Latest Results from the XENON Dark Matter Project

Michael Murra,
WWU Muenster,
on behalf of the XENON collaboration

ICHEP2018 SEOUL
XXXIX INTERNATIONAL CONFERENCE ON high energy PHYSICS
JULY 4 - 11, 2018 COEX, SEOUL

The XENON collaboration

~ 165 scientists

27 institutions

11 countries

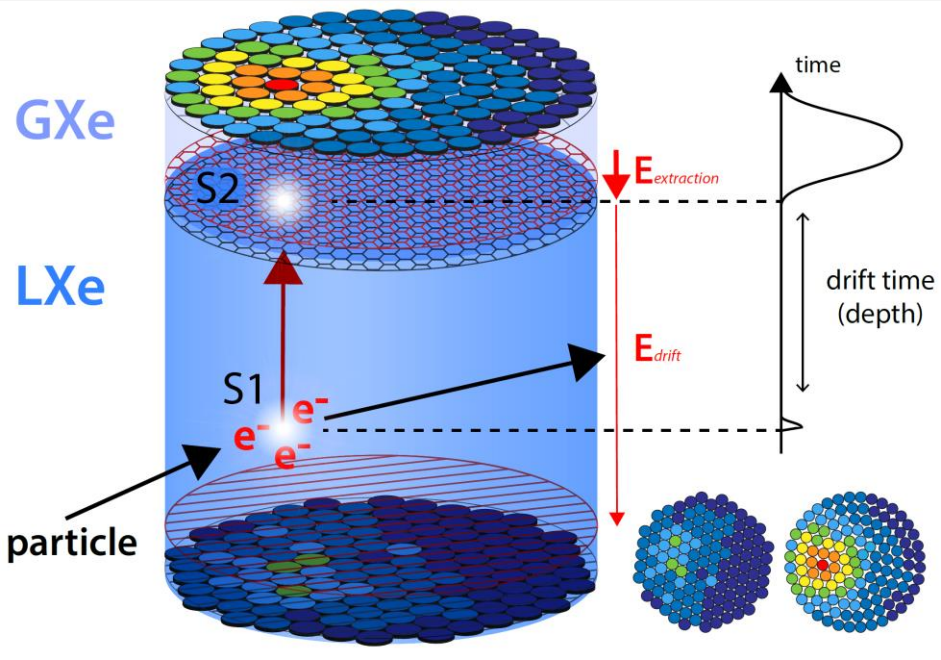
ONE
XENON1T

TWO
BACKGROUNDS

THREE
DARK MATTER SEARCH

FOUR
XENONNT

Dual phase xenon time projection chamber



S1 Light signal**:**
Prompt scintillation photons

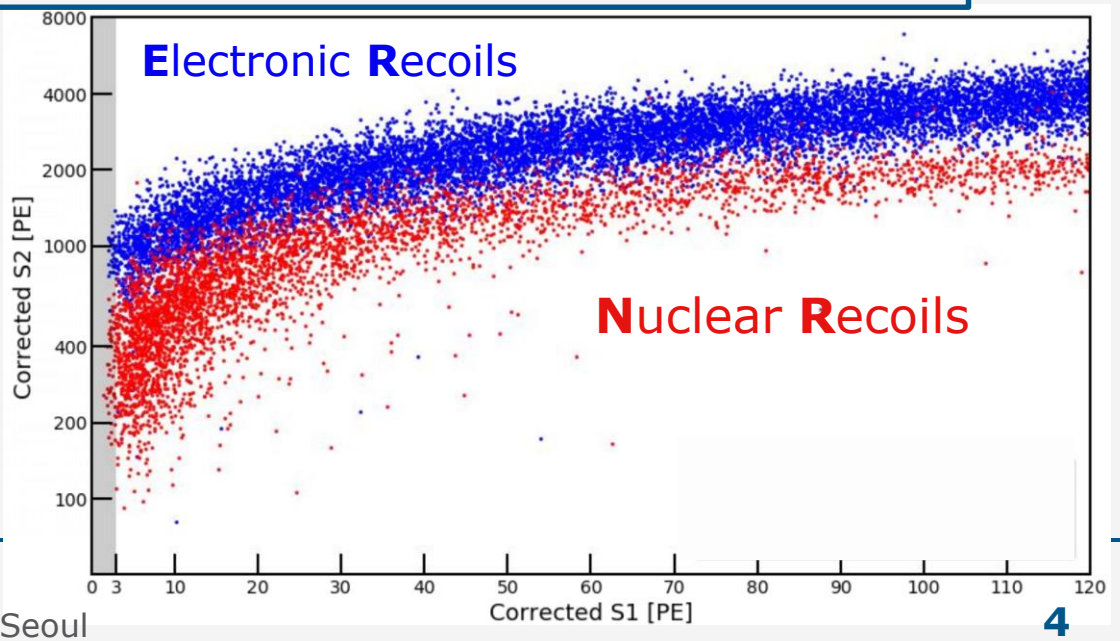
S2 Charge signal:
Secondary scintillation photons from electroluminescence in Gxe due to drifted electrons

3D vertex reconstruction**:**
X,Y: S2 hit pattern
Z: drift time S2-S1

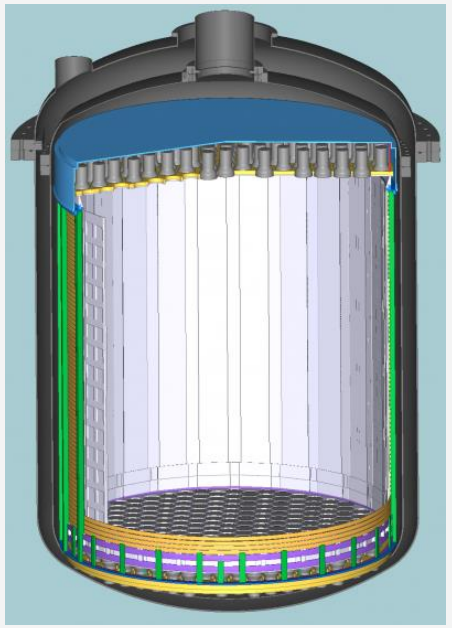
NR (Nuclear Recoils)
WIMP signal, neutrons, CNNS

ER (Electronic Recoils)
γ, β backgrounds

Discrimination from S2/S1
Larger for ER than NR



Enlightening the dark – XENON roadmap

XENON10	XENON100	XENON1T	XENONnT
			
2005 - 2007	2008 - 2016	2012 - 2018	2019 - 2023
25 kg – 15 cm drift	161 kg – 30 cm drift	3.2 tons – 1 m drift	8 tons – 1.5 m drift
$\sim 10^{-43}$ cm²	$\sim 10^{-45}$ cm²	$\sim 10^{-47}$ cm²	$\sim 10^{-48}$ cm²

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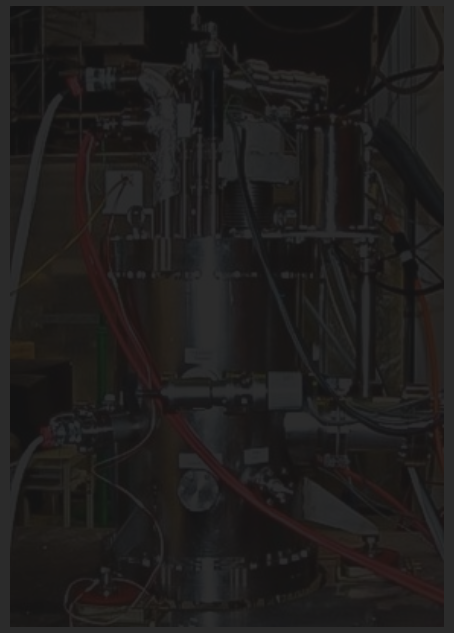			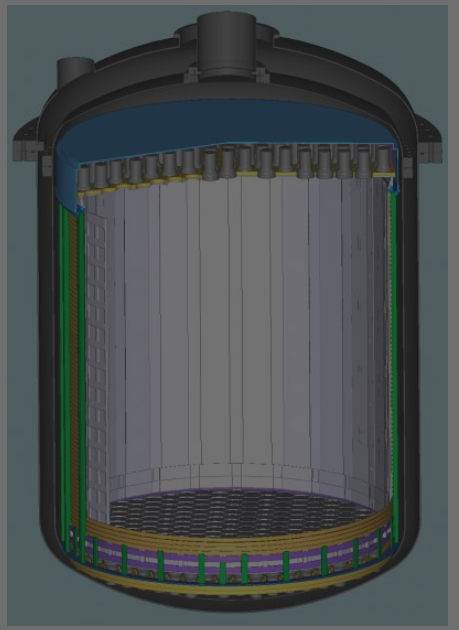
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XENON1T @LNGS (Italy)

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Water tank
700 t ultra-pure water
+
Muon veto
84 PMTs

