CERN

Joint Gravitational Waves and CERN Seminar

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# Cryogenics (CERN)

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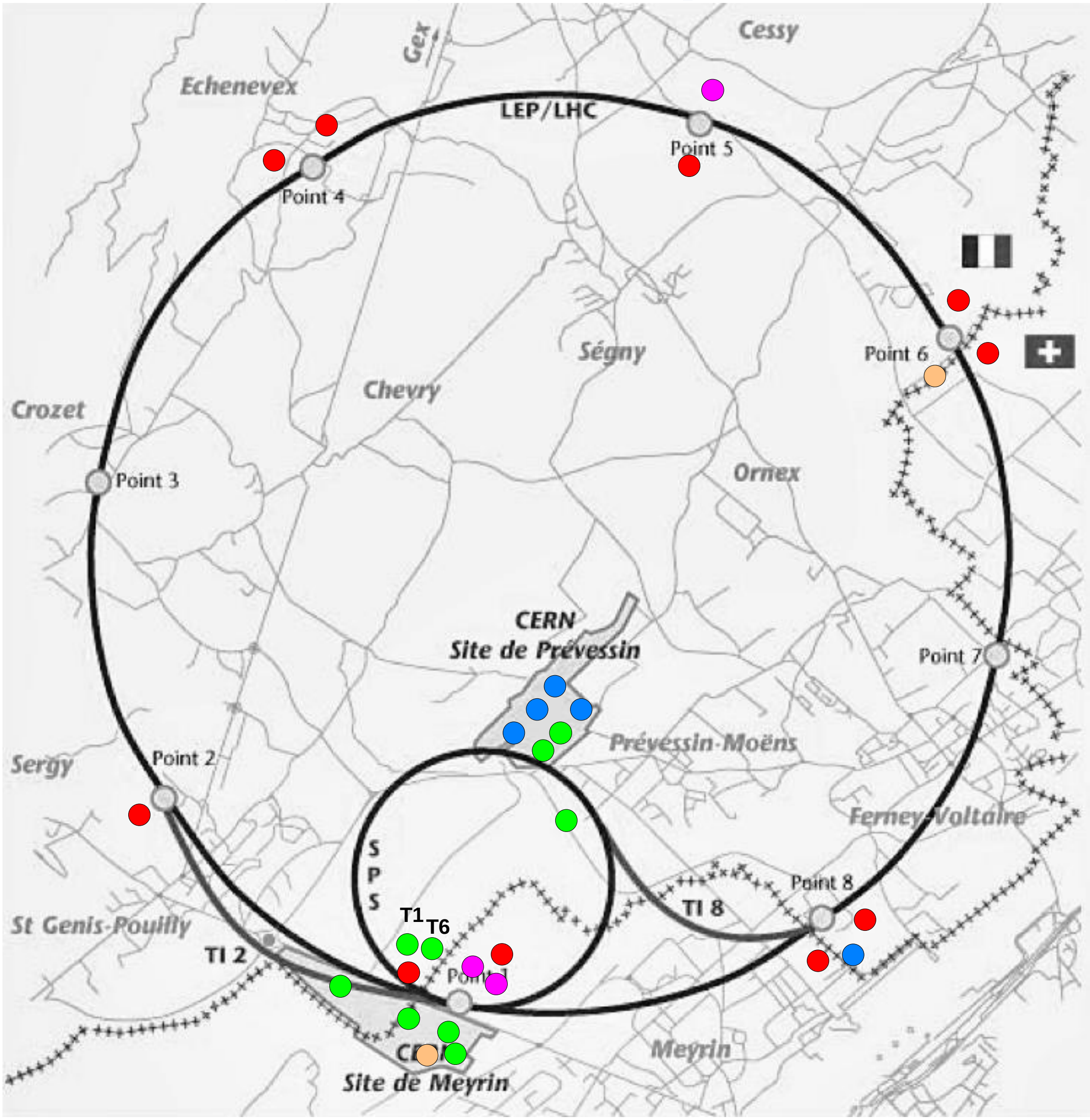
# Content

- Introduction: Cryogenics at CERN (past and present)
- The HL-LHC project and its cryogenic challenges
- The FCC study project and its cryogenic challenges
- The Neutrino Platform and its cryogenic challenges
- The CERN Cryogenic Laboratory (The “Cryolab”) and its services and support to project
- Conclusion

