Summary of R&D Activities at CIEMAT in Particle Accelerators Including Medical Applications & Technology Transfer

Luis García-Tabarés

Electrical Engineering Unit

Department of Technology. CIEMAT

The Electrical Engineering Unit at CIEMAT

STRUCTURE

<table>
<tr><td colspan="2">HEAD: L. García-Tabarés</td><td>ORGANIZATION: T. Martinez</td><td colspan="2">GROUP SECRETARY: P. Ortiz</td></tr>
<tr><td colspan="2">ACCELERATOR TECHNOLOGY: F.Toral</td><td>POWER SYSTEMS: M.Lafoz</td><td colspan="2">DEVELOPMENTS: L. García-Tabarés</td></tr>
<tr><td colspan="2"></td><td></td><td>FABRICATION
J.Calero</td><td>ENGINEERING</td></tr>
<tr><td>J. García</td><td>D. Obradors</td><td>M. Blanco</td><td>P. Abramian</td><td>J.Munilla</td></tr>
<tr><td>D. Gavela</td><td>C. Oliver</td><td>P.Concha</td><td>JL Gutiérrez</td><td>C. Vázquez</td></tr>
<tr><td>A. Guirao</td><td>F. OLivert</td><td>G: Navarro</td><td>LM: Martínez</td><td>B. Ahedo</td></tr>
<tr><td>E. Molina</td><td>L. Podadera</td><td>J. Torres</td><td>A. Casado</td><td></td></tr>
<tr><td>I. Moya</td><td>L. Sánchez</td><td></td><td></td><td></td></tr>
</table>

FACILITIES

Main Offices (Moncloa)

Energy & Superconductivity (J. Camarillo)

Assembly Hall (J. Camarillo)

Ongoing Projects and Collaborations

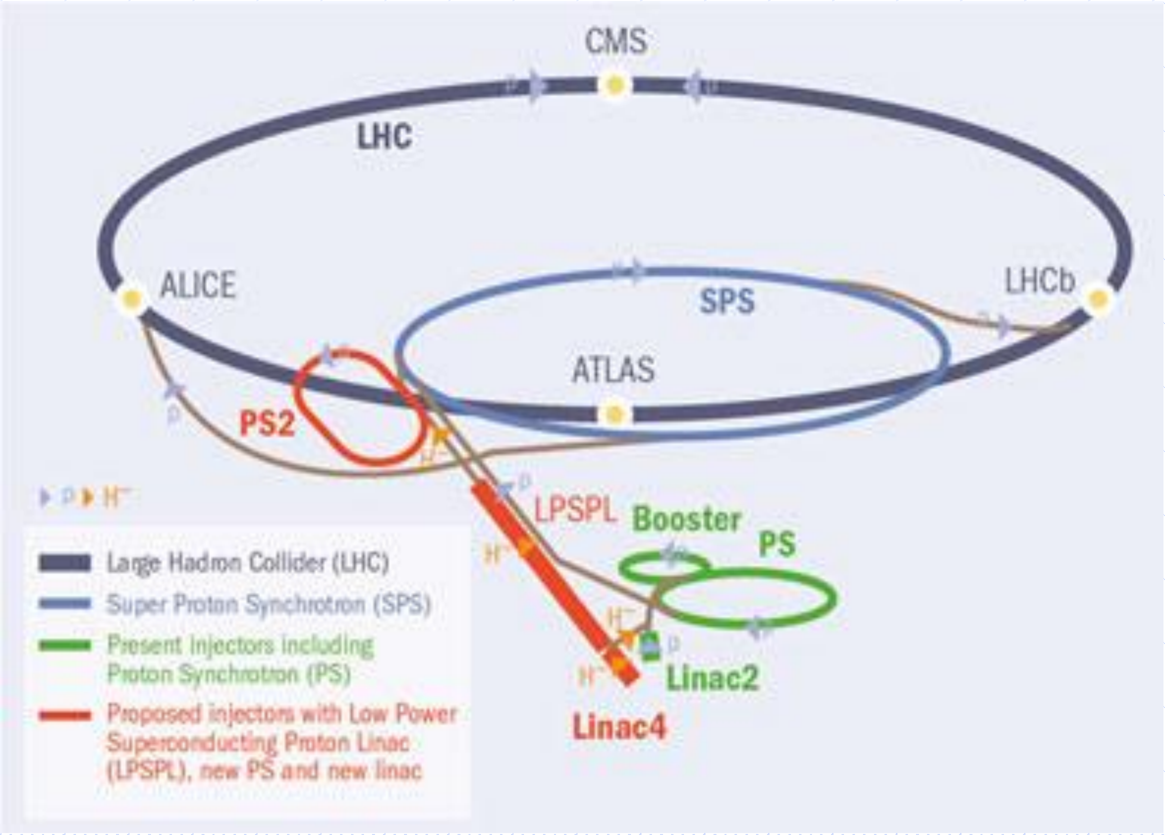
ACCELERATORS	ENERGY
Large Facilities ↓	Storage ↓
XFEL	SA^{2}VE
FAIR	ACEBO
LHC Upgrade	ADIF/CETRAF
CTF3/CLIC	TRAIN2CAR
ILC	
IFMIF	Generation ↓
TIARA/CONECTA	SUPERTURBINES
Small Accelerators for Medical Applications ↓	**UNDIGEN**
MICROTRON	SEA-WEDGE
AMIT	IISIS

- Projects in dark blue involve superconductivity developments
- Projects in bold letter are highly "active" at present

GOBIERNO DE ESPAÑA MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Ongoing Projects and Collaborations



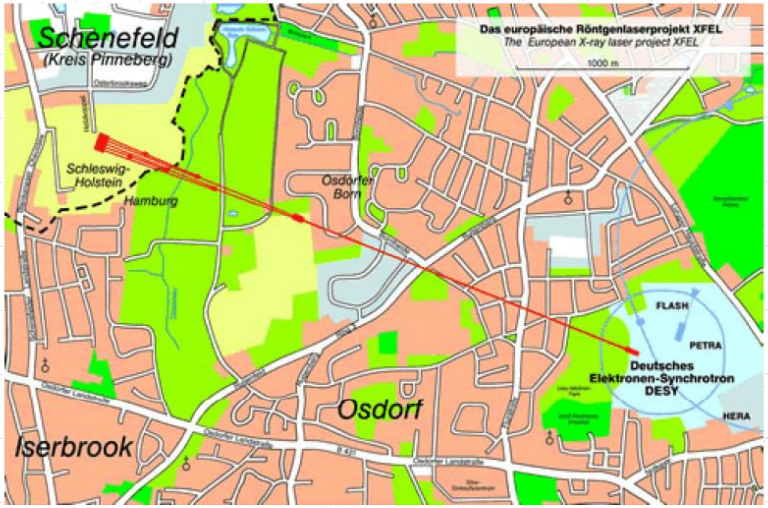
1.-Large Facilities

The E-XFEL Facility

XFEL

E-XFEL (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.

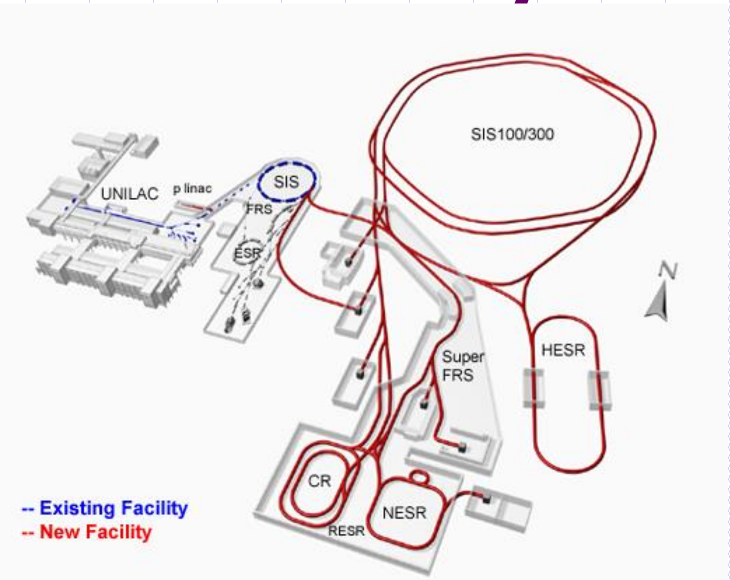


Present CIEMAT contribution to E-XFEL		
COMPONENT	**TYPE**	**QUANTITY**
Superconducting Combined Magnets	SC Magnet	103
Moving Tables (Movers)	Mechanics	91
Electronic Control Racks	Electronics & Instrum.	91
Phase Shifter Magnets	Special Magnet	Contrib. Failed
Possible Future CIEMAT contribution to E-XFEL		
TBD	TBD	TBD

FAIR

The FAIR Facility

FAIR (Facility for Antiproton Ion Research) is an Accelerator Complex with 8 circular accelerators up to 1100 m in circumference and two linear ones up to 3500m for beam transport. It is located in the GSI facilities at Darmstadt. Existing accelerator will be used as injectors for the new machines.



Present CIEMAT contribution to FAIR		
COMPONENT	**TYPE**	**QUANTITY**
Design of the SC Quadrupoles of the Multiplets for the Superfragment Separator.	SC Magnet Design	1
Possible Future CIEMAT contribution to FAIR		
TBD	TBD	TBD

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.

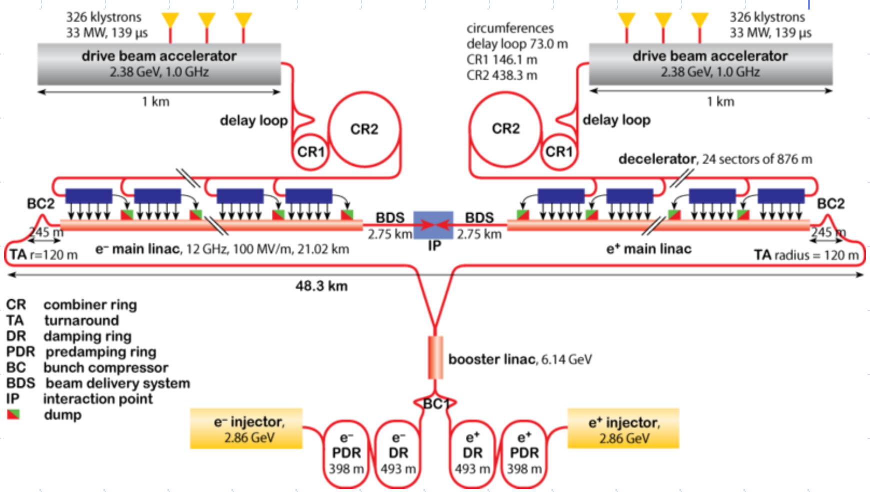
High Luminosity LHC

Present CIEMAT contribution to LHC Upgrade		
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
Possible Future CIEMAT contribution to LHC Upgrade (HI-LUMI)		
SC Nested Corrector Dipoles (Agreed)	SC Magnets	10-15

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.



