Results of the WIMP search with XENON1T

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Introduction

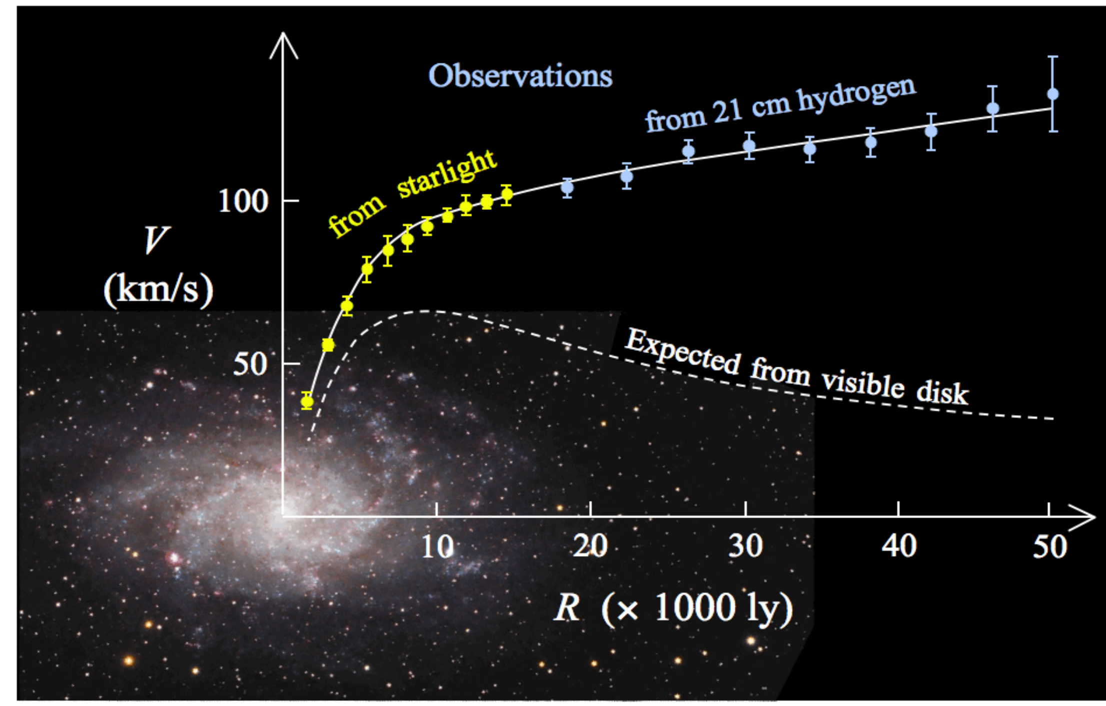
Dark Matter…85% of the matter in the Universe

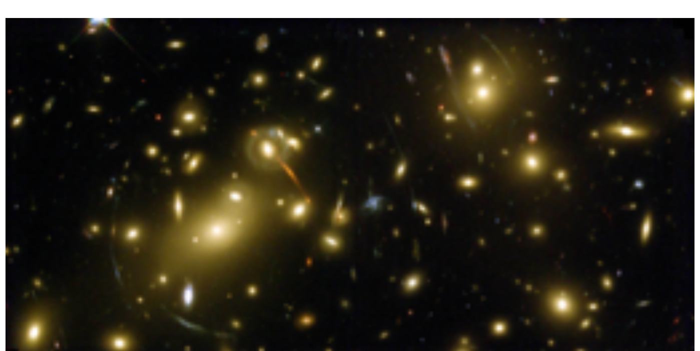
Observation at different scales point towards a Dark Universe with ~ 85% of matter being of unknown type

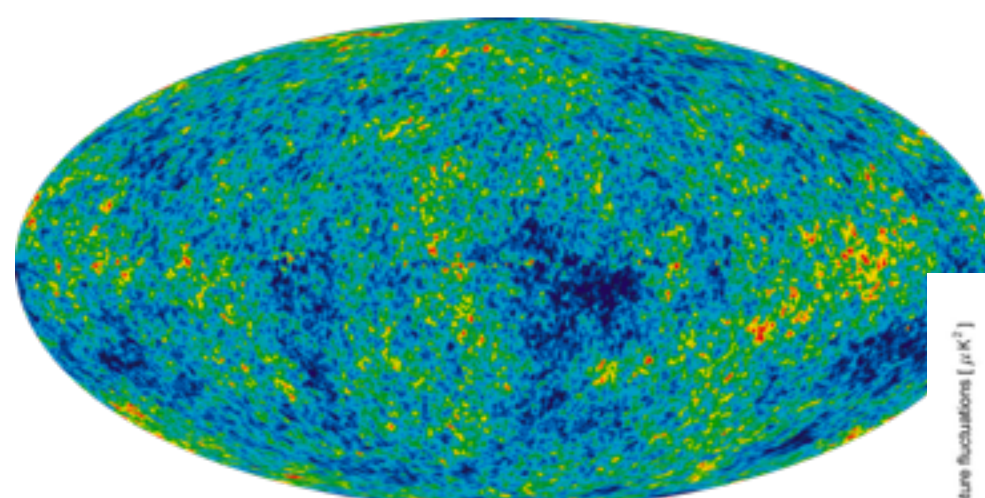
So far, we mostly have "negative" informations

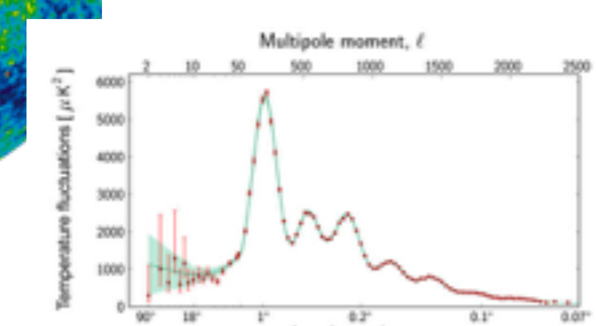
Constraints from astrophysics and searches for new particles:

- ⋆ ***No colour charge***
- ⋆ ***No electric charge***
- ⋆ ***No strong self-interaction***
- ⋆ ***Stable, or very long-lived***

