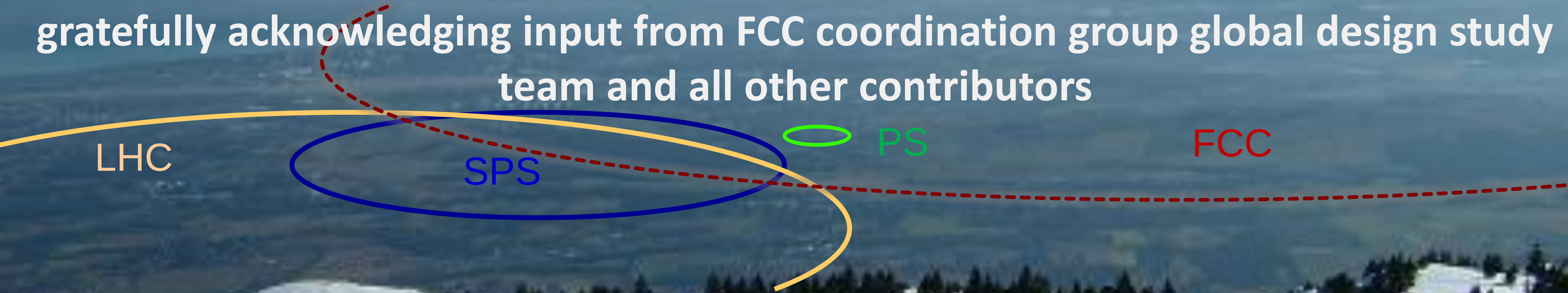
Future Circular Collider Study - Status

Michael Benedikt

gratefully acknowledging input from FCC coordination group global design study team and all other contributors



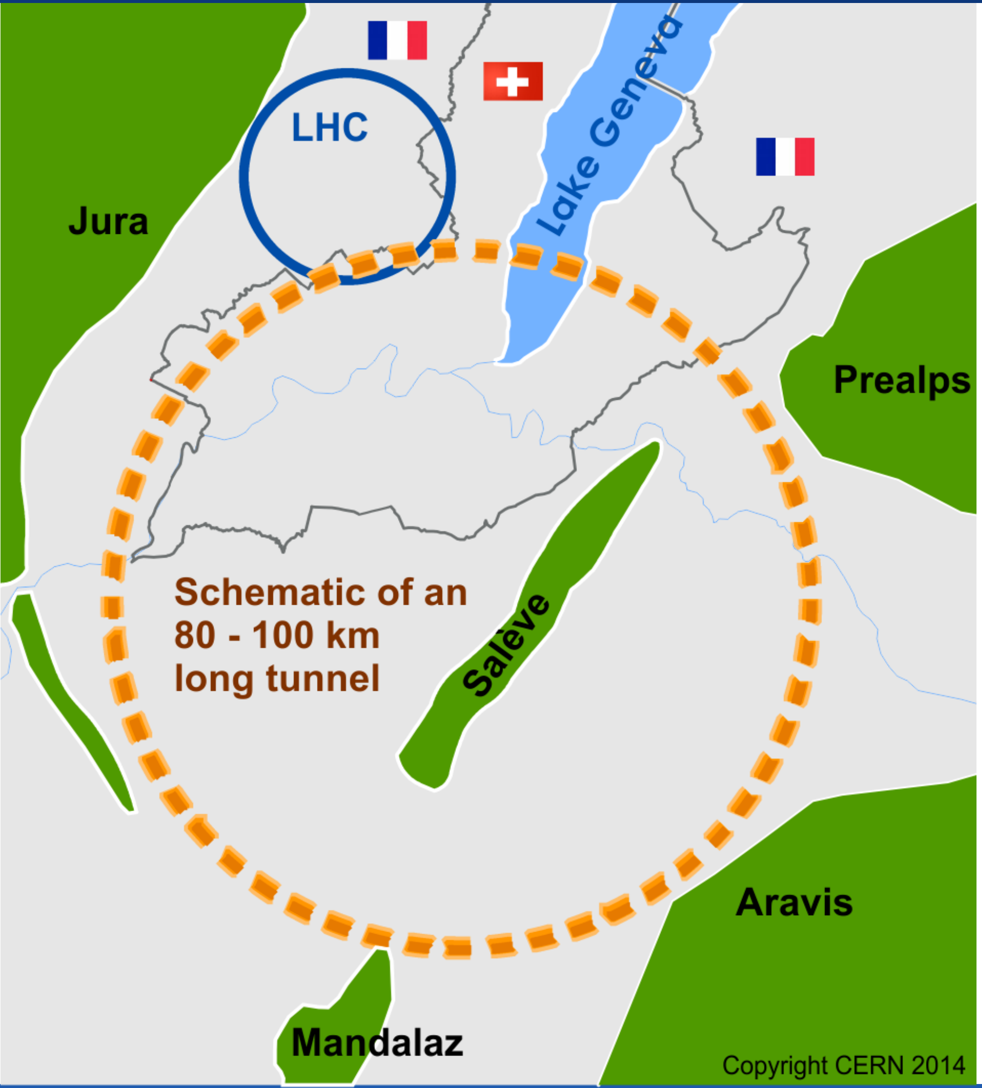
FCC hh ee he

EuroCirCol

http://cern.ch/fcc

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

Scope of FCC Study

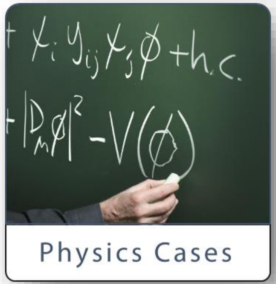


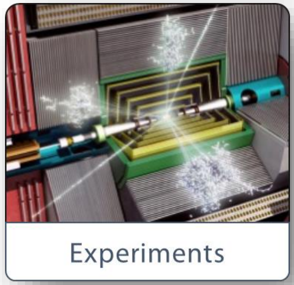
International FCC collaboration (CERN as host lab) to study:

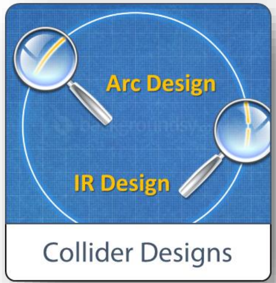
- ***pp*-collider (*FCC-hh*)**
  → main emphasis, defining infrastructure requirements

