Spanish Accelerator R&D

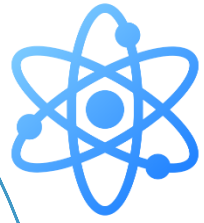
Concepción Oliver
CIEMAT

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

XVI CPAN days – 19 November 2024

Content

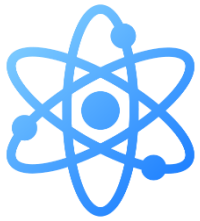


International HEP context

Accelerator R&D Roadmap

Spanish Accelerator Community

*** It's not an exhaustive review of accelerator R&D in Spain. Apologies for any important omission**

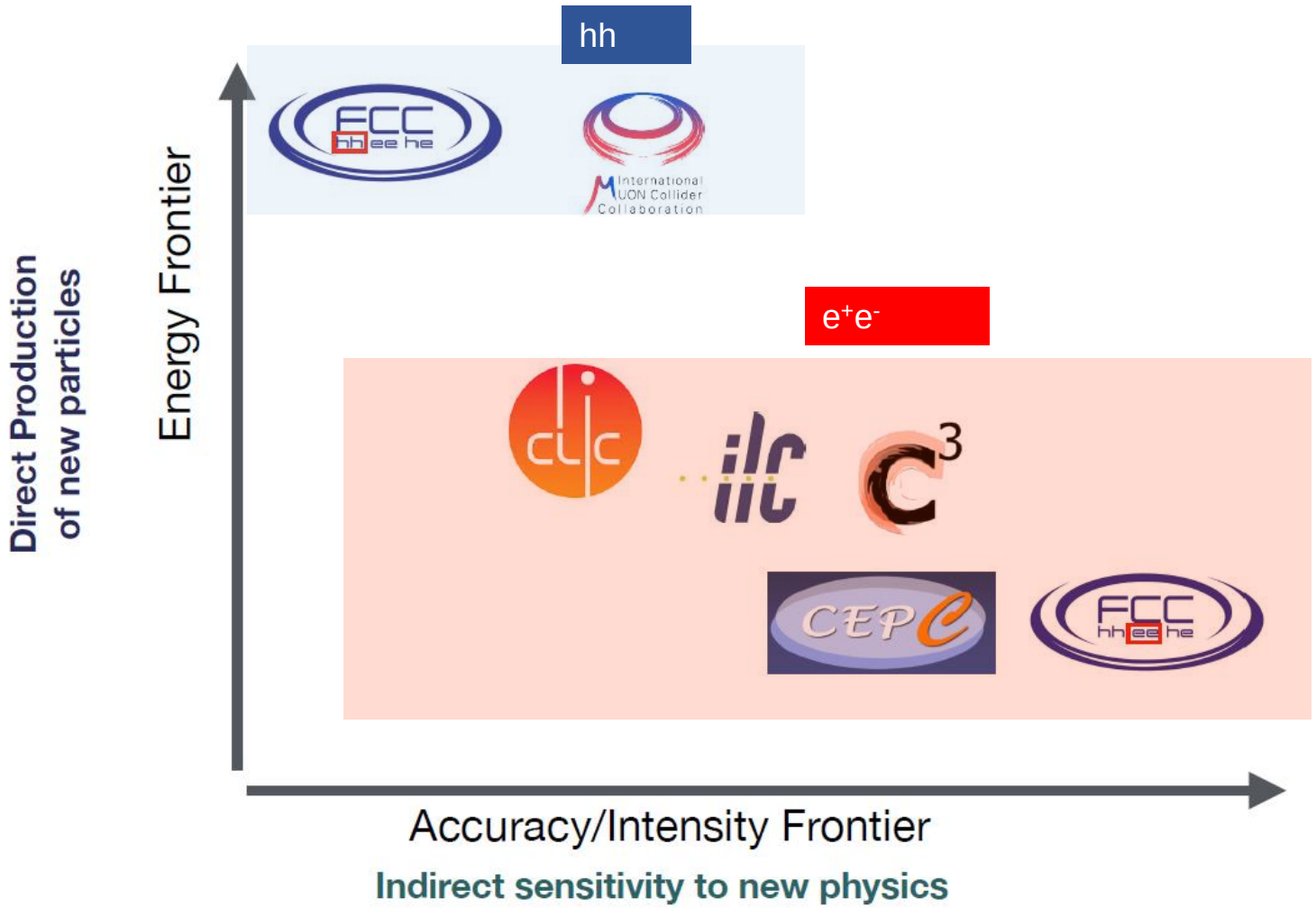


International HEP Accelerators context

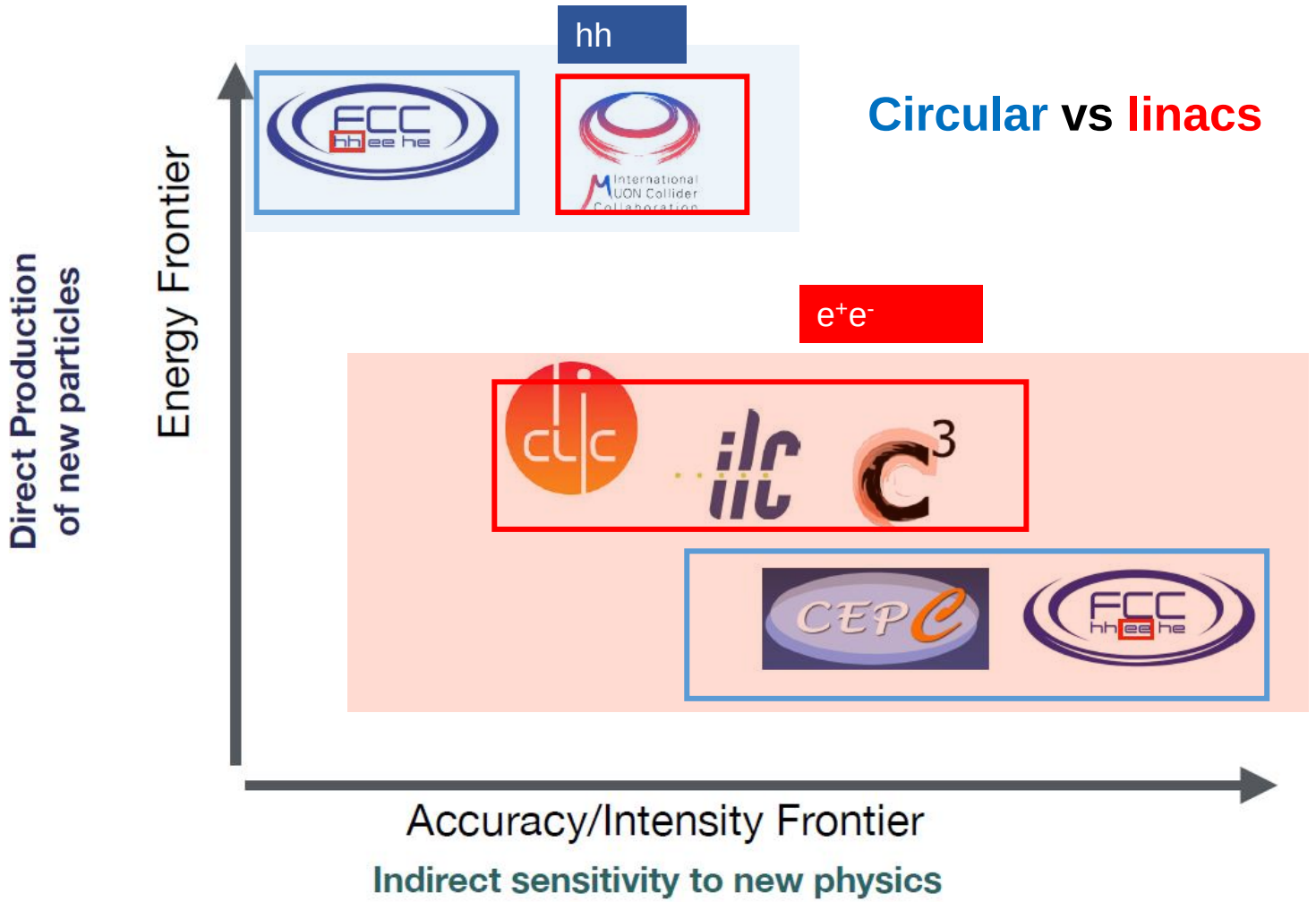
Strategy

	SHORT TERM	MEDIUM TERM	LONG TERM
Accelerator	LHC upgrade (HL-LHC)	e+e- colliders	10 TeV CM colliders
Technology maturity	Ongoing manufacturing	Feasible technology	High R&D and financial effort
Candidates	HL-LHC	ILC, CLIC, FCC-ee, CEPC, C3	FCC-hh, SppC, 10 TeV Muon Collider
	Higher Higgs precision	**Higgs factory / Electroweak/top Physics**	**BSM Physics**

