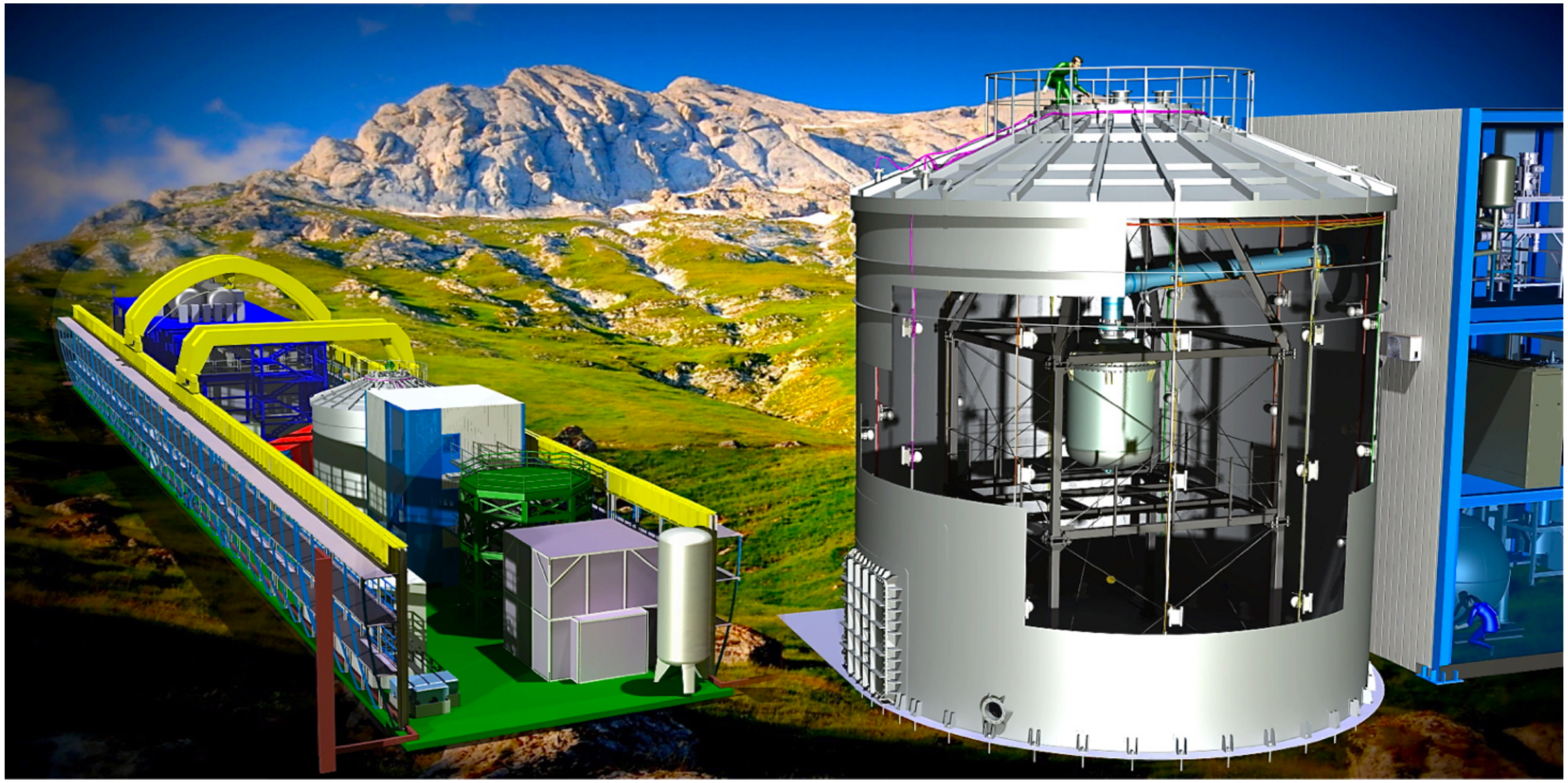
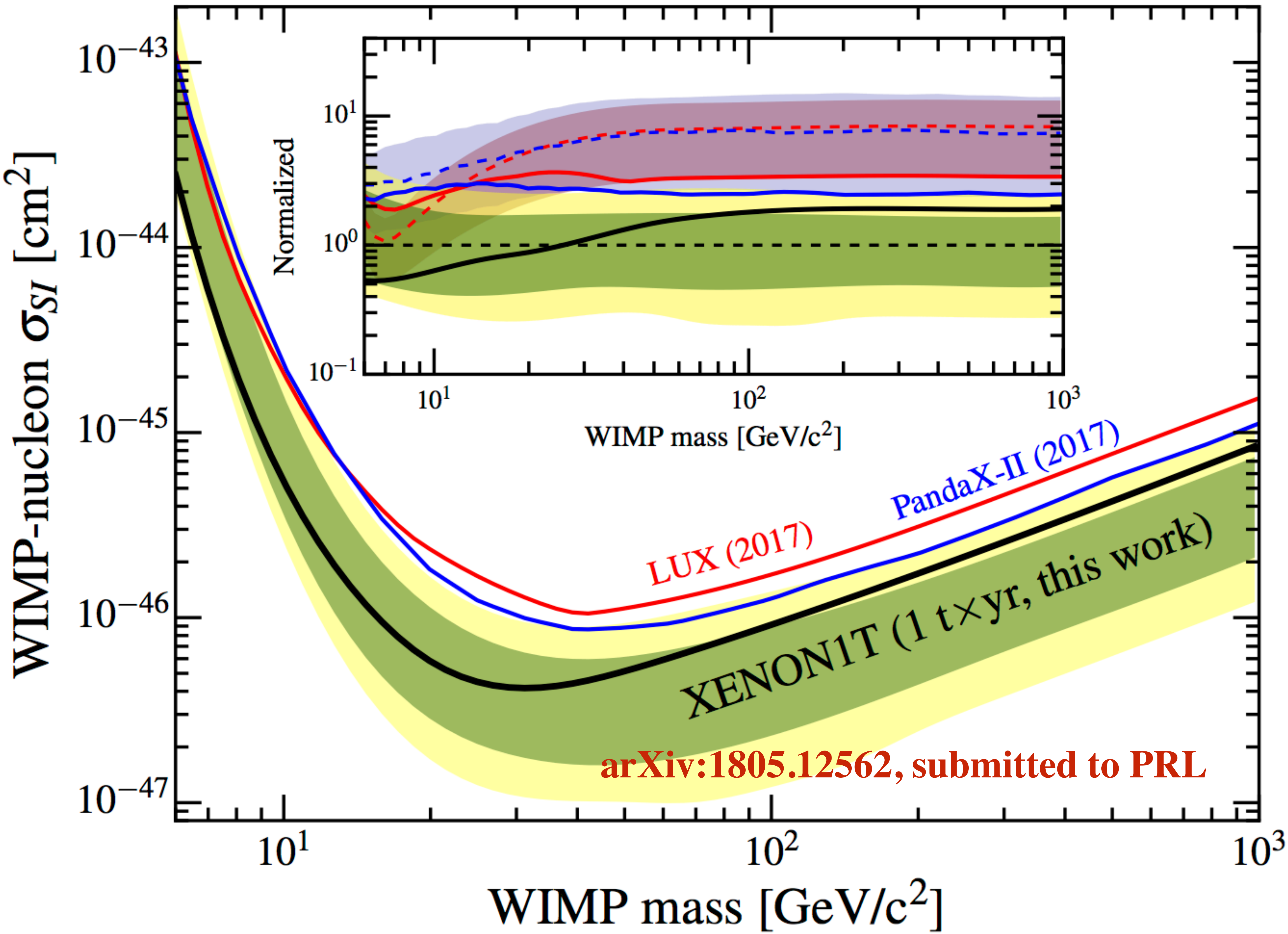
Status and Results of the XENON1T Dark Matter Search



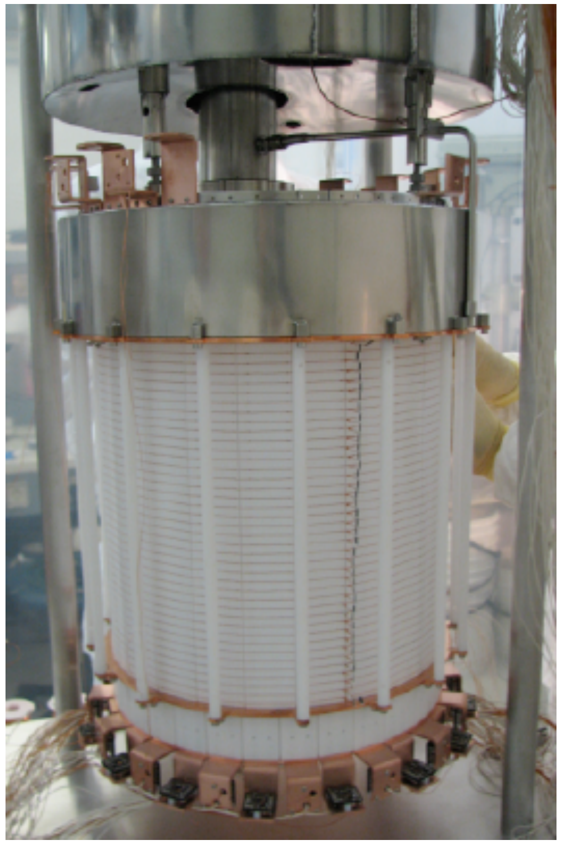
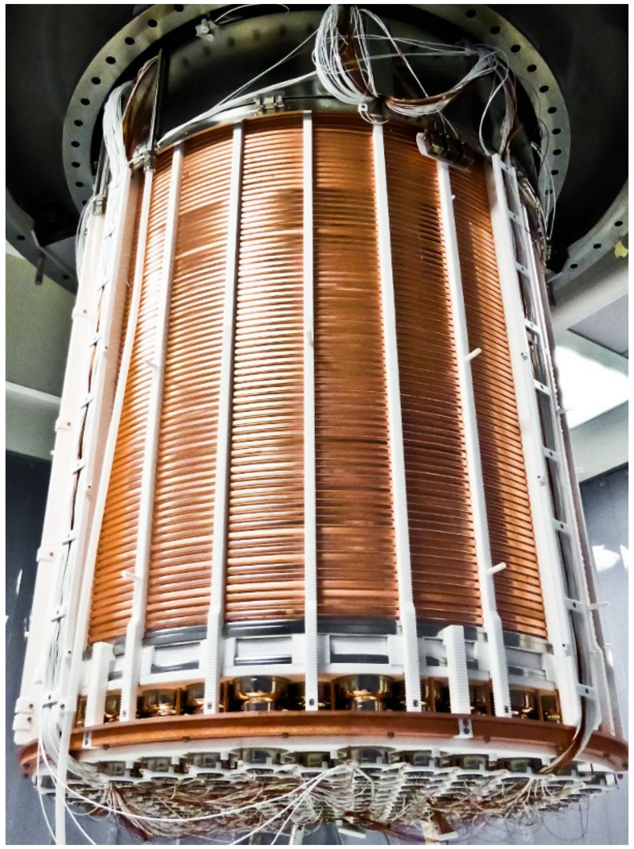
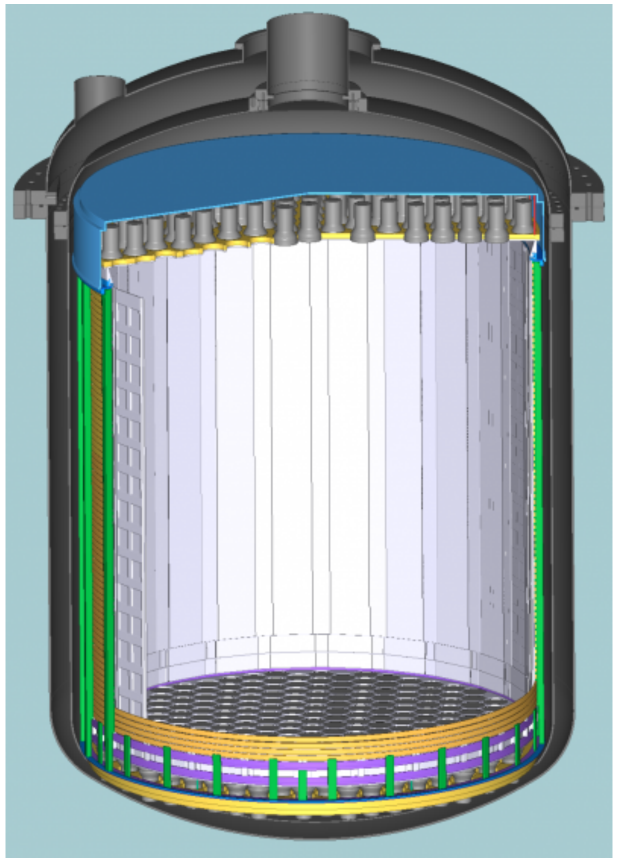
Kaixuan Ni
University of California, San Diego
(On behalf of the XENON Collaboration)