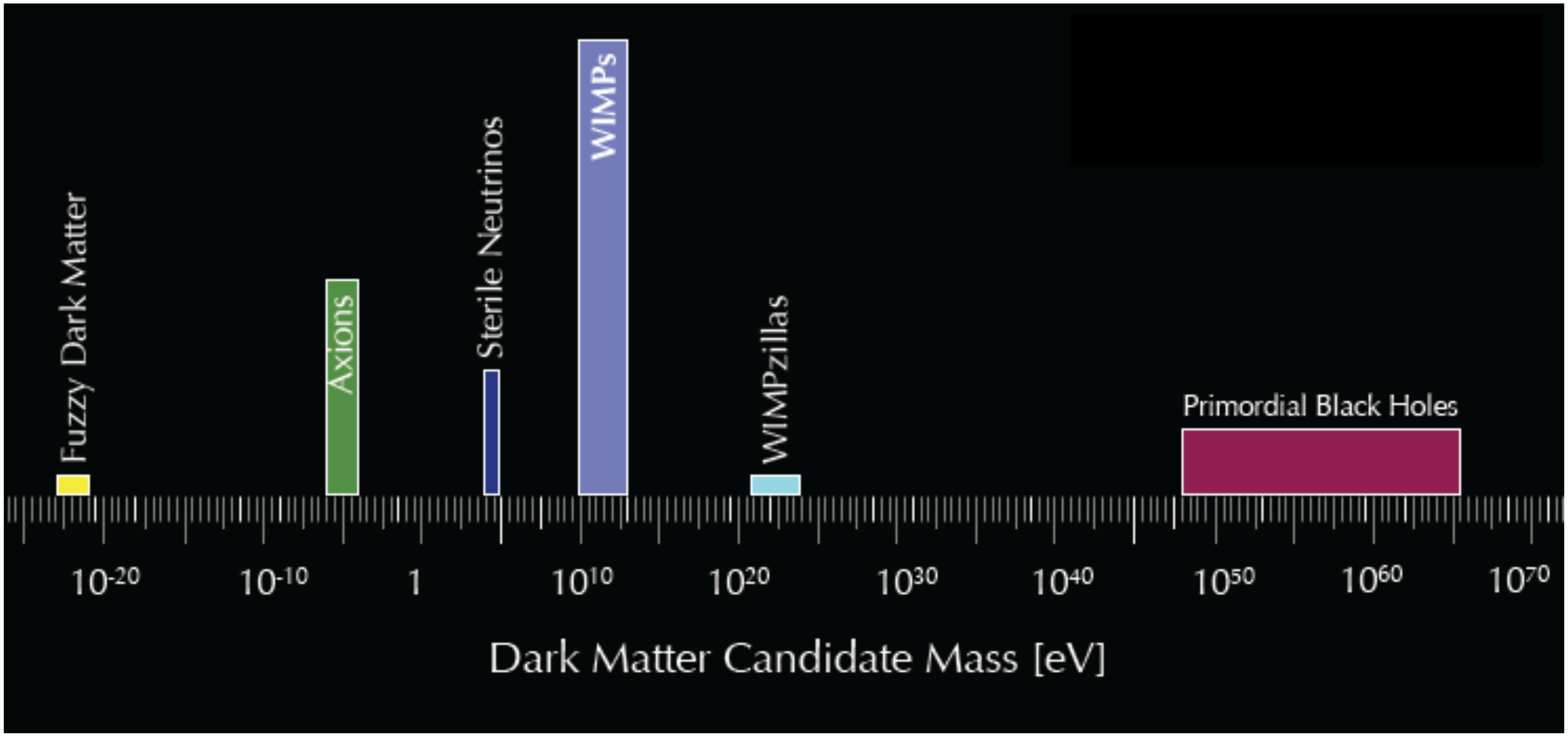






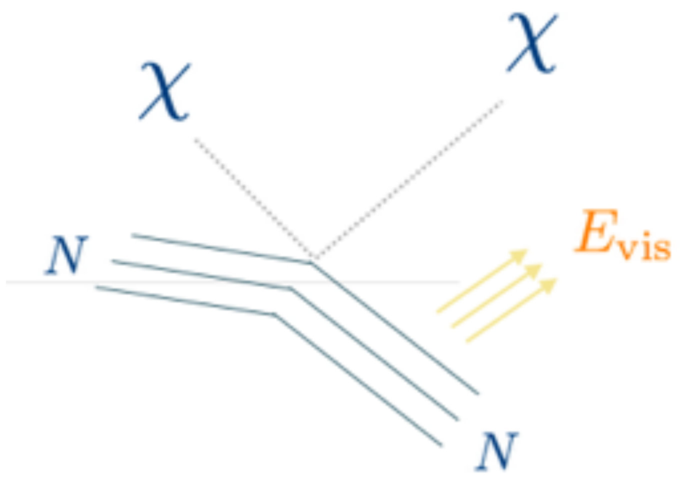


Hypotesis…



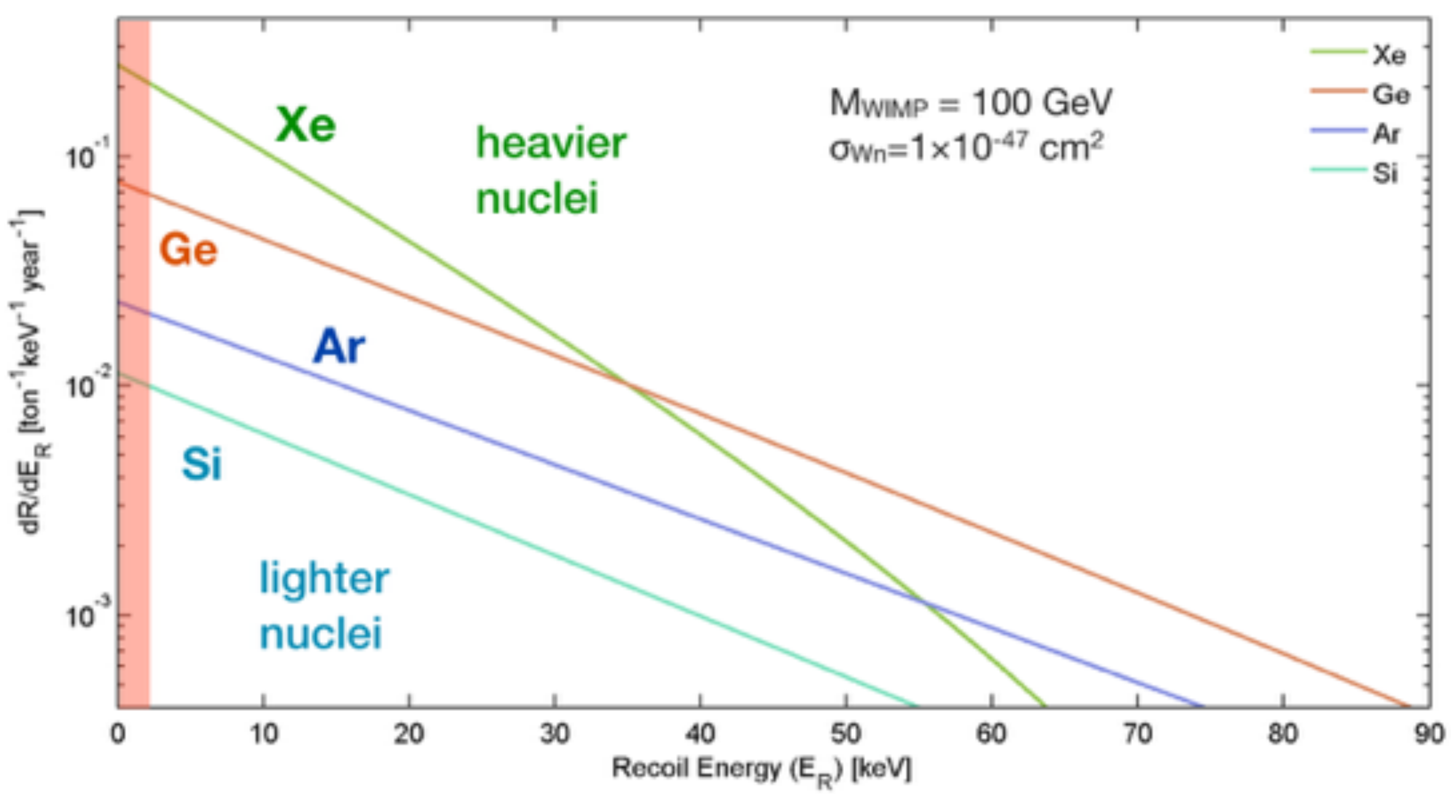
WIMPs are well motivated candidates

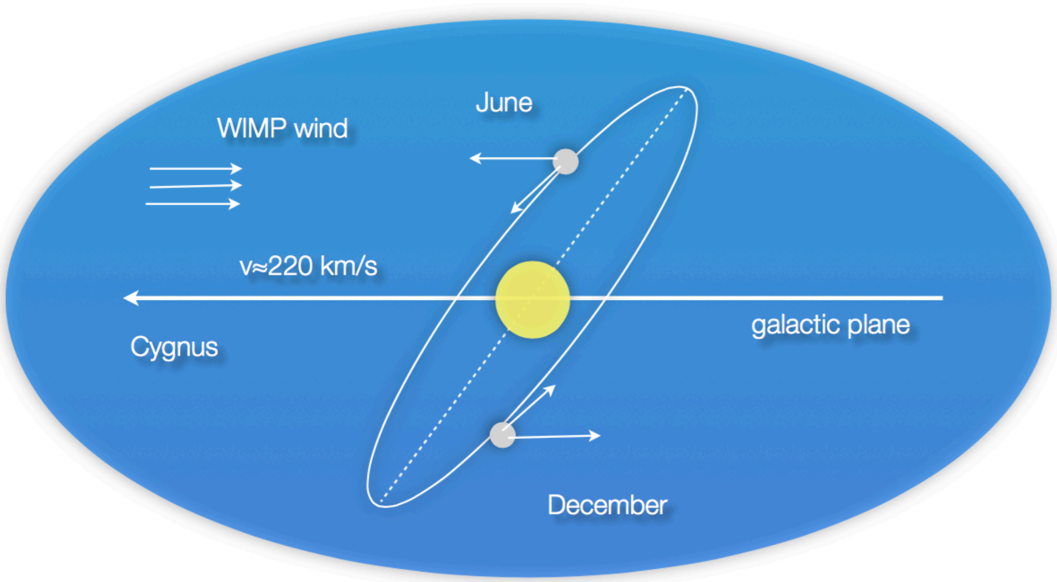
Dark Matter direct Detection



$$E_R = \frac{q^2}{2m_N}$$

Recoiling nucleus energy ~ few tens of keV

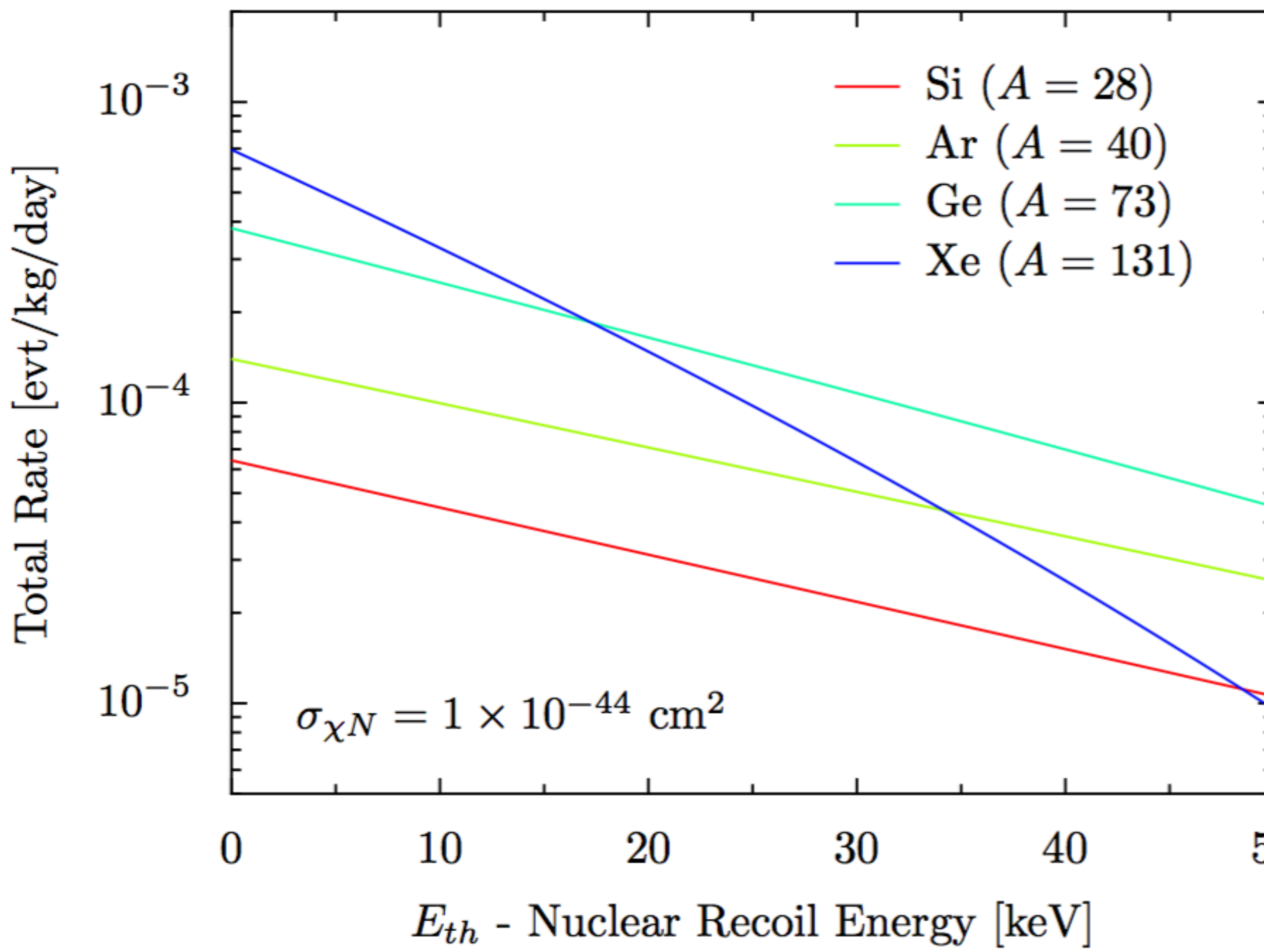




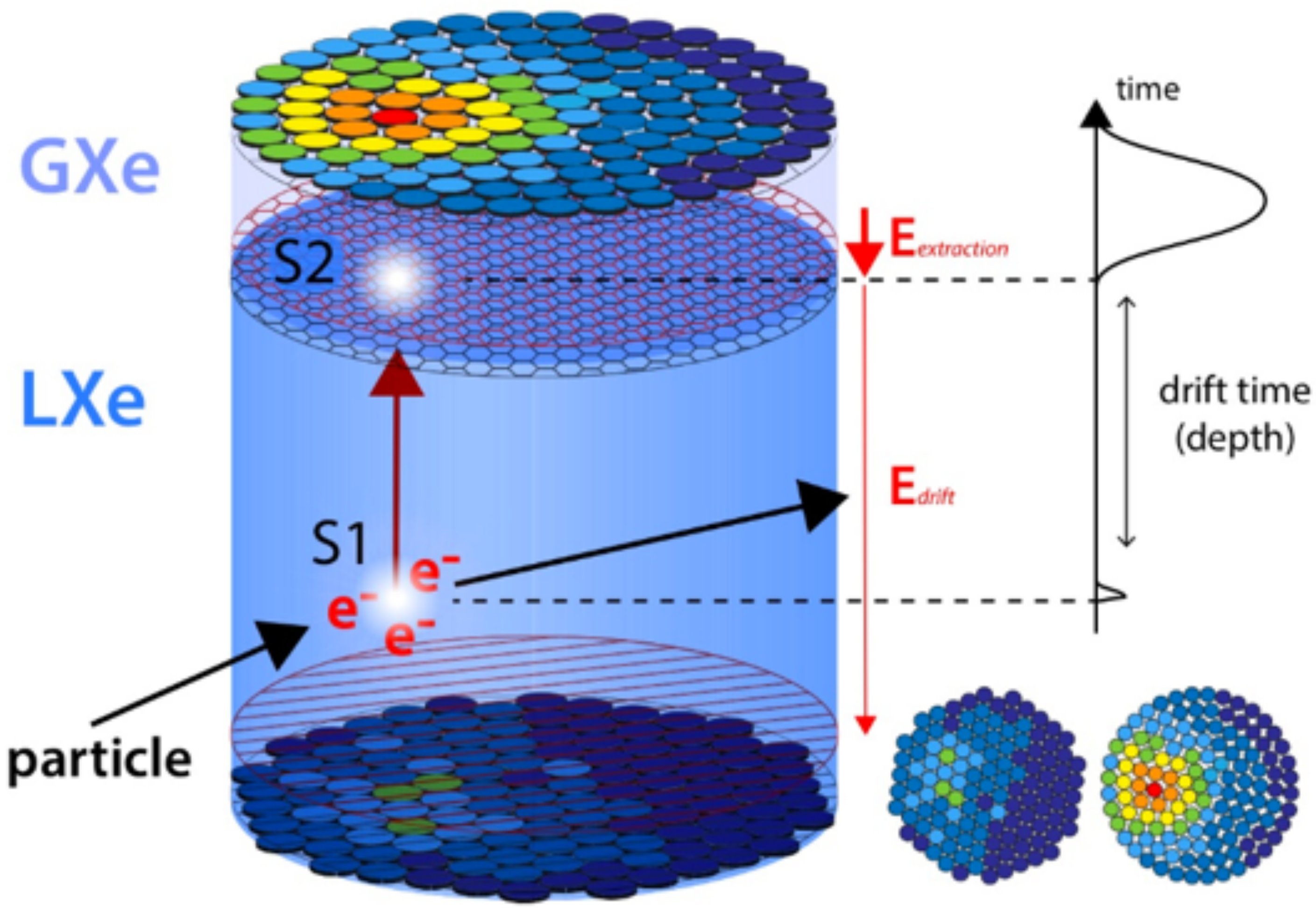
XENON

Why Xenon

- *Large mass number A (131)*
- *50% odd isotopes (^{129}Xe, ^{131}Xe) for SD interactions*
- *No long-lived radioisotopes, Kr can be reduced to ppt levels*
- *High stopping power, i.e. active volume is self-shielding*
- *Efficient scintillator (178 nm)*
- *Scalable to large target masses*
- *Electronic recoil discrimination with simultaneous measurement of scintillation and ionisation*



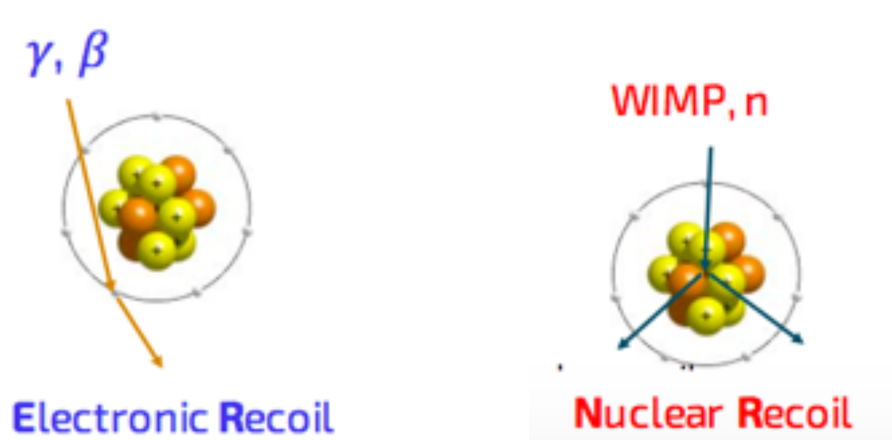
How we use it…two phase TPC

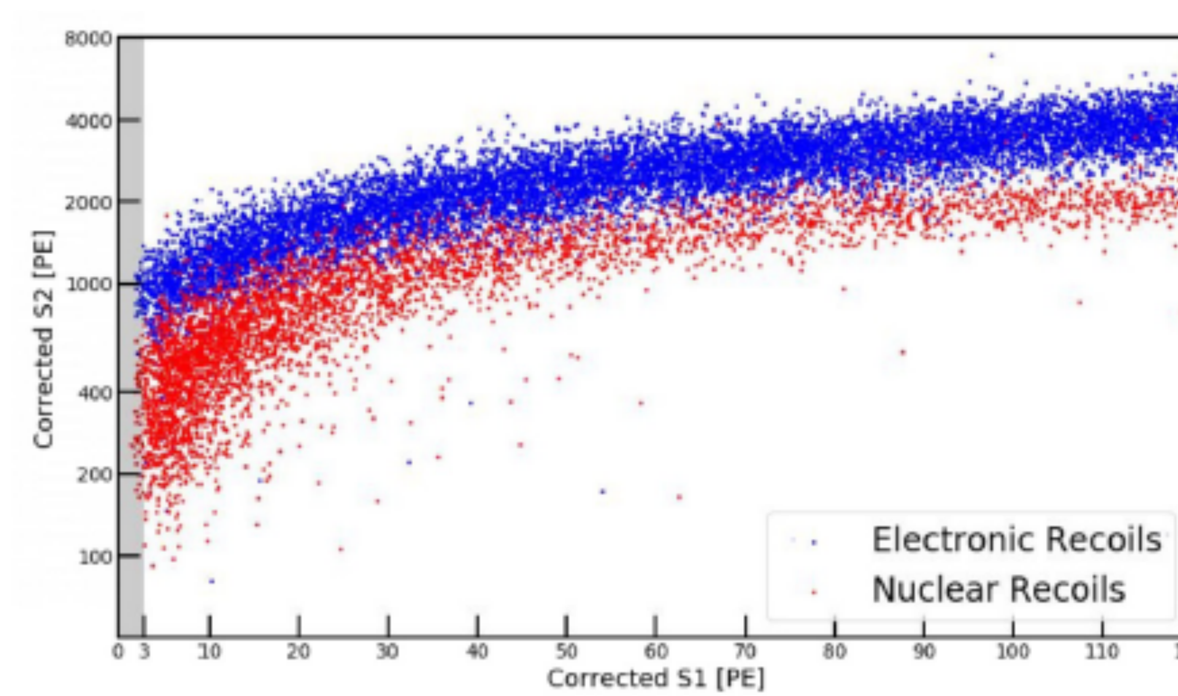


✦ *two signals for each event:*

- ✓ ***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***

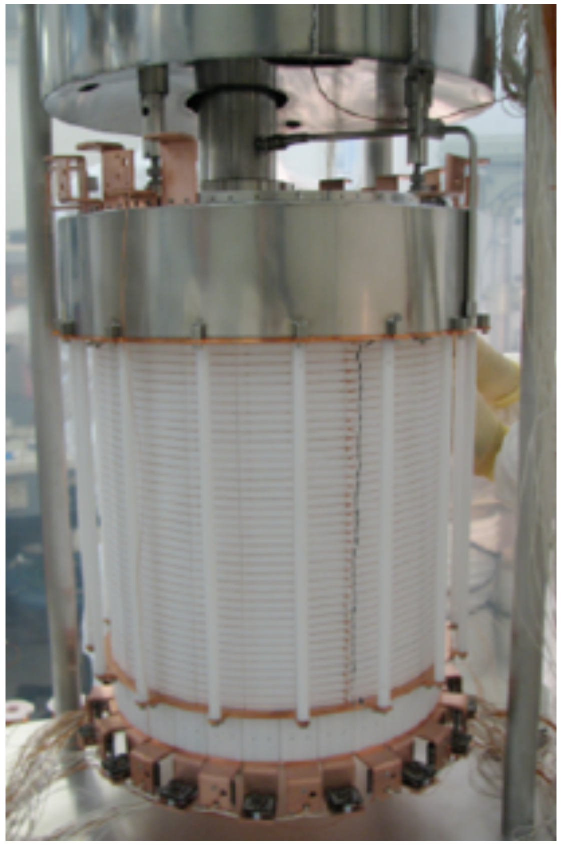
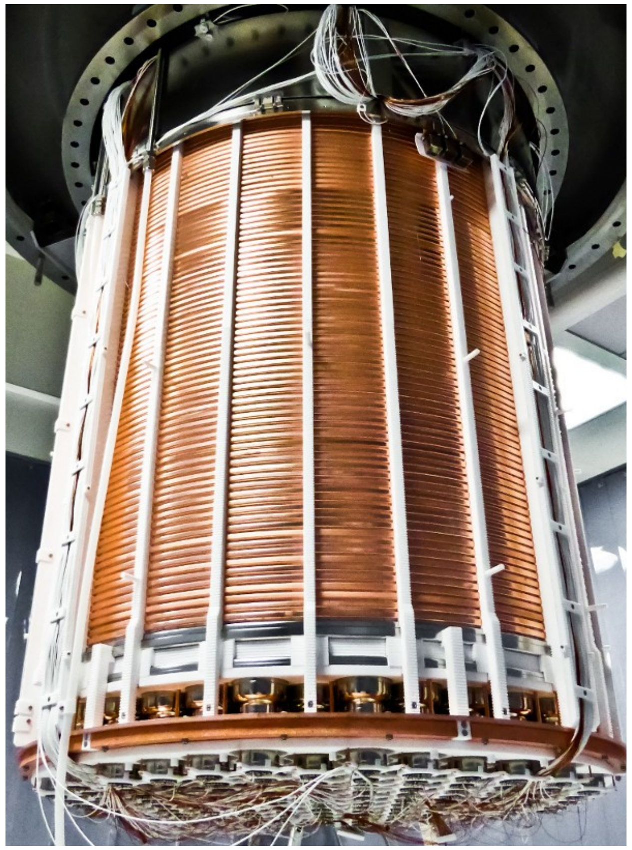
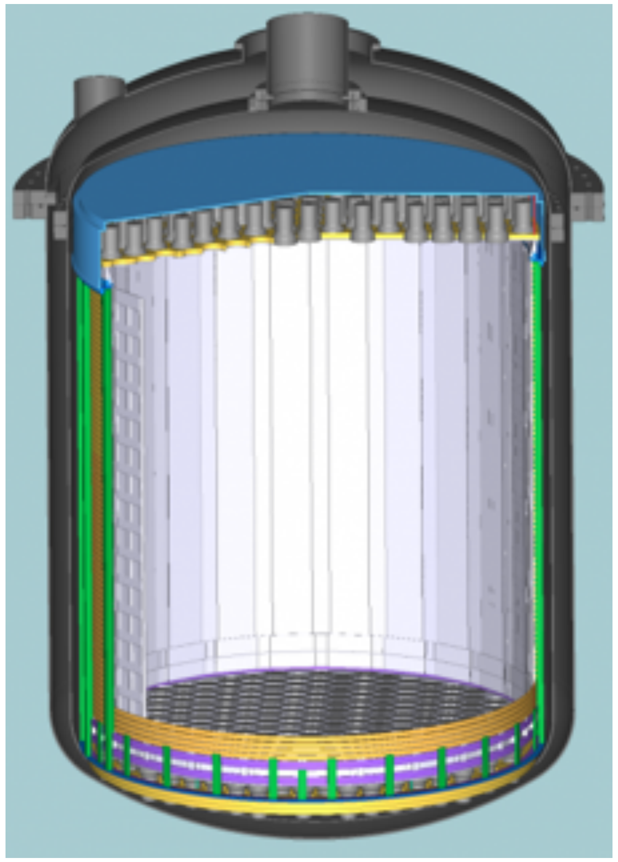
✦ ***Recoil type discrimination form ratio of charge (S2) to light (S1)***





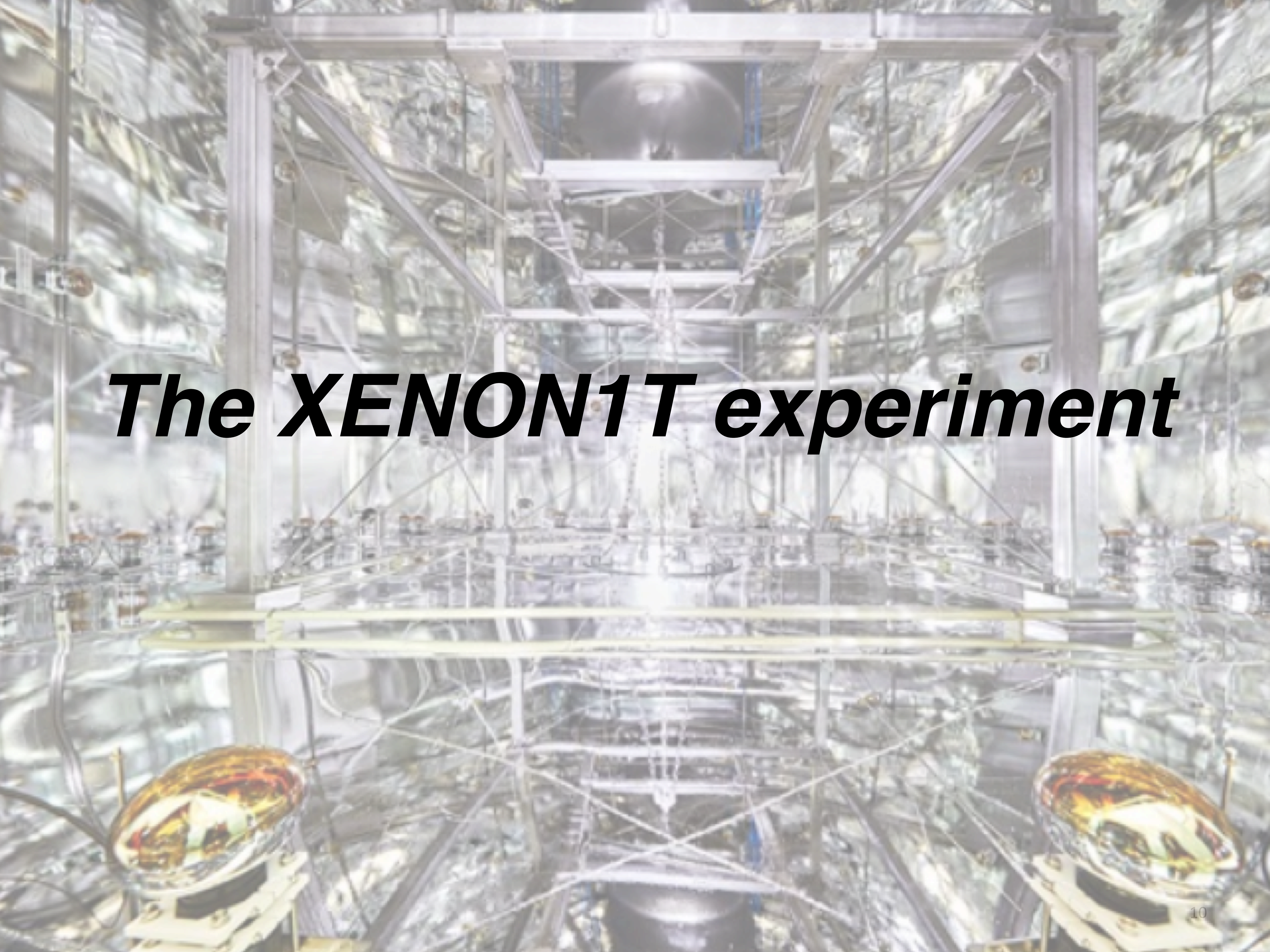
The phases of the XENON Program

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
~10^{-43} cm^2	~10^{-45} cm^2	~10^{-47} cm^2	~10^{-48} cm^2

The XENON1T experiment



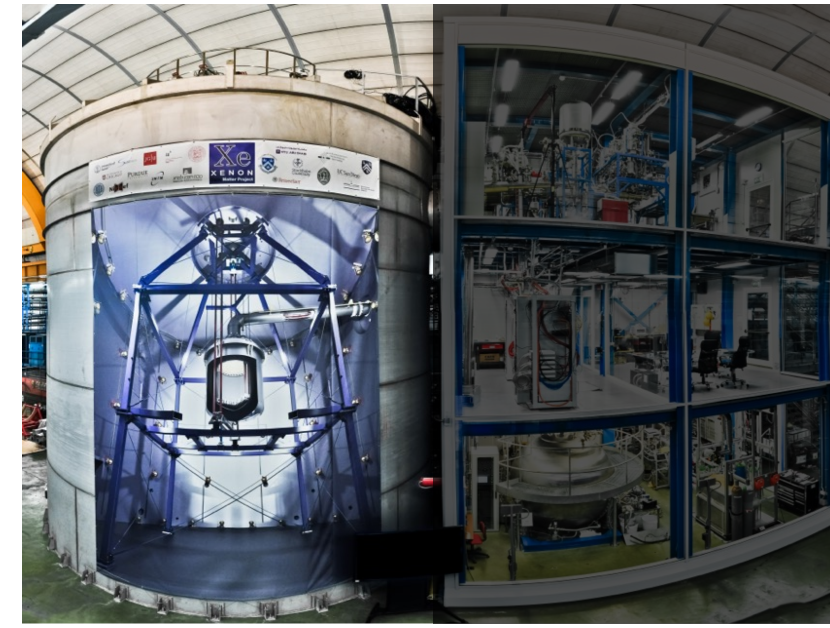
The XENON Collaboration

XENON1T@LNGS
is searching for WIMPs

XENON1T: system overview

Water Cherenkov Muon Veto

- *700 ton pure water instrumented with 84 high-QE 8'' PMTs and reflective film foil on the walls*
- *Active shield against muons*
- *Trigger efficiency > 99.5% for muons in water tank*



