XENON1T

Pushing the limits of WIMP detection

Xe
XENON
Dark Matter Project

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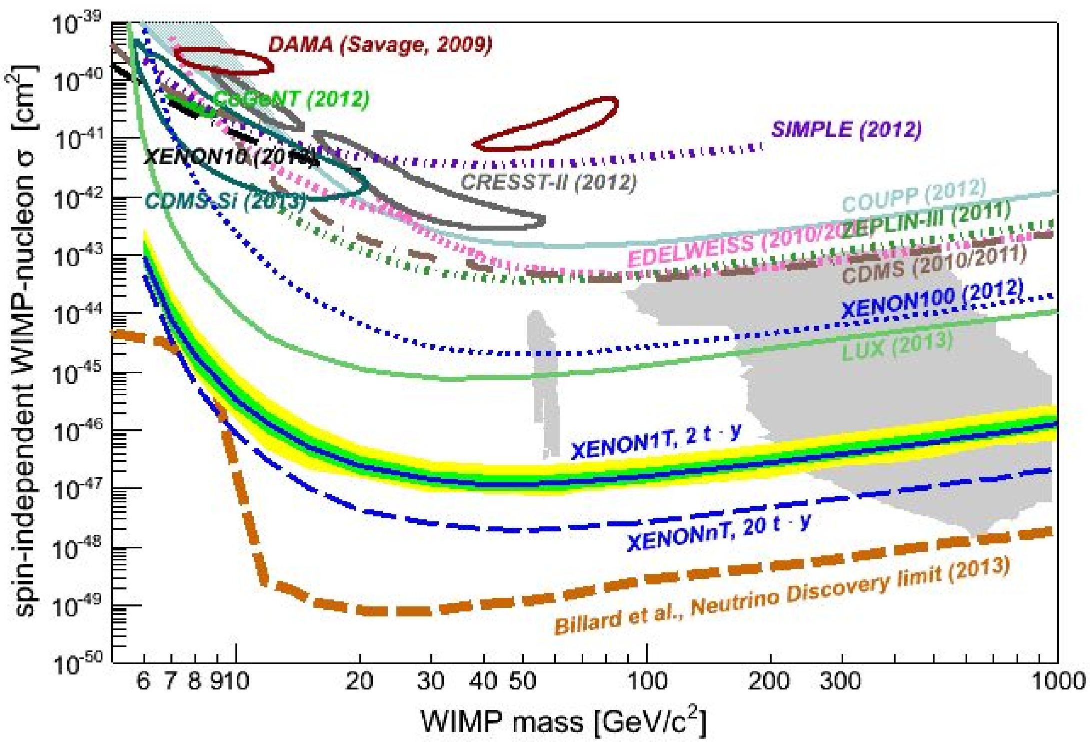
What are we trying to do?

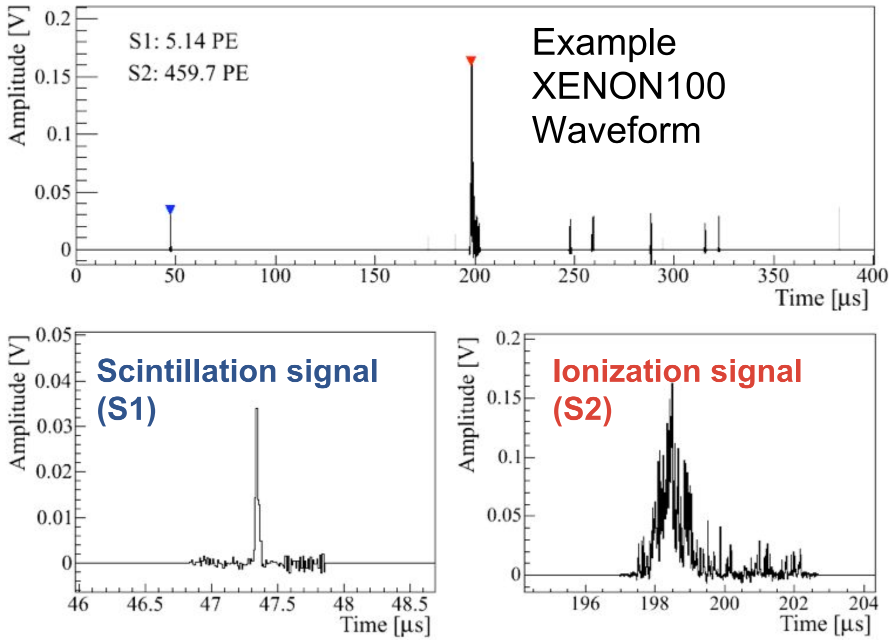
1. Create one of the most radiation-free locations in the world
2. See if we measure anything that can't be explained by current physics
3. If so, check if it is compatible with a **dark matter** signal

