Istituto Nazionale di Fisica Nucleare

XENON Dark Matter Project

The XENON project @INFN-LNGS:
new results from XENON1T and prospects with XENONnT

Marco Selvi
INFN Bologna
(on behalf of the XENON collaboration)

Korea-Italy Bi-lateral Symposium

Daejeon - October 1st, 2018

The XENON Collaboration: ~165 scientists

INFN Istituto Nazionale di Fisica Nucleare

XENON Dark Matter Project

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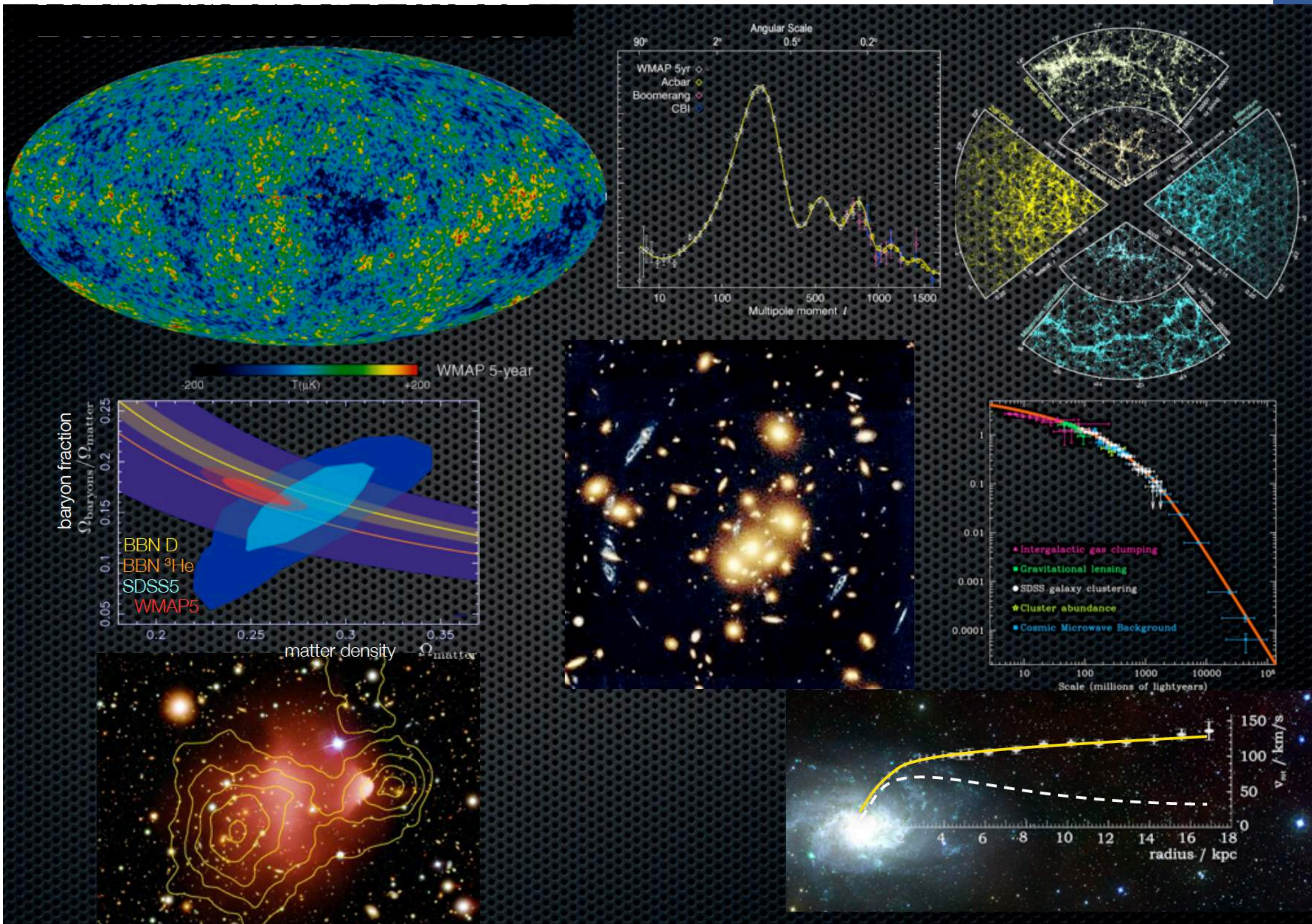
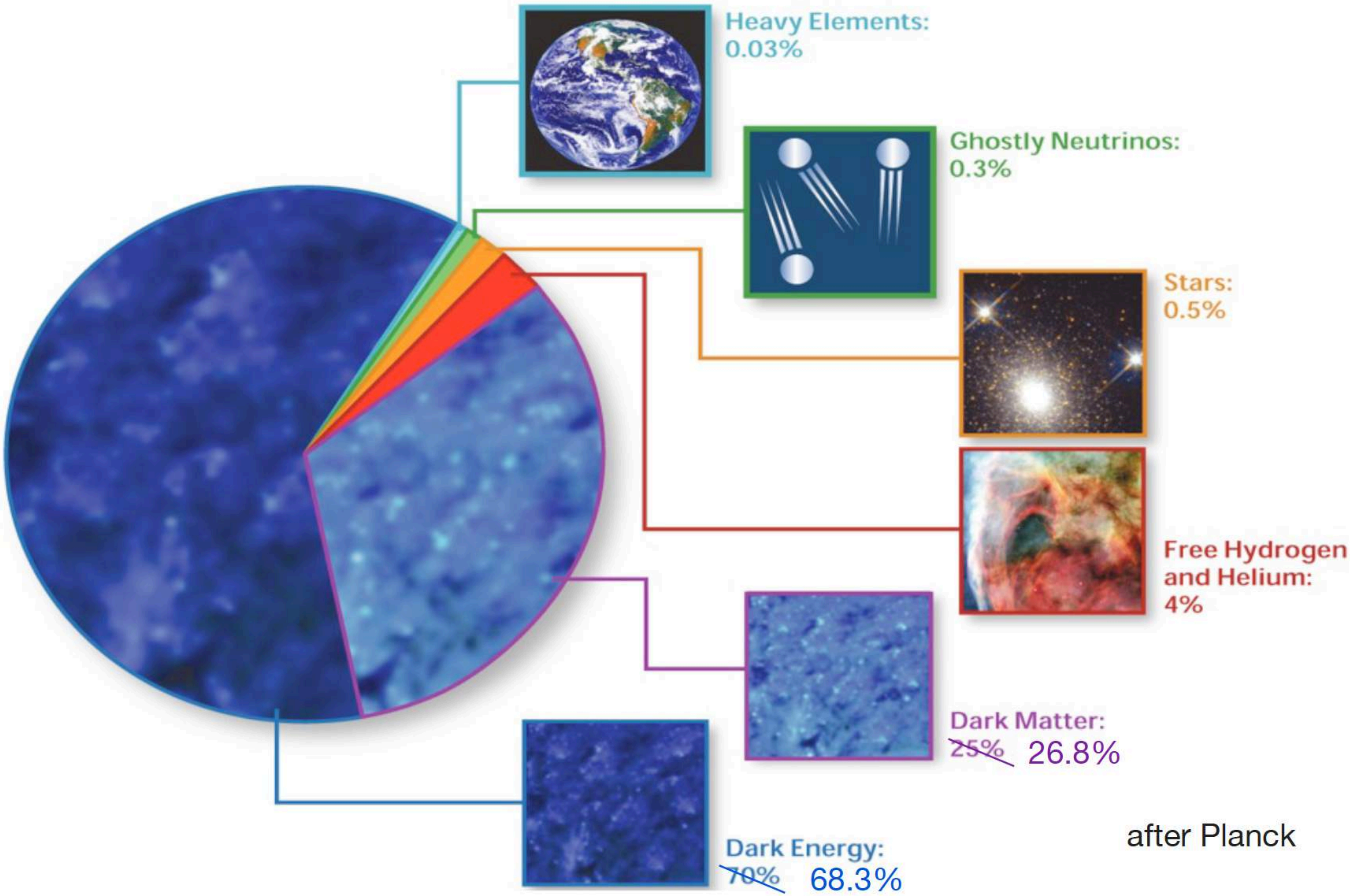
Dark Matter exists



… and it dominates the Universe Matter budget

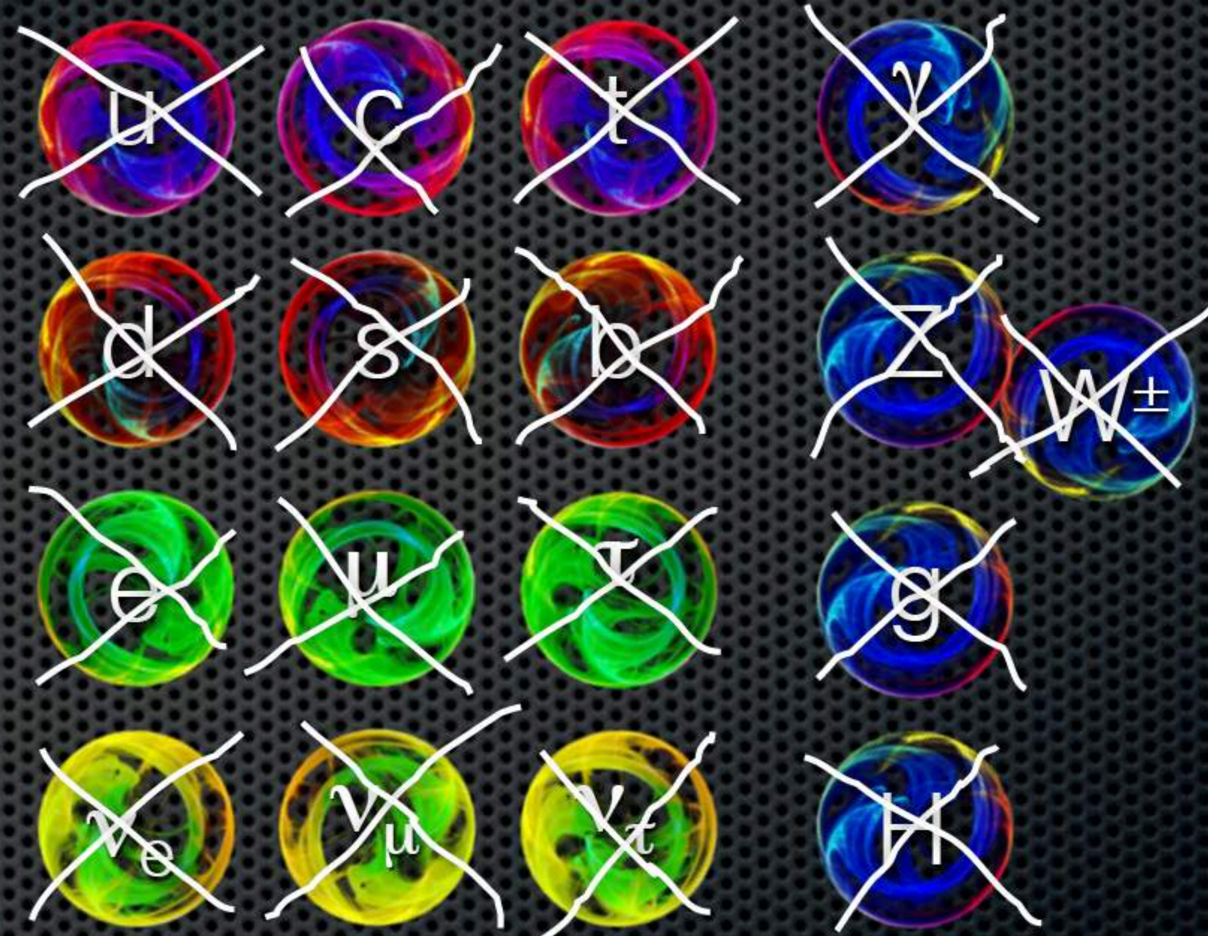


after Planck

… but what is it made of ?

We know Dark Matter has to be

- neutral
- cold
- stable
- no EM interaction
- non-baryonic
- correct density



-> No Standard Model Candidate

The WIMP hypothesis

Weakly Interacting Massive particle

- if a **neutral, massive, weakly interacting particle** (WIMP) existed in the early Universe

$$\chi + \bar{\chi} \leftrightarrow X + \bar{X}$$

- it was in equilibrium as long as the **reaction rate** was larger than the **expansion rate**

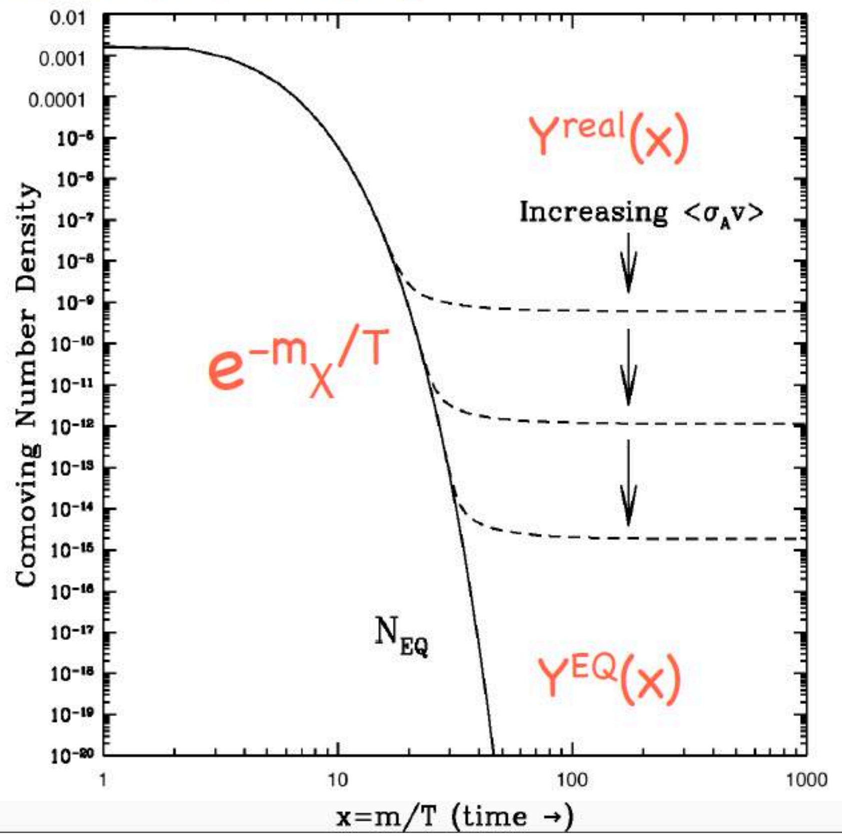
$$\Gamma \gg H$$

- after **Γ drops below H** ⇒ “freeze-out”, we are left with a **relic density**

$$\frac{dn}{dt} = -3Hn - \langle \sigma_{eff} v \rangle \left(n^2 - n_{eq}^2 \right)$$

decrease due to expansion of the Universe

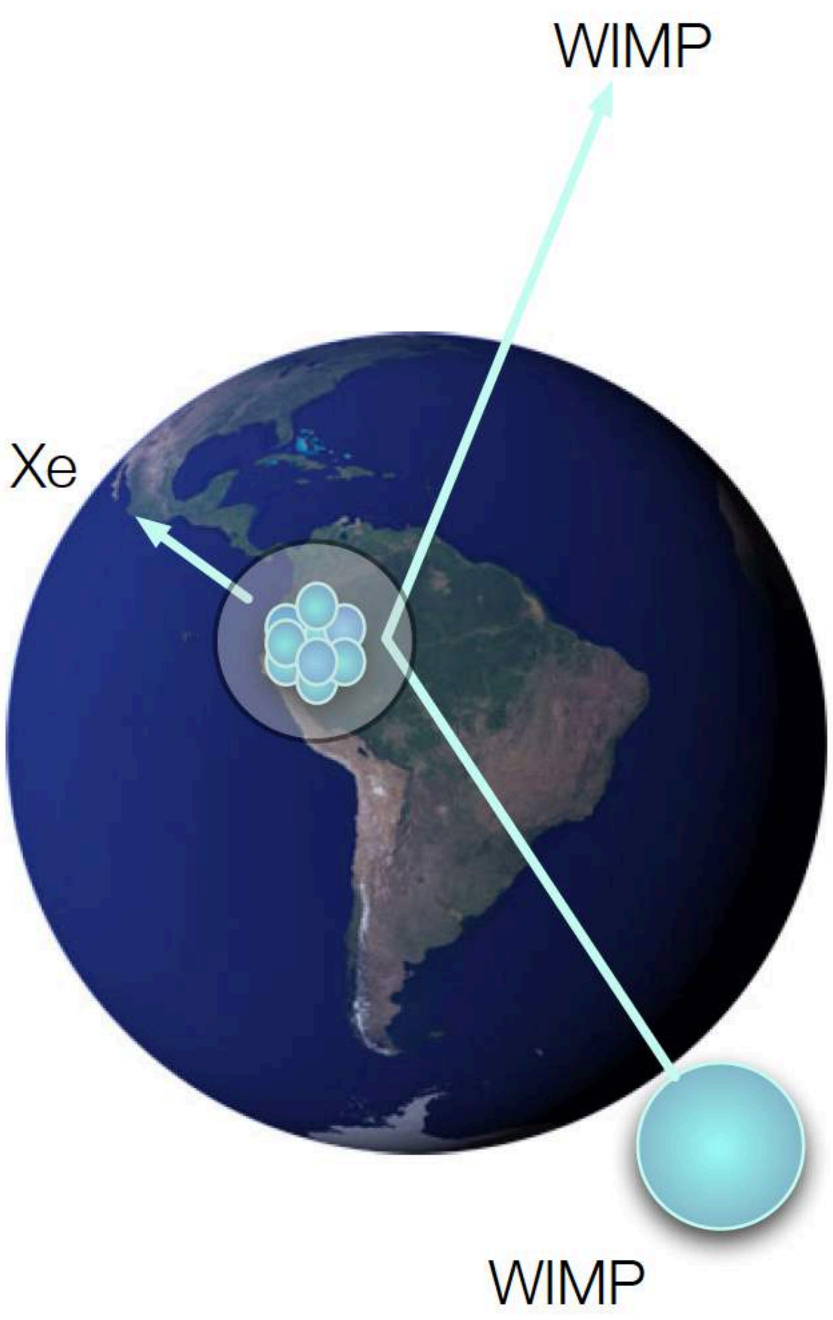
change due to annihilation and creation



Number density now: **integrate from freeze-out to present**

$$\Omega_\chi \propto \langle \sigma_A v \rangle^{-1}$$

WIMP direct detection



- Elastic collisions with nuclei
- The recoil energy is:

$$E_R = \frac{|\vec{q}|^2}{2m_N} = \frac{\mu^2 v^2}{m_N}(1-\cos\theta) \leq 50\ keV$$

- and the expected rate:

$$R \propto N \frac{\rho_\chi}{m_\chi}\langle\sigma_{\chi N}\rangle \qquad \mu = \frac{m_\chi m_N}{m_\chi + m_N}$$

N = number of target nuclei in detector
ρ_χ = local WIMP density, m_χ = WIMP mass
$\langle\sigma_{\chi N}\rangle$ = scattering cross section

Which target ?

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… choose Xenon !!

Xe
XENON
Dark Matter Project

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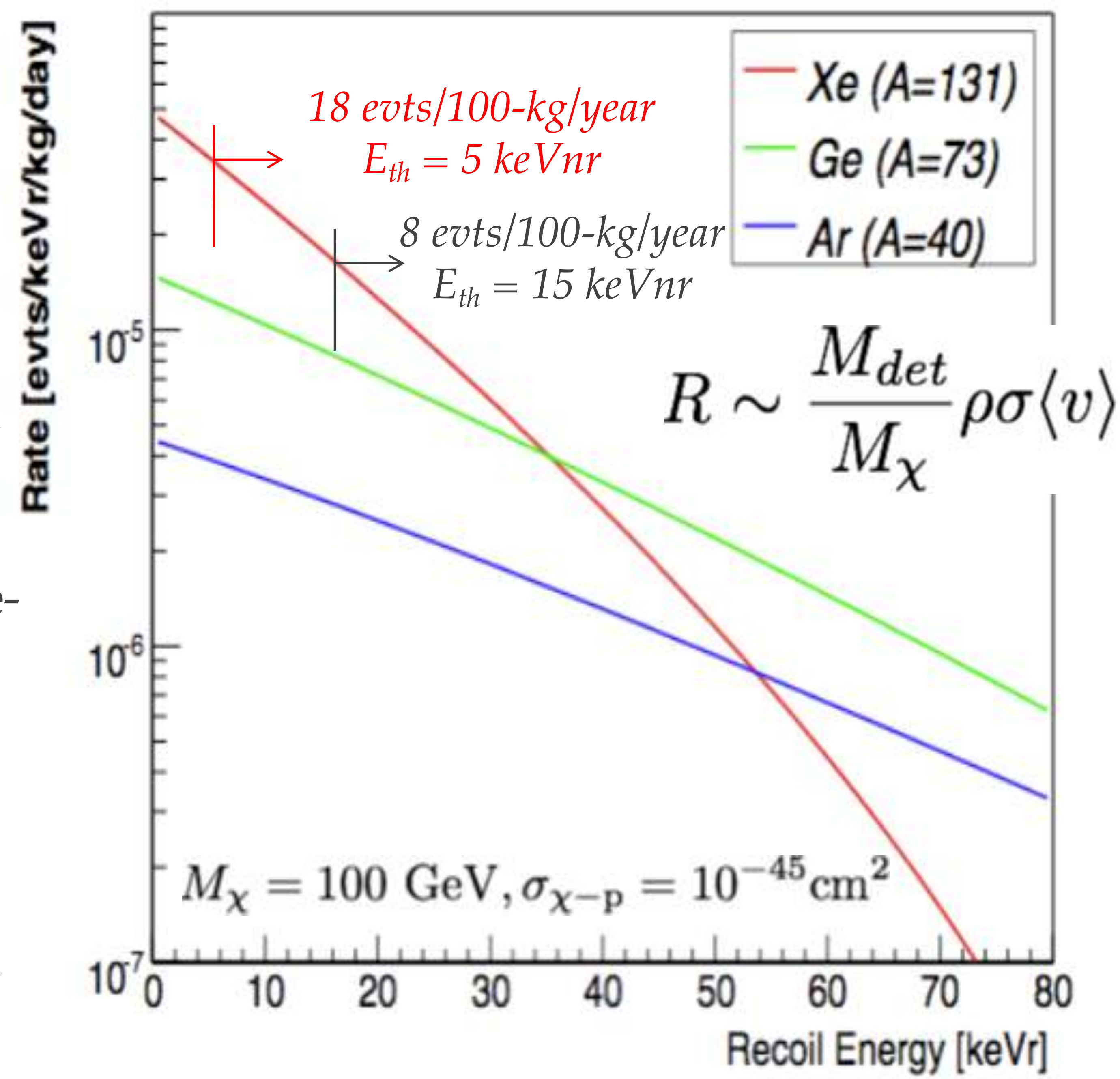
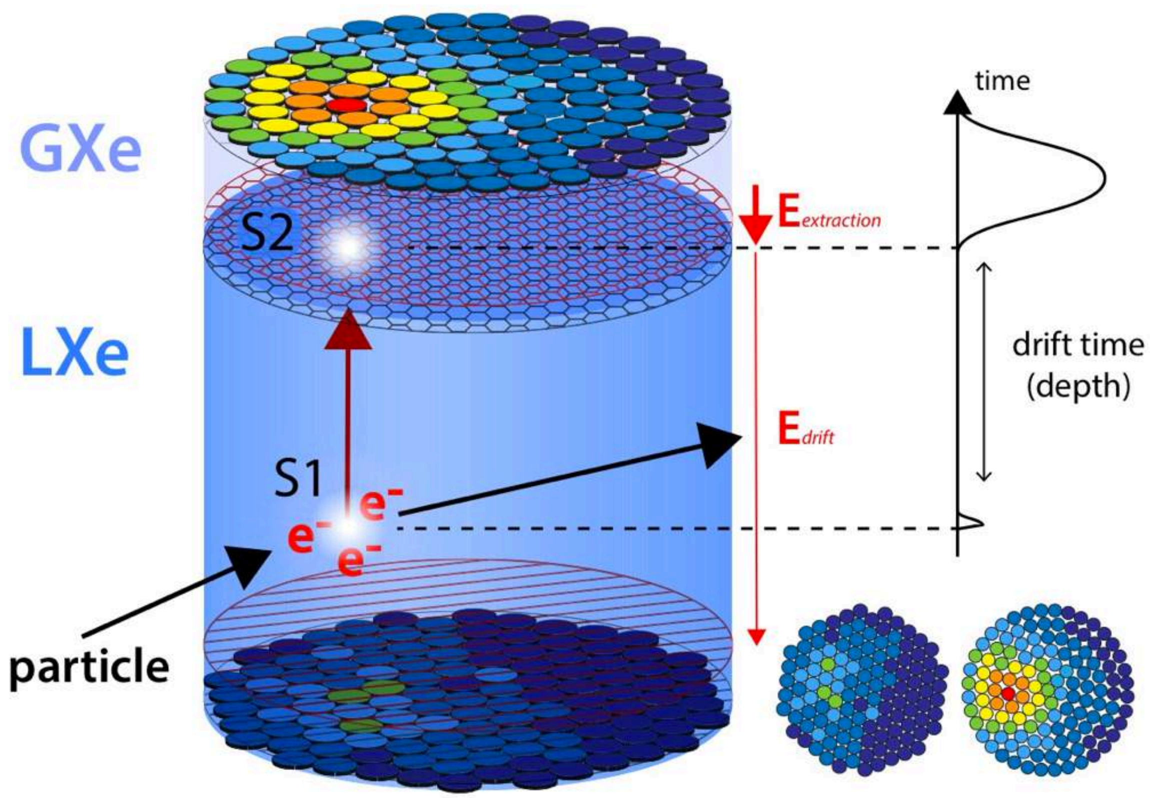
Xenon properties

XENON Dark Matter Project

- High A: large number of SI interactions
- Self shielding: high Z=54 and and high density ρ=2.83 kg/l
- Scalability: possibility to build compact detectors, scalable to larger dimensions
- Odd-nucleon isotopes: high A=131 with ~50% of odd isotopes. Good for SD.
- Wavelength 178 nm: no need for a wave-length shifter
- Intrinsically pure: ^{136}Xe has very small decay rate; Kr can be removed to <ppt
- Charge & light: highest yield among the noble liquids
- "Easy" cryogenics: -100 °C



Two-phase Xe TPC as WIMP detector



S1 Light signal
Prompt scintillation photons
S2 Charge signal
Secondary scintillation in GXe from drifted electrons

👍 Energy reconstruction from combined S1 and S2

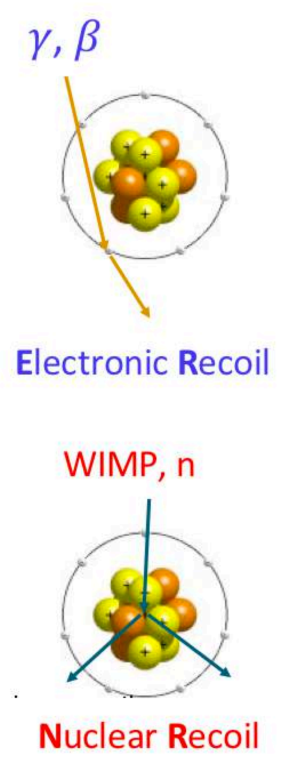
3D vertex reconstruction
X,Y from S2 pattern in top PMT array
Z from drift time

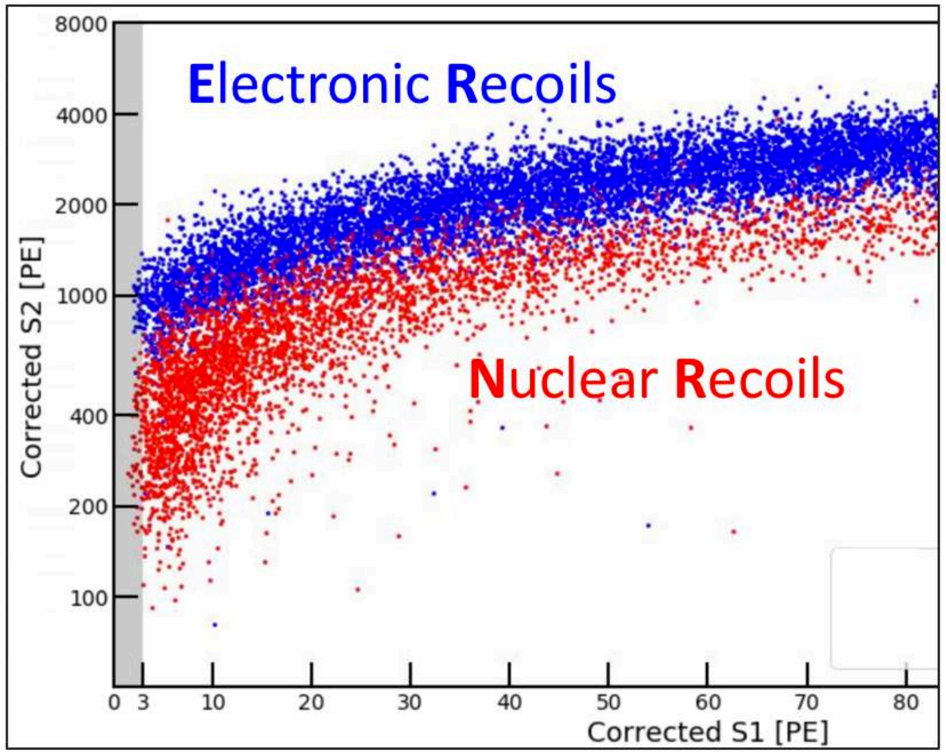
👍 Volume fiducialization
👍 Single/multiple scatters discrimination

NR (Nuclear Recoils)
WIMP signal, neutrons, CNNS

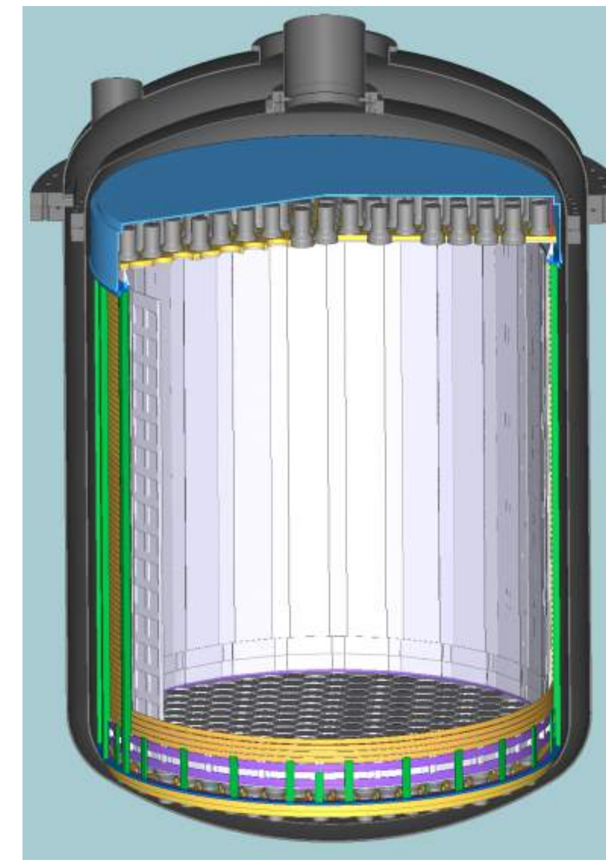
ER (Electronic Recoils)
γ, β backgrounds

