Future Circular Collider Study

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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."*

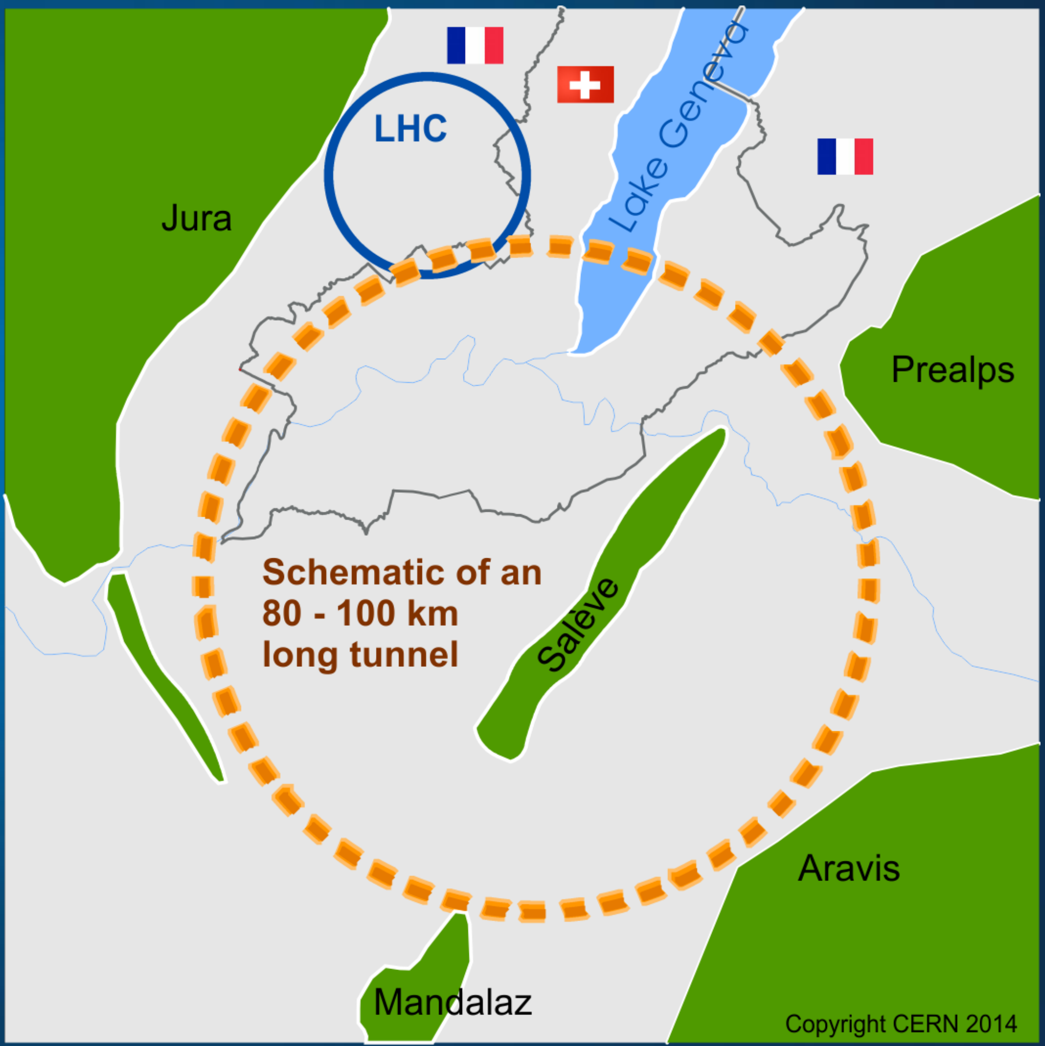
Future Circular Collider Study - SCOPE
CDR and cost review for the next ESU (2018)

Forming an international collaboration to study:

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

~16 T ⇒ 100 TeV *pp* in 100 km
~20 T ⇒ 100 TeV *pp* in 80 km

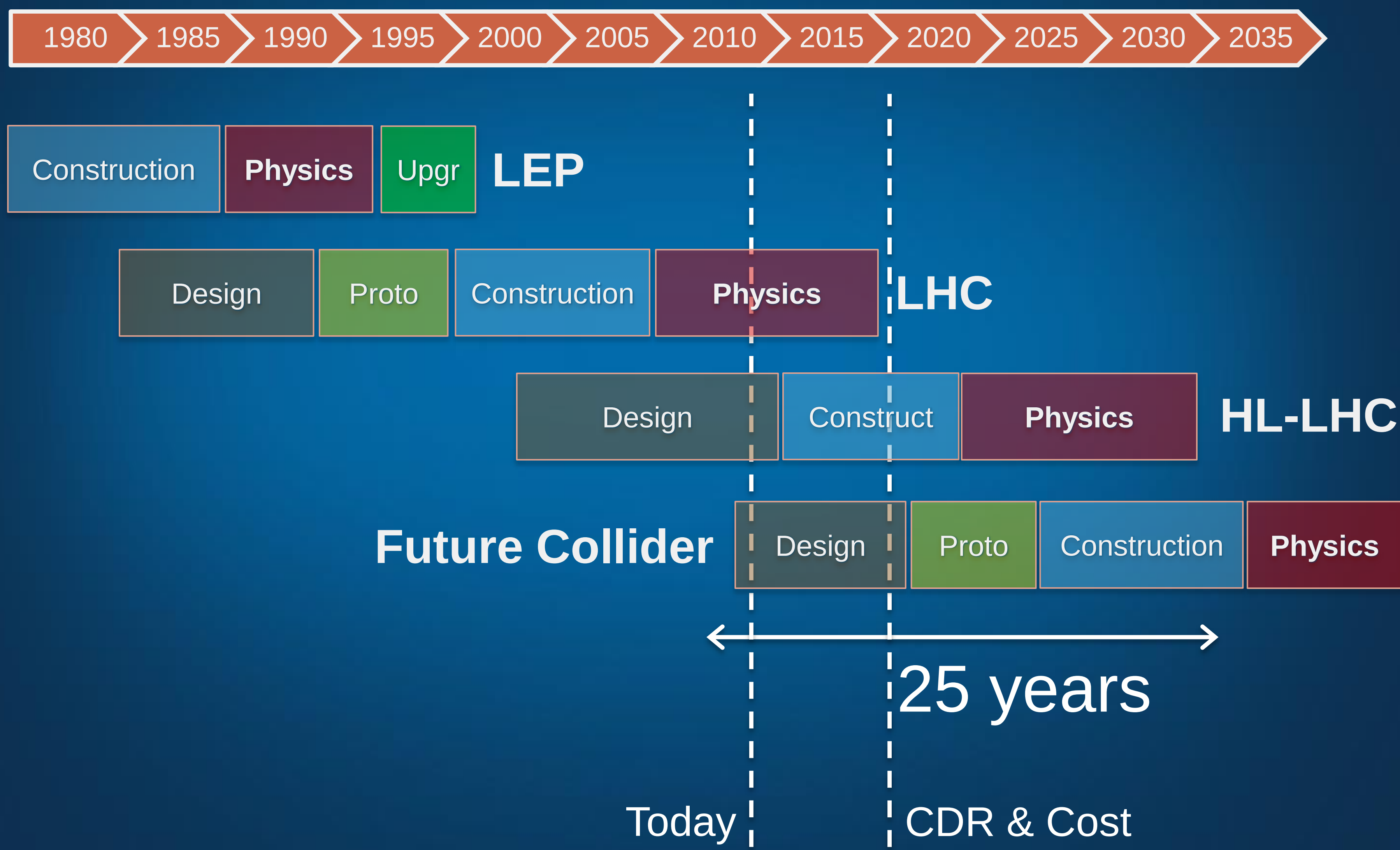
- **80-100 km infrastructure** in Geneva area
- ***e*$^+$*e*$^-$ collider (*FCC-ee*)** as potential intermediate step
- ***p-e* (*FCC-he*) option**



Strategic Goals

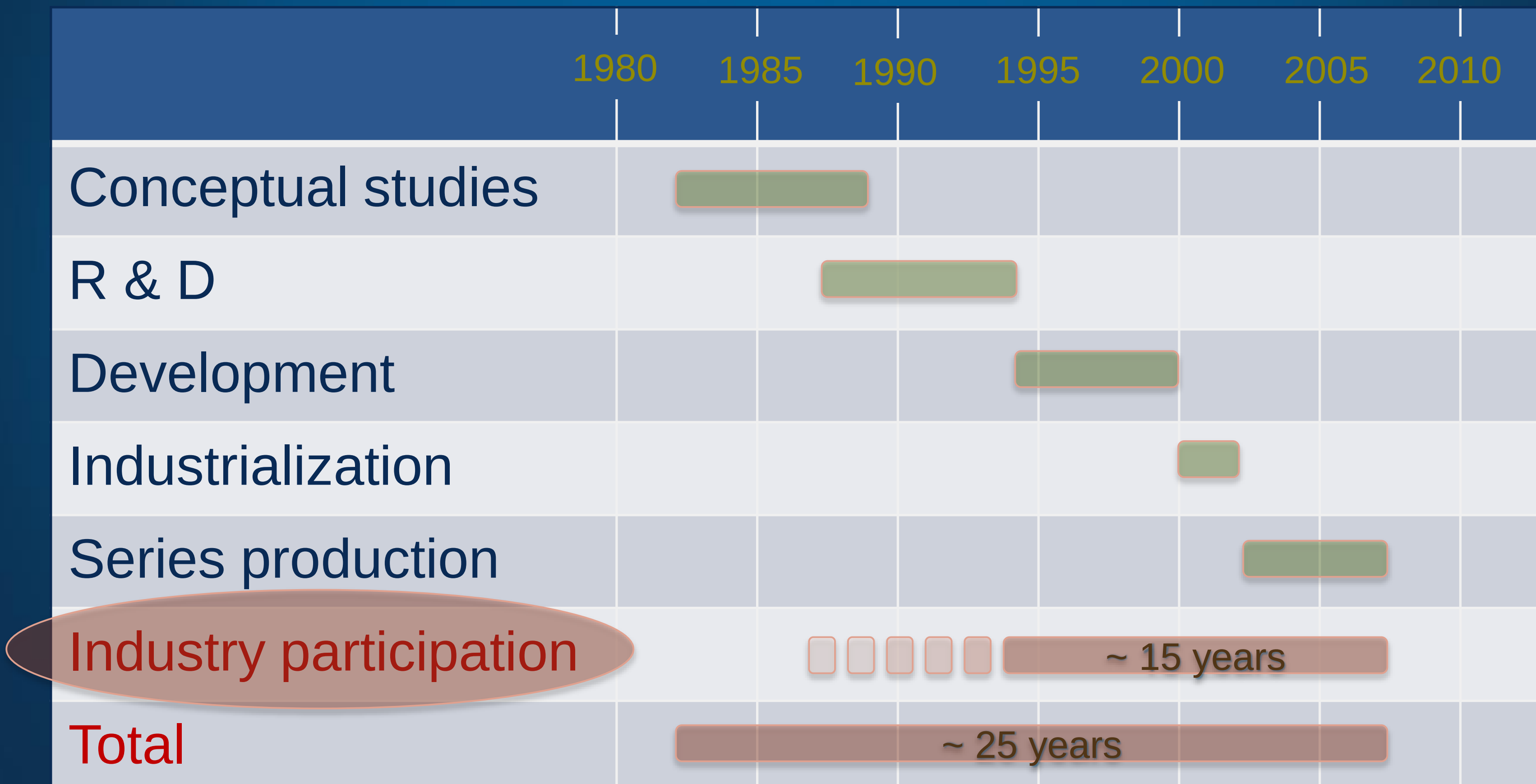
- **Make funding bodies aware** of strategic needs for research community
- **Provide sound basis to policy bodies** to establish long-range plans in European interest
- **Strengthen capacity** and **effectiveness** in high-tech domains
- Provide a **basis for long-term attractiveness of Europe** as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