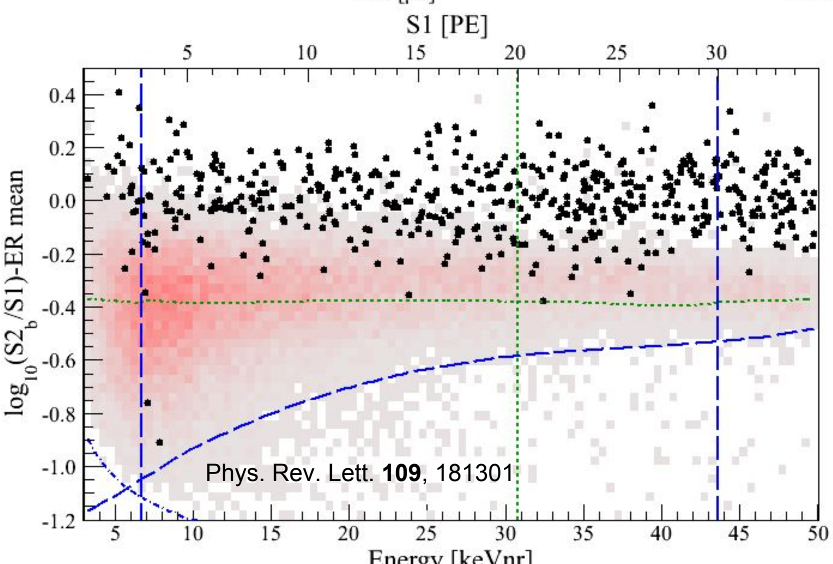
Where are we now?

- Lots of sensitive experiments have seen nothing
- Lots of parameter space is still open



Beauty in simplicity: detection principle





For one reaction we measure

- Scintillation signals (S1)
- Ionization signals (S2)
- The time between them

We perform a straightforward analysis

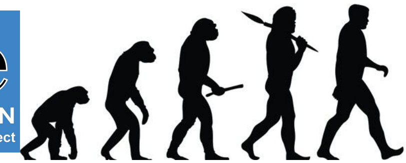
- Demand quality conditions on S1/S2 signals and background conditions
- Demand event location within fiducial volume (position from drift time and S2)
- Get rid of anything that scatters twice

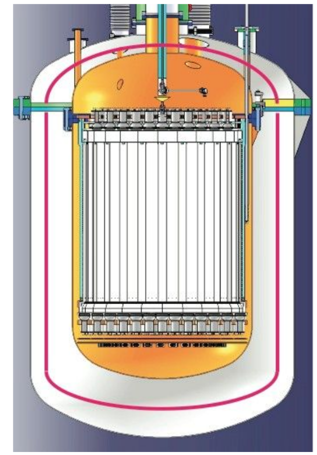
We then observe what is left

- Ratio of S2/S1
- WIMP should be a nuclear recoil
- ER/NR separation 99.75% at 40% NR acceptance (for XENON100)

n.b.! Understanding expected background important!

XENON, step by step





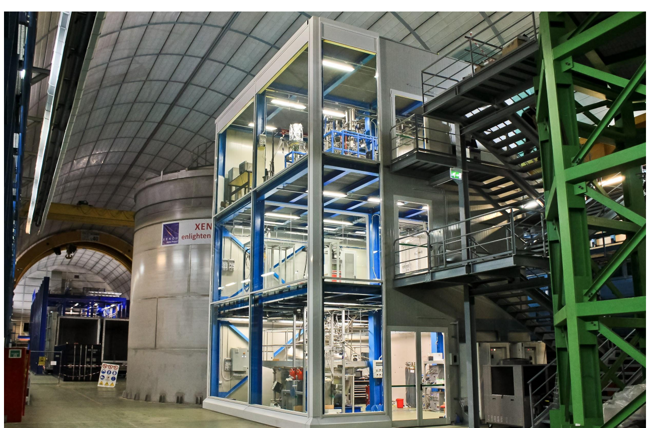
XENON10
Time: Until 2007
Total: 25 kg
Target: 14 kg
Fiducial: 5.4 kg
Limit: ~10^{-43}

XENON100
Time: Since 2008
Total: 162 kg
Target: 62 kg
Fiducial: 48 kg
Limit: ~10^{-45}

