Future Circular Collider Innovation Study FCC-IS

Manuela Boscolo

Riunione della DA con Resp. di servizio, Capi Progetto e Direttore

15 February 2021

INFN LNF Istituto Nazionale di Fisica Nucleare

FCC hh ee he

FUTURE CIRCULAR COLLIDER Innovation Study

http://cern.ch/fcc

CERN

*Work supported by the **European Commission** under the **HORIZON 2020 projects***
***EuroCirCol**, grant agreement 654305; **FCCIS**, grant agreement 951754*

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

photo: J. Wenninger

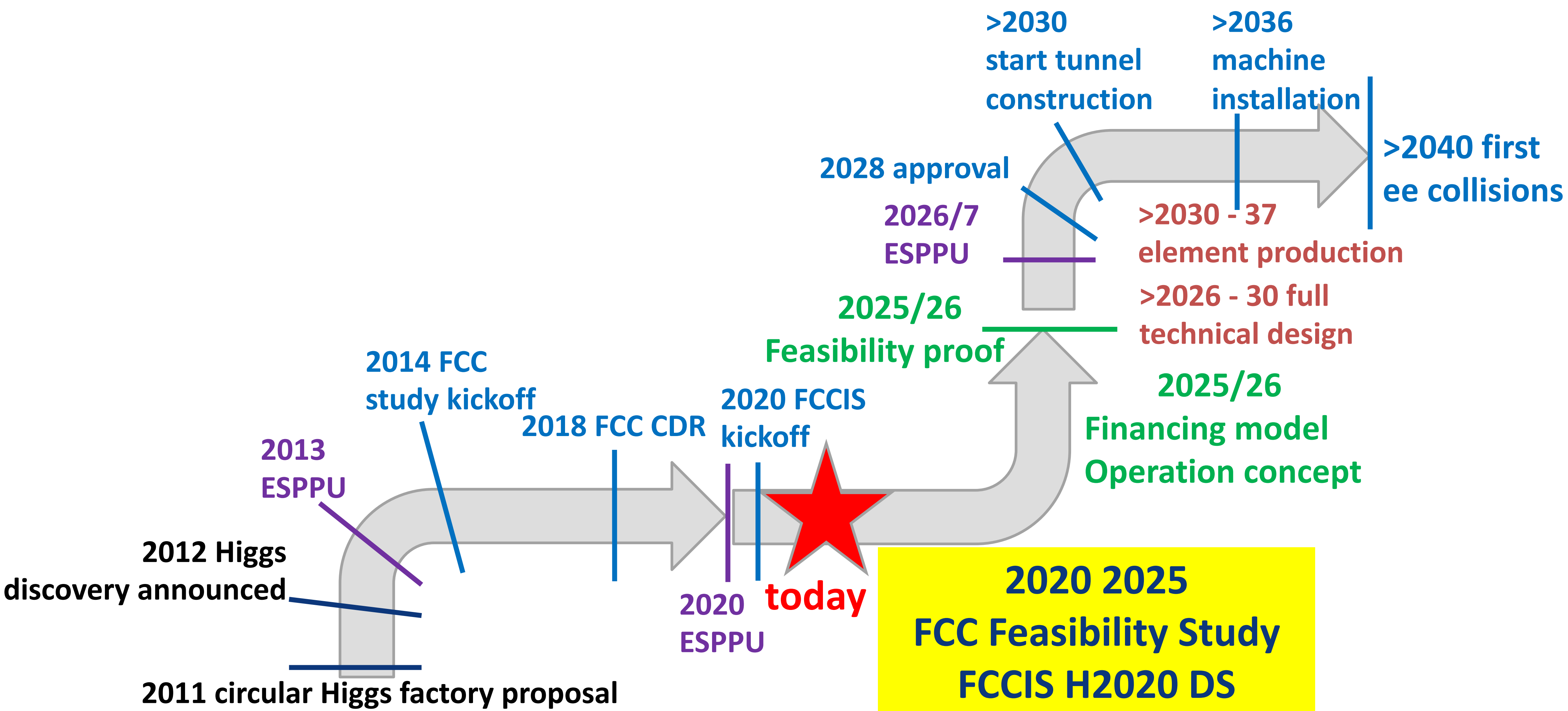
from ESPPU 2020 document

Core sentence and main request "order of the further FCC study":

"Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage. Such a feasibility study of the colliders and related infrastructure should be established as a global endeavour and be completed on the timescale of the next Strategy update."

