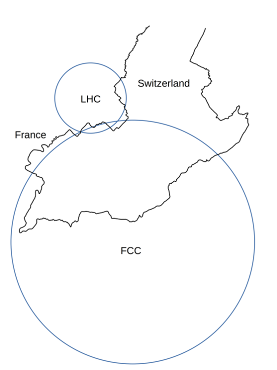
FCC ACCELERATOR ACTIVITIES: ITALIAN INVOLVEMENT



Manuela Boscolo

on behalf of the
FCC Italian collaboration

FUTURE CIRCULAR COLLIDER Innovation Study

INFN LNF

CERN

EuroCirCol A key to New Physics

http://cern.ch/fcc

Outline

- Introduction

- FCC-ee
- FCC-hh

highlight of the Italian contributions going through
the FCC-ee and FCC-hh collider design
with a mention of possible future activities considering our expertise

- Participation to FCC via EU projects
- Collaboration to FCC via MoU and Addendum with CERN
- EU projects with R&D activities of interest for FCC, but not directly for FCC

- Prospect & Outlook

Italy has been involved since the birth of the idea of a e+e- circular collider in 2012 (LEP3-TLEP-FCC)

2012 TLEP workshops

Snowmass

2013 14/Feb. 2013 LNF mini-Workshop: Higgs Factories LEP3 and TLEP, Physics opportunities

2014 Oct '14 MoU INFN-FCC (CDR)

2015 1st **FCCWEEK15** Washington DC

2016 **2nd FCCWEEK16 Rome**

2017 FCC CDR

2018

2019

EPPSU 2020

2021 New MoU INFN-FCC (FS)

2022

Snowmass

2023 FCC FS

2024

2025

EPPSU 2026

new collision scheme named **crab-waist allows to enhance luminosity:**
Italian contribution [Pantaleo Raimondi, LNF]
opens the possibility for high luminosity e+e- circular collider
(2006 for SuperB, validated at DAFNE in 2008)
All future e+e- colliders are based on this concept

CERN-OPEN-2011-047
20 January 2012
Version 2.9
arXiv:1112.2518v1 [hep-ex]

A High Luminosity e^+e^- Collider in the LHC tunnel to study the Higgs Boson

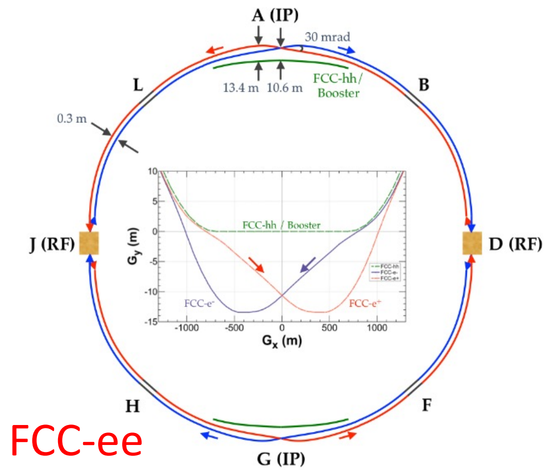
Alain Blondel[1], Frank Zimmermann[2]
[1]DPNC, University of Geneva, Switzerland; [2]CERN, Geneva, Switzerland

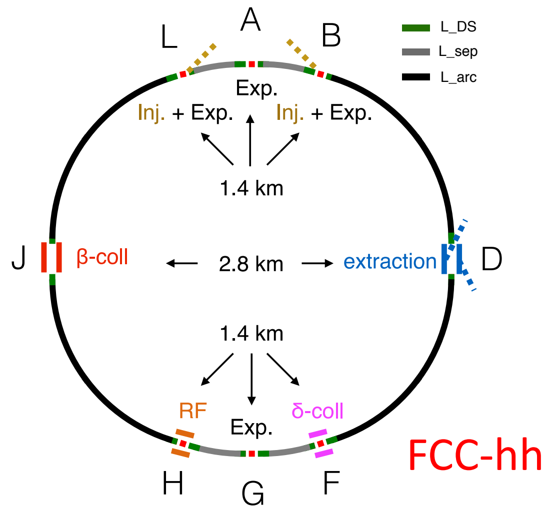
As well for FCC-hh

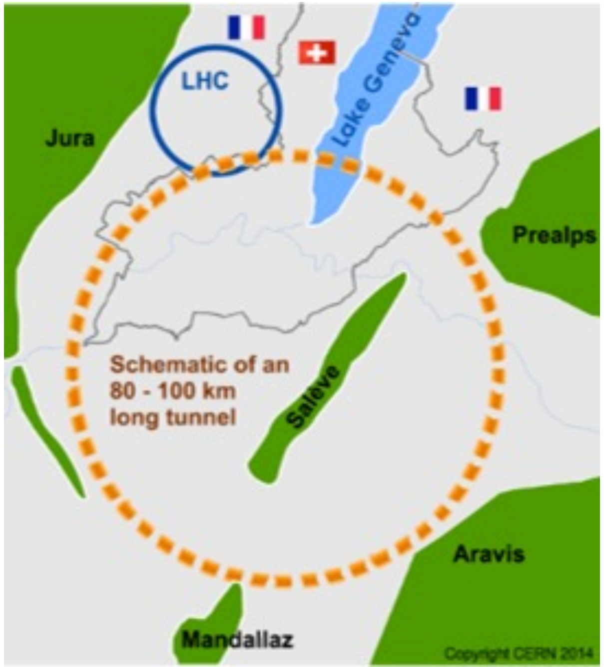
The FCC integrated program inspired by successful LEP – LHC programs at CERN

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







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/

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

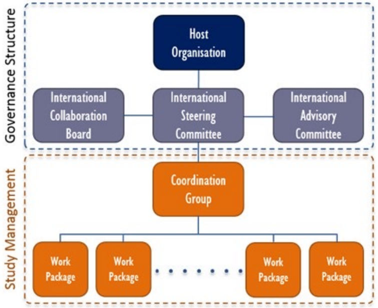
	√s	L /IP ($cm^{-2} s^{-1}$)	Int. L /IP(ab^{-1})	Comments
e^+e^- FCC-ee	~90 GeV Z 160 WW 240 H ~365 top	230 $\times 10^{34}$ 28 8.5 1.5	75 5 2.5 0.8	2-4 experiments Total ~ 15 years of operation
pp FCC-hh	100 TeV	5 $\times 10^{34}$ 30	20-30	2+2 experiments Total ~ 25 years of operation
PbPb FCC-hh	$\sqrt{s_{NN}}$ = 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 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 Concurrent operation with PbPb

F. Gianotti

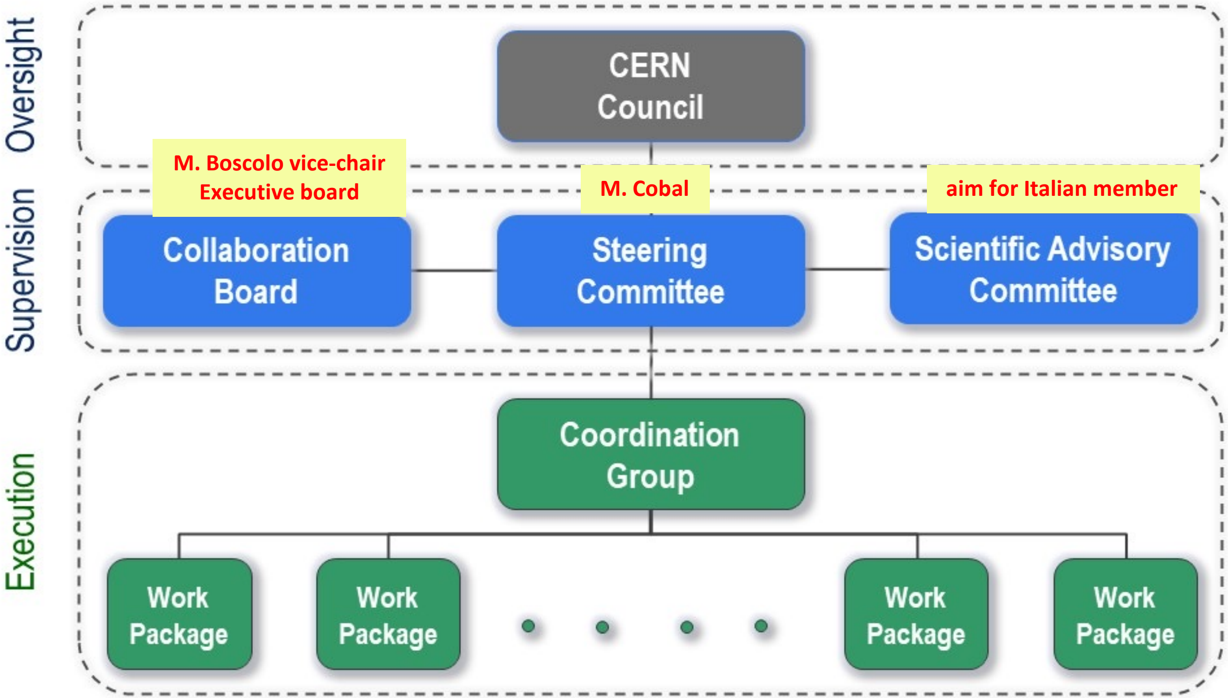
- Feasibility Study: 2021-2025
- If project approved before end of decade → construction can start beginning 2030s
- FCC-ee operation ~2045-2060
- FCC-hh operation 2070-2090++

FCC Feasibility Study - organisational 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

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

- **EU Projects** – NN
- **Collaboration building** – Emmanuel Tsesmelis
- **Communications** – Panagiotis Charitos, James Gillies

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

FCC-ee basic design choices

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 (FCC-hh 4 IPs)

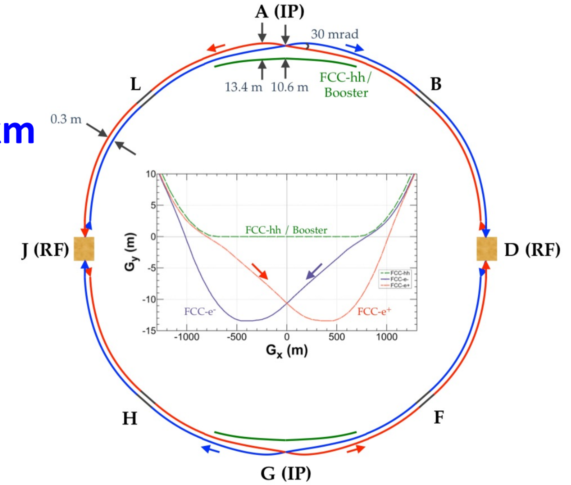
Synchrotron radiation power **50 MW/beam** at all beam energies

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

"**Tapering**" of magnets along the ring to compensate the sawtooth effect

CDR

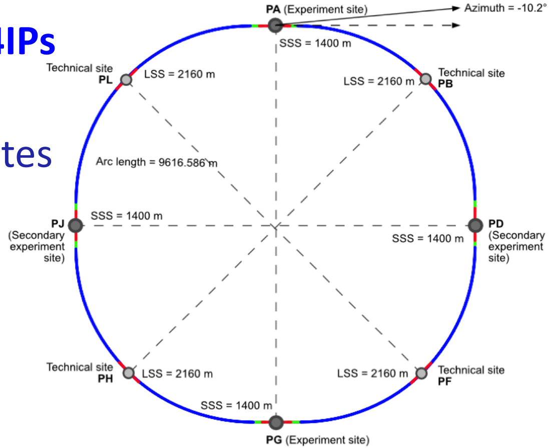
C=97 km



evolution 4IPs

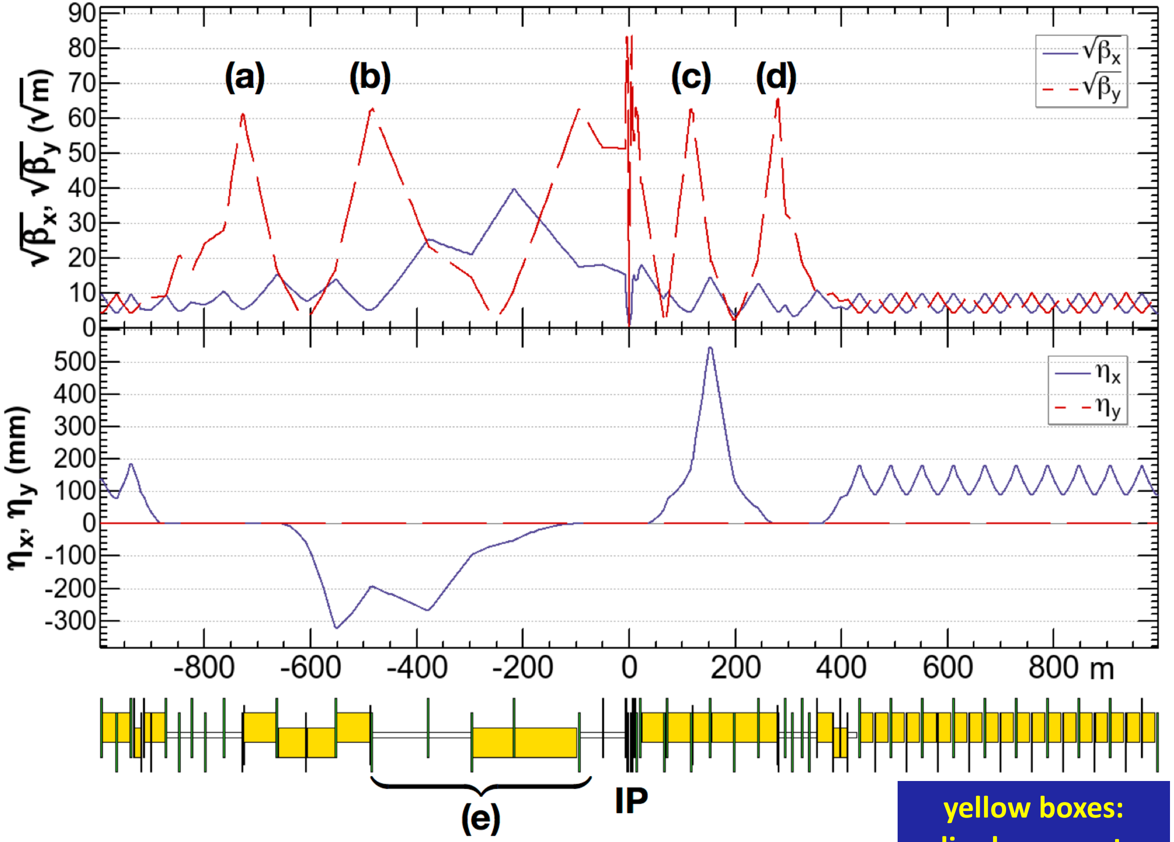
C=91 km

8 surface sites



FCC-ee asymmetric crab-waist IR optics

ttbar 182.5 GeV



yellow boxes: dipole magnets

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**

K. Oide et al., Design of beam optics for the future circular collider e^+e^- collider rings, **Phys. Rev. Accel. Beams 19**, 111005 (2016).

