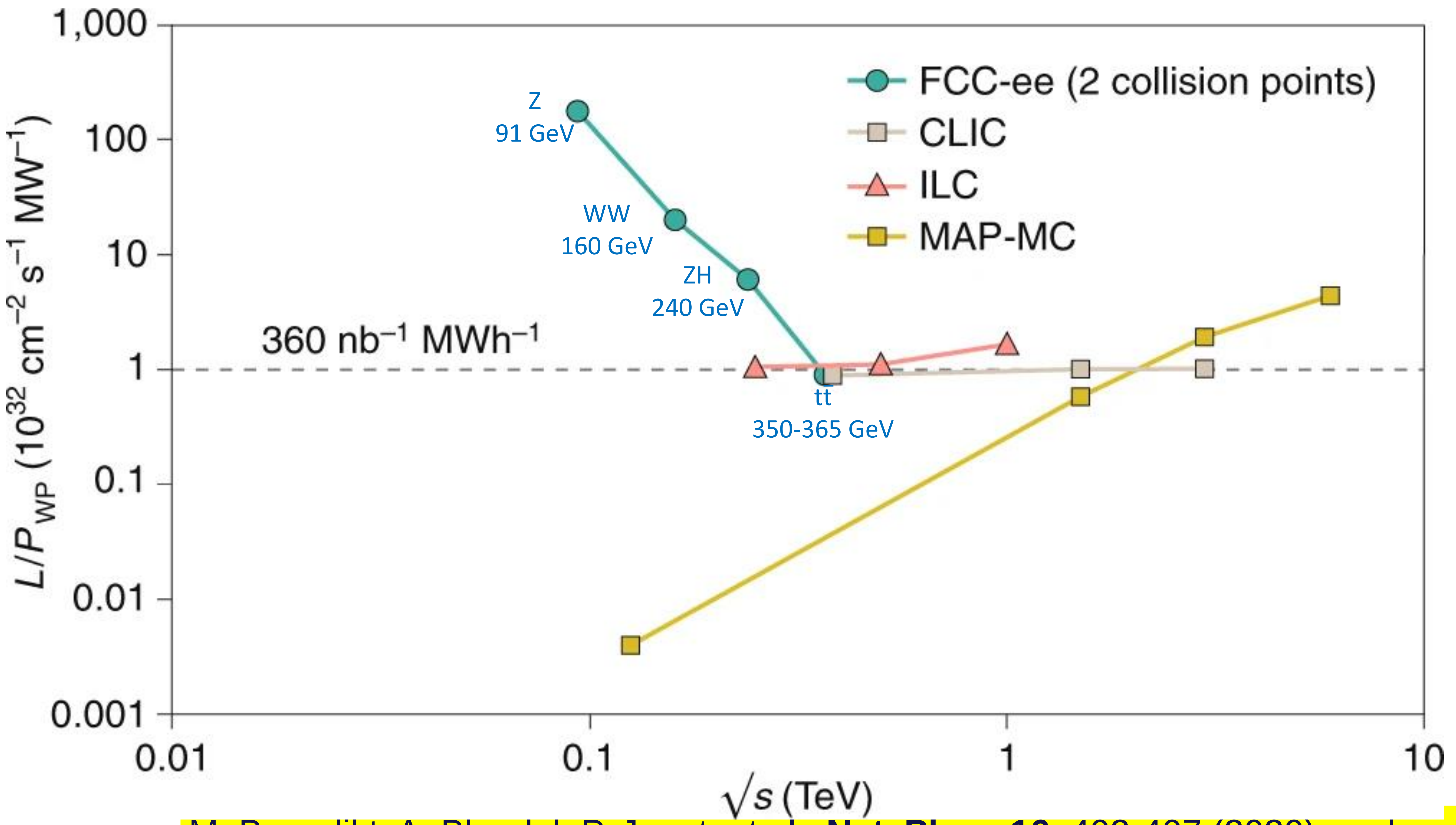
FUTURE CIRCULAR COLLIDER

FCCIS: WP2 Overview

I. Agapov, FCCIS week Dec 2022

FCC-ee: efficient Higgs/electroweak factory and a first step towards FCC-hh



- Cost-efficient Higgs factory
- Technology ready
- First stage of an integrated programme for a 100 TeV collider
- Synergies with other accelerator projects (light sources, EIC, SuperKEKB)
- Next design stage started after CDR

M. Benedikt, A. Blondel, P. Janot, et al., **Nat. Phys. 16**, 402-407 (2020), and **European Strategy** for Particle Physics Preparatory Group, *Physics Briefing Book* (CERN, 2019)

Objectives and role of the FCCIS WP2

Objectives

This work package will deliver a performance optimised machine design, integrated with the territorial requirements and constraints identified by WP 3, considering cost, long-term sustainability, operational efficiency and design-for-impact developed by WP 4. The work builds on two pedestals: (1) the conceptual baseline established in the FCC-ee report and (2) a documentation of the FCC-ee physics programme goals. Involving beneficiaries and partners, the work package has the following objectives:

- Optimise the collider parameters and layout (**CERN**, CEA, DESY, IFJPAN, INFN, BINP, KEK, UOXF)
- Develop and openly document the collider beam optics and lattice design, including the interaction regions (**CERN**, CEA, DESY, BINP, KEK)
- Establish procedures for optics corrections. Determine the beam diagnostics requirements and develop the beam instrumentation. Design the optics corrections and emittance tuning (**DESY**, CERN, KIT, KEK, UOXF)
- Establish the impedance budget for the collider and the booster and evaluate single-beam collective effects for different modes of operation (**INFN**, DESY, CERN)
- Design the collimation system, develop the aperture model and develop the machine protection concept (**CERN**, DESY, INFN)
- Develop the top-up injection scheme (**CEA**, CERN, KEK)
- Develop and document the machine detector interface, final focus, stabilisation measures, background control and luminosity measurements (**INFN**, CERN, CNRS, KEK, UOXF)
- Design and document the full energy booster (**CEA**, CERN)
- Develop techniques for precision energy calibration, especially requirements and procedures for energy calibration using resonant depolarisation in the Z and W running modes, and benchmarking of techniques, like Compton scattering, to extend the energy calibration to higher energy (**KIT**, BINP, CERN)

