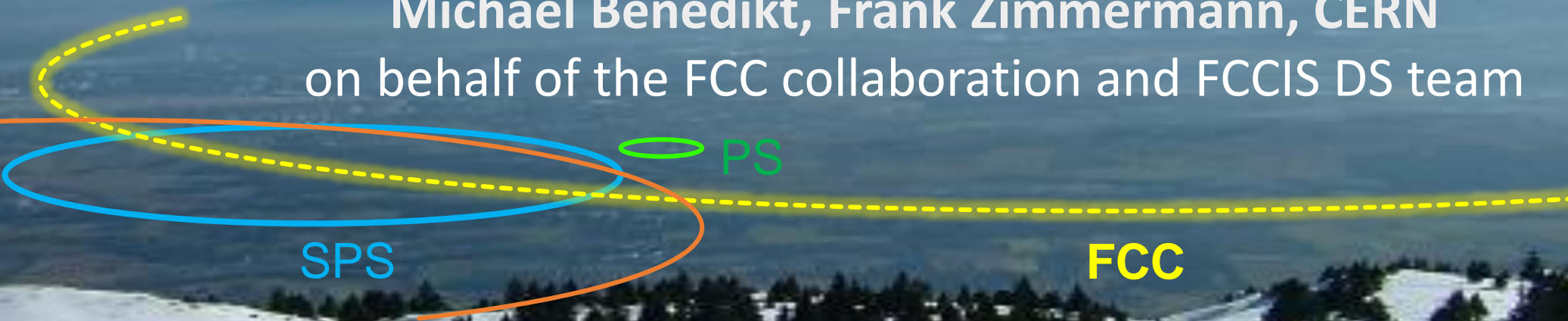


FCC Feasibility Study Status

6th FCC Physics Workshop,
Kraków 23 January 2023

Michael Benedikt, Frank Zimmermann, CERN
on behalf of the FCC collaboration and FCCIS DS team

LHC



SPS

PS

FCC



FUTURE
CIRCULAR
COLLIDER
Innovation Study



<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

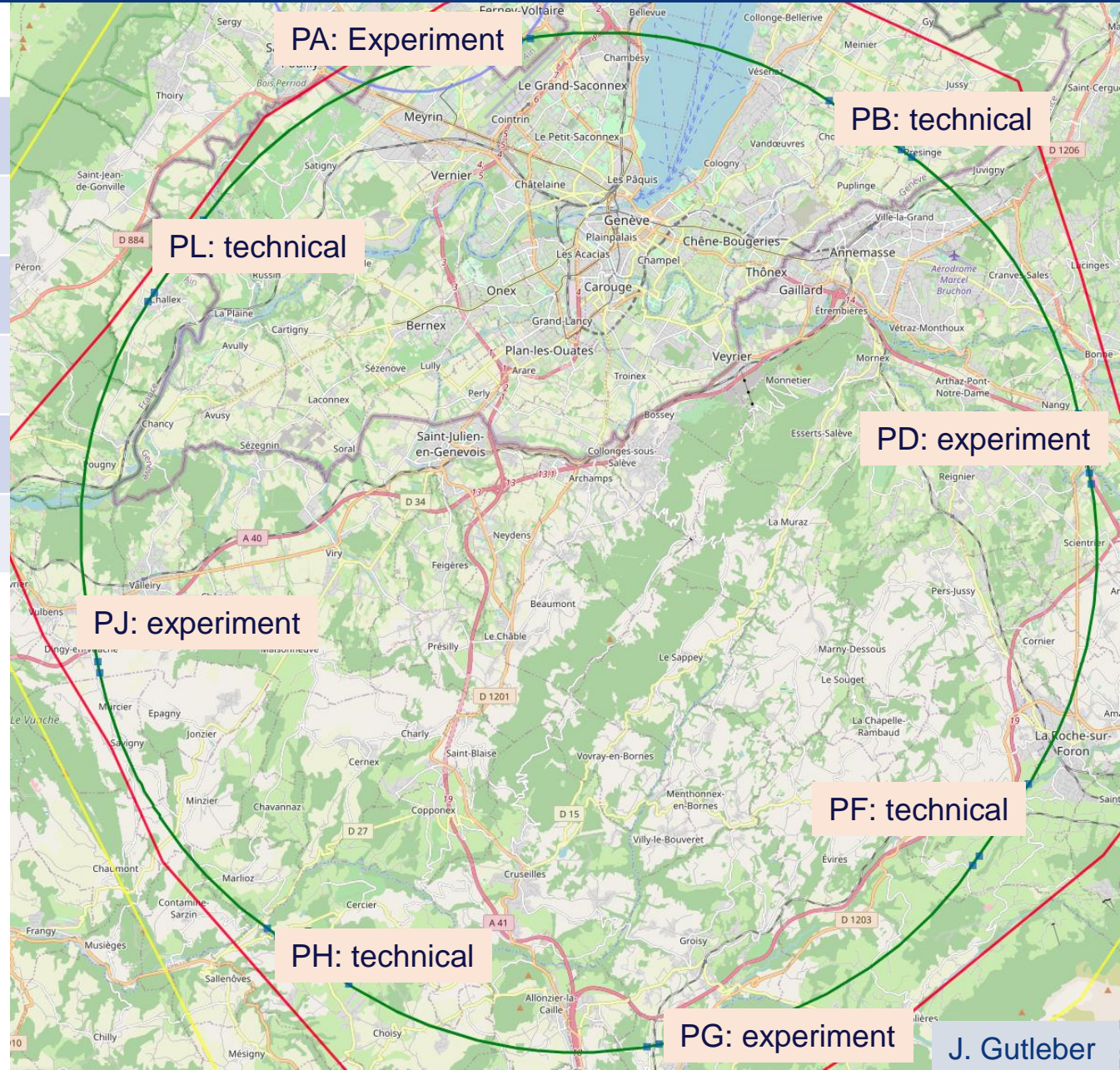
Horizon 2020
European Union Funding
for Research & Innovation

