XMASS / XENON Report

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Kavli IPMU, The University of Tokyo
at the
Workshop on Low BG Technologies 2021
2021.03.24

Overview

- XMASS: detector, achievements, and LowBG technology development
- XENON1T: some relevant results
- XENONnT: important lowBG technologies and prospects

Limited time will not allow me to introduce the Kamioka Observatory,
where the XMASS-1 detector is located...

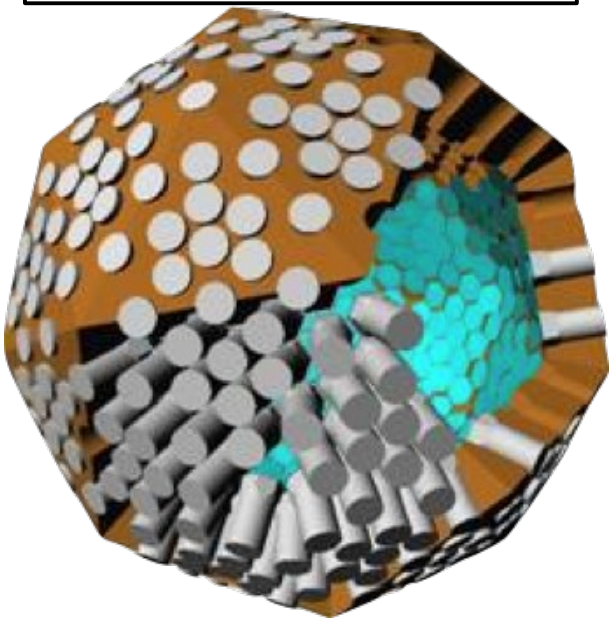
XMASS-1: Detector & Collaboration

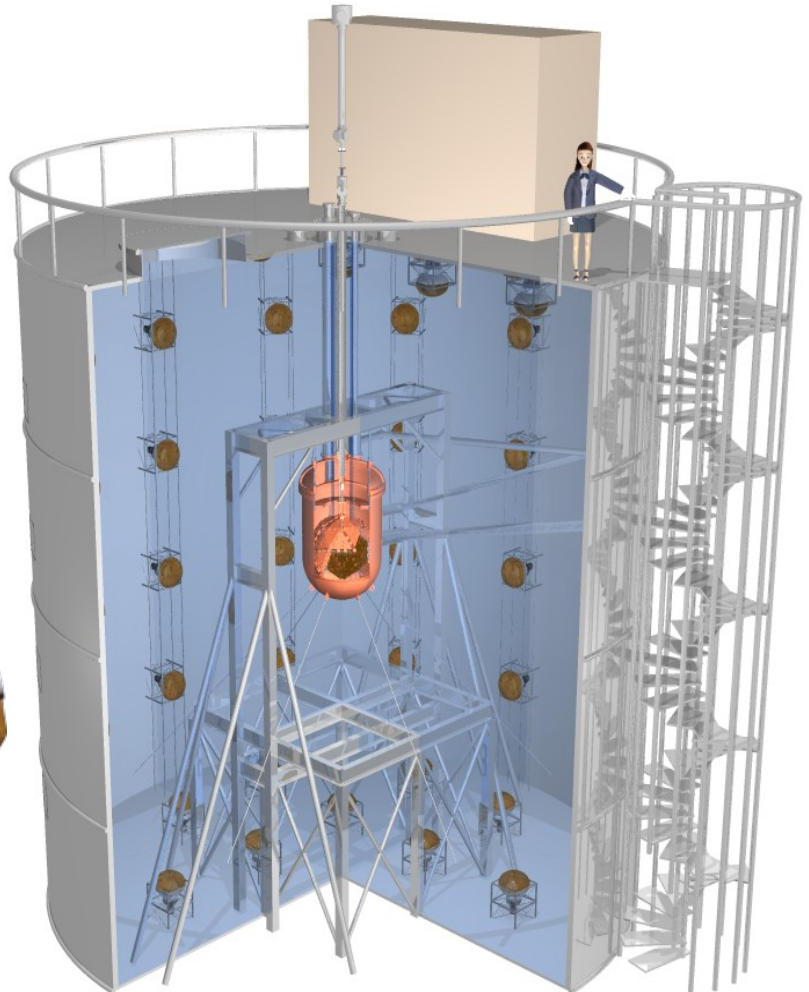
International collaboration:
U. Tokyo (ICRR, KIPMU), Nagoya U. (ISEE, KMI), Kobe U., Tokai U., Gifu U., Miyagi U. of Edu., Yokohama Nat. U., Tohoku U., Tokushima U., Nihon U., Waseda U.
Korea: KRISS, IBS
China: Tsinghua U.

ID: 642 R10789 PMTs
OD: 72 R3600 PMTs
all Hamamatsu

Multi-purpose detector:
- WIMP searches
- other DM particle searches
- double beta/e-capture
- nearby supernova: CEνNS

Longest LXe exposure:
Nov. 2013 – Feb. 2019
→ total lifetime 4.4 years
of stable operation
with its 832 kg active target
(+ commissioning 2010-2012)

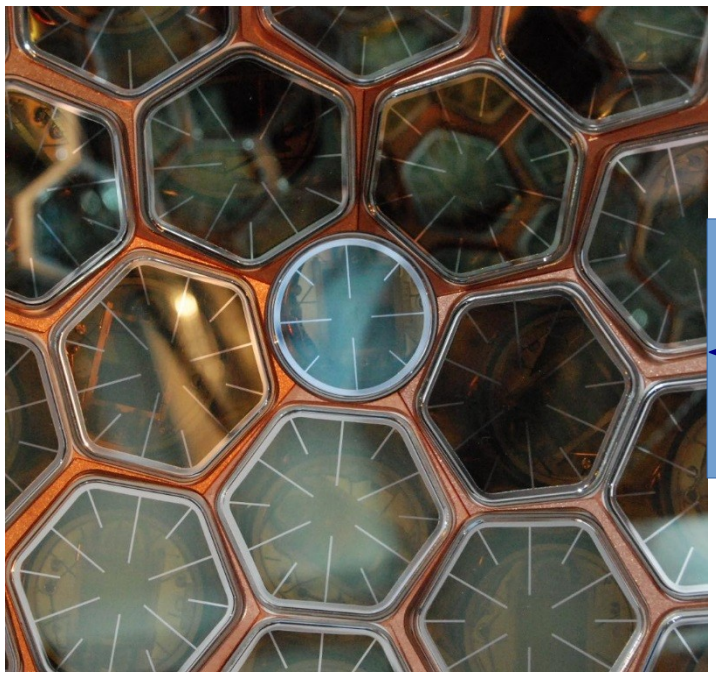




Refurbishment: 2012.03 - 2013.11

Commissioning data revealed problem with Al-seal between PMTs' quartz window and PMTs' body.

Refurbishment implemented measures to prevent scintillation light from β-decays in the seal from
a.) entering the PMT window and b.) entering the detector volume:

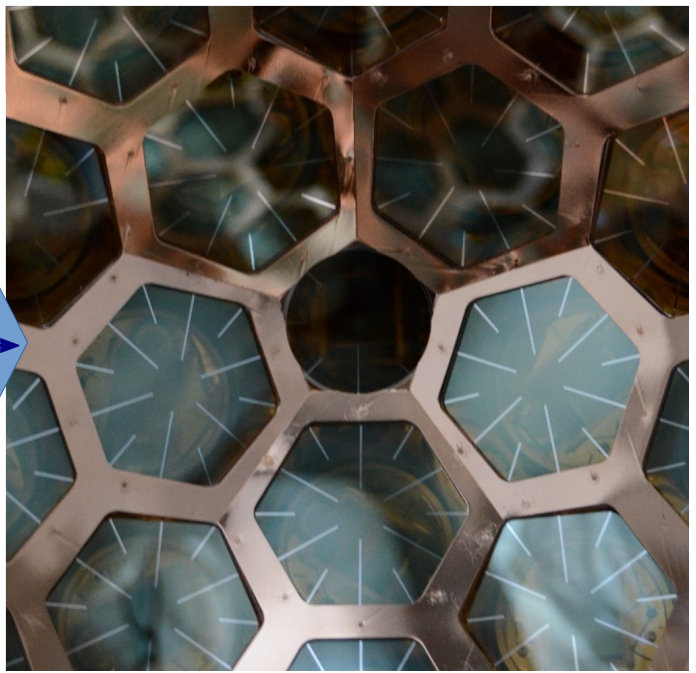


result:

factor 10 BG reduction in full volume,

inner surface pictures from the detector:
← **before** **after** →
refurbishment:
light blocking Cu plates

factor 100 in fiducial volume!!!