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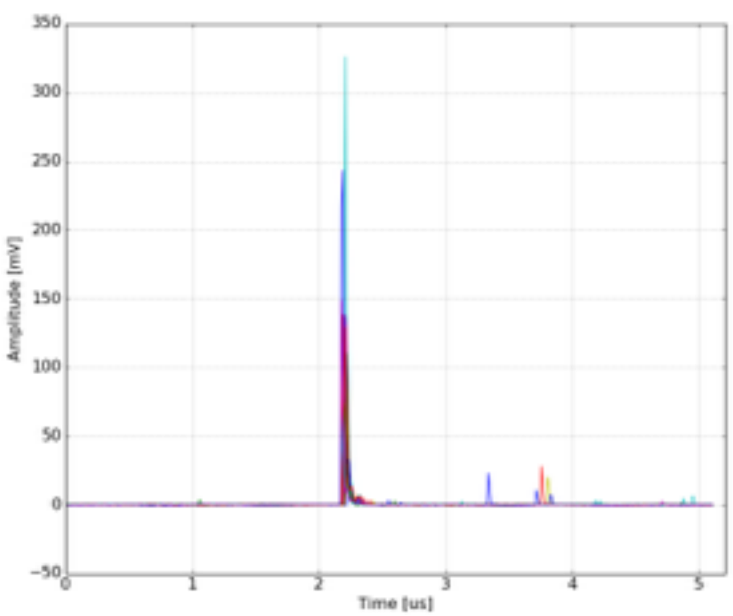
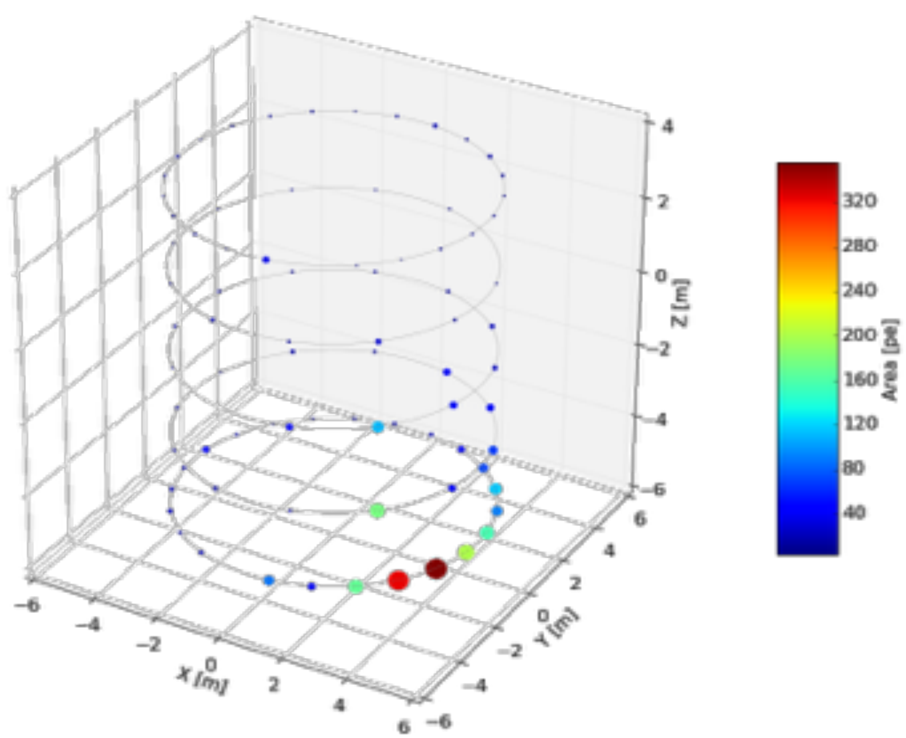
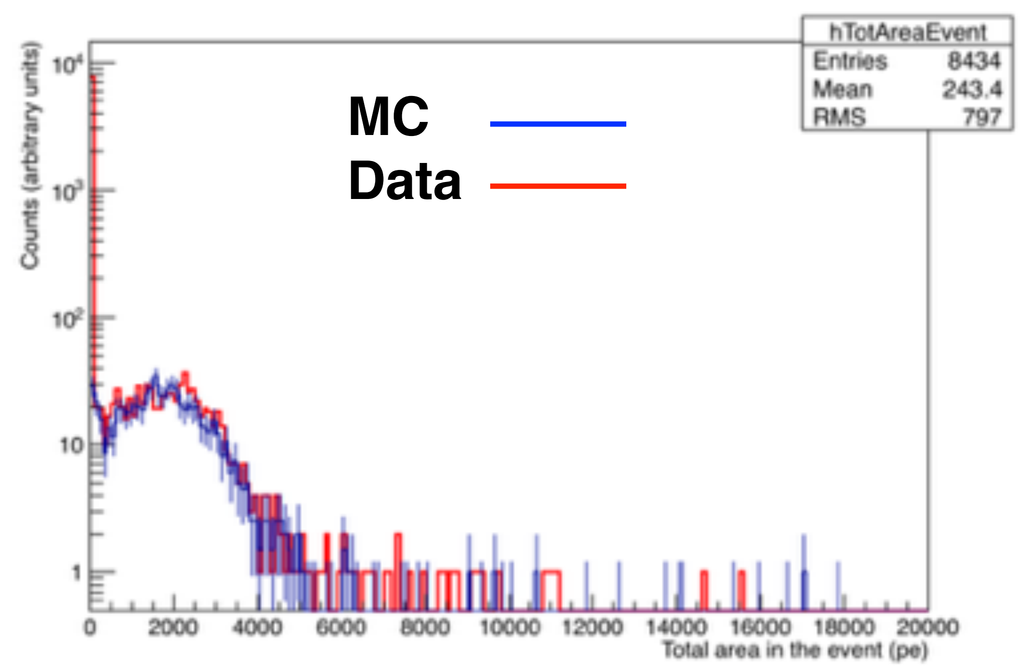
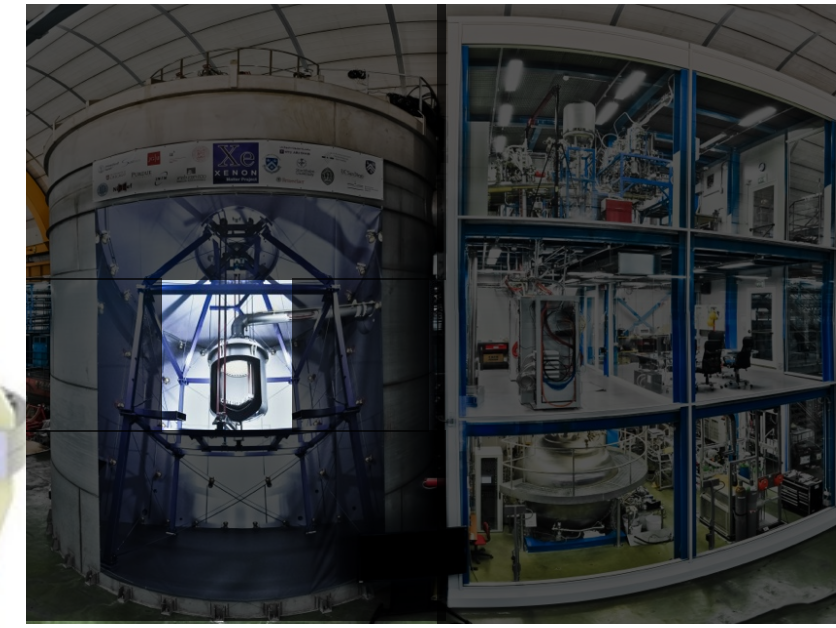






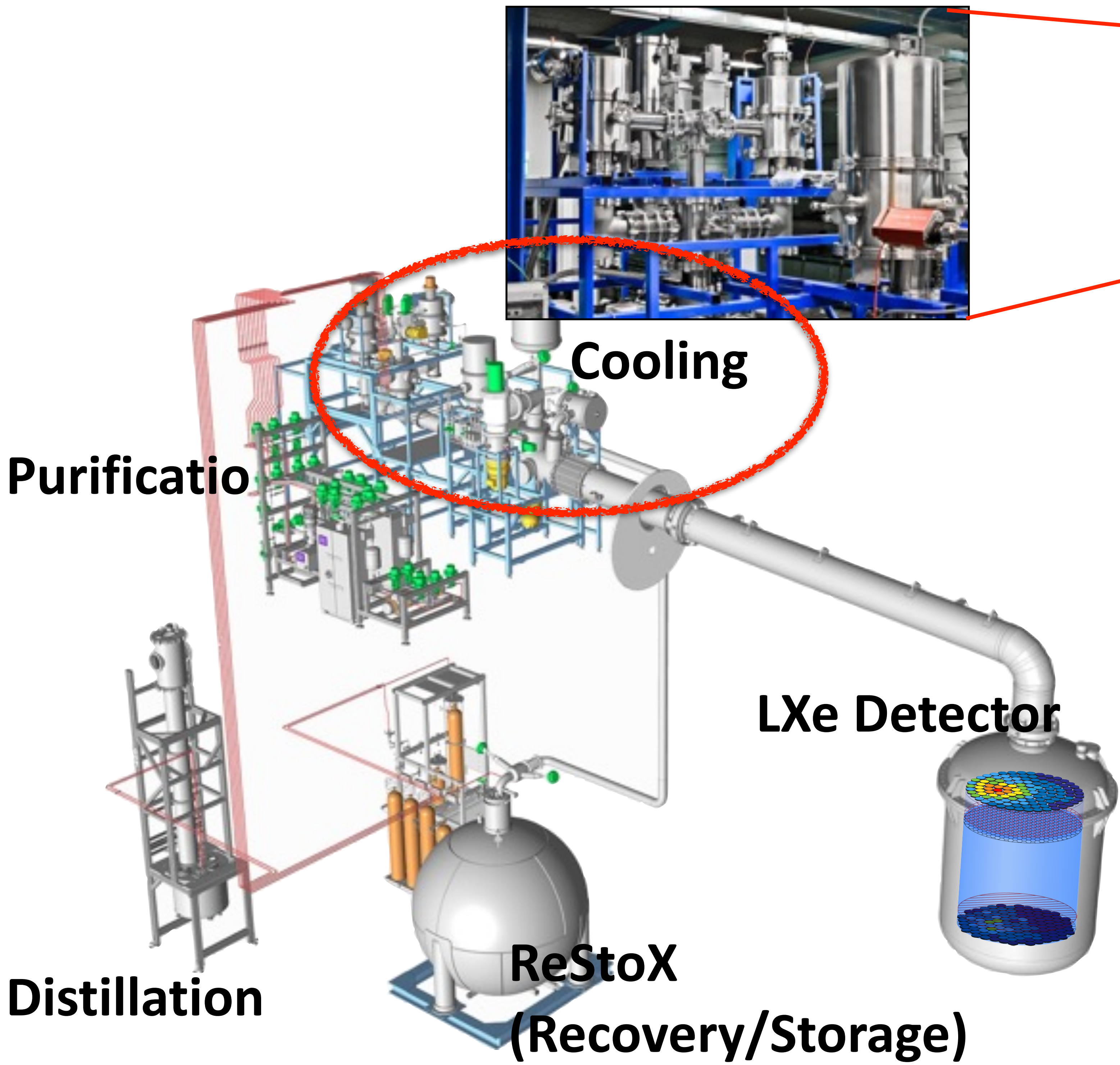
Cosmogenic neutron background suppressed to < 0.01 events/ton/yr

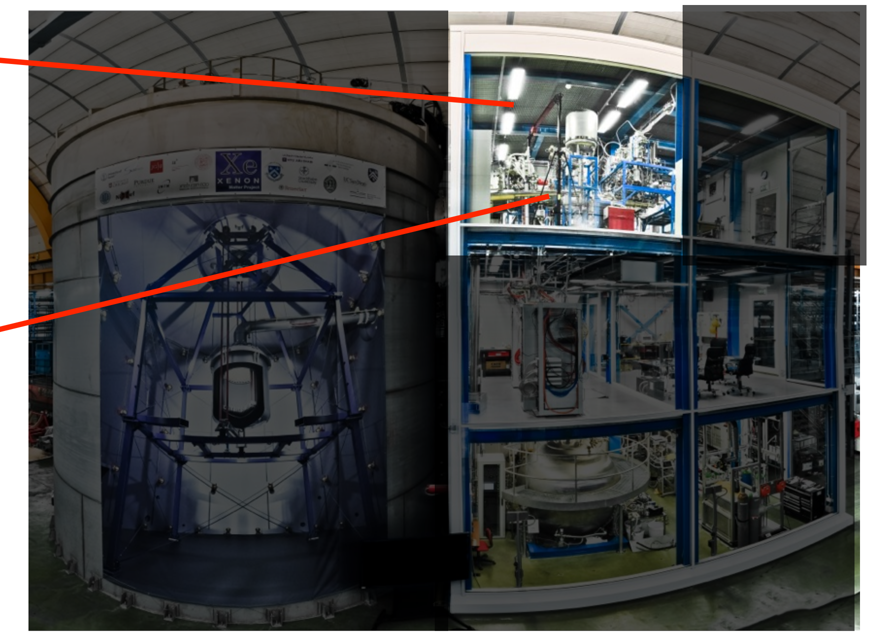
The XENON1T Time Projection Chamber

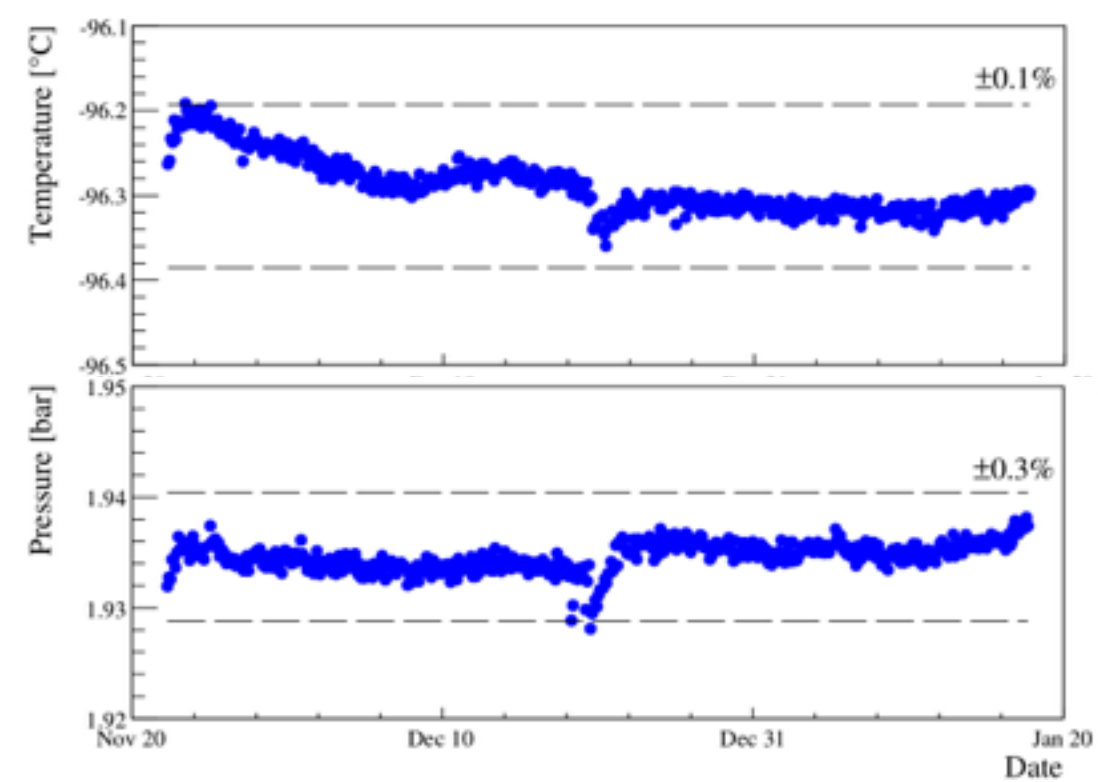


- ⋆ *3.2 t LXe @180 K*
- ⋆ *2.0 t active target viewed by 248 PMTs*
- ⋆ *~1 meter drift length*
- ⋆ *~1 meter diameter*

