FUTURE CIRCULAR COLLIDER
Innovation Study

FCCIS – The Future Circular Collider Innovation Study. This INFRADEV Research and Innovation Action project receives funding from the European Union's H2020 Framework Programme under grant agreement no. 951754.

INFN Istituto Nazionale di Fisica Nucleare

OVERVIEW OF FCC ACCELERATOR ACTIVITIES IN ITALY AND FRANCE

Manuela Boscolo (INFN-LNF)
Angeles Faus-Golfe(IN2P3) and Pierre Verrine (CEA)

2nd FCC Italy & France 2024
4 November 2024 , Venice, Italy

Introduction

- **Highlights of accelerator activities for FCC** at INFN, IN2P3, and CEA/IRFU.
- R&D programs are partially funded by **national institutes** and **in collaboration with CERN** through MoUs, **EU-program FCCIS** (Eurocircol), Swiss **CHART** program
- The R&D presented here is on-going, mainly focused on the preparation for the ESPPU, and will continue in the next years.
- If FCC will be approved these activities are likely to be strengthened and reinforced.

Main areas of Activities

FCC-ee MDI

- Mechanical model
- IR Mock-up
- Backgrounds, Beamstrahlung
- Alignment tolerances & vibration control

FCC-ee Collider Design

- Collective effects
- Monochromatization
- Polarimetry
- Beam-beam

FCC-ee Booster Design

- Optics
- Beam dynamics

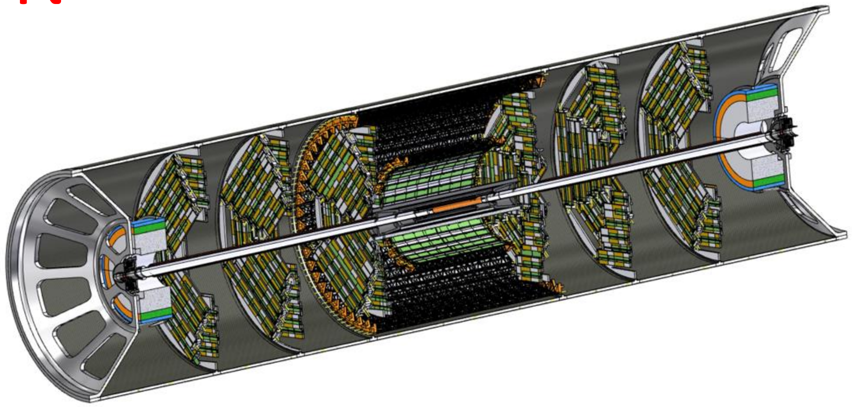
FCC-ee Injector

- e^+ source and capture system
- e^+ damping Ring

Technology R&D

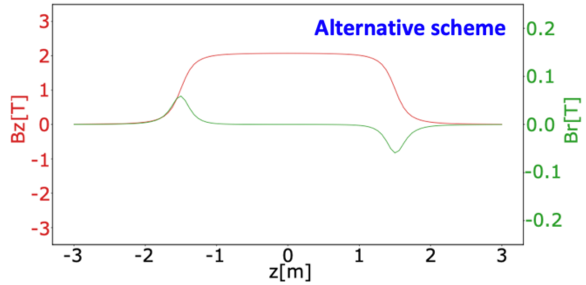
- SRF cavities for FCC-ee
- Magnets for FCC-ee/hh

FCC-ee Machine detector interface (MDI) – INFN



- **Engineered design of the interaction region and its components**
  Light and cooled beam pipes, vertex detector, luminosity calorimeter, bellows, services and routings. LNF, Pisa, Perugia

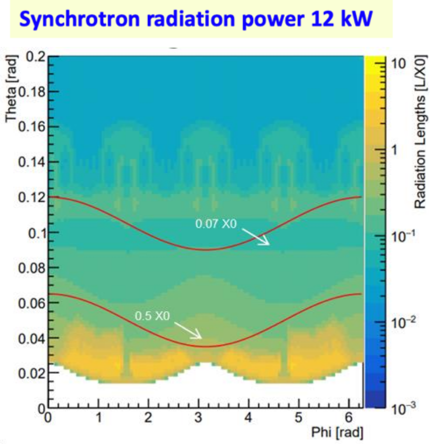
- **Optimisation of the final focus optics and solenoid compensation scheme** LNF
  Aim at reducing the synchrotron radiation produced in the IR, improving the vertical emittance growth, and optimisating space in the crowded area.



