XENON

Xenon Purification for the low background experiment

Masaki Yamashita

Kavli IPMU The University of Tokyo (WPI)

on behalf of the XENON collaboration

地下から解き明かす宇宙の歴史と物質の進化
Unraveling the History of the Universe and Matter Evolution with Underground Physics

科研費 KAKENHI

DMNet

ERAN

2024/2/16

Nagoya Workshop on Technology and Instrumentation in Future Liquid Noble Gas Detectors

Contents

- **Follow up on XENON1T Excess (from purification point of view)**
- **Liquid Phase Purification for XENONnT**

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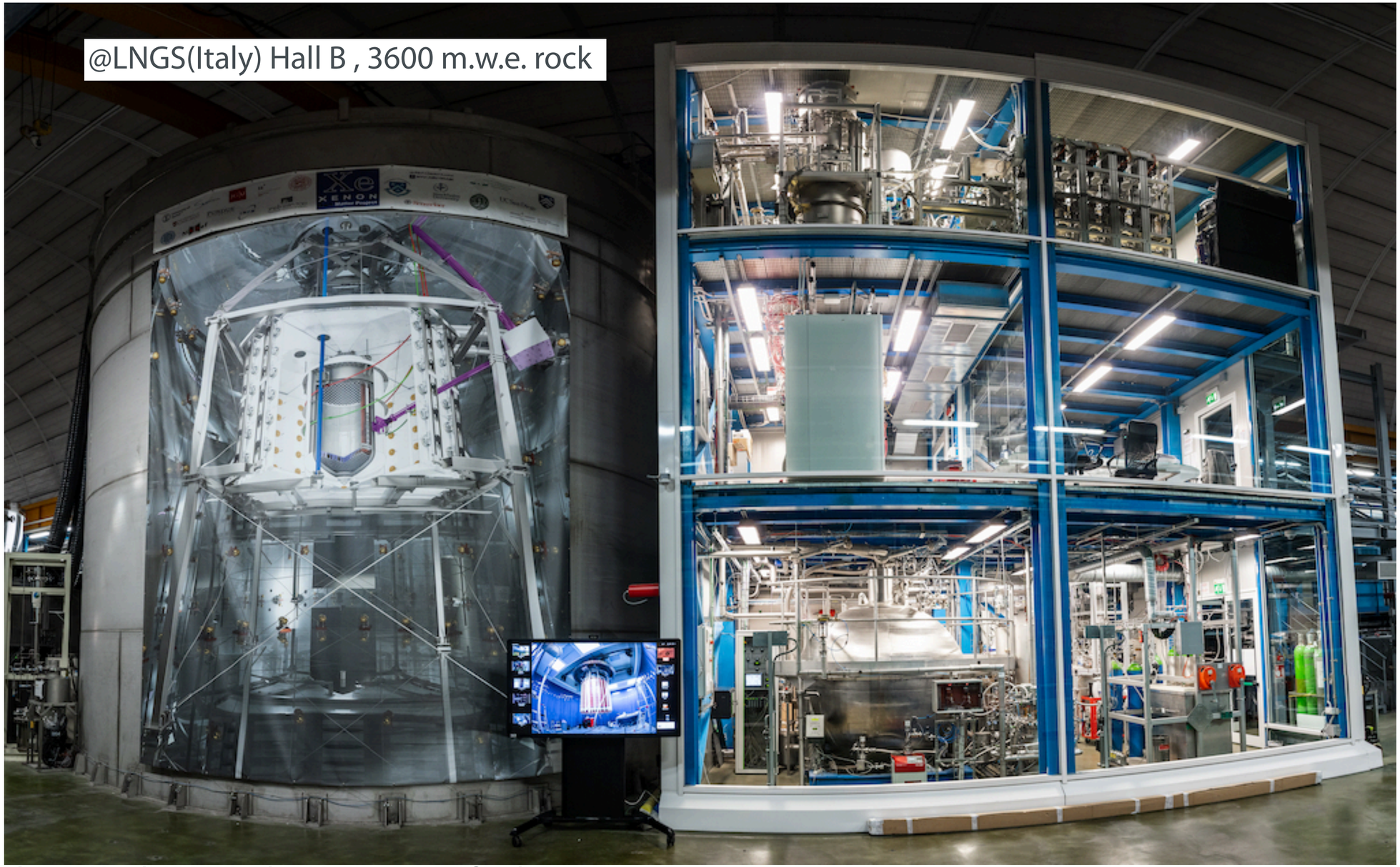
XENON1T Excess follow-up (Tritium background study)

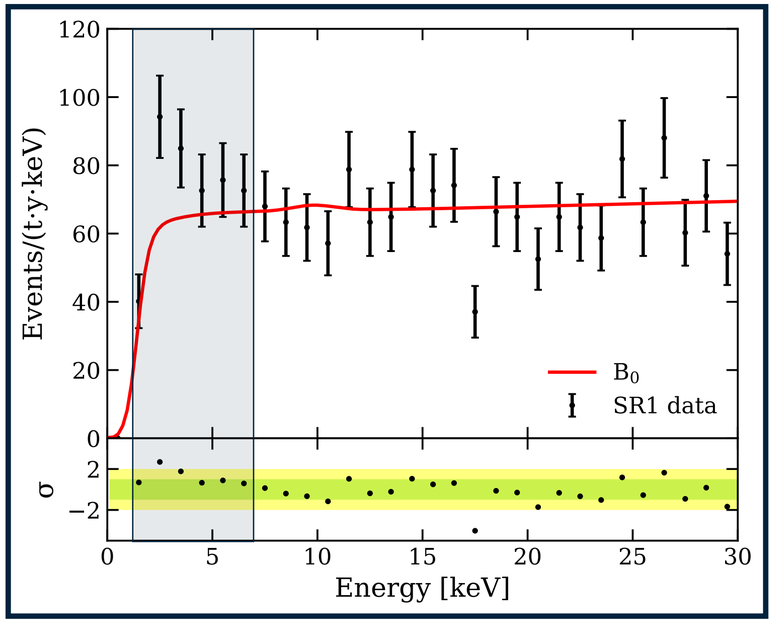
Masaki Yamashita, *Kavli IPMU, The University of Tokyo*

XENONnT (before filling Xe…)

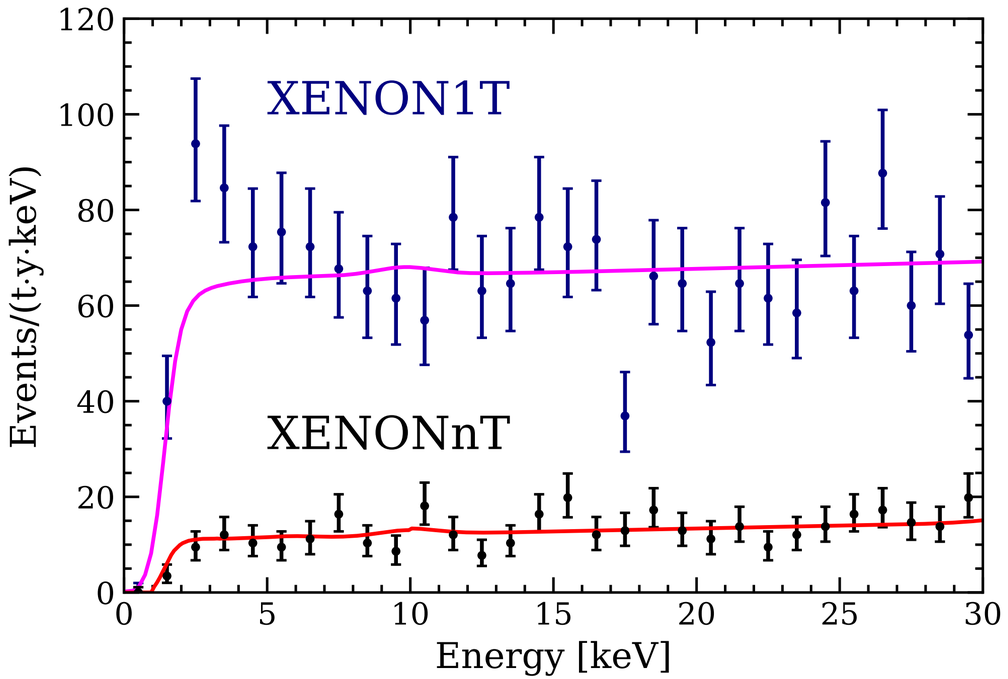


Comments on XENON1T excess

XENON1T excess (2020)



XENONnT excess (2023)



Then, what was it??

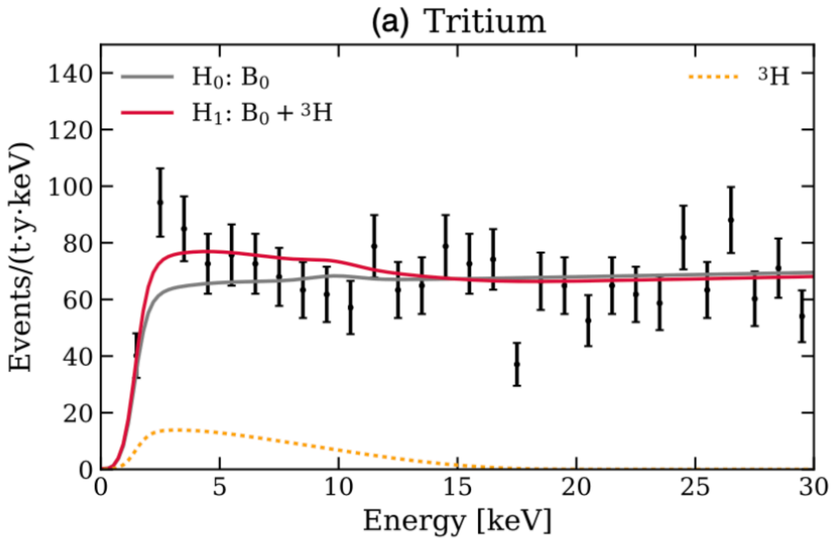
Discussion in XENON1T excess Paper

If all the excess events due to tritium:

Required tritium level: $\sim 10^{-24}\,\mathrm{mol/mol}$

HTO: H2O ratio: $\sim 10^{-17}\,\mathrm{mol/mol}$

*IAEA/WMO, "Global Network of Isotopes in Precipitation. The GNIP Database."
https://nucleus.iaea.1723org/wiser(2015).



