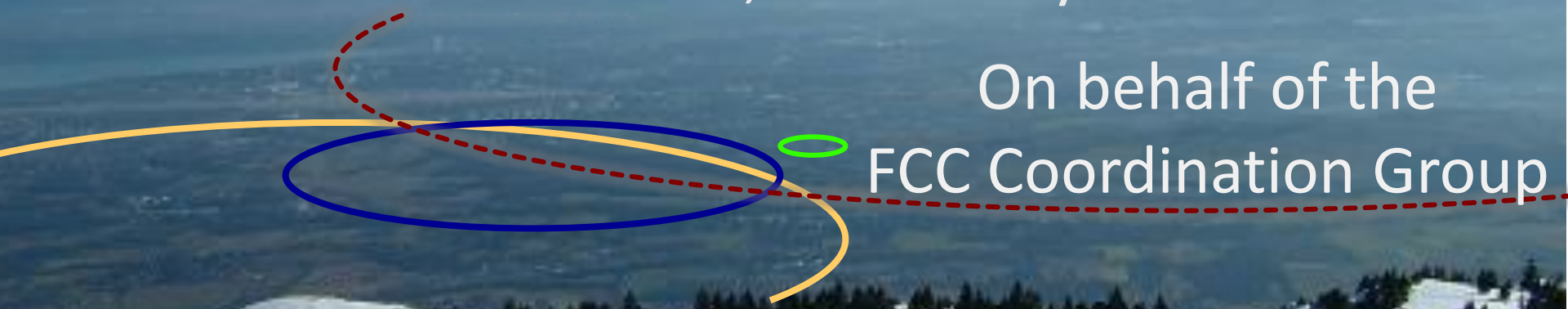
Introduction to the Future Circular Collider Study

Michael Benedikt

CERN Academic Training

Filtration Plant, 2 February 2016

On behalf of the FCC Coordination Group



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

Outline

- Motivation
- FCC Study Scope
- Main Machine Parameters
- Timeline
- FCC Organisation & Collaboration Status

LHC evolution

1983 first LHC proposal, launch of design study
1994 CERN Council: LHC approval
2010 first collisions at 3.5 TeV beam energy
2015 collisions at ~design energy

now is the time to plan for ~2040!

FCC Strategic Motivation

- **European Strategy for Particle Physics 2013:**

  "…to **propose an ambitious post-LHC accelerator project**….., CERN should undertake design studies for accelerator projects in a global context,…with emphasis on proton-proton and electron-positron high-energy frontier machines….coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures,…."

- **ICFA statement 2014:**

  "…. ICFA supports studies of energy frontier circular colliders and encourages global coordination….."

- **US P5 recommendation 2014:**

  "….A very high-energy proton-proton collider is the most powerful tool for direct discovery of new particles and interactions under any scenario of physics results that can be acquired in the P5 time window…."

FCC motivation: pushing the energy frontier

- **A very large circular hadron collider seems the only approach to reach 100 TeV c.m. collision energy in coming decades**
- Access to new particles (direct production) in the few TeV to 30 TeV mass range, far beyond LHC reach.
- Much-increased rates for phenomena in the sub-TeV mass range
  →increased precision w.r.t. LHC and possibly ILC