HEP Timescale



Time Indicator

Case: LHC superconducting dipole magnets



FCC-hh Key Parameters

Parameter	**FCC-hh**	LHC
Energy	**100 TeV c.m.**	14 TeV c.m.
Dipole field	**16 T**	8.33 T
# IP	2 main, +2	4
Luminosity/IP_{main}	**5×10^{34}** $cm^{-2}s^{-1}$	1×10^{34} $cm^{-2}s^{-1}$
Energy/beam	**8.4 GJ**	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	**98 – 16700**	4
Beam current	**6.6 – 1450 mA**	3 mA
Luminosity/IP	**1.8-28** x 10^{34} $cm^{-2}s^{-1}$	0.0012 x 10^{34} $cm^{-2}s^{-1}$
Energy loss/turn	0.03-7.55 GeV	3.34 GeV
Synchr. power	**100 MW**	22 MW
RF Voltage	2.5 – **11 GV**	3.5 GV

Preliminary, subject to evolution

Tevatron (closed)

Circumference: **6.2 km**

Energy: **2 TeV**

Large Hadron Collider

Circumference: **27 km**

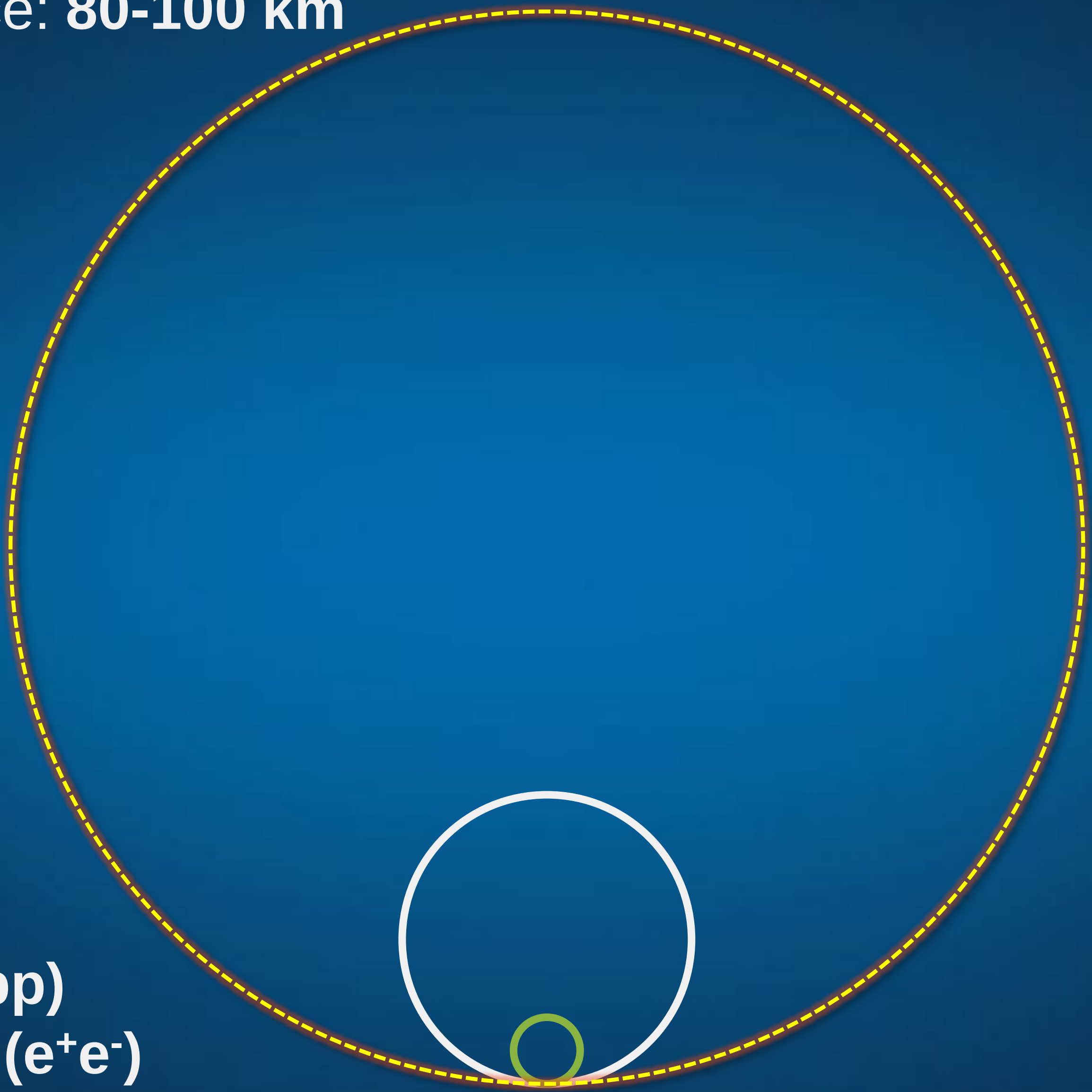
Energy:

- 14 TeV (pp)

- 209 GeV (e^+e^-)

Future Circular Collider

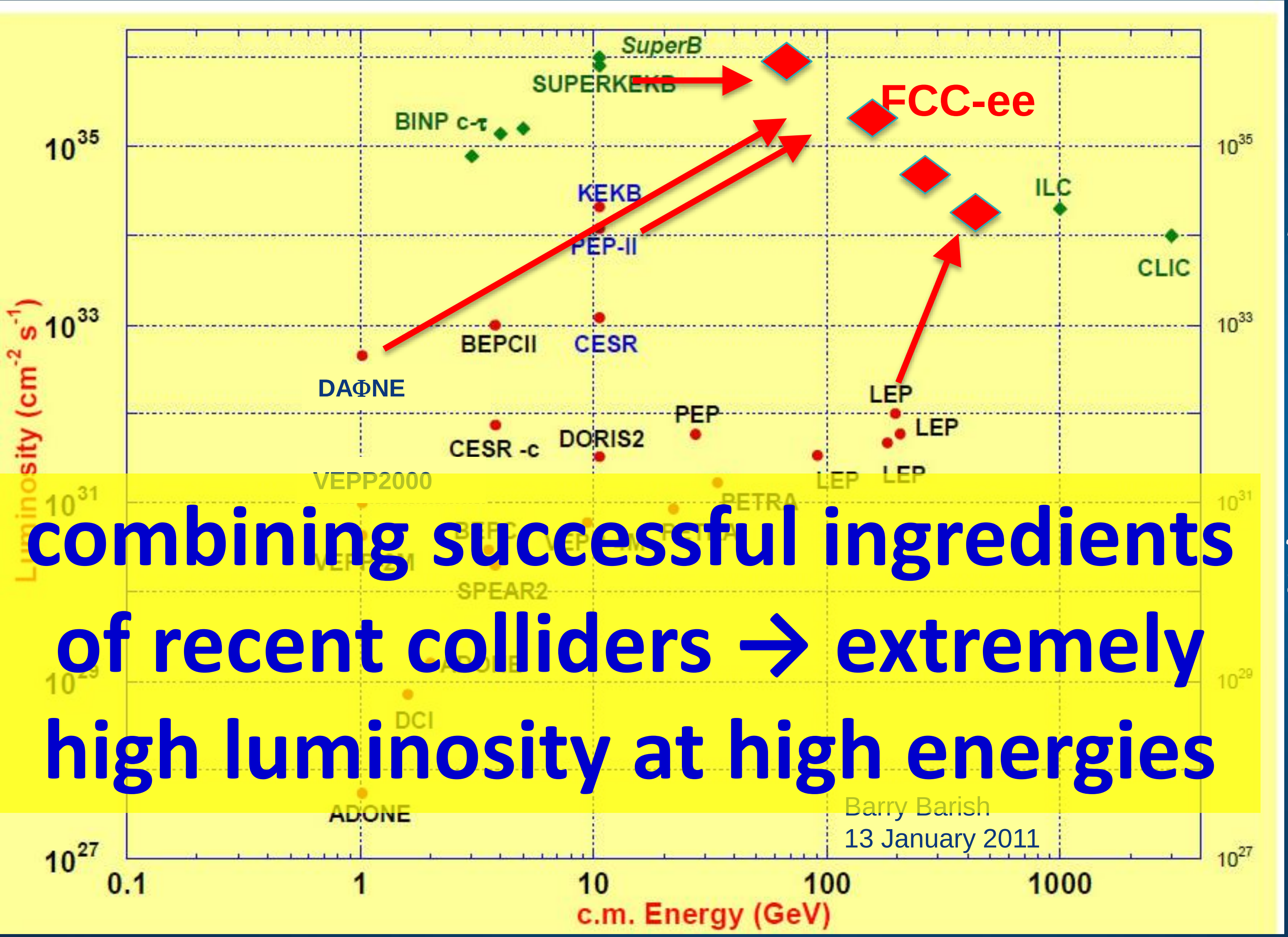
Circumference: **80-100 km**



Energy:

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

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



combining successful ingredients of recent colliders → extremely high luminosity at high energies

