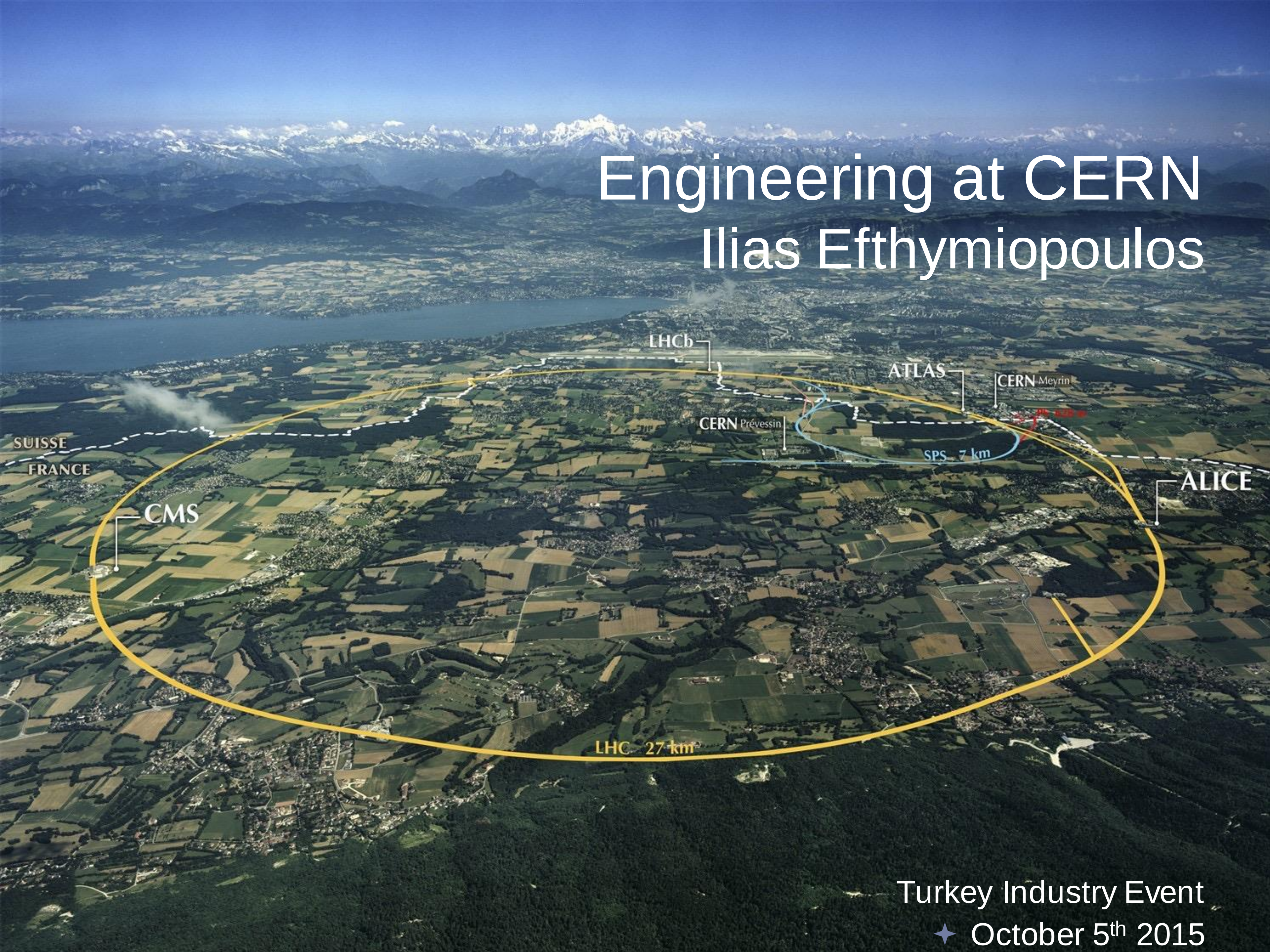
# Engineering at CERN

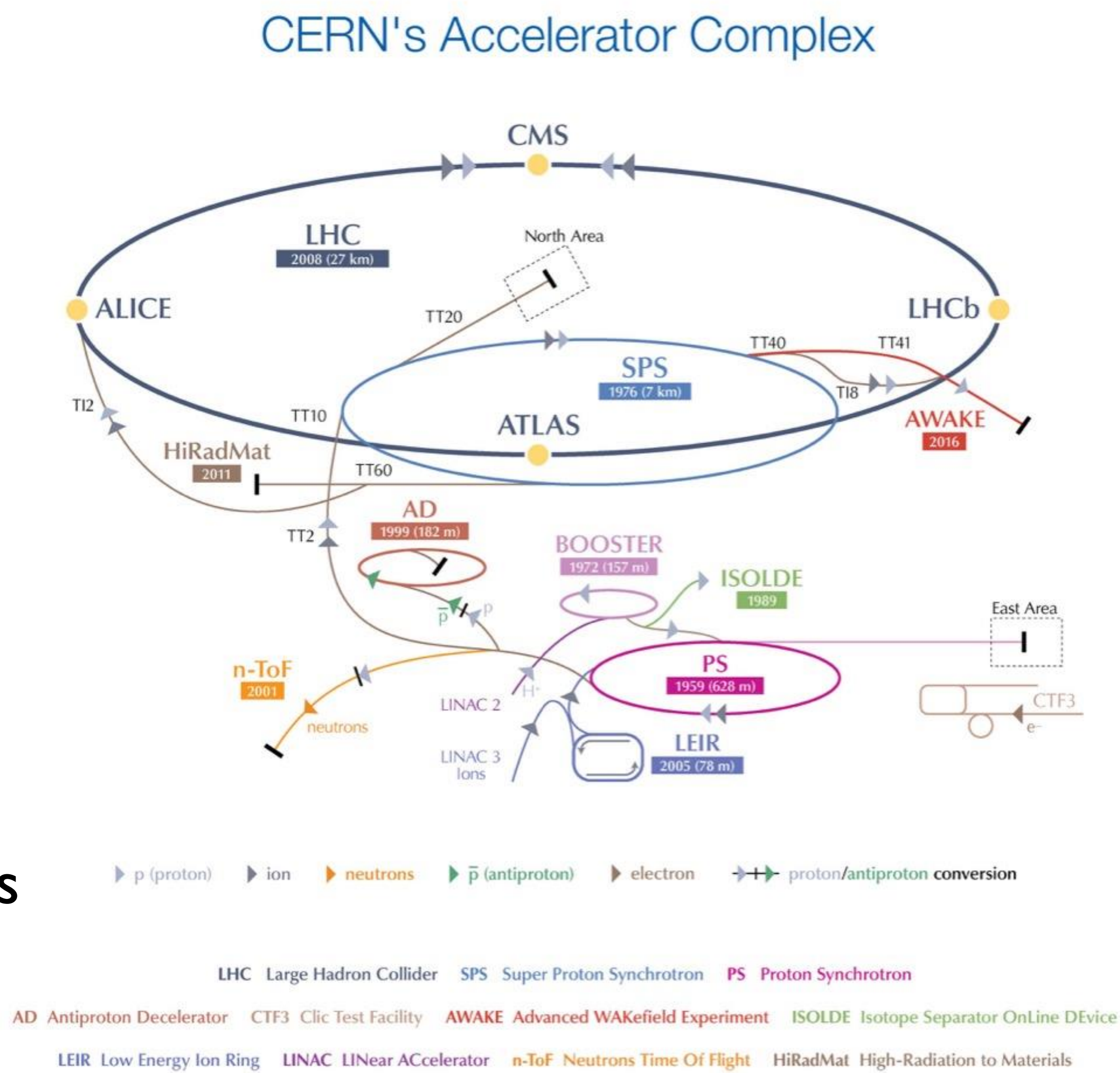
Ilias Efthymiopoulos




Turkey Industry Event

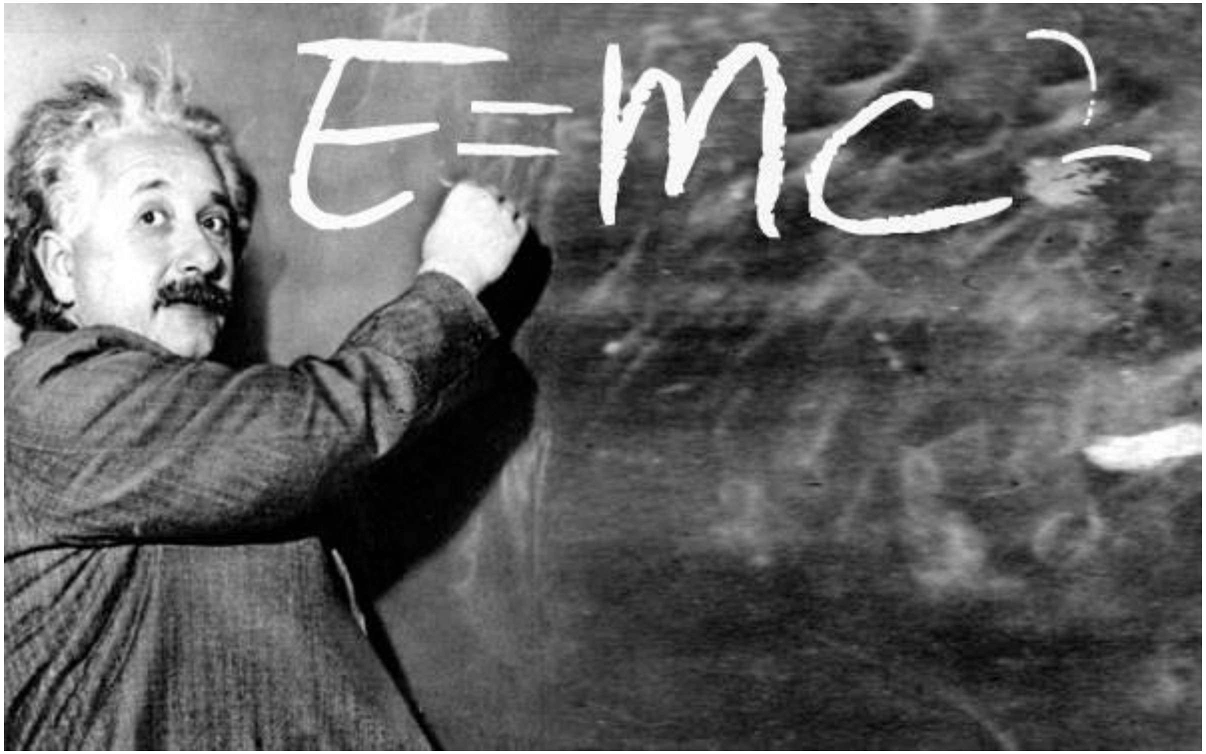
October 5th 2015

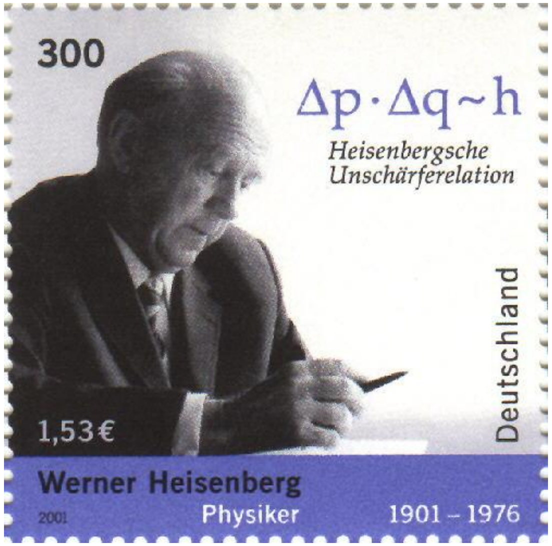
- 50 km of accelerators
- LHC : 27km, superconducting ring, 4 large experiments
- Injectors : normal conducting, 6 experimental areas and 2 irradiation facilities