XMASS-1 Achievements

... other than sheer lifetime ...

Astroparticle Physics:	2021, 2019, 2017, 2009
Physics Letters B:	2020, 2019x2, 2018, 2016x2
JINST:	2020
NIM A	2019, 2018, 2016, 2015, 2013, 2011, 2008
PTEP:	2018, 2017, 2015, 2014
Physical Review D:	2018
Physical Review Letters:	2014

24 peer reviewed publications, *and counting!!!*

Half of these were technical in nature (equipment and measurements relating to scintillation).

XMASS relevance and legacy at the low BG, high sensitivity frontier:

- first liquid xenon detector to deploy a water shield
- first studies of xenon purification in the liquid phase

Some physics analyses are still ongoing: stay tuned for more results!!!

For publication details pls see: http://www-sk.icrr.u-tokyo.ac.jp/xmass/dispatches/publications/index-e.html

... almost forgot:

- There are three “Top 10%” papers reported from XMASS!

Percentile in Subject Area, top 10% citation in Apr. 2016-Dec. 2020. (Web of Science, Incites)

○調査の結果、当該研究所等の研究者の論文のうち、被引用回数が当該研究分野の上位10%以内にランクされた論文（Top10論文数）がある場合は、直近のデータを分野ごとに記入してください。【単独・NW総・NW個・国際】

分野名	論文名	発表者名	引用数
ESI: Physics	Direct dark matter search by annual modulation in XMASS-I, Physics Letters B 759, 272-276	XMASS Collaboration	29
ESI: Physics	Direct dark matter search by annual modulation with 2.7 years of XMASS-I data, Phys. Rev. D 97, 102006	XMASS Collaboration	17
ESI: Physics	A direct dark matter search in XMASS-I, Physics Letters B 789, Pages 45-53	XMASS Collaboration	14

The 3rd paper was identified as a top 1% paper cited in the period of Sep.-Oct. 2019.

ESI（Essential Science Indicators）の高被引用論文（Highly Cited Papers 及び Hot Papers）

(slide stolen from spokesperson’s intro at last collaboration meeting :-)

Surface (and Bulk) BG Measurements

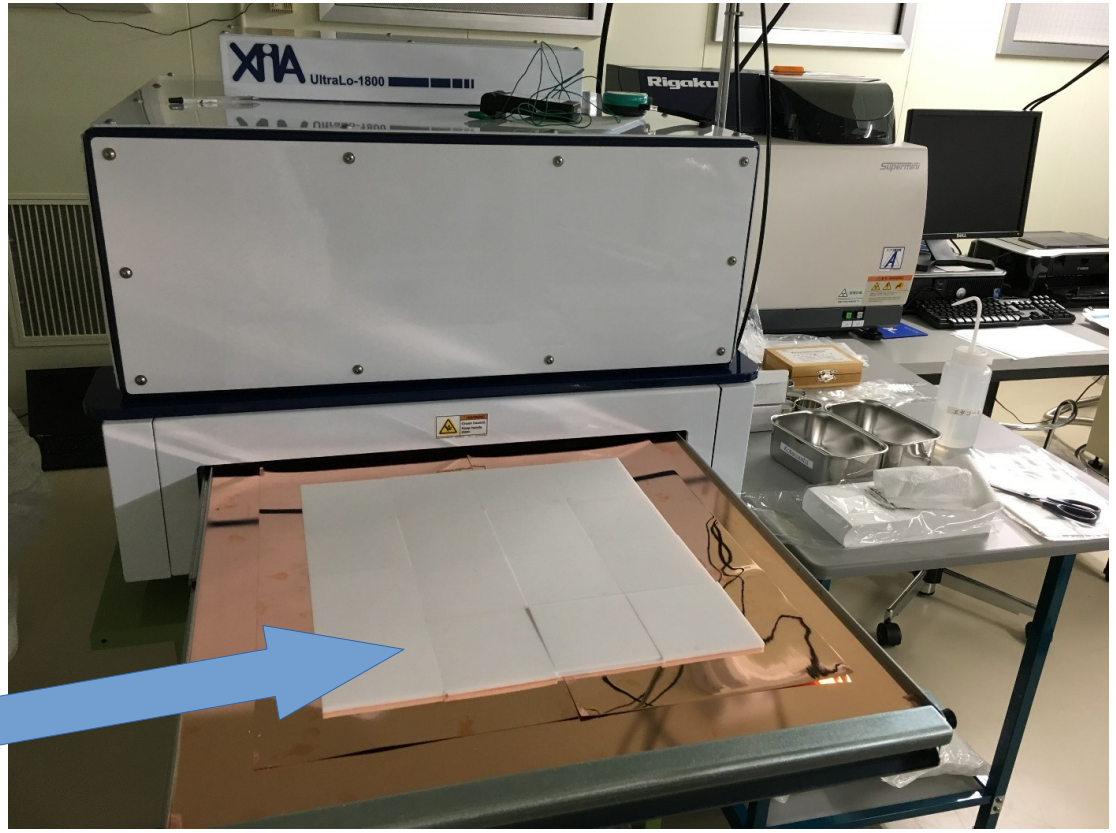
at Kavli-IPMU's Kamioka Branch:

XIA Ultra-Lo 1800 alpha counter:
designed to measures alpha radiation from sample surfaces

Used in XMASS to study surface contamination and cleaning for detector assembly. Installed in underground class 1000 clean room.

XMASS also developed method to study bulk contamination with this instrument:
NIMA 884 (2018) 157-161

Used for XENONnT to study surface treatment for TPC PTFE samples.



Sensitivity reached for ^{210}Pb and ^{210}Po bulk contamination: a few mBq/kg

XENONnT

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

Chicago · Tsinghua University · UCSD · Rice · Purdue

located @ LNGS in Italy:

11 countries
27 institutions
~170 members

JP:
3
18

nT-JP

Tokyo · Nagoya · Kobe

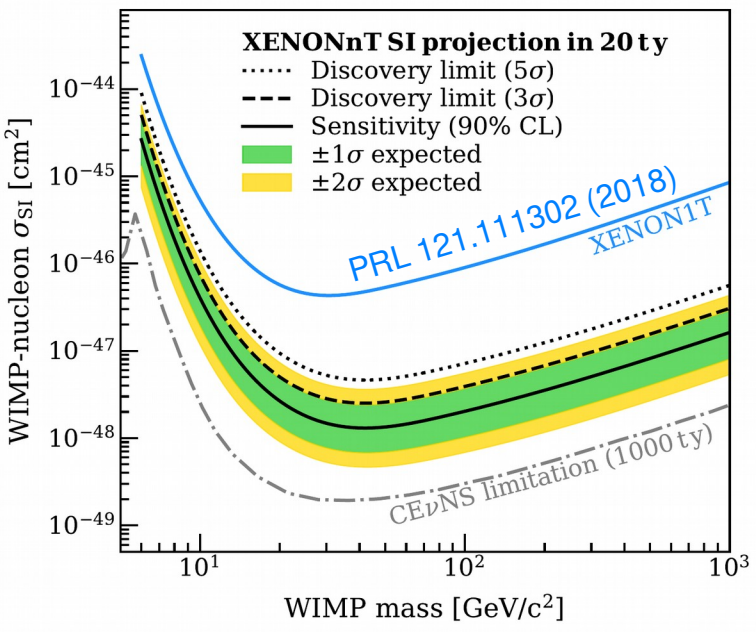
Subatech · Coimbra · LPNHE · Torino · Bologna · L'Aquila · LNGS · Napoli · Weizmann · NYUAD

