

## 2nd World Summit on Dark Side of the Universe

23-30 June 2018, University of Antille, Guadeloupe, Islands, France

Marcello Messina

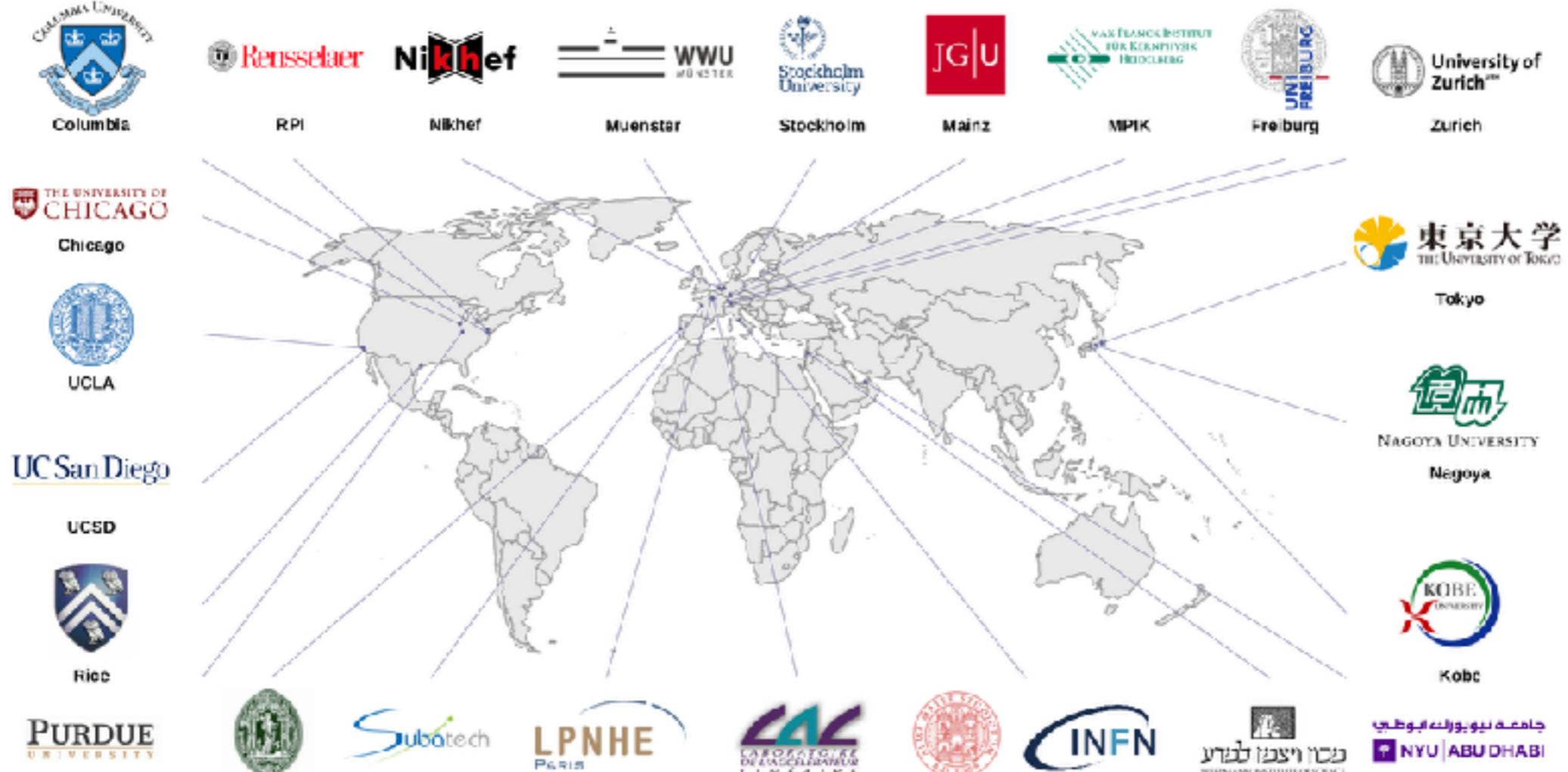
on behalf of the XENON collaboration

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



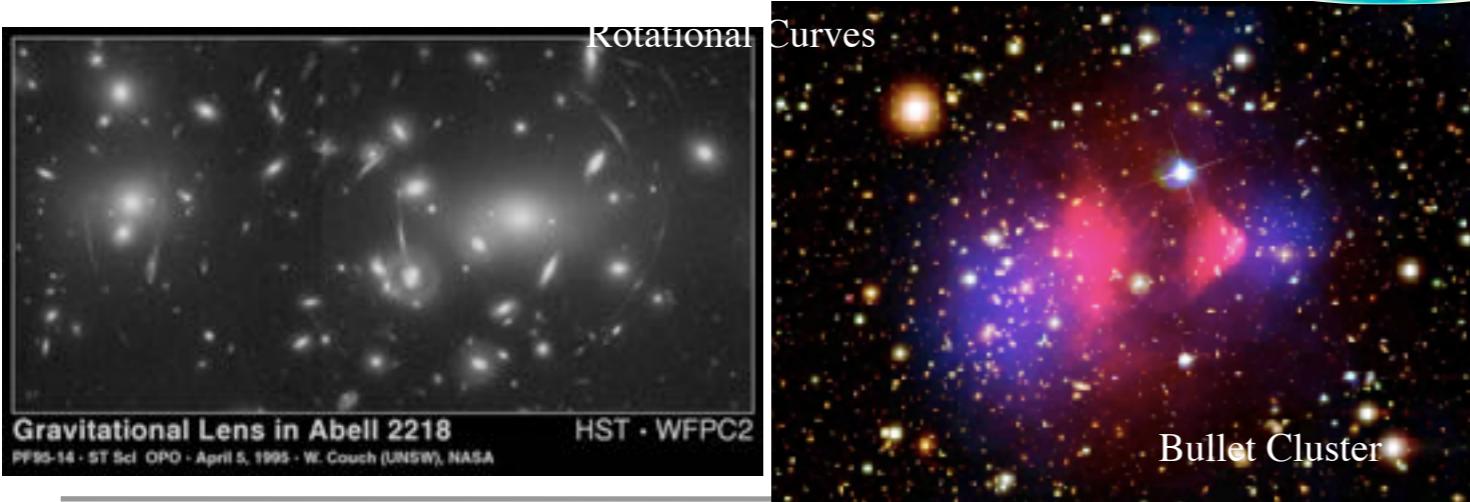
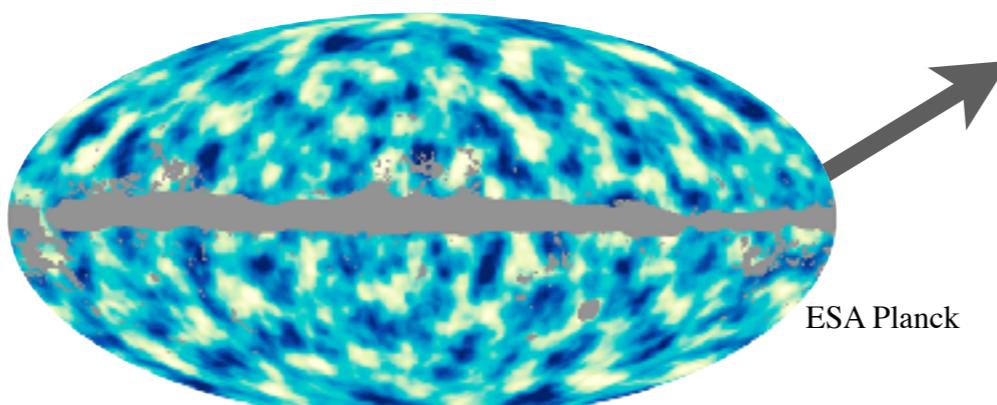
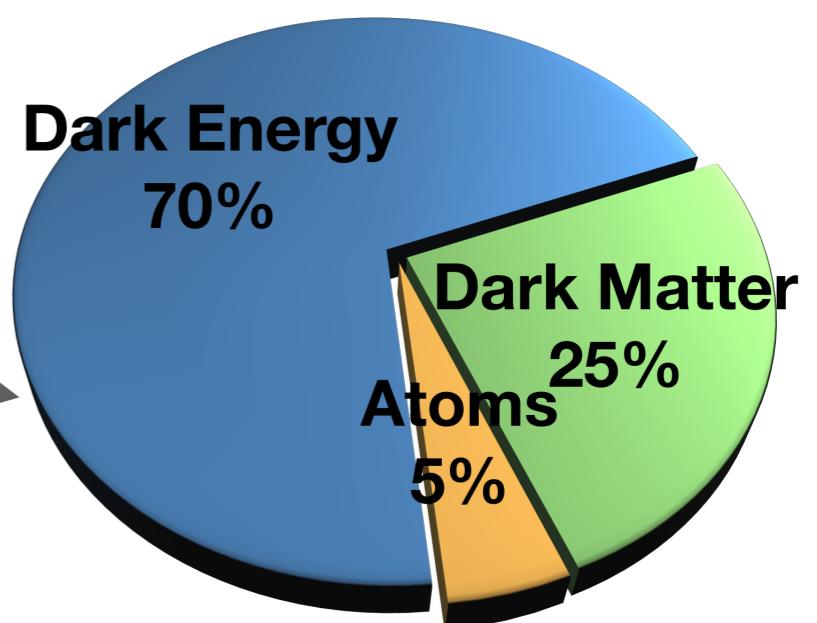
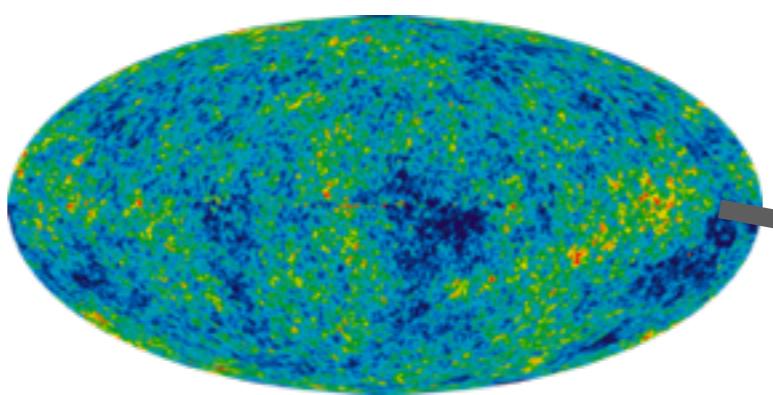
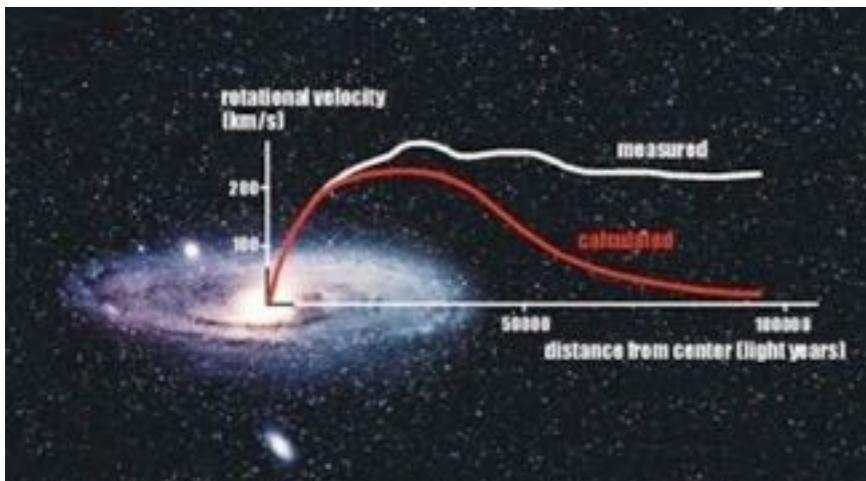
# The XENON Collaboration:

## 165 scientists 25 Institutions and 11 Countries



# Evidence for Dark Matter

- **Astrophysical Observations**



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

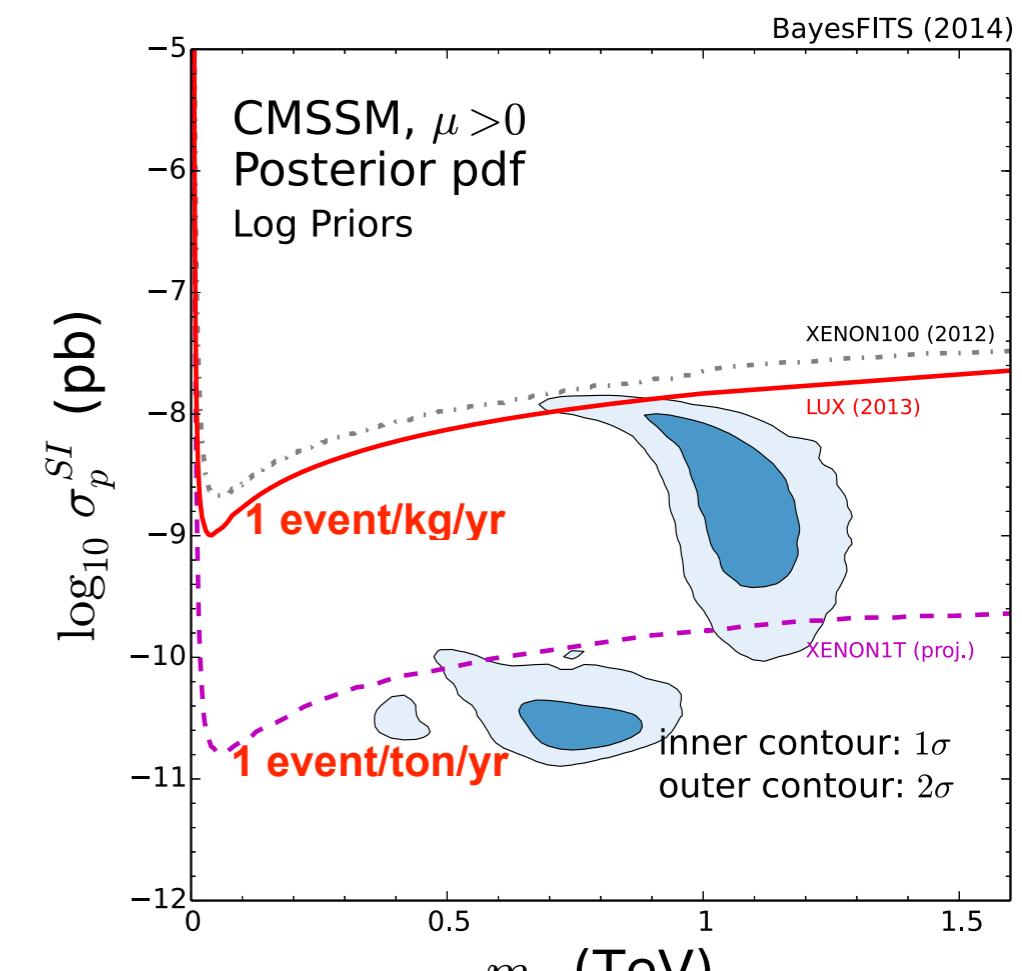
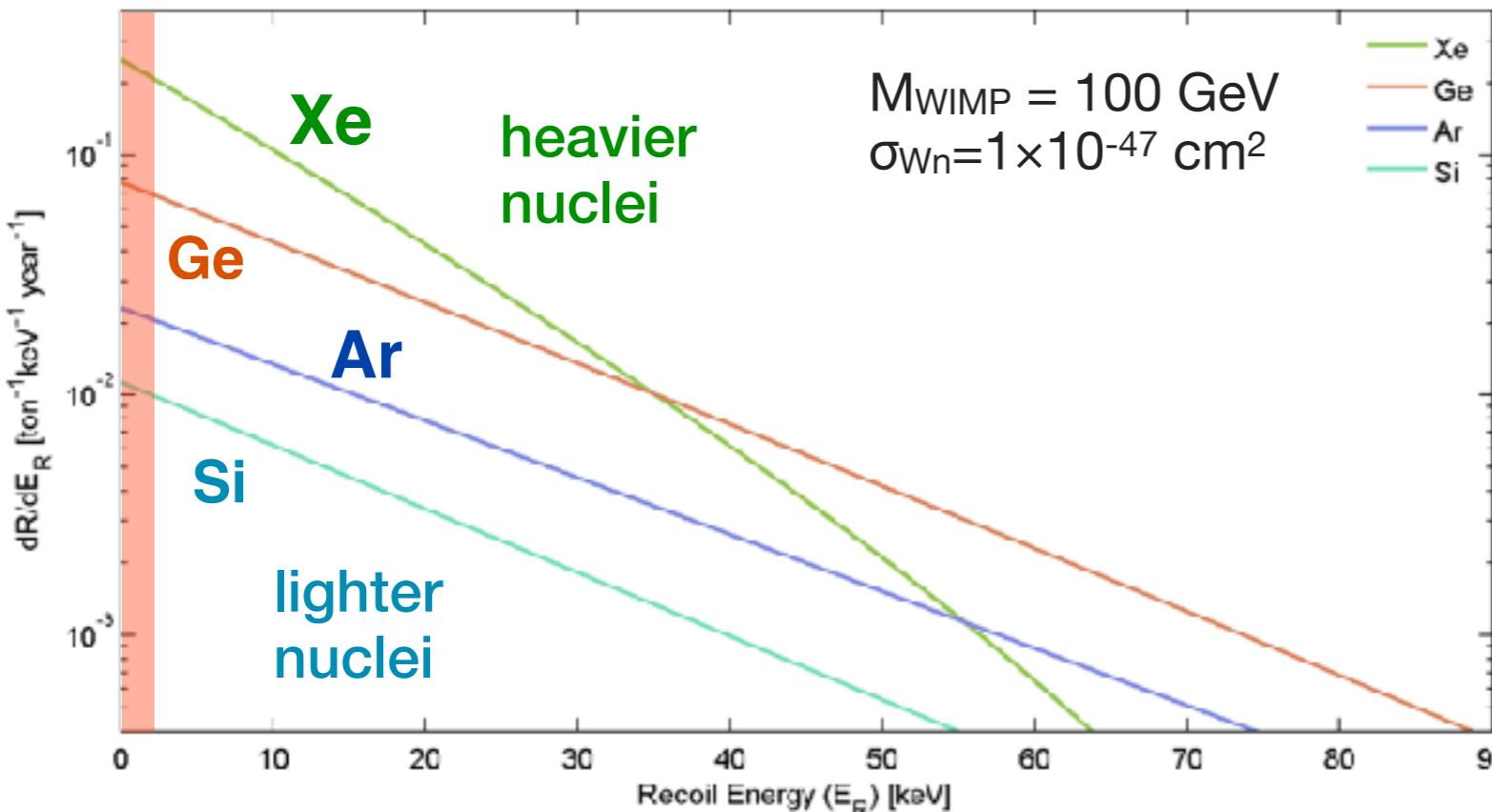
**Possible candidates:**  
**WIMPs**

# Observables: Rate

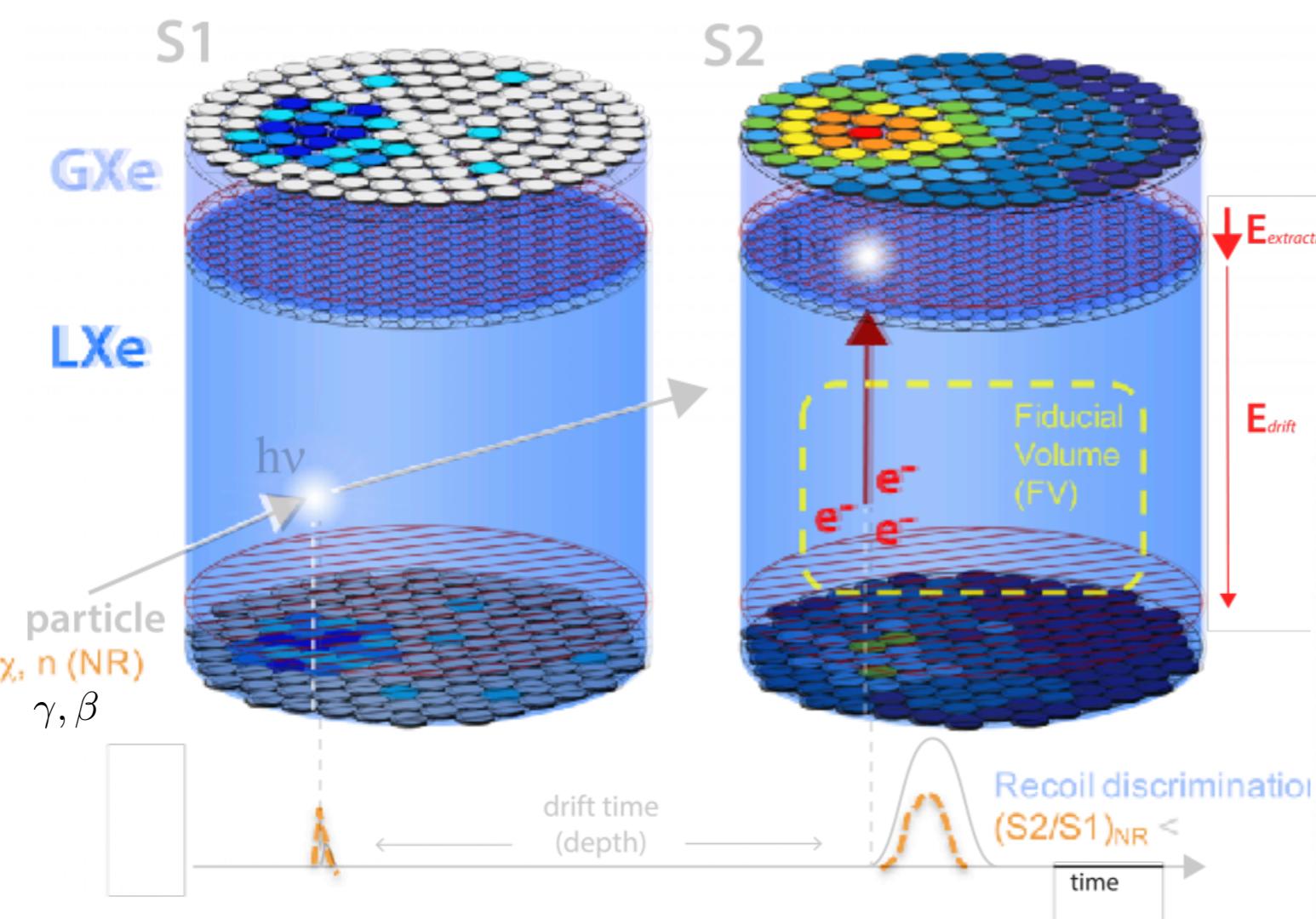
## Event rate in a terrestrial detector

Detector physics	Particle/nuclear physics	Astrophysics
$N_N, E_{th}$	$m_W, d\sigma/dE_R$	$\rho_0, f(v)$

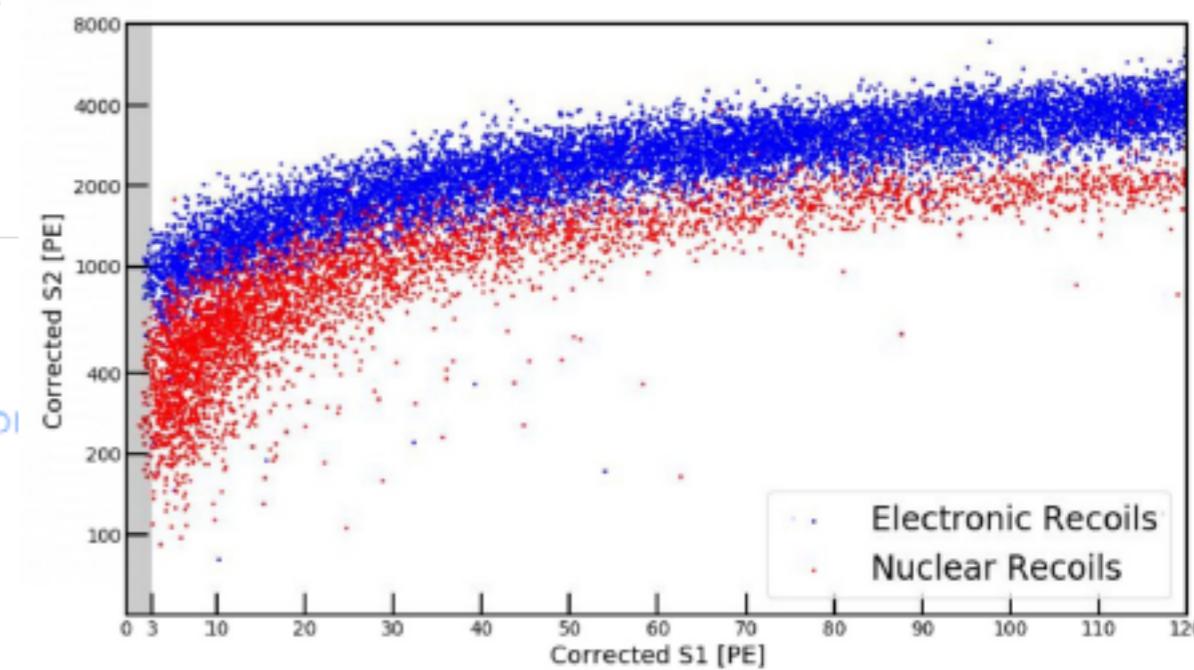
$$R \sim N_N \times \frac{\rho_0}{m_W} \times \langle v \rangle \times \sigma$$



