Future Circular Collider Study

EuCARD 2 Annual Meeting
28 March 2017, Glasgow
University of Strathclyde

M. Benedikt, F. Zimmermann

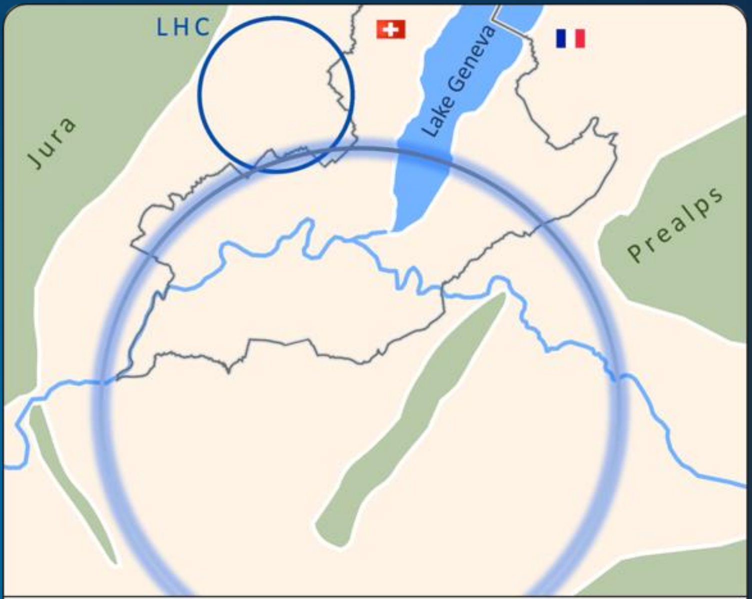
gratefully acknowledging input from FCC coordination group global design study team and all other contributors

http://cern.ch/fcc

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

FCC key parameters

- **pp** collider (FCC-hh)
  - Defines infrastructure requirements
  - **16 Tesla** magnets →
    - **100 TeV** centre of mass in
    - **100 km** long tunnel
- **e^+e^-** collider (FCC-ee)
  - Potential intermediate step
  - **Extreme luminosities** at 90–350 GeV
- **HE LHC** based on 16T FCC magnets
- Infrastructures
  - **Leverage** existing CERN accelerator complex, know-how and successful management of largest-scale science projects
  - **Build on** a history of **international trust and collaboration** across cultures, political systems

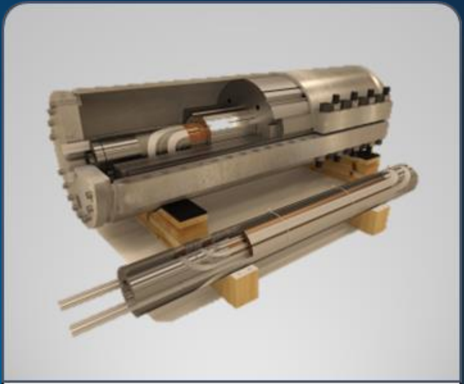


Schematic of an 80 – 100 km long tunnel

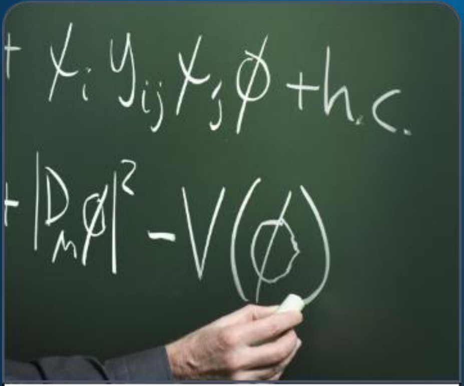
Study Scope

Collider Designs

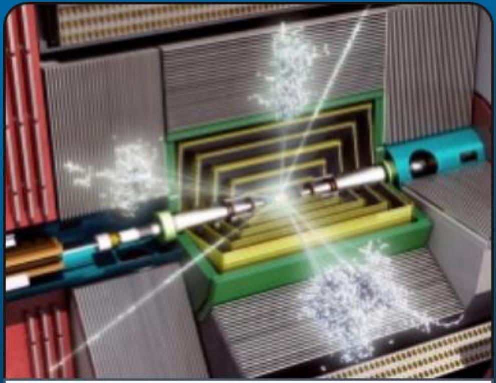
Infrastructures



R&D Programs



Physics Cases



Experiments

Cost Estimates

FCC - a child of EuCARD …

HE-LHC'10, EuCARD-AccNet Mini-Workshop on "**High-Energy LHC**," Malta, 14-16 **October 2010** *(Physics: 2.5 not enough, larger tunnel!)*

1st EuCARD AccNet **LEP3 Day**, CERN, 18 **June 2012** *(100-km tunnel)*

2nd EuCARD AccNet **LEP3 Workshop**, CERN 23 **October 2012**

3rd EuCARD AccNet **TLEP3 Day**, CERN, 10 **January 2013**

Joint Snowmass-EuCARD/AccNet-HiLumi meeting "Frontier Capabilities for Hadron Colliders 2013'" or "**EuCARD VHE-LHC Day**," 21 **Feb. 2013**

4th and 5th **TLEP** mini-WS, CERN, 4-5 **April 13,** FNAL. 25-26 **July 13**

and EuCARD-2

EuCARD-2 XCOLL **TLEP6** workshop, CERN, 16-18 **October 2013**

FCC Kick-Off Meeting, U. Geneva, 12-15 **February 2014**

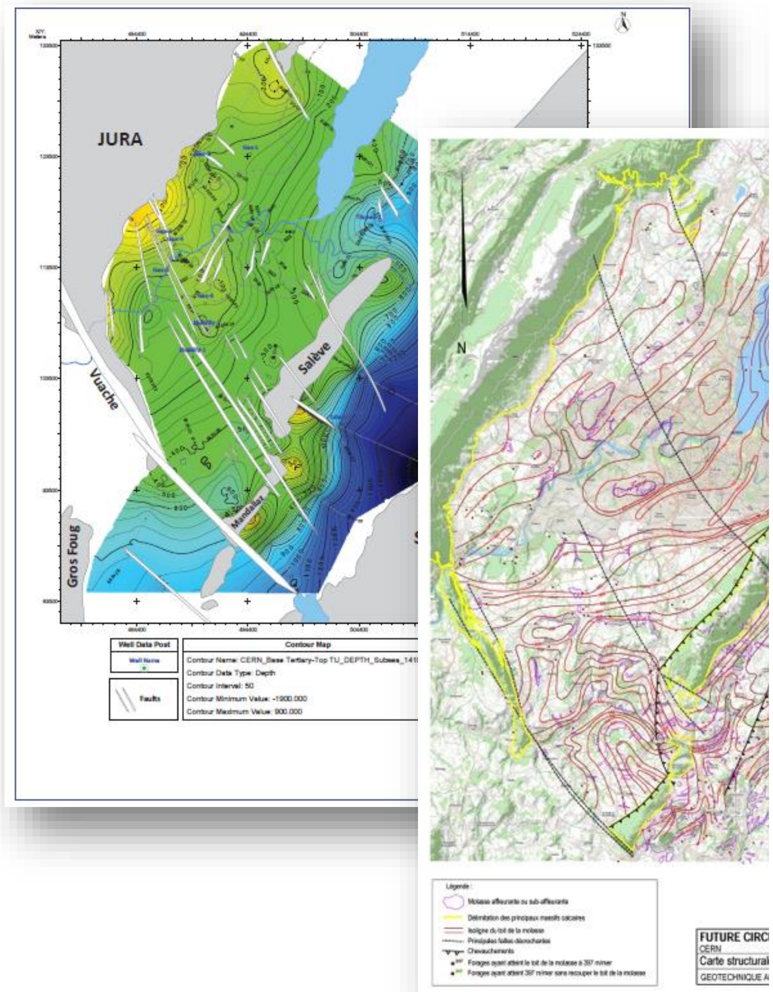
ICFA-EuCARD-2 "**Higgs Factory**" 14, Beijing, 9-12 **Oct. 2014**

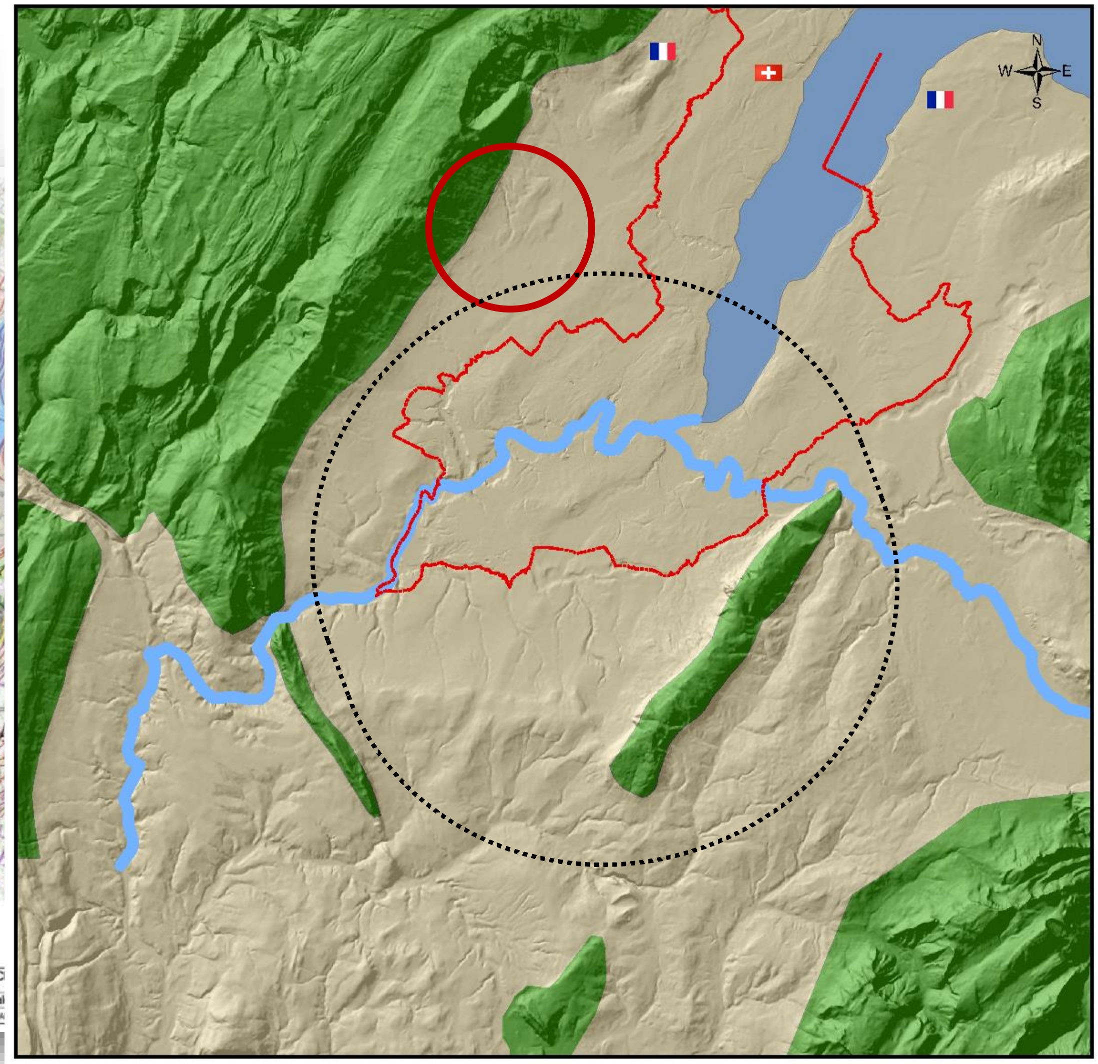
First Annual FCC Meeting, Washington DC, 23-29 **March 2015**