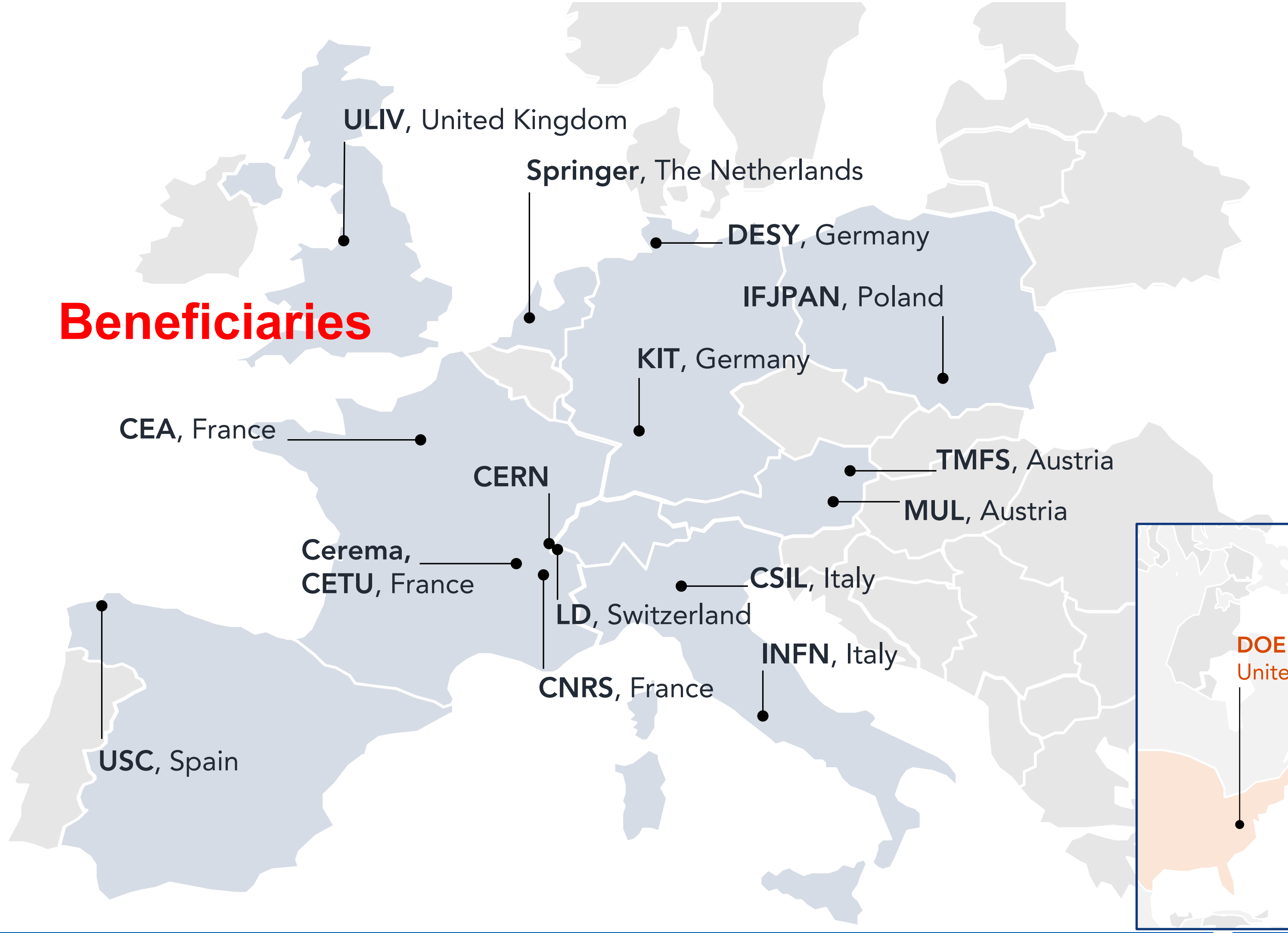
MOTIVATION of the FCC study

FCC roadmap

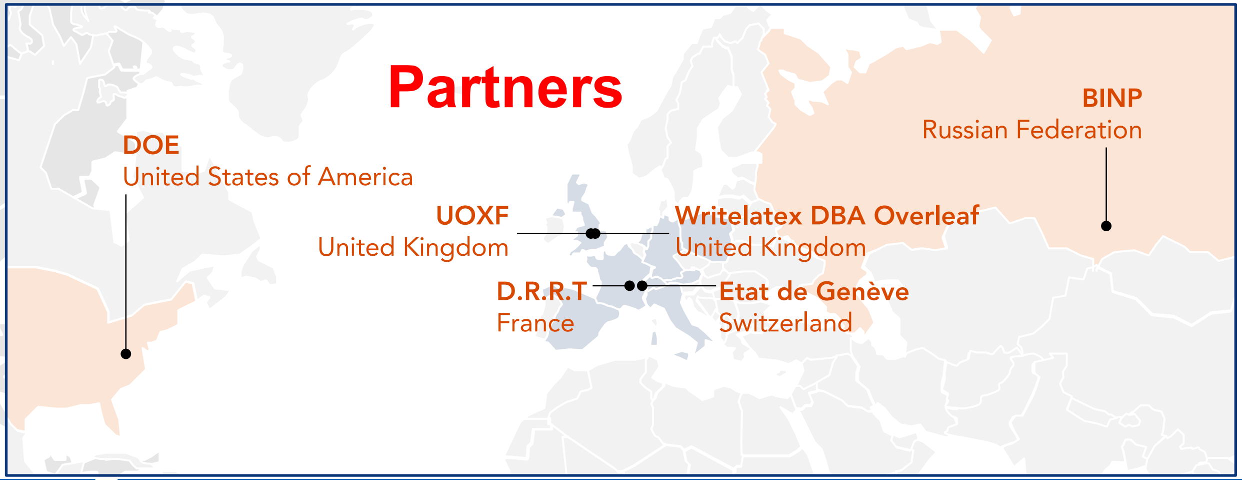


2020 2025
FCC Feasibility Study
FCCIS H2020 DS

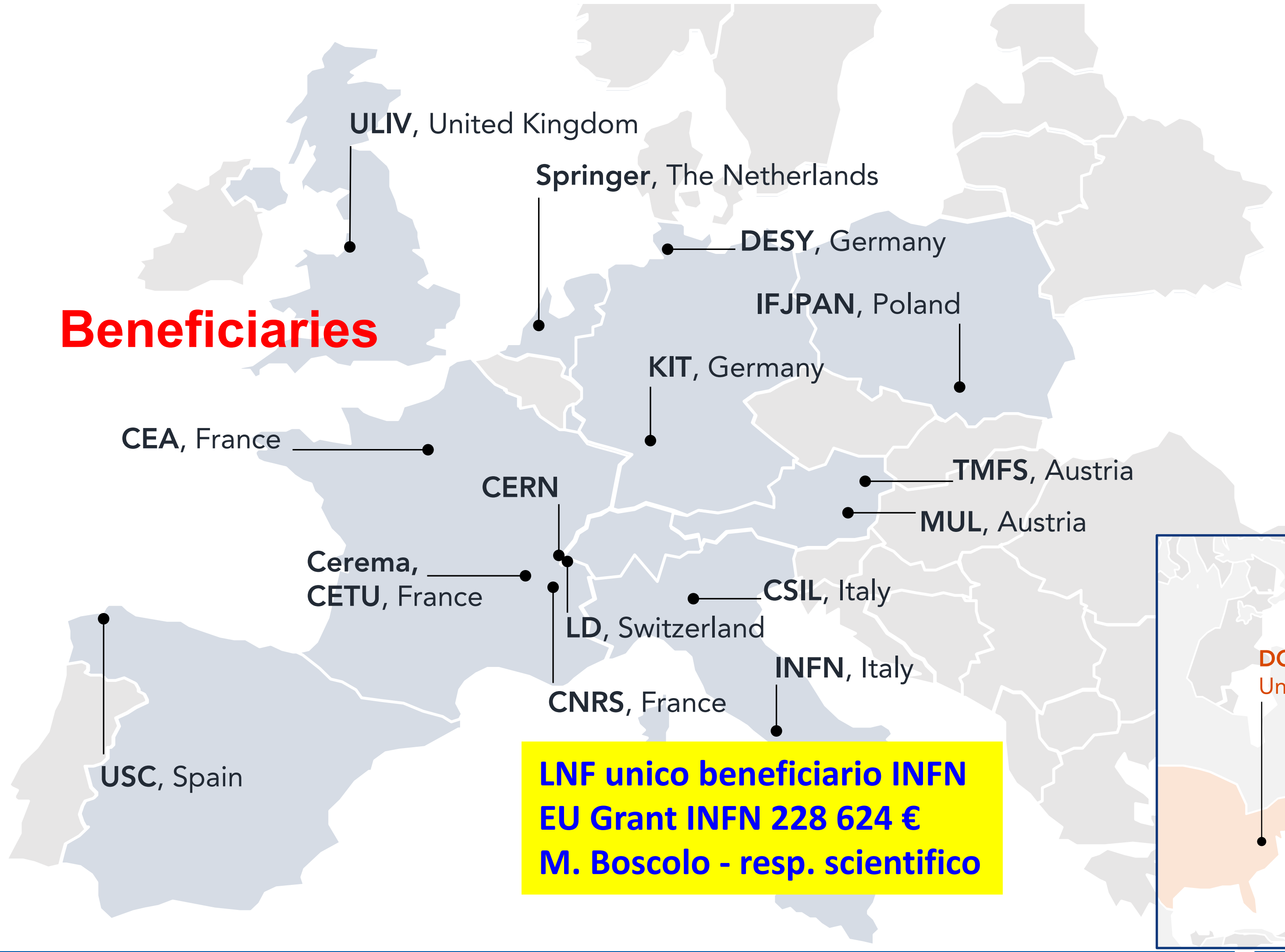
H2020 DS FCC Innovation Study 2020-24



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



H2020 DS FCC Innovation Study 2020-24



LNF unico beneficiario INFN
EU Grant INFN 228 624 €
M. Boscolo - resp. scientifico

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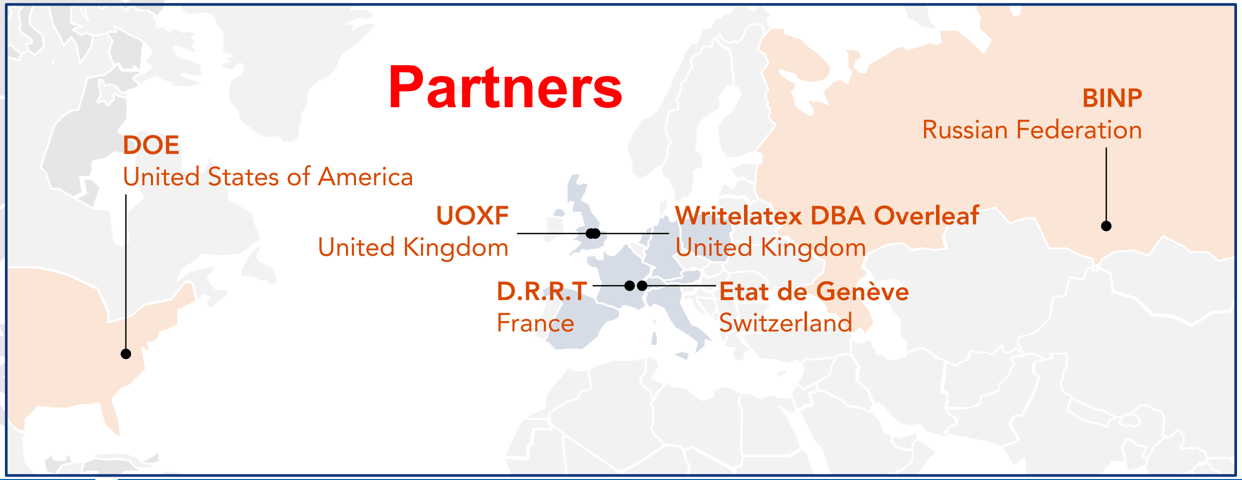


FCCIS Work Packages

WP1: study management

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.

WP3: integrate Europe

Develop a feasible project scenario compatible with local – territorial constraints while guaranteeing the required physic performance.

WP4: impact & sustainability

Develop the financial roadmap of the infrastructure project, including the analysis of socio-economic impacts.

WP5: leverage & engage

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).

FCCIS WP2 FCC-ee Collider Design

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, participants: CEA, CERN, CNRS, KIT, IFJPAN, **INFN**, partner BINP)

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

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

FCC-ee basic design choices

double ring e^+e^- collider ~100 km

follows footprint of FCC-hh, except around IPs

crab-waist optics [ArXiv.070233]