# 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)

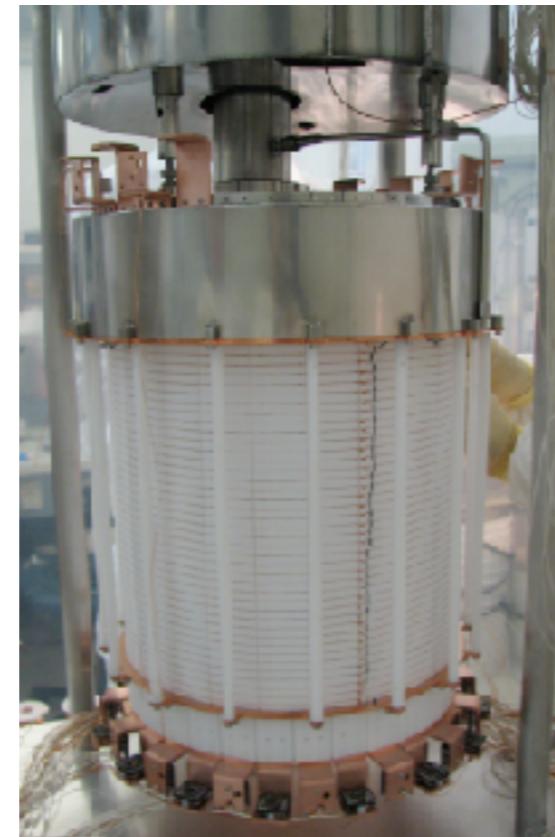


# The XENON legacy

XENON10  
2005-2007



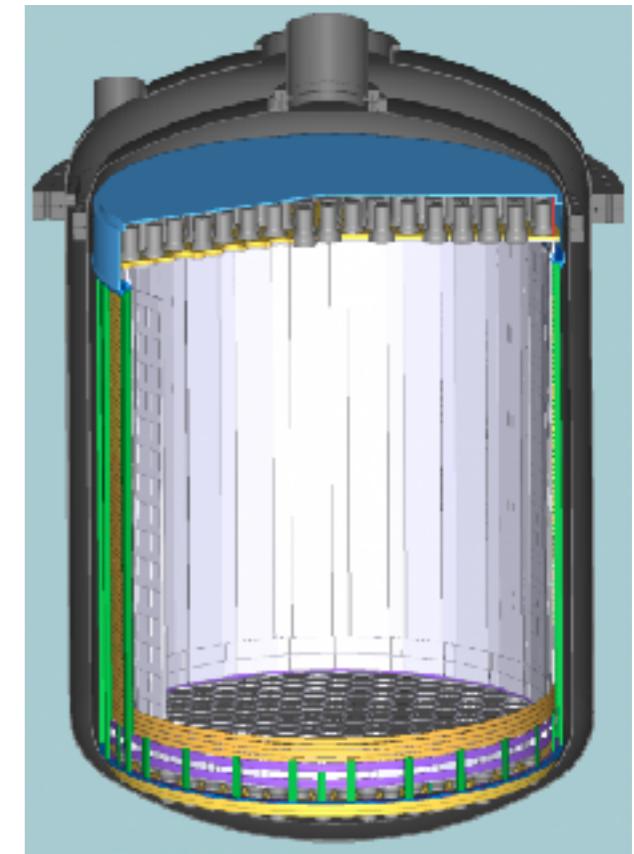
XENON100  
2008-2016



XENON1T  
2012-2018



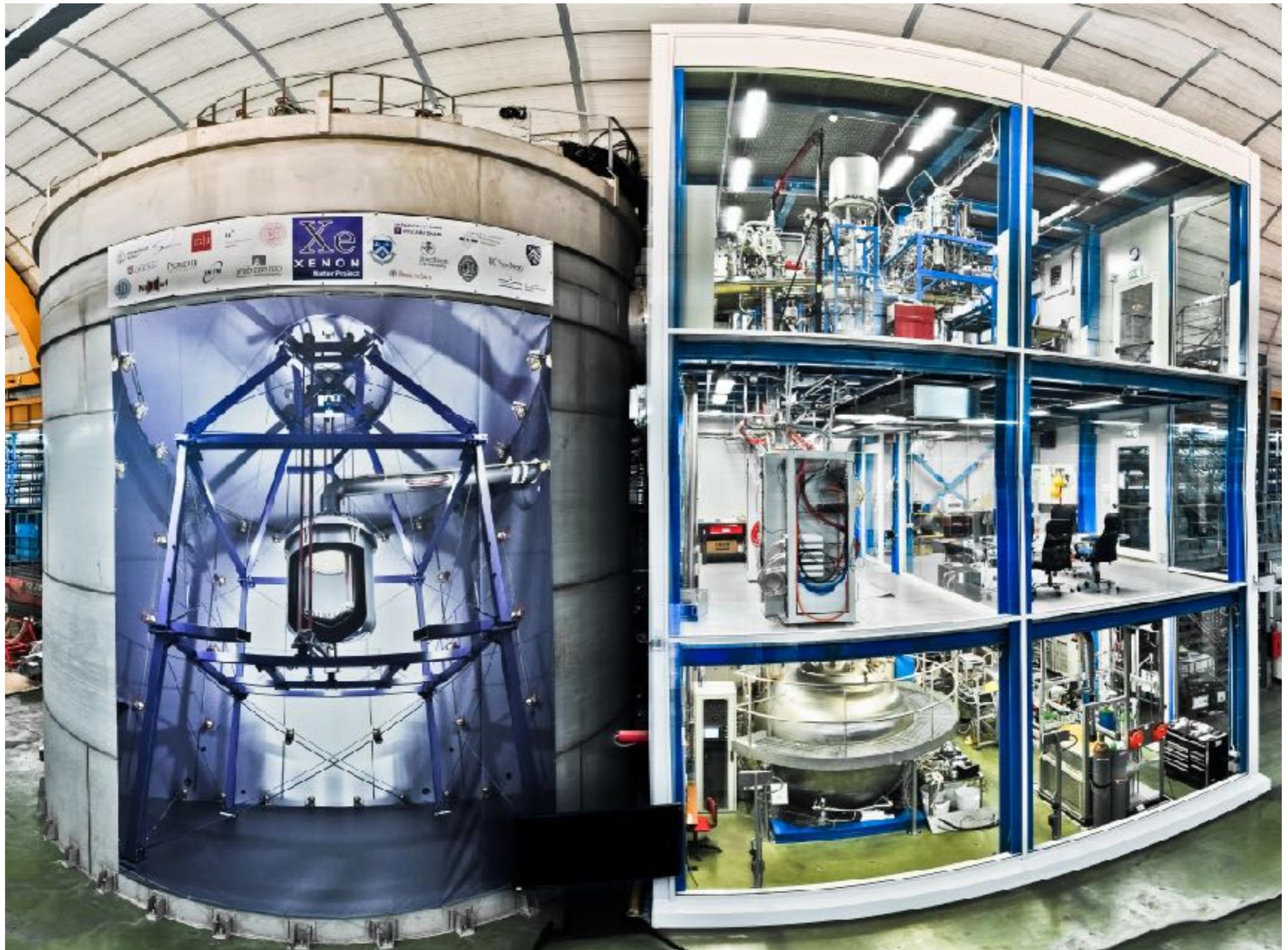
XENONnT  
2019-2023



25 kg	161 kg	3.2 ton	8 ton
15cm drift	30 cm drift	1 m drift	1.5 m drift
$\sim 10^{-43} \text{ cm}^2$	$\sim 10^{-45} \text{ cm}^2$	$\sim 10^{-47} \text{ cm}^2$	$\sim 10^{-48} \text{ cm}^2$
BG~1000 (keV t y) $^{-1}$	BG~5 (keV t y) $^{-1}$	BG~0.2 (keV t y) $^{-1}$	BG~0.02 (keV t y) $^{-1}$

