FCC Feasibility Study Status

6th FCC Physics Workshop, Kraków 23 January 2023

Michael Benedikt, Frank Zimmermann, CERN

on behalf of the FCC collaboration and FCCIS DS team

http://cern.ch/fcc

*Work supported by the **European Commission** under the **HORIZON 2020 projects EuroCirCol**, grant agreement 654305; **EASITrain,** grant agreement no. 764879; **ARIES**, grant agreement 730871, **FCCIS**, grant agreement 951754, and **E-JADE,** contract no. 645479*

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

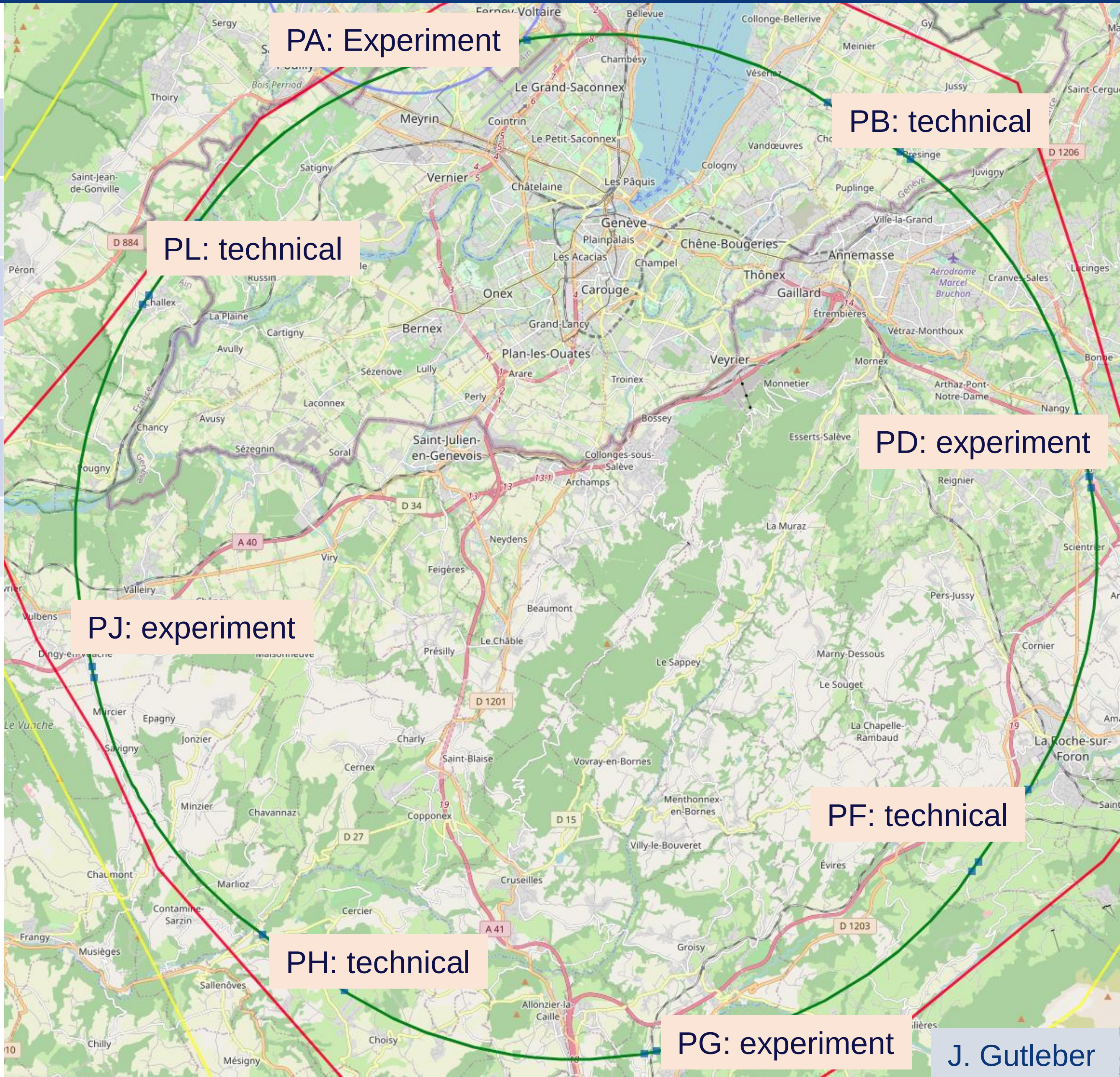
photo: J. Wenninger

optimized placement and layout

8-site baseline “PA31-3.0”

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

- 8 sites – less use of land, <40 ha instead 62 ha
- Possibility for 4 experiment sites in FCC-ee
- All sites close to road infrastructures (< 5 km of new road constructions for all sites)
- Vicinity of several sites to 400 kV grid lines
- Good road connection of PD, PF, PG, PH suggest operation pole around Annecy/LAPP
- **Exchanges with ~40 local communes in preparation**



J. Gutleber

Progress with regional activities

- CERN visits of Elus from Departments Haute Savoie, Ain and Canton Geneva
- Information meetings and exchanges with presidents and prefets of Ain and Haute Savoie to prepare regional activities
- All communes concerned by FCC trace were approached directly via information letters co-signed by Prefet de la region ARA and CERN DG for France and Conseiller d'Etat de Geneve and CERN DG for Switzerland.
- Consultations with individual communes presently ongoing.
- Technical discussions on territorial implementation, water use, excavation material reuse, etc. started with department 74 Haute Savoie.