New collision scheme adopted by all future e^+e^- circular colliders

- **Crab-waist** based on two ingredients:
  - concept of **nano-beam scheme** **(vertical squeeze of the beam at IP and horizontal crossing angle increased, reducing the instantanous overlap area, allowing for a lower β_y*)**
  - **crab-waist sextupoles**

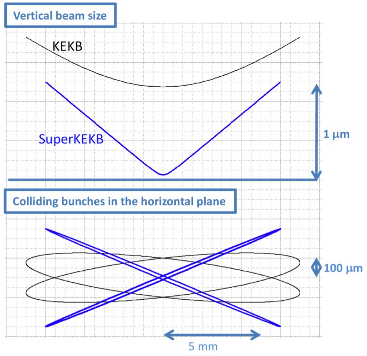


Figure 2: Schematic view of the nanobeam collision scheme.

https://arxiv.org/pdf/1809.01958.pdf

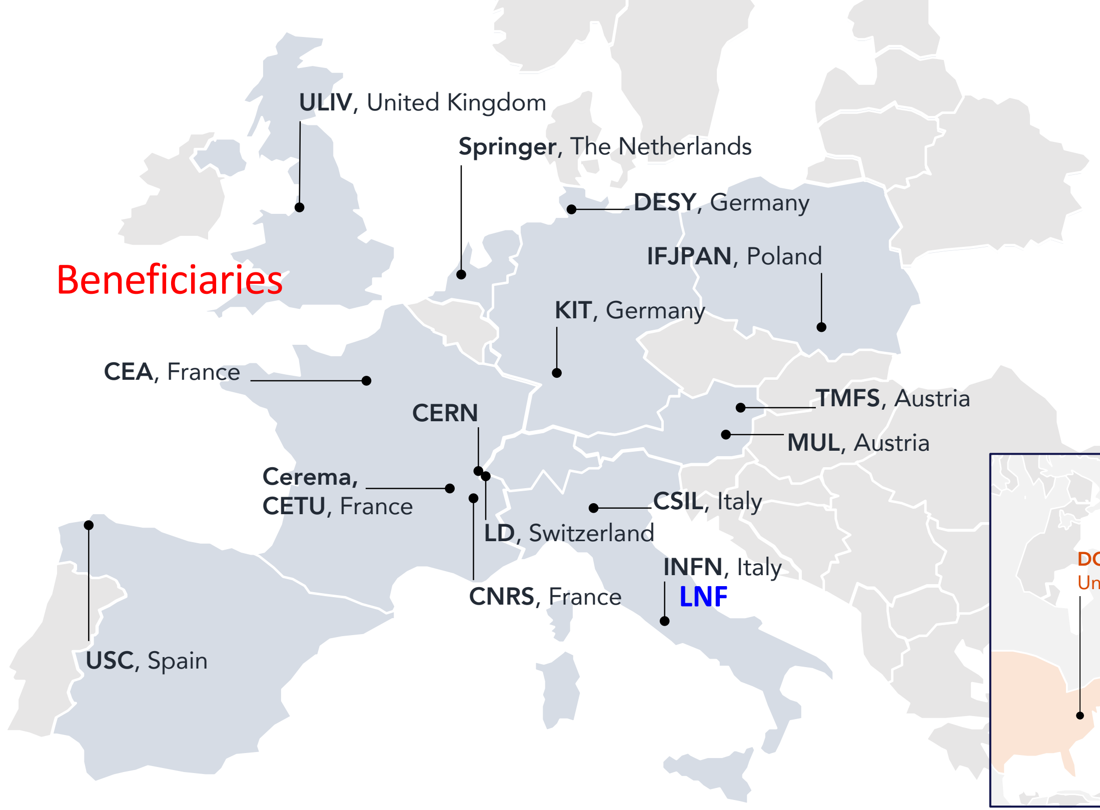
- Smaller beams at IP → higher luminosity & higher backgrounds
  (IP bkgs and beam losses in the FF quads due to the very high β-function)
- First Successful validation test performed at **DAFNE** (2008) link
- In summer 2020 SuperKEKB successfully implemented the FCC-ee *virtual* crab-waist, crab waist w/o new sextupoles (but reducing the strength of an existing FF sextupole) [K. Oide]

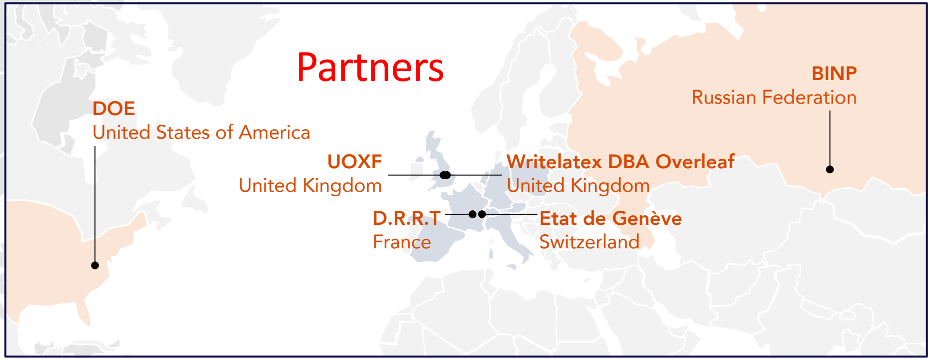
- Tight and packed interaction region with first final focus quadrupole QD0 inside detector

Commissioning of SuperKEKB as a test-bed for FCC-ee It allows experience on topics where R&D is not straightforword w/o beams, i.e. backgrounds modeling

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





INFN-LNF participates to FCCIS

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

FCCIS Work Packages

WP1: study management (CERN)

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.

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).

Coordination (M. Boscolo INFN-LNF, M. Sullivan SLAC)

INFN involvement,

expertise at INFN, interest for additional contribution?

Task 1. 3D engineering design of IR and MDI mechanical layout with integration (INFN-LNF)

1.1 Beam pipe design
1.2 Cryogenic Magnets integration
1.3 Shielding against hard SR & collision debris
1.4 IP detectors integration, i.e. lumical, VXD, support & alignment & maintenance & cabling
1.5 Vacuum sys. integration
1.6 Supporting structures design
1.7 Thermal simulations
1.8 Management of electrical and hydraulic connections/routing
1.9 Mechanical IR assembly, disassembly & repair procedures
1.10 Project Design Management

Key deliverables: **3D CAD model of whole IR** ; Preliminary structure design; Thermal and mechanical simulations; Civil engineering requirements (CERN); **Prototypes (IR vacuum chamber INFN-LNF),** alignment devices (CERN))

Task 2. BG, beam loss & rad.

2.1 Top-up injection backgr. incl. beam-beam and dedicated collimation, masking and shielding; comparing backgr. situation for different injection schemes
2.2 SR bkg with masking & shielding optim
2.3 Other single-beam BG(res.gas, Touschek, thermal γ)
2.4 Beam losses and backgr. from collisions processes: beamstrahlung, $\gamma\gamma$ collisions, bhabha, luminosity, including spent beam tracking and shielding optimization
2.5 Software tool development, link MDI codes and FCCSW
2.6 Simulation evaluation of backgrounds in detectors and mitigation
2.7 Tail collimation & machine protection strategy
2.8 Collimation scheme and strategy incl. IR collimators
2.9 Shielding of IR magnets against collision debris
2.10 Handling of incident beamstrahlung (diagnostics?)
2.11 Beam abort system: requirements, abort gaps, signal processing, etc.
2.12 Protection against rare devastating events e.g. dust
2.13 Mask + collimation hardware design
2.14 Geant4 model +/- m from IP
2.15 Neutron radiation in IR area, Fluka

Key deliverables: Masking, shielding, collimation systems; Injection scheme(s), Background sustainability by detectors; Machine protection strategy

Task 3. Conceptual design of IR elements/systems

3.1 IR Magnets design w. field map (solenoid compensation), supports, spatial tolerance, el.-magn. forces, OP conditions
3.2 Cryostat design, dimensioning cooling systems
3.3 Luminosity calorimeter & lumi. meas. including alignment
3.4 Vertex detector & possibly other IP detectors
3.5 IR beam abort sensors
3.6 Remote vacuum connection
3.7 IR vacuum system, coatings & possible HOM absorbers
3.8 IR beam diagnostic devices, Beamstrahlung monitor
3.9 Shielding experimental environment?

Key deliverables:
Prototypes (FF magnets, remote vacuum connection)

Task 4. Alignment tolerances & vibration control

4.1 Alignment specifications
4.2 Alignment/survey strategy & requ'ts
4.3 Vibration study, stabilization strategy, etc.
4.4 Feedback systems for beam collision adjustment ; feedback to maintain luminosity with top-up injection

Key deliverables: Alignment/survey strategy; Stabilization strategy; IP Feedback design

Task 5. Heat Load Assessment Sapienza & LNF

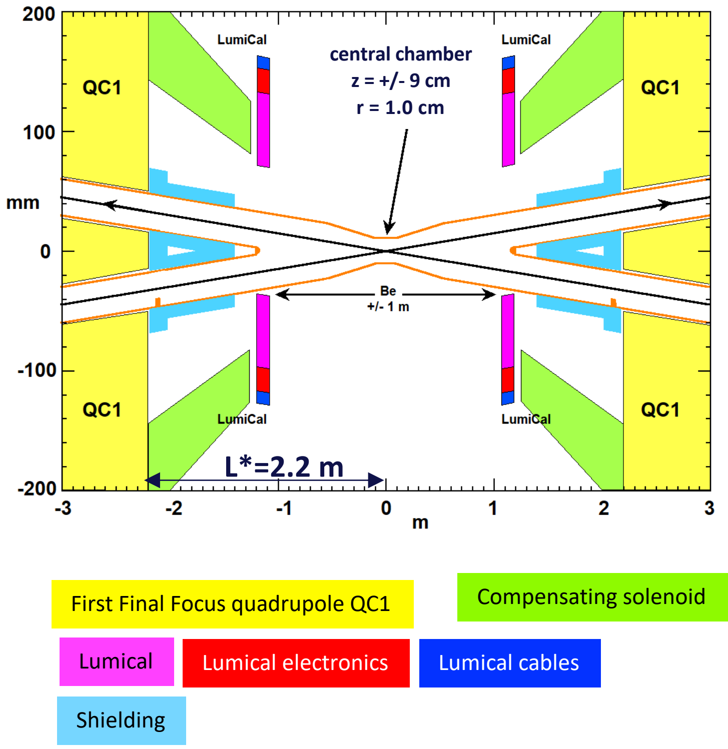
5.1 Resistive wall
5.2 Geometric impedance, HOM heat load, HOM absorbers
5.3 Heat load from SR, Beamstrahlung, radiative Bhabhas
5.4 Electron clouds
5.5 Cooling of detector elements

Key deliverable: Thermal power budget

Interaction region and machine detector interface design is part of FCCIS (LNF)
partial funding from CSN1 RD_FCC activity

FCC-ee Interaction Region

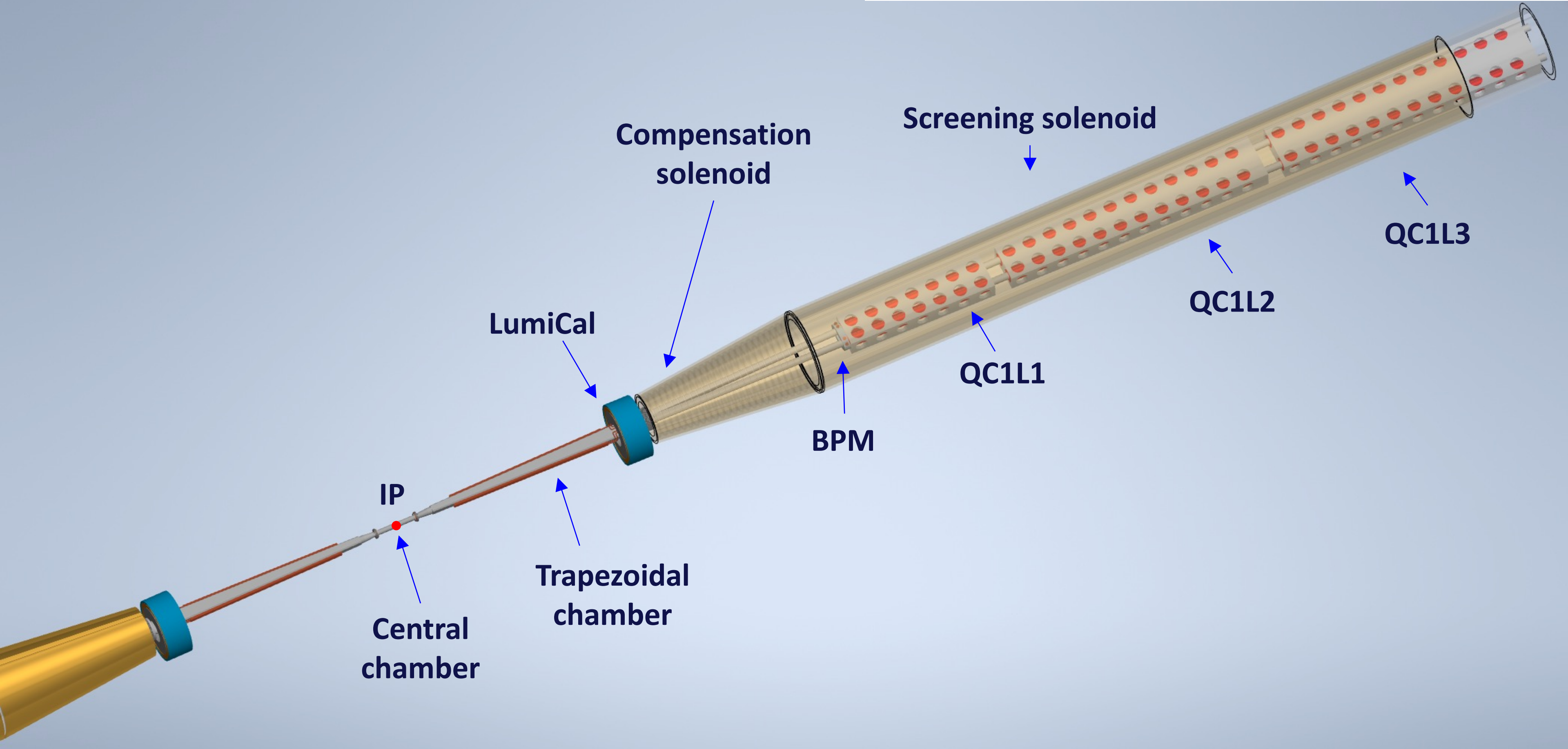
- **B(detector) = 2 T**
- **Flexible** design, one IR compatible for all beam energies
- **Compact** design: **QC1 and compensation solenoids inside detector** as a consequence of crab-waist scheme, nano-beams
- all elements required to be inside a cone of 100 mrad wrt beam axis
  - vibrations mitigation
  - alignment and monitoring system
  - feedback for beam orbit and luminosity
- **High intensity run @Z** (vacuum, residual gas, collective effects, ..)
- **High energy run @ttbar**
- **Synchrotron radiation**
- **Beamstrahlung**
- **Luminosity detector** @Z: absolute meas. to **10^{-4}** (low angle Bhabha)



M. Boscolo et al. EPJ+ 2021

3D view of IR

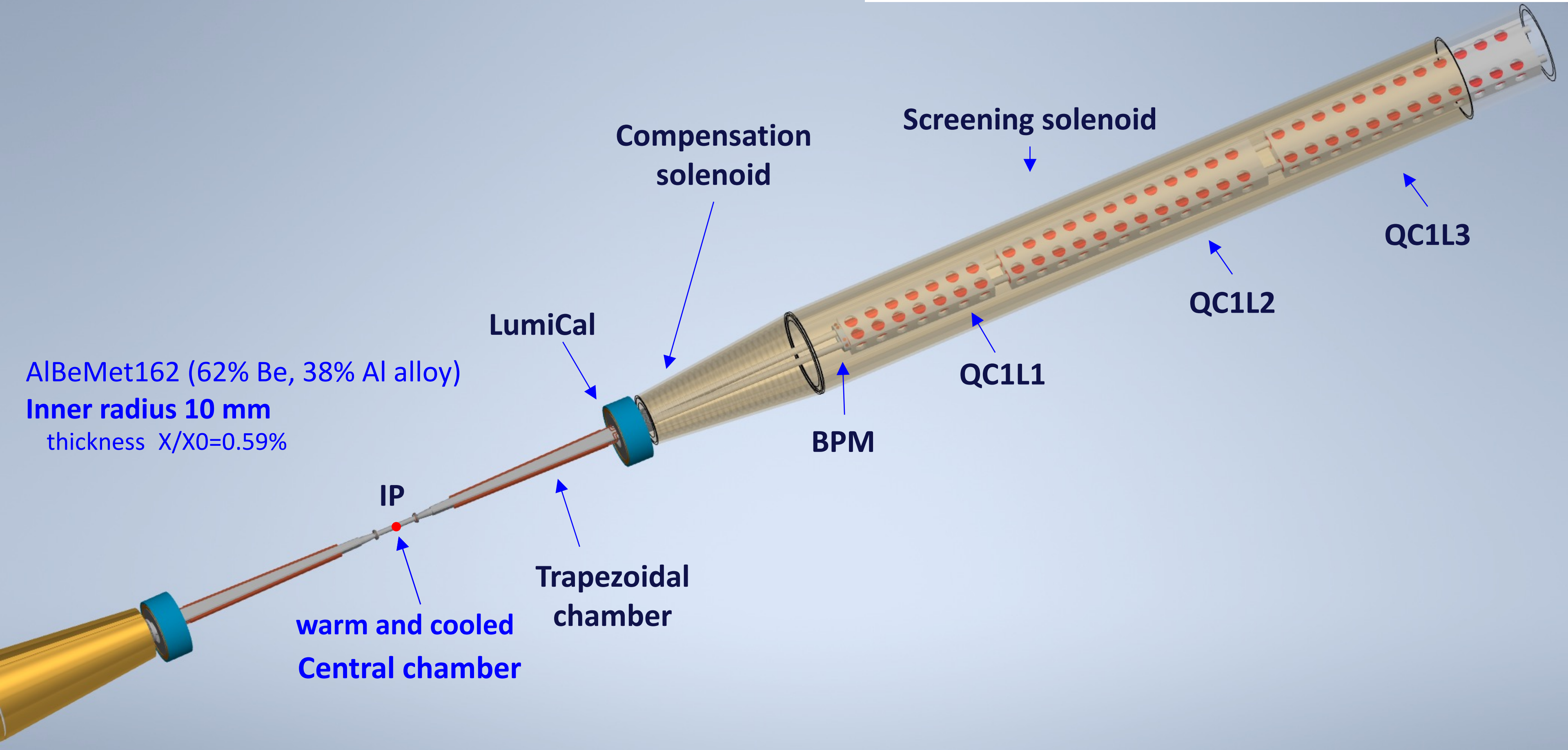
LNF acc. div. mechanical engineering group coordinates the 3D engineering design of IR and MDI
L. Pellegrino, F. Fransesini, S. Lauciani, G. Sensolini