# XENON1T experiment

All Systems protected by 1400 m of rock



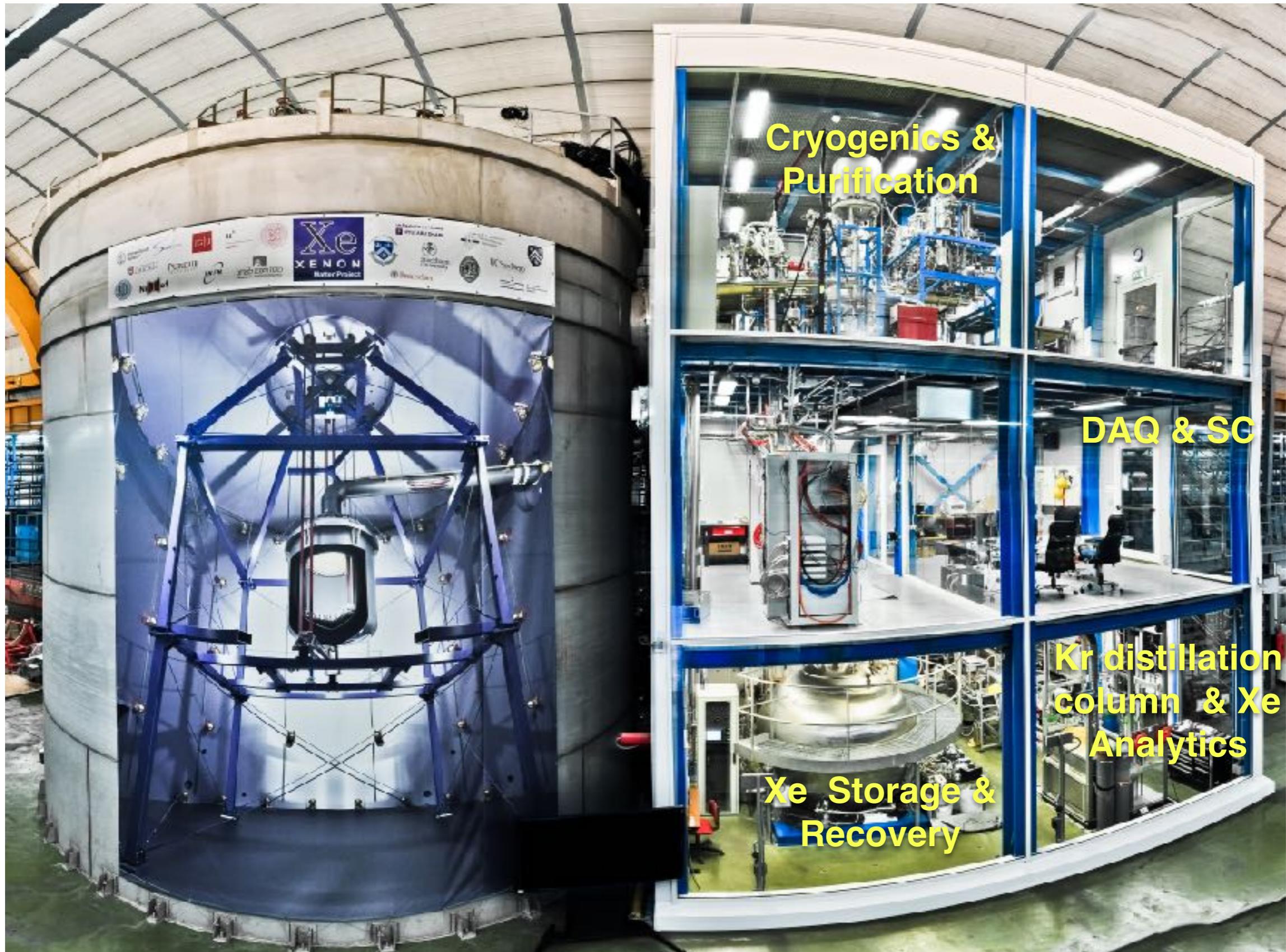
# XENON1T experiment

All Systems protected by 1400 m of rock



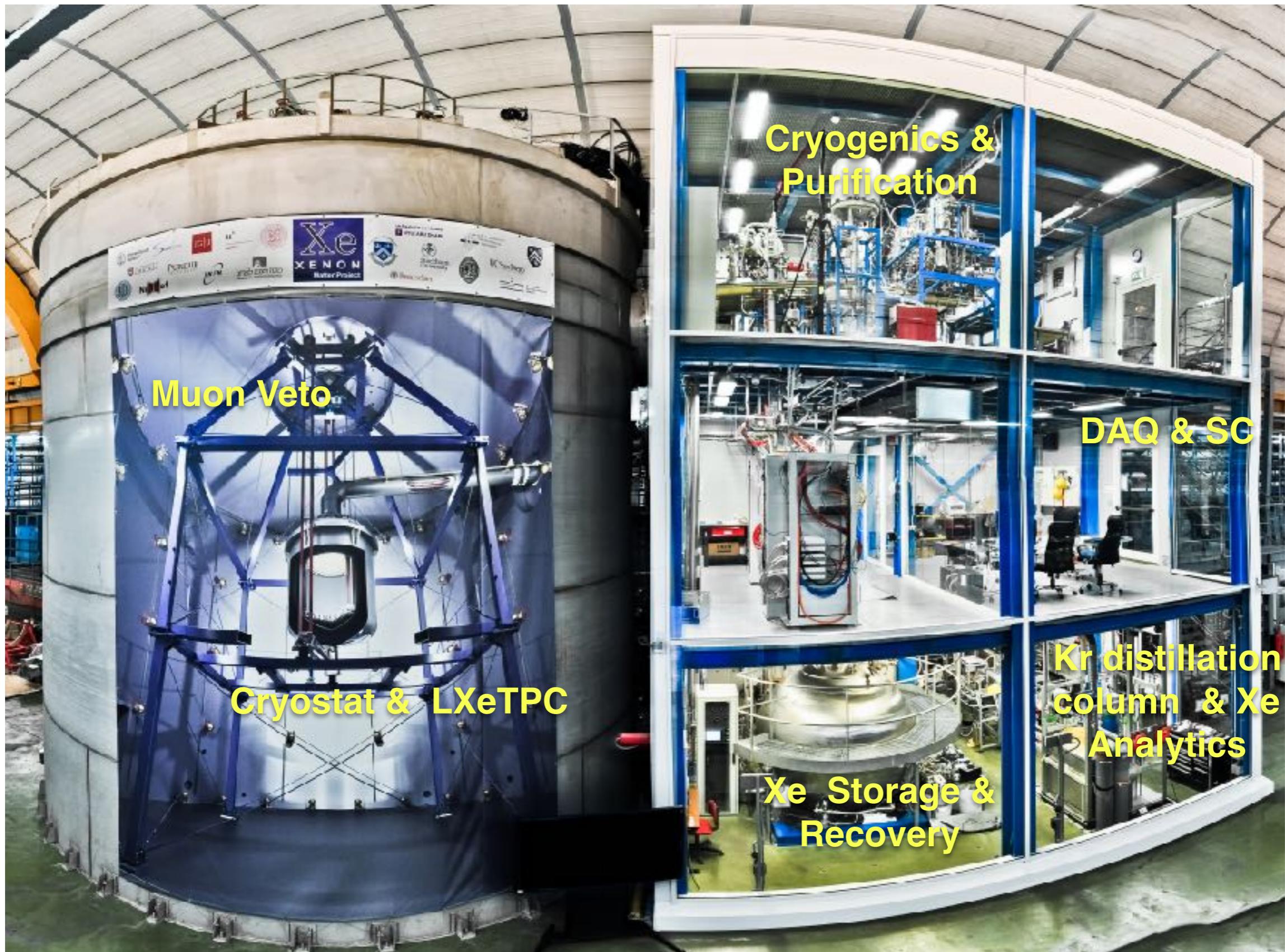
# XENON1T experiment

All Systems protected by 1400 m of rock



# XENON1T experiment

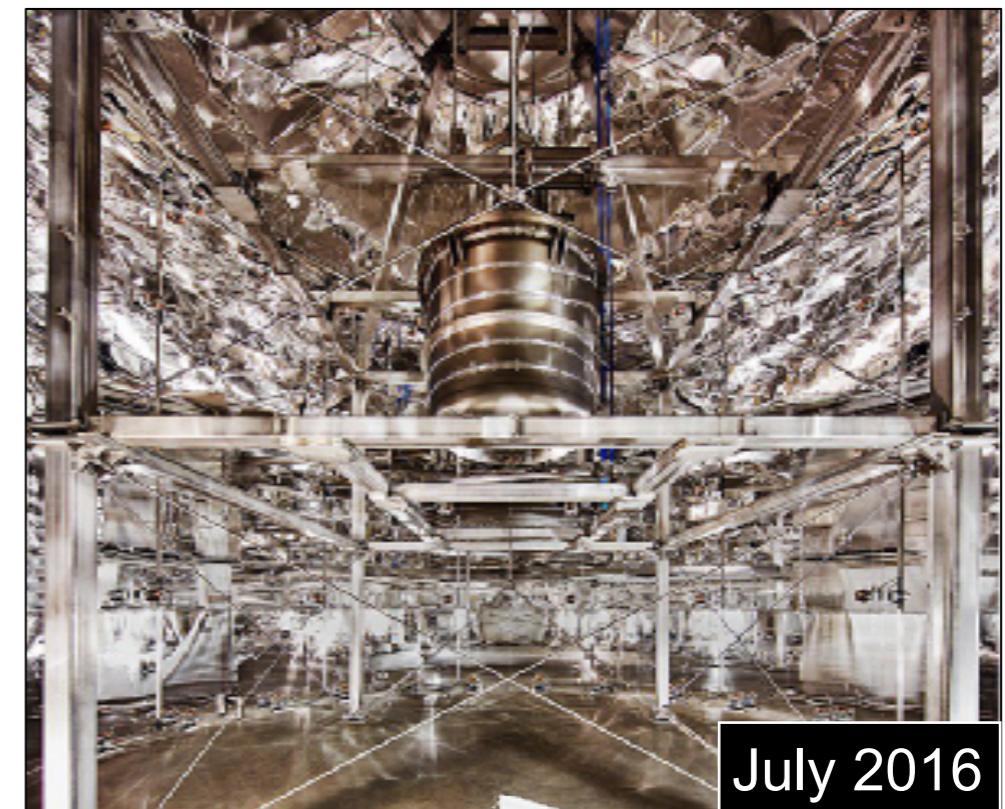
All Systems protected by 1400 m of rock



# Water Cherenkov Muon Veto

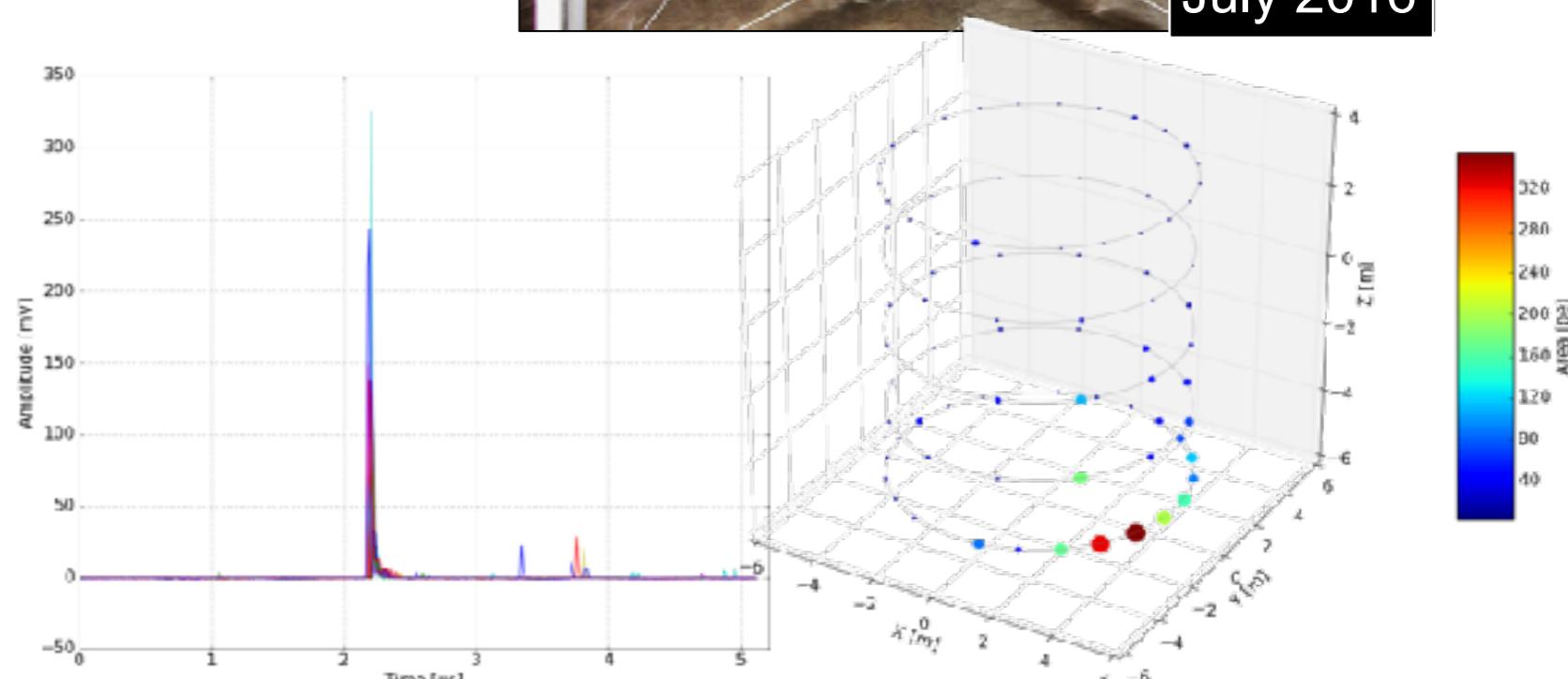


July 2013



July 2016

- 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

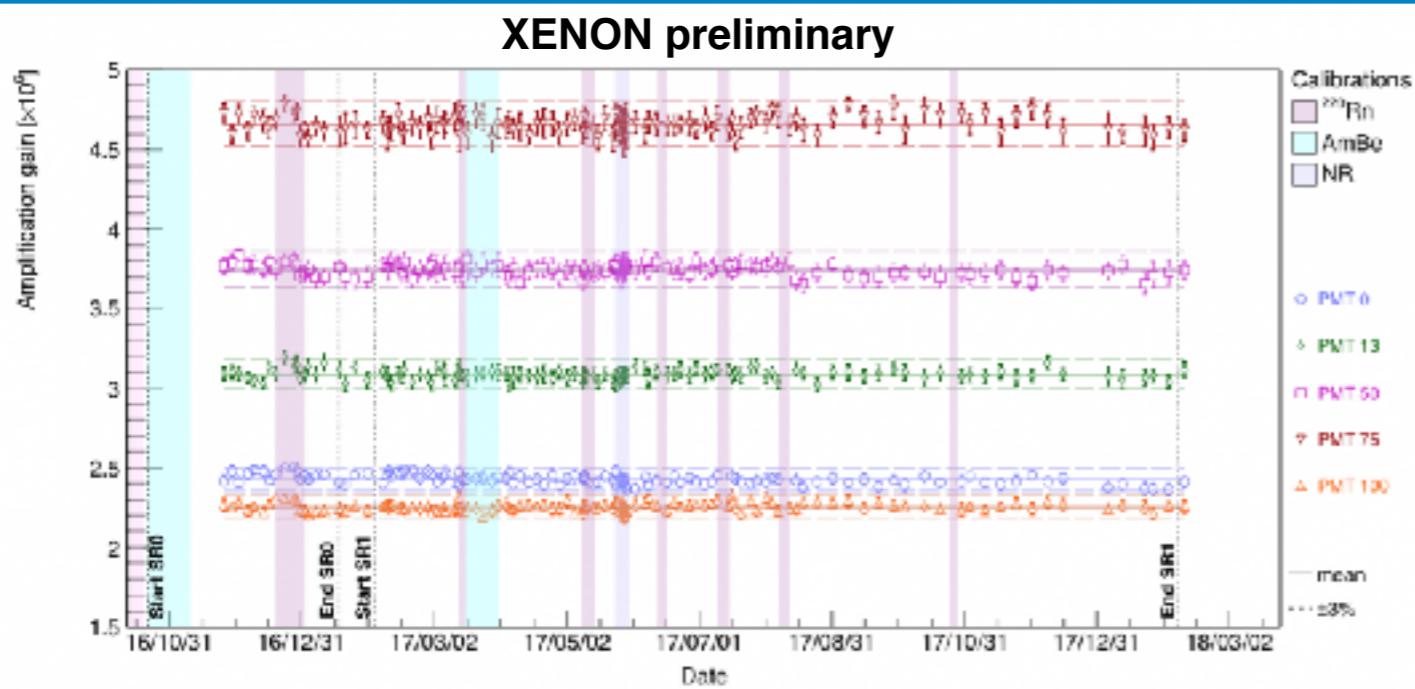


- $h=97 \text{ cm}$ ,  $d=96 \text{ cm}$
- total mass 3.2 t LXe @180 K
- 2.0 t active target
- drift field  $\sim 100 \text{ V/cm}$

# The XENON1T Light Detection System

Eur. Phys. J. C 75 (2015) n 11, 546

XENON preliminary

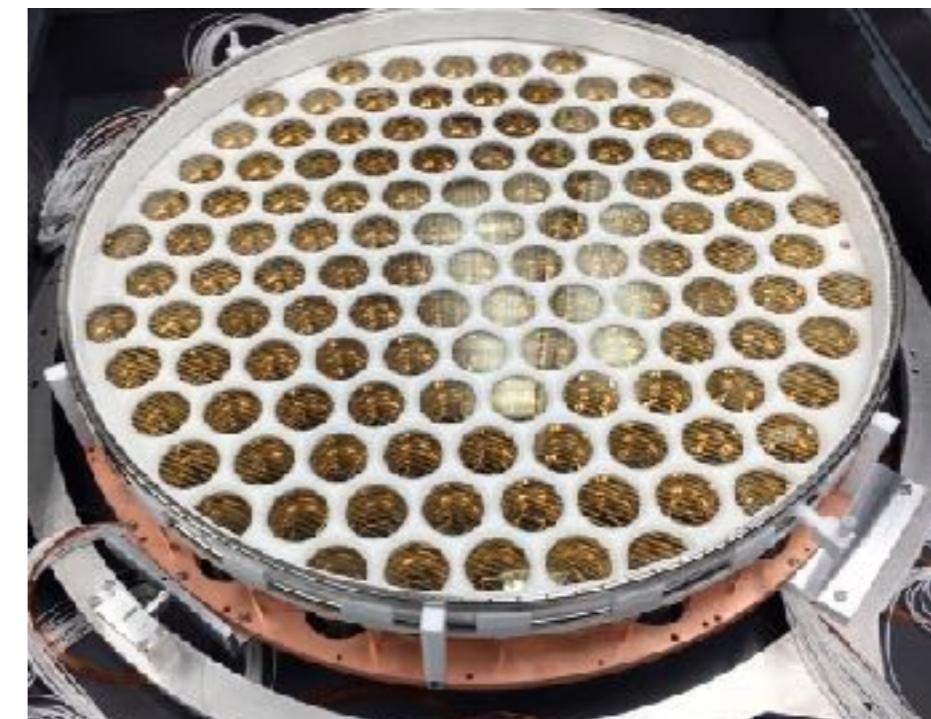


- 248 3-inch low-radioactivity Hamamatsu R11410-21 PMTs arranged in two arrays.
- 35% QE @ 178 nm
- each PMT digitized at 100MHz
- operating gain  $1-5 \times 10^6$  @ 1.5kV stable within **1-2 %**
- SPE acceptance ~94%
- High reflectivity PTFE lining of entire inner volume
- Highly-transparent (>90%) grid

Top array and PTFE lining the inner volume of the field cage

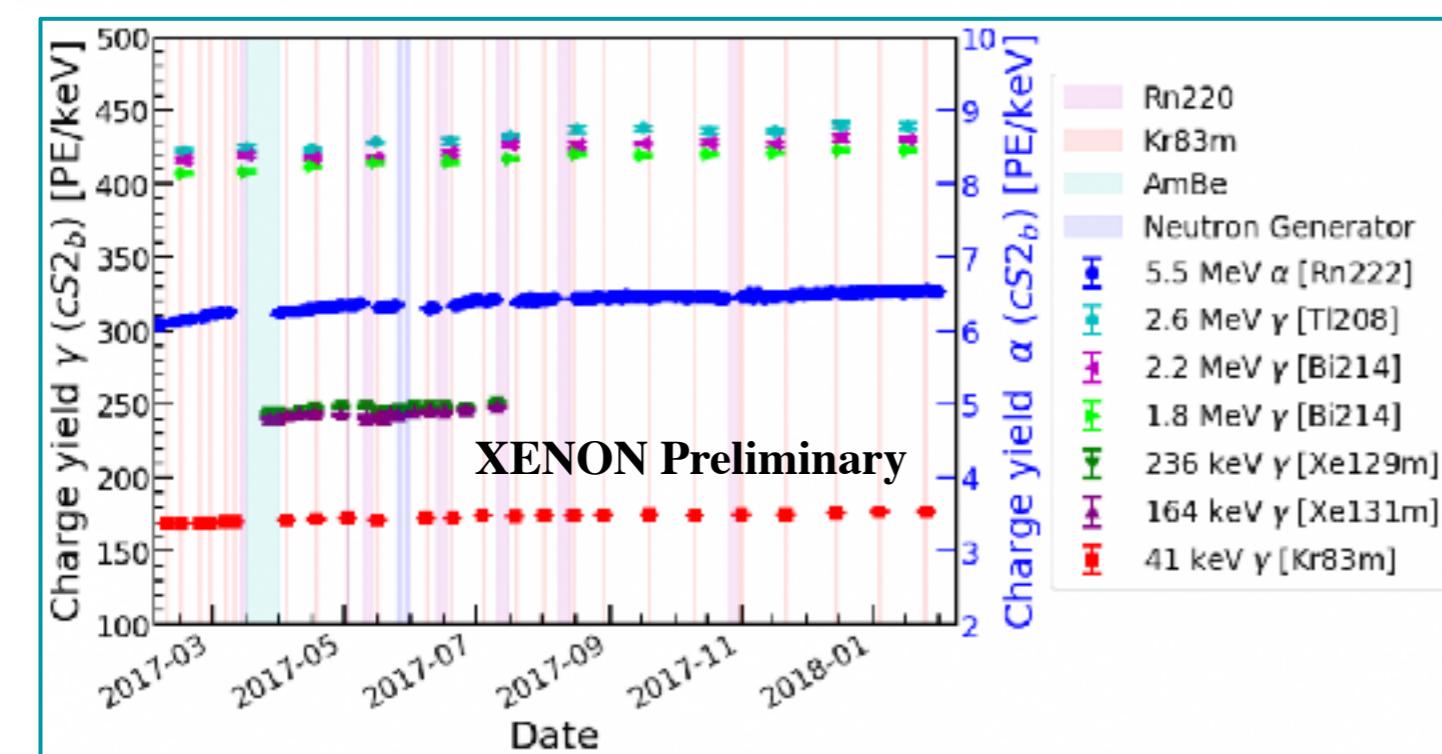
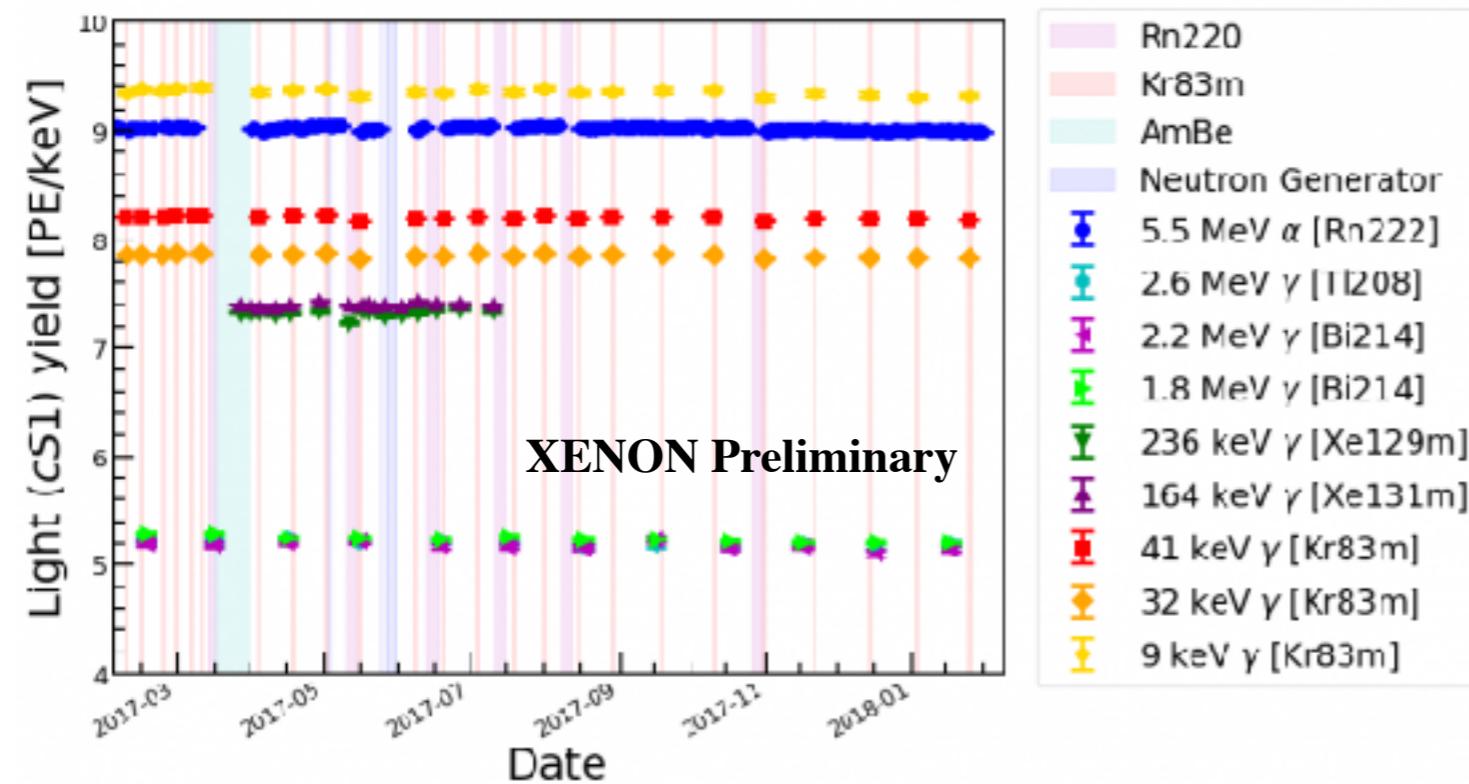