HEP colliders



HEP colliders



Circular vs linacs

Challenges

Circular e^+e^-

$$P \approx 3\,X\,10^{-7}\left(\frac{1\,km}{R}\right)^2\left(\frac{E}{m}\right)^4 eV/s$$

- Power loss
- Large dimension

Linear e^+e^-

- Upgradeable
- No multiple turns
- High RF power (proportion to V^2)
- Electric field optimization

Circular pp

$$B \approx 3\left(\frac{E}{1\,TeV}\right)\left(\frac{1\,km}{R}\right)T$$

- Large radius
- Very high magnetic field

Circular muon collider

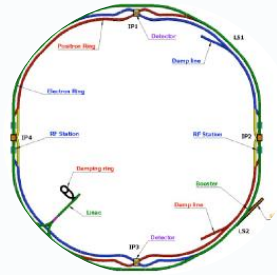
- Elementary particle
- Heavier than p → no power loss
- Lower energy
- R&D in technology

Higgs Factory: candidates

Circular e+e- colliders

FCC-ee: *CERN*
Viability study

CEPC: China
TDR, approval pending

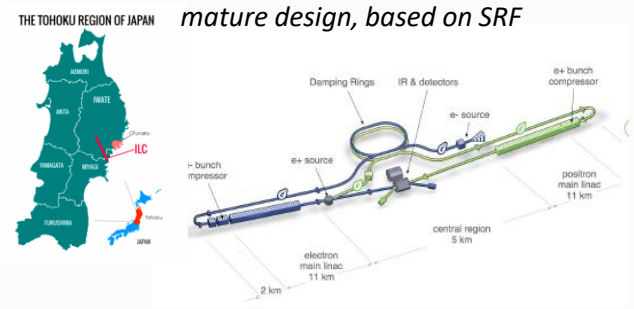


Large size, power consumption

Linear e+e- colliders

ILC: 250/500 GeV

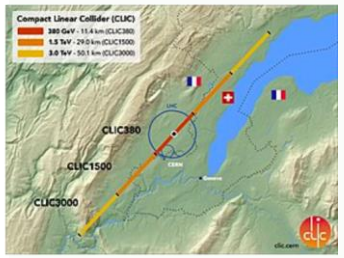
mature design, based on SRF

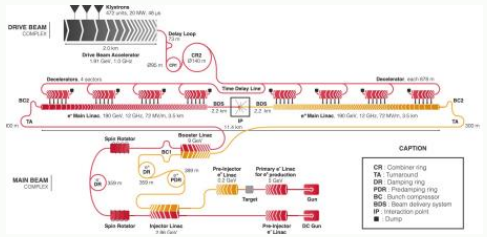


20.5 km, Japan/Europe

CLIC 380/1000/3000 GeV

high gradient beam drive RF for higher energy

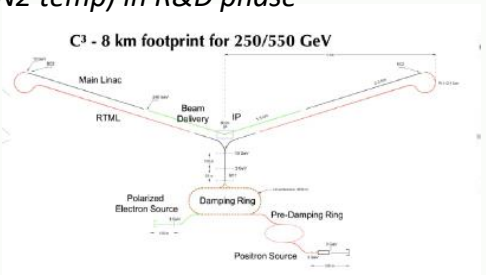




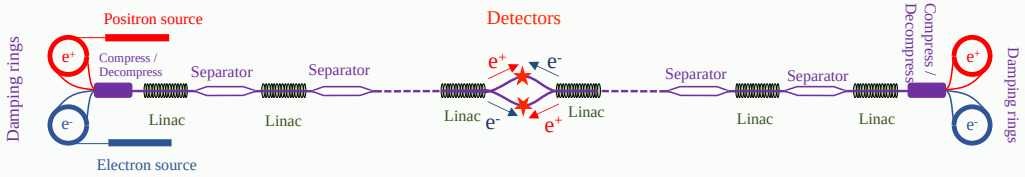
11.4 km

C³: 250/550 GeV... > TeV

Cu cavity (LN2 temp) in R&D phase

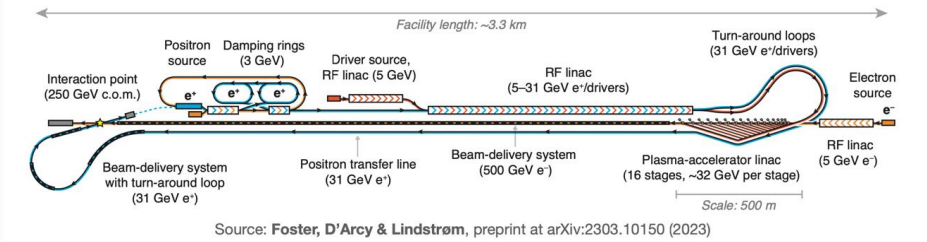


Recirculating Linacs



HALHF

Wakefield accelerator, 3.3 km, built anywhere



Source: **Foster, D'Arcy & Lindstrøm**, preprint at arXiv:2303.10150 (2023)

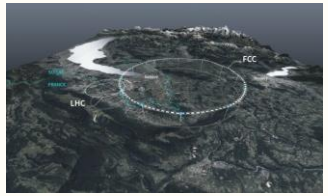
Long term candidates

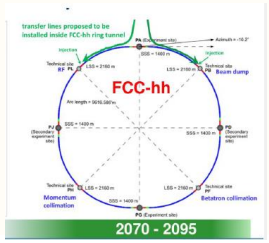
Timeline determined by:

- R&D requirements (e.g., HFM)
- High construction and operation cost (Sustainability!!)

FCC-hh: pp at √s=80-100 TeV

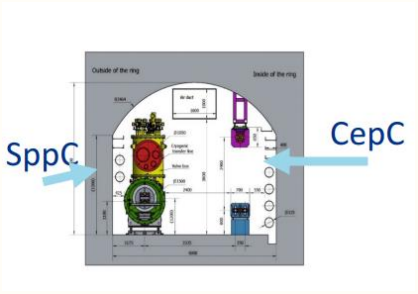
- Tunnel FCCee, CERN experience, 4 collision points (+)
- R&D magnetic field (14-16 T?)





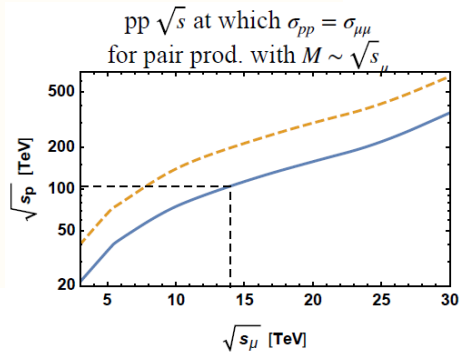
SppC: √s=125 TeV

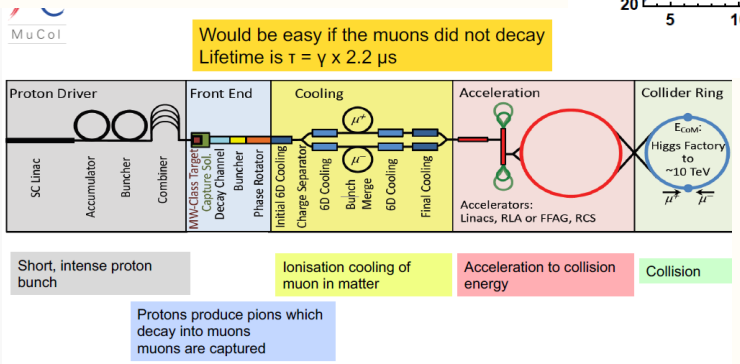
- CepC tunnel
- 20 T magnets
- Intermediate stage with 12 T magnets



Muon collider

- Lower energy for 10 TeV CM physics
- Smaller (10 km circumference) , more luminosity/TWh (+)
- Technological challenges (-)
  - ✓ Cryomodules operating a high B
  - ✓ 20 T HTS solenoid
  - ✓ Muon cooling system
  - ✓ Neutrino effect