# The Interest for Accelerators

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

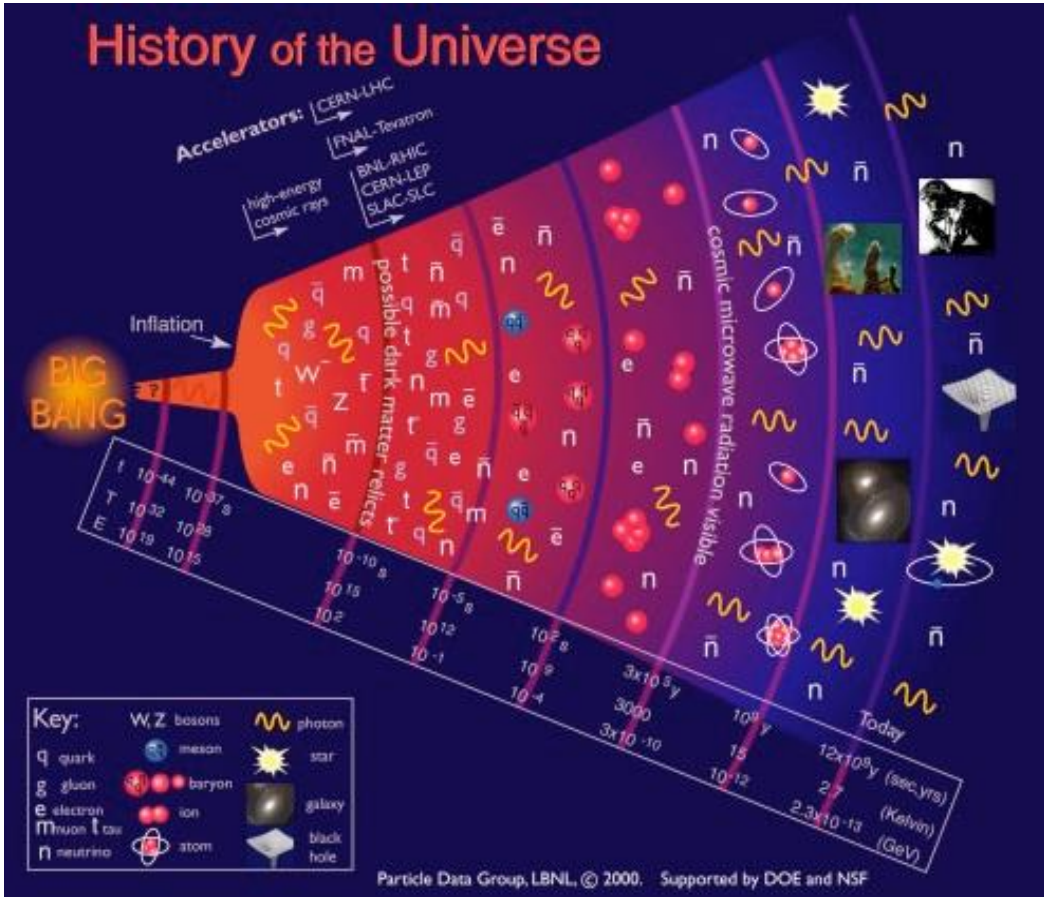


- Our model for the creation of the Universe

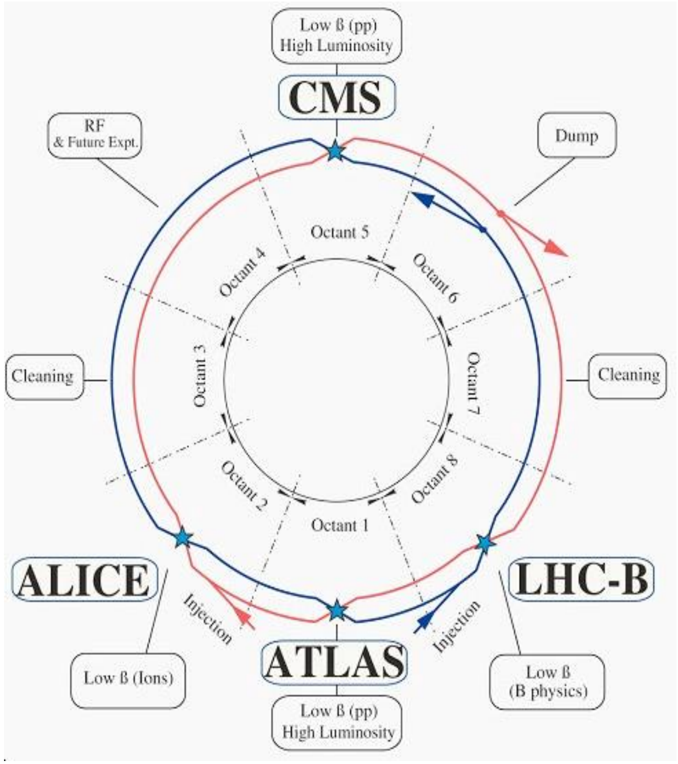
Big-bang :
Initial Energy is converted to mass

$E \Rightarrow Mass$



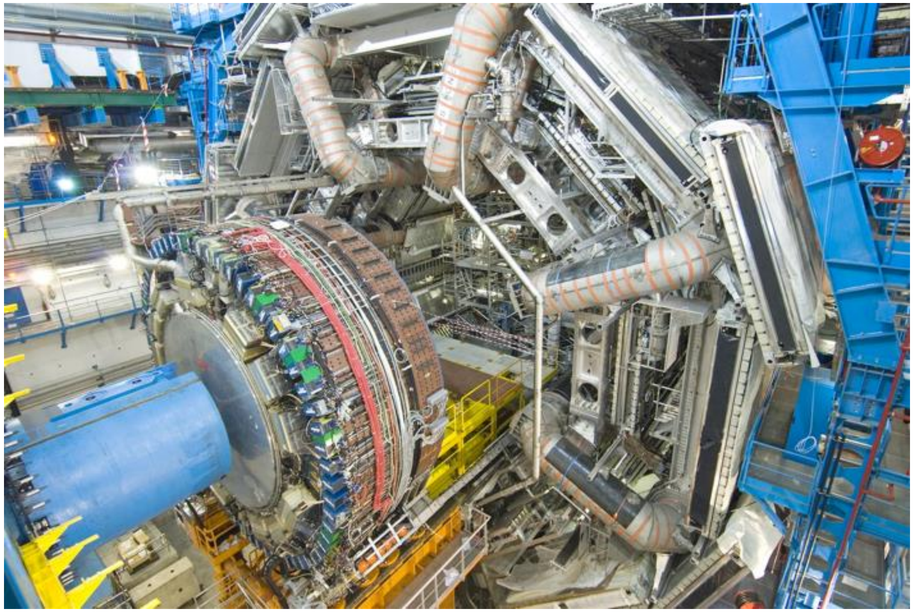
# HEP - Basics

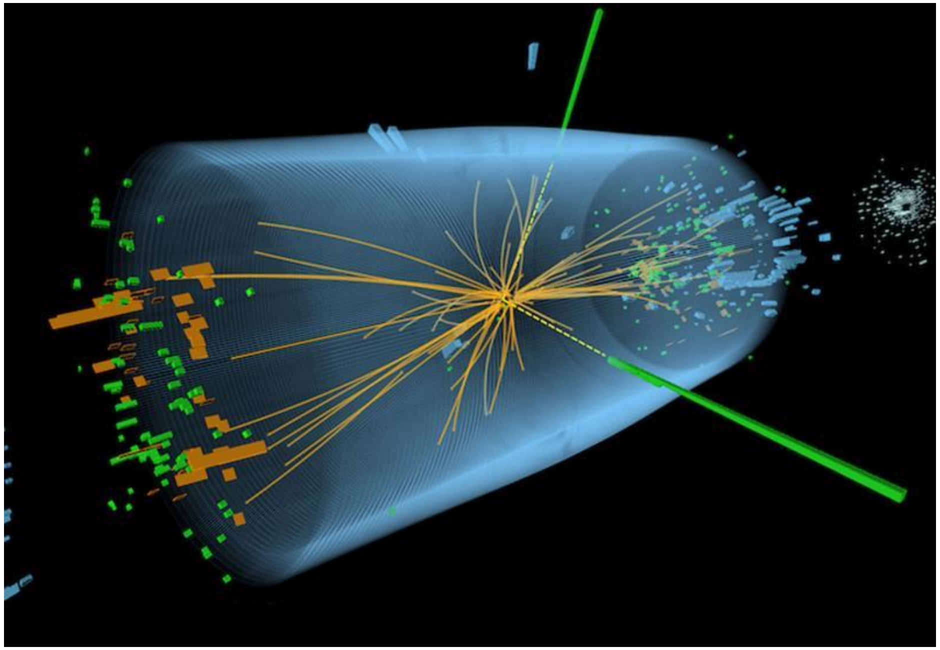
- The role of accelerators
  - Step I : start from known (massive) particles (M) – protons, electrons
  - Step II : accelerate them, give to each particle lot of energy, i.e. lot of energy in a small volume (proton size ~$10^{-15}$ m)
  - Step III : collide them, i.e. create instantaneous "pure" energy – (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



