Status of CIEMAT Activities in the Development of Particle Accelerators

Fernando Toral Fernández

on behalf of

Accelerator Technology Group

Electrical Engineering Division

Department of Technology

CIEMAT

The Electrical Engineering Division at CIEMAT

STRUCTURE

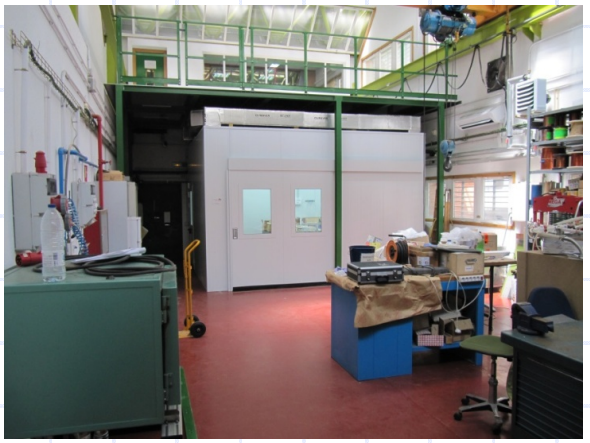
ELECTRIC ENGINEERING DIVISION

- ACCELERATOR TECHNOLOGY UNIT
- ELECTROMECHANICAL TECHNOLOGY UNIT
- POWER SYSTEMS UNIT

FACILITIES

Main Offices (Moncloa)

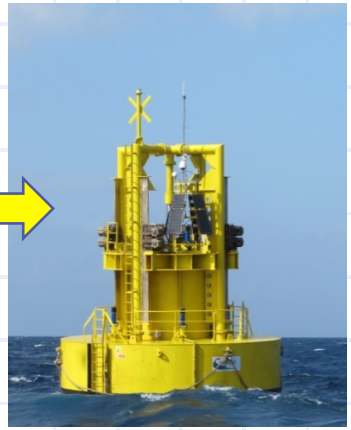
Energy & Superconductivity (J. Camarillo)



Assembly Hall (J. Camarillo)

Ongoing Projects and Collaborations

ACCELERATORS	POWER SYSTEMS
Large Facilities ↓	**Storage ↓**
E-XFEL	SA^{2}VE
FAIR	ACEBO
LHC Hi-Lumi (CERN)	ADIF/CETRAF
CTF3/CLIC (CERN)	TRAIN2CAR
FCC (CERN)	
ILC	
IFMIF	**Generation ↓**
TIARA	SUPERTURBINES
Small Accelerators ↓	UNDIGEN
AMIT CYCLOTRON	SEA-WEDGE
UPC MICROTRON	IISIS

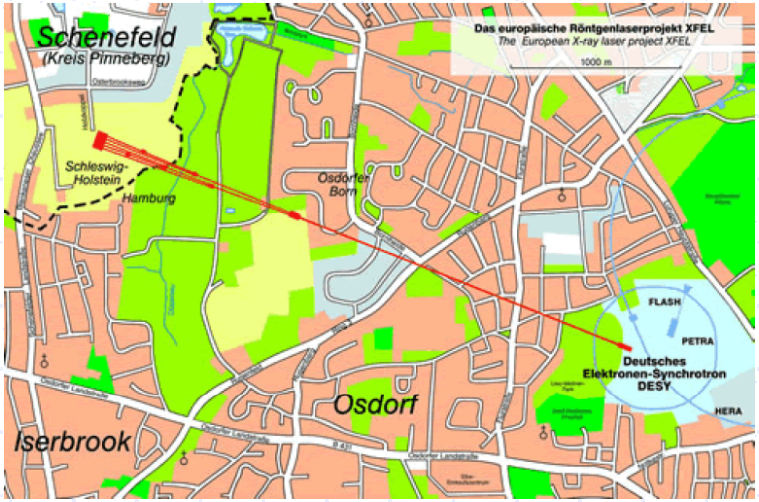


The E-XFEL Contribution

The E-XFEL Facility

XFEL

E-XFEL (European X-Ray Free Electron Laser) is a 100 ns pulse laser source working in the band from 0.085 to 6 nm. It will be located inside DESY facilities in Hamburg.
It consists of a Superconducting LINAC (cavities & magnets) up to 17GeV and an array of undulators based on permanent magnets.

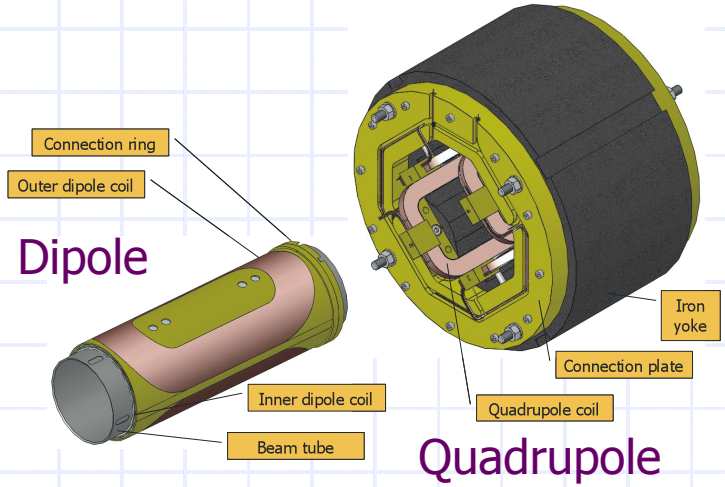


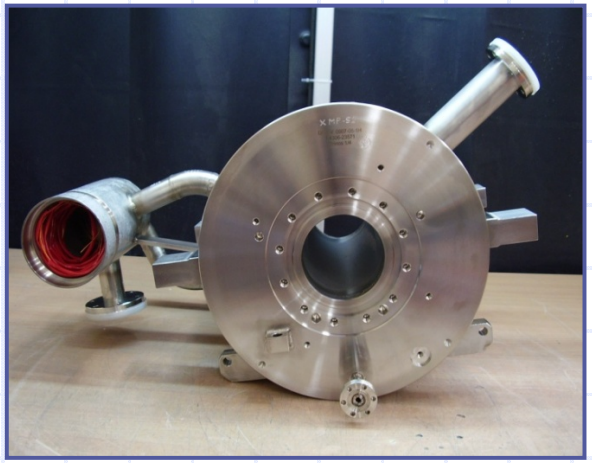
Present CIEMAT contribution to E-XFEL		
COMPONENT	**TYPE**	**QUANTITY**
Superconducting Combined Magnets	SC Magnet	103
Moving Tables (Movers)	Mechanics	101
Electronic Control Racks	Electronics & Instrum.	101
Phase Shifter Magnets	Insertion Magnet	Only prototypes

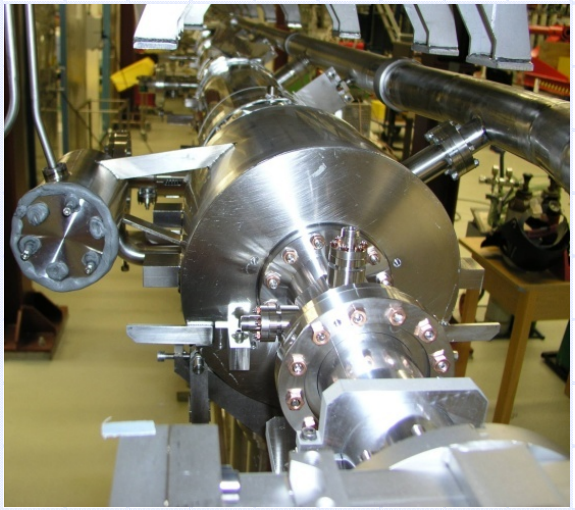
CIEMAT Contribution to E-XFEL

SC MAGNETS

Superconducting Magnet for E-XFEL for the Main LINAC



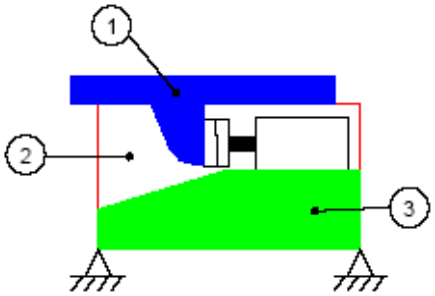


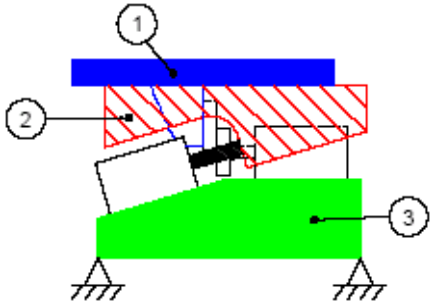


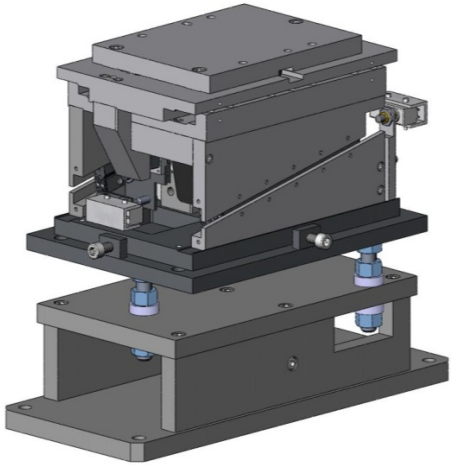
Type: Combined	Quadrupole	Dipole (2)
Integrated Field	5.97 T	0.75E-3 Tm
Inner Diameter	94.4 mm	83.6 mm
Op. Current	50 A	
Technology	NbTi Superferric	
Industrialization	YES: Different prototypes at CIEMAT & Industry Series manufactured at Industry	

