Direct Dark Matter Detection

with

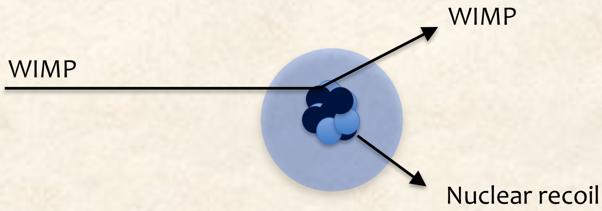
XENON1T

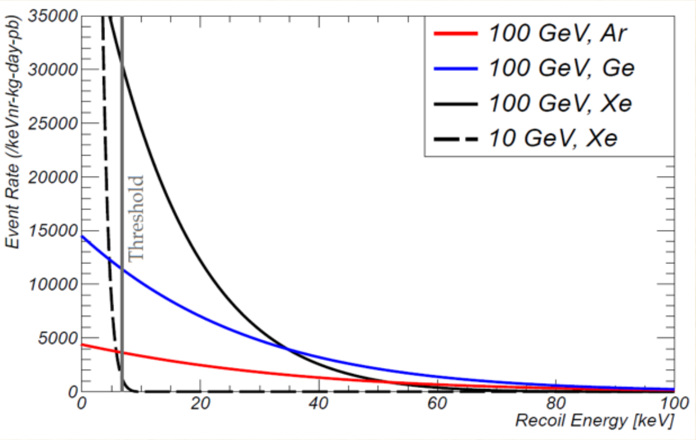
M. Galloway (U. Zürich) *on behalf of the* XENON Collaboration

XENON Dark Matter Project

Direct Detection with Xenon

Aim to observe elastic scattering of WIMP to deduce m, σ

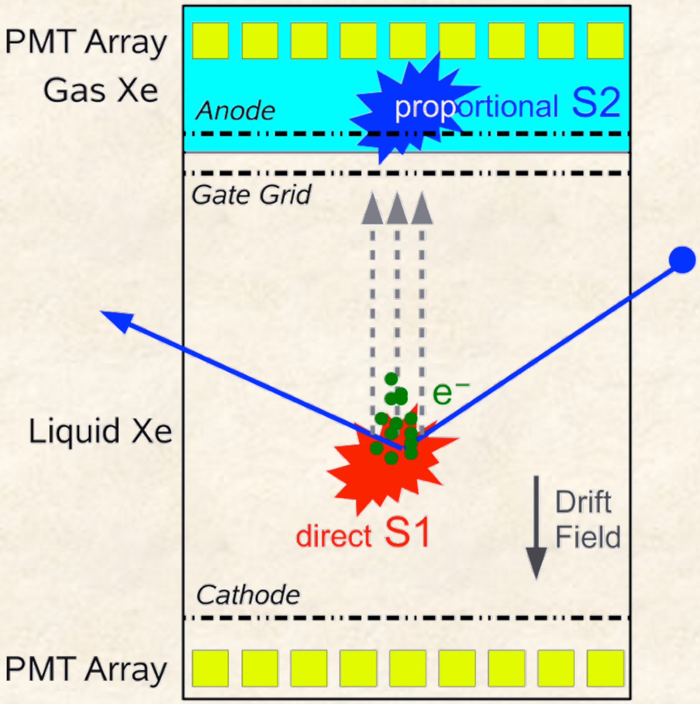




- **Efficient scintillator**: fast response, high light yield, 178 nm emission
- **High atomic mass**: A ~ 131 (spin-independent interactions scale as A^2), even/odd isotopes allow for both scalar and axial couplings
- **Self-shielding**: Z=54, $\rho = 3\ \mathrm{g\ cm^{-3}}$
- Liquid at 182 K at 2 bar (above LN2 temp)
- Low intrinsic radioactivity
- Scalable

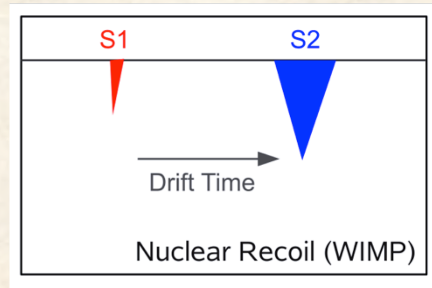
Detection Method

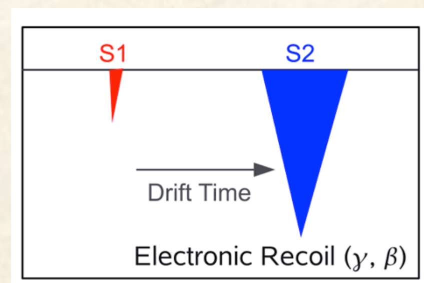
Time Projection Chamber (TPC)



Initial Interaction:
Prompt Scintillation (Lxe)

Drifted electrons:
Proportional Scintillation (Gxe)





→ **Event type**

$(S2/S1)_{NR} < (S2/S1)_{ER}$

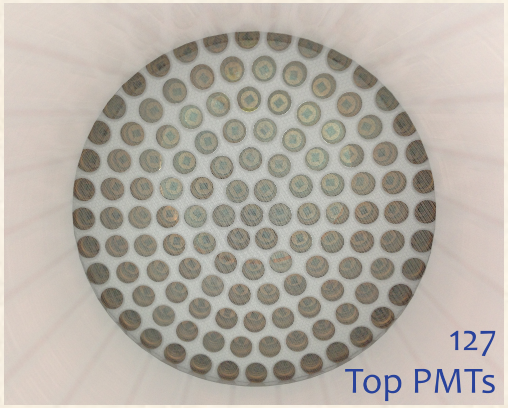
→ **Z-position**
Drift time proportional to Interaction depth

→ **X-Y position**
Hit pattern of S2 on top photosensors

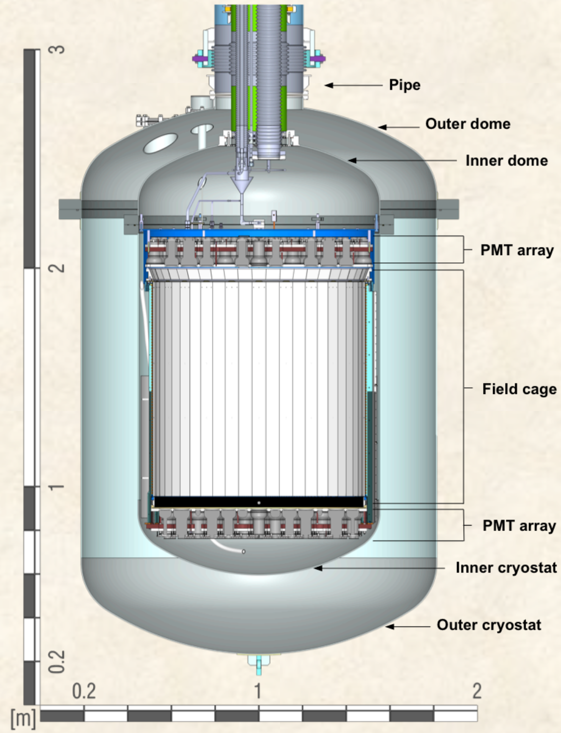
→ *Discrimination and fiducialization*

XENON1T TPC

Photosensors

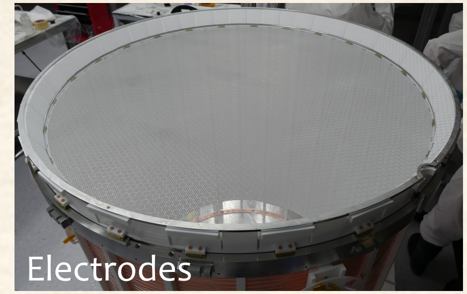


Hamamatsu 3” PMTs
QE ~34% @ 175 nm
Ave. gain ~5 x 10^6 at 1.5 kV



- Target mass 2 t Lxe (filled 04/2016)
- High-reflectivity Teflon to optimize light collection
- Radioassay of all materials (PMTs*) to mitigate internal backgrounds

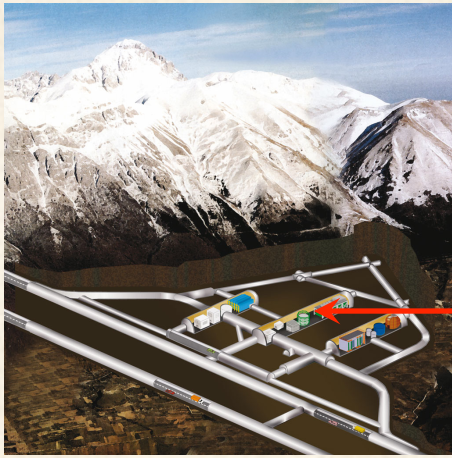
Electric field

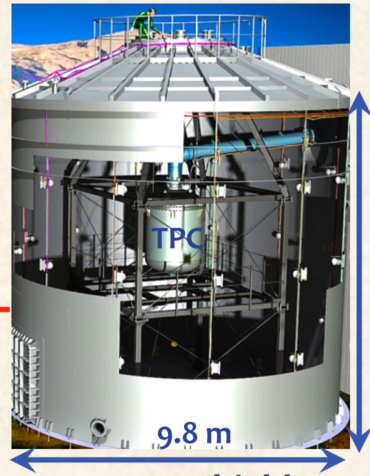


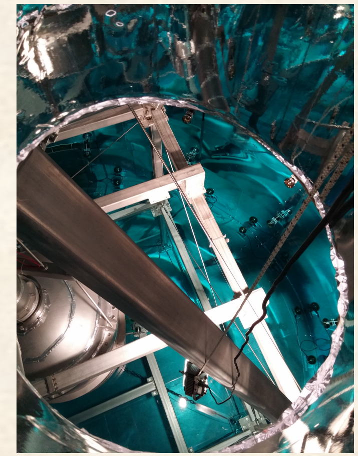
SS meshes and Au-plated SS wires
~90 – 97% transparency
74 OFHC Cu field-shaping rings