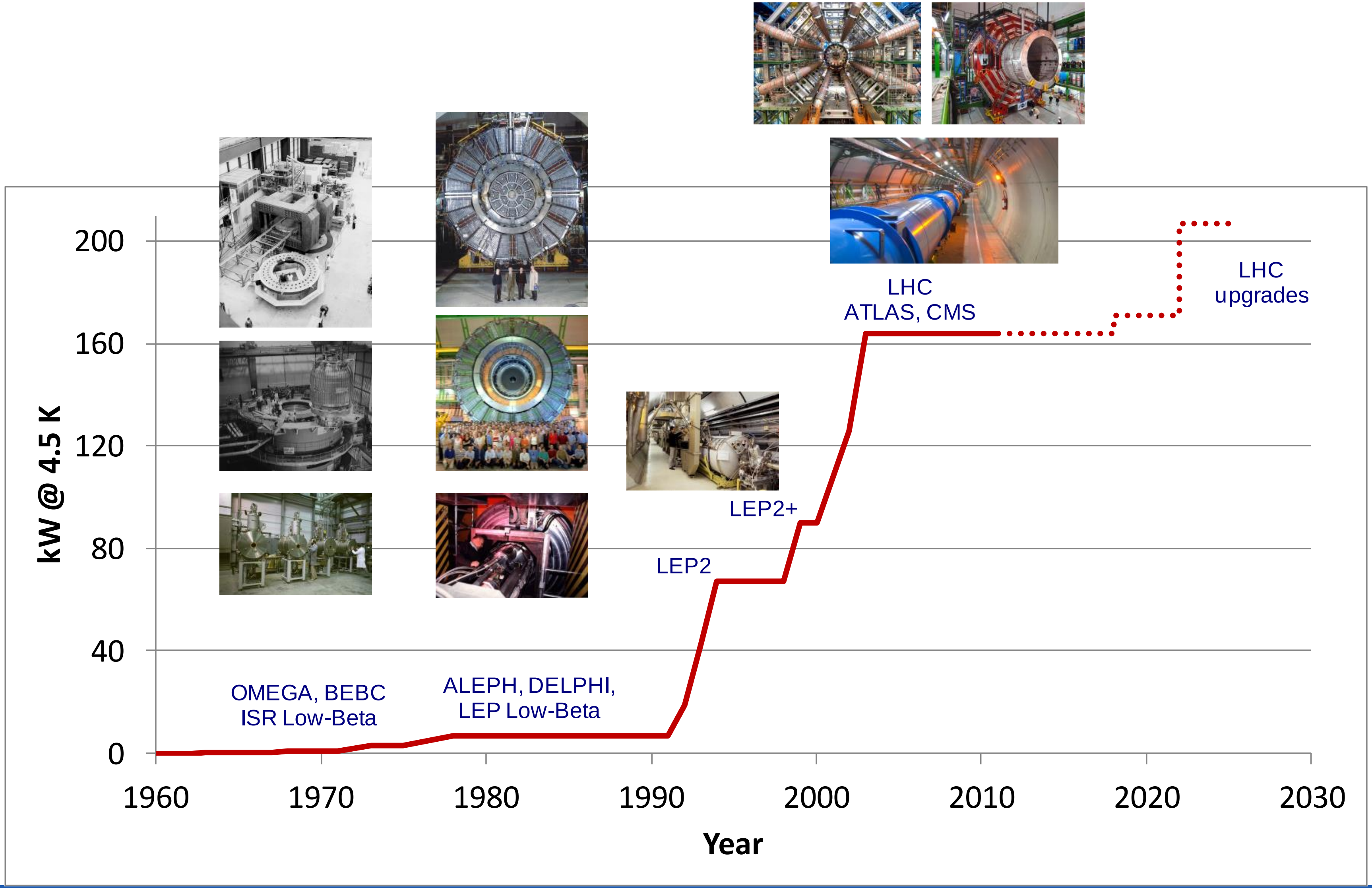
# Cryogenic plant inventory at CERN



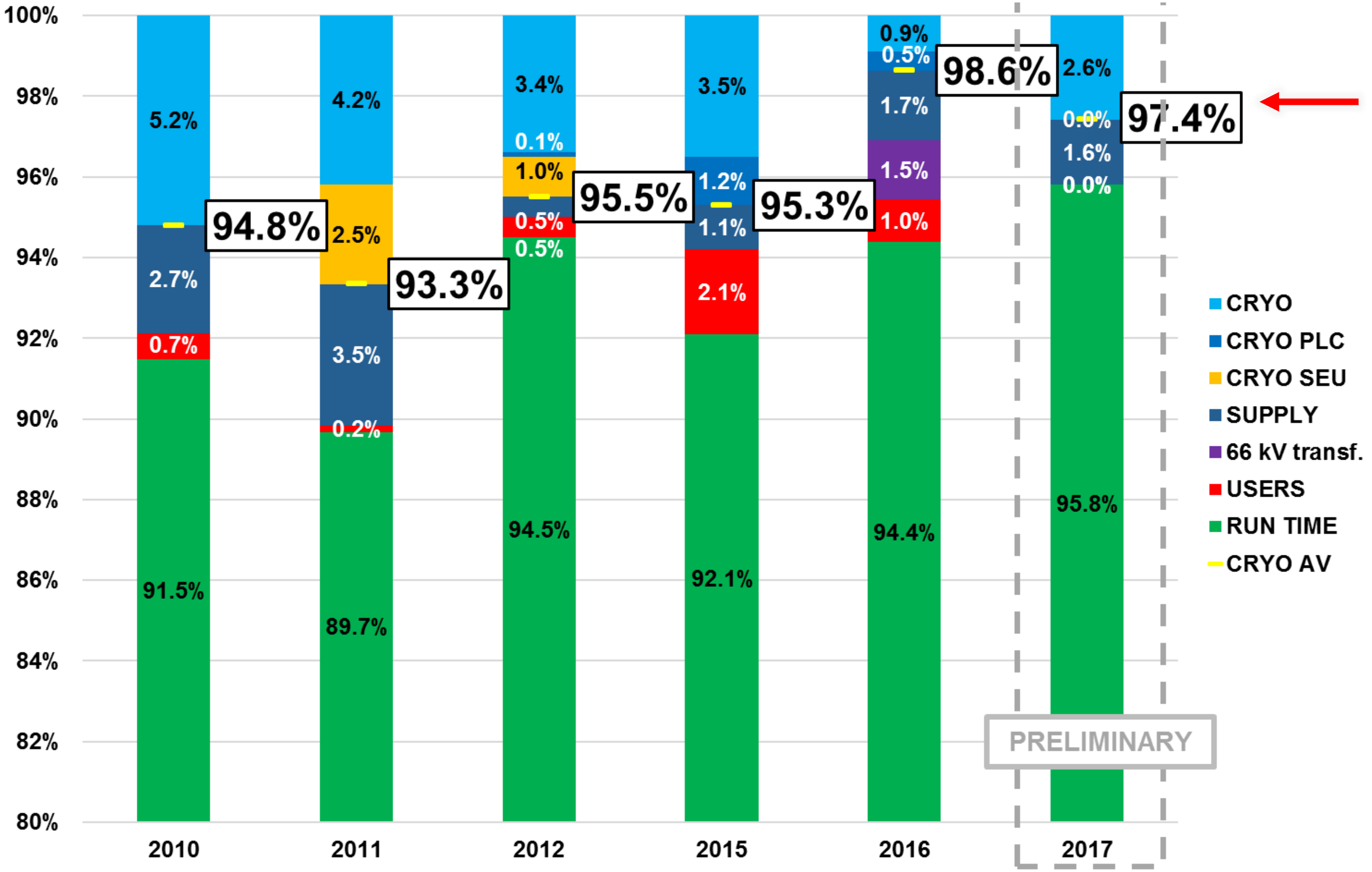

- LHC Accelerator
- LHC Detectors
- Other Detectors
- Test Areas
- General services