The name of the game of a hadron collider is energy reach

$$E \propto B_{dipole} \times \rho_{bending}$$

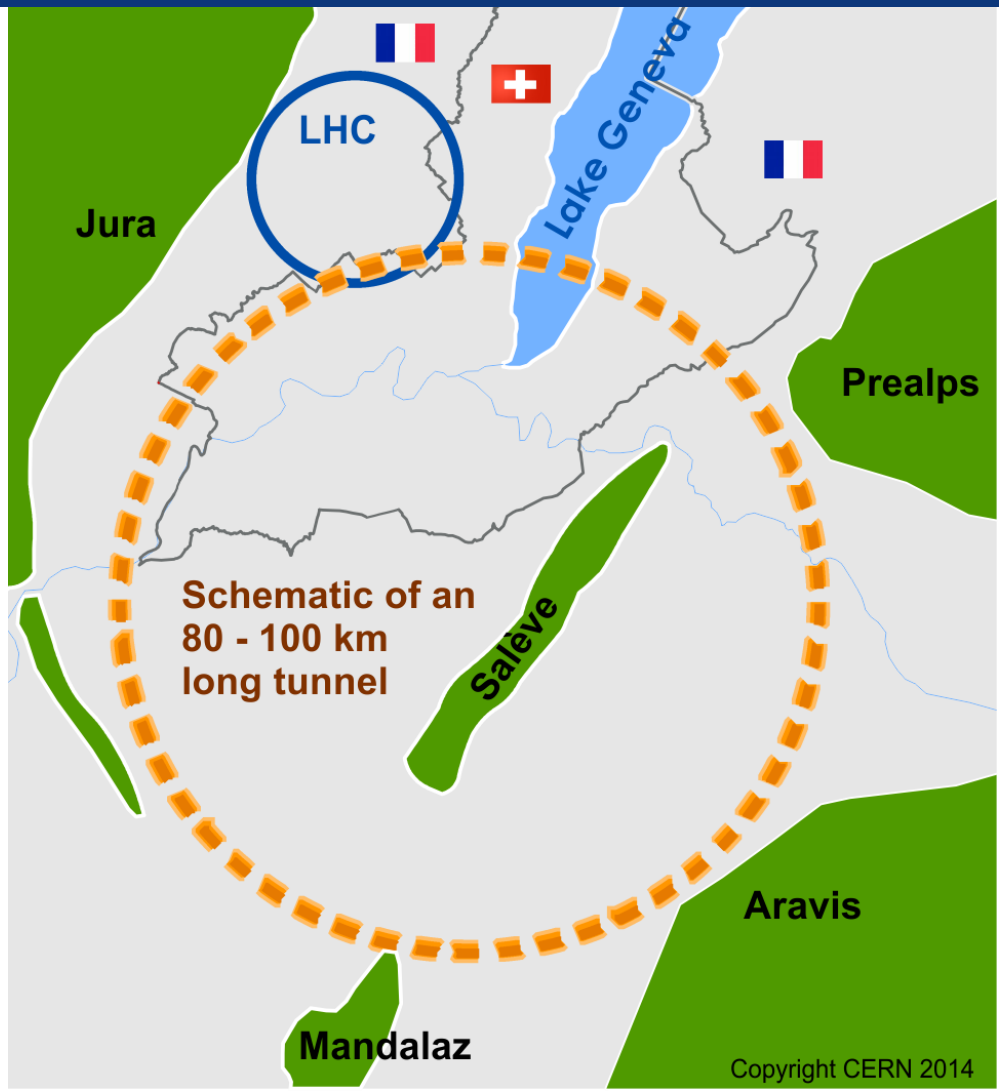
Cf. LHC: factor ~4 in radius, factor ~2 in field → O(10) in E_{cms}

Future Circular Collider Study
GOAL: CDR and cost review for the next ESU (2018)

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

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

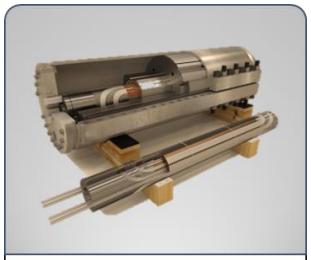
  ~16 T ⇒ 100 TeV *pp* in 100 km
- **80-100 km tunnel infrastructure** in Geneva area
- ***e*$^+$*e*$^-$ collider (*FCC-ee*)** as potential intermediate step
- ***p-e* (*FCC-he*) option**
- **HE-LHC** with *FCC-hh* technology



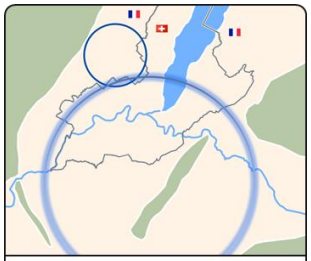
FCC Scope: Accelerator and Infrastructure

Collider Designs

FCC-hh: **100 TeV pp collider as long-term goal**
→ defines infrastructure needs
FCC-ee: **e^+e^- collider**, potential intermediate step
FCC-he: **integration aspects** of pe collisions

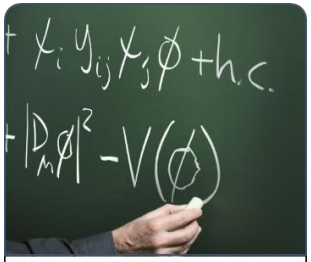

R&D Programs

key technologies
pushed in dedicated R&D programmes, e.g.
16 Tesla magnets for **100 TeV** pp in **100 km**
SRF technologies and RF power sources


Infrastructures

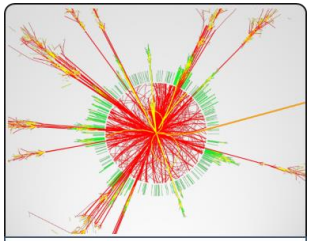
tunnel infrastructure in Geneva area, linked to CERN accelerator complex;
site-specific, as requested by European strategy