- ca. 40 associated members
- Funding junior positions (PhD Student, postdoc) at 3rd party labs

WP2 organizaton

WP2 Collider Design

Meeting	Agenda	Video conferencing
Task 2.1 Work package coordination	Indico category	Zoom auto-join url
Task 2.2 FCC-ee Optics	Indico category	See Indico
Task 2.3 FCC-ee MDI	Indico category	See Indico
Task 2.4 Booster	Indico category	Zoom auto-join url
Task 2.5 EPOL	Indico category	See Indico

Tasks

Task 2.1: Work package coordination (lead: DESY, participants: CEA, CERN, CNRS, KIT, IFJPAN, INFN)

DESY, with the assistance from CERN, coordinates the tasks in this WP to ensure consistency of the work according to the project scope and plan. DESY organises the regular coordination meetings, workshops, manages the scope, reviews the progress, distributes information within the WP and manages the interfaces and collaborative with other WPs. IFJPAN coordinates the interfaces with theoretical and experimental physics communities. A specific person at CERN plans and follows up the documentation and open-access data publications concerning the experimentally tested beam optics at particle accelerators which are made available free of charge by the beneficiaries. DESY, CEA, CERN and KIT focus on the accelerator design coordination. INFN coordinates the work around the interaction region. CERN coordinates the interfaces with partners BINP and UOXF and for the territorial layout and placement requirements (DRRT, EdG). CERN allocates a person for the configuration management of the beam optics, lattice and the element database. CERN produces an open Product Breakdown Structure (PBS, **M2.1**) and disseminates data on Zenodo. The editing of the collider-related chapters of the design report (**D5.5**, WP5) is with CERN.

Tasks

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

Develop the parameters and machine layout, starting from the physics programme requirements (**D2.1**) and iteratively ensure that the design matches the physics research requirements with tasks 2.1 and 2.3 (IFJPAN). Study different numbers of interaction points (IPs) and compare their respective performance (CERN). Analyse and mitigate impedance and single-beam collective effects in the collider rings (INFN). Develop the positioning concept (CNRS). Conceive an effective beam diagnostics architecture, specify the device functions and performance (KIT). Understand the measurement needs and the level of precision required for a layout of the longitudinal beam diagnostics system. Develop a diagnostics concept based on an electro-optical setup for bunch-by-bunch measurements of the longitudinal profile and centre of gravity of the bunches. Time-resolved measurements of the horizontal beam size in a dispersive section are proposed as an approach to measure the energy spread. Test (D2.4) prototype diagnostics at the KARA accelerator (KIT). Develop the concept for the global orbit control system. Verify optics correction and vertical emittance tuning procedures in beam tests (D2.4) at the PETRA III (DESY) storage-ring or, at VEPP-4M at BINP and at SuperKEKB (KEK) (**D2.2**). Integrate the findings in the main deliverable of the project (**D5.6**)

- Many developments within FCC Study
- FCCIS resources matrixed to the study

Tasks

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

Ensure that the interaction region design meets the collider performance goals and develop an accelerator-detector interface coherently with task 2.2. Develop a 3D model of the interaction region, including final quadrupole and solenoid magnets, support structures, cooling schemes, and vacuum system. Develop heat-load budget and determine cooling requirements. Analyse vibration and stability. Develop and refine concepts for the luminosity measurement. Analyse and propose effective design measures to control the background and to protect the machine. Design the collimation system, develop a collider aperture model and develop an accelerator-detector protection concept. Review the SuperKEK IP feedback (KEK) architecture, performance, merits and limitations. Experimental beam studies (**D2.4**) exploring the sensitivity of the beam-beam performance to IP optics aberrations are planned at DAΦNE (INFN) and at SuperKEKB (KEK) with the crab-waist collision scheme. Document the interaction region design (**D2.2**) and integrate the findings in the main deliverable (**D5.6**).

- INFN successfully leads the MDI effort

Tasks

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

Design a full-energy booster and integrate it with the collider using a top up injection scheme (**D2.3**). This work comprises optics design, including injection and extraction region and beam transfer to the collider rings, field quality and dynamic aperture at injection and during the ramp and collective effects. Determine the minimum acceptable injection energy. Integrate the findings in the project's main deliverable (**D5.6**).

- CEA successfully leads the booster effort

Tasks

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

Develop and validate the optics correction and spin-matching procedures for establishing the transverse polarisation to achieve high-precision centre-of-mass energy calibration in cooperation with task 2.2 and 2.3. Refined energy calibration through resonant depolarisation with pilot bunches, polarisation wigglers and error assessment is an enabler for the extreme statistical precision and experimental accuracy at the Z pole and at the WW threshold. Plan tests (**D2.4**) with resonant depolarisation at KARA (KIT) and energy measurement at VEPP4M (BINP). Possibly study an alternative energy calibration using Compton backscattering, benchmark the two methods in low energy running modes, and extrapolate to higher energy. Document (**D5.6**) the design, including the elements and expected performance with a level of detail that permits starting the detailed technical design.