- **Detector backgrounds** evaluation, material budget optimisation.
- **Beamstrahlung** radiation dump and induced backgrounds.
- **Collimation scheme** with beam losses from halo beam, beam-gas, thermal photons.

LNF

- **3T solenoid design -** ***NEW*** *talk by S. Mariotto, MDI session* Milano



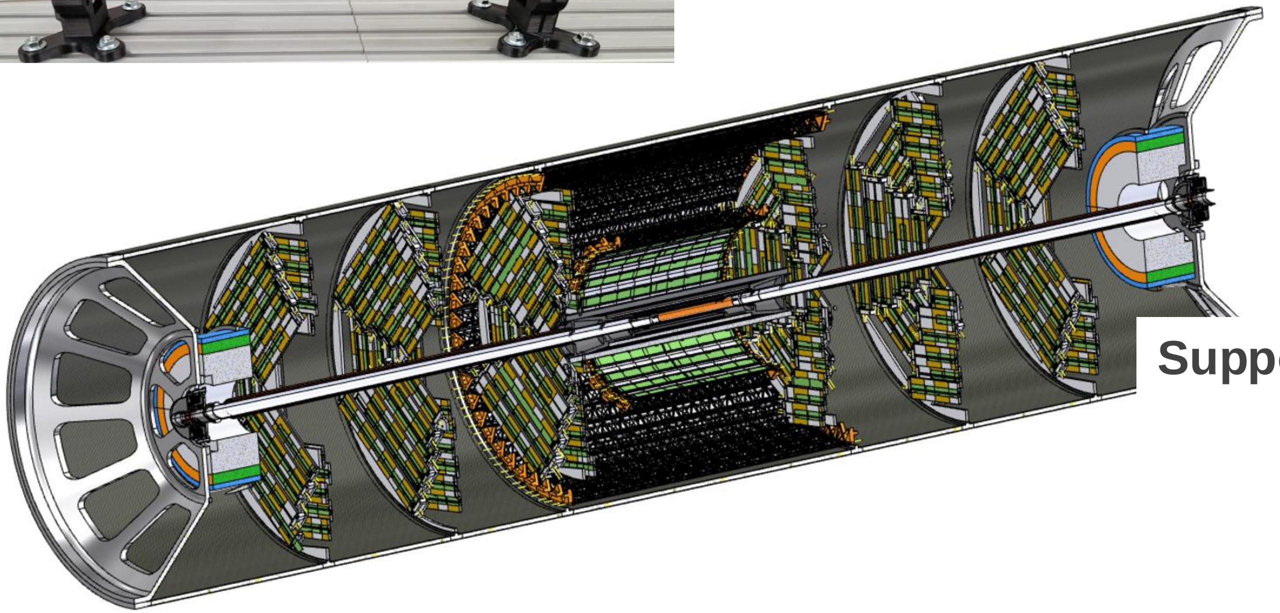
R&D Full scale IR mockup at LNF in collaboration with Pisa and CERN

Goal: design validation, buckling test, assembly and cooling/services test

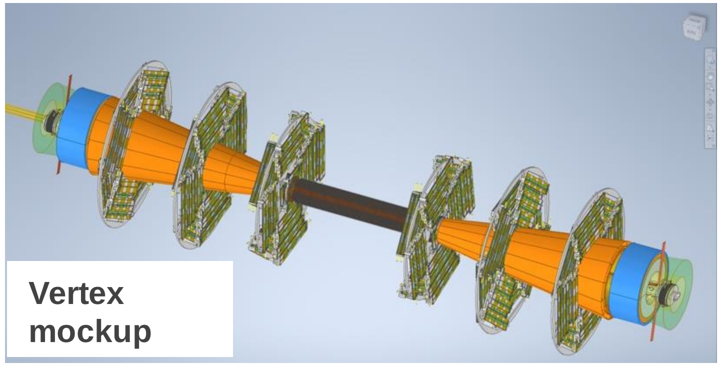
Central chamber: double layer with paraffin cooling

Ellipto-conical chamber with water cooling manifolds

new!

