WEIZMANN INSTITUTE OF SCIENCE

Xe XENON Dark Matter Project

Results From a Tonne-Year Dark Matter Search With XENON1T

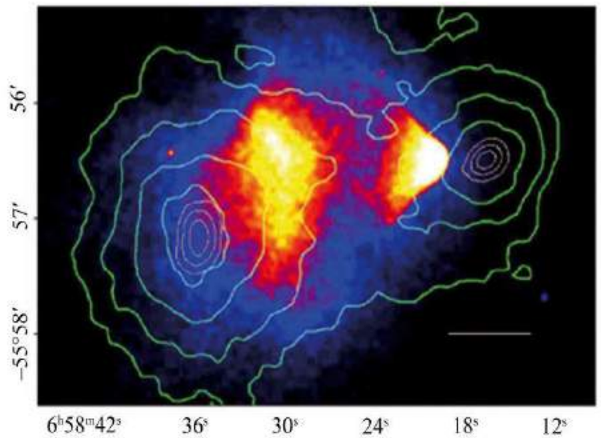
Ran Itay, Weizmann Institute of Science

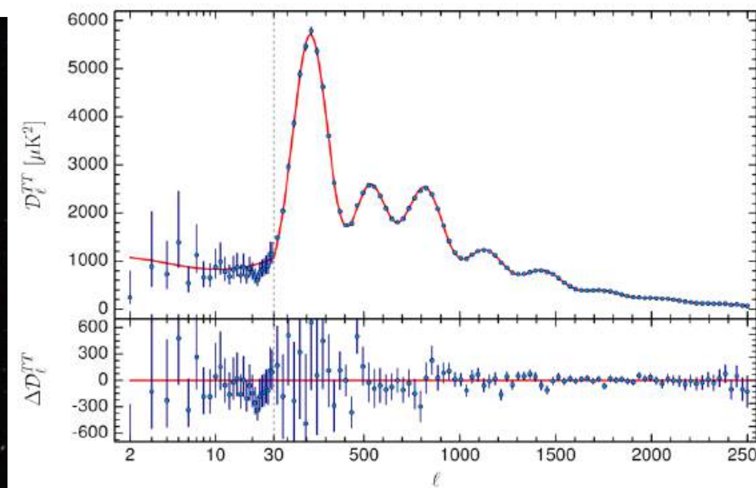
For the XENON collaboration

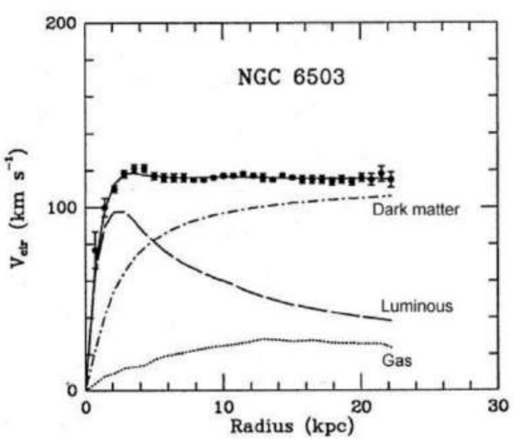
6th International Workshop for the Design of the ANDES Underground Laboratory

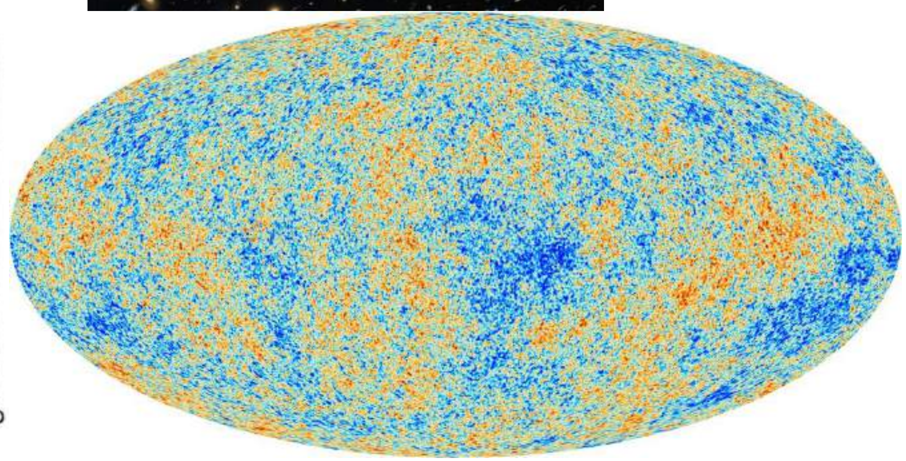
August 2018

Evidence for DM

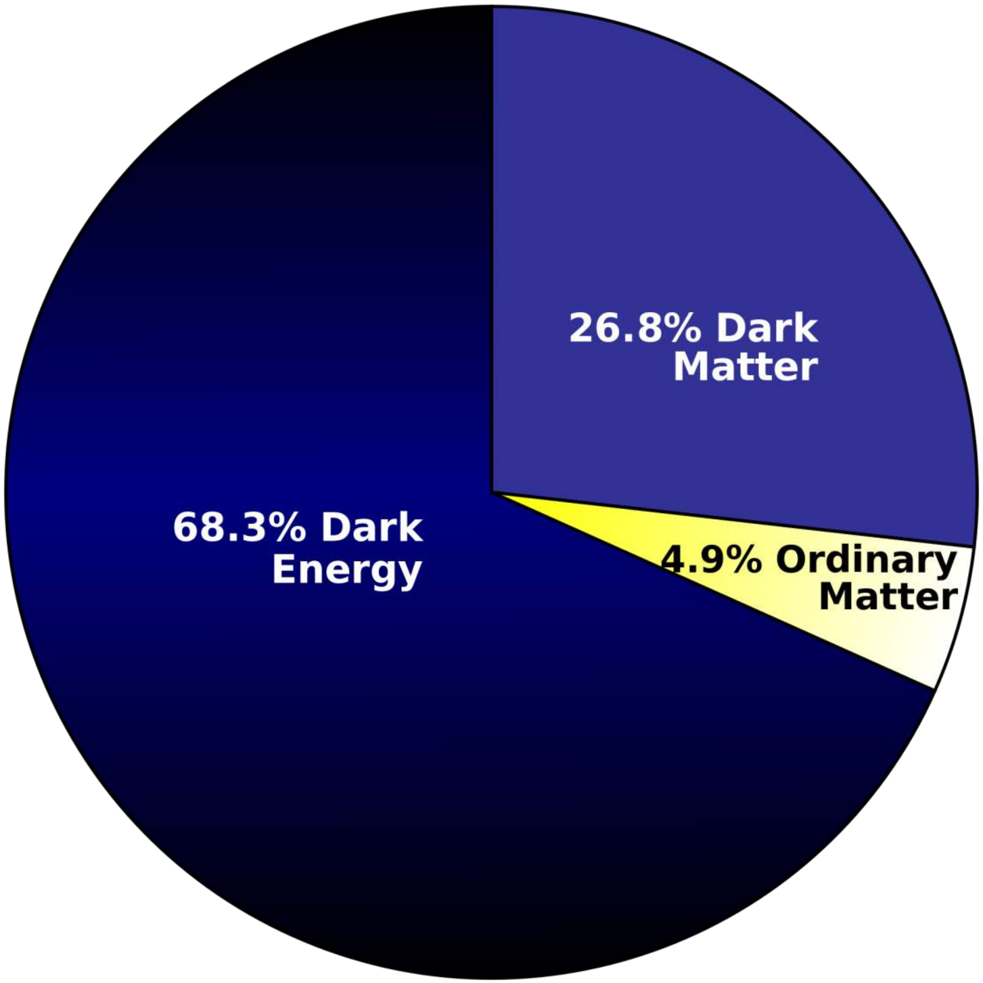




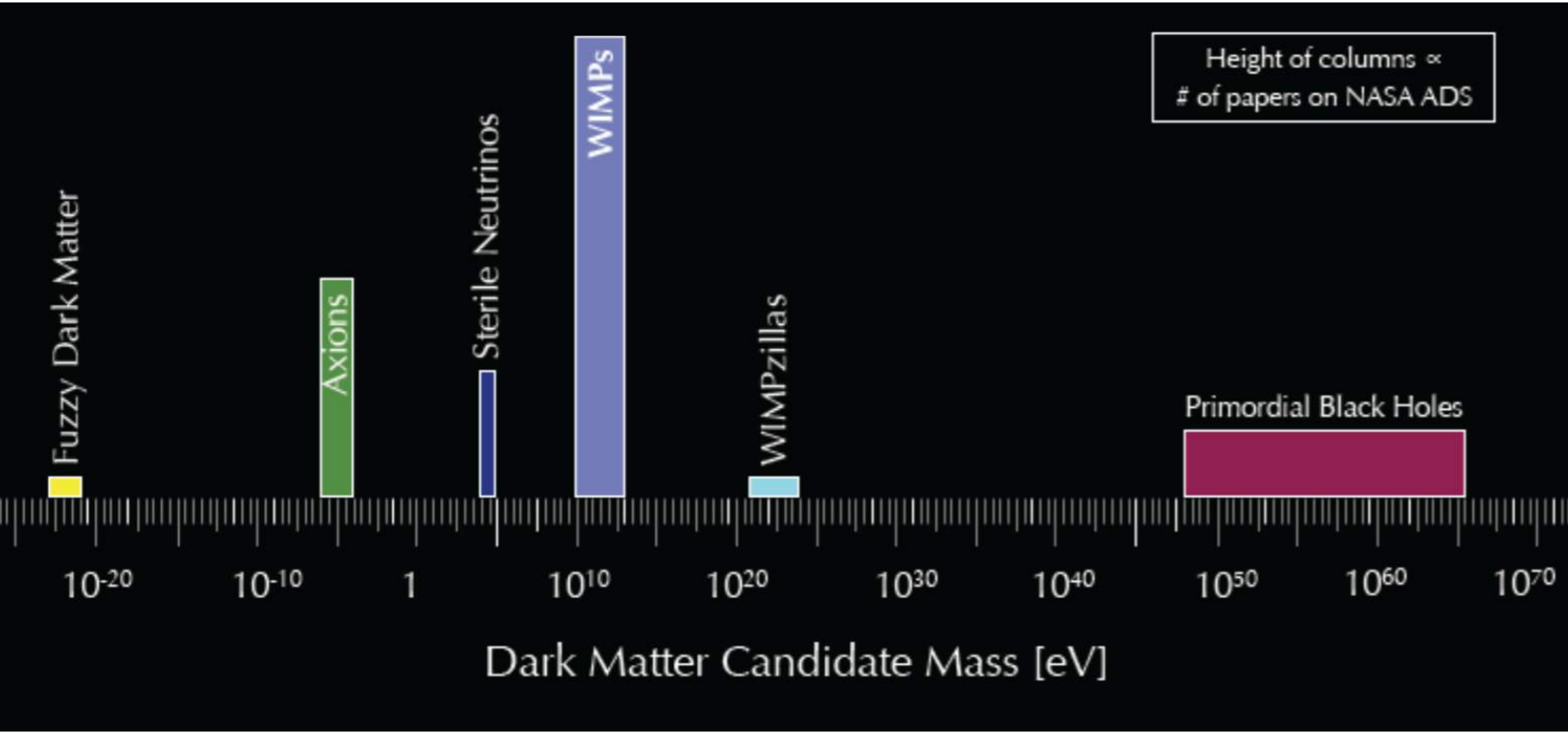




DM Evidence



DM Candidates



Direct Detection

Typical assumptions:

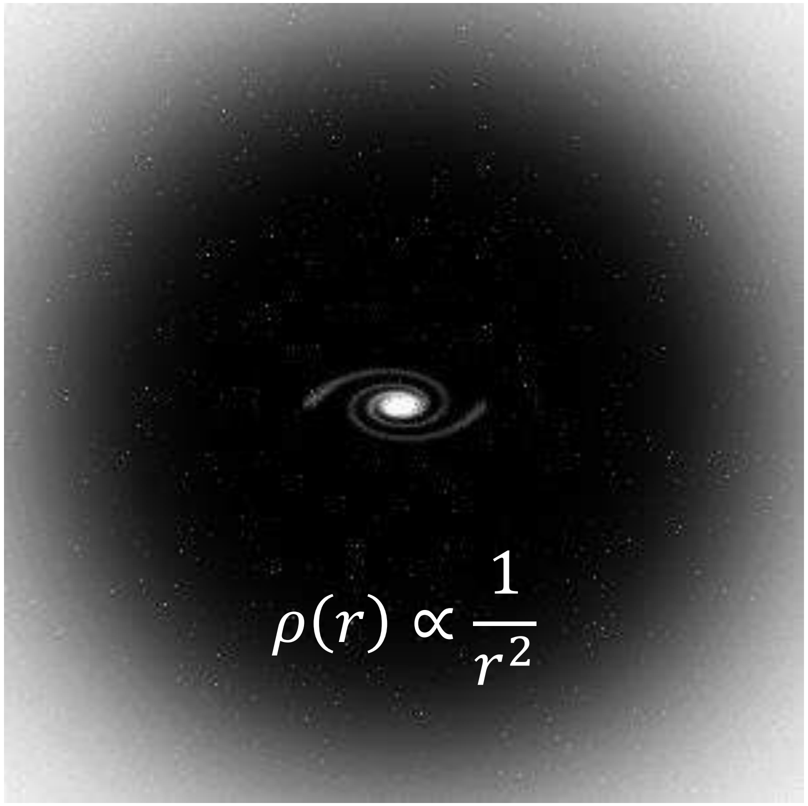
- Local density ~ 0.3 GeV/cm^3
- Velocity distribution – Maxwell-Boltzmann
- Average velocity ~ 230 km/s