The XENON1T Cryogenic Plants

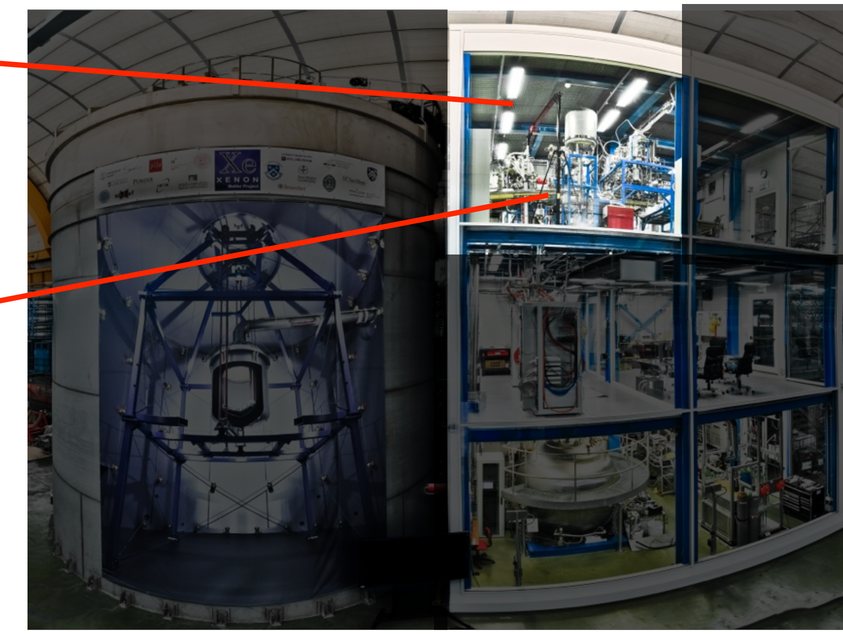


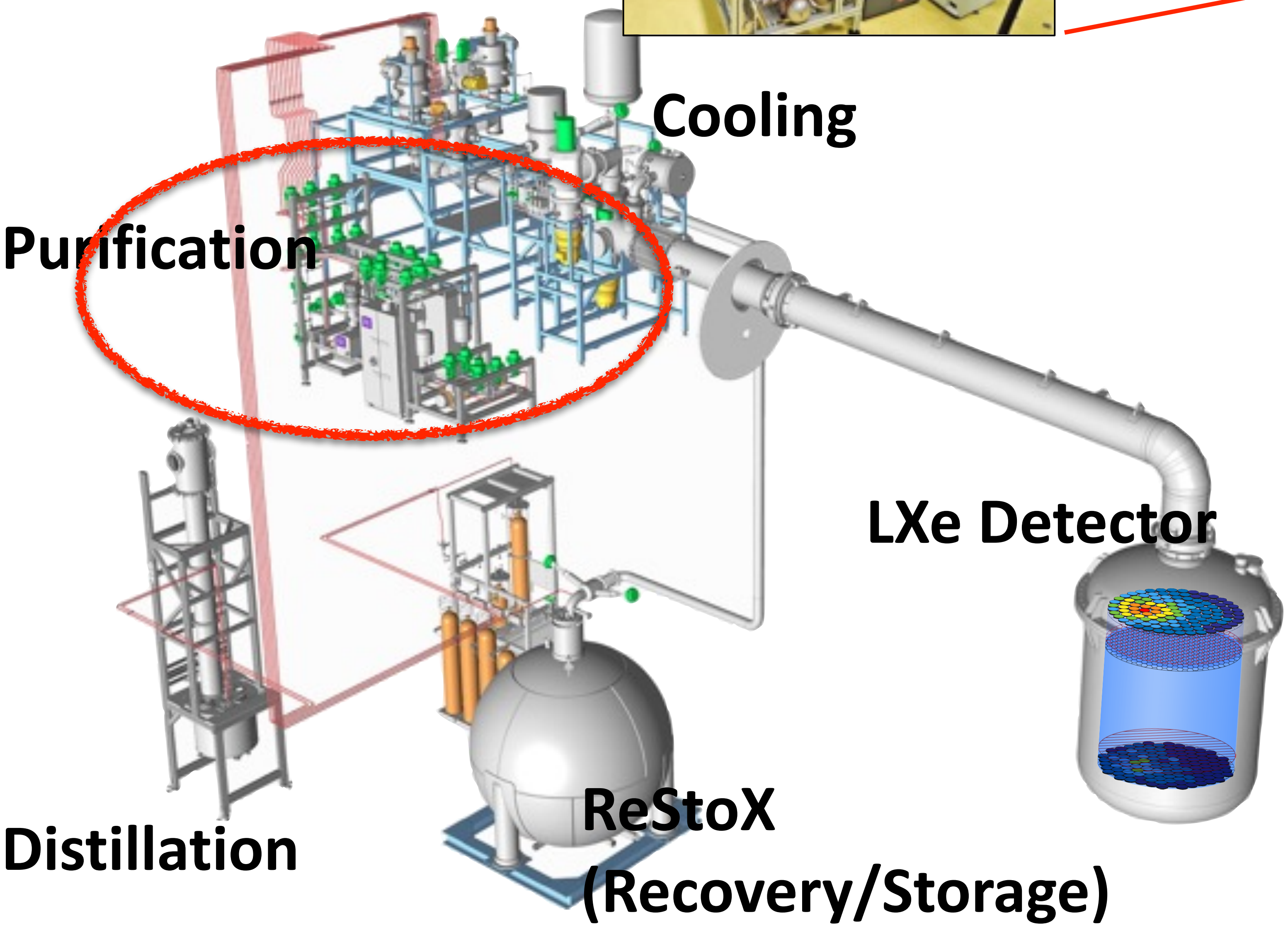




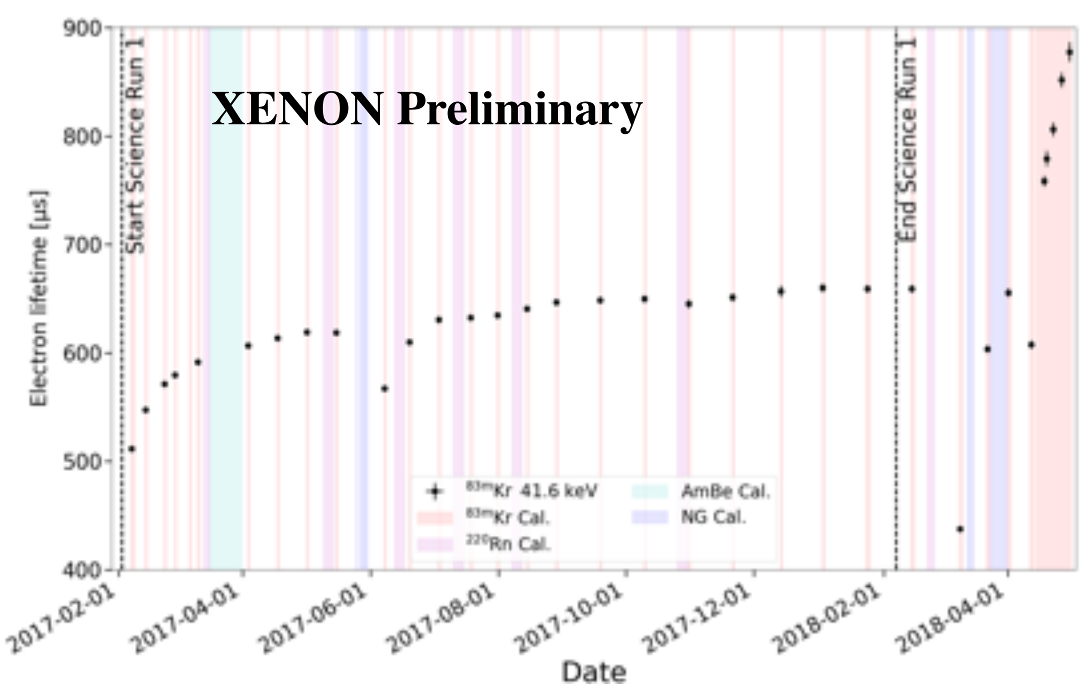
LXe temperature and GXe Pressure stable

Xenon Purification



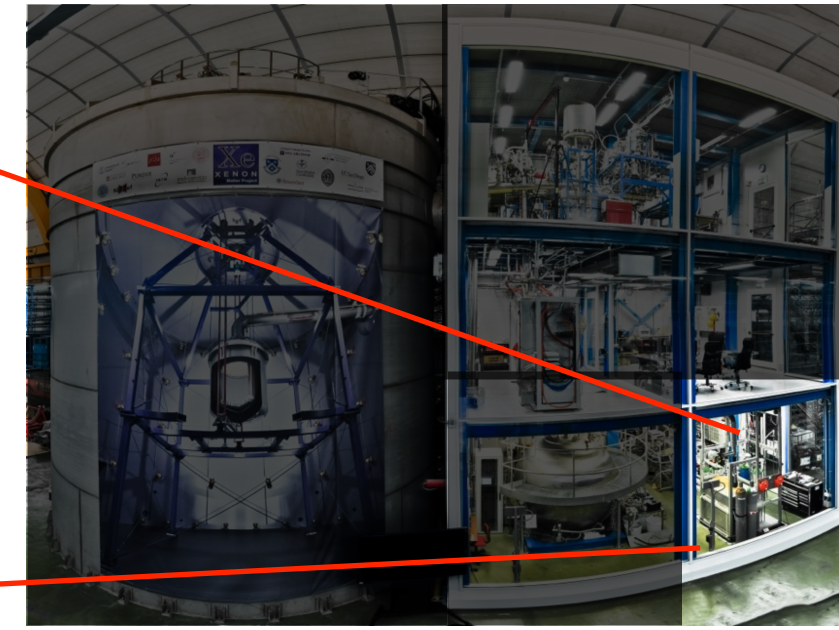


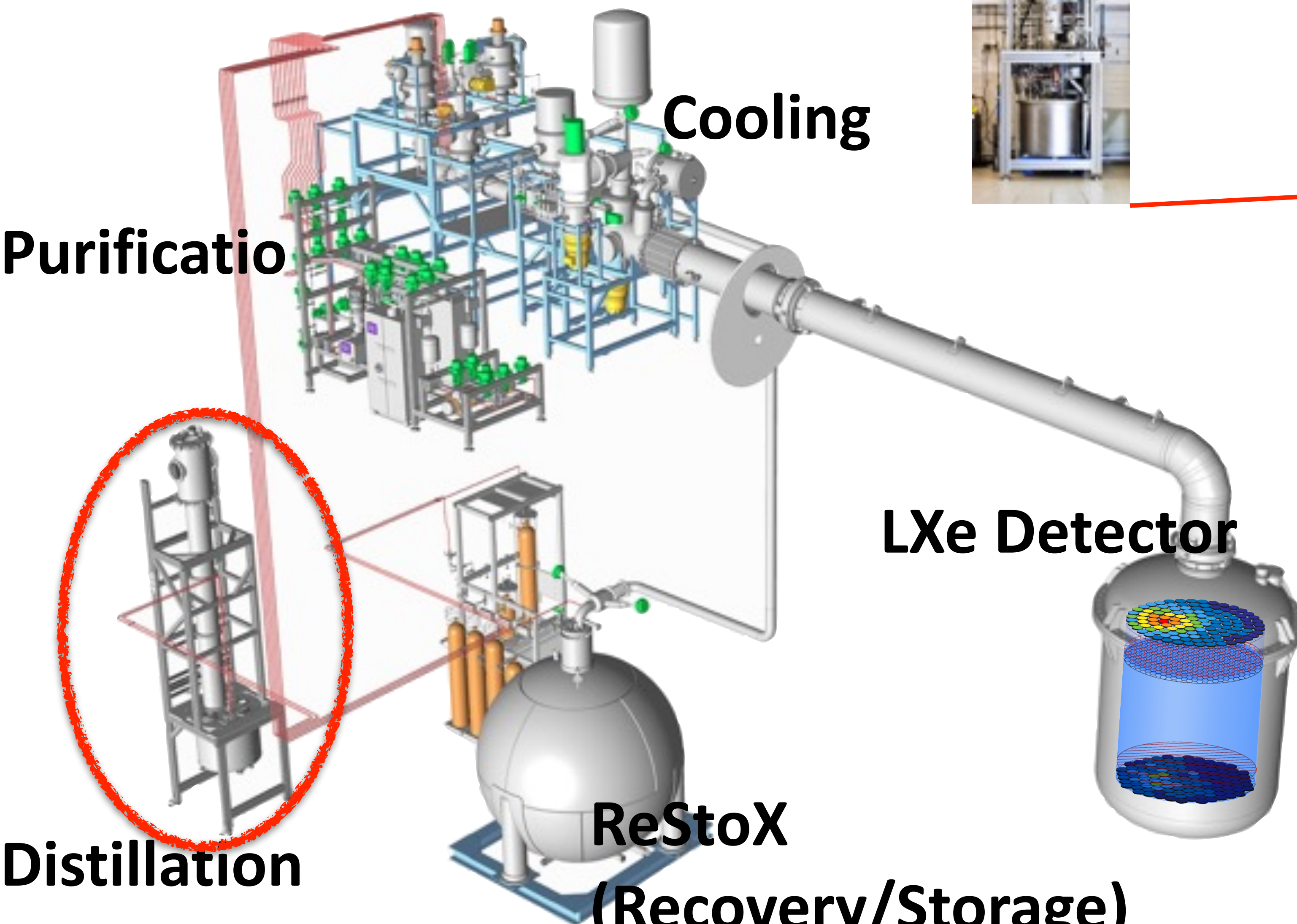
electron lifetime is monitored regularly with ERs calibration sources.

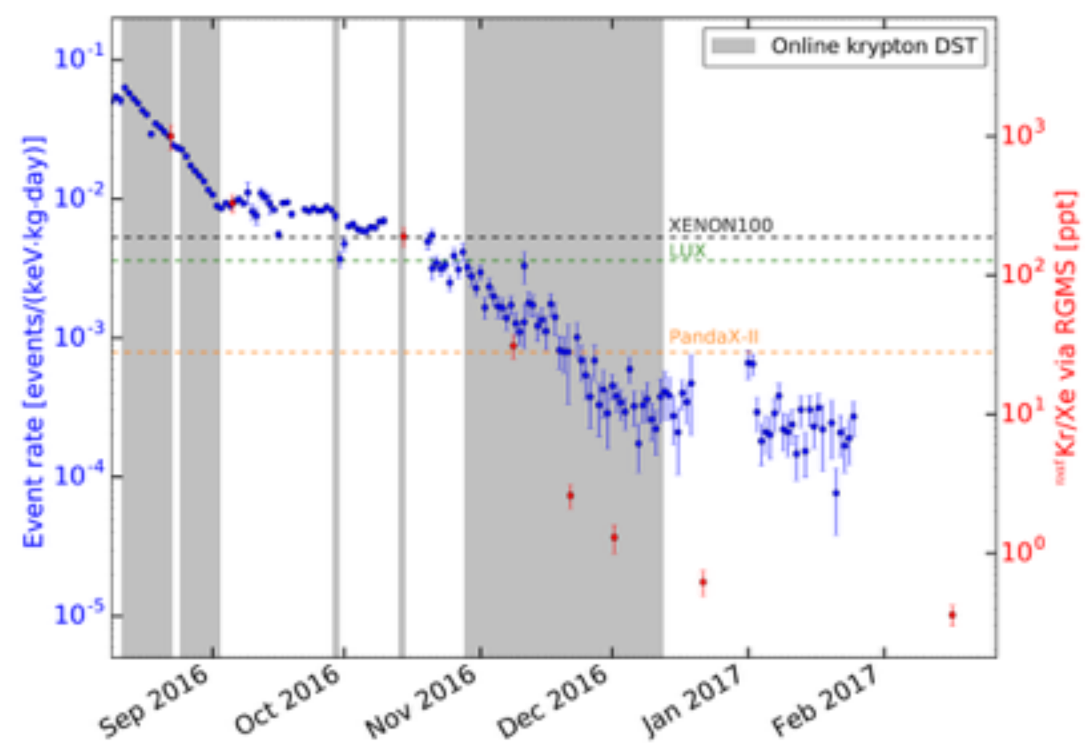


Kr/Xe Distillation

- *Commercial Xe: 1 ppm - 10 ppb of Kr*
- *XENON1T sensitivity requires: ~0.5 ppt: 5.5 m distillation column, 6.5 kg/h throughput > 6.4×10^5 separation, output concentration < 48 ppq (RGMS)*







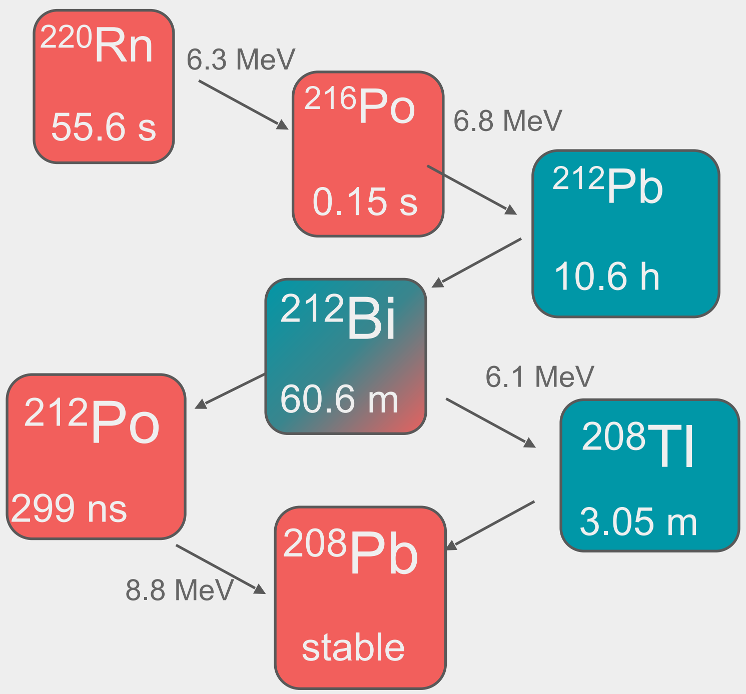
EPJ-C 77, 2017

Detector Characterisation

Calibration Sources

ER

^{220}Rn: Low Energy ER

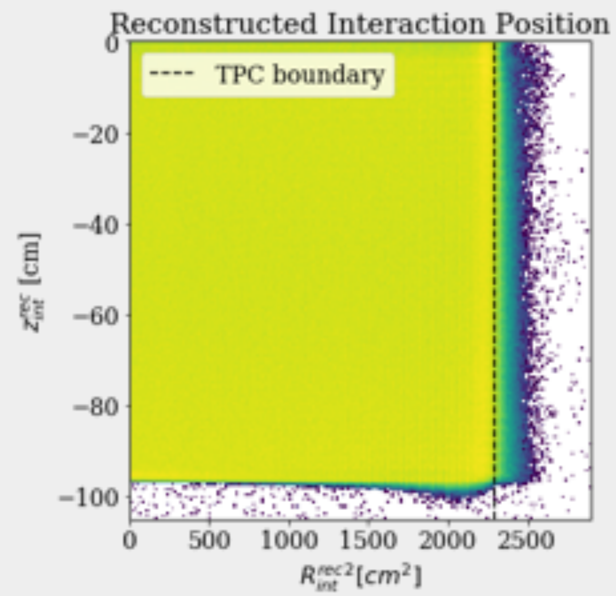


Type: Internal
Freq: 1-2 Months
Length: Few days

Stable background conditions after a couple days (10.6h longest $T_{1/2}$)

Spatial

^{83m}Kr: Stability and Monitoring

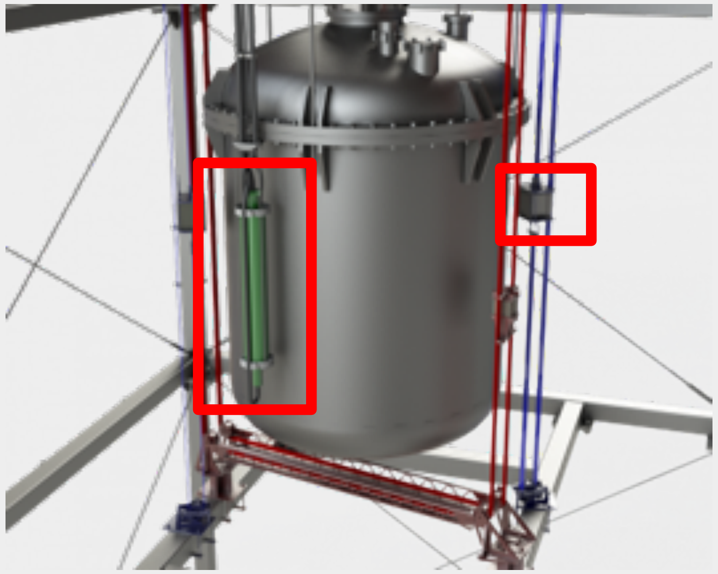


Type: Internal
Freq: 2-3 weeks
Length: 1 day
Half life: 1.83h

9.4 keV and 32.1 keV lines (~150 ns delay) homogeneous in volume

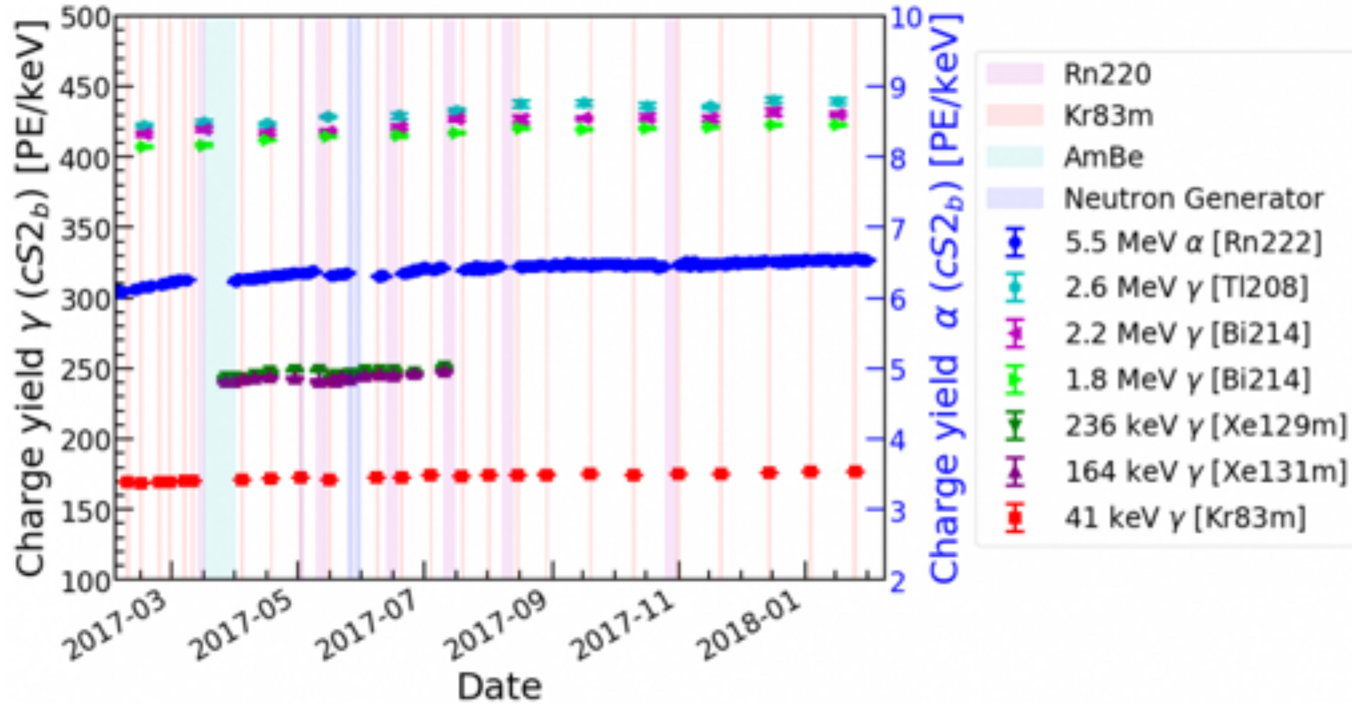
NR

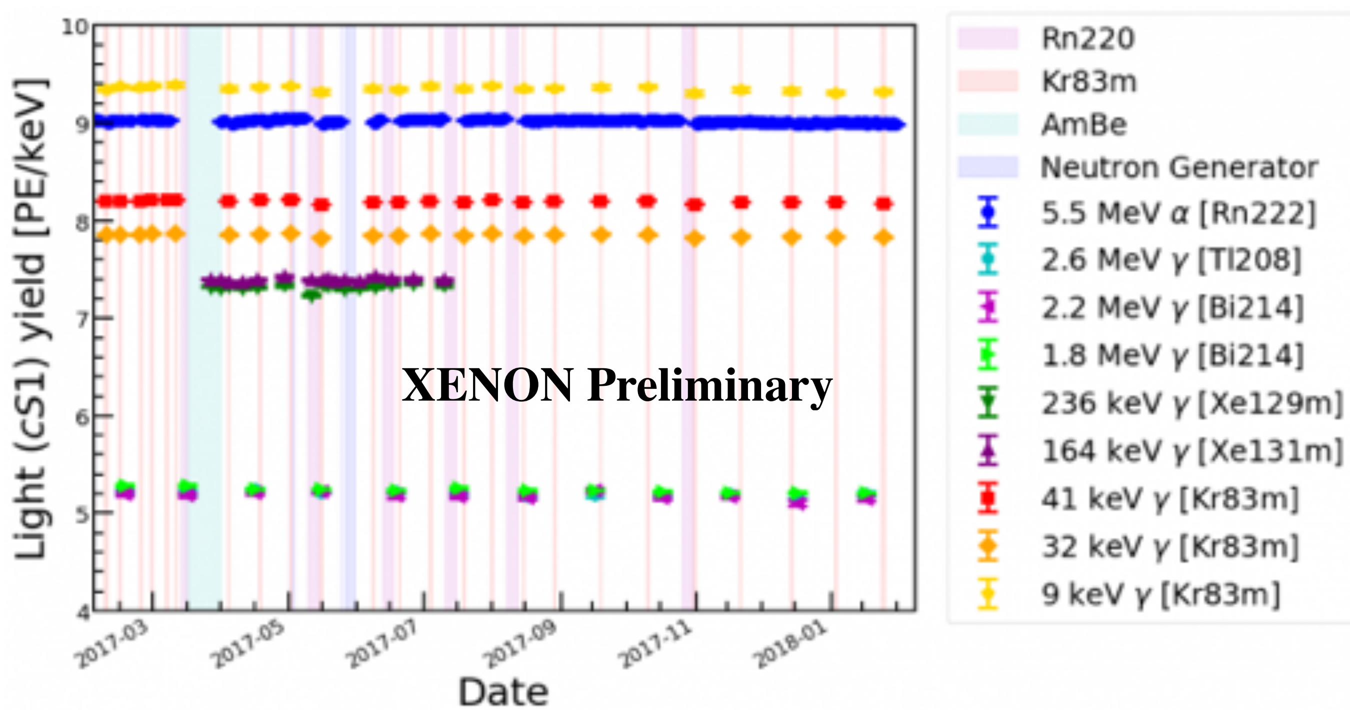
Neutrons: Signal



Type: External
Freq: As needed
Length: 6 weeks (AmBe)
2 days (generator)