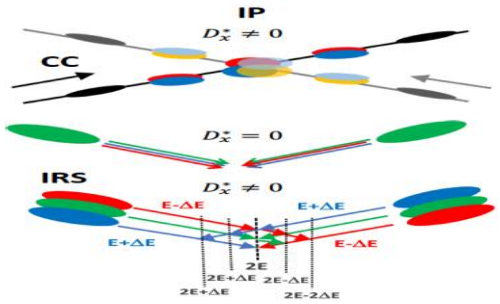


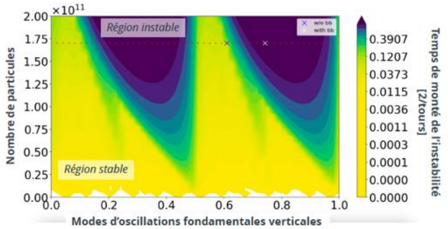
Support tube



Integration and overall assembly targeting Q4-2025

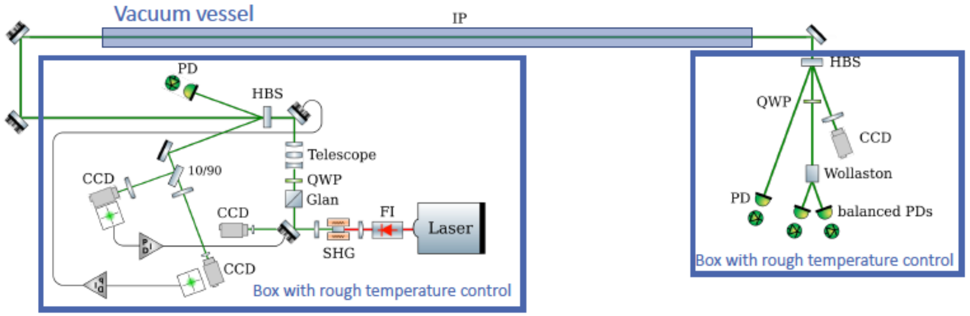
Collider design





IN2P3

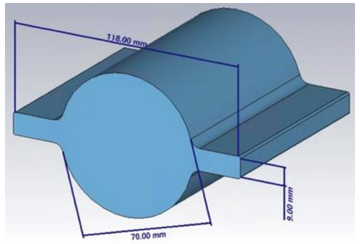
- Monochromatization optics
  - IR Optics with horizontal/vertical dispersion at IP ($D^*_{x,y}$)
  - Possible experimental tests at DAFNE/SuperKEKB/BEPCII
- Beam-Beam studies
  - including more precise wakefield model and possible experimental studies.
- Compton polarimetry
  - Laser system and pixelized detectors
- Stabilisation, vibration and positioning & uniform waves analysis
- R&D on HTS IR quadrupole and its cooled beam pipe (emerging new studies)



(see talk M. Merchand (LAPP) , Acc-1 session)