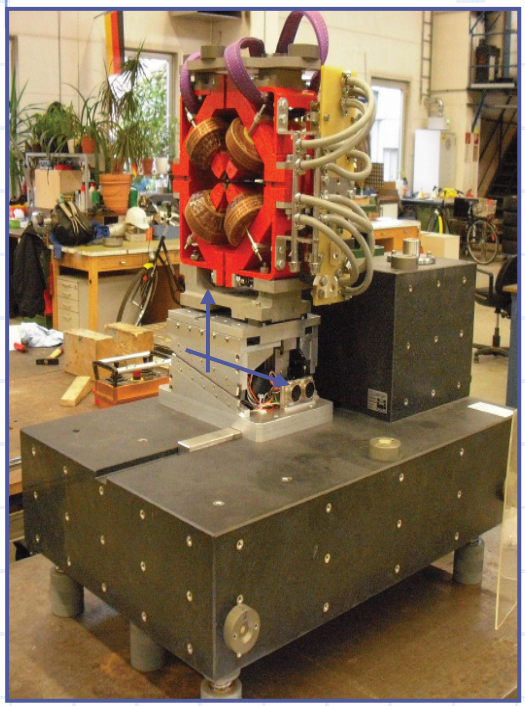
MECHANICS

Moving Tables for E-XFEL









Type	2-axes Quadrupole Positioning Table
Range	±1.5mm
Repetitivity	≤1 μ m
Max Load to move	70 kg
Technology	St.Steel & Aluminium. Closed Loop
Industrialization	YES: Different prototypes at CIEMAT & Industry Series manufactured at Industry in two batches.

ELECTRONICS & INSTRUMENTATION

CIEMAT Contribution to E-XFEL

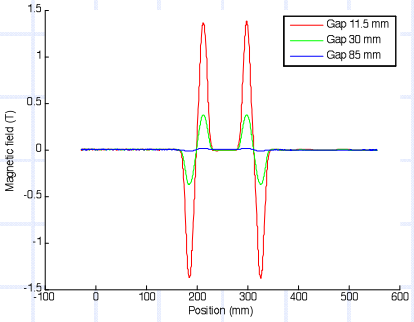
ICR for E-XFEL

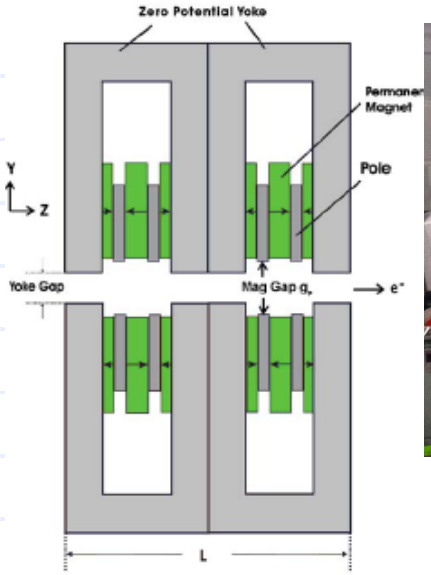
Type	Intersection Control Rack
Description	Control electronics for the Quadrupole Moving Tables and the Phase Shifter.
Dimensions	1000 x 500 x 500 mm
Technology	Forced air cooling and high security cabling. Based on Beckhoff Modules.
Industrialization	YES Different prototypes at CIEMAT & Industry Series manufactured at Industry.

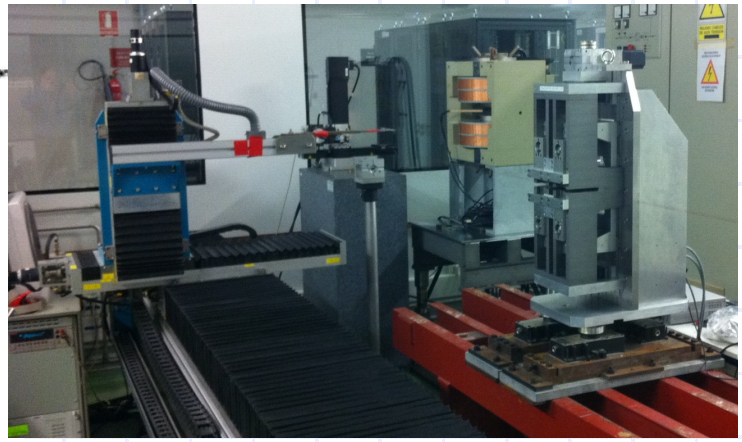
CIEMAT Contribution to E-XFEL

SPECIAL MAGNETS

Phase Shifters for E-XFEL







Magnetic measurements at CELLS

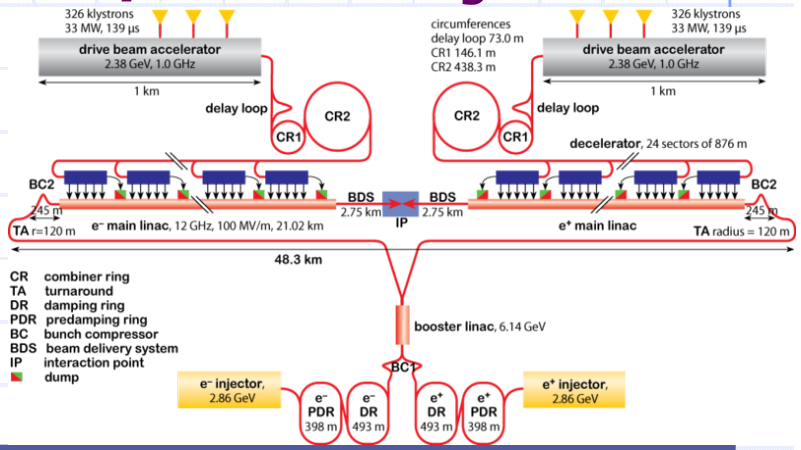
Type	Rare Earth Permanent Magnet
First Field Integral	≤0.004 Tmm
Second Field Integral	≤0.67 Tmm^2
Gap	10.5 ÷ 100 mm
Technology	NbFeB Magnets + Pure Iron Yoke. Controlled air gap with stepping motors
Industrialization	YES: Different prototypes at CIEMAT & Industry

The CLIC Project

The CLIC/CTF3 Project

CLIC/CTF3

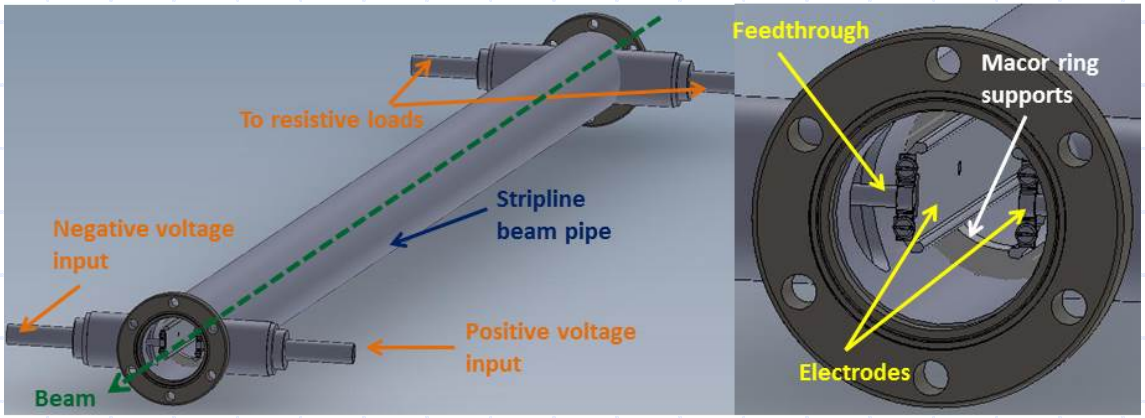
CLIC is a proposal for an up to 3TeV Linear Collider, which is based on a two beam scheme to achieve the required accelerating gradients. It uses non superconducting radiofrequency components which are called PETS for the drive beam and Accelerating Structures for the main beam. A validating test facility called CTF3 has already been successfully operated.