photo: J. Wenninger

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**



Progress with regional activities

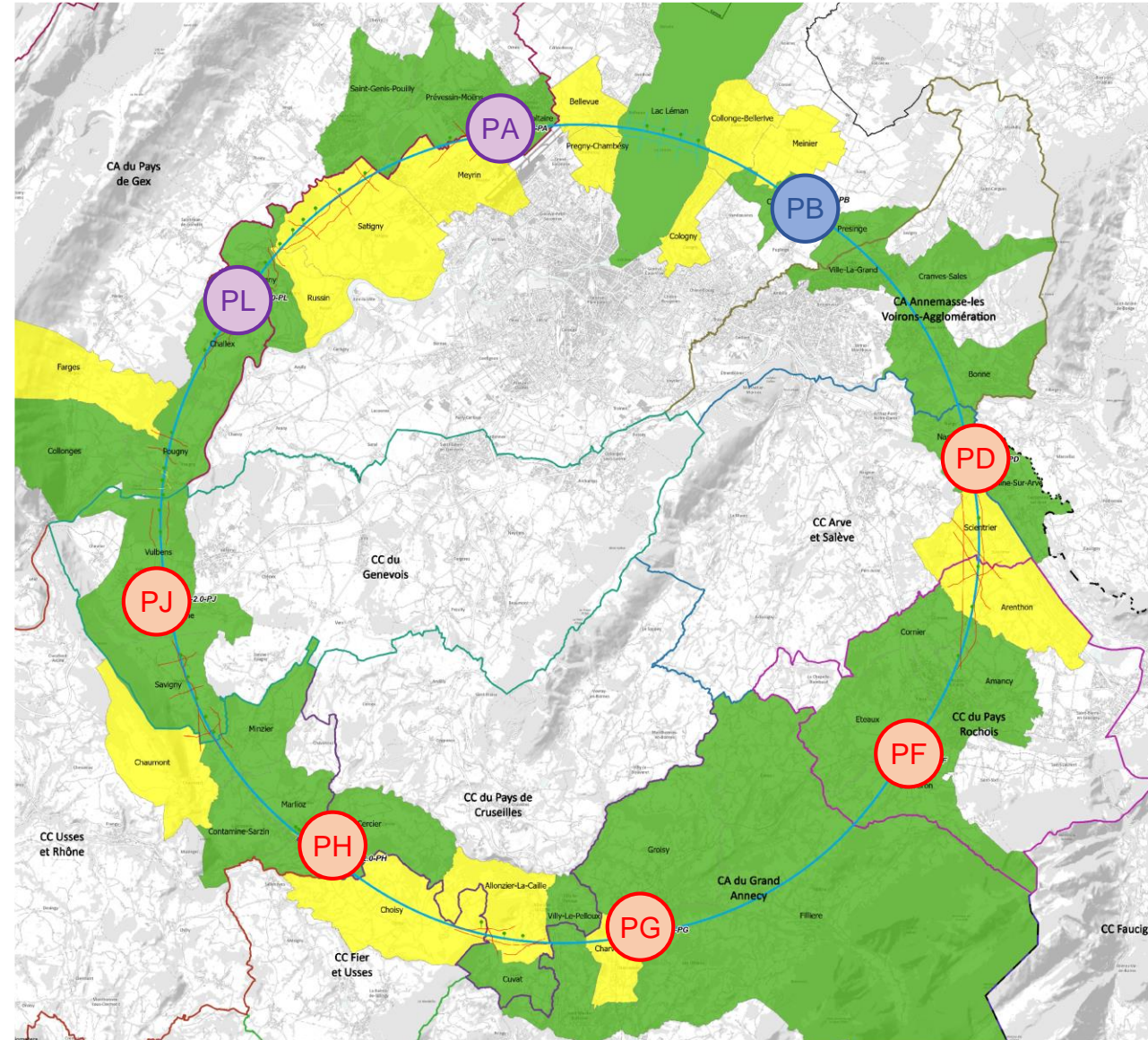
- CERN visits of Elus from Departments Haute Savoie, Ain and Canton Geneva
- Information meetings and exchanges with presidents and prefets of Ain and Haute Savoie to prepare regional activities
- All communes concerned by FCC trace were approached directly via information letters co-signed by Prefet 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.

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



Brochure (digital & printing)

QUAND SERONS-NOUS PRÈS DE CHEZ VOUS ?
Un calendrier prévisionnel est consultable sur le site web www.fcc-faisabilite.eu. Il est régulièrement mis à jour en fonction de la progression effective du travail sur le terrain ou des conditions météorologiques qui influencent notre capacité à procéder aux relevés.

AVEZ-VOUS DES QUESTIONS ?
Nous répondons volontiers à vos questions tout au long de cette étude de mesure. N'hésitez pas à nous contacter pour mieux comprendre la nature de nos interventions ou nous faire part de vos observations.

