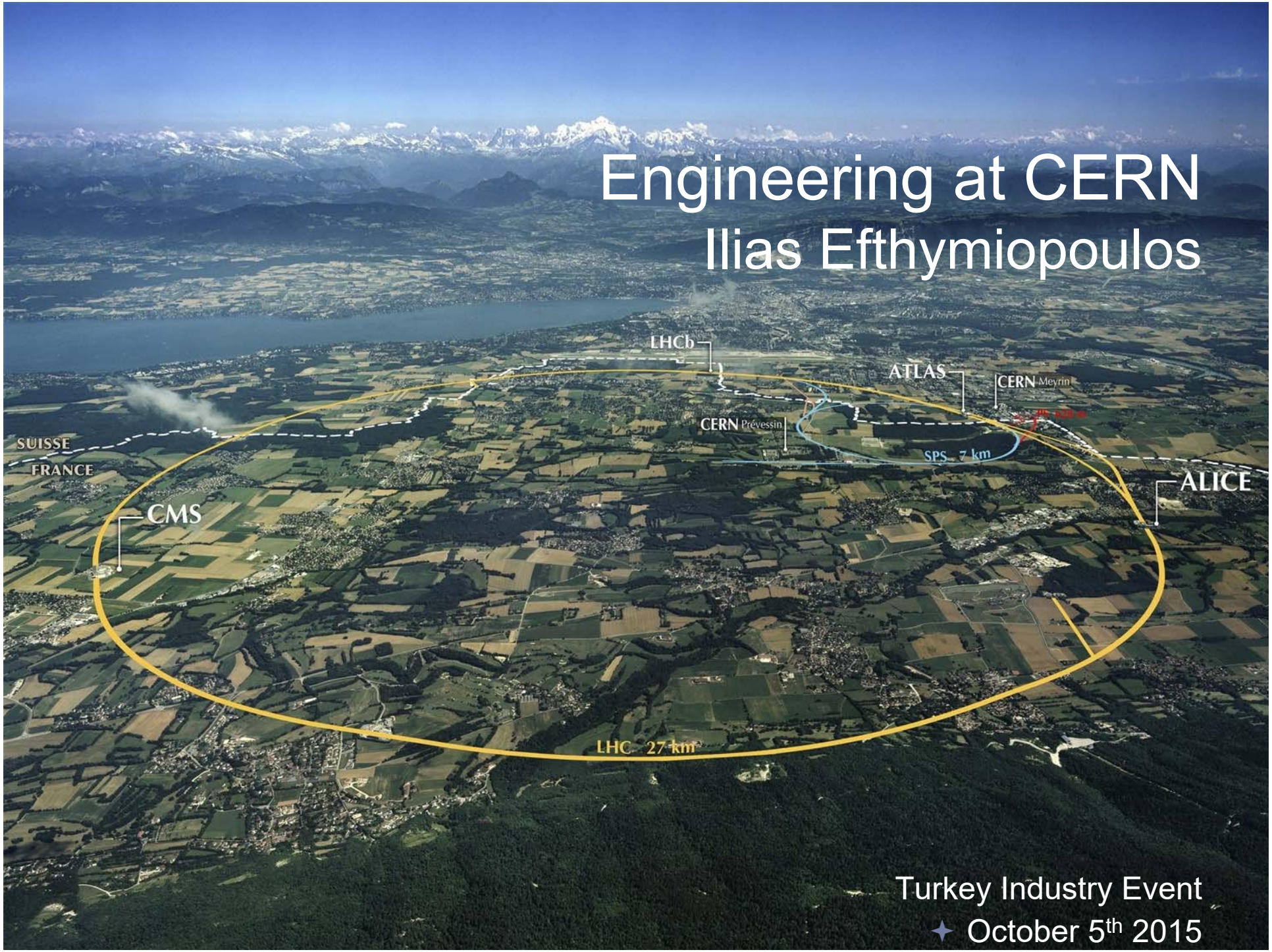


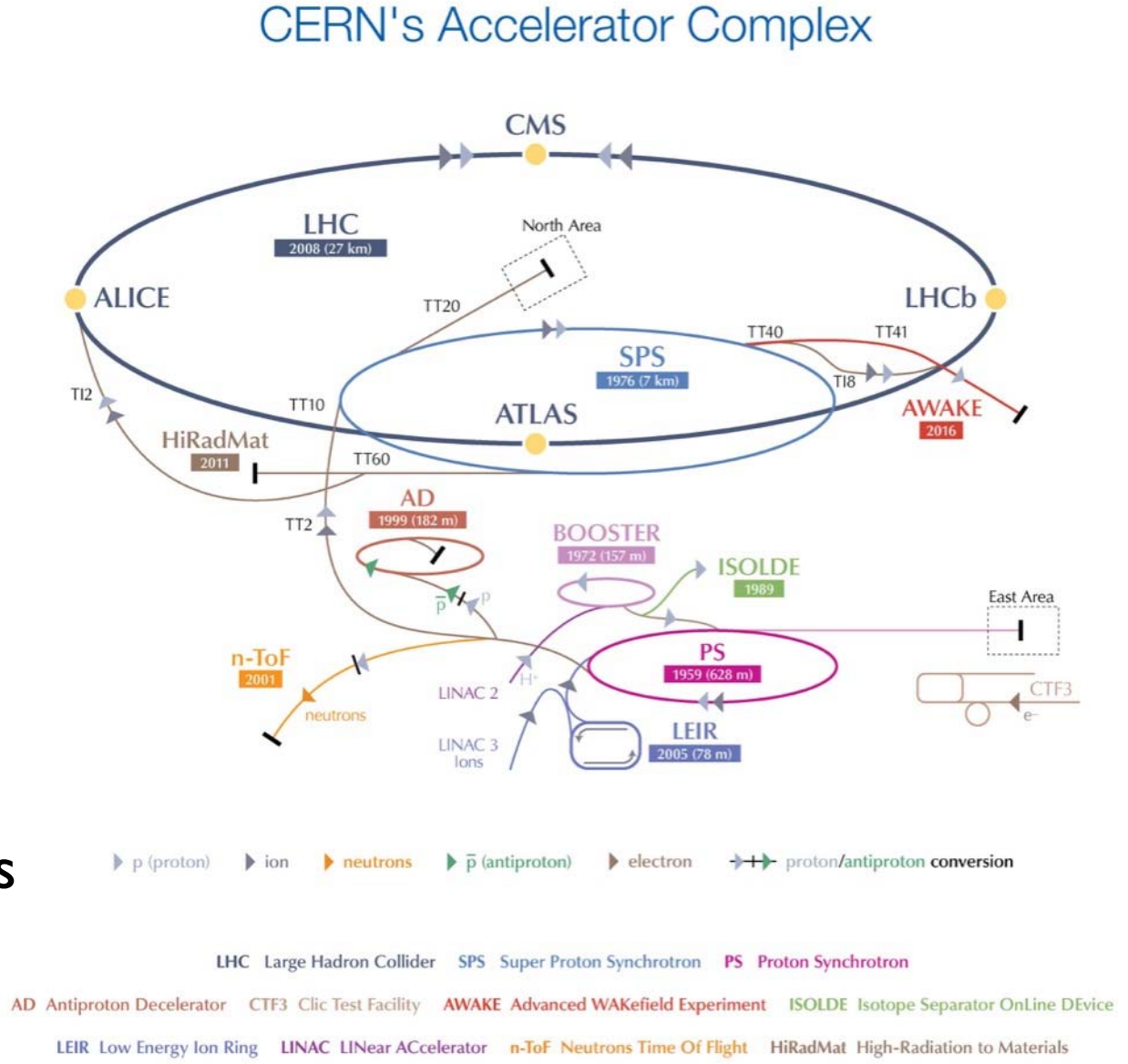
Engineering at CERN

Ilias Efthymiopoulos

Turkey Industry Event

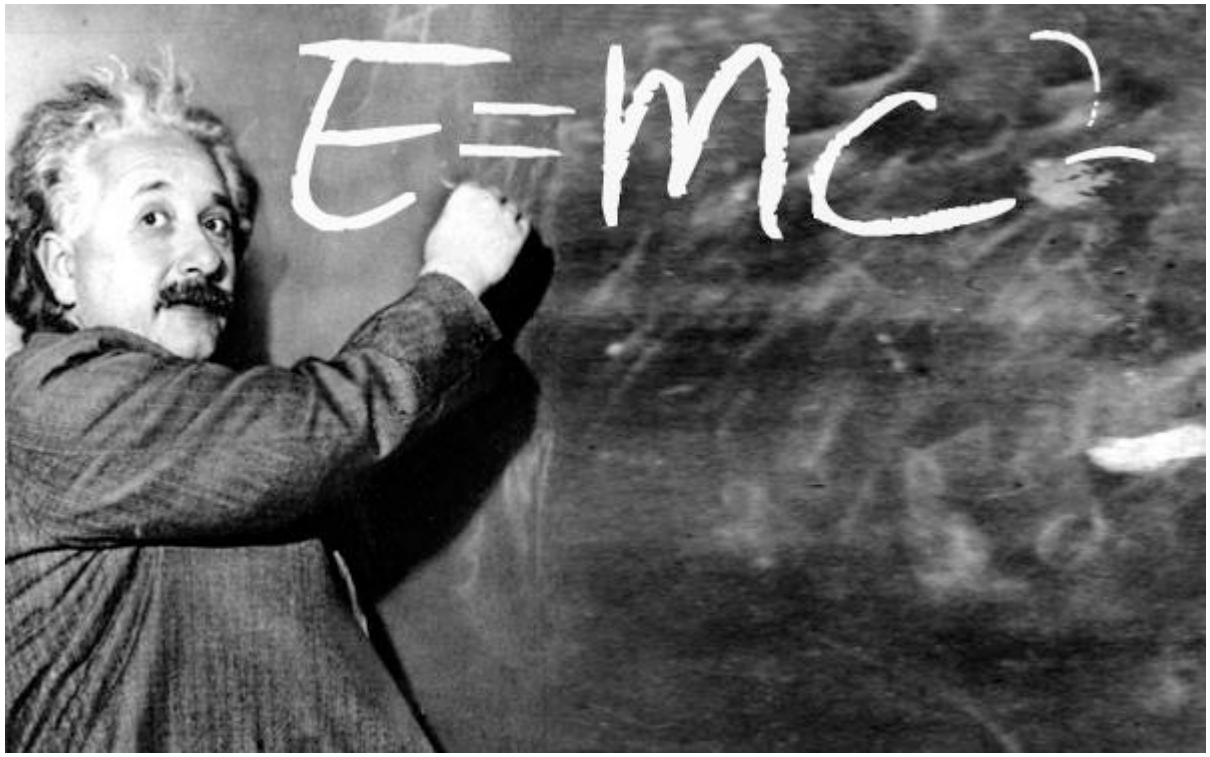
✦ October 5th 2015

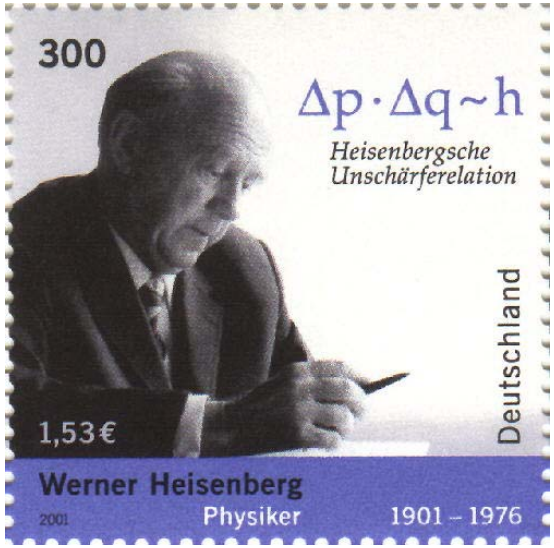
- 50 km of accelerators
- LHC : 27km, superconducting ring, 4 large experiments
- Injectors : normal conducting, 6 experimental areas and 2 irradiation facilities



The Interest for Accelerators

- Accelerators are often called "time machines" – why that?
  - My 3-slides introduction to High-Energy Physics



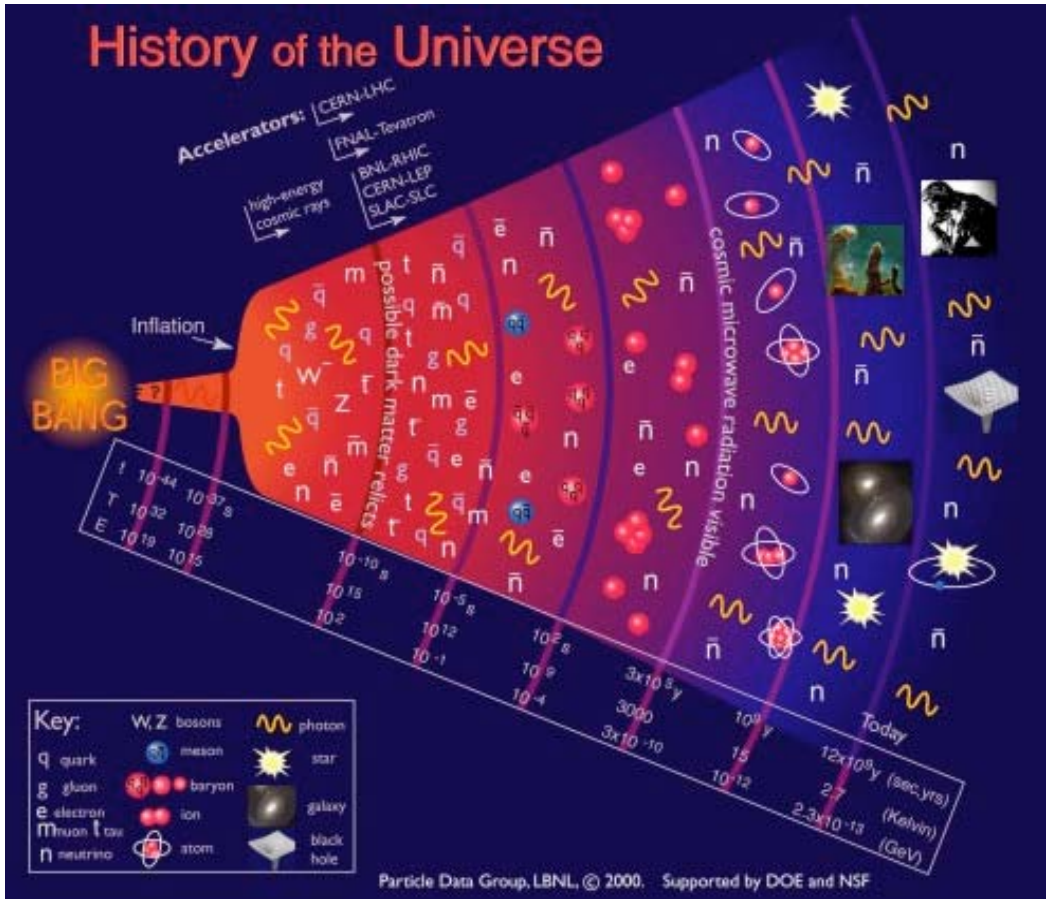


HEP - Basics

- Our model for the creation of the Universe

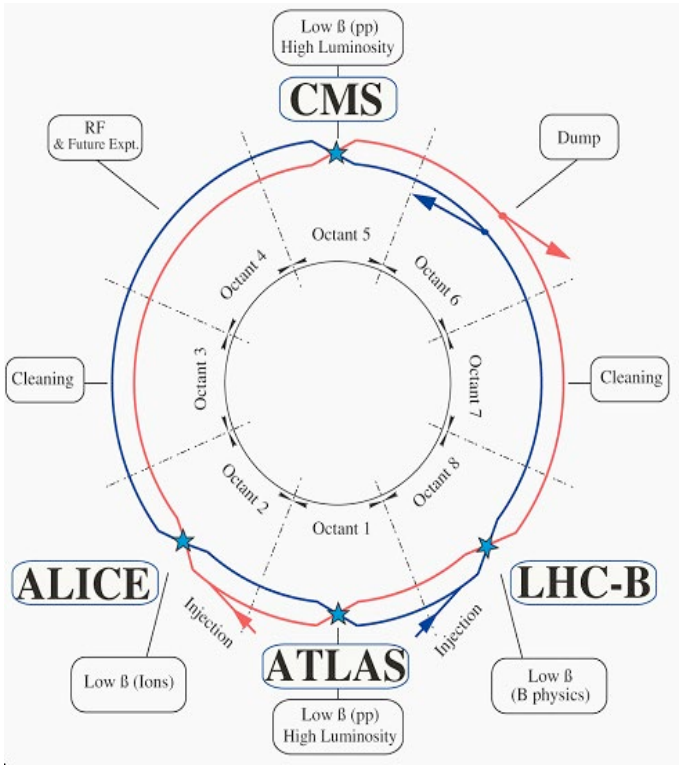
Big-bang :
Initial Energy is converted to mass