External Calibrations
AmBe, Cs-137, Th-228, D-D neutron generator

Cryostat

TPC
3.2 t LXe
248 PMTs

Cryogenic
+
Purification
+
Internal Calibrations
Kr-83m, Rn-220

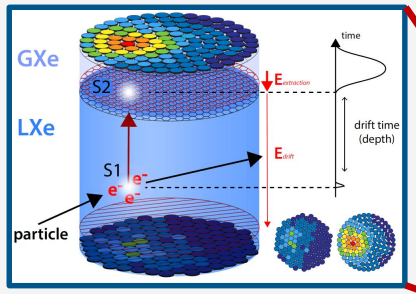
DAQ
+
Slow control

Distillation column
Kr, Rn removal

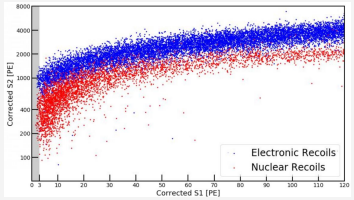
Xe Storage and Recovery
Up to 7 tons

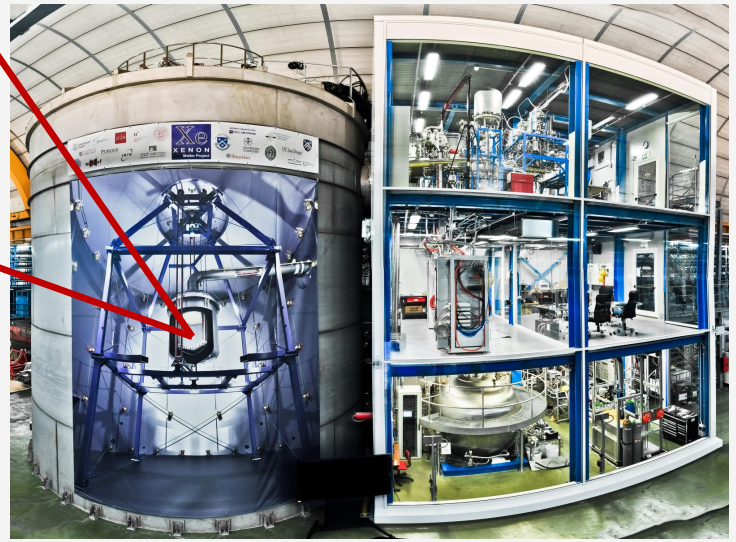
Bottle rack

Eur. Phys. J. C. (2017) 77:881



3D reconstruction
ER – **NR** - discrimination





TWO
BACKGROUNDS

THREE
DARK MATTER SEARCH

FOUR
XENONNT

Electronic Recoil backgrounds

Intrinsic contaminants Kr-85 and Rn-222 (Pb-214)

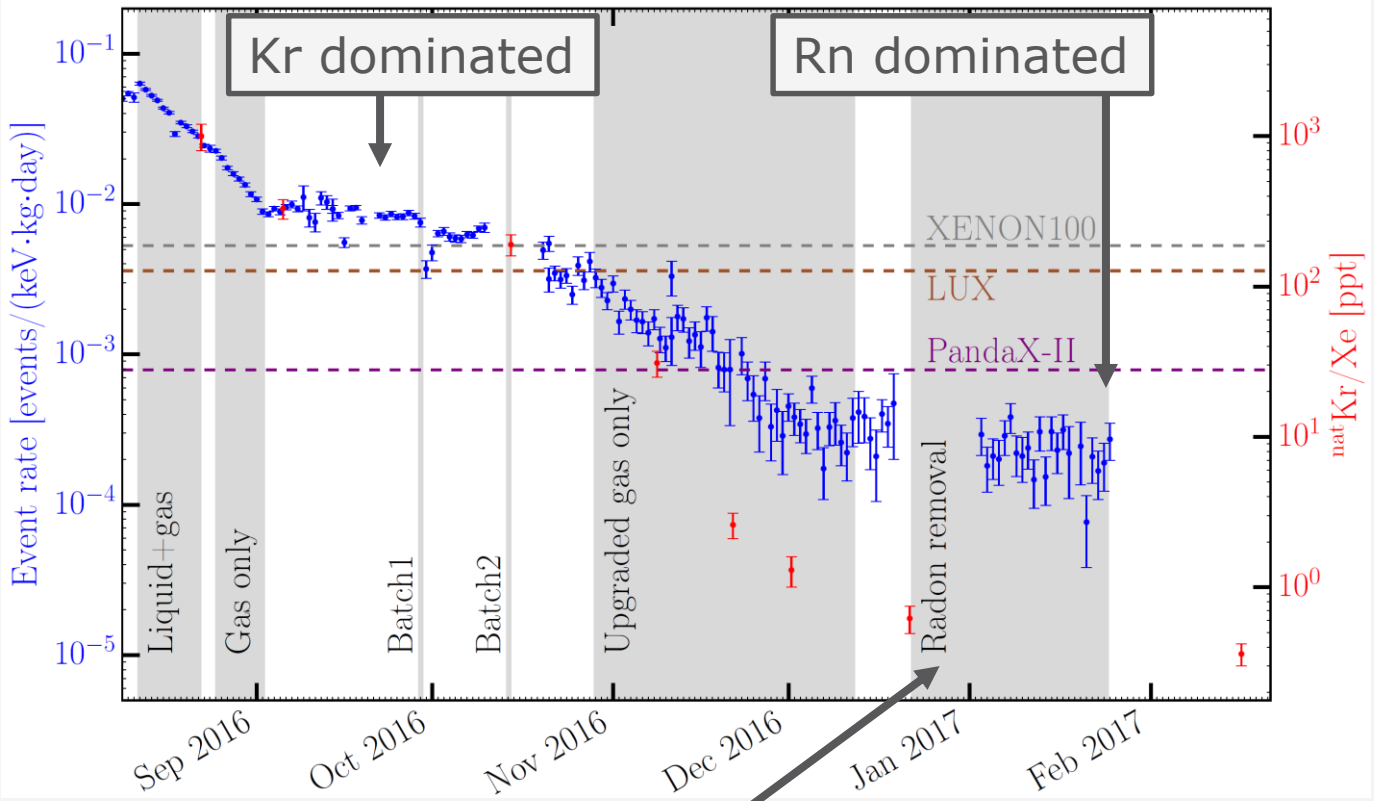
→ Leakage events from the low energy β-spectrum contaminate ROI for dark matter search
→ Material screening to avoid radon emanation
→ Krypton reduction by cryogenic distillation

^{nat}Kr/Xe in SR1:
(0.66 ± 0.11) ppt

^{222}Rn/Xe in SR1:
(13.3 ± 0.8) μBq/kg

Type	Fraction [%]
^{222}Rn (^{214}Pb)	85.4
^{85}Kr	4.3
solar ν	4.9
Materials	4.1
^{136}Xe	1.4

Expectations in 1 t FV, in [1,12] keVee, single scatters, Pb-214 = 10μBq/kg, **before ER/NR discrimination**



M. Murra, PhD thesis, 2018

Eur. Phys. J. C. (2017) 77, 275
Eur. Phys. J. C. (2017) 77, 358

JCAP 04, 027 (2016) with updated SR1 values

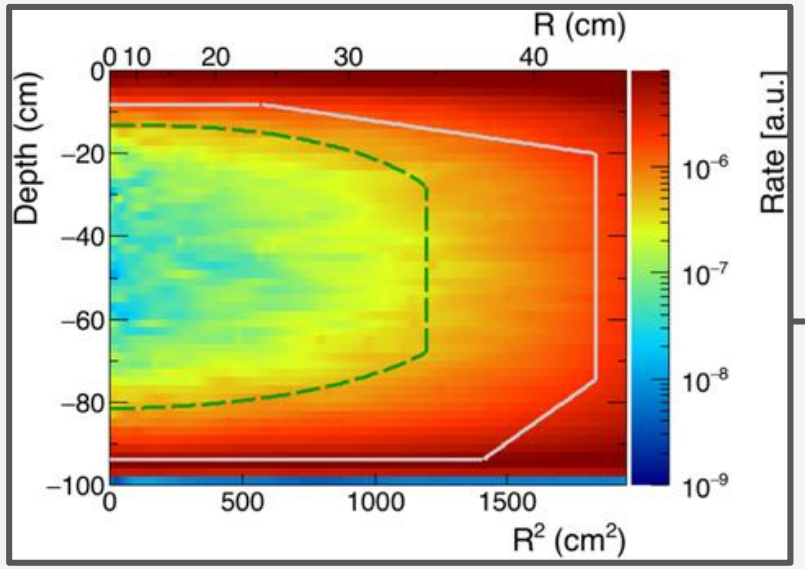
Radon further reduced by ~20% with cryogenic distillation during 2nd half of SR0

Nuclear Recoil backgrounds

Cosmogenic neutrons
Induced by cosmic muons. Reduced to negligible contribution by rock overburden, water passive shield and active Cherenkov Muon Veto. JINST 9, P11006 (2014)

Radiogenic neutrons
From (α,n) and spontaneous fission in detector's materials. Reduced via radiopure material selection, scatter multiplicity and fiducialization. Eur. Phys. J. C. (2017) 77:890