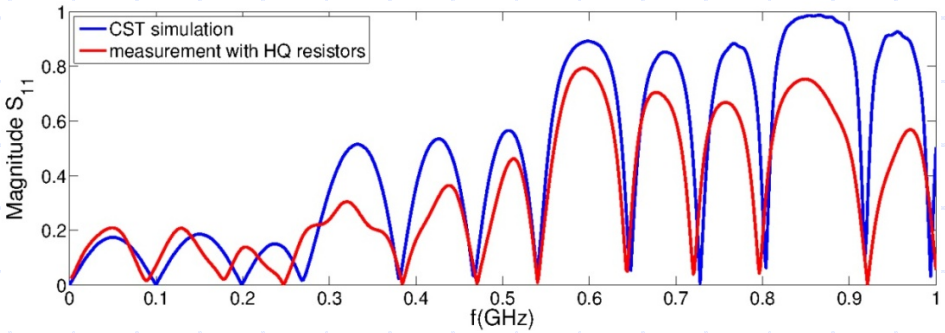


Present CIEMAT contribution to CTF3/CLIC		
COMPONENT	**TYPE**	**QUANTITY**
Septa Extraction Magnets	Resistive Magnet	2
Corrector Window-Frame Dipole	Resistive Magnet	15
Moving Tables (Movers)	Mechanics	15
Tail Clipper Kicker & Fast Kicker	Pulsed Magnet	1+1
Kicker for CLIC Damping Ring	Pulsed Magnet	1
Power Extraction Transfer Structures (PETS) for TBL	RF	12 (Partial Contrib.)
Double Length PETS for CLIC	RF	2
Future CIEMAT contribution to CLIC		
Accelerating Structures – TD26CC	RF	1
Longitudinally Variable Field Dipole	Hybrid Magnet	1

SPECIAL MAGNETS

Kickers for CLIC Damping Rings (in collaboration with IFIC)

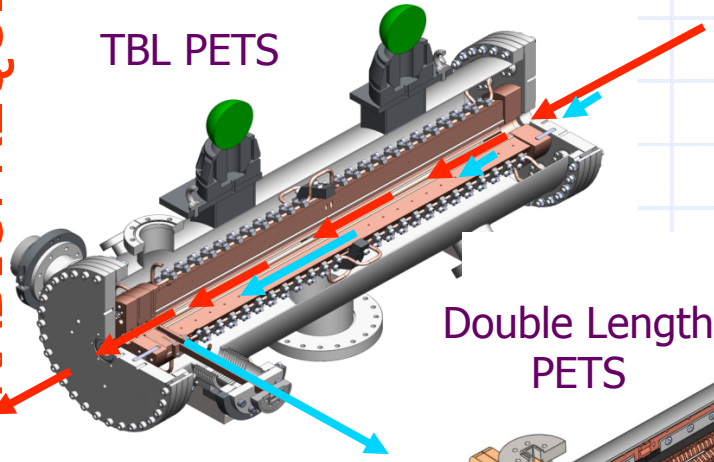


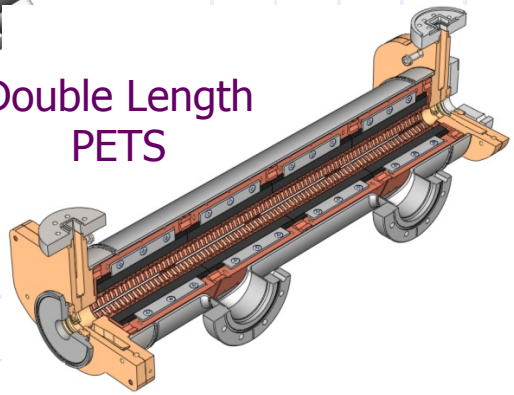


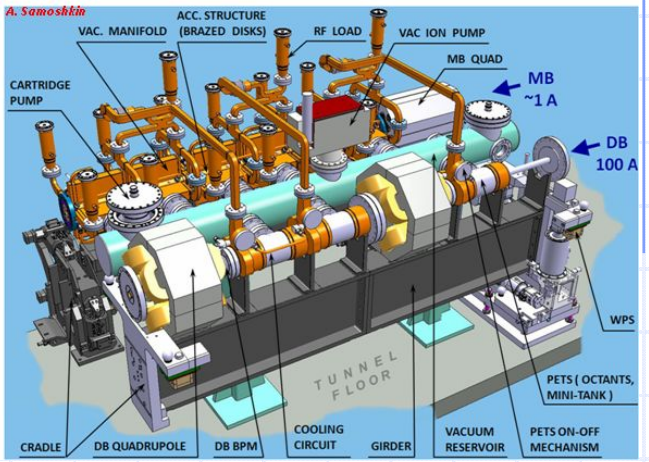
Type	Damping Ring
Nº of Modules	1
Deflection	1.5 mrad
Rise time	≤560 ns
Effective length	1700 mm
Op. Voltage	±12.5 kV
Technology	Stripline
Industrialization	YES: Prototype made at Industry

RADIOFREQUENCY

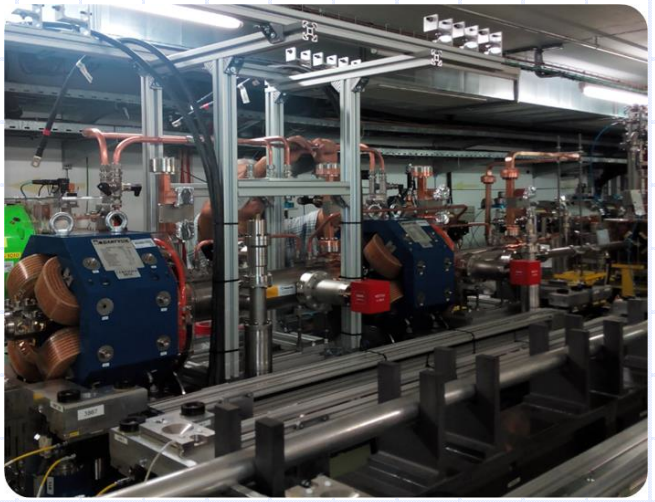
Power Extraction Transfer Structures (PETS) for CLIC







Type	TBL PET	Double Length PET
Op. Frequency	12 GHz	12 GHz
Length	4 x CLIC	2 x CLIC
Technology	Warm in Octants	Warm in Octants: Minitank, Integrated Couplers
Industrialization	YES: Partial Supplies by Industry	



The LHC Upgrade

The LHC Upgrade

LHC Upgrade

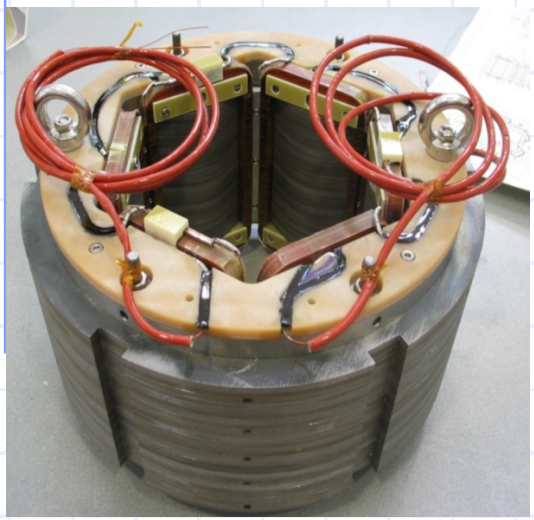
In a first phase, LHC has been working at 8 TeV and 75% of its nominal luminosity. After a 2 year shutdown, luminosity will be increased to 100% and energy to 14 Tev. From 2018 to 2021 it is foreseen to increase the luminosity to 200% and after 2023, it should be increased again by a factor of 5 to 10, after significant changes in the machine.