👍 **Recoil type identification from S2/S1**
Larger for ER than NR

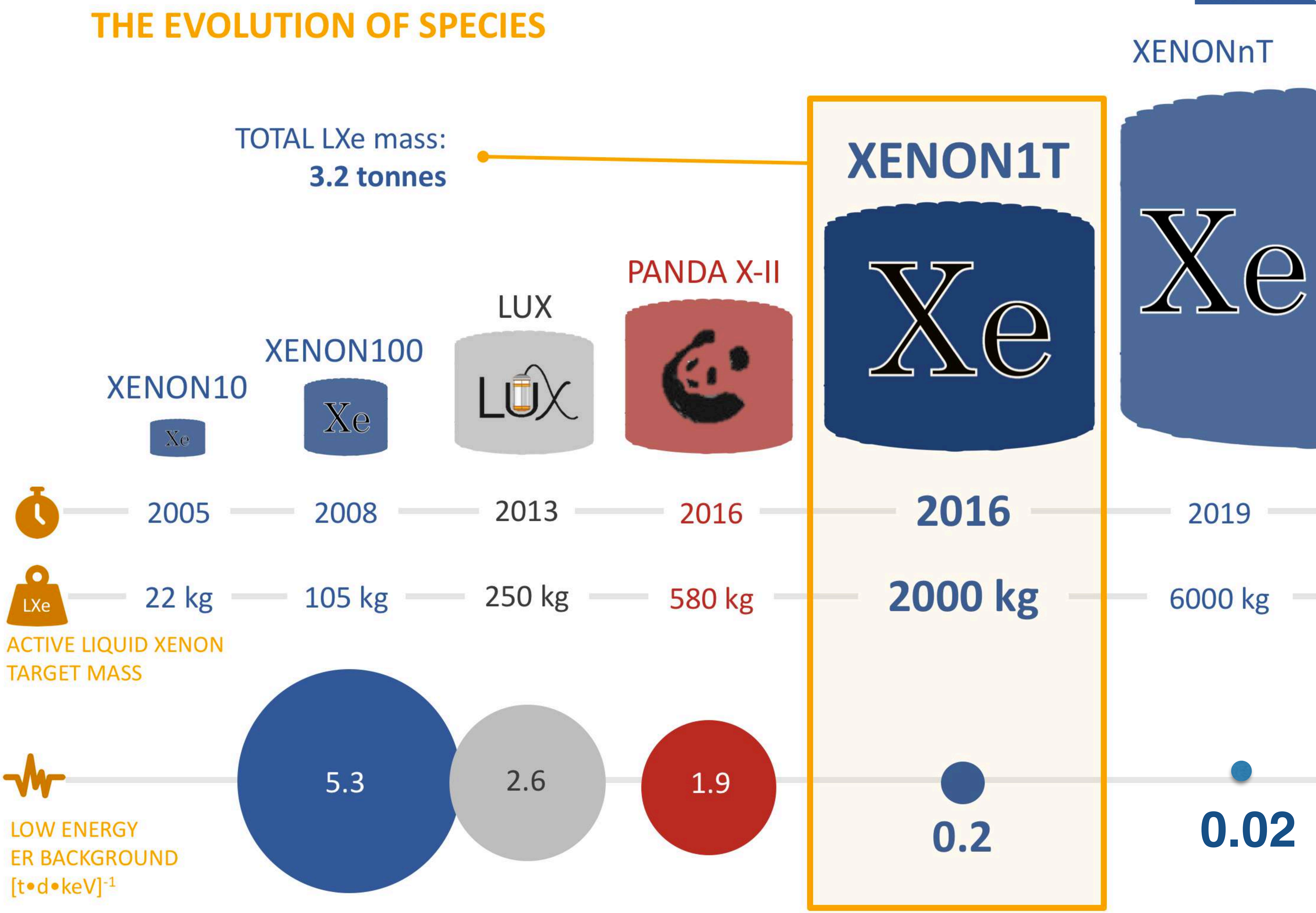




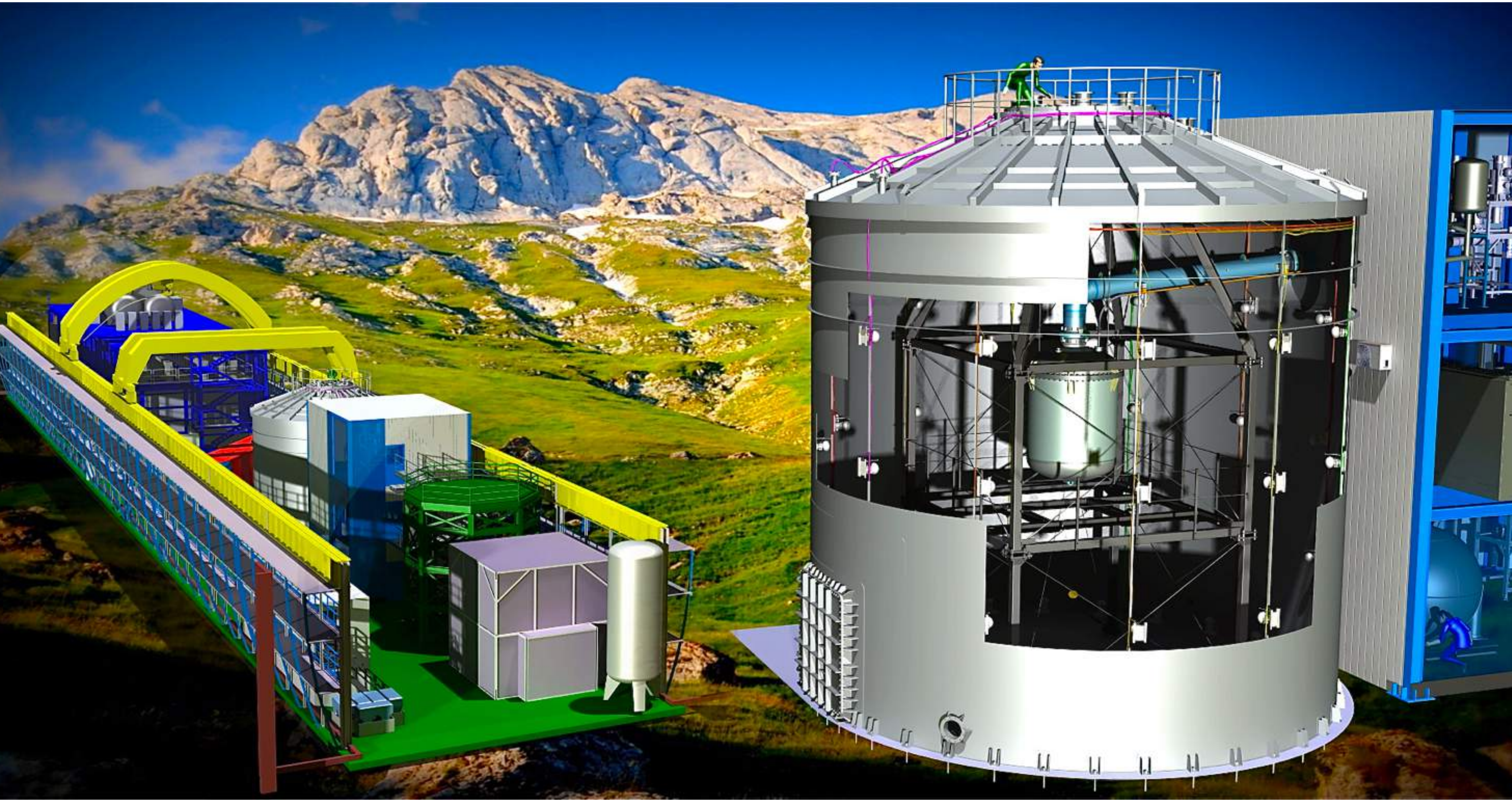
The phases of XENON

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

Impressive evolution of LXeTPCs



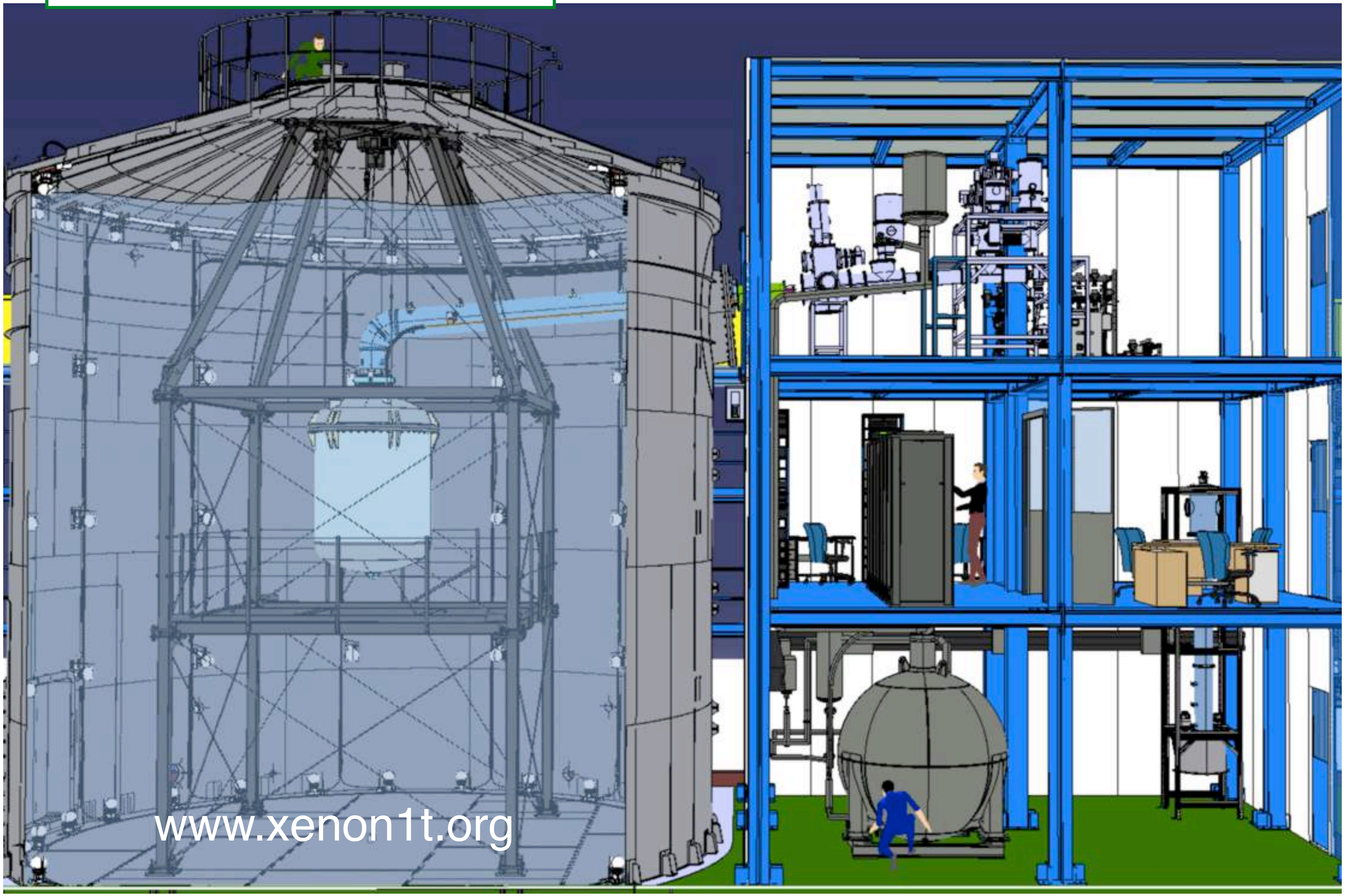
The XENON1T Experiment @ LNGS



The XENON1T Experiment @ LNGS

XENON1T: All Systems

**E. Aprile et al.,
"The XENON1T Dark Matter Experiment",
EPJ C 77, 881 (2017).**



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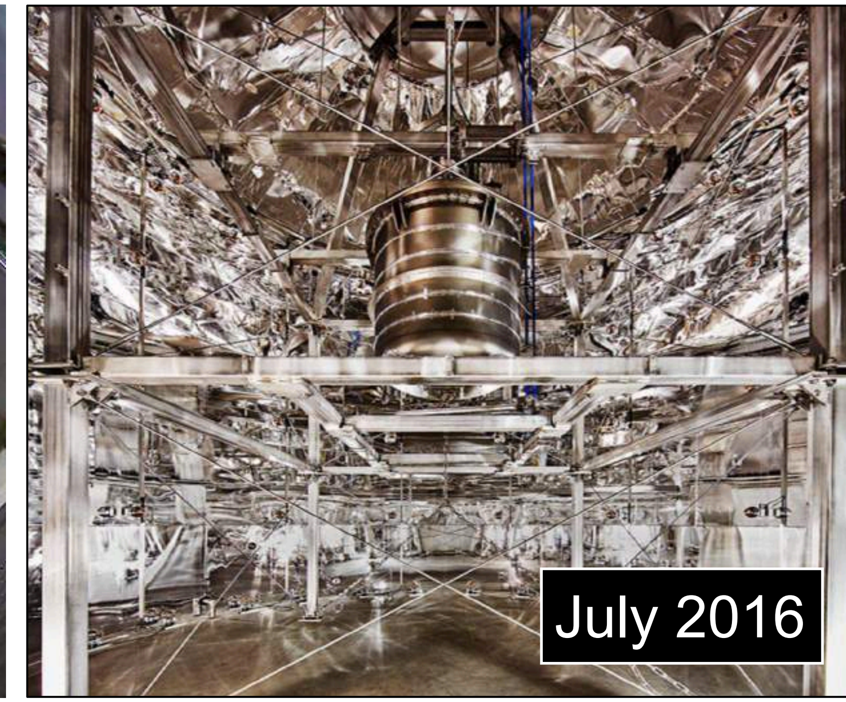
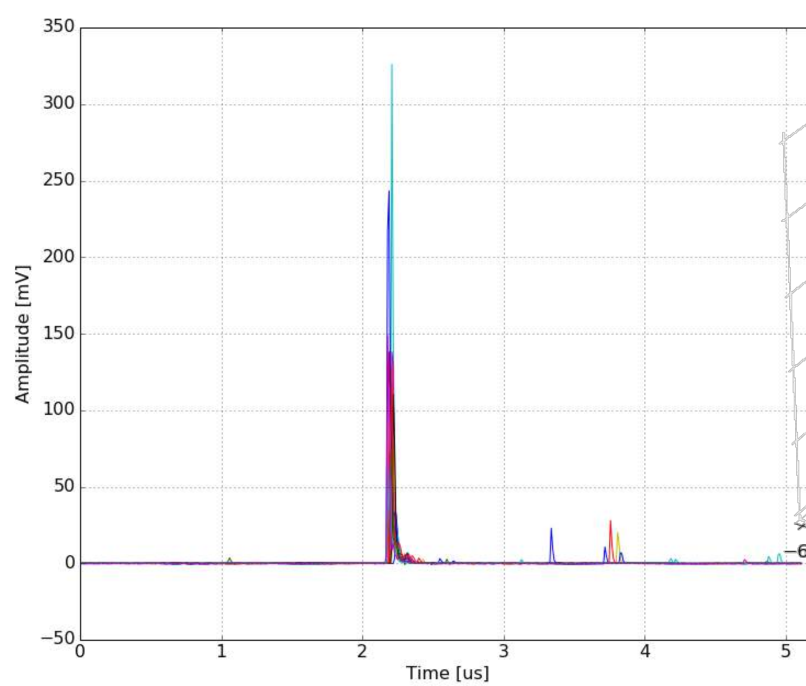
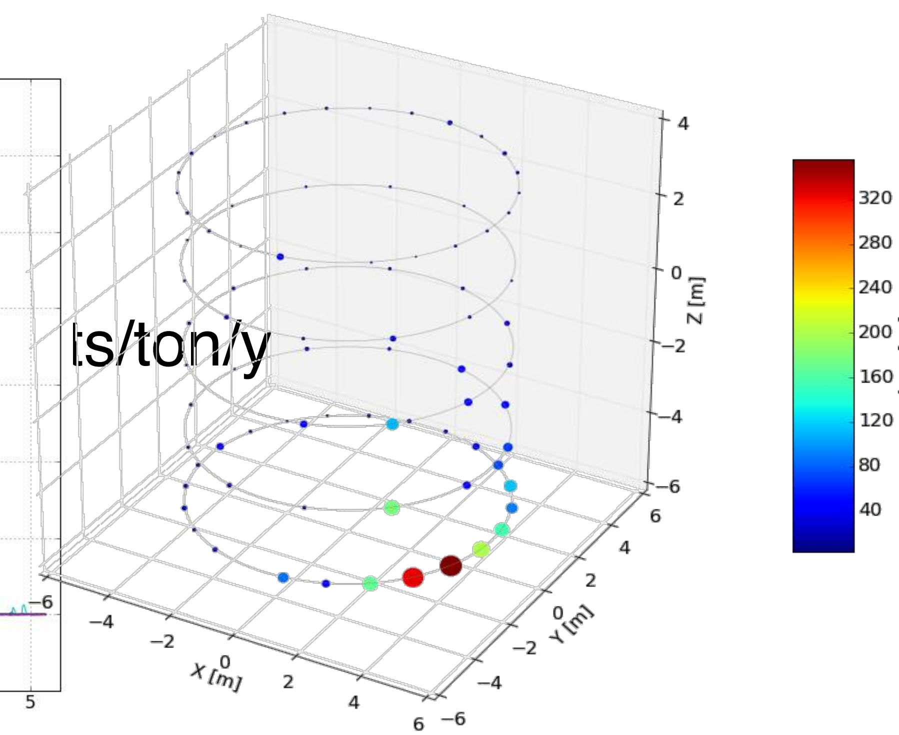
Water Cherenkov Muon Veto



- 700 ton pure water instrume
- Active shield against muons
- Trigger efficiency > 99.5% for mu
- Cosmogenic neutron backgroun ts/ton/y





JINST 9, 11007 (2014)

The XENON1T Time Projection Chamber

Understanding the Detector

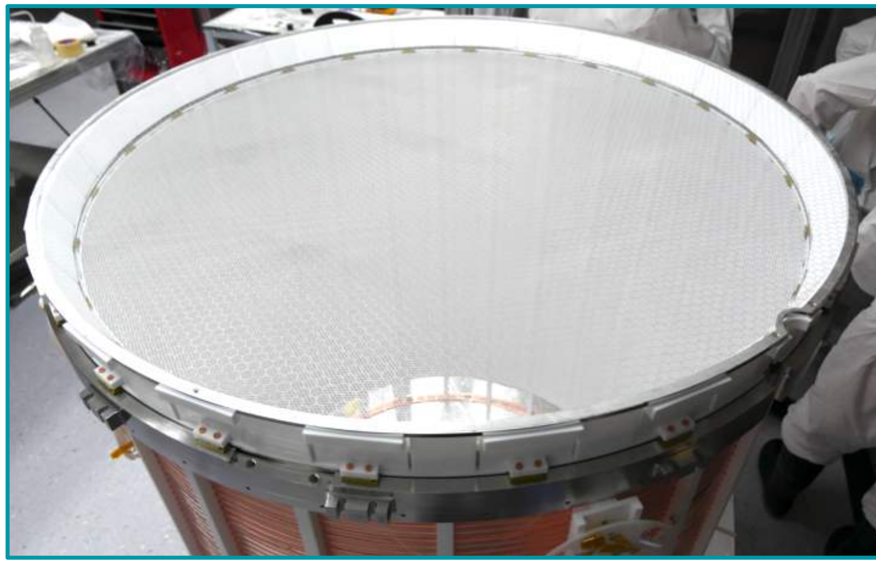
The XENON1T Light Detection System

- 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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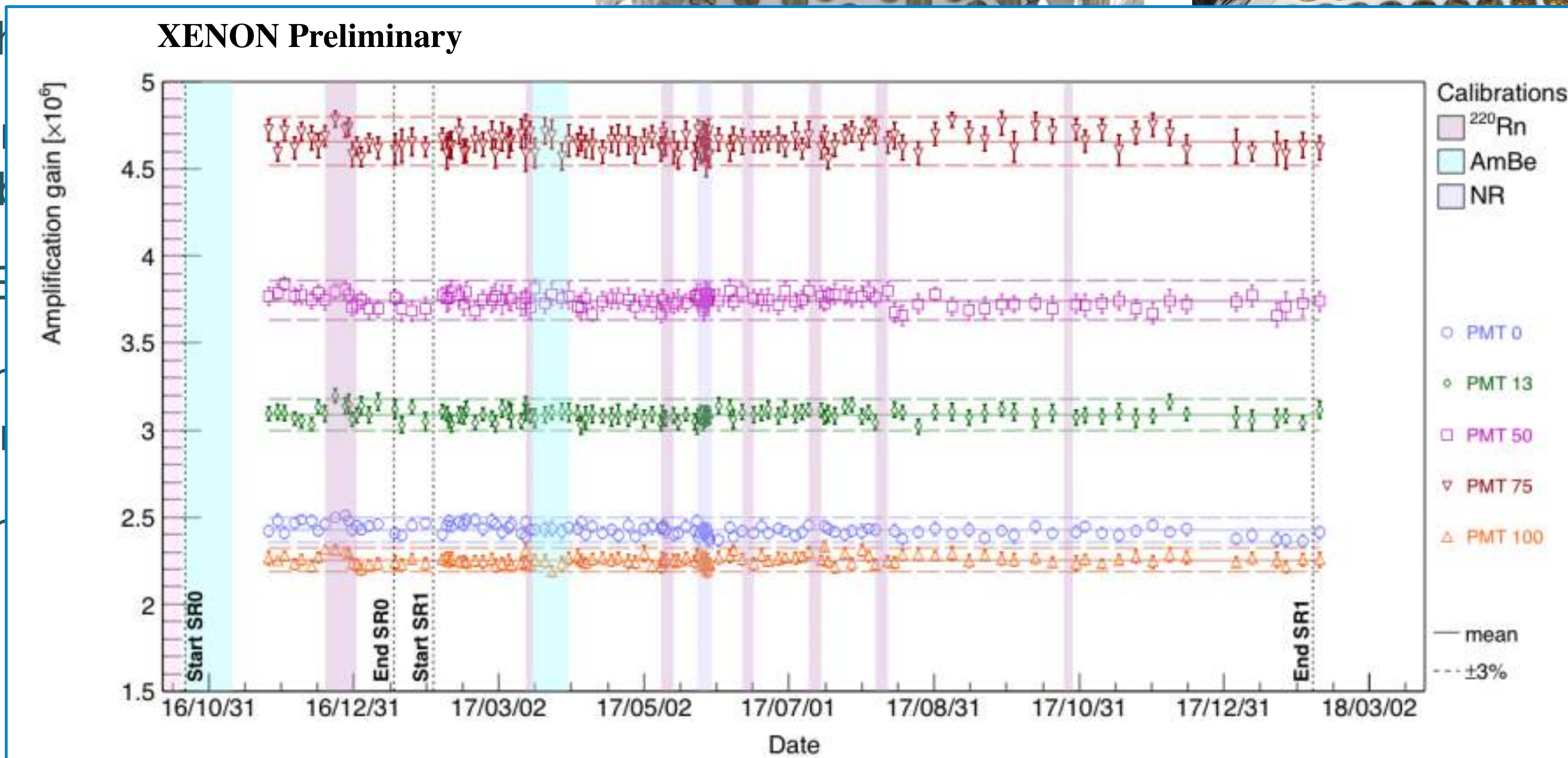
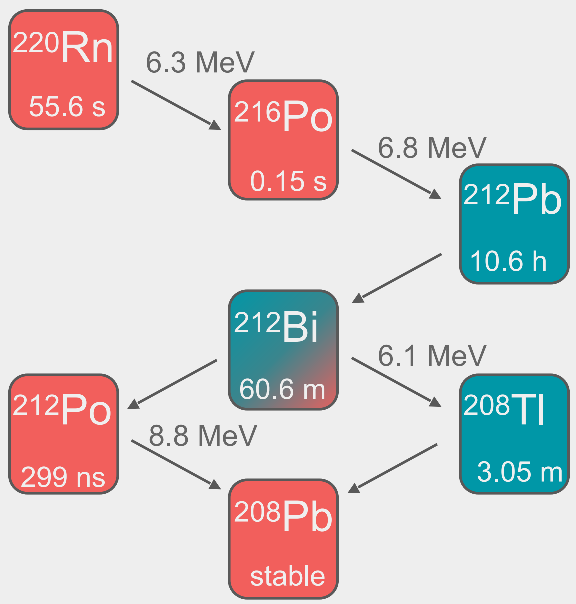
n array



Calibration Sources

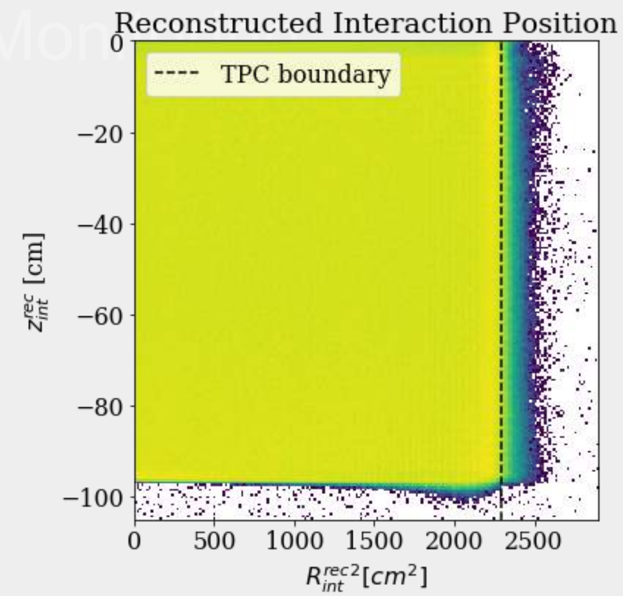
^{220}Rn: Low Energy ER



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

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

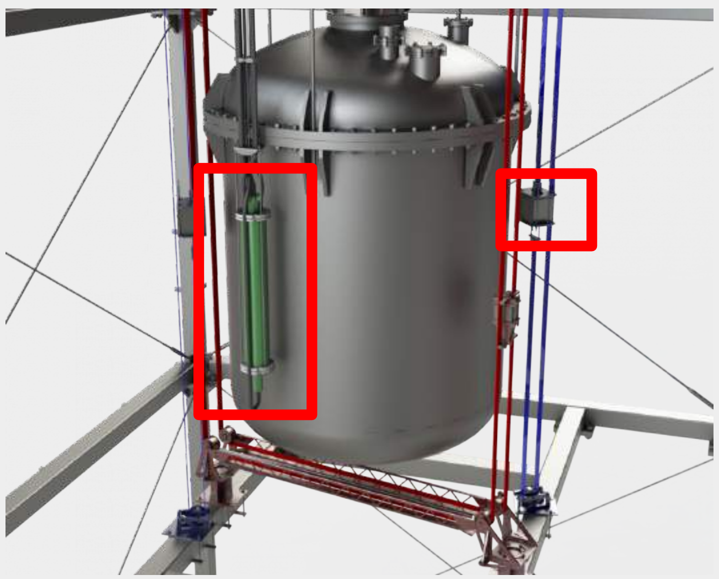
^{83m}Kr: Stability and Mon



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

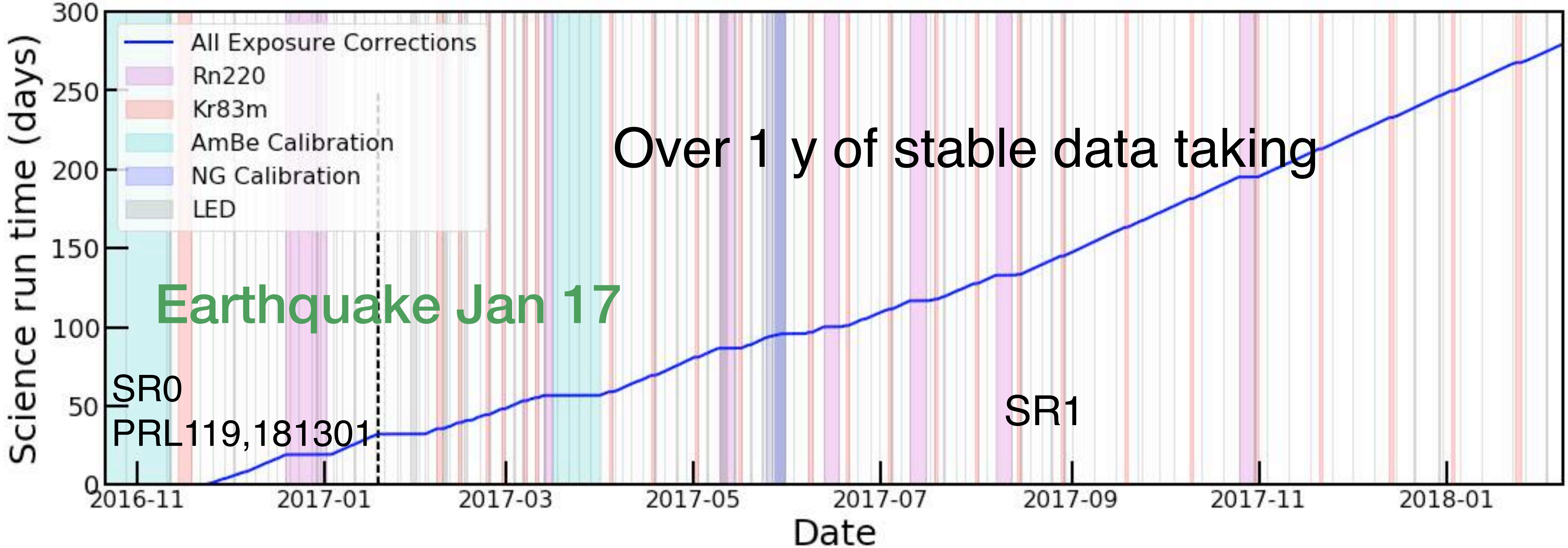
Neutrons: Signal Response



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

XENON1T: science and calibration data

- 279 days high quality data (livetime-corrected) spanning more than 1 year of stable detector's operation. The LXeTPC has been "cold" since Spring 2016
- 1 tonne x year exposure given 1.3 tonne fiducial volume: the largest reported to-date with this type of detector
- Experiment still running smoothly and collecting more data



Data Analysis: overview

XENON1T (real waveforms)

Geant4 + waveform simulation

Raw data Processor (PAX)

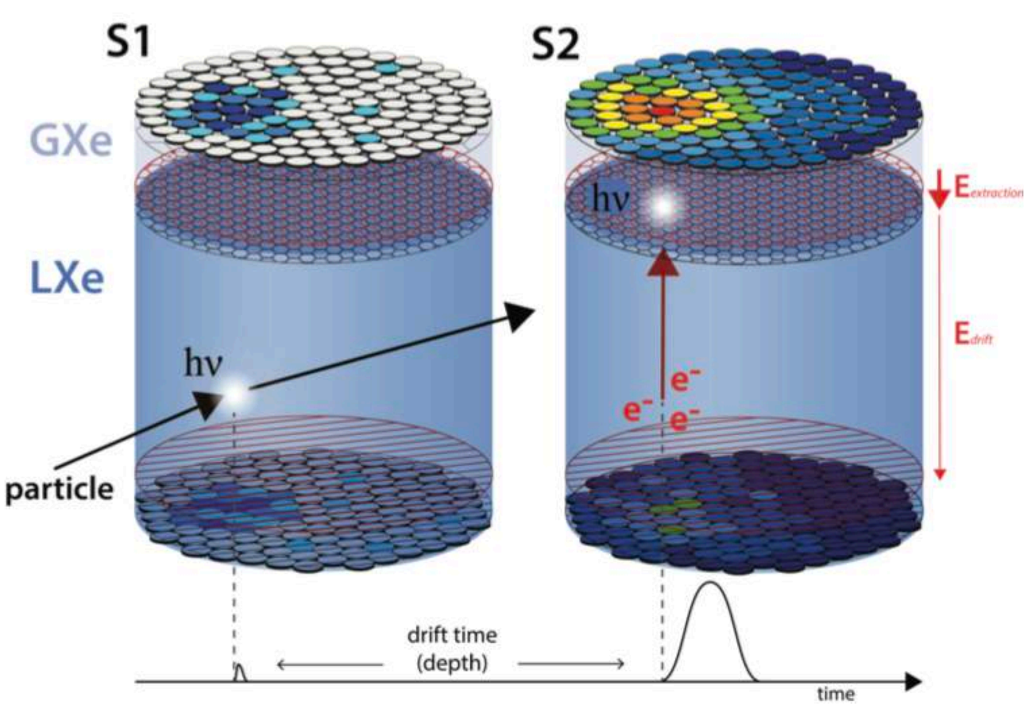
- peak-finding
- S1, S2 identification
- Interactions Reconstruction
  - position
  - energy
  - interaction type
  - …