WIMP Interaction:

- Very small rate – O(1) event/ton/year ?
- Low energy - O(10-100keV)

Direct detection requirement:

- Large detector mass
- Ultra low background



XENON Dark Matter Project

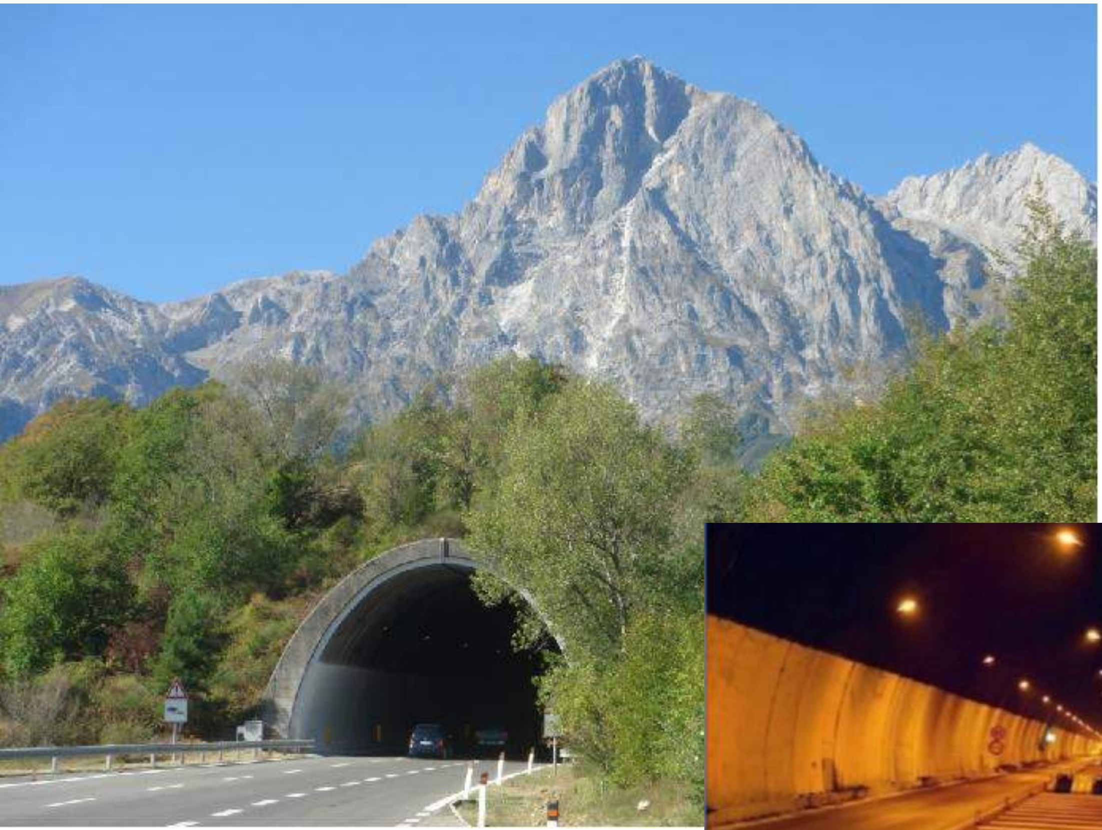
Columbia · RPI · Nikhef · Muenster · Stockholm · Mainz · MPIK, Heidelberg · Freiburg · Zurich

Chicago · UCLA · UCSD · Rice

Tokyo · Nagoya · Kobe

The XENON Collaboration
11 countries
25 Institutes
~165 Scientists

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




Aosta
Bolzano
Como
Milan
Verona
Trieste
Venice
Turin
Genoa
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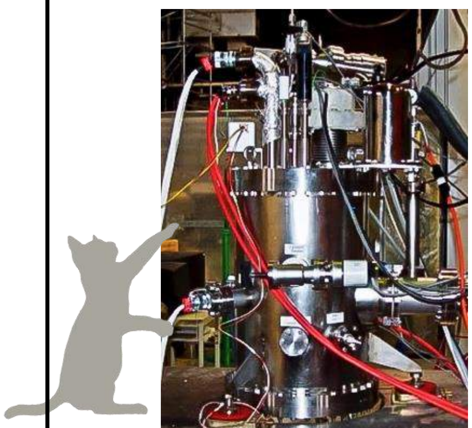
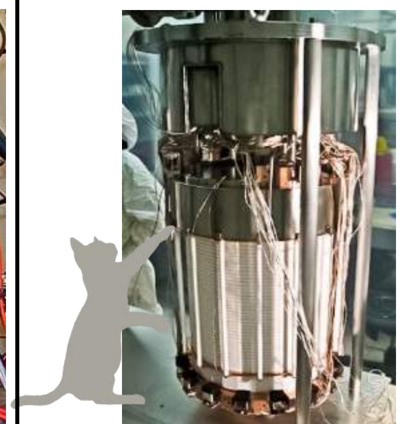
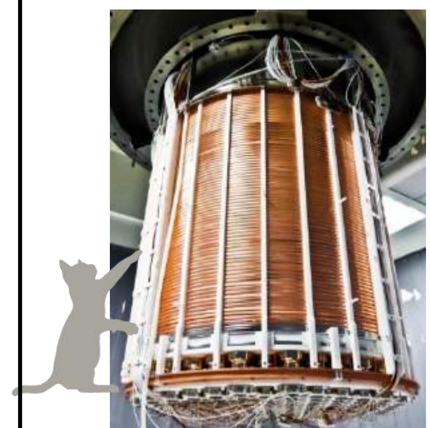
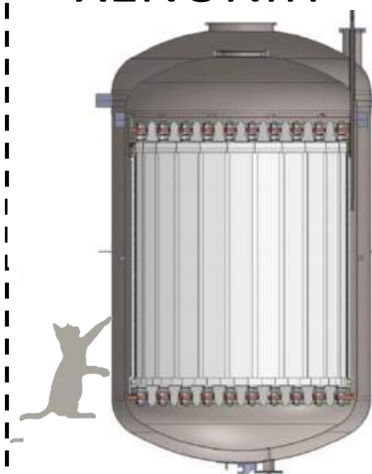
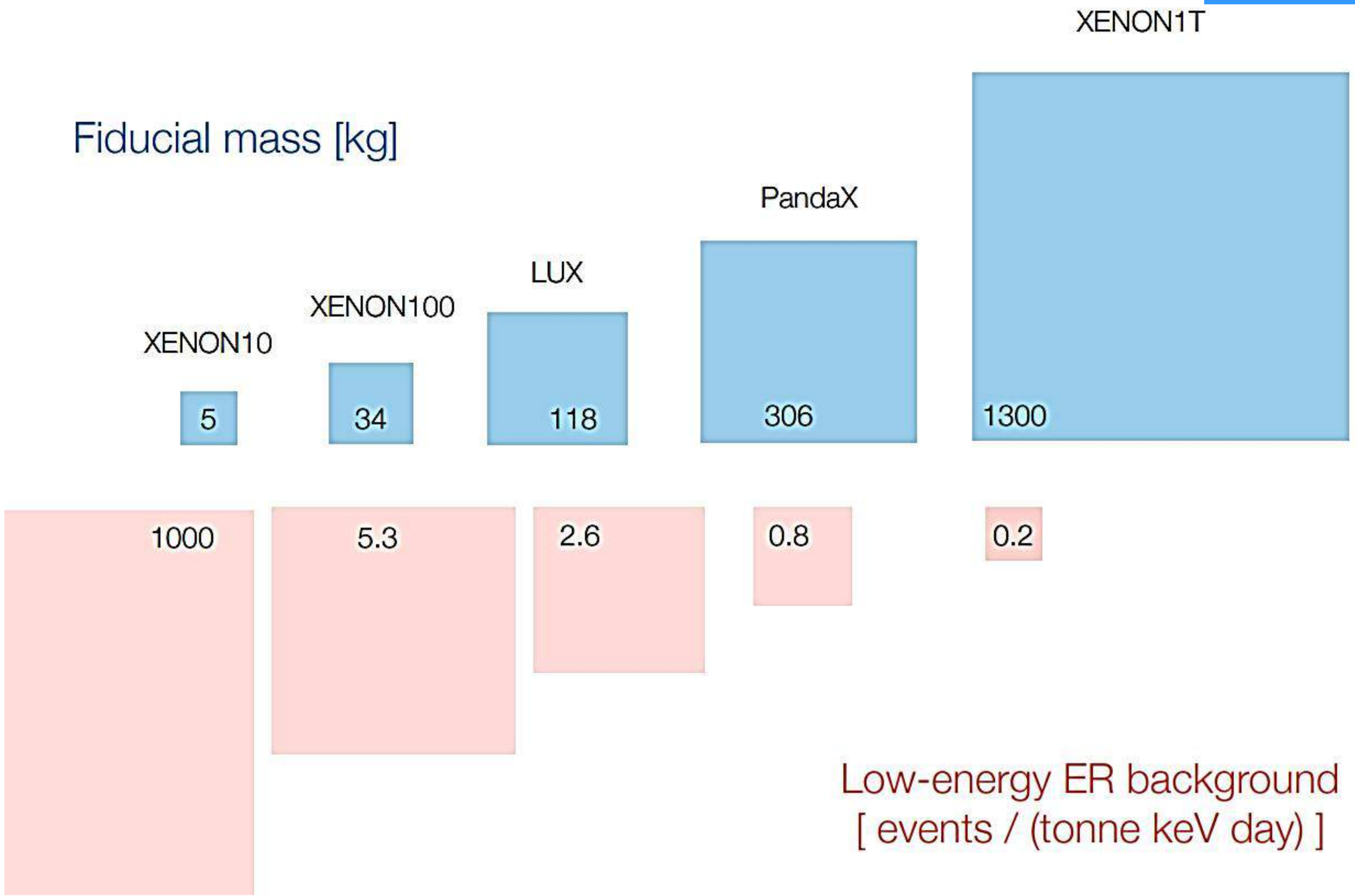
Bologna
Ravenna
La Spezia
Pisa
Florence
Cinque Terre
Ancona
Perugia
Ascoli Piceno
L'Aquila
Pescara
Gargano Penninsula
Rome
Costa Smeralda
Olbia
Naples
Bari
Alghero
Amalfi Coast
Matera
Lecce
Oristano
Maratea
Cagliari
Tropea
Palermo
Reggio Calabria
Val di Noto
Agrigento
Siracusa
N


I.N.F.N
STOP

Timeline of the Xenon Program

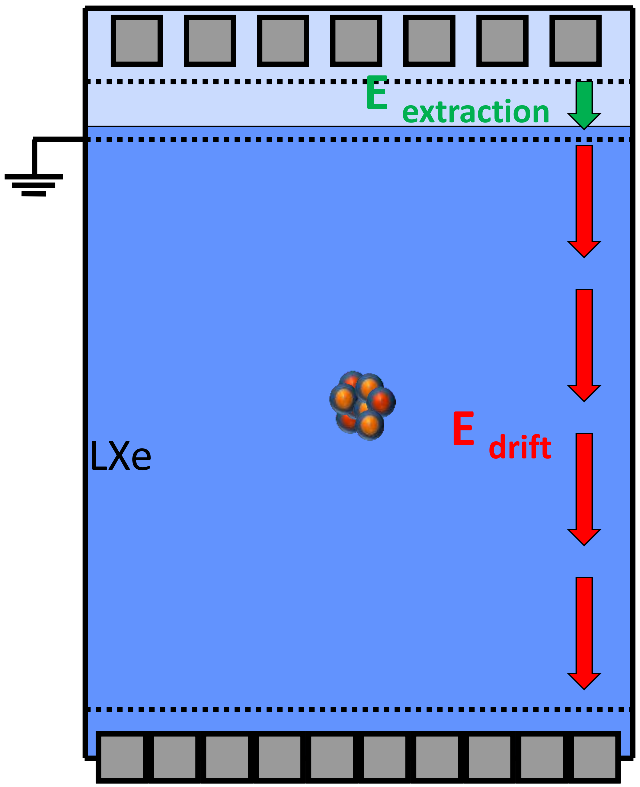





	XENON10	XENON100	XENON1T	XENONnT
Era	2005-2007	2008-2016	2012-2018	2019-2023
Mass	25 kg	161 kg	3200 kg	~8000 kg
Drift	15 cm	30 cm	100 cm	150 cm
Status	Achieved (2007)	Achieved (2016)	**Achieved (2018)**	Projected (2023)
σ_{SI} Limit **(@50 GeV/c²)**	8.8×10^{-44} cm²	1.1×10^{-45} cm²	7×10^{-47} cm	1.6×10^{-48} cm²