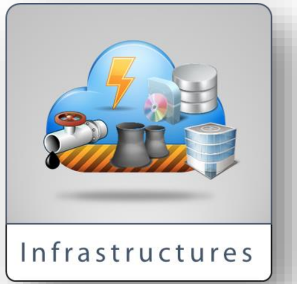
  ~16 T ⇒ 100 TeV *pp* in 100 km

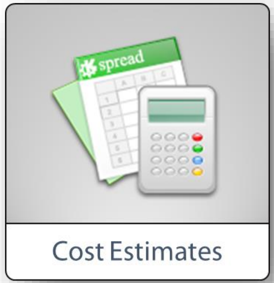
- **~100 km tunnel infrastructure** in Geneva area, site specific
- ***e^+e^-* collider (*FCC-ee*),** as potential first step
- **HE-LHC** with *FCC-hh* technology
- ***p-e* (*FCC-he*) option,** integration of one IP, e from ERL
- **CDR for end 2018**



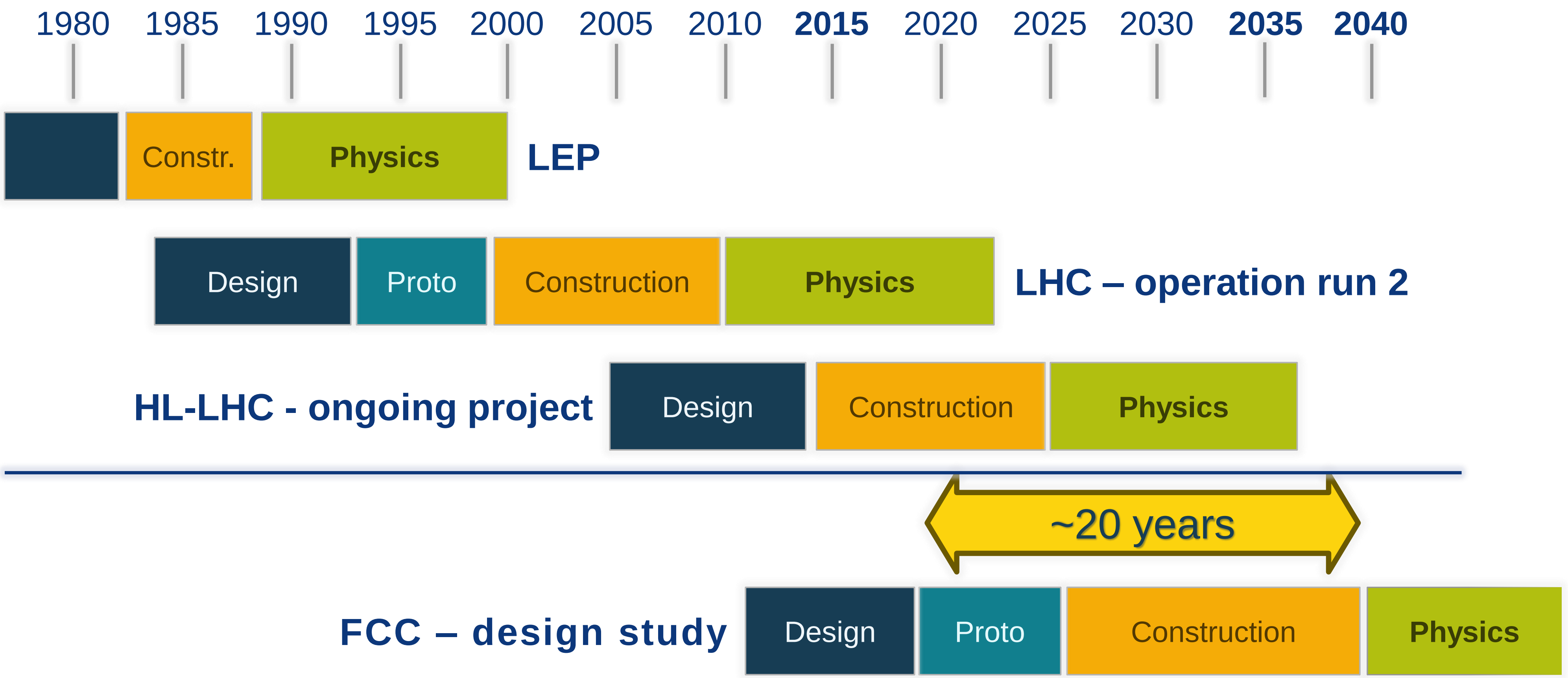








CERN Circular Colliders & FCC



Must advance fast to be ready with new research infrastructure for ~ 2040
Goal of phase 1: CDR by end 2018 for next update of European Strategy

FCC-pp collider 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 collider 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

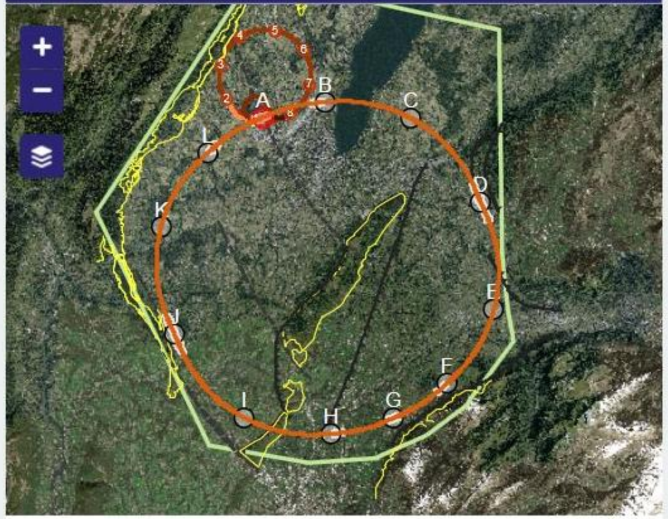
Implementation - new footprint baseline

Alignment | Shafts | Query

Choose alignment option
V4variation_v2017-2
Tunnel elevation at centre:322mASL
Grad. Params
Azimuth (°): -23.5
Slope Angle x-x(%): 0.3
Slope Angle y-y(%): 0.08
LOAD | SAVE | CALCULATE
Alignment centre
X: 2499941 Y: 1107760

	CP 1		CP 2	
	Angle	Depth	Angle	Depth
LHC	37°	49m	-40°	83m
SPS		121m		126m
TI2		121m		126m
TI8		51m		118m