Detector Calibration

Background Modeling

Statistical Interpretation

Physics Results



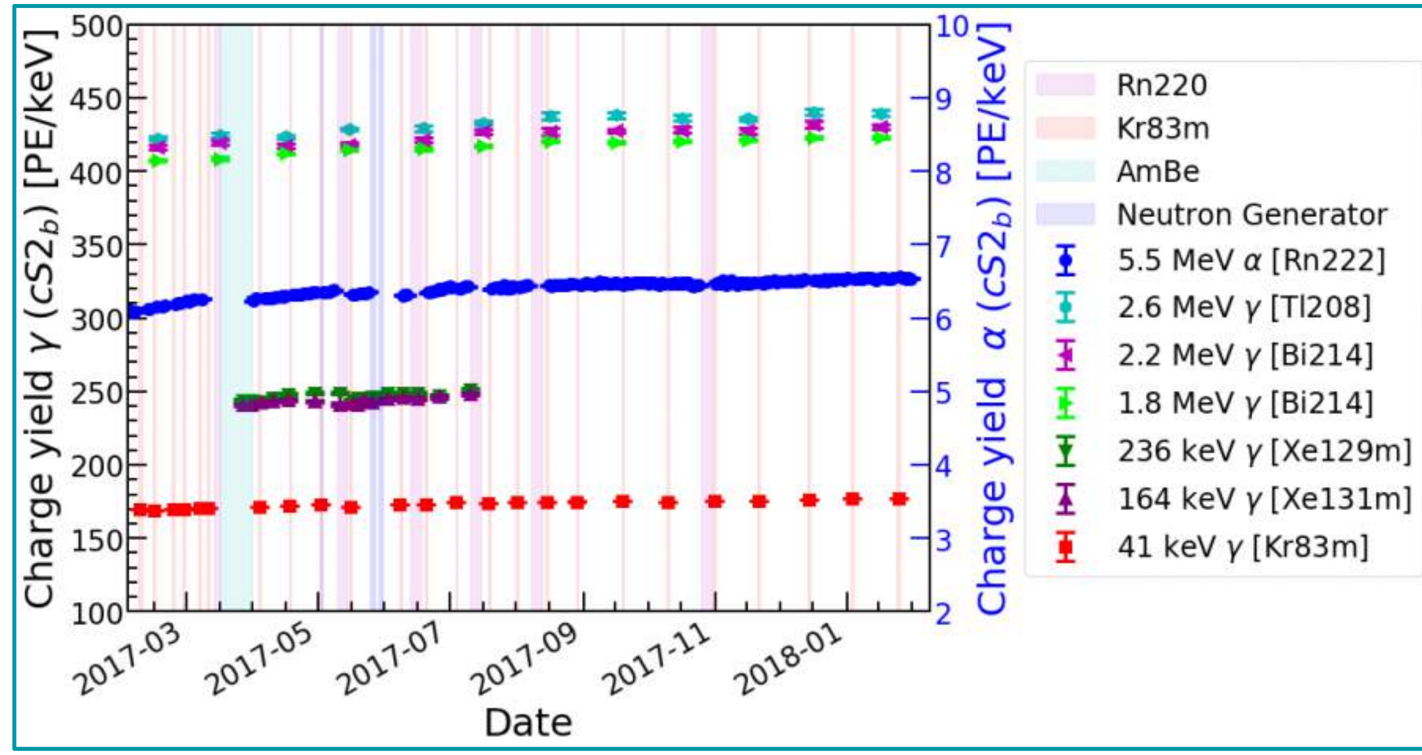
P A X

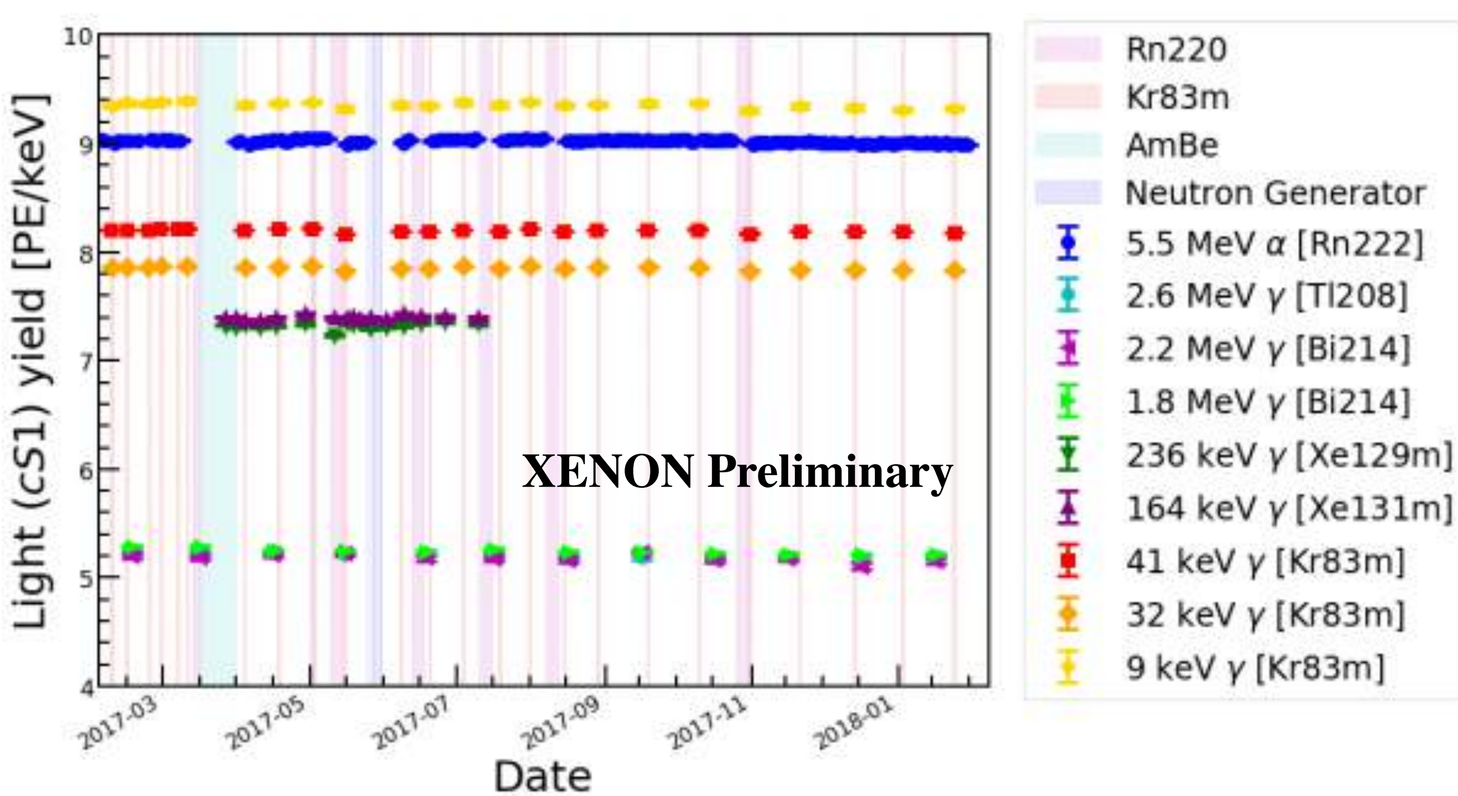
Processor for Analyzing XENON

Developed by the XENON collaboration **Publicly available to the community**
https://github.com/XENON1T/pax

Light and Charge Signals Stability

Position dependence of light (solid angle) and charge (attenuation length) signals very well understood through measurement with ^{83m}Kr, ^{222}Rn alphas. Excellent agreement with optical Monte Carlo simulations and with model of purity evolution

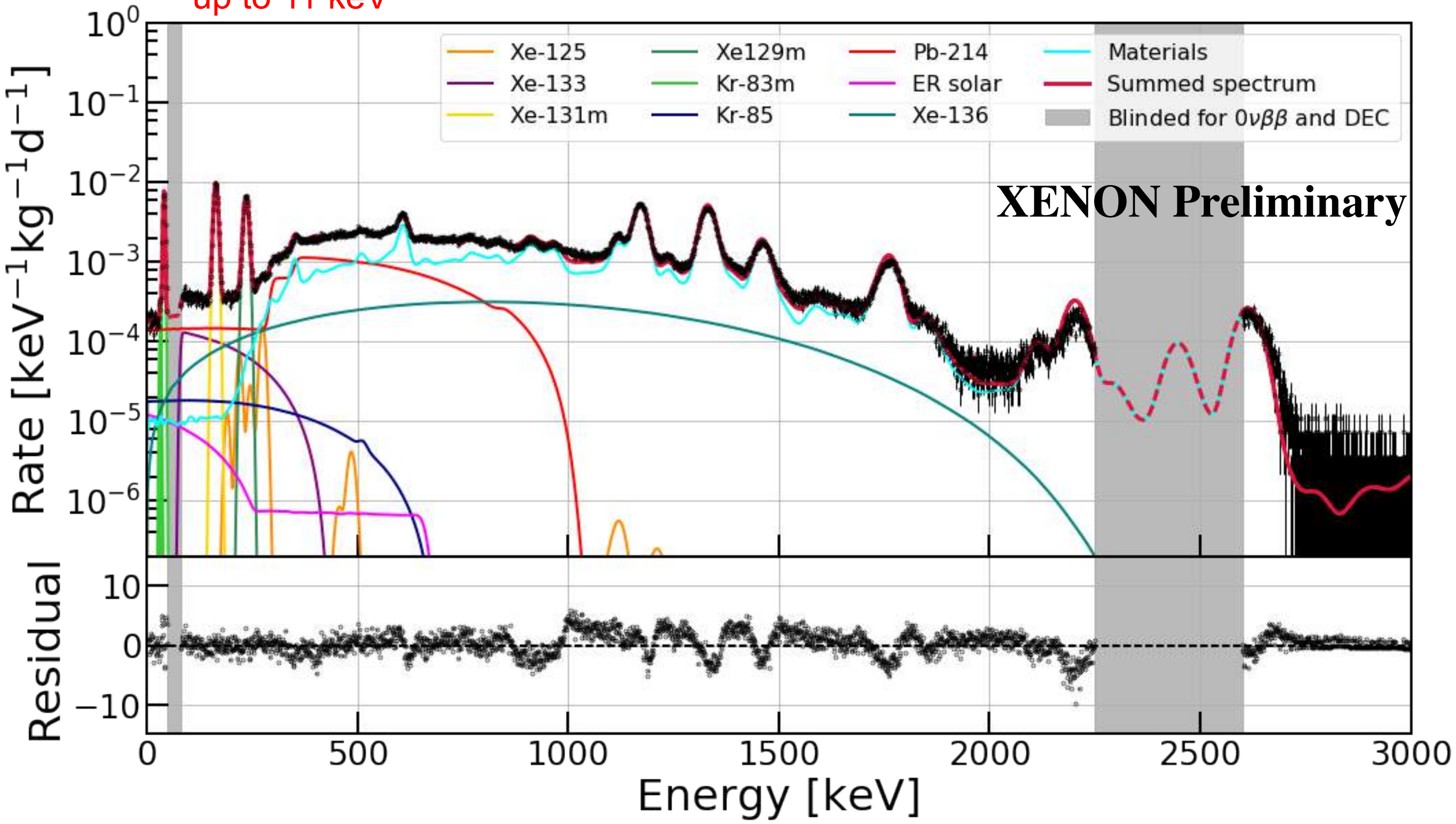




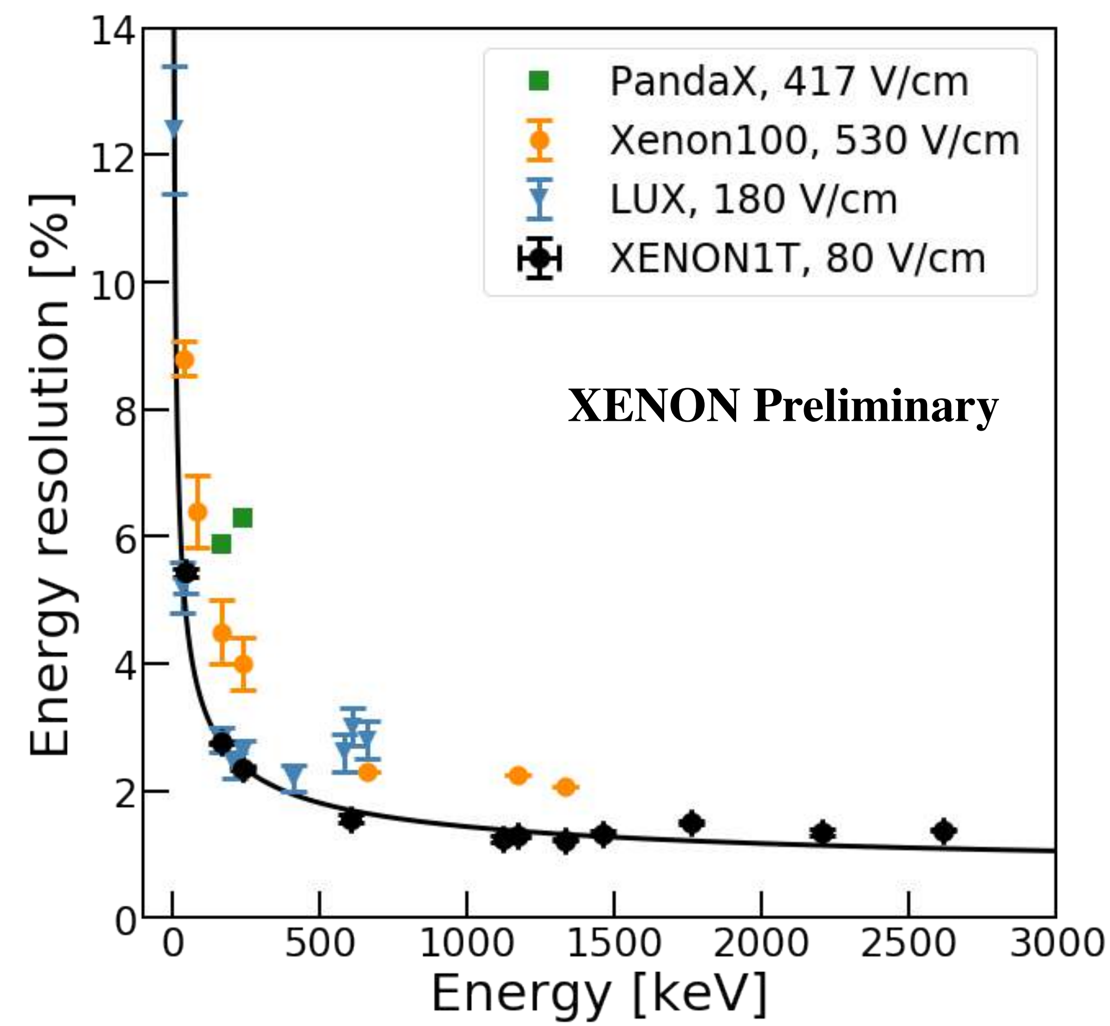
Light and charge yield stability monitored with several sources:

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

Energy Resolution

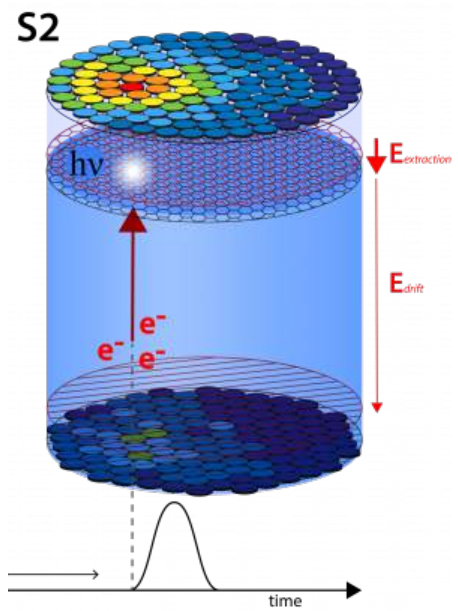


- Energy reconstructed from anti correlated S1 and S2. Excellent linearity from keV to MeV
- Best energy resolution measured with this large LXeTPC ~1.6% resolution (sigma) at 2.5 MeV



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

Position Reconstruction

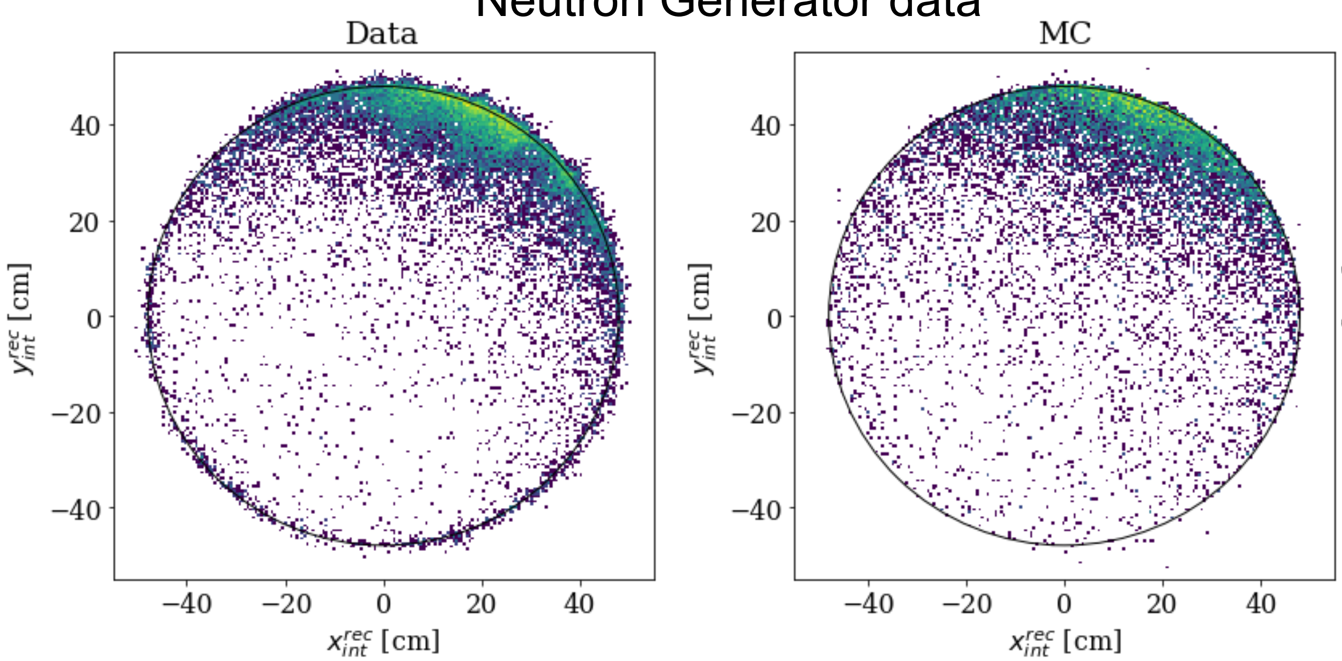


X-Y reconstruction via **neural network**:
- **Input:** charge/channel top array
- **Training:** Monte Carlo simulation

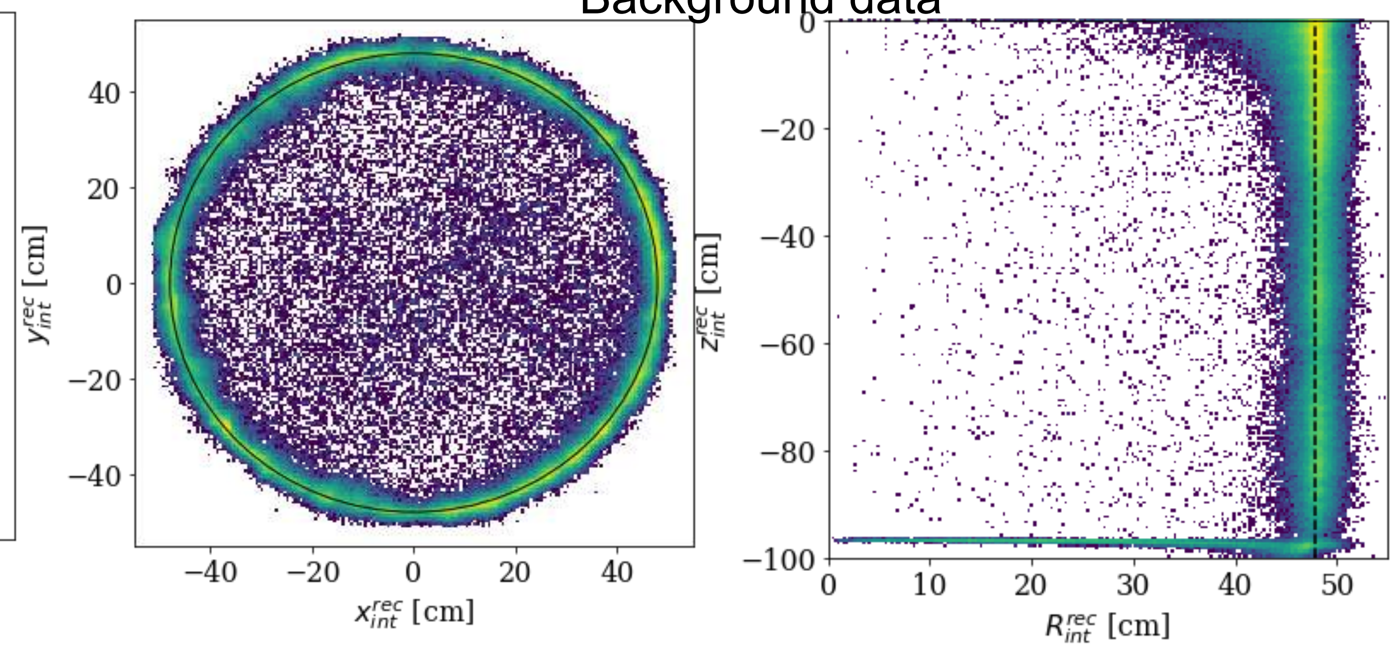
Position resolution using ^{83m}Kr
- Two interactions (9, 31 keV), same x-y
- Position resolution (1-2 cm)
- PMT diameter (7.62 cm)

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

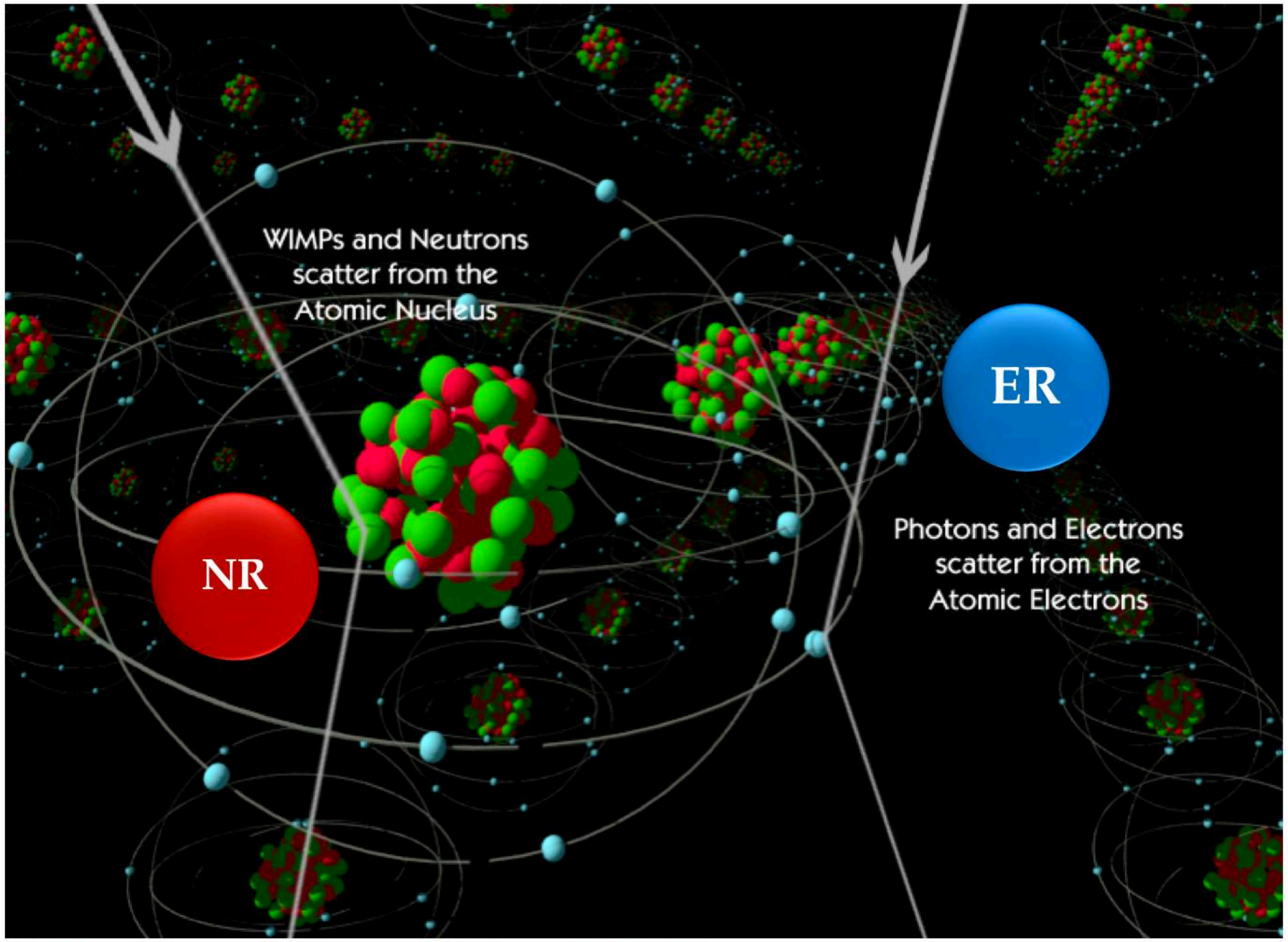


Background data



Understanding the Backgrounds

ER and NR Backgrounds



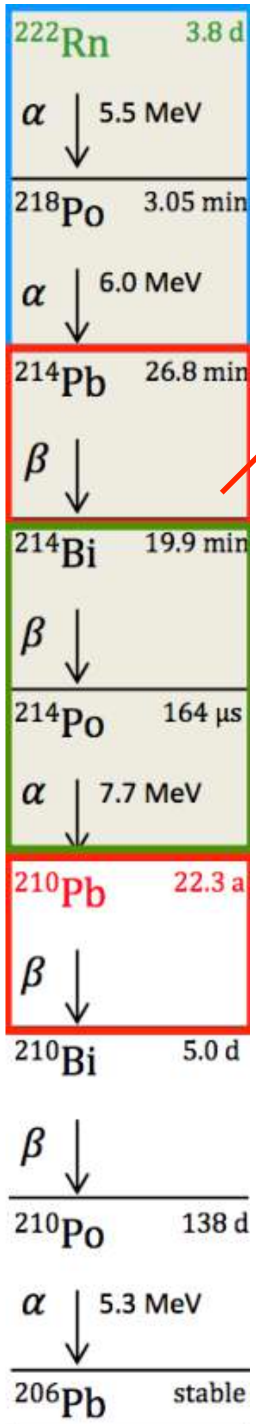
Electron recoils (ER):

- low energy Compton scatters from the radioactive contaminants in the detector components: U and Th chains, ^{40}K, ^{60}Co, ^{137}Cs.
- Intrinsic contaminants: β decays of ^{222}Rn daughters, ^{85}Kr, ^{136}Xe.
- Elastic scattering of solar neutrinos off electrons.

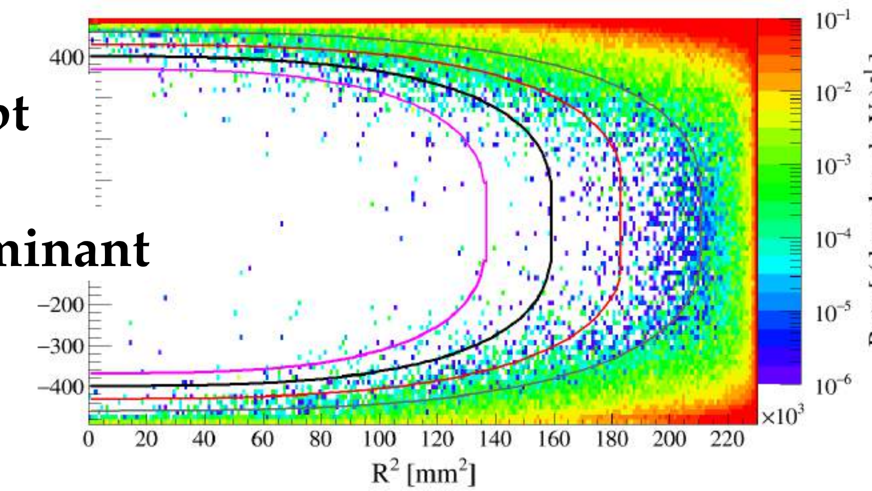
Nuclear Recoils (NR):

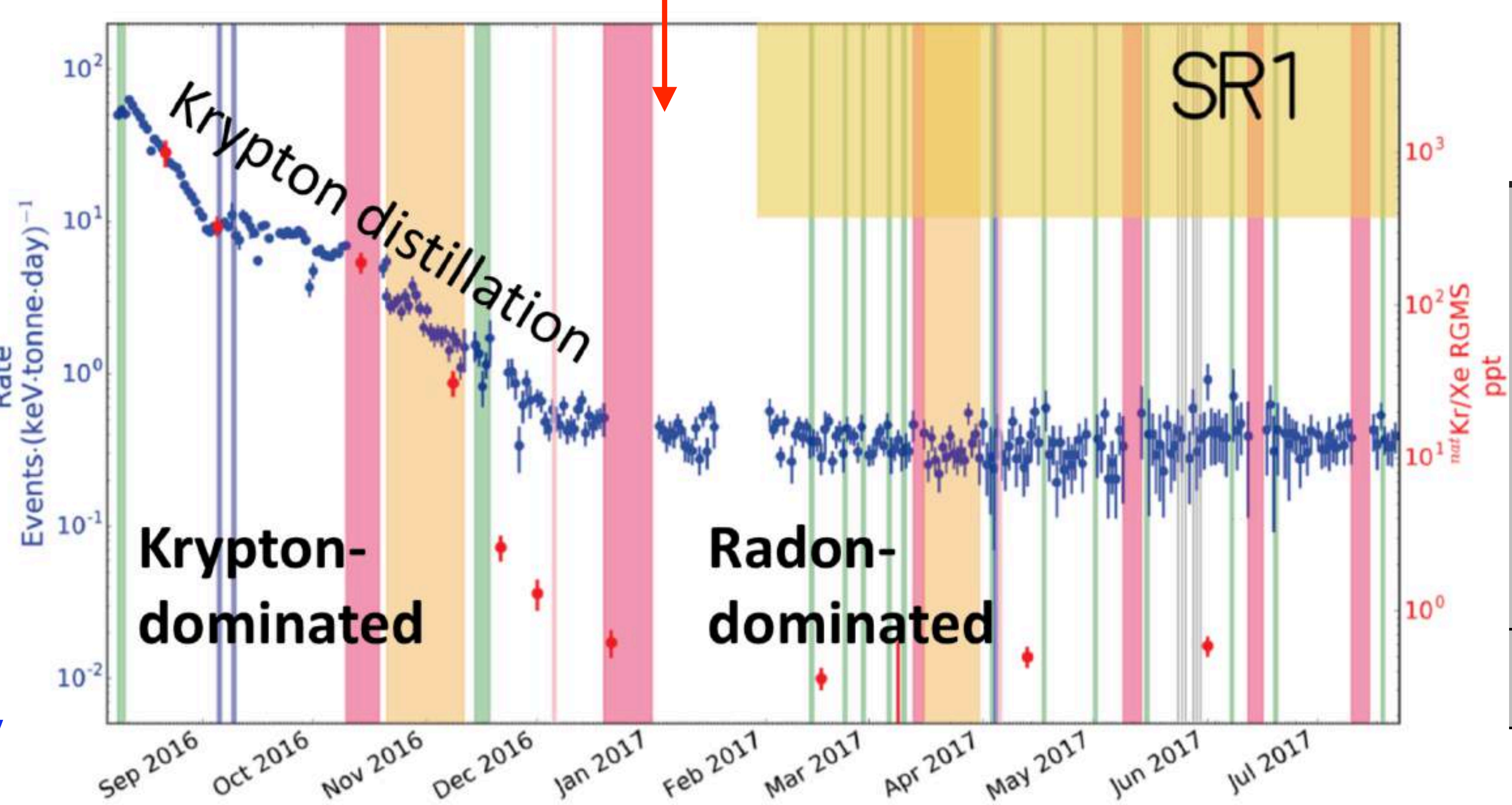
- Radiogenic neutrons: spontaneous fission and (α, n) reaction from the U and Th chains in the detector components.
- Muon-induced neutrons.
- Coherent scattering of neutrinos (mostly solar) off the Xe nuclei.