Coherent Elastic neutrino-nucleus scattering
Mainly from ^{8}B solar ν. Constrained by flux and cross section measurement. Irreducible background at very low energy (< 1 keV)



Type	Fraction [%]
Cosmogenic neutrons	<2.0
Radiogenic neutrons	96.5
CEνNS	2.0

Expectations in 1 t FV, in [4,50] keVnr, single scatters

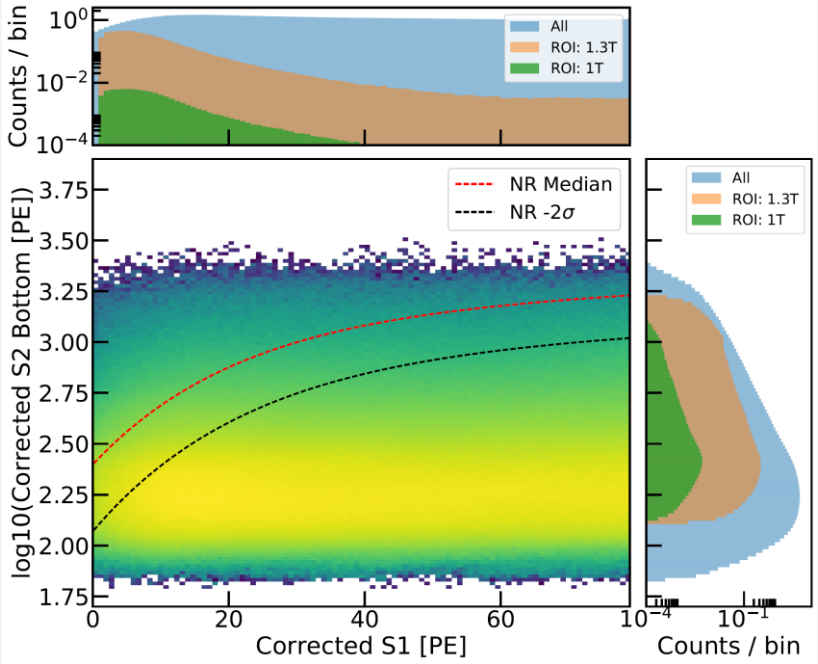
Other backgrounds

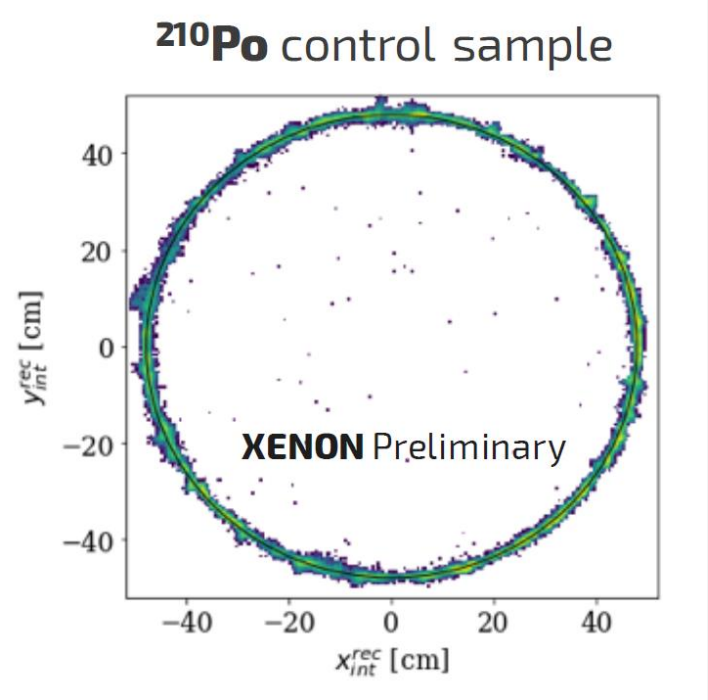
Accidental coincidence

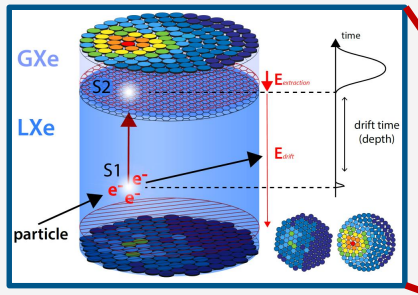
- Lone-S1 signals may accidentally coincide (AC) with lone-S2 signals. → **fake interactions**
- Empirical model verified with ^{220}Rn calibration data and background sidebands.

Surface events

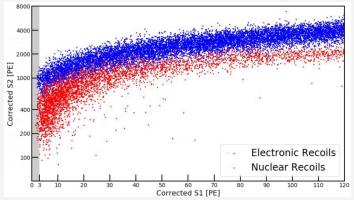
- ^{210}Pb from ^{222}Rn chain plates out on PTFE surfaces.
- S2 signal losses when ^{210}Pb β-decay happens on surface. → **leakage into signal region**
- Data driven model based on ^{210}Po surface control samples.

