Future Circular Collider (FCC) Study

FCC
hh ee he

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EuCARD-2, DESY, 22nd May 2014

Outline

- Motivation & scope
- Parameters & design challenges
- Study organization, study time line
- Preparing global FCC collaboration
- Summary

Summary: European Strategy Update 2013

Design studies and R&D at the energy frontier

….“to propose an ambitious **post-LHC accelerator project at CERN** by the time of the next Strategy update”:

d) 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 high-gradient accelerating structures****,*
- ***in collaboration with national institutes, laboratories and universities worldwide.***

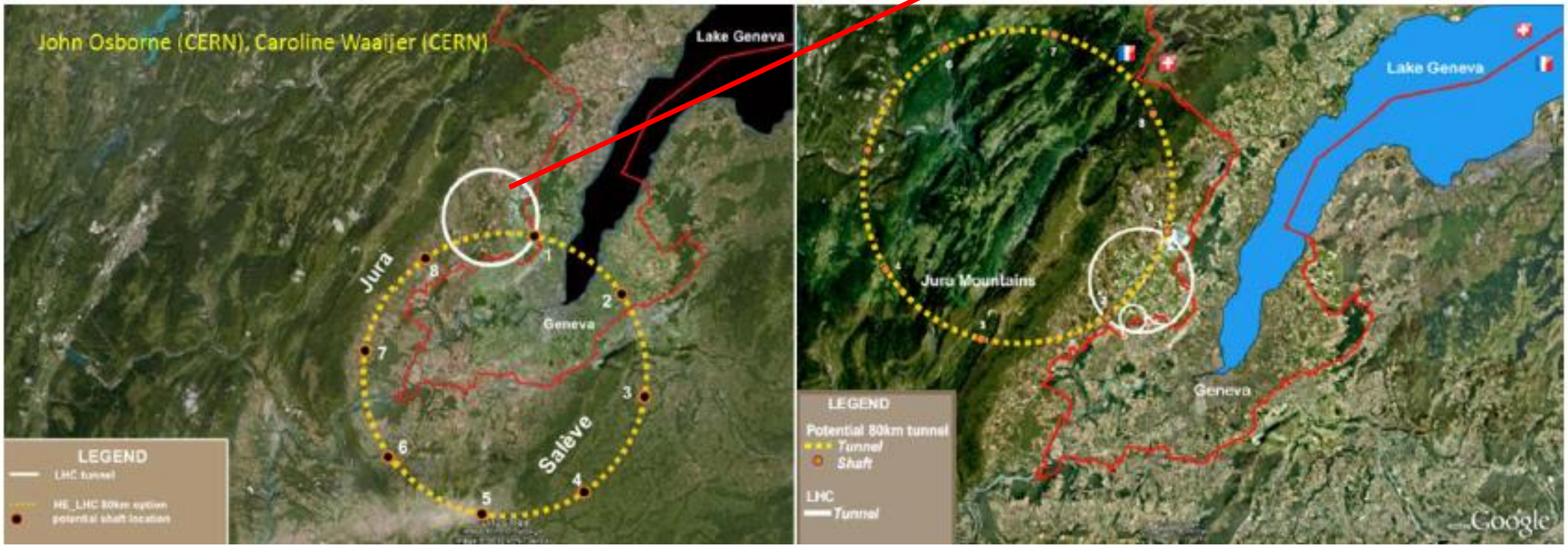
- **http://cds.cern.ch/record/1567258/files/esc-e-106.pdf**

Exploratory studies VHE-LHC

First studies on a new 80 km tunnel in the Geneva area

- **42 TeV** with 8.3 T using present LHC dipoles
- **80 TeV** with 16 T based on Nb_3Sn dipoles
- **100 TeV** with 20 T based on HTS dipoles