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Preferred implementation PA31-3.0 91 km

1. **PA – Ferney Voltaire** (FR) – experimental site
2. **PB – Présinge/Choulex** (CH) – technical site
3. **PD – Nangy** (FR) – technical/experimental site
4. **PF – Etaux** (FR) – technical site
5. **PG – Charvonnex/Groisy** (FR) – experimental site
6. **PH – Cercier** (FR) – technical site
7. **PJ – Vulbens/Dingy en Vuache** (FR)

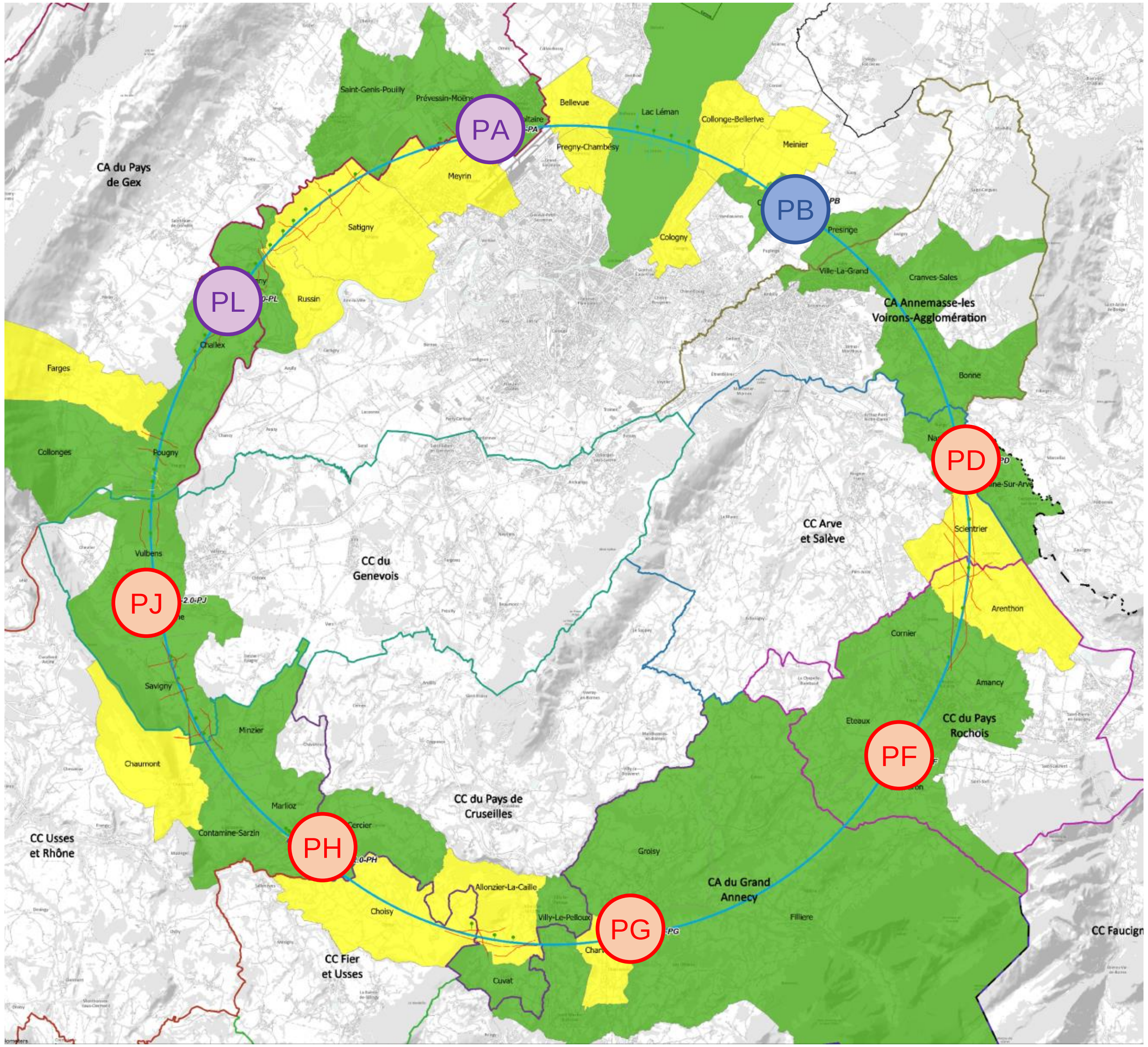
– technical/experimental site

8. **PL – Challex** (FR) – technical site

First meetings with communes concerned in France (31) and Switzerland (10)

Rencontrée

Rendez-vous proposé / programmé



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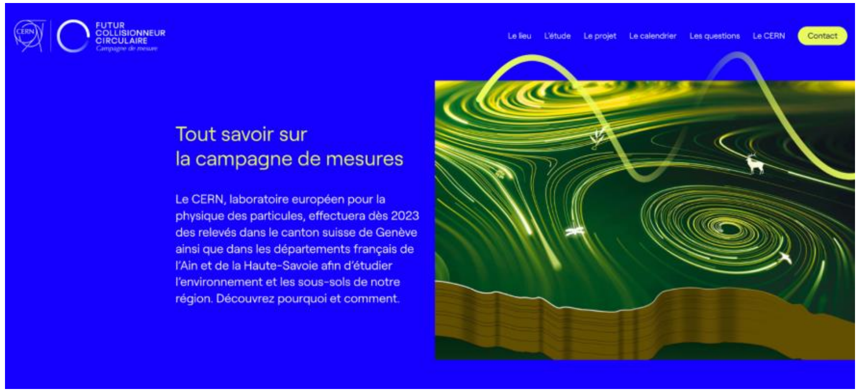
Accompanying communication material for site investigations

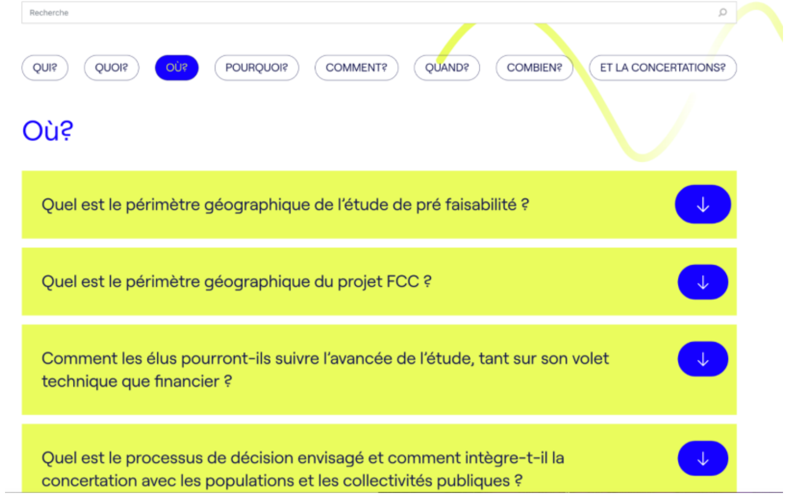
Brochure (digital & printing)

Website: fcc-faisabilite.eu



Video

Upcoming: FAQ + Calendar.