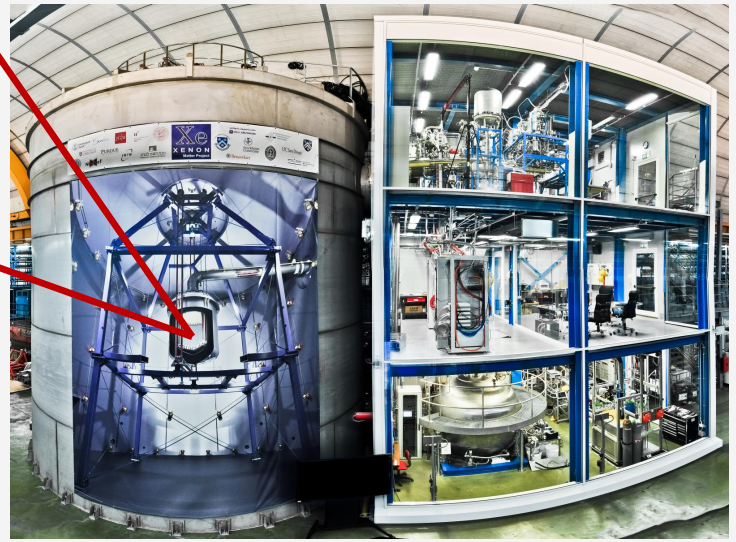


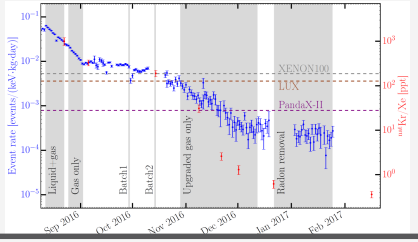


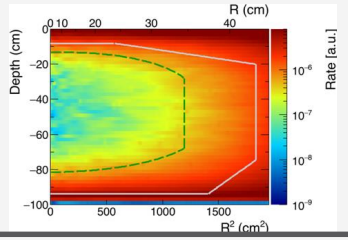


3D reconstruction
ER – NR - discrimination



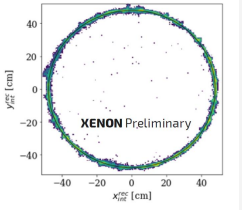






Electronic Recoils	Nuclear Recoils
Accidental Coincidence	Surface Events

Lone S1
+
Lone S2



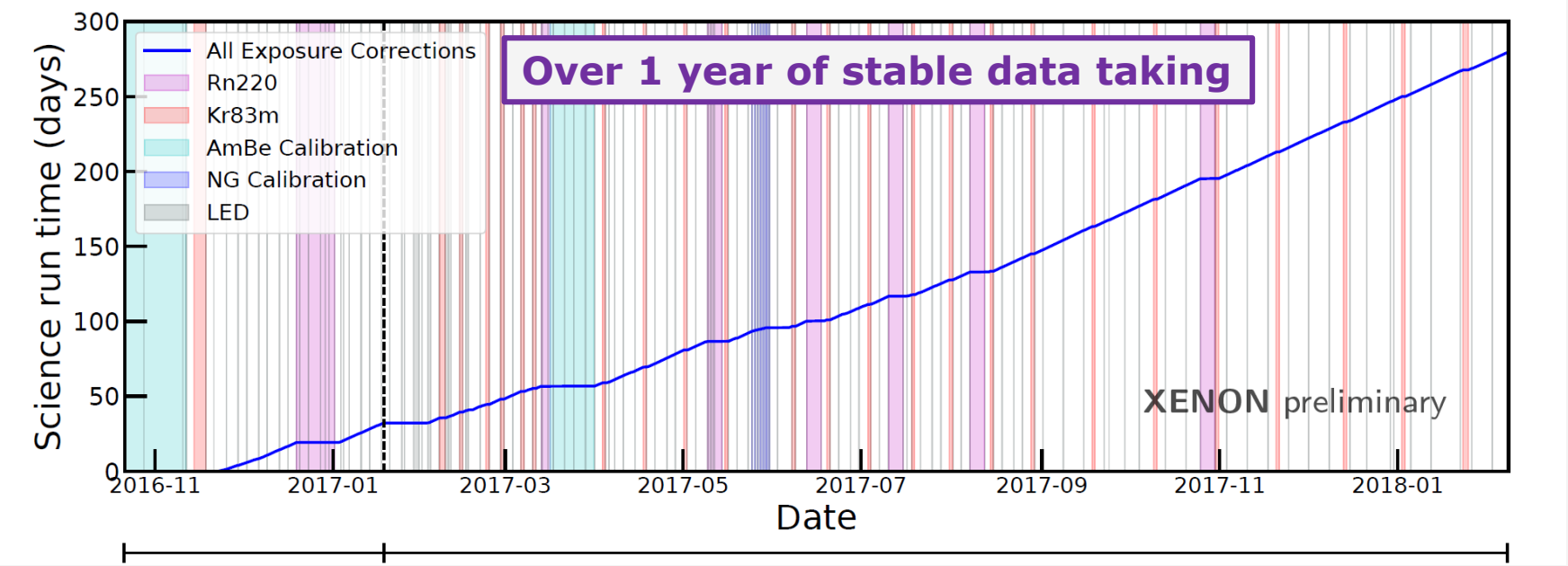
THREE

DARK MATTER SEARCH

FOUR

XENONNT

Exposure



Science **R**un **0** (**SR0**) 23.1 days
PRL 119, 181301

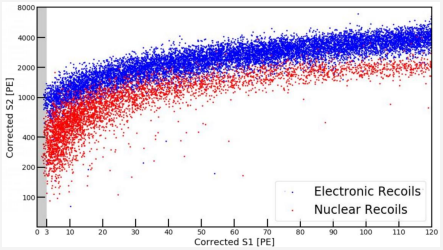
Science **R**un **1** (**SR1**) 246.7 days

The result presented today combines both science runs for 278.8 days total livetime.
→ **1 tonne x year** exposure given **1.3 tonne fiducial volume.**

Signal region **blinded** for SR1, **re-blinded** for SR0 + **salted**.

ER and NR calibration

Electronic Recoils
-
^{220}Rn



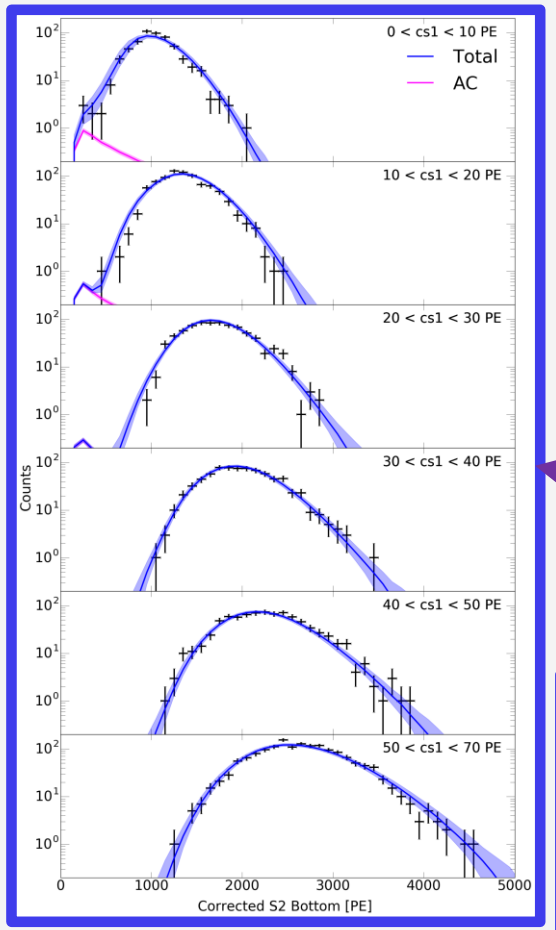
Nuclear Recoils
-
Neutron generator

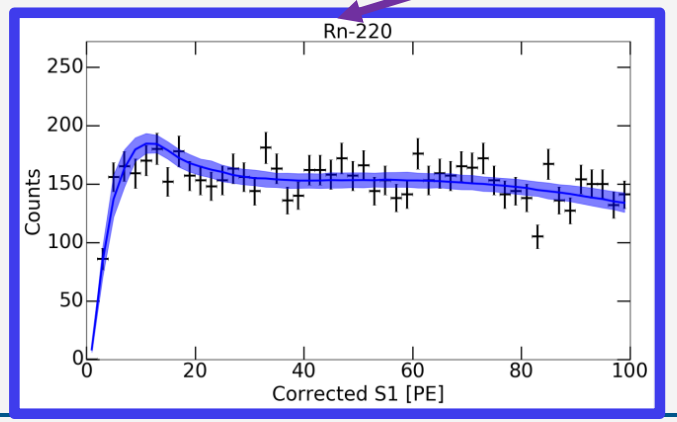
Particle propagation with detailed detector geometry and LXe physics modeled.

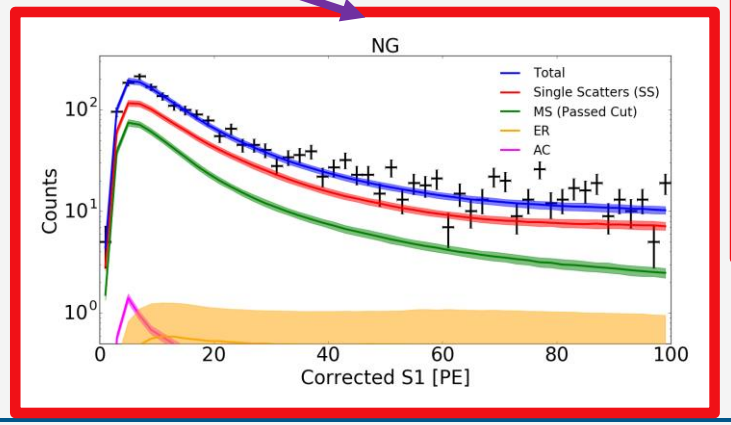
Parameters tuned and constrained by calibration data.