HE-LHC :33 TeV with 20T magnets



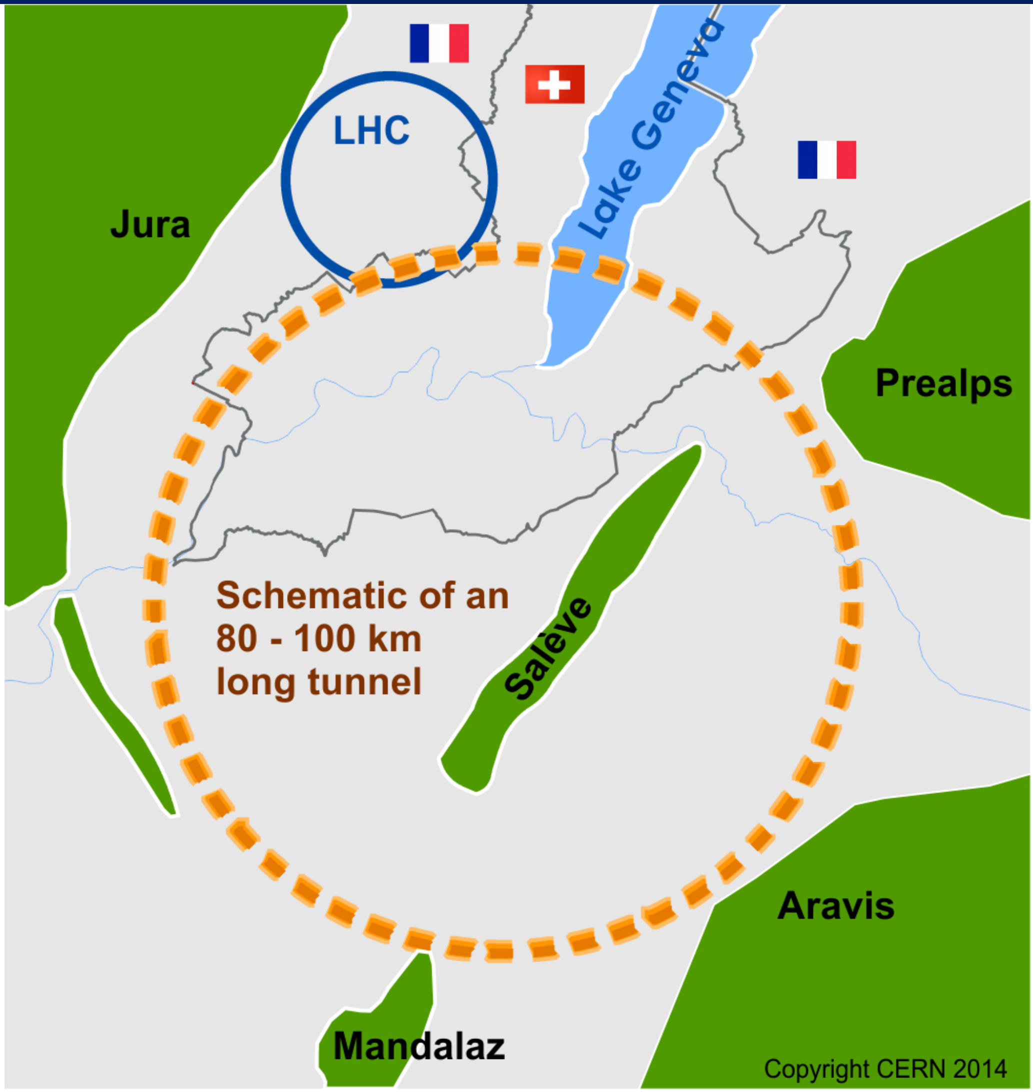
Future Circular Collider Study - SCOPE
CDR and cost review for the next ESU (2018)

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

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



FCC motivation: pushing energy frontier

High-energy hadron collider *FCC-hh* as long-term goal

- **Seems only approach to get to 100 TeV range** in the coming decades
- High energy and luminosity at affordable power consumption
- **Lead time design & construction > 20 years** (LHC study started 1983!)

