Direct Dark Matter Search with XENONnT

S. Moriyama (ICRR & Kavli-IPMU, The Univ. of Tokyo)
on behalf of the XENON collaboration

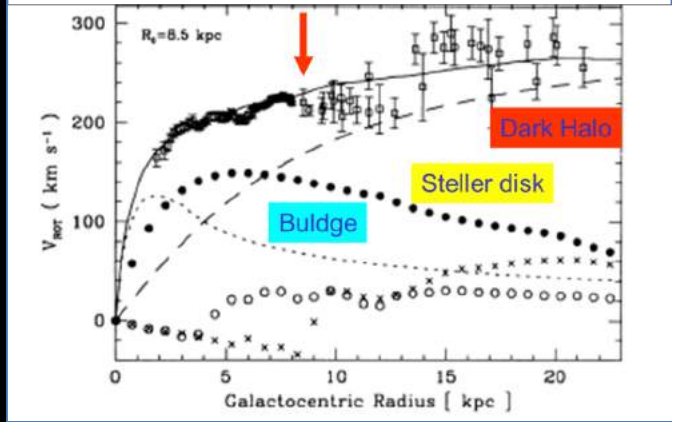
March 8, 2019, International symposium on “Revealing the history of the Universe with underground particle and nuclear research”

Scientific Importance of detection of dark matter

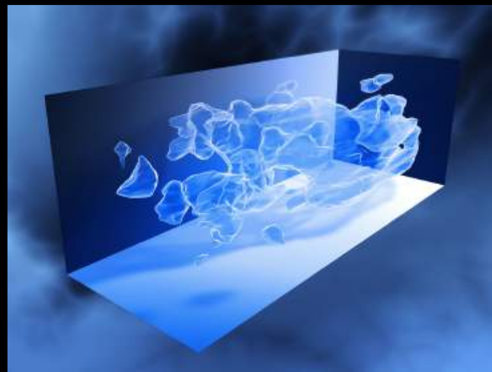
Xe
XENON
Dark Matter Project

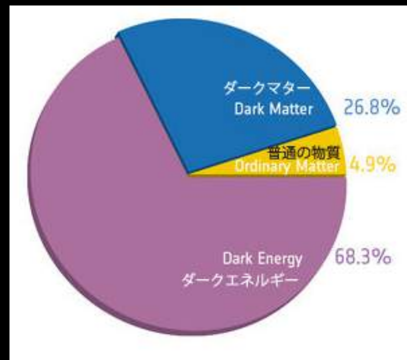
Understanding the nature of dark matter is one of the most important issues in the particle astrophysics.

R.P.Olling and M.R.Merrifield MNRAS 311, 369- (2000)

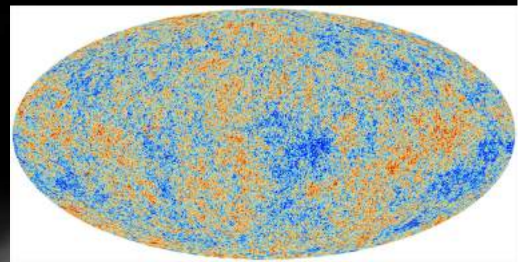


Strong evidence on dark matter: Cluster of galaxies, rotation curve of galaxies, lensing effect, large scale structure, cosmic microwave background, etc.





Identification of dark matter must be a breakthrough in understanding the universe filled with “unknowns”.



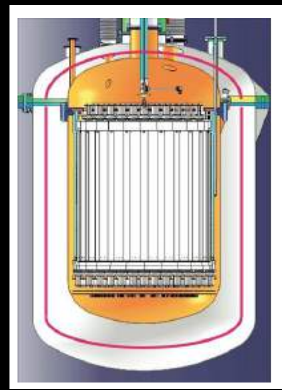
The XENON collaboration

XENON Dark Matter Project

~170 collaborators
27 institutions

XENON program

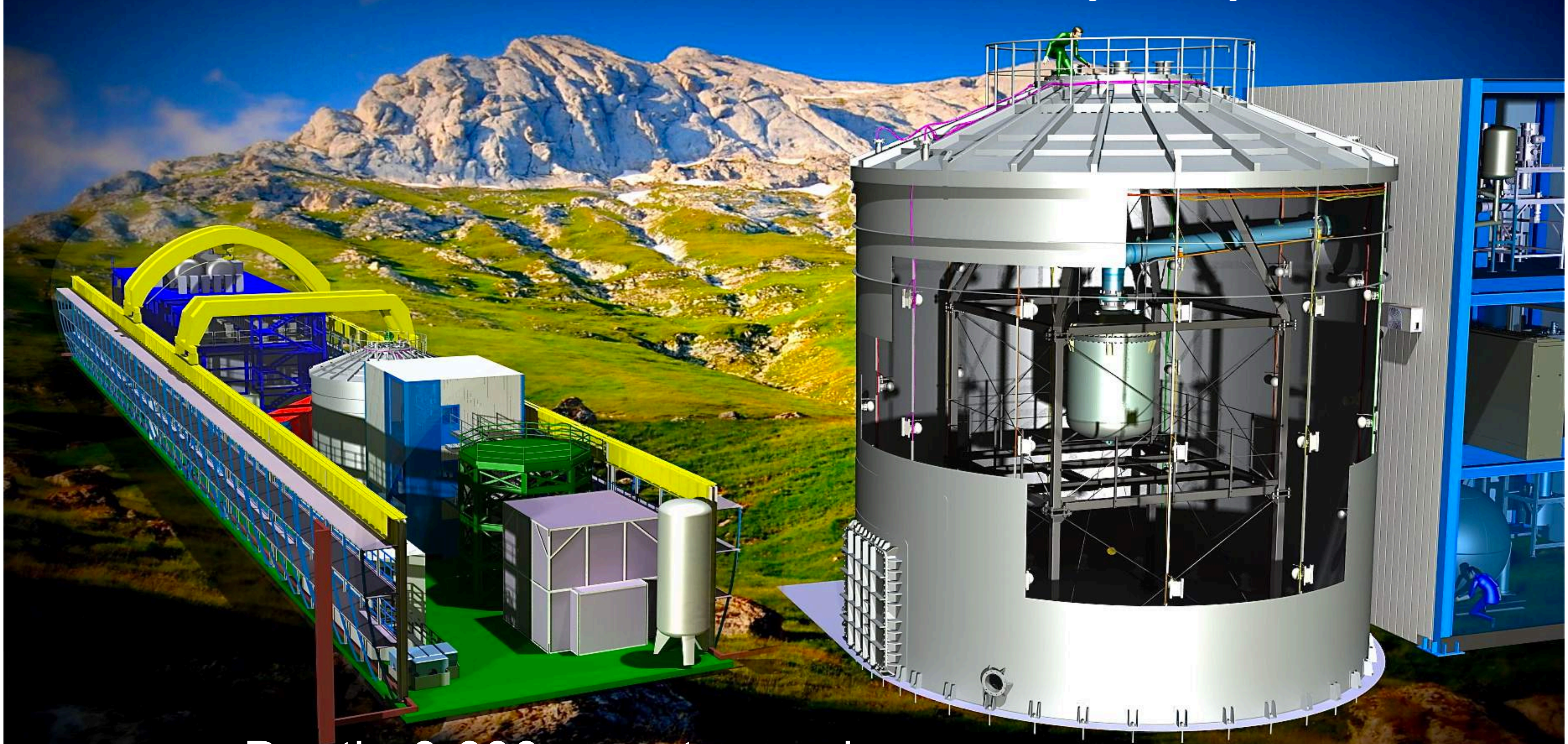
Liquid xenon: scalable for sensitive WIMP dark matter search.
Dual phase: 3D TPC, excellent separation of e/n recoils.
Low energy thre.: ~5 keV_{nr} and lower for electron recoils because of high light yield

XENON10	XENON100	XENON1T	XENONnT
			
Total Xe: 25 kg	Total Xe: 162 kg	Total Xe: 3.2 ton	Total Xe: ~8.4 ton
Target: 14 kg	Target: 62 kg	Target: 2 ton	Target: 5.9 ton
Fiducial: 5.4 kg	Fiducial: 34/48 kg	Fiducial: 1.3 ton	Fiducial: ~4 ton
Limit: ~$10^{-43}cm^2$	Limit: ~$10^{-45}cm^2$	Limit: ~$10^{-47}cm^2$	Limit: ~$10^{-48}cm^2$

2005 2010 2015 2020

Experimental site

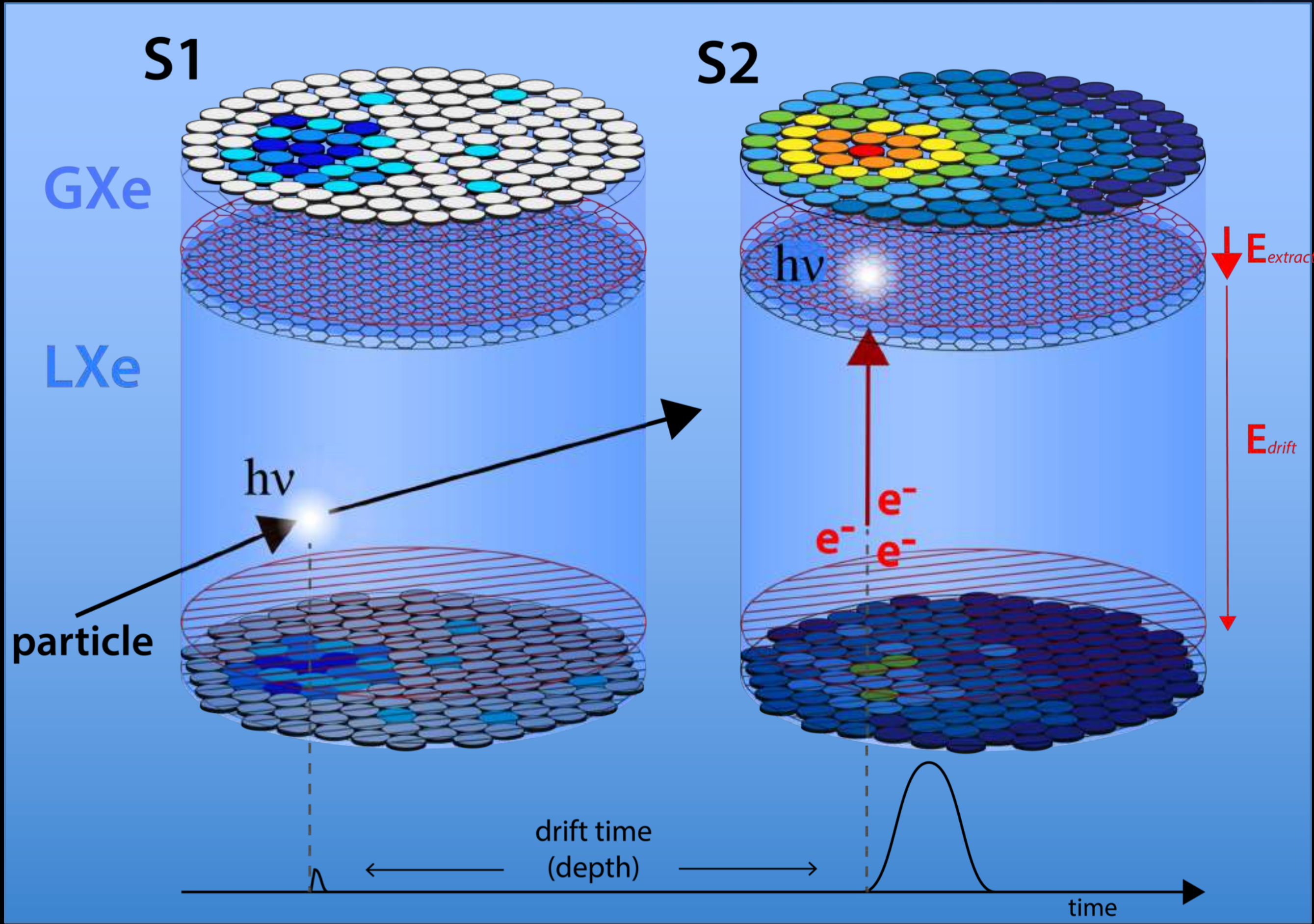
LNGS Gran Sasso National Laboratory, Italy



Depth: 3,600 m water equiv.