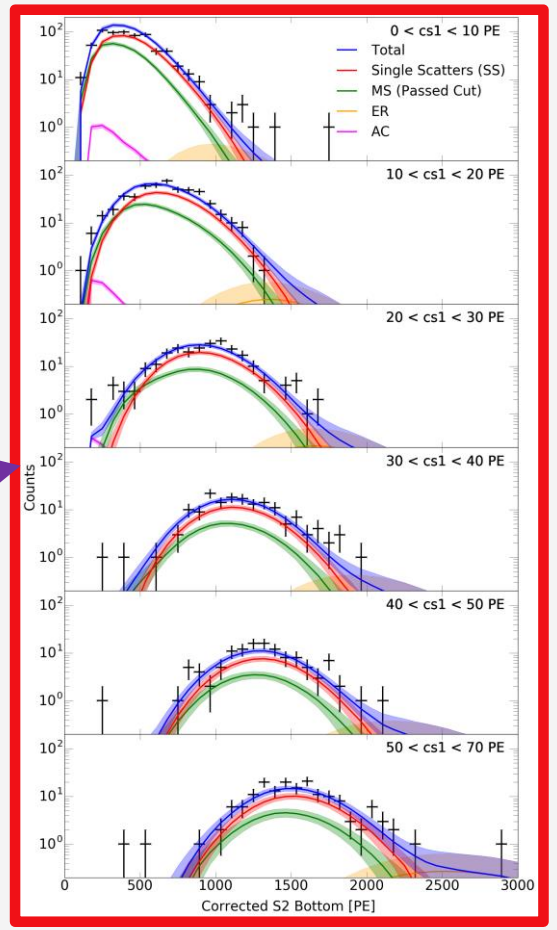
S2 projections in S1 slices

S1 projection









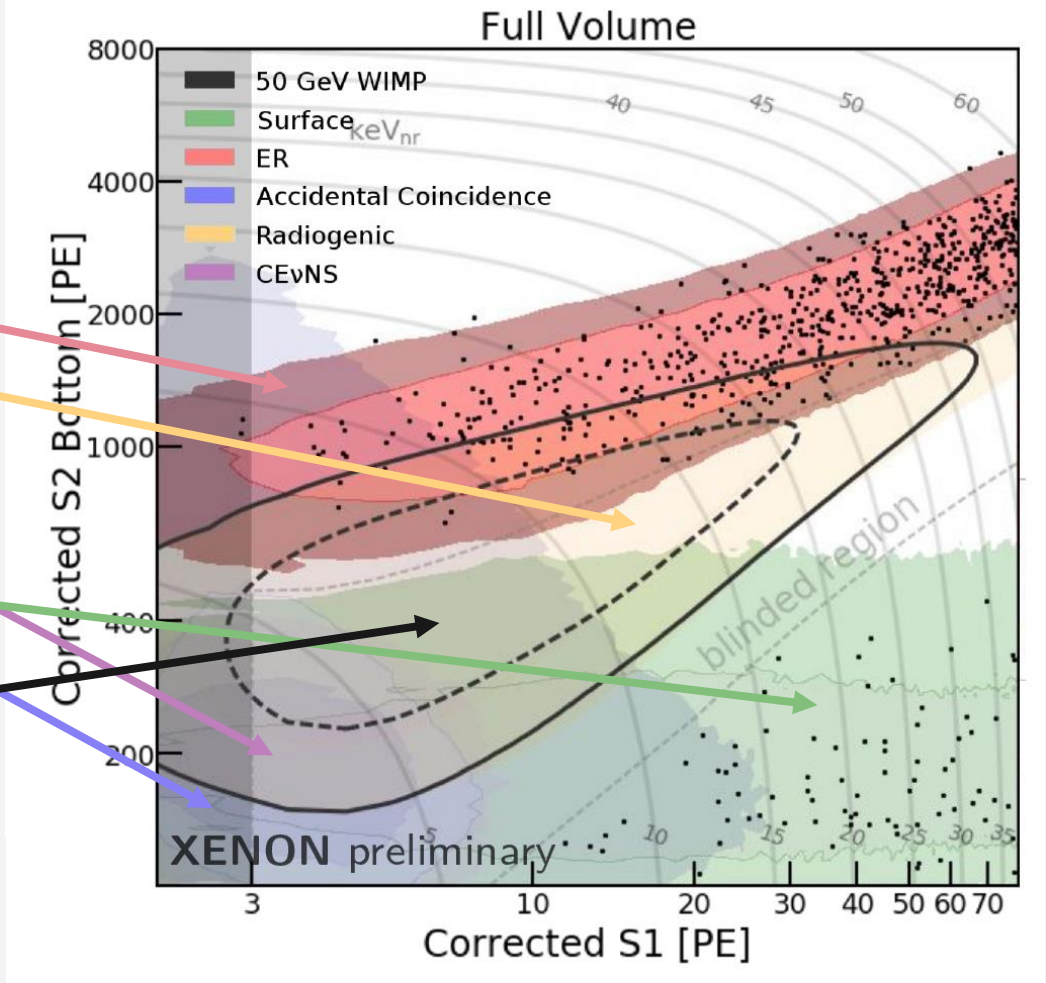
~99.7% ER rejection in NR reference region [NR median,-2σ]

Background predictions

	1.3 t	0.65 t	Mass
Type	**Full ROI**	**NR reference**	**(S2,S1) region**
ER	627 ± 18	0.6 ± 0.13	
neutrons	1.43 ± 0.66	0.14 ± 0.07	
CEνNS	0.05 ± 0.01	0.01	
AC	$0.47^{+0.27}$	$0.04^{+0.02}$	
Surface	106 ± 8	0.01	
Total BKG	**735 ± 20**	**0.8 ± 0.14**	

WIMP

50 GeV/c²



Background models

In 4-dimensional space: S1, S2, r, z

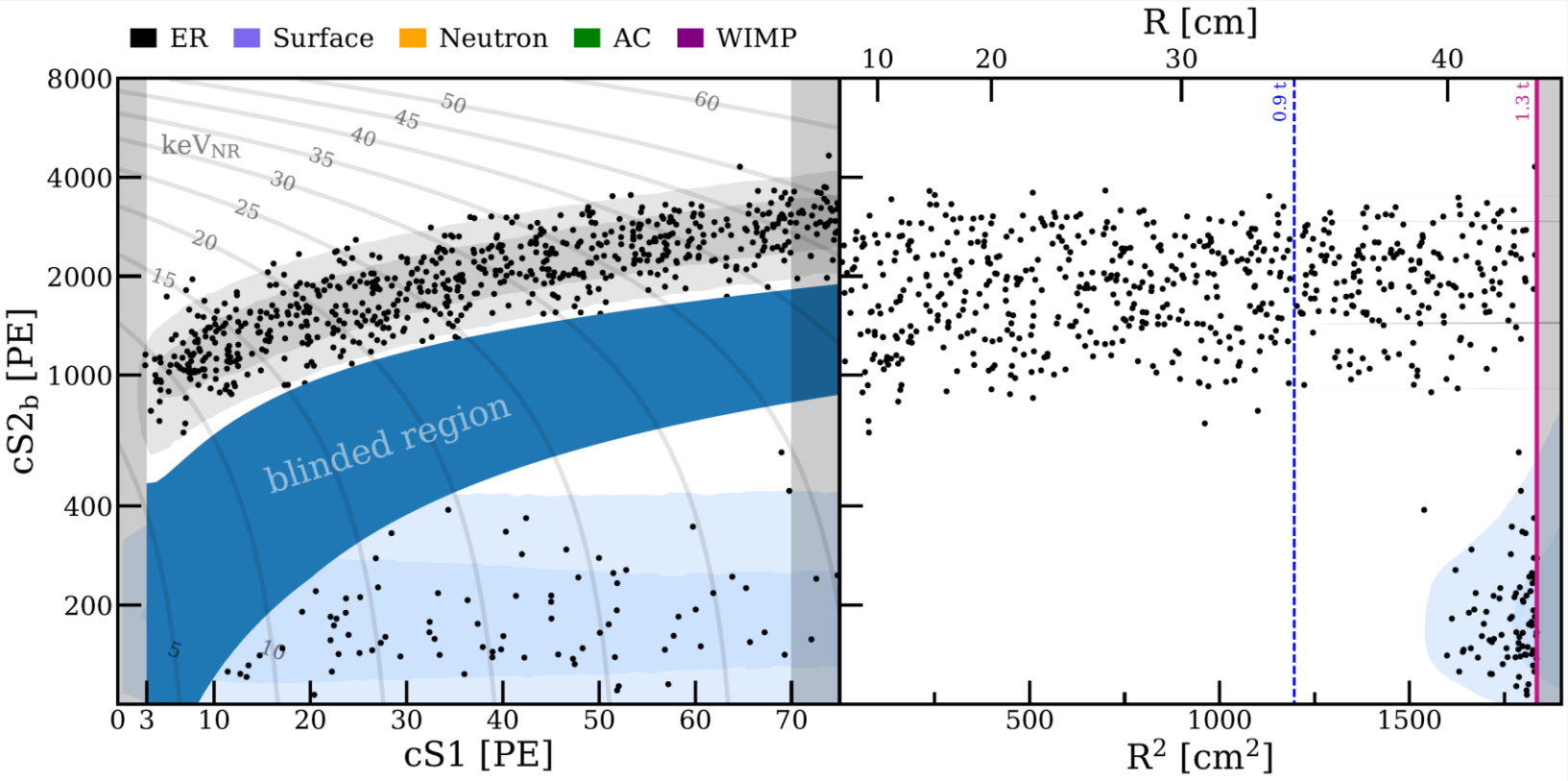
Statistical inference

Done with PLR analysis in 1.3 t fiducial volume and full (S1,S2) space, corresponding to [4.9, 40.9] keVnr and [1.4, 10.6] keVee.

NR reference region

Between NR median and -2σ quantile. **Numbers in table are for illustration; final results from complete PLR statistical inference.**