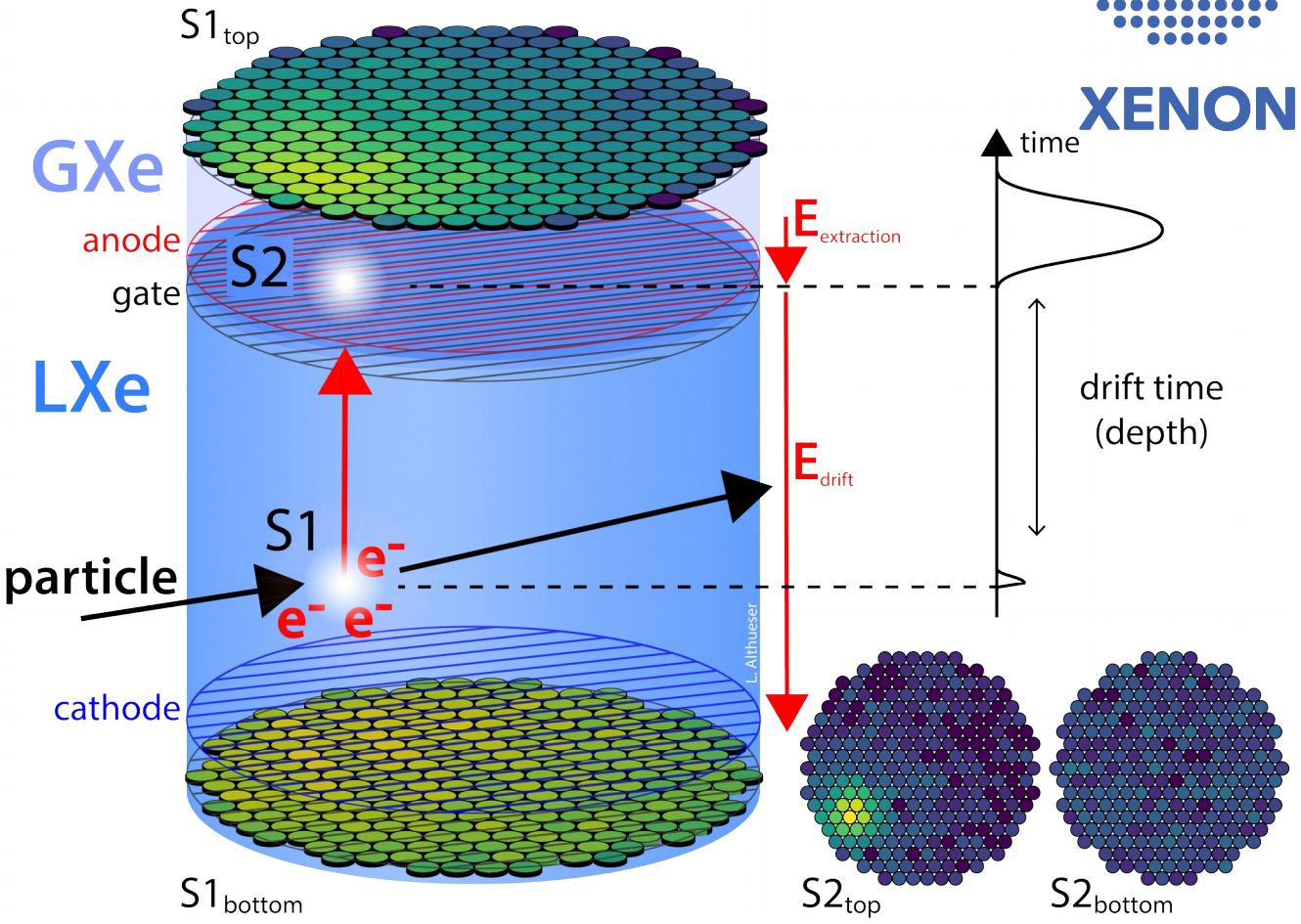
XENON(nT)'s Liquid Xenon TPC:

2 phase TPC advantage:

independent measurements of
S1 (scintillation) and S2 (ionization)

→ **ER vs. NR discrimiation:**

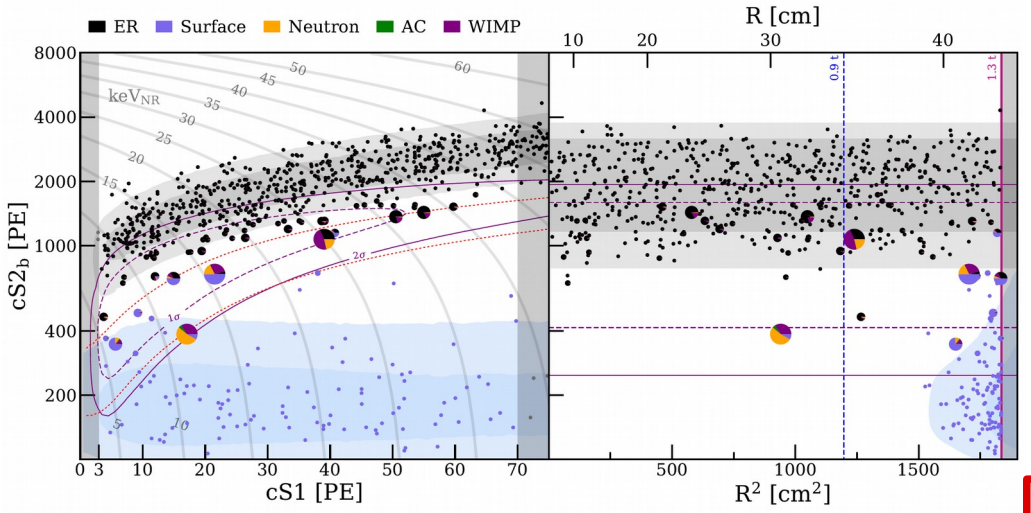


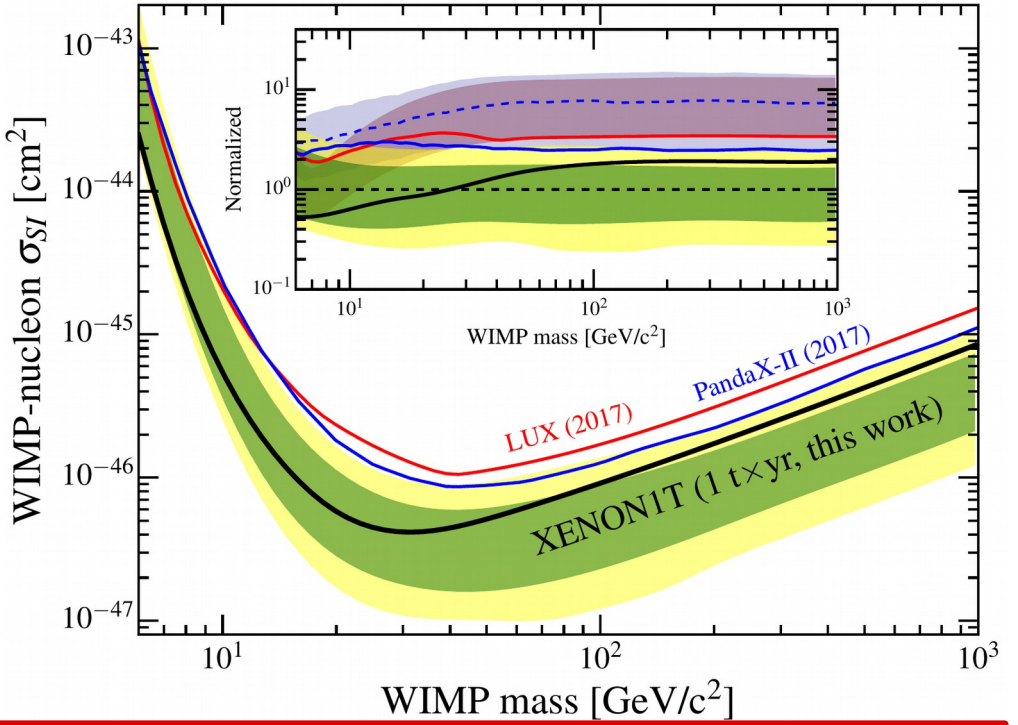


X1T Spin Independent WIMP Limits:

PRL 121 111302 (2018): Current world best limit

from 278.8 days of X1T data:
(1.30 ± 0.01) ton fiducial target mass
BG in region of interest [1.4, 10.6 keV_{ee}]:
82^{+5}_{-3}(sys) ± 3(stat) events/ton/year/keV_{ee}





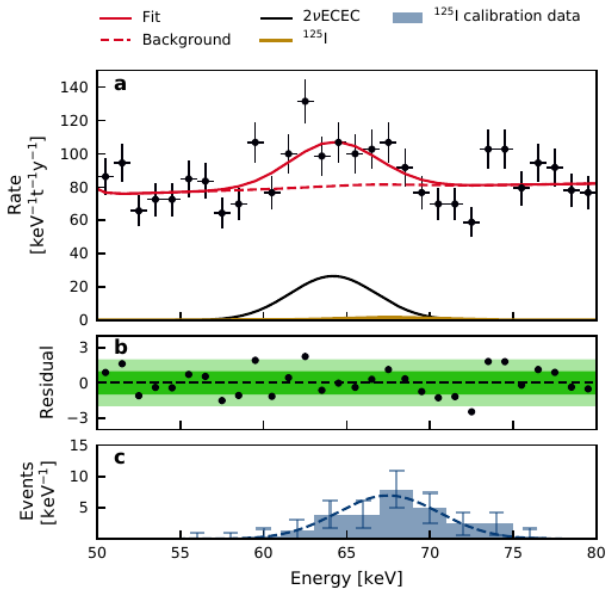
minimum: 4.1 × 10^{-47} cm^2 @ 30 GeV/c^2, 90% CL

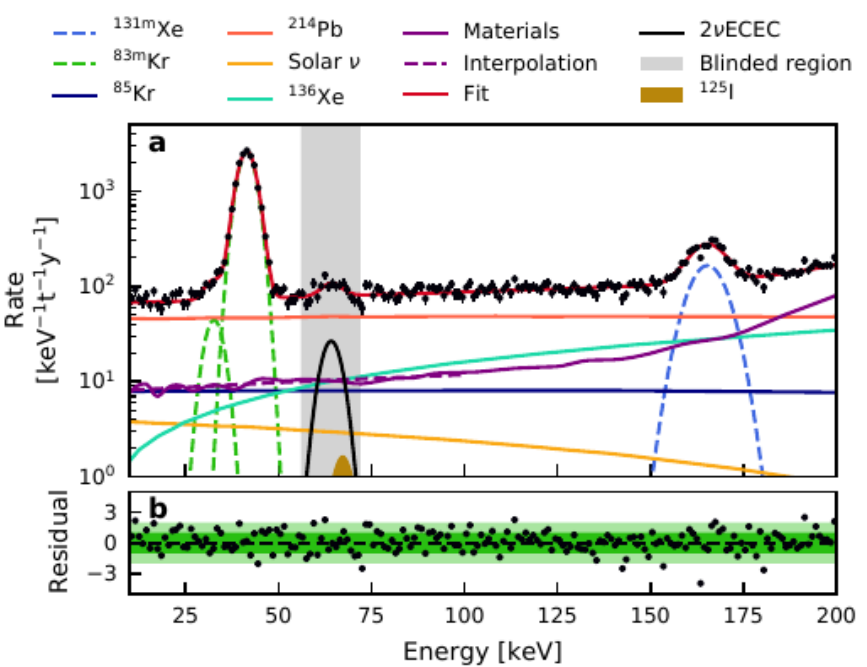
X1T Double e^- Capture on ^{124}Xe

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

double K-shell capture → look for **X-rays and Auger electrons** from the excited progeny:

XENON1T result in **Nature 568, 532-535**: **$T_{1/2} = (1.8 \pm 0.5_{stat} \pm 0.1_{sys}) \times 10^{22}$ years**





(earlier: **XMASS** in **PTEP 2018 053D03:**
limit only due to ^{125}I BG from neutron capture on ^{124}Xe)

PRD 102, 072004 (2020)

XENON1T's LowER Excess:

a new challenge:

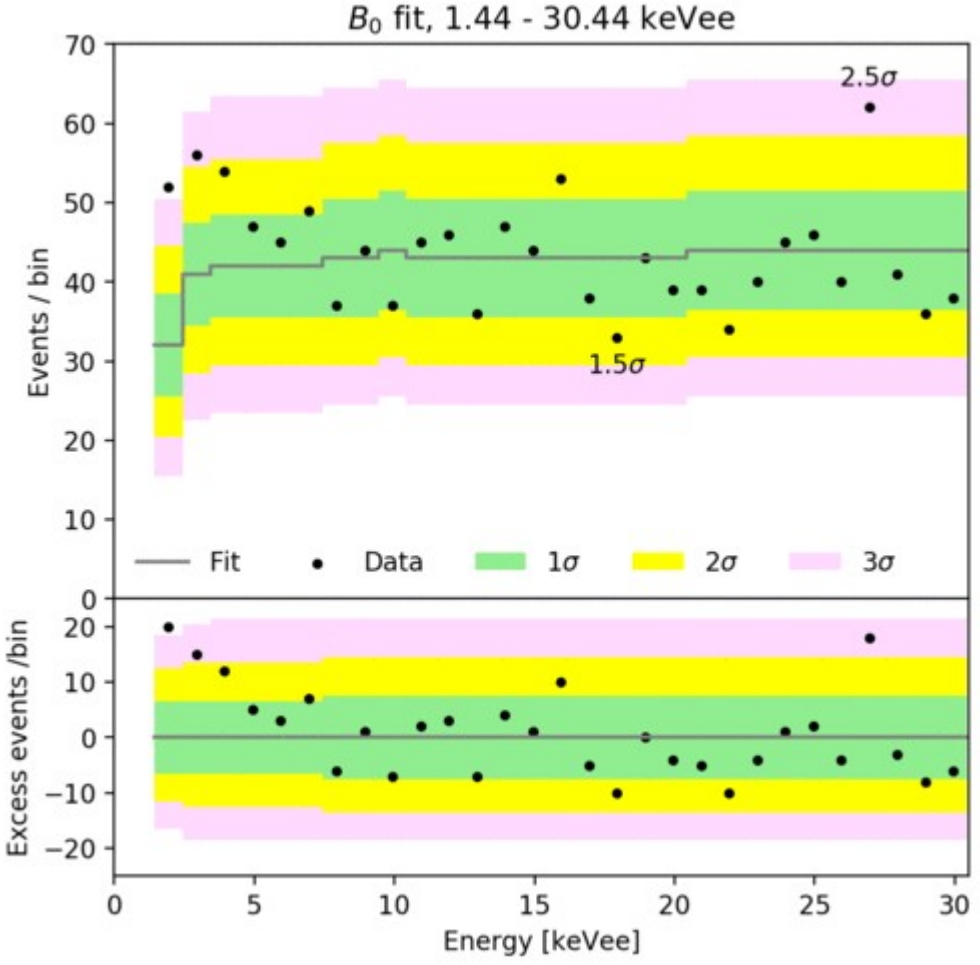
favored over BG model:

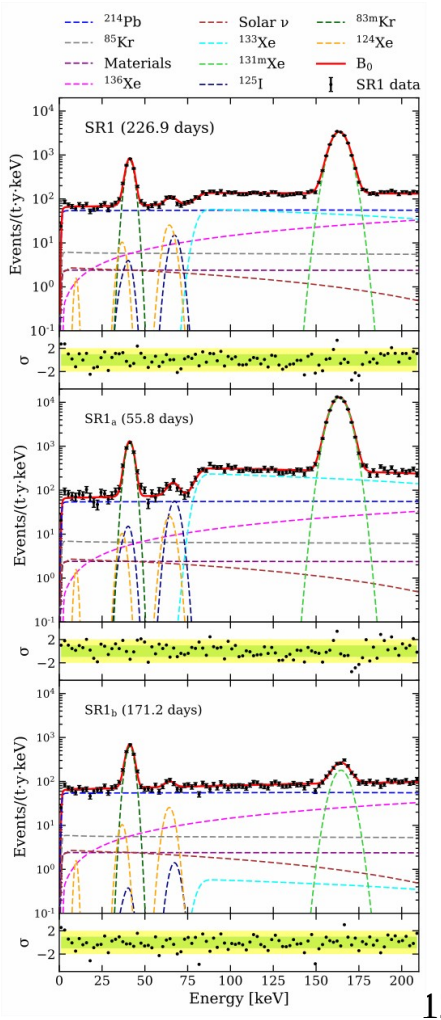
- axion: **3.4σ**
- neutrino magnetic moment: **3.2σ**

(note: both in strong tension w/stellar models!)

