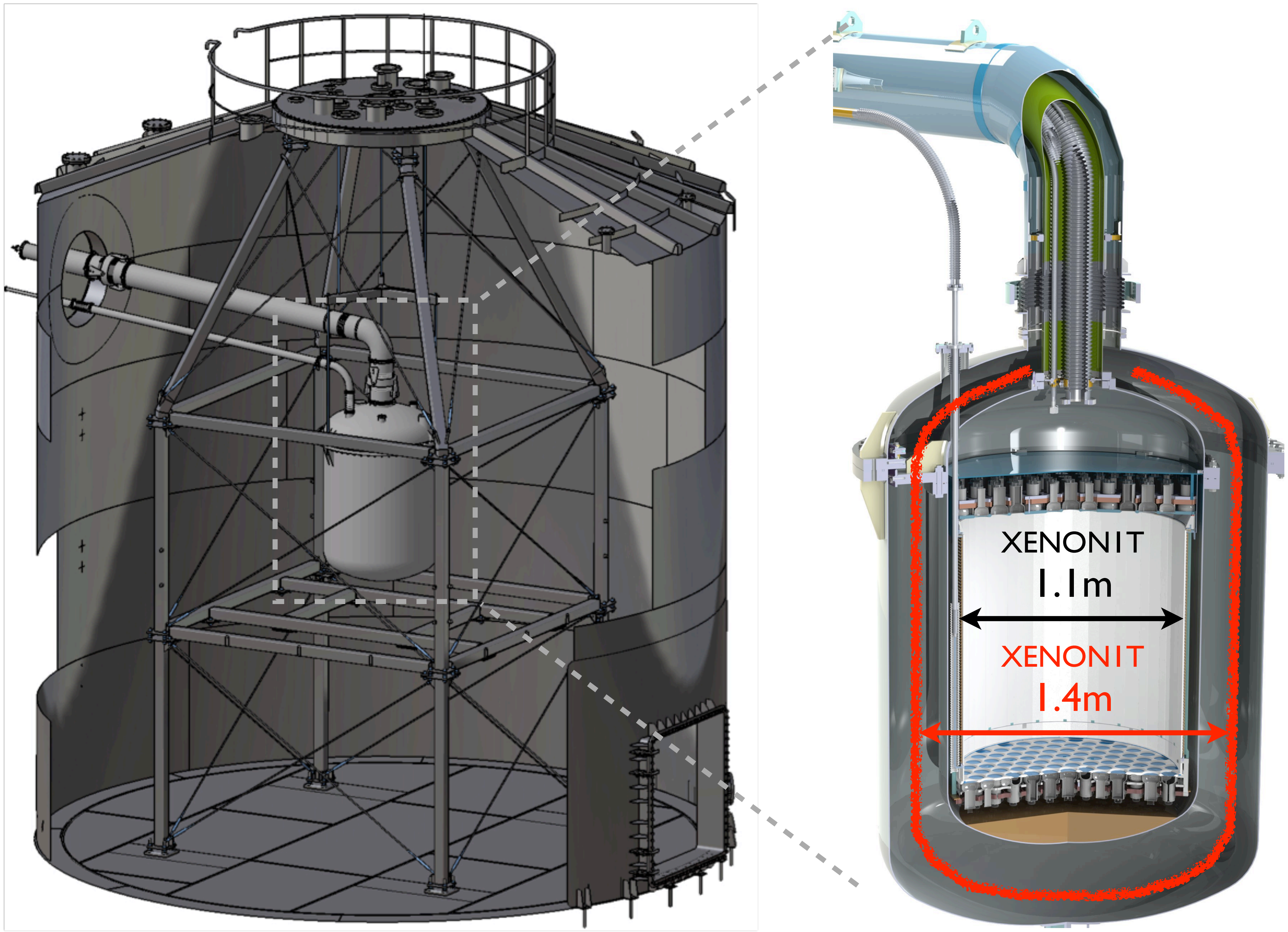
From XENON1T to XENONnT



