Latest results of 1 tonne x year Dark Matter Search with XENON1T

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on behalf of the XENON collaboration

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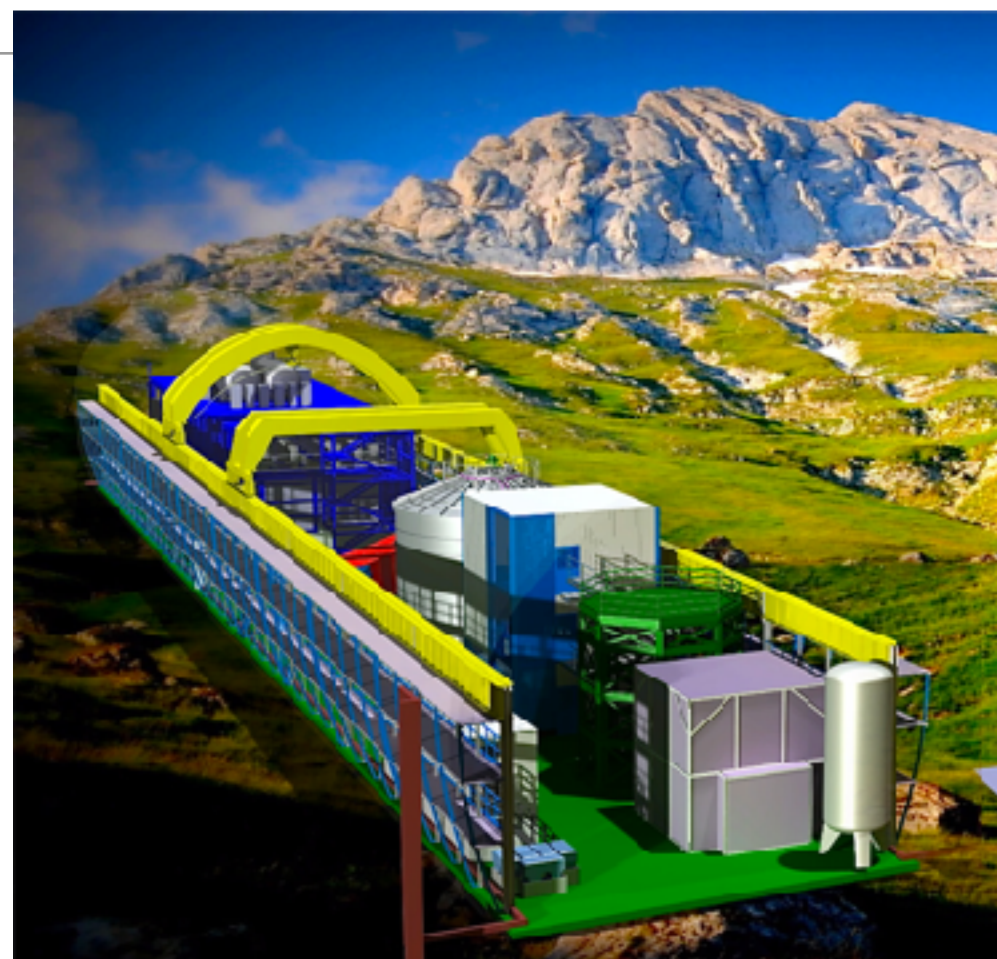
Seventh Workshop on Theory, Phenomenology and Experiments in Flavor Physics
FP-Capri2018
8-10 June 2018, Capri, Villa Orlandi, Italy



www.xenon1t.org

The XENON Collaboration:

165 scientists 25 Institutions and 11 Countries

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

Chicago

UCLA

UCSD

Rice

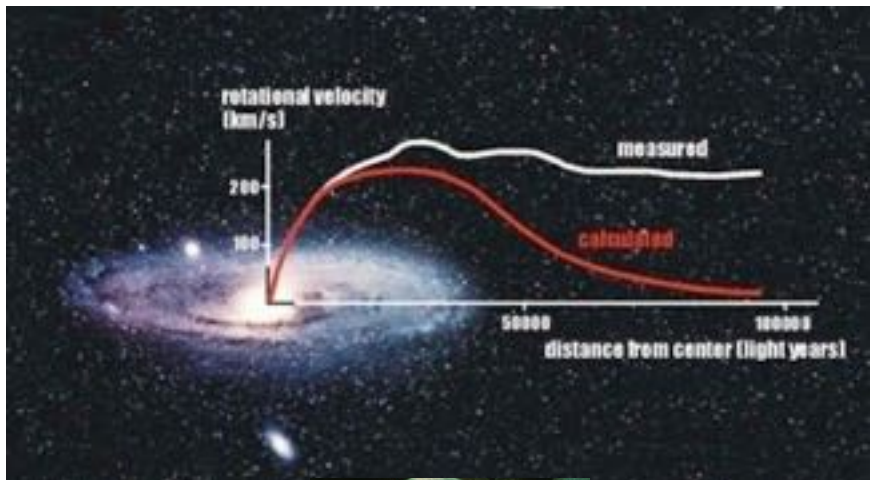
Tokyo

Nagoya

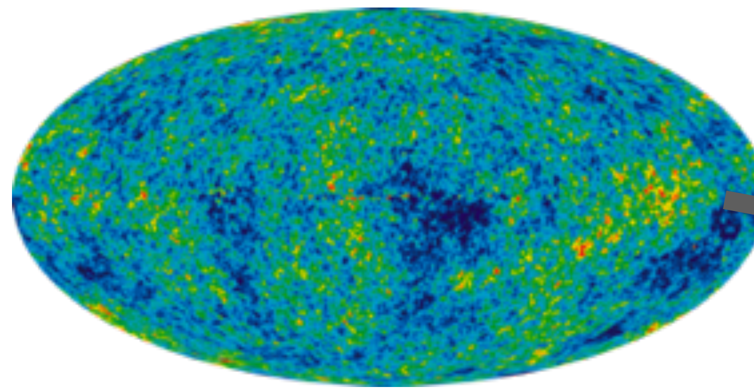
Kobe

Evidence for Dark Matter

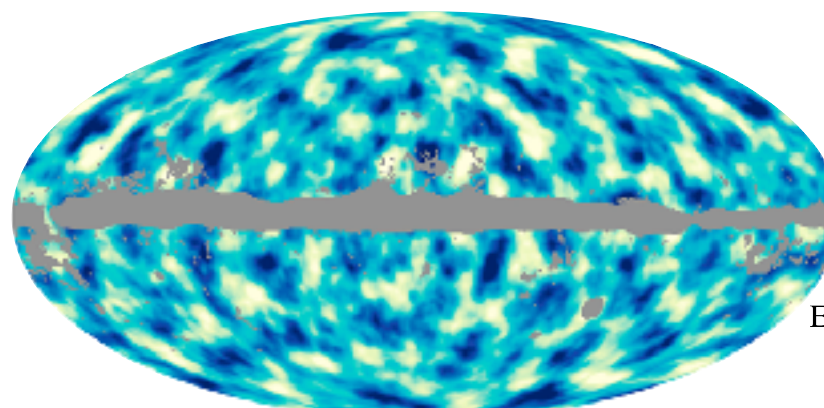
- Astrophysical Observations



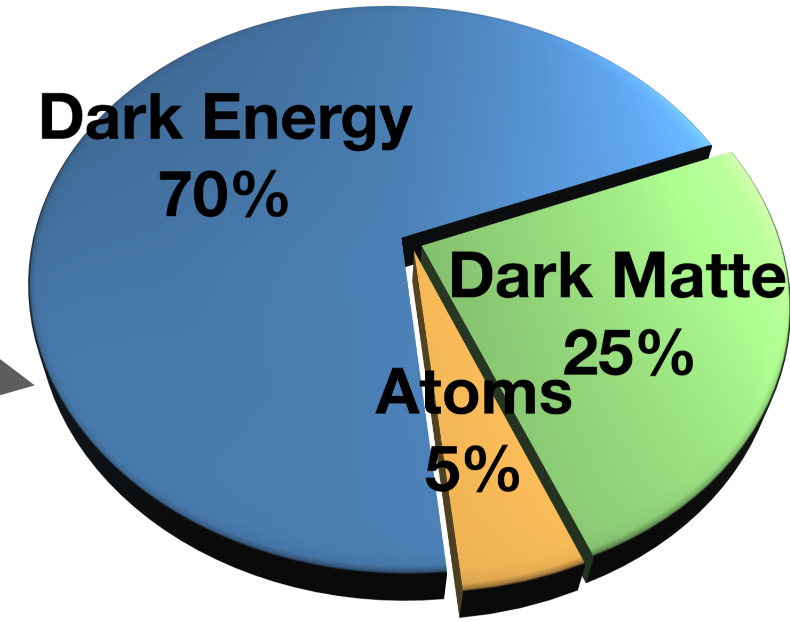
Rotational Curves

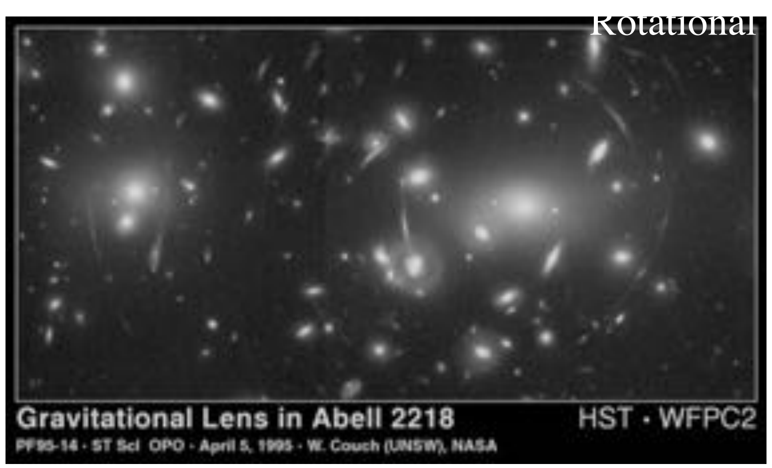


WMAP



ESA Planck





Bullet Cluster

All consistent with ~25% dark matter (give or take).

Possible candidates:

WIMPs

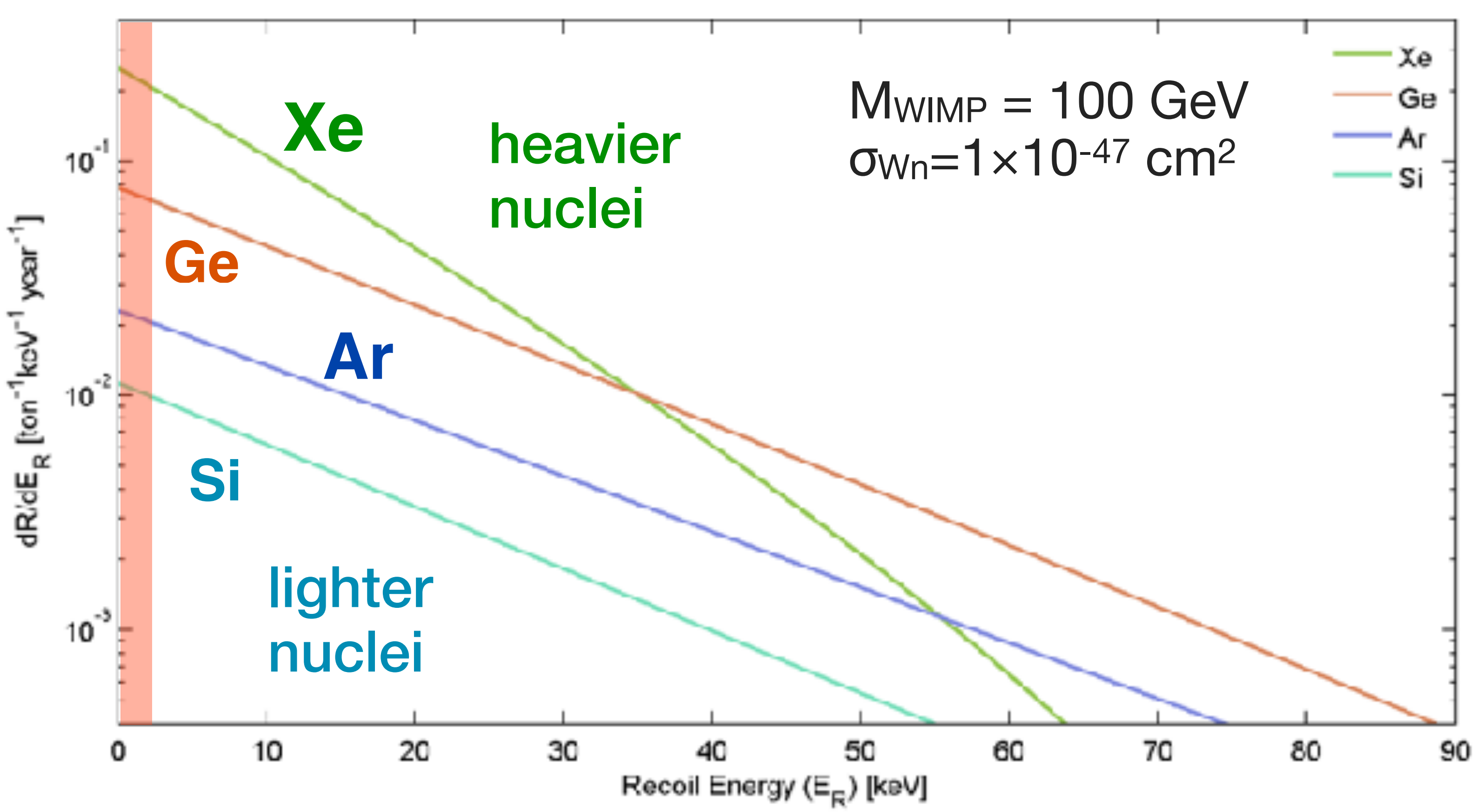
Observables: Rate

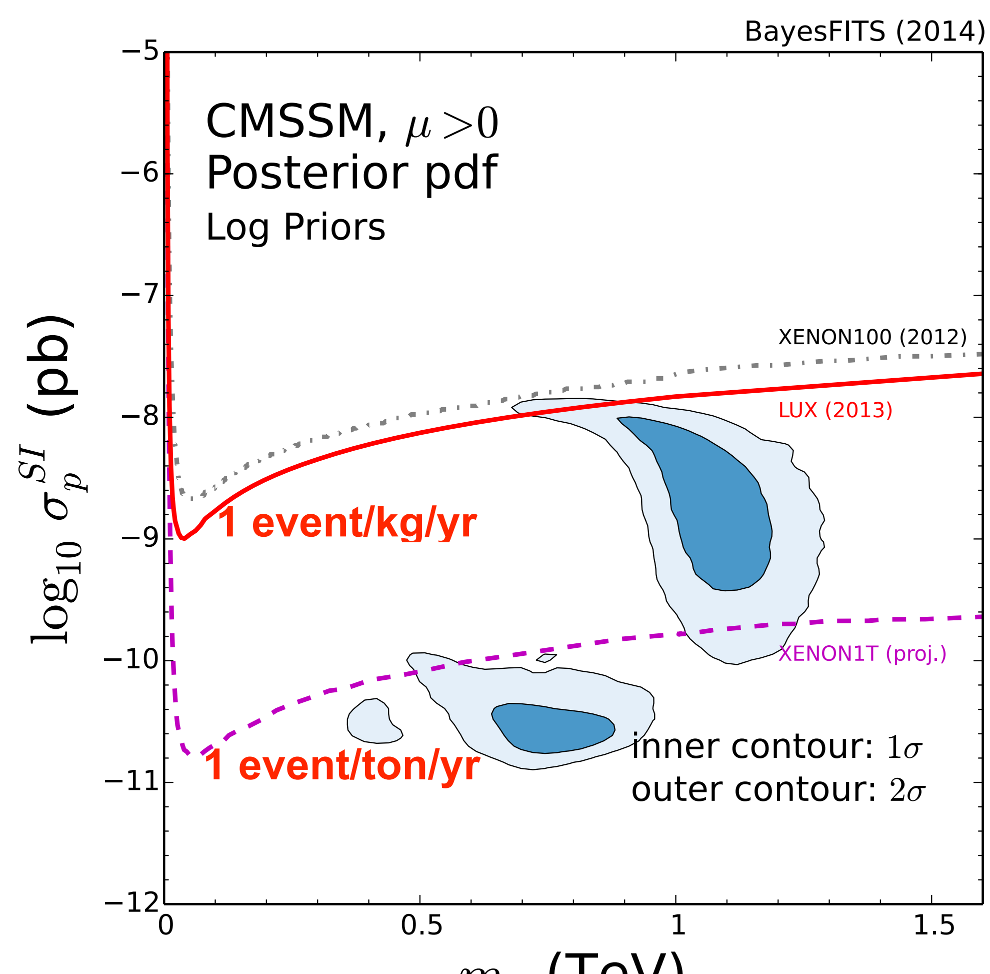
Event rate in a terrestrial detector

Detector physics **Particle/nuclear physics** **Astrophysics**

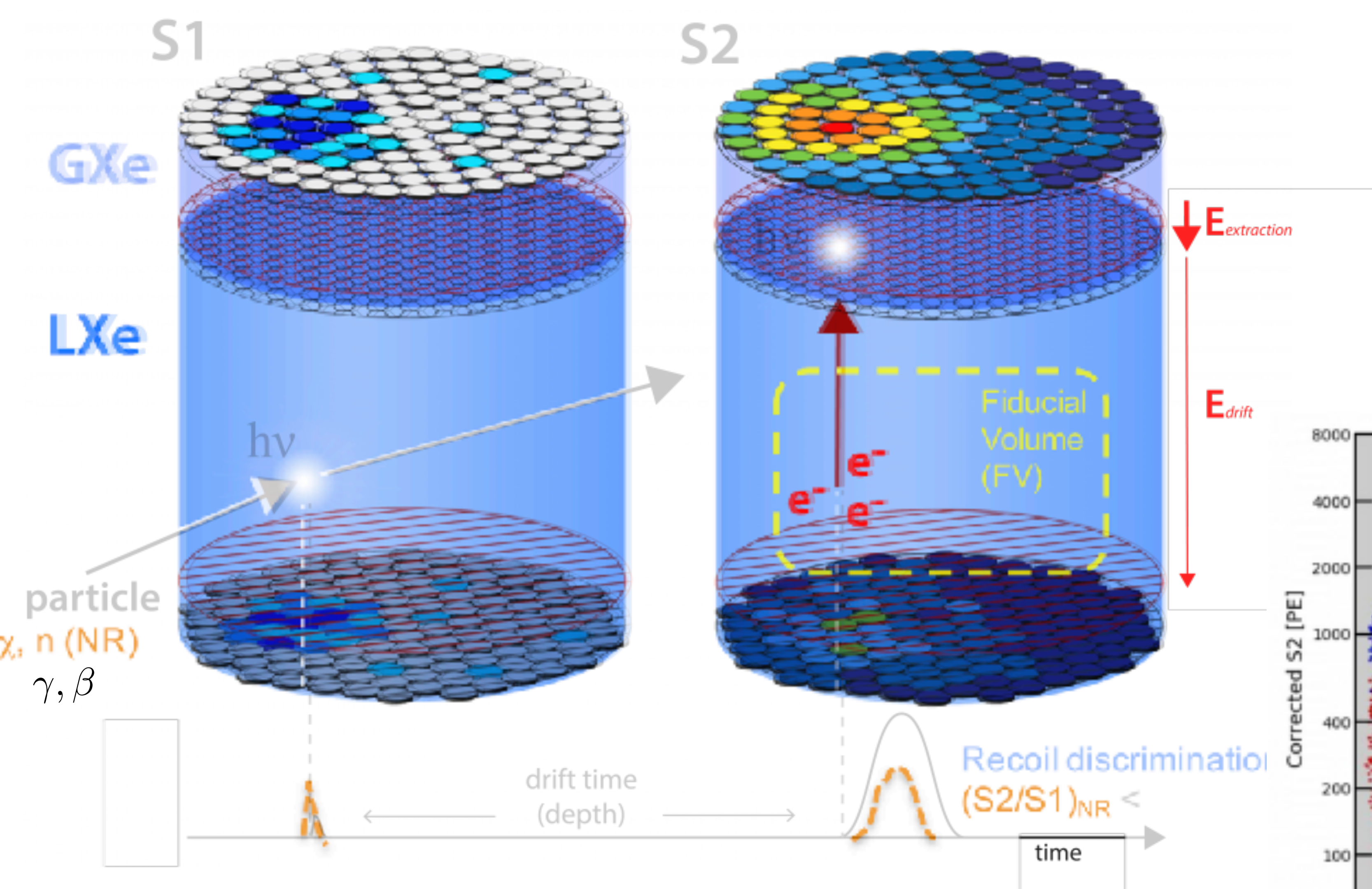
N_N, E_{th} $m_W, d\sigma/dE_R$ $\rho_0, f(v)$

$$R \sim N_N \times \frac{\rho_0}{m_W} \times \langle v \rangle \times \sigma$$

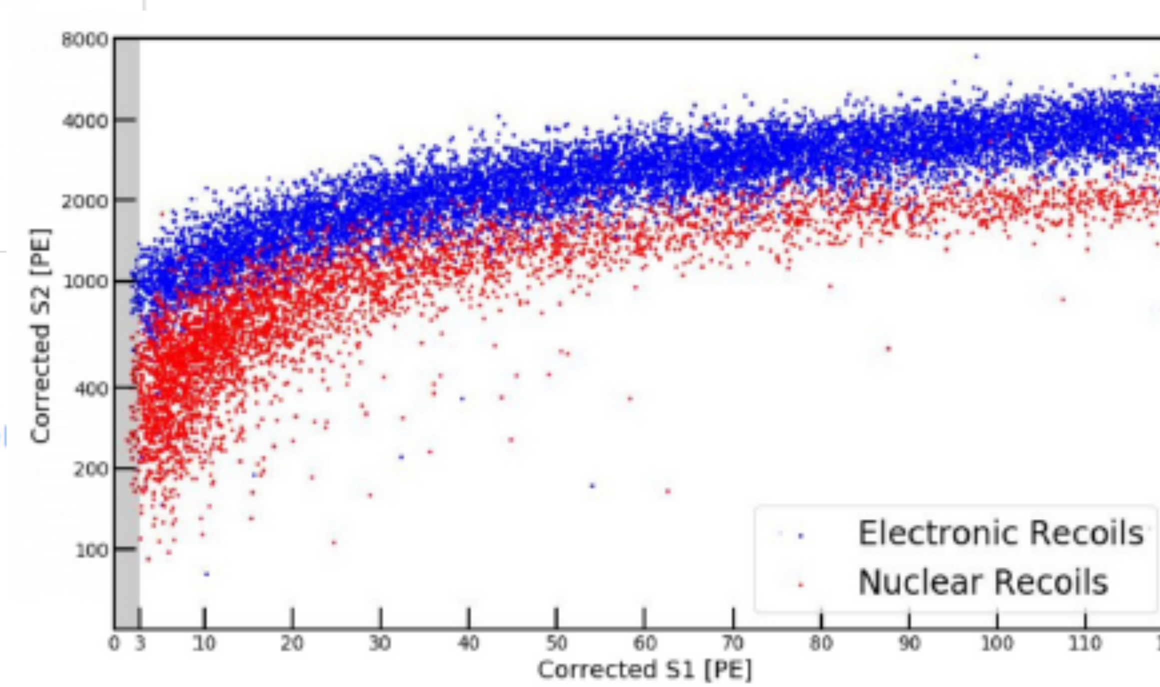




Two-phase Xe Time Projection Chamber as WIMP detector



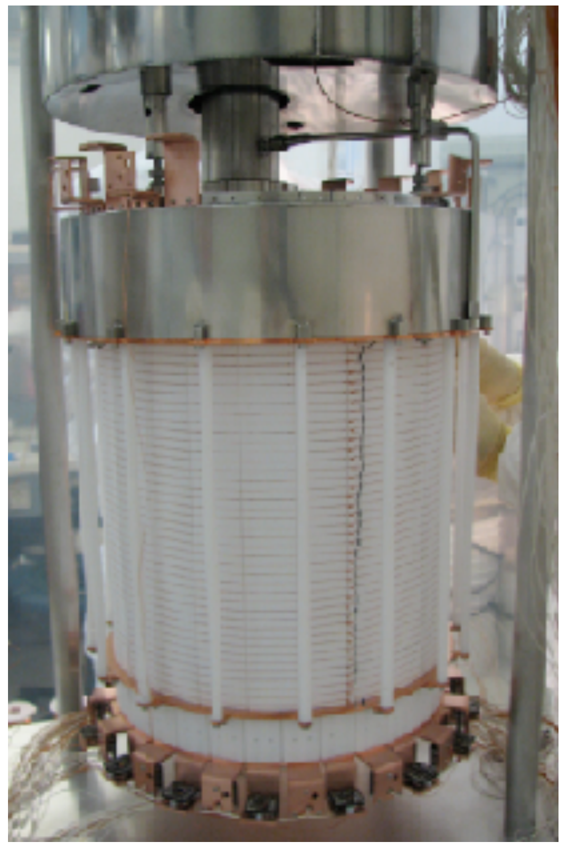
- *two signals for each event:*
  - *Energy from S1 and S2 area*
  - *3D event imaging: x-y (S2) and z (drift time)*
  - *self-shielding, surface event rejection, single vs multiple scatter events*
- *Recoil type discrimination form ratio of charge (S2) to light (S1)*



