

# Future Circular Collider Study

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[cern.ch/fcc](http://cern.ch/fcc)



# European Strategy Update 2013

*“CERN should undertake **design studies** for accelerator projects in a **global context**, with emphasis on proton-proton and electron-positron **high-energy frontier** machines.”*

# Future Circular Collider Study - SCOPE

## CDR and cost review for the next ESU (2018)

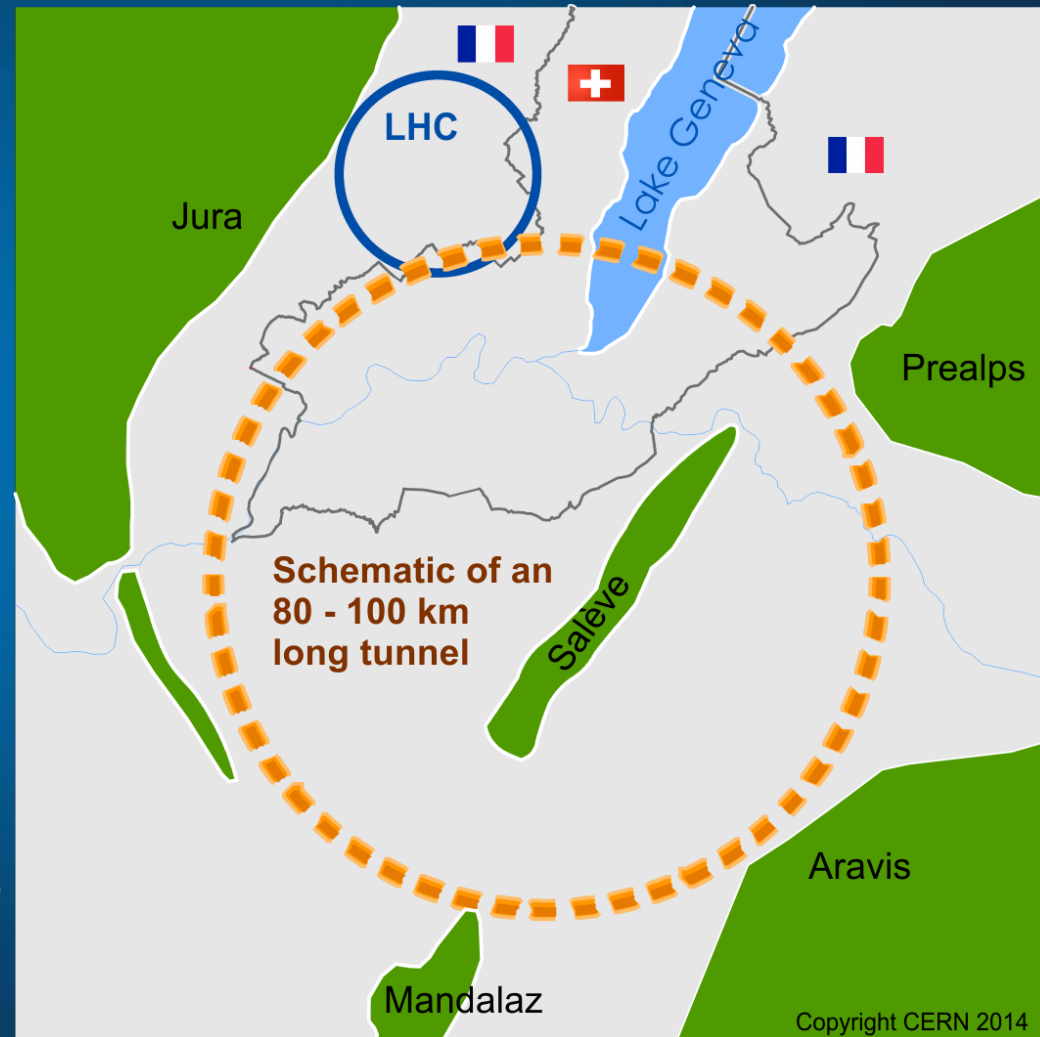
Forming an international collaboration to study:

- $pp$ -collider (*FCC-hh*)  
→ defining infrastructure requirements

~16 T  $\Rightarrow$  100 TeV  $pp$  in 100 km

~20 T  $\Rightarrow$  100 TeV  $pp$  in 80 km

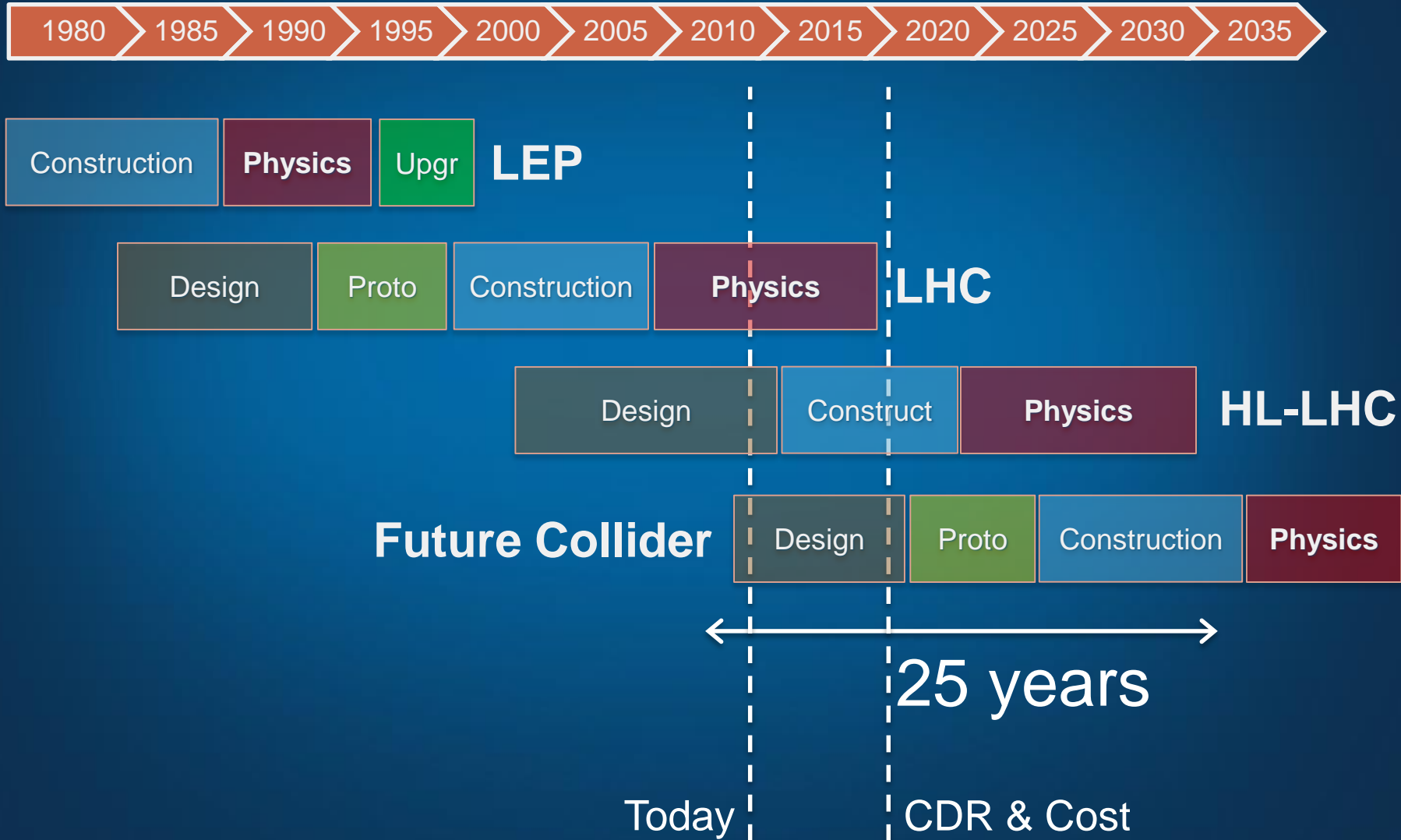
- 80-100 km infrastructure in Geneva area
- $e^+e^-$  collider (*FCC-ee*) as potential intermediate step
- $p-e$  (*FCC-he*) option



# Strategic Goals

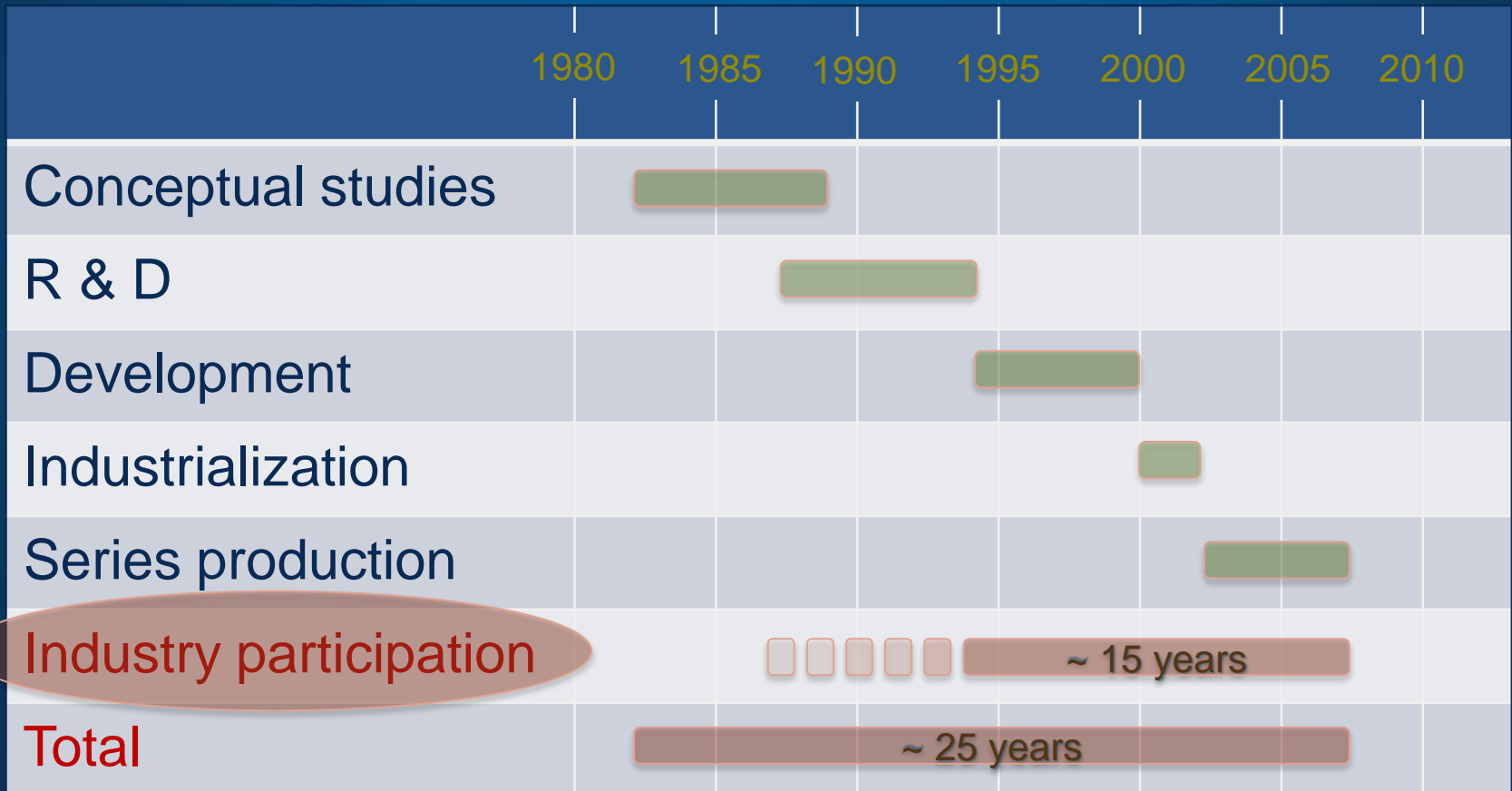
- **Make funding bodies aware** of strategic needs for research community
- **Provide sound basis to policy bodies** to establish long-range plans in European interest
- **Strengthen capacity** and **effectiveness** in high-tech domains
- Provide a **basis for long-term attractiveness of Europe** as research area

