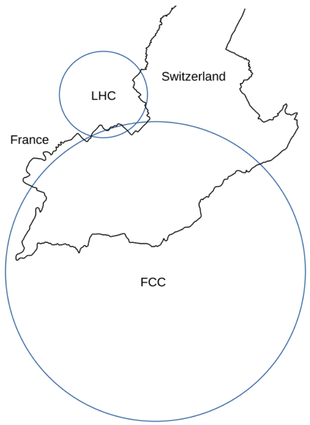
INFN LNF
Istituto Nazionale di Fisica Nucleare




# FCC @LNF

Manuela Boscolo

**Frascati, Divisione Acceleratori**
**9 Febbraio 2023**

FUTURE CIRCULAR COLLIDER
Innovation Study

**Work supported by the European Commission under the HORIZON 2020 project FCCIS, grant agreement 951754**

# Outline

- Management progetto

  MB: co-chair collaboration board, and member of executive board, membro del Technical Coordination Meeting, WP leader e nell'INFN (convener WP acceleratore in RD_FCC)

- Coinvolgimento della divisione acceleratori dei LNF
  - Disegno Regione Interazione in tutti gli aspetti, dagli studi di macchina al layout meccanico
  - Damping Ring
  - Effetti collettivi

- Altre attivita' INFN sulla macchina
  - SRF LNL, e+ source, Diagnostica, magneti IR

- Discussione

10:05 → 10:20 **Damping Ring**
**Speaker:** Catia Milardi (Istituto Nazionale di Fisica Nucleare)

10:20 → 10:35 **MDI mechanical model**
**Speaker:** Francesco Fransesini (Istituto Nazionale di Fisica Nucleare)

10:35 → 10:50 **FCC-ee Backgrounds**
**Speaker:** Andrea Ciarma (LNF)
FCCatLNF.pdf

10:50 → 11:05 **FCC Impedance Budget**
**Speaker:** Mostafa Behtouei (Istituto Nazionale di Fisica Nucleare)

# Timeline LEP3-TLEP-FCC

| | Year | |
|---|---|---|
| Higgs Boson Discovery | 2012 | 20/Jan/12 A. Blondel and F. Zimmermann, TLEP, ArXiv:1112.2518v1 |
| Snowmass | 2013 | 14/Feb/13 LNF mini-Workshop: Higgs Factories LEP3 and TLEP, Physics opportunities (chair, MB) |
| | 2014 | MoU INFN-FCC (CDR preparation phase) |
| 1st FCCWEEK15 Washington DC | 2015 | |
| | 2016 | 2nd FCCWEEK16 Rome (LOC chair, MB) |
| | 2017 | |
| CDR phase | 2018 | EUROCIRCOL (resp. MB) FCC-hh |
| CDR Release | 2019 | |
| EPPSU | 2020 | |
| | 2021 | MoU INFN-FCC (FS report) |
| | 2022 | 21/March/22 Rome, First FCC Italy workshop<br>21/Nov/22 Lyon, FCC Italy-France workshop |
| Snowmass | 2023 | |
| Feasibility Study Phase | 2024 | FCCIS (resp. MB) FCC-ee |
| FS Report Release | 2025 | |
| EPPSU | 2026 | |

**RD_FA** [CSN1] resp. naz. F. Bedeschi
**WP2: MDI** (convener MB)

**RD_FCC** (RD_FA - WP MC)

**WP2: Acceleratore** (convener MB)

# Conceptual Design & input to ESPPU ‘19/20


## FCC-Conceptual Design Reports (end 2018):

- **Vol 1 Physics, Vol 2 FCC-ee, Vol 3 FCC-hh, Vol 4 HE-LHC**
- CDRs published in **European Physical Journal C (Vol 1) and ST (Vol 2 – 4) [Springer]**

EPJ C 79, 6 (2019) 474 , EPJ ST 228, 2 (2019) 261-623 , EPJ ST 228, 4 (2019) 755-1107 , EPJ ST 228, 5 (2019) 1109-1382

EPJ is a merger and continuation of *Acta Physica Hungarica, Anales de Fisica, Czechoslovak Journal of Physics, Fizika A, Il Nuovo Cimento, Journal de Physique, Portugaliae Physica* and *Zeitschrift für Physik*. 25 European Physical Societies are represented in EPJ, including the DPG.

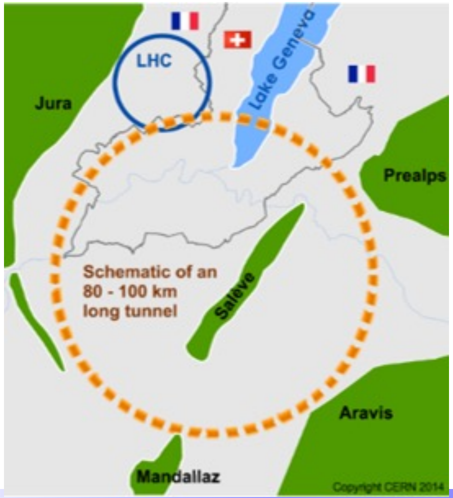
## Summary documents input to EPPSU 2019/20

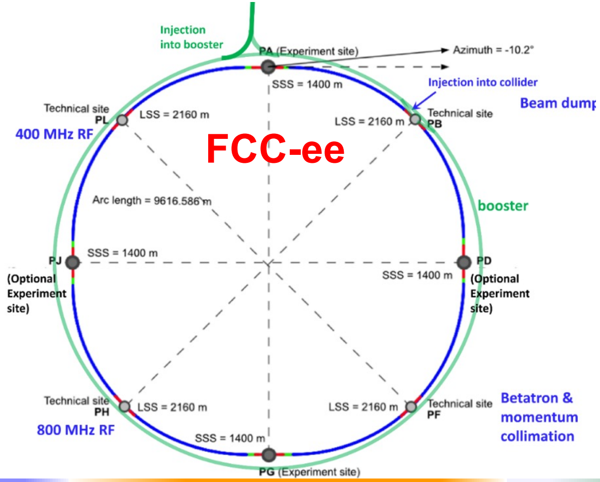
- **FCC-integral, FCC-ee, FCC-hh, HE-LHC**, at http://fcc-cdr.web.cern.ch/

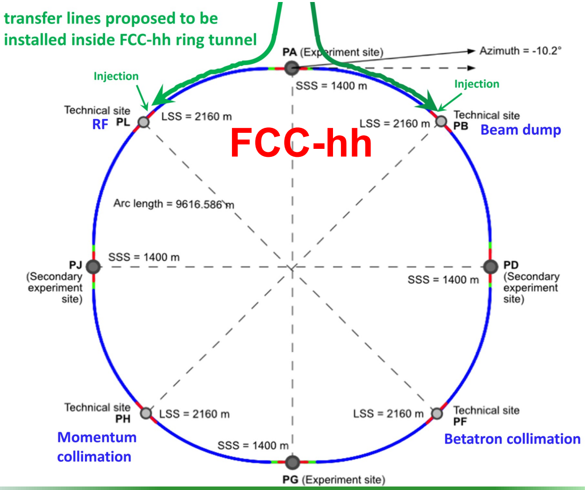
# The FCC integrated program inspired by successful LEP – LHC programs at CERN

Comprehensive long-term program, maximizing physics opportunities

- Stage 1: **FCC-ee** (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & and top factory at highest luminosities
- Stage 2: **FCC-hh** (~100 TeV) as natural continuation at energy frontier, with ion and eh options
- Complementary physics
- Common civil engineering and technical infrastructures
- Building on and reusing CERN's existing infrastructure
- FCC integrated project allows seamless continuation of HEP after HL-LHC




2020 - 2040 | 2045 - 2060 | 2065 - 2090

FUTURE CIRCULAR COLLIDER

# optimized placement and layout



## 8-site baseline "PA31-3.0"

| | |
|---|---|
| **Number of surface sites** | 8 |
| **LSS@IP** (PA, PD, PG, PJ) | 1400 m |
| **LSS@TECH** (PB, PF, PH, PL) | 2032 m |
| **Arc length** | 9.6 km |
| **Sum of arc lengths** | 76.9 m |
| **Total length** | **90.6 km** |

8 sites – less use of land, <40 ha instead 62 ha

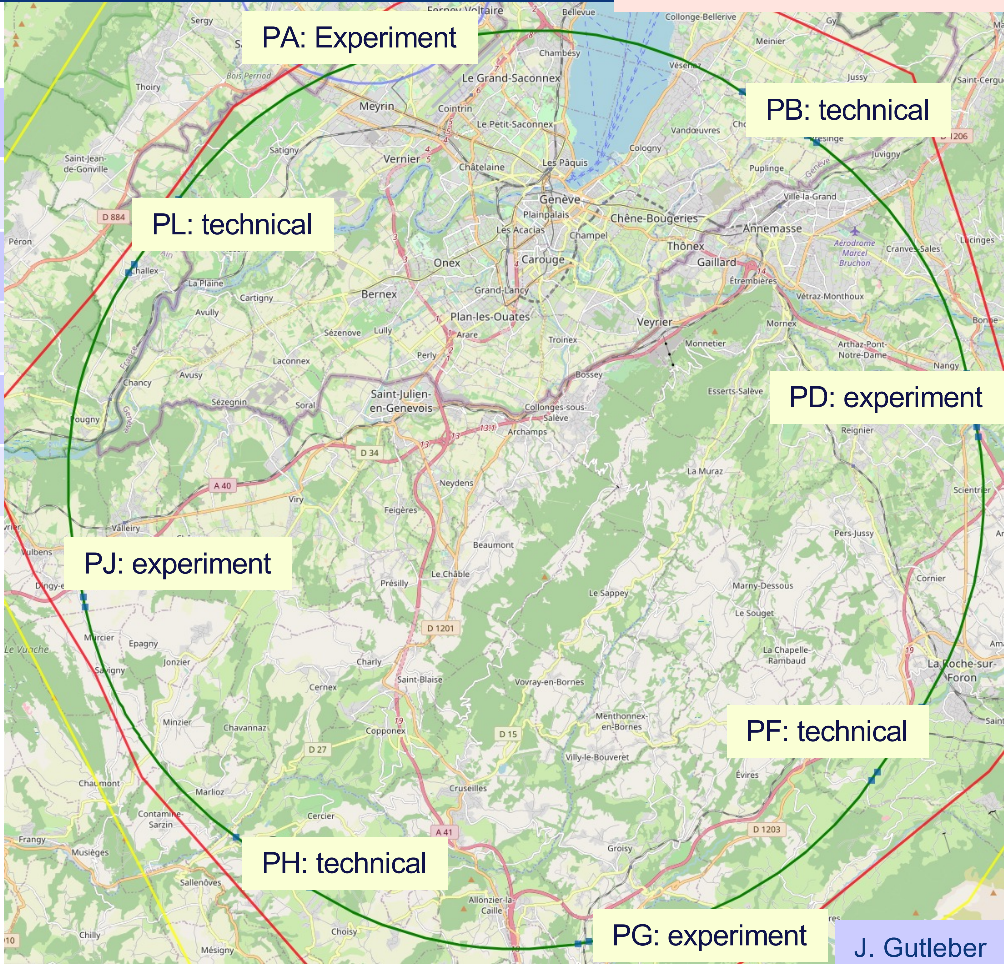
Possibility for 4 experiment sites in FCC-ee

