



# Cryogenics at CERN

D. Delikaris, Head of Cryogenics Group, Technology Department

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# Agenda

**Brief Introduction to CERN & Cryogenics**

**The Accelerators & Detectors Complex**

**The Cryogenics Group at CERN**

**Present & future cryogenic refrigeration capacity**

**Use of Cryogenics; Cryogenic Plants**

**Management of Cryogen at CERN**

**Forthcoming Estimated Procurements for Cryogenic Systems (over 2023-2027)**

**Summary**

# CERN, European Organization for Nuclear Research, an Intergovernmental Organization for the High Energy Physics

<https://home.cern/about/who-we-are/our-governance/member-states>

CERN is run by 23 Member States, and many non-European countries are involved in different ways

MEMBER STATES  
ASSOCIATE MEMBERS IN THE PRE-STAGE TO MEMBERSHIP  
ASSOCIATE MEMBER STATES  
OBSERVERS

Cryogenics at CERN; DD



# Cryogenics @ CERN: definition

The branch of physics dealing with the production and effects of very low temperatures

<https://en.oxforddictionaries.com/definition/cryogenics>; *Oxford Dictionaries*

All scientific and technological disciplines dealing with cryogenic temperatures below 120 K

<http://dictionary.iifir.org/search.php>; *International Dictionary of Refrigeration*

The 120 K temperature limit referring to the normal boiling points of the main atmospheric gases

Krypton (119.8 K), **Methane** (111.6 K), **Oxygen** (90.2 K), Argon (87.3 K), Nitrogen (77.4 K), **Neon** (27.1 K), Hydrogen (20.3 K), Helium (4.2 K)

# Cryogenics @ CERN: mandate

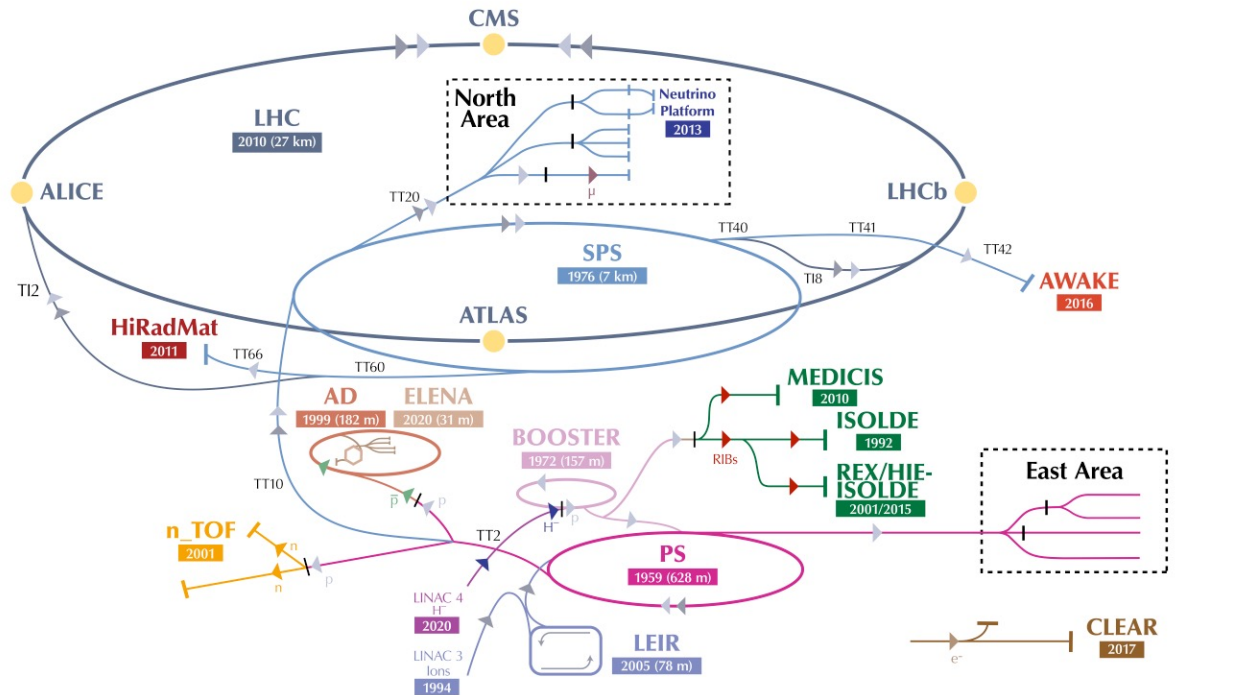
- All scientific and technological disciplines dealing with cryogenic temperatures below 120 K; production and effects of very low temperatures
- Design, construction, commissioning, operation & maintenance and upgrade of the cryogenic systems for CERN accelerators complex, detectors, cryogenic laboratory, test facilities and infrastructures
- Low-temperature R&D and tests program at the Cryogenic Laboratory
- Supply of bulk cryogenic fluids CERN-wide (helium, nitrogen, argon, krypton)
- World-wide consultancy and support in cryogenic design and cryogenic instrumentation



# The Accelerators at CERN (Injectors upgraded)

The CERN accelerator complex  
*Complexe des accélérateurs du CERN*

# LHC



▶  $H^-$  (hydrogen anions) ▶ p (protons) ▶ ions ▶ RIBs (Radioactive Ion Beams) ▶ n (neutrons) ▶  $\bar{p}$  (antiprotons) ▶  $e^-$  (electrons) ▶  $\mu$  (muons)