3D view of IR

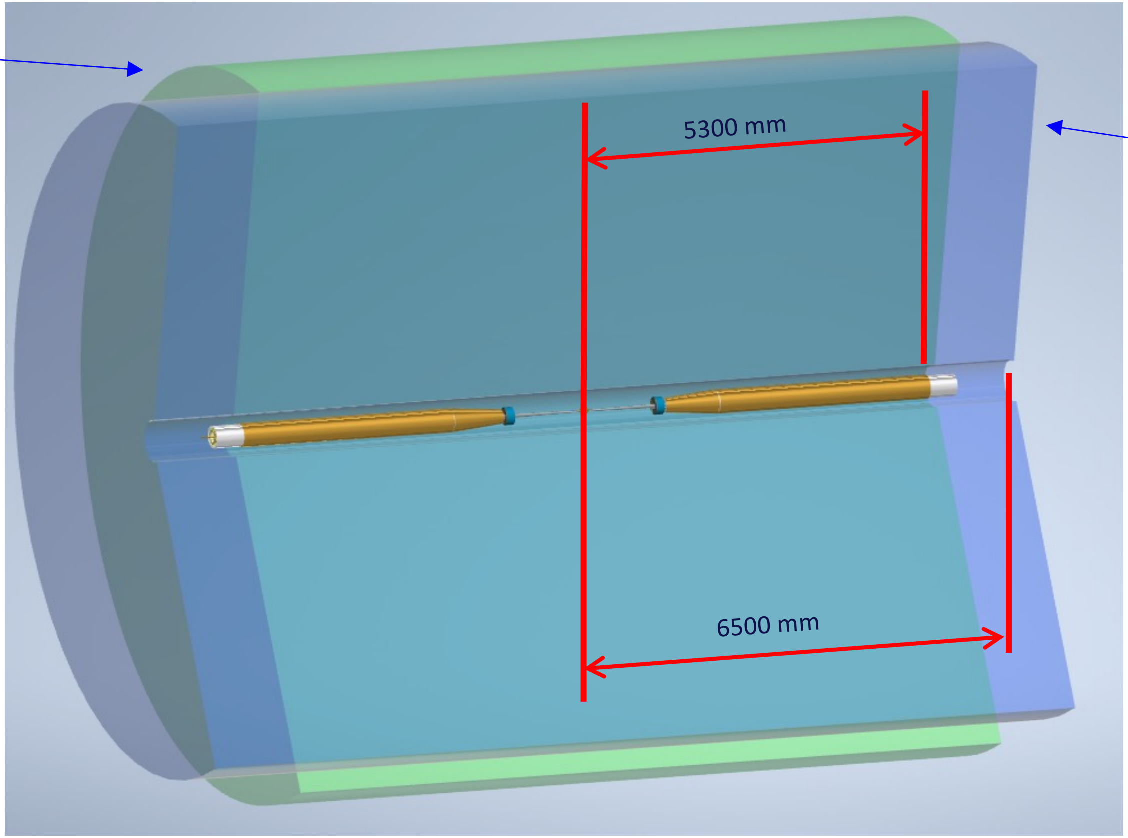
LNF acc. div. mechanical engineering group coordinates the 3D engineering design of IR and MDI
L. Pellegrino, F. Fransesini, S. Lauciani, G. Sensolini

AlBeMet162 (62% Be, 38% Al alloy)
Inner radius 10 mm
thickness X/X0=0.59%



Assembly of the IR with two detector concepts

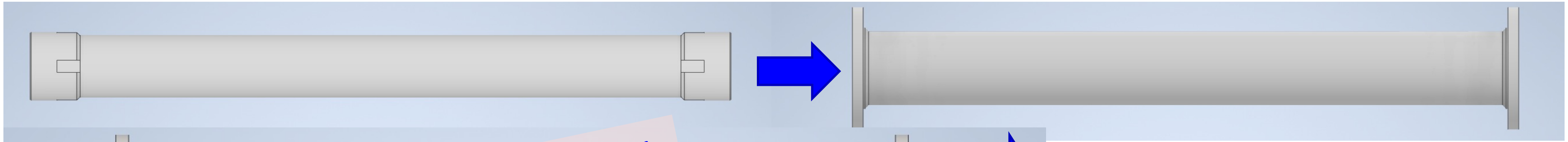
CLD



IDEA

Central chamber

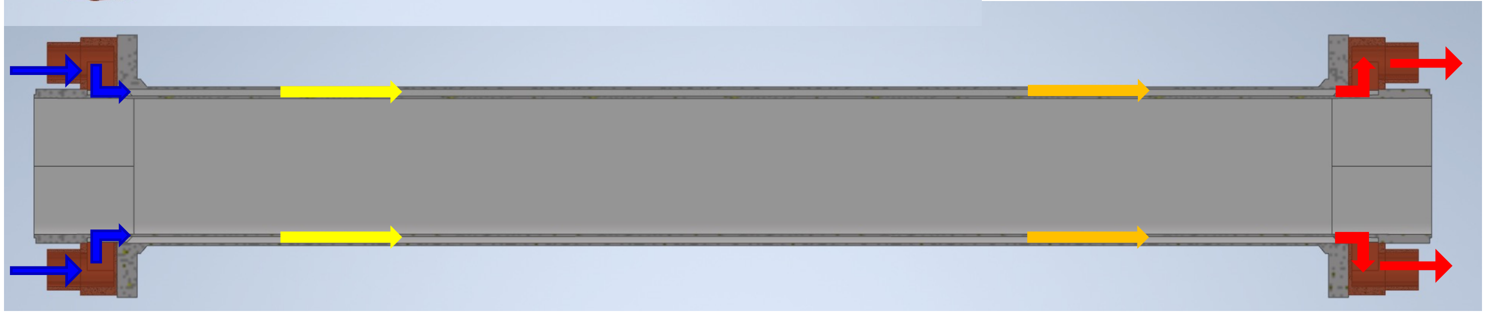
Insertion of the internal part



Thick copper deposition, an innovative technique, to create the cooling inlet and outlet

just discussed at our last MDI meeting 14/3/22 https://indico.cern.ch/event/1134680/

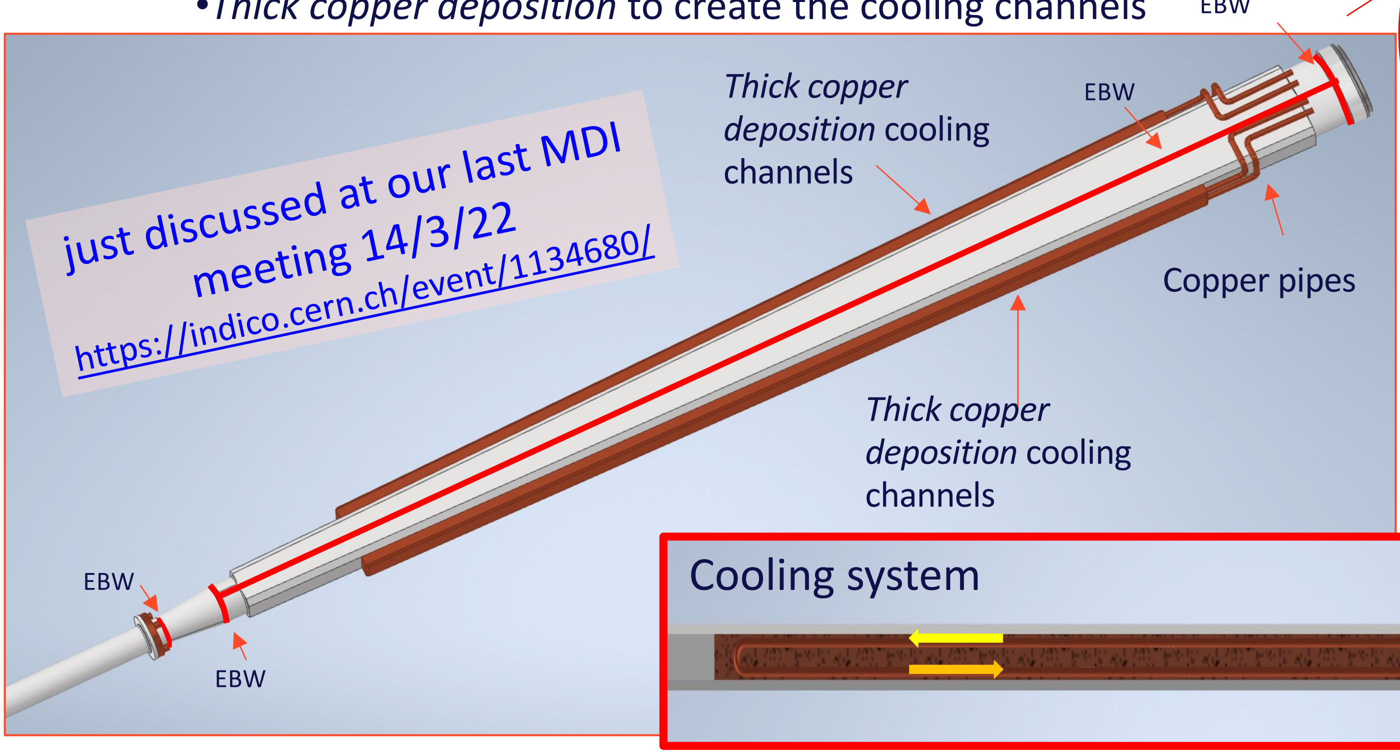
After the assembly, the deposition creates the block for the cooling, assuring the hydraulic tightness between the external and internal part

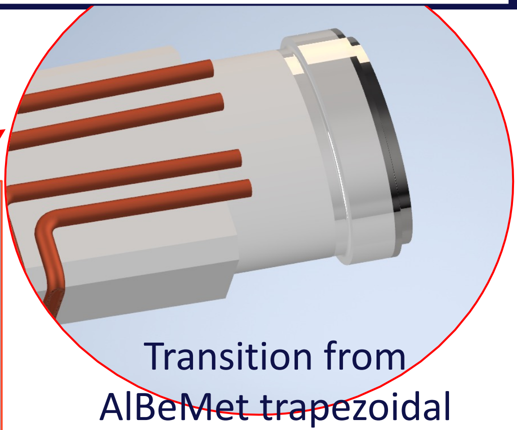


Paraffin cooling system

Trapezoidal chamber

- Two Electron Beam welded shells
- *Thick copper deposition* to create the cooling channels





The cooling channel is created using the "*thick copper deposition*", this technique allows to create complex geometry during the deposition.

Magnets of the Interaction Region

- **Two superconducting anti-solenoids** INSIDE the detector (for the detector solenoid compensation scheme)
- **Final Focus superconducting quadrupole** at 2.2 m from the IP, inside detector and embedded in one anti-solenoid (named screening solenoid)

QC1 based on **Canted Cos theta (CCT)** design, with max gradient 100 T/m, 4.2 K, SC wires.

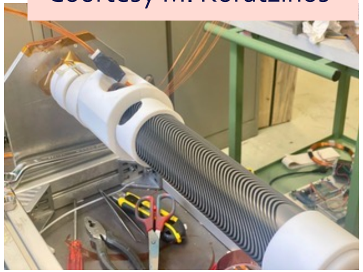
FCC-ee FF SC quadrupole has a very similar design to that proposed for SuperB (similar space constraints) by INFN-Ge P. Fabbricatore, S. Farinon, R. Musenich

5th Physics workshop 10/2/22 link

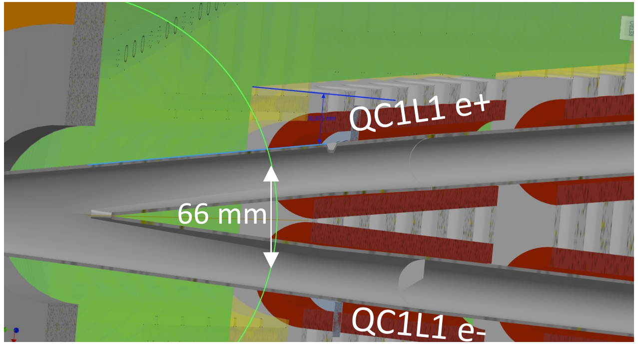
IR magnets are challenging and crucial system for the FCC-ee collider success. Work needed to develop the engineering model

Cryostat for SC IR magnets also needed

Courtesy M. Koratzinos



prototype during construction, tested at warm at CERN



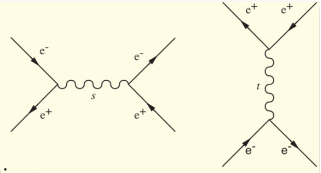
minimum distance between the magnetic centers of e+/e- for QC1L1 is only 66 mm

Low angle Bhabha monitor as fast monitoring

H. Burkhardt,
5th Physics workshop 10/2/22

Standard "elastic" Bhabha scattering

$$\sigma \approx \frac{16\pi\alpha^2}{s}\left(\theta_{\rm min}^{-2} - \theta_{\rm max}^{-2}\right) \quad ; \quad 16\pi\alpha^2 = 1042 \text{ nb GeV}^2$$



LEP experiments 50 - 100 mrad σ = 38 nb similar to z-cross sections

LEP machine small angle monitor : ~ **100 x** larger cross section

LEP : 4-12 bunches, **L_{IP} ~ 2e31 $cm^{-2}s^{-1}$**, rates **~ 0.7 Hz experiments** **~ 70 Hz machine monitors**

theoretical limits, rough estimate :

beam divergences ~ 100 μrad LEP, ~ 50 μrad FCC ~ same in both planes

detector acceptance, minimum angle ~ 20 × beam divergence or 2 mrad LEP, 1 mrad FCC

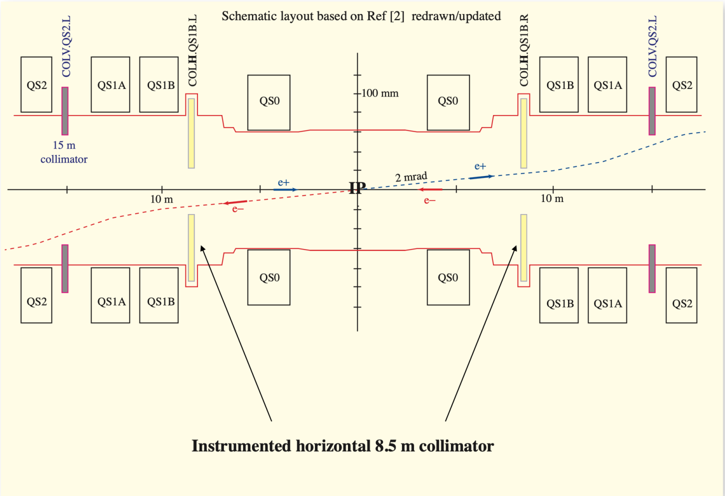
allowing for up to ~ $(25\text{-}50)^2$ or ~ 1000× larger cross section than 50 mrad experiments monitors

FCC-ee Z, **L = 1.97e32 $cm^{-2}s^{-1}$ / bunch** and IP (2.9e32 $cm^{-2}s^{-1}$ at top energy)

Exp. Lumi Bhabha rate **~ 7 Hz / bunch** (x9600 = 70 kHz all bunches)

Small angle monitor 100x more, **~ 700 Hz** useful for online monitoring bunch by bunch

LEP luminosity monitor



compact silicon tungsten calorimeter
to monitor luminosity and background

Interesting and useful to study in machine + detector collaboration the possibility of a small angle (elastic) Bhabha detector ~ 9 m from the IP for **online bunch-by-bunch interaction rate monitoring**

Participation to experiment lumi detector would also be welcome

Fast luminosity monitor at LEP

G. Diambrini-Palazzi, et al. NIM A 349 (1994) 27-31

Nuclear Instruments and Methods in Physics Research A 349 (1994) 27–31
North-Holland

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

Fast luminosity monitor at LEP

C. Bini, D. De Pedis, G. De Zorzi, G. Diambrini-Palazzi*, G. Di Cosimo, A. Di Domenico, P. Gauzzi, D. Zanello
Dipartimento di Fisica, Università "La Sapienza", Roma and INFN Sezione di Roma, Italy

Received 11 November 1993

Luminosity measurement detecting single bremsstrahlung photons emitted in the e+e- collisions.
This measurement worked very well at ADONE.
FCC-ee might need for a double arm coincidence.