- EPOL working group established

Objectives

Report No.	Report title	Lead Beneficiary	Due date	Description
M2.1	Product breakdown structure (see FCCeePBS)	CERN	01/07/2021	Structured document of collider elements in tabular form publicly released on Zenodo (Green, open data).
D2.1	Collider performance, beam optics and design considerations baseline	CERN	01/11/2021	A technical report describing the baseline layout and the lattice together with a workable beam optics. The report includes the achievable performance and what remains to be addressed.
D2.2	Interaction region and machine detector interface design	INFN	01/07/2023	3D CAD proof-of-principle engineered mechanical design of the interface between the accelerator and detector components in the interaction region.
D2.3	Full-energy booster design	CEA	01/03/2024	A report describing the minimum acceptable injection energy into the booster, the lattice concept together with a workable beam optics, the ramp strategy and the top-up injection into the collider.
D2.4	Experimental characterisations of particle collider key performance enablers	DESY	01/05/2024	A report summarising the results from the experimental verifications of performance enabling techniques at various accelerators. Analysis of the beam-beam behaviour for the crab waist collision scheme and possibly, its sensitivity to various optics aberrations at the collision point.

Challenges and problems encountered

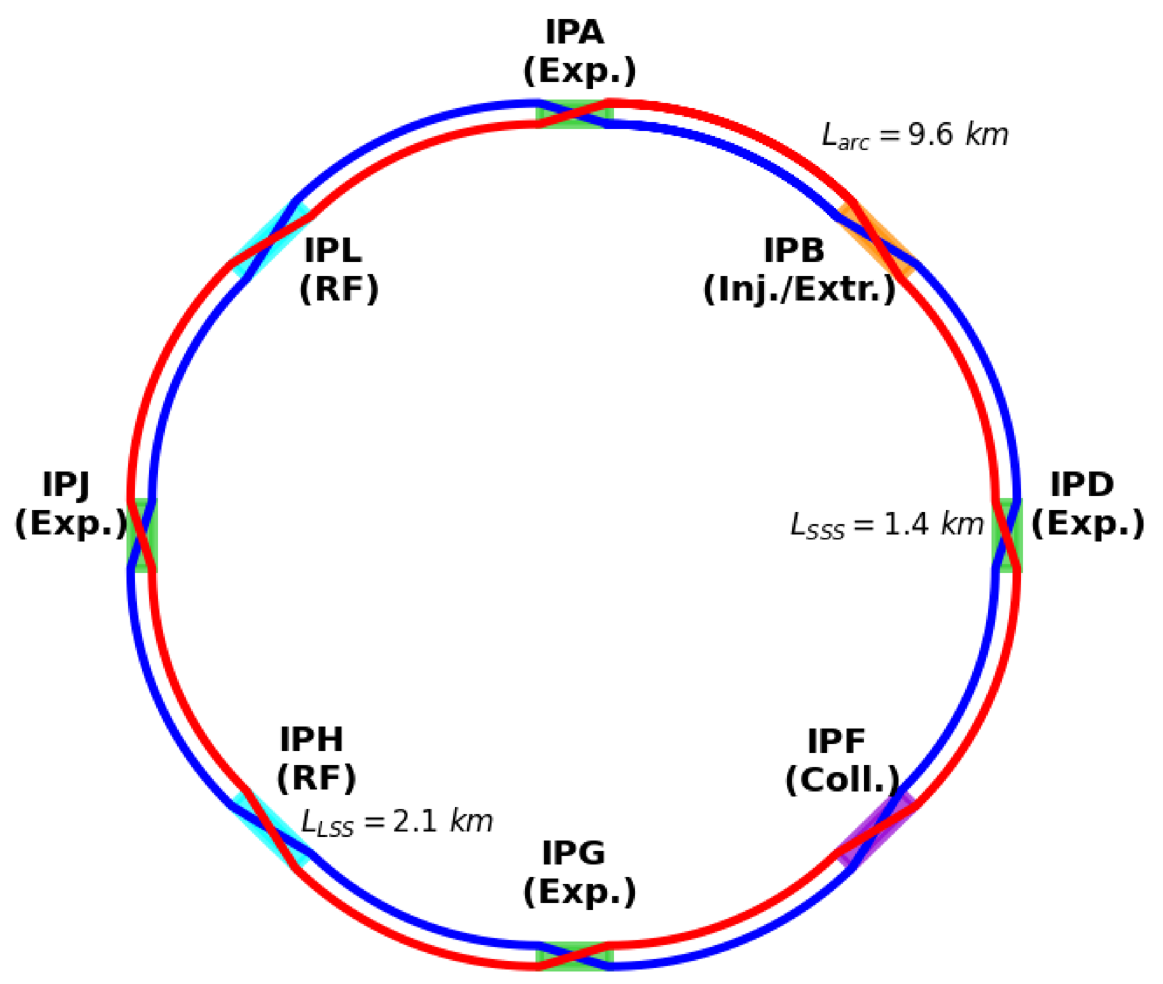
- Project proposal written pre-pandemic, project started in the pandemic
- Ways of work changed in the meantime
- Even last year’s FCCIS workshop was during travel and access restrictions
- Some participants became unavailable due to unfolding of later events
- While other players entered the FCC Study
- Organization of the FCC study progressed
- FCCIS will meet all the goals, but some revision of objectives and role within the FCC study might be beneficial