LHC - Large Hadron Collider // SPS - Super Proton Synchrotron // PS - Proton Synchrotron // AD - Antiproton Decelerator // CLEAR - CERN Linear Electron Accelerator for Research // AWAKE - Advanced WAKEfield Experiment // ISOLDE - Isotope Separator OnLine // REX/HIE-ISOLDE - Radioactive Experiment/High Intensity and Energy ISOLDE // MEDICIS // LEIR - Low Energy Ion Ring // LINAC - LINear ACcelerator // n\_TOF - Neutrons Time Of Flight // HiRadMat - High-Radiation to Materials // Neutrino Platform

THE LARGE HADRON COLLIDER



LE GRAND COLLISIONNEUR DE HADRONS



# Main Accelerators & Detectors technologies

**Electrical fields** to accelerate beams: superconducting radiofrequency cavities

**Magnetic fields** to steer, kick & focus beams for accelerators, particles tracking and identification for detectors: superconducting magnets

**Vacuum** nearly absolute ( $10^{-13}$  atm) in accelerators beam pipes to avoid beam interaction with existing matter

**Cryogenics** to cool down magnets & cavities at 4.5 K or 1.8 K (and less for specific applications) generating and maintaining superconductivity (quasi absence of electrical resistivity)

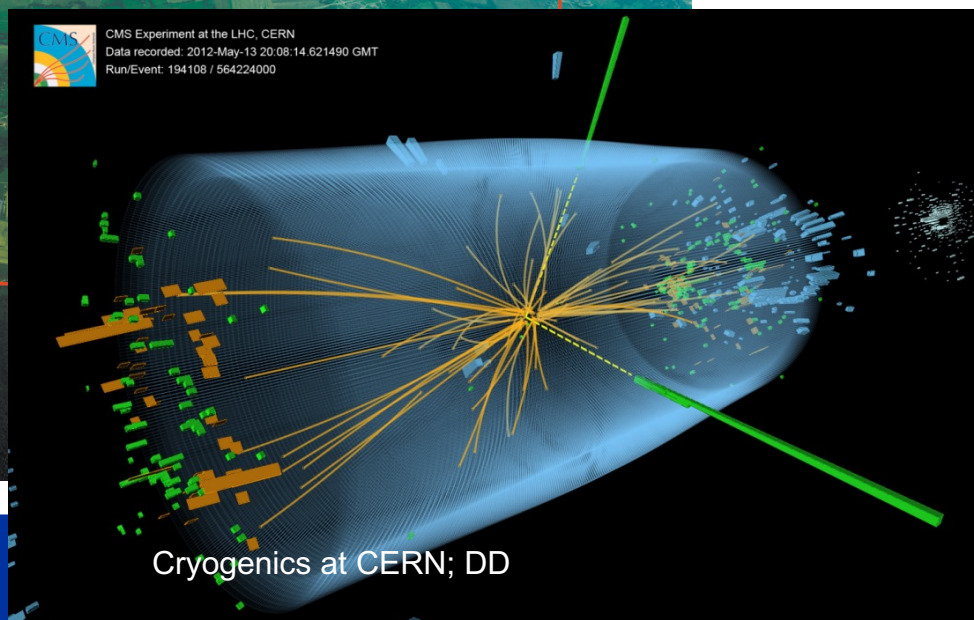
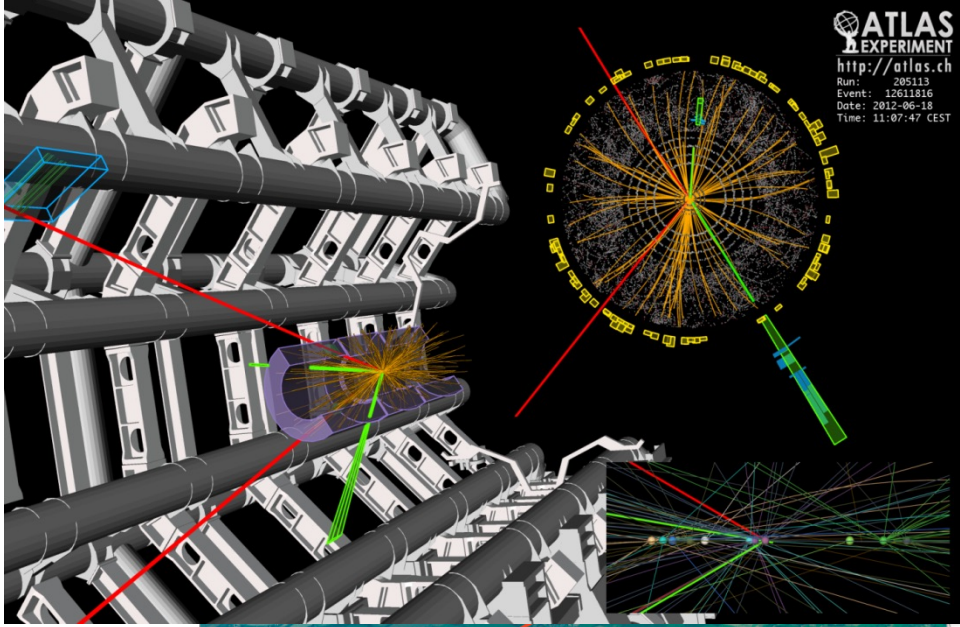
**Powering** energy for all