FCCIS – H2020 Mining the Future Competition

www.cern.ch/miningthefuture

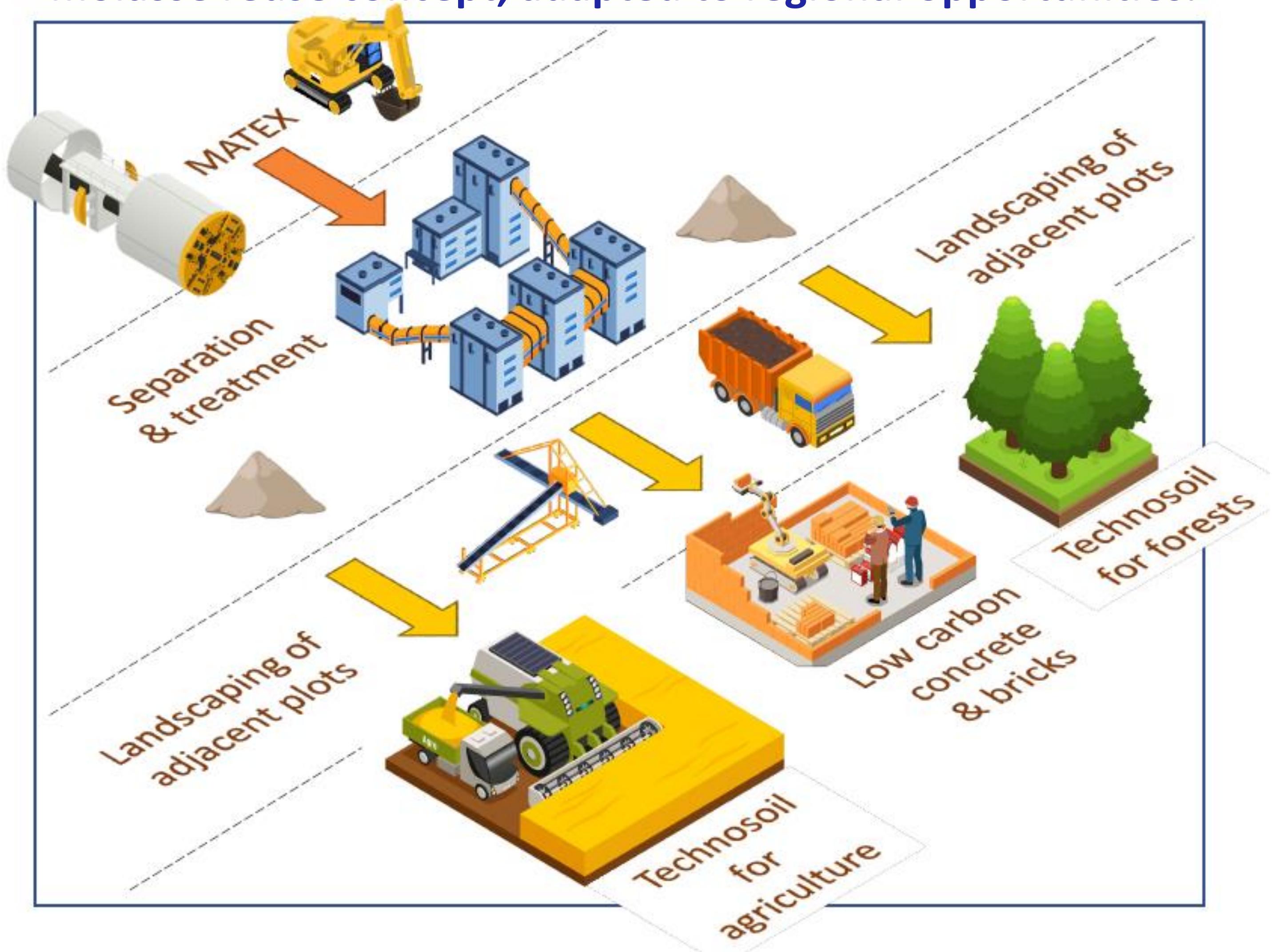
The Mining the Future contest by the FCC collaboration, CERN and Montanuniversität Leoben, with the support of the EU-funded H2020 FCCIS project identified sustainable reuse solutions for these excavated materials.

Individuals | For-profit organisations | Non-profit, academia and HE | IEIOs

Marketing campaign: >3 million people reached

FCCIS – H2020 Mining the future competition results

- **Four consortia were qualified for the second stage.**
- **All four proposals could contribute to an integrated molasse reuse concept, adapted to regional opportunities.**



- **AMBERG consortium:** In-situ characterisation (Crossbelt elemental analyzer) and preparation for use as construction material on site (spray-concrete with binder from bio-mineral materials), Production of construction elements without cement/concrete.

  BG consortium: online-analysis and preparation of Molasse for construction elements from sandstone, sabd, filing material for concrete, low-carbon concrete, terra cotta bricks, etc.

  ARCADIS consortium: usage of clay and sand materials enriched with limestone as stabiliser for production of bricks by pressurizing, mobile plants for on-site production of bricks, replacement of construction materials with high CO2 bilan during production;

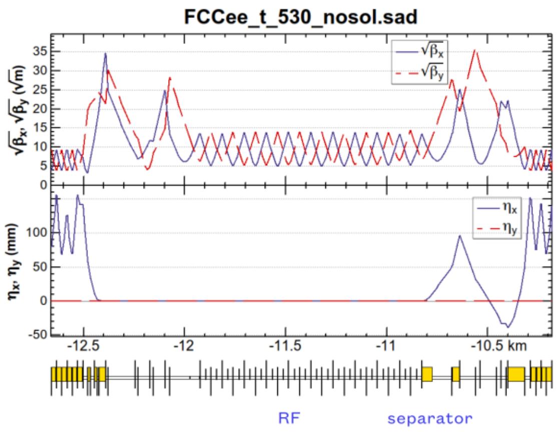
  EDAPHOS consortium: Combining mineral (Molasse) material and organic material to produce fertile soil with on-site production plants by using mikrobiology to accelerate humus creation. Fertile soil as top layer for agricultural use, recultivation.