EuCARD-2 XPOL workshop on "Polarization Issues in Future High Energy Circular Colliders"

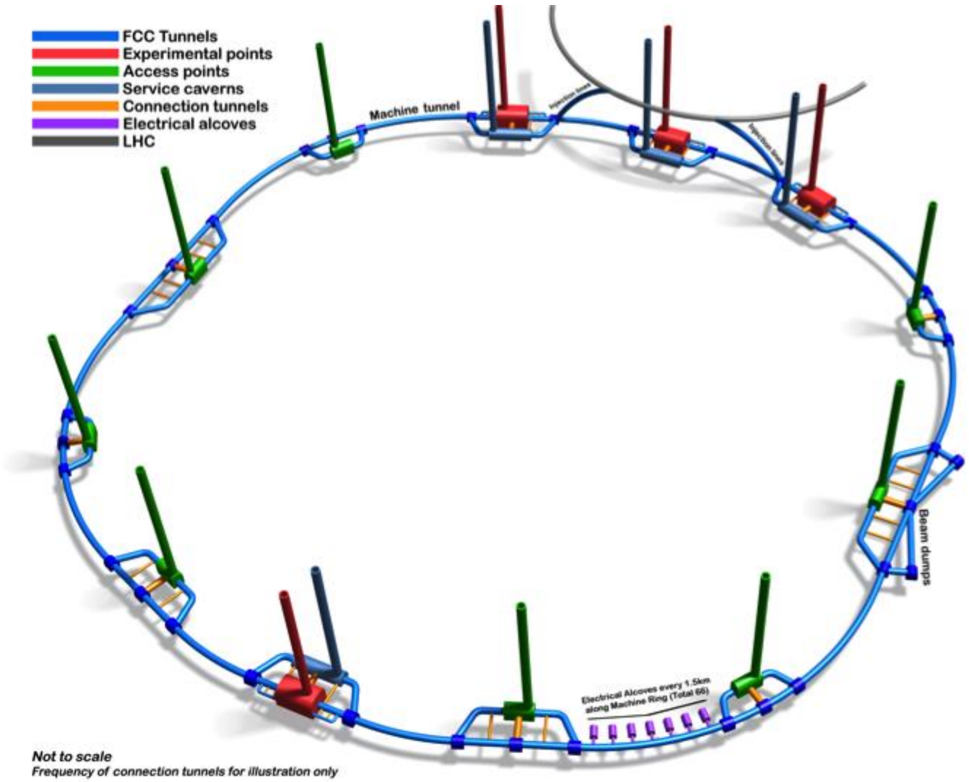
Data Integration for CE Concepts

Tunnel Optimisation Tool developed with ARUP

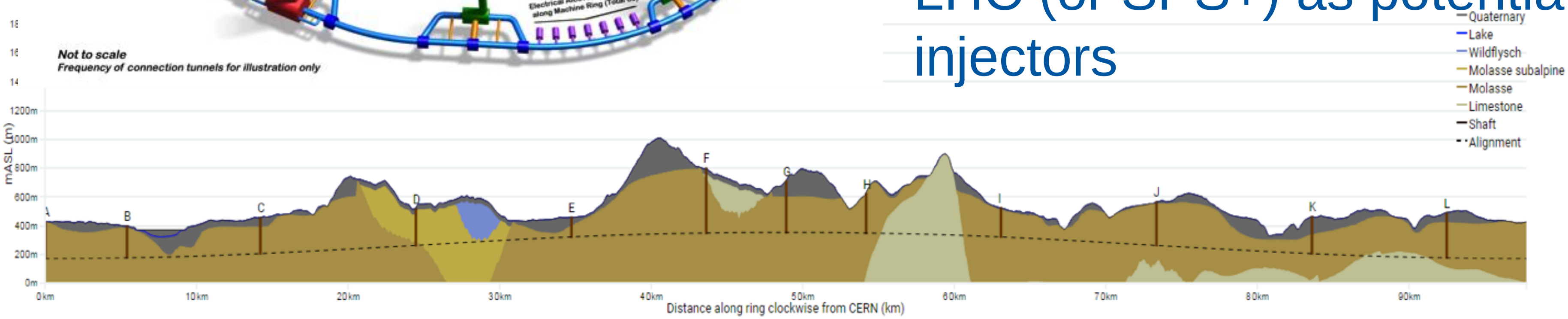




Civil Engineering Studies



- Develop realistic construction concepts (technical, organisational, financial)
- Assess feasibility and cost
- Study baseline variations (implementation, circumf., vertical implementation)
- LHC (or SPS+) as potential injectors



97.75 km FCC baseline tunnel

Alignment | Shafts | Query

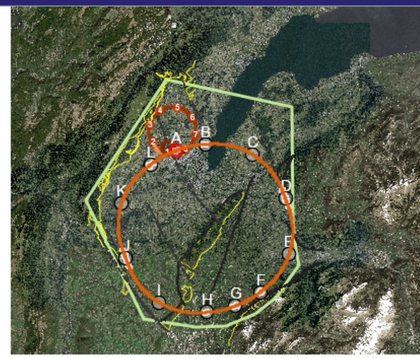
Choose alignment option
V4-97.75-30.82-30.07
Tunnel elevation at centre:272mASL
Grad. Params
Azimuth (°): -20.5
Slope Angle x-x(%): 0.6
Slope Angle y-y(%): 0

LOAD | SAVE | CALCULATE

Alignment centre
X: 2500180 Y: 1107801

	CP 1		CP 2	
	Angle	Depth	Angle	Depth
LHC		157m		185m
SPS		231m		231m
TI2		231m		231m
TI8		160m		221m

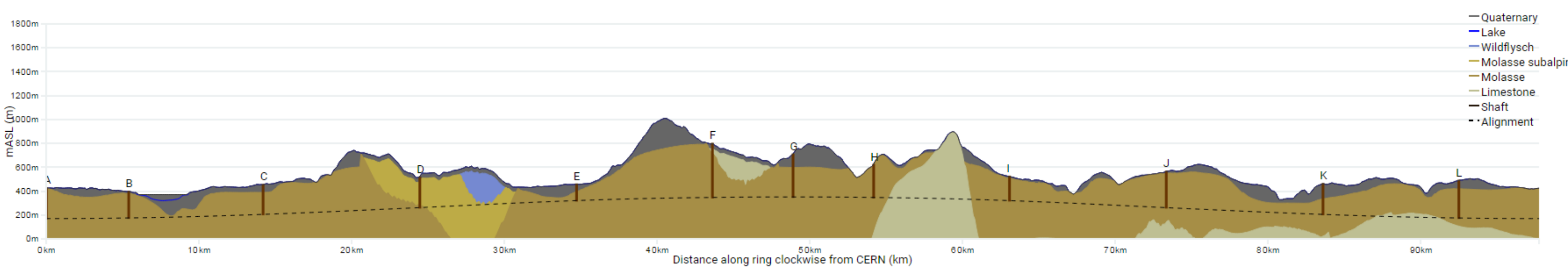
Alignment Location



Geology Intersected by Shafts | Shaft Depths

Point	Shaft Depth (m)				Geology (m)		
	Actual	Molasse SA	Wildflysch	Quaternary	Molasse	Urgonian	Limestone
A	253	0	0	0	253	0	0
B	220	0	0	15	204	0	0
C	248	0	0	63	185	0	0
D	254	196	0	40	17	0	0
E	136	0	0	57	79	0	0
F	450	0	0	40	377	0	33
G	357	0	0	109	248	0	0
H	273	0	0	0	273	0	0
I	202	0	0	12	189	0	0
J	302	0	0	13	289	0	0
K	256	0	0	124	132	0	0
L	313	0	0	68	245	0	0
Total	3264	196	0	542	2492	0	0

Alignment Profile



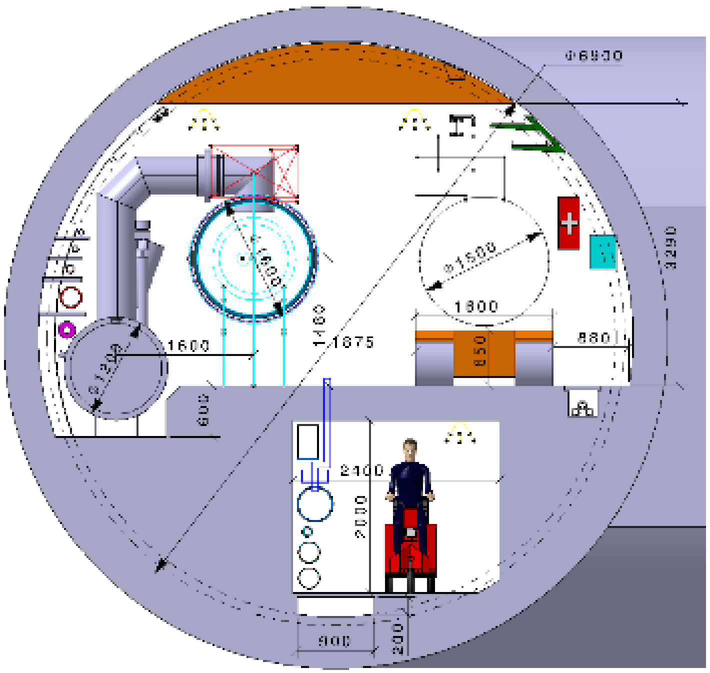
Geology Intersected by Tunnel | Geology Intersected by Section

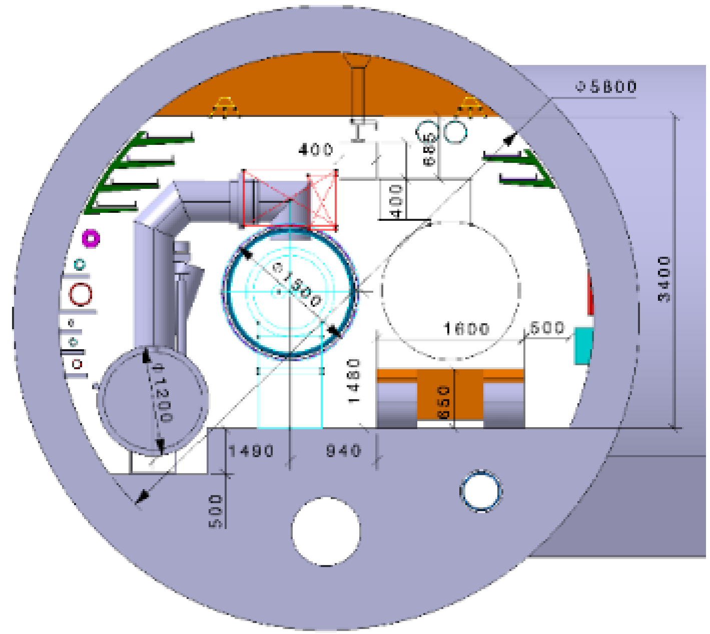
84.4% | 5.8% | 9.7%

John Osborne, Joanna Stanyard, Matthew Stuart (CERN-SMB-SE)

Tunnel section and safety concept

- Tunnel concept
  - Separate non-technical zone vs. fire compartments
  - Single tunnel vs. double tunnel





Impact on

Ventilation
Integration
Transport
Accessibility
Etc.