# HEP Timescale



# Time Indicator

**Case:** LHC superconducting dipole magnets



# FCC-hh Key Parameters

Parameter	FCC-hh	LHC
Energy	<b>100 TeV c.m.</b>	14 TeV c.m.
Dipole field	<b>16 T</b>	8.33 T
# IP	2 main, +2	4
Luminosity/IP <sub>main</sub>	<b>5 x 10<sup>34</sup> cm<sup>-2</sup>s<sup>-1</sup></b>	1 x 10 <sup>34</sup> cm <sup>-2</sup> s <sup>-1</sup>
Energy/beam	<b>8.4 GJ</b>	0.39 GJ
Synchr. rad.	28.4 W/m/apert.	0.17 W/m/apert.
Bunch spacing	25 ns (5 ns)	25 ns

Preliminary, subject to evolution

# FCC-ee Key Parameters

Parameter	FCC-ee	LEP2
Energy/beam	45 – 175 GeV	105 GeV
Bunches/beam	<b>98 – 16700</b>	4
Beam current	<b>6.6 – 1450 mA</b>	3 mA
Luminosity/IP	<b>1.8-28</b> x 10 <sup>34</sup> cm <sup>-2</sup> s <sup>-1</sup>	0.0012 x 10 <sup>34</sup> cm <sup>-2</sup> s <sup>-1</sup>
Energy loss/turn	0.03-7.55 GeV	3.34 GeV
Synchr. power	<b>100 MW</b>	22 MW
RF Voltage	2.5 – <b>11 GV</b>	3.5 GV

Preliminary, subject to evolution



**Tevatron** (closed)

Circumference: **6.2 km**



Energy: **2 TeV**

# Large Hadron Collider

Circumference: **27 km**

Energy:

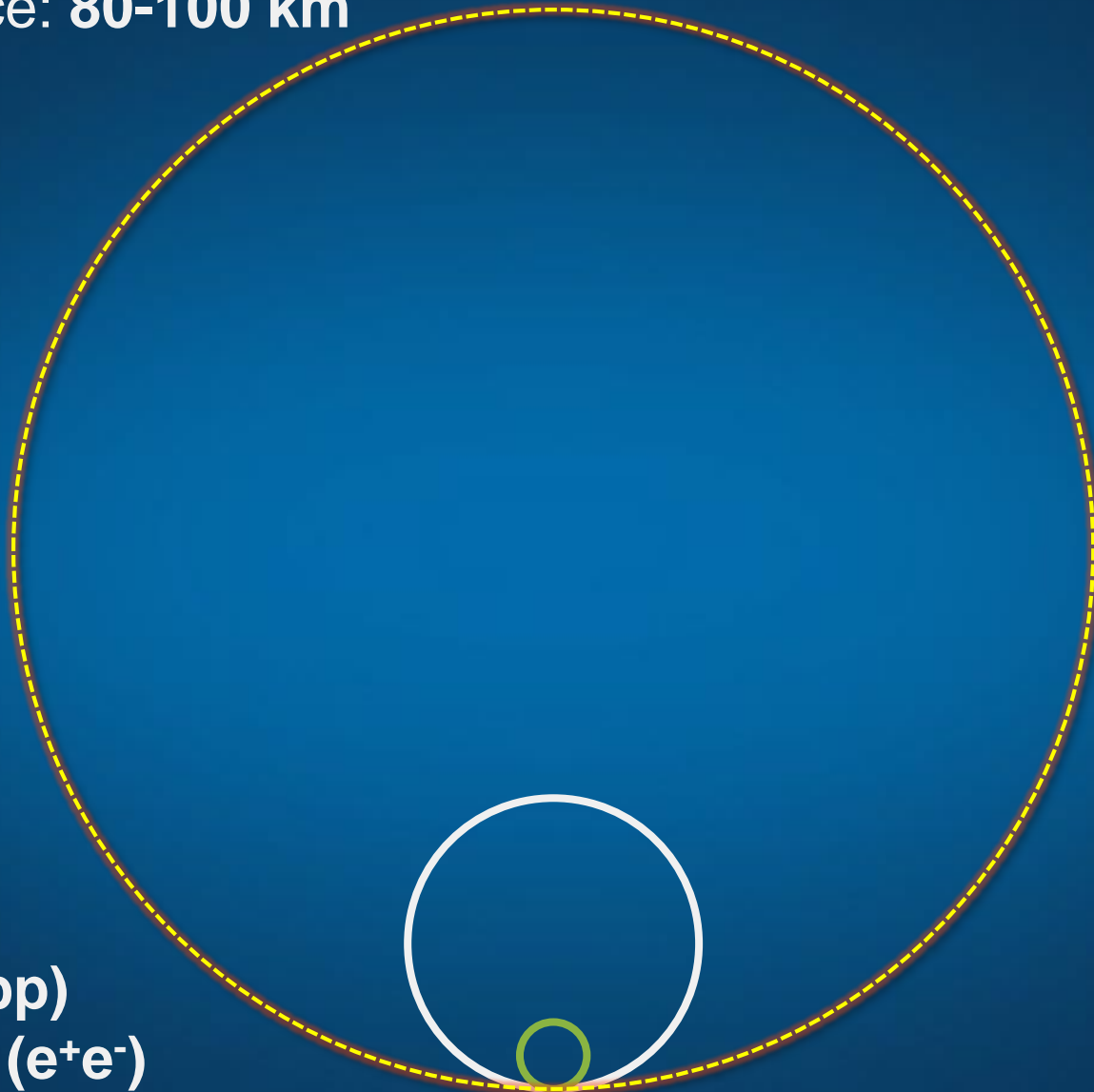
- **14 TeV (pp)**

- **209 GeV ( $e^+e^-$ )**



# Future Circular Collider

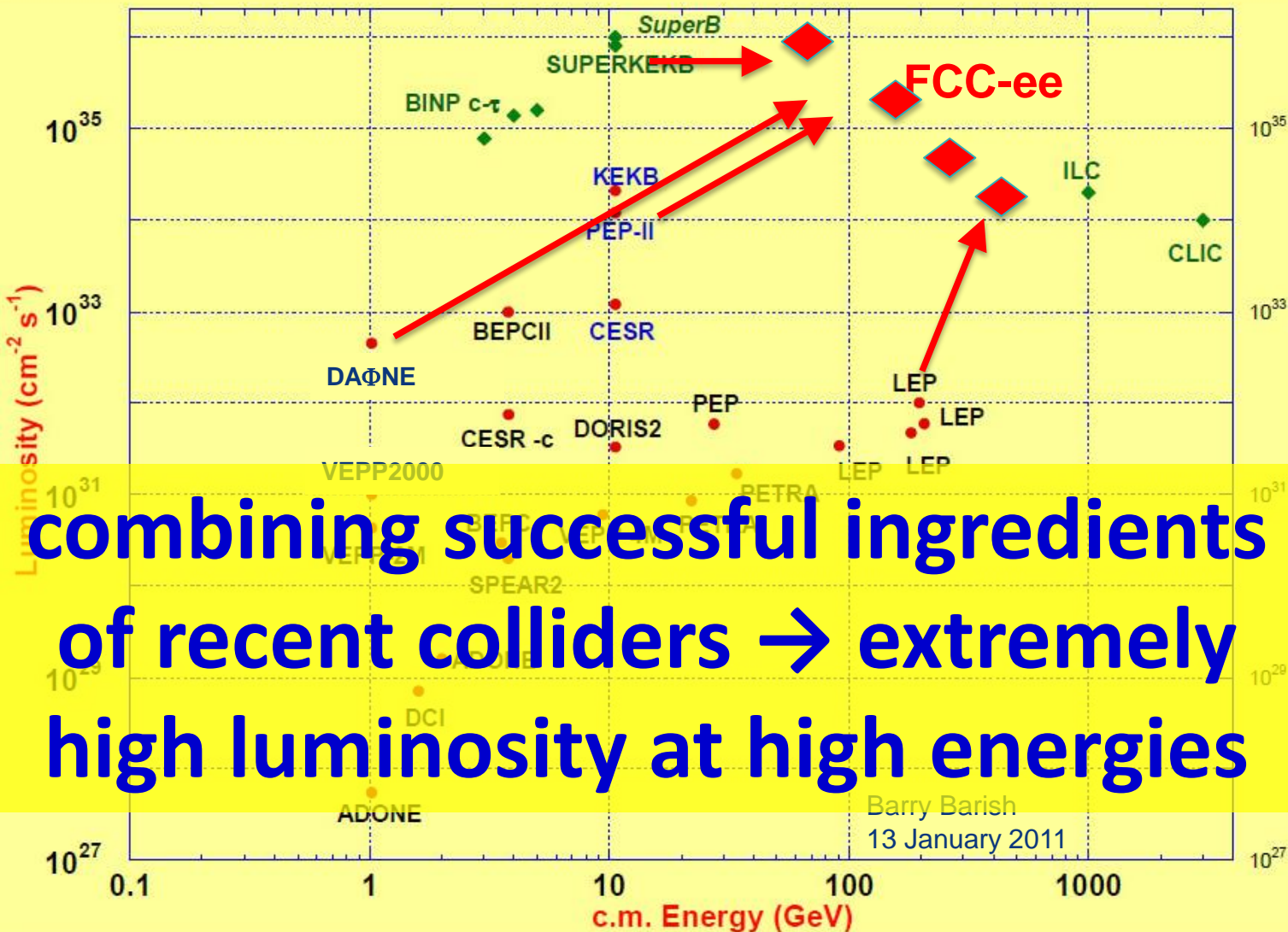
Circumference: 80-100 km



Energy:

- 100 TeV (pp)
- >350 GeV ( $e^+e^-$ )