Le FCC s'inscrirait dans un territoire en pleine concertation avec l'ensemble de ses habitants. L'étude en cours est une phase permettant d'imaginer concrètement son implantation géographique.

info@fcc-faisabilite.eu www.fcc-faisabilite.eu

Étude d'une nouvelle génération d'accélérateur circulaire souterrain à l'horizon 2040

CAMPAGNE DE MESURE DANS NOTRE RÉGION
Le CERN, Laboratoire européen pour la physique des particules, effectuera dès 2023 des relevés dans le canton suisse de Genève ainsi que dans les départements français de l'Ain et de la Haute-Savoie afin d'étudier l'environnement et les sous-sols de notre région. Découvrez pourquoi et comment.

Étude d'une nouvelle génération d'accélérateur circulaire souterrain à l'horizon 2040

Website: fcc-faisabilite.eu

Le lieu L'étude Le projet Le calendrier Les questions Le CERN Contact

Tout savoir sur la campagne de mesures

Le CERN, laboratoire européen pour la physique des particules, effectuera dès 2023 des relevés dans le canton suisse de Genève ainsi que dans les départements français de l'Ain et de la Haute-Savoie afin d'étudier l'environnement et les sous-sols de notre région. Découvrez pourquoi et comment.

Video

Des équipes du CERN vont parcourir le canton de Genève

Upcoming: FAQ + Calendar.

POURQUOI CONDUIRE CES ÉTUDES ?
À ce stade de lancement de nos pré-études portant sur la possible implantation d'un accélérateur de particules souterrain, le CERN a besoin de recueillir et compiler des données de natures géographiques, géologiques et environnementales.

MIEUX CONNAÎTRE LA SURFACE ET LE SOUS-SOL
Les études de terrain et de l'environnement permettront de cartographier parfaitement les sols et les sous-sols en des points ciblés.

Étude vise à répertorier et inventorier la nature et la topographie des surfaces, la biodiversité des milieux, les zones urbanisées et leurs architectures, des naturalistes, des ingénieurs du sol et du sous-sol, munis par exemple de sondes et d'appareils photo.

Aussi, vous pourriez fort bien croiser près de chez vous, des géologues, des environnementalistes, des naturalistes, des ingénieurs du sol et du sous-sol, munis par exemple de sondes et d'appareils photo.

Trois domaines clés cartographiés

- La biodiversité des milieux** afin que les axes du tunnel de l'installation soient les moins perturbés et perturbants pour les espèces de faune et flore présentes. Il s'agit également d'étudier la création de zones protégées ou restaurées autour des axes de surface.
- Les caractéristiques des localités** qui accueillent des axes de tunnel géométriquement envisagés afin de proposer la vie communautaire, l'identité architecturale et l'activité économique.
- La nature des strates géologiques** en se penchant de haute précision du tunnel circulaire afin de connaître la composition fine de leur épaississement, de leur stabilité et de la présence éventuelle de failles. La composition des couches sera également étudiée afin d'anticiper une éventuelle déstabilisation due aux matériaux excavés.

Les moyens utilisés

2023 - Techniques classiques de mesure avec des relevés multiples et approfondis, des cartographes, des inventaristes de la faune et de la flore, des analyses de'eau, de l'air, de l'hydrologie ainsi que de la pollution sonore et lumineuse.

2024 - Techniques innovatrices de cartographie du sous-sol au moyen de données géométriques et géophysiques. Elles permettront d'obtenir une image des couches géologiques sans nécessiter de forages.

M-2024 - Forages exploratoires de petite taille et de courte durée à l'usage des données géométriques et géophysiques sur la stabilité des couches de sol, afin d'obtenir la topographie des matériaux du sous-sol, dans des zones qui recroiseront les axes particuliers pour l'ouvrage souterrain.

Recherche

QUI? QUOI? OÙ? POURQUOI? COMMENT? QUAND? COMBIEN? ET LA CONCERTATIONS?

Où?

Quel est le périmètre géographique de l'étude de pré faisabilité ?

Quel est le périmètre géographique du projet FCC ?

Comment les élus pourront-ils suivre l'avancée de l'étude, tant sur son volet technique que financier ?

Quel est le processus de décision envisagé et comment intègre-t-il la concertation avec les populations et les collectivités publiques ?



