

FCCIS WP2 Workshop – Welcome !



FUTURE
CIRCULAR
COLLIDER
Innovation Study

*Ilya Agapov, Michael Benedikt,
Michael Hofer, Katsunobu Oide, Tor
Raubenheimer, Frank Zimmermann*

on behalf of the FCCIS WP2 team

LHC

PS

SPS

FCC



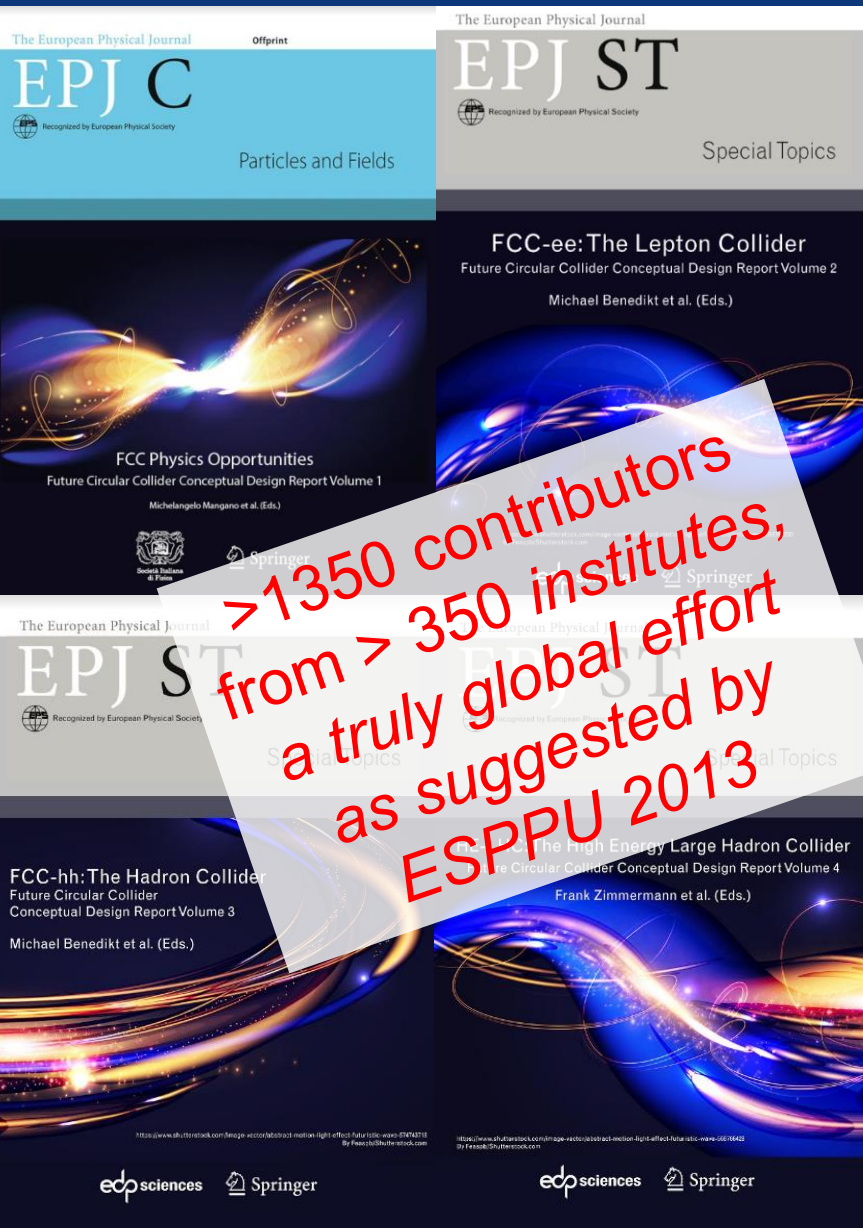
European
Commission

Horizon 2020
European Union funding
for Research & Innovation



Work supported by the **European Commission** under the **HORIZON 2020** project **FCCIS**, grant agreement 951754.

photo: J. Wenninger



- **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*, *Portugalicae 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/>

ESPP Update 2020 “High-priority future initiatives”

- An **electron-positron Higgs factory is the highest-priority next collider**. For the longer term, the European particle physics community has the ambition to operate a **proton-proton collider at the highest achievable energy**.
- “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..”**

→ launch of Future Circular Collider Feasibility Study in summer 2021

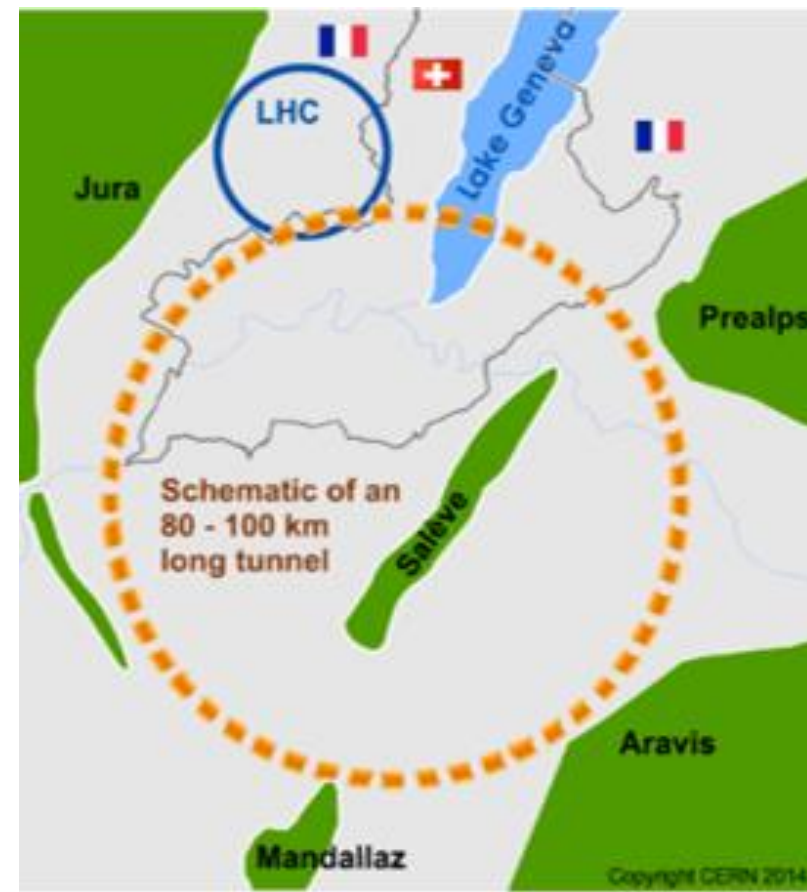
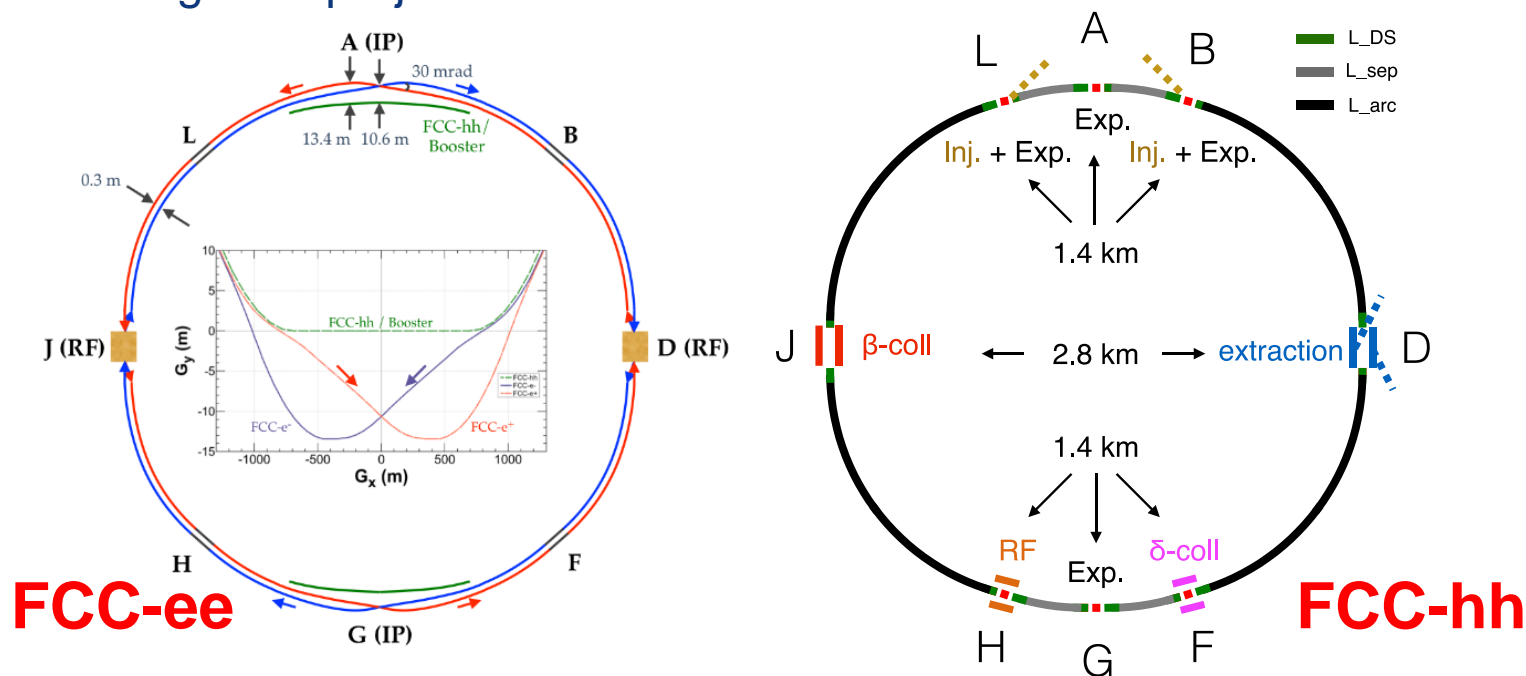