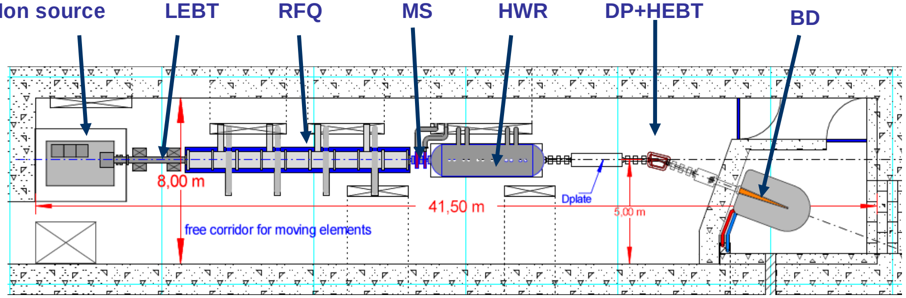
Present CIEMAT contribution to CTF3/CLIC		
COMPONENT	**TYPE**	**QUANTITY**
Septa Extraction Magnets	Resistive Magnet	2
Corrector Window-Frame Dipole	Resistive Magnet	15
Moving Tables (Movers)	Mechanics	15
Tail Clipper Kicker	Special Magnet	1
Fast Kicker	Special Magnet	1
Power Extraction Transfer Structures (PETS) for TBL	RF	12 (Partial Contrib.)
Double Length PETS for CLIC	RF	1
Possible Future CIEMAT contribution to CLIC		
TBD	TBD	TBD

The IFMIF Project

IFMIF

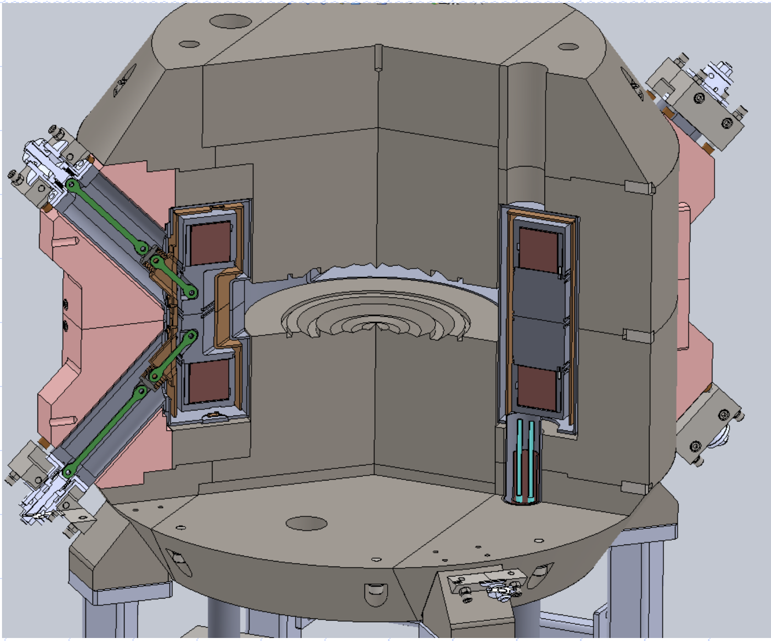
The Unit also collaborates in the IFMIF project: a 40 MeV, 125 mA deuteron accelerator acting on a lithium target to generate neutrons to test materials for the first commercial fusion reactor : the DEMO. To validate the IFMIF concept, the so called EVEDA phase has been launched, including a Linear Accelerator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

IFMIF-EVEDA Accelerator



Present CIEMAT contribution to IFMIF-EVEDA		
COMPONENT	**TYPE**	**QUANTITY**
Solenoid Magnets for the DTL	SC Magnet	8
Bunchers for the Matching Section	RF	2
Quadrupoles & Steerers for the MEBT	Resistive Magnets	13
Scrapers for the MEBT	Mechanics	2
Possible Future CIEMAT contribution to IFMIF (Full-Scale)		
TBD	TBD	TBD

Ongoing Projects and Collaborations

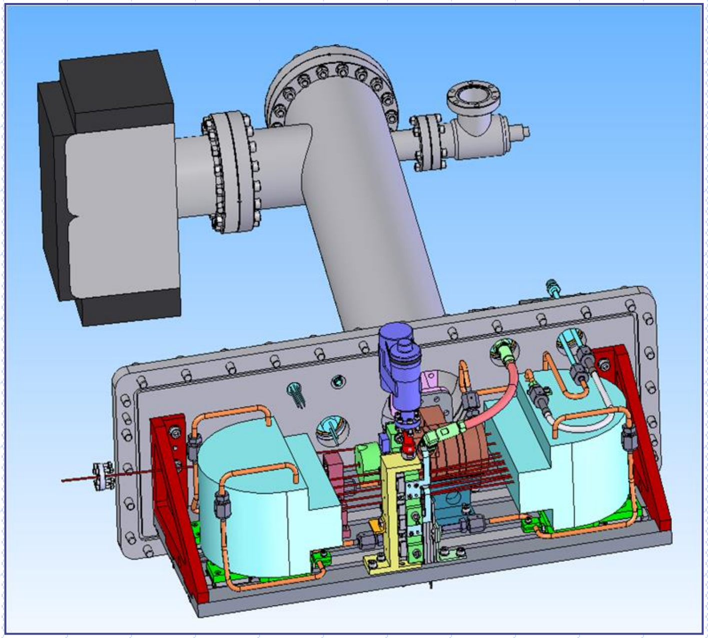


2.-Small Accelerators for Medical Applications

The Microtron Development

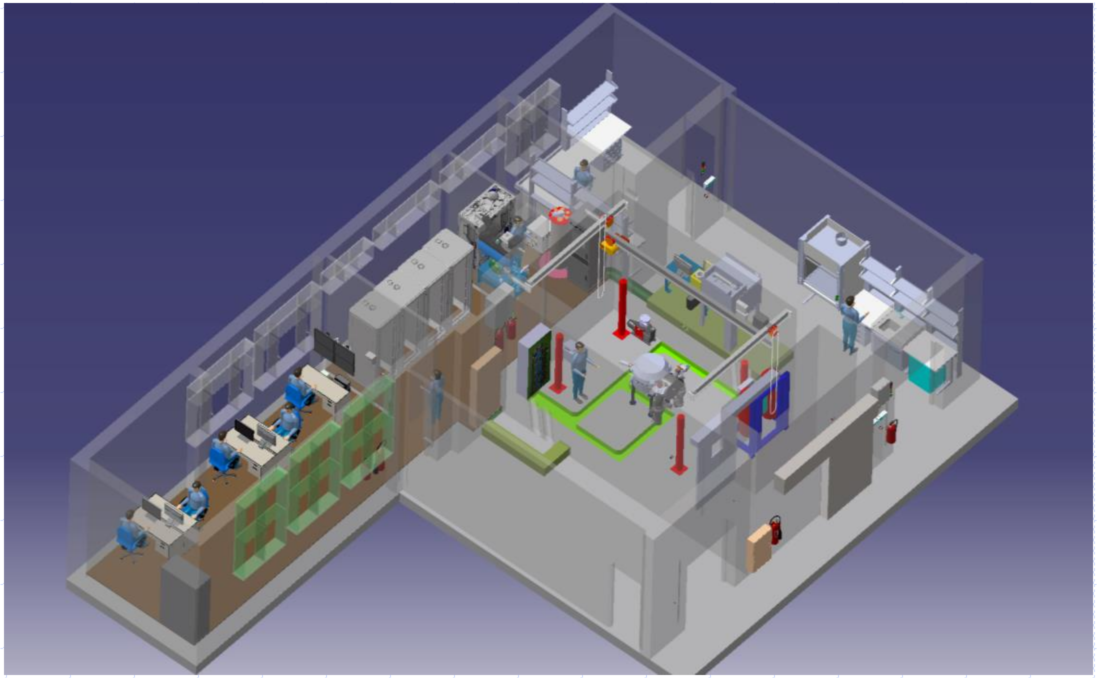
MICROTRON

The CIEMAT Electrical Engineering Unit participates in a project with other national partners for the development and fabrication of a Racetrack Microtron for Intra-Operative Surgery, a 12 MeV, 1 µA machine.



Present CIEMAT contribution to the MICROTRON		
COMPONENT	**TYPE**	**QUANTITY**
LINAC	RF	1
Possible Future CIEMAT contribution to AMIT		
NA	NA	NA

Ongoing Projects and Collaborations



2.1.-Radioisotope Production: The AMIT Project

Radioisotope Production

Radioisotopes are unstable forms of elements. Since they are unstable, they can't be found in nature and they have to be produced artificially.
To make unstable Radioisotopes, we have to change the ratio of Neutrons (N) to Protons (Z) to move outside the Band of Stability.

- **REACTOR BASED PRODUCTION**

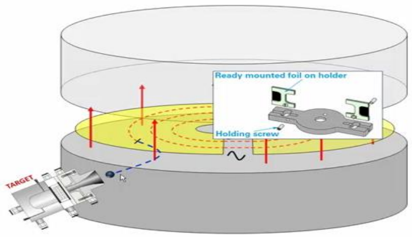
Radioisotopes can be produced in reactors by exposing suitable target materials to the intense reactor neutron flux for an appropriate time.
e.g: Mo-99

- **ACCELERATOR BASED PRODUCTUION**

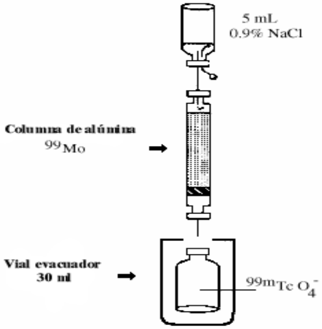
The irradiation of a stable element target with accelerated particles produce positron emitting isotope. e.g: ^{11}C, ^{18}F, ^{13}N

A (p,q) B

A Stable element irradiated
B Generated isotope
p Accelerated particle
q Particle emitted in the reaction



- **GENERATOR BASED PRODUCTION**



Is a container with a parent isotope (long half-life) adsorbed in a ceramic column, which decays relatively slowly into a daughter isotope (short half-life).
An eluent is passed through the column to separate the daughter from the parent.