→ **Must start studying now to be ready for 2035/2040**

Lepton collider *FCC-ee* as potential intermediate step

- Would provide/share **part of infrastructure**
- Important **precision measurements** indicating the energy scale at which new physics is expected
- Search for **new physics in rare decays of *Z, W, H, t*** and rare processes

Lepton-hadron collider *FCC-he* as option

- High precision **deep inelastic scattering and Higgs physics**

Most aspects of collider designs and R&D non-site specific.
Tunnel and site study in Geneva area as ESU requests.

Hadron collider FCC-hh parameters

PRELIMINARY

Energy	**100 TeV c.m.**
Dipole field	**~ 16 T (design limit) [20 T option]**
Circumference	**~ 100 km**
#IPs	2 main (tune shift) + 2
Beam-beam tune shift	0.01 (total)
Bunch spacing	**25 ns [5 ns option]**
Bunch population (25 ns)	$1\text{x}10^{11}$ p
#bunches	10500
Stored beam energy	**8.2 GJ/beam**
Emittance normalised	$2.15\text{x}10^{-6}$m, normalised
Luminosity	**$5\text{x}10^{34}$ $cm^{-2}s^{-1}$**
β^*	1.1 m [2 m conservative option]
Synchroton radiation arc	**26 W/m/aperture (filling fact. 78% in arc)**
Longit. emit damping time	**0.5 h**

FCC-hh: some design challenges

- **Optics and beam dynamics**
  - Optimum lattice design, maximise filling factor of arcs
  - IR design & length (&#) of straight section
  - Field quality requirements and dynamic aperture studies

- **Impedances, instabilities, feedbacks**
  - Beam-beam, e-cloud, etc.
  - Feedback simulation & system conception

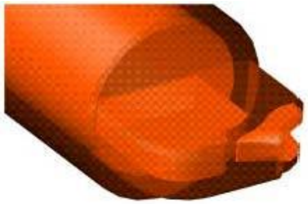
- **Synchrotron radiation damping**
  - Controlled blow up? Smaller bunch spacing with low emittance?, …

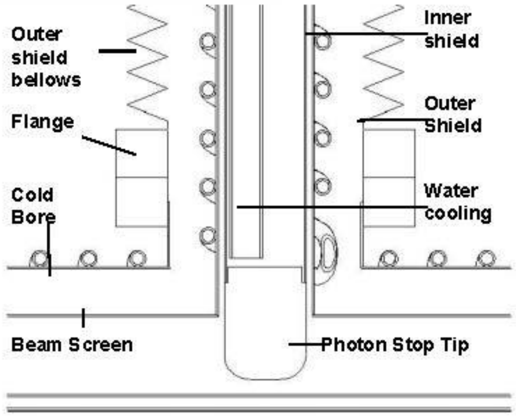
- **Energy in beam & magnets, dump, collimation; quench protection**
  - **Stored beam energy and losses critical: 8 GJ/beam (0.4 GJ LHC)**
  - Collimation, losses, radiation effects: very important
  - Synergies to intensity frontier machines (SNS, FRIB, etc.)

FCC-hh: Synchrotron Radiation Heat Load

- **High synchrotron radiation load on beam pipe**
  - **Up to 26 W/m/aperture in arcs, total of ~5 MW for the collider**
  - (LHC has a total of 1W/m/aperture from different sources)

- **Three strategies to deal with this**
  - **LHC-type beam screen**
    - Cooling efficiency depends on screen temperature, higher temperature creates larger impedance → 40-60 K?
  - **Open midplane magnets**
    - Synergies with muon collider developments
  - **Photon stops**
    - dedicated warm photon stops for efficient cooling between dipoles
    - as developed by FNAL for VLHC





http://inspirehep.net/record/628096/files/fermilab-conf-03-244.pdf
Also P. Bauer et al., "Report on the First Cryogenic Photon Stop Experiment," FNAL TD-03-021, May 2003