~ 30 cryogenic plants in operation spread over 30 km! (from 0.1 to 18 kW @ 4.5 K)
+ ~ 6-7 new cryogenic plants in the pipeline

# Installed cryogenic power at CERN



# Availability of LHC cryogenics

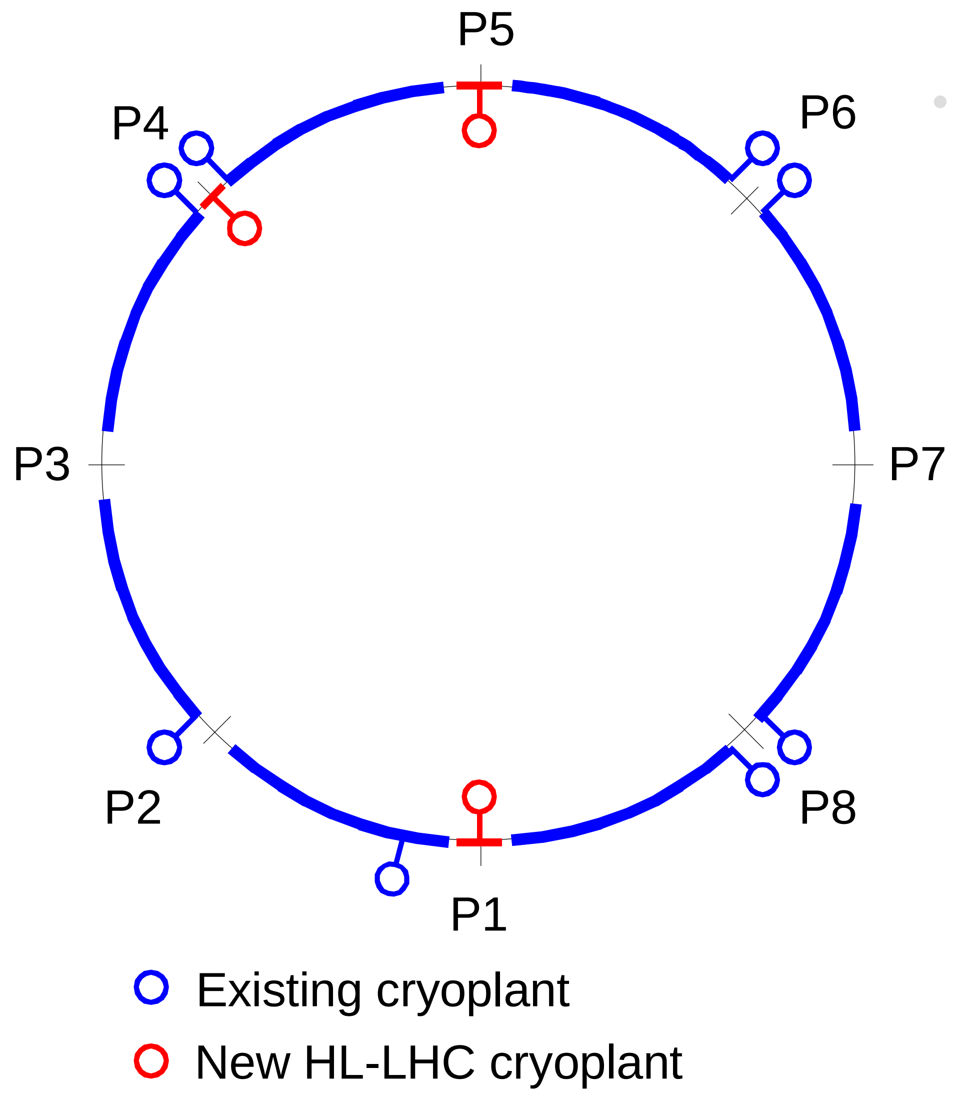



Availability for 8 cryogenic plants operating in parallel:

- i.e. an availability per plant of 99.1 % to 99.8 %.

- i.e about 0.4 to 1.5 days lost per plant and per year during physics.

