FCC - EuroCirCol

Status and Plans

M. Benedikt

gratefully acknowledging input from FCC coordination group the global design study team, EuroCirCol and all contributors

http://cern.ch/fcc

*Work supported by the **European Commission** under the HORIZON 2020 project EuroCirCol, grant agreement 654305*

Contents

- Study status and major evolution during last 12 months
- Further study planning towards Conceptual Design Report
- EASITrain H2020 training network

FCC-hh parameters

parameter	FCC-hh		HE-LHC	HL-LHC	LHC
collision energy cms [TeV]	100		27	14	14
dipole field [T]	16		16	8.33	8.33
circumference [km]	97.75		26.7	26.7	26.7
beam current [A]	0.5		1.12	1.12	0.58
bunch intensity [10^{11}]	1	1 (0.2)	2.2 (0.44)	2.2	1.15
bunch spacing [ns]	25	25 (5)	25 (5)	25	25
synchr. rad. power / ring [kW]	2400		101	7.3	3.6
SR power / length [W/m/ap.]	28.4		4.6	0.33	0.17
long. emit. damping time [h]	0.54		1.8	12.9	12.9
beta* [m]	1.1	0.3	0.25	0.20	0.55
normalized emittance [μm]	2.2 (0.4)		2.5 (0.5)	2.5	3.75
peak luminosity [10^{34} cm^{-2}s^{-1}]	5	30	25	5	1
events/bunch crossing	170	1k (200)	~800 (160)	135	27
stored energy/beam [GJ]	8.4		1.3	0.7	0.36

FCC-ee parameters

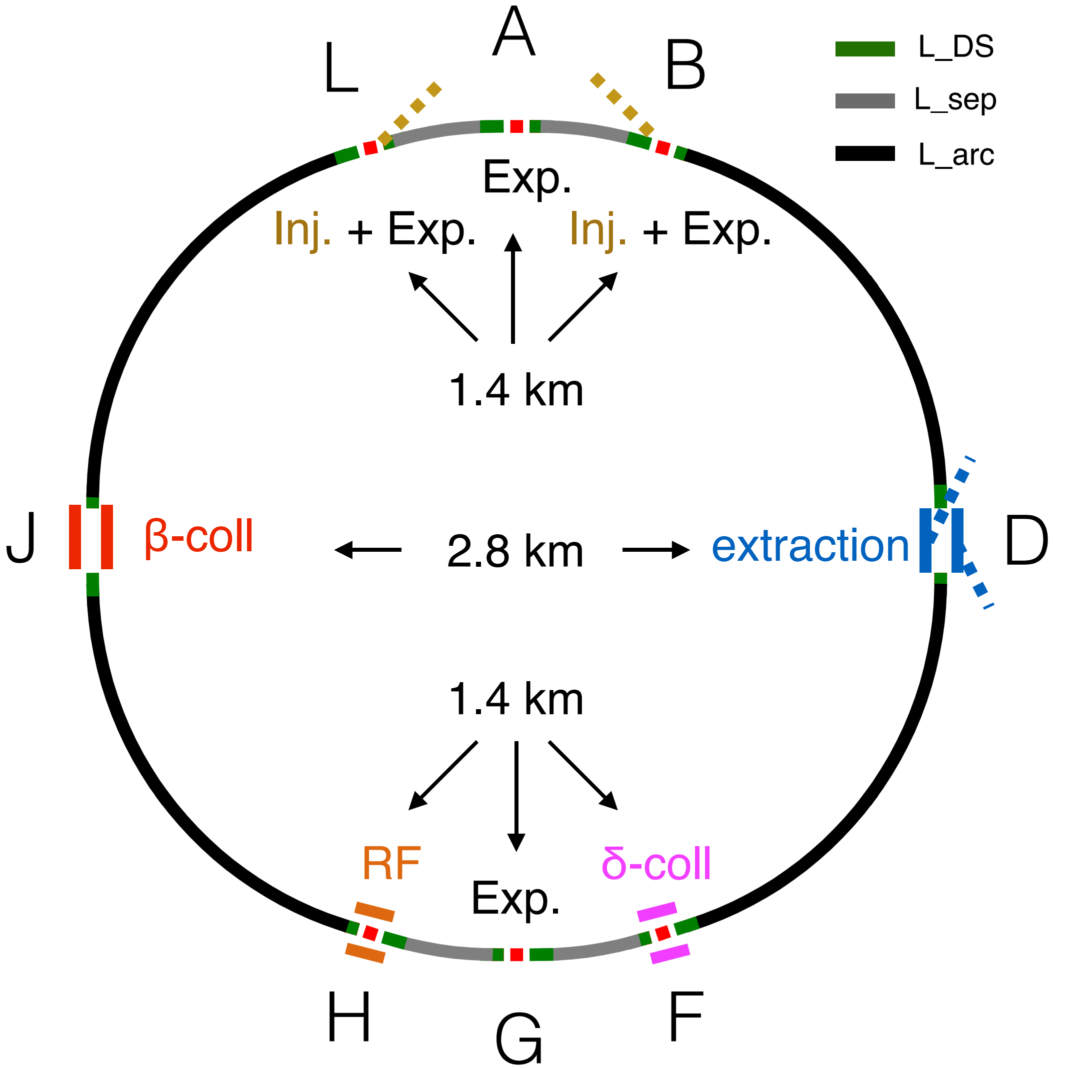
parameter	Z	W	H (ZH)	ttbar
cm collision energy [GeV]	91	160	240	350
beam current [mA]	1400	147	29	6.4
no. bunches	71000	7500	740	62
bunch intensity [10^{11}]	0.4	0.4	0.8	2.1
bunch spacing [ns]	2.5 / 5.0	40	400	5000
SR energy loss / turn [GeV]	0.036	0.34	1.71	7.72
total RF voltage [GV]	0.25	0.8	3.0	9.5
long. damping time [turns]	1280	235	70	23
horizontal beta* [m]	0.15	1	1	1
vertical beta* [mm]	1	2	2	2
horiz. geometric emittance [nm]	0.27	0.26	0.61	1.33
vert. geom. emittance [pm]	1.0	1.0	1.2	2.66
bunch length with SR & BS [mm]	4.1	2.3	2.2	2.9
luminosity [10^{34} $cm^{-2}s^{-1}$]	130	16	5	1.4

FCC-hh new layout

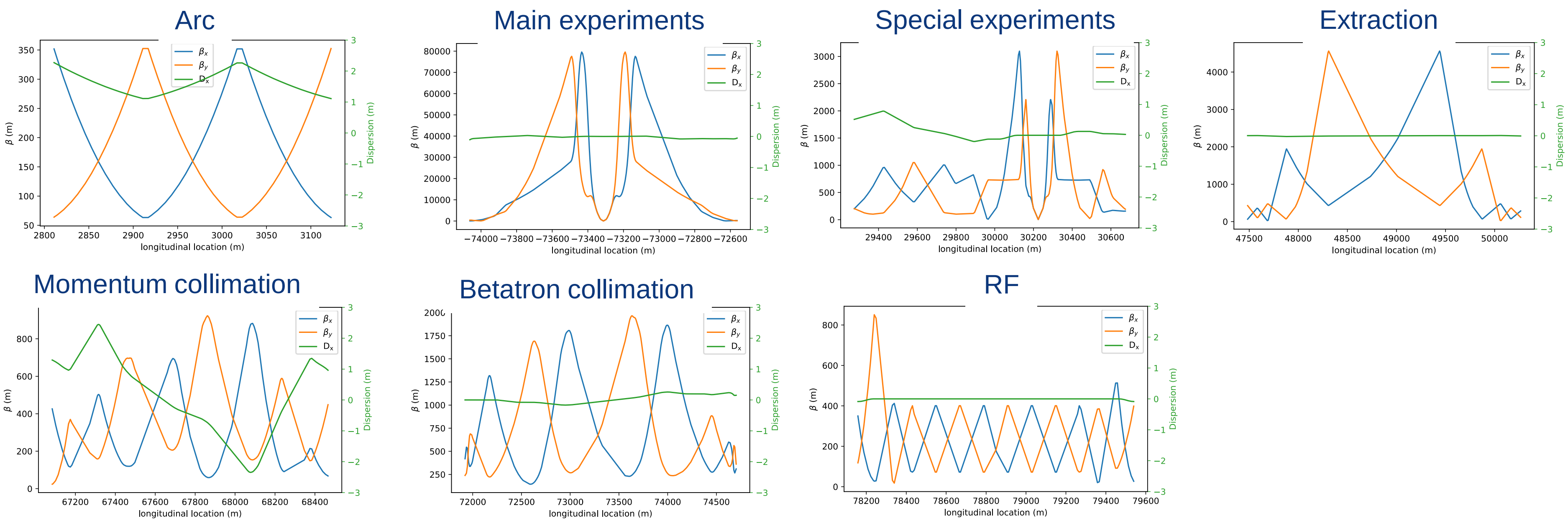
New features:

- **Overall length 97.75 km**
- **Economy length 2.25 km**
- Injections upstream side of experiments
- **Avoids mixing of extraction region and high-radiation collimation areas**

Taking this layout as fixed
(for CDR preparation)



Integrated FCC-hh lattice



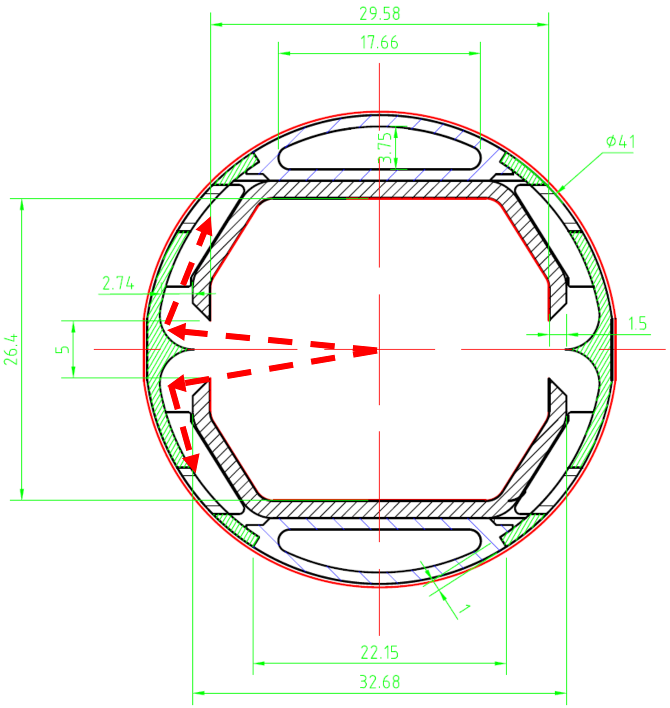
Full integrated lattice exists

- Lattice imperfection studies are progressing well, injection dyn. aperture OK, @collision ongoing
- Dynamic aperture optimization in iteration with magnet design (balancing errors at injection/collision)
- Tentative specifications for magnets correctors and alignment tolerances

Cryogenic beam vacuum

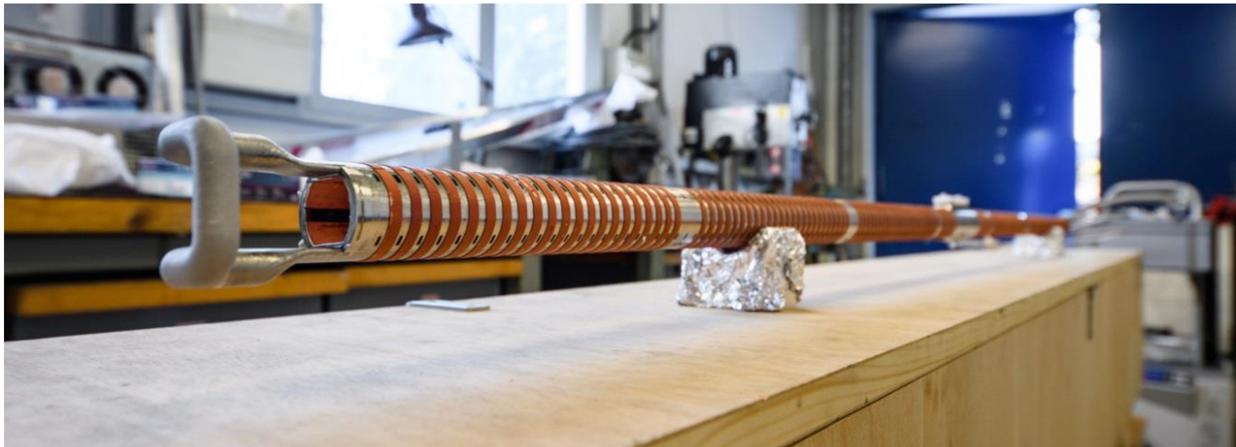
One of the most critical elements for FCC-hh

- Absorption of synchrotron radiation at ~50 K for cryogenic efficiency (5 MW total power)
- Provision of beam vacuum, suppression of photo-electrons, electron cloud effect, impedance, etc.

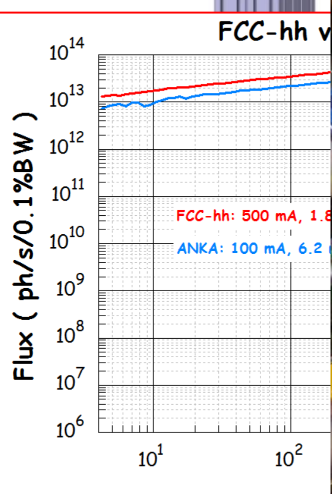


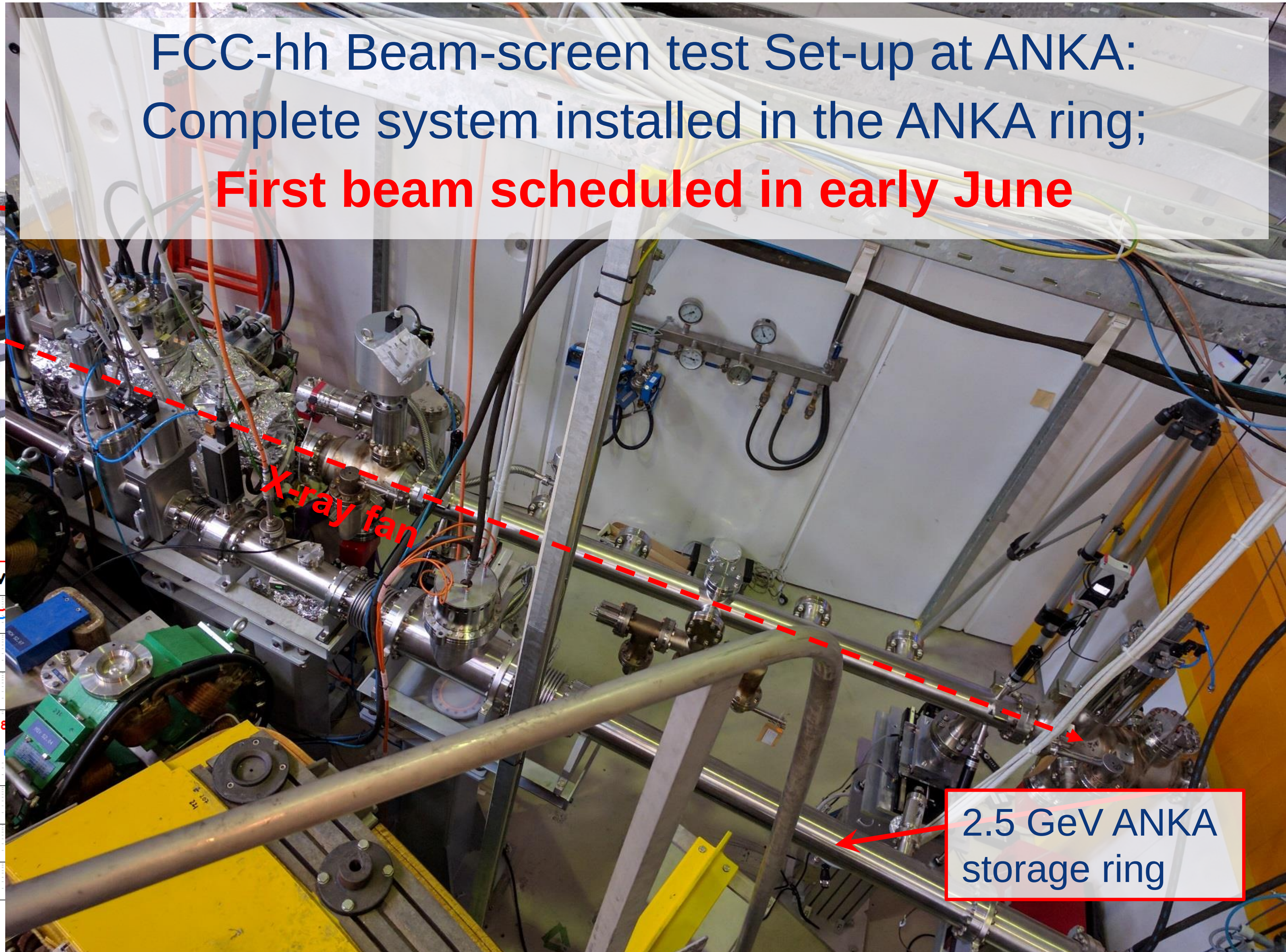
FCC Beamscreen prototype for test at ANKA:

Copper rings for heat transfer to cooling tubes



Beam screen tests @ ANKA





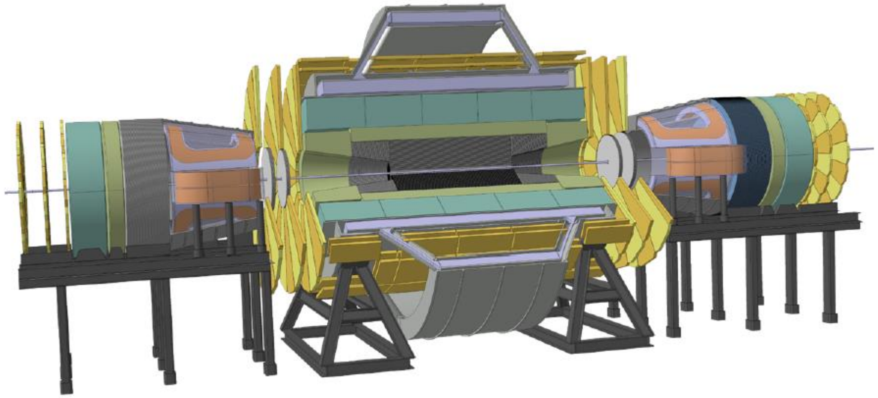
FCC-hh detector new reference design

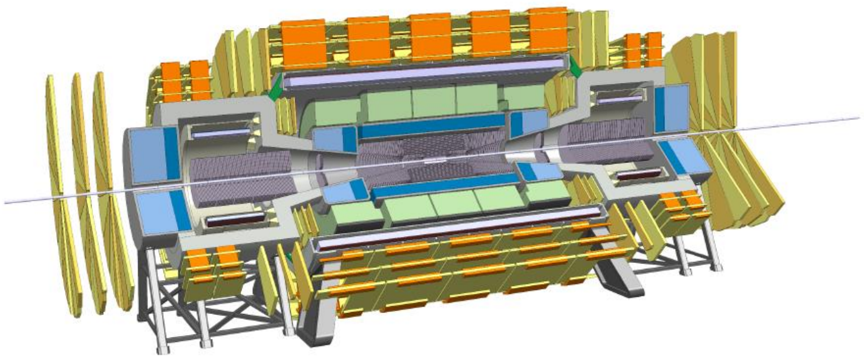
6T, 12m bore solenoid, 10Tm dipoles, shielding coil

→ 65 GJ Stored Energy
→ 28m Diameter
→ >30m shaft
→ Multi Billion project

4T, 10m bore solenoid, 4T forward solenoids , no shielding coil

→ 14 GJ Stored Energy
→ Rotational symmetry for tracking !
→ 20m Diameter (≈ ATLAS)
→ 15m shaft
→ ≈ 1 Billion project





Implementation
new footprint baseline

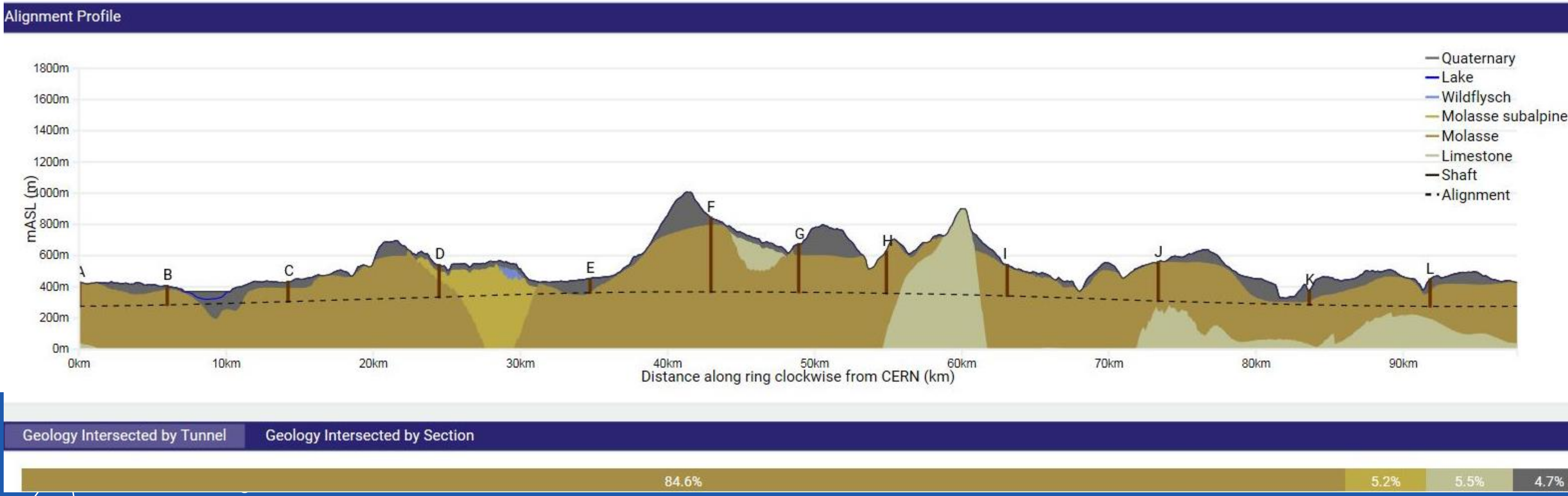
Optimisation in view of accessibility surface points, tunneling rock type, shaft depth, etc.

Tunneling

- Molasse 90%, Limestone 5%, Moraines 5%

Shallow implementation

- ~ 30 m below lakebed
- Reduction of shaft length and technical installations
- One very deep shaft **F** (RF or collimation), alternatives being studied, e.g. inclined access

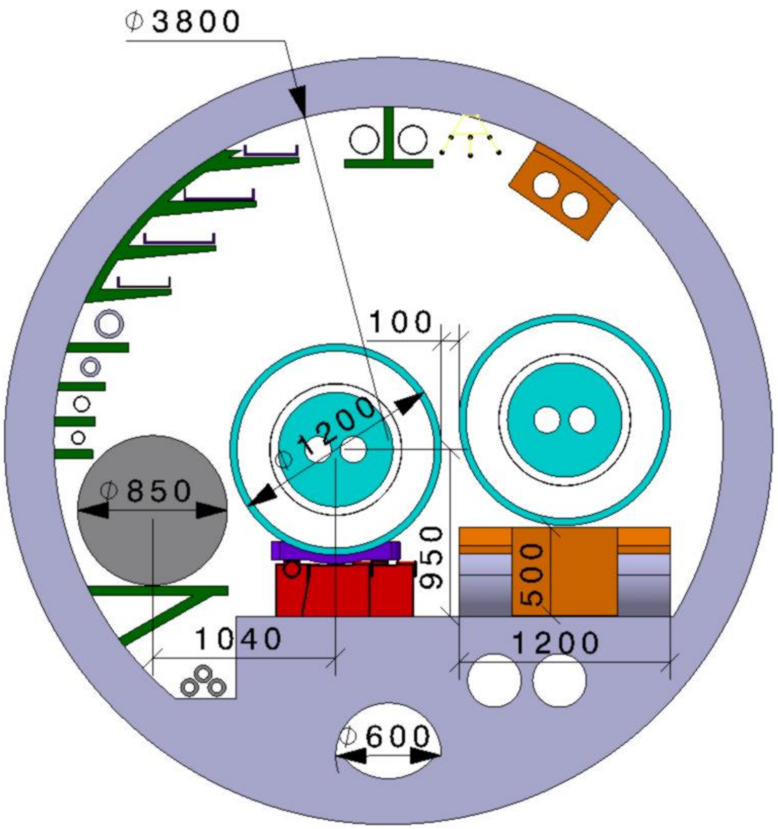


HE-LHC integration aspects

Present working hypothesis for HE LHC design:

No major CE modification on machine tunnel and caverns

- Similar geometry and layout as LHC machine and experiments
- Due to 16 T dipole field and increased cryogenic load, magnet cryostat and cryo distribution line (QRL) larger than for LHC.
- Challenges for tunnel integration and QRL & 16 T cryostat design.
- **Maximum magnet cryostat external diameter compatible with LHC tunnel: 1200 -1250 mm**
- **Classical 16 T cryostat design based on LHC approach gives ~1500 mm diameter!**



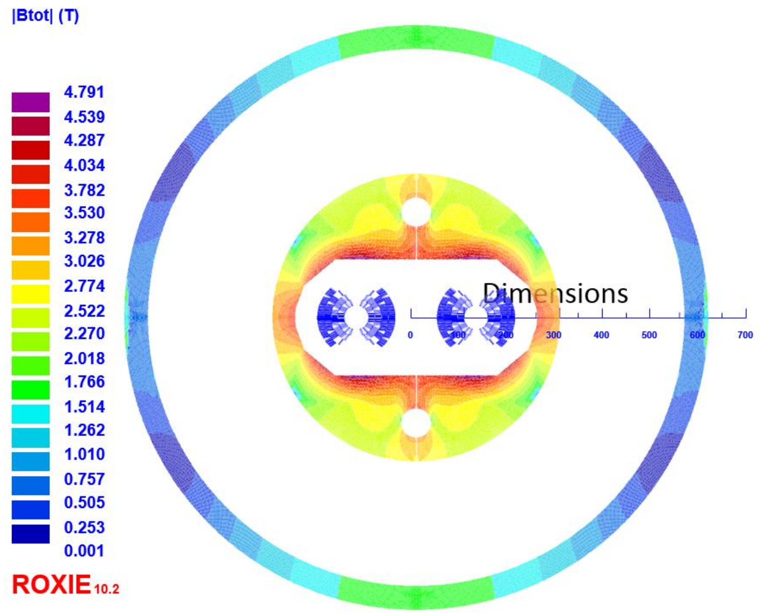
16 T dipole integration approach

Design strategy: develop a single 16 T magnet, compatible with both HE LHC and FCC-hh requirements:

- Goal is reduction of diameter to ~1200 mm
- Options und consideration:
  - Allow stray-field,cryostat as (partial) return-yoke
  - Active compensation with (simple) shielding coils
  - Optimization of inter-beam distance
  - *(QRL integrated in magnets, → negative impact on integral field because of longitudinal space required for service module (5%))*

- **Smaller diam. also relevant for FCC-hh**
- **→ Design optimization for specific project after decision**

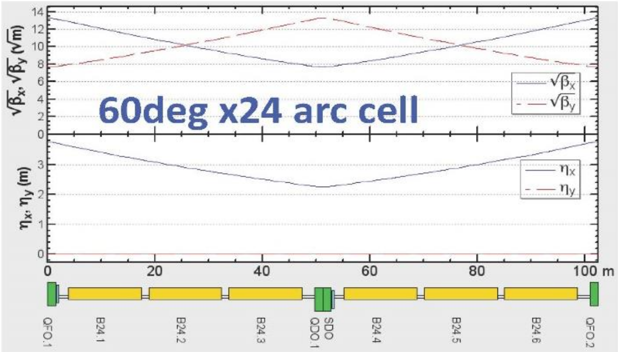
Example magnetic cryostat coldmass 40t, total mass 62t

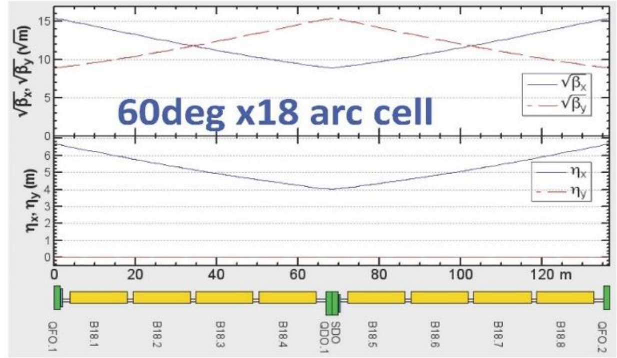


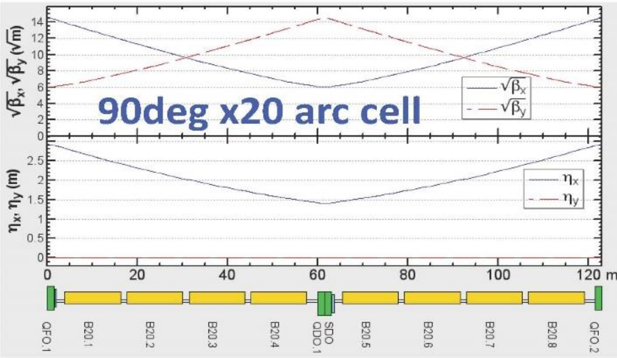
Only magnetic elements shown

Description	ID in mm	OD in mm
Iron yoke	-	600
Aluminium shrinking cylinder	600	740
Stainless steel He tight shell	740	760
Al radiation shield	934	940
Vacuum vessel (magnetic steel)	1120	1220

HE-LHC optics design work







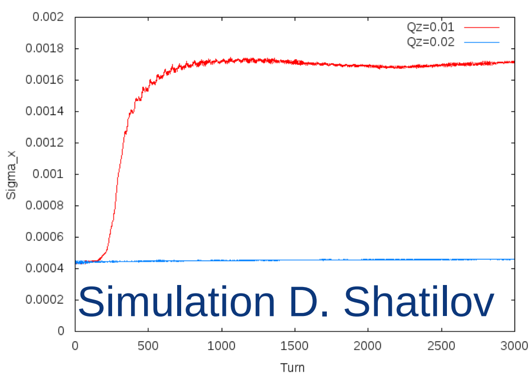
Studying various arc-cell options, optimizing dipole field, quadr. & sext. strengths, geometry & dynamic aperture, aperture requirements, injection energy, etc.

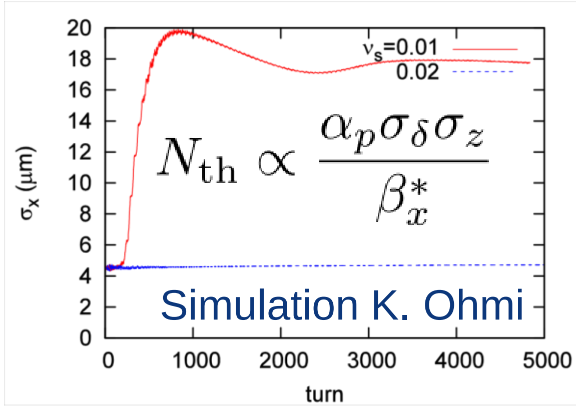
	24 x 60 deg	18 x 60 deg	20 x 90 deg
dipole length, m	13.56	14.1	12.39
number of dipoles	1280	1280	1424
dipole field, T	16.3	15.68	16.04
cell quad gradient, T/m	289.5	215.9	340.0

FCC-ee new optics baseline

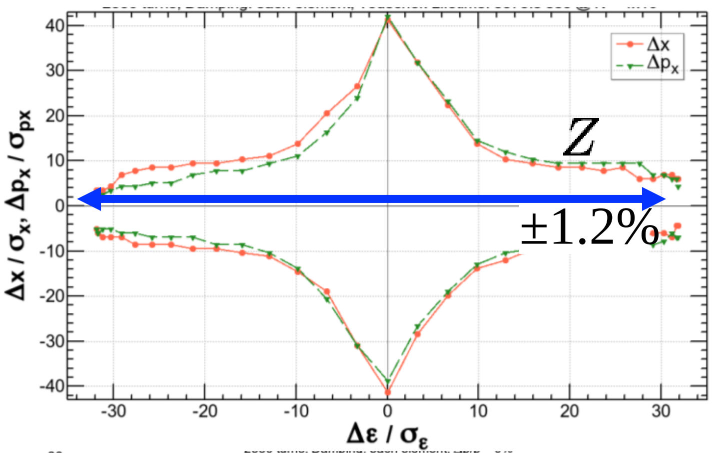
Motivations for optics changes since Rome:

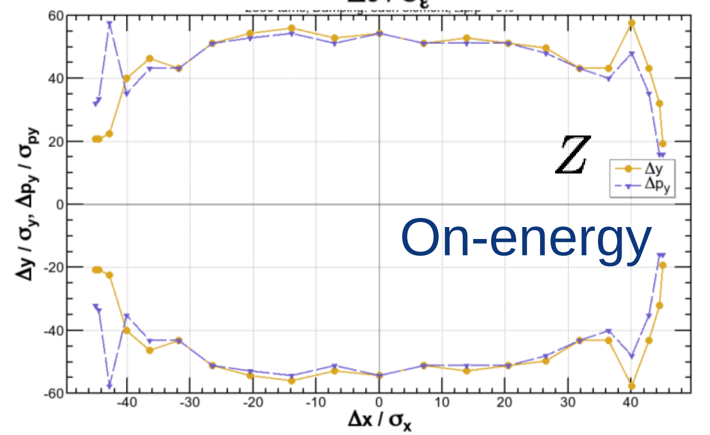
- Mitigation coherent beam-beam instability at Z working point
    - Smaller βx*
    - 60°/60° cell in the arc (larger emittance and momentum compaction), also mitigates microwave instability
- Fitting ee layout to the footprint of FCC-hh layou
- Adapt optics for the "Twin Aperture Quadrupole scheme for arc quadrupoles





Dynamic aperture studies
45.6 GeV, $\beta^*_{x,y}$ = (0.15 m, 1 mm)

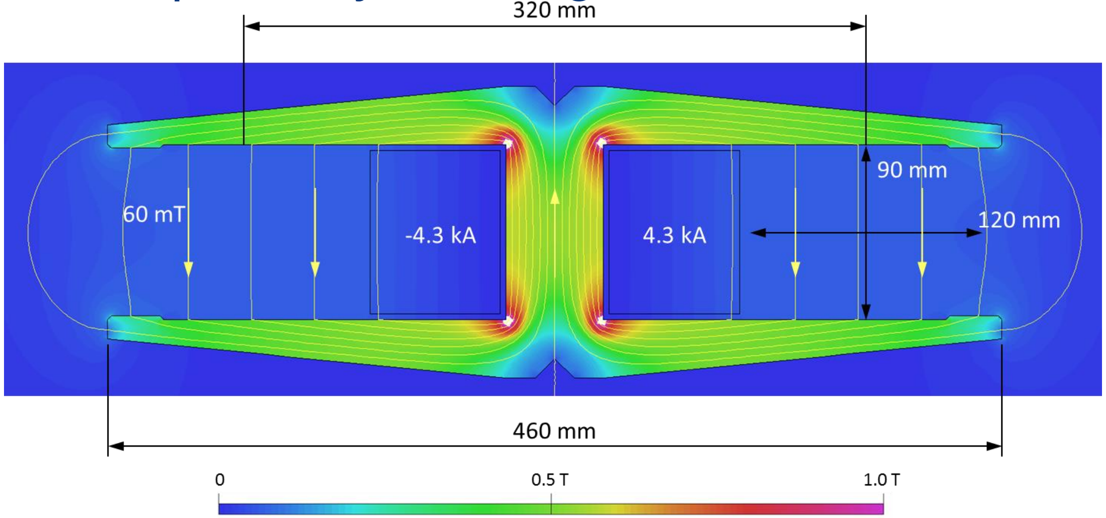




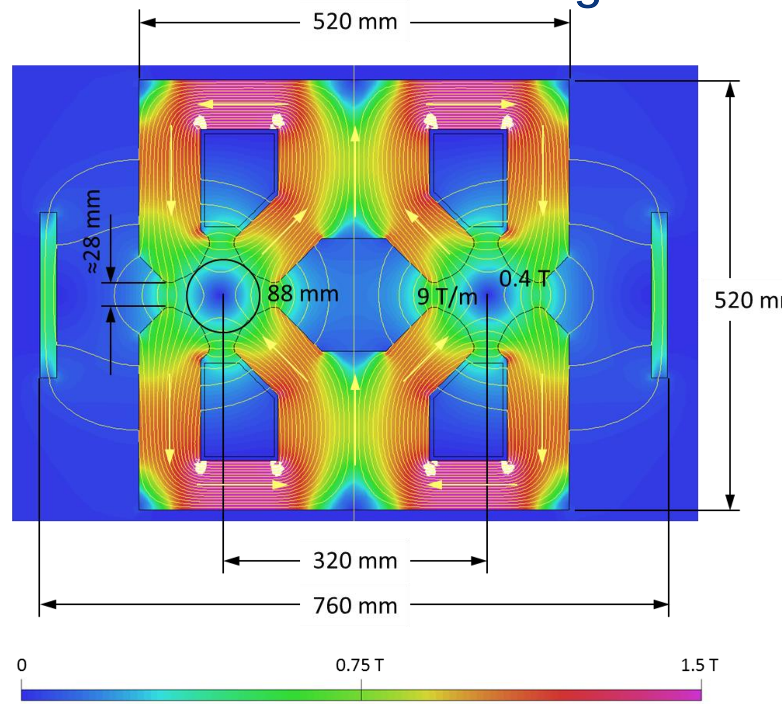
FCC-ee dual aperture main magnets

Prototypingof main dipole and quadrupole magnets (~1 m units)

Dipole:
twin aperture yoke, single busbars as coils



Quadrupole:
twin 2-in-1 design



- **Considerable savings in Ampere-turns and power consumption by novel dual aperture designs**
- **Power consumption twin quad: 22 MW at 175 GeV with Cu coil (half of single-aperture quads) and power consumption twin dipole: = 17 MW at 175 GeV with Al bus bar**

FCC-ee RF staging scenario

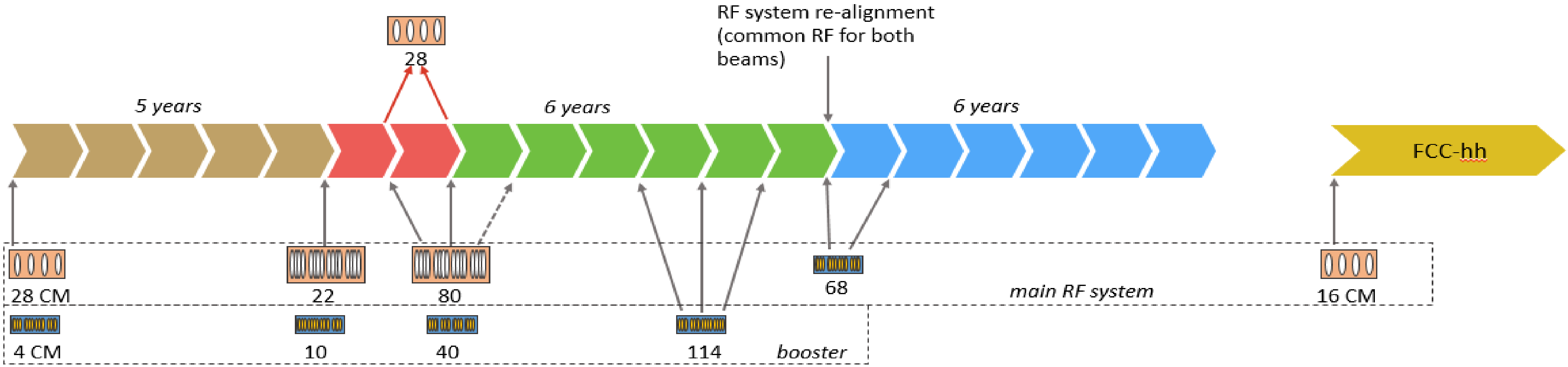
Three sets of RF cavities to cover all options FCCee & Booster:

"Ampere-class" machine

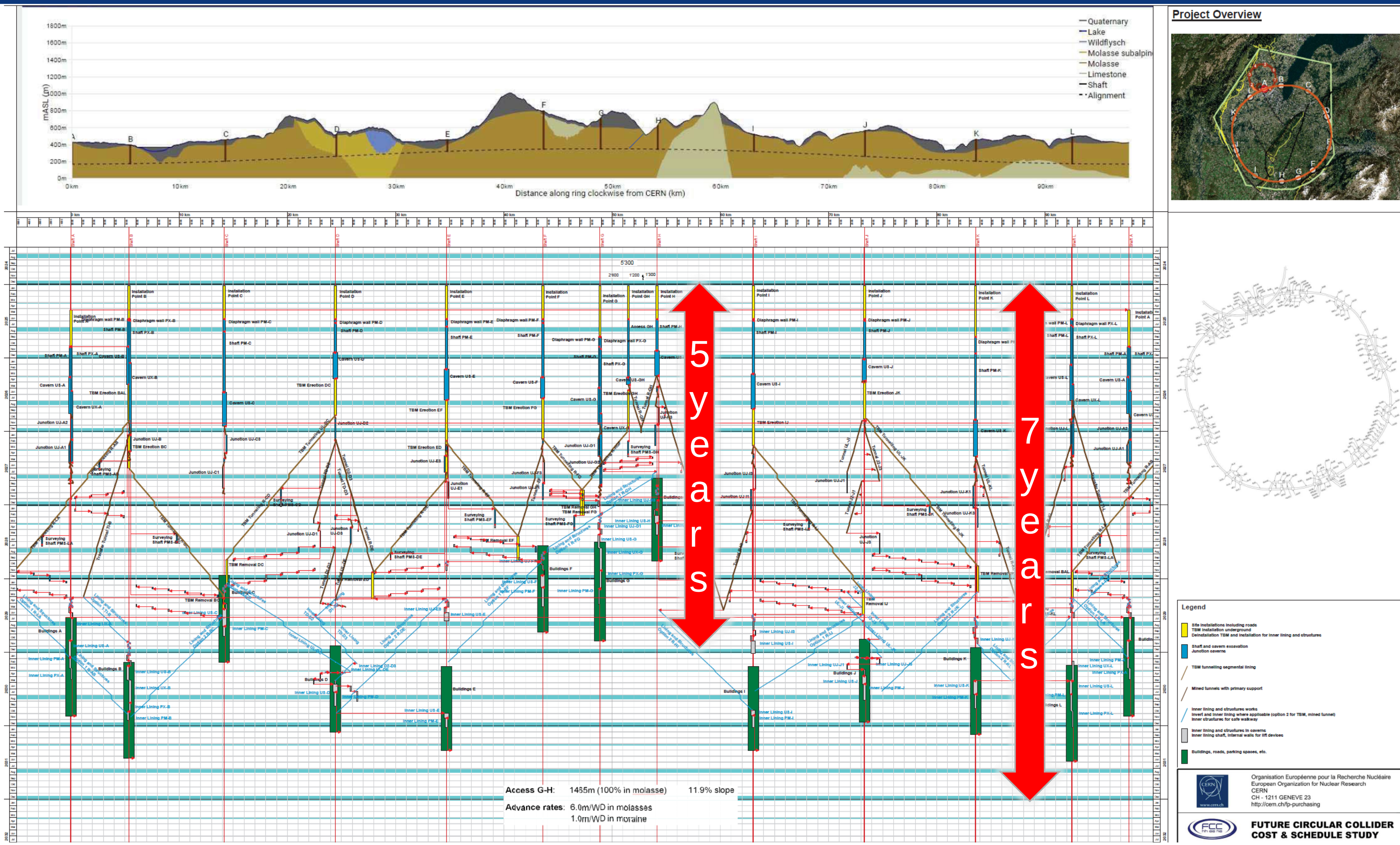
	V_tot (GV)	n_bunch	I_beam (mA)
Z	0.2	91500	1450
W	0.8	5260	152
H	3	780	30
t	10	81	6.6

"high gradient" machine

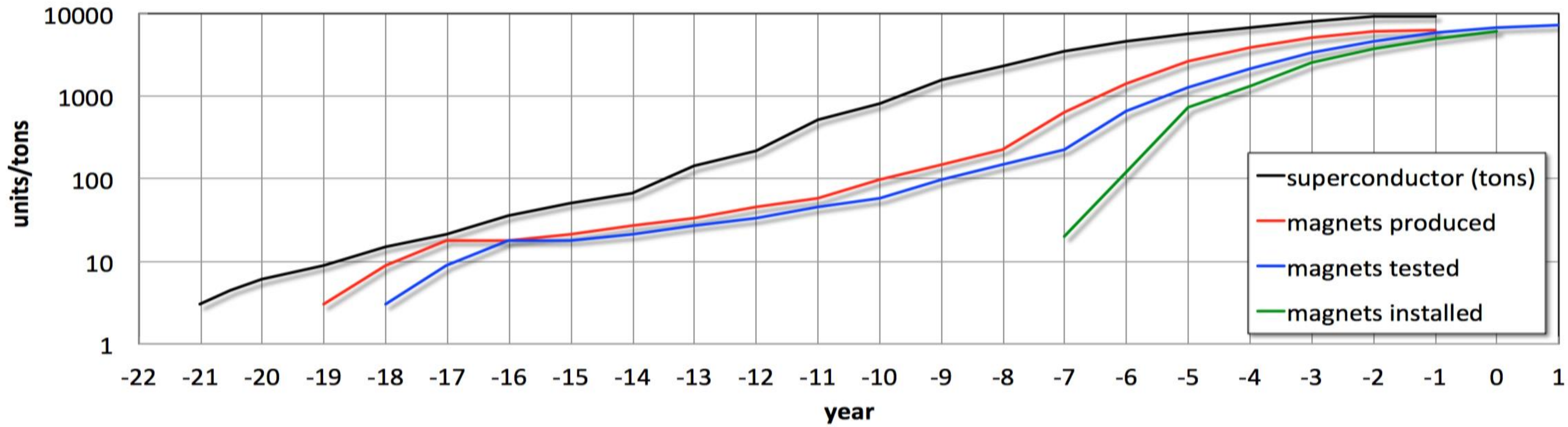
- **Installation sequence comparable to LEP (≈30 CM/shutdown)**
- **high intensity (Z, FCC-hh): 400 MHz mono-cell cav, ≈ 1MW source**
- **high energy (W,H,t): 400 MHz four-cell cavities**
- **booster and t machine complement: 800 MHz four-cell cavities**