High Luminosity LHC

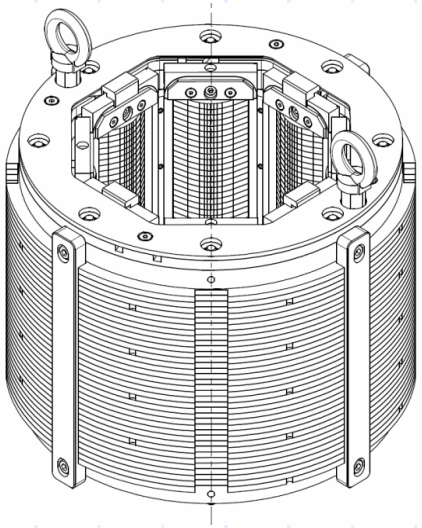
Present CIEMAT contribution to LHC Upgrade and HL-LHC		
COMPONENT	**TYPE**	**QUANTITY**
Radiation Resistant SC Sextupole Corrector Magnet	SC Magnet	1
Radiation Resistant SC Octupole Corrector Magnet	SC Magnet	1
Participation in the Cabling for the LHC Long Shutdown	Manpower	8 man-year
Development of a Nested Dipole	Superconductor	1 Prototype
Participation in the development of Superconducting Links	HTc Superconductor	Prototyping
Participation in the development of a Static VAR Compensator	Solid State	Prototyping

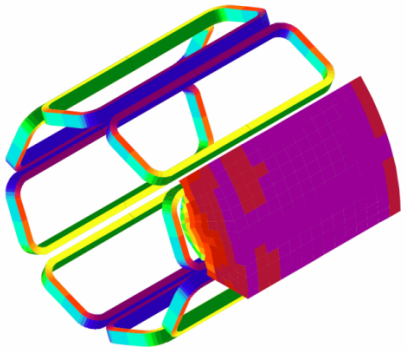
SC MAGNETS

Superconducting Magnets for LHC Hi-Lumi

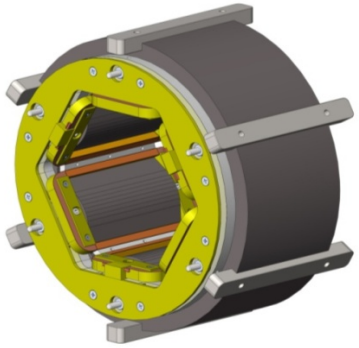


Sextupole





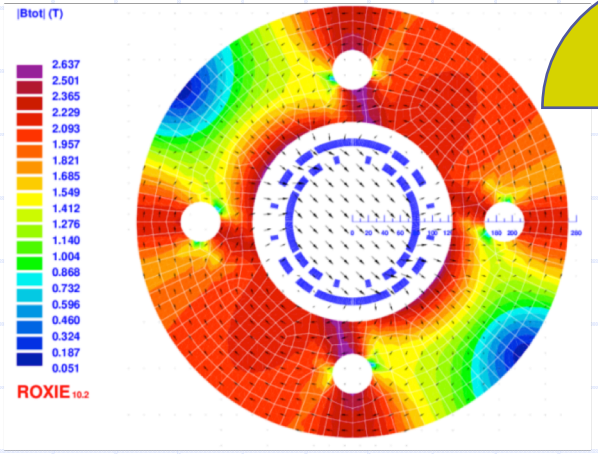
Octupole

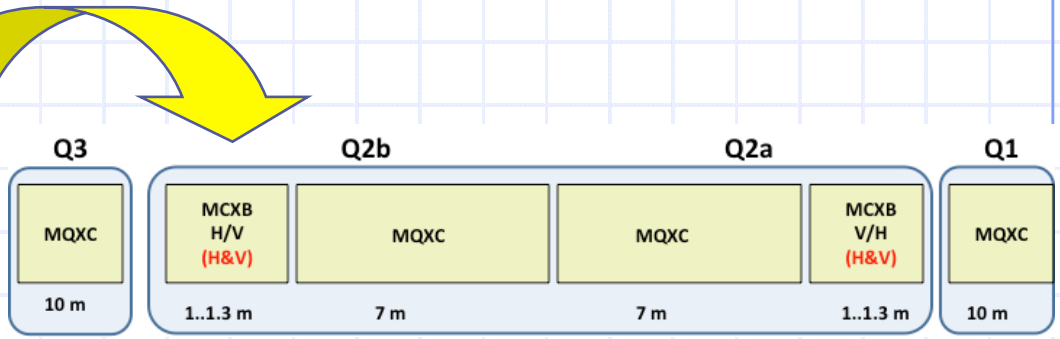


Type	Sextupole	Octupole
Integrated Field	0.055 Tm	0.035 Tm
Physical Length	160 mm	160 mm
Op. Current	100 A	100 A
Technology	NbTi Superferric	NbTi Superferric Rad. Resistant
Industrialization	HI-Lumi LHC Magnets will be based on this development	

SC MAGNETS

Superconducting Magnets for LHC Hi-Lumi





MCBXS H&V Combined Corrector Dipole

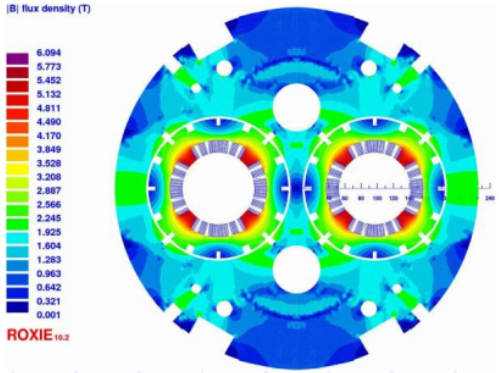
Type	Combined Corrector Dipole
Integrated Field	2.5 Tm
Physical Length	1200 mm
Aperture	150 mm
Technology	Nested NbTi Coils @ 1.9K
Industrialization	Yes (TBD)

UPDATED MILESTONES	
Feb 2015	Conceptual Desing
June 2016	Fabrication Drawings
Sep 2017	1st Prototype Finished
Dec 2017	Tests @ CERN
CERN: 50% Personnel & 100% Materials CIEMAT: 50% Personnel & 100% Tooling	

The QUACO Project

The QUACO project draws together several research infrastructures with similar technical requirements in magnet development, which will allow the avoidance of unnecessary duplication of design effort and reduce overall cost through economies of scale using a **joint procurement process**. By pooling efforts, the partners in QUACO will act as a single buyer group with sufficient momentum for potential suppliers to consider the phased development of the requested magnets. QUACO's goal is to create a paradigm shift in the industrialization of the new generation of superconducting magnets.

QUACO Project is a self-contained and consistent part of the High Luminosity LHC Project, focusing on the design, development and procurement of superconducting magnets.
The final result of the project will be 2 pilot magnets (Q4 type) necessary for HI-LUMI LHC.



Participants:

1) The European Organization for Nuclear Research (CERN),
2) Commissariat A L'Energie Atomique Et Aux Energies Alternatives (CEA),
3) Centro de Investigaciones Energéticas, Medioambientales Y Tecnológicas (CIEMAT),
4) Narodowe Centrum Badan Jadrowych (NCBJ).

EU Funding (PCP Program):
Total cost in the proposal 6,647,895.00 €
Maximum grant amount 4,653,523.88 €

The FTECs Program

The FTEC (Formacion en las TEcnologias del CERN) Trainee Programme has been established through a bilateral agreement between CERN and CIEMAT with the contribution of the SEIDI from the Ministerio de Economía y Competitividad, as well as the CDTI.

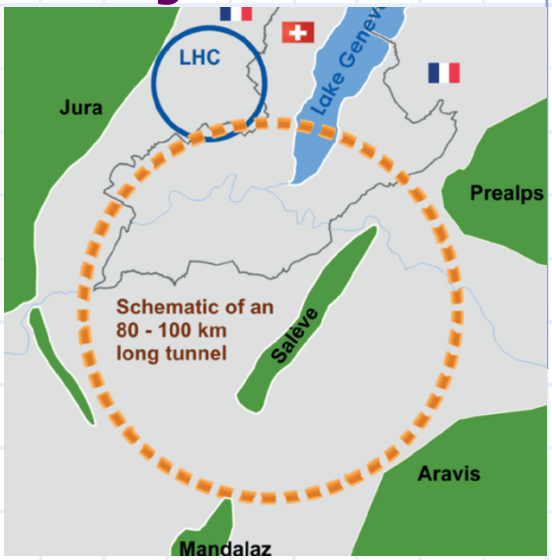
This programme is aimed at recent graduates from university or higher technical institutes seeking further training in a wide area of projects. Selected trainees will join a team working at CERN and have the opportunity to enlarge their knowledge through participation in the hi-tech activities of the laboratory, in fields such superconducting and resistive magnets, power converters and their associated electronics, cryogenics and vacuum technologies and electronics for detectors, including radiation resistance issues, and related activities on infrastructures with a potential industrial return.

