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

Filippo Resnati (CERN EP/NU)
with input from J. Boyd, J. Bremer, M. Chalifour, D. Mladenov

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Considerations for LAr TPC cryostat

Considering an active mass of 20 ton*

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

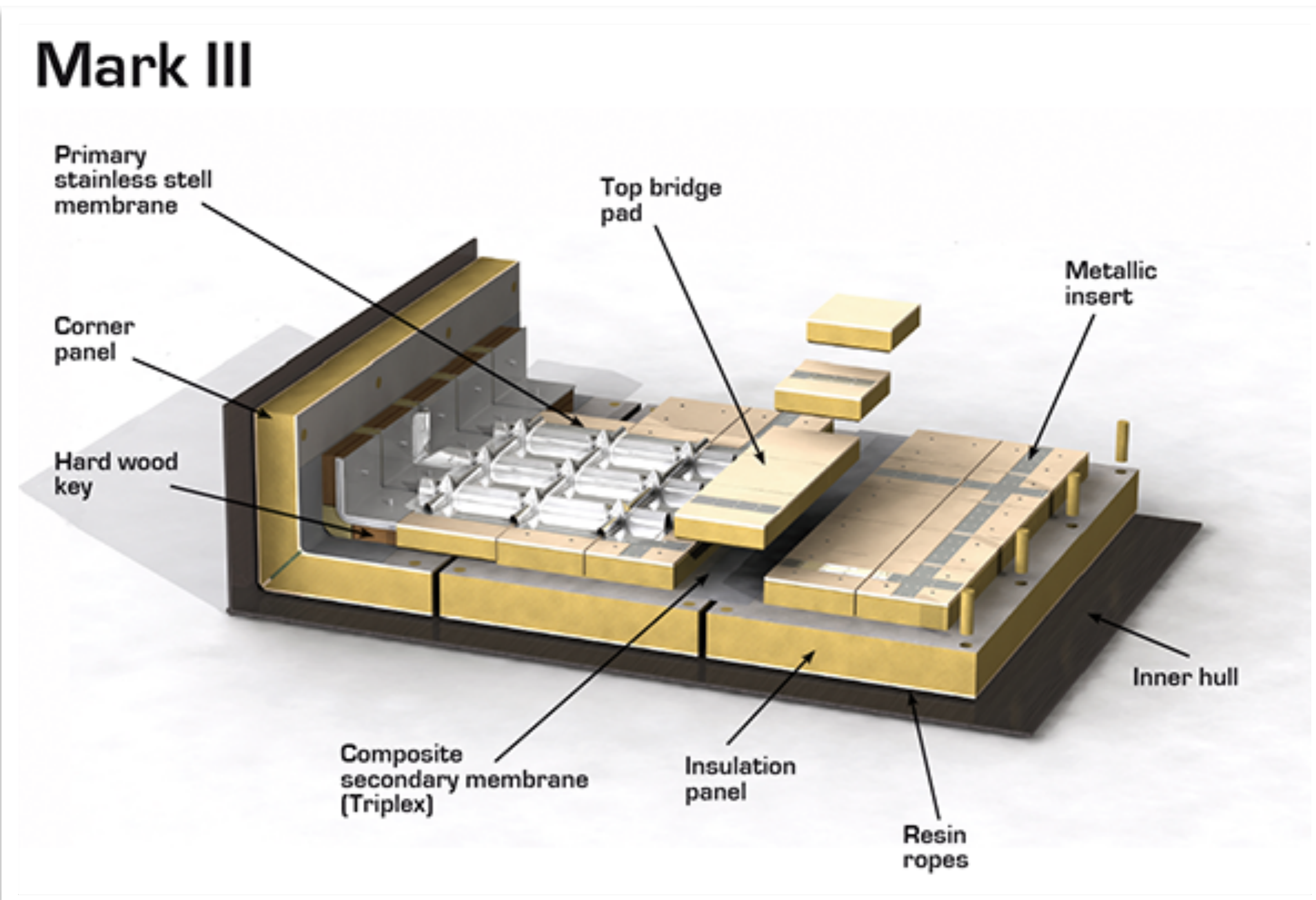
Royalties owner: GTT (France)
Construction licensee: among several Gabadi (construction of ProtoDUNEs)
Applications:

- LNG carriers (>200000 m^3 in 5 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