# The Large Hadron Collider (LHC) at CERN

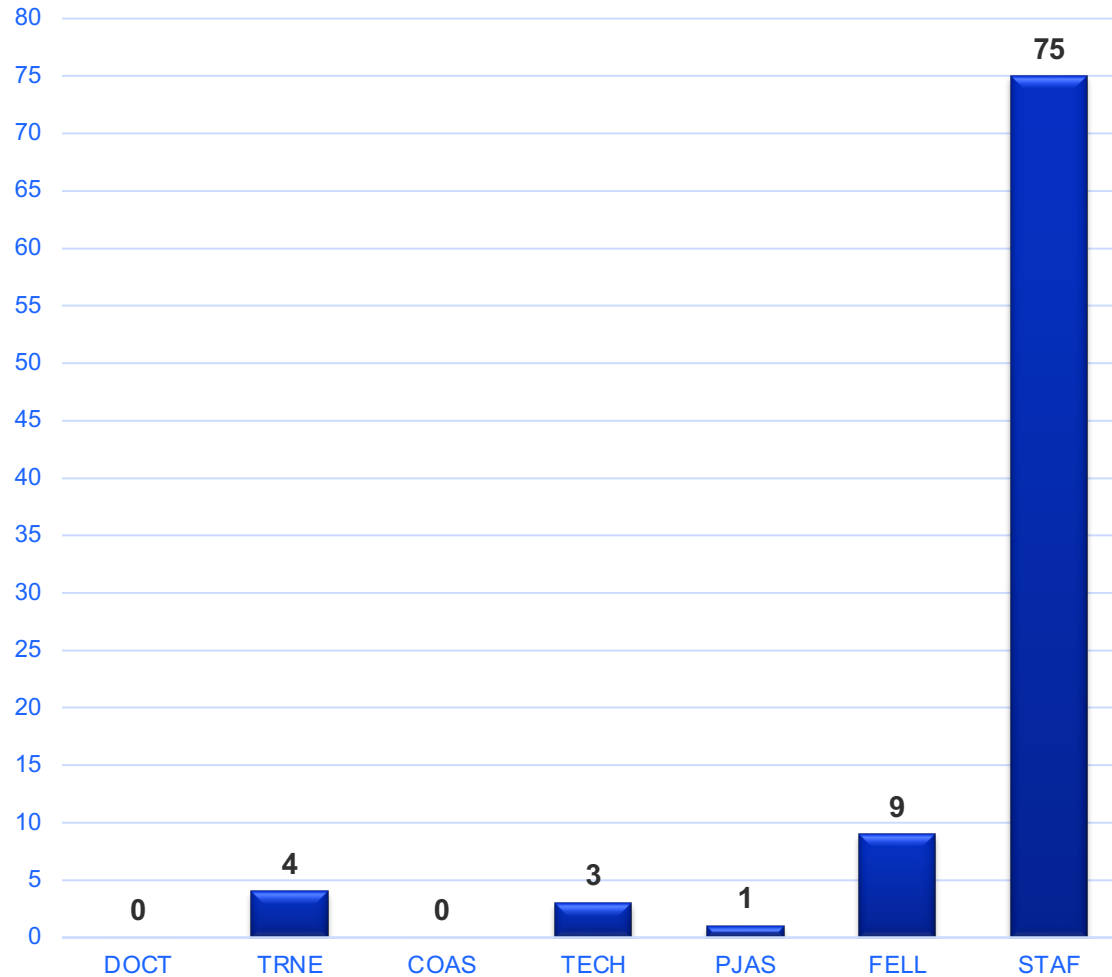






# The Cryogenics group

Status Codes Distribution



- Cryogenic Laboratory (R&D)
- Mechanical Engineering
- Process Controls, Instrumentation & Electrical Engineering
- Maintenance Management & Logistics
- Operation