FCC-hh: high-field magnet targets

- **FHC baseline is 16T Nb_3Sn technology for ~100 TeV c.m. in ~100 km**

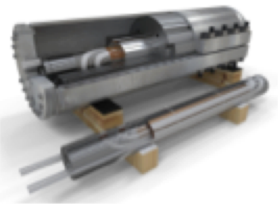
Goal: 16T short dipole models by 2018 (America, Asia, Europe)

Develop Nb_3Sn-based 16 T dipole technology,
- with sufficient aperture (~40 mm) and
- accelerator features (field quality, protect-ability, cycled operation).
- In parallel conductor developments

- **In parallel HTS development targeting 20 T.**
- **HTS insert, generating o(5 T) additional field, in an outsert of large aperture o(100 mm)**

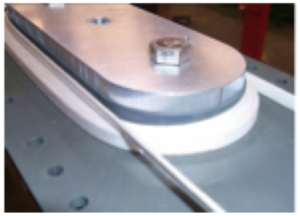
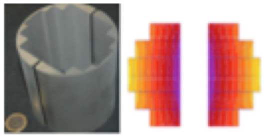
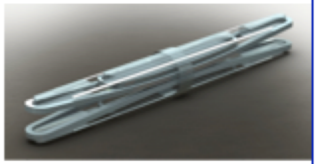
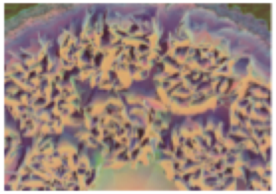
Goal: Demonstrate HTS/LTS 20 T dipole technology in two steps:
- a field record attempt to break the 20 T barrier (no aperture), and
- a 5 T insert, with sufficient aperture (40 mm) and accel. features

Running programs – LTS (Nb3Sn)

Program	Goals	Main partners	Status	
US-base program	High field Nb_3Sn dipoles as technology demonstrators	DOE (BNL, FNAL, LBNL)	D20 reached 13.5 T (50 mm) in 1997, HD1 reached 16 T (0 mm) in 2004. LD1 shell and conductor procured	
EuCARD FReSCa2	13 T (100 mm) Nb_3Sn dipole	EuCARD collaboration (CEA, CERN)	SMC reached 13.5 T (0 mm) in 2013, RMC in construction, FReSCa2 structure procured and tested at CERN, coils in fabrication at CEA	
US-LARP	140 T/m (150 mm) Nb_3Sn quadrupoles for the LHC IR upgrade	DOE US-LARP (BNL, FNAL, LBNL), CERN	Short HQ models (120 mm), long LQ prototype (90 mm) tested, QXF (150 mm) models in production (US-LARP and CERN)	
11 T	11 T (60 mm) Nb_3Sn dipoles for the LHC DS collimators	FNAL, CERN	2 short models tested, 1 mirror in test at FNAL, first model in production at CERN	

NOTE: program at TAMU not reported

Running programs – HTS

Program	Goals	Main partners	Status
US-base program	High field HTS small models as technology demonstrators	DOE (BNL, FNAL, LBNL)	BSCCO racetracks produced and tested (self field) at LBNL. CCT design and prototyping work, first model (NbTi) reached 2.5 T in 2013 
EuCARD HTS insert	6 T (0 mm) HTS dipole insert for FReSCa2 (19 T)	EuCARD collaboration (INPG, CEA)	Short racetrack coils in test at INPG 
EuCARD2	5 T (40 mm) HTS short dipole (also as insert for FReSCa2 (18 T)	EuCARD2 collaboration (CERN, CEA), S-Innovation, US-BSCCo	Superconductor material studies in progress, conceptual designs 
US-BSSCo	Increase J_e of BSCCO-2212 to 600 A/mm^2 for high B physics (30 T all SC user facility)	DOE (BNL, FNAL, LBNL), NHMFL	BSCCO-2212 production restarted at OST in collaboration with CERN, OPHT furnaces, cabling R&D 
S-Innovation	HTS-based compact accelerator systems	Kyoto University, KEK	Conceptual design studies, test of a racetrack HTS at 77 K (self field) to determine field quality