Required concentration of H2O or H2 in Xe to explain the excess

~100 ppb

H_2O in XENON1T: O(1) ppb, otherwise can not detect such a light yield

O2 in XENON1T: <1ppb, otherwise can not drift electrons

H2 is also similar level?? (~ppb ??)

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Atmospheric Tritium Concentration

- We contacted tritium experts in Japan.
- Experts: A fusion reactor that uses tritium as a fuel will become a significant source of atmospheric tritium. => monitoring
- HT/H2 ~ HTO/H2O X 10^5 in Japan (US, France)
- **Italy?**

Table 1. Range of average annual values for atmospheric tritium concentrations and specific activities

Species	Concentration, mBq/m^3	Specific activity, TU
HTO	18.7–23.3	14.6–16.7
HT	27.5–48.5	$5.5 \cdot 10^5$–$1.0 \cdot 10^6$
CH_3T	11.6–15.6	$3.2 \cdot 10^4$–$4.5 \cdot 10^4$

Journal of Radioanalytical and Nuclear Chemistry, Vol. 239, No. 3 (1999) 527-531

Atmospheric Tritium Concentration

XENON

With the help of tritium experts, we measured the atmospheric tritium concentration. (Kakiuchi, IES)

Measurement @LNGS in Italy

	period	HTO [TU*]	HT [TU*]
Kamioka Underground	2021/11/30-12/23	2.4+/-0.1	(1.6+/-0.02)x10^5
Kamioka Surface	2022/5/24-6/7	6.7+/-0.1	(1.3+/-0.02)x10^5
LNGS・surface	2022/1/29-2/10	5-10 **	(1.1+/-0.02)x10^5

* 1TU = 10^{-18}

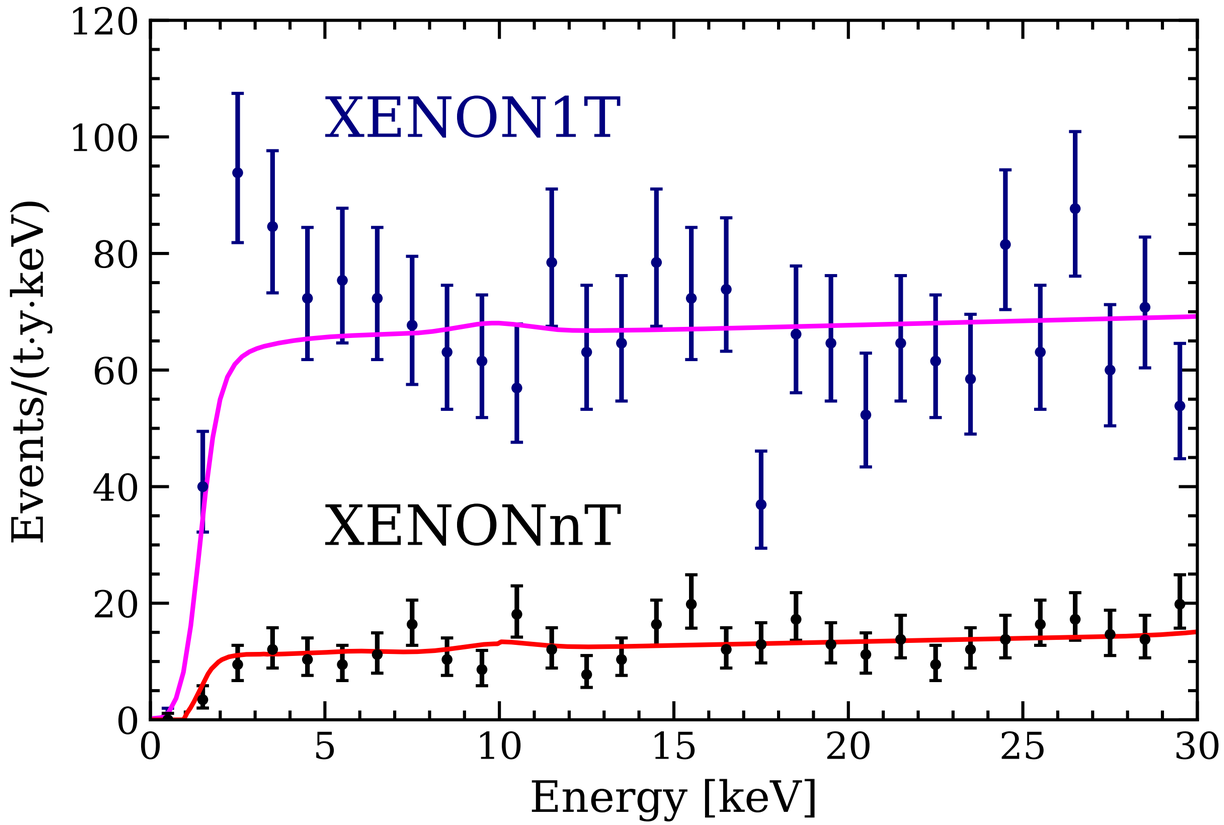
** W. Plastino et al., Radiat. Meas. 42, 68 (2007)

XENON1T excess ~ ppt H2 impurity in LXe
(We are not able to measure ppt H2 impurity in LXe …)
-> future work

@LNGS

Countermeasure at XENONnT

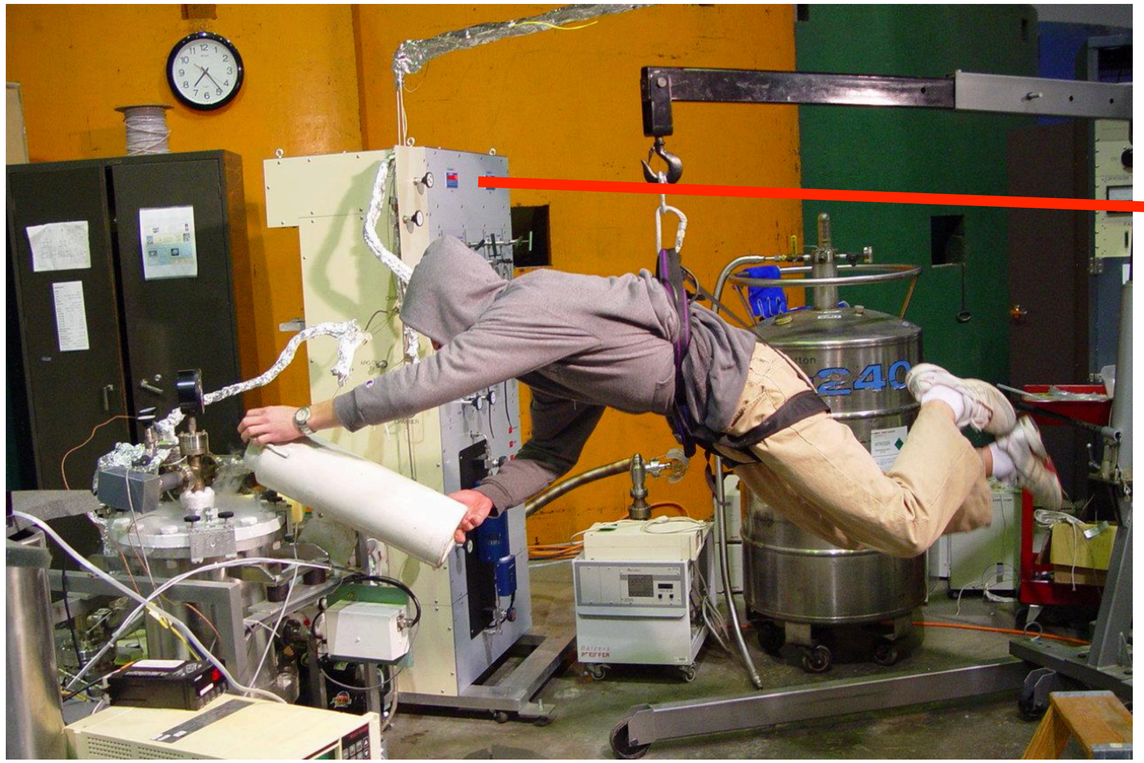
- The TPC was outgassed for a period of about three months before filling the cryostat with GXe.
- Before cooling down and filling, the cryostat and TPC were treated by continuously circulating GXe for ~3 weeks.
- Following these measures, the hydrogen removal units were regenerated before the start of SR0.



