Thoughts on cryostat, infrastructure, and safety for an FPF LAr TPC detector

Most of this was presented at the 2nd FPF workshop in 2021

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with input from J. Boyd, J. Bremer, M. Chalifour, D. Mladenov

Considerations for LAr TPC cryostat

Considering an active mass of 20 ton* (no attempt to define requirements of the detector itself)

Modular assembly approach for installation underground

Tightness and LAr purification for drift electron lifetimes of *O*(3 ms) (*O*(100 ppt) O_2^{eq})

LAr in a close loop, re-condensing boil-off, reduce heat input

Passive insulation for failsafe long-term operation

Withstand hydrostatic pressure, overpressure of few 100 mbarg and detector weight

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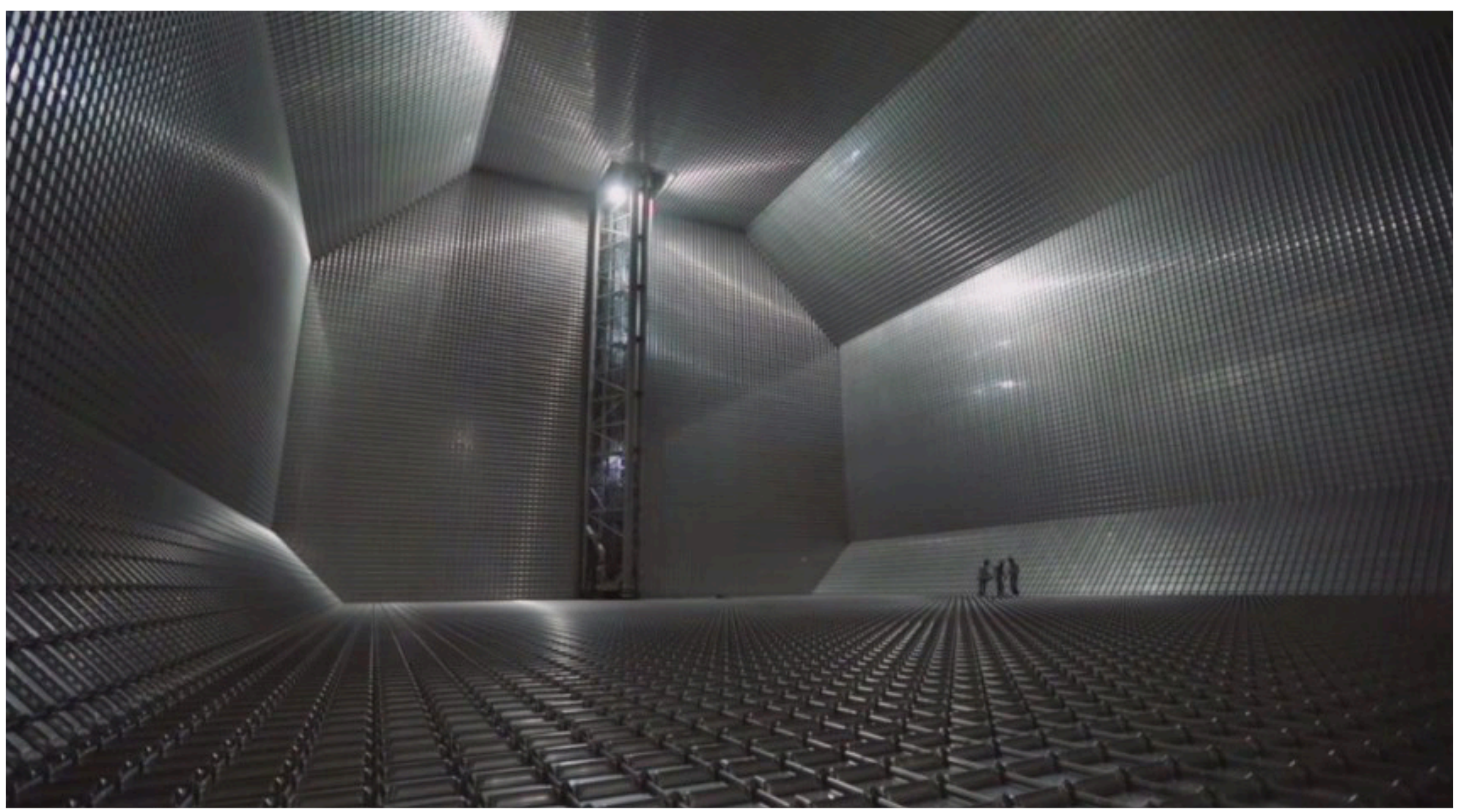
FLArE–10 (10 tonnes) : $L = 480$ m, $\Delta = 7$ m, $S_T = (1 \text{ m} \times 1 \text{ m})$,

FLArE–100 (100 tonnes) : $L = 480$ m, $\Delta = 30$ m, $S_T = (1.6 \text{ m} \times 1.6 \text{ m})$,

The technology

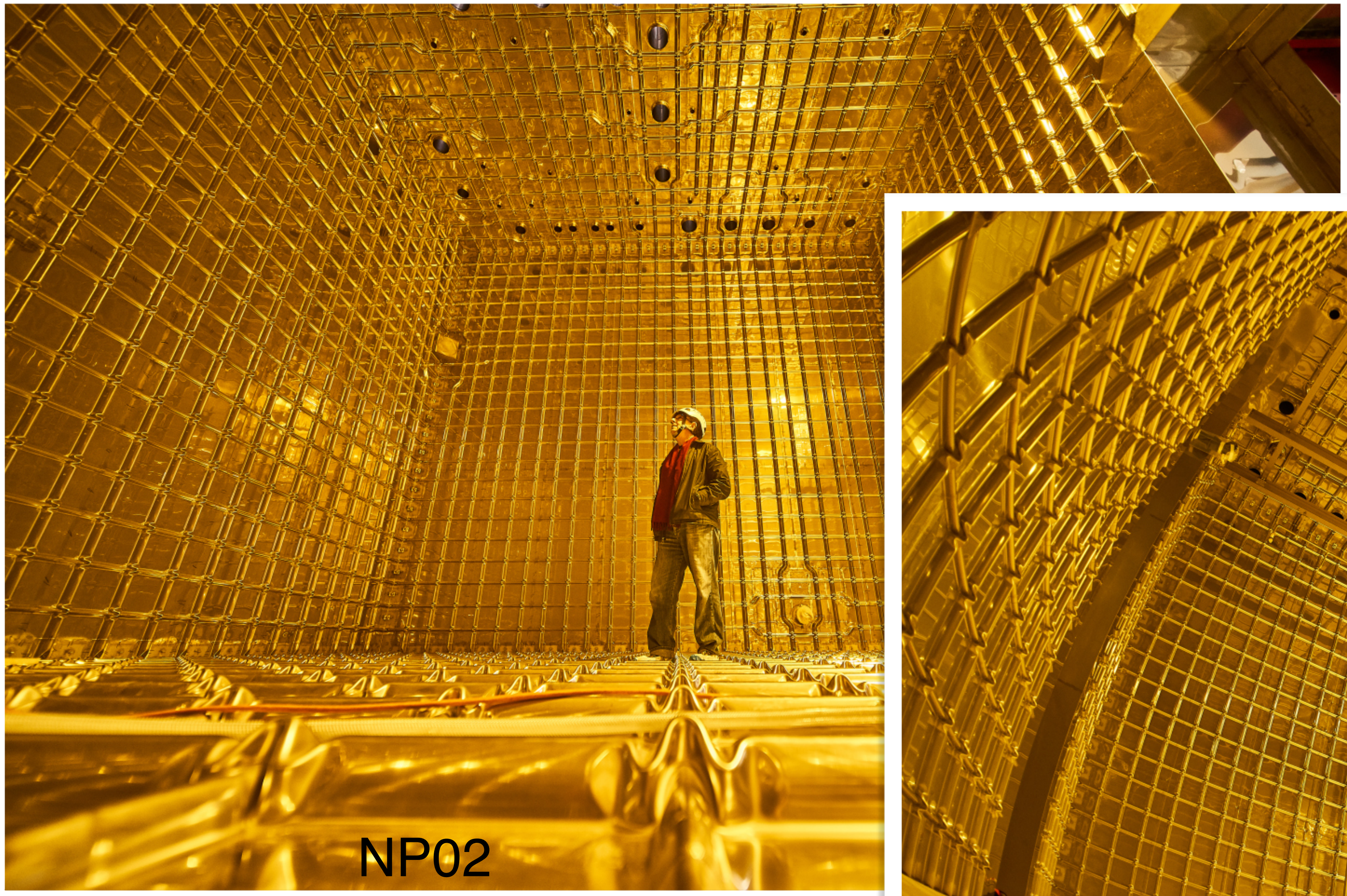
Royalties owner: GTT (France)
Construction licensee: firms homologated for components construction and installation
Applications:
- LNG carriers (>200000 m^3 in 3 sub-tanks)
- Floating storages and re-gasification vessels
- Land storage tanks
- Fuel tank for vessels
- *Cryostats for liquid argon Time Projection Chambers*