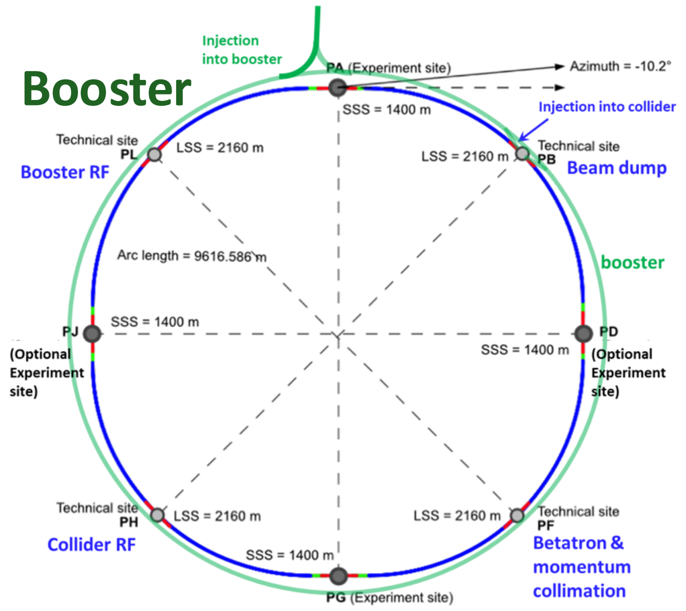
INFN-Roma1, LNF

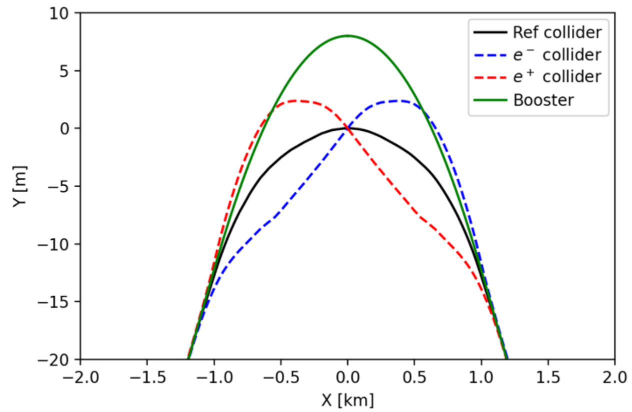
- Collective effects, single bunch and multibunch instabilities
- Beam-beam and coupling impedance



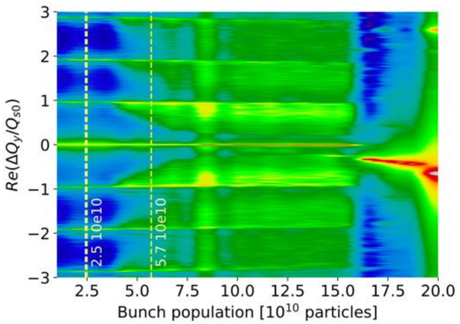
Booster Design – CEA

- Optics design
- Dynamic aperture
  - also with AI techniques
- Parameter table
- Tuning strategy





- Collective effects INFN-Roma1, LNF



Bunch population scan at injection energy

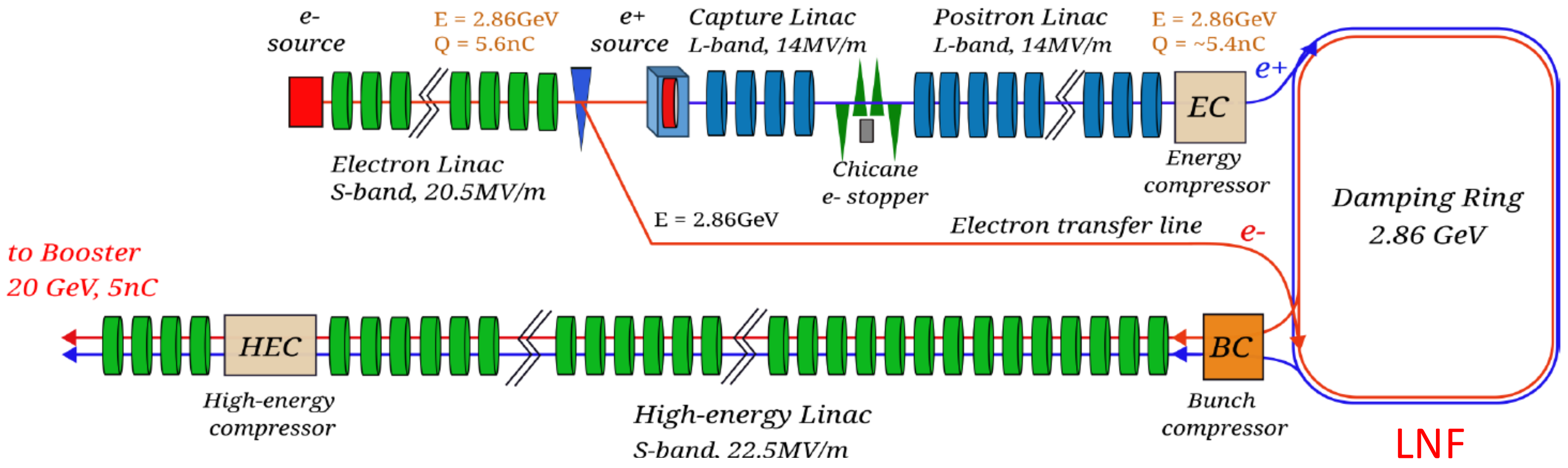
Running mode		Z	W	ZH	$t\bar{t}$
Injection option		LINAC/SPS			
Circumference	[km]	91.174			
Injection energy	[GeV]	20/16			
Extraction energy	[GeV]	45.6	80	120	182.5
Number bunches / ring		11200	1780	440	60
Maximum particle number / bunch N max	[10^{10}]	$\geq$ 2.5 (4 nC)			
Particles / bunch in top-up	[10^{10}]	2.14	0.87	0.69	0.93
RF frequency	[MHZ]	800			
Arc optics FODO		60°/60°		90°/90°	
Momentum compaction		14.9×10^{-6}		7.34×10^{-6}	
Coupling		2×10^{-3}			
Injection horizontal emittance (norm.)	[µm]	10/190			
Injection vertical emittance (norm.)	[µm]	10/4			
Extraction horizontal equilibrium emittance (RMS)	[nm]	0.26	0.81	0.63	1.45
Extraction vertical equilibrium emittance (RMS)	[pm]	0.53	1.62	1.25	2.90