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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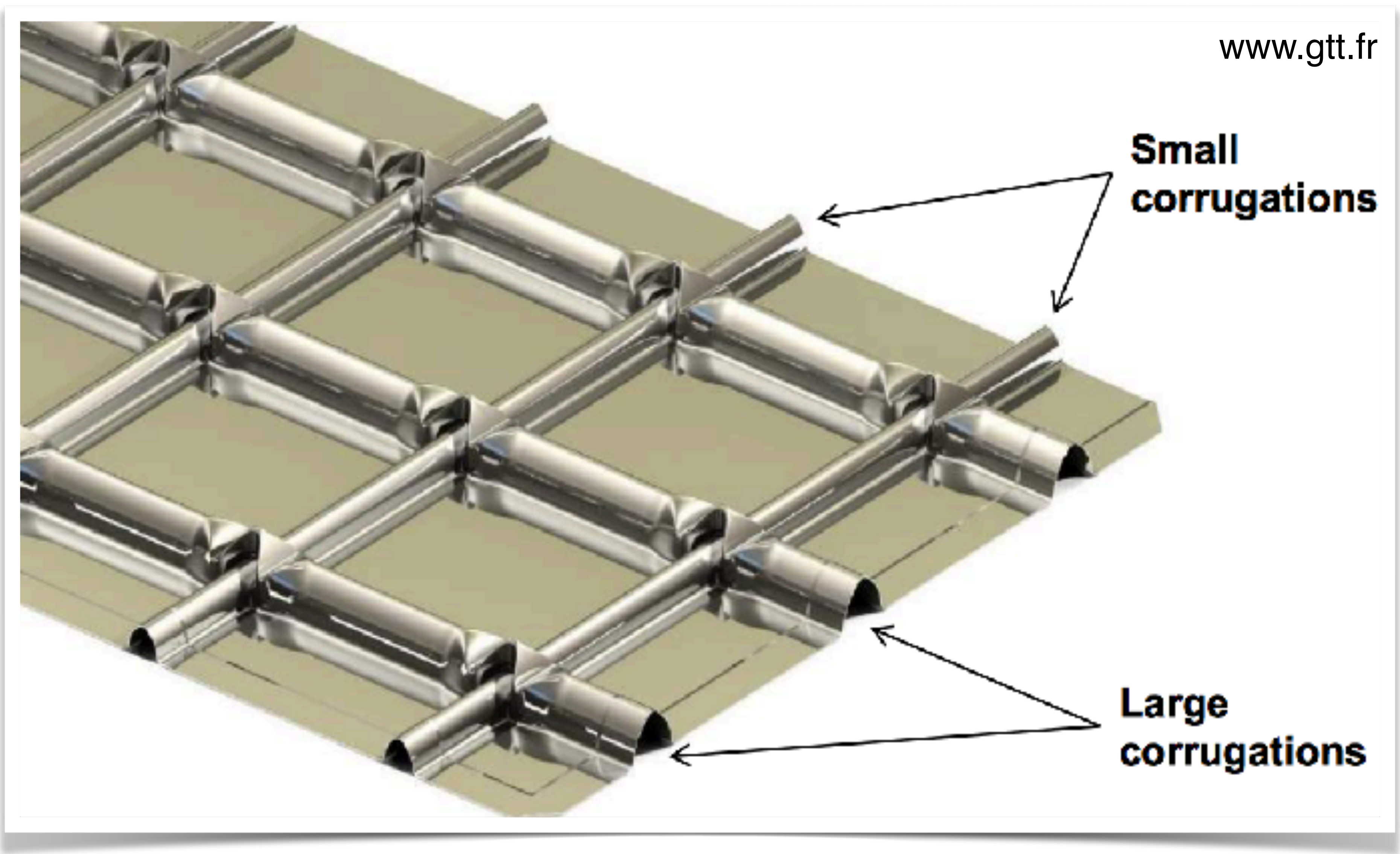
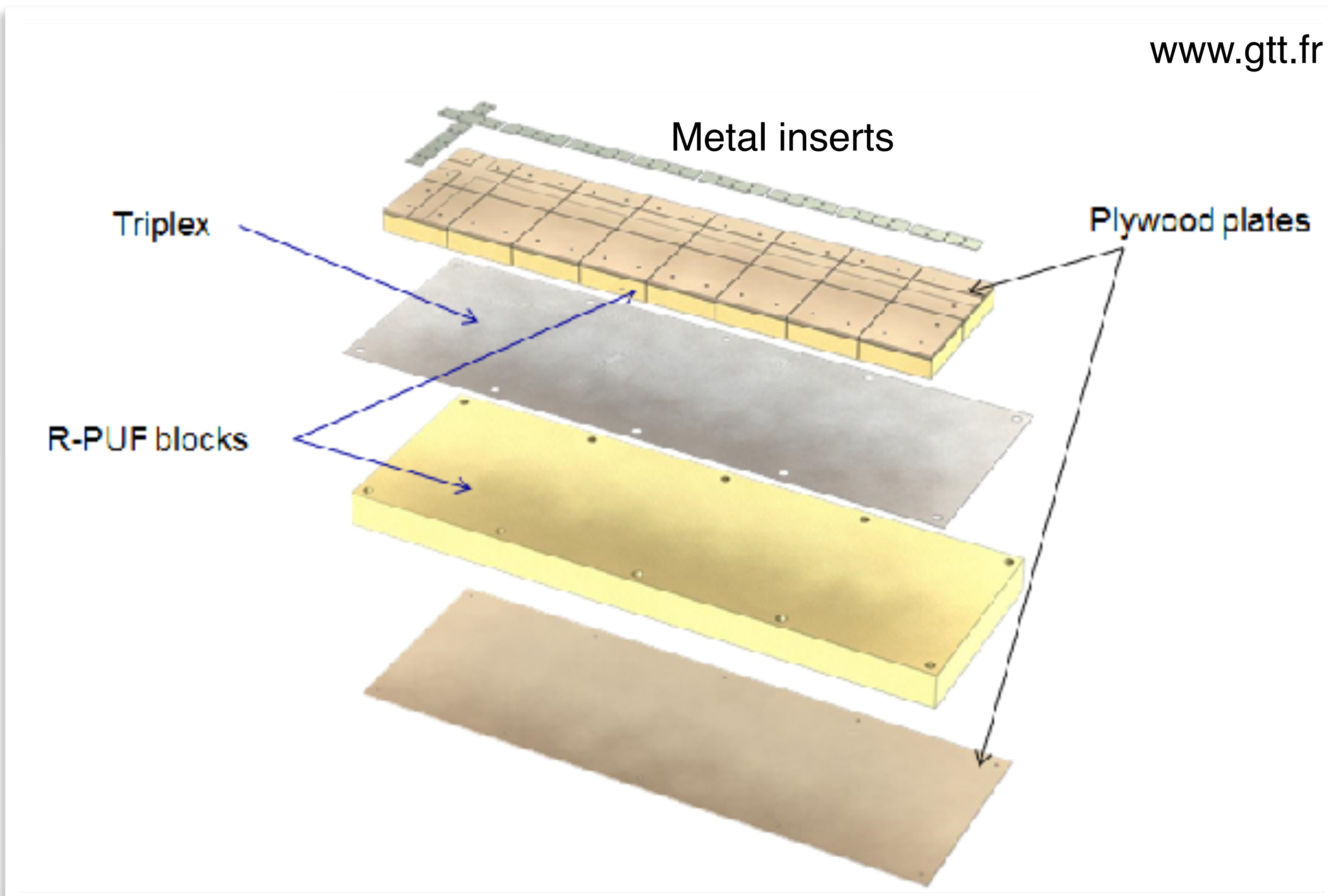
GTT Mark III technology