NOTE: program at Carolina University not reported

Summary on high-field magnets

- **U.S. research has been very strong in the past years in superconducting high-field magnet technology:**
  - **Highest field achieved in dipole configuration (LBNL, 16 T)**
  - Hosting the industrial superconductor production with highest critical current density (OST RRP, 3300 A/mm^2 at 12 T and 4.2 K)
  - Vigorous program for the industrial production of a BSCCO-2212 round wire with the characteristics required by high-field applications

- **Fruitful collaborations between CERN, CEA, US-DOE Laboratories and other institutes and universities. E.g.**
  - **EuCARD, EuCARD 2 collaborations FReSCa2 + HTS inserts**
  - **US-LARP collaboration for HL-LHC quadrupole production** of approximately half of the triplet magnets, as required for LHC LS3
  - **FNAL/CERN collaboration for the 11 T LHC dipole design** and demonstration of the technology required for a for the LHC

- **These are excellent pre-requisites for a strong international collaboration on high-field magnet R&D that will be essential for FCC studies.**

Lepton collider FCC-ee parameters

- **Design choice: max. synchrotron radiation power set to 50 MW/beam**
  - Defines the max. beam current at each energy.
  - 4 Physics working points
  - Optimization at each energy (bunch number & current, emittance, etc).

Parameter	TLEP-Z	TLEP-WW	TLEP-H	TLEP-tt_{bar}	LEP2
E/beam (GeV)	45	80	120	175	104
I (mA)	1450	152	30	6.6	3
Bunches/beam	16700	4490	170	160	4
Bunch popul. [10^{11}]	1.8	0.7	3.7	0.86	4.2
L (10^{34} cm^{-2}s^{-1})	28.0	12.0	4.5	1.2	0.012

- For TLEP-H and TLEP-t the beam lifetime of ~few minutes is dominated by Beamstrahlung (momentum acceptance of 2%).

FCC-ee: some design challenges

- **Short beam lifetime from Bhabha scattering and high luminosity**
  - Top-up injection
- **Lifetime limits from Beamstrahlung**
  - Flat beams (very small vertical emittance, β^* ~ 1 mm)
  - Final focus with large (~2%) energy acceptance
- **Machine layout for high currents, large #bunches at Z pole and WW.**
  - Two rings and size of the RF system.
- **Polarization and continuous high precision energy calibration at Z pole and WW, where natural polarization times are ~ 15 hours.**

- **Important expertise available worldwide and potential synergies:**
- **Beam optics, experimental insertions, machine detector interface ⇔ ILC, B-factories, SLAC, BNL**
- **Transverse Polarization ⇔ RHIC, SLC:**
  - Polarization optimization, snakes for physics with polarized beams.

FCC-ee: RF - relevant parameters

Main RF parameters

- Synchrotron radiation power: 50 MW per beam
- Energy loss per turn: 7.5 GeV (at 175 GeV, t)
- Beam current up to 1.4 A (at 45 GeV, Z)
- Up to 7500 bunches of up to 4 x 10^{11} e per ring.
- CW operation with top-up operation, injectors and top-up booster pulsed