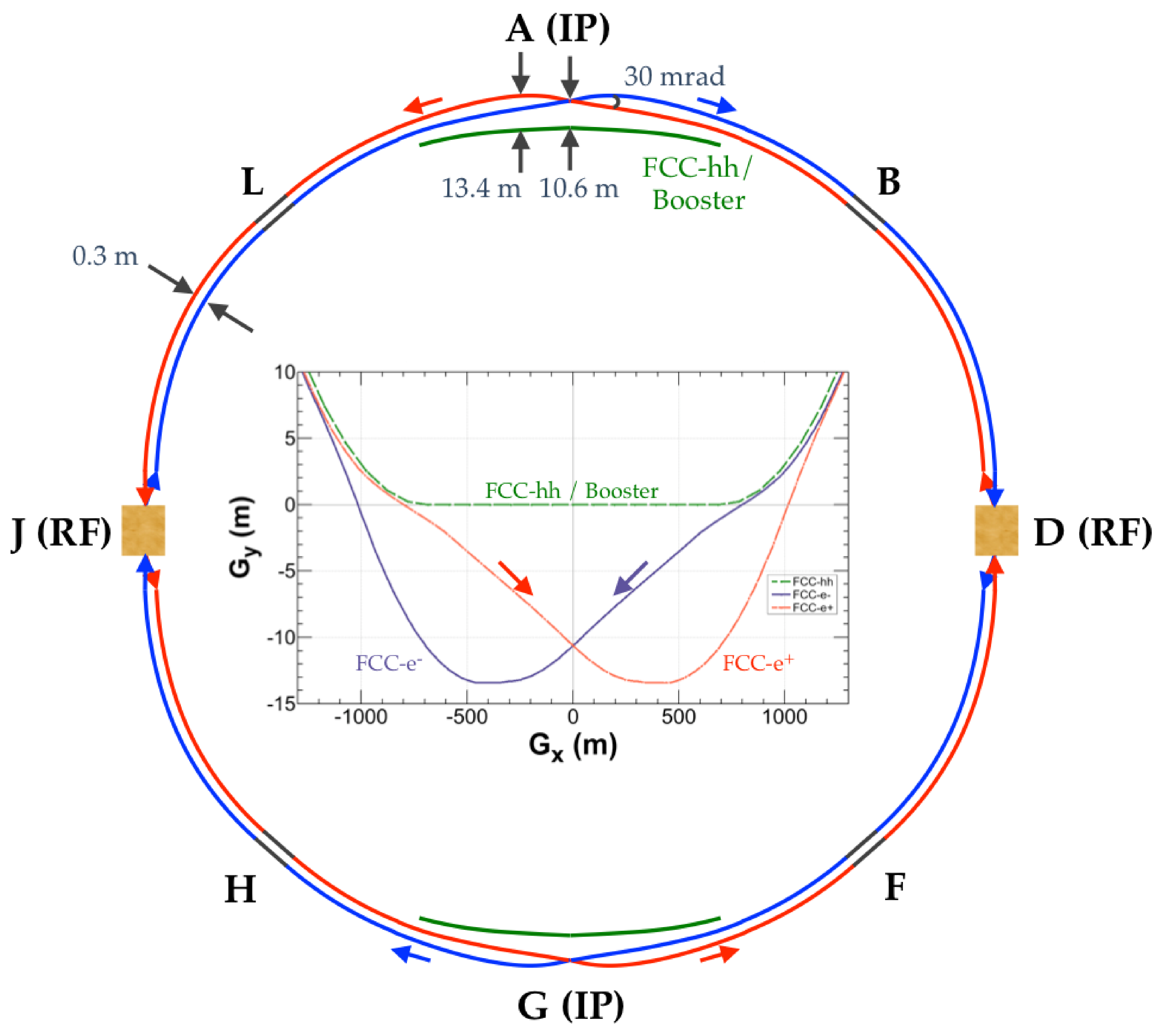
FCCIS events

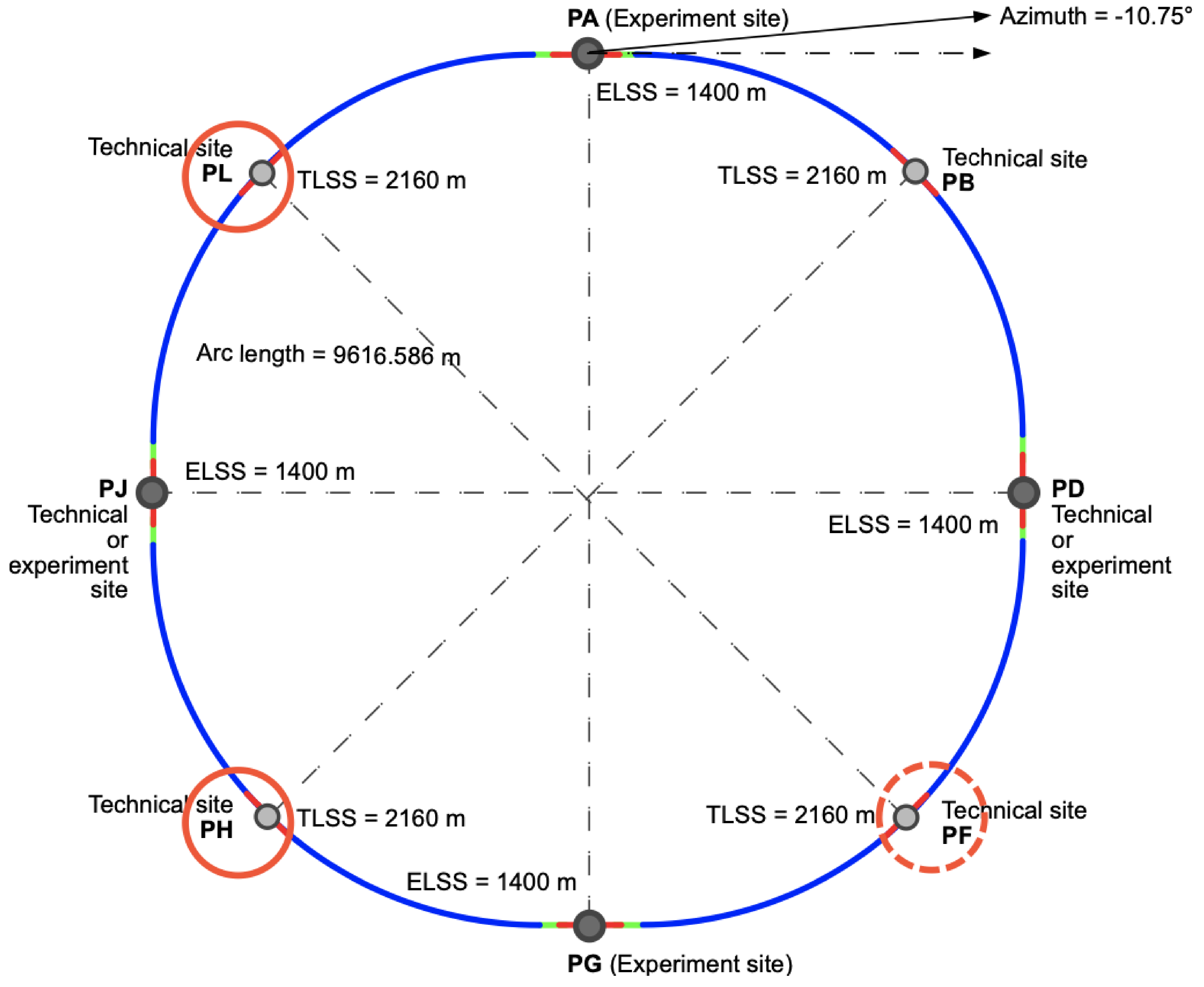
- FCCIS drives a large number of meetings and exchange activities, in particular the now becoming traditional FCCIS week in addition to the summer FCC week