## Professional class:

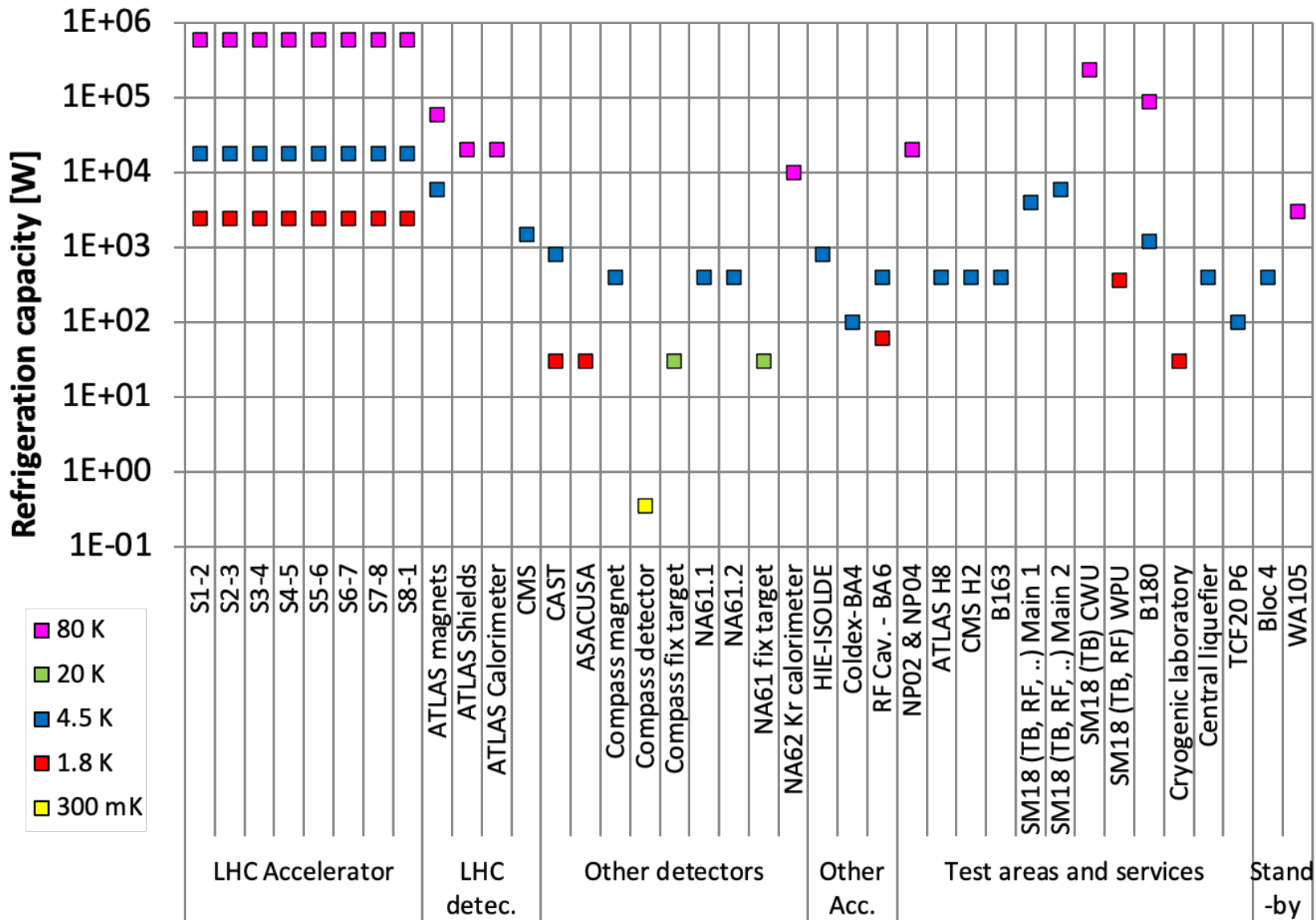
- 59% Technical work,
- 41% Scientific & Engineering work

## Industrial support resources (service contracts):

General mechanical, electrical,  
instrumentation support: 18 FTE

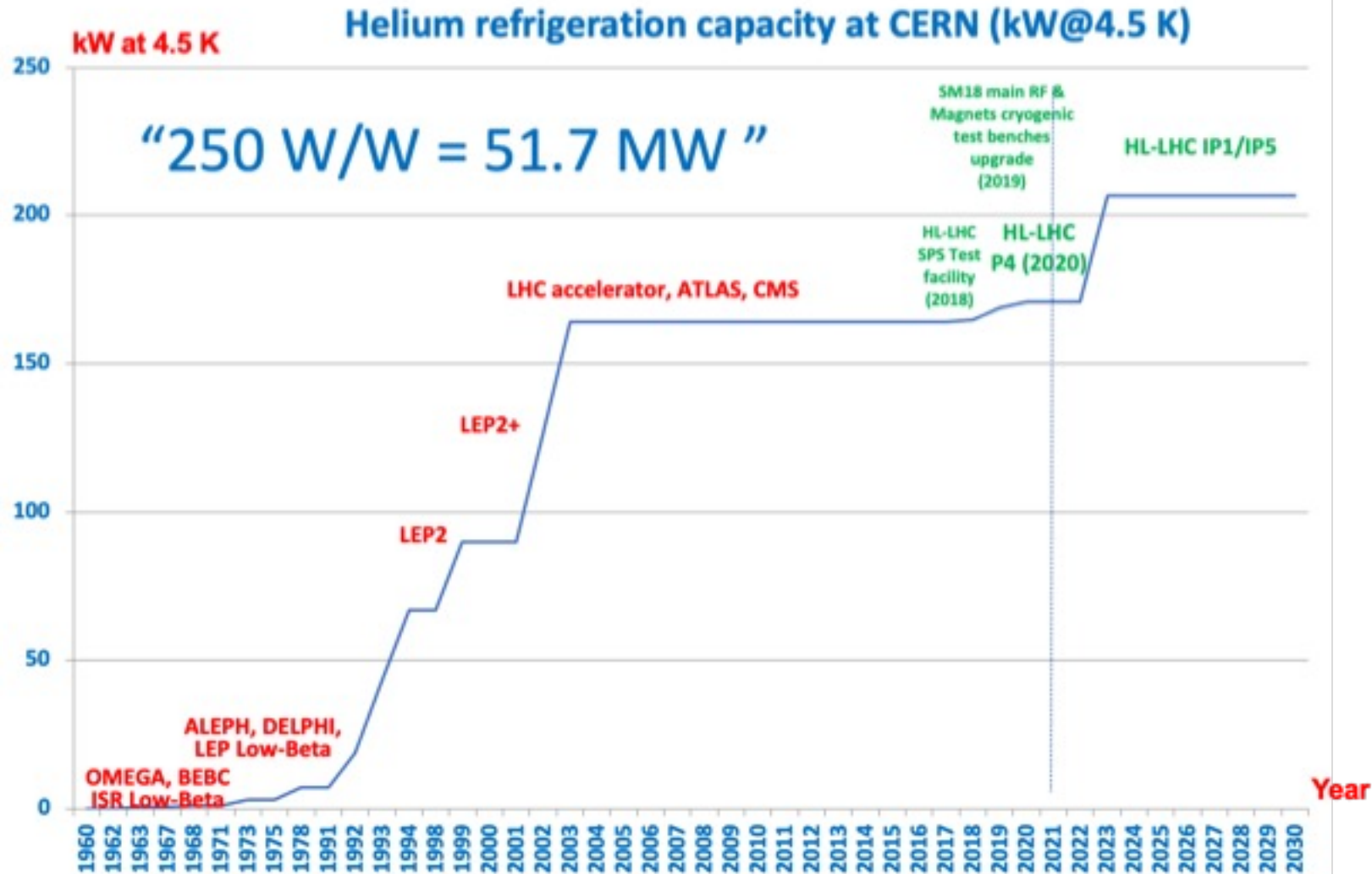
Maintenance & Operation (M&O)  
dedicated service contract: 47 FTE