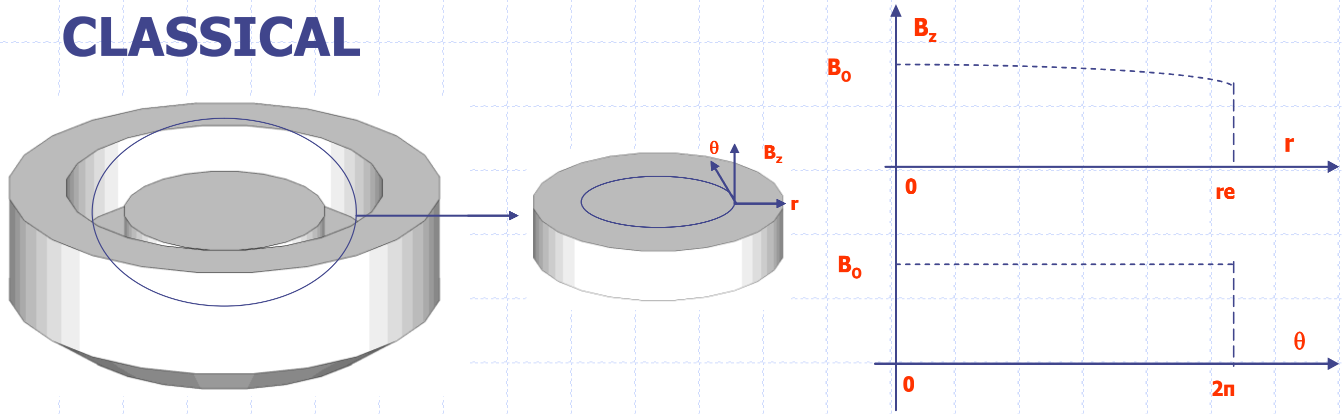
e.g: Mo-99/Tc-99m Generator
Ge-68/Ga-68 Generator

Medical Applications

ISOTOPE	PRODUCTION	$T_{1/2}$	USE	RADIOPHARMACEUTICAL	INDICATIONS
^{18}F	Cyclotron	110 min	Diagnostic	^{18}F-Fluorodeoxyglucose ([^{18}F]-FDG)	-Assessment of glucose metabolism in the brain, cancer, cardiovascular diseases, and infectious, autoimmune, and inflammatory diseases.
				^{18}F-Fluorocholine ([^{18}F]-FCH)	-Used in patients with suspected prostate cancer recurrence.
				^{18}F -Sodium fluoride ([^{18}F]- NaF)	-Monitoring of bone metastasis in breast, gastric, and prostate cancers.
				^{18}F-Fluorodopa ([^{18}F]- FDopa)	-Differential diagnosis of Parkinson's disease
				^{18}F-Fluoromisonidazole ([^{18}F]-FMISO)	-Detection of tumour hypoxia in vivo.
				^{18}F-Fluorotimidine ([^{18}F]-FLT)	-Used to detect tumour proliferation
^{11}C	Cyclotron	20,4 min	Diagnostic	Choline C-11	-Used in patients with suspected prostate cancer recurrence.
				Methionine C-11	-Detecting tumours with high rates of protein synthesis
^{13}N	Cyclotron	10 min	Diagnostic	$^{13}NH4+$	-Myocardial perfusion
^{67}Ga	Cyclotron	78 h.	Diagnostic	–	-Detection of Hodgkin's lymphoma and infections and inflammatory diseases.
^{123}I	Cyclotron	13 h	Diagnostic	Sodium Iodide I-123	-Thyroid images
^{131}I	Reactor	8 d	Therapy	Sodium Iodide I-131	-Treatment of Graves disease, thyroid carcinoma including metastatic disease.
^{68}Ga	^{68}Ge – ^{68}Ga Generator	68 min	Diagnostic	[^{68}Ga]-peptides	-Neuroendocrine tumours
^{99m}Tc	^{99}Mo – ^{99m}Tc Generator	6 h	Diagnostic	^{99m}Tc -MAG-3	-Renal studies
				^{99m}Tc-MDP, ^{99m}Tc-HDP, ^{99m}Tc-HMDP,	-Bone scanning
				^{99m}Tc-MIBI	-Diagnosis of reduced coronography perfusion and myocardial infarction, Scinti-mammography, Parathyroid imaging.
				99mTc-MAA	-Pulmonary perfusion scintigraphy