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, constructed in Korea.
Special components for angle and corner pieces, LAr valves, and roof penetrations.



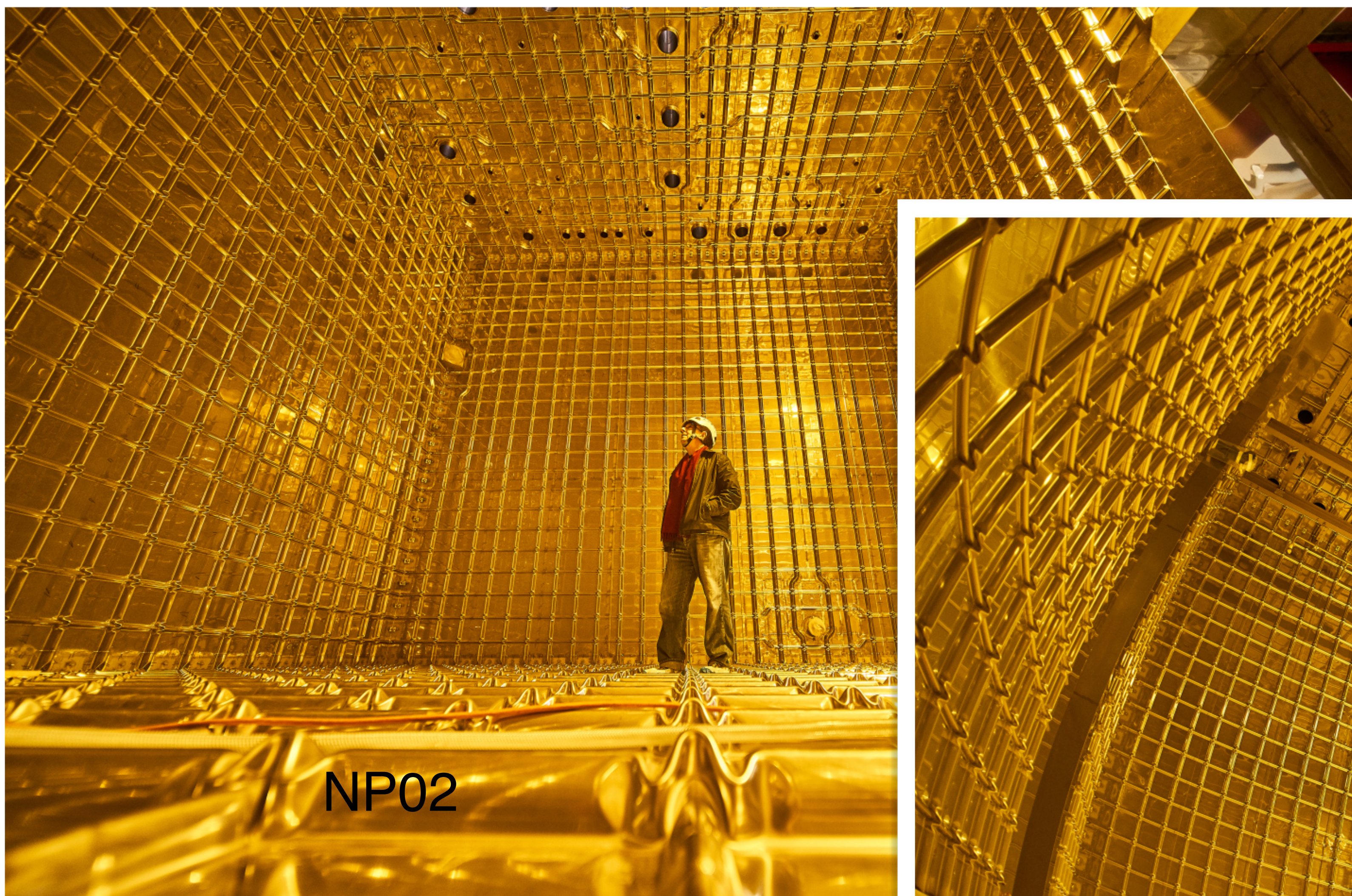
GTT Mark III technology

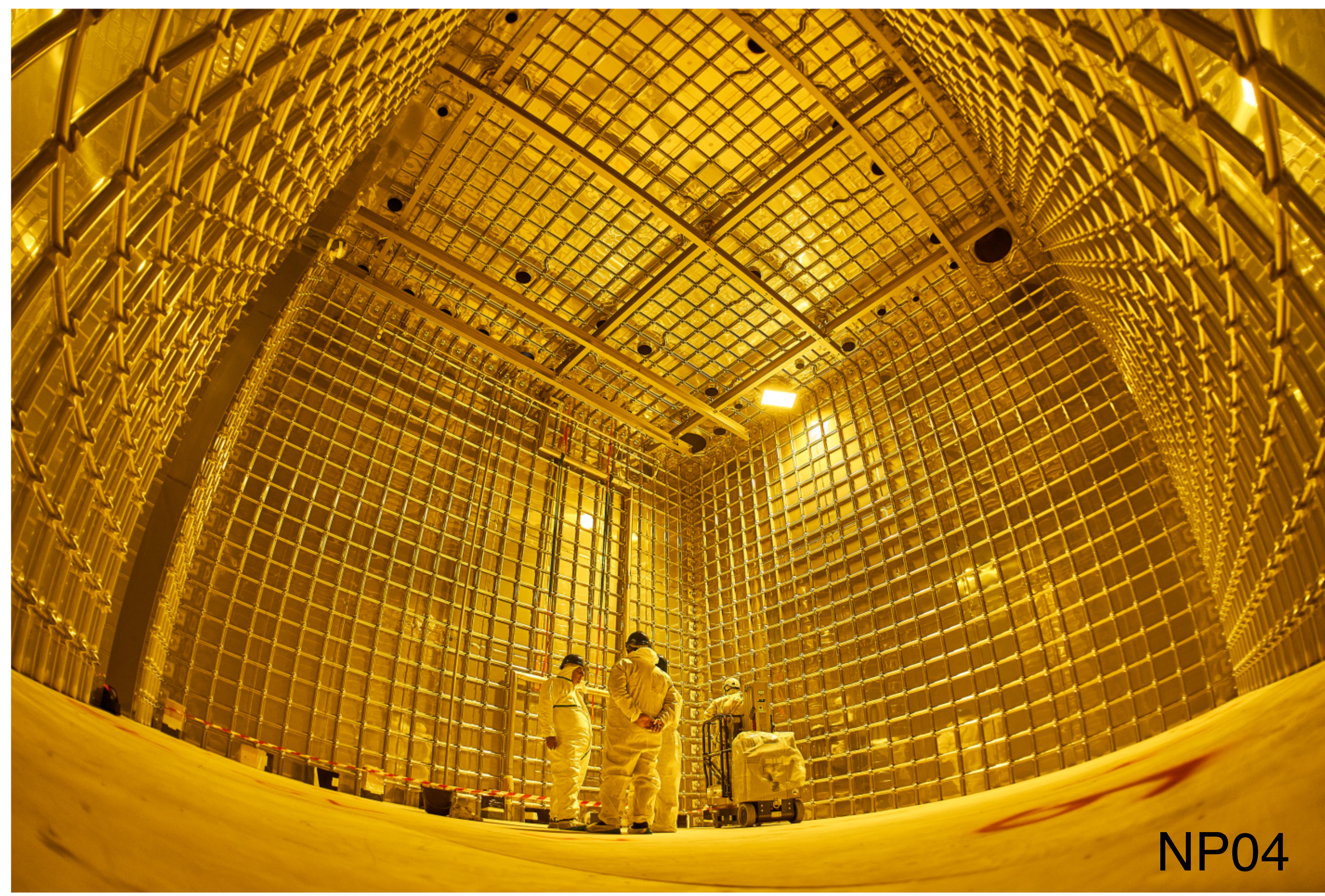
Insulation:
Two layers of polyurethane foam (90 kg/m³) separated by the secondary membrane.
Metal inserts on the plywood serve as welding points for the primary membrane.
No direct metal contact between warm structure and primary membrane.
Highly standardised prefabricated components, constructed in Korea.
Special components as for corrugated membrane.