diameter 9.6 m x 10 m water Cherenkov shield

Dual phase LXe detector



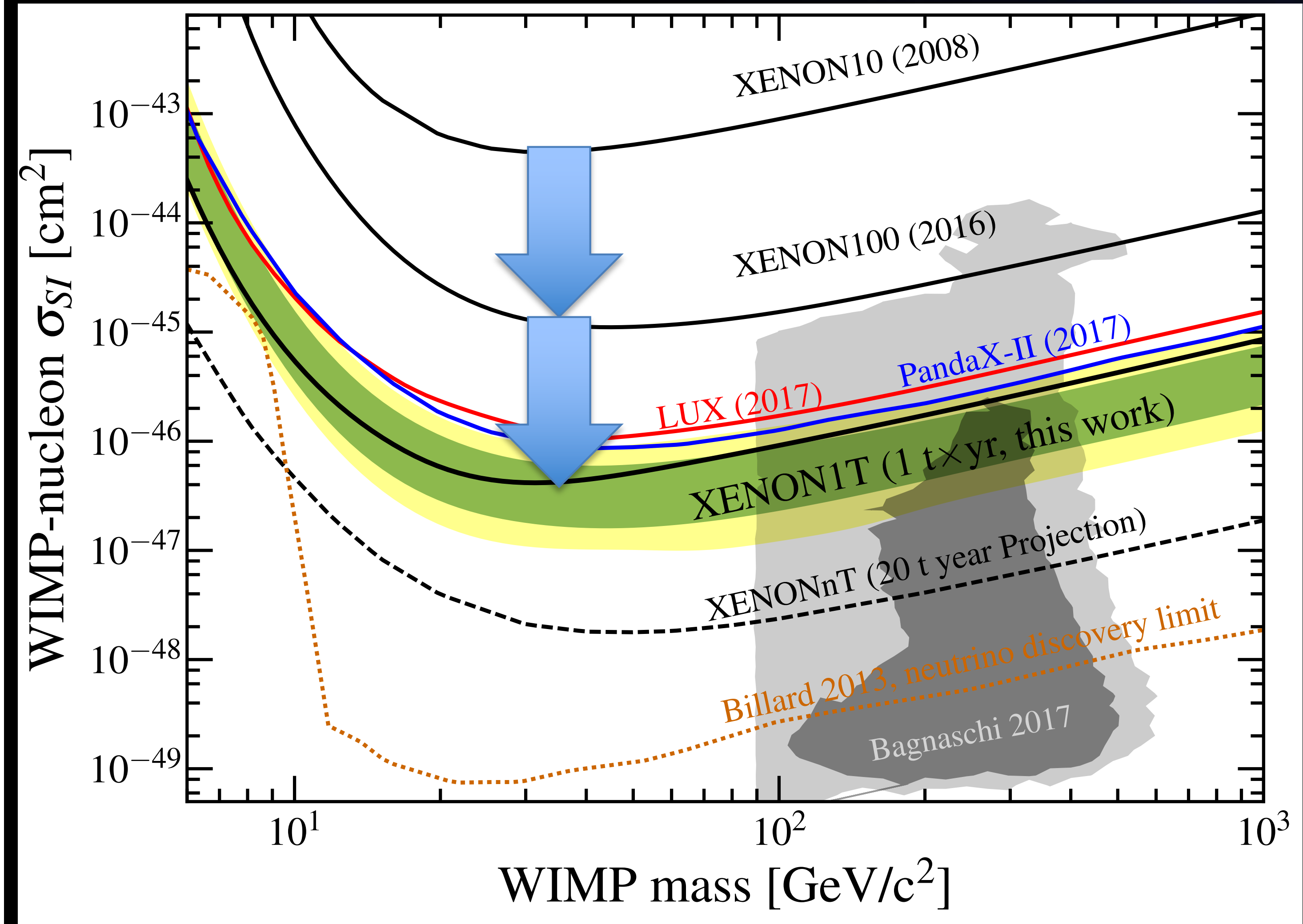
S1 and S2:
Energy & particle identification

Drift time: Z position
Photon distribution of S2:
X&Y position determination

Energy deposition in TPC causes scintillation light S1 in liquid xenon target

Electrons from ionization extracted into the gas phase and amplified: S2.

Results from XENON1T



Phys. Rev. Lett. 121, 111302 (2018)

1.0 t year
(1.3 ton, 278.8 d)

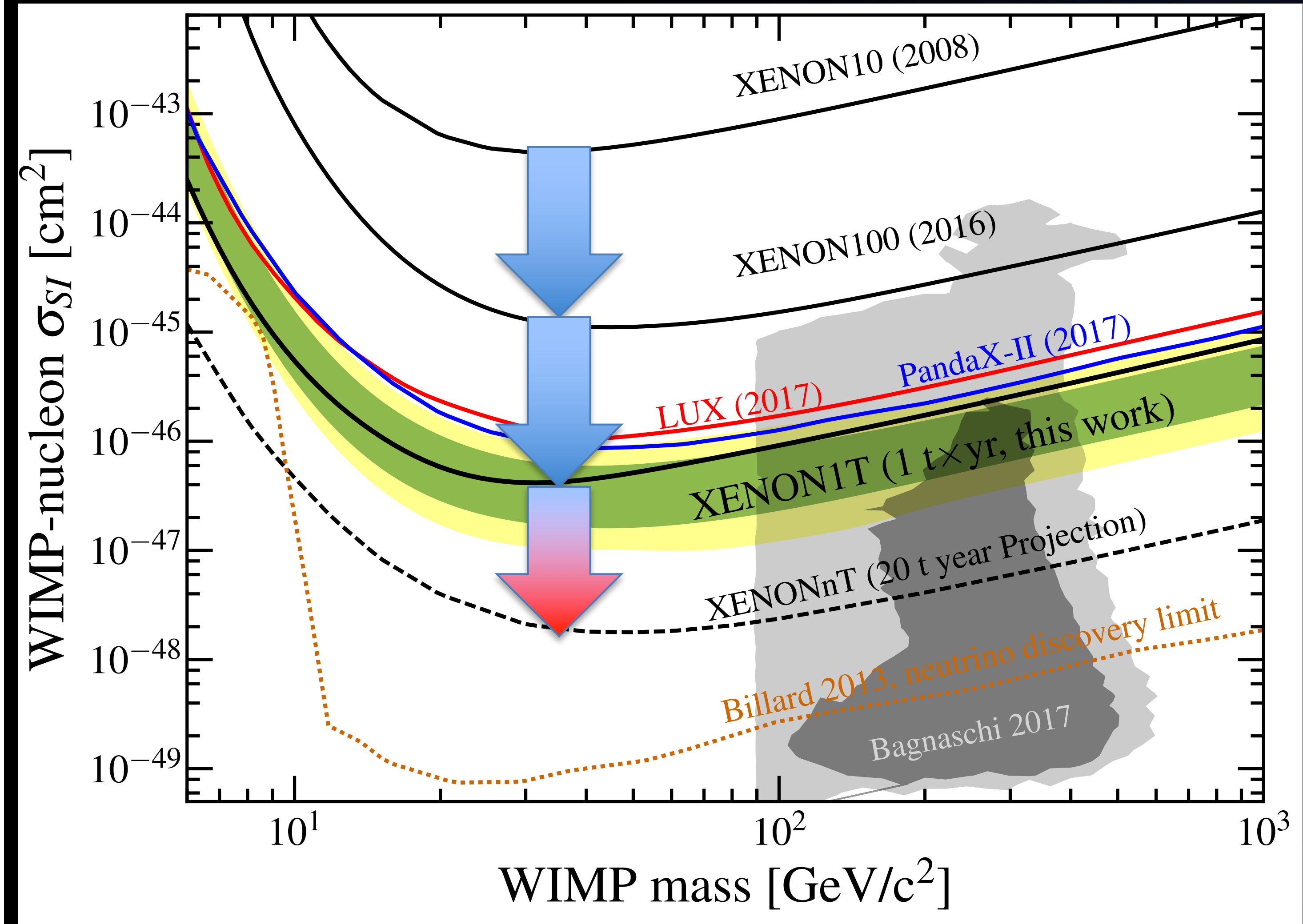
Electron Recoil BG
$82\pm^{5}_{3}\pm3$/t yr keV_{ee}
~ 2.2×10^{-4} /kg d keV_{ee}

99.7% ER rejection

$4.1\times10^{-47}cm^2$
@ 30 GeV, 90% C.L.

XENON1T is the world's most sensitive experiment!

Toward discovery: XENONnT



One order of magnitude higher sensitivity

20 t year (x20)
(~ 4 ton x 5 yrs)

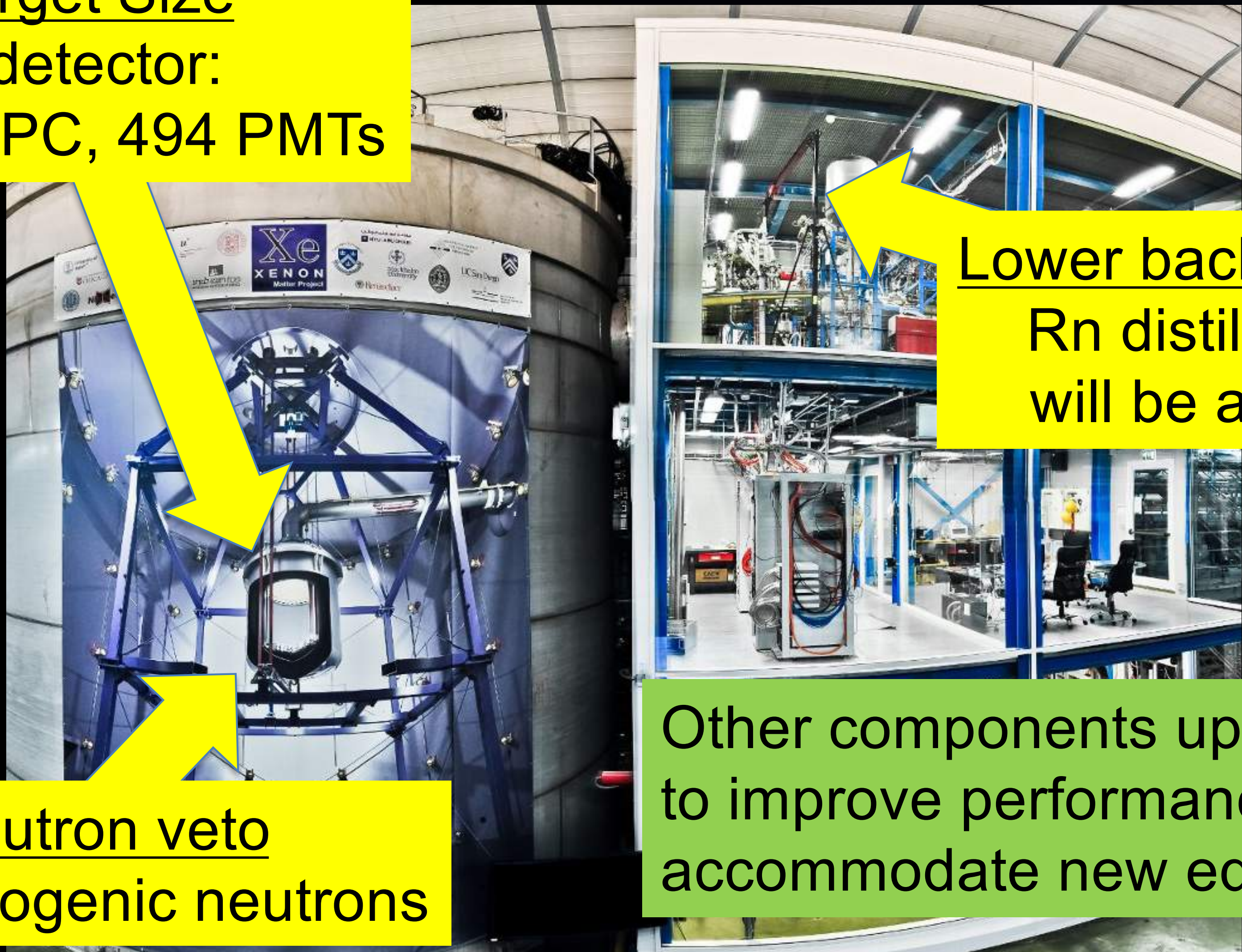
Background (x~1/10)

~2x10^{-48}cm^2 (x~1/10)
@ 30 GeV, 90% C.L.

Construction ongoing.
Commissioning started last year!

Larger Exposure, lower BG, improved performance!