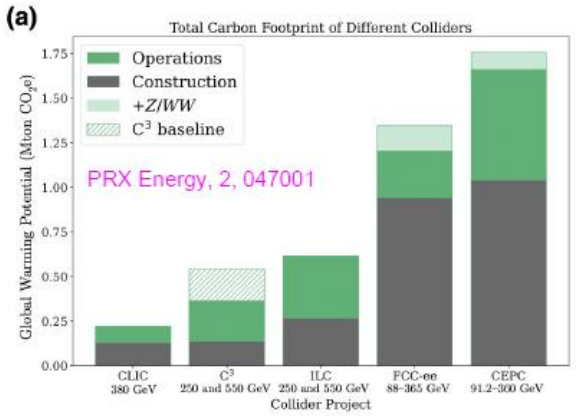
CLIC 3 TeV

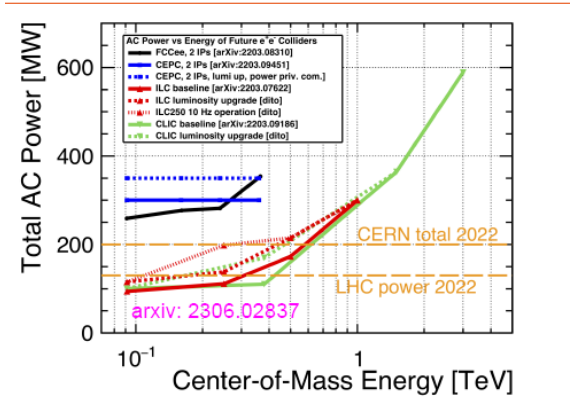
- CDR, demo facilities (+)
- Large dimensions and high power consumption (-)

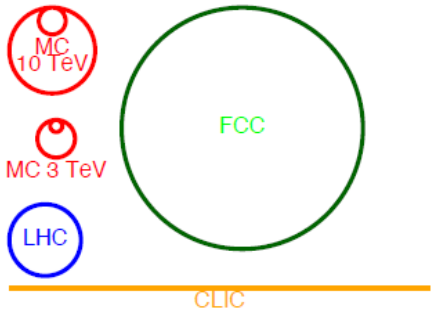
HEP accelerators: comparison

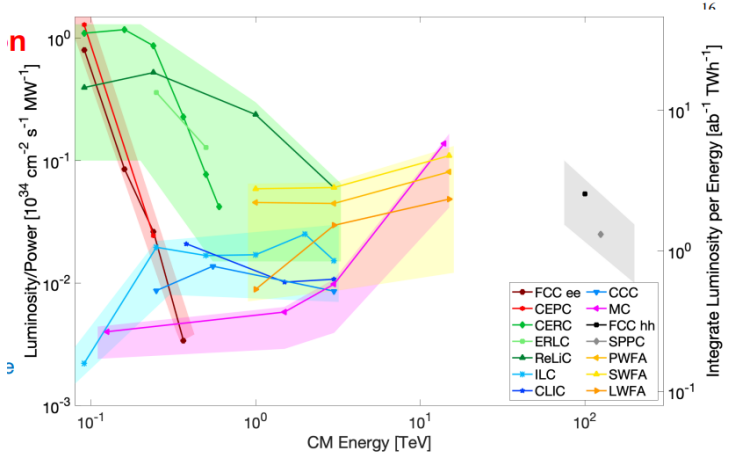
Required R&D:

- Medium term (ILC, CLIC, FCCee),
- Medium-Long term (FCC, linac upgrade, SppC)
- Very long term (Muon collider, Plasma …)









- ❑ Sustainability
- ❑ Geopolitics
- ❑ Community engagement
- ❑ Leadership
- ❑ Upgrade possibilities
- ❑ Funding timeline

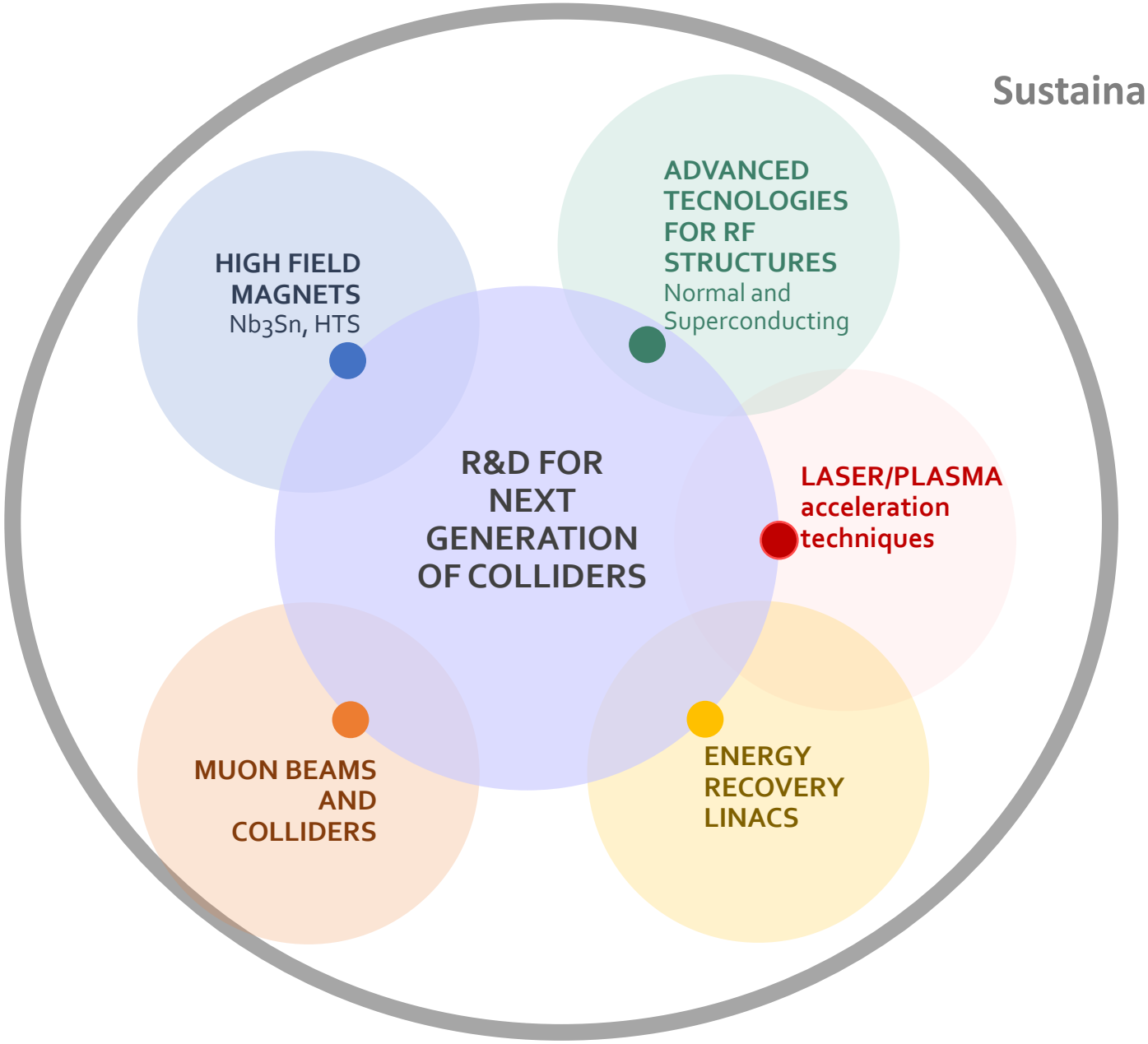
Nombre	Energía TeV	Consumo potencia (MW)	Tamaño (km)	Complejidad	Riesgo	Coste	Años para física
FCC-ee (0.24 TeV)	0,24	290	91	1	1	12-18	13-18
CEPC (0.24 TeV)	0,24	340	100	1	1	12-18	13-18
ILC (0.25 TeV)	0,25	140	20,5	1	1	7-12	<12
CLIC (0.38 TeV)	0,38	110	11,4	2	2	7-12	13-18
CCC (0.25 TeV)	0,25	150	3,7	1	1	7-12	13-18
CERC (0.24 TeV)	0,24	90	91	2	2	7-18	>25
ReLiC (0.24 TeV)	0,24	315	20	2	2	7-18	>25
ERLC (0.24 TeV)	0,24	250	30	2	2	12-18	>25
XCC (0.125 TeV)	0,125	90	1,4	2	2	4-7	19-25
MC (0.13 TeV)	0,13	200	0,3	1	3	4-7	19-24
ILC (3 TeV)	3	400	59	2	2	18-30	19-24
CLIC (3 TeV)	3	550	50,2	3	2	18-30	19-24
CCC (3 TeV)	3	700	26,8	2	1	12-18	19-24
ReLiC (3TeV)	3	780	360	3	3	30-50	>25
MC (3 TeV)	3	230	10	2	3	7-12	19-24
LWFA (3 TeV)	3	340	1,3	2	4	12-80	>25
PWFA (3 TeV)	3	230	14	2	4	12-30	19-24
SWFA (3 TeV)	3	170	18	2	4	12-30	>25
MC (10 TeV)	10	300	27	3	3	12-18	>25
LWFA (15 TeV)	15	1030	6,6	3	4	18-80	>25
PWFA (15 TeV)	15	620	14	3	4	18-50	>25
SWFA (15 TeV)	15	450	90	3	4	18-50	>25
FCC-hh (100 TeV)	100	560	91	2	3	30-40	>25
SPPC (125 TeV)	125	400	100	2	3	30-80	>25