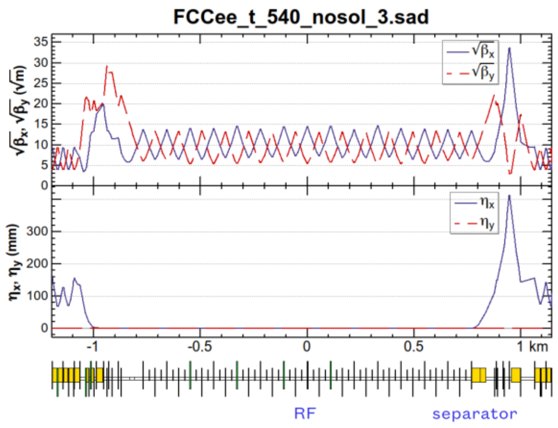
recent FCC-ee beam optics development

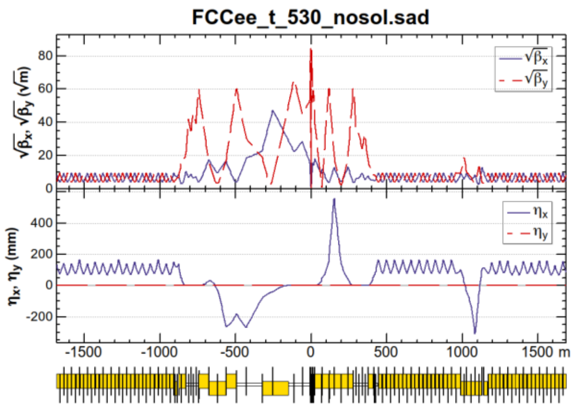
Points B, F, H & L (RF and other technical straights)

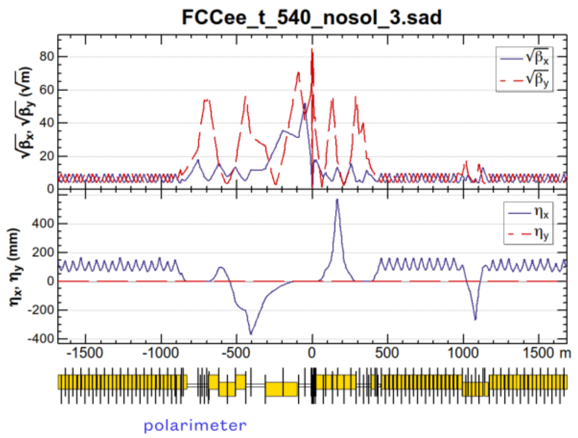
Points A, D, G & J (experimental straights)

Katsunobu Oide







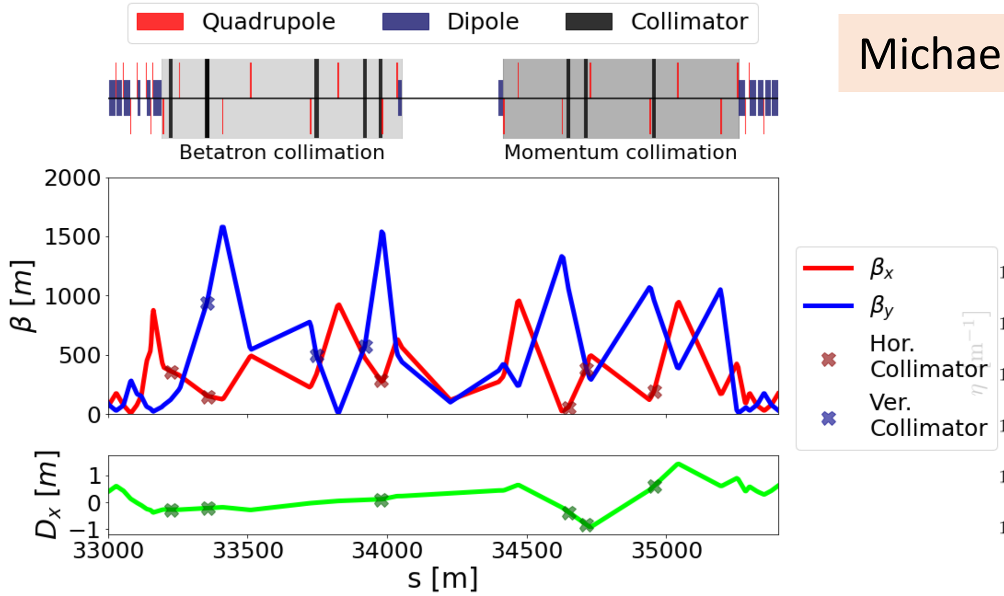


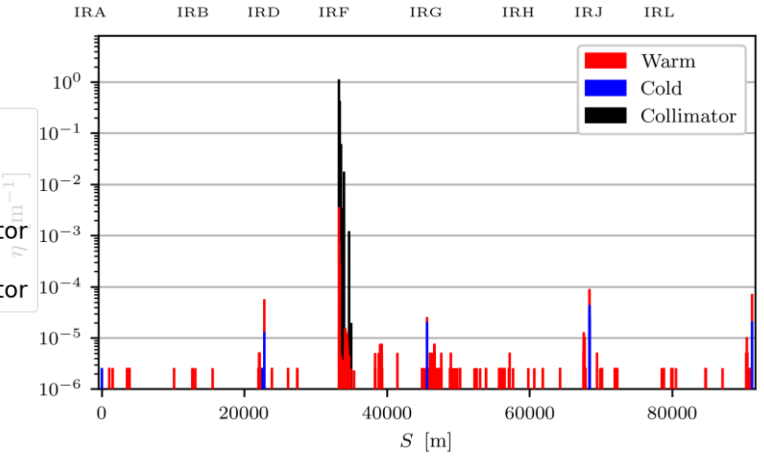
New collimation optics for 4 IPs

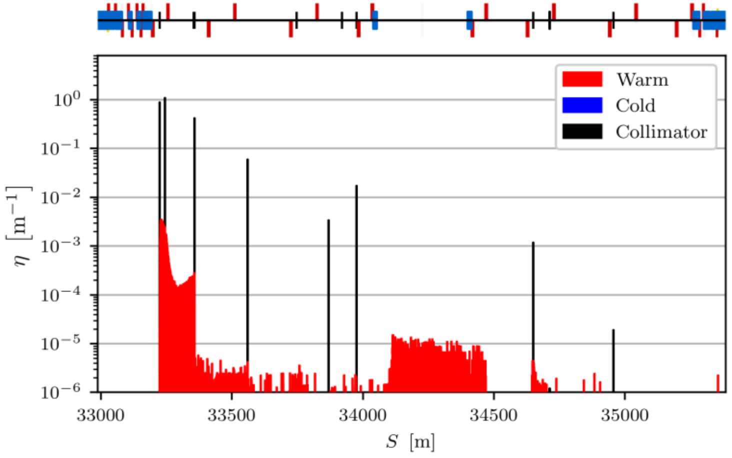
and associated loss maps (global and local)

