The XENON Dark Matter Project at Gran Sasso National Laboratory

Andrea Molinario

PATRAS 2019

XENON collaboration

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

Chicago

UCLA

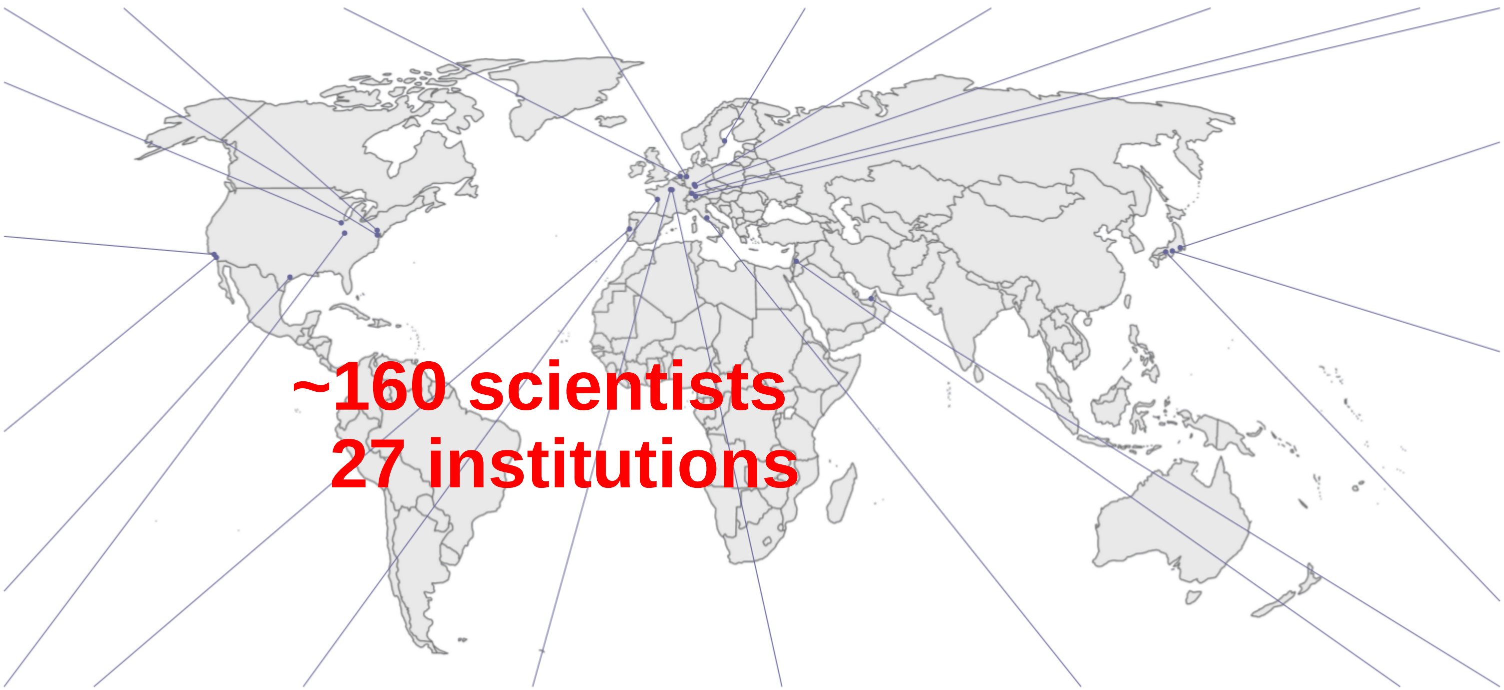
UCSD

Rice

Tokyo

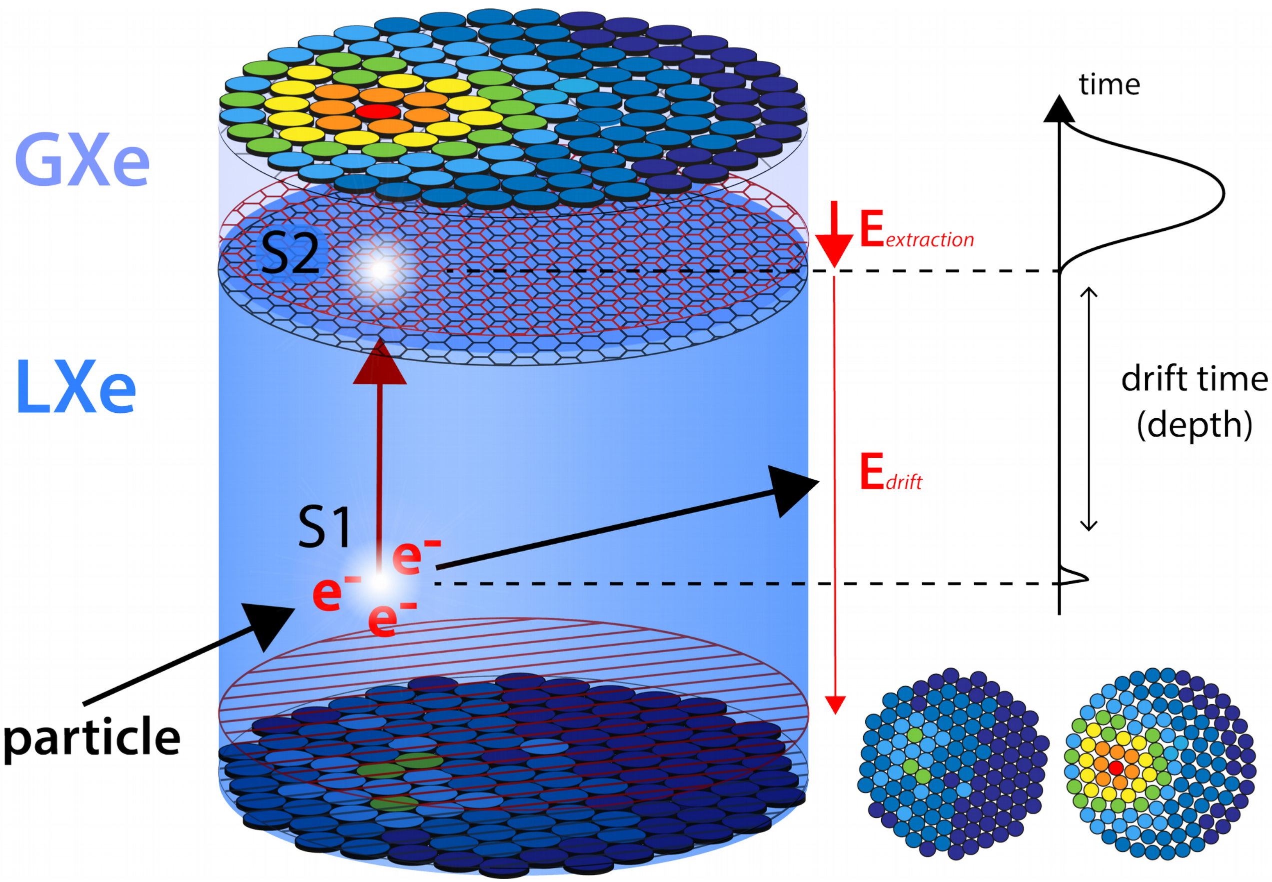
Nagoya

Kobe



Purdue | Coimbra | Subatech | LPNHE | LAL | Bologna | LNGS | Torino | Napoli | Weizmann | NYUAD

Dual-phase Xenon TPC



Liquid Xenon

High density, self-shielding

Good scintillator

No long-living radioactive isotope

Time Projection Chamber

3D position

ER/NR discrimination

Multiple scatter rejection

Low energy threshold

Scalable to multi-ton

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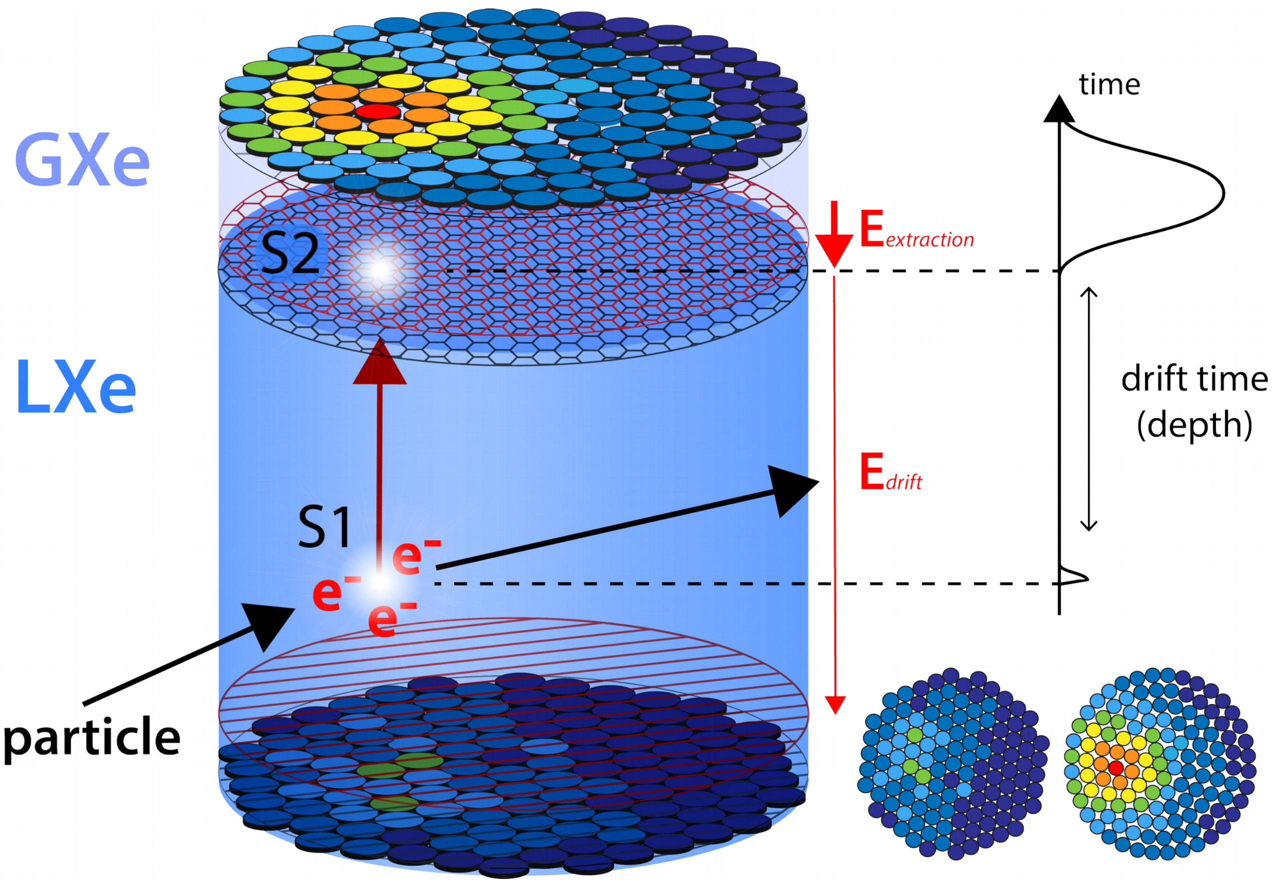

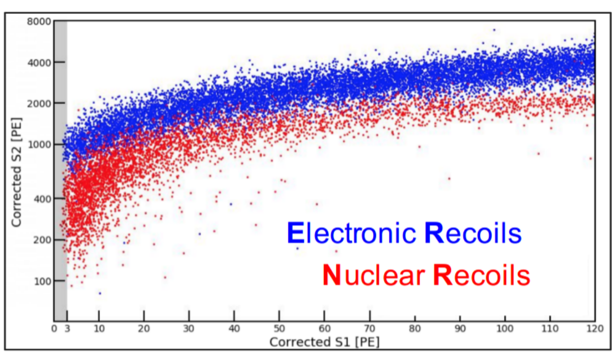

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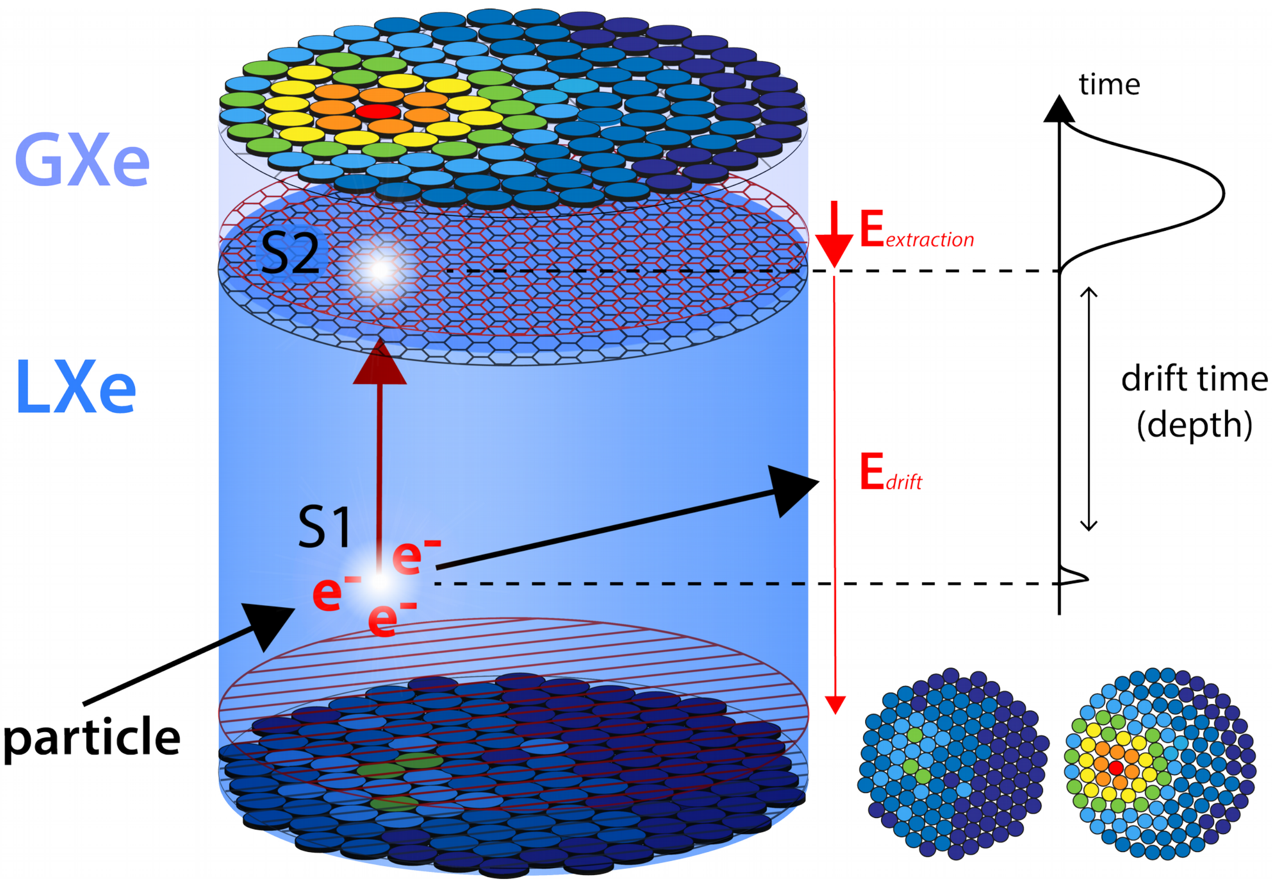