Accelerator R&D Roadmap

2022 ACCELERATOR ROADMAP

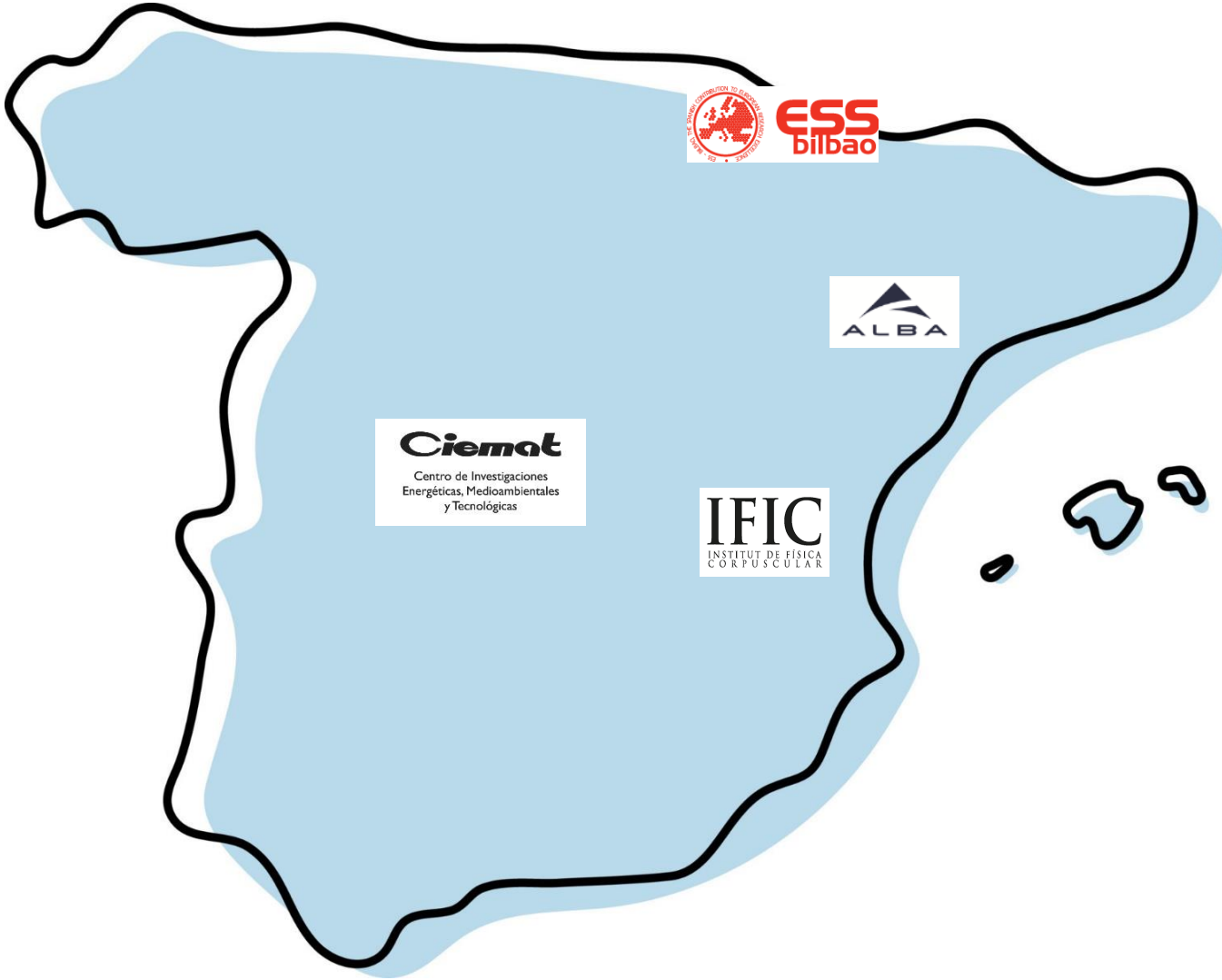
- The European Laboratory Directors Group (LDG) was mandated by CERN Council in 2021 to oversee the accelerator technology R&D programme.
- It defined the R&D roadmap in 2022, reflecting the consensus position of the accelerator R&D community.