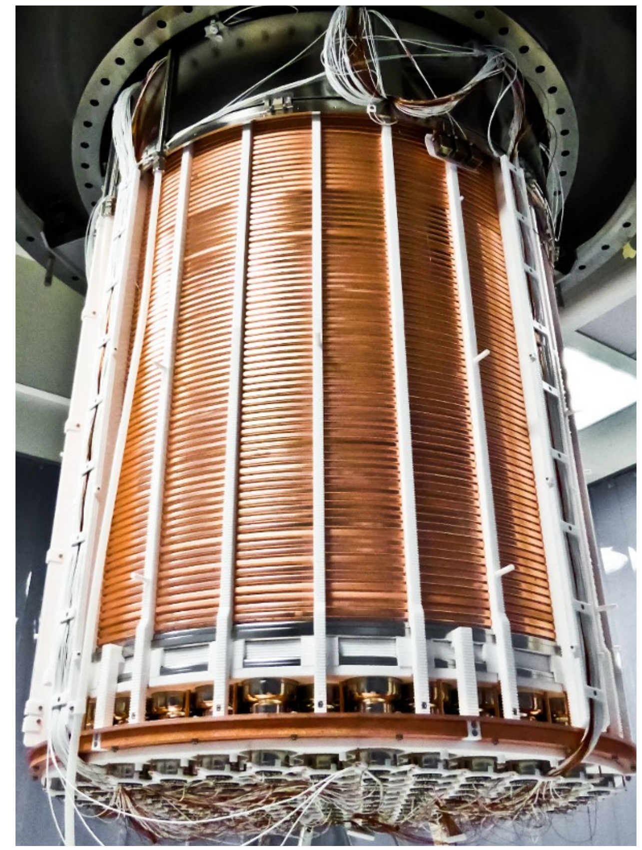
The XENON legacy

XENON10

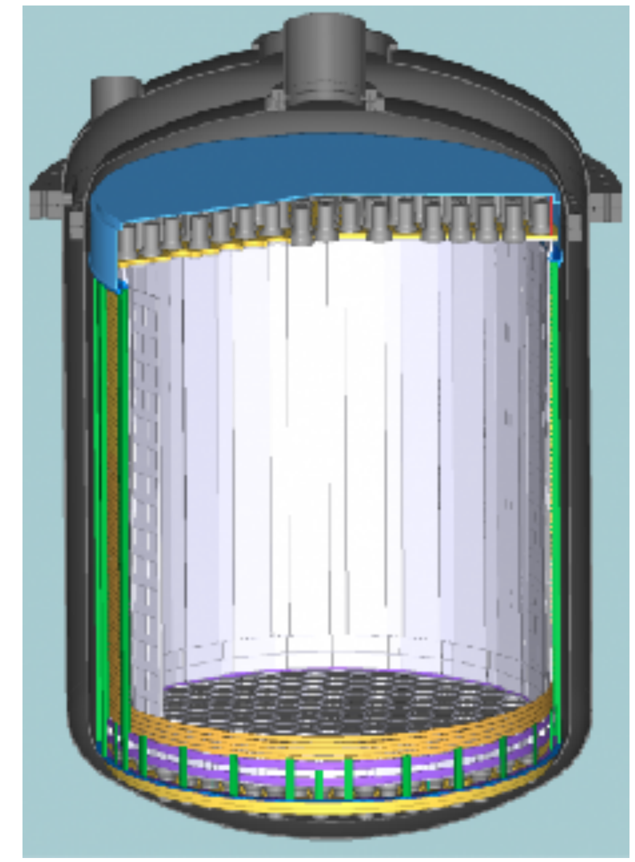
XENON100



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
BG~1000	BG~5.3	BG~0.2	BG~??

XENON1T experiment

All Systems

E. Aprile et all, “The XENON1T Dark Matter experiment, EPJ C 77, 881 (2017)

XENON1T experiment

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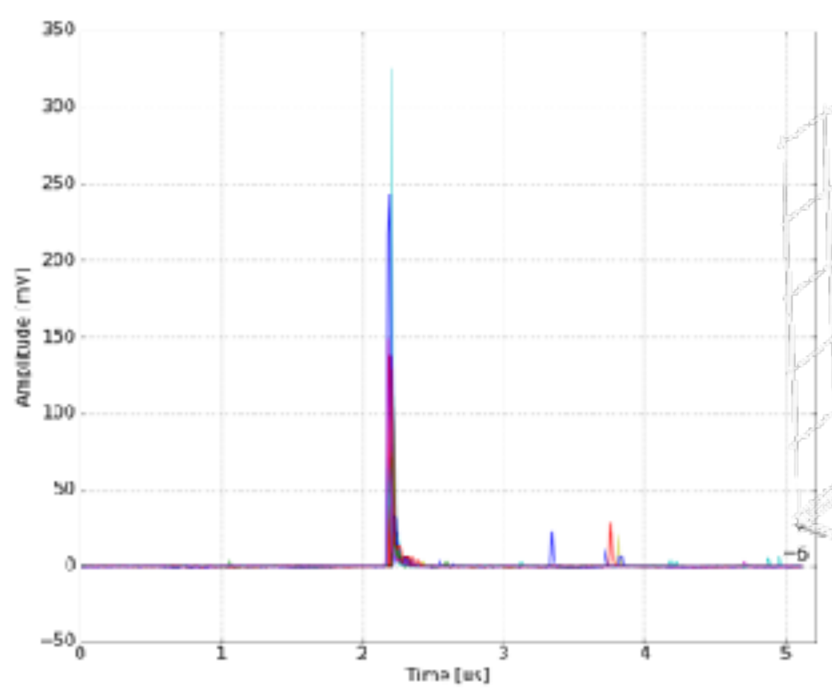
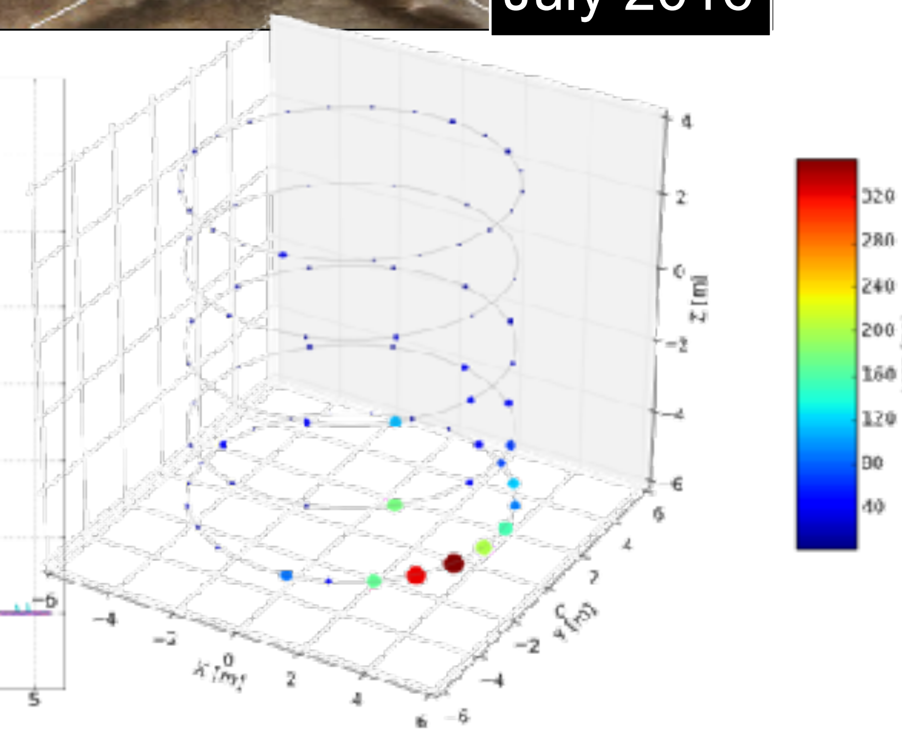
Water Cherenkov Muon Veto

- 700 t pure water instrumented with 84 high-QE 8'' PMTs
- Active shield against muons
- Trigger efficiency > 99.5% for muons in the water tank
- Cosmogenic neutron background suppressed to < 0.01 events/t/yr





JINST 9, 11007 (2014)

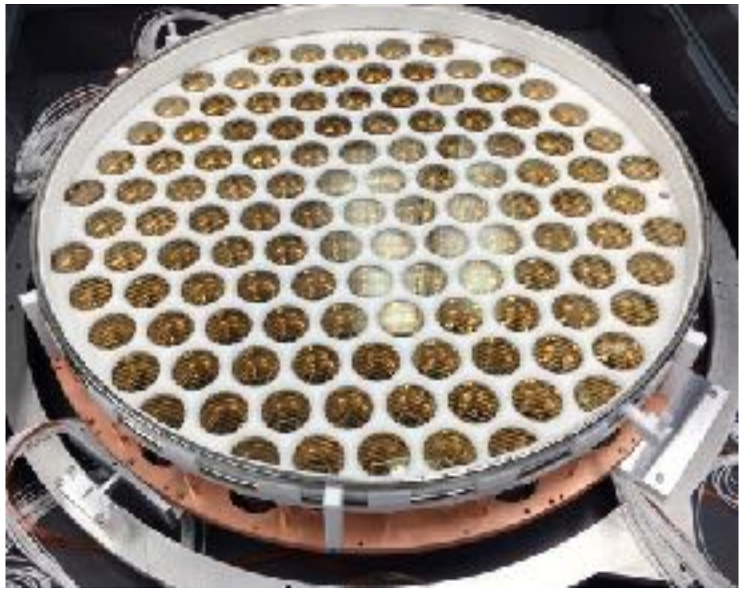
The XENON1T Time Projection Chamber

The XENON1T Light Detection System

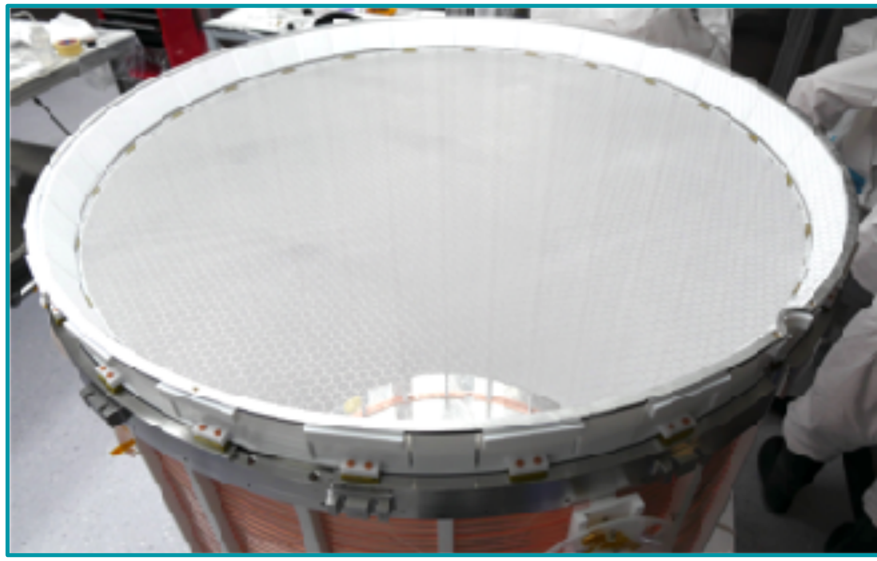
- 248 3-inch low-radioactivity Hamamatsu R11410-21 PMTs arranged in two arrays.
- 35% QE @ 178 nm
- each PMT digitized at 100MHz
- operating gain 1-5x10^6 @ 1.5kV stable within 1-2 %
- SPE acceptance ~94%
- High reflectivity PTFE lining of entire inner volume
- Highly-transparent (>90%) grid electrodes