LEP:
- high energy
- SR effects

B-factories:
KEKB & PEP-II:
- high beam currents
- top-up injection

DAFNE: crab waist

Super B-factories
S-KEKB: low β_y^*

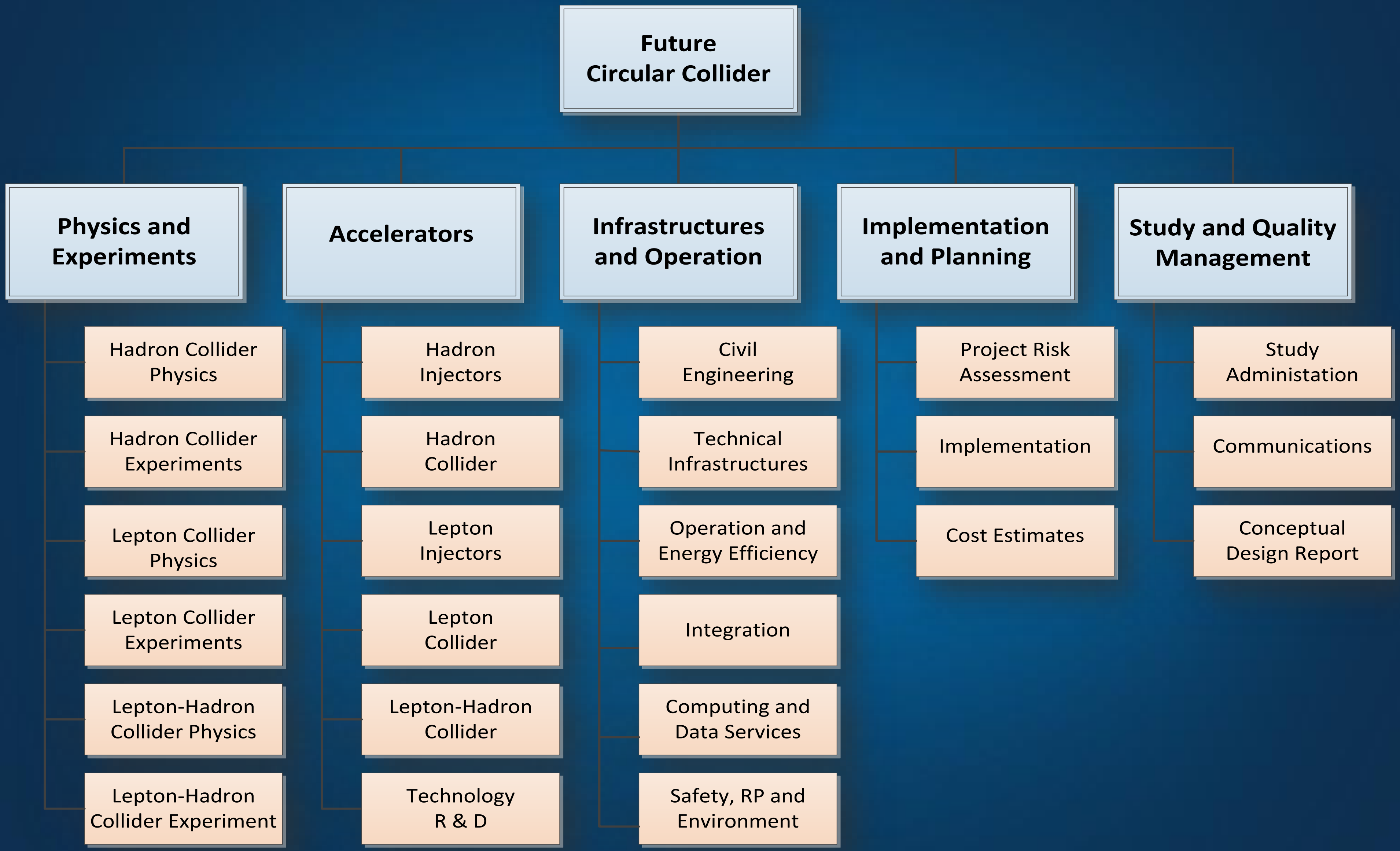
KEKB: e^+ source

HERA, LEP, RHIC:
- spin gymnastics

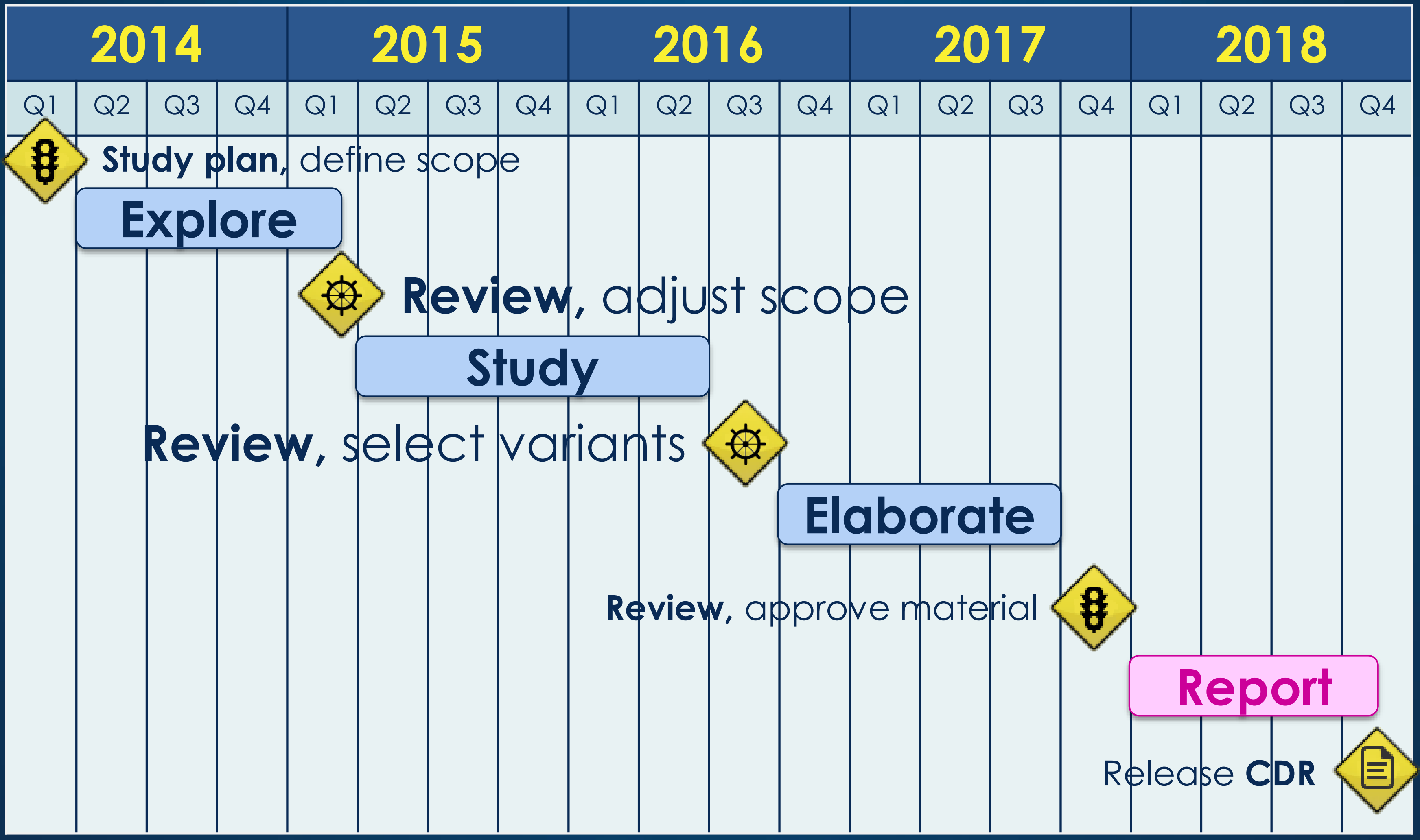
Role of CERN

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

FCC WBS top level



Study Timeline



Key Technologies

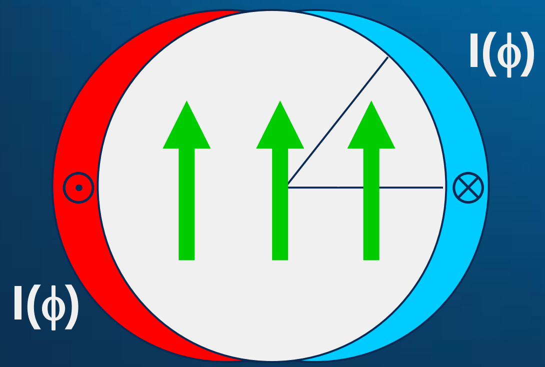
- 16 T superconducting magnets
- Superconducting RF cavities
- RF power sources
- Synchrotron radiation
- Affordable & reliable cryogenics
- Reliability & availability concepts

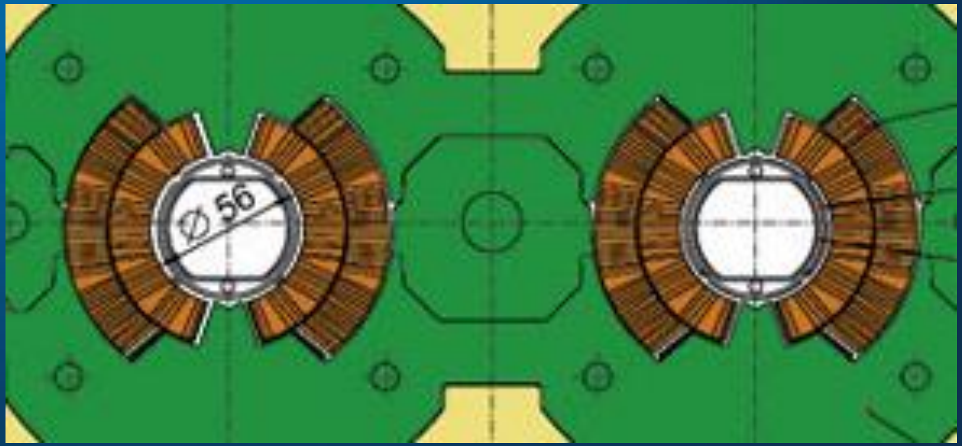
High –field SC dipoles

- **SC dipole: field defined via current distribution**
  - High current densities close to the beam for high fields
  - Only possible with super conductors I > 1 kA/mm2

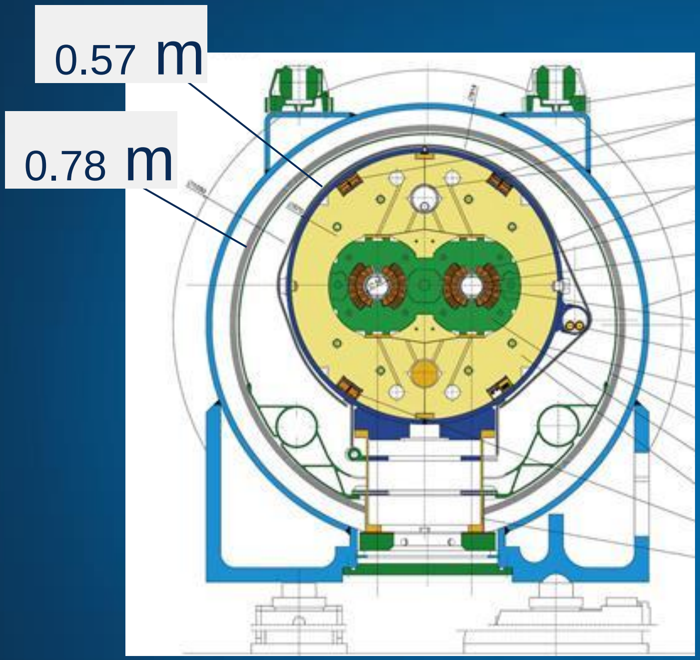
- **Ideal coil geometry for dipolar fields:**
  - Azimuthal current distribution **$I(\phi) = I_0\cos(\phi)$ Dipol**, ($I_0\cos(2\phi)$ Quadrupol)
  - 2 horizontally displaced circles