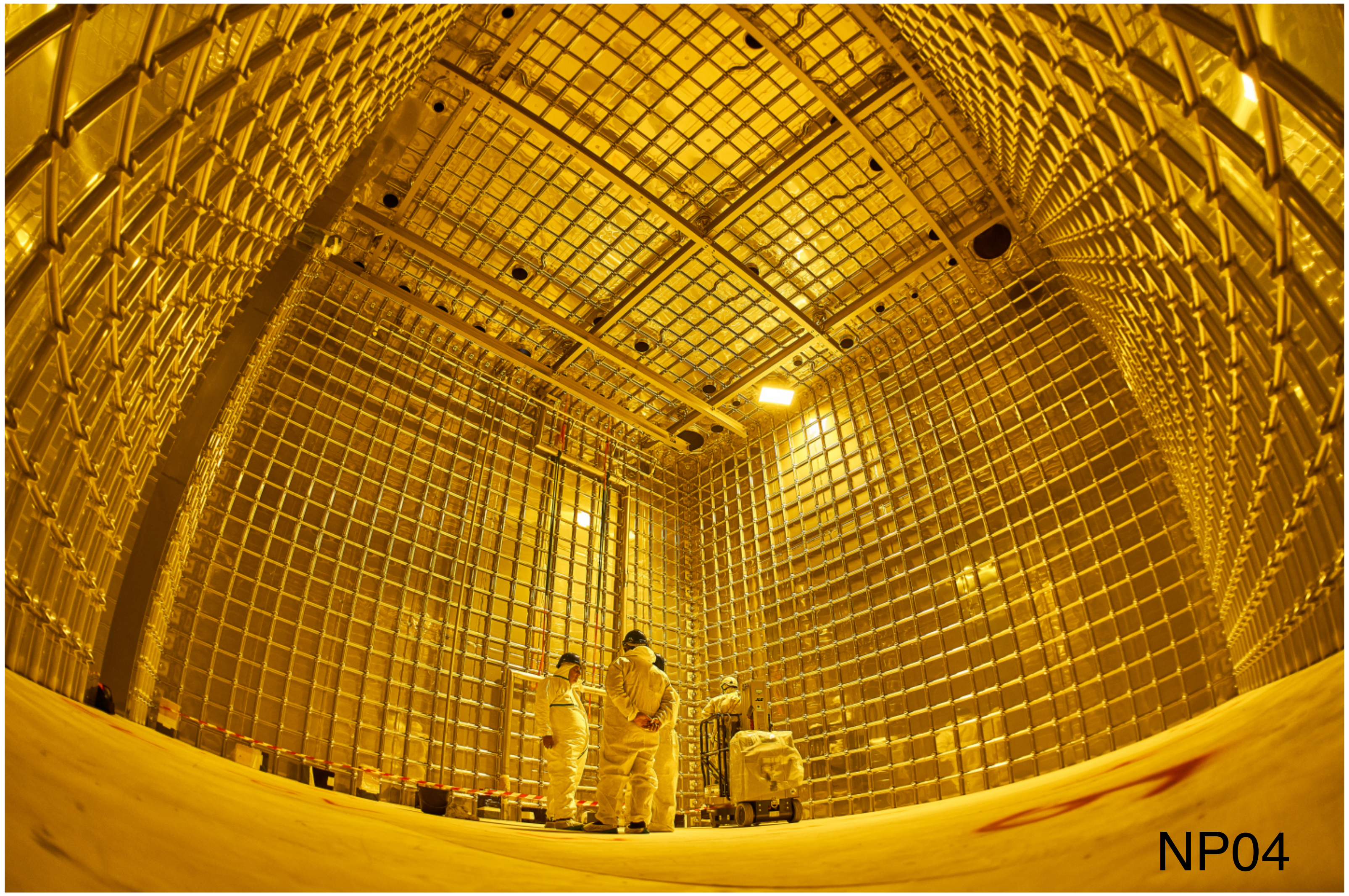


www.gtt.fr

ProtoDUNEs

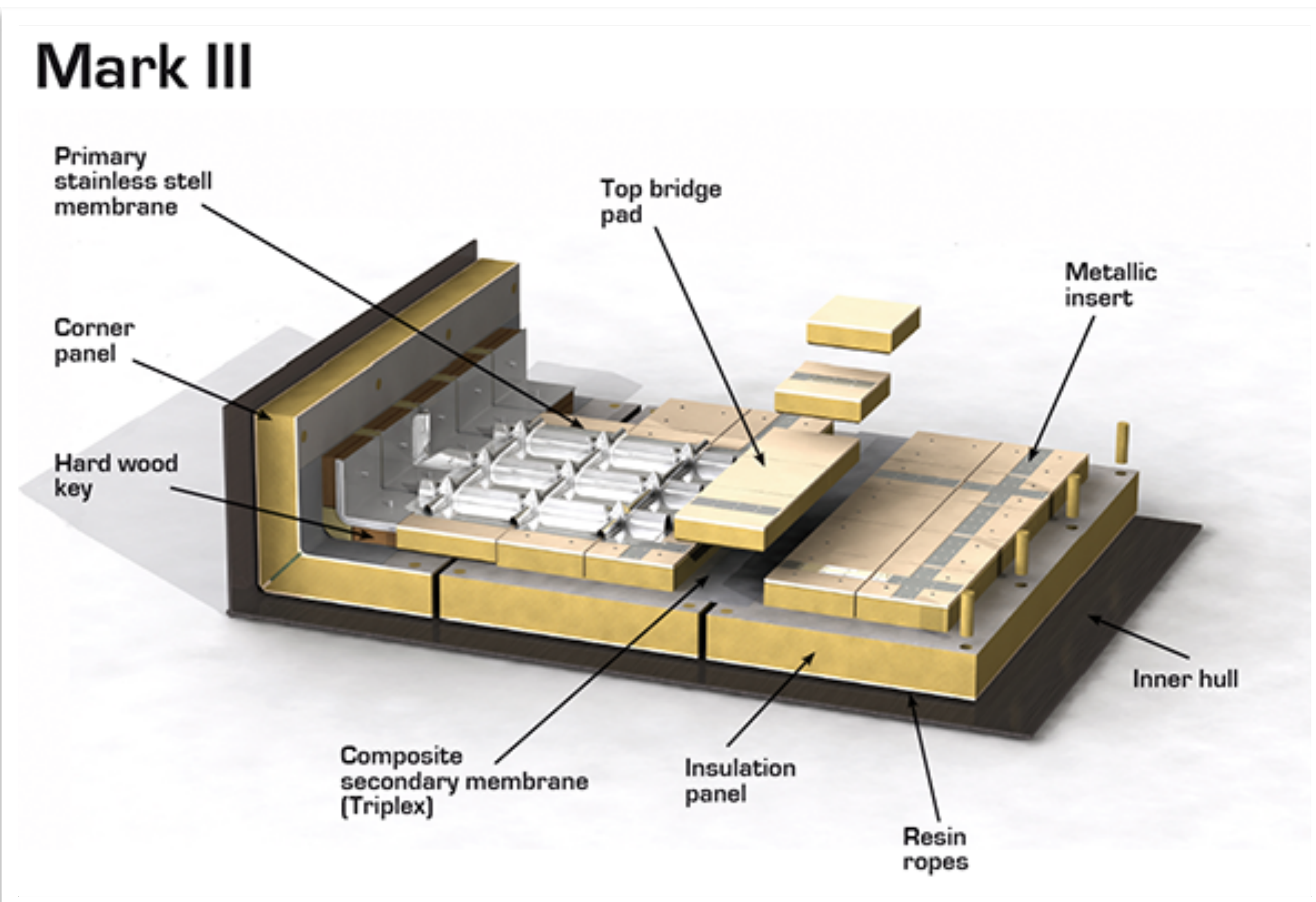
Two (NP02 and NP04) membrane cryostats containing ~750 ton of ultra pure argon.
Prototype and demonstrate of TPC technologies for DUNE far detectors.
- NP04 exposed to North Area charge particle beam and operated till summer 2020.
- NP02 operated from summer 2019 to fall 2020.





GTT Mark III technology

Primary membrane: in contact with the liquid. Flexible and elastic to accomodate wave impacts, vessel deformation, thermal expansion and contraction. Not self supporting.
Thermal insulation: passive, modular, in between and directly connected to the primary membrane and the *hull*.
Hull: the warm structure, sustains and support the entire system.



