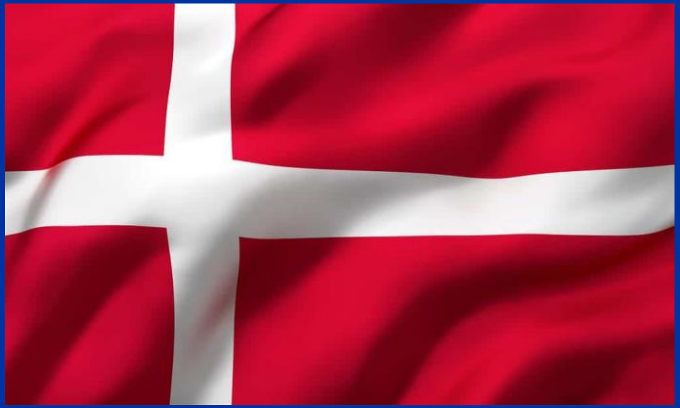


Training on CERN’s ultrahigh vacuum technology

Welcome and introduction

Paolo Chiggiato

October 5th-6th, 2023

CERN

Founded in 1954

23 Member States

Austria, Belgium, Bulgaria, Czech Republic, **Denmark**, Finland, France, Germany, Greece, Hungary, Israel, Italy, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovak Republic, Spain, Sweden, Switzerland and United Kingdom.

3 Associate Member States in the pre-stage to Membership

Cyprus, Estonia and Slovenia

7 Associate Member States

Croatia, India, Latvia, Lithuania, Pakistan, Türkiye and Ukraine

Observer Status

Japan (LHC) and the United States of America (LHC and HL-LHC)
European Union (CERN) and UNESCO (CERN)

CERN Governance

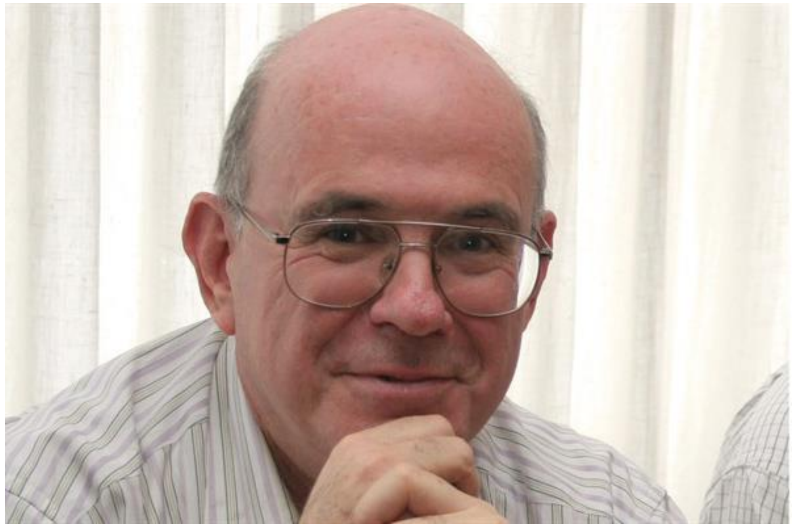
The **CERN Council** is the highest authority of the Organization and has responsibility for all-important decisions. It controls CERN's activities in scientific, technical and administrative matters.

The Council is assisted by the **Scientific Policy Committee** and the **Finance Committee**.

The **Director-General**, appointed by the Council, manages the CERN Laboratory.

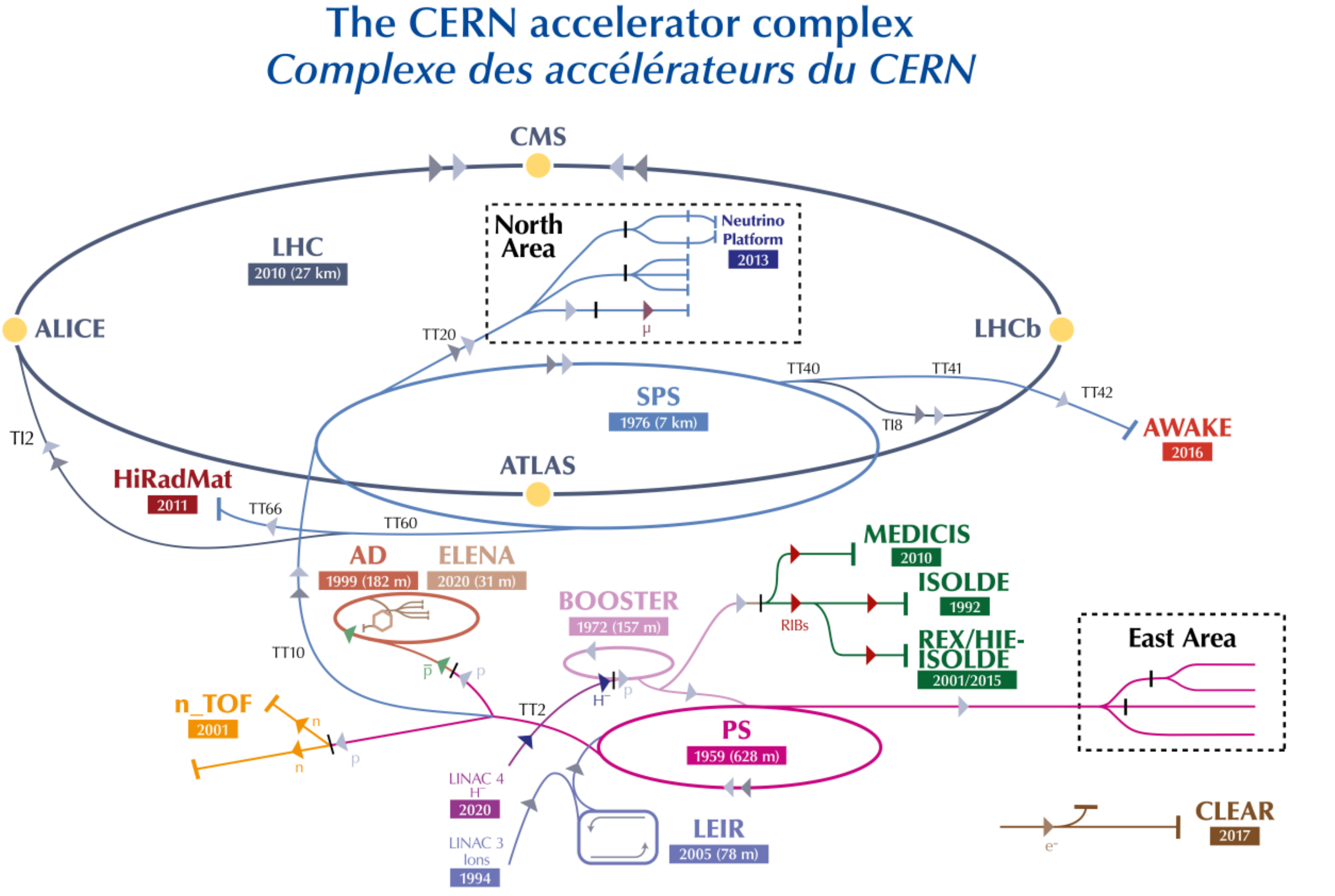
The Director-General is assisted by a **directorate** and runs the Laboratory through a structure of **departments**.

Director-General of CERN, **Fabiola Gianotti**



President of the CERN Council, **Eliezer Rabinovici**

The CERN's accelerator complex



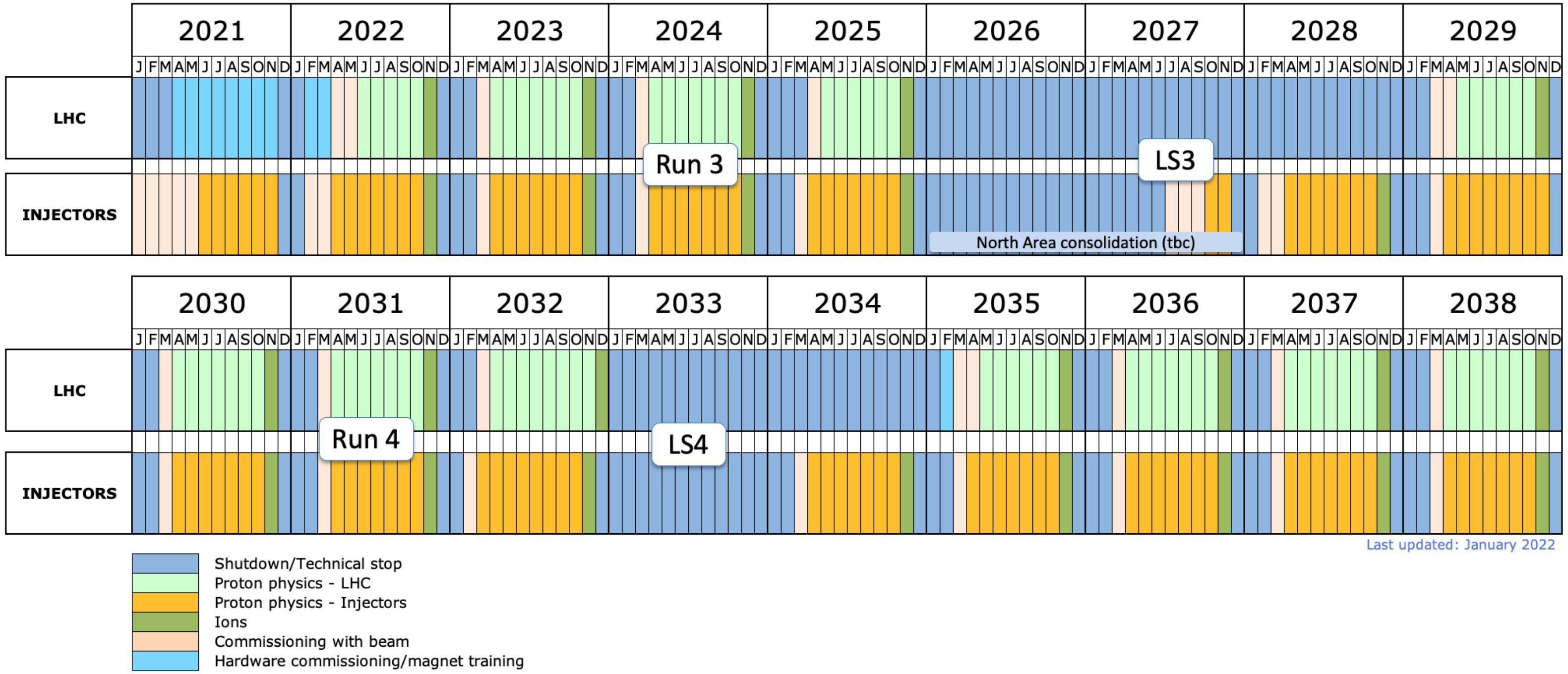
H⁻ (hydrogen anions) · p (protons) · ions · RIBs (Radioactive Ion Beams) · n (neutrons) · $\bar{p}$ (antiprotons) · e^- (electrons) · μ (muons)