The FCC integrated program inspired by successful LEP – LHC programs at CERN

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



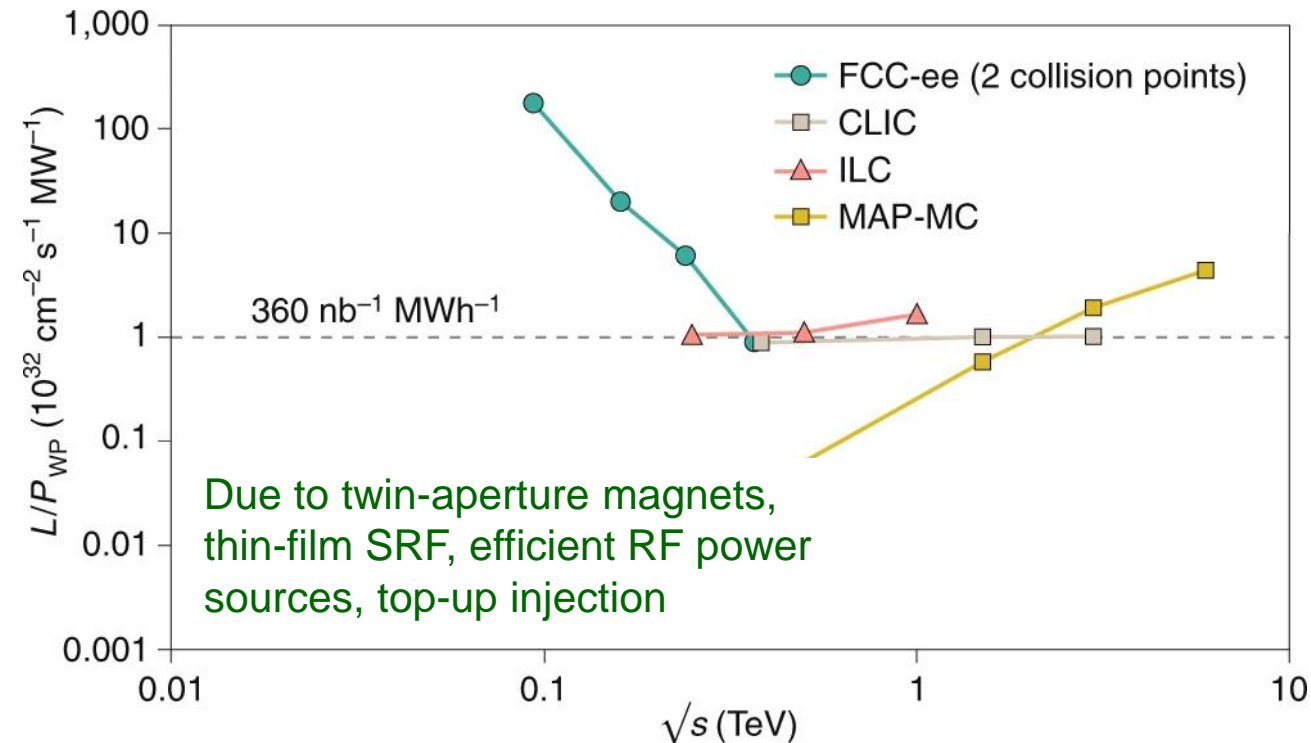
Luminosity vs. capital cost

- for the H running, with 5 ab^{-1} accumulated over 3 years and 10^6 H produced, the total investment cost (~ 10 BCHF) corresponds to \rightarrow **10 kCHF per produced Higgs boson**
- for the Z running with 150 ab^{-1} accumulated over 4 years and 5×10^{12} Z produced, the total investment cost corresponds to \rightarrow **10 kCHF per 5×10^6 Z bosons**

This is the number of Z bosons collected by each experiment during the entire LEP programme !

Capital cost per luminosity dramatically decreased compared with LEP !

Luminosity vs. electricity consumption

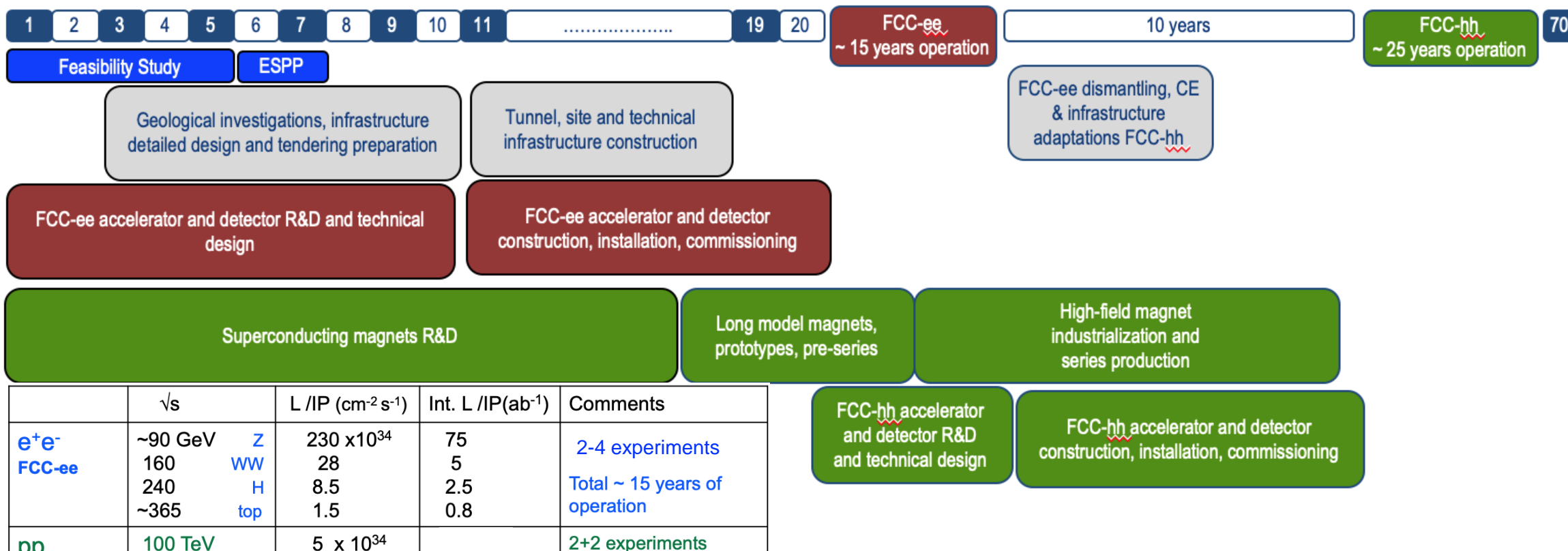


**Highest lumi/power of all proposals
Electricity cost ~ 200 CHF per Higgs boson**



Timeline of the FCC integrated programme

Technical
schedule

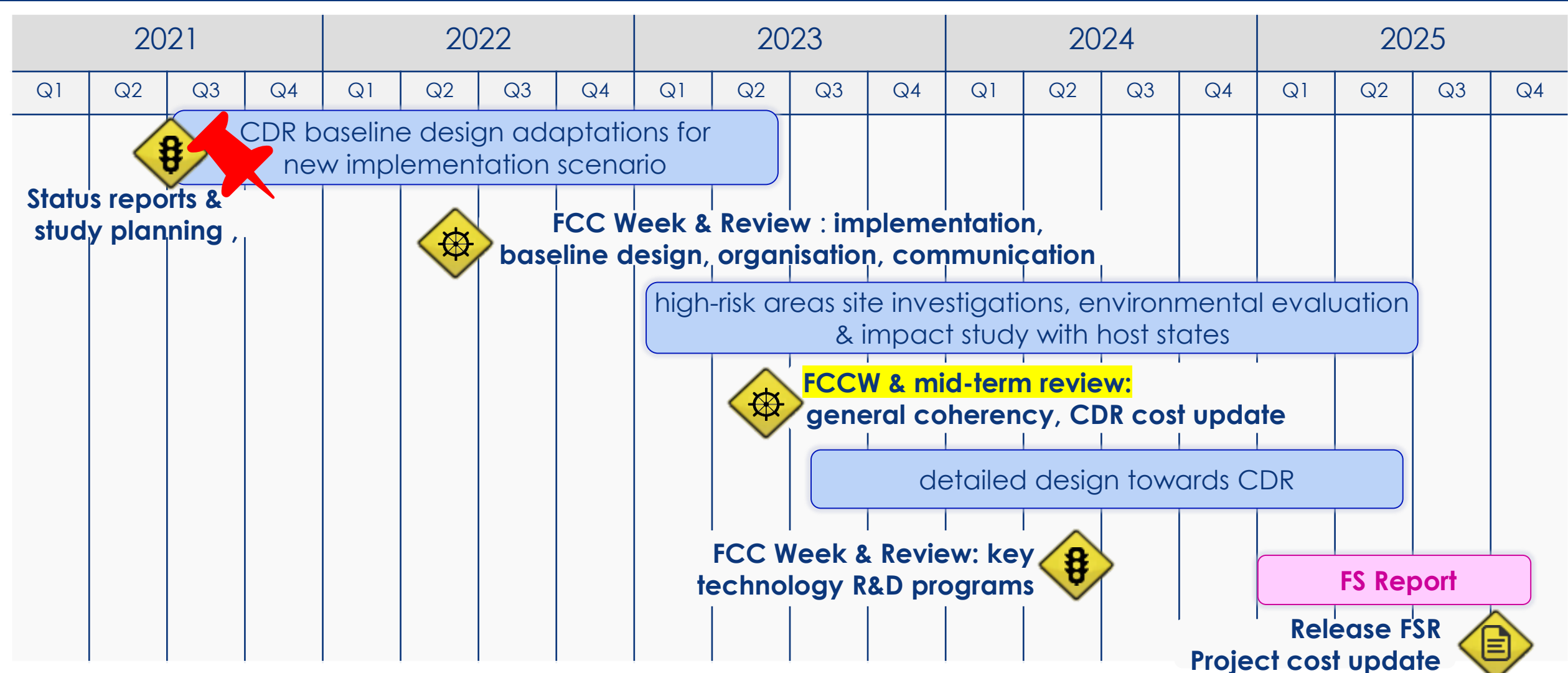


	\sqrt{s}	L /IP (cm ⁻² s ⁻¹)	Int. L /IP(ab ⁻¹)	Comments
e⁺e⁻ FCC-ee	~90 GeV Z 160 WW 240 H ~365 top	230 x 10 ³⁴ 28 8.5 1.5	75 5 2.5 0.8	2-4 experiments Total ~ 15 years of operation
pp FCC-hh	100 TeV	5 x 10 ³⁴ 30	20-30	2+2 experiments Total ~ 25 years of operation
PbPb FCC-hh	$\sqrt{s_{NN}} = 39\text{TeV}$	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	$\sqrt{s_{eN}} = 2.2\text{ TeV}$	0.5 10 ³⁴	1 fb ⁻¹	60 GeV e- from ERL Concurrent operation with PbPb