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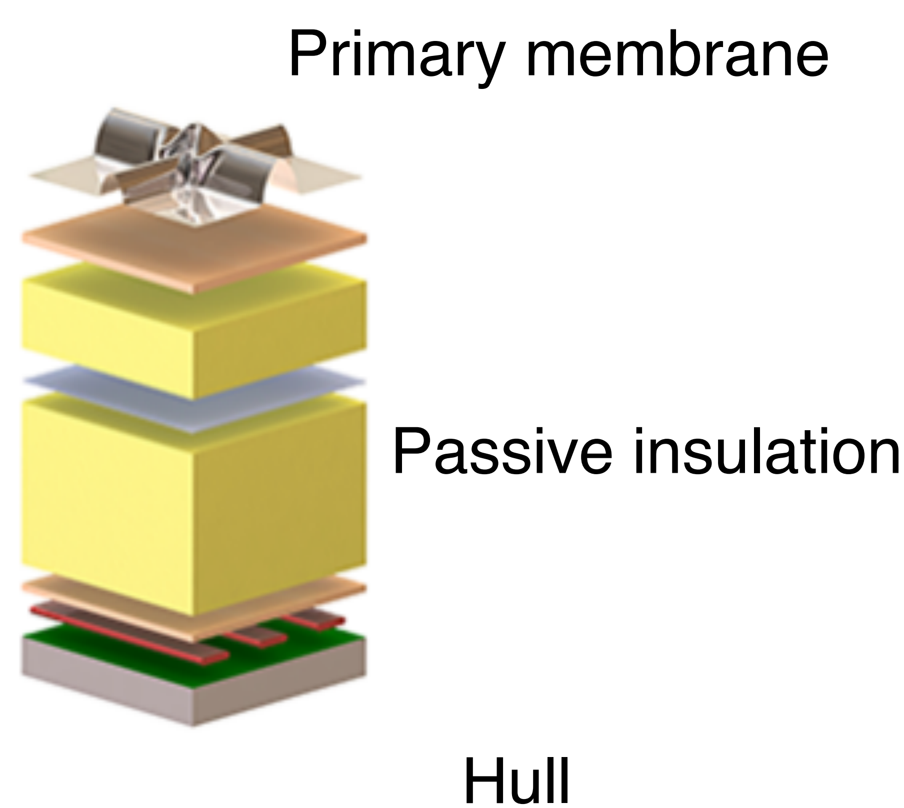
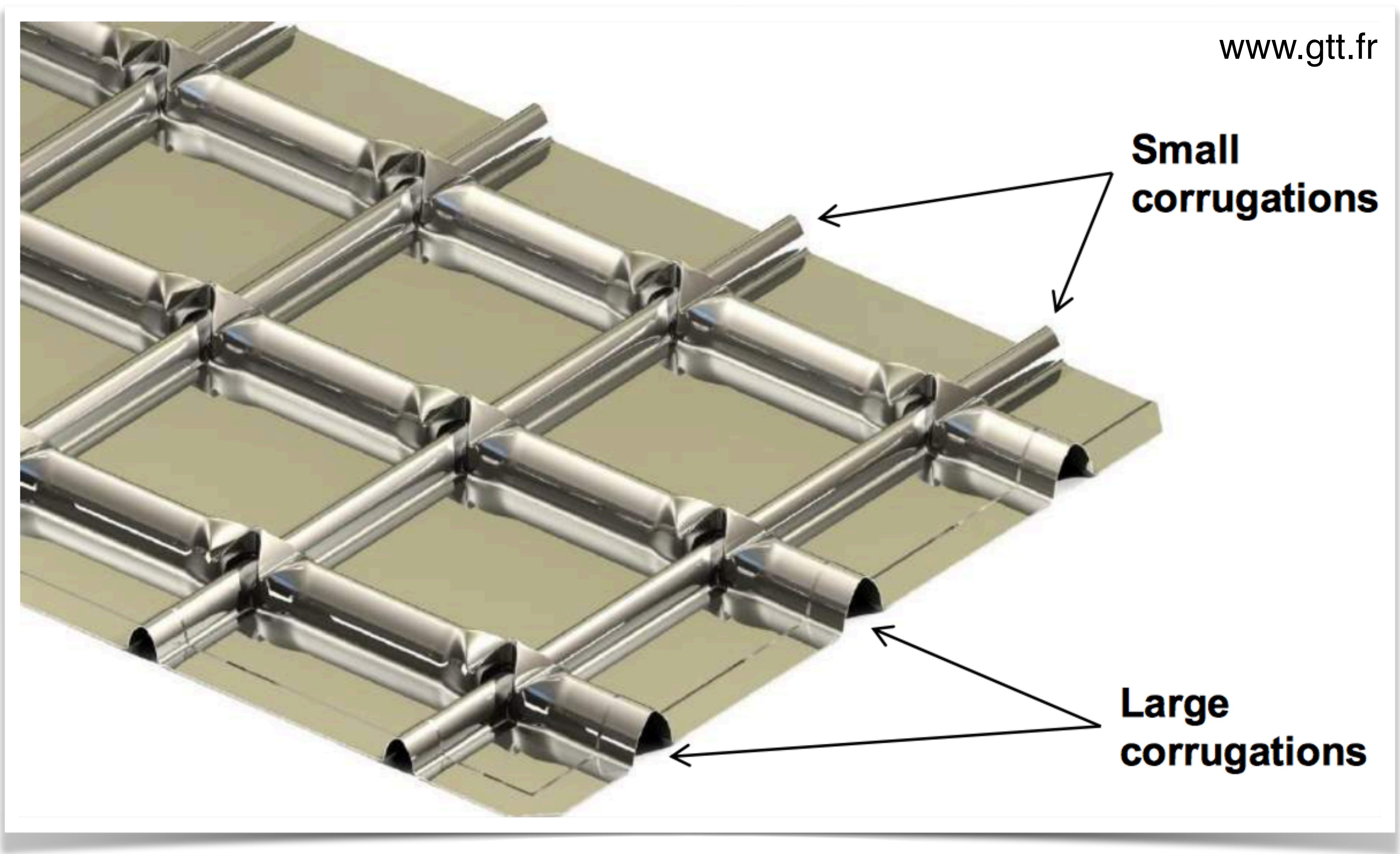


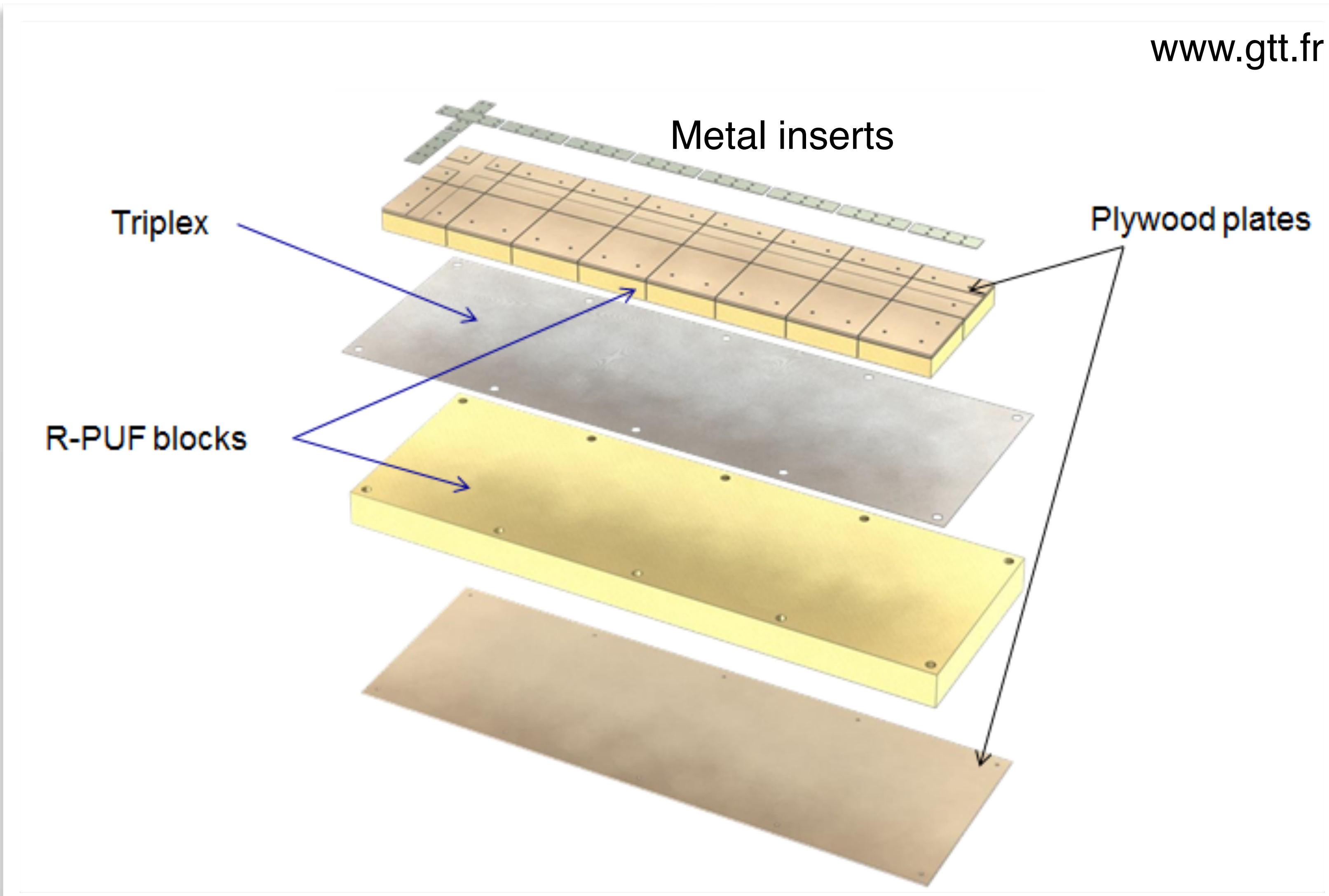
GTT Mark III technology

Primary membrane:
Stainless Steel 304L, 1.2 mm thick, ~1 m x ~3 m 'tiles' (eventually welded together), with corrugation (acting as springs) along the two orthogonal directions (340 mm pitch).
Highly standardised components.
Special components for Protego valves (input to purification), and roof penetrations.