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

LHC Roadmap

LHC
Run-3

LS3: final implementation of
HL-LHC’s modifications



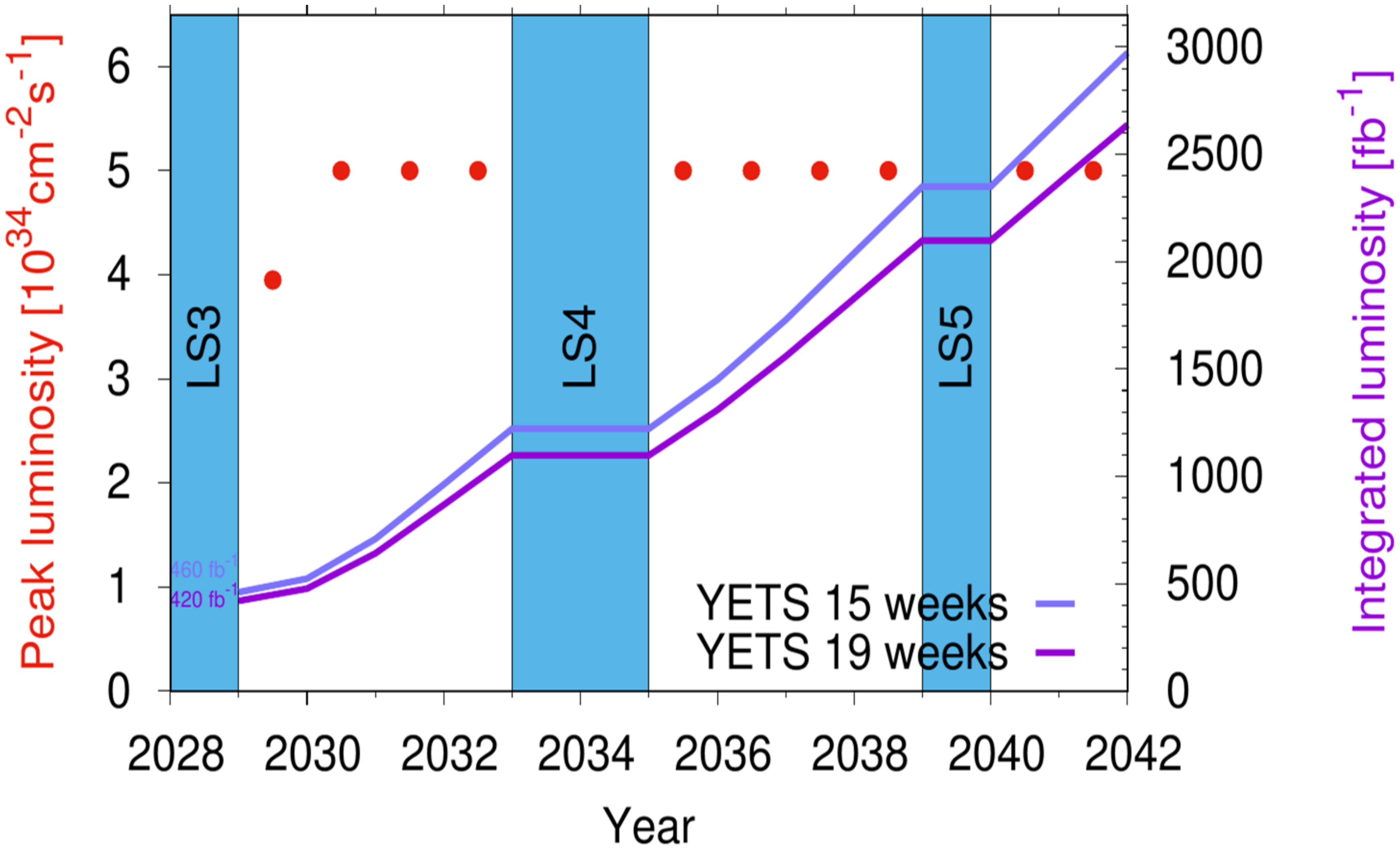
Objectives of HL-LHC

At present, **HL-LHC is the most important CERN's project**. Its objective is an **annual** LHC integrated luminosity of **250 fb^{-1}(#) in ATLAS and CMS** for 12 years of operation (3000 fb^{-1}).

To achieve this ambitious goal:

- The LHC **injector chain** has been **upgraded**:
  - Bunch population from 1.15 to 2.2×10^{11}.
  - Emittance reduction from 3.4 to 2.0 μm at the SPS extraction.
- The beam optics in **IP1 (ATLAS) and IP5 (CMS)** will be **improved to increase beam focusing**.

(#) A single fb^{-1} (inverse femto-barn) is equivalent to 7×10^{13} proton-proton collisions.



Peak luminosity [10^{34}cm^{-2}s^{-1}]
Integrated luminosity [fb^{-1}]
LS3
LS4
LS5
460 fb^{-1}
420 fb^{-1}
YETS 15 weeks
YETS 19 weeks
Year

Other physics frontiers: antimatter

nature

Explore content ⌄ About the journal ⌄ Publish with us ⌄

nature > articles > article

Article | Open Access | Published: 27 September 2023

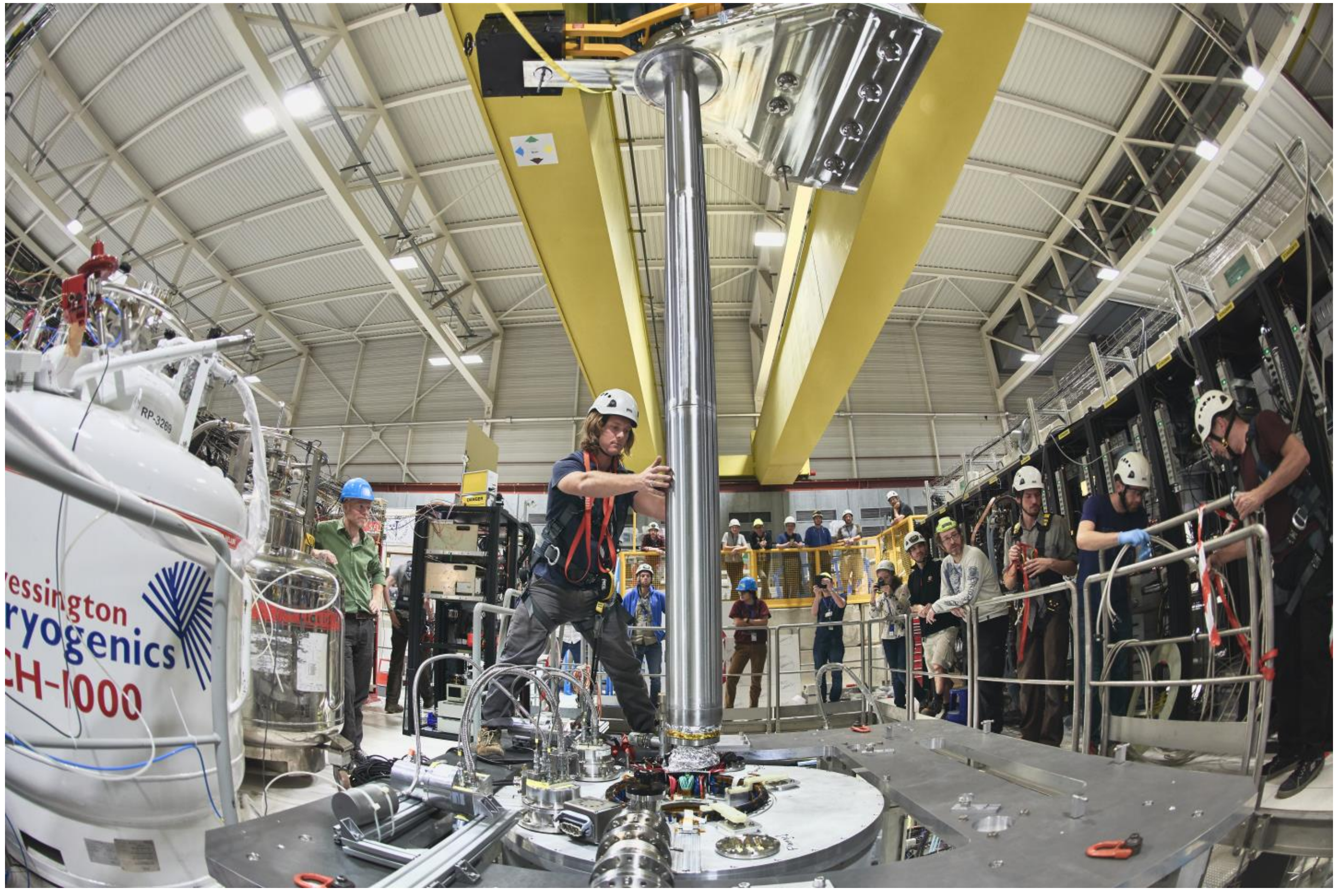
Observation of the effect of gravity on the motion of antimatter

E. K. Anderson, C. J. Baker, W. Bertsche, N. M. Bhatt, G. Bonomi, A. Capra, I. Carli, C. L. Cesar, M. Charlton, A. Christensen, R. Collister, A. Cridland Mathad, D. Duque Quiceno, S. Eriksson, A. Evans, N. Evetts, S. Fabbri, J. Fajans, A. Ferwerda, T. Friesen, M. C. Fujiwara, D. R. Gill, L. M. Golino, M. B. Gomes Gonçalves, ... J. S. Wurtele + Show authors

Nature **621**, 716–722 (2023) | Cite this article

Abstract

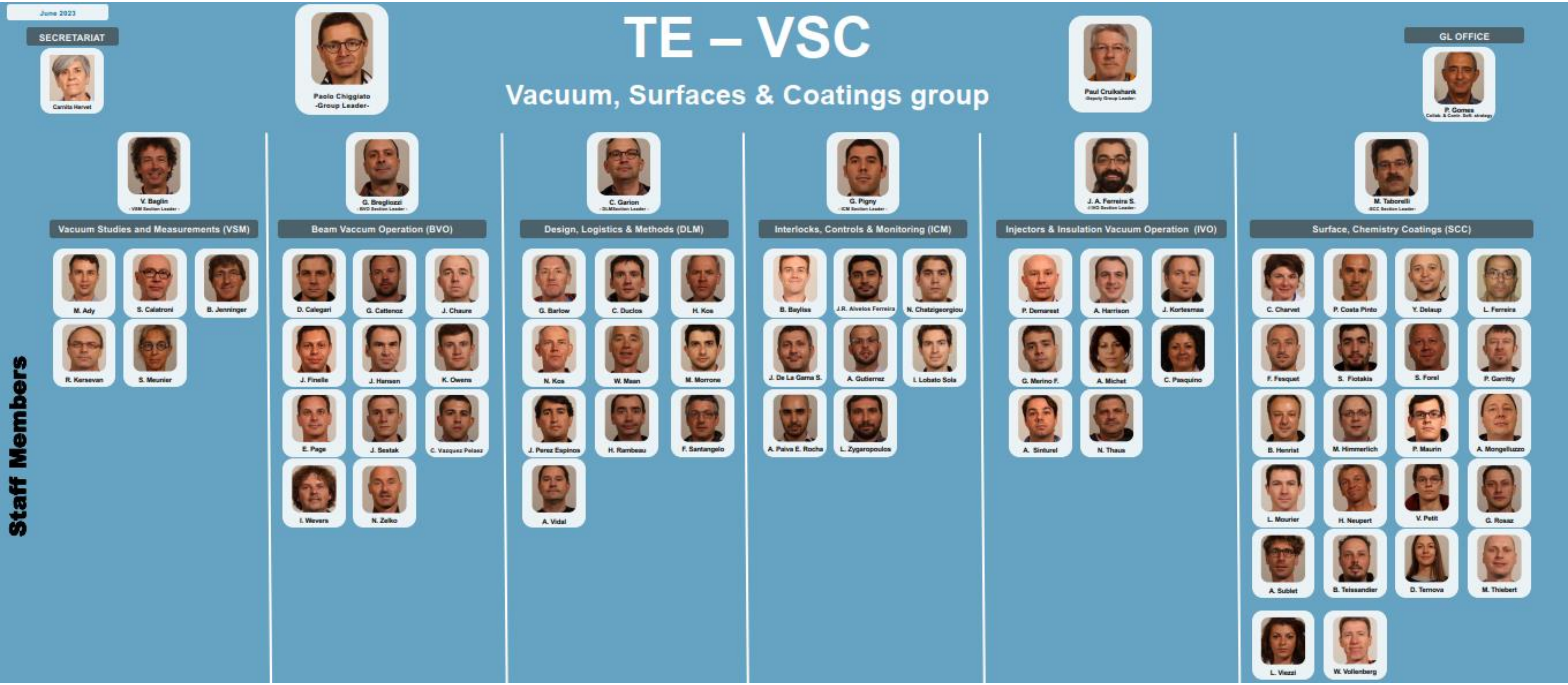
Einstein's general theory of relativity from 1915[1] remains the most successful description of gravitation. From the 1919 solar eclipse[2] to the observation of gravitational waves[3], the theory has passed many crucial experimental tests. However, the evolving concepts of dark matter and dark energy illustrate that there is much to be learned about the gravitating content of the universe. Singularities in the general theory of relativity and the lack of a quantum theory of gravity suggest that our picture is incomplete. It is thus prudent to explore gravity in exotic physical systems. Antimatter was unknown to Einstein in 1915. Dirac's theory[4] appeared in 1928; the positron was observed[5] in 1932. There has since been much speculation about gravity and antimatter. The theoretical consensus is that any laboratory mass must be attracted[6] by the Earth, although some authors have considered the cosmological consequences if antimatter should be repelled by matter[7,8,9,10]. In the general theory of relativity, the weak equivalence principle (WEP) requires that all masses react identically to gravity, independent of their internal structure. Here we show that antihydrogen atoms, released from magnetic confinement in the ALPHA-g apparatus, behave in a way consistent with gravitational attraction to the Earth. Repulsive 'antigravity' is ruled out in this case. This experiment paves the way for precision studies of the magnitude of the gravitational acceleration between anti-atoms and the Earth to test the WEP.