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

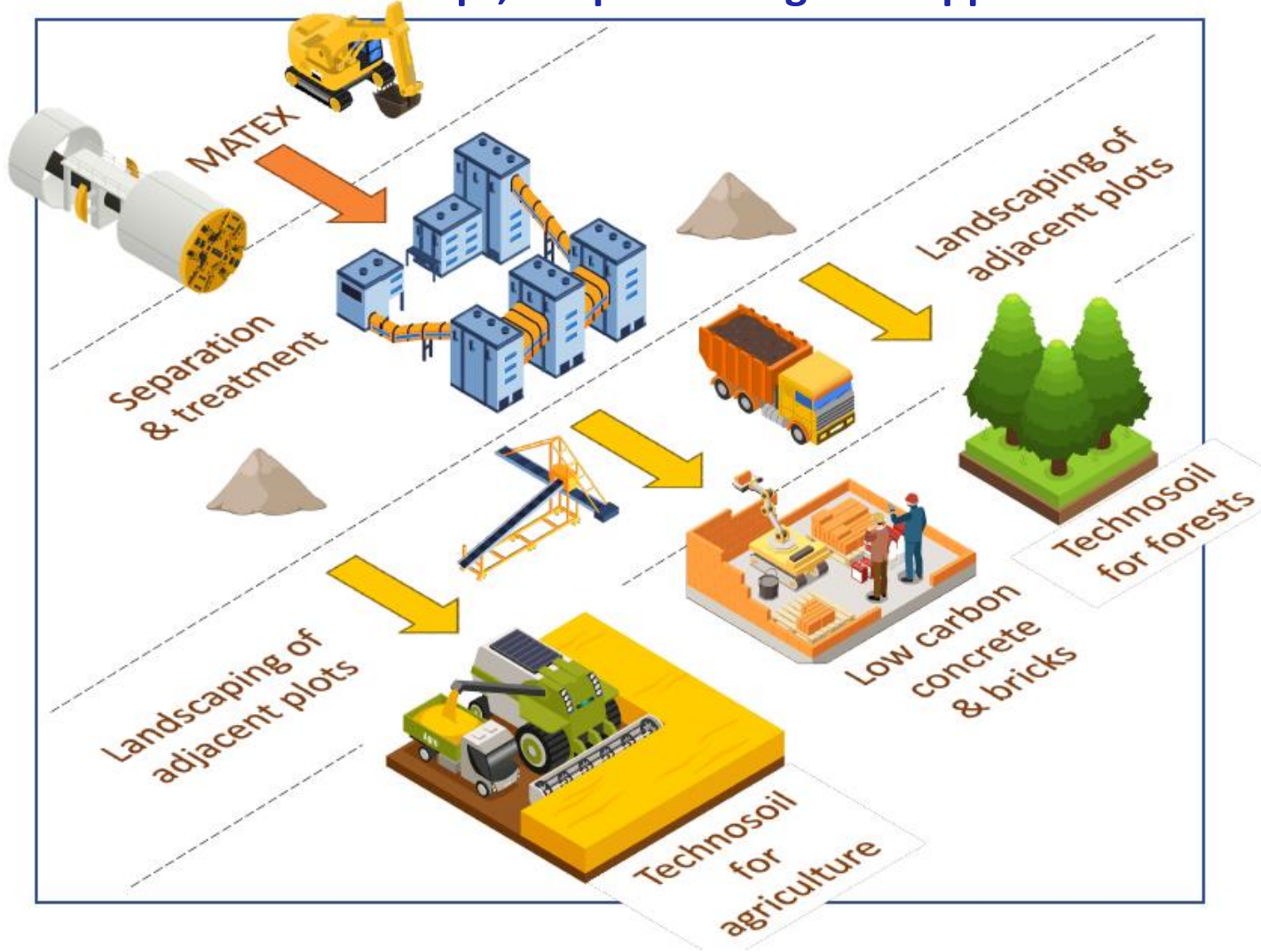


Marketing campaign: >3 million people reached

Audience reach	Total reach	3.3M	Total on Facebook	992.6K	Total on Twitter	2.3M	Total on LinkedIn	20.4K
	Monthly reach	67.8K	On Facebook	0.3	Monthly on Twitter	67.8K	Monthly on LinkedIn	0.0
Engagements	Total engagement	168.0K	Total on Facebook	121.7K	Total on Twitter	51.8K	Total on LinkedIn	21.4K
	Monthly engagement	737.0	Total on Facebook	0.0	Monthly on Twitter	737.0	Monthly on LinkedIn	0.0
Website visits	Total page views	7.4K	Total visitors	4K				
	Monthly page views	649.0	Monthly visitors	315				
Interest in applying	Total downloads	253	Total clicks to Zenodo	61	Total clicks to apply	134		
	Monthly downloads	253	Monthly clicks to Zenodo	61	Monthly clicks to apply	134		

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.

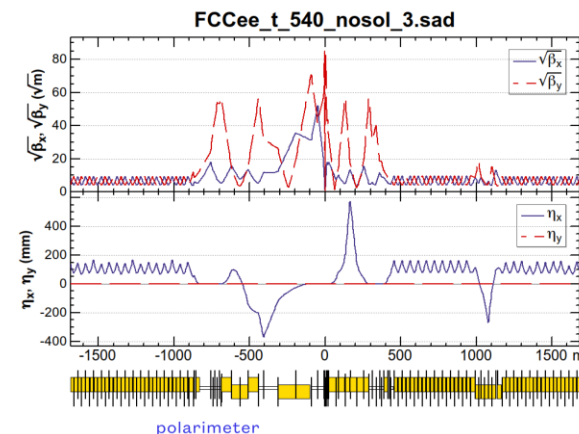
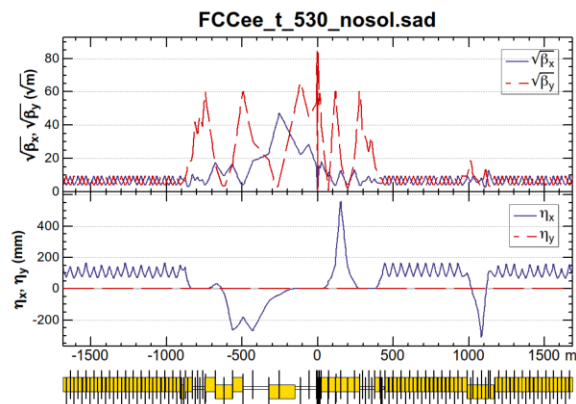
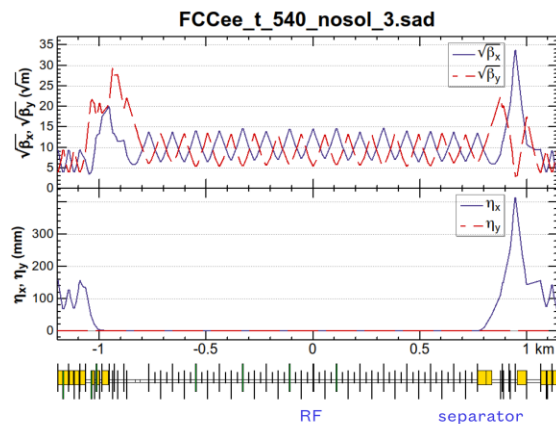
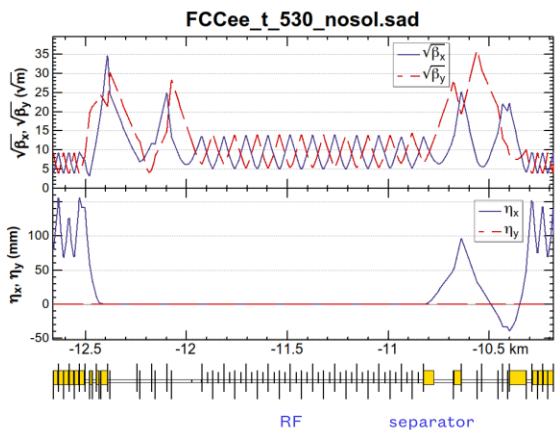