All sites close to road infrastructures (< 5 km of new road constructions for all sites)

Vicinity of several sites to 400 kV grid lines

Good road connection of PD, PF, PG, PH suggest operation pole around Annecy/LAPP

**Exchanges with ~40 local communes in preparation**



FUTURE CIRCULAR COLLIDER

# Timeline of the FCC integrated programme

Technical schedule

1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | .................... | 19 | 20 | FCC-ee ~ 15 years operation | 10 years | FCC-hh ~ 25 years operation | 70

Feasibility Study
ESPP
Geological investigations, infrastructure detailed design and tendering preparation
Tunnel, site and technical infrastructure construction
FCC-ee dismantling, CE & infrastructure adaptations FCC-hh
FCC-ee accelerator and detector R&D and technical design
FCC-ee accelerator and detector construction, installation, commissioning
Superconducting magnets R&D
Long model magnets, prototypes, pre-series
High-field magnet industrialization and series production
FCC-hh accelerator and detector R&D and technical design
FCC-hh accelerator and detector construction, installation, commissioning

| | √s | | L /IP ($cm^{-2} s^{-1}$) | Int. L /IP($ab^{-1}$) | Comments |
|---|---|---|---|---|---|
| $e^+e^-$ FCC-ee | ~90 GeV<br>160<br>240<br>~365 | Z<br>WW<br>H<br>top | 230 x$10^{34}$<br>28<br>8.5<br>1.5 | 75<br>5<br>2.5<br>0.8 | 2-4 experiments<br>Total ~ 15 years of operation |
| pp FCC-hh | 100 TeV | | 5 x $10^{34}$<br>30 | 20-30 | 2+2 experiments<br>Total ~ 25 years of operation |
| PbPb FCC-hh | $\sqrt{s_{NN}}$ = 39TeV | | 3 x $10^{29}$ | 100 $nb^{-1}$/run | 1 run = 1 month operation |
| ep Fcc-eh | 3.5 TeV | | 1.5 $10^{34}$ | 2 $ab^{-1}$ | 60 GeV e- from ERL<br>Concurrent operation with pp for ~ 20 years |
| e-Pb Fcc-eh | $\sqrt{s_{eN}}$ = 2.2 TeV | | 0.5 $10^{34}$ | 1 $fb^{-1}$ | 60 GeV e- from ERL<br>Concurrent operation with PbPb |

F. Gianotti

- Feasibility Study: 2021-2025
- If project approved before end of decade → construction can start beginning 2030s
- FCC-ee operation ~2045-2060
- FCC-hh operation 2070-2090++

FUTURE CIRCULAR COLLIDER

# Mid-Term Review & Cost Review, autumn '23

M. Benedikt, FCC FS Status,
FCC physics workshop, Krakow 23-27/Jan/23

**Mid-term review report, supported by additional documentation on each deliverable, will be submitted to review committees and to Council and its subordinate bodies, as input for the review.**

**Results of both general mid-term review and the cost review should indicate the main directions and areas of attention for the second part of the Feasibility Study**

## Infrastructure & placement

- Preferred placement and progress with host states (territorial matters, initial states, dialogue, etc.)
- Updated civil engineering design (layout, cost, excavation)
- Preparations for site investigations

## Technical Infrastructure

- Requirements on large technical infrastructure systems
- System designs, layouts, resource needs, cost estimates

## Accelerator design FCC-ee and FCC-hh

- FCC-ee overall layout with injector
- Impact of operation sequence: Z, W, ZH, $t\bar{t}$ vs start at ZH
- Comparison of the SPS as pre-booster with a 10-20 GeV linac
- Key technologies and status of technology R&D program
- FCC-hh overall layout & injection lines from LHC and SC-SPS

## Physics, experiments, detectors:

- Documentation of FCC-ee and FCC-hh physics cases
- Plans for improved theoretical calculations to reduce theoretical uncertainties towards matching FCC-ee statistical precision for the most important measurements.
- First documentation of main detector requirements to fully exploit the FCC-ee physics opportunities

## Organisation and financing:

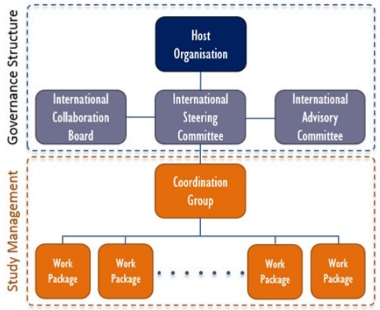
- Overall cost estimate & spending profile for stage 1 project

## Environmental impact, socio-economic impact:

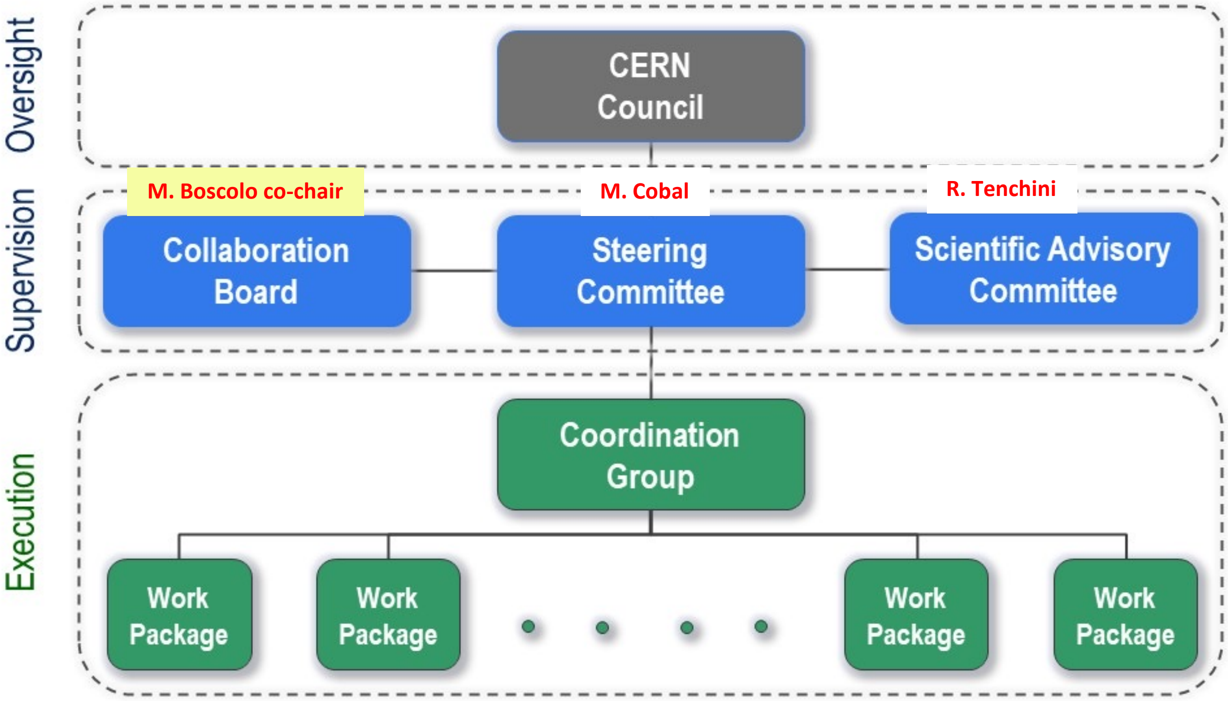
- Initial state analysis, carbon footprint, management of excavated materials, etc.
- Socio-economic impact and sustainability studies

# FCC Feasibility Study - organizational structure

- New structure very similar to the first phase of the FCC Study (2014-2020), leading to the Conceptual Design Report as input to the ESPPU.




- Classical structure common to CERN projects.



# FCC Feasibility Study – coordination team and contact persons

FCC

**EU Projects**
NN

**Collaboration building**
Emmanuel Tsesmelis

**Communications**
Panagiotis Charitos, James Gillies

**Study Support and Coordination**
Study Leader: Michael Benedikt
Deputy Study Leader: Frank Zimmermann

**Study Support Unit**
IT: Sylvain Girod
Procurement: Adam Horridge
Quality control: NN
Resources: Sylvie Prodon
Scheduling, quality mangement: NN
Secretariat: Julie Hadre

## Physics, Experiments and Detectors
Patrick Janot
Gavin Salam

- **Physics programme** – Matthew McCullough, Frank Simon
- **Detector concept** – Mogens Dam
- **Physics performance** – Patrizia Azzi, Emmanuel Perez
- **Software and computing** – Gerardo Ganis, Clément Helsens

## Accelerators
Tor Raubenheimer
Frank Zimmermann

- **FCC-ee collider design** – Katsunobu Oide
- **FCC-hh design** – Massimo Giovannozzi
- **Technology R&D** – Roberto Losito
- **FCC-ee booster design** – Antoine Chancé
- **FCC-ee injector** – Paolo Craievich, Alexej Grudiev
- **FCC-ee energy calibration polarization** – Alain Blondel, Jorg Wenninger
- **FCC-ee MDI** – Manuela Boscolo, Mike Sullivan

## Technical Infrastructures
Klaus Hanke

- **Integration** – Jean-Pierre Corso
- **Geodesy & survey** – Hélène Mainaud Durand
- **Electricity and energy management** – Jean-Paul Burnet
- **Cooling and ventilation** – Guillermo Peon
- **Cryogenics systems** – Laurent Delprat
- **Computing and controls infrastructure, communication and network** – Dirk Duellmann
- **Safety** – Thomas Otto
- **Operation, maintenance, availability, reliability** – Jesper Nielsen
- **Transport, installation concepts** – Cristiana Colloca

## Host State processes and civil engineering
Timothy Watson

- **Administrative processes** – Friedemann Eder
- **Placement studies** – Johannes Gutleber, Volker Mertens
- **Environmental evaluation** – Johannes Gutleber
- **Tunnel, subsurface design** – John Osborne
- **Surface sites layout, access and building design**

## Organisation and financing models
Paul Collier (interim)

- **Project organisation model**
- **Financing model** – Florian Sonnemann
- **Procurement strategy and rules**
- **In-kind contributions**
- **Operation model** – Paul Collier, Jorg Wenninger

# Attivita’ FCC e’ in Gruppo1

Attivita’ strutturata in work packages, ognuno con coordinatore

| | |
|---|---|
| WP1 Physics & simulation | (P. Azzi/PD) |
| WP2 Accelerator | (M. Boscolo/LNF) |
| WP3 Silicon/Vertex detectors | (M. Caccia/MI, A. Andreazza/MI) |
| WP4 Drift chamber | (F. Grancagnolo/LE) |
| WP5 MPGD for muon/preshower | (P. Giacomelli/BO) |
| WP6 Dual readout calorimetry | (R. Ferrari/PV) |

**RD_FA** (2017-2020)
resp naz F. Bedeschi

**WP2: FA MDI**
convener M. Boscolo

**RD_FCC** (2021- )
resp naz F. Bedeschi

**WP2: FCC MDI**
convener M. Boscolo

**WP2: FCC Acceleratore**
convener M. Boscolo

2017 2018 2019 2020 2021 2022

https://agenda.infn.it/event/29752/

FCC Accelerator activities: Italian involvement (M.Boscolo)

