Large Scale Xenon Storage

Workshop on Xenon Detector 0νββ Searches: Steps Towards the Kilotonne Scale

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Storage approaches

- Usually expressed as the last thing to think about
- “Easy since we have efficient bottles”
- nat-Xenon or enr-Xenon is similar
- No Loss

- Standard bottles are not meant to cryopump LXe with LN2
- 300 t of LXe = 6 000 x (50 kg bottles) !
  - 6,000 connexions !
  - 750 m^2 with 8 bottles / m^2

For comparison:
SNOLAB : 3,000m2
LNGS : 18,000m2

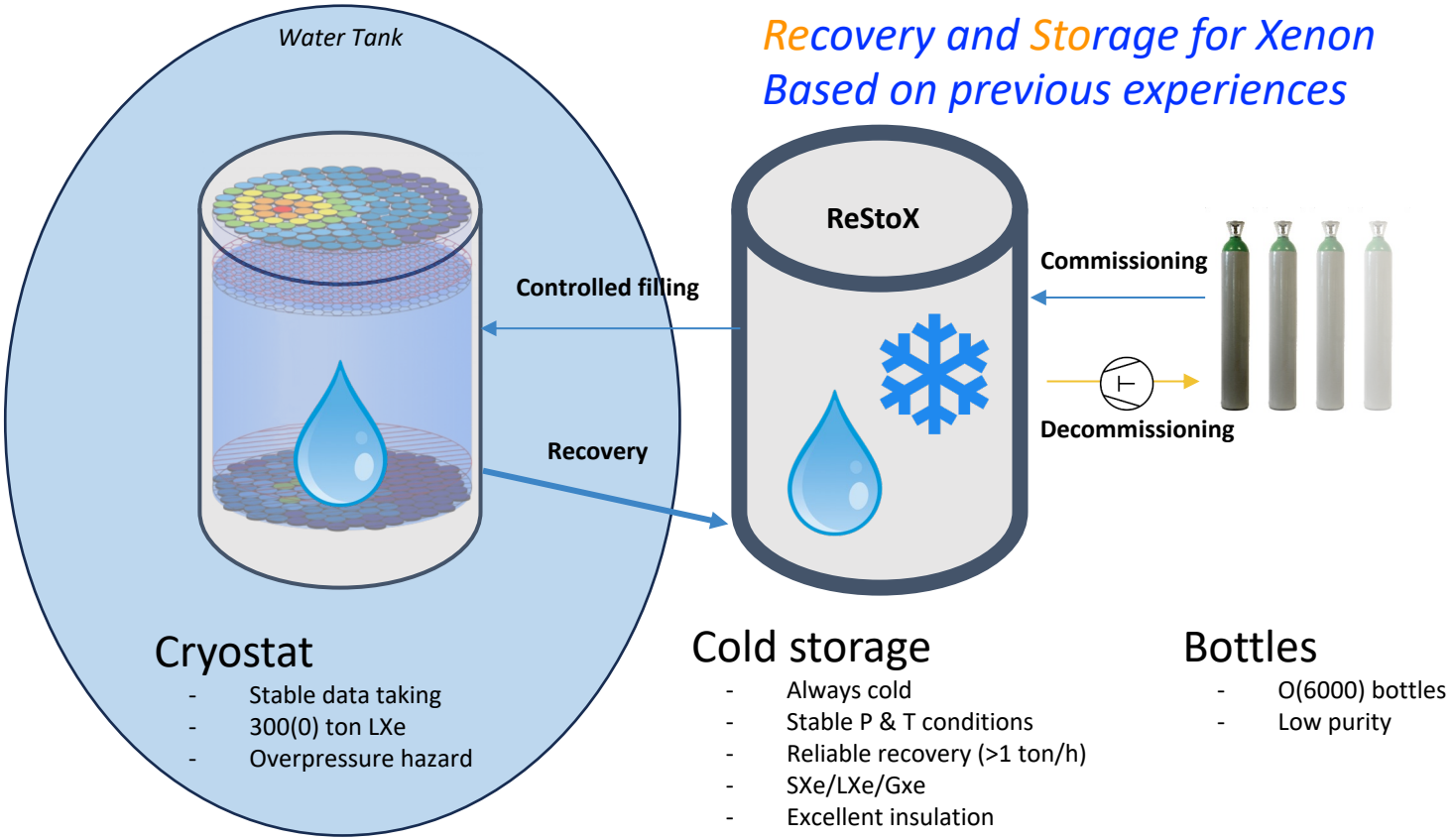
Transfert from / to storage

Key functionalities	Operating Modes
A) Initial storage	1) Empty / Warm / Under Vacuum 2) Ready to receive Xe from bottles *before or after pre-purification* 3) During the construction of the detector, safely store and manage Xe. 4) Continuous purification through getters
B) Filling the detector	5) Distribution & Pre-cooling the TPC 6) Filling Xe into the detector
C) Level adjustment & Distribution	7) Easy transfert to the experiment 8) Distribution for other subsystem too
D) Recovery	9) Standby : always cold (LN2 T°) for recovery (cryo-pumping) 10) Recovery from detector (voluntary or emergency-triggered)