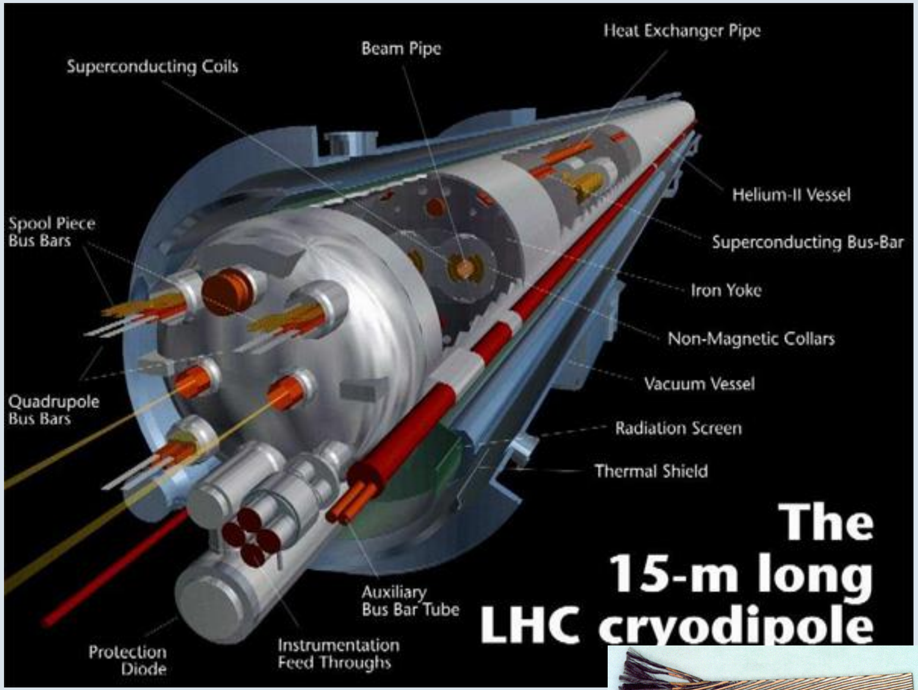


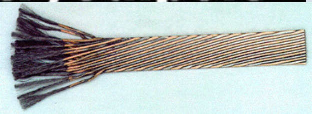
# The CERN Accelerators

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

- equipment of leading-edge technology and engineering

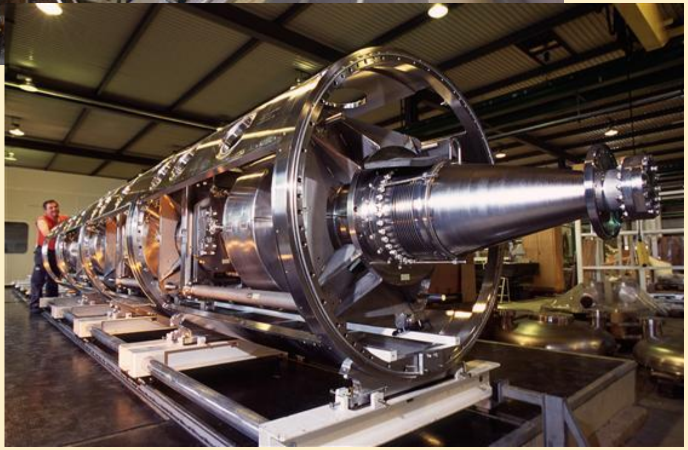
**LHC Superconducting dipoles**



- 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

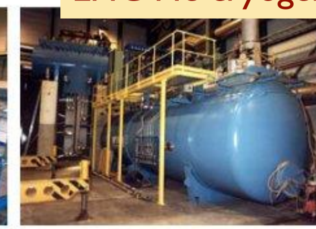
**LHC Superconducting RF – 400 MHz**



# The CERN Accelerators

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

LHC He cryogenics



...or station and liquid ...gen pre-cooler

Ex-LEP 4.5 K cold boxes

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

...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

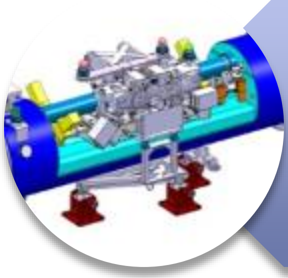
### Engineering Department

- 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**

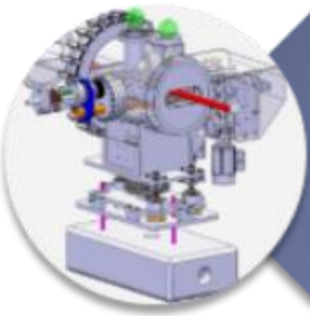
Industrialization process
Workshops at CERN, or outside, final assembly
Procurement of raw material or components
Technical Subcontracting for component production or full assemblies

**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

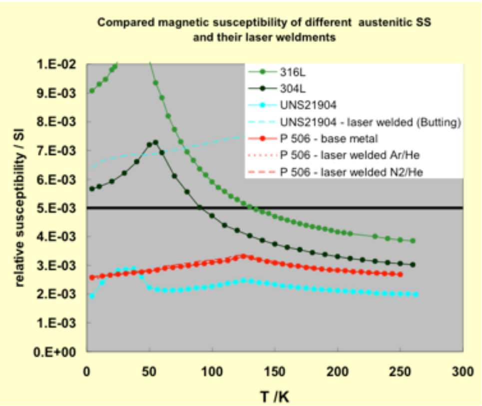
## Materials & Metrology

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

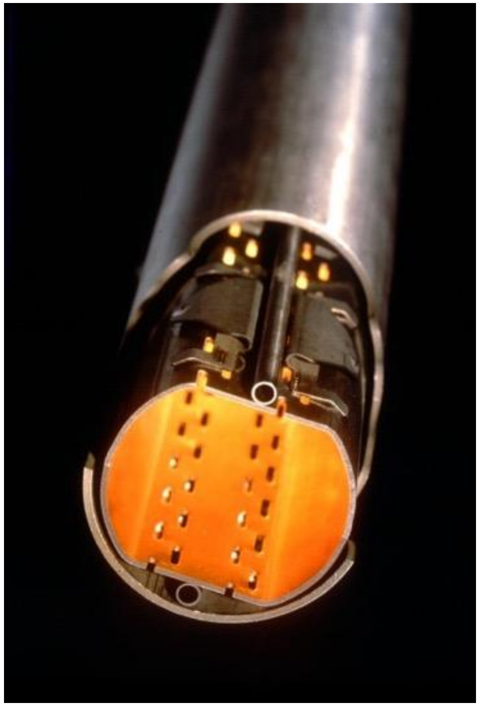
Courtesy Alessandro Dallocio

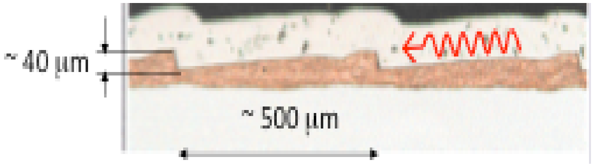
## **LHC Beam Screen and Cooling Capillaries** - *A concentrate of Technology*

# Mechanical & Materials Engineering









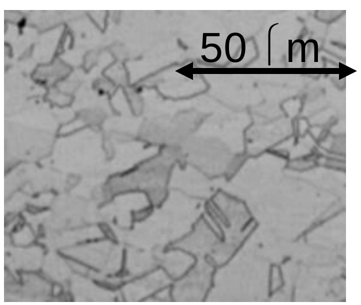

- **Development of Materials and Manufacturing Solutions**
  - Development of a new non-magnetic stainless steel with magnetic susceptibility £ $5\times10^{-3}$ in weld and parent material at operating T (5 K to 20 K), readily weldable, not sensitive to hot cracking
  - Co-lamination of stainless steel 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

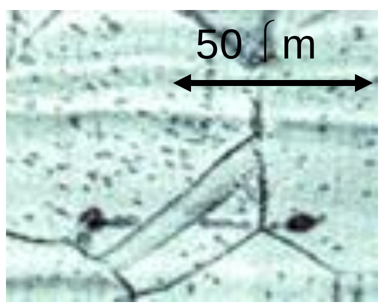
## An innovative near net shaping technique for the end covers of the LHC dipole magnets