In a paper published last week in *Nature*, the **ALPHA** collaboration at CERN's Antimatter Factory shows that, within the precision of their experiment, atoms of antihydrogen – a positron orbiting an antiproton – fall to Earth in the same way as their matter equivalents.

CERN's Vacuum, Surfaces and Coatings (VSC) group

72 Staff members



Around 50 students, trainees, early career graduate

Budget and expenditure

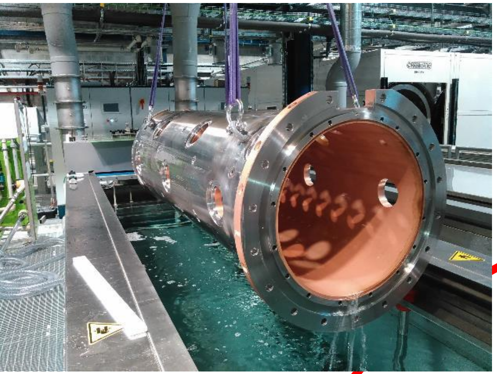
Payment budget in 2023:

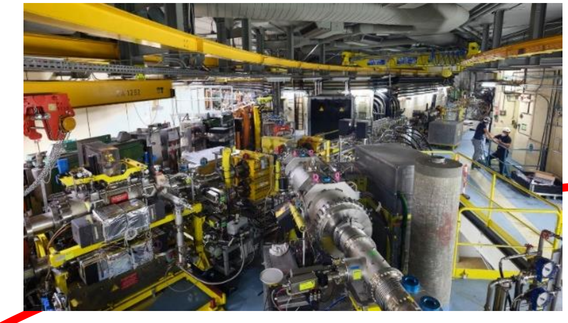
Operational budget: ≈ 5 MCHF
Project budget: ≈ 13 MCHF (mainly HL-LHC)

Most important lines of **expenditure in operation**:

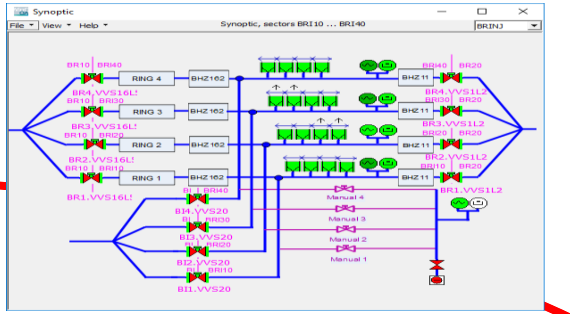
- Blanket contracts
- Industrial support
- CERN internal services
- CERN store
- Associate member of the personnel.

DTL tanks for ESS

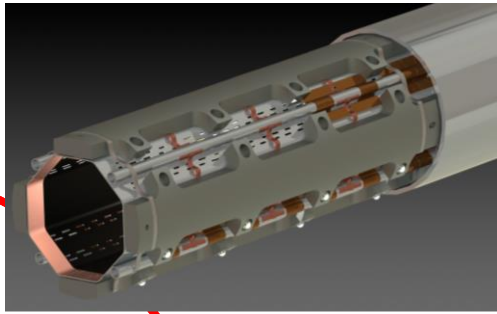




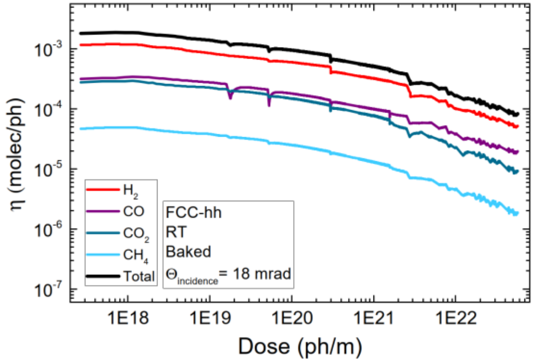
Operation Maintenance Consolidation



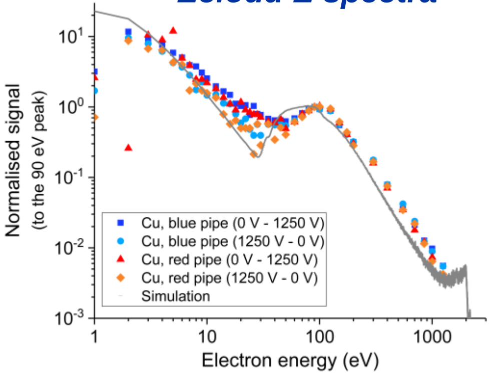
HL-LHC triplet BS



FCC-hh meas. at KARA



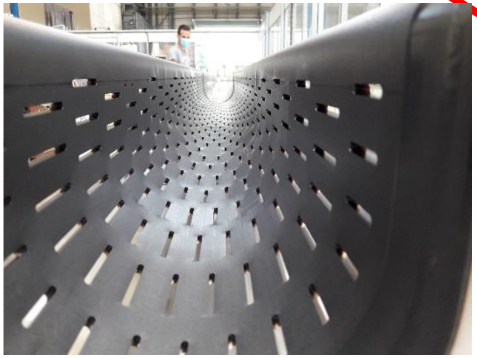
Ecloud E spectra



Services for HEP community

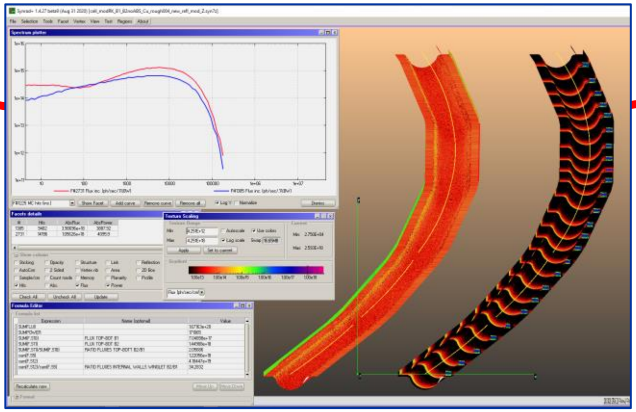
TE-VSC

HL-LHC Project



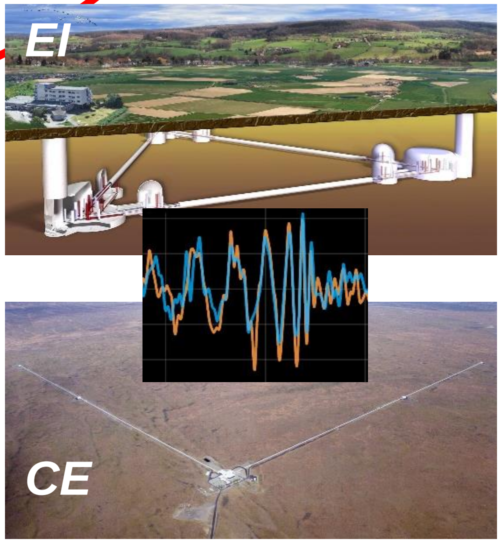
a-C coated RF shield of TDI

Studies



FCC-ee photoadsorbers positioning

Collaborations

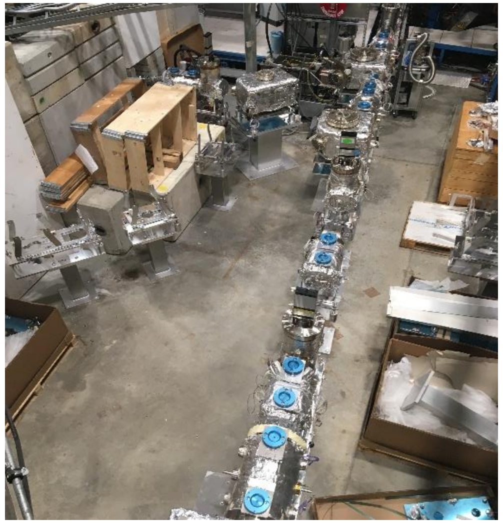


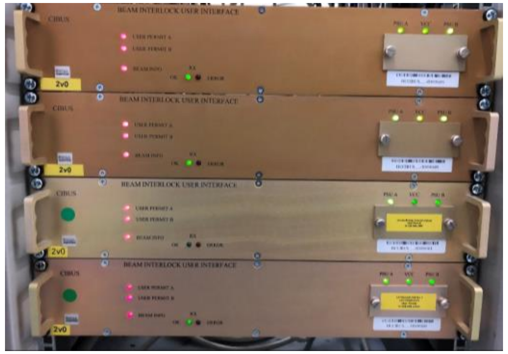
Vacuum systems at CERN

Vacuum systems of CERN's accelerators

Machine	*Type*	*Year*	*Energy*	*Bakeout*	*Pressure [mbar]*	*Length*
Linacs, Booster, ISOLDE, PS, n-TOF and Antimater						**2.6 Km**
Linac 4	linac	2018	160 MeV	ion pumps	10^{-7}	40 m
ISOLDE	electrostatic	1992	60 keV	_	$\mathbf{10^{-6}}$	150 m
REX-HIE ISOLDE	linac	2001-2016	5.5 MeV/u	partly	10^{-7}-10^{-12}	50 m
MEDICIS		2017	_	_	10^{-6}	10 m
Linac 3	linac	1994	4.2 MeV/u	ion pumps	10^{-8}	30 m
LEIR	accumulator	1982/2005	72 MeV/u	complete	10^{-12}	78 m
PSB	synchrotron	1972-2020	1-2 MeV	ion pumps	10^{-9}	157 m
PS	synchrotron	1959	26 GeV	ion pumps	10^{-9}-10^{-10}	628 m
AD	decelerator	1999	100 MeV	complete	10^{-10}	182 m
ELENA	decelerator	2016		complete	$\mathbf{10^{-12}}$	31 m
PS to SPS TL	transfer lines	1976	26 GeV	_	10^{-8}	1.3 km
SPS complex						**15.7 Km**
SPS	synchrotron	1976		extractions	10^{-9}	7 km
SPS North Area		1976		_	10^{-3}-10^{-8}	1.2 km
SPS HiRadMat	transfer line	2011	450 GeV	_	10^{-8}	1.4 km
SPS to LHC TL		2004/06		_	10^{-8}	2 x 2.7 km
AWAKE	wakefield acc	2017		_	10^{-8}	730 m
LHC						**109 Km**
LHC Arcs (Beam vacuum)				_	$<10^{-8}$	50 km
LHC Arcs (insulation vacuum)				_		50 Km
LSS RT separated beams	collider	2007	2 x 7 TeV			2 x 3.2 km
LSS RT recombination				complete	$<10^{-10}$	570 m
Rxperimental areas						180 m
Beam dump lines TD62/68	transfer lines	2006	7 TeV	_	10^{-8}	2 x 720 m