# First FCC-Italy workshop 21-22 March `22

Strong interest by the President and the INFN Board to consolidate the Italian collaboration in FCC


04 APRILE 2022

## IL PRIMO WORKSHOP ITALIANO SUL GRANDE ACCELERATORE DEL FUTURO

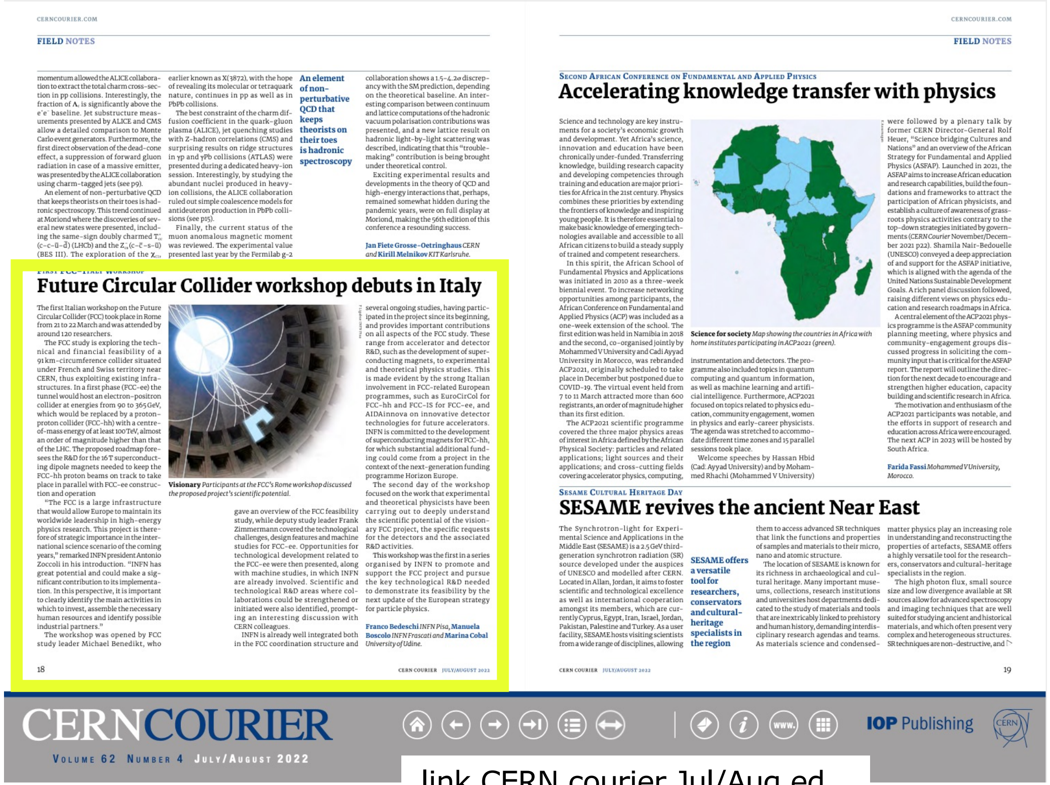
Si è recentemente tenuto a Roma il First FCC-Italy Workshop, il primo workshop italiano dedicato al progetto per il successore del Large Hadron Collider al CERN, il Future Circular Collider. All'evento, organizzato dall'INFN, hanno partecipato 120 ricercatori e ricercatrici, e sono state presentate 15 relazioni.

Nell'ultimo documento sulla strategia europea per la fisica delle particel[le] approvato dal Council del CERN nel giugno 2020, FCC è indicato come il progetto futuro di massima priorità: da qui è iniziato un vasto programm[a] di studi di fattibilità, che costituirà un input importante per la prossima edizione dell'Update della Euroepan Strategy for Particle Physics.

Il progetto FCC prevede una nuova macchina acceleratrice molto più potente dell'attuale LHC, con una circonferenza di circa 91 km in un tunnel sotto il territorio francese e svizzero, in prossimità del CERN per sfruttarne le infrastrutture già esistenti. In una prima fase (FCC-ee) il tunnel dovrebbe ospitare un collisore di elettroni e positroni di energia variabile da 90 a 365 GeV. Successivamente, questo verrebbe sostituito da un collisore di protoni (FCC-hh) con un'energia nel centro di massa di 100 TeV, quasi un ordine di grandezza superiore a quel di LHC. L'idea è di partire con FCC-ee e in parallelo proseguire il lavoro di R&D necessario per realizzare i dipoli di 16 T necessari a mantenere la traiettoria dei protoni di 50 TeV di energia all'interno dell'anello.

"Con FCC si lavora a una grande infrastruttura che garantirebbe all'Europa di mantenere la sua leadership nella ricerca in fisica delle alte energie: il progetto è dunque di importanza strategica nel panorama internazionale negli anni a venire", ha sottolineato Antonio Zoccoli, presidente dell'INFN, nel suo discorso di apertura in occasione del workshop. "L'INFN ha grandi potenzialità e può dare un contributo notevole alla sua realizzazione: in questa prospettiva è quindi importante identificare con chiarezza le principali attività dove investire, coalizzare le necessarie risorse umane e individuare possibili partner industriali".

link INFN news




link CERN courier Jul/Aug ed.

# Attività INFN RD_FCC

Alcune attivita' gia' ben inserite nel Feasibility study (FS) e sono in corso da tempo e quindi ci sono accordi CERN-INFN tramite addendum/MoU e fondi esterni, altre sono nuove

| | | Fondi esterni |
|---|---|---|
| • **Disegno IR & MDI** | **LNF** | FCCIS [2 Addenda (CERN-LNF)] |
| • **Effetti collettivi** | **Roma1, LNF** | FCCIS [MoU (CERN-Sapienza), sinergia con Arya-CSN5 |
| • **Damping Ring** | **LNF** | CHART (Swiss program) [Add. (CERN-LNF)] |
| • **Cavita' SRF** | **LNL** | sinergia con SAMARA-CSN5, iFAST |
| • **Detector Solenoid e magneti della IR** | **INFN-Ge** | sinergia con PNRR-IRIS |
| • **Sorgente di positroni** | **INFN-Mi, INFN-Fe** | |
| • **Diagnostics for bunch intensity control** | **INFN-Mi** | |

# Team LNF

Mostafa Behtouei
Manuela Boscolo
Andrea Ciarma
Antonio De Santis
Francesco Fransesini
Stefano Lauciani
Mauro Migliorati (Roma1)
Catia Milardi
Luigi Pellegrino
Simone Spampinati
Mikhail Zobov

**Il team e' organizzato nell'INFN attraverso l'attivita' CSN1 RD_FCC WP2 Acceleratore**

attivita' sinergiche
FCCIS H2020
CHART (Swiss funding)

Giacomo Broggi (CERN Doctoral Student, PhD Fisica Acceleratori Sapienza, relatrice interna MB)
Ogur Etisken (post-doc INFN)
Enrico Di Pasquale

**FTE ~ 7**

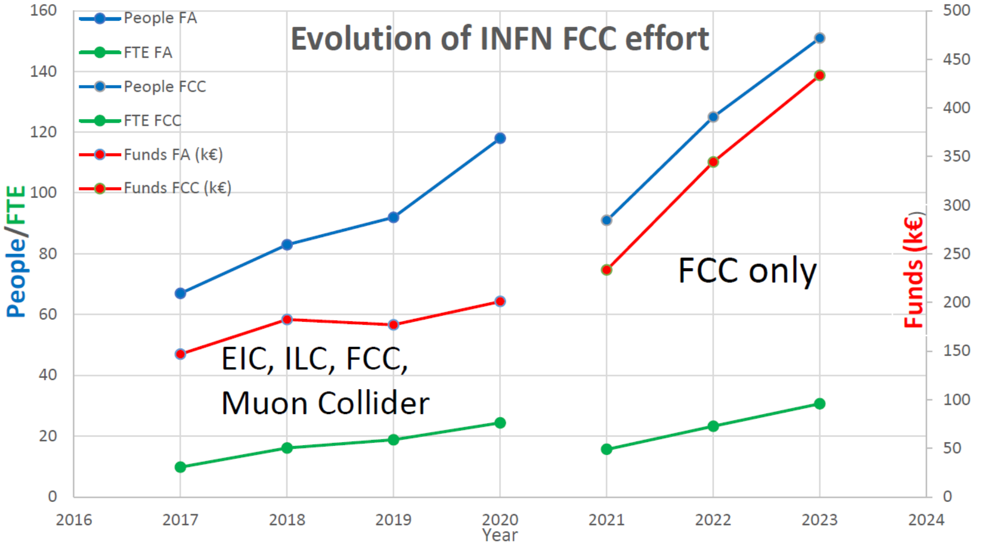
# RD_FCC

## INFN FCC Work Packages

- **WP1: Physics and software**
  - All 19 INFN sections
- **WP2: Accelerator**
  - GE, LNF, LNL, MI
- **WP3: Silicon Detectors**
  - GE, MI, PI, TO
- **WP4: Drift Chamber**
  - BA, LE
- **WP5: MPGD muon**
  - BO, FE, LNF
- **WP6: DR calorimetry**
  - BO, MI, MIB, NA, PI, PV, RM1, RM3

## Current situation

| Sezione | Total FTE | Scientists |
|---|---|---|
| BA | 2.40 | 11 |
| BO | 3.40 | 16 |
| CT | 1.80 | 4 |
| FE | 1.50 | 7 |
| FI | 0.15 | 2 |
| GE | 0.75 | 8 |
| LE | 1.10 | 6 |
| LNF | 4.85 | 15 |
| LNL | 0.10 | 1 |
| MI | 3.45 | 7 |
| MIB | 0.10 | 1 |
| NA | 1.00 | 9 |
| PD | 1.25 | 9 |
| PI | 2.10 | 21 |
| PV | 4.10 | 12 |
| RM1 | 0.30 | 2 |
| RM3 | 0.90 | 5 |
| TO | 0.90 | 10 |
| UD | 0.55 | 5 |
| Totali | 30.70 | 151 |




Encouraging Evolution of the personpower and of the support

**Nel 2022 ci sono state molte novita'**
**Acceleratori crescono come richiesto dal top management**

# Progetti su FCC presentati alla giunta INFN per la European Strategy for Particle Physics Update (ESPPU)

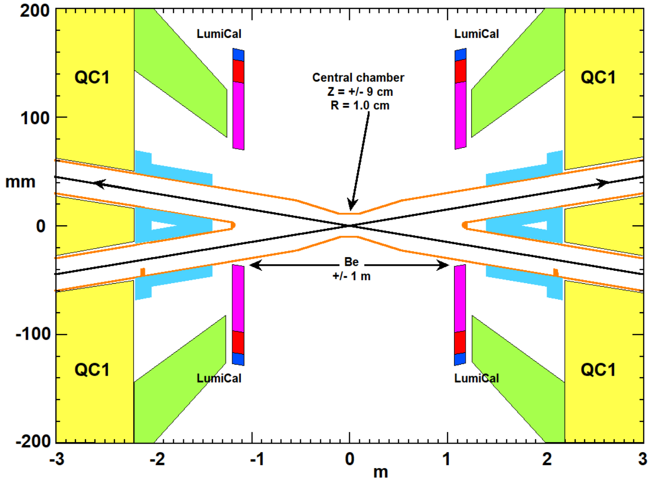
- FCC-ee IR and MDI full-scale Experimental Validation
  - Interaction Region design including mock-up (first attempt toward executive design)
  - Beam backgrounds, beam and synchrotron radiation collimators
  - Background shielding and dump
- FCC-ee Injector
  - damping ring and transfer lines design
  - Injection ?
  - Positron source? (synergy with INFN-Fe, INFN-Mi ?)
- FCC-ee SRF