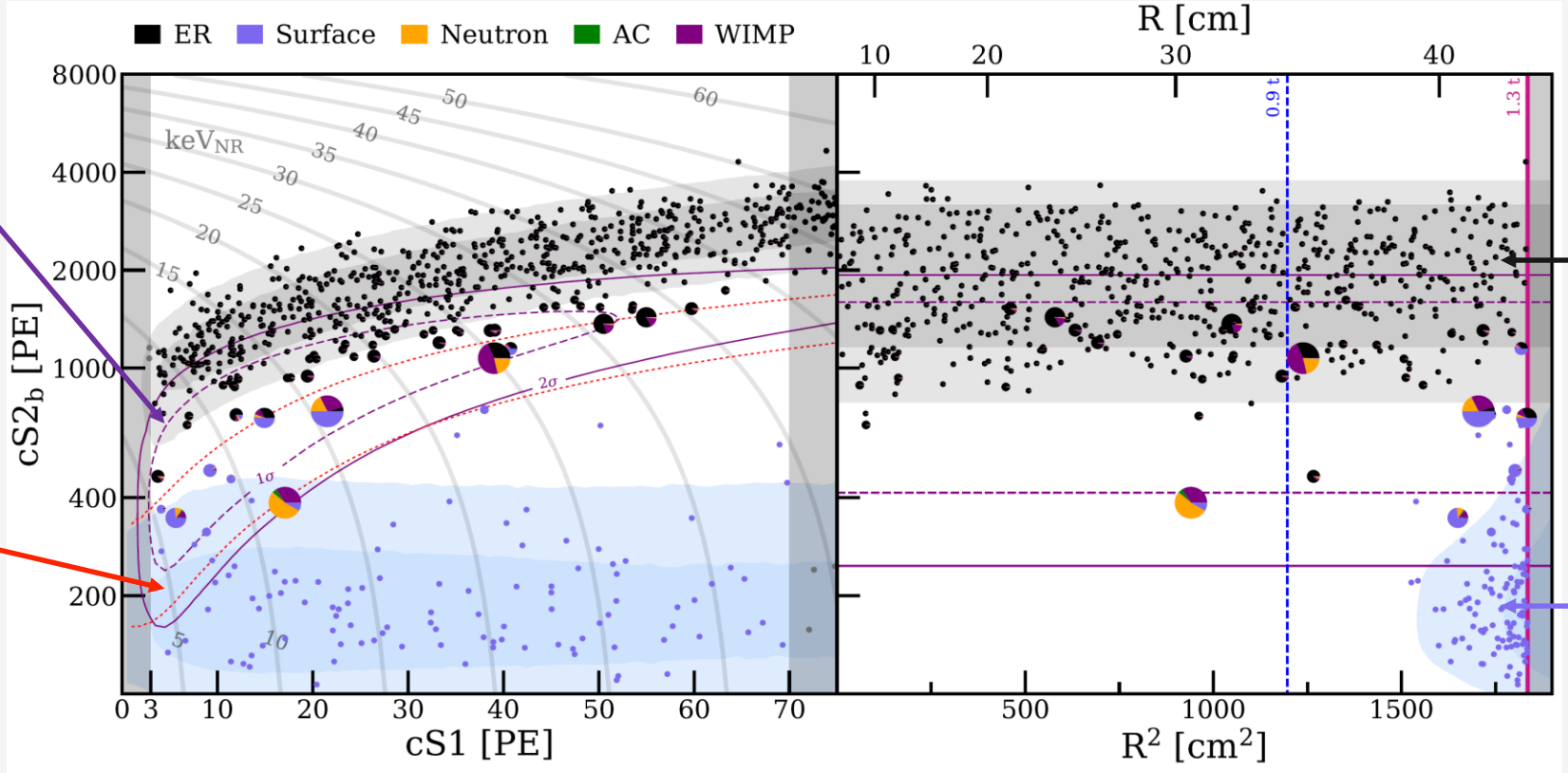
Blinded data



Results: Unblind + Desalt!

200 GeV
WIMP signal
shape
1-2σ contours

--- NR
Reference region



ER
background

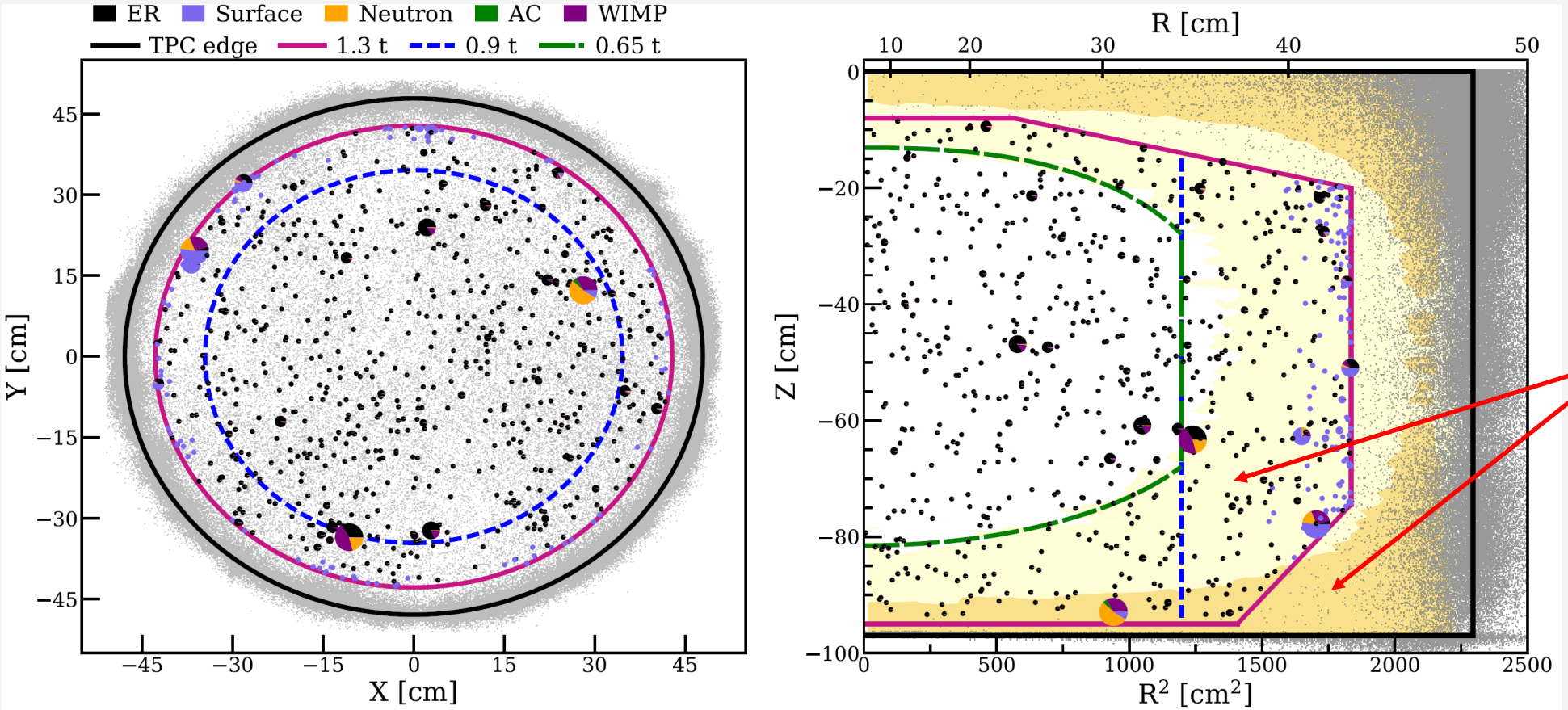
Surface
background

Pie charts

Events passing all selection criteria are shown as pie charts representing the relative PDF from each component for the best-fit model for 200 GeV WIMP (σ_{SI}=4.7 · 10^{-47} cm^2).

Larger charts → Larger WIMP probability

Results: Spatial Distribution



Neutron background 1-2σ contours

Core volume (0.65 t)

Distinguish WIMPs over neutron background

Results: Sensitivity and Limit

Spin-independent WIMP-nucleon cross section
Strongest exclusion limits (at 90% CL) on WIMP mass > 6 GeV/c².

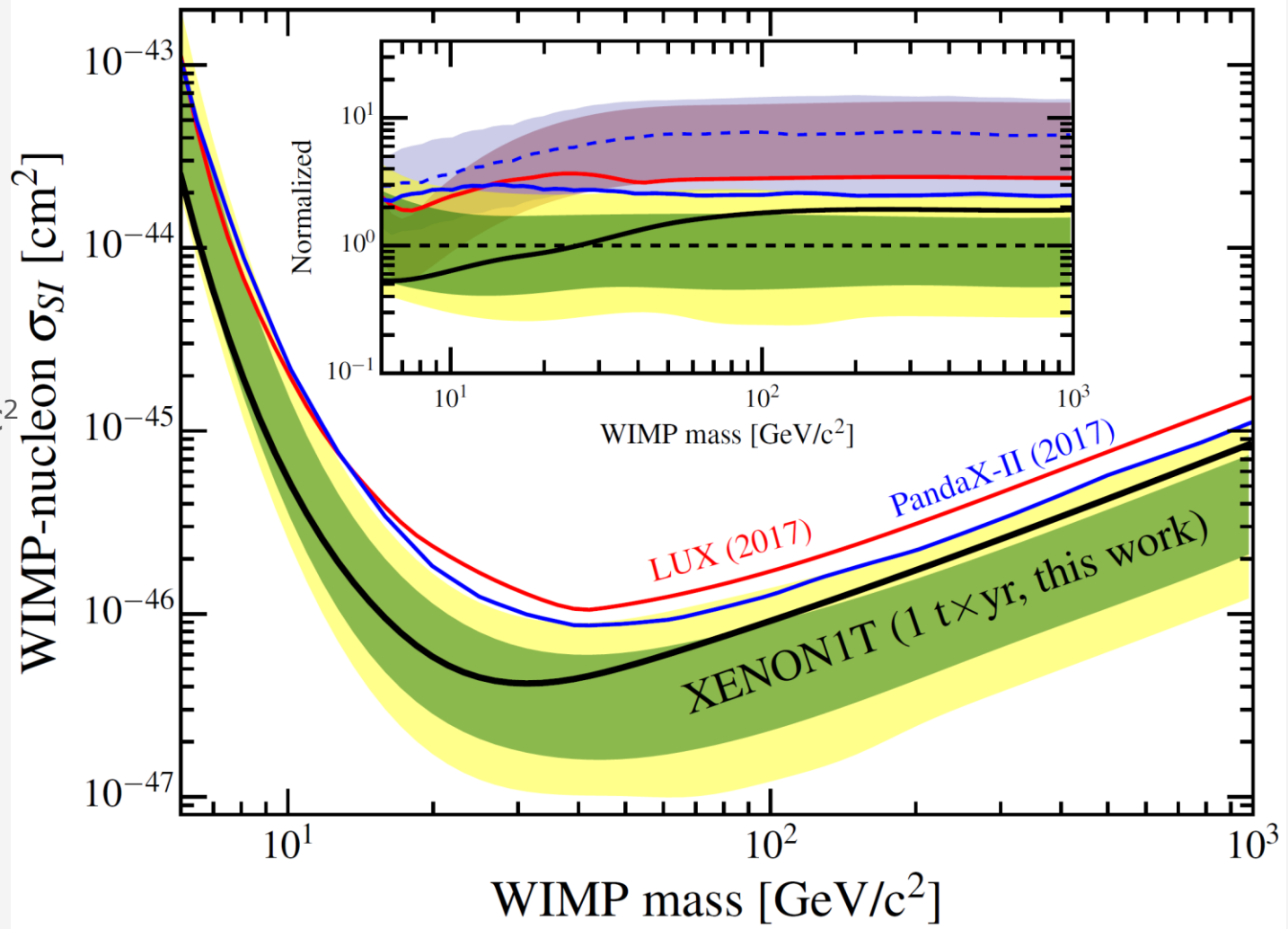
Sensitivity
7 times better than previous generation experiments (LUX, PANDAX-II)