High Vacuum	**≈ 12**
UHV-XHV	**≈ 65**
Insulation vacuum	**≈ 50**
	≈ 127 km

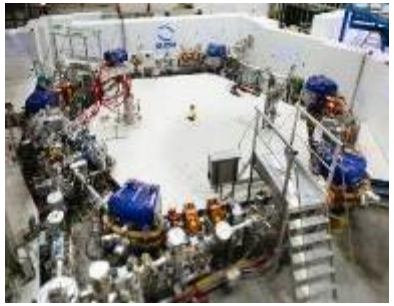




Linac4 <2*10^{-7} mbar*

PSB <5*10^{-8} mbar*

PS <2*10^{-8} mbar*



ELENA <4*10^{-12} mbar

SPS LSS <10^{-7} mbar*

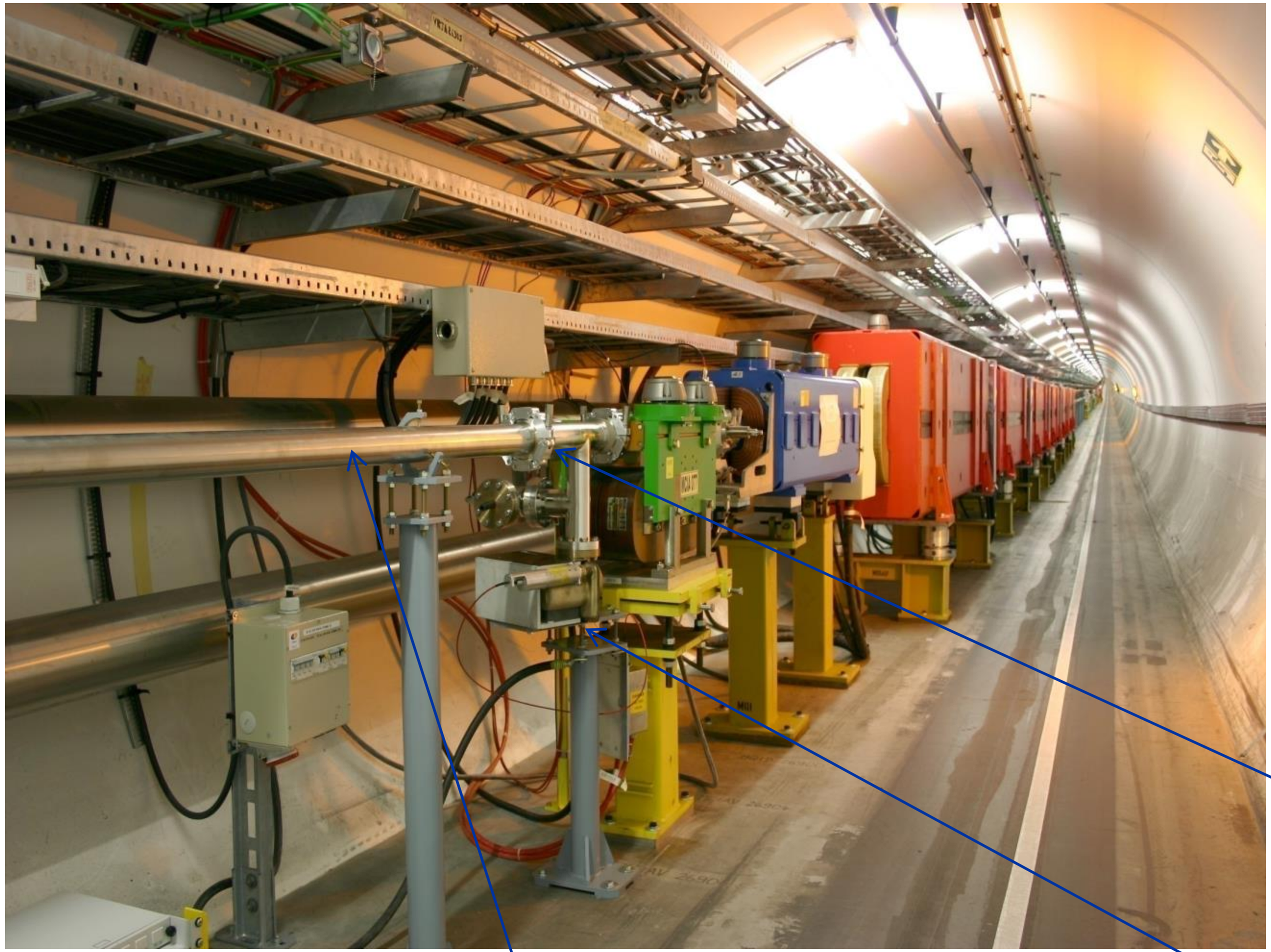
* After 24 h pumpdown

LHC arcs <10^{-8} mbar

LHC LSS <10^{-10} mbar

Unbaked systems	Cryogenic systems	Baked systems
TMP, ion pumps, Ti sublimators	Cryopumping	Ion pumps, NEG coating

127 km long vacuum system



Vacuum systems are made of **several components**. The connection between them is obtained by **flanges**.

Main vacuum components for accelerators and their supply
(Nico Kos' contribution)

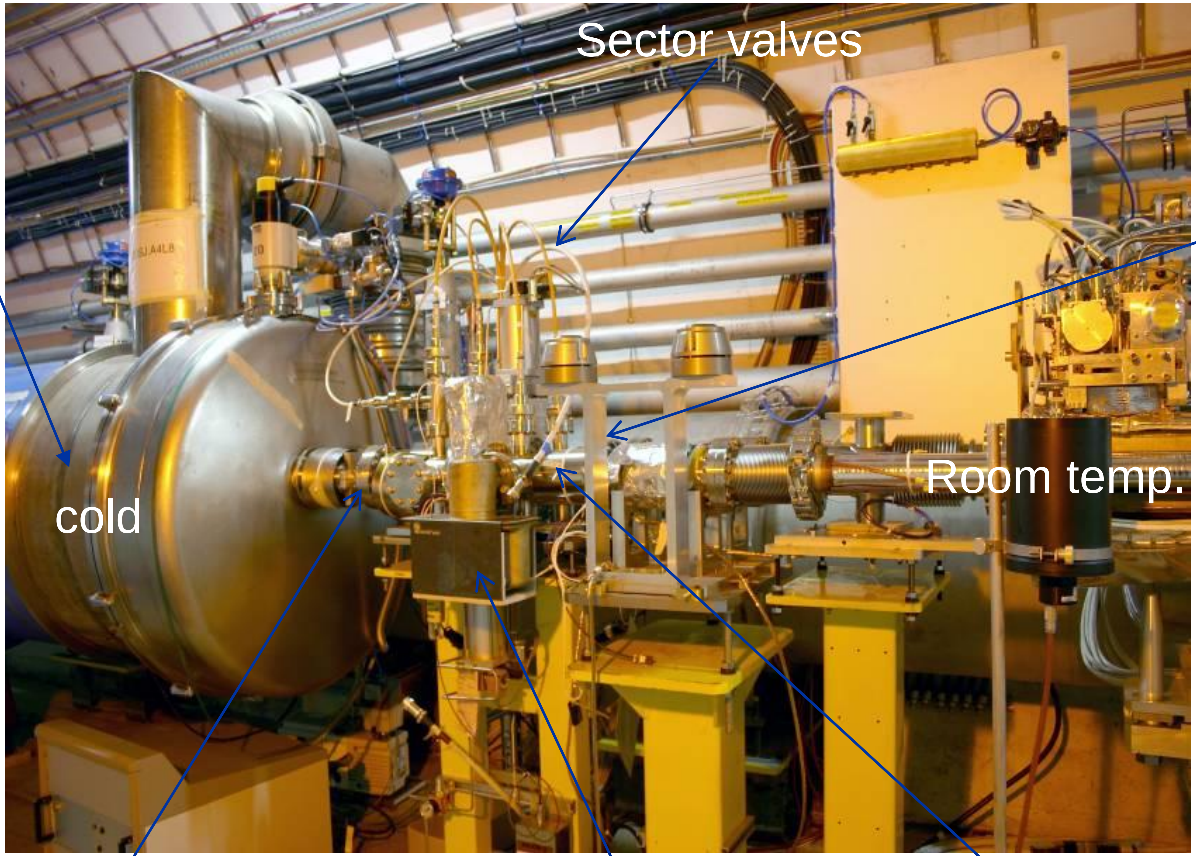
Flange

Beam pipe

Pump (sputter ion pump)

Vacuum for thermal insulation of cryogenic equipment

(Jose Ferreira's contribution)



Beam pipe & NEG coating

Flange

Pump (sputter ion pump)

Pressure measurement

A vacuum sector is delimited by **gate valves**.

The pressure is monitored in each vacuum sector by **gauges**.

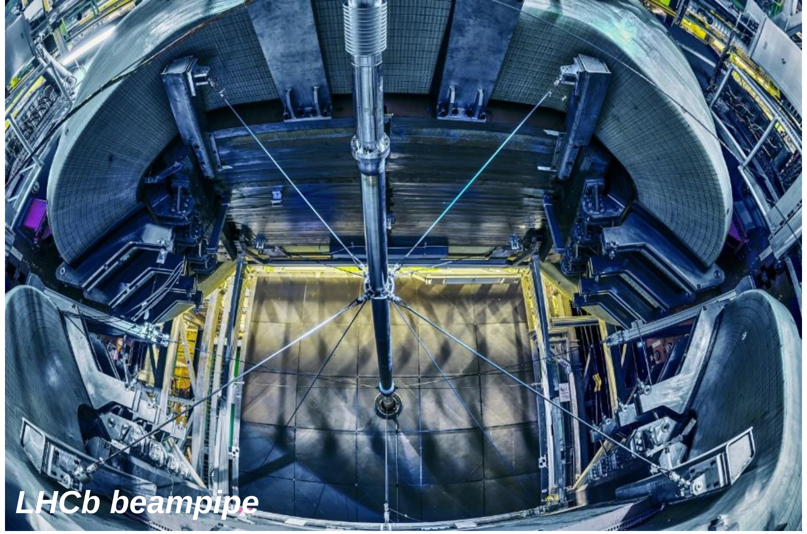
The beam pipes can be at different temperatures

Beam pipe & NEG coating

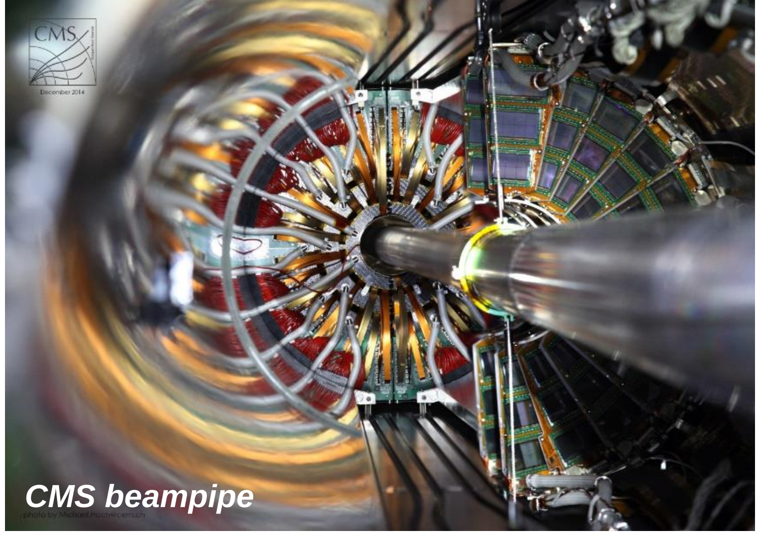
Gauge

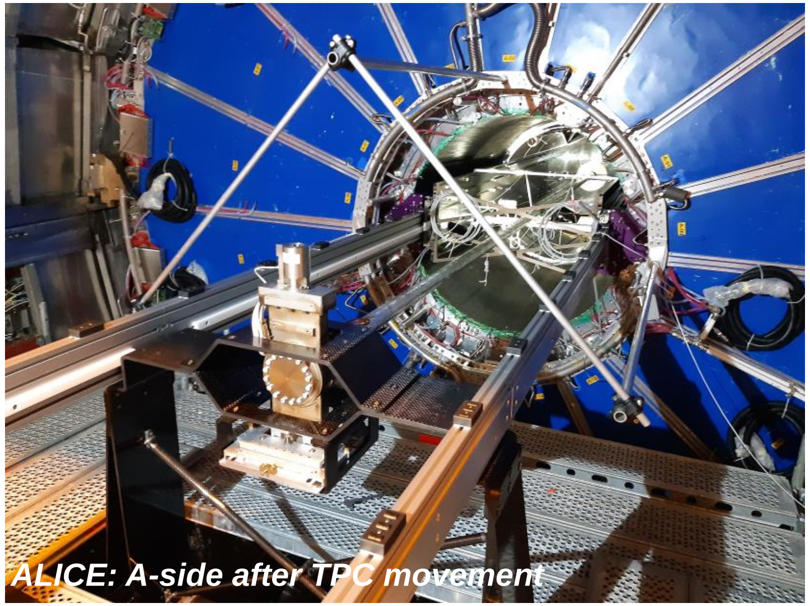
Pump (sputter ion pump)