# Overall HL-LHC cryogenic layout



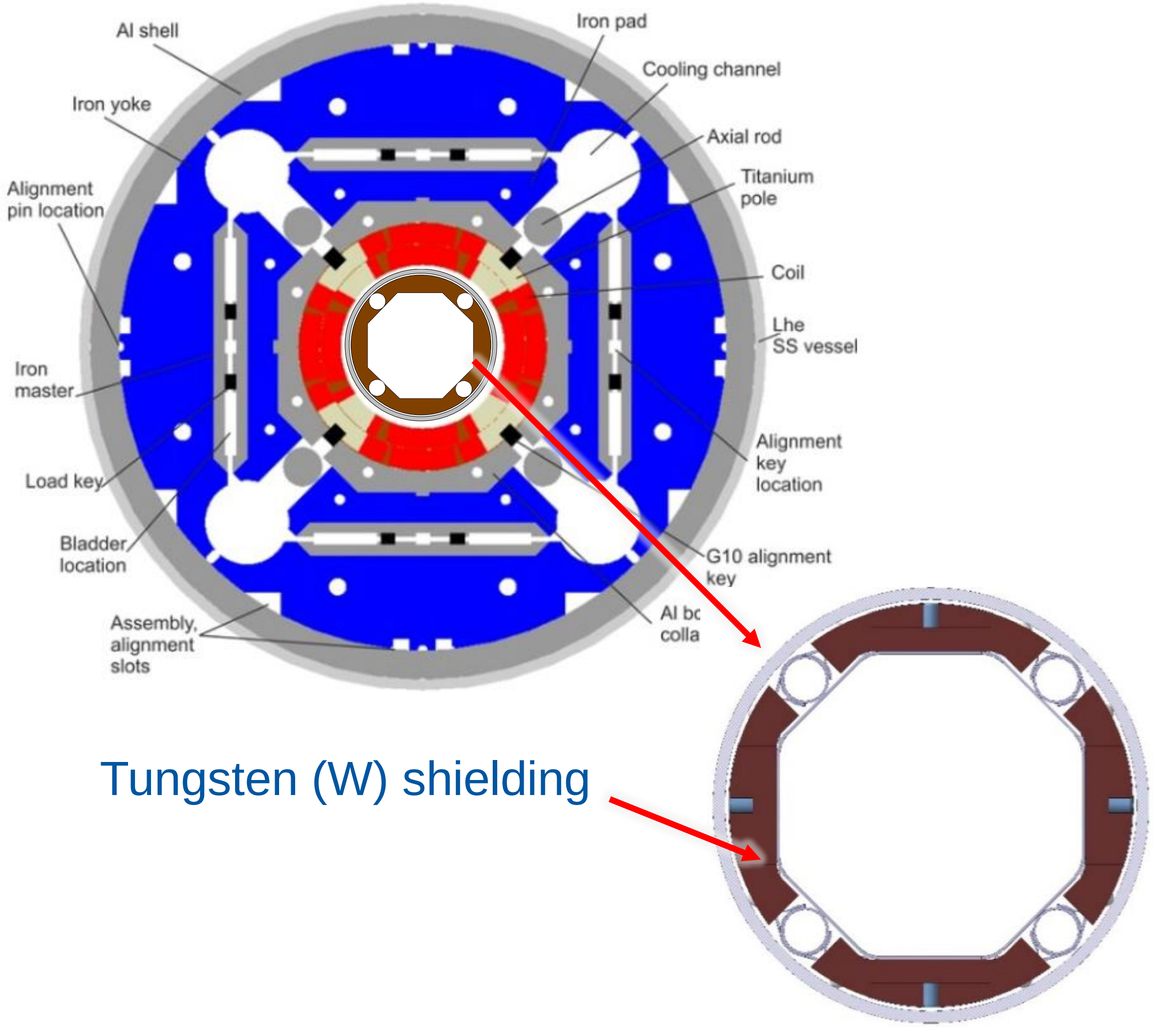

- HL-LHC cryogenic upgrade:
  - 2 new cryogenic plants
    (~18 kW @ 4.5 K including 3 kW @ 1.8 K) at P1 and P5 for high-luminosity insertions.
  - 1 new cryogenic plant
    (~4 kW @ 4.5 K) at P4 for SRF cryo-modules. (Alternative under study: upgrade of 1 existing LHC cryogenic plant)

# Main HL-LHC cryogenic challenges

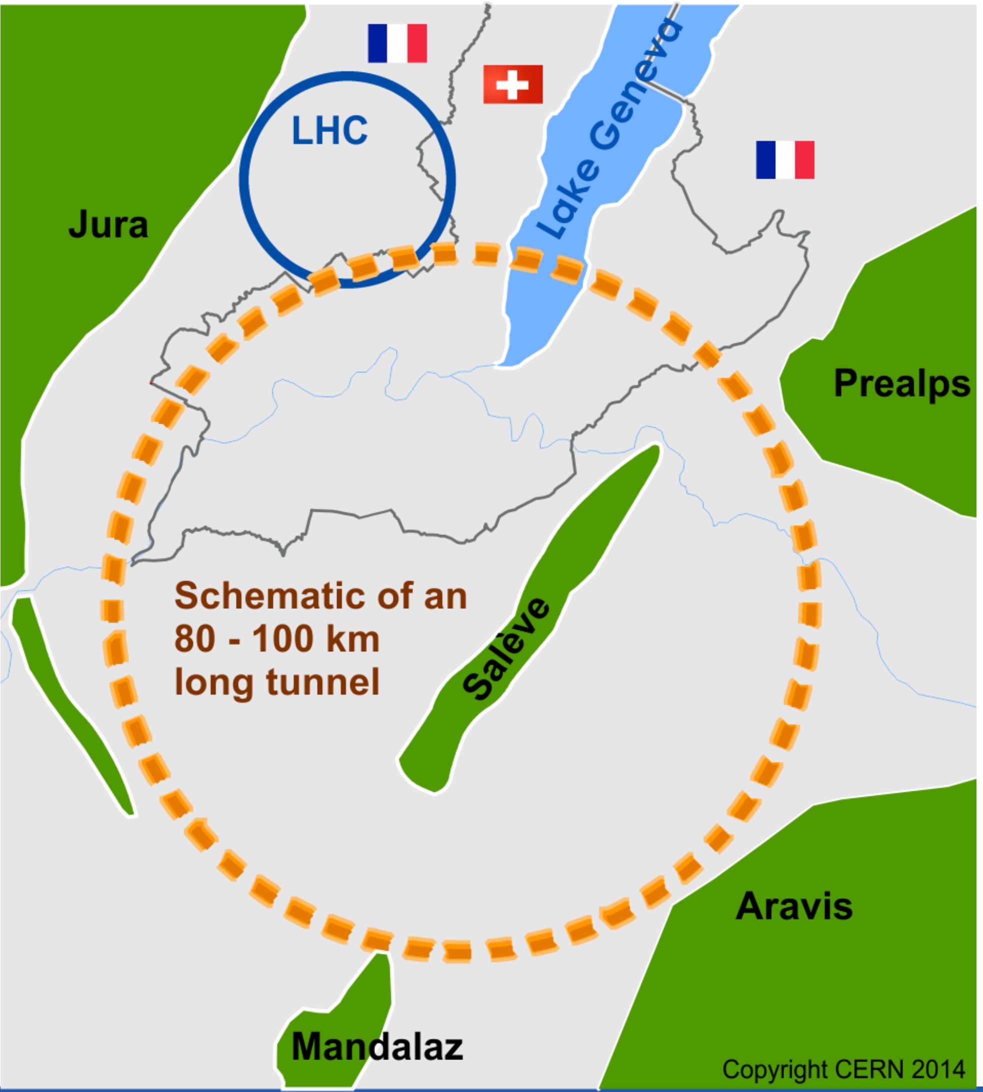
- Cryogenic plants: Based on LHC design (no specific R&D)