Alternatives

CLASSICAL



Decreases with r

Decreases with r

$$f_g \approx \frac{eB}{2\pi m_p}$$

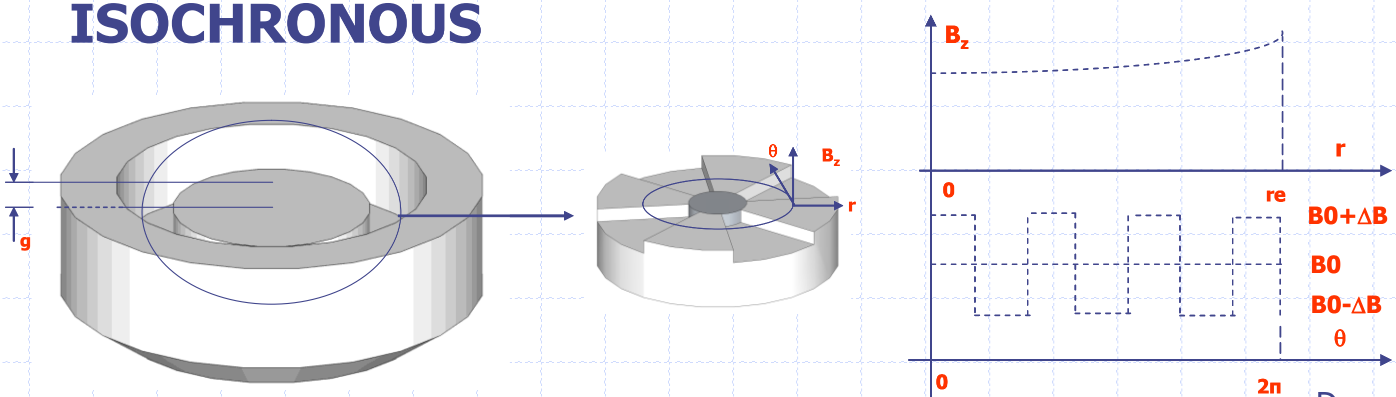
Increases with r

Increasess with r

No electrical frequency compensation > Loss of synchronism

ISOCHRONOUS

Constant



$$f_g \approx \frac{eB}{2\pi m_p}$$

Increases with r

Decreases with r

Decreases with r

No need for electrical frequency compensation > Strong focusing

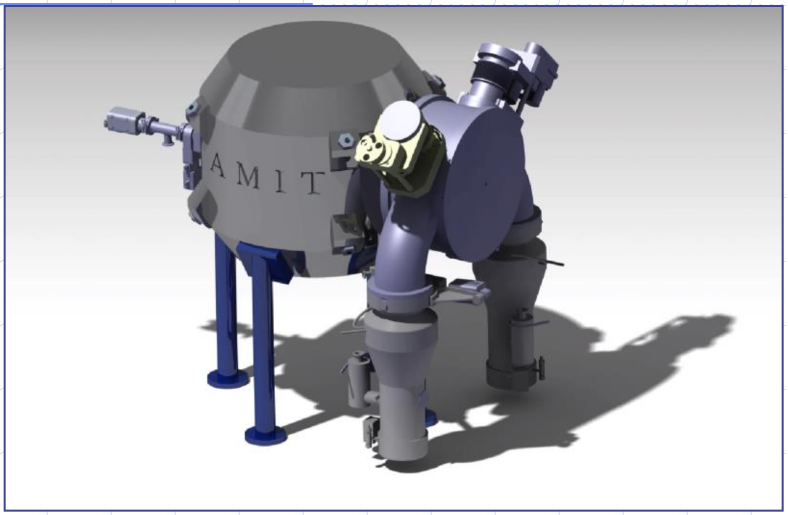
SYNCHROCYCLOTRON

$$f_g \approx \frac{eB}{2\pi m_p}$$

Electrical frequency compensation > Synchronism achieved & pulsed operation

Increases with r

The AMIT Project

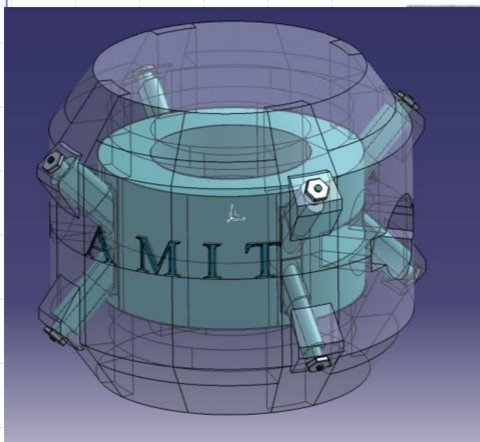


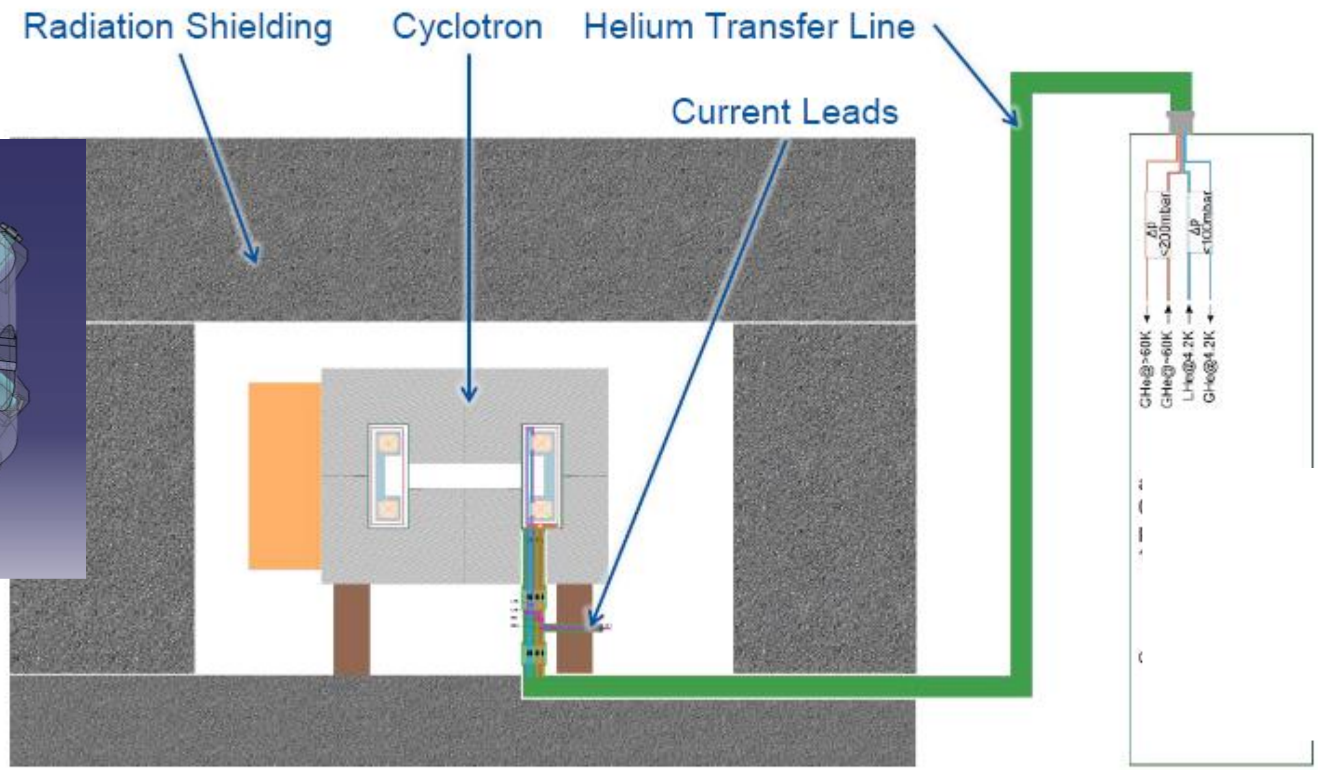
PARAMETER	VALUE	UNITS
GENERAL		
Energy	>8.5	MeV
Current	>10	µA
Cyclotron Type	Classical	
MAGNET		
Type	Low Tc Superconductor	
Configuration	Warm Iron	
Superconductor	NbTi	
Central Field	4	T
RF SYSTEM		
Configuration	One 180º Dee	
Accelerating Voltage	> 60	kV per Dee
ION SOURCE		
Type	Internal	
Ions	H^-	

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 Cyclotron for ^{11}C and ^{18}F production. It includes the development and fabrication of the targets and the installation of a complete experimental facility.

Present CIEMAT contribution to AMIT		
COMPONENT	**TYPE**	**QUANTITY**
Complete Superconducting Cyclotron Prototype	Accelerator	1
Possible Future CIEMAT contribution to AMIT		
Participation in Cyclotron Industrialization & Commercialization	Industrial Alliance	TBD

The Magnet of the AMIT Cyclotron





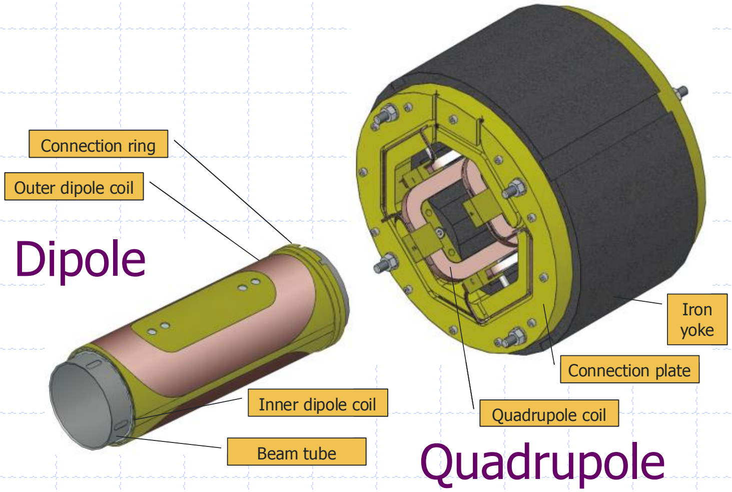
The AMIT Cyclotron uses a NbTi superconducting warm iron magnet suspended from the iron. It is cooled down using a helium recirculation external system.

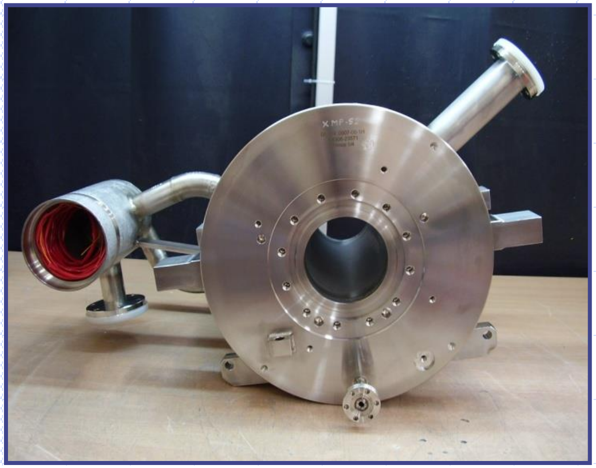
Contribution by Components

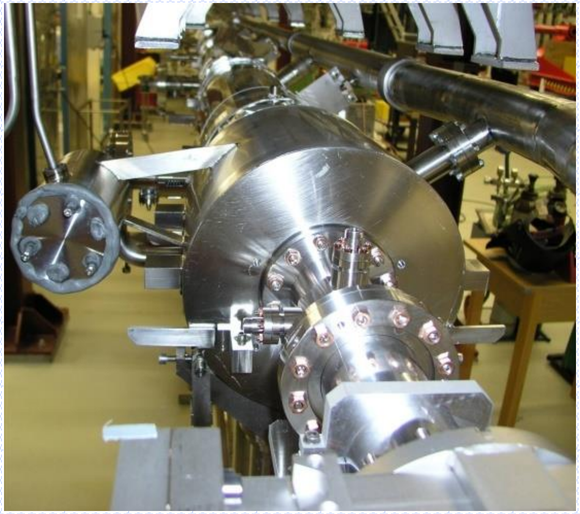
SC MAGNETS

SC Magnets (1)

Superconducting Magnet for E-XFEL for the Main LINAC





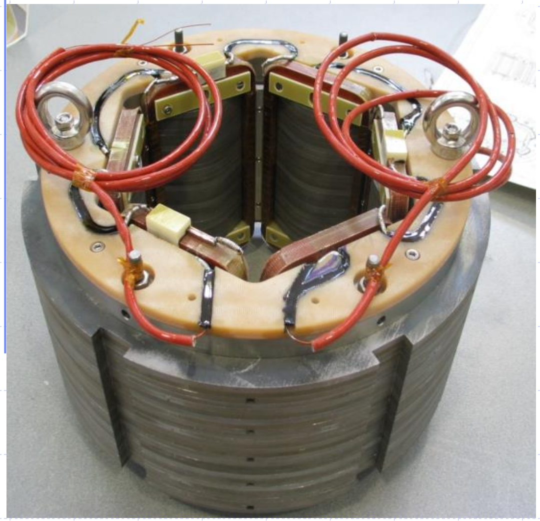


Type: Combined	Quadrupole	Dipole (2)
Integrated Field	5.97 T	0.75E-3 Tm
Inner Diameter	94.4 mm	83.6 mm
Op. Current	50 A	
Technology	NbTi Superferric	
Industrialization	Yes: Series by ANTEC+ TRINOS Vacuum Projects	

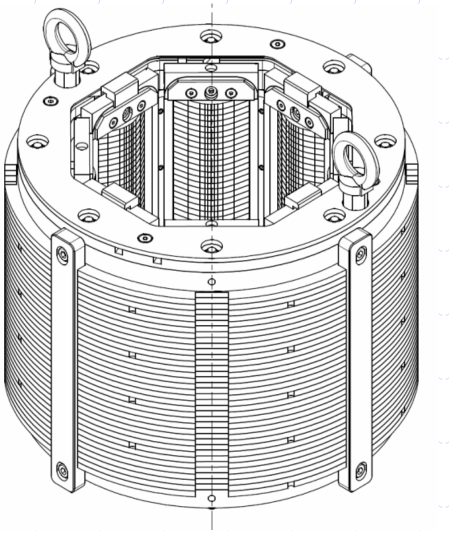
SC Magnets (2)

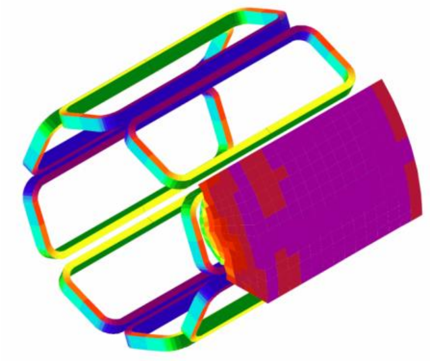
SC MAGNETS

Superconducting Magnets for LHC Hi-Lumi

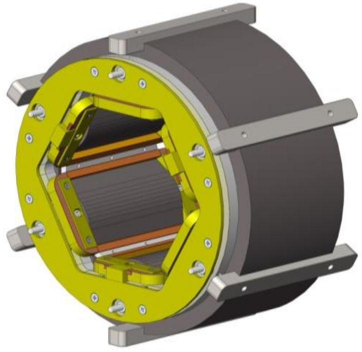


Sextupole





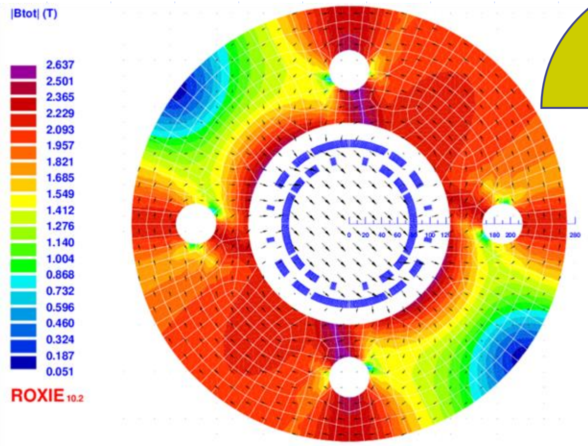
Octupole

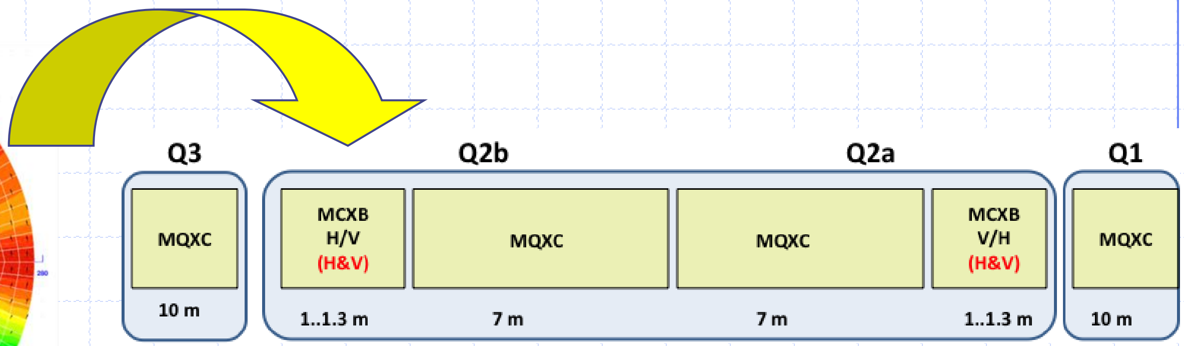


Type	Sextupole	Octupole
Integrated Field	0.055 Tm	0.035 Tm
Physical Length	160 mm	160 mm
Op. Current	100 A	100 A
Technology	NbTi Superferric	NbTi Superfereric Rad. Resistant
Industrialization	NO	NO