NDM2018, IBS, Daejeon, Korea, 2018.6.29-7.4

XENON1T New Results: the most stringent SI limits for WIMP masses above 6 GeV

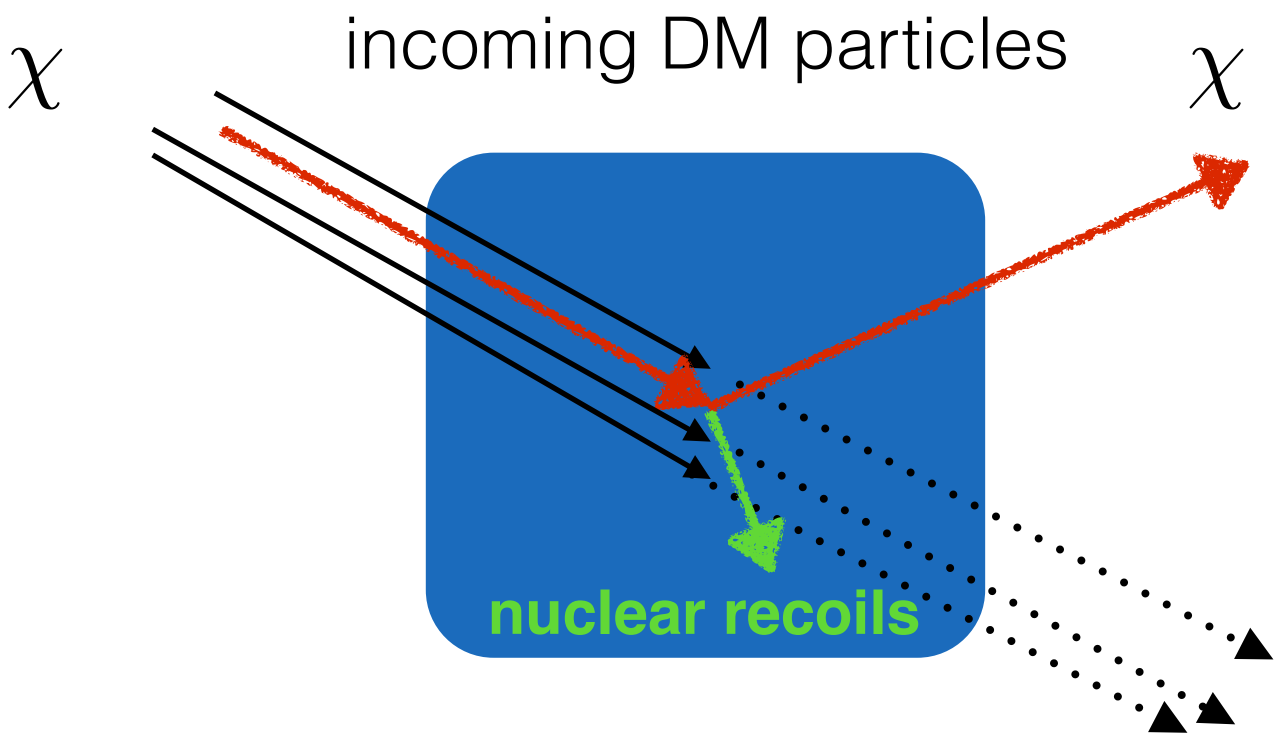


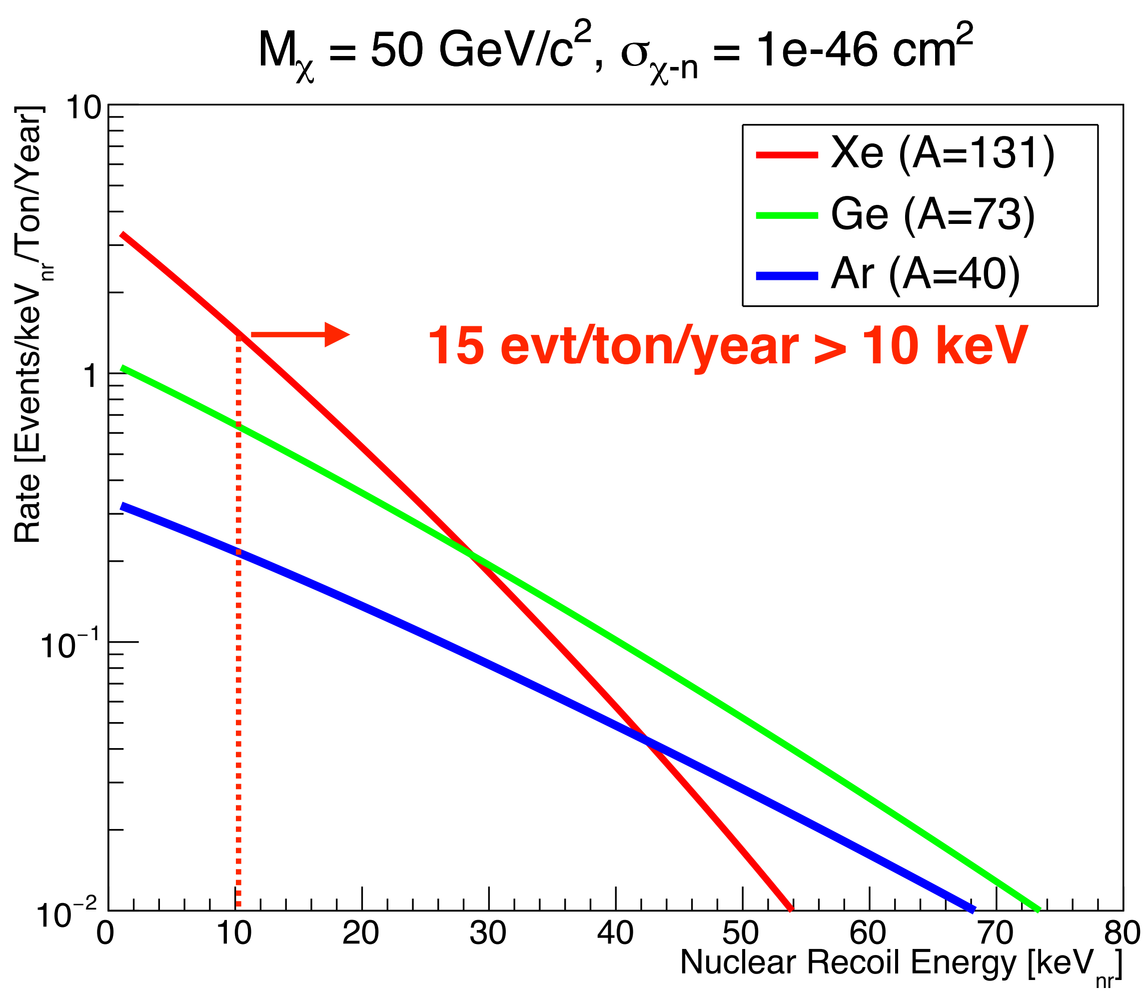
The XENON Dark Matter Search Program

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

The Scientific Goals of the XENON Program





- **Primary goal**: detecting nuclear recoils from elastic scattering of GeV~TeV scale WIMPs through both SI and SD interactions
- **Other DM channels:**
  - low-mass (GeV-scale) DM through "ionization-only" approach
  - sub-GeV DM via electron scattering
  - axion, ALPs, dark photons etc.
- **Other rare event searches:**
  - 0vbb, DEC
  - solar and supernova neutrinos, etc.

The XENON Collaboration: ~165 scientists

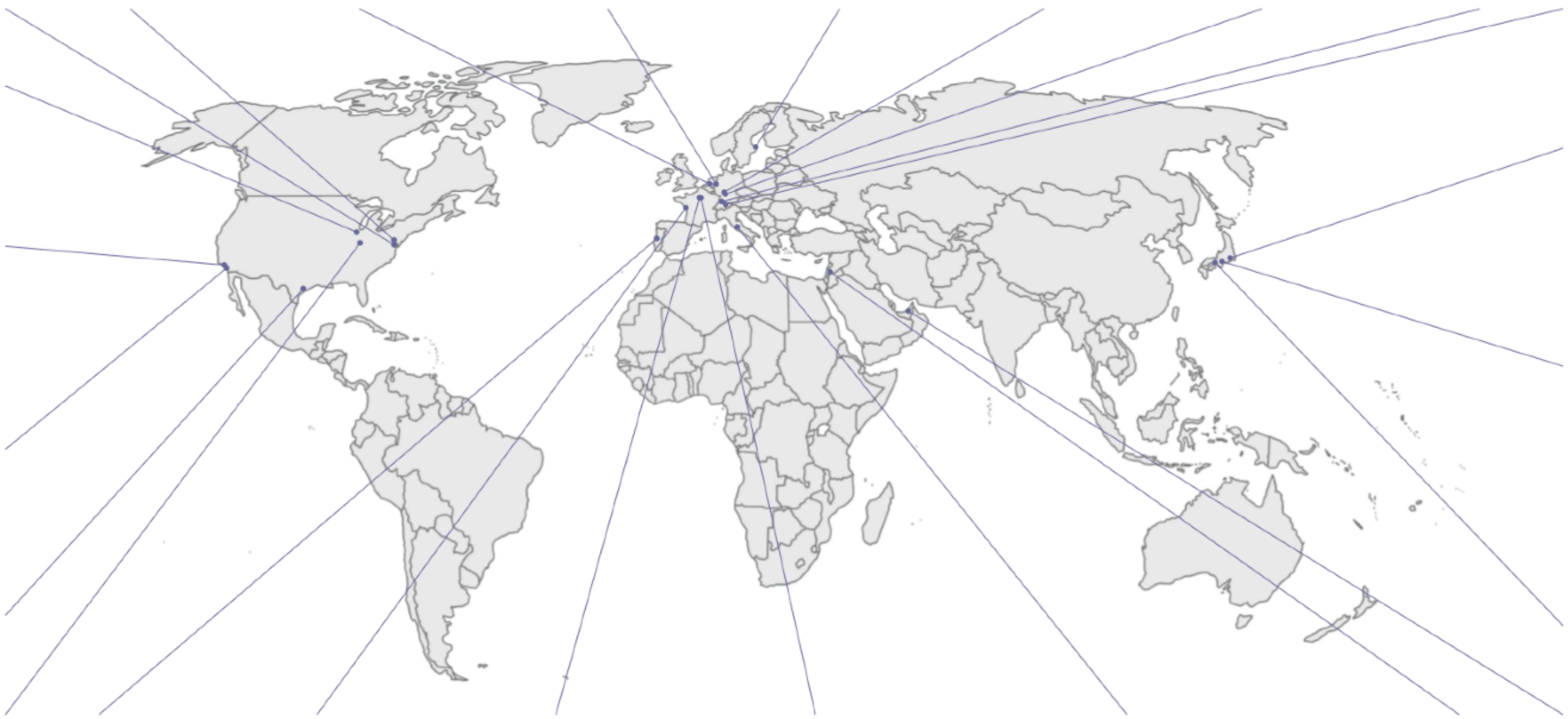
Columbia | RPI | Nikhef | Muenster | Stockholm | Mainz | MPIK | Freiburg | Zurich

Chicago

UCLA

UCSD

Rice

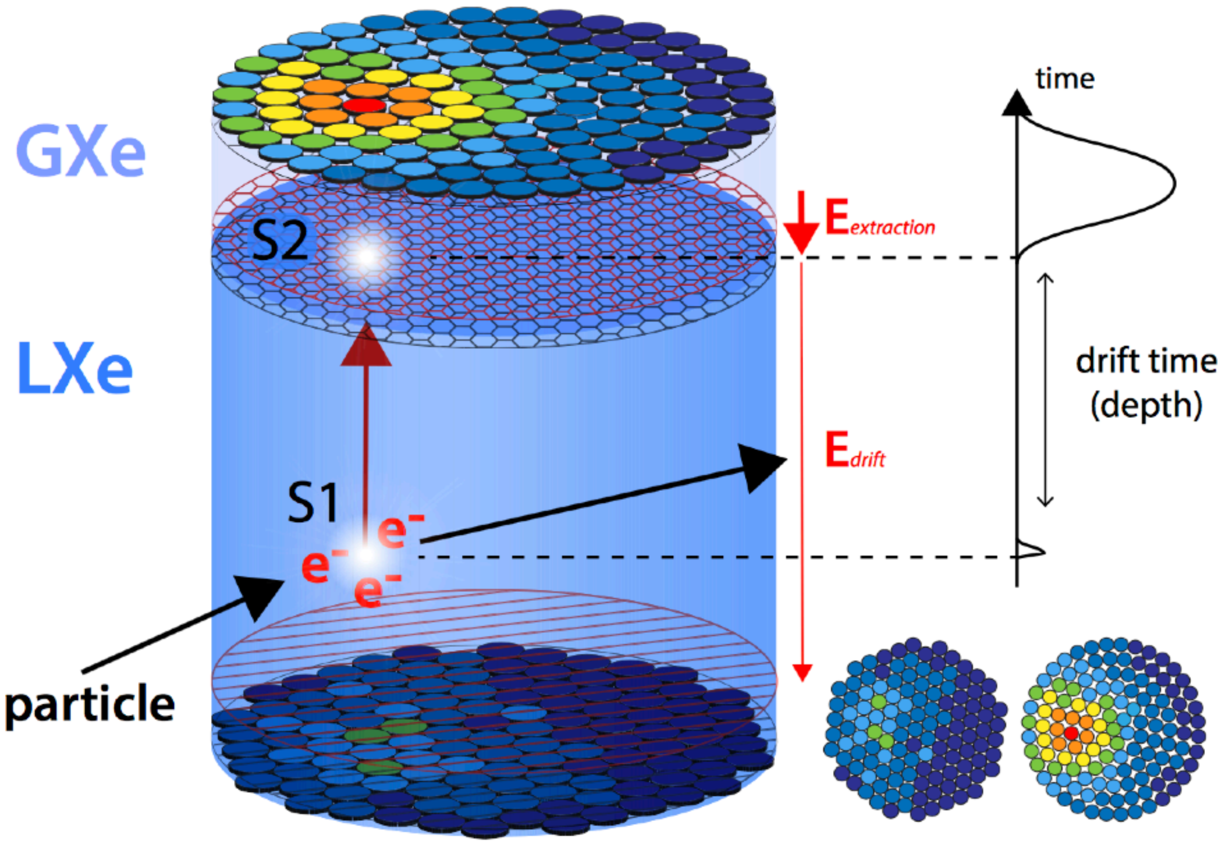


Tokyo

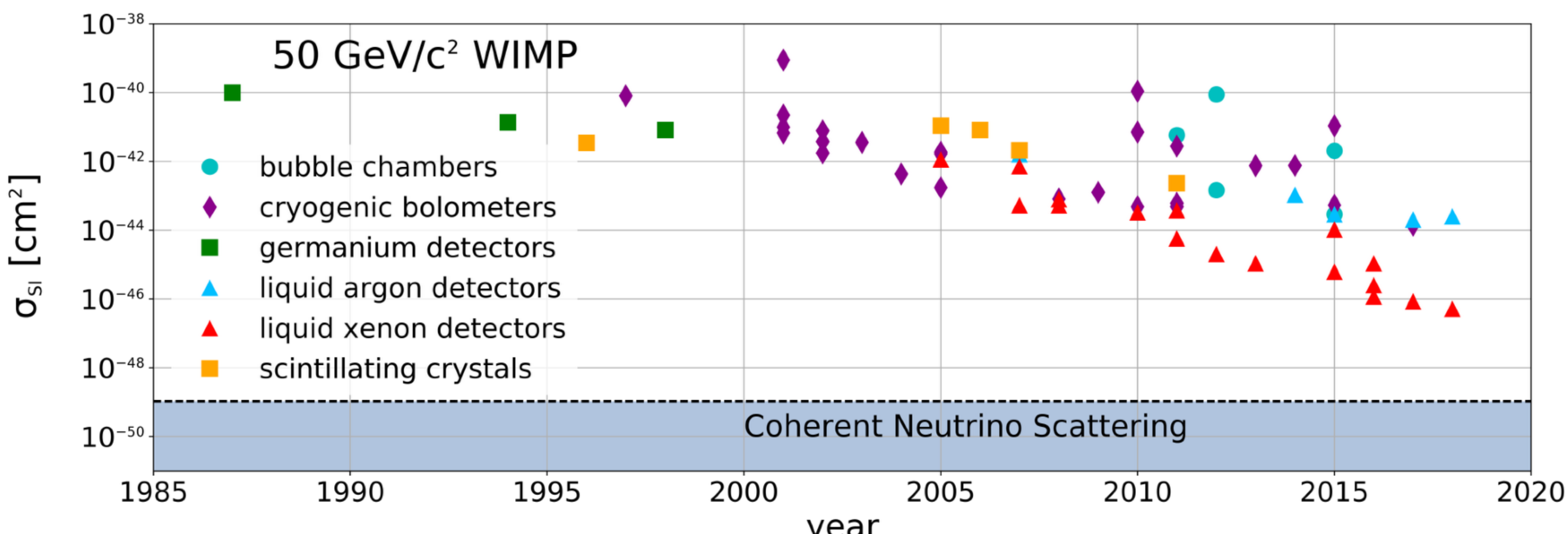
Nagoya

Kobe

Two-phase Xenon Time Projection Chamber for dark matter searches



- ✦ *Two signals for each event:*
  - ✦ *Energy from S1 and S2 area*
  - ✦ *3D event imaging: x-y (S2) and z (drift time)*
  - ✦ *self-shielding, surface event rejection, single vs multiple scatter events*
- ✦ *Recoil type discrimination from ratio of charge (S2) to light (S1)*

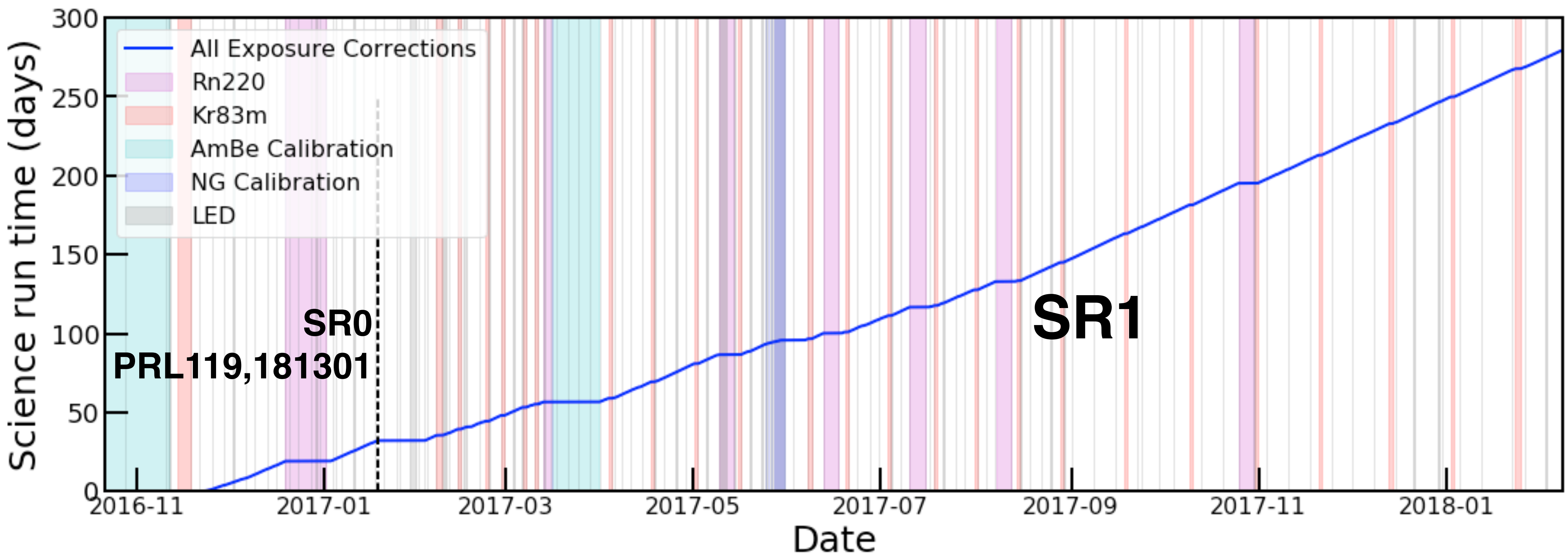


The XENON1T Time Projection Chamber

The XENON1T Dark Matter Experiment at Gran Sasso

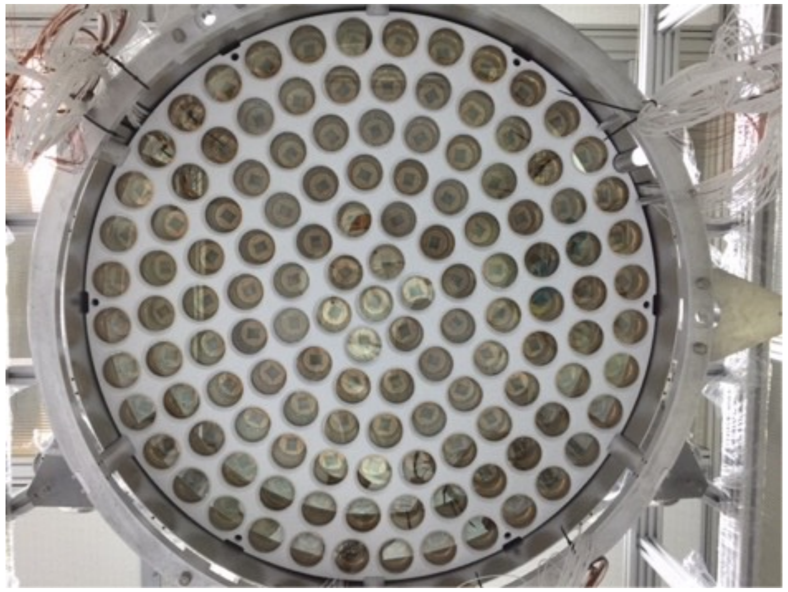
XENON1T Data taking

- 279 live-days DM data collected between Nov. 2016 and Feb. 2018.
- The detector is still running and more data are collected after Feb.2018