- Cooling of inner-triplet quadrupoles:
  - Cold-masses at 1.9 K: ~25 W/m of specific heat loads (factor 2-3 w/r to the present triplets) → Cooling with parallel bayonet heat exchangers (R&D)

  - Beam screens at 40-60 K:
    → ~25 W/m of specific heat loads (factor ~10 w/r to standard LHC beam-screens).
  - → Heavy W-shielding: R&D on supporting system to the cold-bore at 1.9 K with high thermal resistance



# Scope of FCC Study

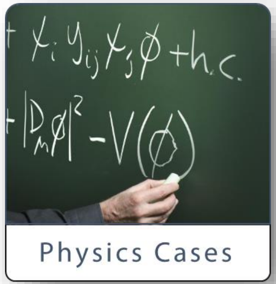


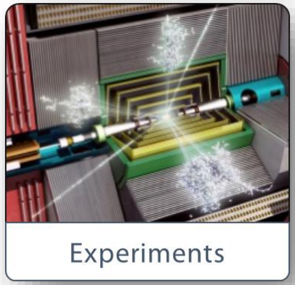

**International FCC collaboration (CERN as host lab) to study:**

- ***pp*-collider (*FCC-hh*)**
  → main emphasis, defining infrastructure requirements

  **~16 T ⇒ 100 TeV *pp* in 100 km**

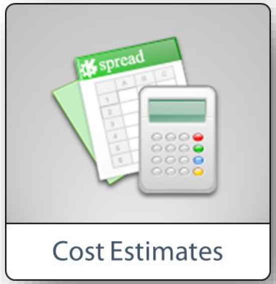
- **~100 km tunnel infrastructure**
  in Geneva area, site specific
- ***e*$^+$*e*$^-$ collider (*FCC-ee*),**
  as potential first step
- ***p-e* (*FCC-he*) option,**
  integration one IP, e from ERL
- **HE-LHC** with *FCC-hh* technology
- **CDR for end 2018**