Bottom array



# Light and Charge Signals Stability

stability of many more variables are checked as function of time

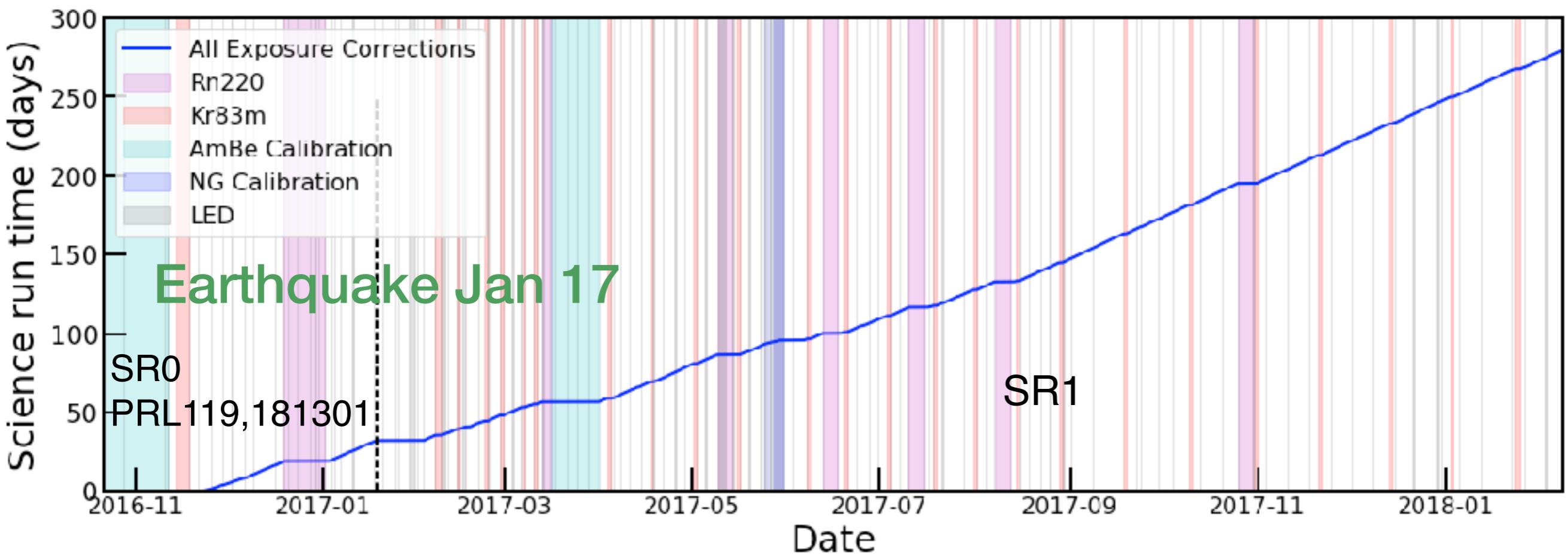


Light and charge yield stability monitored with several sources:

- $^{222}\text{Rn}$  decays
- Activated Xe after neutron calibrations
- $^{83\text{m}}\text{Kr}$  calibrations
- $^{214}\text{Bi}$  and  $^{208}\text{Tl}$  for high energy calibration
- Stability is within % 0.2 and 2 % for light and charge respectively.

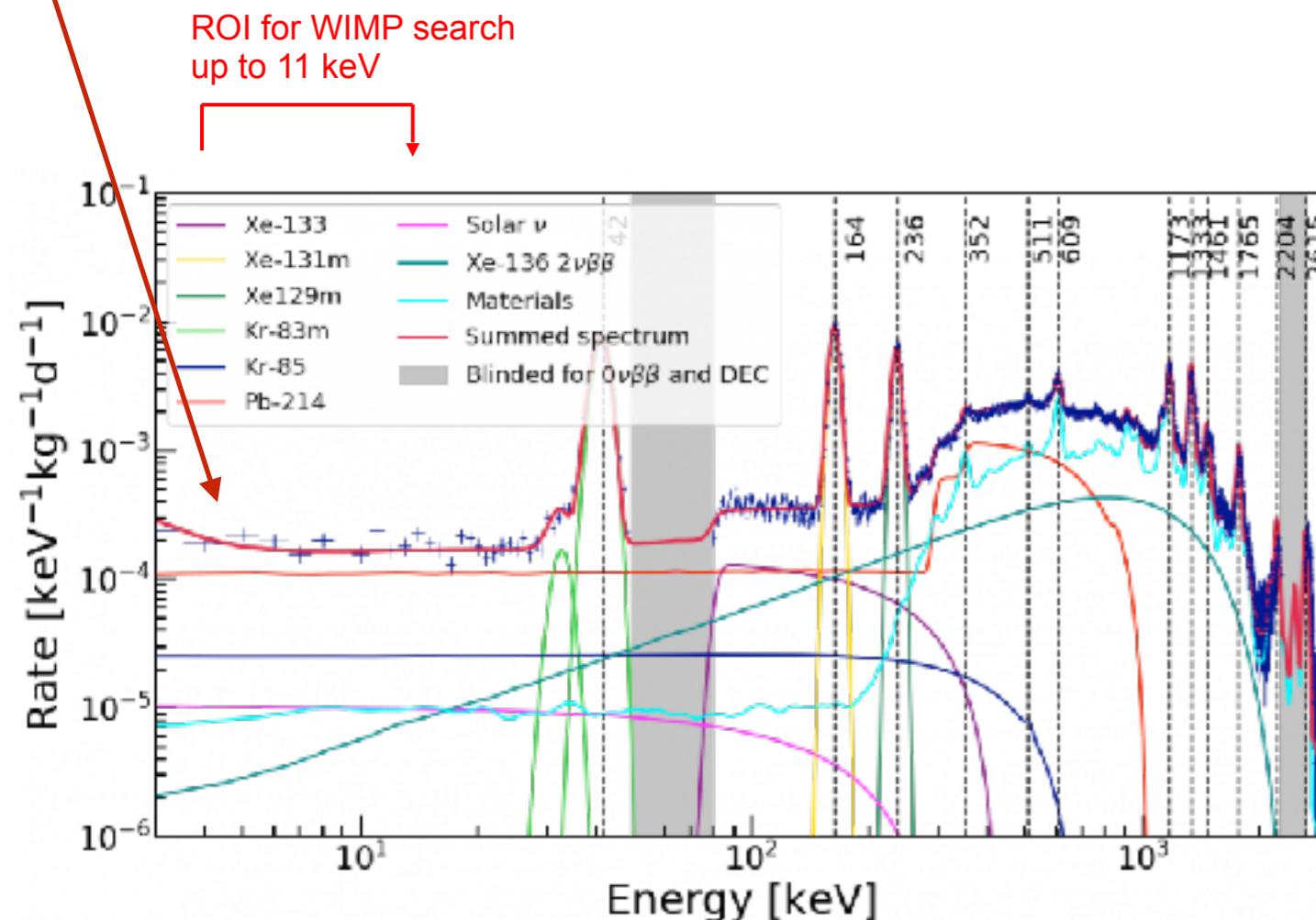
# XENON1T: science and calibration data

- 278.8 days of DM data taking since Spring 2016 (corrected for dead time included)
- SR0 32.1 days, SR1 246.7 days
- The largest exposure reported so far with this type of detector



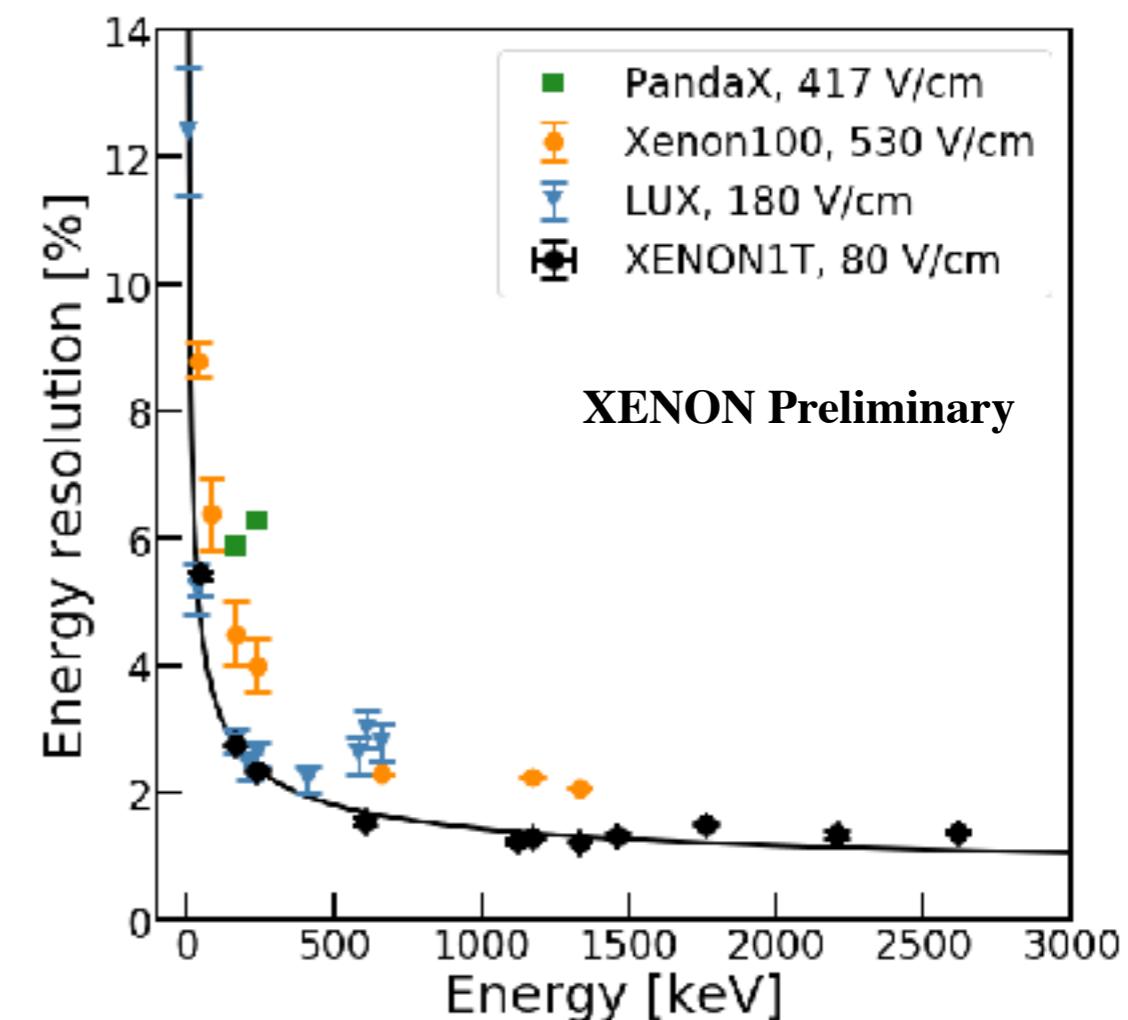
# Energy Resolution

Soon  $^{37}\text{Ar}$  calibration will provide a calibration peak in this region

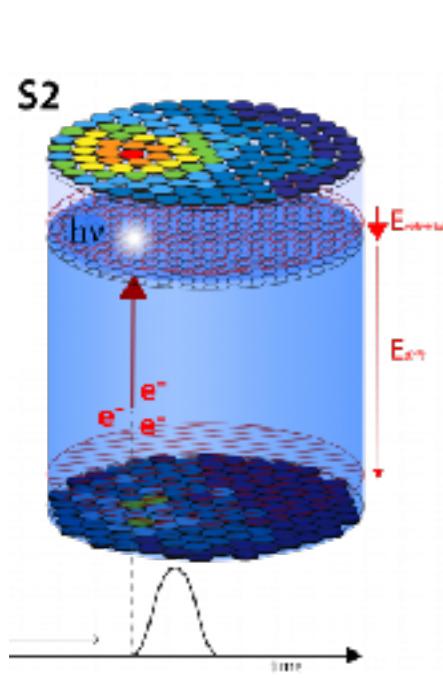


- Good agreement between predicted and measured background spectrum
- $^{85}\text{Kr}$ : ~0.66 ppt;  $^{214}\text{Pb}$ : ~ 10 uBq/kg

- 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



# Position Reconstruction



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

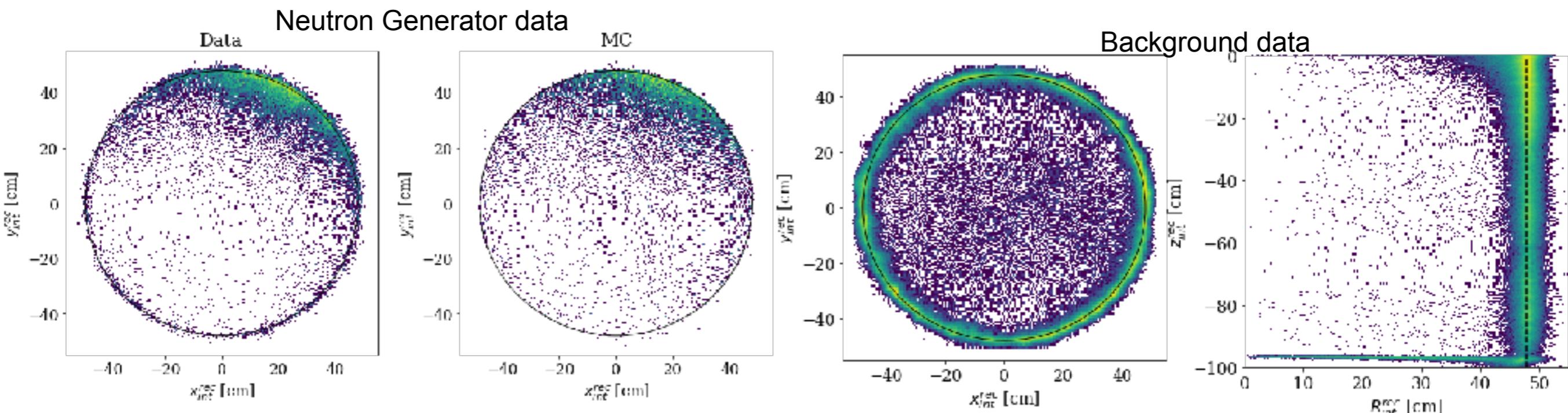
- **Input:** charge/channel top array
- **Training:** Monte Carlo simulation