- **AMBERG consortium:** In-situ characterisation (Crossbelt elemental analyzer) and preparation for use as construction material on site (spray-concrete with binder from bio-mineral materials), Production of construction elements without cement/concrete.
- **BG consortium:** online-analysis and preparation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

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

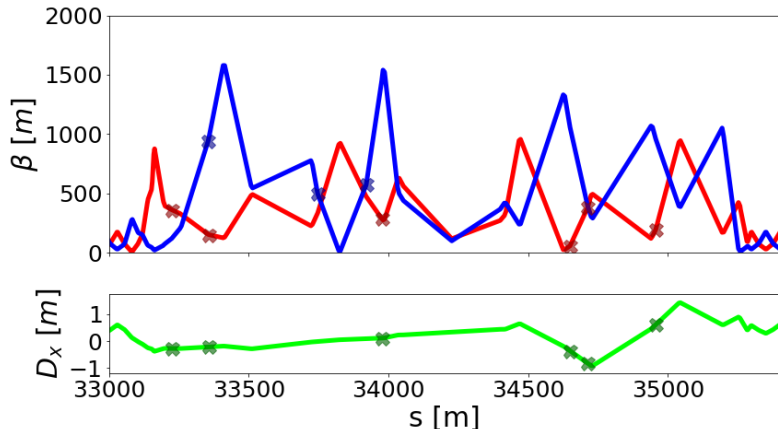
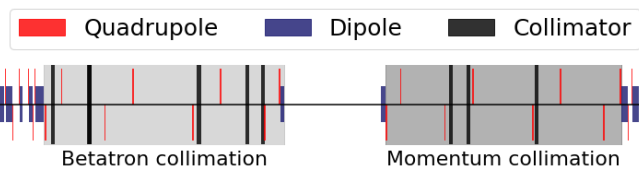
Points A, D, G & J (experimental straights)

Katsunobu Oide

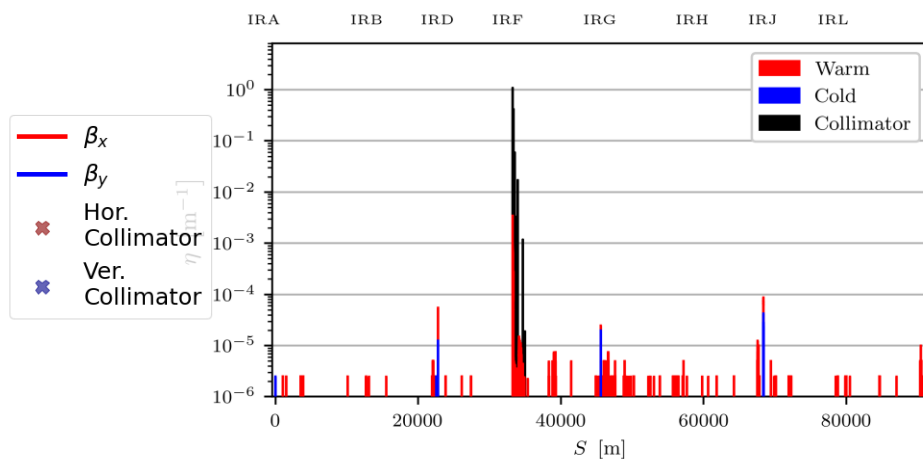


New collimation optics for 4 IPs

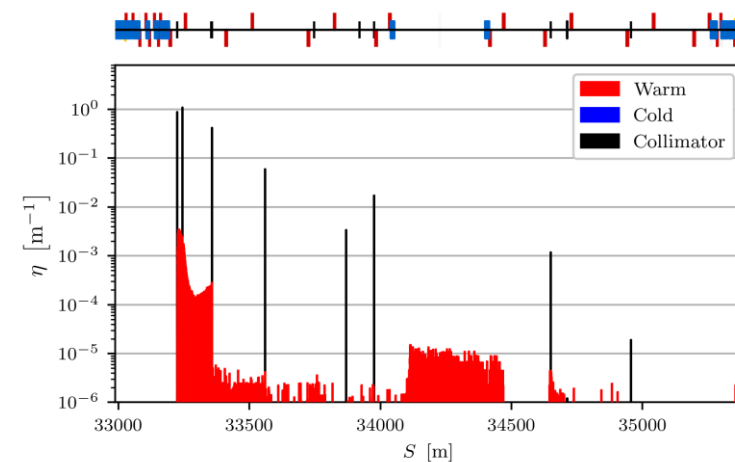
and associated loss maps (global and local)