FCC Scope: Physics & Experiments



Physics Cases

physics opportunities
discovery potentials



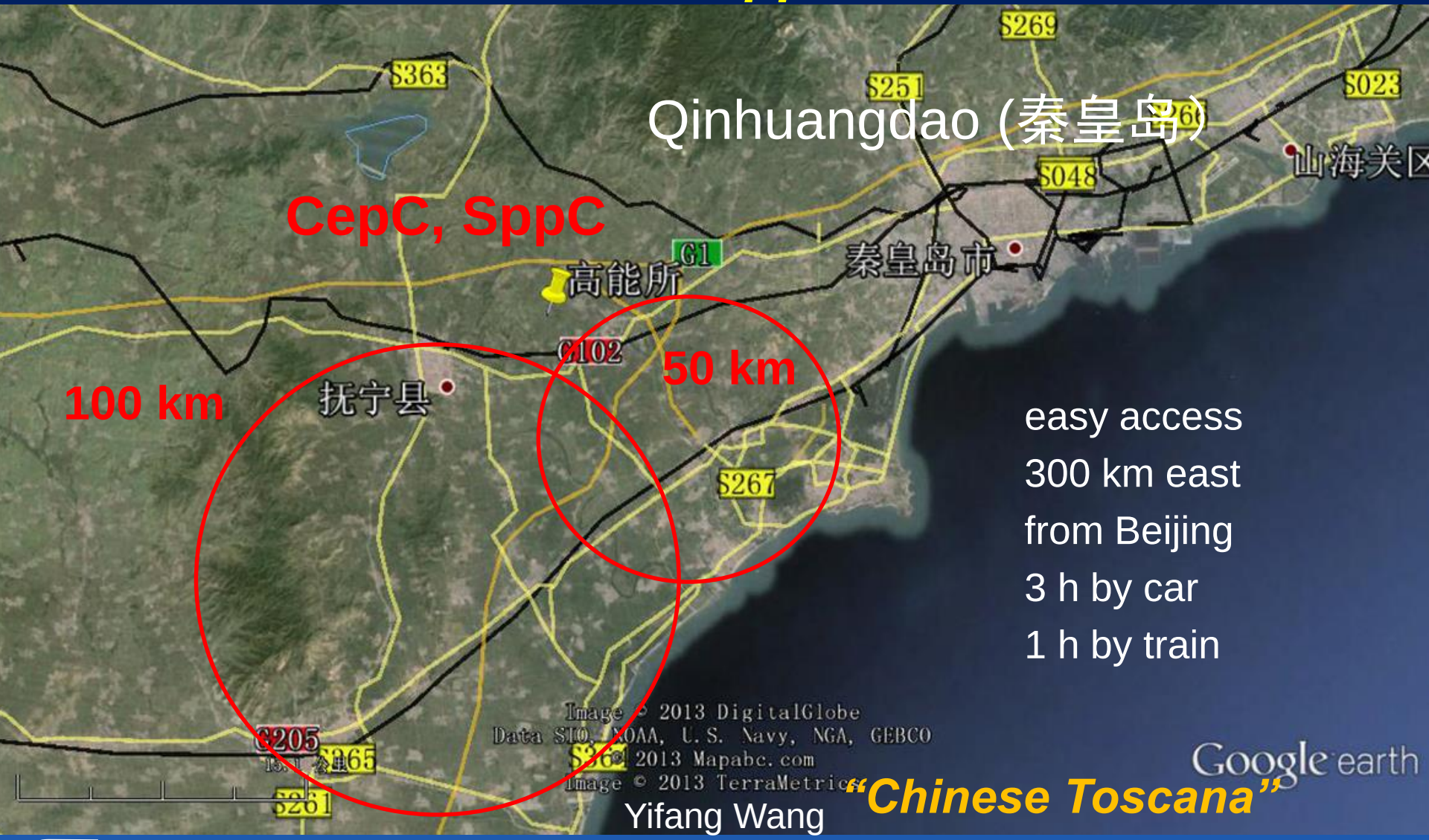
Experiments

experiment concepts for hh, ee and he
machine Detector Interface studies
concepts for **worldwide data services**

Cost Estimates

overall cost model ;
cost scenarios for collider options
including infrastructure and injectors ;
implementation and governance models

CepC/SppC study (CAS-IHEP) 54 km (baseline)
e^+e^- collisions ~2028; *pp* collisions ~2042



hadron collider parameters

Parameter	FCC-hh		SPPC	LHC	HL LHC
collision energy cms [TeV]	100		71.2	14	
dipole field [T]	16		20	8.3	
# IP	2 main & 2		2	2 main & 2	
bunch intensity [10^{11}]	1	1 (0.2)	2	1.1	2.2
bunch spacing [ns]	25	25 (5)	25	25	25
luminosity/Ip [10^{34} $cm^{-2}s^{-1}$]	5	~25	12	1	5
events/bunch crossing	170	~850 (170)	400	27	135
stored energy/beam [GJ]	8.4		6.6	0.36	0.7
synchrotron radiation [W/m/aperture]	30		58	0.2	0.35