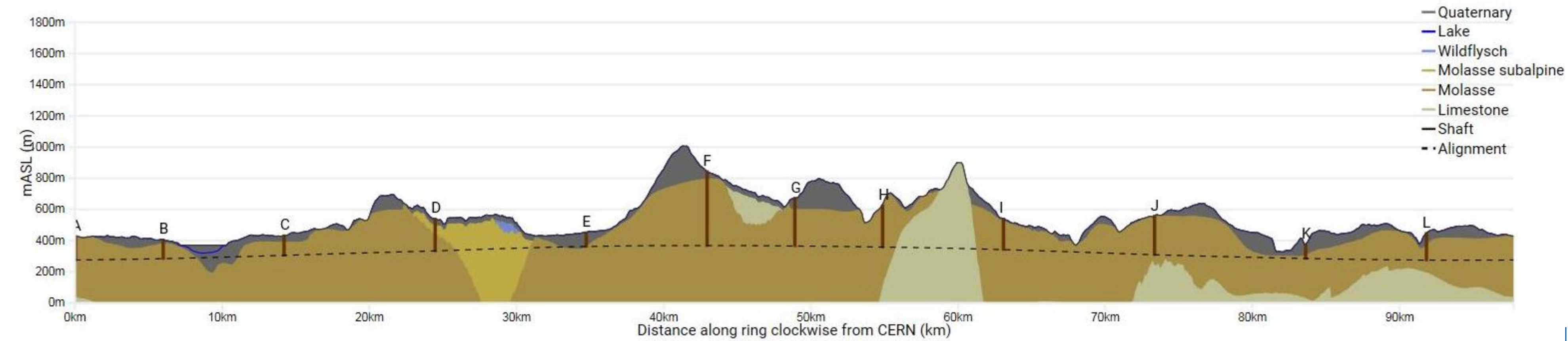
Alignment Location



Geology Intersected by Shafts | Shaft Depths

	Shaft Depth (m)			Geology (m)			
Point	Actual	Molasse SA	Wildflysch	Quaternary	Molasse	Urgonian	Limestone
A	152	0	0	0	152	0	0
B	121	0	0	26	95	0	0
C	127	0	0	44	83	0	0
D	205	66	0	40	100	0	0
E	89	0	0	89	0	0	0
F	476	0	0	49	427	0	0
G	307	0	0	73	234	0	0
H	266	0	0	0	266	0	0
I	198	0	0	11	187	0	0
J	248	0	0	1	247	0	0
K	88	0	0	70	18	0	0
L	172	0	0	89	83	0	0
Total	2449	66	0	492	1892	0	0

Alignment Profile



Geology Intersected by Tunnel | Geology Intersected by Section

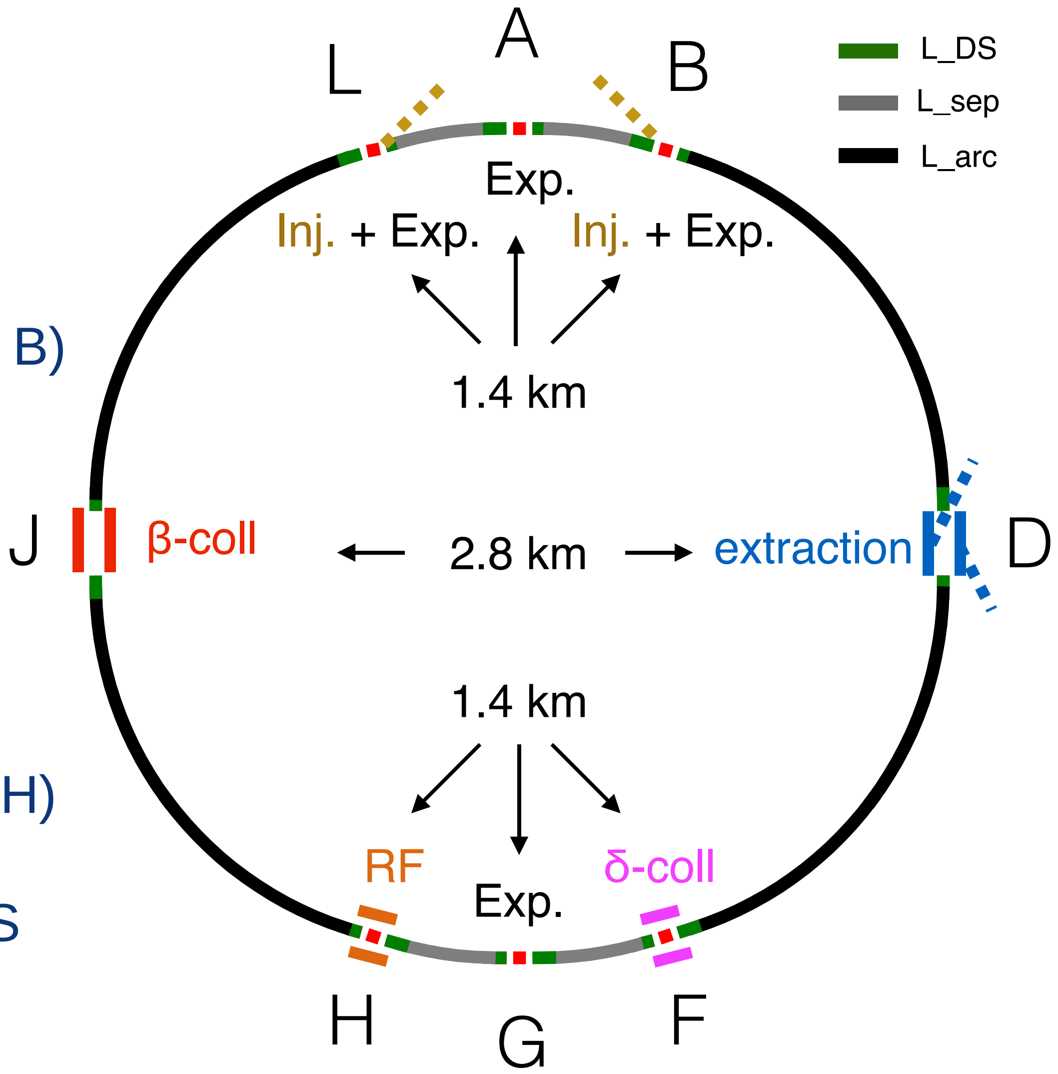
Optimisation criteria
- tunneling rock type,
- shaft depth accessibility
- surface points, etc.