E ⇒ Mass



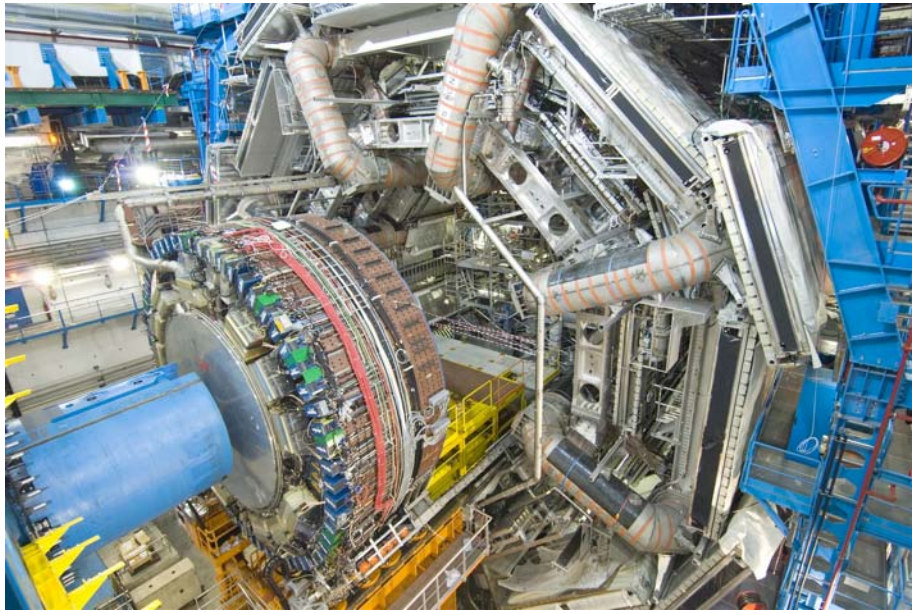
HEP - Basics

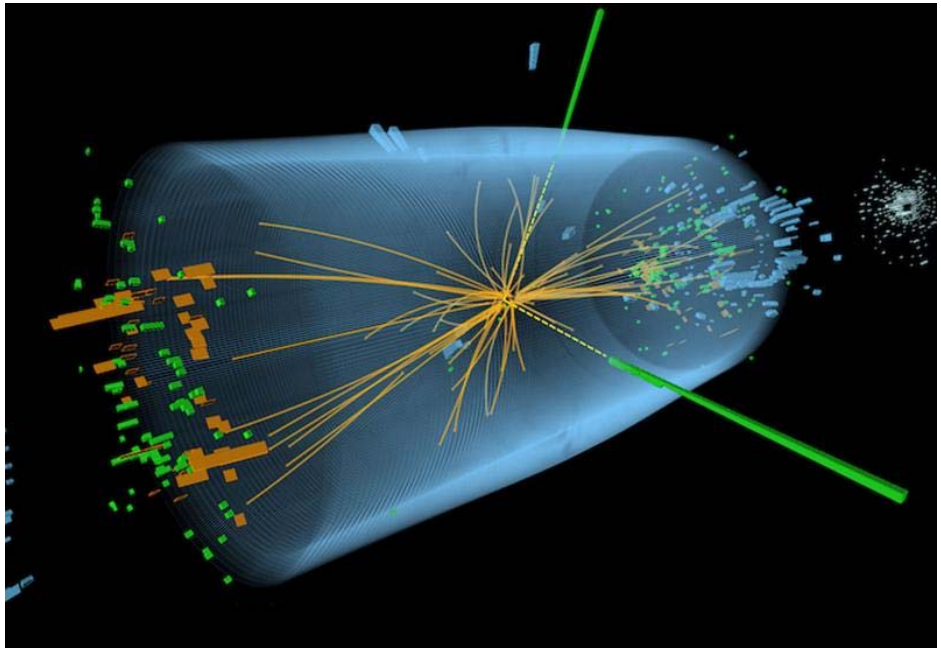
- The role of accelerators
  - Step I : start from known (massive) particles (M) – protons, electrons
  - Step II : accelerate them, give to each particle lot of energy, i.e. lot of energy in a small volume (proton size ~10^{-15} m)
  - Step III : collide them, i.e. create instantaneous "pure" energy – (E)
  - Step IV : the available energy is converted back to mass (M) as during the big-bang
    - Higher the energy ⟶ heavier particles can be created, probe earlier in the Universe time scale



Constant need for more performant accelerators of higher energy and beam intensity

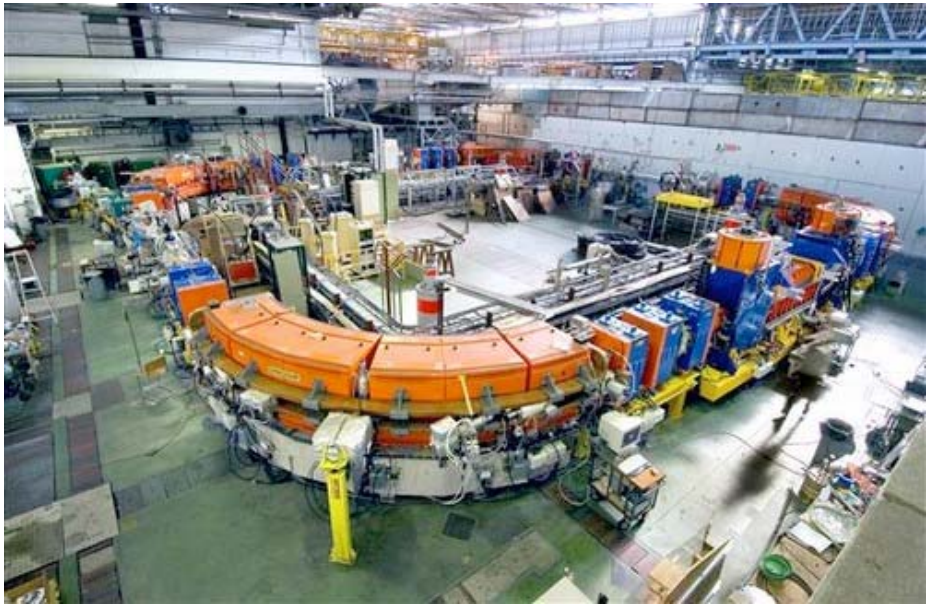
- The Particle Detectors
  - Step V : capture, identify and count the produced particles - compare with theoretical models





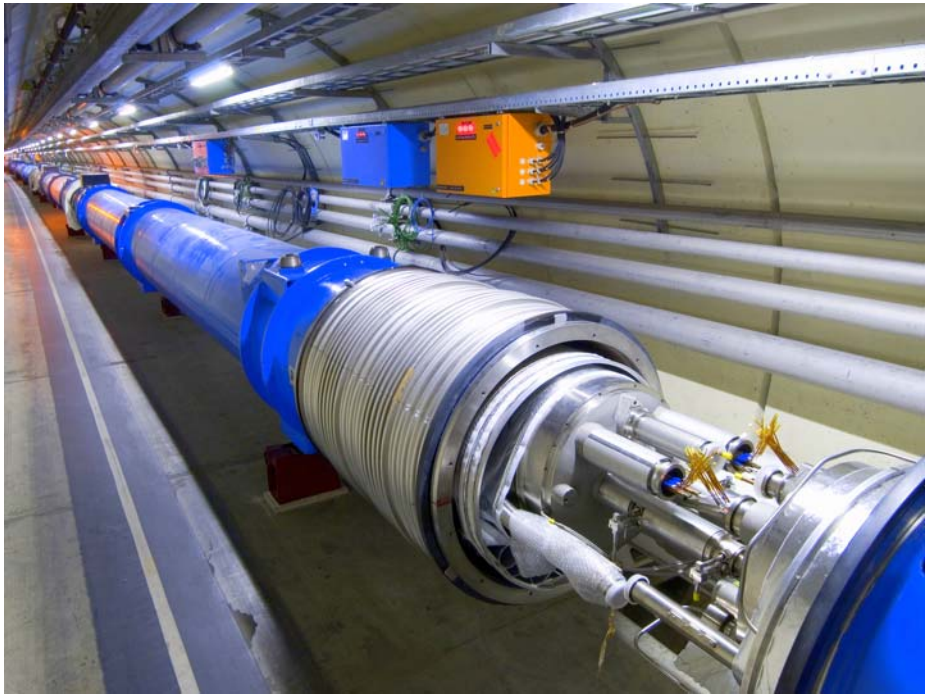
The CERN Accelerators

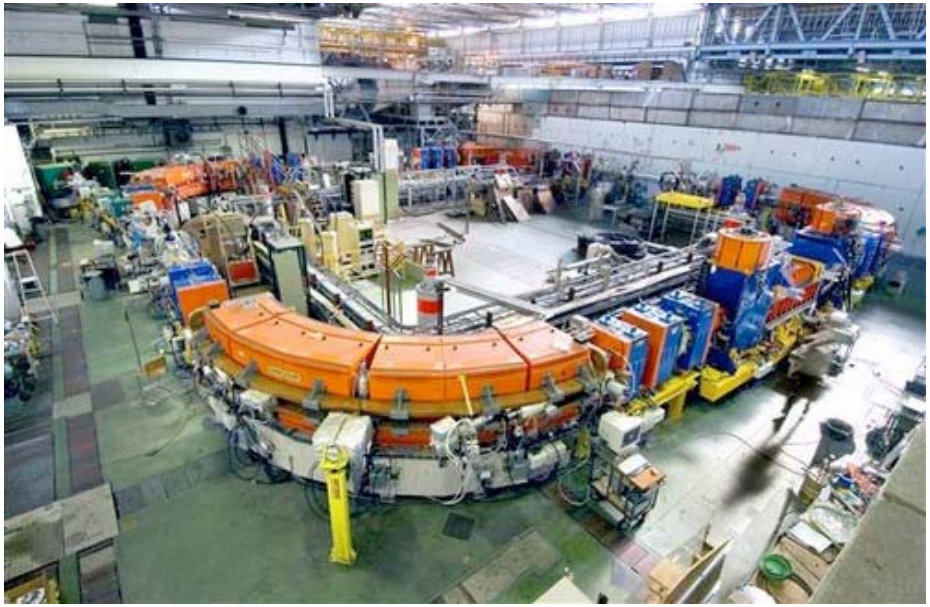
- Large complex installations,
  - Mainly in underground tunnels (30-180m depth)
  - Or surface installations



The CERN Accelerators

- Large complex installations,
  - surface or underground tunnels (30-180m depth)
  - equipment of leading-edge technology and engineering
    - magnets, RF cavities, beam instrumentation

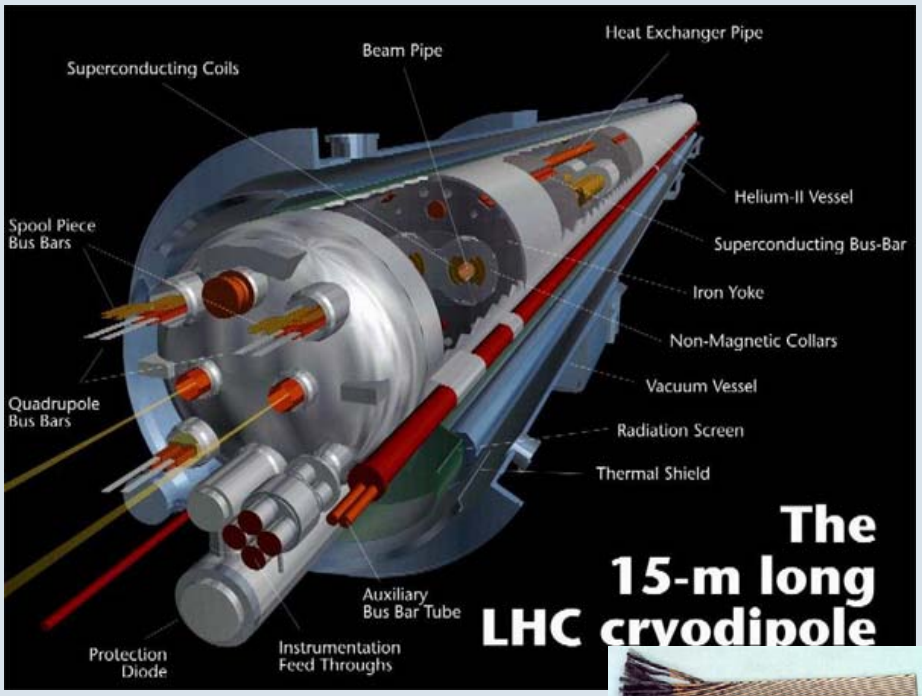




The CERN Accelerators

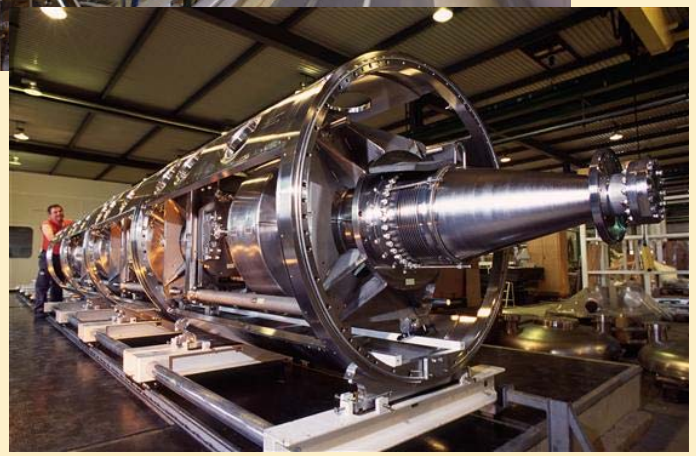
- equipment of leading-edge technology and engineering

LHC Superconducting dipoles



- 8.4 T magnetic field
- 11.8 kA in the NbTi superconducting cable
- Maintained at 1.9k (-271.3 °C)
- 10^{-10} 10^{-11} mbar vacuum for the beam

LHC Superconducting RF – 400 MHz



The CERN Accelerators

- But also large installations of supporting infrastructure
  - scaled-up versions of industrial solutions and applications

400/18kV 90MVA transformers for the SPS pulsed loads

LHC He cryogenics

or station and liquid gen pre-cooler

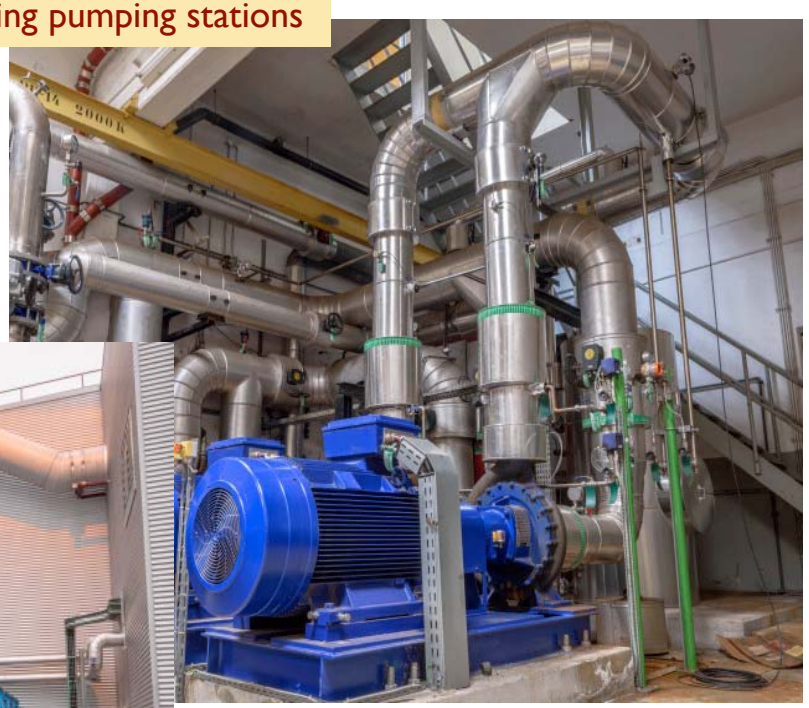
Ex-LEP 4.5 K cold boxes

r bank for energy
- PS POPS

The CERN Accelerator Complex

Cranes and handling tools

Cooling pumping stations



Ventilation systems

The Accelerator Sector

Director of Accelerators

Beams Department

- Beam Design (accel. Physics)
- Beam Production (sources, linac)
- Beam Acceleration (radiofrequency – RF)
- Detection
- Controls
- Operation

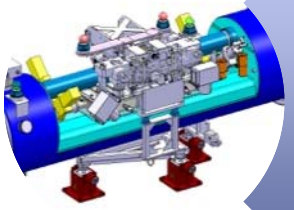
Engineering Department

- Mech. Engineering
- El. Engineering
- Handling Engineering
- Cooling & Ventilation
- Industrial Controls
- Mater-beam interactions
- Beams & Experiments
- Project Engineering & Quality Assurance

Technology Department

- Magnet technology (warm & superconducting)
- Vacuum surfaces & coating
- Cryogenics
- Machine protection
- Beam Transfer (injection, extraction)
- El. Power Converters

Equipment Lifecycle



R&D Engineering & Design

Functional/Technical specifications
Design, prototyping and testing
Integration studies
Collaboration with Universities, Laboratories and Industry

Production

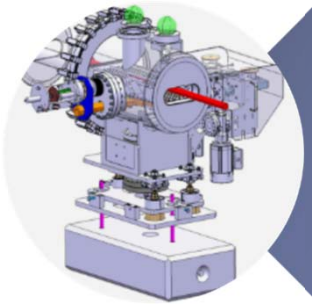
Industrialization process
Workshops at CERN, or outside, final assembly
Procurement of raw material or components
Technical Subcontracting for component production or full assemblies

Installation, Operation Maintenance

CERN core teams: technical services, handling Planning, Quality Assurance, Safety
Technical Subcontracting for installation support and maintenance services

EN-MME Group

Mechanical & Materials Engineering



Engineering & Design

- Design Office:
  - 40 designers and engineers
  - CATIA / SmarTeam, ANSYS, LS-Dyna...
- Experimental Mechanics Lab.