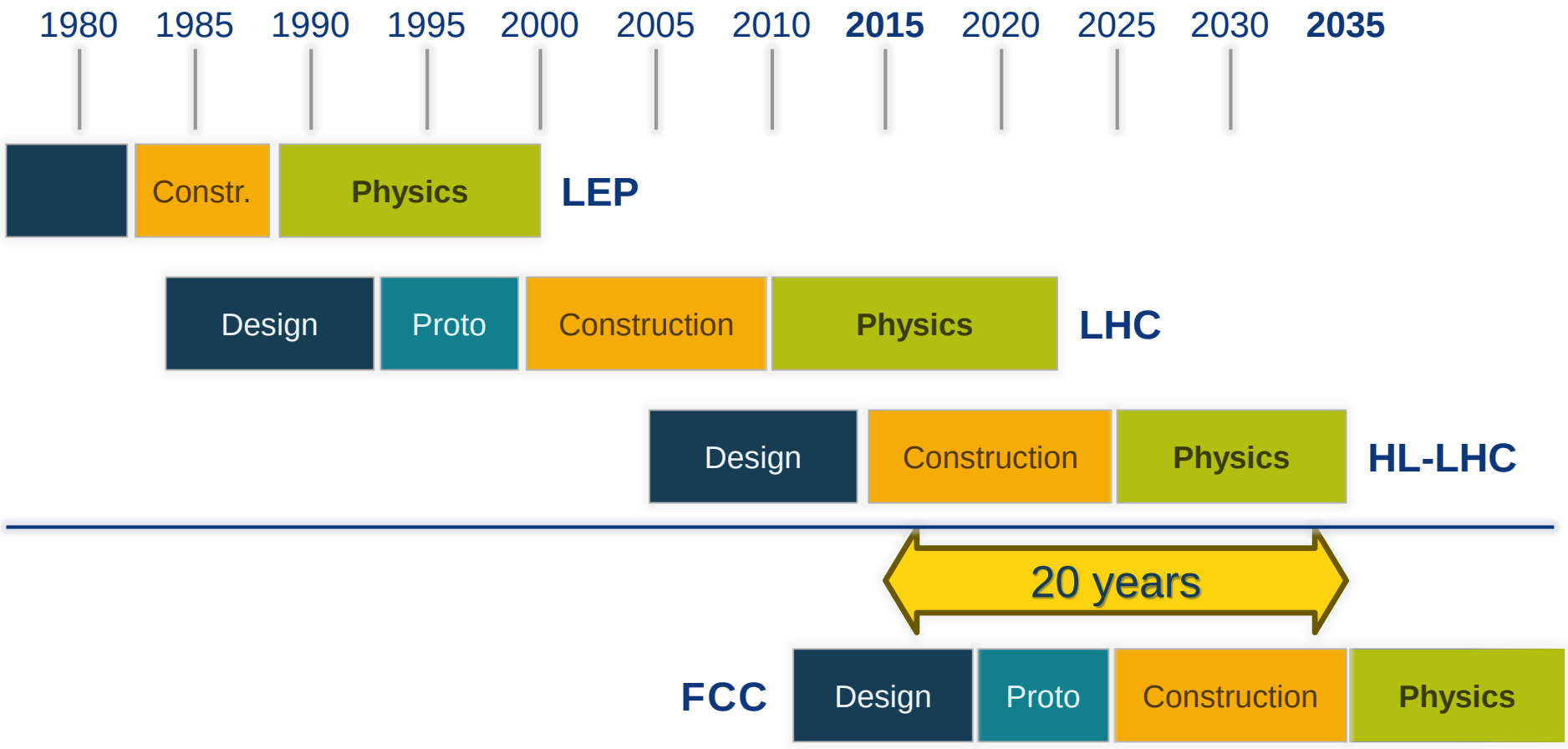
lepton collider parameters

parameter	FCC-ee			CEPC	LEP2
energy/beam [GeV]	**45**	**120**	**175**	**120**	105
bunches/beam	90000	770	78	50	4
beam current [mA]	1450	30	6.6	16.6	3
luminosity/IP x 10^{34} $cm^{-2}s^{-1}$	**70**	**5**	**1.3**	**2.0**	0.0012
energy loss/turn [GeV]	0.03	1.67	7.55	3.1	3.34
synchrotron power [MW]	**100**			**103**	22
RF voltage [GV]	0.08	3.0	10	6.9	3.5