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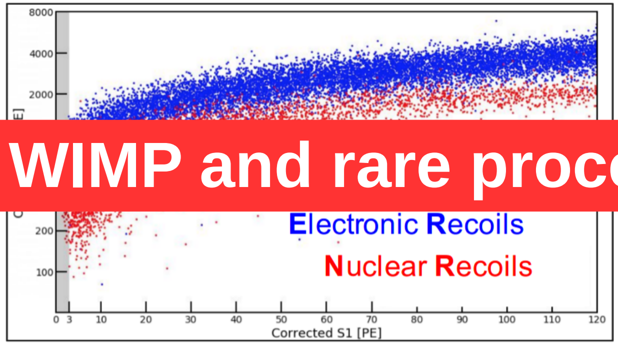
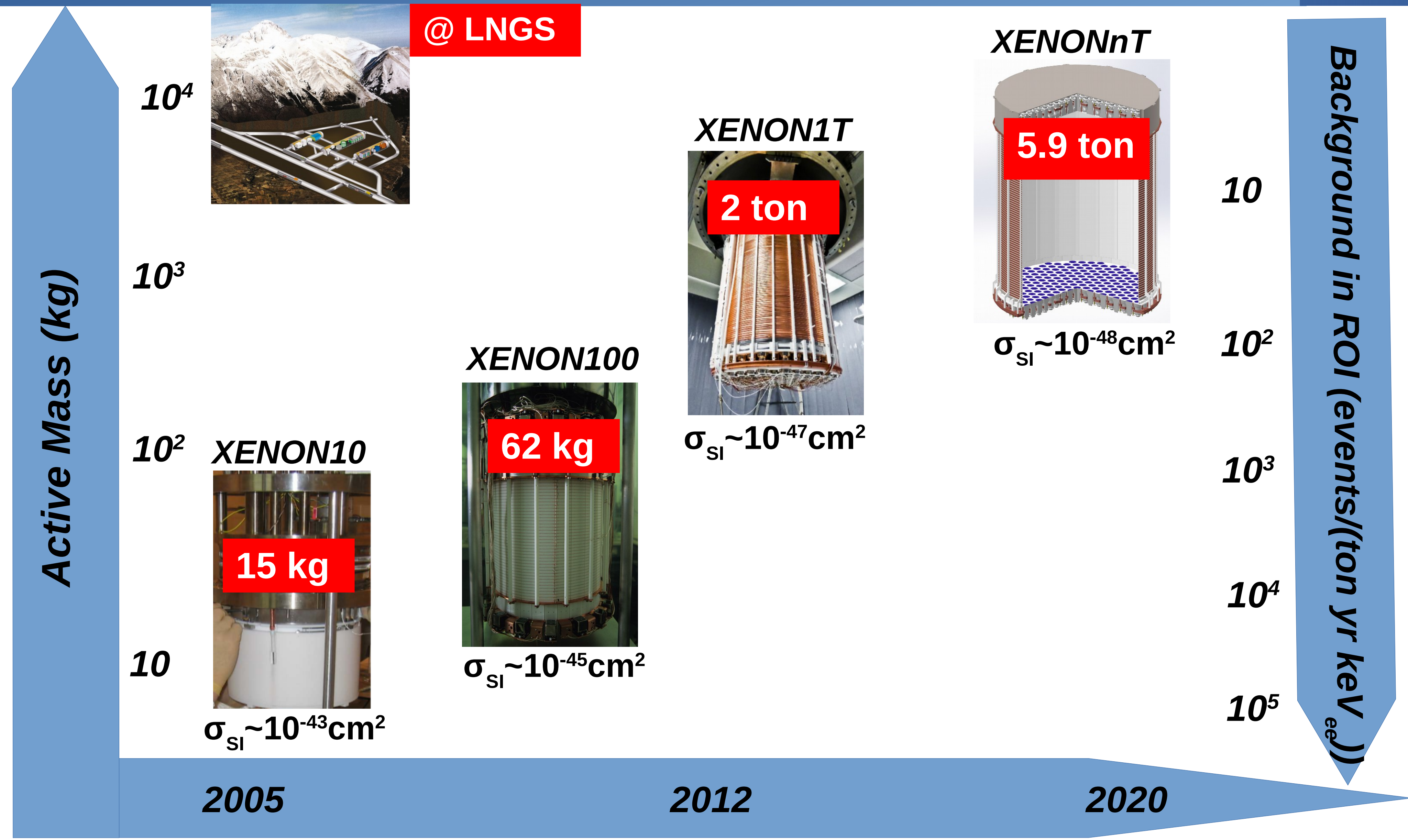