GTT Mark III technology

Insulation:
Two layers of polyurethane foam (90 kg/m^3) separated by the secondary membrane.
Metal inserts on the plywood serve as welding points for the primary membrane.
No direct metal contact between warm structure and primary membrane.
Highly standardised components.
Special components for Protego valves, and roof penetrations.



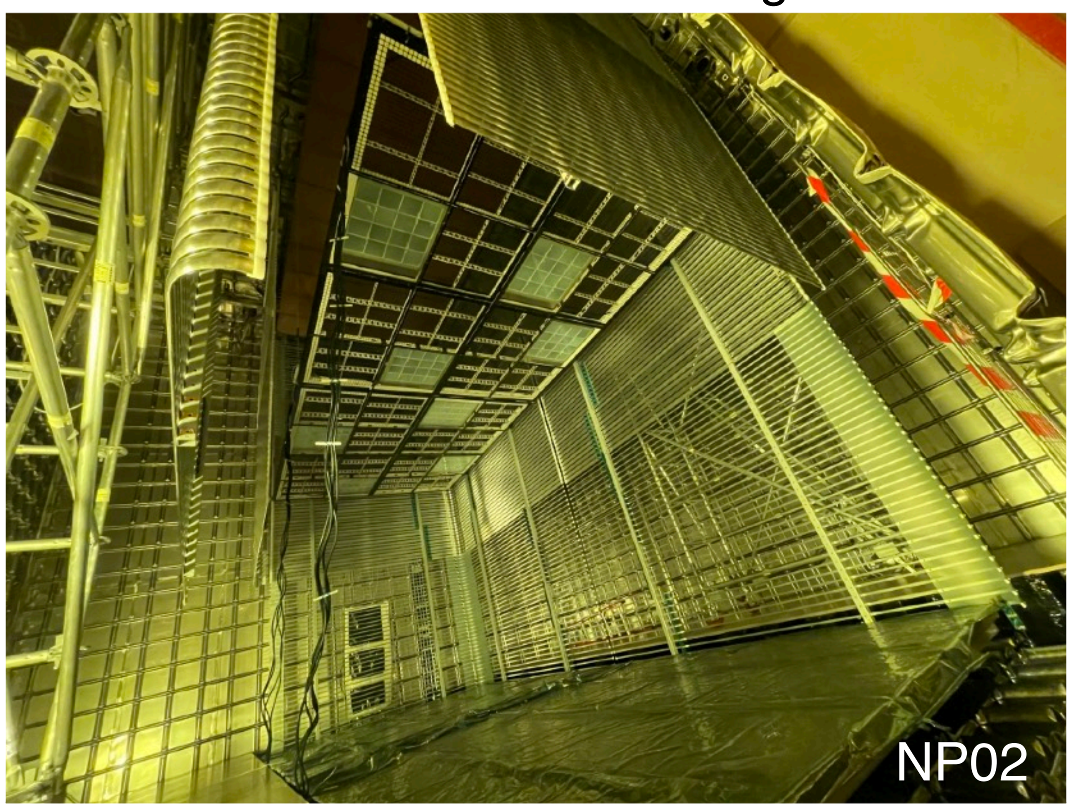
Two flavours of TPCs

Horizontal Drift
- APA: three sets of wires winded around a SS frame
- Electronics in LAr including digitisation
- Drift of 3.5 m, CPA at -175 kV nominal voltage
- PDS embedded in the APA frames

Vertical Drift
- CRP: perforated PCBs stuck with electrodes segmented
- Top CRPs readout with accessible electronics
- Bottom CRPs electronics in LAr including digitisation
- Cathode in the middle, 6.5 m drift, -300 kV nominal
- PDs on the cryostat walls and on the cathode

Phase 2 installation completed

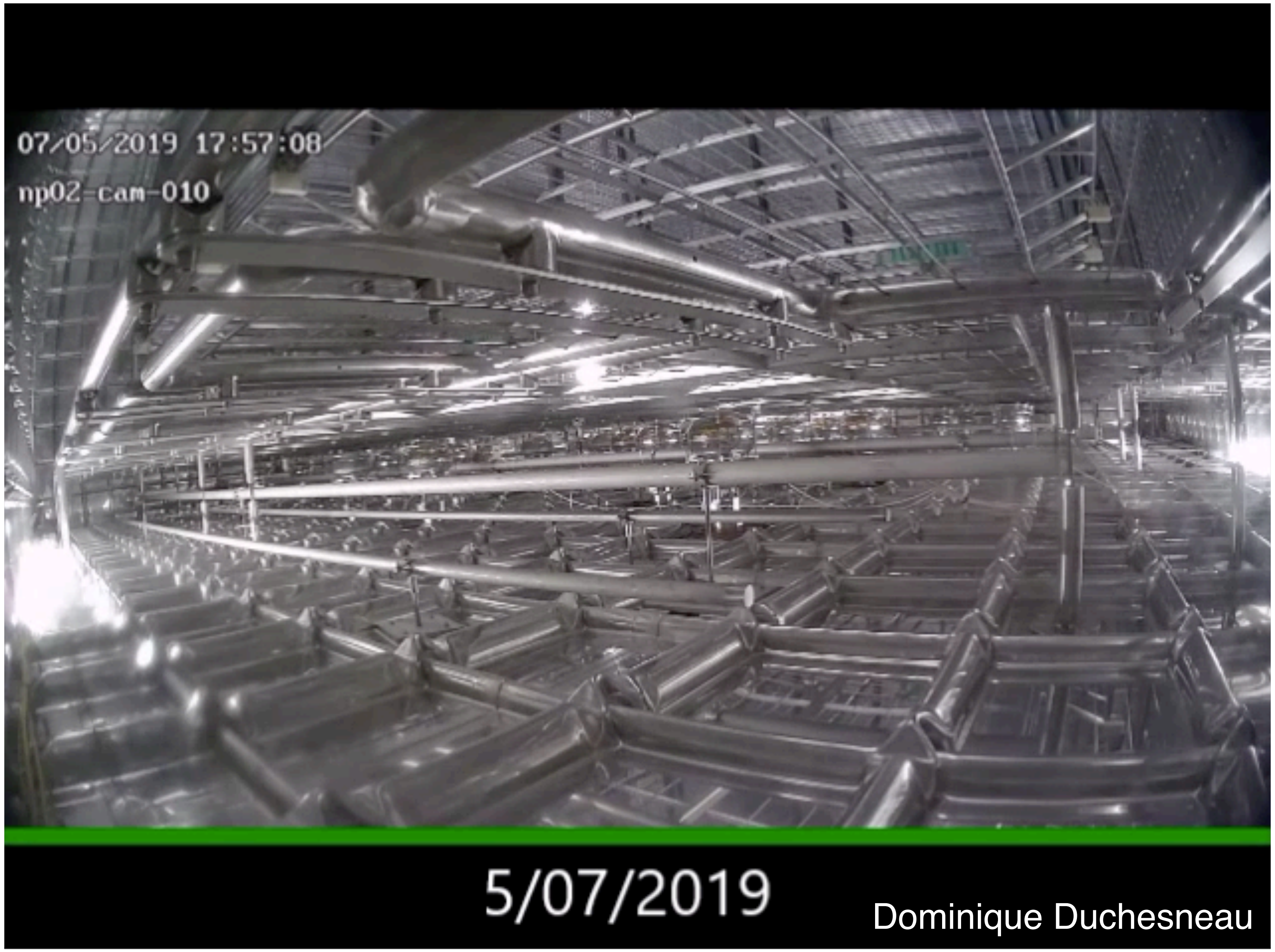
Installation in final stage



There are **other types** of TPC implementation, for instance exploiting:
- pixelated readout on PCB with electronics in LAr
- optical (proportional scintillation in Argon vapour above the liquid) readout

NP02 filling

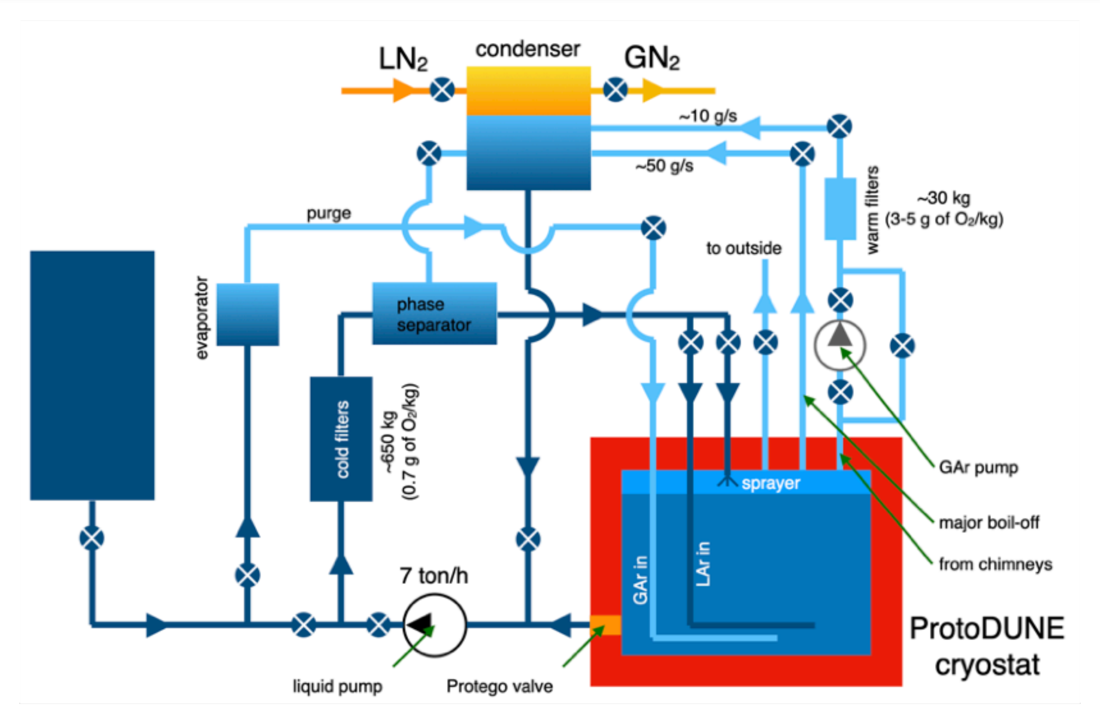
Video: https://cernbox.cern.ch/index.php/s/AjG1OX7kUjX23s0