- Tritium ??? **3.2σ**
- bosonic DM: peak @2.3keV: **3.0σ**
- not likely ^{37}Ar !!!

XENONnT will find out!





LowER Excess Interpretations?

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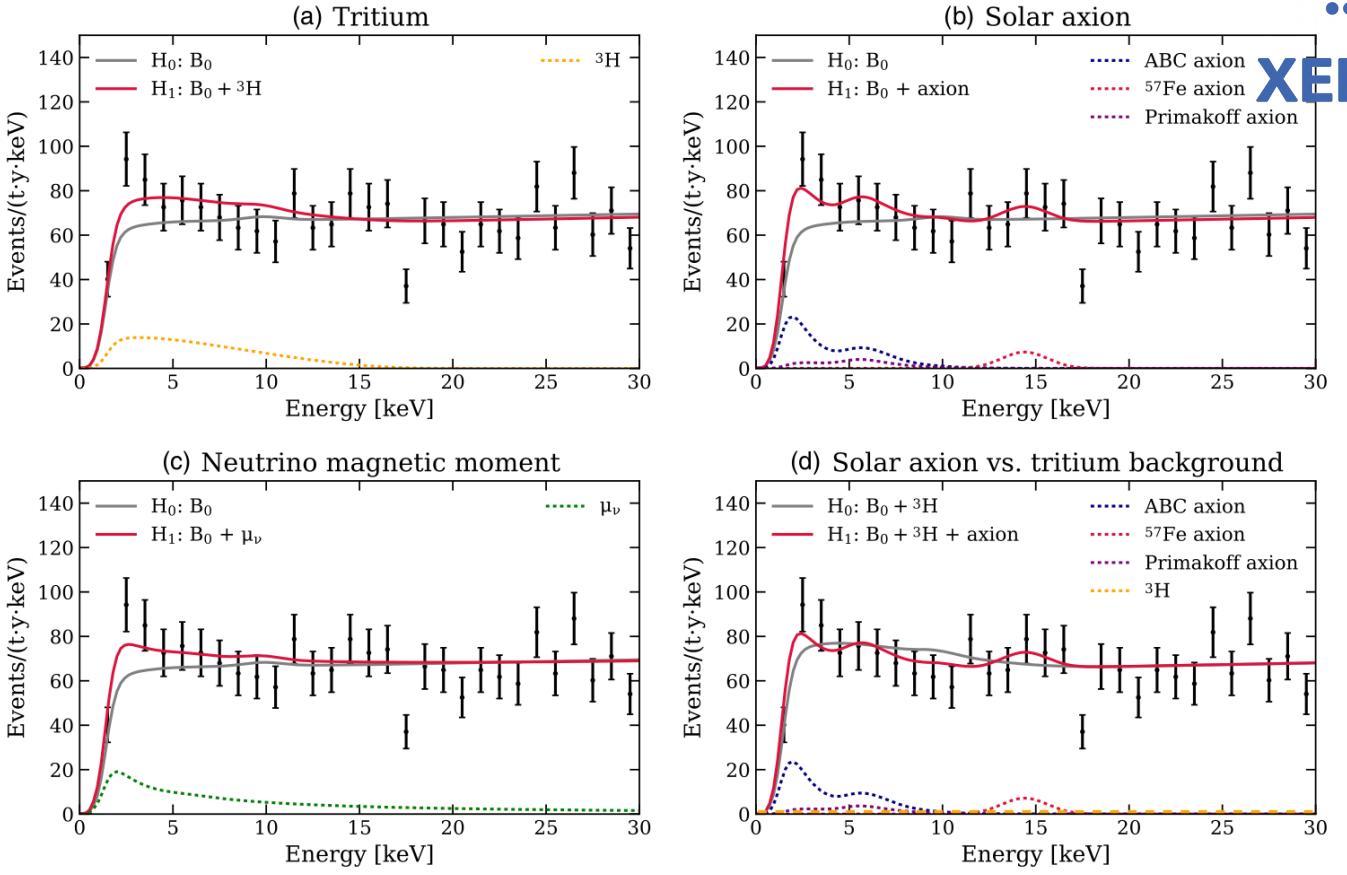


XENONnT: Upgrade of XENON1T

Enlarged dual phase TPC
→ ~4 ton fiducial volume

← to exploit and support this new size, XENONnT needs to:

2 frontiers:
1. SG extraction
2. BG reduction

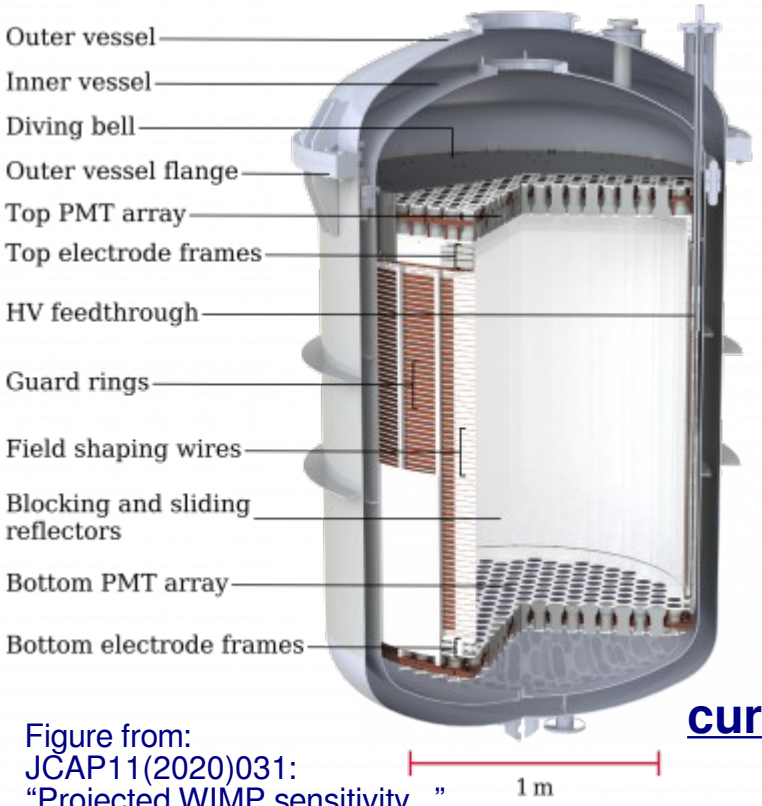
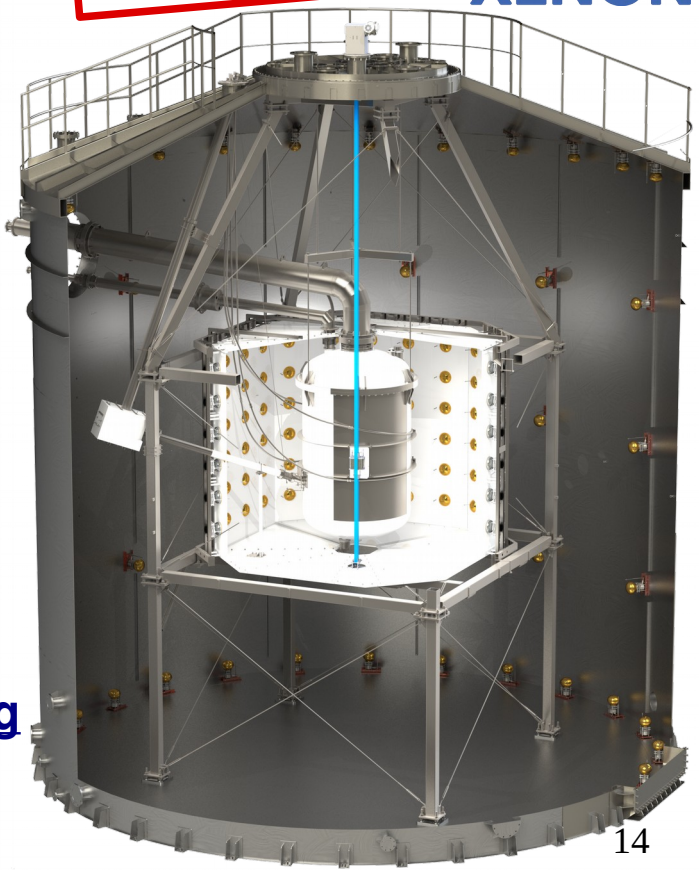