Mid-term parameter table

Extraction horizontal equilibrium emittance (RMS)	[nm]	0.26	0.81	0.63	1.45
Extraction vertical equilibrium emittance (RMS)	[pm]	0.53	1.62	1.25	2.90
Injection Energy loss / turn	[MeV]	1.514/0.6203			
Extraction Energy loss / turn	[MeV]	40.93	387.7	1963	10500
Injection bunch length	[mm]	4/5.5			
Extraction bunch length	[mm]	4.38	3.55	3.34	1.94
Injection RMS energy spread	[10^{-3}]	1/4			
Extraction RMS energy spread	[10^{-3}]	0.38	0.67	1.01	1.53
Injection Maximum relative energy acceptance	[%]	3			
Extraction Maximum relative energy acceptance	[%]	0.36	0.76	0.49	2.39
Injection RF voltage	[MV]	104.9/82.97		52.85/41.36	
Extraction RF voltage	[MV]	49.48	458.6	2015	11533
Filling time	[s]	28/31.5	8.9/9.6	4.4/4.75	0.6/0.95
Ramp time	[s]	0.32/0.37	0.75/0.8	1.25/1.3	2.03/2.08
Flat top	[s]	1.9	0	0	0
Total cycling time	[s]	30.54/ 34.14	10.4/11.2	6.9/7.35	4.66/5.11

Positron source and capture system – IJCLAB / INFN

→ positron flux of **~1.35×10¹³ e⁺/s.** *Demonstrated at SLC (a world record for existing accelerators):* ***~6 ×10¹² e+/s***

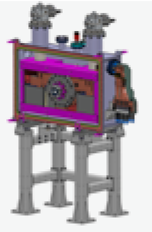


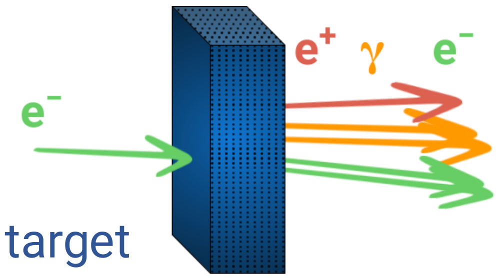
5.4 nC e+/bunch at the DR* → 13.5 nC e+/bunch at the exit of the Positron Linac, considering **60% of losses** due to transport, collimation and injection in the DR (**safety margin of 2.5**).