2022 ACCELERATOR ROADMAP



Spanish Accelerator Community

SPANISH MAIN* CONTRIBUTORS TO ACCELERATOR R&D FOR FUTURE COLLIDERS

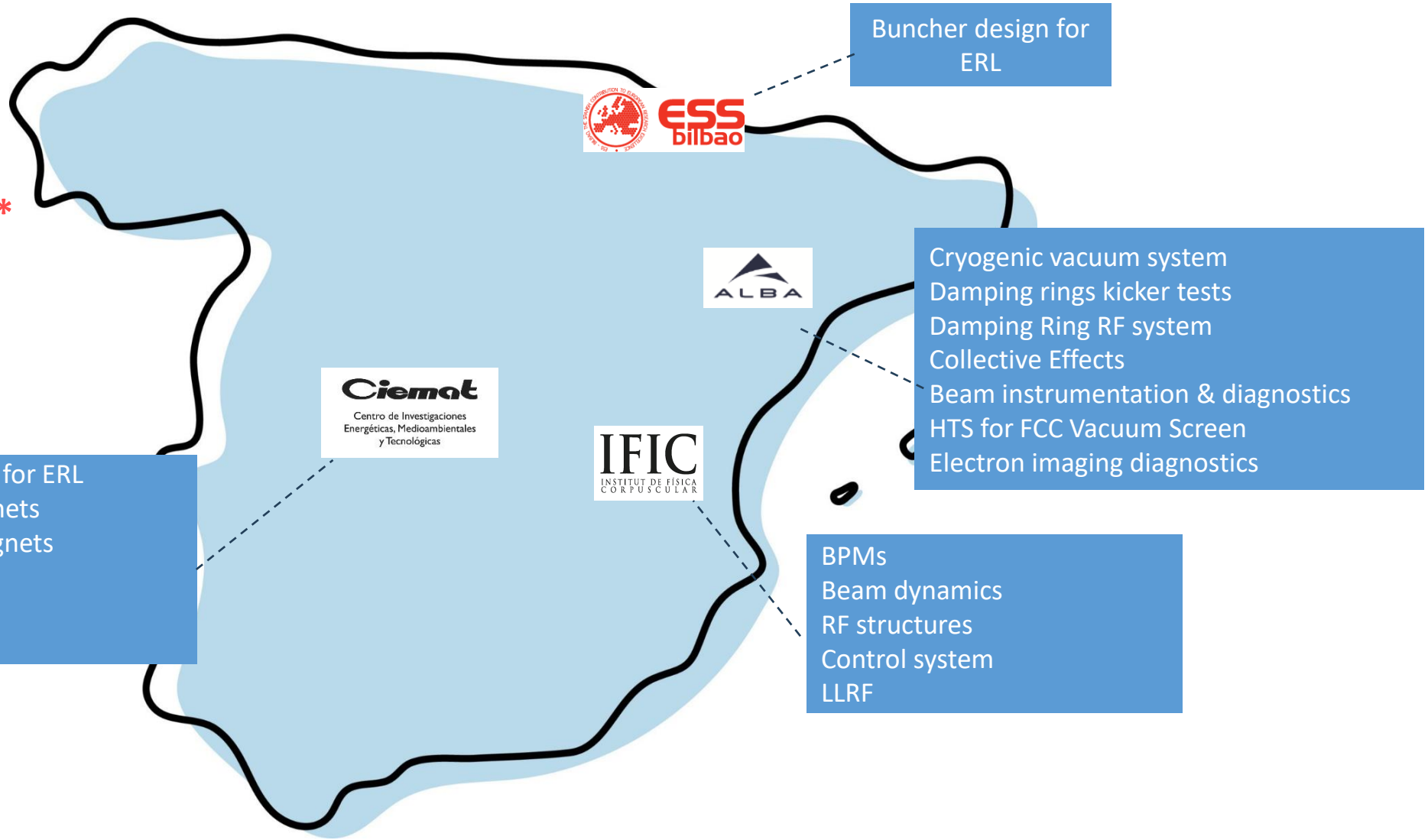


* In addition to CLPU, potential contribution to accelerators from DONES, etc

SPANISH MAIN CONTRIBUTORS TO ACCELERATOR R&D FOR FUTURE COLLIDERS

SPANISH MAIN* CONTRIBUTORS TO ACCELERATOR R&D FOR FUTURE COLLIDERS

EXPERIENCE IN HEP ACCELERATORS *



*** Only main experience in HEP accelerators in shown in this slide**

Spanish Accelerator contribution to HEP Projects*

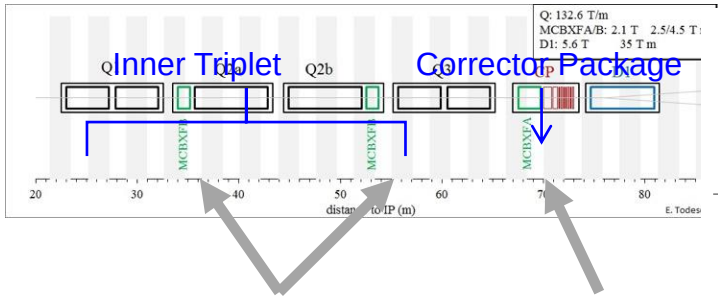
* The order of appearance in this presentation does not mean order of importance/preference

HL-LHC

Contribution to HL-LHC

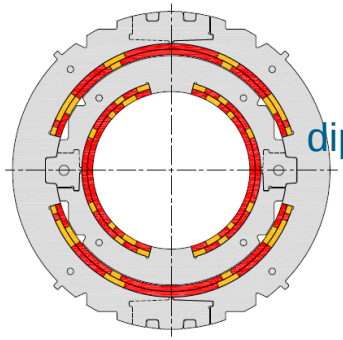
MCBXF (CIEMAT)

MCBXF is an orbit corrector magnet located in the Inner Triplet, the closest group of magnets to the interaction points. Inner Triplet will be upgraded for HL-LHC.

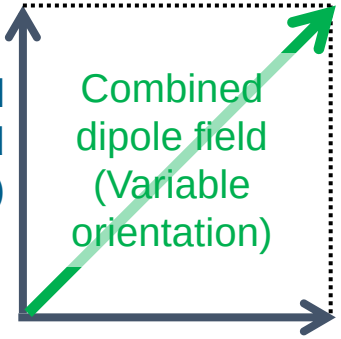


MCBXFB **(2.5 T·m)**

MCBXFA **(4.5 T·m)**

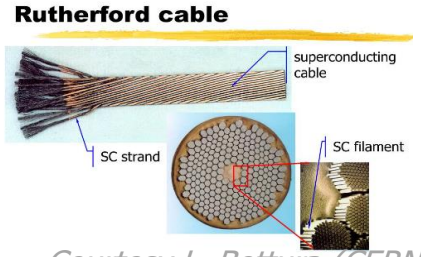


Vertical dipole field (2.1 T)

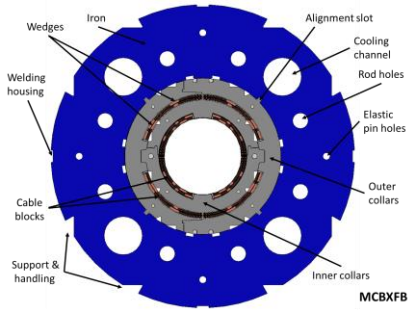


First nested superconducting accelerator magnet with mechanical torque locking

- **MCBXFB: Short magnets**
  - Two prototypes (MCBXFBP1, MCBXFBP2) at CIEMAT facilities
  - Series of 12 magnets
- **MCBXFA: Long magnets**
  - Prototype (MCBXFAP1) at CIEMAT facilities
  - Series of 6 magnets



Courtesy L. Bottura (CERN)



Courtesy of J.A. García Matos

Coil fabrication techniques not previously used due to the high number of turns.

Dipoles, endplates and iron laminations

Assembled in collaboration with CERN (927 laboratory)

ILC

Contribution to ILC

- Technical activities indicated as critical and covered in the ILC Technology Network (ITN)
- Spain contributes via CIEMAT and IFIC groups to important accelerator aspects

EAJADE
Europe-America-Japan Accelerator Development Exchange Programme

The European ITN activities – 2023

European ITN studies are distributed on five main activity areas:

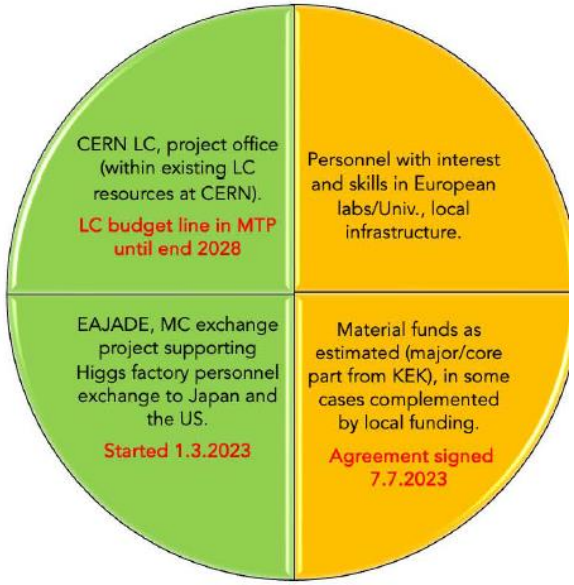
A1 with three SC RF related tasks
- SRF: Cavities and Cryo Module (INFN, CEA, DESY, IJCLAB?)
- Crab-cavities (STFC, CERN?)
- Main Linac elements: ML quads and cold BPMs (CIEMAT, IFIC)

A2 Sources
- Pulsed magnet (Uni.H, DESY, CERN)
- Wheel/target (the same and UK groups)

A3 Damping Ring including kickers
- Low Emittance Ring lab(s) (UK?)

A4 ATF activities for final focus and nanobeams
- On-going/restarted (Oxford, DESY, IJCLAB, CEA, CERN, IFIC)
- MDI here ?

A5 Implementation including Project Office
- Dump, CE, Cryo – earlier efforts at CERN, possible follow up being considered
- Sustainability, Life Cycle Assessment (CERN, DESY, CEA, UK groups?)
- EAJADE started (EU funding) SHOW groups?