At the first bending magnet downstream the IP we will have all the radiation coming from the IR.

28 C. Bini et al. / Nucl. Instr. and Meth. in Phys. Res. A 349 (1994) 27–31

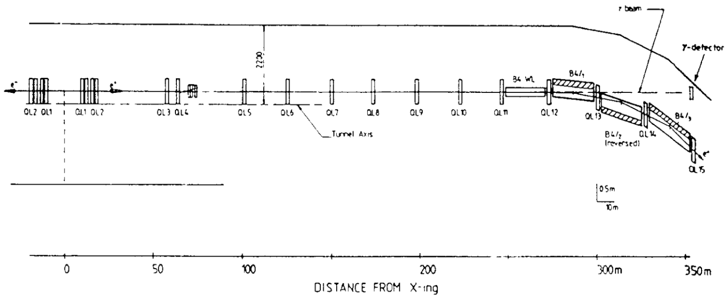


Fig. 1. A sketch of LEP half straight section from IP-1 to the LEP-5 detector. Notice that photons leave the LEP vacuum pipe at about 300 m from IP-1.

At **FCC-ee** at the Z the high beam current and low emittance will produce intense beamstrahlung radiation, that will hit the first bending area (in addition to radiative Bhabha and Synch. Rad.)
This is potentially very precise monitoring of collision offsets in both x and y for centre-of-mass energy control
8/3/22 first brainstorming with experts of beam dump, high rad environment and MDI

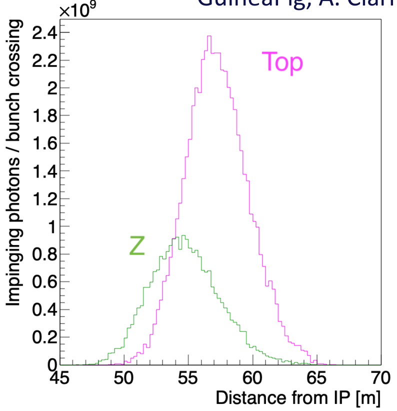
Beamstrahlung monitor for center-of-mass energy measurements

Radiation from the colliding beams is intense (380 kW over cm^2 section!)

Beam energy	Beamstrahlung Radiation power	<Eγ>
45.6 GeV	387 kW	2 MeV
182.5 GeV	89 kW	67 MeV

M. Boscolo et al : IPAC21 MDI

GuineaPig, A. Ciarma



potentially very precise monitoring of collision offsets in both x and y.

-- operations

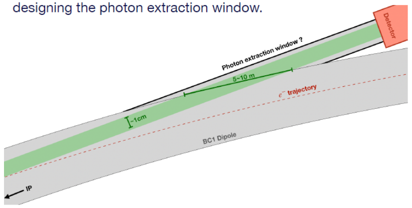
-- centre-of-mass energy control

-- basically un **instrumented beam dump**.

What detector system?

high rad situation akin to neutrino beam monitoring!

While the spot size is ~1x1cm², due to the very small impinging angle on the beam pipe wall (~1mrad) the region hit by the photons is **several meters long** on the longitudinal dimension, so this should be taken in consideration when designing the photon extraction window.



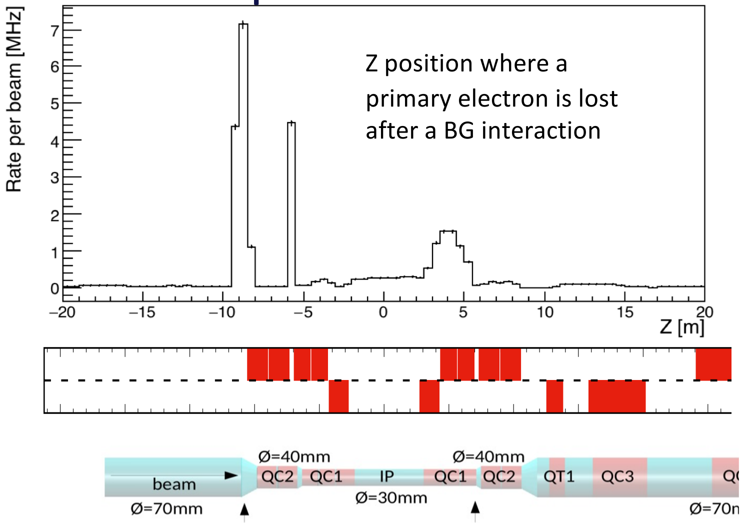
- The direction and intensity of the **beam-beam kick** are proportional to the offset between the beams.
- Because the radiation is produced collinear to the beams, it will carry the information of the offset.

M. Boscolo, F. Collamati (LNF)
H. Burkhardt (CERN)

Inelastic Beam Gas scattering in the IR (CDR)

MDISim(*) used to import in Geant4

IR Loss map



FCC-ee energy	Loss Rate +/-20m from IP [MHz]
Z	147
W	16
H	3
t	0.5

tracked into lumical showing negligible backgrounds rates
constant pressure assumed 10^{-9} mbar

New beam loss maps are in progress with with multi-turn simulations to define the collimation scheme, also for the MDI area with ABP collimation team

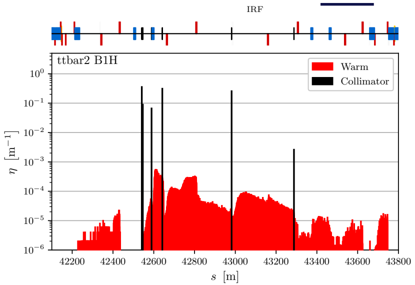
Phys.: Conf. Ser. 1067 022012 (2018)

(*) H Burkhardt and M Boscolo IPAC15-TUPTY031 (2015)

Beam backgrounds simulations

- We work with the collimation team to supply the background events to track in the detector.
- Work needed to choose the background level for the background sources.

link



- Activity in progress includes
- Collimation tracking code development,

  e.g. radiation damping & tapering, to be included (not required for hadrons)

  Geant4 and Fluka integrated in the simulation
- Physical aperture

- Goal: Loss maps, collimation scheme -> **background events to be tracked in the detector**

Single beam backgrounds, Tail collimation

Geant4 model required for various meters from IP to track primary losses hitting the beam pipe through the experimental environment, i.e. Luminosity monitor and detector, allowing shielding optimization.

Beam background experience at Belle-II/SuperKEKB

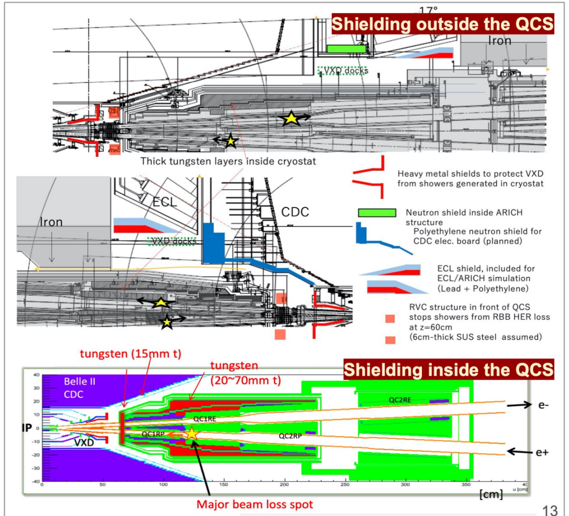
- SuperKEKB as test-bed for FCC-ee
- Many aspects regarding detector protection were not properly foreseen at the early design stage
- An important lesson learned from KEKB to SuperKEKB upgrade, the MDI group advice:
  It's critically important to reserve enough space at the early stage of the design for shielding between the final focusing and detector!
- Similar approach to handling of synchrotron radiation

Italian colleagues working on Belle-II might bring their experience to FCC-ee background studies

holds for other topics

Beam-induced background countermeasures: EM showers towards Belle II

- Most of IR beam losses occur inside the QCS
  - Partially considered in the TDR 2010
- Many detectors start to see single-event upsets (SEU) of FPGAs electronics boards
  - SEUs are presumably from neutrons created in the EM showers
  - Initially, no shielding was implemented
  - Still acceptable level
- Installed additional detector protection
  - Heavy metal shield inside VXD
  - Polyethylene+lead shield inside ECL, ARICH & CDC
- Planned detector protection
  - Additional bellows shield is under discussion
  - Extra neutron shields are being designed



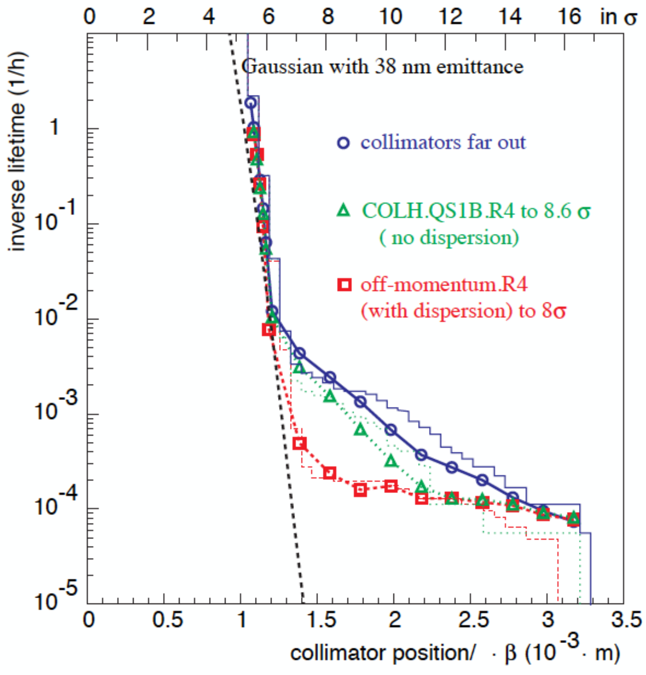
Based on H. Nakayama slides, KEK, IPAC'21

Andrii NATOCHII, University of Hawaii 13

Non-Gaussian tails

LEP

Measured by scraping with loss monitors

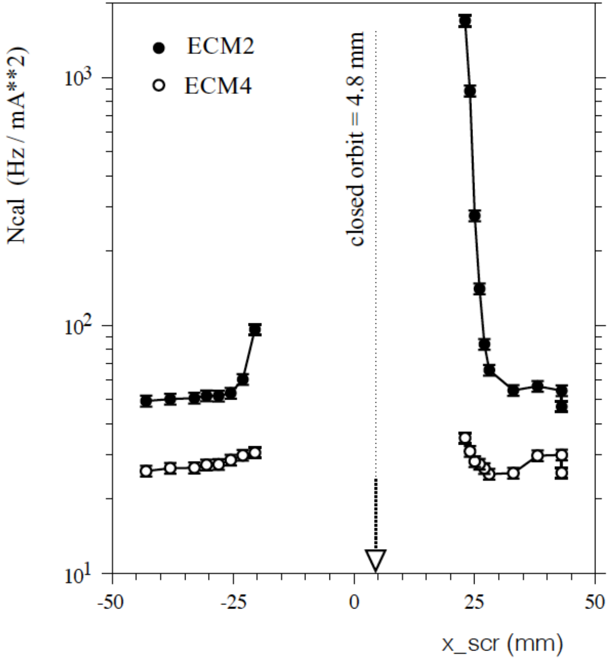


H. Burkhardt, CERN-SL-99-061-AP, PR-STAB 3, 091001 (2000)

Horizontal plane

DAFNE

Measured by scraping with KLOE sectors endcaps calorimeter



Touschek scattering dominated machine

M. Boscolo, G. von Holtey et al, PAC01, EPAC02
M. Boscolo, P. Raimondi PR-STAB 15 104201 (2012)

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

Collective effects

activity included in FCCIS
partially co-funded by INFN-CSN5 Arya activity

- 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

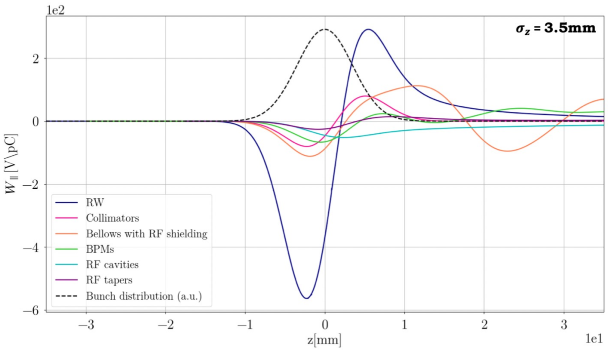
  can be cured with bb
- Single beam collective effects in transverse plane: transverse mode coupling instability (TMCI)

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)

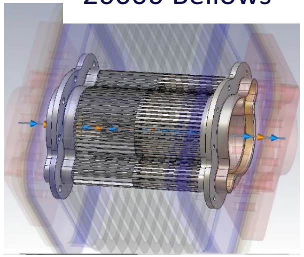
Impedance budget evaluation

Longitudinal impedance model (CDR)

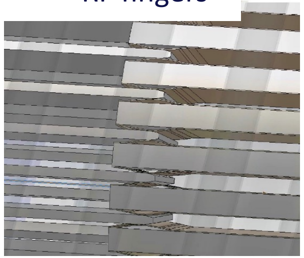


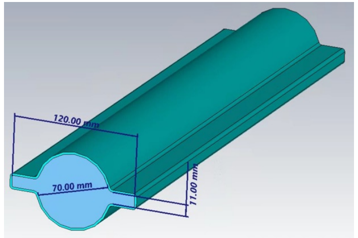
Component	Number	k_{loss}[V/pC]	P_{loss}[MW]
Resistive Wall (100nm)	97.75 km	210	7.95
Collimators	20	18.69	0.7
RF cavities	52	17.14	0.65
RF double tapers	13	24.71	0.93
BPMs	4000	40.11	1.5
Bellows	20 000 ~~8000~~	49.01	1.85
Total		**359.6**	**13.6** 3.7x smaller than 50 MW (SR)

20000 Bellows

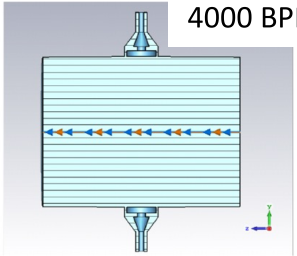


RF fingers

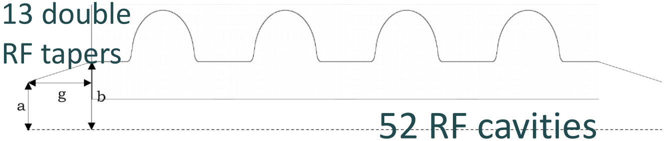




4000 BPM



13 double RF tapers



52 RF cavities

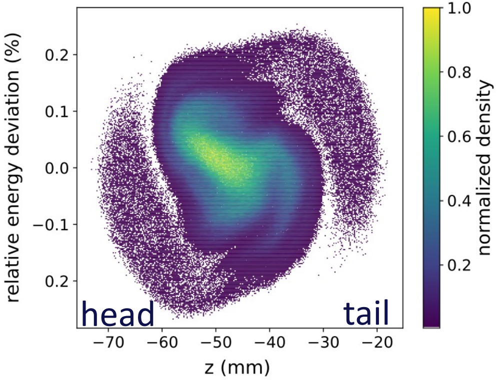
update with 4IPs layout and with new parameters table in progress

Single beam: microwave instability

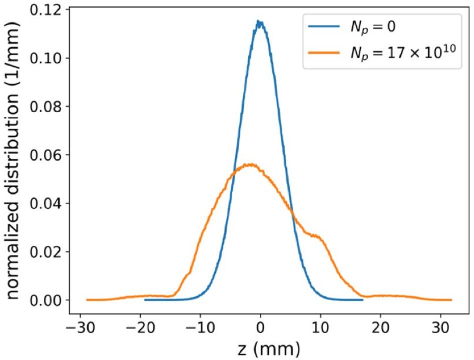
FCC-ee Z pole (CDR parameters)

Longitudinal Impedance-related bunch lengthening and energy spread

due to energy loss the bunch
is shifted toward its head
strong synchrotron oscillations
due to the microwave instability



longitudinal position wrt unperturbed synchronous phase at z=0



bunch shape distortion/lengthening (red curve)

PyHT, SBSC codes

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

SINGLE Beam: transverse mode coupling instability (TMCI)

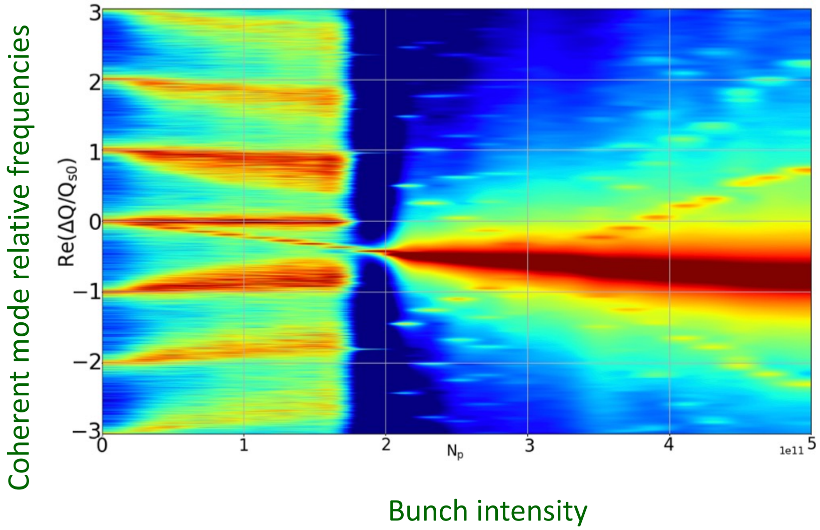
FCC-ee Z pole (CDR parameters)

TMCI threshold strongly depends on the bunch length, which, in turn, is affected by the longitudinal dynamics.
Simulations performed also with PyHEADTAIL by taking into account both the longitudinal and transverse RW wakefield.