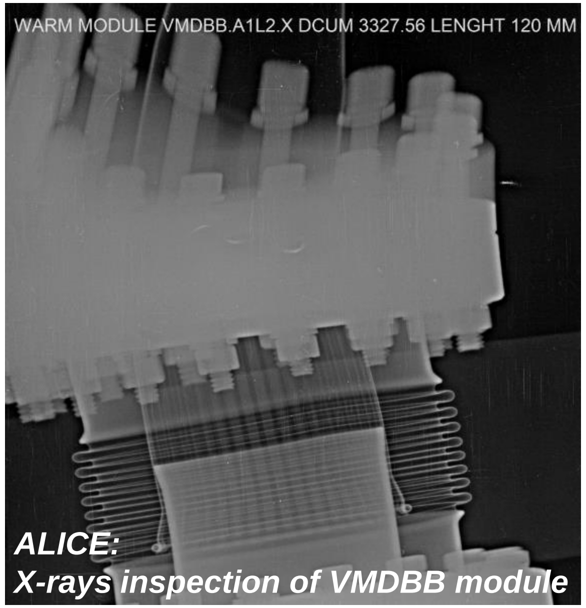
Flange


LHCb beampipe


LHCb beampipe


CMS beampipe


ALICE: A-side after TPC movement

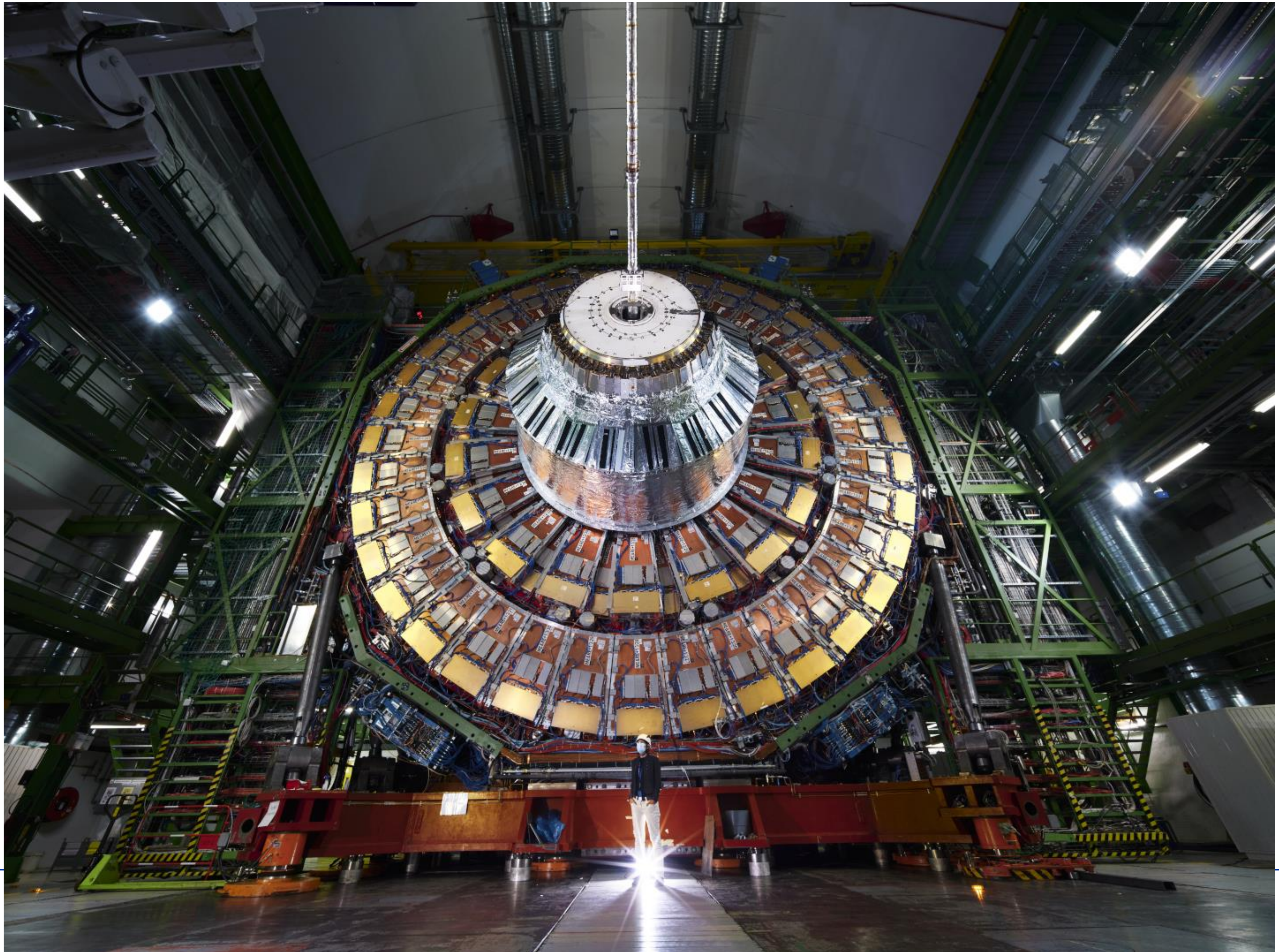


ALICE:
X-rays inspection of VMDBB module


ATLAS beampipe dismounting

Operation, maintenance, consolidation and upgrade of LHC experimental vacuum system

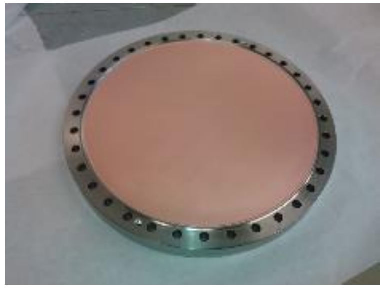
(Josef Sestak's contribution)



A selected number of facilities and competences

The main CERN’s workshop for chemical surface treatments
(*Leonel Ferreira’s contribution)*

Chemical surface treatments

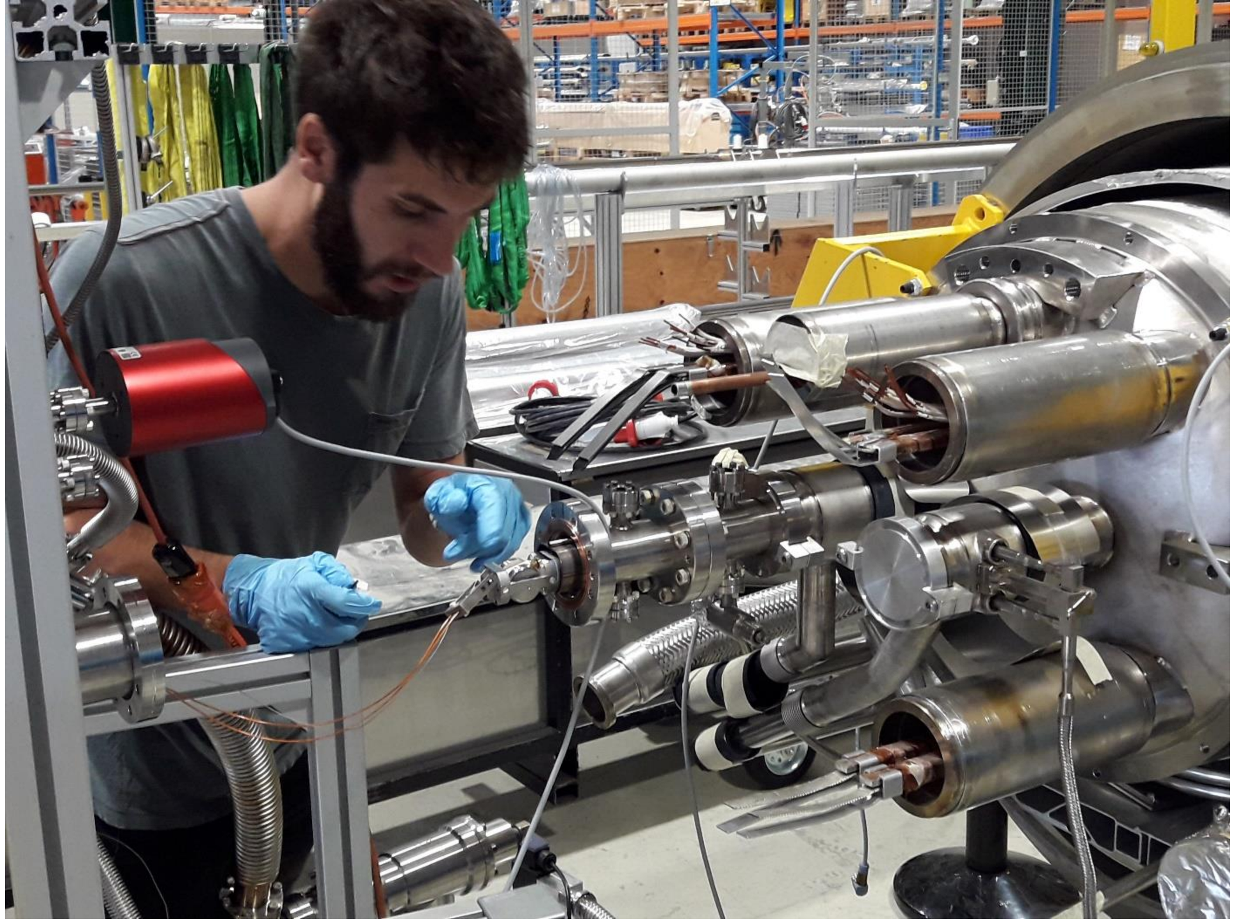


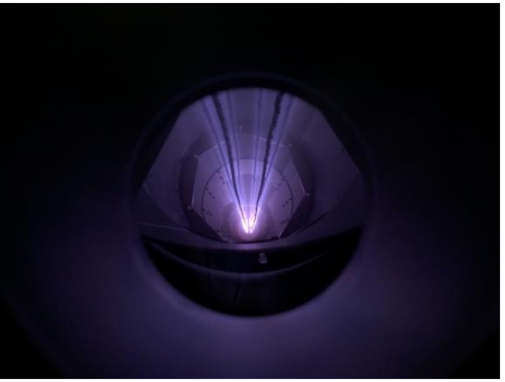


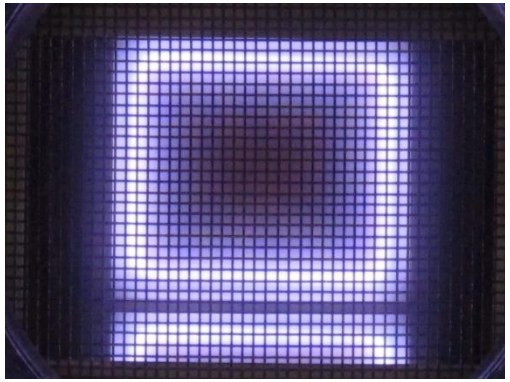


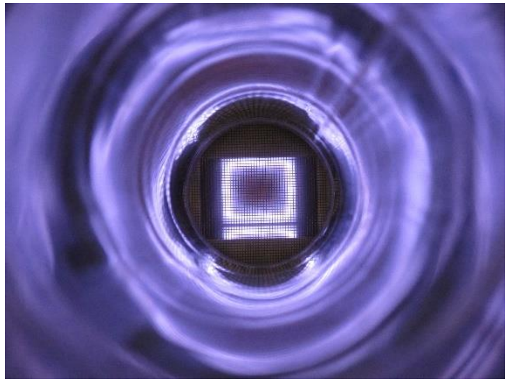
Coatings

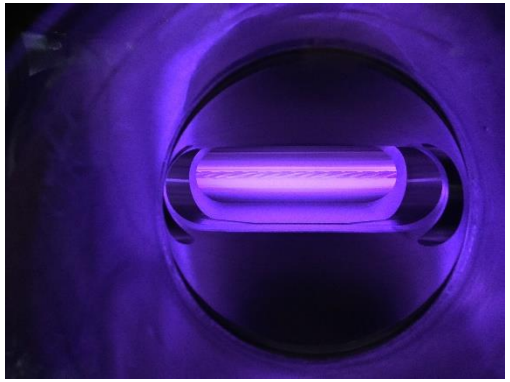
(Guillaume Rosaz's contribution)

