The XENON Dark Matter Search: Status and Prospects

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UCLA Dark Matter 2018
Los Angeles, February 21, 2018

The XENON Collaboration: 160 scientists

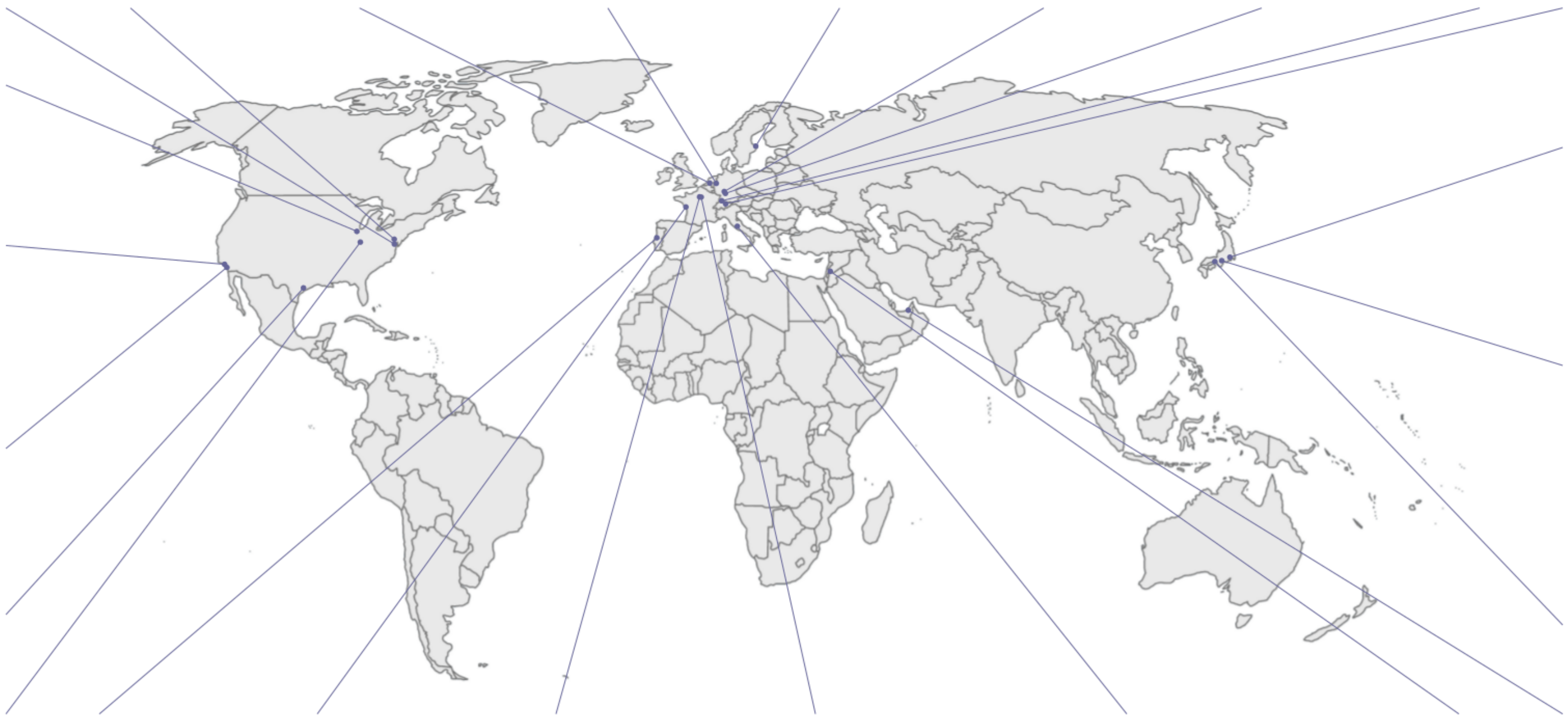
Columbia RPI Nikhef Muenster Stockholm Mainz MPIK Freiburg Zurich

Chicago

UCLA

UCSD

Rice



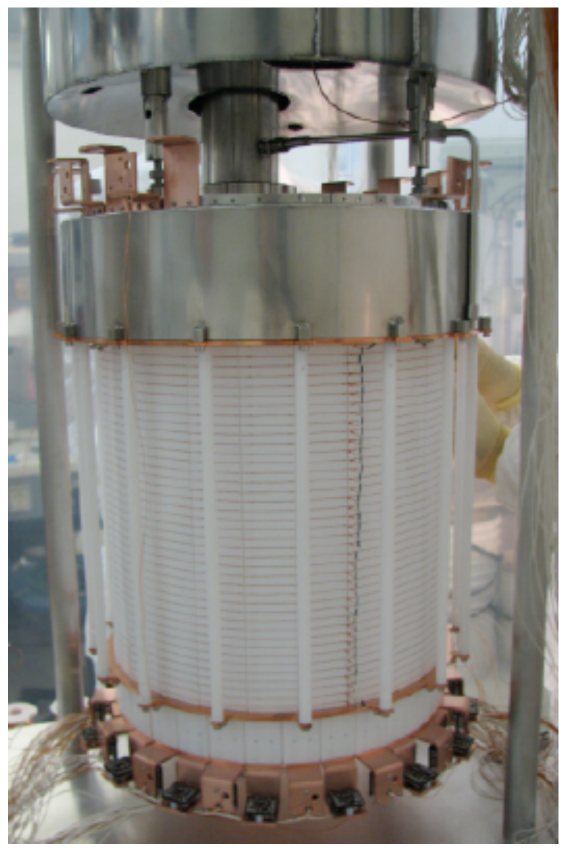
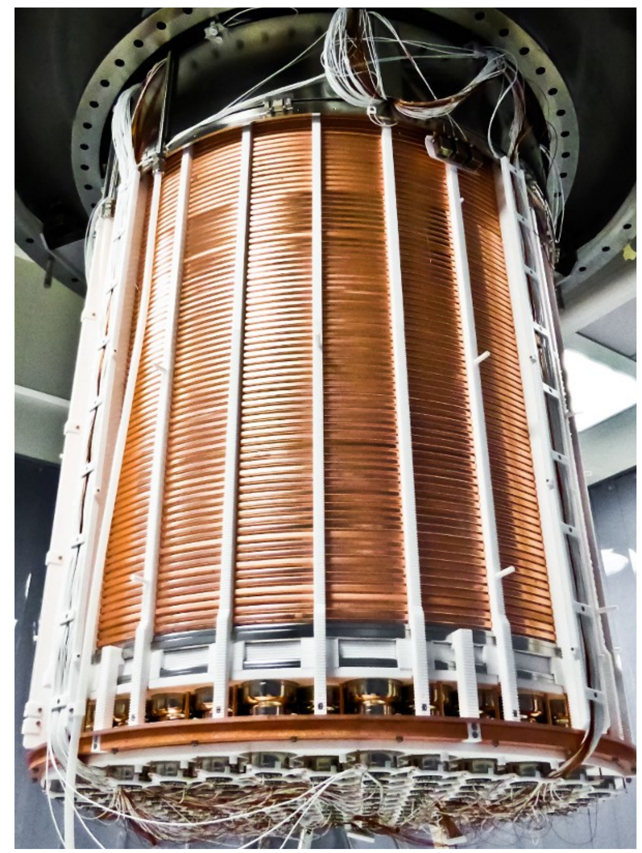
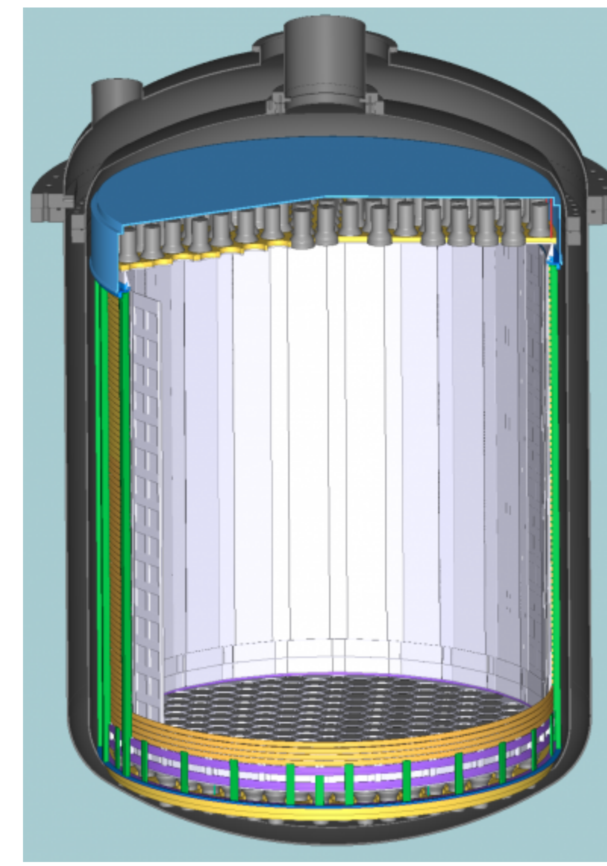
Tokyo

Nagoya

Kobe

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
$\sim 10^{-43}$ cm^2	$\sim 10^{-45}$ cm^2	$\sim 10^{-47}$ cm^2	$\sim 10^{-48}$ cm^2

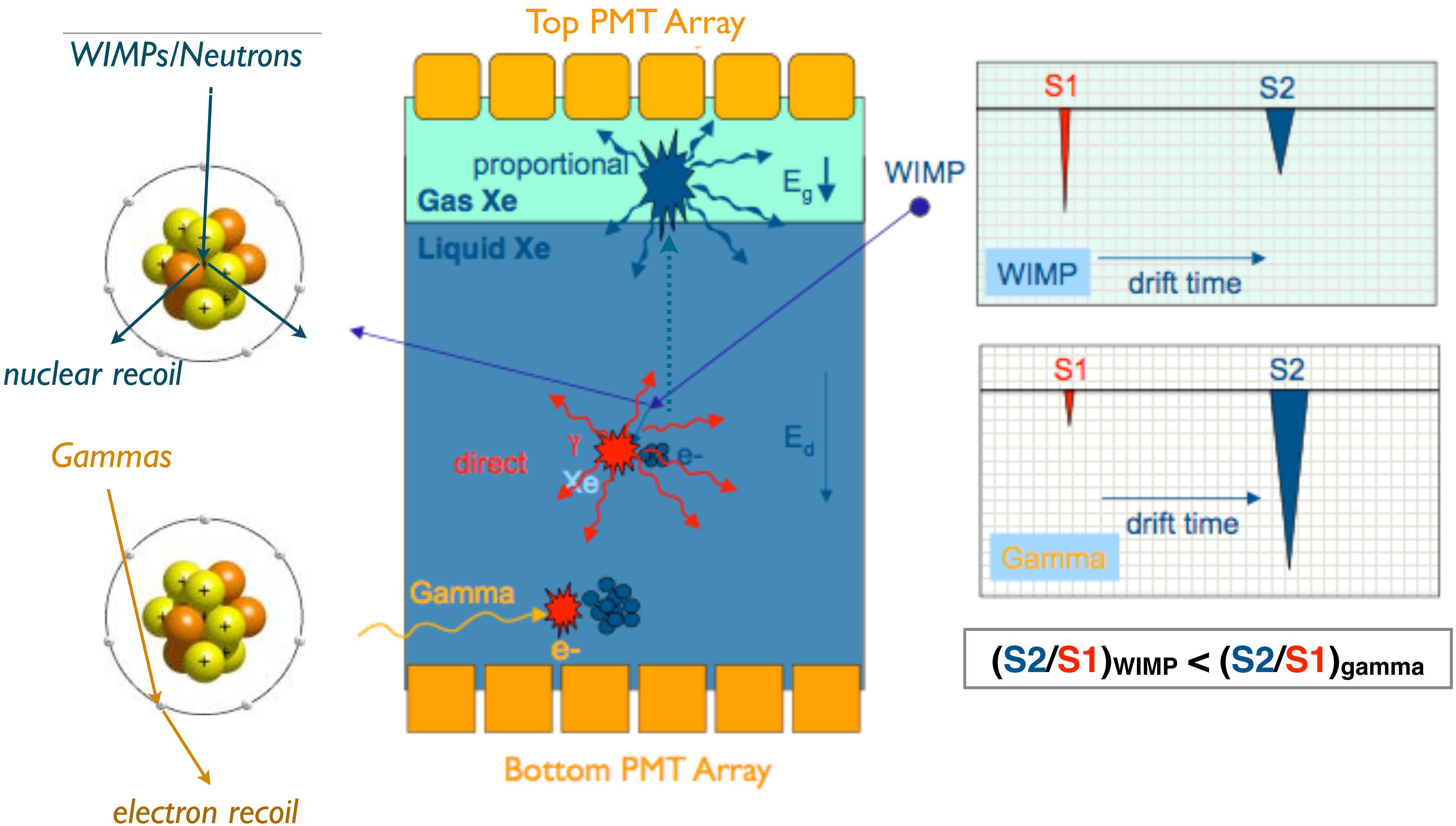
Why Liquid Xenon for a Dark Matter Detector?

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

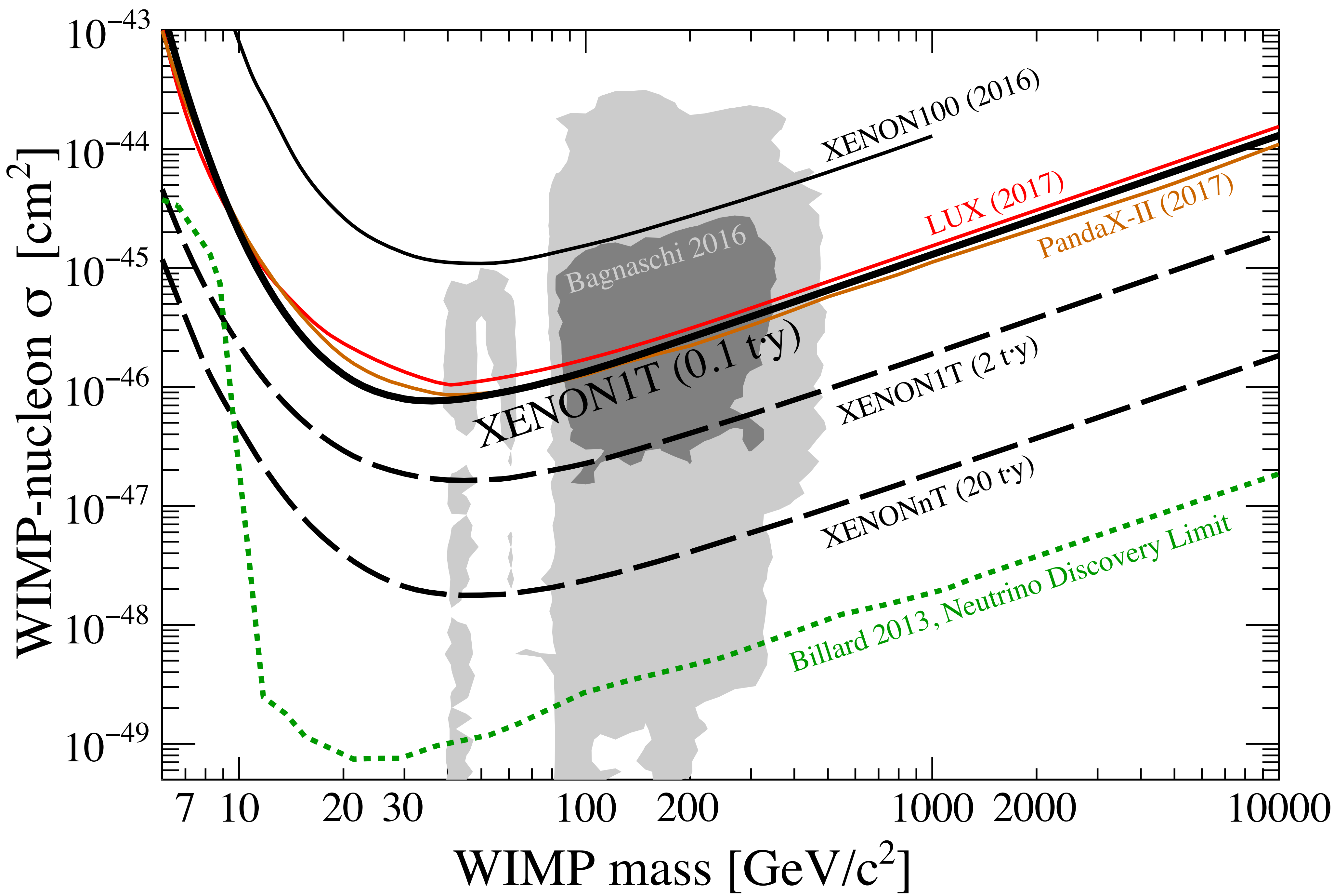
- ✦ *dense liquid (3 g/cc) for a massive WIMP target at modest cost (~2000 \$/kg) and scale*
- ✦ *large nucleus and isotopes with nuclear spin to probe SI and SD interactions with one target*
- ✦ *demonstrated long term operation of a detector with more than 3 tonnes of LXe thanks to improved cryogenic and purification technologies*
- ✦ *no intrinsic radioactivity other than Kr85 which we have shown can be effectively reduced with cryogenic distillation for Kr/Xe at sub-ppt level*
- ✦ *ionization and scintillation yields in LXe highest among noble liquids: detect both signals in a homogeneous 3D position sensitive detector*

Two-phase Xe Time Projection Chamber as WIMP detector

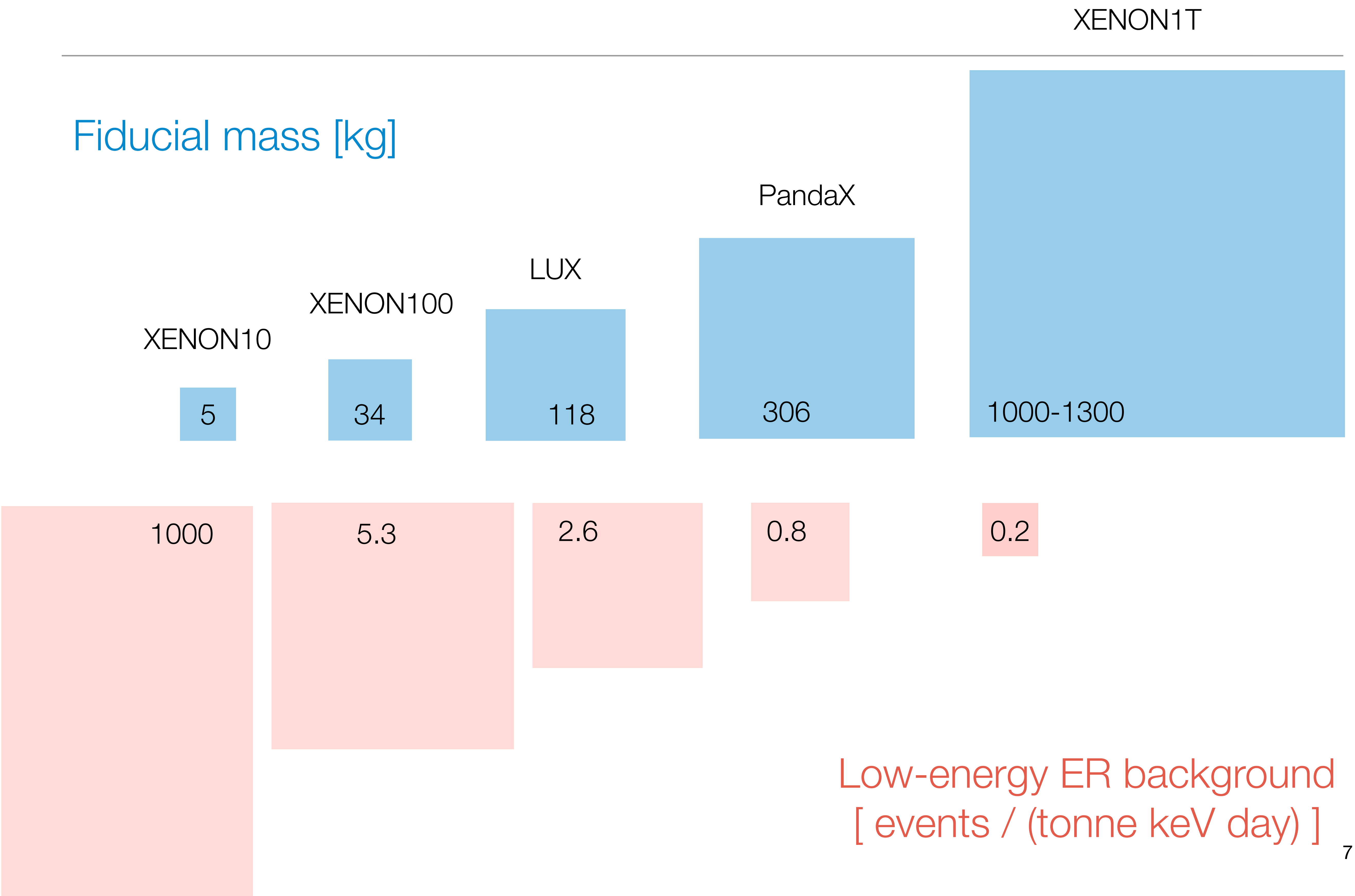


$(S2/S1)_{WIMP} < (S2/S1)_{gamma}$

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



The impressive evolution of LXeTPCs as WIMP detectors



The XENON1T Experiment at LNGS

www.xenon1t.org

XENON1T Overview

EPJ C 77, 881 (2017)