NP02/NP04 vs LNG tanks

- More stringent heat input
- Smaller (~8x8x8 m^3 compared to ~30x30x40 m^3)
- LAr (single spice) denser than LNG (multiple spices)
- Extreme purity requirements (< 100 ppt O_2^{eq})
- Side penetration for LAr circulation and purification
- Penetrations on the roof for detector feedthroughs
- Beam entrance (less dense insulation where beam passes)
- Detector installation after cryostat completion
- Temporary Construction Opening closure after detector
- Fewer thermal cycles
- No serious sloshing risks (even in case of earthquake)

ProtoDUNE cryogenics

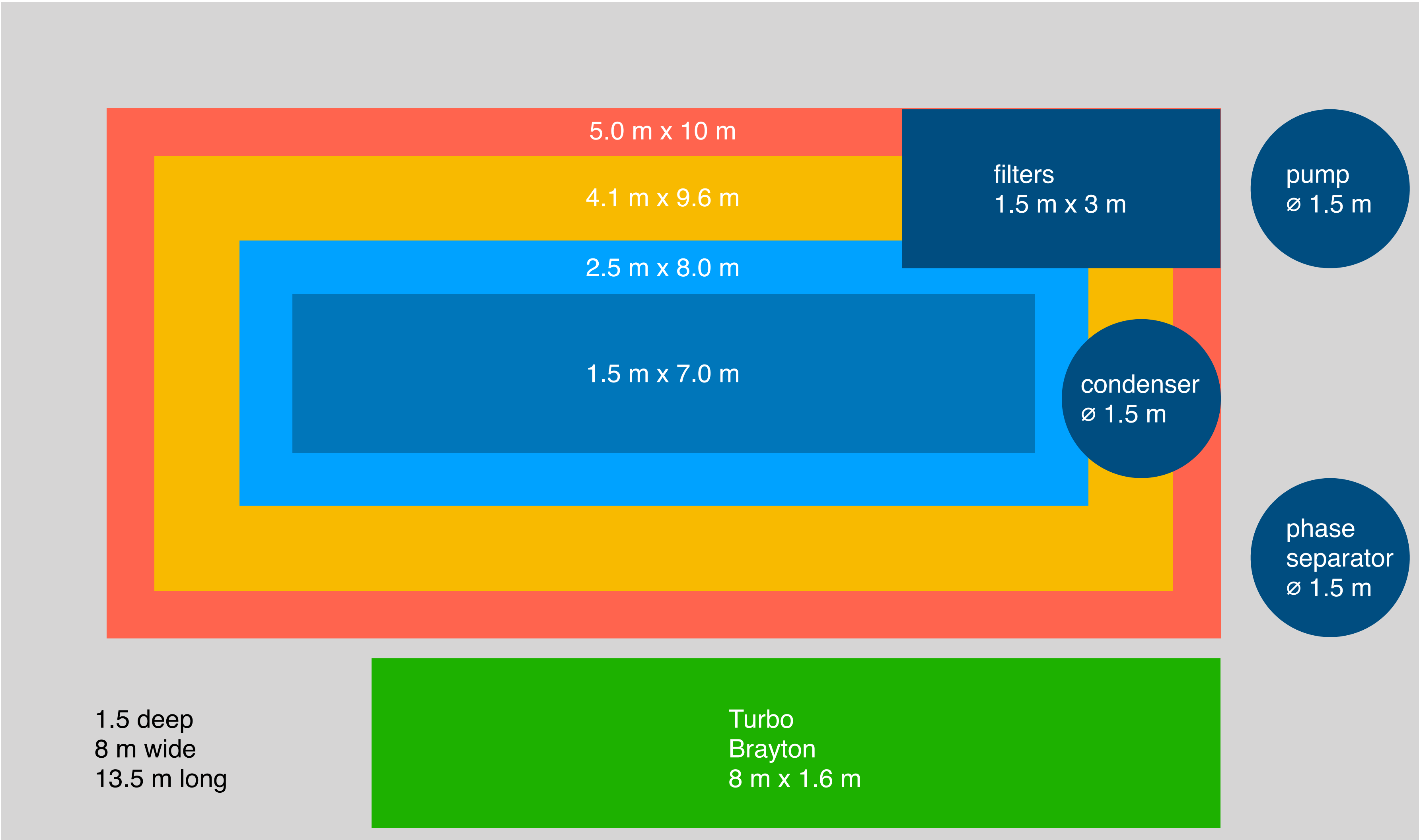


Functions:
- Keep stable thermodynamic condition in the cryostat
- Achieve and maintain the required LAr purity
- Mix uniformly the LAr (temperature, contaminants, …)
- Close system: condense the boil-off
- Provide the cryogenic safety in any conditions

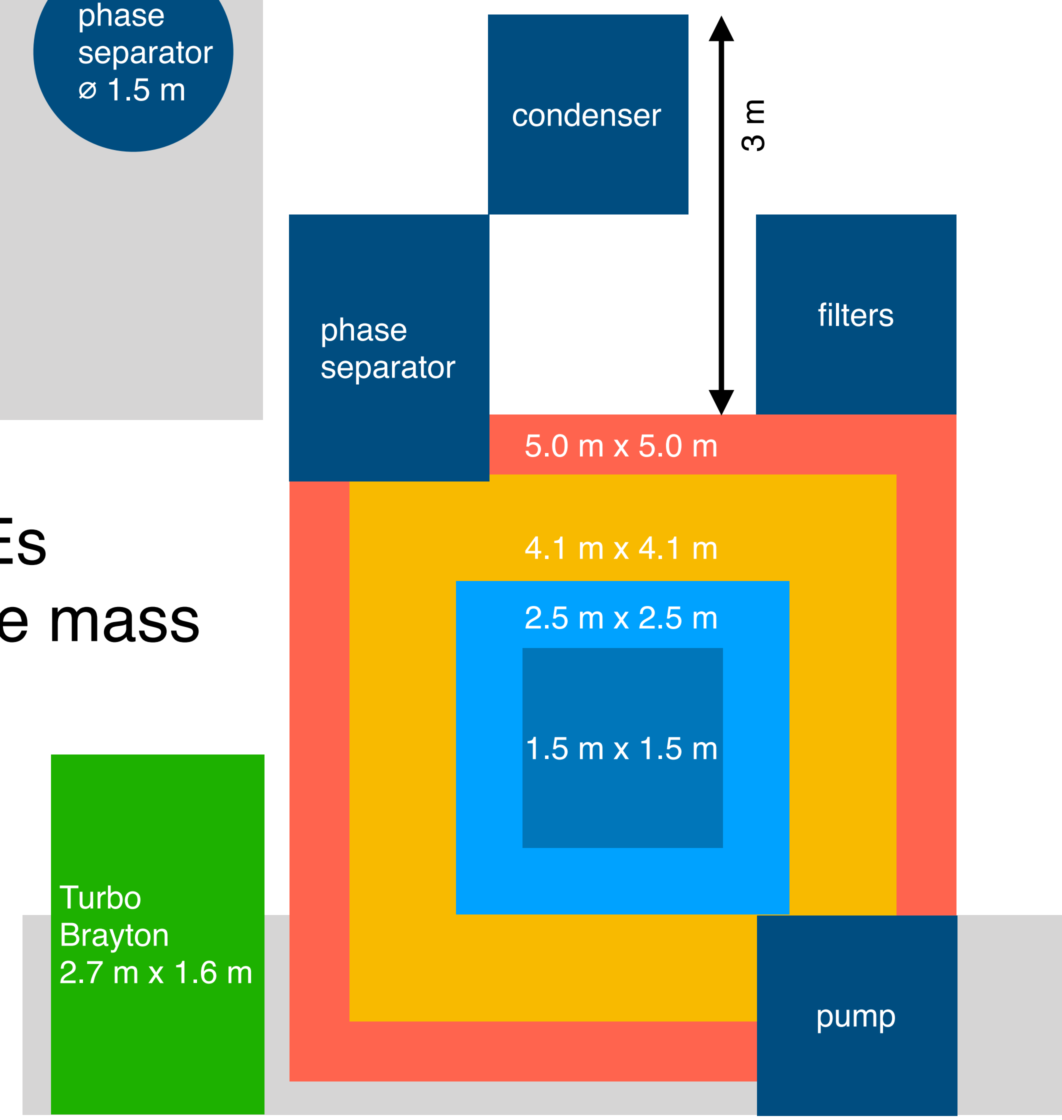
***External* cryogenics:**
- storage of the LAr for filing
- stores and provides LN2 for cooling
- mix the gas for the filter regeneration