Ideal for WIMP and rare processes search

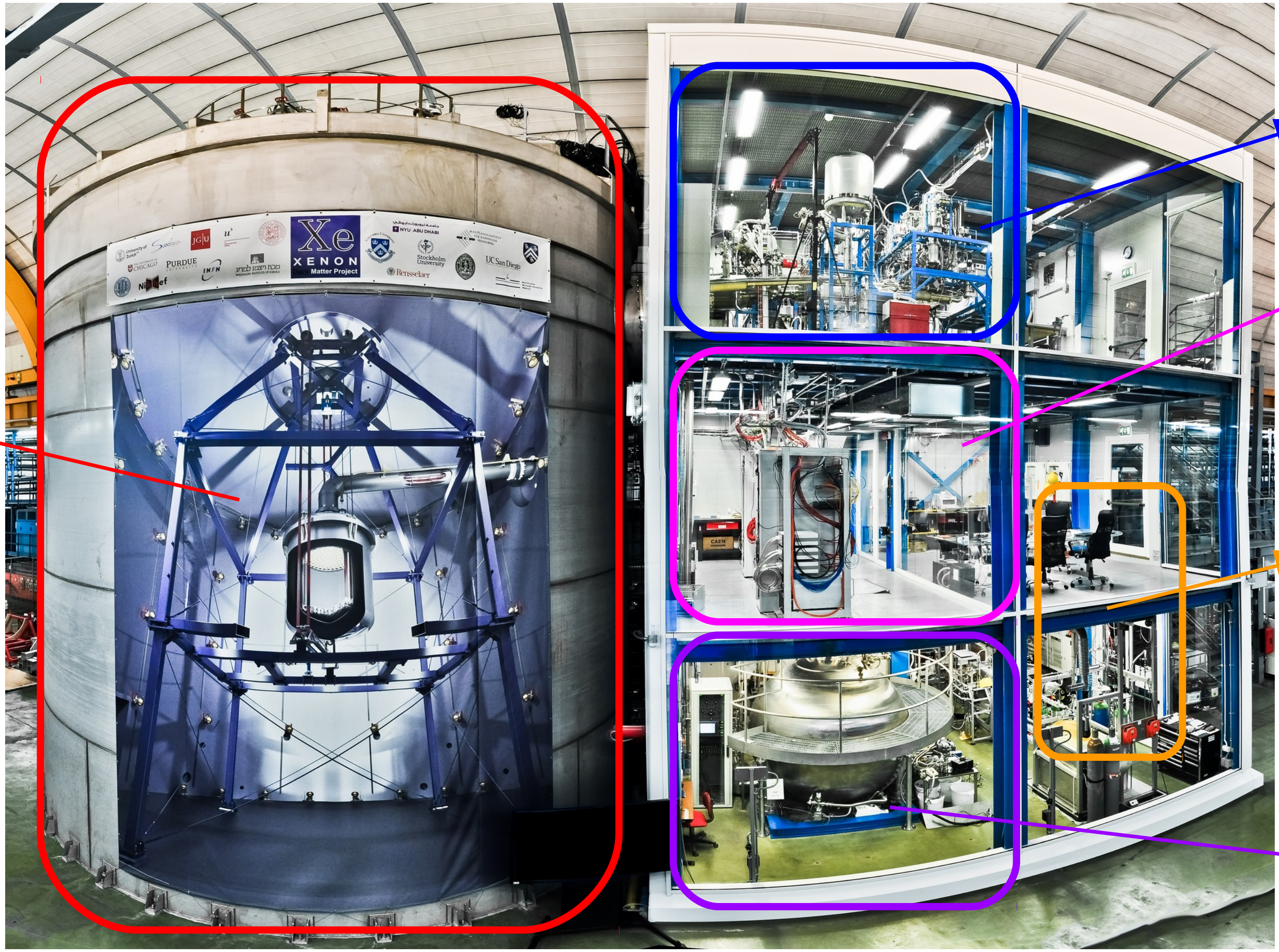
Timeline of the project

XENON Dark Matter Project



XENON1T

Water tank
Muon Veto



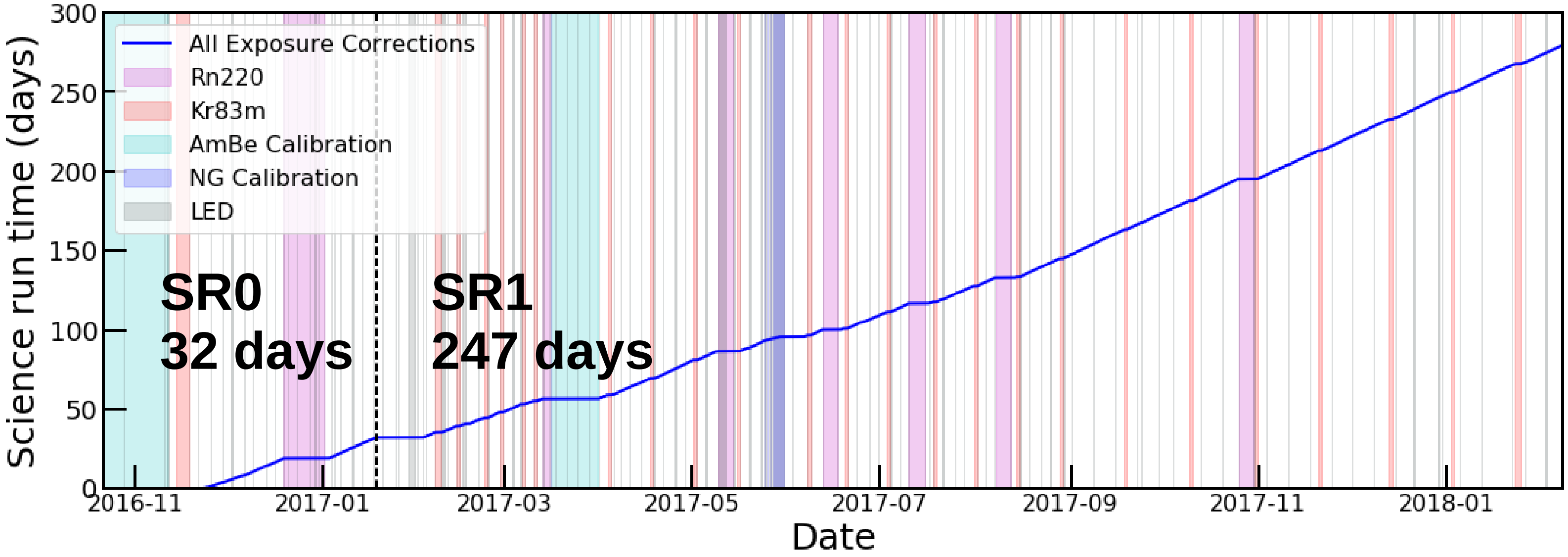
Cryogenics
Purification

Electronics
DAQ

Kr distillation
column

Recovery
and
Storage

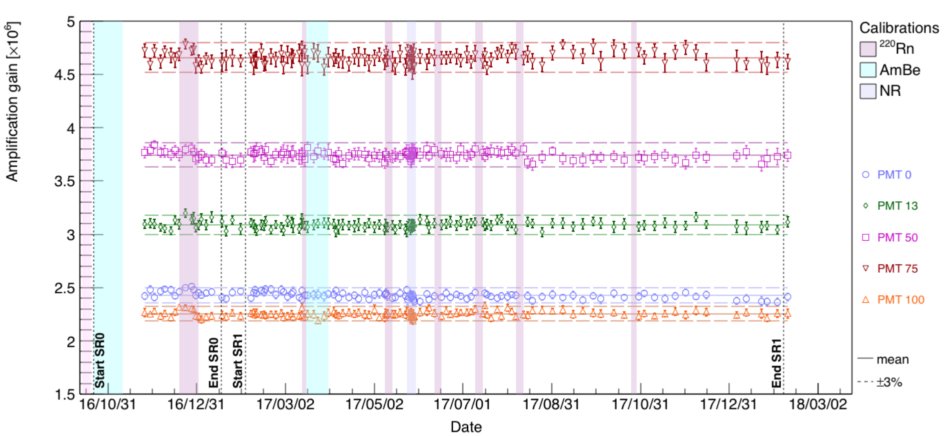
Data taking

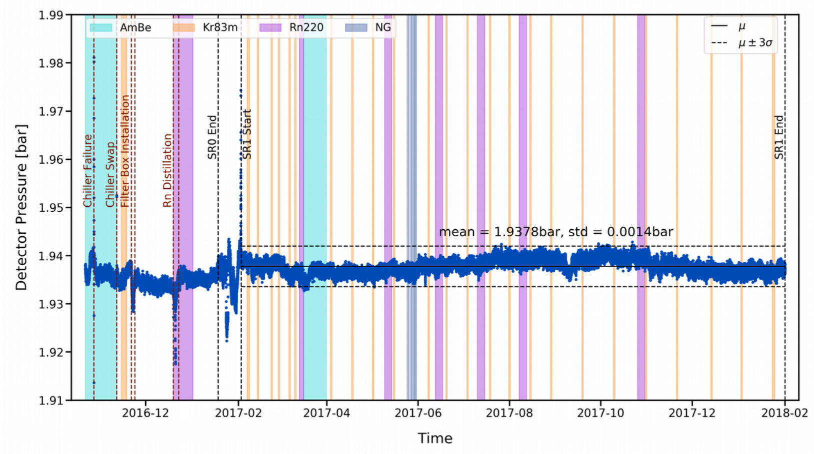


278.8 days

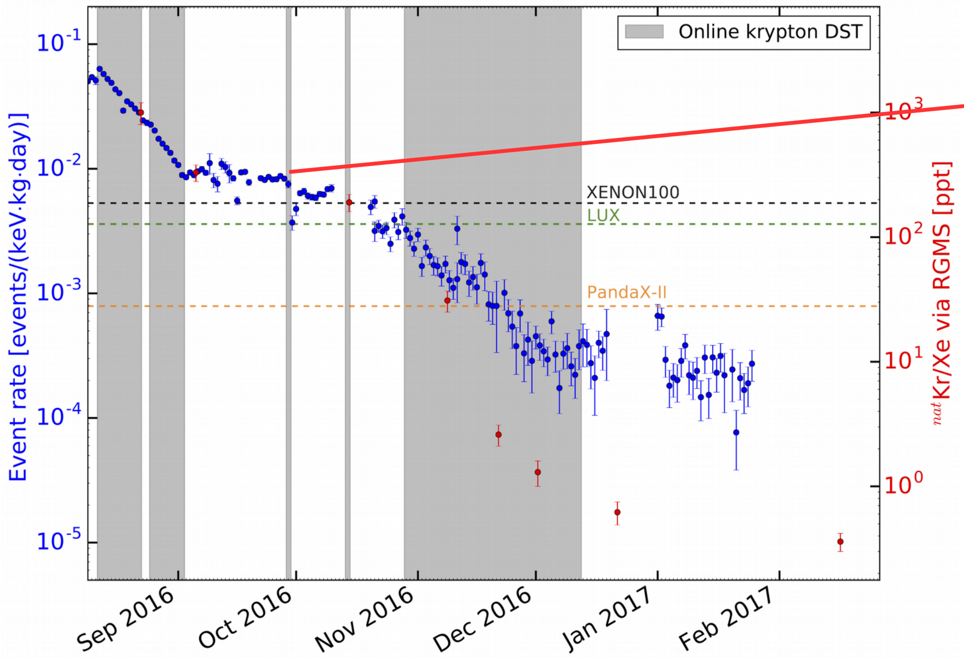
1 ton-year exposure

Monitoring the stability of the detector and PMTs





Electronic recoil background



Initially Kr-dominated

Kr concentration reduced by distillation from 1 ppb to 0.7 ppt

SR1 ER background dominated by ^{222}Rn (mainly ^{214}Pb β-decay)

Source	Fraction [%]	Mitigation strategy
^{222}Rn	85	S2/S1, material selection
Solar ν	5	S2/S1
^{85}Kr	4	S2/S1, distillation
Materials	4	S2/S1, material selection, fiduc.
^{136}Xe	1	S2/S1

ER background in the ROI

82^{+5}_{-3}(syst) ± 3 (stat) events/(ton yr keV$_{ee}$)

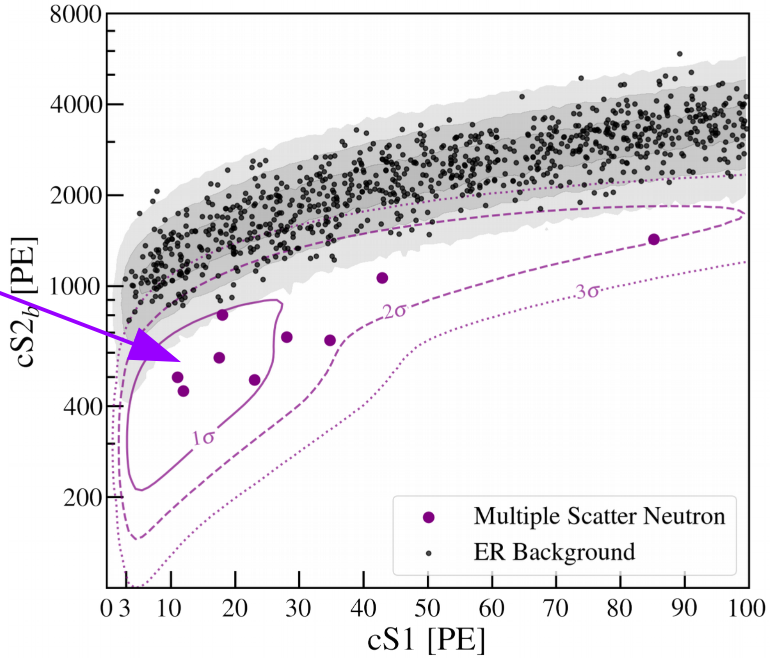
Lowest ER background for a dark matter detector

Nuclear recoil background

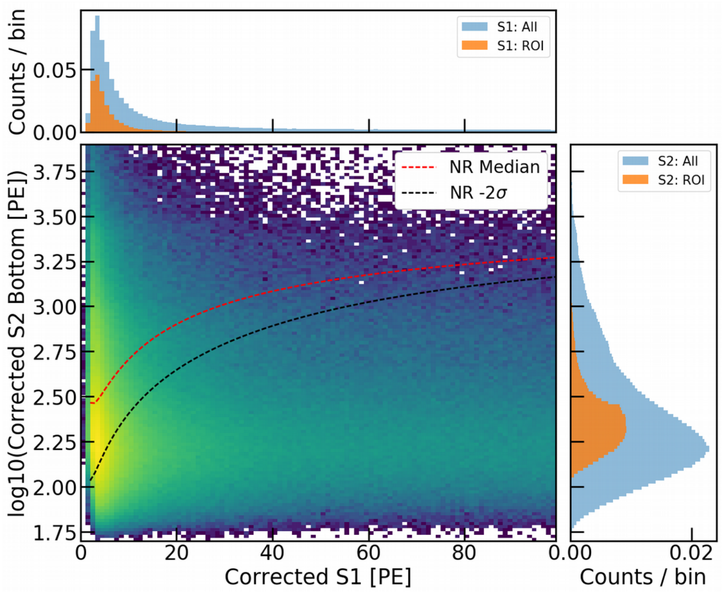
Source	Mitigation strategy
Radiogenic neutrons (from materials)	Material selection, reject multiple scatter, fiducialization
CEνNS (mainly ^{8}B solar ν)	
Cosmogenic neutrons	Muon Veto, reject multiple scatter, fiducialization

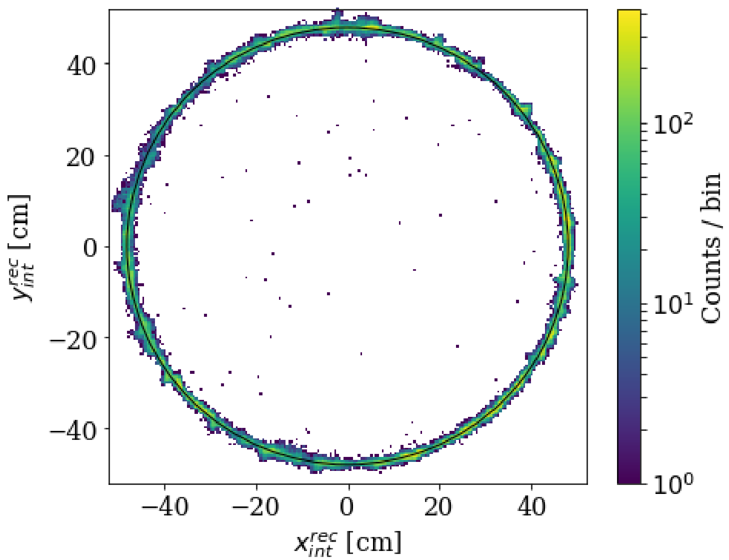
Dedicated search for multiple scatter events found 9 candidates with (6.4±3.2) expected

Constrain the expected single-scatter neutron event rate



Other backgrounds





Accidental coincidences

Random pairing of lone S1 and S2

Background model derived from data and used in likelihood estimation

Surface events

^{222}Rn progeny plate-out on the inner surface of PTFE panels

Charge loss which reduces S2 size

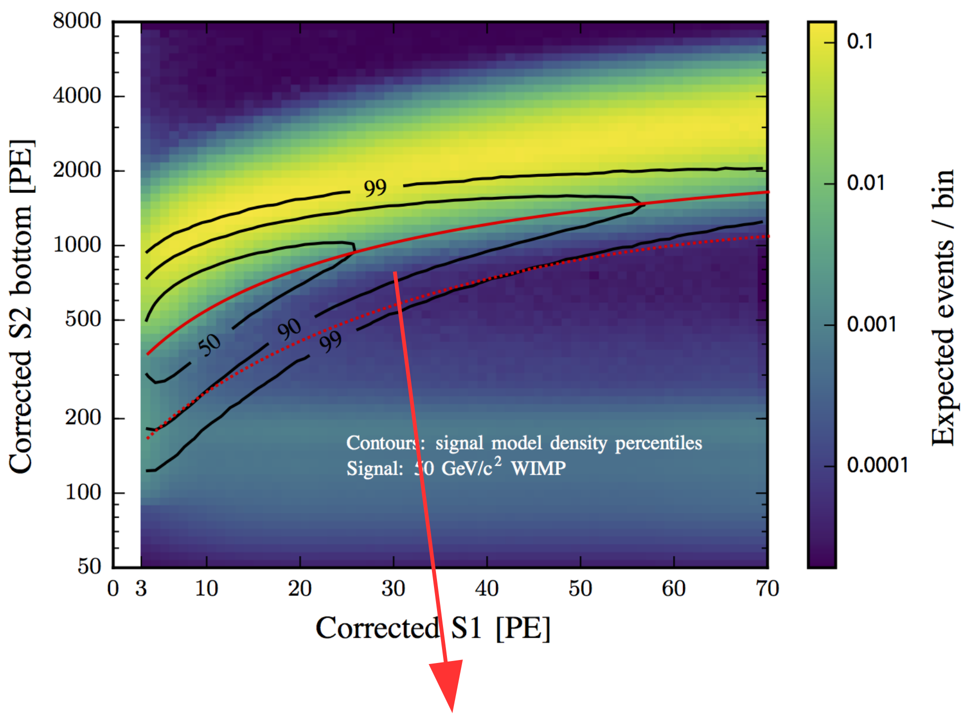
Events shifted in NR band

Data-driven background model

Background predictions

ROI corresponds in average to
[4.9, 40.9] keV_{nr} ([1.4, 10.6] keV_{ee})