Technical shaft, diameter 13.5 m

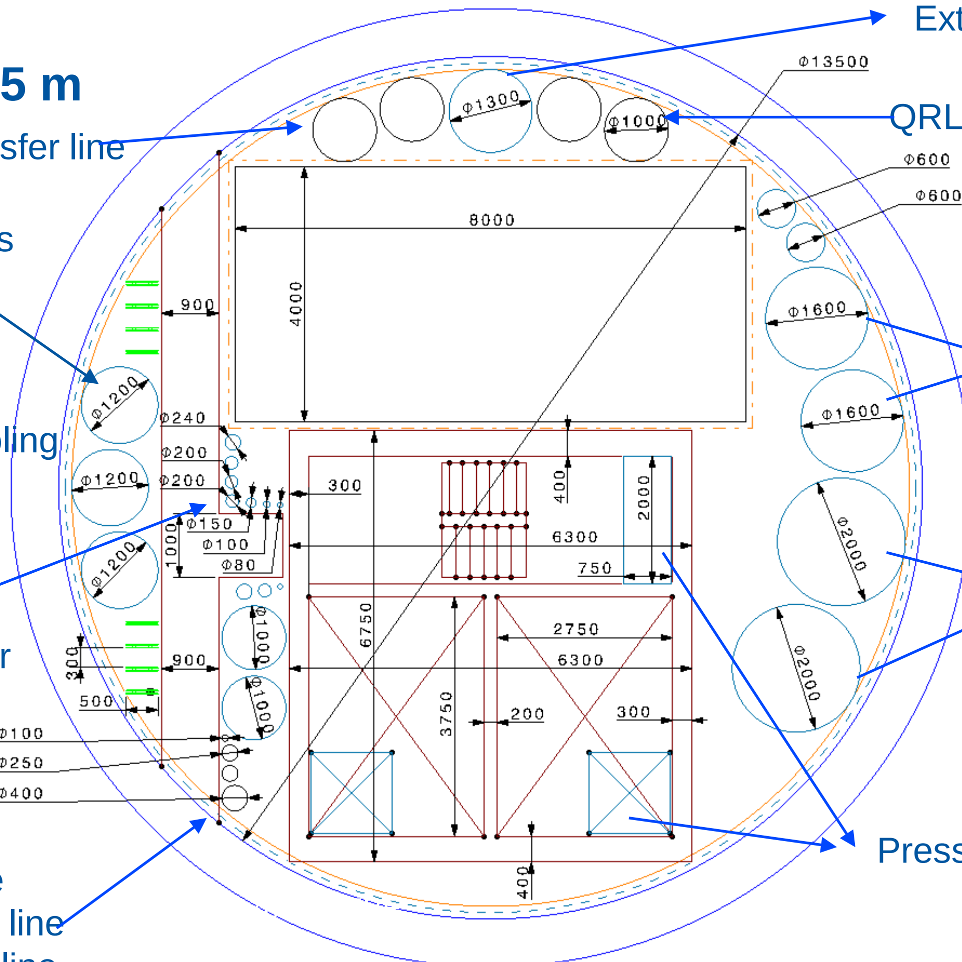
Cross section with inner diameter 13.5 m

QRL DN 1000 Vertical transfer line

Emergency Extraction Ducts (3 Ducts)

Pipes:
- DN 200 - Primary water cooling
- DN 240 - Chilled water
- DN 150 - Fire fighting
- DN200 - Make up water
- DN80 - Compressed air
- DN80 - Demineralized water
- DN100 - Waste water
- DN200 - Clear water drain

QRL Pipes:
- DN 100 - Helium ring line
- DN 250 - Warm recovery line
- DN 400 – Quench buffer line



Extraction Duct from Safe Tunnel

QRL DN 1000 Vertical transfer line

Ventilation Duct Machine Area (In/Out)

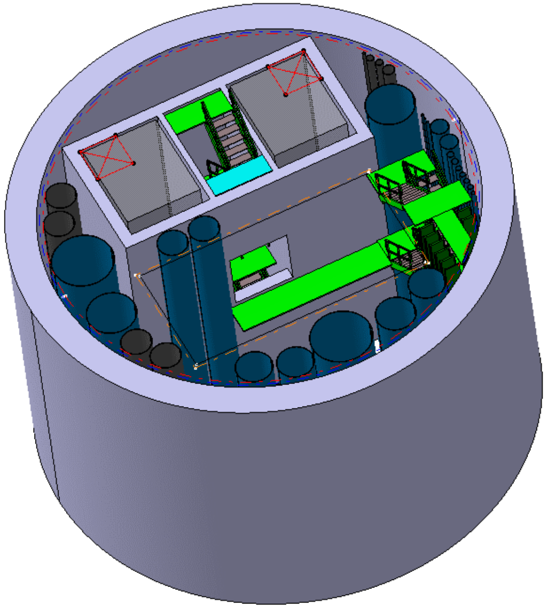
Ventilation Duct UAs Underground Cavern (In/Out)