- ☐ 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++

Feasibility Study Timeline

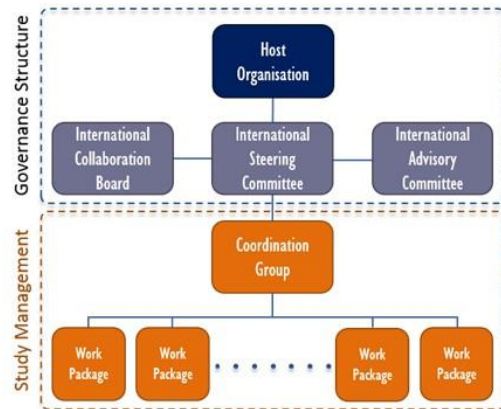
M. Benedikt



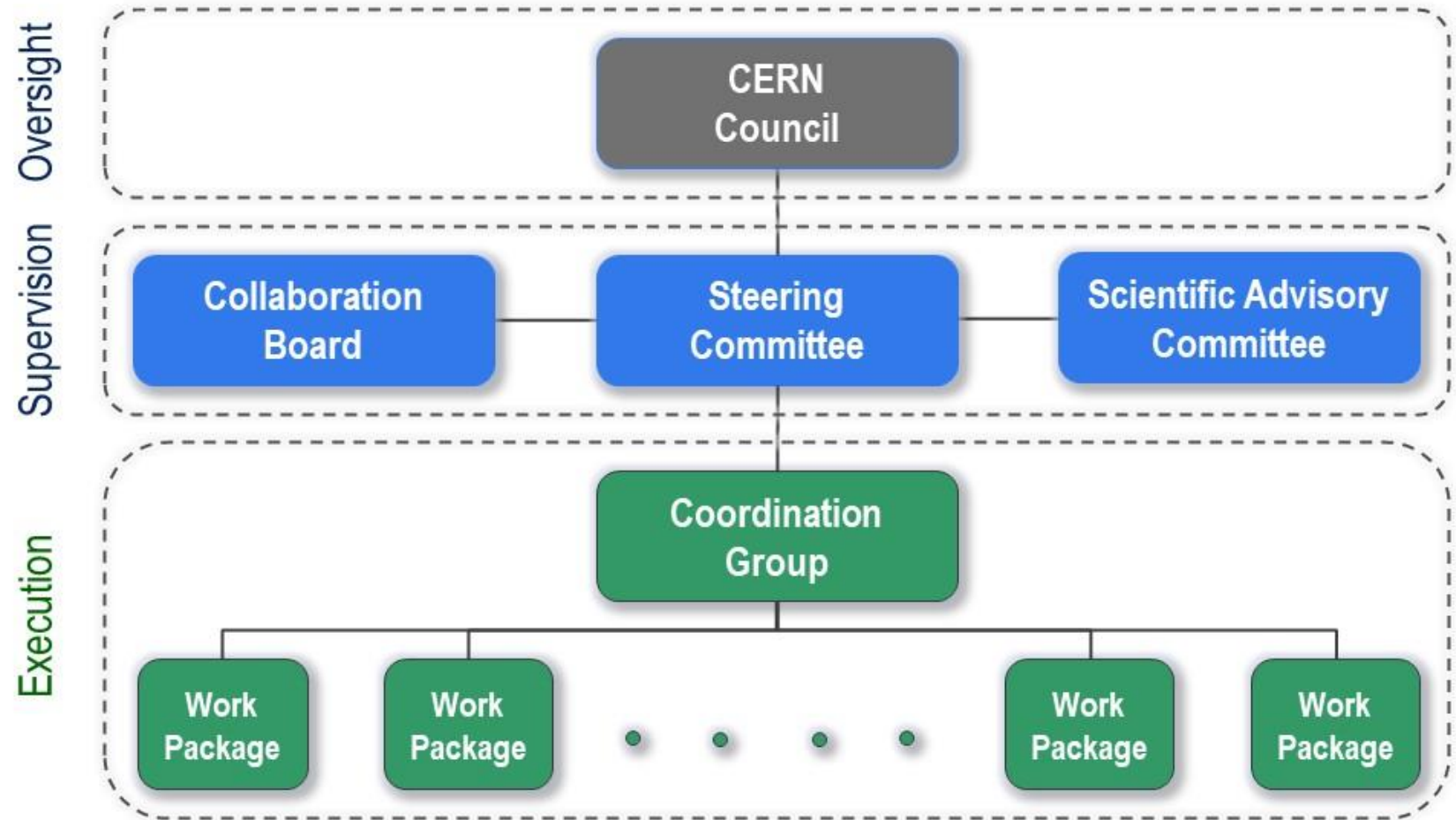


FCC Feasibility Study - organisational structure

- 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 Collaboration Board meetings on 14 September & 12 October 2021

- **Prof. Philippe CHOMAZ** from CEA.IRFU (France) has been elected as CB Chair for entire Feasibility Study period (end 2025)

CB Executive Committee (CBEC) with 2 vice chairs:

- **Dr. Manuela BOSCOLO** from INFN-LNF (Italy) and
- **Prof. Andrew LANKFORD** from UC Irvine (USA) have been elected as CB vice chairs

Next step: **CB appointment of five Steering Committee Members**

By 16th November 2021 out of the 147 former FCC collaboration members:

- **119 have confirmed their interest to continue in the FCC FS, 28 have not yet replied**

The **new Memorandum of Understanding for the FCC Feasibility Study** is available at:

<https://twiki.cern.ch/twiki/bin/view/FCC/FCCMoU>



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

147

Institutes

30

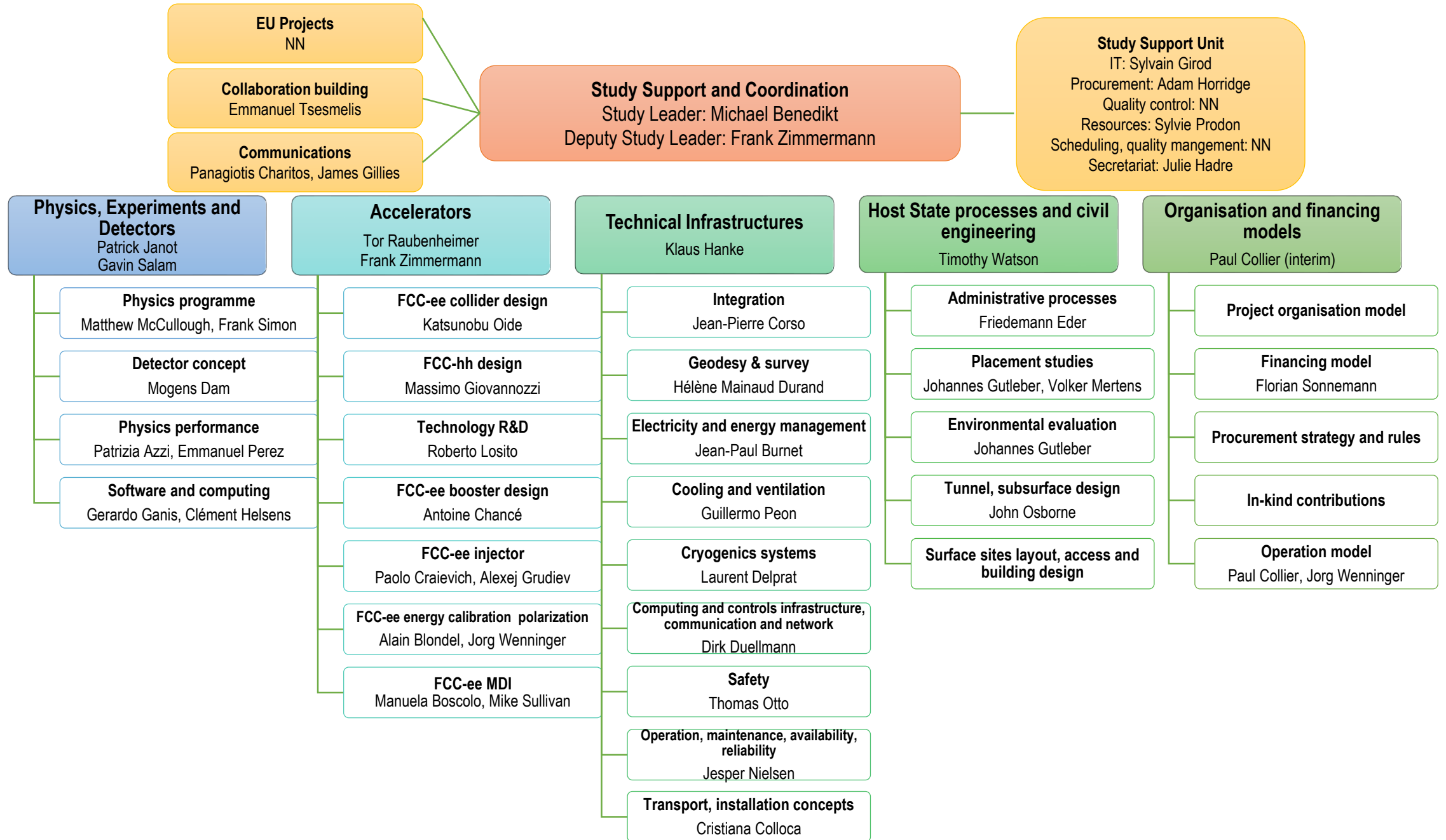
Companies

34

Countries



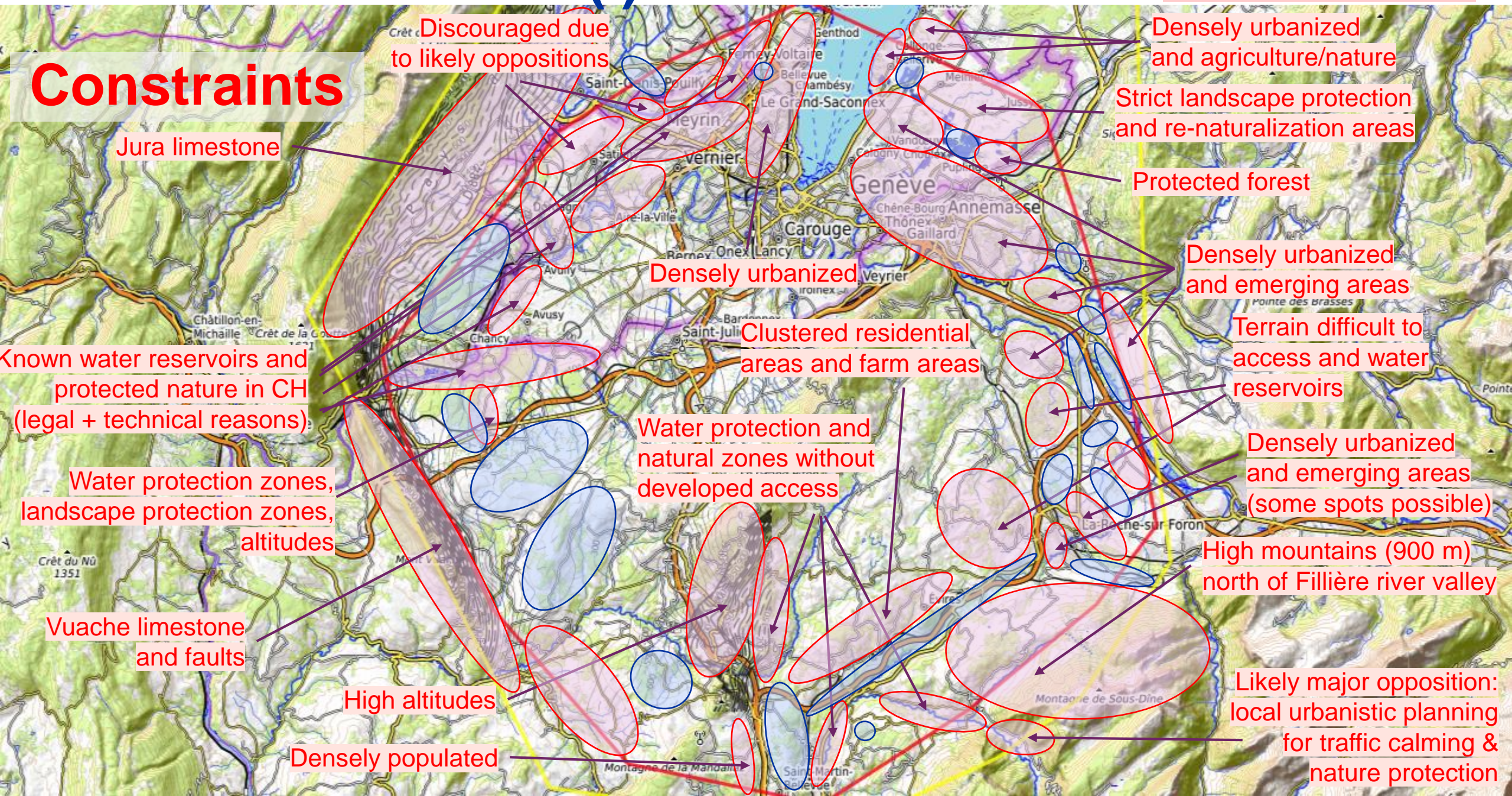
FCC Feasibility Study – coordination team and contact persons