FCC-ee: 2 separate rings

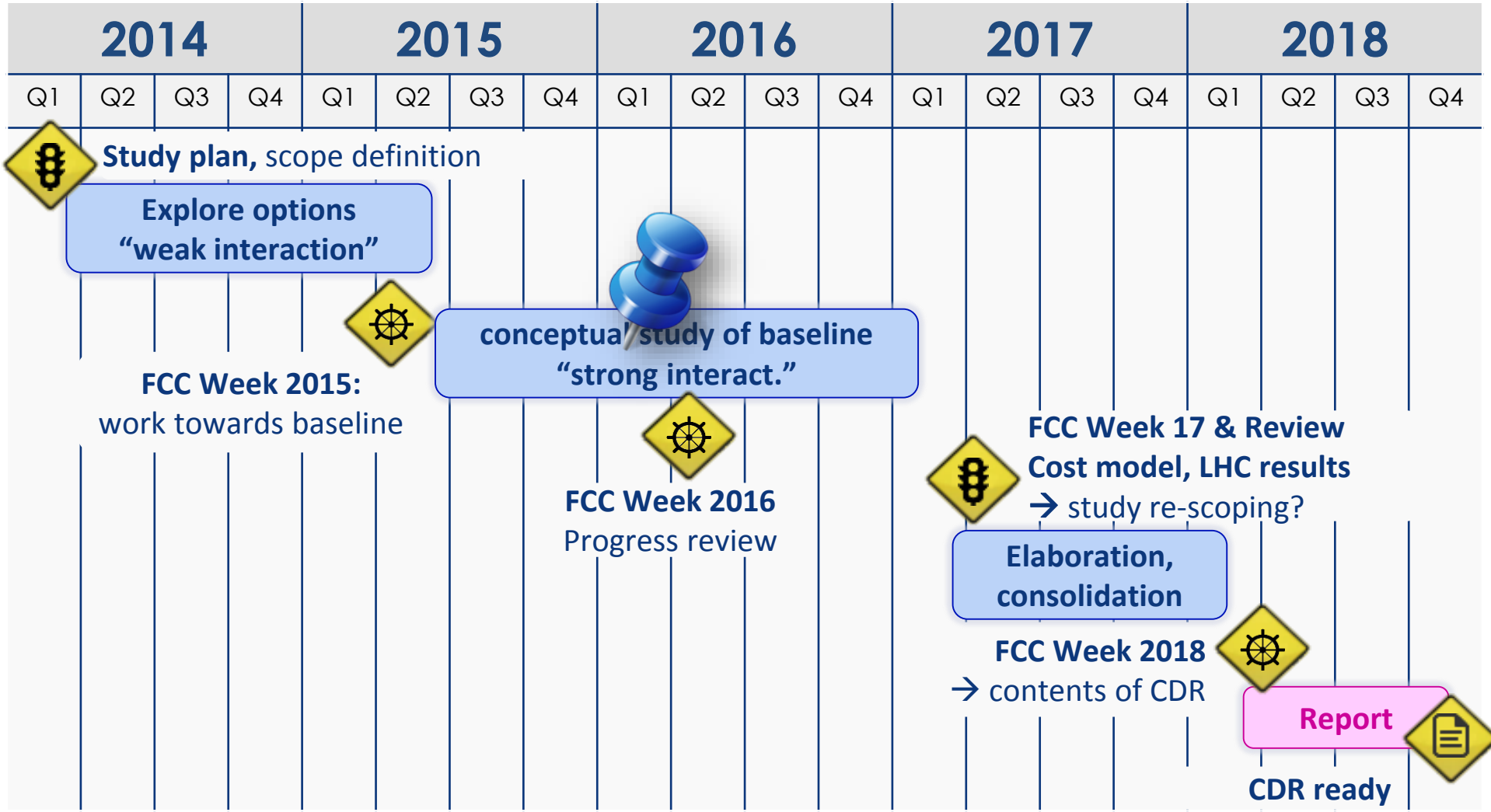
CEPC baseline: single beam pipe like LEP