- Capture System and Positron Linac
  - HTS solenoid or flux concentrator IJCLab
  - AI techniques for beamline optimization INFN-Milano
- Crystal-based positron source INFN-Ferrara/IJCLab
- Use of AI for global optimization IJCLab

HTS solenoid

18.2 T @15K@2kA reached for stack of 4 coils

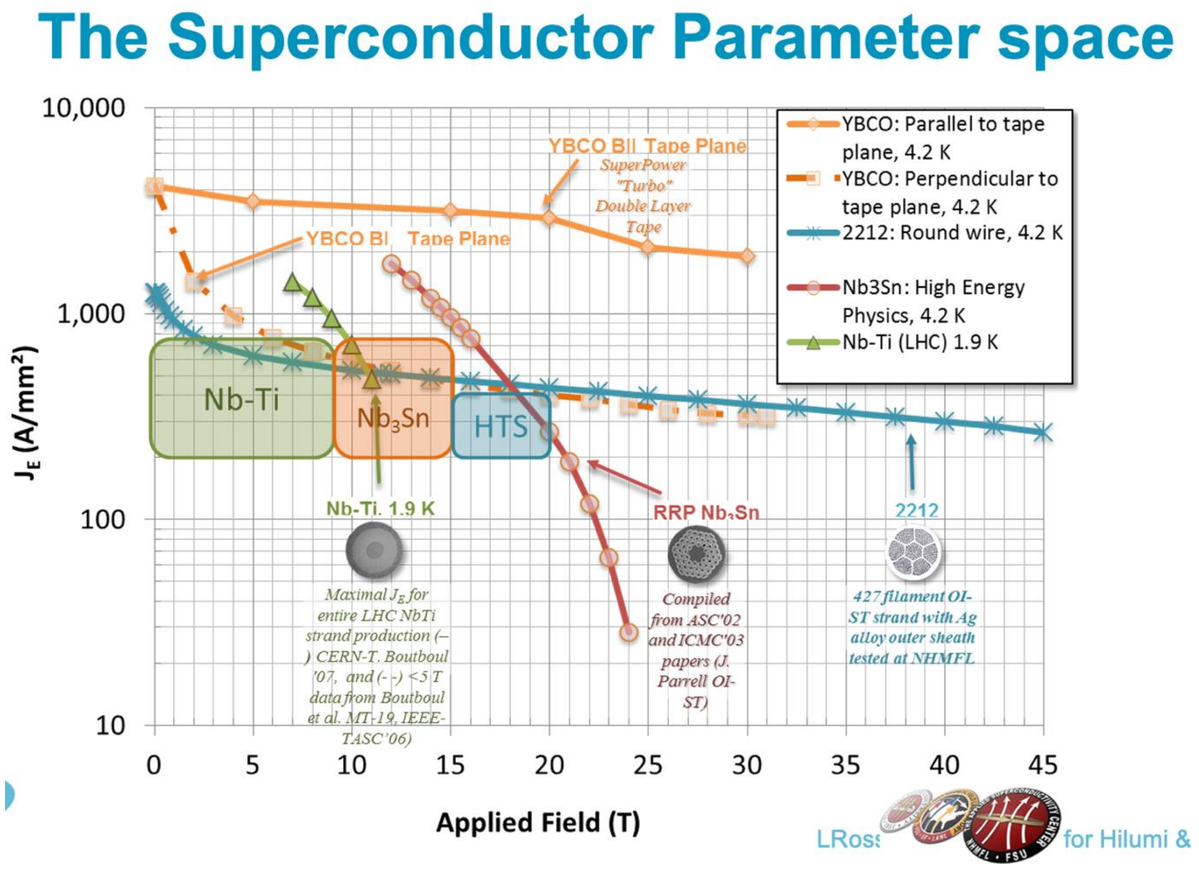


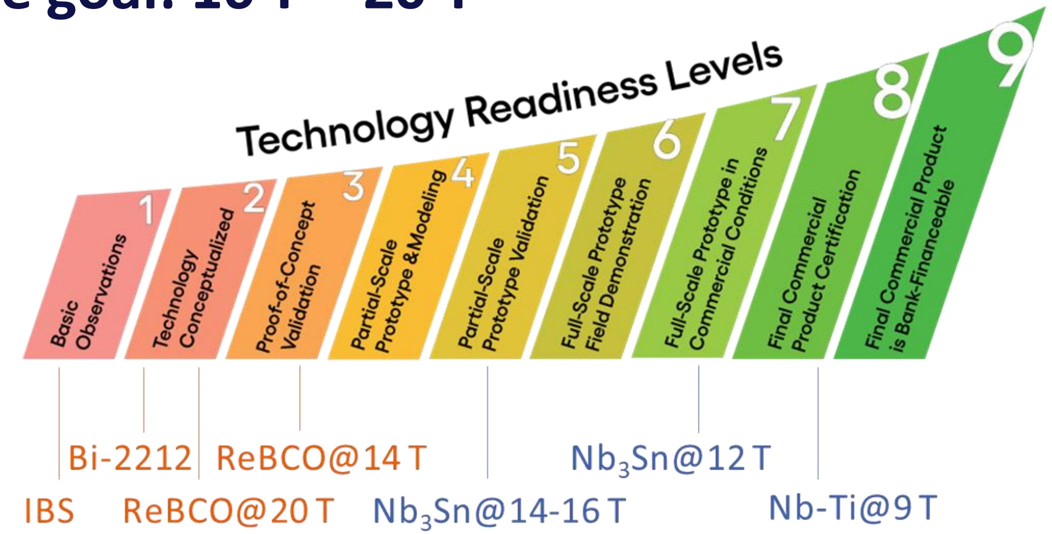


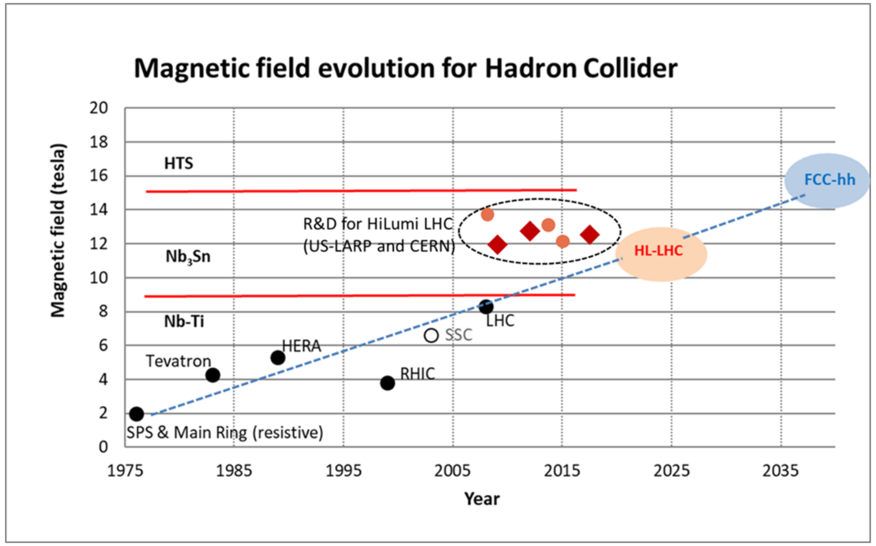
Crystalline target

High-field magnets for FCC-hh

Ultimate goal: 16 T – 20 T







For FCC-hh the 14 T magnet target is realistic, can reach between 85-90 TeV,