SC Magnets (3)

Superconducting Magnets for LHC Hi-Lumi





MCBXS H&V Combined Corrector Dipole

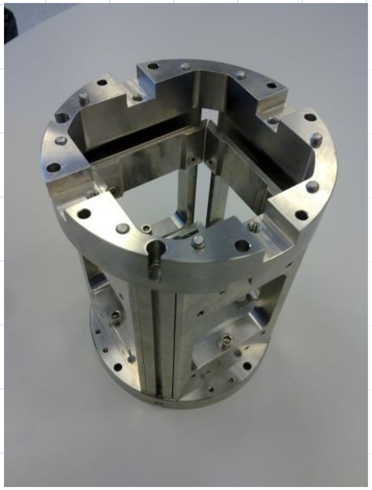
Type	Combined Corrector Dipole
Integrated Field	2.5 Tm
Physical Length	1200 mm
Aperture	150 mm
Technology	Nested NbTi Coils @ 1.9K
Industrialization	Yes (TBD)

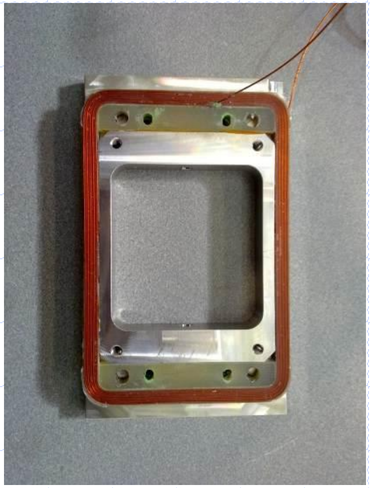
DATE	MILESTONE
June 2014	Conceptual Desing
Feb 2015	Fabrication Drawings
Feb 2016	1st Prototype Finished
Nov 2016	Tests @ CERN
CERN: 50% Personnel & 100% Materials CIEMAT: 50% Personnel & 100 % Tooling	

SC Magnets (4)

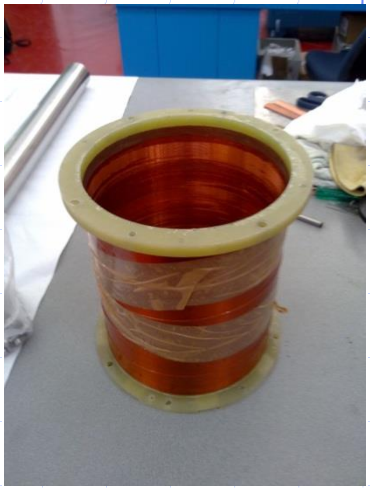
SC MAGNETS

Superconducting Magnet for LIPAc

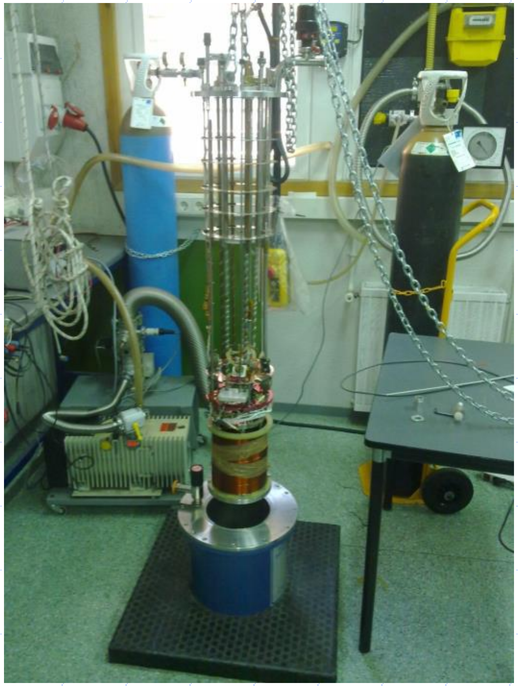




Dipoles



Solenoids

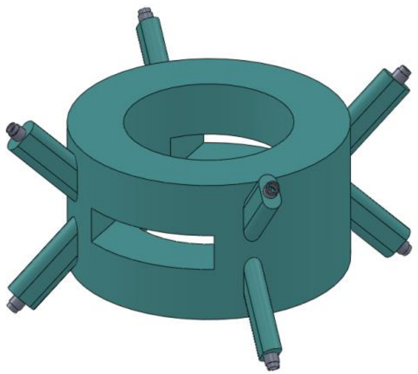


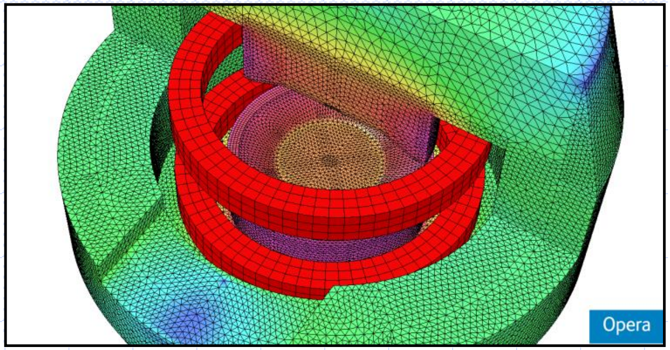
Type: Combined	Solenoid (2)	Dipole (2)
Integrated Field	1.1 Tm	3.51 mTm
Overall Length	400 mm	
Op. Current	210 A	50 A
Technology	NbTi Wet Impregnation	NbTi Mould Impregnation
Industrialization	YES: TBD for series production	

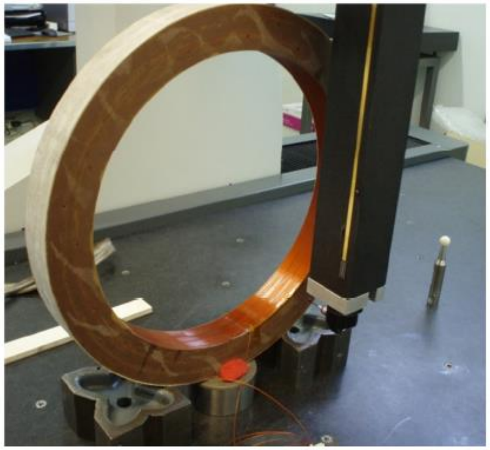
SC MAGNETS

SC Magnets (5)

Superconducting Magnet for AMIT



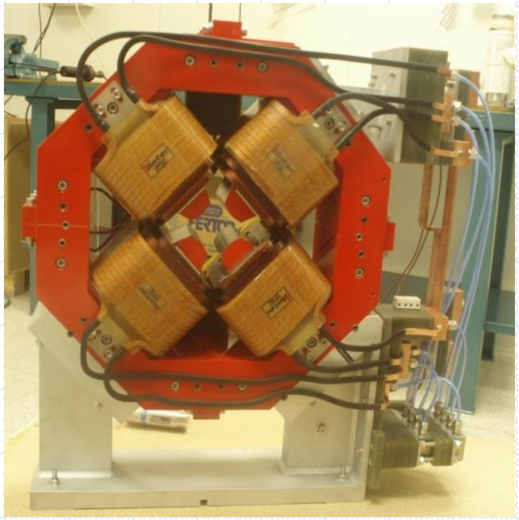




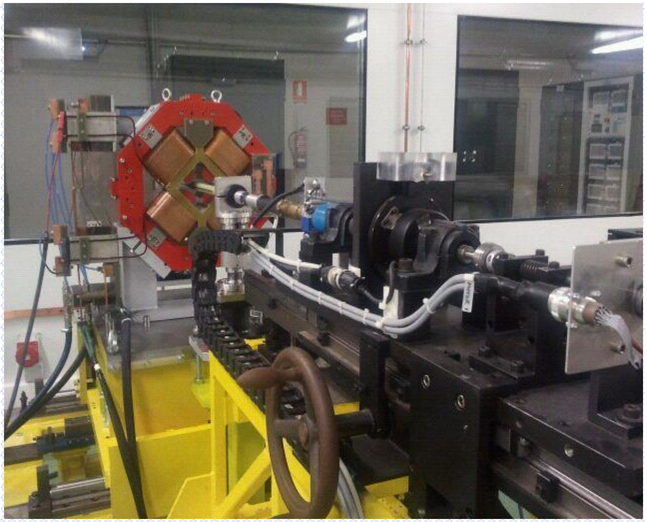
Type:	2 Solenoid in Hemholtz Coils Config.
Central Field	4.0 Tm
Overall Diameter	700 mm
Op. Current	110 A
Technology	NbTi Wet Impregnation 2 phase helium cooling
Industrialization	YES: Prototype by ANTEC + TRINOS Vacuum Projects