Proximity cryogenics:
- manages the warm gas
- recovers the boil off
- push LAr through filtration system

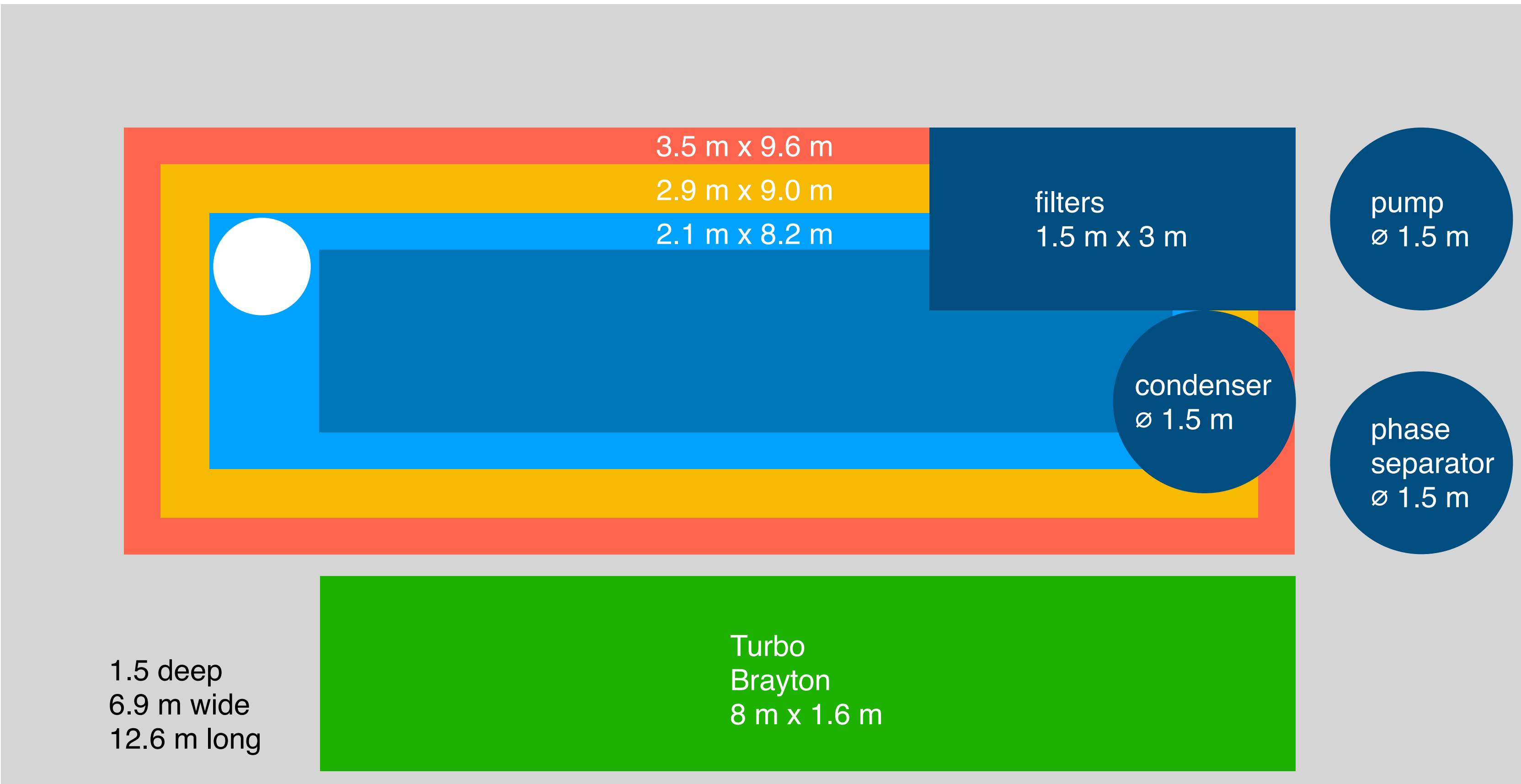
How it may look like for FPF



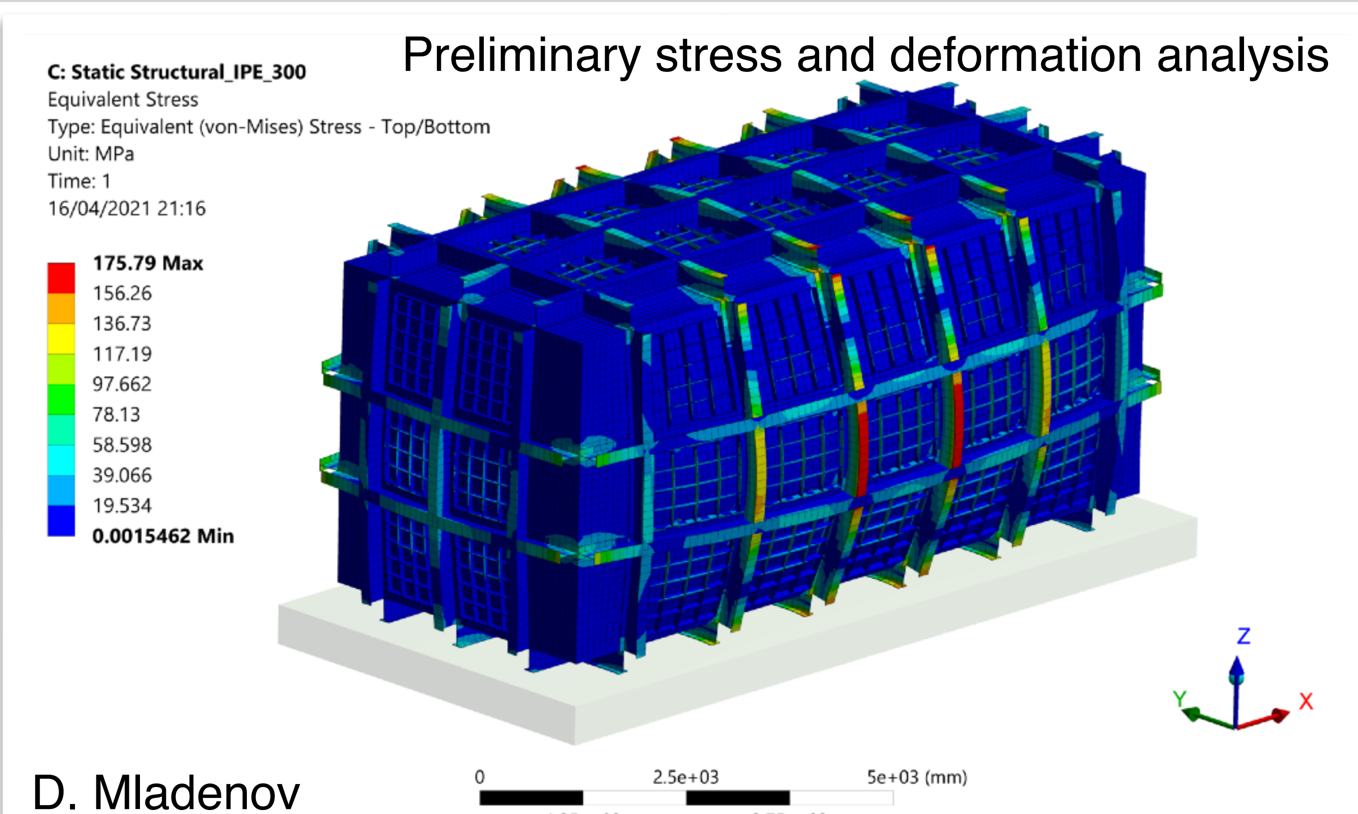
First guess scaling solutions adopted for ProtoDUNEs
Volume occupied excessive with respect to the active mass
Expensive implications on the cavern excavation
TPC must be aligned to the LoS.
How the detector is installed? Side opening?