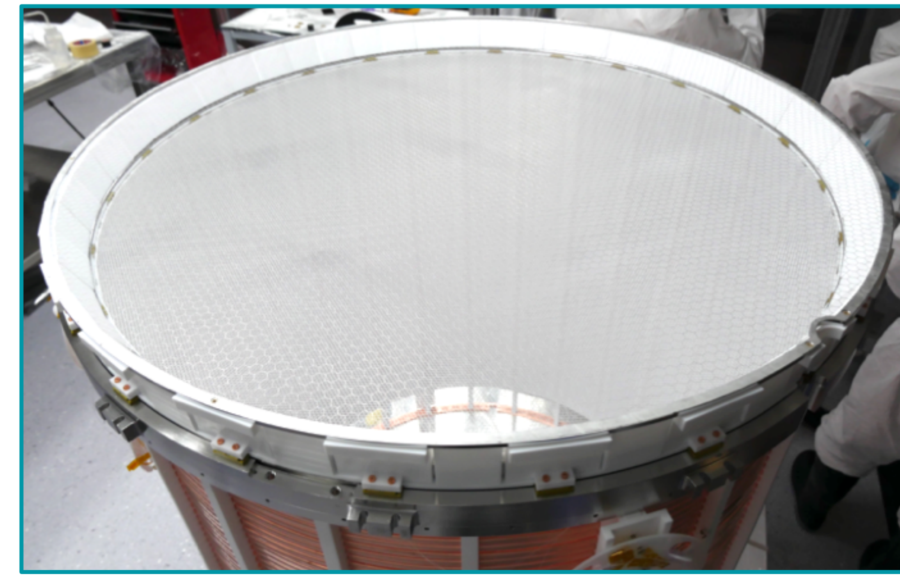
SR0+SR1 combined DM search released: arXiv:1805.12562