EPJC 75 (2015) 11, 546

127 PMTs in the top array



121 PMTs in the bottom array



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EPJC 75 (2015) 11, 546

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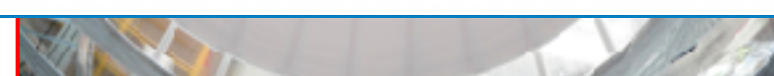
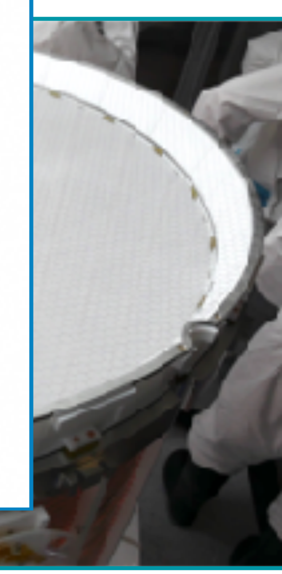
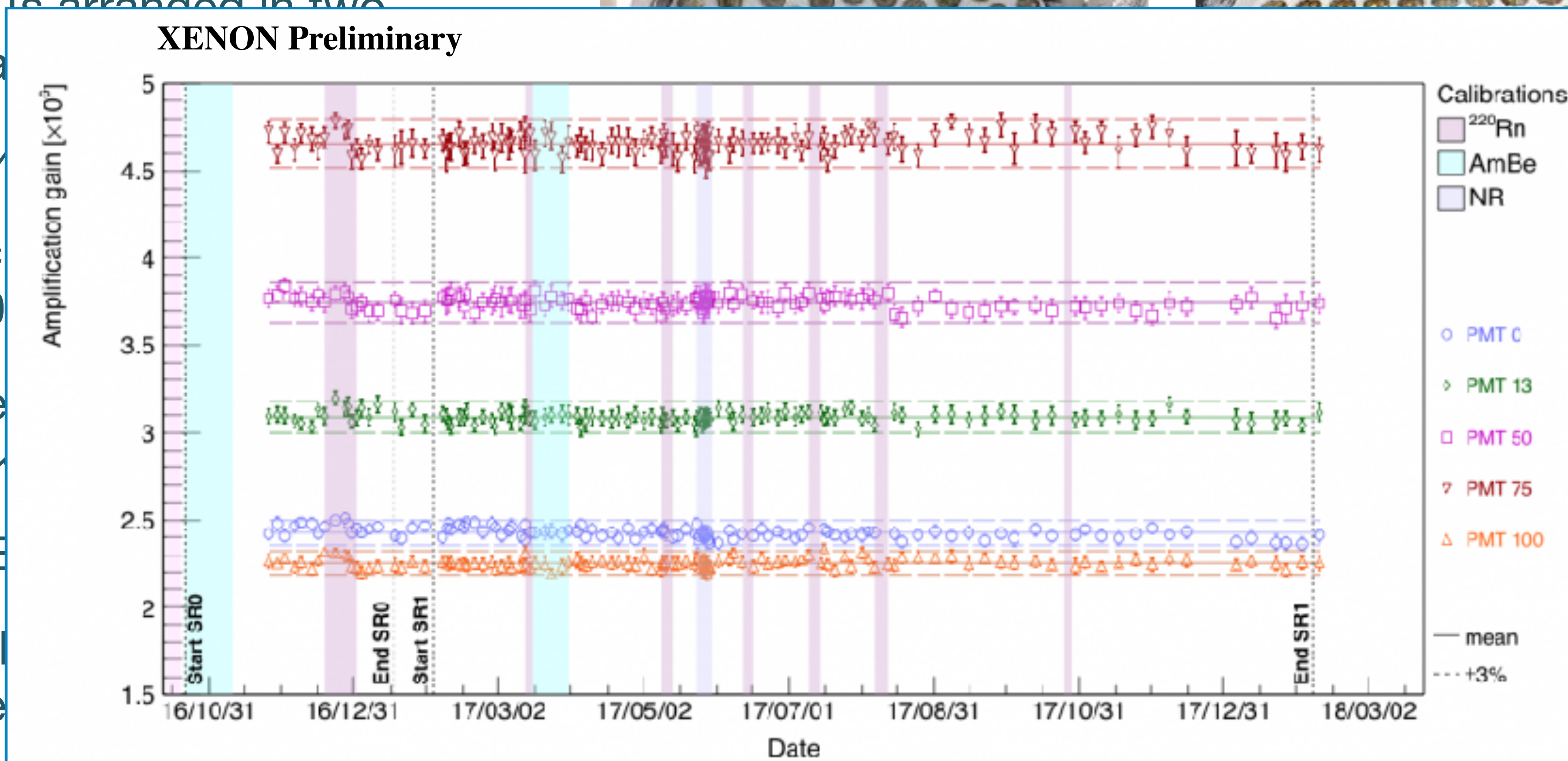
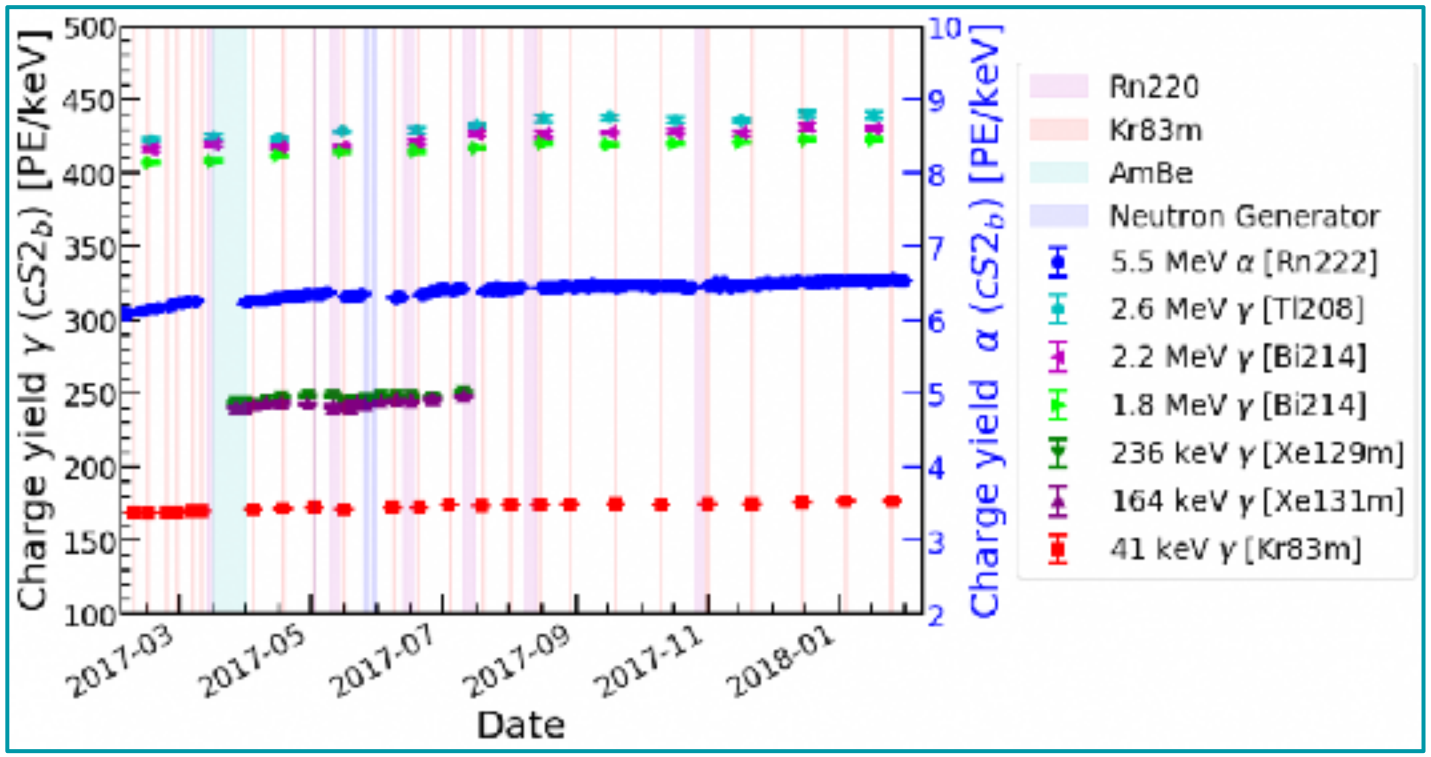


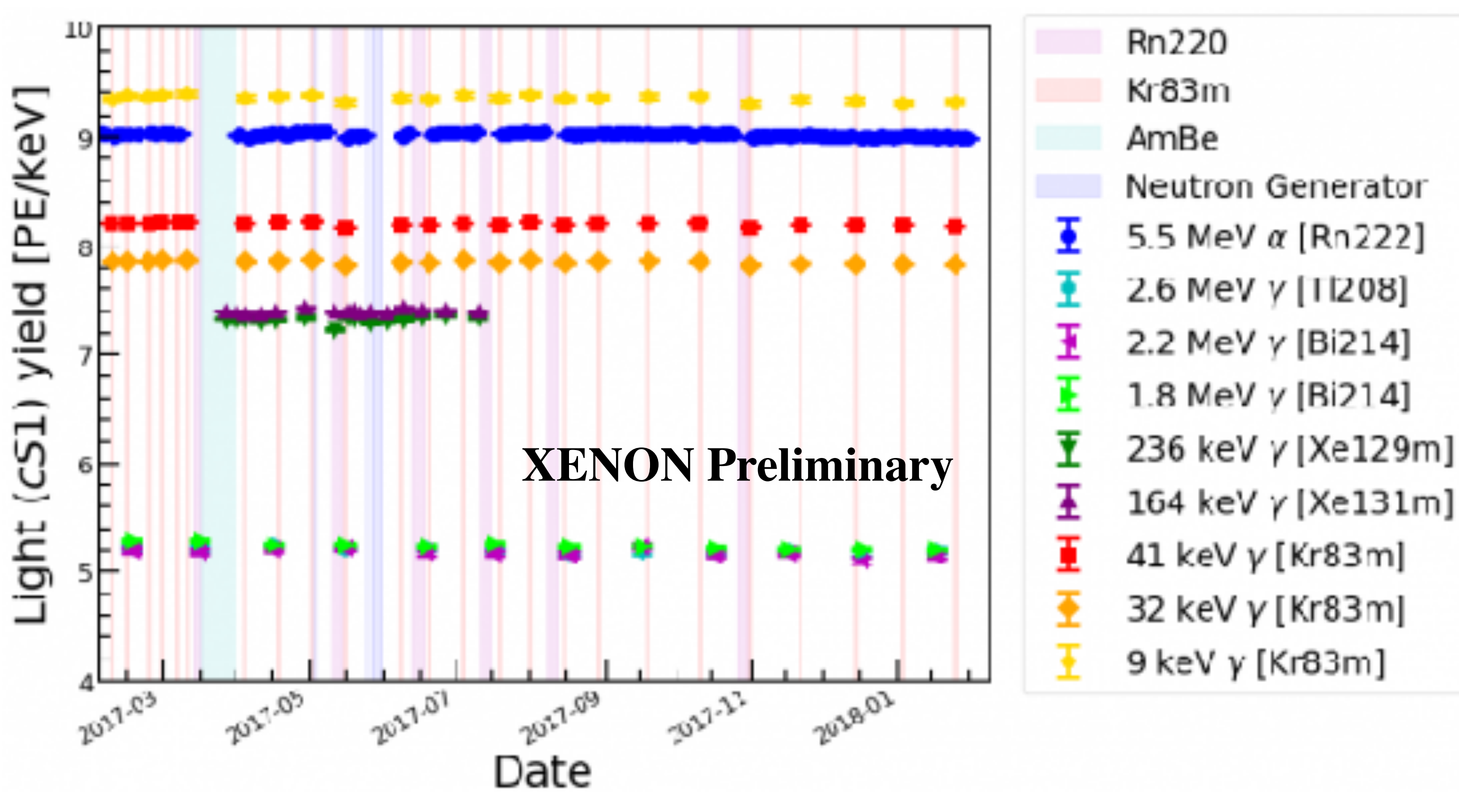




Light and Charge Signals Stability

stability of many more variables are checked as function of time



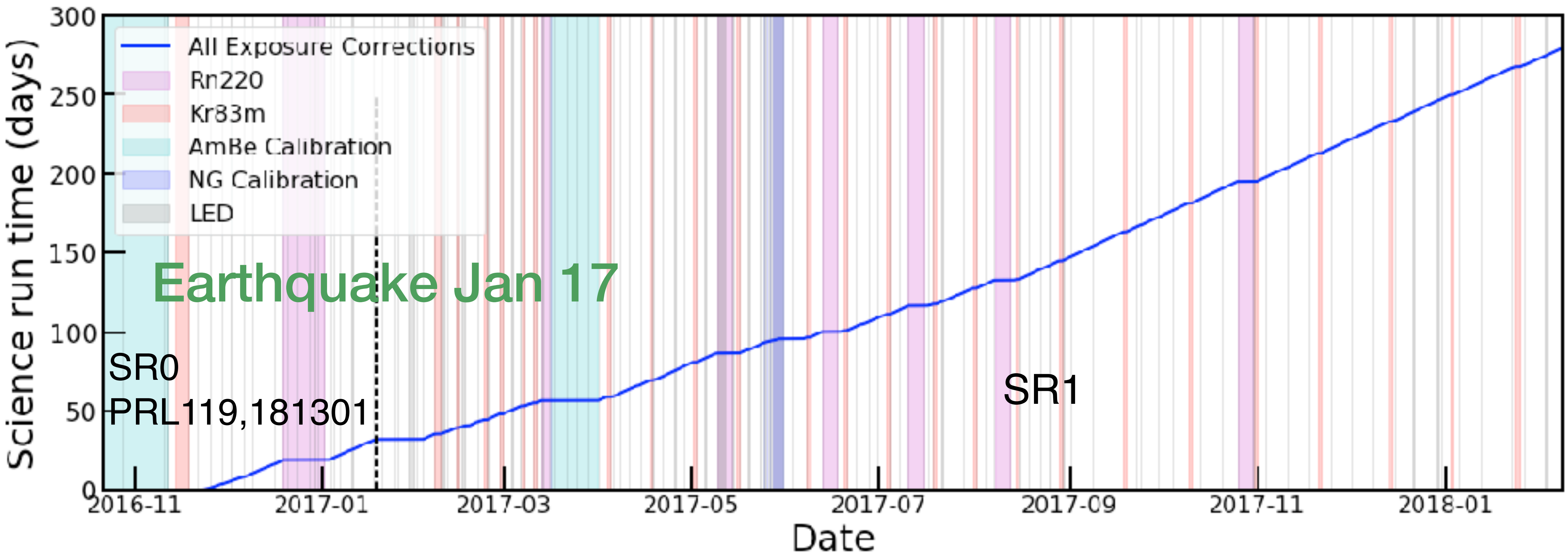


Light and charge yield stability monitored with several sources:

- ^{222}Rn daughters
- Activated Xe after neutron calibrations
- ^{83m}Kr calibrations
- ^{214}Bi and ^{208}Tl for high energy calibration
- Stability is within a few %

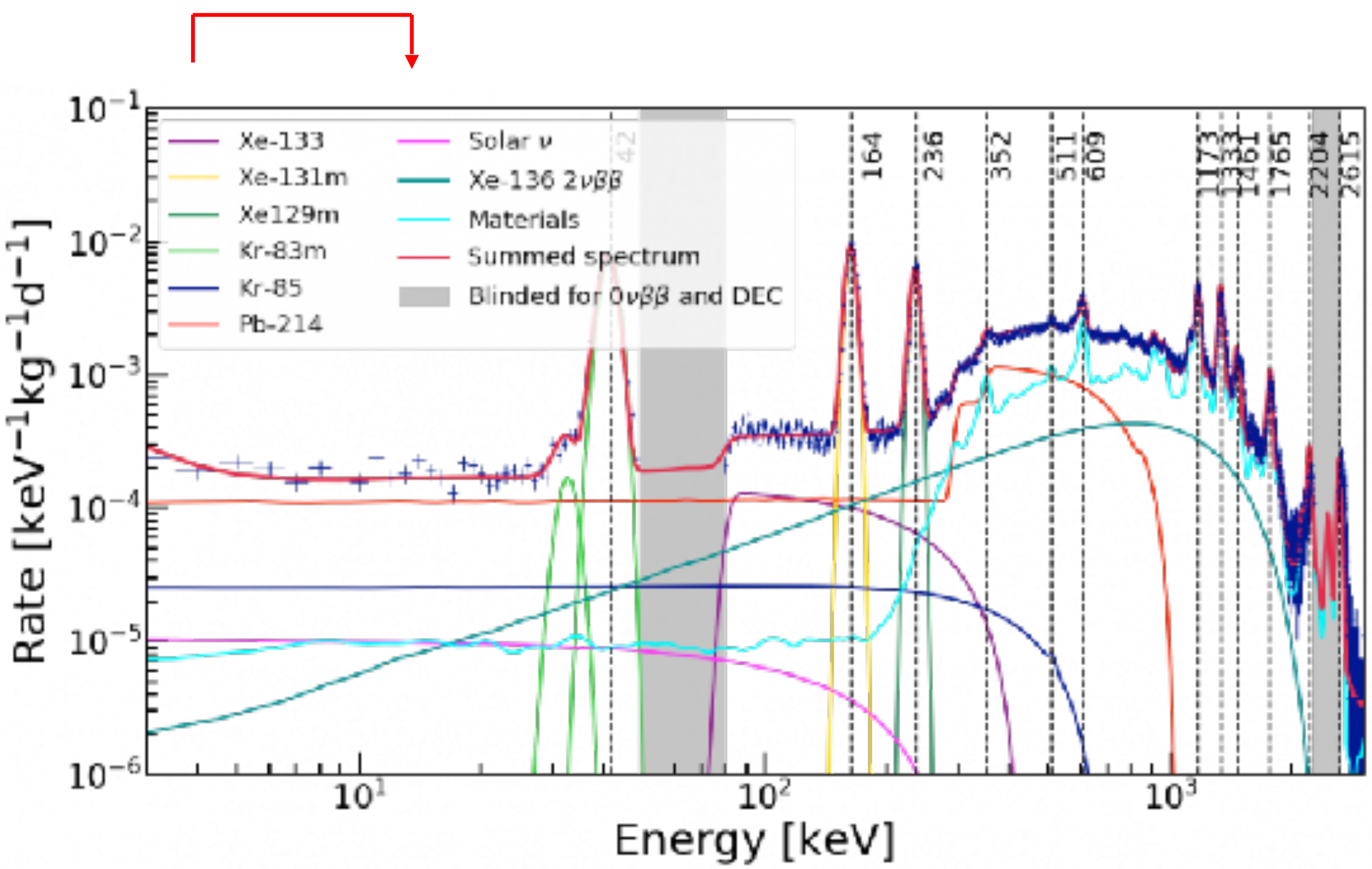
XENON1T: science and calibration data

- 279 days of DM data taking since Spring 2016
- The largest exposure reported so far with this type of detector

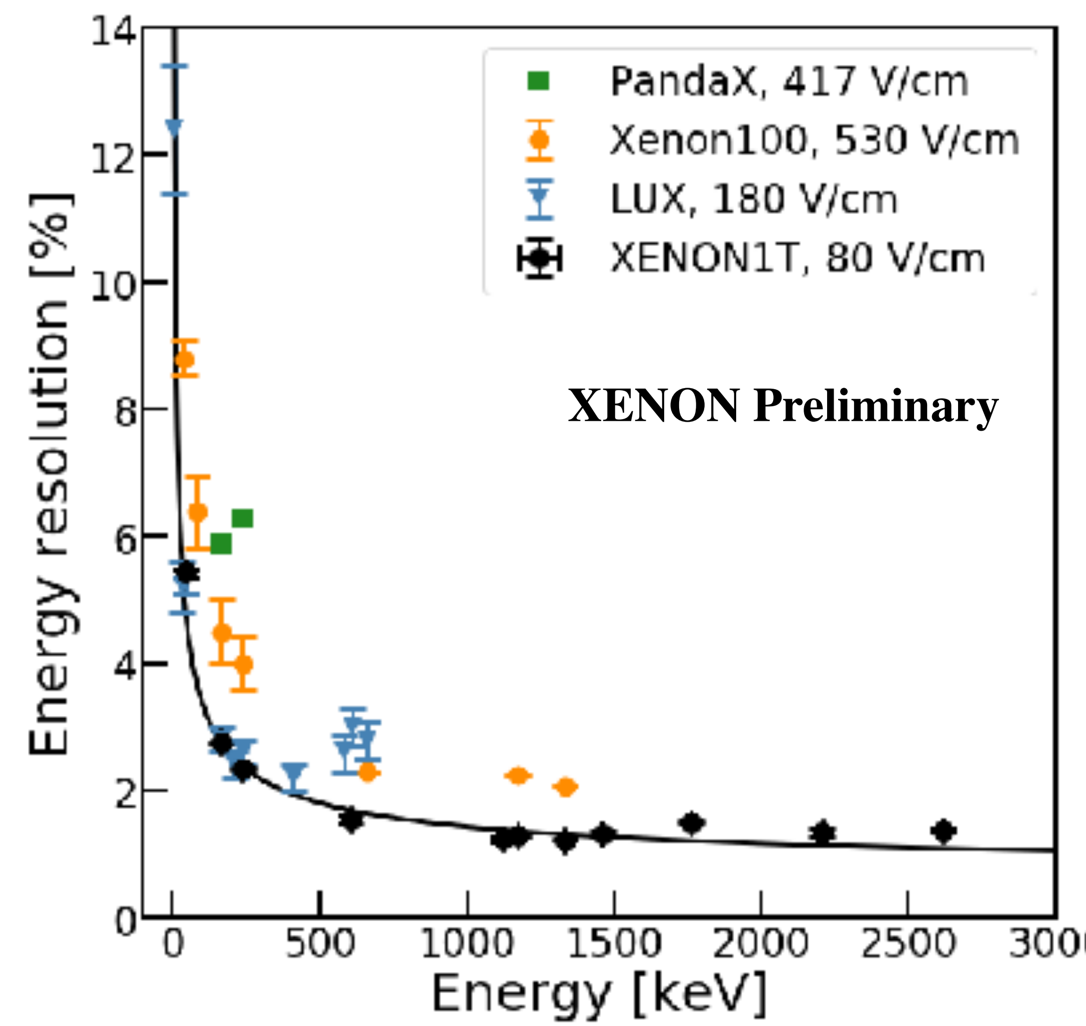


Energy Resolution

ROI for WIMP search
up to 11 keV

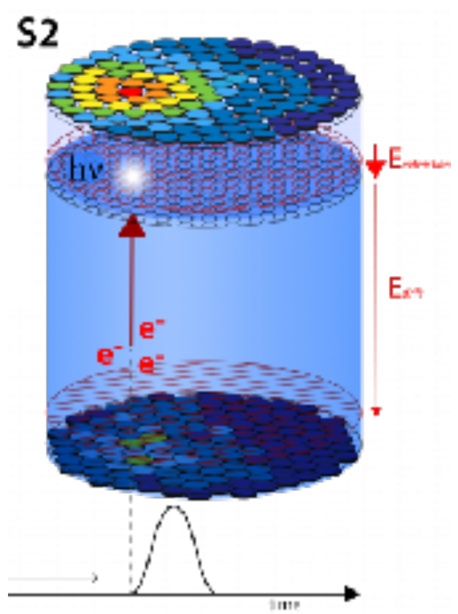


- Energy scale from a combination of S1 and S2. Excellent linearity from keV to MeV
- Best energy resolution ever measured with a LXeTPC ~1.6% at 2.5 MeV and 6% at 40 keV



- Good agreement between predicted and measured background spectrum
- ^{85}Kr: ~0.66 ppt; ^{214}Pb: ~ 10 uBq/kg

Position Reconstruction



X-Y reconstruction via **neural network**:

- **Input:** charge/channel top array
- **Training:** Monte Carlo simulation

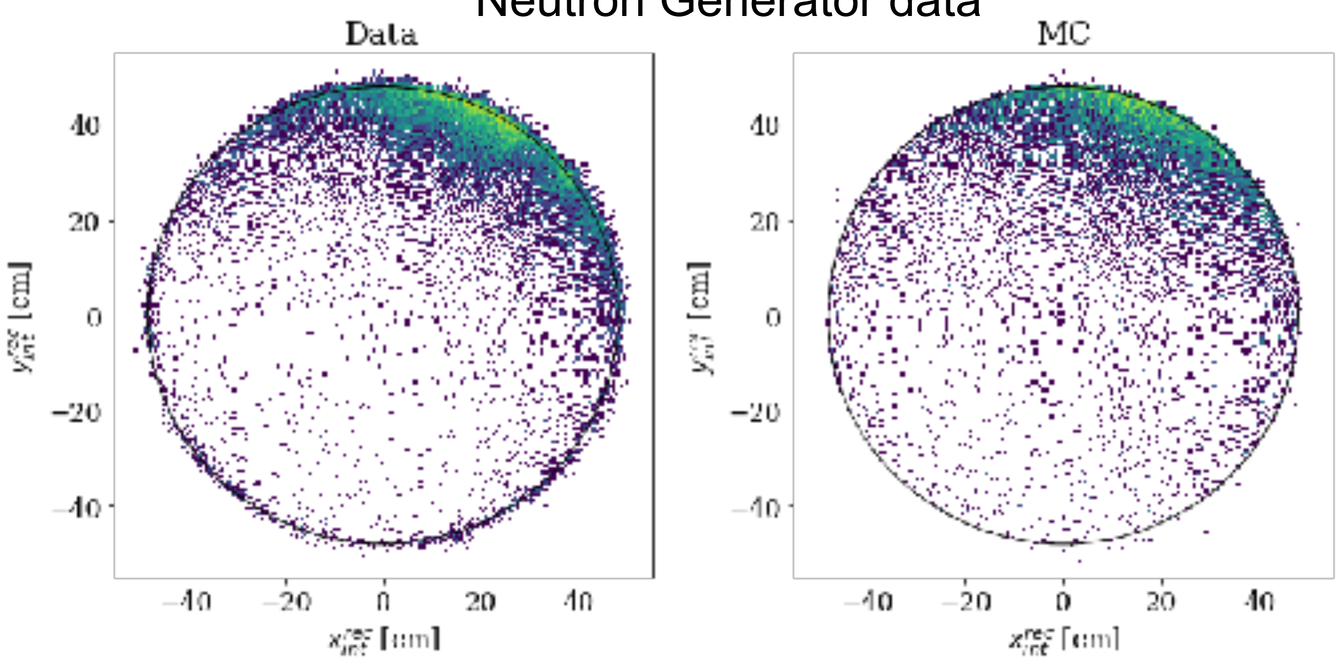
Position resolution using ^{83m}Kr

- Two interactions (9, 31 keV), same x-y
- Position resolution (1-2 cm)