Light and Charge Signals Stability



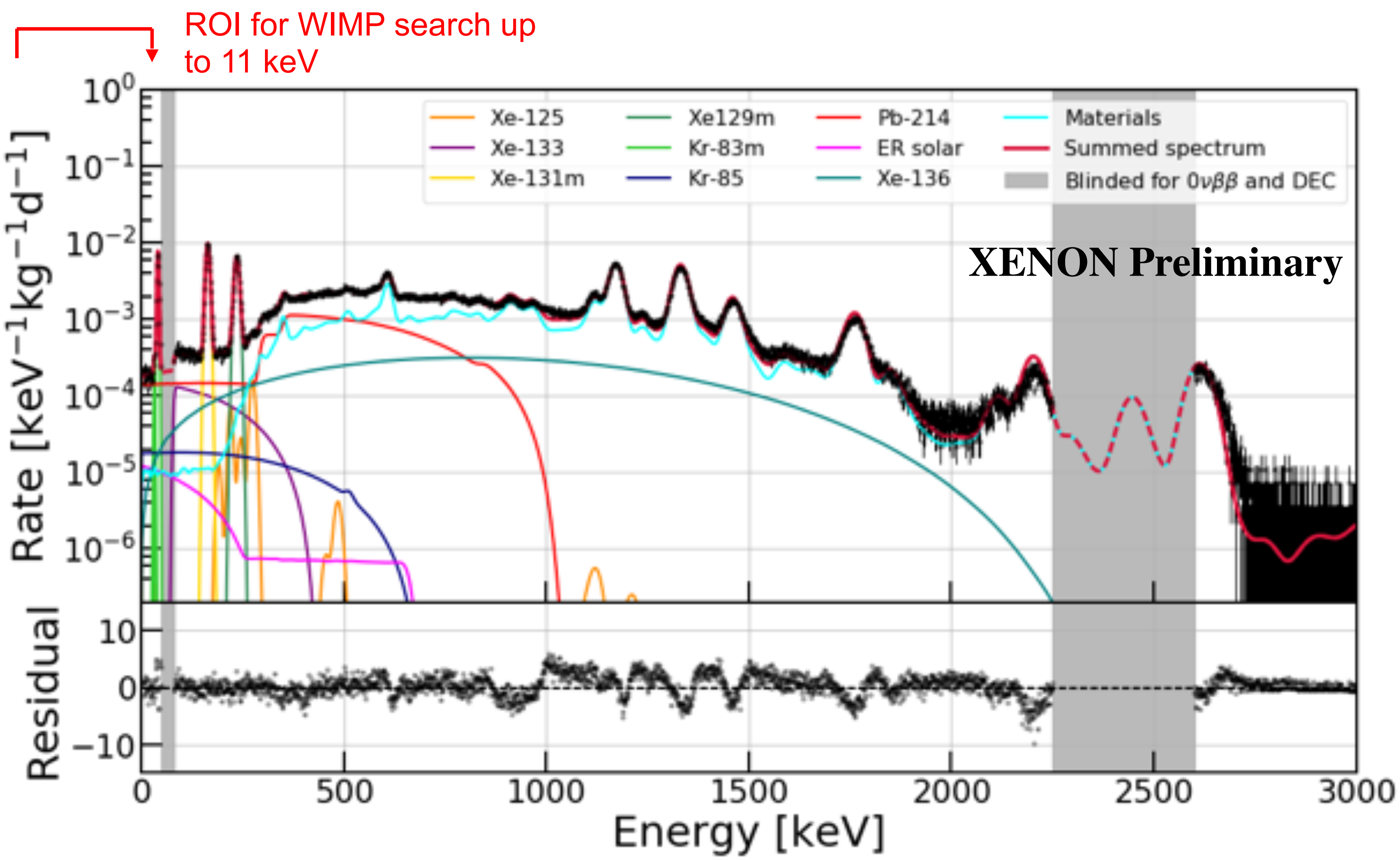


Light and charge yield stability monitored with several sources:

- ***^{222}Rn***
- ***Activated Xe after neutron calibrations***
- ***^{83m}Kr calibrations***
- ***Stability is within a few %***

Position dependence of light and charge signals understood (^{83m}Kr and ^{222}Rn)
Agreement with optical Monte Carlo simulations and with model of purity evolution.

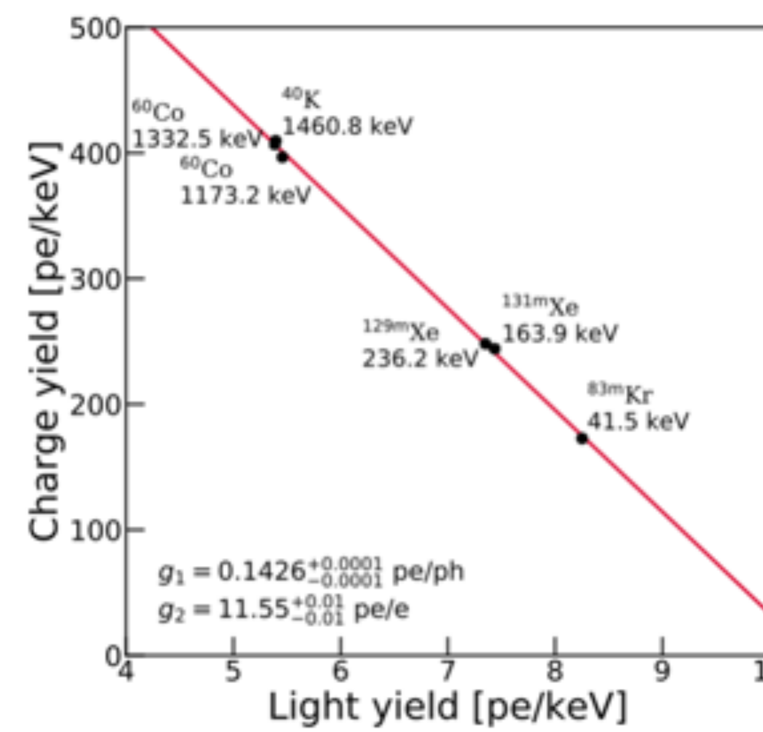
Energy Resolution



- ***Good agreement between predicted and measured background spectrum***
- ***Kr: ~0.66 ppt; Pb214: ~ 10 μBq/kg***
- ***Gammas based on screening measurements***

Energy reconstructed from anti correlated S1 and S2. Excellent linearity from keV to MeV

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



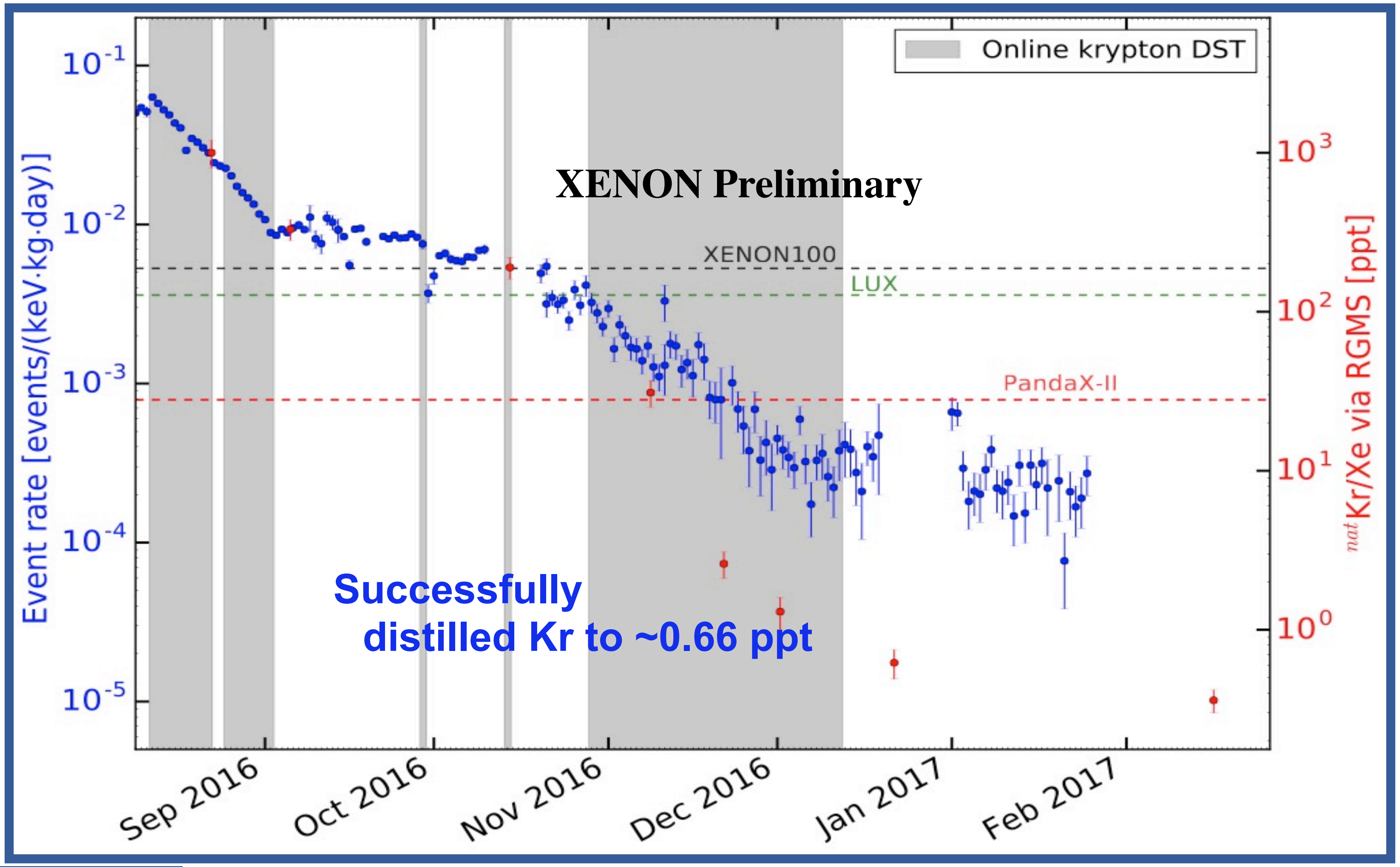
g1 = 0.143 ± 0.007 (sys) PE/photon corresponds to a photon detection efficiency of 12.5 ± 0.6%

g2: the amplification of charge signal corresponds to near full extraction of charges from the liquid.

Backgrounds

Electronic Recoil Backgrounds

- ***^{222}Rn : 10 μBq/kg. Careful surface emanation control and further reduction by online cryogenic distillation.***
- ***^{85}Kr : sub-ppt Kr/Xe thanks to cryo-distillation***



Source	Rate [t^{-1} y^{-1}]	Fraction [%]
^{222}Rn	620 ± 60	85,4
^{85}Kr	31 ± 6	4,3
Solar ν	36 ± 1	4,9
Materials	30 ± 3	4,1
^{136}Xe	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

Nuclear Recoil Backgrounds

- *Cosmogenic μ-induced neutrons significantly reduced by rock overburden and muon veto*
- *Coherent elastic ν-nucleus scattering, constrained by ^{8}B neutrino flux and measurements, 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 n	0.6 ± 0.1	96,5
CEvNS	0,012	2,0
Cosmogenic	< 0.01	< 2.0

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

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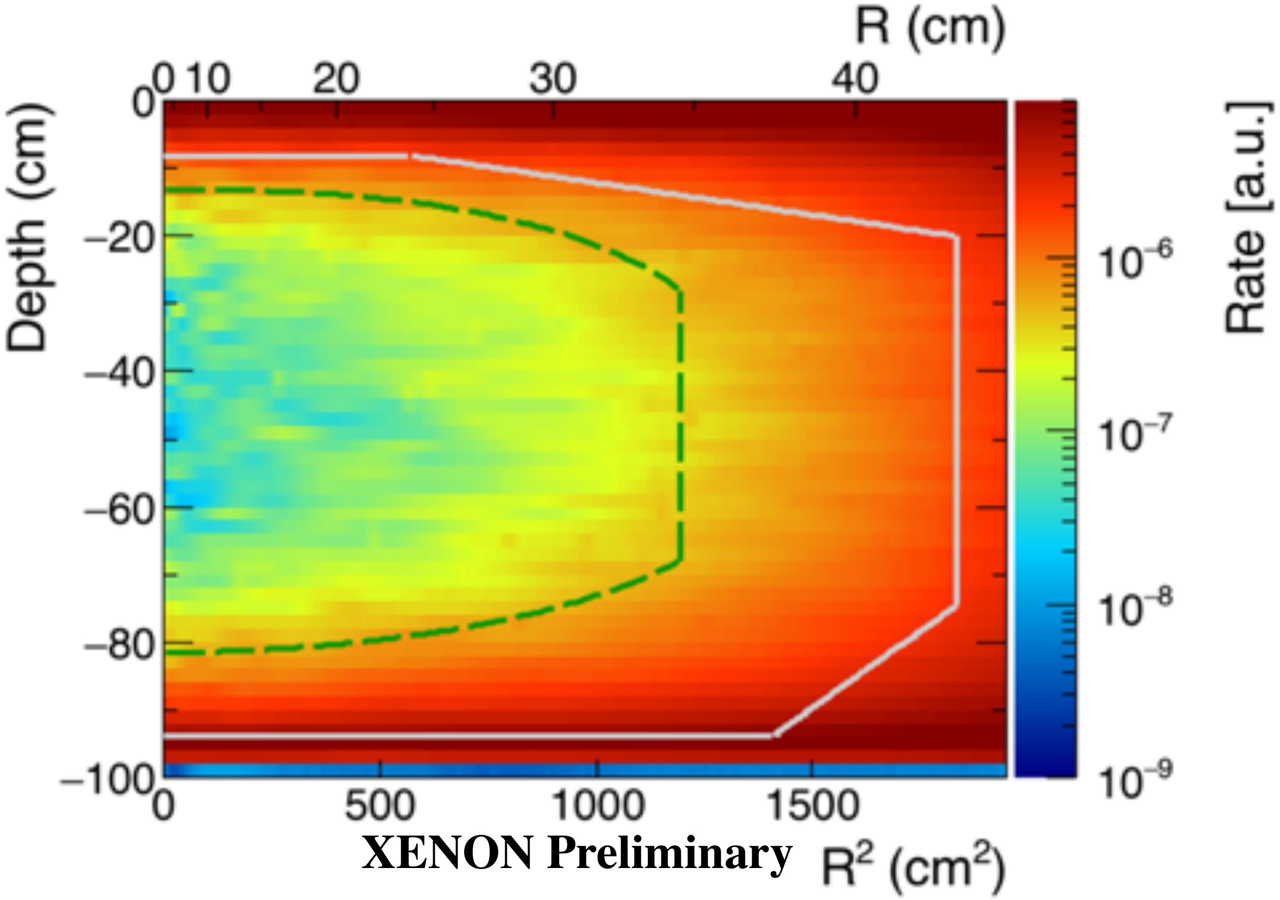
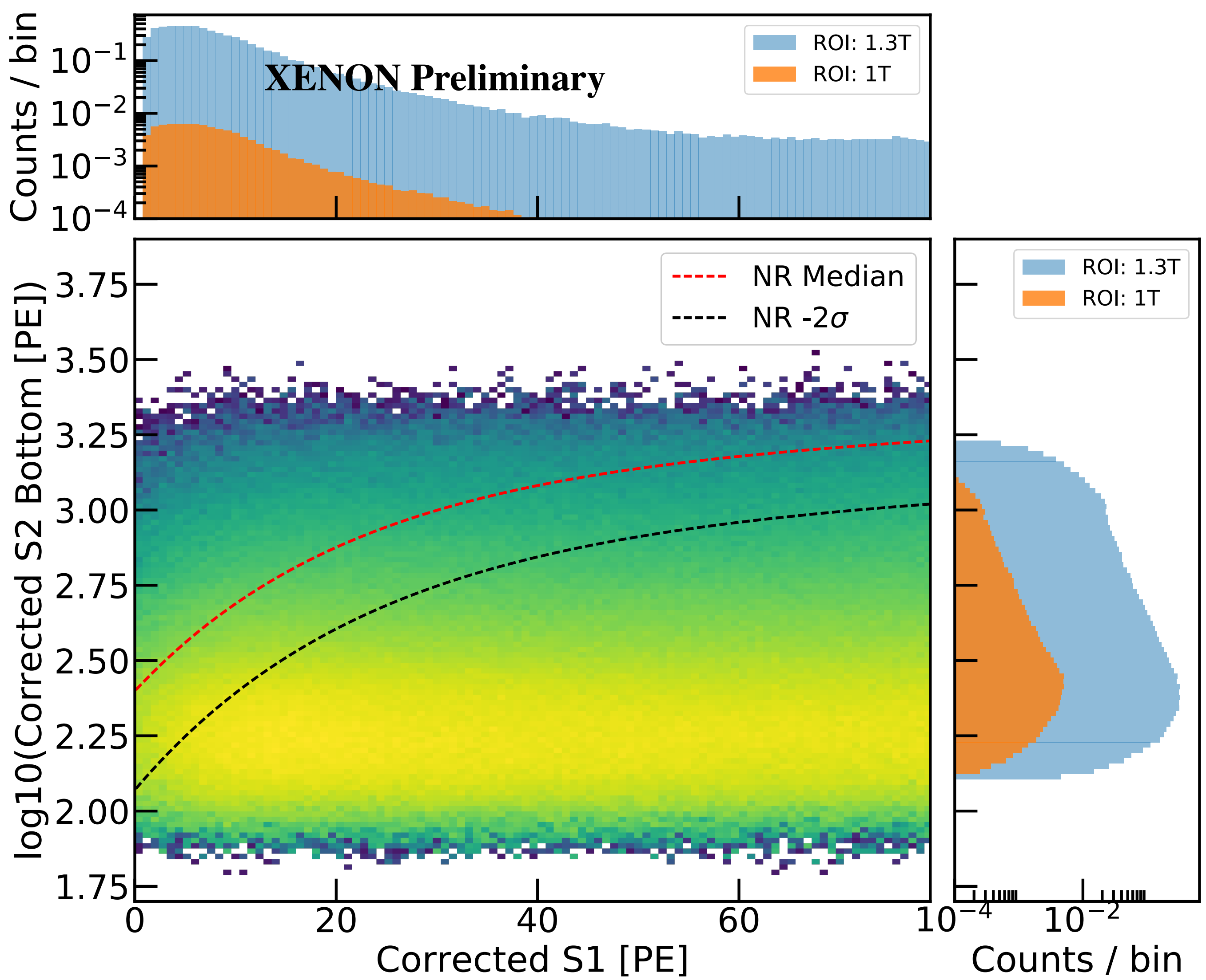
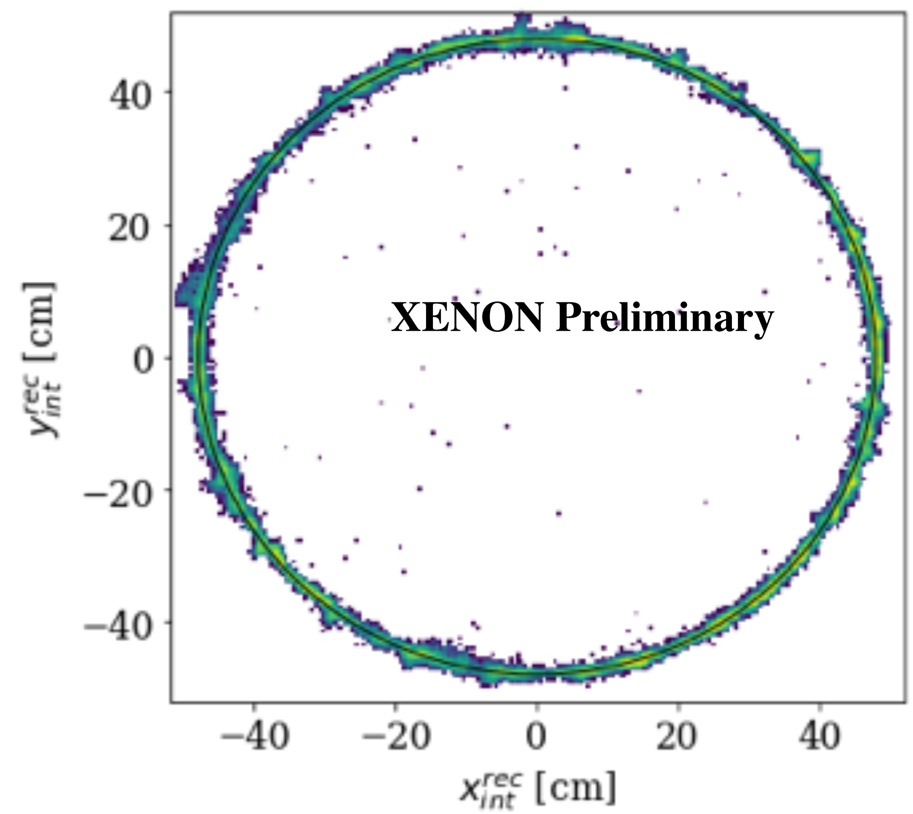