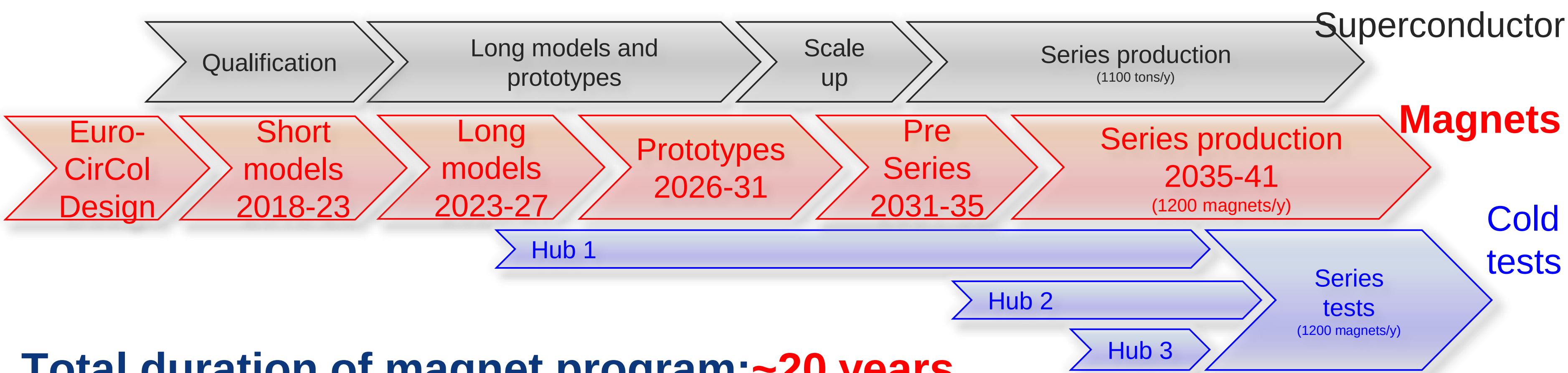


CE schedule studies



16 T magnet R&D schedule

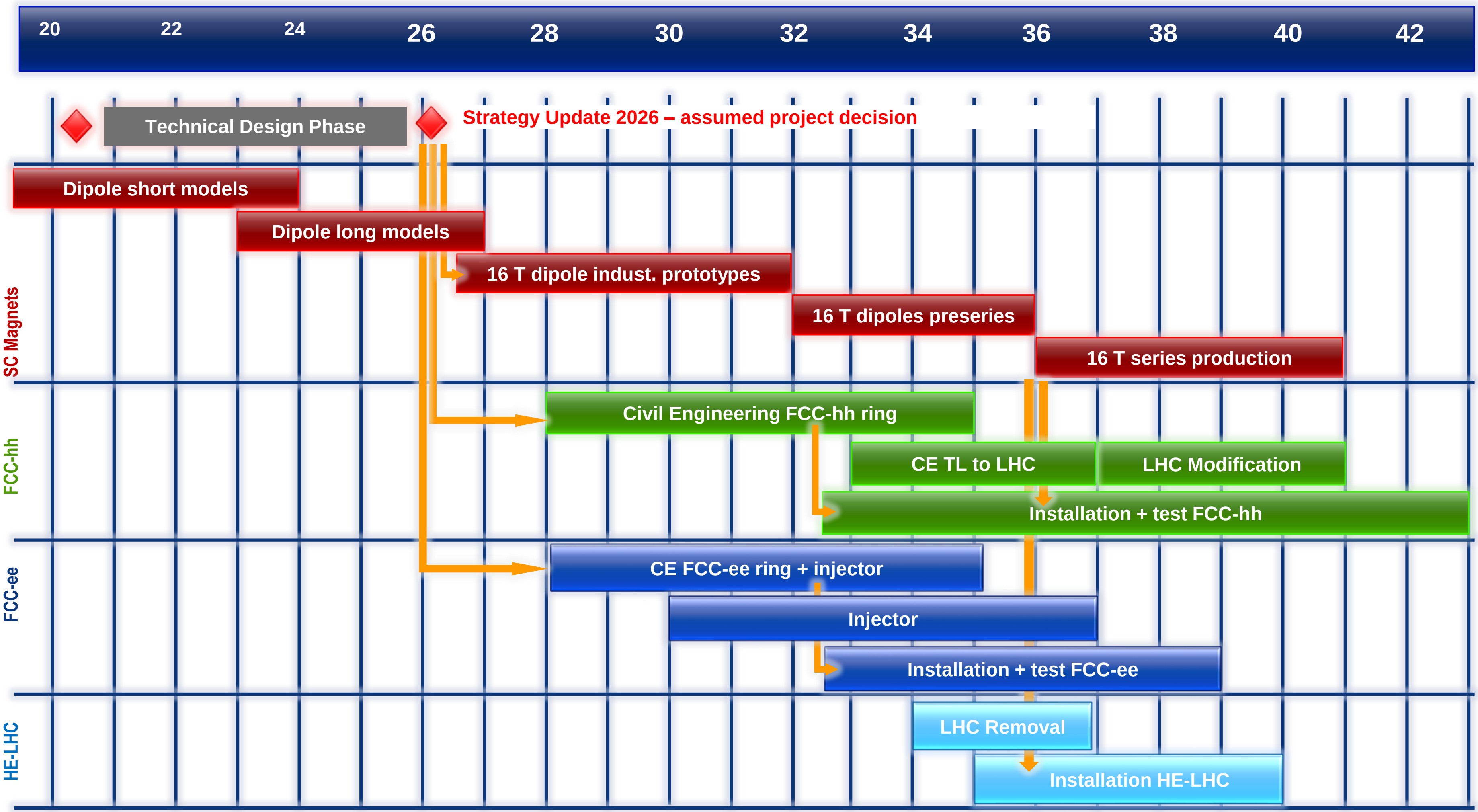




Total duration of magnet program:~20 years

Follows HL-LHC Nb3Sn program with long models in industry from 23/24

Draft Schedule Considerations

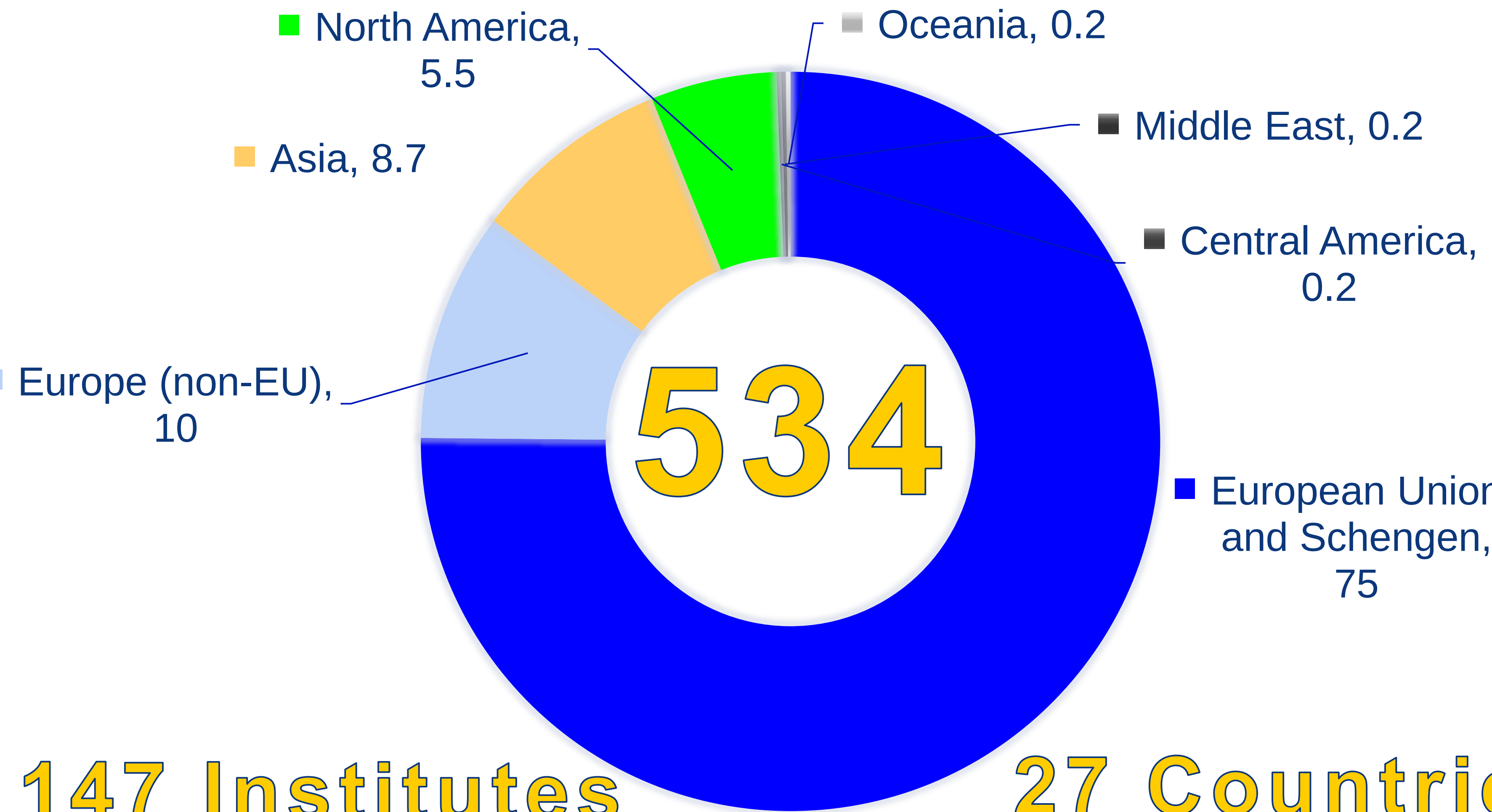


\FCC Week 29 May – 2 June 2017

Tuesday (30.5)				Wednesday (31.5)					Thursday (1.6)			
FCC-hh machine design review Design (1)	Conductor Development Program (1)	*FCC-ee physics & experiment review Run plan and SM precision measurements*	SRF Recent designs and progress	FCC-hh machine design: SppC and selected topics	16 T magnets review EuroCirCol (1)	*FCC-hh review Physics potential of FCC-hh*	FCC-ee review Optics & instrumentation		Special technologies Beam vacuum	I&O review CE, electricity, ventilation, logistics, transport	FCC-ee Beam dynamics	*FCC-hh experiment review Calorimetry & trigger*
R. Aleksan (CEA)	A. Ballarino (CERN)	G. Iacobucci (UNIGE)	R. Rimmer (JLAB)	A. Faus-Golfe (CNRS)	E. Todesco (CERN)	J. Lykken (FNAL)	J. Seeman (SLAC)		F. Perez (ALBA)	C. Prasse (FIML)	B. Holzer (CERN)	B. Heineman (DESY)
Coffee Break				Coffee Break					Coffee Break			
FCC-hh machine design review Design (2)	Conductor Development Program (2)	*FCC-ee physics & experiment review Higgs, top and flavour*	SRF Materials	FCC-hh machine design: Selected topics	16 T magnets review EuroCirCol (2)	Common experiment software	FCC-ee review Machine Detector Interface		Special technologies Other directions for R&D	16 Tesla magnets US Programme	FCC-ee review Injector	*FCC-hh experiment review Physics performance*
F. Cerutti (CERN)	C. Senatore (UNIGE)	D. Bortoletto (UOXF)	V. Palmieri (INFN LNL)	O. Boine-Frankenheim (TU Darmstadt)	A. Zlobin (FNAL)	P. Allport (Uni Birmingham)	K. Oide (KEK)		A. Ryazanov (Kurchatov)	P. Vedrine (CEA)	I. Papaphilippou (CERN)	A.Etienvre (CEA)
Lunch				Lunch				International Advisory Committee (closed session)	Lunch			EuroCirCol mid-term review (closed session)
								G. Dissertori (ETH)				R. Aleksan (CEA)
FCC-hh machine design review Beam performance and specifications	Conductor Development Program (3)	*FCC-ee physics & experiment review Direct discovery & detectors*	SRF review RF system concepts and requirements	Special technologies review FCC-hh beam handling	16 T Magnets Models & Technology ERMC-RMM-Wound Conductor	*FCC-hh experiment review Detector requirements & concepts*	FCC-ee review Energy calibration & polarization	Economic impact of CERN colliders (1)	Special technlogies Other Magnets	I&O review Cryogenics	*FCC-he review Accelerator & interation region*	Comon detector technologies
M. Migliorati (INFN)	D. Larbalestier (Florida State Uni)	L. Linssen (CERN)	J. Zhai (IHEP)	M. Sullivan (SLAC)	S. Gourlay (LBL)	D. Charlton (Uni Birmingham)	E. Levichev (BINP)	M .Florio (Uni Milano)	E. Fischer (GSI)	D. Delikaris (CERN)	R. Assmann (DESY)	G. Tonelli (INFN)
Coffee Break				Coffee Break					Coffee Break			