The FCC Project

The FCC Project

The FCC Project

CERN has recently launched a feasibility conceptual study for post-LHC particle accelerator options, considering the technology research and development programs that would be required to build a future circular collider in the range of 100 TeV. Among other initiatives, an international collaboration called EuroCirCol has been awarded with a H2020 grant to address the main issues of the future machine.

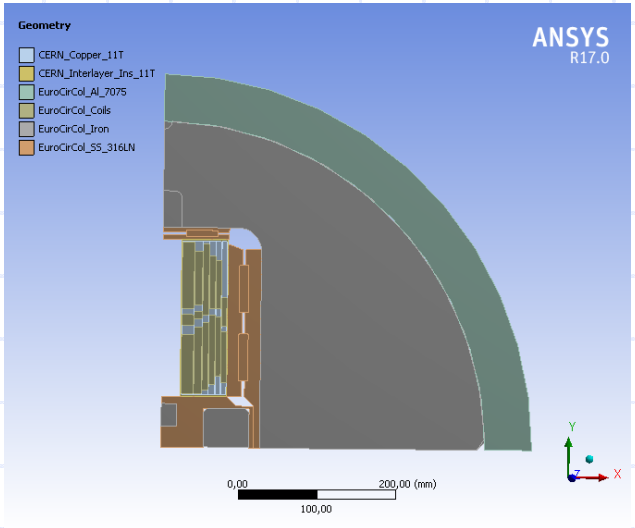


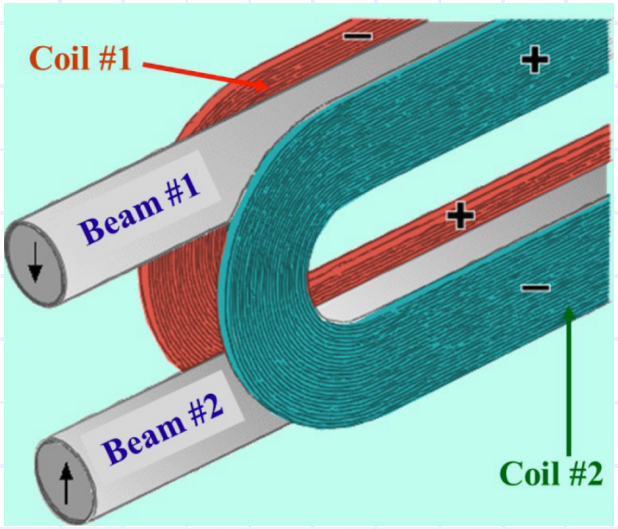
Present CIEMAT contribution to the EuroCirCol Project (FCC)

WorK Package	WP Description	CIEMAT Contribution
WP1	Management, Coordination and Implementation	--
WP2	Arc Design: Conceptual design of the largest fraction of the collider ring	--
WP3	Design of the experimental insertion regions	--
WP4	Design of the cryogenic beam vacuum system considering the enormous synchrotron radiation level	4,5 person·year
WP5	High-Field superconducting magnet design for fields up to 16T	4,0 person·year

SC MAGNETS

Superconducting Magnets for FCC: EuroCirCol





Common coil dipole

Type	Main Dipole
Main field	16 T
Physical Length	14.3 m
Aperture	50 mm
Technology	Nb_3Sn @ 1.9K (TBC)
Industrialization	Yes (TBD)

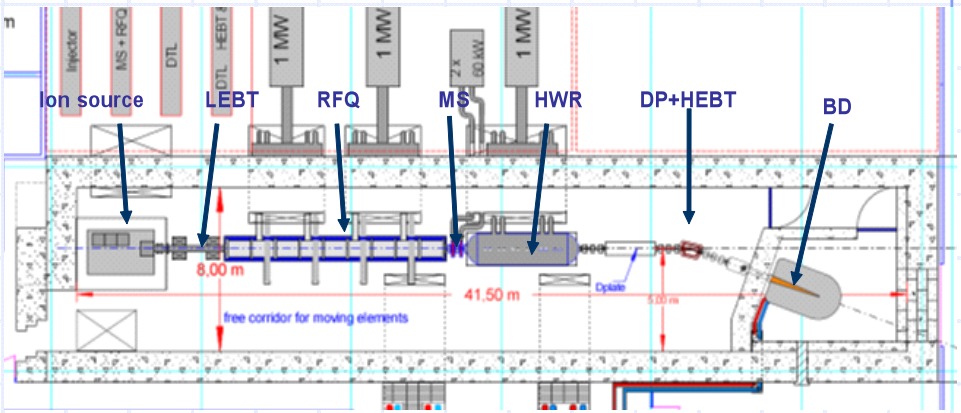
UPDATED MILESTONES	
May 2016	Design choice
June 2017	Detailed design
Dec 2018	Fabrication drawings
EuroCircol - H2020 Funded Project	

The IFMIF Contribution

The IFMIF Project

IFMIF

The Division also collaborates in the IFMIF project: a 40 MeV, 125 mA deuteron accelerator acting on a lithium target to generate neutrons to test materials for the first commercial fusion reactor : the DEMO. To validate the IFMIF concept, the so called EVEDA phase has been launched, including a Linear Accelerator (LIPAc) with a current of 125 mA and an energy of 9 MeV.



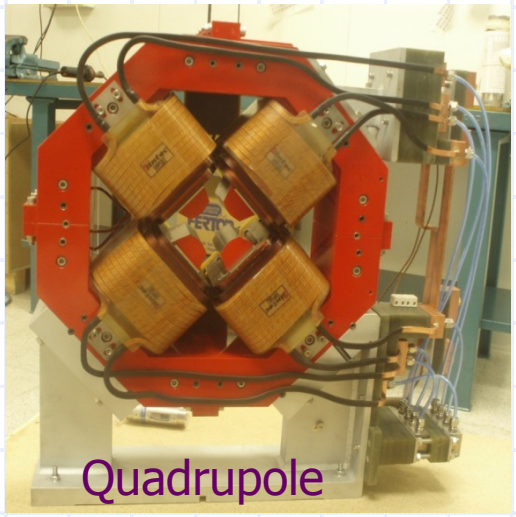
Present contribution to IFMIF-EVEDA		
COMPONENT	**TYPE**	**QUANTITY**
Magnet Packages for the DTL	SC Magnet	8
Bunchers for the Matching Section	RF	2
Medium Energy Beam Transport Line	Accelerator Subassembly	1
Beam Instrumentation	Instrumentation	--
Possible Future contribution to IFMIF (Full-Scale)		
Activities for Future Fusion Accelerators	RF, Beam instrumentation, Optics, etc.	N/A

Note: the contribution to IFMIF from our colleagues at CIEMAT Fusion Group is not included here. It consists of the RF power system, the High Energy Beam Transport Line and the Beam Dump.