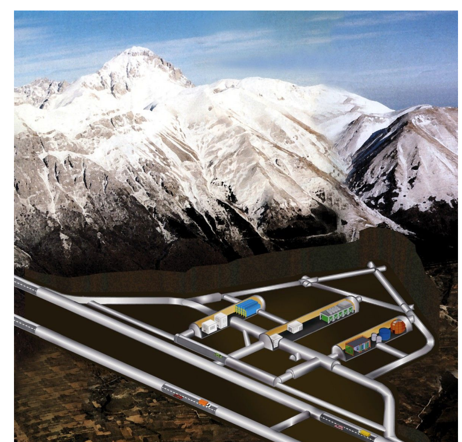
XENON1T
Time: From 2015
Total: 3.5 ton
Target: 2 ton
Fiducial: 1 ton
Limit: ~10^{-47}

XENONnT
Time: From 2018
Total: 7.5 ton
Target: 6 ton
Fiducial: 4.5 ton
Limit: ~10^{-48}

DARWIN
Time: 2020s
Total: 50 ton
Target: 42 ton
Fiducial: 30 ton
Limit: ~10^{-49}



XENON1T located in Hall B at LNGS, Gran Sasso, Italy



How do you improve sensitivity?

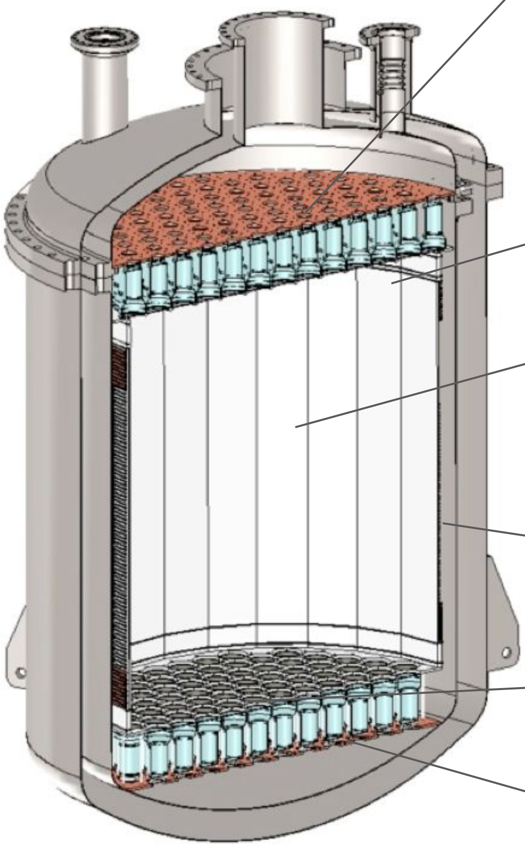
XENON Dark Matter Project

1. **Build a bigger, better experiment (target mass, detector design)**
    - Technically challenging (but we did it)
        - Cryogenics: liquify about 3.5 tons of xenon and maintain it stably
        - Homogeneous E field over 1m drift distance
        - High light yield: only PMTs and high-reflectivity PTFE visible from inside
        - Calibration non-trivial (self-shielding = prefer internal calibrations)

2. **Reduce backgrounds**
    - Every piece of the detector is radioactive!
        - Minimize material budget
        - Screen everything, choose cleanest materials
    - Muons can create neutron background
        - Put everything under a mountain (LNGS: 3500 m.w.e.) ~10^6 reduction in muons
        - Active cherenkov muon veto [JINST 9, P11006 (2014)]
    - xenon is not pure enough off-the-shelf
        - ^{85}Kr source of background → distilled out
        - Electronegative impurities reduce signal → continuous purification