Production

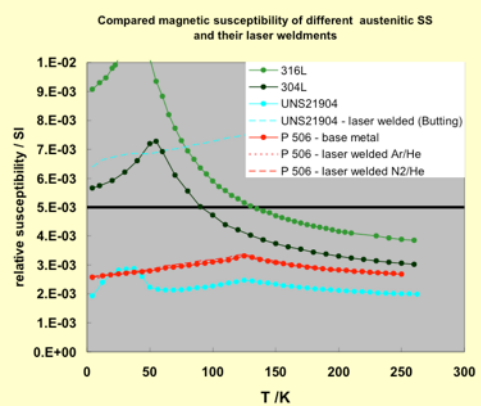
- Mechanical workshop (4000 m^2):
  - 50 technicians and engineers
  - CNC machining
  - Assembly & metal forming
  - Welding (TIG, MIG, electron beam, laser, vacuum brazing)
- Technical Subcontracting Service

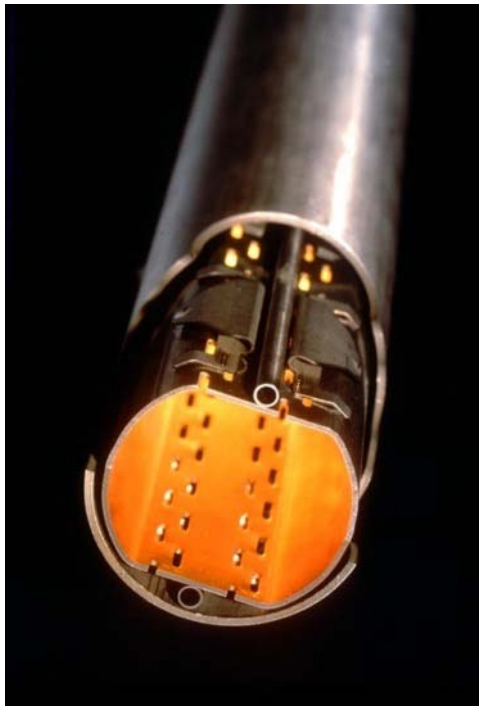
Materials & Metrology

- Material science consultancy:
  - metallurgical analyses, microscopy, mechanical tests
- NDT: US, radiography, tomography
- Metrology: 350 m^2 lab. equipped with CMM.

Courtesy Alessandro Dallocio

Mechanical & Materials Engineering



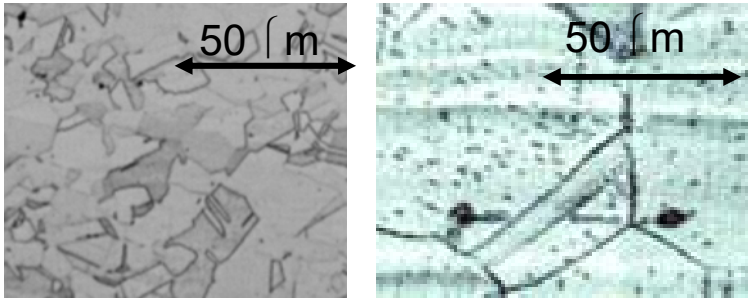


- **Development of Materials and Manufacturing Solutions**
  - Development of a new non-magnetic stainless steel with magnetic susceptibility £ 5×10^{-3} in weld and parent material at operating T (5 K to 20 K), readily weldable, not sensitive to hot cracking
  - Co-lamination of stainless steel with Cu, in order to avoid electroplating requiring a Ni strike increasing the magnetic susceptibility
  - Pumping slots with some randomness in the slot locations to limit resonances
  - Saw teeth in the arcs on Cu (40 mm height and 500 mm pitch) to reduce forward reflectivity against electron cloud build-up
  - Attachment of cooling tubes by millions of laser spot welds to be guaranteed leak tight

Courtesy Francesco Bertinelli

An innovative near net shaping technique for the end covers of the LHC dipole magnets

2500 stainless steel (316LN) covers



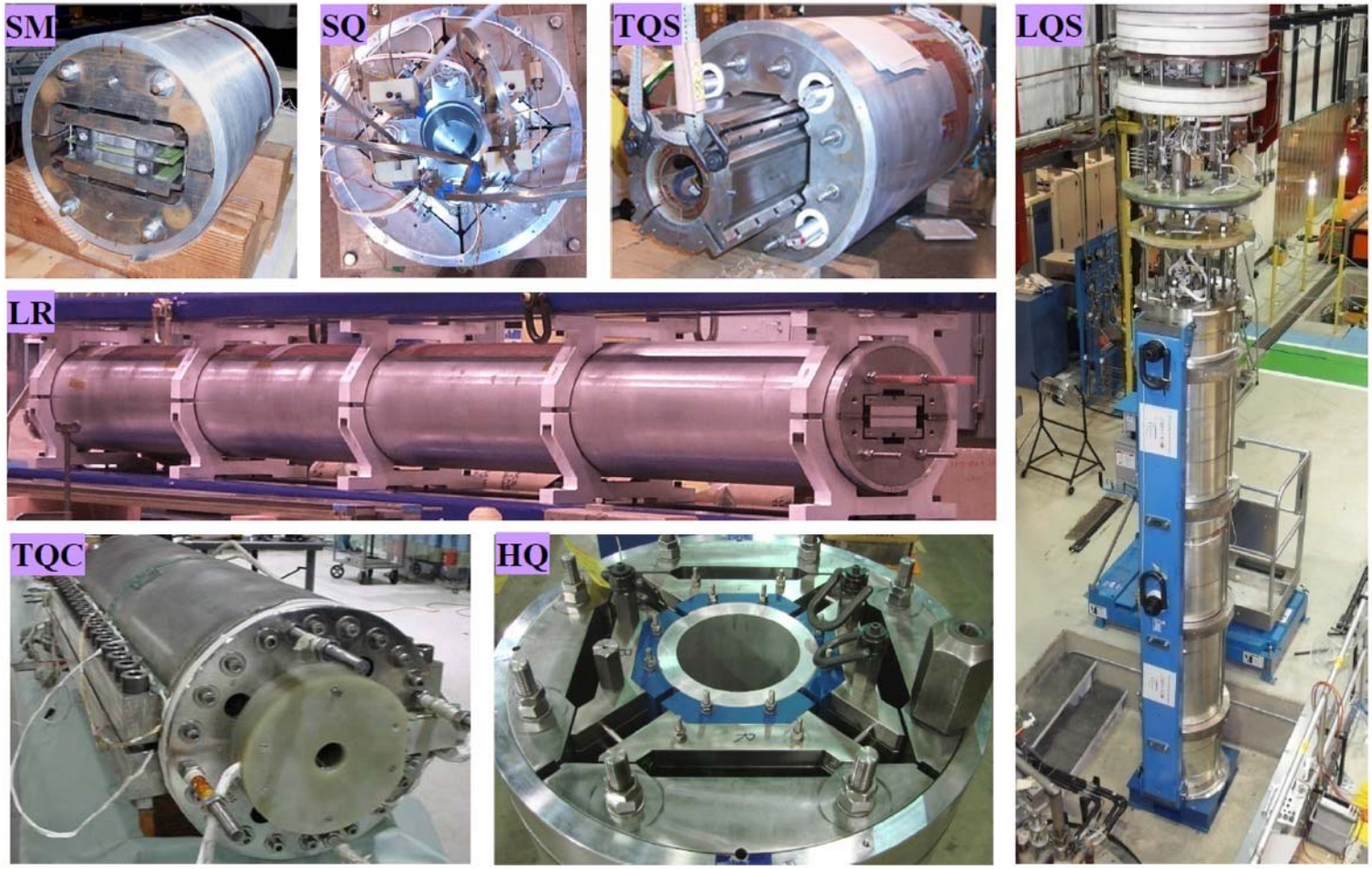
Powder Metallurgy Forged

- **Powder Metallurgy (PM) and Hot Isostatic Pressing (HIP)**
  - First application of the technology on a broad scale to large size components for cryogenic use
  - Leak tight to gaseous He at 300 K under 2.6 MPa (test pressure)
  - Leak tight to superfluid He at 1.9 K under 0.13 MPa (operating pressure)
  - 25 thermal cycles 1.9 K Þ 300 K Þ 1.9 K (over 20 years)
  - Ductility to be guaranteed at low T (impact toughness 120 J/cm2 at 4.2 K)
  - Compatible with its environment (wrought 316LN)
  - Fine microstructure, excellent dimensional stability
  - Cost effective compared to wrought (forged), cast, welded solutions