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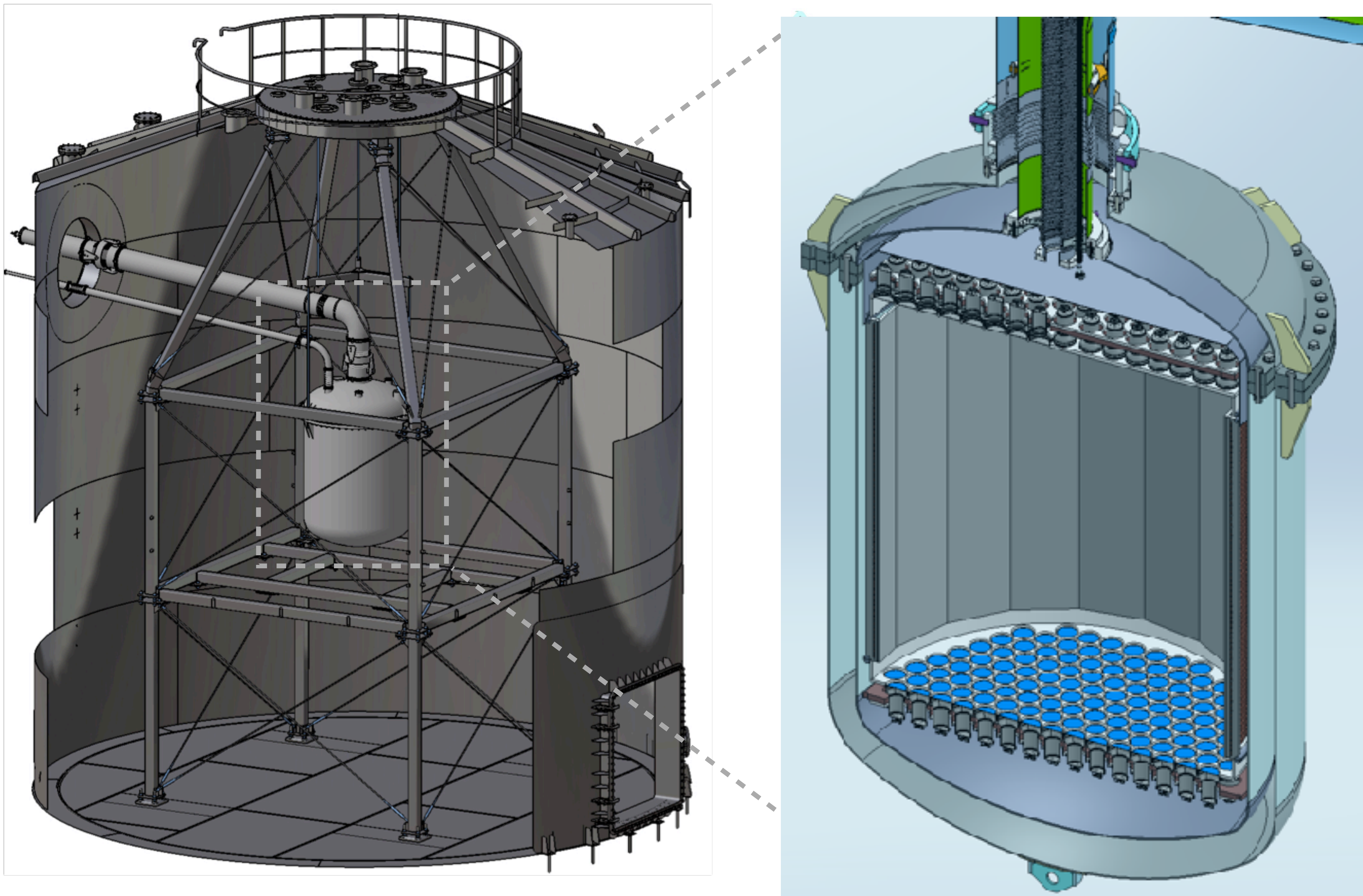
From XENON1T to XENONnT