Placements studies (i)

J. Gutleber, V. Mertens

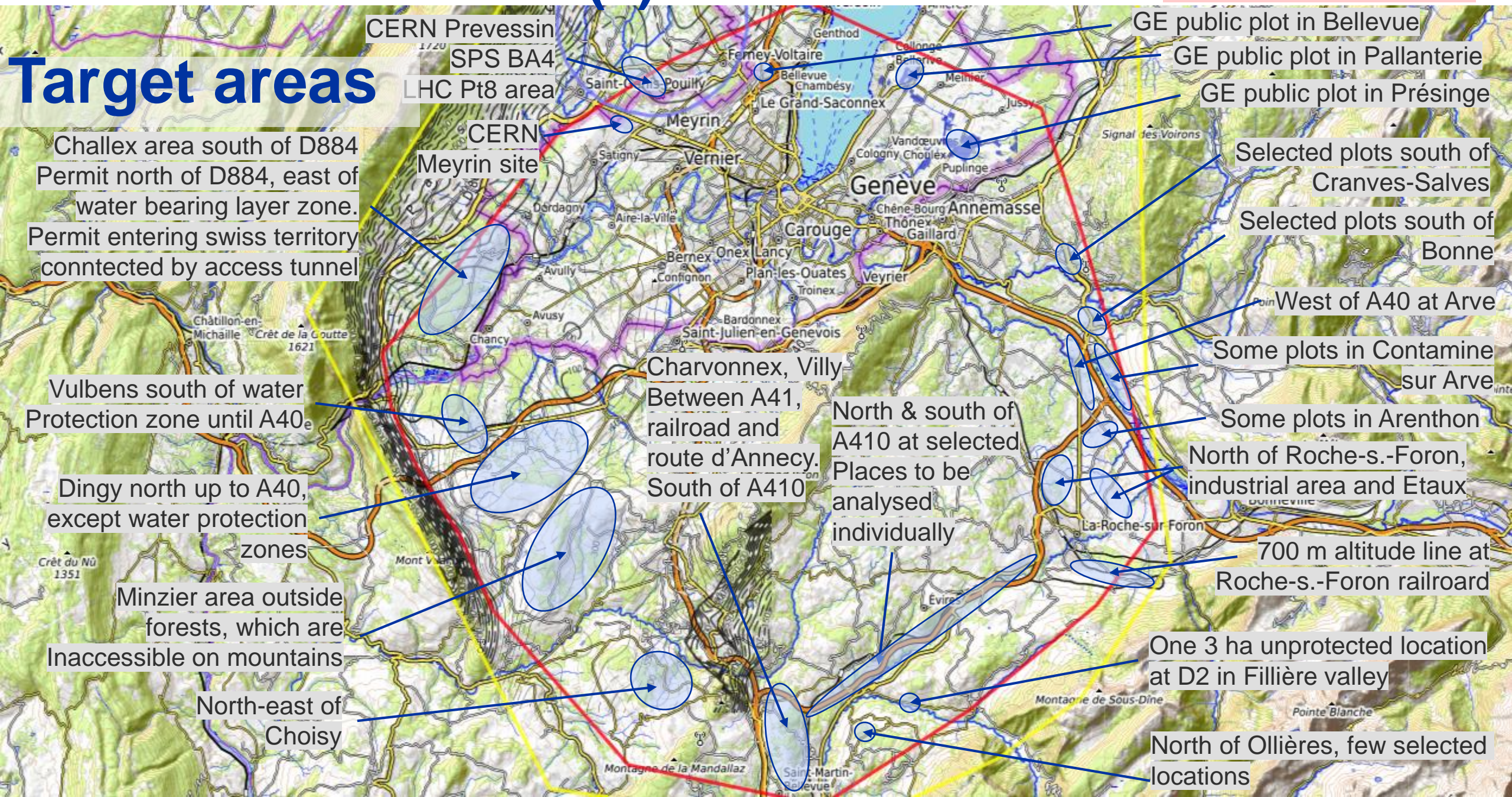
Constraints



Placements studies (ii)

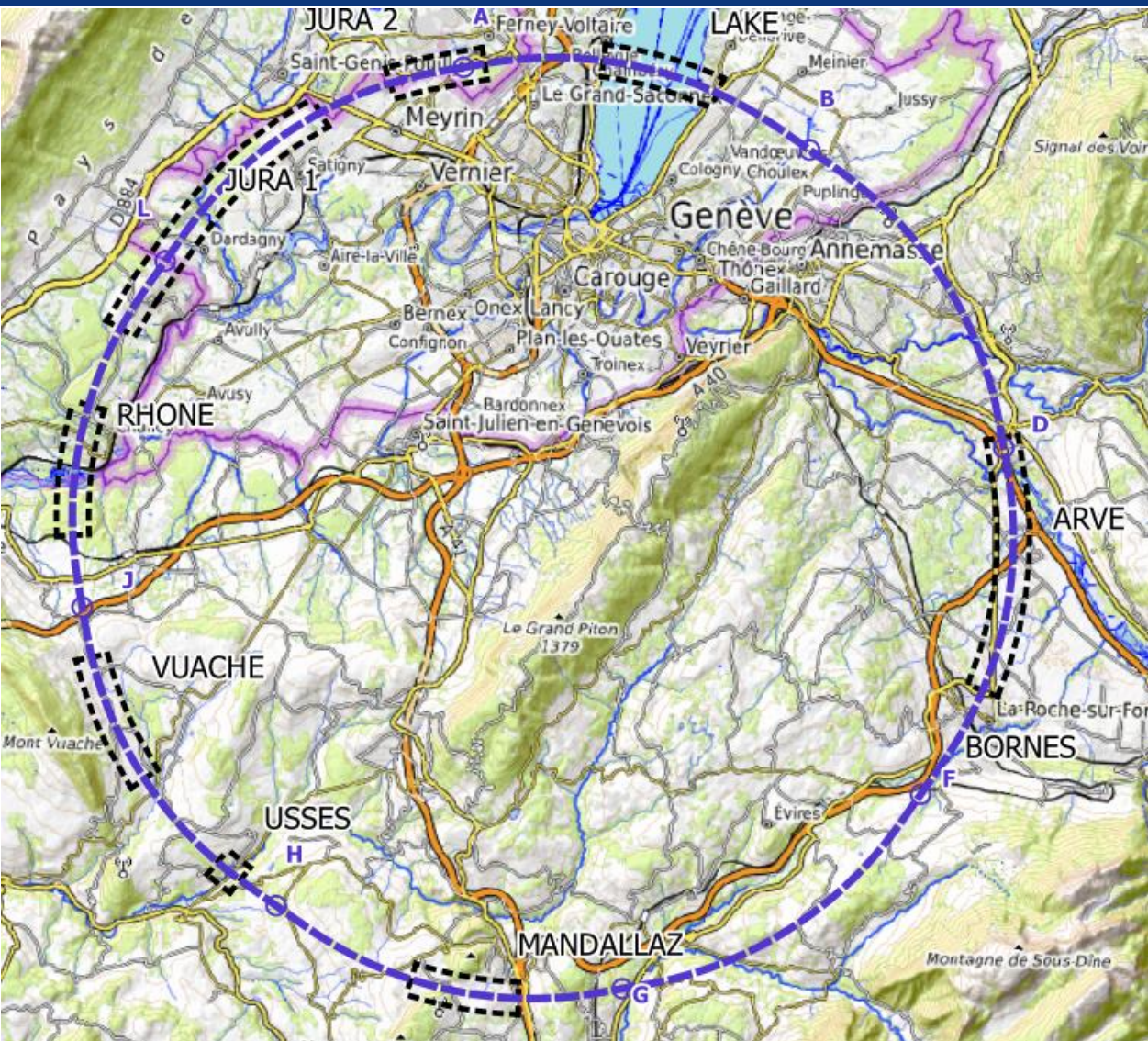
J. Gutleber, V. Mertens

Target areas





Plans for high-risk area site investigations



JURA, VUACHE (3 AREAS)

Top of limestone

Karstification and filling-in at the tunnel depth

Water pressure

LAKE, RHÔNE, ARVE AND USSES VALLEY (4 AREAS)

Top of the molasse

Quaternary soft grounds, water bearing layers

MANDALLAZ (1 AREAS)

Water pressure at the tunnel level

Karstification

BORNES (1 AREA)

High overburden molasse properties

Thrust zones

Site investigations planned for mid 2023 – mid 2025:
~40-50 drillings, 100 km of seismic lines

FCC-ee basic design choices - CDR

Double ring e⁺ e⁻ collider

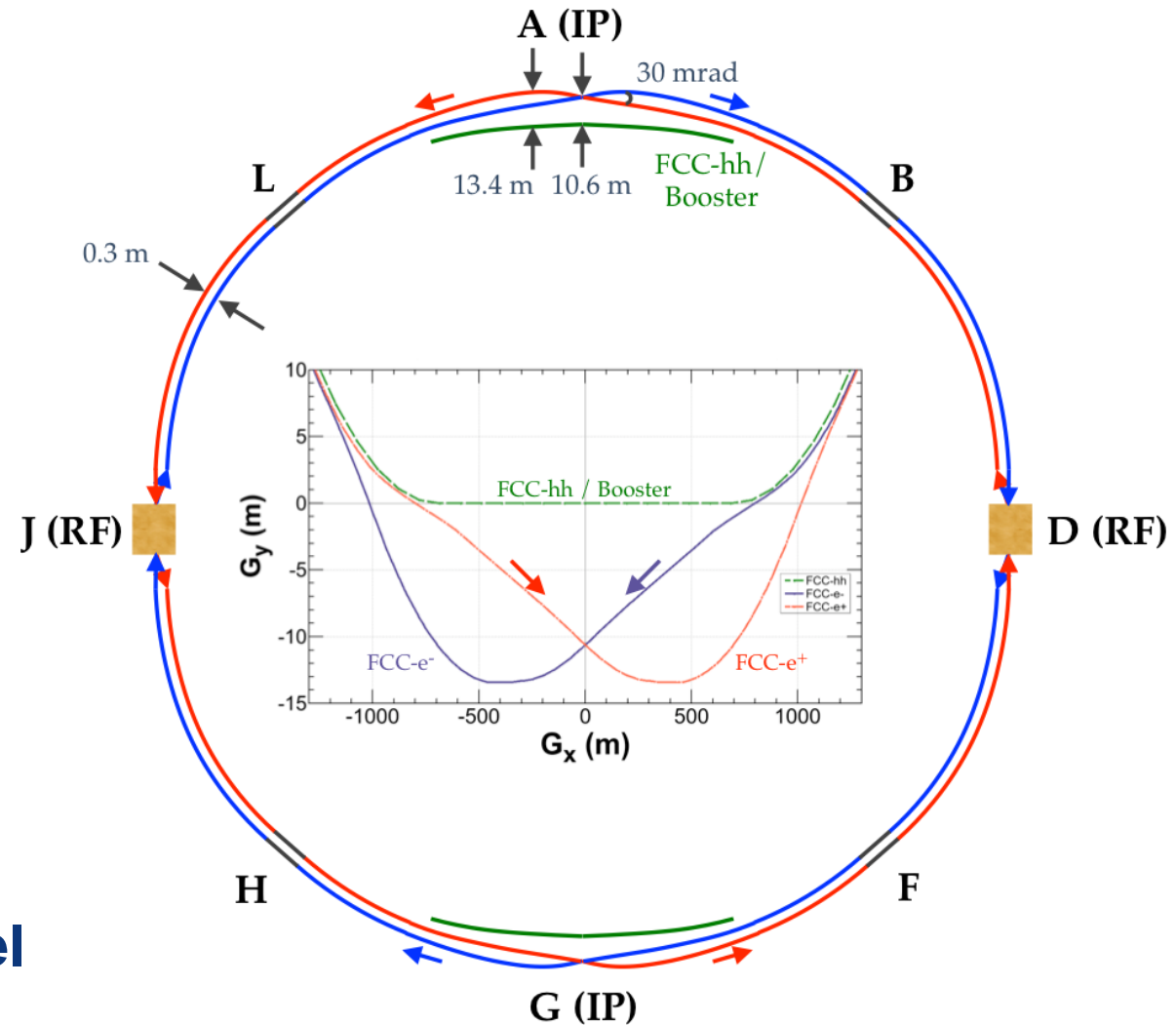
Common footprint with FCC-hh,
except around IPs