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 to 0.66 ppt**
- **Materials radioactivity (HPGe gamma screening): subdominant**

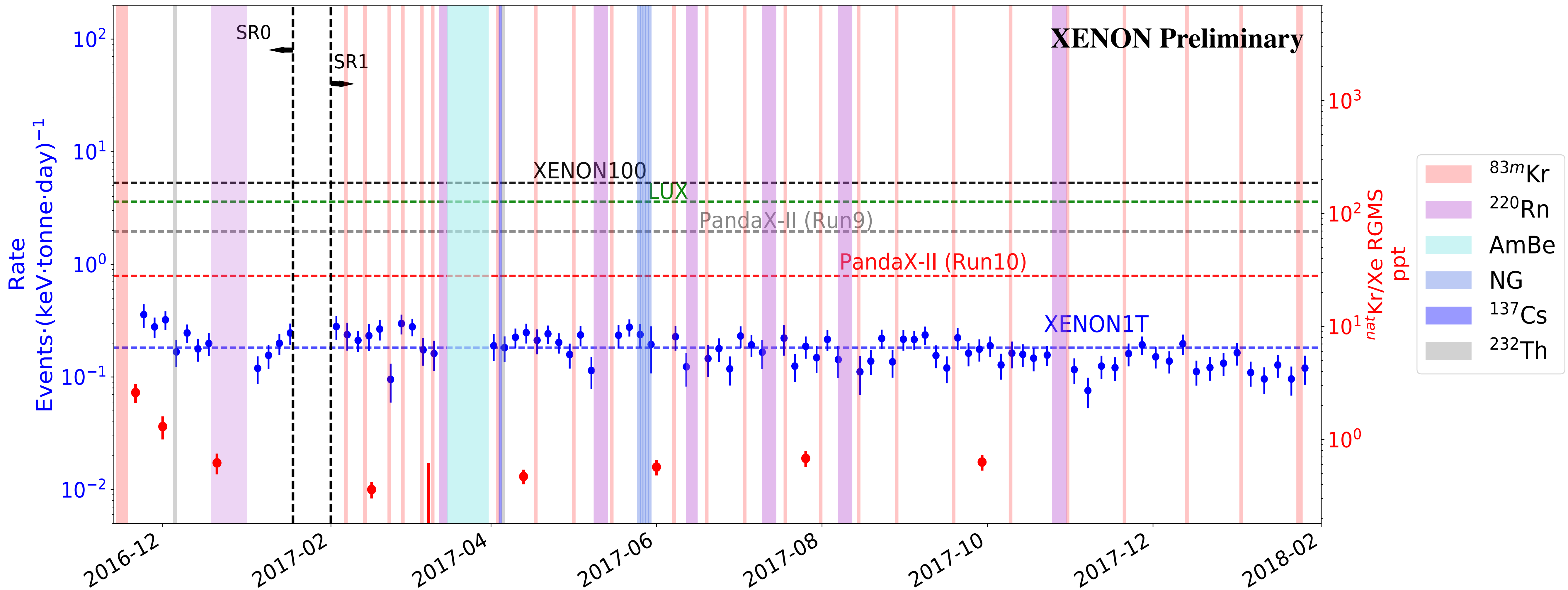




Source	Rate [t^{-1} y^{-1}]	Fraction [%]
222Rn	620 ± 60	85,4
85Kr	31 ± 6	4,3
Solar ν	36 ± 1	4,9
Materials	30 ± 3	4,1
136Xe	9 ± 1	1,4
Total	720 ± 60	

Successfully distilled Kr to ~0.66 ppt

ER Background Evolution



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

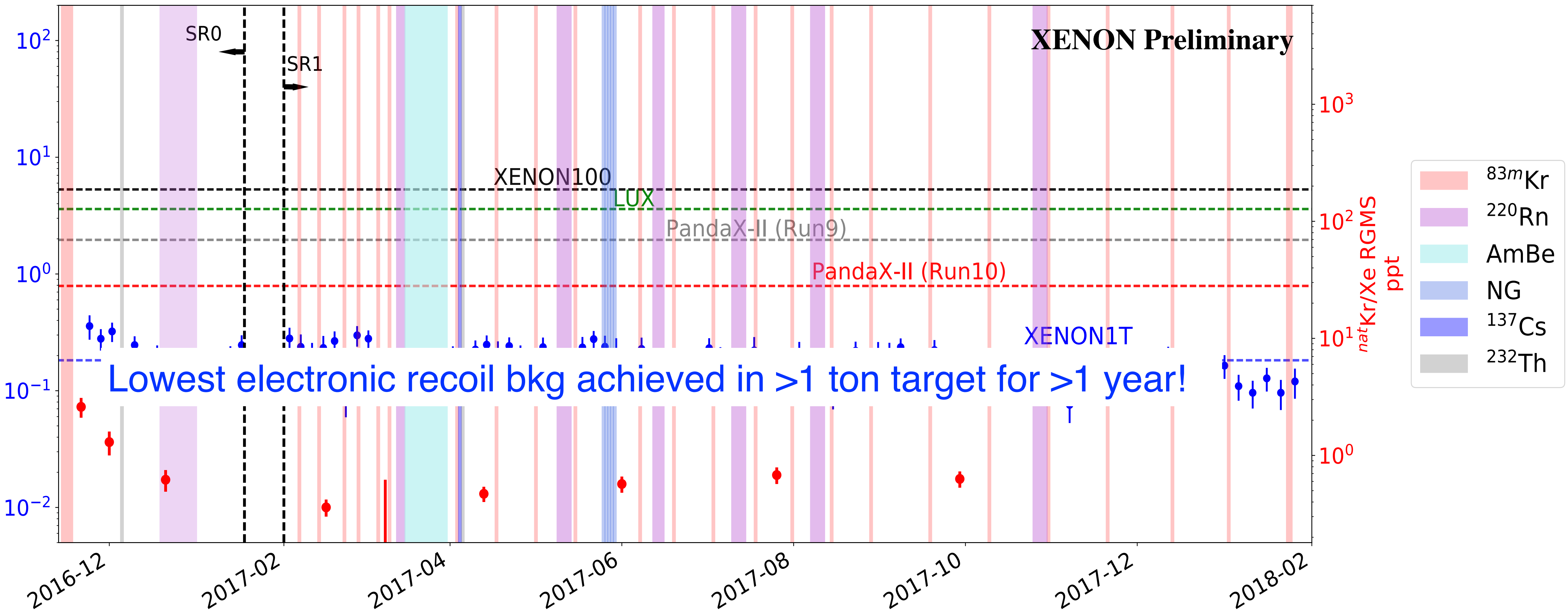
(75 ± 6) events / (ton·year·keV)

Measured:

(82 $^{+5}_{-3}$ (syst.) ± 3 (stat)) events / (ton·year·keV)

Lowest ER background ever achieved in a DM detector !

ER Background Evolution



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Nuclear Recoil Backgrounds

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

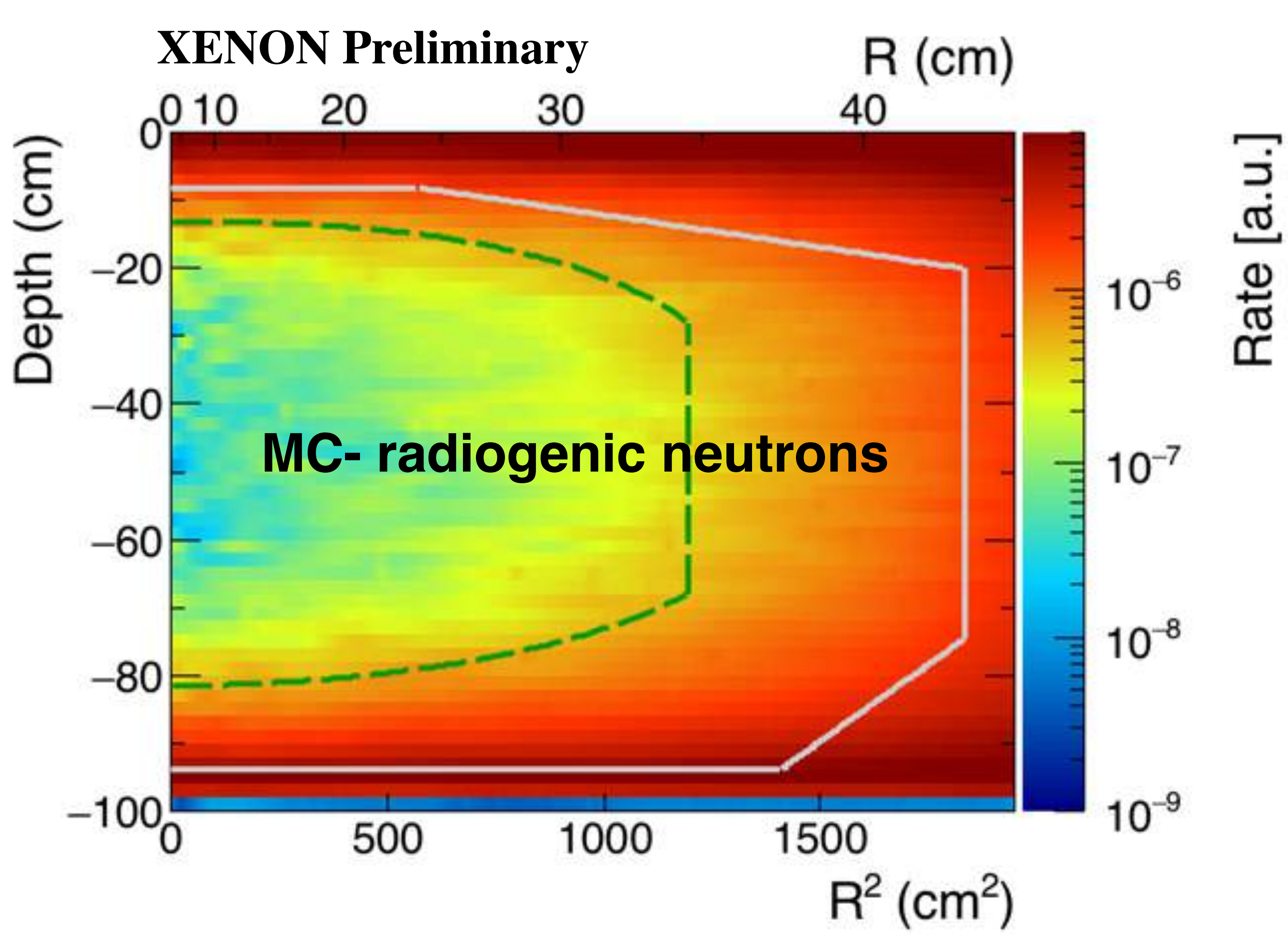
Coherent elastic ν-nucleus scattering, constrained by ^{8}B neutrino flux and measurements, is an an irreducible background at very low energy (1 keV)

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
CEνNS	0,012	2,0
Cosmogenic n	< 0.01	< 2.0

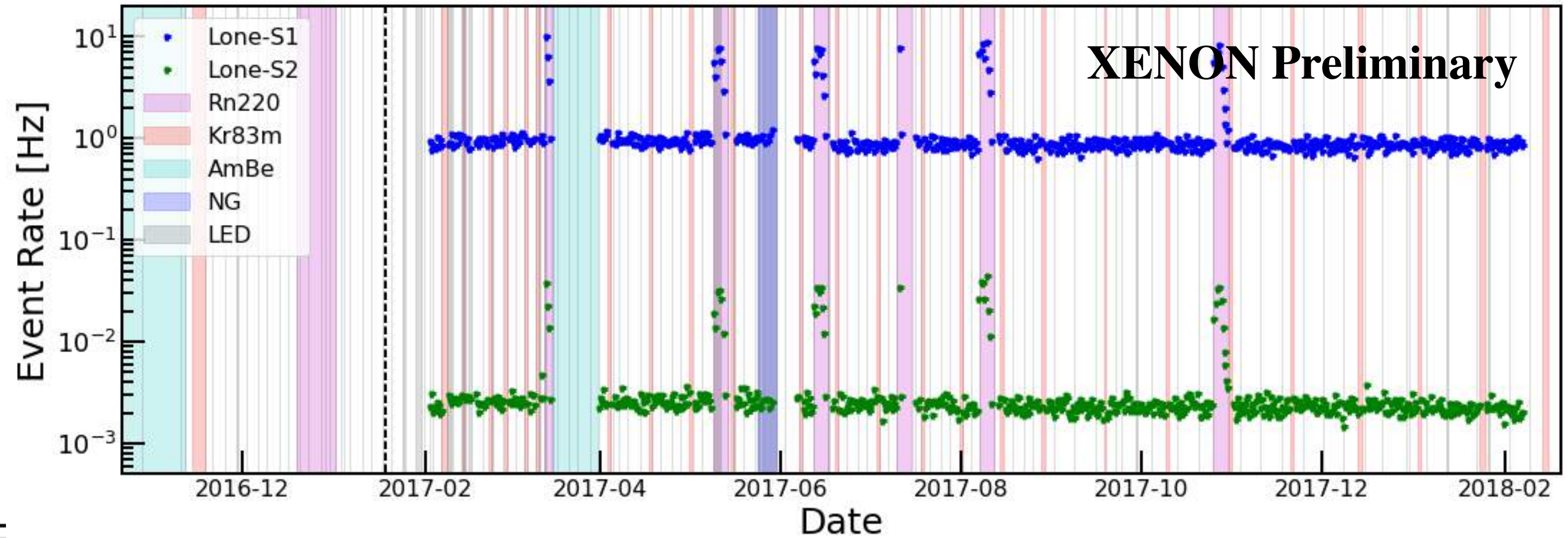
(Expectations in 4-50 keV search window, 1t FV, single scatters)

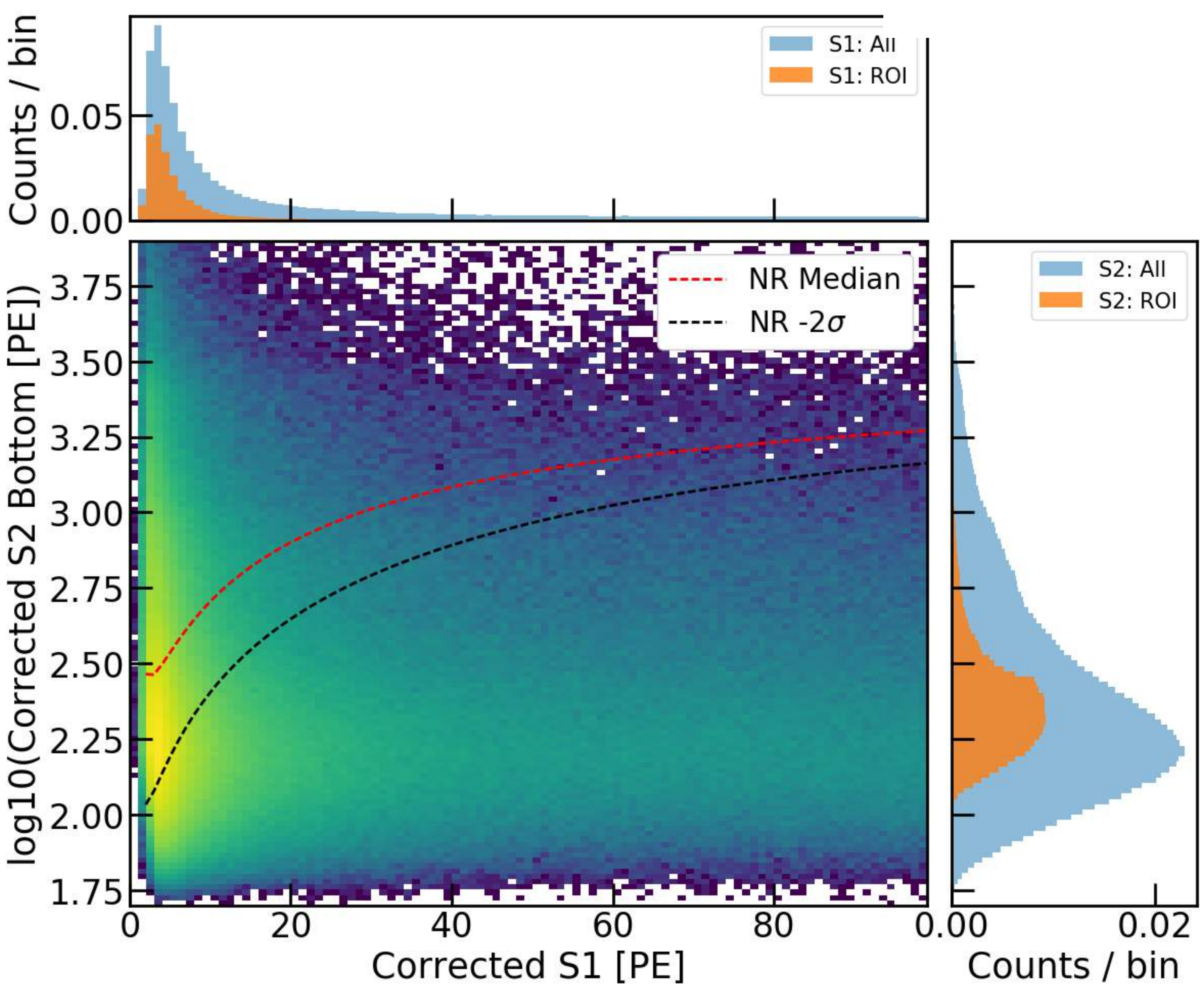
JCAP04 (2016) 027



Accidental Coincidence 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



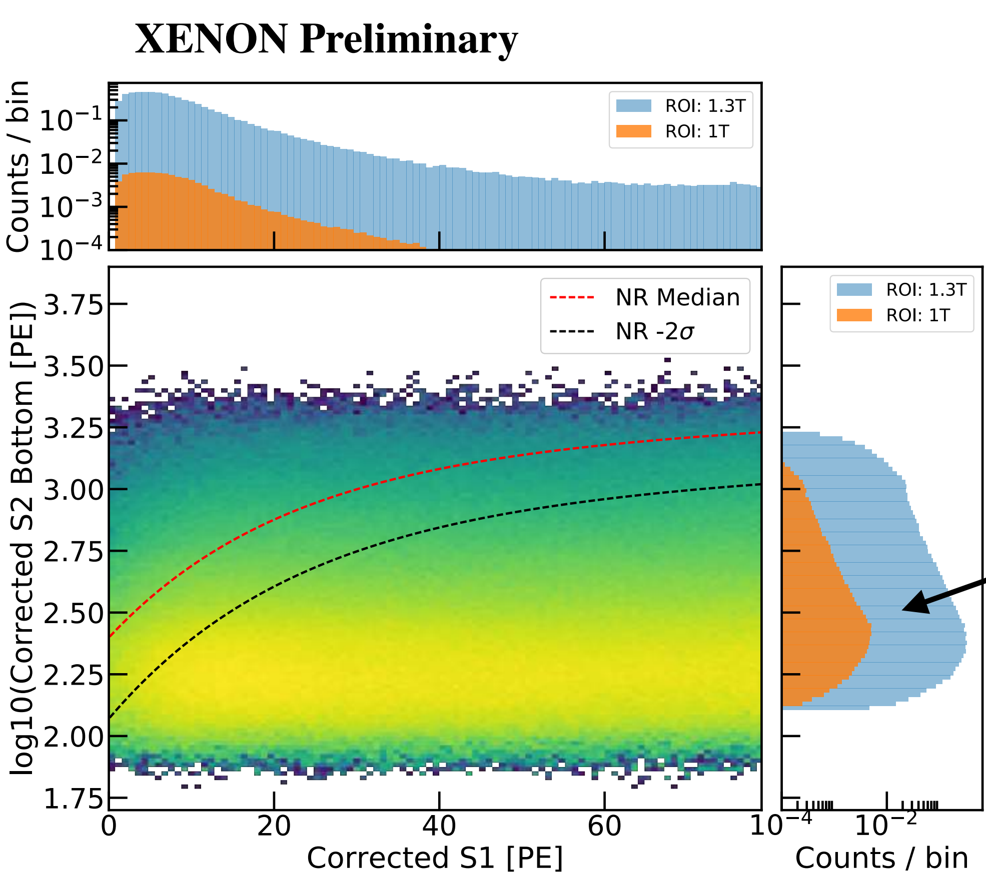


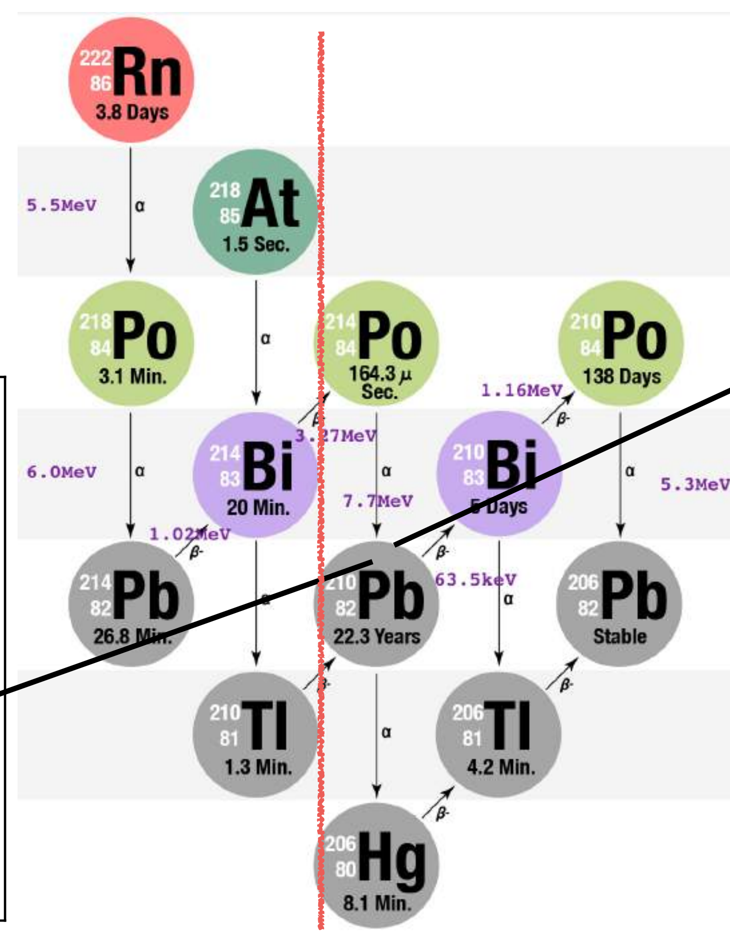
Empirical model shows an overall small rate in the ROI for NRs

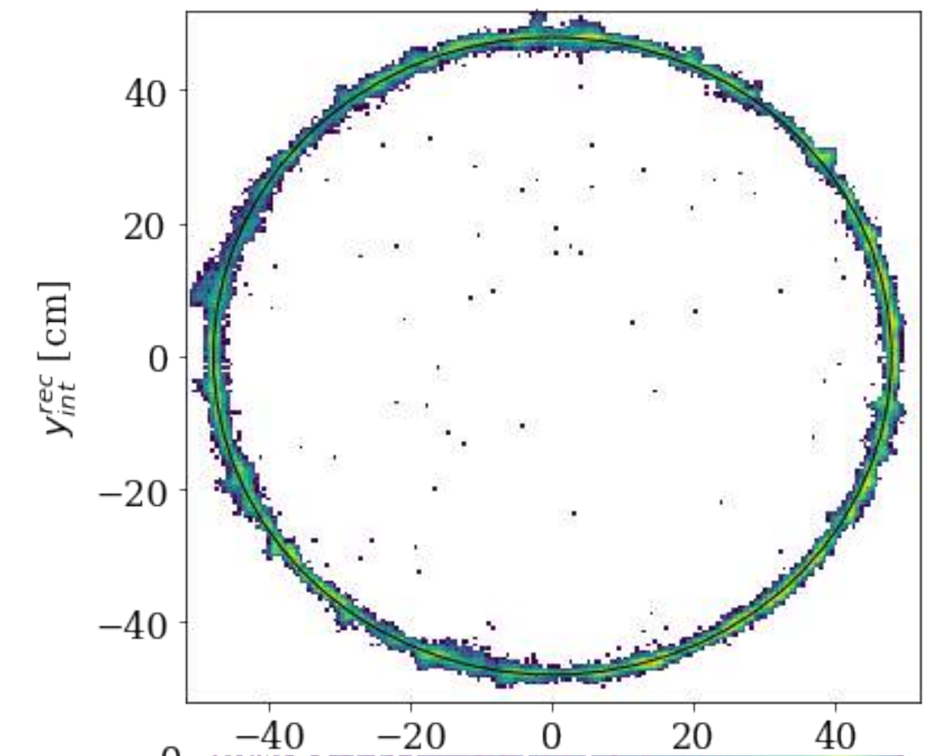
- Select unpaired S1/S2 from data
- Randomly pair to form events
- Apply selection conditions from analysis
- Performance verified with ^{220}Rn data and background sidebands

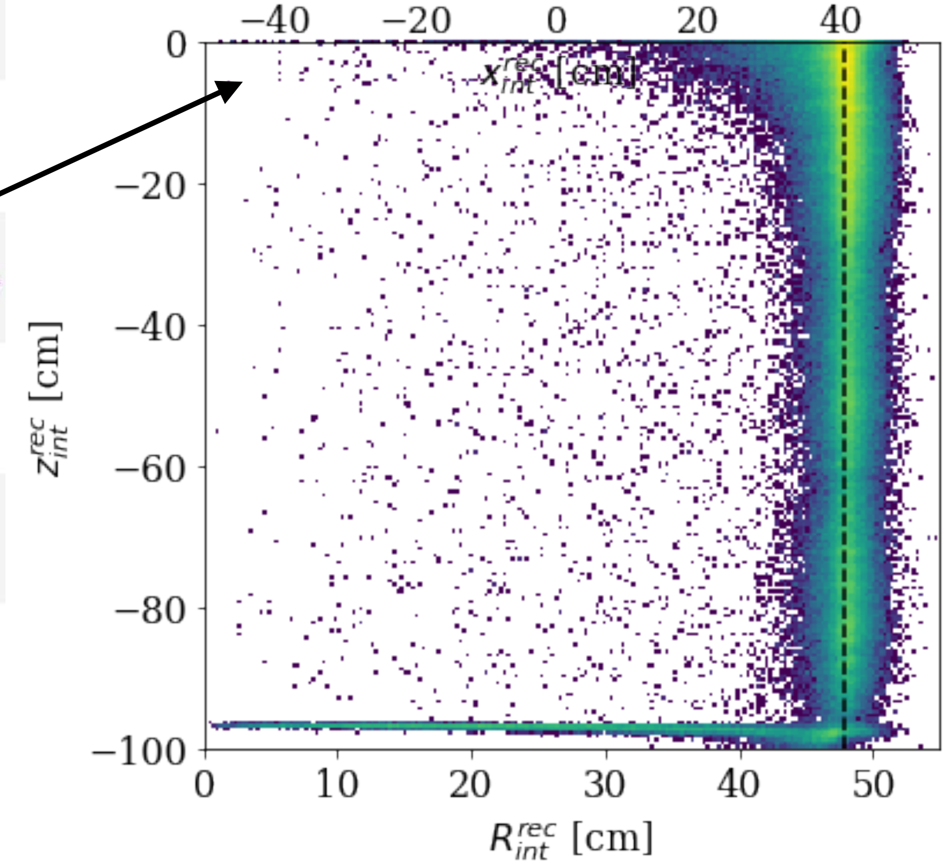
Surface Background

- Pb210 and Po210 plate-out on PTFE surface produce events with reduced S2 -> can be mis-reconstructed into NR signal region
- Suppressed by fiducialization of volume
- Data-driven model derived from surface event control samples