First look on basic choices and RF system dimension

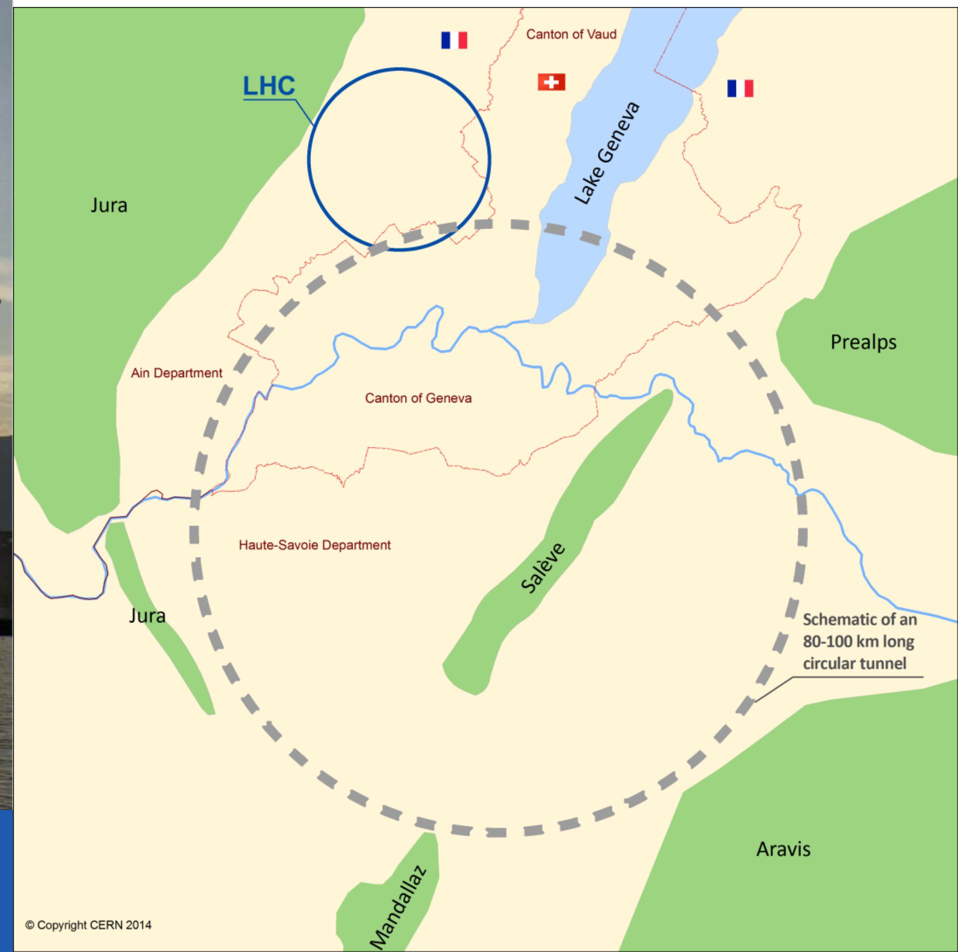
- Frequency range (200 … 800) MHz with ~400 MHz as starting point
  - Initial choice based on present frequencies (harmonics of 200 MHz FHC)
  - Disadvantage lower frequency: mechanical stability, He amount for cooling, size …
  - Disadvantage higher frequency: denser HOM spectrum (multi-cell), BBU limit, larger impedance, smaller coupler dimensions
- System dimension compared to LHC:
  - **LHC 400 MHz → 2 MV and ~250 kW per cavity, (8 cavities per beam)**
  - **Lepton collider ~600 cavities 20 MV / 180 kW RF → 12 GV / 100 MW**

FCC-ee: RF main R&D areas

- **SC cavity R&D**
  - Large Q_0 at high gradient and acceptable cryogenic power!
  - E.g.: Recent promising results at 4 K with Nb_3Sn coating on Nb at Cornell, $800\ ℃ \div 1400\ ℃$ heat treatment at JLAB, beneficial effect of impurities observed at FNAL.
  - **Relevant for many other accelerator applications**
- **High efficiency RF power generation from grid to beam**
  - Amplifier technologies
  - Klystron efficiencies beyond 65%, alternative RF sources as Solid State Power Amplifier or multi-beam IOT, e.g. ESS solution with industry (CPI in U.S.)
  - **Relevant for all high power accelerators, intensity frontier (drivers), (e.g. νstorm, LBNE, DAEδALUS, μcoll,)**
- **R&D Goal is optimization of overall system efficiency and cost!**
  - Power source efficiency, low loss high gradient SC cavities, operation temperature vs. cryogenic load, total system cost and dimension.