*arXiv:1503.07698

Passive and Active Shield





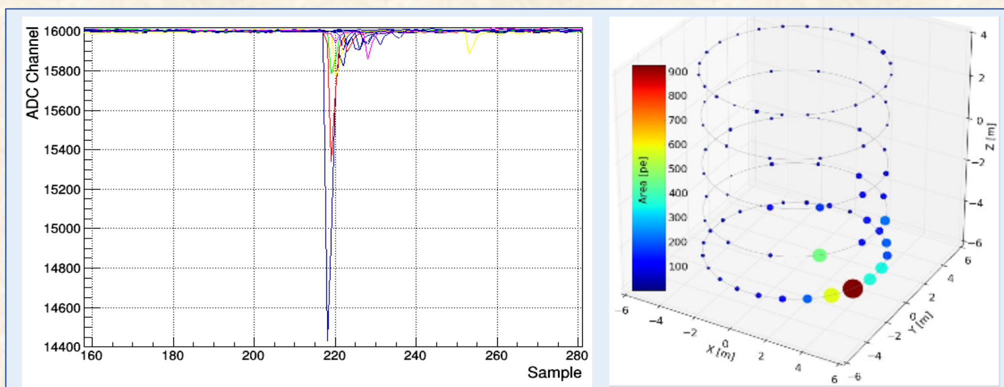


Laboratori Nazionali Gran Sasso
3600 m water equivalent
Muon reduction by factor 10^6

Water Shield
~700 m³ DI H_2O
External background reduction

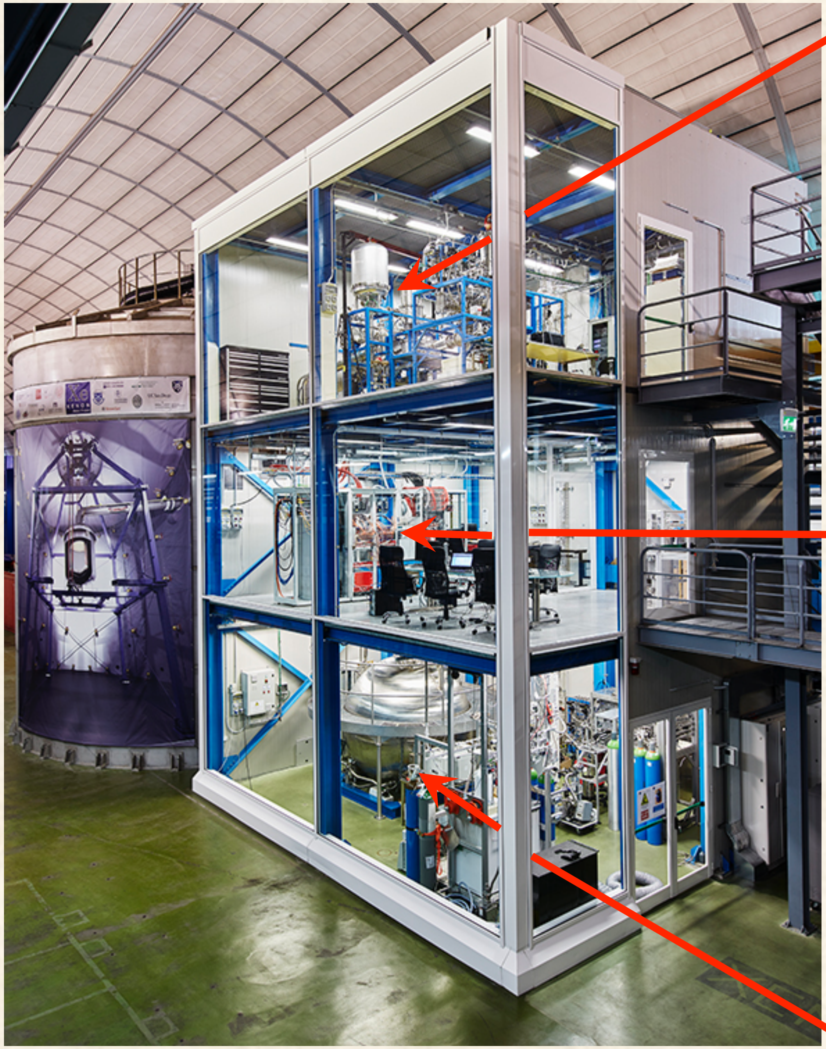
Cherenkov Detector
Tank instrumented with 84 high-QE 8" PMTs
Active rejection through coincidence tagging*

First Detected Muon!



*arXiv:1406.2374

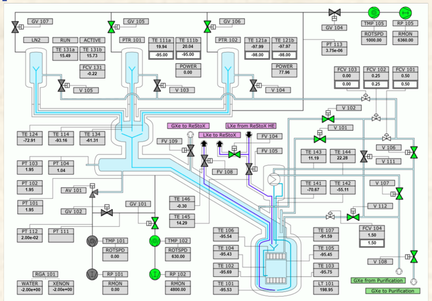
Infrastructure



Cryogenics, Xe purification

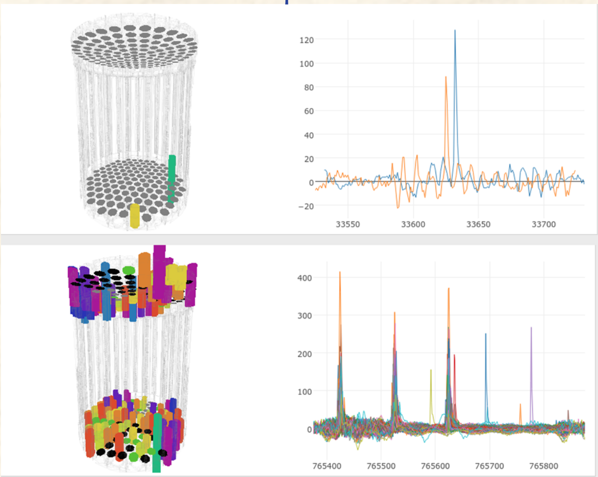
Slow control

- Safeguards Xe and critical subsystem operations
- Secure remote access



DAQ electronics

- Continuous readout at 1/3 p.e.
- Software trigger (flexible algorithms)
- Can handle rates up to 1 KHz

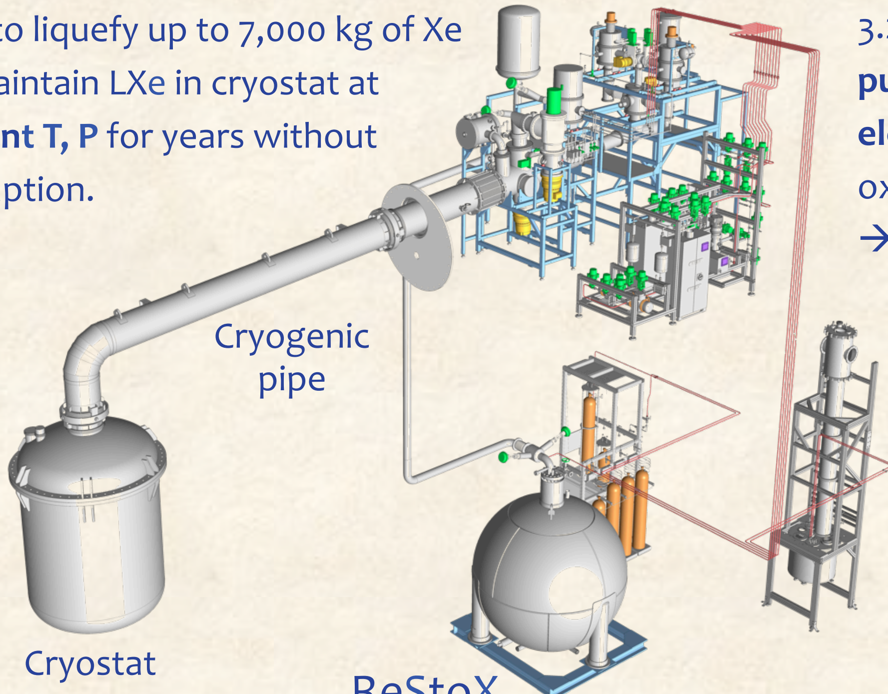


Xe storage and analytics, Distillation

Xe Cryogenics and Purification

Cryogenic system

- Cools to liquefy up to 7,000 kg of Xe
- Can maintain LXe in cryostat at **constant T, P** for years without interruption.