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

Present status on implementation
- 90-100 km fits well geological situation in Geneva basin
- LHC suitable as potential injector

FCC-hh layout and optics

- Two high-luminosity experiments (A & G)
- Two other experiments combined with injection (L & B)
- Two collimation insertions
  - Betatron cleaning (J)
  - Momentum cleaning (F)
- Extraction insertion (D)
- Clean insertion for RF only (H)
- Compatible with LHC or SPS as injector



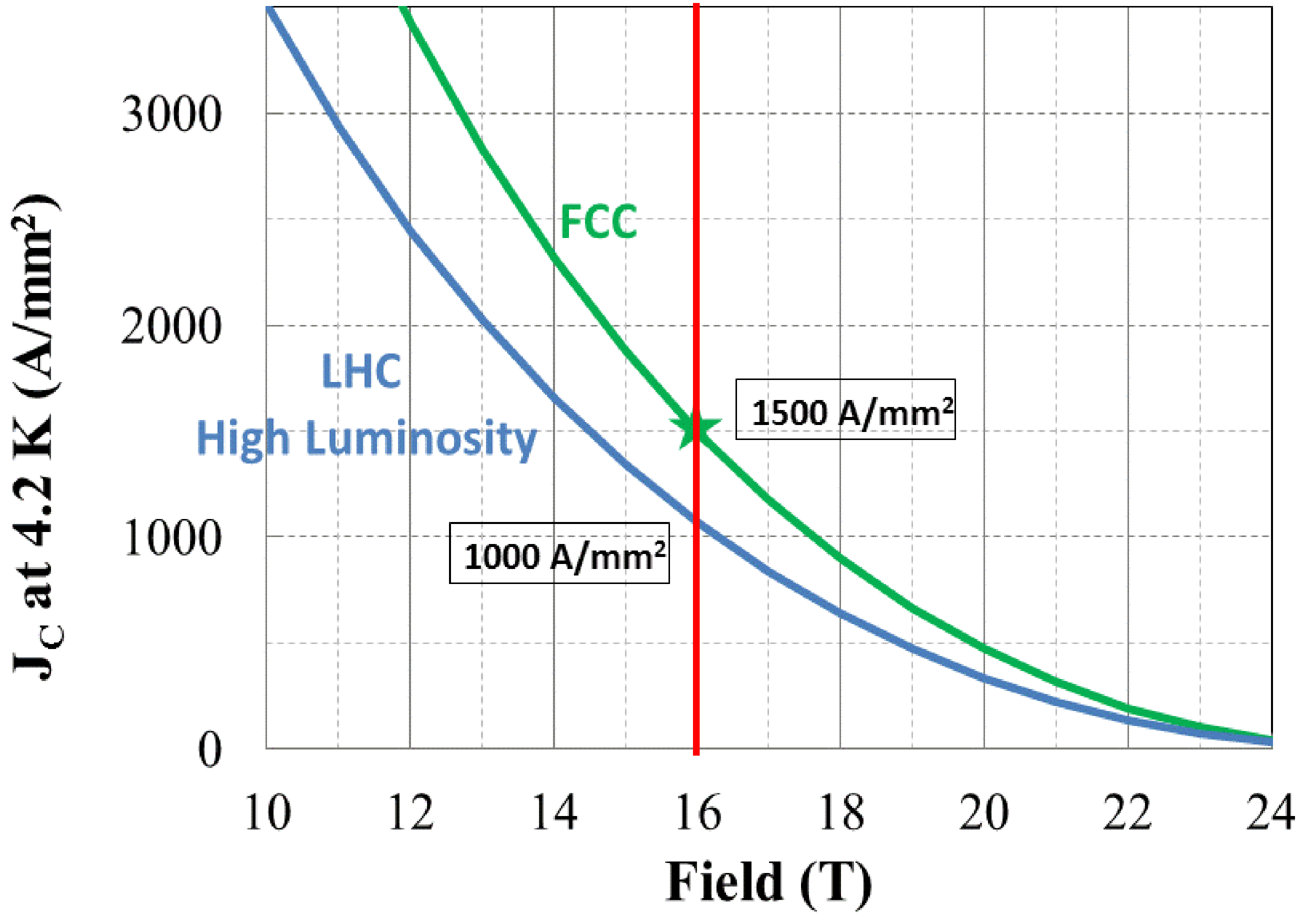
Full integrated lattice existing

- **Beam dynimcs studies confirm design goals**
- **Focus on optimization of collimation system and extraction system performances**

- **Based on EuroCirCol DS**
- **Contributions from EPFL**

Nb_3Sn conductor program

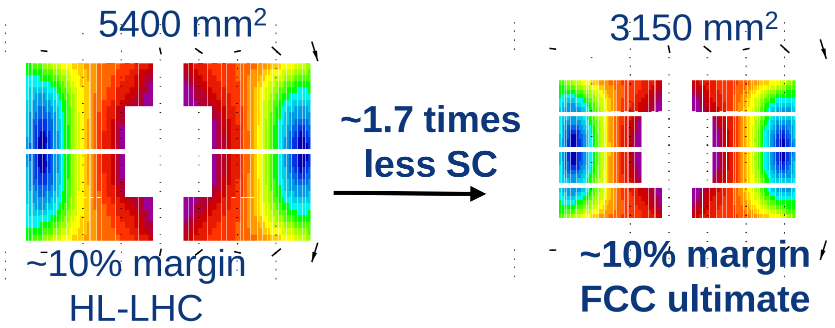
Nb_3Sn is one of the major cost & performance factors for FCC-hh / HE LHC



Main development goals until 2020:

- J_c increase (16T, 4.2K) > 1500 A/mm² i.e. 50% increase wrt HL-LHC wire
- R&D collaborations with TU Wien and Uni Geneva (amongst others)