15Y R&D + 15Y industrialization and production.

E. Todesco

High-field magnets for FCC-hh

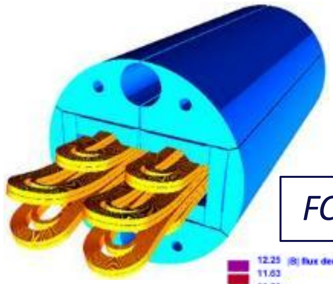
Ultimate goal: 16 T – 20 T

12 T Nb_3Sn Dipole Magnet

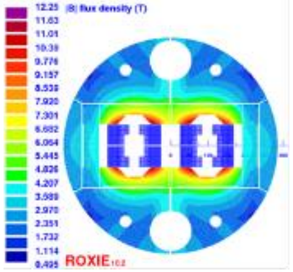
12 T

- Robust concepts using a **partnership with industry** INFN-Mi, INFN-Ge
- Technology developments in the lab CEA

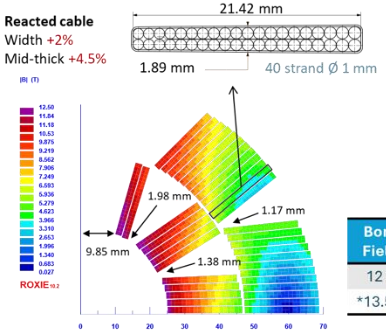
  R&D activities:
  - Thermomechanical behaviour of Nb_3Sn conductors during heat treatment
  - Mechanical tests of Nb_3Sn cables