Even at low intensities, several frequency lines start to appear for each azimuthal mode.

transverse effect no beamstrahlung

TMCI instability including the longitudinal impedance



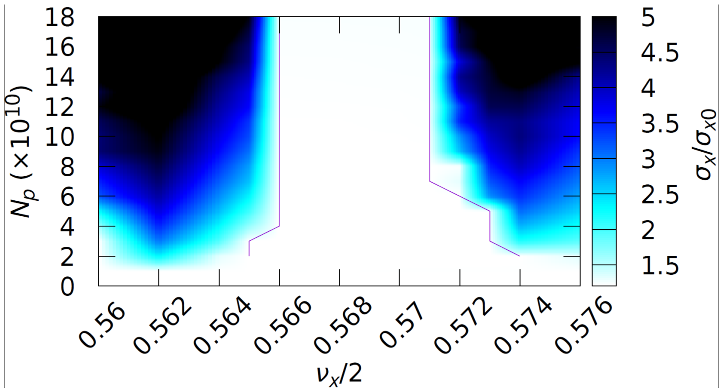
Real part of the tune shift as a function of intensity, considering the combined effect of longitudinal and transverse wakefields for the resistive wall case.

E. Carideo, M. Migliorati, M. Zobov, F. Zimmermann et al., IPAC2021 link

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

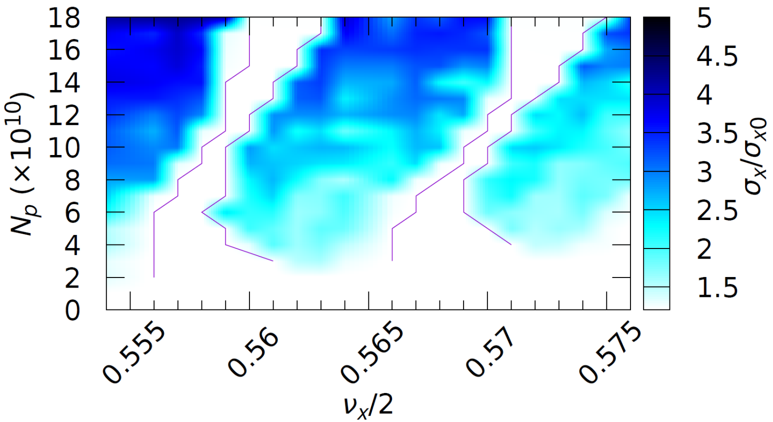
FCC-ee Z pole (CDR parameters)

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



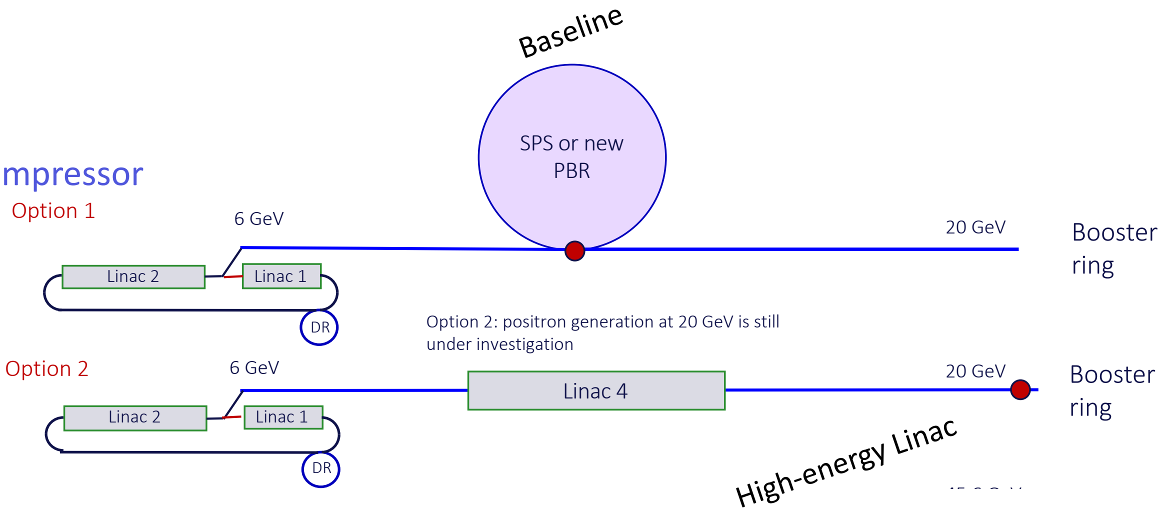
Blow-up of the horizontal beam size $\sigma x / \sigma x\ 0$ as a function of the bunch population and of the horizontal betatron tune by including the impedance

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

FCC-ee injector complex

Project in CHART: Collaboration between PSI and CERN with external partners: CNRS-IJCLab (Orsay), BINP (Novosibirsk), INFN-LNF (Frascati), SuperKEKB (interested in the P^3 project) – observer, INFN-Ferrara – radiation from crystal

- e- gun
- Linac (two linacs in present scheme)
  - up to 6 GeV
  - positron production
- Damping ring @1.54 GeV
  - Bunch compressor and energy compressor
- Pre-booster ring up to 16 GeV
  - SPS (baseline)
  - Alternative design
- Main booster ring

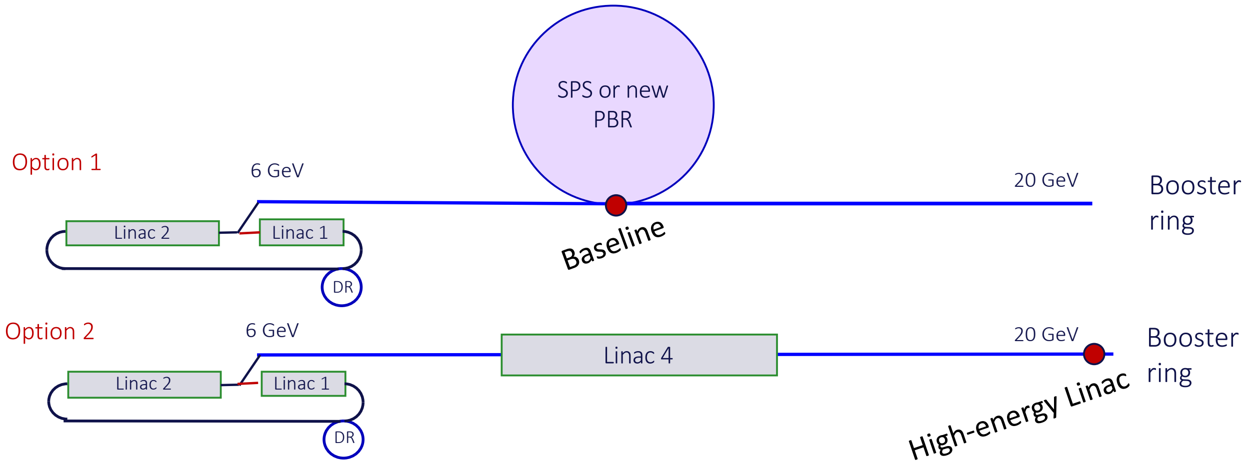


MAIN RINGS

- Transferred to the collider by accumulating current for the full filling or single injection for top-up
- **Interleaved** filling of e+/e- and **continuous top-up** (able to accommodate **bootstrapping**)
- Full filling below **20 min** for both species, but also able to accommodate bootstrapping
- Top-up target time, based on 3-5 % of current drop due to corresponding lifetime

Injector complex: Target parameters and two main options

	Baseline	HE Linac	Unit	
Ring for injection	PBR	BR		
Injection energy	6	20	GeV	
Bunch population	2.1	2.1	1.E+10	Charge 3.4 nC, margin for Injector design: x2
Repetition rate	200	200	Hz	Injection for Z-mode, 50 Hz@W, H, tt
Number of bunches	2	2		
Bunch spacing	15, 17.5, 20	15, 17.5, 20	ns	Multiple of 2.5 ns (400 MHz)
Normalized emittance (x, y) (rms)	50, 50	50, 50	mm.mrad	
Bunch length (rms)	1	1	mm	
Energy spread (rms)	0.1	0.1	%	Critical parameter: can be larger?

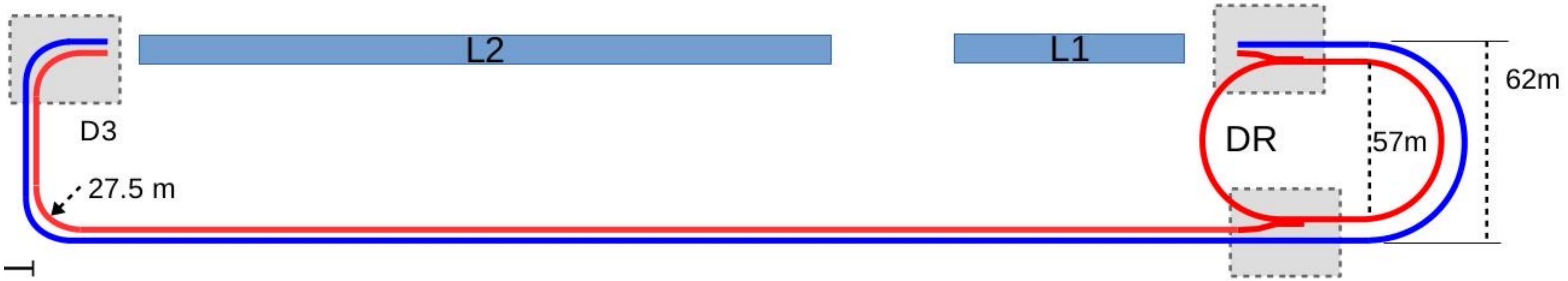


Other important requests:

- The bunch by bunch intensity will randomly vary 0 to 100%, depending on the intensity balance between the collider rings
- Bunch-by-bunch injection intensity fluctuation: 3%

C. Milardi (LNF) leads the activity WP4
A. De Santis (LNF)

FCC_ee Injector complex: transfer line and damping ring (WP4)



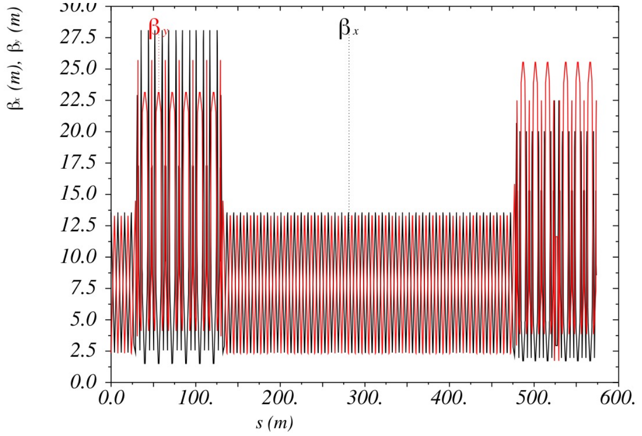
Revised design w.r.t. CDR-0 in order to:

- Introduce a modular structure able to easily follows LINAC's design developments
- Allow efficient transport and operation during FCC injections
- Reduce transfer lines footprint to minimize installation and operational costs

On Going Activities:

- Transfer line start-to-end simulation with PTC and Elegant for electrons
- Design of LINAC to DR for positron Transfer Line

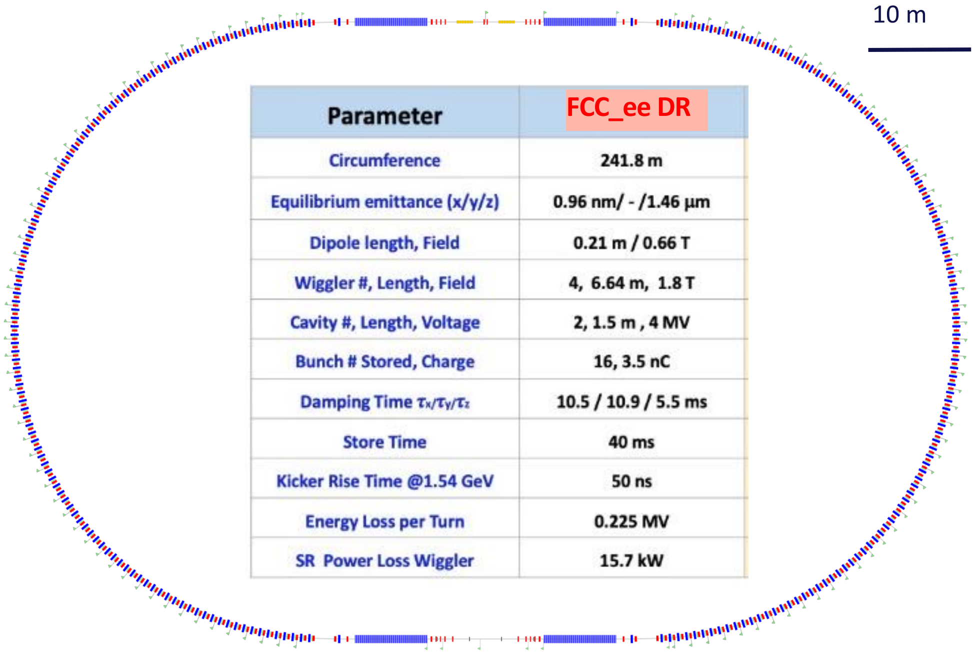
Betatron amplitudes (Hor/Ver) for electrons transfer line



C. Milardi (LNF) leads the activity WP4
A. De Santis (LNF)

FCC_ee Injector complex: transfer line and damping ring

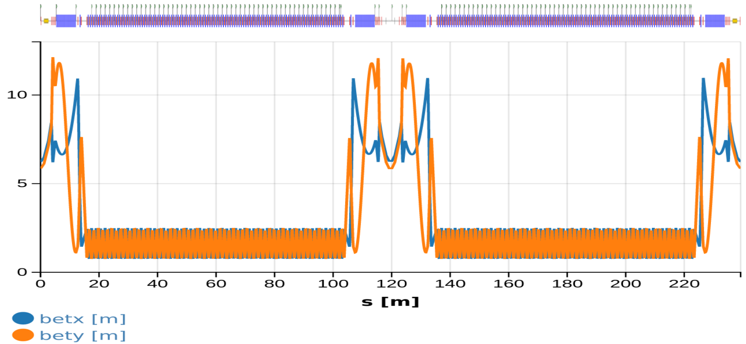
Damping Ring (DR) studies rely on the initial layout provided by K. Oide and S. Ogur (CDR-0)



Parameter	FCC_ee DR
Circumference	241.8 m
Equilibrium emittance (x/y/z)	0.96 nm/ - /1.46 µm
Dipole length, Field	0.21 m / 0.66 T
Wiggler #, Length, Field	4, 6.64 m, 1.8 T
Cavity #, Length, Voltage	2, 1.5 m , 4 MV
Bunch # Stored, Charge	16, 3.5 nC
Damping Time $\tau_x/\tau_y/\tau_z$	10.5 / 10.9 / 5.5 ms
Store Time	40 ms
Kicker Rise Time @1.54 GeV	50 ns
Energy Loss per Turn	0.225 MV
SR Power Loss Wiggler	15.7 kW