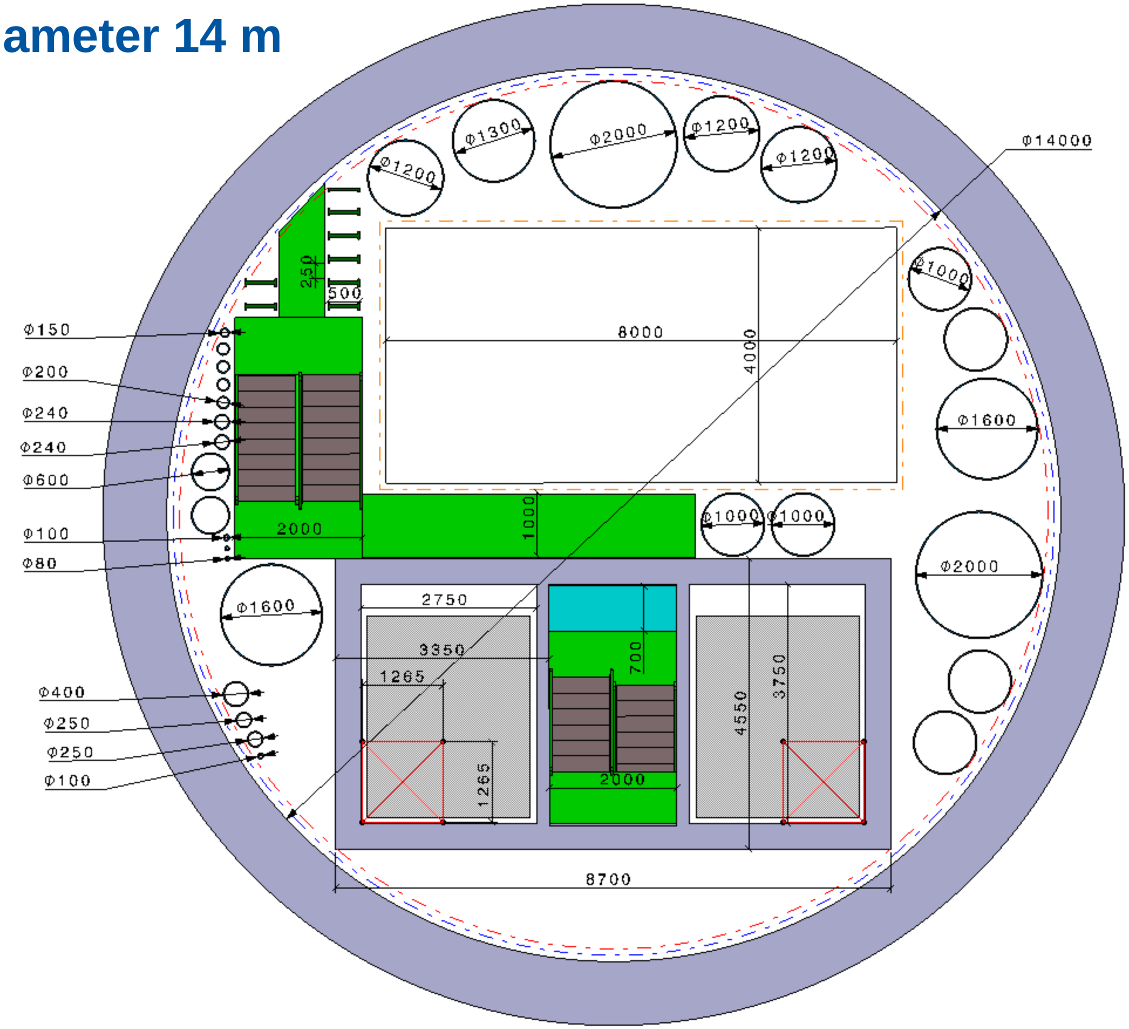
Pressurization Duct Shaft and Lift Cage

FCC Shaft cross section with diameter 14 m

Gray line – QRL Pipes

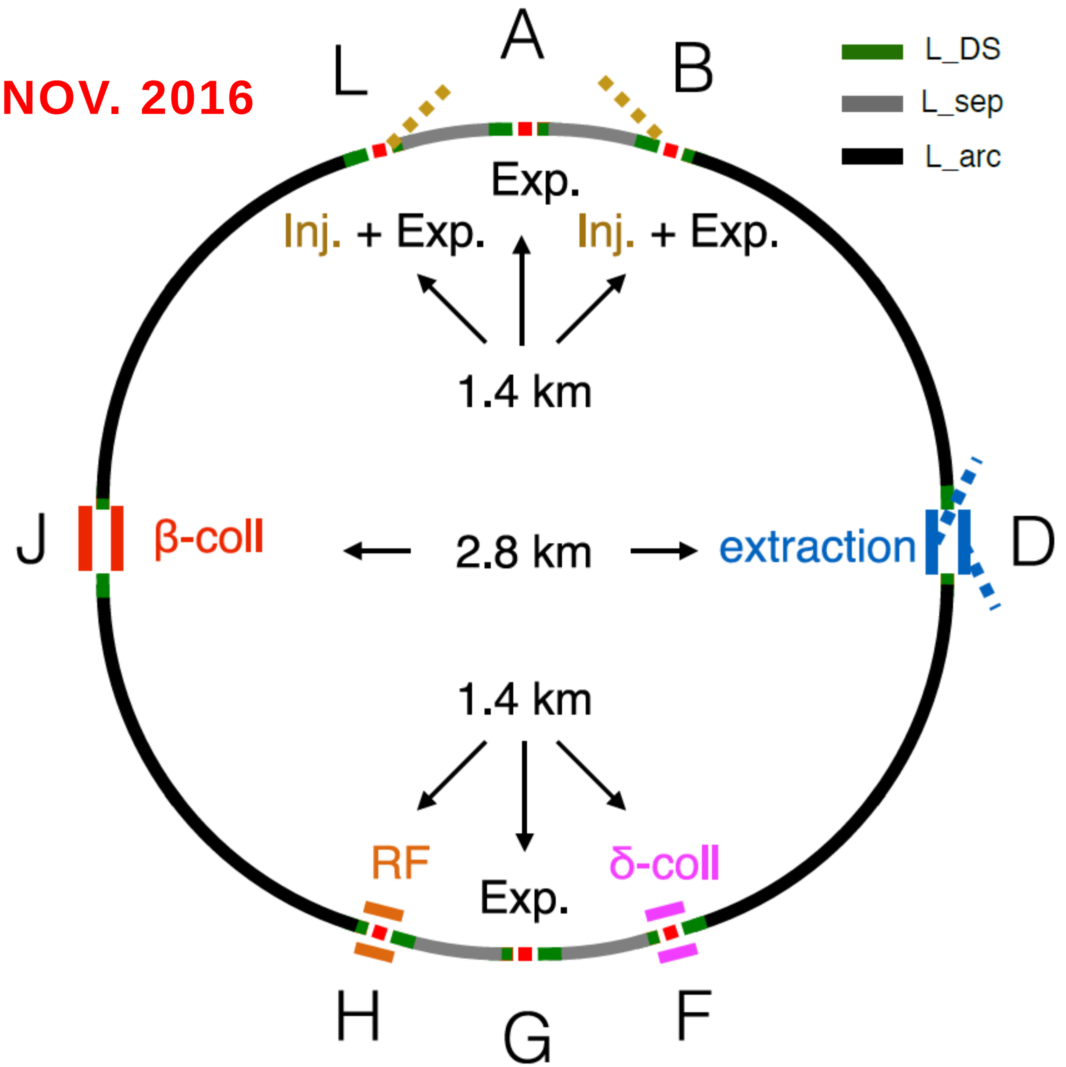
Blue Line – CV Services





FCC-hh layout

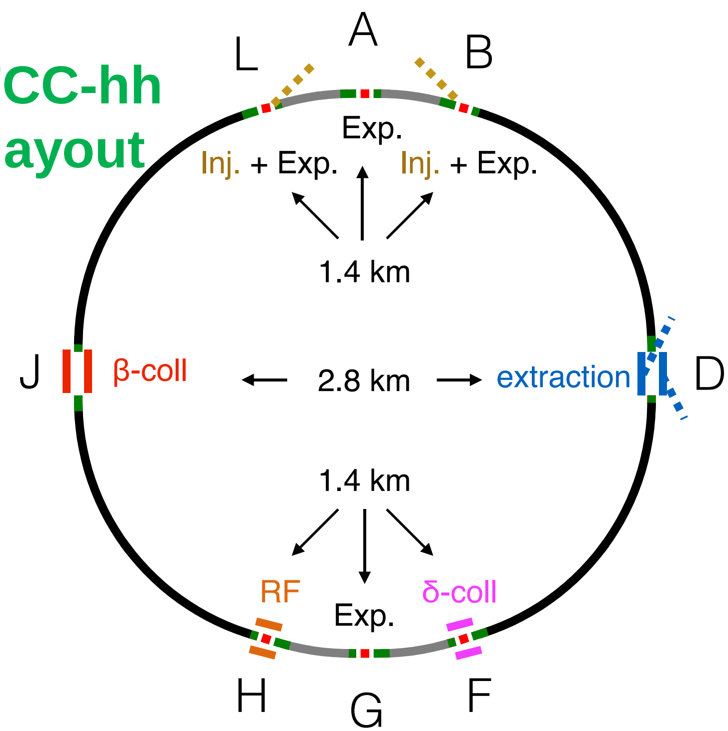
NEW LAYOUT NOV. 2016

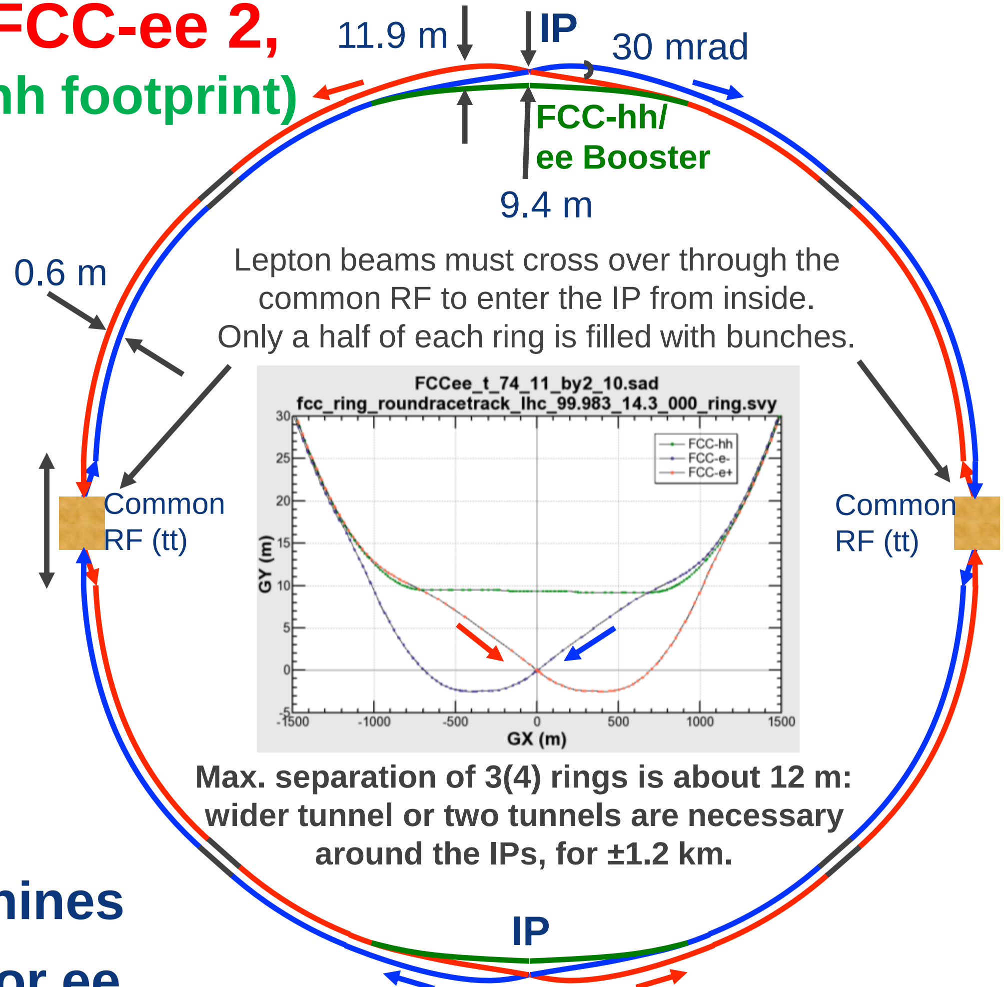


Common layouts for hh & ee

FCC-ee 1, FCC-ee 2,
FCC-ee booster (FCC-hh footprint)

FCC-hh layout

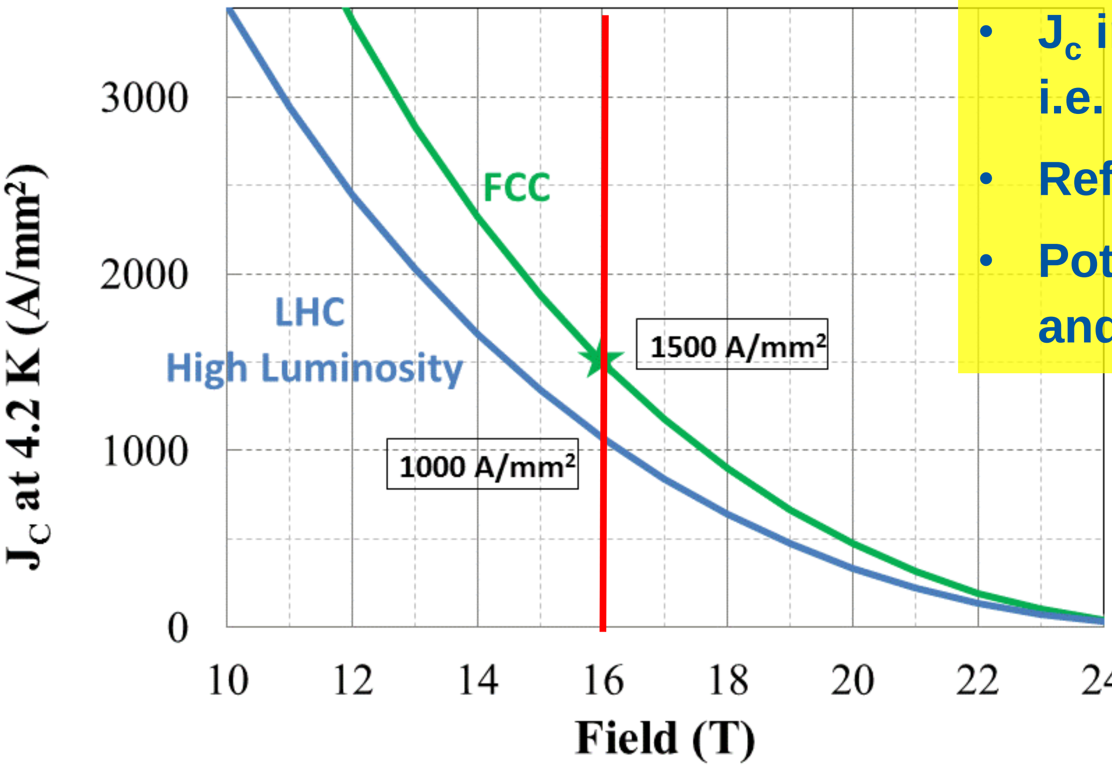




- **2 main IPs in A, G for both machines**
- **asymmetric IR optic/geometry for ee to limit synchrotron radiation to detector**