# Cryogenics @ CERN: large T spectrum





# Cryogenics @ CERN: large power (refrigeration & energy)





# Cryogenics equipment (typical)



18 kW @ 4.5 K  
Warm compressors  
station



18 kW @ 4.5 K cold boxes  
(Air Liquide and Linde)

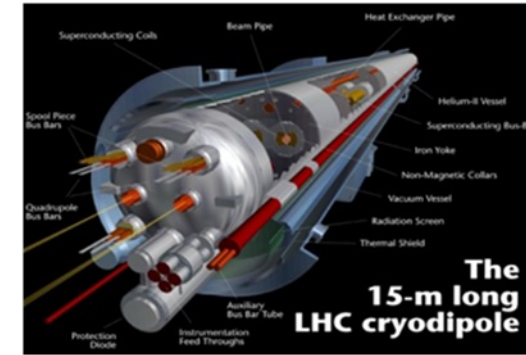
Cold compressors (1.8 K)  
(IHI-Linde and Air Liquide)



# Use of Helium Cryogenics (1/2)

## LHC accelerator

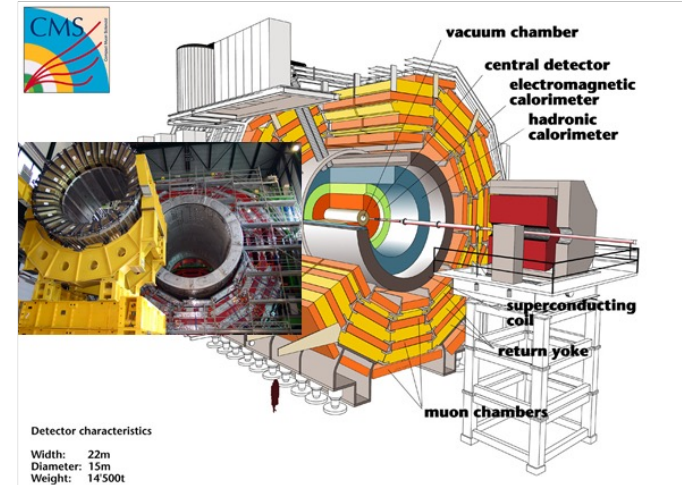
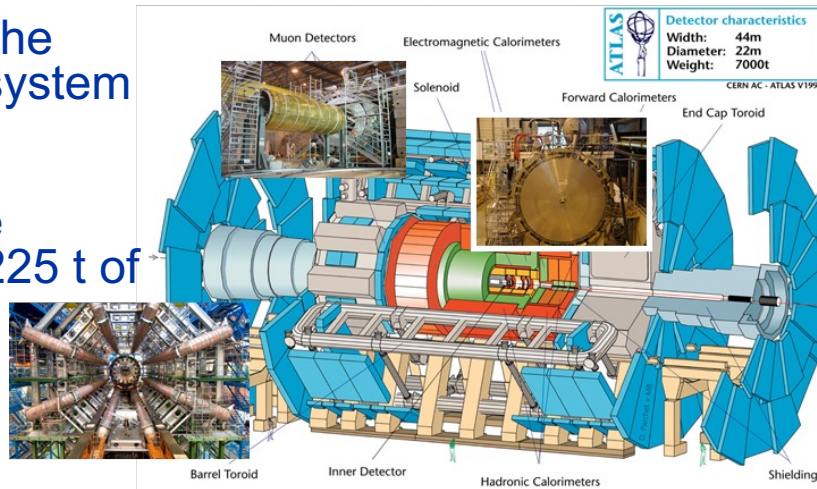
Cooling at 1.9 K of the superconducting magnets (36'000 t of cold mass) distributed over the 26.7 km underground accelerator