# FCC-ee exploits lessons & recipes from past $e^+e^-$ and $pp$ colliders



- LEP:
  - high energy
  - SR effects
- B-factories:*
  - KEKB & PEP-II:
    - high beam currents
    - top-up injection
  - DAΦNE: crab waist
- Super B-factories*
  - S-KEKB: low  $\beta_y^*$
- KEKB:  $e^+$  source
- HERA, LEP, RHIC:
  - spin gymnastics

# Role of CERN

- **Host** the study
- **Prepare** organisation frame
- **Setup** collaboration
- **Identify** R&D needs
- **Estimate** costs

# FCC WBS top level

**Future  
Circular Collider**

**Physics and  
Experiments**

Hadron Collider  
Physics

Hadron Collider  
Experiments

Lepton Collider  
Physics

Lepton Collider  
Experiments

Lepton-Hadron  
Collider Physics

Lepton-Hadron  
Collider Experiment

**Accelerators**

Hadron  
Injectors

Hadron  
Collider

Lepton  
Injectors

Lepton  
Collider

Lepton-Hadron  
Collider

Technology  
R & D

**Infrastructures  
and Operation**

Civil  
Engineering

Technical  
Infrastructures

Operation and  
Energy Efficiency

Integration

Computing and  
Data Services

Safety, RP and  
Environment

**Implementation  
and Planning**

Project Risk  
Assessment

Implementation

Cost Estimates

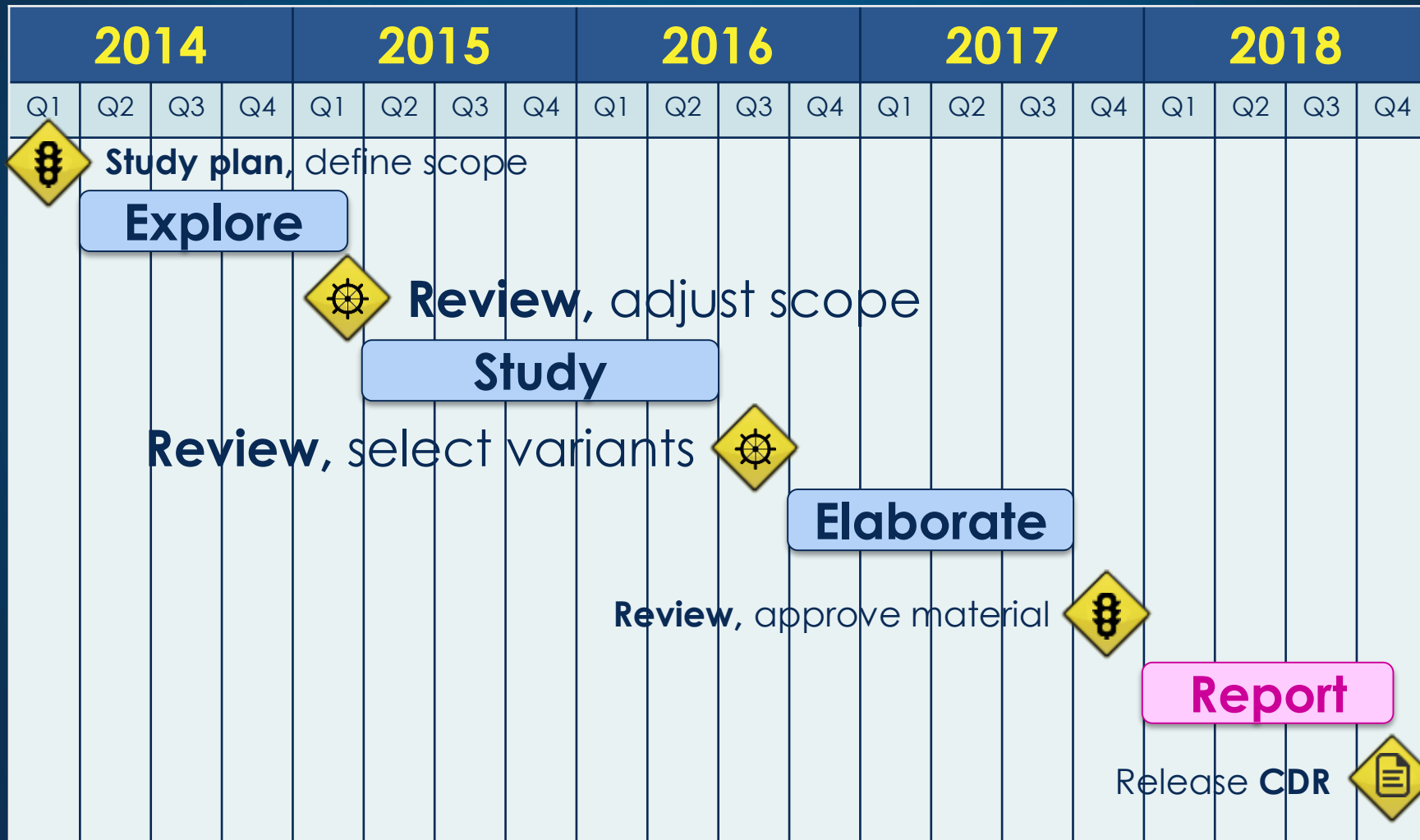
**Study and Quality  
Management**

Study  
Administration

Communications

Conceptual  
Design Report

# Study Timeline



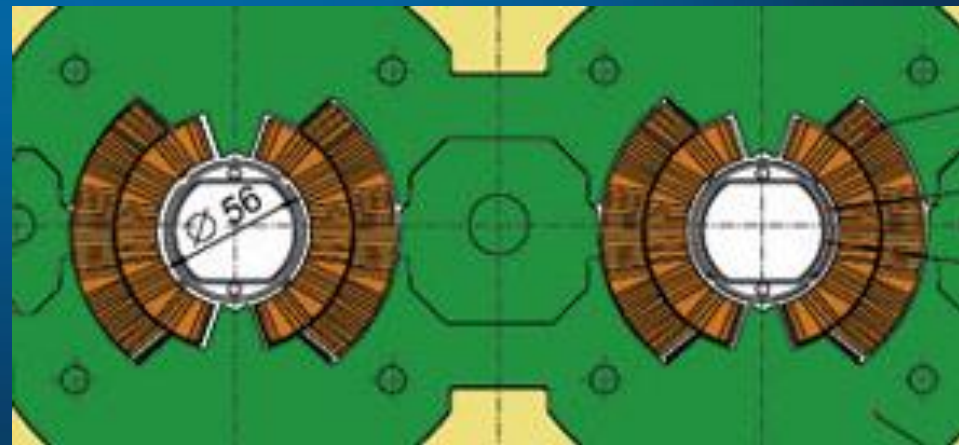
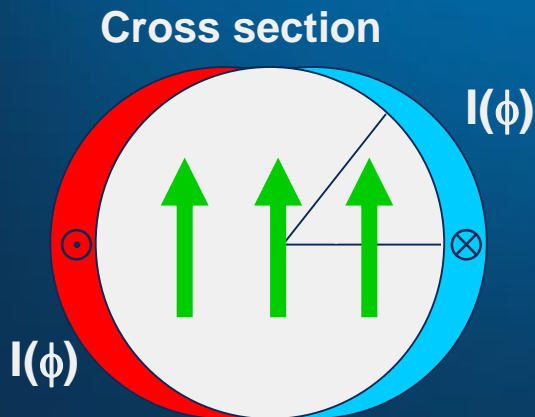
# Key Technologies

- 16 T superconducting magnets
- Superconducting RF cavities
- RF power sources
- Synchrotron radiation
- Affordable & reliable cryogenics
- Reliability & availability concepts

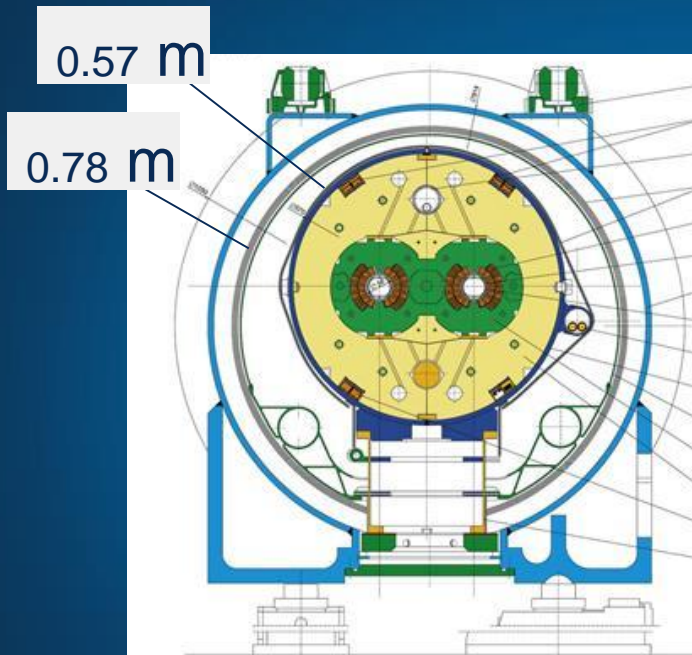


# High –field SC dipoles

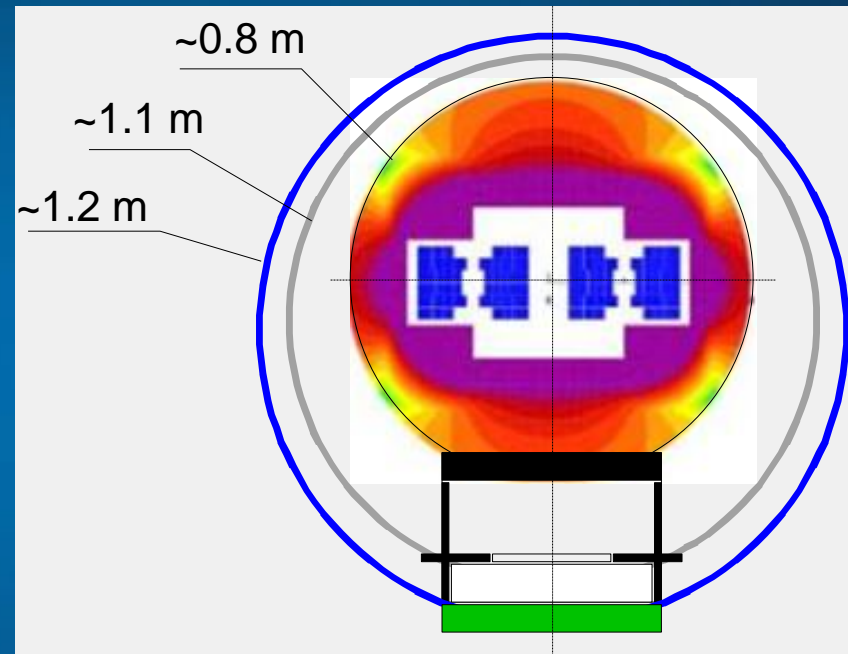
- **SC dipole: field defined via current distribution**
  - High current densities close to the beam for high fields
  - Only possible with super conductors  $I > 1 \text{ kA/mm}^2$
- **Ideal coil geometry for dipolar fields:**
  - Azimuthal current distribution  $I(\phi) = I_0 \cos(\phi)$  Dipol, ( $I_0 \cos(2\phi)$  Quadrupol)
  - 2 horizontally displaced circles