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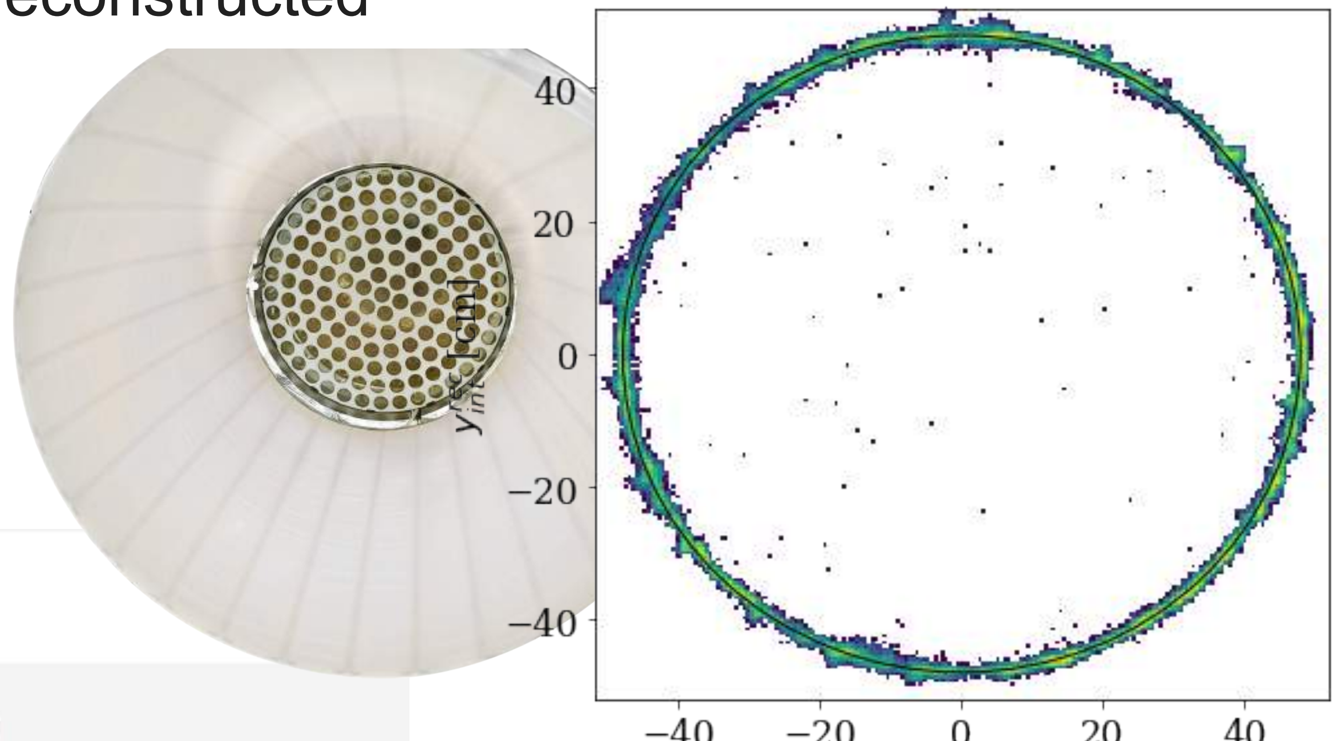
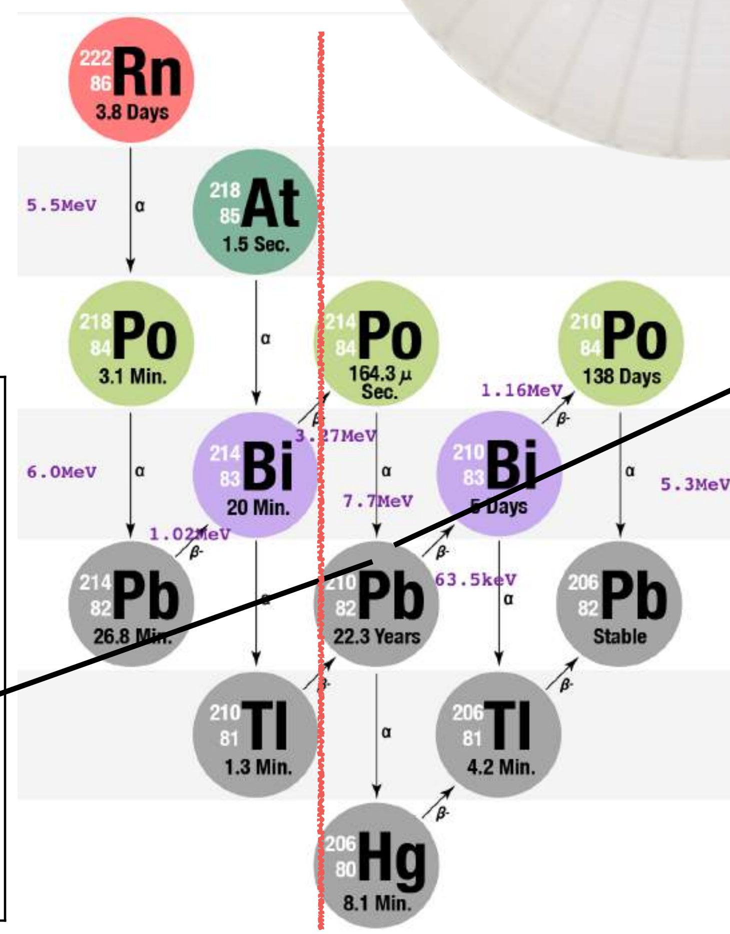
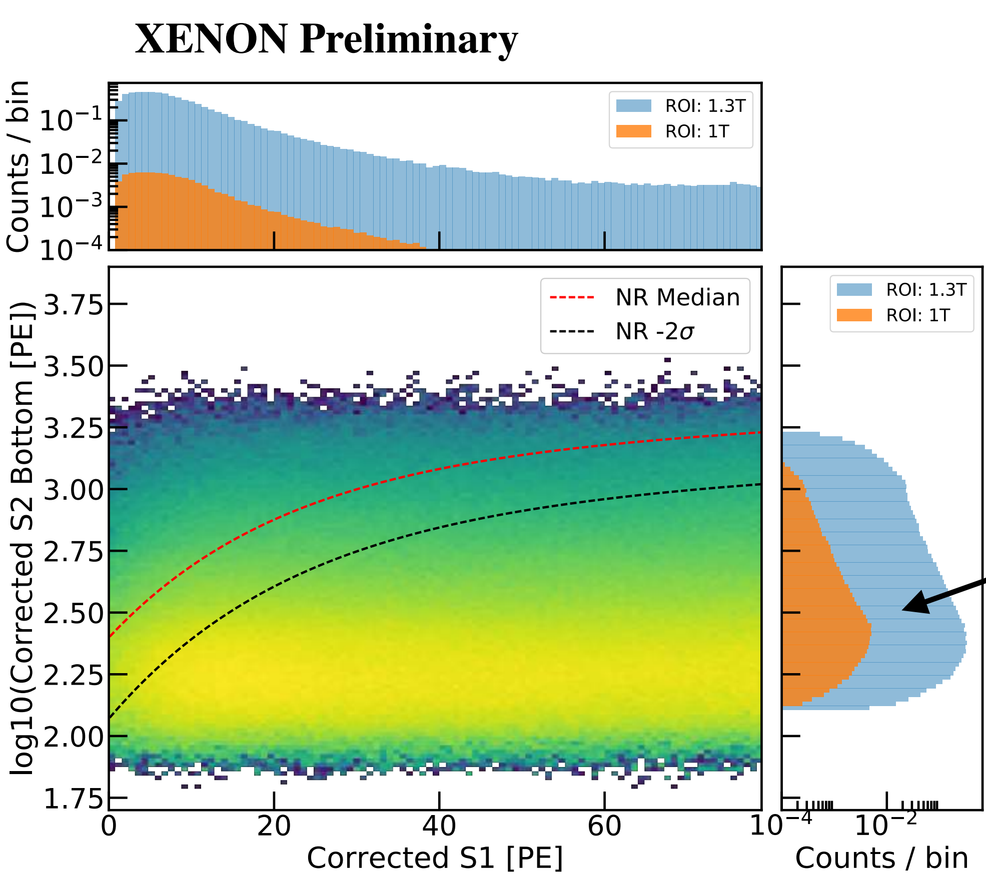
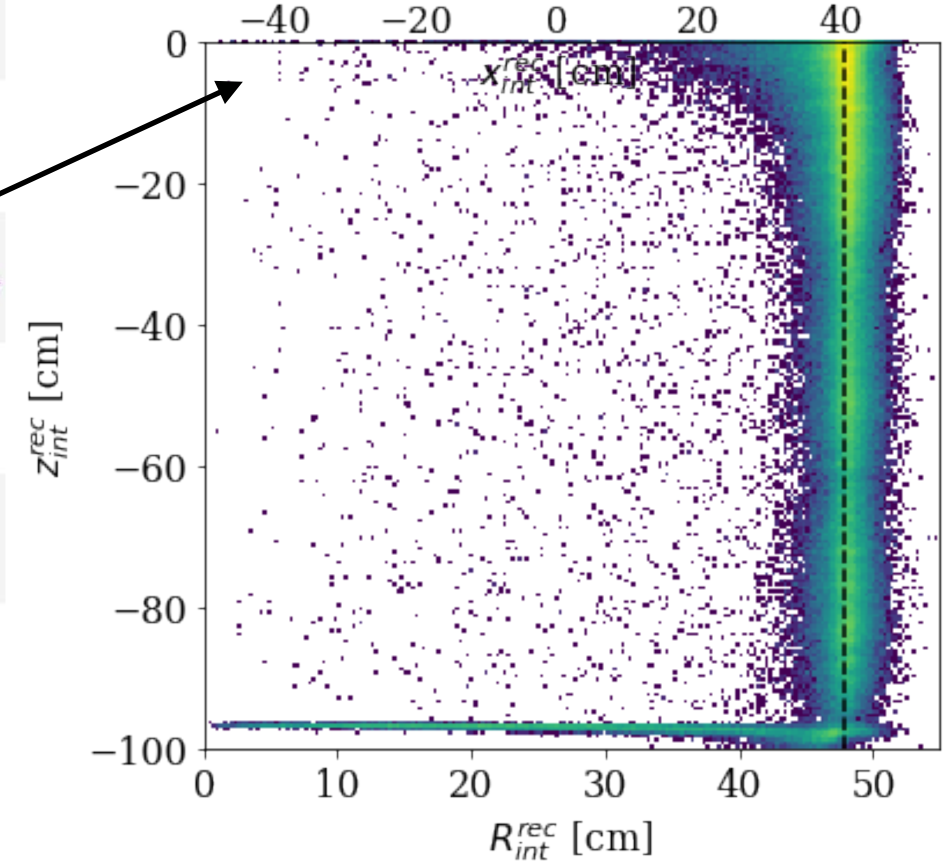


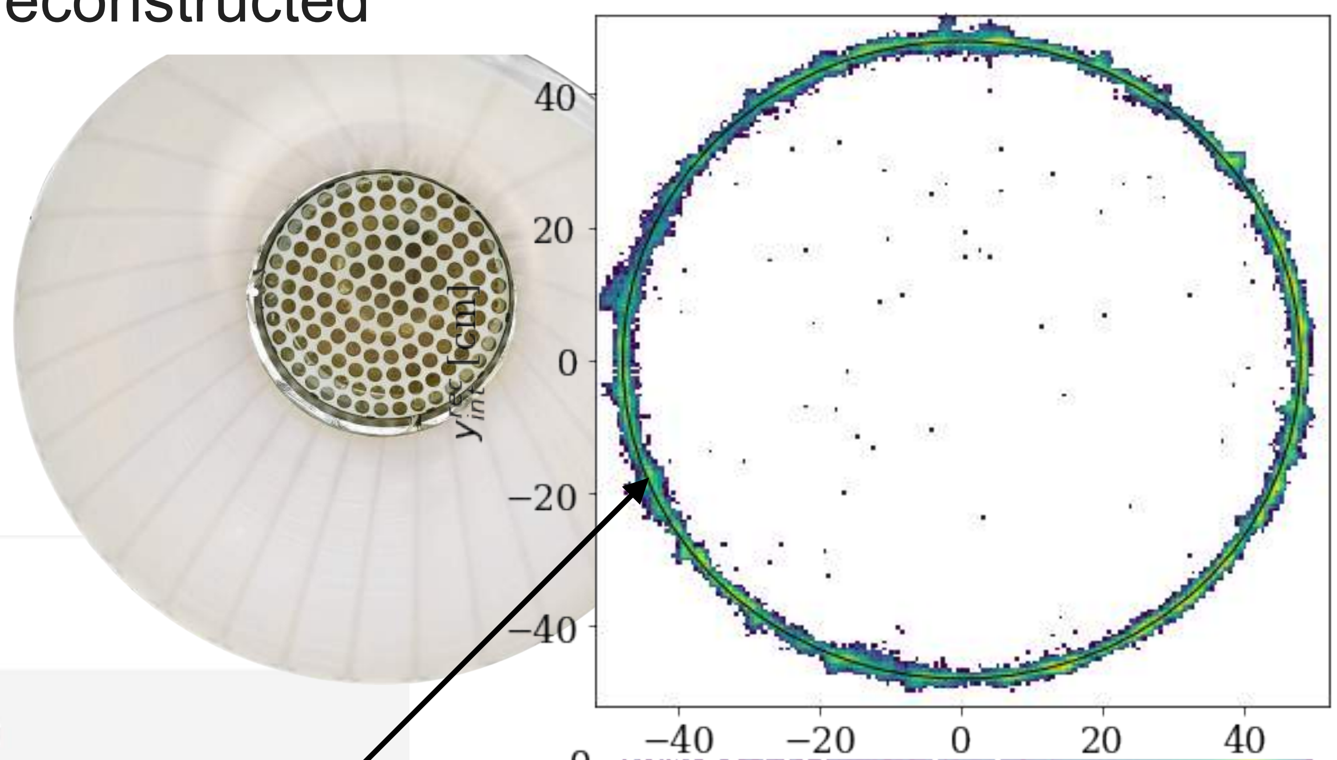


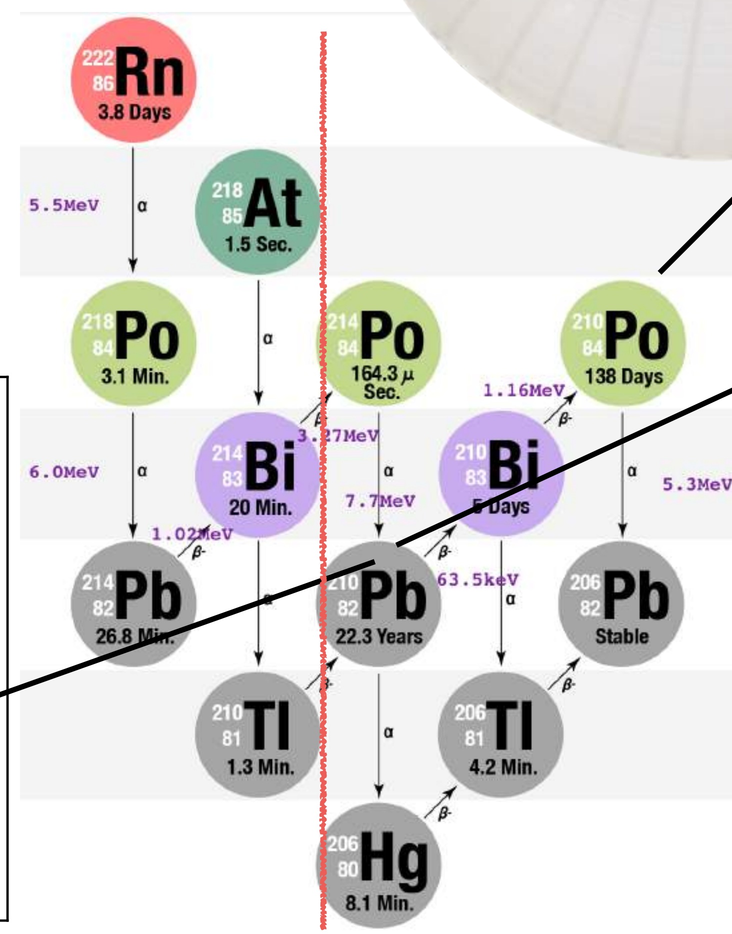


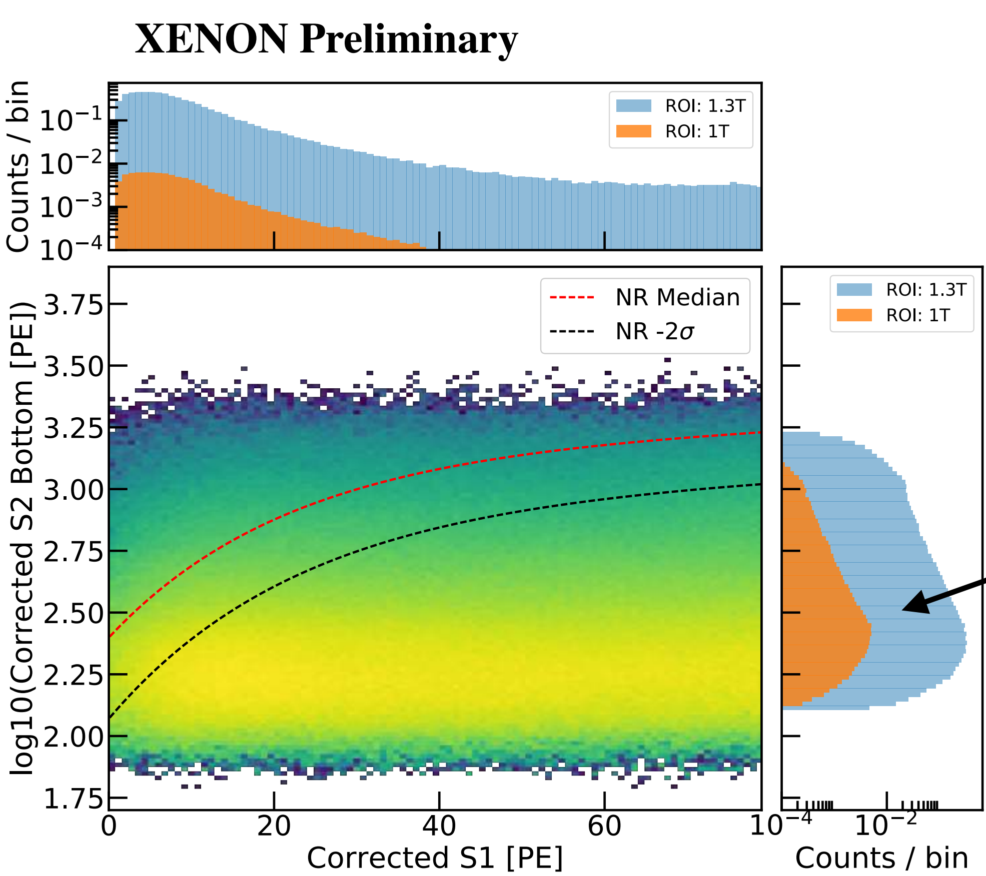


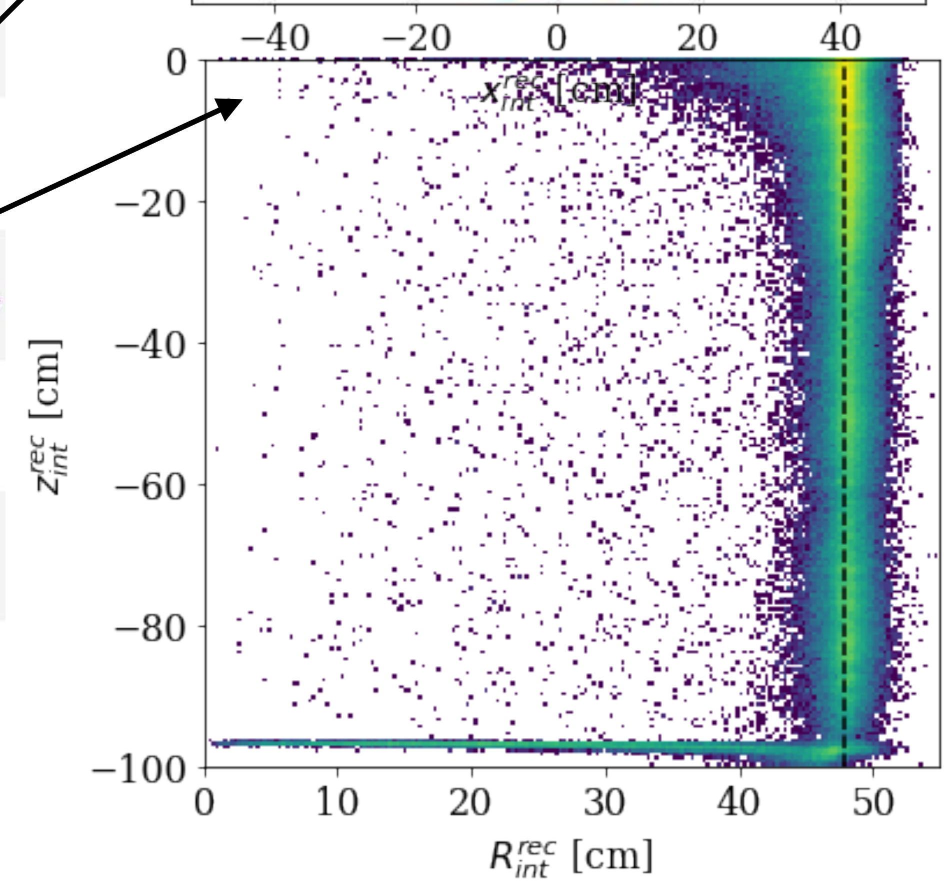
Surface Background

- Pb210 and Po210 plate-out on PTFE surface produce events with reduced S2 -> can be mis-reconstructed into NR signal region
- Suppressed by fiducialization of volume
- Data-driven model derived from surface event control samples









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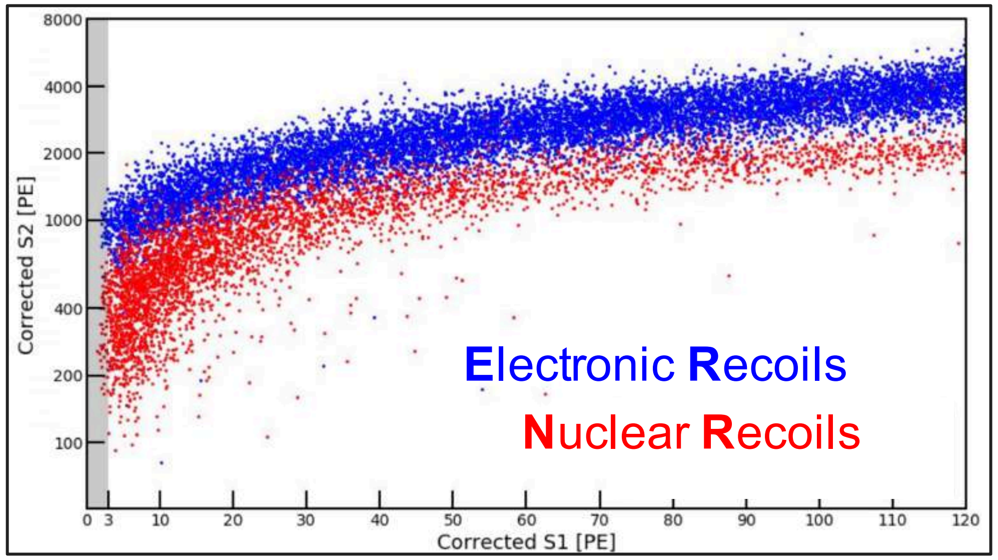
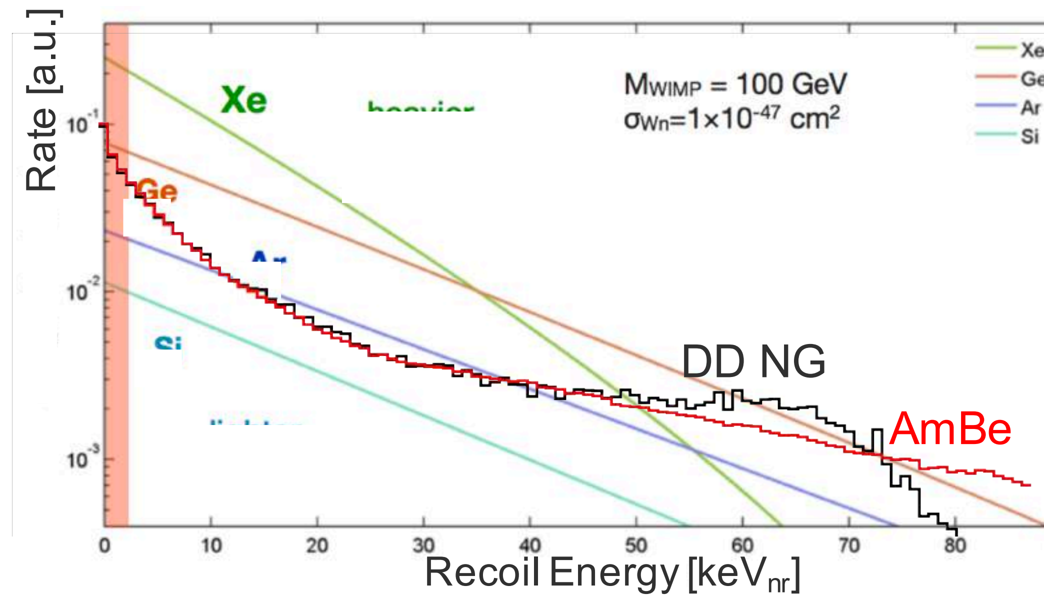
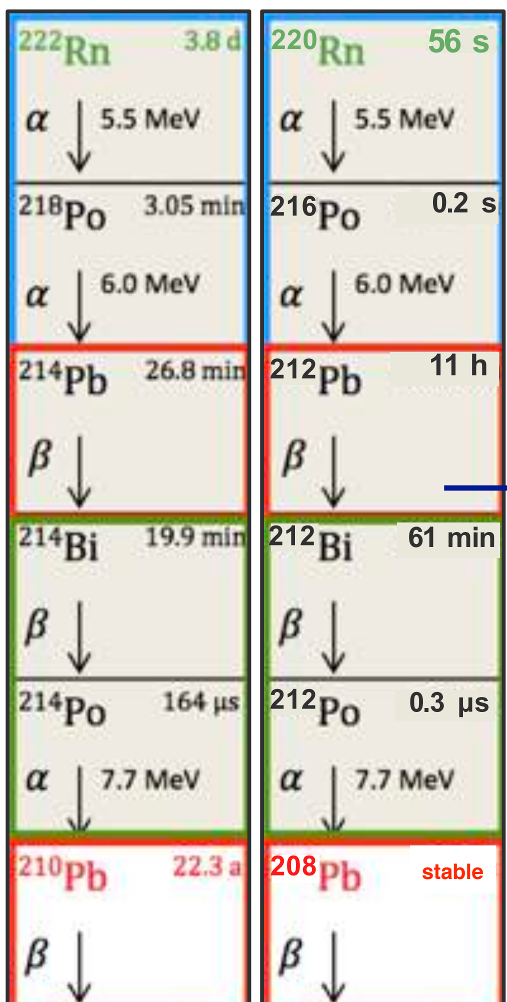
Response to Electronic and Nuclear Recoils