Water tank and Cherenkov muon veto

Cryostat and support structure for TPC

Time projection chamber

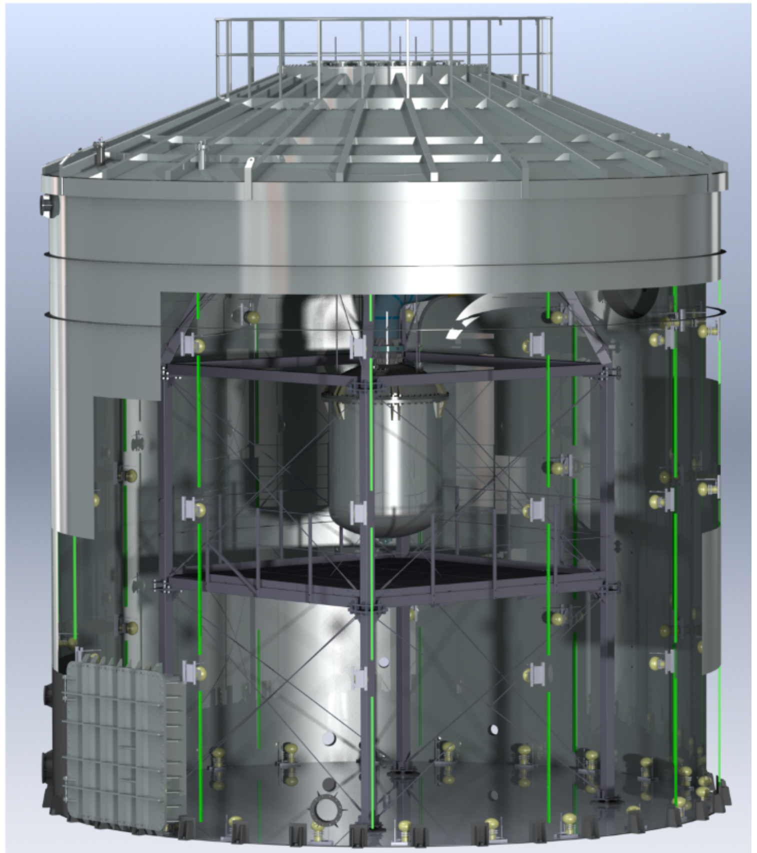
Umbilical pipe (cables, xenon)

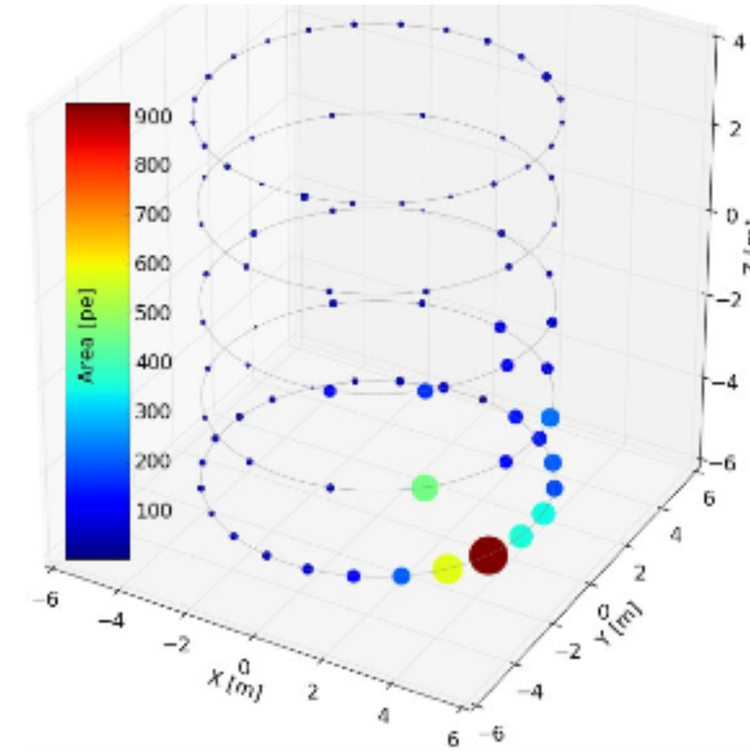
Cryogenics and purification

Data acquisition and slow control

Xenon storage, handling and distillation column

The XENON1T Water Cherenkov Muon Veto





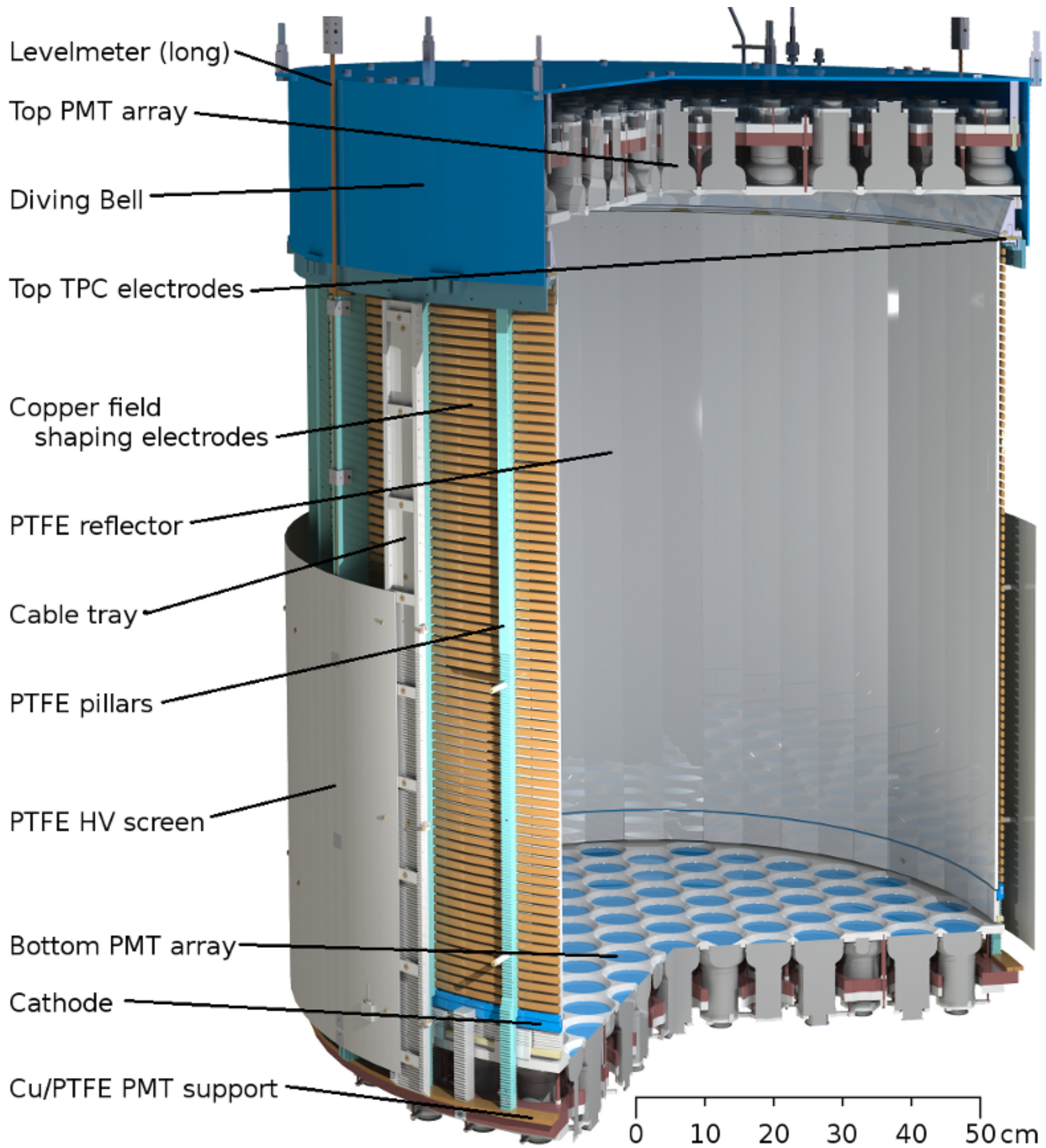
- 84 x 8 “ PMTs (R5912) with high QE and gain
- Taking data with a stable configuration: R = 0.45 Hz

SR	Coverage (%)	μ-Tag. Eff. (%)	Shower Tag. Eff. (%)
0	96	99.5	43
1	99	99.5	43

Muon-induced nuclear recoil background rate in SR1
$1.2\ 10^{-2}$ (events/year) in 1 ton fiducial volume

The XENON1T Time Projection Chamber

Time Projection Chamber- Details

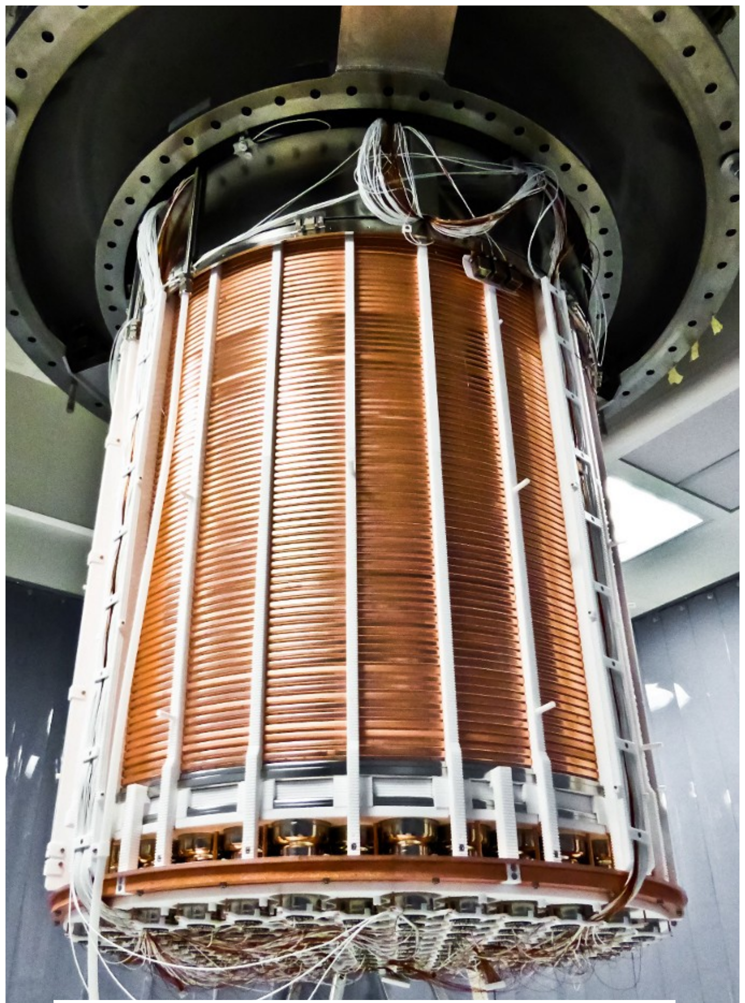


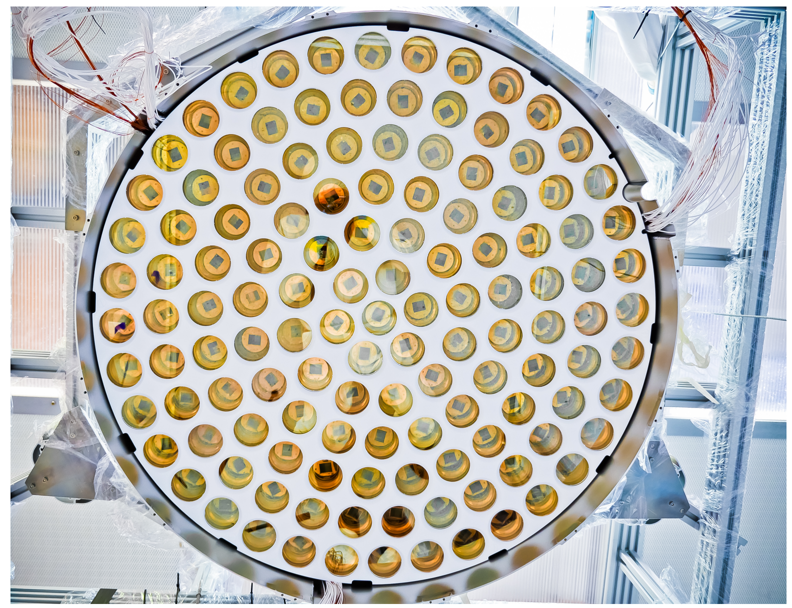
EPJ C 77, 881 (2017)

- 96 cm diameter defined by 24 interlocking PTFE panels, optimized for VUV-reflectivity
- 96 cm drift length with E-field shaped by 74 OFHC Cu rings
- 5 electrodes (cathode, anode, gate, 2 screening meshes)
- custom-made HV feedthrough to bias the cathode. 120- 80 V/cm
- liquid level controlled by diving bell pressurized by gas flow: 4 level meters inside the bell, 30µm precision; 2 long meters outside
- all materials selected for lowest background