## Position resolution using $^{83m}\text{Kr}$

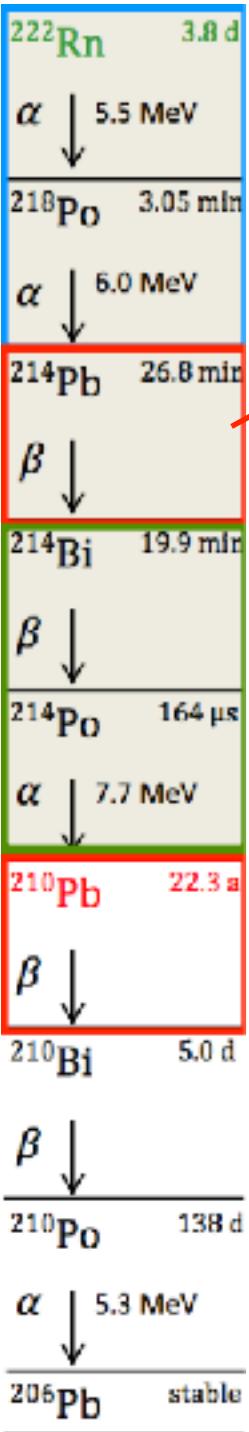
- Two interactions (9, 31 keV), same x-y
- Position resolution (1-2 cm)

## Position corrections using $^{83m}\text{Kr}$

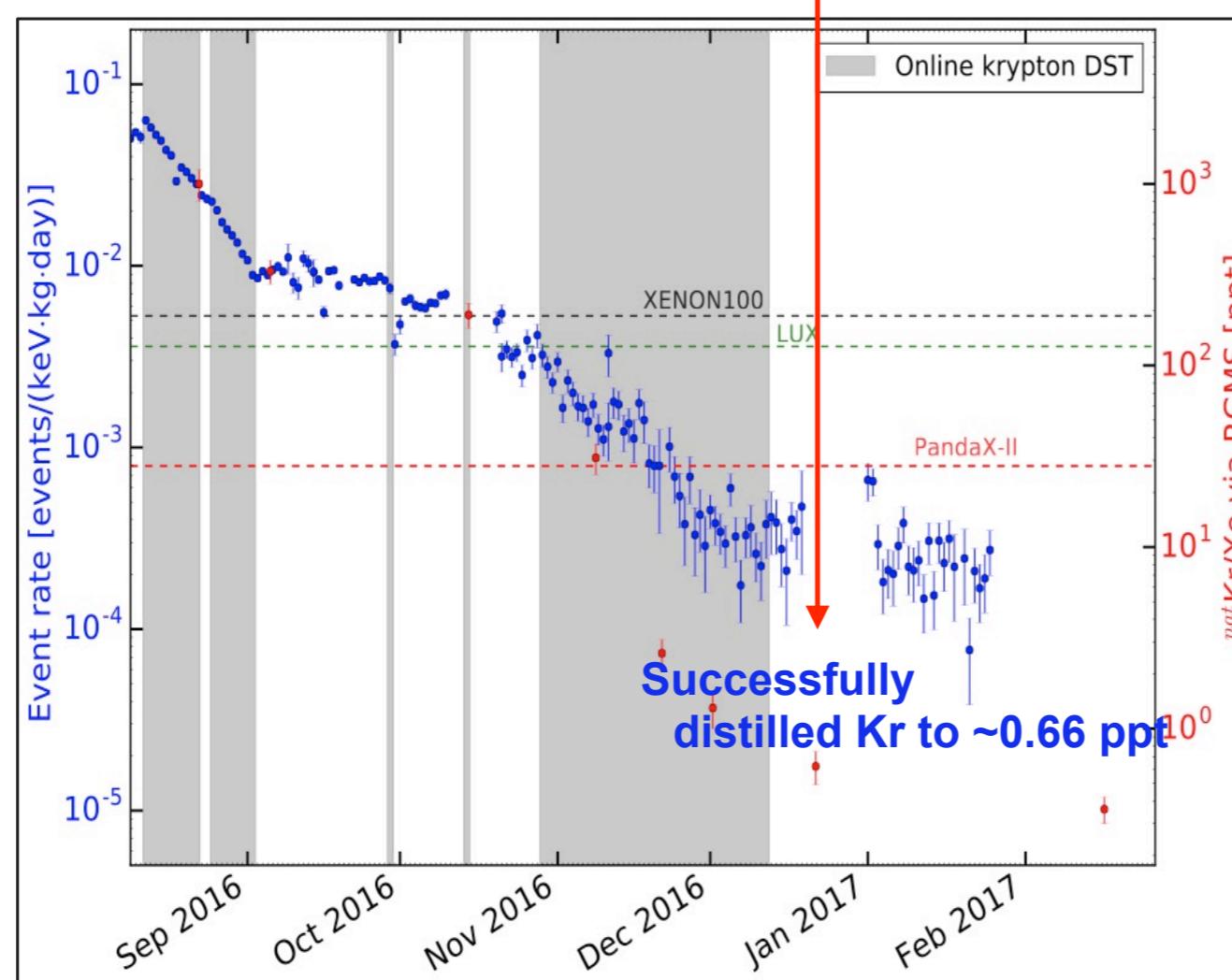
- **Drift field distortion**
- Localized inhomogeneities from inactive PMTs
- Data-derived correction verified by comparison to MC with several event sources



# 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

JCAP04 (2016) 027

(Expectations in 1-12 keV search window, 1.3 t FV,  
single scatters in the ROI

Source	Events/(keV t y)	Fraction [%]
$^{214}\text{Pb}$	$56 \pm 6$	85.4
$^{85}\text{Kr}$	$7.7 \pm 1.3$	4.3
Solar $\nu$	$2.5 \pm 0.1$	4.9
Materials	$8 \pm 1$	4.1
$^{136}\text{Xe}2\nu\beta\beta$	$0.8 \pm 0.1$	1.4

**A glance to the future:**  
a new magnetic pump for Xe circulation, significantly improved the purity, i.e. e lifetime, and reduced the Rn level, and so the ER background.  
Soon updates on all parameters and prediction mentioned will be published

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

**$(75 \pm 6) \text{ events / (t}\cdot\text{year}\cdot\text{keV)}$**

**Measured:** in 1300 kg FV and below 25 keVee

**$(82^{+5}_{-3} \text{ (syst)} \pm 2 \text{ (stat)}) \text{ events / (t}\cdot\text{year}\cdot\text{keV)}$**

**Lowest ER background ever achieved in a DM detector !**

# Nuclear Recoil Backgrounds

Cosmogenic  $\mu$ -induced neutrons significantly reduced by rock overburden and muon veto

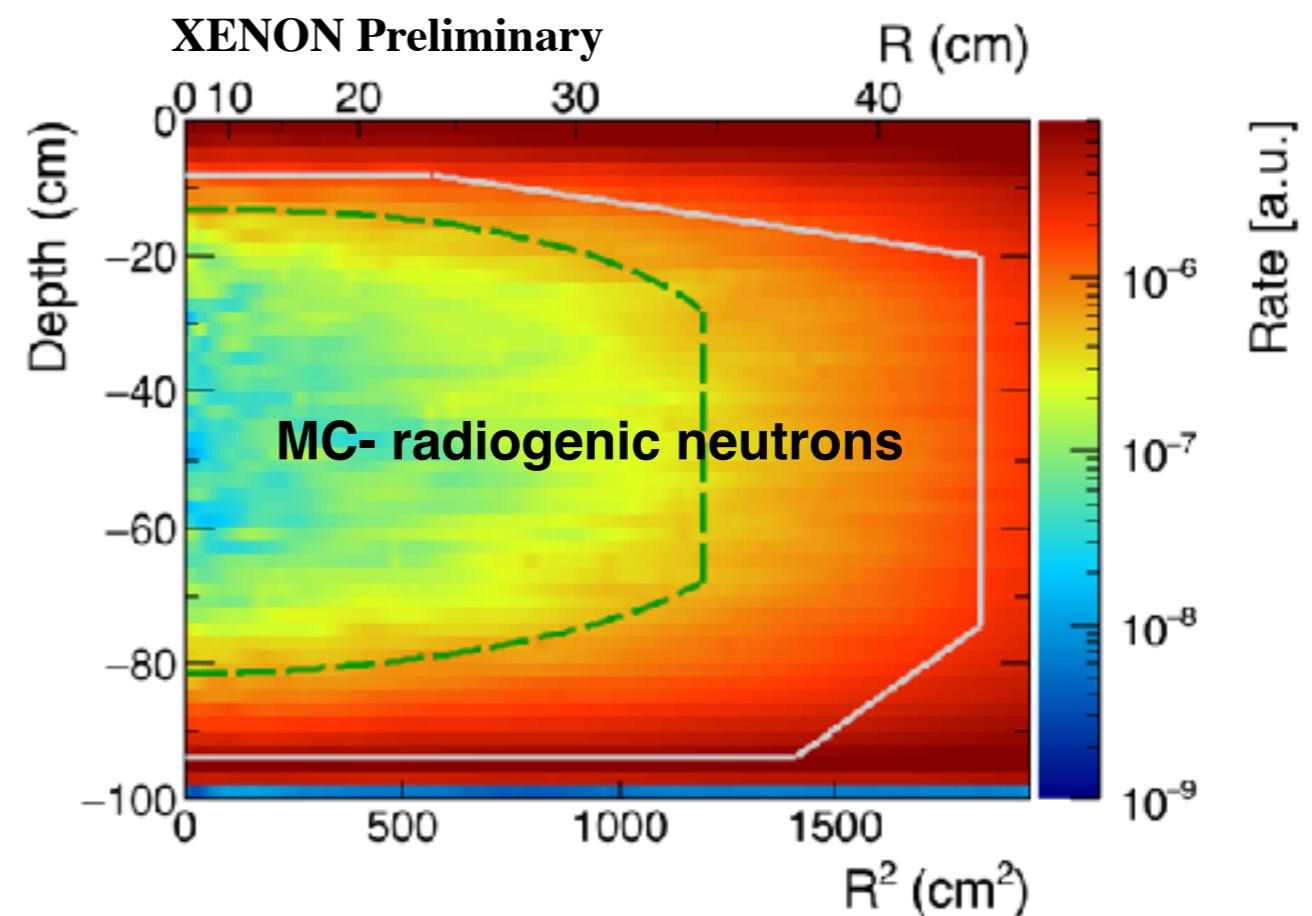
Coherent elastic  $\nu$ -nucleus scattering, is an irreducible background at very low energy (1 keV)

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

Source	Rate [ $\text{t}^{-1} \text{y}^{-1}$ ]	Fraction [%]
<b>Radiogenic <math>\nu</math></b>	$0.6 \pm 0.1$	96.5
<b>CEvNS</b>	0.012	2.0
<b>Cosmogenic <math>\nu</math></b>	< 0.01	< 2.0

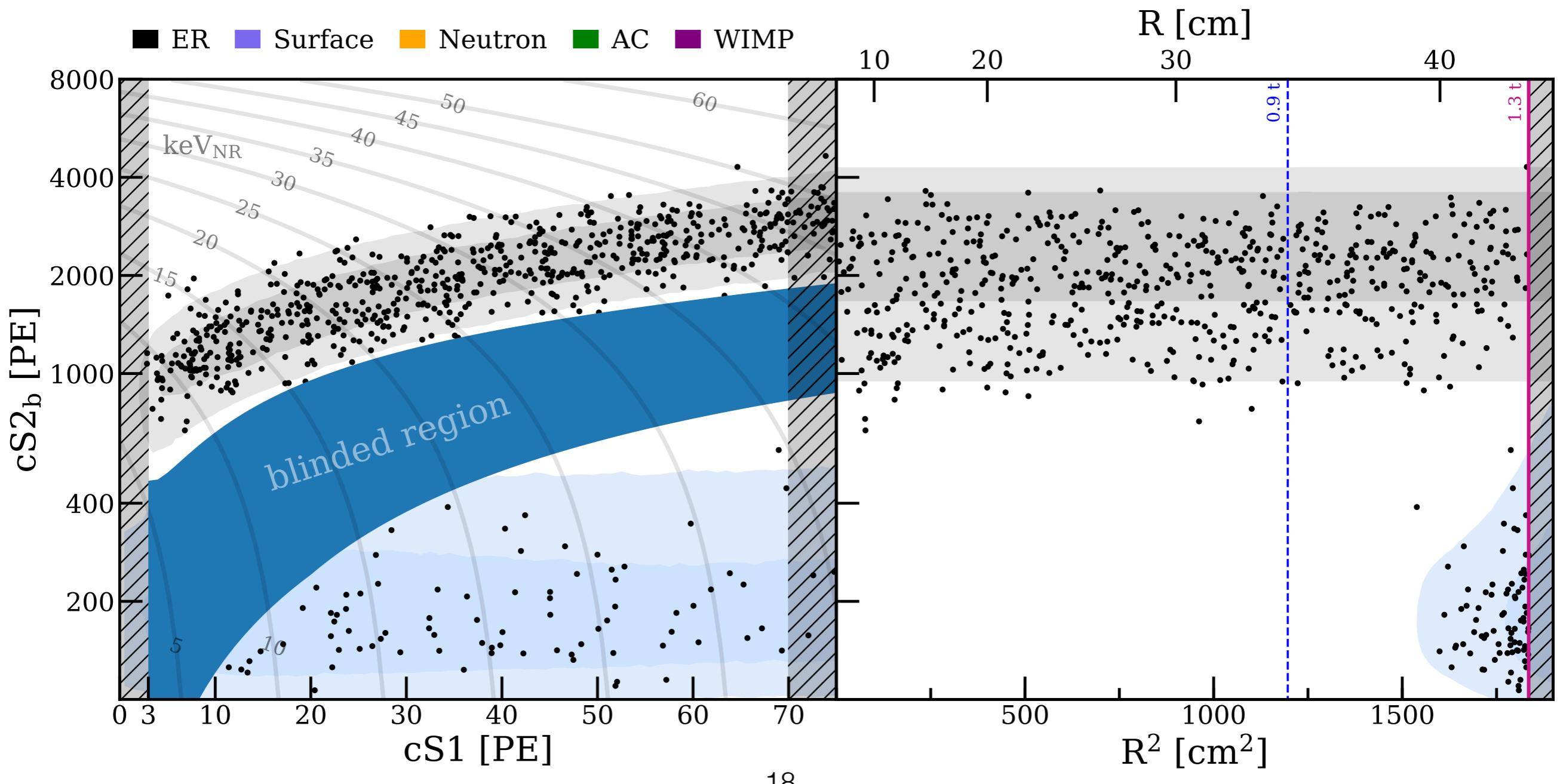
(Expectations in 4-50 keV search window, 1t FV, single scatters)