2500 stainless steel (316LN) covers




Powder Metallurgy



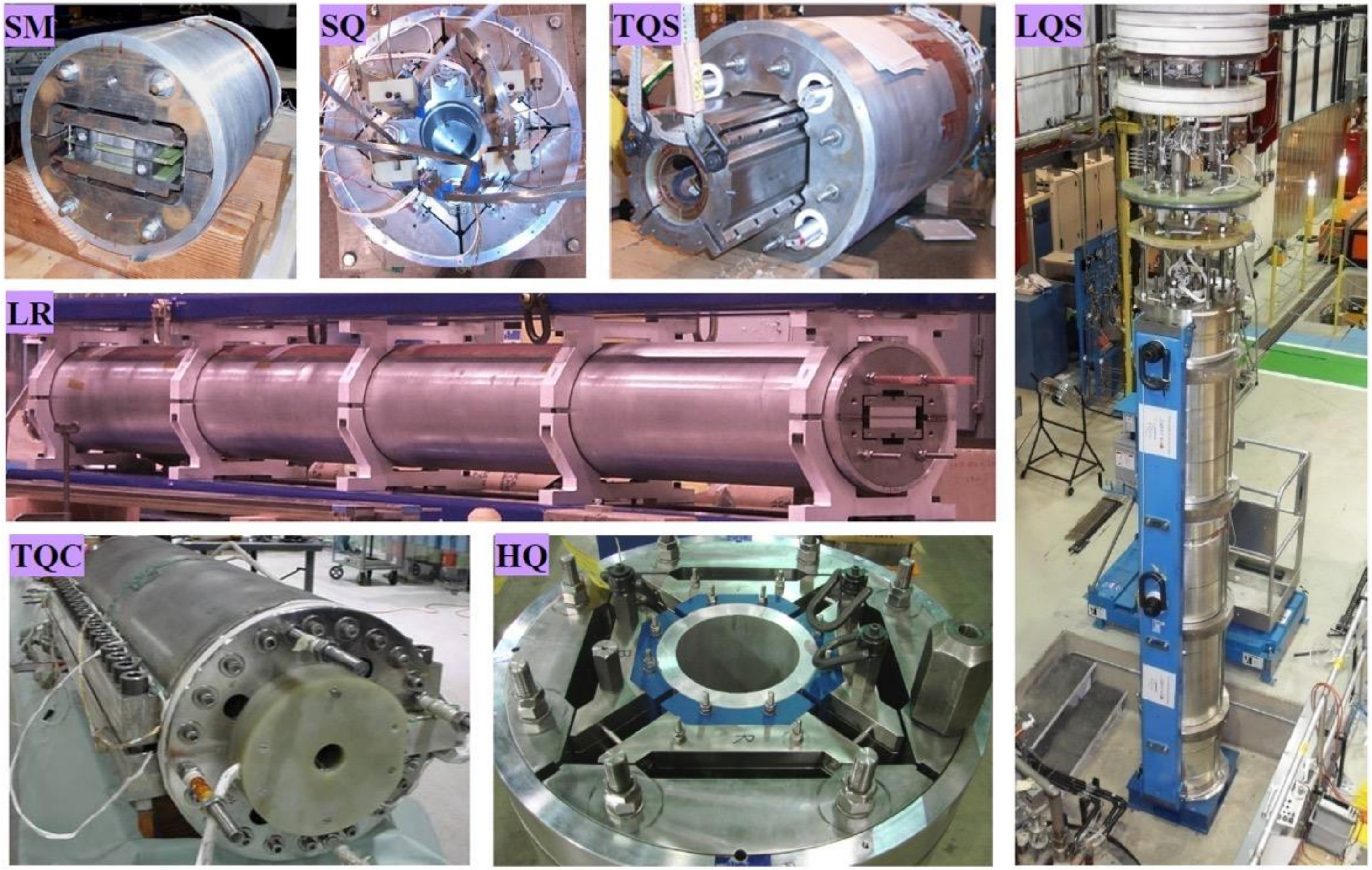

Forged

- **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

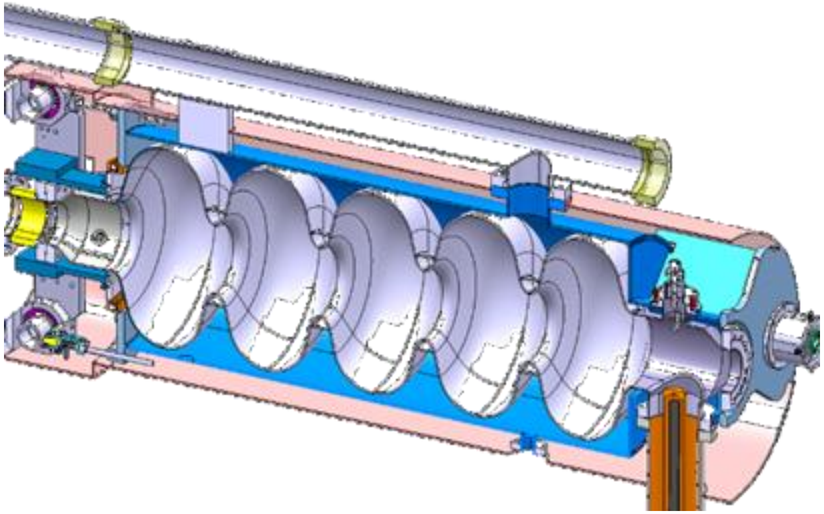
- Superconducting Magnets




Courtesy Alessandro Dallocio

# Mechanical & Materials Engineering

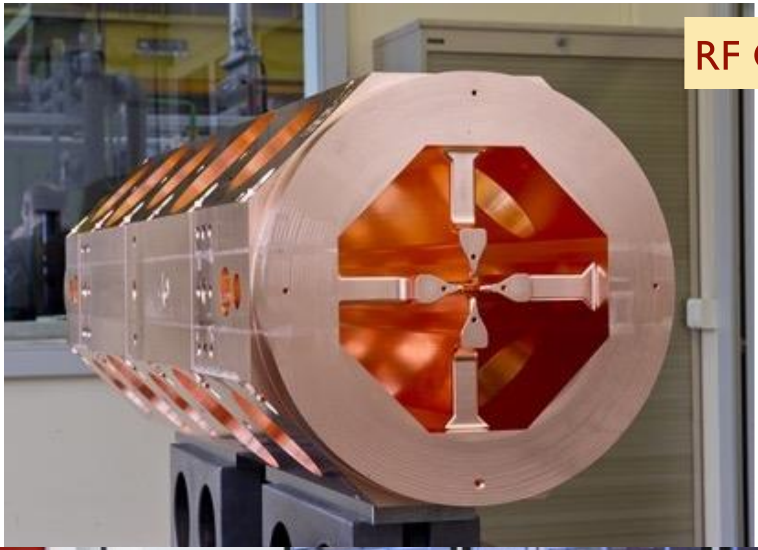
- Superconducting RF cavities



Courtesy Alessandro Dallocio

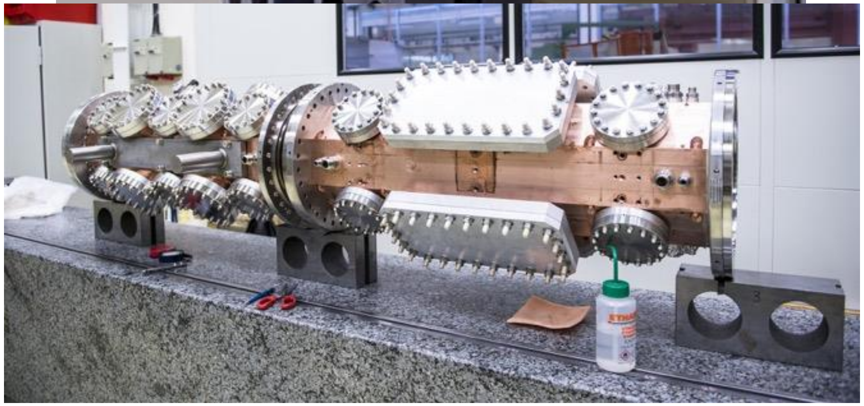
# Mechanical & Materials Engineering

- Beam line equipment



RF Quadrupole – LINAC4

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



Drift Tube Linac (DTL) – LINAC4

- 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<br><br>Welding of stainless steel (316, 316L/LN, 304)<br>Welding of aluminium<br>Welding of Cu/Brass and Cu Allloys<br>Welding of Titanium |
| Laser welding |
| Electron beam welding |
| Explosion bonding |
| Soldering |
| Vacuum brazing |

- 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) |

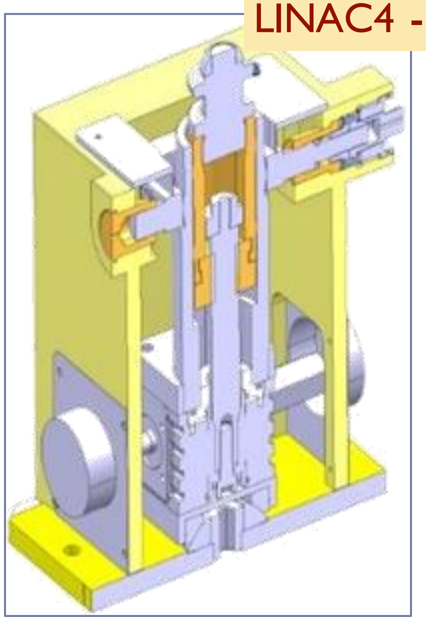
| Metal Forming |
|---|
| Forging: particularly customized forged pieces (Stainless steel 316LN, Cu alloys, Al alloys…) |
| Extrusion |
| Casting (Iron and Aluminum) |
| Spin forming (Al, Cu, SS, Nb) |
| Punching, Fine Blanking, Deep Drawing |
| Forging: particularly customized forged pieces (Stainless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

Courtesy Alessandro Dallocio

# Mechanical & Materials Engineering

- Subcontracting Service
  - recent activities

LINAC4 - jacks



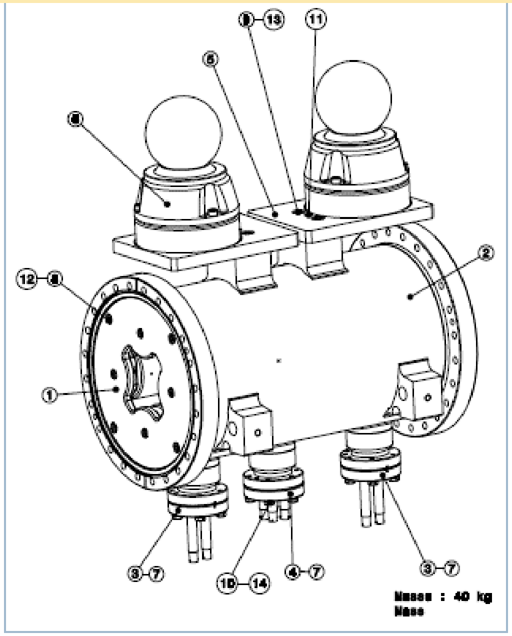
DTL girder

Courtesy Alessandro Dallocio

# Mechanical & Materials Engineering

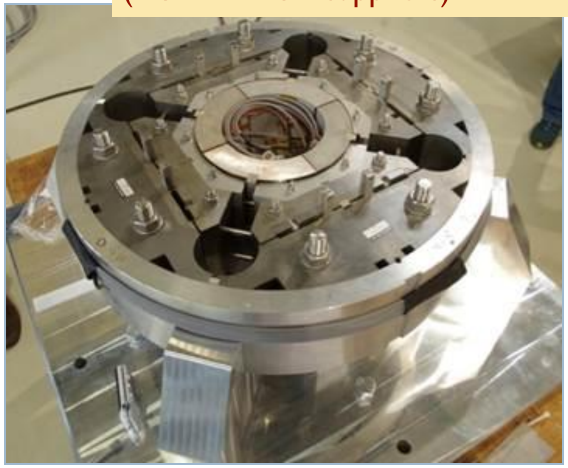
- Subcontracting Service
  - recent activities

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



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

HL-LHC : new SQXF large aperture 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)*


APPROVED

Engineering Department

BRAZING PROCEDURE QUALIFICATION RECORD

BPQR (QMOB)

N° B-2014-01

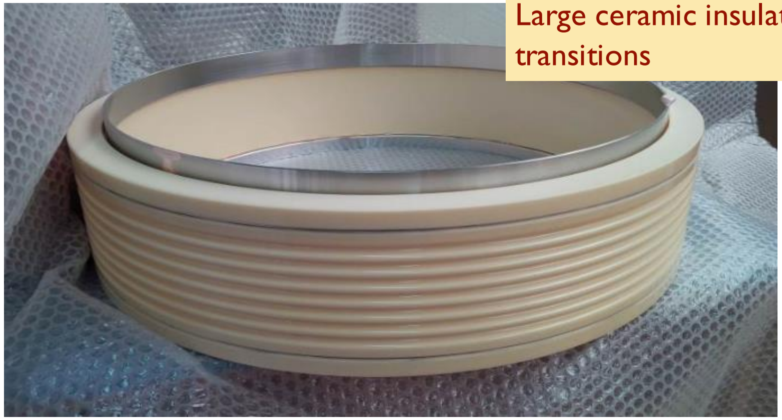
FRESCA : magnet impregnation tool
*(BEsuppliers)*

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

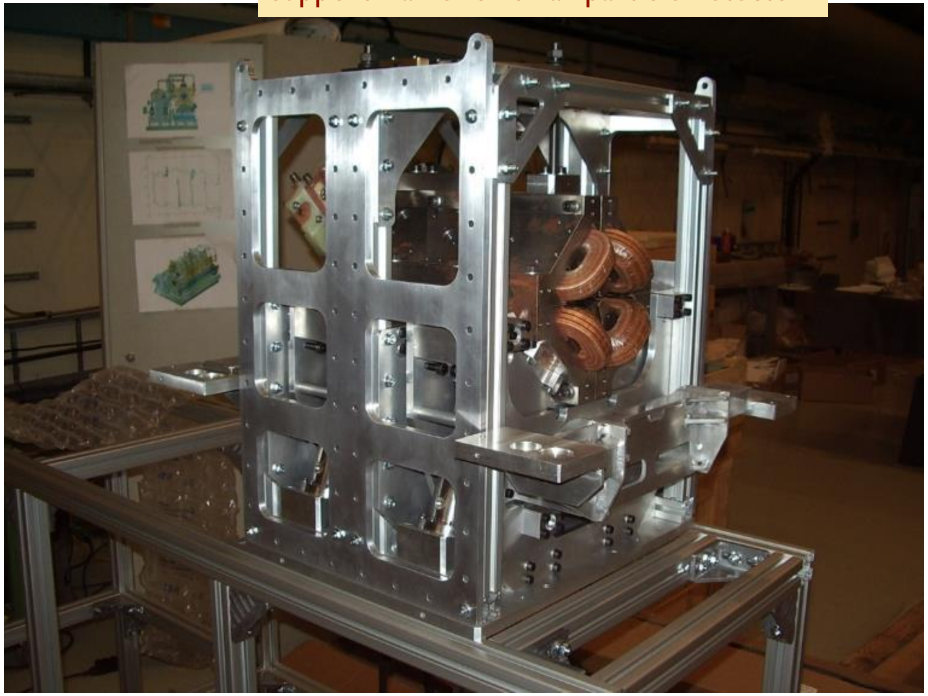
Courtesy Alessandro Dallocio

# Mechanical & Materials Engineering

- Subcontracting service
  - Recent activities

Lifting tool for magnets

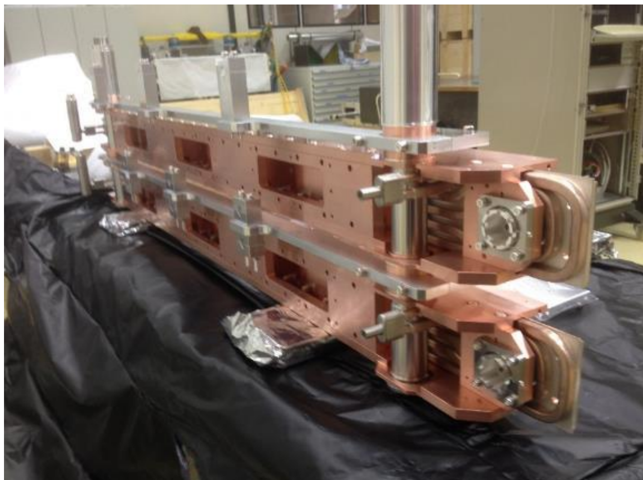
Support frame for small particle detector



Courtesy Alessandro Dallocio

# Mechanical & Materials Engineering

- Subcontracting service
  - Recent activities



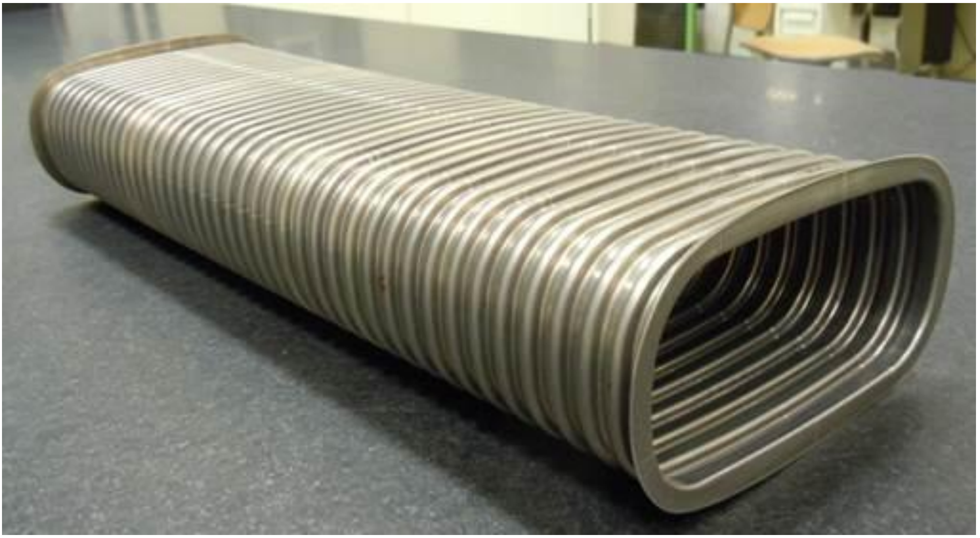
Component production for new HiRadMat Experiment on material R&D for LHC collimators