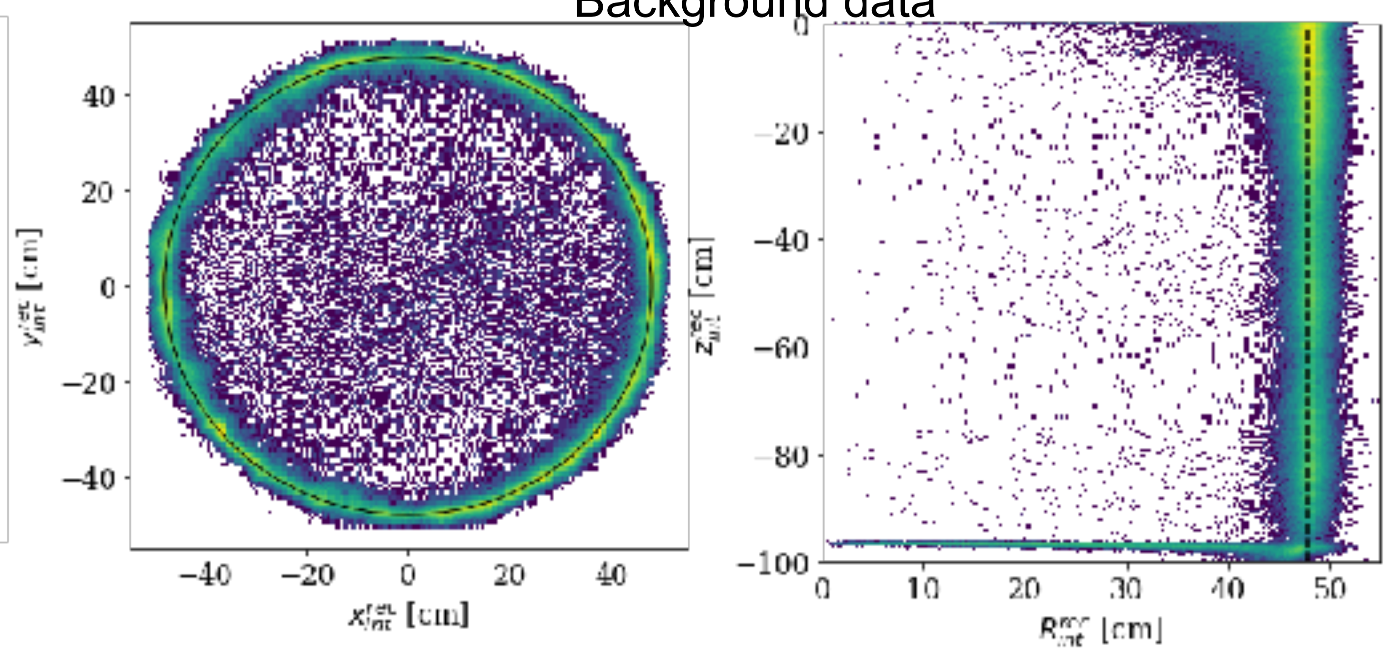
Position corrections using ^{83m}Kr

- **Drift field distortion**
- Localized inhomogeneities from inactive PMTs
- Data-derived correction verified by comparison to MC with several event sources

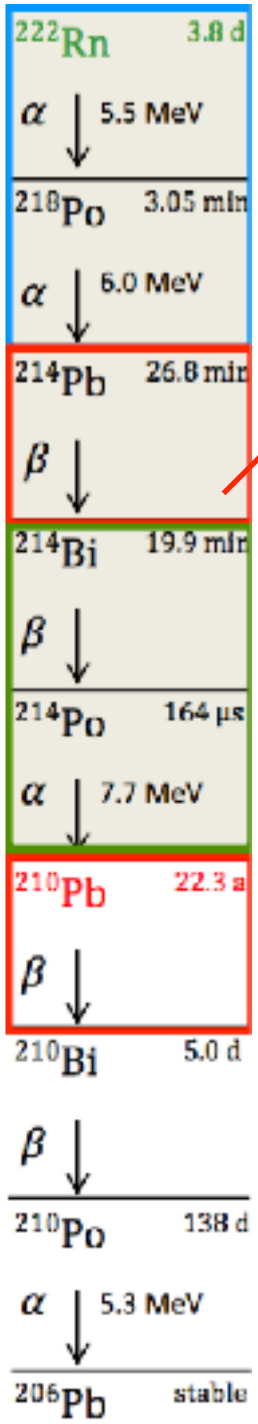
Neutron Generator data



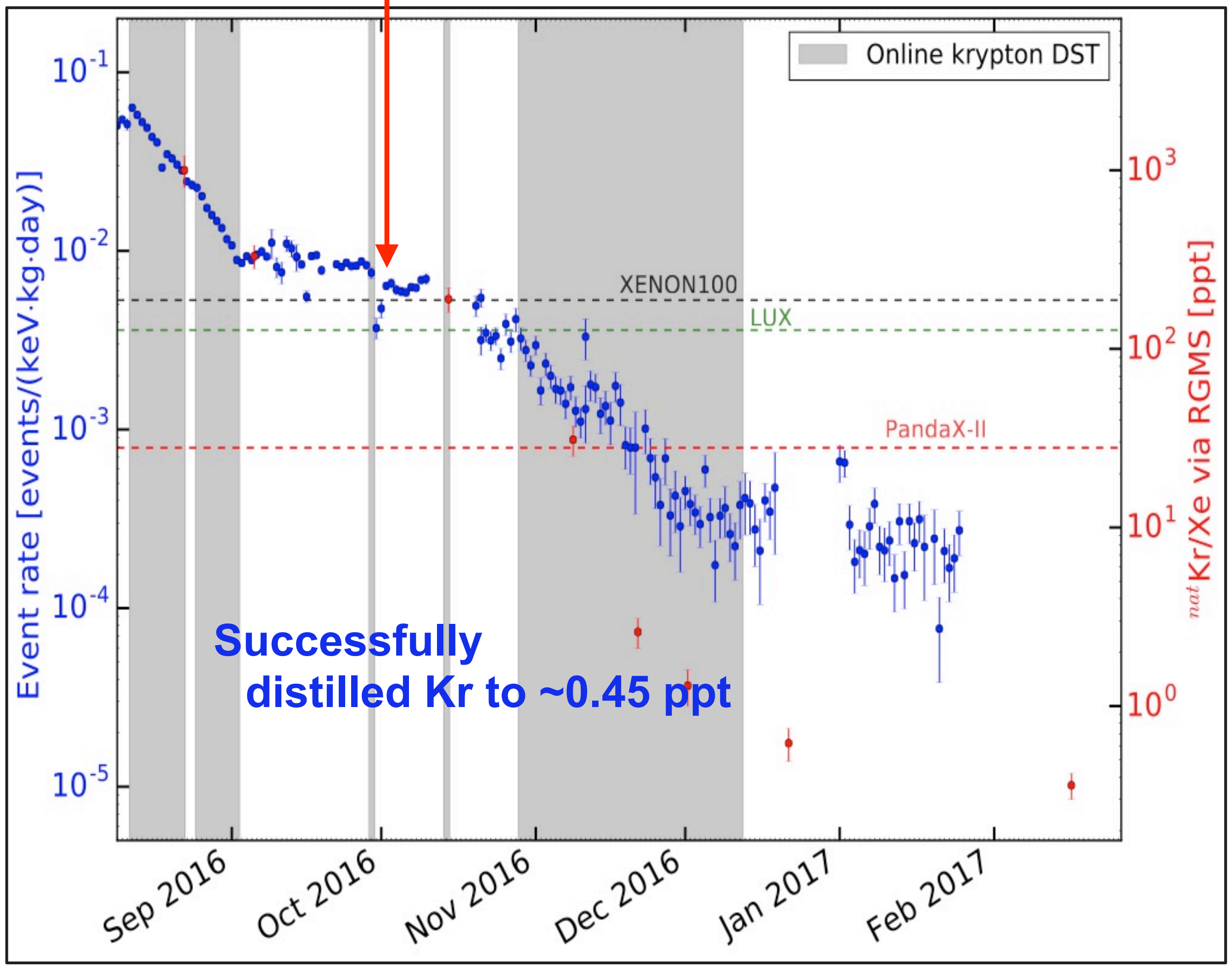
Background data



Electronic Recoil Backgrounds



- **Rn222 : 10 uBq/kg**
  - **Achieved with careful surface emanation control and measurements**
  - **Further reduction with online cryogenic distillation**
- **Kr85 : sub-ppt Kr/Xe**
  - **Achieved with online cryogenic distillation**
- **Materials radioactivity (HPGe gamma screening): subdominant**



ER Background Evolution

Source	Rate [t^{-1} y^{-1}]	Fraction [%]
222Rn	620 ± 60	85.4
85Kr	31 ± 6	4.3
Solar ν	36 ± 1	4.9
Materials	30 ± 3	4.1
136Xe	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

Predicted: (considering considering 10 uBq/kg of ^{214}Pb and 0.66 ppt of Kr):

(71 ± 7) events / (t·year·keV)

Measured: in 1300 kg FV and below 25 keVee

(82^{+5}_{-3} (syst)± 2 (stat)) events / (t·year·keV)

Lowest ER background ever achieved in a DM detector !

Nuclear Recoil Backgrounds

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

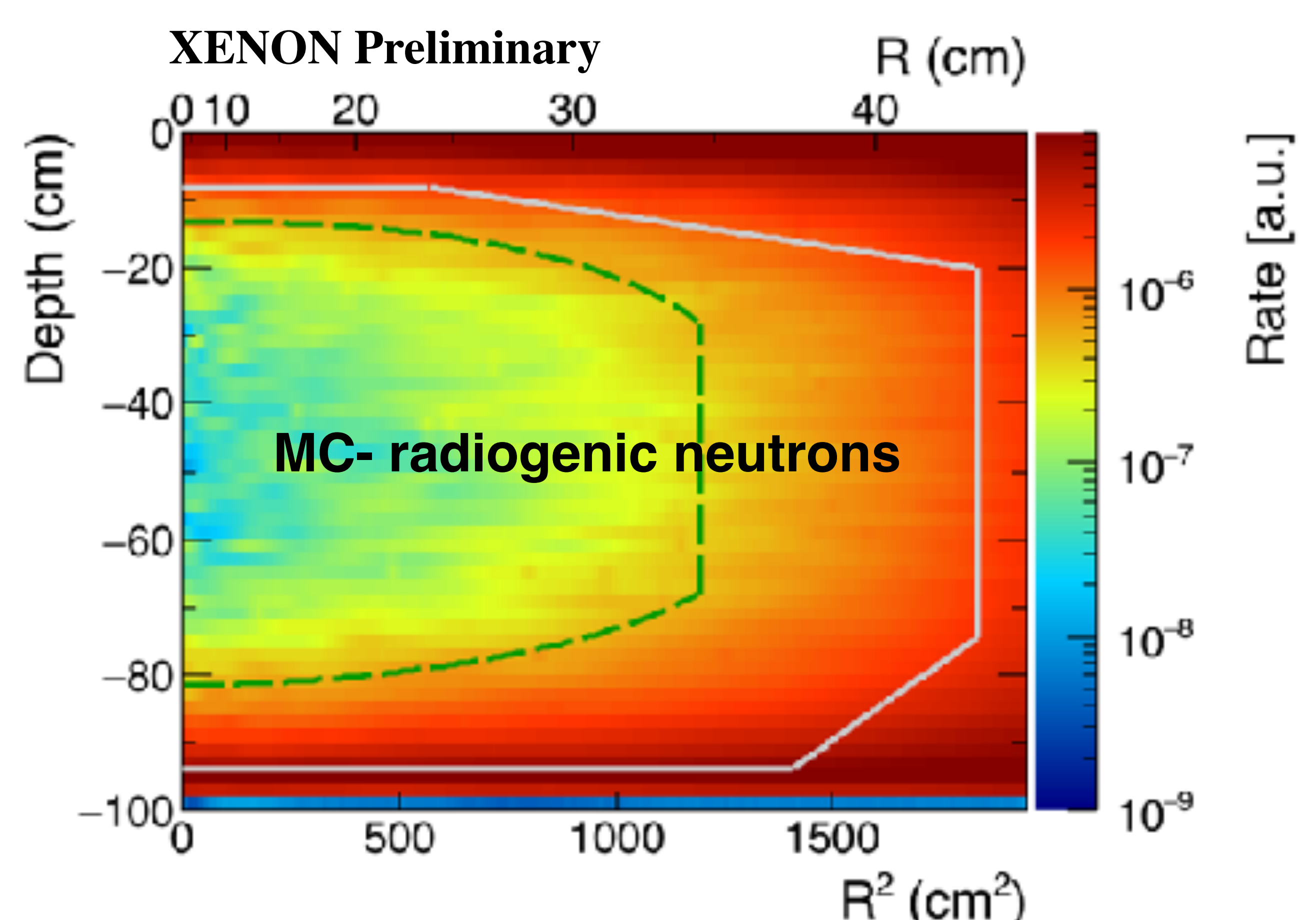
Coherent elastic ν-nucleus scattering, is an an irreducible background at very low energy (1 keV)