Background model in 4 dimensions:
S1, S2, R, Z



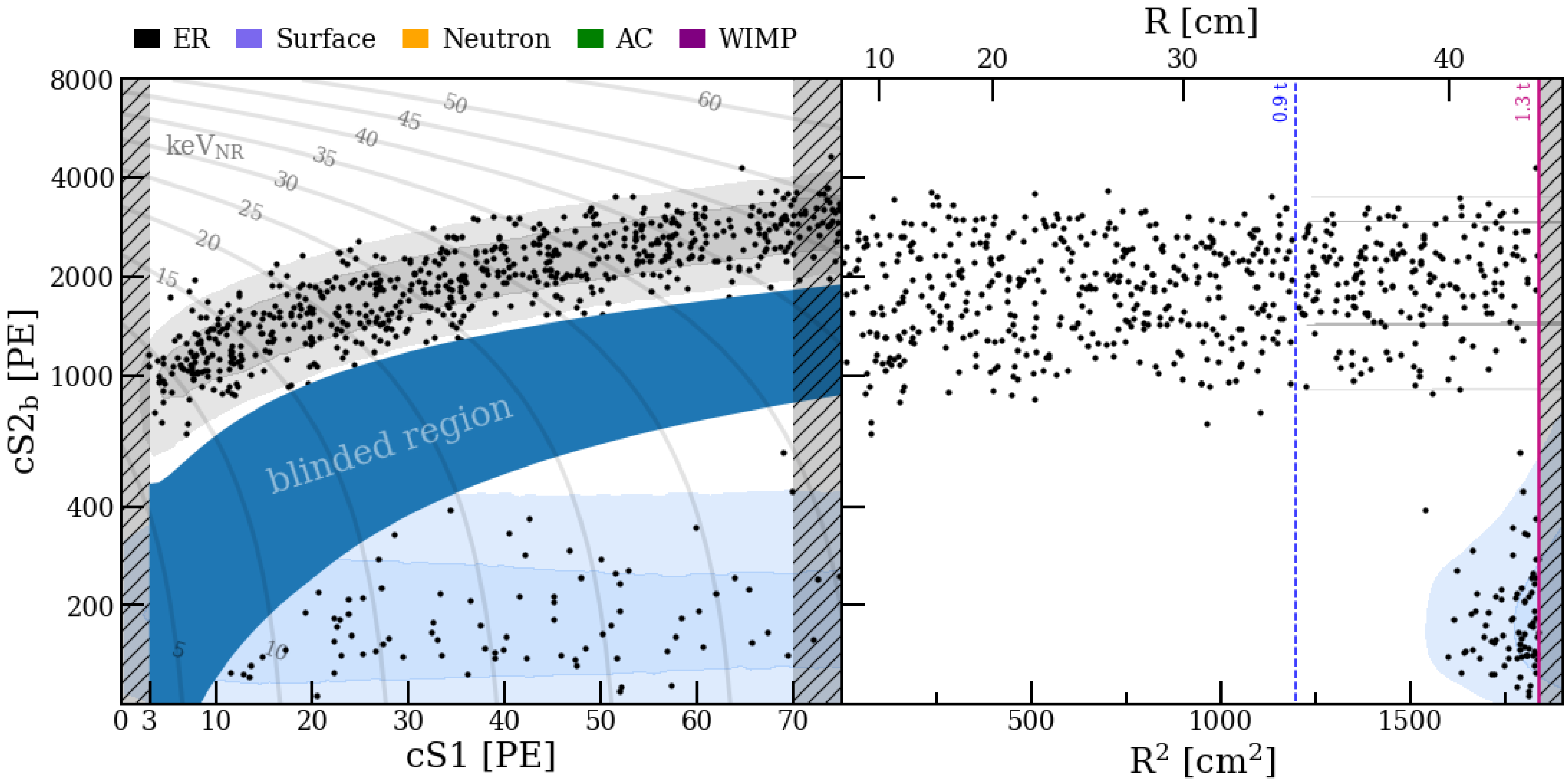
Mass (ton)	1.3	1.3	0.9
($cS1$, $cS2_b$)	Full	Reference	Reference
ER	627 ± 18	1.62 ± 0.30	1.12 ± 0.21
Neutron	1.43 ± 0.66	0.77 ± 0.35	0.41 ± 0.19
CEνNS	0.05 ± 0.01	0.03 ± 0.01	0.02
AC	$0.47^{+0.27}_{-0.00}$	$0.10^{+0.06}_{-0.00}$	$0.06^{+0.03}_{-0.00}$
Surface	106 ± 8	4.84 ± 0.40	0.02
Total BG	735 ± 20	7.36 ± 0.61	1.62 ± 0.28

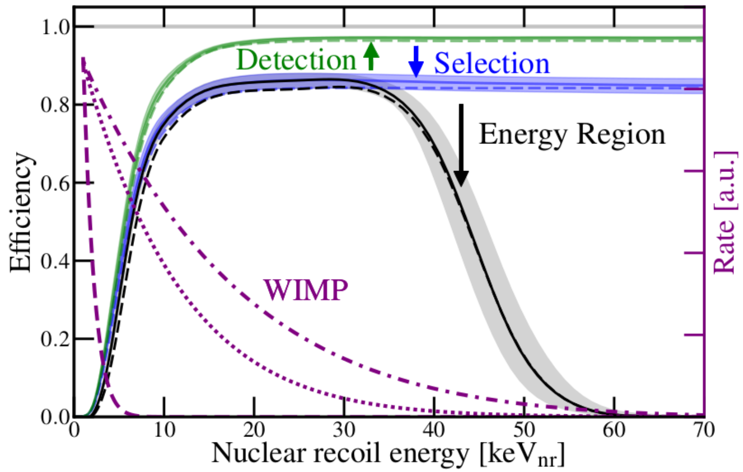
NR reference region

50% NR acceptance with 99.75% ER rejection

Statistical inference in 1.3 t fiducial volume and full (S1, S2) space

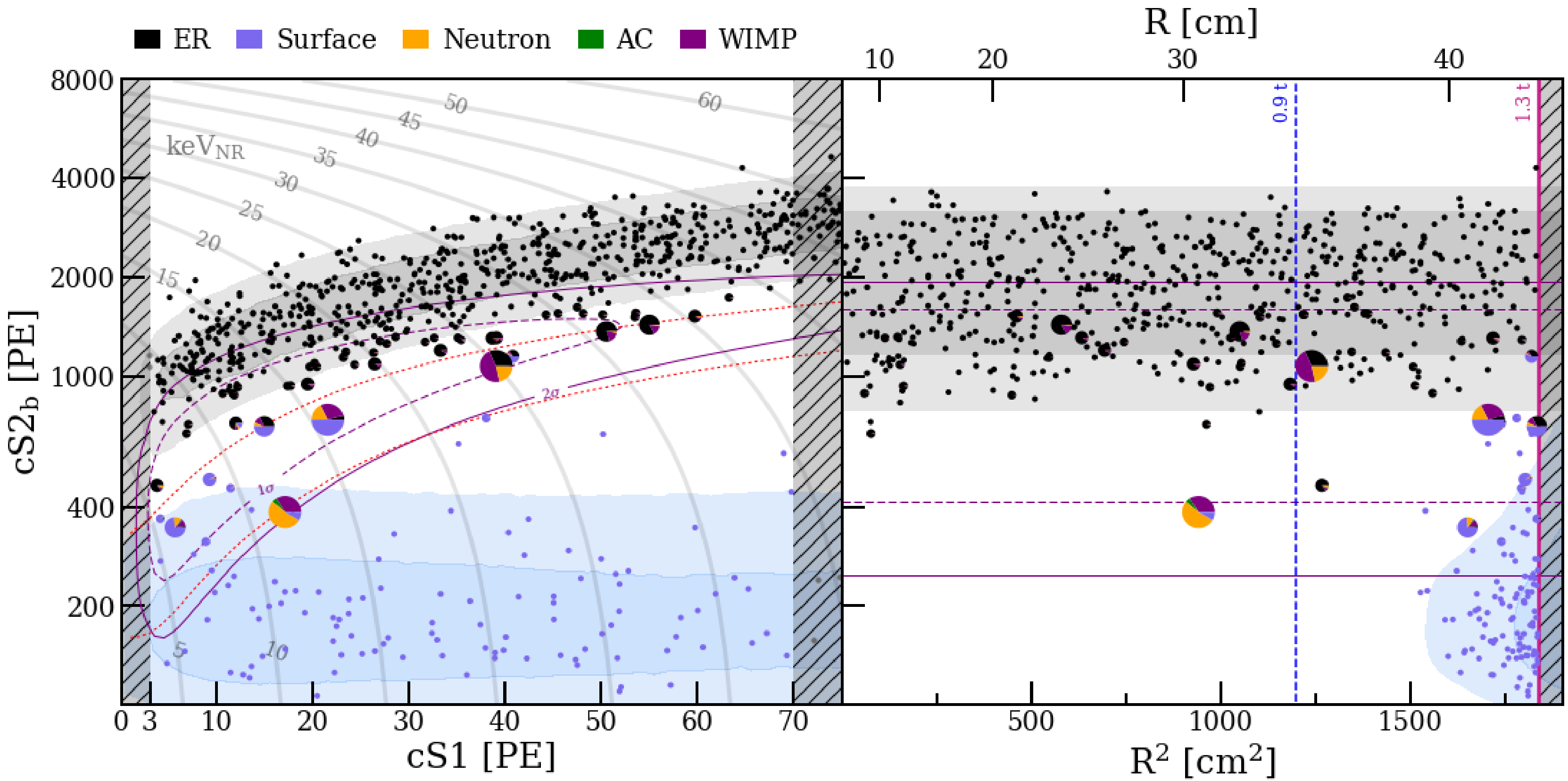
SI-WIMP result





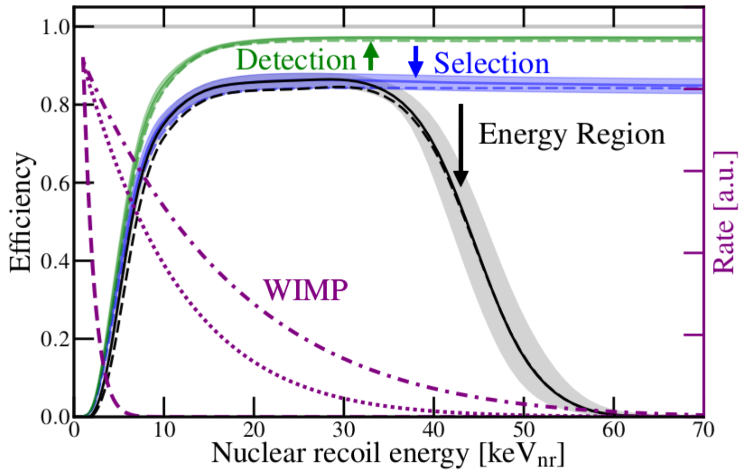
All selection criteria were defined before unblinding

SI-WIMP result

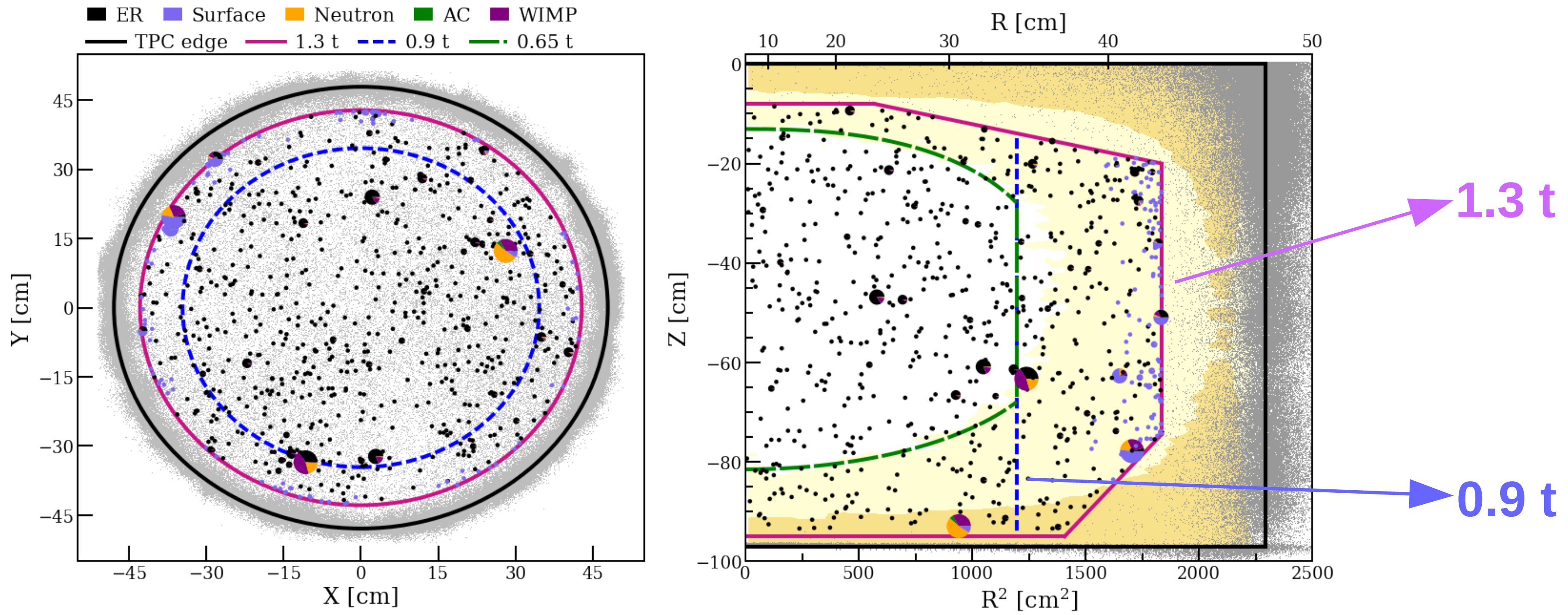


Events that pass all cuts are shown

They are shown as pie charts representing the best-fit probabilities of the background and signal (200 GeV WIMP) components at each event