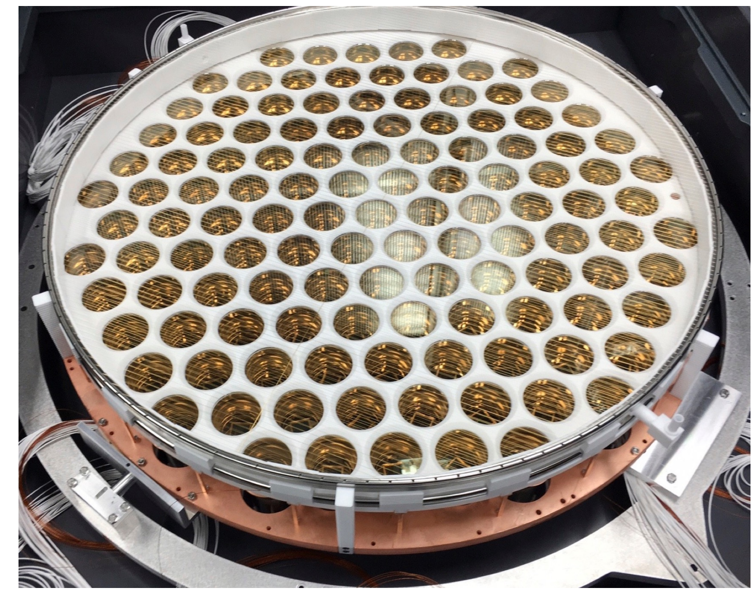
XENON1T Photomultipliers

- 248 3-inch, low-radioactivity R11410-21 PMTs with 34.5 % average QE at 178 nm



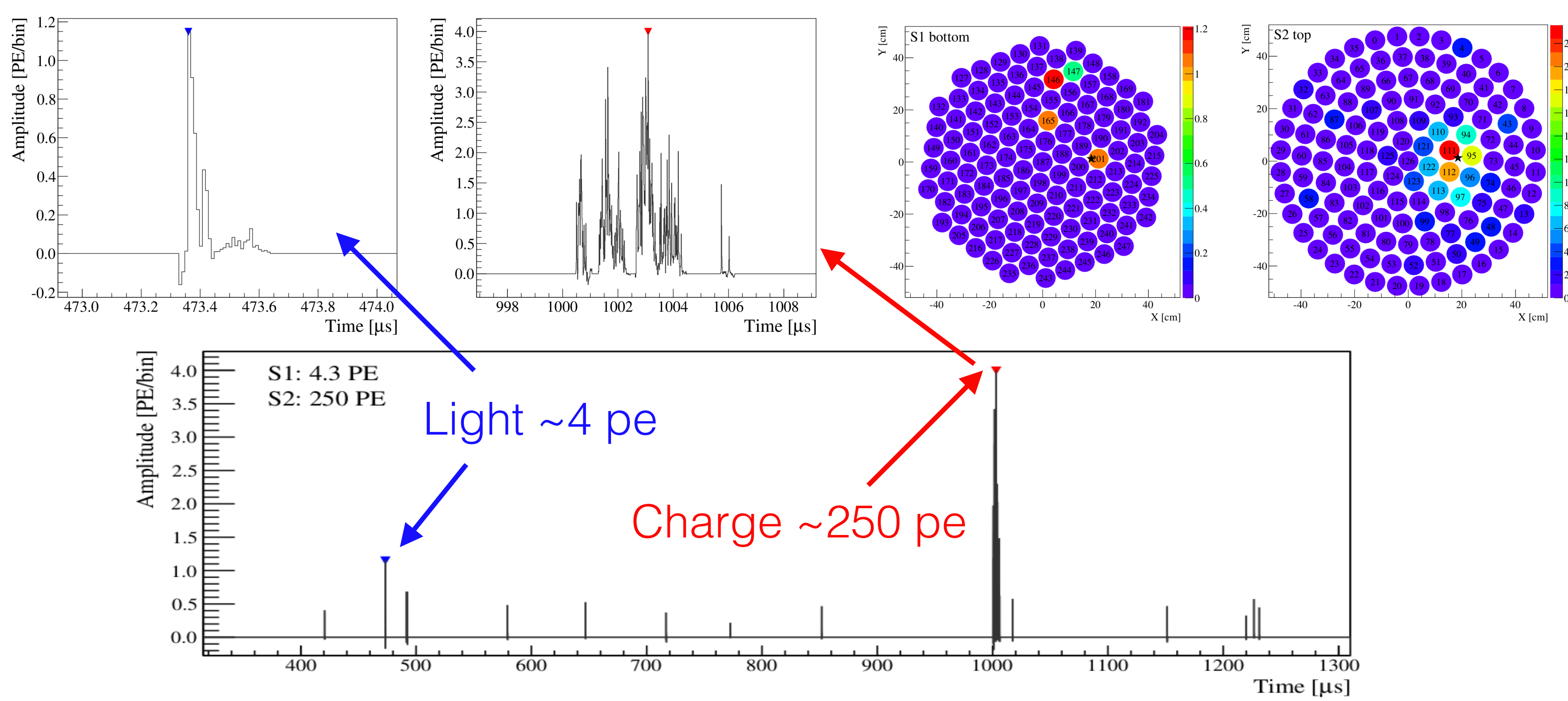


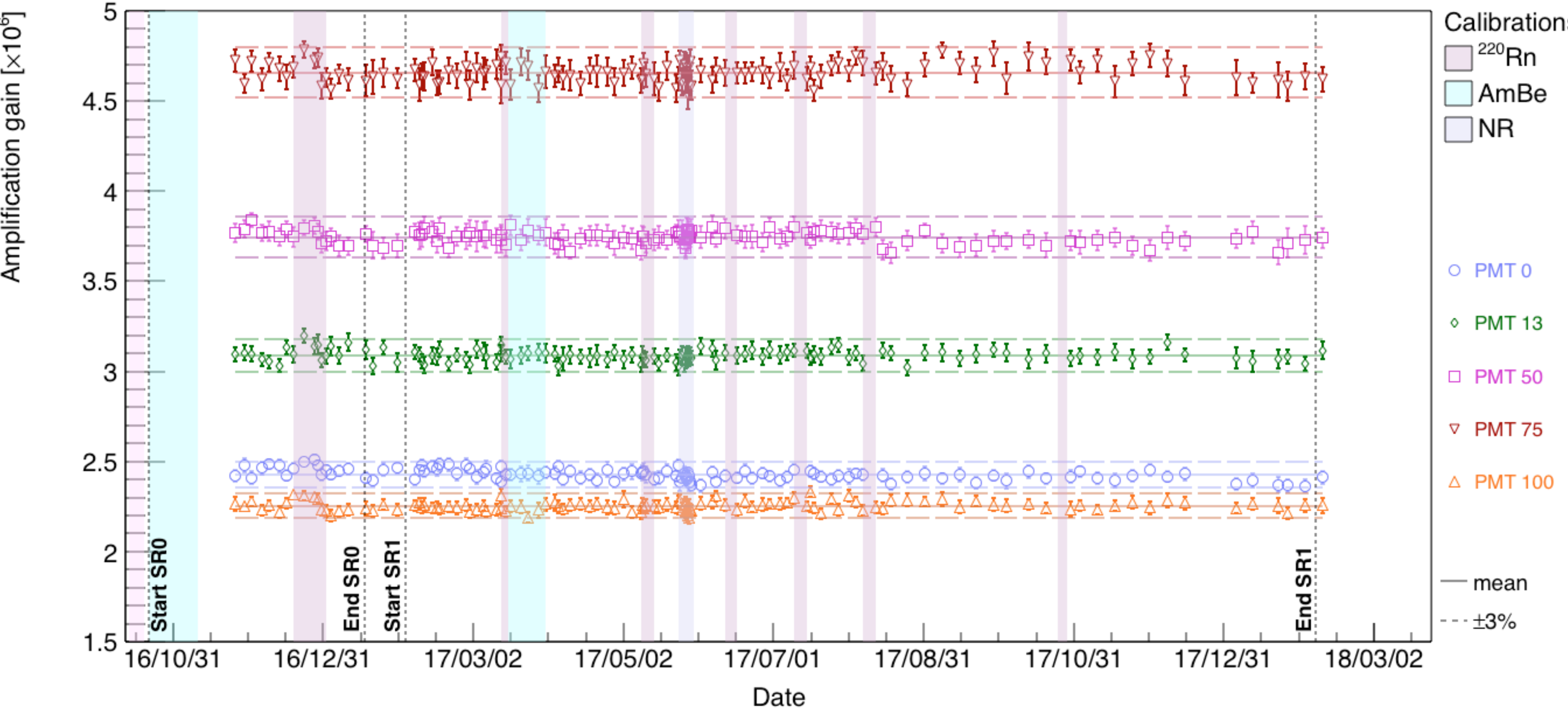
127 PMTs in the top array

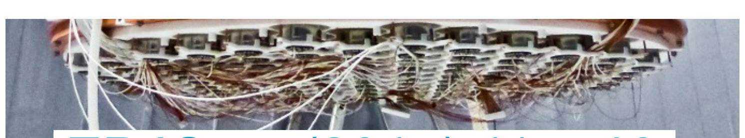


121 PMTs in the bottom array

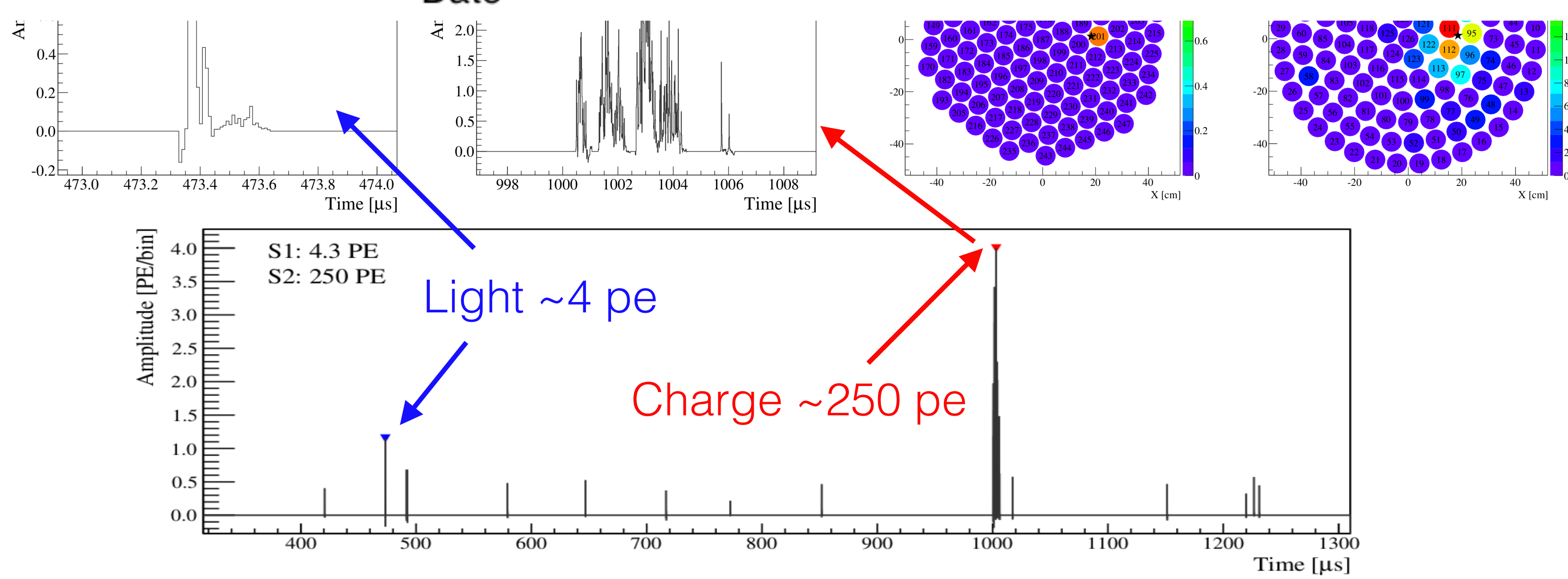
EPJC 75 (2015) 11, 546



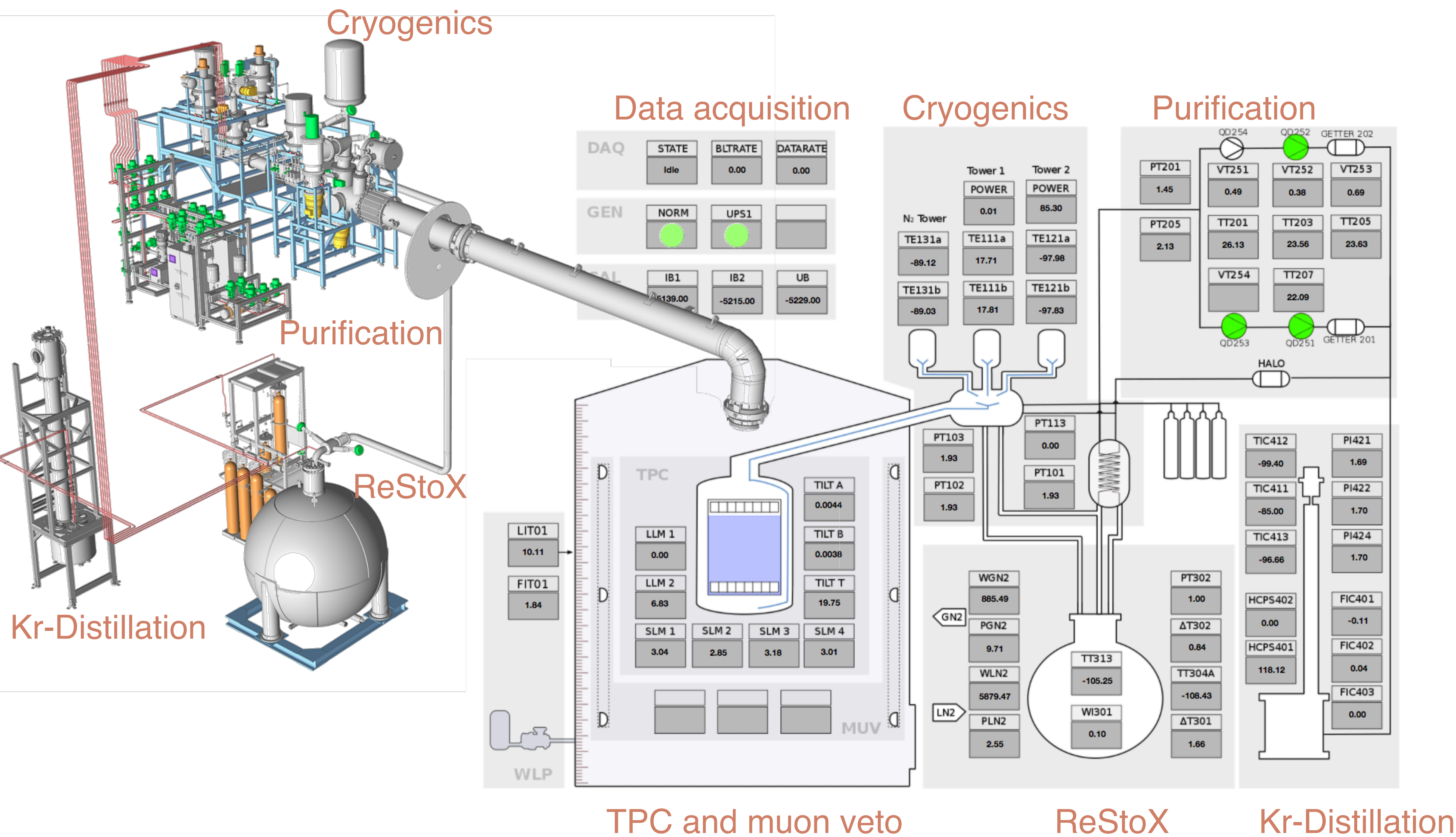




EPJC 75 (2015) 11, 546

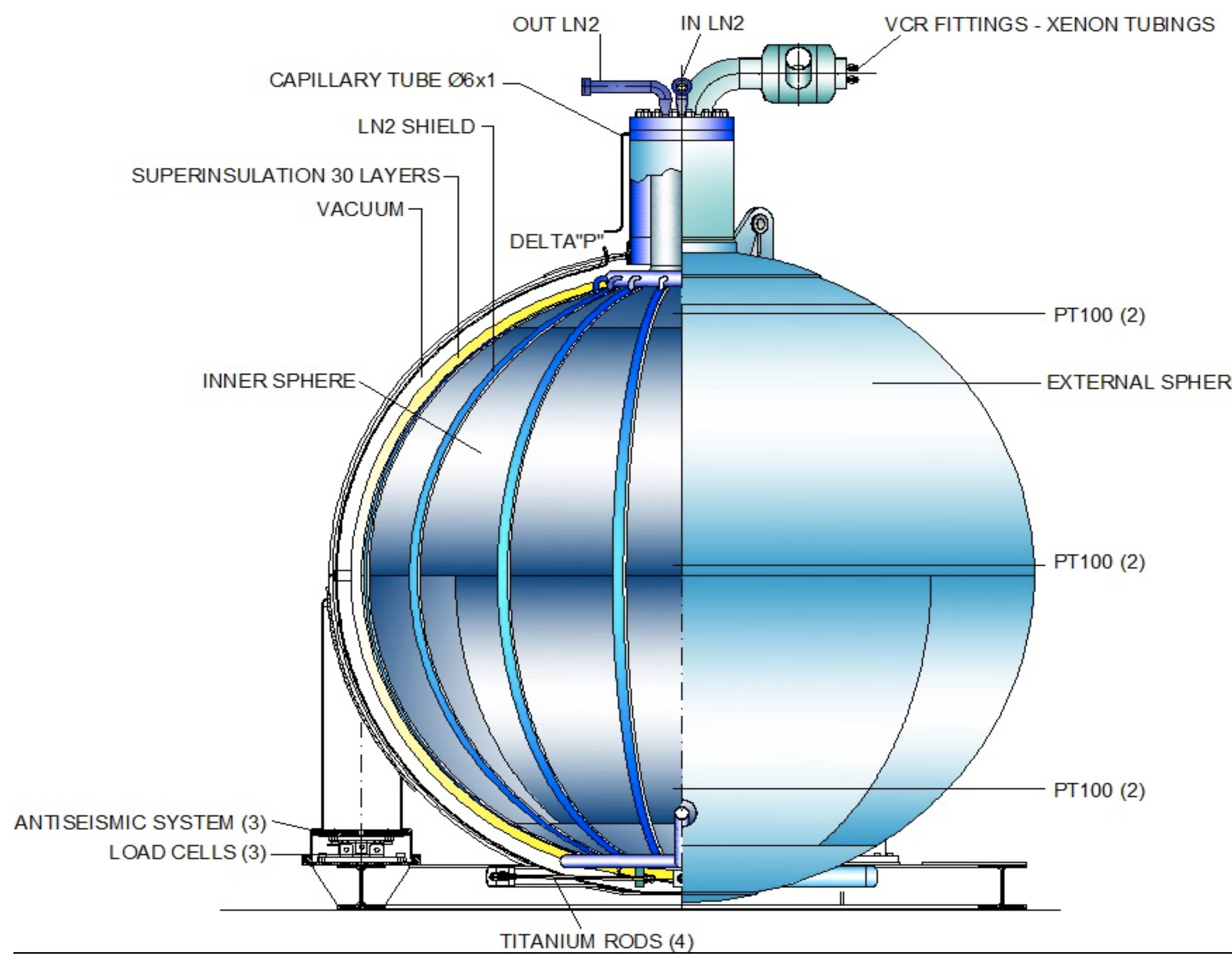


XENON1T Cryogenic Plants



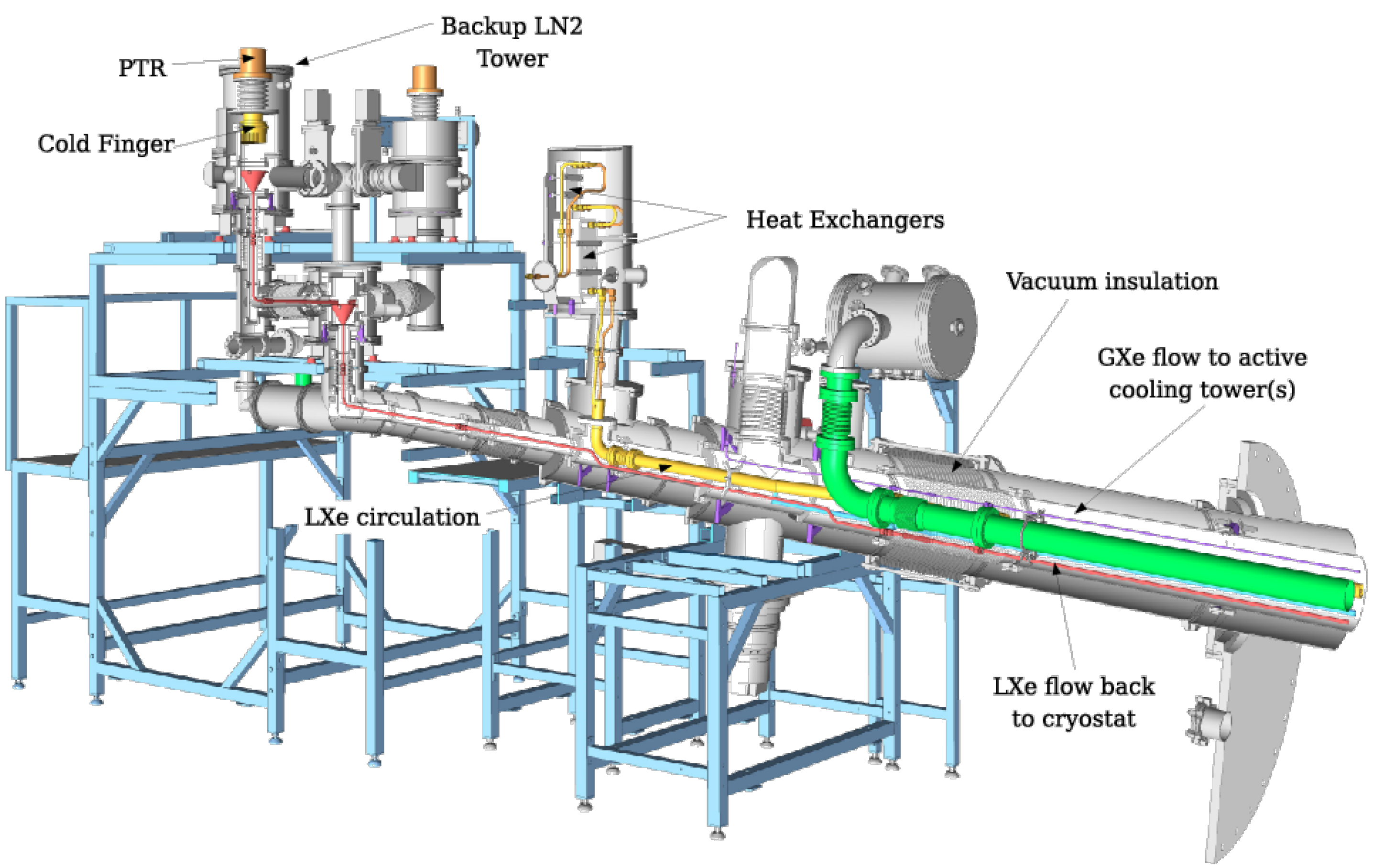
The Xe Recovery & Storage System

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



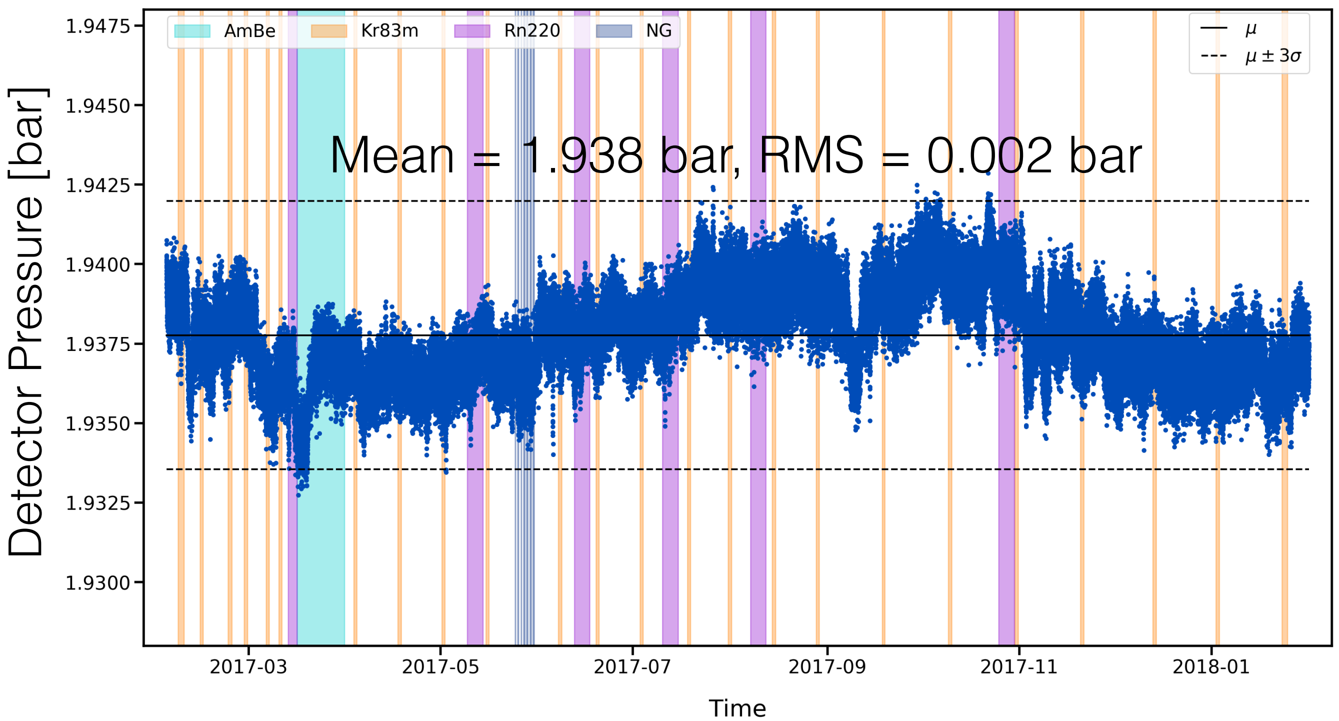
The Cryogenic System