Figure from:
JCAP11(2020)031:
"Projected WIMP sensitivity..."

- suppress electronegative contaminations in LXe:
  → **liquid purification**
- suppress ^{222}Rn (ER BG):
  → **Rn distillation**
- tag radiogenic neutrons
  → **neutron veto**
- LXe emergency storage
  → **new storage**

these main upgrades are **currently under commissioning** at LNGS



2 frontiers:
1. SG extraction
2. BG reduction

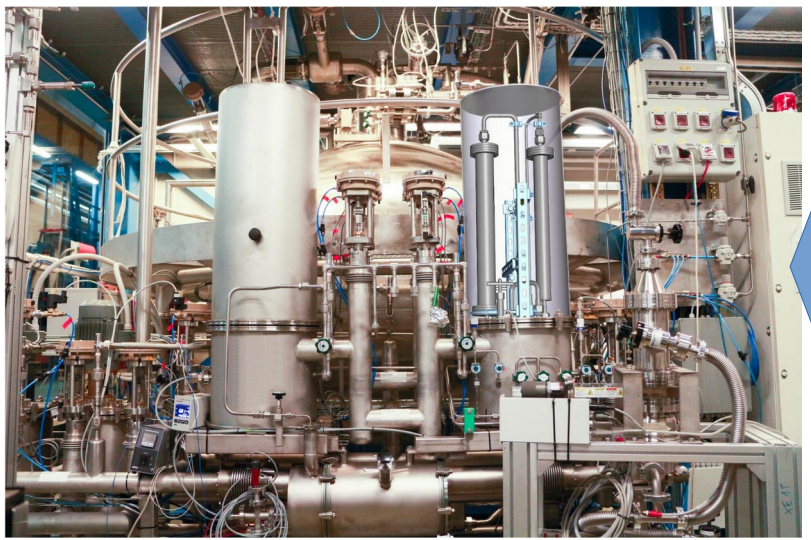
JP in XENONnT

XENON

purification of xenon in its liquid phase:

to continually remove electronegative contaminants eluding from detector materials

processing 2 liter/minute of liquid xenon and achieve electron lifetimes **> 7 ms** >> max. drift time !!!
(measured with Kamioka-built "purity monitor")

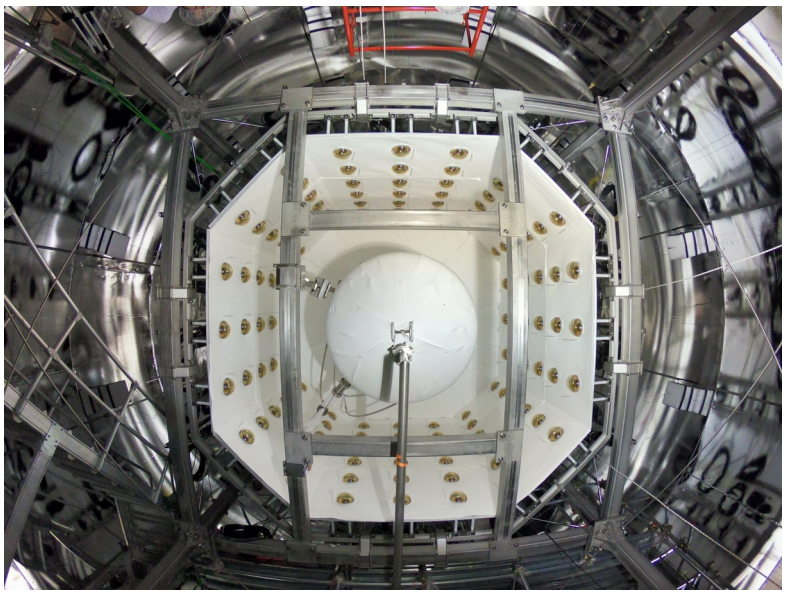


monitor:
Noboyuki Kato
(ICRR, UT)
adsorbent:
Masaki Yamashita
(ISEE, Nagoya)

neutron veto:

to **tag (α,n) neutrons** from detector materials around the target mass !!!

Kamioka technology:
Gd loaded Water Cherenkov detector



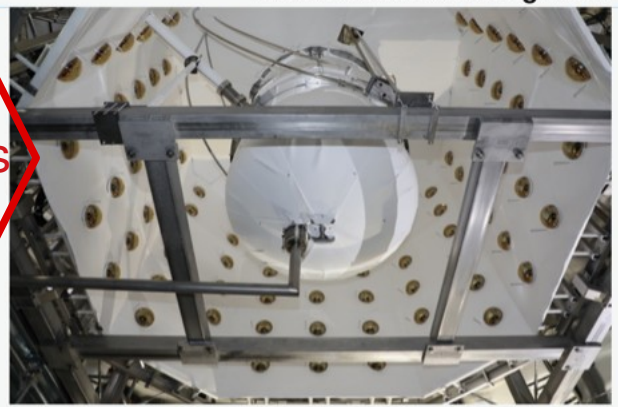
XENONnT Neutron Veto Commissioning

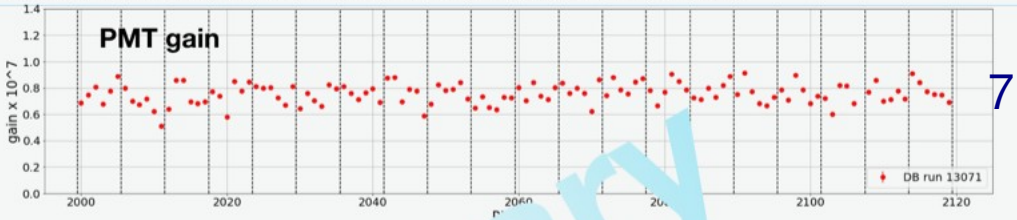
still pure water: no Gd yet !!!

neutron Veto

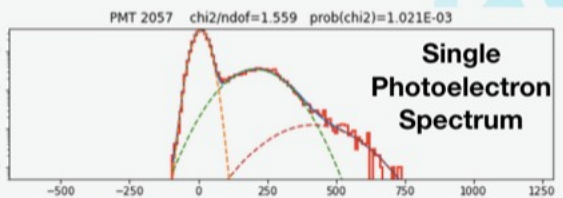
120 8” PMTs to detect Cerenkov light from n-capture, inside a high reflectivity volume around the cryostat.
Under commissioning since the tank has been filled with demi-water in December 2020.