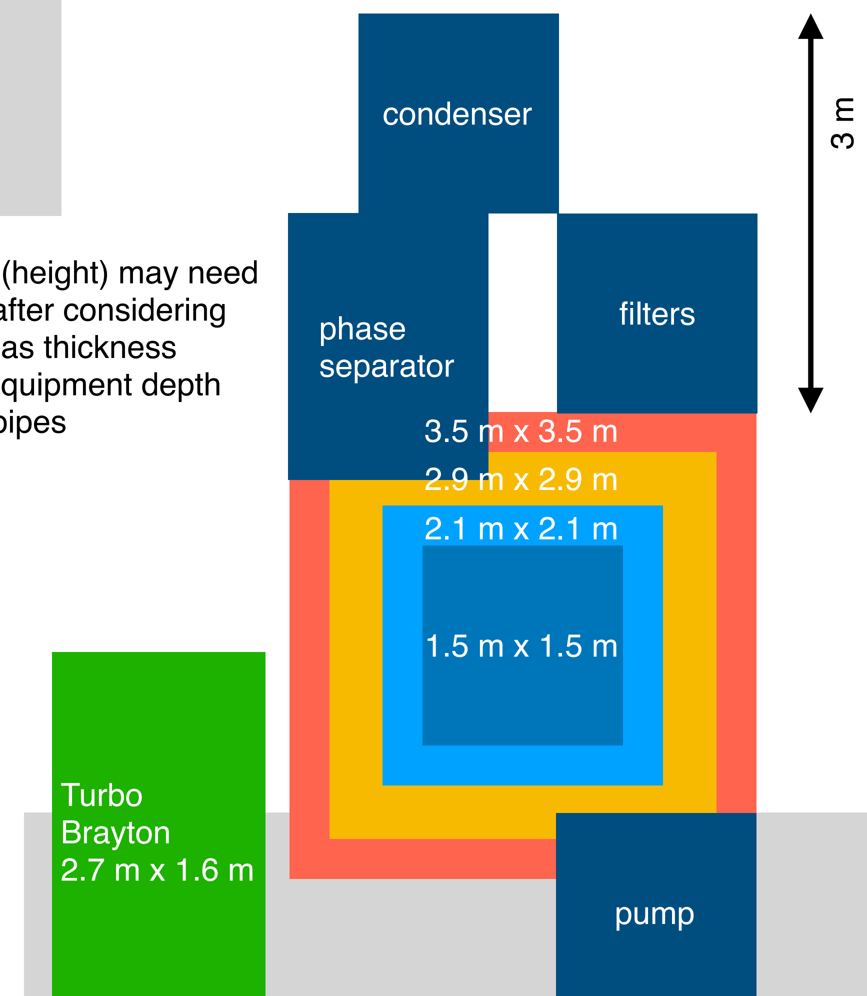
How it may look like for FPF



- Reduced to 30 cm the non-instrumented LAr layer.
- Insulation thickness reduced to 40 cm (~increase the heat input (*O*(4 kW)).
- Reduce structural thickness.
- Manhole for egress added.



Dimensions (height) may need to increase after considering
- minimum gas thickness
- minimum equipment depth
- cryogenic pipes



Considerations on cryogenics

Total heat load of ~8 kW (4 kW cryostat, 1 kW GAr circuit, 1 kW LAr purification, 1 kW electronics, 1 kW other inefficiencies)

Analogous approach as for ProtoDUNEs:
- Pressurised LN_2 for re-condensing the argon vapour
- Forced LAr circulation at a rate of 1 volume in 5 days => 600-700 kg/h
- Proximity cryogenics order of 1 MCHF

Main cooling (instead of exhausting evaporated N2):
- Turbo-Brayton (~8 m x 1.6 m x 2.7 m) TBF-80 unit (~10 kW cooling) in the cavern
- 100 kW electrical power (max), 5 kg/s water (max)
- Order of 3 MCHF

LAr and LN_2 lines down shaft:
- GAr/GN_2 out 30 cm diameter
- GAr in 10 cm (vacuum jacket included)
- LN_2 20 cm (vacuum jacket included)
- LAr 20 cm (vacuum jacket included)


https://advancedtech.airliquide.com

Dewars on surface:
- 50 m^3 LAr
- 10 m^3 LN_2

Safety related issues

Oxygen deficiency is the main risk associated to the LAr TPC

Possible connection to LHC tunnel needed as second emergency escape route

GAr and GN_2 exhausts released to the surface

Position of the cryostat and cryogenics away from the main egress and escape route

Trench needed under cryostat to catch any argon leaks
- ~1.5 m deep, ~footprint of cryostat + 1.5 m clearance on each side (~12.6 x 6.9 m^2)
- More than 10 min to fill with warm argon gas at a flow equivalent to the LAr purification
- For alignment with LoS, cryostat need to be raised from the trench floor

Ventilation (push and extraction)
- Air extraction in the proximity of the cryostat/cryogenics
- Constant air circulation with alarms if ventilation not working
- Dimensioning should follow a detailed risk assessment

ODH alarms in cavern and in the trench with trigger to increased air extraction
Possibly personal ODH required to access the cavern (or the trench) as well

Handling requirements

- Cryostat would be assembled in the cavern (possibly as first device installed)

- Biggest pieces for transport to the cavern: 6 m x 1 m x 0.5 m (a guess, but if constraints arise, at the design level this figure can be changed)

- Overhead crane that reaches the entire surface where the cryostat will be installed is needed

- Cryogenics components on the cryostat will exceed significantly the cryostat roof. To limit the cavern height, the crane could be locked out from this region when cryo is present (solution need to be found to instal the cryogenic components)

- Cooling unit (~8 x 1.6 x 2.7 m^3) needs to be transported in 1 piece. It can be lowered vertically and turned in the cavern. 25 ton crane should suffice

- At least two man-lifts and a fork-lift are needed during cryostat and cryogenic installation. The outside walls of the cryostat need to be accessible with man-lifts.

Summary

- Cryostat and cryogenics are among the main constraints on the dimension of the cavern

- Basic considerations on cryostat, cryogenics and infrastructure requirements

- LNG storage tank solutions fit well LAr TPC cryostat requirements

- Significant experience at CERN in building and operating large LAr TPCs (e.g. ProtoDUNEs)

- Need to include early in the discussion possible installation procedures of the detector

- Compact and maintenance-free industrial solution for the main cooling unit identified

- No insurmountable problem found in safety related aspects

Additional slides

GN_2 management

The insulation space (mostly occupied by passive insulation) is filled with GN_2.

GN_2 management consists of valves and controls to assure at all times slight overpressure in the insulation space with respect to the atmosphere.

It makes sense that this task is taken care by the cryogenic system.

The system must cope with the variation of the atmospheric pressure and with the filling and emptying phases. Consumption:
- During normal operation expected small (compensate leaks and slow atm pres variations).
- During cool-down and filling expected larger (depending on the cool-down speed).

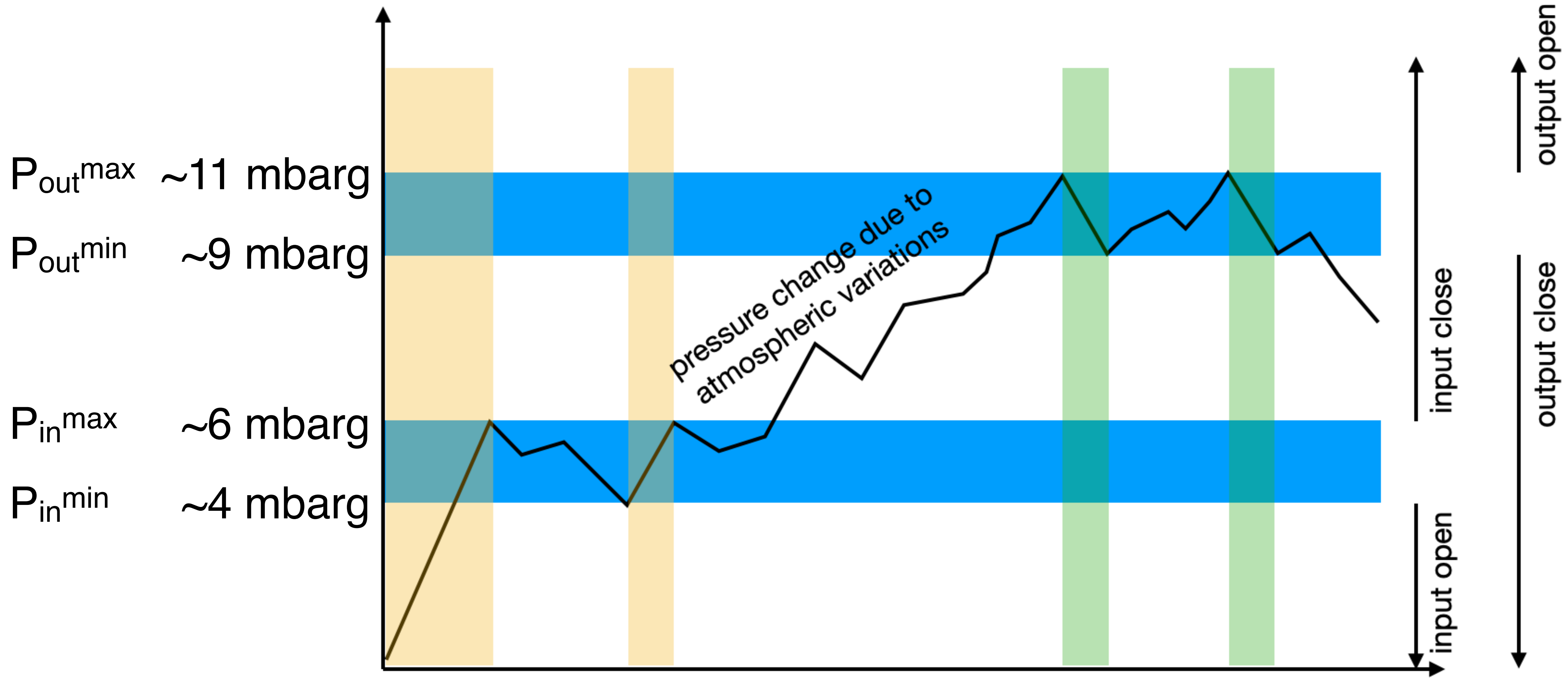
Two input and two output in the two independent insulation spaces + pressure measurements.
The relative pressure P is regulated as following (P in the order of 5 - 10 mbarg):
- Input valve opens when $P < P_{in}^{min}$ and closes when $P > P_{in}^{max}$
- Output valve opens $P > P_{out}^{max}$ and $P < P_{out}^{min}$

Two or more overpressure valves are installed directly on the cryostat.