CERN Circular Colliders and FCC

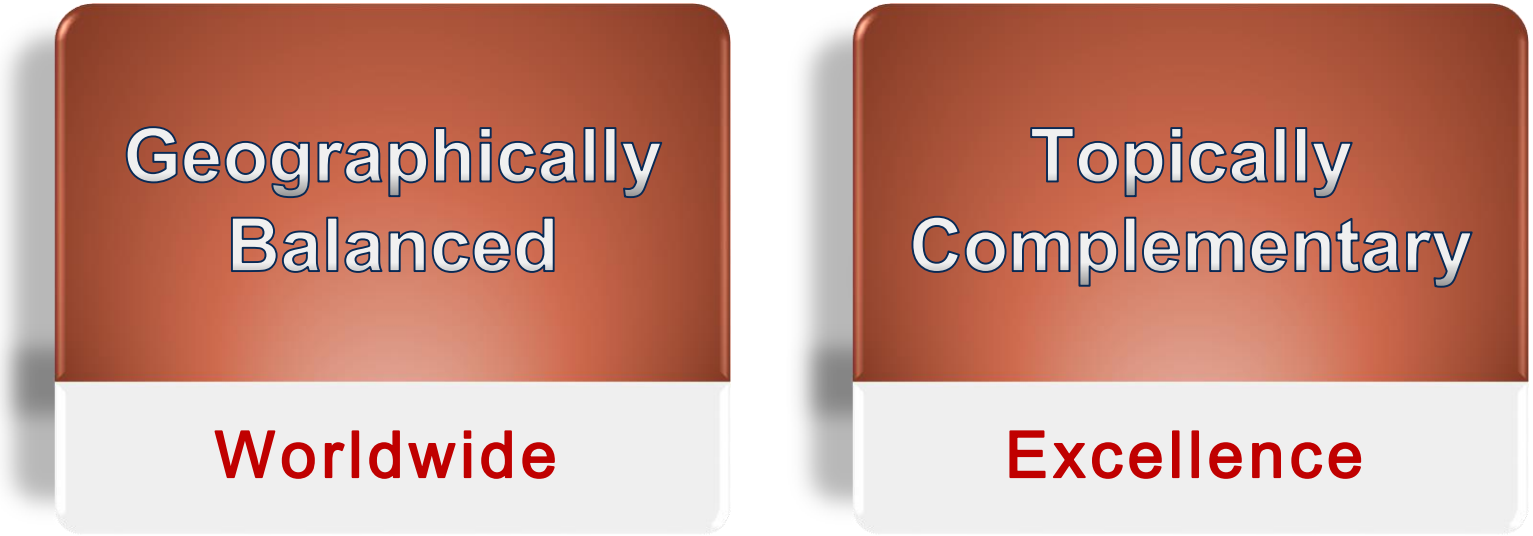


CDR by end 2018 for next strategy update

CDR Study Time Line



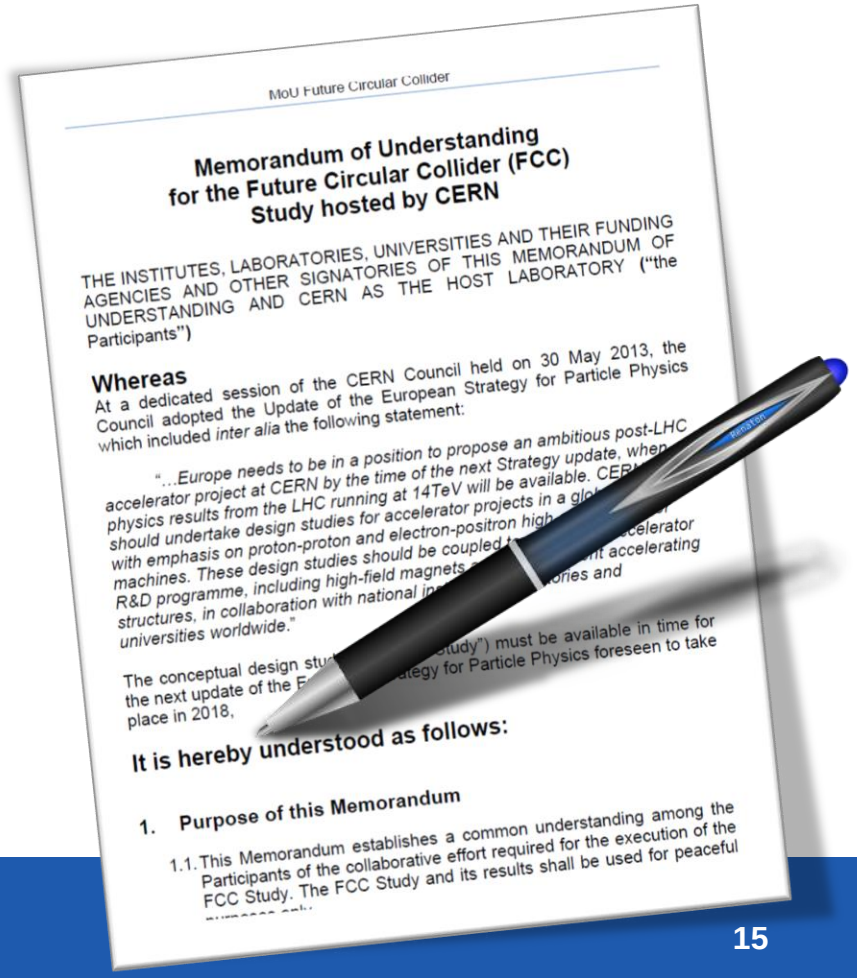
Overall FCC Study Setup



- carried out by global collaboration
- universities, laboratories & industry worldwide
- hosted by CERN

FCC Collaboration

- A **consortium** of partners based on a Memorandum Of Understanding (MoU)
- Working together on a **best effort basis**
- Pursuing the same **common goal**
- **Self governed**
- **Incremental & open** to academia and industry


MoU Future Circular Collider

Memorandum of Understanding for the Future Circular Collider (FCC) Study hosted by CERN

THE INSTITUTES, LABORATORIES, UNIVERSITIES AND THEIR FUNDING AGENCIES AND OTHER SIGNATORIES OF THIS MEMORANDUM OF UNDERSTANDING AND CERN AS THE HOST LABORATORY ("the Participants")

Whereas

At a dedicated session of the CERN Council held on 30 May 2013, the Council adopted the Update of the European Strategy for Particle Physics which included *inter alia* the following statement:

"...Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14TeV will be available. CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and new accelerating structures, in collaboration with national institutes, laboratories and universities worldwide."