large horizontal crossing angle **30 mrad**

asymmetric IR optics to limit synchrotron radiation towards the detector

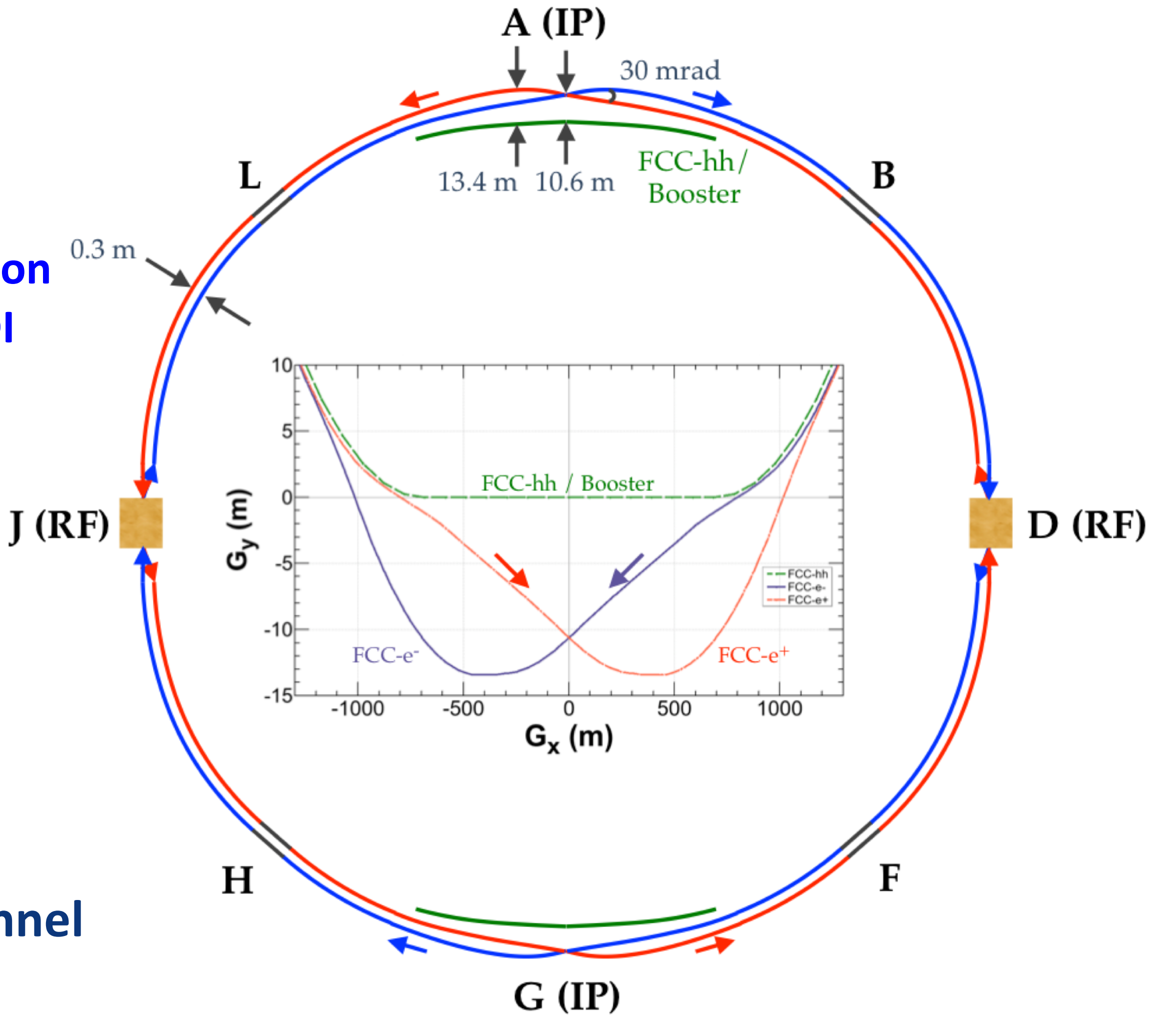
great impact on the MDI layout!

presently 2 IPs (alternative layouts with 3 or 4 IPs under study)

synchrotron radiation power 50 MW/beam at all beam energies; tapering of arc magnet strengths to match local energy

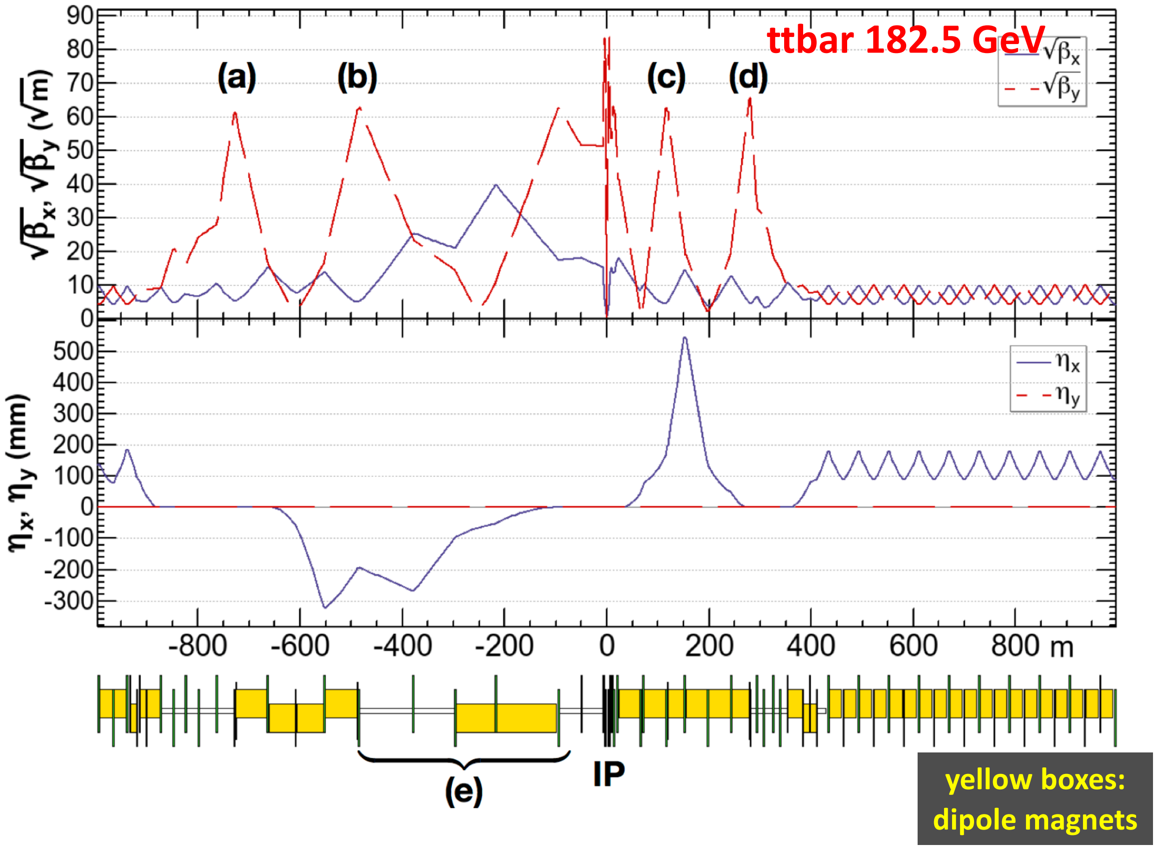
common RF for $t\bar{t}$ running

top-up injection requires **booster synchrotron in collider tunnel**



FCC-ee: The Lepton Collider, **Eur. Phys. J. Spec. Top. 228**, 261–623 (2019)
K. Oide et al., **Phys. Rev. Accel. Beams 19**, 111005 (2016)

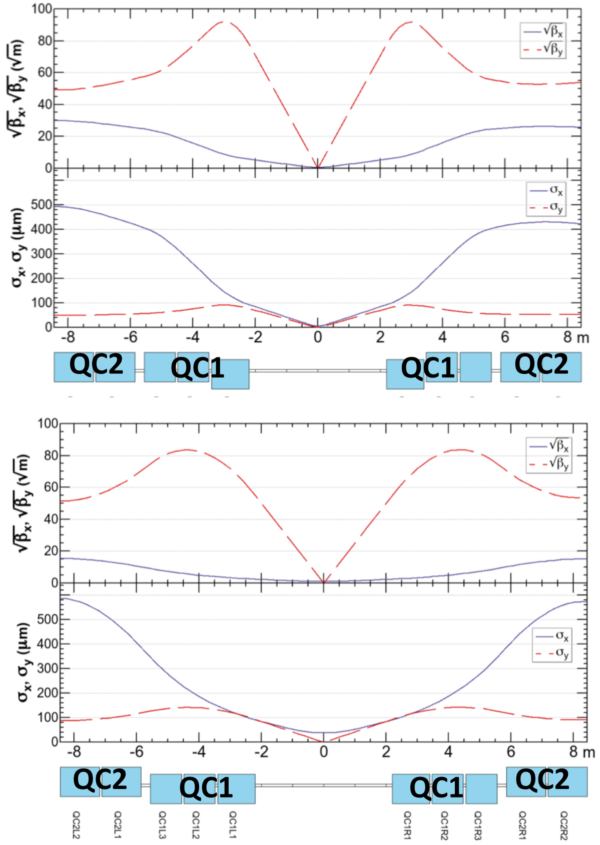
Interaction Region optics



Asymmetric optics suppresses SR toward the IP,

$E_{critical}$ <100 keV from 450 m from the IP

Final Focus optics



Z-pole

E_{beam} = 45.6 GeV

Only first slice of QC1 is defocusing horizontally

$t\bar{t}$

E_{beam} = 182.5 GeV

All three slices of QC1 are defocusing horizontally

Flexible optics design:
final focus doublet in three slices

Coinvolgimento dell'INFN (WP2)

- **Task 2.3 Interaction Region & Machine Detector Interface design (INFN-lead)**
- **Collective effects & impedances**

Possible experimental tests at DAFNE

''The (cw) scheme was invented at INFN...
The practical work at PETRA-III (DESY), KARA (KIT), DAFNE and potentially other facilities such as VEPP-4M (BINP) provides the opportunity to validate the performance enabling concepts....
The particle collider beam optics will be verified experimentally in existing particle accelerators at CERN, ESRF and INFN-LNF for which transnational access will be provided free of charge for the consortium. ...''