Courtesy Francesco Bertinelli

Mechanical & Materials Engineering

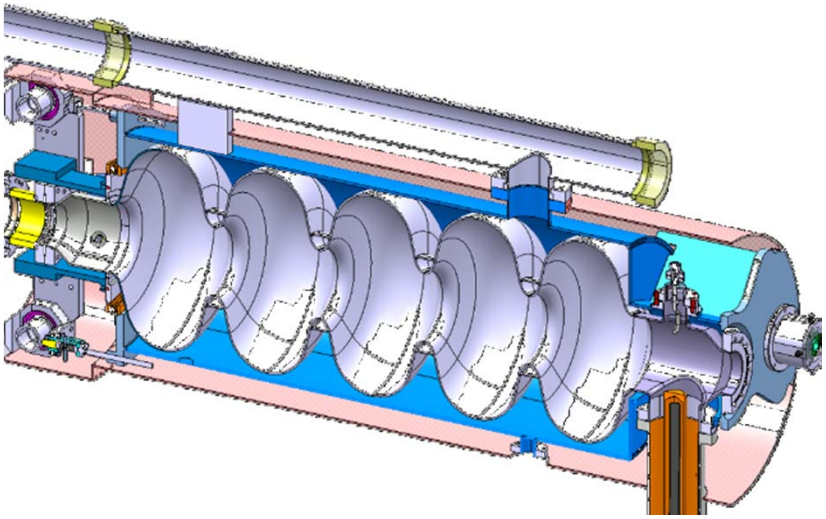
- Superconducting Magnets



Courtesy Alessandro Dallocio

Mechanical & Materials Engineering

- Superconducting RF cavities



Courtesy Alessandro Dallocio

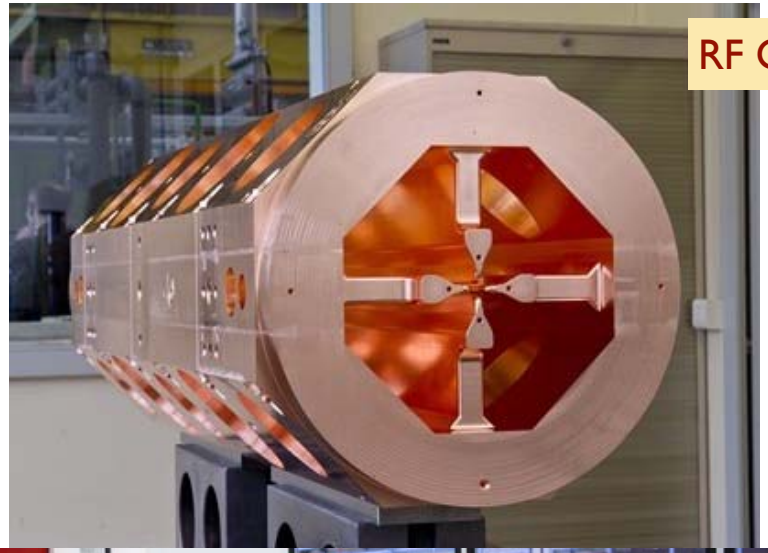
Mechanical & Materials Engineering

- Warm RF cavities

Courtesy Alessandro Dallocio

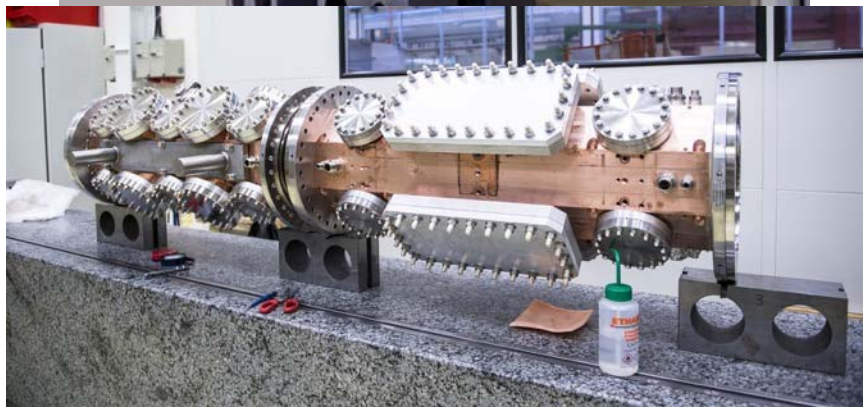
Mechanical & Materials Engineering

- Beam line equipment

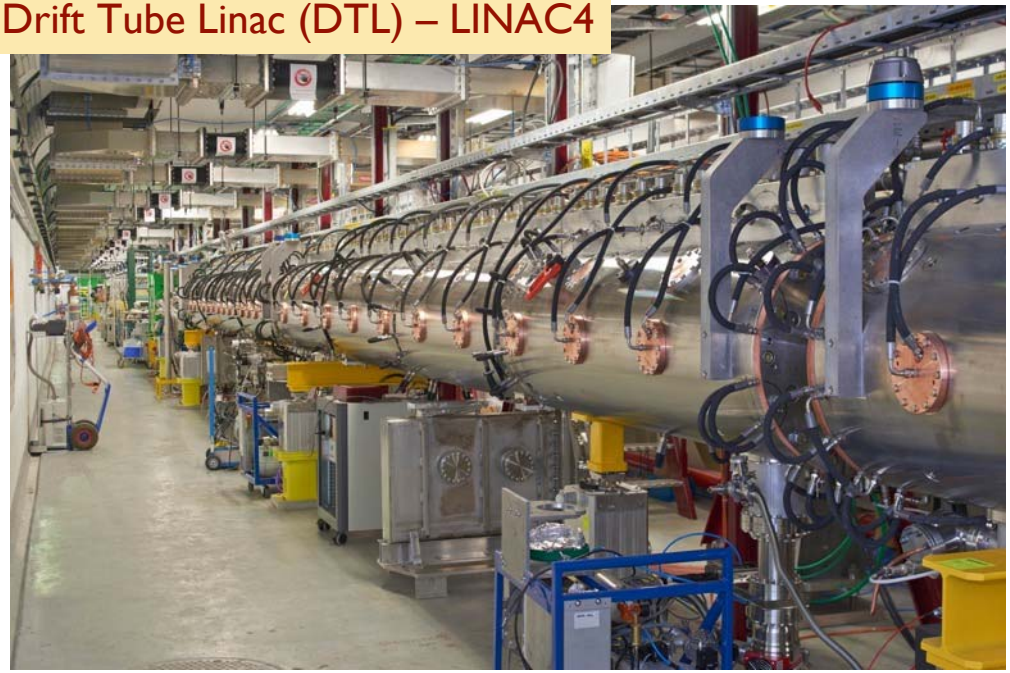


RF Quadrupole – LINAC4

- Precision machining (few µm)
- Brazing in vacuum, 1m long pieces



Drift Tube Linac (DTL) – LINAC4



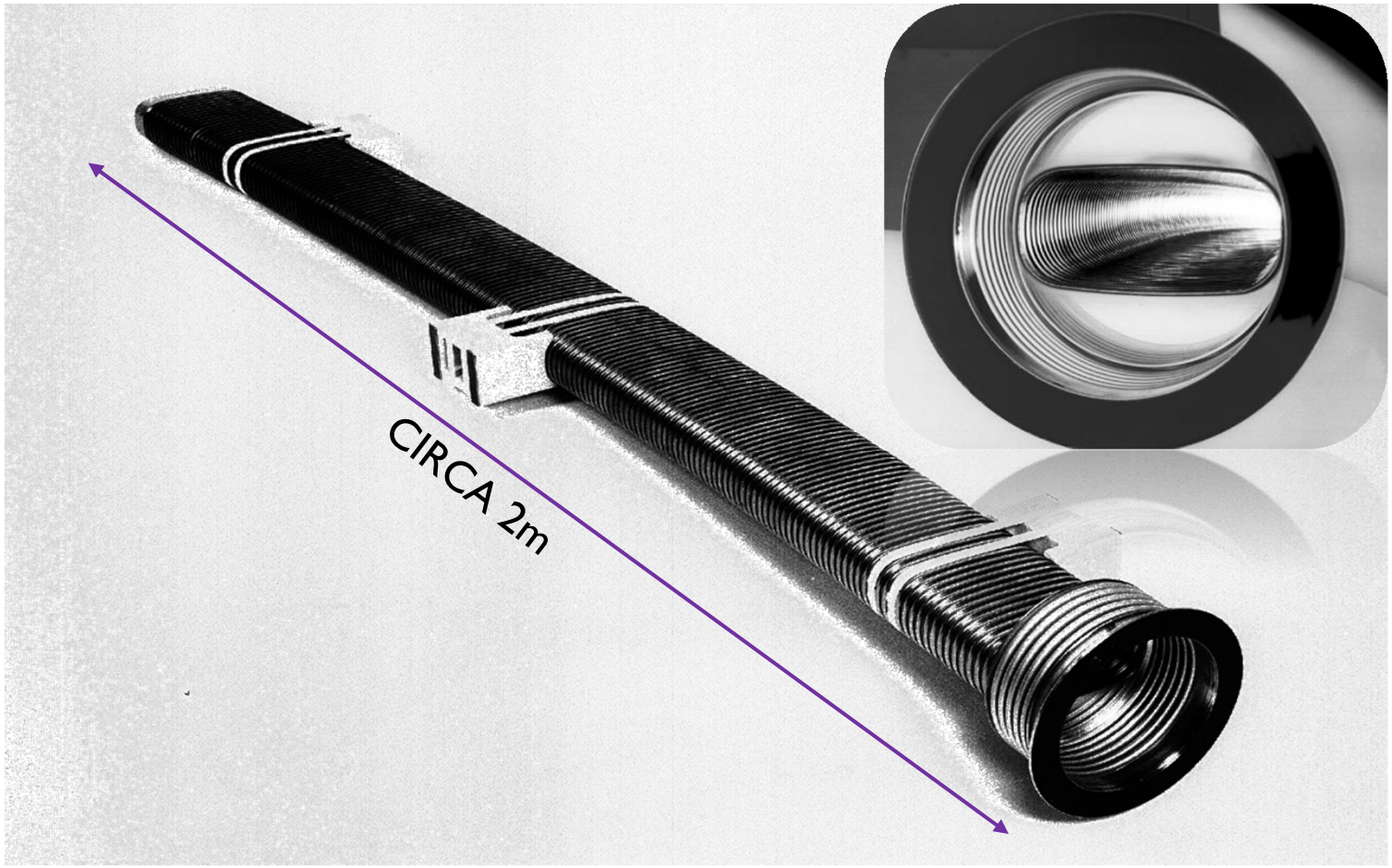
Mechanical & Materials Engineering

- Beam line equipment

Courtesy Alessandro Dallocio

Mechanical & Materials Engineering

- Vacuum chambers



Courtesy Alessandro Dallocio

Mechanical & Materials Engineering

- Subcontracting Service
  - What kind of skills we are looking for?

Machining
High precision machining on large/very large components (Steel, Stainless steel, Al, Cu Alloys, Ti, W, Mo, Nb…)
Ultra precise machining on small/medium size components (Stainless steel, Cu Alloys, Al,)
Production and machining of ceramics and plastics (small, medium, large size)
EDM (wire erosion): all technologies providing precise tolerances and complex shapes.

Welding/Brazing
TIG/MIG Welding of stainless steel (316, 316L/LN, 304) Welding of aluminium Welding of Cu/Brass and Cu Allloys Welding of Titanium
Laser welding
Electron beam welding
Explosion bonding
Soldering
Vacuum brazing

Mechanical & Materials Engineering

- Subcontracting Service
  - What kind of skills we are looking for?

Various
Additive Manufacturing (especially with metals)
Thermal treatment (large components)
Surface treatments (cleaning, UHV cleaning, Ni coating, Si coating, Cu coating, anodization…)
Die forming (casting)

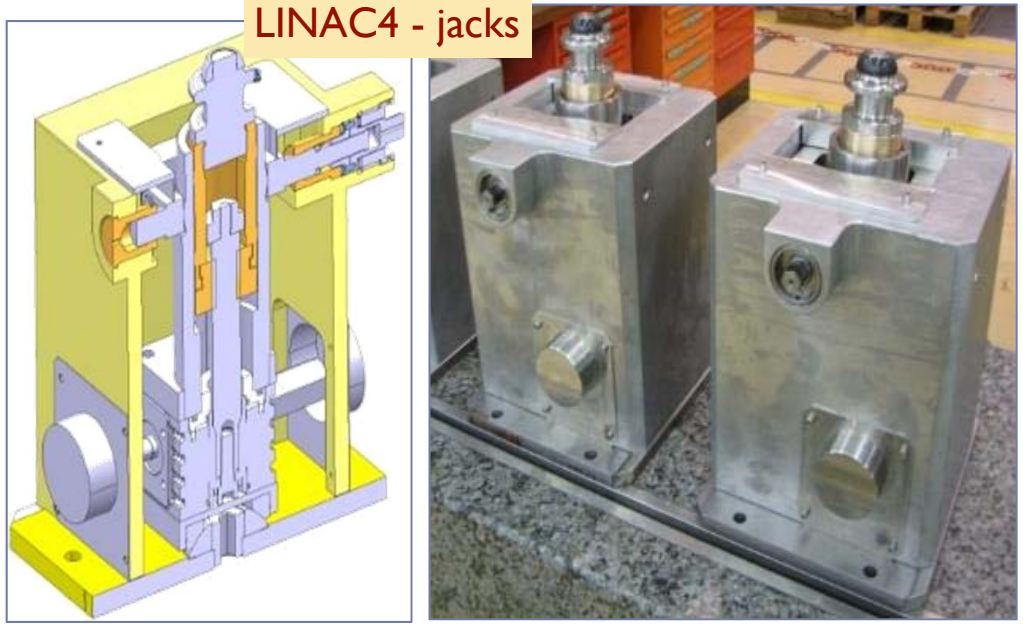
Metal Forming
Forging: particularly customized forged pieces (Stainless steel 316LN, Cu alloys, Al alloys…)
Extrusion
Casting (Iron and Aluminum)
Spin forming (Al, Cu, SS, Nb)
Punching, Fine Blanking, Deep Drawing
Forging: particularly customized forged pieces (Stainless steel 316LN, Cu alloys, Al alloys…)

Courtesy Alessandro Dallocio

Mechanical & Materials Engineering

- Subcontracting Service
  - recent activities

LINAC4 - jacks



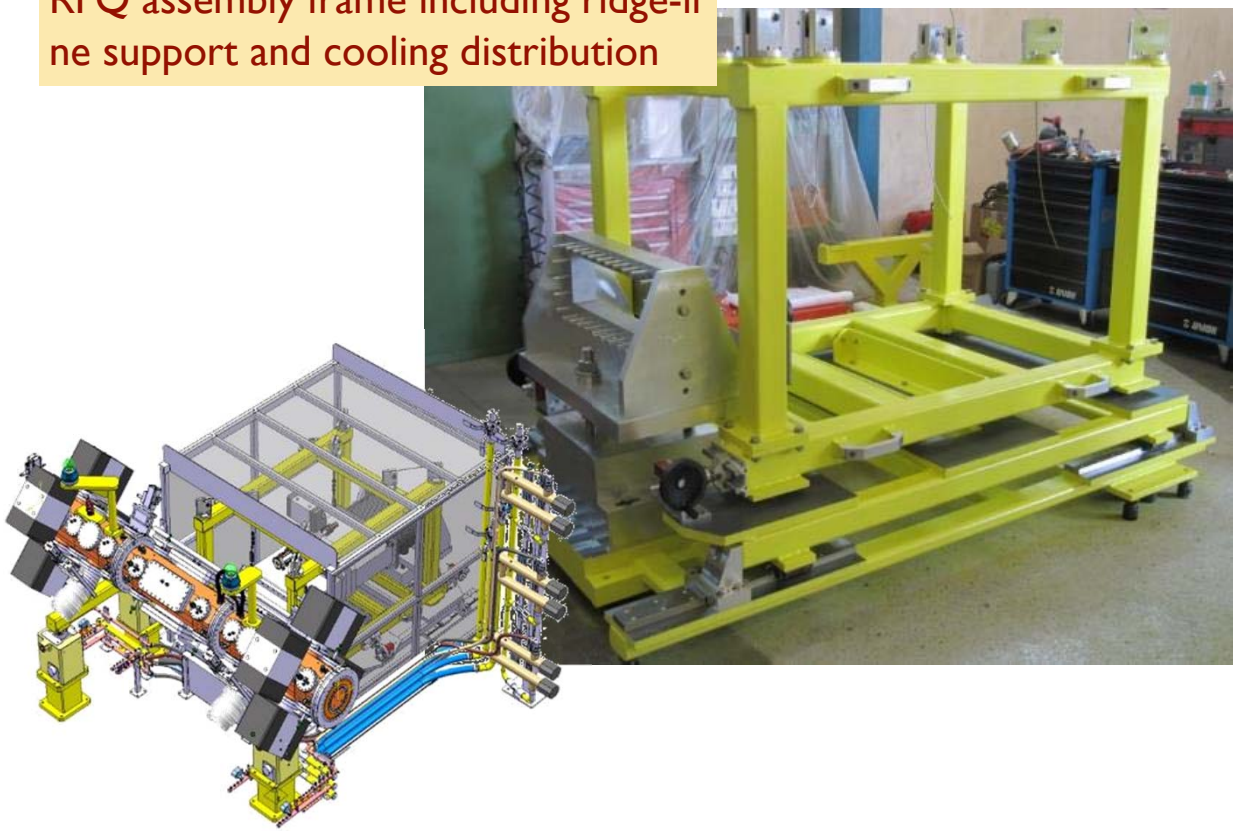
DTL girder

Courtesy Alessandro Dallocio

Mechanical & Materials Engineering

- Subcontracting Service
  - recent activities

RFQ assembly frame including ridge-line support and cooling distribution



Full scale (~2m) DTL tank segment

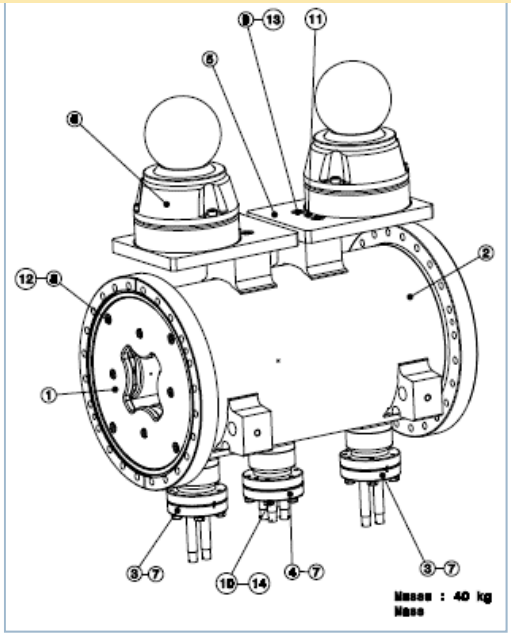
Courtesy Alessandro Dallocio

Mechanical & Materials Engineering

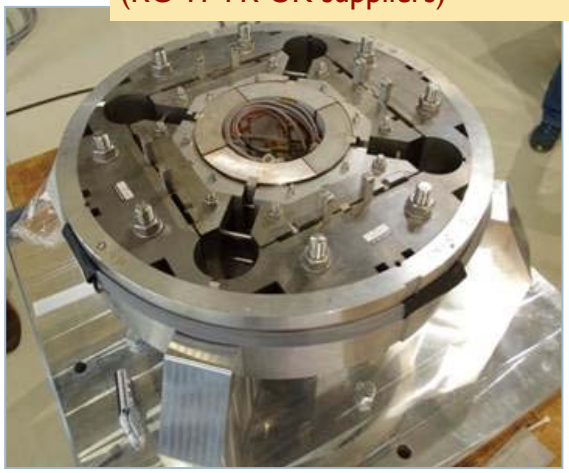
- Subcontracting Service
  - recent activities

LiU-PSB : First prototype of BHZ chambers fo r new PSB H- injection
(CZ-CH suppliers)

ELENA – Series production of electrostatic qu adrupole (60 pcs)
(Synergy CERN – NO,RS industrial suppliers)



HL-LHC : new SQXF large apert ure quad, short prototype
(RO-IT-FR-UK suppliers)



Courtesy Alessandro Dallocio

Mechanical & Materials Engineering

- Subcontracting Service
  - recent activities

HIE-ISOLDE : thermal shield
(CERN – Ni-plating in collaboration with FR firm)

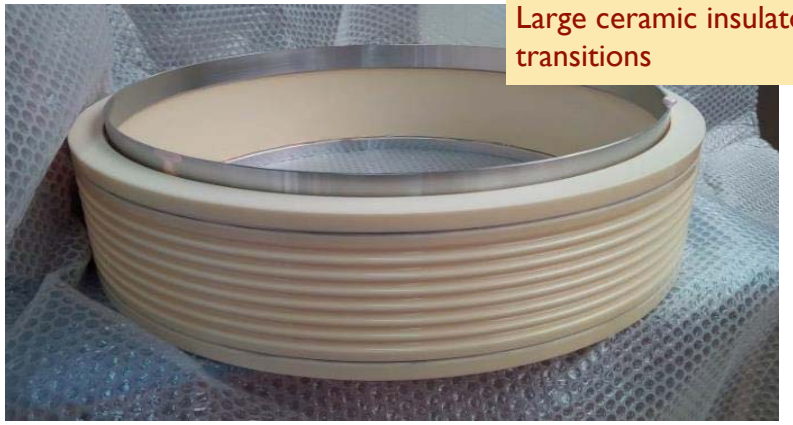
FRESCA : magnet impregnation tool
(BEsuppliers)