Step 1: The Bigger Detector

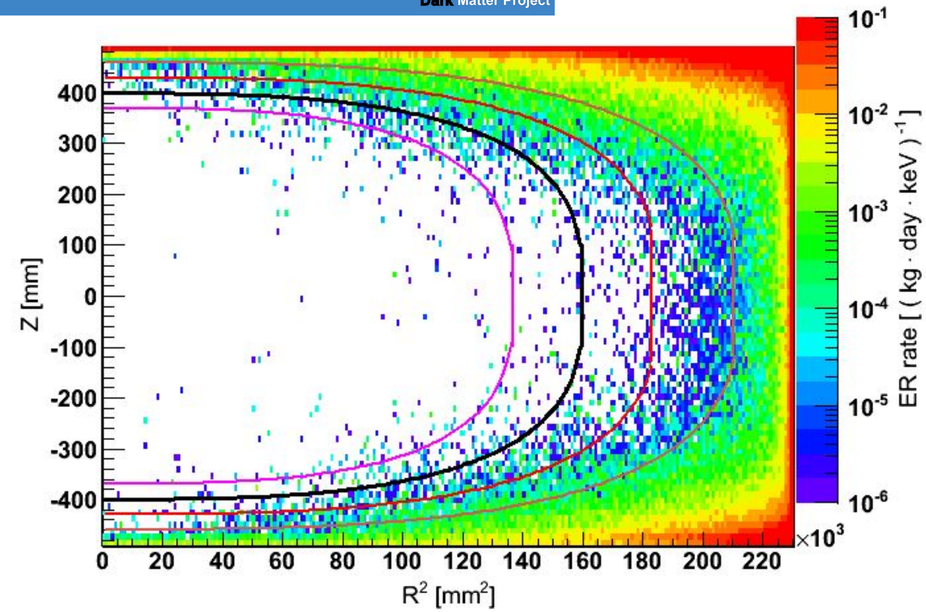
Xe XENON Dark Matter Project



Electronic Recoil Background

Direct Material Background

- Cleanest materials chosen, material budget minimized
  - 60% from cryostat arXiv:1503.07698
  - 25% from PMTs/bases
  - 15% from TPC stainless steel
  - 1% from Cu and PTFE



Impurities in xenon

- ^{222}Rn
  - Minimize leakage into cryo system (i.e., hermetically sealed pumps)
  - Low radon emanation components
  - Dedicated radon emanation measurements

- ^{85}Kr
  - Kr exists in high-purity commercial LXe at ppb level
  - ^{85}Kr/^{nat}Kr about 1%
  - Dedicated distillation system → ^{nat}Kr to ppq level!

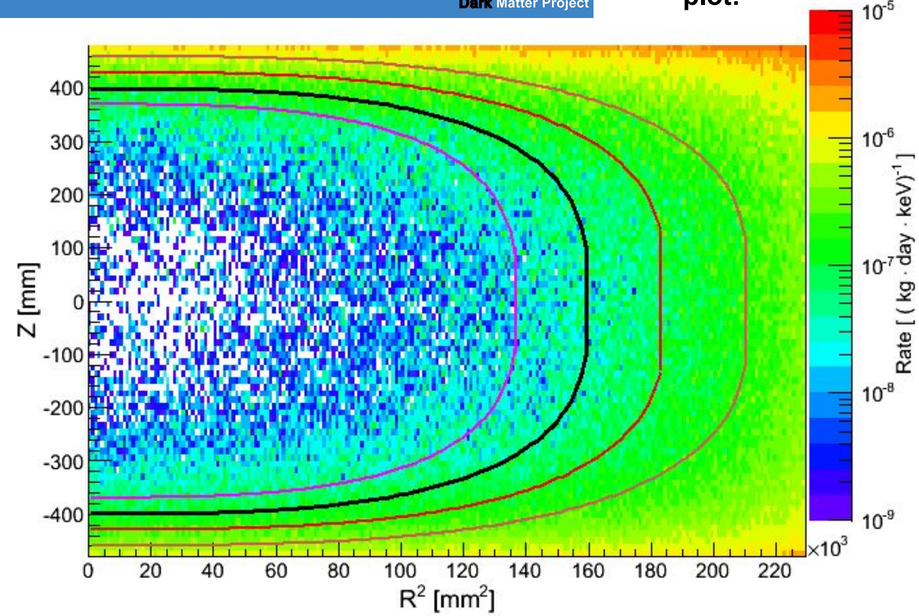
Source	Count [$t^{-1}y^{-1}$]	Fraction [%]
Materials	27 ± 3	17.8
^{222}Rn	56 ± 11	36.8
^{85}Kr	28 ± 6	18.4
Solar neutrinos	32 ± 1	21.1
^{136}Xe	9 ± 5	5.9
Total	152 ± 15	100

(2-12 keV search window, 1t FV, single scatters, before ER/NR discrimination)

See: S. Lindemann, H. Simgen, Eur.Phys.J.C 74, 2746 (2014)

Nuclear Recoil Background

Note: z-axis factor of 10^4 lower than prev plot!



Radiogenic neutrons

- (α, n) reactions from U- and Th- chains and spontaneous fission
- Mimic WIMP signal (many are single scatter, many penetrate into fiducial volume)
- Reduction via careful material selection and minimization of material budget

Muon-induced neutrons

- Produced by muon interactions with rock and detector materials
- Active muon veto blocks neutrons and tags muons and muon showers [JINST 9, P11006 (2014)]
  - >99.5% efficiency for muons crossing the water tank
  - >70% efficiency for muon showers for muons not crossing the water tank

Coherent neutrino scattering

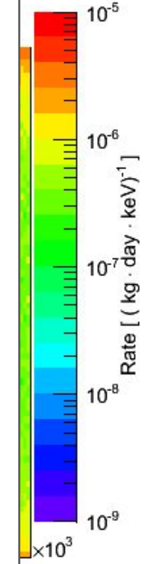
- Irreducible background
- Larger at very low energies (1keV)
- Nearly no contribution above threshold of 5 keV