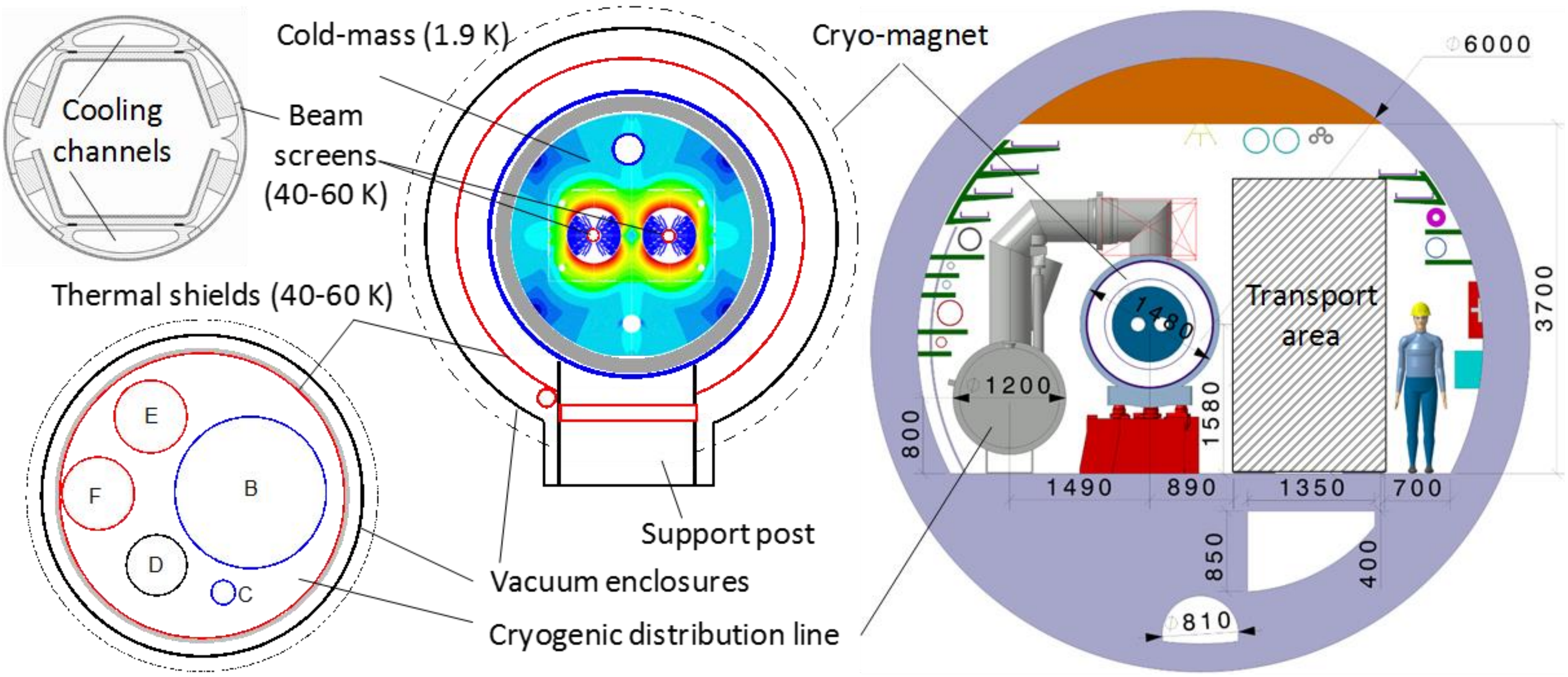





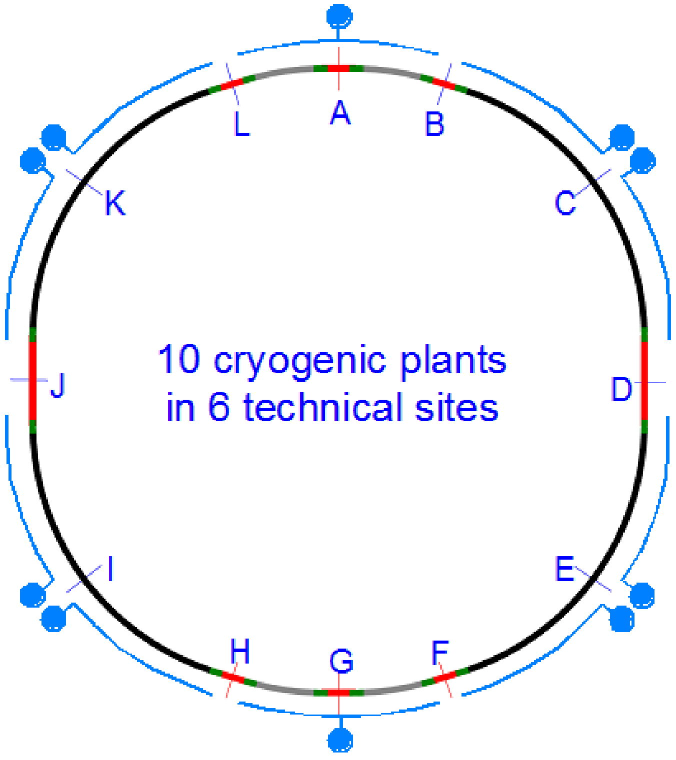




# FCC-hh: tunnel cryogenics



# Main FCC challenges

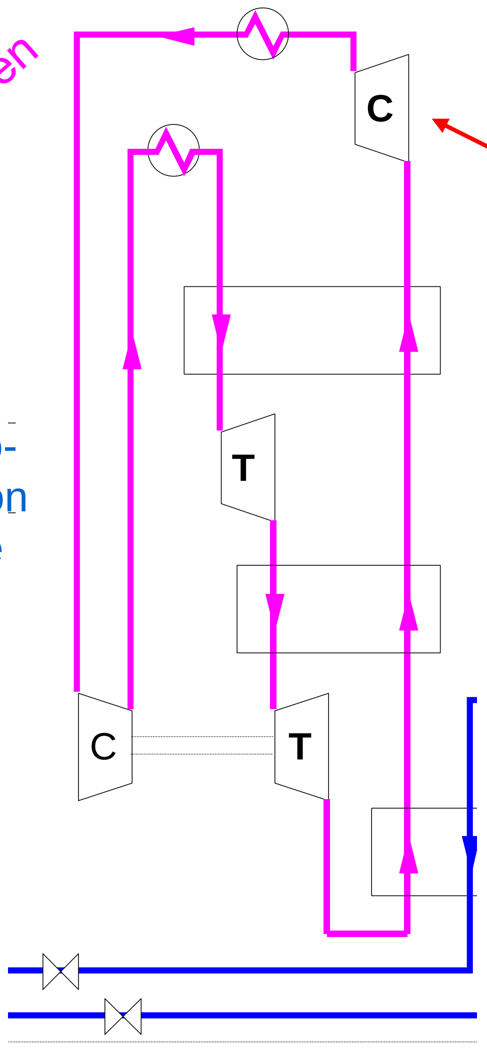


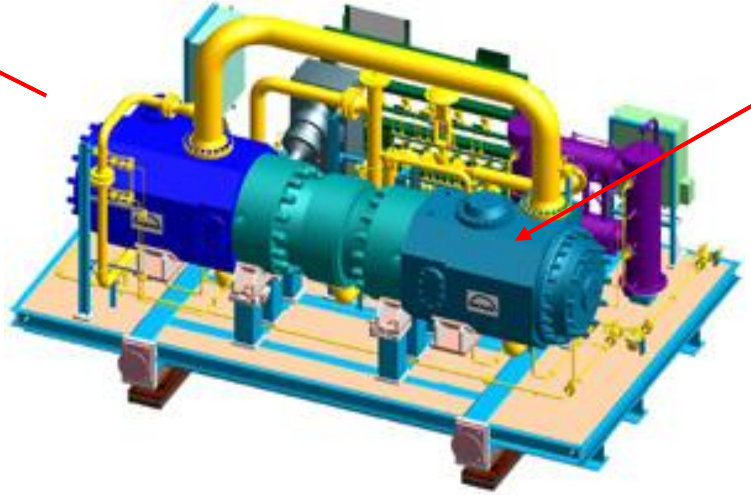

- Synchrotron radiation: 5 MW @ 40-60 K
- SC magnet cooling: 120 kW @ 1.9 K
  - → 10 cryogenic plants (100 kWeq @ 4.5 K) i.e. unit refrigeration capacity ~ factor 4 w/r to the present State-of-the-Art (R&D).
  - → Cold-compressor size ~ factor 5 w/r to the present State-of-the-Art (R&D).
- High-pressure (50 bar) cryogenic distribution
  - → Invar® technology to avoid complicated and risky bellows-compensation units (R&D).
- High magnetic stored energy (35 MJ per dipole)
  - → ~ factor 5 w/r to LHC dipole
  - → Development of larger quench safety relief valves.

# Ne-He cycle: 750-1000 kW between 40 and 60 K

TU Dresden

Turbo-Brayton cycle



Courtesy of MAN Diesel & Turbo

**Hermetically sealed centrifugal compressors:**
- No dry gas seals, no lube-oil system and no gearbox
- Use of high speed induction motor (up to 200 Hz) and active magnetic bearings. The motor is cooled by process gas and directly coupled to the barrel type compressor.