Purification system

3.2 t Lxe constantly in recirculation, **purification for electronegative elements** (O_2, H_2O) with hot zirconium oxide getter pump

→ Light yield, electron lifetime

Krypton Distillation Column

Removes Kr from Xe:

Kr/Xe_{nat} ~ 10^{-9} – 10^{-6}

radioactive $^{85}Kr/^{Nat}Kr$ ~ 10^{-11}

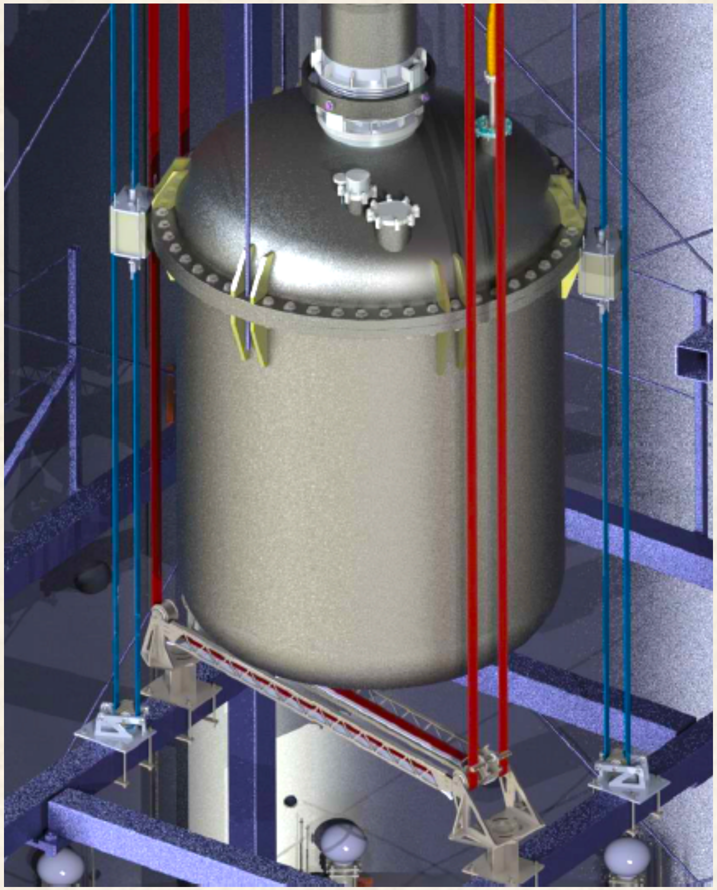
(internal background)

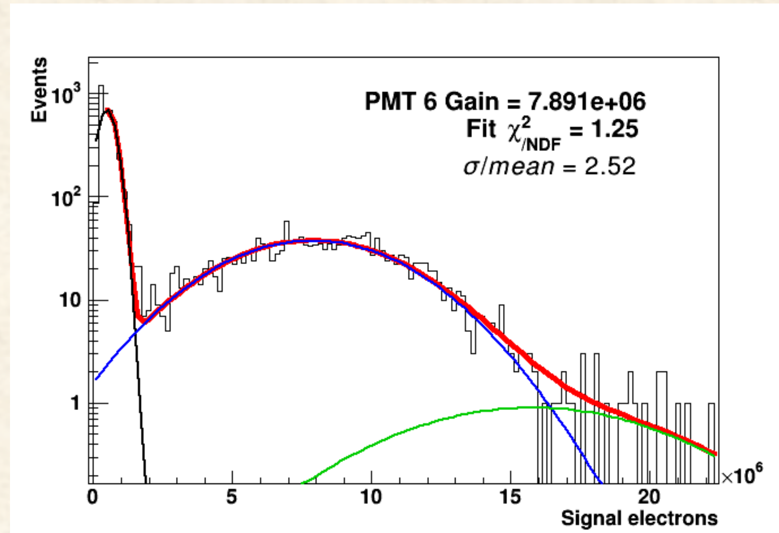
→ **$^{nat}Kr/Xe < 0.2$ ppt**

ReStoX

- 2.1 m OD sphere, stores **~7.6 t** of LXe or GXe
- Maintain and fill at high purity
- **Fast recovery:** ~few hours

Calibrations

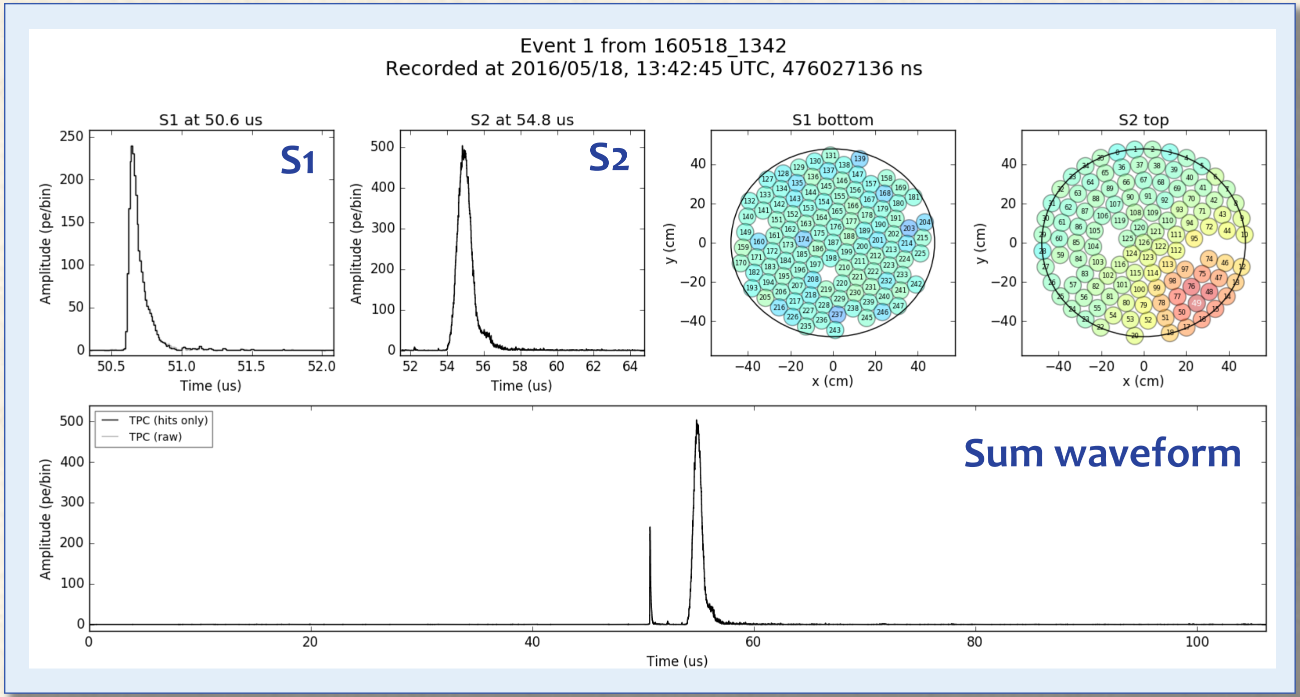




- Deployable external calibration sources
- short-lived internal sources
- Regular PMT gain calibrations with LEDs
- D-D neutron generator for NR band

→ Currently monitoring light yield and Xe purity

Commissioning Status



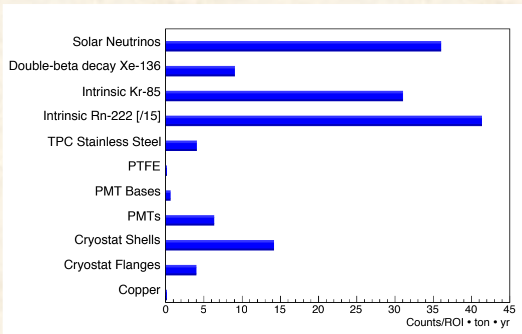
One of the first S1 + S2 pairs!