EAJADE: Information at LINK

EAJADE: Europe-America-Japan Accelerator Development Exchange Program

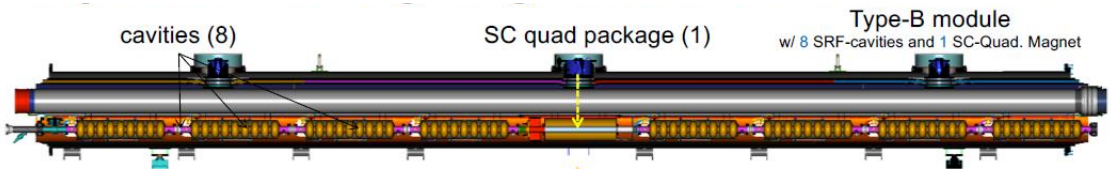
- Marie Sklodowska-Curie Research and Innovation Staff Exchange (SE) action, funded by the EU under Horizon-Europe Grant agreement ID: 101086276

  - National members: IFIC
  - Associated non-academic partners in Spain: INEUSTAR

From J. Fuster

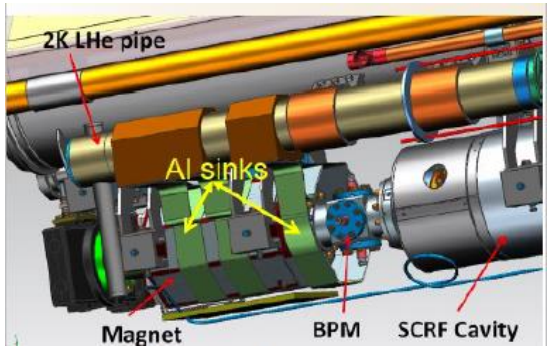
Contribution to ILC

- Development of the SC Quadrupole package combined with BPM at the center of the cryomodule (B) of the SRF string for beam acceleration



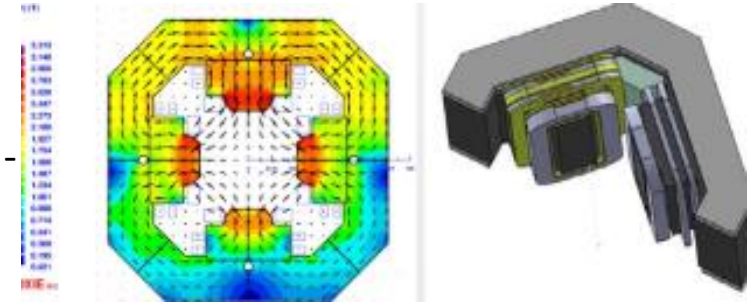
Development of a cold cavity Beam Position Monitor (BPM)

- High precision BPM with a time nanometer resolution (<369 ns) and a spatial resolution < 1µm
- ILC beam bunch by bunch measurements (fast readout electronics)
- Low beam dynamics impact (wakefields studies)
- Ultra high-vacuum and cryogenic temperatures performance
- Special mechanical design for ease cleaning



Main quadrupole magnet combined with dipole corrector and IFIC BPM

- Conduction cooled to avoid the need of a He cryostat
- Splitable magnet for assembly out of the clean area
- National MAGNEXT Project: design, fabrication and characterization of conduction-cooled coils with large temperature margin (in collaboration with KEK).



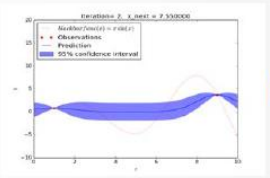
Contribution to ILC

ATF3 programme (final focus, nanobeams)

- ATF2 beamline is the only existing test accelerator in the world to test the final focus system (FFS) of linear colliders.
- The following 3 research topics are important topics to be pursued at the ATF.
  - wakefield mitigation
  - correction of higher-order aberration
  - training for ILC beam tuning
- The technical research at ATF2 beamline has proceeded, and should continue to be based on the ATF international collaboration, or its extension (welcome to new collaborators).

Wakefield test station

Octupole magnets for higher-order aberration



Maximum search algorithms to be applied to beam tuning (Machine Learning)

ATF2 beamline

Very relevant studies for any linac and Higgs factory closely related to low emittances and nano beams, e.g. alignment, stabilisation, instrumentation, beam-dynamics, etc.

- Strong European leadership with several group from **France, UK, Spain, Germany and also CERN, also extensively used for PhD training**
- A future ATF3 programme has been defined and reviewed internationally, supported also by MC researcher exchange programmes as EJADE and EAJADE

From J. Fuster

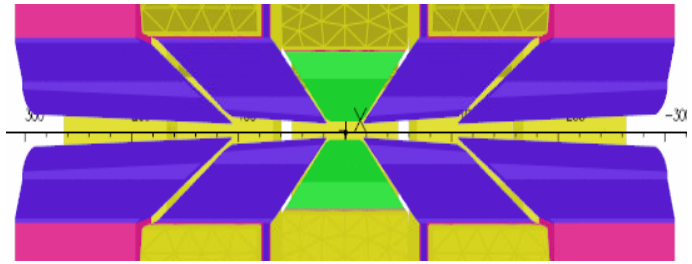
IFIC
INSTITUT DE FÍSICA CORPUSCULAR

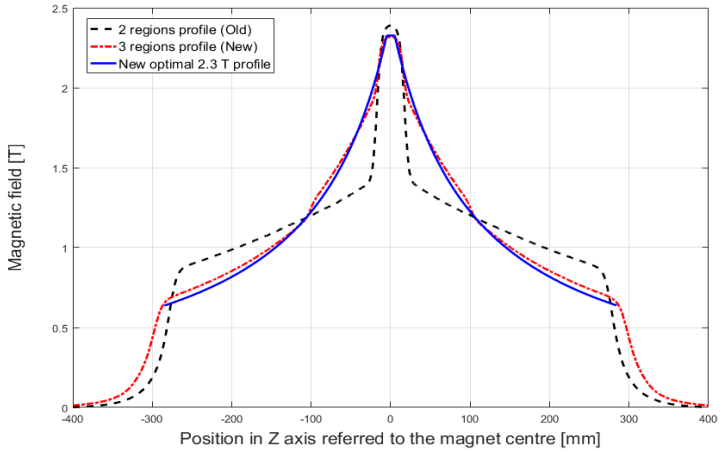
- ❑ Training of PhD students on ILC beam tunning (in EAJADE framework)
  - One month stay of 3 IFIC students in ATF in 2023 in nanobeam activities
- ❑ Emittance preservation studies: emittance measurement in Damping Ring, in extraction line and in the FFS.
- ❑ OTR commissioning in extraction line in next December 2024
- ❑ Linac beam dynamics modelling and simulations
  - ❑ RF-Track model of ATF linac (space-charge, wakefields...)

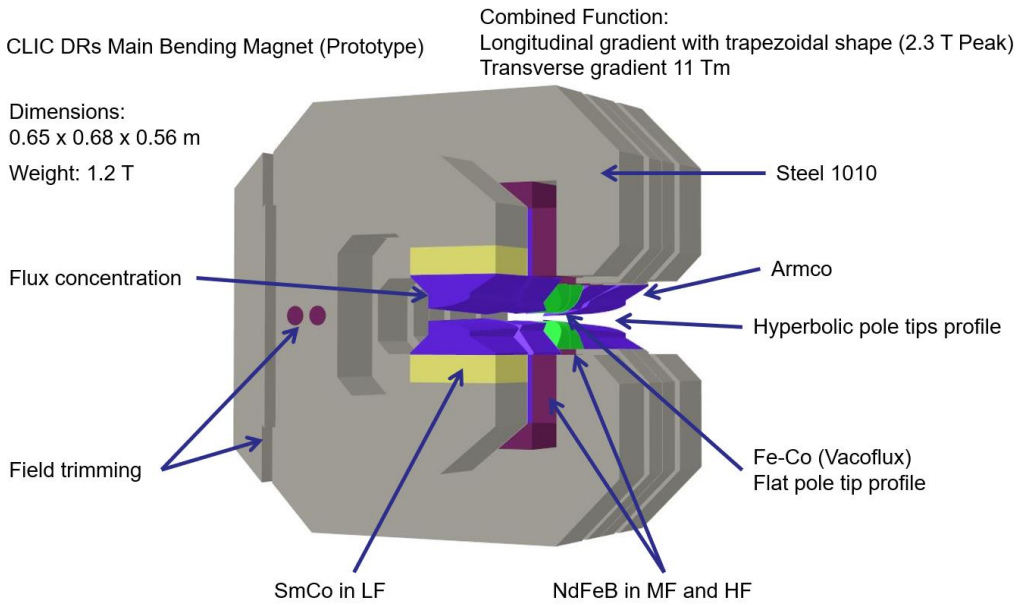
CLIC

CLIC: permanent magnets

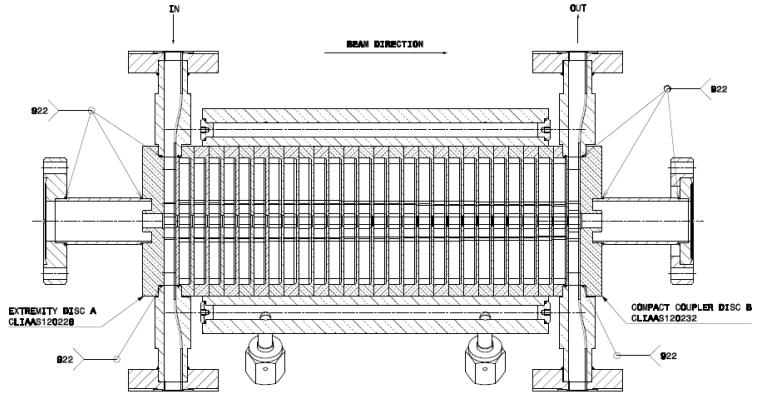
- Development of dipole magnets with variable longitudinally field based on permanent magnets: low-emittance damping rings.