Staff scientifico coinvolto

- Manuela Boscolo
- Luigi Pellegrino
- Mikhail Zobov e M. Migliorati, Sapienza & INFN-Roma1
- + TD col grant EU-H2020 FCCIS

FCC-ee MDI study

- MDI/IR **engineering design** and **mechanical layout with integration**
- **Backgrounds study** (SR, single and IP bkgs, sustainability by the detector, shieldings, top-up injection bkg,..)
  → Related to the MDI layout design: **masks, shieldings, collimators**
  → Related to optics design, with requirements especially to dynamic aperture, energy acceptance
  → Beam-beam and beamstrahlung stability
- **Luminosity measurement**
- **IR magnets**
- **IR beam diagnostics and IP detectors**
- **Alignment tolerances & vibration control**
  - ➢ tight tolerances for alignment of magnets, very good orbit stability and vibrations control required
- **IR heat load assessment**

Different areas of activity with various expertise required: accelerator and experimental physics, engineering, technology

MDI/IR engineering design and mechanical layout with integration (INFN-lead)

Preliminary

- Beam pipe design
- Magnet integration including el.-magn/ forces
- Cryostat integration
- Shielding against hard synchrotron radiation & collision debris
- IP detectors integration (luminosity calorimeter, vertex detector) support & alignment
- Vacuum system integration
- Supporting structures
- Thermal simulations
- Manageament of electrical and hydraulic connection/routing
- Mechanical IR assembly, disassembling & repair procedures

forming collaboration with CERN, LAPP, SLAC, EIC(BNL), ...

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

Richiesta di impegno alla DA

Il progetto dura 4 anni (fine novembre 2024)
1/7/23 milestone: IR&MDI design

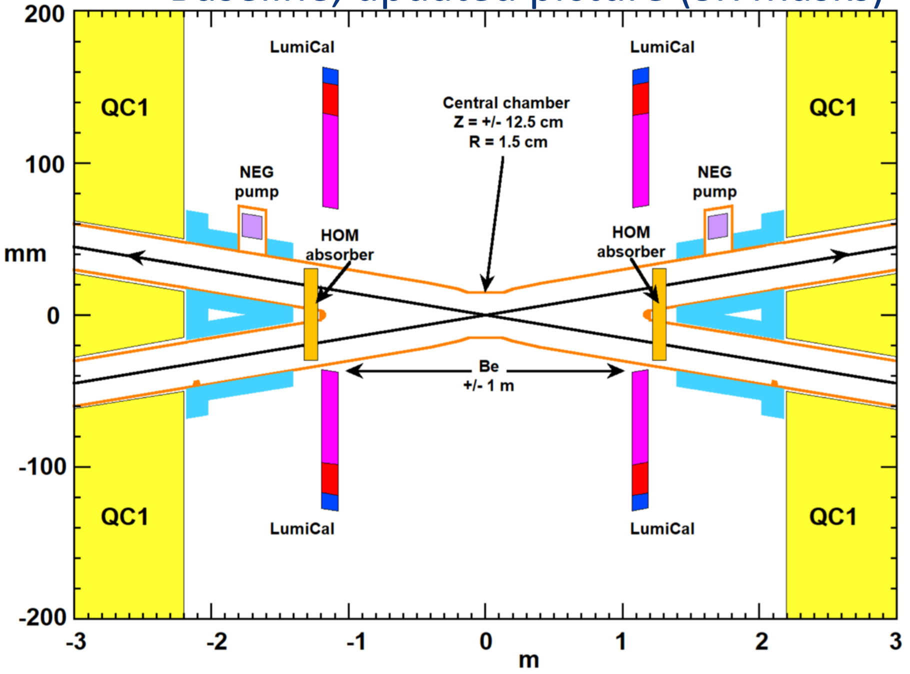
staff scientifico	FTE Timesheets	commento
Manuela Boscolo	6 PM/year	impegno *quasi* al 80-90%
Luigi Pellegrino	1.2 PM/year	impegno necessario per realizzare disegno meccanico della IR di FCC-ee
Mikhail Zobov	1.2 PM/year	collaborazione con Mauro Migliorati (che non puo' rendicontare perche' non LNF né INFN)
AdR	12 PM/year	impegno al 100%

richieste servizi	commento
servizio ingegneria meccanica	molto importante per adempiere all'impegno preso del disegno meccanico della IR e MDI: 1 disegnatore dedicato al progetto sarebbe l'optimum

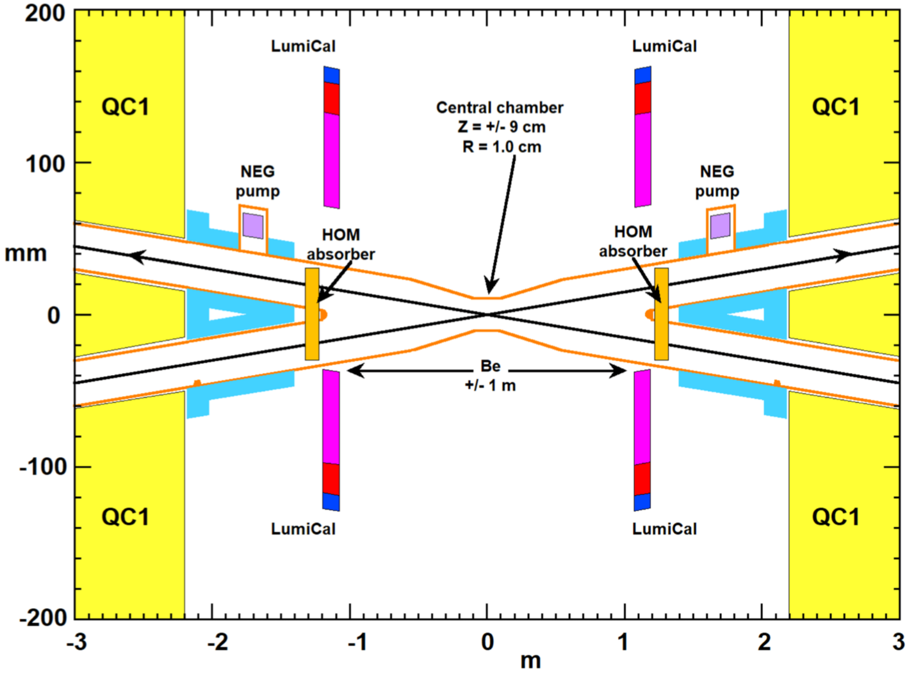
Andrea Ciarma, borsista INFN-LNF ha vinto una fellow al CERN dal 1/2/21 su FCC-ee MDI: alla fine dei 2 anni contiamo di riaverlo in DivAcc

FCC-ee MDI Layout

Baseline, updated picture (SR masks)



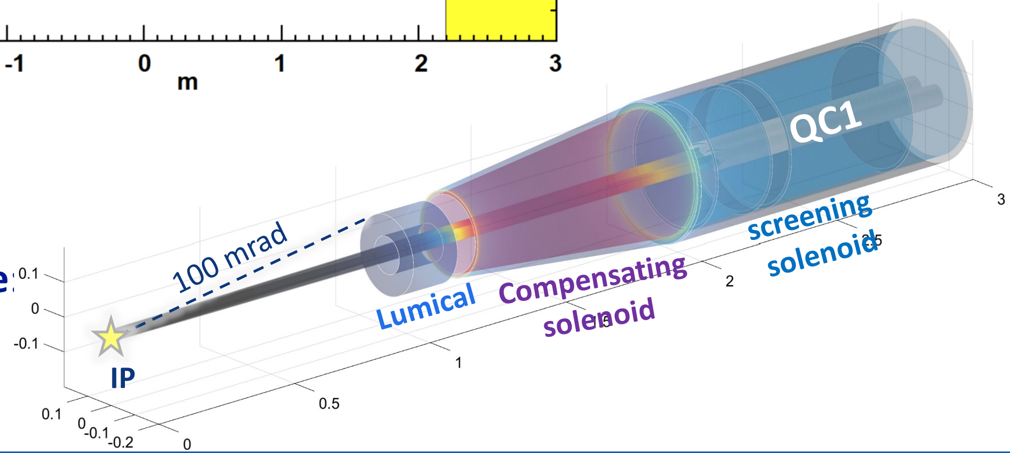
1 cm radius central chamber



Not shown in the above layouts, for the **detector solenoid compensation scheme**:

screening solenoid shields the detector field inside the quads

compensating solenoid in front of the first quad to reduce the ε_y blow-up



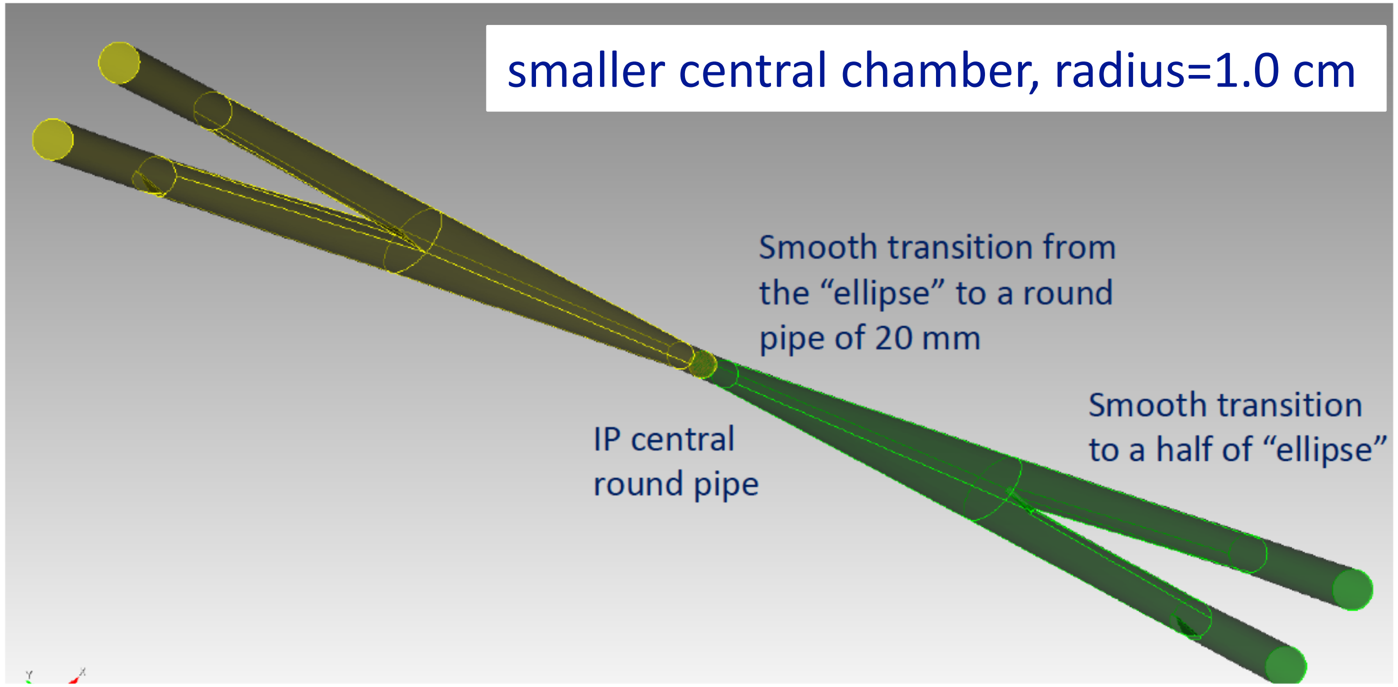
IR beam pipe model

Recently, a **new study** with a **smaller central beam pipe model** was performed [L. Pellegrino, FCCWEEK2020]

The model was used for wakefield calculations showing the great advantage that **HOM absorbers are no longer required.** [A. Novokhatski, FCCWEEK2020]

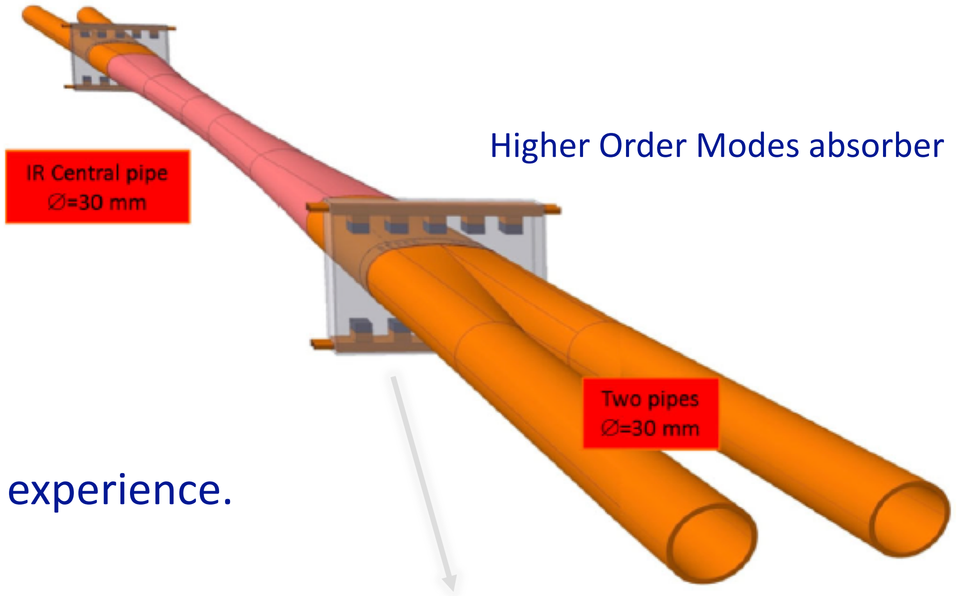
The impact on **synchrotron radiation** in the central chamber has been checked finding acceptable values. [M. Sullivan, FCCWEEK2020]

First studies performed by the detector group are encouraging.
More studies are are planned.



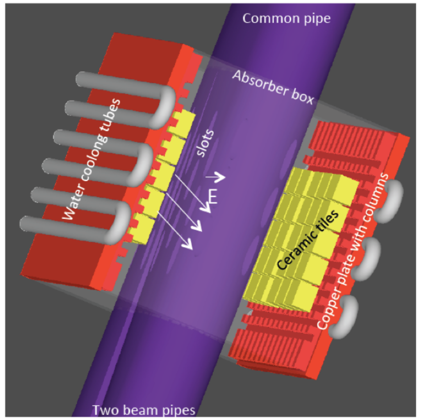
IR beam pipe model (CDR)

The incoming pipes and the central beam pipe have the same diameter of 30 mm
Special transition from two beam pipes to a common central pipe.



HOM absorbers are necessary, they are described in Ref. [A. Novokhatski et al. PR-AB 20, 111005 (2017)]
They are based on the property of the trapped modes, following the PEP-II experience.

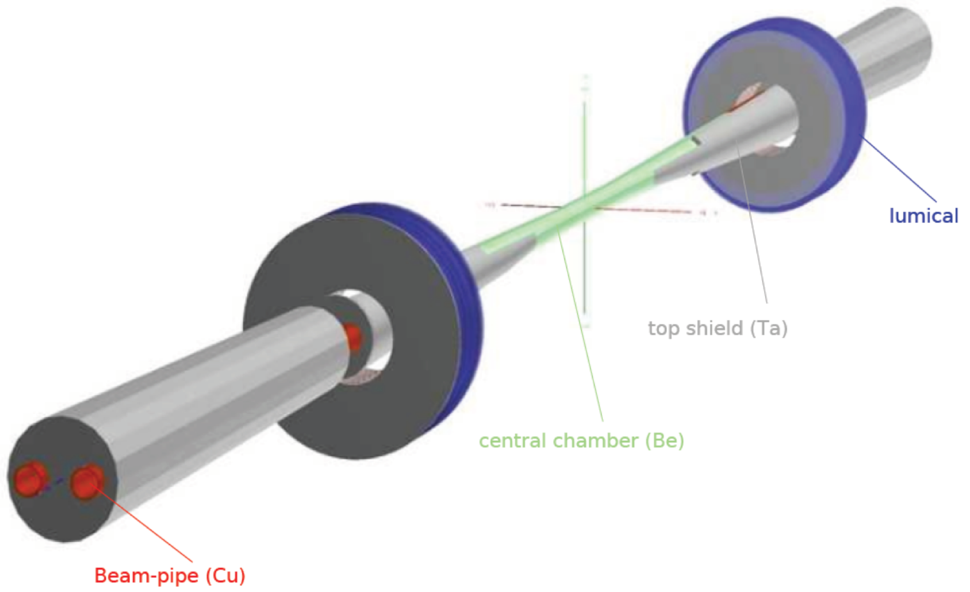
The absorber vacuum box is placed around the beam pipe connection. Inside the box we have ceramic absorbing tiles and copper corrugated plates. The beam pipe in this place has **longitudinal slots**, which connect the beam pipe and the absorber box. Outside the box we have stainless steel water-cooling tubes, braised to the copper plates. The **HOM fields**, which are generating by the beam in the Interaction Region **pass through the longitudinal slots into the absorber box**. Inside the absorber box these fields are **absorbed by ceramic tiles**, because they have high value of the loss tangent. The **heat from ceramic tiles** is transported through the copper plates **to water cooling tubes**.



Backgrounds Studies

Requirement of developing and updating software tools

- **Synchrotron radiation background**
  - different codes used, complementary with each other (MDISim, Synch_bkg, SynRad+) and impact on detector investigated
- **Generation of background sources**
  - IP backgrounds
  - Single beam backgrounds:
- **Tracking beam scattered particles**
  - **IR loss map → and track into detectors**
  - **loss maps around the ring → for collimation study**
  - Multiturn tracking for IP and single beam bkgs
  - Collimation scheme
  - Beam tails



Geant4 model for the detector backgrounds studies (CDR)