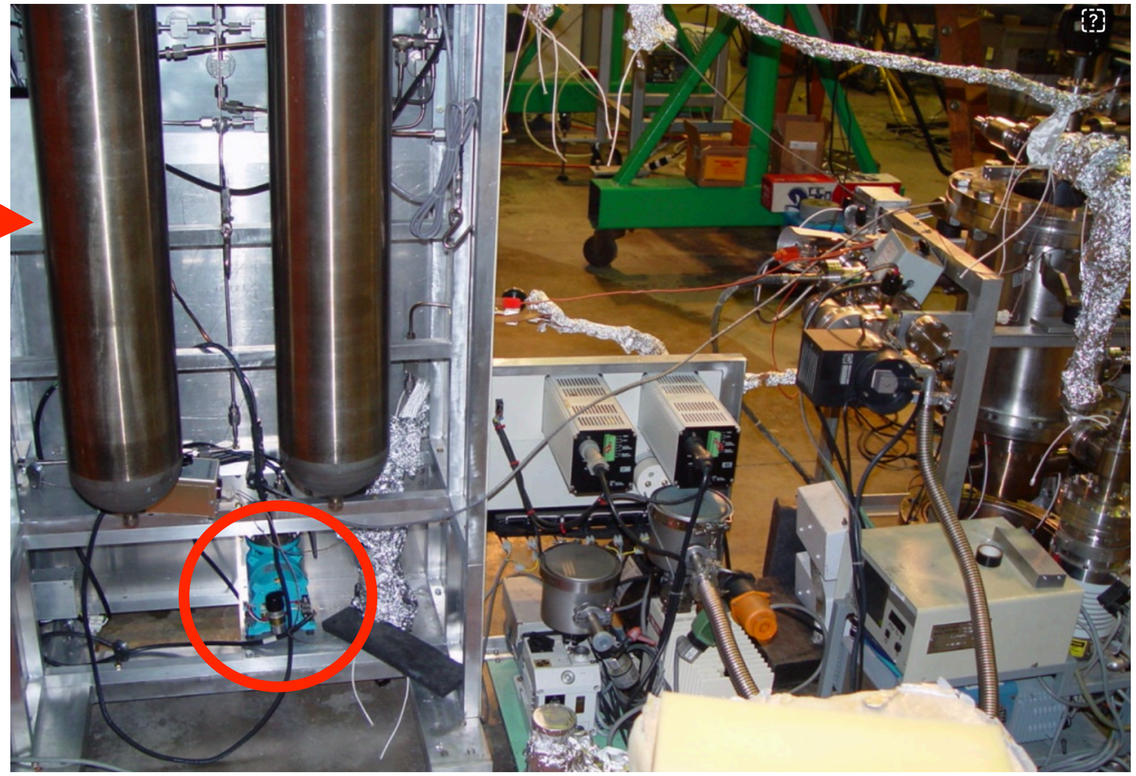
Liquid Phase Purification

Xe gas recirculation

2003



from P. Sorensen talk



small gas circulation pump

GXe Pump

~2003 R&D

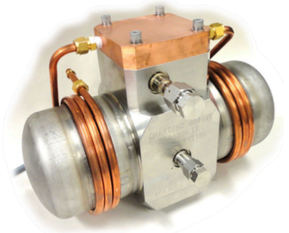
a few SLPM

2007 ~
XENON10& XENON100

2.6 SLPM/ 5 SLPM

2017
XENON1T

QDrive



Magnetic Piston Pump

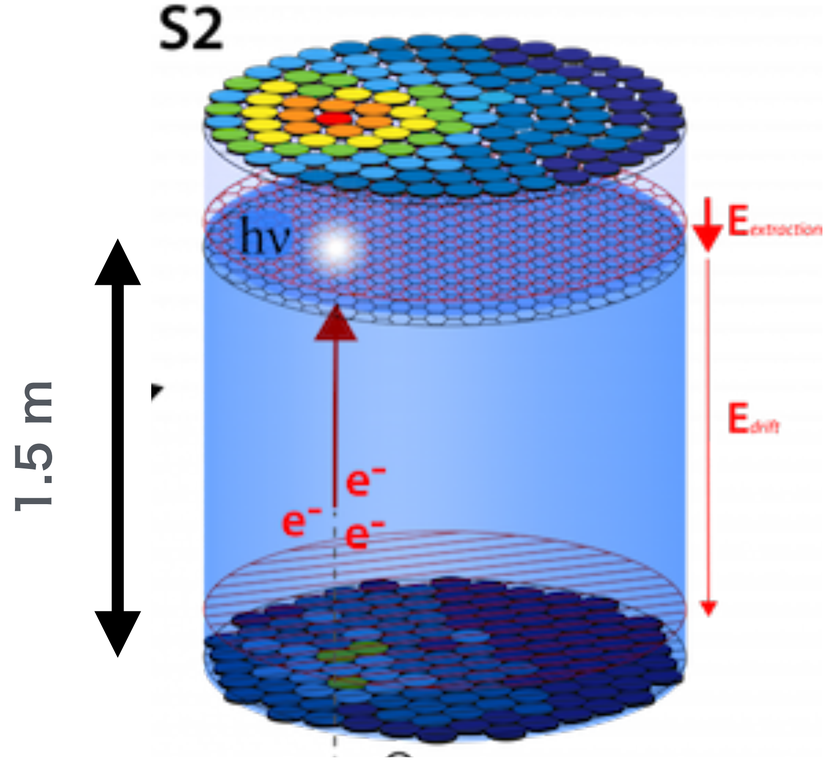
~50/70 SLPM

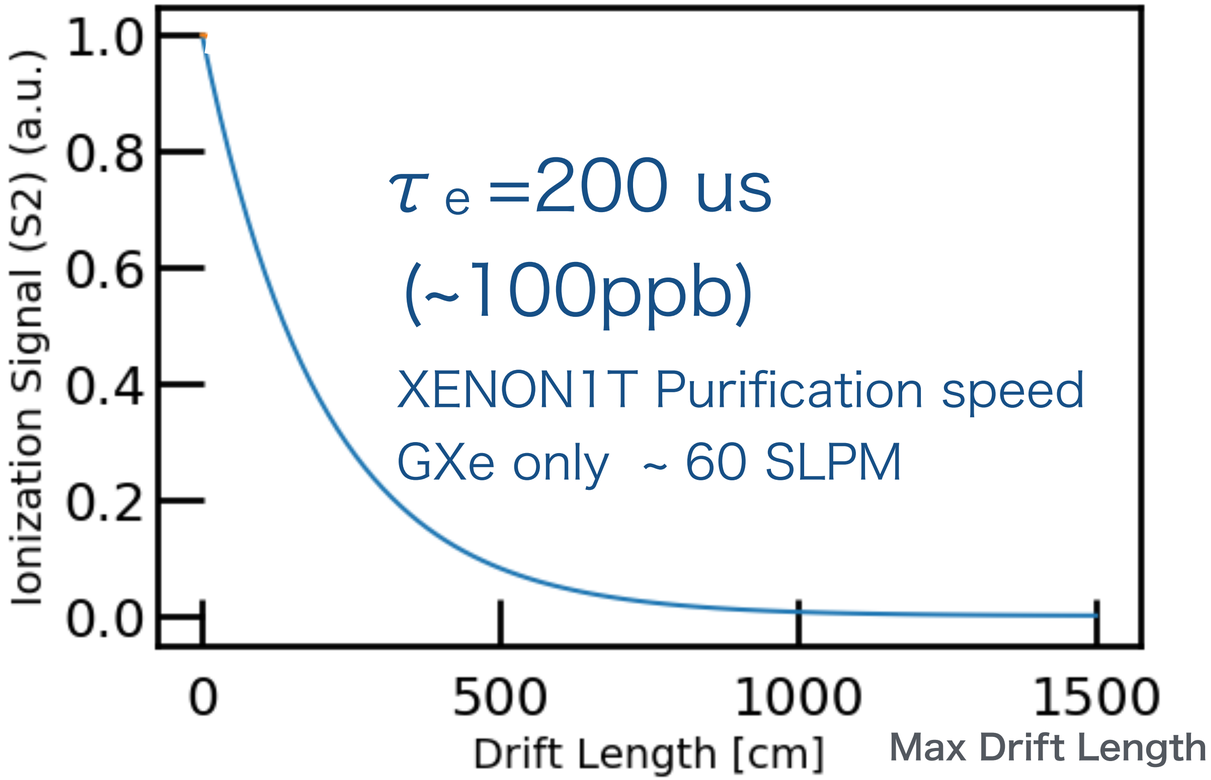
XENONnT?

Eur. Phys. J. C (2018) 78:604

What level of Electron lifetime is required?

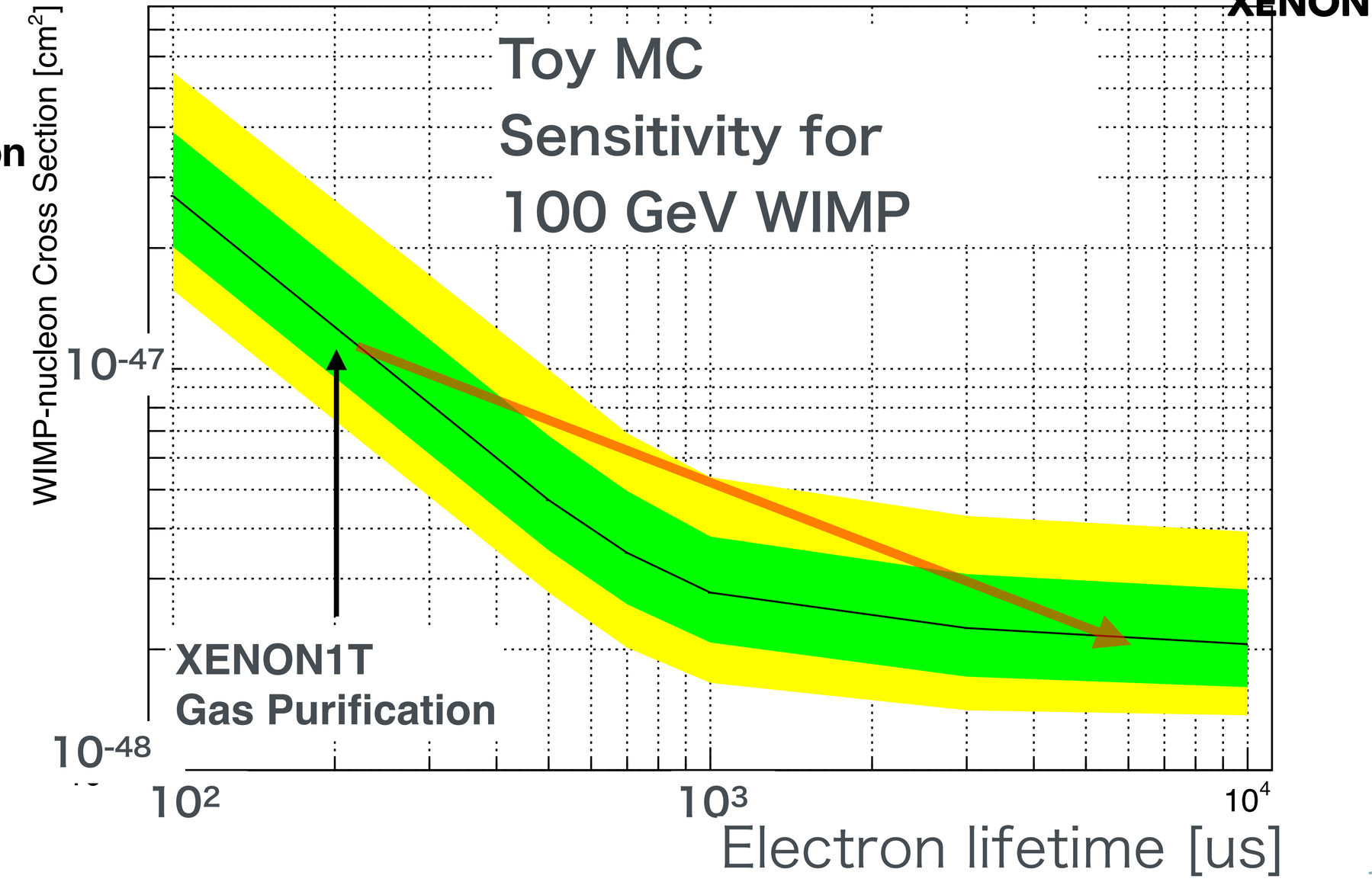
- The ionization signal (S2) depends on the impurity in LXe.
  - Elenctronegavie impurities such as O2 capture an electron.
  - Better e-life is better, but how much do we need? The science cases should drive it.