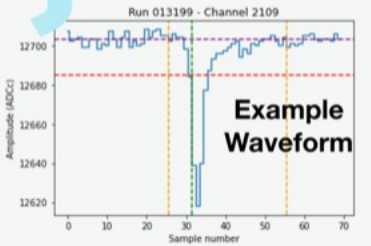
PMTs in:
20 columns
6 rows



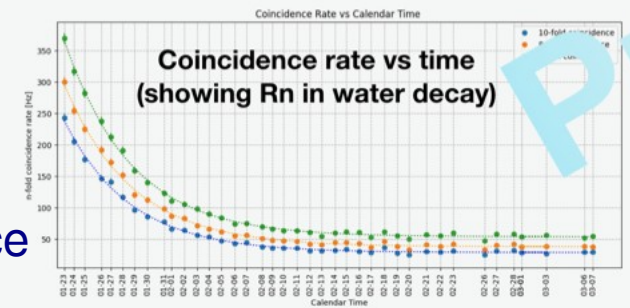


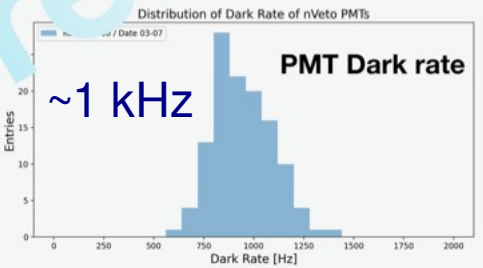
7 - 8 × 10^7

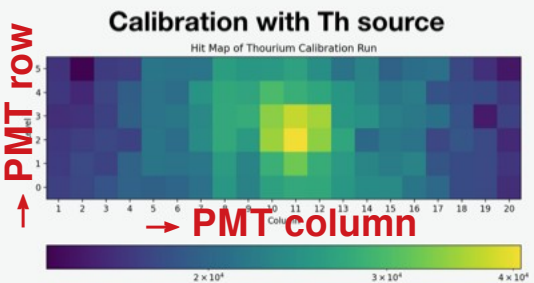




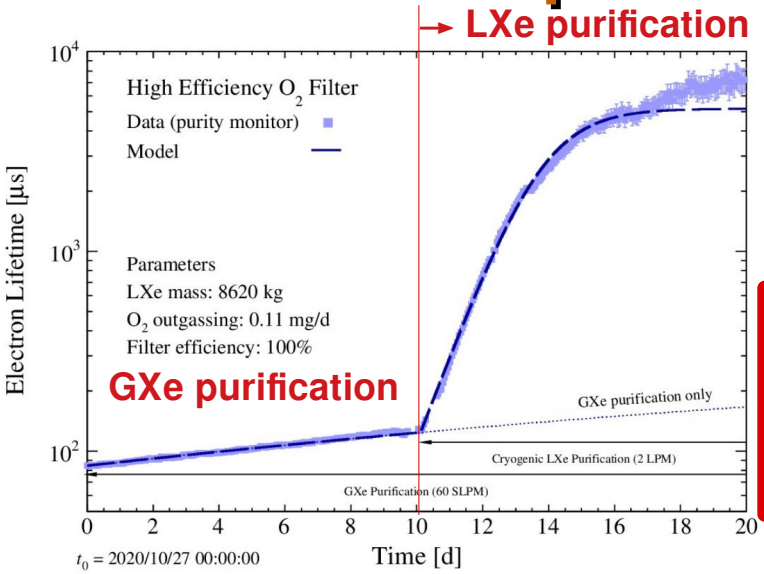
50 Hz
for 6-fold
coincidence







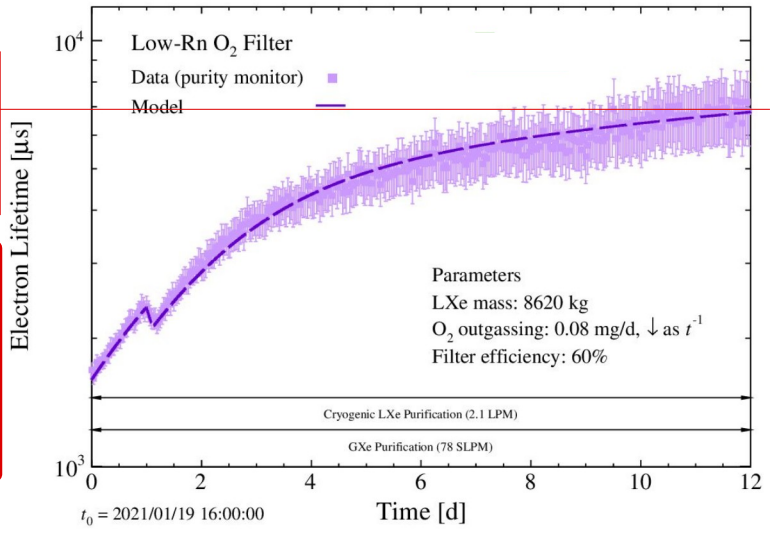
Glimpses of a Bright Future:



7 ms and rising

XENONnT's liquid phase xenon purification is working !!!

(was 0.6 ms in XENON1T)



^{222}Rn distillation with magnetically-coupled piston pumps: target is 1 µBq/kg

concept: EPJ C77 (2017) 358 XENON1T had 11 µBq/kg in SR1
4.5 µBq/kg in SR2 with Rn-distillation

pumps: EPJ C78 (2018) 604

XENONnT *before* Rn-distillation already down to ~3.5 µBq/kg; more to come...

Conclusions:

- **Liquid xenon** has dominated the DM search frontier for many years now.

- **XMASS** pioneered many analyses outside of the immediate DM searches:
  solar axions, ^{124}Xe double electron capture, nearby SN CEνNS sensitivity…
  and provided a model independent check on DAMA/LIBRA from its xenon target.

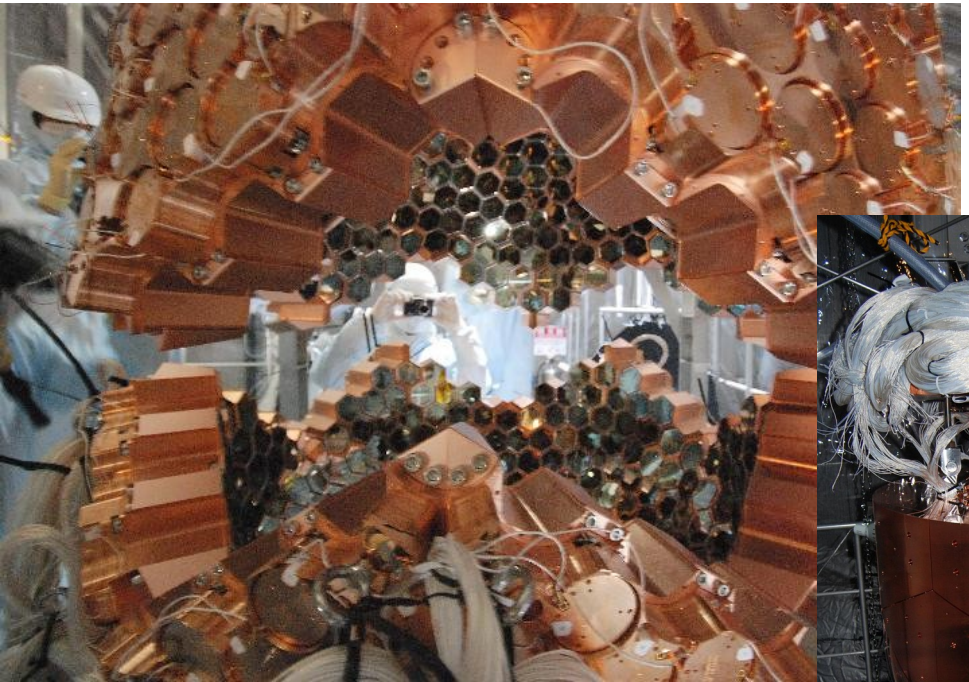
- **XENON1T** is continuing to analyze data and produce papers. Highlights:
  - provided the strongest limits on WIMPs with masses > 3 GeV/c^2
  - measured(!) the ^{124}Xe lifetime for the double electron capture
  - observed a low energy ER excess; to be re-visited with XnT

- **XENONnT** is based on the proven and well characterized materials and components it inherited from XENON1T - starts from a solid basis!
  Commissioning of the upgrades is ongoing - stay tuned

- **G3** LXe detector (after XENONnT, LZ, and Panda4T): **DARWIN** ...