## LHC physics detectors

**ATLAS**, cooling at 4.5 K of the superconducting magnetic system (1'275 t of cold mass)

**CMS**, cooling at 4.5 K of the superconducting solenoid (225 t of cold mass)

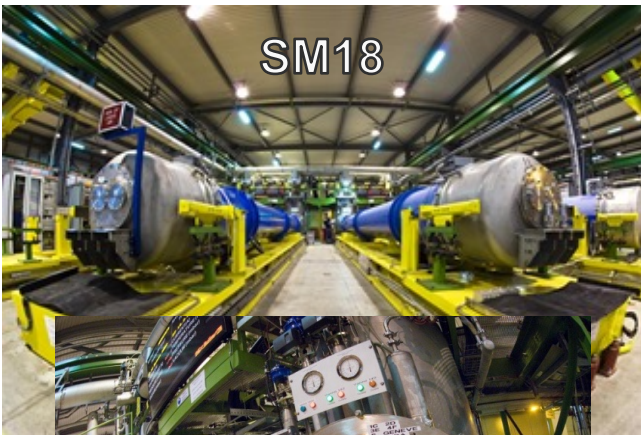




# Use of Helium Cryogenics (2/2)

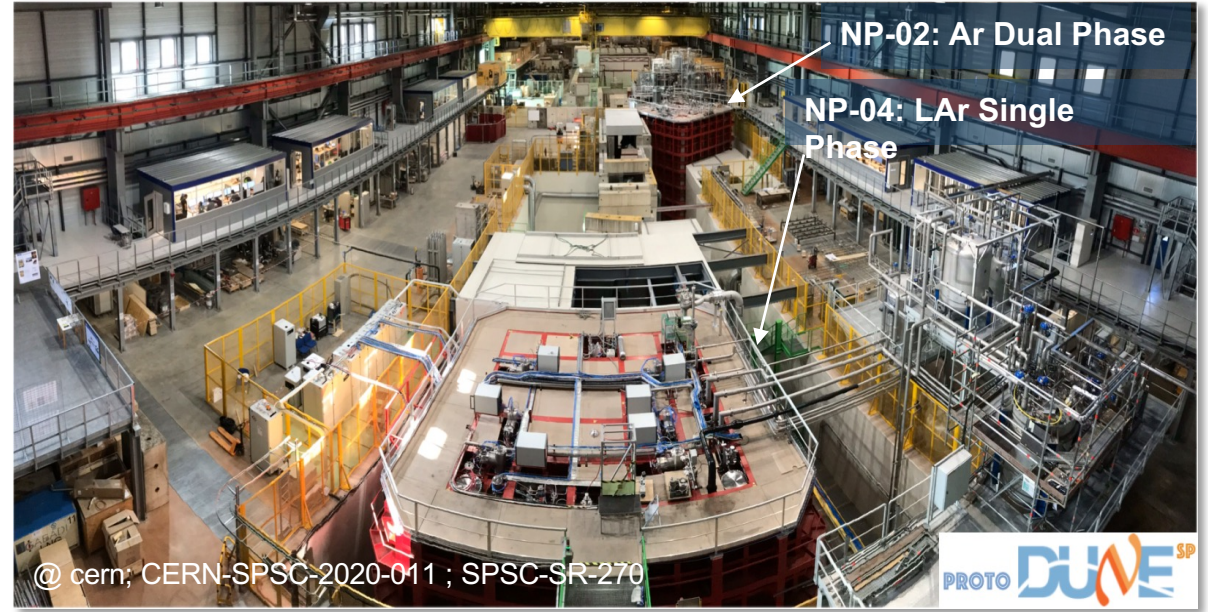
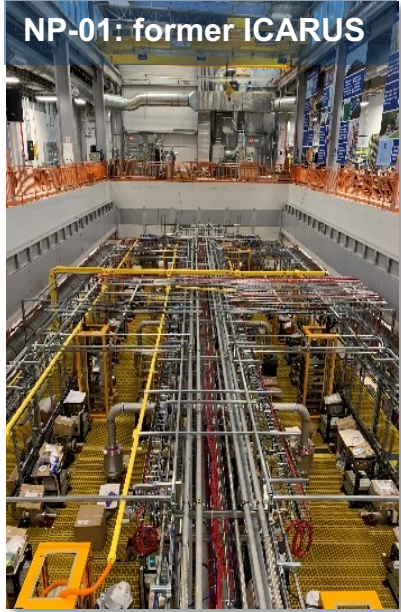
CERN wide helium refrigeration systems for:

- ✓ Test benches for accelerator magnets, cables and wires, RF cavities
- ✓ Detectors' components tests (magnets and sub-detectors)
- ✓ Large magnetic spectrometers for fixed target physics experiments
- ✓ Cryogenic laboratory test bench facilities
- ✓ In situ helium liquefaction for users without dedicated cryogenic plant





# Neutrino platform facilities (CERN & US); LArgon



## At CERN:

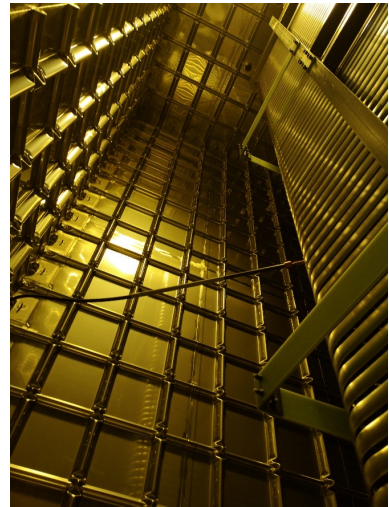
- NP02/NP04 : liquid argon single/double phase prototype neutrino detector installed and operated; liquid argon volume 550 m<sup>3</sup>/600 m<sup>3</sup> respectively