# Cryo-magnet cross sections

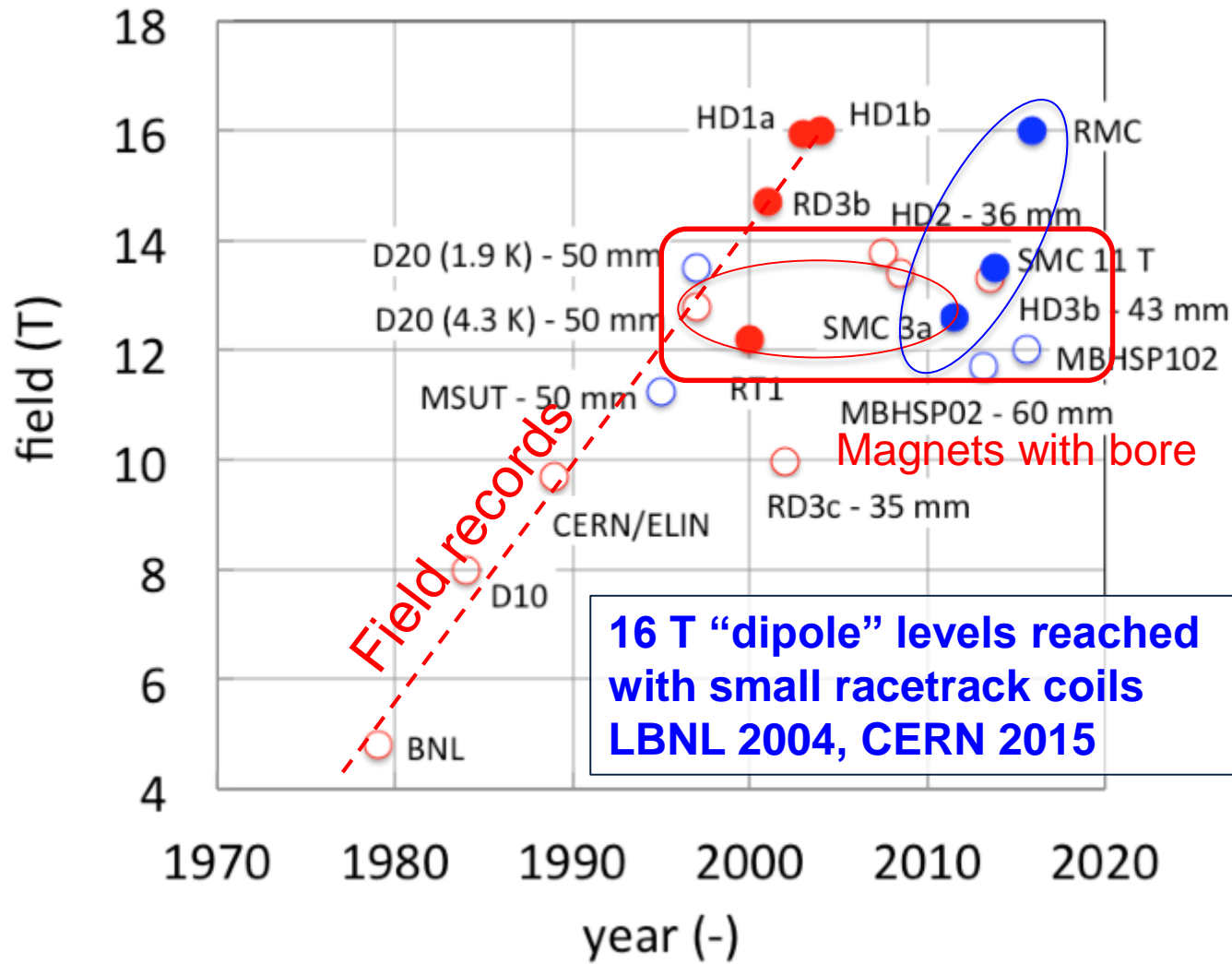


**LHC**  
**cos theta**



**FCC-hh**  
**block coil**  
**Nb<sub>3</sub>Sn as SC material**

# Towards 16 T magnets

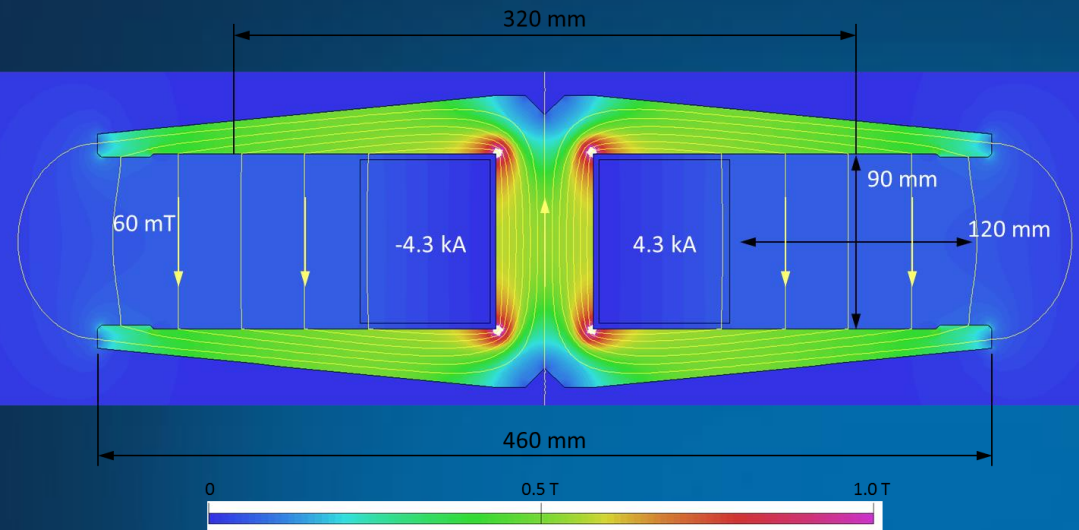


LBNL HD1



CERN RMC

# Efficient 2-in-1 FCC-ee arc magnets

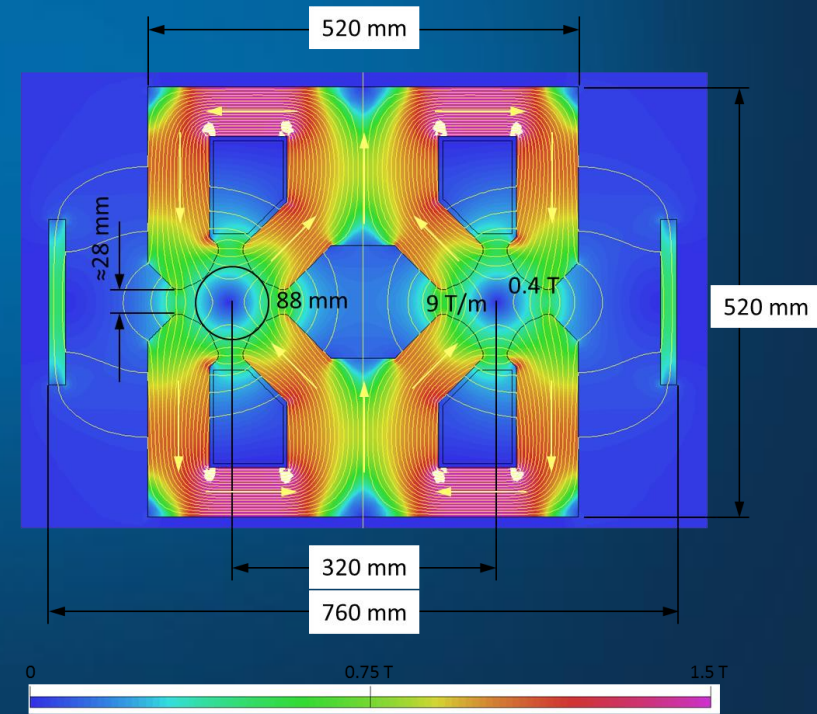


**Dipole:**  
twin aperture yoke  
single busbars as coils

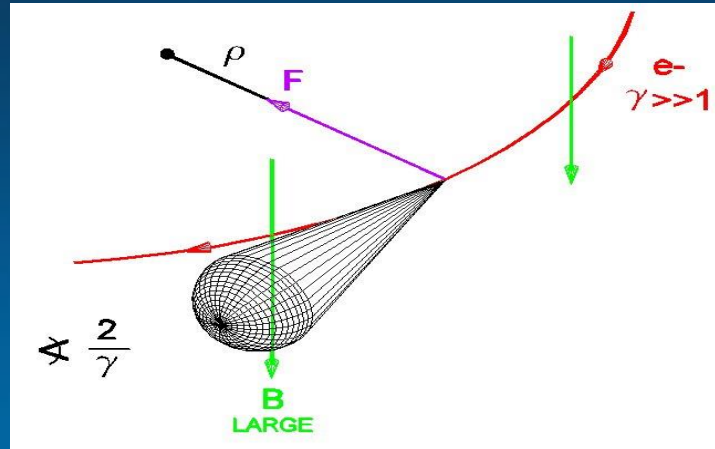
**Quadrupole:**  
twin 2-in-1 design

- 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



# Synchrotron radiation



- Charged particles on a curved trajectory irradiate energy:

$$\Delta E \sim \text{const} \cdot \gamma^4 / r = \text{const} \cdot (E/E_0)^4 / r = \text{const} \cdot (E/m_0)^4 / r$$

- Energy loss  $\Delta E$  must be compensated and corresponding heat has to be removed from cold mass of SC magnets (for hadron collider)

$$\Delta W = \Delta Q \cdot (T - T_{\text{tief}}) / T_{\text{tief}} = \Delta Q \cdot (300 - 1.9) / 1.9 \sim 155 \cdot \Delta Q$$

For realistic process efficiency is  $\sim 1000$ : 1 W @ 1.9 K == 1 kW @ room temp.