Anode at 3kV
Cathode at 8.05 kV
Meshes at 1.5 kV

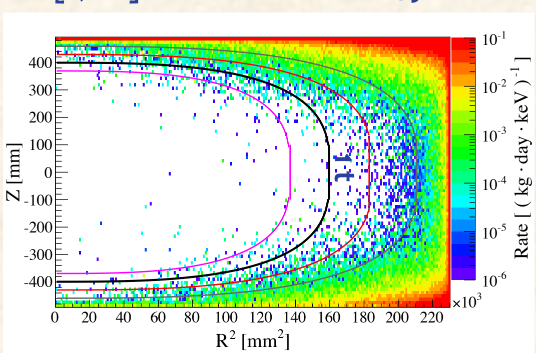
Expected Backgrounds

Based on detailed Geant4 Monte Carlo using radioassay results*

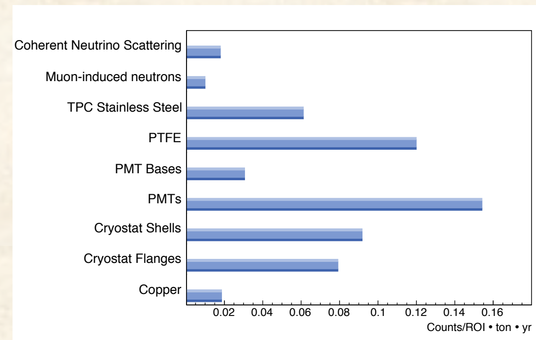
Electron Recoil



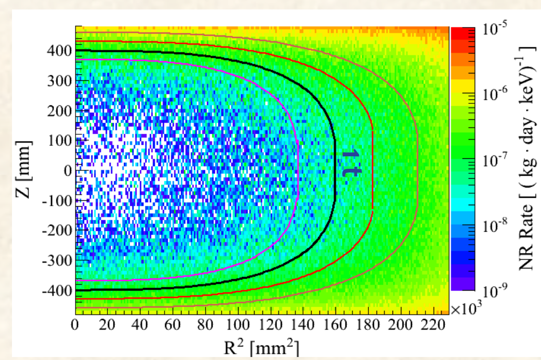
[1, 12] keV: ***1.62 events/yr***



Nuclear Recoil



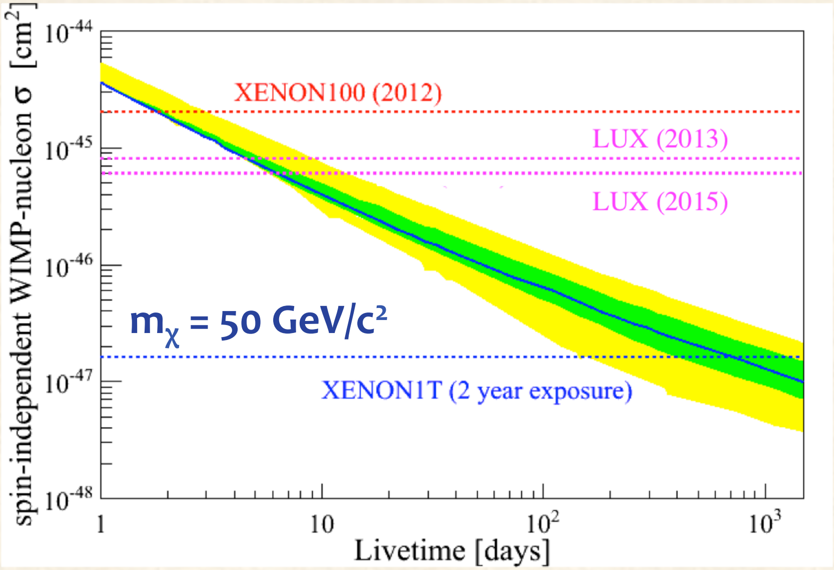
[4, 50] keV: ***0.46 events/yr***

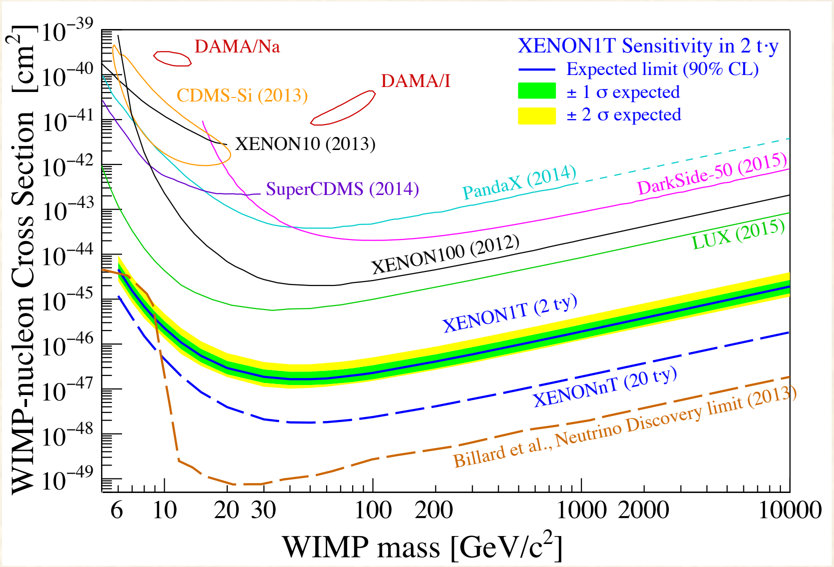


1 t Fiducial Volume , Single Scatter
99.75% S2/S1 discrimination, 40% NR acceptance

*arXiv:1512.07501

Projected Sensitivity



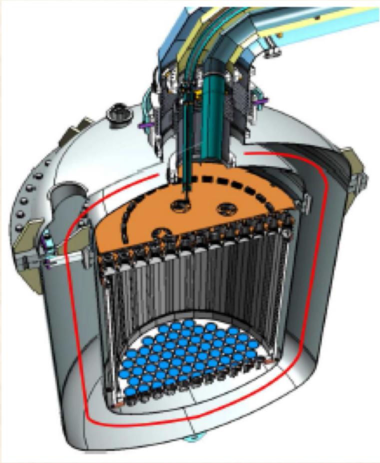


- Expected to overcome presently world-leading limits just within **10 days** of data taking in dark matter mode.
- Expected to reach with a **2 t·y** exposure a sensitivity to spin-independent WIMP-nucleon interactions of **1.6 x 10^{-47} cm²** for a **50 GeV/c²** (99.75% ER rejection, 40% acceptance NR and 1 tonne fiducial volume).

Summary and Outlook

XENON1T is here!

- Commissioning status:
  - ✓ Cryogenics, purification efficiency and operation of all infrastructures demonstrated.
  - ✓ Cherenkov light from muons observed.
  - ✓ Regular data taking with DAQ and subsequent data analysis.
  - ✓ LXe purification ongoing, electron lifetime increasing.
  - ✓ Initial HV tests successful, resulting in first light/charge (S1/S2) pairs from LXe interactions!!!
- First science run expected this fall, with sensitivity to other physics channels expected



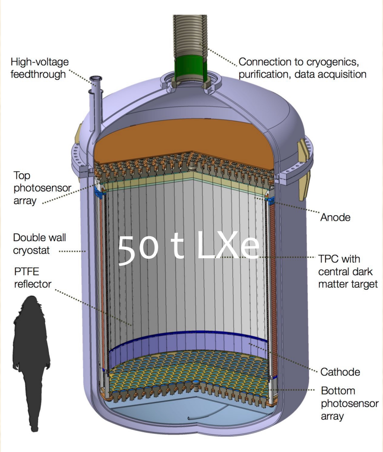
XENONnT
2018

Xe target mass ~7.6 **t**

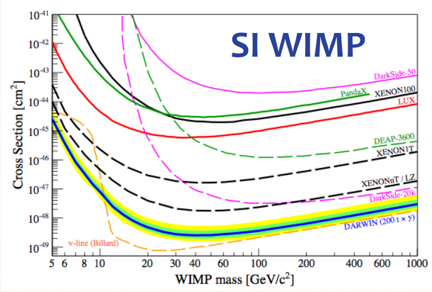
Expected Sensitivity

(50 GeV, 202x):

2 x 10^{-48} cm²



darwin-observatory.org*
~ 10^3 photosensors
2.6 m drift length, 2.6 m diameter TPC



*arXiv::1606.07001

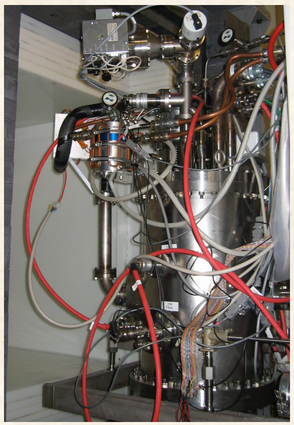
Thank you!