XENONnT upgrade: overview



Target Size
Central detector:
larger TPC, 494 PMTs

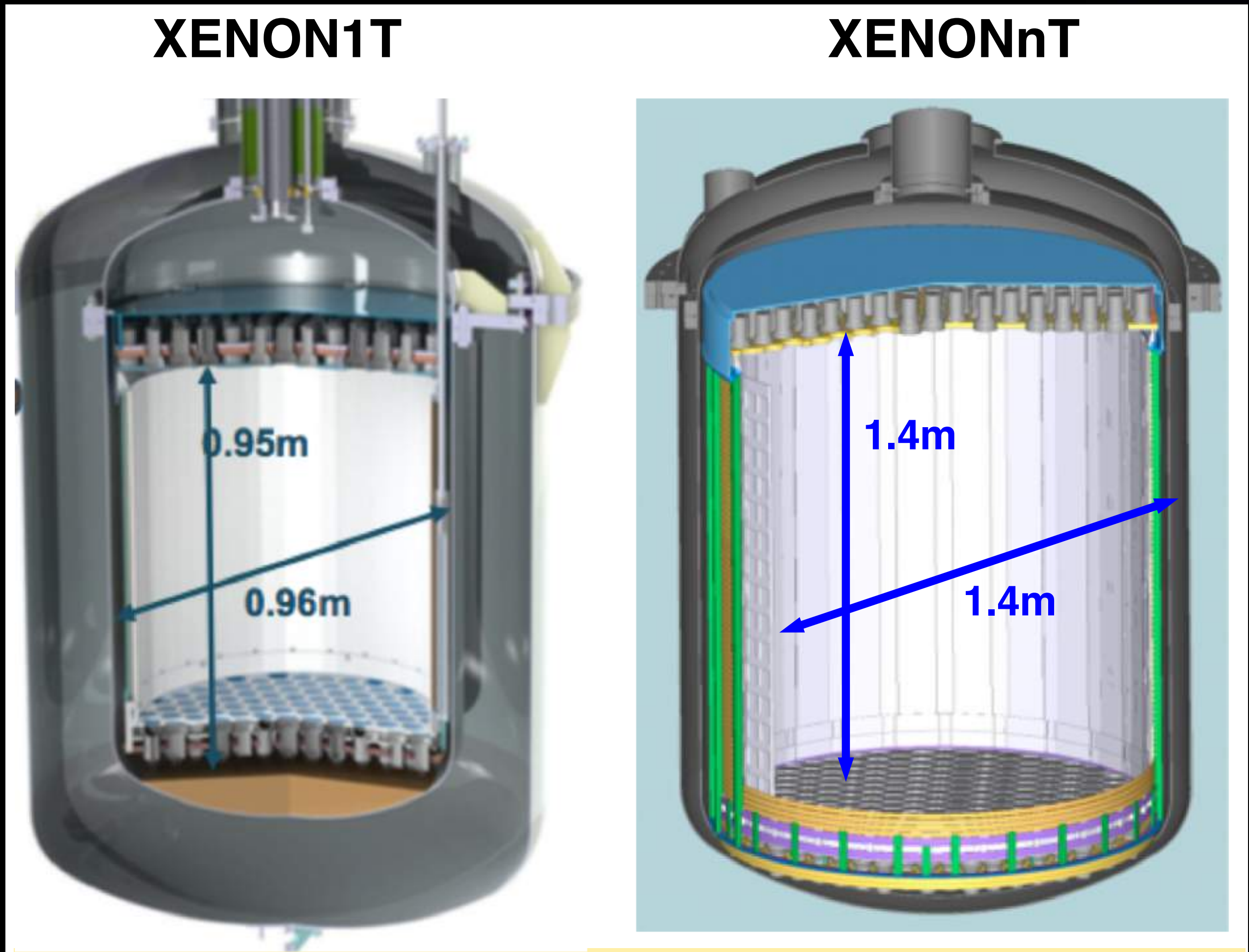
Lower background
Rn distillation
will be added

Neutron veto
tags radiogenic neutrons

Other components upgraded to improve performance and accommodate new equipment

XENON1T stopped and construction already started

XENONnT upgrade: size

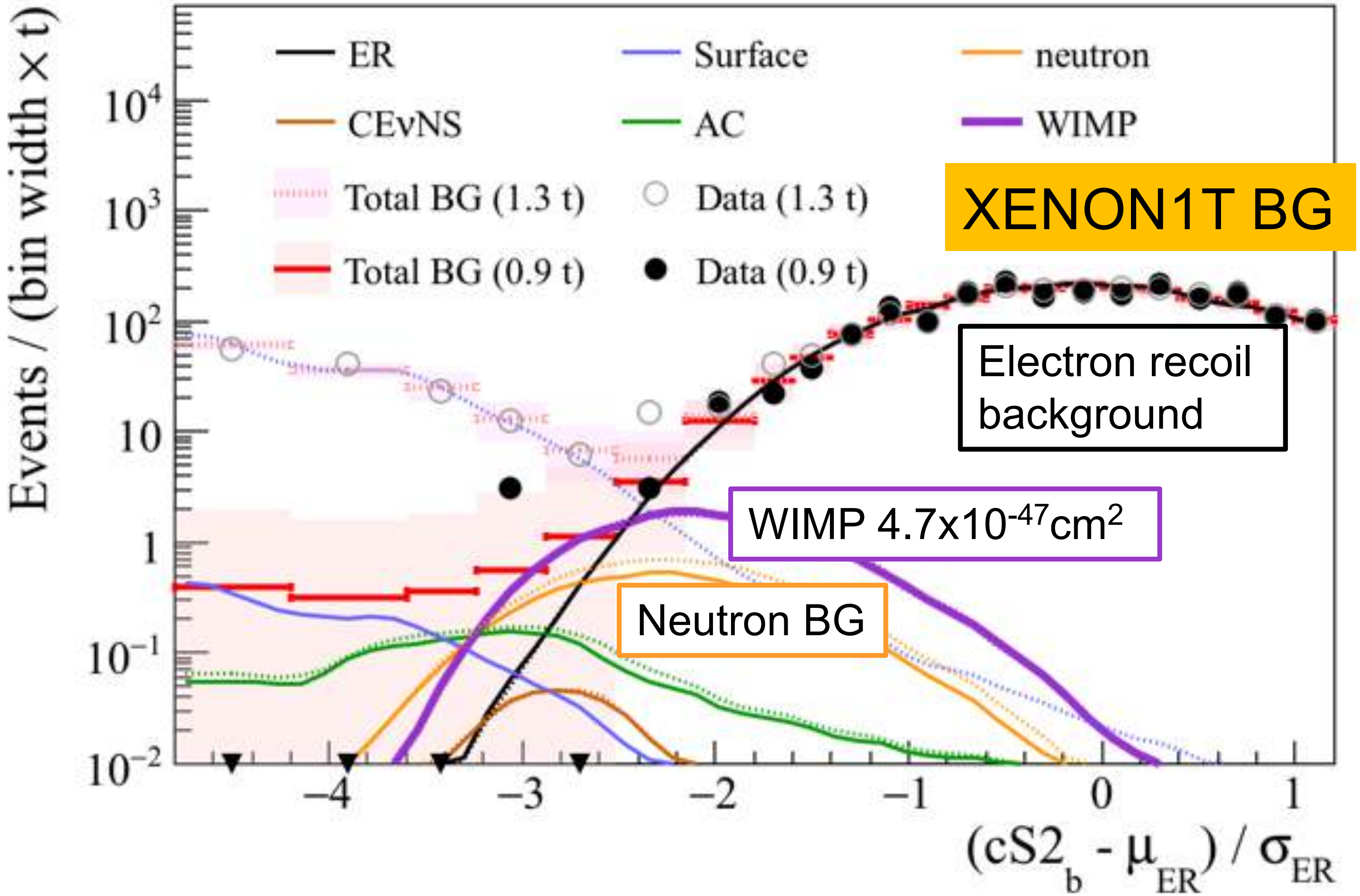


Active target mass
2 ton → 5.9 ton
Fiducial mass
1.3 ton → ~4 ton expected

The outer cryostat will be extended.
Large TPC is being built.
The number of PMTs is doubled.
Storage for larger amount of liquid xenon is added.
Liquid phase Xe purification is being added.

XENONnT upgrade: BG

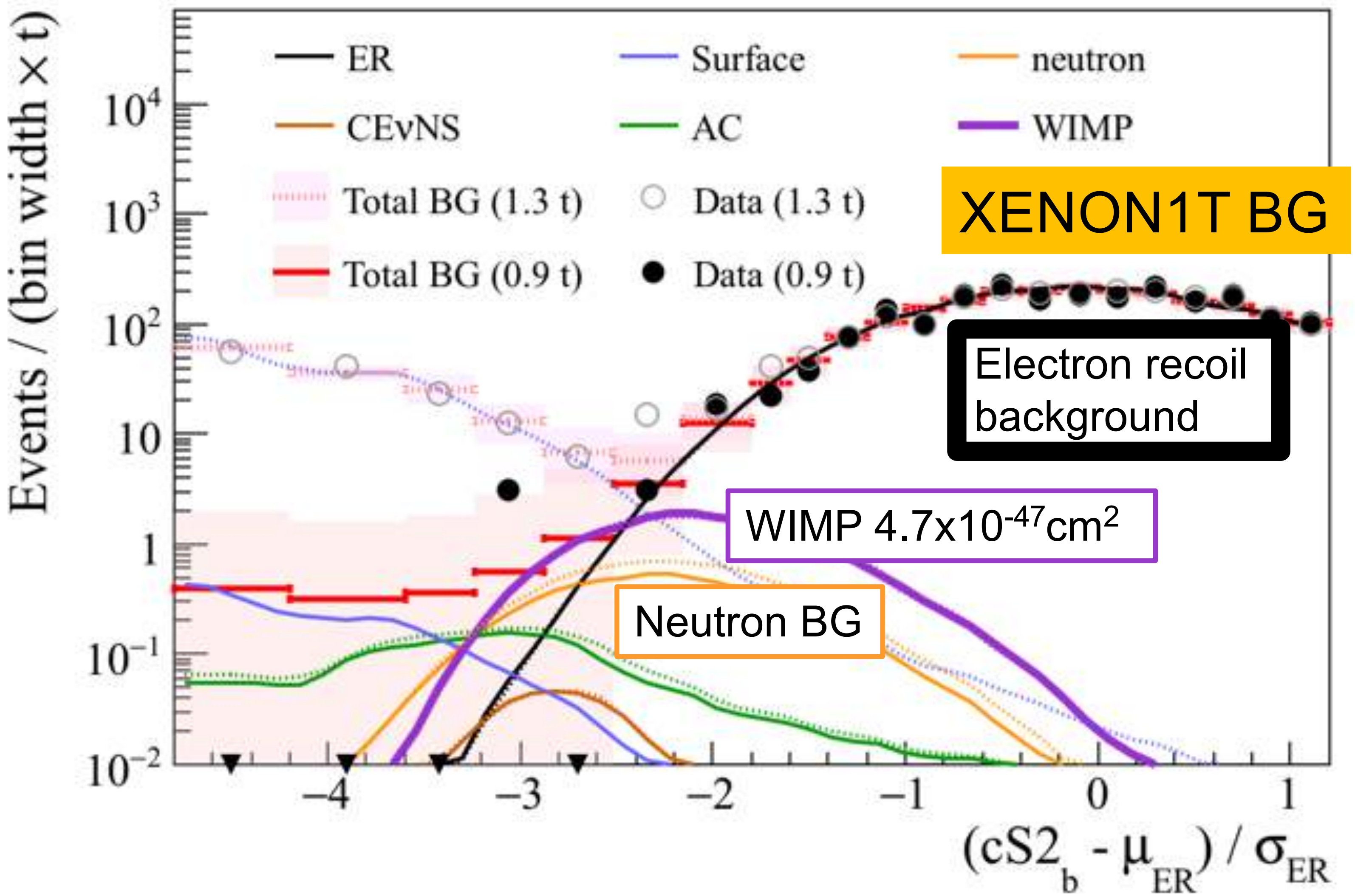
E. Aprile et al., PRL 121, 111302 (2018)



Electron recoil BG (Rn), neutron BG need to be reduced

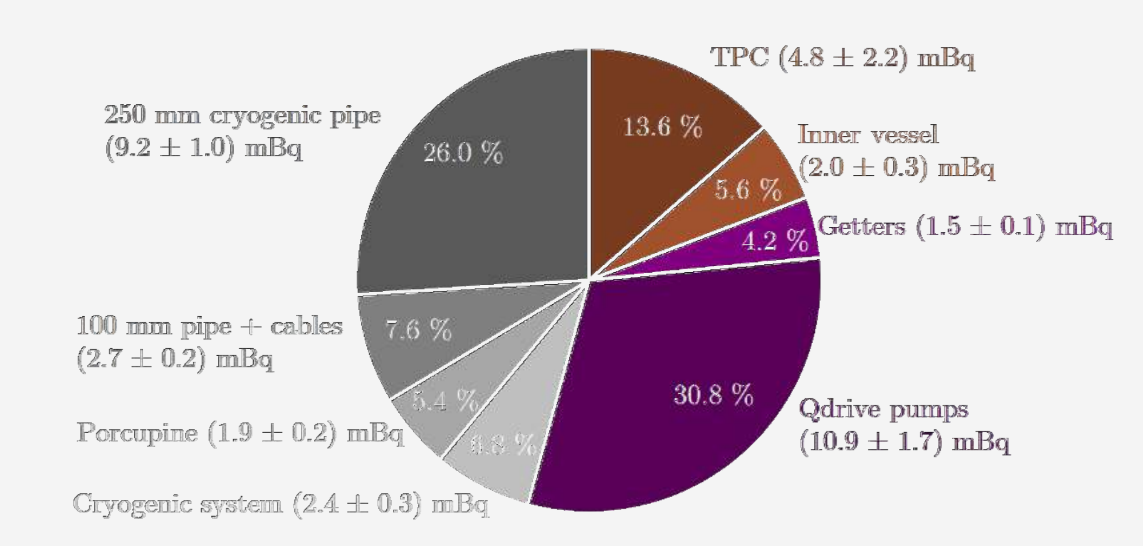
XENONnT upgrade: BG

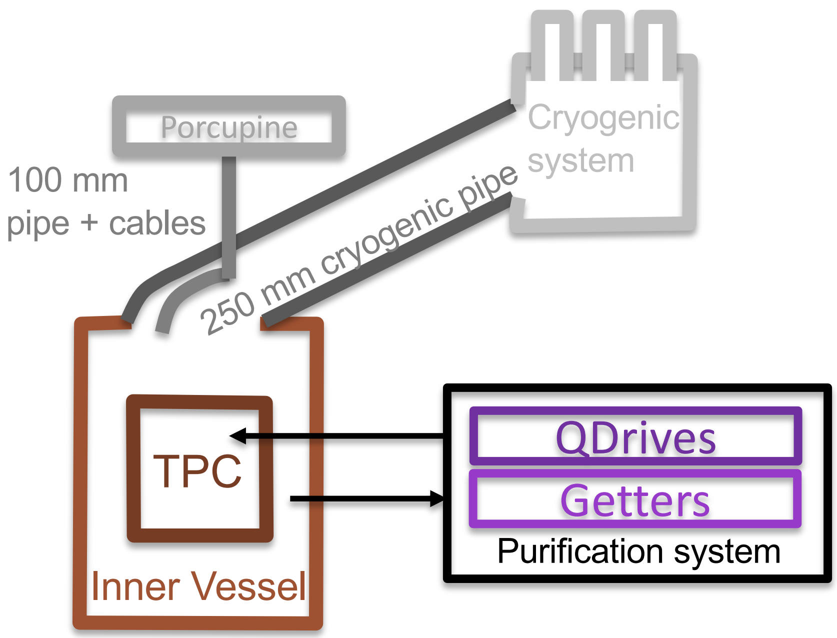
E. Aprile et al., PRL 121, 111302 (2018)