Michael Hofer

Andrey Abramov







Review of SRF Systems Layout with Associated CE and TI Concepts

Reviewers: Sergey Belomestnykh (FNAL), Alain Chabert (SFTRF), Erk Jensen (CERN, retired), Peter Mcintosh (STFC), Andrew Parker (University of Cambridge – Chairperson), Thomas Peterson (SLAC), Laurent Tavian (CERN), Silvia Verdu Andres (BNL) Frank Zimmermann (CERN – Secretary)

- constructive feedback on general progress with RF concepts
- underlining importance of energy efficiency, incl. making use of waste heat
- full support for high-Q SRF R&D program on bulk Nb and Nb/Cu cavities
- suggestion for higher Q_0 for 800 MHz bulk Nb cavities (3E10 instead 2E10)
- support for separation of collider and booster RF in different locations
- recommendation to continues high-efficiency RF power source R&D with industrial partners to reduce overall power consumption

updated FCC-ee RF parameters, incl. 10% margin

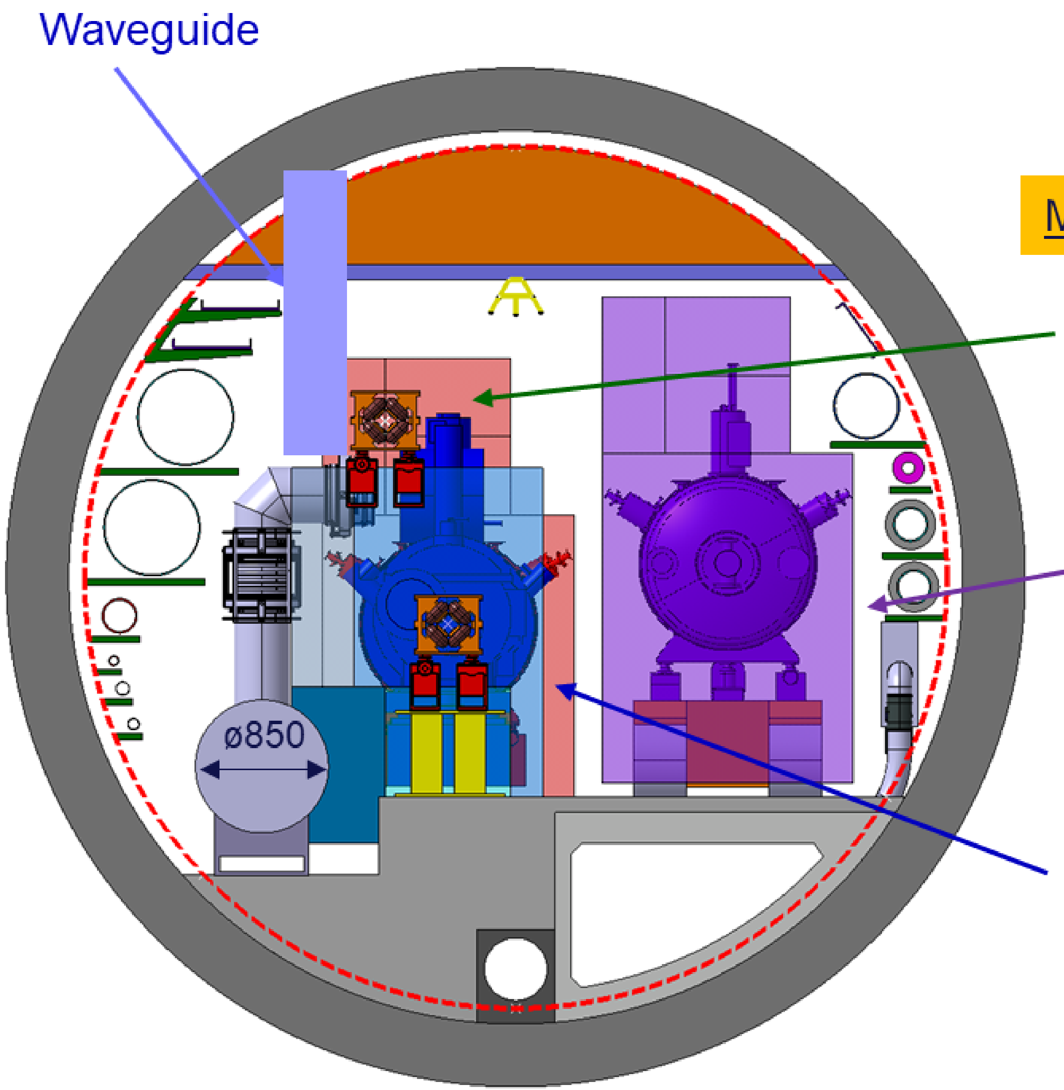
O. Brunner, F. Peauger

07-Nov-22	Test in vertical cryostat of bare cavity		Test in vertical cryostat of cavity equipped with helium tank and HOM couplers		Test in cryomodule configuration (with FPC)		Operation in the machine	
	Eacc (MV/m)	Q0	Eacc (MV/m)	Q0	Eacc (MV/m)	Q0	Eacc (MV/m)	Q0
1-cell 400 MHz	6.9	3.3E+09	6.6	3.2E+09	6.3	3.0E+09	5.7	2.7E+09
2-cell 400 MHz	13.2	3.3E+09	12.6	3.2E+09	12	3.0E+09	10.8	2.7E+09
5-cell 800 MHz	27.6	3.6E+10	26.3	3.5E+10	25	3.3E+10	**22.5**	**3.0E+10**

Total # of cryo-modules (entire FCC ee program) = 14x2+65+109+134 = 336

07-Nov-22	Z		W		H		ttbar2		
	per beam	booster	per beam	booster	2 beams	booster	2 beams	2 beams	booster
Frequency [MHz]	400	800	400	800	400	800	400	800	800
RF voltage [MV]	120	140	1050	1050	2100	2100	2100	9200	11300
Eacc [MV/m]	5.72	5.34	10.95	21.55	10.78	22.42	10.78	22.52	22.50
# cell / cav	1	5	2	5	2	5	2	5	5
Vcavity [MV]	2.14	5.00	8.20	20.19	8.08	21.00	8.08	21.10	21.08
#cells	56	140	256	260	520	500	520	2180	2680
# cavities	56	28	128	52	260	100	260	436	536
# CM	14	7	32	13	65	25	65	109	134
T operation [K]	4.5	2	4.5	2	4.5	2	4.5	2	2
dyn losses/cav [W]	19	0.4	147	6	142	6	142	43	6
stat losses/cav [W]	8	8	8	8	8	8	8	8	8
Qext	6.0E+04	2.5E+05	1.1E+06	8.3E+06	1.1E+06	8.6E+06	9.4E+06	4.2E+06	4.6E+07
Detuning [kHz]	9.777	5.606	0.472	0.131	0.096	0.025	0.031	0.028	0.005
Pcav [kW]	962	192	385	95	379	99	45	202	18
Energy [GeV]	45.6	45.6	80.0	80.0	120.0	120.0	182.5		182.5
energy loss [MV]	38.49	38.49	364.63	364.63	1845.94	1845.94	9875.14		9875.14
Beam current [A]	1.400	0.140	0.135	0.0135	0.0534	0.005	0.010	0.010	0.001