XENON1T
Fiducial mass [kg]
PandaX
LUX
XENON100
XENON10
5
34
118
306
1300
1000
5.3
2.6
0.8
0.2
Low-energy ER background
[events / (tonne keV day)]

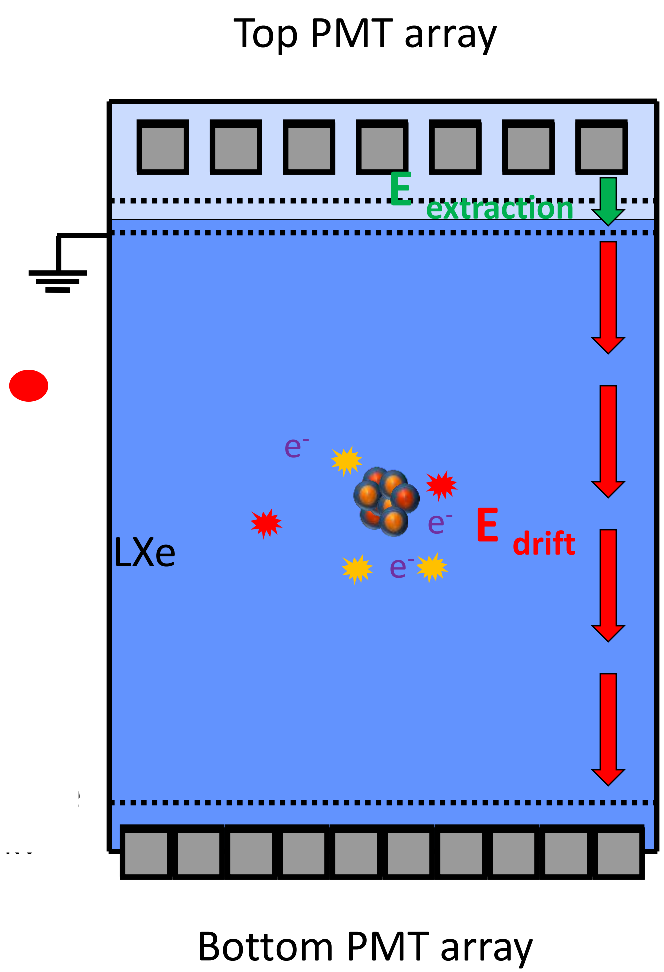
Detection Principle

Top PMT array

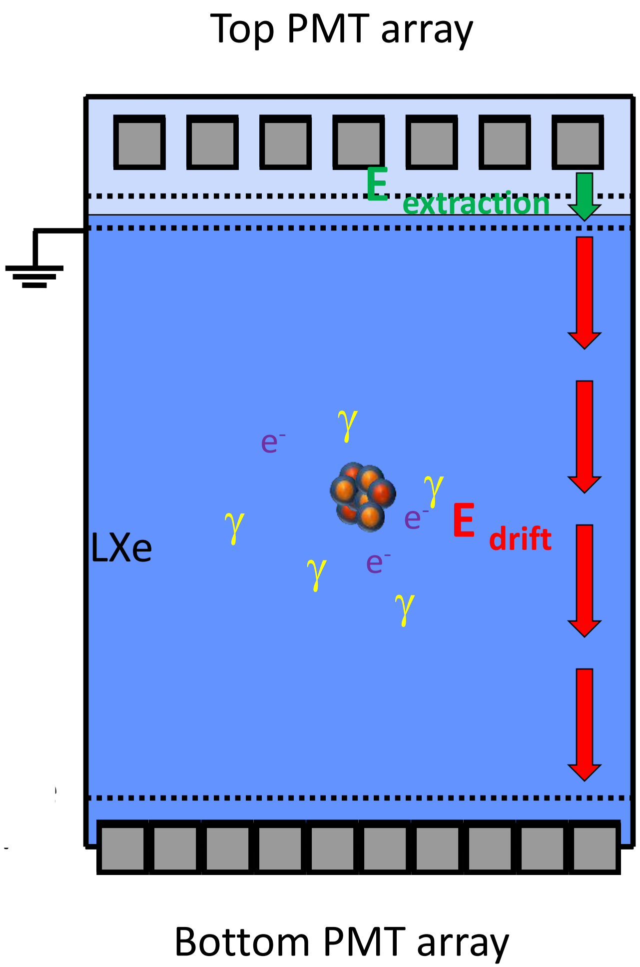


Bottom PMT array

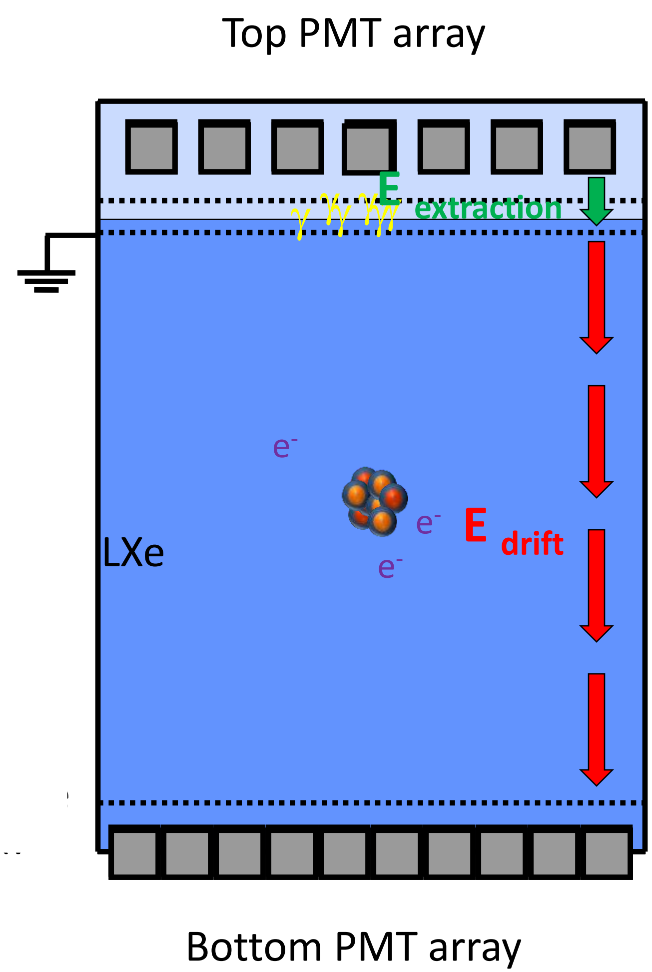
Detection Principle



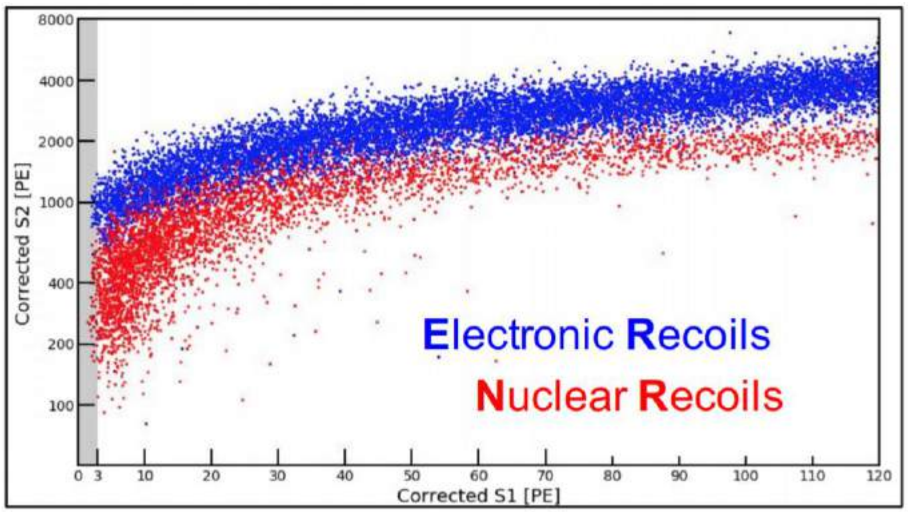
Detection Principle



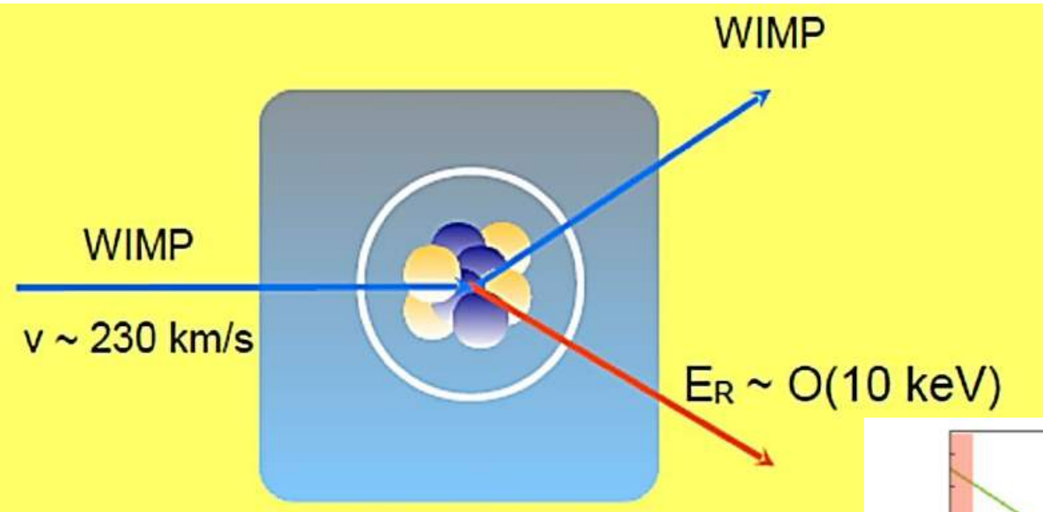
Detection Principle



- β , γ – background
- WIMP (signal) , Neutrons, CNNS

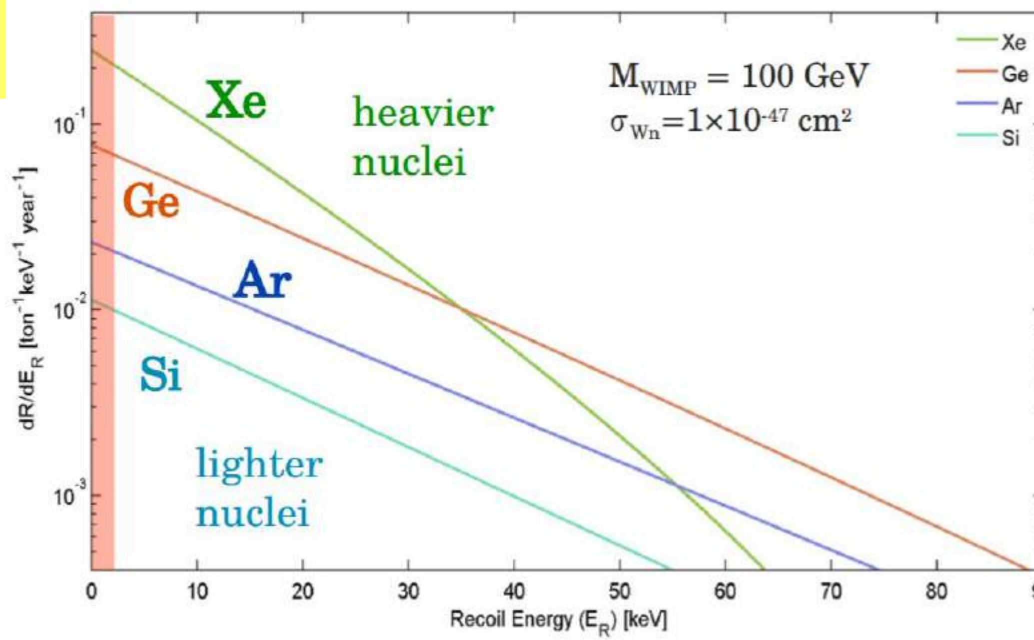


Why Xenon



$$R \propto \rho_0 \sigma N A^2$$

- R – Event rate in the detector
- ρ_0 - Local DM density (0.3 GeV/c^2)
- σ – WIMP-Nucleon cross section
- N – Number of nuclei
- A – Atomic number (~130)