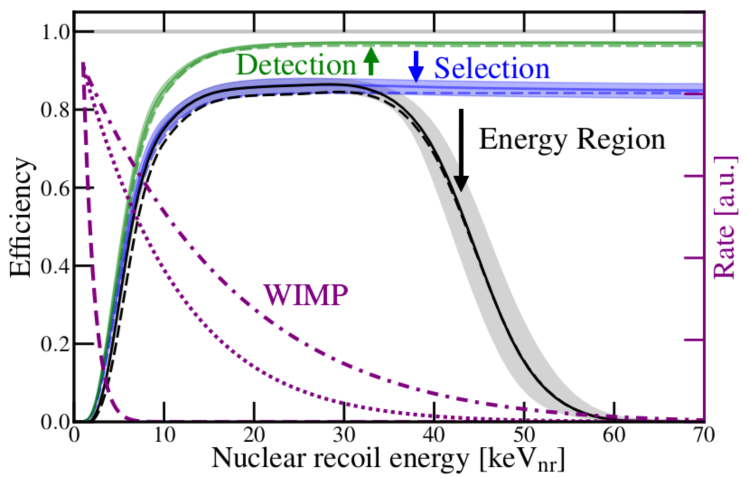


SI-WIMP result



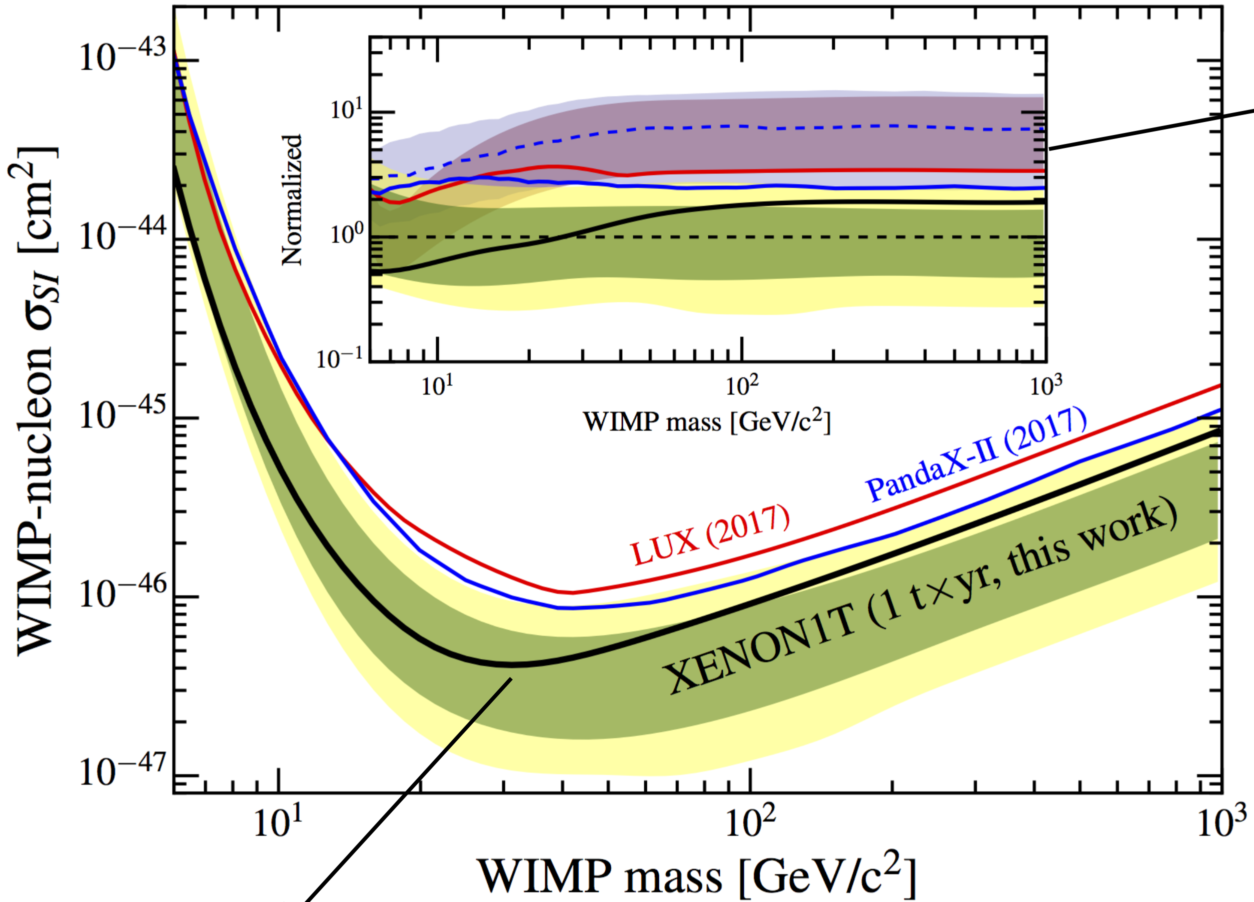
Performed unbinned profile likelihood, model uncertainties included as nuisance parameters

Maximum radius of 1.3 t fiducial volume set by surface event contribution.



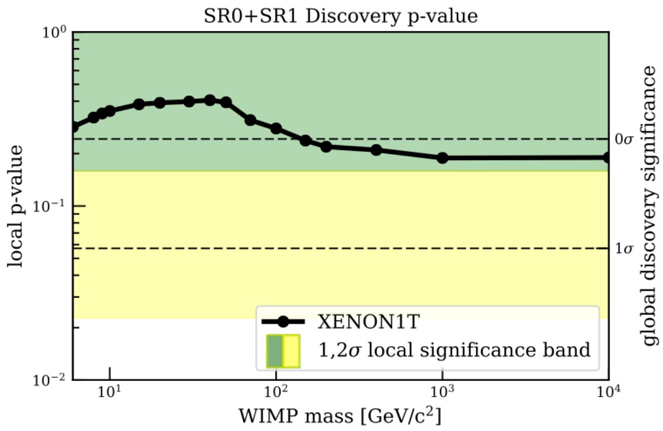
SI-WIMP result

E. Aprile et al., Phys. Rev. Lett. 121, 111302 (2018)



Median sensitivity 7 times better than previous experiments

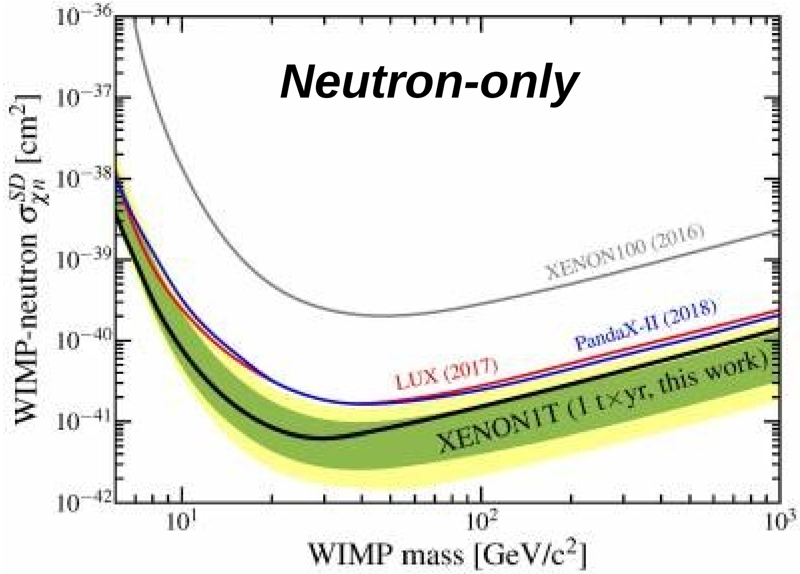
No significant excess (>3σ) in the 1.3 tons fiducial volume at any WIMP mass

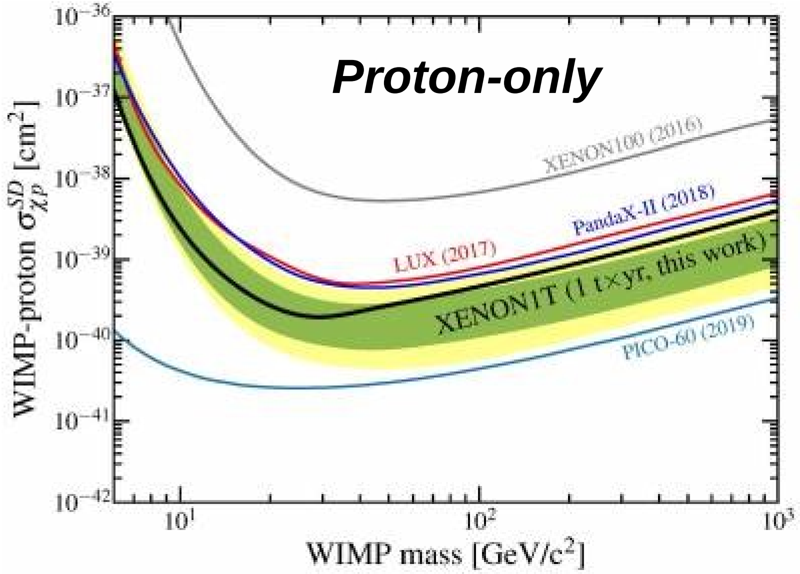


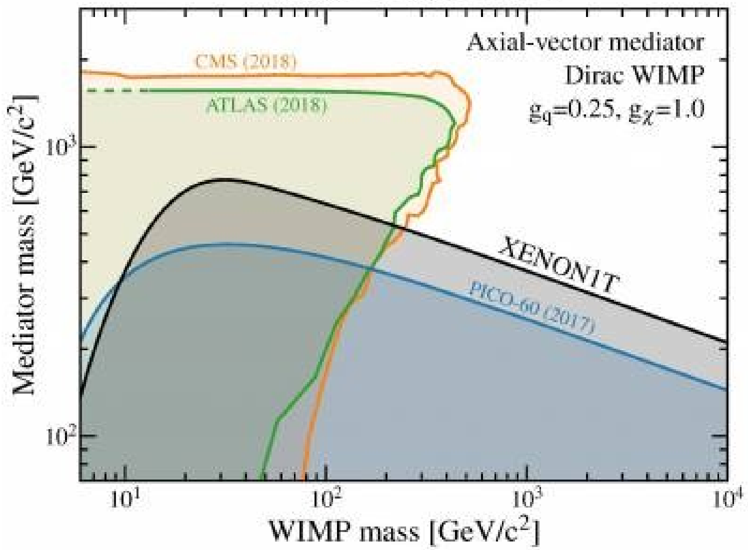
σ_{SI}<4.1*10^{-47} cm^2 (90% C.L.) @ 30 GeV/c^2

SD-WIMP result

E. Aprile et al., Phys. Rev. Lett. 122, 141301 (2019)







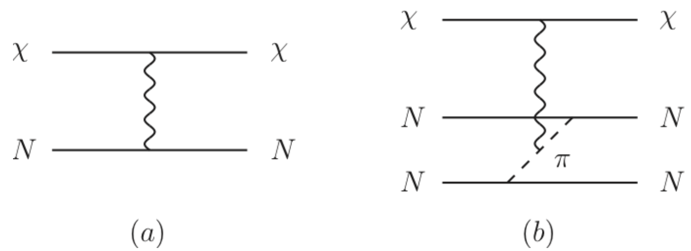
Same event selection criteria for a SD search

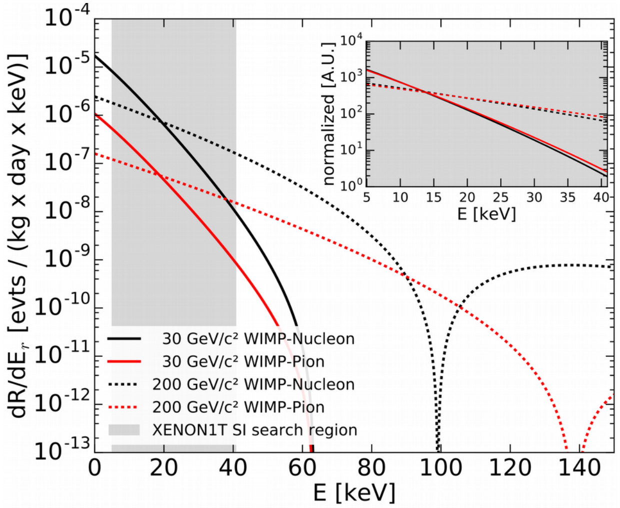
Most stringent limit on WIMP-neutron scattering cross section

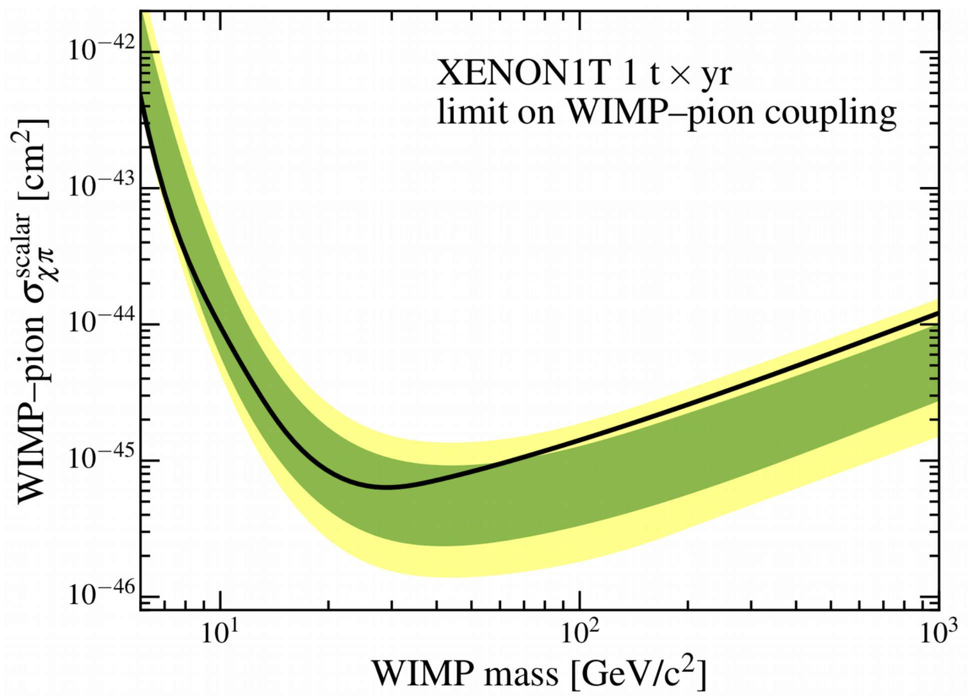
Exclude new parameter space in isoscalar theory with axial-vector mediator