Courtesy Alessandro Dallocio

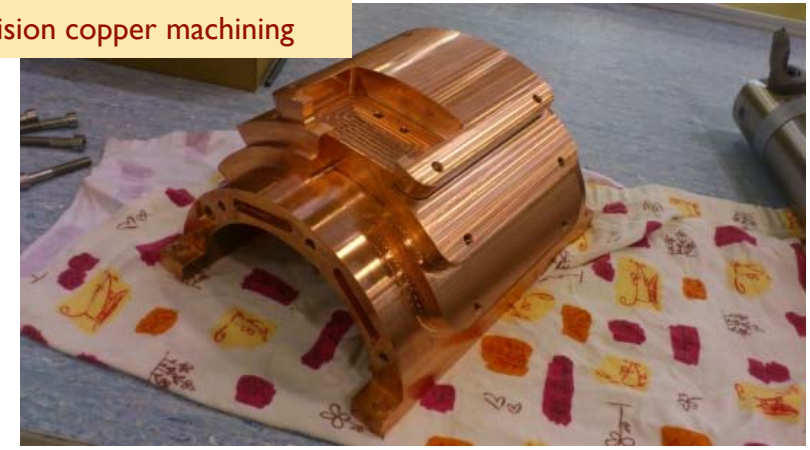
Mechanical & Materials Engineering

- Subcontracting service
  - Recent activities

Large ceramic insulator with brazed transitions



High-precision copper machining



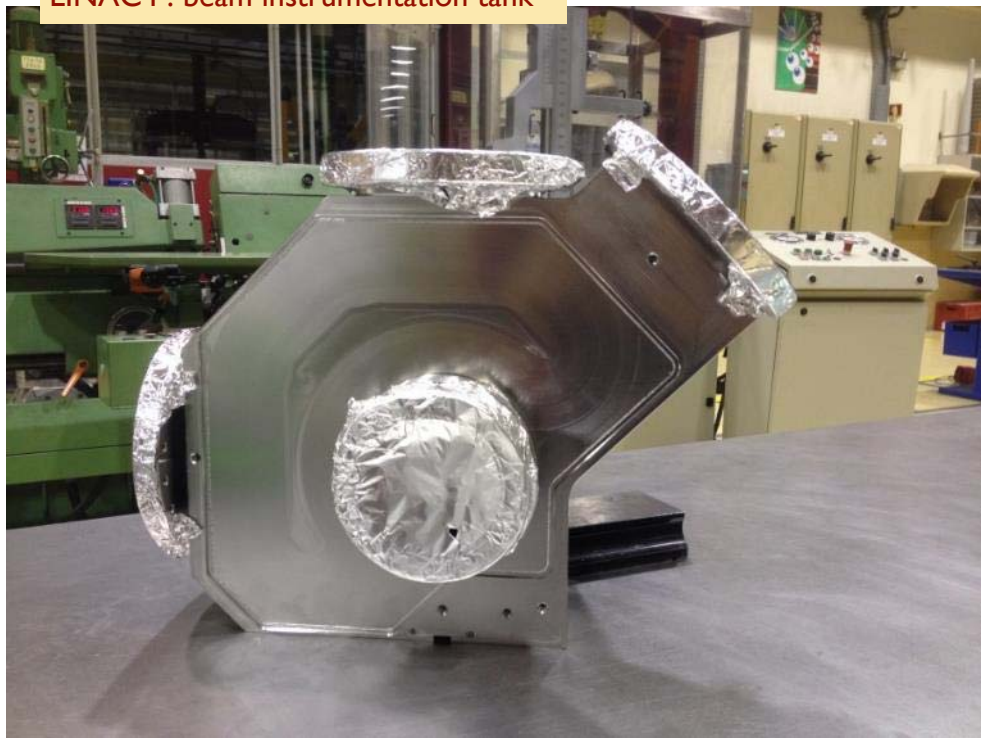
HIE-ISOLDE : Large structure for clean room

Courtesy Alessandro Dallocio

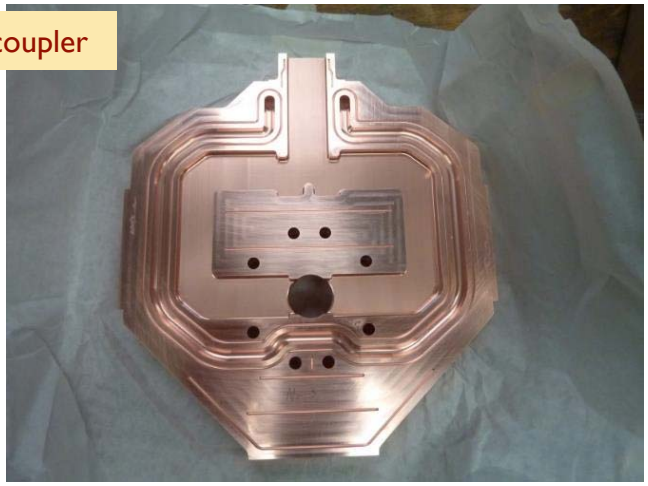
Mechanical & Materials Engineering

- Subcontracting service
  - Recent activities

LINAC4 : beam instrumentation tank



RF coupler

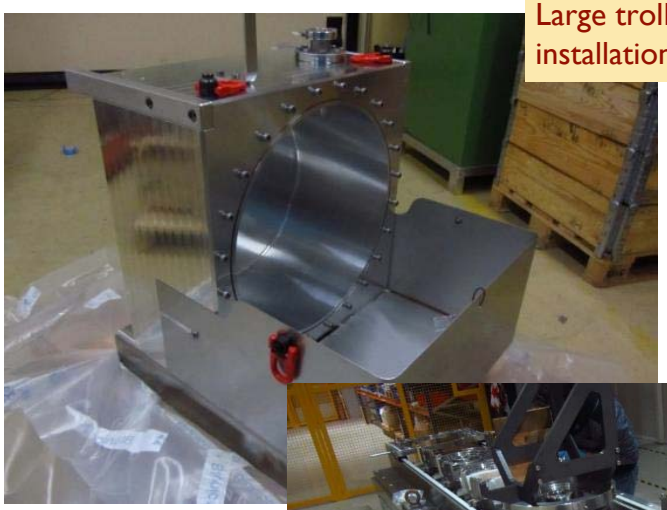


Beam instrument – high-percision mac hining of 316LN

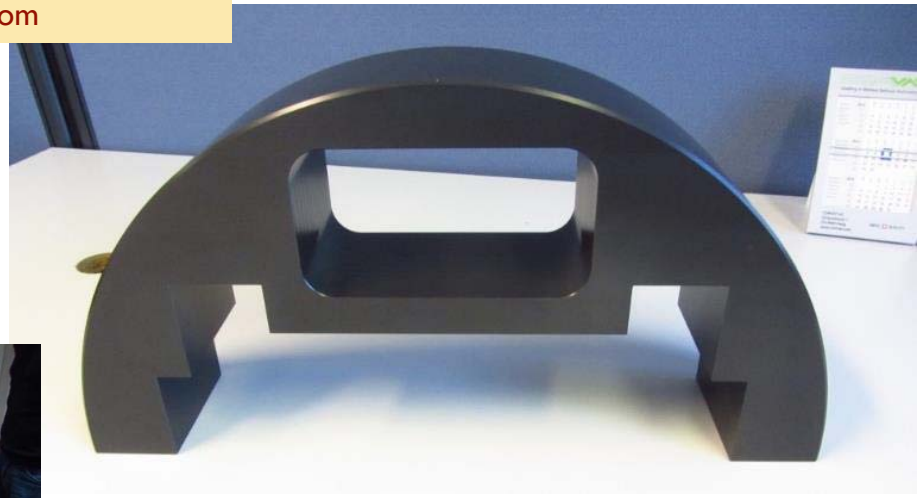
Courtesy Alessandro Dallocio

Mechanical & Materials Engineering

- Subcontracting service
  - Recent activities



Large trolley for the HIE-ISOLDE RF cavities installation into the clean room



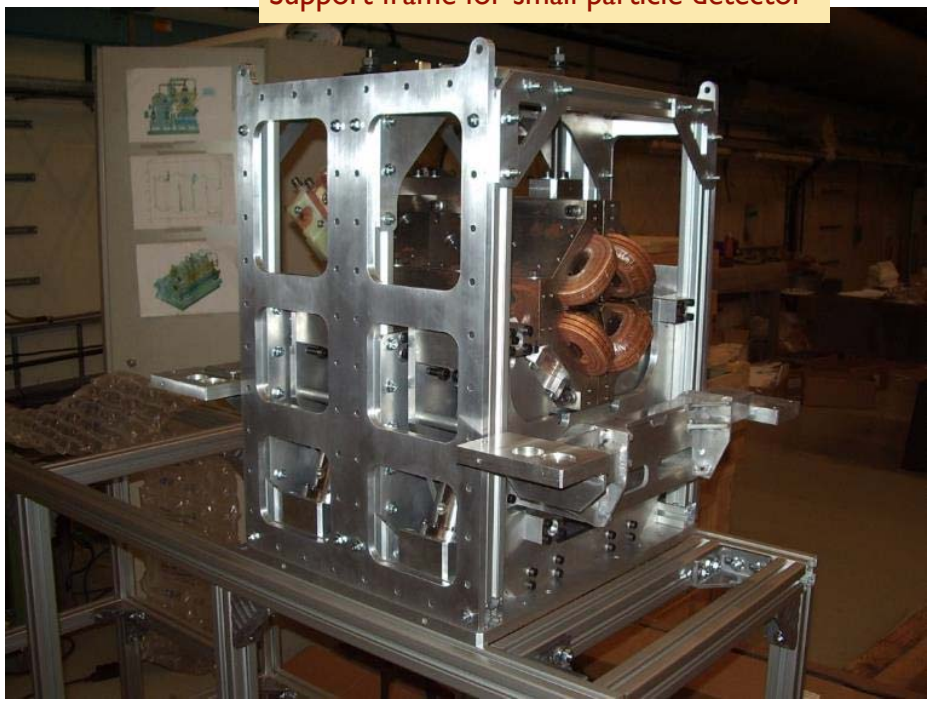
Courtesy Alessandro Dallocio

Mechanical & Materials Engineering

- Subcontracting service
  - Recent activities

Lifting tool for magnets

Support frame for small particle detector



Courtesy Alessandro Dallocio

Mechanical & Materials Engineering

- Subcontracting service
  - Recent activities

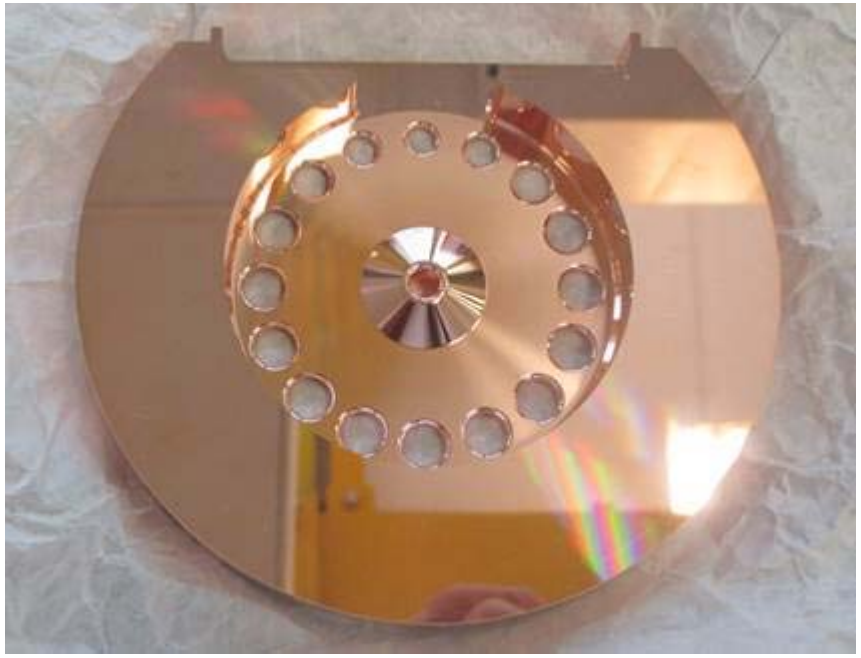
Component production for new HiRa dMat Experiment on material R&D for LHC collimators

Courtesy Alessandro Dallocio

Mechanical & Materials Engineering

- Subcontracting service
  - Recent activities

New undulated vacuum chambers

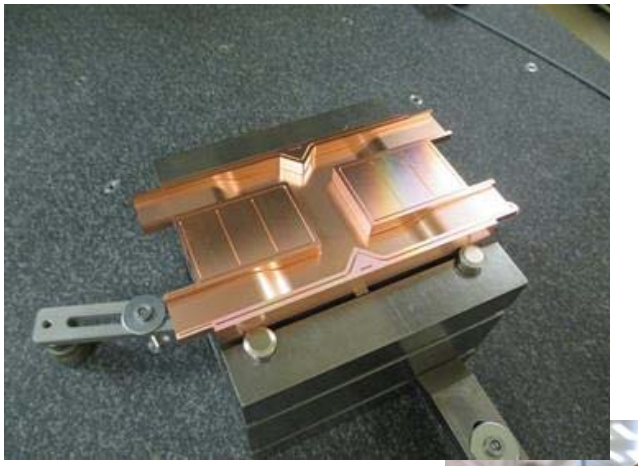


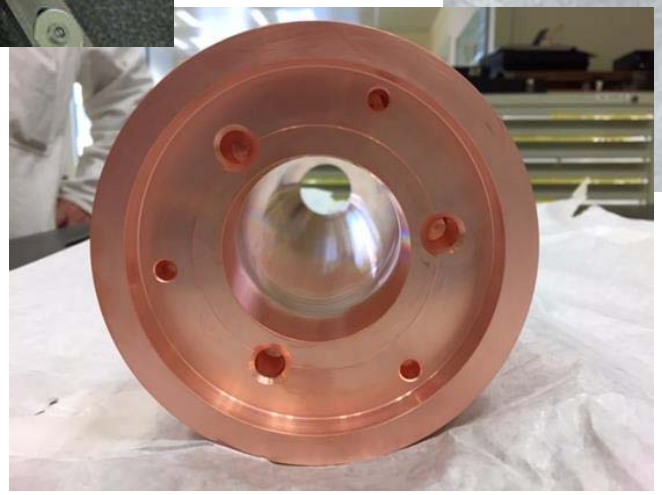
Ultra precise machining of RF cells for R&D on future Medical Accelerators

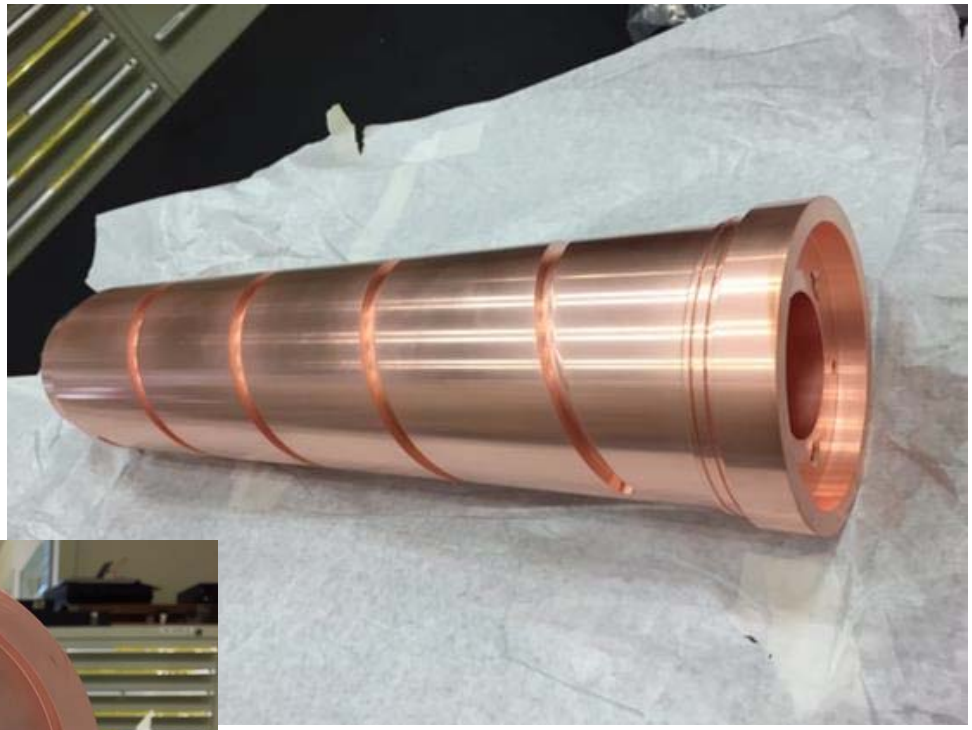
Courtesy Alessandro Dallocio

Mechanical & Materials Engineering

- Subcontracting service
  - Recent activities







RF pulse compressor on Cu OFE 3D Forged

Courtesy Alessandro Dallocio


μ-beam
RA-01
PANEL G21

EN - CV Group

Cooling & Ventilation

- Cooling systems, pumping stations, installations and fluid distribution systems for the CERN accelerators & experiments

Cooling plants (raw, demineralised water, C_3F_8, C_6F_{14})	***150***
Pipelines	***800 km***
Hydrants	***800 points***
Cooling towers (450 MW)	***22***
Chilled water plants 6-12 °C (73 MW)	***35***
Water network with three pumping stations	***5'400 m^3/h***

Water consumption equivalent to a city of 45'000 people
10% consumption of the Canton de Geneva

