Xe
XENON
Dark Matter Project

KMI

XENONNT:
THE NEXT STEP IN XENON DARK MATTER SEARCH

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DBD18@HAWAII, OCTOBER 22 2018

xenon1t.org

THE XENON PROGRAM

170 scientists

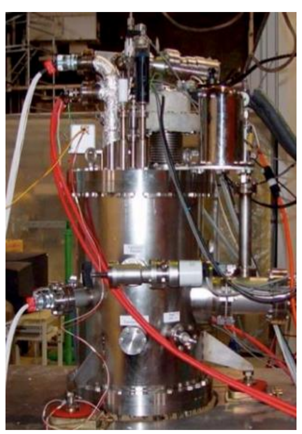
27 institutions

11 countries

Collaboration meeting@Coimbra, Sep 2018

THE XENON (AND DARWIN) PROGRAM

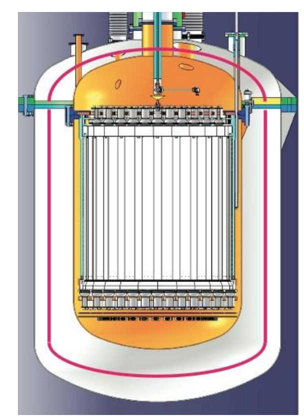
- LXe target: excellent for DM WIMPs scattering
- Detector: two-phase LXeTPC: 3D position sensitive calorimeter.
- Background discrimination:
  - simultaneous light (S1) & charge (S2) detection
  - single site interactions, fiducialization, and self shielding
- High light yield (S1) + proportional scintillation (S2)
  - low energy threshold for nuclear recoils (~ 5 keV, lower for ionization only)



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

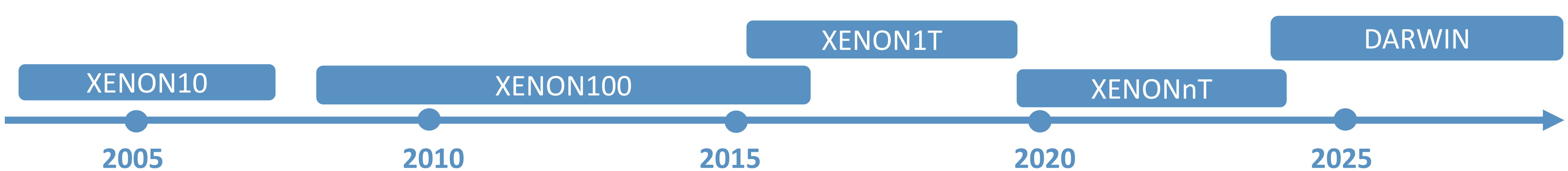
XENON100
Total Xe: 162 kg
Target: 62 kg
Fiducial: 34/48 kg
Limit: ~10^{-45}

XENON1T
Total Xe: 3.2 ton
Target: 2 ton
Fiducial: 1 ton
Limit: ~10^{-47}

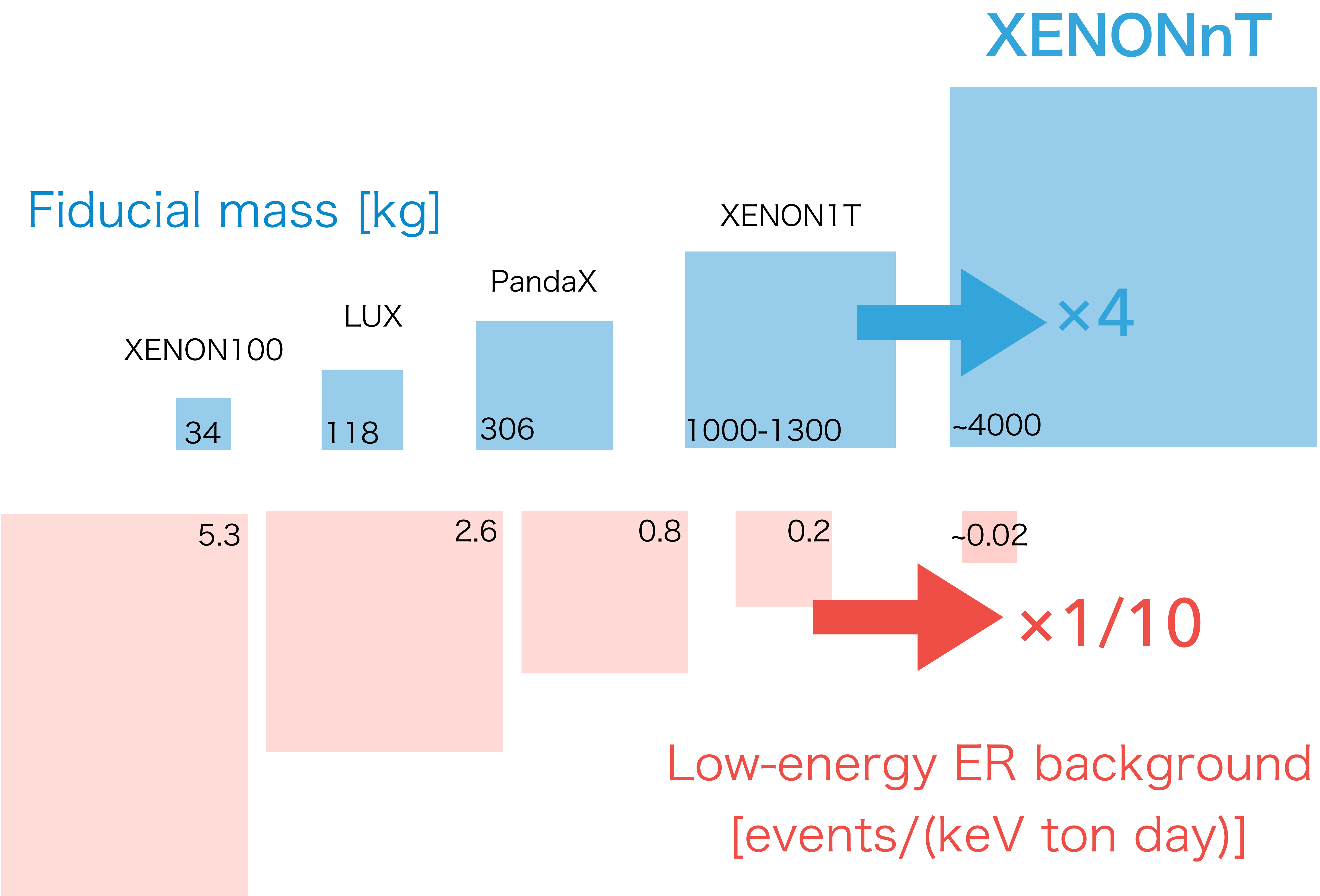


XENONnT
Total Xe: ~8.4ton
Target: 5.9ton
Fiducial: ~4ton
Limit: ~10^{-48}

DARWIN
Total Xe: 50 ton
Target: 40 ton
Fiducial: 30 ton
Limit: ~10^{-49}



DETECTOR MASS AND BACKGROUNDS



SUMMARY OF XENONNT PROGRAM

Minimal Upgrade

The XENON1T infrastructure and sub-systems were originally designed to **accommodate a larger LXe TPC**.

Fiducial Xe Target

XENONnT TPC:

total Xe mass = ~8.4 t

target mass = 5.9t

fiducial mass = ~4 t

Total # of PMTs ×2:
494 PMTs

(253 top, 241 bottom)

Background

Record low-back levels in XENON1T dominated by ^{222}Rn-daughters.

Identified strategies to effectively **reduce ^{222}Rn by ~ a factor of 10**.

Fast Turnaround

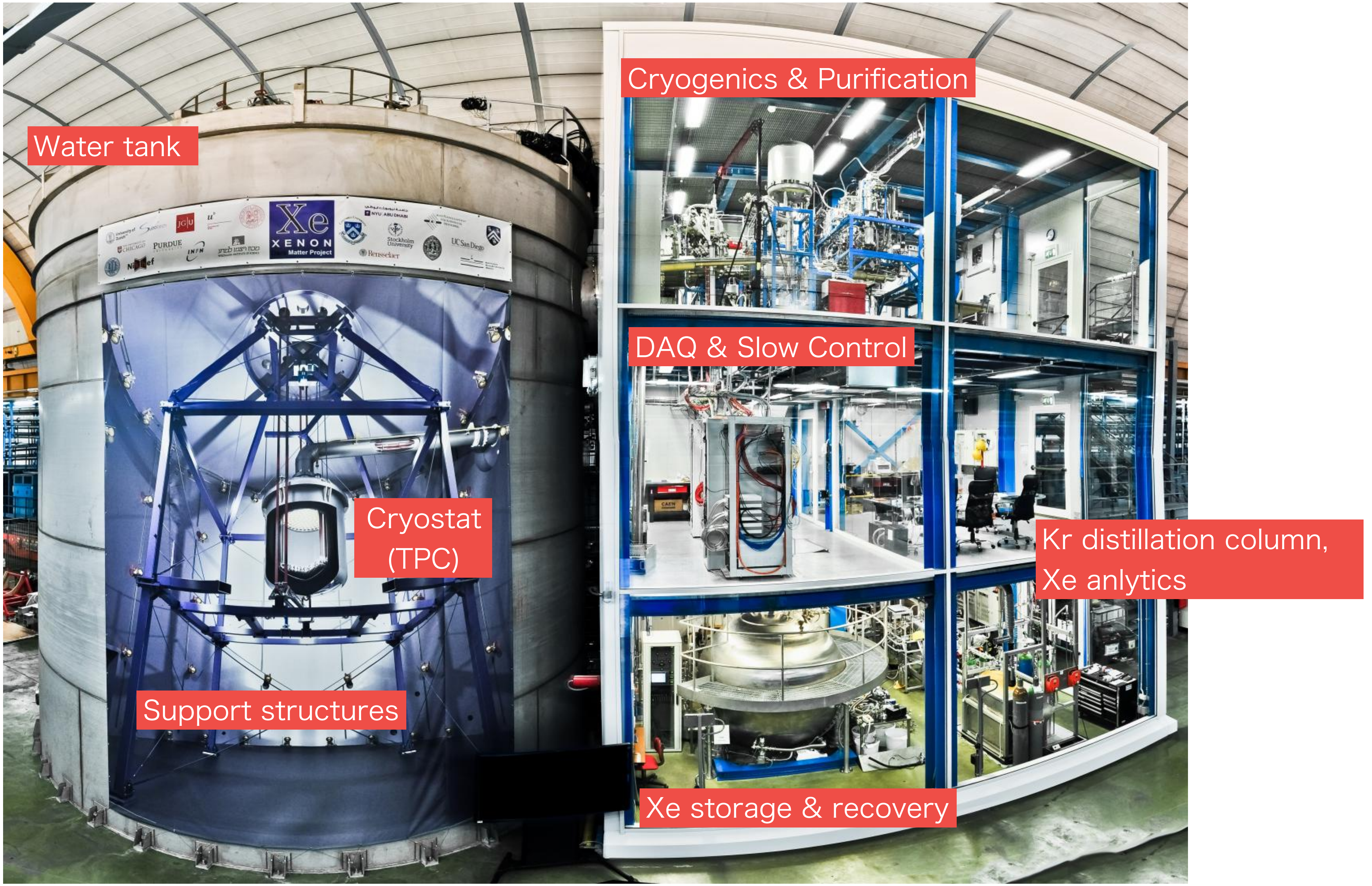
Use **XENON1T sub-systems,** already tested

Fast pace:

Installation starts in 2018 commissioning in 2019 Summer

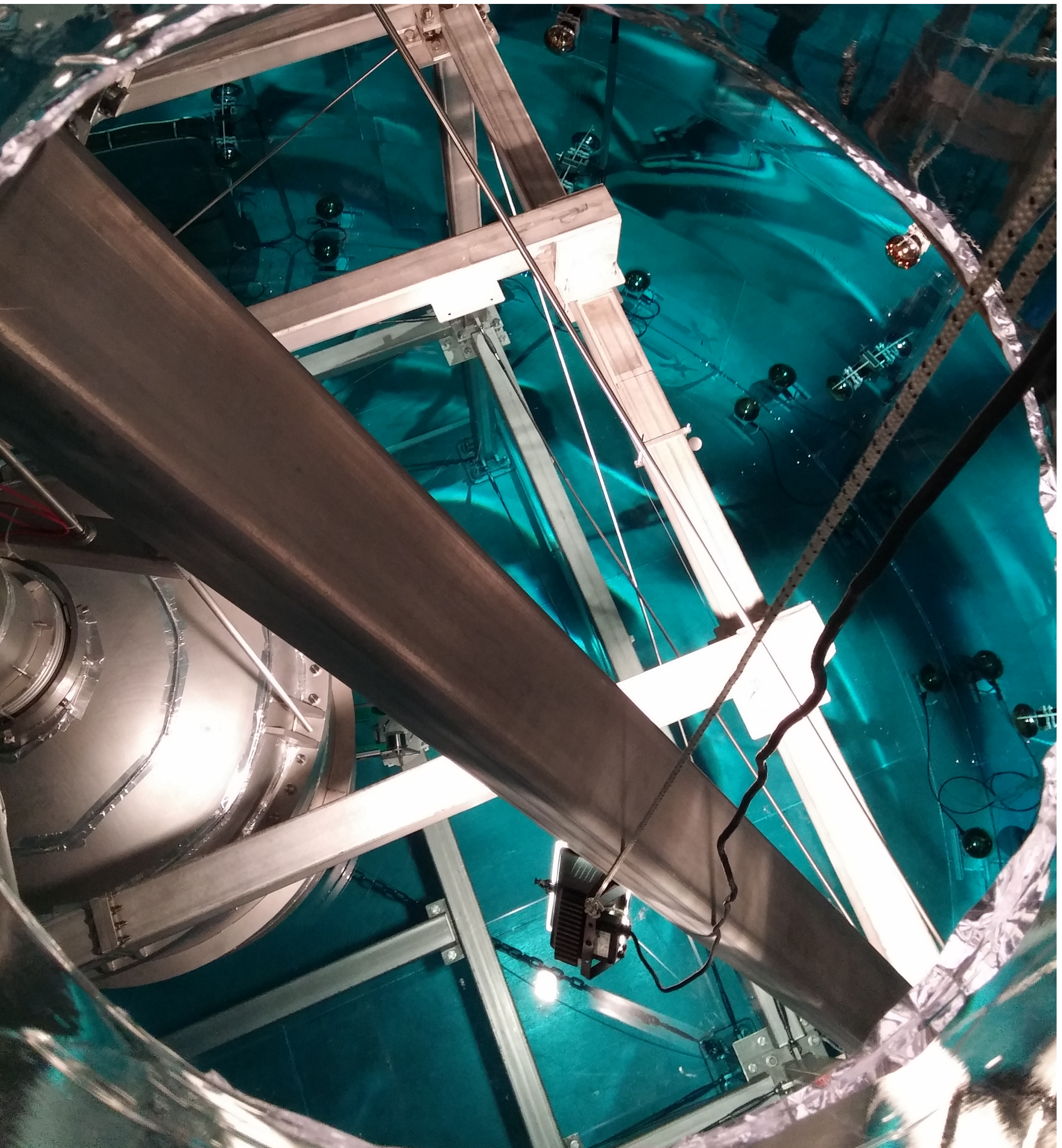
WATER TANK, SUPPORT STRUCTURES, EXPERIMENT BUILDING

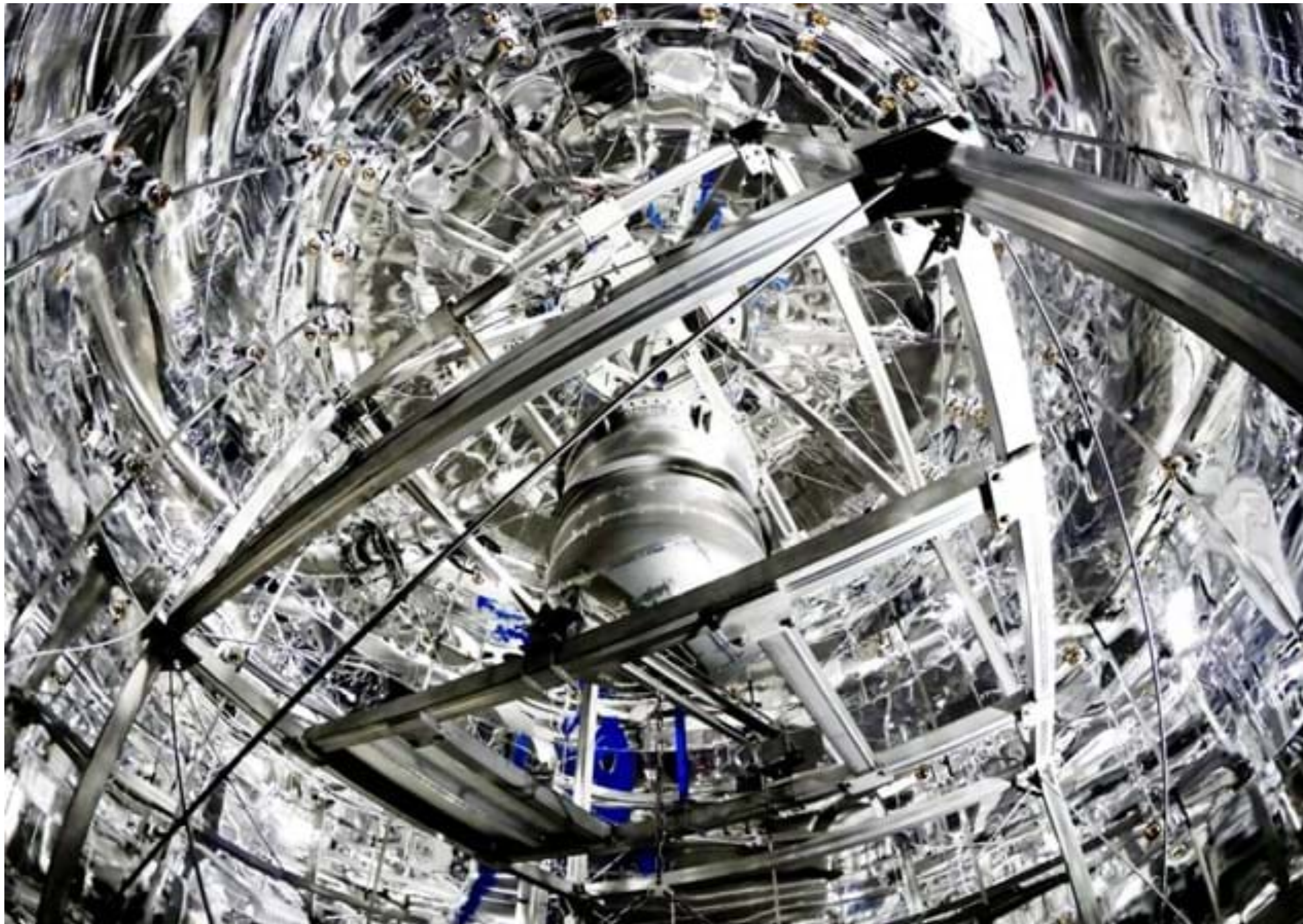
- Reuse large investment in money and time for design, safety review, approval by authorities, construction + commissioning



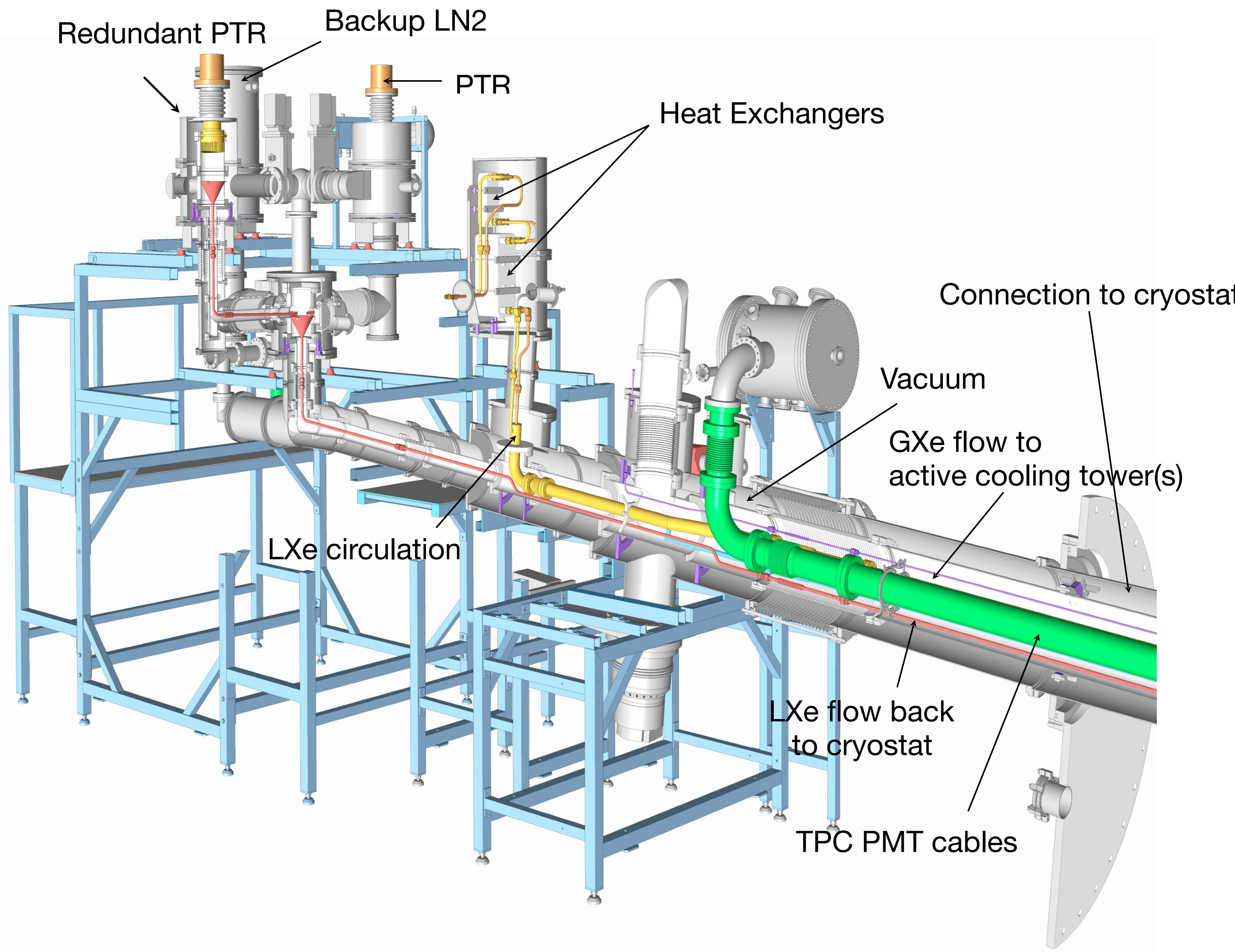
SYSTEMS REUSED: WATER CHERENKOV MUON DETECTOR

- Passive shield against external radioactivity
- 700 t of continuously purified water
- tank clad with high-refectivity polymer foil
- instrumented with 84 high-QE 8” PMTs (R5912) to tag muon-induced background
- Trigger efficiency for muons (MC): > 99.5% JINST 9 P11006 (2014)





SYSTEMS REUSED: CRYOGENICS



	XENON1T	XENONnT Getter+Cryo
Total heat load	150 W	~275 W
Vessel (static)	~20 W	~40 W
GXe/LXe purification	~40 W@55 SLPM	~70 W@100 SLPM
Cryogenic LXe purification	NA	~70 W@5000 SLPM
Heat pipe loss (dynamic)	~85 W	~85 W
PMT arrays	5 W	$\lesssim$ 10 W

XENON1T:

- 2 Pulse Tube Refrigerators (cooling power 240W), one in use, one as backup for maintenance
- 1 LN cold head (cooling power >300W) as emergency cooler
- Total heat load = 150W

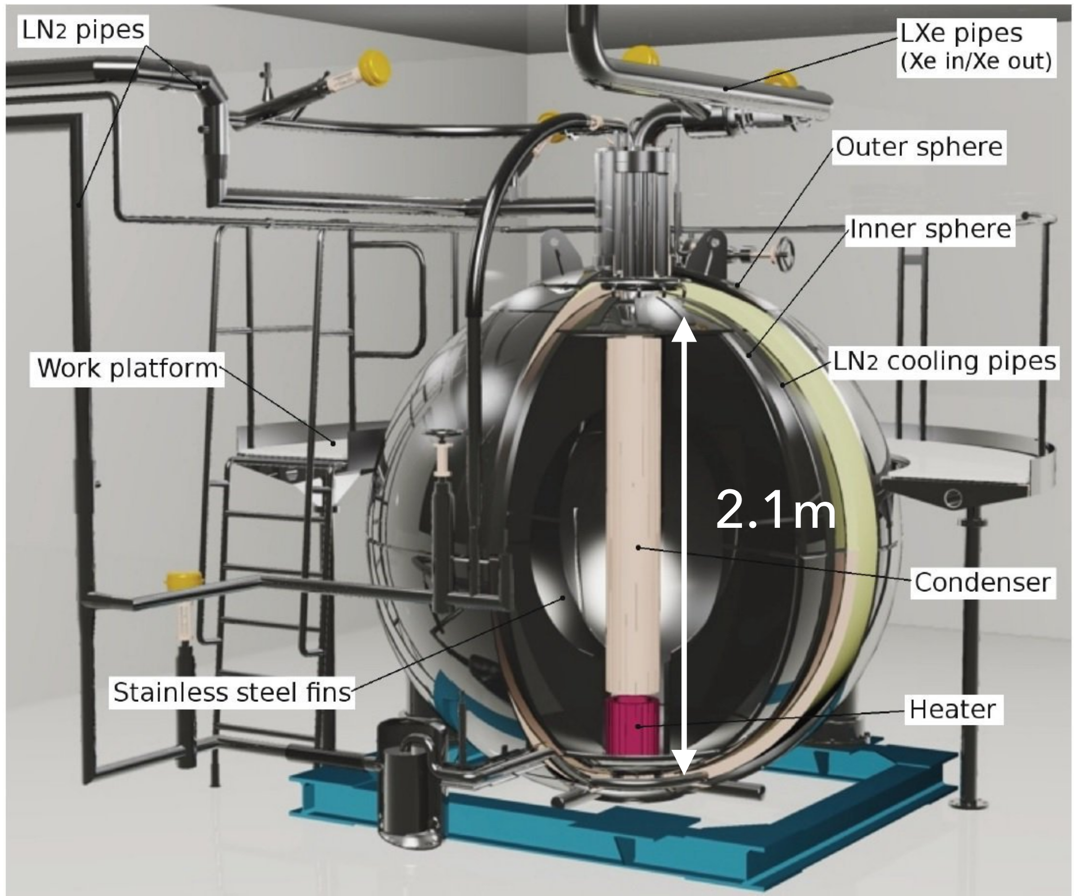
XENONnT:

- Use the same cryogenic system: Expected total heat load: 275W
- Operated with a single PTR (~150W) + continuous cooling with LN2 cold heat
- Tested the stability of combined PTR/ LN2 cooling in XENON1T last May

XENON RECOVERY AND STORAGE

ReUse XENON1T ReStoX

- Vacuum-insulated storage system with capacity of 7.6 t of Xe (gaseous, liquid or solid)
- LN2 based cooling system (35 kg / d)
- Fast recovery in case of accident/ maintenance (~50kg/h)
- Maximum pressure: 73 bar
- Fully controlled by SCS



Additional ReStoX2

- Foam-insulated storage system with capacity of 10 t of Xe (gaseous, liquid or solid)
- Very fast recovery with Xe freezing (1t / hour)
- Maximum pressure: 71.5 bar
- LN2 consumption for recovery: ~ 8000 kg
- Construction completed
- Already delivered to LNGS, commissioning and tests are ongoing!

SYSTEMS SCALED UP: ELECTRONICS, DAQ, COMPUTING, SLOW CONTROL

Electronics / DAQ:

- Scale-up of DAQ frontend & trigger:
  → only minor modifications required
- further parallelization to read out more than double number of channels
- expand online waveform analysis to reduce data amount
- New custom-made PMT amplifiers allow for a (low gain) second readout of the bottom PMT array for $0\nu\beta\beta$ of 136Xe
- all hardware in place, ordered or under construction (amps)

Computing:

- Same computing/processing framework as XENON1T https://github.com/XENON1T
- Scalable: based on OSG/EGI resources and LHC-developed data management
- Improvements in structures and procedures
- Extra storage under procurement

Slow Control:

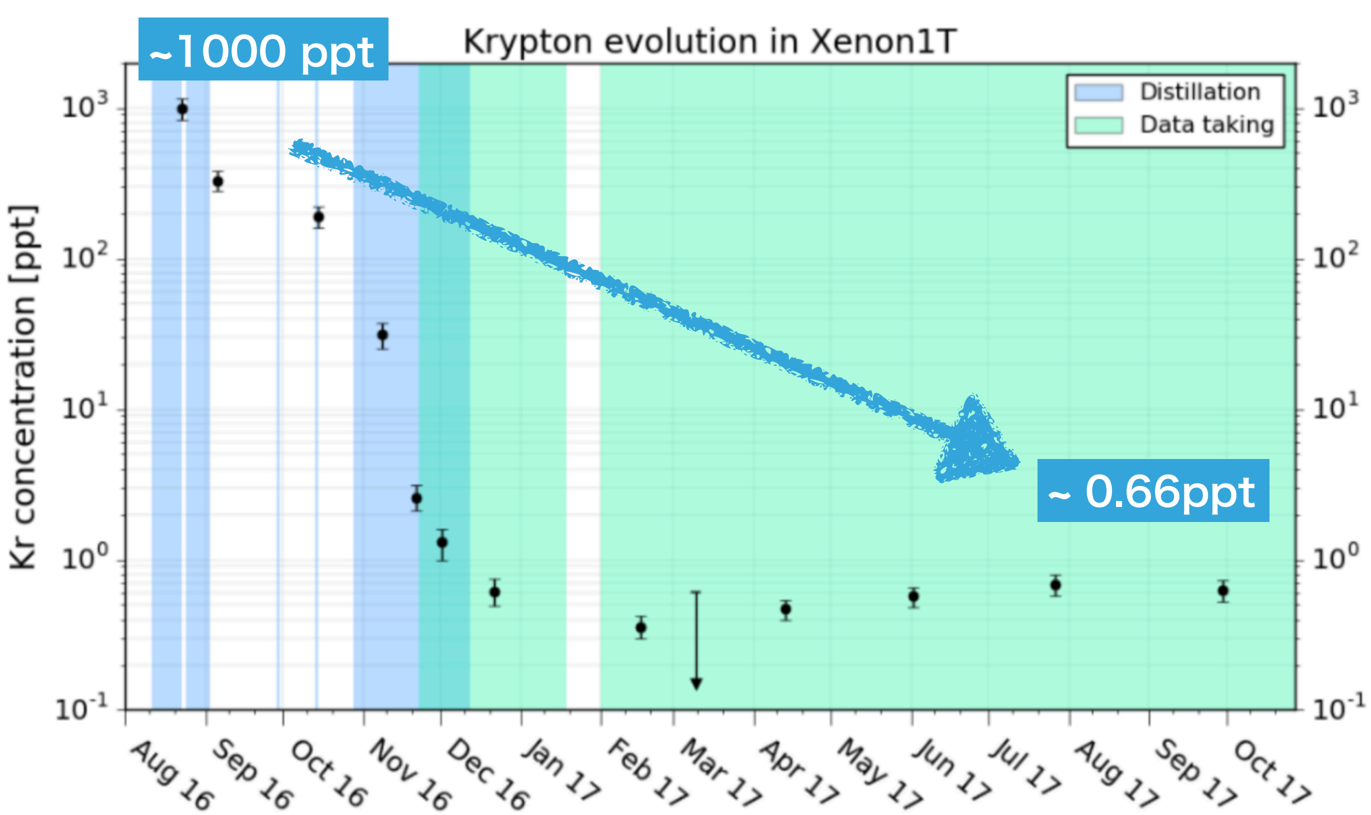
- Same GE/SCADA -based framework as extensively tested with XENON1T
- Extend to new systems (RESTOX2, LXePUR, Neutron Veto, etc.)

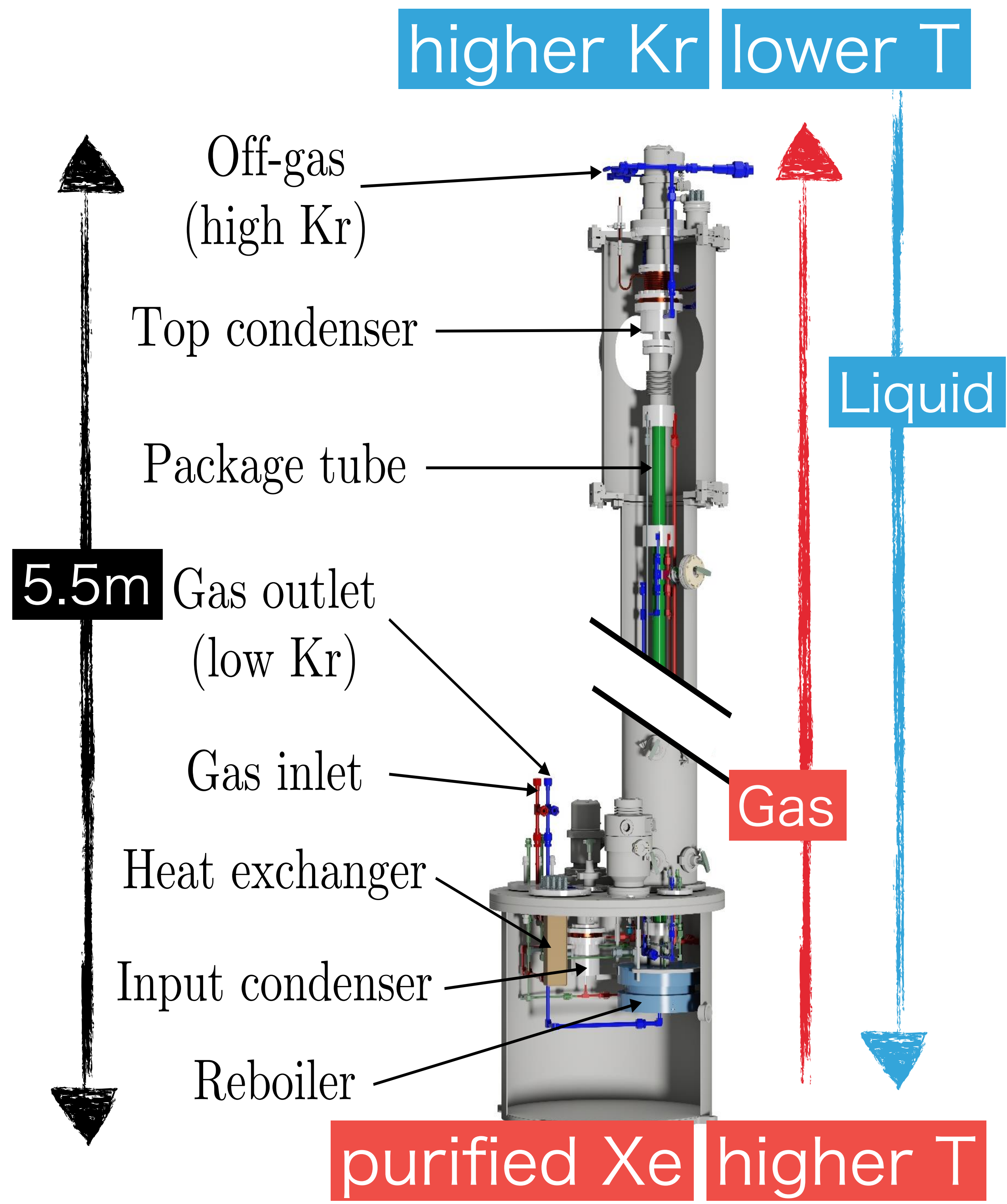
SYSTEMS REUSED: KR DISTILLATION COLUMN

Eur. Phys. J. C (2017) 77:275
Eur. Phys. J. C (2017) 77:881

XENON1T

- Commercial Xe: 1 ppm - 10 ppb ^{nat}Kr,
- ^{85}Kr is unstable ($T_{1/2}$ = 10.8 y, Q-value = 687 keV)
- Solution: 5.5 m cryogenic distillation column
- Utilizes different vapor pressure:
  - Kr: 20900 mbar@178K, Xe: 2010 mbar@178K
- Feeding flow rate: 8.3 SLPM (3kg/h)
  - Thermodynamically stable up to 18 SLPM (6.5 kg/h)
- Measured separation: 6.4×10^5 @8.3 SLPM, < 48 ppq (RGMS)