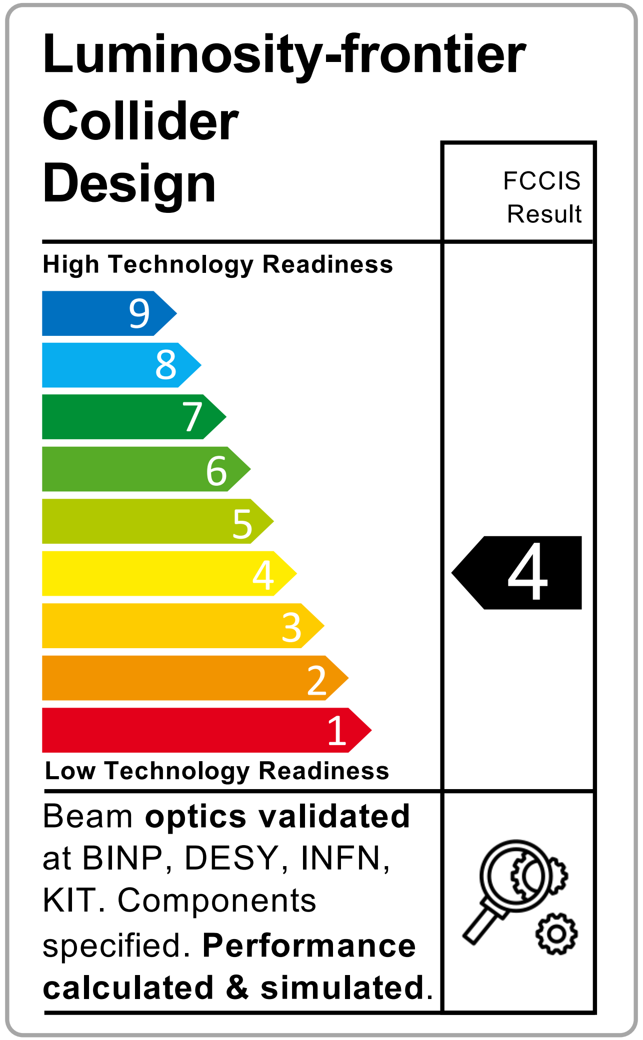
Conclusion

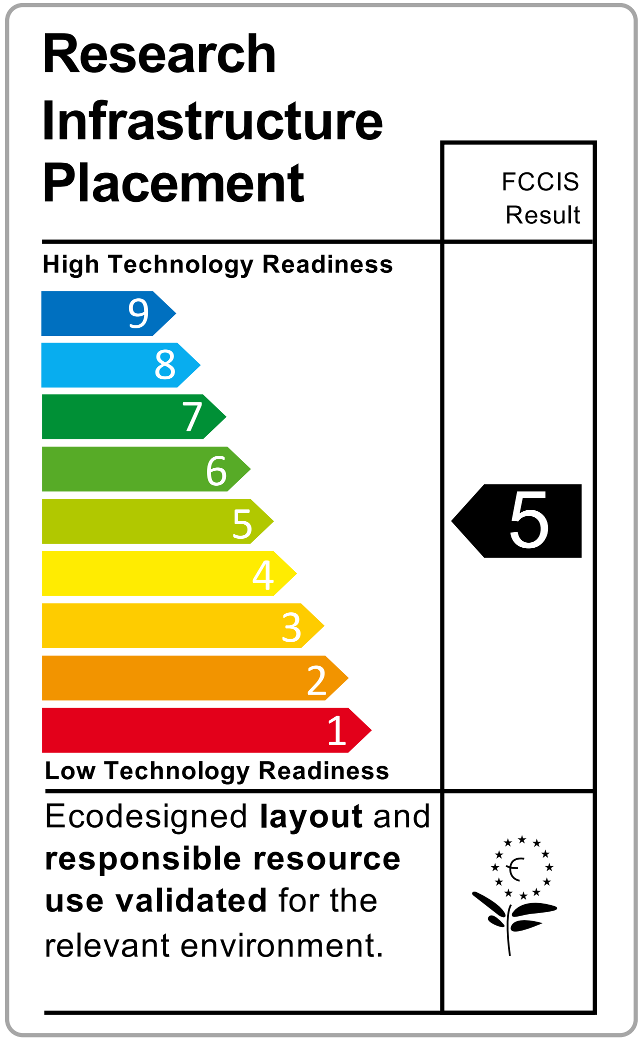
- **Many exciting challenges for the design with state-of-the art technologies and experience on past and present colliders like DAFNE (FCC-ee is e e+e- collider based on the crab-waist scheme invented at Frascati)**
- **The LNF lead the IR & MDI design: tremendous effort is needed in the next years to produce a conceptual and mechanical design**
- **CERN groups (TE, APB, EP, ...) are joining the effort and are starting to work on the design, they are willing to build prototypes and hire technical students, post-docs, fellows, ... 20ME allocated to FCC in the next 5y mid-term plan**
- **Great opportunity!**

spare slides

Objectives of FCCIS (Description of Action)

- O1: **Design a circular luminosity frontier particle collider** with a research programme to remain at the forefront of research
- O2: **Demonstrate the technical and organizational feasibility** of a 100 km long, circular particle collider
- O3: **Develop an innovation plan for a long-term sustainable research infrastructure** that is seamlessly integrated in the European research landscape
- O4: **Engage stakeholders** from different sectors of the society
- O5: **Demonstrate the role and impact of the research infrastructure in the innovation chain**, focusing on responsible resource use and managing environmental impacts





FCC integrated project technical schedule

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	15 years operation	34	35	36	37	38	39	40	41	42	43	~ 25 years operation	70

Project preparation & administrative processes

Permis-sions

Update Permis sions

Funding strategy

Funding and in-kind contribution agreements

Funding and in-kind contribution agreements

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 R&D and technical design

FCC-ee accelerator construction, installation, commissioning

FCC-hh accelerator R&D and technical design

FCC-hh accelerator construction, installation, commissioning

Set up of international experiment collaborations, detector R&D and concept development

FCC-ee detector technical design

FCC-ee detector construction, installation, commissioning

FCC-hh detector R&D, technical design

FCC-hh detector construction, installation, commissioning

Superconducting wire and magnet R&D, short models

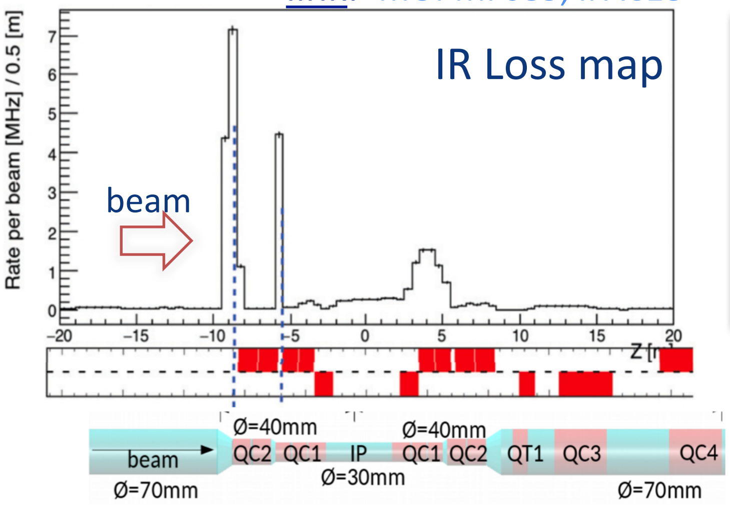
Long model magnets, prototypes, preseries

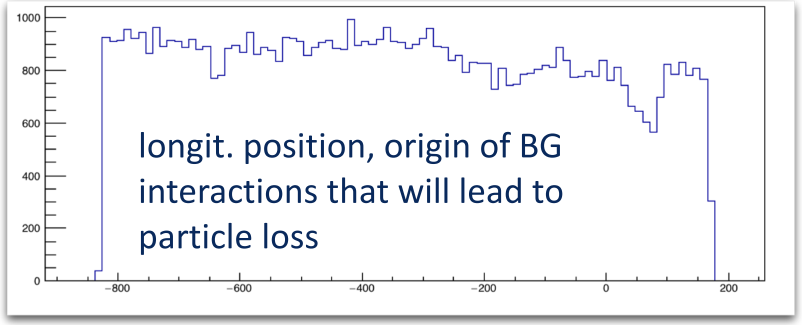
16 T magnet industrialization and series production

Single beam backgrounds:
beam-gas bremsstrahlung

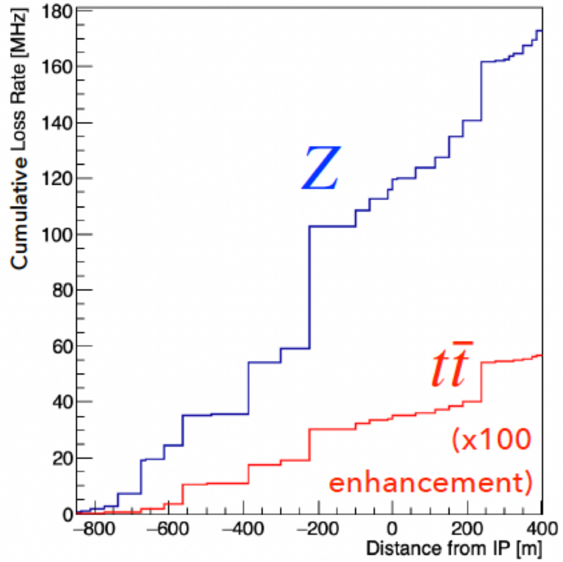
MDISim used to import in Geant4

link: MOPMF085, IPAC18





Loss Rates



indipendent simulation based on MAD-X particle tracking link

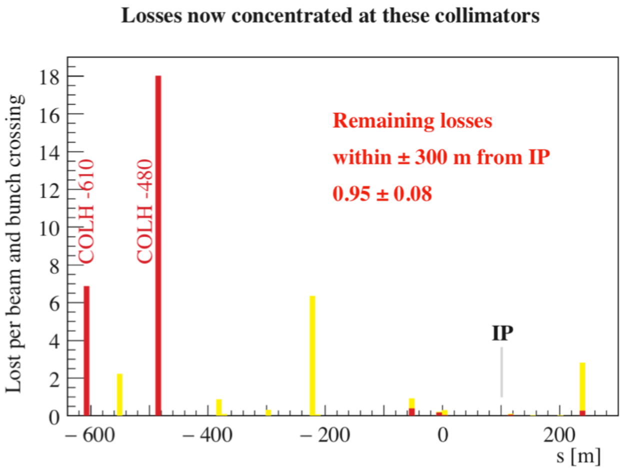
FCC-ee energy	Loss rate [-800;+200] m from IP [MHz]	Loss Rate [-20;+20] m from IP [MHz]
Z	147	29 tracked into lumical
W	16	3
H	3	0.5
t	0.5	0.1