Features of bottle's storage

Feature	Bottles
Connections	Many
Cleaning	Extensive
Xe weight measurment	Problematic
Monitoring P & T	partially
Control P & T	partially
Footprint underground	~ 6,000 bottles
LN2 consumption for recuperation	High loss
N2 boil off	In the cavern
0_2 alams	Many (maybe)
Purification during storage	Feasible
Power failure	Pneumatic logic possible
Welding failure	Problematic

A new concept of storage : ReStoX



- Storage in GXe / LXe / SXe
- High level of purity
- Storage in case of cooling power loss

- Available all time for the experiment (& sub-systems)
  - Construction / Commissioning / Data taking / Maintenance / Decommissioning
  - Cleanliness / Security / Storage & Recovery

ReStoX - Previous experiences

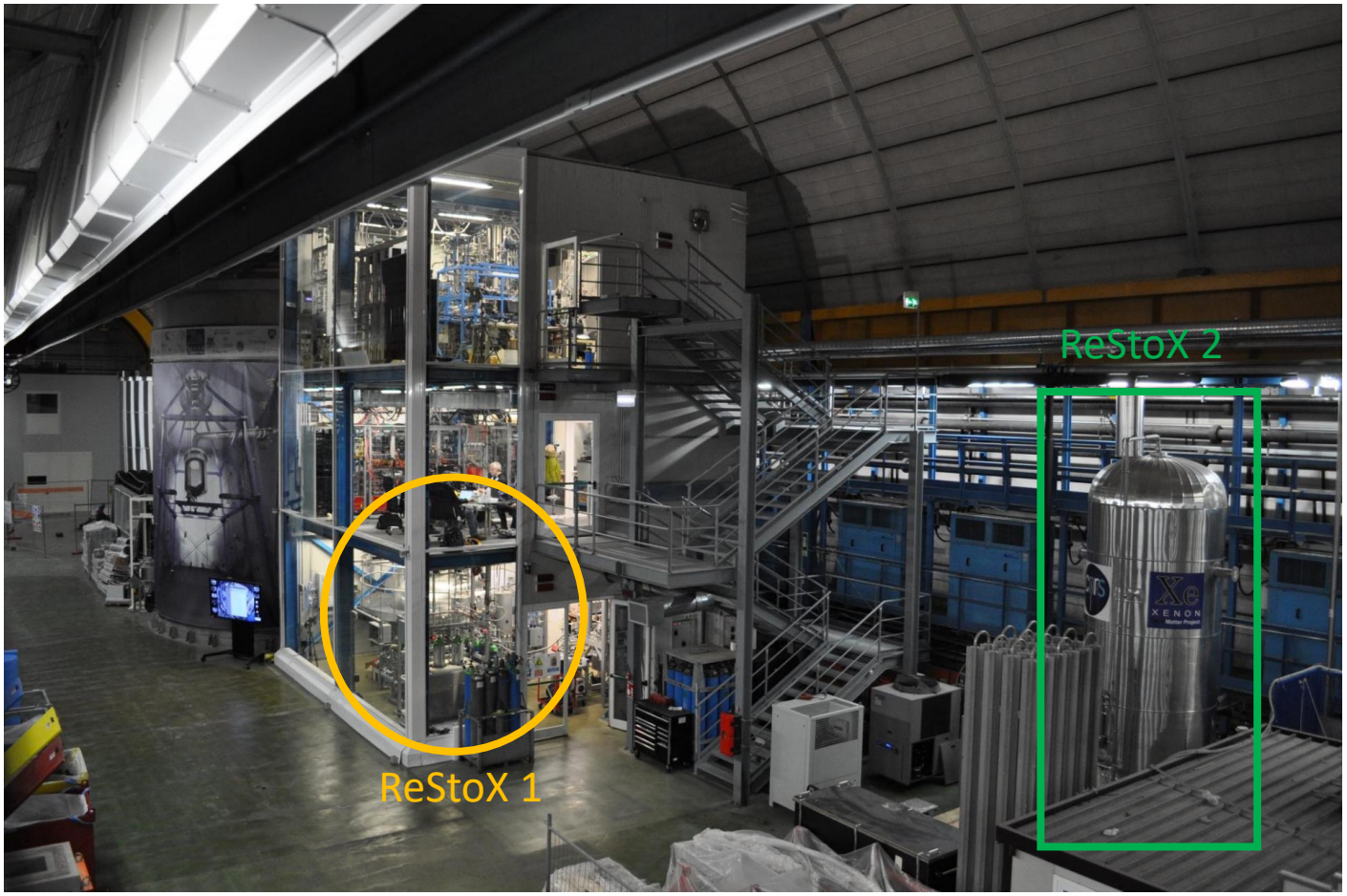
Knowledge of handling large LXe quantity (10t)
Since 2014