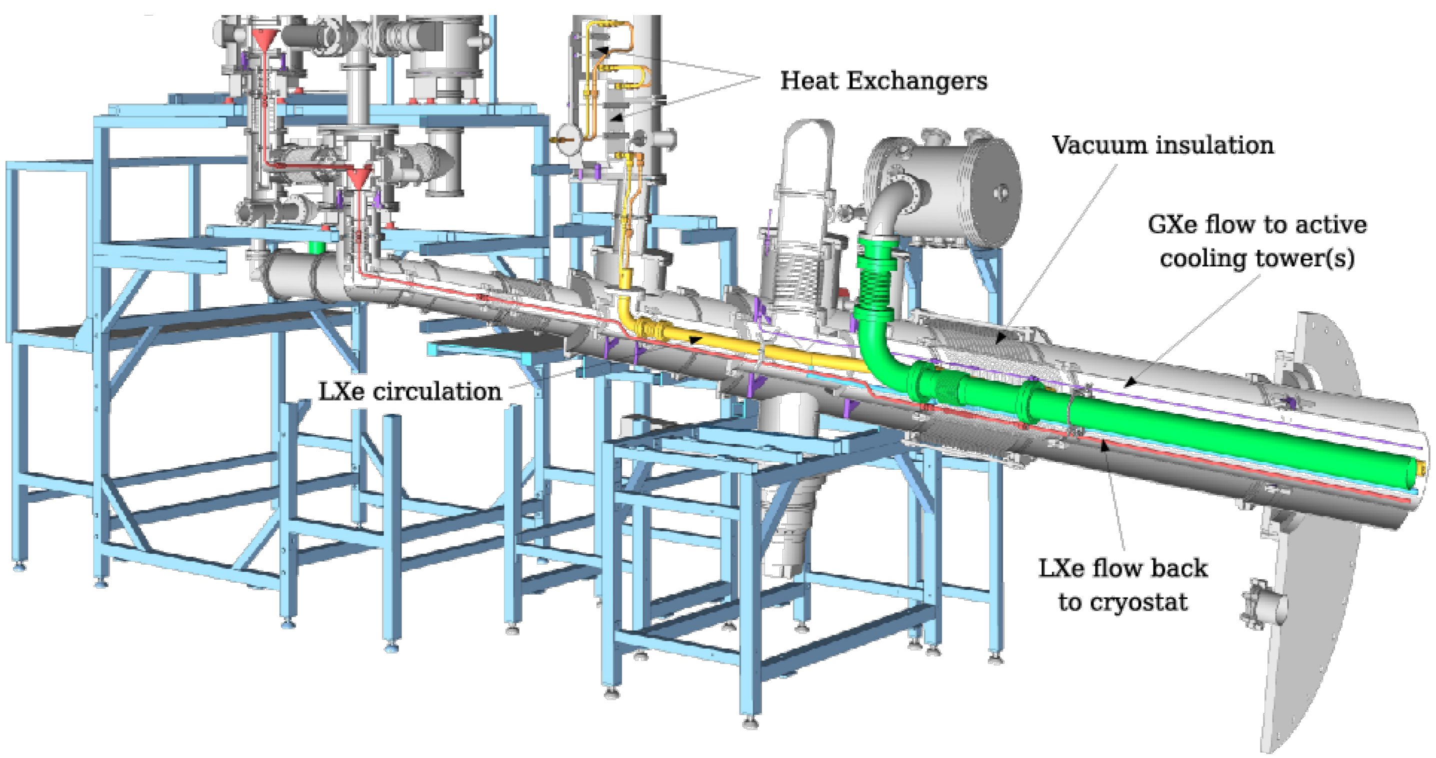
- Liquefies and maintains xenon in liquid state, provides stable conditions for data taking
  - Two redundant PTR cooling systems and one LN_2 cooling tower backup
  - Efficient two-phase heat exchangers
  - Detector cold with stable pressure/ temperature since Fall 2016!



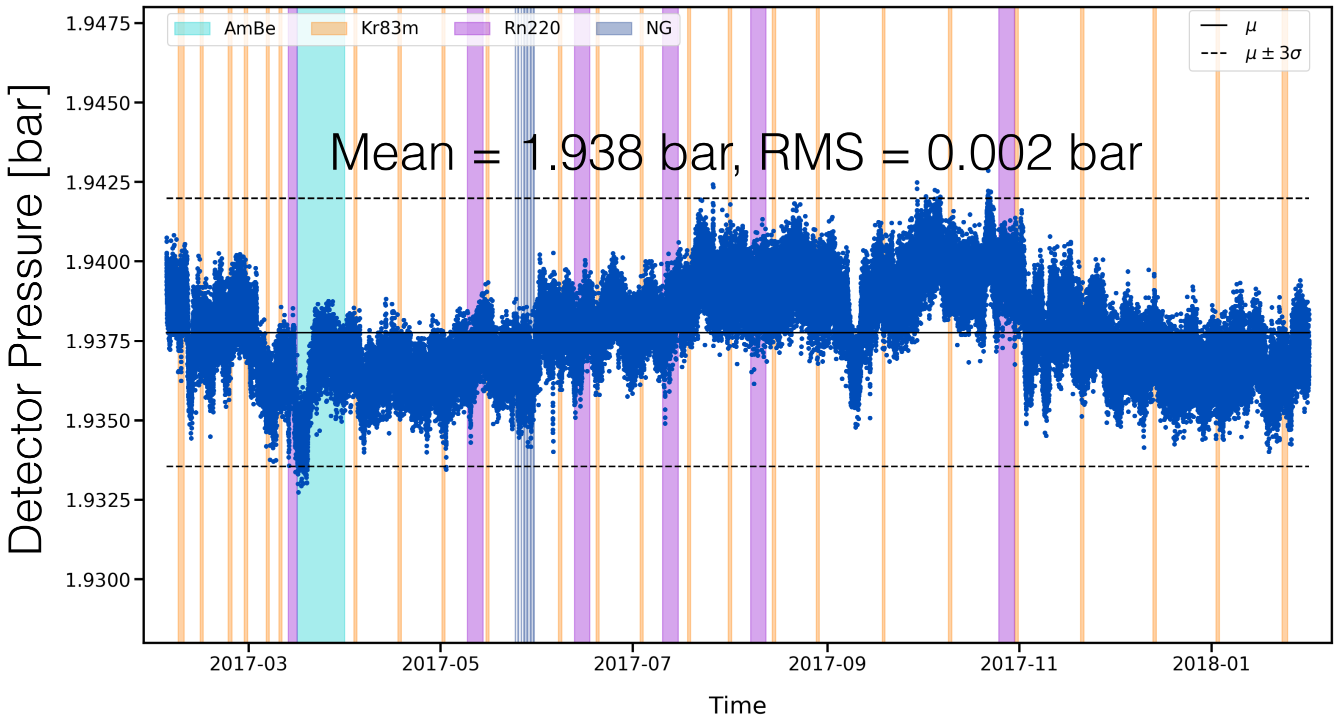
The Cryogenic System

te, provides stable conditions for data taking





The Cryogenic System



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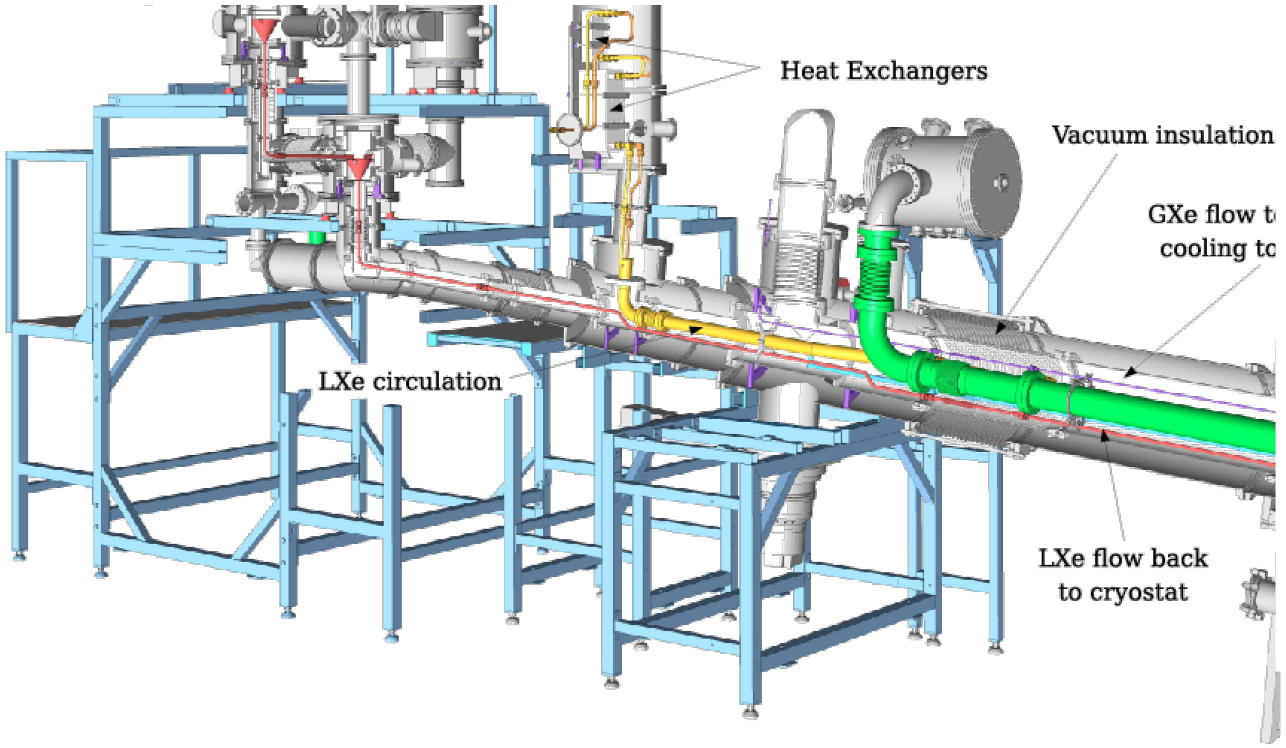
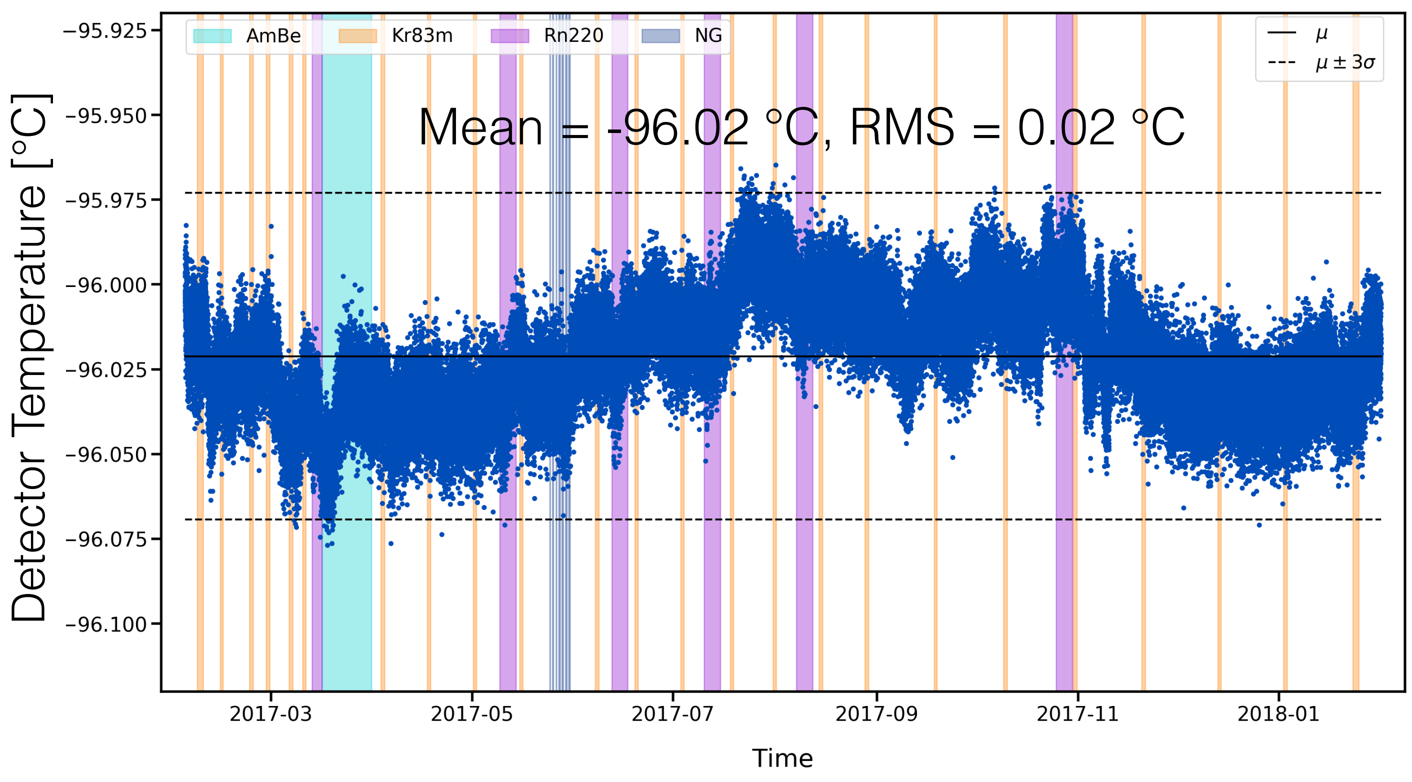
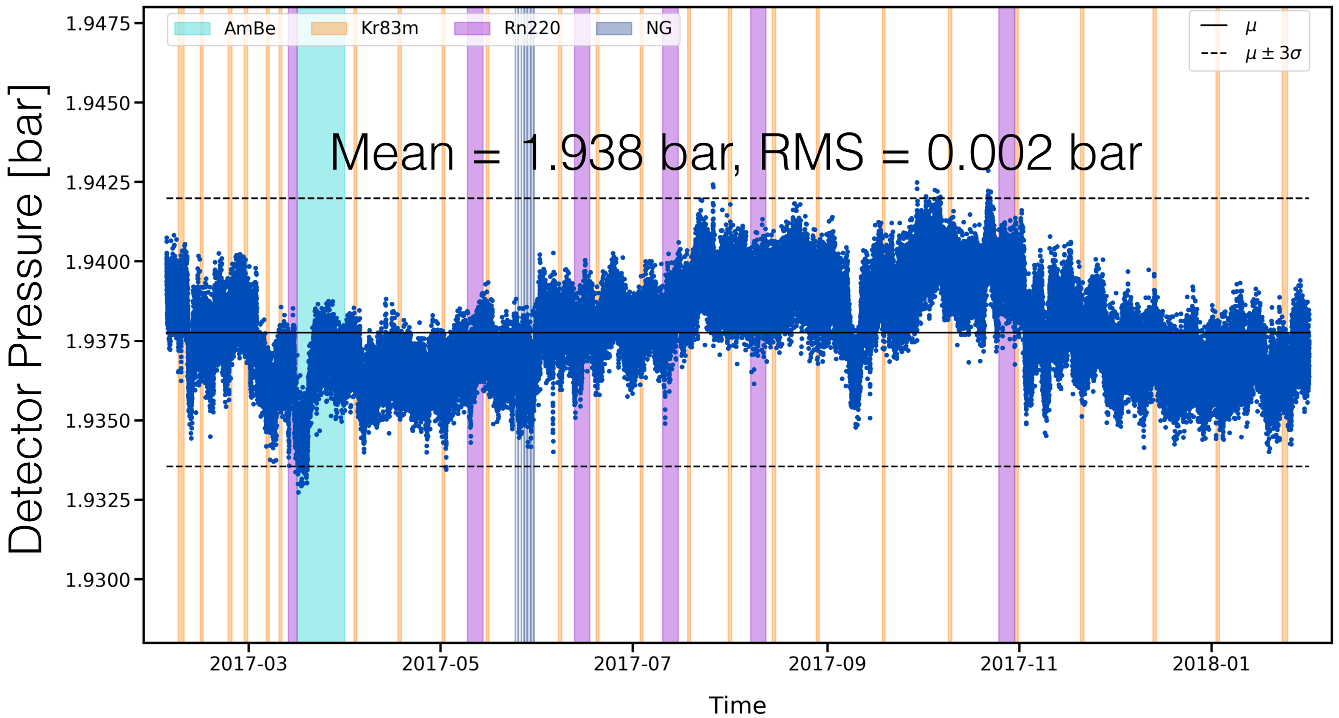
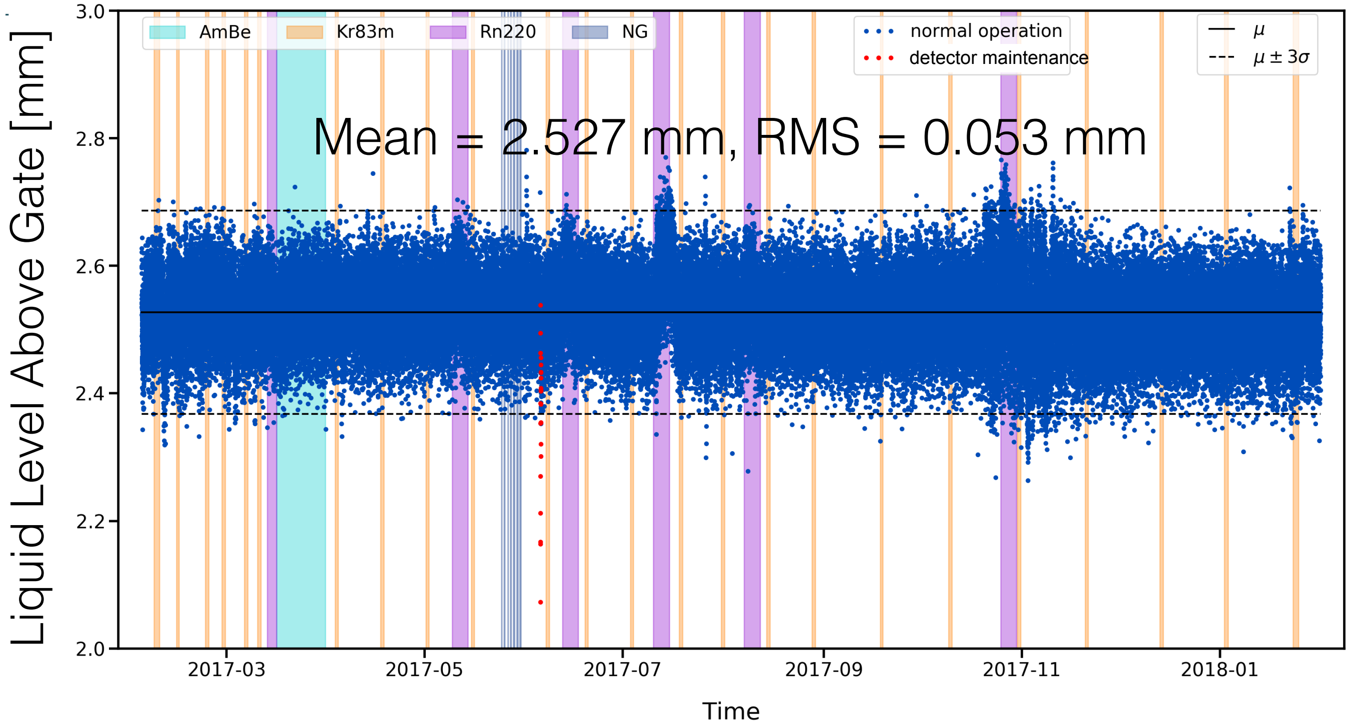
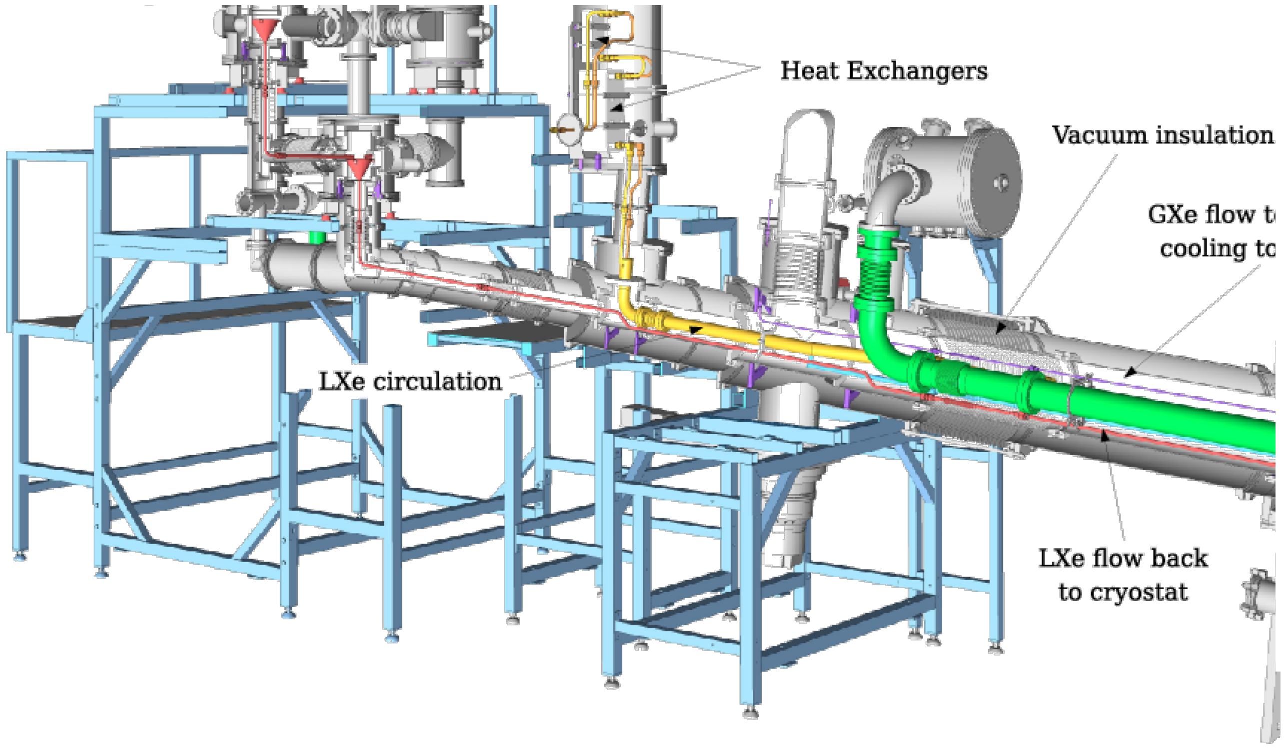