## At Fermilab, US (proximity cryogenics from CERN):

- NP01: former ICARUS detector (600 m<sup>3</sup> of liquid argon) installed as far detector: in operation
- NP03: near detector (300 m<sup>3</sup> of liquid argon) ; to be commissioned

Now start working on the LBNF/DUNE proximity cryogenics in US: **cooling and re-condensing gaseous argon, purification and recirculation of LAr (70kt)**

**Cryostats (inner dimensions, liquid and gas): 65m x 15m x 15m (next slide...)**





# Cryogen (helium, nitrogen, argon, krypton)

**Helium** inventory at CERN: **170 t (today)**

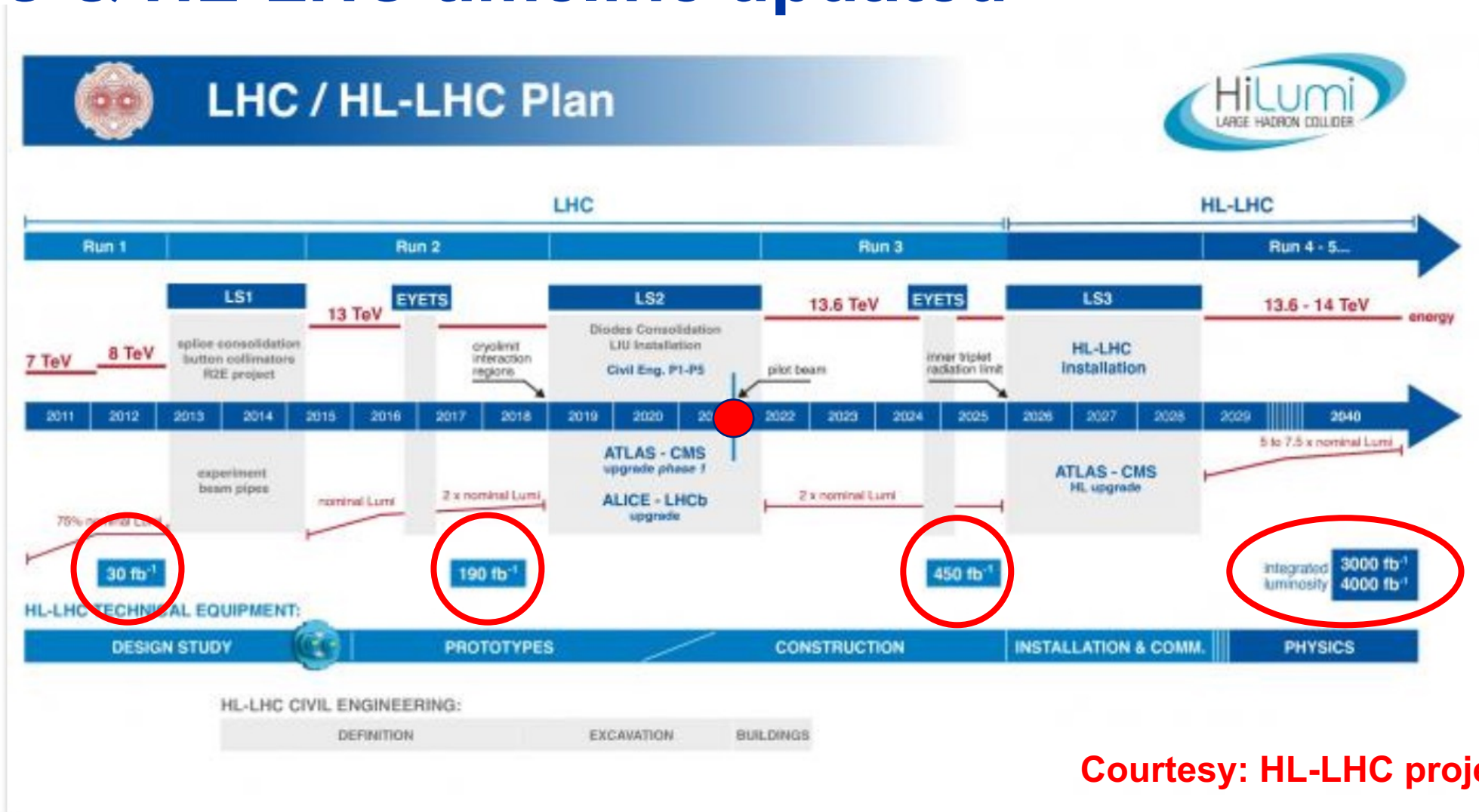
- LHC (accelerator & detectors) helium full inventory: **136 t**
- Strategic permanent storage : **20 t**

**Nitrogen** liquid for LHC (accelerator & detectors) full cool down: **11'500 t**  
(equivalent to 500 **ISO**-transportable containers delivered)

**Argon** liquid for Neutrino platform and ATLAS calorimeter: up to **1'800 t**

**Krypton** liquid for NA62 calorimeter: **24 t**

# LHC & HL-LHC timeline updated



Courtesy: HL-LHC project, March 2022

LHC / HL-LHC Plan updated in February 2022

# CERN's Forthcoming Estimated Procurements for Cryogenic Systems (1/2)

**CERN public scale**  
 <200 kCHF  
 >200 kCHF , < 750 kCHF  
 >750kCHF, <5 MCHF  
 >5 MCHF, <10 MCHF  
 >10 MCHF  
 MS: Market survey  
 IT: Invitation to Tender