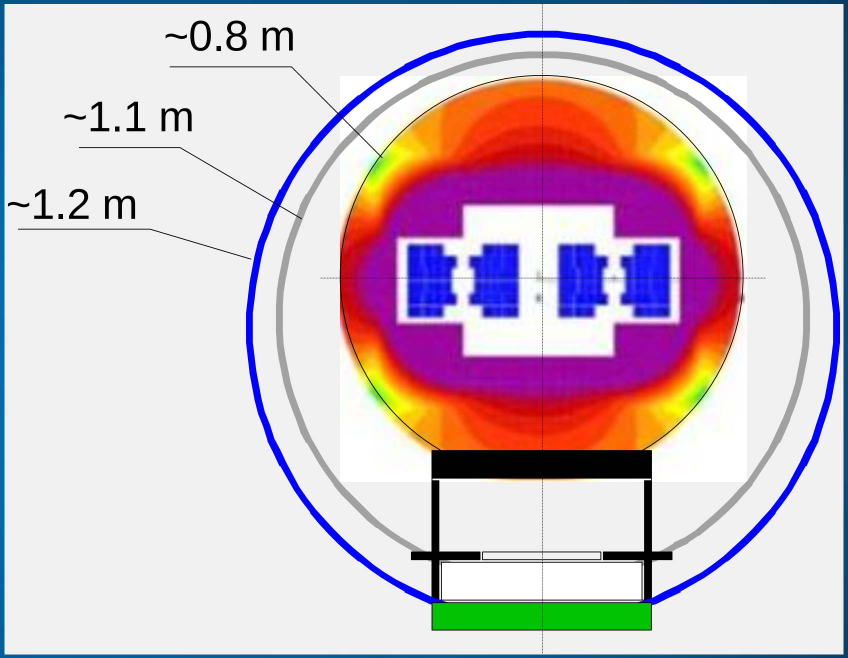
Cross section





Cryo-magnet cross sections

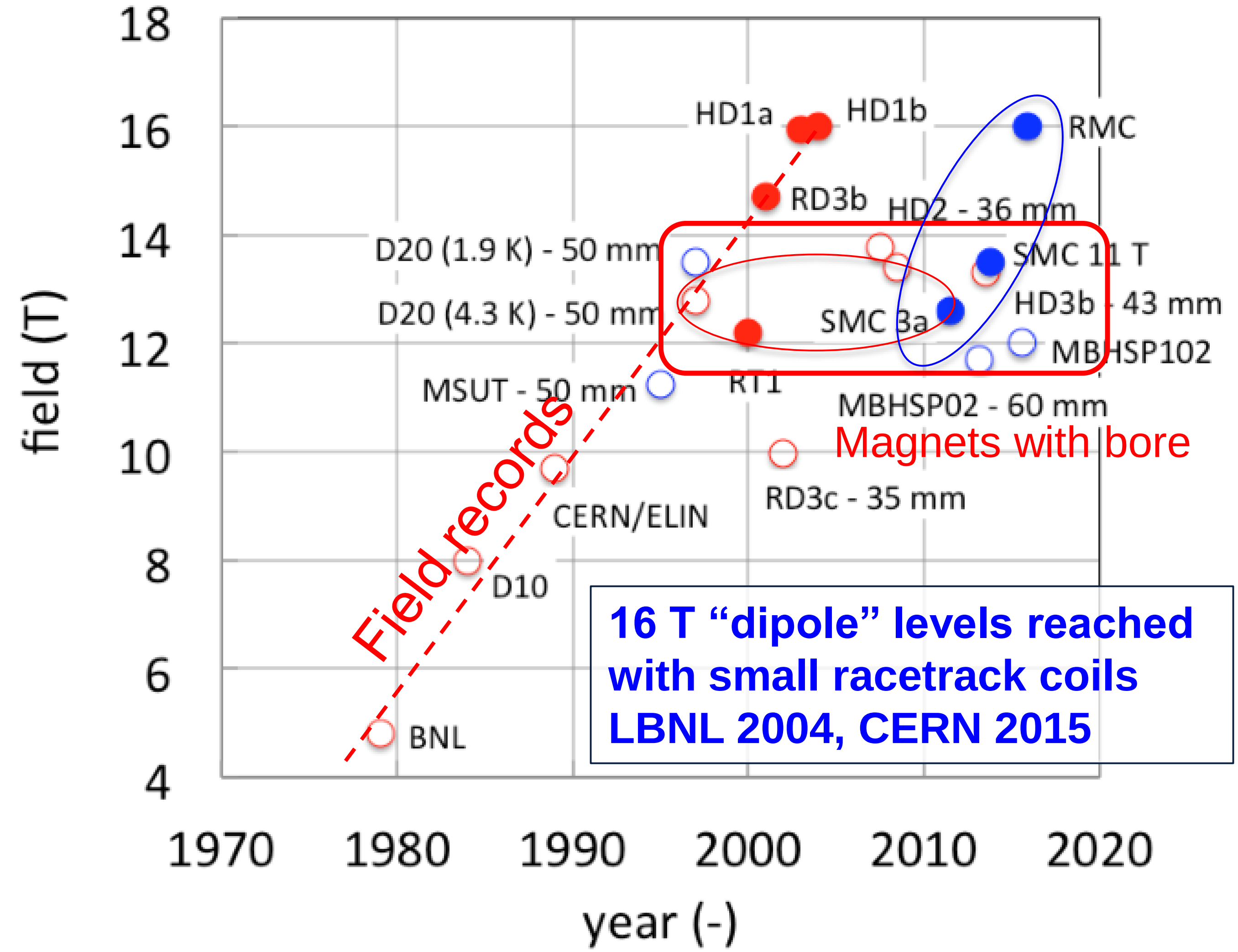




LHC
cos theta

FCC-hh
block coil
Nb3Sn as SC material

Towards 16 T magnets

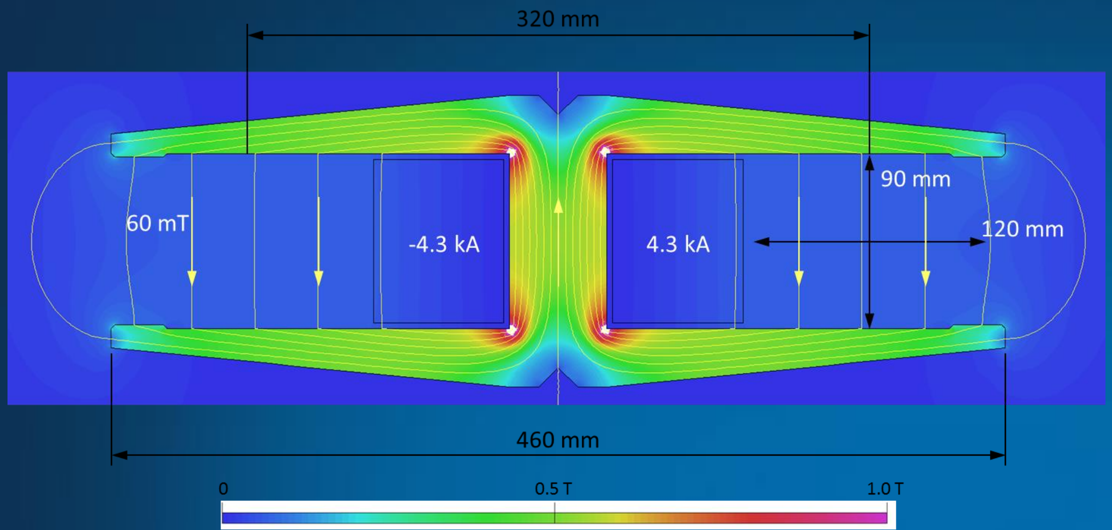


16 T "dipole" levels reached with small racetrack coils LBNL 2004, CERN 2015

LBNL HD1

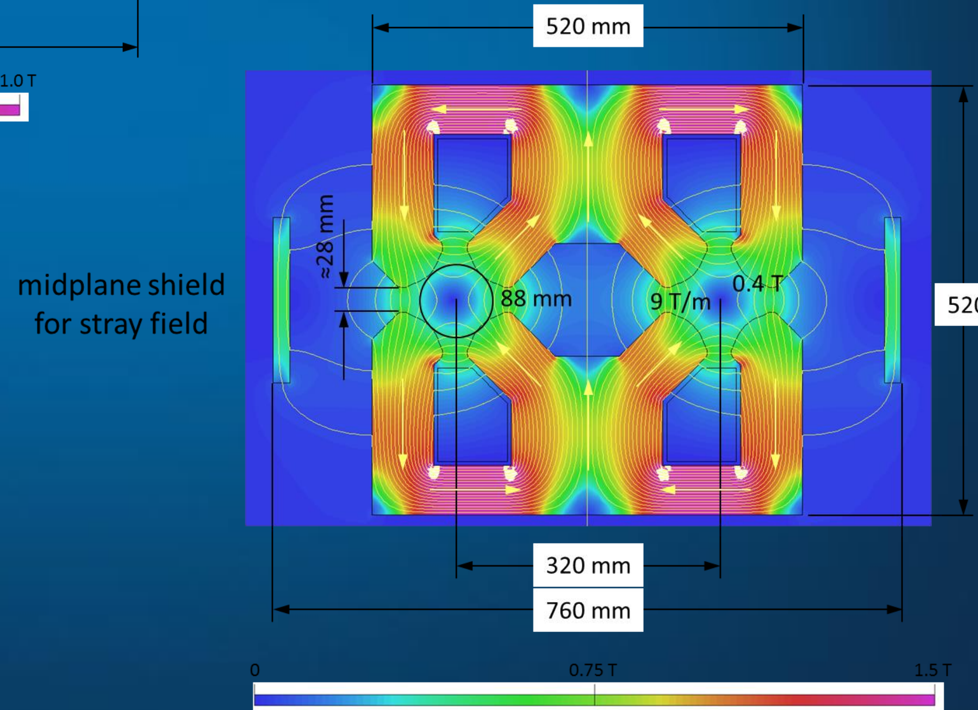
CERN RMC

Efficient 2-in-1 FCC-ee arc magnets



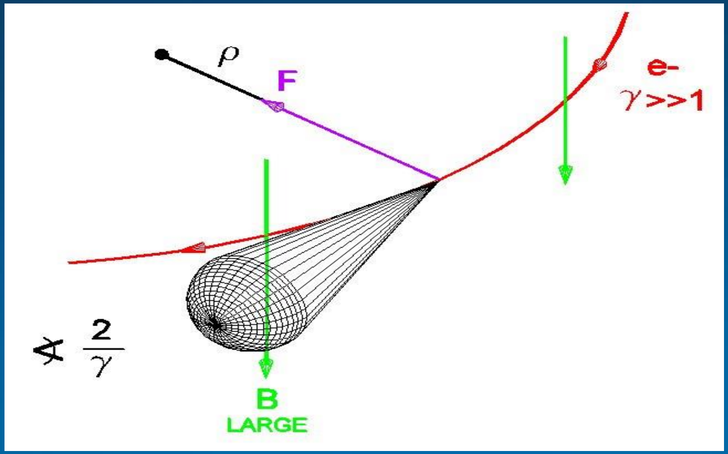
Dipole:
twin aperture yoke
single busbars as coils

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,…**

Synchrotron radiation



- **Charged particles on a curved trajectory irradiate energy:**

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

  - **Energy loss ΔE must be compensated and corresponding heat has to be removed from cold mass of SC magnets (for hadron collider)**

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

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

Vacuum system – beam screen – cryogenic load

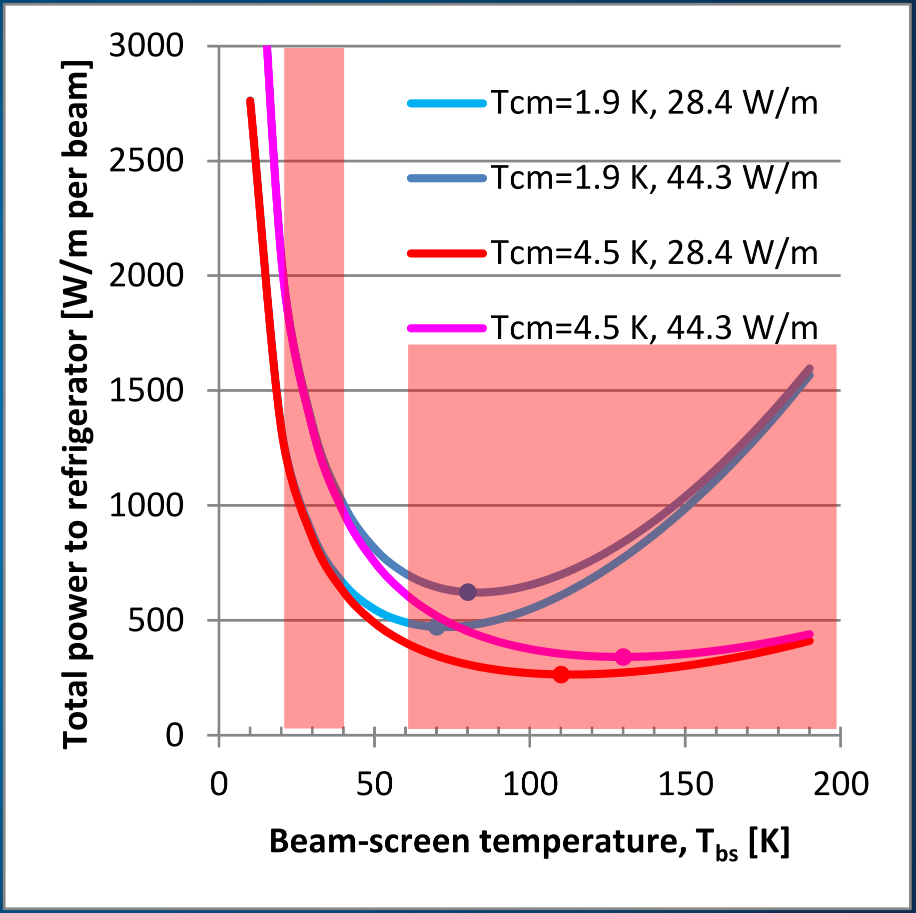
Total electrical power to refrigerator $P_{ref.}$ considering:

- 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:

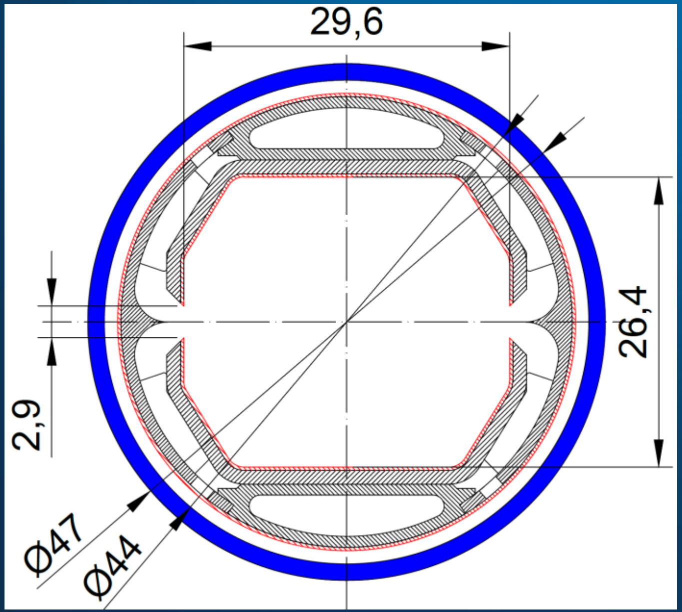
- **~30 W/m/beam (@16 T)** (LHC <0.2W/m)
- **5 MW total in arcs**