# Vacuum system – beam screen – cryogenic load

Total electrical power to refrigerator  $P_{ref.}$  considering:

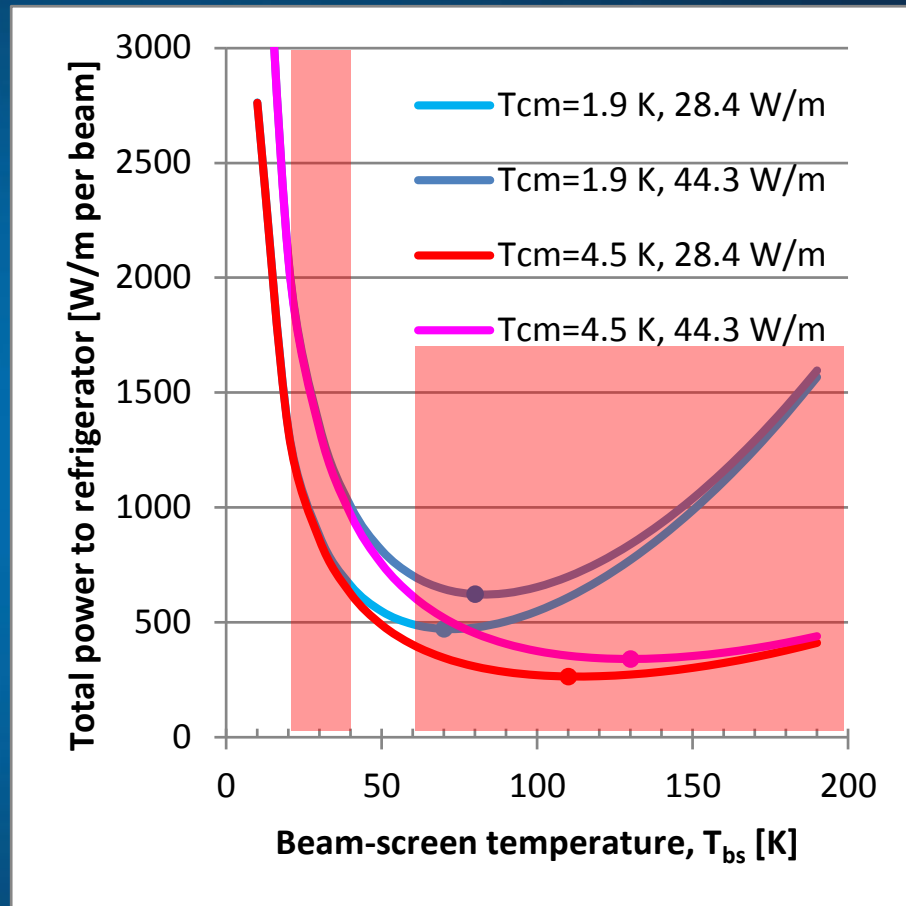
- a beam screen similar to that of the LHC
- refrigerator efficiencies identical to those of the LHC.

$T_{cm} = 1.9$  K, optimum for  $T_{bs} = 70$ -80 K

$T_{cm} = 4.5$  K, flat optimum for  $T_{bs} = 120$  K

**Temperature range 40-60 K retained**

**To limit cryogenic load to ~100 MW.**



Forbidden by vacuum and/or by surface impedance

# Synchrotron radiation beam screen prototype

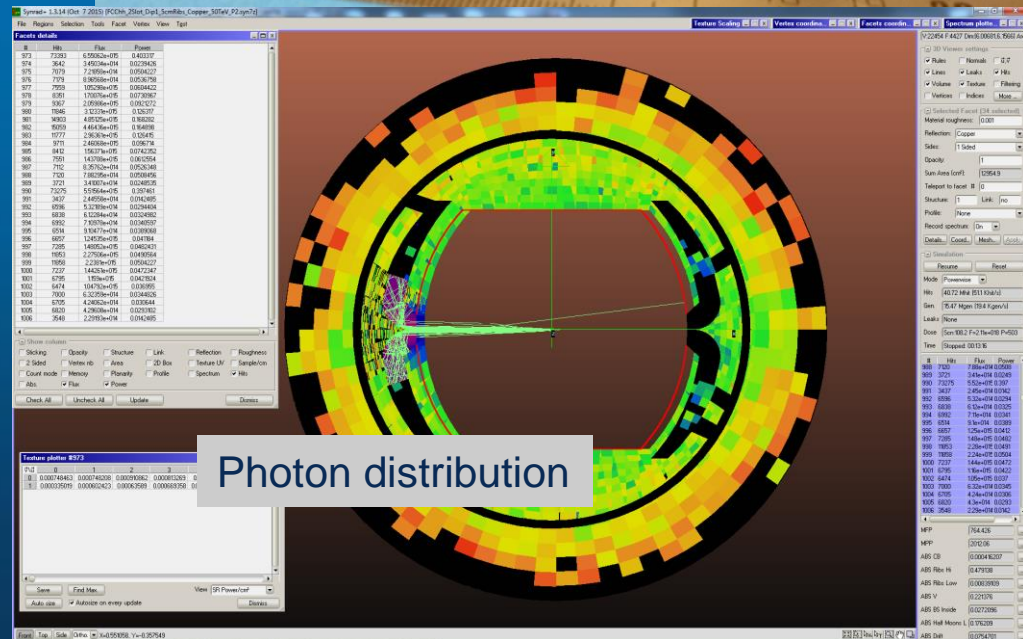
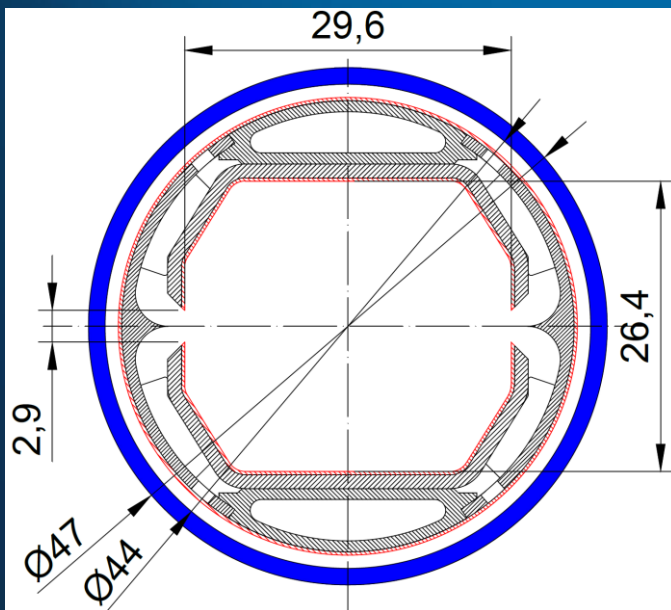
High synchrotron radiation load of protons @ 50 TeV:

- ~30 W/m/beam (@16 T) (LHC <0.2W/m)
- 5 MW total in arcs

New Beam screen with ante-chamber

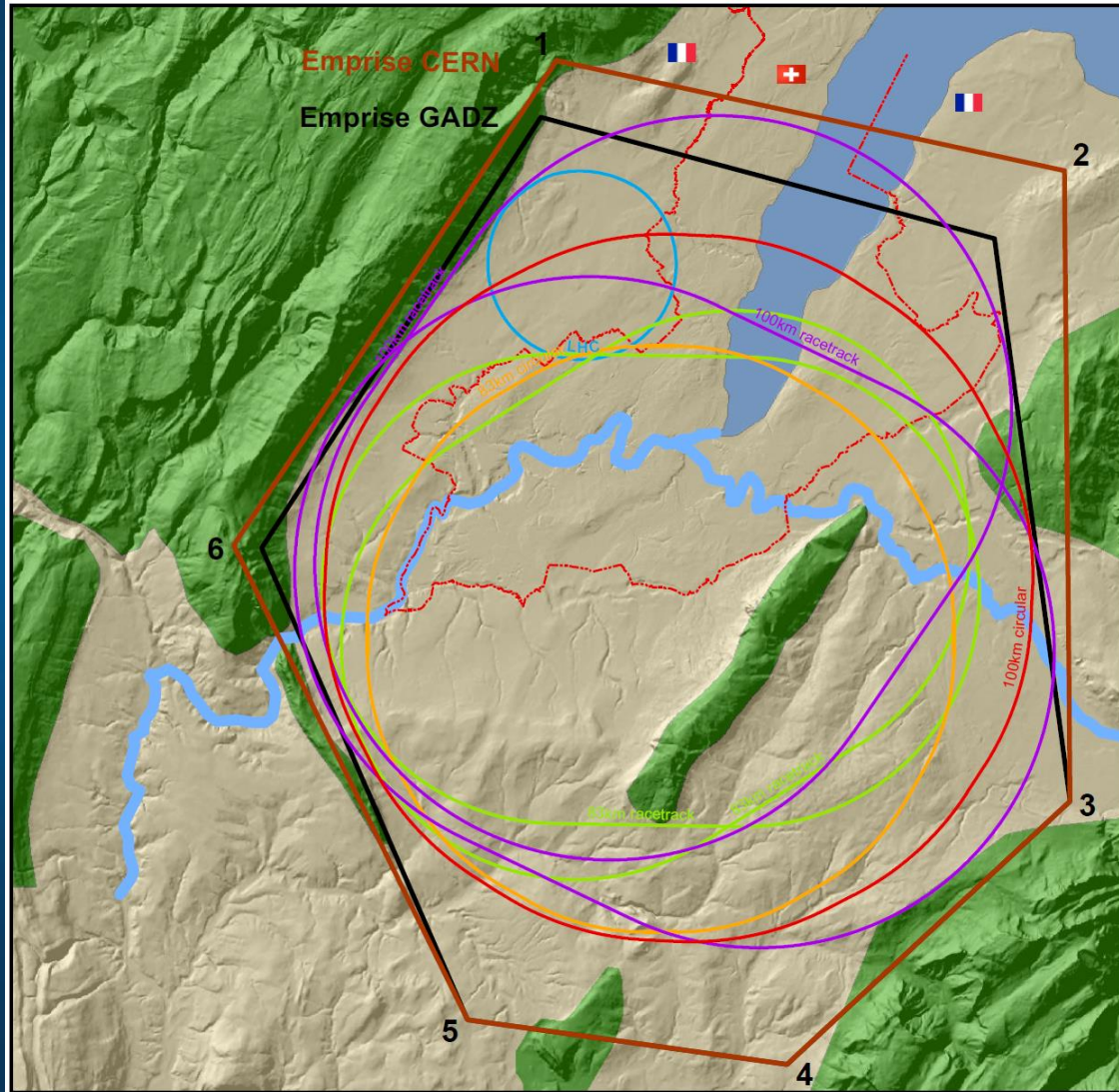
absorption of synchrotron radiation at 50 K to reduce cryogenic power avoids photo-electrons, helps vacuum