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

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

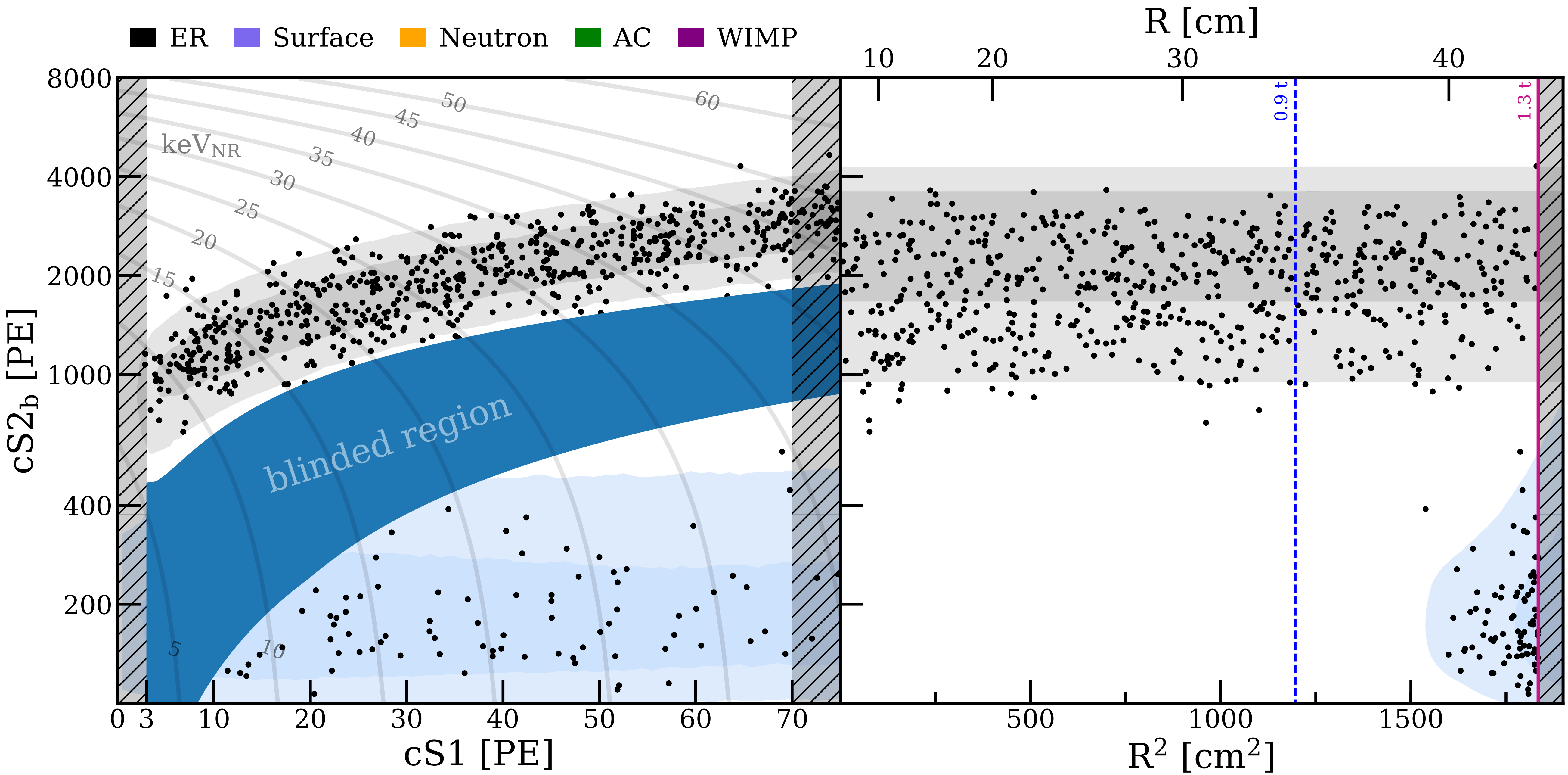
(Expectations in 4-50 keV search window, 1t FV, single scatters)

JCAP04 (2016) 027

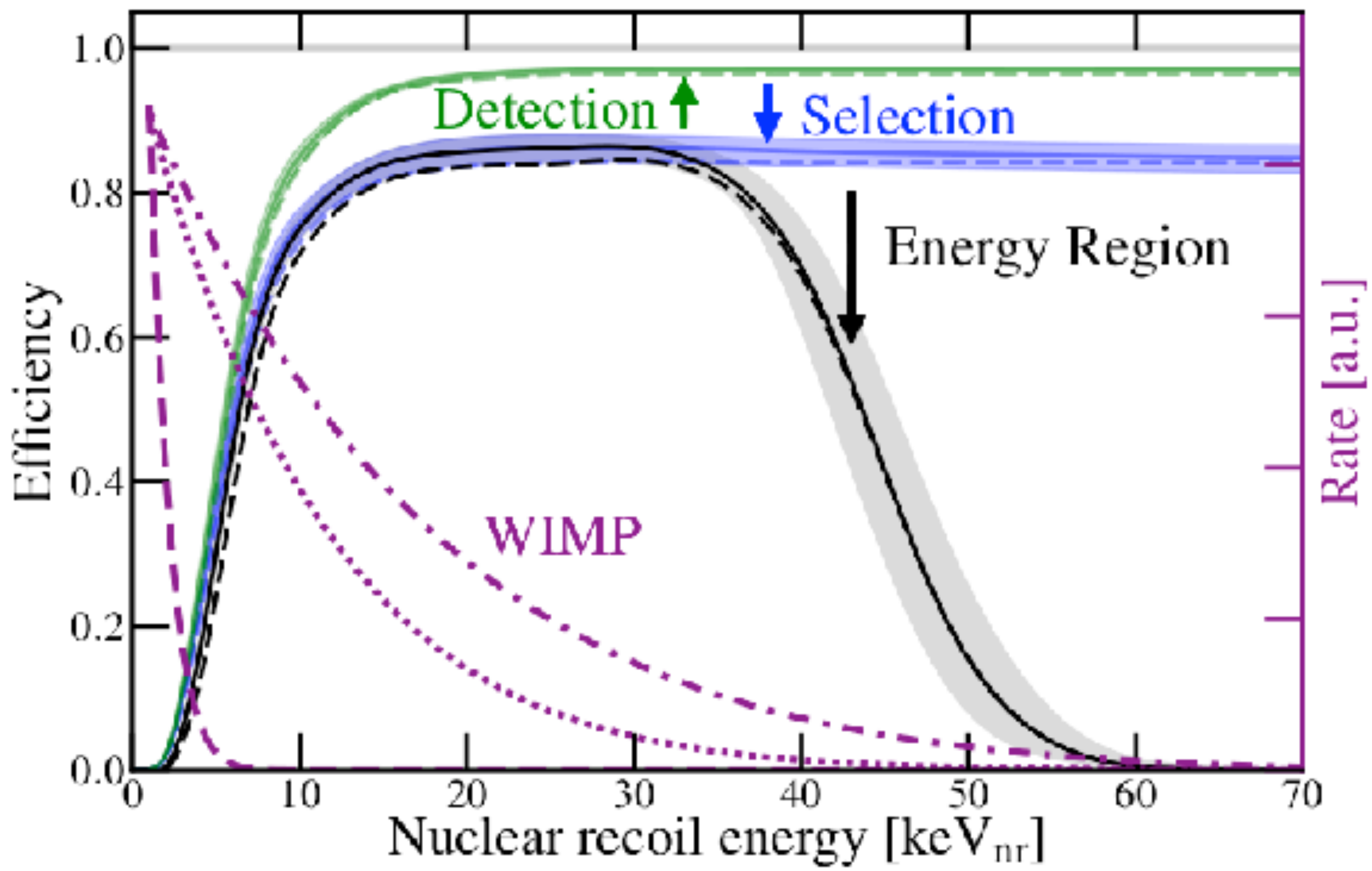


Dark Matter Search Data: Blinded and salted

- Blinding: to avoid potential bias in event selection and the signal/background modeling the nuclear recoil ROI (S2 vs S1 only) was blinded from the start of SR1 analysis (and SR0 re-analysis).
- Salting: to protect against post-unblinding tuning of cuts and background models, an undisclosed number and type of event was added to data



Event Selection & Detection Efficiency



- Detection efficiency dominated by 3-fold coincidence requirement
- Selection efficiencies estimated from control or MC data samples
- Search region defined within 3-70 PE in cS1
- 10 GeV (dashed) 50 GeV (dotted) and 200 GeV (dashed and dotted) WIMP spectra shown

Background prediction and Unblinding

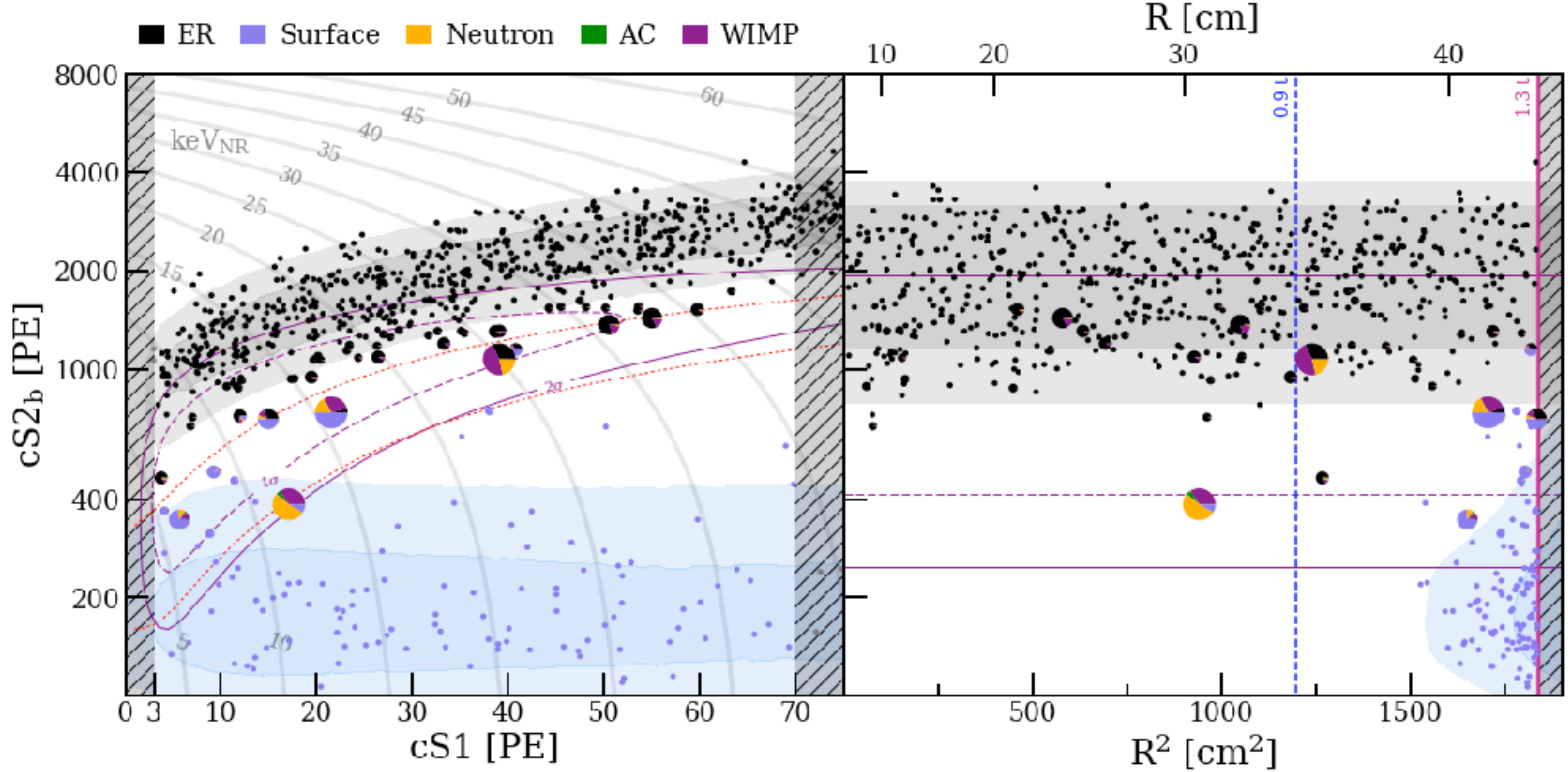
FV volume increased from 1 tonne (in SR0 First Result) to 1.3 tonne thanks to improvements in position reconstruction

Mass	1.3t	1.3t	0.9t
(S2, S1)	Full	Reference	Reference
ER	627±18	1.62±0.30	1.12±0.21
Neutron	1.43±0.66	0.77±0.35	0.41±0.19
CEνNS	0.05±0.02	0.03±0.01	0.02
AC	$0.47^{+0.27}_{-0.00}$	$0.10_{-0.00}^{+0.06}$	$0.06_{-0.00}^{+0.03}$
Surface	106±8	4.84±0.40	0.02
BG	735±20	7.36±0.61	1.62±0.28
Data	**739**	**14**	**2**
WIMPs best-fit (200GeV)	3.36	1.70	1.16