[JCAP04 \(2016\) 027](#)

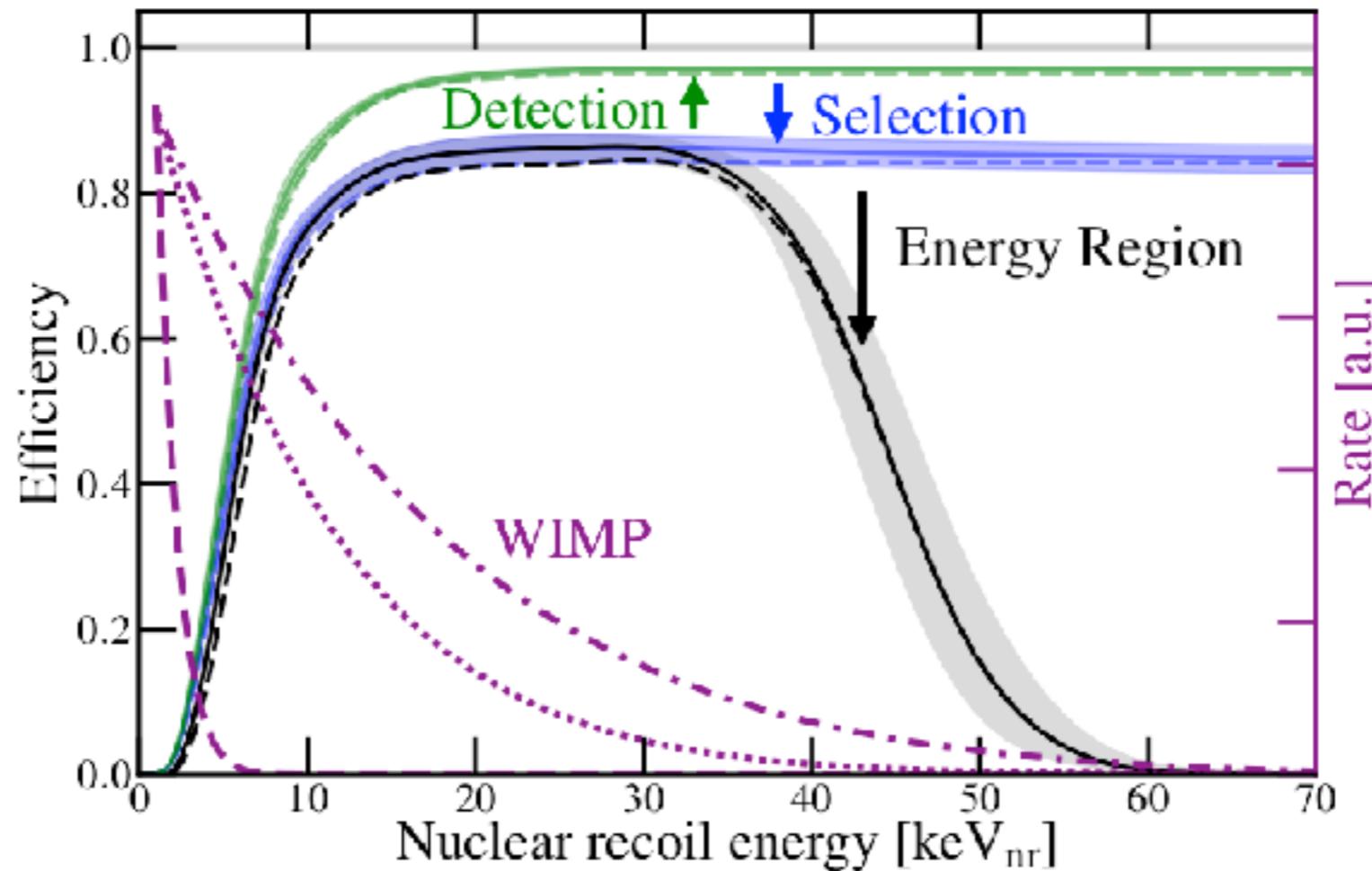


# Dark Matter Search Data: Blinded and salted

- 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

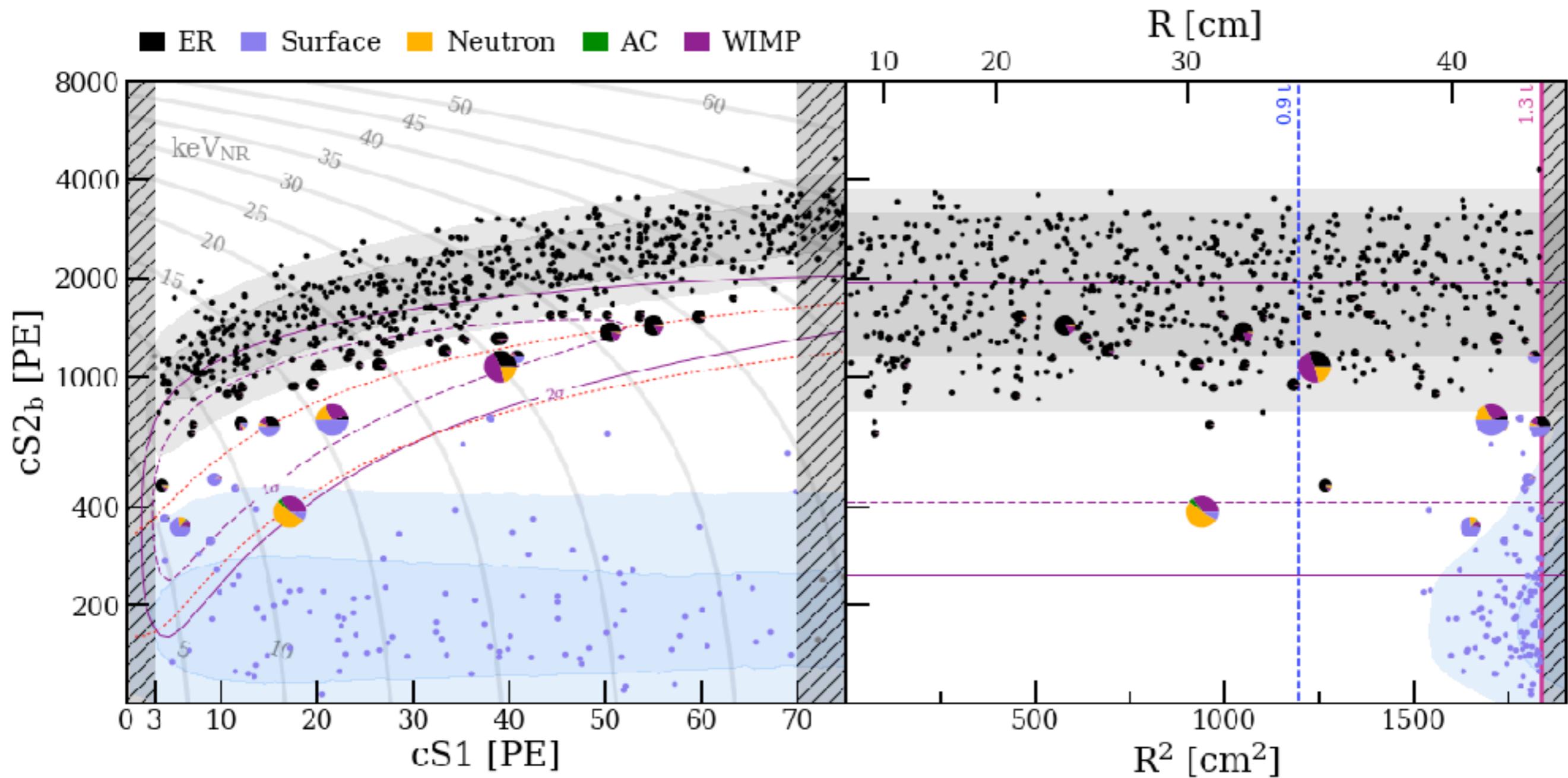
FV volume increased from 1 tonne (in SR0 First Result) to 1.3 tonne thanks  
to improvements in position reconstruction

Mass	1.3 t	1.3 t	0.9 t
(S2, S1)	Full	Reference	Reference
ER	$627 \pm 18$	$1.62 \pm 0.30$	$1.12 \pm 0.21$
Neutron	$1.43 \pm 0.66$	$0.77 \pm 0.35$	$0.41 \pm 0.19$
CE <sub>v</sub> NS	$0.05 \pm 0.02$	$0.03 \pm 0.01$	0.02
AC	$0.47^{+0.27}_{-0.00}$	$0.10^{-0.00}_{+0.06}$	$0.06^{-0.00}_{+0.03}$
Surface	$106 \pm 8$	$4.84 \pm 0.40$	0.02
BG	$735 \pm 20$	$7.36 \pm 0.61$	$1.62 \pm 0.28$
Data	<b>739</b>	<b>14</b>	<b>2</b>
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

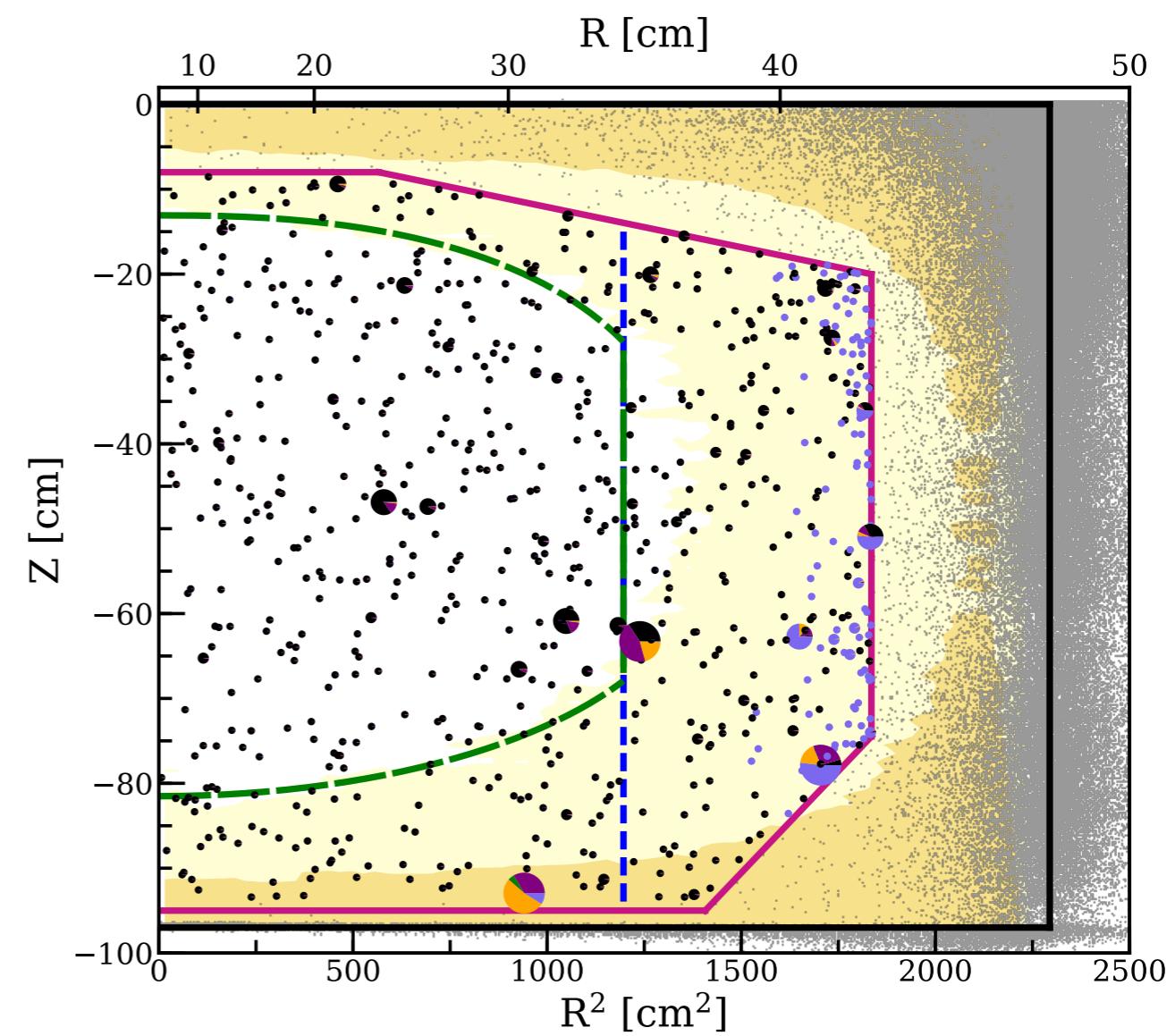
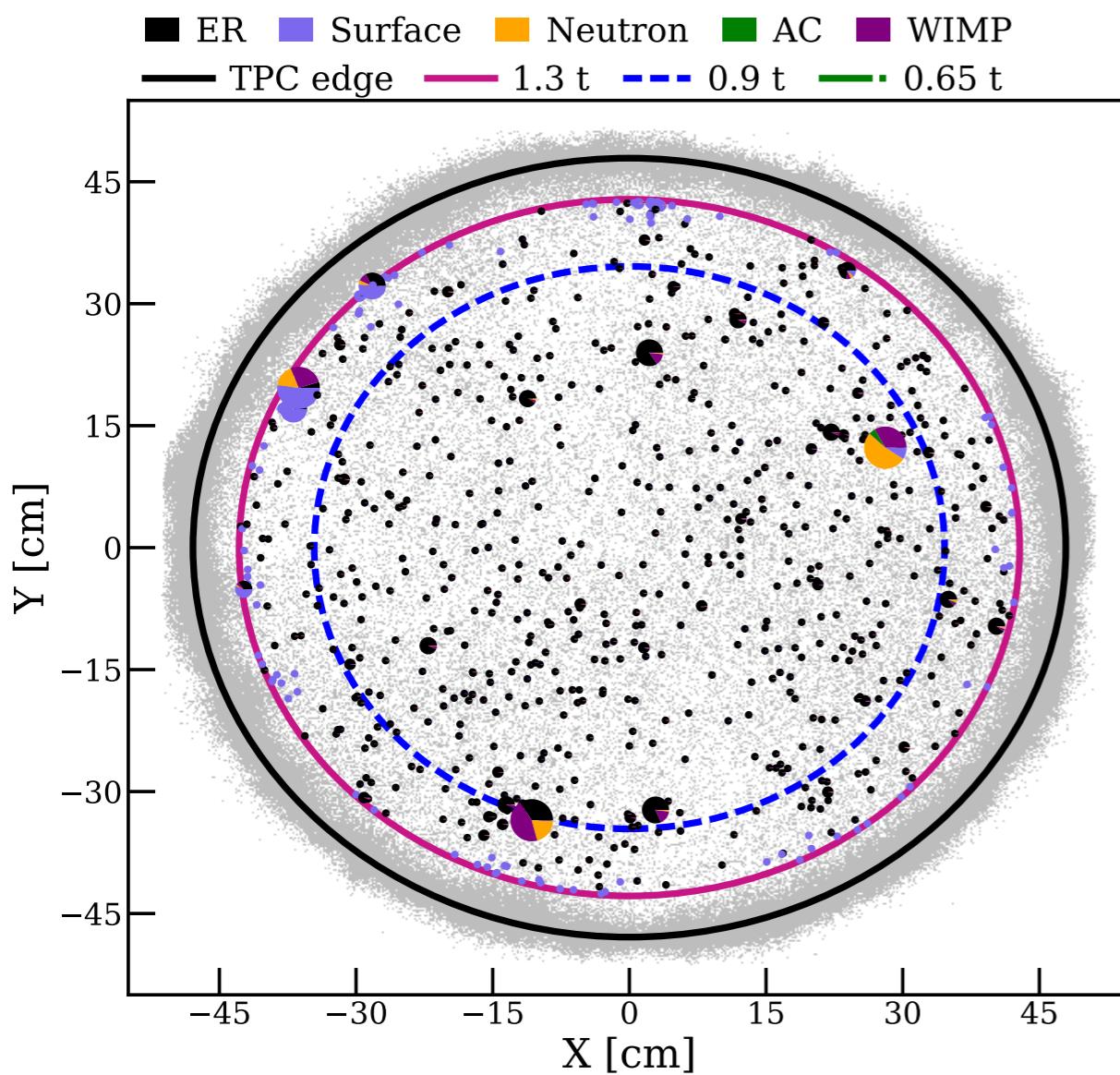
# Dark Matter Search Results