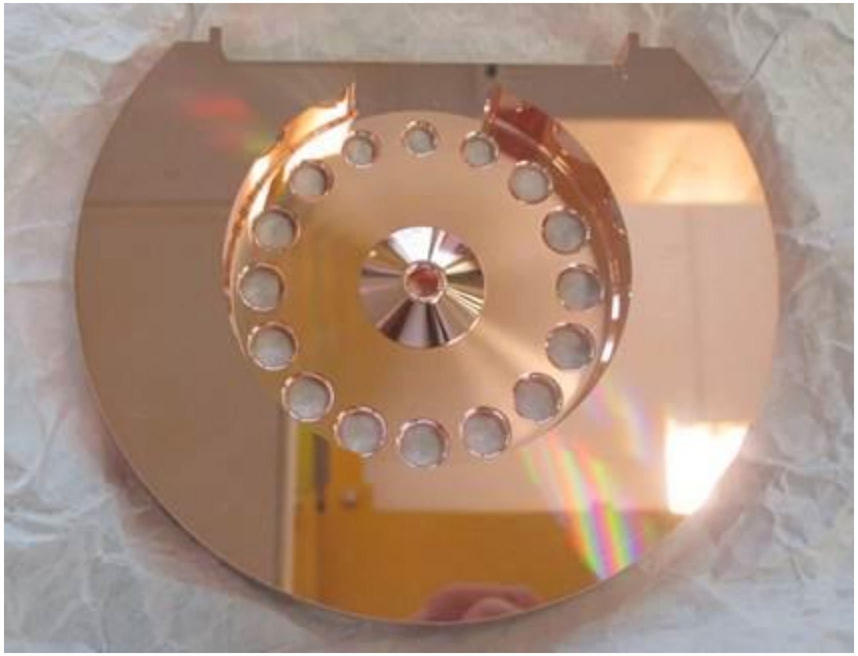
Courtesy Alessandro Dallocio

# 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

# 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*

# EN - CV Group

## Ventilation

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

| | |
|---|---|
| ***Heating, ventilation and air conditioning*** | ***1'500 units***<br>***from 2'000 to 120'000 $m^3/h$ each*** |
| Compressed air | ***14 stations***<br>***200 km network*** |

| | **km** | **$m^3/h$** |
|---|---|---|
| *Eurotunnel* | 50 | *540'000* |
| ***LHC*** | ***27*** | ***290'000*** |



Roberto Saban

Turkish ILO Visit - August 4th 2015

# EN - CV Group

## Cooling & Ventilation

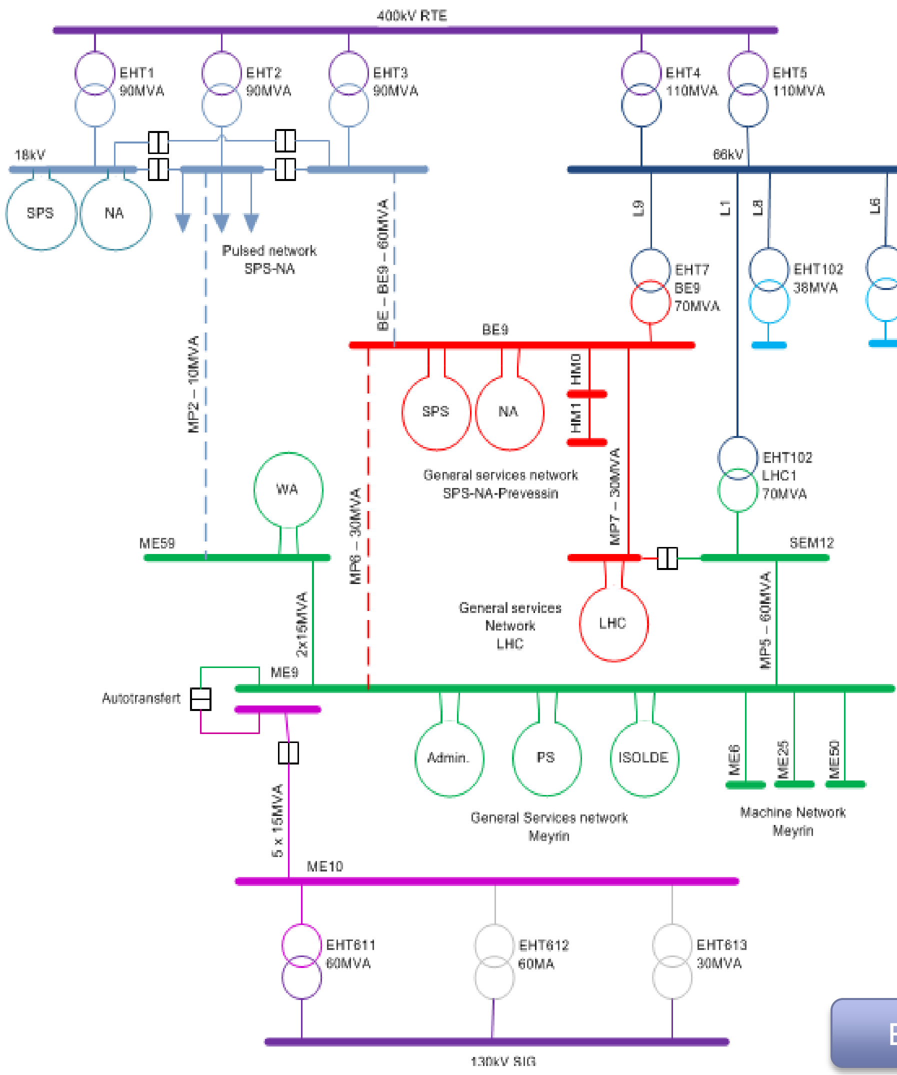

# EN - EL Group

## Electrical Engineering

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

# Electricity Distribution

Normal source EDF > 300 MW



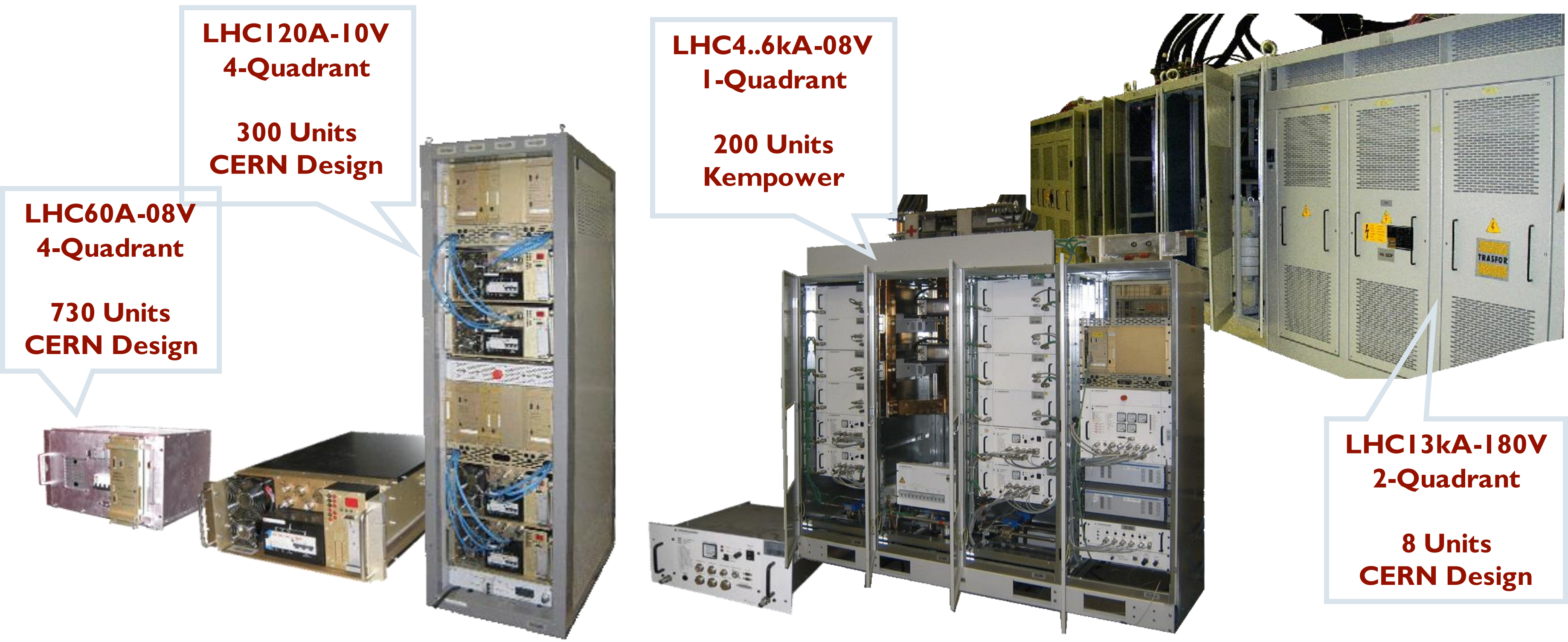

Annual Consumption 1.26 TWh
⅙ of Geneva

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



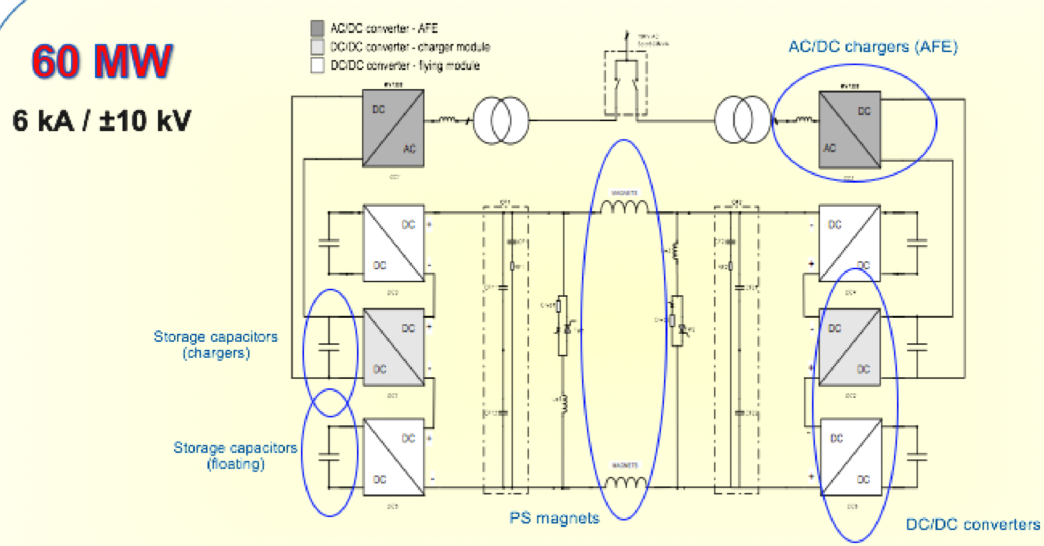

Courtesy Jean-Paul Burnet

# TE - EPC Group

# Pulsed Power Converters

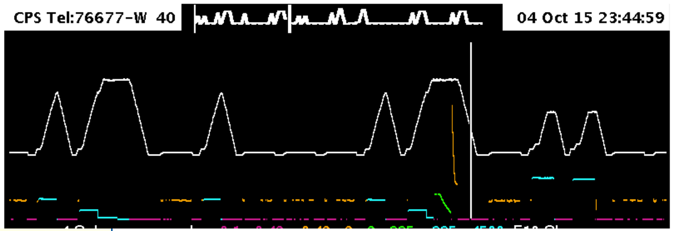
**Power converter with integrated energy storage**

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)