The XENON1T Light Detection System

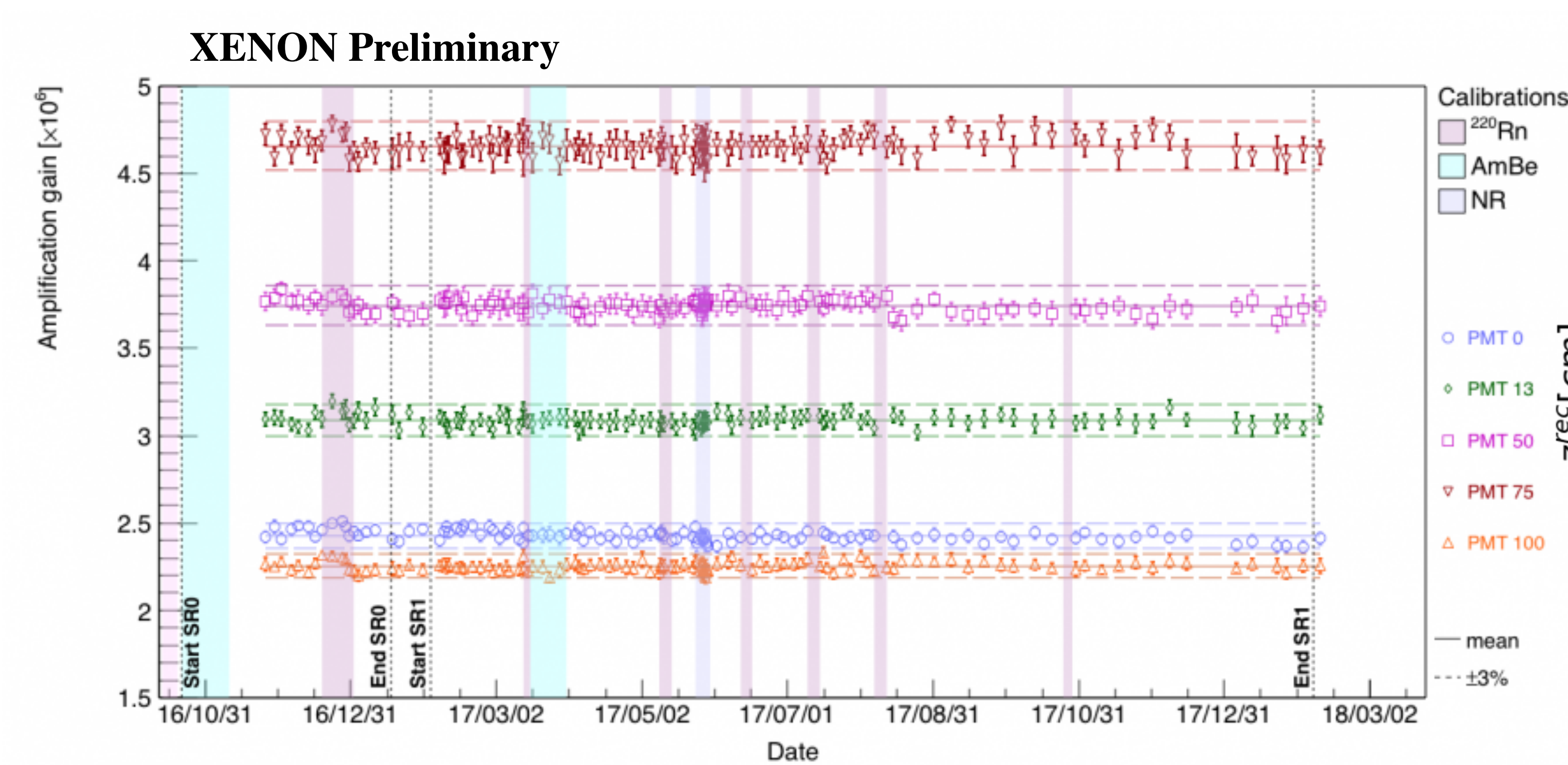


127 PMTs in the top array

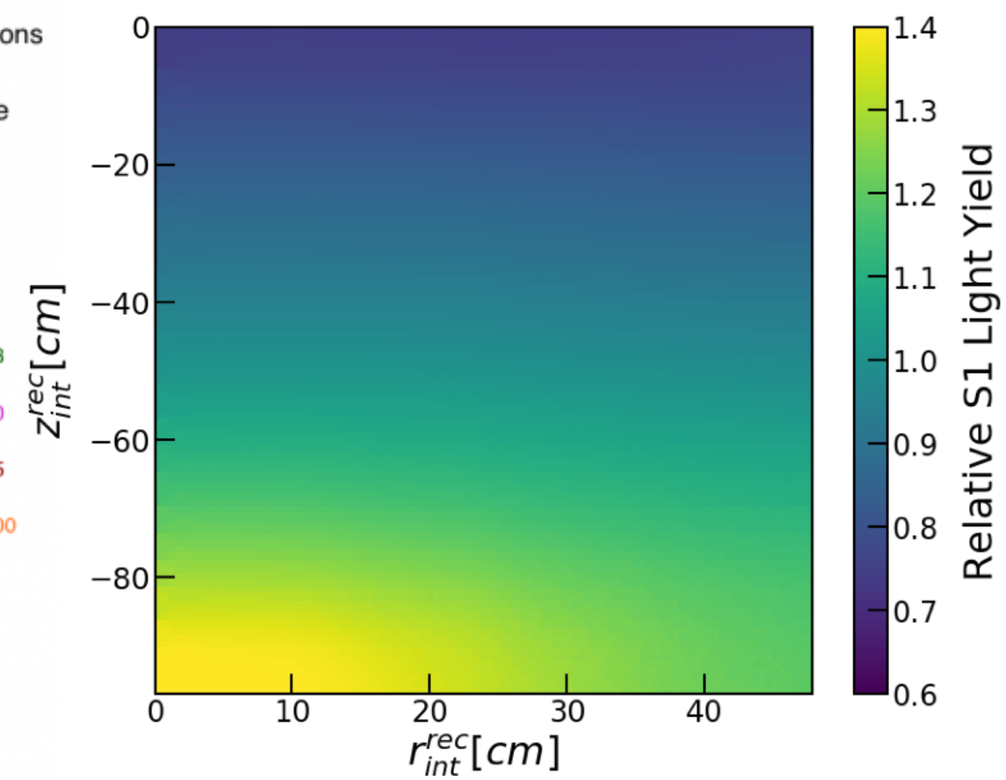
121 PMTs in the bottom array



PTFE reflectors & transparent meshes

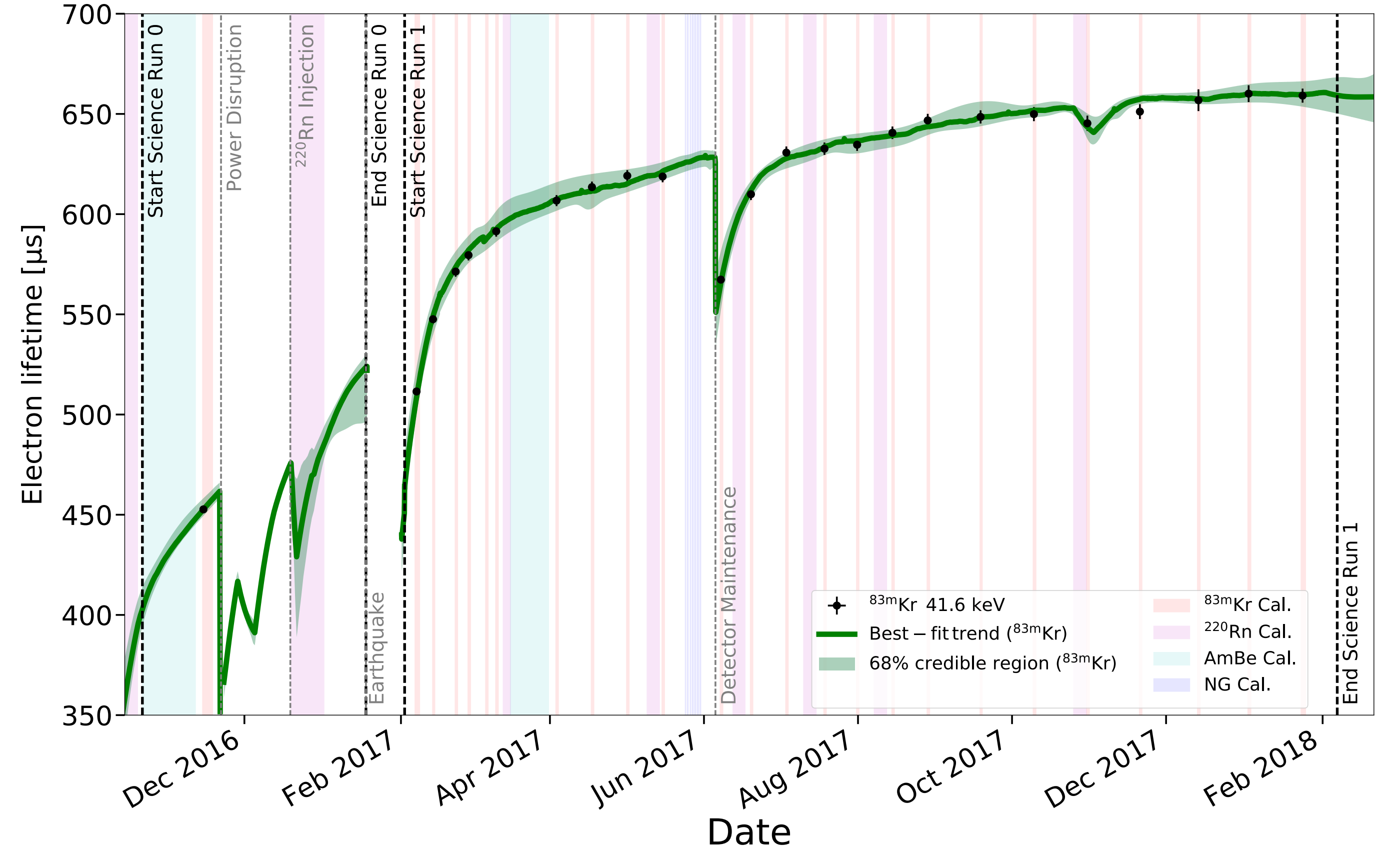


PMT gain stability

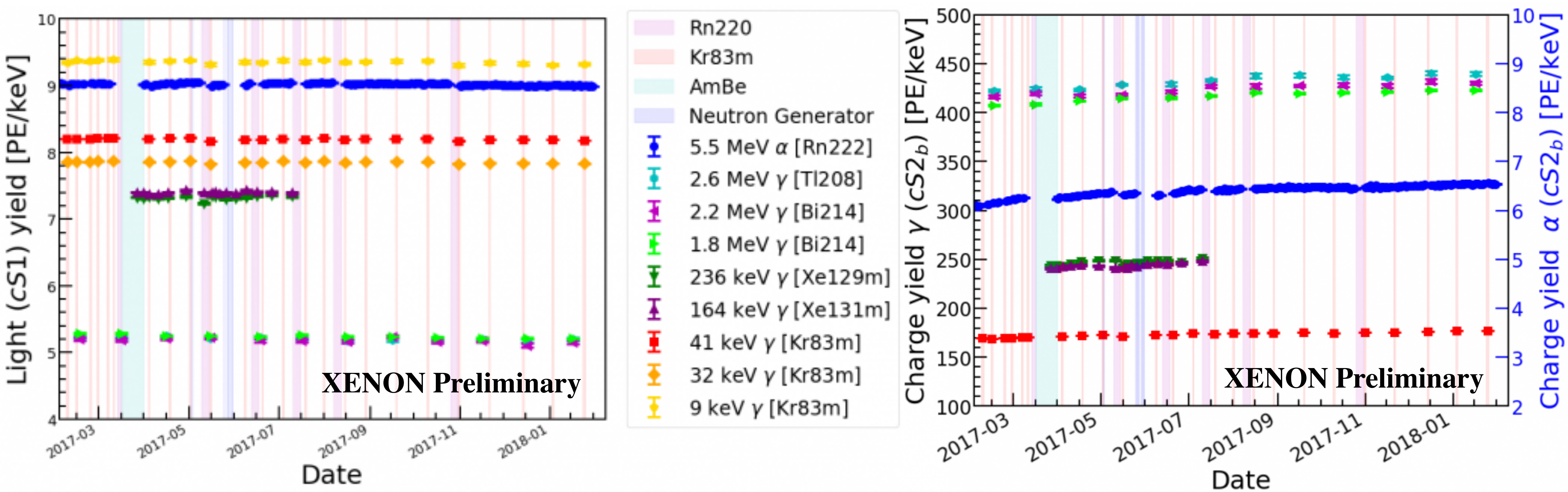


S1 Position dependence

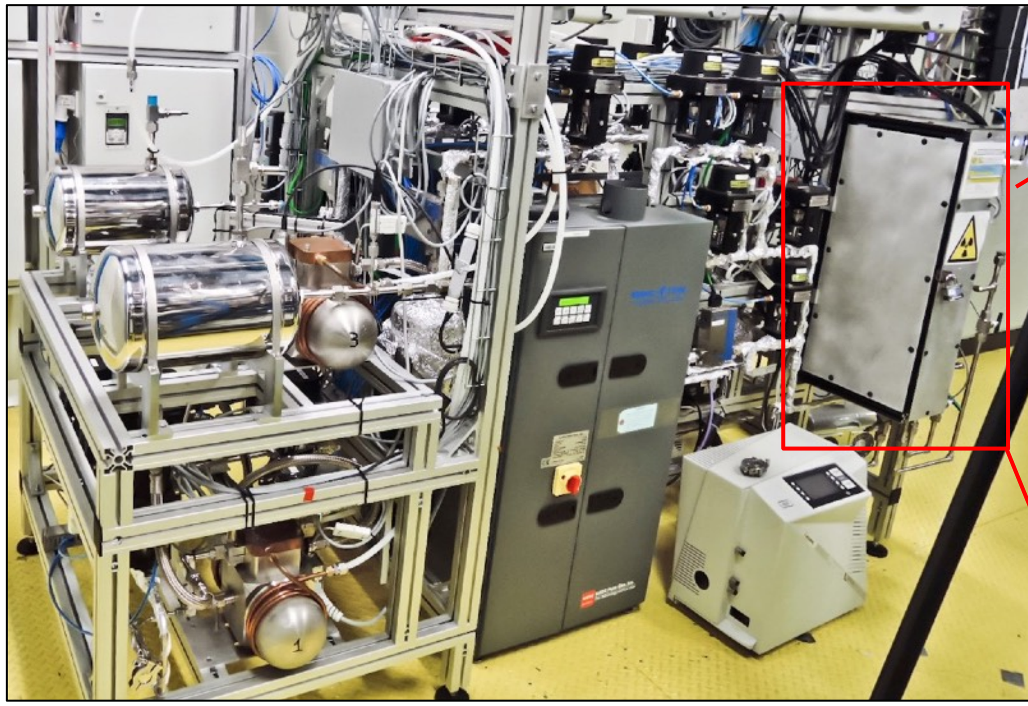
Improving the liquid xenon purity



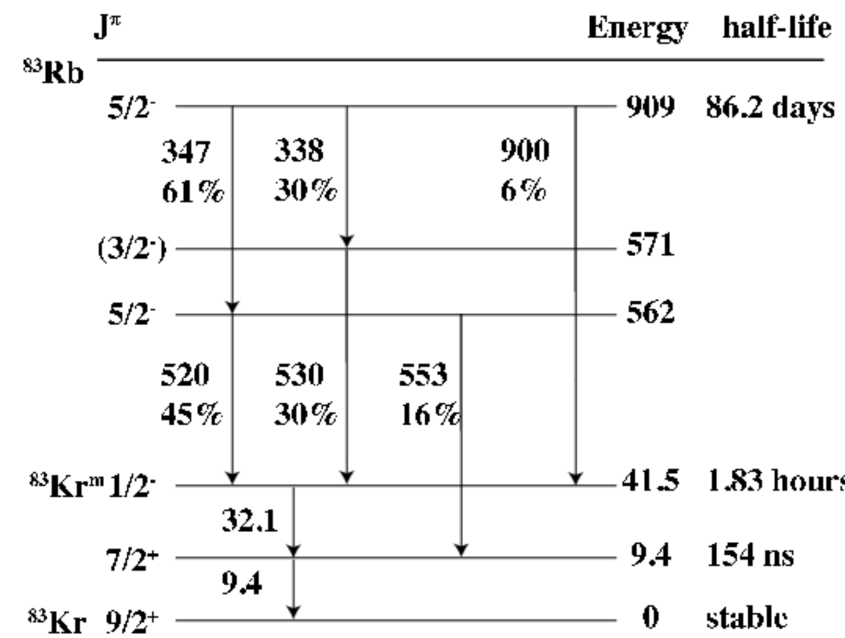
Stability of light and charge yields



Detector Calibrations



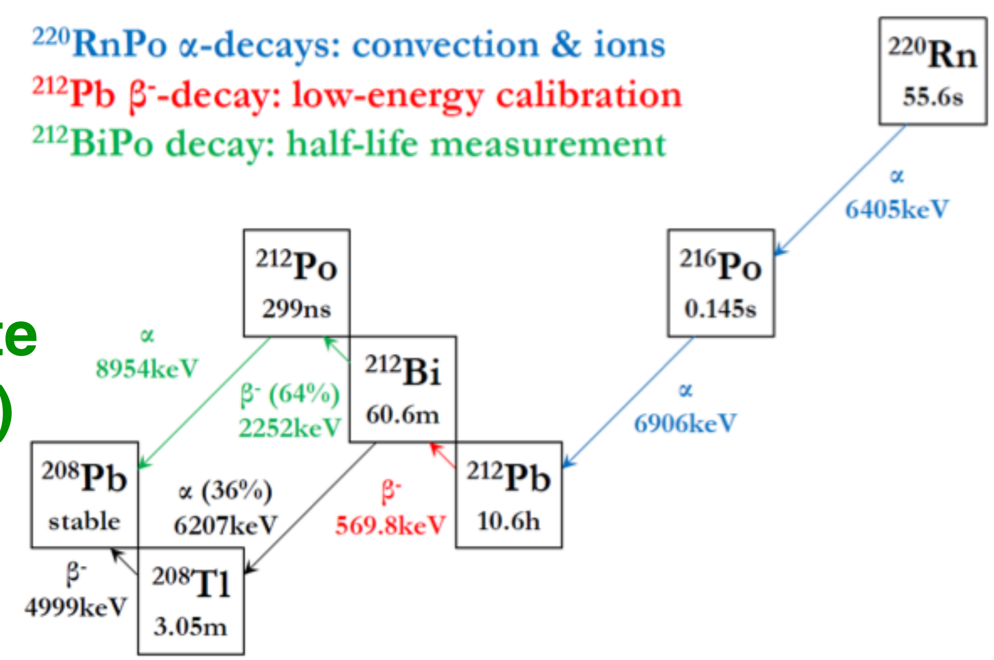
^{83m}Kr: to calibrate the energy response



AmBe neutrons

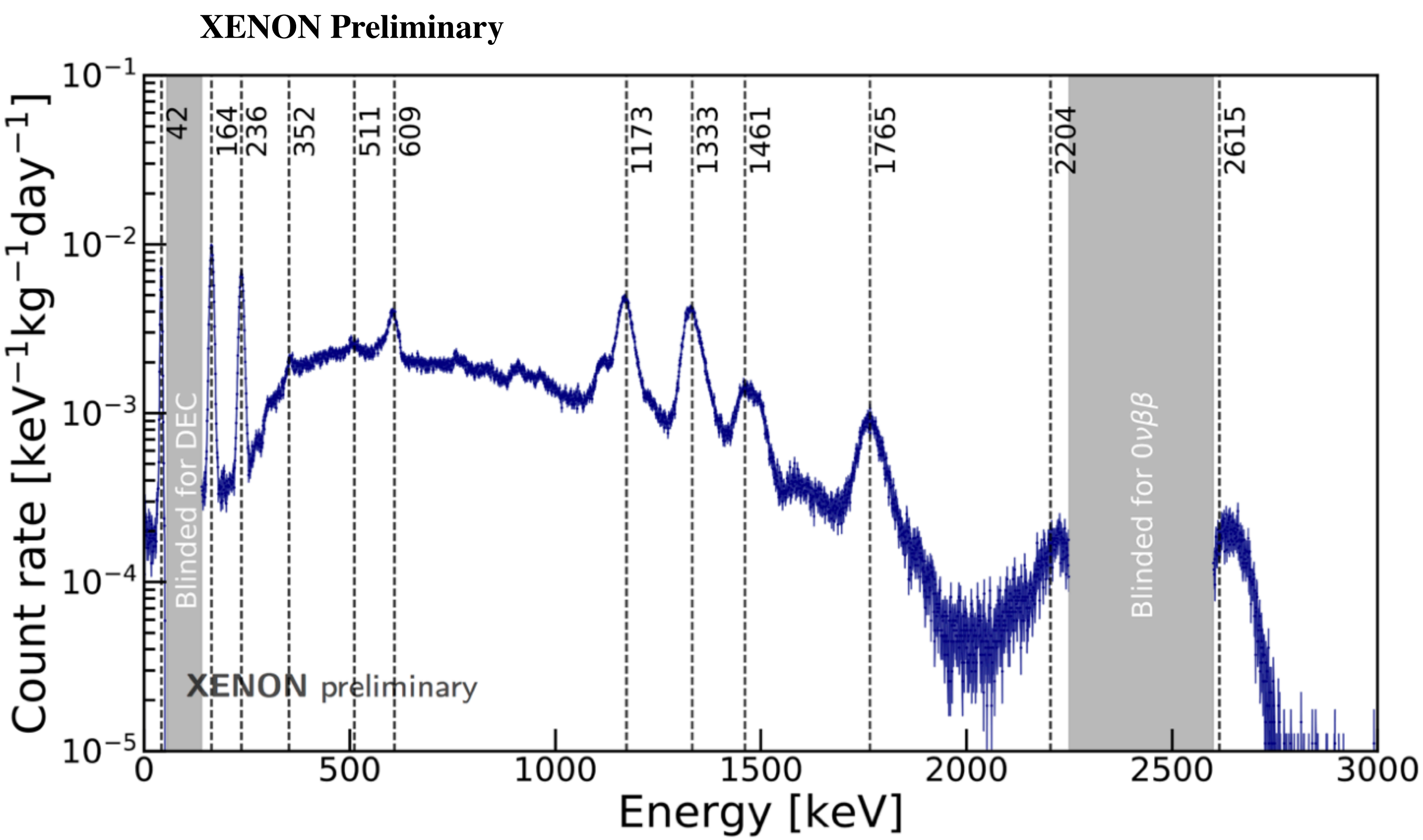
use neutrons to calibrate the Nuclear Recoil (NR) signals

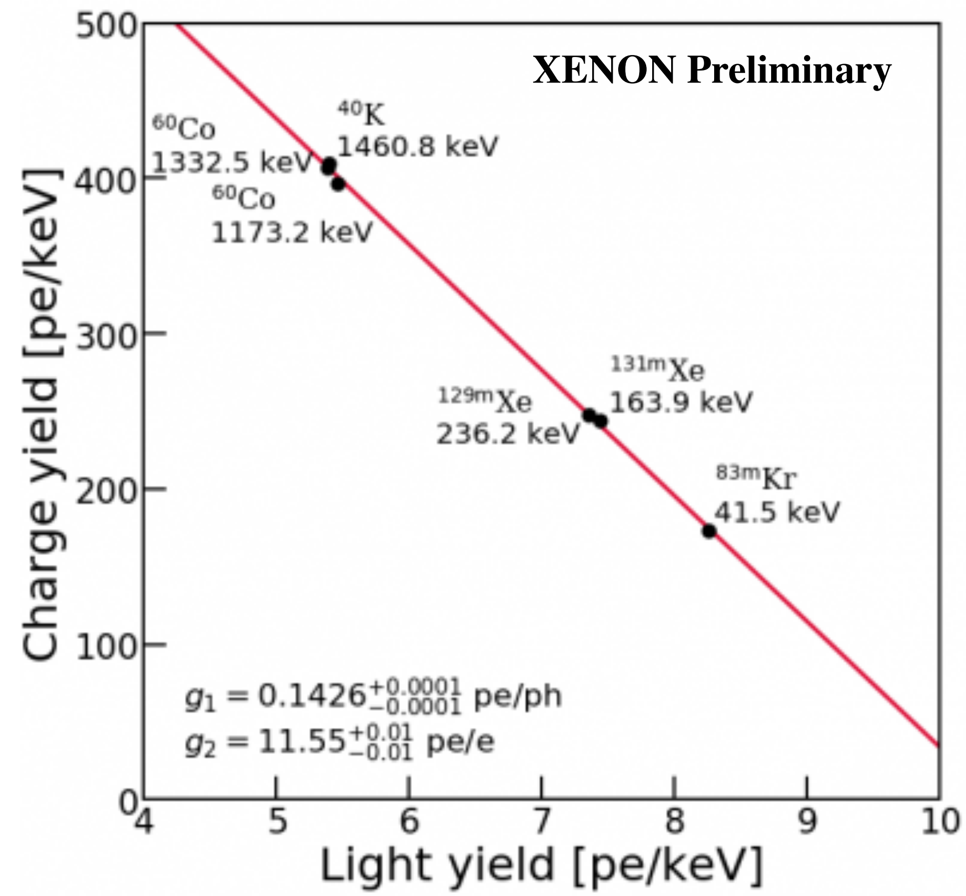
^{220}Rn: to calibrate the Electronic Recoils (ERs)