ReStoX are LXe recovering, storage and distribution stations,
High Pressure, Safebox

- **ReStoX1 in XENON1T (& XENONnT) – 7,6 t LXe**
  - Columbia University – New York (USA)
  - Mainz University (Germany)
  - Subatech (France)
- **ReStoX2 in XENONnT - 10 t LXe**
  - LAL (France)
  - LPNHE (France)
  - Subatech (France)
- **(nEXO - 5 t LXe-136)**
  - Subatech (France)
- **(DARWIN - 50 t LXe-136)**
  - Subatech (France)
- **ReStoX in XEMIS - 200 kg LXe**
  - Air Liquide (France)
  - Subatech (France)

XEMIS

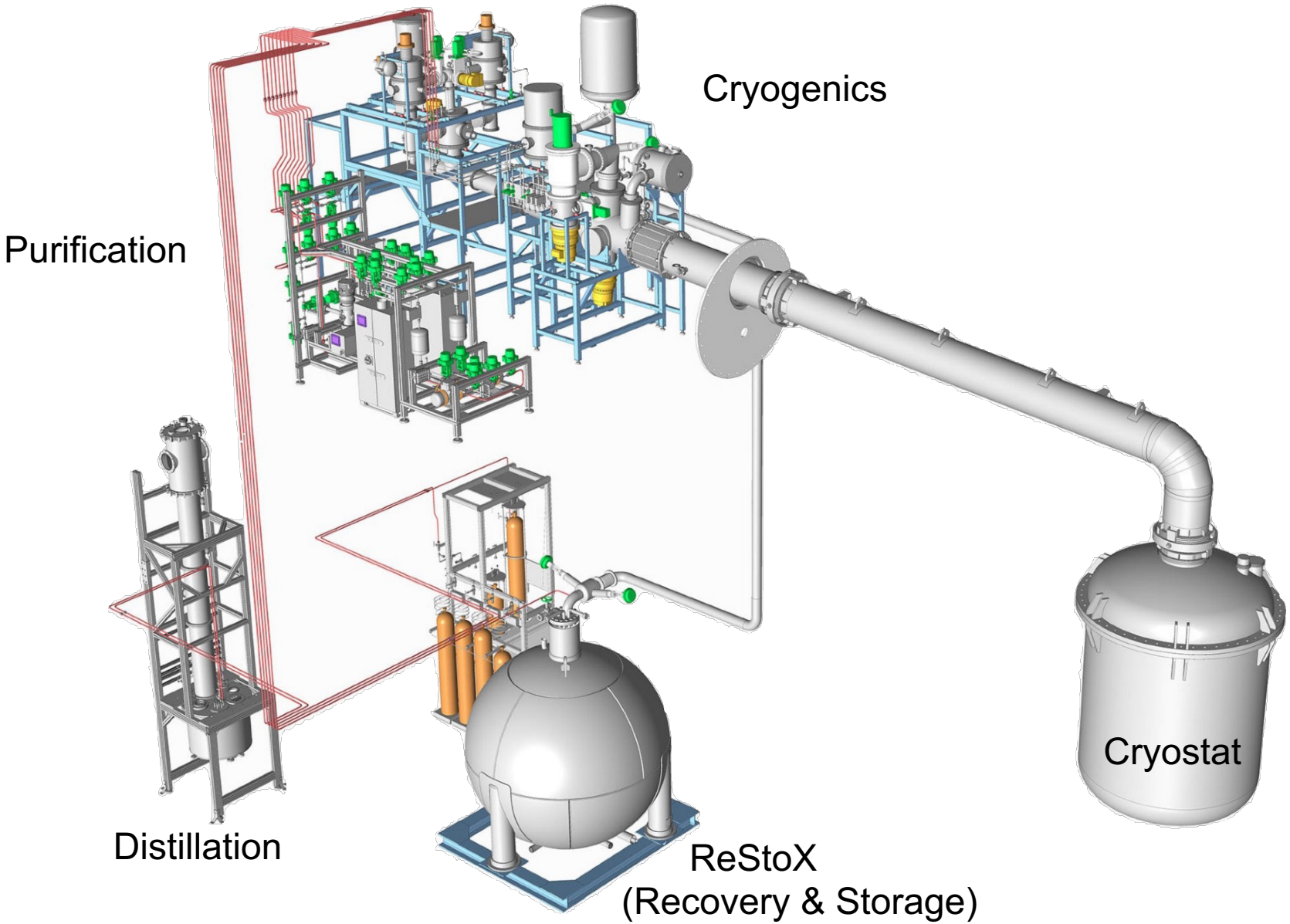
XENONnT facility



ReStoX1: Emergency recovery up to 7.6 tons of LXe
Passive: No active cooling required to keep Xe contained

ReStoX2: Very fast recovery > 1t/h up to 10t.
Passive: No active cooling required to keep Xe contained

XENON1T Plant



ReStoX 1 & 2 - comparison

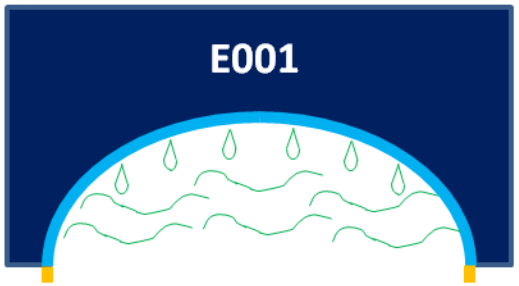
Table 3.4: Comparison between ReStoX and ReStoX2.