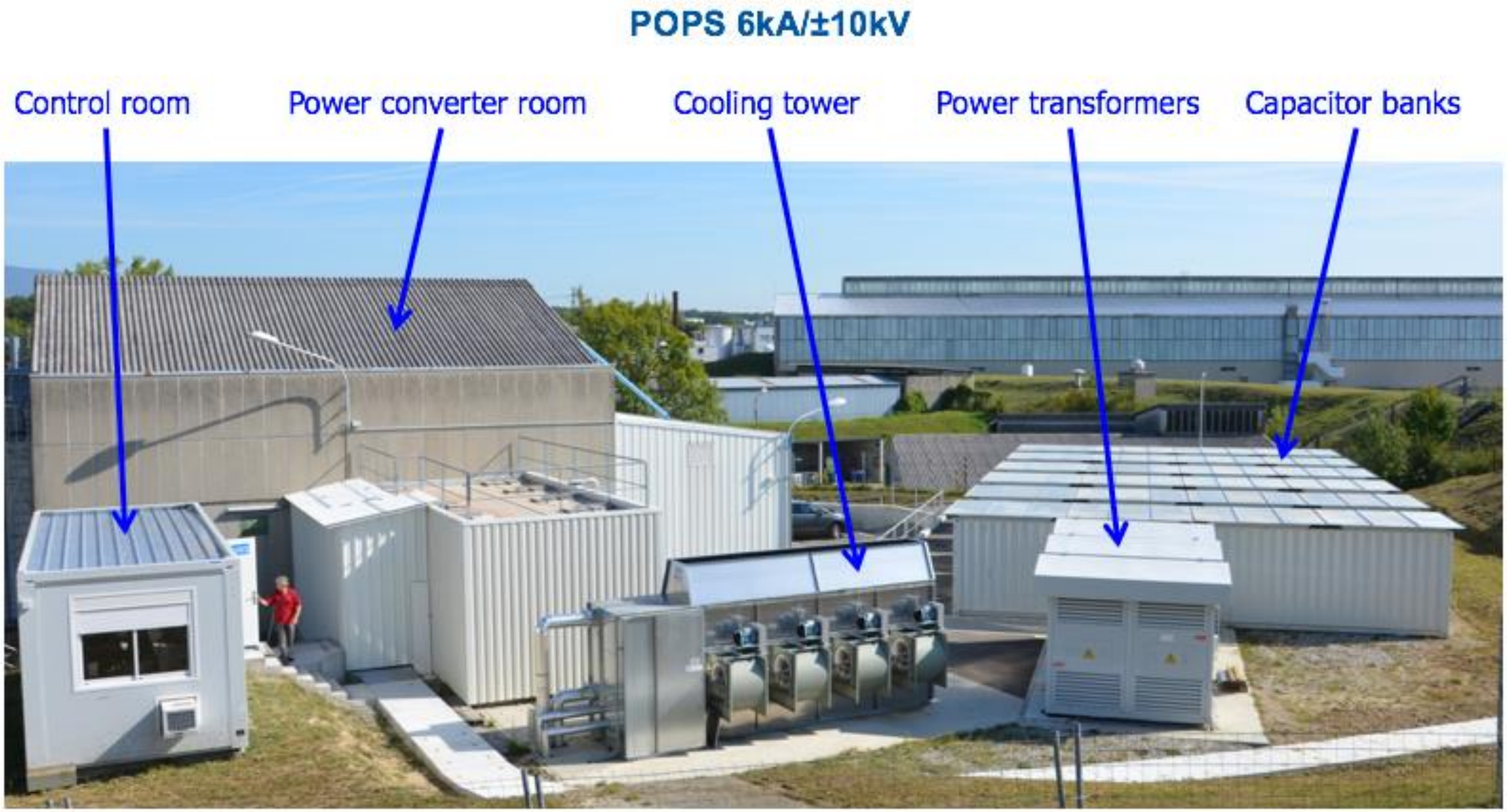

PC machine pulsing scheme – basic scycle 1.2 s

Courtesy Jean-Paul Burnet

# TE - EPC Group

# Pulsed Power Converters

- The PS pulsed power supply




Courtesy Jean-Paul Burnet

# EN - MEF Group

## 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

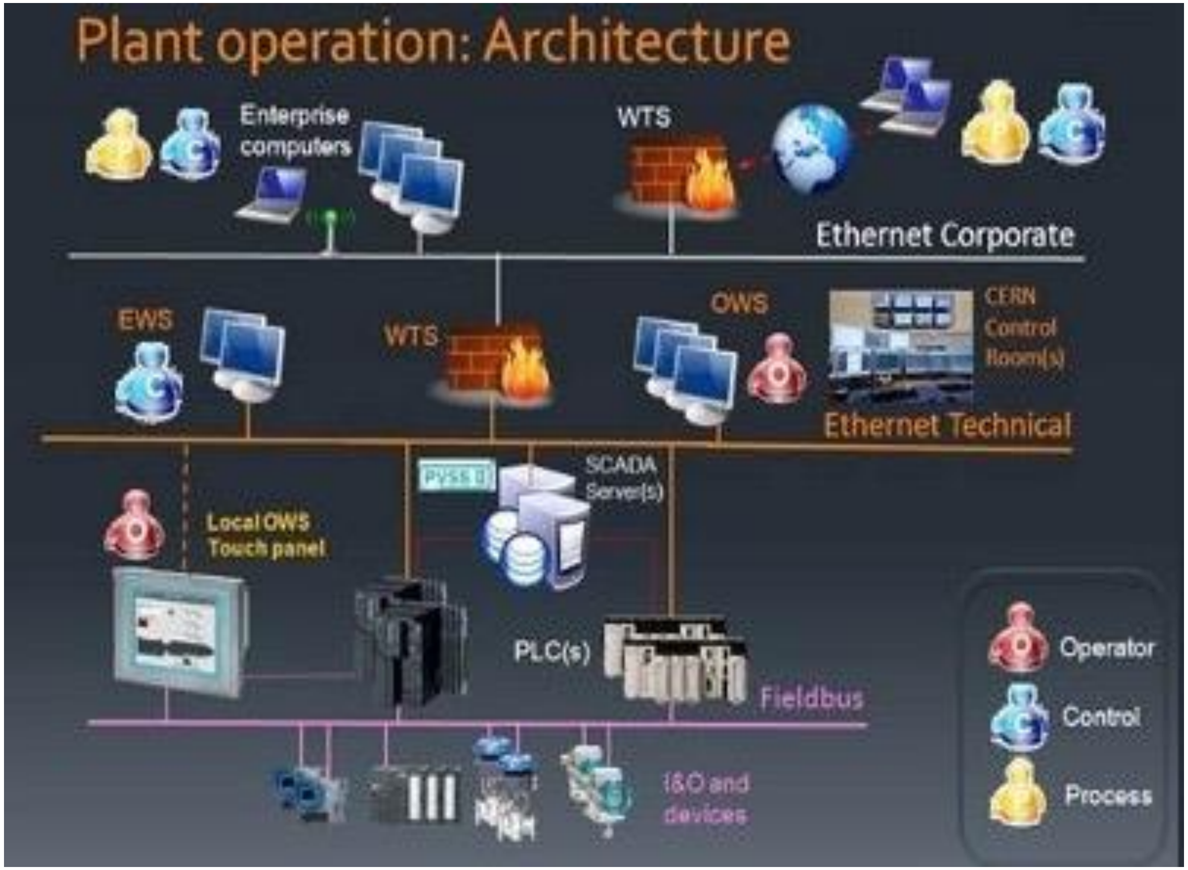
TOTAL : 1500 machines (Value 25 M€)


Courtesy Ingo Ruhel

# EN – ICE Group

## Industrial Controls

- Large and medium scale industrial control systems deployed throughout CERN




Courtesy Philippe Gayet

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

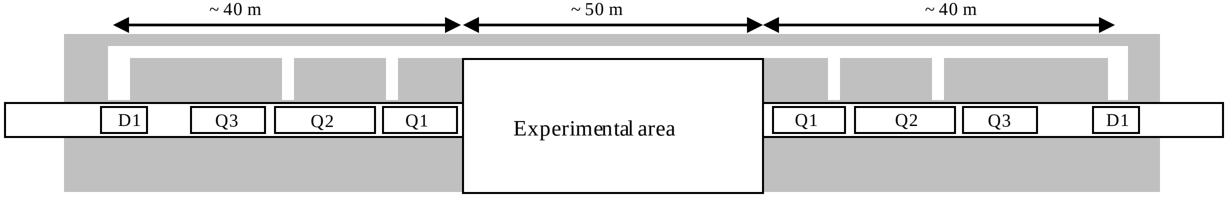

Roberto Saban
Turkish IEO Visit - August 4th 2015

# 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

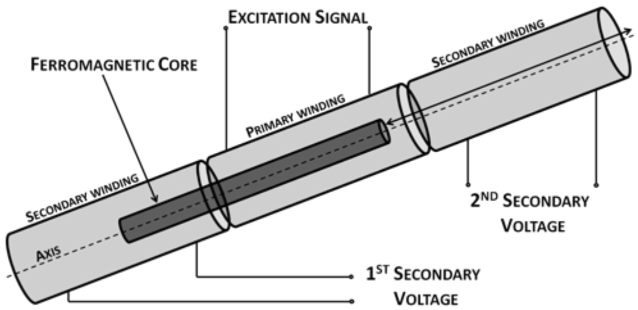
- Inner triplets - LHC
  - 0.1 mm in all directions
  - Permanent monitoring through water level and wires
  - Survey galleries in the high luminosity IPs
  - Motorized jacks



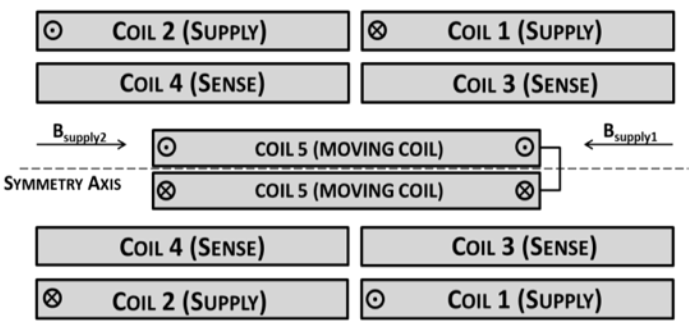

Courtesy Dominique Missiaen

## Special Instrumentation

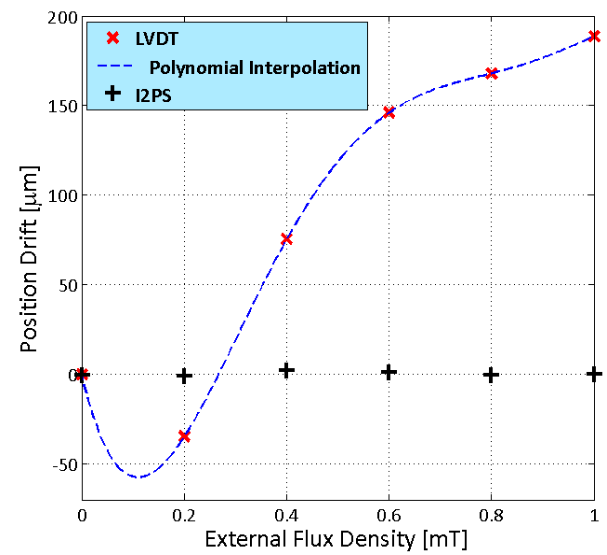
- # Rad-hard Magnetic Field immune positioning sensors