Columbia
RPI
Nikhef
Mainz
Stockholm
Muenster
Chicago
MPIK
UCLA
Bern
UCSD
Zurich
Rice
NYUAD
Purdue
Coimbra
Subatech
Bologna
LNGS
Torino
Weizmann

Backup

XENON Collaboration

XENON10



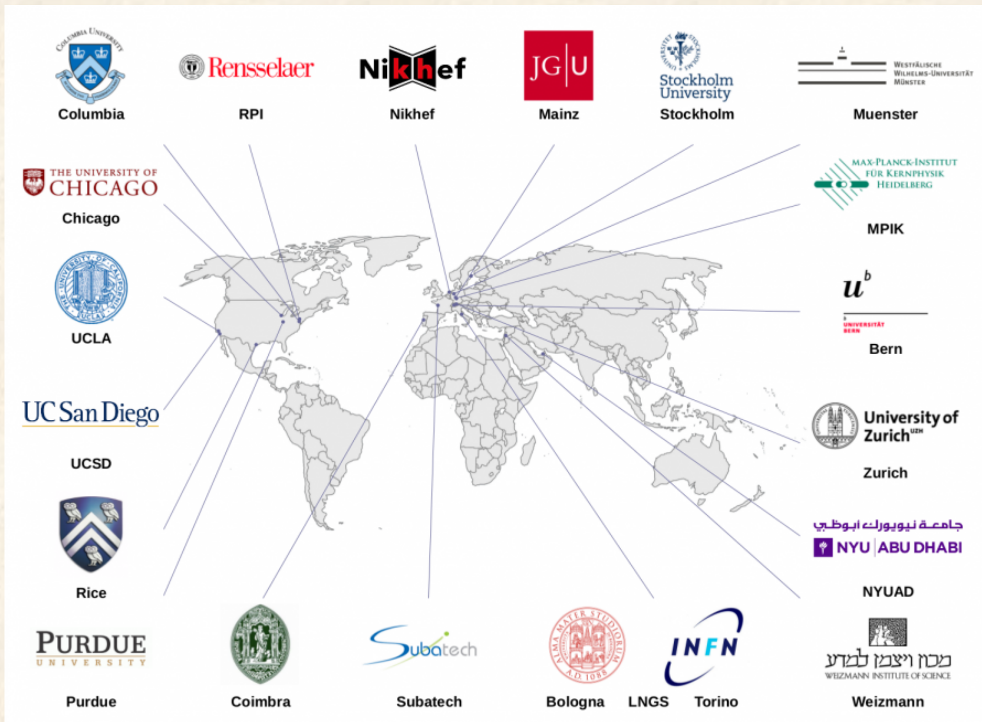
15 cm

2005 – 2007

Xe **15 kg**

8.8 x 10^{-44} cm²

(100 GeV, 2007):



21 institutions, 10 countries, ~150 scientists

XENON100

30 cm

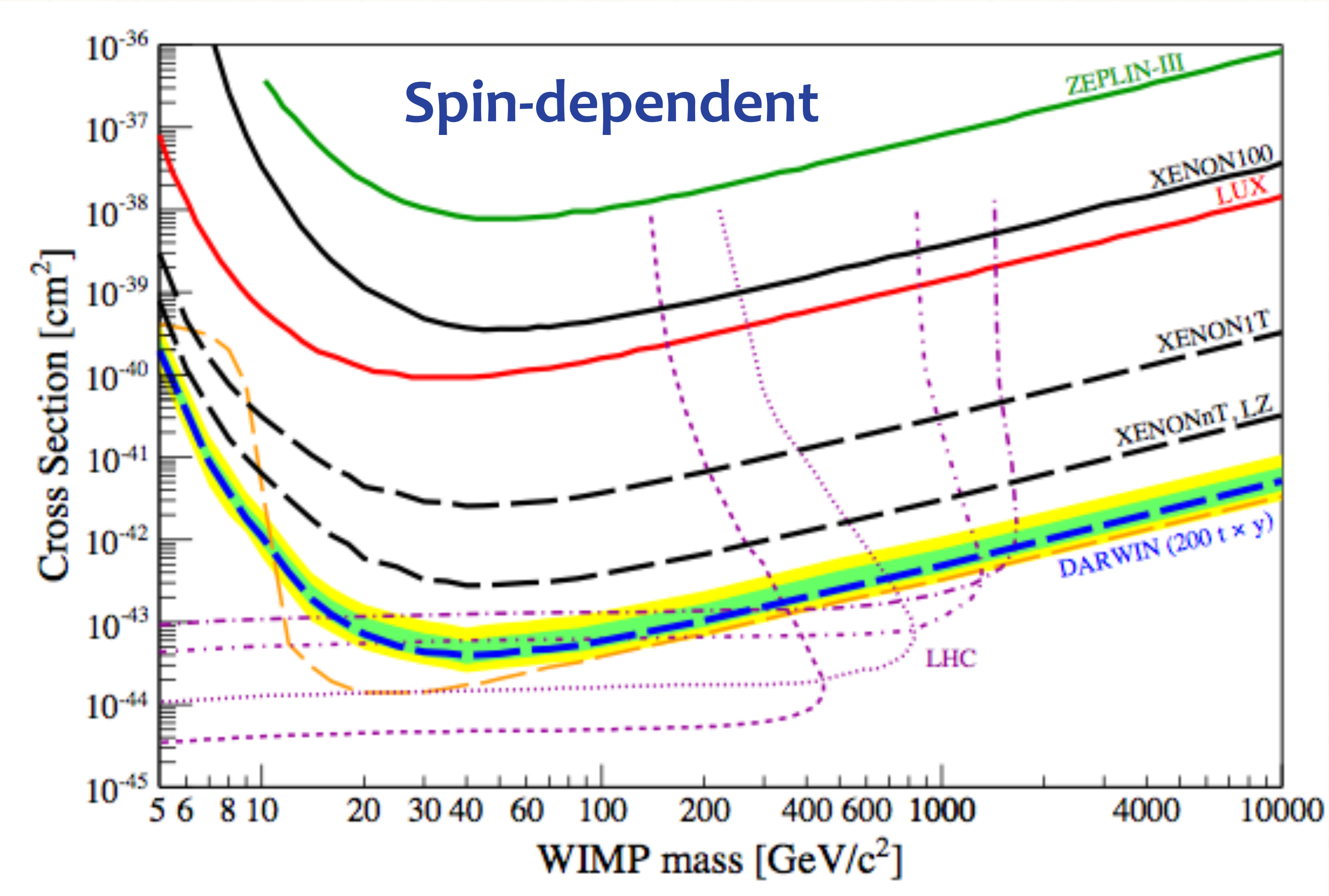
2008 – present

Xe **62 kg**

2.0 x 10^{-45} cm²

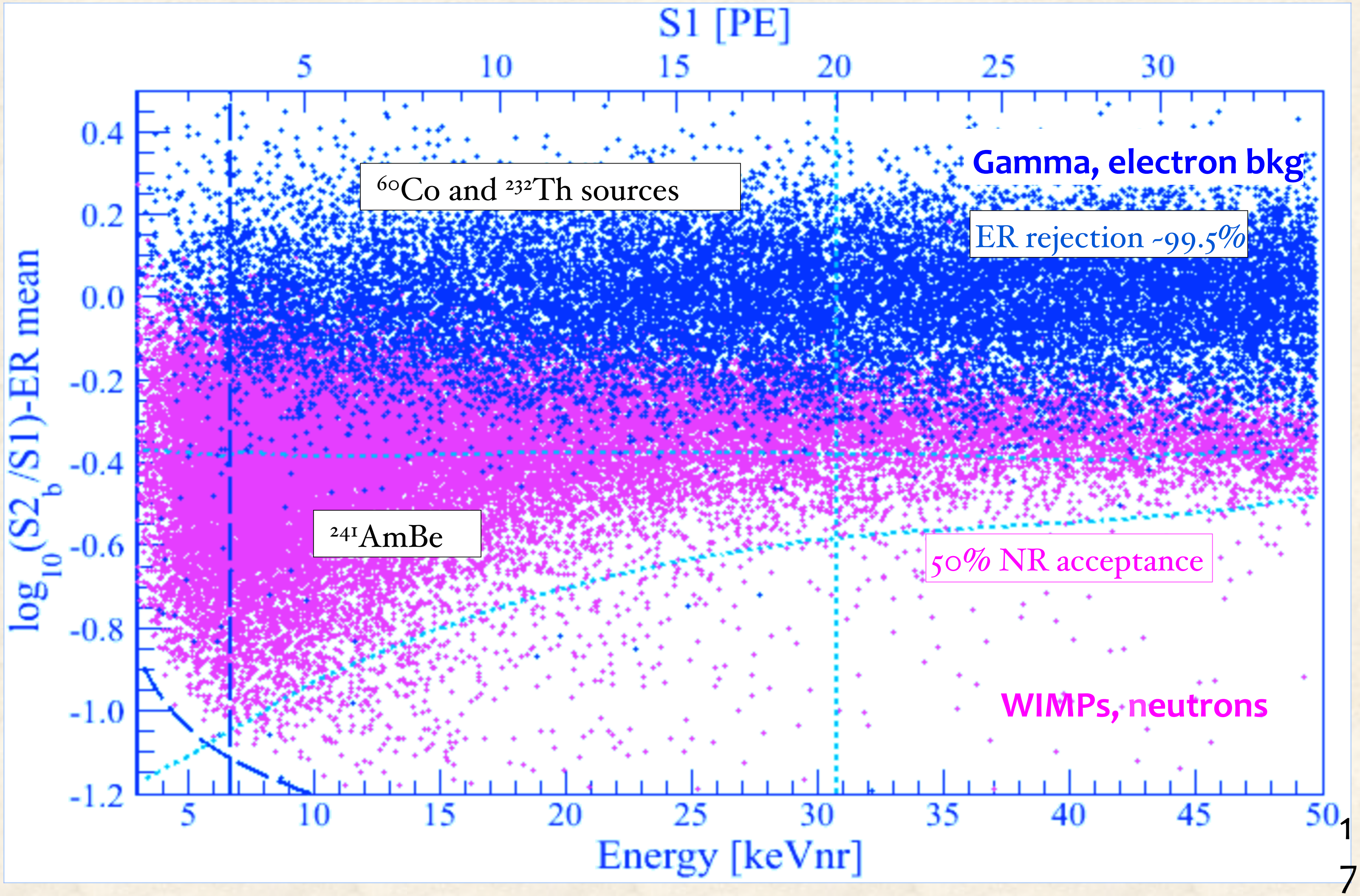
(55 GeV, 2012)