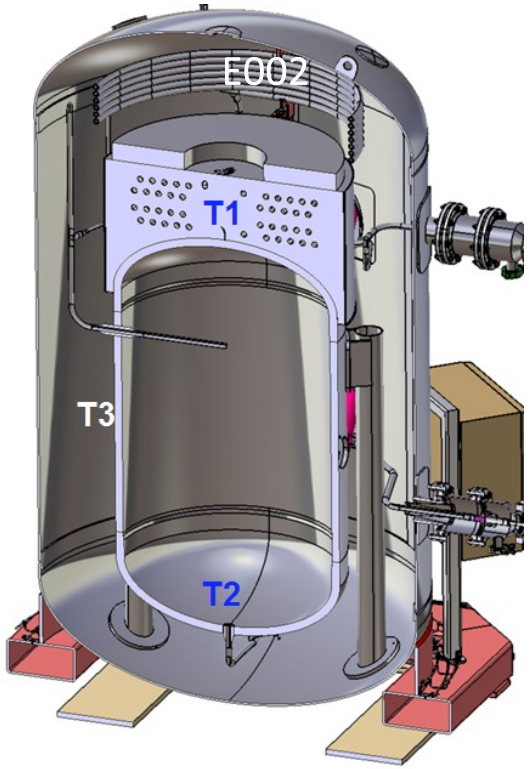
Description	ReStoX	ReStoX2
Dimension	2.1 m ⌀ sphere	(1.45 m, 5.5 m) cylinder
Phase	GXe, LXe, SXe	GXe, LXe, SXe
Maximum pressure	73 bar	71.5 bar
Capacity	7.6 t	10 t
Recovery speed	$\sim$ 50 kg/h	$\sim$ 1000 kg/h
LN_2 consumption in operation	35 kg/d	0 kg/d
LN_2 consumption for recovery	25 kg/h	$\sim$ 8000 kg

XEMIS project

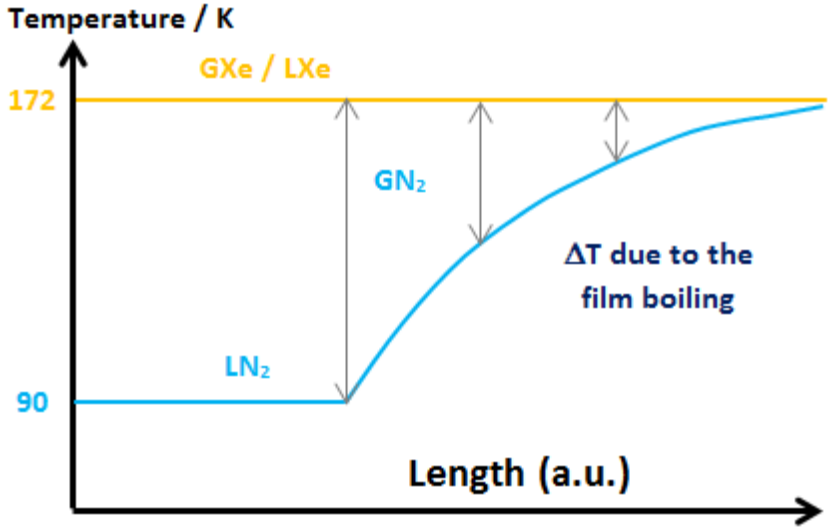
- XEnon Medical Imaging System (XEMIS)
  - Hospital facility for low activity small animal imaging
- Compact set with 3 components
  - Closed loop with 200 kg of Xenon