ProtoDUNEs

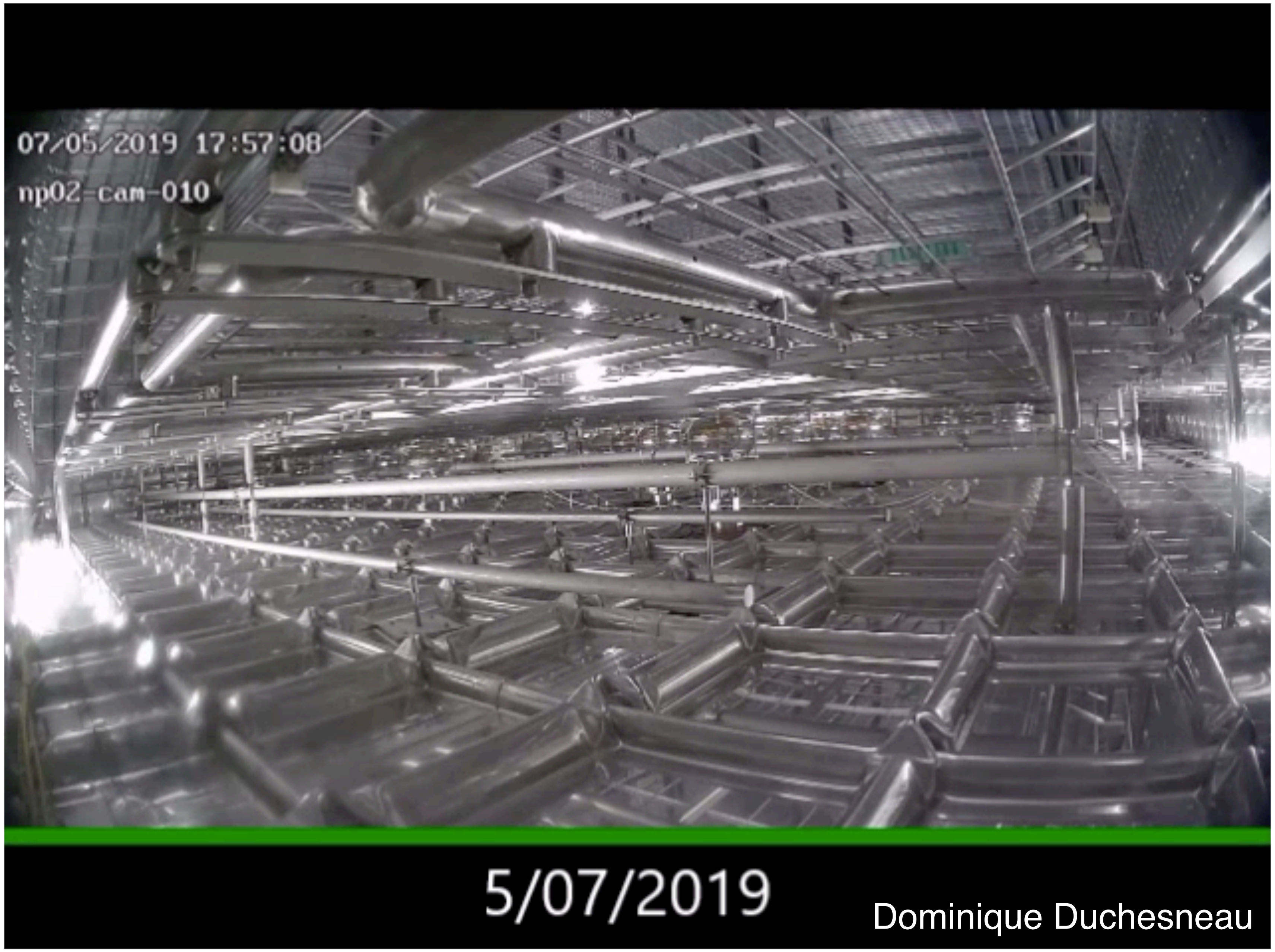
Two (NP02 and NP04) membrane cryostats containing ~750 ton of ultra pure argon.
Prototype and demonstrate of TPC technologies for DUNE far detectors.
- NP04 exposed to North Area charge particle beam and operated till summer 2020.
- NP02 operated from summer 2019 to fall 2020.





NP02 filling

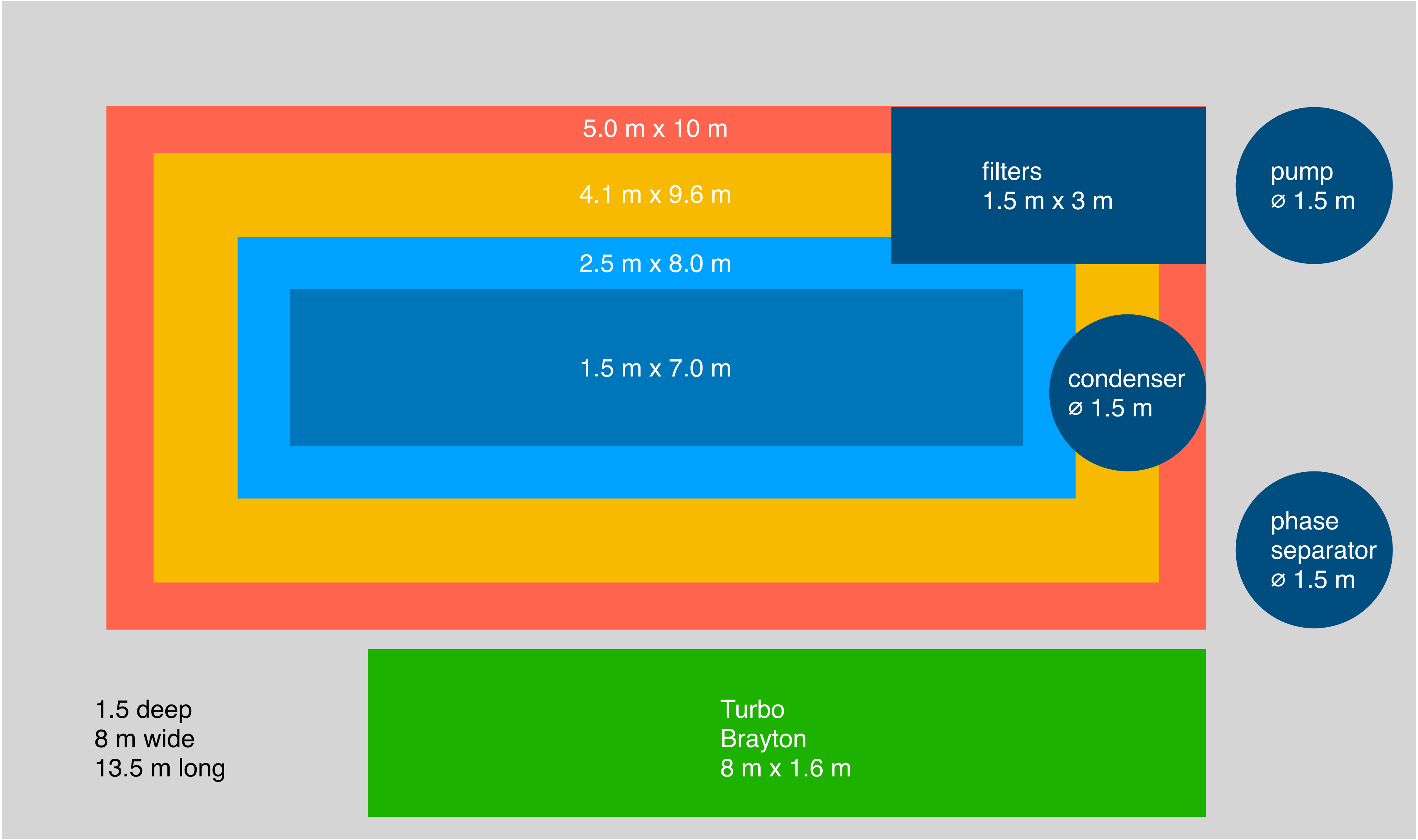
Video: https://cernbox.cern.ch/index.php/s/AjG1OX7kUjX23s0