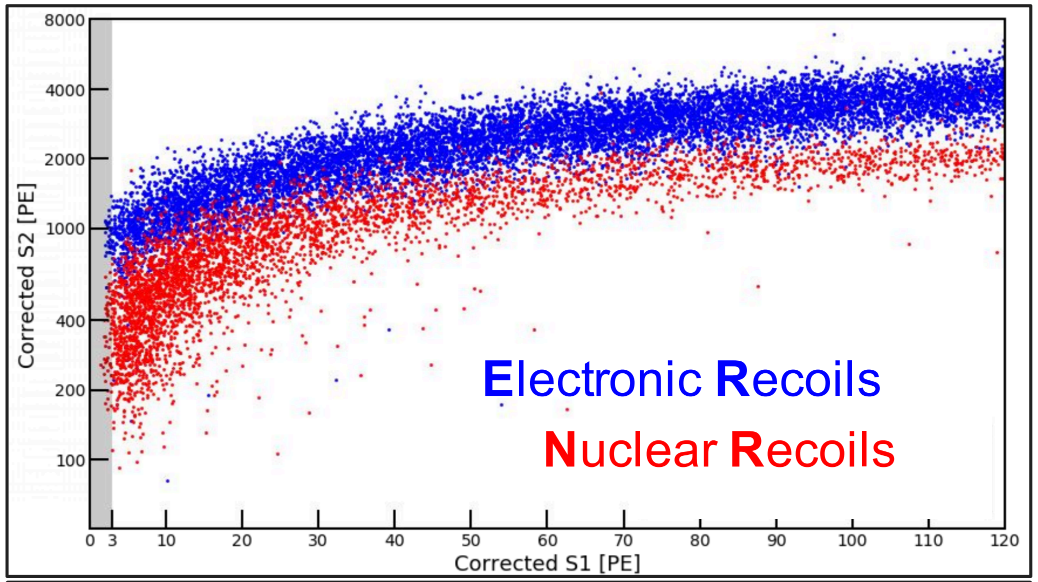
Surface Background

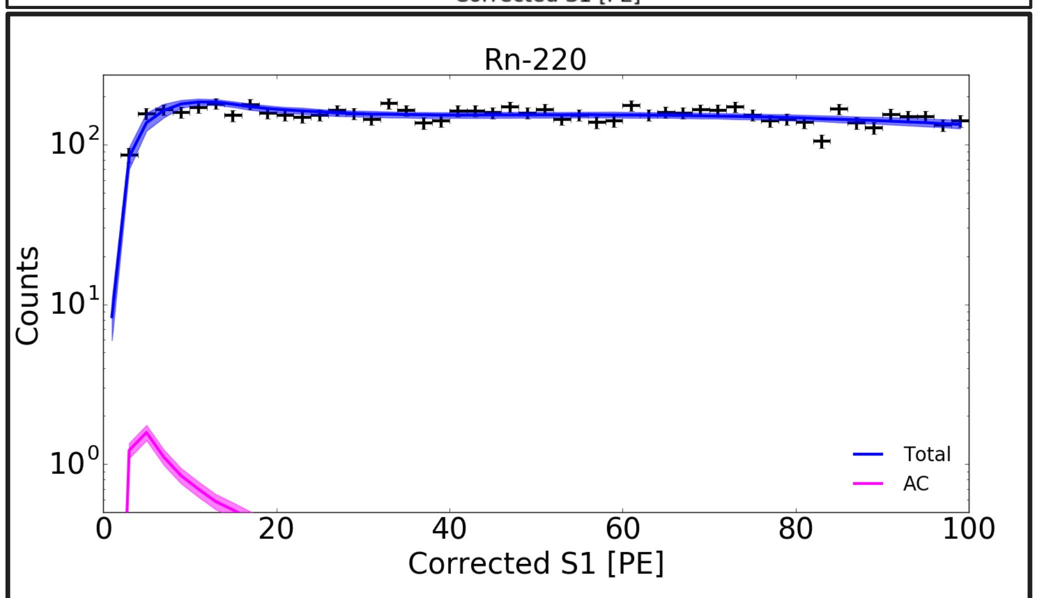
- ^{210}*Pb and* ^{210}*Po plate-out on PTFE surface produce events with reduced S2 -> can be mis-reconstructed into NR signal region*
- *Data-driven model derived from surface event control samples*

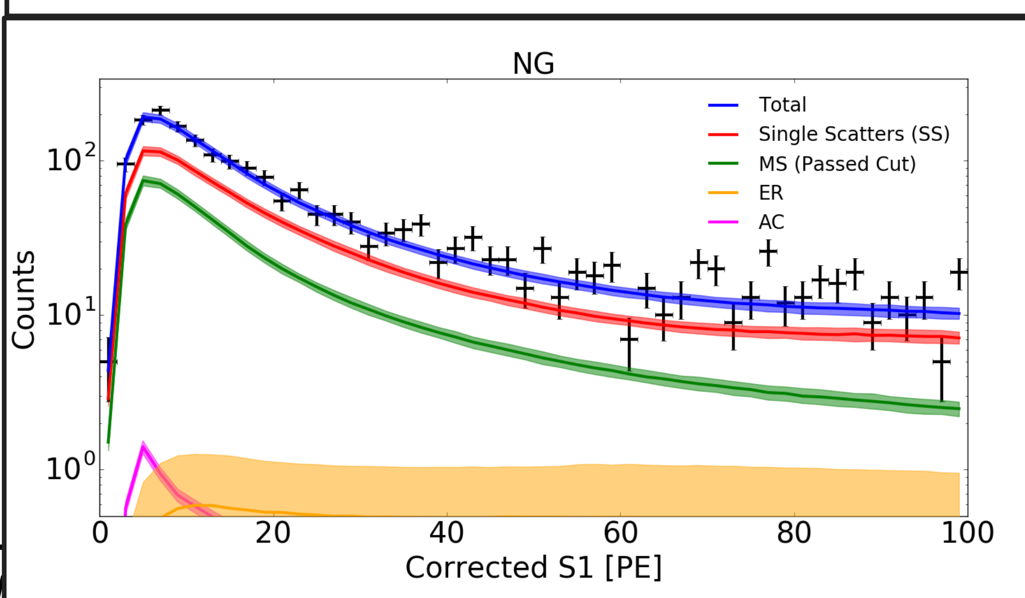




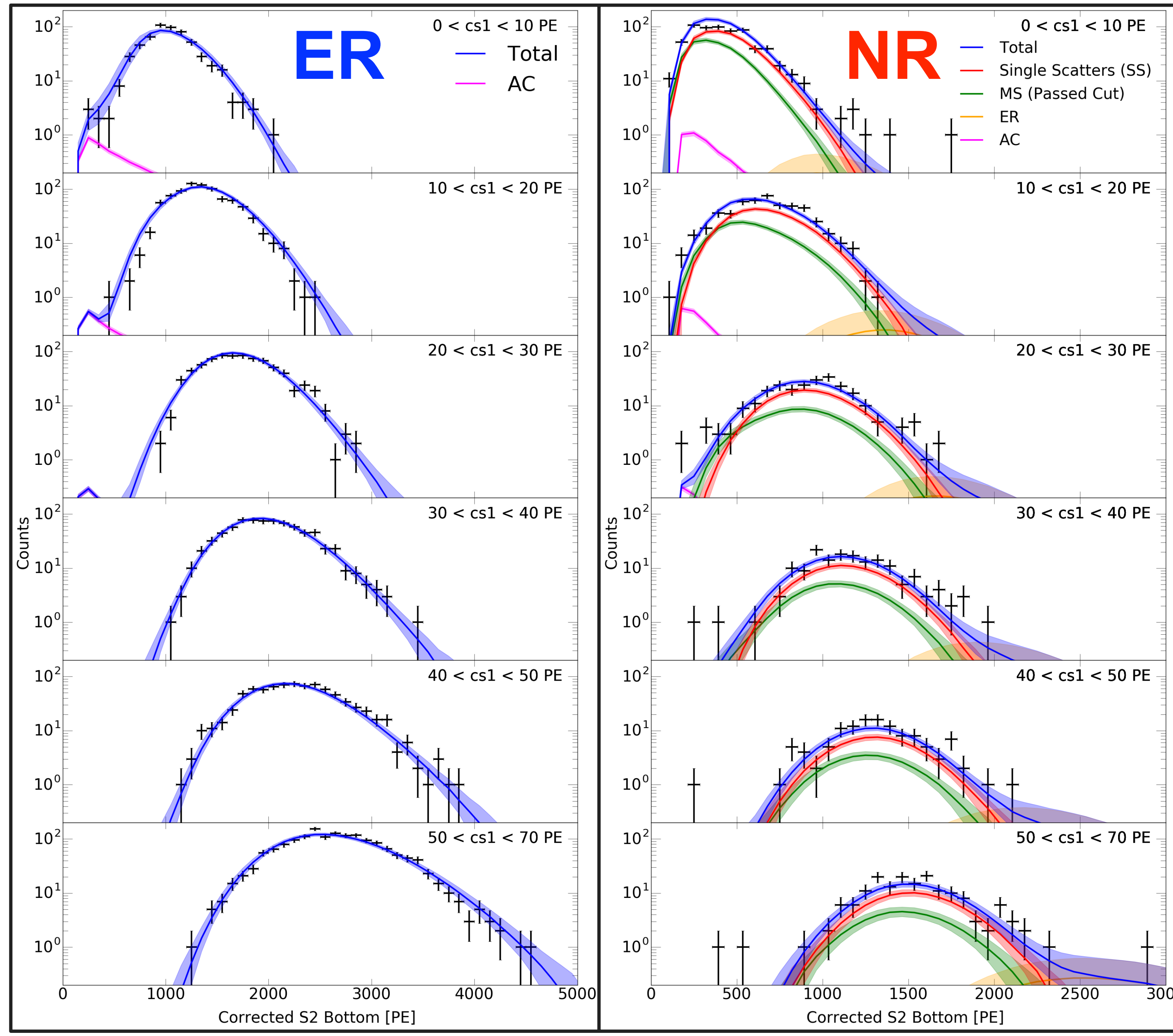
Calibrating ERs and NRs







Particle propagation with detailed detector geometry and LXe physics modelled
Parameters tuned and constrained by calibration data

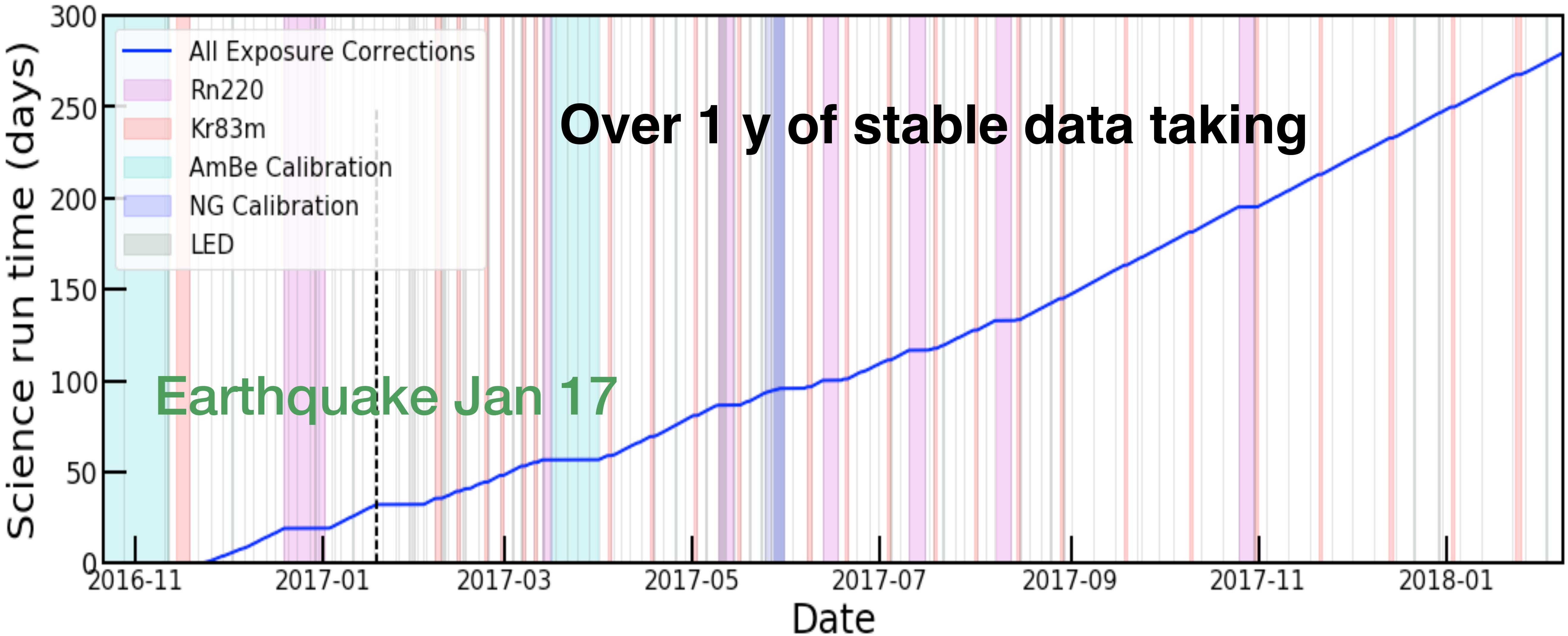


ER rejection: ~99.7% with NR acceptance within [-2σ, median] for both runs.

Results

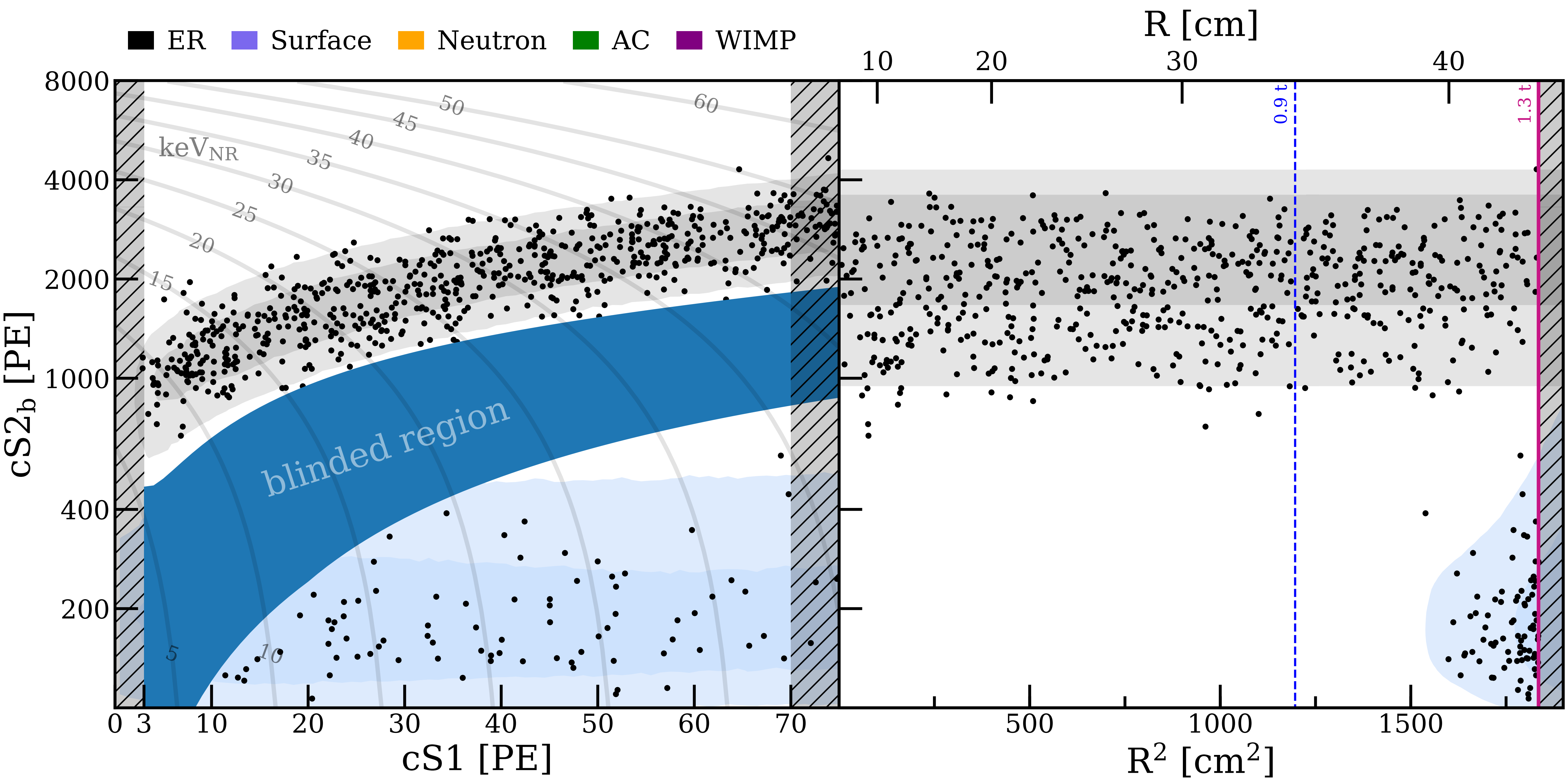
XENON1T: exposure

- *279 days high quality data*
- *1.3 tonne fiducial volume (1 tonne x year exposure)*
- *Still running*



Dark Matter Search Data: Blinded and salted

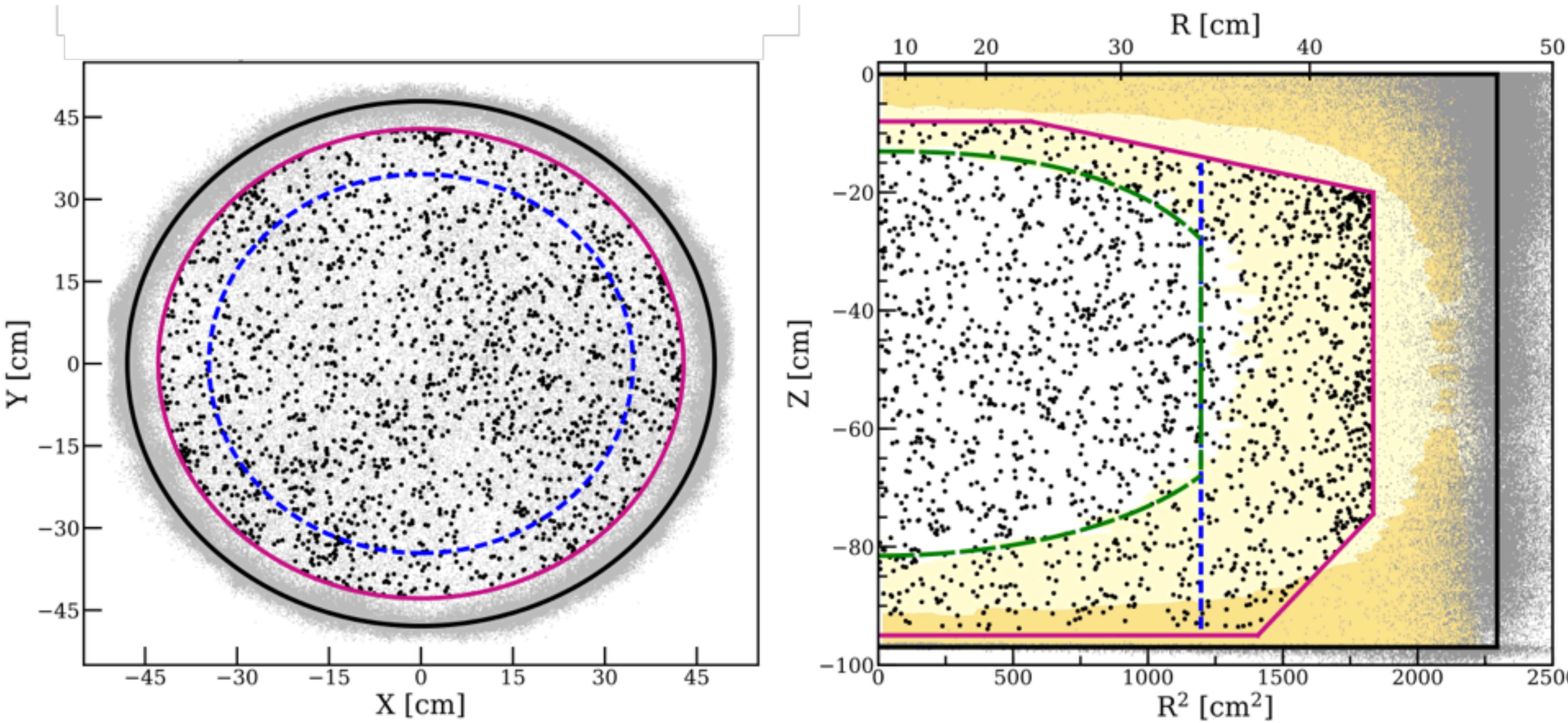
- **Blinding:** to avoid potential bias in event selection and the signal/background modelling
- **Salting:** to protect against post-unblinding tuning of cuts and background models