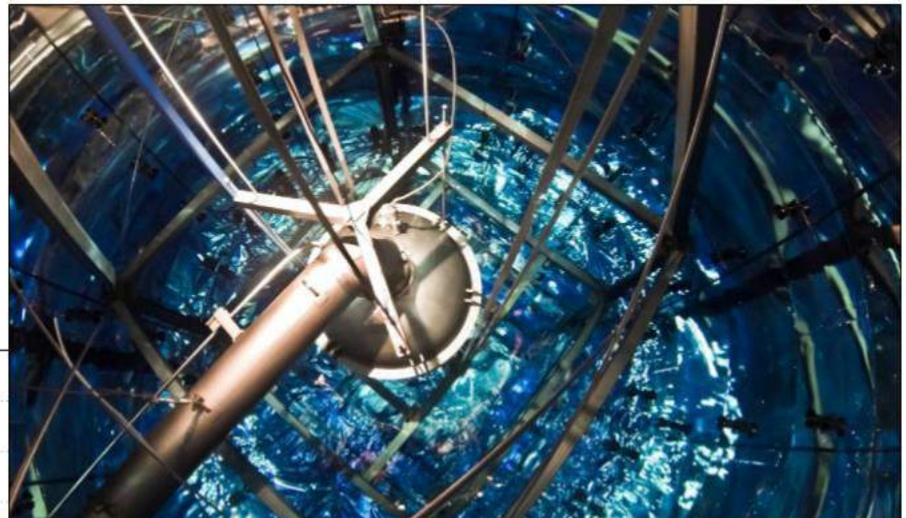


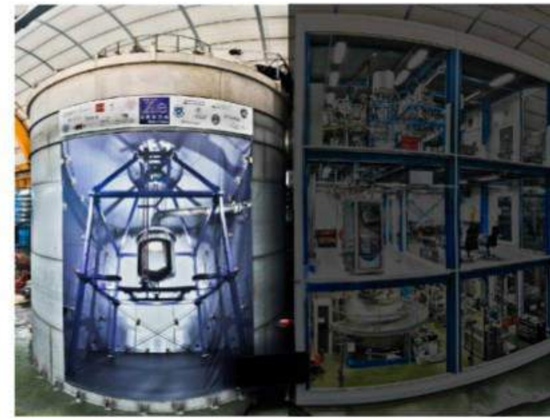
XENON1T

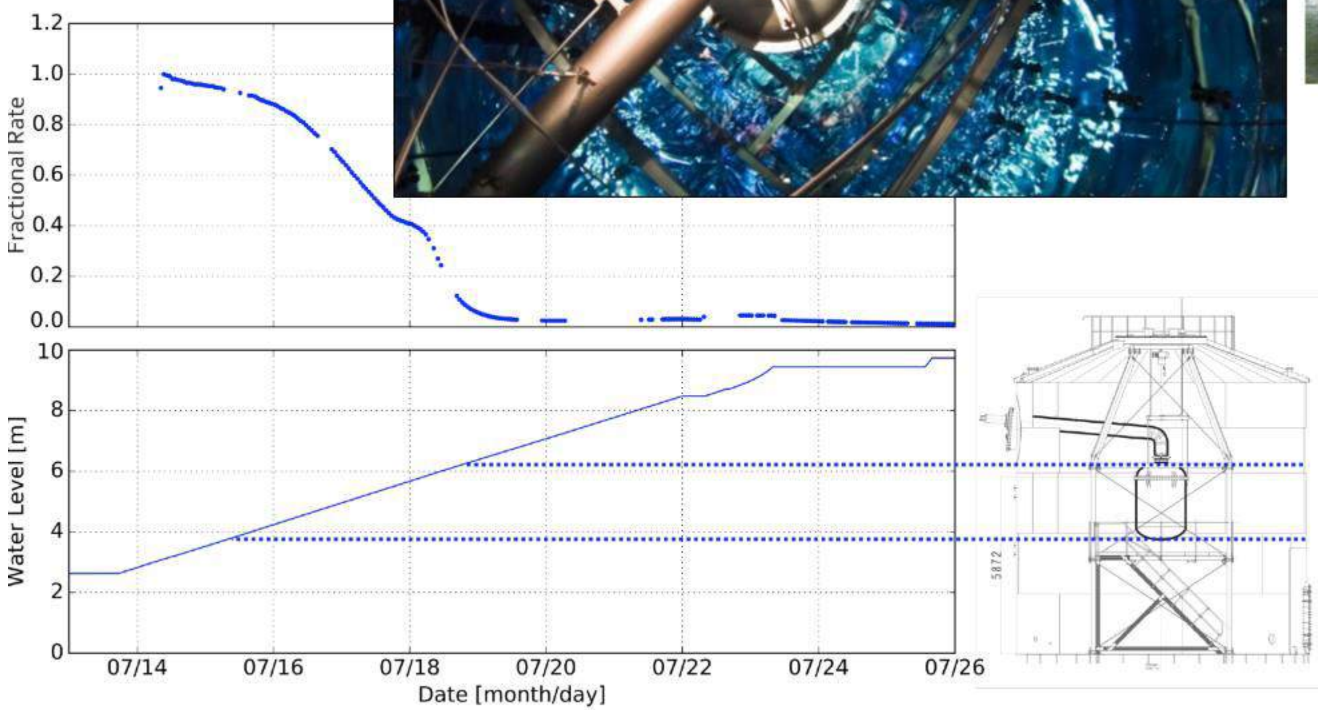
XENON1T

arXiv: 1708:07051

Water Tank

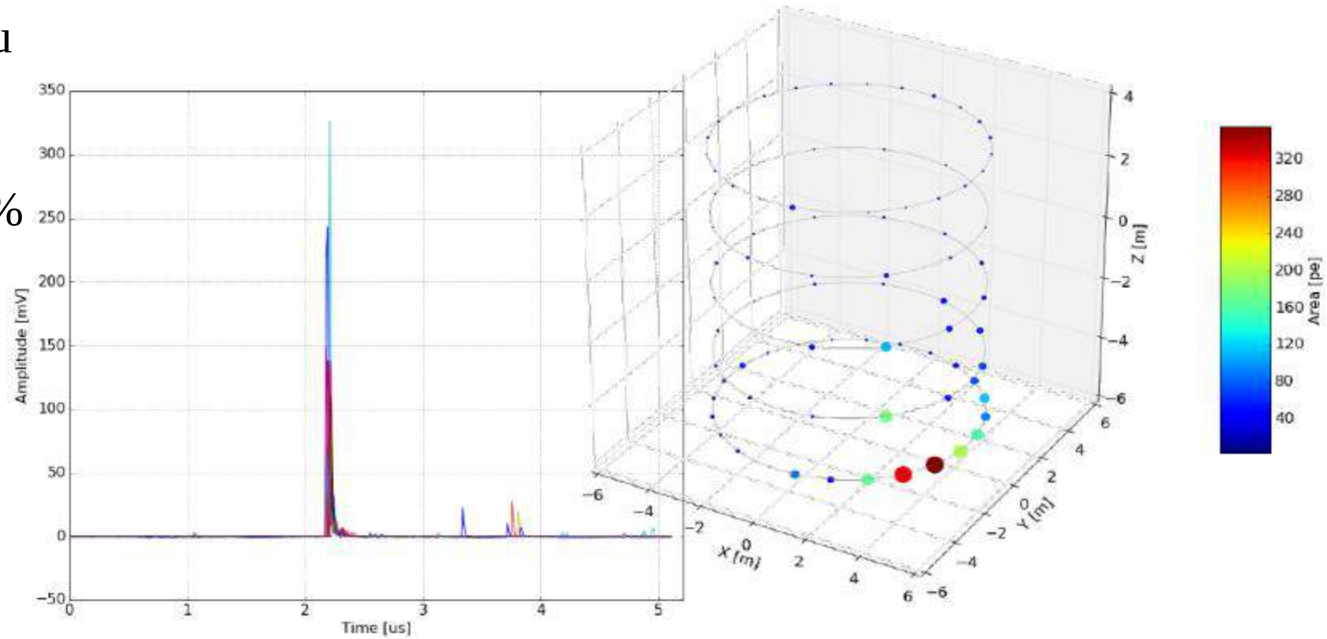





1.2
1.0
0.8
0.6
0.4
0.2
0.0
Fractional Rate
10
8
6
4
2
0
Water Level [m]
07/14
07/16
07/18
07/20
07/22
07/24
07/26
Date [month/day]
5872

Water Tank

- Active against muons.
- 84 High QE 8" Hamamtsu PMTs
- Trigger efficiency > 99.5%
- Cosmogenic neutrons suppressed <0.01 events/ton/year.



JINST 9, 11007 (2014)

XENON1T TPC

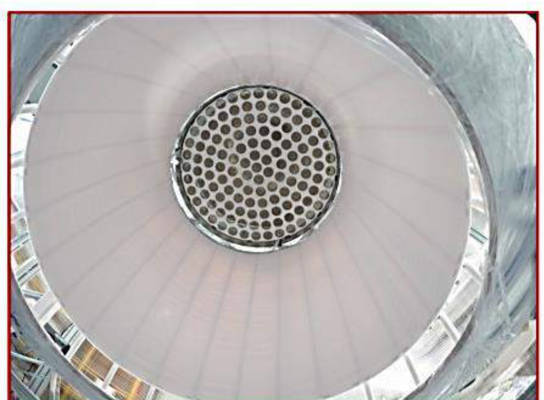
- 3.2t of LXe, 2t in TPC
- 248 PMTs
- ~1m diameter
- ~1m length
- ~120 V/cm drift

The XENON1T Light Detection System

- 248 3-inch Hamamatsu R11410-21 PMTs
- 35% QE @ 178nm
- SPE acceptance ~94%
- High reflective PTFE lining of entire inner volume