ReStoX for XEMIS

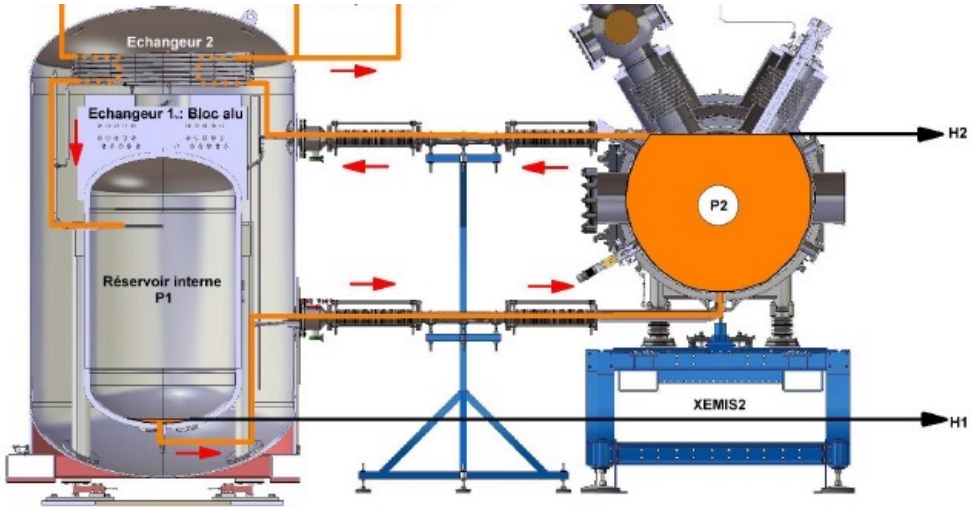




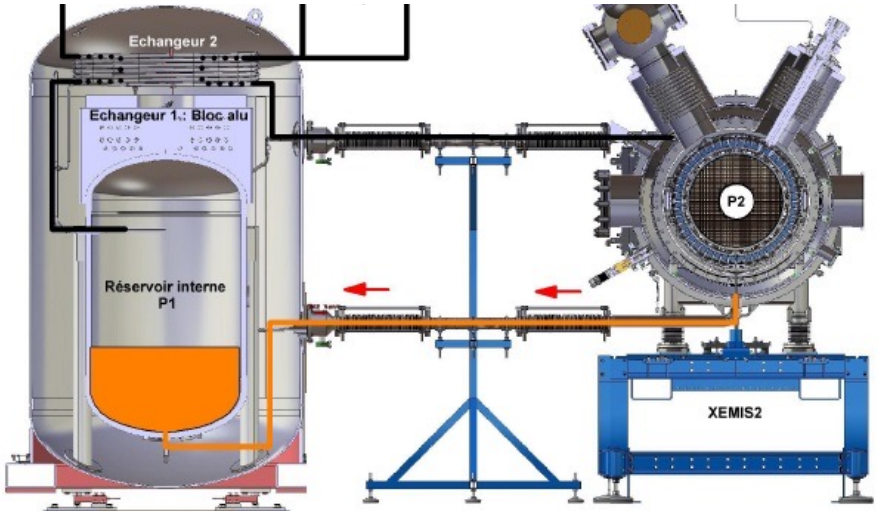
- Double walled vacuum & perlite insulated shell
- Internal capacity of 280 L for storing 200 kg of Xe up to 71 bar a in any condition
- Two exchangers (E001 and E002)
  - E001 (LN_2/Xe): from 0,1 kW to 11 kW
  - E002 (Xe/Xe): interface hot and cold parts, up to 250 W