Resistive Magnets

Resistive Magnet for LIPAc



Quadrupole

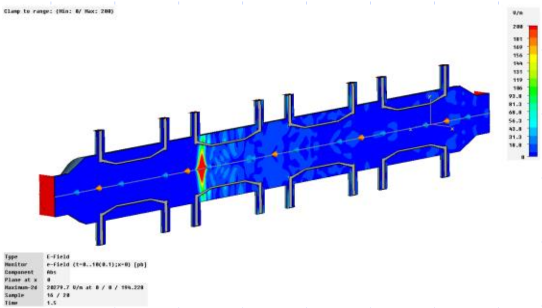


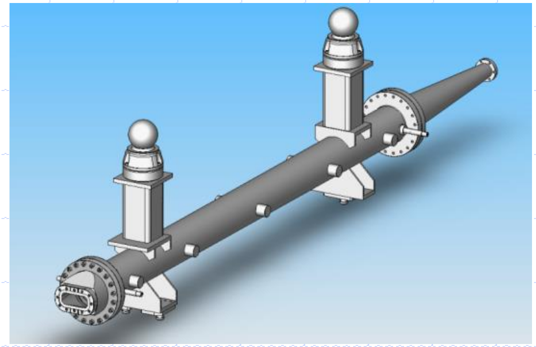
Type: Combined	Quadrupole	Dipole
Integrated Field	0.068 ÷ 0.163 Tm	3.51 mTm
Inner Diameter	56 ÷ 136 mm	
Op. Current	178 ÷ 313 A	50 A
Technology	Water Cooled Radiation Resistant	Air Cooled Radiation Resistant
Industrialization	YES: First Prototype made at ANTEC	

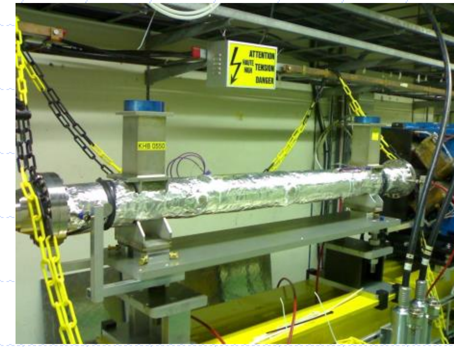
SPECIAL MAGNETS

Special Magnets (1)

Kickers for CTF3







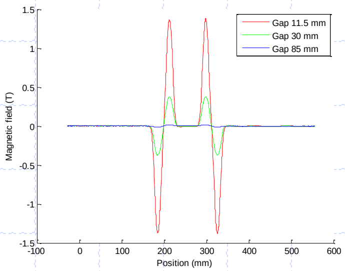
Extraction kicker

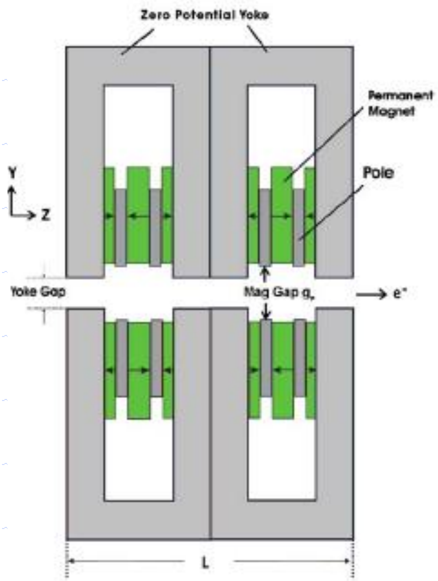
Tail Clipper

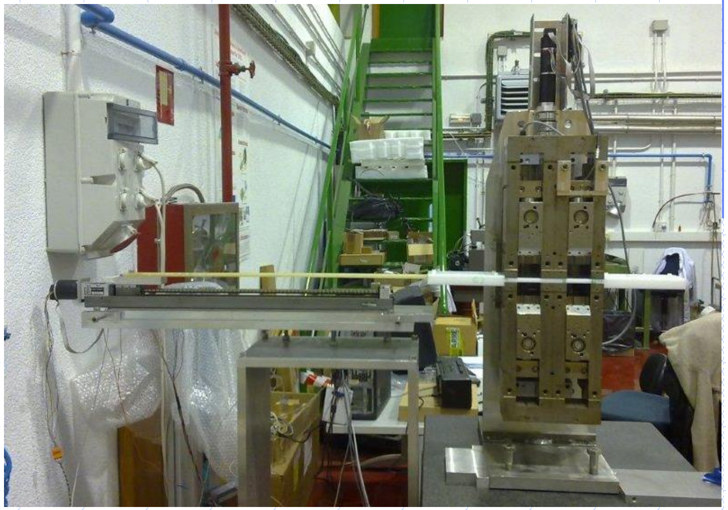
Type	Strip-Line Extraction kicker	Strip-Line Tail Clipper
Nº of Modules	1	4
Deflection	5 mrad	1.2 mrad
Rise time	≤70 ns	≤5ns
Length	2000 mm	4 x 1625 mm
Op. Voltage	14.4 kV	4 x 2 kV
Technology	Full Stainless Steel Tapered Ends Transmission Line	
Industrialization	YES: Prototypes partially made at TRINOS Vacuum Projects	

Special Magnets (2)

Phase Shifters for E-XFEL



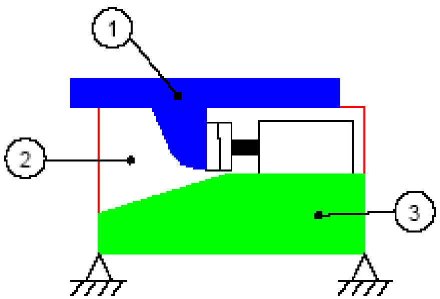


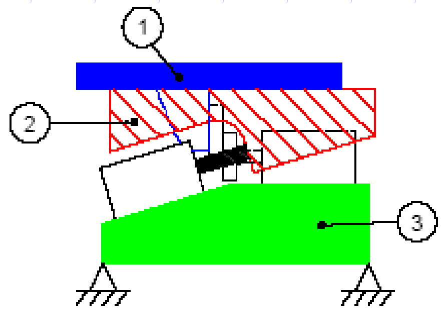


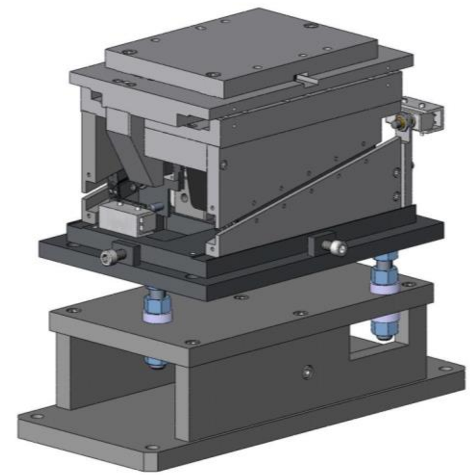
Type	Rare Earth Permanent Magnet
First Field Integral	≤0.004 Tmm
Second Field Integral	≤0.67 Tmm^2
Gap	10.5 ÷ 100 mm
Technology	NbFeB Magnets + Pure Iron Yoke
Industrialization	YES: 3 Prototypes by INDEX, DMP-HTS & HUERTA Series Production rejected by E-XFEL

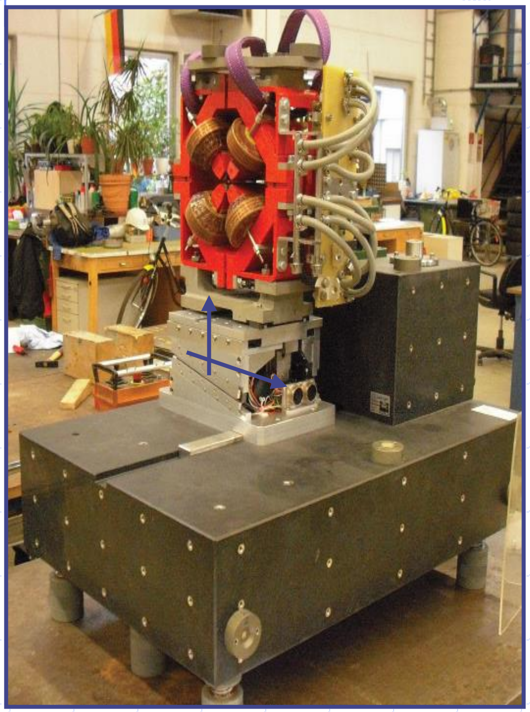
Mechanics (1)

Moving Tables for E-XFEL







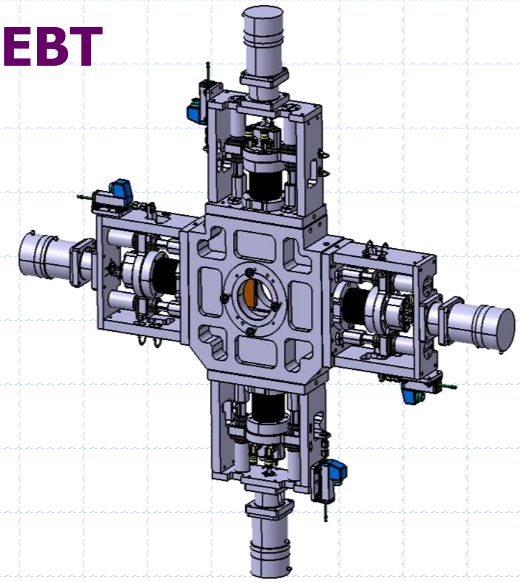


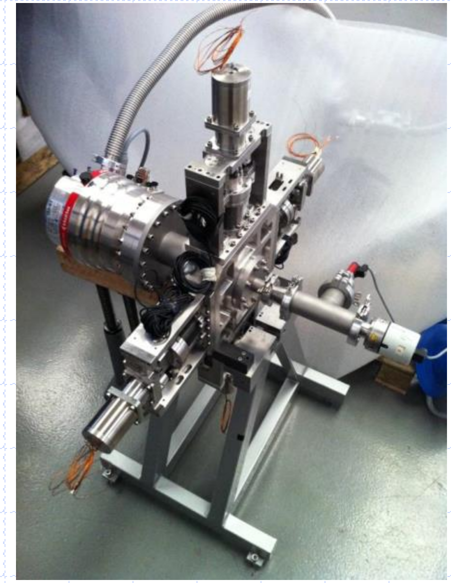
Type	2-axes Quadrupole Positioning Table
Range	±1.5mm
Repetitivity	≤1µm
Max Load to move	70 kg
Technology	St.Steel & Aluminium. Closed Loop
Industrialization	YES: Prototypes made at AVS, NOVALTI,INDEX,APM,HUERTA, DMP-HTS, RAMEM Series to be done at DMP-HTS & RAMEM