Fiducial Volume Optimization

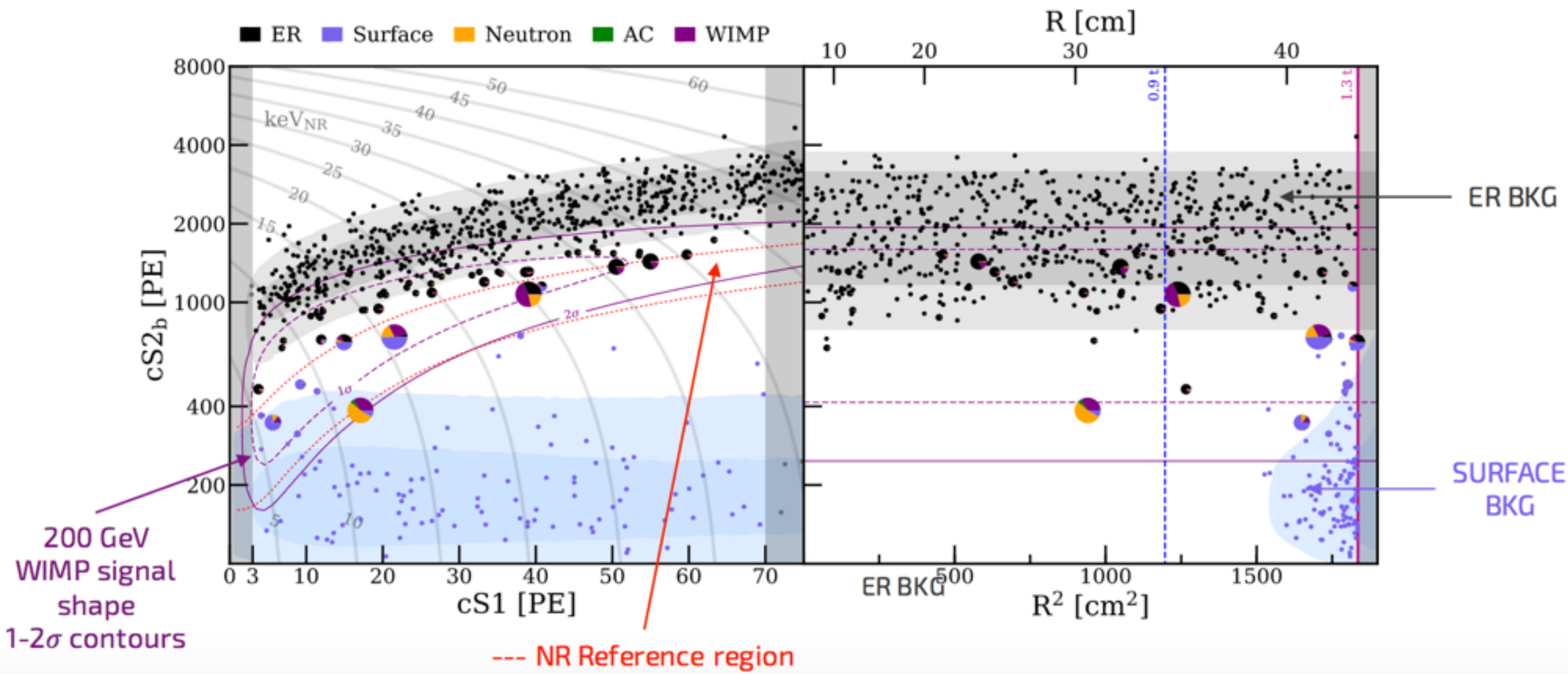
Optimize FV prior to unblinding to reduce materials and surface background

- **FV volume increased from 1 tonne (in SR0 First Result) to 1.3 tonne**
- **new surface background model allowed inclusion of radius, R, in statistical inference**



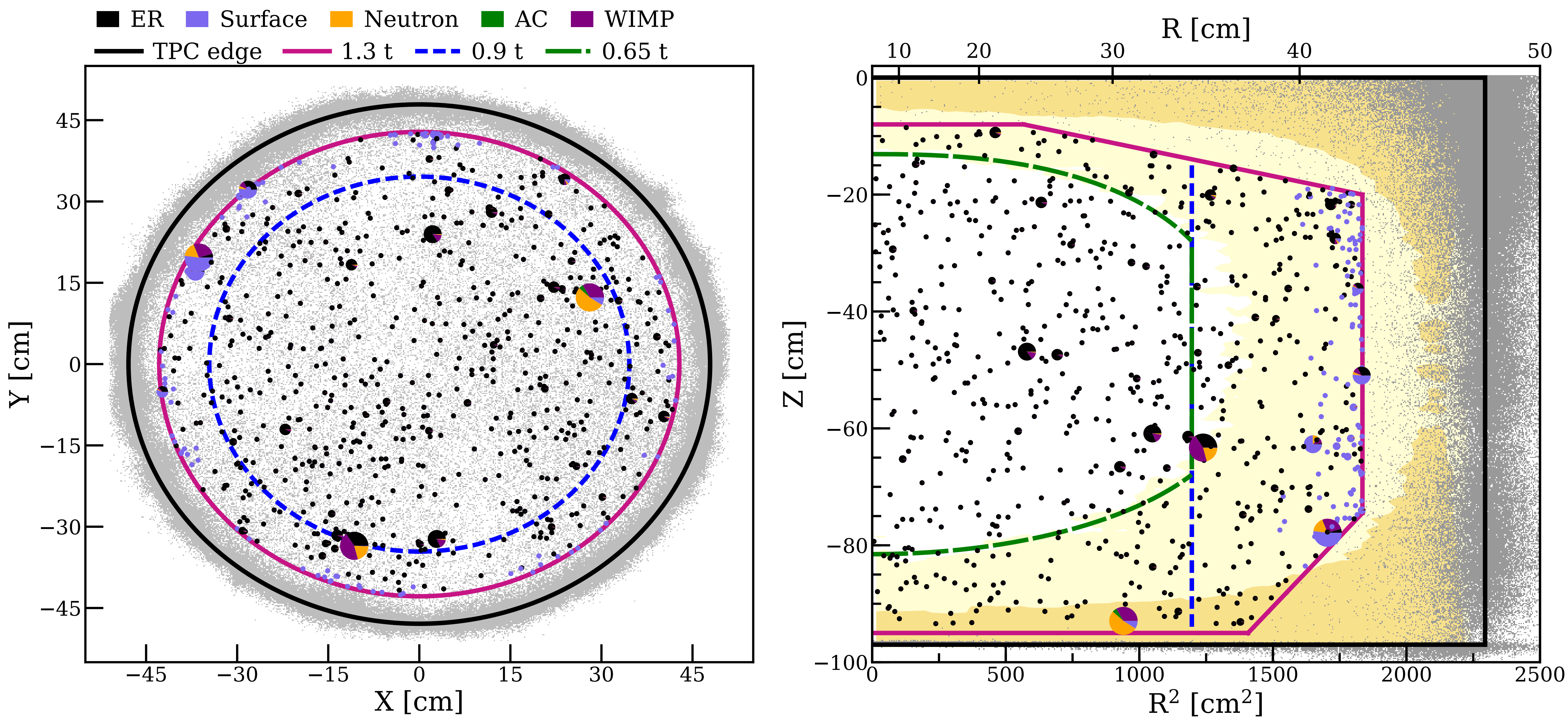
Dark Matter Search Results

- ***Results interpreted with unbinned profile likelihood analysis in cs1, cs2, R space***
- ***piechart indicate the relative PDF from the best fit of 200 GeV/c² WIMPs with a cross-section of 4.7x10⁻⁴⁷ cm²***



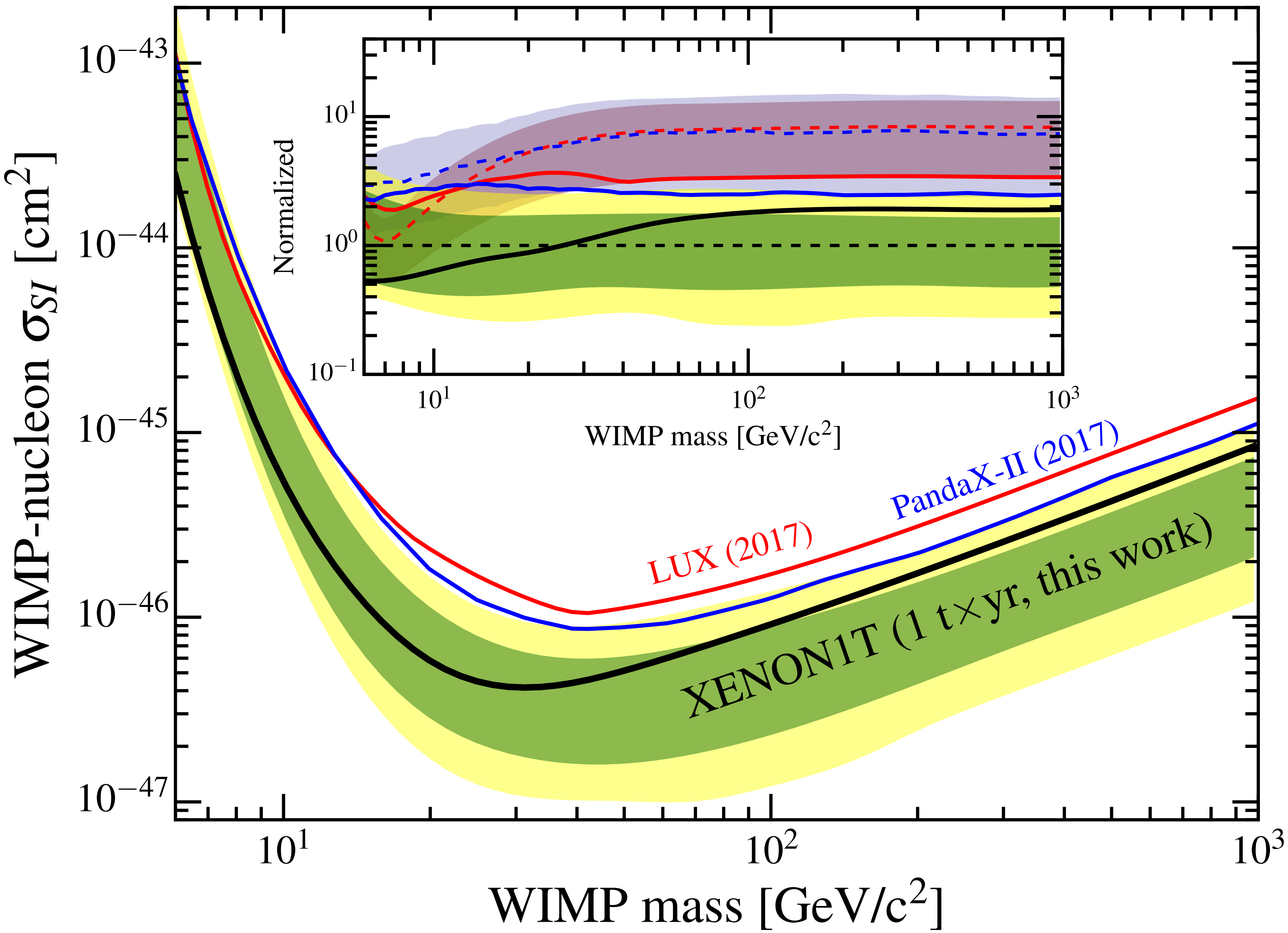
Spatial Distribution of Dark Matter Search Data

- **Core volume** to distinguish WIMPs over neutron background



XENON1T Dark Matter Search Results

Spin Independent WIMP-nucleon cross Section: most stringent 90% CL upper limit on WIMP-nucleon cross section at all masses above 6 GeV



Factor of 7 more sensitivity compared to previous experiments (LUX, PandaX-II)

Submitted to PRL
arXiv:1805.12562

1 sigma upper fluctuation at higher WIMP masses

Local p-value ~0.2 (at 200 GeV/c^2).

No significant excess (>3 sigma) is observed.

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

What next…XENONnT

MINIMAL UPGRADE

XENON1T infrastructure and sub-systems originally designed for a larger LXe TPC

FIDUCIAL XE TARGET

Fiducial mass: ~4 t

Target LXe mass: 5.9 t

Total LXe mass: 8 t

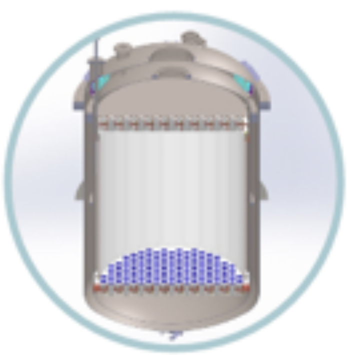
BACKGROUND

Identified strategies to reduce ^{222}Rn backgorund by a factor ~10

FAST TURNAROUND

Installation starts in 2018

Commissioning in 2019



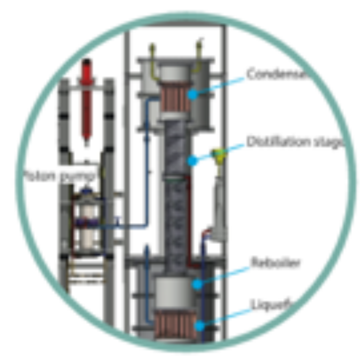
NEW TPC

Larger inner cryostat

476 PMTs

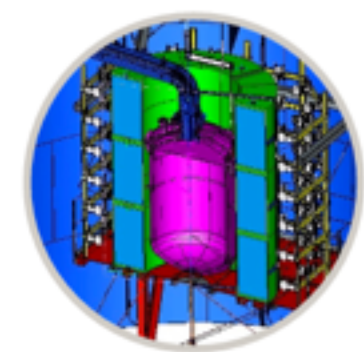
LXe PURIFICATION

Faster cleaning of large LXe volume (5000 SLPM)



RADON DISTILLATION

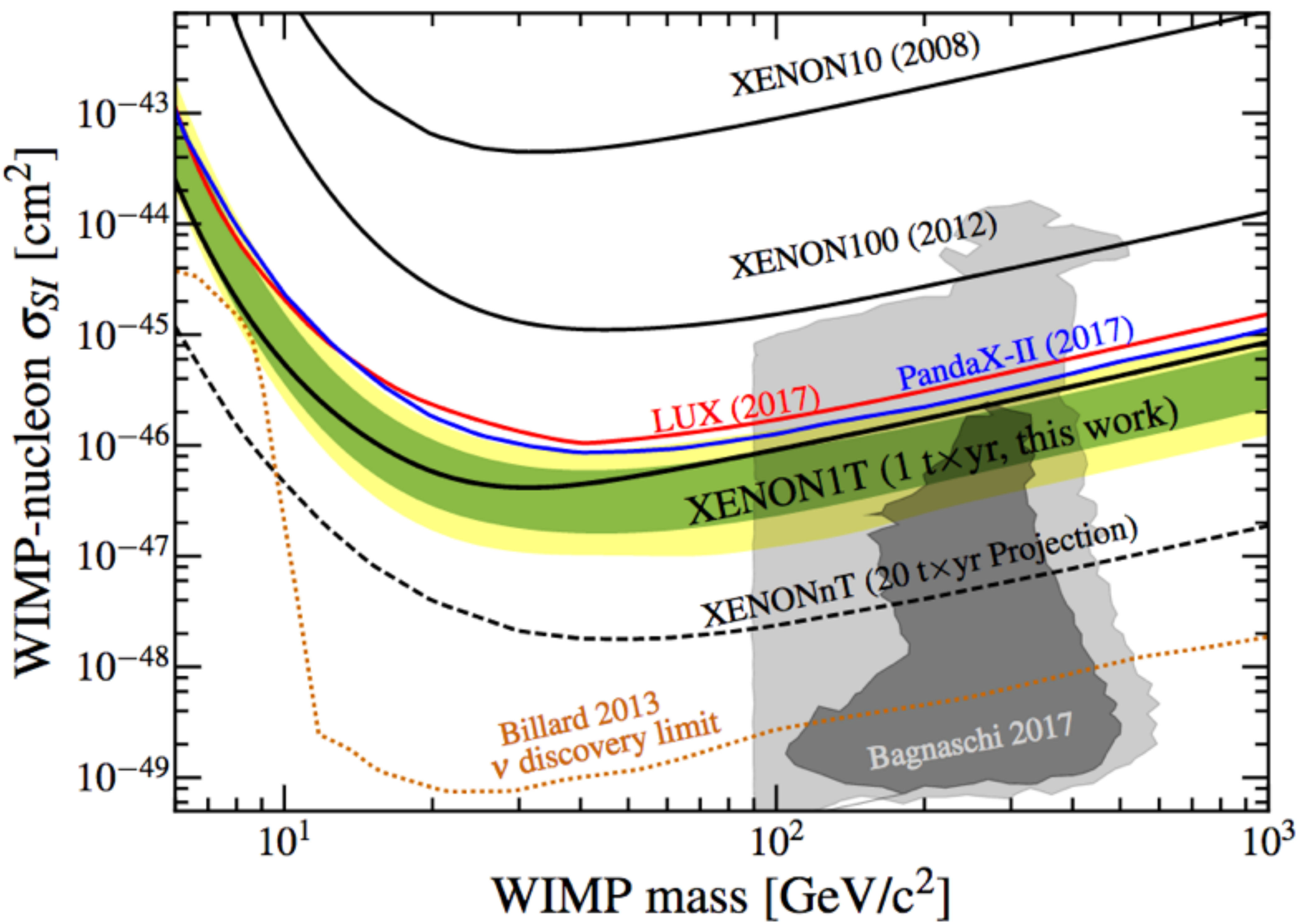
Online removal of ^{222}Rn emanated inside the detector