Electron recoil BG (Rn), neutron BG need to be reduced

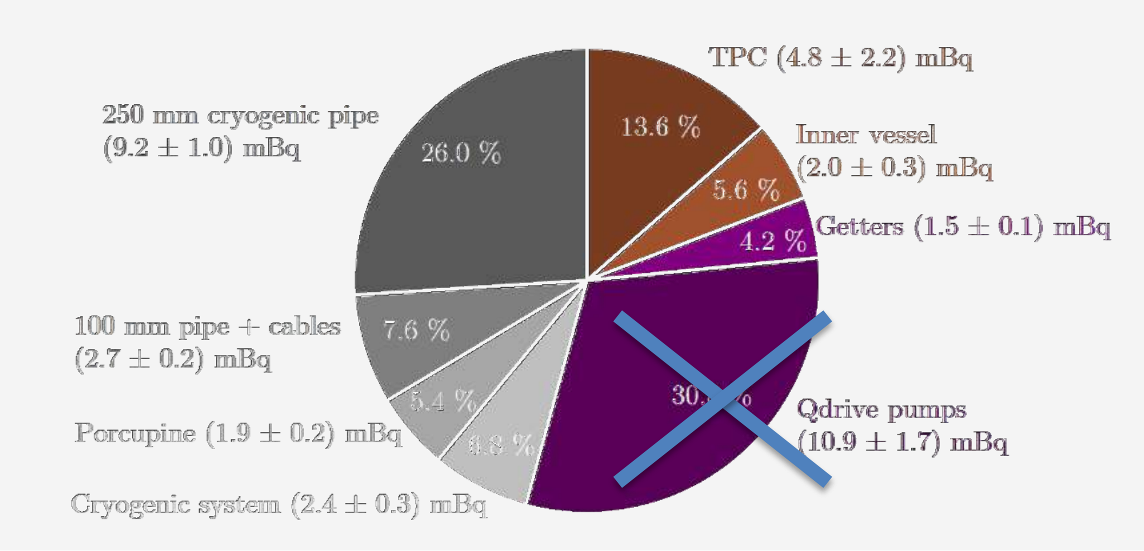
Rn in XENON1T and XENONnT

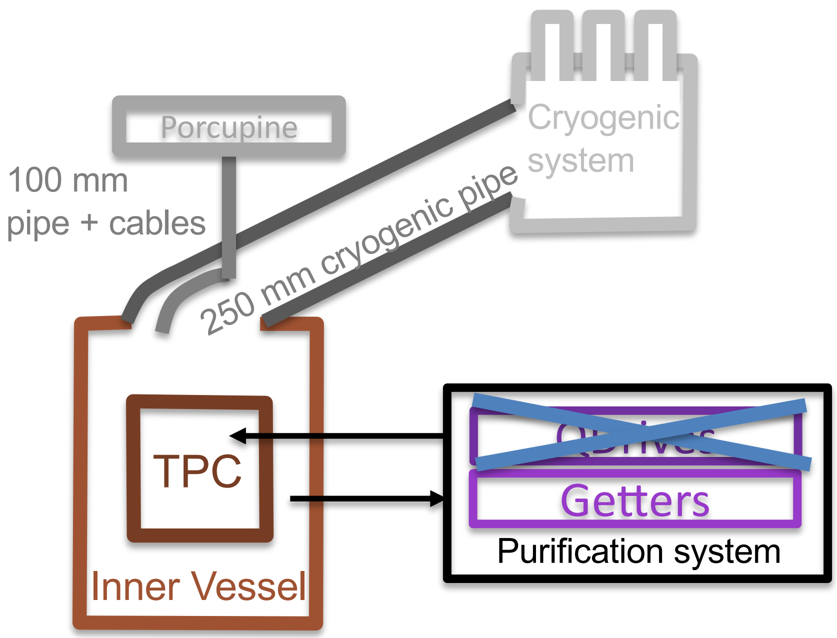




XENON1T ~10μBq/kg

Rn in XENON1T and XENONnT



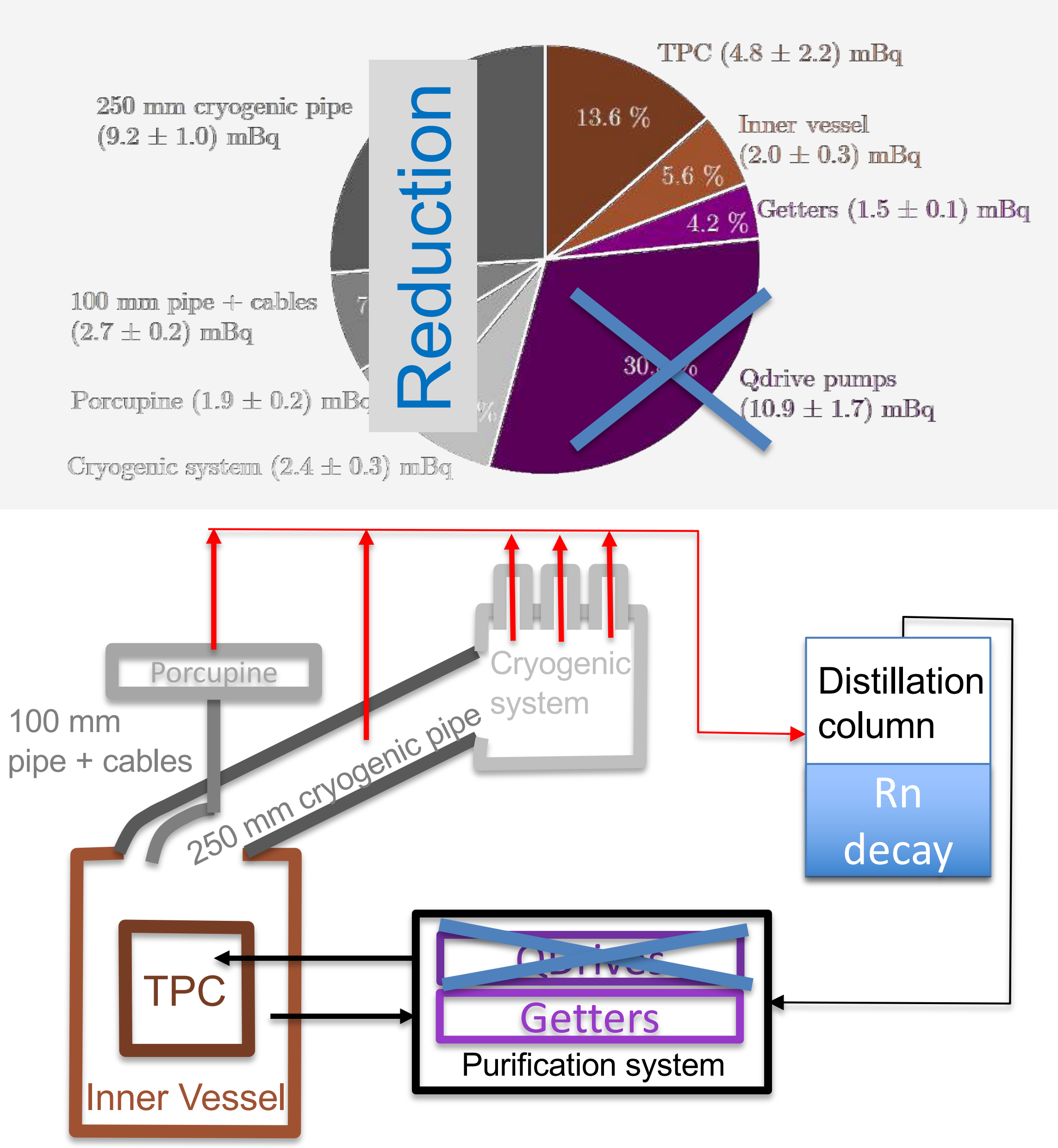


XENON1T ~10μBq/kg

31%: QDrive pump

→reduce by pump exchange

Rn in XENON1T and XENONnT



XENON1T ~10μBq/kg

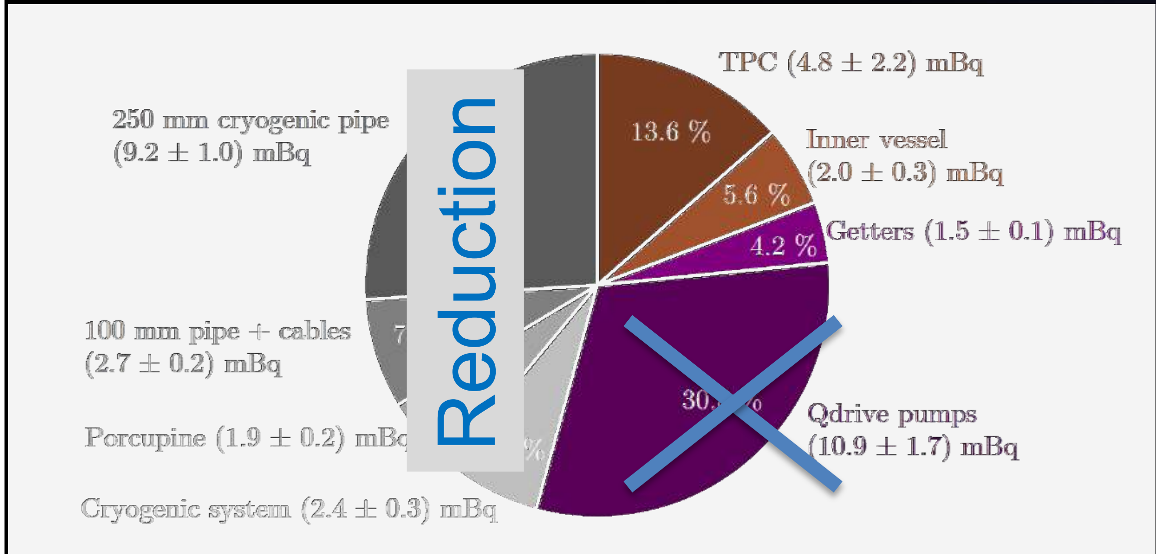
31%: QDrive pump

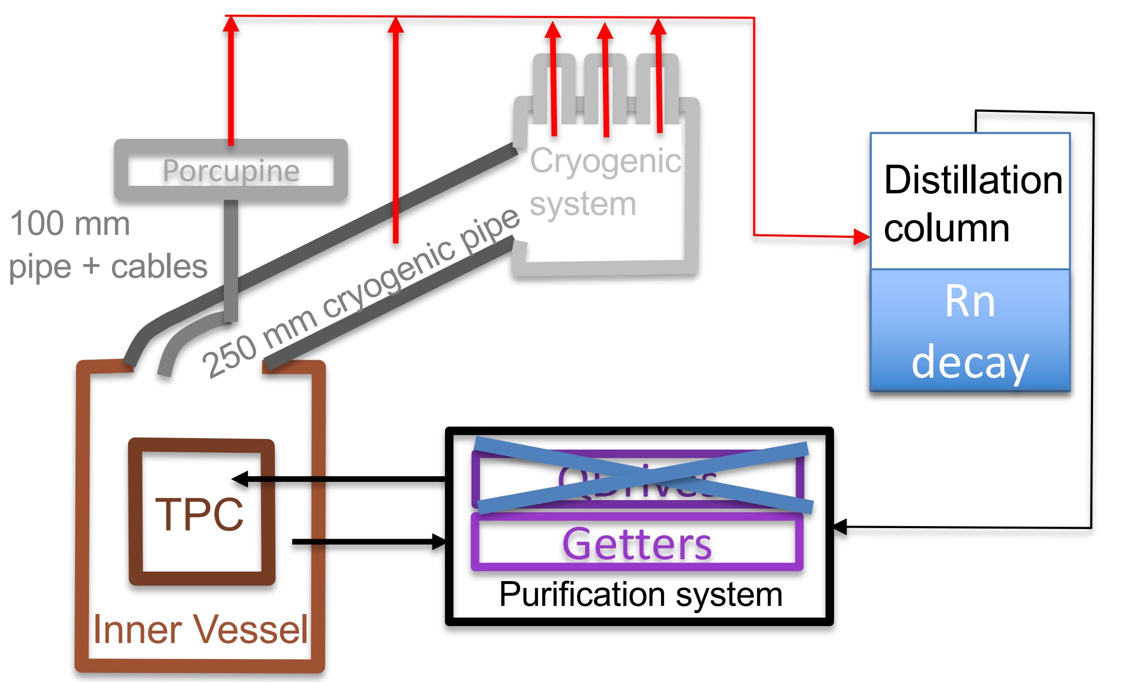
→reduce by pump exchange

46%: Cryogenic pipes

→reduce by extracting and remove radon before it enter the TPC using dist. col.