SYSTEMS REUSED: KR DISTILLATION COLUMN

Eur. Phys. J. C (2017) 77:275
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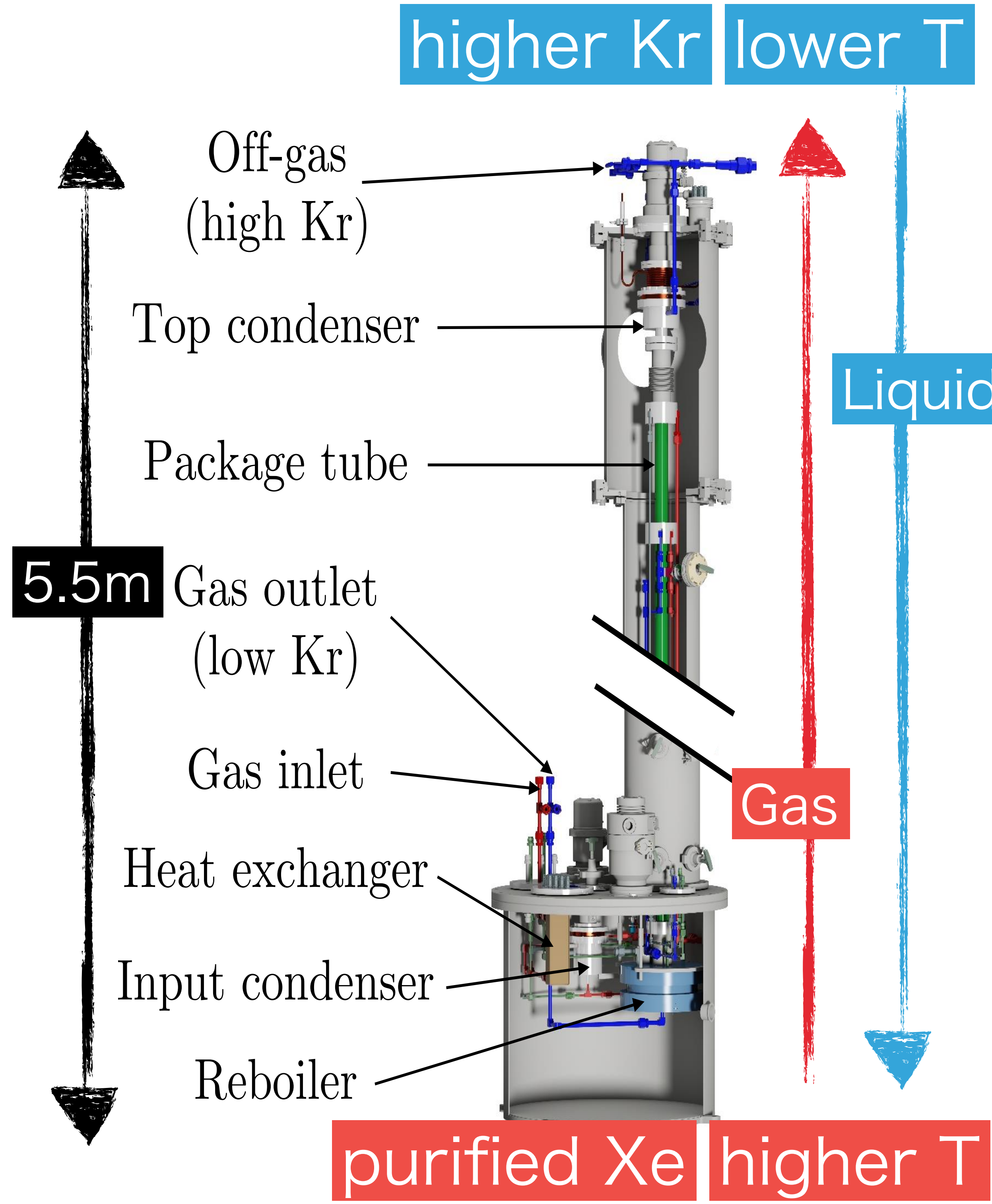
XENONnT

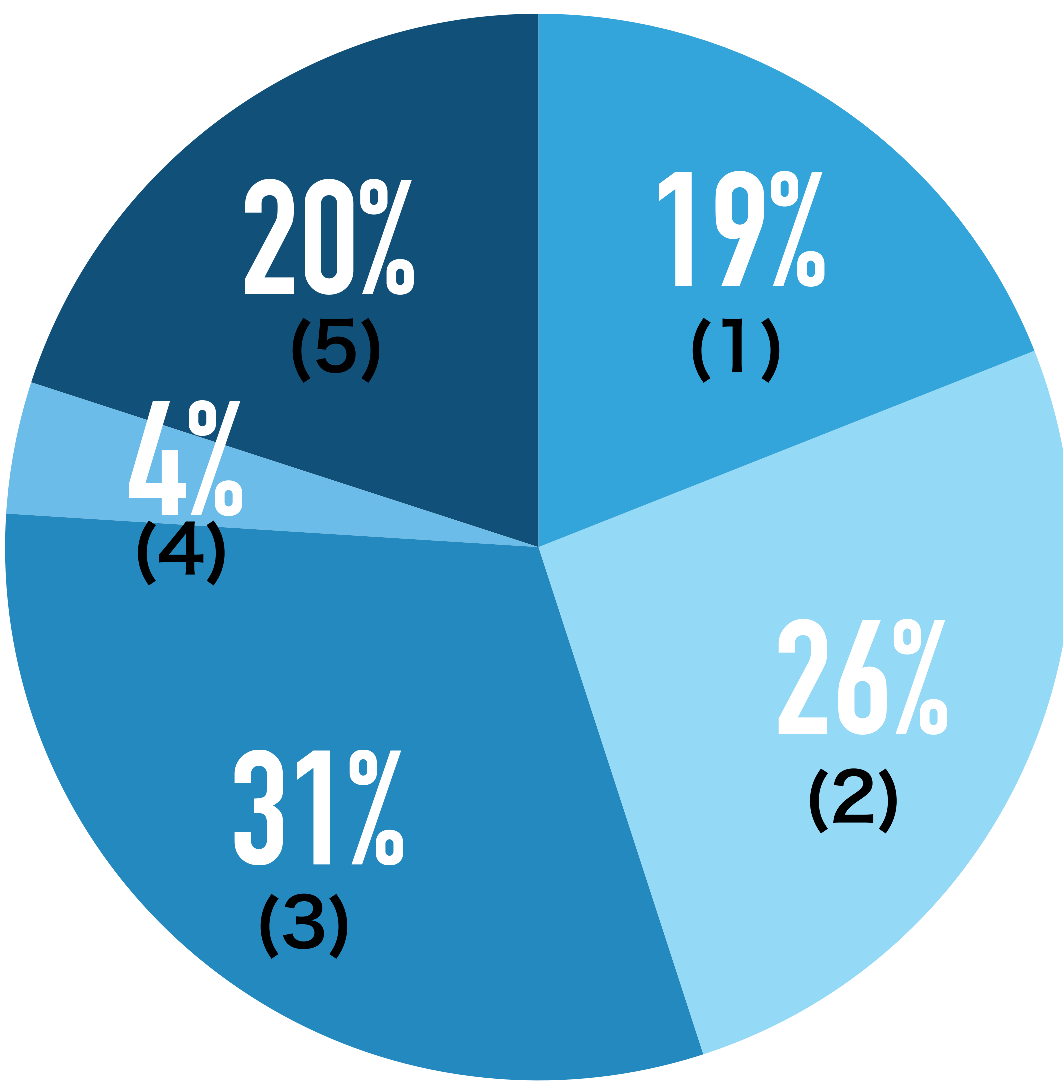
- use the same column
- pre-distilled 8 t of gas. Distillation campaign will start at Jan. 2019
- will start run with ~ 0.2ppt (XENON1T: 0.66ppt)
- improve only by a factor 10 (small!), down to 20 ppq.
- Column has been shown to reach natKr/Xe < 26 ppq (90% CL)



^{222}RN BACKGROUND IN XENON1T

Type I sources

- Emanation of Rn inside the TPC + Cryostat: ~19% (1)
- can only be diluted by fast recirculation with pass through Rn removal system



Type II sources

- Emanation of Rn outside the TPC
- can be fully removed by extraction of GXe and pass through efficient Rn removal system

(2) Cryopipe (LXe transfer line)

(3) QDrive pump

(4) Hot getter

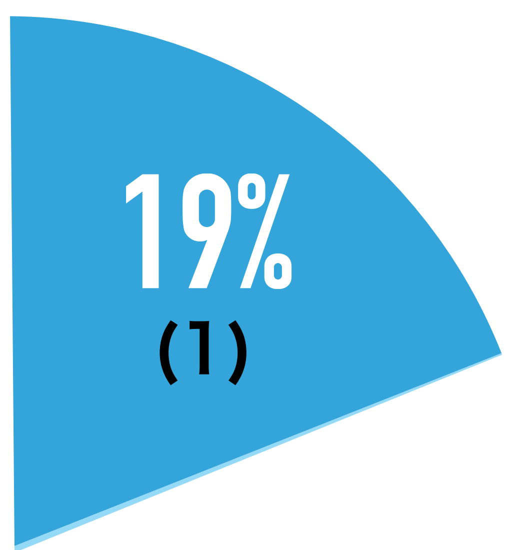
(5) Pipes + Cables

- Total Type I+II: **~10 μBq/kg**

^{222}RN BACKGROUND IN XENONNT

Type I sources

- Emanation of Rn inside the TPC & inner cryostat: ~19% (1)
- Dilution factor: Rn lifetime (5.5 d) / recirculation time
- Factor 2 reduction requires flow of 170 slpm in 5.5d (= 8 t / 5.5d = 60 kg/h = 170 SLPM)



Type II sources

- Emanation of Rn outside the TPC
- can be fully removed by extraction of GXe and pass through efficient Rn removal system (See details later)

(2) Cryopipe (LXe transfer line)

(3) QDrive pump ← **Can be removed by pump exchange**

(4) Hot getter

(5) Pipes + Cables

- Total Type I+II: **~1 μBq/kg**

Plus: aiming at additional reduction of Rn background by material screening / selection and surface treatments.

UPGRADE: GASEOUS XE PURIFICATION

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

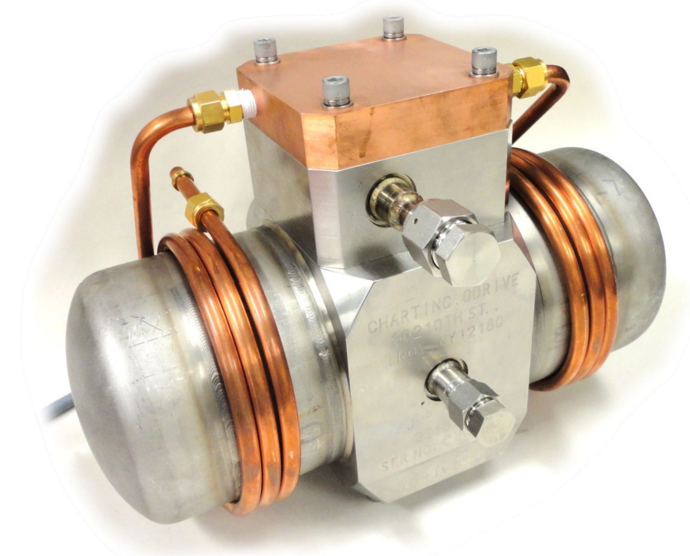
Goals

- Increase mass flow to 120 slpm (12 g/s) to
  - improve electron lifetime
  - reduce Rn background from type I sources with Rn removal column

Improvements

- Replace QDrive by new magnetic piston pump
- Enlarge tube diameter
- Use higher flow getter filters
- Tested on 1T:
  - Flow: 75 slpm (54 slpm with 3 Q-drive)
  - Inlet pressure: 1.6 bar, compression: 1.5 bar
  - Could remove type II Rn source from QDrive circulation pump
- nT: Increase flow to 120 slpm with pre-charging of magnetic piston pump using QDrive