- Results interpreted with un-binned profile likelihood analysis in  $cs1$ ,  $cs2$ ,  $R$ ,  $z$  space
- piechart indicate the relative PDF from the best fit of 200 GeV/c<sup>2</sup> WIMPs with a cross-section of  $4.4 \times 10^{-47} \text{ cm}^2$

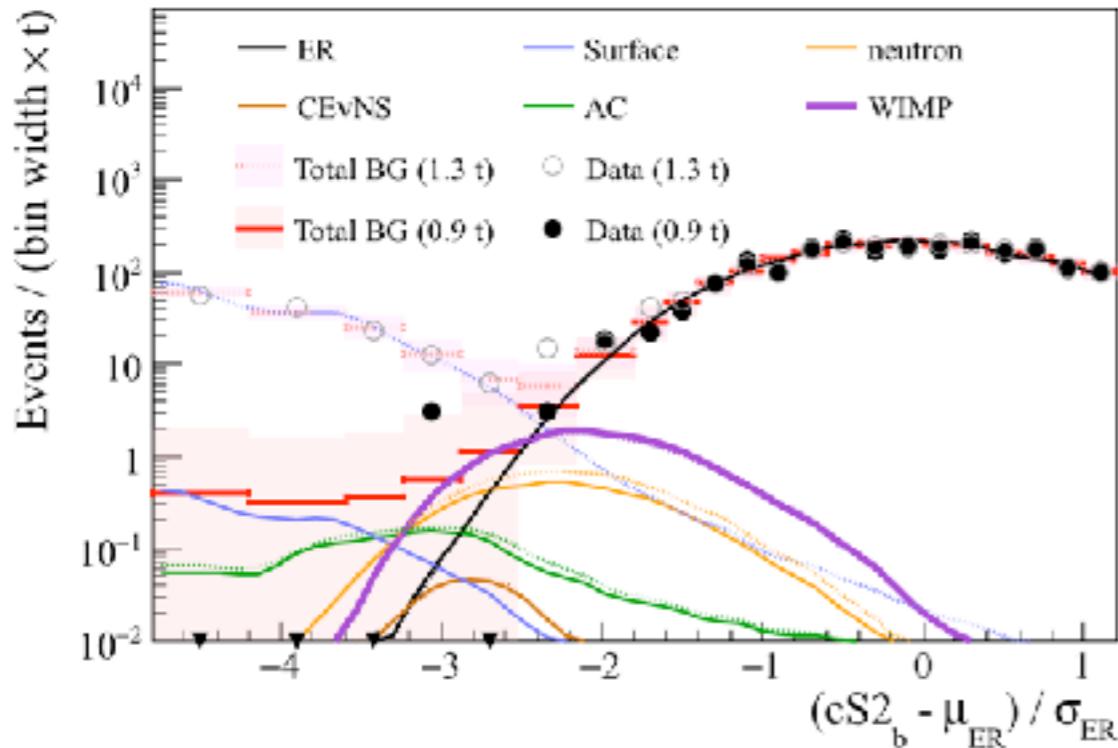


# Spatial Distribution of Dark Matter Search Data

- **Core volume** (0.65 t) designated to distinguish WIMPs over neutron background in two bins, in/out core volume.

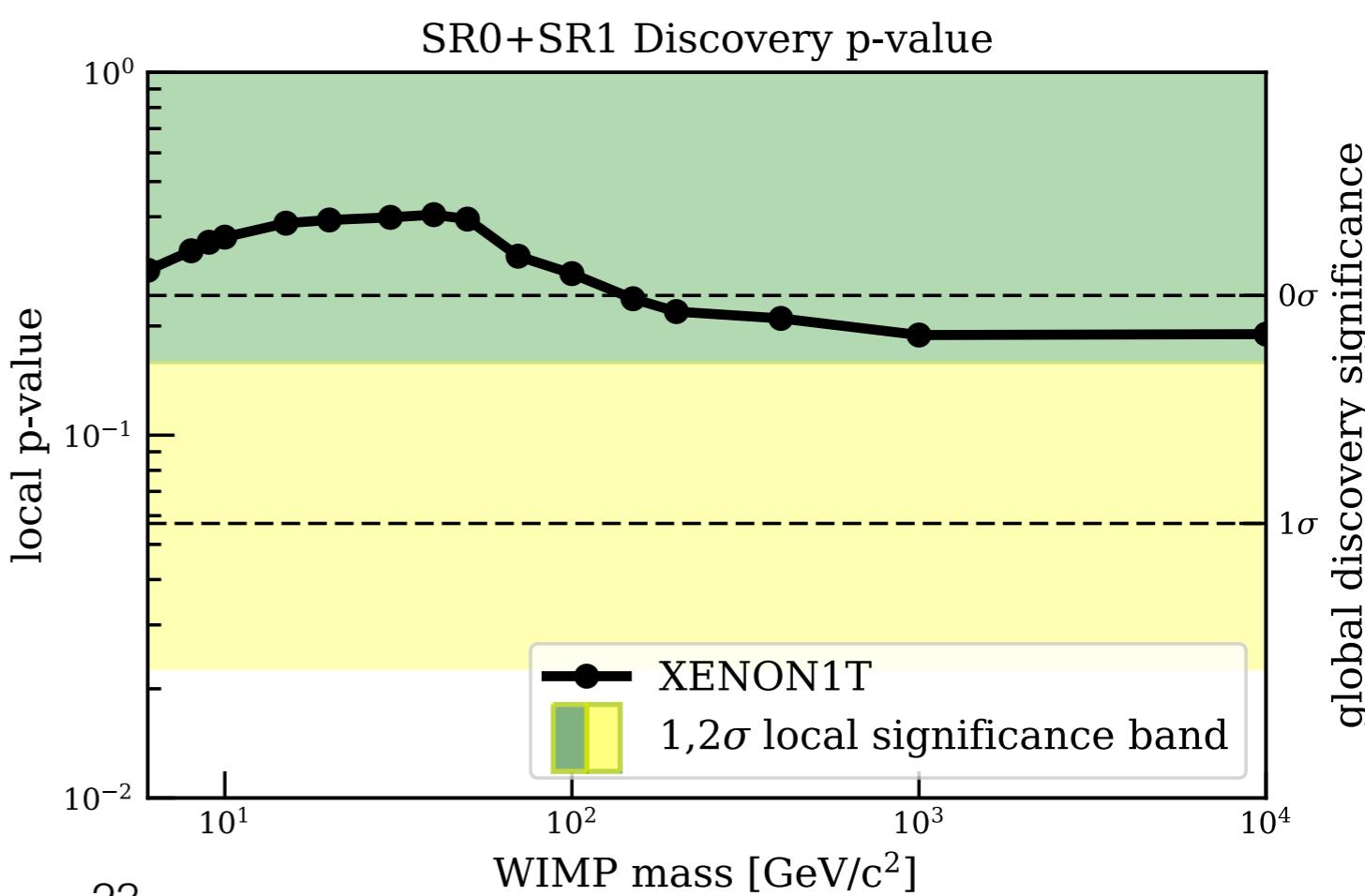


# Statistical Interpretation

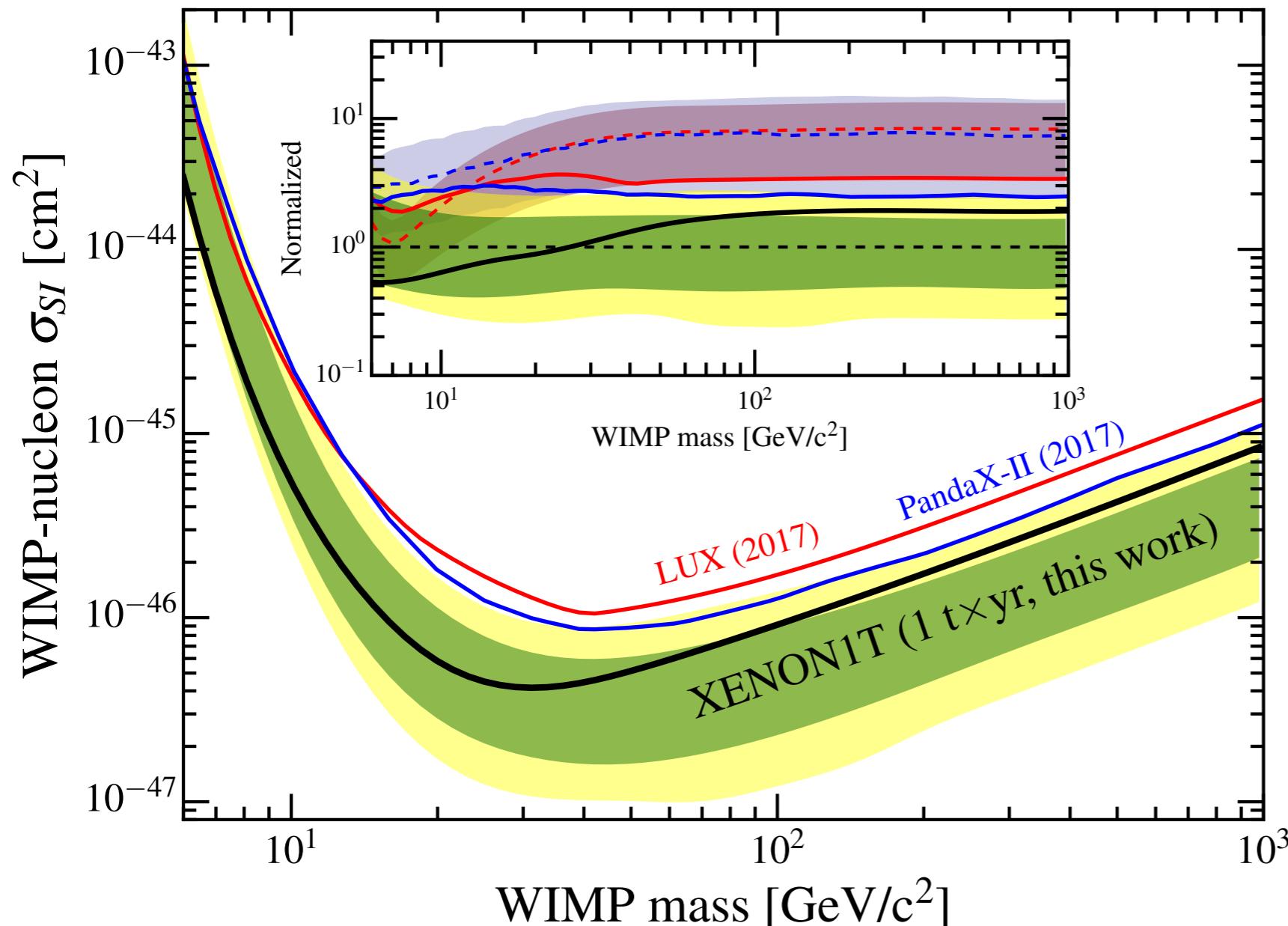


- No significant ( $>3$  sigma) excess at any scanned WIMP mass
- Background only hypothesis is accepted although the p-value of  $\sim 0.2$  at high mass (200 GeV and above) does not disfavor a signal hypothesis either

- Extended un-binned profile likelihood analysis
- Example left: Background and 200 GeV WIMP signal best-fit predictions, assuming  $4.4 \times 10^{-47} \text{ cm}^2$ , compared to data in 1.3T and 0.9T
- Most significant ER & Surface backgrounds shape parameters included



# 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
- $\sim 1$  sigma upper fluctuation from median sensitivity

**Minimum at  $4.1 \times 10^{-47} \text{ cm}^2$  for a WIMP of  $30 \text{ GeV}/c^2$**

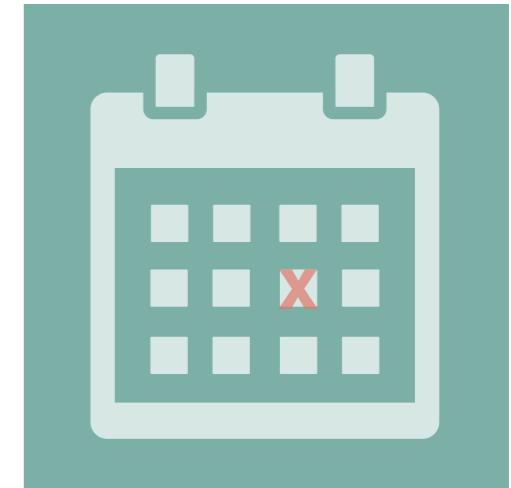
# The next step: XENONnT

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  $^{222}\text{Rn}$ -daughters.  
Identified strategies to effectively **reduce  $^{222}\text{Rn}$  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 WIMP mass above 6 GeV/c<sup>2</sup>? Yes
  - ✓ Am I disappointed not having found DM? Yes
  - ✓ Is there another episode? Yes: XENONnT