The conceptual design study ("the Study") must be available in time for the next update of the European Strategy for Particle Physics foreseen to take place in 2018,

It is hereby understood as follows:

1. **Purpose of this Memorandum**

1.1. This Memorandum establishes a common understanding among the Participants of the collaborative effort required for the execution of the FCC Study. The FCC Study and its results shall be used for peaceful

FCC International Collaboration

- 72 institutes
- 26 countries + EC

Status: 1 February 2016

FCC Collaboration Status

72 collaboration members & CERN as host institute, 1 Feb. 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
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
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
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

- Main aspects of hadron collider design: arc & IR optics design, 16 T magnet program, cryogenic beam vacuum system
- **Recognition of FCC Study by European Commission.**

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

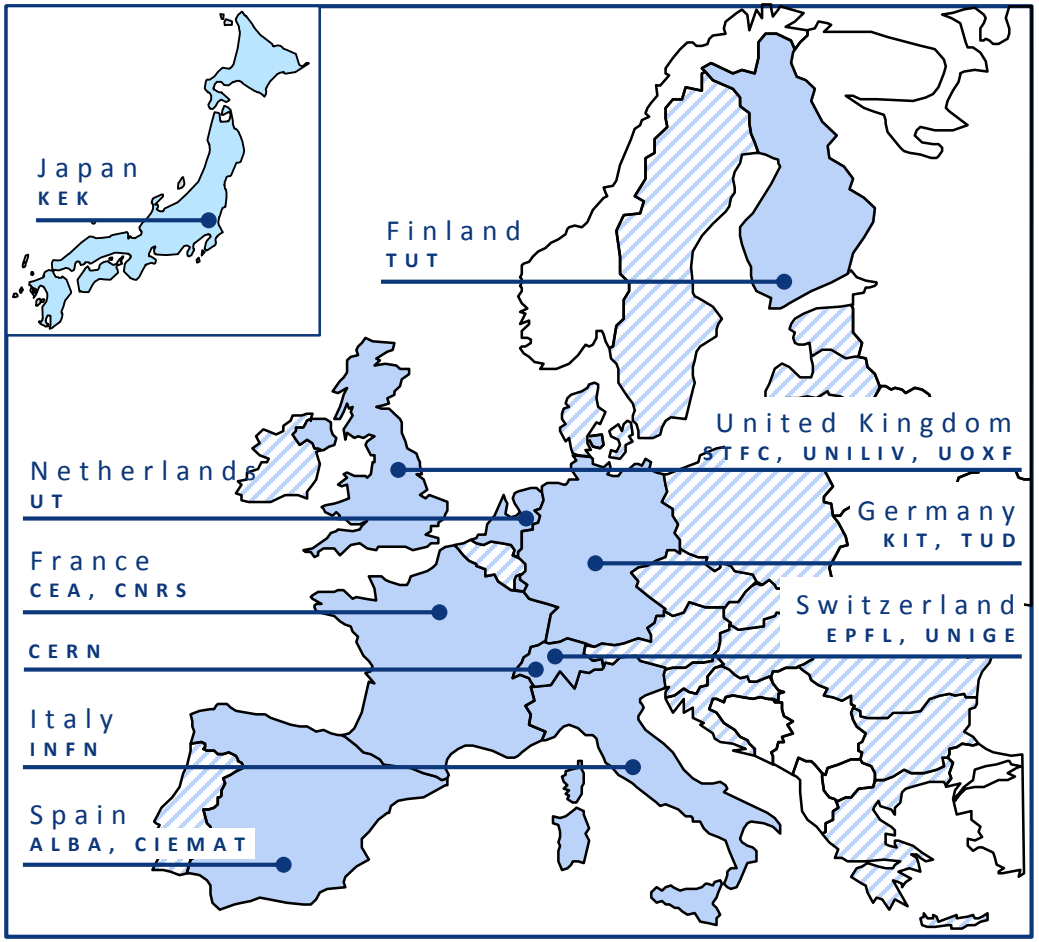
Cost Baseline

EuroCirCol

Resources provided and work carried out **by worldwide collaboration**.