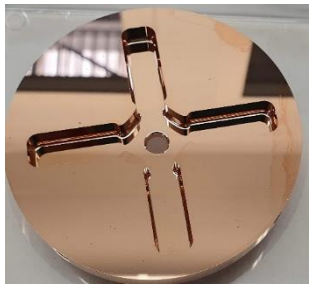


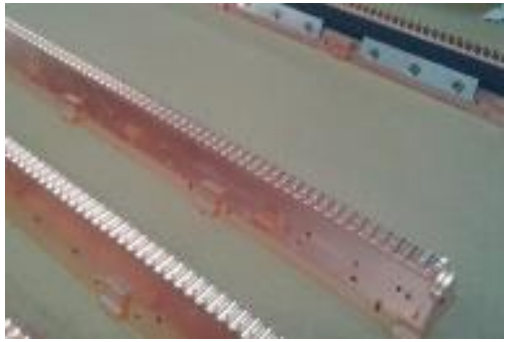


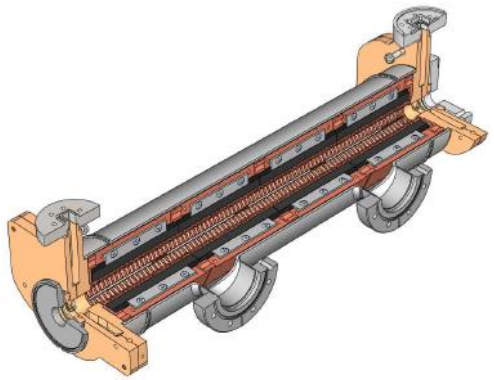
CLIC: RF structures



TD26CC







- Disks manufactured by Spanish Industry (EGILE)
- Tolerances fully achieved
- Pending RF tests at CERN

Manufacturing of **Power Extraction and Transfer Structures (PETS)**

IFIC CONTRIBUTION TO CLIC

IFIC
INSTITUT DE FÍSICA CORPUSCULAR

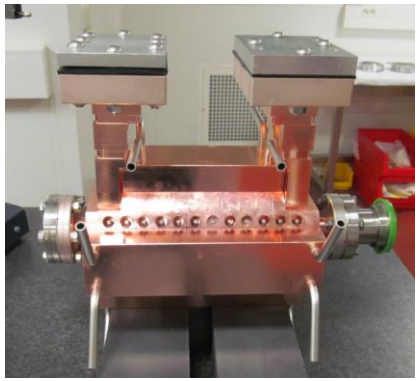
CLIC project

- R&D contract IFIC-CERN, IFIC-CSIC collaboration on CLIC-CERN: KE2638/BE. 2015-18.
  - Development of Xboxes RF test-stands
  - Operation of Xboxes test-stands (RF conditioning)
  - Breakdown studies for CLIC
  - Development of a High-Power S-Band Radio-Frequency (RF) system at IFIC

XBOX3 test-stand

CLIC technology transfer

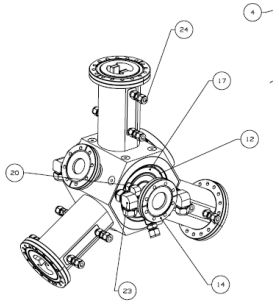
- R&D contract IFIC-CERN, KE3968/BE, Breakdown studies and tests of S-Band structures for medical applications at HG-RF lab at IFIC. 2019-2021.



First prototype of the KT medical proton linac structure

ALBA CONTRIBUTION TO CLIC

- Contract KE with CLIC-CERN (2017-2020):
  - WP1: Damping Ring Stripline Kicker tests
  - WP2: Collective Effects
  - WP3: **Beam Instrumentation & Diagnostics**
  - WP4: Damping Ring **RF System**



- EU H2020 - ARIES – ADA (2017-2021)
  - WP8: **Diagnostics** for future accelerators

- Contract KE with FCC-CLIC-CERN (2018-2021-2024)
  - Novel **electron imaging diagnostics** for future accelerators

FCC

FCC HFM program

January 2024: revised mandate of HFM

- ❑ 14 T is the operational field target for Nb3S
  - Shall be reached at 80% of short sample at 1.9 K, with “improved HL-LHC conductor” jc=1200 A/mm2 at 4.2 K
  - Design (and mechanics, and protection …) shall be scalable to 15 m
- ❑ For HTS, we are not able to give today a target, but rather a 15-20 T range

March 2024, FCC steering board, **energy reach**

- ❑ HFM should also focus on the global optimization of the system
- ❑ Setting target of 14 T operational field for FCC-hh Nb3Sn option gives 85 TeV with present lattice (83% filling factor)
- ❑ Further optimization can provide 90 TeV (87% filling factor)

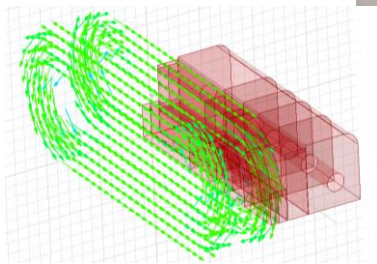
Open research lines:

- ❑ The temperature of operation of FCC-hh magnets is under study (Operation at 4.5 K could improve the energy efficiency, although the superconductor performance is not so good)
- ❑ High critical temperature superconductors (HTS) properties are in constant development during the last years. HTS magnets could be used for FCC-hh collider in different ways: hybrid magnets, correctors…

CIEMAT contribution to FCC:

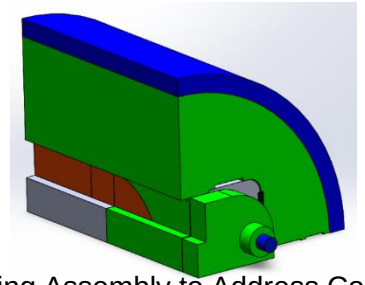
- CIEMAT is contributing to this effort by collaborating with the **HFM program** led by CERN.
- CIEMAT is commissioning **SMART-Lab**, a new facility to prototype high field magnets.

- 16 T dipole in common coil configuration (Nb_3Sn)
  - Double aperture dipole based on 2 flat (racetrack) coils powered in opposite directions.
  - Simple geometry easier to produce, in principle, with brittle conductors like Nb_3Sn.



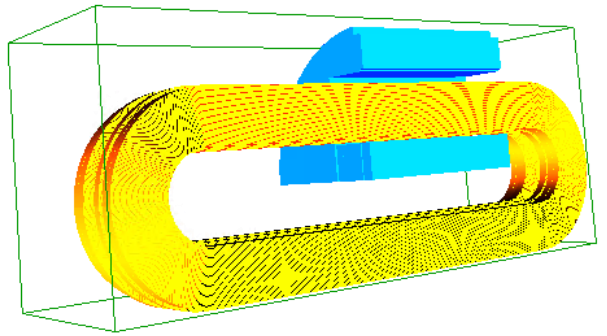
- CIEMAT is working on two high field magnets in common coil configuration:
  - **ISAAC**: a model magnet using existing coils produced at CERN.
  - **DAISY**: a 14 T magnet demonstrator with 50 mm aperture.
- The previous magnets are based on Nb3Sn coils, but parallel efforts are being organized to work also on high critical temperature superconductors (HTS).
- CIEMAT has the committment to be part of the HFM Board research laboratories team, in a long-term collaboration, sharing the objectives for the ESPP with translational aims.