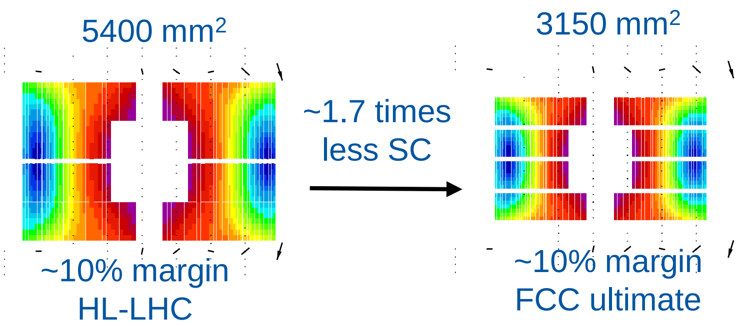
Nb_3Sn conductor program

Nb_3Sn is one of the major cost & performance factors for FCC-hh and is given highest attention



Main development goals until 2020:

- J_c increase (16T, 4.2K) > 1500 A/mm² i.e. 50% increase wrt HL-LHC wire
- Reference wire diameter 1 mm
- Potentials for large scale production and cost reduction



Collaborations FCC Nb_3Sn program

Procurement of state-of-the-art conductor for protoyping:

- **Bruker**– **European / OST** – **US**

Stimulate conductor development with regional industry:

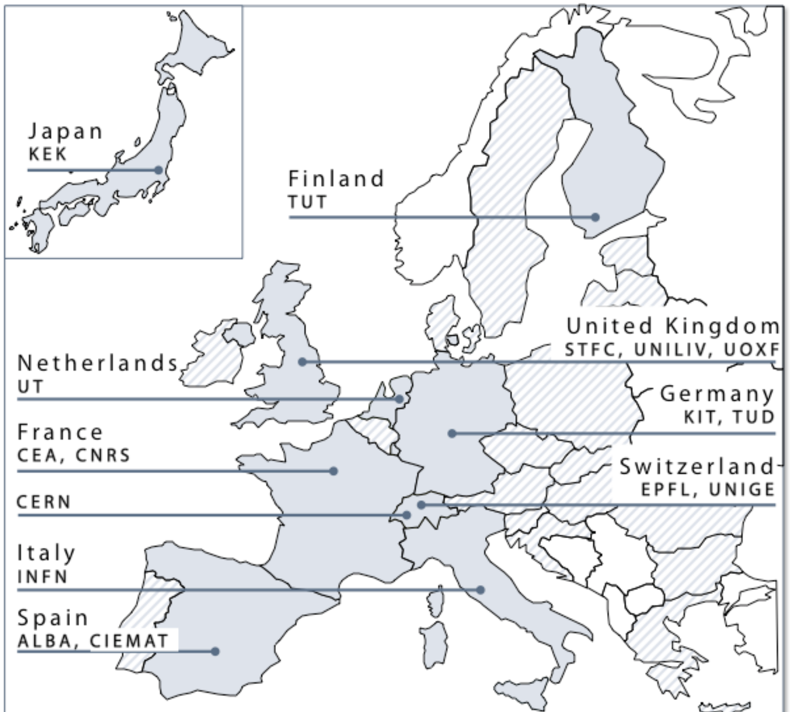
- **CERN/KEK** – **Japanese** contribution. Japanese **industry** (JASTEC, Furukawa, SH Copper) and laboratories (Tohoku Univ. and NIMS).
- **CERN/Bochvar High-technology Research Inst.** – **Russian** contribution. Russian **industry** (TVEL) and laboratories
- **CERN/KAT** – **Korean** **industrial** contribution
- **CERN/Bruker**– **European** **industrial** contribution

Characterisation of conductor & research with universities:

- **Europe: Technical Univ. Vienna, Geneva University, University of Twente**
- **Applied Superconductivity Centre** at Florida State University

New US DOE MDP effort – **US** activity with **industry** (OST) and labs

EU H2020 DS 'EuroCirCol' on 16 T dipole & vacuum system design



EuroCirCol consortium, federating 16 partners, 1 from Japan and 1 IEIO

European Union Horizon 2020 program

- Support for FCC study
- Grant agreement 654305
- 3 MEURO co-funding

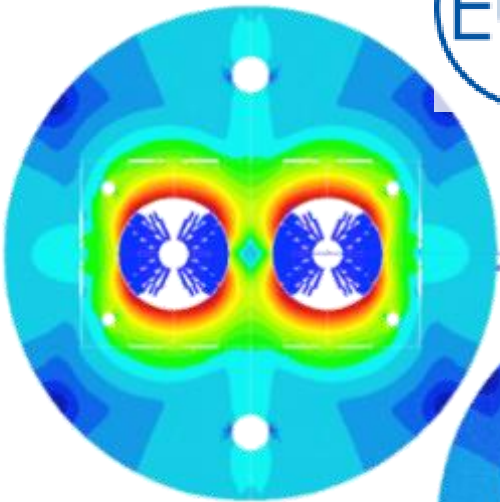
Scope:

FCC hadron collider

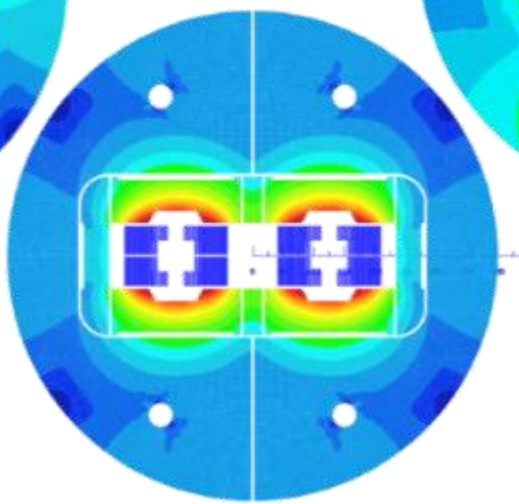
- Optics Design
- Cryo vacuum design
- 16 T dipole design, construction folder for demonstrator magnets

16 T dipole options and plans

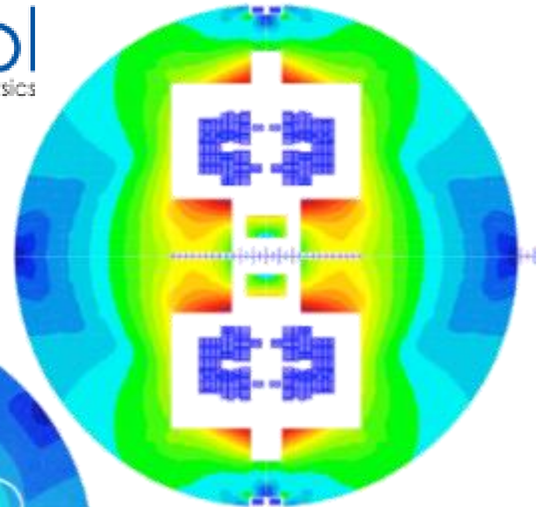
Cos-theta



Blocks

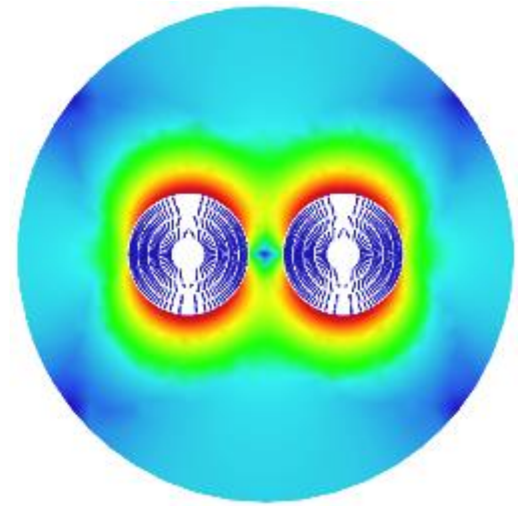


Common coils



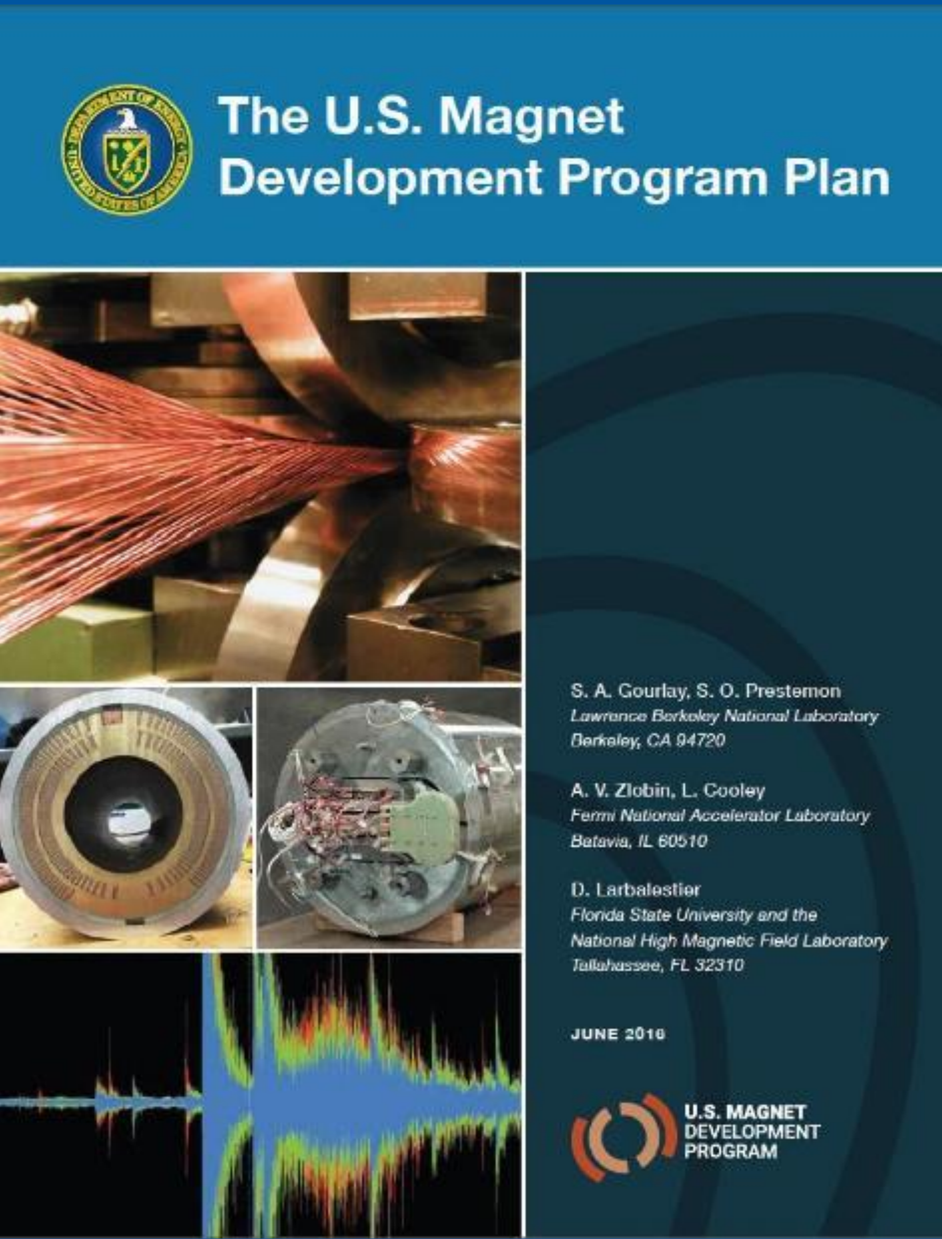
Swiss contribution
via PSI

Canted
Cos-theta



- **Down-selection of options end 2017 for detailed design work**
- **Model production 2018 – 2022 → Collaborations being signed now**
- **Prototype production 2023 - 2025**

US Magnet Development Program



The U.S. Magnet Development Program Plan

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JUNE 2016

U.S. MAGNET DEVELOPMENT PROGRAM

Program (MDP) Goals:

GOAL 1:

Explore the performance limits of Nb_3Sn accelerator magnets with a focus on minimizing the required operating margin and significantly reducing or eliminating training.