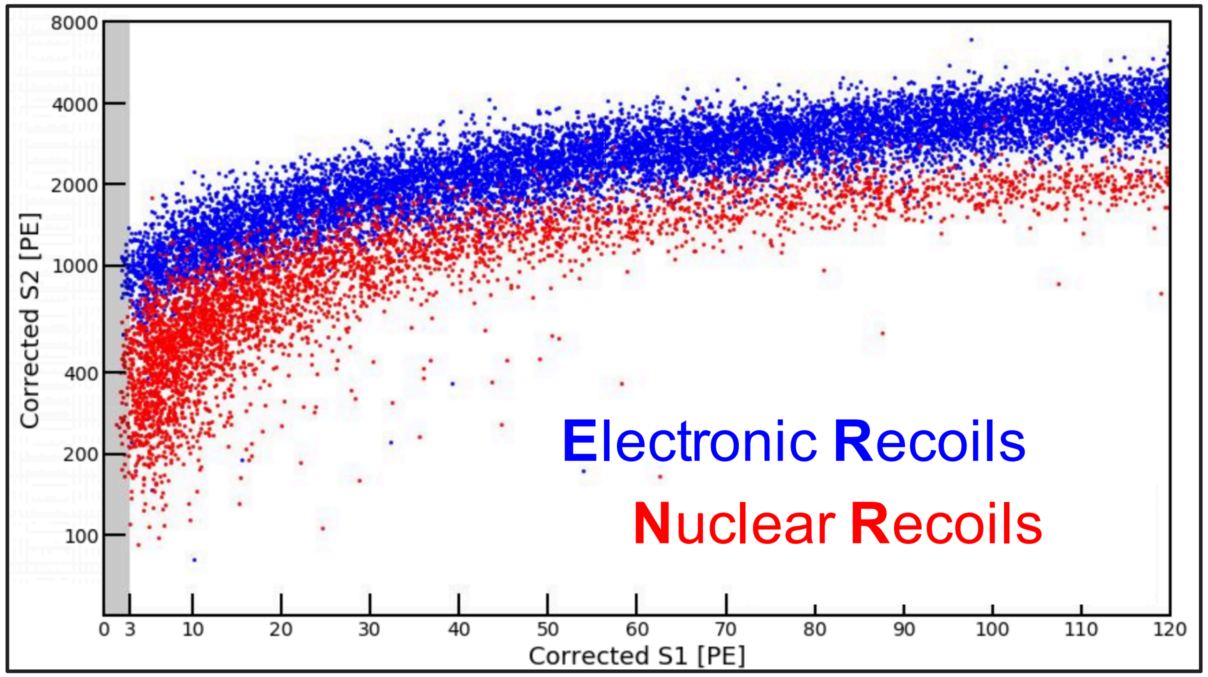


Energy (g1, g2) calibration with fixed energy gammas

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

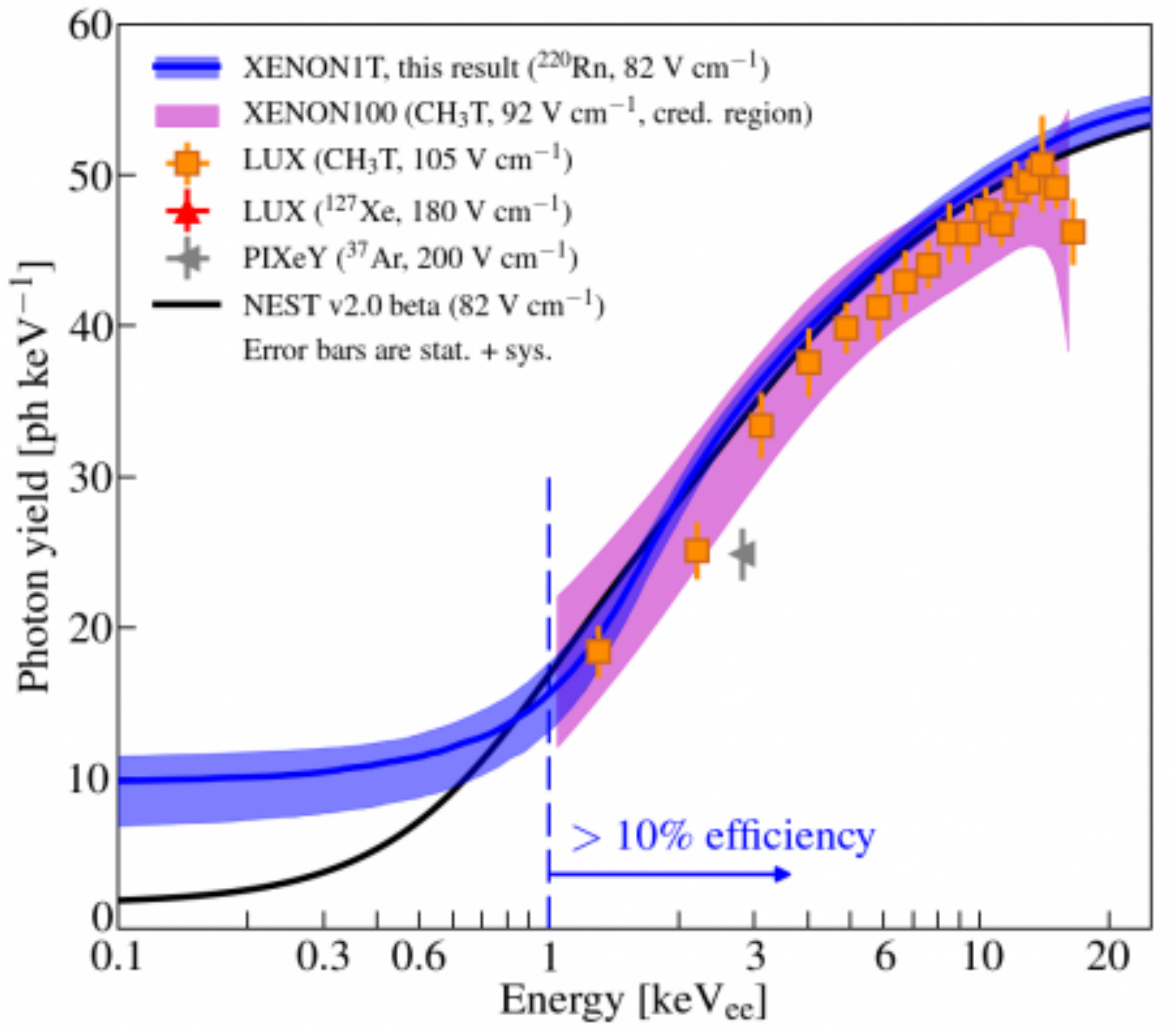


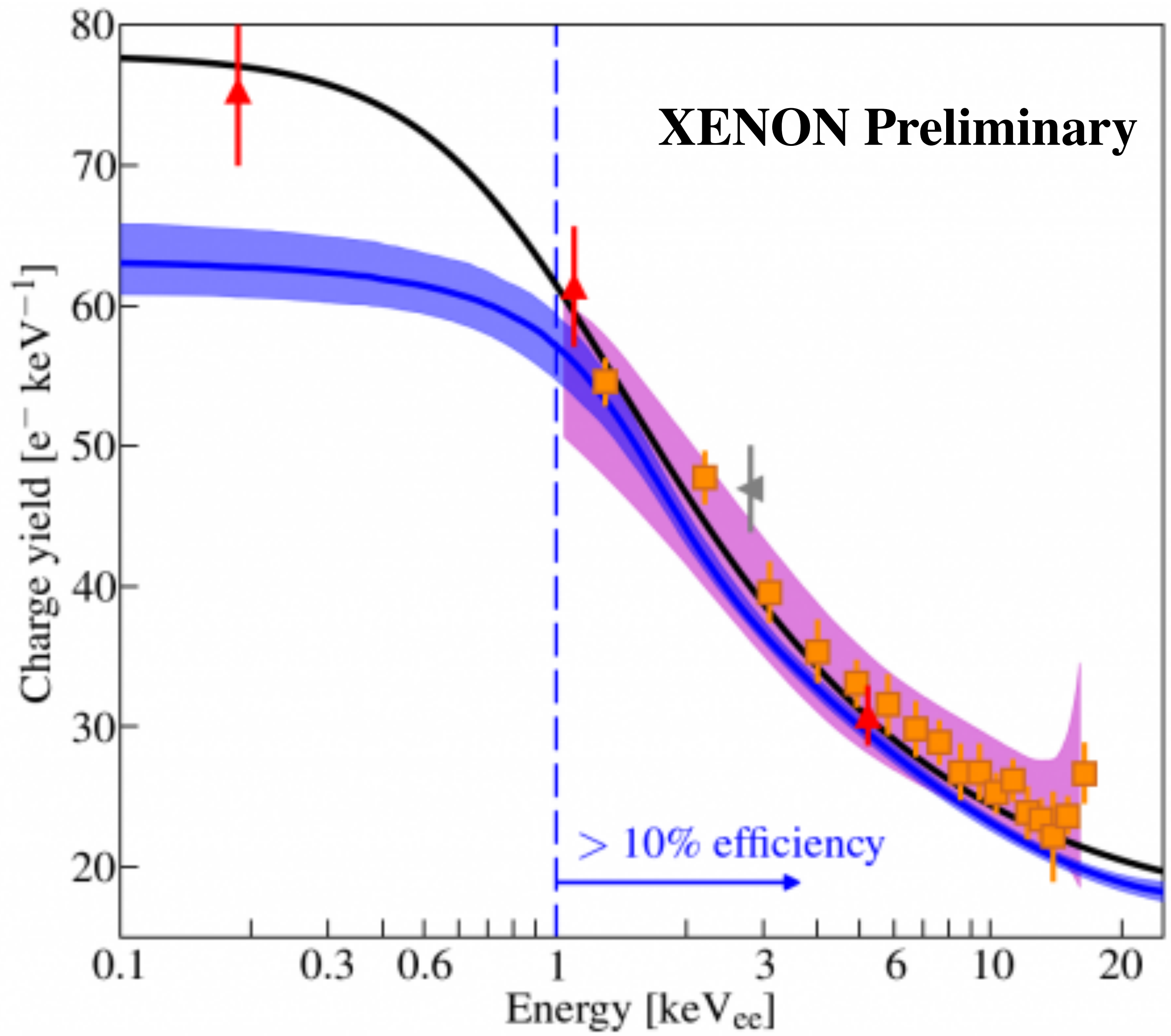


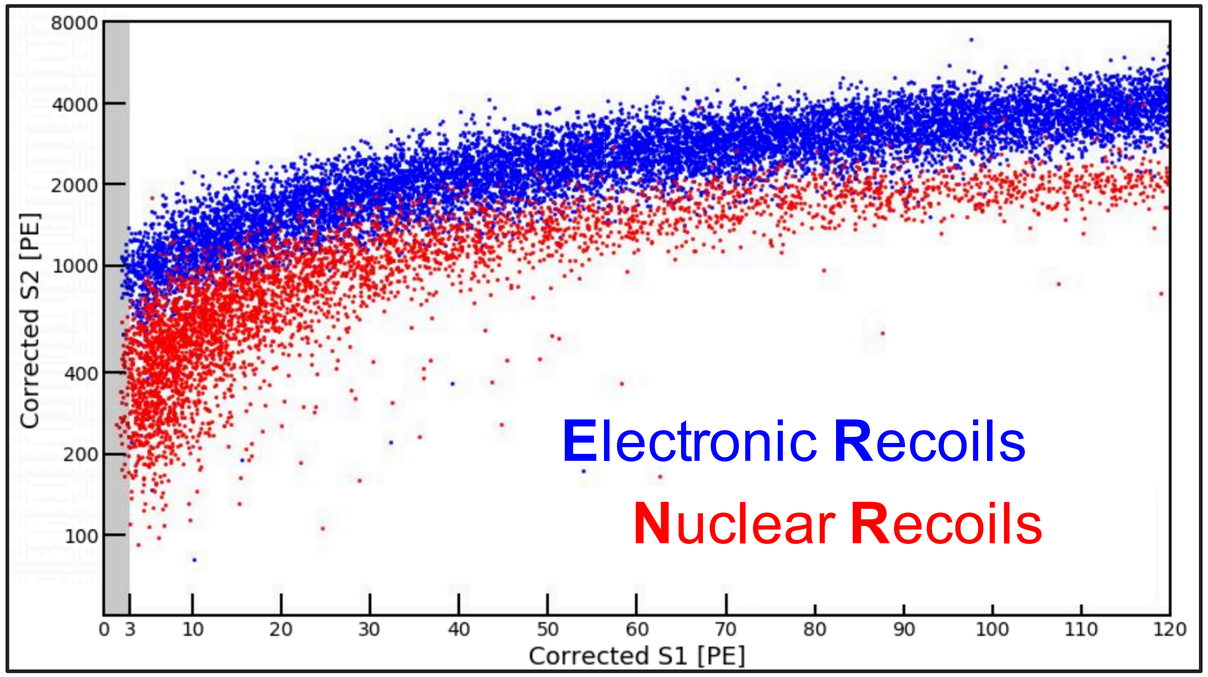


Low energy responses to Electronic and Nuclear Recoils are obtained using simultaneous fit to the Rn220 and neutron calibration data with detailed detector geometry and LXe physics model

Electronic Recoils Response in XENON1T

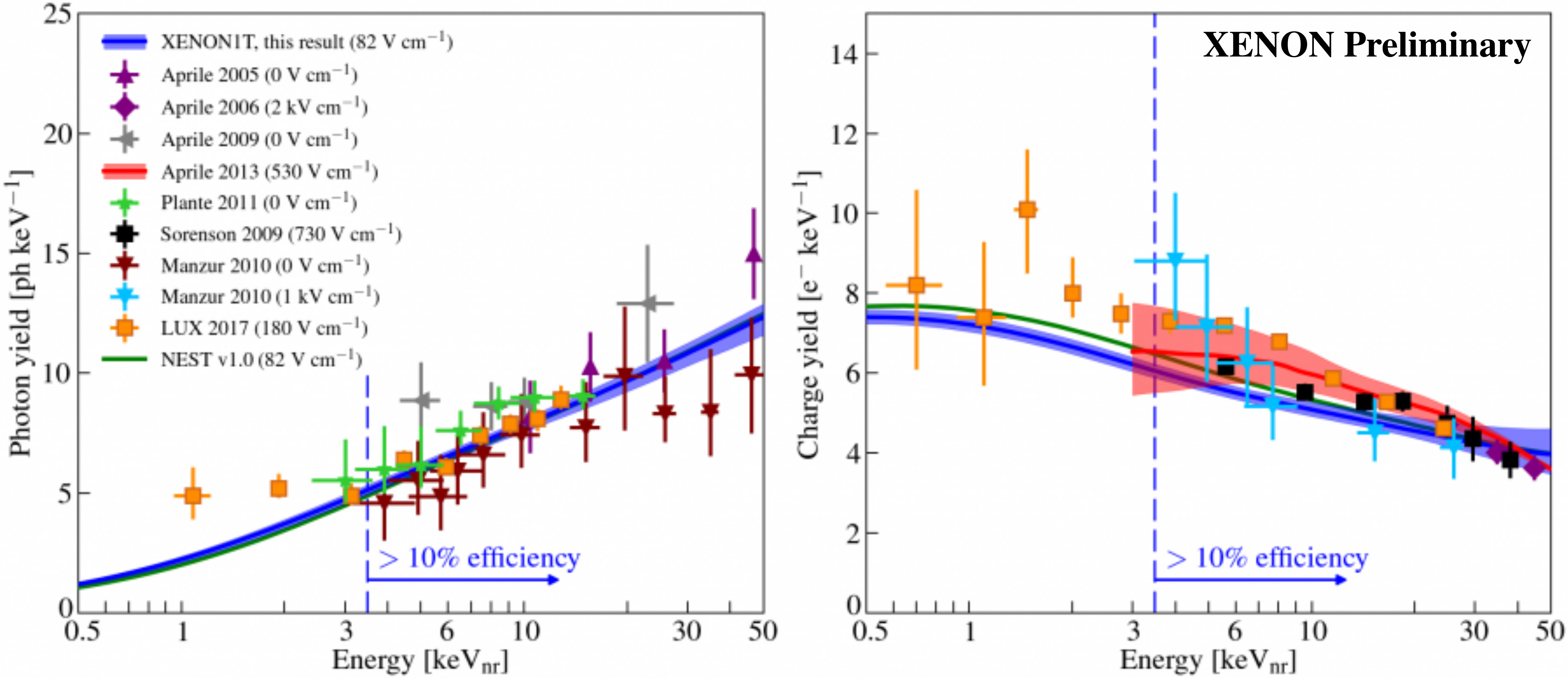




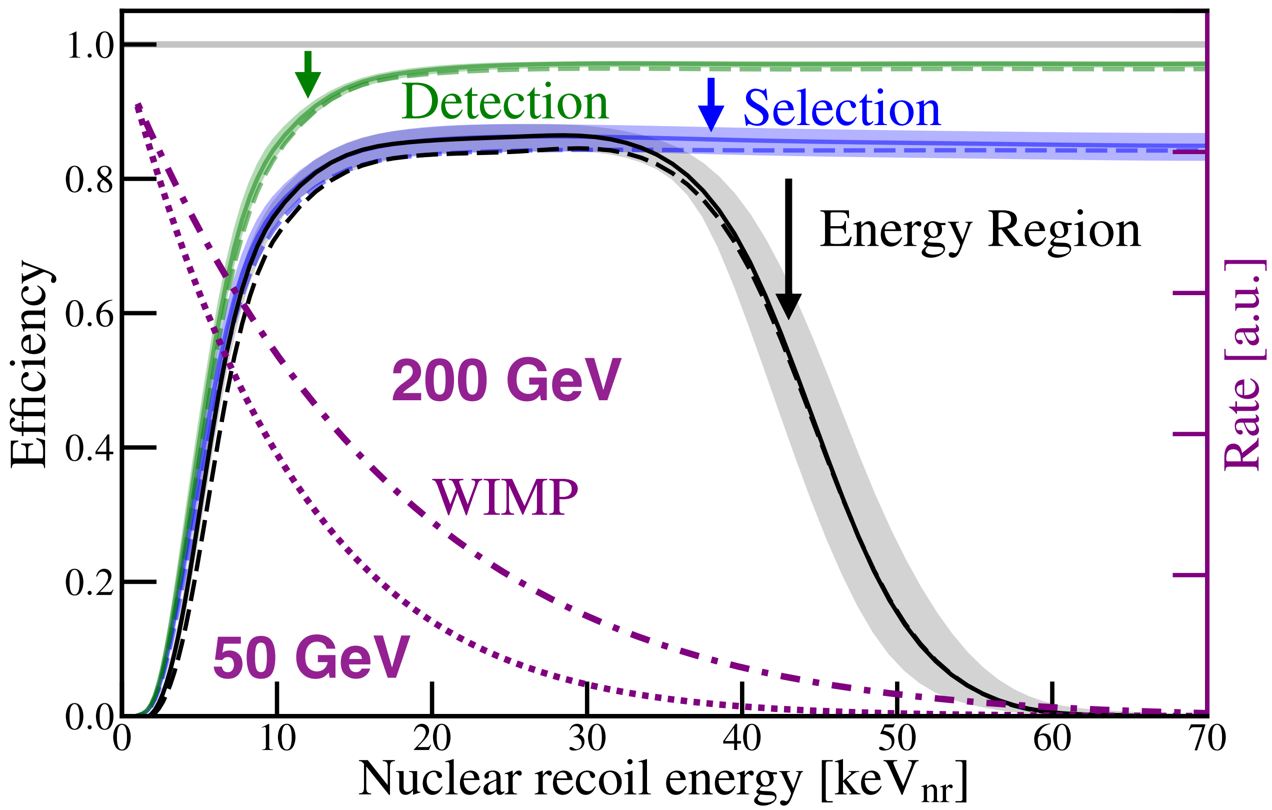


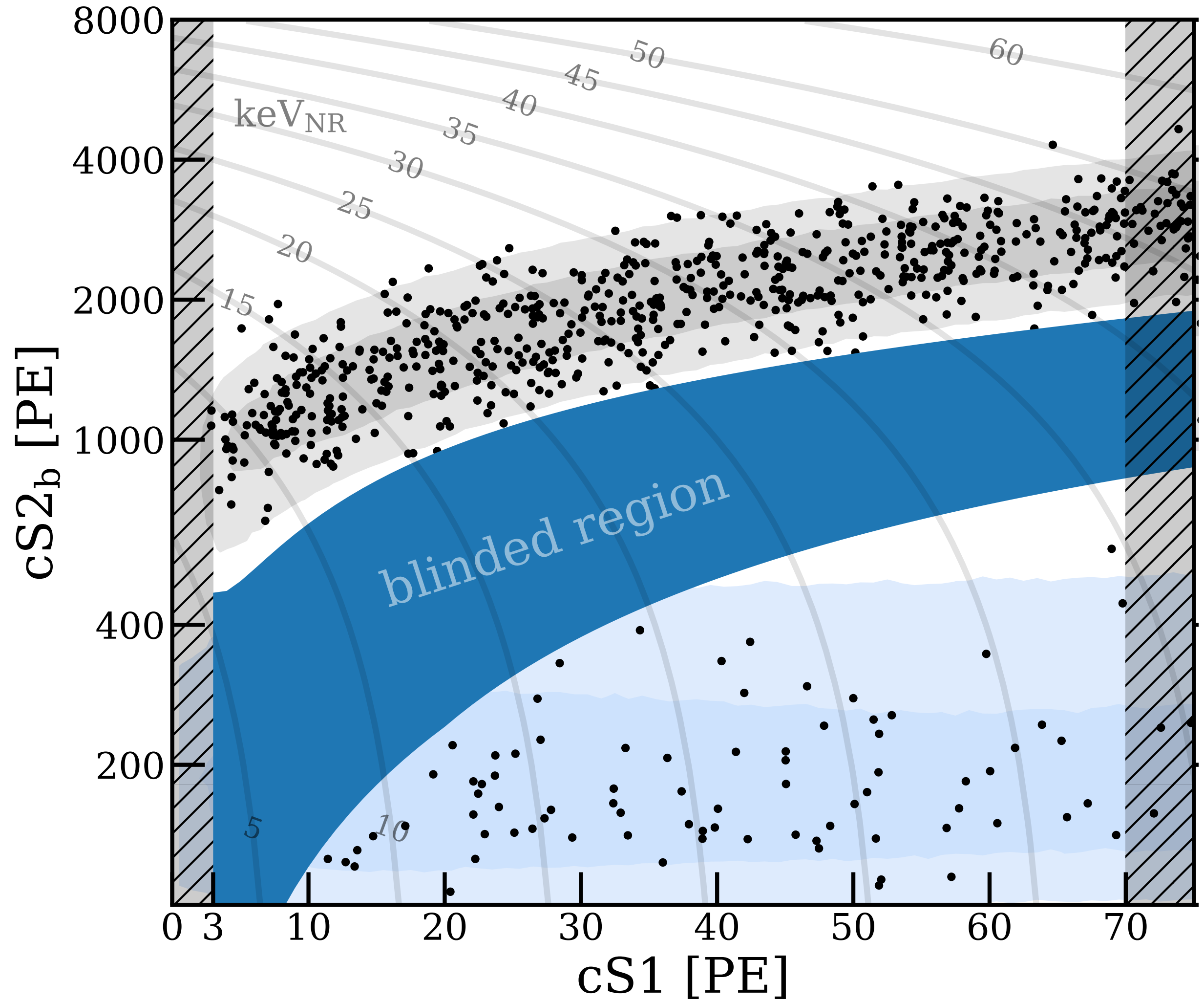
Low energy responses to Electronic and Nuclear Recoils are obtained using simultaneous fit to the Rn220 and neutron calibration data with detailed detector geometry and LXe physics model