Gravitational recovery

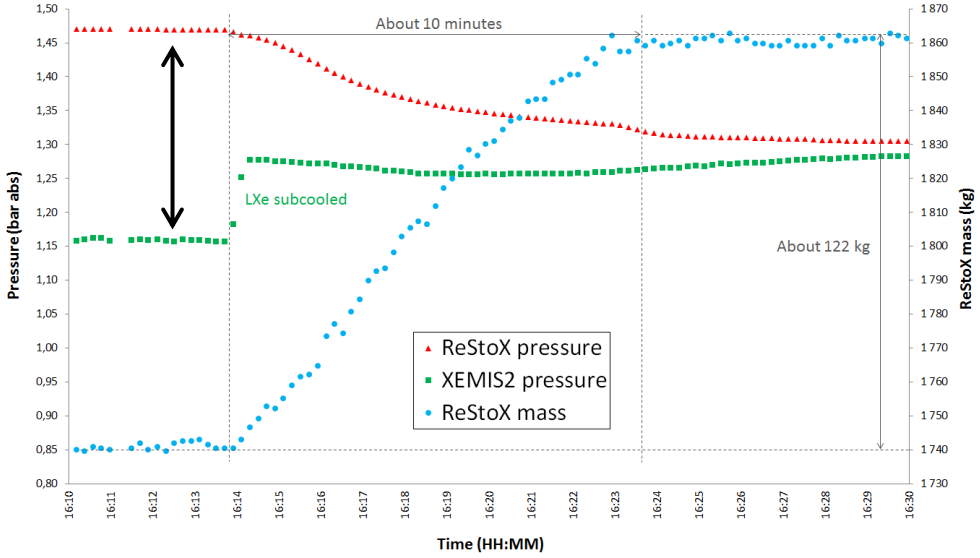


BEFORE



AFTER

L. Virone et al., Nucl. Instrum. Meth. Volume 893, (2018)



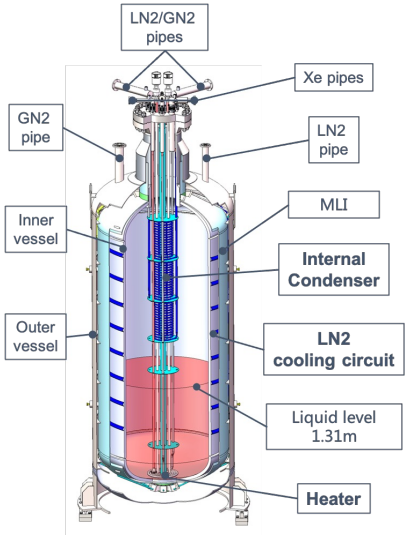
Equivalent to 732 kg/h

FIRST-X in PandaX

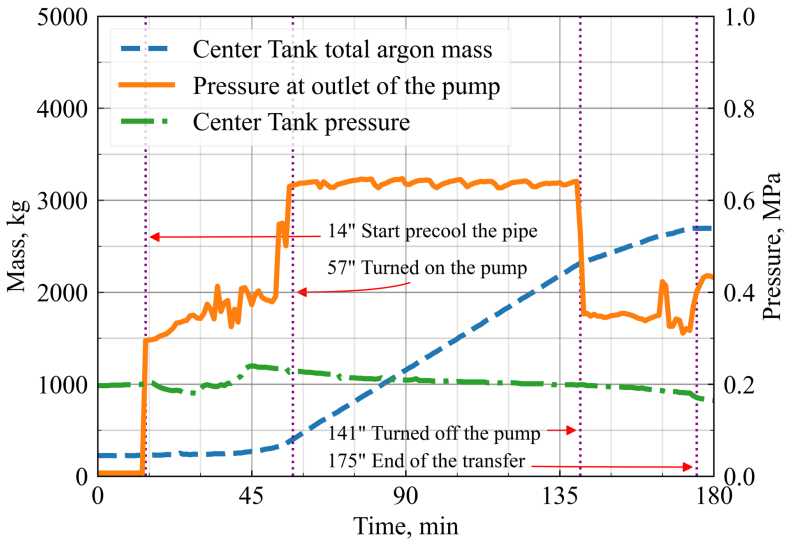
Filling, Recovery,
and
Storage of Xenon

arXiv:2301.06044
Submitted to
JINST06044v2

5x (6 t)



1390 kg/h LAr = 2140 kg/h LXe



Comparison between ReStoX & cylinders

Feature	ReStoX	Bottles
Connections	Few	Many
Cleaning	Limited	Extensive
Xe weight measurment	Easy & All time	Problematic
Monitoring P & T	All time	partially
Control P & T	Condenser & heater	partially
Footprint underground	Limited	~ 6,000 bottles
LN2 consumption for recuperation	Very efficient = already cold with excellent insulation	High loss
N2 boil off	Dedicated tube	In the cavern
0_2 alams	None	Many (maybe)
Purification during storage	Easy	Feasible
Power failure	Pneumatic logic & Slow control	Pneumatic logic possible
Welding failure	Dramatic	Problematic

What about 300 t ?

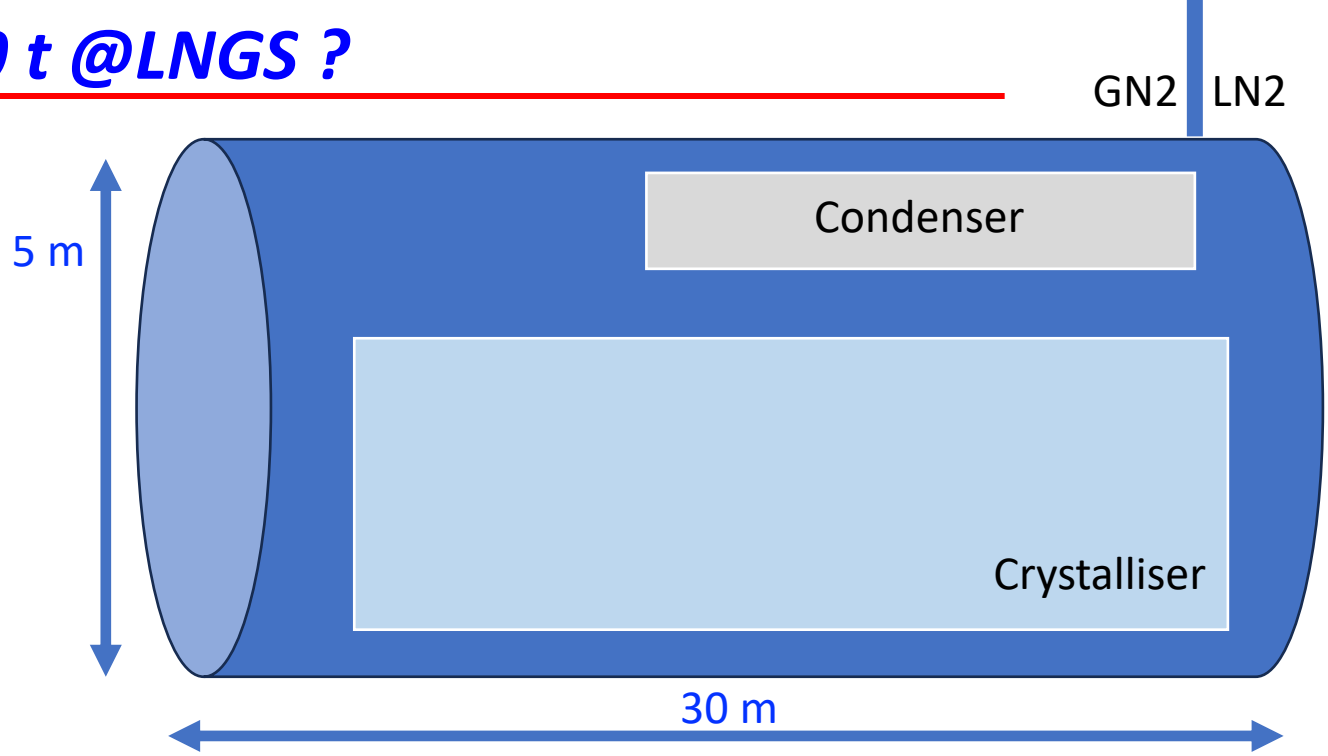
Where : LNGS-like or SNOLAB-like laboratory?