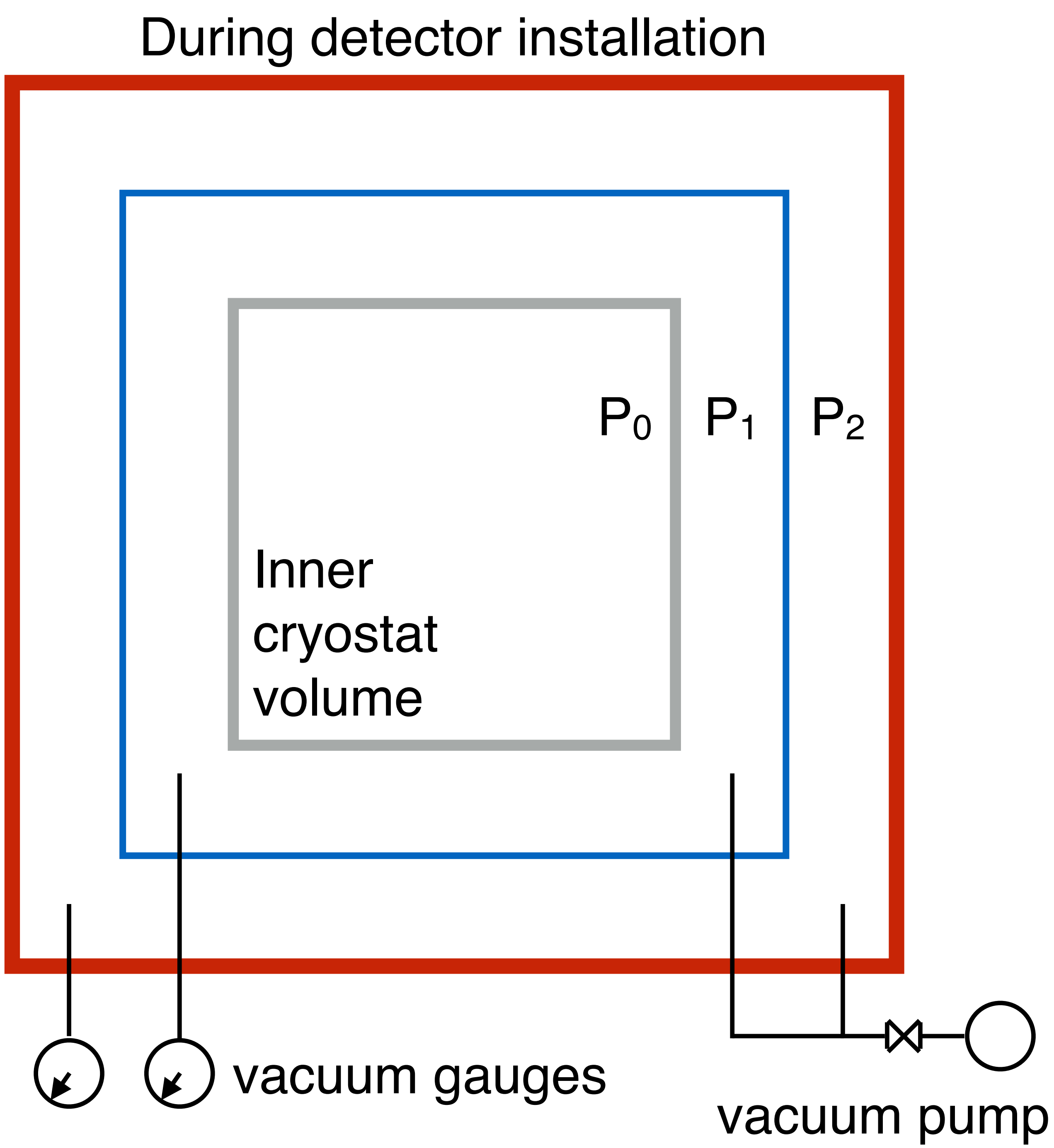
Gas analyser (Residual Gas Analyser (RGA) based or more sensitive) may be installed on the output to monitor the gas composition (presence of Ar traces).

GN_2 in the insulation

Robust approach that can cope with any situation

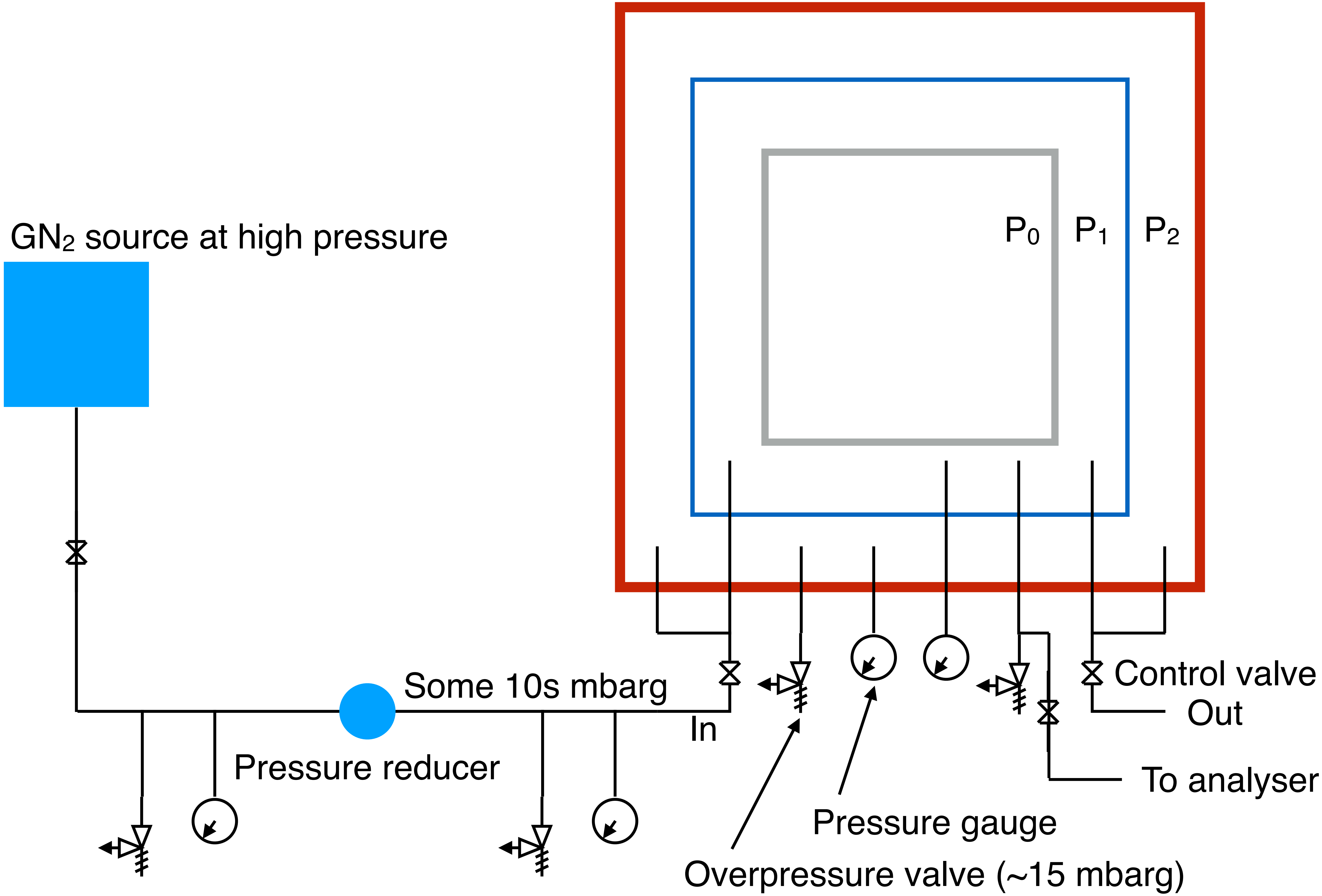


During detector installation



P_0 = atm
$P_1 = P_2 \sim 800$ mbara
Constantly monitor P_1 and P_2

Possible scheme



Few additional points

In general $P_0 \geq P_1 \geq P_2$.

After cryostat completion the two insulation spaces should be connected together (from the outside): $P_1 = P_2$.

Since the gas analyser most likely requires a constant gas flow, instead of sampling the gas from the output, the gas can be taken from an additional sample point.

During the cryostat construction and the membrane leaks tests the insulation space is filled with helium at room temperature with a slight overpressure with respect to the inner volume.

Before cool-down, the insulation space must be purged abundantly with GN_2. Possibly the maximum GN_2 flow may be required in this phase.