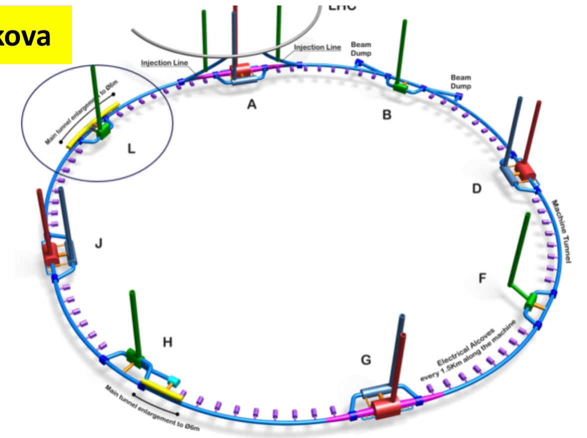
integration studies: FCC-ee RF section (ttbar), point L



Machine tunnel 5.5 m in diameter

Collider Center

F. Valchkova



- Entire collider RF in section L
- Entire booster RF in section H
- Lattice adaptatîon to optimize space for cryomodules
- Considerations on grouping cryo-modules and number of cold-warm transitions for overall optimum configuration.
- QRL Ø along 800 MHz section 0.85 m.

Review of CE and TI requirements for FCC experimental sites

Reviewers: Austin Ball (STFC), Alain Chabert (SFTRF), Peter Krizan (Jozef Stefan Institute), Rolf Lindner (CERN), Andrew Parker (University of Cambridge – Chairperson), Roberto Tenchini (INFN Sezione di Pisa), Frank Zimmermann (CERN – Secretary)

- endorses the baseline concept for the FCC experiment site underground structures of an experimental cavern with a single experimental shaft for the main detector, linked via a transfer tunnel to the service cavern, with a second shaft (cf. CMS),
- suggests detailed study of implications of the stray field from unshielded FCC-hh detector magnets and to consider alternatives with shielded magnet systems.

FCC-ee MDI developments - examples

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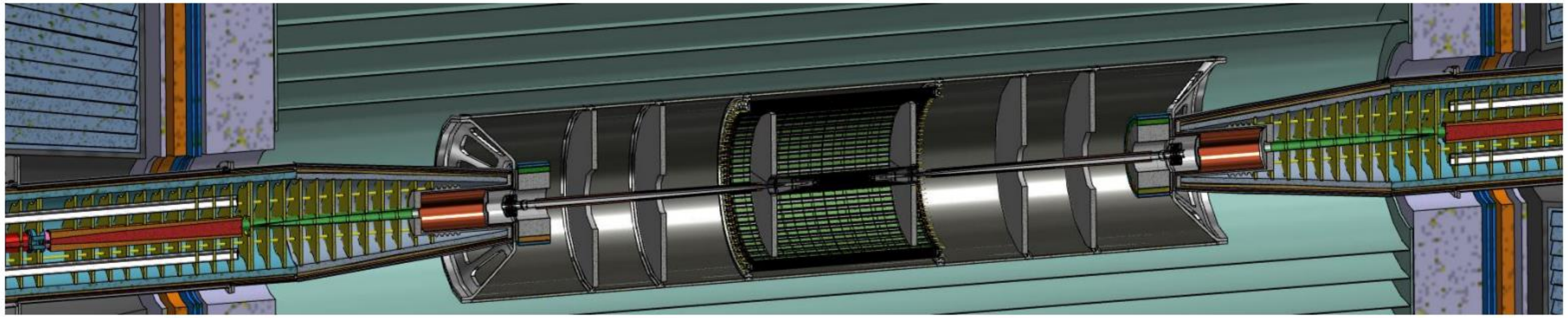
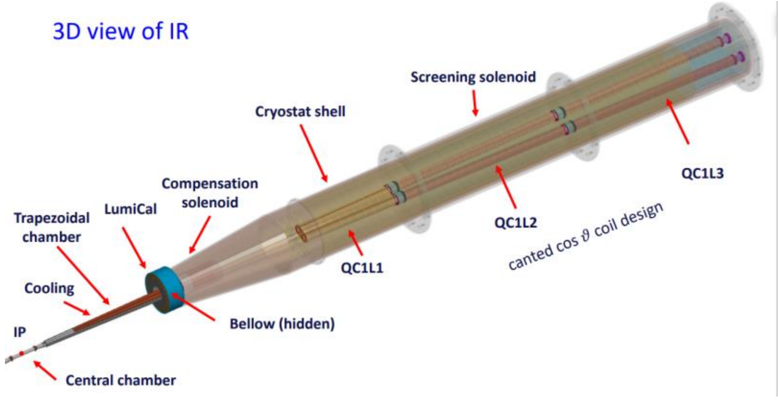
Novel outer support tube for central beam pipe and vertex detector

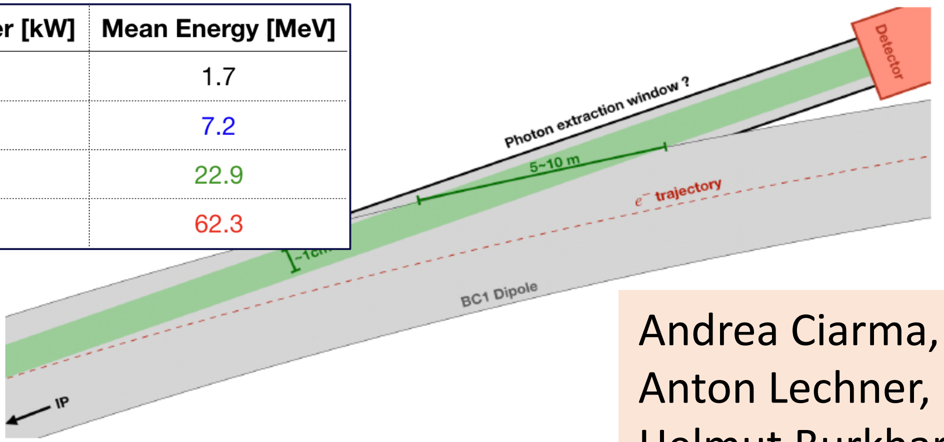
Manuela Boscolo, Fabrizio Palla, Filippo Bosi