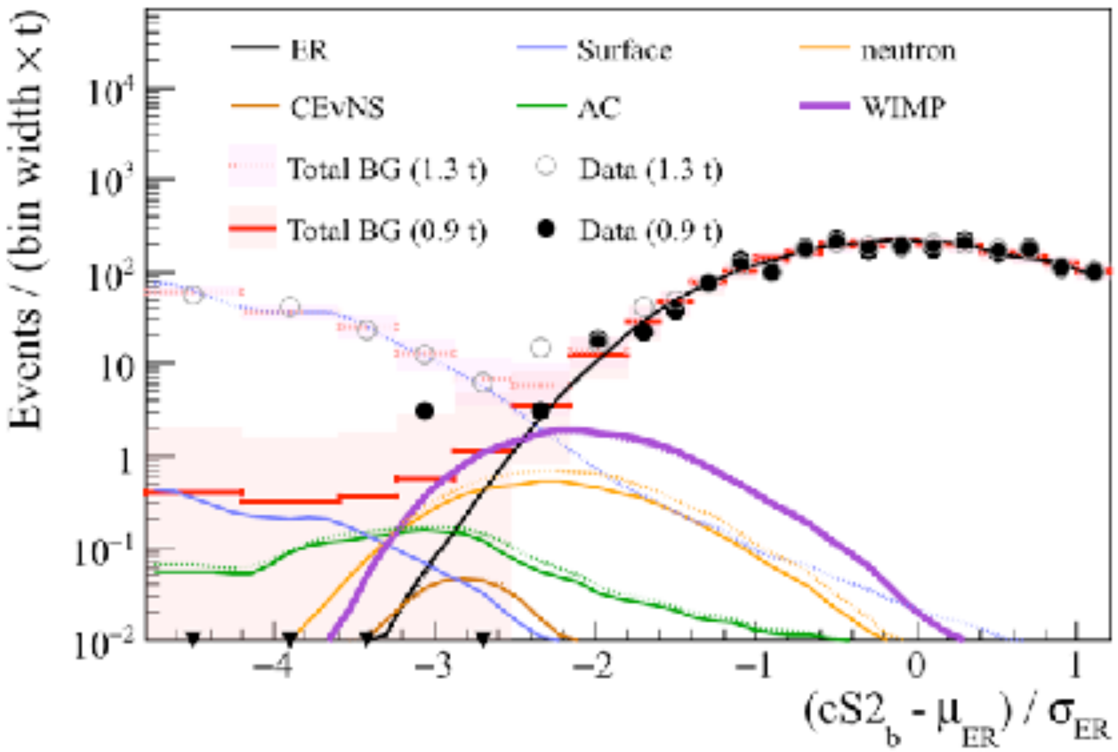
- Reference region is defined as between NR median and NR - 2sigma
- ER is the most significant background and uniformly distributed in the volume
- Surface background contributes most in reference region, but its impact is subdominant in inner R
- Neutron background is less than one event, and impact is further suppressed by position information
- Other background components are completely sub-dominant
- Numbers in the table are for illustration. Statistical interpretation is done by profile likelihood analysis

Dark Matter Search Results

- Results interpreted with un-binned profile likelihood analysis in cs1, cs2, r space
- piechart indicate the relative PDF from the best fit of 200 GeV/c^2 WIMPs with a cross-section of 4.7×10^{-47} cm^2

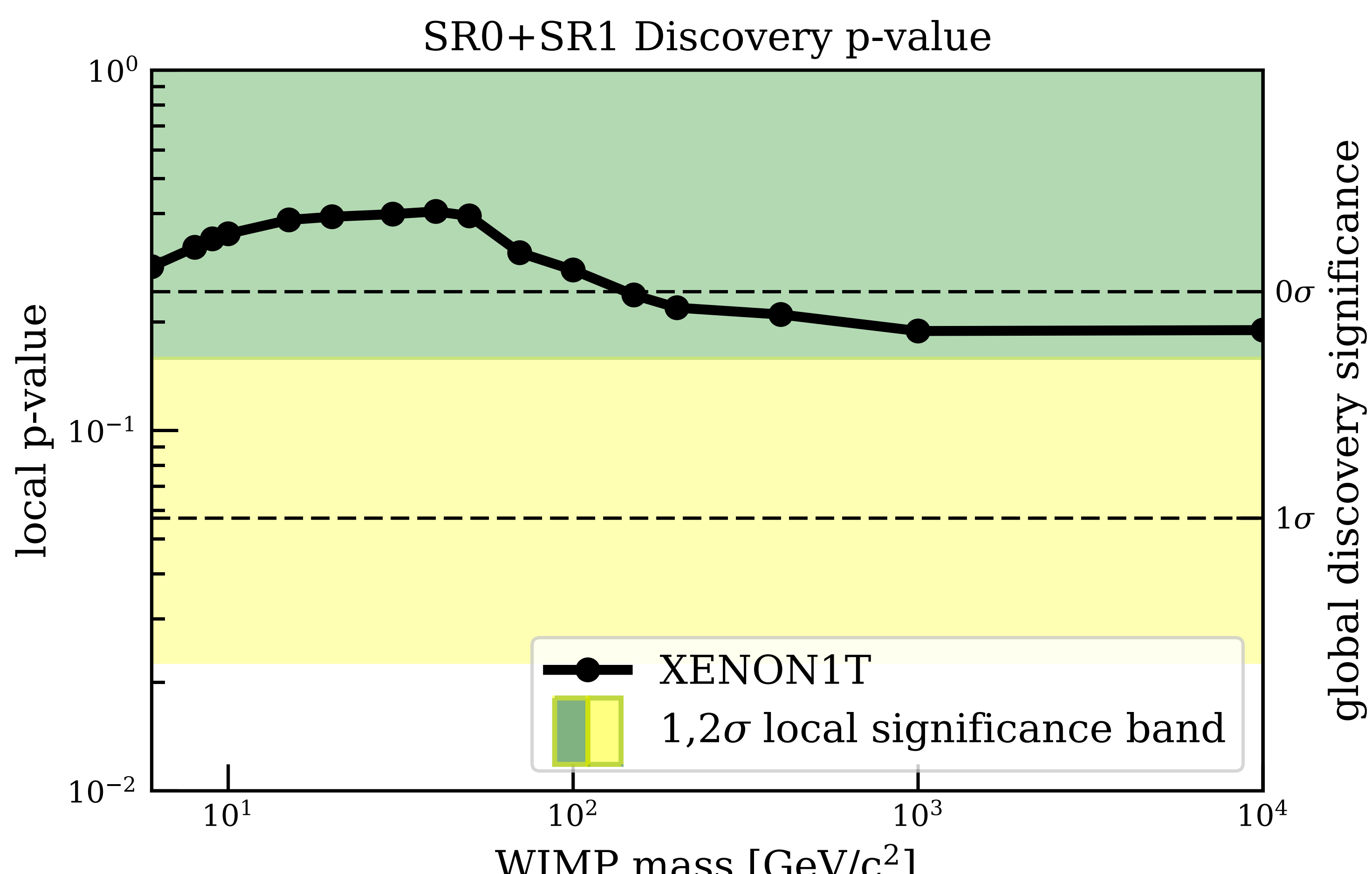


Statistical Interpretation

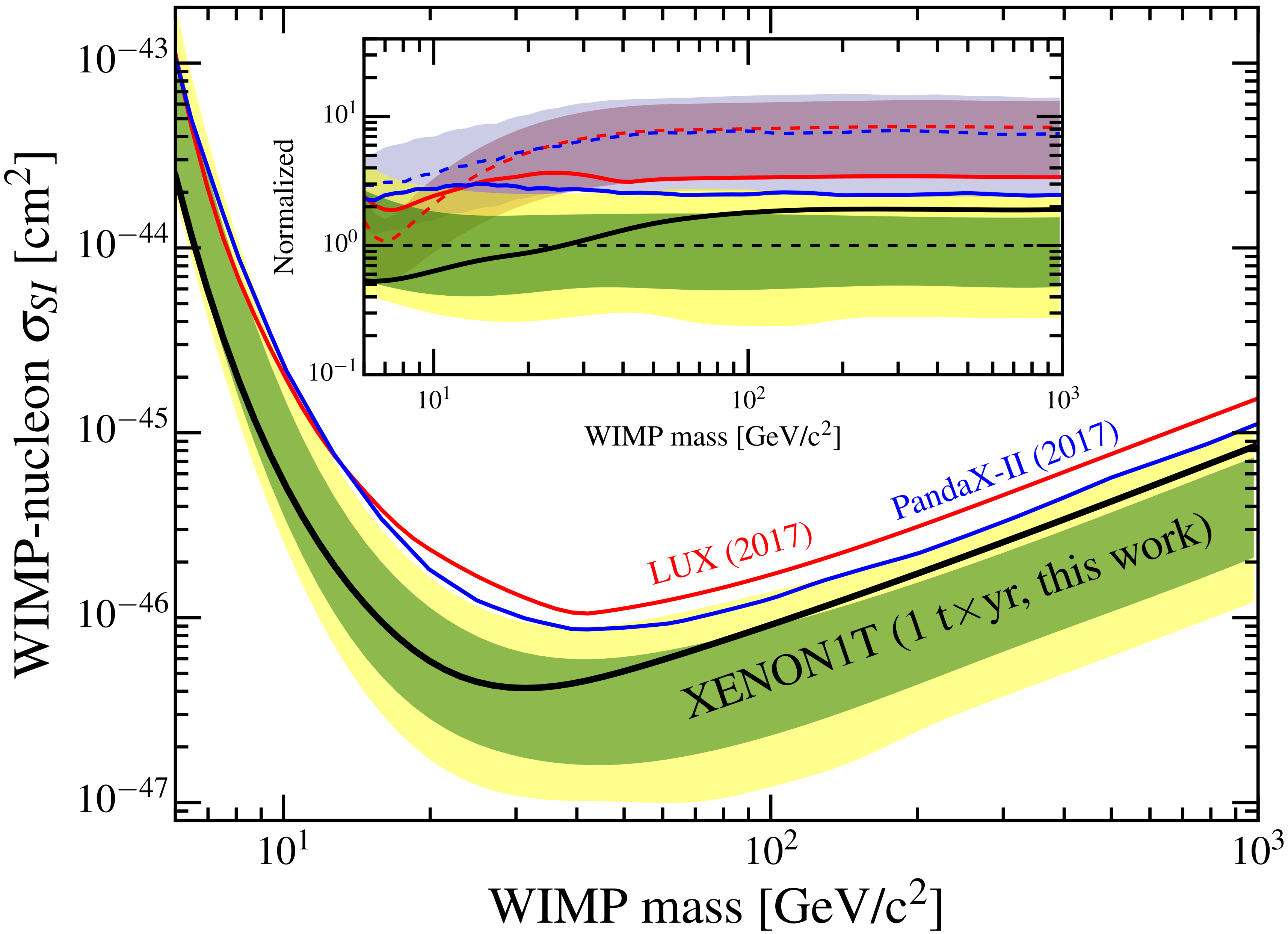


- Extended un-binned profile likelihood analysis
- Example left: Background and 200 GeV WIMP signal best-fit predictions, assuming 4.7 x 10^{-47} cm^2, compared to data in 1.3T and 0.9T
- Most significant ER & Surface backgrounds shape parameters included

- No significant (>3 sigma) excess at any scanned WIMP mass
- Background only hypothesis is accepted although the p-value of ~0.2 at high mass (200 GeV and above) does not disfavor a signal hypothesis either



XENON1T Dark Matter Search Results



- Most stringent 90% CL upper limit on WIMP-nucleon cross section above 6 GeV
- Factor of 7 more sensitivity compared to previous experiments
- ~ 1sigma upper fluctuation from median sensitivity

Minimum at 4.1x10^{-47} cm^2 for a WIMP of 30 GeV/c^2

The next step: XENONnT

Aprile et al., Eur. Phys. J. C (2017) 77: 881. *XENON1T sub-systems*

Aprile et al., JCAP 77 (2016), 358. *online Rn-removal*

Aprile et al., Eur. Phys. J. C (2017) 77: 275. *online Kr-removal*

Aprile et al., JCAP 4 (2016), 27. *sensitivity*

Minimal Upgrade

The XENON1T infrastructure and sub-systems were originally designed to ***accommodate a larger LXe TPC***.

Fiducial Xe Target

XENONnT TPC features:

total Xe mass = 8 t

target mass = 5.9 t

fiducial mass = ~4 t

Background

Record low-back levels in XENON1T dominated by ^{222}Rn-daughters.

Identified strategies to effectively ***reduce ^{222}Rn by ~ a factor 10***.

Fast Turnaround

Use ***XENON1T sub-systems,*** already tested

Fast pace:

Installation starts in 2018

commissioning in 2019

Summary

- XENON1T experiment:
  - ✓ Is it the LXE TPC with largest exposure? Yes
  - ✓ Is it the experiment with lowest background in any DM detector? Yes
  - ✓ Did we put the strongest limit at hight WIMP mass? Yes
  - ✓ Am I disappointed not having found DM? Yes
  - ✓ Is there another episode? Yes: XENONnT

arXiv:1805.12562, Sub. to PRL