- **Very good agreement between the two indipendent simulation codes**
- **Plan to use realistic pressure density plots, and continue this study**

Single beam backgrounds:
Thermal photons

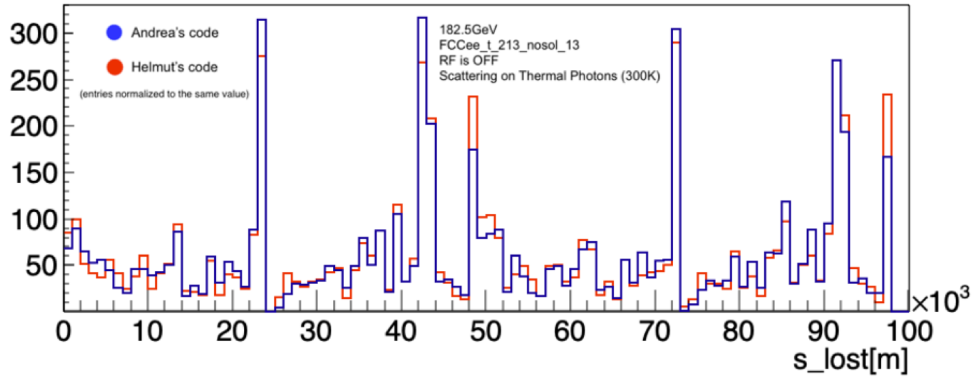
First described in 1987 by V. Telnov , main single beam lifetime limitation in LEP, well measured and simulated using the algorithm described in SL/Note 93-73

[H. Burkhardt, FCC WEEK2019]



Thermal γ 31.2 ± 0.5 |s|<1.5 km from IP lost/beam/crossing
of which 11.1 ± 0.3 |s|< 300 m

Loss map@ttbar



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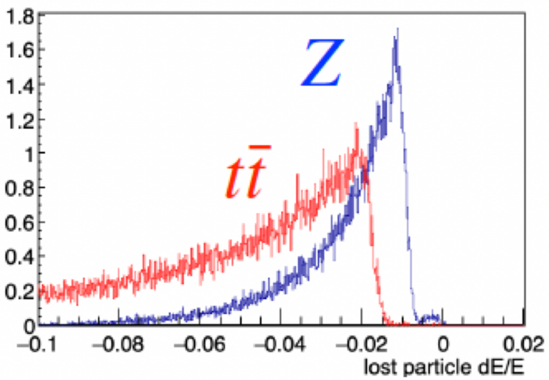


lost particles energy spectrum

link: [FCC WEEK 2020, A. Ciarma]

This is not expected a relevant process for FCC-ee

Status of Global FCC Collaboration

Increasing international collaboration as a prerequisite for success:

links with science, research & development and **high-tech industry** will be essential to further advance and prepare the implementation of FCC

141
Institutes

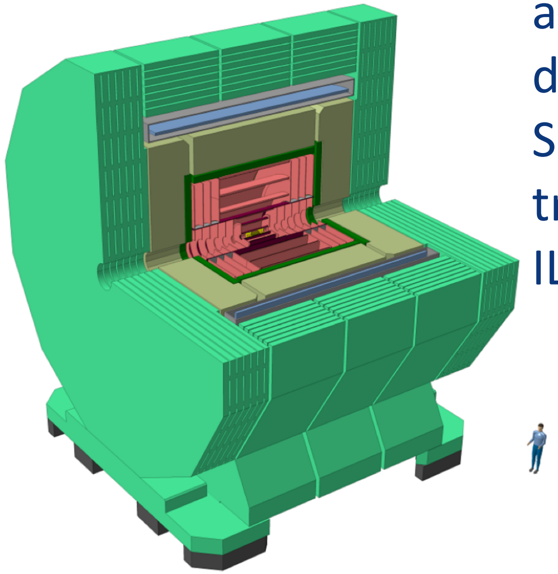
30
Companies

34
Countries

EC
H2020

FCC-ee Detectors

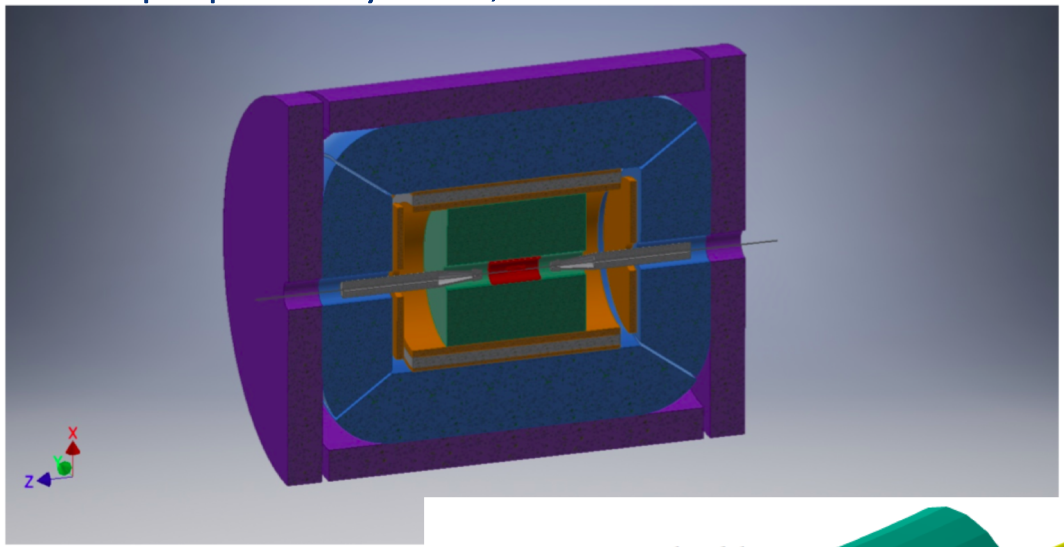
CLD Detector

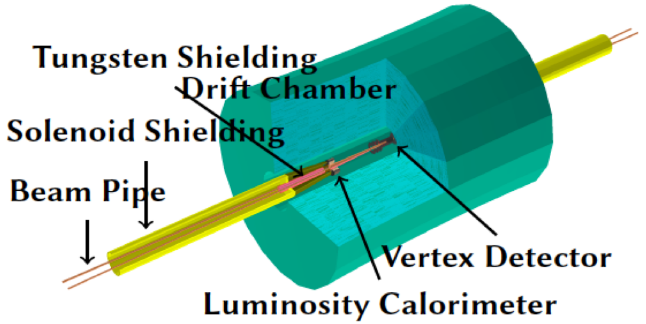


adaptation of the CLIC detector model (**2T**)
Silicon-based vertex and tracking detectors
ILCSoft

IDEA detector

proposed by INFN, also for CEPC

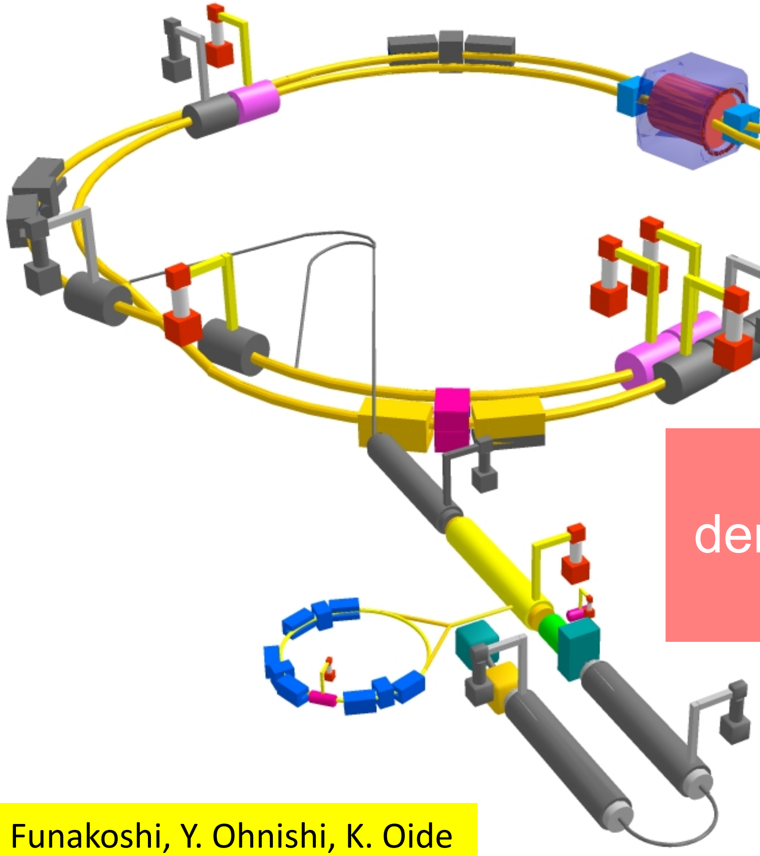




Impact of background in detectors found manageable
evaluated: SR (with Ta shielding), Beamstrahlung, Incoherent Pair Production at CLD, $\gamma\gamma$ to hadrons, Radiative bhabhas, Beam-gas
→ **This study is in progress** with a refined G4 model, and with more bkgs simulation, i.e. with the spent beam particles, ...