QDrive

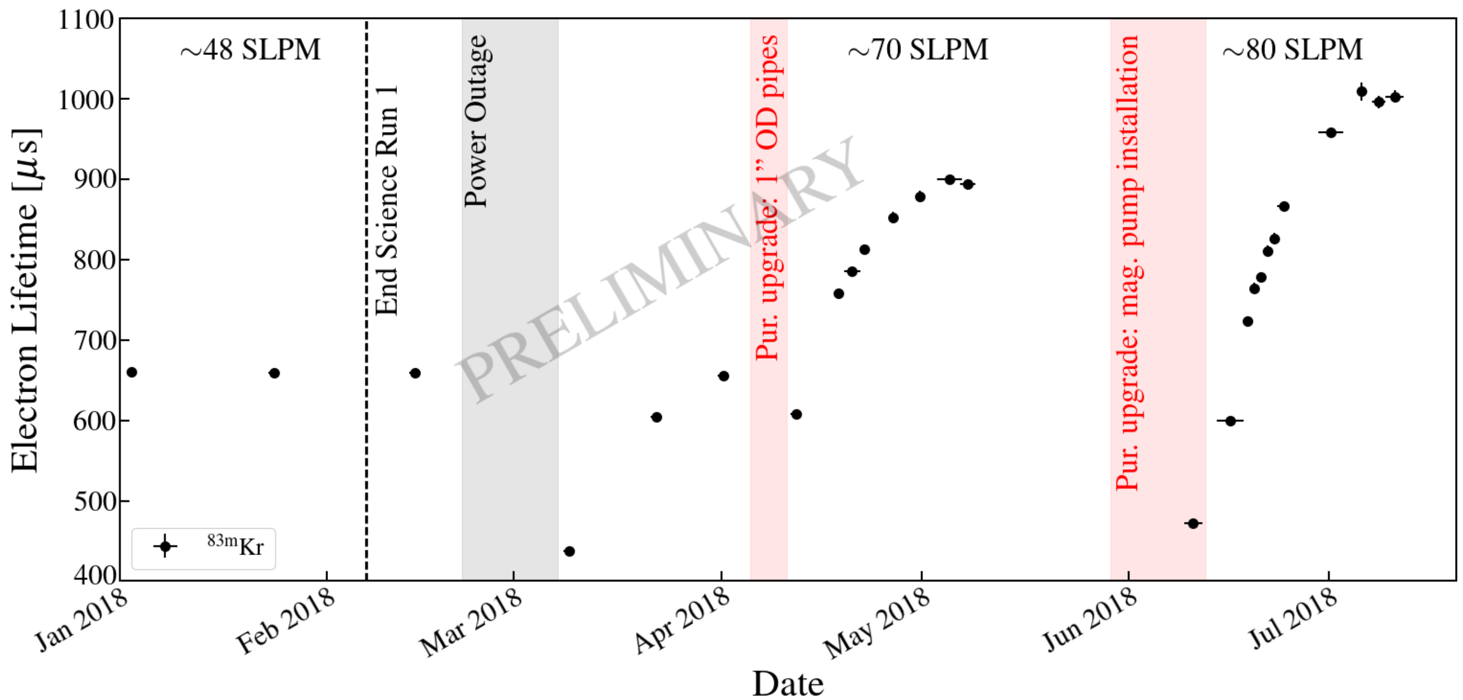


Magnetic Piston Pump

UPGRADE: GASEOUS XE PURIFICATION

Eur .Phys. J. C (2017) 77: 6
Eur .Phys. J. C (2018) 78: 604

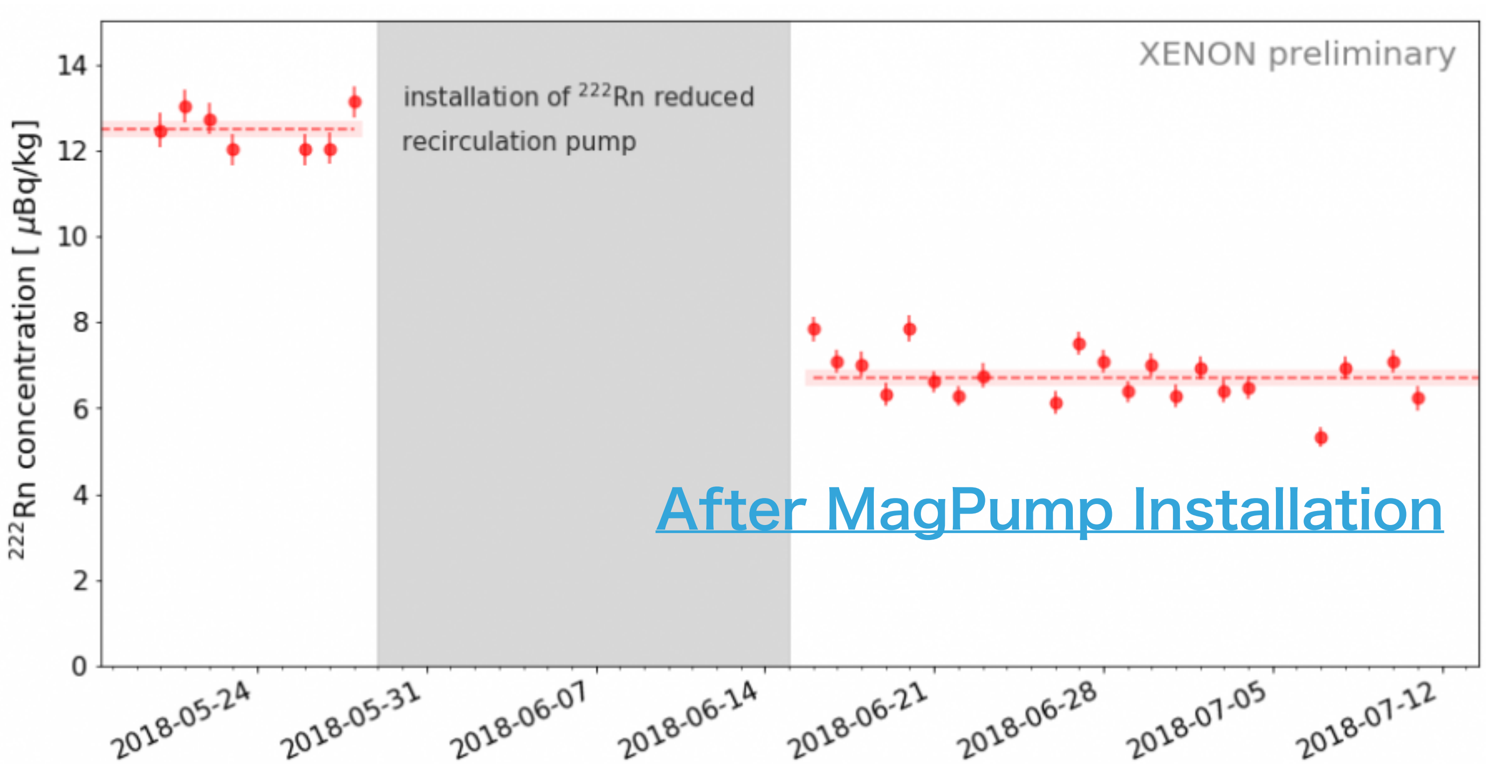
Electron lifetime



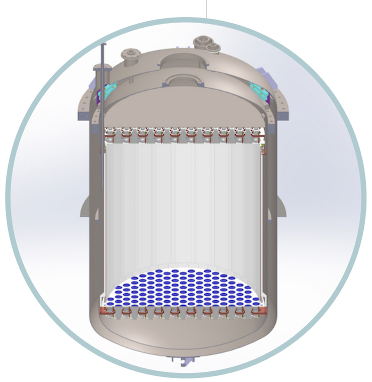
- Now electron lifetime reaches ~ 1ms
- Magnetically-coupled piston pump reduces 45% of Radon BG w.r.t SR1

Period	Conc. [μBq/kg]
SR1	11.8 ± 0.2
+ MagPump	6.3 ± 0.1

^{222}Rn concentration



After MagPump Installation



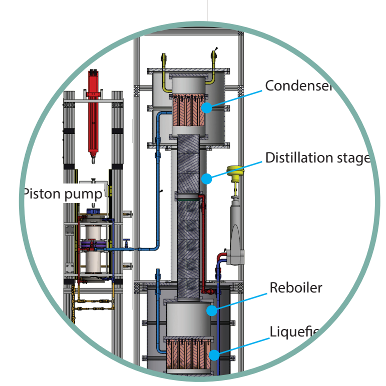
New TPC

5.9-ton Time Projection Chamber

LXe Purification

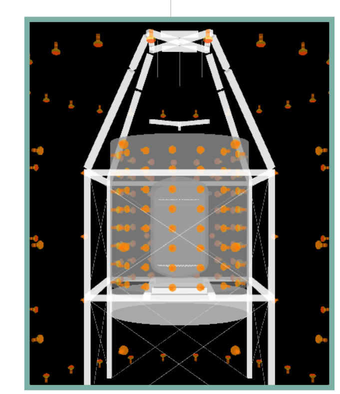
To achieve fast cleaning of the large LXe volume (> 5L/min LXe, 2500 SLPM)

↕ GXe purification (120 SLPM)



Radon Distillation

To online remove the ^{222}Rn emanated inside the detector



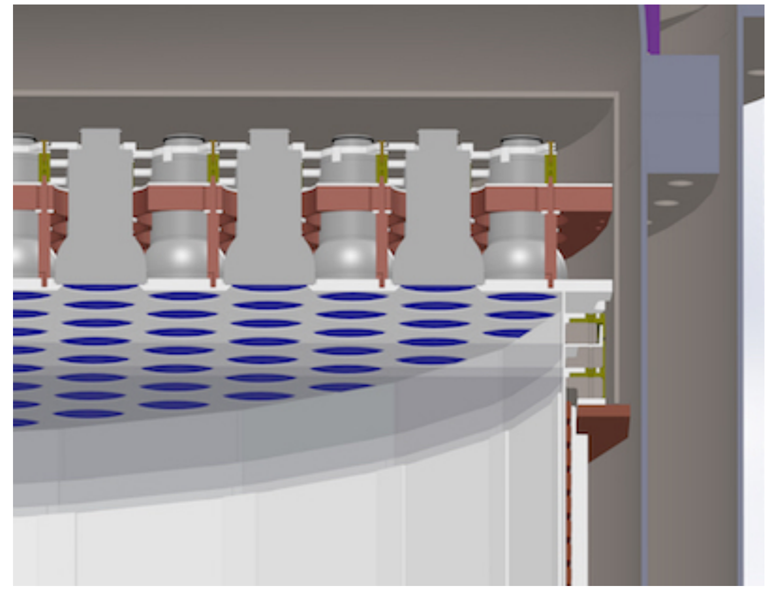
Neutron Veto

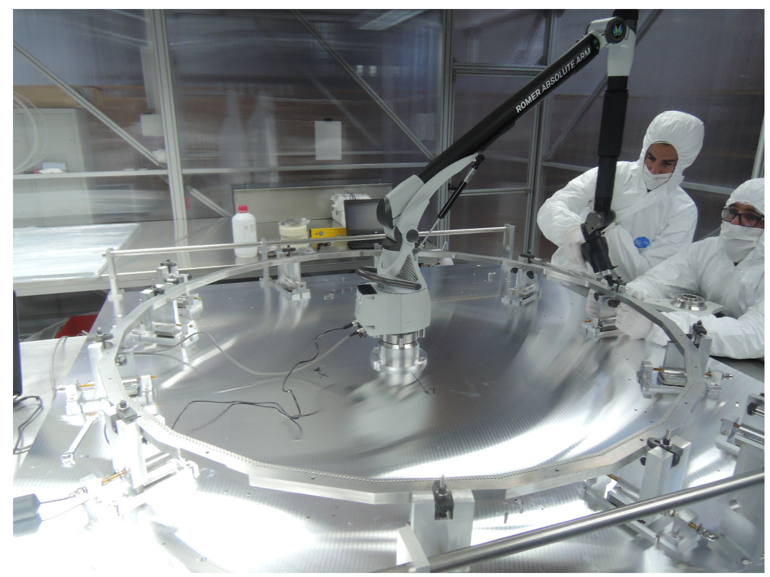
To tag and measure in situ neutron-induced background

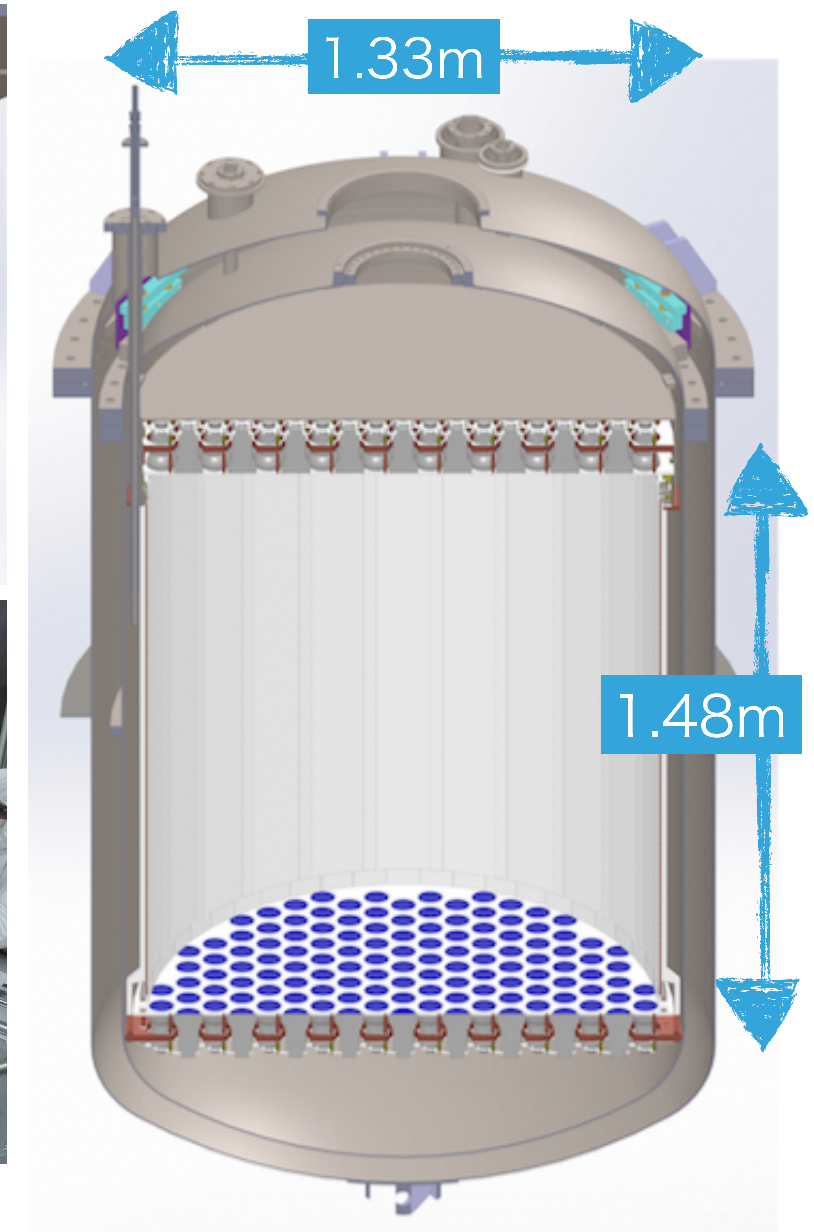
Gd-loaded Water Cherenkov detector

NEW SYSTEM: TPC

- TPC size maximized to fit XENON1T outer cryostat
- same holding structure and leveling mechanism as 1T TPC
- technical design and FEM largely completed → mockup components being tested (electrodes, TPC structure, PMT support, ...)
- optimized for low material budget (PTFE thickness minimized) and reduction of wall charge-up.
- Design drift field strength reduced to more moderate values, requiring only 30kV on cathode
- All TPC electrodes made from single wires