**First beam screen prototype**  
Testing 2017 in ANKA within EuroCirCol



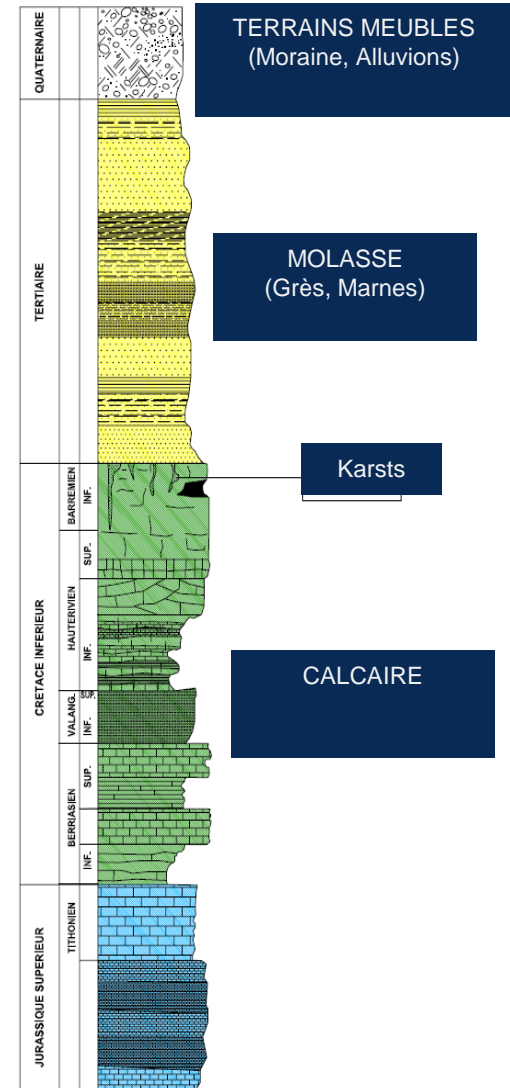
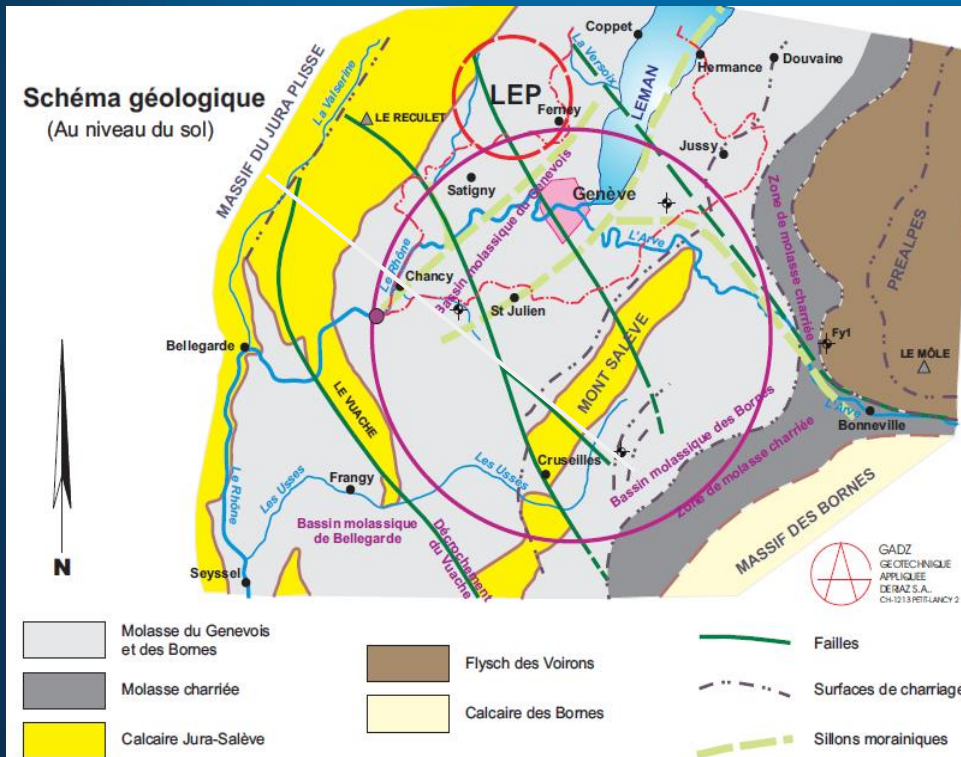
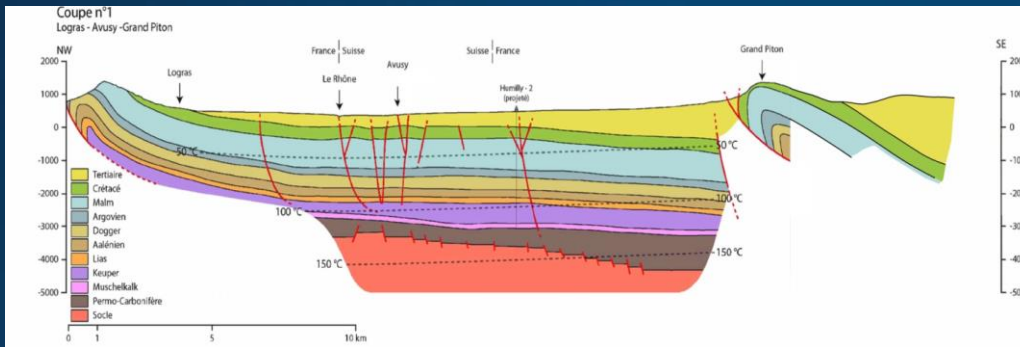
Photon distribution

# Geological studies – machine geometries

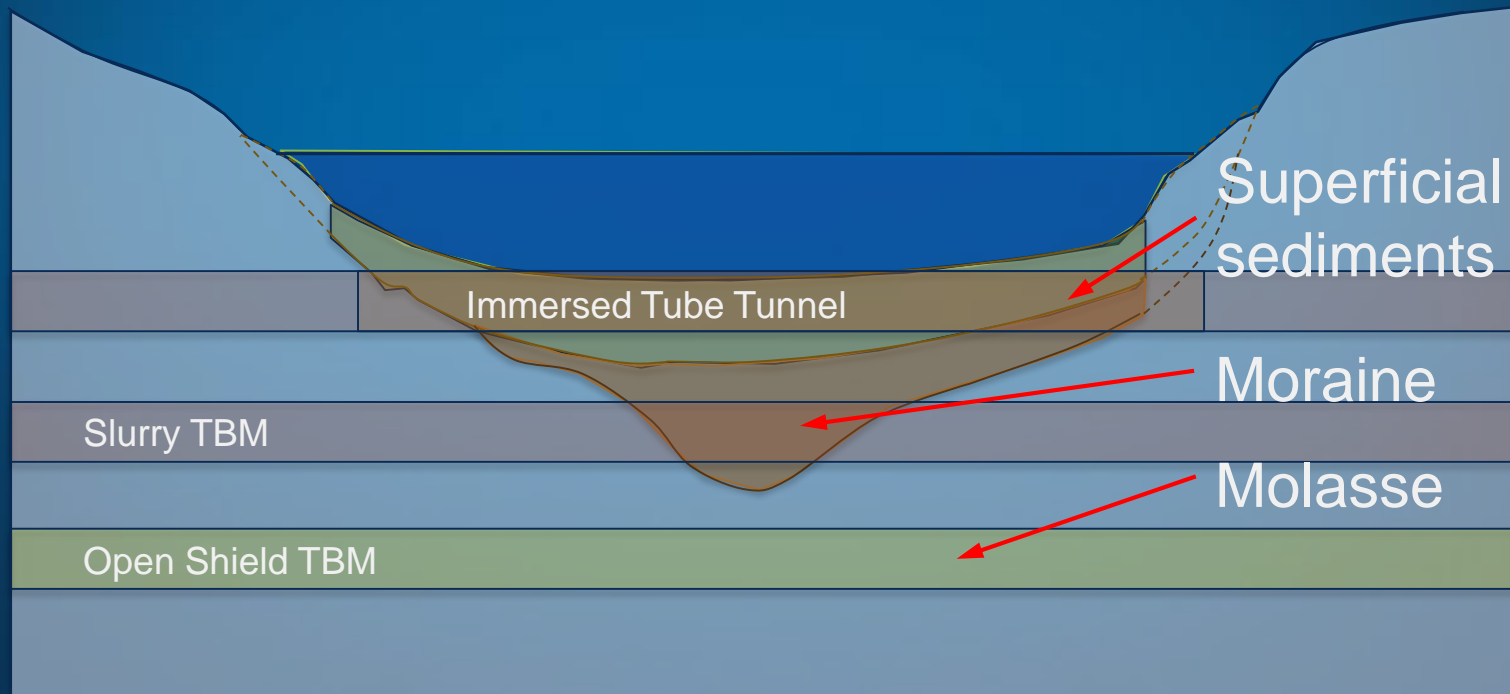




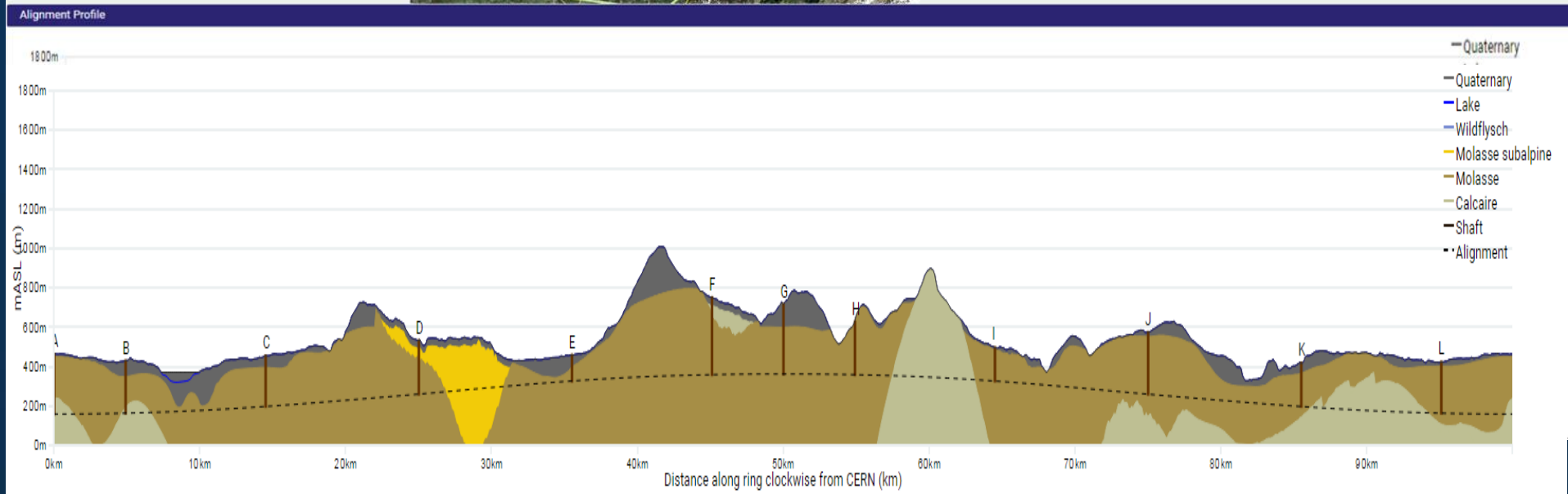
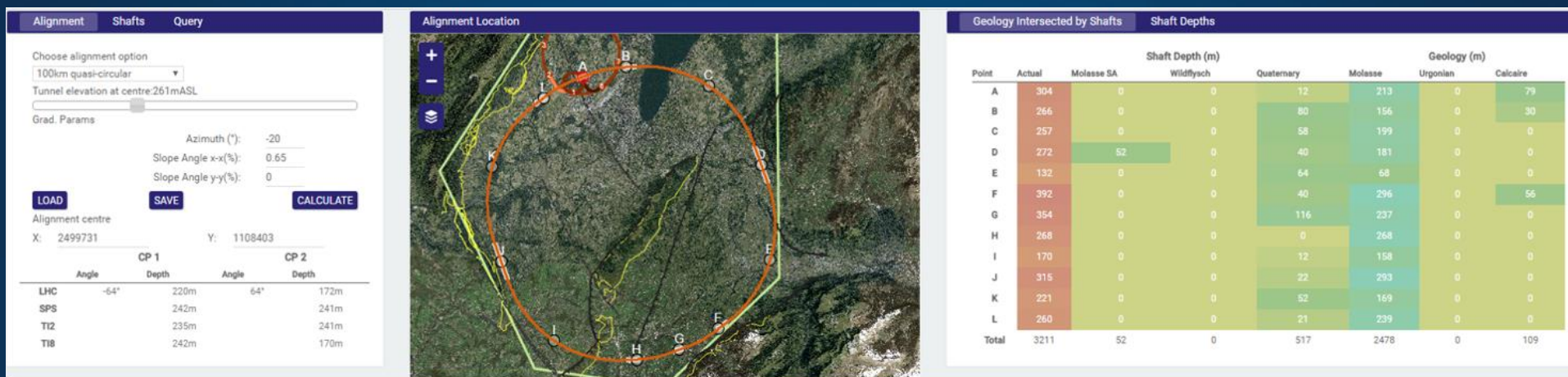
# Geological background