Ventilation

- Ventilation and air conditioning to accelerator installations (surface and underground), experimental areas

Heating, ventilation and air conditioning	***1'500 units from 2'000 to 120'000 m³/h each***
Compressed air	***14 stations 200 km network***

	km	***m³/h***
Eurotunnel	50	*540'000*
LHC	***27***	***290'000***

EN - CV Group

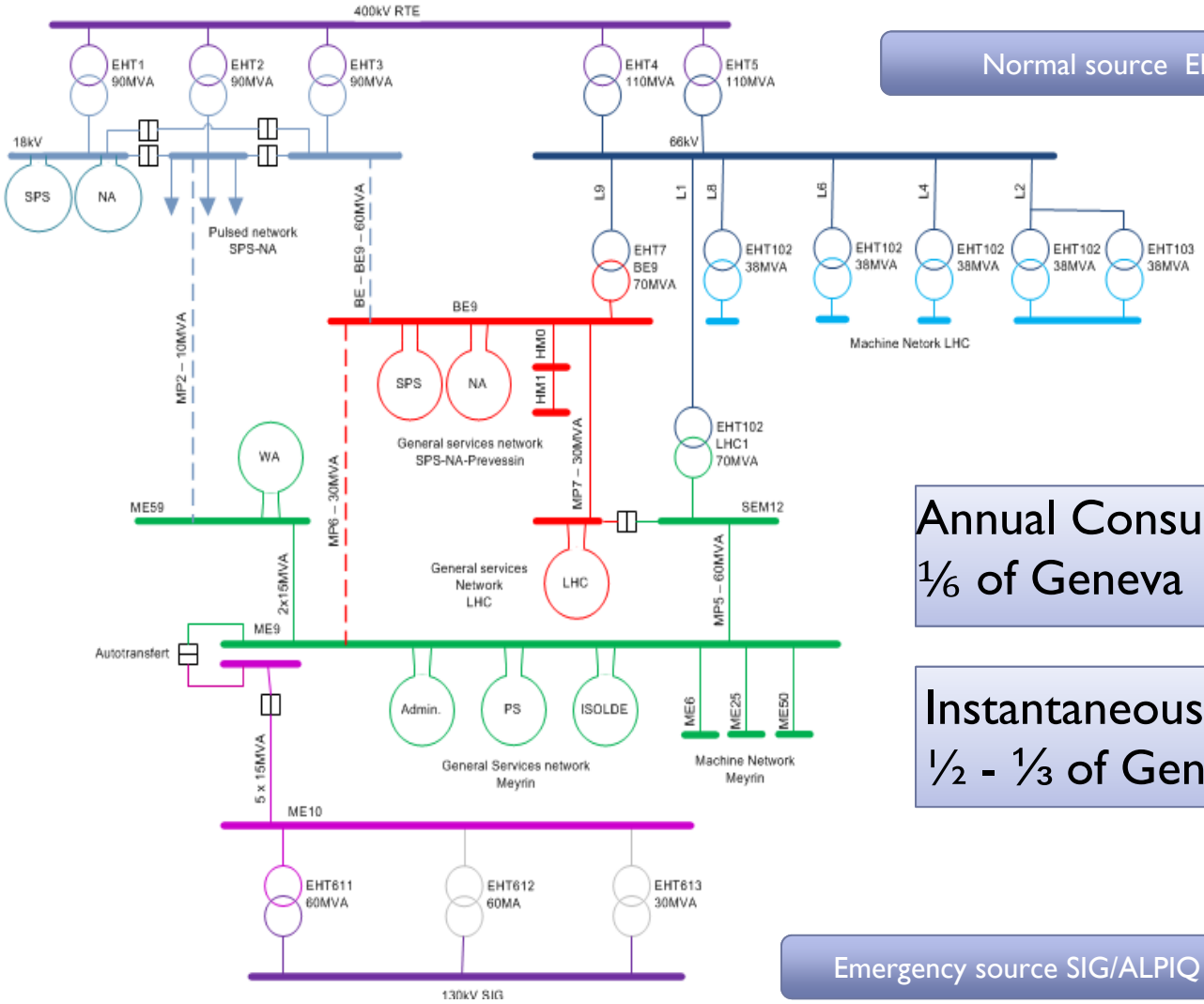
Cooling & Ventilation

EN - EL Group

Electrical Engineering

- Operation, maintenance, extension, and renovation of the CERN electrical distribution network – optimize electrical energy consumption

Electricity Distribution



Normal source EDF > 300 MW

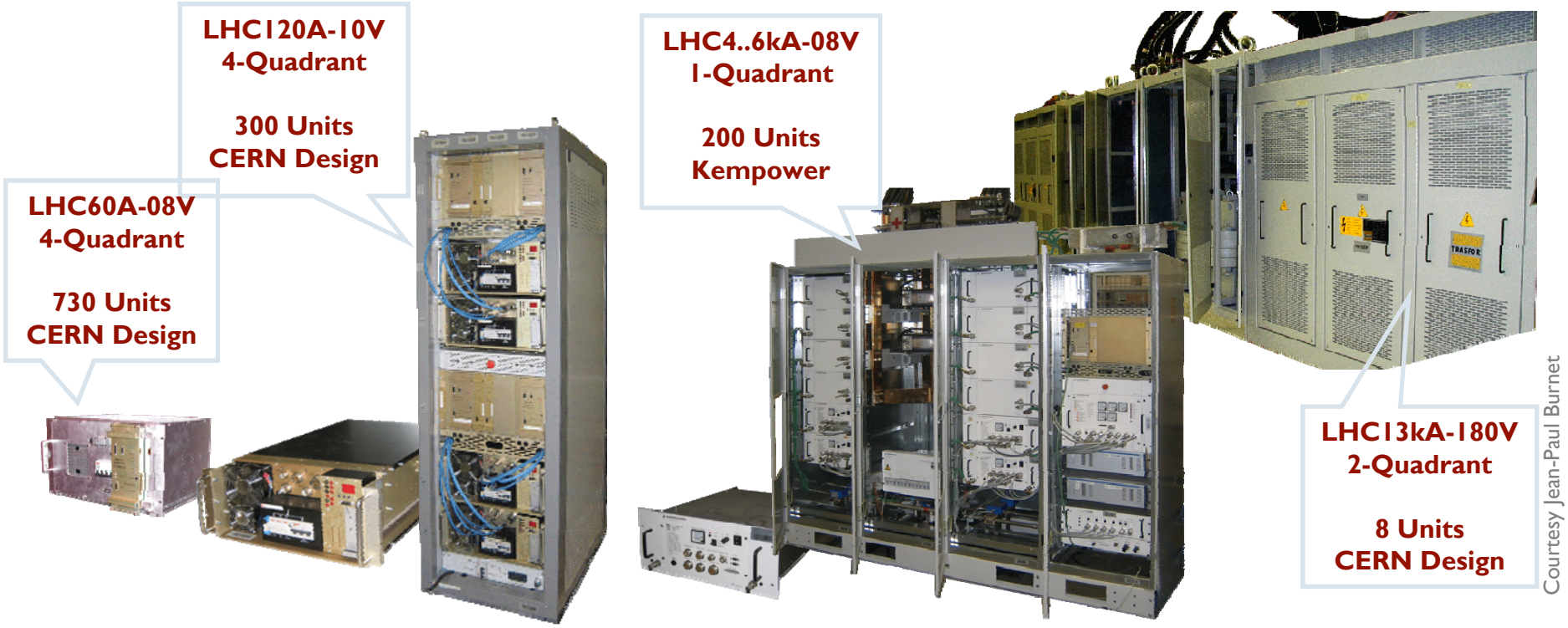
Annual Consumption 1.26 TWh
⅙ of Geneva

Instantaneous Power 180 MW
½ - ⅓ of Geneva

Emergency source SIG/ALPIQ ≤ 60 MW

Power Converters

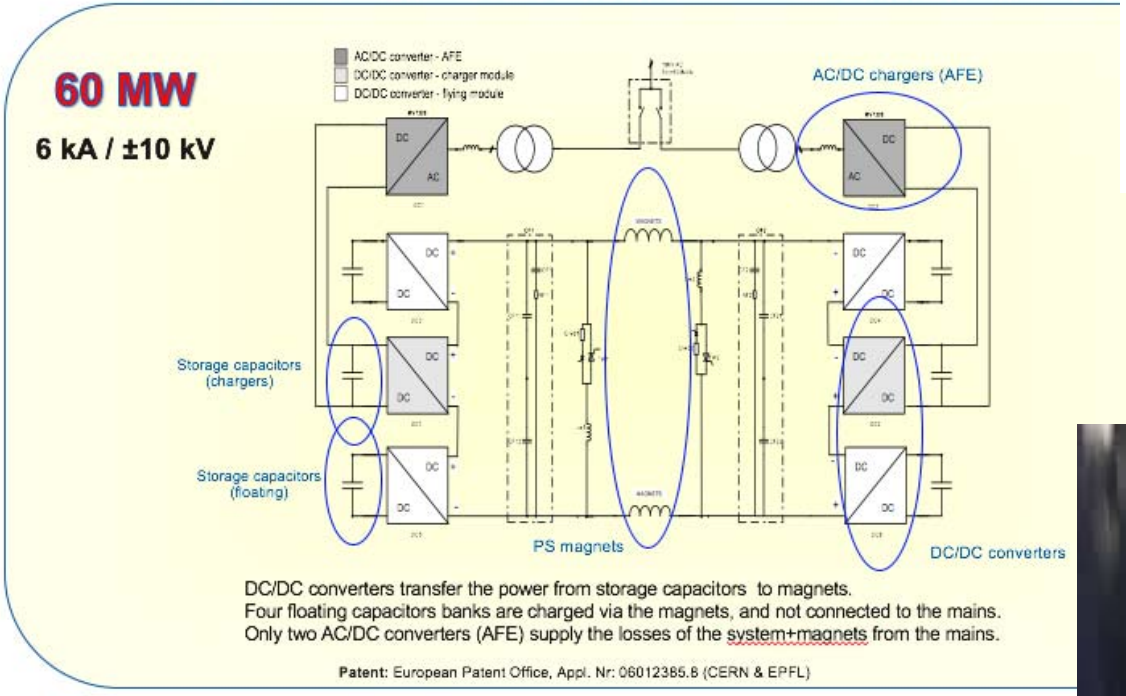
- Power supplies for the accelerator magnets and equipment
  - Transform the AC mains power into adequate conditioned power to the load
  - Key challenges: stored energy, current stability, synchronization



Pulsed Power Converters

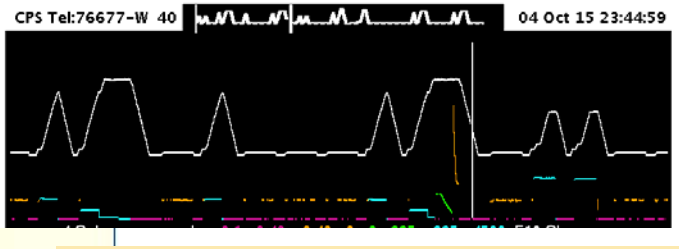
Power converter with integrated energy storage

Decoupling of power power pulses from the network (POPS – Power System for PS)



DC/DC converters transfer the power from storage capacitors to magnets.
Four floating capacitors banks are charged via the magnets, and not connected to the mains.
Only two AC/DC converters (AFE) supply the losses of the system+magnets from the mains.

Patent: European Patent Office, Appl. Nr: 06012385.8 (CERN & EPFL)

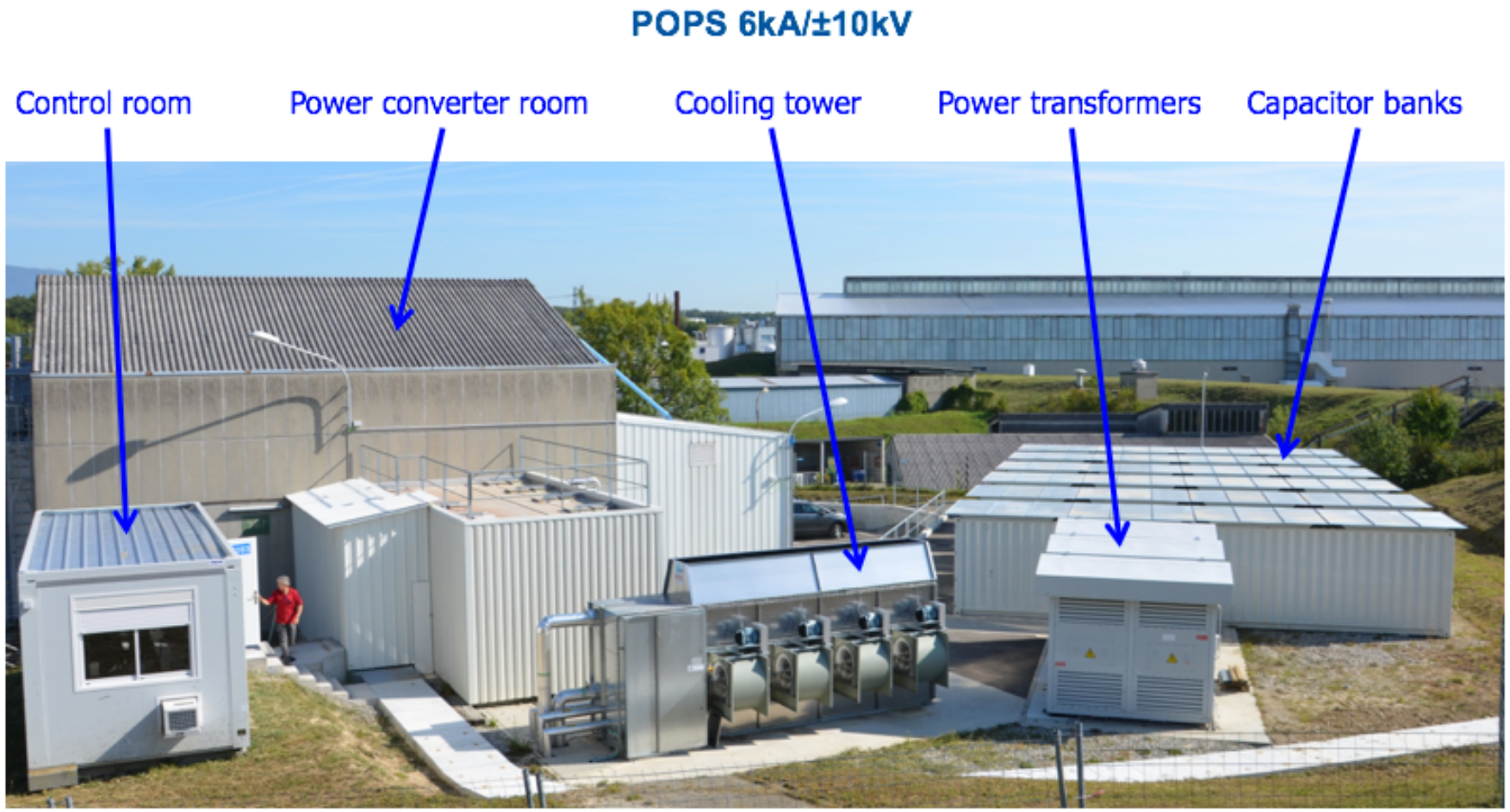


PC machine pulsing scheme – basic scycle 1.2 s

Courtesy Jean-Paul Burnet

Pulsed Power Converters

- The PS pulsed power supply



Courtesy Jean-Paul Burnet

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Transport & Handling

- Manage the complete logistic of transport and handling activities at CERN
  - Development, purchase, operation and maintenance of all transport & handling machines and tools – industrial and custom built

Courtesy Ingo Ruhel

EN - MEF Group

Transport & Handling

- Industrial vehicles

- 30 elevators (diesel) +150 electrical elevators
- 100 platforms
- 1000 manual handling machines
- 60 trucks for special transport
- 180 electrical trolleys

TOTAL : 1500 machines (Value 25 M€)