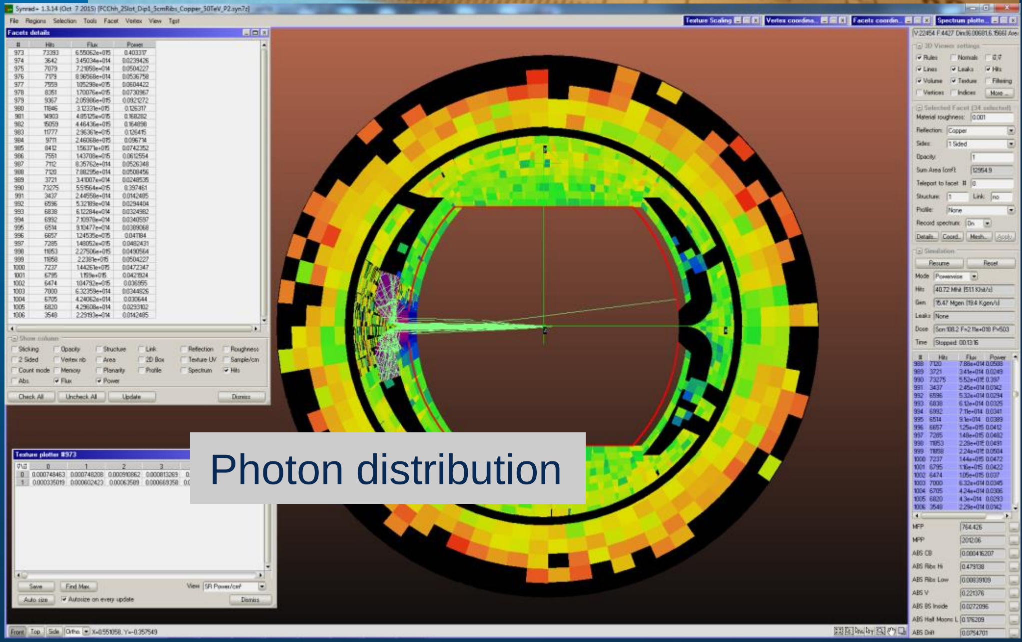
New Beam screen with ante-chamber

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

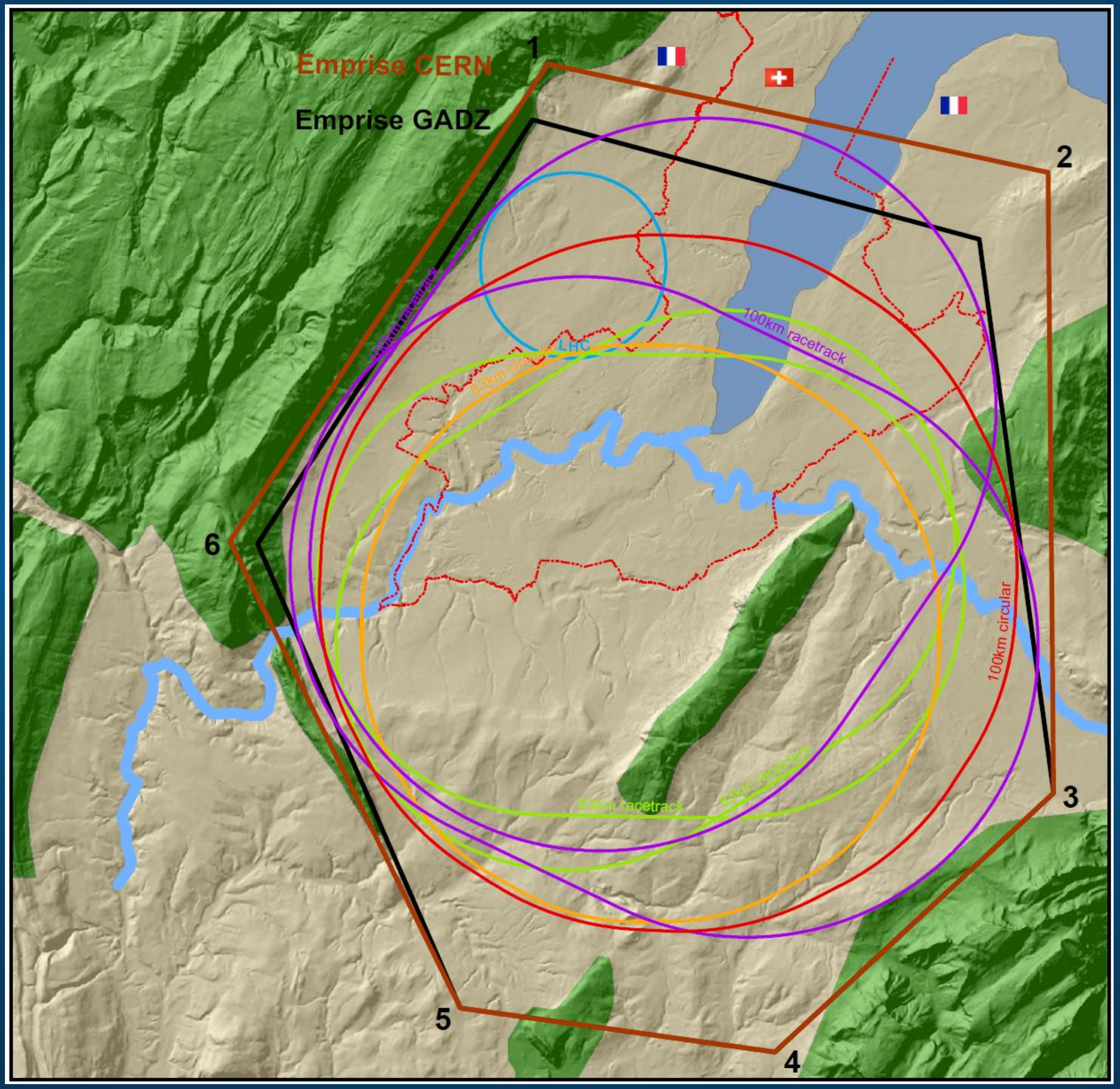
First beam screen prototype

Testing 2017 in ANKA within EuroCirCol

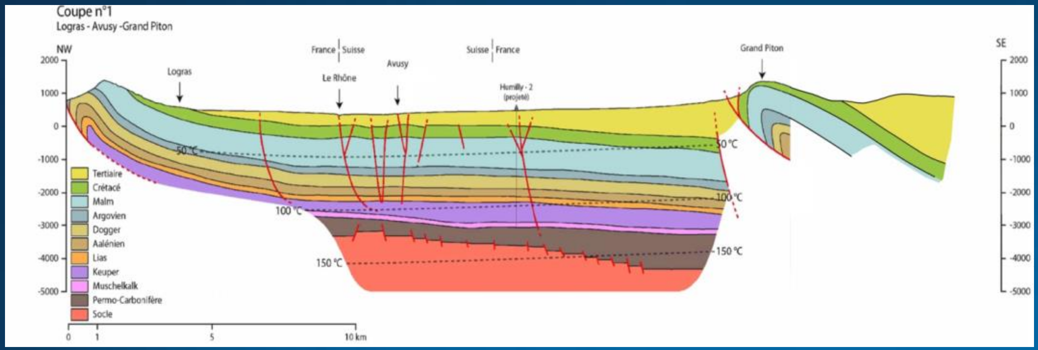


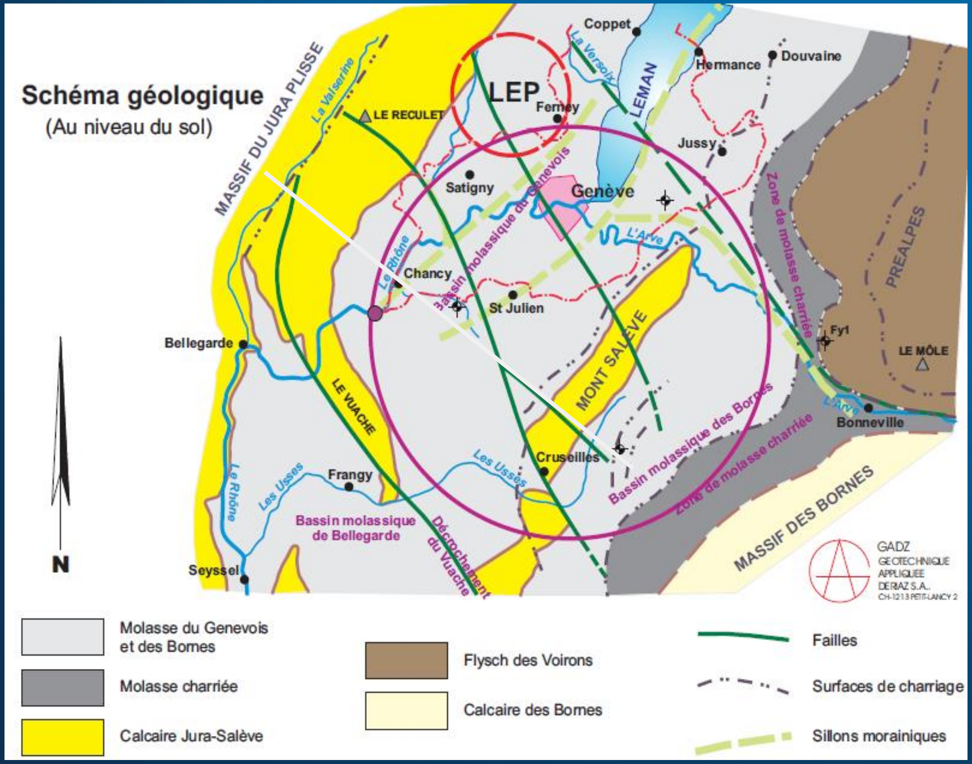


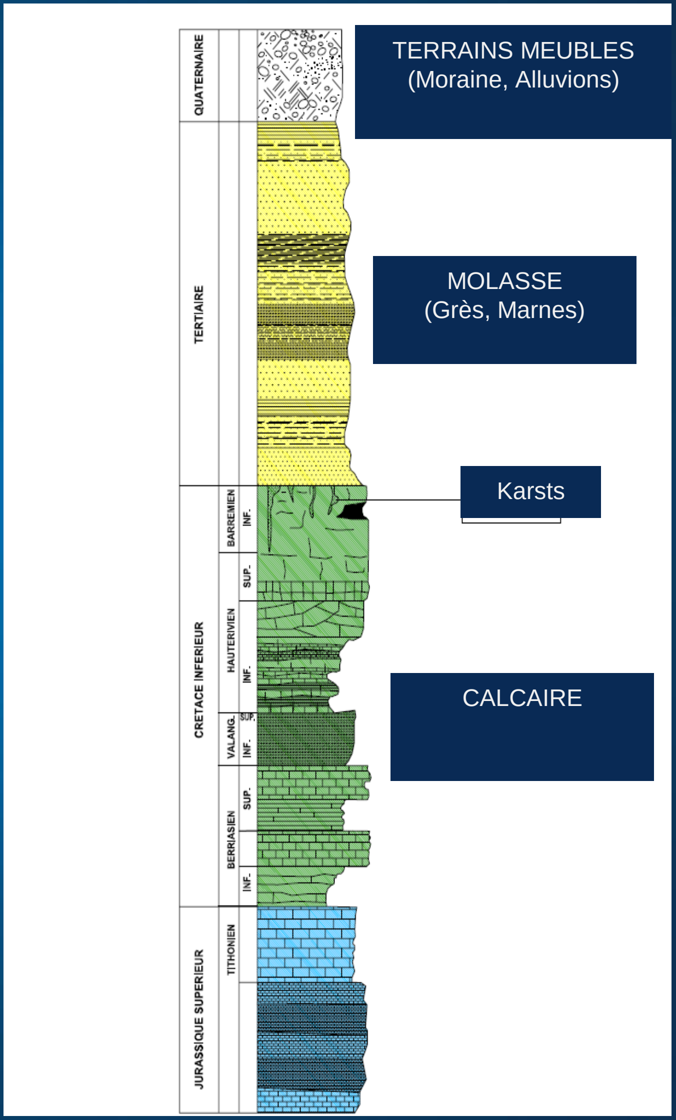
Geological studies – machine geometries



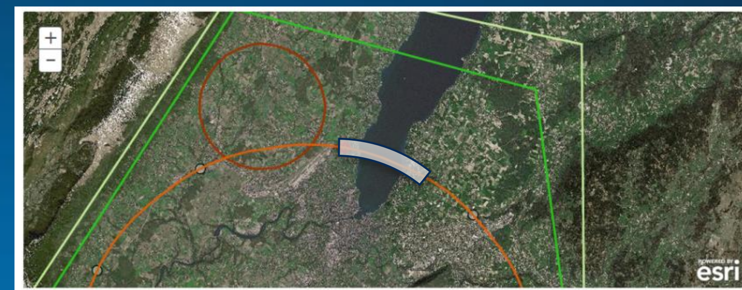
Geological background

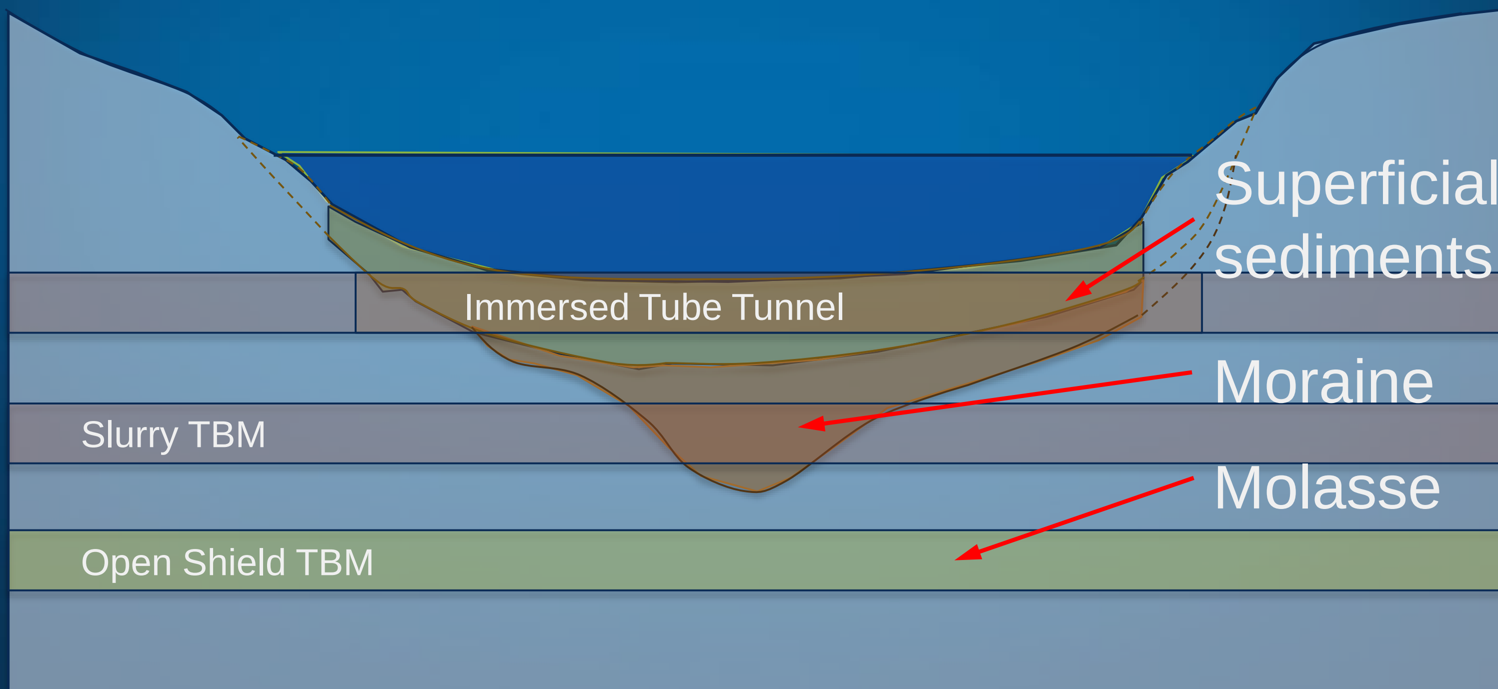




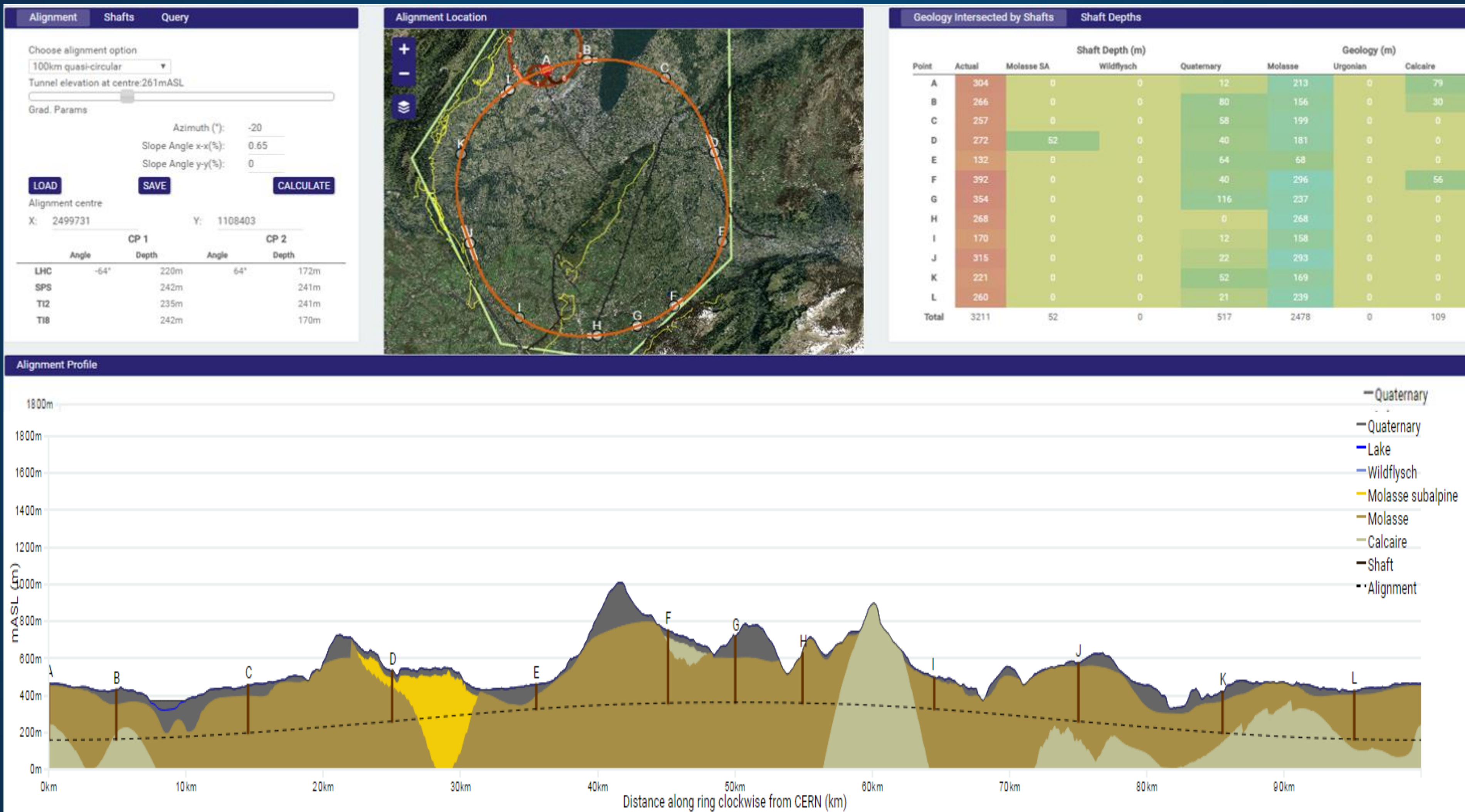


Tunnelling options for crossing the lake

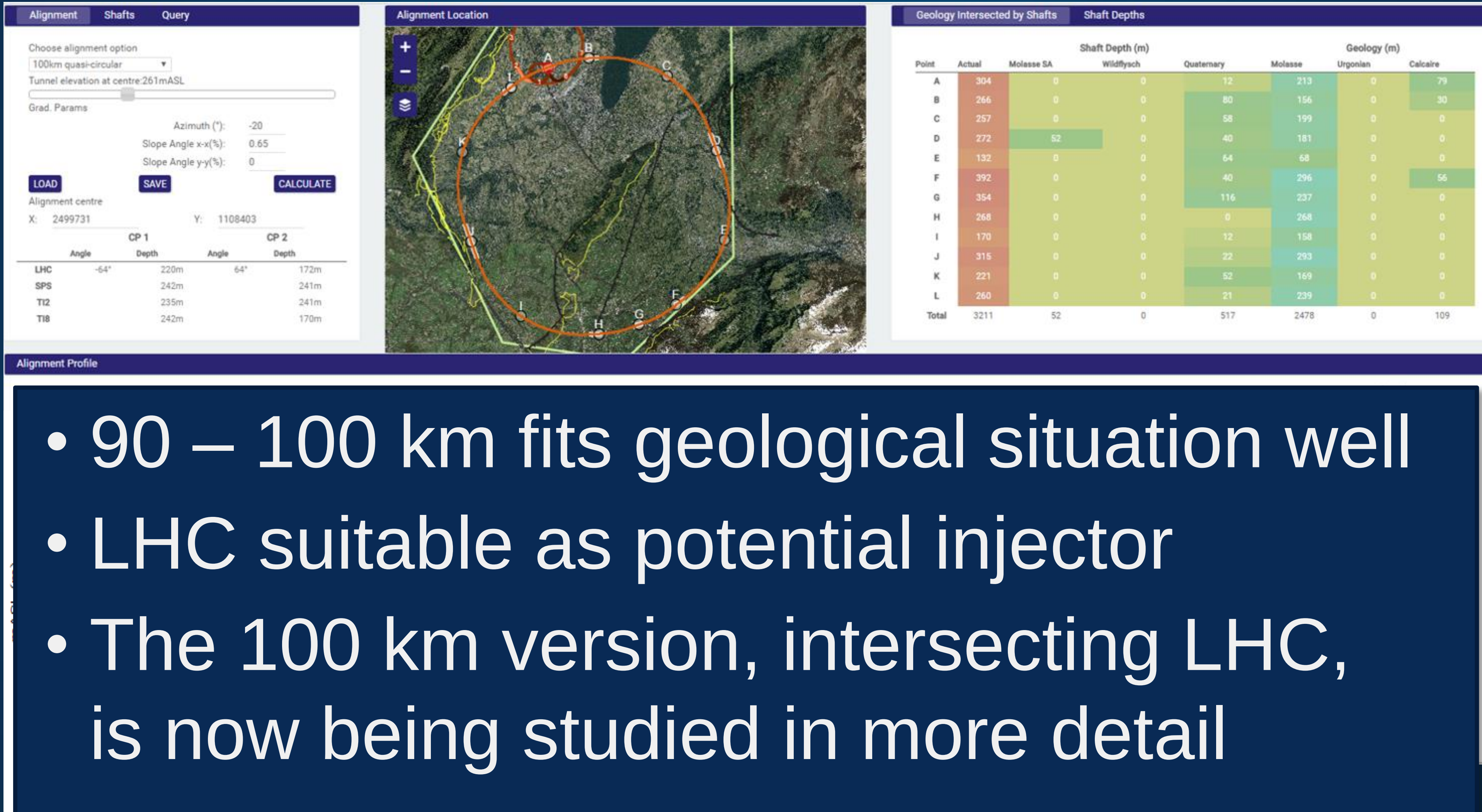