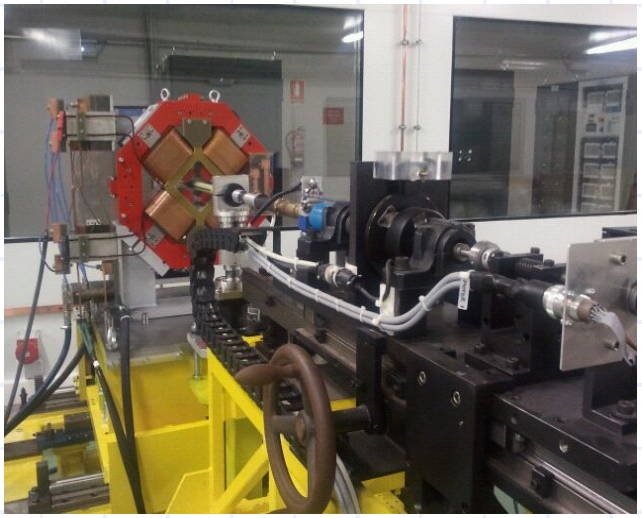
Resistive Magnets

RESISTIVE MAGNETS

Resistive Magnet for LIPAc



Quadrupole



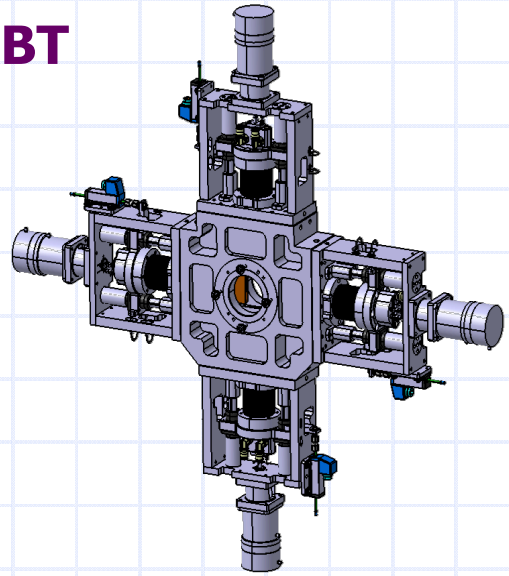
Magnetic measurements at CELLS

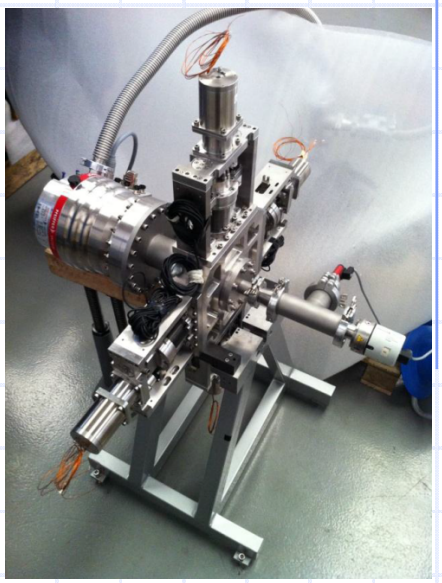
Type: Combined	Quadrupole	Dipole
Integrated Field	0.068 ÷ 0.163 Tm	3.51 mTm
Inner Diameter	56 ÷ 136 mm	
Op. Current	178 ÷ 313 A	50 A
Technology	Water Cooled Radiation Resistant	Air Cooled Radiation Resistant
Industrialization	YES, first 5 units already made by ANTEC	

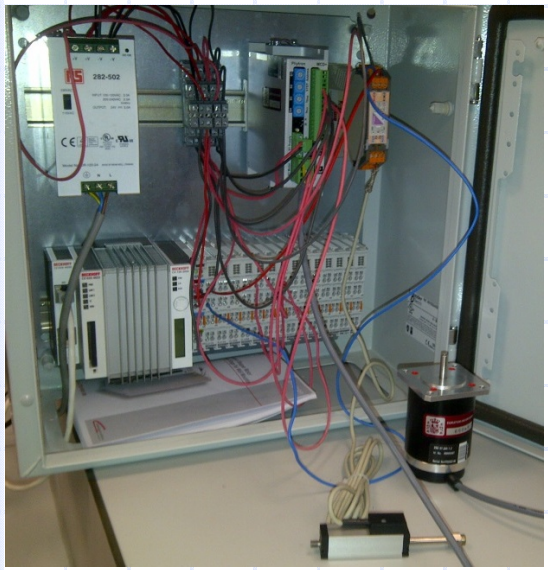
Mechanics (2)

MECHANICS

Scrapers for LIPAc MEBT





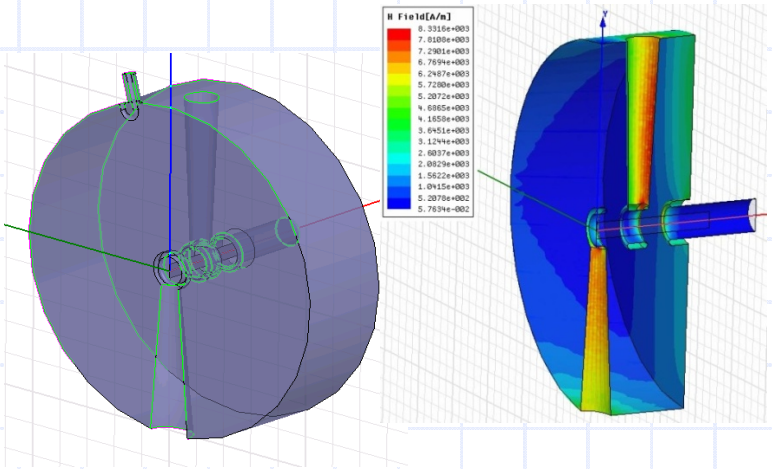


Type	4-Collimator Scraper
Displacement Range	21mm
Movement Precision	20 μ m
Max Dissip .Power	4 x 500 W
Technology	Water-cooled, Step motor controlled in closed loop
Industrialization	YES: First Prototype at AVS finished. The Second one in fabrication

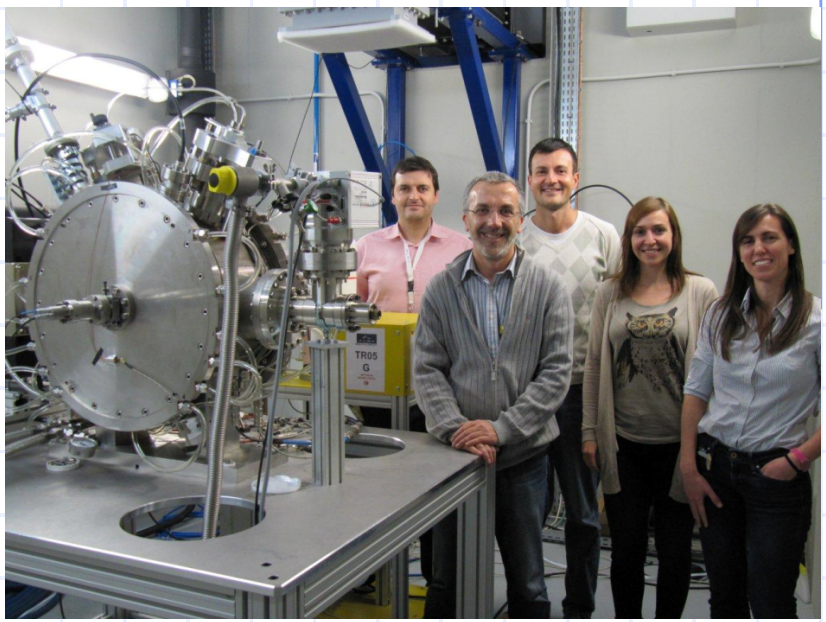
Radiofrequency (2)

RADIOFREQUENCY

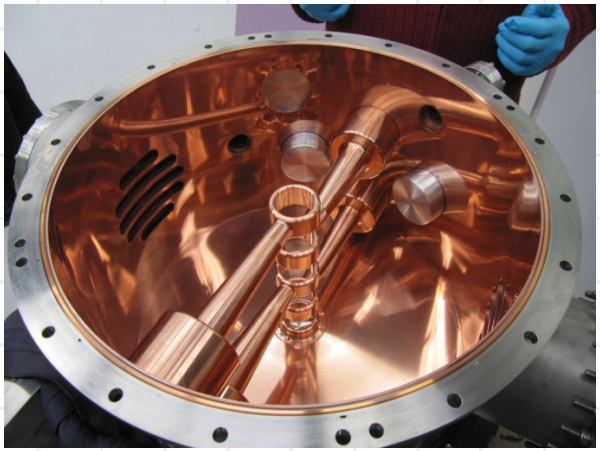
Buncher for LIPAc



Selected IH-Type Resonator



High power test at CELLS



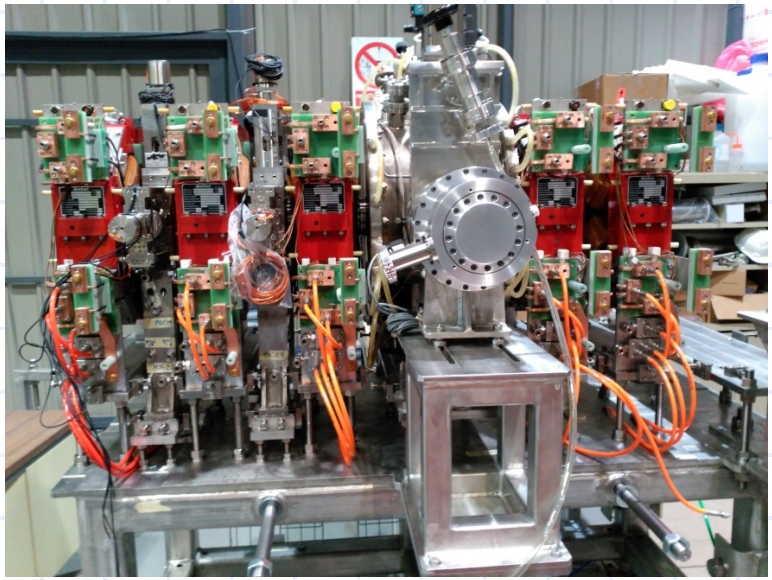
Type	IH Resonator, 4 Acceleration gaps
Frequency	175 MHz
Integrated Voltage	350 kV
Max Dissip. Power	≤10 kW
Technology	Resistive, Water-cooled
Industrialization	YES