Rn in XENON1T and XENONnT





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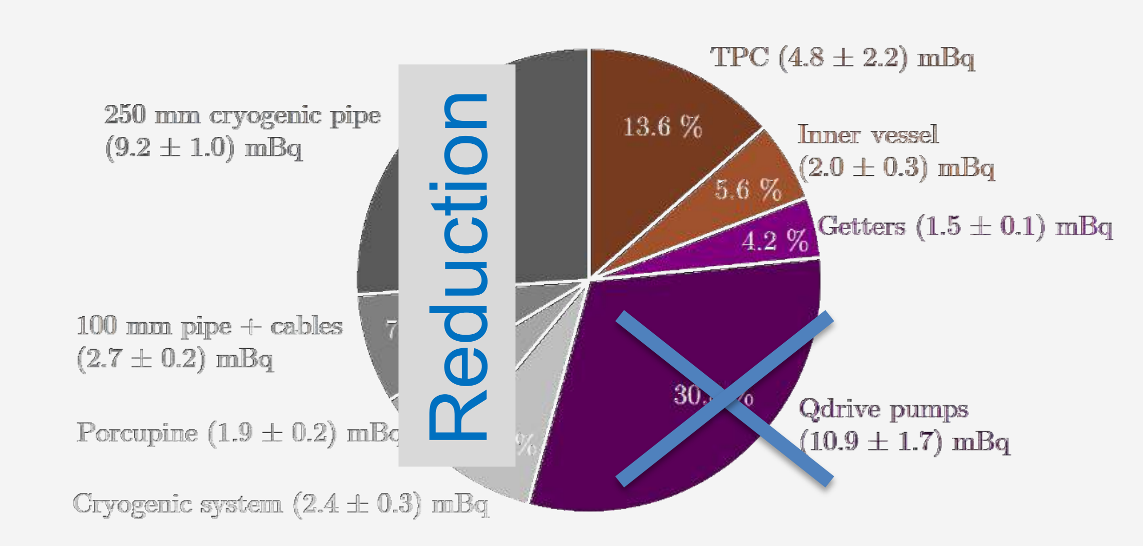
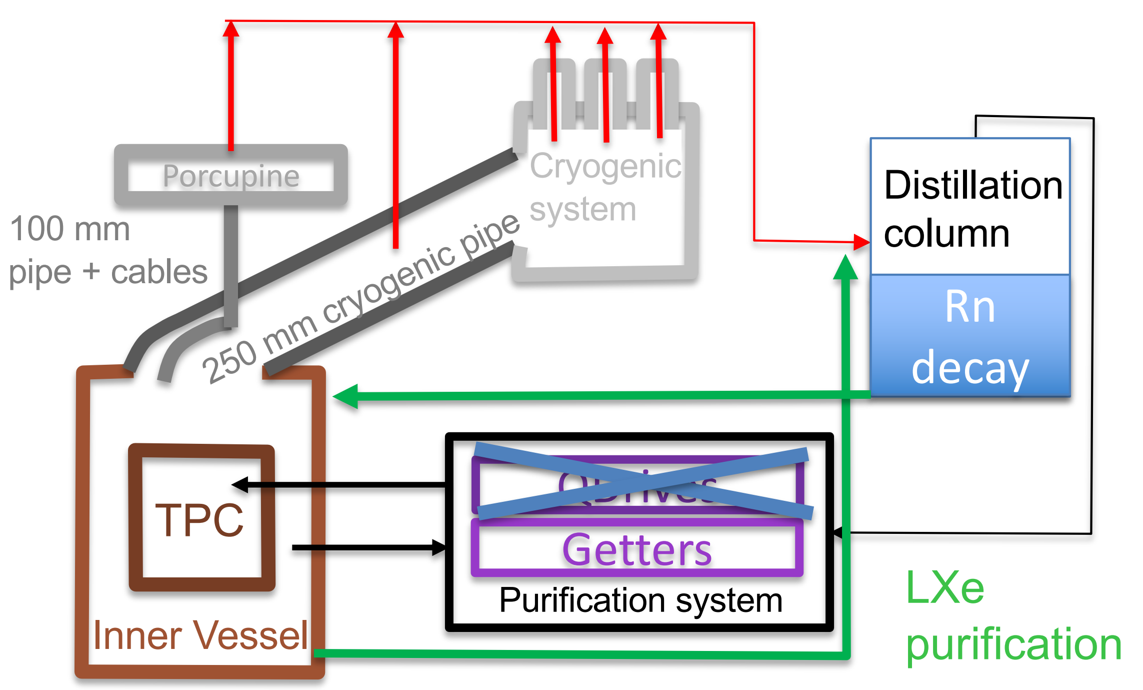
19%: TPC+Inner vessel

→dilute by Rn-depleted LXe

Rn in XENON1T and XENONnT





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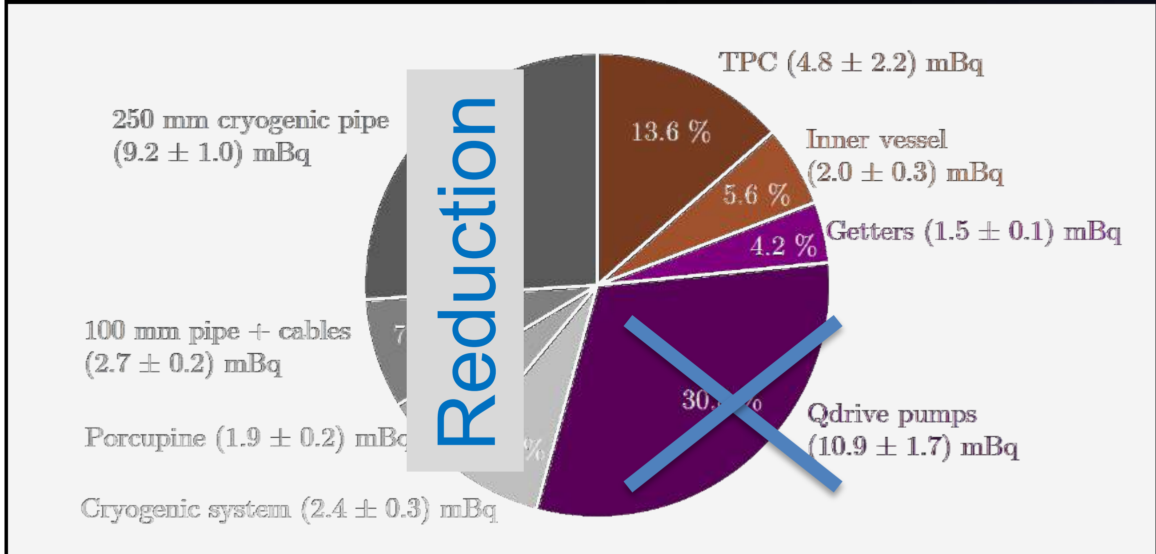
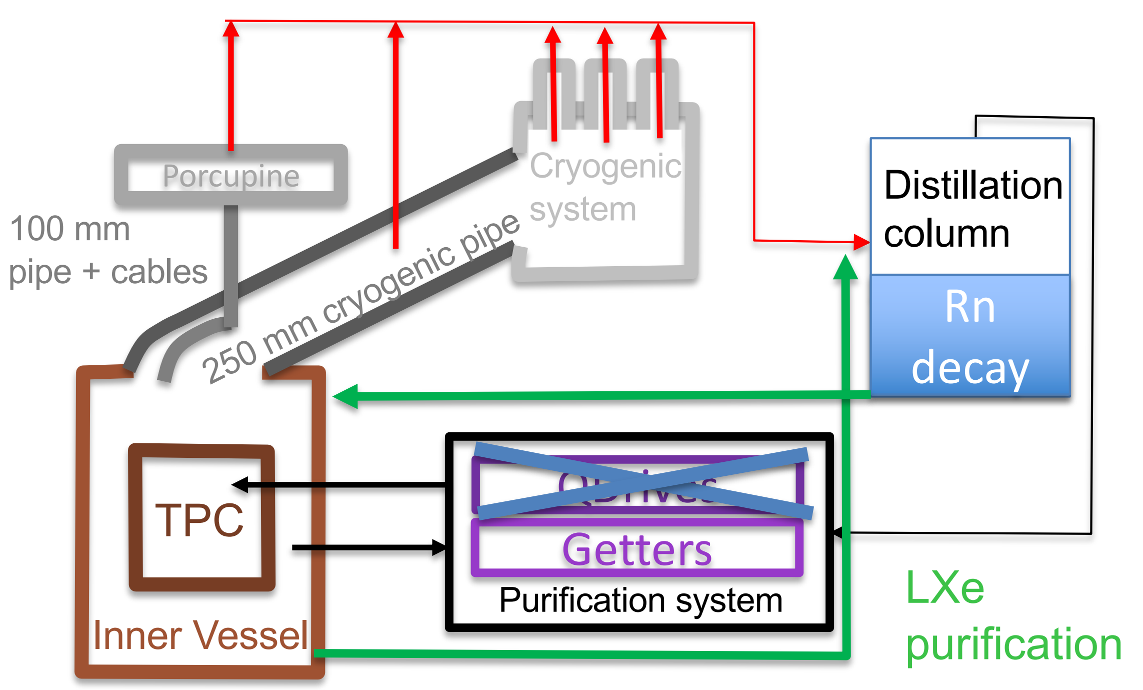
Add LXe purification

Rn in XENON1T and XENONnT





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→dilute by Rn-depleted LXe

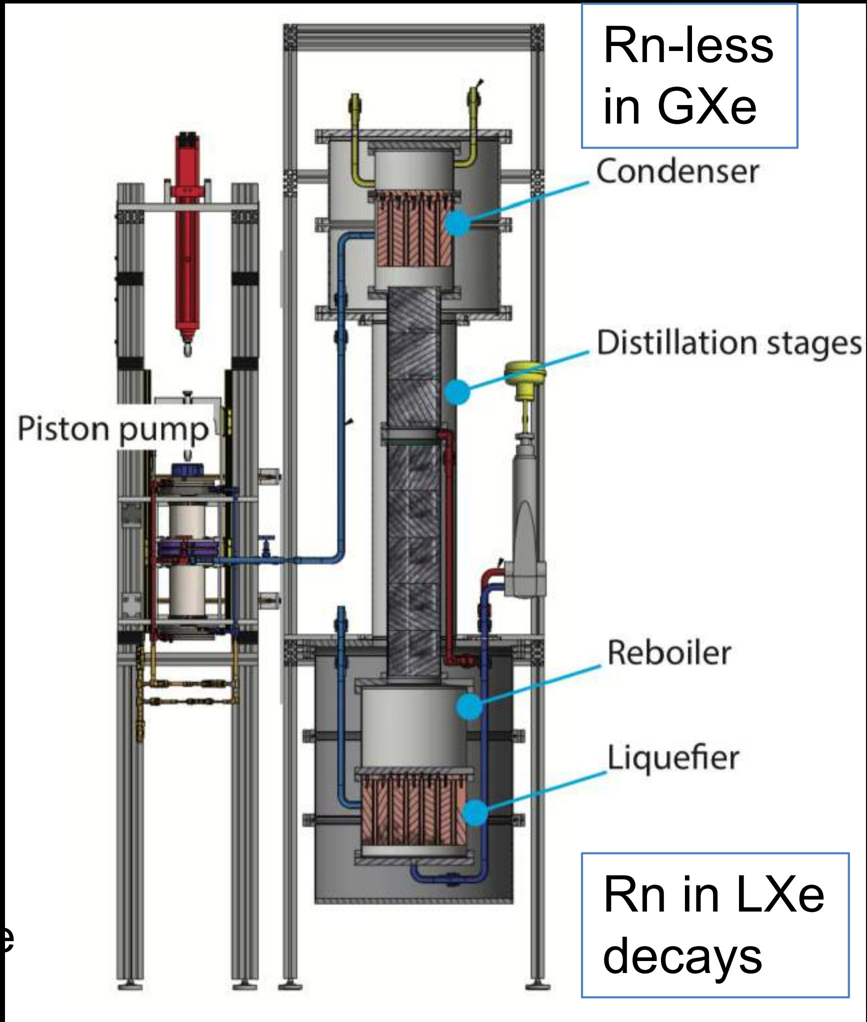
Add LXe purification

Rn screening and clean assembly is more important.

Update the pie chart.