- Inside the same volume of the support tube that holds also the LumiCal
  - Vertex detector supported by the beam pipe
  - Outer Tracker (1 barrel and 6 disks) fixed to the support tube

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

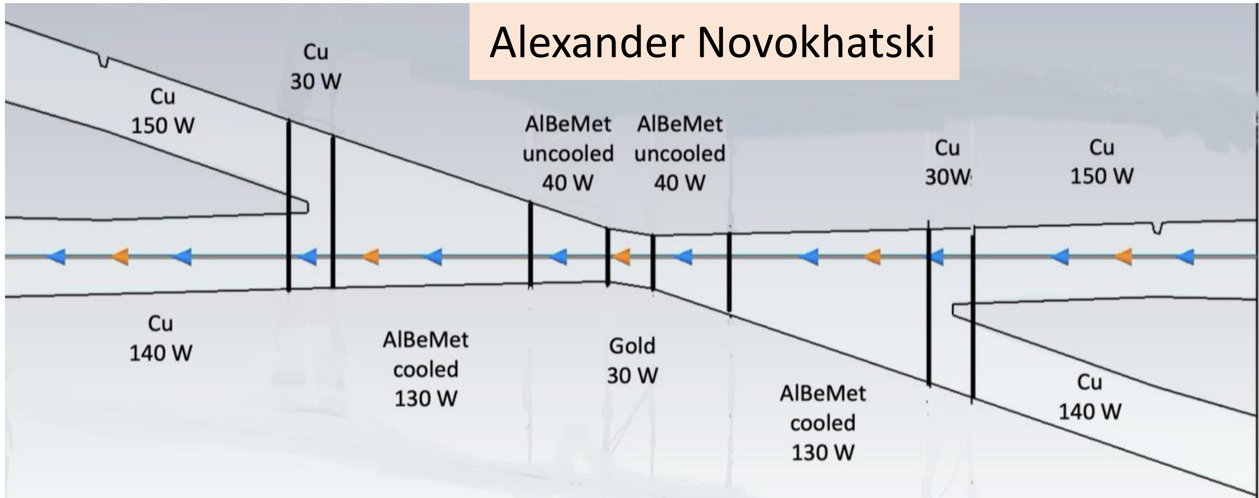


Beamstrahlung dump

Andrea Ciarma, Anton Lechner, Helmut Burkhardt, Manuela Boscolo

IR heat load distribution

Alexander Novokhatski



FCC workshops in 2nd half of 2022

eeFACT'22 – FCC-ee progress; power & performance assessment for future e^+e^-colliders, Frascati (INFN);12-16 Sep'22 – https://agenda.infn.it/event/21199/

FCC-ee energy calibration & polarization, incl. possible exp's at KIT and LNF, CERN; 19-30 Sep'22 – https://indico.cern.ch/event/1181966

ECLOUD'22 – e.g. Vlasov solver for e-cloud driven instabilities; lessons from LHC & SuperKEKB; predictions & countermeasures for FCC-ee/FCC-hh and for EIC, La Biodola (INFN); 25 Sep - 1 Oct'22 - https://agenda.infn.it/event/28336/

FCC-ee MDI workshop – including IR mock-up at LNF; CERN 17-28 Oct'22 https://indico.cern.ch/event/1186798/

FCC-ee beam instrumentation workshop; 21-22 Nov'22 https://indico.cern.ch/event/1209598/

First joint FCC - France&Italy workshop on Higgs, Top, EW, HF and SM physics; Lyon, 21-23 November'22, https://indico.in2p3.fr/event/27968/

FCCIS workshop 2022 including **first meeting of FCC FS SAC**; 5-9 Dec'22 - https://indico.cern.ch/event/1203316/

Electron Ion Collider (EIC)

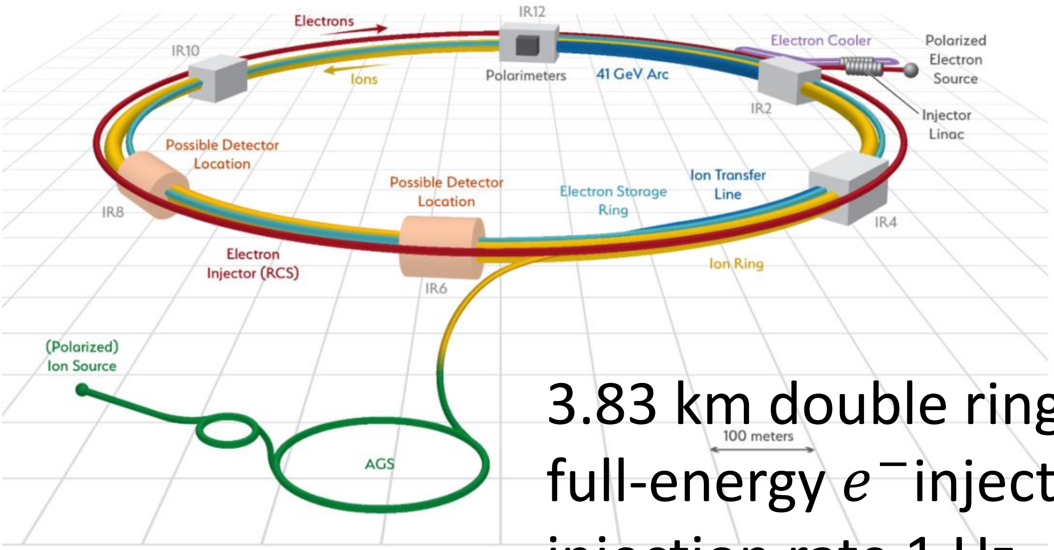
US EIC Electron Storage Ring similar to, but more challenging than, FCC-ee

beam parameters almost identical, but twice the maximum electron beam current, or half the bunch spacing, and lower beam energy

>10 areas of common interest identified by the FCC and EIC design teams, addressed through joint EIC-FCC working groups, still evolving

EIC will start beam operation about a decade prior to FCC-ee

The EIC will provide another invaluable opportunity to train next generation of accelerator physicists on an operating collider, to test hardware prototypes, beam control schemes, etc.