Target Mass	5.9t (cold)
# of PMTs in top	253
# of PMTs in bottom	241
Design drift field	200V/cm
Design extraction field	8kV/cm

NEW SYSTEM: PMT ARRAYS

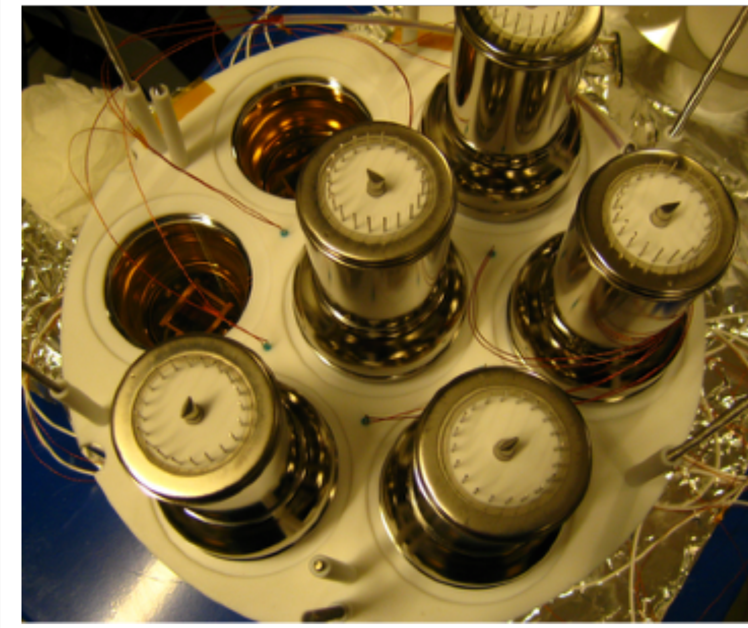
PMT(R11410-21):

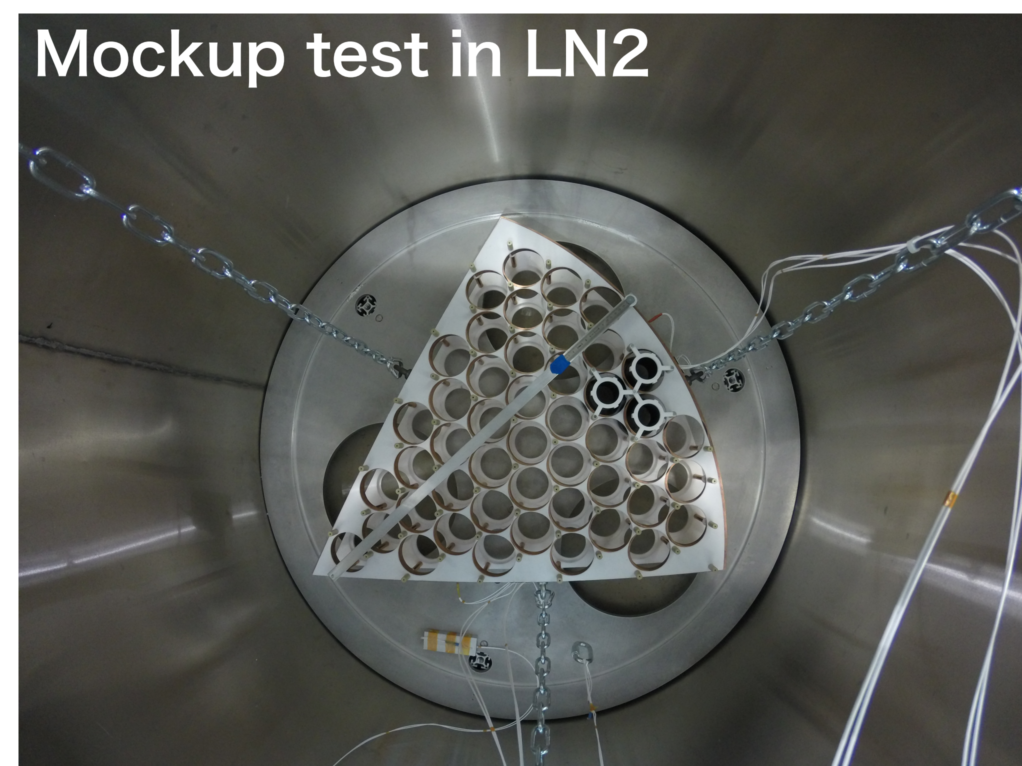
- Each array contains 253 PMTs (top) and 241 (bottom), ~90% of XENON1T PMTs reused
- Initial problems of some 1T PMT production batches (vacuum leak) now under control
- All PMTs are under test in LXe facilities.

PMT Arrays:

- accommodate a thermal shrinkage of ~1cm at the edges of the array;
- allow maximum photo-cathodic area; minimize the PTFE wrt XENON1T design;
- not exert direct force on PMT quartz-cover sealing;
- ensure flatness of the PMT arrays (below 0.7mm deflection) under any circumstances (both during assembly and with the strong buoyancy from LXe)
- Design successfully tested with a slice mockup
  - Behaved as expected through full thermal cycle down to -95C.

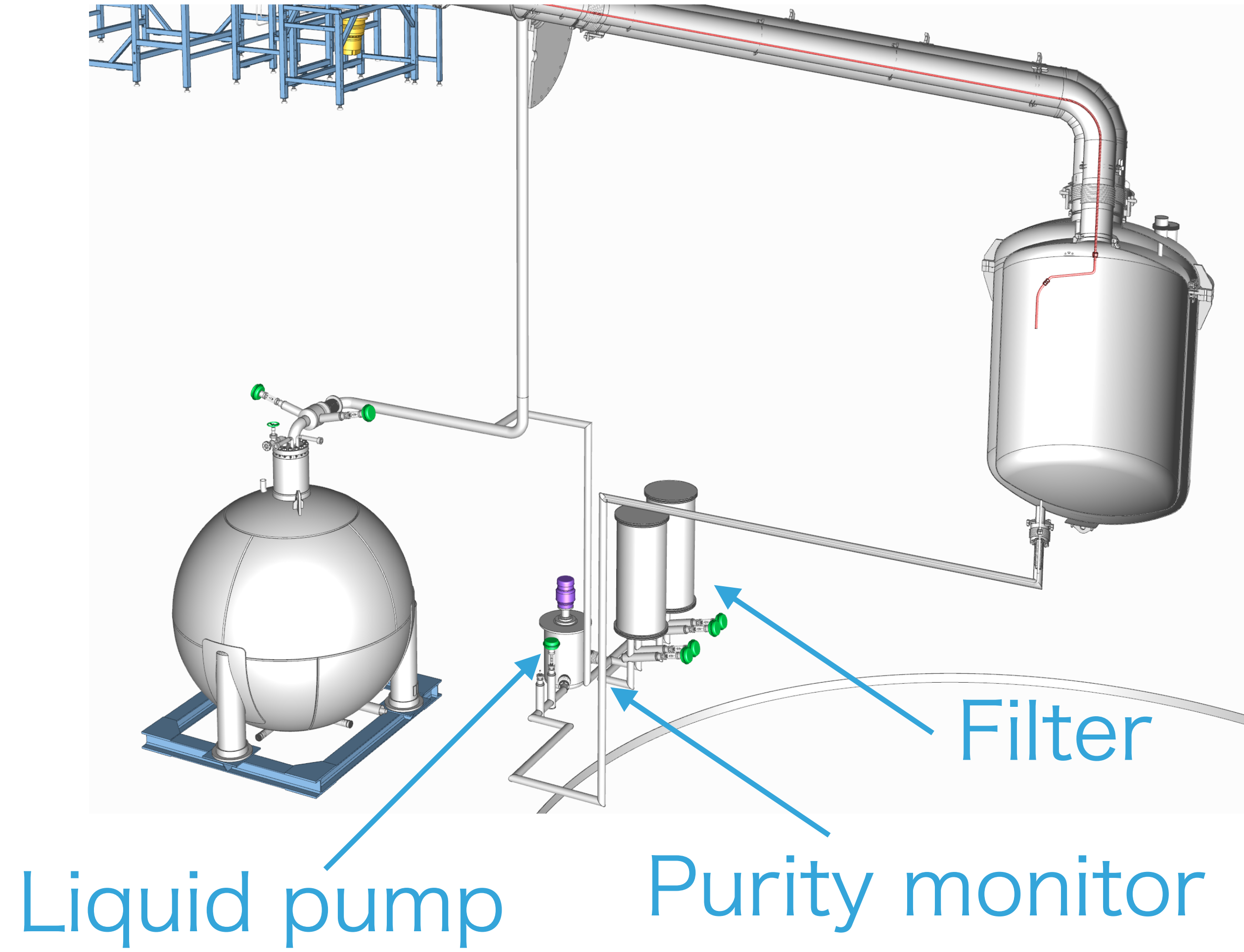
LXe test facilities





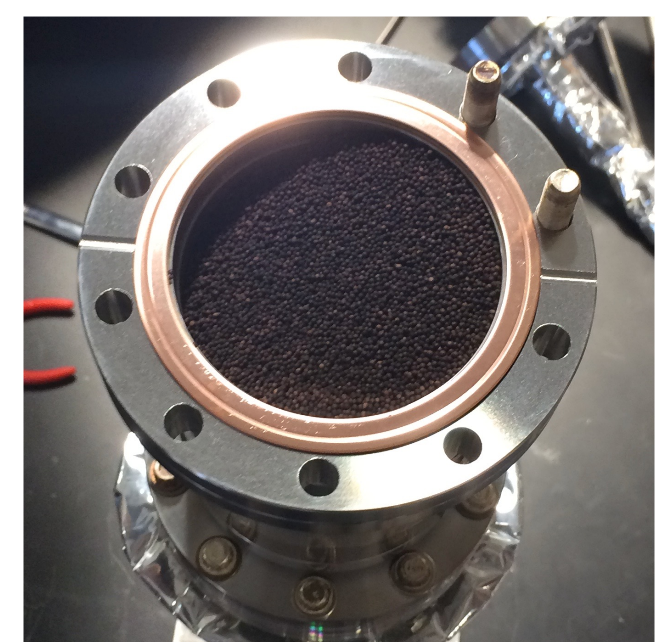
NEW SYSTEM: LIQUID XENON PURIFICATION

- Planned recirculation flow
  - >5 L/min (LXe) (> 2500 slpm GXe)
- Capability to reduce $O_2 \ll 1$ ppb
- 2 redundant commercially-available cryogenic liquid pumps (Barber- Nichols)
- Two custom-developed, regenerable, cryogenic filters ($2Cu+O_2 \rightarrow 2CuO$)
- Installed inside independent vacuum-insulated enclosures for maintenance
- Capability to rapidly measure electron lifetime (tens of seconds) with purity monitor
- Optimization of filter material and measurements of LXe purity ongoing
- Installation will start at 2019 Feb