ISAAC



Investigating Superconducting Assembly to Address Common coil mech

DAISY



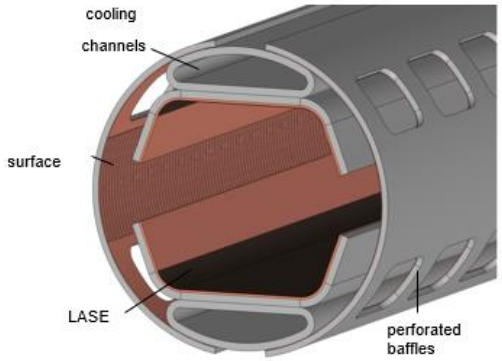
14 T dipole field in an aperture of 50 mm

ALBA CONTRIBUTION TO FCC

- EU H2020 Project EuroCirCol (2018-21)
  - WP4: FCC **Cryogenic Beam Vacuum System**

- Contract KE with FCC-CERN (2018-2021-2023):
  - **High Temperature Superconductors** for the **FCC Vacuum Screen**

- EU H2020 - ARIES – ADA (2017-2021)
  - WP8: **Diagnostics** for future accelerators

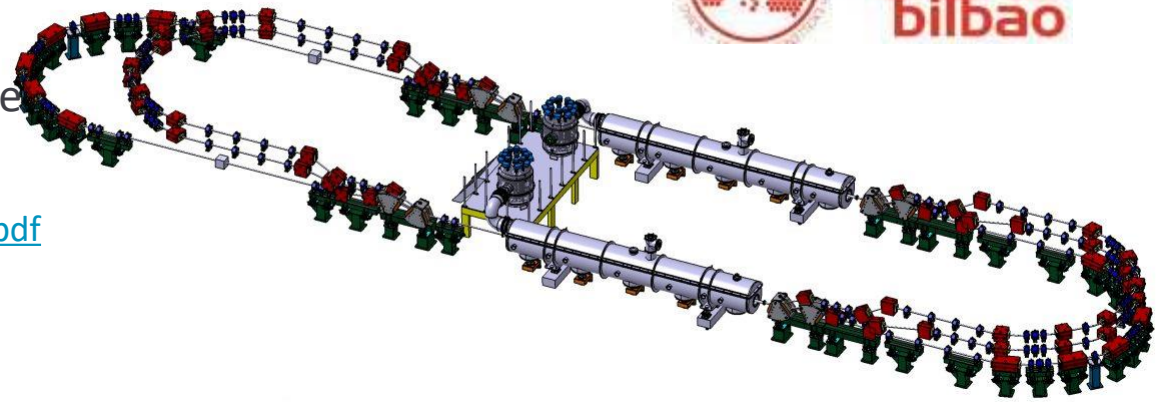


- Contract KE with FCC-CLIC-CERN (2018-2021-2024)
  - Novel **electron imaging diagnostics** for future accelerators

Energy Recovery Linac

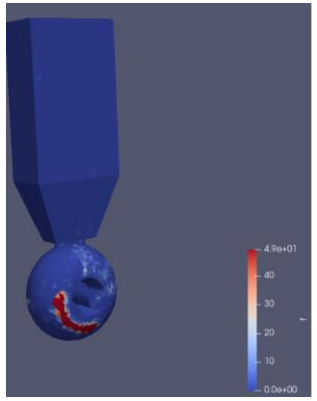
ESS-BILBAO contribution to ERL

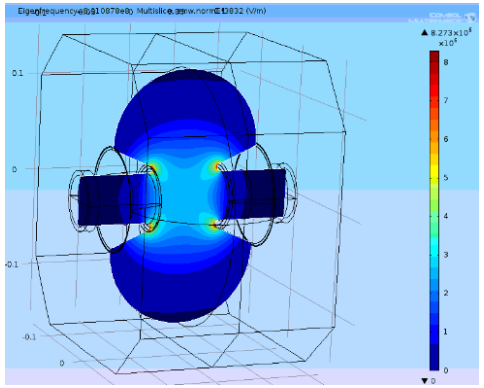
- PERLE is a compact three-pass ERL project based on SRF technology, being as a new generation machine targeting the 10 MW beam power regime.
  - PERLE Conceptual Design Report, https://arxiv.org/pdf/1705.08783.pdf

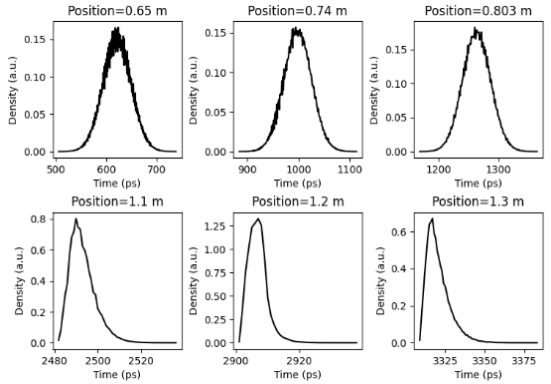


PERLE buncher cavity

- Thermo-mechanical and Multipacting studies
- Manufacturing







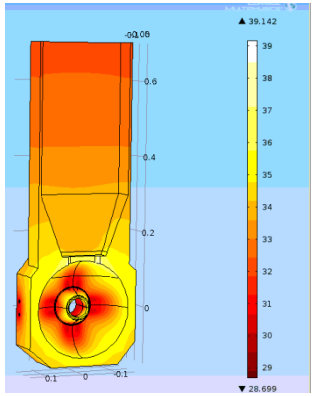
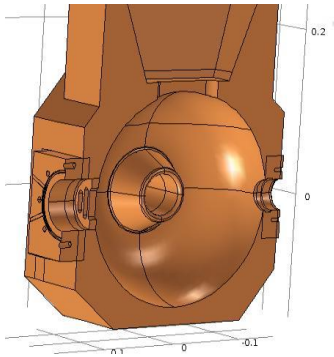


Figure of merit	PERLE buncher cERL-like optimized	Figure of merit	PERLE buncher cERL-like optimized
Input power	5 kW	Iris a	0.070 m
V0	0.21 MV	Iris b	0.020 m
TTF	0.84	Wave guide	WR-975 (274.65 mm, 123.80 mm). Taper=0.5
Gradient (V_0T/L_{cav})	1.392 MV/m	S11dB	-35.81 dB
Power loss	4972 W	ZTT	49.7 MΩ/m
RsTT = $(V0T)^2$ / Ploss	6.26 MΩ	Esurf_max	8.21 MV/m



Industry

Industry as an essential player

Spanish science industry, represented by INEUSTAR

Slide from M. Sánchez (INEUSTAR) in Jornada de la red de futuros colisionadores (July 2024)

ineustar
Asociación Española de la Industria de la Ciencia

CATALOGUE: Spanish Capacities in Large Scientific Facilities

orolia · OX · indra · AWGE TECHNOLOGIES · Jema Irizar Group · TVP · INGECIBER · Egile EXTREMEPRECISION · BTESA BROAD TELECOM · Applus laboratories · Telstar Life Science solutions · FAGOR FAGOR AUTOMATION · fcp felguera calderería pesada, s.a. · sgenia · enwesa · SENER Solutions · antec · MANCISIDOR · MMP · avs added value solutions · RAMEM · SCIENTIFICA · ABENGOA INABENSA · ensa · gamco · ThuneEureka · Arraela · Afarvi Ingeniería y Servicios · INTEGRASYS · ELYTT ENERGY · swisslan precision machining · azbil · enusa · Cryovac · Nortemecánica Fabricamos bienes de equipo...desde 1992 · Fractal · AERnnova · PROCON SYSTEMS · TTI · ALTER TECHNOLOGY · TECNICAS REUNIDAS · doiran TEGIA S.Coop. · grupo dominguis · RYMSA TRYO Group · idom · acciona · SENER · NATEC INGENIEROS · QUASAR SCIENCE RESOURCES, S.L. · EMPRESARIOS AGRUPADOS · CAT·N · KARTEN · gasNatural fenosa · ARQUIMEA · IDESA ingeniería y diseño europeo, s.a. · IBERDROLA Ingeniería y Construcción · NEUREUS TECHNOLOGIES · ase Optics · gtd · tecnatom · serkide integral services · asturfeito spirit of advance · ferrovial · INMEPRE, S.A. · hib HIGH IDENTITY BUILDINGS · COMSA EMTE · ADEX · LEADING METAL-MECHANIC SOLUTIONS · CiTD

*Non exhaustive presentation

Conclusions

Take-home messages

Spanish community with long tradition in accelerator development for future HEP colliders

Developments for both linear and circular colliders

Main contributions in high field magnets, permanent magnets, high gradient cavities, beam diagnostics, RF systems, dumping rings, …

Different R&D institutes involved in different technologies

Industry as important actor in the future developments

Personal view (C. Oliver): High workload in own developments and lack of funding vs future opportunities

Thank you

Thanks to Ibon Bustinduy (ESS-Bilbao), D. Esperante (IFIC), Francis Pérez (ALBA), F. Toral (CIEMAT)