Projected Sensitivity



Xe100 sensitivity for WIMP-neutron coupling: $\sigma_n < 3.5 \times 10^{-40}$ cm² for 45 GeV/c² WIMP

Electron Recoil (ER) & Nuclear Recoil (NR) calibration data (from XENON100)



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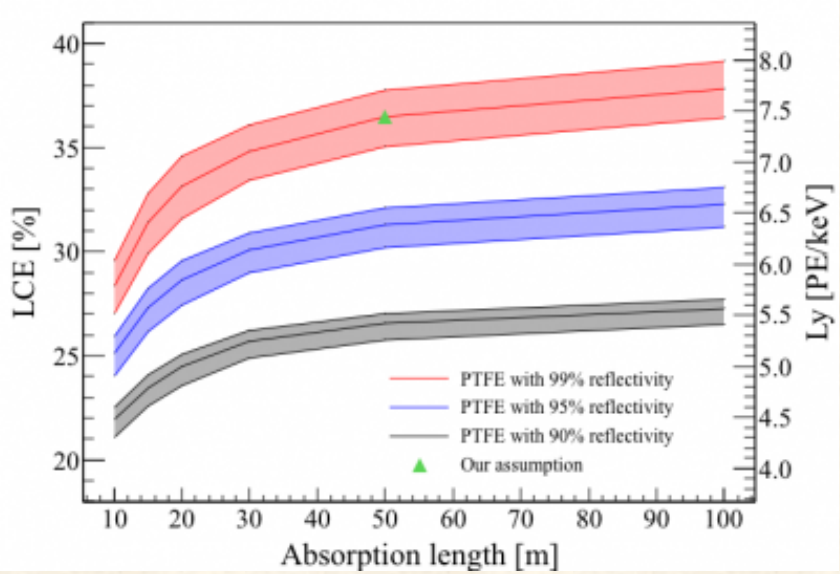
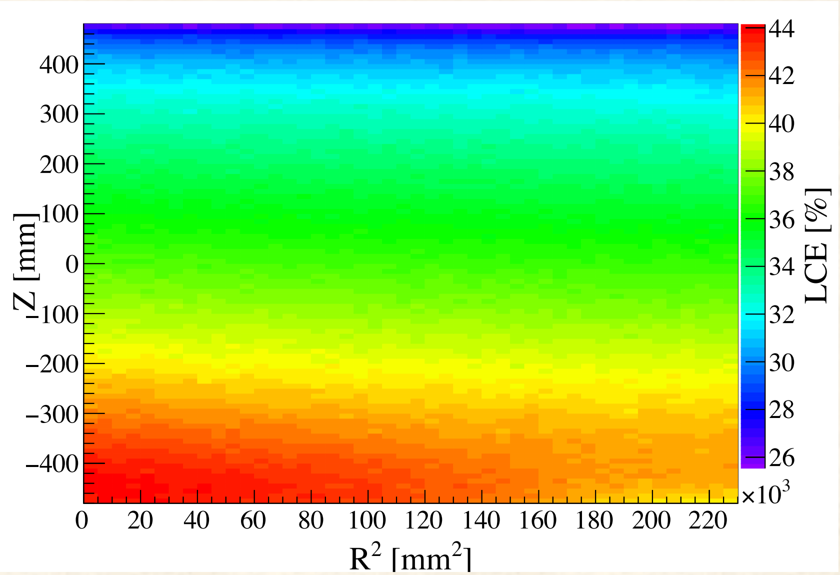
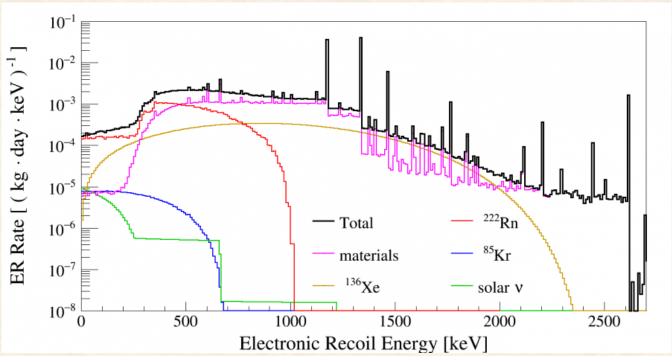
Light Collection

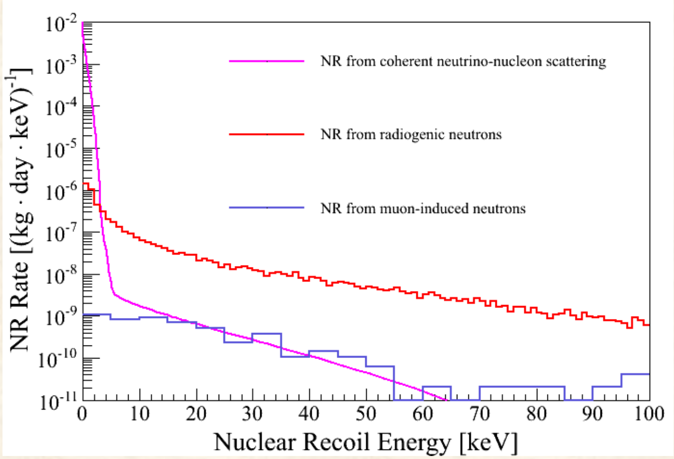




- 30 cm Rayleigh scattering length
- 50 m abosrption length

Expected Backgrounds



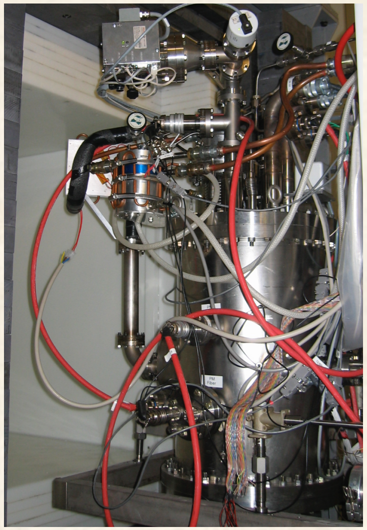


Source	Background (ev/y)
ER from materials	~0.07
^{222}Rn (10 μBq/kg)	~1.39
^{85}Kr (0.2 ppt of ^{nat}Kr)	~0.07
^{136}Xe 2ν2β	~0.02
Solar neutrinos	~0.08
Total ER	~1.62
Total NR	~0.46

Single Scatter, 1 tonne Fiducial Volume, [2, 12] keVee, [5, 50] keVr, 99.75% S2/S1 discrimination, 40% NR acceptance

The XENON Dark Matter Program

XENON10



15 cm

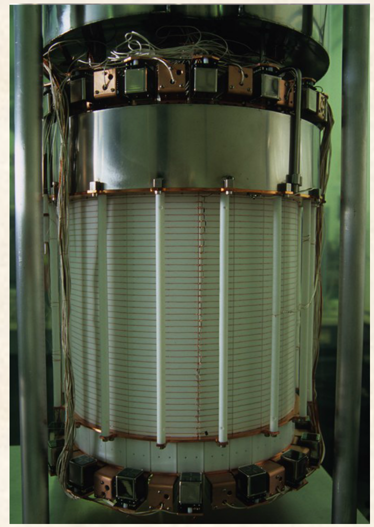
2005 – 2007

Xenon target = **15 kg**

Sensitivity* (100 GeV, 2007):

8.8 x 10^{-44} cm²

XENON100



30 cm

2008 – present

Xenon target mass = **62 kg**

Sensitivity* (55 GeV, 2012):

2.0 x 10^{-45} cm²

XENON1T

~ 1 m

2016

Xenon target mass = **2000 kg**

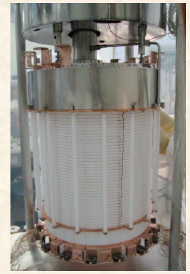
Expected Sensitivity* (50 GeV, 2018):