Source	**Count [$t^{-1}y^{-1}$]**
Radiogenic	0.5 ± 0.1
Muon	<0.01
Neutrino	(1.1 ± 0.2) x 10^{-2}
Total	<1

(5-50 keV search window, 1t FV, before ER/NR discrimination)

Nu

xis factor of
than prev



Radi

●

●

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Muo

●

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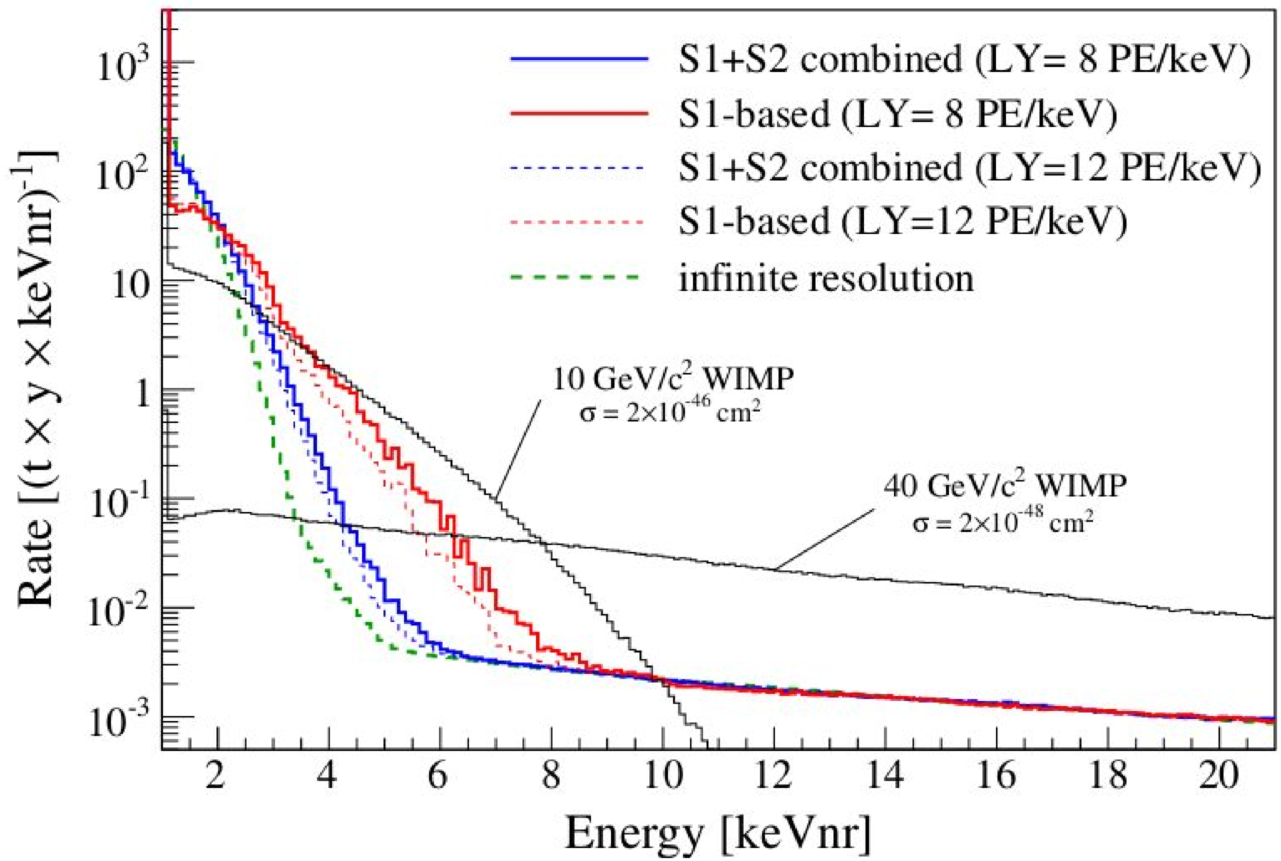