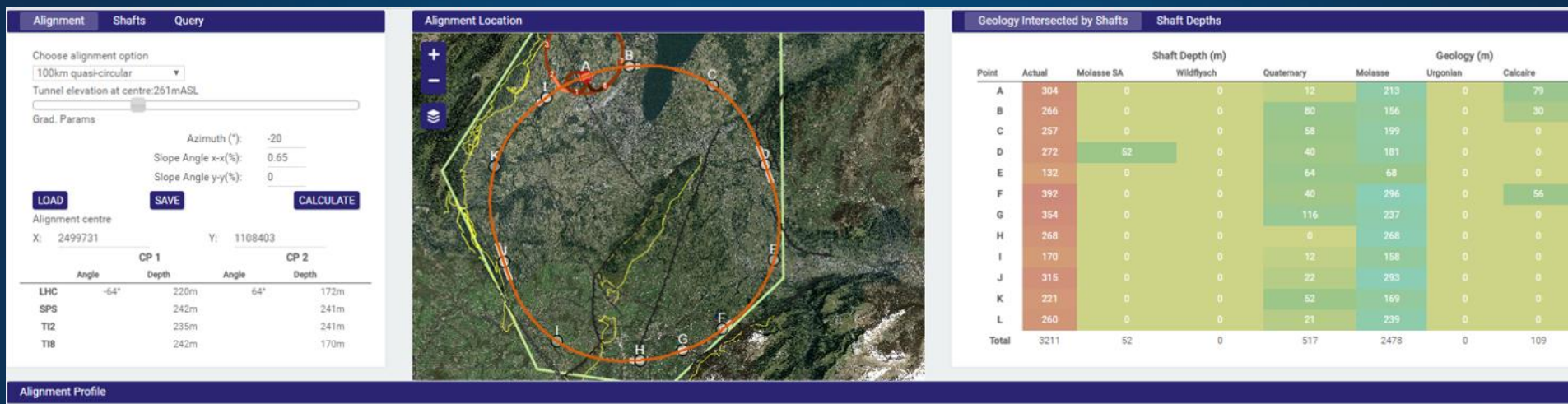
# Tunnelling options for crossing the lake



# Progress on site investigations



# Progress on site investigations



- 90 – 100 km fits geological situation well
- LHC suitable as potential injector
- The 100 km version, intersecting LHC, is now being studied in more detail

# FCC-hh injector studies

## Injector options:

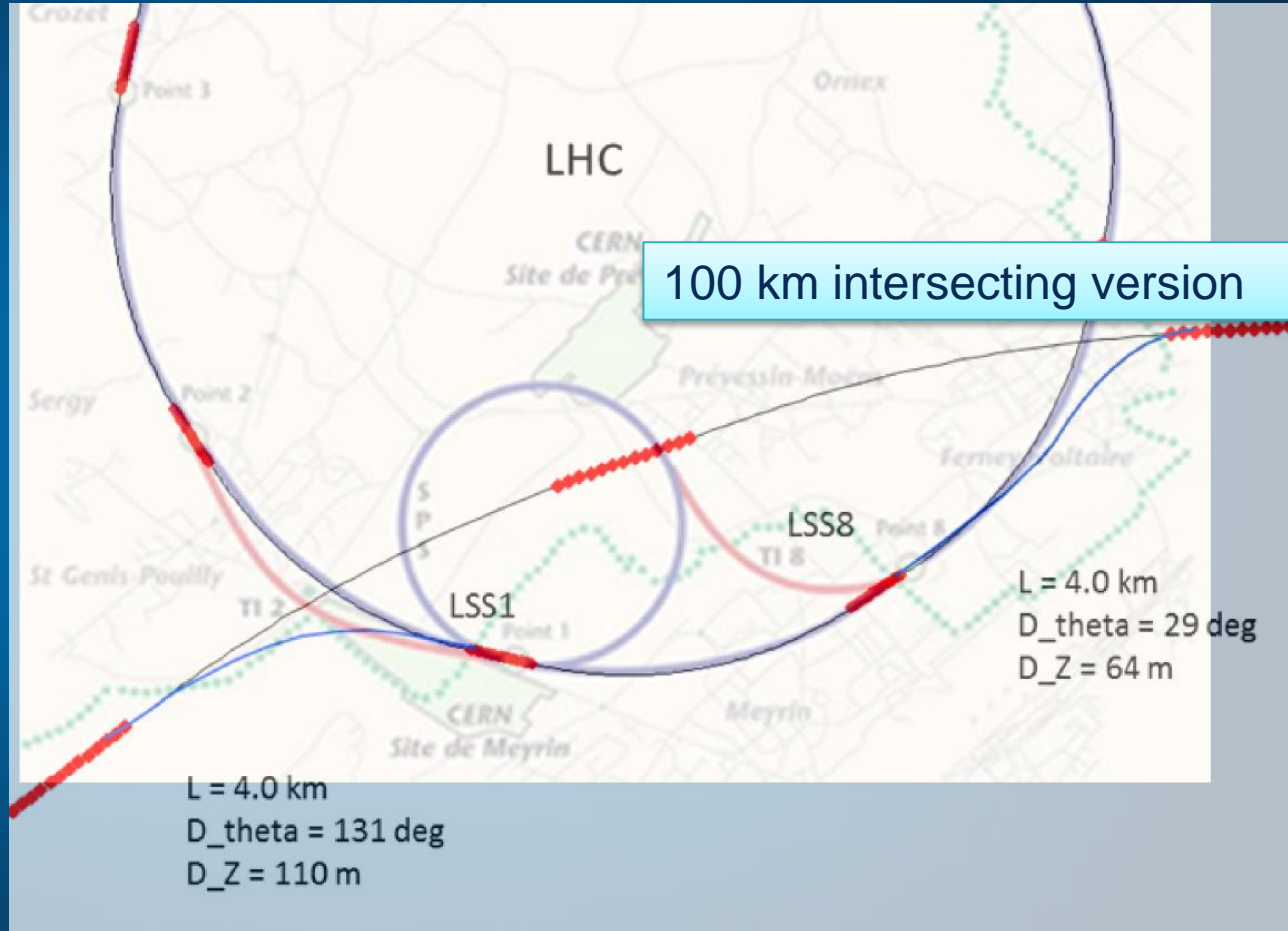
- **SPS → LHC → FCC**
- **SPS/SPS<sub>upgrade</sub> → FCC**
- **SPS-→FCC booster→FCC**

## Current baseline:

- **injection energy**  
**3.3 TeV LHC**

## Alternative options:

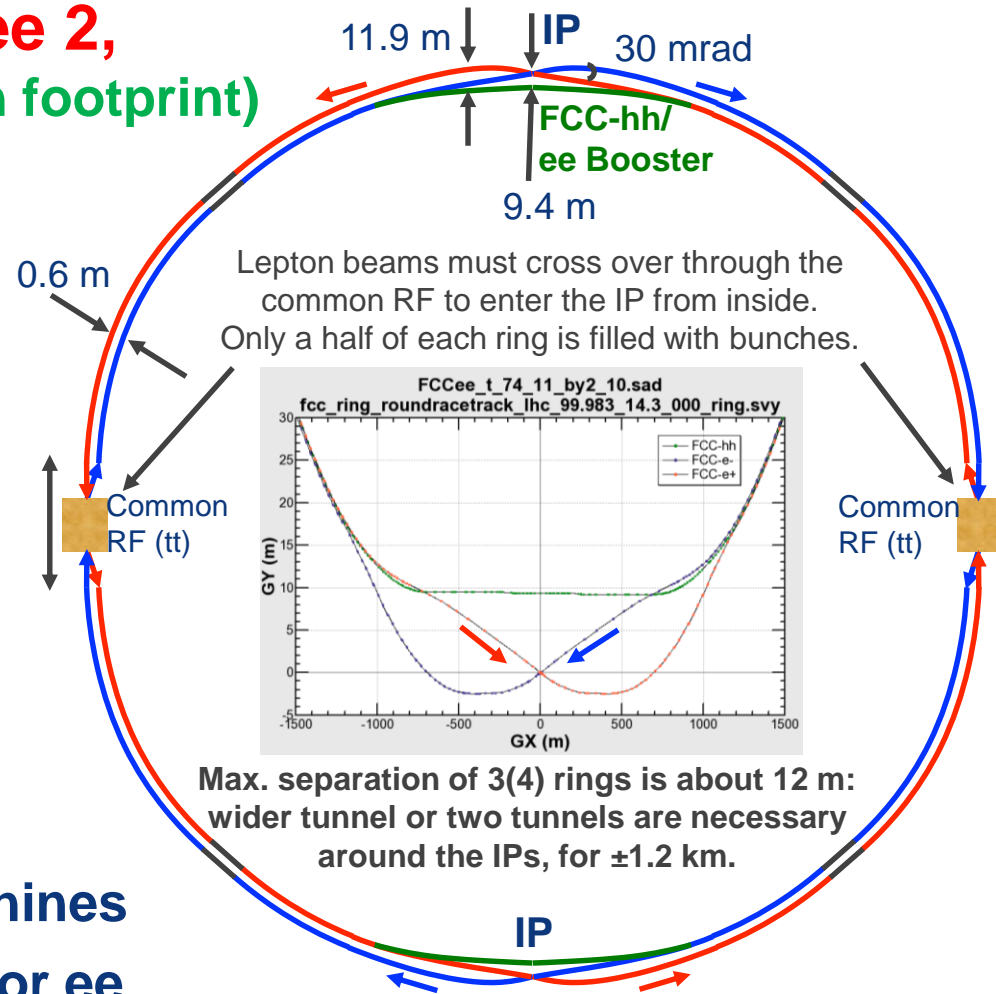
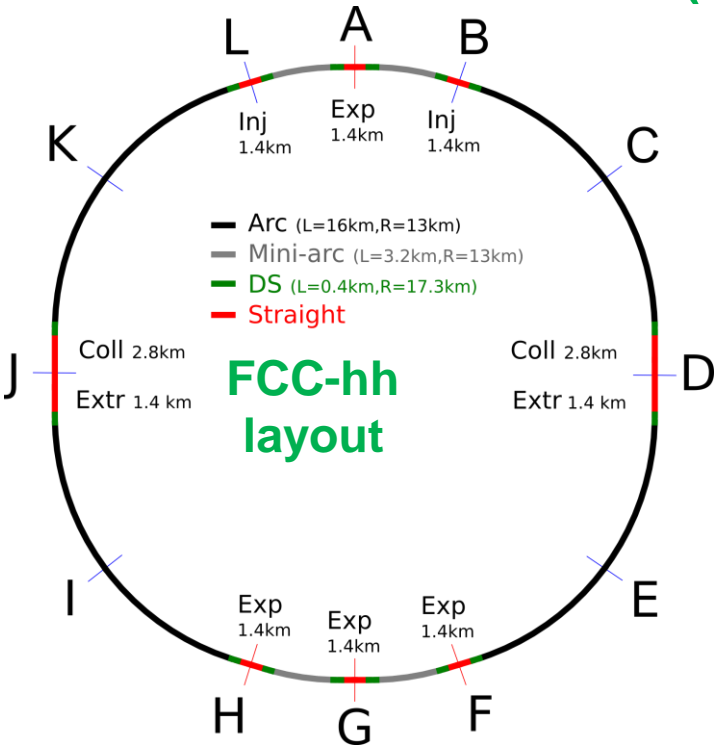
- Injection around 1.5 TeV
- **compatible with: SPS<sub>upgrade</sub>, LHC, FCC booster**