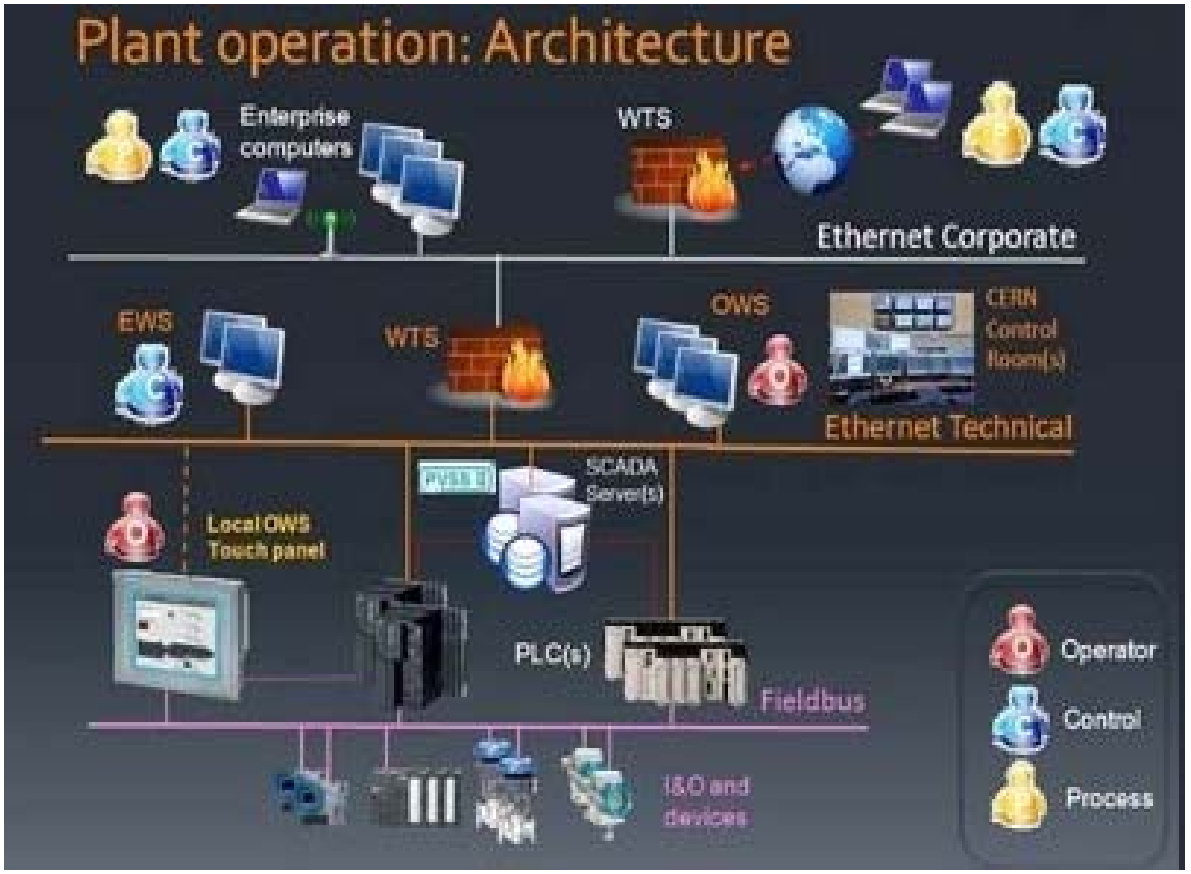
Courtesy Ingo Ruhel

EN – ICE Group

Industrial Controls

- Large and medium scale industrial control systems deployed throughout CERN

- Particular challenges
  - Computer safety
  - Radiation to electronics
  - Uptime/Availability



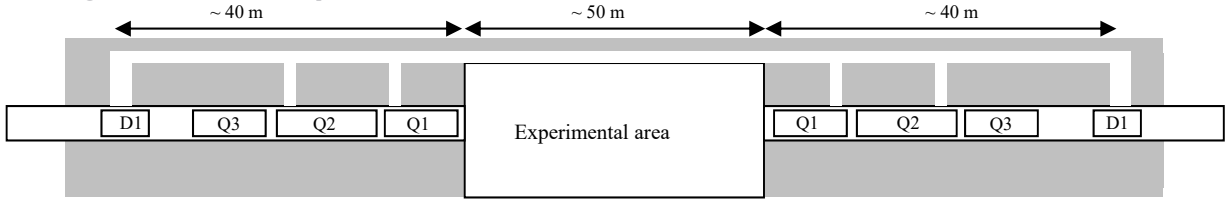
Courtesy Philippe Gayet

Survey & Alignment

- Fiducialisation
  - 2000 cryomagnets

- Alignment of the LHC components in the tunnel
  - Absolute precision 4 mm
  - Relative precision over 150 m 0.15 mm
  - 4000 components

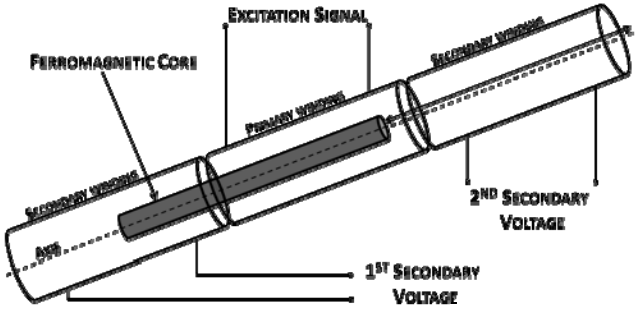
- Inner triplets - LHC
  - 0.1 mm in all directions
  - Permanent monitoring through water level and wires
  - Survey galleries in the high luminosity IPs
  - Motorized jacks



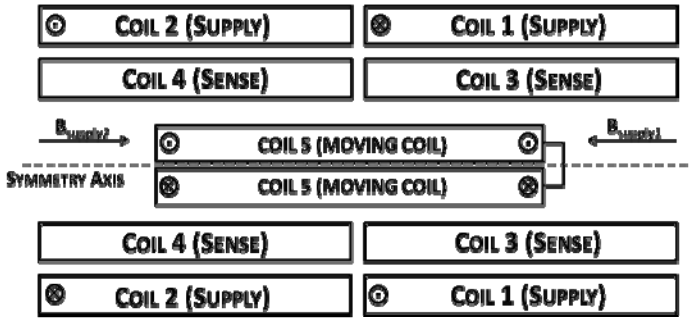
Courtesy Dominique Missiaen

Special Instrumentation

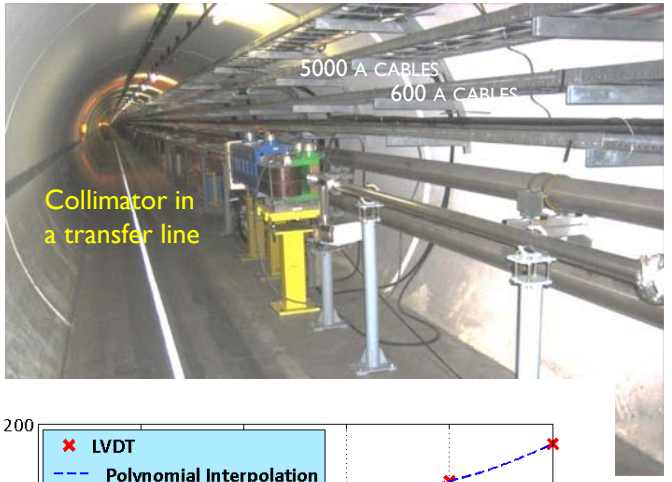
- Rad-hard Magnetic Field immune positioning sensors

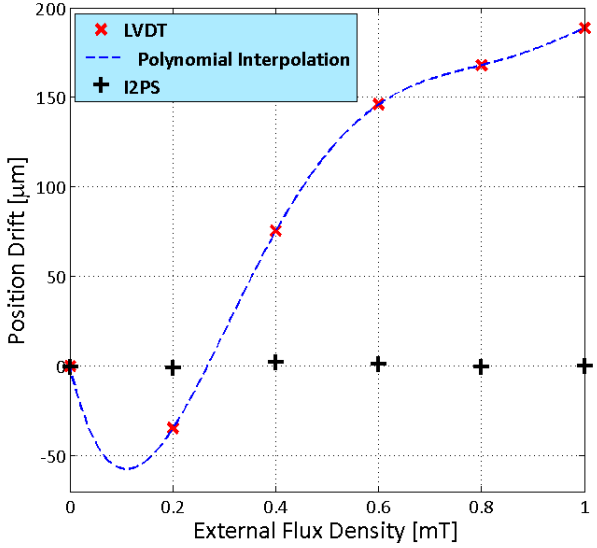


Linear Variable Differential Transformer



Ironless Inductive Position Sensor





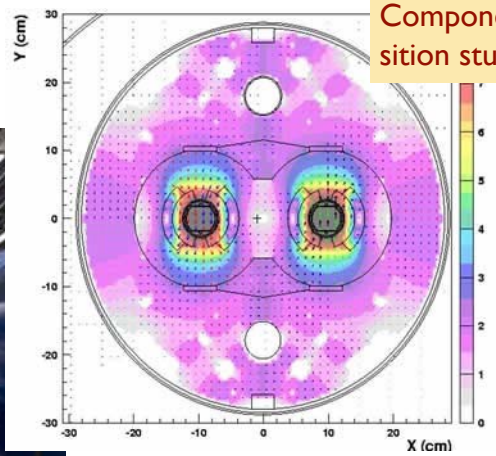
Courtesy Roberto Losito

EN – STI Group

Beam Interactions with Matter

- Studies & know-how on energy deposition, radiation effects to electronics
  - Development of radioactive beam sources @ ISOLDE, CLIC photoinjector, plasma and polarized e^+e^- sources

Tooling for remote installation of LHC collimators



Component Energy Deposition studies

CLIC photoinjector

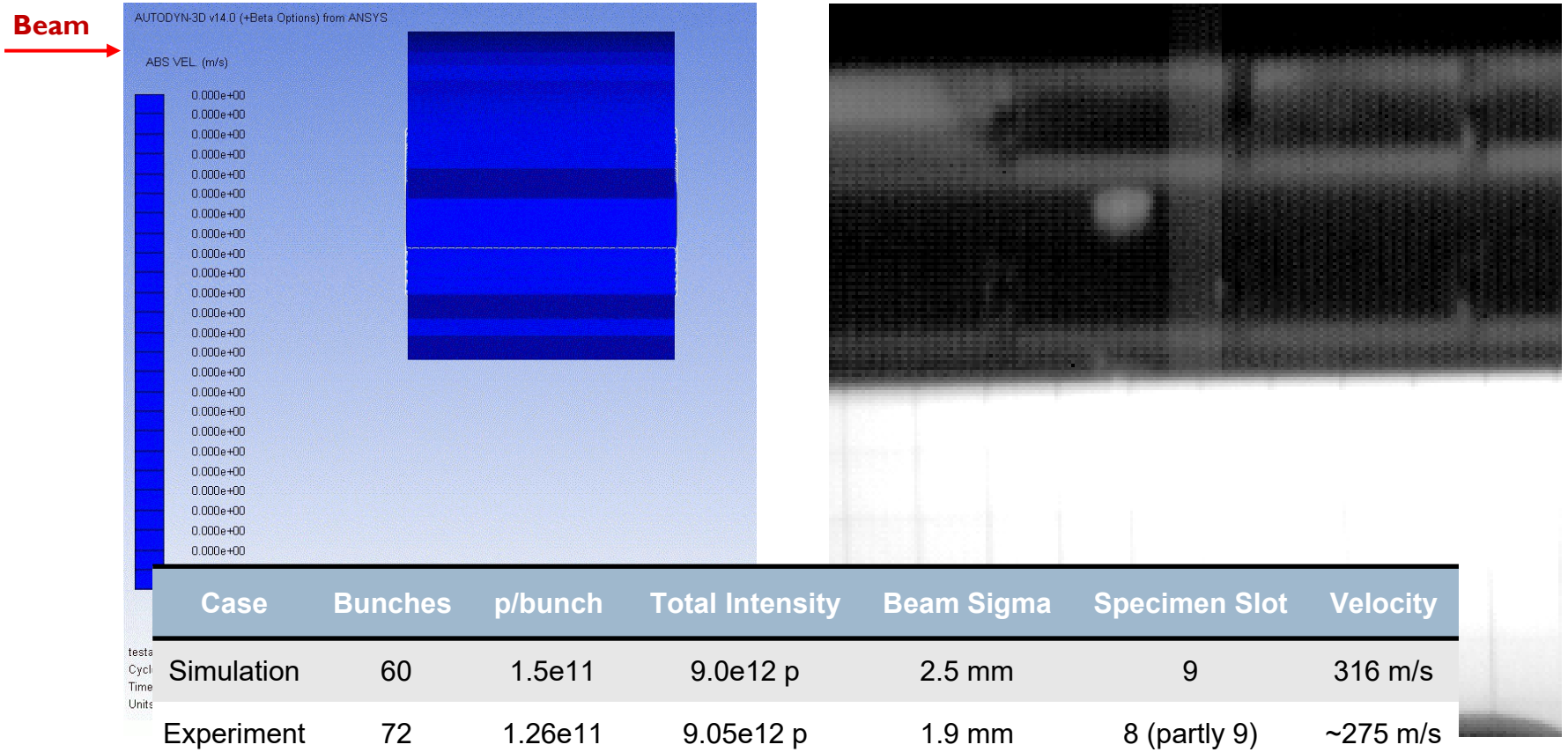
- **HiRadMat – High Radiation to Materials**
  - Provide high-energy (440 GeV), high-intensity (up to 3.4 MJ) pulsed beams to an irradiation area where samples of materials or component assemblies can be tested

TPSG4 collimator and mask t est setup – robustness test

Sample holder for testing different material and configurations – LHC collimator R&D

- R&D on Novel composite Materials

Inermet : comparison between simulation and experiment

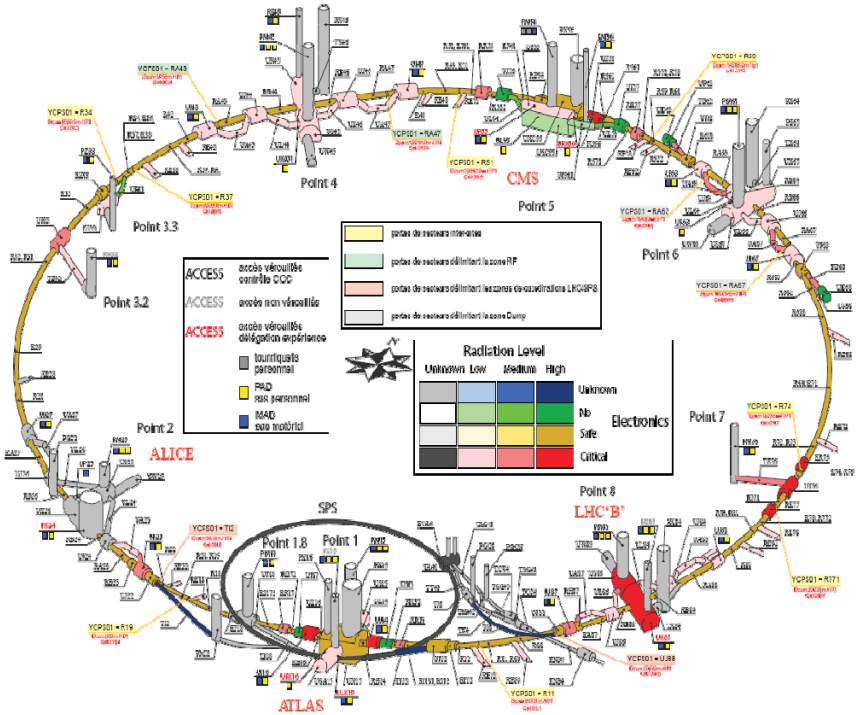


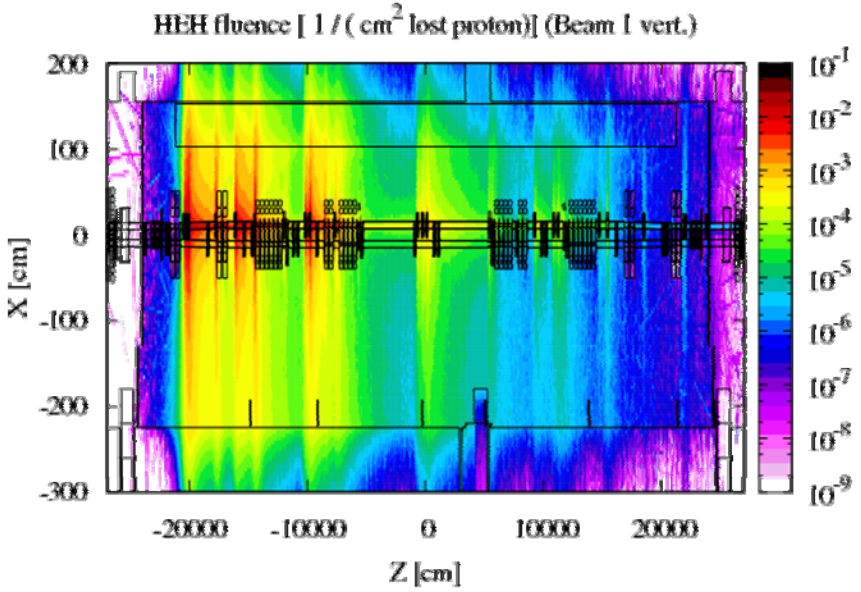
Case	Bunches	p/bunch	Total Intensity	Beam Sigma	Specimen Slot	Velocity
Simulation	60	1.5e11	9.0e12 p	2.5 mm	9	316 m/s
Experiment	72	1.26e11	9.05e12 p	1.9 mm	8 (partly 9)	~275 m/s