Impact on coil section and conductor mass



HE-LHC integration aspects

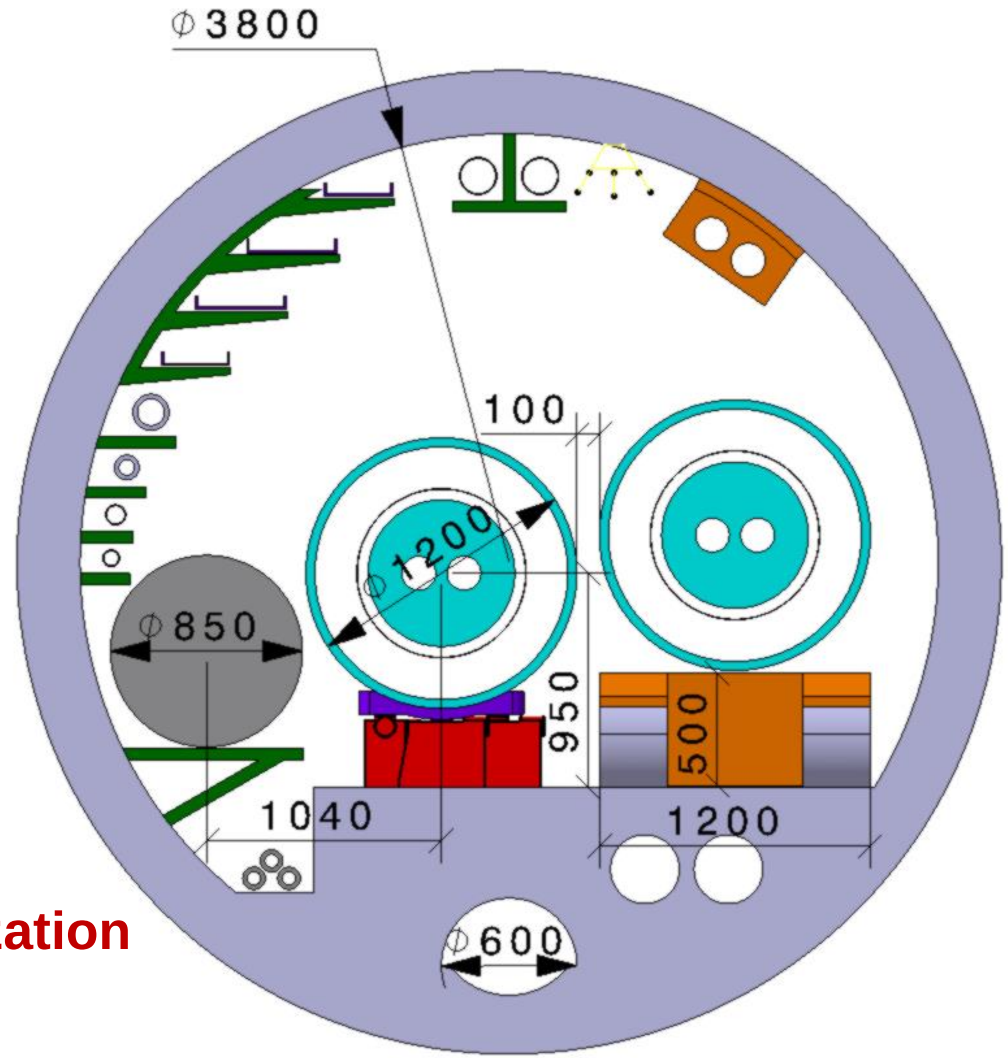
Requirement: No major CE tunnel modifications

- **Maximum magnet cryostat external diameter compatible with LHC tunnel ~1200 mm**
- **Classical 16 T cryostat design based on LHC approach gives ~1500 mm diameter!**

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

- **Allow stray-field and/or cryostat as return-yoke**
- Active compensation with (simple) shielding coils
- **Optimization of inter-beam distance (compactness)**

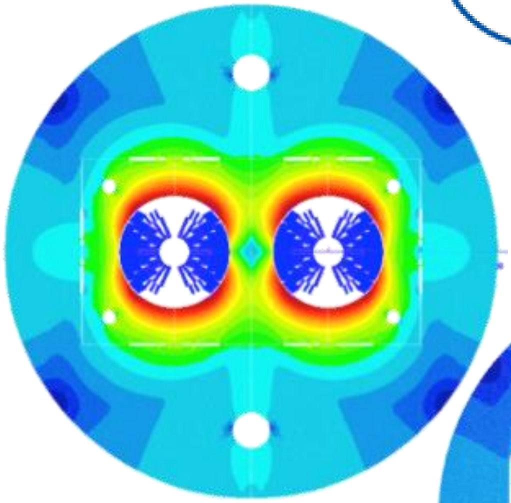
→ **Smaller diam. also relevant for FCC-hh cost optimization**