Progress on site investigations



Progress on site investigations

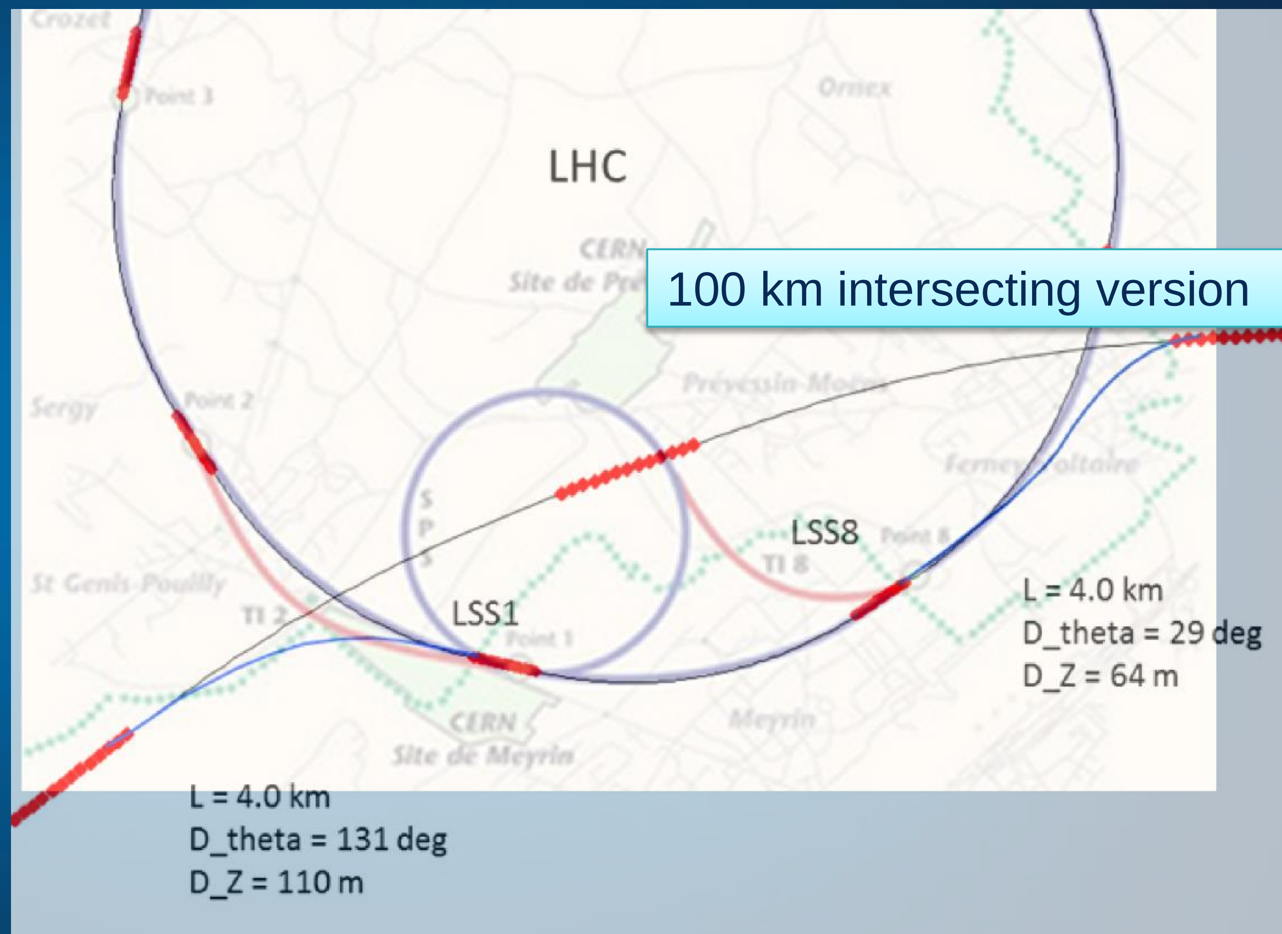


- 90 – 100 km fits geological situation well
- LHC suitable as potential injector
- The 100 km version, intersecting LHC, is now being studied in more detail

FCC-hh injector studies

Injector options:

- **SPS → LHC → FCC**
- SPS/SPS$_{upgrade}$ → FCC
- SPS->FCC booster→FCC



Current baseline:

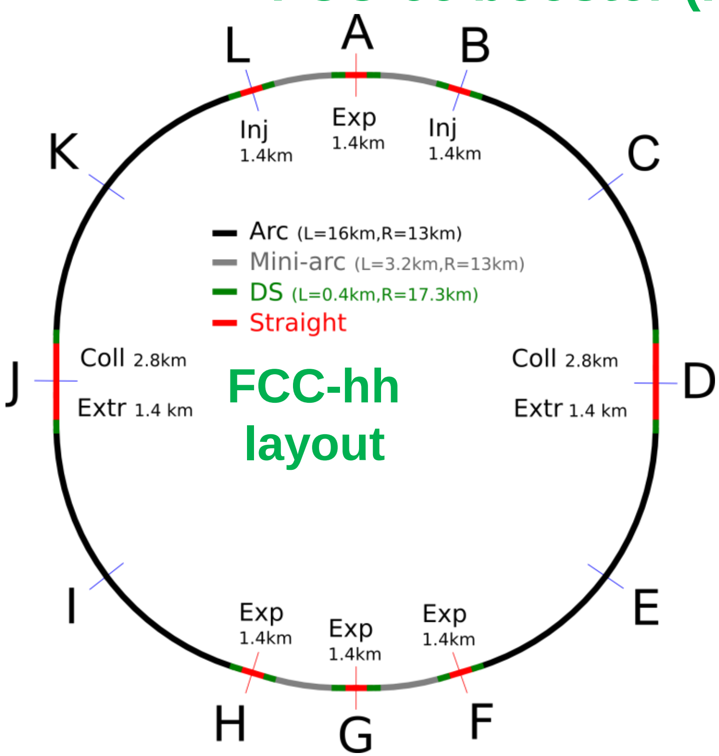
- **injection energy 3.3 TeV LHC**

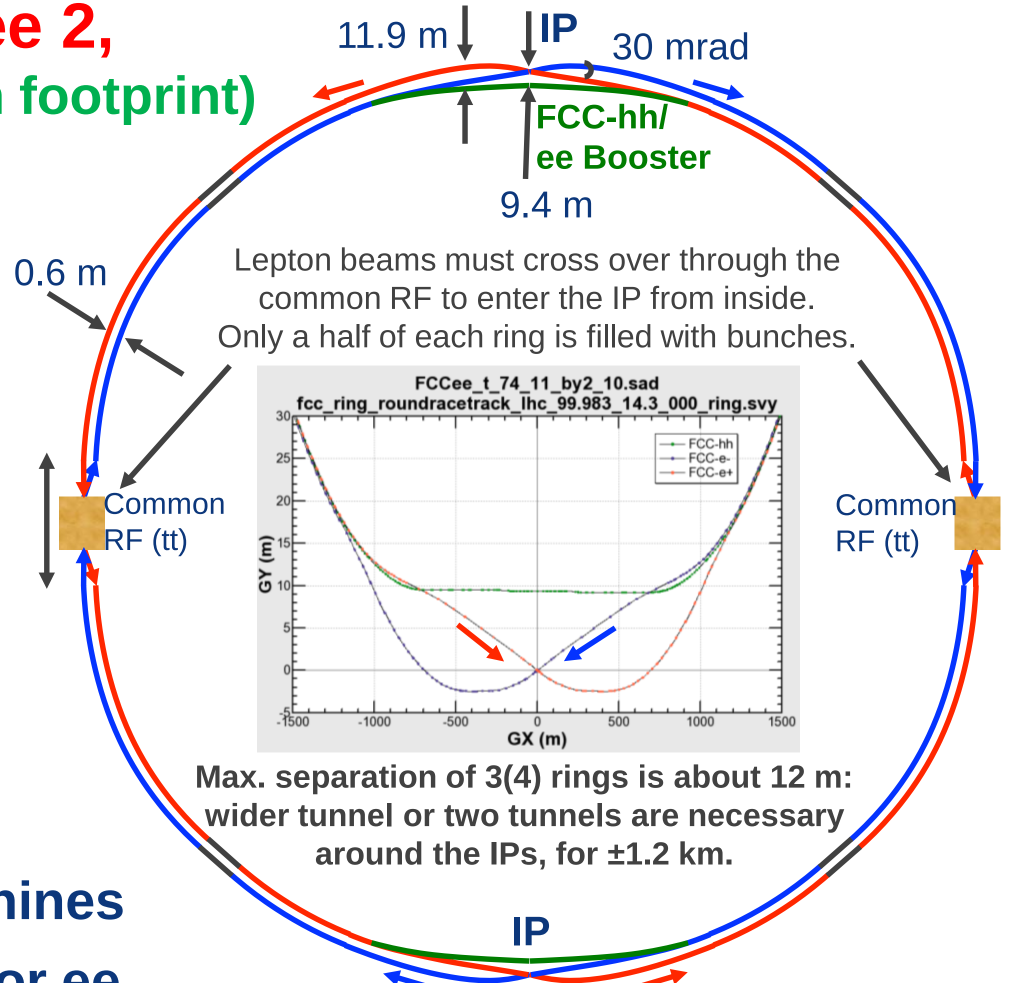
Alternative options:

- Injection around 1.5 TeV
- **compatible with: SPS$_{upgrade}$, LHC, FCC booster**