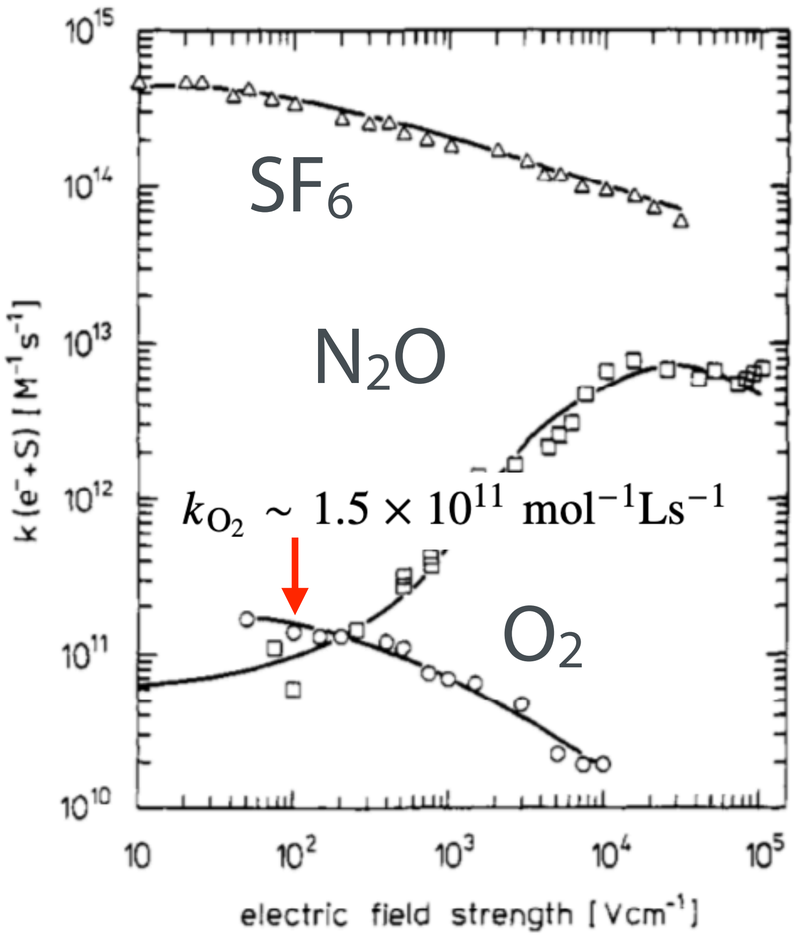


What level of Electron lifetime is required?

- **WIMP Sensitivity depends on**
  - S2 efficiency
  - Energy resolution
- **WIMP mass dependent**
- **S2-only search will impact more**



Electron Lifetime in LXe



George Bakale, et al. The Journal of Physical Chemistry, 80(23):2556–2559, 1976.

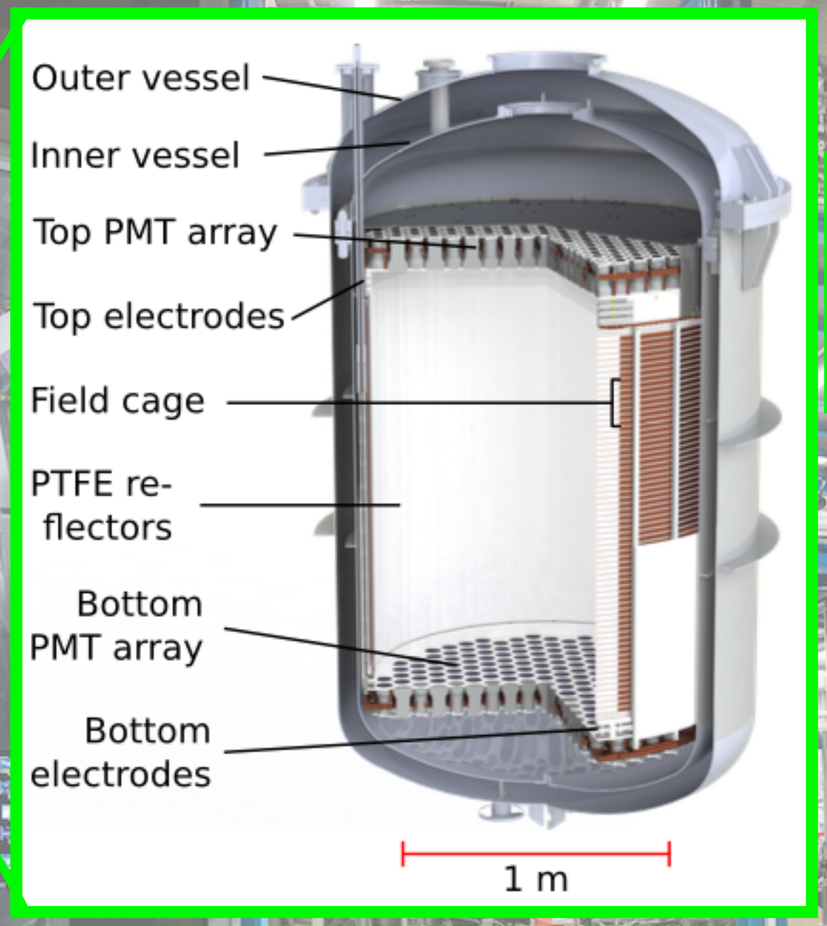
- The ionization signal (S2) depends on the impurity in LXe.
  - Elenctronegavie impurities such as **O_2** capture an electron.

$$\tau_e = \frac{1}{1[\mathrm{ppt}] \cdot n_{\mathrm{Xe}} k_{O_2}} = \frac{131[\mathrm{g \cdot mol^{-1}}]}{10^{-12} \cdot 2.86[\mathrm{g \cdot cm^{-3}}] \cdot 1.5 \times 10^{11}[\mathrm{mol^{-1} \cdot L \cdot s^{-1}}]} \sim 3[\mathrm{ms}]$$

- kO_2 : the rate constant for electron attachment to O_2 impurities
- n_{Xe} : number density of Xe
- O_2 impurity -> 1 ppt

XENONnT: Time Projection Chamber

@LNGS(Italy) Hall B , 3600 m.w.e. rock



- 1.3 m (⌀) × 1.5 m
- 8.5 t LXe in cryostat (2.5x XENON1T)
  - 5.9 t LXe active (3x XENON1T)
  - 494 (3’’) PMTs (2x XENON1T)

What level of Electron lifetime is required?

- The ionization signal (S2) depends on the impurity in LXe.
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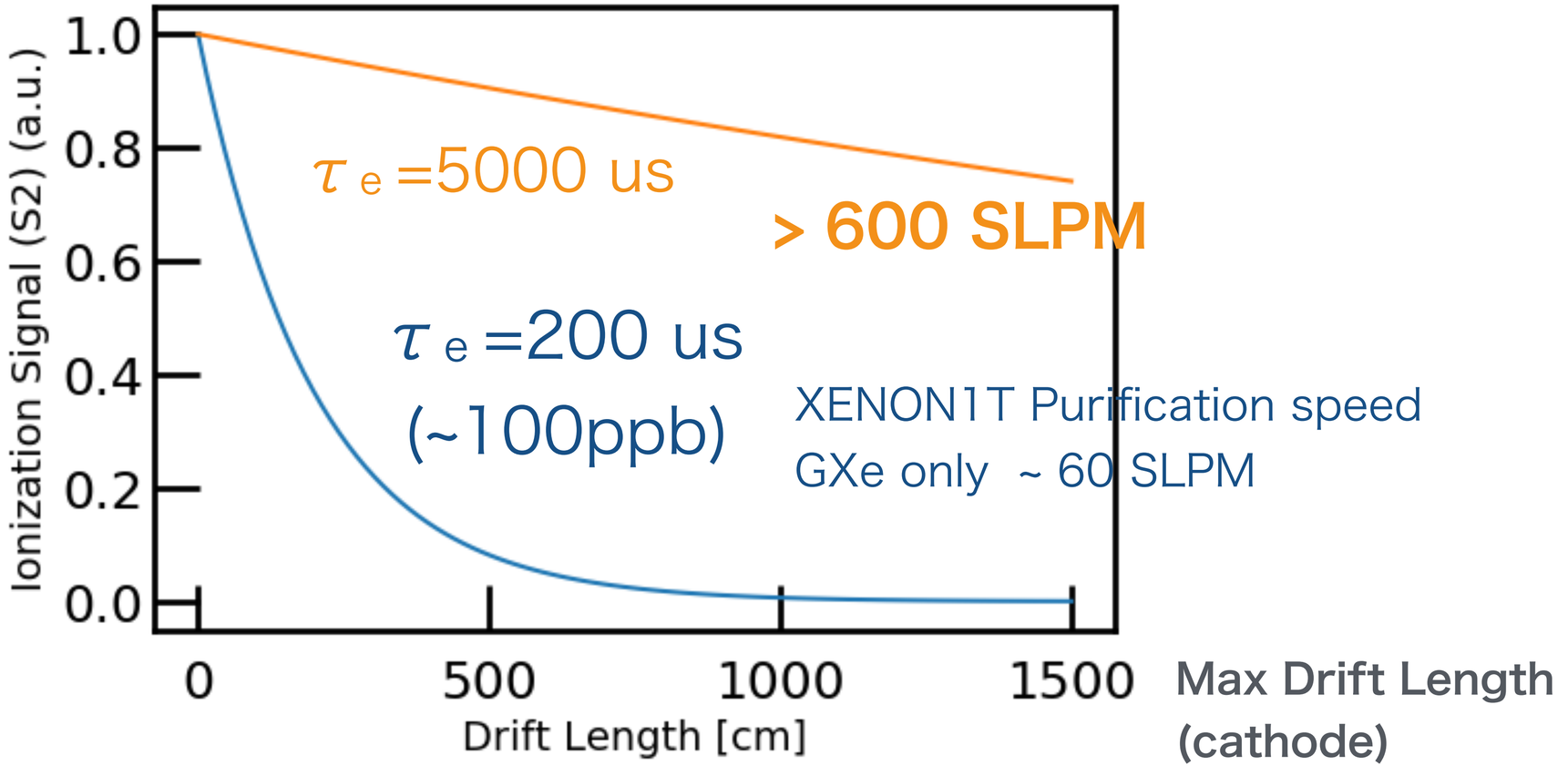
- **Better e-life is better, but how much do we need?** The science cases should drive it.