16 T dipole design activities and options

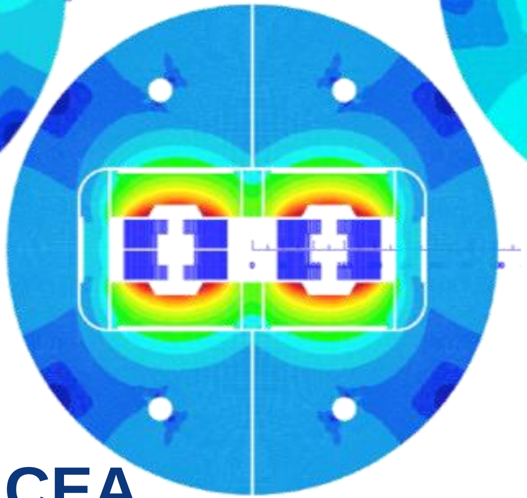
H2020 EuroCirCol A key to New Physics

Cos-theta



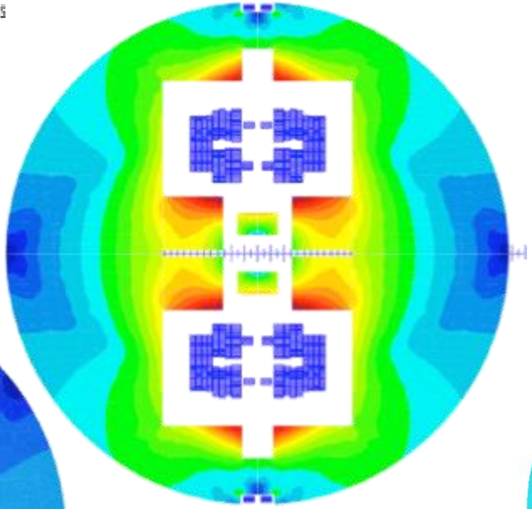
INFN

Blocks



CEA

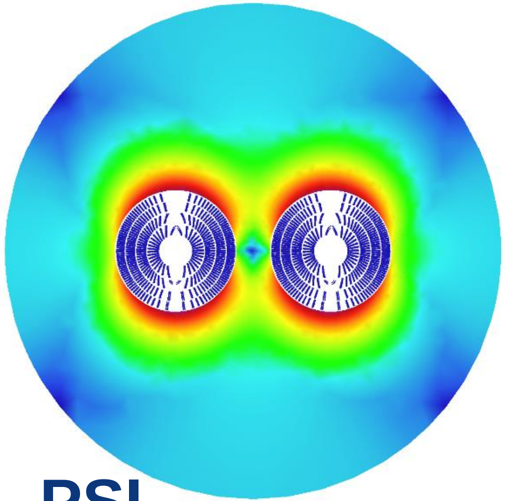
Common coils



CIEMAT

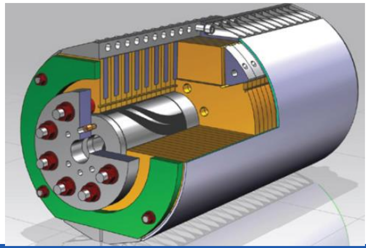
Swiss contribution

Canted Cos-theta



PSI

LBNL



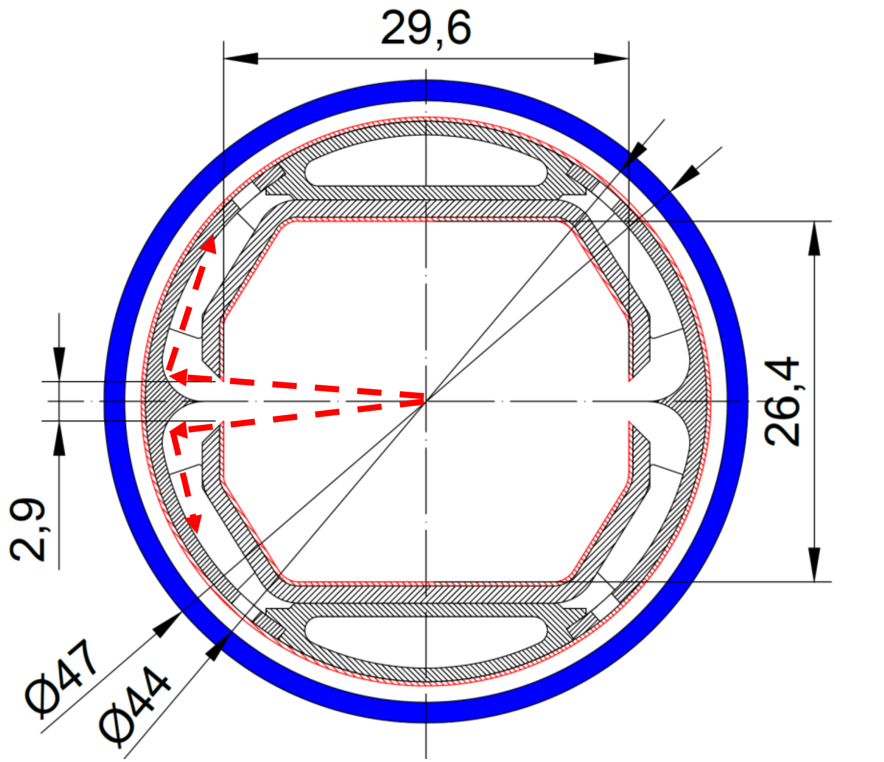
FNAL

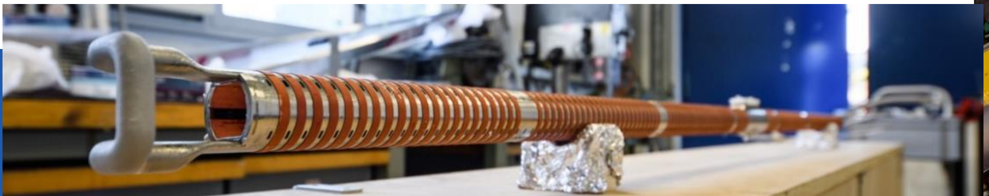
Short model magnets (1.5 m lengths) will be built from 2017 - 2021