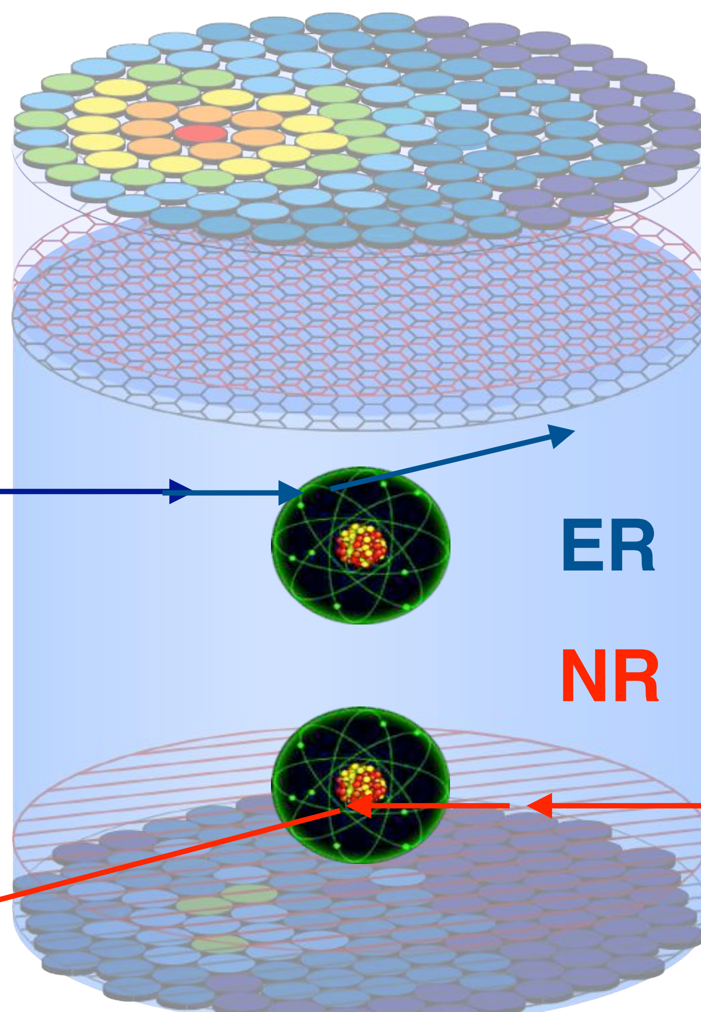
XENON Dark Matter Project

Calibrating ERs and NRs

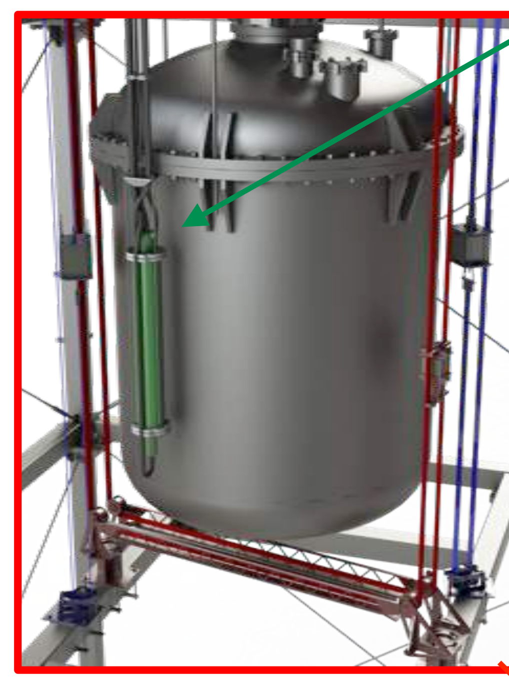


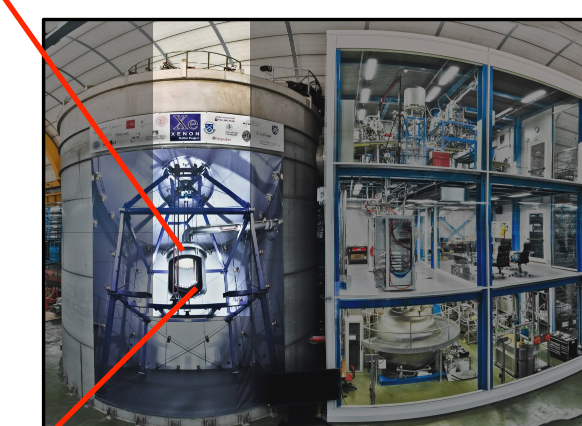






1), DD fusion neutron generator



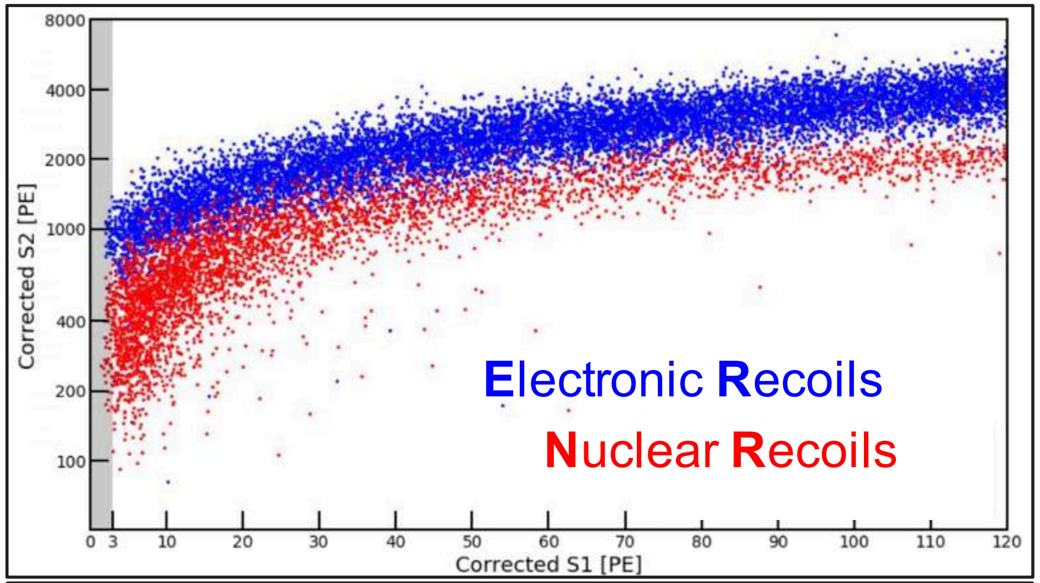


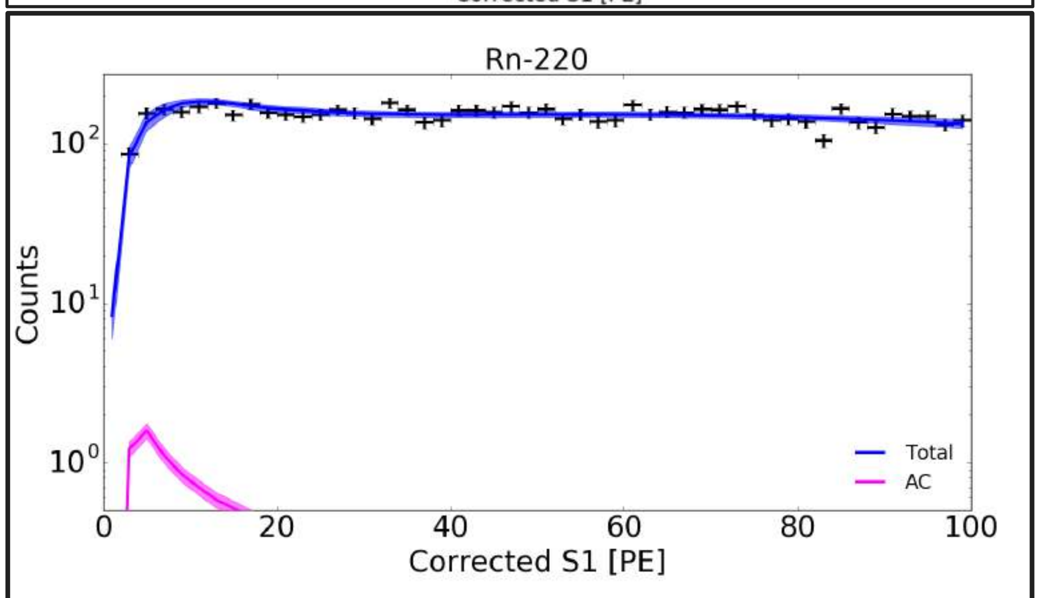
n, WIMPs

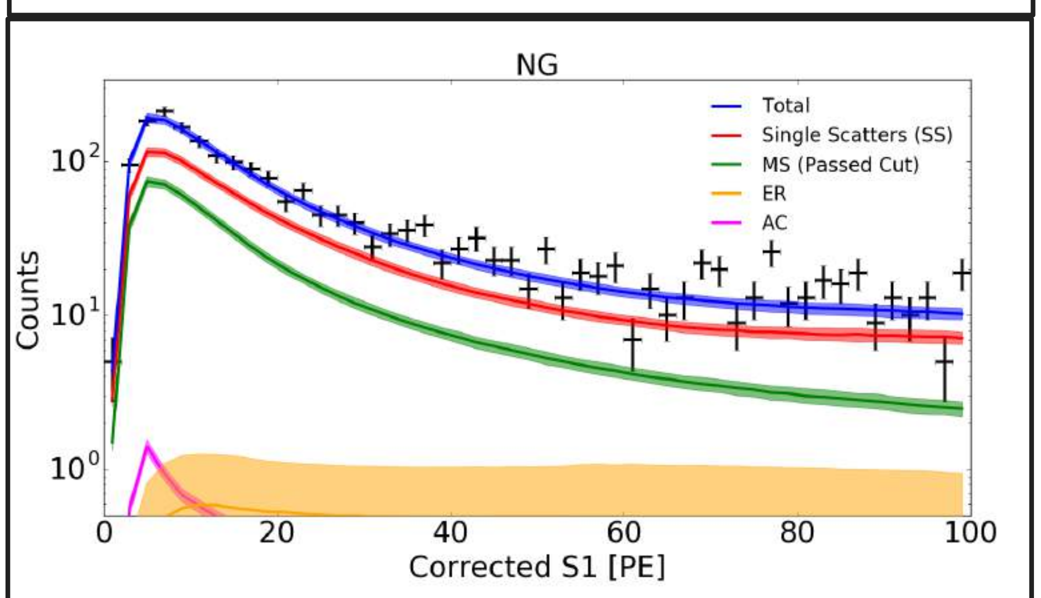
2), AmBe radioactive source

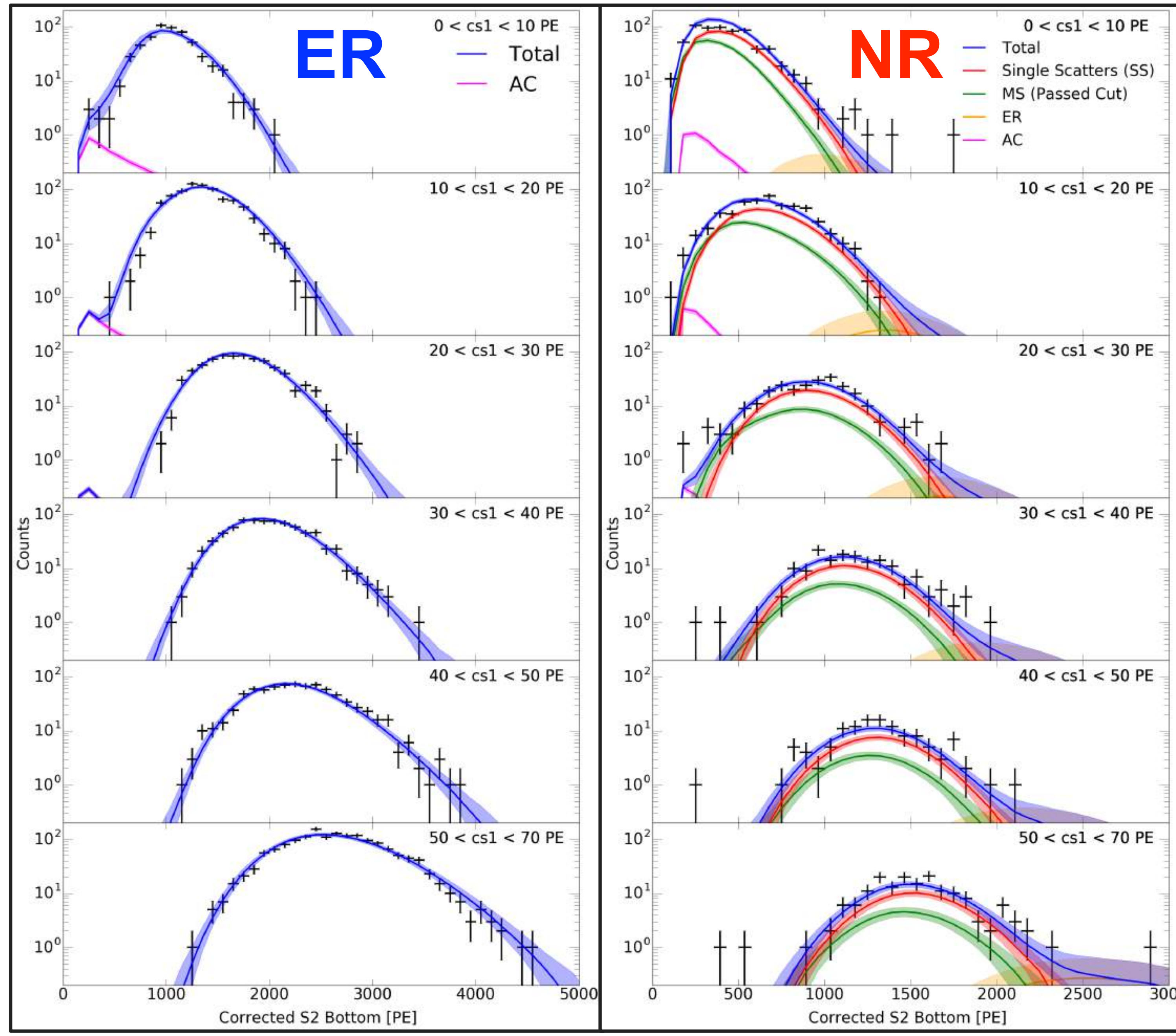
Calibrating ERs and NRs

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





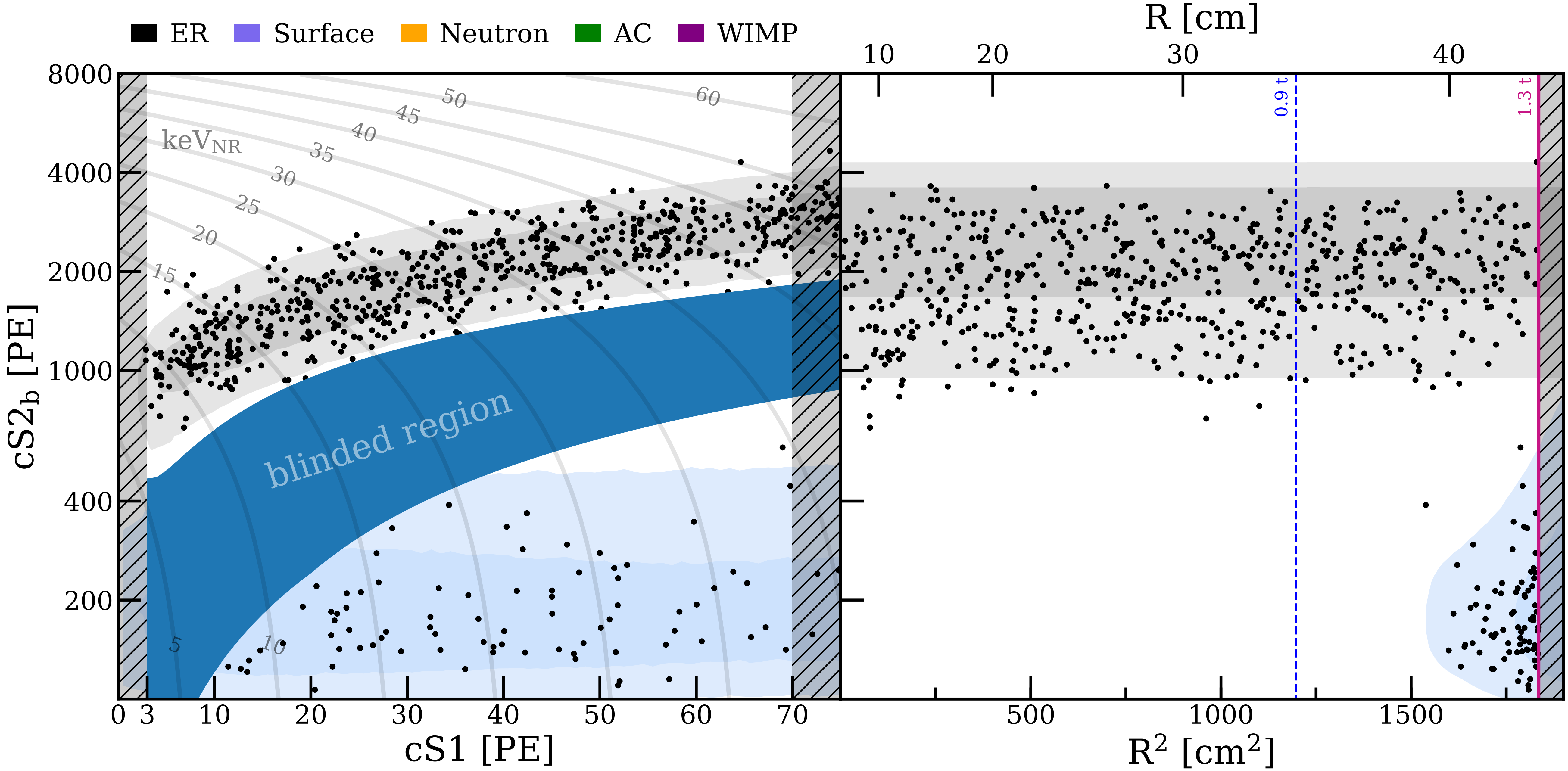




ER rejection: ~99.7% with NR acceptance within [-2σ, median] for both runs.

Dark Matter Search Data: Blinded and salted

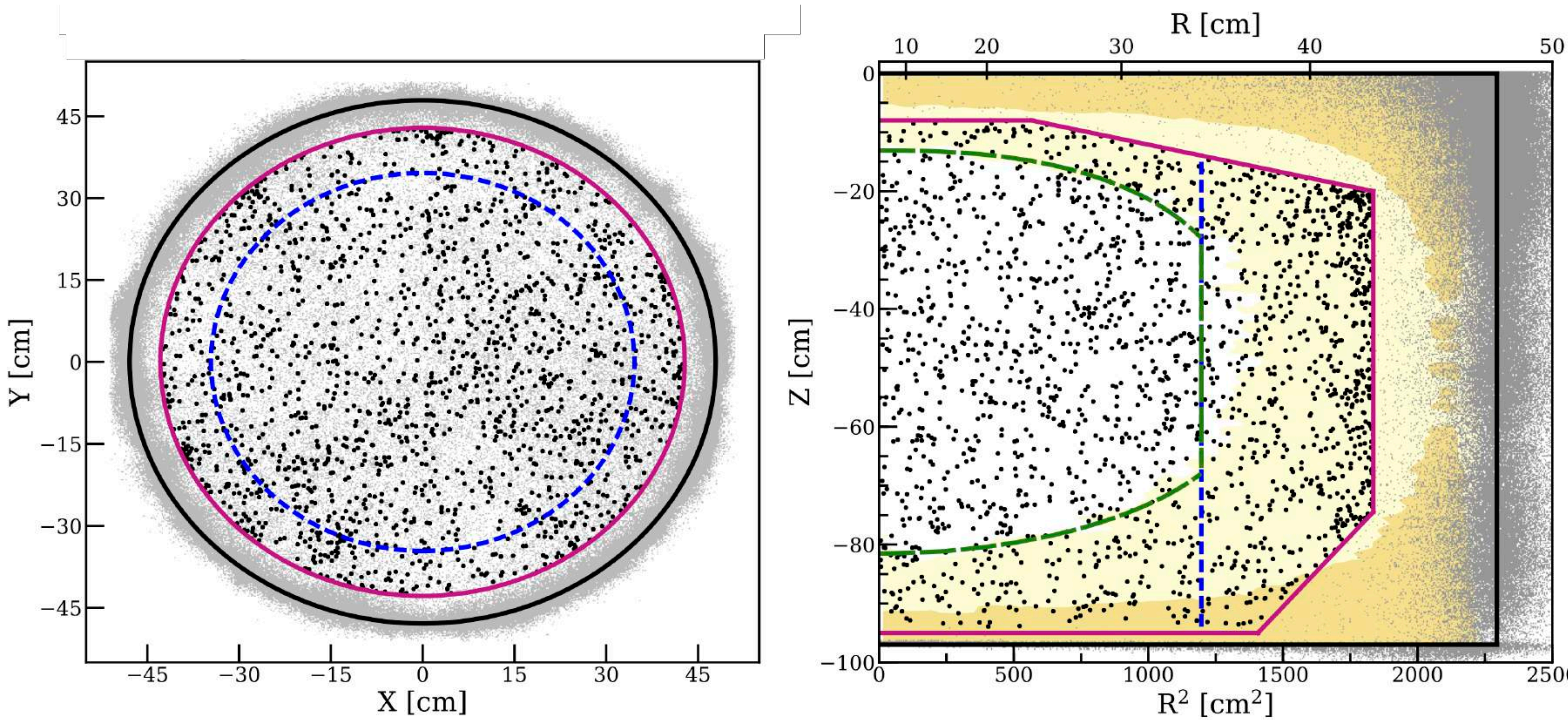
- Blinding: to avoid potential bias in event selection and the signal/background modeling the nuclear recoil ROI (S2 vs S1 only) was blinded from the start of SR1 analysis (and SR0 re-analysis).
- Salting: to protect against post-unblinding tuning of cuts and background models, an undisclosed number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



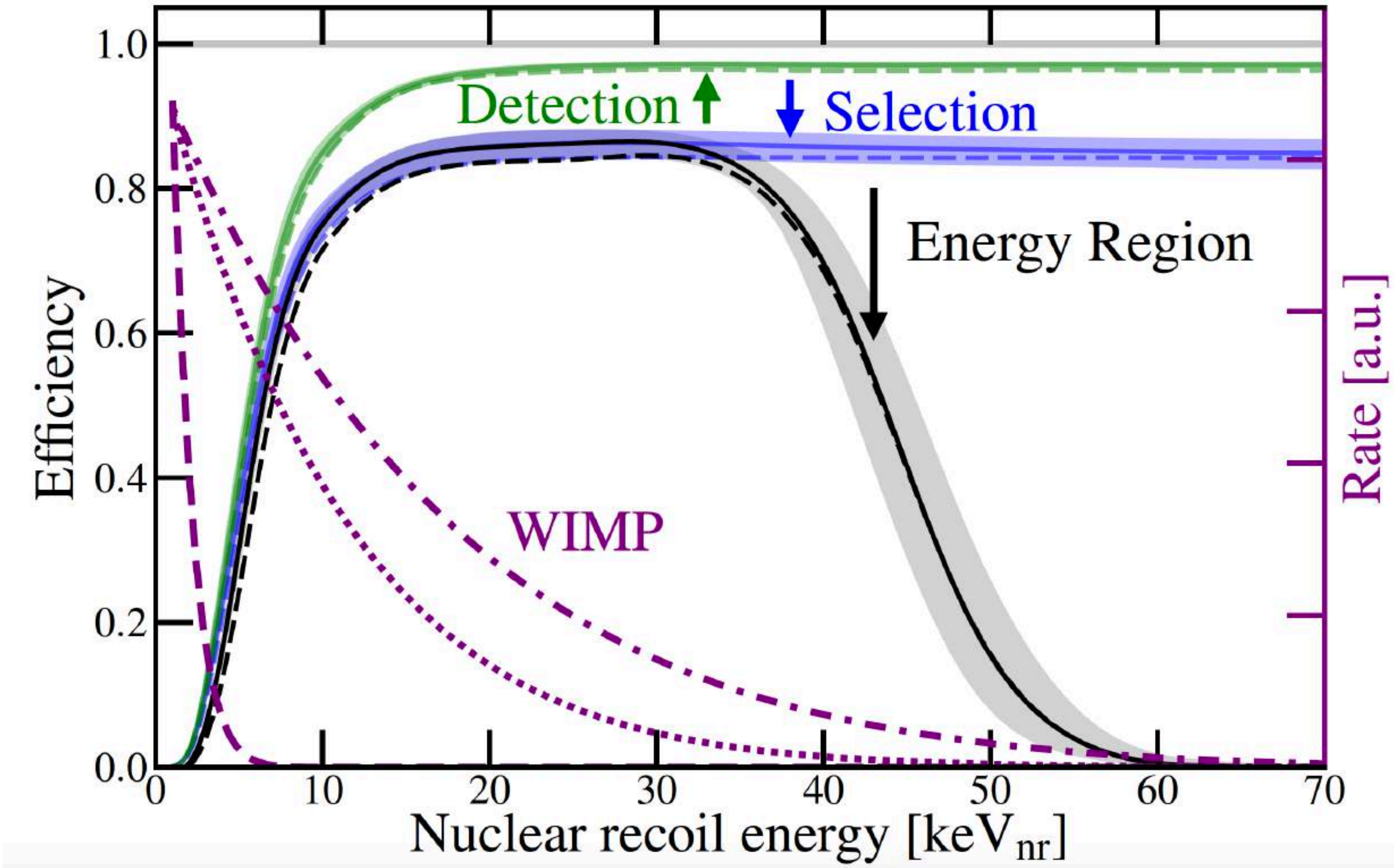
Fiducial Volume Optimization

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 thanks to improvements in position reconstruction, including PTFE charge-up and field corrections
- new surface background model allowed inclusion of radius, R, in statistical inference to maximize useful volume. Analysis space became cS1, cS2b, R and Z



Event Selection & 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
- 10 GeV (dashed), 50 GeV (dotted) and 200 GeV (dashed-dotted) WIMP spectra shown

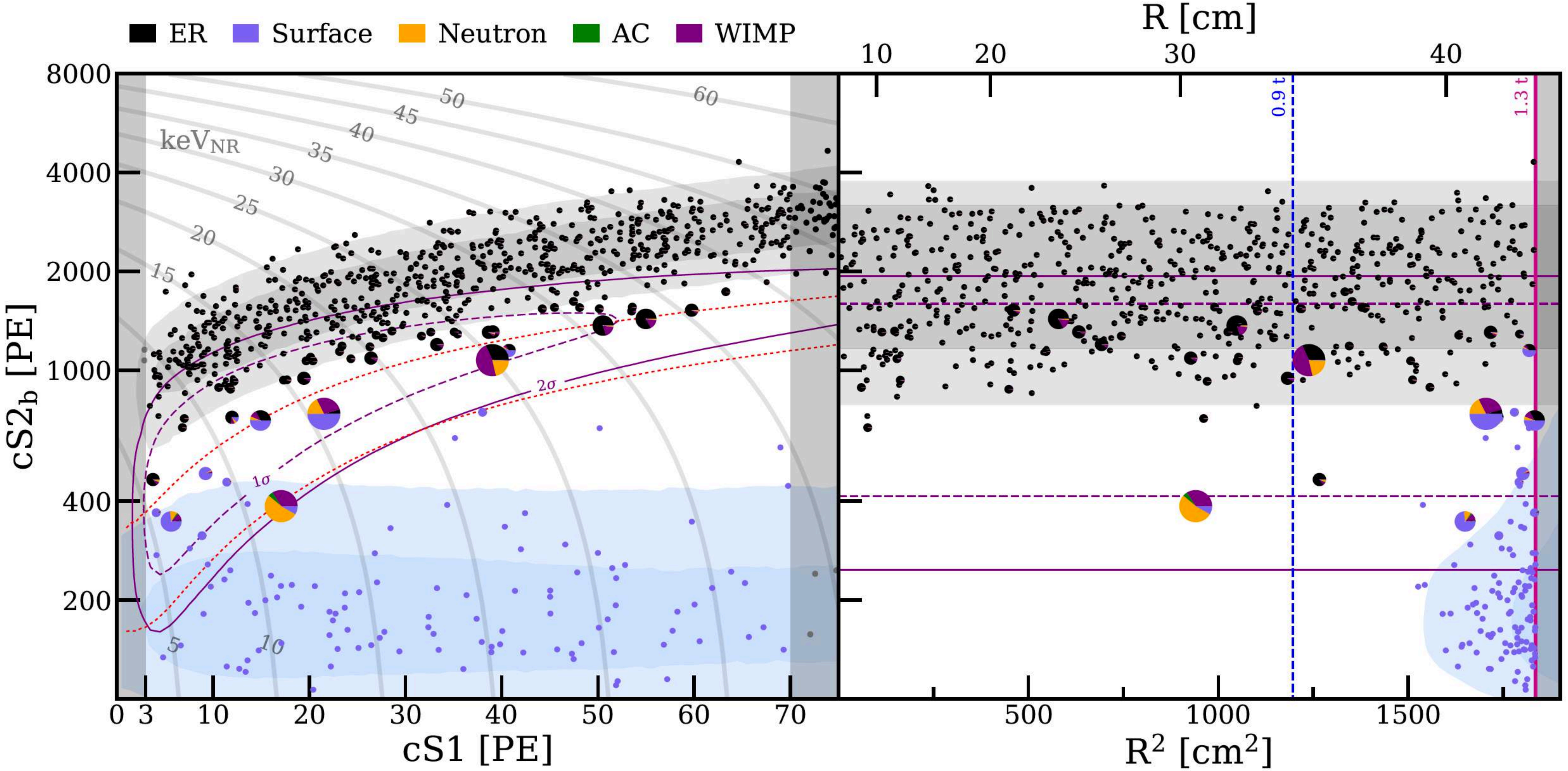
Background prediction and Unblinding

Mass	1.3 t	1.3 t
(S2, S1)	Full	Reference
ER	627±18	1.62±0.30
Neutron	1.43±0.66	0.77±0.35
CENNS	0.05±0.01	0.03±0.01
AC	0.47±0.27	0.10±0.06
Surface	106±8	4.84±0.40
BG	**735±20**	**7.36±0.61**

- 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 just for illustration, statistical interpretation is done based on profile likelihood analysis

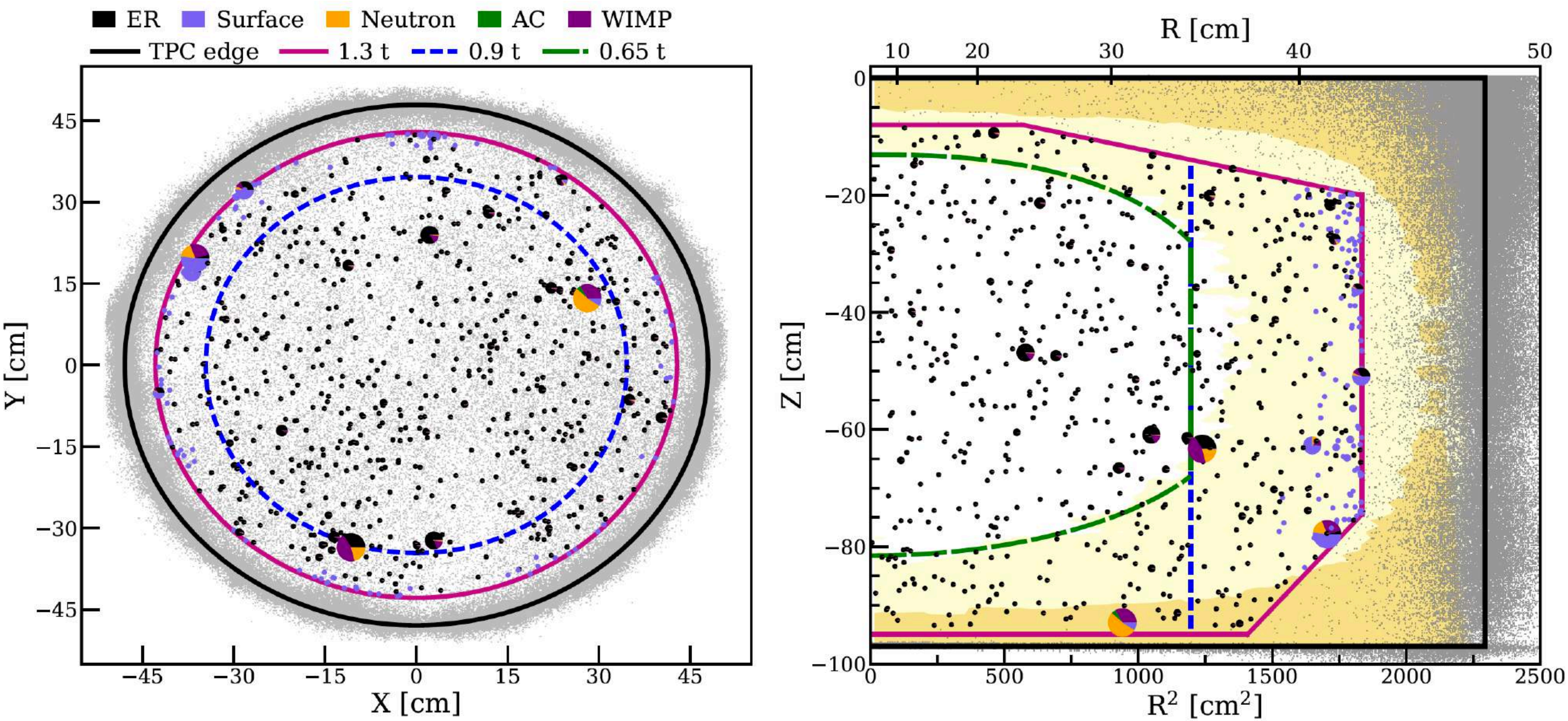
Dark Matter Search Results

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

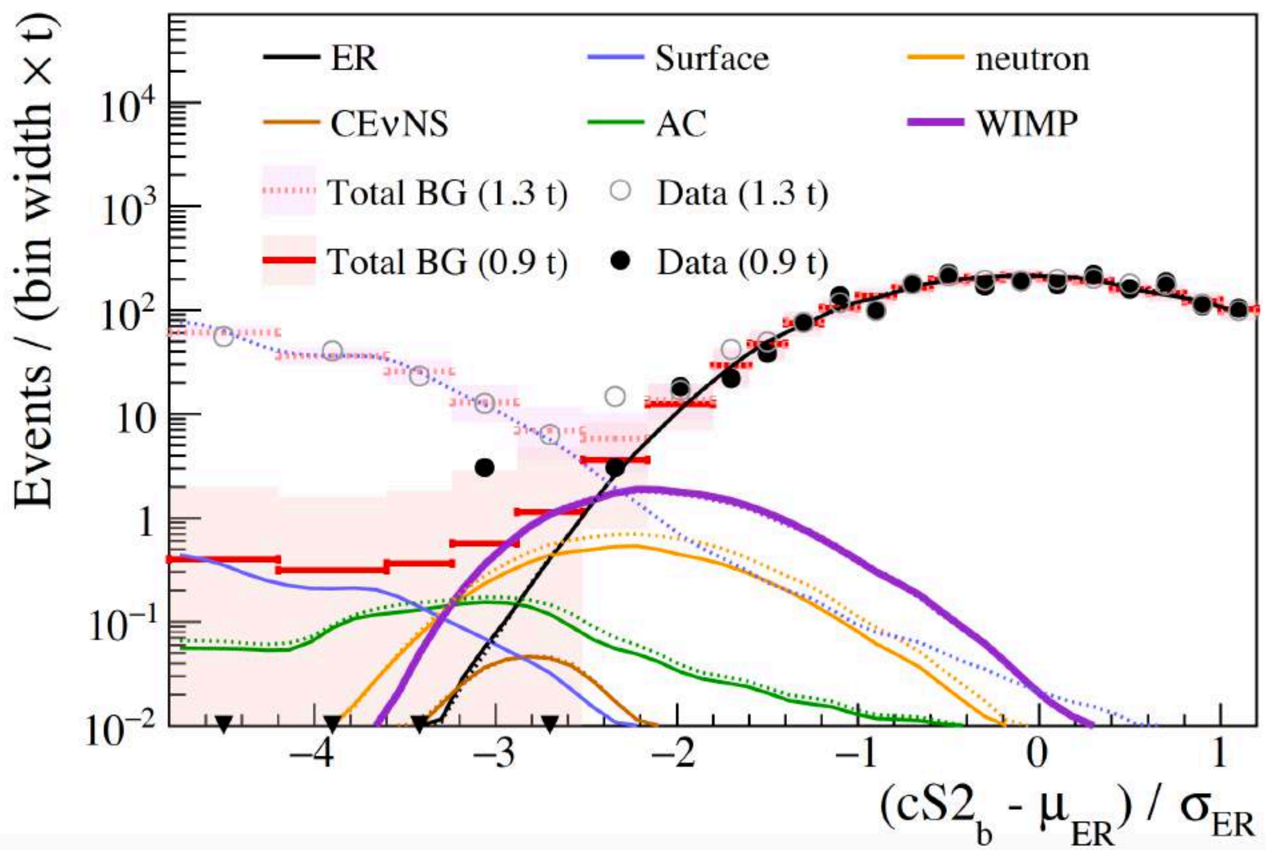


Spatial Distribution of Dark Matter Search Data

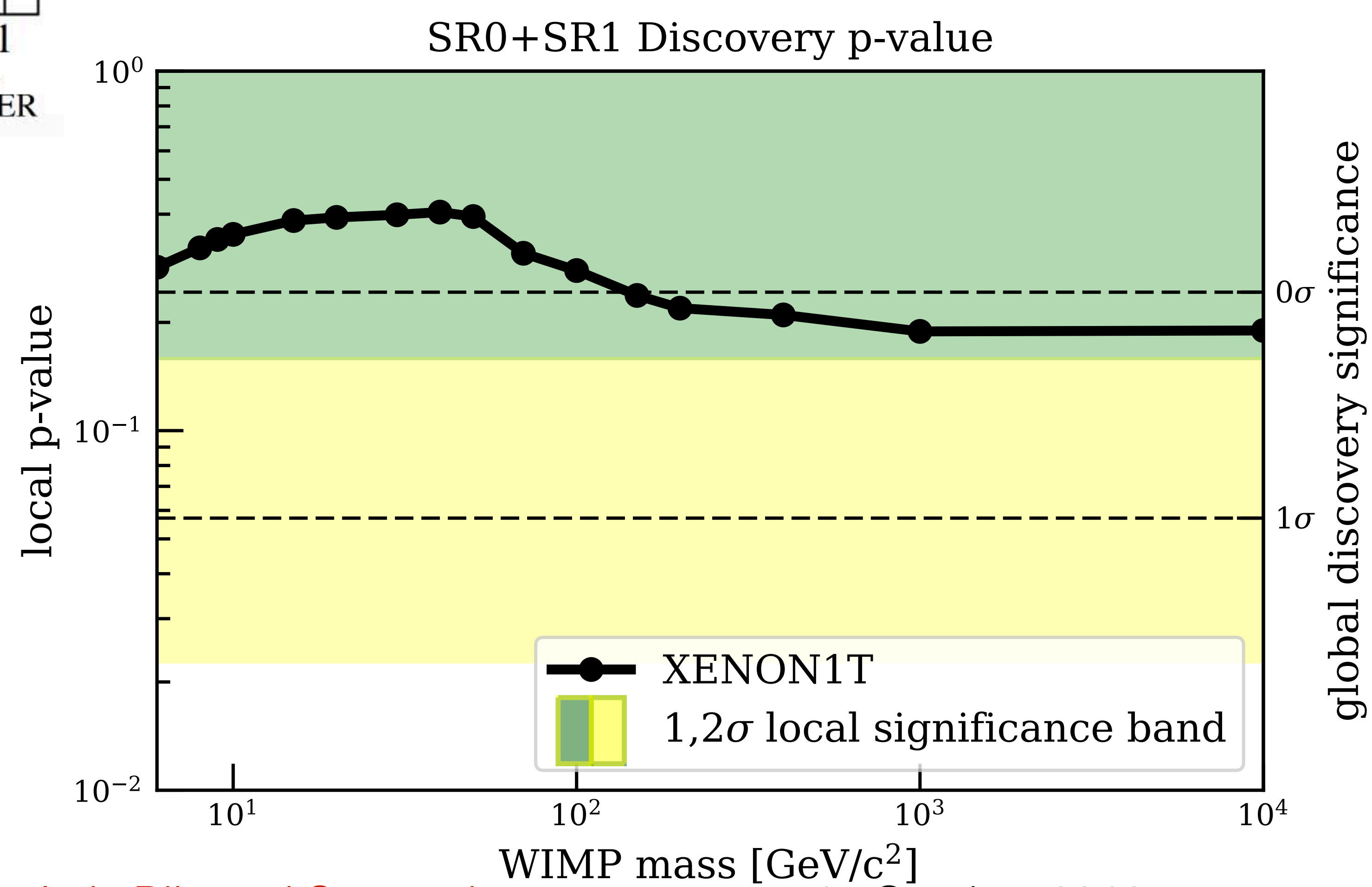
- Results interpreted with unbinned profile likelihood analysis in cS1, cS2, r space
- **Core volume** to distinguish WIMPs over neutron background



Statistical Interpretation



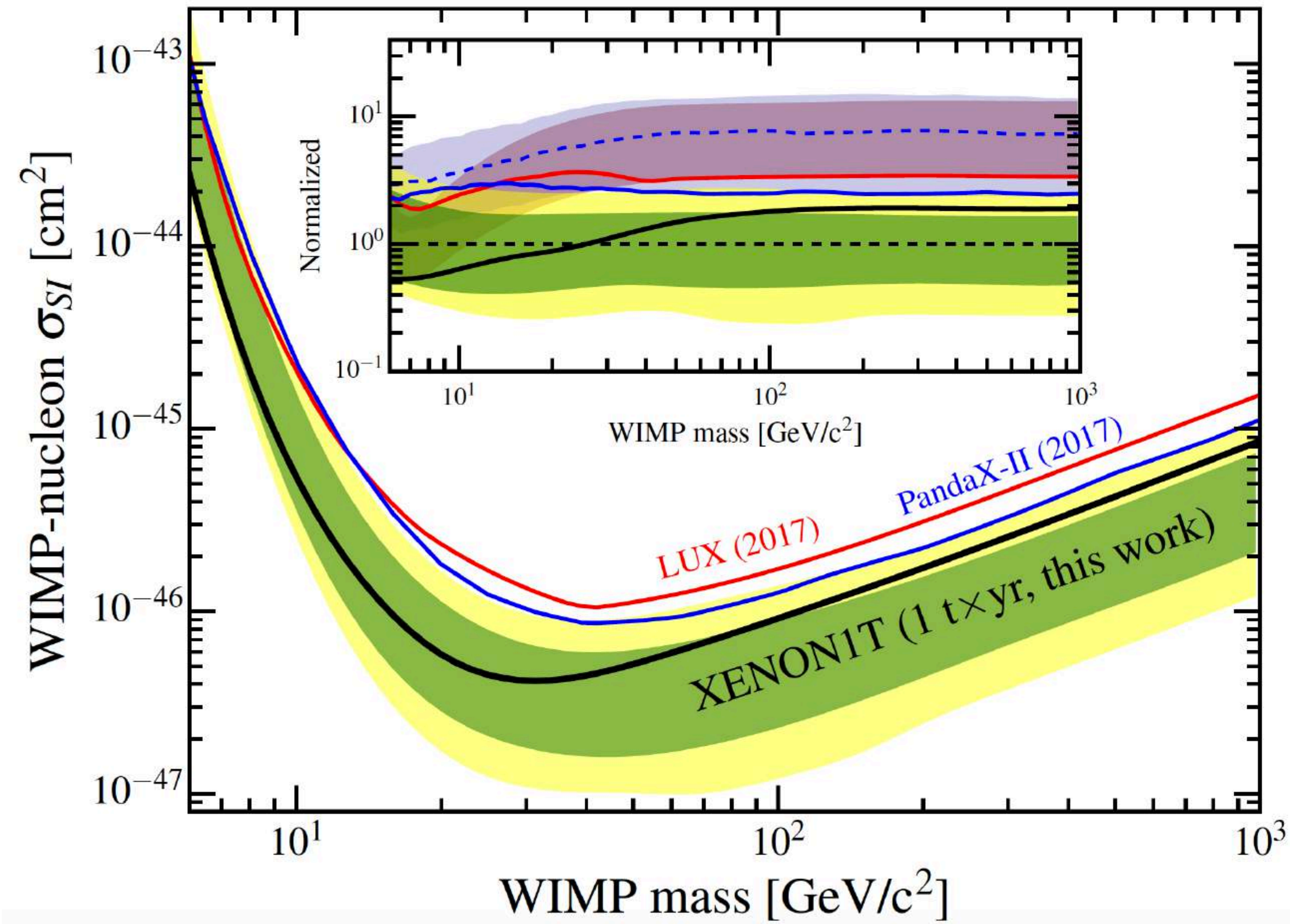
- Extended unbinned profile likelihood analysis
- Example left: Background and 200 GeV WIMP signal best-fit predictions, assuming 4.7 x 10^{-47} cm^2, compared to data in 1.3 t and 0.9 t
- Most significant ER & Surface backgrounds shape parameters included
- Safeguard to protect against spurious mis-modeling of background



- 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

Phys. Rev. Lett. **121**, 111302



- 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)
- ~ 1sigma upper fluctuation at high WIMP masses, could be due to background or signal

Minimum at 4.1×10^{-47} cm^2 for a WIMP of 30 GeV/c^2

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The next step: **XENONnT**

Xe XENON Dark Matter Project

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***.