Challenges

- **A big amount of Xe**
  - Total 8.6 tonne = TPC (8.5t) + others (0.1t), > 600 SLPM recirculation speed
- **A big-size TPC**
  - 1.5 m drift length
- **Ultra-low background**
  - Goal: ^{222}Rn: 1 uBq/kg

=> Liquid Phase Purification

Liquid Phase Purification

MEG: LXe calorimeter 100L prototype (2006)

S. Mihara et al. / Cryogenics 46 (2006) 688–693

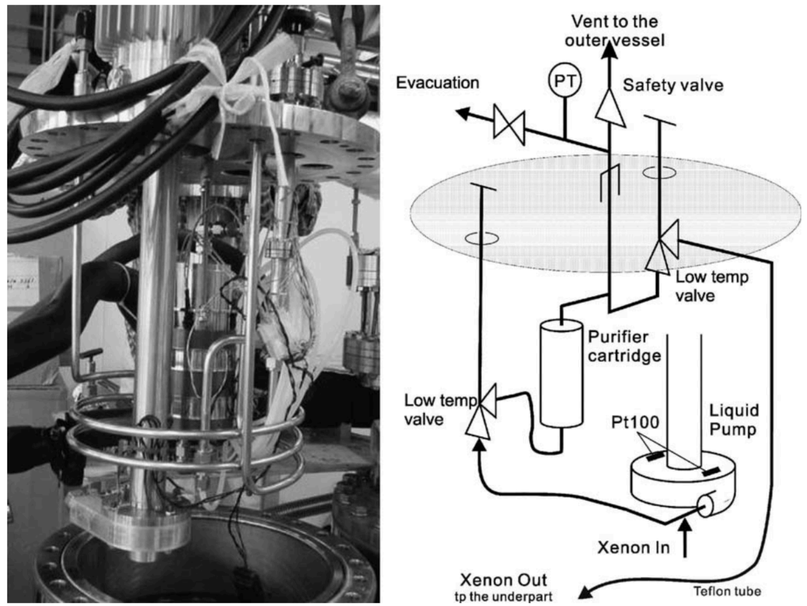
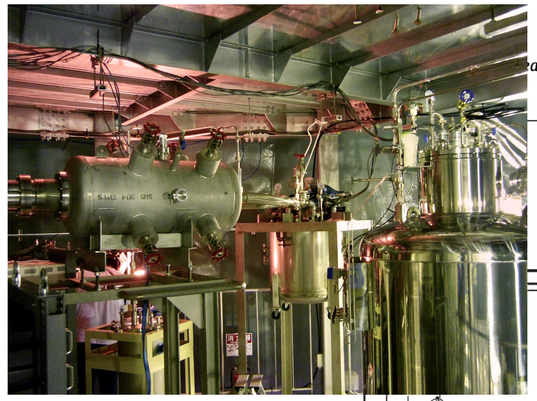
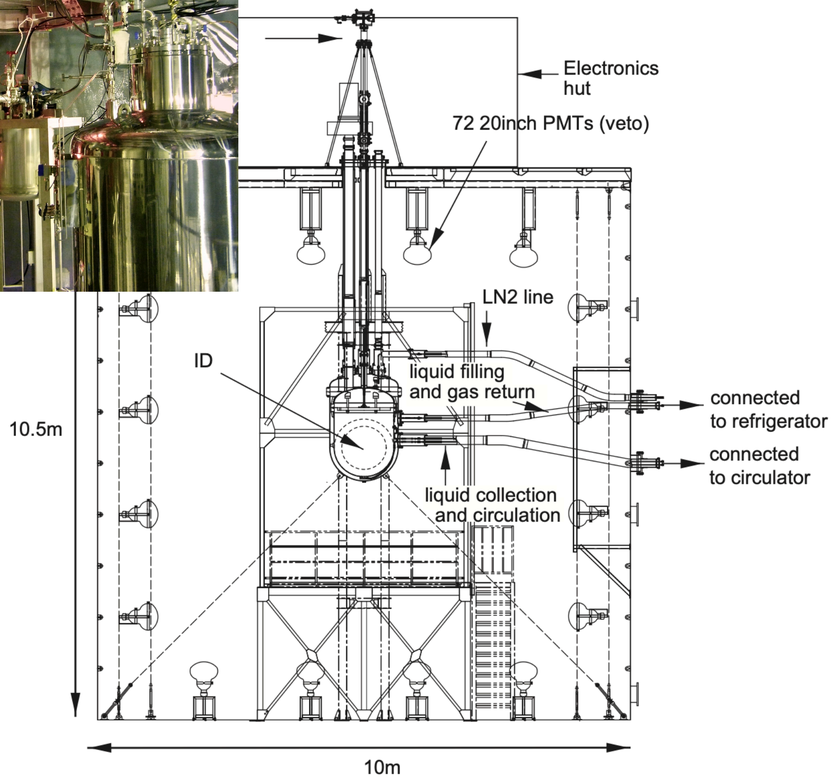


Fig. 3. Purification system to be inserted to the prototype detector (left). Schematic diagram of the purification system (right).

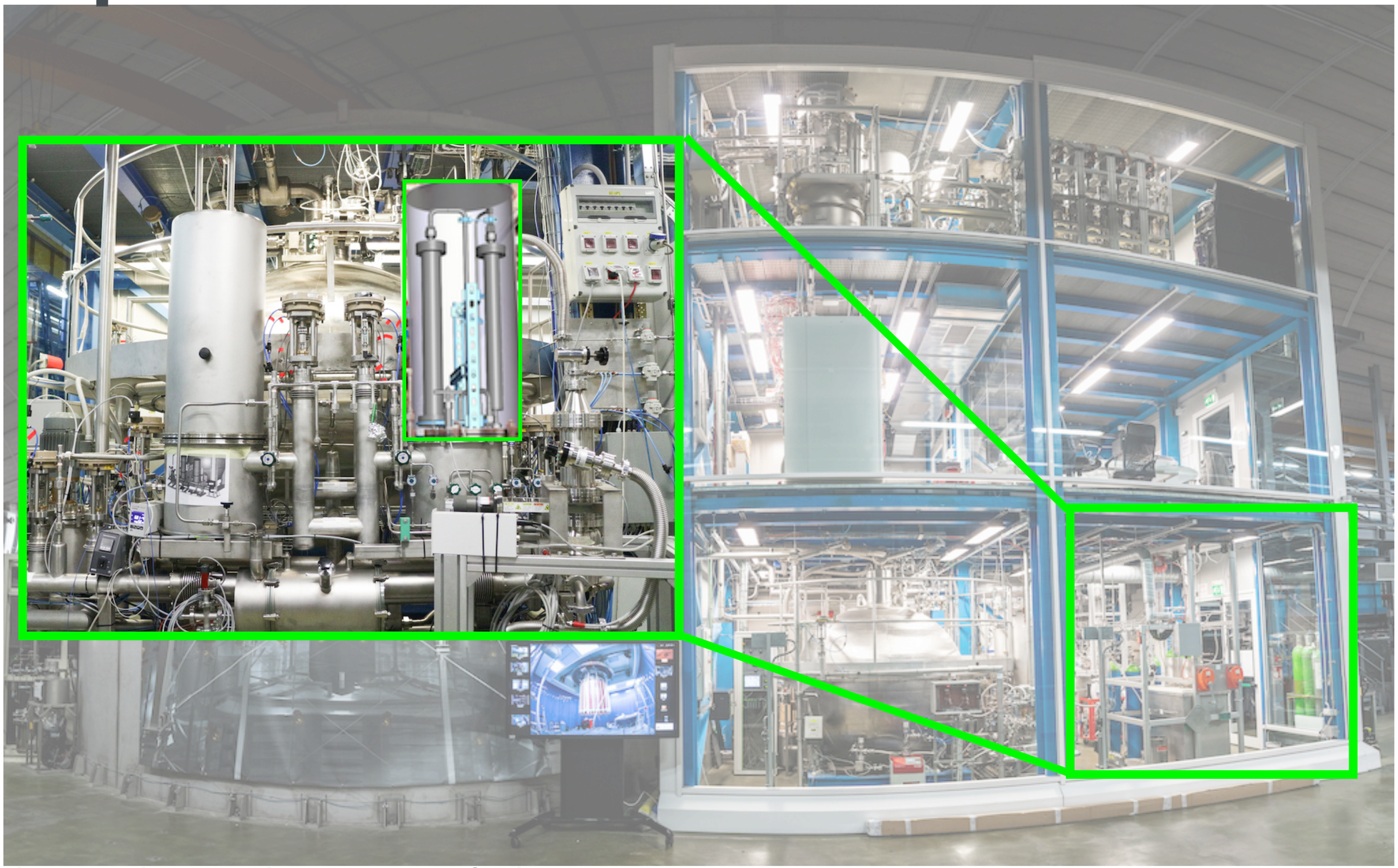
XMASS: 800kg Single Phase LXe for DM (2013)