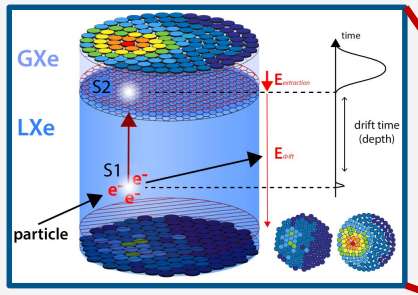
Limit:
~1 sigma under-fluctuation for masses ≲ 8 GeV/c² while over-fluctuation at higher masses

Minimum:

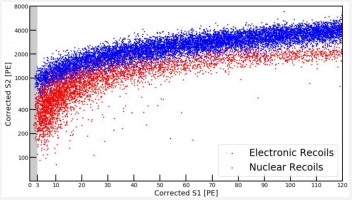
$\sigma_{SI} < 4.1 \cdot 10^{-47}$ cm² at 30 GeV/c²

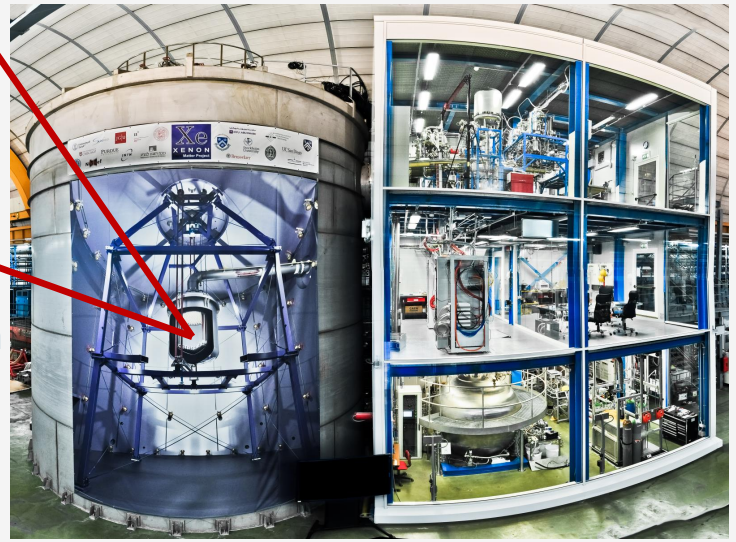
Submitted to PRL
ArXiv: https://arxiv.org/abs/1805.12562

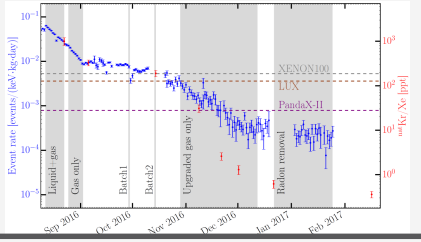


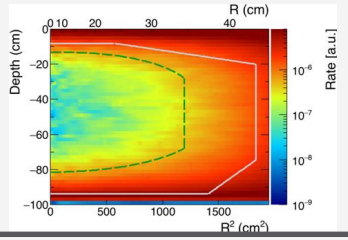


3D reconstruction
ER – NR - discrimination



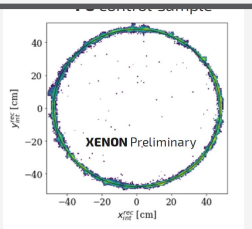






Electronic Recoils	Nuclear Recoils
Accidental Coincidence	Surface Events

Lone S1
+
Lone S2



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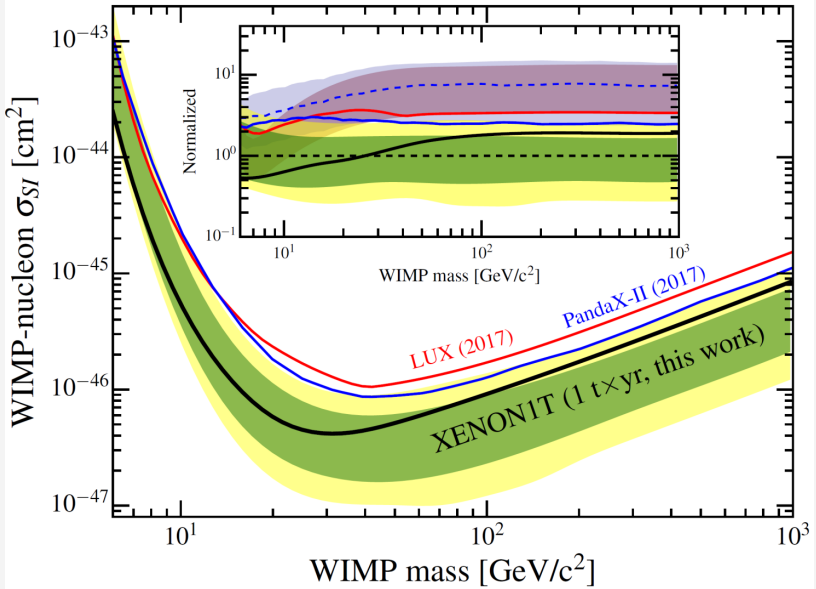


FOUR
XENONNT

Fast Upgrade to XENONnT

Minimal Upgrade
The XENON1T infrastructure and subsystems 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.

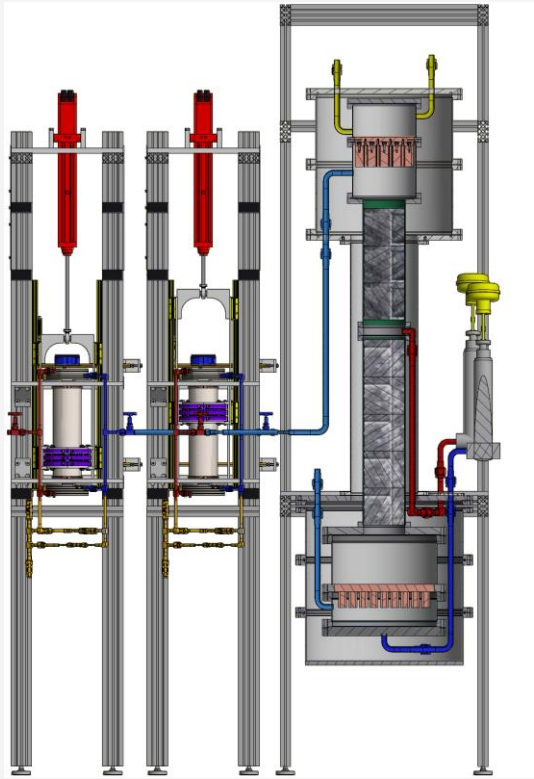
Fast Turnaround
Use XENON1T subsystems, already tested
Fast pace:
Installation starts in 2018
Commissioning in 2019

XENONnT: Radon mitigation

→ Even more careful material selection compared to XENON1T

New radon distillation system

High throughput column with 200 slpm.