3.83 km double ring, full-energy e^- injection, injection rate 1 Hz, every 2 min into same bucket

	EIC	FCC-ee-Z
Beam energy [GeV]	10 (18)	45.6 (80)
Bunch population [10^{11}]	1.7	1.7
Bunch spacing [ns]	10	15, 17.5 or 20
Beam current [A]	2.5 (0.27)	1.39
SR power / beam /meter [W/m]	7000	600
Critical photon energy [keV]	9 (54)	19 (100)

Snowmass Highlights related to FCC

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Snowmass 2021

S&T Collider Science

FNAL, Lia Merminga

Vision: Fermilab continues to be the leading U.S. center for CMS and second leading center in the world after our partner CERN

CERN is our European sister laboratory and our strong partner in many areas

Major decadal goals

- Maximize science from LHC Runs 2 and 3 data – ROC is back in Operations!
- Execute HL-LHC AUP and CMS Detector Upgrade Projects
- Advance R&D towards FCC @CERN

	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32
LHC	*Operations*										
HL-LHC AUP	*Construction*										
HL-LHC CMS	*Construction*								2042		
FCC @CERN	*R&D / Prototyping*										
Future facility @ FNAL		*Physics studies / Pre-conceptual designs*									

Accelerator Frontier "Message"

Steve Gourlay et al.

Snowmass 2021

On Colliders: We need an integrated future collider R&D program to engage in the design and to coordinate the development of the next generation collider projects:

- To address in an integrated fashion the technical challenges of promising future collider concepts that are **not** covered by the existing *General Accelerator R&D* (GARD) program.
- To enable synergistic U.S. engagement in ongoing global efforts (e.g., FCC, ILC, IMCC)
- To develop collider concepts and proposals for options feasible to be hosted in the U.S. (e.g., CCC, HELEN, Muon Collider, etc)

Circular Electron Positron Collider

Xinchou Lou, IHEP

- **CEPC is intended to be an international project** – growing HEP community & support for basic sciences in China
- CDR completed in 2018, TDR scheduled for 2023, engineering design study soon …
- Extensive R&D underway, construction of light sources providing training and validation
- Very tight schedule matched to China's 5-year plan scheme; proposed to begin construction in 15th 5-YP (~2027)
- CEPC being evaluated in two tracks: (1) **China initialized large science projects**, (2) **CAS particle physics facility**
- If CEPC is approved and realized, **it may be a Higgs factory providing data in the 2030s**
- If FCC-ee is approved earlier than CEPC, the group will join force with FCC and contribute in a very significant way

Opportunities for synergy and cooperation between various Higgs factories:

Mid-Term Review & Cost Review, autumn ‘23

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

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

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

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

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

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

Organisation and financing:
- Overall cost estimate & spending profile for stage 1 project

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


FCC
WEEK
2023
5 – 9 June
STAY
TUNED

FUTURE CIRCULAR COLLIDER

FCC FS status summary

Following 2020 European Strategy Update, **organisation structure and major milestones & deliverables for the FCC Feasibility Study (FCC FS) approved by CERN Council in June 2021.** Entire **FCC government structure (**members of **SC, CB, SAC, CG) established (summer 2022).**

Main activities: **developing & confirming concrete implementation scenario,** in collaboration **with host state authorities**, including **environmental impact analysis**, and accompanied by **machine optimisation, physics studies and technology R&D** - **via global collaboration,** supported by **EC H2020 Design Study FCCIS and Swiss CHART. Goal: demonstrate feasibility by 2025/26**

Next milestone is the mid-term review, autumn 2023.

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

Spare slides

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Stage 1: updated parameters

K. Oide, D. Shatilov,

Parameter [4 IPs, 91.2 km, T_{rev}=0.3 ms]	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45	80	120	182.5
beam current [mA]	1280	135	26.7	5.0
number bunches/beam	10000	880	248	36
bunch intensity [10^{11}]	2.43	2.91	2.04	2.64
SR energy loss / turn [GeV]	0.0391	0.37	1.869	10.0
total RF voltage 400/800 MHz [GV]	0.120/0	1.0/0	2.08/0	4.0/7.25
long. damping time [turns]	1170	216	64.5	18.5
horizontal beta* [m]	0.1	0.2	0.3	1
vertical beta* [mm]	0.8	1	1	1.6
horizontal geometric emittance [nm]	0.71	2.17	0.64	1.49
vertical geom. emittance [pm]	1.42	4.34	1.29	2.98
horizontal rms IP spot size [μm]	8	21	14	39
vertical rms IP spot size [nm]	34	66	36	69
beam-beam parameter ξ_x / ξ_y	0.004/ .159	0.011/0.111	0.0187/0.129	0.096/0.138
rms bunch length with SR / BS [mm]	4.38 / 14.5	3.55 / 8.01	3.34 / 6.0	2.02 / 2.95
luminosity per IP [10^{34} $cm^{-2}s^{-1}$]	182	19.4	7.3	1.33
total integrated luminosity / year [ab^{-1}/yr]	87	9.3	3.5	0.65
beam lifetime rad Bhabha + BS [min]	19	18	6	9

Stage 2: FCC-hh (pp) collider parameters

parameter	FCC-hh		HL-LHC	LHC
collision energy cms [TeV]	100		14	14
dipole field [T]	~17 (~16 comb.function)		8.33	8.33
circumference [km]	91.2		26.7	26.7
beam current [A]	0.5		1.1	0.58
bunch intensity [10^{11}]	1	1	2.2	1.15
bunch spacing [ns]	25	25	25	25
synchr. rad. power / ring [kW]	2700		7.3	3.6
SR power / length [W/m/ap.]	32.1		0.33	0.17
long. emit. damping time [h]	0.45		12.9	12.9
beta* [m]	1.1	0.3	0.15 (min.)	0.55
normalized emittance [μm]	2.2		2.5	3.75
peak luminosity [10^{34} cm^{-2}s^{-1}]	5	30	5 (lev.)	1
events/bunch crossing	170	1000	132	27
stored energy/beam [GJ]	7.8		0.7	0.36