Aim to have ~1μBq/kg

Radon distillation column for nT



Tested Kr-column in reverse mode on Xe100 [EPJC (2017) 77:358] and XENON1T (3 slpm): 20% reduction of BG

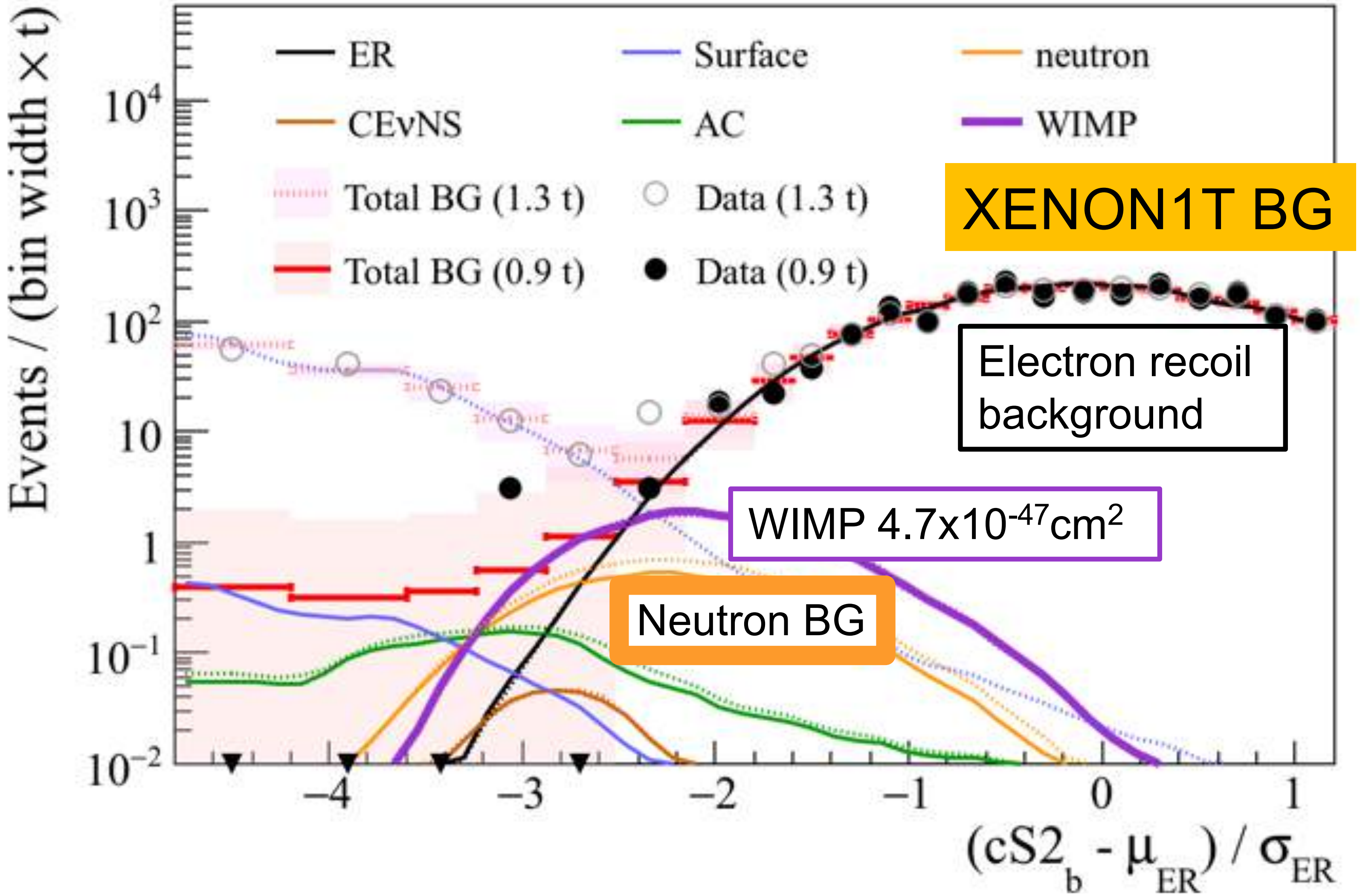
- Kr removal relies on $T_{Kr} < T_{Xe}$
- Rn removal utilizes $T_{Rn} > T_{xe}$
- Inverting the flow in Kr distilla-tion makes Rn staying in reboiler for a long time and decay there.
- Rn-depleted GXe can be obtained at the top. Depletion factor 100

Piston pump 200 slpm =1.7 ton/d
This reduces Type I Rn to ~1/2,
and removes Type II Rn.
→ 1/10 from XENON1T expected.
Need to control Rn emanation.

See PhD M. Murra, WWU Münster 2019

XENONnT upgrade: BG

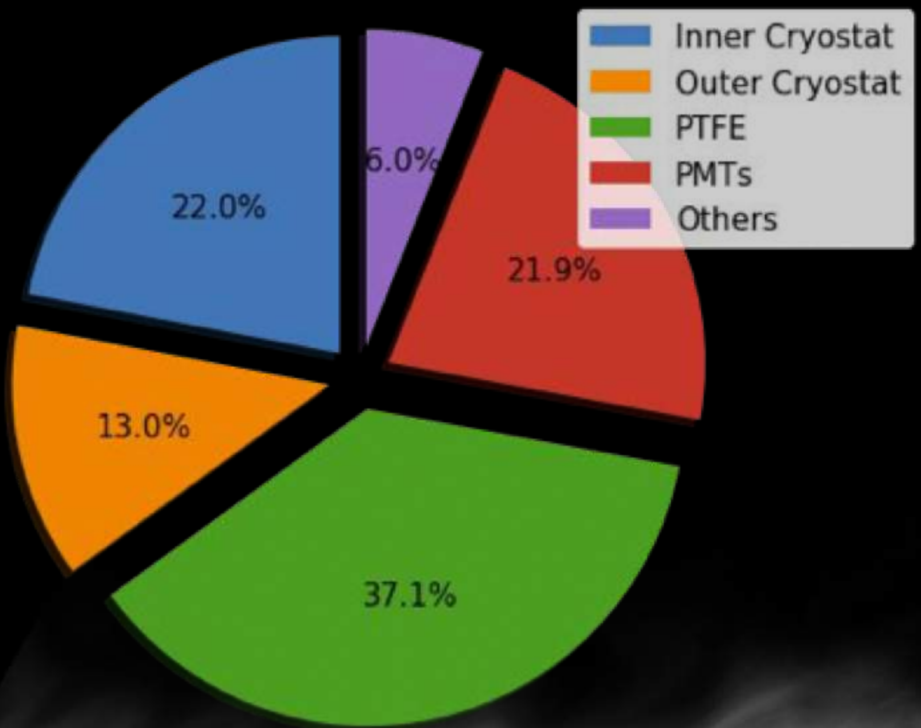
E. Aprile et al., PRL 121, 111302 (2018)

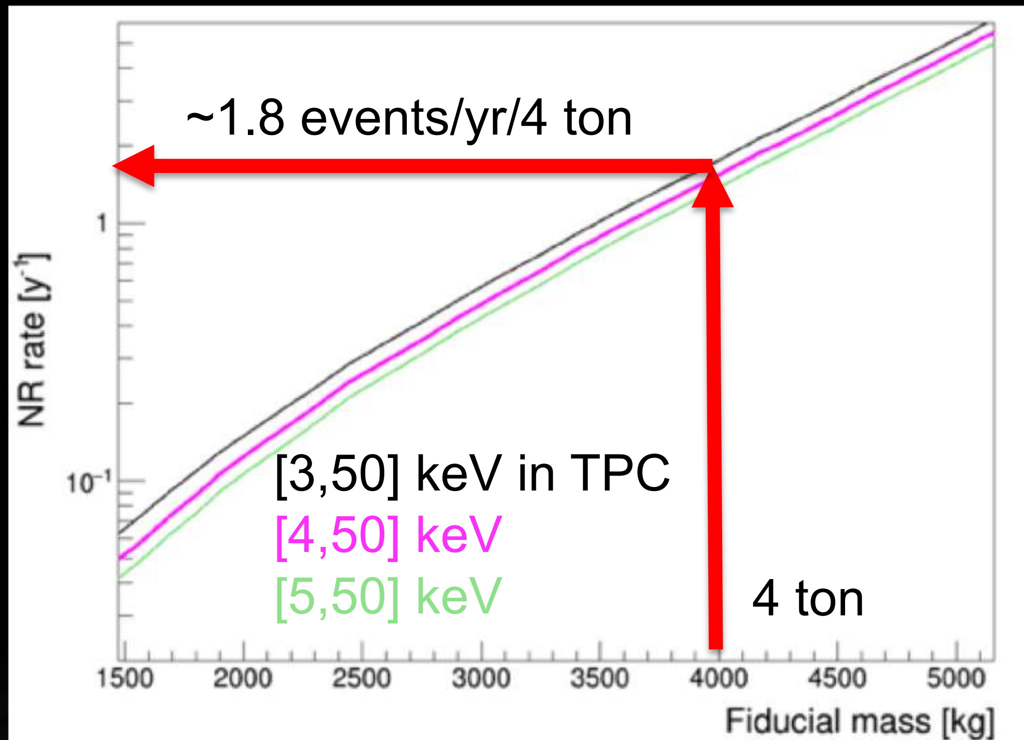


Electron recoil BG (Rn), neutron BG need to be reduced

Background: neutron

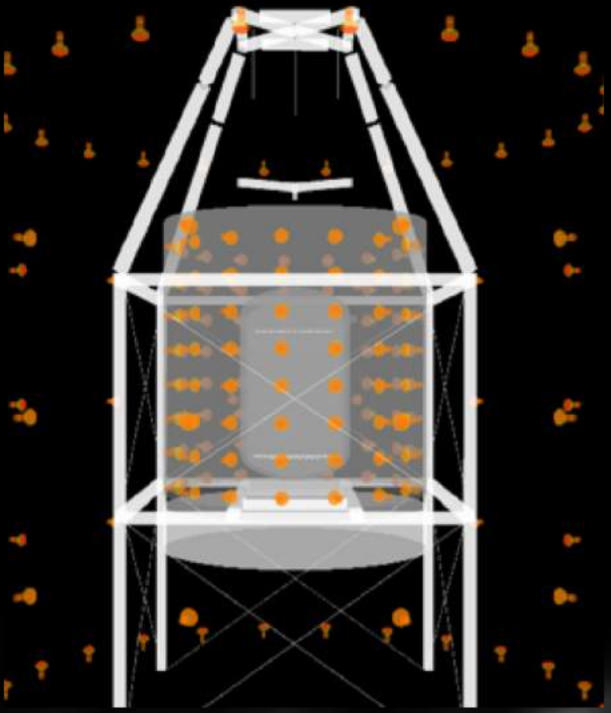
- If Rn can be reduced as aimed for, nuclear recoil becomes dominant background. Only neutrons scattering just once in the TPC become BG ~ 1.8 events/yr in 4 ton FV.
- The detection efficiency for such neutrons needs to be > 80%. Calibration of tagging efficiency is important.



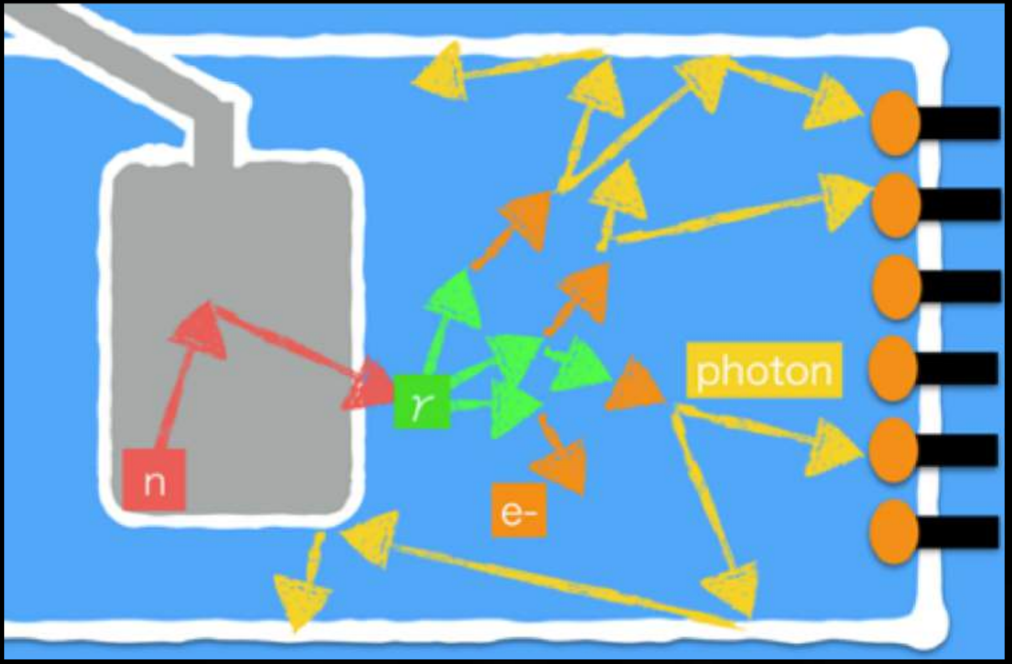


Background: neutron veto

The neutron veto aims to detect radiogenic neutrons from the TPC. Adding 0.2% Gd by weight to the water in the muon veto guarantees that ~95% of these neutrons get captured on Gd rather than H. The 8 MeV gamma cascade from the Gd greatly improves the tagging efficiency.