JCAP 10, 016 (2015), arXiv:1506.08309

muons not crossing the water tank

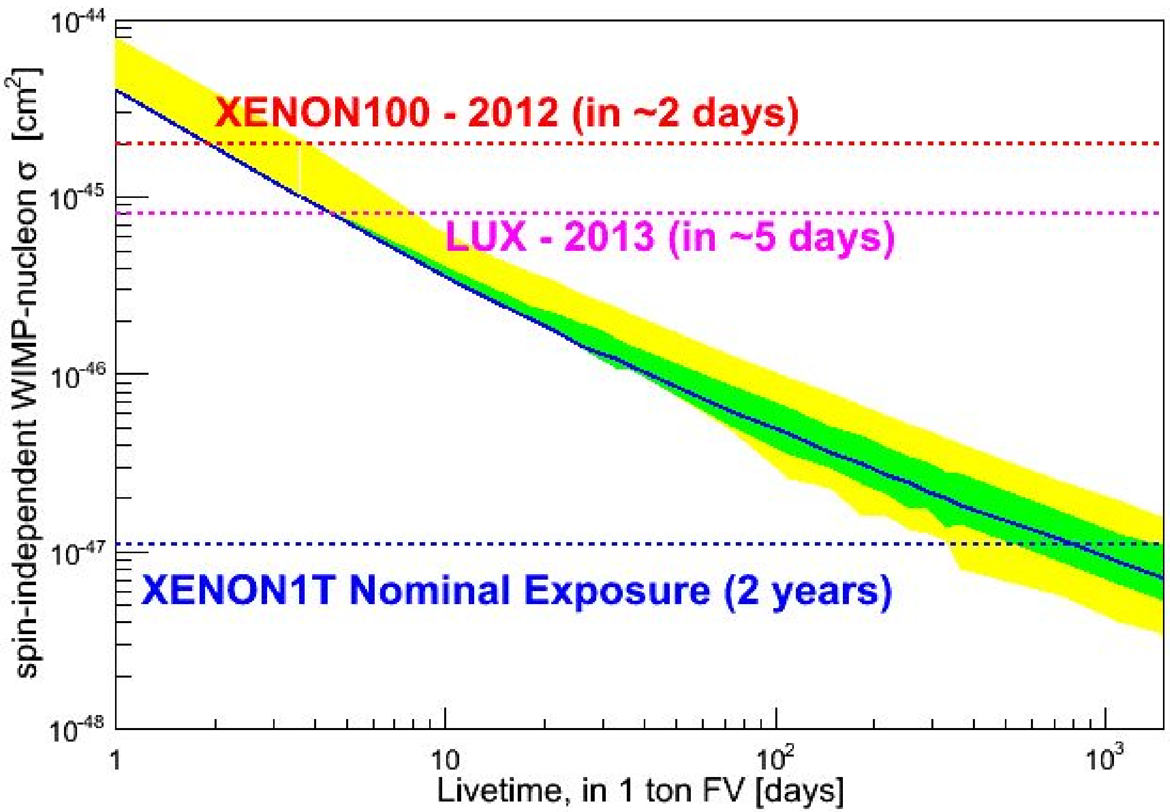
Neutrino	$(1.1 \pm 0.2) \times 10^{-2}$
Total	<1

(5-50 keV search window, 1t FV, before ER/NR discrimination)

Coherent neutrino scattering

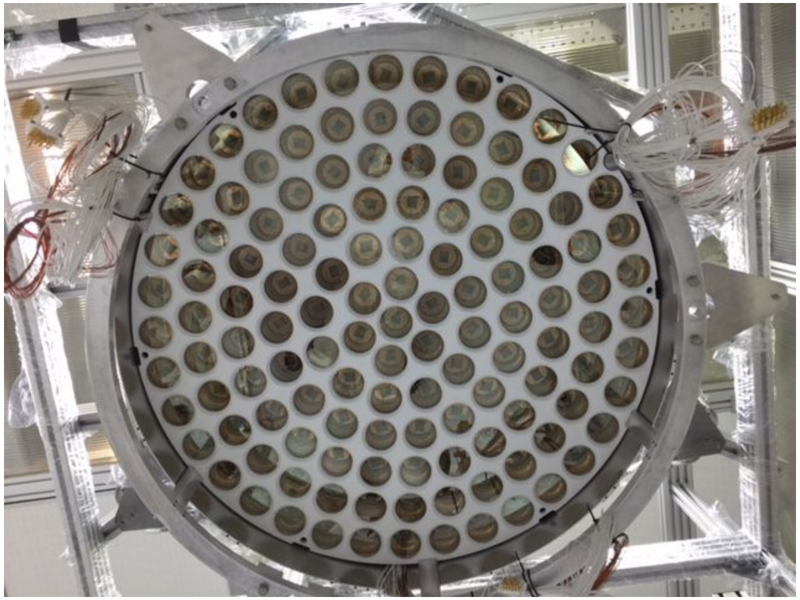
- Irreducible background
- Larger at very low energies (1keV)
- Nearly no contribution above threshold of 5 keV