Decrease neutron background thanks to new active neutron veto.

Fast Turnaround

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

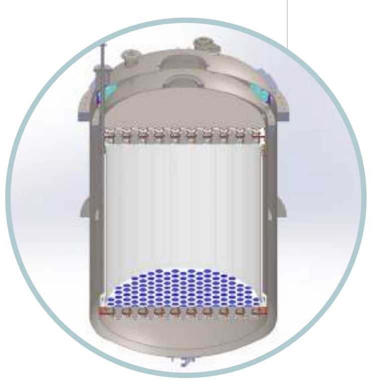
Fast pace:

Installation spring 2019, commissioning by end 2019

The next step: **XENONnT**

XENON1T Infrastructure and sub-Systems (already operative)

Aprile et al., Eur. Phys. J. C (2017) 77: 881

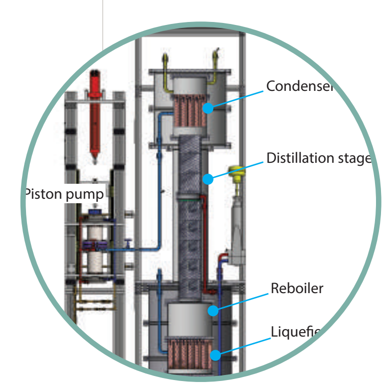


New TPC

5.9-ton Time Projection Chamber

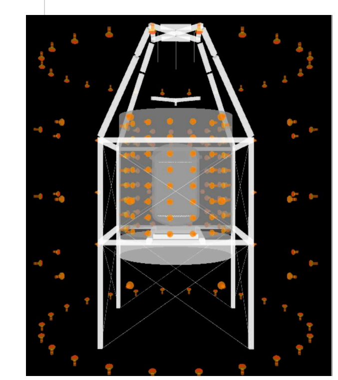
LXe Purification

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



Radon Distillation

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



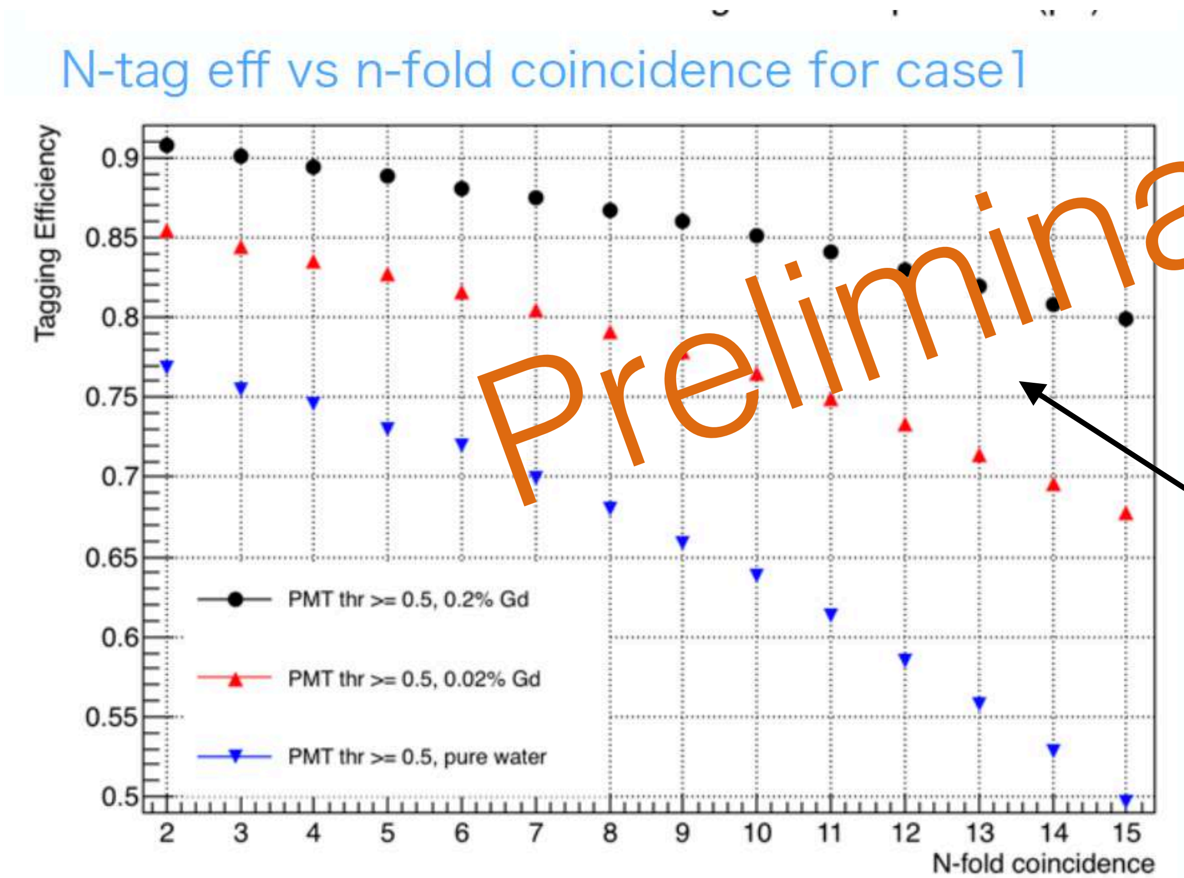
Neutron Veto

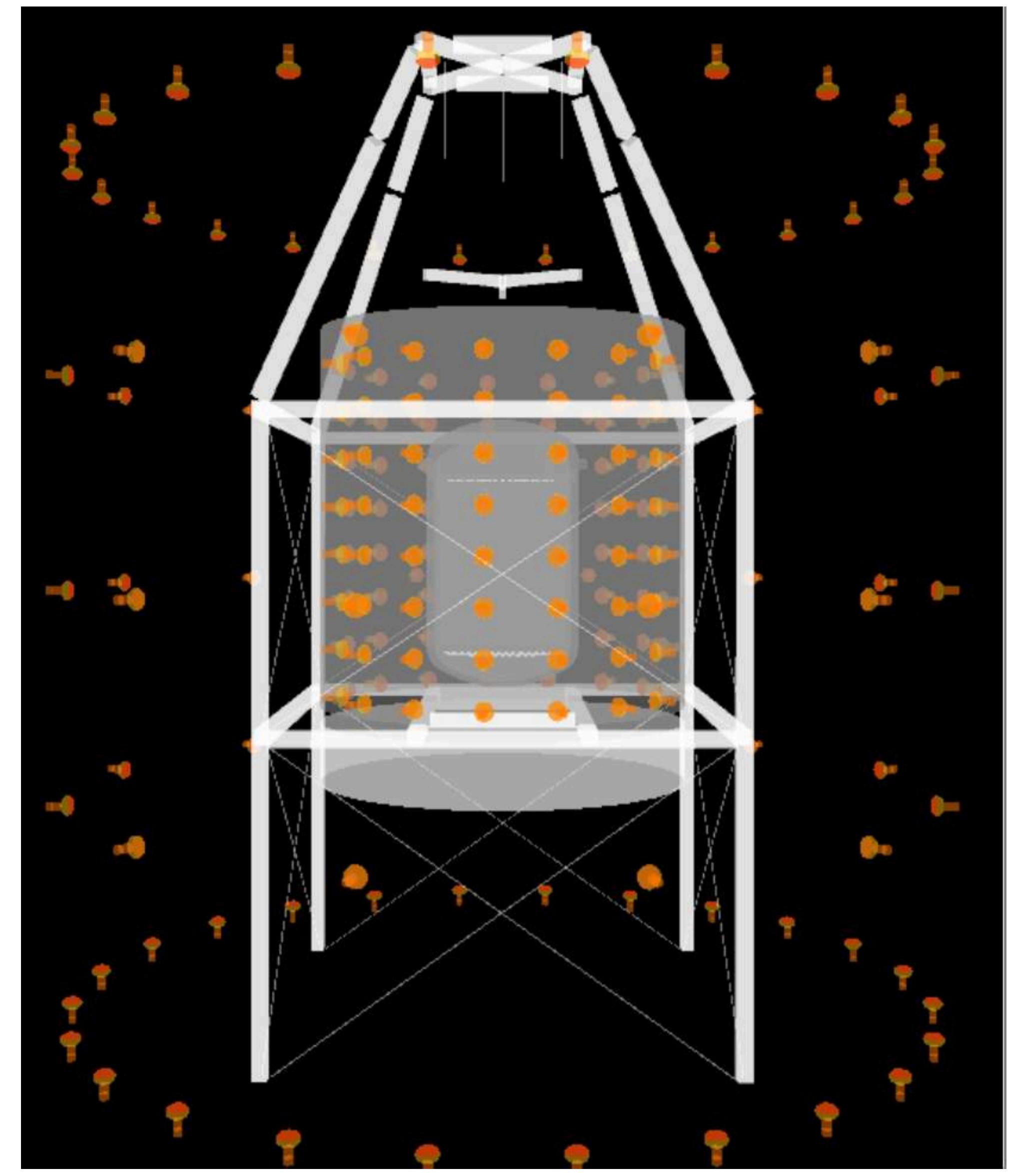
To tag and measure in situ neutron-induced background

Gd-H2O neutron veto

- Gd in the Water of the whole tank: 0.5% of $Gd_2(SO_4)_3$ (Know-how from SuperK colleagues)

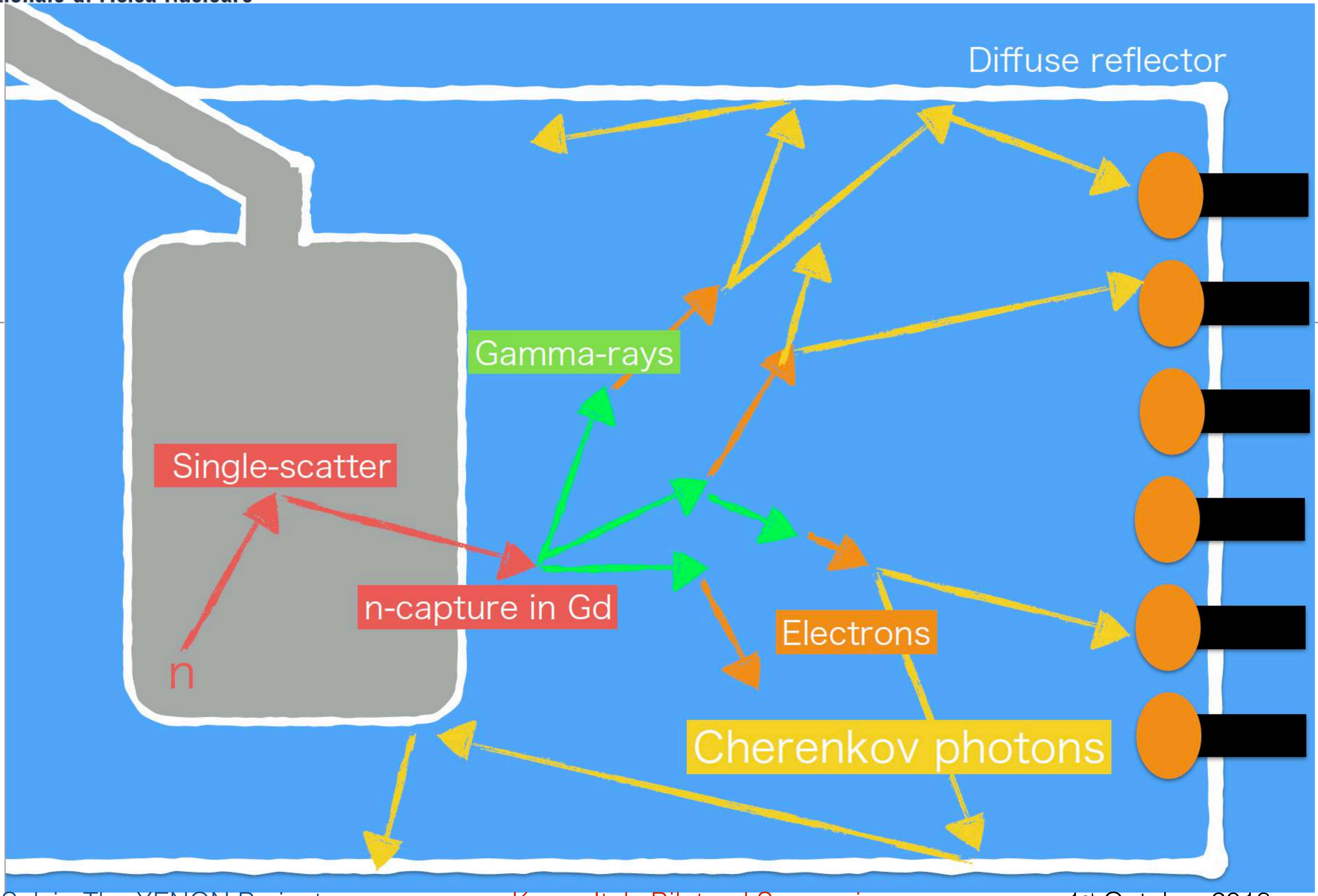
- Inner region, optically separated from the outer Muon Veto, with high LCE (120 PMTs + Tyvec reflector).





Neutron tagging efficiency from MC: > 80%

Gd-H2O MC



Diffuse reflector
Gamma-rays
Single-scatter
n-capture in Gd
n
Electrons
Cherenkov photons

Rn in XENON1T

XENON1T RN-BACKGROUND

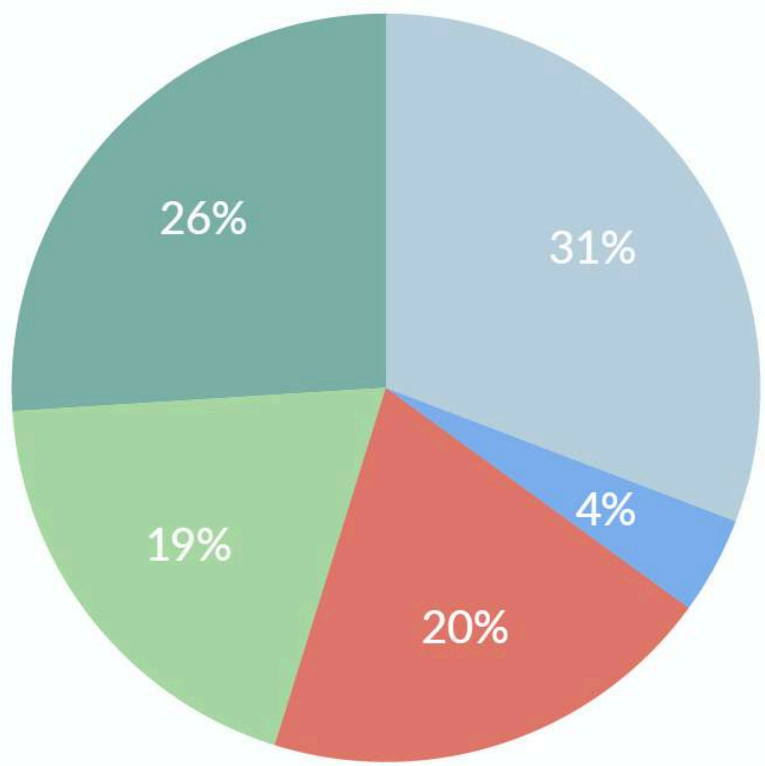
Rn-budget breakdown: emanations measured in XENON1T

TPC+Cryostat

^{222}Rn emanated by materials inside the TPC

Type-I Sources

10uBq/kg



Is the source emanating around the active volume?

Piping + Cables

^{222}Rn emanated by materials within the recirculation and cable pipes

Cryopipe

^{222}Rn emanated within the cryogenic pipe used to transfer LXe

Hot Getter

^{222}Rn emanated by the hot getter used to remove electronegative impurities

QDrive Pumps

^{222}Rn emanated by plastic materials within the recirculation pumps

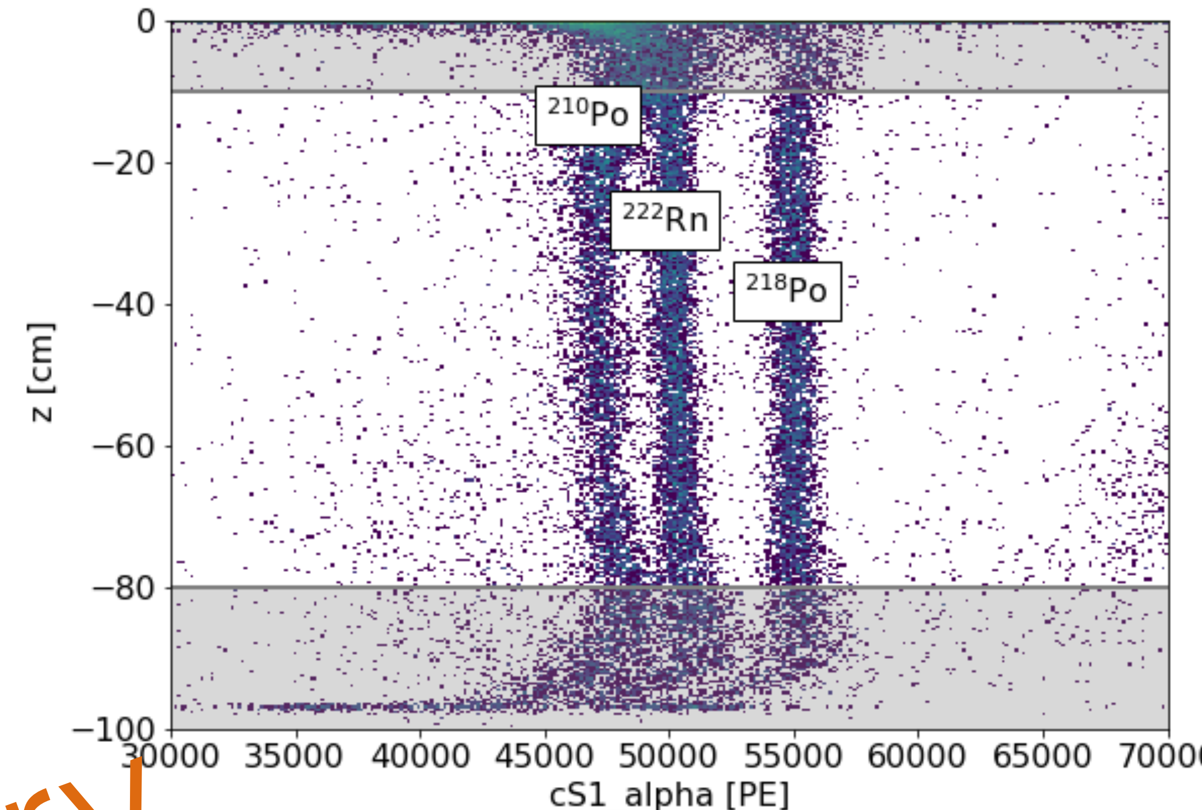
Type-II Sources

Rn reduction

Rn reduction towards XENONnT:
factor of 10 -> 1 uBq/kg

Removed the Q-Drive pump, replaced by the new magnetic piston pump: -50% (Eur. Phys. J. C (2018) 78: 604)

Another -30% with (not yet optimised) online distillation



Preliminary

period	concentration [microBq/kg]	comment
May 19 - May 28	(11.8 ± 0.2)	standard rate during SR0/SR1
June 16 - July 11	(6.3 ± 0.1)	after exchange of QDrives with
August 1 - August 22	(4.3 ± 0.2)	during Rn222 distillation

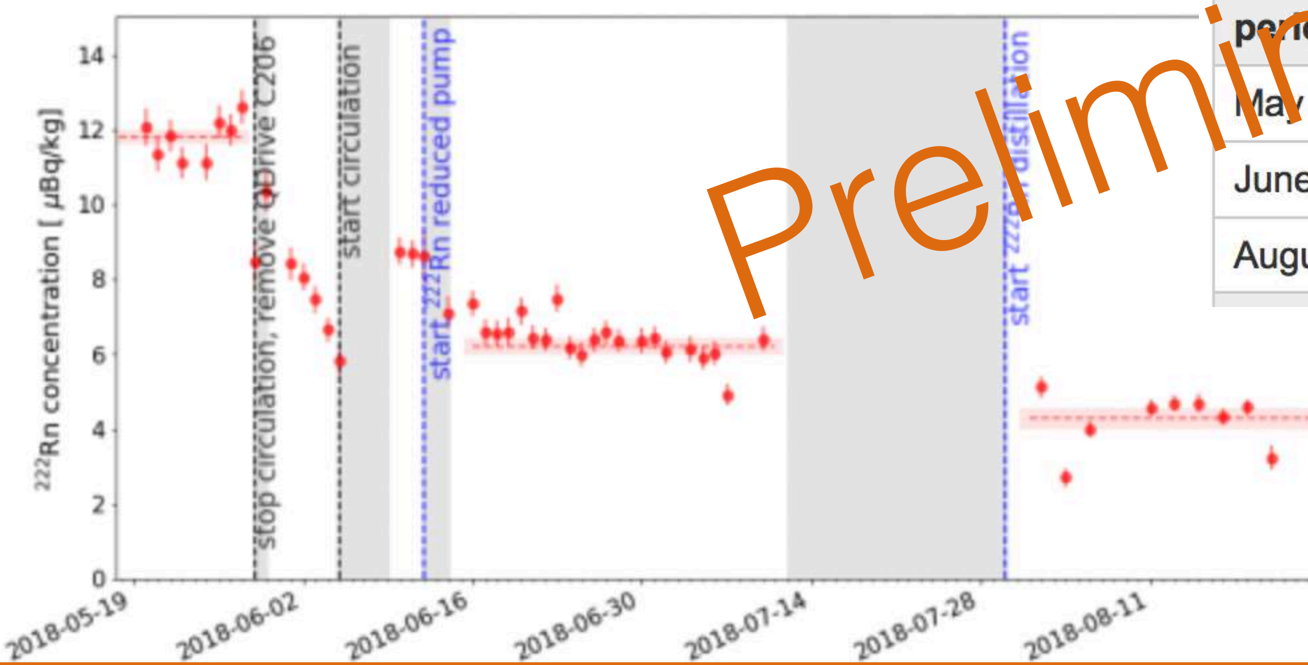
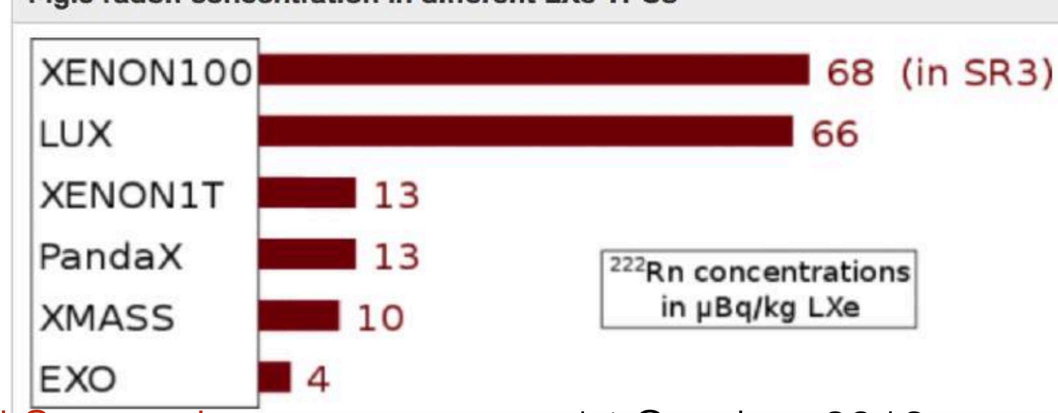


Fig.3 radon concentration in different LXe TPCs



Already close to XENONnT goal !

Increasing e- lifetime

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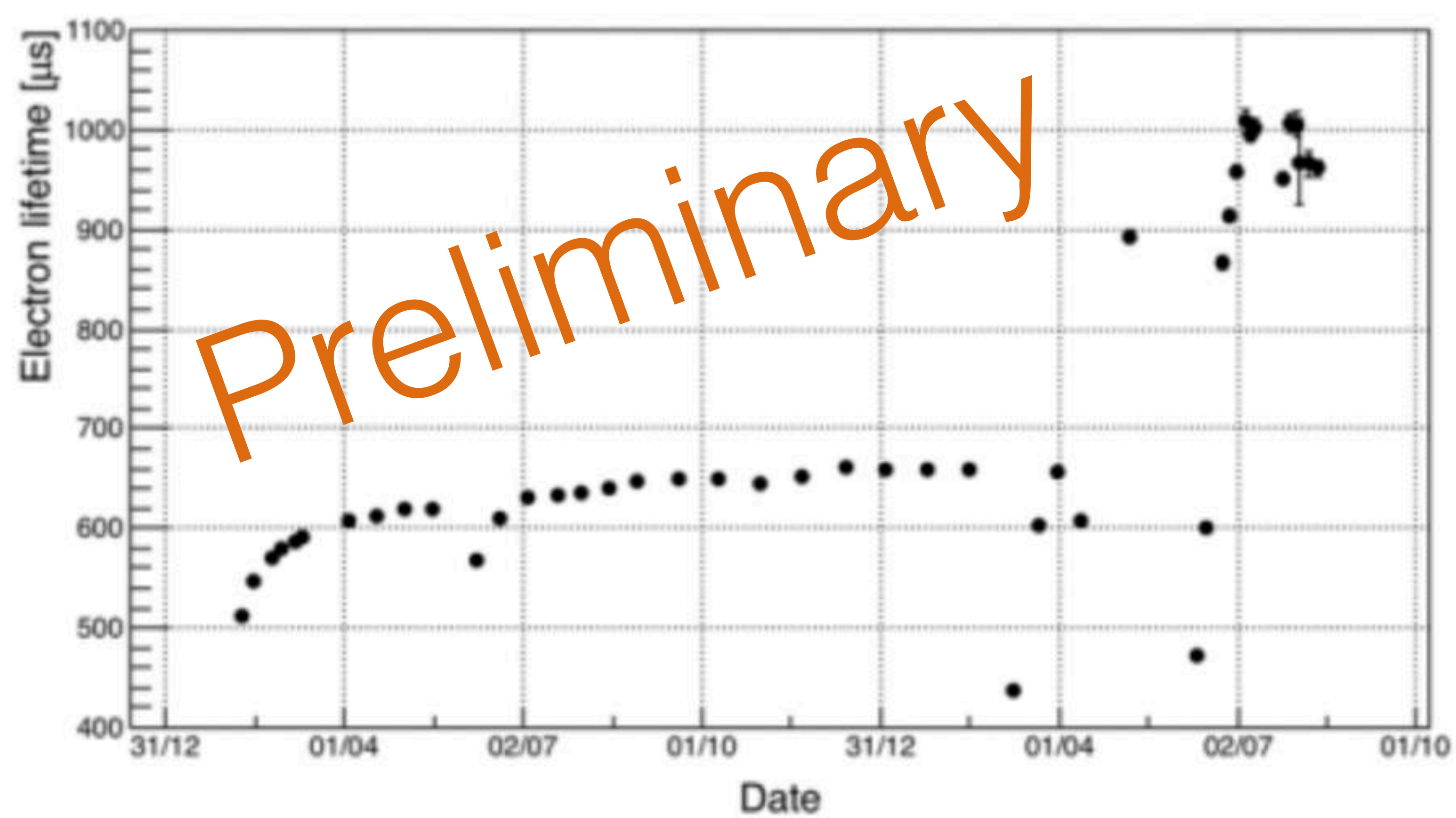
Xe XENON Dark Matter Project

The upgrade in the purification system has been successful also for the electron lifetime, now close to 1 ms (XENONnT goal !)