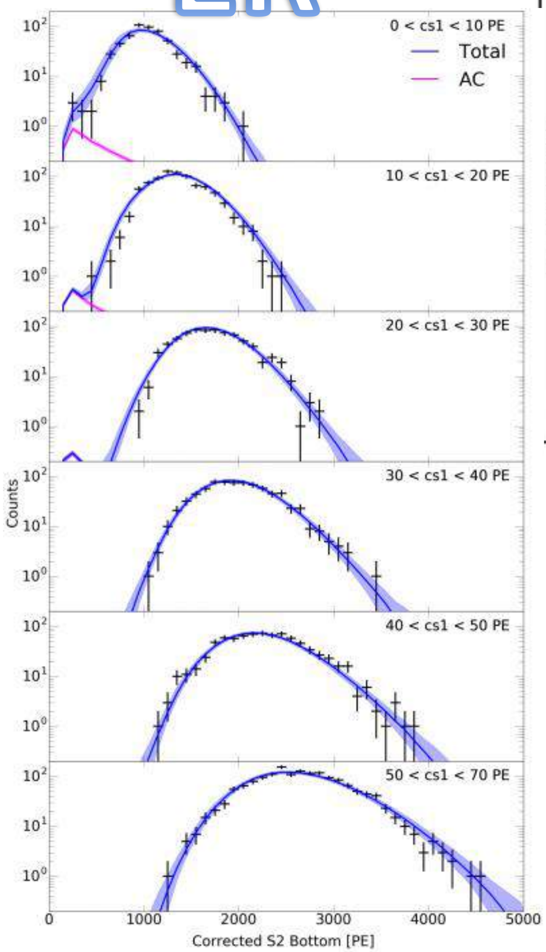
127 PMTs in the top array

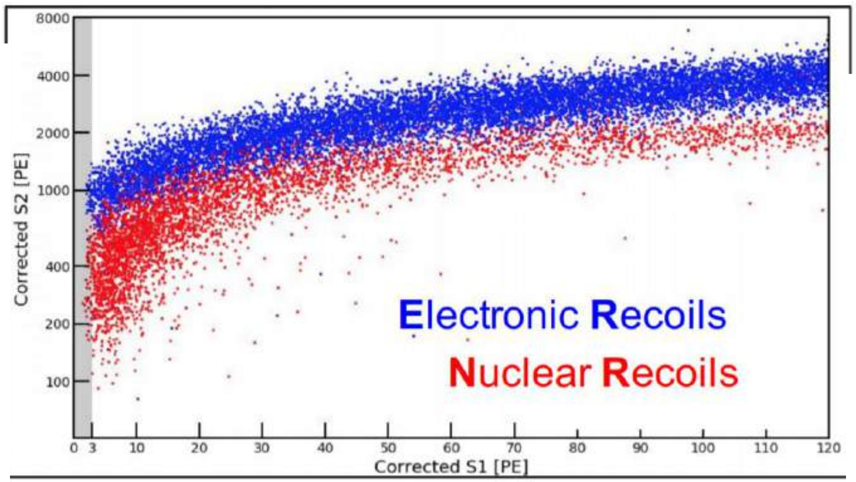
121 PMTs in the bottom array



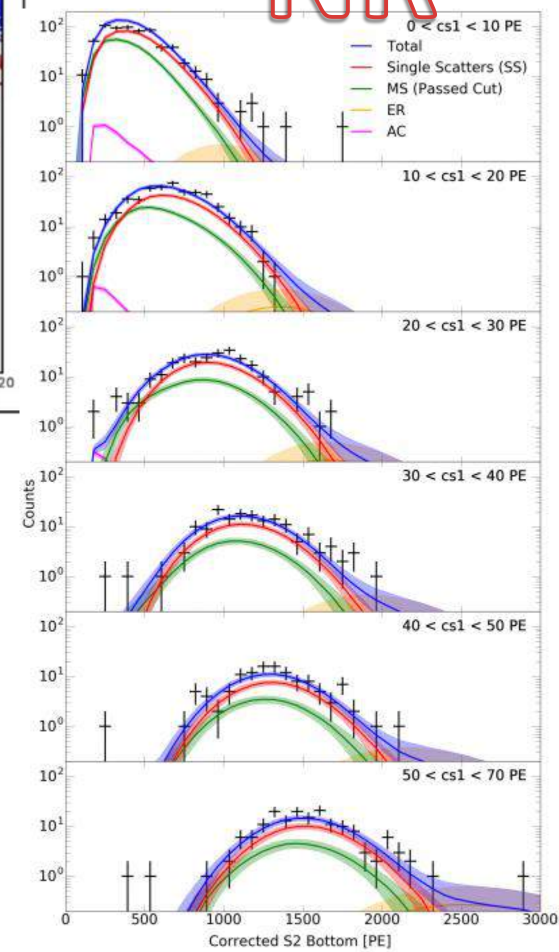
Calibration

ER





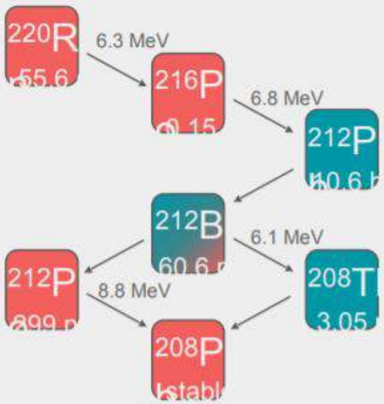
NR



- Calibration data fitted to model, taking LXe response and detector features into account.
- ER rejection ~99.7% with NR acceptance [-2σ,median]

Calibration

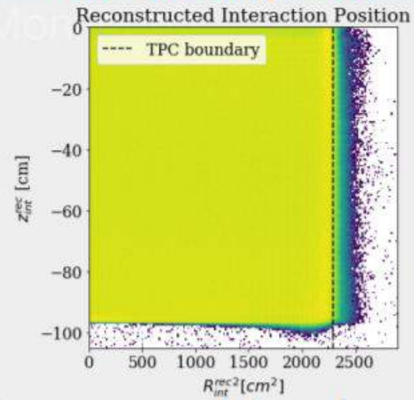
^{220}Rn: Low Energy ER



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

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

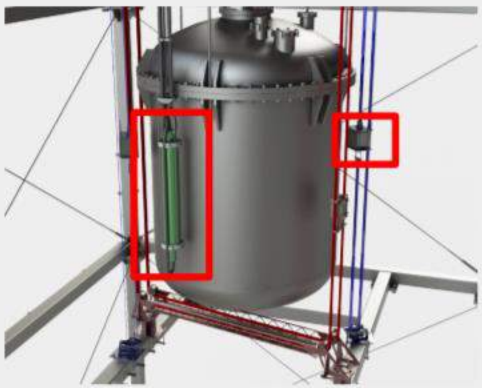
^{83m}Kr :Stability and Monitoring



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

Neutrons: Signal

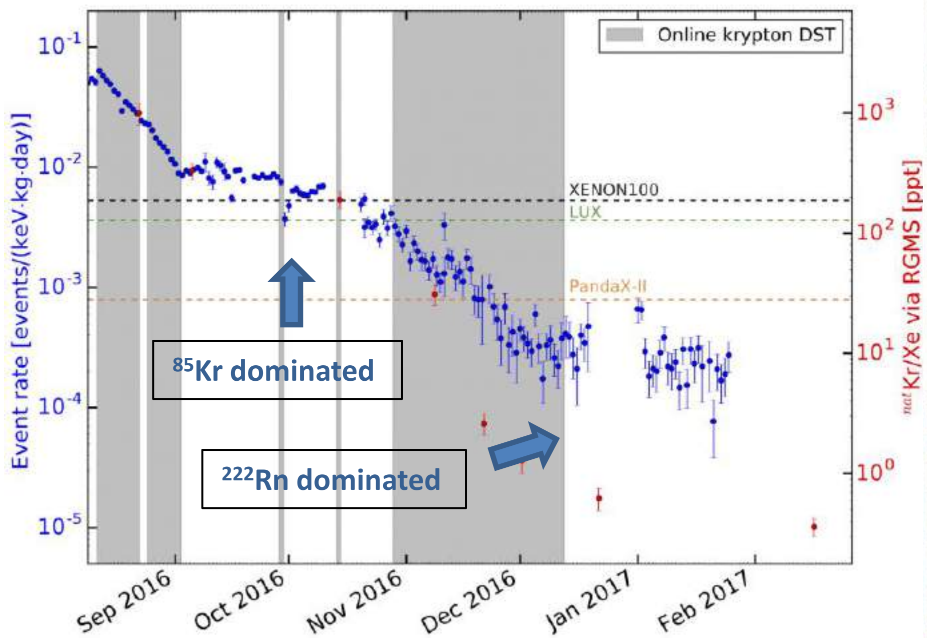


Type: External
Freq: As needed
Length: 6 weeks (AmBe)
2 days (generator)

ER Background

Radio Impurities

- ^{85}Kr: 0.66 ppt Kr/Xe
  - Online Cryogenic distillation
- ^{222}Rn : 13.3 µBq/kg
  - Careful selection of material



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

ER Background

Total

(Expectation in 1-12 keV search window, 1.3t FV, single scatters, before NR/ER discrimination)

Source	Rate [t^{-1} y^{-1} keV^{-1}]	Fraction [%]
^{222}Rn	56 ± 6	75.0
^{85}Kr	7.7 ± 1.3	10.3
Solar ν	2.5 ± 0.1	3.3
Materials	8 ± 1	10.7
^{136}Xe	0.8 ± 0.1	1.1
Total	75 ± 8	
Measured	82 ± 5	

Lowest electronic recoil background ever achieved in a DM detector

ER Background

Total

(Expectation in 1-12 keV search window, 1.3t FV, single scatters, before NR/ER discrimination)

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Materials	8 ± 1	10.7
^{136}Xe	0.8 ± 0.1	1.1
Total	75 ± 8	
Measured	82 ± 5	

Lowest electronic recoil background ever achieved in a DM detector

NR Background

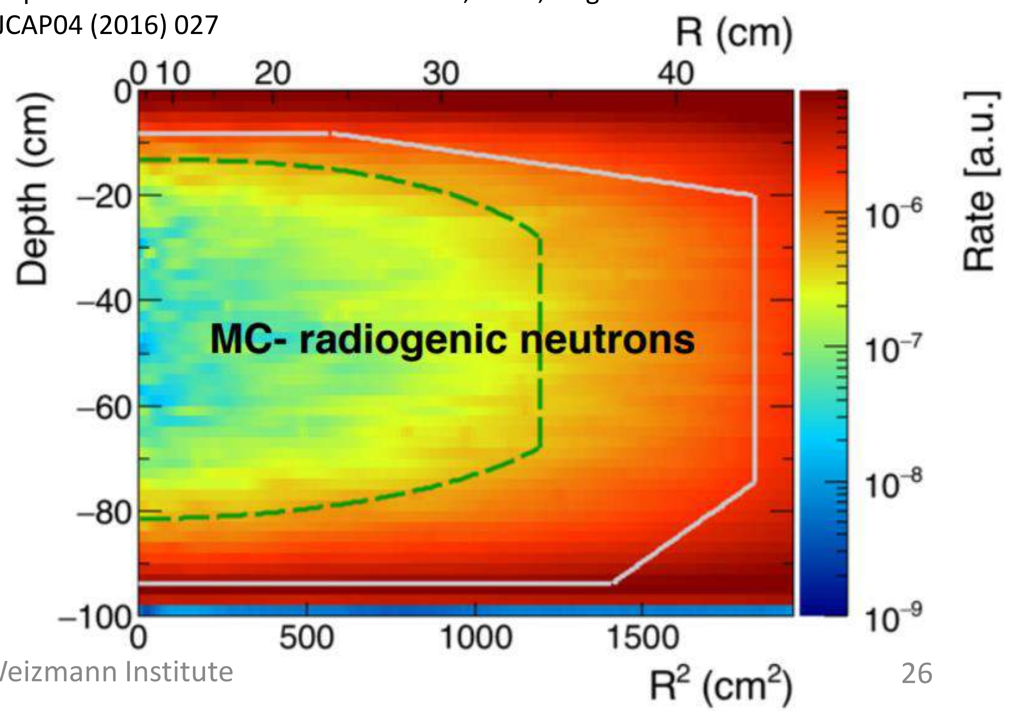
Total

Source	Rate [t^{-1} y^{-1}]	Fraction [%]
Radiogenic n	0.6 ± 0.1	96.5
CNNS	0.012	2
Cosmogenic n	< 0.01	<2

Expectation in 4-50 keV search window, 1t FV, single scatter.

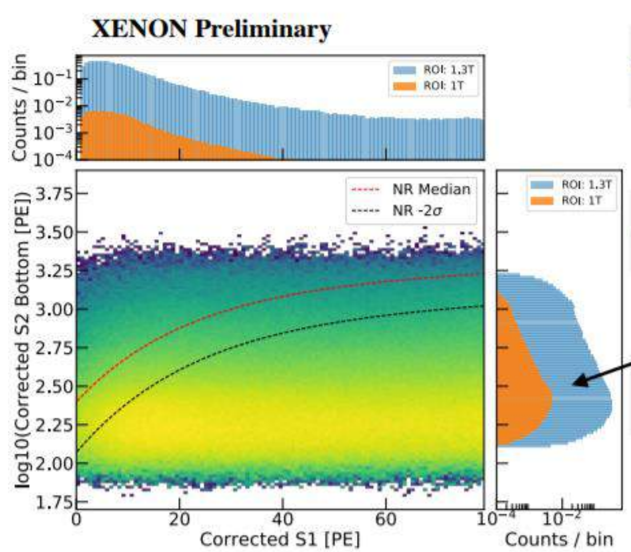
- Cosmogenic μ-induced neutrons significantly reduced by rock overburden and muon veto
- Coherent elastic ν-nucleus scattering, constrained by 8B neutrino flux and measurements, is an irreducible background at very low energy (1 keV)
- Radiogenic neutrons from (α, n) reactions and fission from ^{238}U and ^{232}Th: reduced via careful materials selection, event multiplicity and fiducialization