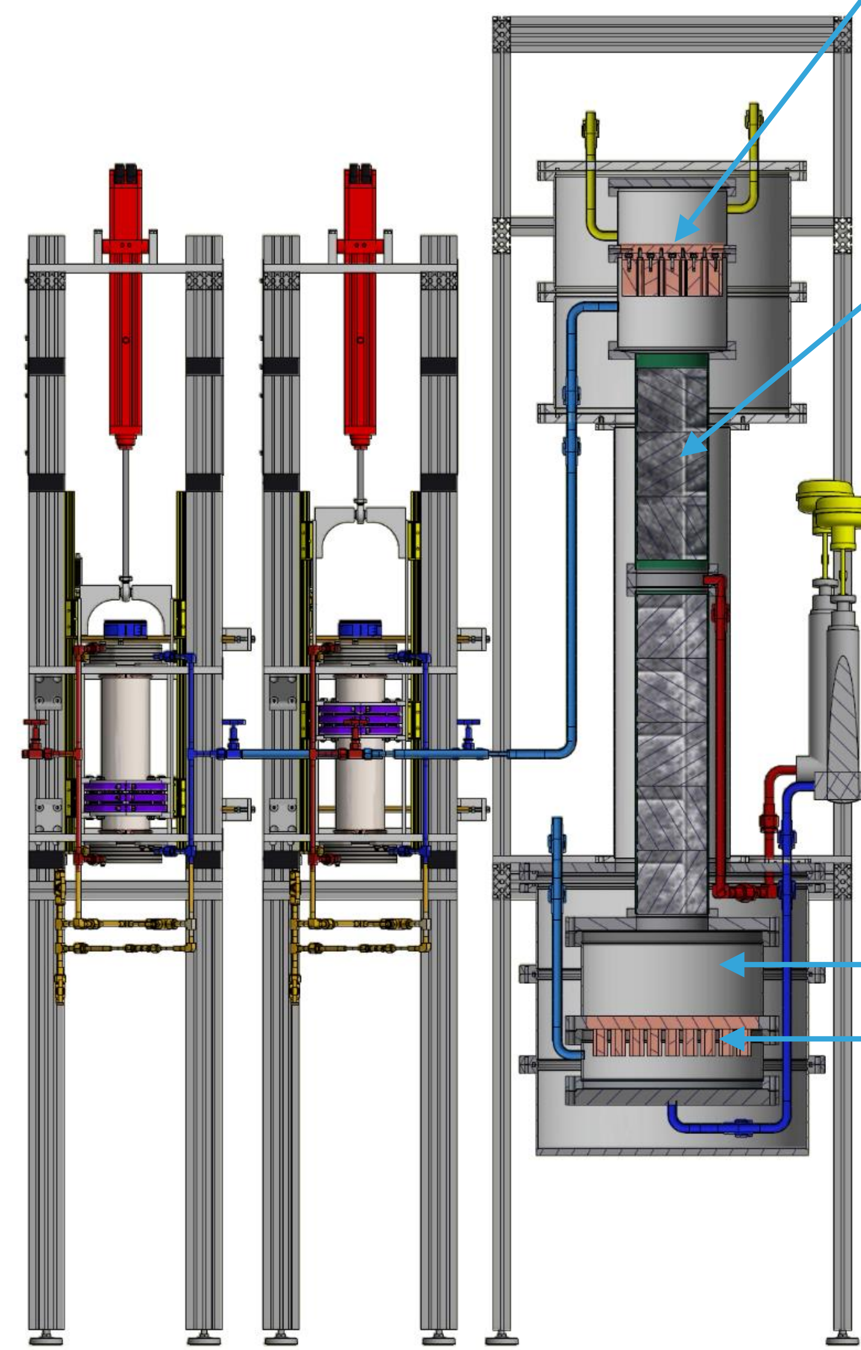
Purity monitor

Alumina pellets with Cu



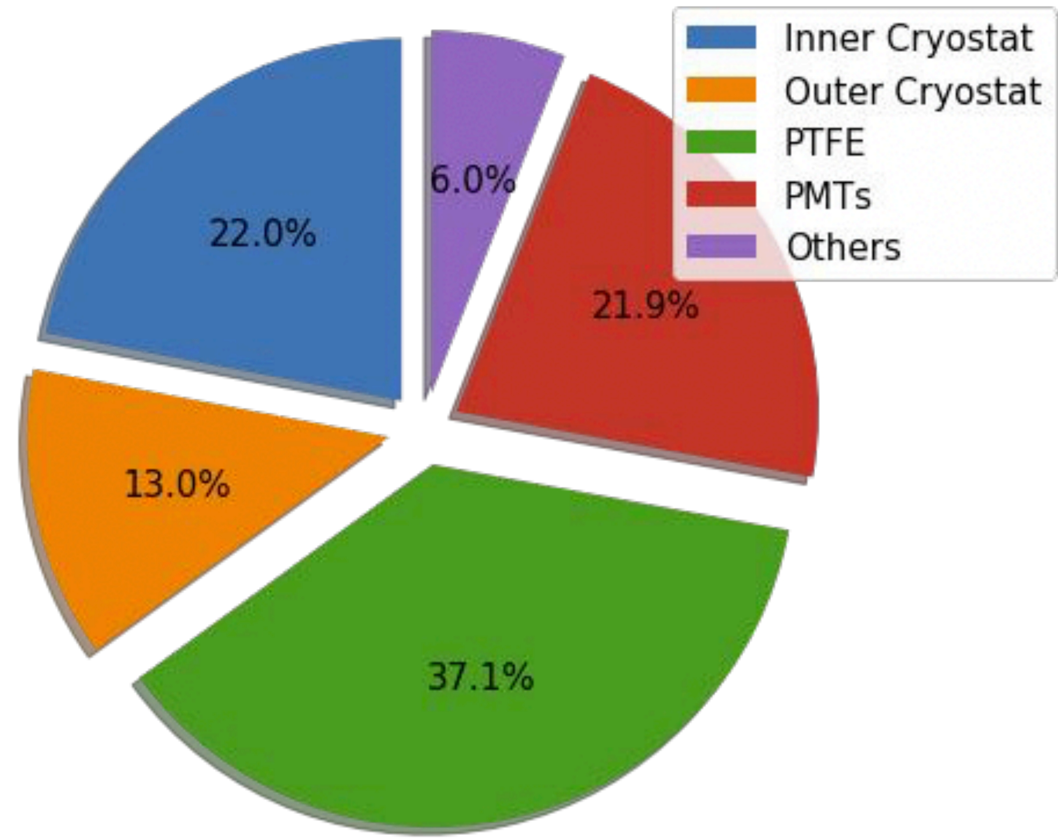
NEW SYSTEM: ONLINE RADON REMOVAL COLUMN

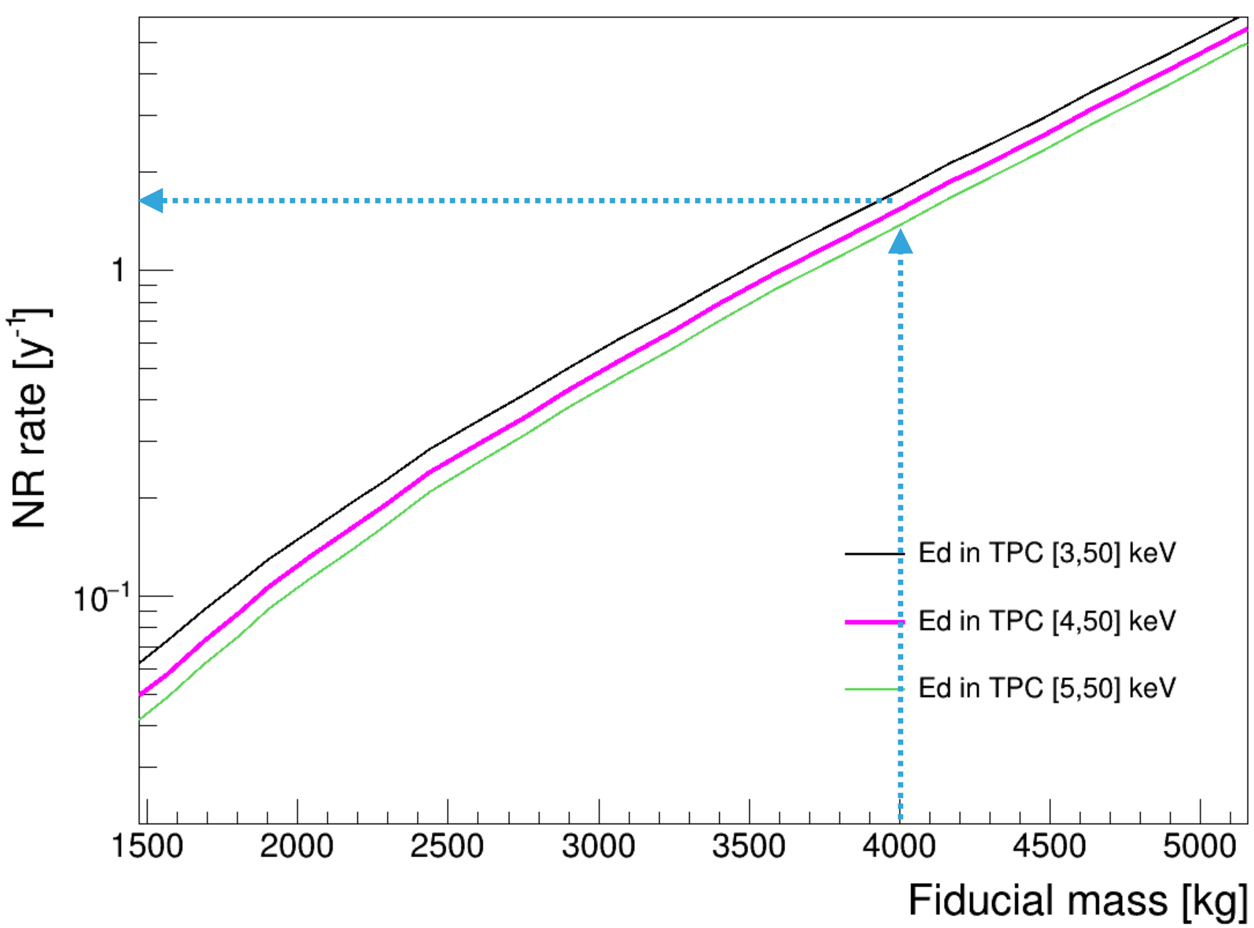
- Cryogenic distillation: remove ^{222}Rn from Xe "off-gas" (fed to TPC) and store in liquefier Rn-enriched Xe.
  - most Rn emanated from the gas system and pipes (type II sources) can be stored away long enough for it to decay (5.5 d lifetime).
- Need enrichment factor of at least ~100 not to remove too much Xe from the TPC.
- Tested Kr-column in reverse mode with XENON100 and XENON1T (3 slpm, not optimized):
  - Rn concentration@XENON1T ~ 4 μBq/kg
  - Reduction by 65 % w.r.t SR1 (factor 2.7) together with magnetic piston pump
- Built optimized Rn column for high throughput (> 200 slpm).
- Upgradable to 400 – 600 slpm (for type I Rn dilution of factors 3-4).



NEW SYSTEM: NEUTRON VETO

- NR becomes dominant background once Rn is removed as planned:
- Raw materials under procurement and screening ongoing
- PRELIMINARY estimate:
  - 1.8±0.4 NR events / yr in [4-50] keVr in 4 t FV without neutron veto, dominated by PTFE





Active neutron veto

- For best DM discovery potential, aim at neutron tagging efficiency > 80%
- Helps modeling neutron background
- Check efficiency with neutron generator/ ^{241}AmBe

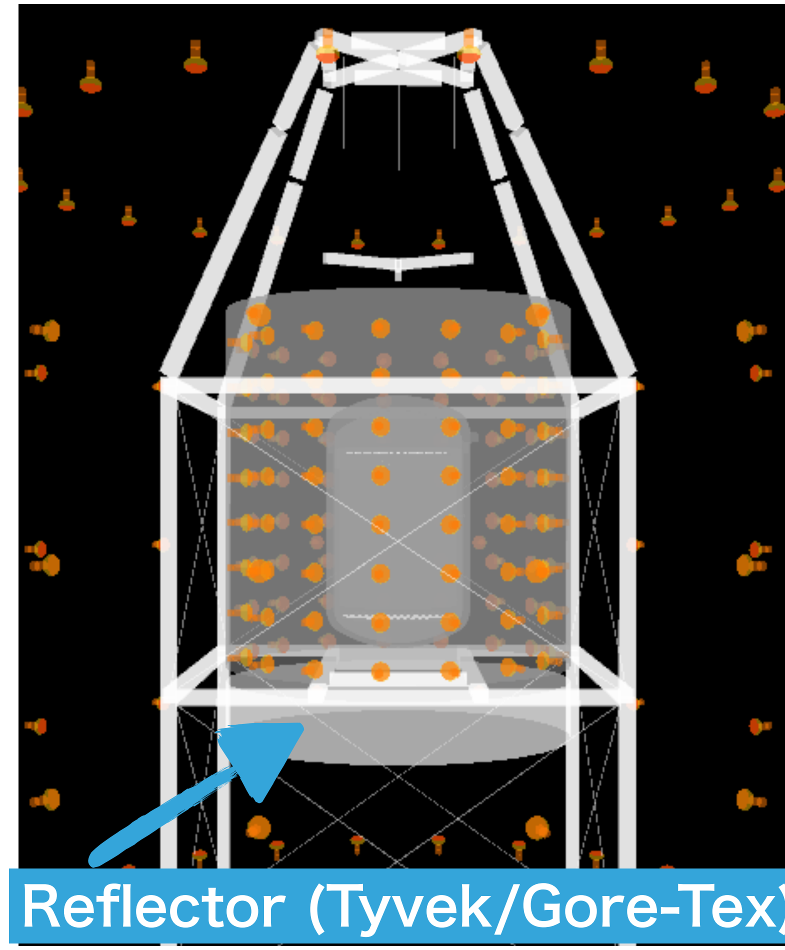
NEW SYSTEM: NEUTRON VETO

We have investigated different options:

- Gd loaded LS (STEREO, DC, Daya-Bay, …)
- Gd Loaded plastic scintillator
- Gd loaded water (EGADS, SuperK-Gd,…)