Courtesy Francesco Bertinelli

Radiation to Electronics

- R2E project : Study the impact of radiation effects on installed electronics in the CERN accelerators
  - Understand the environment and generated effects
  - Equipment inventory and risk analysis/prioritization
  - Implement mitigation options (shielding, relocation)



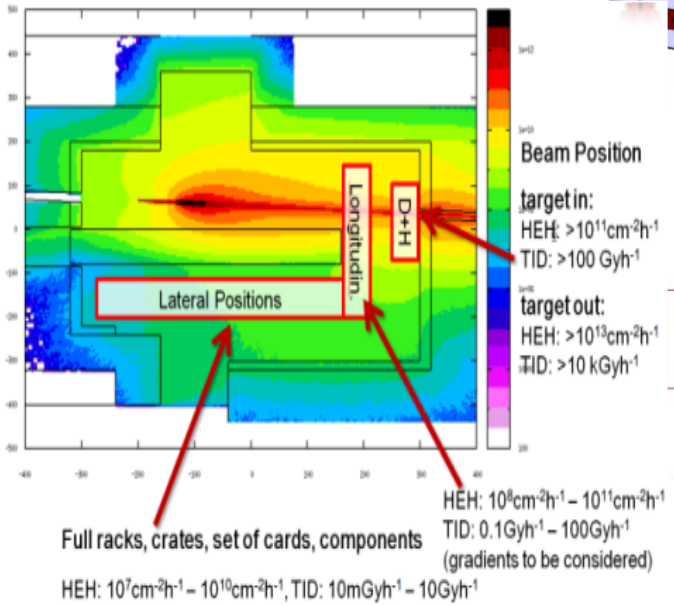


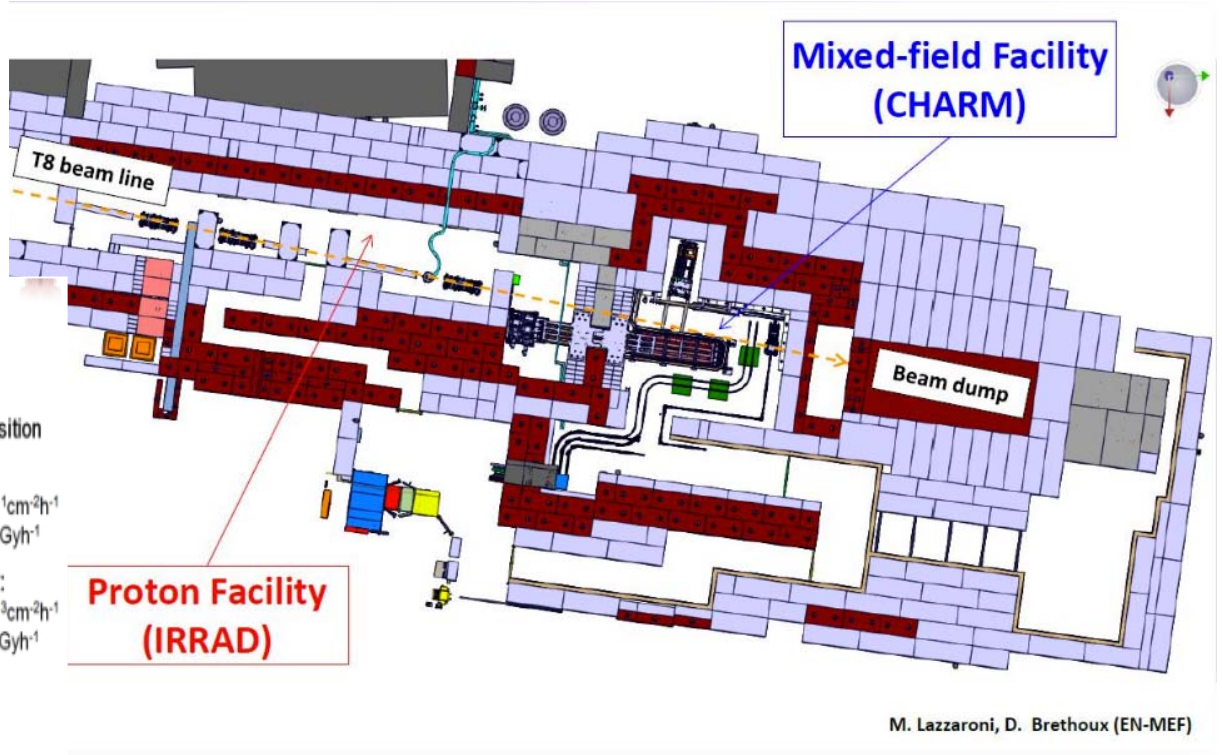
Particle fluence map from simulation (FLUKA) – good agreement with measurements within 20%

Courtesy Markus Brugger

Accelerator R&D Facilities

- **CHARM Facility @ PS**
  - Proton and neutron irradiation area
  - Designed to irradiate detector and accelerator equipment electronics





Courtesy Markus Brugger

Optimized design
- Variable particle fluence with movable shielding-
- Tools for remote installation/removal of the samples

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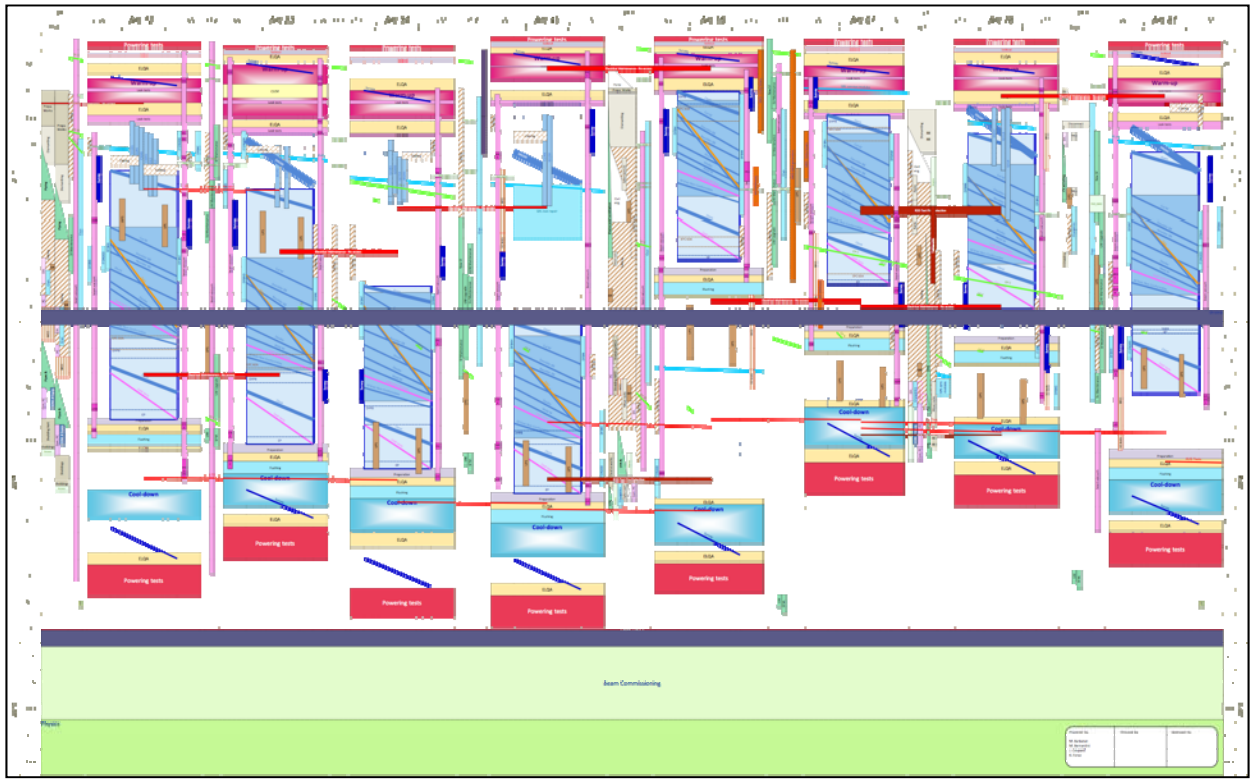
Planning & Quality Assurance

- Planning and coordination of interventions
  - Maintenance, Upgrades, Modifications
- Layout Database, Documentation, Specifications



Courtesy Katy Foraz

Concluding words

- CERN with its large accelerator complex is a unique place where physicists, engineers and industrial partners can work together and produce leading edge results
  - Keep in mind the interplay between high-tech and standard, industrial applications & needs

- It is hard in a single presentation to cover the full spectrum of engineering activities in the Organization.

- I tried to give you a flavor of our activities, in areas that could stimulate the interest for collaboration

CERN – METU Collaboration

Prof. B.Demirkoz

- **Development of a defocusing beam line at the TEAK SANAEM Proton Accelerator Facility @ Ankara**
  - Irradiation area for testing electronics components for space and other applications

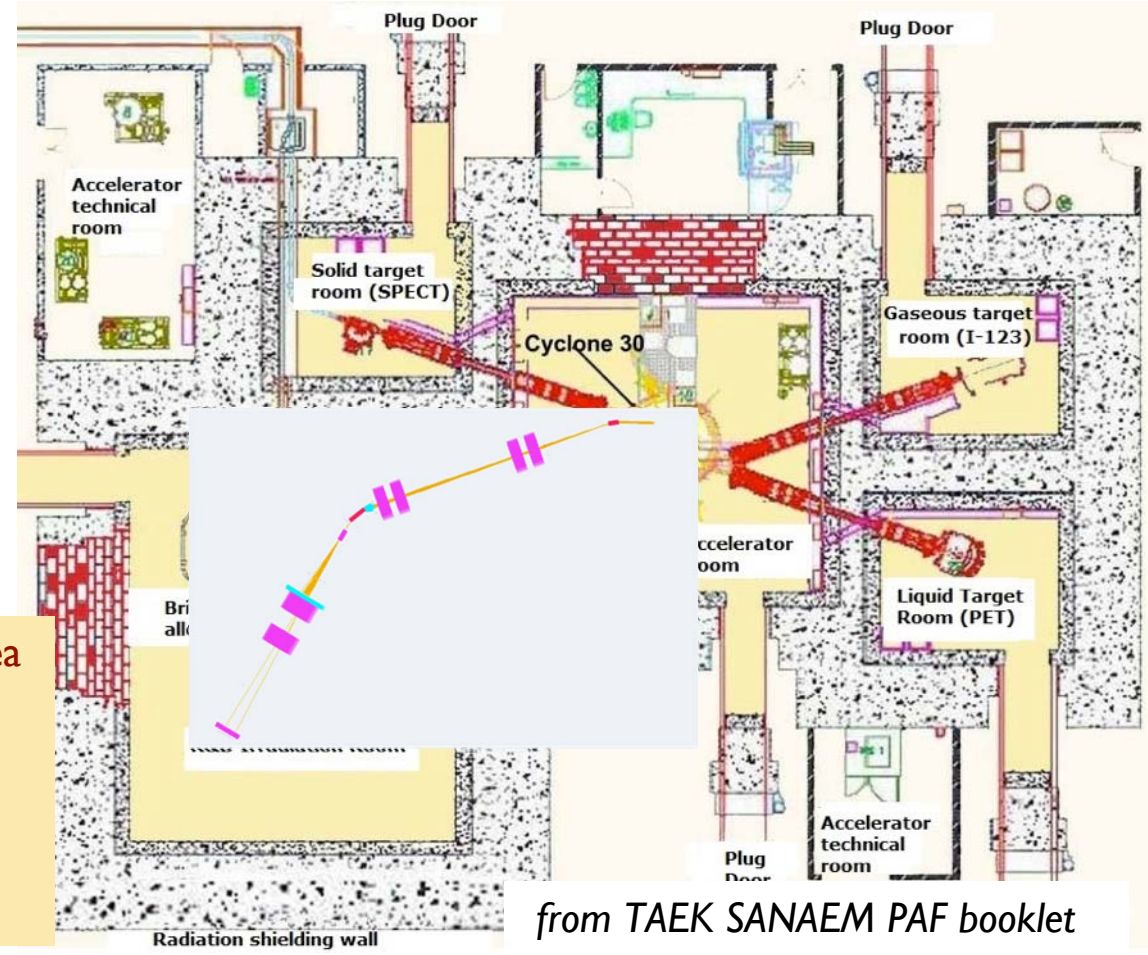
TEAK PAF building

Cyclotron

Beam Parameters – CYCLOTRON
- 30 MeV protons
- Beam current 12μA – 1.2mA

CERN – METU Collaboration

- TAEK SANAEM Proton Hızlandırıcı Tesisi



Beam Parameters – @ Irradiation Area – ESA ESCC No.25100

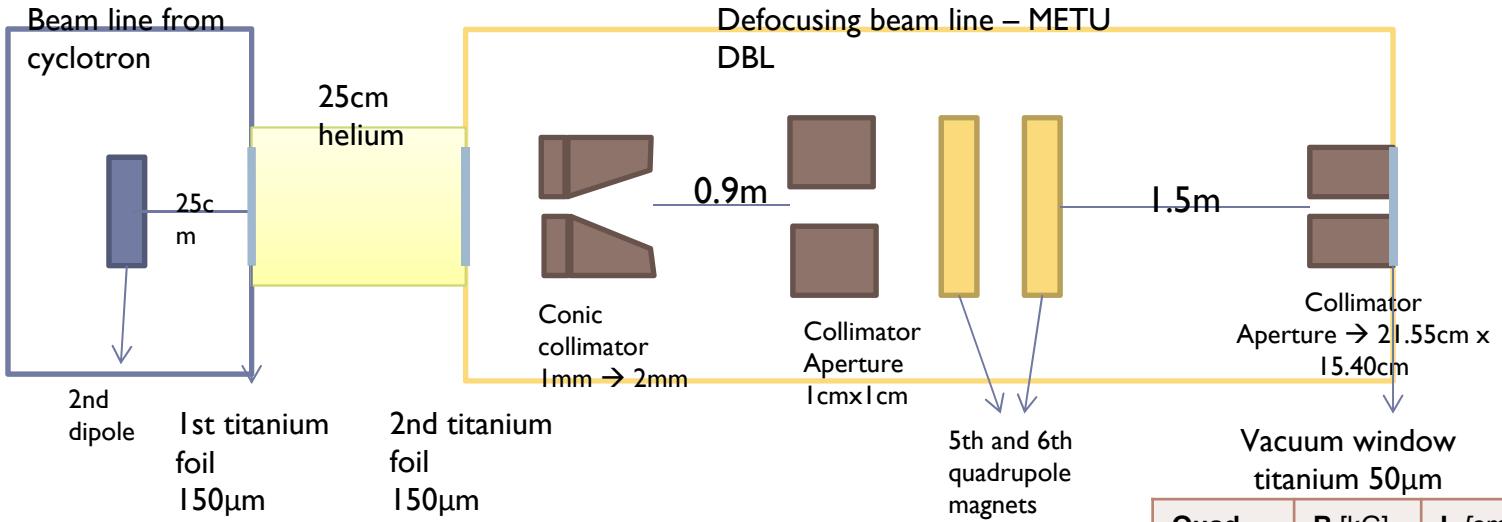
- 20MeV and 200 MeV protons
- Flux : 10^5 p/cm^2/s to ≥ 10^8 p/cm^2/s
- 15.4×21.55 cm irradiation area
- 10% uniformity

from TAEK SANAEM PAF booklet

Courtesy Aysenur Gener

CERN – METU Collaboration

Beam layout and instrumentation



Courtesy Aysenur Gener et.al

Quad	B [kG]	L *[cm]*	D [cm]
5th	4.2	40	8.
6th	-8.0	40	15cm

- Small scale project that nevertheless requires developing skills found in large accelerators
  - Beam design, Magnet design and construction, beam vacuum, windows, instrumentation, test station with movement possibility of samples

An excellent opportunity for collaboration and technology transfer from CERN to Turkish Industry


THANK YOU!