Common layouts for hh & ee

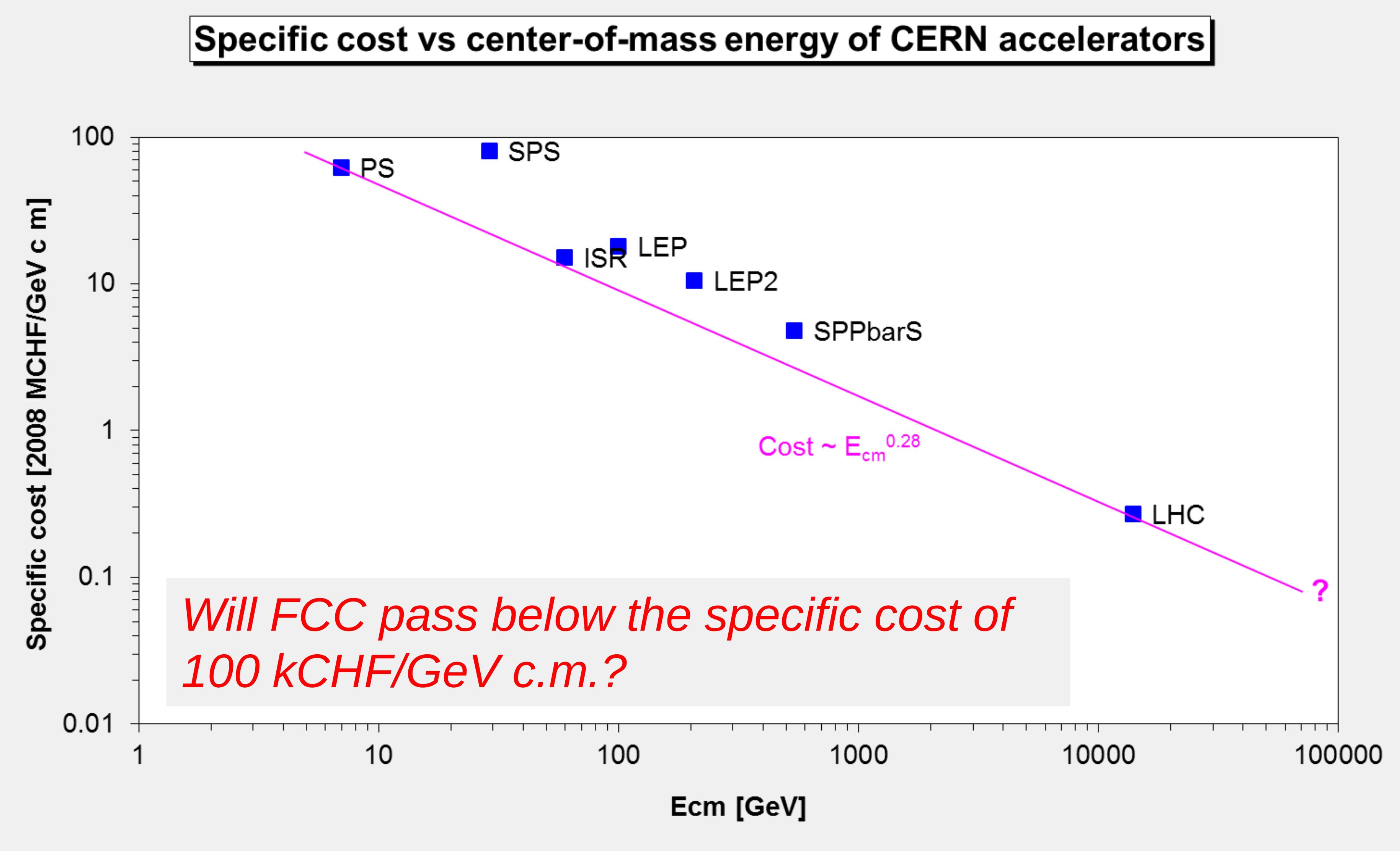
FCC-ee 1, FCC-ee 2,
FCC-ee booster (FCC-hh footprint)





- **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



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

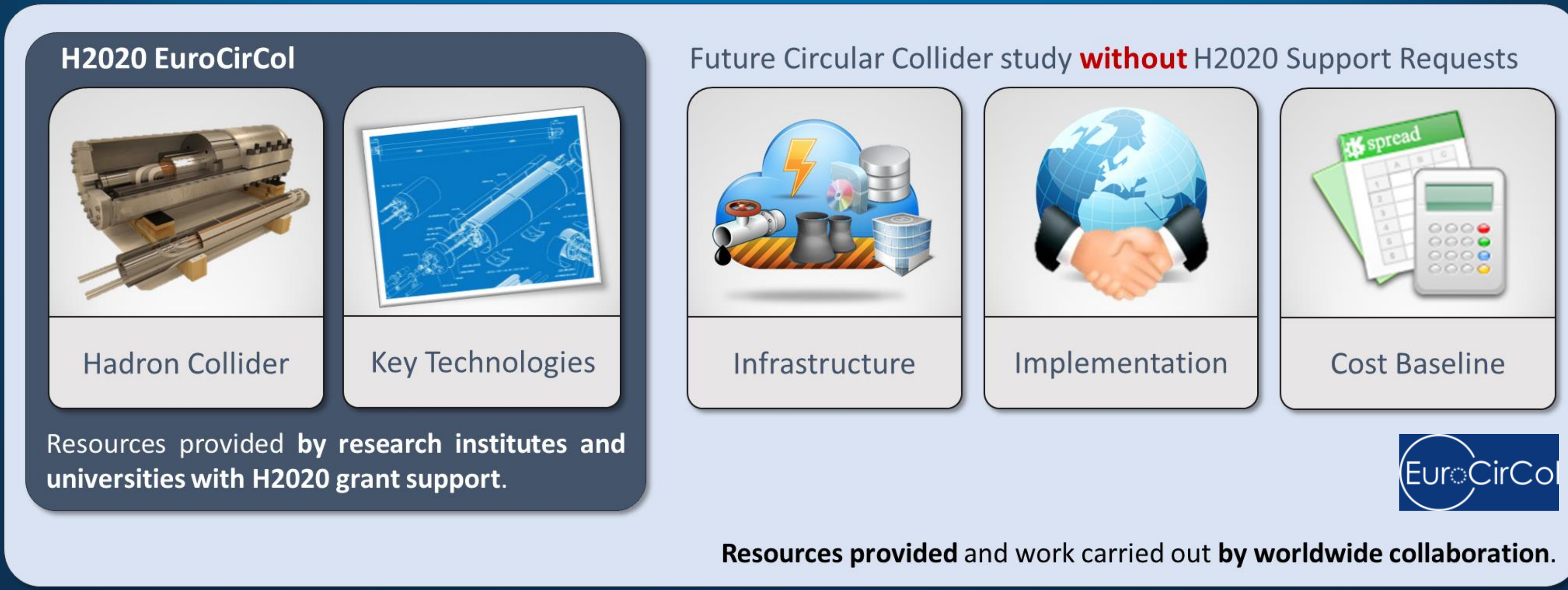
UT Enschede, Netherlands
U Geneva, Switzerland
Goethe U Frankfurt, Germany
GSI, Germany
GWNU, Korea
U. Guanajuato, Mexico
Hellenic Open U, Greece
HEPHY, Austria
U Houston, USA
IIT Kanpur, India
IFJ PAN Krakow, Poland
INFN, Italy
INP Minsk, Belarus
U Iowa, USA
IPM, Iran
UC Irvine, USA
Istanbul Aydin U., 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

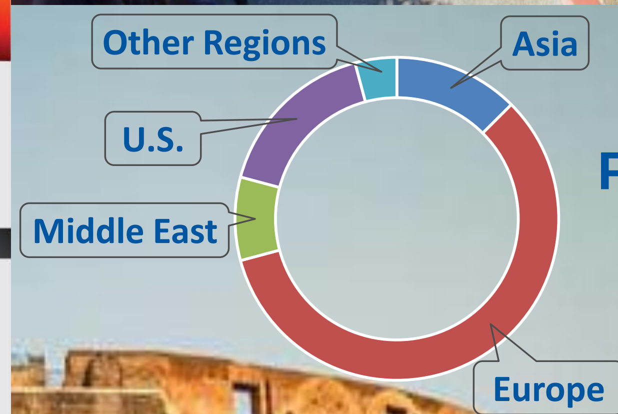
EuroCirCol EU Horizon 2020 Grant

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**



http://cern.ch/fccw2016

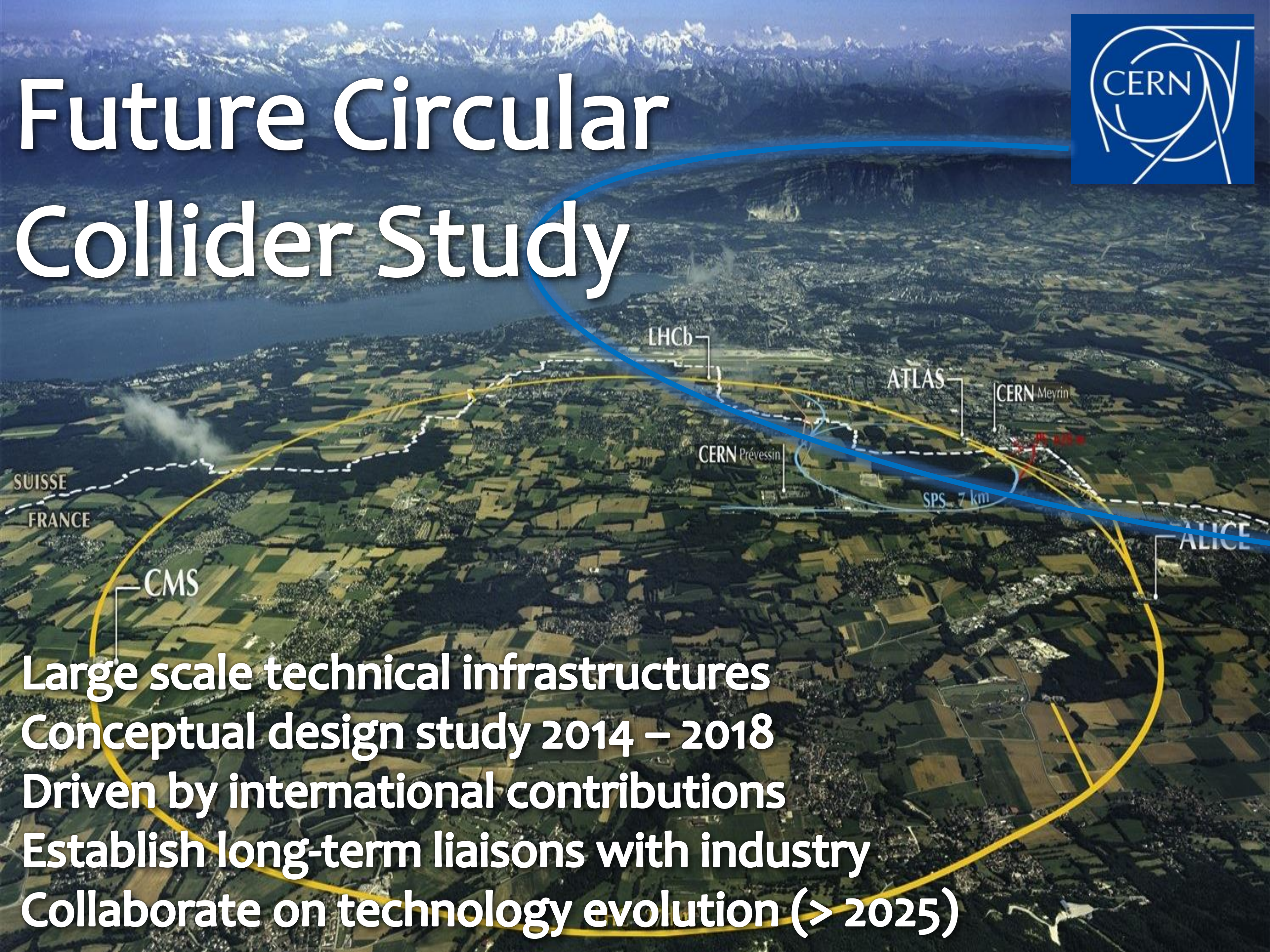


468
Participants

168
Institutes

24
Countries

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