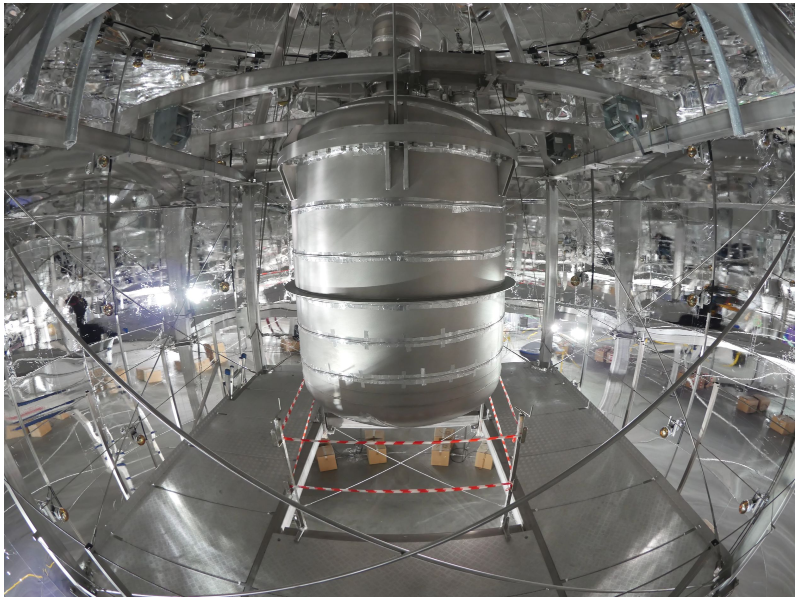
Exposure time

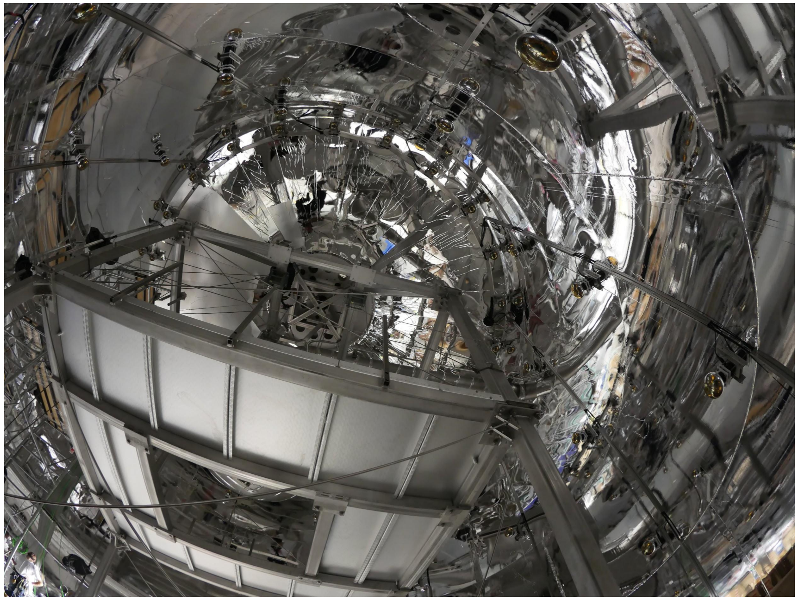


- XENON1T will be exploring new ground very quickly after coming online
- After two years exposure we will have reached our design sensitivity

Things are coming together!







Subsystem spotlight: data acquisition

Readout of 300MB/s (1kHz) for strong calibration sources

- Veto high-energy events in hardware before readout
- Parallelize readout (networked readout PCs)
- Sort pre-triggered data using fast software (MongoDB)