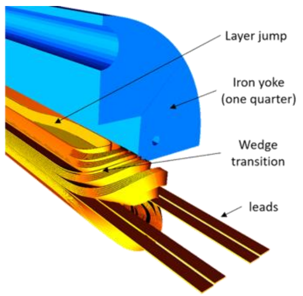


FCC quadrupole



FALCON DIPOLE





Bore Field	Operating Current	Margin on Loadline @ 1.9 K
12 T	20180 A	24.4%
*13.5 T	23000 A	15%

*intended as mechanical limit

High Temperature Superconducting Magnets

- **INFN** strategy: PNNR_IRIS: development of a HTS (REBCO) dipole in the range 8-10 T
- **CEA** strategy : MI (Metal-Insulated) HTS tapes for very high current densities

  Relying on fast turn-over / reduced-risk subscales

Superconducting radio-frequency (SRF) cavities INFN/IN2P3

RF system R&D is key for increasing energy efficiency of FCC-ee

- Nb on Cu 400 MHz cavities
- Bulk Nb 800 MHz cavities, surface treatment techniques, cryomodule design
- RF power source R&D in synergy with HL-LHC

INFN-LNL R&D on surface polishing and SC film coating

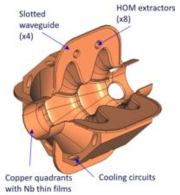
Nb_3Sn coating by Physical Vapor Deposition (PVD)
on a Quadrupole Resonator
@20 mT @400 MHz @4.5K

INFN-Milano R&D on Nb bulk cavities:

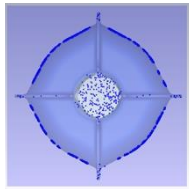
- 1-cells 1.3 GHz: **surface** and **thermal treatments** development & qualification
- 9-cells 1.3 GHz: **industrialization** (9-cells) of the developed process
- **New cryostat dedicated to R&D (**Design specifically for TESLA type single- and multi-cell cavities)

IN2P3
- **Multipacting** modeling on the SRF SWELL cavities
- SRF High-Q & Thermolectrical (800 MHz & bimetal structures)

Slotted Waveguide Elliptical cavity (SWELL)



Multipactor locations



FCC-JLAB prototype 800 MHz at IJCLab

Summary

- Many complementary and synergic areas of R&D for the FCC.
- Italian and French collaborations and common ongoing on
  - Positron source and capture system
  - High field magnets
  - Interaction region and MDI design
  - Collective effects
- Opportunities for expanding the collaboration ?

Additional

CSN1-INFN supports FCC accelerator activity through RD_FCC

WP- Accelerator

Coordinator M. B.

Lab and Units involved:

- Frascati
- Roma1
- Legnaro
- Ferrara
- Milano
- Genova
- Pisa
- Perugia

Coordinated efforts via:

- Doctoral school on Accelerator Physics at University of Rome Sapienza
- CERN technical and doctoral students
- Simil-fellows on accelerator studies? (proposal for discussion)
- Contributions to topical and major conferences/ workshops (IPAC, FCC WEEK, eeFACT, EPS-HEP, ...)
- Participation to international accelerator and technical review committees (EIC, CEPC, SuperKEKB)

12.5 FTE (about 25% of the total FTE involved on RD_FCC)

European projects for FCC Design Study

European Commission | Horizon 2020 European Union funding for Research & Innovation

FCC-hh: EuroCirCol 2015-2019

Strategic activity for the FCC-hh **CDR** and input for the 2019 EPPSU

INFN Involvement in:

- **Experimental insertion region design,** WP3 (LNF)
- **Cryogenic beam vacuum system,** WP4 (LNF)
- **High Field Magnet design,** WP5 (Genova, Milano)

  Exploration of different design options for the 16T Nb_3Sn dipoles

FCC-ee: FCC-IS 2020-2024

Strategic activity for the FCC-ee mid-term and **Feasibility Study** reports and input for the 2025 EPPSU

INFN Involvement in:

- **Collider design,** WP2
  - **IR and MDI design,** task (LNF)
    - **Collective effects,** sub-task (Sapienza, LNF)