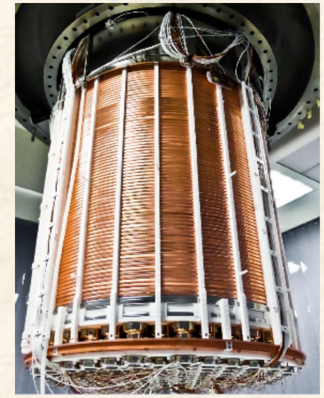
1.6 x 10^{-47} cm²

*SI WIMP

Sensitivity increases with exposure (target mass, time) and background reduction

DARWIN

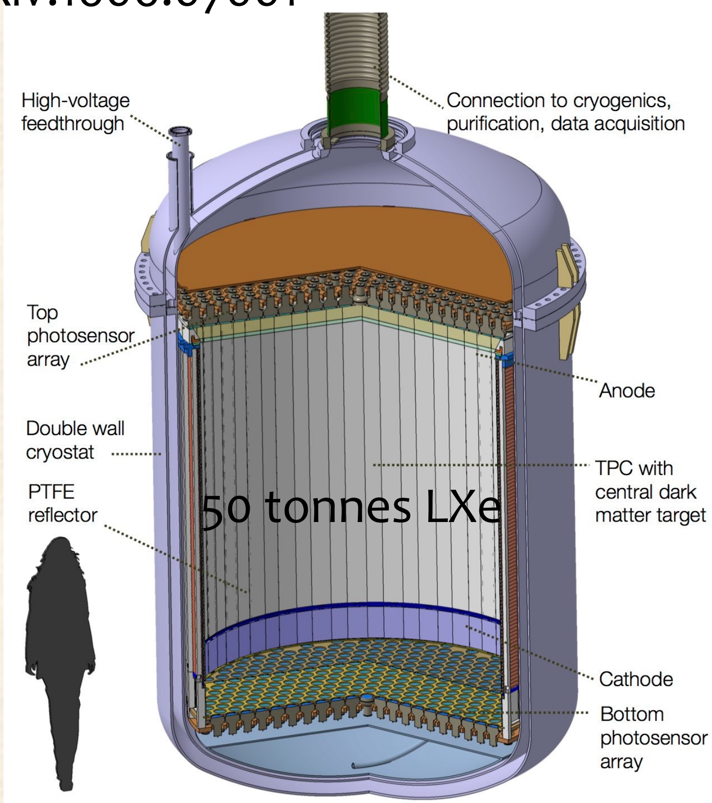




Ultimate LXe TPC at LNGS

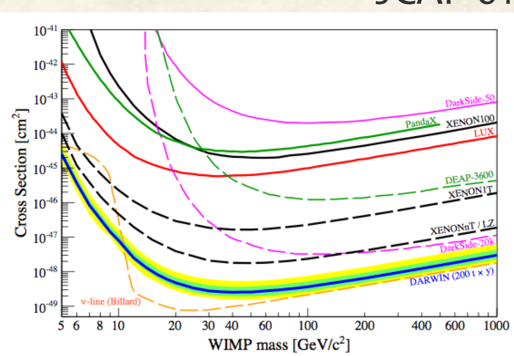
- 50 t (40 t) LXe in total (in the TPC)
- ~ 10^3 photosensors
- 2.6 m drift length, 2.6 m diameter TPC
- **Will reach "neutrino floor", 200 t y exposure**
- **WIMP spectroscopy, and non-WIMP science: axion/ALP search, solar neutrinos, 0nbb-decay of ^{136}Xe, coherent neutrino-nucleus scattering, SN neutrinos**

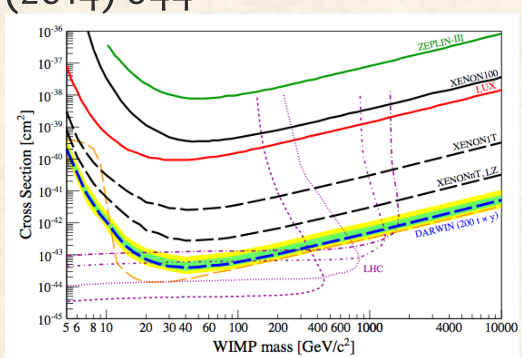
arXiv:1606.07001



darwin-observatory.org

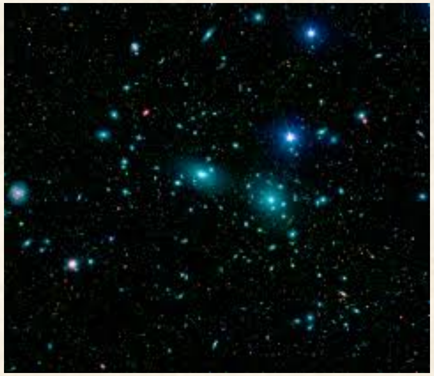
JCAP 01 (2014) 044



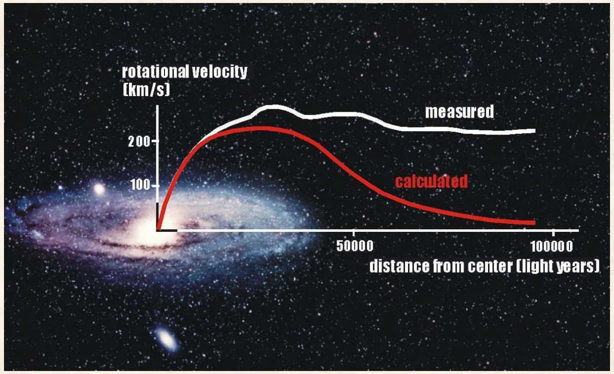


JCAP10 (2015) 016

Dark Matter



Coma Cluster

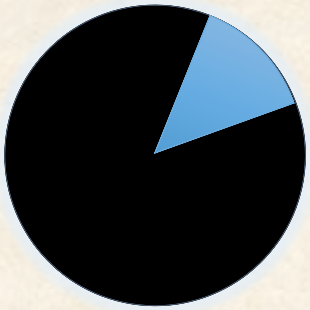


Andromeda Galaxy

Bullet Cluster

Dark matter : Ordinary matter

~5:1



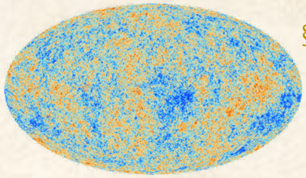
- ☑ Stable (long-lived)
- ☑ Non-baryonic
- ☑ Non-relativistic
- ☑ Interacts gravitationally
- ☑ EM neutral (transparent)

Beyond-SM theories predict a

WIMP

(Weakly Interacting Massive Particle)

Search strategies



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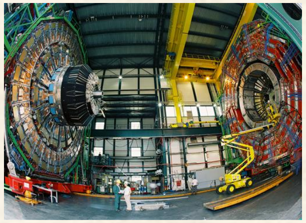
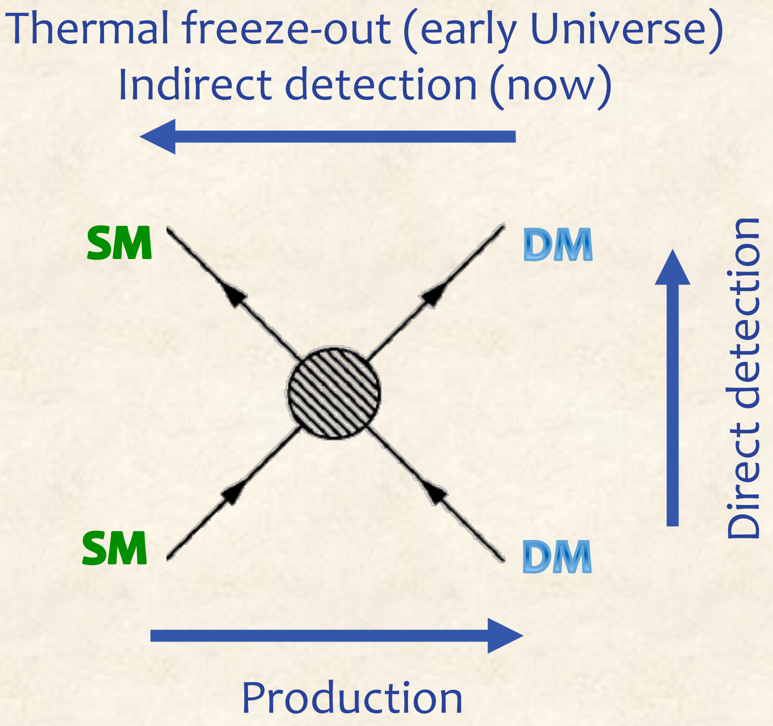




§ Ref: Planck collaboration, Astron. Astrophys. 571 (2014) A16

Direct searches

XENON Dark Matter Project

DM local density (input from cosmology/ astrophysics)

$$\rho_0 = 0.3\ \frac{\mathrm{GeV}}{\mathrm{c^2 cm^3}}$$

Mass of the target

$$\frac{dR}{dE_r} = \frac{\rho_0 M}{m_N m_\chi} \int_{v_{min}}^{v_{esc}} v f(v) \frac{d\sigma}{dE_r} dv^3$$

Mass of target nucleus

Mass of WIMP

WIMP velocity distribution (input from cosmology/ astrophysics)

Interactions of WIMPs with baryonic matter: a priori unknown

XENON Dark Matter Project

The effective interaction Lagrangian would consist of two terms accounting for ***scalar and axial*** *coupling:*

$$\mathcal{L}_{\rm eff} = f_q \bar{\chi}\chi\bar{q}q + d_q \bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q + \dots$$