WIMP-Pion coupling

E. Aprile et al., Phys. Rev. Lett. 122, 071301 (2019)





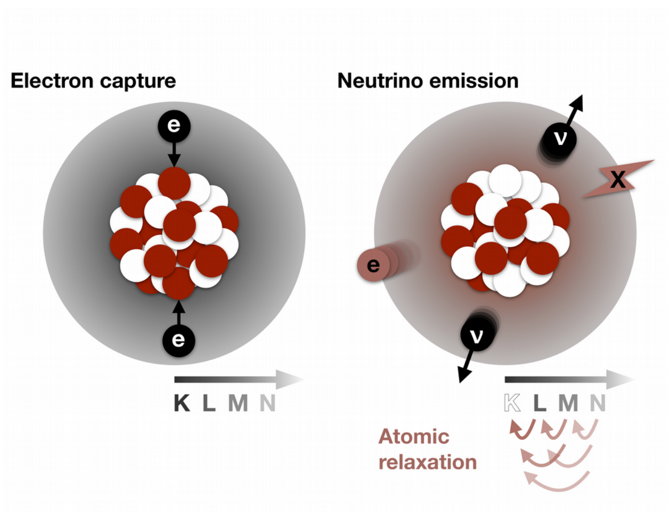


Coupling of WIMP with virtual pion-current between two nucleons

Same falling exponential differential recoil spectrum as WIMP-nucleon interaction

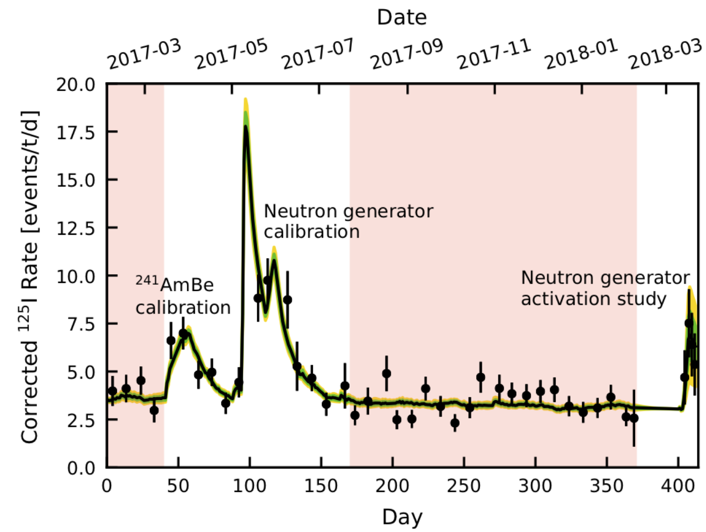
Limit setting as in SI analysis

^{124}Xe Double Electron Capture



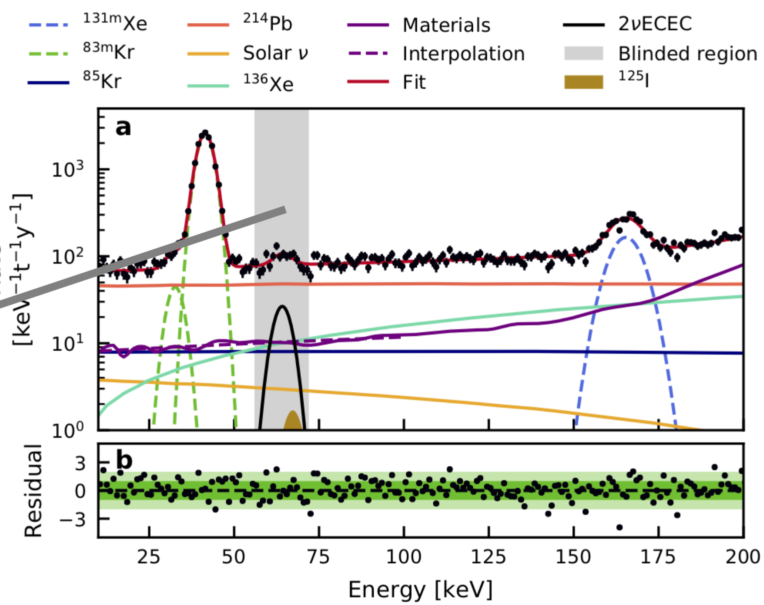
$$^{124}Xe + 2e^{-} \rightarrow {}^{124}Te + 2\nu_e$$

Detection of X-rays and
Auger electrons
Total energy (64.3±0.6) keV



Background from
^{125}I produced by
^{124}Xe activation

Blinded [56-72] keV region



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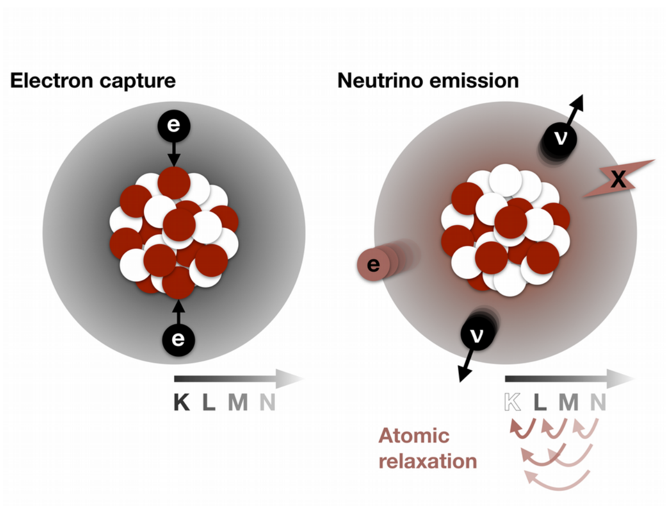

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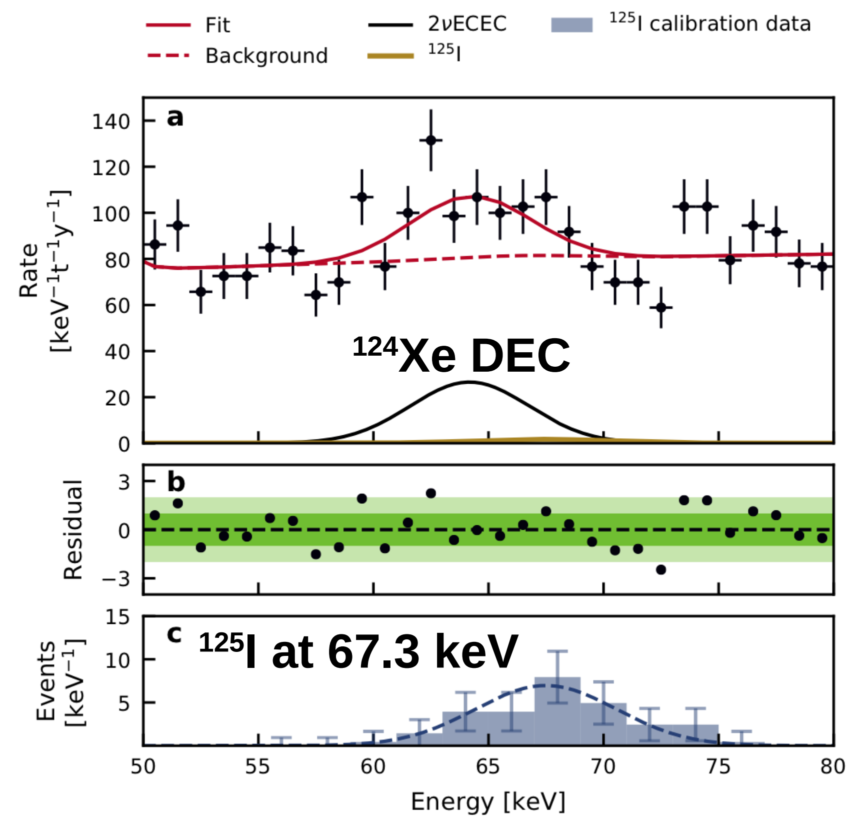
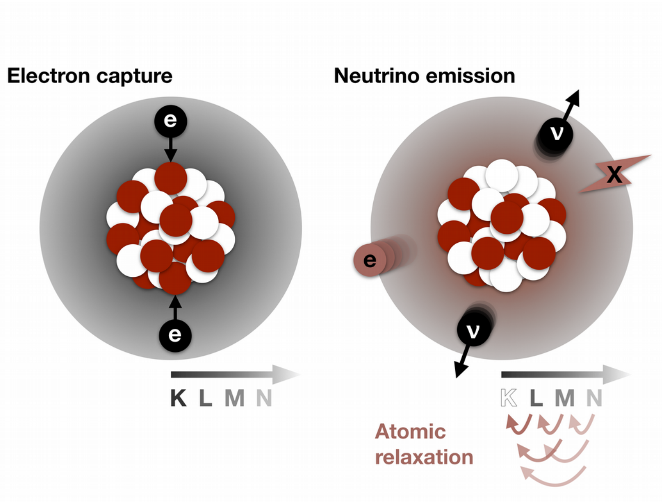


Detected peak at (64.2±0.5) keV with 4.4σ significance

Measured half-life of the process **$T_{1/2}$ = (1.8 ± 0.5$_{stat}$ ± 0.1$_{sys}$) x 10^{22} y**

E. Aprile et al., Nature 568 (2019), no.7753, 532-535

^{124}Xe Double Electron Capture



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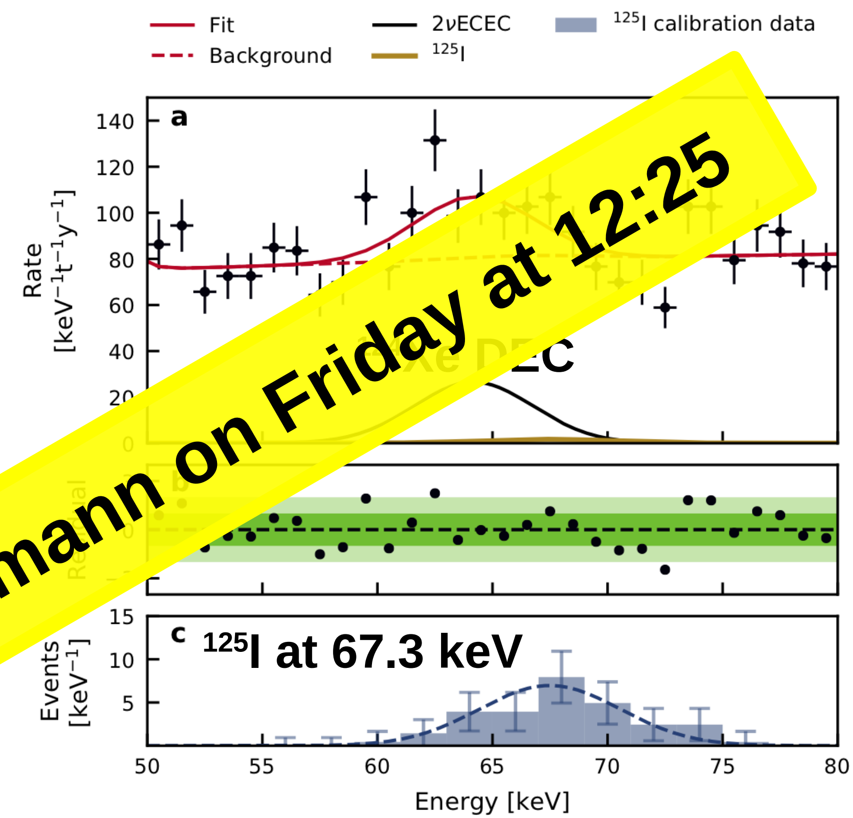

Dedicated talk by S. Lindemann on Friday at 12:25

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Ongoing analysis

S2-only analysis

WIMP search with Migdal effect

ALPs, Super WIMPs,
Dark photons, Solar Axions

Annual modulation

$0\nu\beta\beta$ of ^{136}Xe

^{37}Ar calibration

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Low energy Electronic Recoils