FCC Kick-off Meeting Geneva

http://indico.cern.ch/e/fcc-kickoff



FCC Kick-off Meeting

FCC Kick-off participants

341 registered participants - geographical distribution

Americas (37)
Canada: 1
Mexico: 2
US: 34

Asia (19)
China: 9
Japan: 9
Republic of Korea: 1

Africa (1)
South Africa: 1

Europe (284)
Austria: 1
CERN: 140
Czech Republic: 2
Denmark: 1
France: 30
Germany: 14
Greece: 1
Hungary: 2
Italy: 20
Poland: 6
Portugal: 2
Russia: 8
Serbia: 1
Spain: 11
Sweden: 1
Switzerland: 19 (w/o CERN)
UK: 25

Well-balanced world-wide attendance

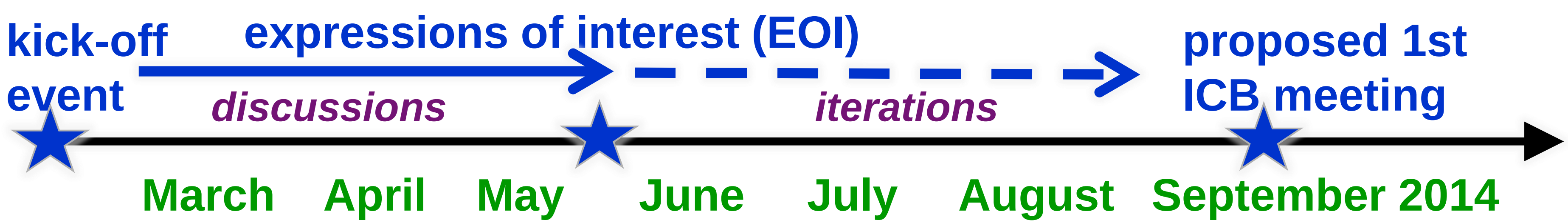
Workshop Goals

Rolf Heuer
Opening talk

- Discussion of all FCC aspects
- Refine scope of the study
- Define schedule, WBS, milestones of the study
- Establish the path towards international collaboration: Expressions of Interest, formation of collaboration, accepting new partners throughout the duration of the study
- Open process

Next steps

- **Establish an international collaboration:**
- Following very positive reactions and the enthusiasm during the Kick-off meeting:
  - → **Invitations to institutes to join collaboration**
  - → Aiming at **expressions of interest by end May 2014** to form nucleus of collaboration by September 2014
  - → Enlargement of the study preparation team
  - → **First international collaboration board meeting 9-10 September at CERN**



FCC EU Design Study Proposal

Horizon2020 call – design study, deadline 02.09.2014

Prepare proposal parallel to FCC collaboration setup

HORIZON 2020

Goals fo EU DS: conceptual design, prototypes, cost estimates, …

From FP7 HiLumi LHC DS → positive experience:

- **5-6 work packages as sub-set of FCC study**
- **~10-15 beneficiaries** (signatories of the contract with EC)

Time line

- **kick-off event** (March)
- *discussions* (March–April)
- **input from interested partners, end of May**
- **complete draft proposal, end of June**
- *iteration, agreements, signatures* (July–August)
- **submission of EU FCC DS proposal, 2 Sept.**

March April May June July August September 2014

Non-EU partners can join as beneficiary – signatory with or w/o EC contribution (contractual commitment) **or as associated partner – non-signatory** (in-kind contribution with own funding, no contractual commitment)

FCC - US Status

- DOE had **limited FCC kick-off participation to 1 representative/laboratory**
- **Still 33 US participants** (many institutes!) attended

- **DOE request not to interfere with US "P5 process"** has been fully respected by FCC study coordination
- Designated **US-DOE contact for FCC: William Barletta, MIT**