**Devono passare dal MAC per fondi addizionali rispetto a CSN1**

# Regione di interazione

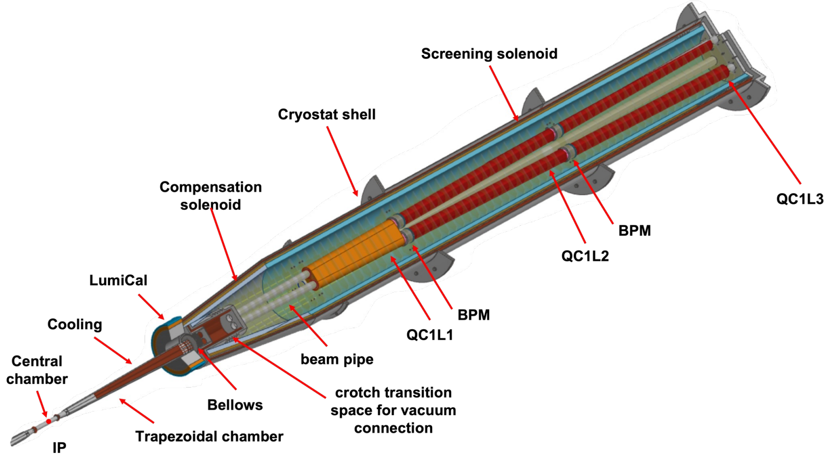
International collaboration MDI team
INFN (leader MB), CERN, CNRS, DESY, SLAC, BNL, NBI, UOXF

# FCC-ee Interaction Region layout




The face of the first final focus quadrupole QC1, and the free length from the IP, L*, is 2.2 m. The 10 mm central radius is foreseen for ± 9 cm from the IP, and the two symmetric beam pipes with radius of 15 mm are merged at 1.2 m from the IP.

**Crab-waist scheme: nano-beams & CW sextp.**




3D view of the FCC-ee IR until the end of the first final focus quadrupole

This will be inside the detector, being the half-length of the detector almost 6 m and the end QC1 at about 8.4 m.

MB , H. Burkhardt, K. Oide, and M. Sullivan EPJ+ 2021
MB et al. Proc. of IPAC

K. Oide et al., PR-AB 19, 111005 (2016)

# FCC-ee asymmetric crab-waist IR optics

**Double ring** e+ e- collider, Common footprint with FCC-hh, except around IPs

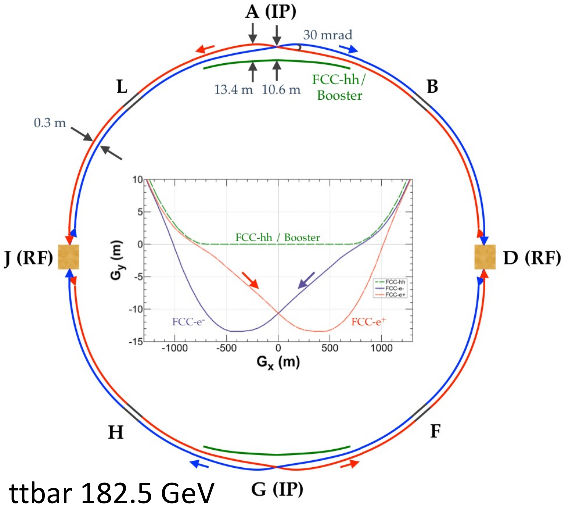
Asymmetric IR layout and optics to limit synchrotron radiation towards the detector

**2 IPs (or 4IPs)** large horizontal crossing angle 30 mrad, **crab-waist** collision optics

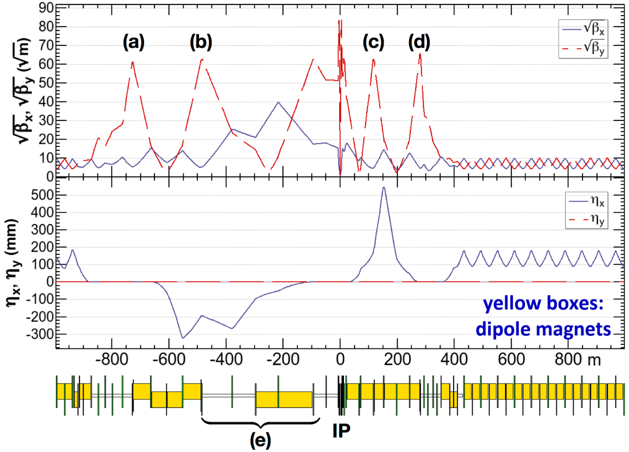
Synchrotron radiation power **50 MW/beam** at all beam energies

**Top-up** injection scheme for high luminosity requires booster synchrotron in collider tunnel

“**Tapering**” of magnets along the ring to compensate the sawtooth effect




ttbar 182.5 GeV




**Novel asymmetric IR optics** to suppress synchrotron radiation toward the IP, **$E_{critical}$ <100 keV from 450 m from IP (e) – lesson from LEP**

**4 sextupoles (a – d) for local vertical chromaticity correction combined with crab waist,** optimized for each working point **– novel “virtual crab waist”, standard crab waist demonstrated at DAFNE**

# High-level Requirements for the IR and MDI region

- **One common IR for all energies, flexible design** from 45 to 182.5 GeV with a constant detector field of **2 T**

  **At Z pole:** Luminosity ~ $10^{36}$ $cm^{-2}s^{-1}$ requires crab-waist scheme, nano-beams & large crossing angle.

  Top-up injection required with few percent of current drop.

  Bunch length is increased by 2.5 times by beamstrahlung

  At **ttbar threshold**: synchrotron radiation, and beamstrahlung dominant effect for the lifetime
- **Solenoid compensation** scheme

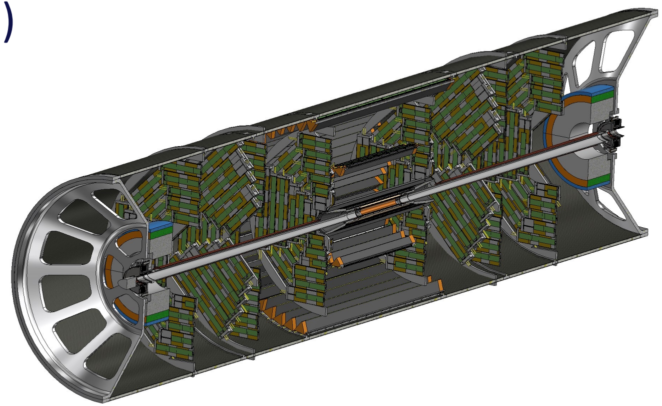
  Two anti-solenoids inside the detector are needed to compensate the detector field
- **The cone angle of 100 mrad cone between accelerator and detector** seems tight,
  - it should be optimized considering constraints on both sides.
- **Luminosity monitor** @Z: absolute measurement to $10^{-4}$ with low angle Bhabhas
  - Acceptance of the lumical, low material budget for the central vacuum chamber
  - alignment and stabilization constraints
- **Critical energy below 100 keV** of the Synchrotron Radiation produced by the last bending magnets upstream the IR at $tt_{bar}$
  - constraint to the FF optics, asymmetrical bendings

# Attivita' disegno IR & MDI

- Disegno della regione di interazione e machine-detector-interface with mock-up (first attempt toward executive design)

Ingegnerizzazione IR & MDI

- Definizione camera da vuoto centrale e fino ai final focus quads
- Disegno soffietto, studio impedenza, carico termico
- Supporti meccanici, tubo di supporto in fibra di Carbonio, ancoraggio al rivelatore
- Integrazione vertex detector, tracker e luminometro [INFN-Pisa Fabrizio Palla, Filippo Bosi]



- Studio dell'impatto dei fondi macchina e radiazione di sincrotrone sui rivelatori, studio delle schermature
- Valutazione e controllo della radiazione prodotta dalla regione di interazione

Also the following topics relevant/critical for the design of the IR

- Remote flange design based on shape-memory-alloy (SMA)
- IR magnets design, key component for the MDI
- IP diagnostics, especially for the constraint to the available space, BPMs – need discussion with BI group
- Supports & vibration control, Alignment system

Giacomo Broggi (CERN doctoral student, Sapienza)
within CERN collimation team & MDI team

# Collimation studies & IR loss maps

- Using newly-developed simulation tools to study collimation for the FCC-ee

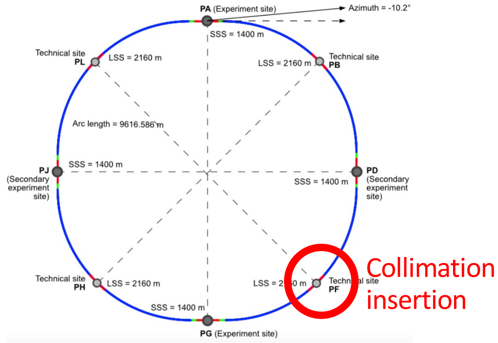
pyAT, Xtrack — Particle tracking

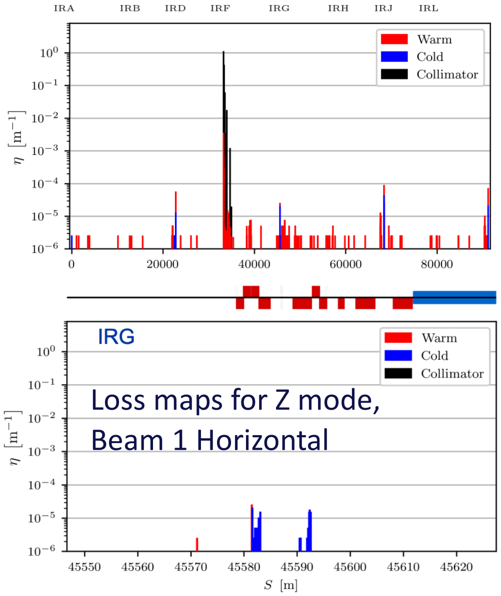
BDSIM (Geant4) — Collimator interactions

Particle transfer at every collimator pass

- First collimation scheme
- Currently focussing on beam halo losses with a workflow similar to LHC studies

- Various beam loss scenarios are being considered
- → The beam loss maps are used to evaluate the impact to the detector using the detector software (Key4HEP)