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)

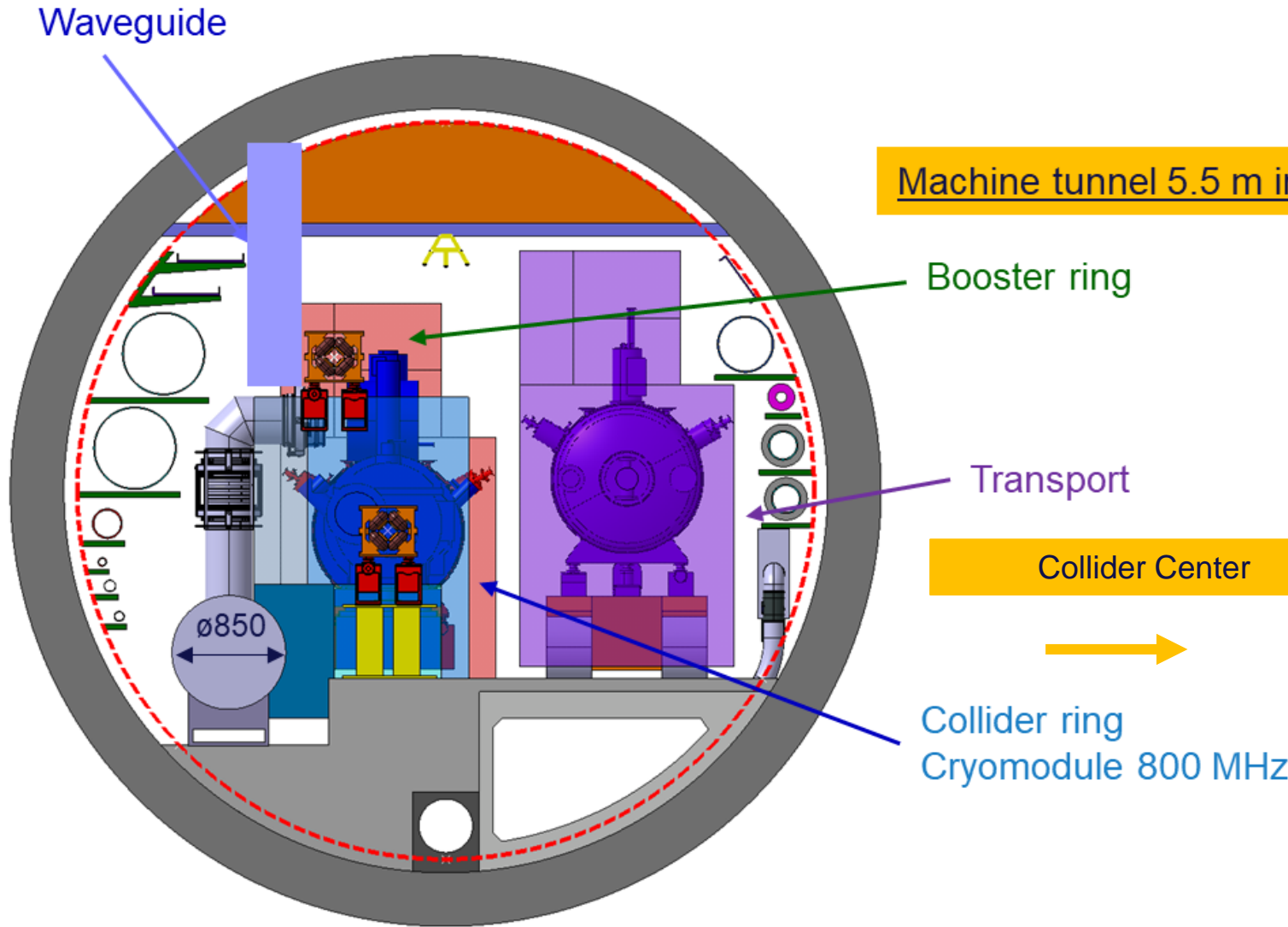
- constructive feedback on general progress with RF concepts
- underlining importance of energy efficiency, incl. making use of waste heat
- full support for high-Q SRF R&D program on bulk Nb and Nb/Cu cavities
- suggestion for higher Q_0 for 800 MHz bulk Nb cavities ($3E10$ instead $2E10$)
- support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

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) ₁₀		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