ar Instruments and Methods in Physics Research A 716 (2013) 78–85

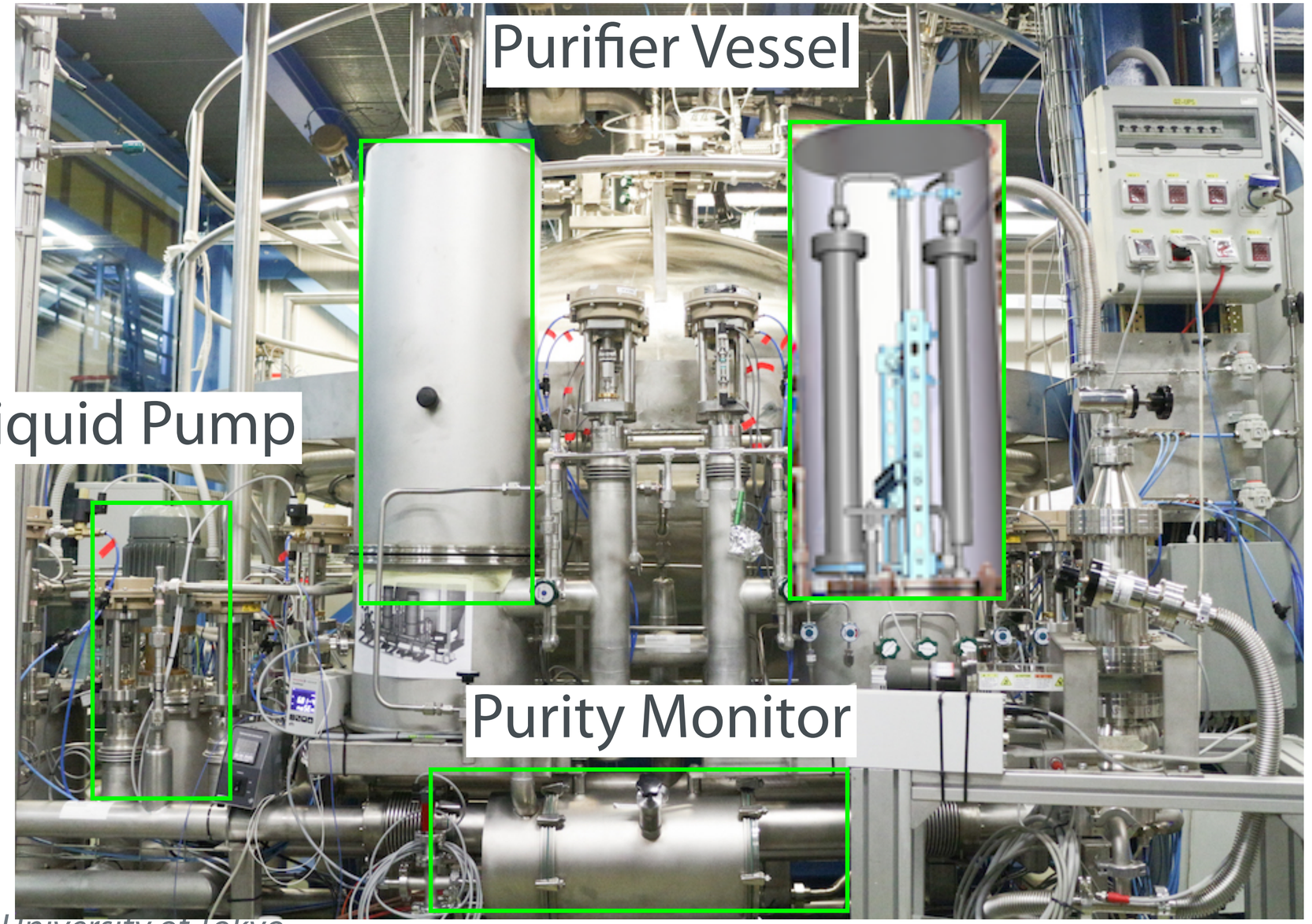


Liquid Phase Purification

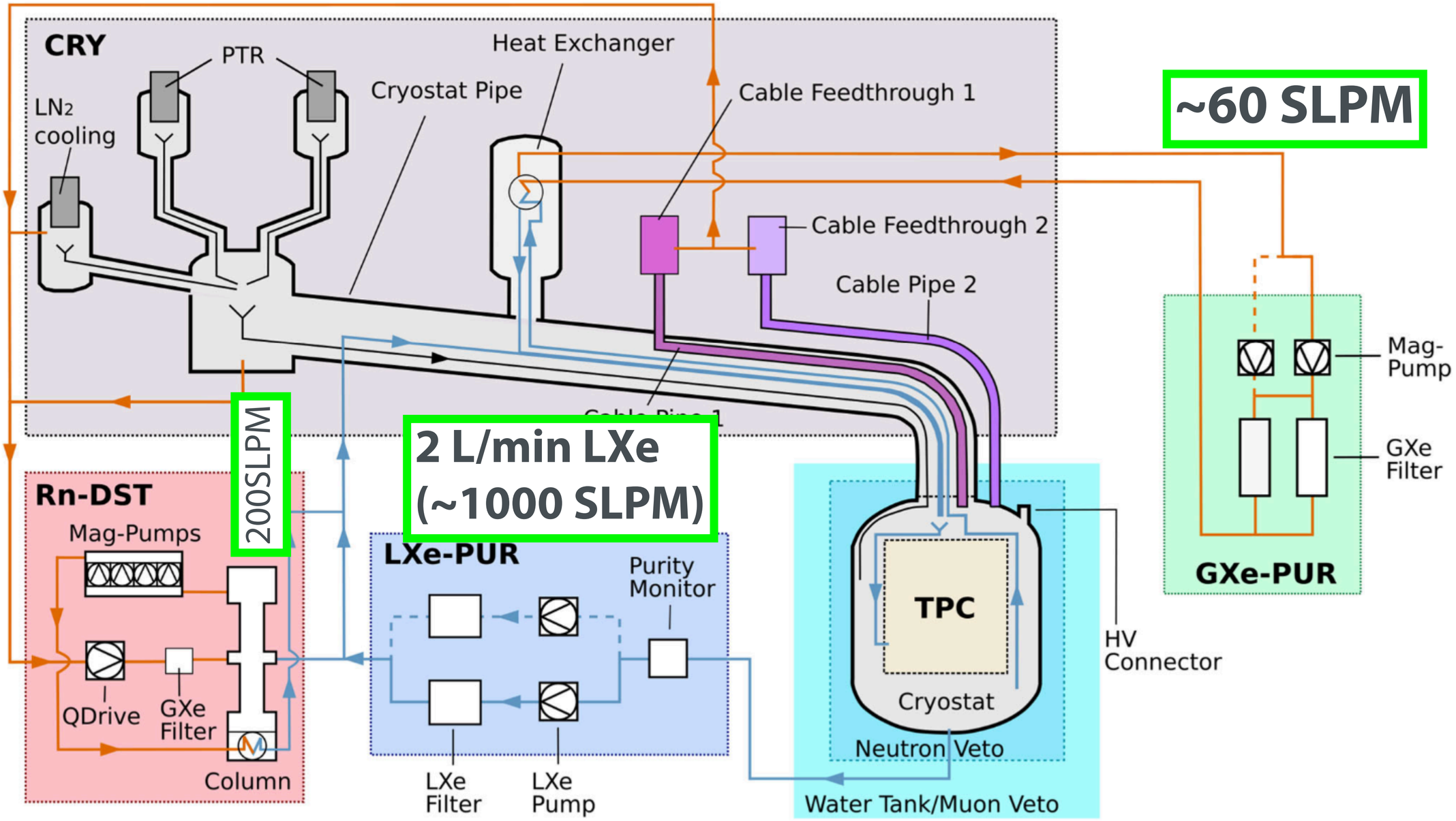


XENONnT: LXePUR system

- LXe pump ~ 2 L/min
  - => 1000 SLPM
  - ~1 day to recirculate entire inventory
- Two redundant cryogenic liquid pumps
- Two redundant LXe purifiers
- The drift chamber (purity monitor) continuously monitors the electron lifetime with an Xe flash lamp.



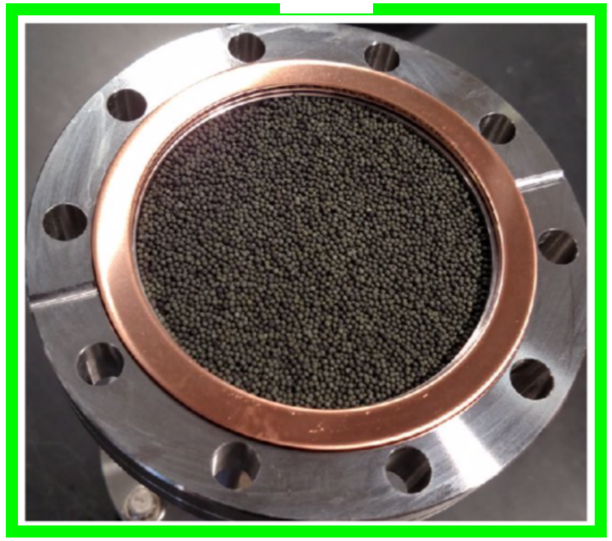
LXePUR


CRY
PTR
Heat Exchanger
LN2 cooling
Cryostat Pipe
Cable Feedthrough 1
Cable Feedthrough 2
Cable Pipe 2
~60 SLPM
Mag-Pump
GXe Filter
GXe-PUR
200SLPM
2 L/min LXe
(~1000 SLPM)
Rn-DST
Mag-Pumps
QDrive
GXe Filter
Column
LXe-PUR
Purity Monitor
LXe Filter
LXe Pump
TPC
Cryostat
HV Connector
Neutron Veto
Water Tank/Muon Veto

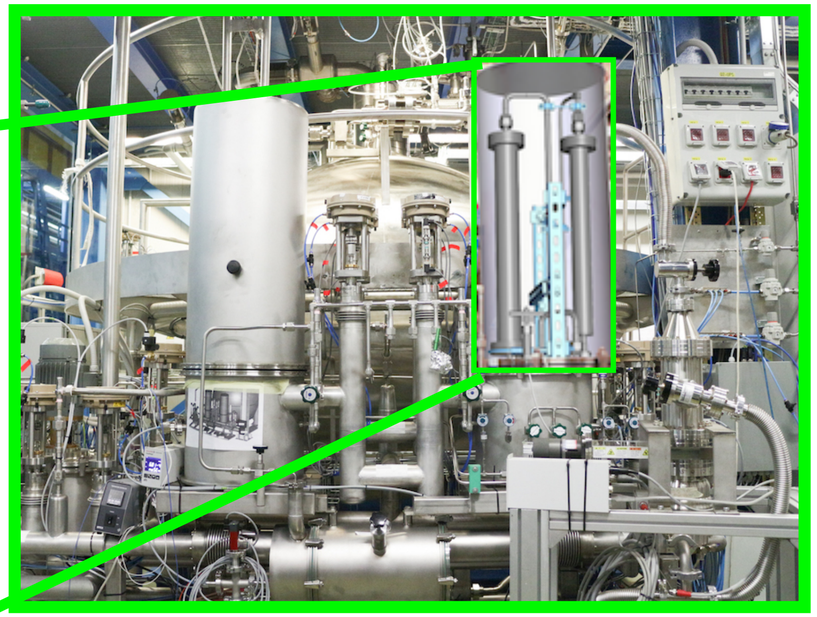
Purifier

XENON

Q5



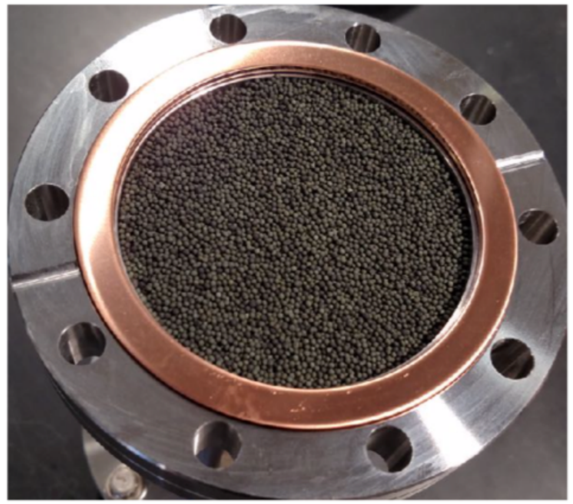
St707



- Molecular sieves works in Liquid (i.e. MEG) but it is quite radioactive.
- Q5 (copper coated alumina) was used in LAr (NIMA(2009) 606).
- We employed two suitable sorbent materials, Q5 and St707 for XENONnT Purification.