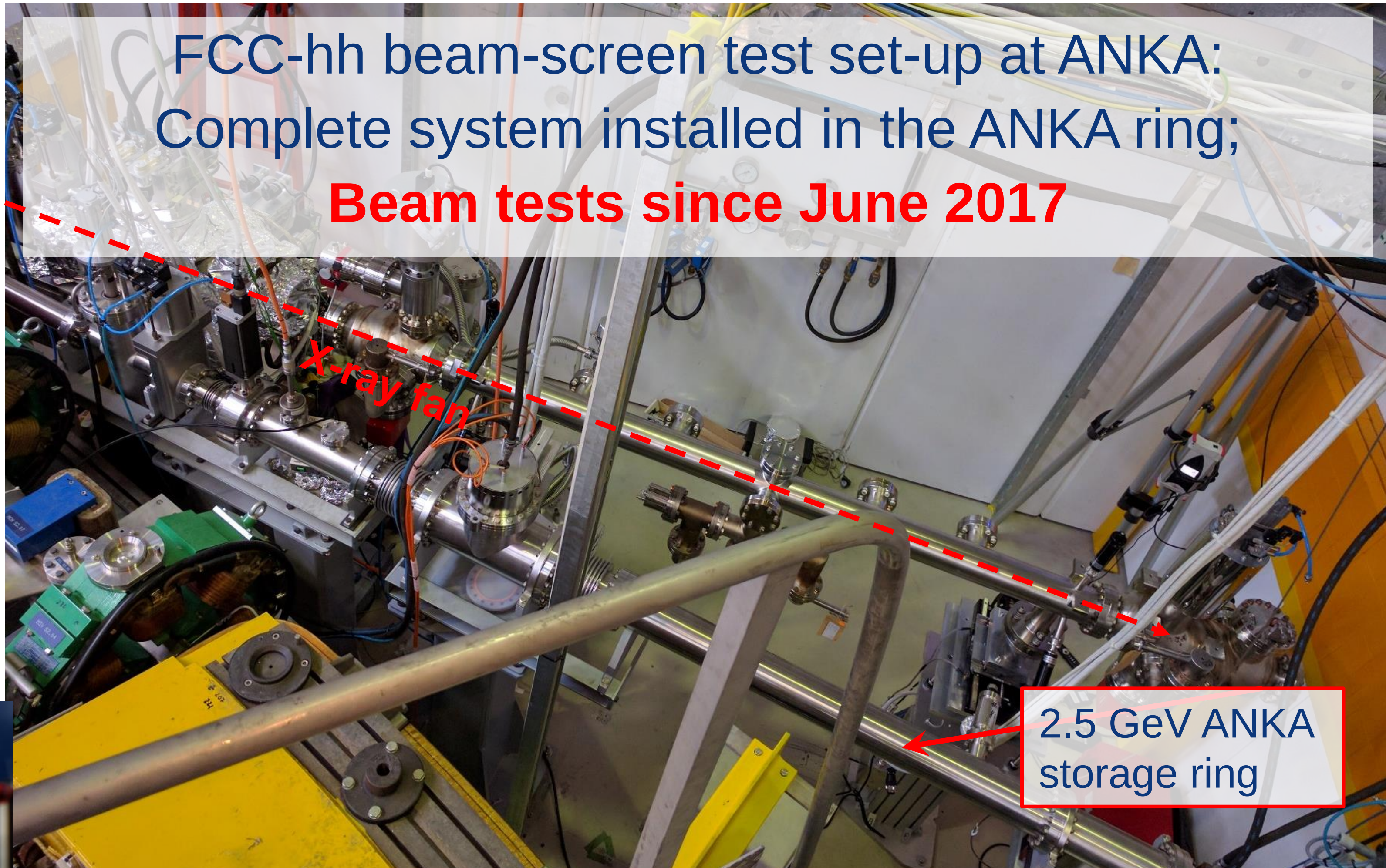
FCC-hh beam screen test @ ANKA

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.



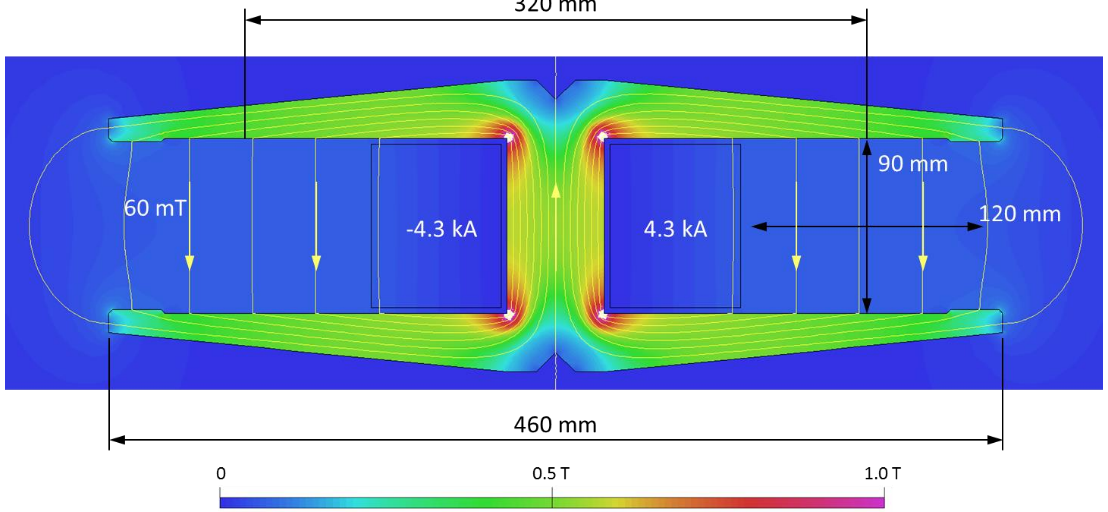




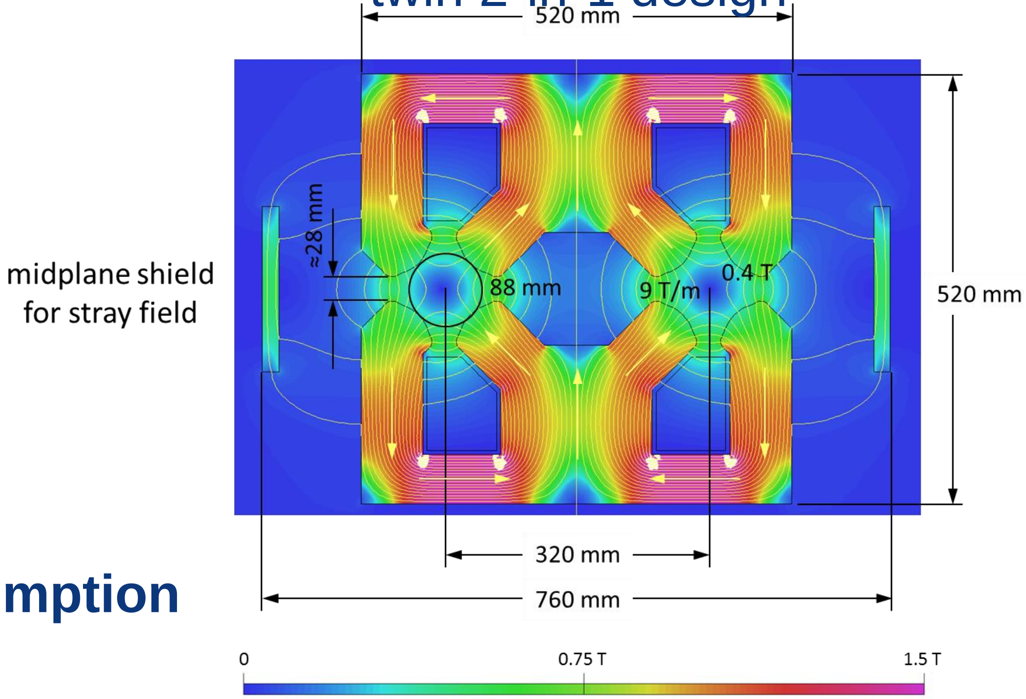
FCC-ee dual aperture main magnets

Prototyping launched of 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**

Efficient klystron technology

- **Development of new klystron bunching technologies to increase RF power production efficiency to almost 90%, was initiated at CERN in 2013 (HEIKA), essential for FCC-ee**

L-band | S-band | C-band | X-band

Core Stabilization Method (CSM)