M. Murra, PhD thesis, 2018

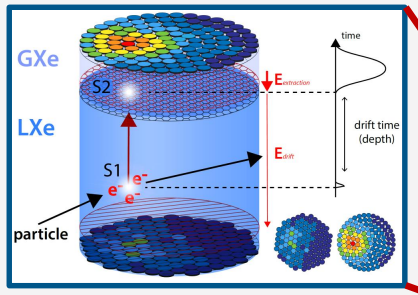
arXiv:1803.08498

New radon-free pump for GXe PUR

Magnetically coupled piston pump was installed at XENON1T in June 2018

→ **Reached ~1 ms electron lifetime**

→ **Radon reduction ~ 45%**



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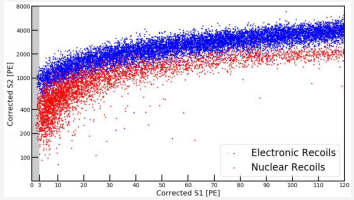
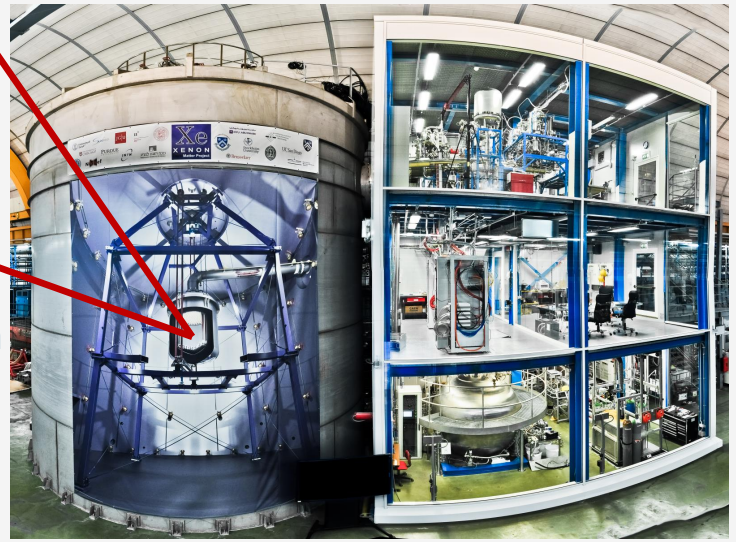
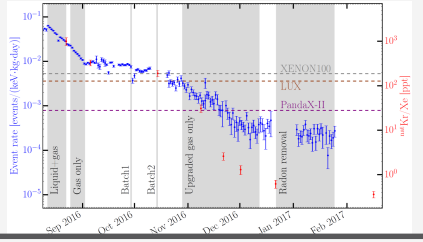
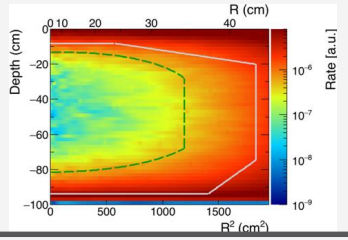








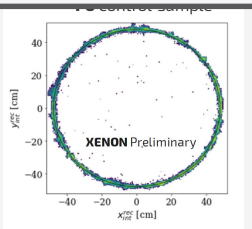
Electronic **R**ecoils

Nuclear **R**ecoils

Accidental **C**oincidence

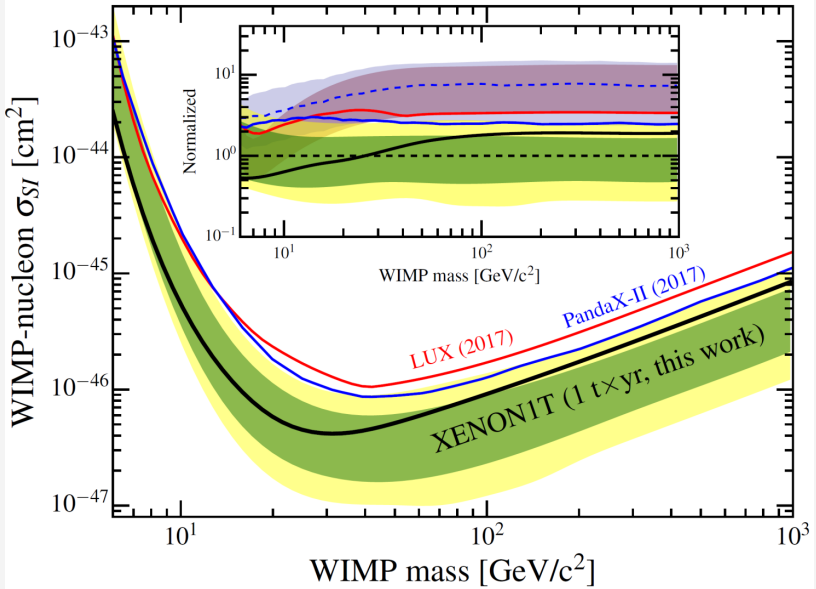
Surface **E**vents

Lone S1
+
Lone S2



Minimum:

$\sigma_{SI} < 4.1 \cdot 10^{-47}$ cm² at 30 GeV/c²



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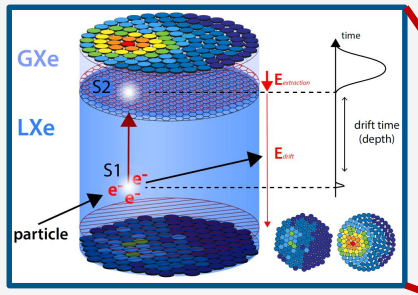
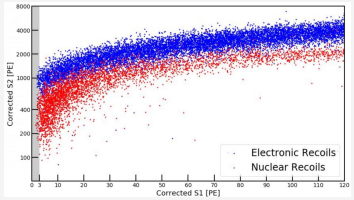
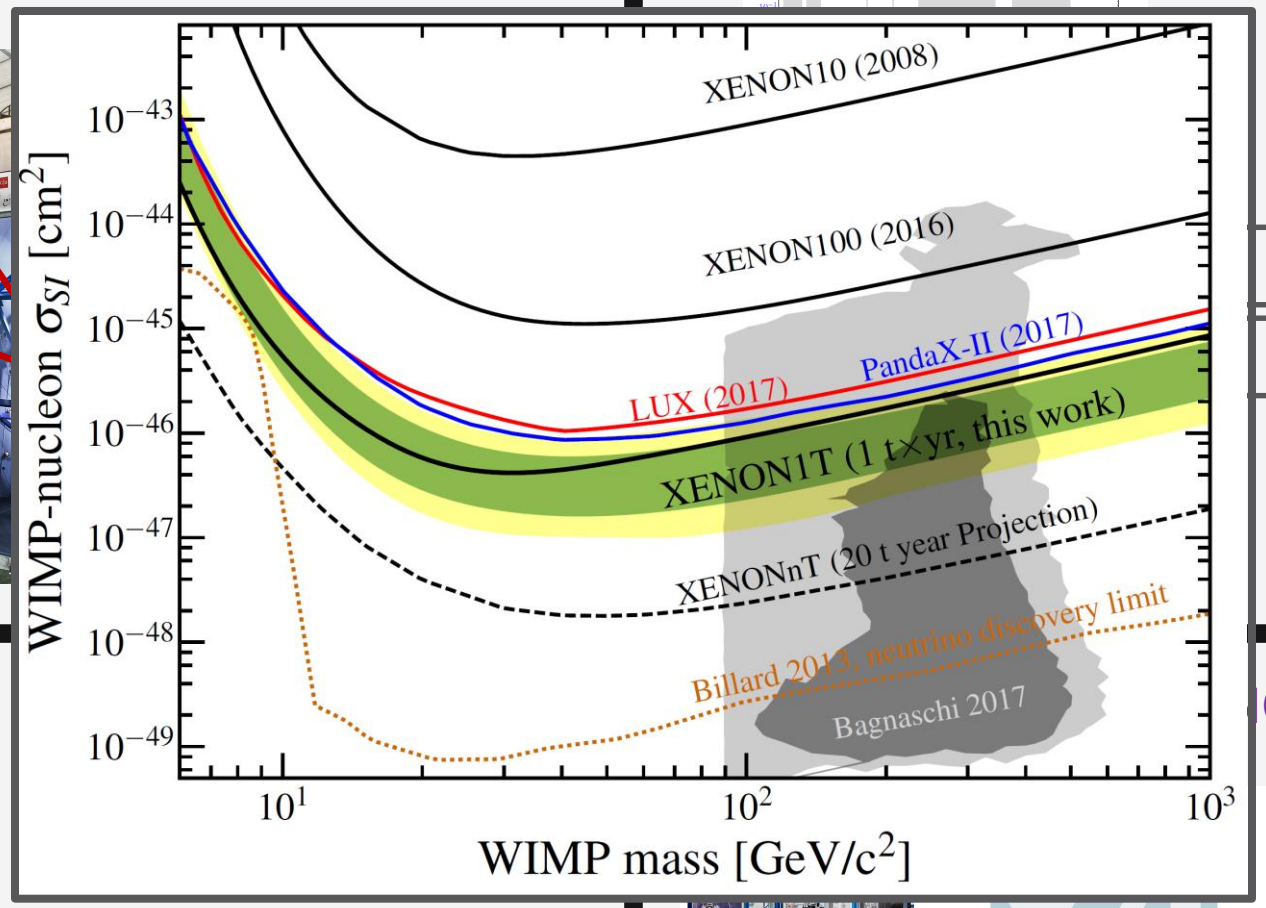
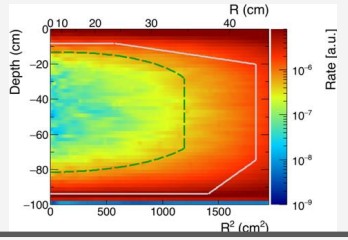
Installation starts in 2018
Commissioning 2019



3D reconstruction
ER – NR - discrimination

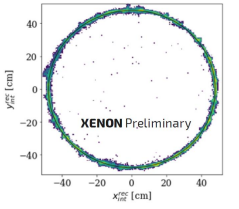






Nuclear **R**ecoils

Surface **E**vents



ONnT

Minimum:

$\sigma_{SI} < 4.1 \cdot 10^{-47}$ cm^2
at 30 GeV/c^2

Stay tuned

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