Asymmetric IR layout and optics to limit
synchrotron radiation towards the detector

2 IPs, large horizontal crossing angle 30 mrad,
crab-waist collision optics
(alternative layouts with 4 IPs under study now)

Synchrotron radiation power 50 MW/beam
at all beam energies

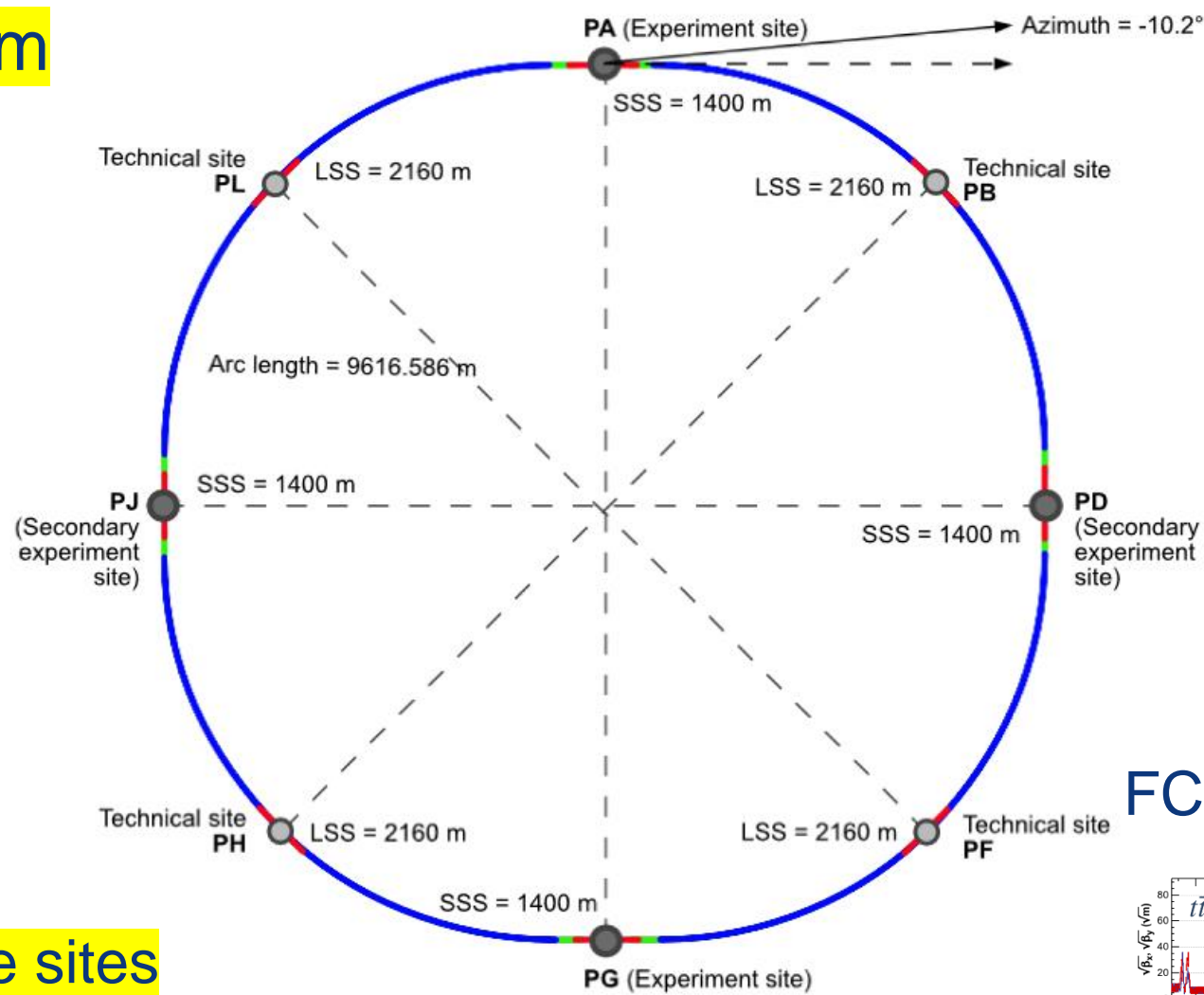
Top-up injection scheme for high luminosity
Requires **booster synchrotron in collider tunnel**





new “lowest risk” placement/optics allows 4 exp’s

C=91 km

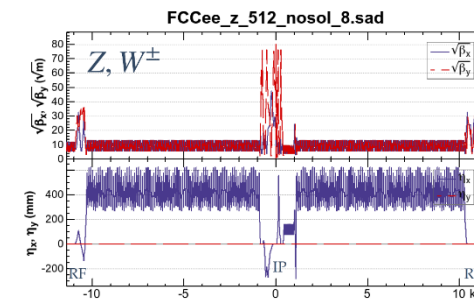
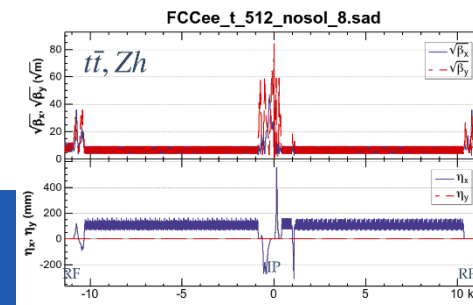


J. Gutleber

perfect symmetry
and
**perfect 4-fold
superperiodicity**

8 surface sites

FCC-ee beam optics for 1/4 ring K. Oide



FCC-ee collider parameters (stage 1)

K. Oide

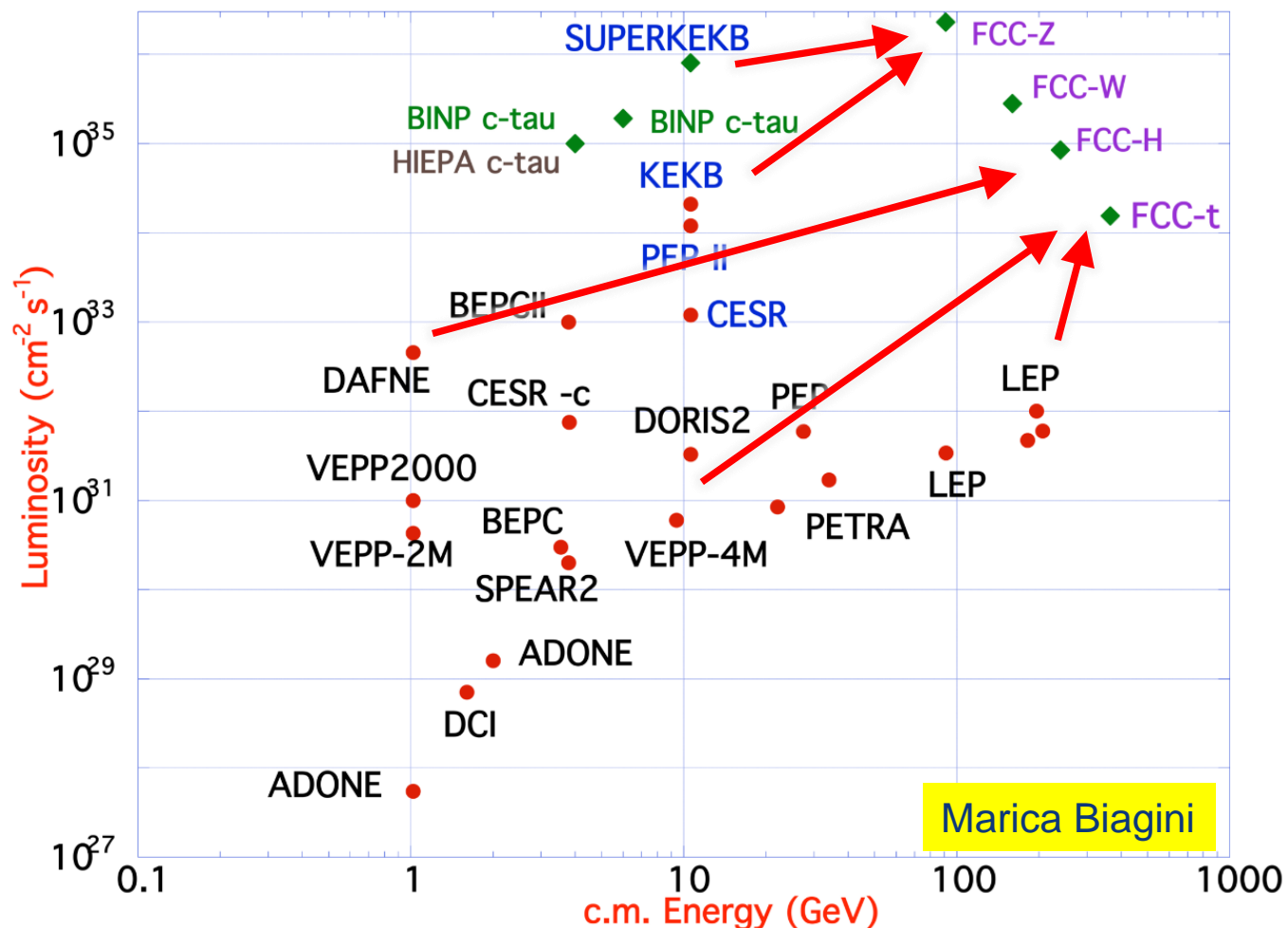
Parameter [4 IPs, 91.2 km circumference]	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45	80	120	182.5
beam current [mA]	1400	135	26.7	5.0
no. bunches/beam	8800	1120	336	42
bunch intensity [10^{11}]	2.76	2.29	1.51	2.26
SR energy loss / turn [GeV]	0.0391	0.37	1.36	10.0
total RF voltage 400/800 MHz [GV]	0.120/0	1.0/0	2.48/0	4.0/7.67
long. damping time [turns]	1170	216	64.5	18.5
horizontal beta* [m]	0.15	0.2	0.3	1
vertical beta* [mm]	0.8	1	1	1.6
horiz. geometric emittance [mm]	0.71	0.28	0.64	1.49
vert. geom. emittance [pm]	1.42	4.34	1.29	2.98
bunch length with SR / BS [mm]	4.32 / 15.2	3.55 / 7.02	2.5 / 4.45	1.67 / 2.54
luminosity per IP [$10^{34} \text{ cm}^{-2}\text{s}^{-1}$]	181	17.3	7.2	1.25
beam lifetime rad Bhabha / BS [min]	19 / -	20 / -	10 / 19	12 / 46

preliminary - for new layout & with 4 IPs



FCC-ee design concept

based on lessons and techniques from past colliders (last 40 years)