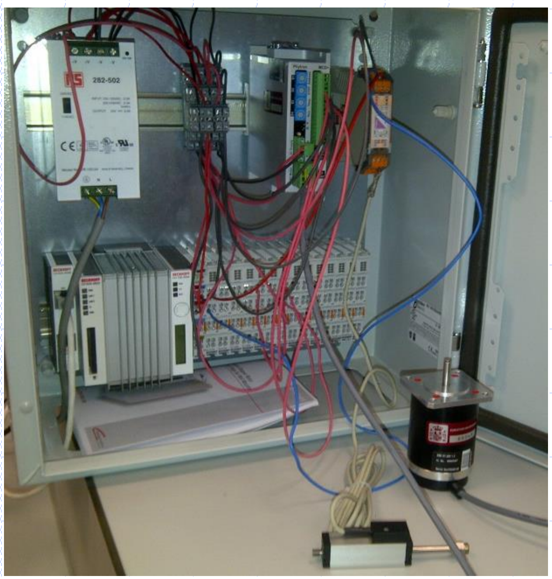
MECHANICS

Mechanics (2)

Scrapers for LIPAc MEBT





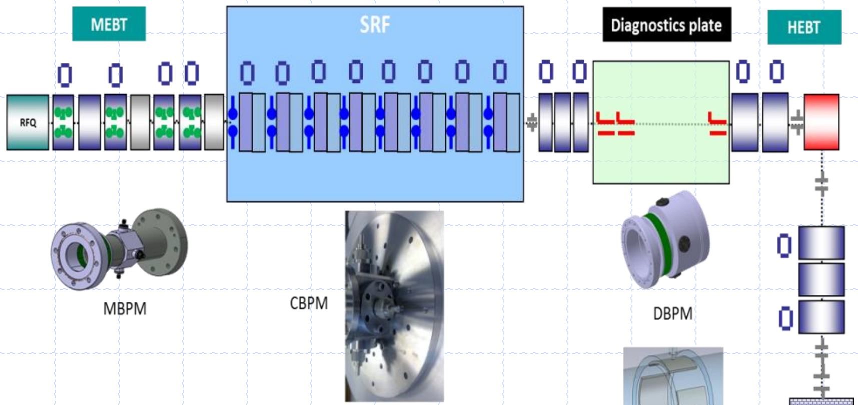


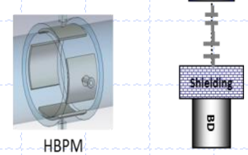
Type	4-Collimator Scraper
Displacement Range	21mm
Movement Precision	20 µm
Max Dissip .Power	4 x 500 W
Technology	Water-cooled, Step motor controlled in closed loop
Industrialization	YES: First Prototype at AVS

Mechanics (3)

MECHANICS

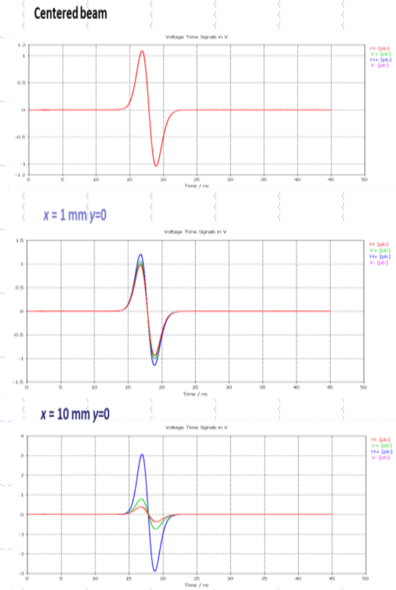
Beam Position Monitors for LIPAc



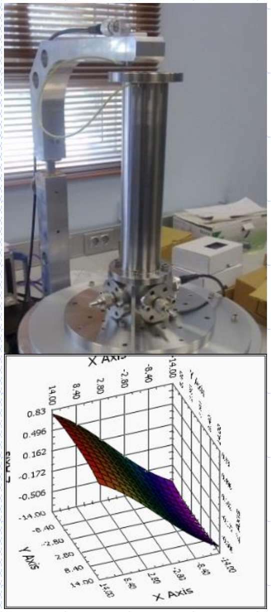


Region	BPM acronym	Aperture	Number	Symbol
MEBT	MBPM	48 mm	4	
SRF	CBPM	50 mm	8	
Diagnostics plate	DBPM	100 mm	3	
HEBT	HBPM	40/130/150 mm	1/3/1	
TOTAL			20	

Beam steerers (hor + vert)



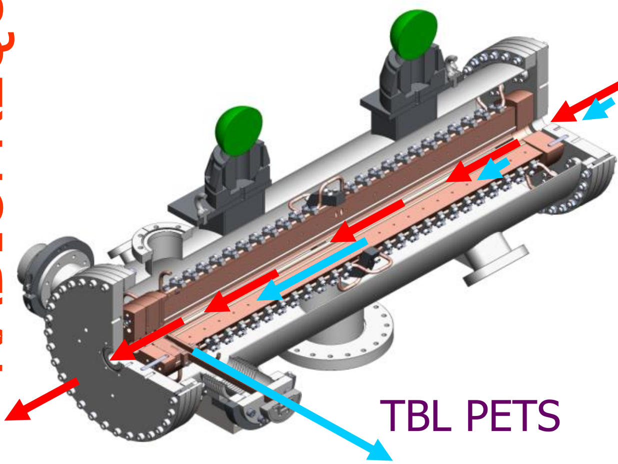
Wire test bench



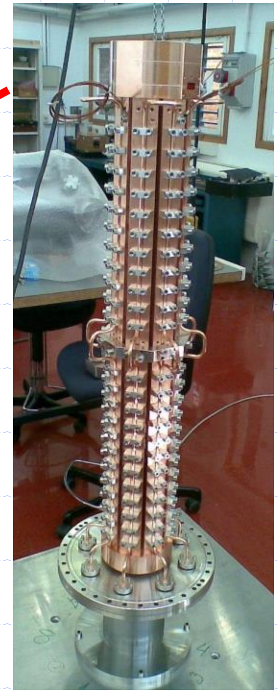
Types (4)	RF pickups for position and phase of beam centroid
Aperture	50 ÷ 130 mm
Resolution	≤100 μm
Accuracy	≤250 μm
Technology	Striplines and buttons. Room & Cryogenic Temp.
Industrialization	YES: 4 MBPM made at TRINOS Vacuum Projects

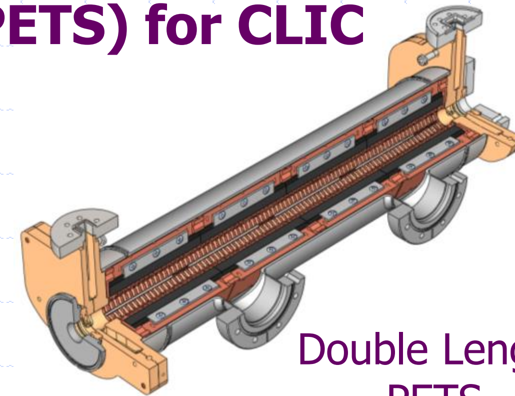
Radiofrequency (1)

Power Extraction Transfer Structures (PETS) for CLIC

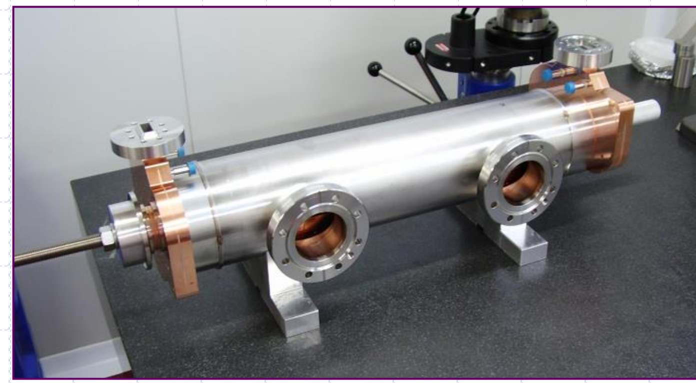


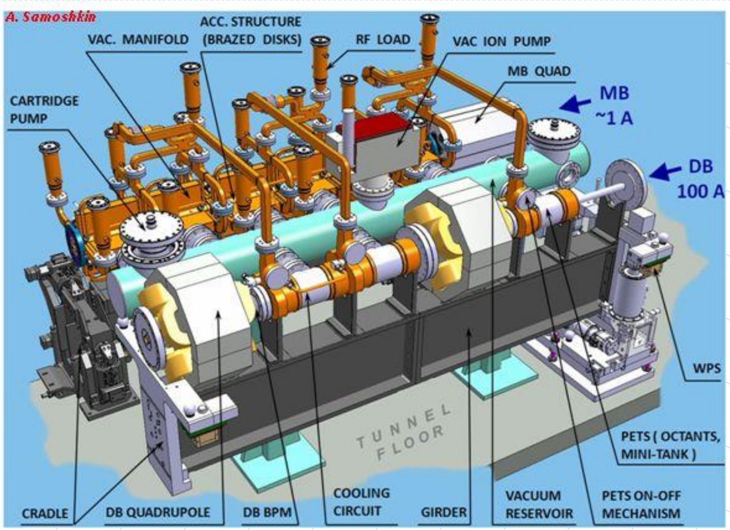
TBL PETS





Double Length PETS



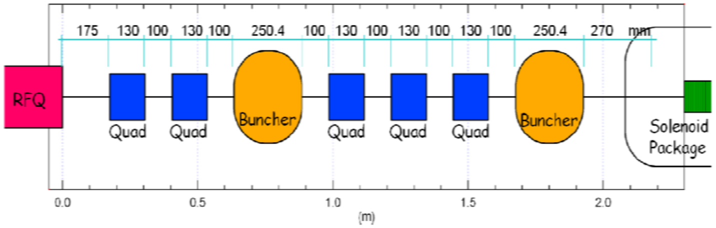


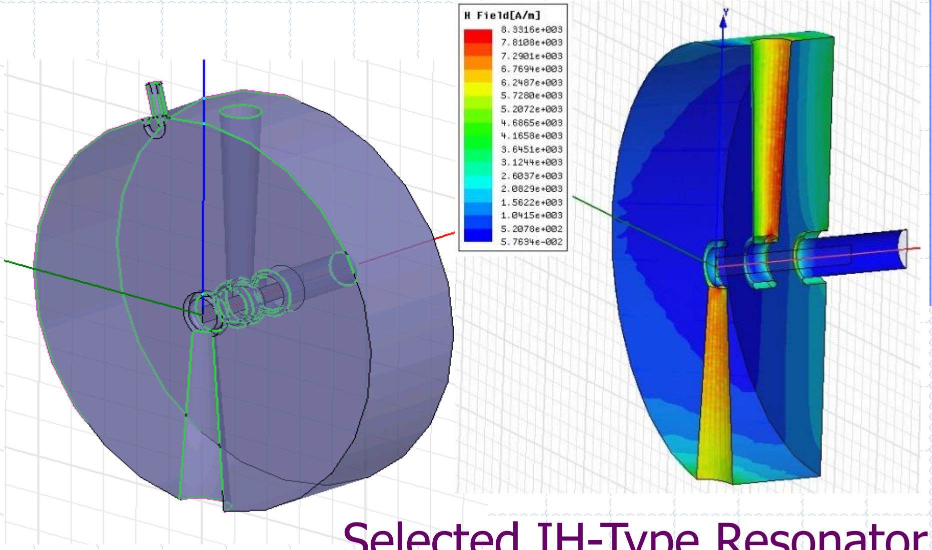
Type	TBL PET	Double Length PET
Op. Frequency	12 GHz	12 GHz
Length	4 x CLIC	2 x CLIC
Technology	Warm in Octants	Warm in Octants: Minitank, Integrated Couplers
Industrialization	YES: Partial Supplies by DMP-HTS, TRINOS Vacuum Projects & HUERTA	