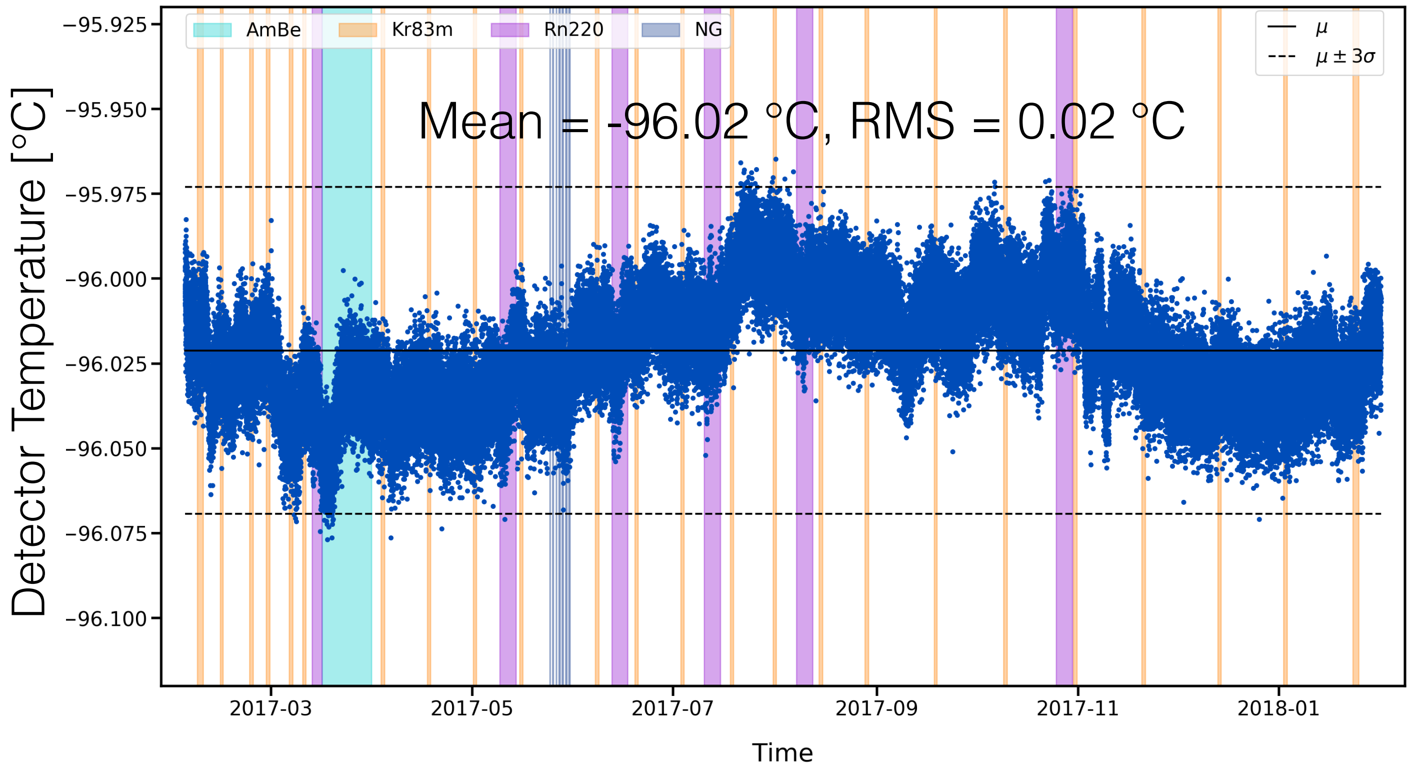


The Cryogenic System



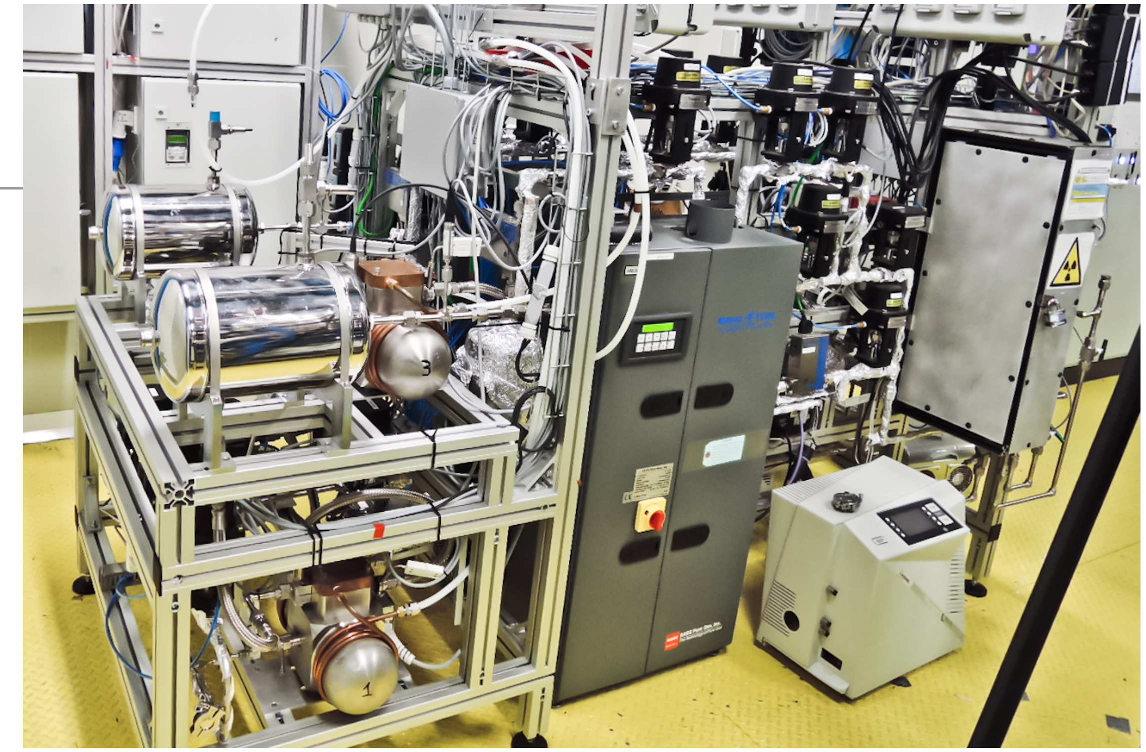




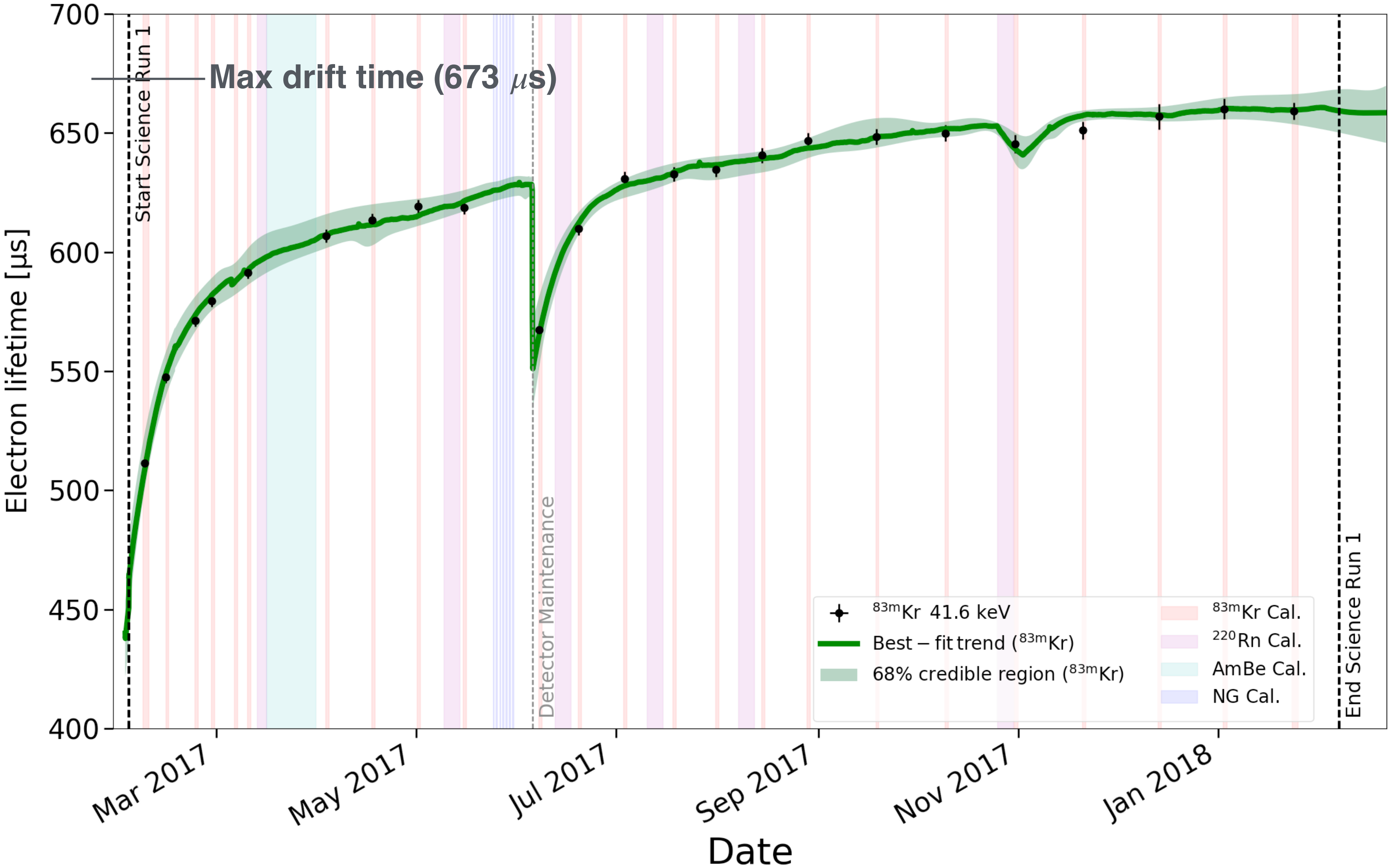


The Gas Purification System

- Continuous gas purification through heated getters
- Charge loss by impurities corrected with e-lifetime measured from ^{83m}Kr calibration and Rn222 alphas



$$S_2(t) = S_2(t_0)e^{(-t/\tau_e)}$$

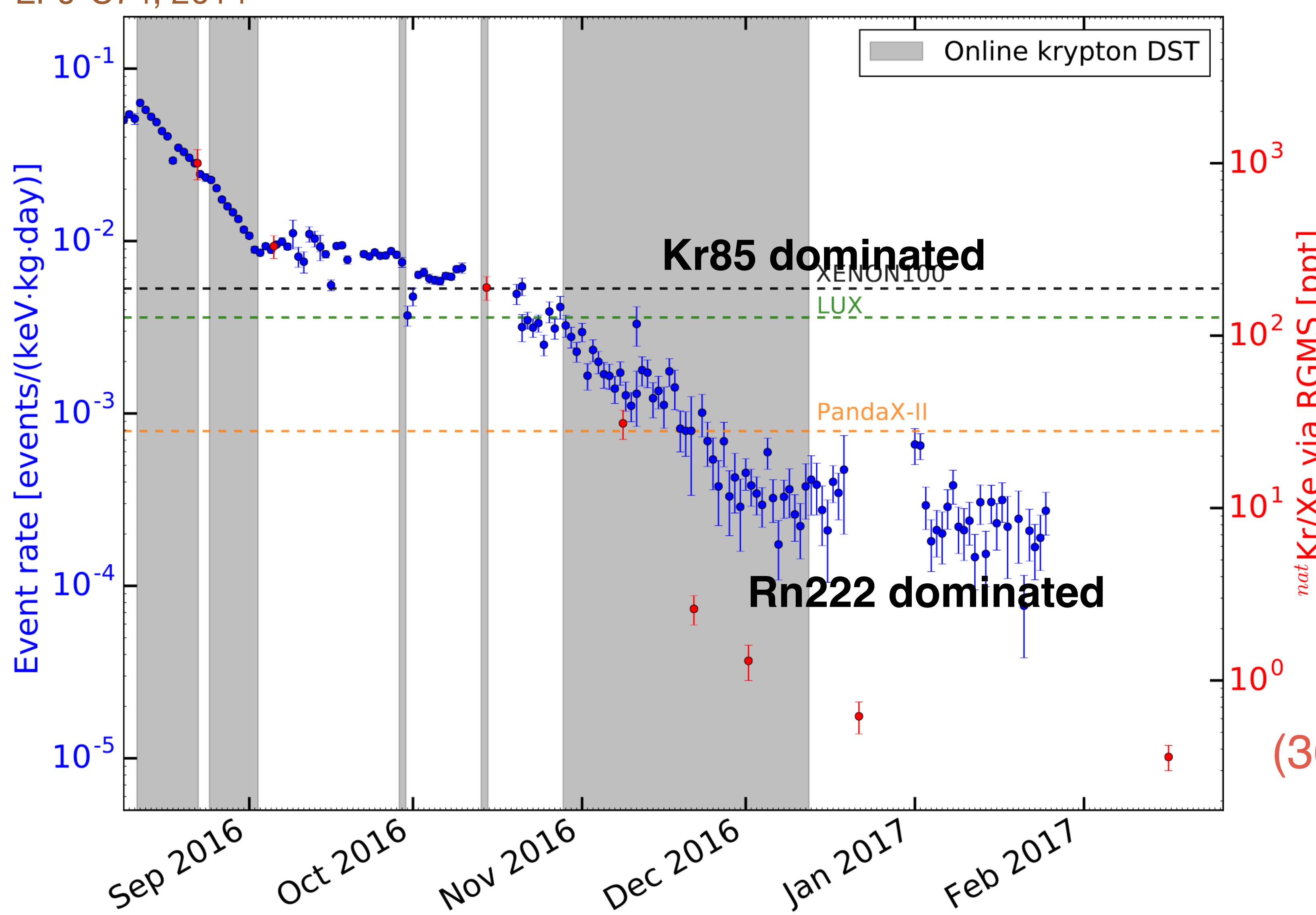


- Model accounts for the different impurity concentrations and outgassing in GXe and LXe, flow rate and other detector conditions
- Maximum electron lifetime achievable is limited by the outgassing of materials and the maximum purification flow rate, itself limited mostly by the circulation pumps

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 < 26 ppq (RGMS)
- on-line distillation used to reduce Kr/Xe while taking data
- Regular samples from TPC measured with a RGMS