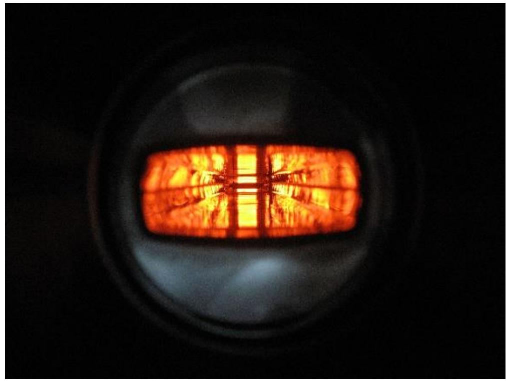






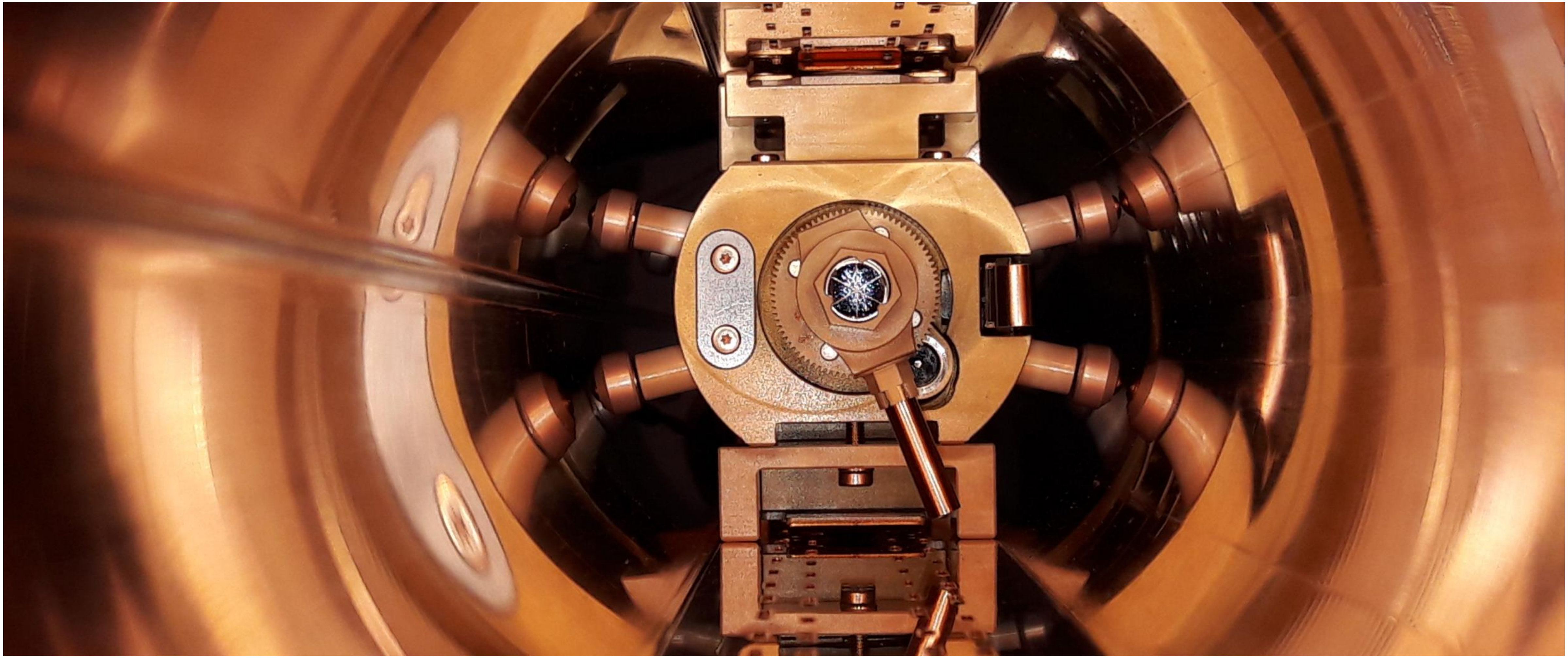






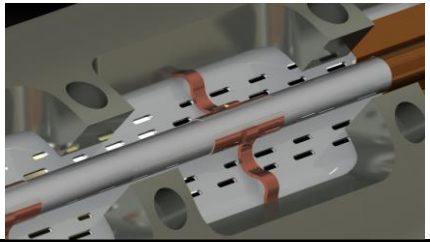
In-situ laser treatment.

Roughening of surfaces by laser to reduce secondary electron emission



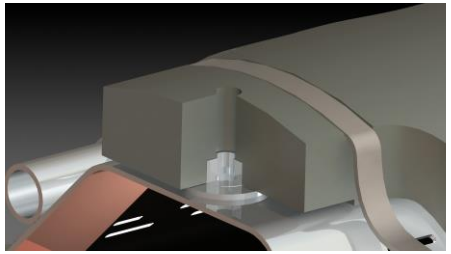
HL-LHC shielded beam screens

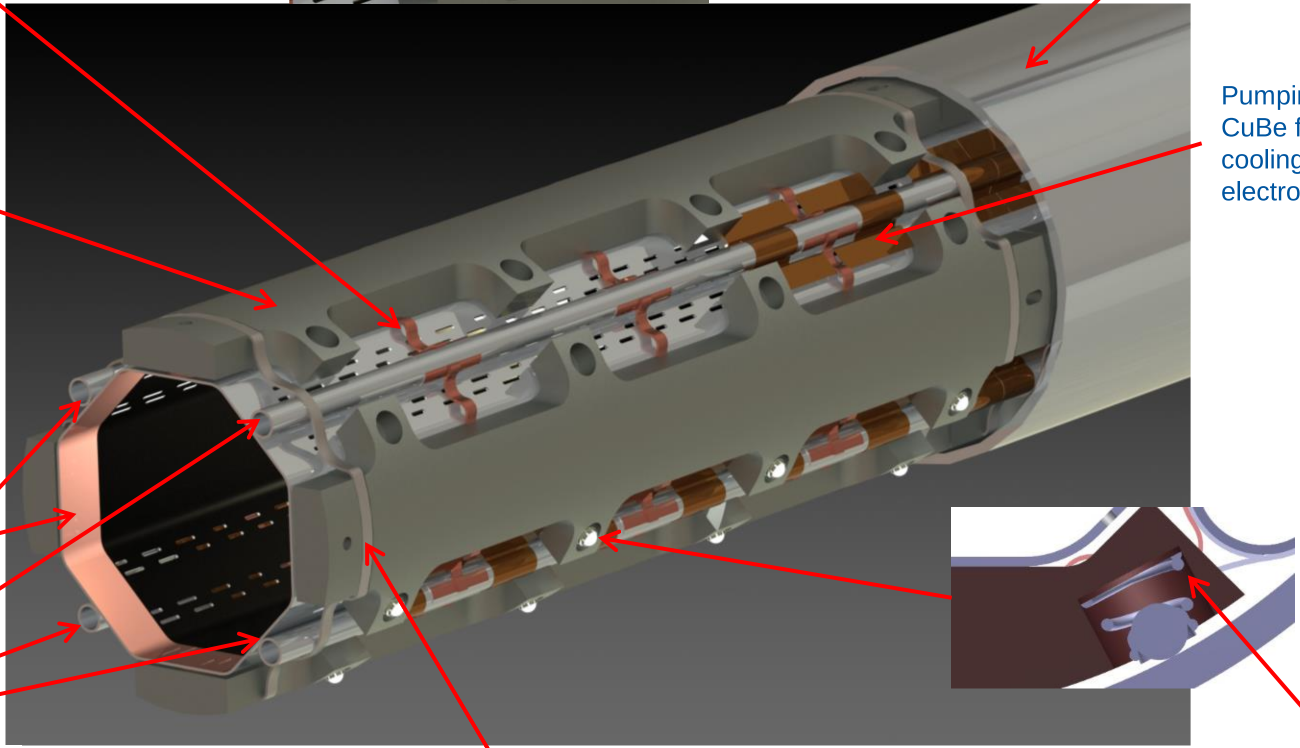
Thermal links:
- In copper (multilayer and solid part)
- Interface plates
- Connected to the absorbers and the cooling tubes



Cold bore (CB) at 1.9 K:
4 mm thick tube in 316LN

Tungsten alloy blocks:
- Chemical composition: 95% W, ~3.5% Ni, ~ 1.5% Cu
- Mechanically connected to the beam screen tube: positioned with pins and titanium elastic rings
- 40 cm long





Pumping slot shields:
CuBe foil clipped on the cooling tube to intercept electrons

Beam screen octagonal tube at 60-75 K:
- Perforated tube (~2%) in High Mn High N stainless steel (1740 l/s/m (H2 at 50K))
- Internal copper layer (75 μm) for impedance
- a-C coating for e- cloud mitigation
- Made of ~3m long segments

P506 cooling tubes:
- Outer Diameter: 10 mm
- Laser welded on the beam screen tube

Elastic compression rings

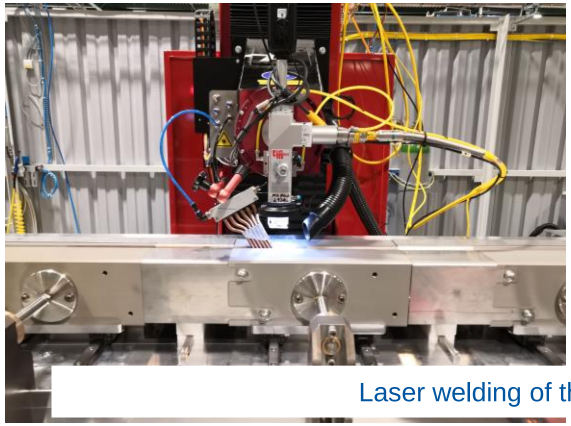
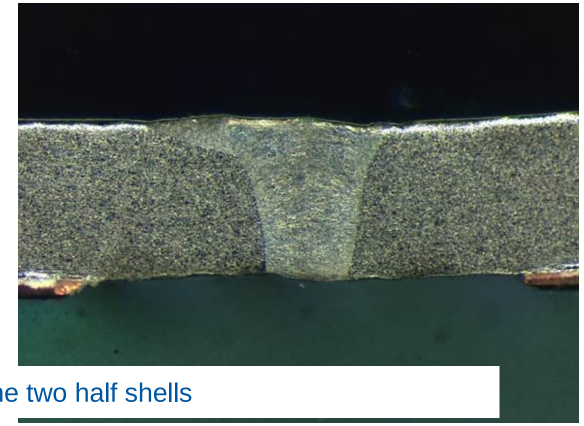
Low thermal conductance elastic supporting system: Ceramic ball and titanium spring

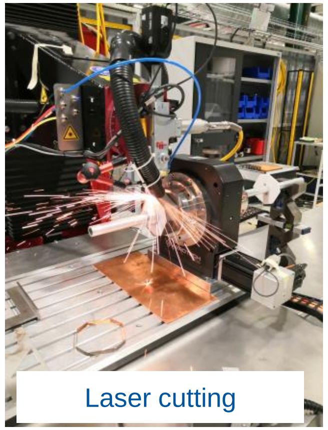
Internal manufacturing of HL-LHC shielded beam screens

Beam screen tubes and thermal links are manufactured at CERN as the shielded beam screen assembly.