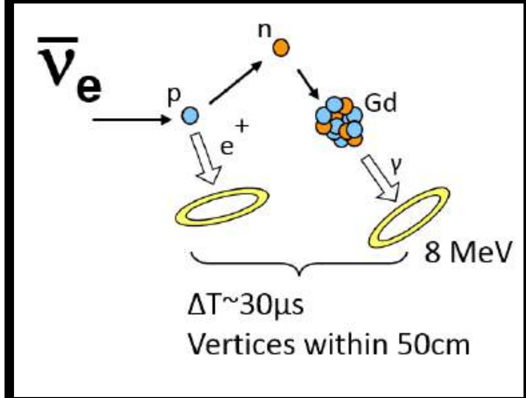


Covered by reflector sheets

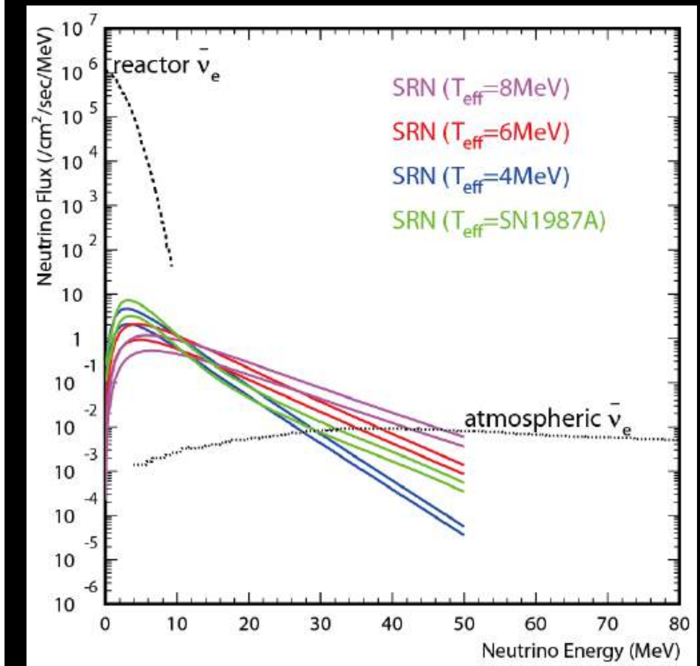


Reflector sheets will contain the Cherenkov emission from the γ conversions. - 120 PMTs will collect the light inside the reflector volume.

Background: neutron veto



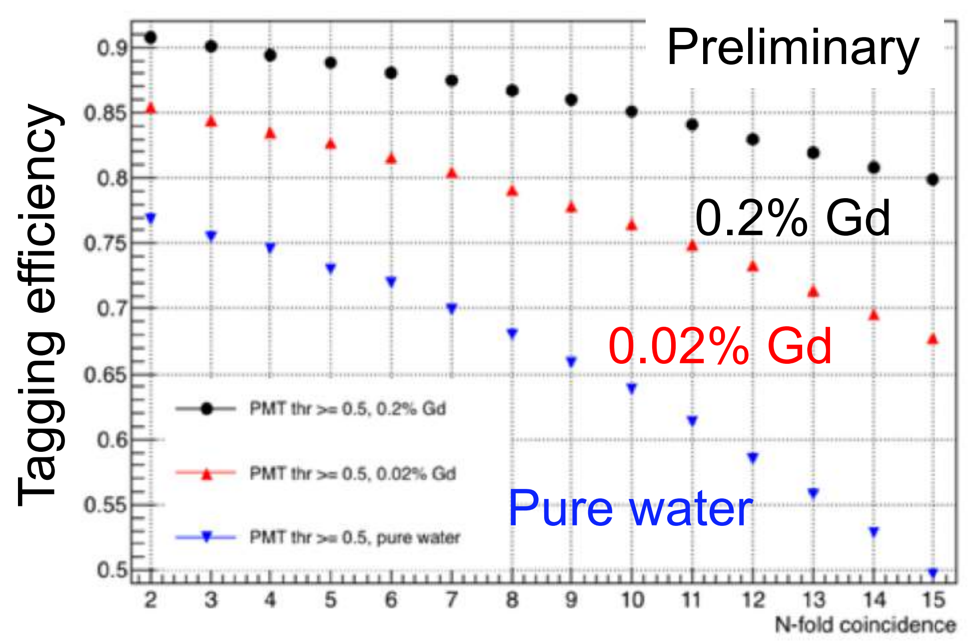
For the first time Super-K Gd technology, developed to detect the supernova relic neutrino, is applied in a dark matter experiment. We also use the G4 Gd gamma ray code developed for Super-K.



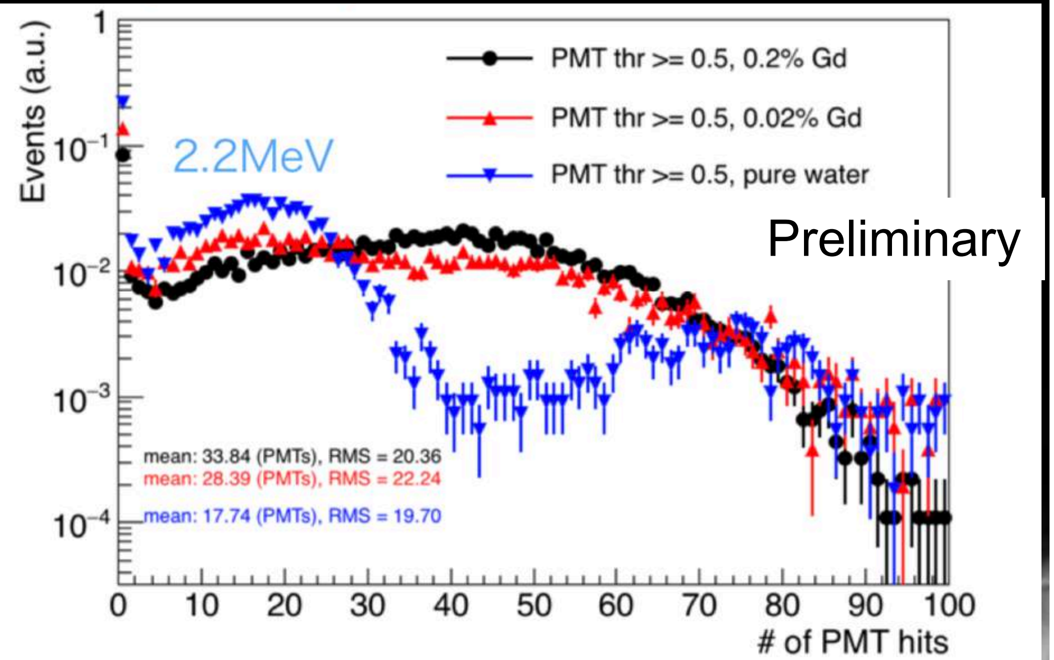
Background: neutron veto

This Gd gamma simulation code (K.Hagiwara et al.) based dedicated gamma ray emission measurements was verified in EGADS. K.Hagiwara et al., PoS KMI2017 (2017) 035

With 120 low RI 8" PMTs inside a simple cylindrical reflector box > 80% of single scatter neutrons are tagged in our simulation; optimization is ongoing. See poster presentation by R. Ueno



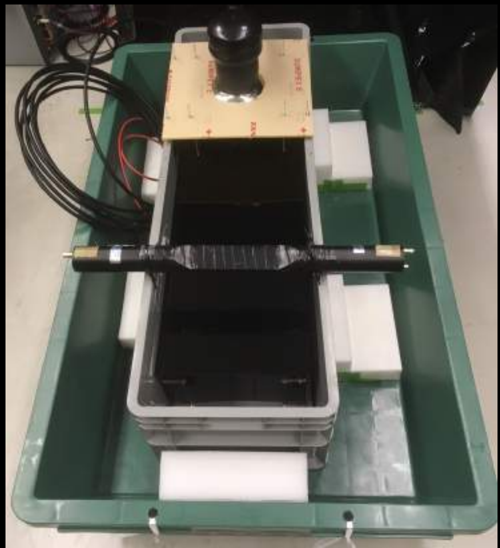
N-fold coincidence of hit PMT

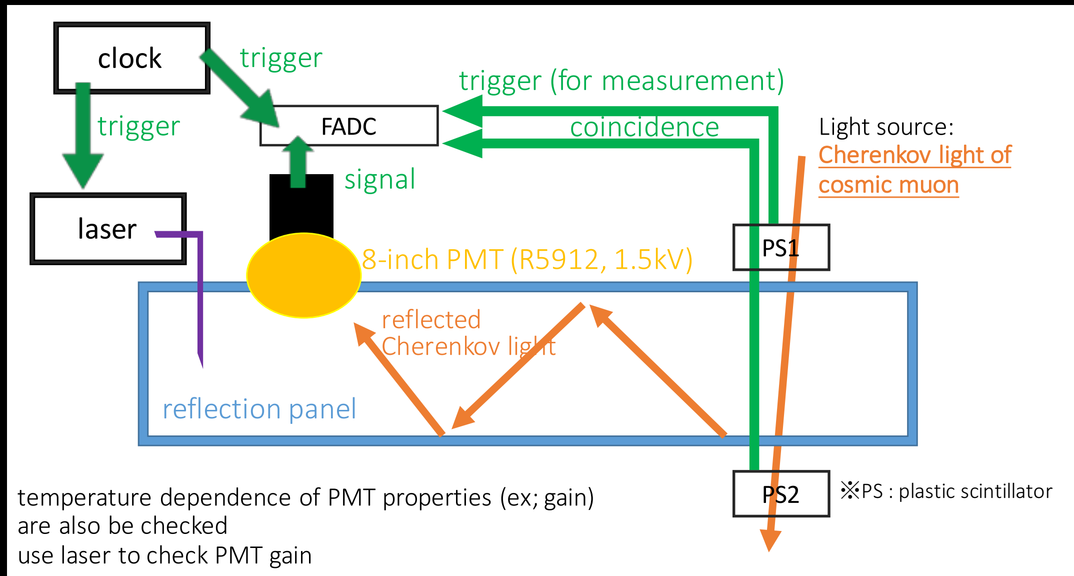


N PMT hit distribution

Background: neutron veto

Various candidate reflectors' reflectivity was measured in air and a relative comparison of their reflectivity in water is ongoing.

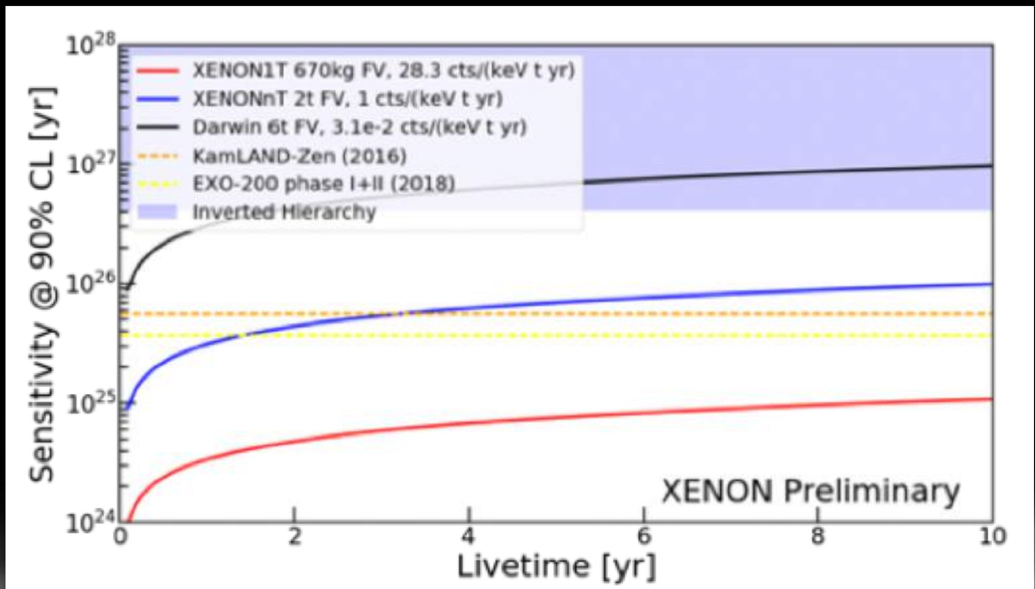




A simplified version of the EGADS Gd-water treatment system will be procured and installed this year.