Linear Variable Differential Transformer




Ironless Inductive Position Sensor

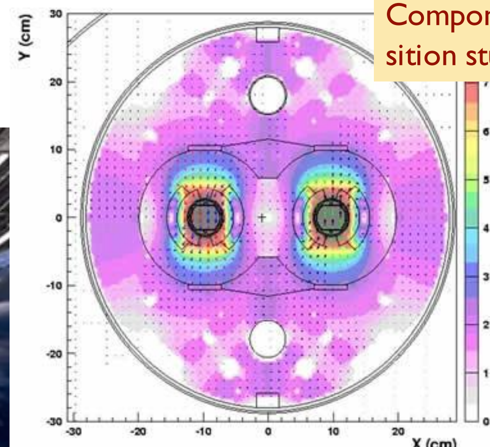




Courtesy Roberto Losito

# EN – STI Group

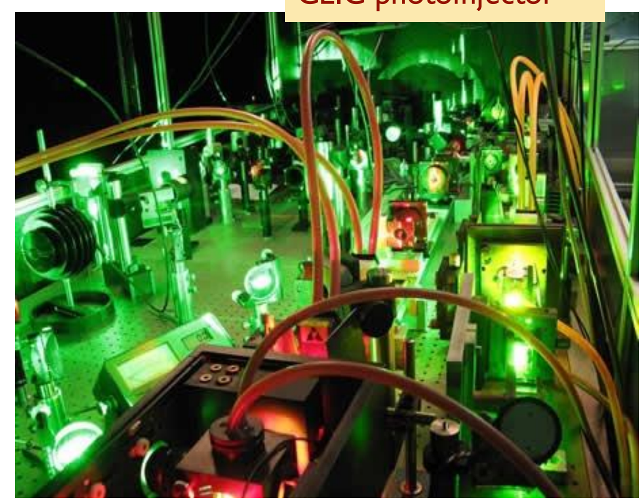
## Beam Interactions with Matter

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




Component Energy Deposition studies

Tooling for remote installation of LHC collimators



CLIC photoinjector

# HiRadMat

## Accelerator R&D Facilities

- **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

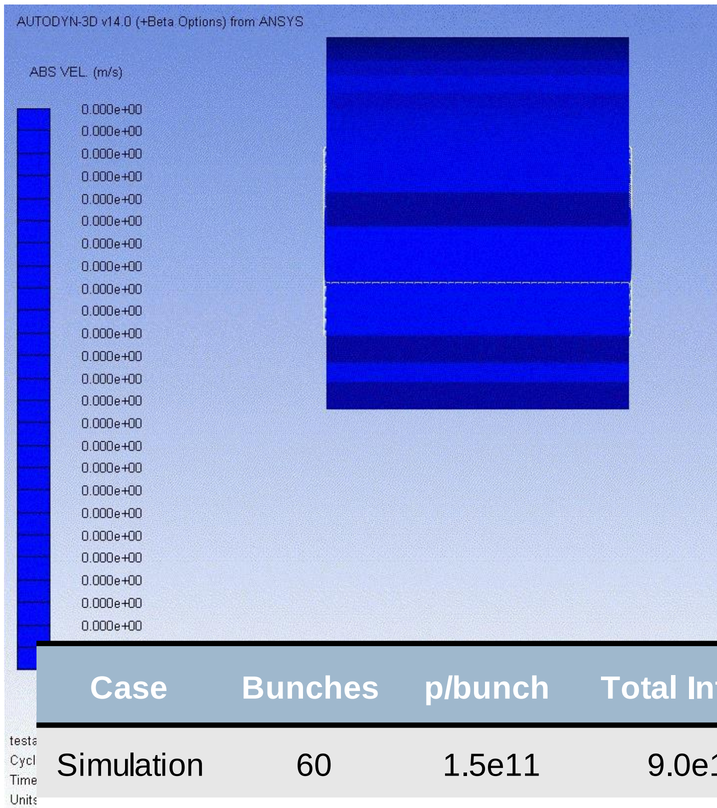
TPSG4 collimator and mask t est setup – robustness test

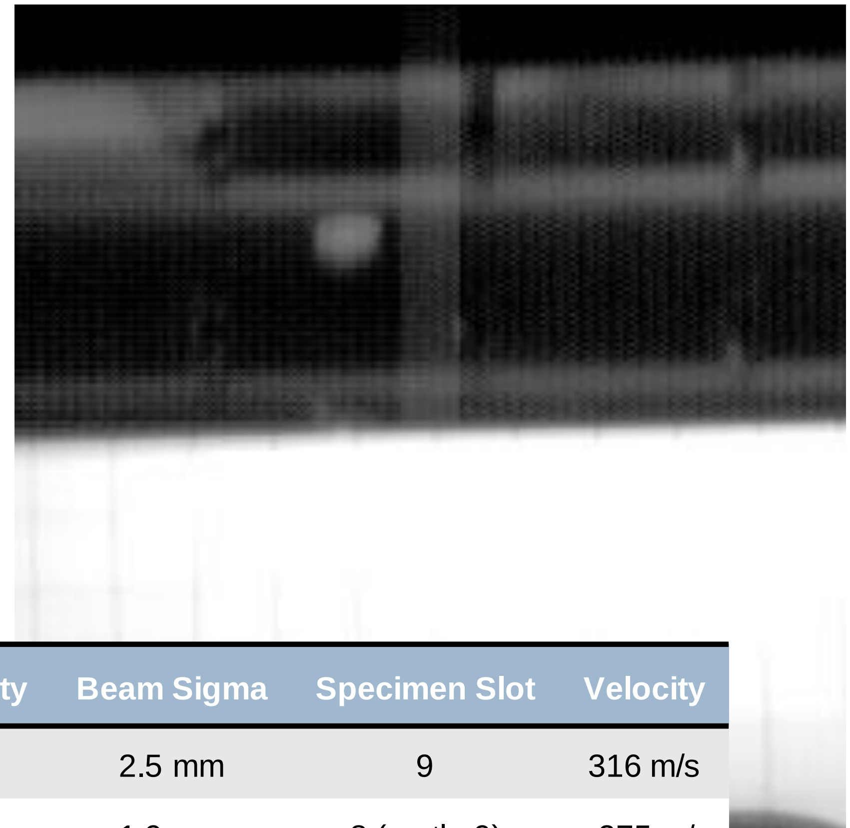
Sample holder for testing different material and configurations – LHC collimator R&D

- # R&D on Novel composite Materials

**Inermet : comparison between simulation and experiment**

Beam →



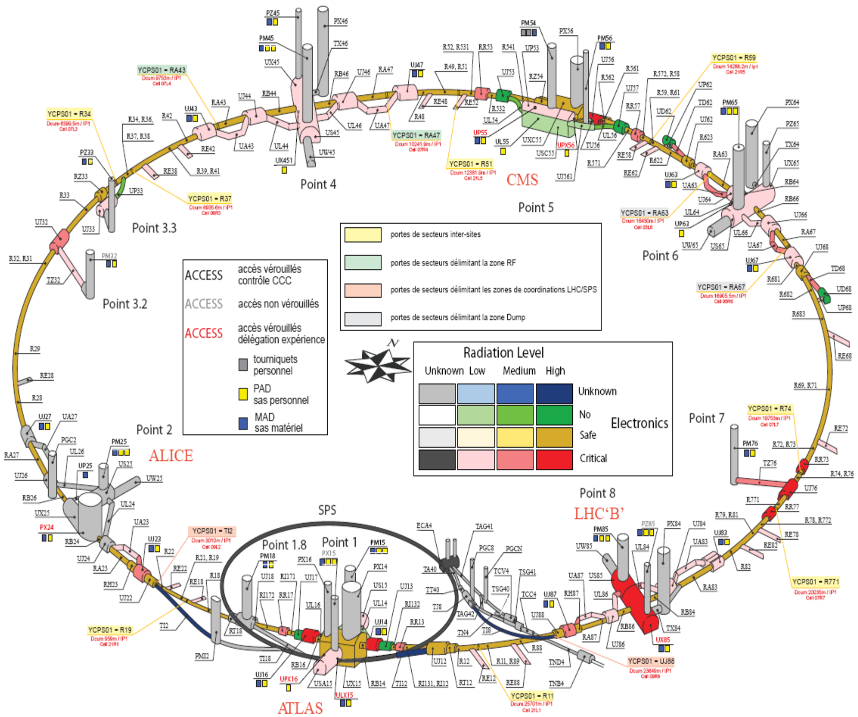
| Case | Bunches | p/bunch | Total Intensity | Beam Sigma | Specimen Slot | Velocity |
|---|---|---|---|---|---|---|
| Simulation | 60 | 1.5e11 | 9.0e12 p | 2.5 mm | 9 | 316 m/s |
| Experiment | 72 | 1.26e11 | 9.05e12 p | 1.9 mm | 8 (partly 9) | ~275 m/s |

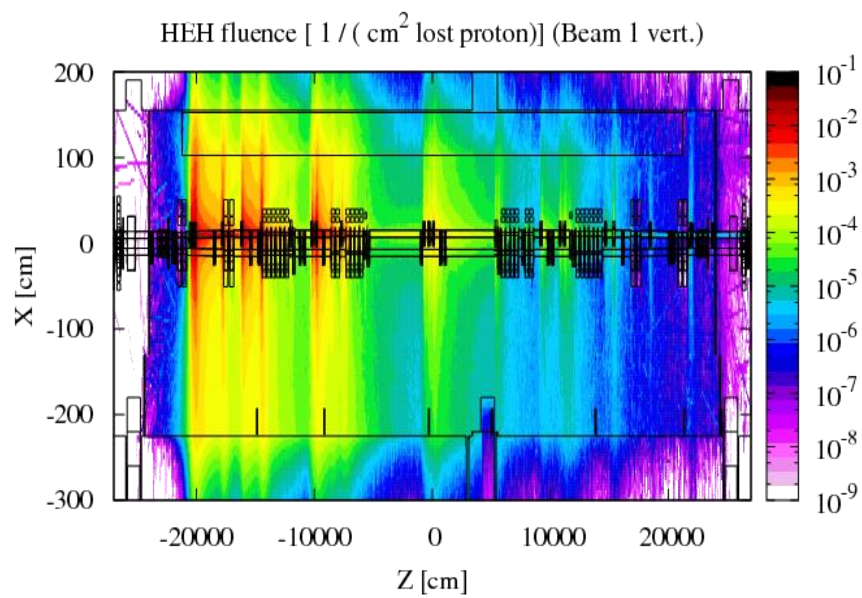
Courtesy Francesco Bertinelli

# EN – STI Group

## 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)



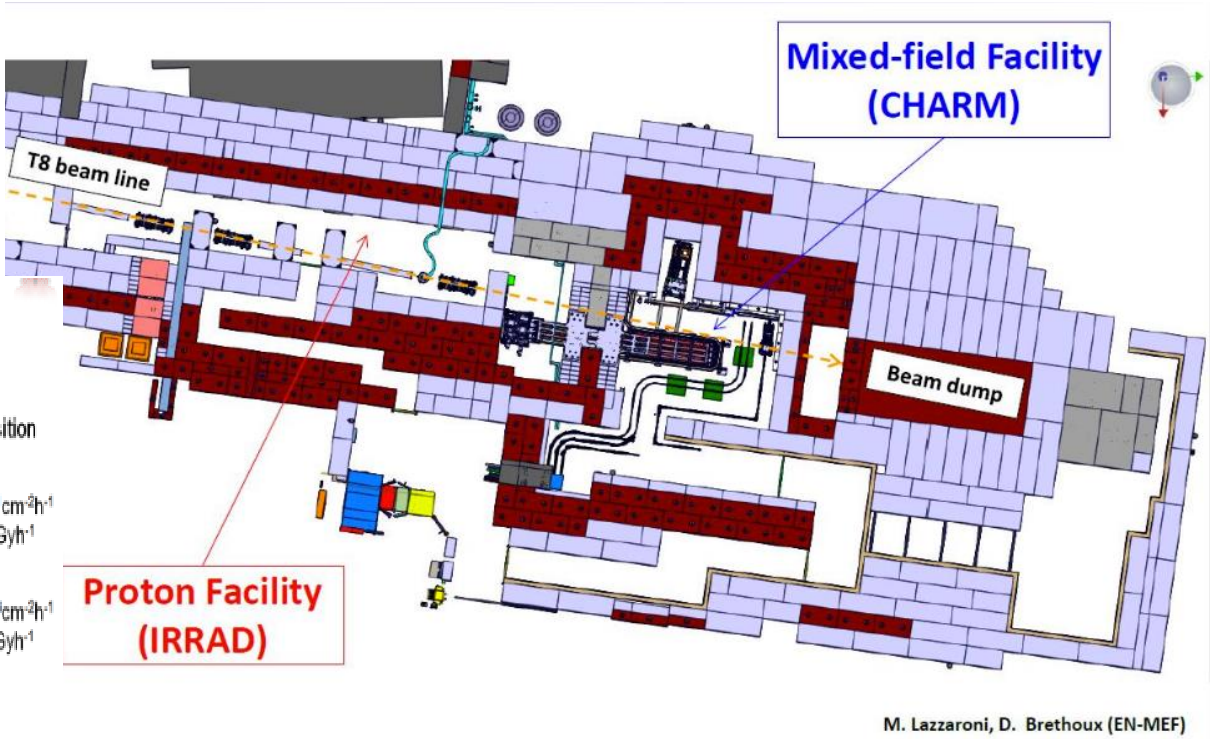

Particle fluence map from simulation (FLUKA) – good agreement with measurements within 20%