Integration Activities

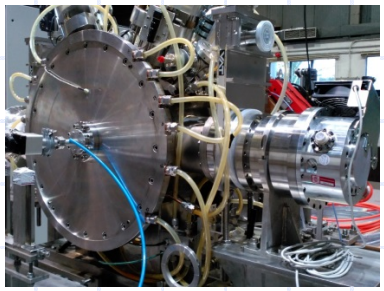
Medium Energy Beam Transport Line (MEBT):

- Compact transport line between RFQ and cryomodules
- Main components: Five combined magnets, two buncher activities, beam scrapers and beam diagnostics.
- Fully designed by CIEMAT; manufactured by Spanish industry
- **MEBT sent to Rokkasho: January 2016**

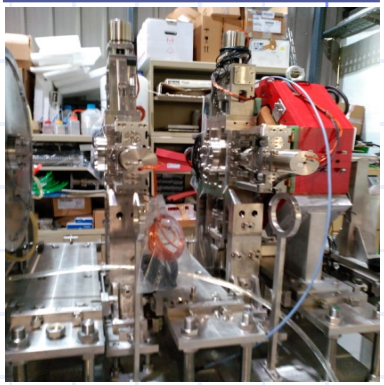
MEBT



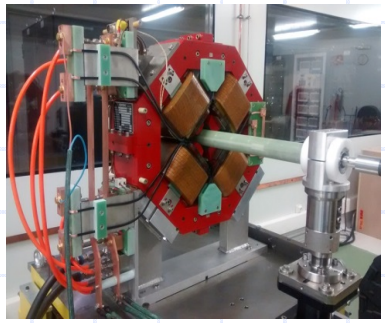
Buncher cavity



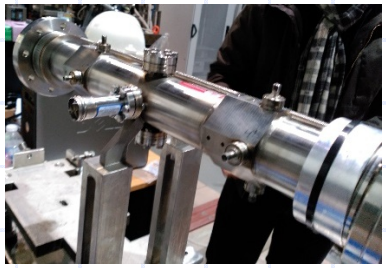
ZScrapers



Combined magnets



Beam position monitors

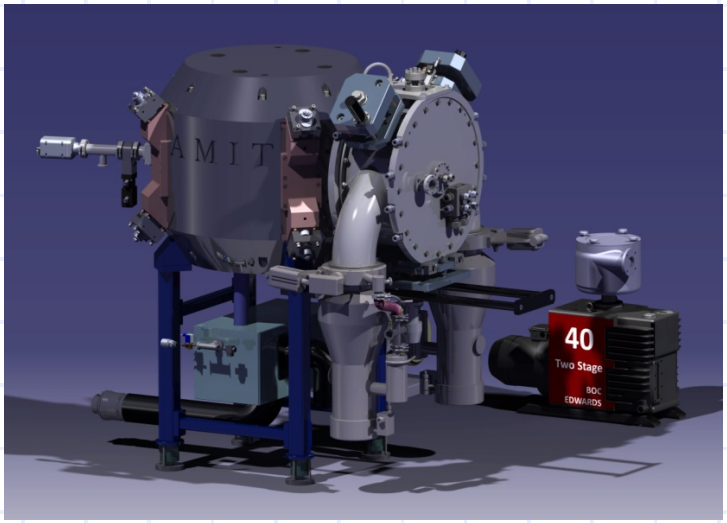


Other ongoing activities:

- Solenoids for high energy accelerating part of LIPAC
- High Energy beam line: magnets, beam diagnostics, beam dynamics
- DONES accelerator: beam dynamics studies since October 2015

The AMIT Project

The AMIT Project

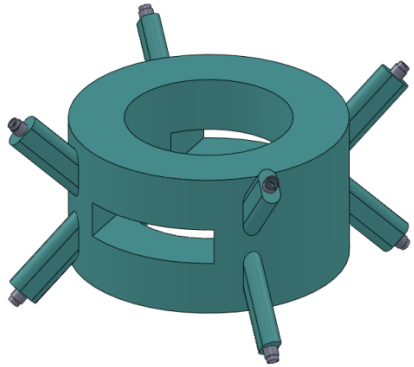


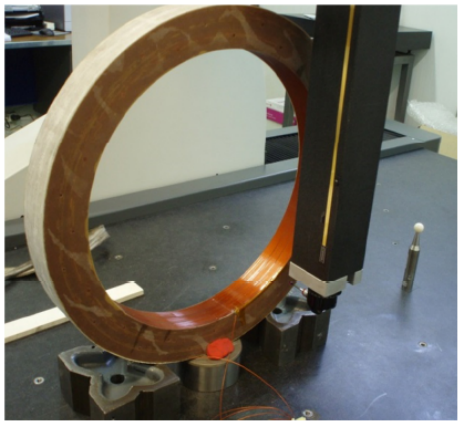
In 2010 the Project AMIT (Advanced Molecular Image Technologies) started. One of the Work Package assigned to CIEMAT consists of the development of a Compact Superconducting 8,5 MeV Cyclotron for ^{11}C and ^{18}F production. It includes the development and fabrication of the targets and the installation of the facility.

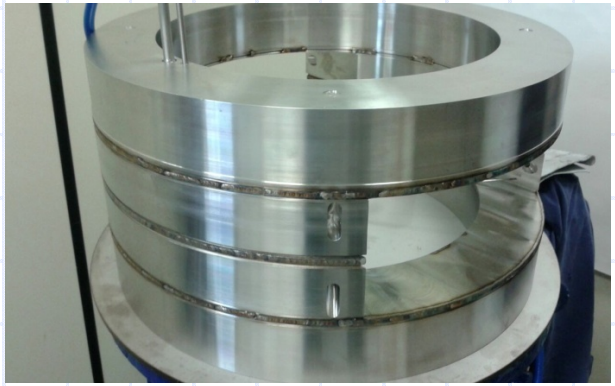
Present CIEMAT contribution to AMIT		
COMPONENT	**TYPE**	**QUANTITY**
Complete Superconducting Cyclotron Prototype	Accelerator	1
Possible Future CIEMAT contribution to AMIT & Other Accelerators for Isotope Production		
Participation in Cyclotron Industrialization & Commercialization	Industrial Alliance	TBD
Participation with CERN in the development of a LINAC	Targets & RF	TBD

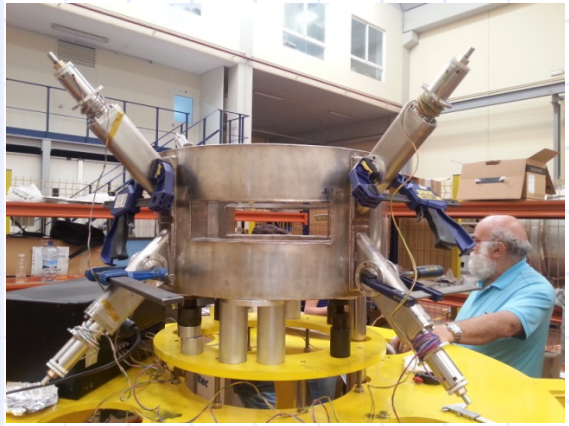
SC MAGNETS

Superconducting Magnet for AMIT





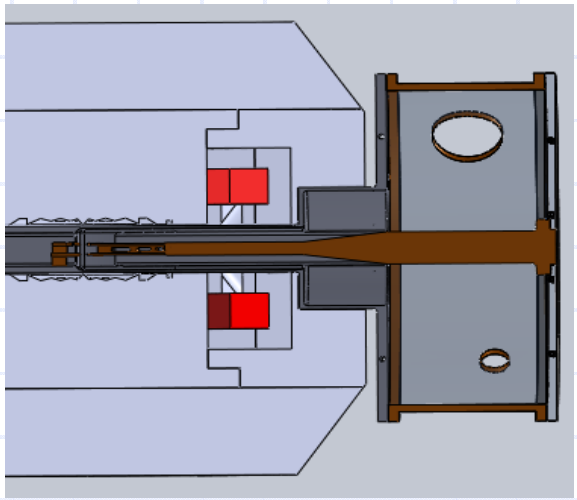


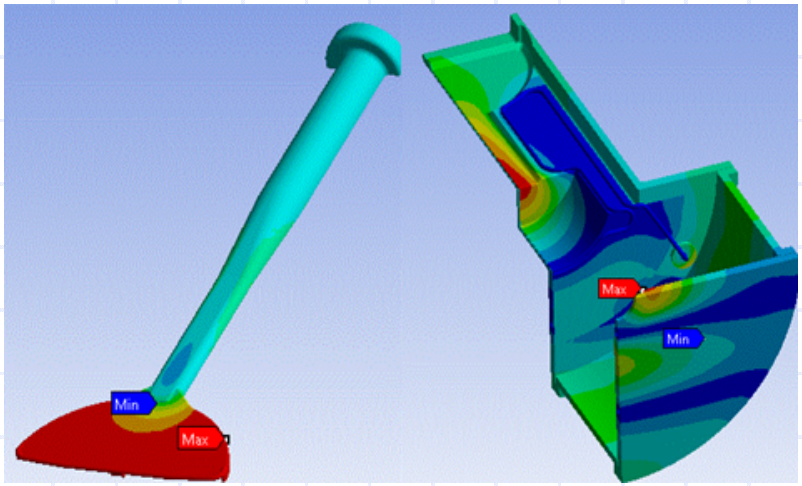


Type:	2 Solenoid in Hemholtz Coils Configuration
Central Field	4.0 T
Overall Diameter	700 mm
Op. Current	110 A
Technology	NbTi Wet Impregnation 2 phase helium cooling
Industrialization	YES: Prototype made at Industry under CIEMAT supervision