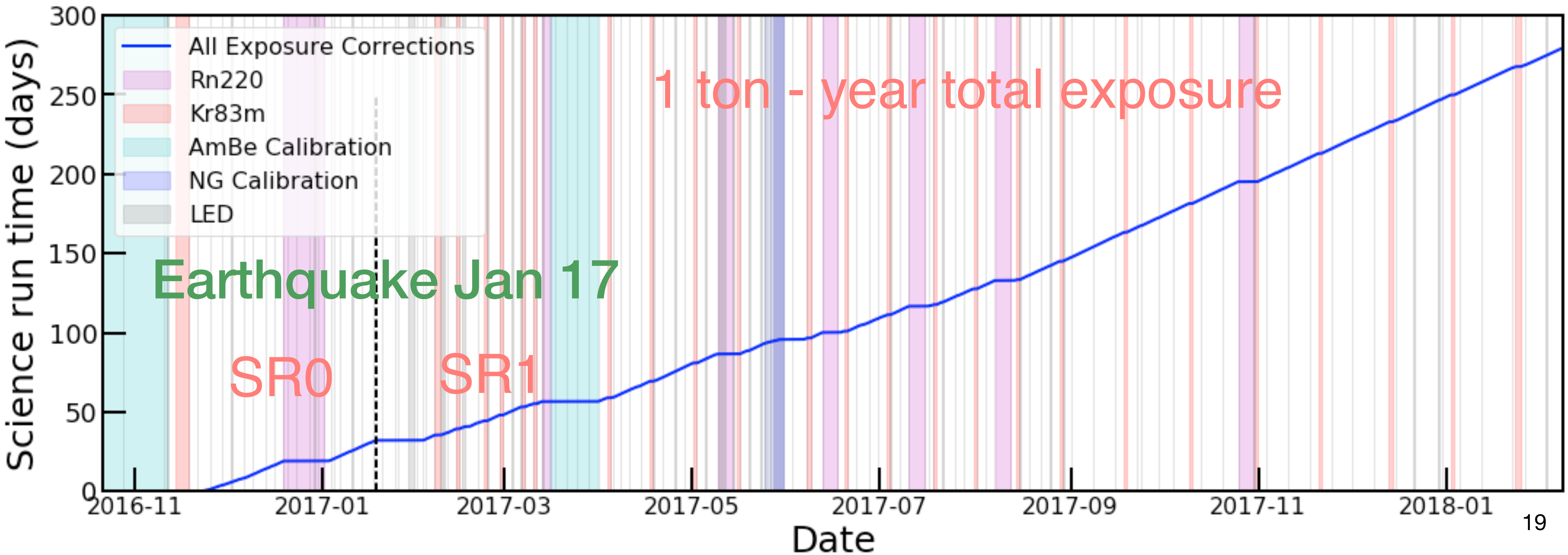
EPJ-C74, 2014



(360 ± 60) ppq

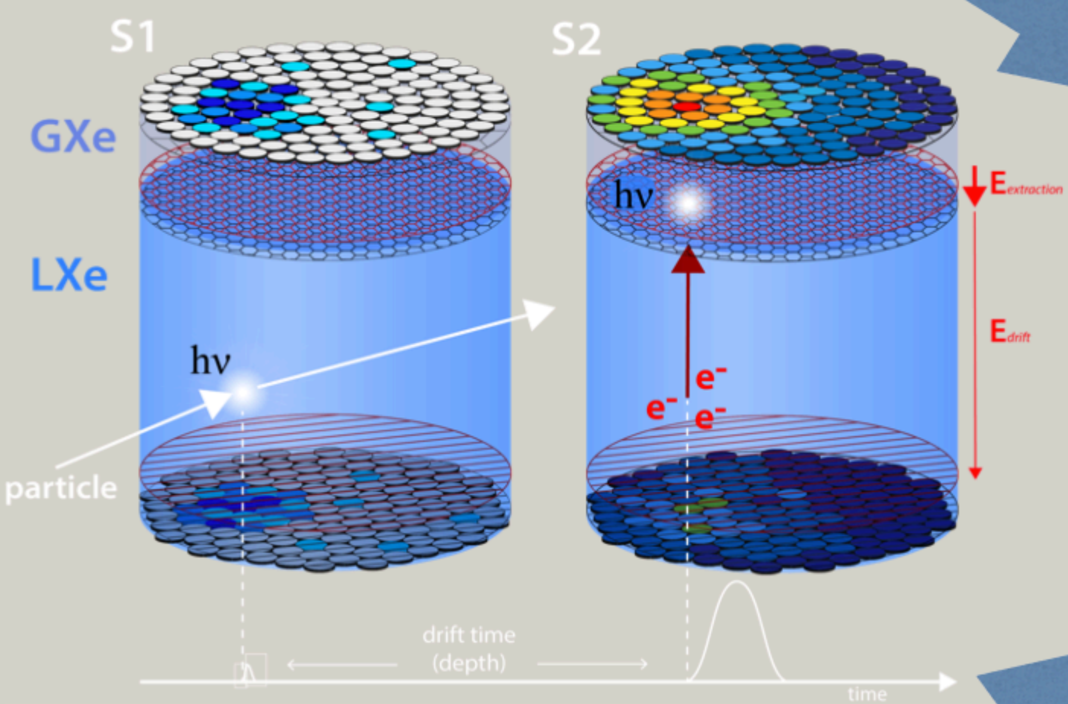
XENON1T Data overview: science and calibration

- Detector still running smoothly and taking data with high efficiency
- SR0 (34.2 days): best SI limit 7.7 x 10^{-47} cm^2 at 35 GeV/cm^2 (PRL 119, 2017)
- SR1 (246.7 days): improved detector stability - calibration statistics - refined analysis
- Total Exposure: 1 ton-year for the estimated 1.3 ton fiducial mass!



XENON1T data analysis

XENON1T
(real waveforms)



Geant4
+waveform
simulation

Raw data
Processor (PAX)

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

see talk by Kaixuan Ni on Friday

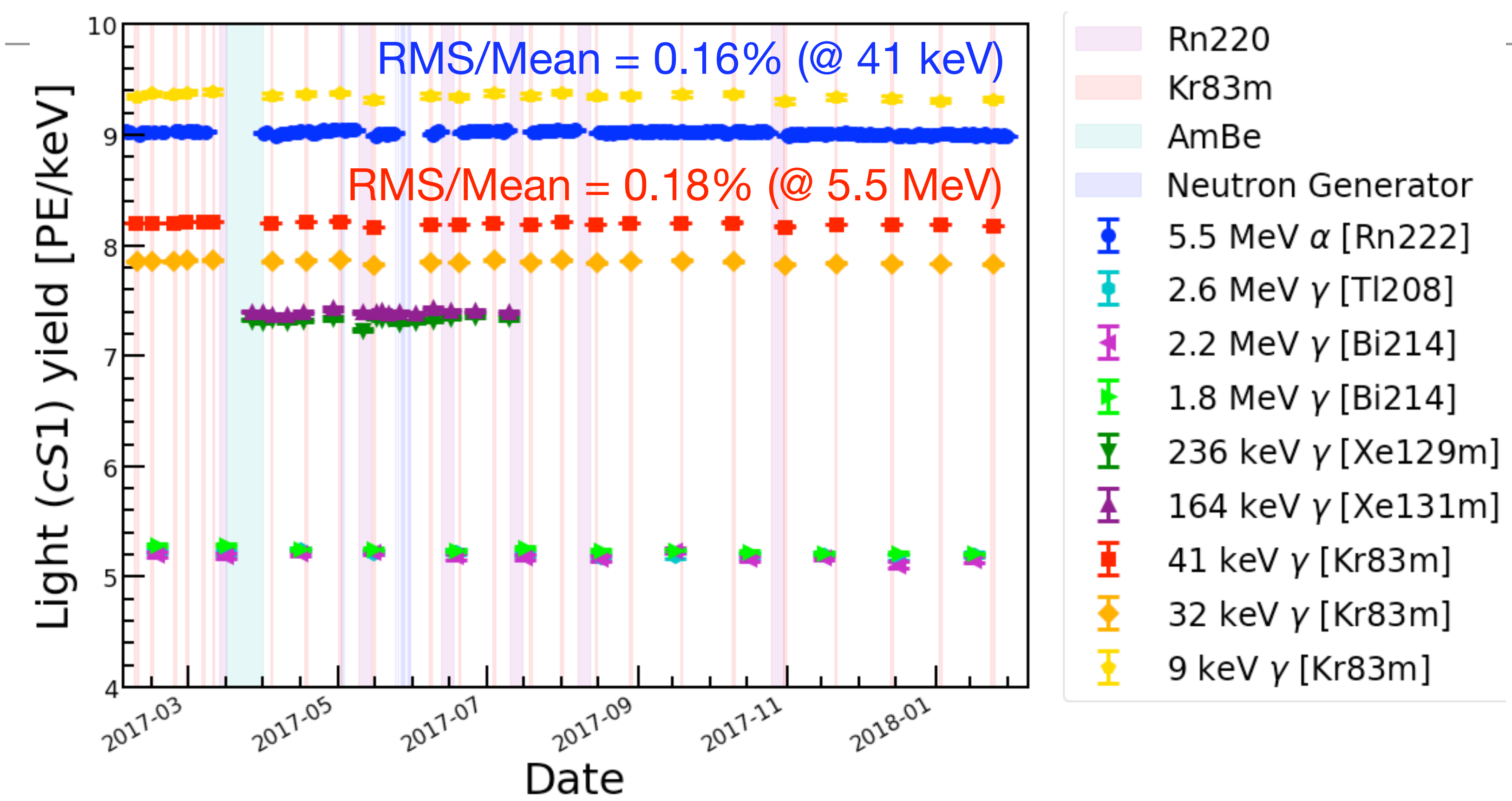
Calibration analysis

Background analysis

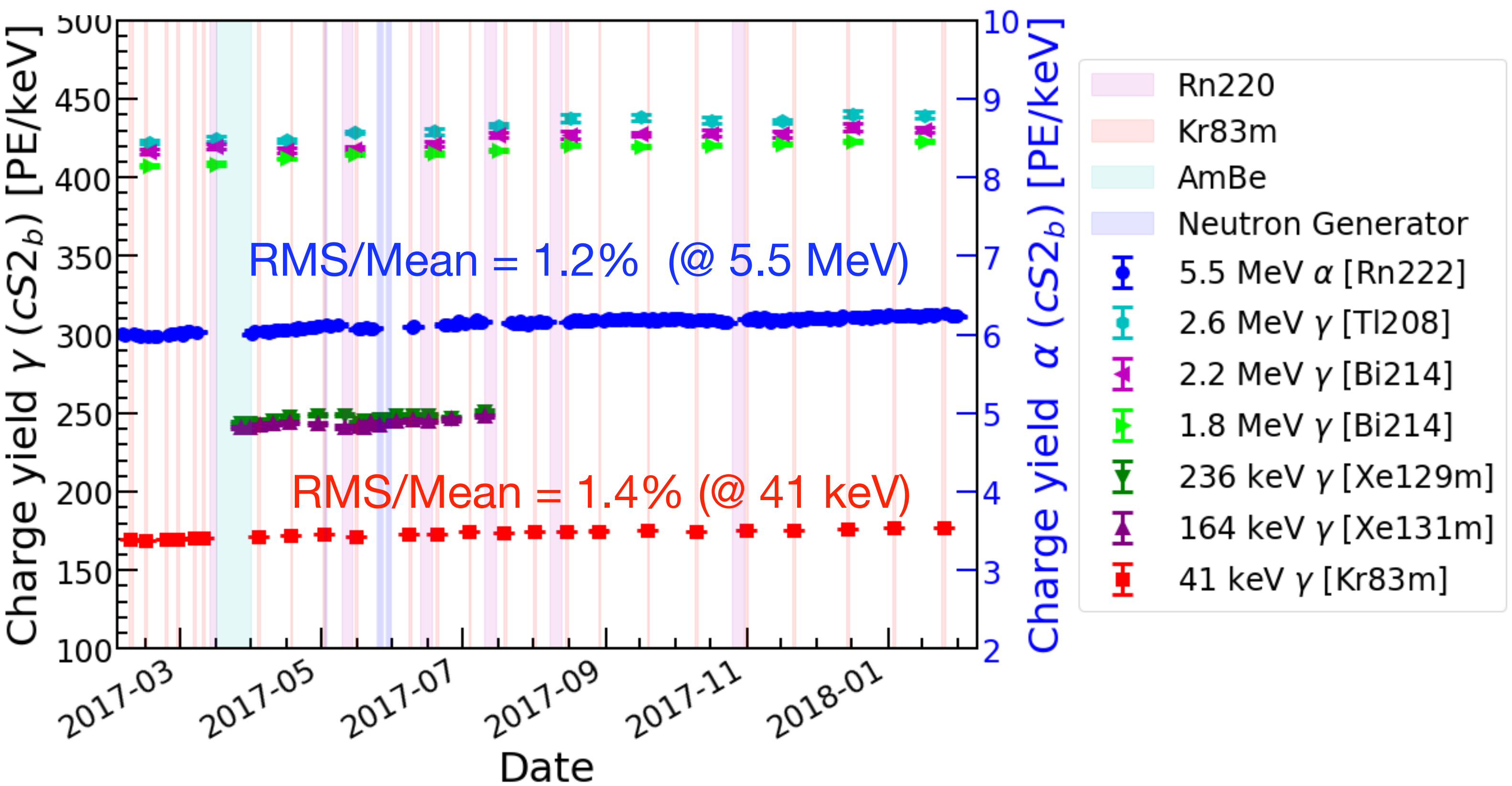
Statistical interpretation

Physics Results

Light and Charge Yields Stability

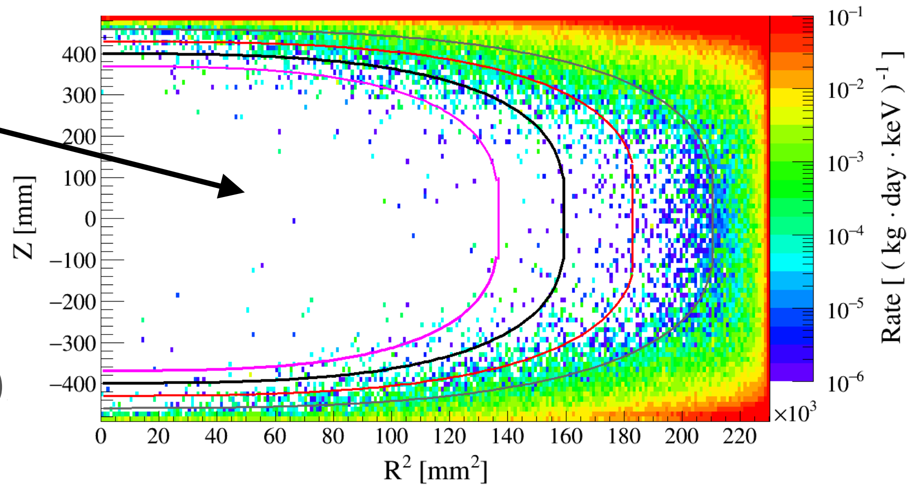


- L_y = (8.02±0.06) pe/keV @ 41.5 keV
- Q_y = (17.2± 0.2) e/keV @ 41.5 keV
- See K. Ni talk for g1/g2 measurement



ER Background: Monte Carlo

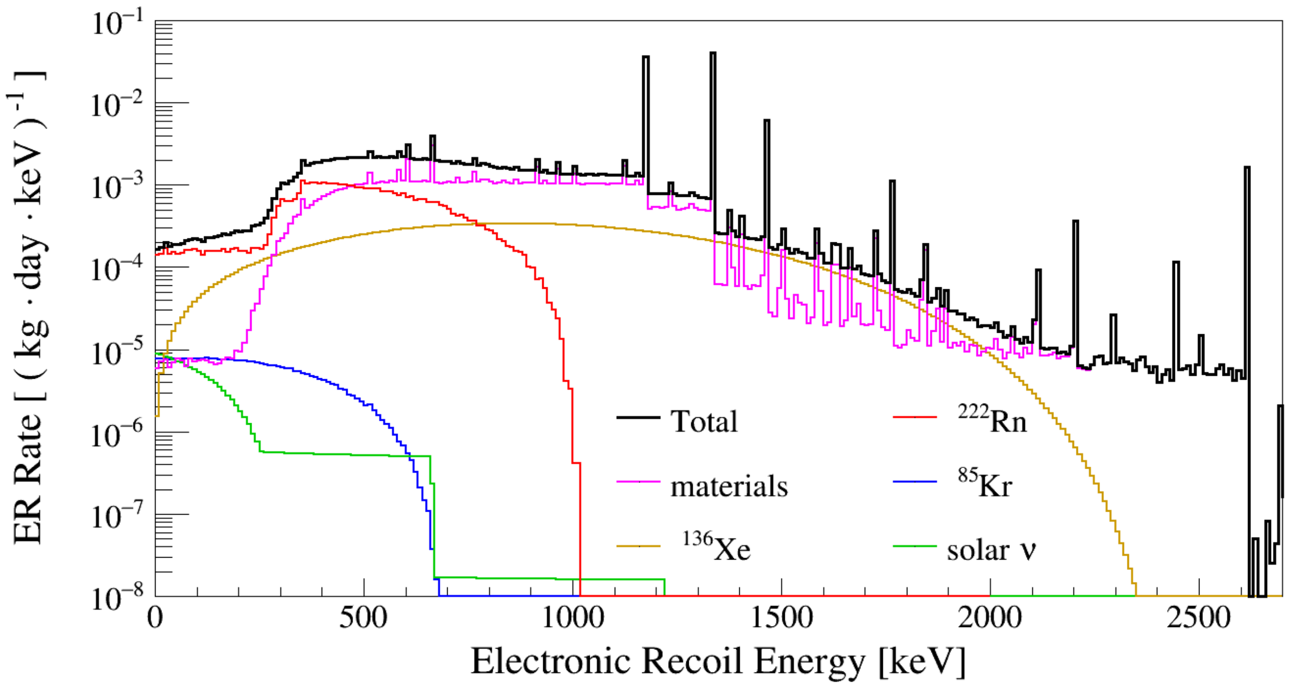
Predictions from MC simulations: ER background from materials is negligible in the 1t FV.

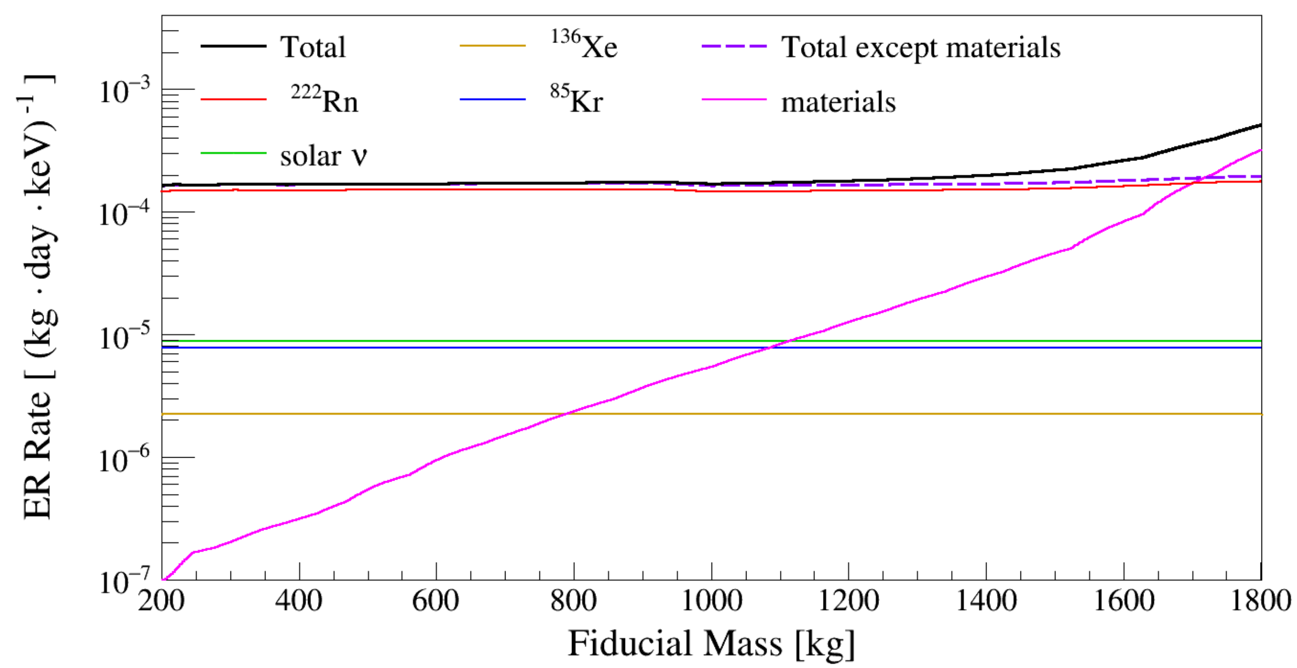


Eur. Phys. J. C77 (2017) no.5, 275 & arXiv:1702.06942

MC assumptions on the intrinsic backgrounds:

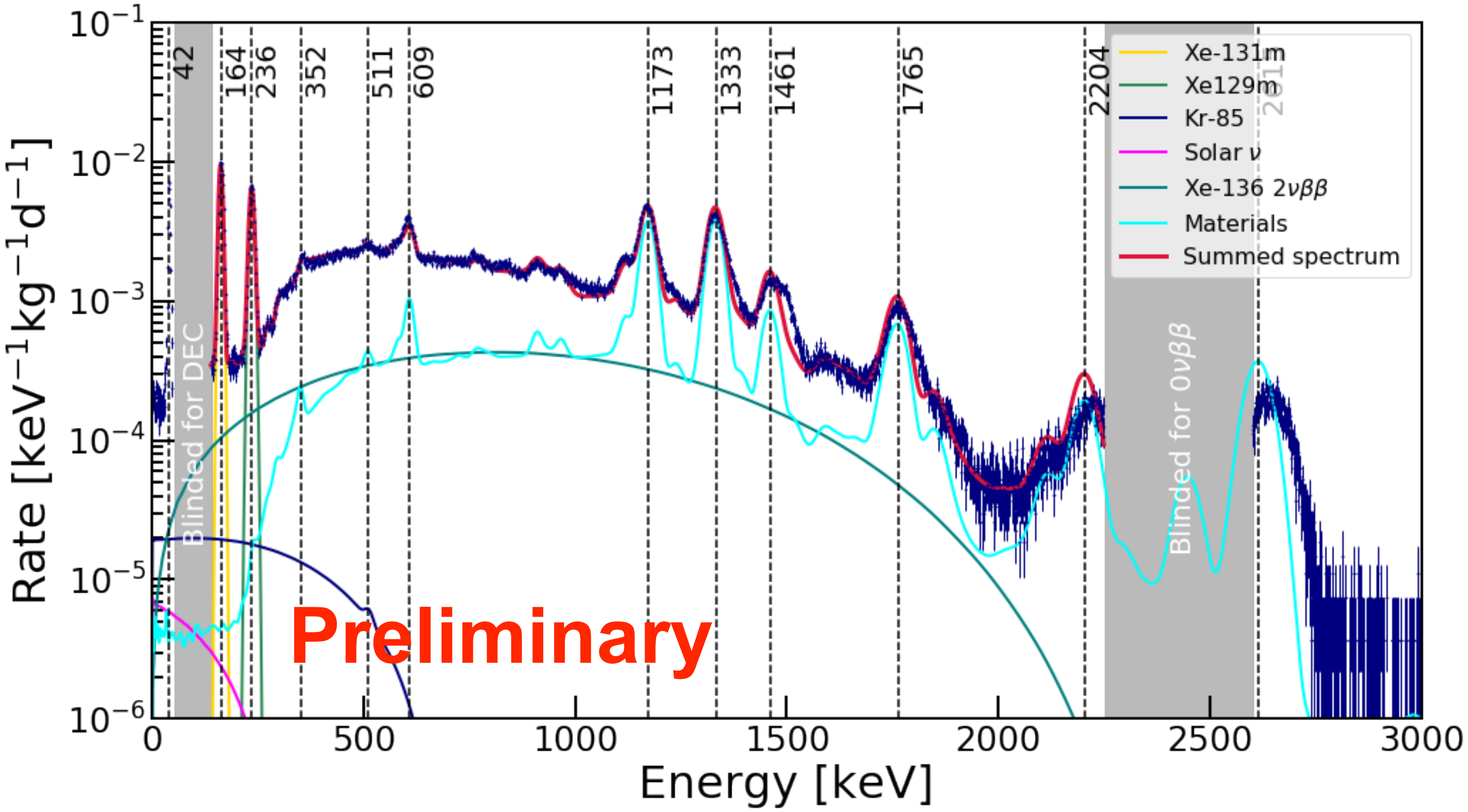
- 0.2 ppt of ^{nat}Kr (achieved in XENON1T distillation column tests),
- 10 μBq/kg of ^{222}Rn (estimation based on Rn emanation measurements)





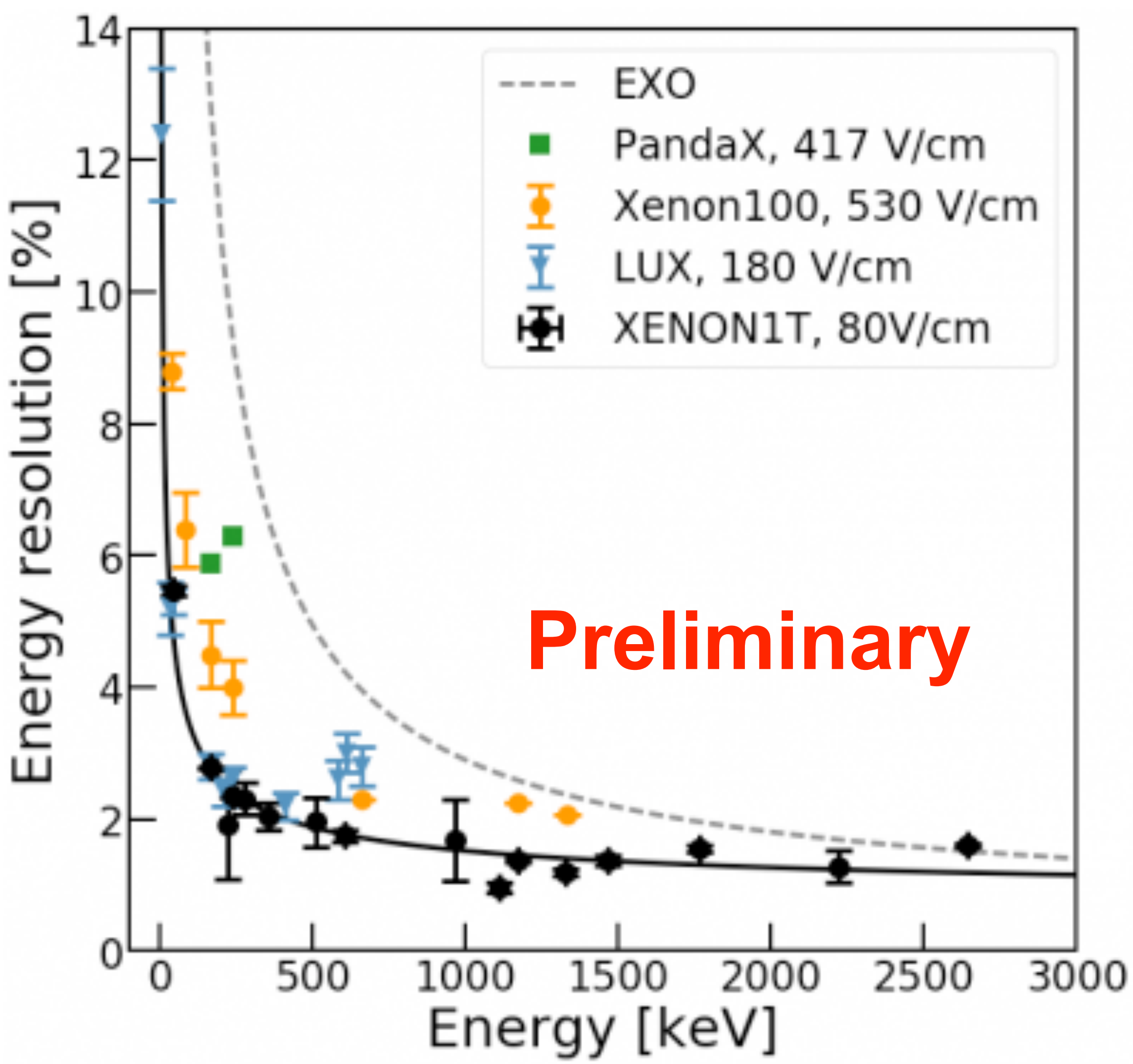
^{222}Rn (mainly from ^{214}Pb β-decay) is the most relevant source of ER background in most of the TPC.