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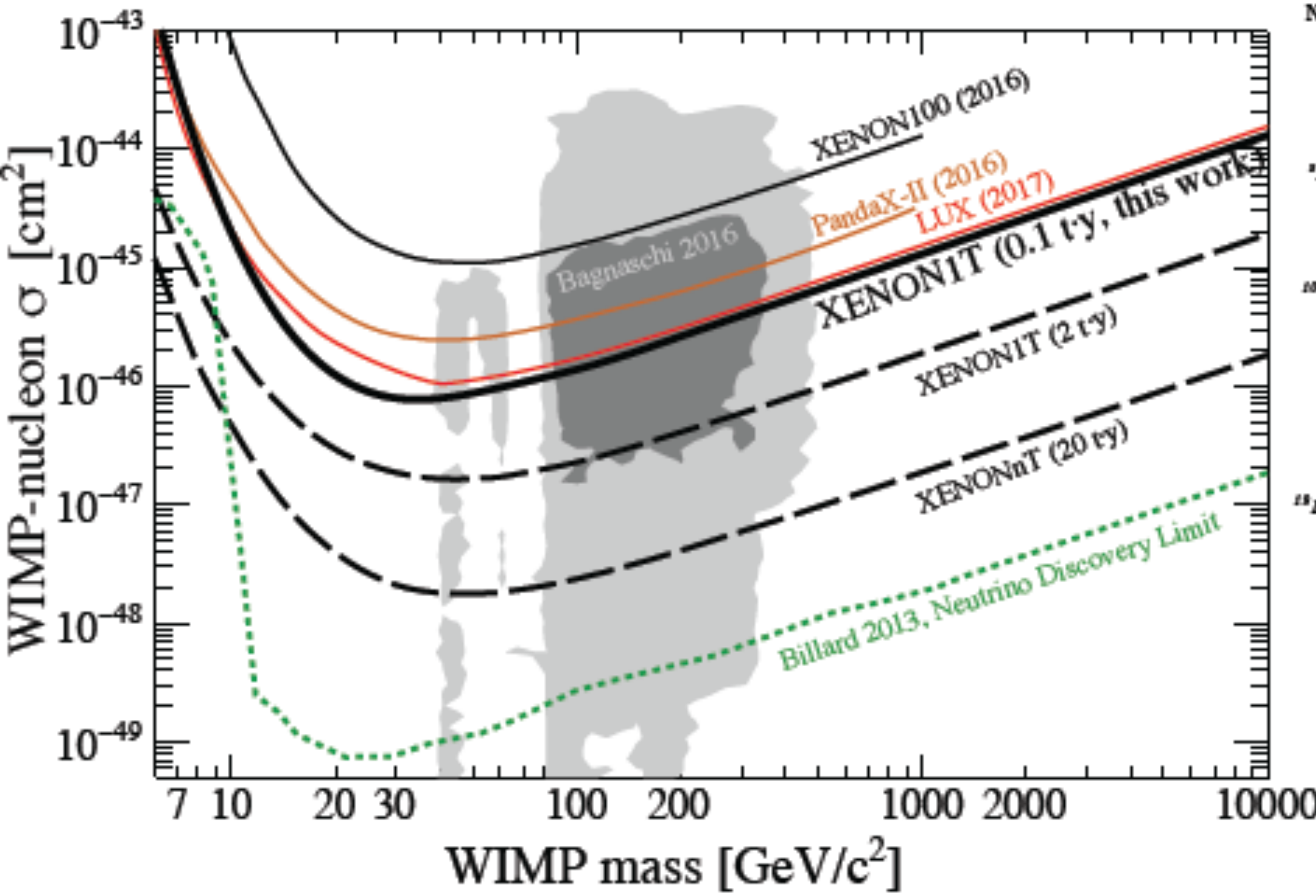
XENON1T Summary