SC MAGNETS

RF Accelerating Cavity for AMIT





Type:	180º dee
Accel. voltage	60 kV
Frequency	60 MHz
Technology	Resistive, water cooled
Industrialization	YES: Prototype made at Industry under CIEMAT supervision

CRYOGENICS

Cryogenic Supply System for AMIT (Collaboration with CERN)

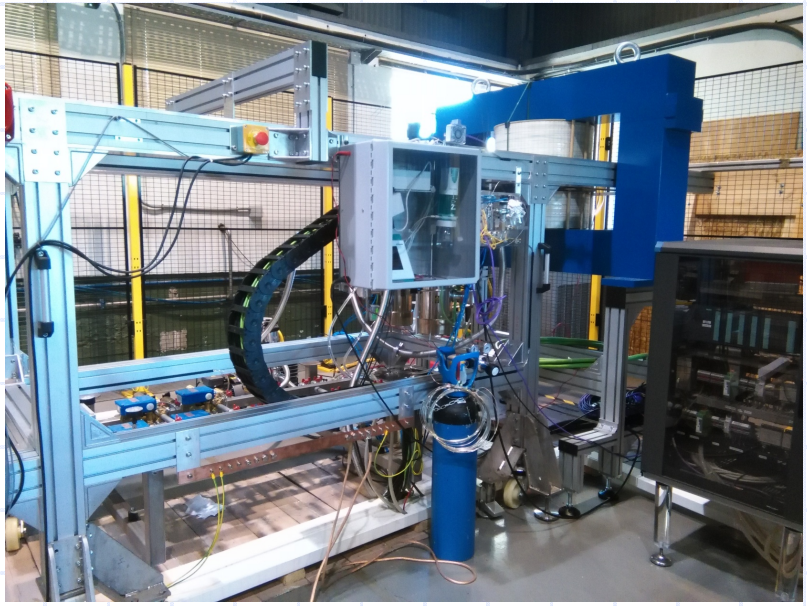
Type:	Cryogenic Refrigerator for the AMIT Magnet
Max. Extracted Power	1,0 W
Refrigeration	Two-Phase Helium @ 4,3K Gas Helium @ 40-70 K
Technology	Helium recirculation in close circuit and re-condensation with a cryocooler
Industrialization	YES One prototype built @ CERN as contribution to the AMIT Project and a second prototype under construction at Industry

Experimental validation of AMIT cyclotron ion source

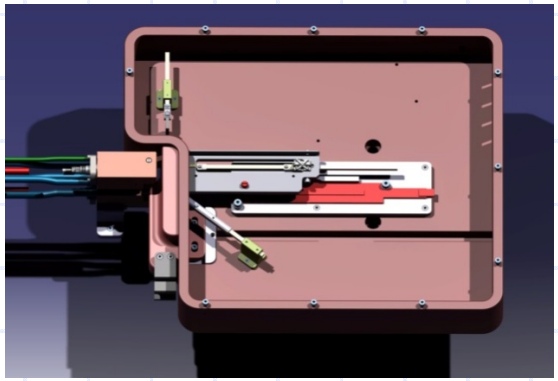
Goals:

- ❑ To analyze the ion source behavior and improve the design
- ❑ Beam characterization and validation of beam dynamics calculations
- ❑ To reduce AMIT commissioning time (some other cyclotron components can also be tested at IST facility)
- ❑ Future: to provide a future ion source test facility open to external collaborations

CIEMAT Building 75



Electrical shield box, beam probes, puller and ion source



- ❖ The ion source is at ground whereas the puller, at positive DC high voltage, will extract the particles.
- ❖ An electrical shield box is installed inside the vacuum chamber. A beam probe, located according to H^- trajectory, will measure the H^- current
- ❖ Beam emittance will be measured with an interceptive method based on slits and wire monitors.

→ **Measurements are on going**

Summary

Summary of Industrial Participation

COMPANY	SUPPLY	TYPE	QUANTITY
ALDERAN	Intersection Control Rack for E-XFEL	Electronics & Instrum.	1 (prot.)
ANTEC	Combined Magnets for E-XFEL (magnet)	SC Magnet	103 SERIES
ANTEC	Magnet for AMIT (magnet)	SC Magnet	1 (prot.)
ANTEC	Quadrupole for IFMIF	Resistive Magnet	1 (prot.)
APM	Moving Tables for E-XFEL	Mechanics	1 (prot.)
AVS	Scrapers for IFMIF	Mechanics	1 (prot.)
CRYOVAC	Cryostat for E-XFEL Magnet Prototype	Mechanics	1 (prot.)
DMP-HTS	Moving Tables for E-XFEL	Mechanics	49 SERIES
DMP-HTS	Buncher for IFMIF	Radiofrequency	1 (prot.)
DMP-HTS	Phase Sifter for E-XFEL	Special Magnet	1 (prot.)
DMP-HTS	PETS for CLIC/CTF3	Radiofrequency	1 (prot.)
ELYTT	Combined Magnet for E-XFEL	SC Magnet	1 (prot.)
INABENSA	Intersection Control Rack for E-XFEL	Electronics & Instrum.	2 (prot.)
INDEX	Moving Tables for E-XFEL	Mechanics	1 (prot.)
NOVALTI	Moving Tables for E-XFEL	Mechanics	1 (prot.)
PINE	Intersection Control Rack for E-XFEL	Electronics & Instrum.	1 (prot.)
RAMEM	Moving Tables for E-XFEL	Mechanics	49 SERIES
SINTERSA	Intersection Control Rack for E-XFEL	Electronics & Instrum.	1 (prot.)
Utillajes HUERTA	LINAC for Racetrack Microtron	Radiofrequency	1 (prot.)
Utillajes HUERTA	Moving Tables for E-XFEL	Mechanics	1 (prot.)
Utillajes Huerta	PETS for CLIC/CTF3	Radiofrequency	1 (prot.)
TRINOS V. P.	Combined Magnets for E-XFEL (vessel)	SC Magnet	103 SERIES
TRINOS V. P.	Magnet for AMIT (vessel)	SC Magnet	1 (prot.)
TRINOS V. P.	Extraction Kickers for CTF3 (CLIC)	Special Magnet	1 (prot.)
TRINOS V. P.	Tail Clipper Kicker for CTF3 (CLIC)	Special Magnet	1 (prot.)
TRINOS V. P.	PETS for CLIC/CTF3	Radiofrequency	1 (prot.)
TRINOS V. P.	Beam Position Monitors for LIPAc	Mechanics	4

Main difficulties to overcome in our daily work:

1.-Our group (30 people) is very small compared with other labs working on accelerators. These machines are multi-physics.

2.-We are devoted to technological developments, but working in a scientific environment: we should not be only evaluated by our publications.

3.-Most of the people in our group have not permanent positions:

a) learning curve is slow and we cannot afford losing trained workers.

b) hiring procedure is very slow.

c) salaries in industry or abroad are higher.

4.-Administrative processes are very time consuming: procurement, hiring people, funding reports, call-for-projects.

Conclusions

1.-CIEMAT Department of Technology has developed a significant technological activity in the field of particle accelerators for more than 25 years.

2.-These activities started for the LHC project, mainly focused on superconducting magnets with a clear and fruitful participation of the Spanish Industry.

3.-From 2010 to present days, CIEMAT has undertaken most of the technical activities of the Spanish contribution to the European XFEL, being in charge of delivering Superconducting Combined Magnets, Quadrupole Moving Tables and Intersection Control Racks in close cooperation with Industry.

4.-CIEMAT is also participating in most of the CERN projects for future accelerators like CLIC, HiLumi LHC or the Future Circular Collider.

5.-There is also a significant and increasing activity at CIEMAT in the field of small and advanced accelerators.

Thank you very much for your attention

fernando.toral@ciemat.es