GOAL 2:

Develop and demonstrate an HTS accelerator magnet with a self-field of 5 T or greater compatible with operation in a hybrid LTS/HTS magnet for fields beyond 16 T.

GOAL 3:

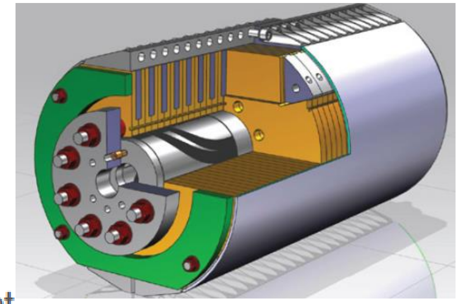
Investigate fundamental aspects of magnet design and technology that can lead to substantial performance improvements and magnet cost reduction.

GOAL 4:

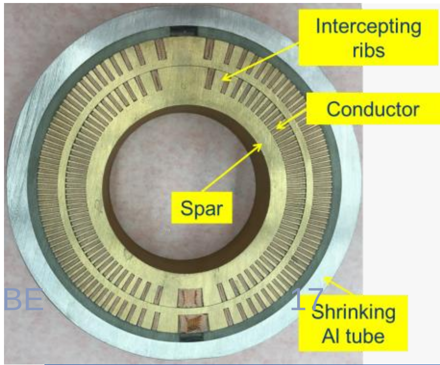
Pursue Nb_3Sn and HTS conductor R&D with clear targets to increase performance and reduce the cost of accelerator magnets.

Under Goal 1:

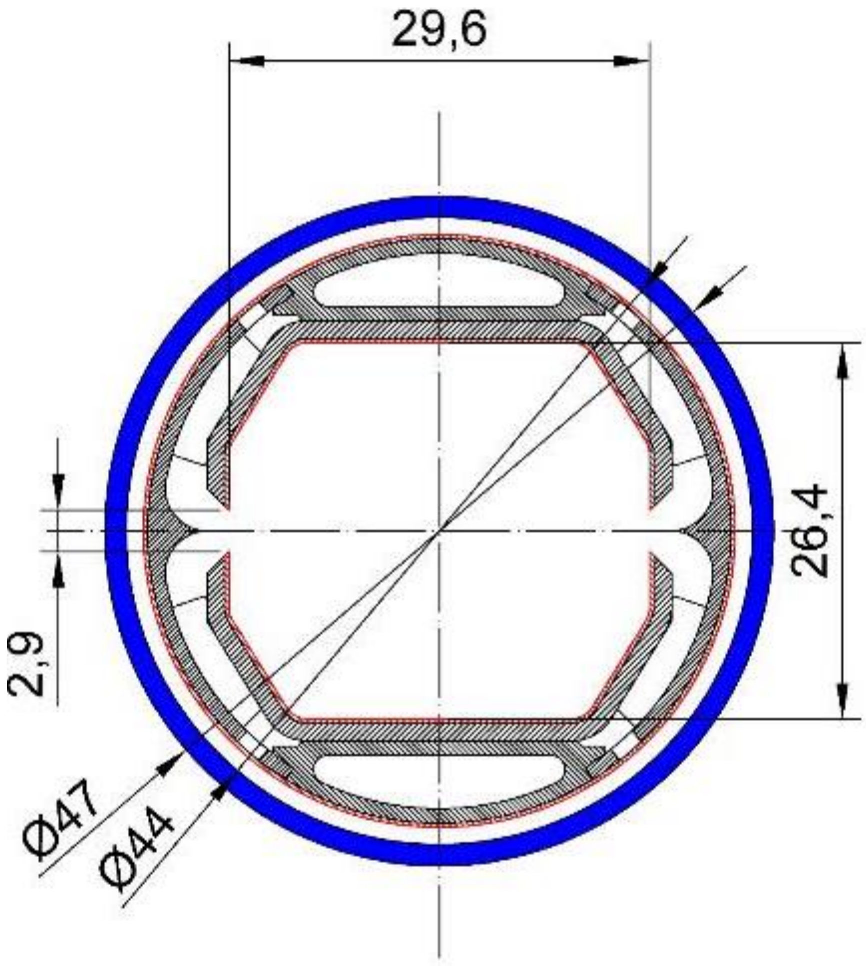
16 T cos theta dipole design



16 T canted cos theta (CCT) design



FCC-hh cryo -vacuum system



FCC-hh: ≈5 MW SR power emitted in cold arcs

beam screen at 40—60 K
(LHC at 5—20 K)
→ better Carnot efficiency;
but higher resistance
→ res. wall instability

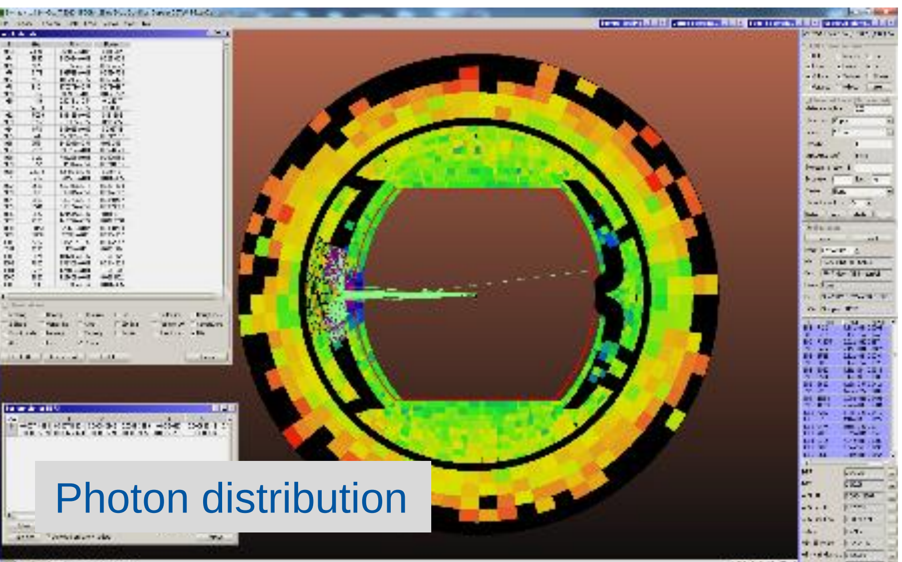
slits & wedge
capture and hide photons
→ no photoelectrons in beam pipe proper

surface treatment reduce SEY?

FCC-hh cryo-vacuum system

FCC-hh beam screen prototypes

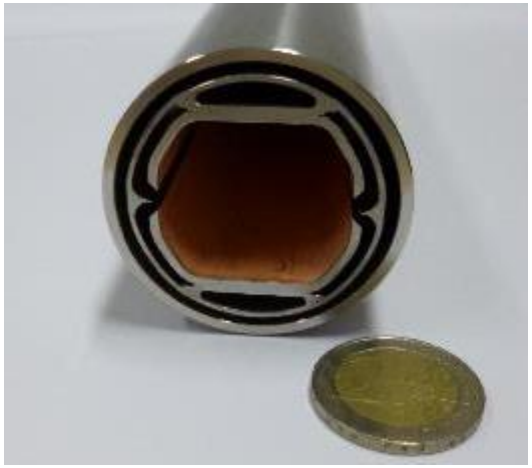
beam tests at KIT ANKA starting May 2017