Purifier

Q5



- Copper coated alumina
- Rn: ~50 mBq/kg
- 475 g/unit (23 mBq/unit)

$$2Cu + O_2 \rightarrow 2CuO$$

regeneration

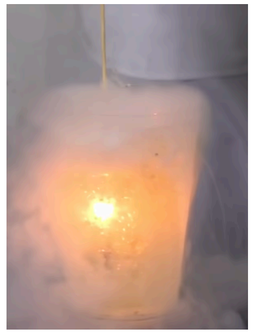
$$CuO + H_2 \rightarrow Cu + H_2O$$

St707

- St707 usually used at 400°C

- Zr-V-Fe alloy (so-called SAES getter)
- 3kg/unit (0.24 mBq/unit)
- The impurities contact the surface, are captured, and chemisorbed onto the getter.

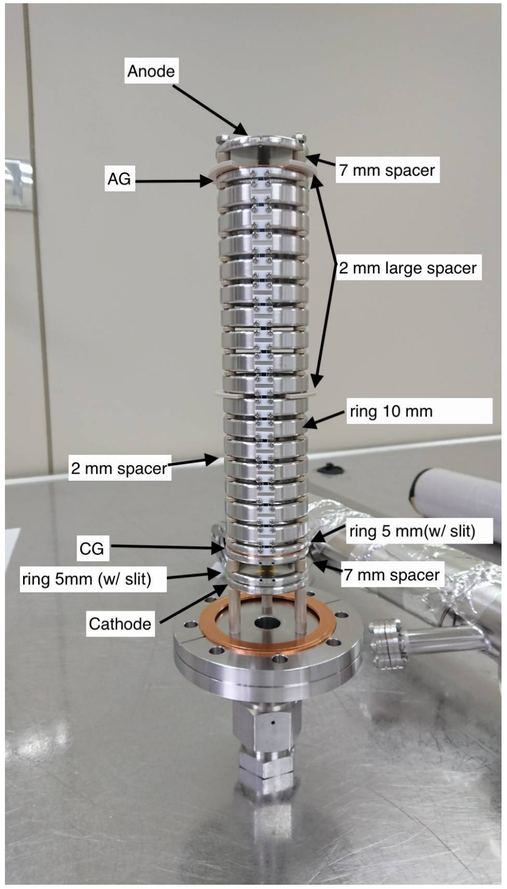
regeneration heat up to ~400 °C



A firework in LN2

Purity Monitor

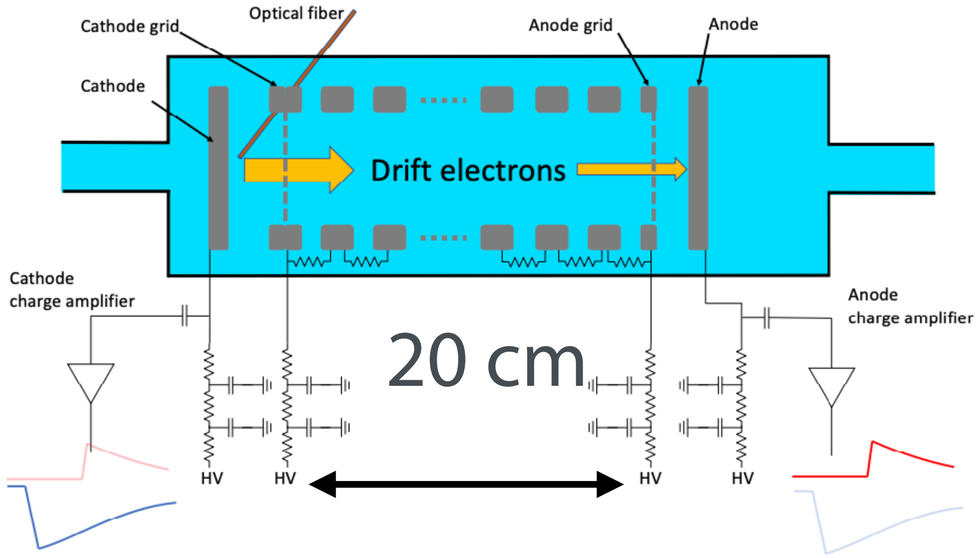
grid

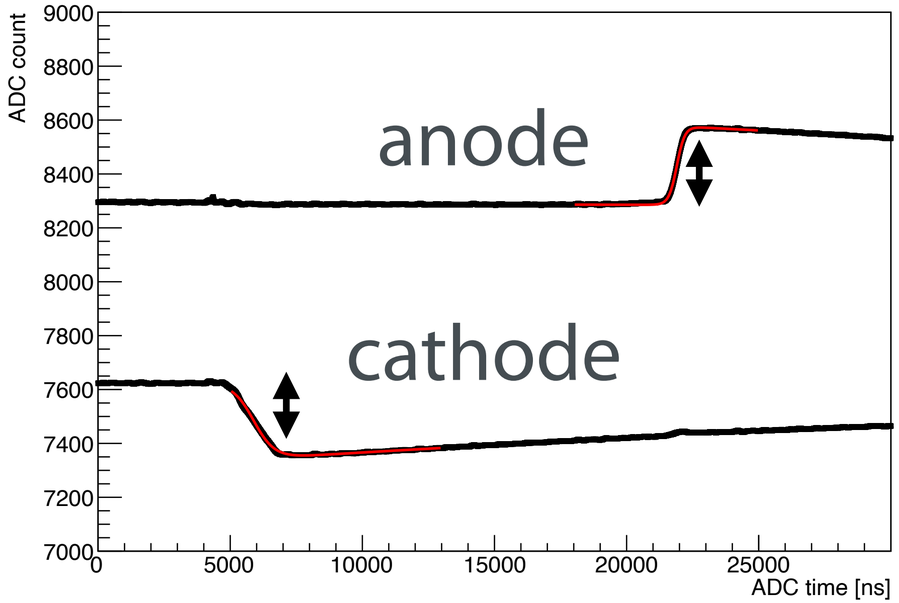


- 20 cm drift length
- Gold coated cathode
- UV light injection by the Xe excimer lamp through optical fiber
- a few us to 30 msec
- ~ 15 interval monitoring

Purity Monitor

XENON





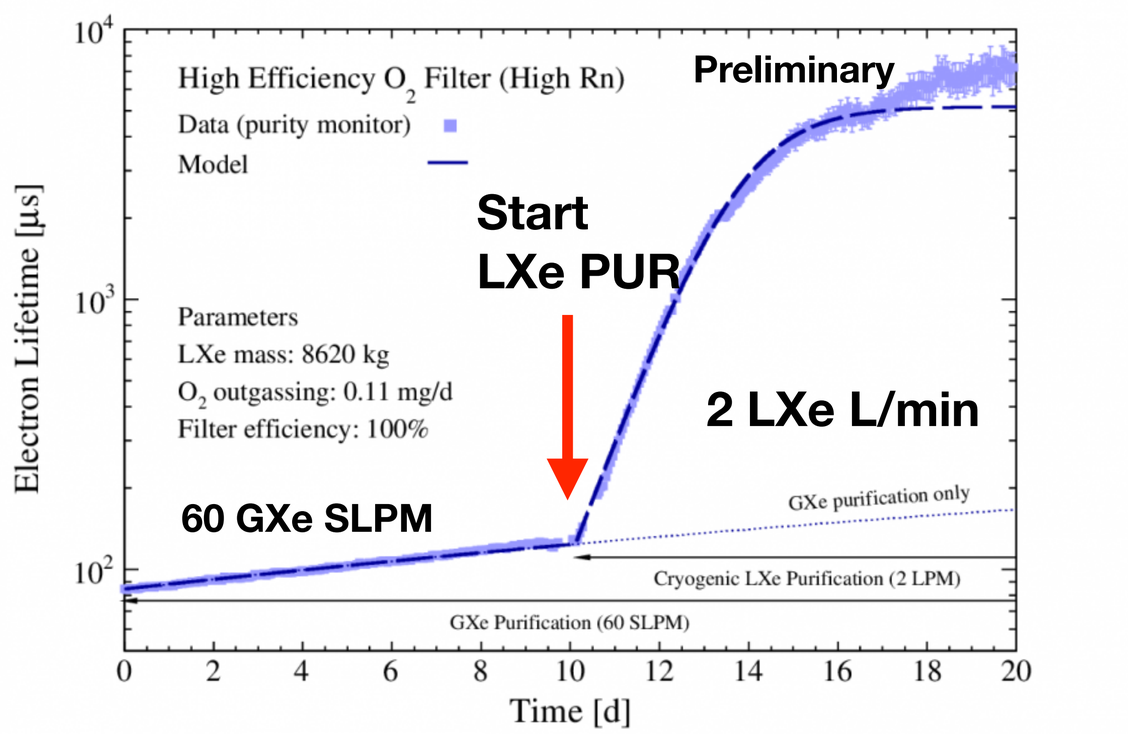
$$\frac{Q_A}{Q_C} \sim e^{-\frac{(\frac{1}{\cdot}\ t_d\ )}{\tau_e}}$$