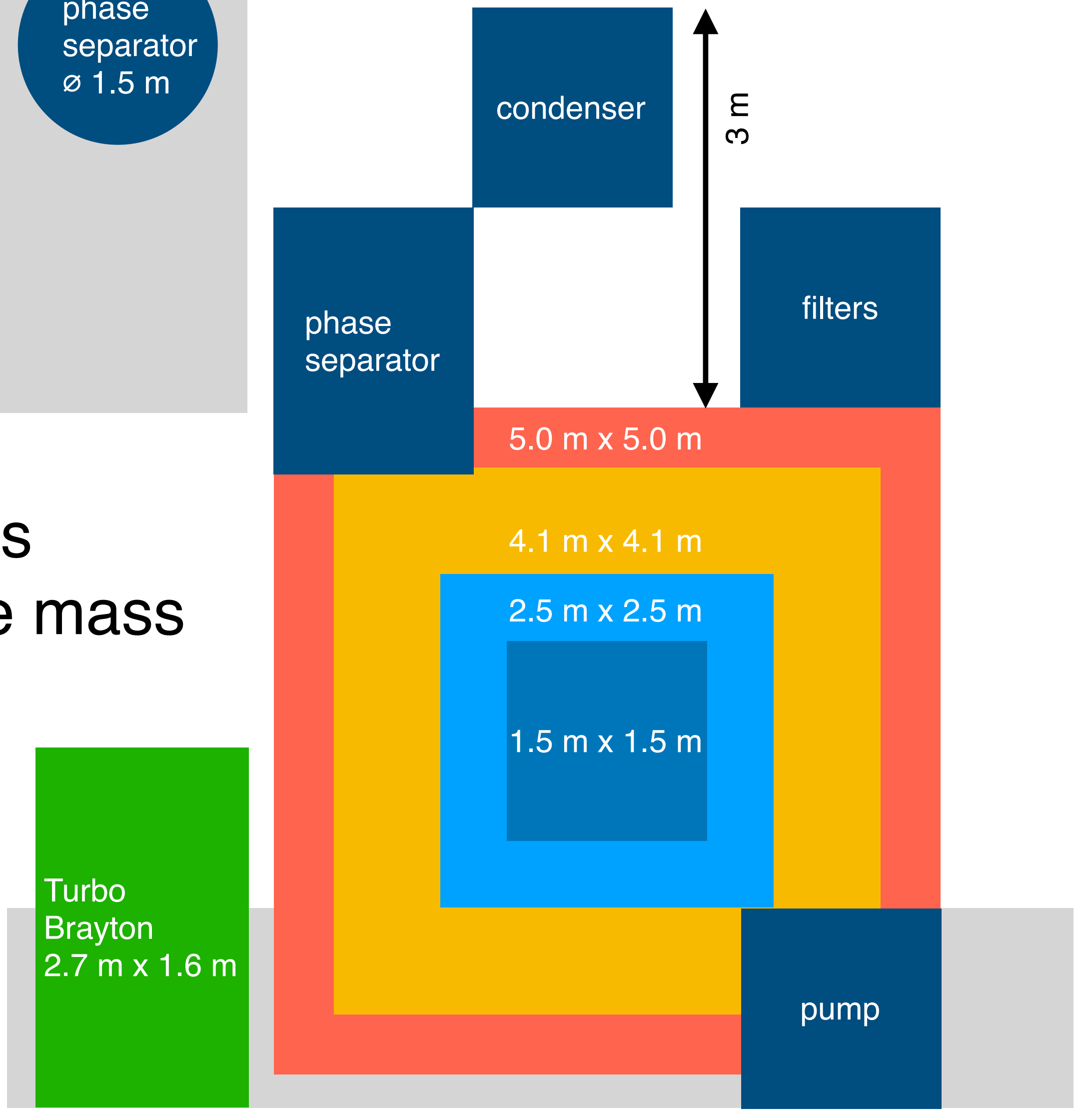
NP02/NP04 vs LNG tanks

- 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)