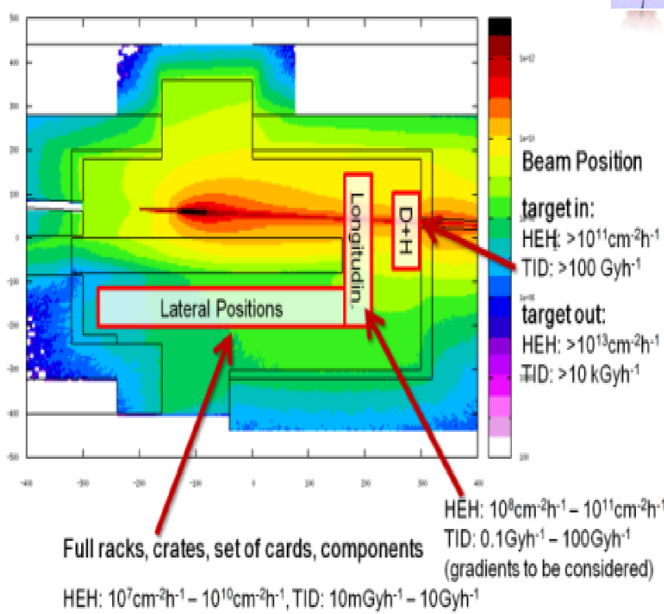
Courtesy Markus Brugger

# EN – STI/MEF Group

# Accelerator R&D Facilities

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



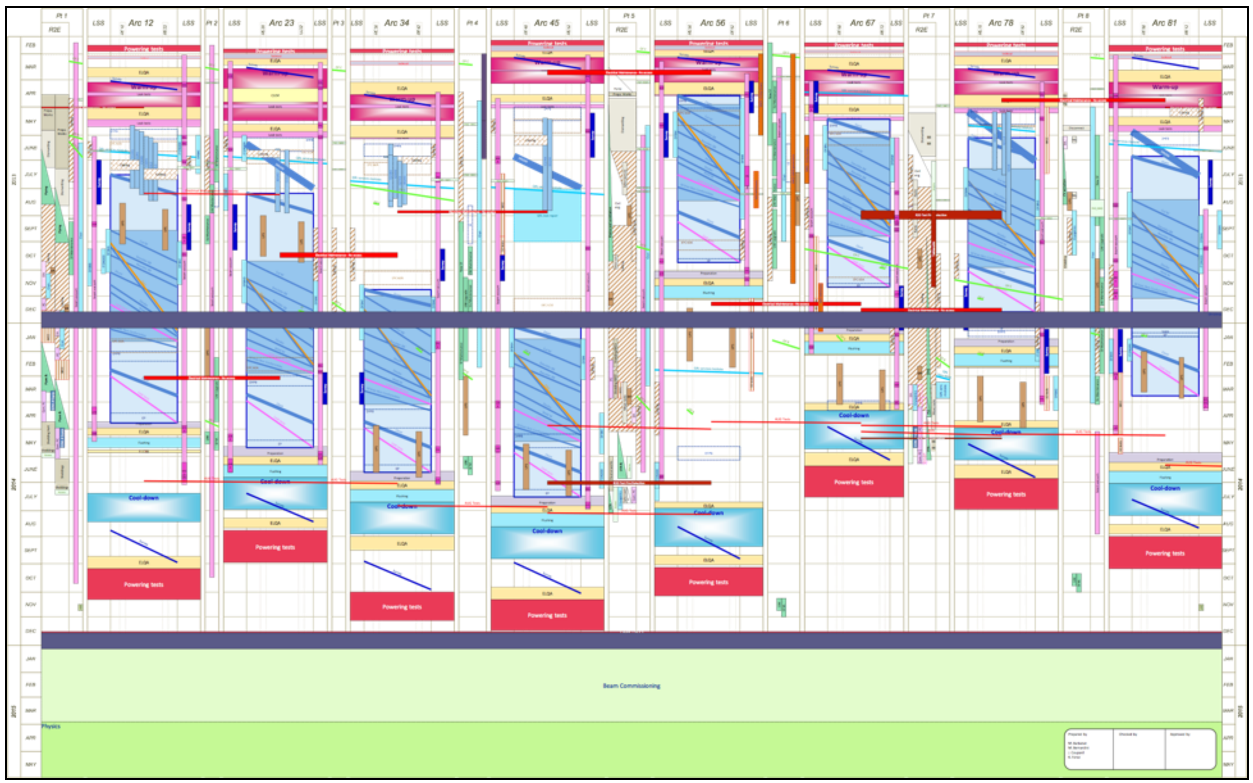

Optimized design
- Variable particle fluence with movable shielding-
- Tools for remote installation/removal of the samples

Courtesy Markus Brugger

# EN – MEF Group

## 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

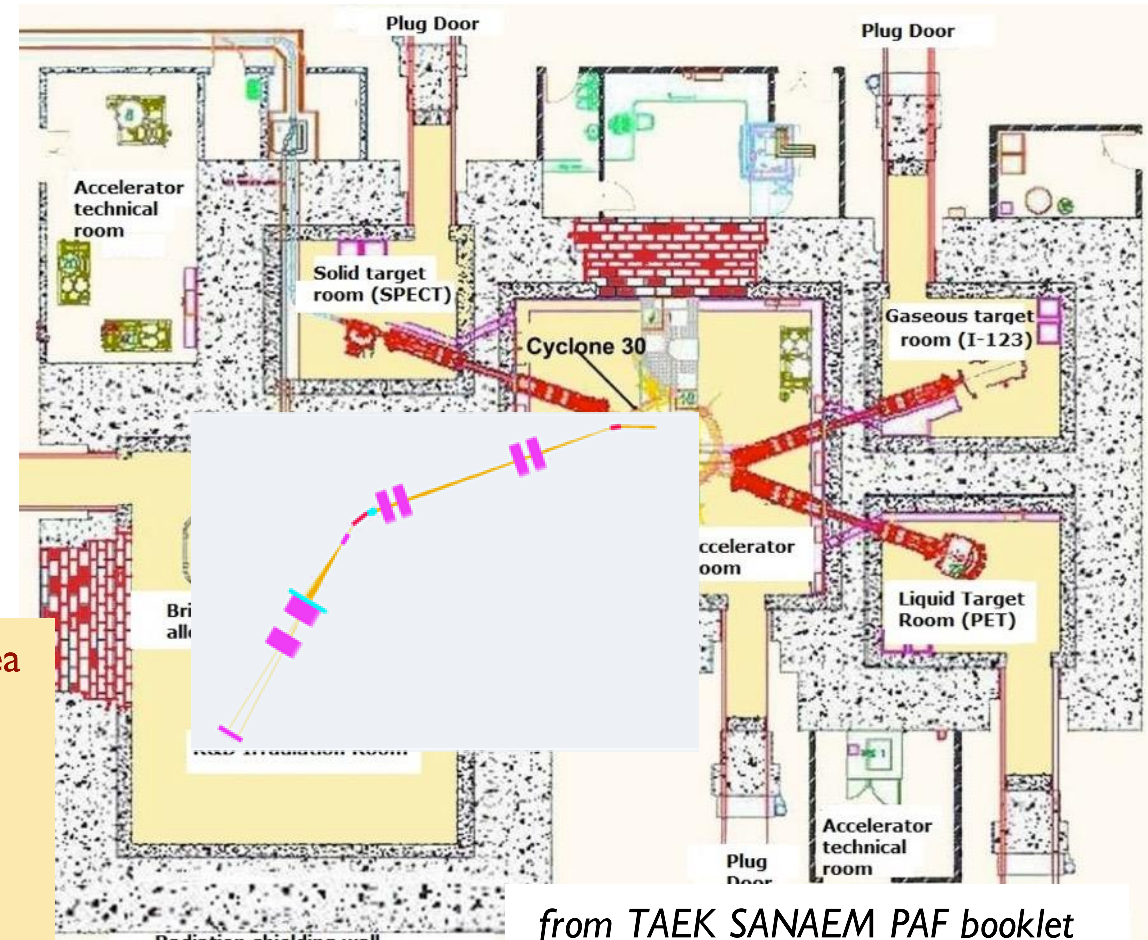
TEAK PAF building


Cyclotron

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

CERN – METU Collaboration

- TAEK SANAEM Proton Hızlandırıcı Tesisi




*from TAEK SANAEM PAF booklet*

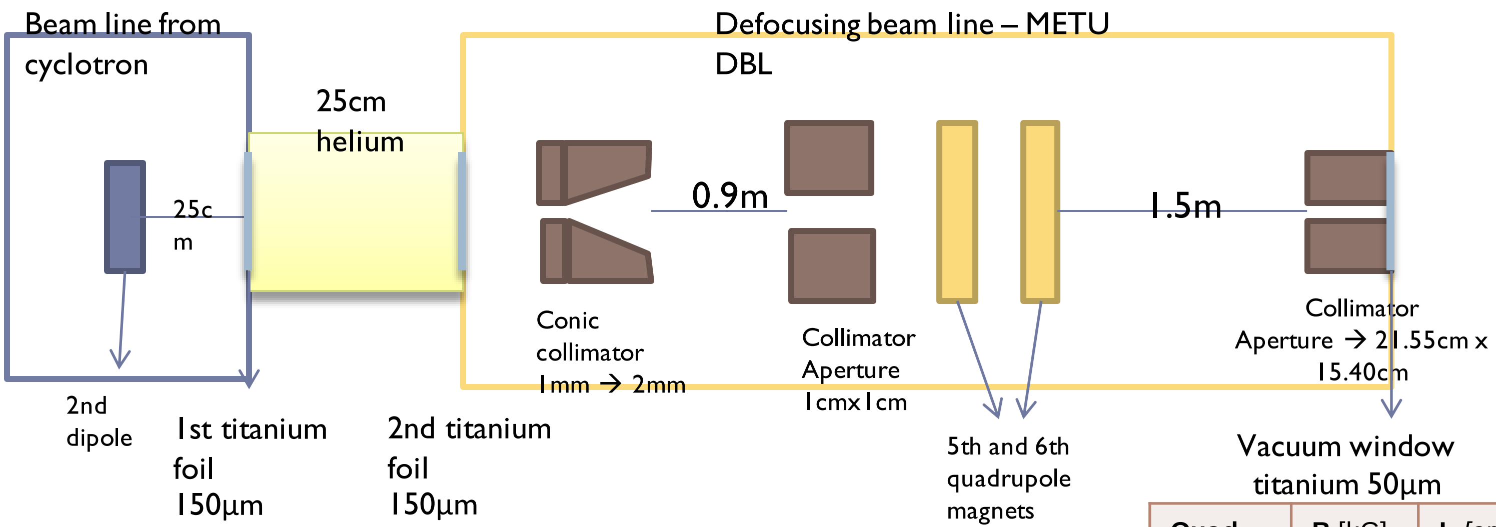
Beam Parameters – @ Irradiation Area – ESA ESCC No.25100

- 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

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!