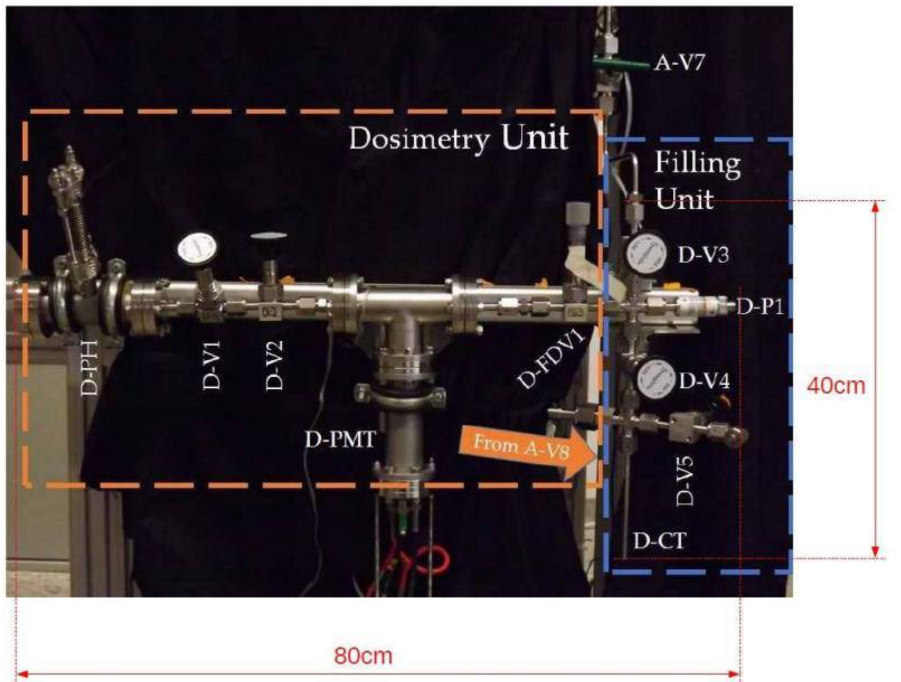
From 06.02.2017 to 13.08.2018

Low en. ER with ^{37}Ar

^{37}Ar decays via electron capture (EC) according to the decay reaction

$$^{37}\mathrm{Ar} \rightarrow {}^{37}\mathrm{Cl} + \nu_e \tag{3.1}$$

and releases x-rays from the capture of the K-shell, L-shell, and M-shell electrons at 2.8224 keV, 0.2702 keV, and 0.0175 keV with branching ratios of 0.90, 0.09, and 0.009 [26]. These x-rays are photoabsorbed in the xenon bulk producing an electron recoil.

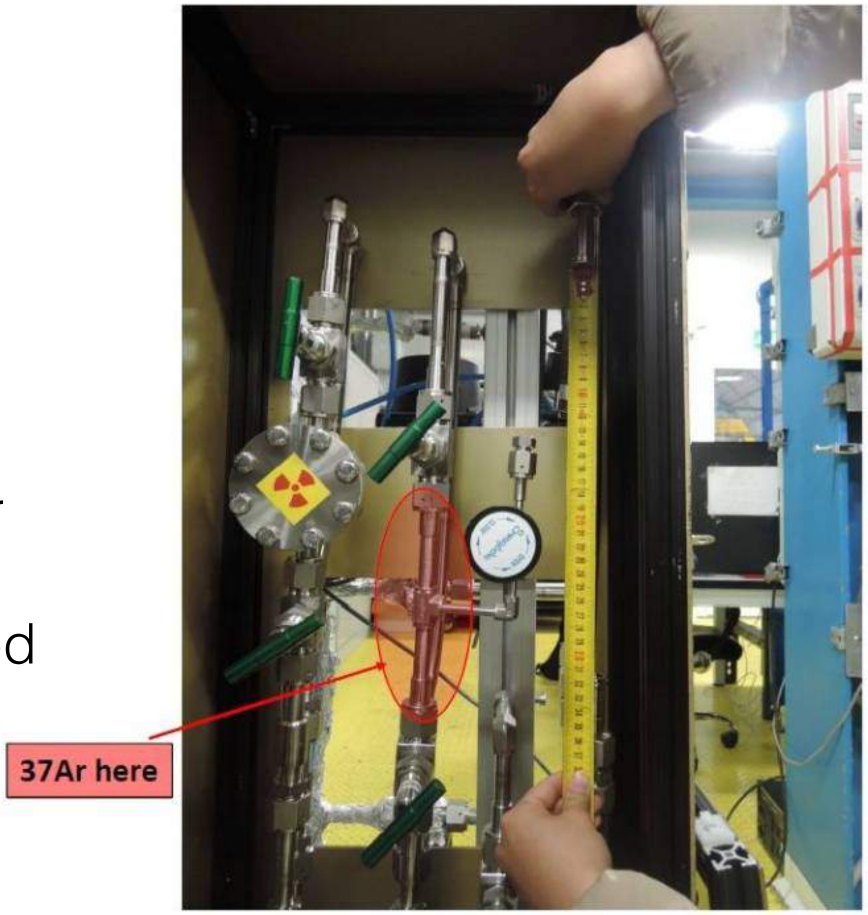


^{37}Ar is produced at the TRIGA research reactor @Mainz via $^{36}\mathrm{Ar}(n,\gamma)^{37}\mathrm{Ar}$

The ampulla is then connected with the XENON1T recirculation system.

^{37}Ar removal:

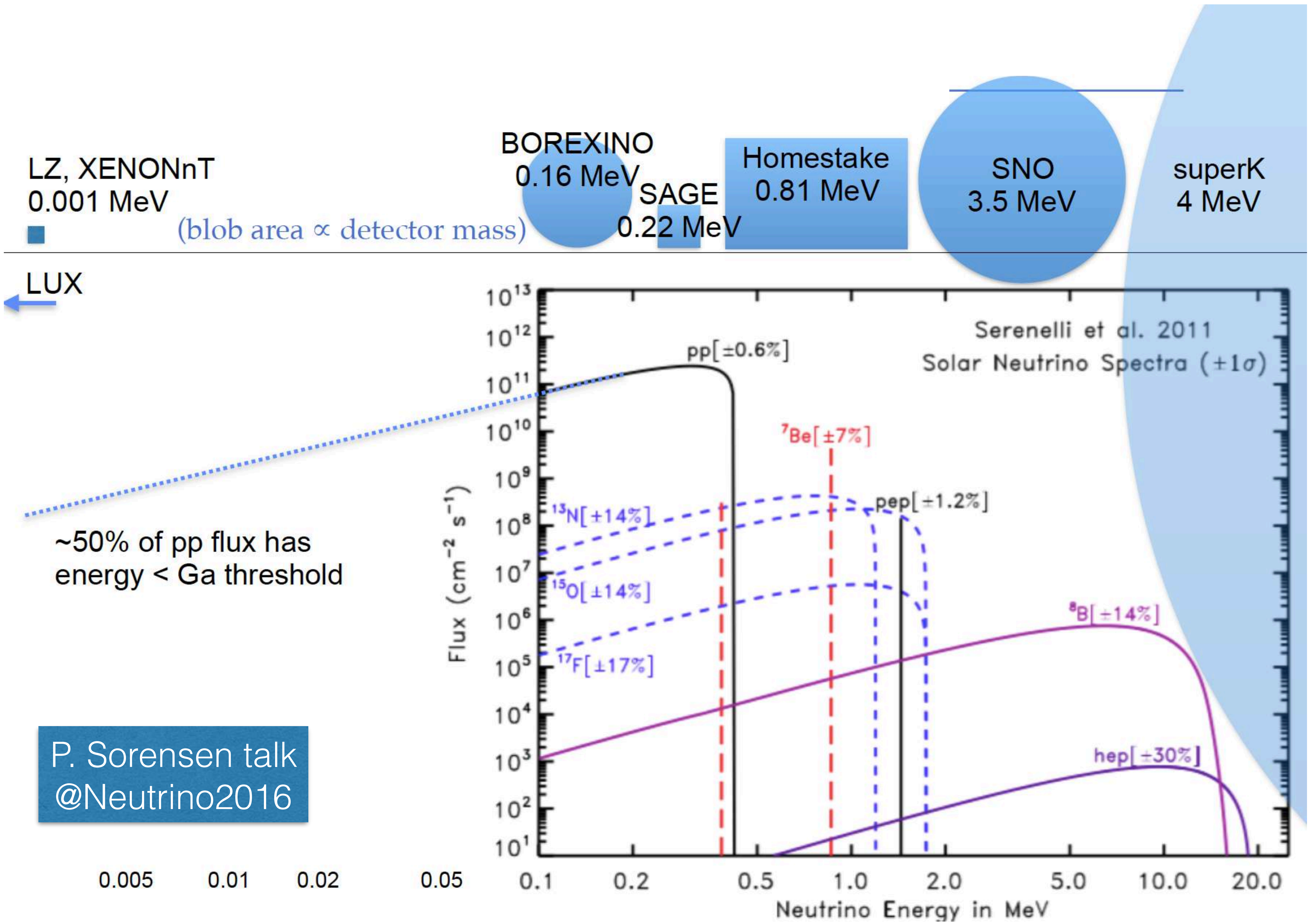
- half-life 35 days
- cryogenic distillation (in principle performances better than for Kr), to be tested in XENON1T, to be used in XENONnT as a "regular" calibration.



XENONnT schedule

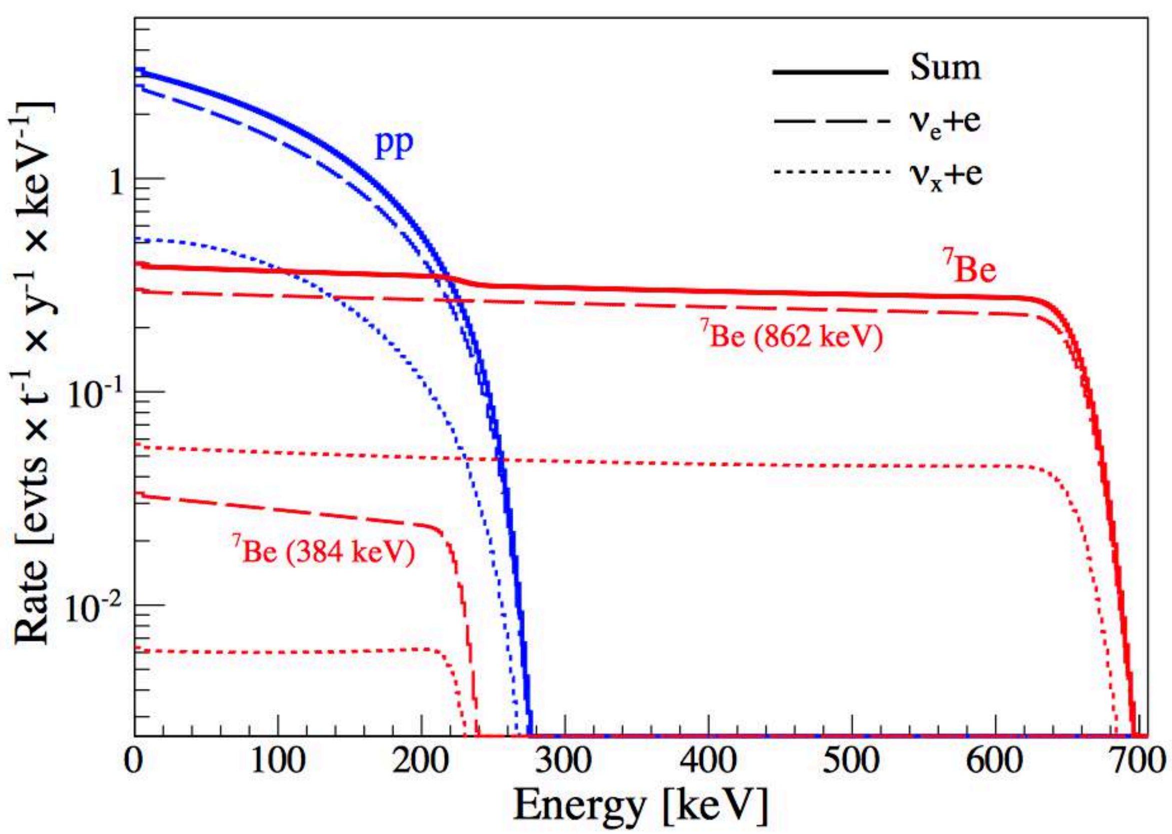
- Jan19: Quit XENON1T operations, decommissioning
- Spring19: Complete installation of new TPC+Cryostat
- July19: Complete installation of the nVeto system
- Sept19: Start TPC Commissioning
- Dec19: Start Science Run

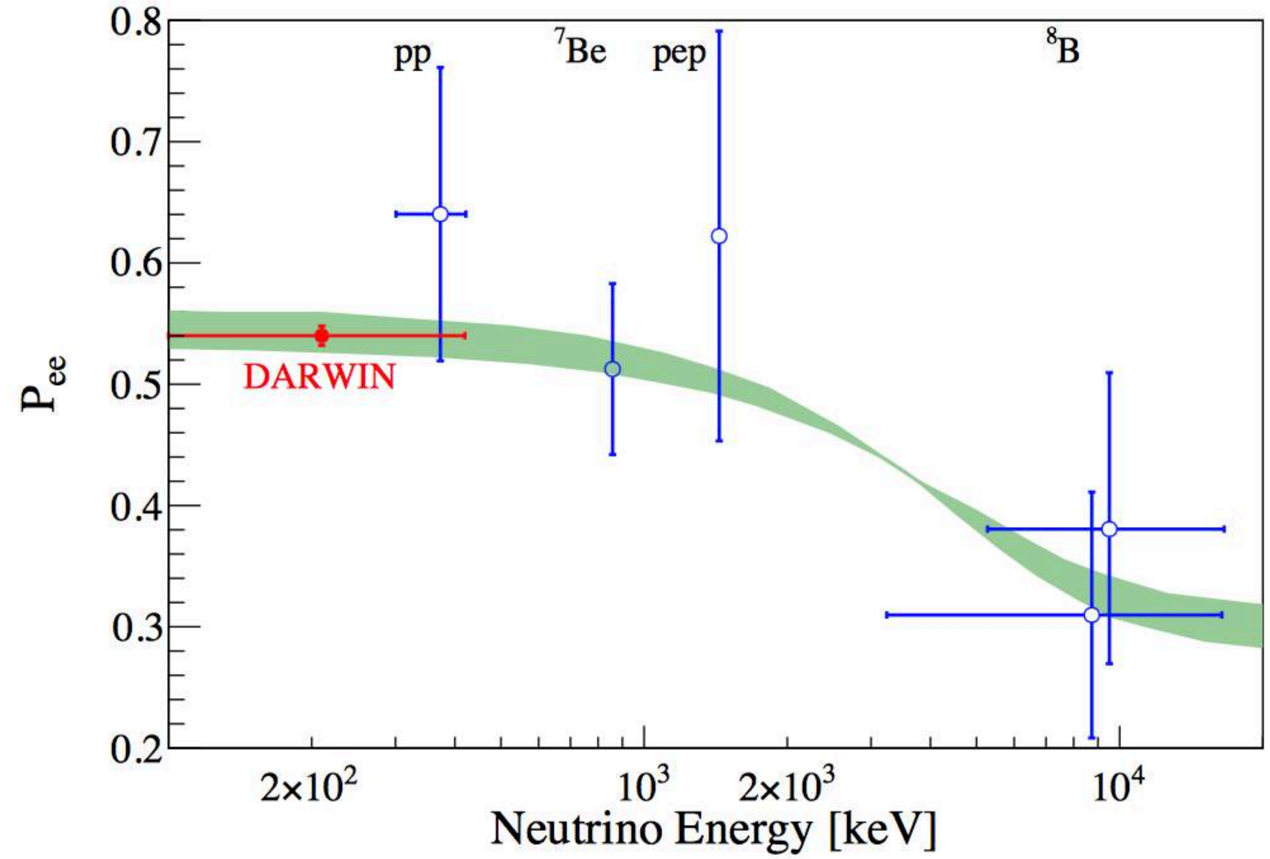
Solar neutrino & detectors



Measuring pp neutrinos

JCAP 1611 (2016) no.11, 017





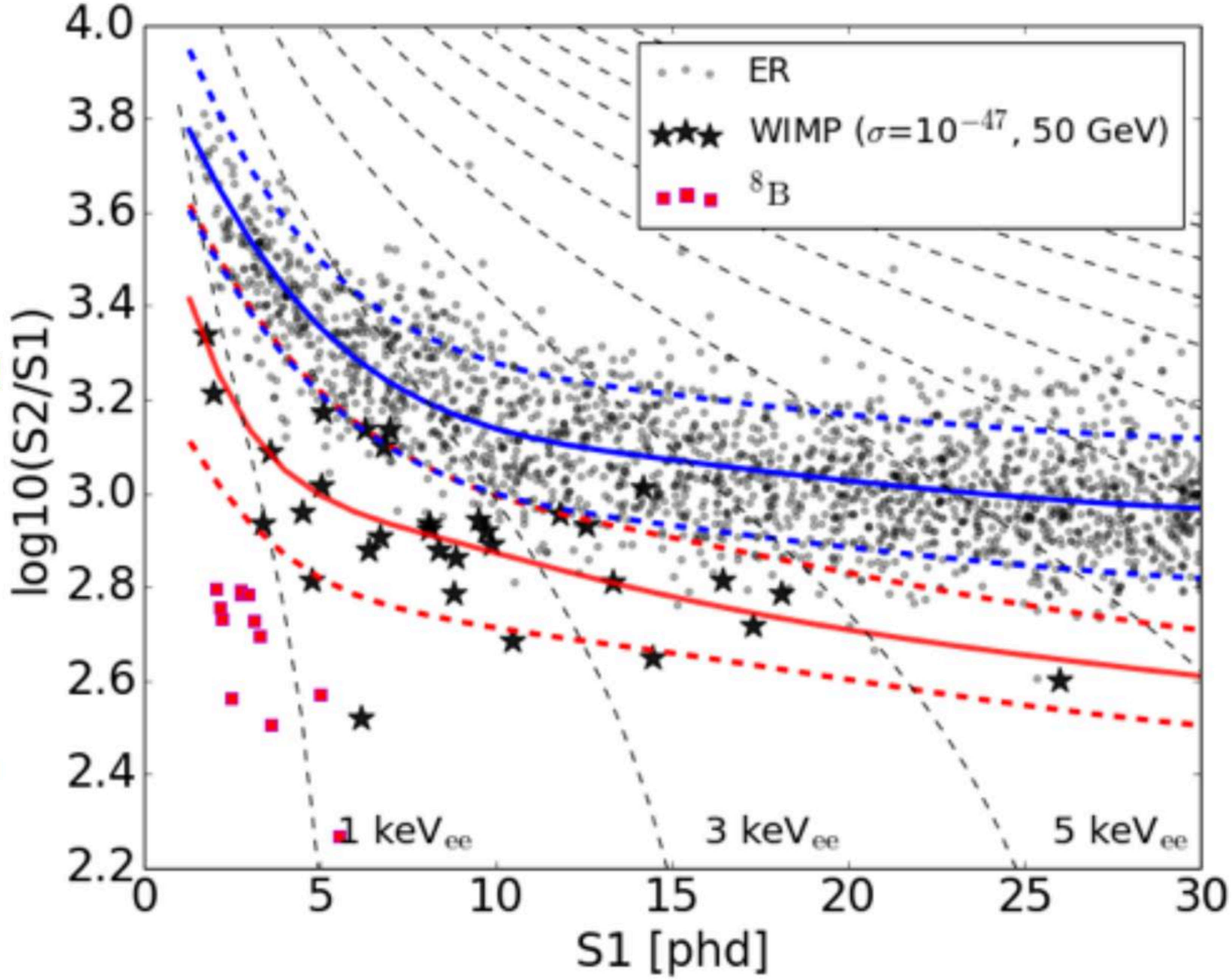
- XENONnT/LZ could reduce the uncertainty on the pp flux to 2.2% (currently Borexino is @10%)
- DARWIN (50t LXe) could bring this down further, to ~1%
- Need to reduce Rn by a factor >10

Solar neutrino NR

$\chi\nu$

- Expect commissioning in 2019
- experiment goal is 1000 days live and 5.6 tonnes fiducial mass
- solar neutrino ER counts (window defined by plot axes): 233 pp, 19 ^{7}Be, a few ^{13}N
- Rn O(100)—O(1000) optimistic and pessimistic cases
  - both compatible with dark matter search goals, but the former makes neutrino physics much more convenient…
- solar neutrino NR counts: 7-70 ^{8}B

as seen by LZ / XENONnT



Neutrinos from SN

$\chi\nu$

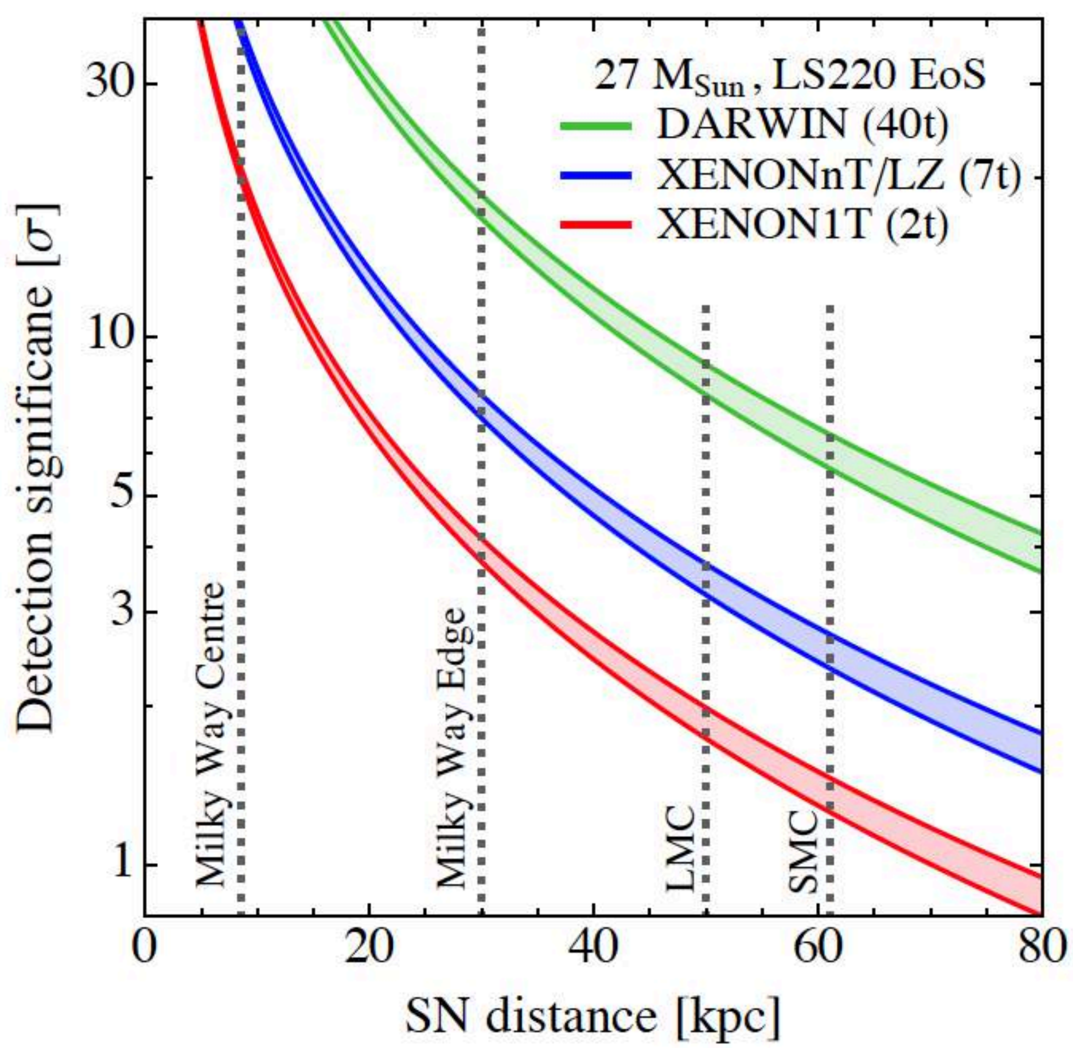
R. Lang, C. McCabe, S. Reichard, M.S., I. Tamborra,
"Supernova neutrino physics with xenon dark matter detectors", Phys. Rev. D 94 (2016) no.10, 103009.

CEvNS with xenon nuclei: not affected by neutrino oscillation

Low energy events -> S2-only analysis
(in the few s burst duration the background rate is small enough: 0.02 / (t s))

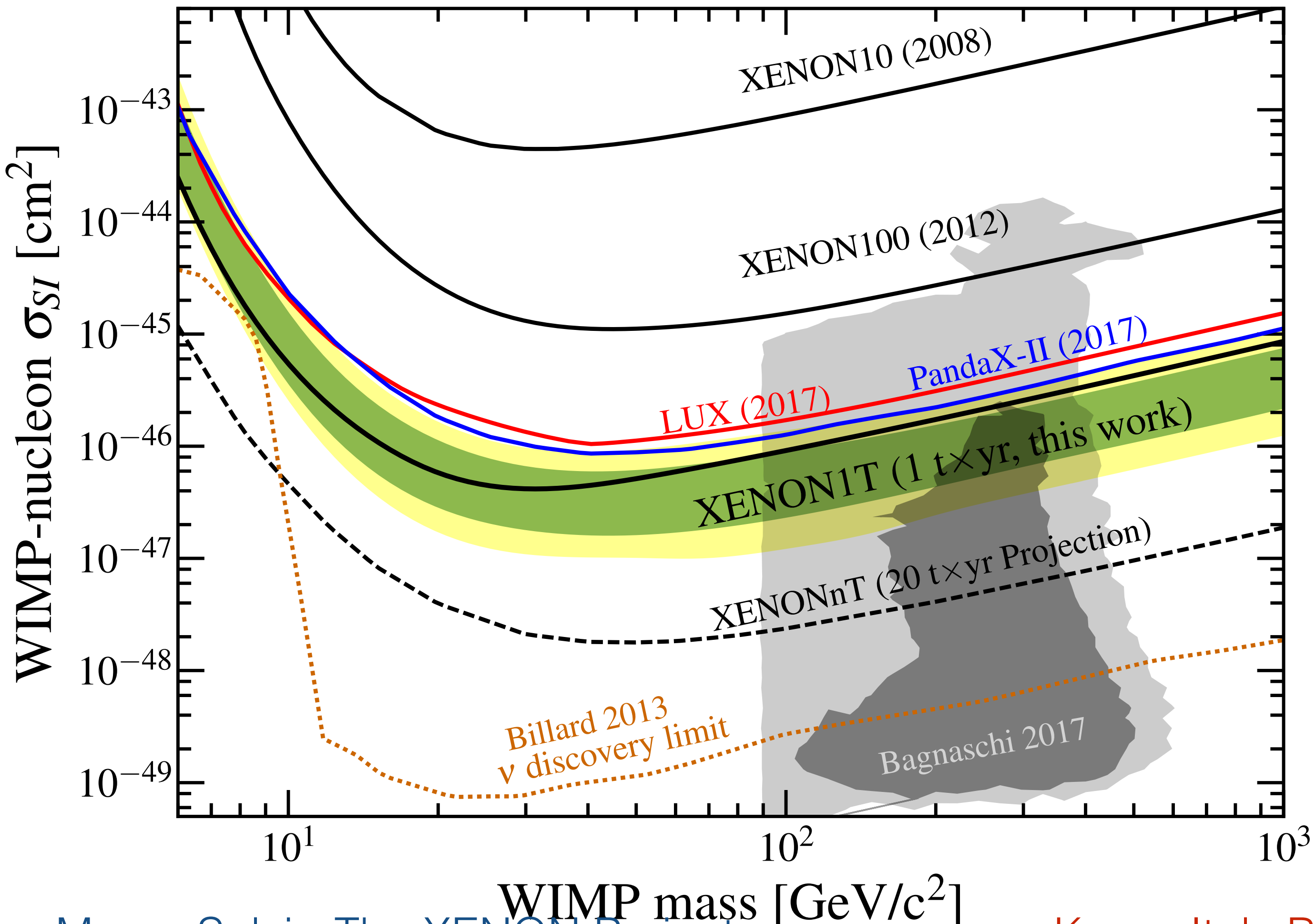
Events per ton of Xe

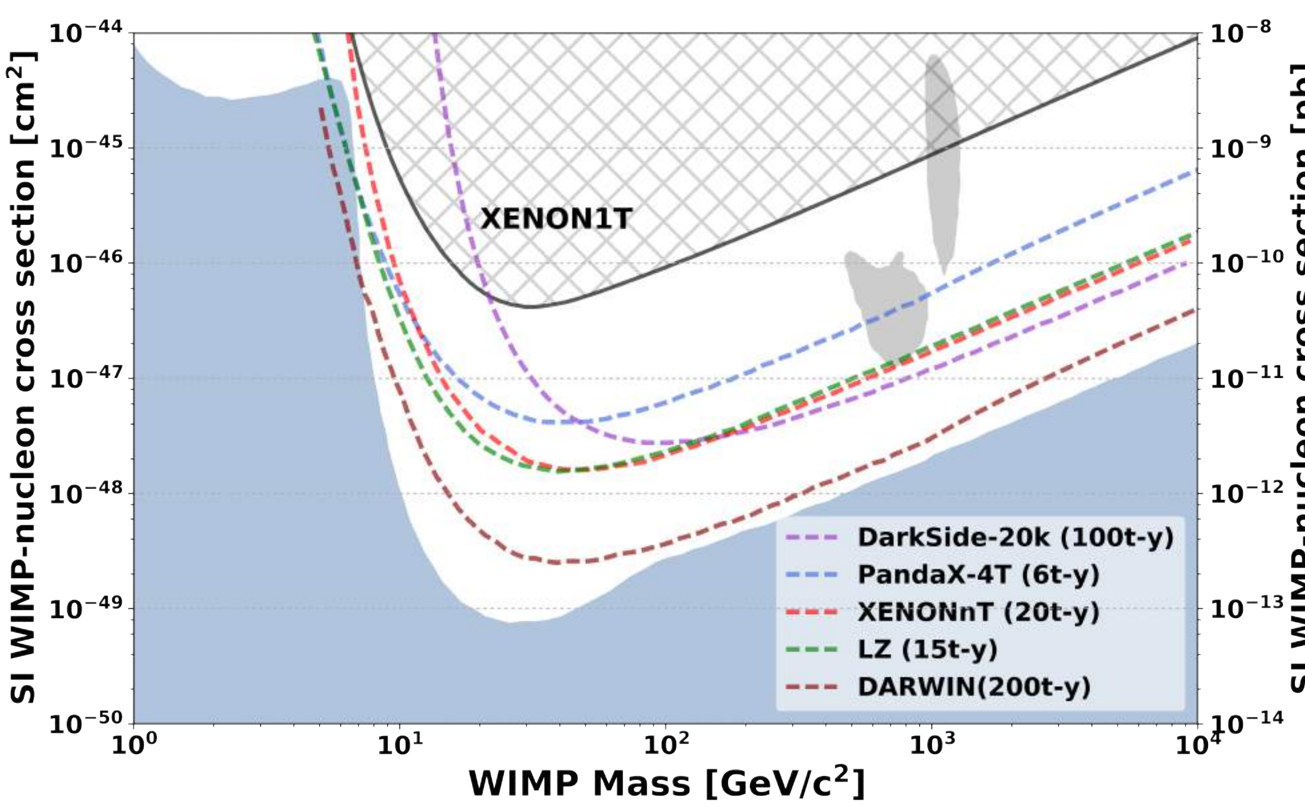
		$27\,M_\odot$		$11\,M_\odot$	
		LS220	Shen	LS220	Shen
$S1_{th}$ [PE]	$\langle N_{ph}\rangle$				
≥ 0	0	26.9	21.4	15.1	12.3
> 0	0	13.3	9.8	6.9	5.2
1	8.3	11.0	8.0	5.6	4.1
2	16.7	7.3	5.1	3.6	2.6
3 ($\star$)	25	5.2	3.5	2.4	1.7
$S2_{th}$ [PE]	$\langle N_{el}\rangle$				
≥ 0	0	26.9	21.4	15.1	12.3
> 0	0	18.5	14.0	9.9	7.6
20	1.2	18.4	14.0	9.8	7.6
40	2.4	18.1	13.7	9.7	7.4
60 ($\star$)	3.6	17.6	13.3	9.4	7.2
80	4.8	17.0	12.8	9.0	6.9
100	6.0	16.3	12.2	8.6	6.5



Summary

- Successfully operated the first multi-ton scale LXeTPC for > 1 year
- Achieved lowest background in any DM detector: 0.2 events / (t keV d)
- The result from a blind analysis of 1 tonne x year data places 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
- The search with XENON1T continues with a larger and better detector, XENONnT, to enable another boost in sensitivity by an order of magnitude
- Nice prospects of using LXe detectors for neutrino physics in the "near" future





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Xe
XENON
Dark Matter Project

Thanks !

Marco Selvi - INFN Bologna
(on behalf of the
XENON collaboration)