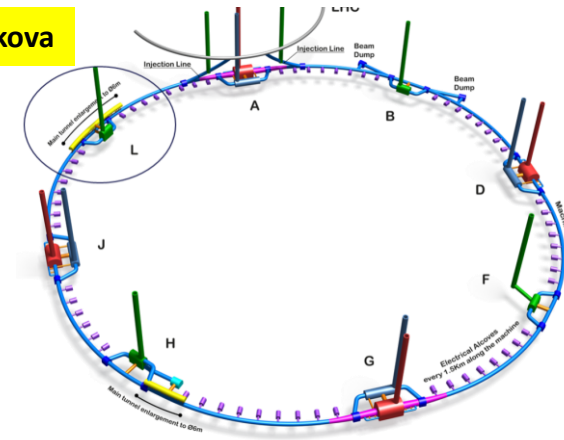
Total # of cryo-modules (entire FCC ee program) = 14x2+65+109+134 = 336

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	<u>14</u>	7	32	13	65	25	<u>65</u>	<u>109</u>	<u>134</u>
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



F. Valchkova



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

Review of CE and TI requirements for FCC experimental sites

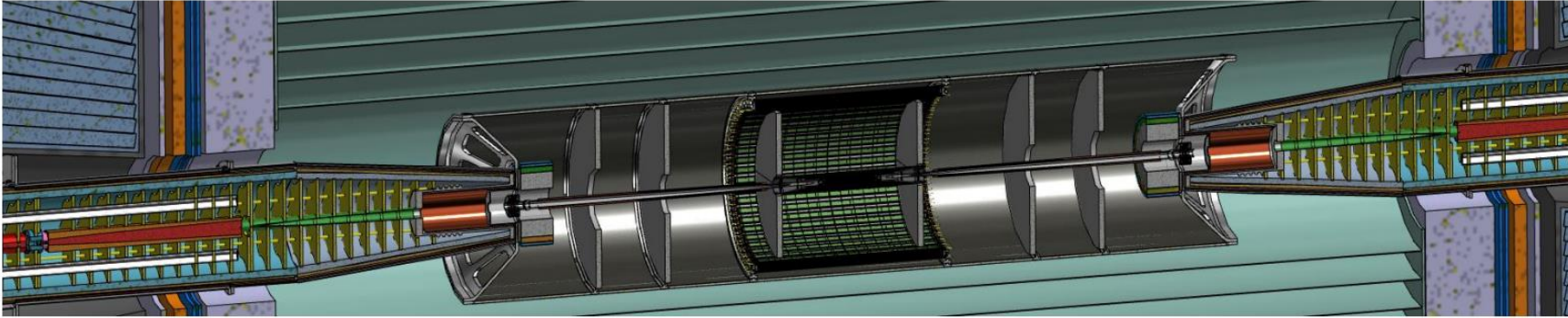
Reviewers: Austin Ball (STFC), Alain Chabert (SFTRF), Peter Krizan (Jozef Stefan Institute), Rolf Lindner (CERN), Andrew Parker (University of Cambridge – Chairperson), Roberto Tenchini (INFN Sezione di Pisa), Frank Zimmermann (CERN – Secretary)

- 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.

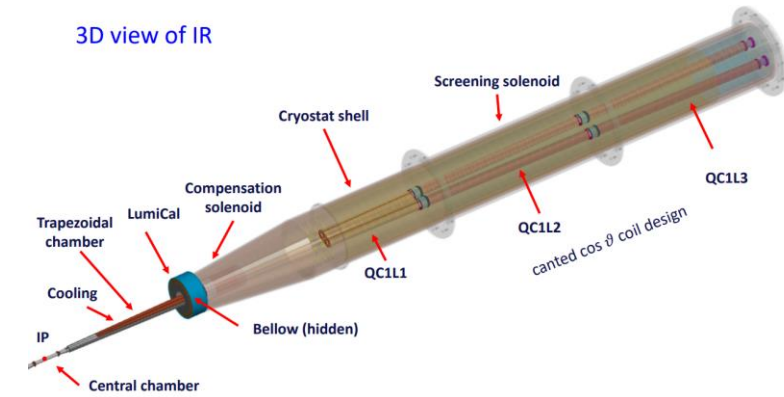
FCC-ee MDI developments - examples

Novel outer support tube for central beam pipe and vertex detector

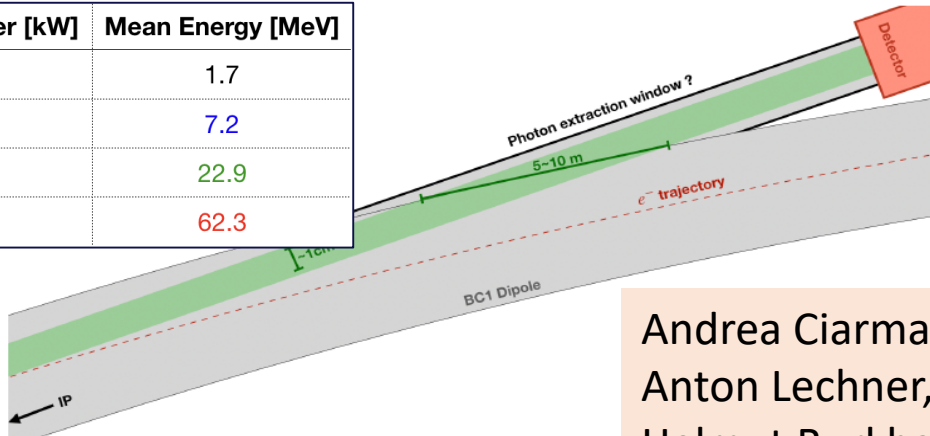
Manuela Boscolo,
Fabrizio Palla,
Filippo Bosi