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



PSI Positron Production (P^3) project

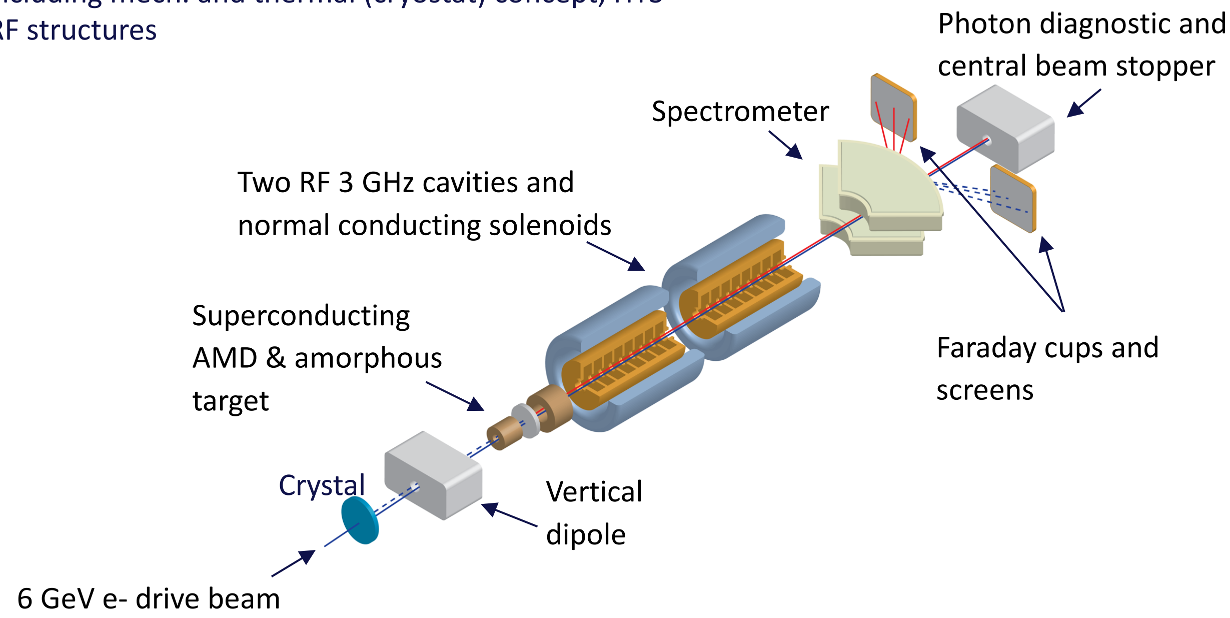
Experiment to validate

- **Positron Yield > 3** (simulation showed > 5) with conventional scheme (simulation vs measurement), Note: SuperKEKB has recently commissioned the upgraded injection system and has achieved a positron yield of 0.5 at 3.5 GeV (status of art of the positron source in operation)
- AMD: **SC Solenoid with HTS technology** including mech. and thermal (cryostat) concept, HTS technology for the solenoids around the RF structures
- Phase 2: hybrid scheme with crystal

Electron beam parameters:

Q = 200 pC@1Hz, E = **6 GeV**

$\varepsilon_{n,x} = 0.2\,\pi$ mm-mrad, $\sigma_x = 2$ mm



PSI Positron Production (P^3) project

Experiment to validate

- **Positron Yield > 3** (simulation showed > 5) with conventional scheme (simulation vs measurement), Note: SuperKEKB has recently commissioned the upgraded injection system and has achieved a positron yield of 0.5 at 3.5 GeV (status of art of the positron source in operation)
- AMD: **SC Solenoid with HTS technology** including mech. and thermal (cryostat) concept, HTS technology for the solenoids around the RF structures

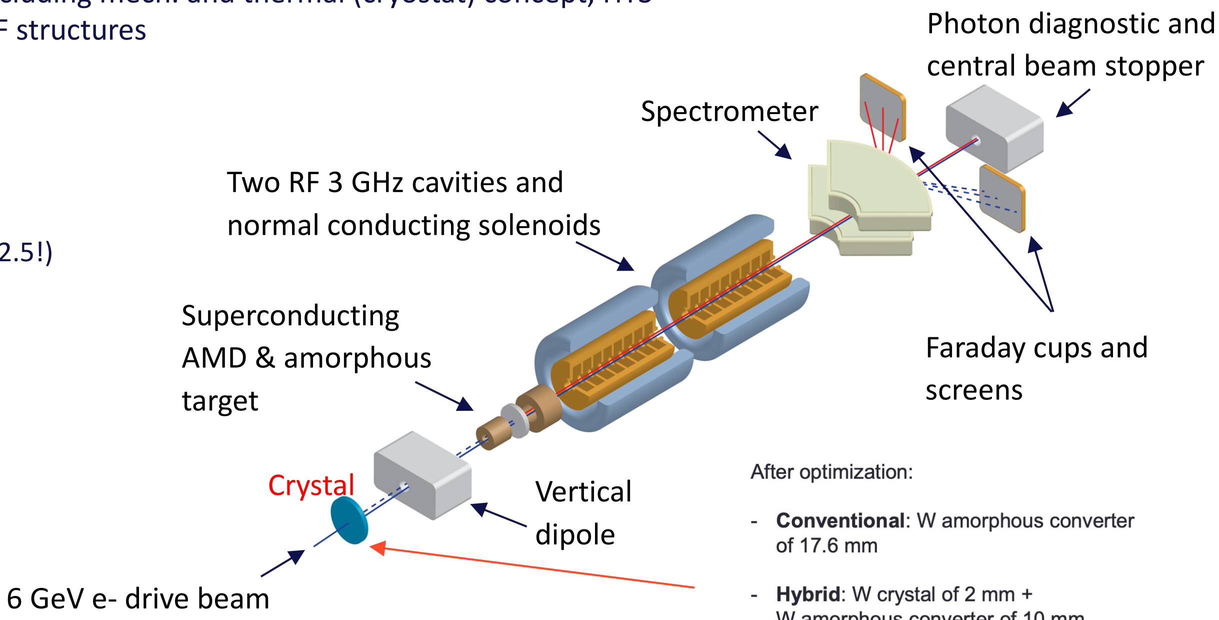
- Phase 2: hybrid scheme with crystal

  L. Bandiera (INFN-FE)

- decrease of the Peak Energy Deposition Density (2.5!) at the same production rate

scheme	conventional	hybrid[2]
target thickness [mm]	17.6	2 + 10
e^+ production rate [N_{e^+}/N_{e^-}]	14.4	15.1
target deposited energy [GeV/e^-]	1.44	0.946
PEDD [GeV/mm^3/e^-]	0.0416	0.0156

L. Bandiera et al. arXiv:2203.07541



After optimization:

- **Conventional**: W amorphous converter of 17.6 mm
- **Hybrid**: W crystal of 2 mm + W amorphous converter of 10 mm

Interest from Legnaro & Milano

Frequency options

Courtesy of F. Peauger

SRF Cavities for FCC-ee

LNL has been involved on SRF R&D for FCC-ee since the beginning of the project (presented later by C. Pira)

L. Monaco(INFN-Mi) will describe the expertise at LASA

400 MHz

1-cell (LHC), 4-cell (LEP)

- Baseline (CDR)
- Z, W, H energies
- Nb/Cu technology

Coaxial, Spoke

600 MHz

2-cell SWELL

- Newly investigated options
- SWELL = very promising !

800 MHz

5-cell

- Baseline (CDR)
- H, tt_{bar} energies
- Bulk Nb
- 2-cell for W ?

1.3 GHz

Technogical demonstrators

- Thin films: HIPIMS, …
- Single cell SWELL

The frequency choice of 600 MHz is mainly driven by the SWELL (Slotted Waveguide Elliptical) cavity, which is not (yet) a proven technology. The study of a back-up solution is envisaged in collaboration with JLAB and the EIC project

A "demo SWELL cavity" at 1.3 GHz will be built and tested at cryogenic temperature all details in talk by C. Pira (LNL)

LNL SRF Activities for FCC

In the framework of the FCC studies:

2015-2019 Collaboration Agreement KE2722/BE/FCC

Forming via spinning of seamless 400 MHz elliptical cavities

The feasibility to produce a 400 MHz seamless cavity was demonstrated

Further developments are necessary to avoid cracks, increase geometry accuracy and internal surface quality

First 400 MHz seamless elliptical cavity prototype

all details by C. Pira (LNL)
co-funded by IFAST and CSN5

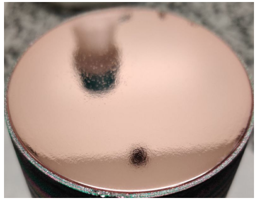
On-going LNL SRF Activities

Surface Treatments by

Plasma Electrolitic Polishing

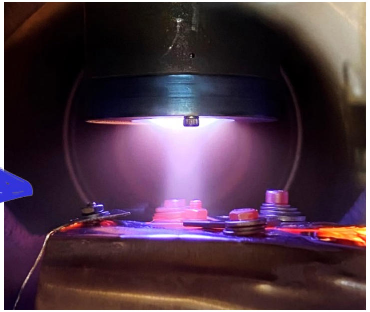
SAMARA
CSN5 INFN experiment

30 micron
4 min



Nb_3Sn target

*via **dipping** of Tin*



Nb_3Sn film

*via **sputtering***

Nb_3Sn on Cu coatings

1.3 GHz prototype in 2025

iFAST SAMARA
CSN5 INFN experiment

FCC-hh

The name of the game of a hadron collider is energy reach

E_{cm} = 100 TeV
Circumference ~ 100 km

$$E \propto B_{dipole} \times \rho_{bending}$$

wrt LHC: factor ~4 in radius, factor ~2 in field → O(10) in Ecm

- A sound baseline for FCC-hh ring exists (heavily driven by LHC design) and developed for the CDR.
- Presently the consolidation design aims at keeping the ring layout synchronous with the developments of the FCC-ee ring.

- Main challenge are the **16 T** dipole magnets required for bending such proton beam. The SC R&D on High Field Magnets is not part of the feasibility study (FS) that will be presented to the next European Particle Physics Strategy Update. **They are a special program that goes in parallel to the FS**

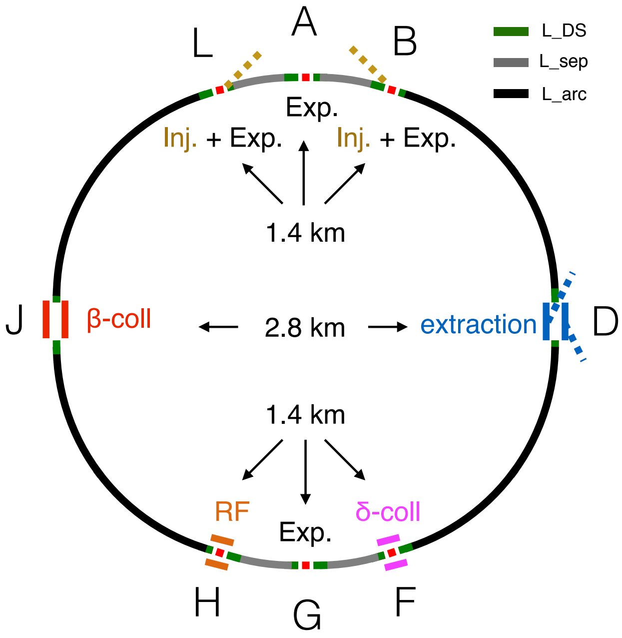
FCC-hh CDR

	HL-LHC	FCC-hh
Cms energy [TeV]	14	100
Int. L., 2 det. [ab^{-1}]	6	30
Operation [years]	12	25
L [$10^{34}cm^{-2}s^{-1}$]	5	20-30
Circumference	26.7	97.75
Arc dipole field [T]	8	16
Bunch dist. [ns]	25	25
Backgr. events/bx	135	<1020
Bunch length [cm]	7.5	8
L* [m]	23	40

31 GHz of pp collisions

Pile-up 1000

4 THz of tracks



Two main IP's in A, G for both machines

Two High Luminosity IPs A/G

Two Lower Luminosity IPs L/B

Similar to layout at LHC

Unprecedented particle flux and radiation levels

10 GHz/cm2 charged particles

≈ 10^{18} cm^{-2} 1 MeV-n.eq. fluence for 30ab^{-1} (first tracker layer, fwd calo)

signal events from "Light" SM particles produced with increased forward boost

-> spreads out particles by 1-1.5 units of rapidity

Key aspects of FCC-hh co-funded by EU-H2020

EuroCirCol

European Commission

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

- 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)

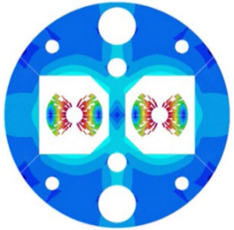
P. Fabbricatore, S. Farinon INFN-Ge
M. Sorbi, Uni. Mi & INFN-Mi, et al.

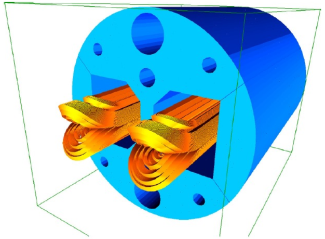
EuroCirCol WP5 strategy

The EuroCirCol WP5 strategy was based on the exploration of different design options for the **16 T Nb_3Sn** dipoles based on the same parameter space:

Cosine theta

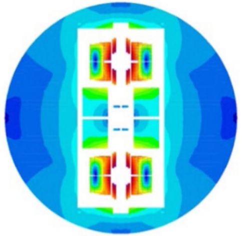
Istituto Nazionale di Fisica Nucleare

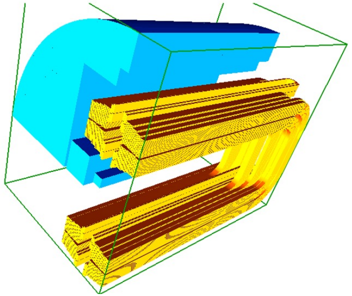




Laboratorio Nacional de Fusión

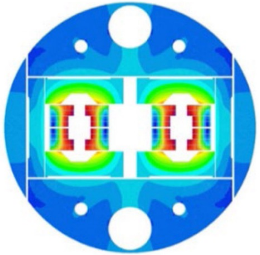
Ciemat

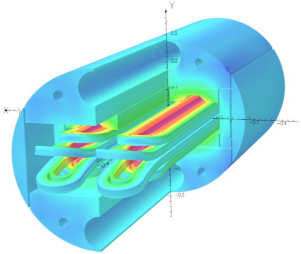




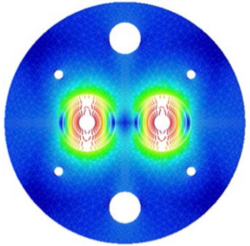
block coil

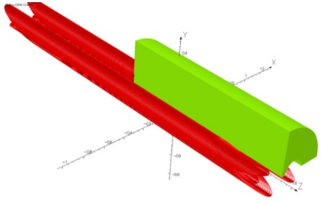
DE LA RECHERCHE À L'INDUSTRIE





PAUL SCHERRER INSTITUT





P. Fabbricatore, S. Farinon INFN-Ge
M. Sorbi, Uni. Mi & INFN-Mi, et al.

The INFN cosϑ option – electromagnetic design

The INFN cosϑ option has been chosen as baseline design for the Conceptual Design Report published in 2019

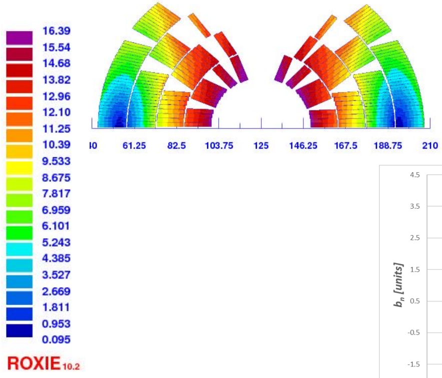
all details on the High Field magnet program in the talk by S. Farinon

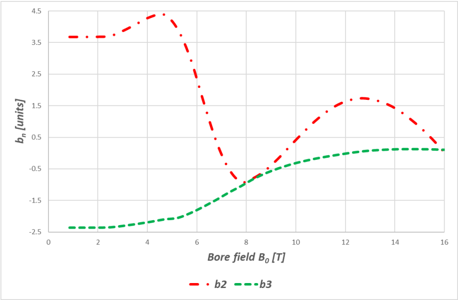
	HF conductor	LF conductor
Strand diameter (mm)	1.1	0.7
Number of strands	22	38
Material	Nb_3Sn	Nb_3Sn
Bare width (mm)	13.2	14
Bare inner thickness (mm)	1.892	1.204
Bare outer thickness (mm)	2.0072	1.3261
Insulation thickness (mm)	0.15	0.15
Keystone angle	0.5°	0.5°
Cu/Non-Cu	0.82	2.08
Operating current (A)	11441	11441
Operating point on Load Line (1.9 K)	86.0%	85.8%
Peak field (T)	16.4	12.71

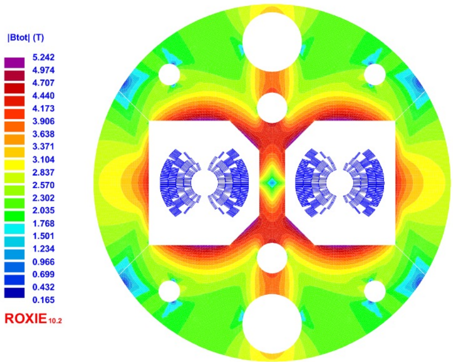
the magnet is in 4 layers, 2 double pancakes, with 2 different kinds of cables:

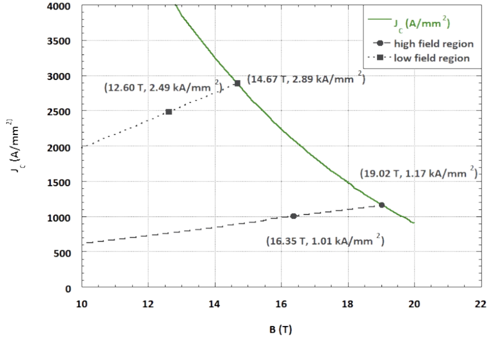
to satisfy the field quality requirements, the cross-talk has been corrected shaping the iron yoke and designing a-symmetric coils

The margin on the load line is 14% for both high and low field region







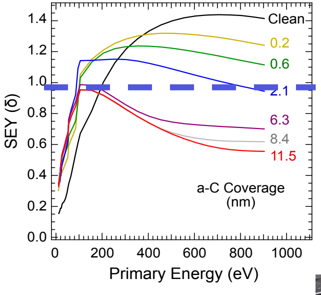


R. Cimino, M. Angelucci, L. Spallino (LNF)

EuroCirCol WP4
co-funded by CSN5

Cryogenics and Vacuum Stability

HL-LHC & FCC-hh

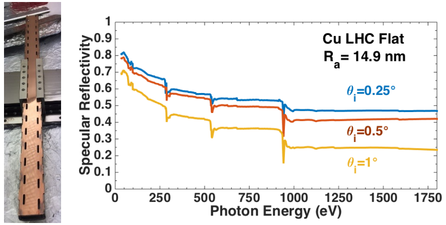


Phys. Rev. Research Rapid. Comm 2, 032030(R) (2020)

Electrons induce:

- Heat load
- Secondary electrons and related instabilities (e- cloud)
- Electron induced desorption

to be studied vs time: SEY, e- induced desorption, surface chemistry



E. La Francesca et al: PR-AB 23, 083101 (2020)

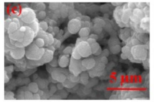
Photons induce:

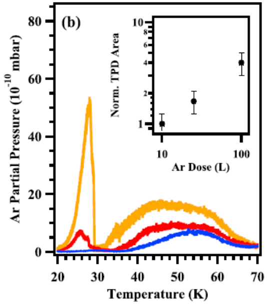
- Heat load
- Photo electrons and related instabilities
- Photo induced desorption

to be studied vs time:

- reflectivity
- photo yield (number of photo-el produced)
- photo induced desorption

Vacuum stability at cryogenics temperature





Appl. Phys. Lett. (2019)
PR-AB (2020)

R. Cimino, M. Angelucci, L. Spallino (LNF)

Electron Cloud instabilities

High synchrotron radiation power

Heat Load

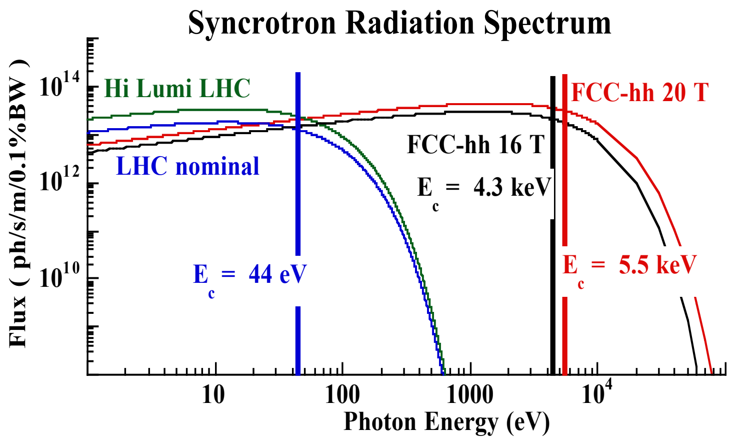
Cryogenics

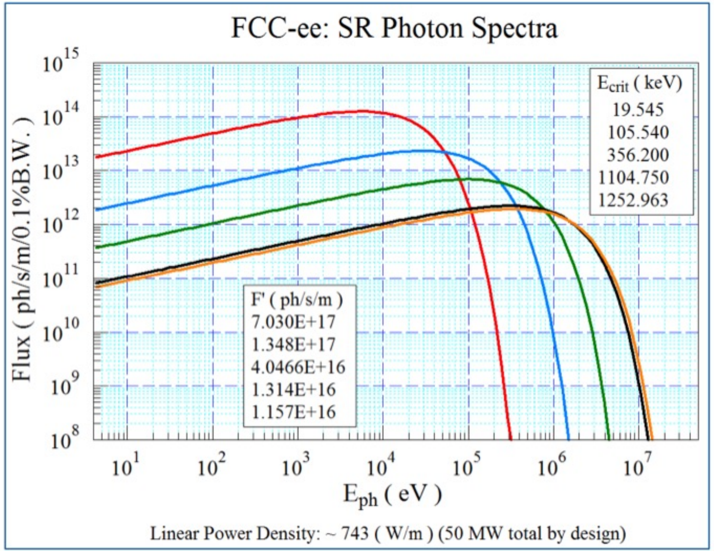
HL-LHC / FCC-hh

FCC-ee

Table 1: Parameters of the proposed FCC-hh, FCC-ee/TLEP, compared with LEP2 and the LHC design.

parameter	LHC (pp) design	FCC-hh	LEP2 achieved	FCC-ee (TLEP) Z	Z (cr. w.)	W	H	$t\bar{t}$
species	pp	pp	e^+e^-	e^+e^-	e^+e^-	e^+e^-	e^+e^-	e^+e^-
E_{beam} [GeV]	7,000	50,000	104	45.5	45	80	120	175
circumf. [km]	26.7	100	26.7	100	100	100	100	100
current [mA]	584	500	3.0	1450	1431	152	30	6.6
no. of bunches, n_b	2808	10600	4	16700	29791	4490	1360	98
τ_{beam} [min]	2760	1146	300	287	38	72	30	23
P_{SR}/beam [MW]	0.0036	2.4	11	50	50	50	50	50
energy / beam [MJ]	392	8400	0.03	22	22	4	1	0.4





High field superconducting materials for high-energy particle accelerators

CNR-Spin, Genova
E Bellingeri, C. Bernini, V Braccini, A Leveratto, A Malagoli, A. Martinelli, A. Saba, A. Traverso.

Dipartimento di Fisica, Università di Genova
M. Cialone, M. Meinero, M. Putti

Topics:

- Study of **Tl(1223) superconducting coatings** for beam impedance mitigation in the Future Circular Collider

- Novel superconducting materials for high field magnets:
  - ***Bi-2212/Ag multifilament ray wires***
  - ***Iron based Superconductor Coated Conductors***

more details at the end of the talk

Conclusion

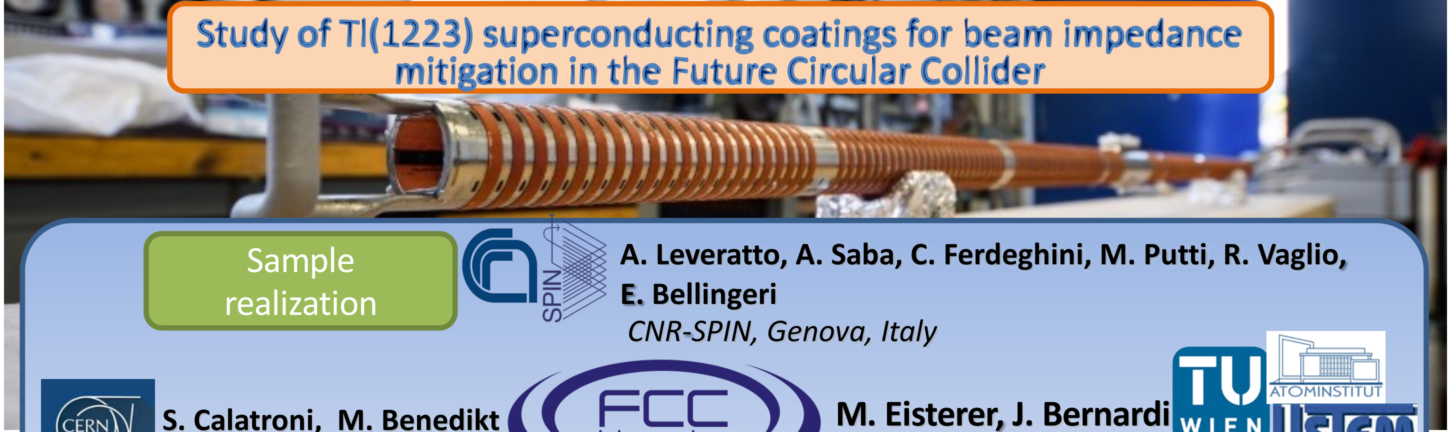
Long term goal: **world-leading HEP infrastructure for 21st century** to push the particle-physics **precision and energy frontiers** far beyond present limits.

Success of FCC relies on strong global participation in all domains.

Unique (might be the only one) opportunity for the community involved on high luminosity and high energy colliders!

Italian contribution well in place at the coordination and individual activity level, need to follow the acceleration of the project to secure full support, strongly needed for its success.

Additional material



Study of Tl(1223) superconducting coatings for beam impedance mitigation in the Future Circular Collider

Sample realization

A. Leveratto, A. Saba, C. Ferdeghini, M. Putti, R. Vaglio, E. Bellingeri
CNR-SPIN, Genova, Italy

S. Calatroni, M. Benedikt
CERN– Switzerland

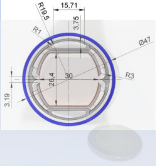
M. Eisterer, J. Bernardi
TU Wien, Vienna, Austria

El. Transport and Microstructure Characterization

N. Pompeo, E. Silva
Università di Roma Tre, Rome, Italy

(dal 2021 nuova collaborazione)

RF measurements



High synchrotron radiation load (SR) of protons @ 100 TeV: 5 MW total in arcs (LHC <0.2W/m)

Copper may not be sufficient - > HTS?

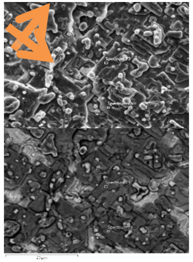
T=50 K (or even 100 K) , B = 16 T , ν=1GHz, High syncrotron radiation intensity, Boundary materials with 100 TeV particles

Tl 1223

YBCO

Parallel Project: Consortium **ICMAB-CSIC, ALBA, UPC, IFAE.**

Electrodeposition: cheap and scalable
Tolerant to stoichiometry
Difficulties in getting pure phase (Tl-1212 always forms)
Small samples shows application compatibility from the point of view of vacuum, SEY and contamination (XPS).



Bi-2212/Ag multifilament ray wires development

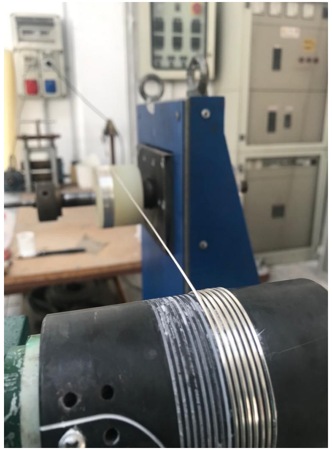
- Several wire shape: round, square, rectangular…
- Multiple architectures, up to >1000 filaments
- Filaments diameter <15 μm
- Not only laboratory lenghts but also >100 m
- Development of small windings
- Complete transport characterization 0 – 16 T , 4.2 – 30 K

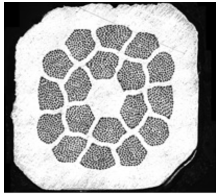
Collaboration with:

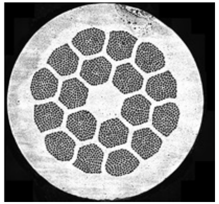
CERN (ADDENDUM FCC-GOV-CC-0086)

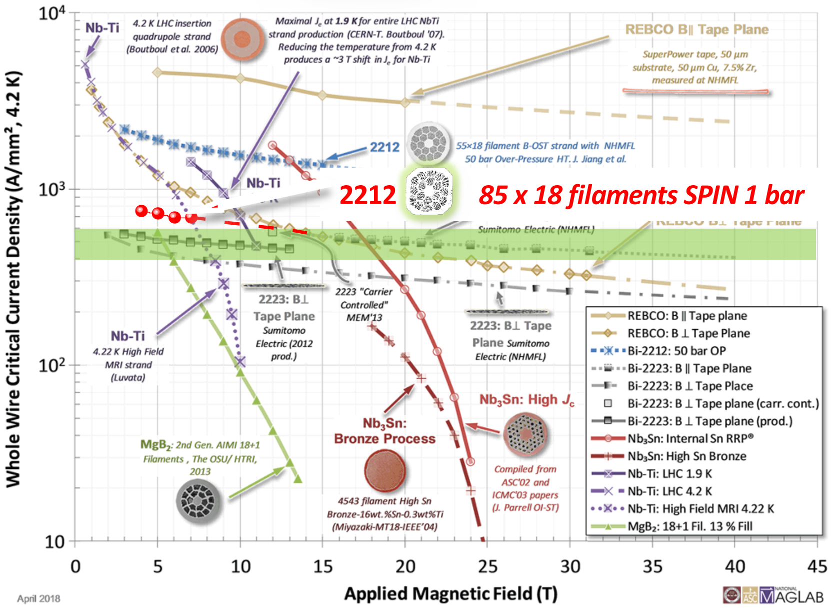
INFN Genova unit

ENEA

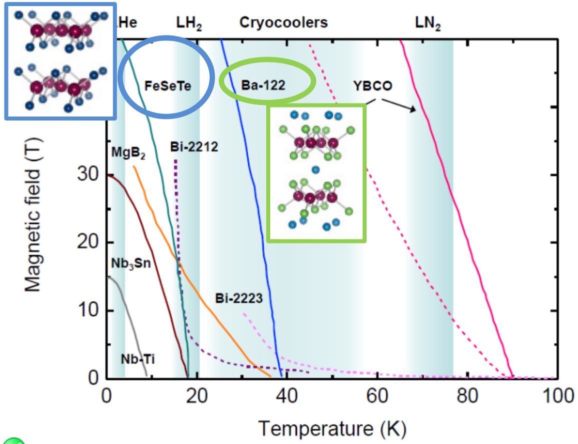


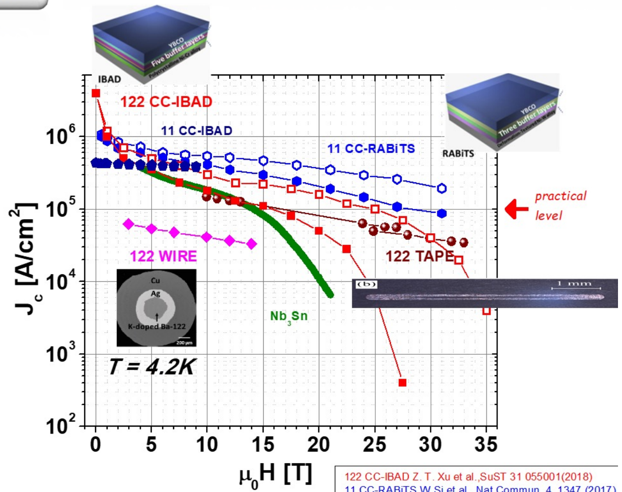






Novel iron based superconductors



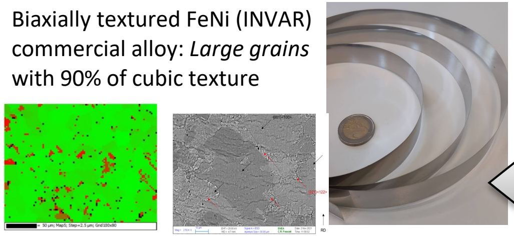


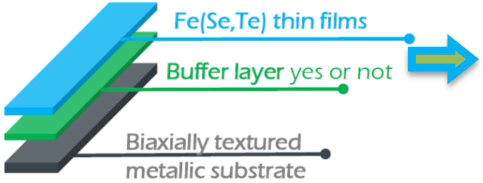
- Large Bc2 > 50 T
- Jc Isotropic and field independent
- Good grain boundary transparency
- Technical conductors (wires and tapes) with Jc above practical level yet developed

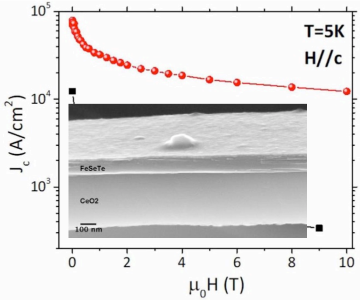
122 CC-IBAD Z. T. Xu et al.,SuST 31 055001(2018)
11 CC-RABiTS W.Si et al., Nat.Commun. 4, 1347 (2017)
11 CC-IBAD Z. T. Xu et al.,SuST 30 035003(2017)
C. Yao et al. iScience 24, 102541 (2021)
S. Pyon et al., SuST 31, 065001 (2020)