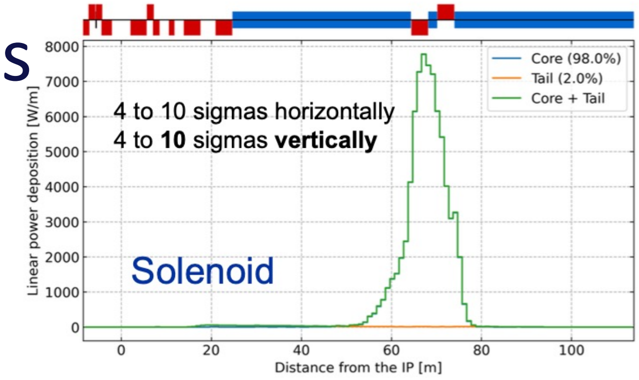



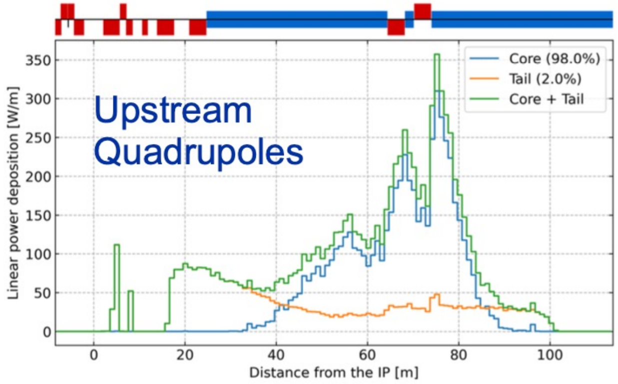
# Synchrotron Radiation backgrounds

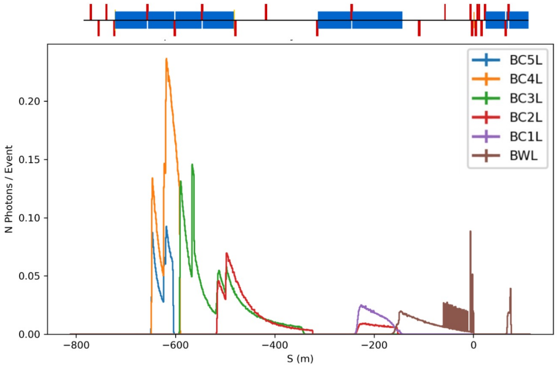
- Interaction region lattices for the 4 operation modes implemented in BDSIM
- Dipole, solenoid and quadrupole radiation evaluated
- Radiation from last bend reaches the IP
- SR photons from solenoid do not hit near the IP
- SR from FF quadrupoles leads to losses near the IP, in particular when beam tails are considered

- injection backgrounds simulations with study of the SR produced by the injected beam, possibly impacting the detector ->

giving the constraints to the injection scheme




SR from dipoles

SR from beam tails in quads and solenoid for Z

Photons tracks impacting the beam pipe are tracked with Key4HEP into the CLD detector, to evaluate occupancy

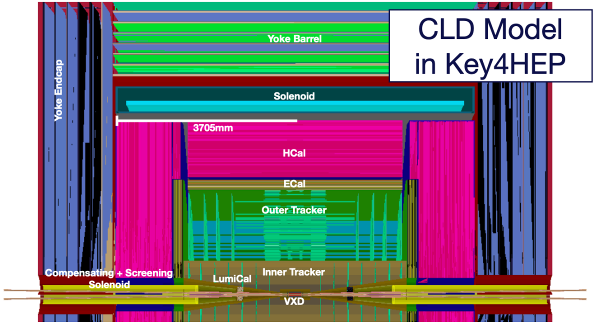
# Detector Backgrounds

CLD detector and MDI model in Geant4 adapted to 10 mm beampipe

Solenoid field map imported in key4hep

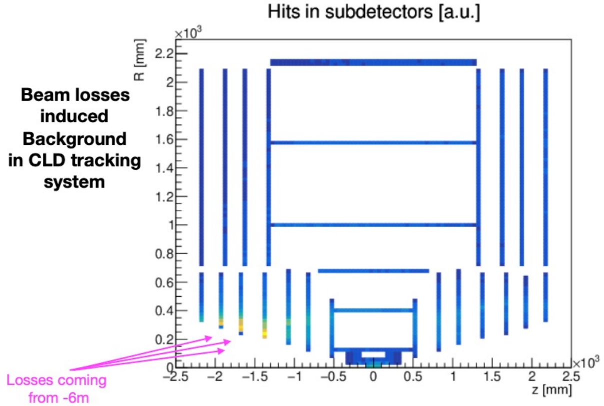
Collision products, beam, and photon losses are now studied

- Occupancy from incoherent pair production tolerable
- Occupancy from beam halo losses only concerning at ttbar, for beam loss scenarios considered until now

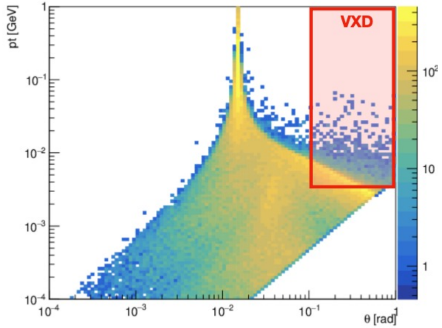



CLD Model in Key4HEP

| | Z | WW | ZH | Top |
|---|---|---|---|---|
| Pairs/BX | 1300 | 1800 | 2700 | 3300 |
| Max occup. VXDB | 70e-6 | 280e-6 | 410e-6 | 1150e-6 |
| Max occup. VXDE | 22.5e-6 | 95e-6 | 140e-6 | 220e-6 |
| Max occup. TRKB | 9e-6 | 20e-6 | 38e-6 | 40e-6 |
| Max occup. TRKE | 110e-6 | 150e-6 | 230e-6 | 290e-6 |




- Preliminary studies show little quench risk for the FF quads due to halo losses.
- Preliminary studies show photon losses absorbed or deflected by mask




Incoherent pair creation

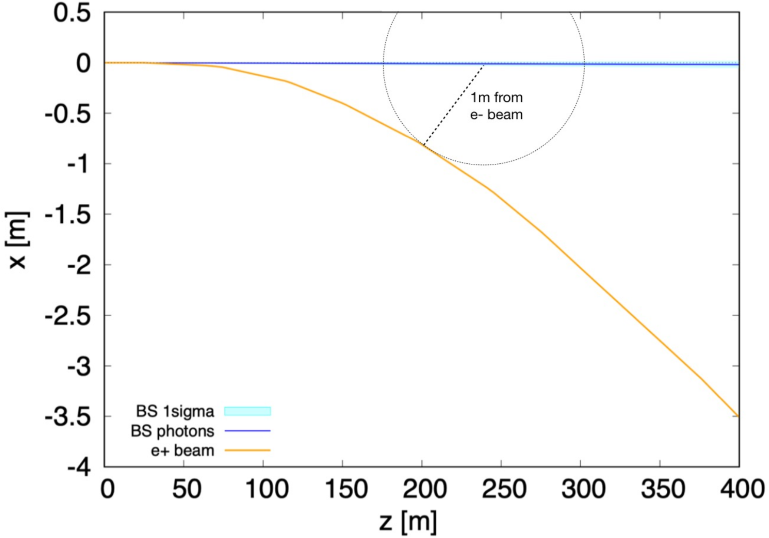
# Beamstrahlung Photon Dump

| | Total Power [kW] | Mean Energy [MeV] |
|---|---|---|
| Z | 370 | 1.7 |
| WW | 236 | 7.2 |
| ZH | 147 | 22.9 |
| Top | 77 | 62.3 |

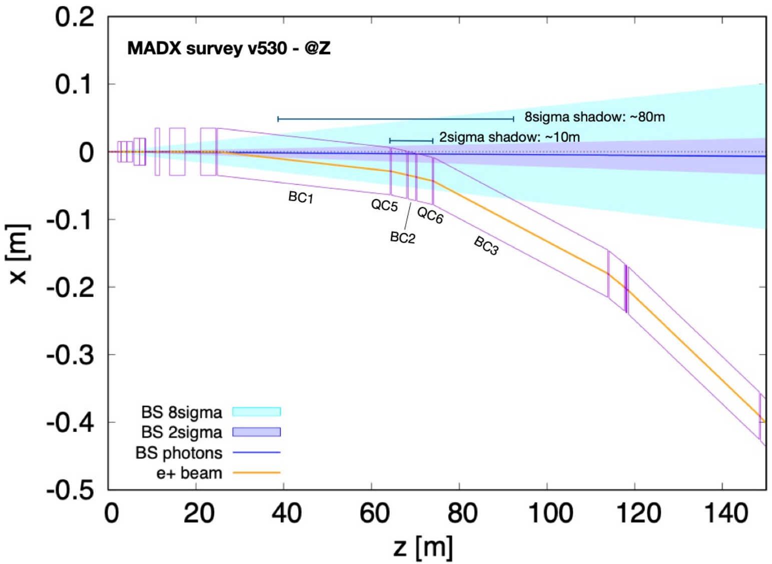
**Radiation from the colliding beams is very intense 370 kW at Z**

**Synchrotron Radiation from the fringe solenoid and anti-solenoid is ~ 77 kW**

An **external dump is preferrable**



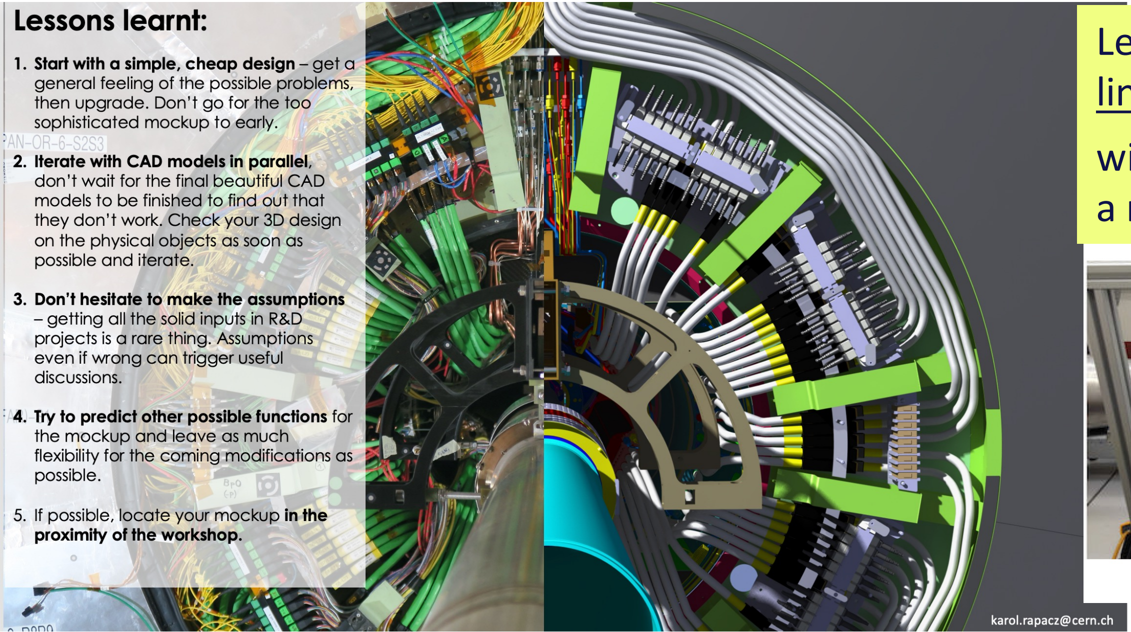

*Plots courtesy Andrea Ciarma*




An external dump is possible with an **extraction line up to at least 300-400 m downstream of the IP, where the electron and photon beams have a separation of about 2-3 m**.