Collider design evolution

- Reduced circumference
- 4 IP baseline







Evolution of collider parameters

- Reduced circumference and 4 IP leads to relaxation of beam 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 [mi	68 / >200	49 / >1000	38 / 18	40 / 18

Beam energy	[GeV]	45.6	80	120	182.5
Layout		PA31-1.0			
# of IPs		4			
Circumference	[km]	91.174117		91.174107	
Bending radius of arc dipole	[km]	9.937			
Energy loss / turn	[GeV]	0.0391	0.370	1.869	10.0
SR power / beam	[MW]	50			
Beam current	[mA]	1280	135	26.7	5.00
Bunches / beam		10000	880	248	40
Bunch population	[10^{11}]	2.43	2.91	2.04	2.37
Horizontal emittance ε_x	[nm]	0.71	2.16	0.64	1.49
Vertical emittance ε_y	[pm]	1.42	4.32	1.29	2.98
Arc cell		Long 90/90		90/90	
Momentum compaction α_p	[10^{-6}]	28.5		7.33	
Arc sextupole families		75		146	
$\beta^*_{x/y}$	[mm]	100 / 0.8	200 / 1.0	300 / 1.0	1000 / 1.6
Transverse tunes/IP $Q_{x/y}$		53.563 / 53.600		100.565 / 98.595	
Energy spread (SR/BS) σ_δ	[%]	0.038 / 0.132	0.069 / 0.154	0.103 / 0.185	0.157 / 0.221
Bunch length (SR/BS) σ_z	[mm]	4.38 / 15.4	3.55 / 8.01	3.34 / 6.00	1.95 / 2.75
RF voltage 400/800 MHz	[GV]	0.120 / 0	1.0 / 0	2.08 / 0	2.5 / 8.8
Harmonic number for 400 MHz		121648			
RF freuqency (400 MHz)	MHz	399.994581		399.994627	
Synchrotron tune Q_s		0.0370	0.0801	0.0328	0.0826
Long. damping time	[turns]	1168	217	64.5	18.5
RF acceptance	[%]	1.6	3.4	1.9	3.0
Energy acceptance (DA)	[%]	±1.3	±1.3	±1.7	-2.8 +2.5
Beam-beam ξ_x/ξ_y [a]		0.0023 / 0.135	0.011 / 0.125	0.014 / 0.131	0.093 / 0.140
Luminosity / IP	[10^{34}/cm^{2}s]	182	19.4	7.26	1.25
Lifetime (q + BS)	[sec]	–		1065	4062
Lifetime (lum)	[sec]	1129	1070	596	744

[a] incl. hourglass

Evolution of collider design

- Baseline with smaller circumference in place, performance evaluated
- New lattice ideas (Pantaleo)

WP2 - Collider design

Convener: Andrey Abramov (CERN)

16:30	**Arcs and Straight sections: beam dynamics studies and optimization** **Speaker**: Dr Pantaleo Raimondi (SLAC National Accelerator Laboratory (US))	30m
17:00	**Final Focus design with local compensation of geometric and chromatic aberrations** **Speaker**: Dr Pantaleo Raimondi (SLAC National Accelerator Laboratory (US))	30m
17:30	**Optic subsystems integration and general considerations** **Speaker**: Dr Pantaleo Raimondi (SLAC National Accelerator Laboratory (US))	30m

Focus on tuning

- Strong collaboration with light source community on optics measurement and correction
- Several common MD shifts performed
- Common software framework emerging (based on pyAT)
- Further synergies via the EU EURIZON programme

FCC-ee tuning team & WG meetings

CERN e-group FCCee_tuning-team:

+ *Anyone is welcome!*

Meetings so far: 22 Sept, 25 Aug, 21 July, 14 Jul, 30 Jun, 9 Jun, 22 Apr, 22 Mar, 17 Mar, 10 Feb, 17 Nov and 10 Nov.