Beam screen tube production:


Forming of 3m long sheets



Laser welding of the two half shells

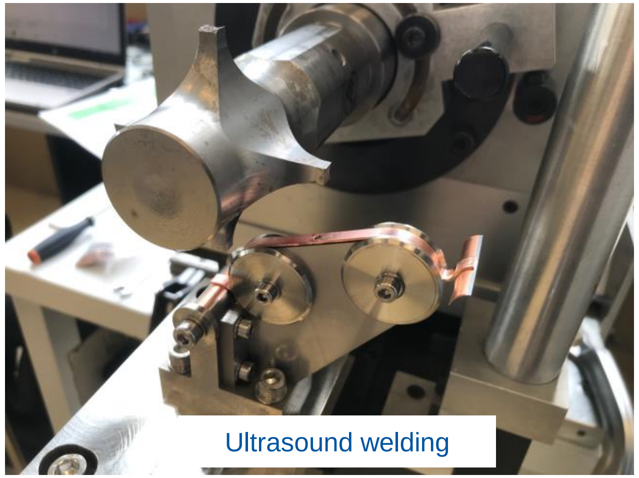

Laser cutting


Forming of 3m long sheets

Thermal link production:

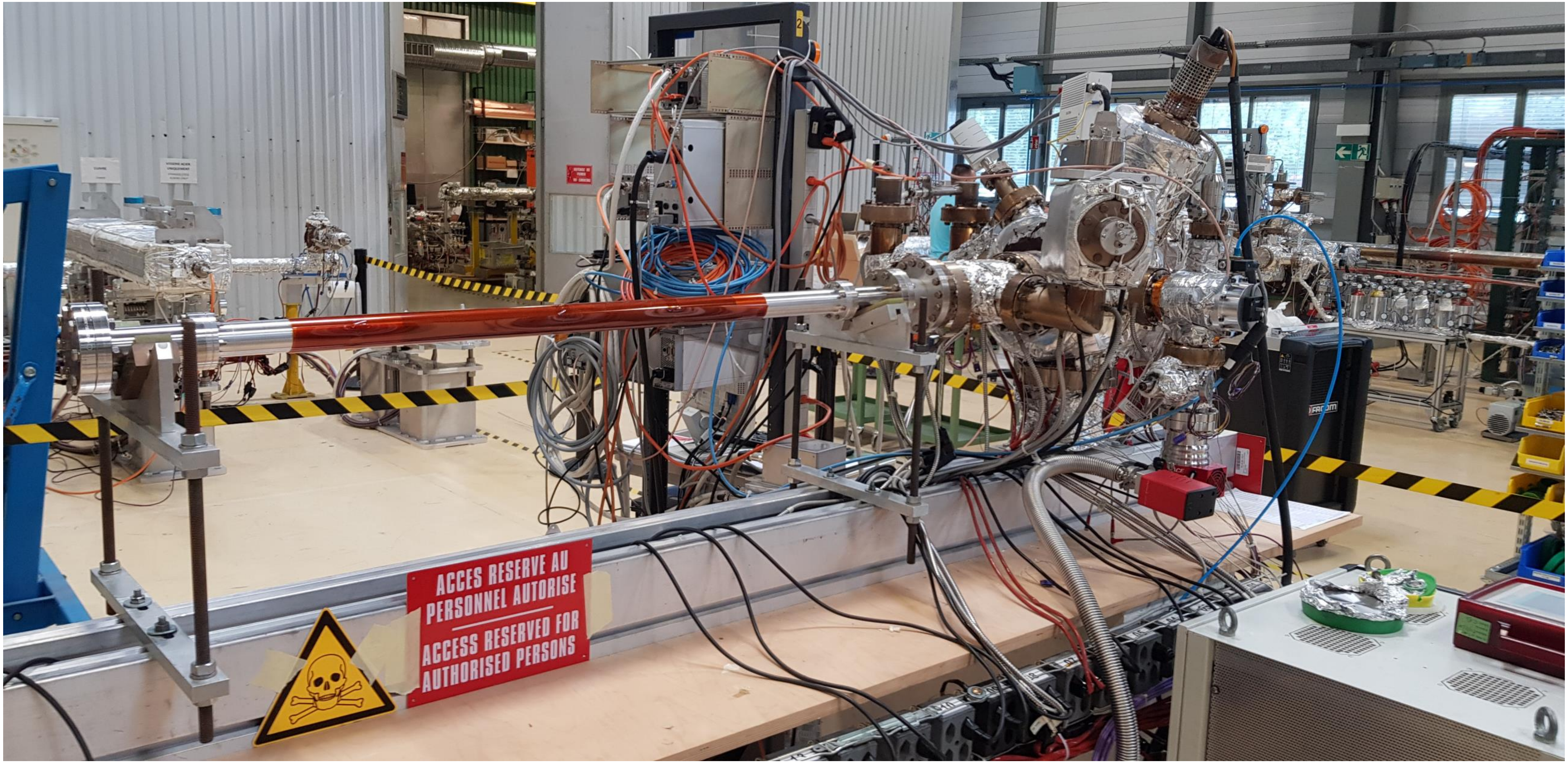

Electron beam welding


Stamping


Ultrasound welding

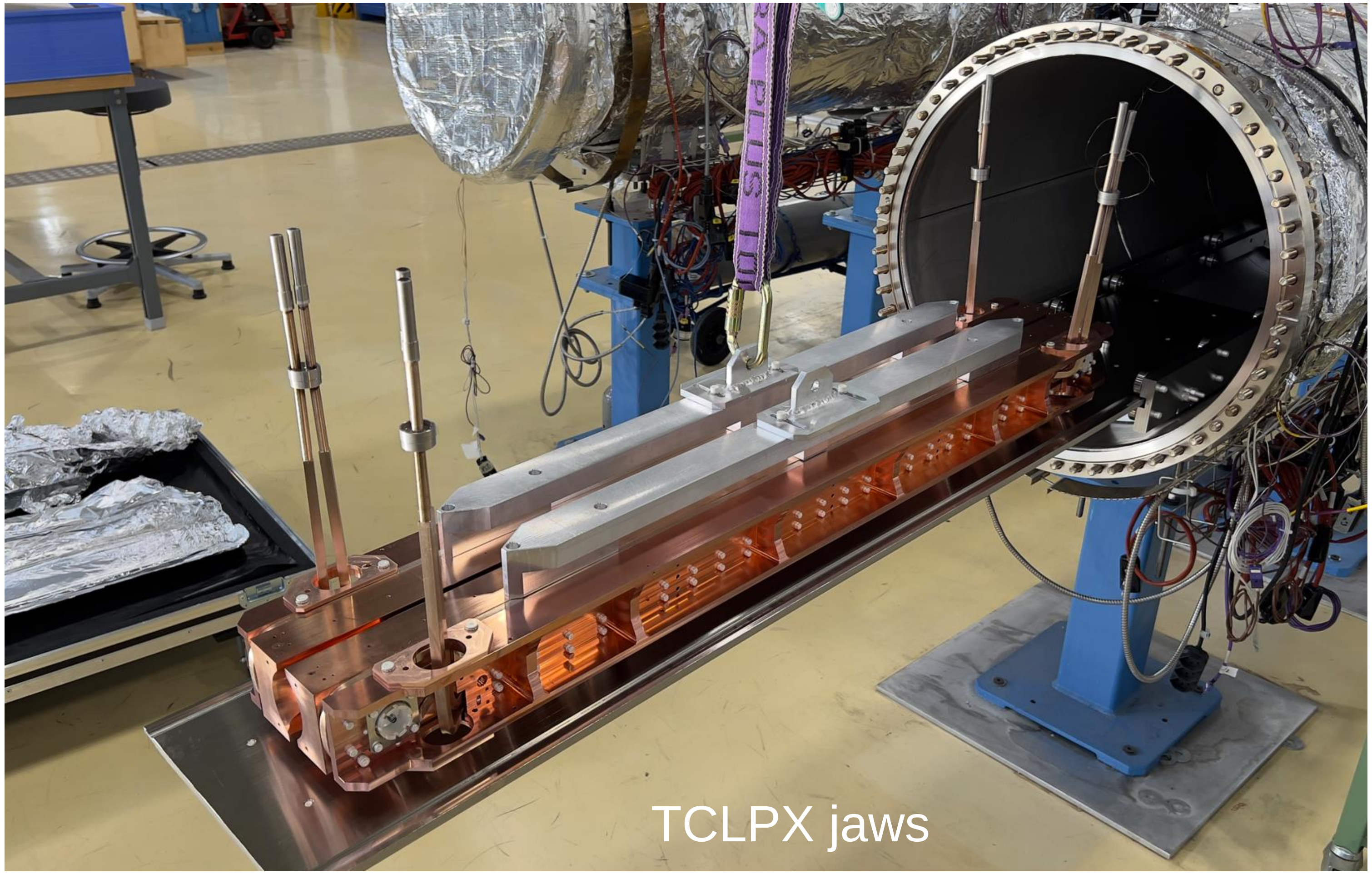
Vacuum measurement: Acceptance tests
(Giuseppe Bregliozzi's contribution)

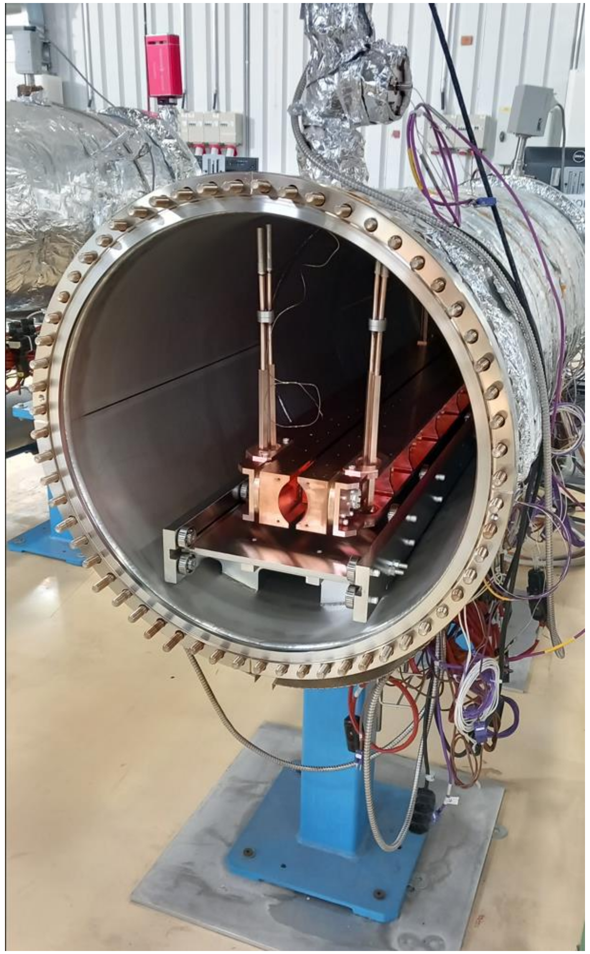
Acceptance tests



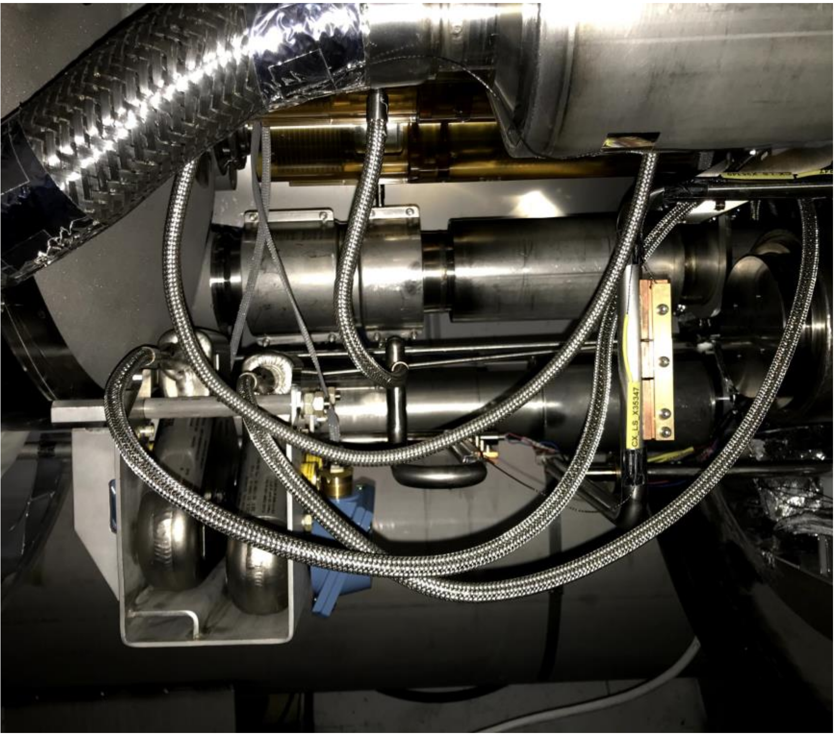
Acceptance tests

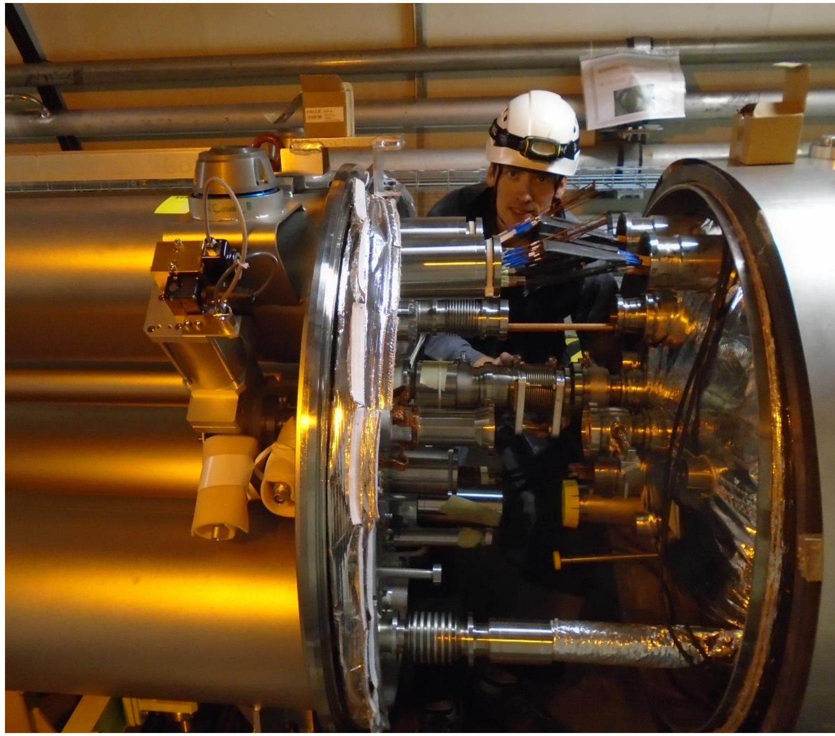
Sub-assembly validations for prototype double beam collimator for HL-LHC