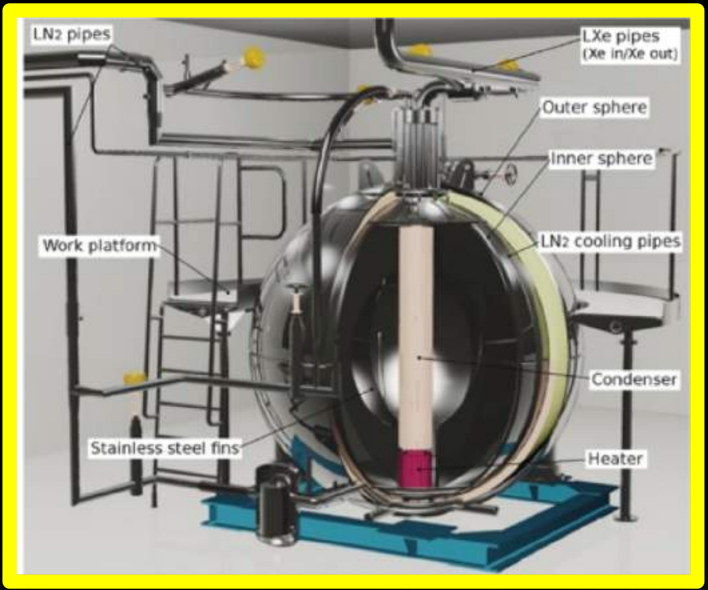
Construction: TPC, PMT array, DAQ

TPC size: 1.33 m$^{\phi}$ x 1.48 m:
  TPC electrode wiring is ongoing.
PMT test completed:
  494 PMTs incl. PMTs from XENON1T
DAQ and electronics:
  Doubling channels + add. for $0\nu\beta\beta$



LXe storage

XENON1T: ReStoX
- Capacity 7.6 ton of Xe
- Vacuum insulated
- Max. pressure 73 bar.
- Fast recovery (~50 kg/h)



XENONnT: + ReStoX2
- Capacity 10 ton of Xe
- Foam insulated
- Max. pressure 71.5 bar
- Very fast recovery (~1 t/h) with Xe freezing
- ~8000 kg of LN2 consumption for recovery

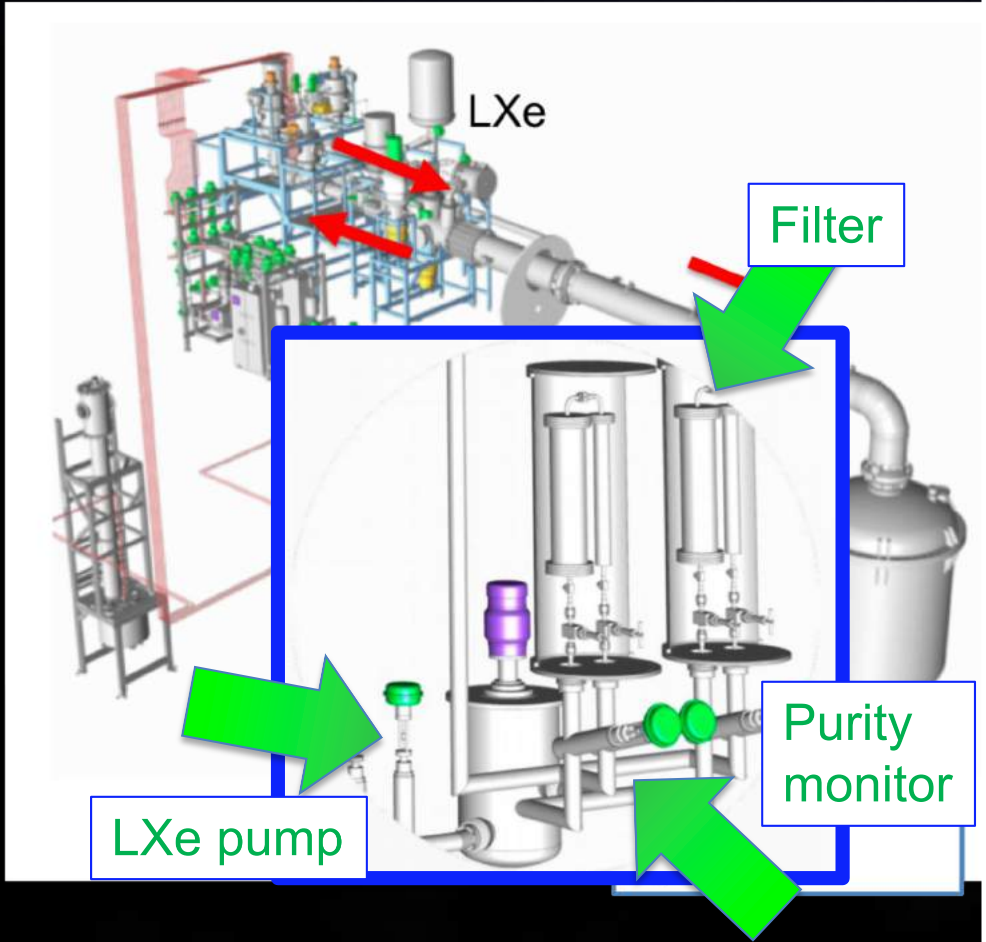
Cleaning inside (water removal) completed and Kr distillation already started to add more xenon.

Construction: LXe purification

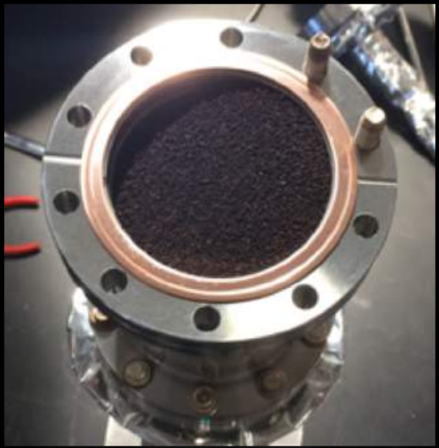
Xe purification to remove electro-negative contamination is crucial to realize good performance of dual phase detectors.

GXe purification ~120 slpm,
= 1.8 t/d with minor modifications

Faster purification necessary
LXe purification ~5 L/min = 21 t/d



Filter: two custom regeneratable cryogenic O_2 filters
$2Cu+O_2 \rightarrow 2CuO$



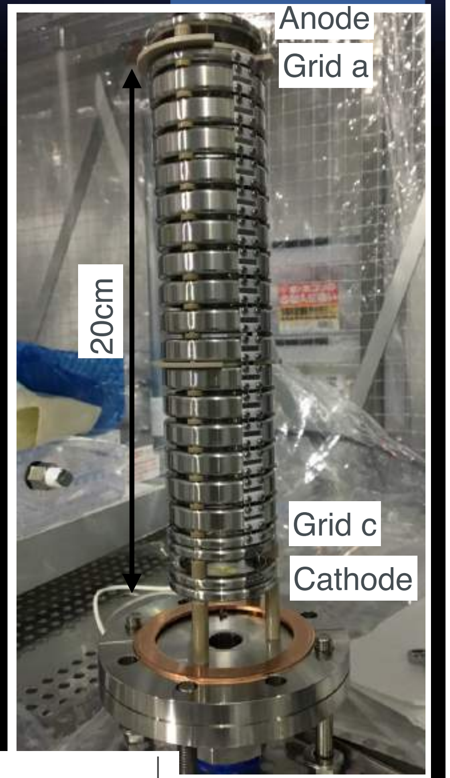
Direct extraction of LXe from the Bottom of the detector.

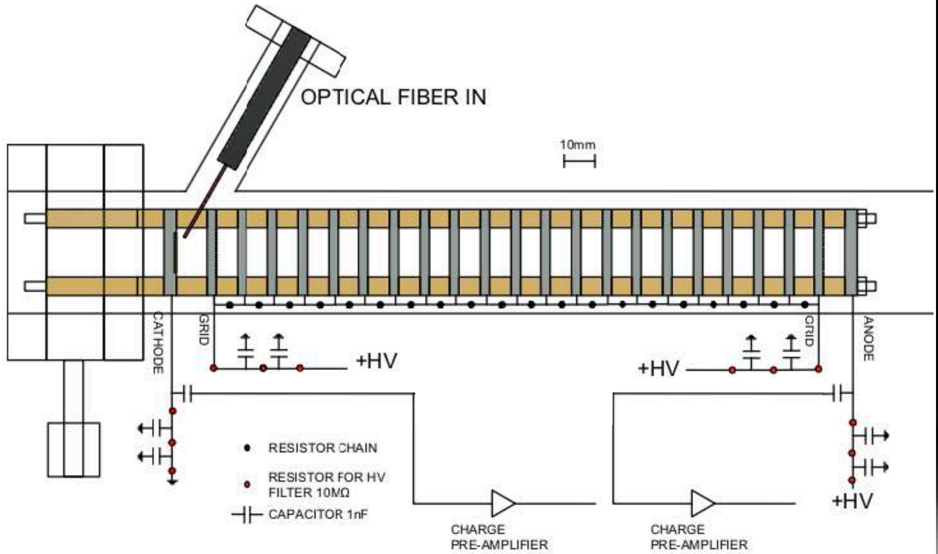
Construction: LXe purity monitor

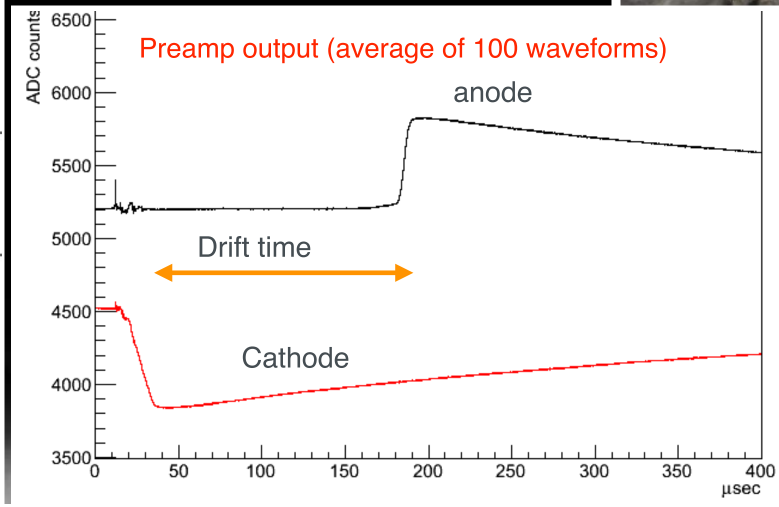
Monitoring LXe purity is important to correct the loss of electrons during drift.

If it is not well corrected, the resolution of S2 and rejection efficiency are degraded.

In the purity monitor electrons produced by flashing a xenon lamp onto a photocathode (Au) are drifted by E field. Induction at the cathode and the anode enable us to measure the loss of electrons on the path.

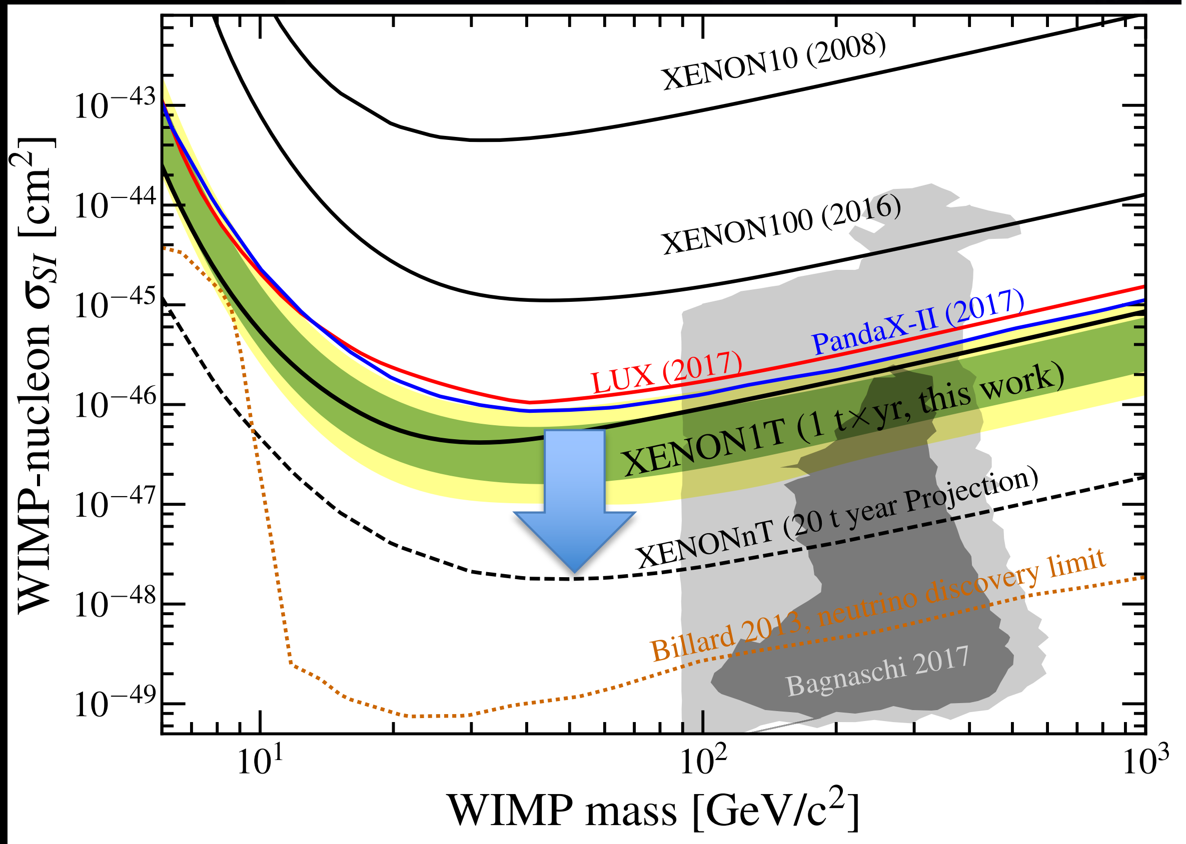






Summary

- XENONnT is designed to explore dark matter particles with unprecedent sensitivity.
- Technical challenges in a larger TPC and large amount of xenon gas.
- Rn and neutron BG reduction important.
- It is planned to start detector commissioning in 2019; construction is ongoing.



Appendix