Last tuning team report in the 157th FCC-ee Optics Design

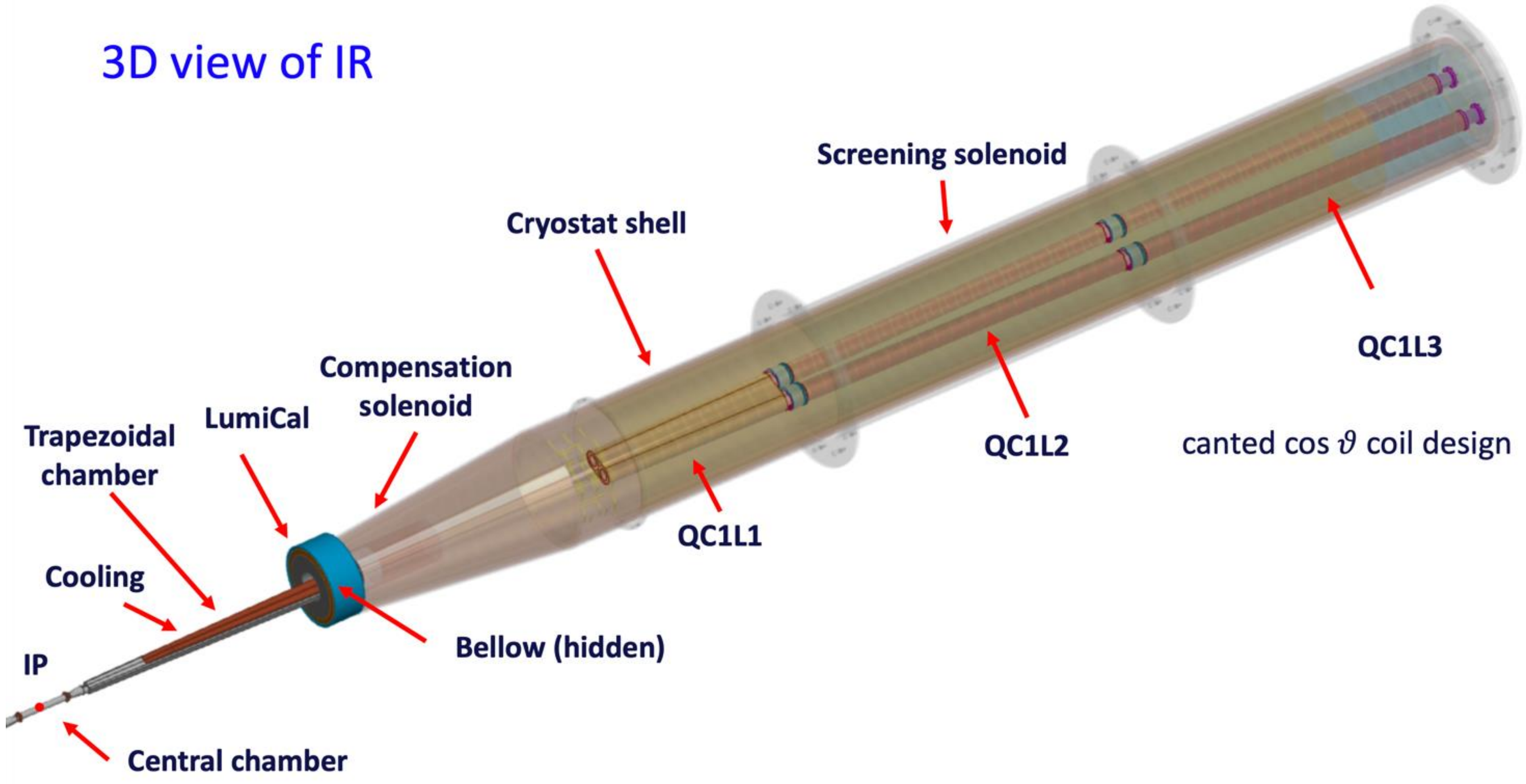
Progress on MDI

FUTURE CIRCULAR COLLIDER

FCC-EIC Joint & MDI Workshop 2022

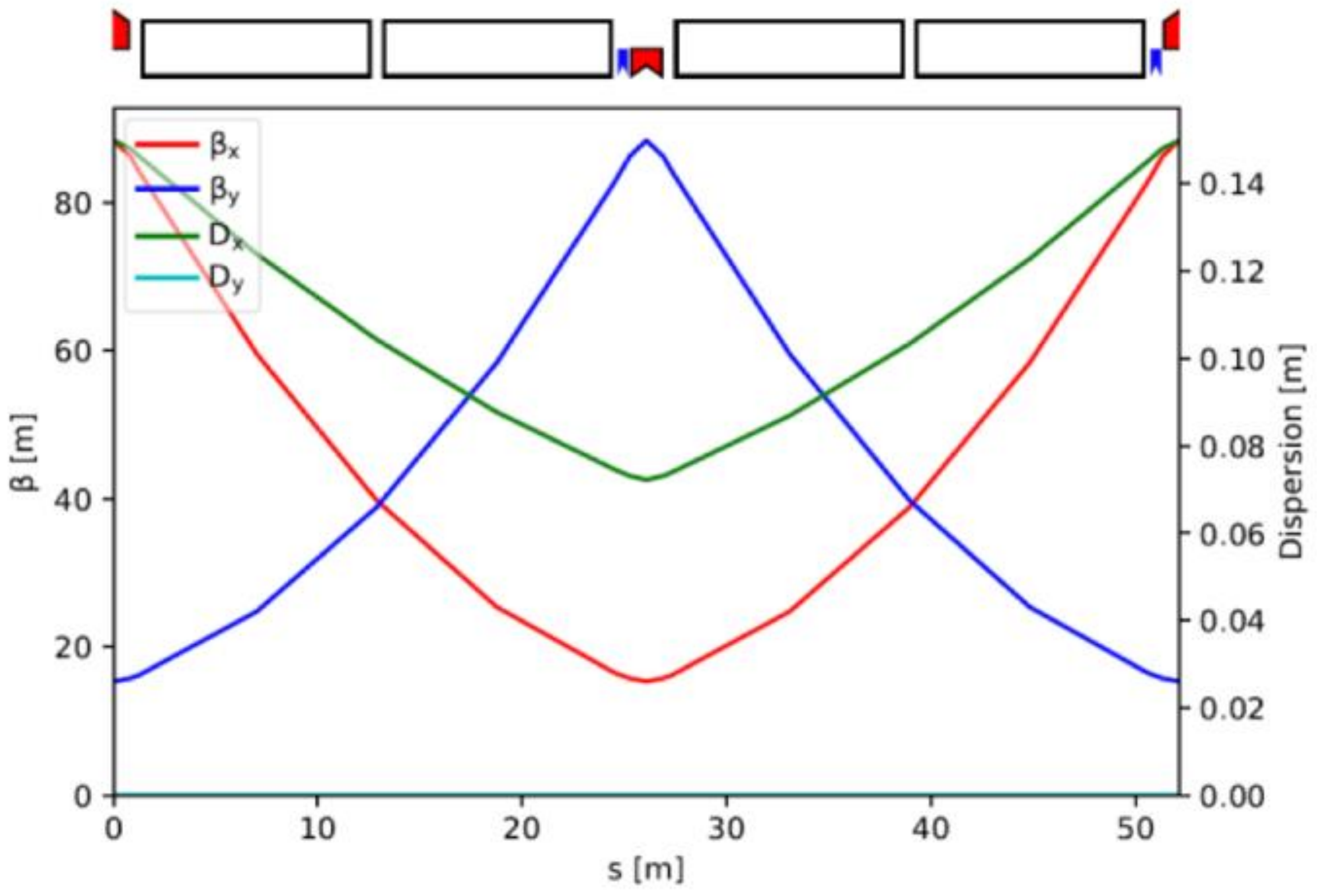
17–28 Oct 2022
CERN
Europe/Zurich timezone