- Trucks can access to LNGS
- Elevator is the only access to SNOLAB
  size ~ 3.2m x 1.3m

- Design has to optimize a variety of factors :
  - Size
  - Cleanliness
  - Ease of use
  - Price
  - …

ReStoX 2 Delivery @ LNGS

What about 300 t @LNGS ?

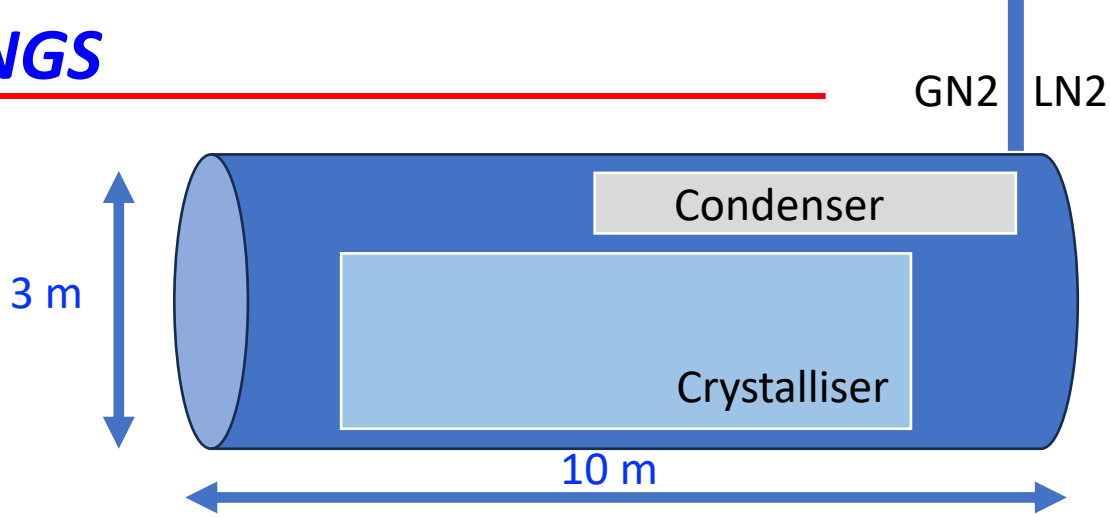


Option 1

1 ReStoX :

- walls of 30cm of SS
- « impossible » to build and weld
- Too much thermal inertia

What about 300t @LNGS



Option 2

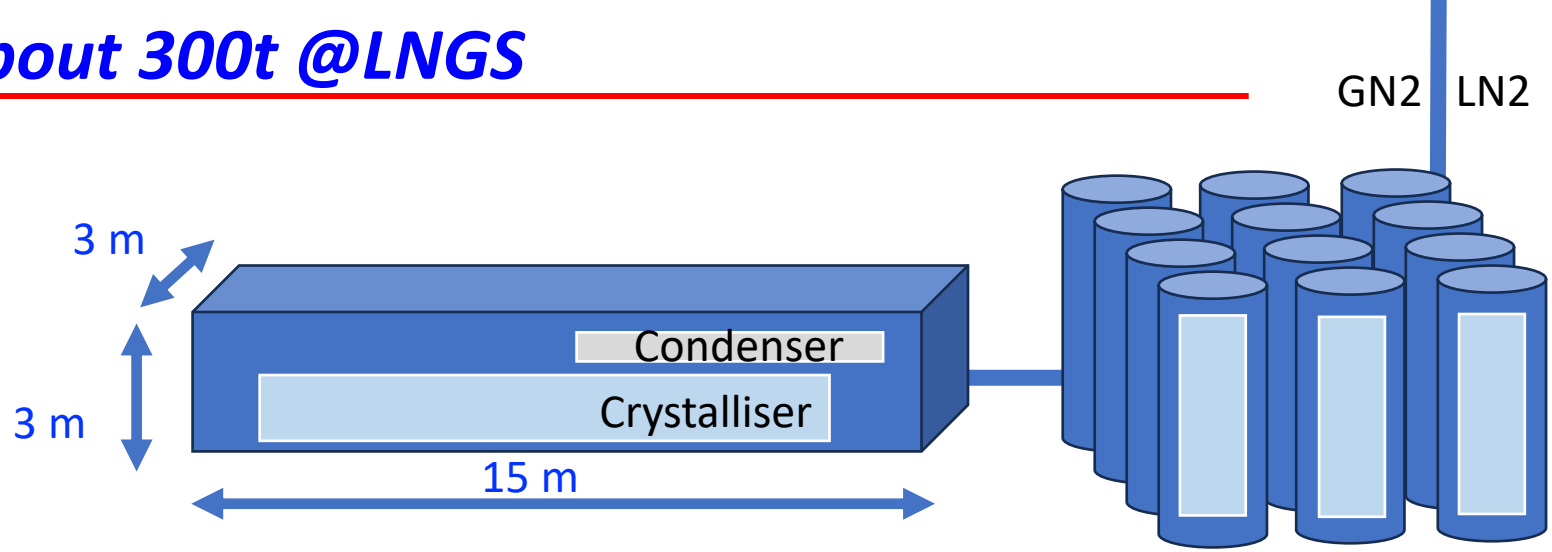
ReStoX Drawn for 50t (DARWIN-like)