Scalar ***Axial***

Cross section:

$$\frac{d\sigma}{dE_R} = \frac{m_T}{2\mu^2 v^2}\left[\sigma_{SI} F^2_{SI}(E_R) + \sigma_{SD} F^2_{SD}(E_R)\right]$$

$$\sigma_{SI} = \frac{4\mu^2}{\pi}\left[Z f_p + (A-Z) f_n\right]^2 \propto A^2$$

Spin-Independent Interaction

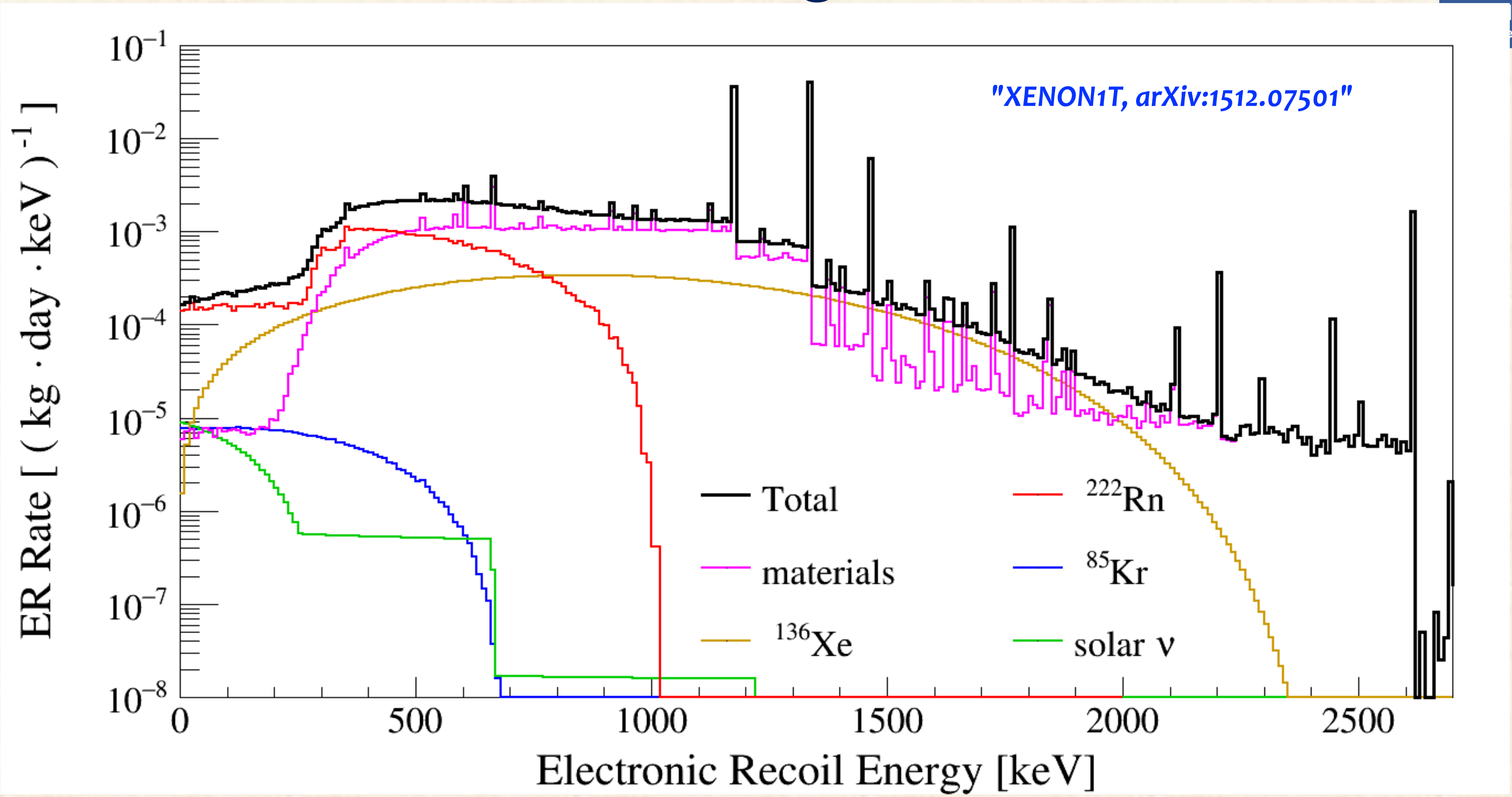
Proportional to A^2
(or geometrical dimensions of nucleus)

$$\sigma_{SD} = \frac{32\mu^2}{\pi} G_F^2 \frac{J+1}{J}\left[a_p\langle S_p\rangle + a_n\langle S_n\rangle\right]^2$$

Spin-Dependent Interaction

Sensitivity requires nucleus with non-zero spin
(i.e. ^{19}F, ^{23}Na, ^{73}Ge, ***^{129}Xe, ^{131}Xe****, ^{133}Cs)*

Electron Recoil Background XENON1T



0.2 ppt of ^{nat}Kr (measured at distillation column)

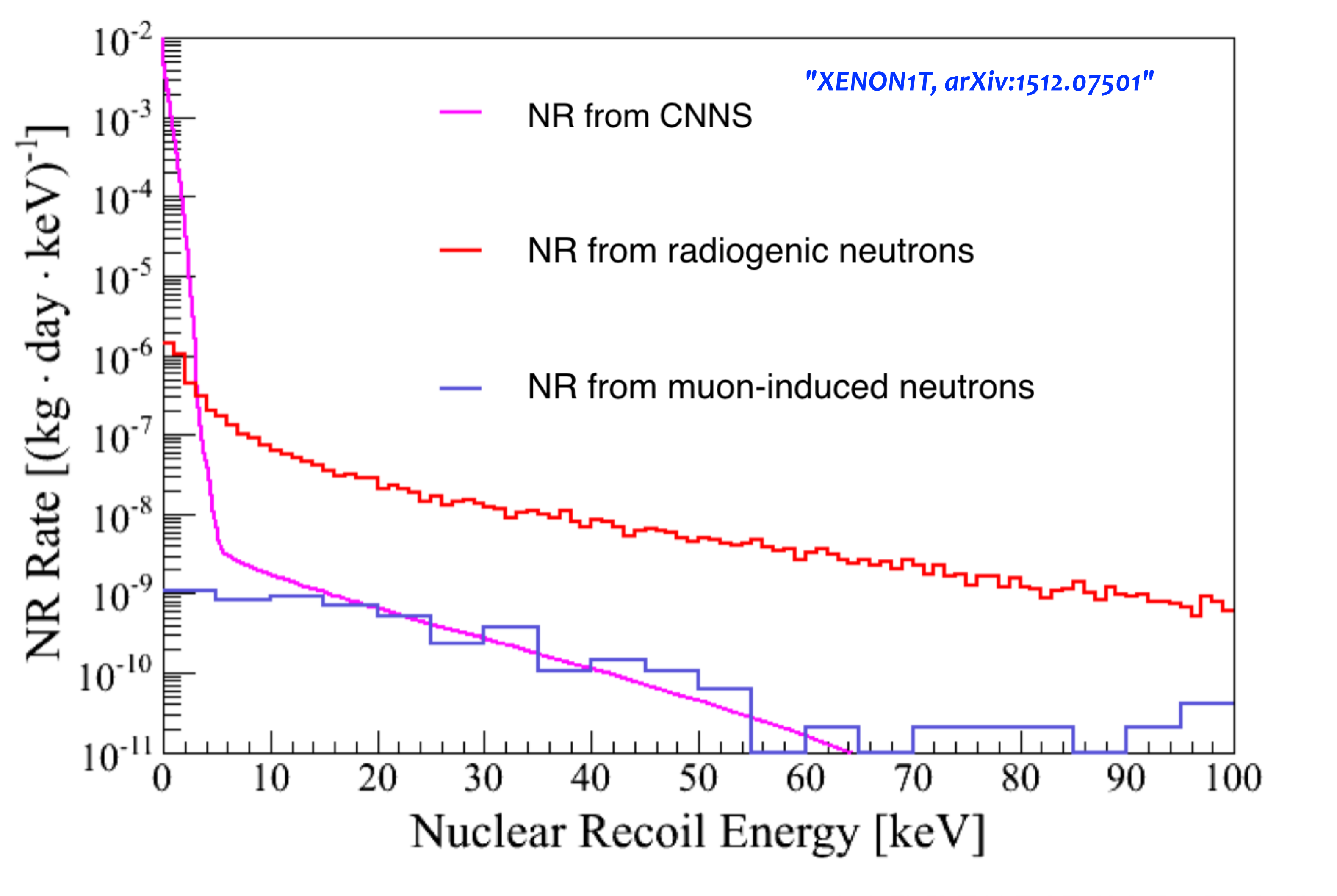
$10\ \frac{\mu Bq}{kg}$ of ^{222}Rn from emanation measurements

Within the ROI, bkg from materials similar to **solar neutrinos** bkg and **^{85}Kr** bkg

Total ER
(1.80 ± 0.15) x 10^{-4} [(kg x day x keV)$^{-1}$]

(before any ER/NR discrimination)

Nuclear Recoil Background XENON1T



Total NR

(0.16 ± 0.03) x 10^{-6} [(kg x day x keV)$^{-1}$]

CNNS = **C**oherent **N**eutrino-**N**ucleon **S**cattering