EuroCirCol Consortium + Associates

CERN	IEIO
TUT	Finland
CEA	France
CNRS	France
KIT	Germany
TUD	Germany
INFN	Italy
UT	Netherlands
ALBA	Spain
CIEMAT	Spain
STFC	United Kingdom
UNILIV	United Kingdom
UOXF	United Kingdom
KEK	Japan
EPFL	Switzerland
UNIGE	Switzerland
NHFML-FSU	USA
BNL	USA
FNAL	USA
LBNL	USA



Consortium Beneficiaries, signing the Grant Agreement

19

FCC Week 2015

IEEE International Future Circular Collider Conference

March 23 - 27, 2015 | Washington DC, USA

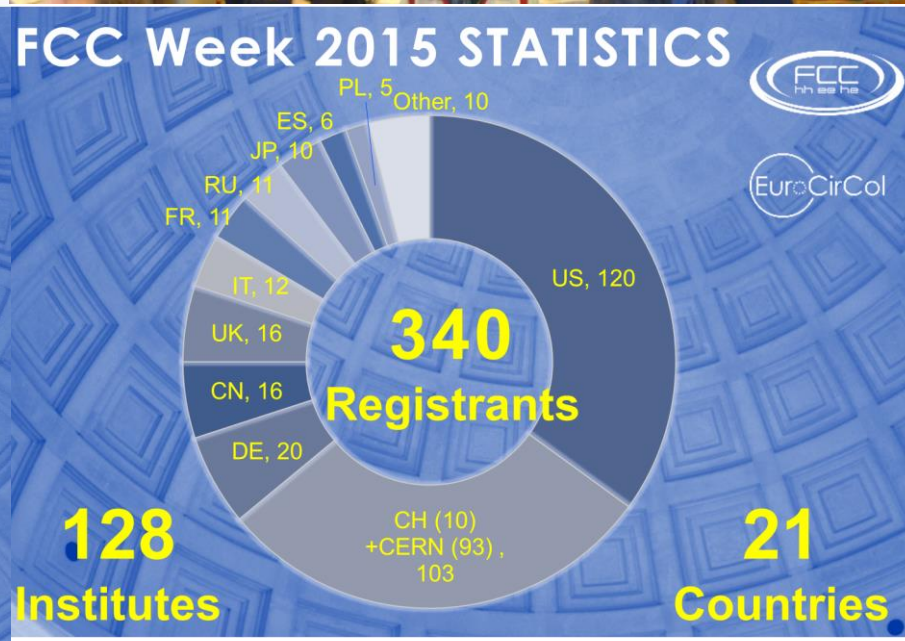
First FCC Week Conference

Washington DC 23-27 March 2015

Organising & Scientific Program Committee:

G. Apollinari (FNAL)
N. Arkani-Hamed (IAS, Princeton)
A. Blondel (U. Geneva)
T. Barklow (SLAC)
W. Barletta (MIT)
M. Benedikt (CERN)
A. Blondel (U. Geneva)
F. Bordry (CERN)
O. Bruning (CERN)
W. Chou (FNAL,IHEP)
P. Collier (CERN)
E. Delucinge (CERN)
M. D'Onofrio (U. Liverpool)
J. Ellis (King's College)
F. Gianotti (CERN)
C. Grojean (ICREA)
J. Incandela (UCSB)
P. Janot (CERN)
E. Jensen (CERN)
J.M. Jimenez (CERN)
M. Klein (U. Liverpool)
P. Lebrun (CERN)
L.K. Len (DOE)
M. Mangano (CERN)
S. Nagaitsev (FNAL)
T. Ogitsu (KEK)
K. Oide (KEK)
V. Palmieri (INFN LNL)
A. Patwa (DOE)
F. Perez (ALBA-CELLS)
C. Potter (CERN)
Q. Qin (IHEP)
R. Rimmer (JLAB)
T. Roser (BNL)
L. Rossi (CERN)
D. Schulte (CERN)
A. Seryi (JAI)
B. Strauss (DOE)
R. Sundrum (U. Maryland)
S. Su (U. Arizona)
M. Syphers (MSU)
L. Tavian (CERN)
E. Todesco (CERN)
R. Van Kooten (Indiana U.)
F. Zimmermann (CERN)

http://cern.ch/fccw2015



Further information and registration
http://cern.ch/fccw2015

EuCARD²

U.S. DEPARTMENT OF ENERGY | Office of Science

FCC Week 2016

Rome, 11-15 April 2016

http://cern.ch/fccw2016

IEEE CSC Council on Superconductivity

SAPIENZA UNIVERSITÀ DI ROMA

Istituto Nazionale di Fisica Nucleare
Sezione di Roma

INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali di Frascati

UNIVERSITA' DEGLI STUDI DI ROMA TorVergata

ROMA TRE UNIVERSITÀ DEGLI STUDI

CERN