Photon distribution

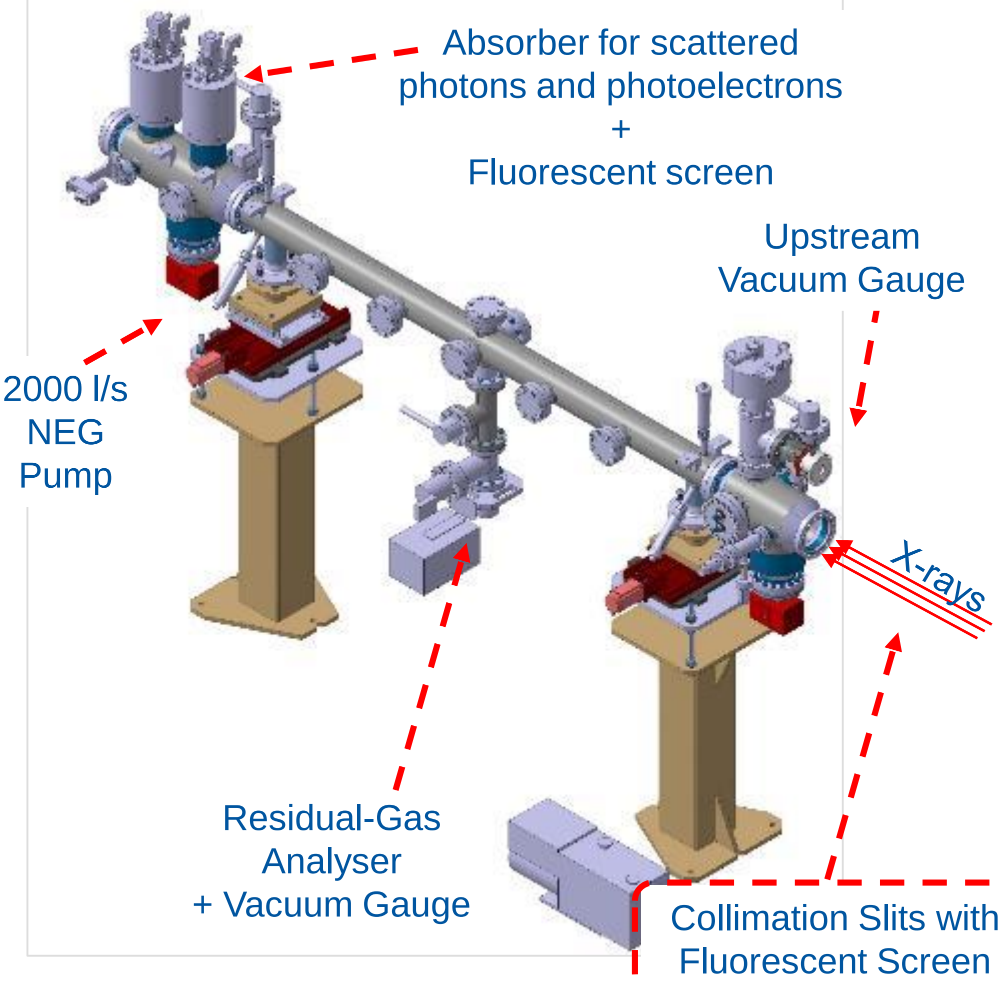
simulation of quench behaviour

Test setup for ANKA



Production of a 30 cm prototype

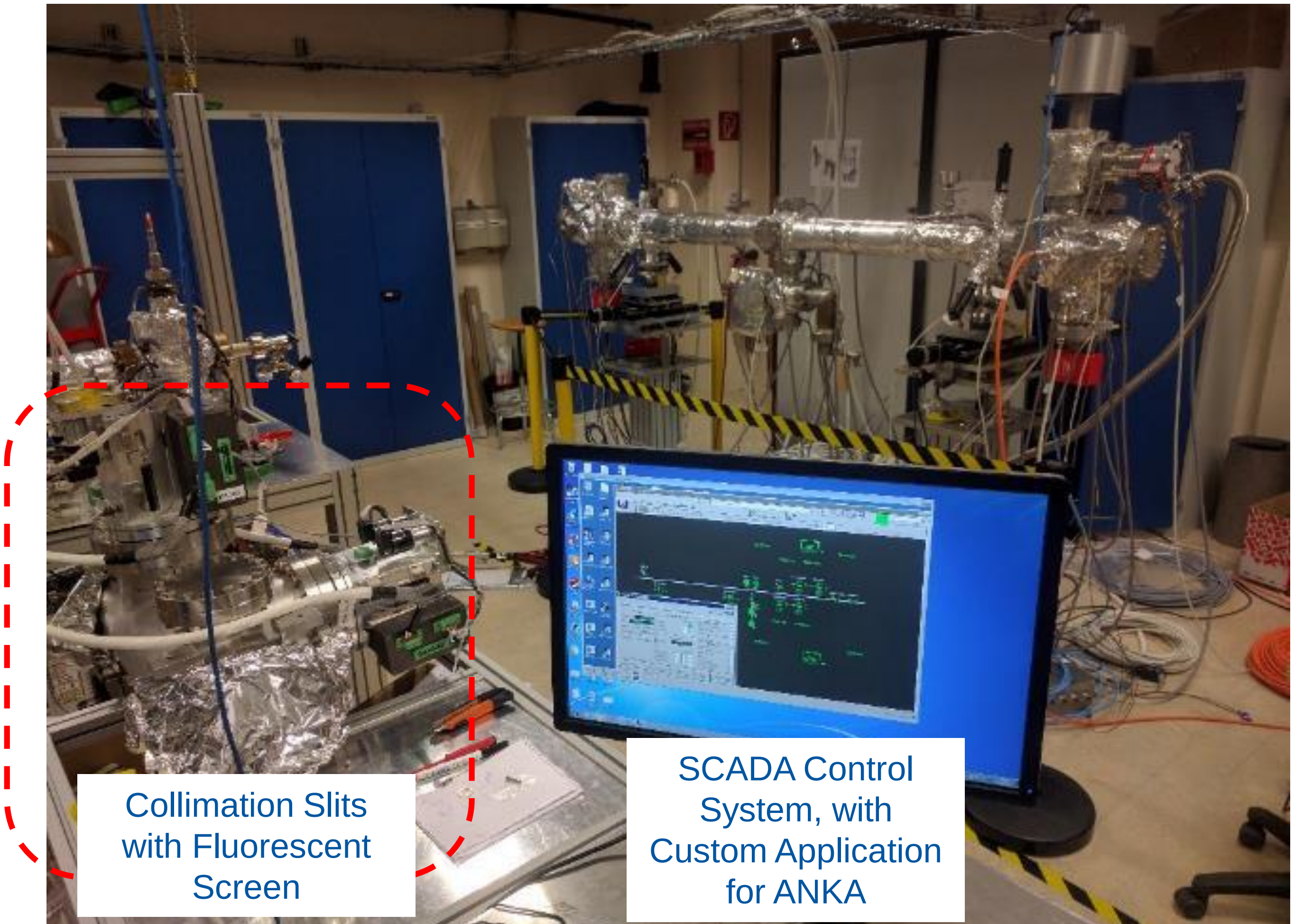
Copper cold sprayed strips on beam screen short prototype



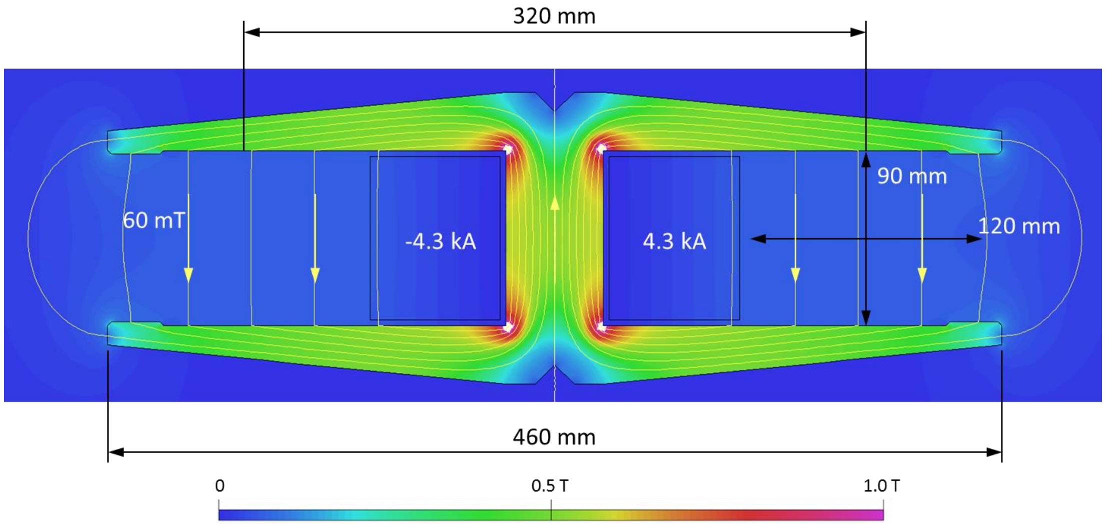
2 m BS Prototype after Cu Cold-Spray

Pre-assembly at CERN

Vacuum tests & control system calibration (CERN Vacuum Group): Passed

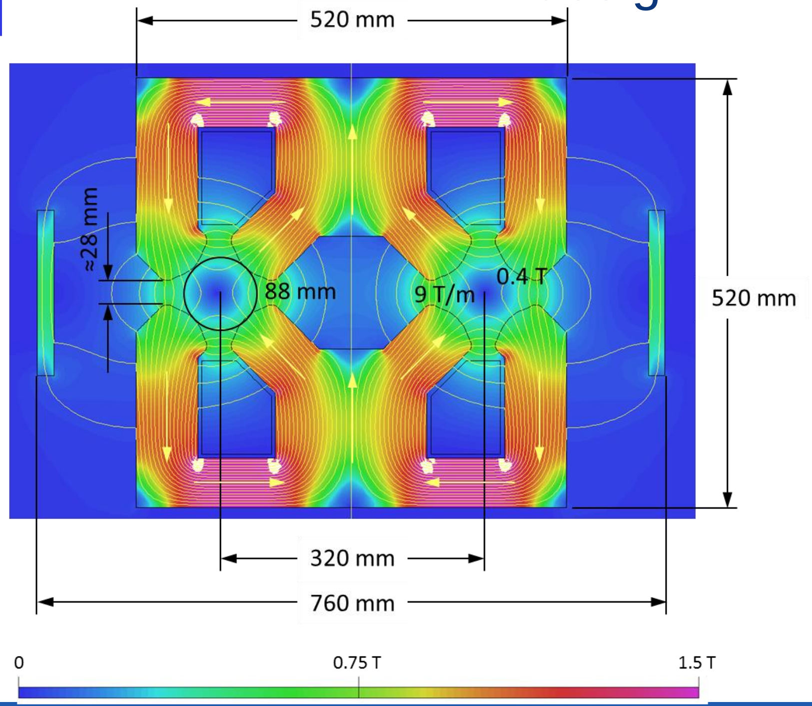


Efficient 2-in-1 FCC-ee arc magnets



Dipole:
twin aperture yoke
single busbars as coils

Quadrupole:
twin 2-in-1 design



- **Novel arrangements allow for considerable savings in Ampere-turns and power consumption**
- **Less units to manufacture, transport, install, align, remove,…**

midplane shield
for stray field

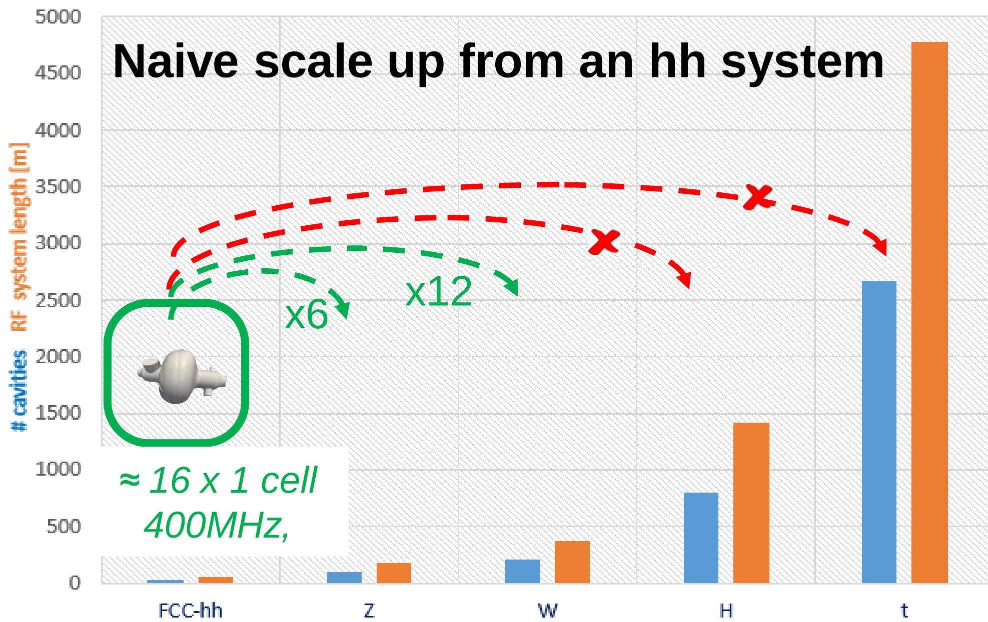
RF system requirements

Very large range of operation parameters

"Ampere-class" machines

	V_{total} GV	$n_{bunches}$	I_{beam} mA	ΔE/turn GeV
hh	0.032		**500**	
Z	0.4/0.2	30000/90000	**1450**	0.034
W	0.8	5162	152	0.33
H	**5.5**	770	30	1.67
t	**10**	78	6.6	7.55