Nuclear Recoil Response in XENON1T



Data selection and signal/background definitions before unblinding





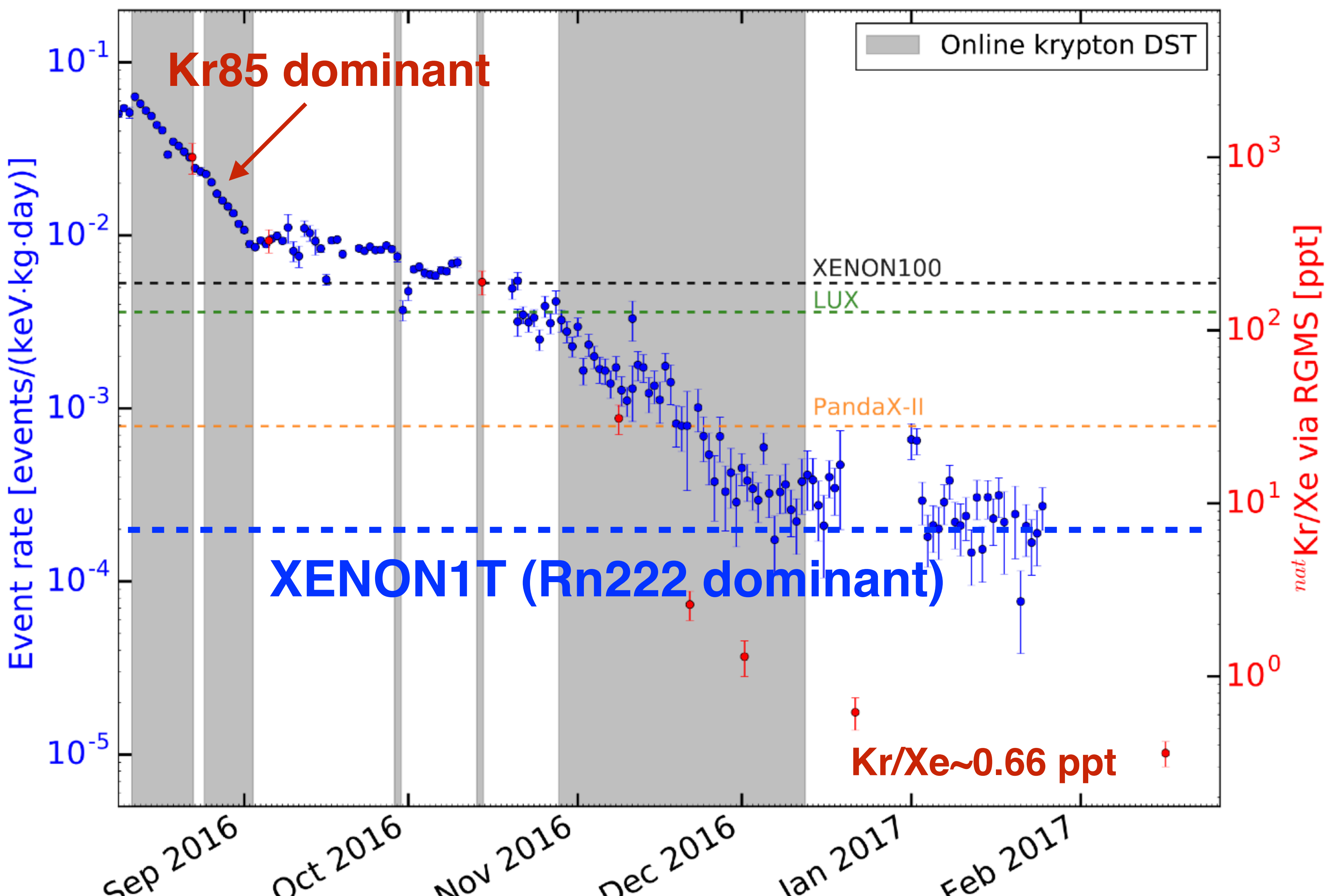
- Search region defined within 3-70 PE in cS1
- Detection efficiency dominated by 3-fold coincidence requirement
- Selection efficiencies estimated from control or MC data samples
- Four-component background model: ER, Surface, AC, NR

Reducing the dominant electronic recoils background

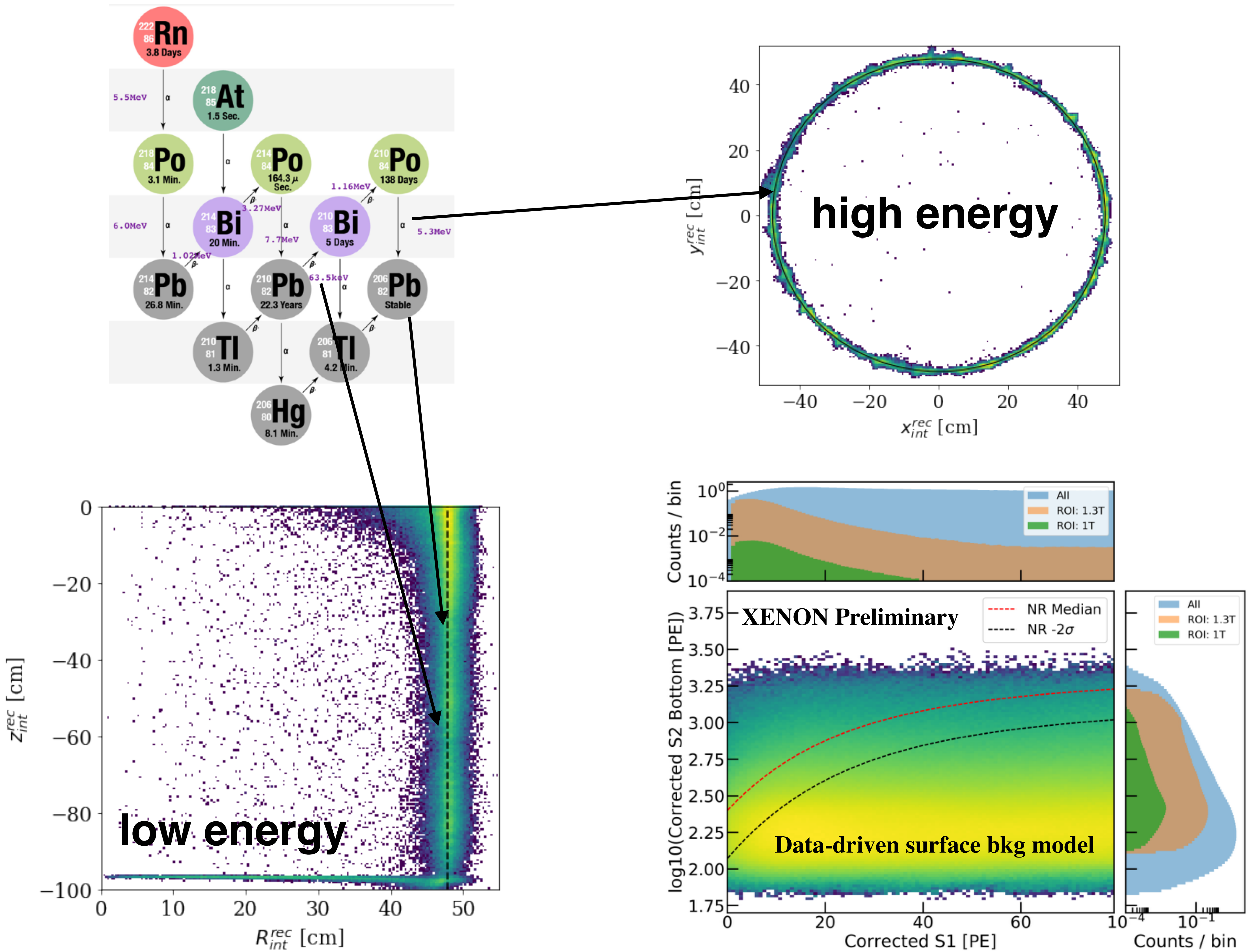
Source	Rate [t^{-1} y^{-1}]	Fraction [%]
Rn222	620 ± 60	85.4
Kr85	31 ± 6	4.3
Solar ν	36 ± 1	4.9
Materials	30 ± 3	4.1
Xe136	9 ± 1	1.4
Total	720 ± 60	

(Expectations in 1-12 keV search window, 1t FV, single scatters, *before ER/NR discrimination*)

JCAP04 (2016) 027

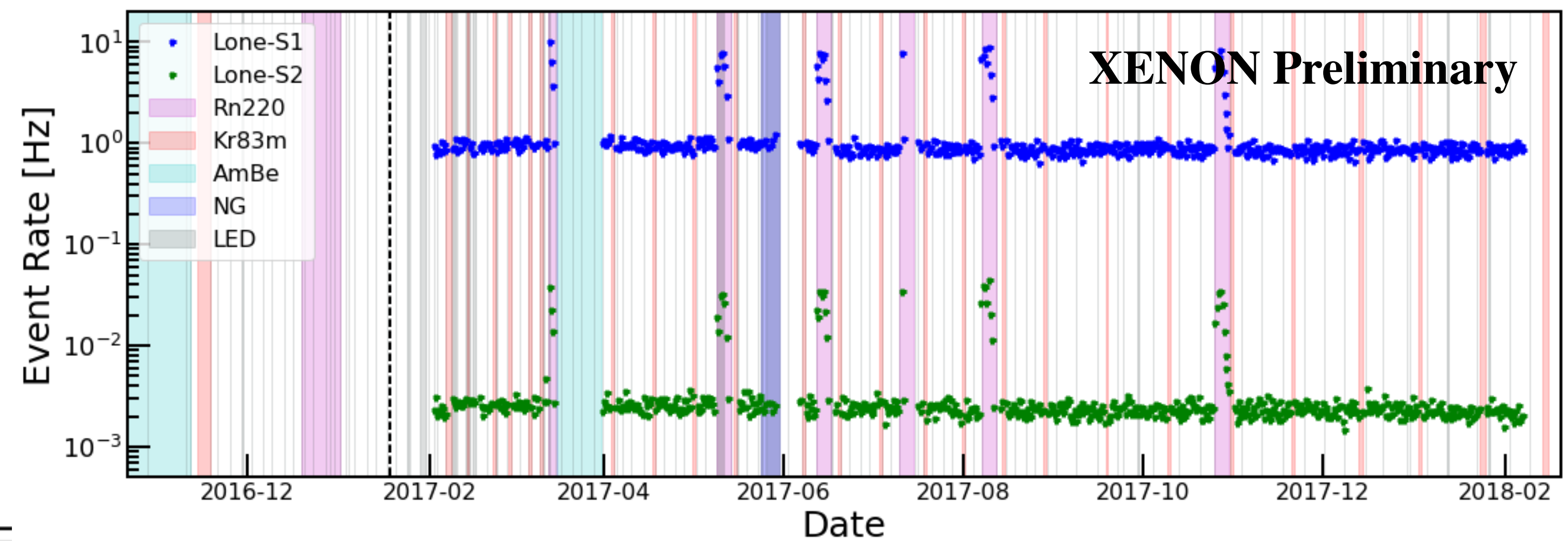


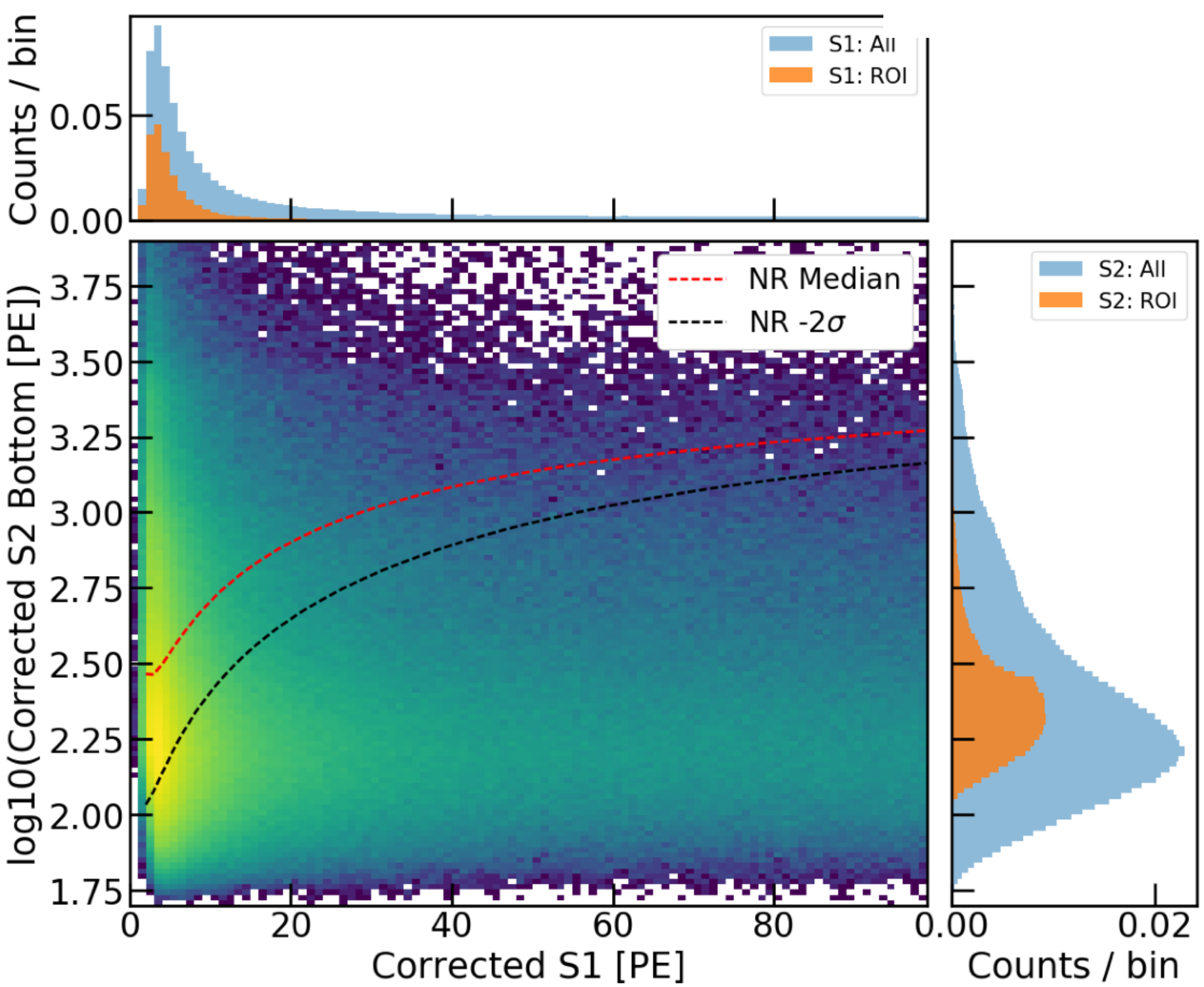
Surface Background: reduced-S2 events from Rn-daughters on the PTFE surface



Accidental Coincidence (AC) Background

A “lone” S1 or S2 signal produced in light and charge insensitive regions of the TPC may be accidentally combined to produce fake events in signal region





Empirical model shows an overall small rate in the ROI for NRs

- Select unpaired S1/S2 from data
- Randomly pair to form events
- Apply selection conditions from analysis
- Performance verified with ^{220}Rn data and background sidebands

Nuclear Recoil Background

Radiogenic neutrons from (α, n) reactions and fission from ^{238}U and ^{232}Th: reduced via careful materials selection, event multiplicity and fiducialization

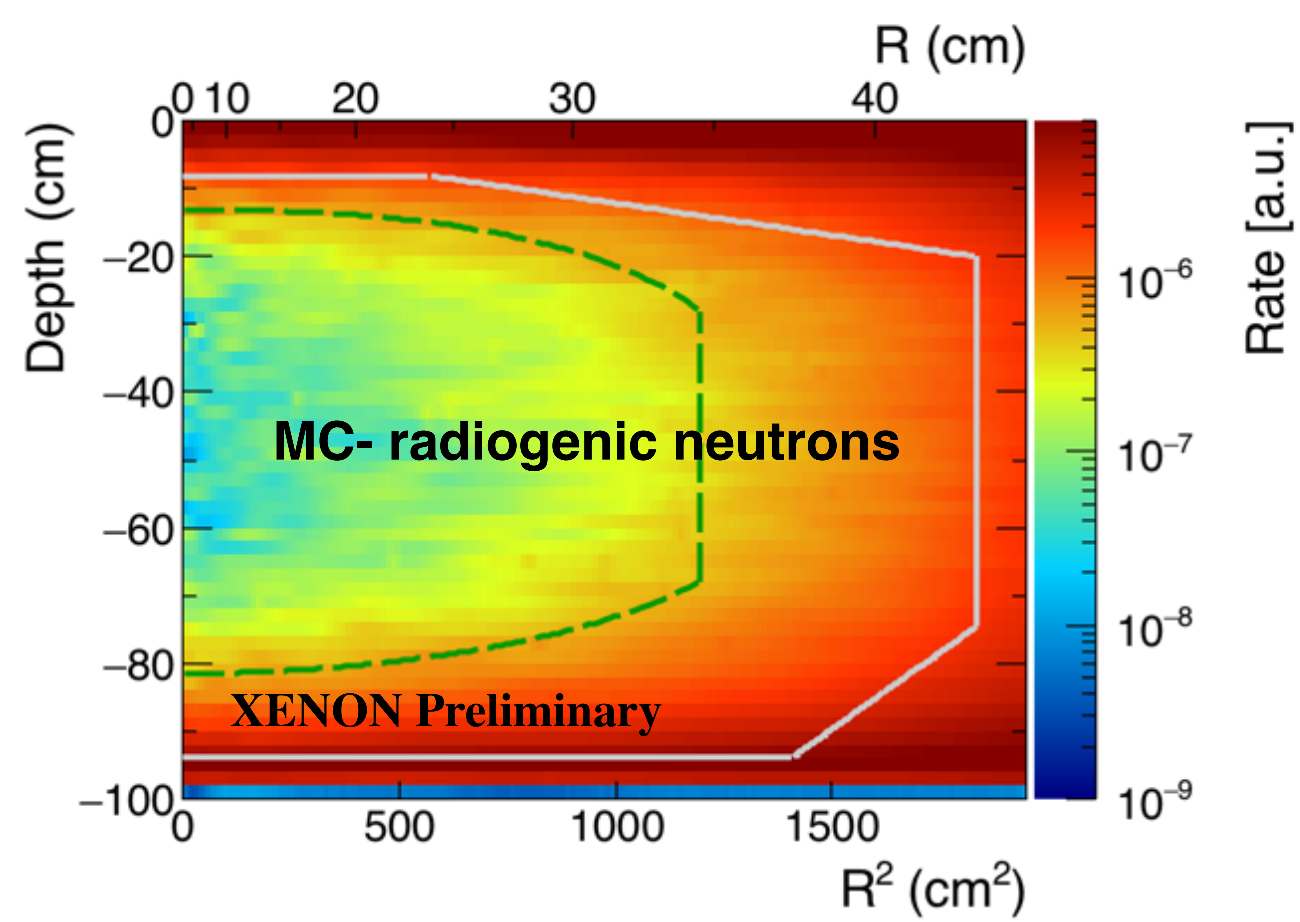
Coherent elastic ν-nucleus scattering, constrained by ^{8}B neutrino flux and measurements, is an an irreducible background at very low energy (1 keV)