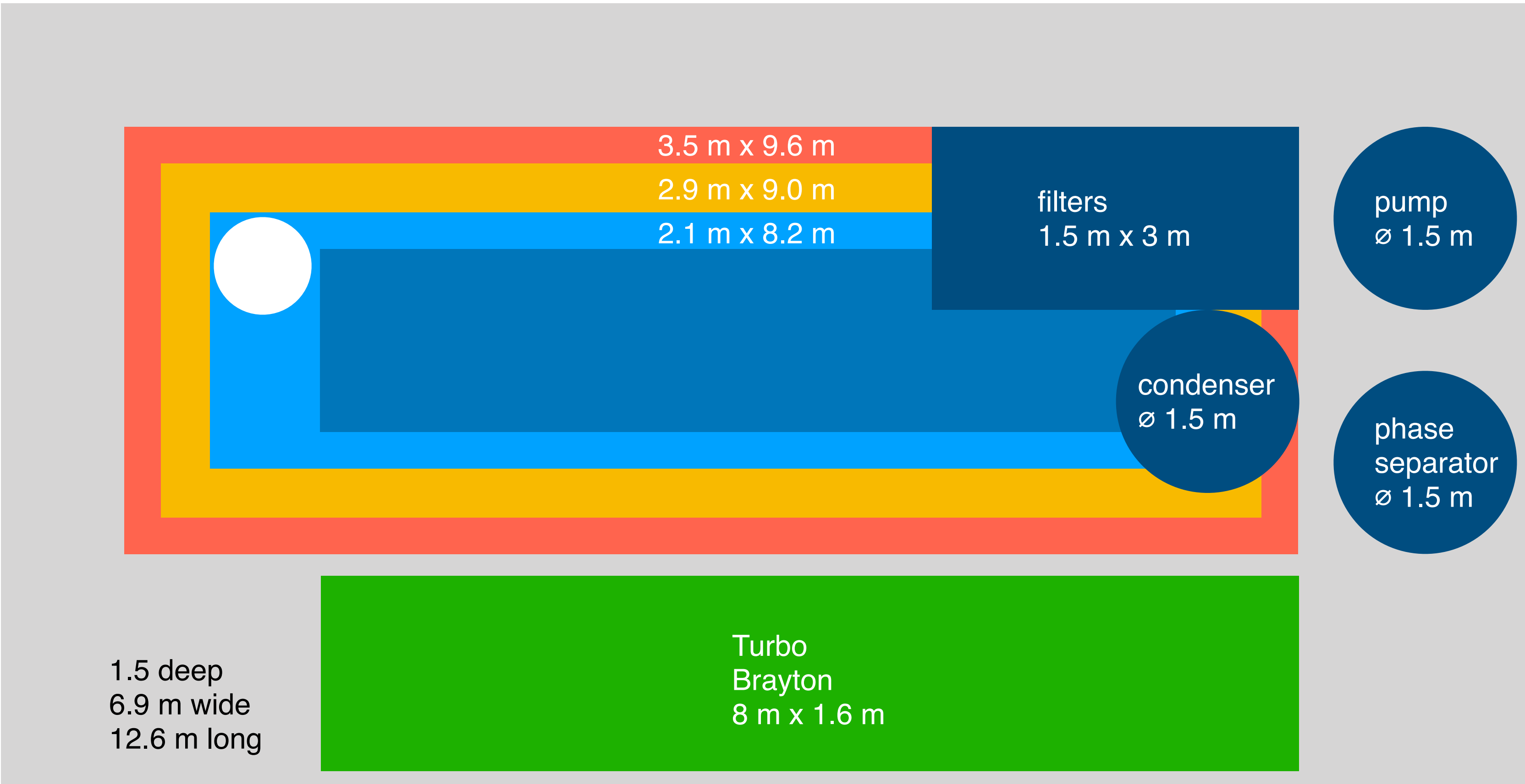
How it may look like for FPF



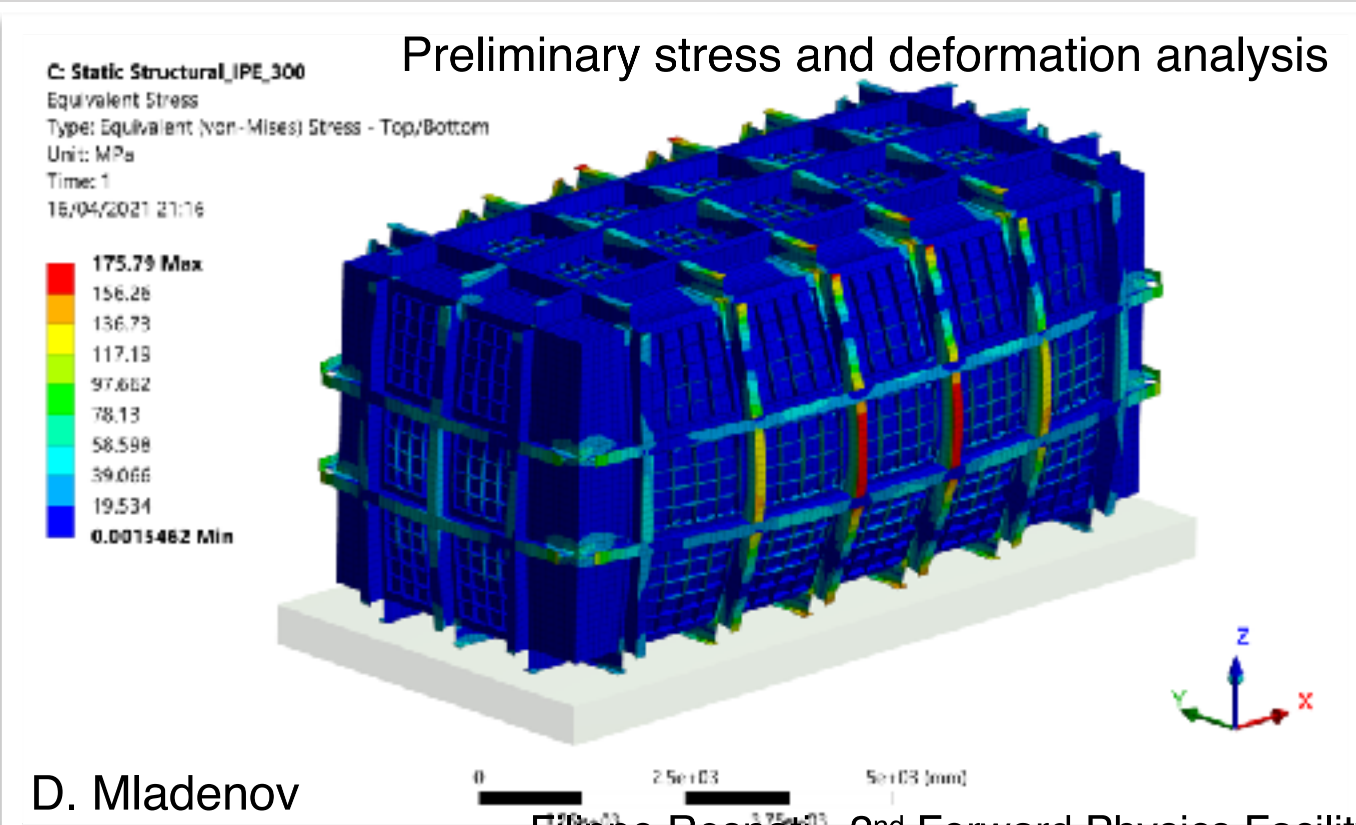
First guess scaling solutions adopted for ProtoDUNEs
Volume occupied excessive with respect to the active mass
Expensive implications on the cavern excavation
TPC must be aligned to the LoS.
How the detector is installed? Side opening?