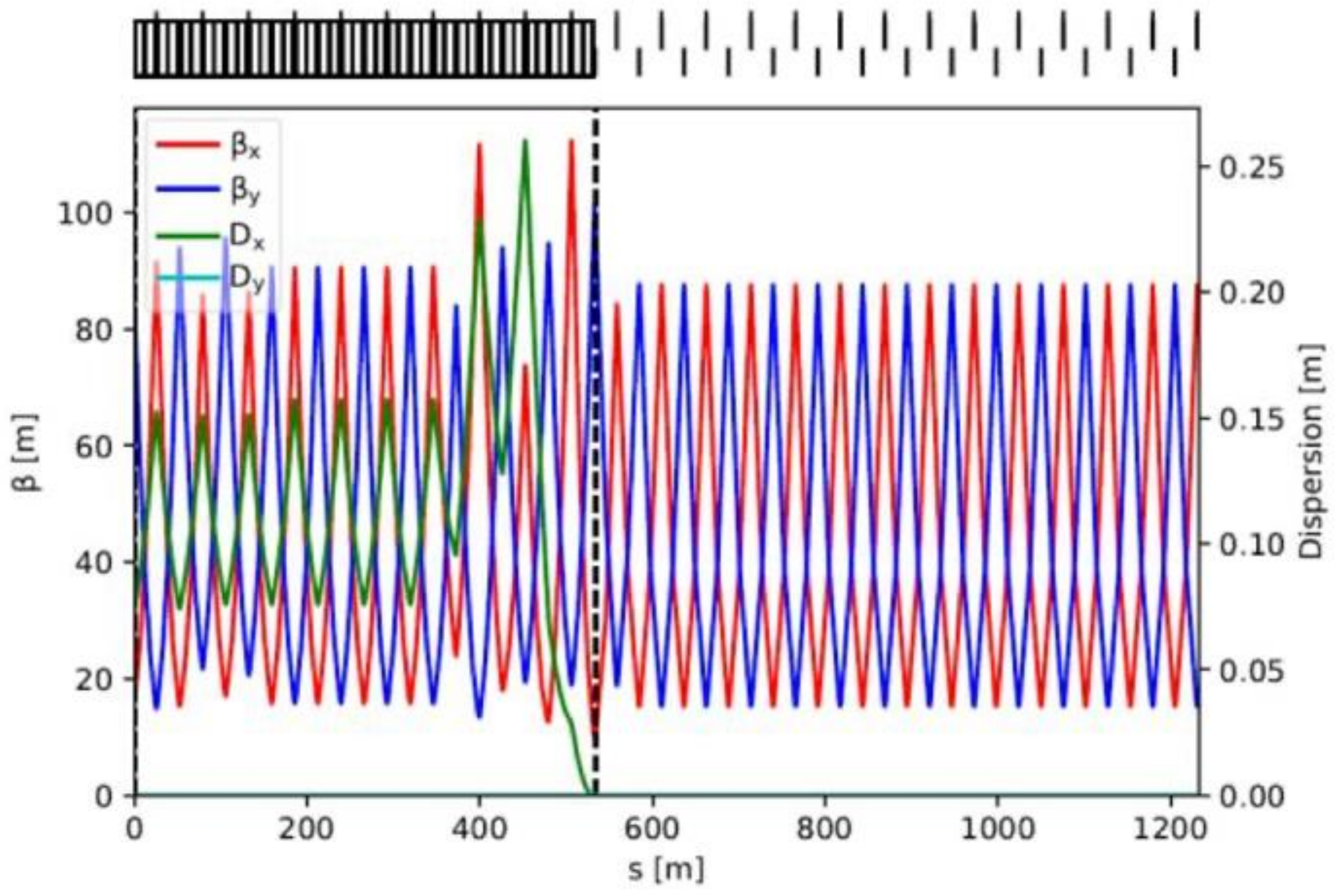
3D view of IR



Progress on Booster

- Booster design ongoing, adaptation to latest layout in place





EPOL working group active

2nd FCC EPOL Workshop September 19 - 30 2022

A. Blondel and J. Keintzel

For the FCC-ee EPOL Workshop Organization

156th FCC-ee Optics Design Meeting
And 27th FCC-IS WP 2.2 Meeting
4th August 2022

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

Program WP2 sessions

TUE

09:00 → 12:30 **WP2 - Collider design** 4/3-006 - TH Conference Roo...

Convener: Tor Raubenheimer (SLAC National Accelerator Laboratory (US))

09:00	**Optics overview** **Speaker**: Dr Katsunobu Oide (High Energy Accelerator Research Organization (JP))	30m
09:30	**Parameters & Challenges** **Speaker**: Dmitry Shatilov (Budker Institute of Nuclear Physics (RU))	30m
10:00	**Tuning status** **Speaker**: Rogelio Tomas Garcia (CERN)	30m
10:30	**Break**	30m
11:00	**IP tuning** **Speaker**: Leon Van Riesen-Haupt (EPFL - Ecole Polytechnique Federale Lausanne (CH))	30m
11:30	**BI workshop summary** **Speaker**: Thibaut Lefevre (CERN)	30m

TUE

13:00 → 17:00 **WP2 - Collider design** 4/3-006 - TH Conference Roo...