Background Data: Energy Spectrum and Energy Resolution



- Excellent energy resolution measured with a large LXeTPC

- Background

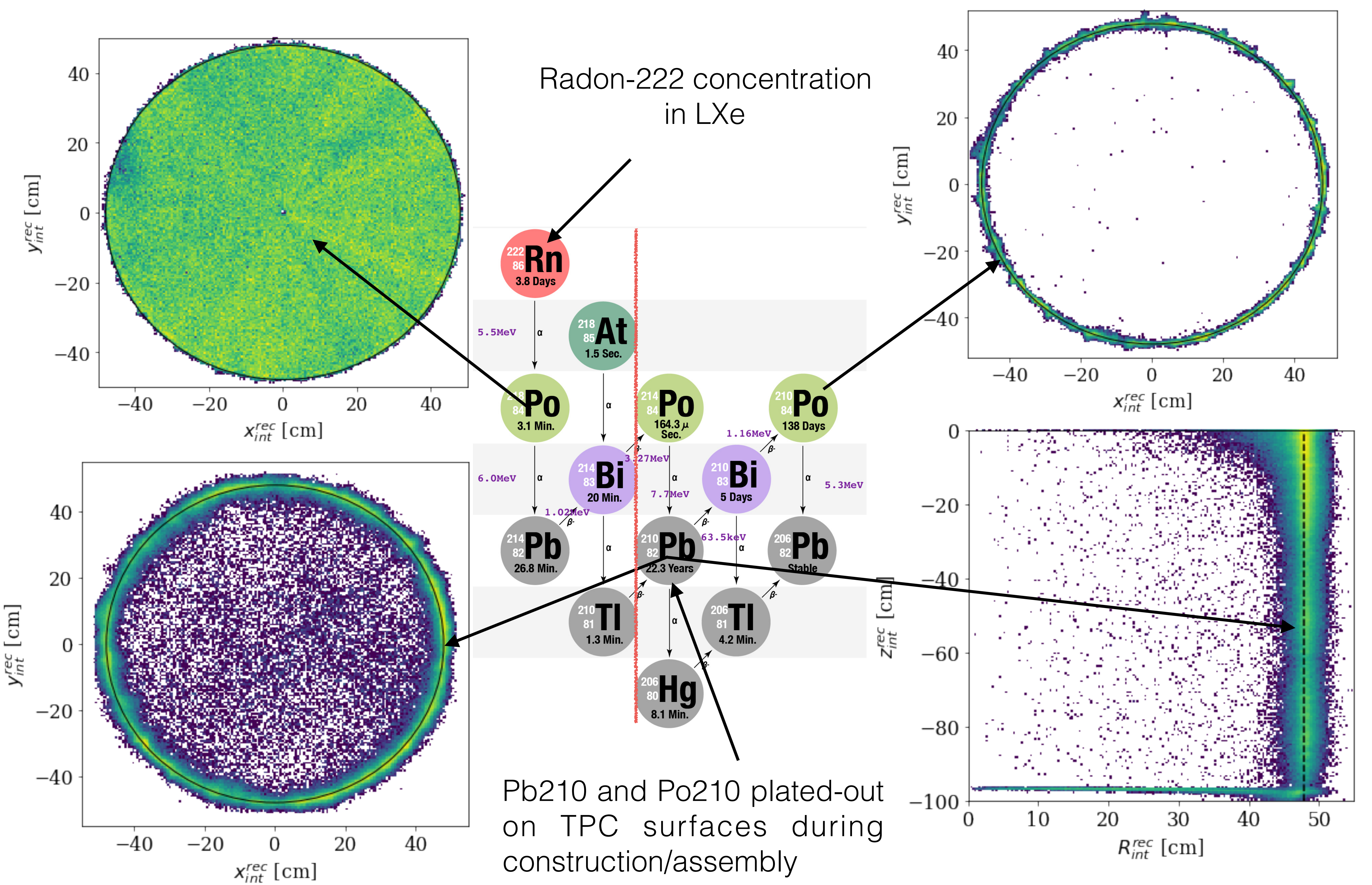


- Good agreement between predicted and measured background spectrum

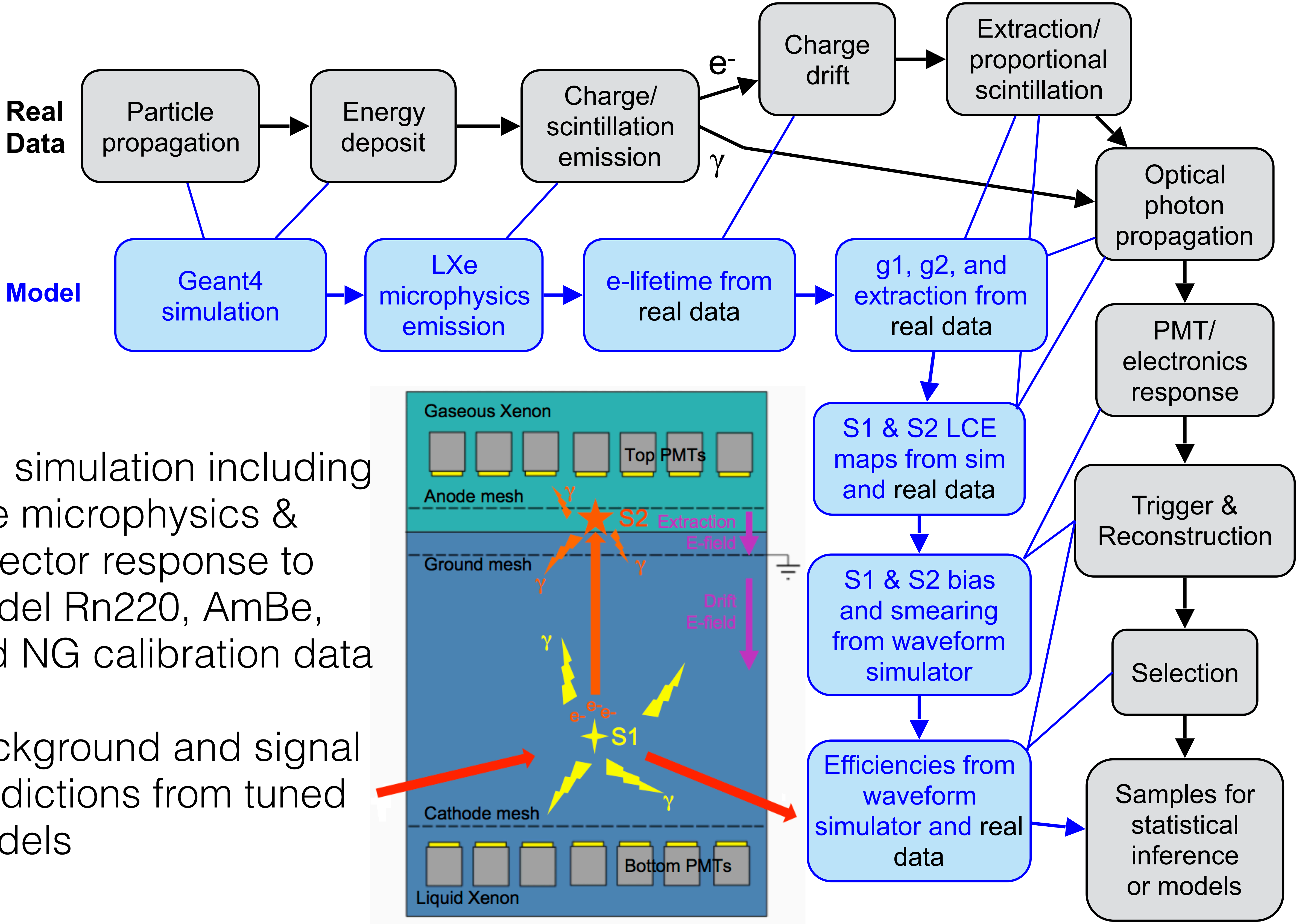
- Kr: ~0.45 ppt; Pb214: ~ 10 uBq/kg

- Gammas based on screening measurements

Seeing Rn-222 decay chain in the XENON1T TPC



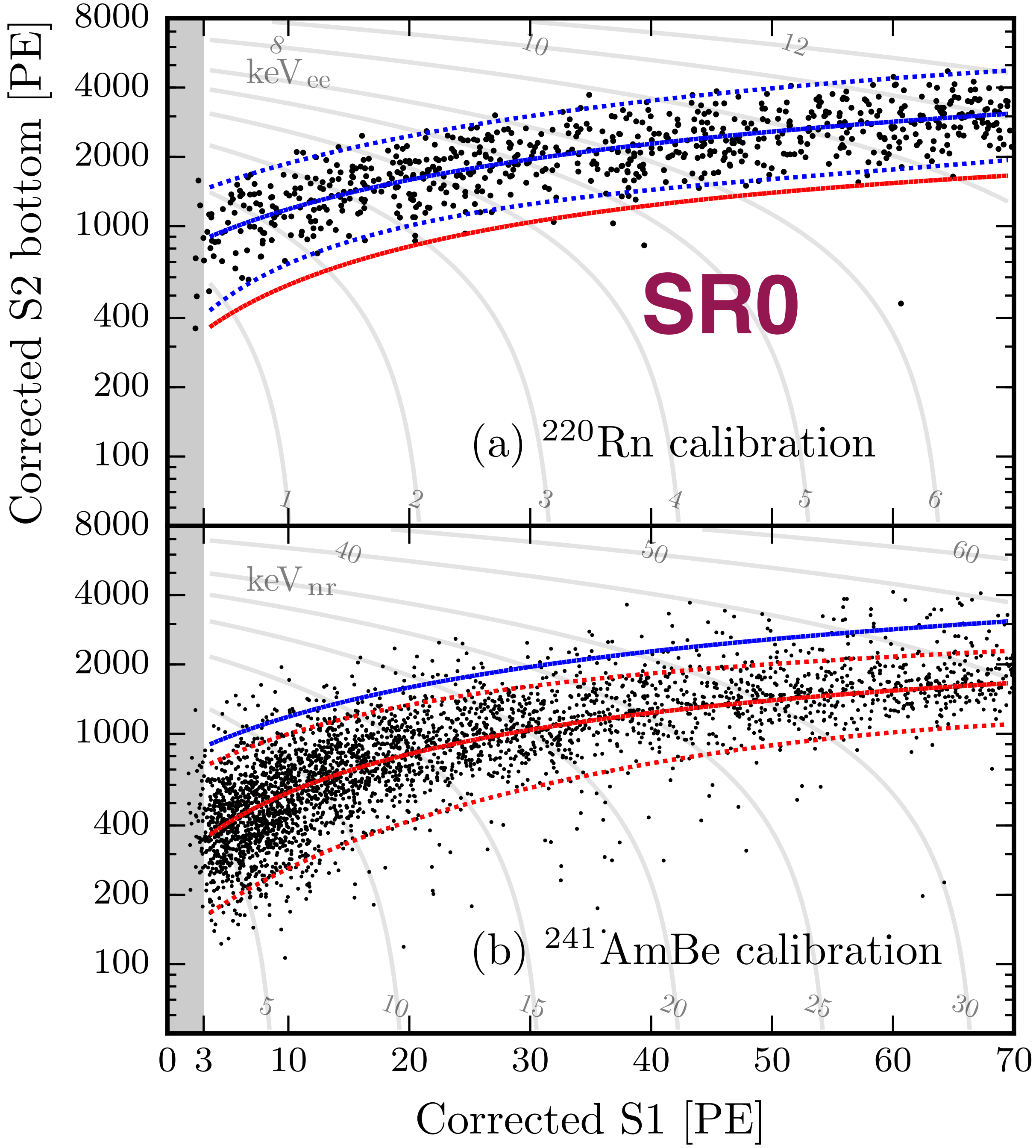
The ER and NR Models

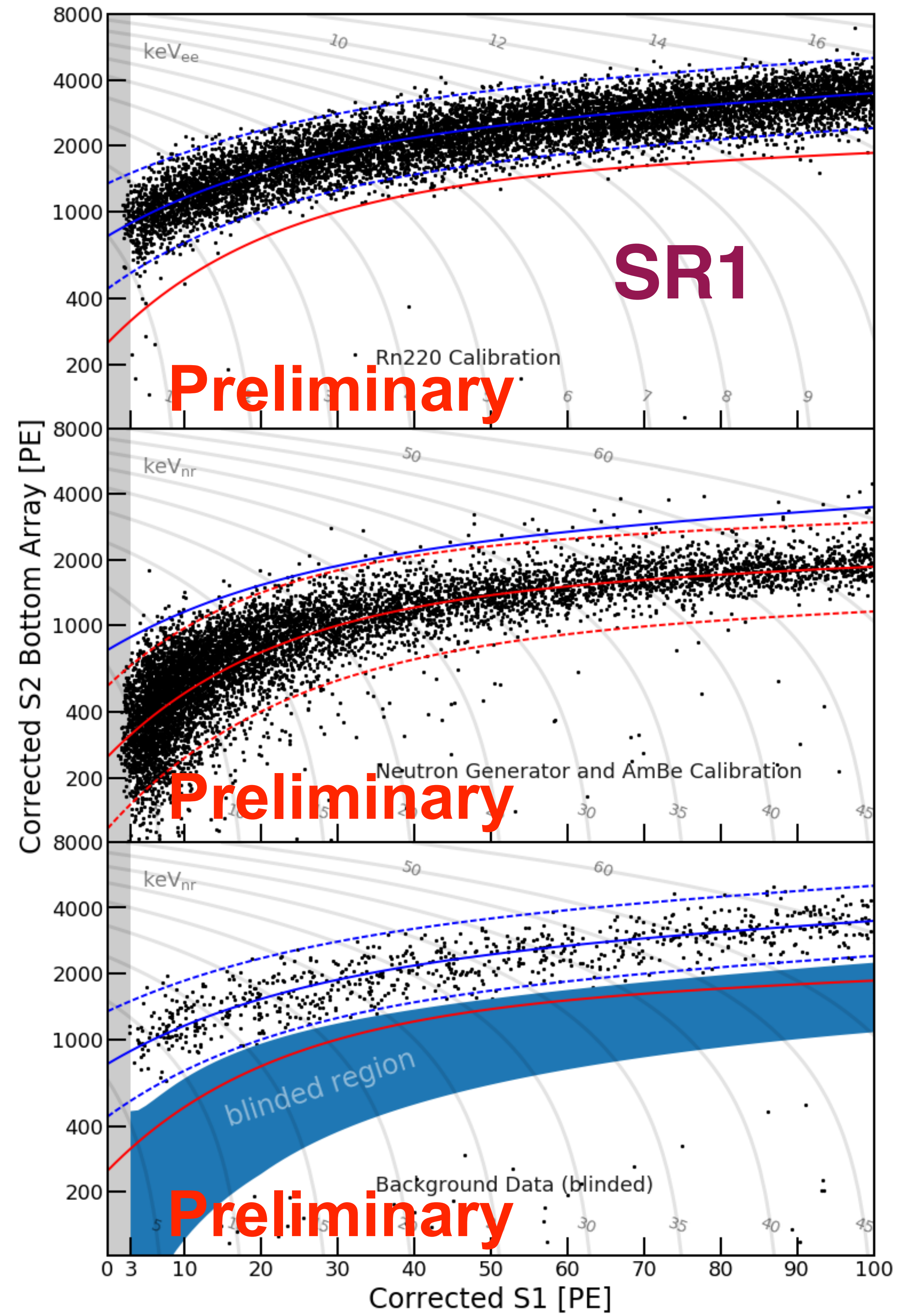


- Full simulation including LXe microphysics & detector response to model Rn220, AmBe, and NG calibration data
- Background and signal predictions from tuned models

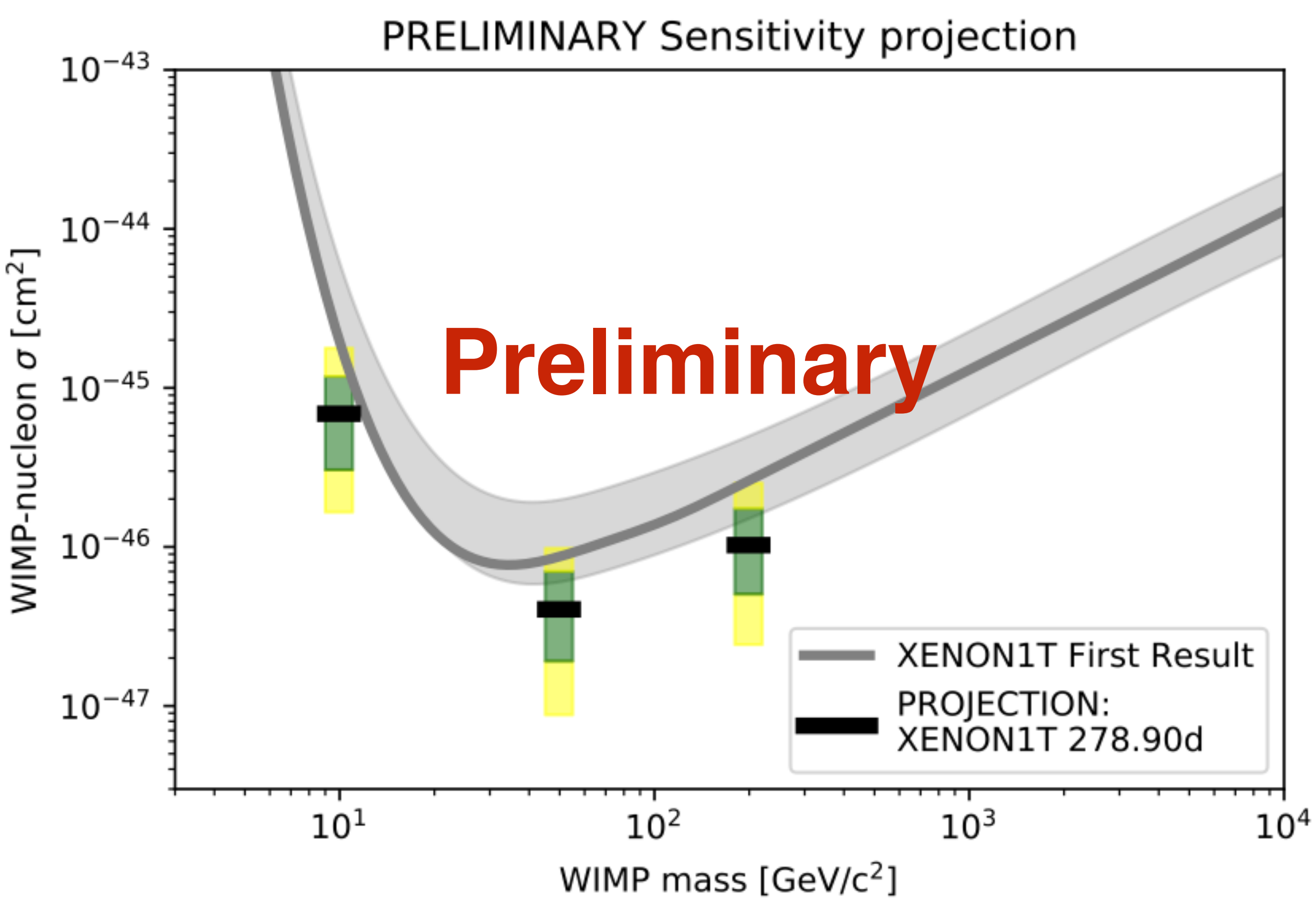
Improved calibration statistics in SR1

Blue: ER, Red: NR; —— : median, ····· : ±2σ

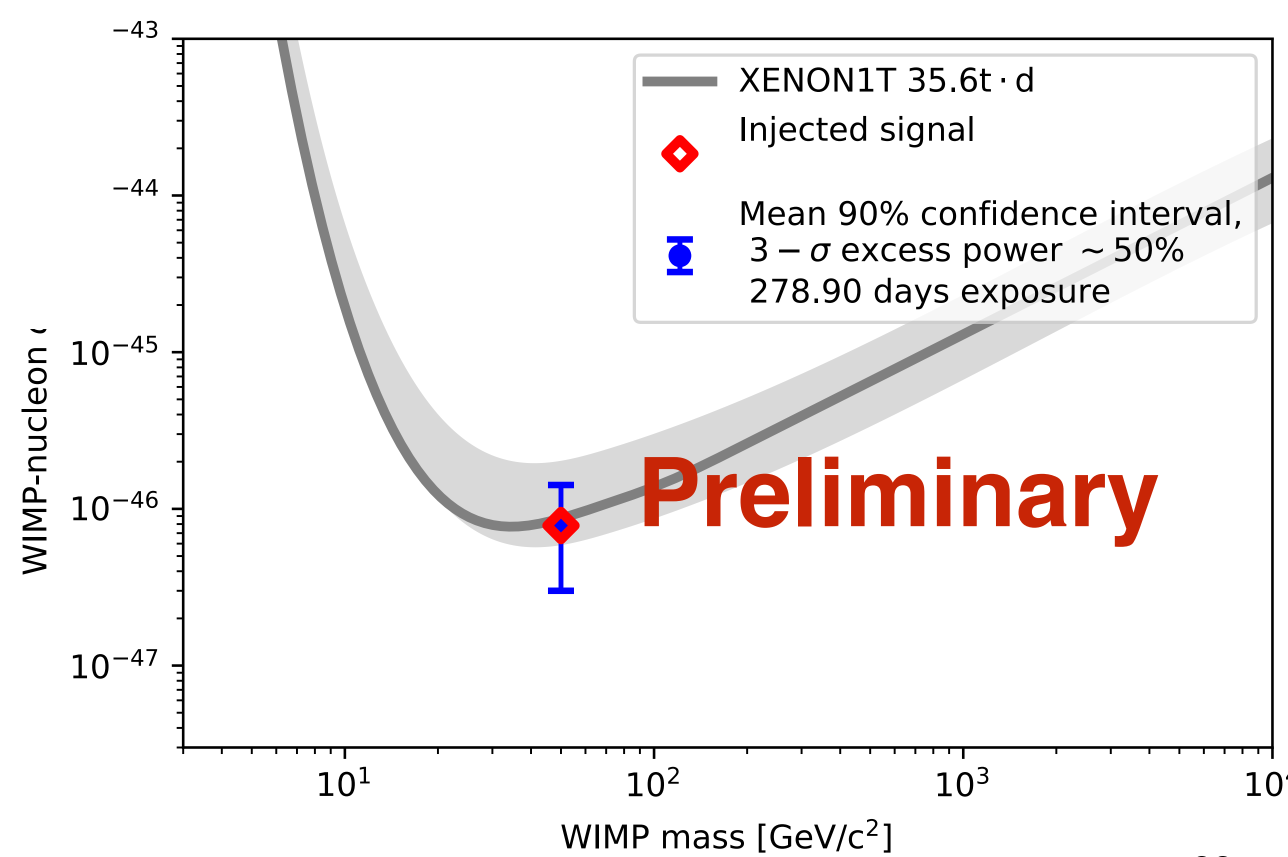




Sensitivity and Discovery Potential

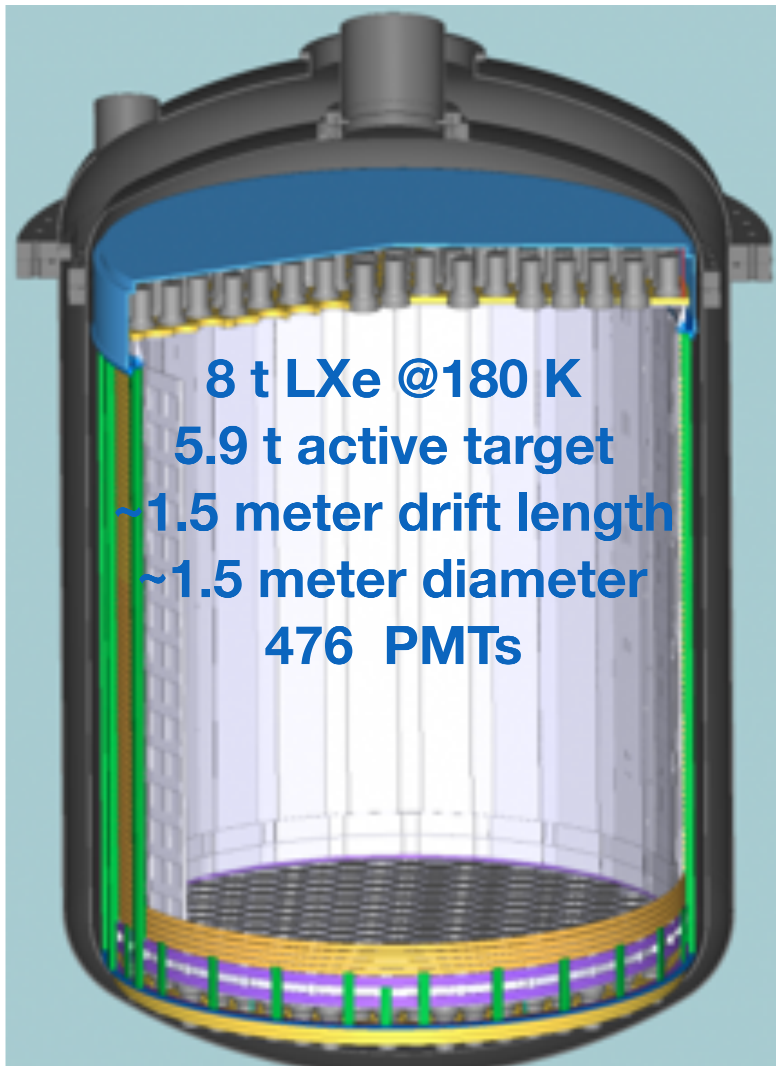


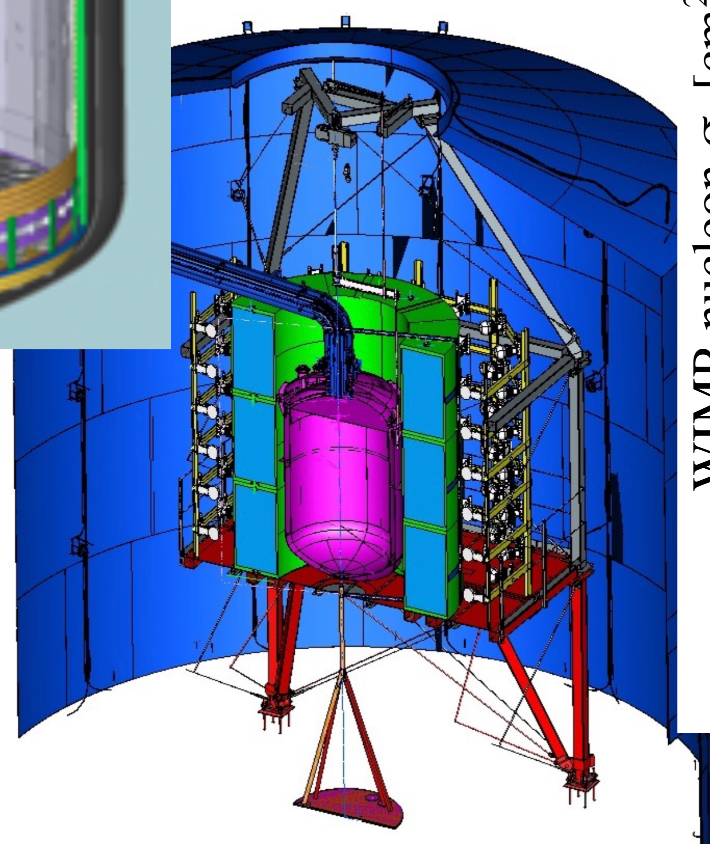
- Given injected signal with cross-section right below our first-results limit, the chance to see a 3-sigma excess in full exposure is ~ 50%



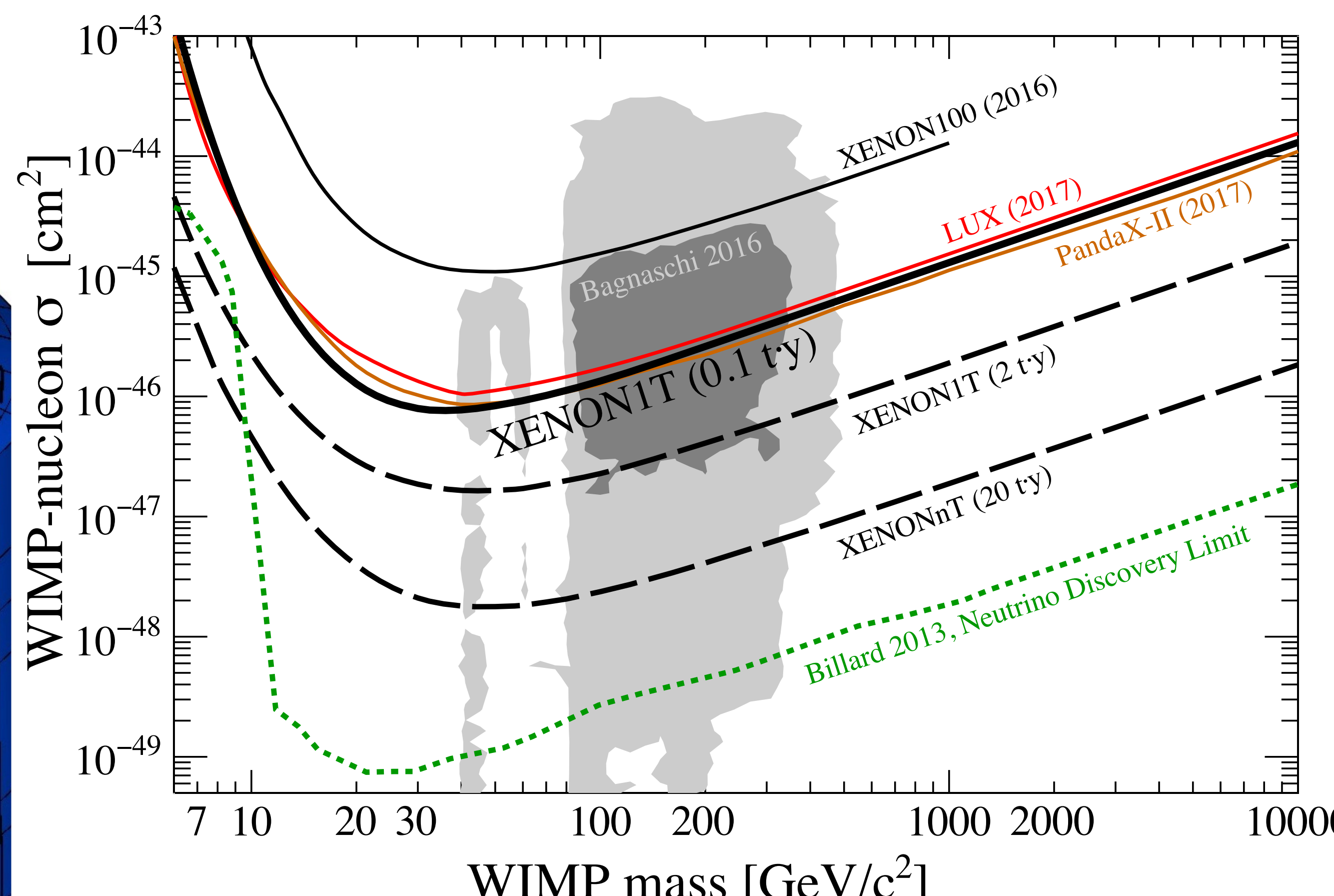
- Expected sensitivity at 3 typical WIMPs masses: 10, 50, 200 GeV
- A factor of 2-3 median sensitivity increase compared to First-Results

Next step: XENONnT to start in 2019





- A rapid upgrade to XENON1T, with a new TPC with 4 x target mass than XENON1T
- Most sub-systems, already operative, designed with this upgrade in mind
- Main challenge: reduce Radon by x 10



Summary

- XENON1T is the first LXeTPC dark matter at the multi-ton scale in operation.
- First result with 34 live days yielded the most stringent limit on SI WIMP cross section.
- Detector has continued to work incredibly well after the break forced by an earthquake.
- 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)
- Collected ~ 1 ton x year dark matter data and large calibration statistics.
  - Data still blinded. Expect world-leading result in March 2018.
  - > 50% chance for a 3 sigma signal if WIMP cross-section at current limit!
- XENON1T continues to take data until we upgrade it to XENONnT. Installation of the new TPC (~6 t Xe target) before end of 2018. See Luca Grandi’s talk.