"high gradient" machines

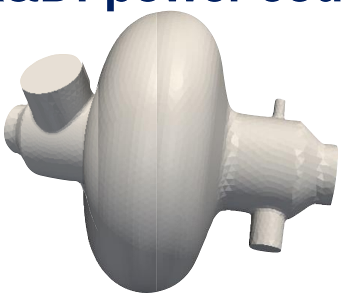


- **Voltage and beam current ranges span more than factor > 10^2**
- **No well-adapted single RF system solution satisfying requirements**

RF system R&D lines

400 MHz single-cell cavities preferred for hh and ee-Z (few MeV/m)

- **Baseline Nb/Cu @4.5 K, development with synergies to HL-LHC, HE-LHC**
- **R&D: power coupling 1 MW/cell, HOM power handling (damper, cryomodule)**



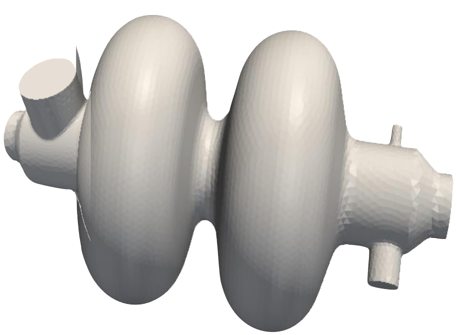
hh ≈ 16 cells per beam

Z ≈ 100 per beam (+ 100 for booster ring)

(**W** ≈ 210 per beam (+ 210 for booster ring))

400 or 800 MHz multi-cell cavities preferred for ee-ZH, ee-tt and ee-WW

- **Baseline options 400 MHz Nb/Cu @4.5 K, ◄—► 800 MHz bulk Nb system @2K**
- **R&D: High Q_0 cavities, coating, long-term: Nb_3Sn like components**

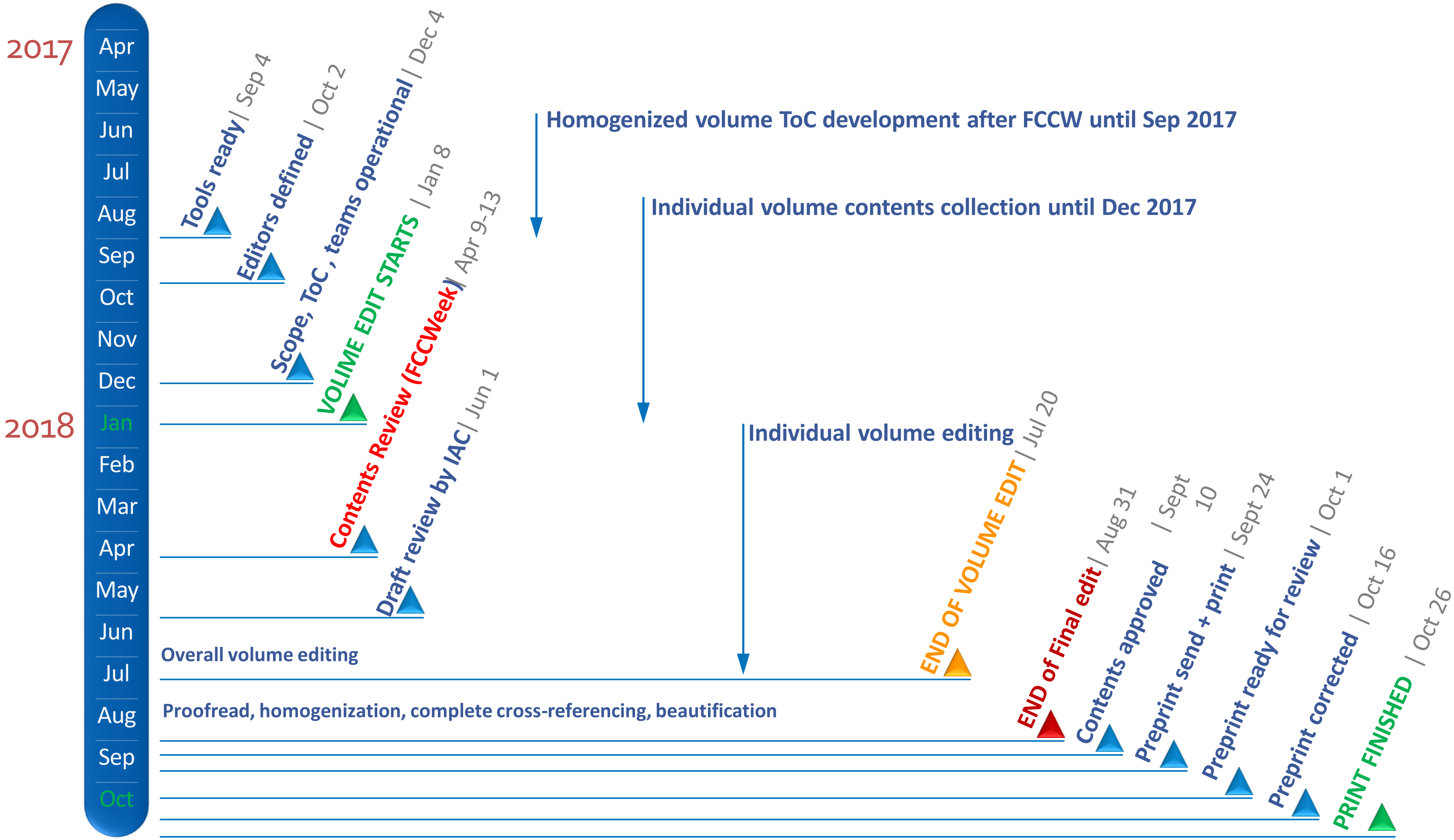


W ≈ 200 per beam (+ 200 for booster)

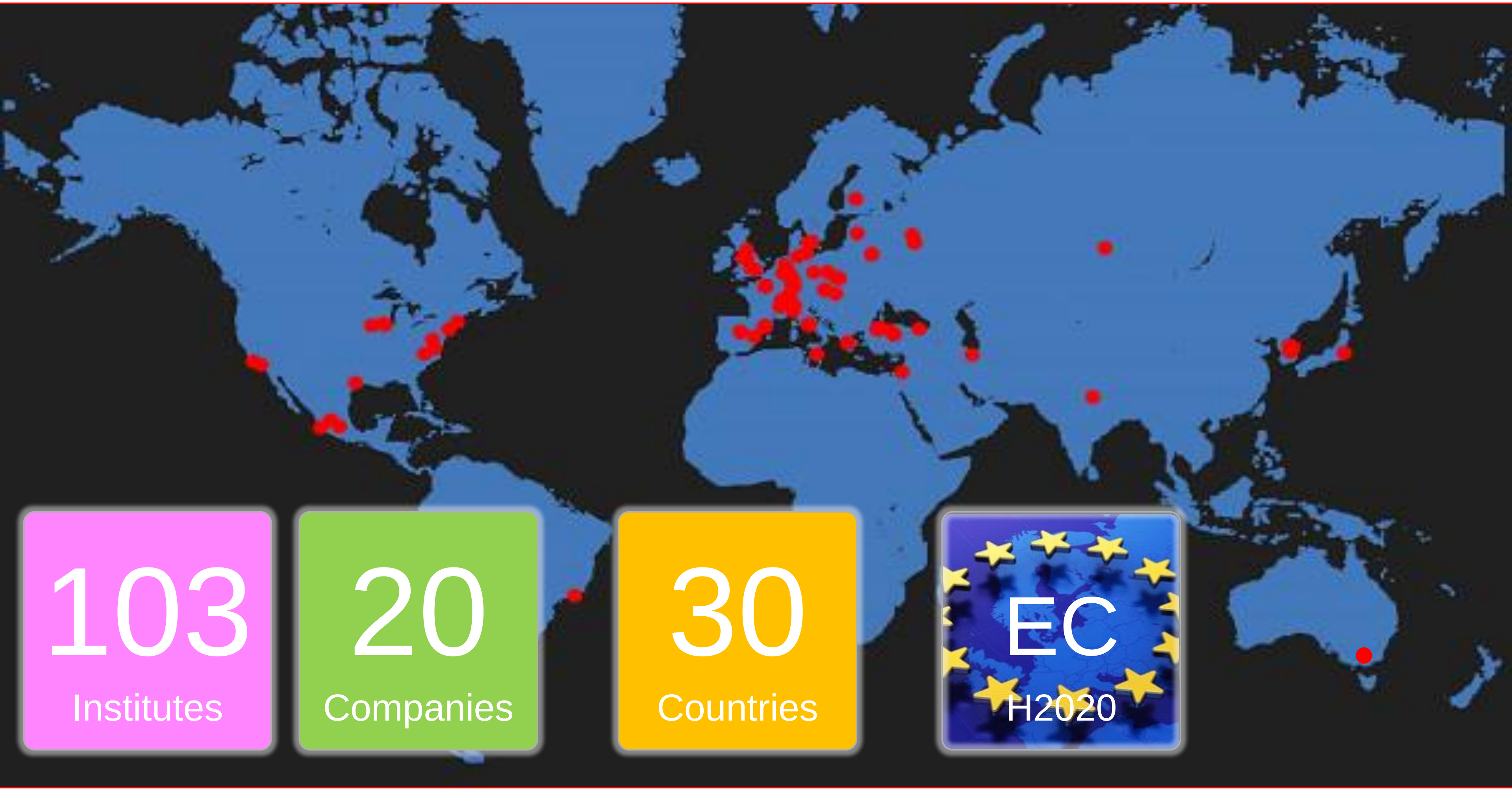
H ≈ 800 per beam (+ 800 for booster)

t ≈ common 2600 cells for both beams (+ 2600 for booster)

FCC-CDR timeline – publication end 2018



Collaboration & Industry Relations



Summary

- FCC study is advancing well towards the CDR for end 2018
- Consolidated parameter sets exists for FCC-hh and FCC-ee machines with complete baseline optics design and beam dynamics compatible with parameter requirements
- First round of geology, civil engineering & infrastructure studies completed
- Excellent progress on SC magnets and cryogenic beam vacuum system design as well as other technical R&D areas.
- Next milestone is study review at FCC Week in Berlin and definition of CDR baseline for tunnel layout and implementation.
- **International collaboration is essential to advance on all challenging subjects and EuCARD(2) has made essential contributions to forming and FCC community.**

FCC WEEK 2017

The annual meetings of the worldwide Future Circular Collider study (FCC) are major international events that follow the progress in every domain which is relevant to develop feasible concepts for a next generation frontier particle accelerate based high-energy physics research infrastructure. This 3rd meeting is jointly organised by CERN and DESY. It is also the annual meeting of the EuroCirCol EC Horizon 2020 Research and Innovation Action project. Previous events took place in Washington and Rome. In 2017 the FCC Week will take place in Berlin, Germany between May 29 and June 2.

http://cern.ch/fccw2017

Register

Registration will be opened on **September 1, 2016**. The

Abstract Submission

Oral presentation is by invitation only and there will be

Venue

A few minutes from Berlin Zoo, the InterContinental hotel