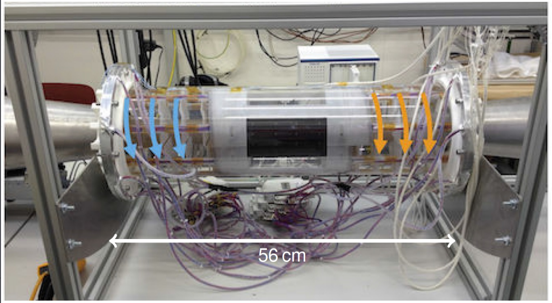
# FCC-ee IR mock-up at Frascati

- Progetto complementare al disegno della IR & MDI
- Progetto presentato alla giunta, previo accordo e con pieno supporto del direttore LNF
- Attendiamo il report prima di discuterne

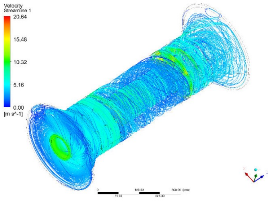



Lessons Learnt from CMS Mock-ups
link talk Andrea Gaddi(CERN)

with considerations on
a mock-up for FCC-ee IR




(a)




(b)

*courtesy F. Duarte Ramos*

IN2P3-IJCLab, INFN-LNF, INFN-Ferrara, INFN-Mi

# FCC-ee Injector

Project in CHART: Collaboration between PSI and CERN with external partners

WP0. Coordination (PSI/CERN)
Task 0.1 Coordination
Task 0.2 Overall parameter optimization

WP1. e+/e- 6 GeV Injector Linacs CERN

WP2. Electron and positron Linac extension study (PSI)

WP3. Positron source: target and capture system (IJCLab)

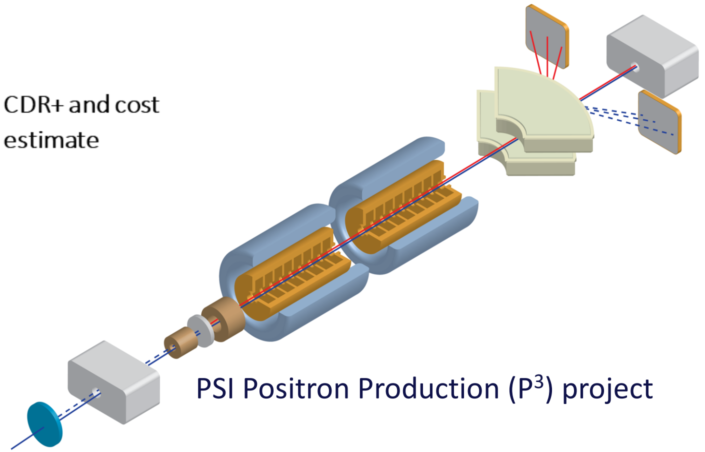
WP4. Damping ring and transfer lines (INFN/LNF)

WP5 CDR+, all partners ❖

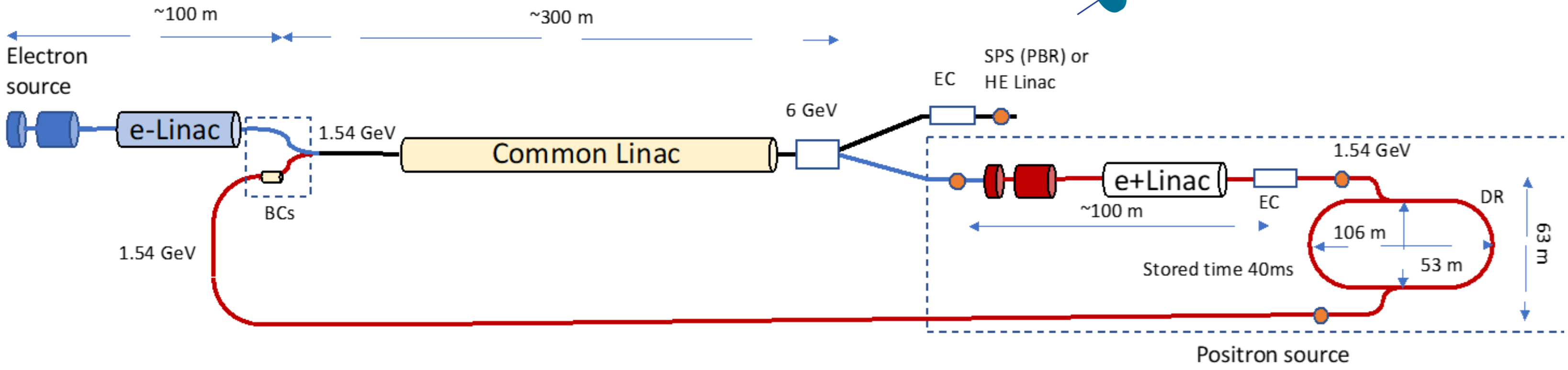
CDR+ and cost estimate

$P^3$ project

WP6. Proof of Principle positron source and capture in SwissFEL (PSI) ❖



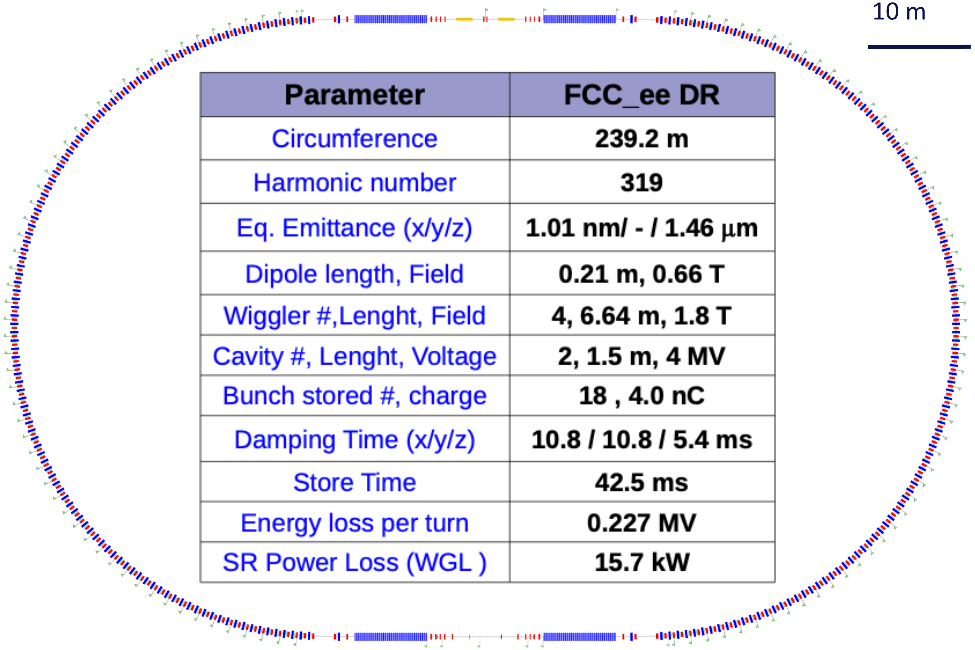
PSI Positron Production ($P^3$) project



INFN-LNF
C. Milardi, A. De Santis, S. Spampinati, O.Etisken

# FCC_ee Injector complex: transfer line and damping ring

Damping Ring (DR) studies rely on the initial layout provided by K. Oide and S. Ogur (CDR-0)




| Parameter | FCC_ee DR |
|---|---|
| Circumference | 239.2 m |
| Harmonic number | 319 |
| Eq. Emittance (x/y/z) | 1.01 nm/ - / 1.46 μm |
| Dipole length, Field | 0.21 m, 0.66 T |
| Wiggler #,Lenght, Field | 4, 6.64 m, 1.8 T |
| Cavity #, Lenght, Voltage | 2, 1.5 m, 4 MV |
| Bunch stored #, charge | 18 , 4.0 nC |
| Damping Time (x/y/z) | 10.8 / 10.8 / 5.4 ms |
| Store Time | 42.5 ms |
| Energy loss per turn | 0.227 MV |
| SR Power Loss (WGL ) | 15.7 kW |

Dynamical aperture between 3.5 and 1.5 sigma for $\frac{\Delta E}{E} \pm 5\%$

Presently **DR design efforts** aim to:

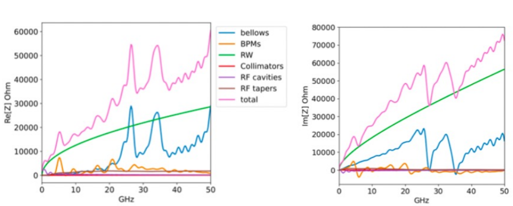
- define injection and extraction line and equipment
- include a real RF section accounting for proper voltage requirements to optimize energy acceptance, power dissipation and energy consumption
- evaluate DR impedance budget
- define vacuum system
- define beam diagnostics
- study other collective effects such as: IBS, CSR, e-cloud

## Project Timeline

- **TDR frozen by summer 2023 for the FCC-ee mid-term review**
- **Cost evaluation by the end 2023**
- **It might very well be that the FCC-ee Injector study will be prolonged beyond the end of 2023.**
- **FCC-ee feasibility report document by end 2025**

M. Migliorati (Sapienza & INFN-Roma1) leads the activity for FCC-ee
M. Zobov (LNF), M. Bethouei (LNF)

# Collective effects



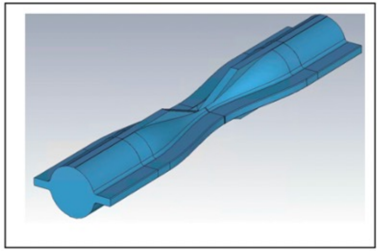

- Impedance budget evaluation in longitudinal and transverse planes:
  - CDR layout, 2IPs done
  - 4IPs present layout with optimization of beam parameters in progress.

    Refined collimators design (SuperKEKB geometry), increased number of bellows, RF baseline cavities 400 MHz
- Single beam collective effects in longitudinal plane: microwave instability

  can be cured with beam-beam
- Single beam collective effects in transverse plane: transverse mode coupling instability (TMCI)

typically not cured in beam-beam collisions. Simulations give us an indication if we can expect problems with the transverse impedance.