Towards a simpler CC template (reduction of costs and complexity, increased Je)

Biaxially textured FeNi (INVAR) commercial alloy: *Large grains* with 90% of cubic texture







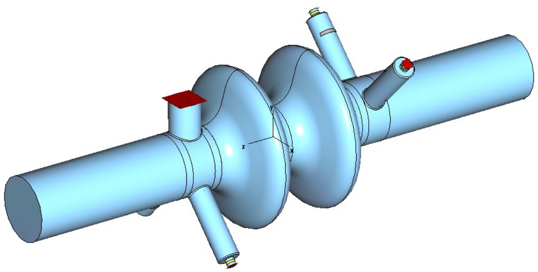
Addendum FCC-GOV-CC-0086

JRC Fusion "High T_c superconductivity for fusion: development of materials and process of production"
within the Joint Research Agreement Eni-CNR

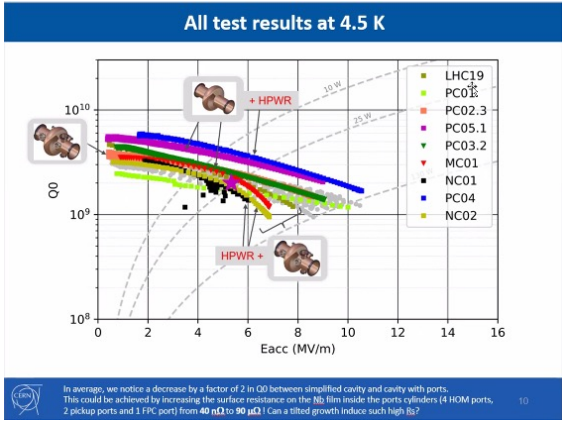
MIUR funded PRIN 2017 HIBiSCUS
High performance - low cost Iron BaSed Coated condUctorS for high field magnets
(PRIN 201785KWLE)

FCC_ee: proposed baseline changes

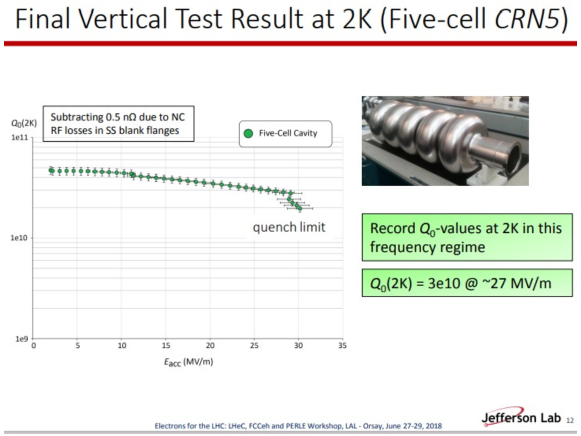
- Replace 4_cells cavities by 2_cells cavities at 400 MHz -> relaxed beam – cavity interactions
- 400 MHz: Consider E_{acc} = 10 MV/m (2_cells cavities), Q_o = 3.E9, 4.5K (eventually 12 MV/m Q_o = 2.E9) – see below
- 800 MHz: Increase E_{acc} from 20 MV/m to 25 MV/m for the bulk Nb 800 MHz system (less conservative but still realistic)
- Booster (Z): consider 400 MHz 2_cells, 4.5K, as the beam current is important (~140mA)
- Booster (W, H, ttbar): consider 800 MHz, 5_cells, 2K, acceleration performances considerations



Sosoho-Abasi Udongwo , Univ. of Rostock



Franck Peauger, TTC meeting 2020



Franck Marhauser, 2018

FCC_ee: the scenarios

Courtesy of F. Peauger

Baseline (CDR)


1 cell ELL_400 (Nb/Cu)


4 cells ELL_400 (Nb/Cu)


5 cells ELL_800 (bulk Nb)

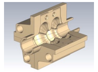
Z

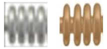
W, H

ttbar complement

→  2 cells

SWELL_600


2 cells SWELL_600 (Nb/Cu)

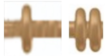

4 cells ELL_600 (bulk Nb or Nb/Cu)

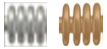
Z, W, H

ttbar complement

→ Full demonstration – phase 3

ELL_600


1-2 cells ELL_600 (Nb/Cu)


4 cells ELL_600 (bulk Nb or Nb/Cu)

Z, W, H

ttbar complement

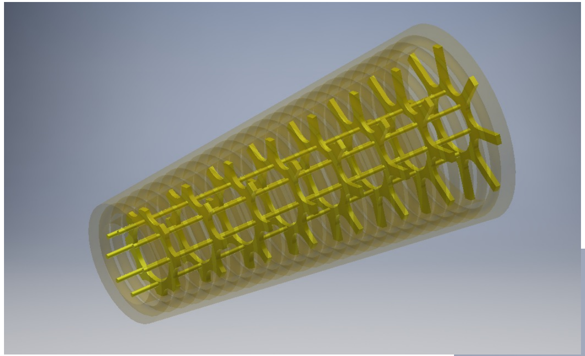
All scenarios -> strong impact on Z (and W) Ibeam

Mix 1_ and 2_ cells -> large impact on timeline

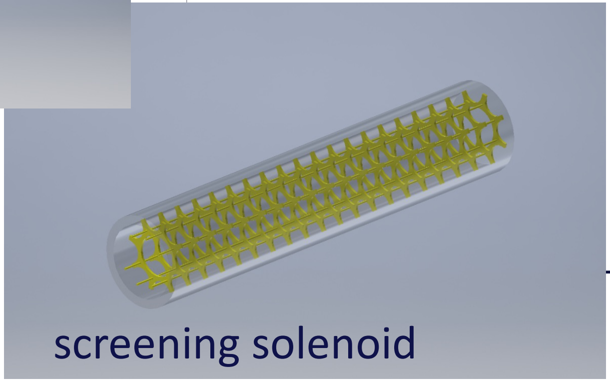
- The baseline is solid but needs to be optimized
- The SWELL validation is a long process –> no decision before end of phase 3 (test with beam)
- For now, Ell_600 MHz is no longer considered

FCC-ee Cryostat sketch concept

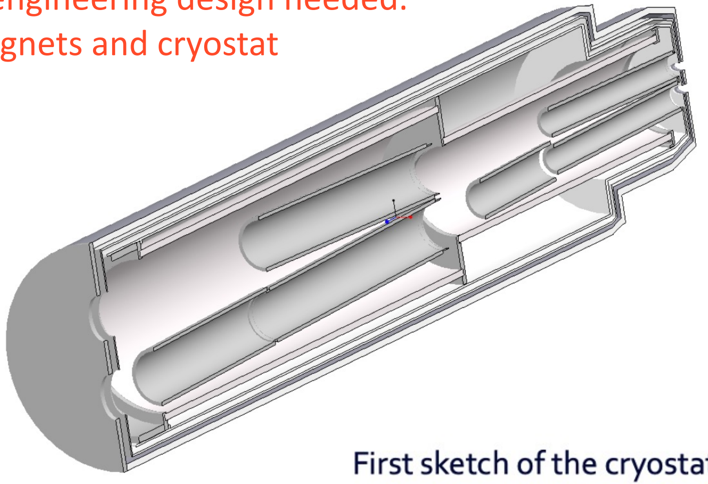
compensating solenoid



M. Koratzinos



FCC-ee Cryostat: progress with engineering design needed.
Italian contribution to the IR magnets and cryostat engineering design?



Stefania Farinon

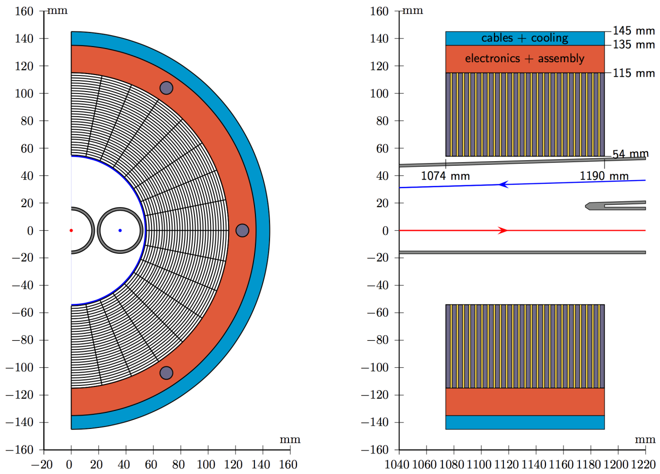
First sketch of the cryostat (370 mm OD). The suspension system (not yet studied) shall be design to hold high axial forces (4 t)

The idea is to use a stiff skeleton which will replace the very heavy cryostat.
All load bearing capability will rely on this skeleton

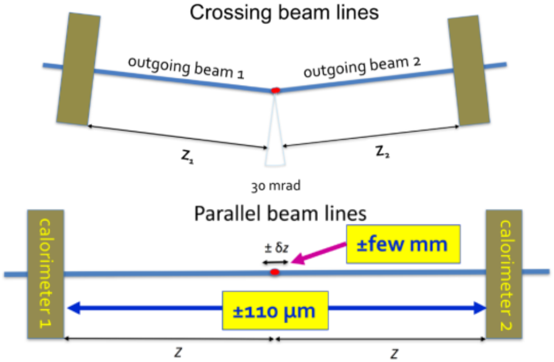
LumiCal

Goal: absolute luminosity measurement to 10^{-4} at the Z

The luminosity calorimeter is a key device in the MDI area: space and alignments requirements, as well as backgrounds tolerances limit



- Bhabha cross section 12 nb at Z-pole with acceptance 65-85 mrad
- The LumiCals are centered on the outgoing beamlines with their faces perpendicular to the beamlines



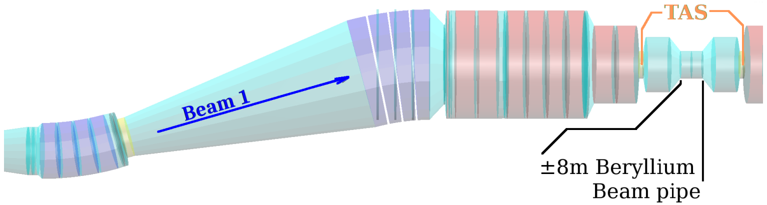
Description already in the CDR.
Update on impact of backgrounds also with updated central chamber, IR layout and new beam parameters.
Activity at the mechanical design level to integrate the device in the IR, design its supports, define alignment strategy.

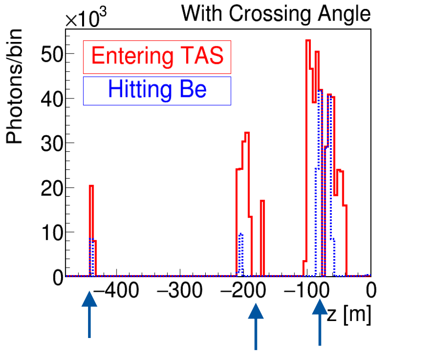
Is there concern about backgrounds in the lumical?

- **Conclusion**: Optimal situation is if interaction point is centered wrt LumiCal coordinate system within the following tolerances:
  - Few hundred microns in radial direction
  - Few mm in longitudinal direction

M. Dam

Synchrotron radiation Backgrounds for the FCC-hh Experiments





- The fraction entering the TAS is ~47 W and ~13 W reach the Be chamber.
- O(0^{10}) photons with critical energy ~1keV
- Also the non-collisions scheme safe limit at 100 W

F Collamati, M. Boscolo *et al* 2017 *J. Phys.: Conf. Ser.* 874 012004 (2018)

M. Boscolo, *FCC WEEK 2019 (Brussels)*

Collaborations

- H2020-INFRADEV design study on:
    - FCC-hh: **EUROCIRCOL** 2015-2019
    - FCC-ee: **FCCIS** 2020-2024

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

- Other activities agreed with MoUs
    - Swiss Chart collaboration: Damping Ring & Transfer lines (LNF)
    - High field magnet program prototype 14 T dipole (but not part of the FCCFS)
    - Uni. Genova, Uni-Roma Tre, CNR-SPIN on High field superconducting materials

Some References

- A. Blondel, F. Zimmermann, 20/1/2012 ArXiv:1112.2518
- crab-waist: Raimondi, Shatilov, Zobov http://arxiv.org/abs/physics/0702033, M. Zobov et al. PRL 104 174801 (2010)
- M. Boscolo et al., "Challenges for the interaction region design of the Future Circular Collider FCC-ee", IPAC21
- SR BKGs: PR-AB 19 (2017) 20, 011008
- M. Boscolo, H. Burkhardt, K. Oide and M.K.Sullivan, "*IR challenges and the machine detector interface at FCC-ee*", EPJ+ (2021) 136:1068 (Essay in Part II) https://doi.org/10.1140/epjp/s13360-021-02031-5
- M. Boscolo, H. Burkhardt, G. Ganis and C. Helsens, "*Review and outlook of accelerator-related codes and their interplay with the experiments software*", EPJ+ (2021) (Essay in Part IV)
- E. Carideo, M. Migliorati, M. Zobov et al., "Transverse and Longitudinal Single Bunch Instabilities in FCC-ee", IPAC2021 https://inspirehep.net/files/4f207f8aa1440c15002ba284ca02444c
- BB+long impedance: https://link.springer.com/content/pdf/10.1140/epjp/s13360-021-02185-2.pdf
- *M.Migliorati, E.Carideo, D.De Arcangelis, Y.Zhang and M.Zobov, Eur. Phys. J. Plus 136, 1190 (2021)*
- SBSC code: M.Migliorati,S.Persichelli,H.Damerau,S.Gilardoni,S.Hancock,L.Palumbo,Beam-wallinteraction in the CERN Proton Synchrotron for the LHC upgrade. Phys. Rev. Accel. Beams 16, 031001 (2013)
- L. Bandiera et al. arXiv:2203.07541 Crystal-based pair production for a lepton collider positron source
- O. Azzolini , G. Keppel, C. Pira, 400 MHz SEAMLESS COPPER CAVITY IN THE FRAMEWORK OF FCC STUDY, Proc. of SRF2019 MOP007
- M. Zanierato , O. Azzolini, E. Chyhyrynets, V. Garcia Diaz, G. Keppel, F. Stivanello, C. Pira, Nb3Sn FILMS DEPOSITIONS FROM TARGETS SYNTHESIZED VIA LIQUID TIN DIFFUSION, Proc. of SRF2021
- E. Chyhyrynets , O. Azzolini, R. Caforio, V. A. Garcia Diaz, G. Keppel, F. Stivanello, C. Pira, APPLICATION OF PLASMA ELECTROLYTIC POLISHING ONTO SRF SUBSTRATES
- M. Angelucci et al. : Phys. Rev. Research Rapid. Comm 2, 032030(R) (2020)
- E. La Francesca et al: PR-ABST 23, 083101 (2020)
- M. Angelucci and R. Cimino; Synchrotron Radiation Science and Applications. Springer Proceedings in Physics, vol 220. (2021)
- L. Spallino et al. , Appl. Phys. Lett. (2019)
- L. Spallino et al. , Phys. Rev. Accel. Beams (2020)

Some related references

- MDI meetings: https://indico.cern.ch/category/5665/
- 1st MDI workshop http://indico.cern.ch/event/596695
- 2nd MDI workshop https://indico.cern.ch/event/694811
- K. Oide et al, *Design of beam optics for the future circular e+e- collider rings*, PR-AB 19, 111005 (2016) link:
- M. Boscolo, H. Burkhardt, M. Sullivan, *Machine detector interface studies: Layout and synchrotron radiation estimate in the future circular collider interaction region*, PR-AB 20, 011008 (2017) link
- A. Novokhatski, M. Sullivan, E. Belli, M.G. Costa, R. Kersevan, *Unavoidable trapped mode in the interaction region of colliding beams*, PR-AB 20, 111005 (2017) link
- E. Belli et al, PR-AB 21, 111002 (2018) link
- H Burkhardt and M Boscolo, *Tools for flexible optimisation of IR designs with application to FCC*, IPAC15-TUPTY031 (2015)
- M Boscolo, O R Blanco-Garcia, H Burkhardt, F Collamati, R Kersevan, M Lueckhof, *Beam-gas background characterization in the FCC-ee IR*, *Phys.: Conf. Ser.* **1067** 022012 (2018) link
- M Boscolo et al, *Machine detector interface for the e+e- future circular collider*, 62th ICFA ABDW on high luminosity circular e+e- colliders, eeFACT18, Hong Kong (2019) link