RADIOFREQUENCY

Radiofrequency (2)

Buncher for LIPAc



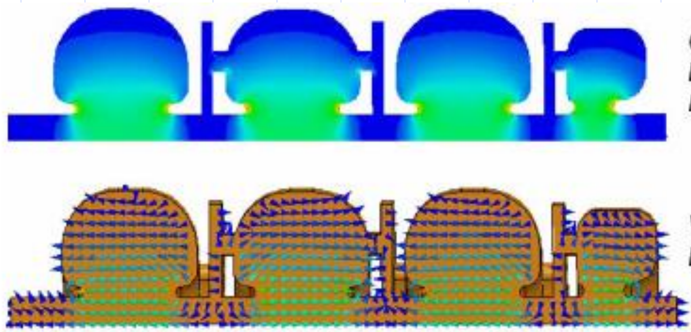


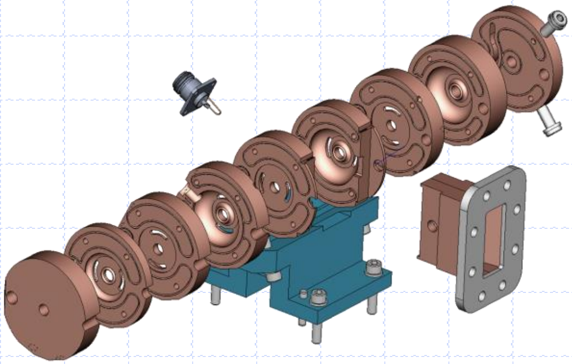
Selected IH-Type Resonator

Type	IH Resonator, 4 Acceleration gaps
Frequency	175 MHz
Peak Electric Field	24 kV
Max Dissip. Power	≤100 kW
Technology	Resistive, Water-cooled,
Industrialization	YES: First Prototype to be done at DMP-HTS

Radiofrequency (3)

LINAC for a Racetrack Microtron



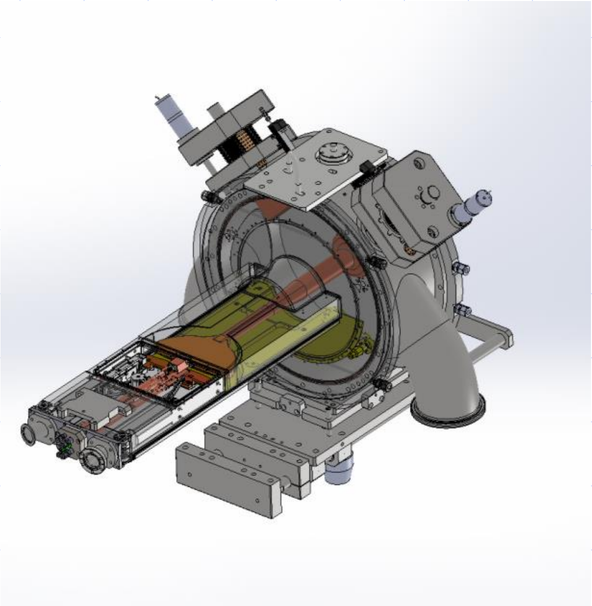


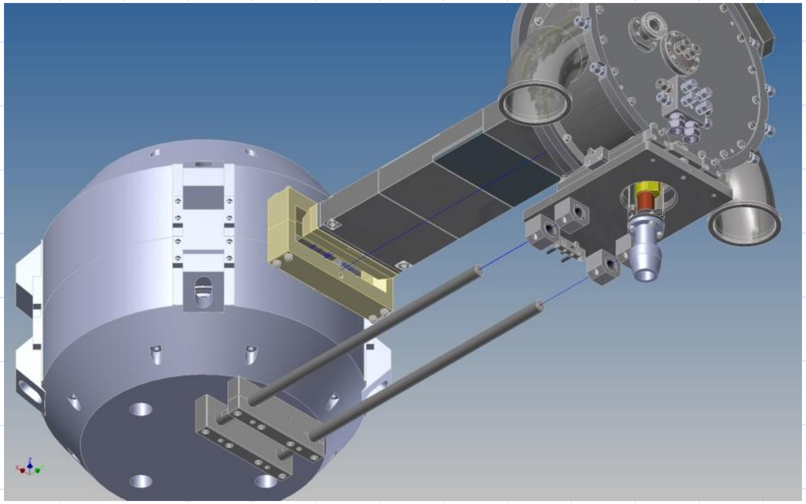
Type	Standing Wave C-Band Linac
Frequency	5712 MHz
Gain per turn	2 MeV
Pulsed Dissip. Power	600 kW
Quality Factor	9860
Technology	3 and ½ Copper Cells with coupling slots
Industrialization	YES: First Prototype partially done at HUERTA

RADIOFREQUENCY

Radiofrequency (4)

RF System for a Superconducting Compact Cyclotron



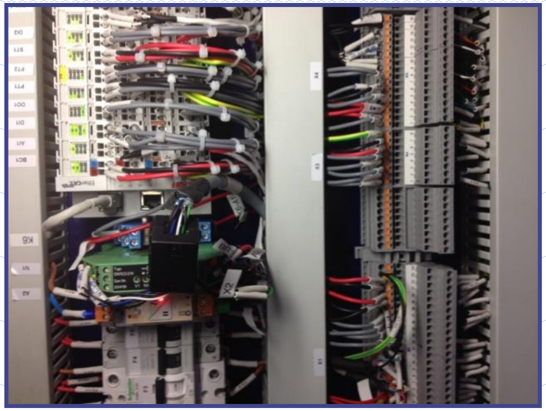


Type	1 Dee + 1 Stem + 1 Resonator
Frequency	60.134 MHz
Gain per gap	60 keV
Dissip. Power	5360 W
Quality Factor	5250 (Unloaded)
Technology	Resistive, Water Cooled
Industrialization	1st Prototype at Industry

Electronics & Instrumentation (1)

ELECTRONICS & INSTRUMENTATION

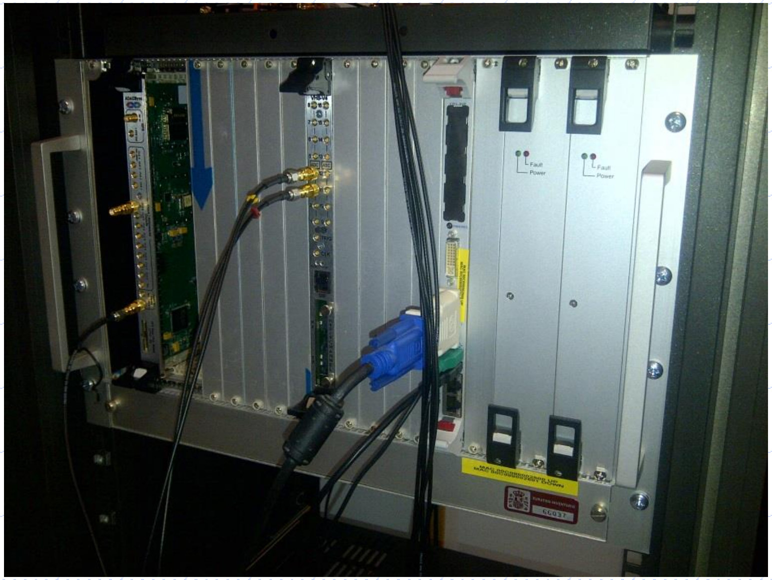
ICR for E-XFEL

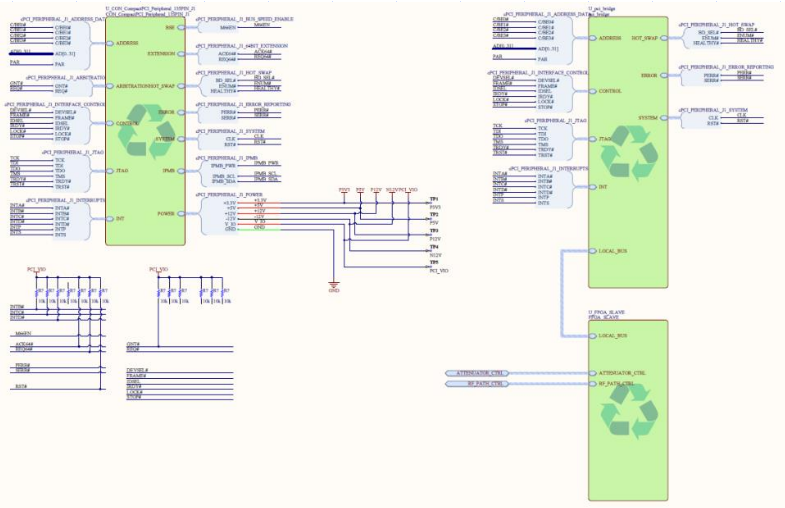


Type	Intersection Control Rack
Protection	IP54
Dimensions	1000 x 500 x 500 mm
Technology	Forced air cooling and high security cabling. Based on Beckhoff Modules
Industrialization	YES: 4 Prototypes done at ALDERAN, INABENSA, PINE & SINTERSA. Series at PINE

Electronics & Instrumentation (2)

Electronics for the Beam Position Monitors for LIPAc





Type	Acquisition electronics for BPMs
Nº of Channels	8 (2 BPMs per card)
Position Resolution	10 µm
Phase resolution	0.3º
Technology	Data Acquisition System based on 14 bit ADC per channel
Industrialization	YES: Prototype at CIEMAT. Series TBD

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.)
DMP-HTS	Moving Tables for E-XFEL	Mechanics	44 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.)
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.	91 series
RAMEM	Moving Tables for E-XFEL	Mechanics	44 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