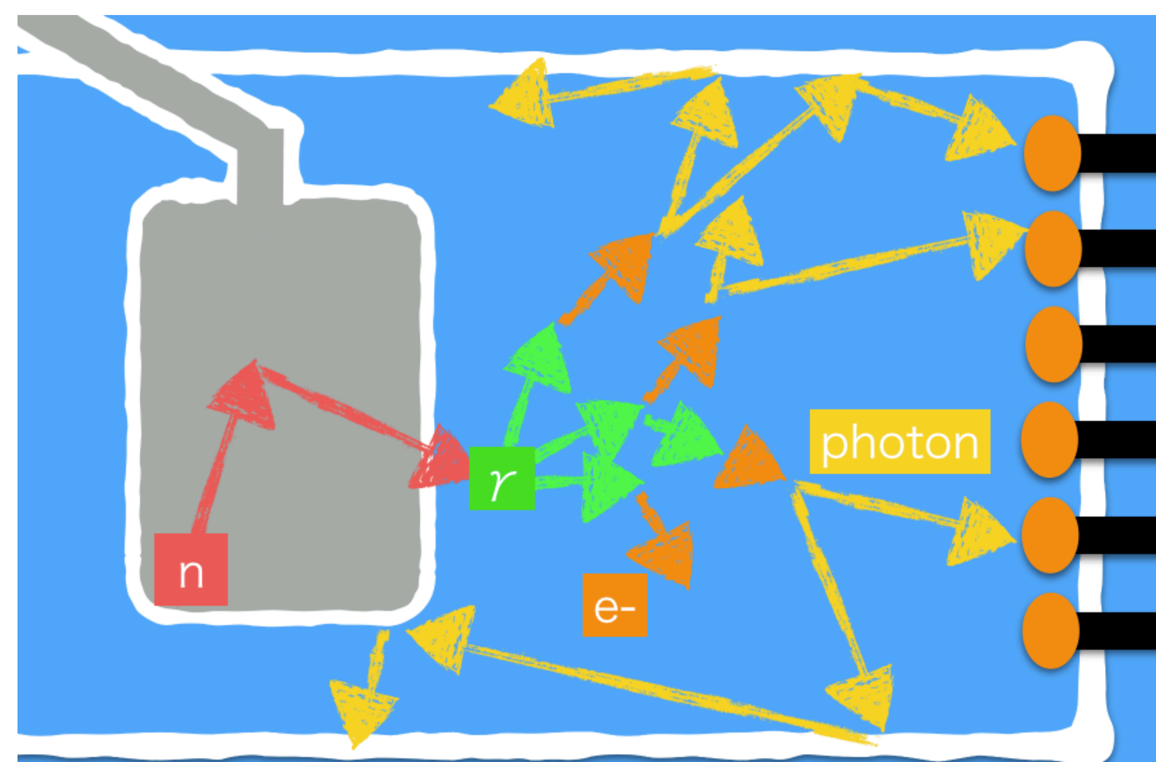
Feasible, mature, safe, affordable, schedule,

→ **We chose Gd loaded water!**



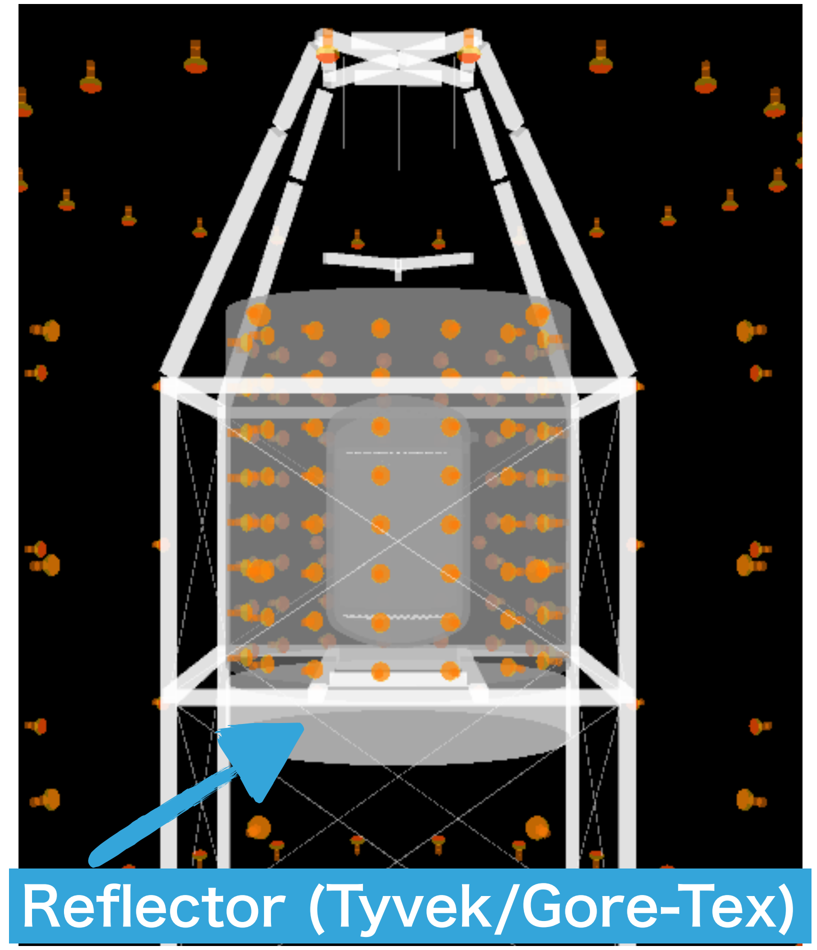
Cherenkov light from Compton electrons of gamma-rays (8MeV) cascade from n-Capture

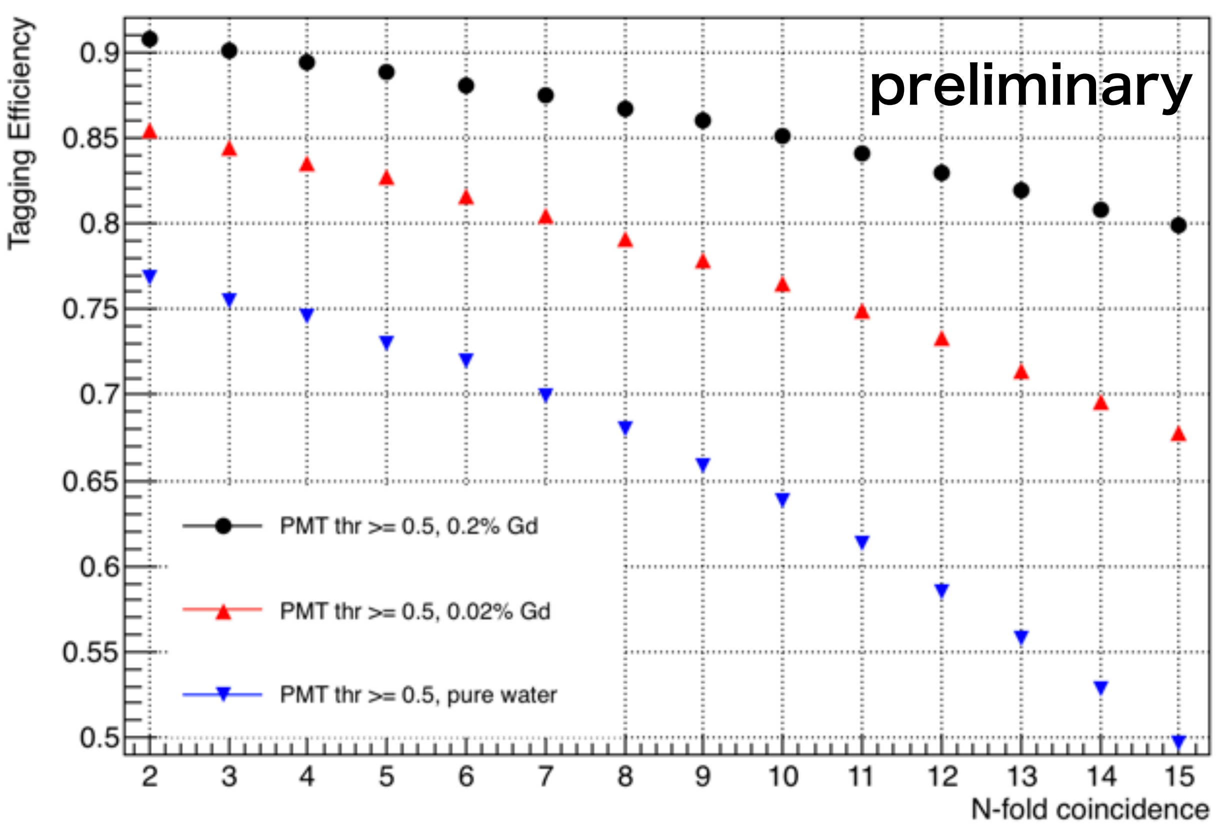
- Add 0.5% of $Gd_2(SO_4)_3 \cdot 8H_2O$ in XENON water tank
  - > 90% of neutrons captured in Gd
- 120 extra PMTs (8-inch R5912, same as for XENON1T muon veto)
- Add inner high light-yield volume, optically separated from MV (Tyveck/Gore-Tex reflector)
  - Shielded from external radioactivity

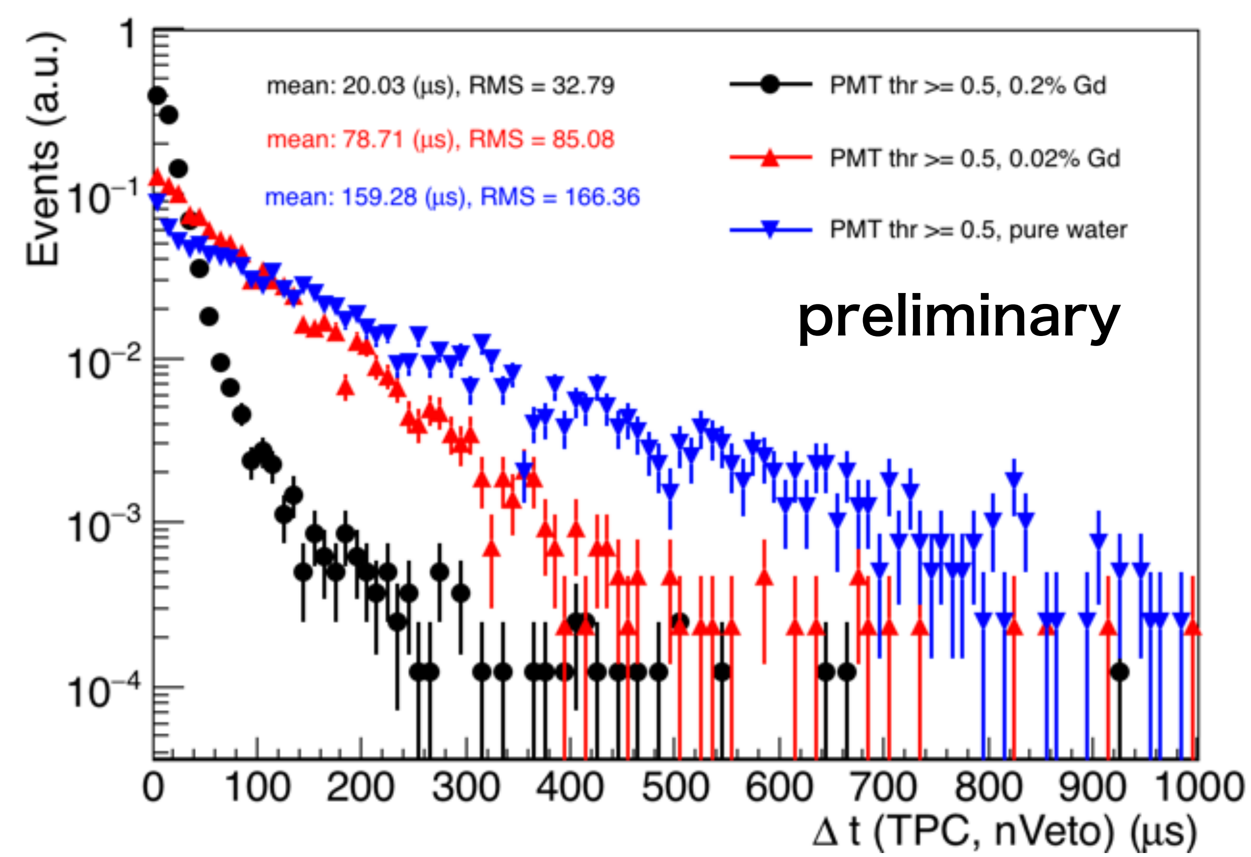


NEW SYSTEM: NEUTRON VETO

- Established technology @ EGADS (= Test facility for SK-Gd)
- Veto efficiency comparable to the LS-Gd (~80%) achievable with highly reflective reflector (Tyvek/Gore-Tex)
- All Gd relevant components are external to tank
- XENONnT will start with pure water
  - check TPC performance, cryostat leakage, …
  - does not delay the overall XENONnT schedule
- minimal obstruction for calibration sources
- no gap in azimuthal coverage of the n-veto







OUTLOOK

XENONnT schedule:

- Construction already started in 2018
- XENON1T still running well with improved background
  - keep operational throughout 2018 for science data and testing
  - Rn concentration@XENON1T of ~ 4μBq/kg has been achieved
  - Achieved energy resolution of ~1% (σ) at Q-value of 0νββ of 136Xe
  - Will test ^{37}Ar source for low-energy ER calibration
- Commissioning of XENONnT will start at 2019 Summer