Backup

The XMASS-1 Inner Detector



These pictures were taken in
Feb. 2010
(before commissioning)

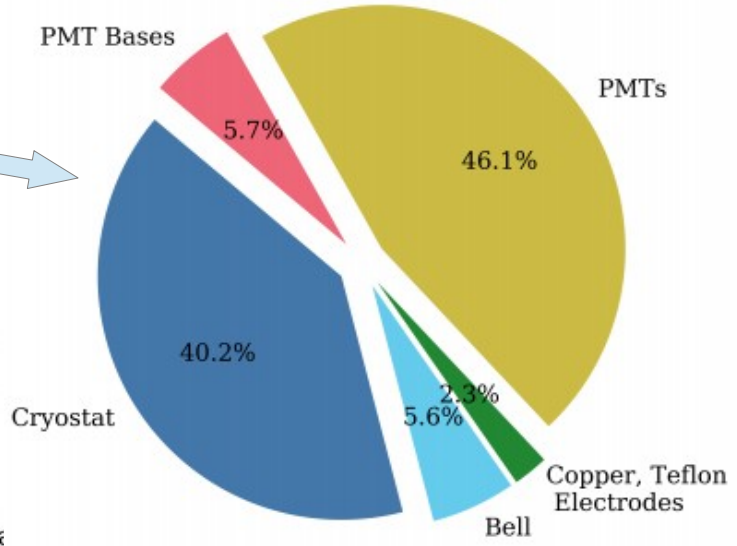
For the 4.4 year stable data taking period the inside had been modified during the refurbishment.

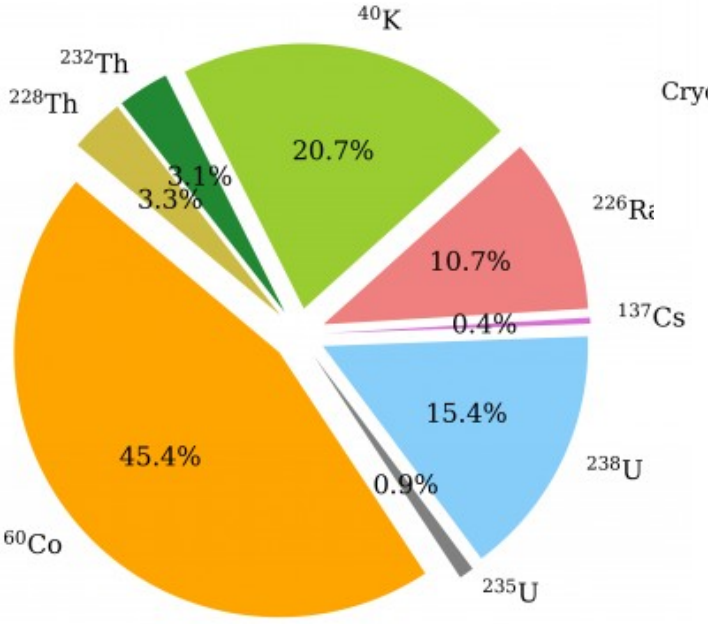
XENONnT Background sources

Electron Recoil background sources:

by hardware

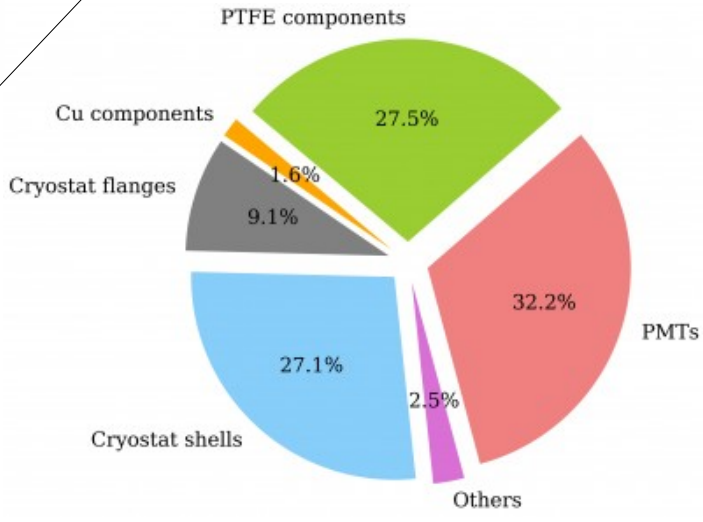
by isotope

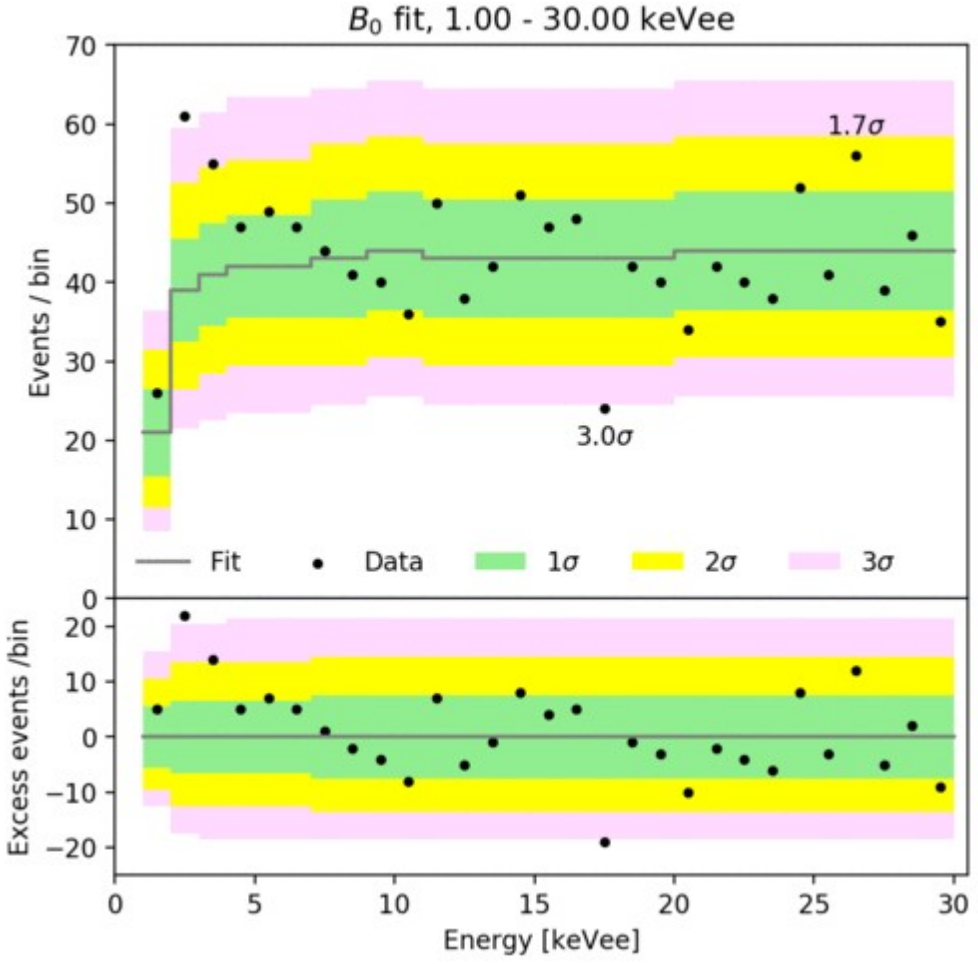




NR BG

(neutron sources):




B_0 fit, 1.00 - 30.00 keVee
Events / bin
Excess events /bin
Energy [keVee]
1.7σ
3.0σ
Fit
Data
1σ
2σ
3σ

XENON