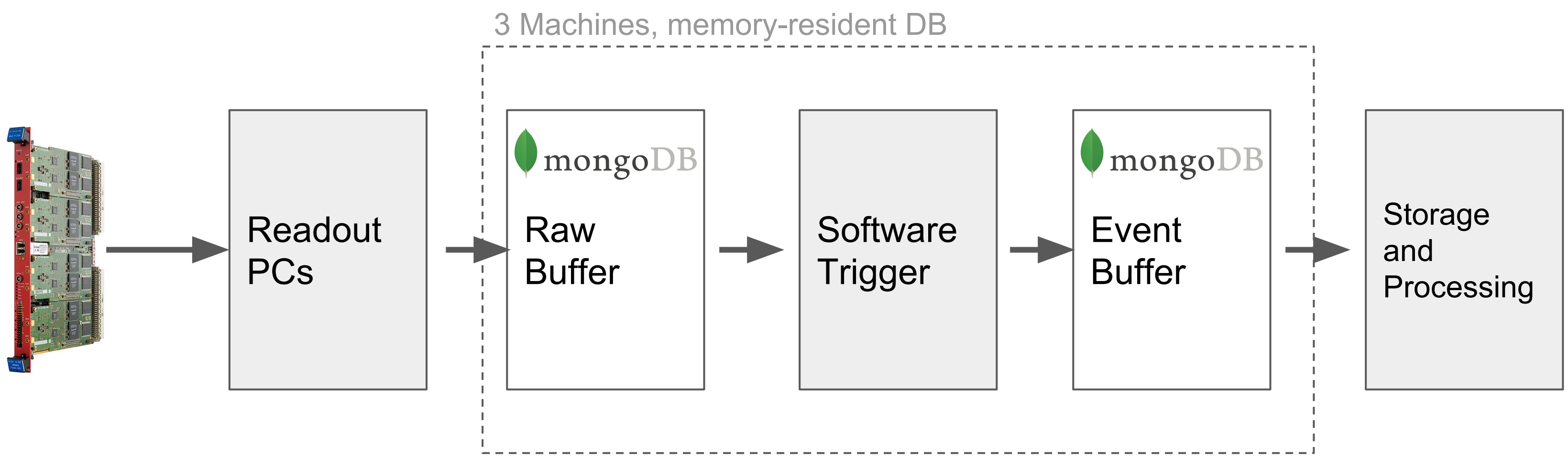
Low energy threshold for improved low-mass sensitivity

- Custom digitizer firmware
- Readout of individual channels
- ⅓ p.e. threshold/channel
- No loss of sensitivity in trigger

Robust Design for long-term use

- Off-the-shelf electronics (same as in XENON100)
- Open-source, industry-standard software
- Software trigger shares XENON1T data processor codebase

How it looks in schematic



CAEN V1724 Digitizers

- 100 MHz, 8 channels
- Synchronized readout through several readout PCs

Custom firmware:

- Channels trigger independently
- On-board delay for high-energy veto

MongoDB

- Fast, noSQL database
- Very popular in industry and data science

We use it to:

- Buffer the data
- Sort the data
- Retrieve the data

Online Trigger

- Fast (real-time) pre-trigger selection using database
- Trigger selection algorithms built into data processor → flexible!

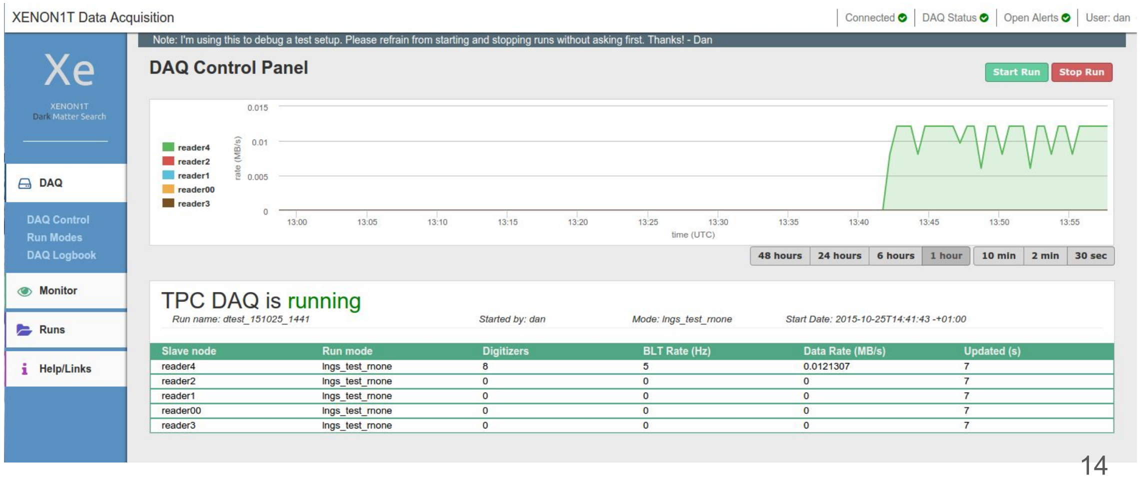
How it looks in real life...

How it looks to an operator

Frontend on the web

- Access control, logging
- Start, stop, configure system
- Monitor data online, in real time

Easy to build because of integration with pro-grade databases in the system



Conclusions

XENON1T has almost finished installation

- TPC construction finished within days
- Installation in cryostat in a couple weeks
- Several subsystems already commissioned

XENON1T will be the most sensitive WIMP search ever performed

- Largest target mass ever realized in a DM direct detection experiment
- Very low backgrounds through strict material selection and designs

XENONnT will follow soon

- Upgrade design built-in from the ground up
- Re-use of most existing systems but one order of magnitude better limit
- Another **order of magnitude** sensitivity!