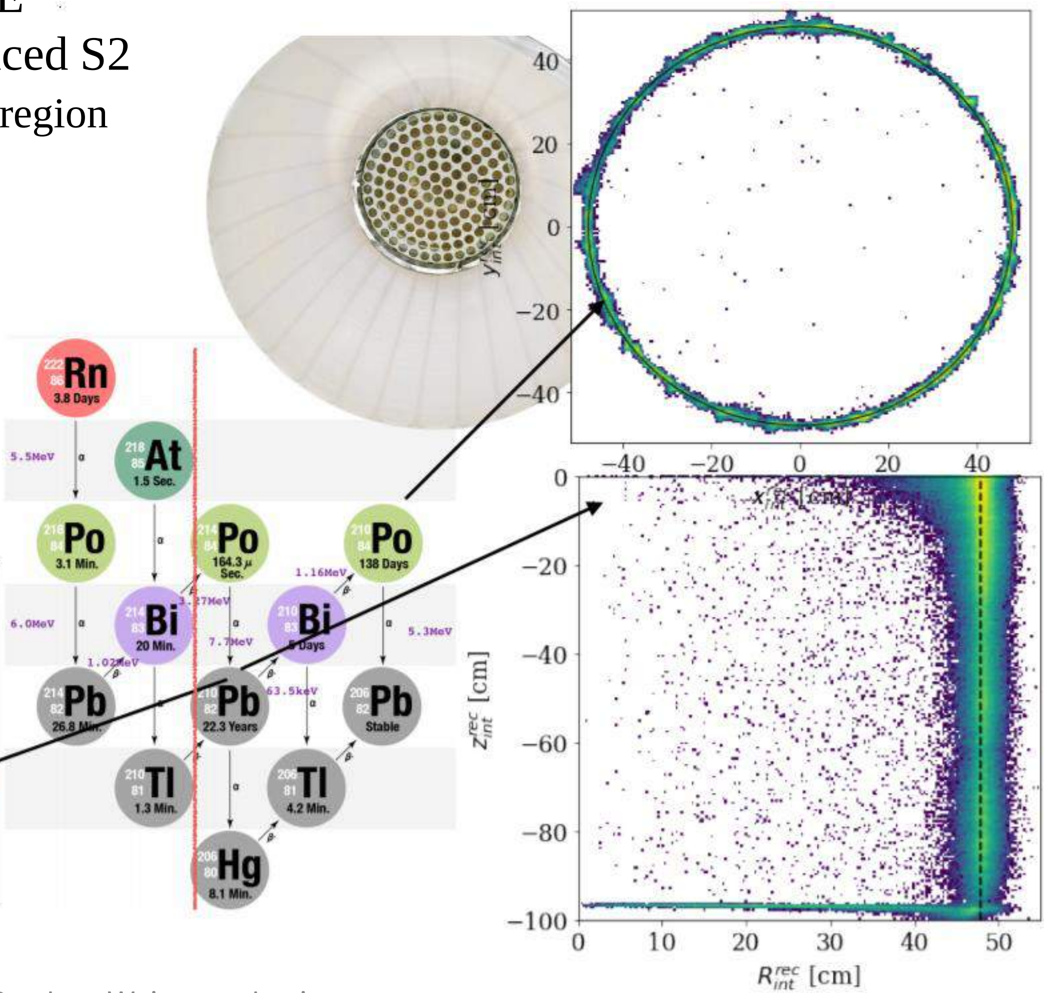
JCAP04 (2016) 027



Surface Materials Background

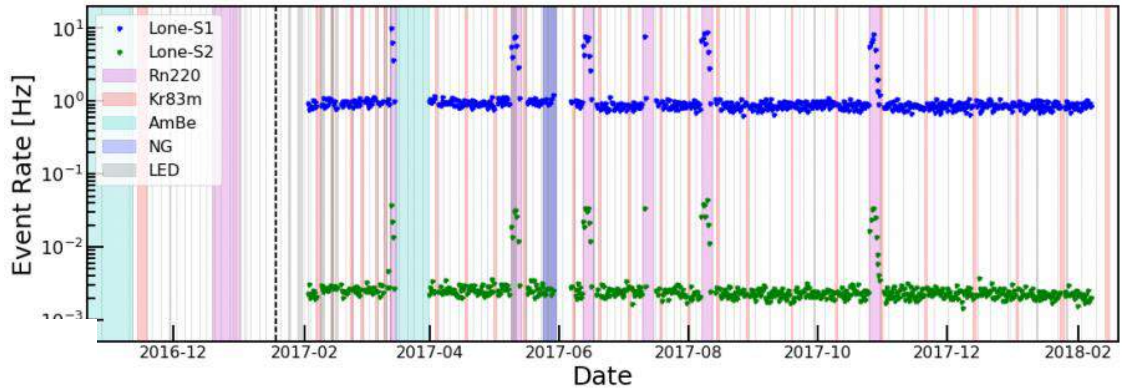
- ^{210}Pb and ^{210}Po plate-out on PTFE surface produce events with reduced S2 -> mis-reconstructed into NR signal region
- Suppressed by fiducialization
- Data driven model

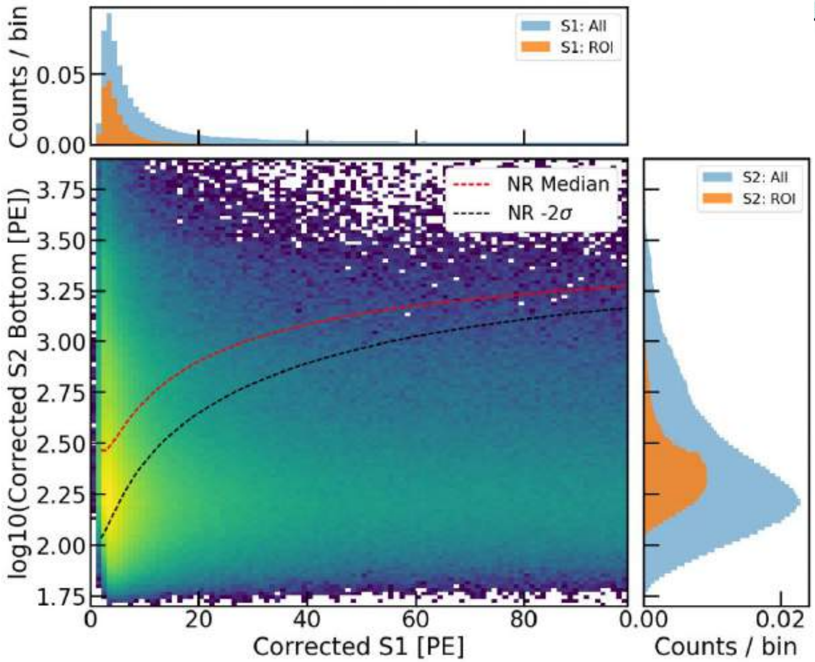




Accidental Coincidence Background

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 220Rn data and background sidebands

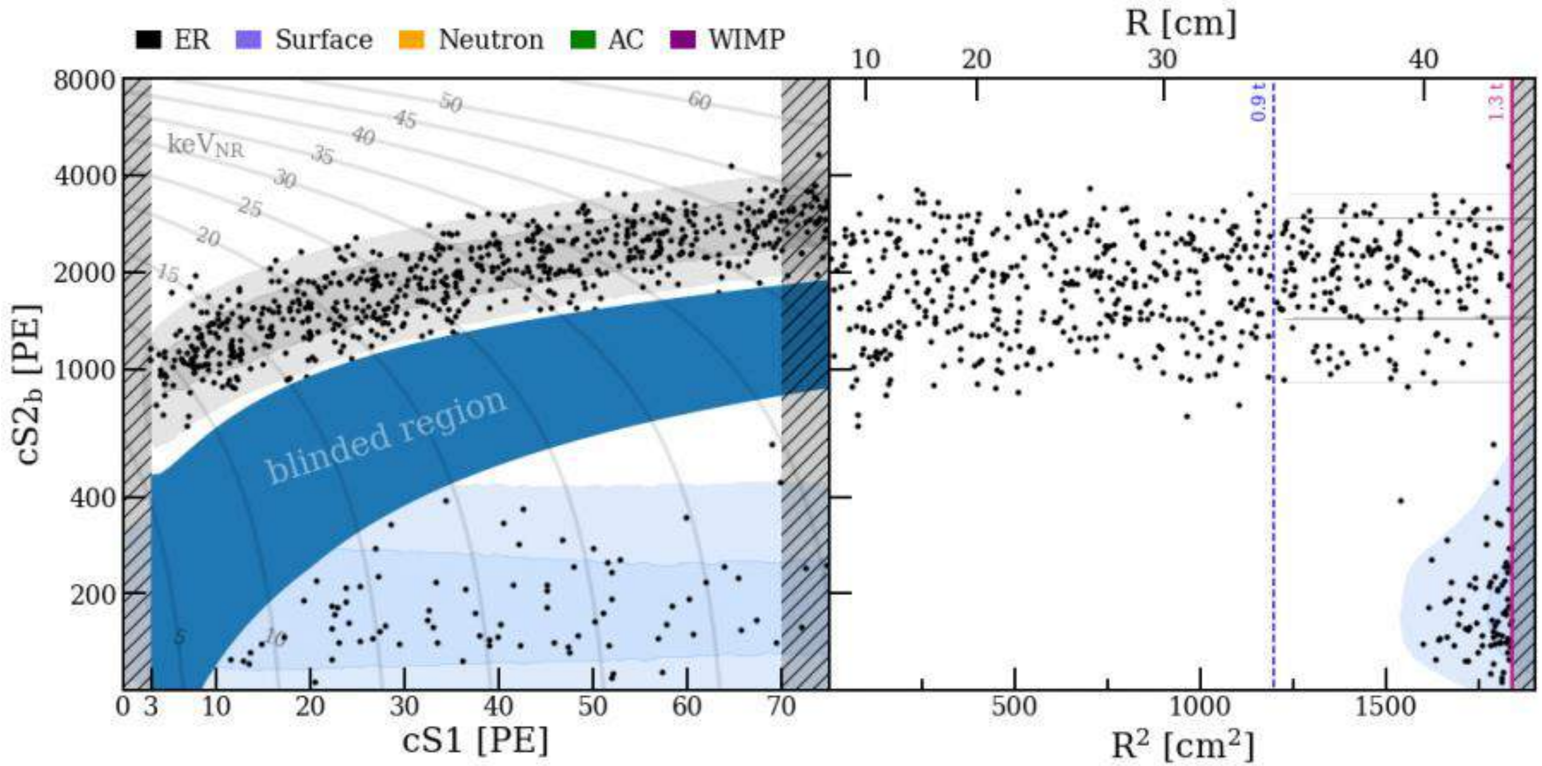
DM Search Data

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 reanalysis).

Salting:

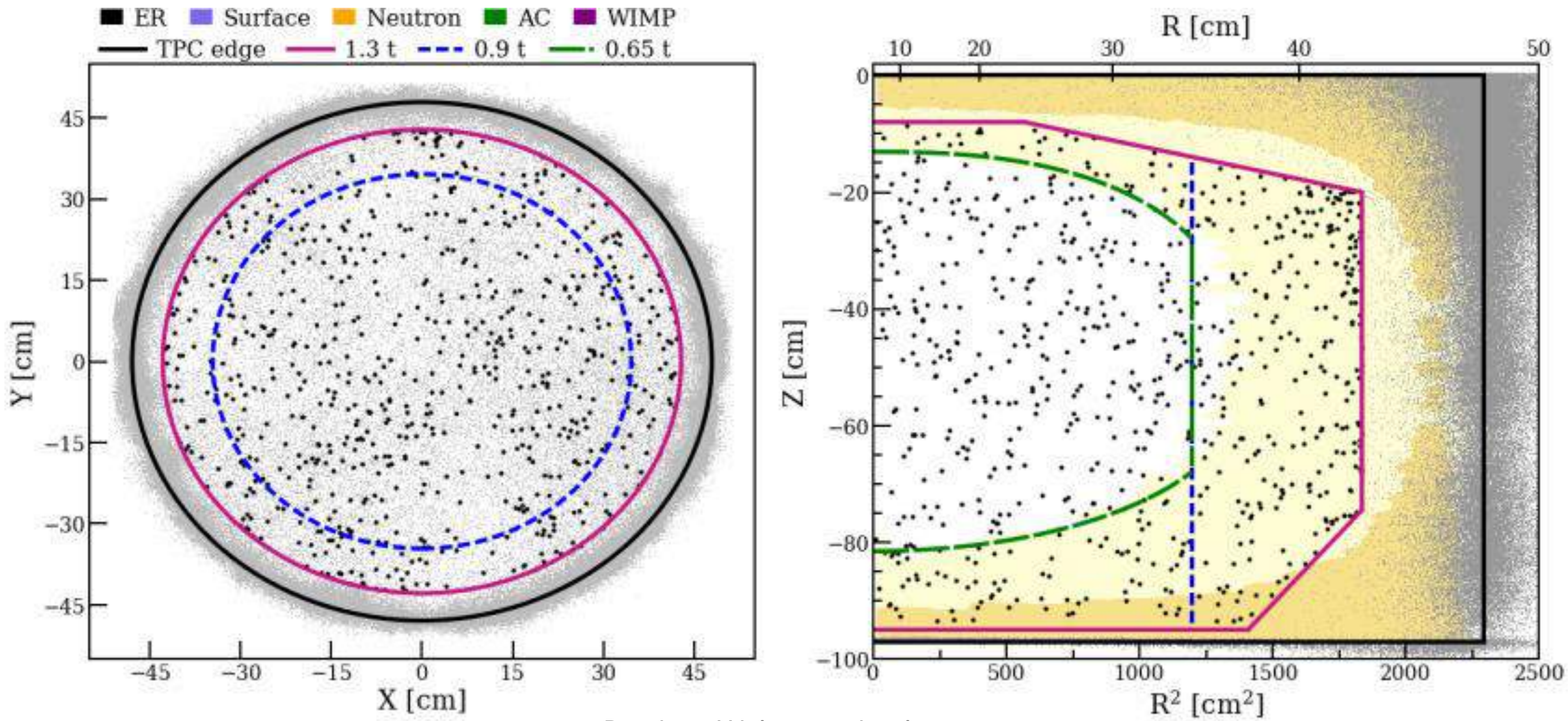
To protect against post-unblinding tuning of cuts and background models, an undisclosed number and type of events was added to data