- Beam-beam interaction including the longitudinal impedance
- Impedance and collective effects for the FCC-ee Booster (in collaboration with DESY)

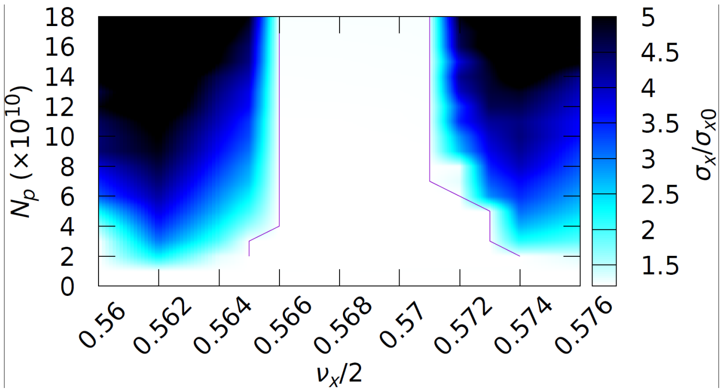

SuperKEKB Collimator model

https://accelconf.web.cern.ch/ipac2022/doi/JACoW-IPAC2022-WEOXGD1.html

# Horizontal beam size blowup due to beam-beam interaction coupled to longitudinal impedance

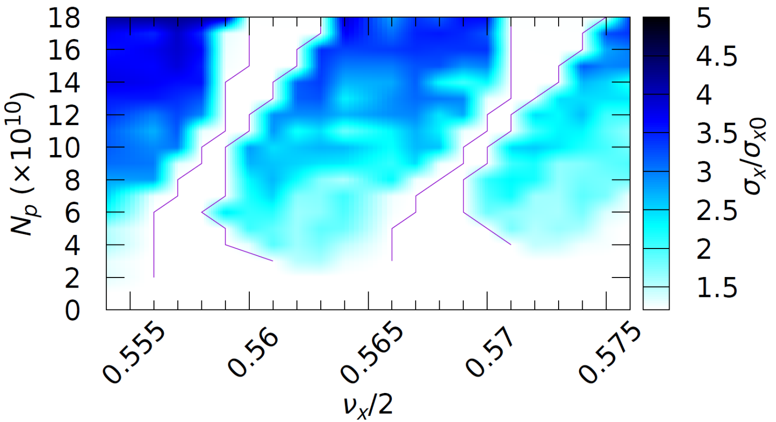
FCC-ee Z pole (CDR parameters)

**Without longitudinal impedance**




Blow-up of the horizontal beam size $\sigma x / \sigma x\, 0$ as a function of bunch intensity and the horizontal betatron tune without impedance

**With longitudinal impedance**




Blow-up of the horizontal beam size $\sigma x / \sigma x\, 0$ as a function of the bunch population and of the horizontal betatron tune by including the impedance

M.Migliorati, M.Zobov, et al. EPJ+ (2021) link

# Summary

- INFN ben rappresentata nella governance FCC
- A Frascati attivita’ cruciali del progetto
  - Disegno Regione di Interazione
  - Disegno Damping Ring e transfer line
  - Impedenze ed effetti collettivi

- Attivita’ in RD_FCC - CSN1
- Partecipazione al progetto EU FCCIS, collaborazioni internazionali, CHART Swiss program

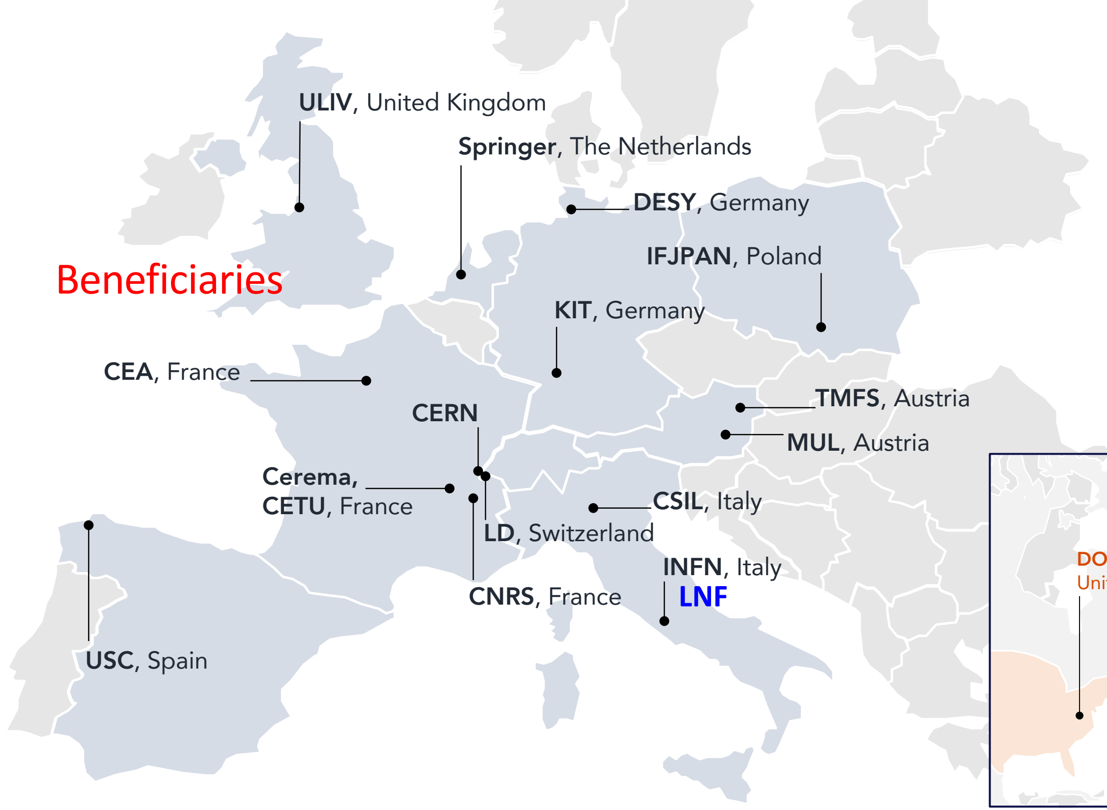
- Operazione a DAFNE: opportunita’ unica

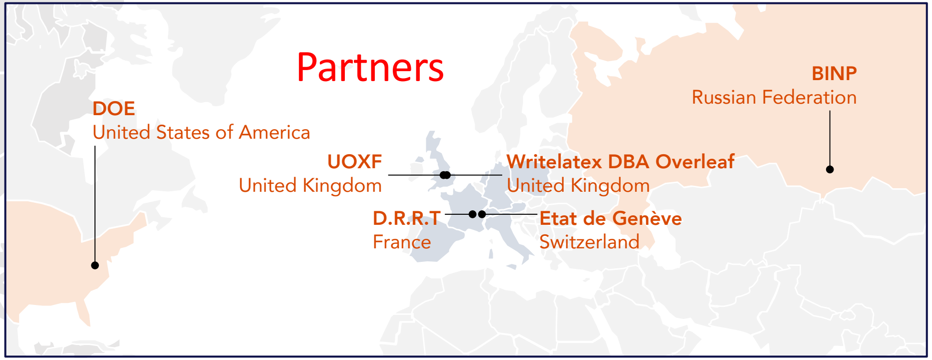
- Meeting periodici

# Infos about FCCIS & EUROCIRCOL INFRADEV EU-H2020
# e sinergie con altri fondi esterni

# FCC Innovation Study (FCCIS) EU- H2020

| Topic | INFRADEV-01-2019-2020 |
|---|---|
| Grant Agreement | FCCIS 951754 |
| Duration | 48 months |
| From-to | 2 Nov 2020 – 1 Nov 2024 |
| Project cost | 7 435 865 € |
| EU contribution | 2 999 850 € |
| Beneficiaries | 16 |
| Partners | 6 |




2 AdR, 1 art.36

# FCCIS H2020-INFRADEV Design Study

INFN Scientific coordinator M.Boscolo

**WP2: collider design** (DESY) Deliver a performance optimised machine design, integrated with the territorial requirements and constraints, considering cost, long-term sustainability, operational efficiency and design for socio-economic impact generation.

**Task Interaction region and machine detector interface** design
(lead: M. Boscolo, participants: CERN, CNRS, DESY partners BINP and UOXF)

**Subtask:** Analyse and mitigate **impedance and single-beam collective effects** in the collider rings (M. Migliorati)

WP3: integrate Europe (CERN) Develop a feasible project scenario compatible with local – territorial constraints while guaranteeing the required physic performance.

WP4: impact & sustainability (CSIL, *Centro Studi Industria Leggera, Italy*) Develop the financial roadmap of the infrastructure project, including the analysis of socio-economic impacts.

WP5: leverage & engage(IFJ PAN) Engage stakeholders in the preparation of a new research infrastructure. Communicate the project rationale, objectives and progress. Create lasting impact by building theoretical and experimental physics communities, creating awareness of the technical feasibility and financial sustainability, forging a project preparation plan with the host states (France, Switzerland).

# FCC-IS H2020-INFRADEV

Design study, mainly post-doc/phd fundings

| Partner | EU Funding |
|---|---|
| CERN | N/A |
| CEA | 188 910 |
| CEREMA | 314 660 |
| CETU | 108 005 |
| CNRS | 302 265 |
| CSIL | 197 695 |
| DESY | 474 695 |
| IFJ PAN | 139 375 |
| **INFN** | **285 780** |
| KIT | 178 850 |
| LD | 176 225 |
| MUL | 101 185 |
| SN | 189 660 |
| SMFS | 204 035 |
| ULIV | 85 910 |
| USC | 52 600 |
| SUM | **2 999 850** |

## WP2: collider design

Deliver a performance optimised machine design, integrated with the territorial requirements and constraints, considering cost, long-term sustainability, operational efficiency and design for socio-economic impact generation.

**Task 2.1**: Work package coordination – Ilya Agapov (DESY), deputy Frank Zimmermann (CERN) (lead: DESY, participants: CEA, CERN, CNRS, KIT, IFJPAN, INFN)

**Task 2.2:** Collider design (lead: DESY, CEA, CERN, KIT, IFJPAN, INFN, BINP)

- Analyse and mitigate impedance and single-beam collective effects in the collider rings (INFN) M. Migliorati

**Task 2.3:** Interaction region and machine detector interface design (lead: INFN, participants: CERN, CNRS, DESY, partners BINP and UOXF) M. Boscolo

**Task 2.4**: Full energy booster and top-up injection design (lead: CEA, participants: CERN, INFN, BINP)

**Task 2.5**: Polarisation and energy calibration (lead: KIT, participants: CERN, partner BINP)

WP2: **Beam Tests** (CERN, DESY, INFN, KIT, BINP, UOX, PSI, KEK)

facilities: KARA, DAFNE, PETRA III, VEPP-4M, SuperKEKB

| | | | | |
|---|---|---|---|---|
| M2.1 | MS4 | Milestone | Product Break- down Structure | 01/07/2021 |
| D2.1 | D4 | Deliverable | Performance, optics and design baseline | 01/11/2021 |
| D2.2 | D5 | Deliverable | IR & MDI design | 01/07/2023 |
| D2.3 | D6 | Deliverable | Full-energy booster design | 01/03/2024 |
| D2.4 | D7 | Deliverable | Experimental characterisation of key enablers | 01/05/2024 |
| D5.6 | D21 | Deliverable (WP5) | FCC-ee design report | 01/11/2024 |

European Commission

EuroCirCol

# FCC-hh Key aspects funded by H2020-INFRADEV Design Study EUROCIRCOL

resp. M. Boscolo

**Strategic activity for the FCC CDR and cost review for the EPPSU in 2019**

(2015-2019) 3 MEuro, INFN grant: **422 k€**

AdR + Art.36
3 TI ai LNF
+ … INFN

- WP3: **Experimental insertion region design** (M. Boscolo, LNF)
  Impact of synchrotron radiation emitted by protons on detector and machine components and develop mitigation techniques (outcome study: only tens of W reach the central Be chamber, not an issue)
- WP4: **Cryogenic beam vacuum system** (R. Cimino, LNF)
  SR power ~30W/m/beam in arcs, total 5 MW (LHC 7kW), 100 MW of cooling power
  → R&D planned at DAFNE (MoU)
- WP5: **High field magnet design** (S. Farinon, Ge)
  The target field strengths to the order of 16 T require novel concepts and R&D studies
  → High field magnet program