Cosmogenic μ-induced neutrons significantly reduced by rock overburden and muon veto

Source	Rate [t^{-1} y^{-1}]	Fraction [%]
Radiogenic n	0.6 ± 0.1	96.5
CEνNS	0.012	2.0
Cosmogenic n	< 0.01	< 2.0

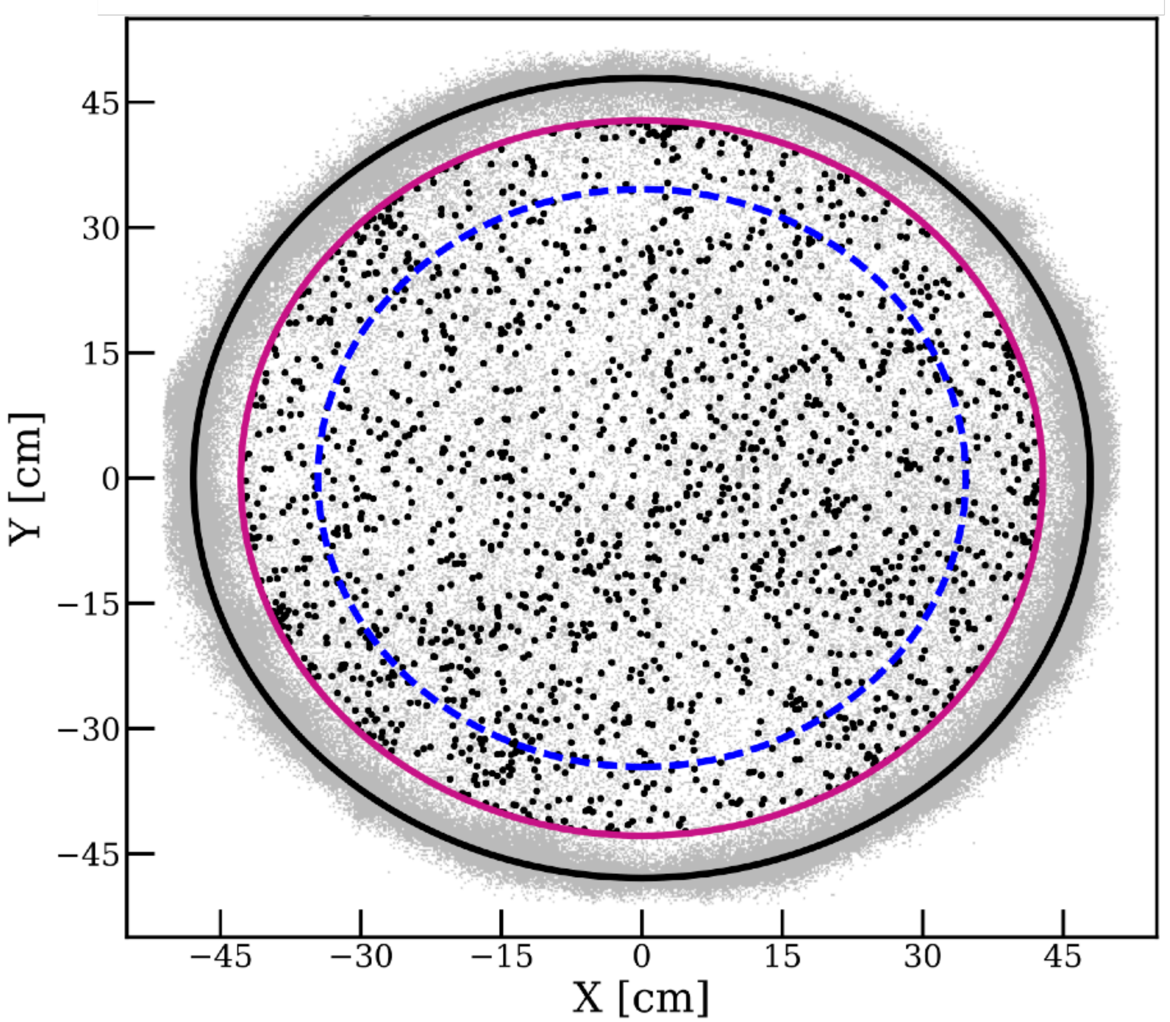
(Expectations in 4-50 keV search window, 1t FV, single scatters)

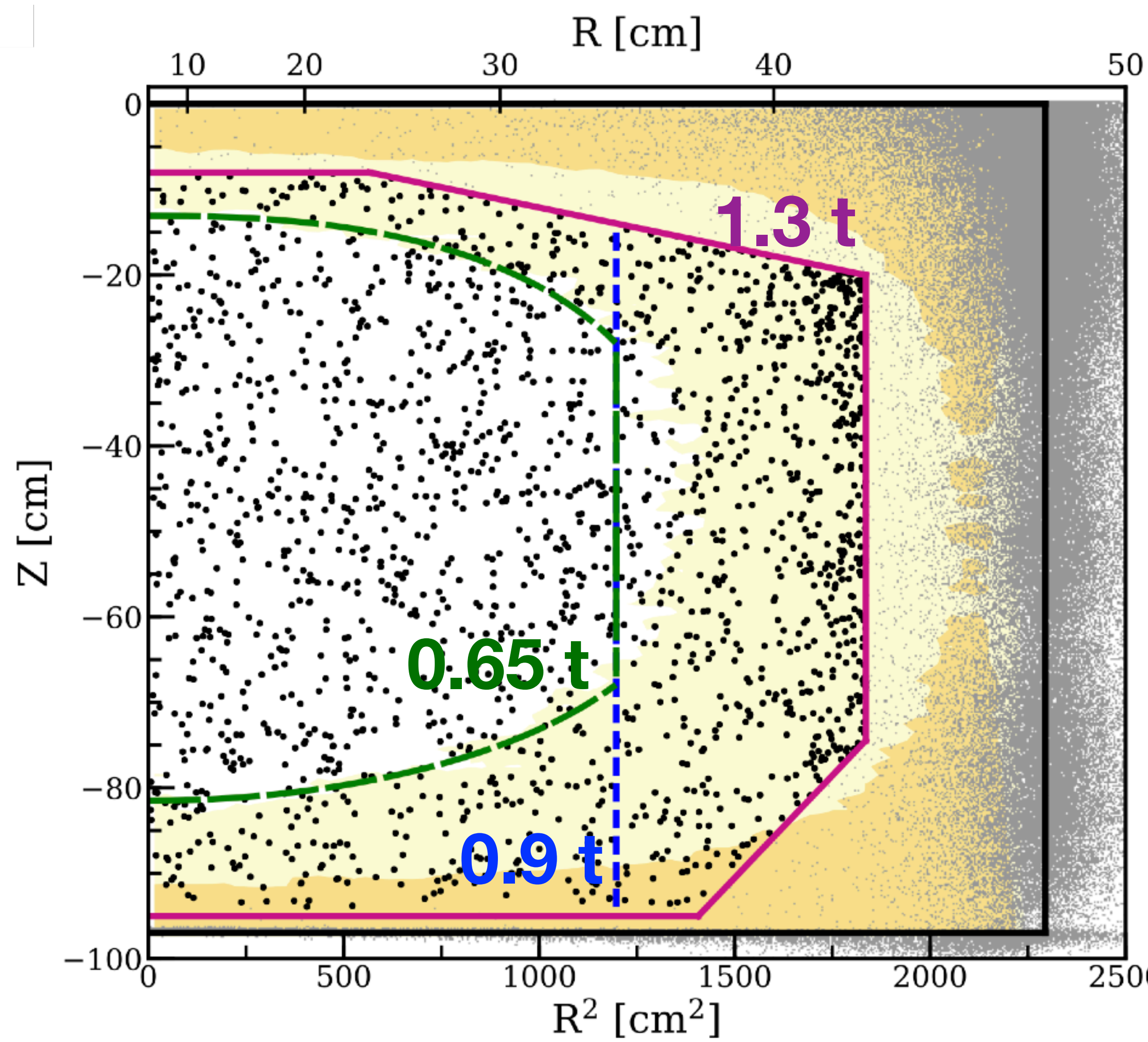
JCAP04 (2016) 027



Fiducial volume optimization

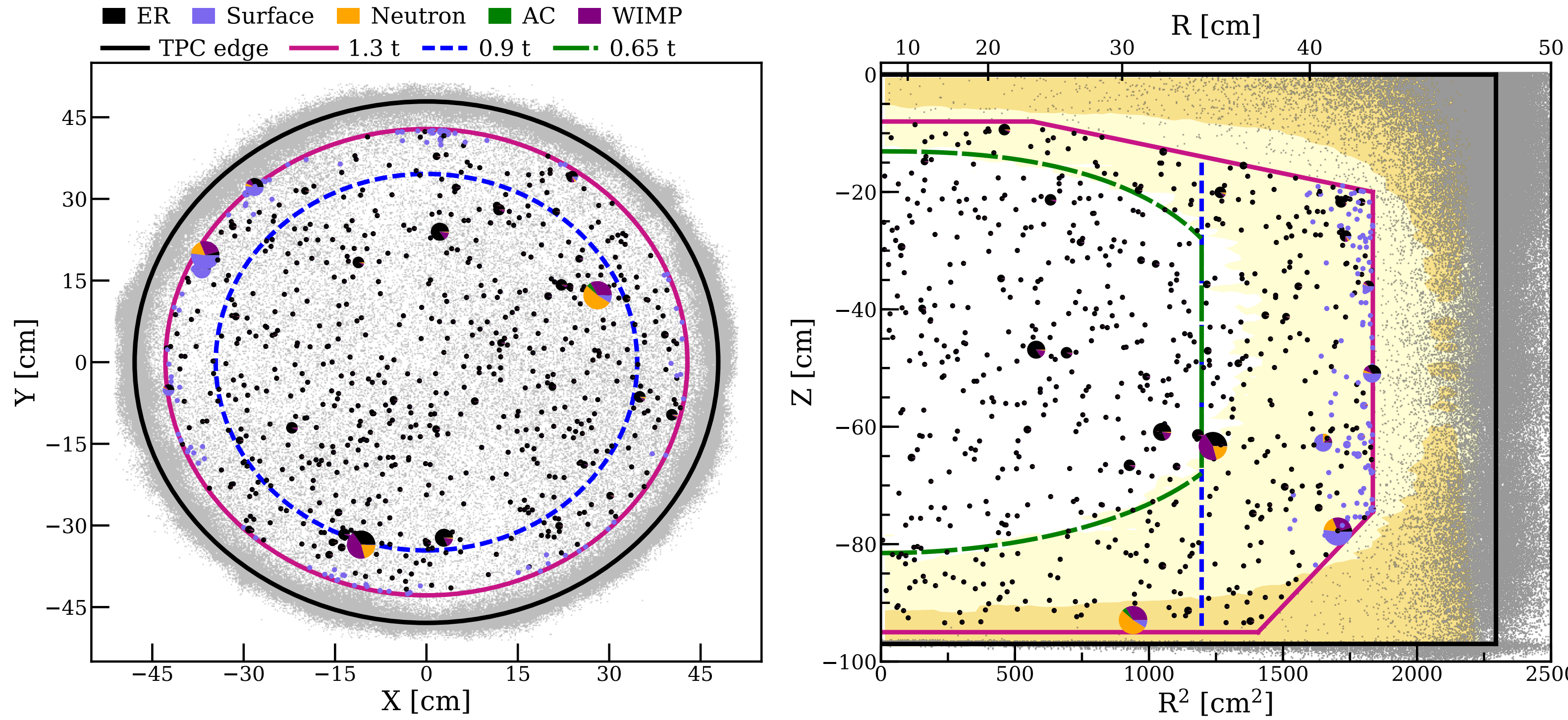
- **new surface background model allowed inclusion of radius, R, in statistical inference to maximize useful volume. Analysis space became cS1, cS2b, R and Z**