$$\tau_e = -\frac{t_d}{\ln\left(Q_A/Q_C\right)}$$

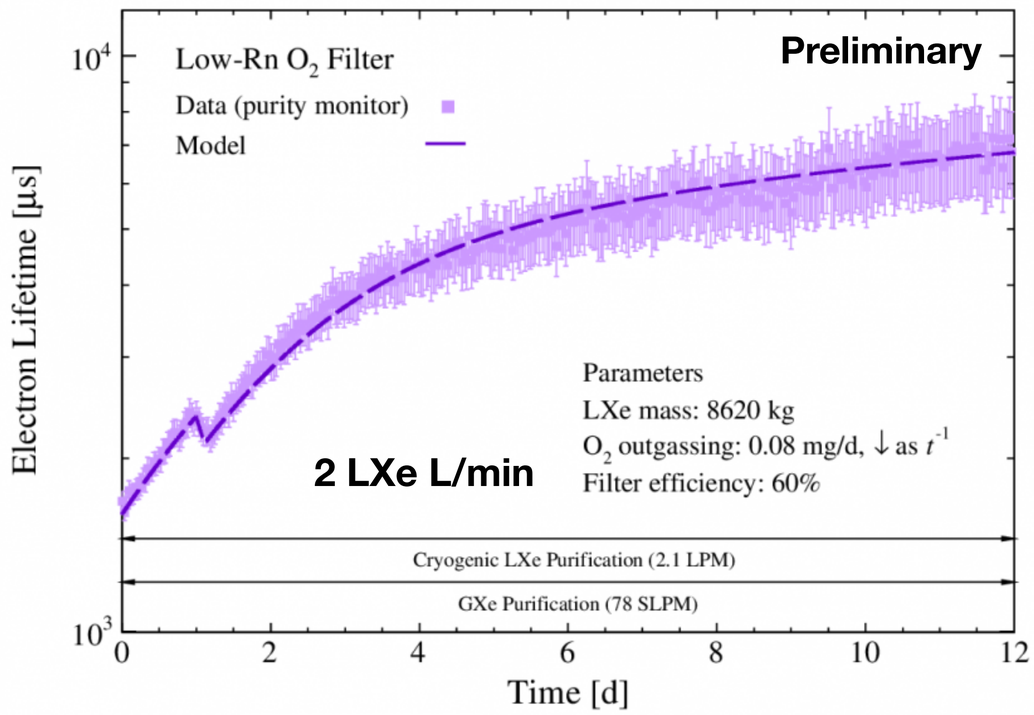
LXe Purification Results: Commissioning phase

XENON

Q5

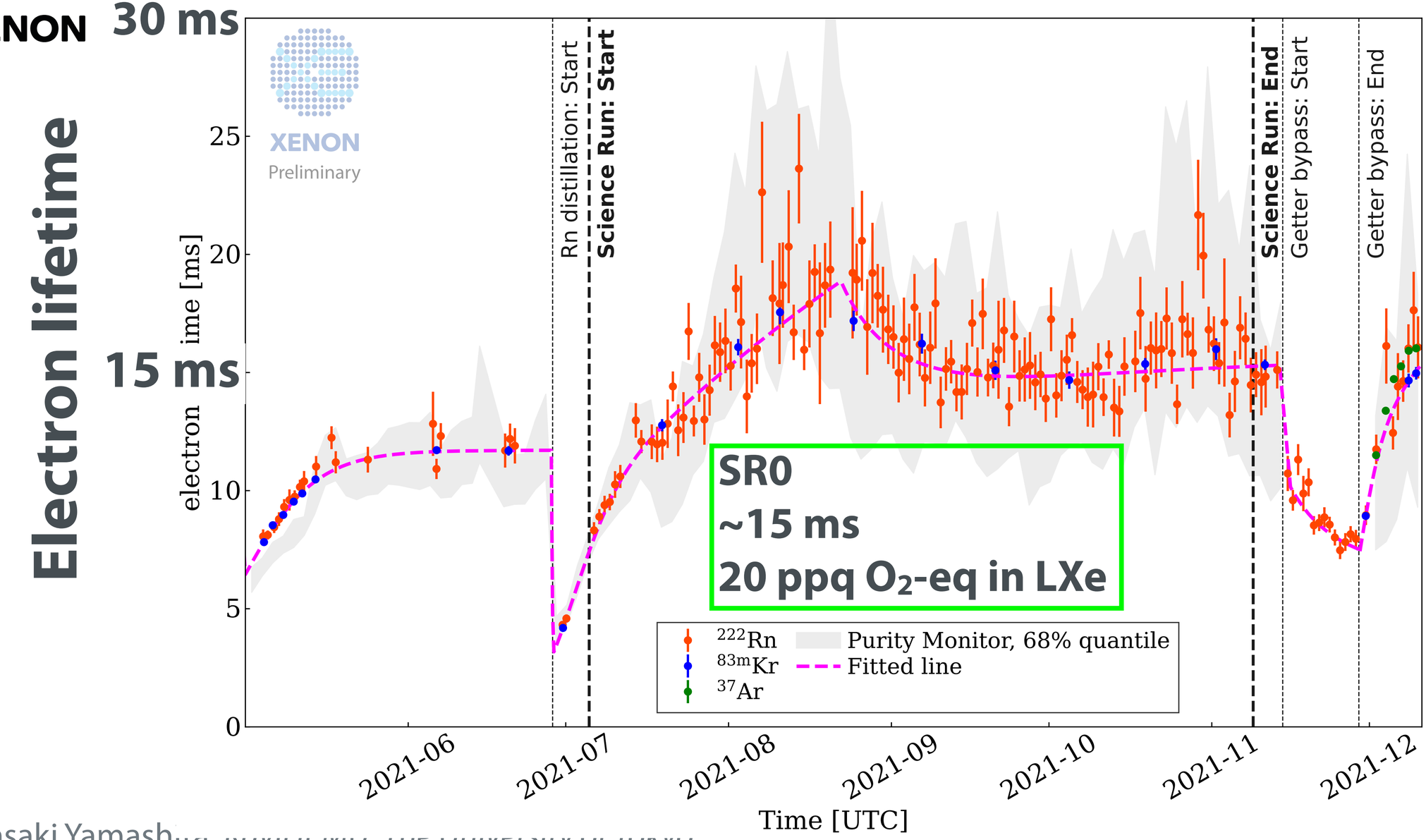


St707



- Q5: 5ms electron lifetime in 5 days, ε ~ 100% => for initial stager
- St707: > 10ms after one month, ε ~ 60% => For science run
- Outgas rate: ~ 0.1mg/d (O_2 equivalent)

Electron lifetime during Science Run



Purity Monitor

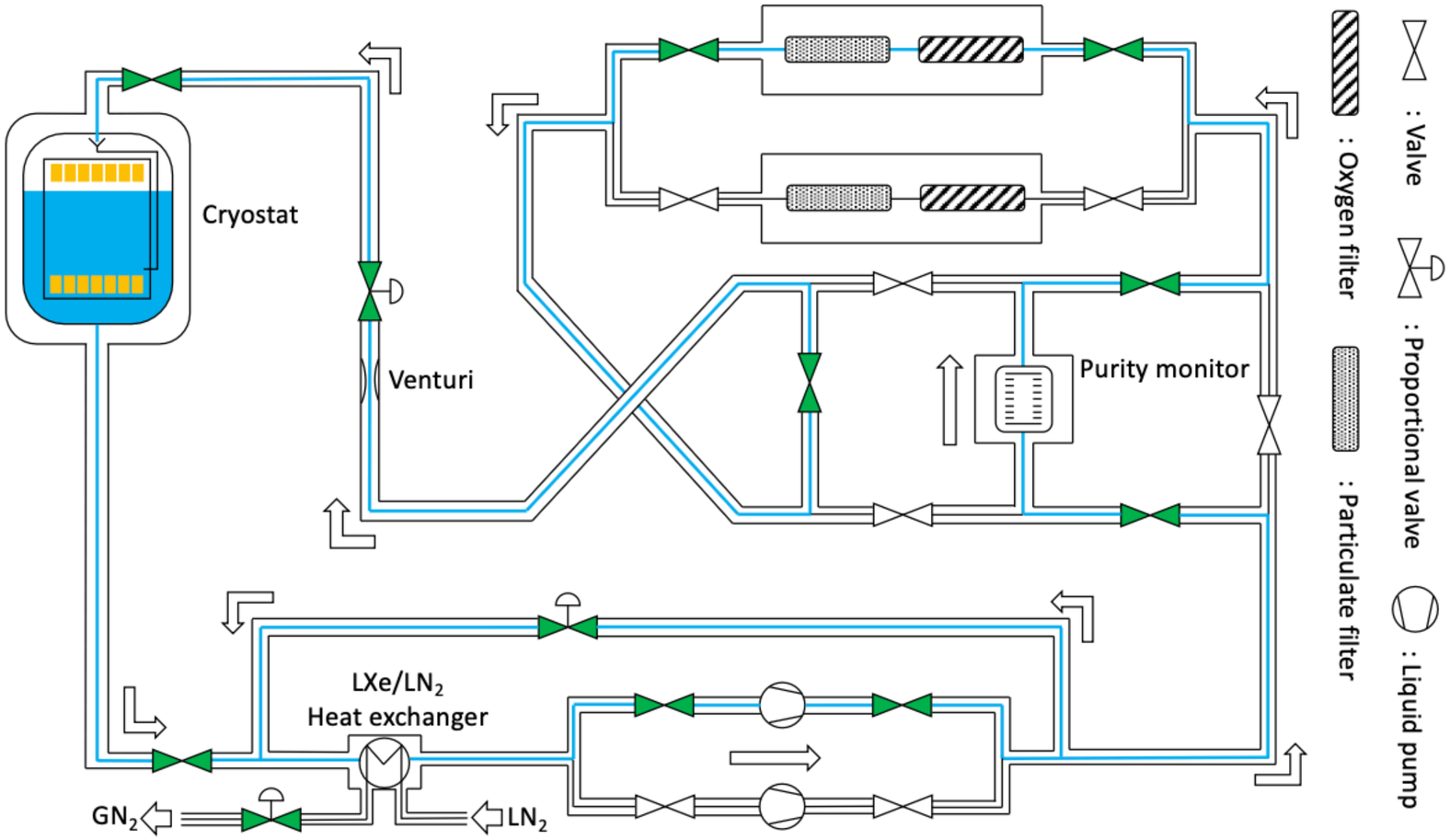
^{83m}Kr

^{222}Rn

Summary

- We have measured the atmospheric tritium concentration in Japan and in Italy.
  - HT/H_2 is ~ 10^5 higher than HTO/H_2O.
  - We should pay attention for a future experiment such as DARWIN/XLZD.
- Liquid Phase purification has been successfully performed in XENONnT.
  - low radioactive sorbent material in LXe
  - 15 ms electron lifetime
  - St707 has been operated for more than one year.

XENON


Cryostat
Venturi
Purity monitor
LXe/LN2
Heat exchanger
GN2
LN2
: Valve
: Proportional valve
: Liquid pump
: Oxygen filter
: Particulate filter