# Common layouts for hh & ee

FCC-ee 1, FCC-ee 2,

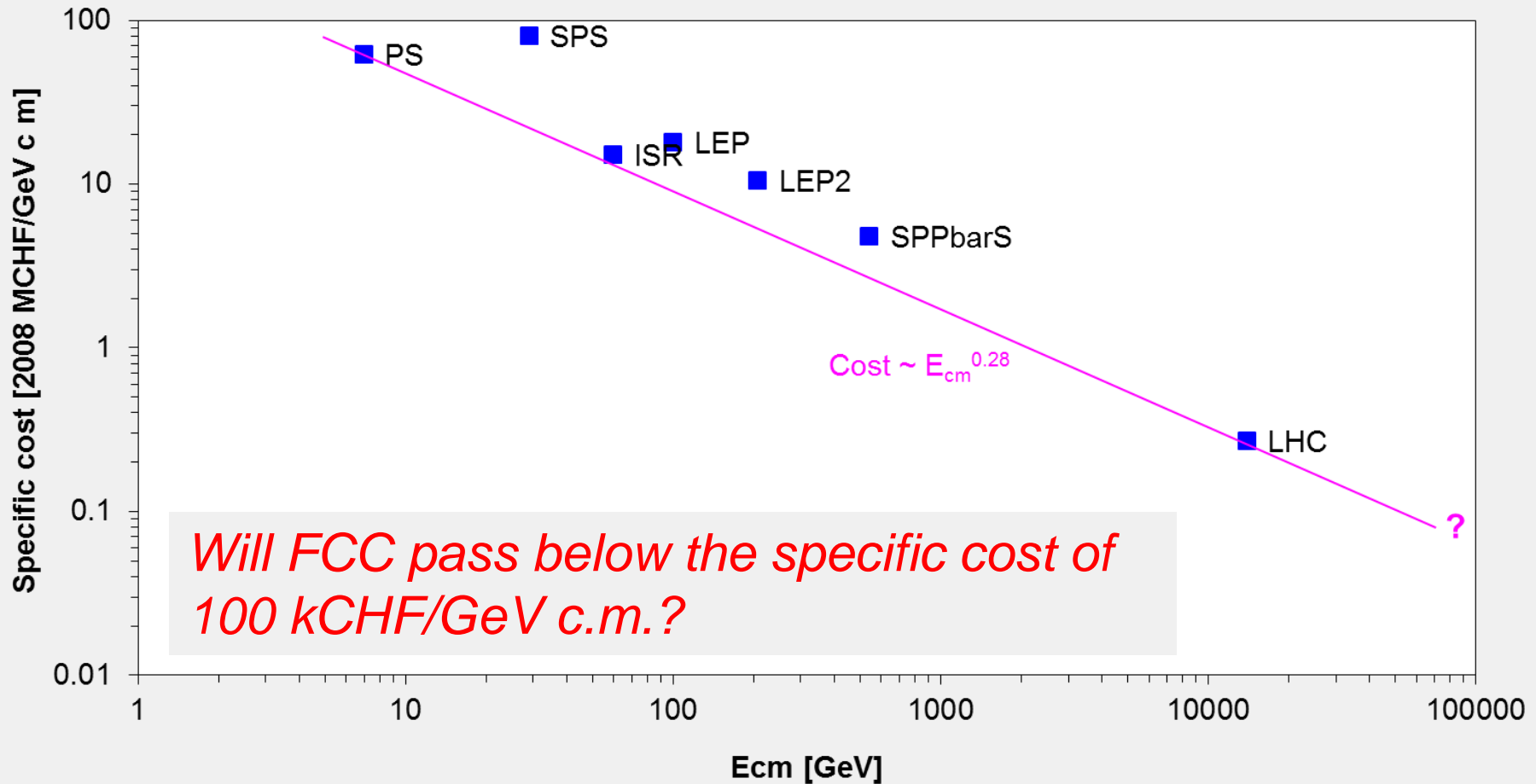
FCC-ee booster (FCC-hh footprint)



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

# A sustained decrease in specific cost

Specific cost vs center-of-mass energy of CERN accelerators



*Will FCC pass below the specific cost of 100 kCHF/GeV c.m.?*

# FCC International Collaboration

- 75 institutes
- 26 countries + EC



Status: April, 2016



# FCC Collaboration Status

75 collaboration members & CERN as host institute, April 2016

ALBA/CELLS, Spain  
Ankara U., Turkey  
U Belgrade, Serbia  
U Bern, Switzerland  
BINP, Russia  
CASE (SUNY/BNL), USA  
CBPF, Brazil  
CEA Grenoble, France  
CEA Saclay, France  
CIEMAT, Spain  
Cinvestav, Mexico  
CNRS, France  
CNR-SPIN, Italy  
Cockcroft Institute, UK  
U Colima, Mexico  
UCPH Copenhagen, Denmark  
CSIC/IFIC, Spain  
TU Darmstadt, Germany  
TU Delft, Netherlands  
DESY, Germany  
DOE, Washington, USA  
ESS, Lund, Sweden  
TU Dresden, Germany  
Duke U, USA  
EPFL, Switzerland

UT Enschede, Netherlands  
U Geneva, Switzerland  
Goethe U Frankfurt, Germany  
GSI, Germany  
GWNW, Korea  
U. Guanajuato, Mexico  
Hellenic Open U, Greece  
HEPHY, Austria  
U Houston, USA  
IIT Kanpur, India  
IFJ PAN Krakow, Poland  
INFN, Italy  
INP Minsk, Belarus  
U Iowa, USA  
IPM, Iran  
UC Irvine, USA  
Istanbul Aydin U., Turkey  
JAI, UK  
JINR Dubna, Russia  
Jefferson LAB, USA  
FZ Jülich, Germany  
KAIST, Korea  
KEK, Japan  
KIAS, Korea  
King's College London, UK

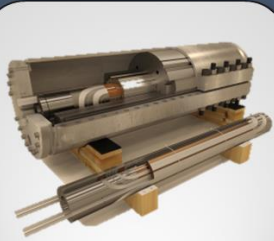
KIT Karlsruhe, Germany  
KU, Seoul, Korea  
Korea U Sejong, Korea  
U. Liverpool, UK  
U. Lund, Sweden  
MAX IV, Lund, Sweden  
MEPhI, Russia  
UNIMI, Milan, Italy  
MIT, USA  
Northern Illinois U, USA  
NC PHEP Minsk, Belarus  
U Oxford, UK  
PSI, Switzerland  
U. Rostock, Germany  
RTU, Riga, Latvia  
UC Santa Barbara, USA  
Sapienza/Roma, Italy  
U Siegen, Germany  
U Silesia, Poland  
TU Tampere, Finland  
TOBB, Turkey  
U Twente, Netherlands  
TU Vienna, Austria  
Wigner RCP, Budapest, Hungary  
Wroclaw UT, Poland

# EuroCirCol EU Horizon 2020 Grant

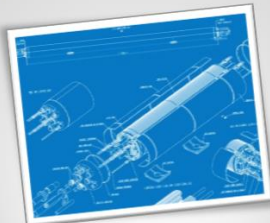
## EC contributes with funding to FCC-hh study

- EuroCirCol H2020 Design Study, launched in June 2015, is in full swing now and makes essential contributions to the FCC-hh work packages:
- **Arc & IR optics, 16 T dipole design, cryogenic beam vacuum system**

### H2020 EuroCirCol



Hadron Collider



Key Technologies

Resources provided by research institutes and universities with H2020 grant support.

### Future Circular Collider study **without** H2020 Support Requests



Infrastructure



Implementation



Cost Baseline

Resources provided and work carried out by worldwide collaboration.



# FCCWEEK 2016

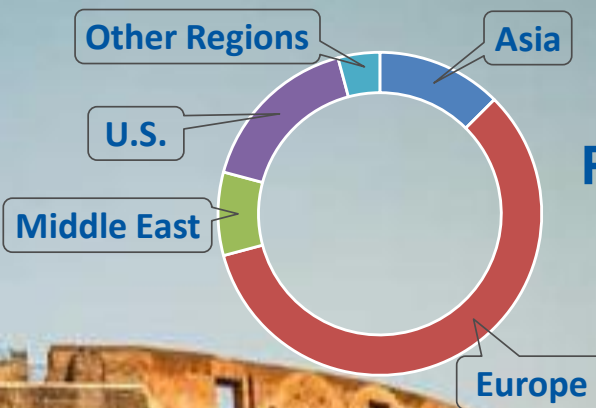
International Future Circular Collider Conference

## ROME 11-15 APRIL

[fccw2016.web.cern.ch](http://fccw2016.web.cern.ch)



<http://cern.ch/fccw2016>



**468**  
Participants

**168**  
Institutes

**24**  
Countries

### ORGANISING & SCIENTIFIC PROGRAMME COMMITTEE:

G. Apollinari (FNAL)  
S. Asai (U. Tokyo)  
A. Ball (CERN)  
A. Ballarino (CERN)  
B. Barletta (MIT)  
M. Benedikt (CERN)  
A. Blondel (U. Geneva)  
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G. Tonelli (U. Pisa)  
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J. Wenninger (CERN)  
F. Zimmermann (CERN)  
F. Zwirner (U. Padova)



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IEEE





# Future Circular Collider Study



Large scale technical infrastructures  
Conceptual design study 2014 – 2018  
Driven by international contributions  
Establish long-term liaisons with industry  
Collaborate on technology evolution (> 2025)



# FCC Week 2017



**29 May – 2 June 2017**

**Berlin, Germany**