ALPs, Super WIMPs,
Dark photons, Solar Axions

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^{37}Ar calibration

Tests after SR1

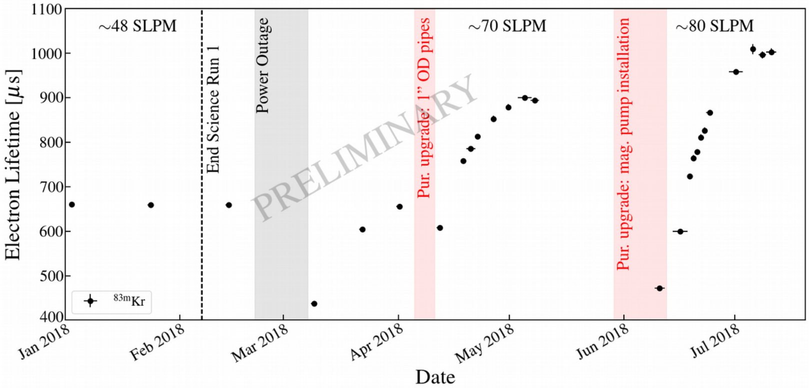
XENON Dark Matter Project

Upgrade of purification system

New magnetic pump

Increased purification of gas flow

1 ms electron lifetime reached

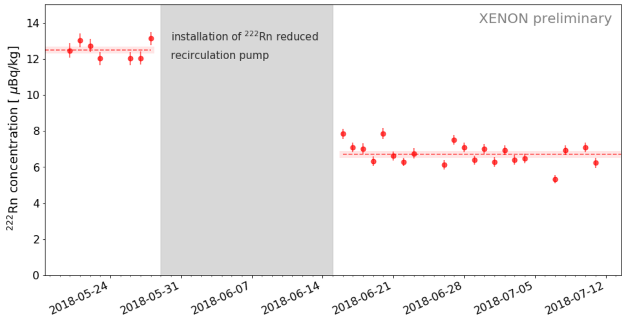


Rn-removal

With new magnetic pump Radon reduced by 45%

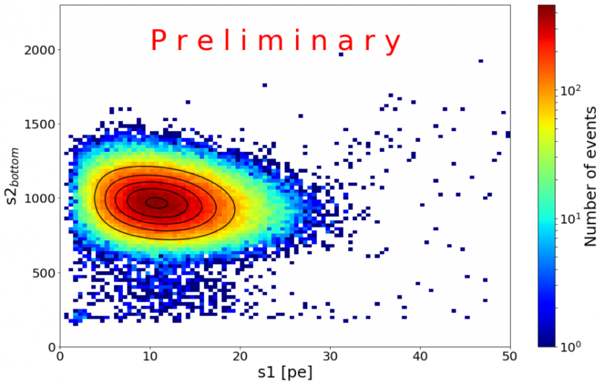
Rn distillation tested, another 30% reduction

Factor 4 above XENONnT goal (1μBq/kg)

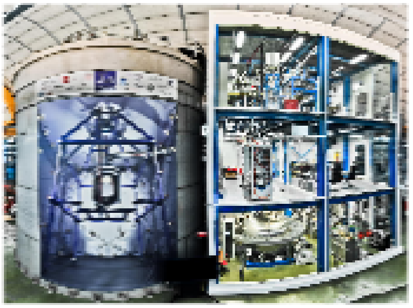


^{37}Ar calibration

Test of new calibration source for low energy ER (2.8 keV, 0.27 keV)



XENONnT

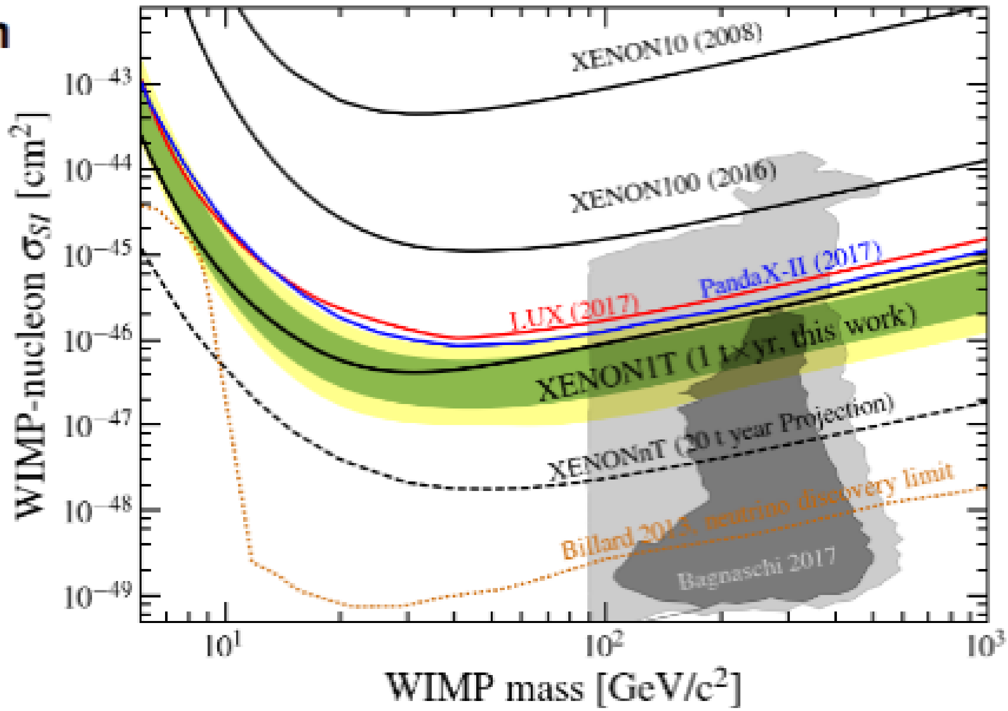


Use most of XENON1T subsystem

To increase sensitivity by one order of magnitude:

$\sigma_{SI} \sim 10^{-48}$ cm^2

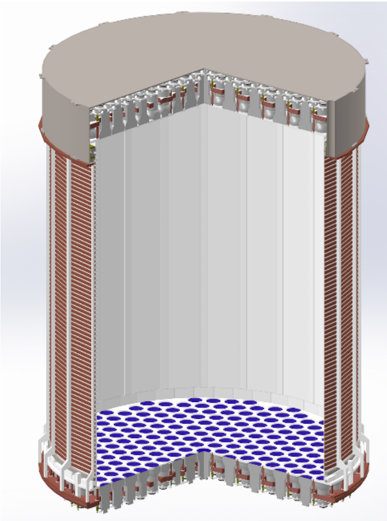
Construction in 2019



Increase fiducial mass by factor 4

Reduce background by factor 10

New features XENONnT



NEW TPC

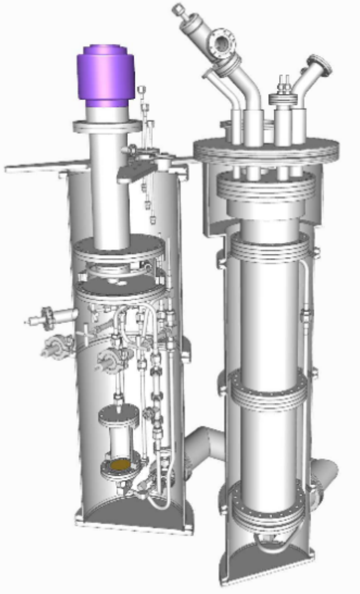
494 PMTs

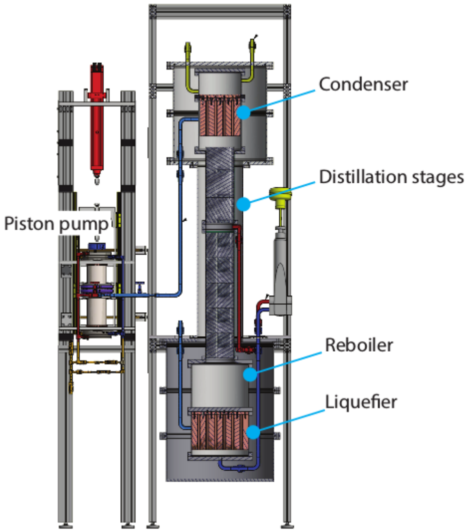
1.5 m height
1.3 m diameter

LXE PURIFICATION

Much faster purification speed

Possible to purify the 8 t of Xe in a reasonable time





RADON DISTILLATION COLUMN

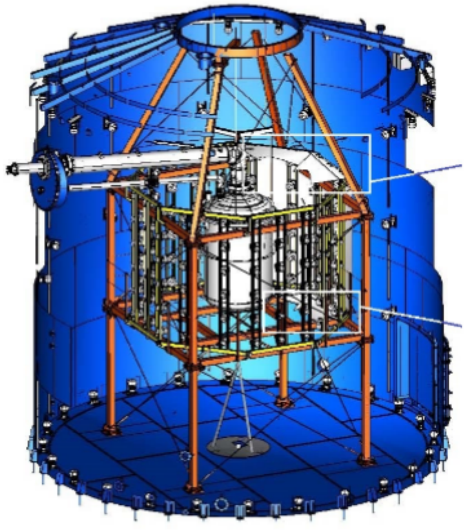
Goal 1 μBq/kg Rn contamination

Rn distillation already tested in XENON1T

NEUTRON VETO

0.2% Gd-doped water

120 additional PMTs around cryostat



Conclusions

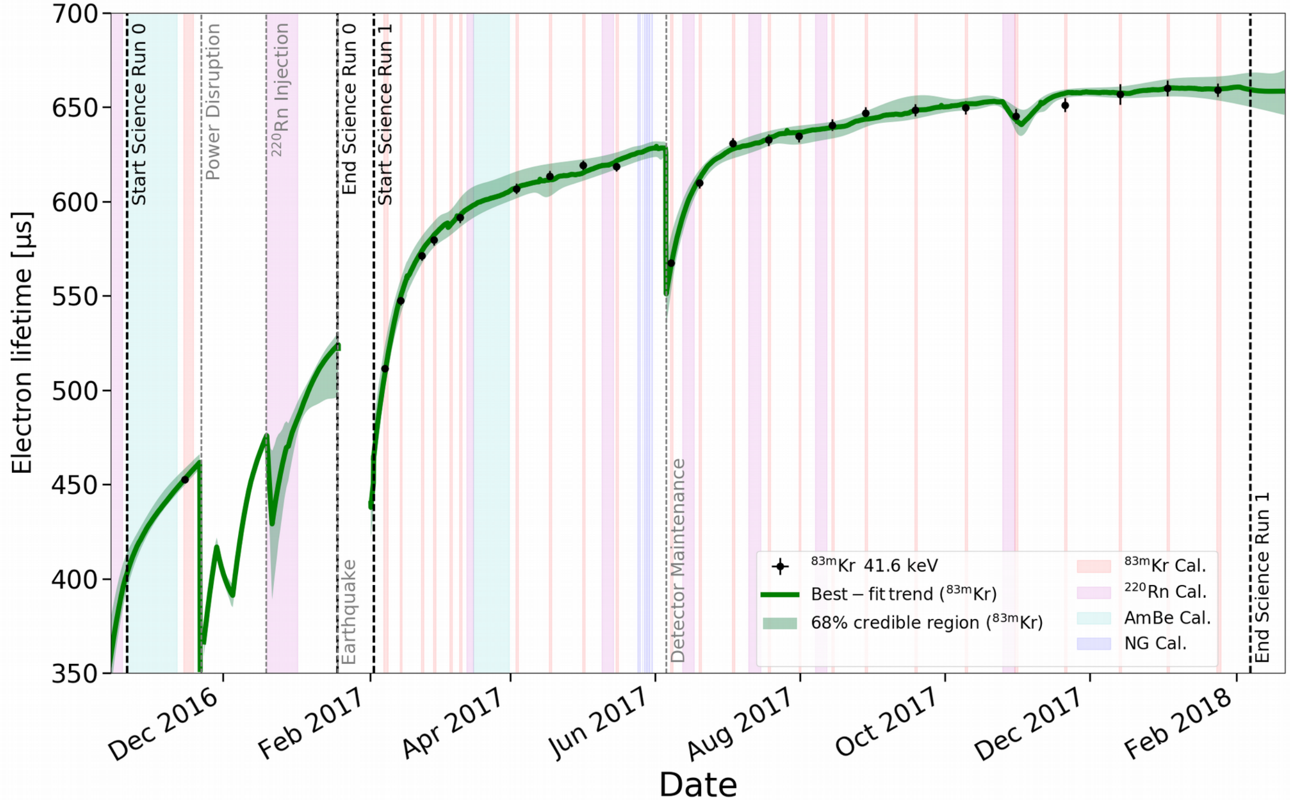
XENON1T reached 1 ton-year exposure with the lowest ER background for a dark matter detector

Most stringent limit for WIMP-nucleon SI cross section was set for WIMP masses greater than 6 GeV/c^2

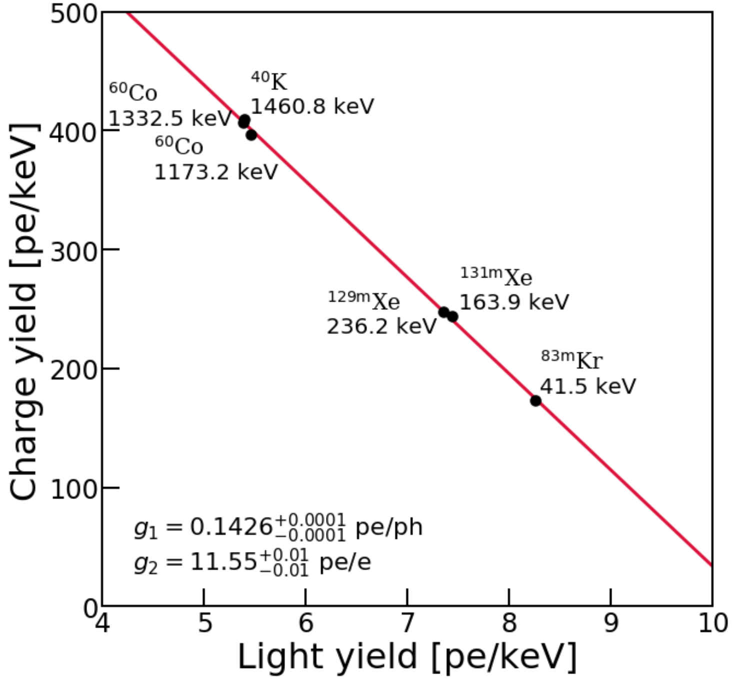
First detection of double electron capture of ^{124}Xe, longest half-life ever measured