- Transportable on a truck to go underground
- Electropolished with highest standard
- Pressure tested before delivery

Can imagine 6x (50t ReStoX)

Underground footprint < 200 m^2

What about 300t @LNGS



Option 3

1 ReStoX for standard operation – low pressure (10 bars)

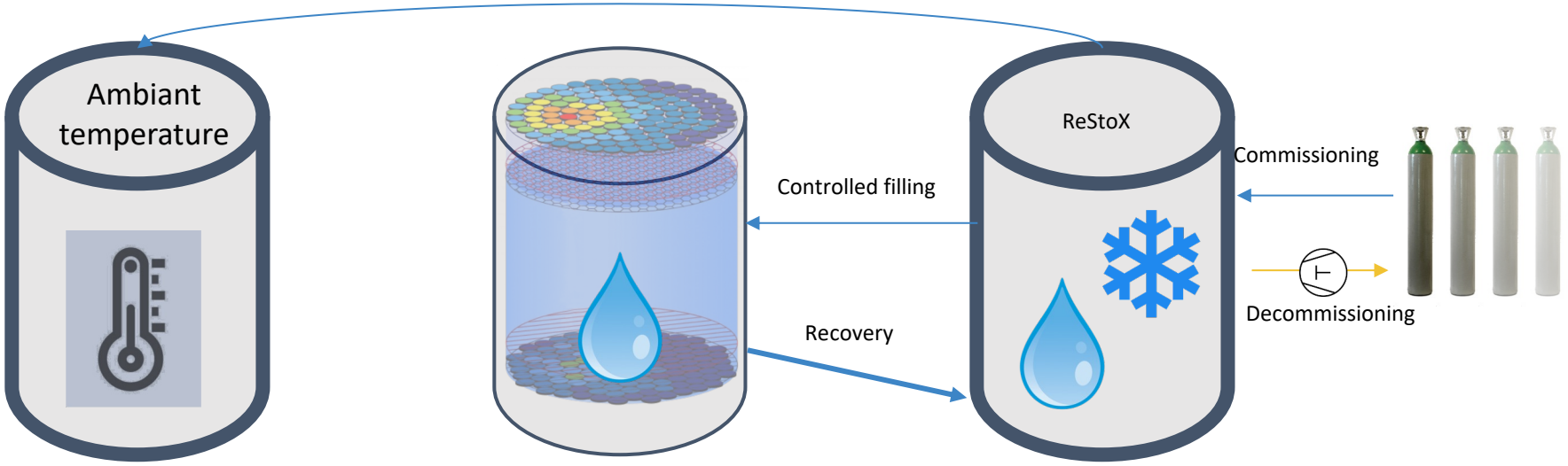
(4m x 4m x 20m already shipped for LAr)

Can be transported or built underground
High purity standard garantied

+ 30 x 10t ReStoX2 for emergency & long term storage

Underground footprint ~ 300 m^2

Summary



Extra storage
- Extra volume

Cryostat
- Stable data taking
- 300(0) ton LXe
- Overpressure hazard

Cold storage
- Always cold
- Stable P & T conditions
- Reliable recovery (>>1 ton/h)
- SXe/LXe/Gxe
- Excellent insulation

Bottles
- O(6000) bottles
- Low purity

- Cryopumping transfert
- Safe-box for the (enr)-Xe in any conditions.
- Key Component of the Xe handling system
- Dynamic / active / flexible part of the system.
- LN2 cooling with permanent access.

- Mature design already tested on installations.
- In use in the XENON1T/nT since 2014 no loss nor major issue to be reported.
- Answer to all storage and distribution issues.
- Gravitational recovery possible