FV Optimization

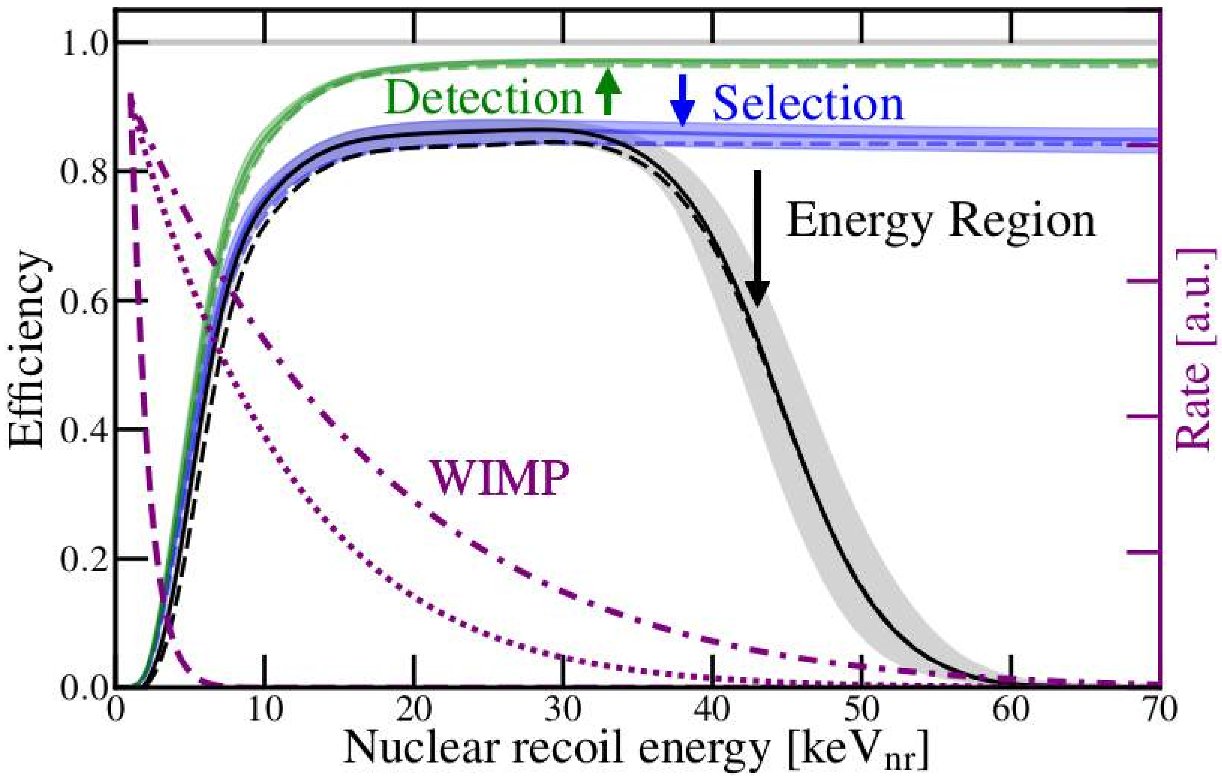
Optimize FV prior to unblinding to reduce materials and surface background

- 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 **S1, S2b, z and R**



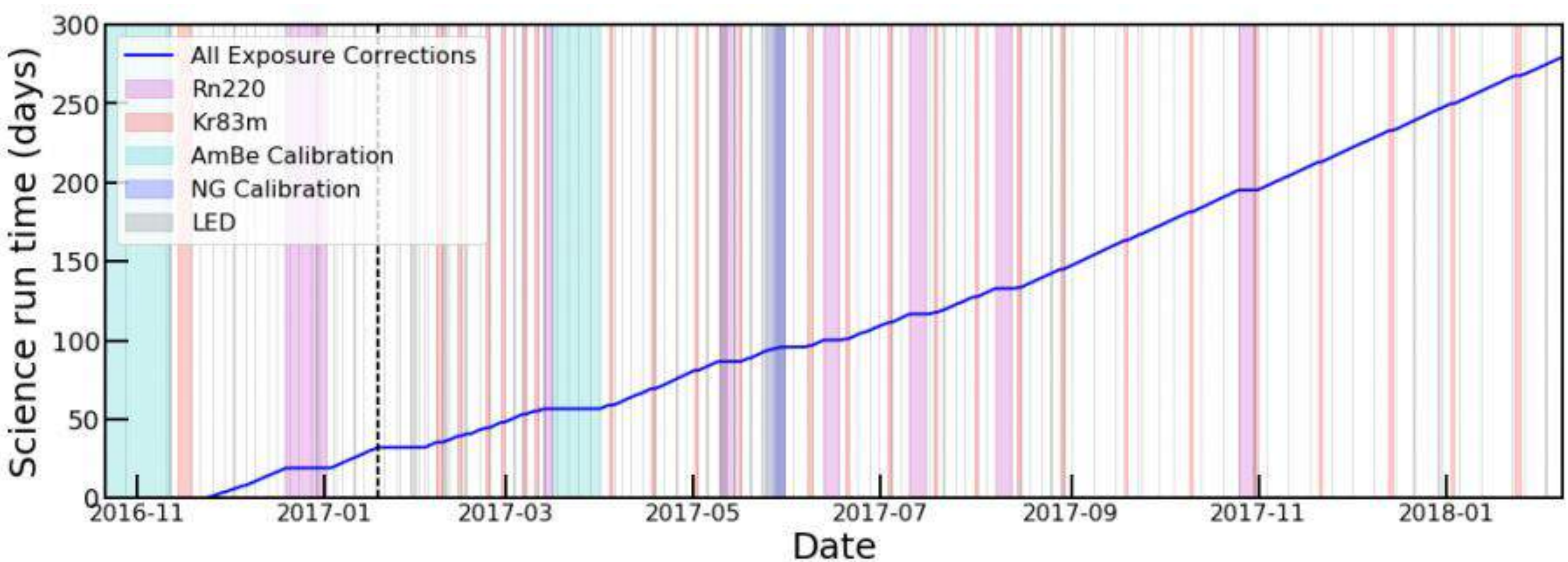
Event Selection & Data Efficiency

- Detection efficiency dominated by PMT 3-fold coincidence requirement
- Selection efficiencies estimated from control or MC data samples
- Search region defined within 3-70 PE in S1
- 10 GeV (dashed), 50 GeV (dotted) and 200 GeV (dashed-dotted) WIMP spectra shown



Exposure

- 32.1 days (SR0) + 246.7 (SR1) = 278.8 live days (corrected)
- 1.3 tonne FV giving exposure of 1 tonne X year, the largest reported exposure for this type of detector.



RESULTS

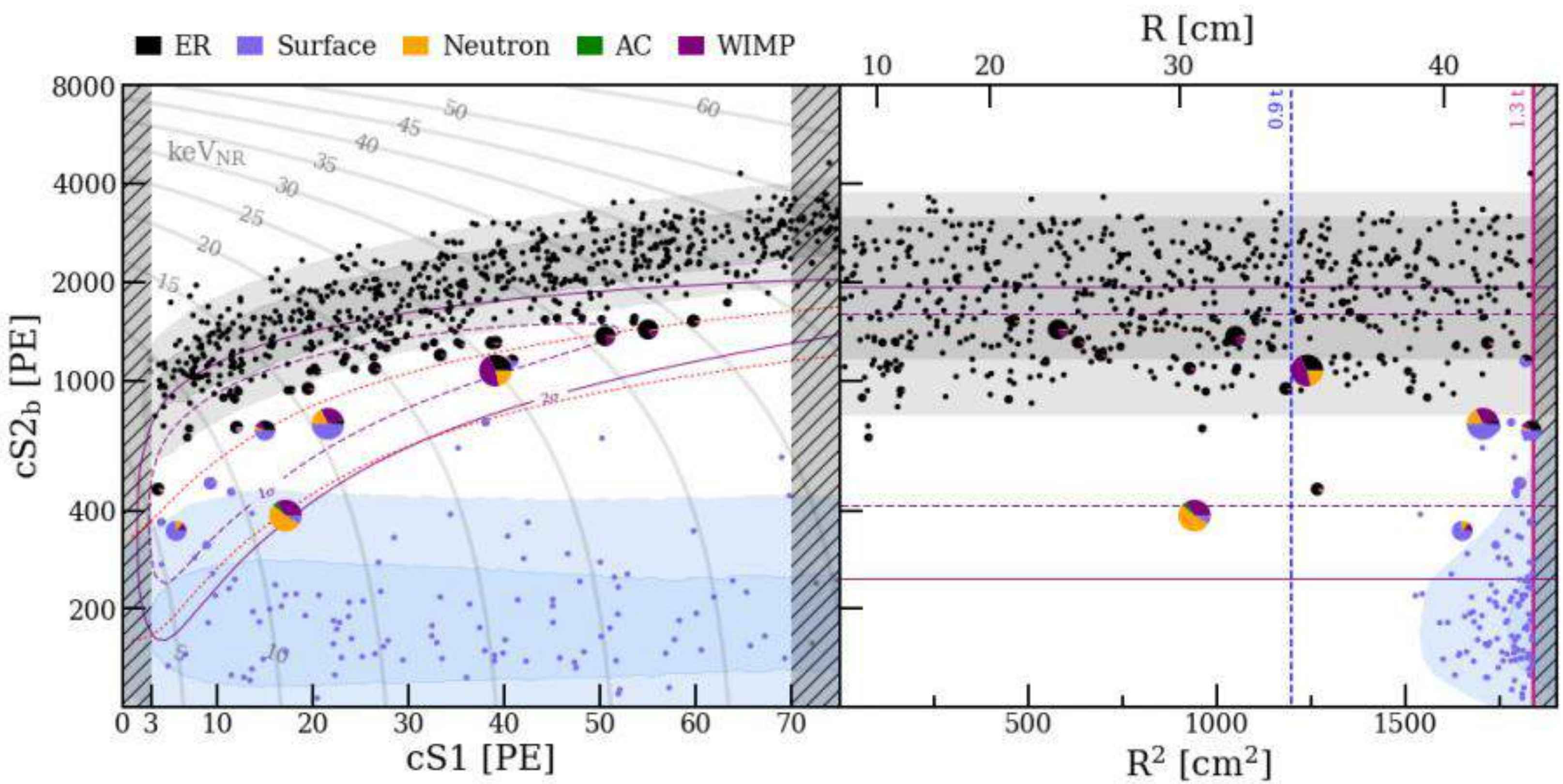
Results

Mass	1.3t	1.3t
Region	Full	Reference
ER	627 ± 18	1.62 ± 0.3
Neutron	1.43 ± 0.66	0.77 ± 0.35
CNNS	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
Data	739	14
WIMPs Best-Fit for m = 200 GeV: 4.7×10^{-47} cm^2	3.56	1.7

- Reference region is defined for a 50GeV WIMP signal between the median and -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
- **Full statistical interpretation is done based on profile likelihood analysis**

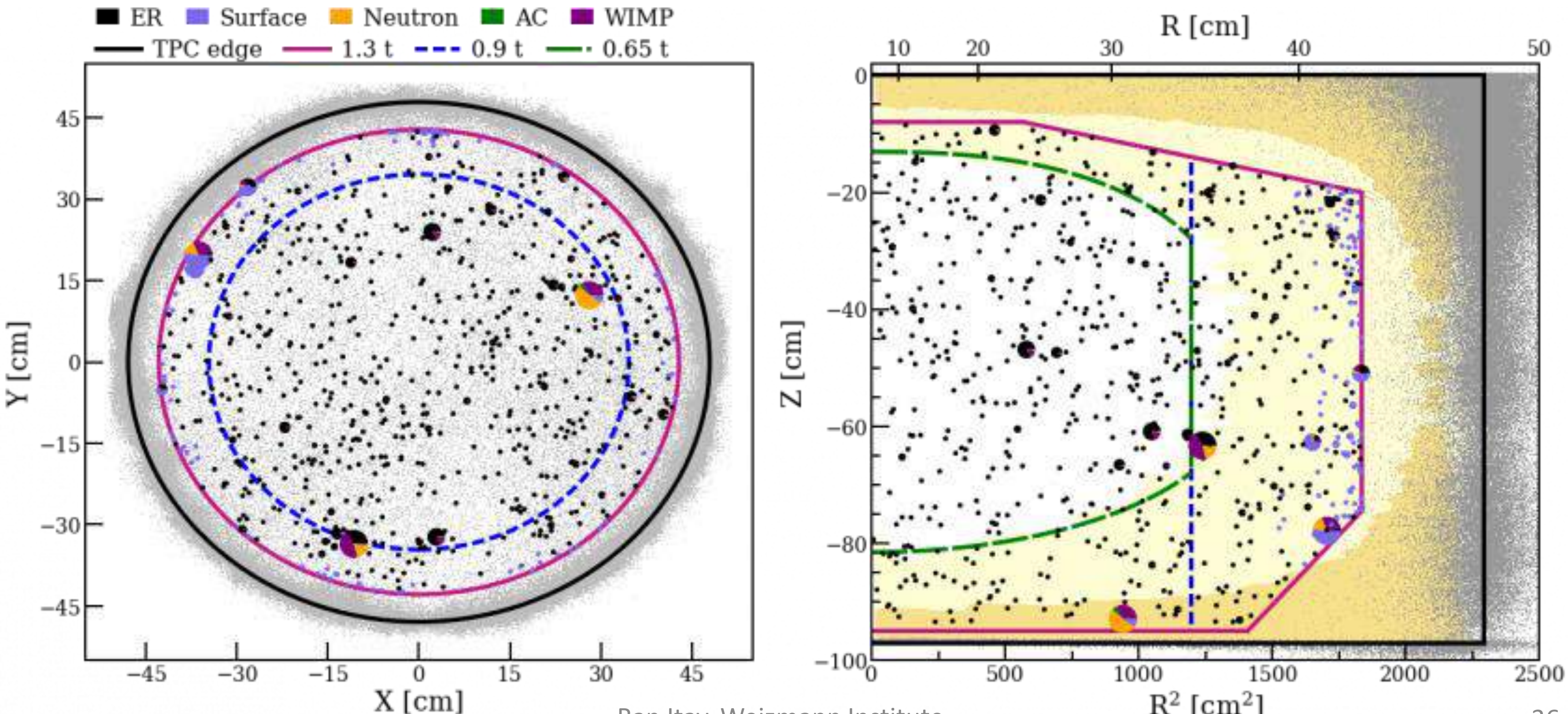
Results

- Results interpreted with unbinned profile likelihood analysis in s1, s2, r space.
- Pie-chart indicate the relative PDF from the best fit of 200 GeV/c^2 WIMPs with a cross-section of 4.7x10^{-47} cm^2.