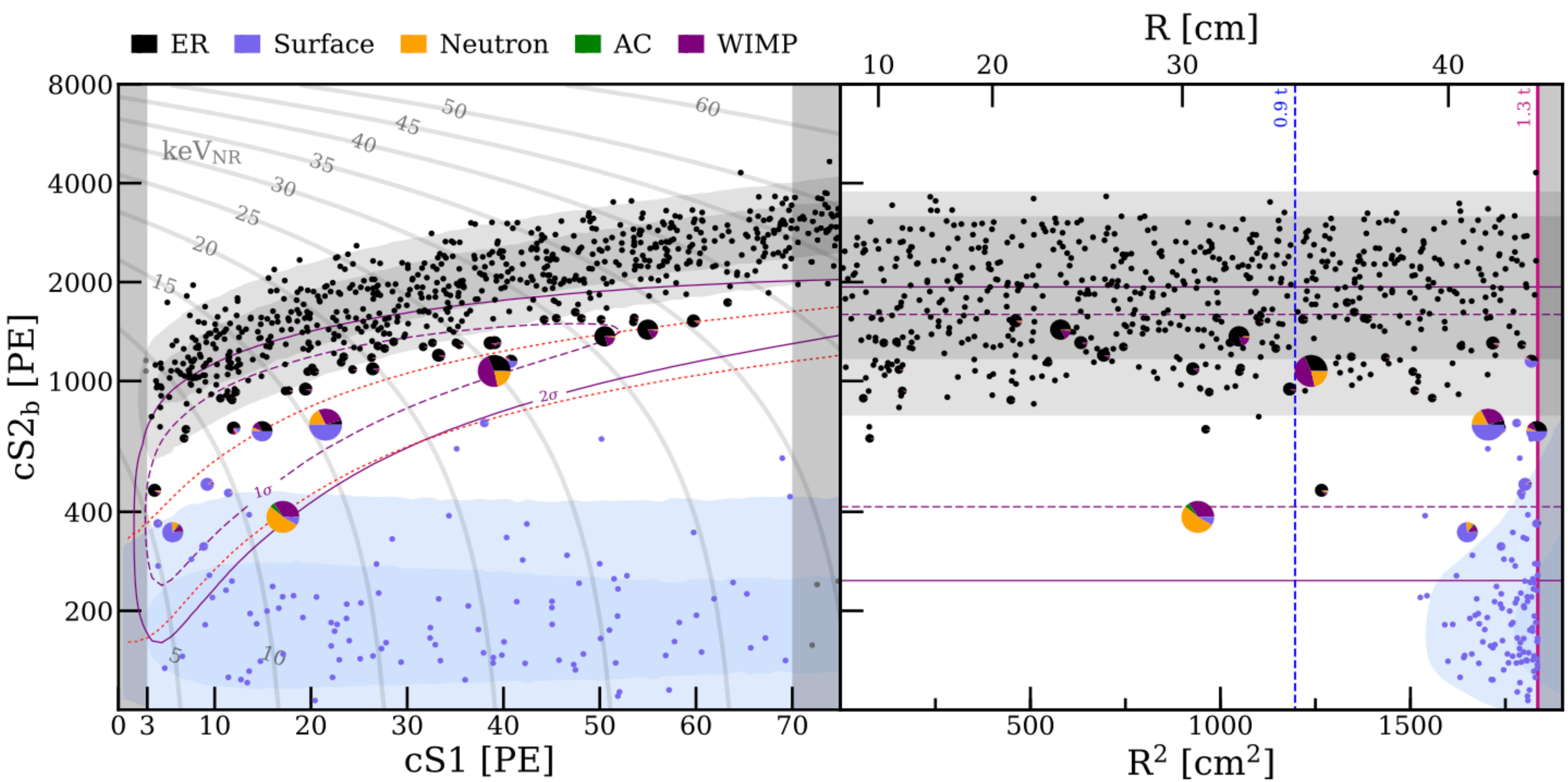




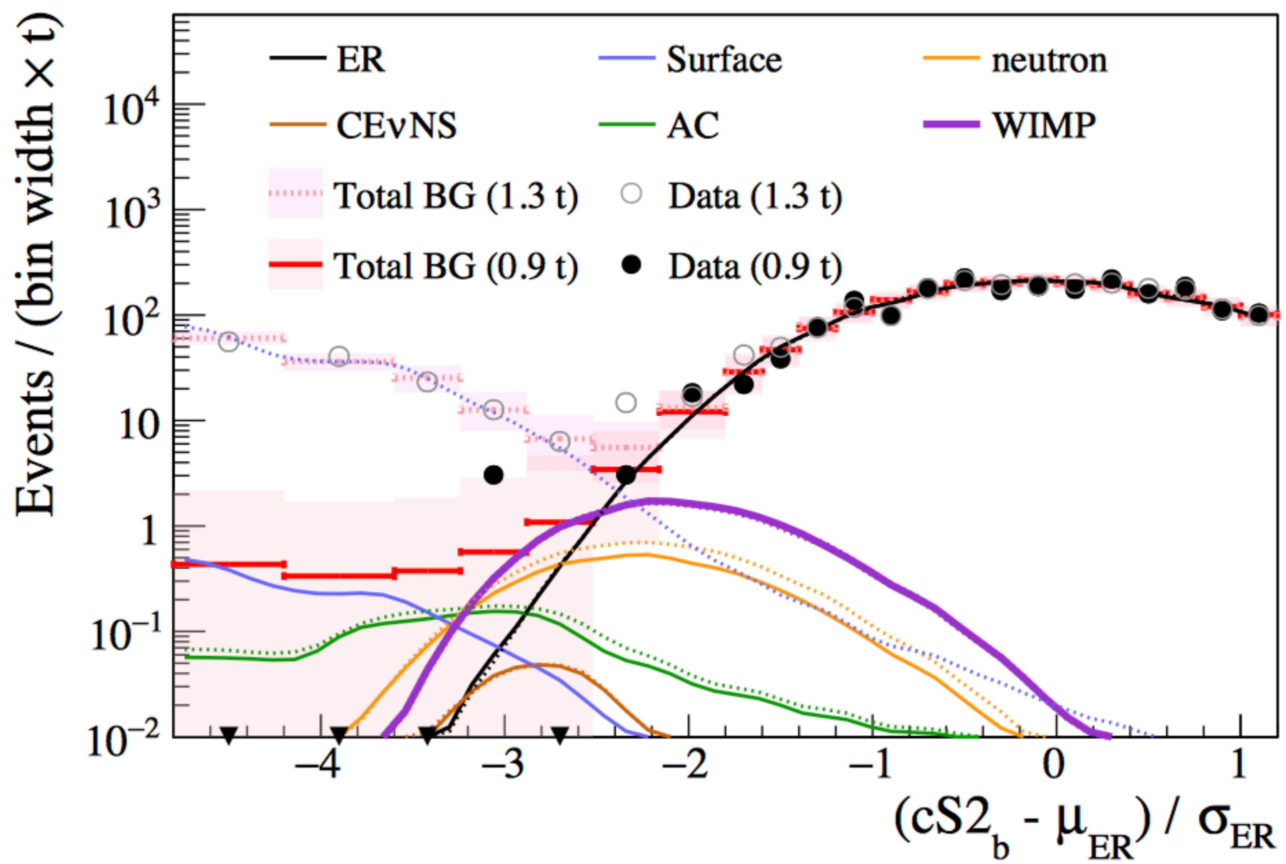
after unblinding

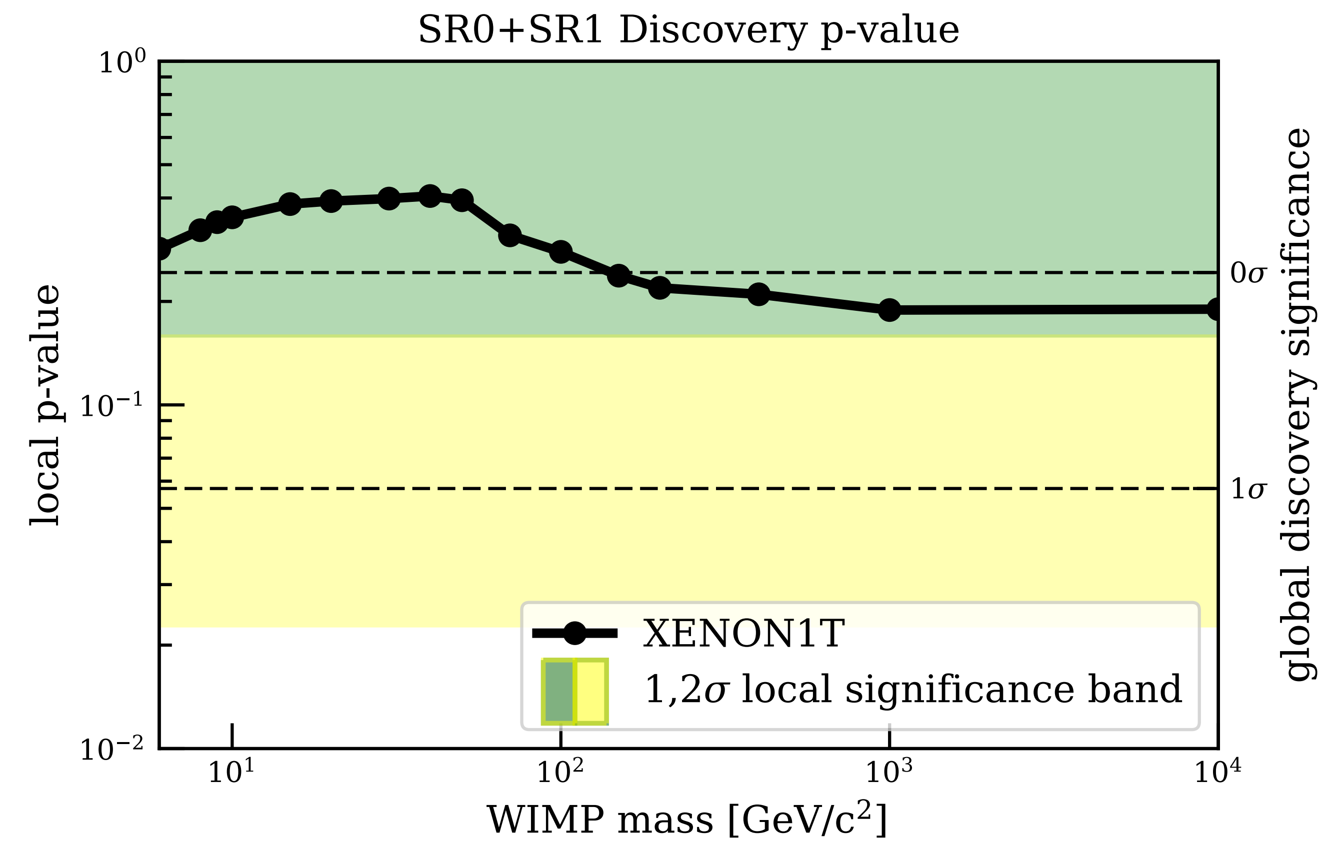
Piecharts indicate the relative PDF of background and the best-fit of 200 GeV/c² WIMPs at cross-section of 4.7x10⁻⁴⁷ cm²





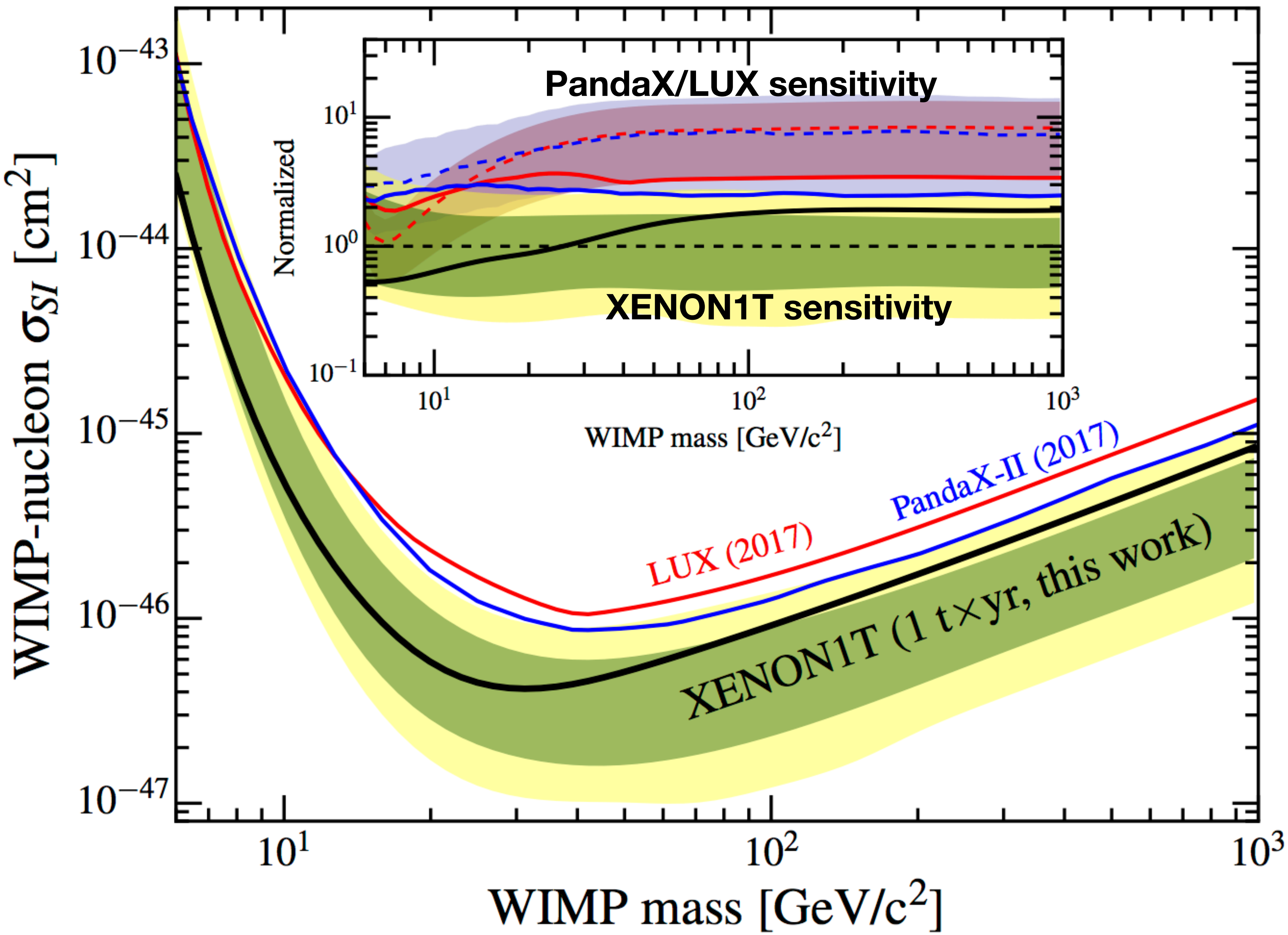
Statistical Interpretation





- **unbinned profile likelihood analysis in cS1, cS2, R space**
- **Example show the best-fit of 200 GeV WIMPs at cross-section of 4.7×10^{-47} cm^2**
- **p-value for background-only hypothesis: ~0.2 for high WIMP masses**
- **No significant (>3 sigma) excess at any scanned WIMP masses**

XENON1T Dark Matter Search Results



- x7 improvement in sensitivity compared to LUX/PandaX-II
- Most stringent SI limits for all WIMP masses above 6 GeV
- ~ 1sigma upper fluctuation at high WIMP masses

What's the current status of XENON1T?

- **Many physics analysis topics being explored:**
  - extending to higher energy: EFT, inelastic DM, DEC, 0vbb, etc.
  - lowest ER rate ever achieved to probe leptophilic dark matter, ER annual modulation, etc.
  - ionization-only search: low-mass (1-10 GeV), light (sub-GeV), and hidden sector dark matter, etc.
- **XENON1T keeps taking science data** with better detector performance following upgrades (for XENONnT)
  - improved electron lifetime (now reaching ~1 ms)
  - reduced radon in the bulk!

Upgrading XENON1T to XENONnT

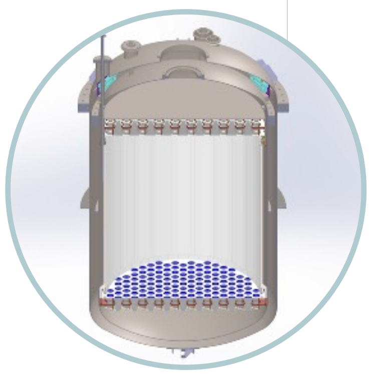
XENONnT: our detector gets larger and better!

XENON1T Infrastructure and sub-Systems already operative

1/10 reduction of background and x10 sensitivity improvement

Some upgrades already implemented and working!

Fast turnaround: commissioning in 2019

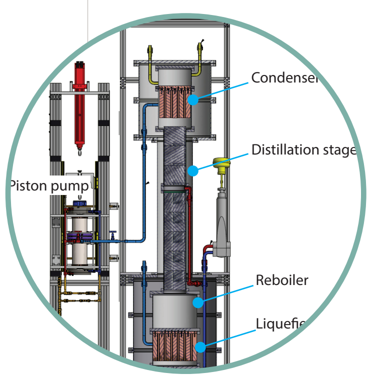


New TPC

5.9-ton Time Projection Chamber

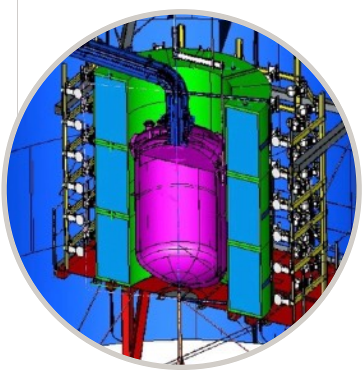
LXe Purification

To achieve fast cleaning of the large LXe volume (5000 SLPM)



Radon Distillation

To online remove the ^{222}Rn emanated inside the detector

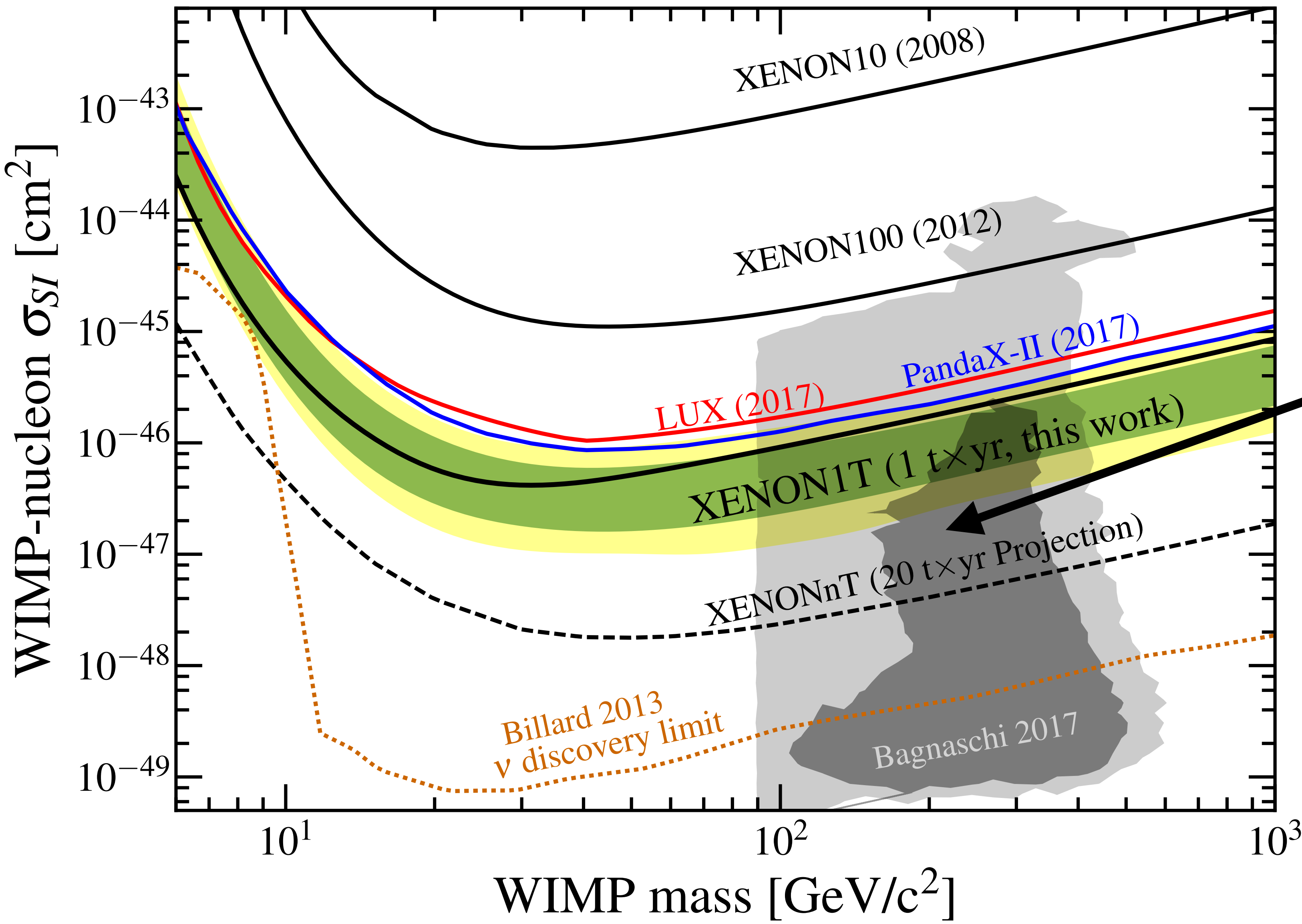


Neutron Veto

To tag and measure in situ neutron-induced background

Summary

- **XENON1T placed the most stringent SI limits for all WIMP masses above 6 GeV**
- **XENON1T keeps taking science data with improved detector performance**
- **XENONnT is on track, commissioning in 2019, with a x10 boost in sensitivity**



detect this dark matter by 2025!