FCC-hh machine design review Injectors	Conductor: Electromechanical characterization	*FCC-ee physics & experiment review Synergies & complementarities*	SRF review Directions for R&D	Special technologies review Recent design & progress	Other Magnets	*FCC-hh experiment review Magnet & tracking*	FCC-ee review Collective effects & top-up injection	Economic impact of CERN colliders (2)	I&O review Operation, reliability, safety	16 Tesla magnet review Status towards the CDR	FCC-eh: Physics	HE LHC design
P. Spiller (GSI)	M. Eisterer (TU Vienna)	J. Ellis (Uni London)	S. Posen (FNAL)	S. Casalbuoni (KIT/ANKA)	T. Ogitsu (KEK)	N. Wermes (Uni Bonn)	M. Biagini (INFN)	M .Florio (Uni Milano)	Ll. Mirales (CERN)		M. D'Onofrio	A. Seryi (JAI)

- **Total 260 presentations and 50 poster contributions**
- **EuroCirCol mid-term review integrated, reviewer: Prof. O. Kester**

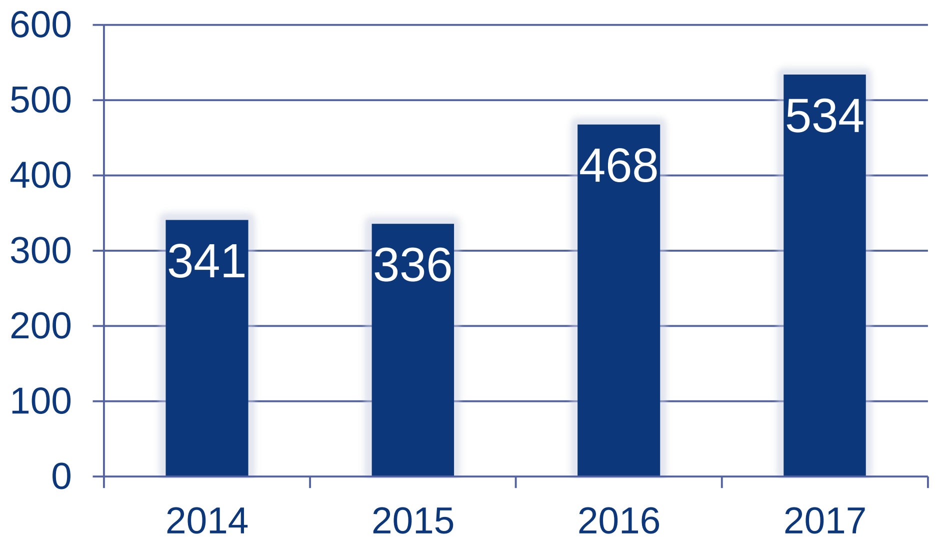
FCC Week participants by region

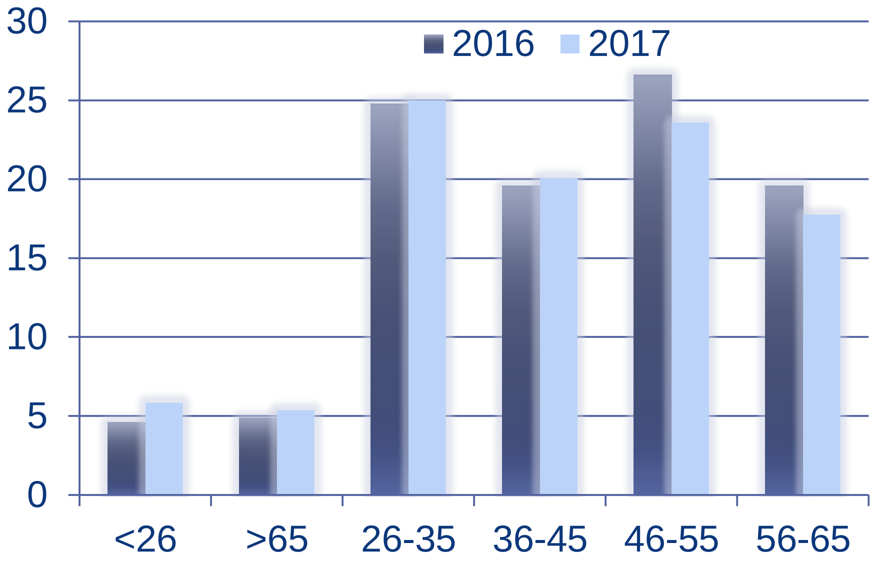


147 Institutes

27 Countries

FCC Week Participants





Conceptual Design Report

1 – PHYSICS

Physics opportunities across all scenarios

2 Hadron Collider Summary

3 – Hadron Collider Comprehensive

- Accelerator
- Injectors
- Technologies
- Infrastructure
- Operation
- Experiment
- eh

4 Lepton Collider Summary

5 – Lepton Collider Comprehensive

- Accelerator
- Injectors
- Technologies
- Infrastructure
- Operation
- Experiment

6 High Energy LHC Summary

7 – High Energy LHC Comprehensive

- Accelerator
- Injectors
- Infrastructure

Refs to FCC-hh, HL-LHC, LHeC

CDR planning

2017
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2018
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct

- ToC & Volume layout definition | Jun
- Guidelines, tools ready, editorial teams operational | Sep
- VOLUME EDIT STARTS | Oct
- Contents review by IAC (FCCWeek) | Apr 9-13
- Review session with IAC | May 15
- END OF VOLUME EDIT | June 30
- Overall editing: Proofread, homogenization, cross-referencing, polishing
- END of Final edit | Aug 31
- PRINT FINISHED | Oct 26

H2020 EASITrain ITN

European Advanced Superconductivity Innovation & Training Network

- **Selected for funding by EC in May 2017**
- **15 Early Stage Researchers (not yet PhD) paid for 36 months.**
- **Start: 1. October 2017, Duration: 48 months**
- **Timeline and events:**
  - **Kick-off meeting: 5. – 6. September 2017 at CERN**
  - **All job applications until 1. October 2017 – job offers published**
  - **All jobs filled until 31. December 2017**
  - **Introduction Workshop at CERN, 11. – 23. March 2018**
  - **EASISchool 1 in Vienna, Austria, 19. – 31. August 2018**
- **Status:**
  - **Declaration of Honour signed by all beneficiaries and partners**
  - **Financial planning completed with CERN FI and distributed**
  - **Consortium agreement (based on DESCA model) completed with CERN LS, distribution this week**

EASITrain Topics

- SC wires at low temperatures for magnets (Nb_3Sn, MgB_2, HTS)
- Superconducting thin films for RF and beam screen (Nb_3Sn, Tl)
- Electrohydraulic forming for RF structures
- Turbocompressor for Nelium refrigeration
- Magnet cooling architectures

I-CUBE

13 Beneficiaries

12 Partners

Collaboration & Industry Relations