# EuroCirCol Participants person months

H2020-INFRADEV Design Study 2015-2019, 3ME,
INFN grant: 422k€ , LNF (WP3, WP4); Ge & Lasa (WP5)

| Partner | WP1 | WP2 | WP3 | WP4 | WP5 | Total PM | Total Cost | EU Funding |
|---|---|---|---|---|---|---|---|---|
| CERN | 128 | 90 | 42 | 84 | 80 | 424 | € 3,587,500 | € 138,000 |
| TUT | | | | | 40 | 40 | € 325,188 | € 166,000 |
| CEA | | 108 | | | 36 | 144 | € 1,018,770 | € 514,000 |
| CNRS | | 64 | | | | 64 | € 508,667 | € 213,000 |
| KIT | | | | 15 | | 15 | € 124,500 | € 63,000 |
| TUD | | 84 | | | | 84 | € 553,905 | € 278,000 |
| **INFN** | | | **30** | **94** | **36** | **160** | **€ 836,938** | **€ 422,000** |
| UT | | | | | 38 | 38 | € 219,185 | € 110,000 |
| ALBA | | | | 100 | | 100 | € 332,858 | € 169,000 |
| CIEMAT | | | | 54 | 48 | 102 | € 383,250 | € 193,000 |
| STFC | | | 48 | 96 | | 144 | € 595,665 | € 299,000 |
| UNILIV | 22 | | | | | 22 | € 256,844 | € 192,000 |
| UOXF | | | 88 | | | 88 | € 760,691 | € 242,000 |
| KEK | | 12 | | | 12 | 24 | € 158,445 | € 0 |
| EPFL | | | 36 | | | 36 | € 360,000 | € 0 |
| UNIGE | | | | | 24 | 24 | € 176,730 | € 0 |
| SUM | 150 | 358 | 244 | 443 | 314 | 1509 | € 10,199,135 | € 2,999,000 |

77 k€ WP3 (Experimental Env.)
208 k€ WP4 (cryogenic chamber)
137 k€ WP5 (high field magnets)

# Future Circular Collider Study at CERN: INFN contributions to the accelerator study

**situation until end of 2020**

CDR and cost review for the next European Strategy Update in 2018

## FCC-hh Hadron Collider:

- Machine Detector Interface (LNF)
- Cryogenic beam vacuum system (LNF)
- High field (16 T) magnet R&D (Ge, Lasa)

in the framework of
**EU H2020 Grant EuroCirCol:**
started on June 1st 2015, for 4 years.
**Core aspects of 100 TeV energy frontier hadron collider design**
(422k€ all'INFN)

## FCC-ee Lepton Collider

- Machine Detector Interface (LNF)- Convenership
- Impedance Evaluation (Sapienza, INFN-Roma1)
- Thin film technology for SRF cavities (Legnaro)

# Fondi esterni su FCC

- H2020 EU Funding: won **two INFRADEV** programs dedicated only to FCC:
  - FCC-hh: **EUROCIRCOL** 2015-2019
  - FCC-ee: **FCCIS** 2020-2024

- Other activities agreed with MoUs CERN/INFN
  - Damping Ring & Transfer lines (LNF)
  - High field magnet program (INFN-Genova & LASA) prototype 14 T (16T) dipole (but not part of the FCC FS)

- Other EU fundings where some FCC activities are included:
  - **EASITRAIN** 10/2017 – 09/2021
  - **I.FAST** (followed from ARIES)

# Attivita’ di macchina nell’INFN in altre sedi tutte in RD_FCC WP acceleratore

LNL, C. Pira

# INFN SRF activities for FCC-ee

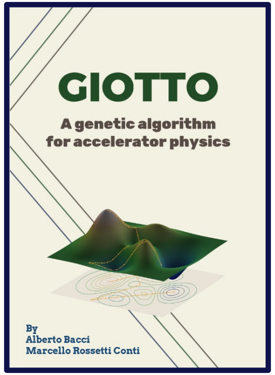
*Possible collaboration in two research lines:*

1. **Deposition of $Nb_3Sn$ films on Cu via magnetron sputtering** (ongoing project in iFAST)
   Explore alternative SRF materials for FCC to improve the Quality Factor
2. **Innovative polishing techniques for Cu substrates**
   Scaling Plasma Polishing to Cu cavities to improve Cu surface quality (one of the issues limiting thin films SRF cavities)

Cu QPR pre and post Plasma Electropolishing treatment

INFN-Mi, A. Bacci, M. Rossetti Conti

# Genetic Interface for OpTimizing Tracking with Optics

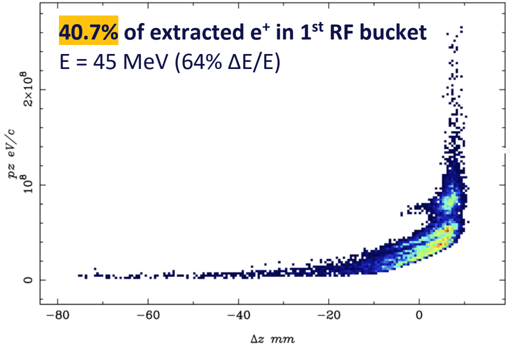



**One of first AI codes for beam line design & optimization.**
**Solves complex multi-objective problems** (correlated parameters, space-charge like) & statistical analysis (machine jitters studies).

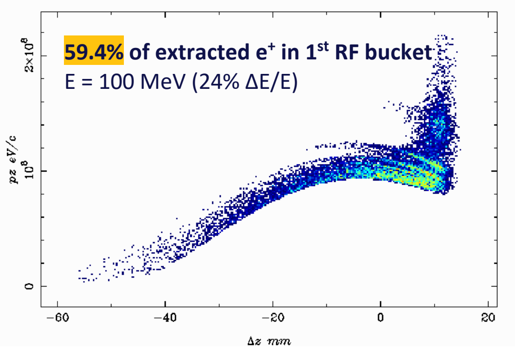
- Electron acceleration to drive the positron source by using code like Astra and Elegant
- Simulation of the electron+target interaction (i.e. positron generation) by using codes like Geant4 and/or Fluka
- Entrapment chain study and optimization **by using the GIOTTO code. Main goals: to maximize positrons flux and beam quality**.
- Foreseen formalization of the activity with a PSI group that is working on a similar activity.

## @ FCC-ee: first application in $e^+$ capture line

**Starting Point**




**GIOTTO Optimized Point**




**Successfully used in important projects, as: EUPRAXIA, MARIX, SPARC_LAB, ELI-NP**

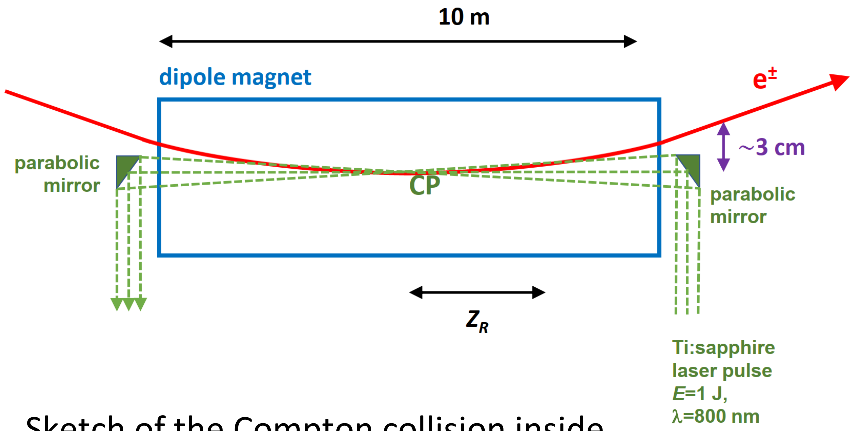
PRAB **22** (2019) - NIM A **909** (2019) - JAP **133** (2013)

Illya Drebot (INFN-Mi)

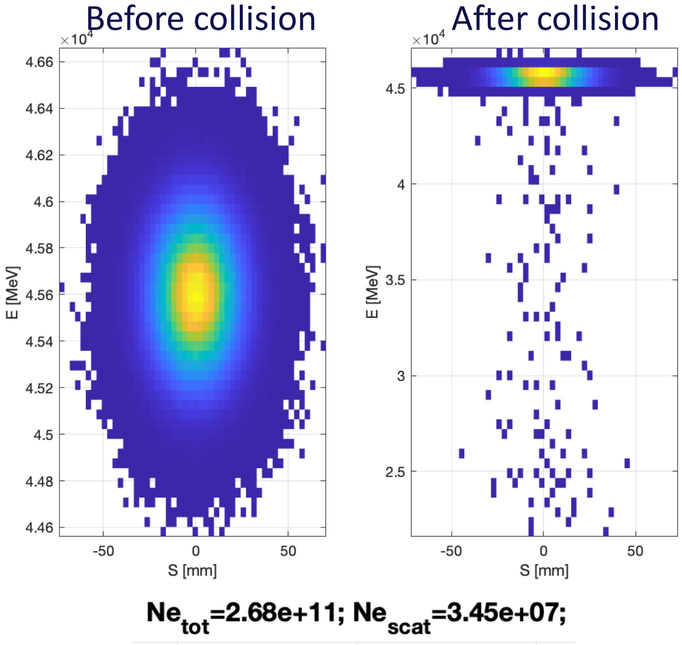
# Diagnostics and bunch intensity control via Compton scattering

**Motivation:**

- In FCC-ee the intensity of colliding bunches must be tightly controlled, with a maximum charge imbalance between collision partner bunches of less than 3–5%.
- **Laser Compton backscattering could be used to adjust and fine-tune the bunch intensity.**




Sketch of the Compton collision inside a single 10 m long dipole.




- **To-Do**: Find optimal position for Compton IP and optimise focusing parameters to increase efficiency of collision
- **Next step:** start simulation with polarisation for beam diagnostics

R. Musenich, S. Farinon (INFN-Ge)

# Detector solenoid & IR magnets

- **Contributo allo sviluppo del solenoide per il rivelatore IDEA con R&D sul conduttore.**

  Attualmente i magneti per rivelatori sono avvolti con conduttori basati sulla lega NbTi ($T_c$=9 K). La stabilità rispetto a eventi che possono provocare il quench è garantita da un rivestimento di allumino puro realizzato per co-estrusione. Al momento non esistono più aziende che forniscono questi conduttori.
  Tra le possibili alternative, l'uso di conduttori a base di $MgB_2$ ($T_c$=39 K) è particolarmente interessante e promettente.
  La fase iniziale (2023) riguarda uno studio di principio di magneti avvolti con $MgB_2$.
  La seconda fase richiederà un R&D specifico sui conduttori .

- **Contributo alla modellizzazione final focus quads QD0, molto simile a quello di SuperB, e test.**

  La Sezione di Genova ha il software e le competenze per la modellizzazione nonché le attrezzature per i test funzionali (a 4.2 K) su modelli e prototipi.