Lowest background DM experiment:
0.193±0.025 events/keV/ton/day

World's best sensitivity and analysis of new data ongoing



First Dark Matter Search Results from the XENON1T Experiment

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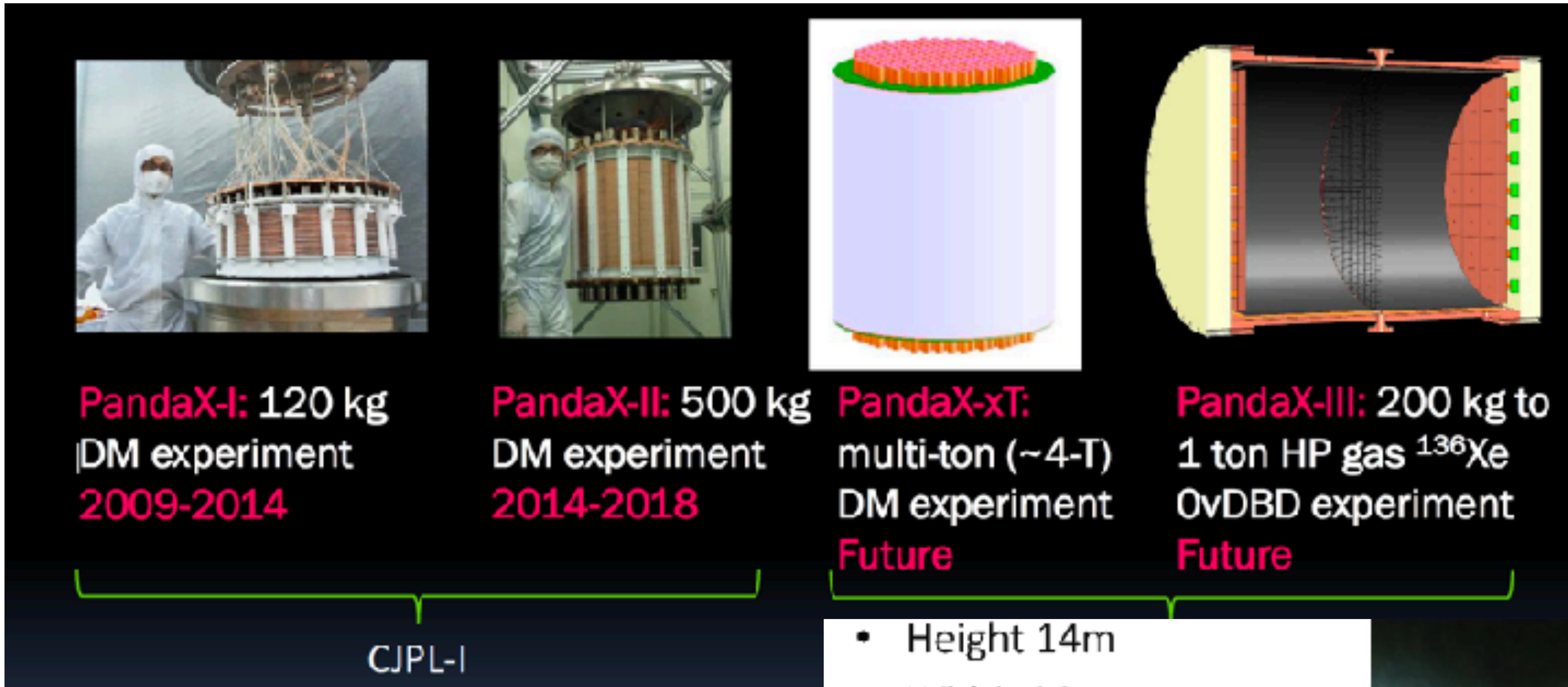
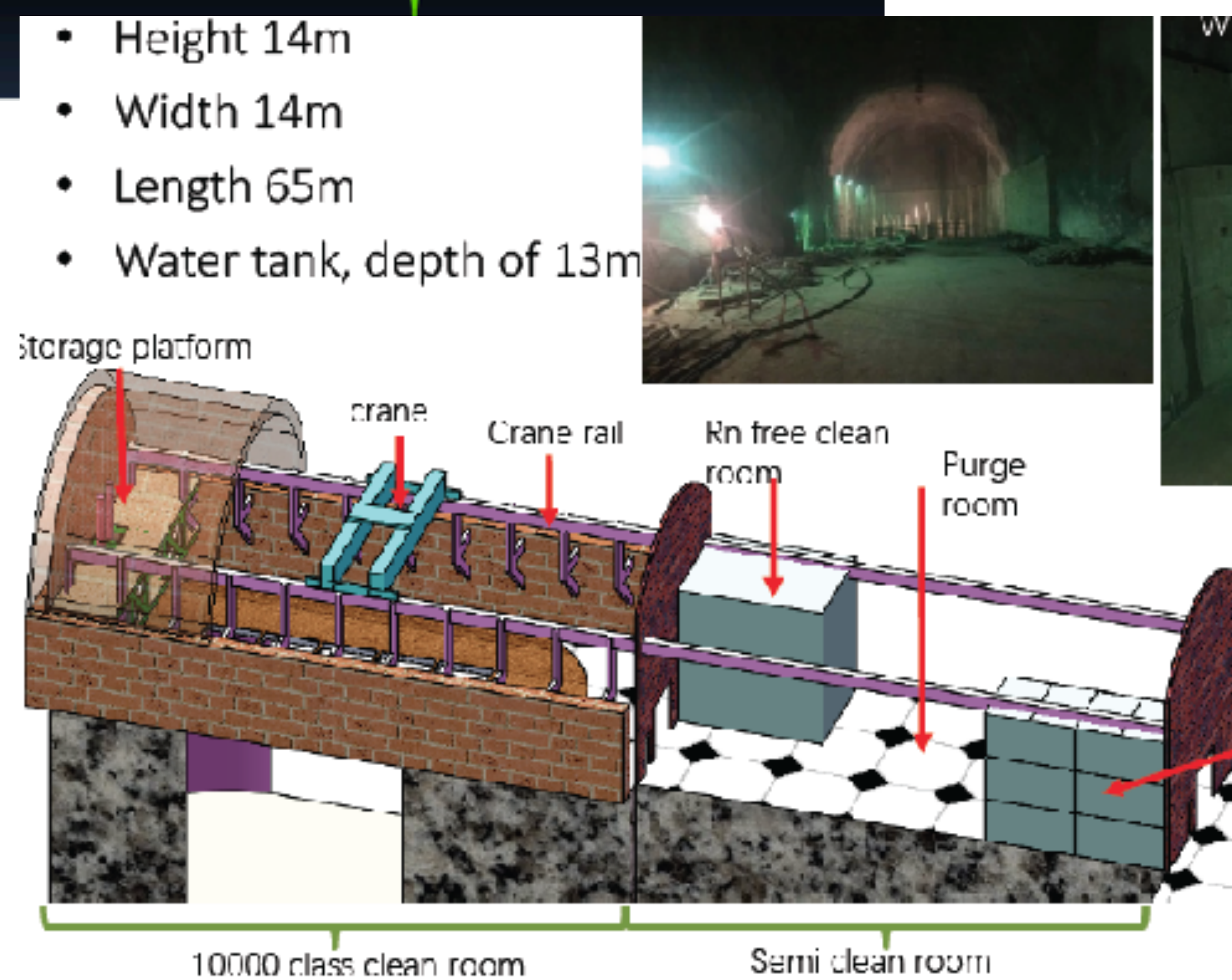
(Dated: May 17, 2017)