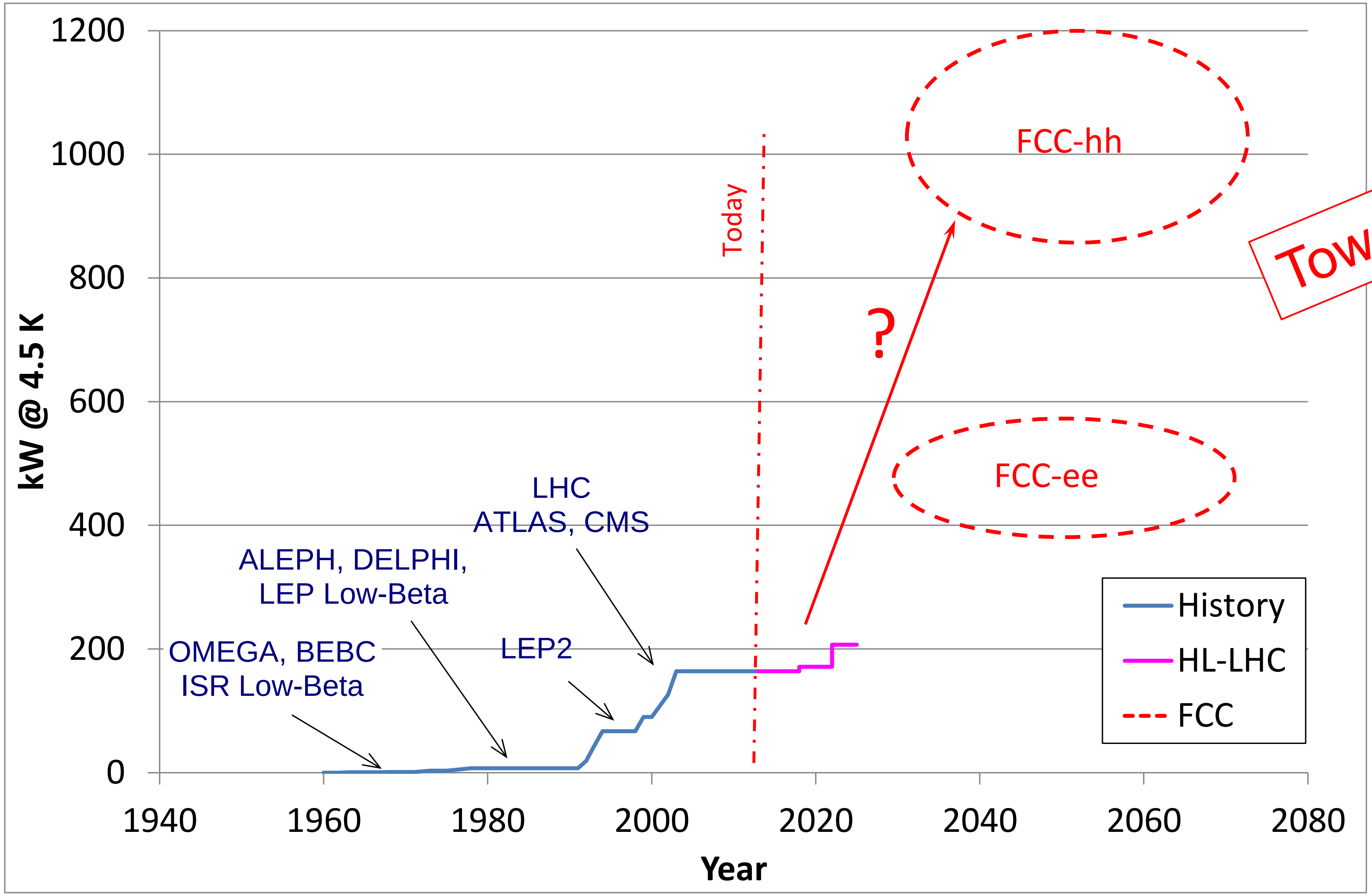
Difficult to get high compression ratio and high compression efficiency with pure helium (light mono-atomic gas):

→ Compression of a mixture of helium and neon (~75-25 %) (OK with neon as refrigeration T > 40 K)

→ The warm compression efficiency is improved

→ Expected global efficiency with respect to Carnot → **42 %**

# Main FCC cryogenics challenges: Cryogenic power




Towards 1 MW @ 4.5 K !

# Cryogenic systems for CERN Neutrino Platform activities

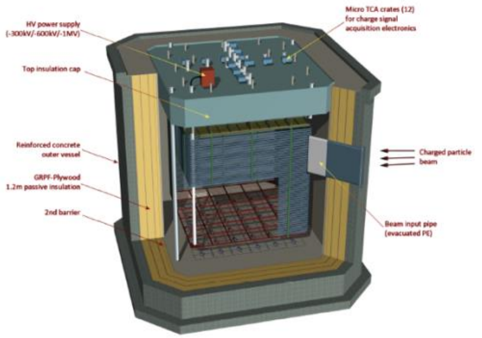

Non vacuum insulated membrane cryostat

Non vacuum insulated membrane cryostats (7.5 W/m$^2$) are developed and prototyped for the DUNE experiment to be housed in four ultra pure liquid argon cryostats with a volume of 12.000 m$^3$ each, operating at ~88 K. Advantage of these cryostats: no insulation vacuum rupture, heat load is known under all circumstances. These cryostats can not be brought to sub-atmospheric conditions, purification system at warm to be developed