B-factories: KEKB & PEP-II:

double-ring lepton colliders,
high beam currents,
top-up injection

DAFNE: crab waist, double ring

S-KEKB: low β_y^* , crab waist

LEP: high energy, SR effects

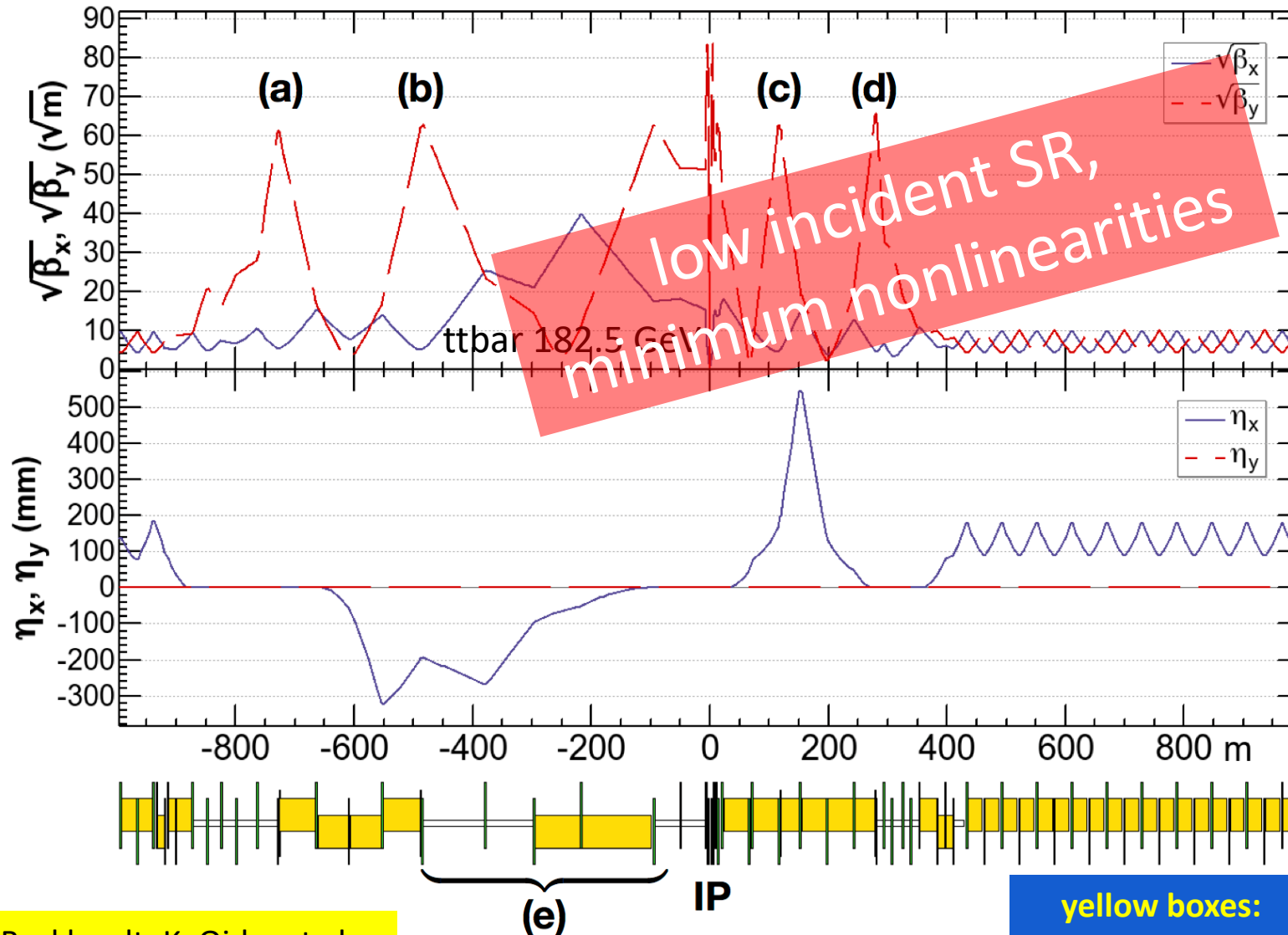
VEPP-4M, LEP: precision E calibration

KEKB: e^+ source

HERA, LEP, RHIC: spin gymnastics

combining successful ingredients of several recent colliders → highest luminosities & energies

new: FCC-ee asymmetric crab-waist IR optics



Novel asymmetric IR optics to suppress synchrotron radiation toward the IP, $E_{\text{critical}} < 100$ keV from 450 m from IP (e) – **lesson from LEP**

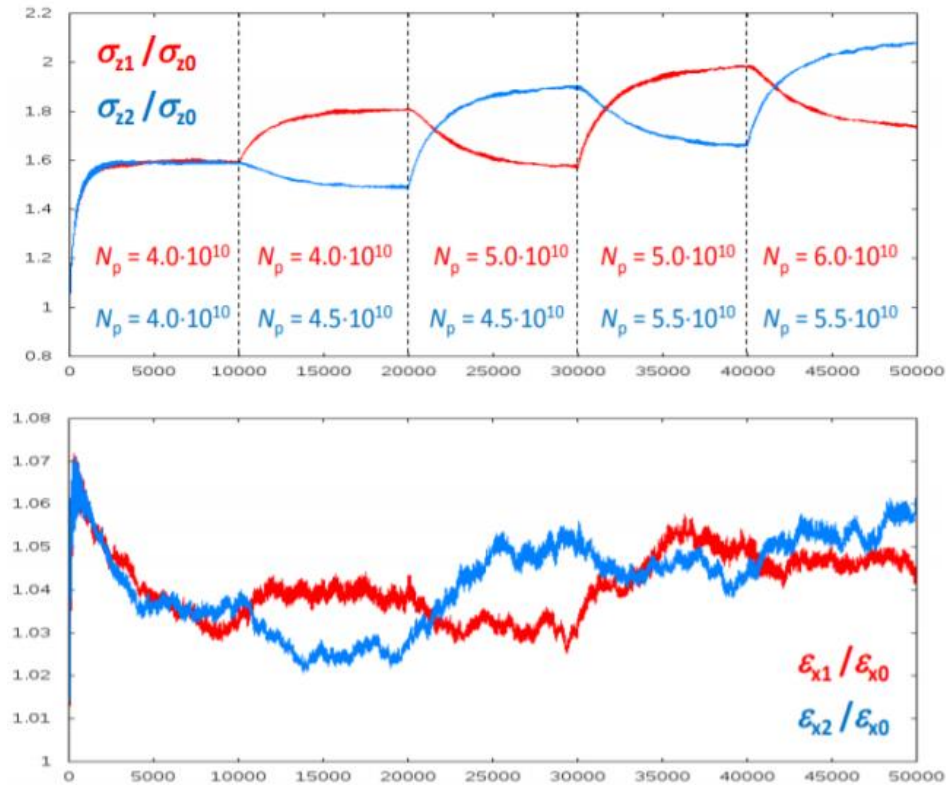
4 sextupoles (a – d) for local vertical chromaticity correction combined with crab waist, optimized for each working point – novel “virtual crab waist”, standard crab waist demonstrated at DAFNE

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



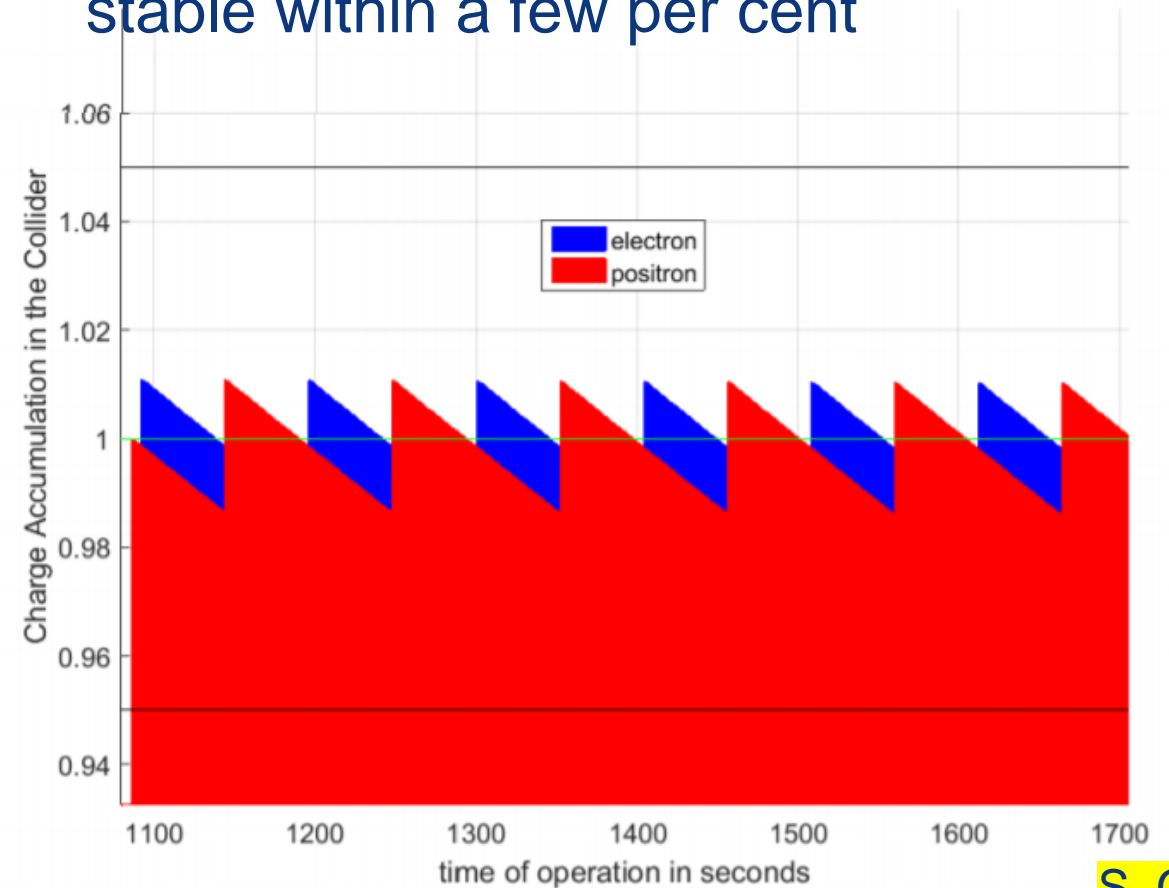
new: “bootstrapping” & top-up injection

injection from zero, alternating between beams to avoid beam-beam flip-flop effect