- 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



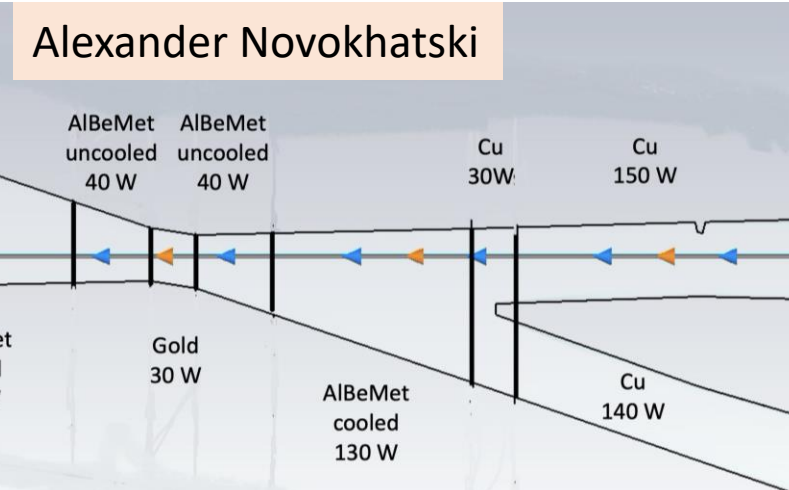
	Total Power [kW]	Mean Energy [MeV]
Z	370	1.7
WW	236	7.2
ZH	147	22.9
Top	77	62.3



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>

ELOUD'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/>



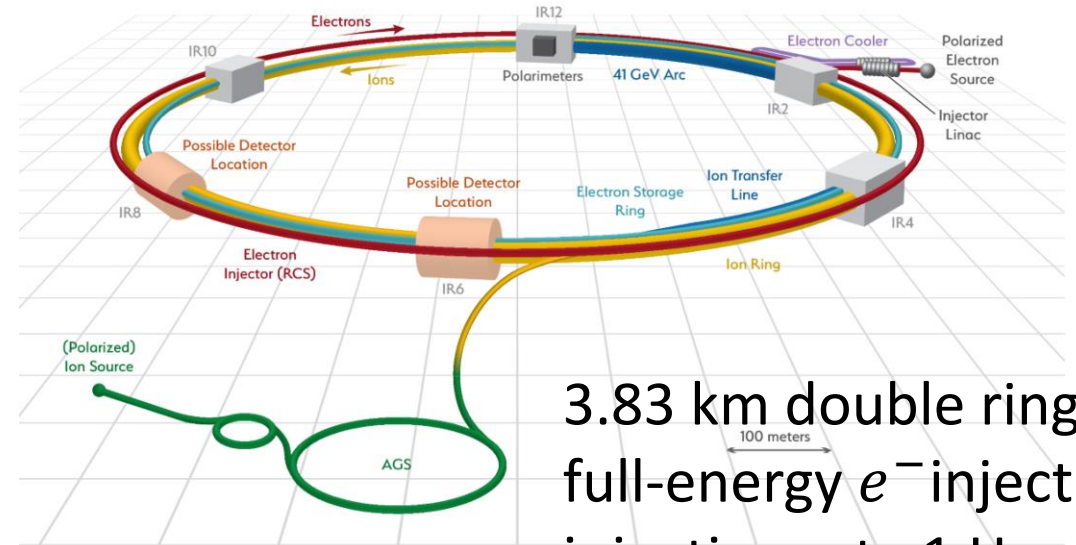
US EIC Electron Storage Ring similar to, but more challenging than, FCC-ee

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)

S&T Collider Science

FNAL, Lia Meringa

Accelerator Frontier “Message”

Steve Gourlay et al.



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

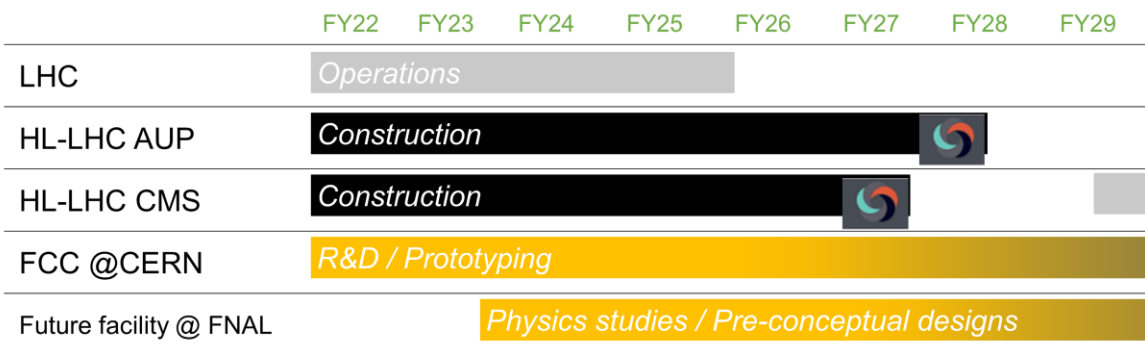
CERN is our European sister laboratory and our strong partner in many areas

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



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

- **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

Xinchou Lou, IHEP

Opportunities for synergy and cooperation between various Higgs factories:

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



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

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 [$10^{34} \text{ cm}^{-2}\text{s}^{-1}$]	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 [$10^{34} \text{ cm}^{-2}\text{s}^{-1}$]	5	30	5 (lev.)	1
events/bunch crossing	170	1000	132	27
stored energy/beam [GJ]	7.8		0.7	0.36