We report the first dark matter search results from XENON1T, a ~2000-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 34.2 live days of data acquired between November 2016 and January 2017. Inside the (1042±12) kg fiducial mass and in the [5, 40] keV_{nr} energy range of interest for WIMP dark matter searches, the electronic recoil background was $(1.93 \pm 0.25) \times 10^{-4}$ events/(kg × day × keV_{ee}), the lowest ever achieved in 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 GeV/c^2, with a minimum of 7.7×10^{-47} cm^2 for 35-GeV/c^2 WIMPs at 90% confidence level.

PandaX @ CJPL



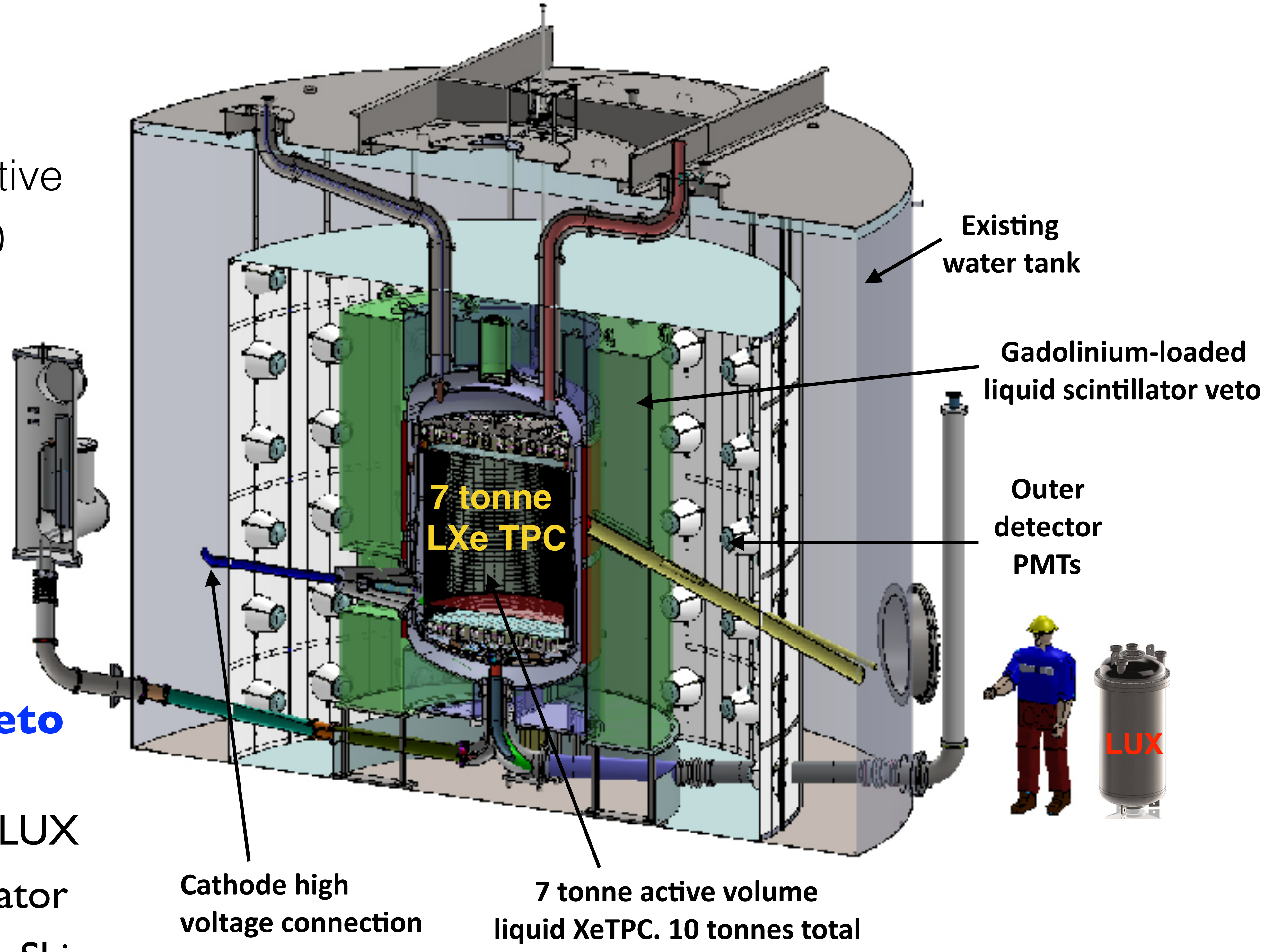


- Future: PandaX-xT: multi-ton (~4 T)
  - Projected sensitivity ~10^{-47} cm^2
  - Commissioning 2019-2020
- Eventual goal: ~30T detector in CJPL to "neutrino floor" sensitivity

from J. Liu's talk at Pheno 2017

LUX- ZEPLIN (LZ) @ SURF

- 10 T of LXe, 7 T active
- Turning on by 2020



- **3-component veto system:**
  - ✦ Water tank from LUX
  - ✦ Gd-loaded scintillator
  - ✦ Instrumented LXe Skin

DARWIN - towards WIMP spectroscopy

darwin-observatory.org JCAP10(2015)016

- **Design study for 50 tonne LXe detector**
- **Background goal: dominated by neutrinos**
  - WIMP spectroscopy
  - many other channels (solar neutrinos, double beta decay of ^{136}Xe, axions, bosonic SuperWIMPs)