D. Shatilov

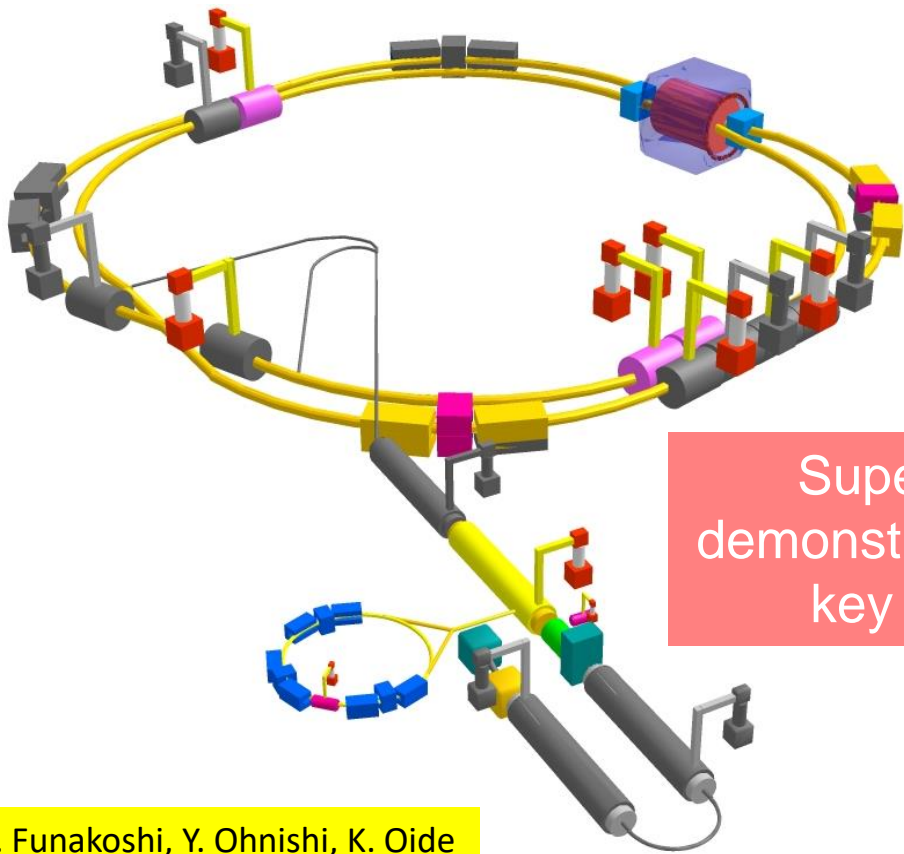
alternating replenishment of the two colliding beams, keeping beam currents stable within a few per cent



S. Ogur

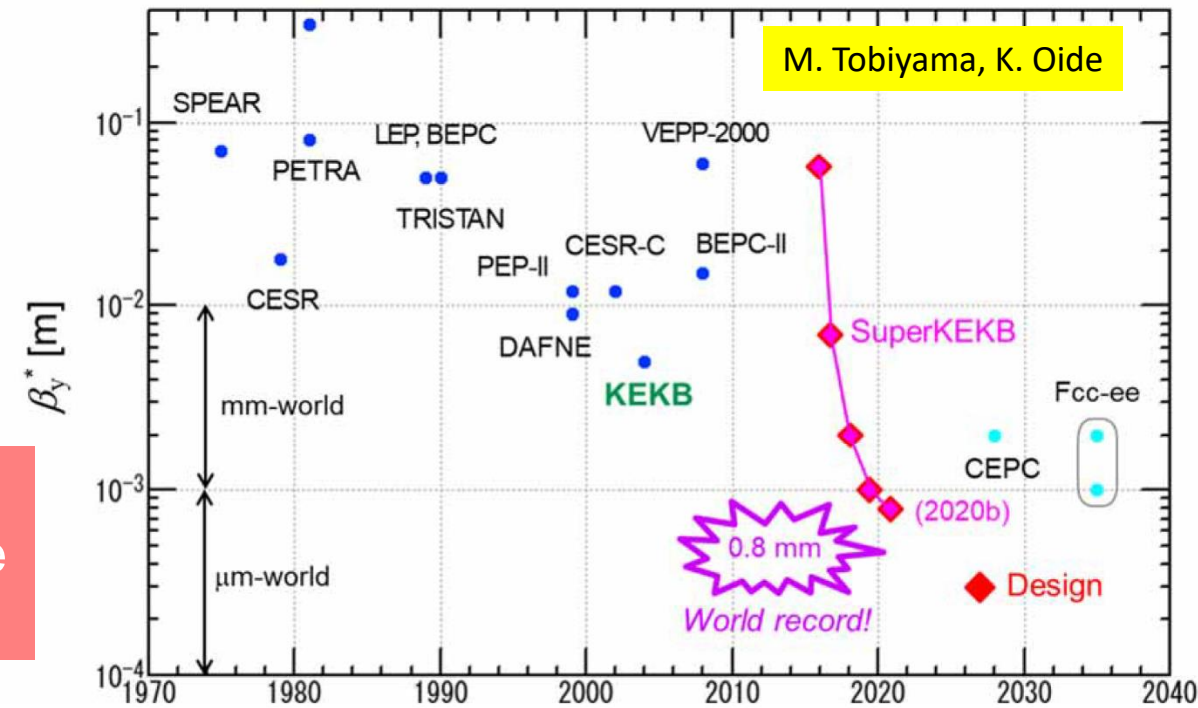
SuperKEKB – pushing luminosity and β^*

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



SuperKEKB is demonstrating FCC-ee key concepts

Y. Funakoshi, Y. Ohnishi, K. Oide



$\beta_y^* = 0.8 \text{ mm}$ achieved in both rings – using the FCC-ee-style “virtual” crab-waist collision scheme

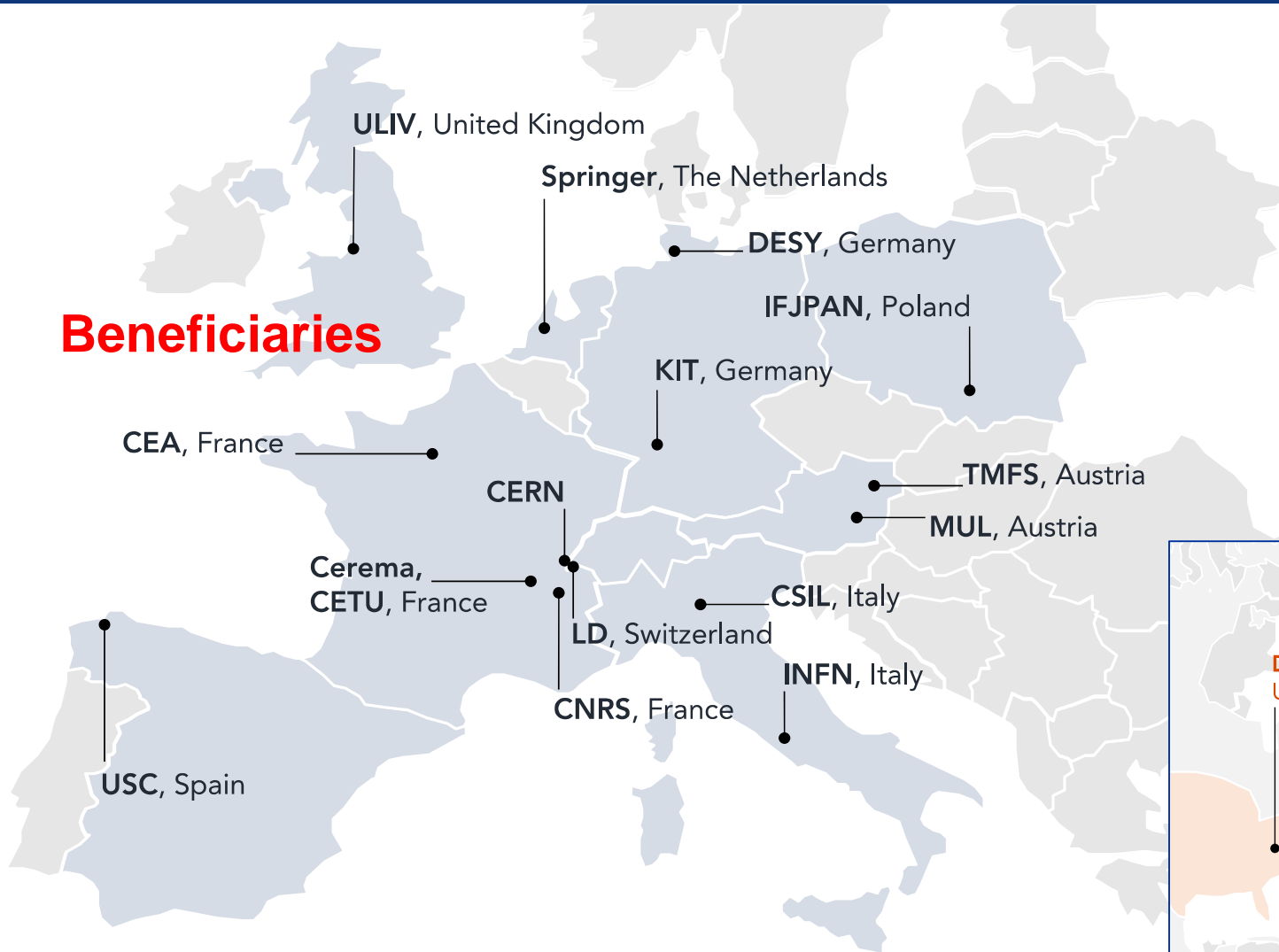
new world record $L = 3.12 \times 10^{34} \text{ cm}^{-2}\text{s}^{-1}$ on 22 June '21

FCC Status and Outlook

- Following the European Strategy Update, the **organization structure and major milestones and deliverables for the FCC Feasibility Study** were approved by the CERN Council in June 2021.
- Main activities concern the **development and confirmation of a concrete 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 the **EC H2020 Design Study FCCIS, with the goal to demonstrate feasibility by 2025/26**.
- Long term goal: **world-leading HEP infrastructure for 21st century** to push the particle-physics **precision and energy frontiers** far beyond present limits.

H2020 DS FCC Innovation Study 2020-24

Beneficiaries



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

Partners



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)

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).