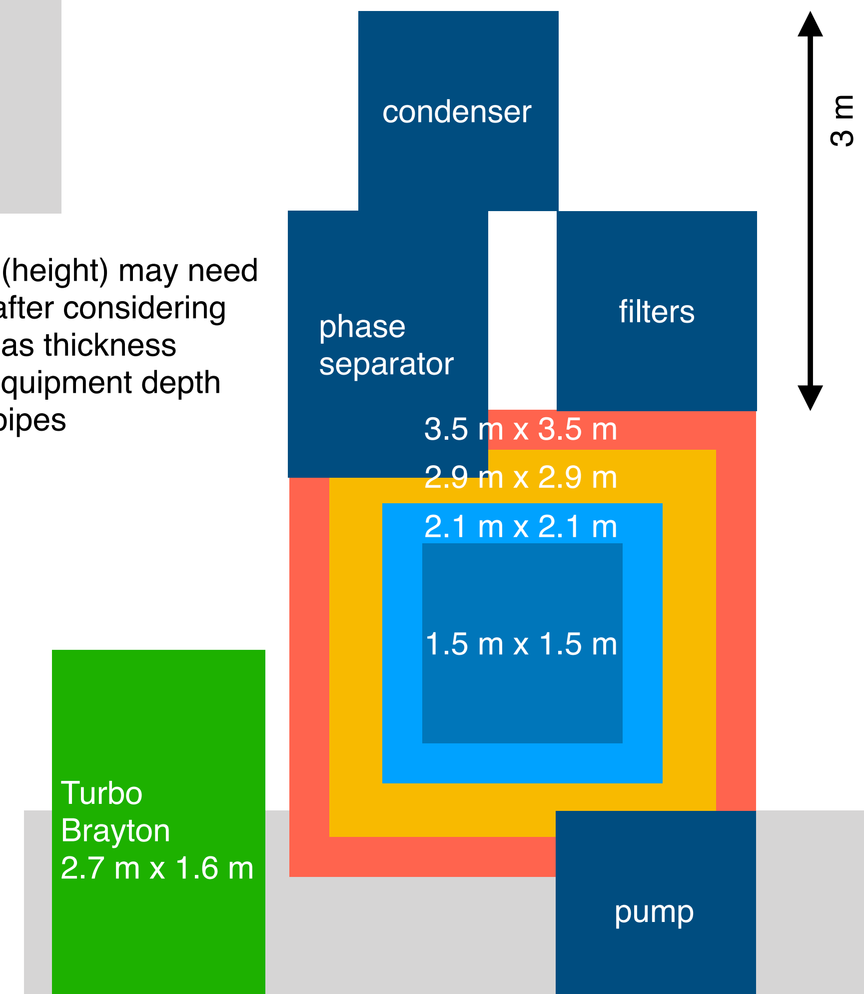
How it may look like for FPF



- 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:
- 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)

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
- Straw man 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