NEUTRON VETO

Tagging and in-situ measurement of neutron-induced background

What next…XENONnT



Summary

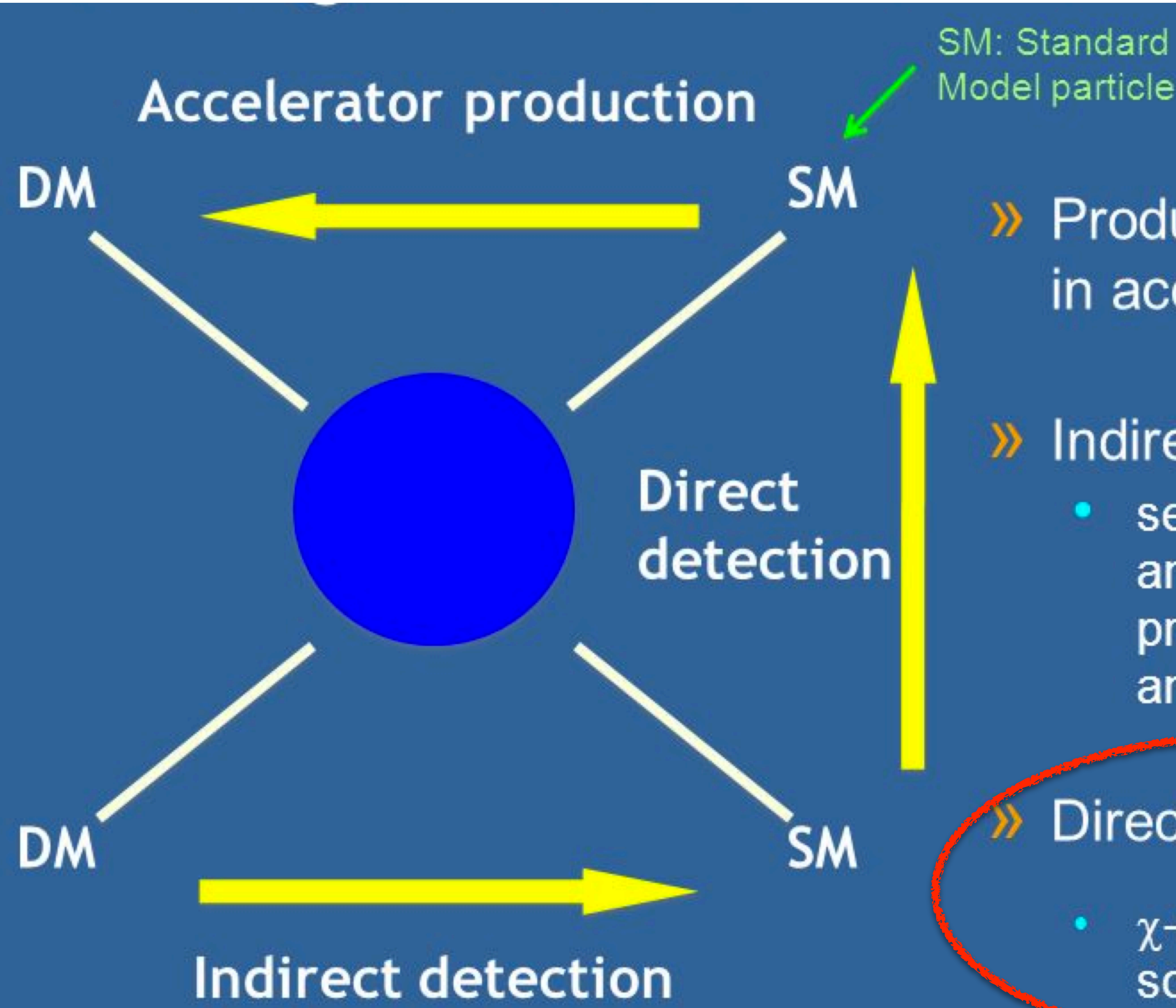
- ***First multi-ton scale LXeTPC for > 1 year***
- ***Lowest background in any DM detector: 82 events / (t y keV)***
- ***Strongest limit above 6 GeV/c^2 on WIMP-nucleon SI cross-section at 4.1x10^{-47} cm^2 for a WIMP of 30 GeV/c^2***
- ***XENON1T is continuing data taking***
- ***XENONnT will improve the sensitivity by another order of magnitude in the next 5 years***

www.xenon1t.org

twitter.com/xenon1t

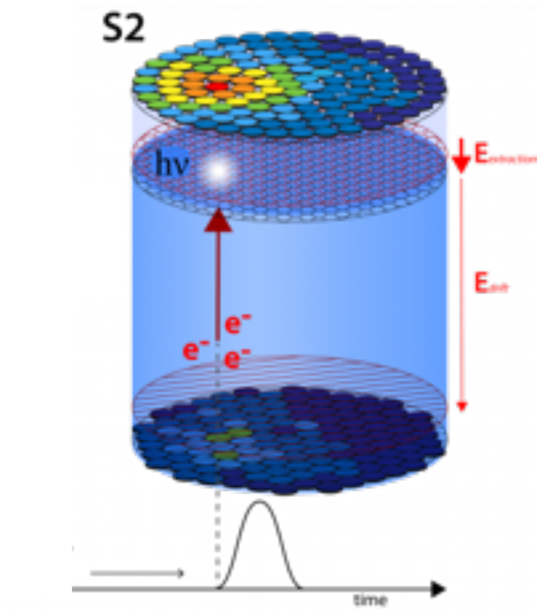
EXTRA

How to search for Dark Matter



- Production in accelarators (LHC)
- Indirect detection:
  - search for annihilation/decay products of χ's (self-antiparticle)
- Direct detection:
  - χ-nucleus elastic scattering

Position Reconstruction

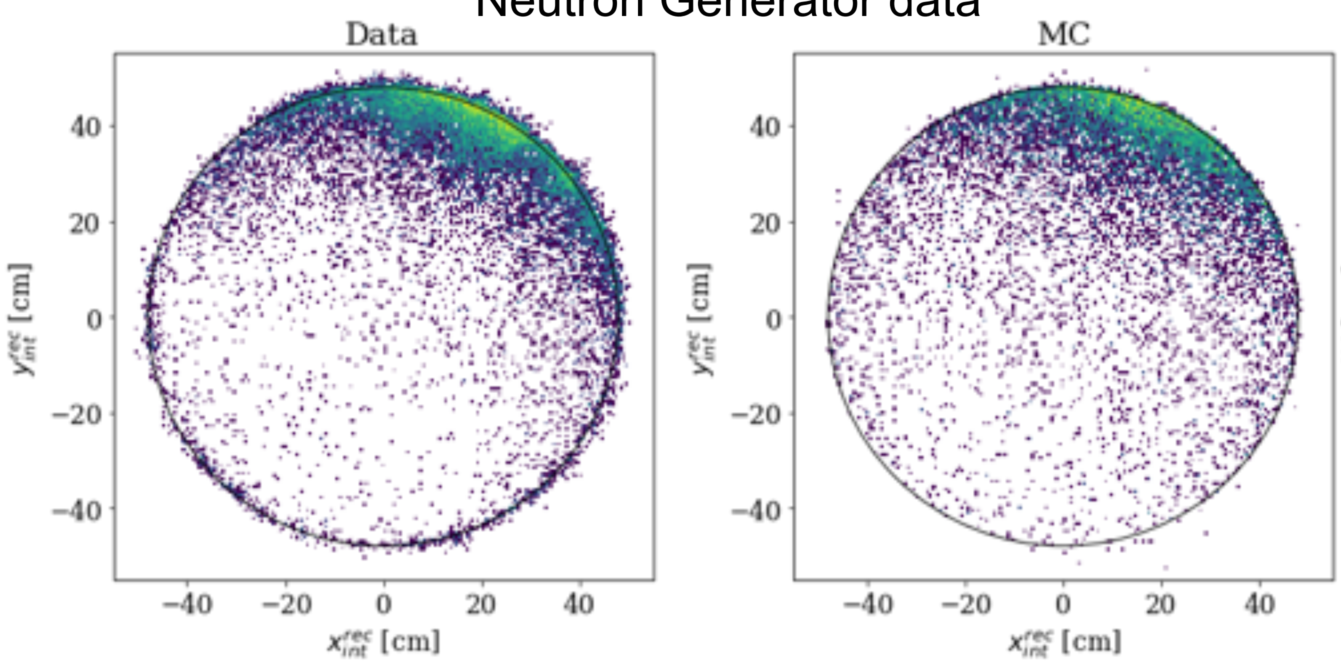


X-Y reconstruction via **neural network**:
- **Input:** charge/channel top array
- **Training:** Monte Carlo simulation

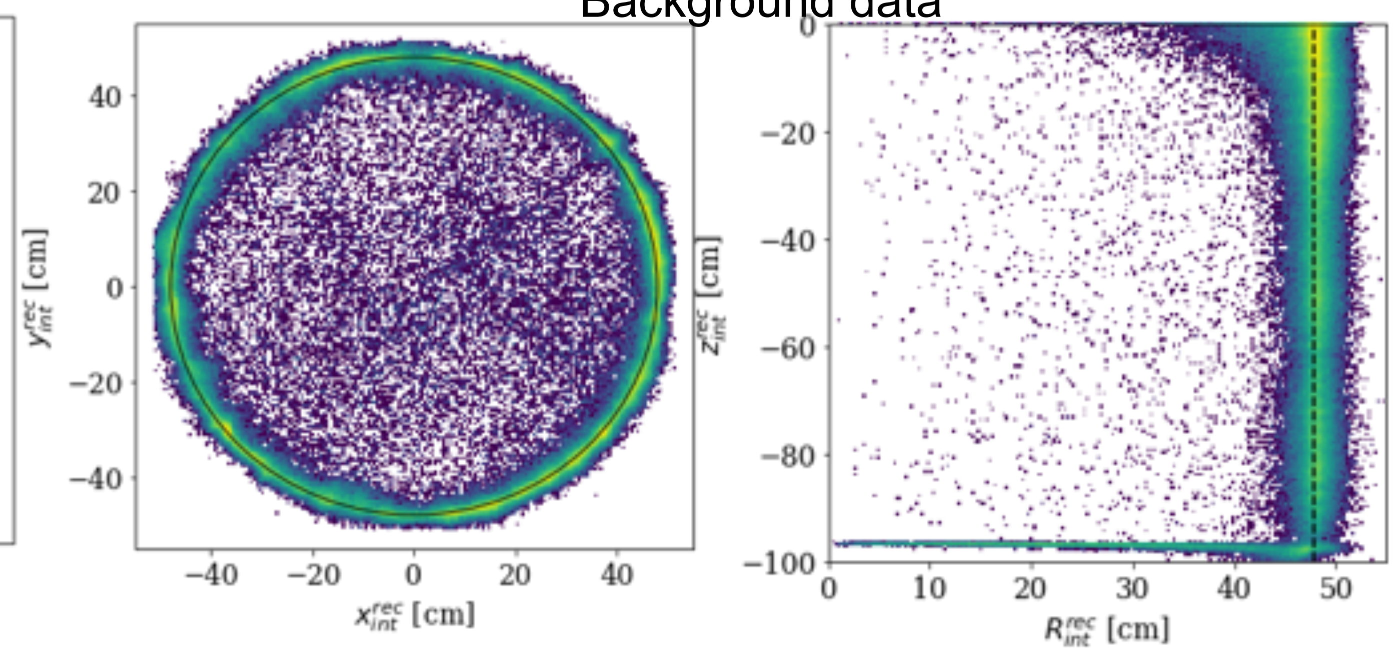
Position resolution using ^{83m}Kr
- Two interactions (9, 31 keV), same x-y
- Position resolution (1-2 cm)
- PMT diameter (7.62 cm)

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



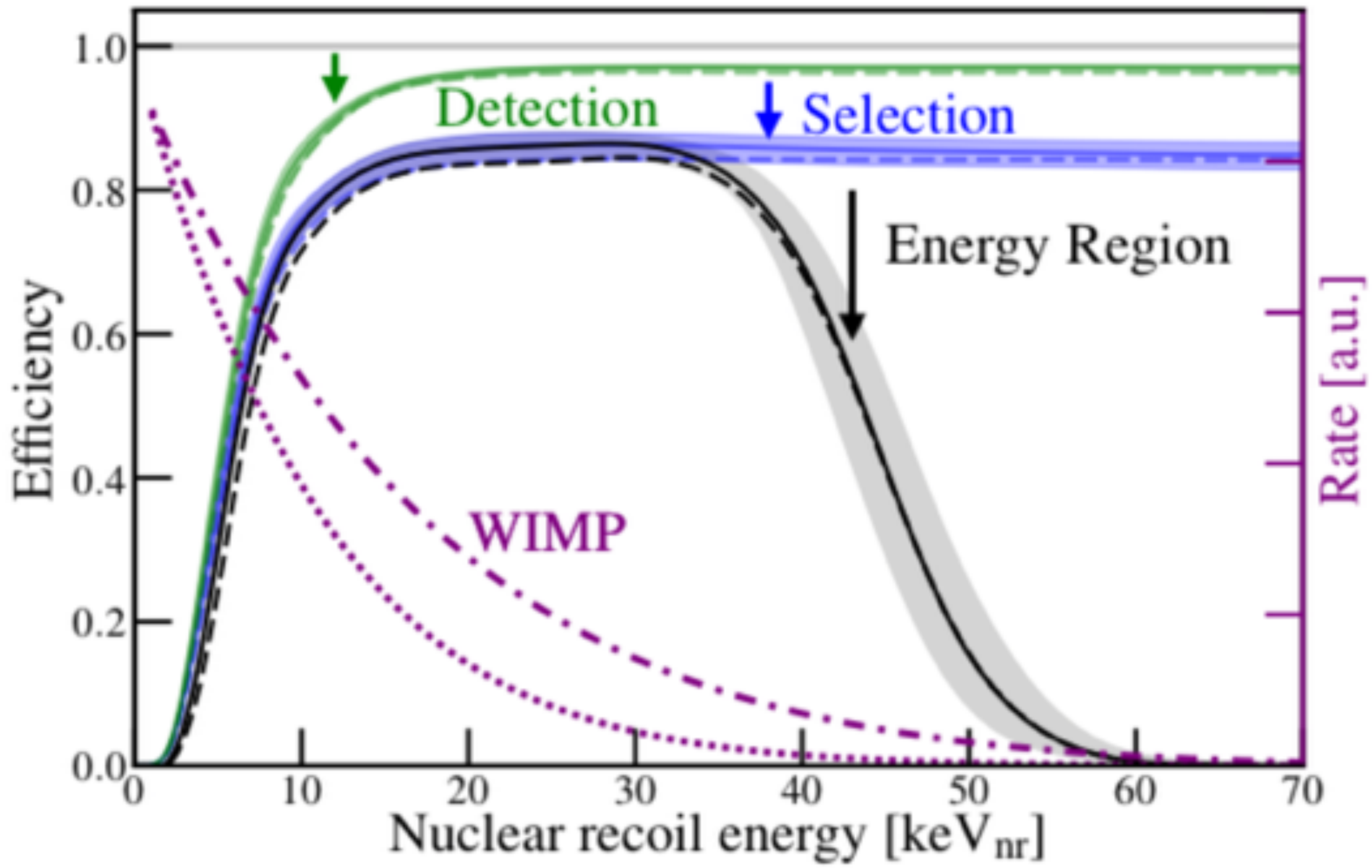
Predicted and observed data

Reference and smaller fiducial masses are illustrative. Data analysis and statistical inference is performed on the full dataset with PLR approach and backgrounds/signal shape accounted.

Mass	1.3 t	1.3 t	0.9 t	0.65 t
($cS1$, $cS2_b$)	Full	Reference	Reference	Reference
ER	627 ± 18	1.62 ± 0.30	1.12 ± 0.21	0.60 ± 0.13
neutron	1.43 ± 0.66	0.77 ± 0.35	0.41 ± 0.19	0.14 ± 0.07
CEνNS	0.05 ± 0.01	0.03 ± 0.01	0.02	0.01
AC	$0.47^{+0.27}_{-0.00}$	$0.10^{+0.06}_{-0.00}$	$0.06^{+0.03}_{-0.00}$	$0.04^{+0.02}_{-0.00}$
Surface	106 ± 8	4.84 ± 0.40	0.02	0.01
Total BG	735 ± 20	7.36 ± 0.61	1.62 ± 0.28	0.80 ± 0.14
$\mathrm{WIMP}_{\text{best-fit}}$	3.56	1.70	1.16	0.83
Data	739	14	2	2

WIMP expectation under best-fit model at m=200 GeV (cross-section = 4.7×10^{-47} cm^2)

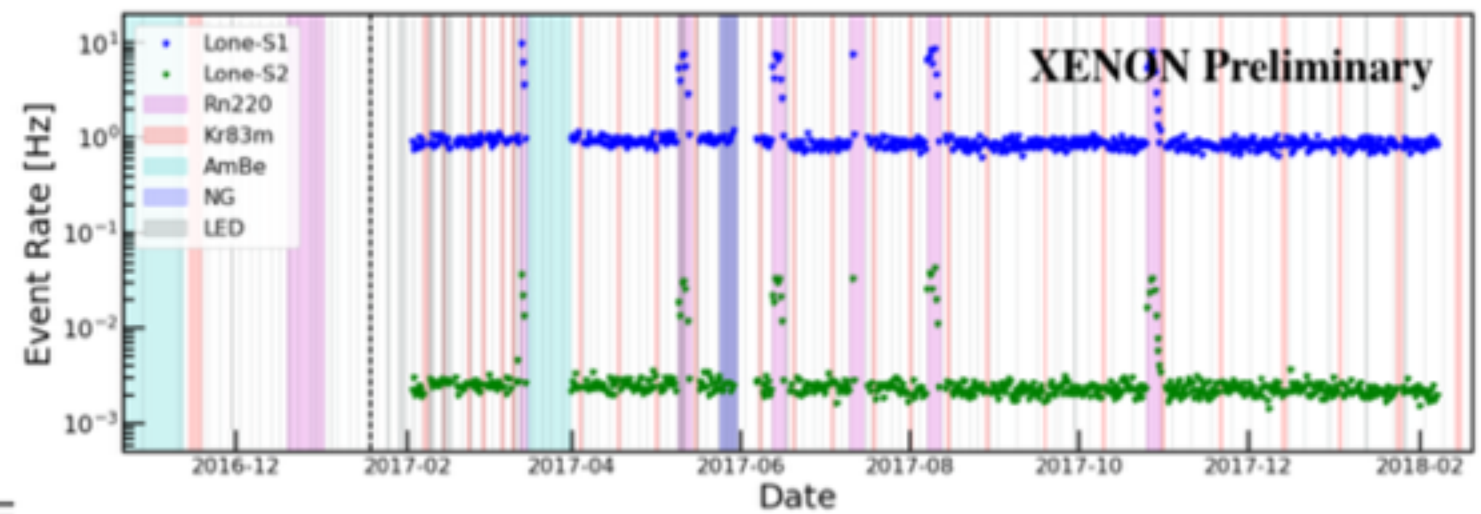
Data selection and detection efficiency

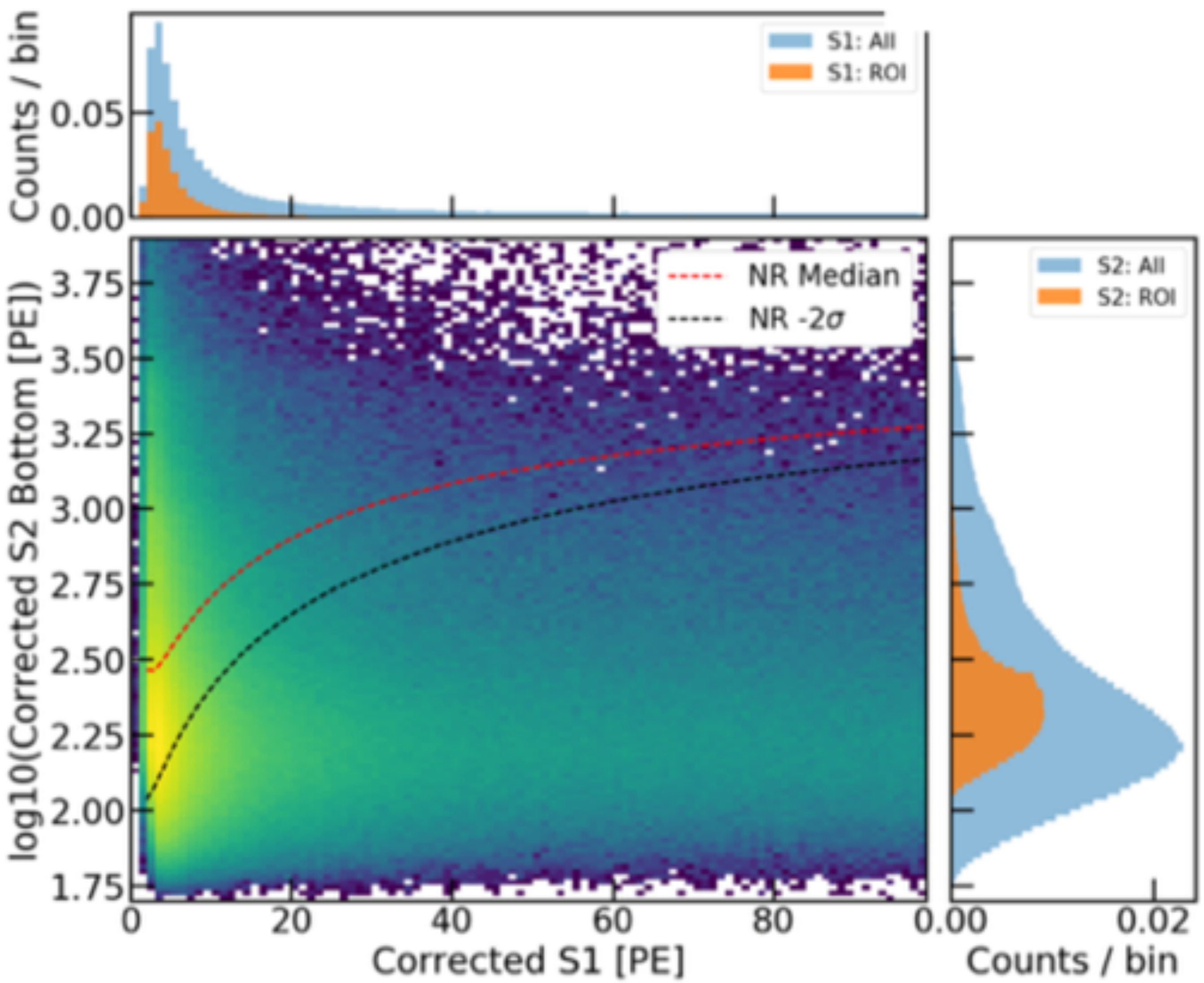


- Detection efficiency dominated by 3-fold coincidence requirement
    - Estimated via novel waveform simulation including systematic uncertainties
- Selection efficiencies estimated from control or MC data samples
- Search region defined within 3-70 PE in cS1
- 50 GeV (dotted) and 200 GeV (dashed and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

Accidental coincidences

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