FCC Physics Workshop 7-11 February 22

Liverpool, UK

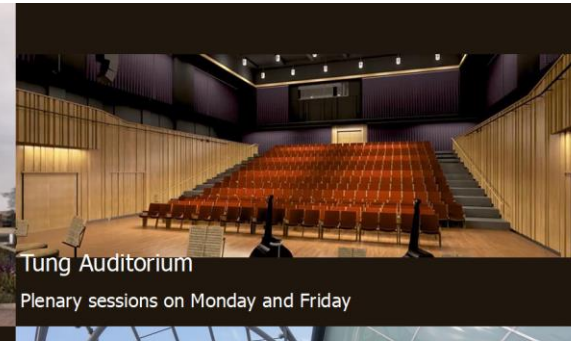


**5th FCC
PHYSICS
WORKSHOP**

LIVERPOOL
07 - 11 February 2022

In-person meeting for the first limited number of registering attendees
www.cern.ch/FCCPhysics2022

**FUTURE
CIRCULAR
COLLIDER**



number of in-person participants limited to ~160 (first come -- first served)

- registration fee: 300£
- broadcast on zoom

Date	Monday 7.2.22		Tuesday 8.2.22		Wednesday 9.2.22		Thursday 10.2.22		Friday 11.2.22	
Location	UoL Campus		ACC		ACC		ACC		UoL Campus	
	Coffee/Tea		Coffee/Tea		Coffee/Tea		Coffee/Tea		Coffee/Tea	
Morning	Plenary	Yoko Ono LT	Parallel	Rm 4A, 4B, 14, 12	Parallel	Rm 4A, 4B, 14, 12	Plenary	Rm 11	Plenary	Yoko Ono LT
	Coffee Break		Coffee Break	Rm 12	Coffee Break	Rm 12	Coffee Break	Rm 11	Coffee Break	
	Plenary	Yoko Ono LT	Parallel	Rm 4A, 4B, 14, 12	Parallel	Rm 4A, 4B, 14, 12	Plenary	Rm 11	Plenary	Yoko Ono LT
	Lunch		Lunch	Rm 12	Lunch	Rm 12	Lunch	Rm 11		
Afternoon	Plenary	Yoko Ono LT	Parallel	Rm 4A, 4B, 14, 12	Excursion	Around Liverpool City Centre	Plenary	Rm 11		
	Coffee Break		Coffee Break	Rm 12			Coffee Break	Rm 11		
	Plenary	Yoko Ono LT	Parallel	Rm 4A, 4B, 14, 12			Plenary	Rm 11		
Evening	Drinks and Posters	Atrium CTL	Outreach Event	Anglican Cathedral	Dinner	Liver Building				



In Paris 30 May to 3 June 2022

***We are looking forward
to seeing you there !***

DESY –

- doctoral student **Elaf Musa** (optics correction) started at DESY in June 2021
- postdoc: **Ali Rajabi** (impedance) started at DESY in August 2021
- **doctoral student position (MDI), goal: recruitment by winter 2021/22?**

CEA –

- PhD student for the booster (**Hervé de Grandsaignes**) started from March 2021

INFN –

- **postdoc mechanical engineer Francesco Franesini (LNF)** started in 4 May 2021; possible first visit to CERN unclear due to pandemic
- postdoc position for impedance & collective effects (Sapienza); candidate could start January 2022
- possibly 2nd postdoc at INFN-LNF ?

KIT -

- doctoral student **Michael Reissig** (beam diagnostics) joined the team from March 2021

LAPP Annecy

- postdoc **Eva Montbarbon**
- **2nd postdoc mech engineer starts on 1 December 2021**

U Oxford –

- CERN doctoral student with Oxford U (IP feedback); candidate might be found in 2022



WP2 formal accomplishments

- WP2 milestones and deliverables in 2021

M2.1	MS4	Milestone	Product Break- down Structure <i>Delivered ! Ghislain Roy</i> <u>Product Breakdown Structure Zenodo</u>	01/07/2021
D2.1	D4	Deliverable	Collider performance, beam optics and design considerations baseline <i>Delivered !</i> <u>Collider performance, beam optics and design considerations baseline Zenodo</u>	01/11/2021



Grant Agreement No: 951754

FCCIS

Future Circular Collider Innovation Study

Horizon 2020 Research and Innovation Framework Programme, Research and Innovation Action

MILESTONE REPORT

PRODUCT BREAKDOWN STRUCTURE

Document identifier:	FCCIS-P1-WP2-MS4
Due date:	End of Month 8 (July 2021)
Date:	30/06/2021
Work package/unit:	WP2 Collider Design
Organisation:	CERN
Version:	V1.0
Status:	RELEASED
Domain:	Accelerators
Keywords:	Collider Elements Structure

Abstract:

The Product Breakdown Structure (PBS) of the Future Circular Collider (FCC) is presented. The first instance of the PBS is described in its current format, and the plans to further develop the PBS in the coming months and years are outlined.

Structured document of collider elements in tabular form publicly released on Zenodo (Green, open data).

Grant Agreement No: 951754

FCCIS

Future Circular Collider Innovation Study

Horizon 2020 Research and Innovation Framework Programme, Research and Innovation Action

DELIVERABLE REPORT

COLLIDER PERFORMANCE, BEAM OPTICS AND DESIGN CONSIDERATIONS BASELINE

Document identifier:	FCCIS-P1-WP2-D2.1
Due date:	End of Month n (November 2021 Year)
Report release date:	Error! Not a valid bookmark self-reference.
Work package:	WP2 Collider Design
Lead beneficiary:	CERN
Document status:	IN WORK
Domain:	Accelerators
Keywords:	

Abstract:

We report a preliminary FCC-ee baseline layout for optimised placement, comment on the associated beam optics and the expected performance, and highlight some of the issues that remain to be addressed.

FCC IS WP2 “Working Weeks” with integrated “FCC Accelerators & Beam Physics Day”

29 November – 10 December 2021

Frank Zimmermann, FCCC CGM #127, 29 October 2021
with input from Michael Hofer, Manuela Boscolo et al.
thanks to Julie Hadre and Suzanne Chibli

<https://indico.cern.ch/event/1085318>

FCC Accelerators and Beam Physics Day, 2 December 2021

<https://indico.cern.ch/event/1090005/> (max. 41 live persons)

Agenda

1. FCC Accelerator Pillar - Plan and milestones, Tor Raubenheimer
2. ee Collider Design - Open points and where help is needed, Katsunobu Oide
3. Booster Design - Open points and where help is needed, Antoine Chance
4. Collective Effects - Open points and where help is needed, Mauro Migliorati
5. FCC-hh design - Open points and where help is needed, Massimo Giovannozzi
6. Collimation for ee and hh - Open points & where help is needed, Andrey Abramov
7. MDI - Open points and where help is needed, Manuela Boscolo
8. Pre-injector complex - Open points and where help is needed, Paolo Craievich
9. Energy calibration - Open points and where help is needed, Alain Blondel
10. Code development - Tatiana Pieloni
11. Other open points, Frank Zimmermann
12. FCC FS - Motivations, goals, timeline, org., collaborations, Michael Benedikt

FCCIS WP2 workshop program – week 1

Monday 29 Nov 2021	Overview, Parameters, Optics and correction 1	Chairs: Angeles Faus-Golfe, Michael Hofer, Frank Zimmermann
9h00-9h25	Welcome, Overview, and FCC-ee Parameter Choices	Frank Zimmermann
9h25-9h30	Workshop information and logistics	Michael Hofer
9h30-10h00	Parameter optimisation at different working point	Dmitry Shatilov
10h15-10h45	Status of the FCC-ee optics and next step	Katsunobu Oide
10h45-11h15	Optics correction	Tessa Charles
Tuesday 30 Nov 2021	Code development	Chairs: Tatiana Pieloni, Gianni Iadarola
9h00-9h20	Optics repository	Ghislain Roy
9h20-9h40	MAD-X/PTC development and plans	Riccardo De Maria
9h40-10h00	Code comparison and lattice models	Leon van Riesen-Haupt
10h15-10h45	FCC-ee software framework	Felix Carlier
10h45-11h15	XSuite	Gianni Iadarola

Wed 1 Dec 2021	Collimation, Beam-Beam	Chair: Xavier Buffat
9h00-9h30	Layout and optics for a collimation insertion	Michael Hofer
9h30-10h00	Status of collimation simulations for the FCC-ee	Andrey Abramov
10h15-10h45	Beam-beam	Peter Kicsiny
10h45-11h15	Beam-beam studies using Lifetrack	Dmitry Shatilov
Thu 2 Dec 2021	FCC-ee Accelerators and Beam Physics Day https://indico.cern.ch/event/1090005/	Chairs: Edda Gschwendtner, Yannis Papaphilippou
Friday 3 Dec 2021	MDI	Chair: Manuela Boscolo
9h00-9h20	MDI status and plans	Manuela Boscolo
9h20-9h40	Mechanical Model	Francesco Franesini
9h40-10h00	CAD integration	Luigi Pellegrino
10h15-10h35	Alignment system in the IR/MDI	Leonard Watrelot
10h35-10h55	Vibration tolerance for IP and arc magnets, feedback performance criteria	Katsunobu Oide
10h55-11h15	MAD-X simulations of vibration in the MDI	Eva Montbarbon
11h15-11h35	Strategy for Vibration suppression:mechanics & control aspects	Laurent Brunetti
13h30-14h00	Low angle radiative Bhaba monitor	Alain Blondel
14h00-14h30	CCT magnet design (followed by CCT Q1 magnet tour)	Mike Koratzinos

FCCIS WP2 workshop program – week 2

Monday 6 Dec 2021	Optics Correction (part 2), and Beam Measurements	Chair: Rogelio Tomas
9h00-9h30	Beam stabilisation and optics correction for PETRA IV	Ilya Agapov
9h30-10h00	Optics corrections & experience at ESRF-EBS	Simone Liuzzo
10h15-10h45	Optics Measurements at SuperKEKB	Jacqueline Keintzel
10h15-10h45	LHC Optics Corrections	Tobias Persson
	Afternoon: SC tours (2 pm and 4 pm)	
Tuesday 7 Dec 2021	Optics Booster, injection	Chair: Masamitsu Aiba, Michael Hofer
9h00-9h30	Pre-Booster	Ozgur Etisken
9h30-10h00	High-Energy Booster	Antoine Chance, Barbara Dalena, Herve De Grandsaignes
10h15-10h45	Injection and Extraction in the collider	Rebecca Louise Ramjiawan
10h15-10h45	Tracking studies in the collider ring	Patrick Hunchak
10h45-11h05	Design studies for the FCC-ee beam dump	Alexander Krainer

FCCIS WP2 workshop program – week 2 cont'd

Wed 8 Dec 2021	Collective effects	Chair: Mauro Migliorati
9h00-9h30	Impedance models and single-beam instabilities- Overview	Mauro Migliorati
9h30-10h00	Impedance model & TMCI threshold	Emanuela Carideo
10h30-11h00	Impedance of bellows and flanges	Chiara Antunono
11h00-11h30	Modelling of the FCC resistive wall impedance	Ali Rajabi
15h00-15h30	Electron cloud in the arcs	Fatih Yaman
15h30-16h00	Electron cloud in the arc quadrupoles	Damian Ayim
Thu 9 Dec 2021	Vacuum, Radiation Environment, Polarisation	Chair: Tor Raubenheimer
9h00-9h30	FCC-ee vacuum system & pressure forecast	Roberto Kersevan
9h30-10h00	Energy deposition & radiation levels in the arcs	Barbara Humann
10h15-10h45	Polarisation and precision energy calibration, overview and plans	Alain Blondel
Fri 10 Dec 2021	Closing	Chair: Ilya Agapov
9h00-11h00	Summary and close out	Ilya Agapov, Frank Zimmermann

thanks much for participating -

enjoy the WP2 two-week workshop !