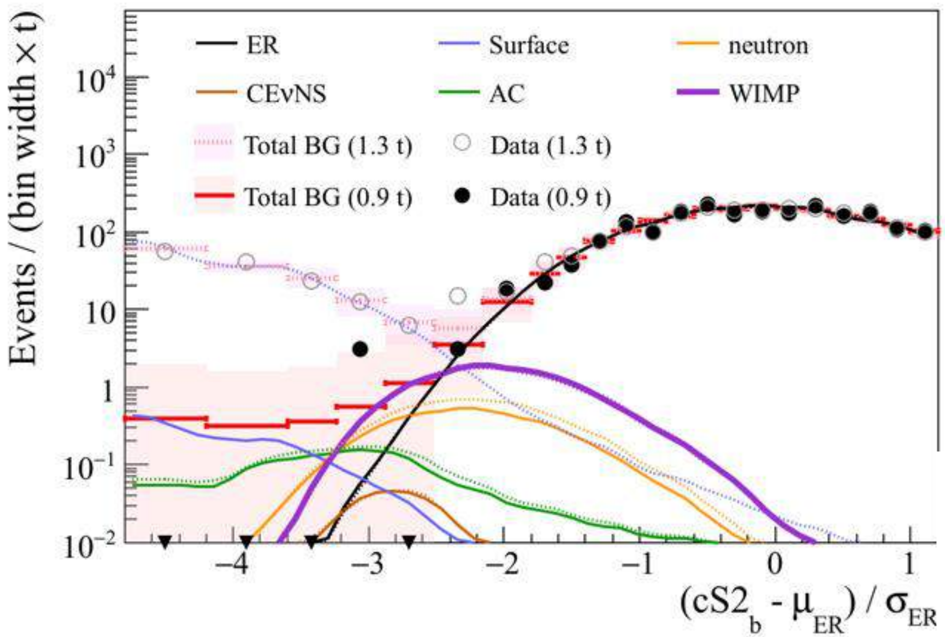


Results

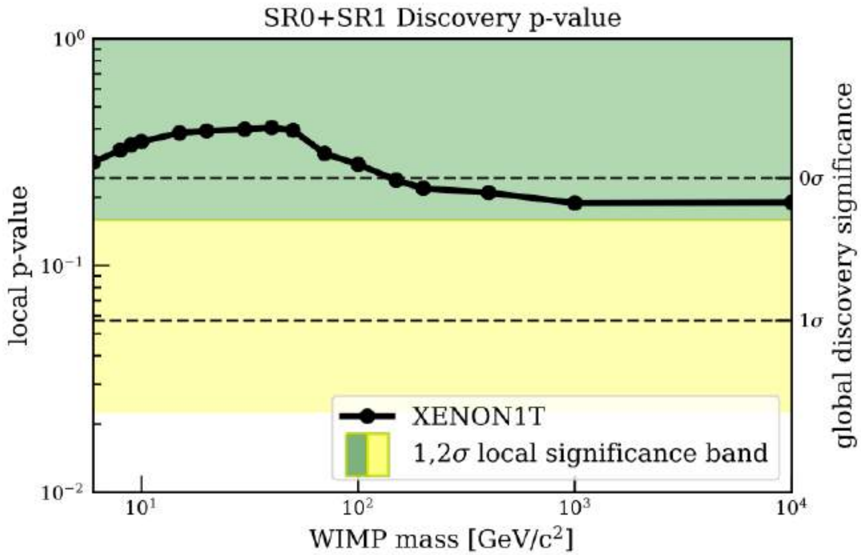
- Results interpreted with unbinned profile likelihood analysis in s1, s2, r space.
- Core volume to distinguish WIMPs over neutron background.



Results



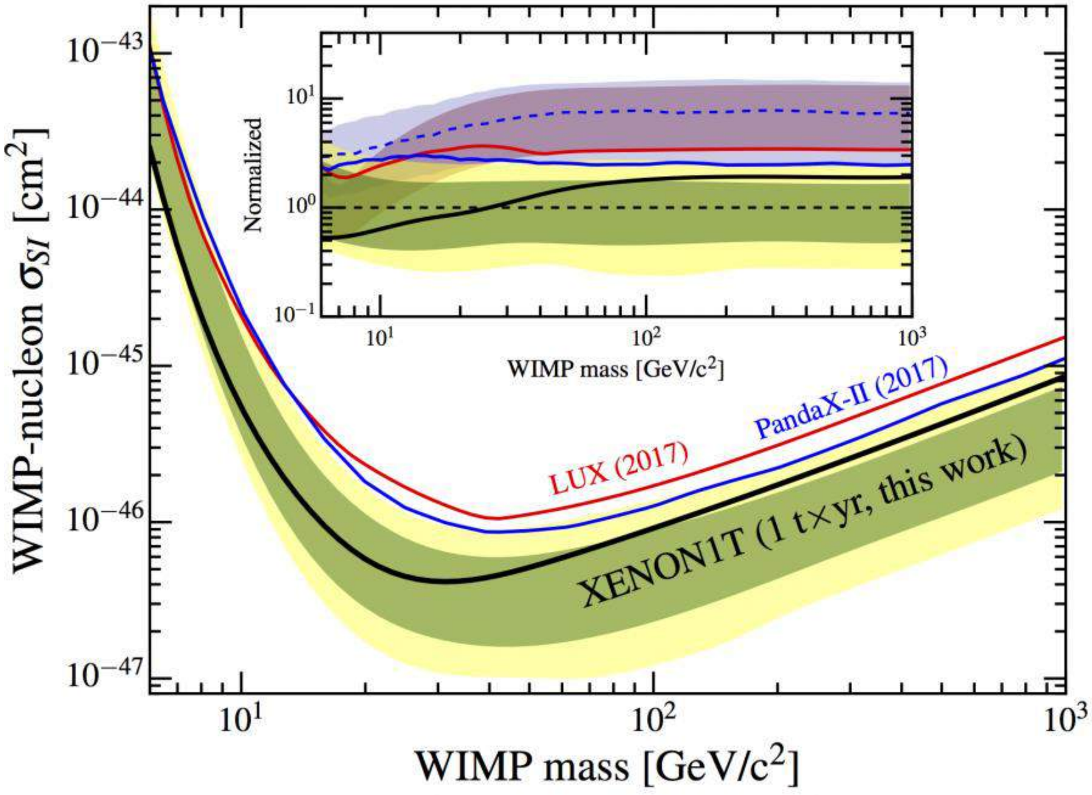
- Background and 200 GeV WIMP signal best-fit predictions, assuming 4.7 x 10^{-47} cm^2 , compared to data in 1.3 t and 0.9 t
- Most significant ER & Surface backgrounds shape parameters included
- Safeguard to protect against spurious mismodeling of background



- No significant (>3σ) excess at any scanned WIMP mass

Results

- 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)



FUTURE

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

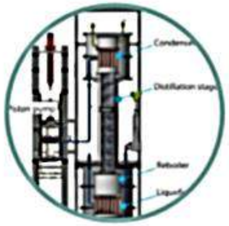
Installation starts in 2018
Commissioning in 2019

NEW TPC

Larger inner cryostat
476 PMTs

LXe PURIFICATION

Faster cleaning of large LXe volume (5000 SLPM)



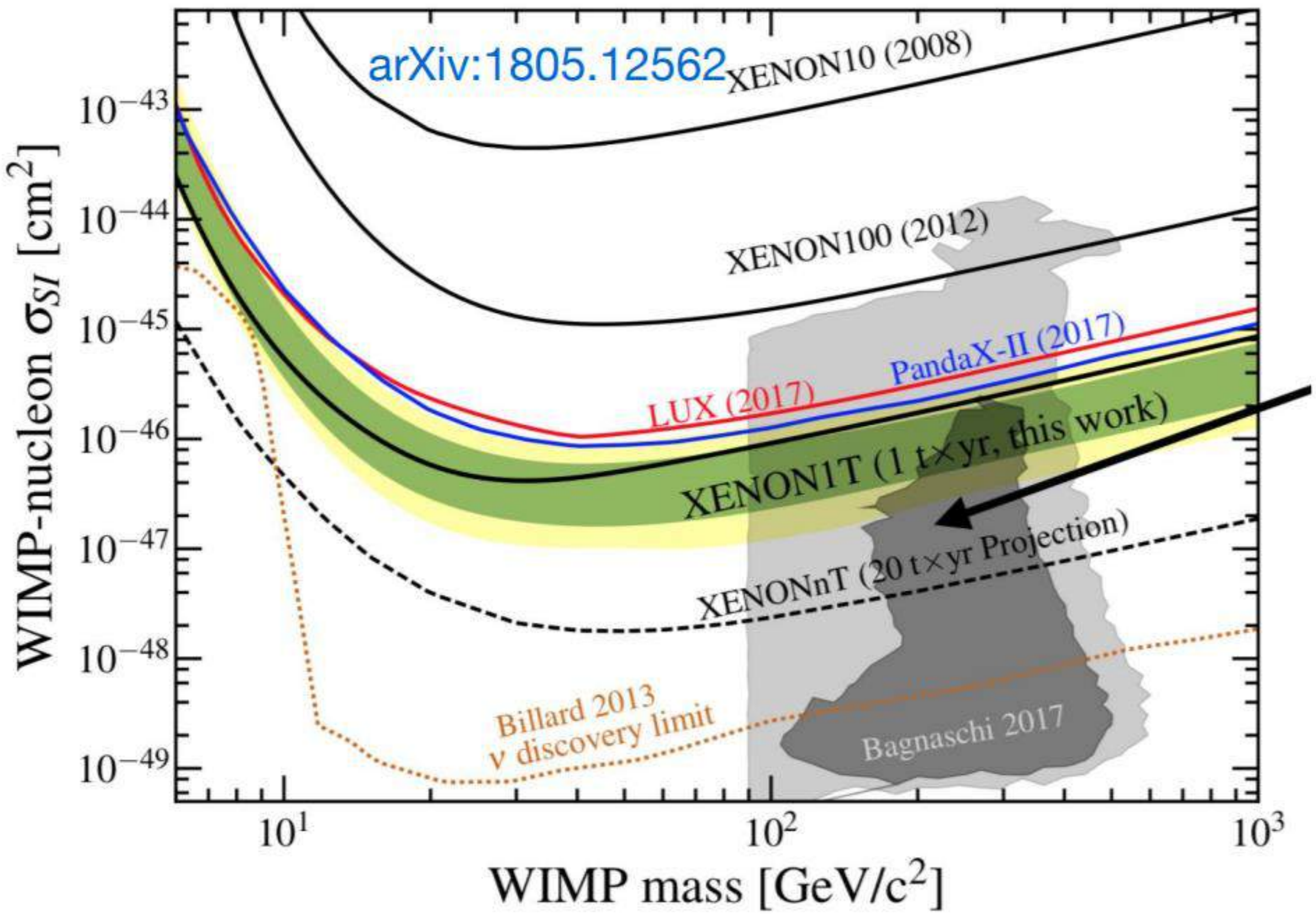
RADON DISTILLATION

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

NEUTRON VETO

Tagging and in-situ measurement of neutron-induced background

XENONnT


arXiv:1805.12562
XENON10 (2008)
XENON100 (2012)
LUX (2017)
PandaX-II (2017)
XENON1T (1 t×yr, this work)
XENONnT (20 t×yr Projection)
Billard 2013
ν discovery limit
Bagnaschi 2017
WIMP-nucleon σ_{SI} [cm^2]
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
10^1
10^2
10^3
WIMP mass [GeV/c^2]

Summary

XENON1T

- The XENON1T took a full tonne X year of DM search data, and has the highest sensitivity for all WIMP masses > 6 GeV
- Lowest background ever achieved in a DM detector
- **No SI WIMP signal was found**
- XENONnT upgrade in full speed – expecting first light in 2019!
- Many more results on the way – ER, axions, DEC, modulation, EFT...

Questions

Backup Slides