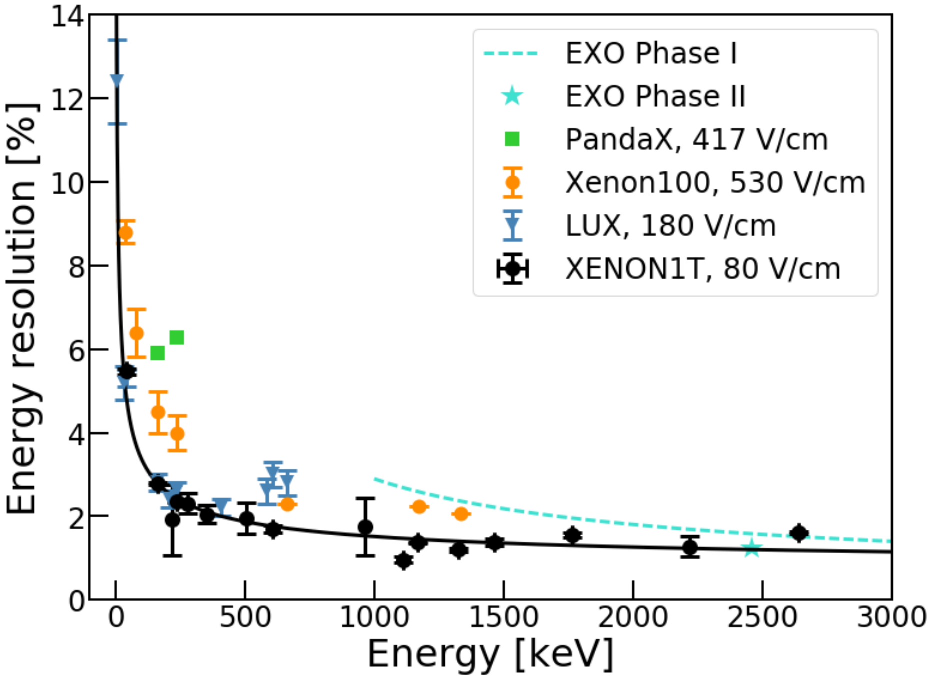
Upgrade to XENONnT is ongoing, expected to start data taking by the end of 2019

Calibrations (1)

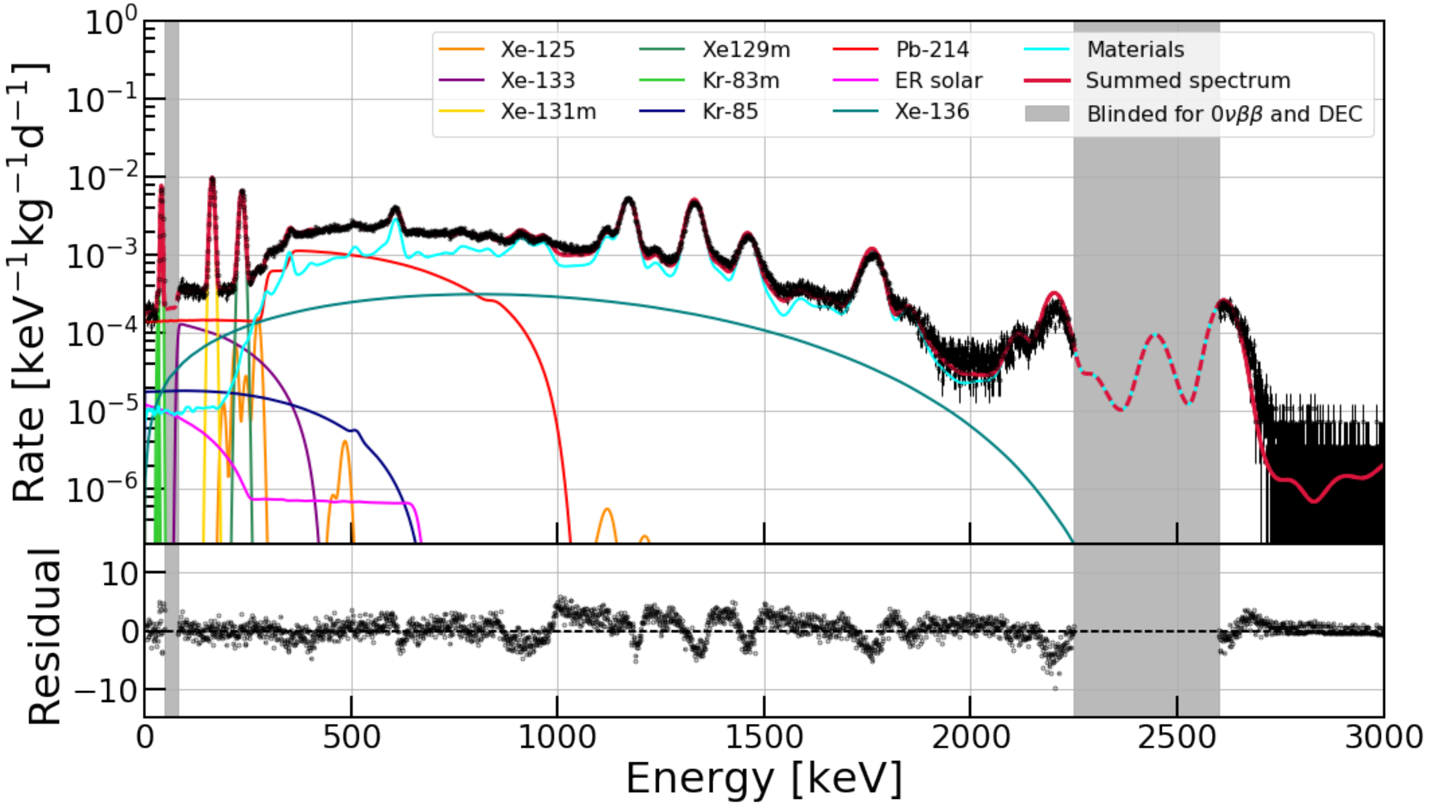


Calibrations (2)

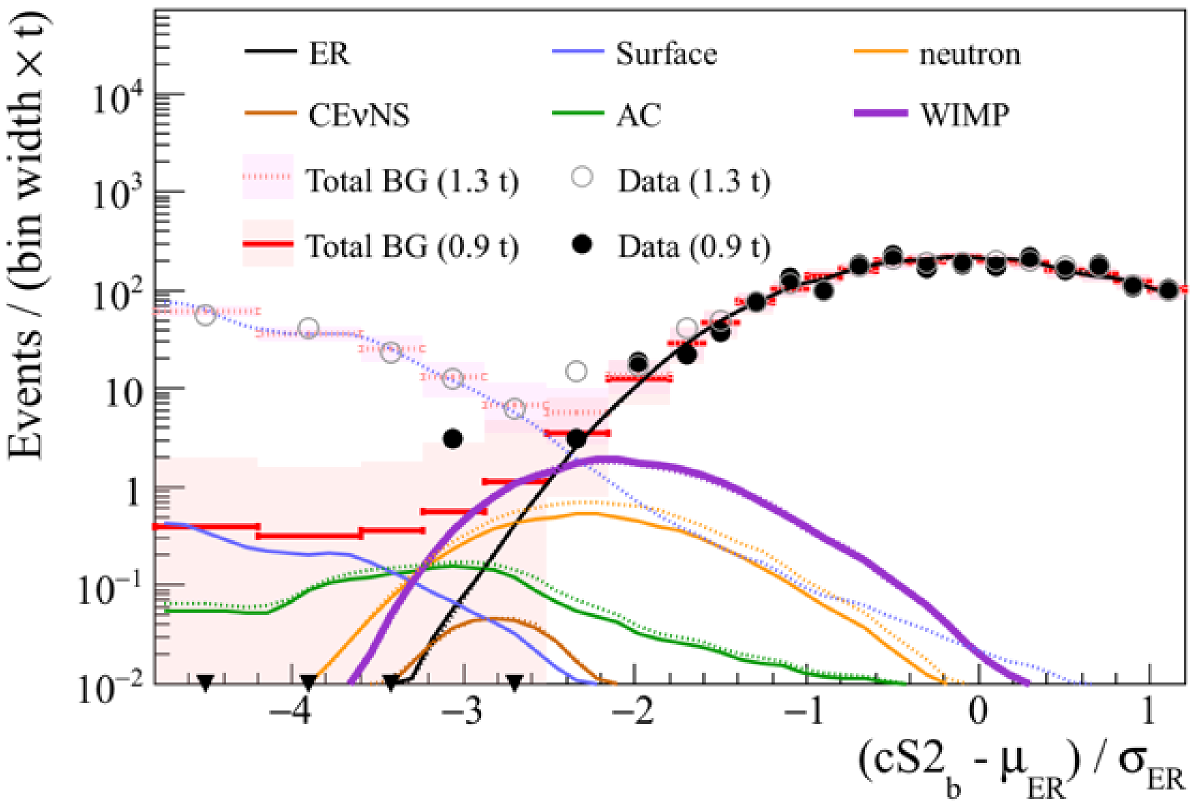




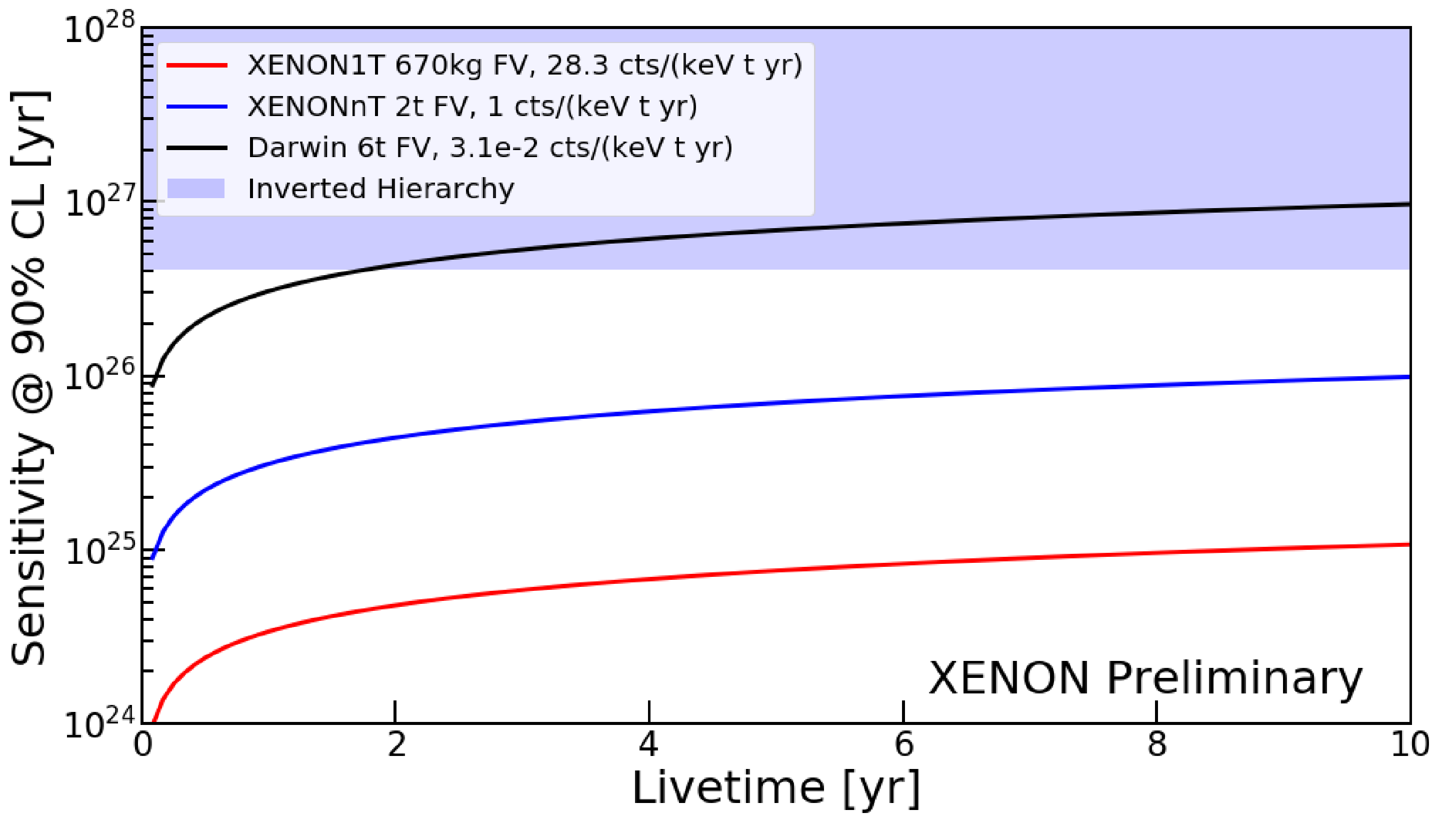
Data – MC matching



SI-WIMP result



0νββ decay



XENON1T 670kg FV, 28.3 cts/(keV t yr)
XENONnT 2t FV, 1 cts/(keV t yr)
Darwin 6t FV, 3.1e-2 cts/(keV t yr)
Inverted Hierarchy
XENON Preliminary
Sensitivity @ 90% CL [yr]
Livetime [yr]
10^28
10^27
10^26
10^25
10^24
0
2
4
6
8
10