LHC,FCC,ESS,ILC

1/6 MW

Medical/industrial

Bunching, Aligning and Collecting Method (BAC)

5-10 MW, <60kV

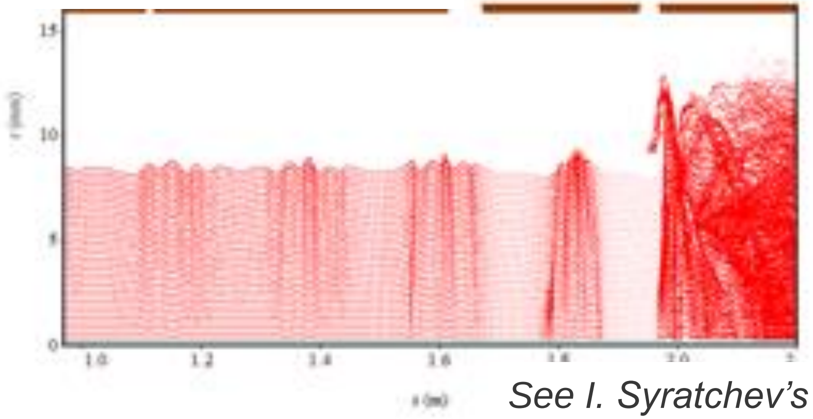
Kladistron

CLIC, klystron based X-band FEL

Core Oscillation Method (COM)

50+ MW

- **Towards fabrication of the first high efficiency CSM tube**
- **Presently negotiations with industry for protoype production for end 2018**
- **Single beam, 1.4 MW, 0.8 GHz, 134 kV, 12.55 A**
  85.7% efficiency in simulations



See I. Syratchev's talk on Tuesday

EASITrain Marie Curie Training Network

European Advanced Superconductivity Innovation and Training Network

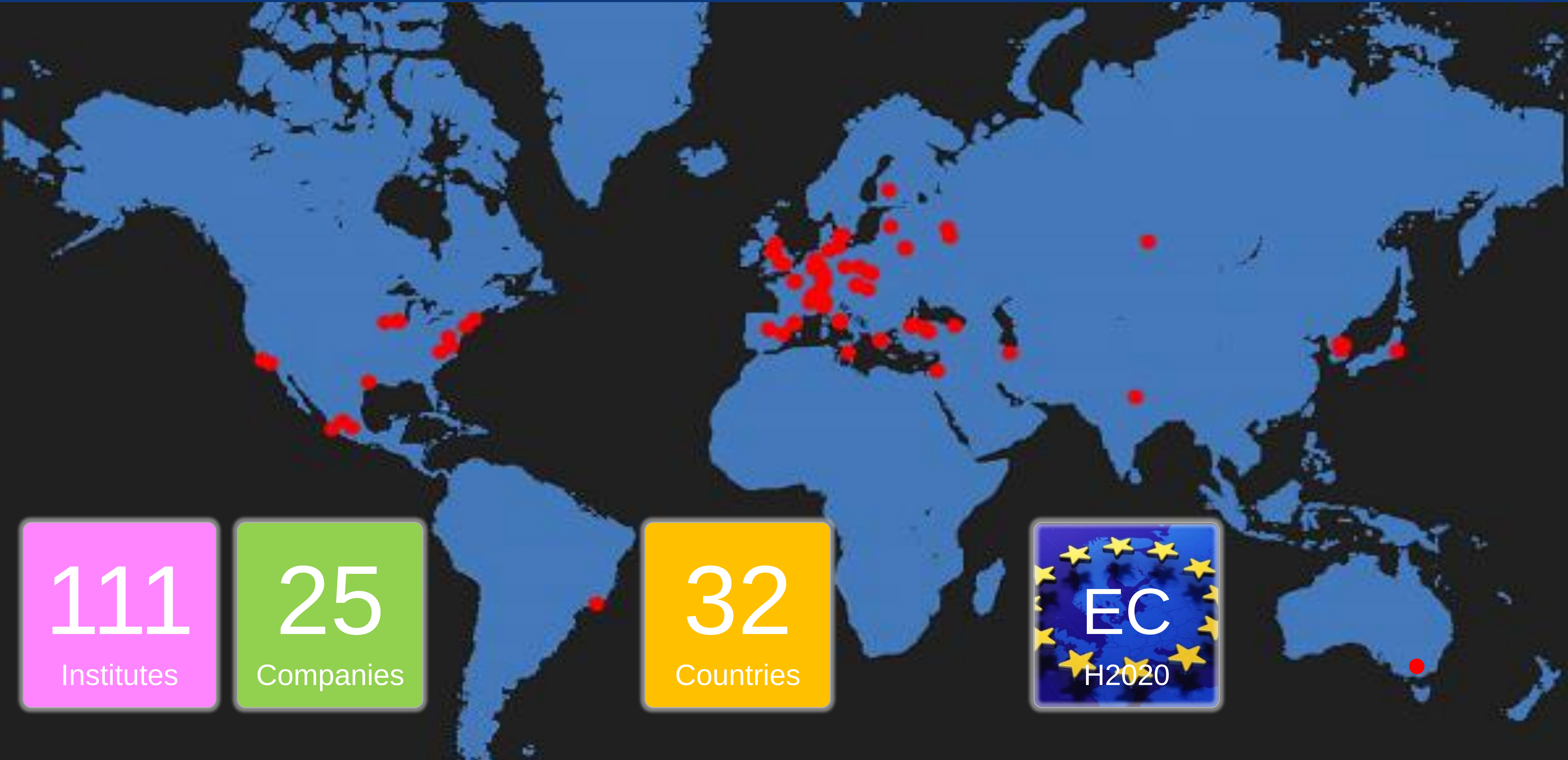
➢ **selected for funding by EC in May 2017, start 1 October 2017**

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

13 Beneficiaries

12 Partners

FCC Collaboration & Industry Relations



111 Institutes

25 Companies

32 Countries

EC H2020

Summary and outlook

- Confirmed parameter sets for FCC-hh, FCC-ee, HE-LHC and FCC-he as solid basis for the Design Report end 2018
- Work ongoing on optimisation of machine designs as well as on technology R&D topics
- International FCC collaboration is growing steadily, addressing all the challenging subjects and research lines
- Strong contributions from Austrian and Swiss Institutes and Universities to the FCC Study