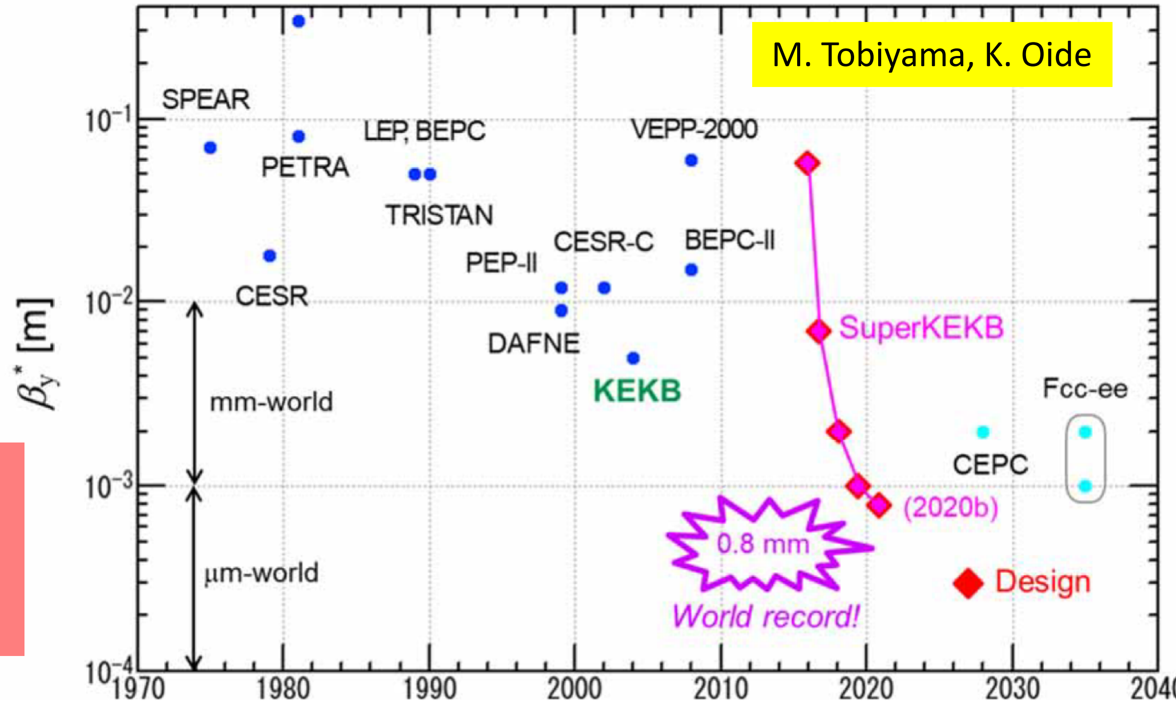
SuperKEKB – pushing luminosity and β*

Design: double ring e^+e^- collider as *B*-factory at 7(e^-) & 4(e^+) GeV; design luminosity ~8 x 10^{35} $cm^{-2}s^{-1}$; β_y^* ~ 0.3 mm; nano-beam – large crossing angle collision scheme (crab waist w/o sextupoles); beam lifetime ~5 minutes; top-up injection; e^+ rate up to ~ 2.5 10^{12} /s ; under commissioning



Y. Funakoshi, Y. Ohnishi, K. Oide

SuperKEKB is demonstrating FCC-ee key concepts



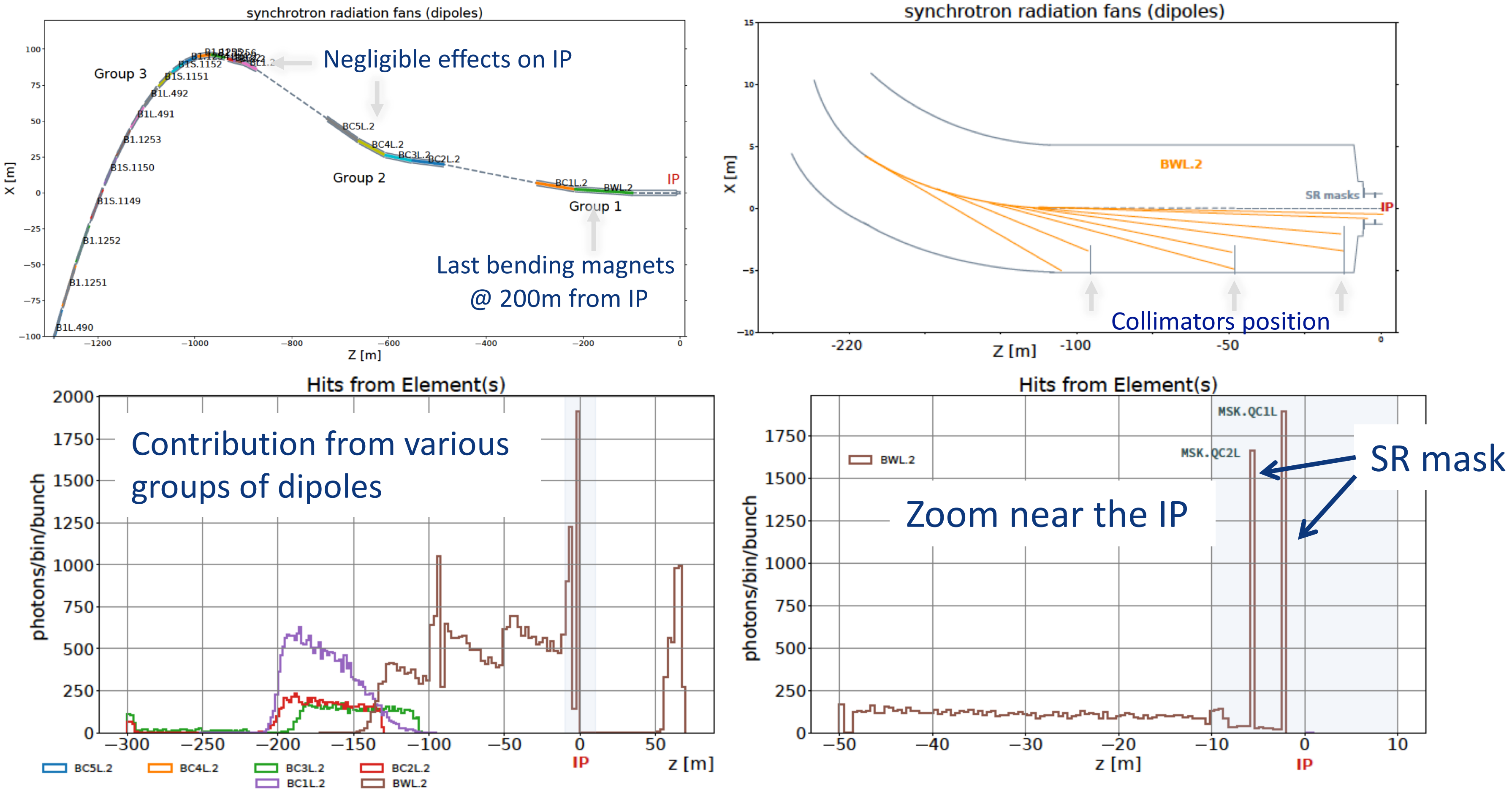
β_y^* = 0.8 mm achieved in both rings – using the FCC-ee-style "virtual" crab-waist collision scheme

FCC-ee Collider Parameters

parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45	80	120	182.5
beam current [mA]	1390	147	29	5.4
no. bunches/beam	16640	2000	393	48
bunch intensity [10^{11}]	1.7	1.5	1.5	2.3
SR energy loss / turn [GeV]	0.036	0.34	1.72	9.21
total RF voltage [GV]	0.1	0.44	2.0	10.9
long. damping time [turns]	1281	235	70	20
horizontal beta* [m]	0.15	0.2	0.3	1
vertical beta* [mm]	0.8	1	1	1.6
horiz. geometric emittance [nm]	0.27	0.28	0.63	1.46
vert. geom. emittance [pm]	1.0	1.7	1.3	2.9
bunch length with SR / BS [mm]	3.5 / 12.1	3.0 / 6.0	3.3 / 5.3	2.0 / 2.5
luminosity per IP [10^{34} cm^{-2}s^{-1}]	230	28	8.5	1.55
beam lifetime rad Bhabha / BS [min]	68 / >200	49 / >1000	38 / 18	40 / 18

Synchrotron Radiation collimators

Ref. MDISim



M. Luckof

Status and Outlook

- **1st phase** of FCC design study **completed → baseline machine designs,** performance matching physics requirements, in **4 CDRs**
- **Integrated FCC programme** was submitted to the European Strategy Update 2019/20 → Request for feasibility study as basis for project decision by 2026/27.
- **Next steps: concrete local/regional implementation scenario** in collaboration **with host state authorities**, accompanied by **machine optimization, physics studies and technology R&D**, performed **via global collaboration** and supported by **EC H2020 Design Study FCCIS, to prove feasibility by 2025/26.**
- Long term goal: a **world-leading HEP infrastructure for the 21st century** to push the particle-physics **precision and energy frontiers** far beyond present limits.
- Welcome all new participants to the FCC feasibility study phase and FCCIS project.