System	CERN public scale	2023	2024	2025	2026	2027
Helium Turbo-expanders, spares	>200 kCHF , < 750 kCHF	IT				
Supply of High-Grade Helium	>10 MCHF				MS, IT	
Supply of Liquid Nitrogen	>5 MCHF, <10 MCHF	MS, IT				
Supply of Liquid Argon	>200 kCHF , < 750 kCHF	MS, IT				
Industrial support for cryogenics M&O	>10 MCHF	MS, IT				
LBNF argon condenser system (Swiss Confederation contribution); install. In US	>750kCHF, <5 MCHF	IT(CH)				
Dark Side 20k liquid argon proximity cryogenics; install. In Italy	>200 kCHF , < 750 kCHF	MS, IT				
Major overhauling helium compressors at manufacturer's premises	>750kCHF, <5 MCHF			IT		
Major overhauling helium cold compressors at manufacturer's premises	>200 kCHF , < 750 kCHF					IT
Major overhauling 3.3 kV electrical motors for helium compressors	>200 kCHF , < 750 kCHF			MS, IT		

# CERN's Forthcoming Estimated Procurements for Cryogenic Systems (2/2)

## CERN public scale

<200 kCHF

>200 kCHF , < 750 kCHF

>750kCHF, <5 MCHF

>5 MCHF, <10 MCHF

>10 MCHF

MS: Market survey

IT: Invitation to Tender

## HL-LHC cryogenic equipment

CERN has already adjudicated the helium cryogenic plants and distribution line

System	CERN public scale	2023	2024	2025	2026	2027
Supply of gaseous helium vessels	>750 kCHF, <5 MCHF	IT				
Supply of liquid nitrogen vessels	>200 kCHF , < 750 kCHF	IT				
Supply of electrical controls cabinets	>200 kCHF , < 750 kCHF	MS	IT			
Warm interconnection piping infrastructure (2x1.5 km, DN200)	>750 kCHF, <5 MCHF	MS, IT				
Cryogenic valves (control, quench)	>200 kCHF , < 750 kCHF	MS, IT				
Onsite re-work of existing cryogenic distribution multi-header line	>750 kCHF, <5 MCHF	MS	IT			
Cryogenic instrumentation (PT, LD, Actuators)	>750 kCHF, <5 MCHF	MS	IT			
Cryogenic instrumentation (Rad Tol Electronics, 1500 cards, 50 crates)	>750 kCHF, <5 MCHF	MS	IT			



# Summary

**Cryogenics at CERN:** since 1960's for cooling components on accelerators, physics detectors & test facilities

**Very large spectrum** of cryogenic engineering & working conditions (applications and refrigeration capacity @ T K)

**Implementation & successful operation** of “state of the art” industrial cryogenic equipment at the edge of the present technology: The LHC cryogenic system (26.7 km, cooling @1.8 K, 80 ton of He II)

**Availability to users:**

**Before the LHC era:** nearly 590'000 running hours have been cumulated over 15 years with a mean availability rate of 99%

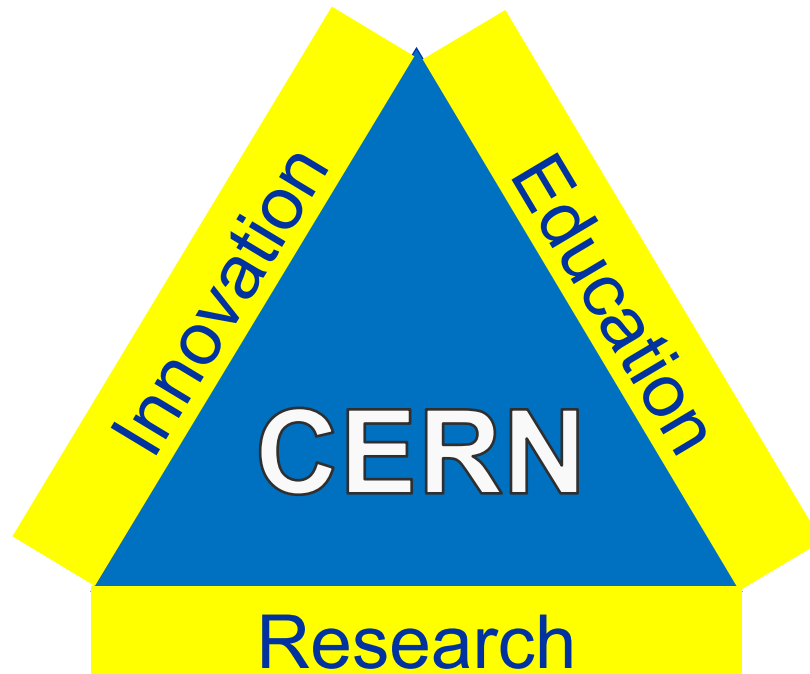
**The present LHC** mean availability is situated around 98%; impressive progress despite the incomparable complexity with the previous era

**Procurement and management** of large cryogen inventory (helium, argon and nitrogen)

Specification, procurement, installation, commissioning, operation & maintenance of **new cryogenic plants**

**Consultancy & R&D** in low temperature domains

# Thank you for your attention





[home.cern](https://home.cern)