Leak detection of cryogenic equipment





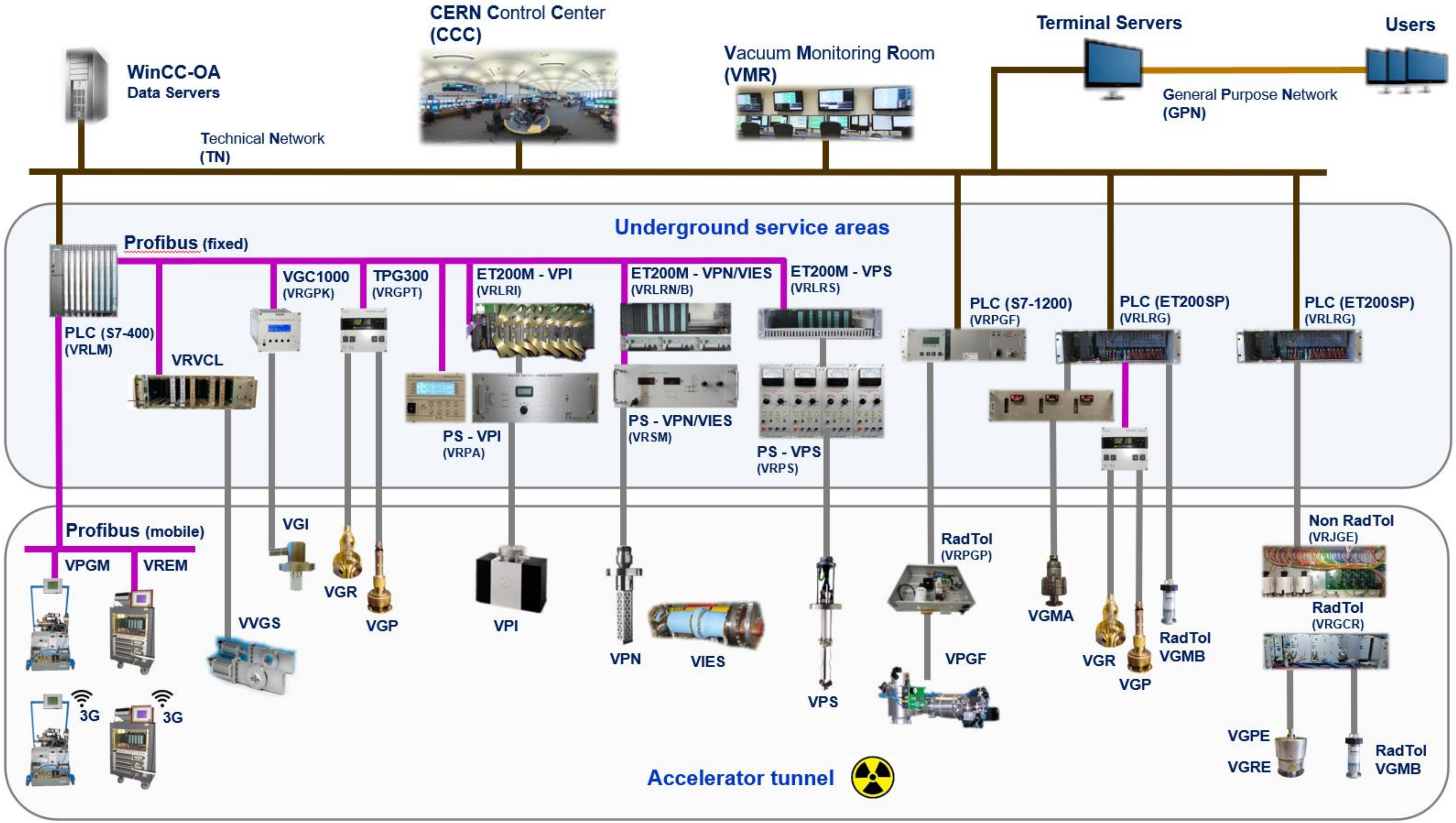
Leak detection for ARIA

Instrumentation

(Gregory Pigny's contribution)

- Pressure range from 10^{-4} to 10^{-12} mbar (10^{-14} mbar in labs)
- **9000** vacuum instruments to be controlled and monitored:
  - 3900 gauges
  - 520 Fixed Pumping Groups
  - 3100 Ion Pumps; 280 NEG Pumps; 270 Sublimation Pumps
  - 720 Sector Valves
  - Mobile equipment (only during technical stops): 176 Mobile Pumping Groups, 100 Bake-out racks
- 400 PLCs; **3000** Industrial or Custom Controllers
- 15 SCADA applications

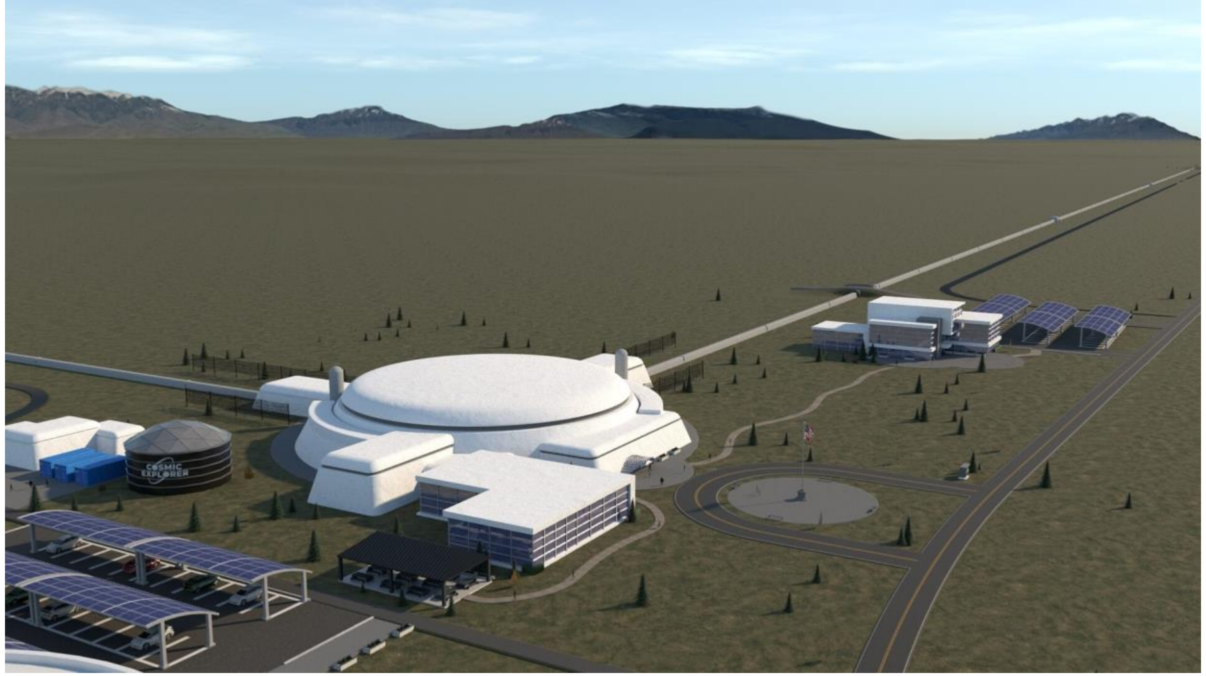
Vacuum Control System | Architecture



The future after the HL-LHC project

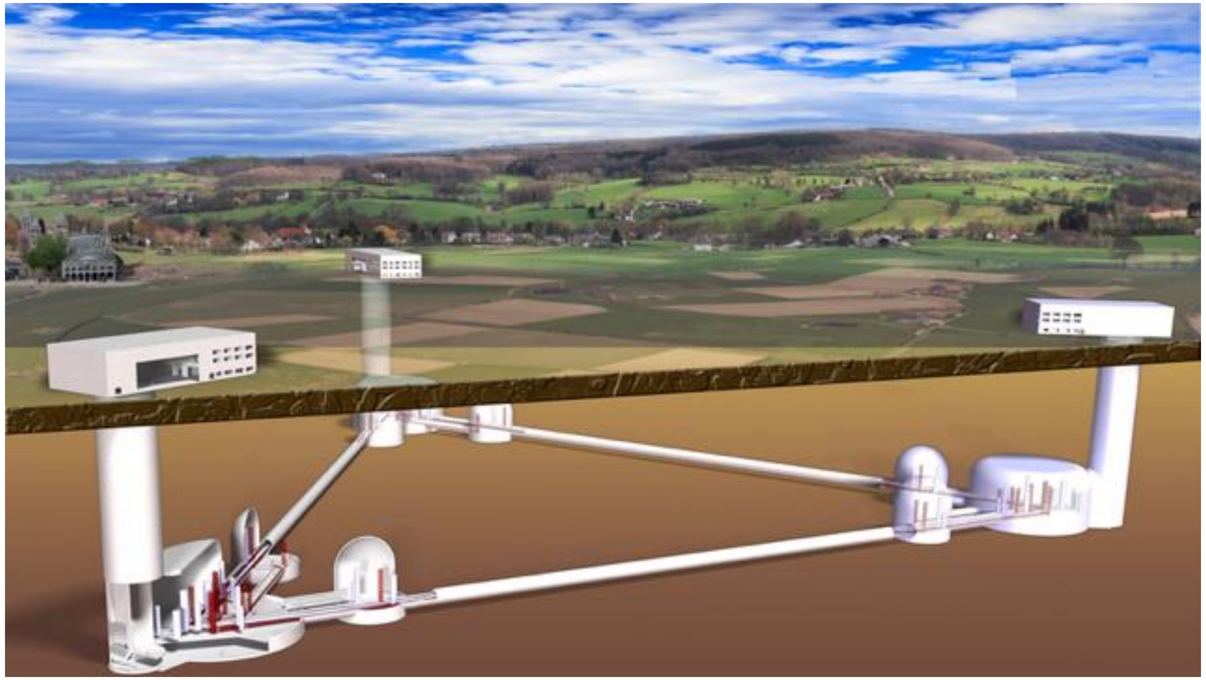
- FCC-ee (Roberto Kersevan’s contribution)
- Muon collider
- Physics beyond colliders (Sergio Calatroni’s contribution)
- Participation in other European projects

Support to other scientific equipment
Example: future GW telescopes



Einstein Telescope: **120 km** of ≈1.0-m diameter vacuum pipes.

Three possible sites: Sardinia (Italy), Dutch-German-Belgium border and Eastern Saxony (Upper Lusatia, Germany).



Cosmic Explorer: two installations 80x2=**160 km** of 1.2-m diameter vacuum pipes.

CERN