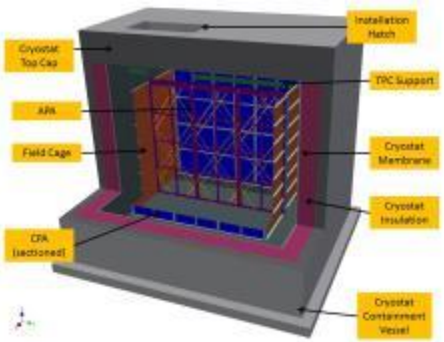
Involvement of CERN cryogenics group in the Dune project:

- Development of a liquid argon purification system, guaranteeing a purity of the liquid argon in the cryostats at a level of several ppt of oxygen equivalent;
- Development of cryogenic systems for the DUNE prototypes, able to cope with heat load of these cryostats;
- Design, tendering, fabrication follow-up, installation and commissioning of the cryogenic systems for the prototypes at CERN and at Fermilab;
- Operation of large volume liquid argon cryostats operated at CERN
  - Pressure range between 1.05 and 1.30 bar abs. (cryostat design)
  - Gradient smaller than 1 K over any two points in the liquid argon detector volume;

30 m$^3$ Dual Phase prototype at CERN (operational at CERN)



600 m$^3$ Dual-Phase prototype under construction at CERN



600 m$^3$ Single Phase prototype under construction at CERN

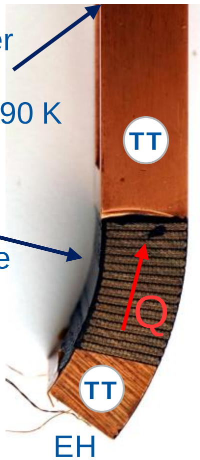
# The cryogenic laboratory (Services and Projects)

## Low temperature material property test stands

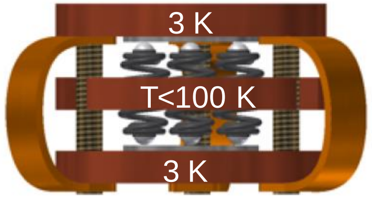
Thermal conductivity & diffusivity

Tc & RRR

11 T coil sample




Hi-Lumi beam screen





SC films and bulk

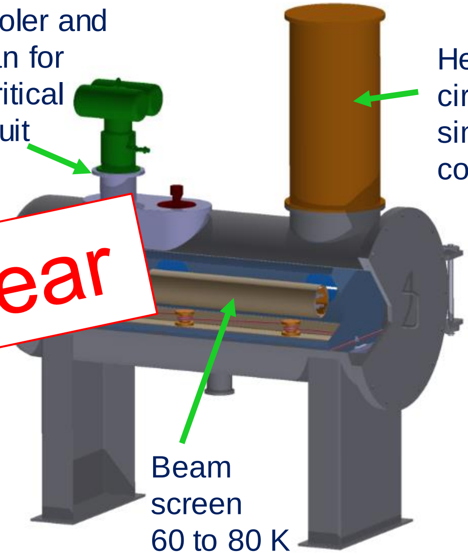
## Cryogenic infrastructure for tests at 1.7 K < T < 90 K

Near Tc characterization

Hi-Lumi Beam Screen

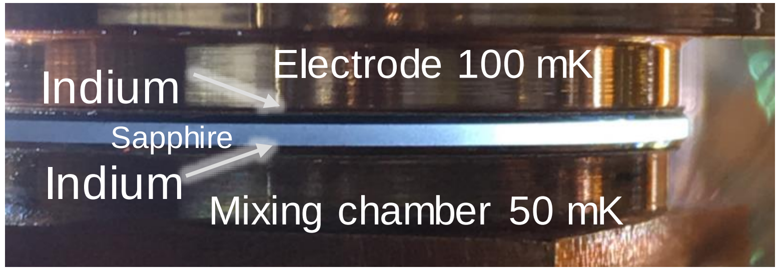
Nb$_3$Sn strands at 17 K


Tungsten based BS

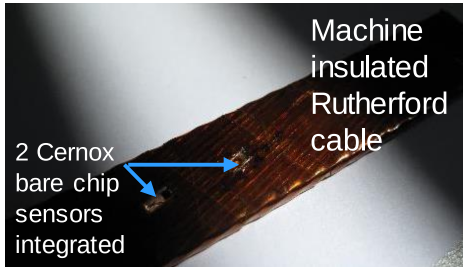


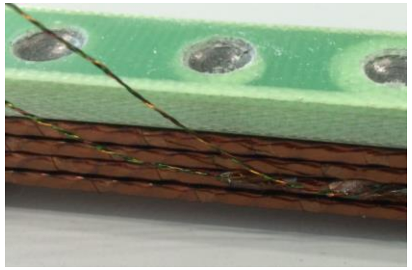

**Cryolab capacity: ~30 projects per year**

Ultra low temperature heat transfer at interfaces for Antimatter traps

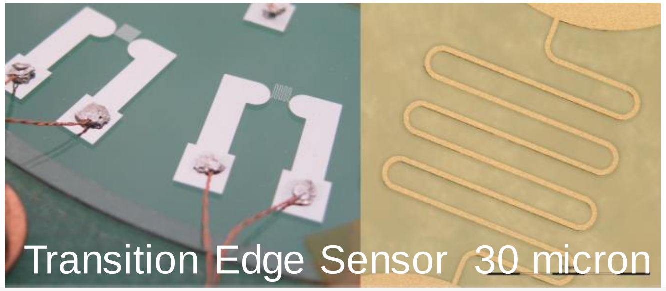



He II transient heat transport in confined geometries of Rutherford cable stacks



Quench localisation on SRF cavities => He II second sound with TES



# Conclusion

- CERN is a center of excellence in cryogenics thanks to its long experience (> 50 years) and its challenging projects which require to push the boundaries of the State-of-the-Art.
- CERN present study and R&D program is focused on HL-LHC, on the Neutrino Platform and on FCC.
- The cryogenic laboratory is the central pillar for small & medium-size S&D in cryogenics.
- R&D could also be done via industrial partners (e.g. quench valves, sub-cooling heat exchangers, cold compressors…)

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