Convener: Dr Pantaleo Raimondi (SLAC National Accelerator Laboratory (US))

13:00	**Preliminary budget of alignment tolerances and time scales** **Speaker**: Tor Raubenheimer (SLAC National Accelerator Laboratory (US))	30m
13:30	**Survey and alignment options for FCC** **Speaker**: Helene Mainaud Durand (CERN)	30m
14:00	**Arc half-cell configuration project & mock-up** **Speaker**: Federico Carra (CERN)	30m
14:30	**Tunnel integration** **Speaker**: Fani Valchkova (Sofia Technical University-Unknown-Unknown)	30m
15:00	**Break**	30m
15:30	**Towards beam-beam simulations for FCC-ee** **Speaker**: Peter Kicsiny (EPFL)	30m
16:00	**Analytical Beam-Beam approach** **Speaker**: Khoi Le Nguyen Nguyen (EPFL - Ecole Polytechnique Federale Lausanne (CH))	30m
16:30	**Beam-beam simulations** **Speaker**: Dmitry Shatilov (Budker Institute of Nuclear Physics (RU))	30m

WED

09:00 → 12:00 **WP2 - Collider design** — 160/1-009 (CERN)

Convener: Michael Hofer (CERN)

- **09:00** **Impedance and collective effects** — 30m
  Speakers: Emanuela Carideo (Sapienza Universita e INFN, Roma I (IT)) , Mauro Migliorati (Sapienza Universita e INFN, Roma I (IT))
- **09:30** **VACI-suite: A Versatile code to calculate resistive wall impedance and Wakefield in arbitrary cross-sections** — 30m
  Speaker: Ali Rajabi (DESY)
- **10:00** **RF** — 30m
  Speaker: Mr Franck Peauger (CERN)
- **10:30** **Break** — 30m
- **11:00** **Collimation** — 30m
  Speaker: Andrey Abramov (CERN)
- **11:30** **Backgrounds** — 30m
  Speaker: Andrea Ciarma (CERN)

WED

13:00 → 15:00 **WP2 - Collider design** 160/1-009 (CERN)

Convener: Guy Wilkinson (University of Oxford (GB))

13:00	**MDI workshop summary** **Speaker**: Manuela Boscolo (INFN e Laboratori Nazionali di Frascati (IT))	30m
13:30	**MDI mechanical model and mockup plans** **Speaker**: Francesco Fransesini	30m
14:00	**Vibrations : evaluation of their impact** **Speakers**: Eva Montbarbon (Centre National de la Recherche Scientifique (FR)) , Mr Stanislas Garbon	30m
14:30	**Break**	30m

WED

15:00 → 16:30 **WP2 - Collider design** 160/1-009 (CERN)

Convener: Dr Tatiana Pieloni (EPF Lausanne)

15:00 **Vlasov solver for e-cloud & combined effects** 30m

Speaker: Sofia Carolina Johannesson (EPFL - Ecole Polytechnique Federale Lausanne (CH))

15:30 **Electron cloud build-up simulation studies for FCC-ee** 30m

Speaker: Luca Sabato (EPFL - Ecole Polytechnique Federale Lausanne (CH))

16:00 **Ecloud 2** 30m

Speaker: Fatih Yaman (Izmir Institute of Technology (IYTE))

16:30 → 18:00 **WP2 - Collider design**

Convener: Andrey Abramov (CERN)

16:30 **Arcs and Straight sections: beam dynamics studies and optimization** 30m

Speaker: Dr Pantaleo Raimondi (SLAC National Accelerator Laboratory (US))

17:00 **Final Focus design with local compensation of geometric and chromatic aberrations** ¶ 30m

Speaker: Dr Pantaleo Raimondi (SLAC National Accelerator Laboratory (US))

17:30 **Optic subsystems integration and general considerations** 30m

Speaker: Dr Pantaleo Raimondi (SLAC National Accelerator Laboratory (US))

THU

09:00 → 12:00 **WP2 - Collider design** 874/1-011 (CERN)

Convener: Jacqueline Keintzel (CERN)

09:00	**Booster overview** **Speakers**: Dr Antoine Chance (CEA Irfu) , Barbara Dalena (CEA-Irfu & Université Paris-Saclay (FR))	30m
09:30	**Injection & Extraction** **Speaker**: Michael Hofer (CERN)	30m
10:00	**Beam-beam & Impedance** **Speaker**: Yuan Zhang (IHEP-CAS)	30m
10:30	Break	30m
11:00	**Vacuum status** **Speaker**: Roberto Kersevan (CERN)	30m
11:30	**SR Background** **Speaker**: Kevin Daniel Joel Andre (CERN)	30m

13:00 → 15:30 **WP2 - Collider design** 874/1-011 (CERN)

Convener: Ilya Agapov (Deutsches Elektronen-Synchrotron (DE))

13:00	**EPOL Workshop summary** **Speaker**: Jacqueline Keintzel (CERN)	30m
13:30	**Beam tests at KIT/KARA** **Speaker**: Bastian Haerer	20m
13:50	**Beam tests at SuperKEKB and PETRA IV** **Speaker**: Jacqueline Keintzel (CERN)	20m
14:10	**Possible Monochromatization test at DAFNE** **Speaker**: Dr Angeles Faus-Golfe (IJClab IN2P3 CNRS-Université Paris-Saclay (FR))	10m
14:20	**Optics Matching with Arc Errors** **Speaker**: Cristobal Garcia (EPFL - Ecole Polytechnique Federale Lausanne (CH))	30m
14:50	Break	40m

THANK YOU

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