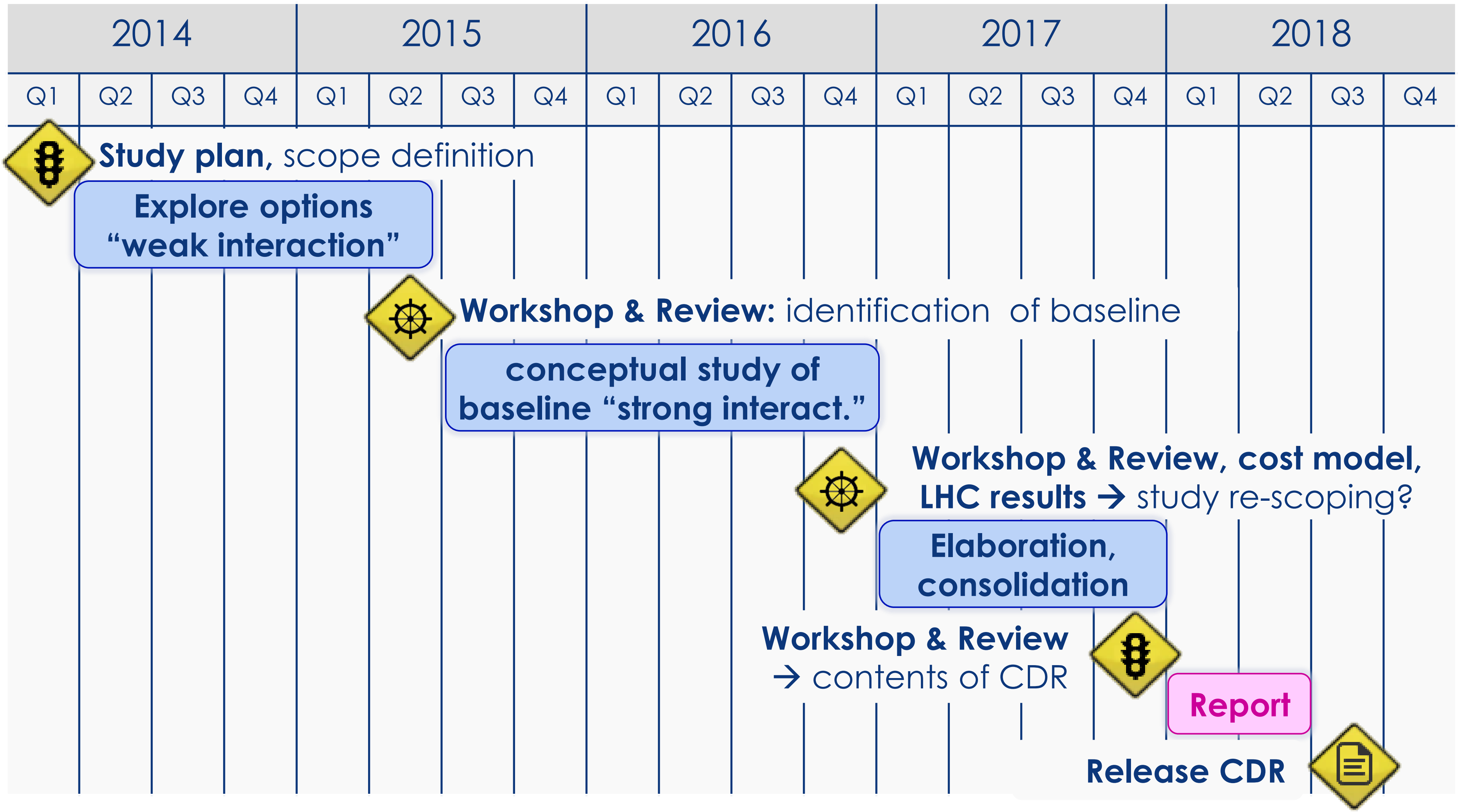
- **US has relevant expertise**: SSC, VLHC, HL-LHC, RHIC, Tevatron, CEBAF, SNS, ... US could make **significant contributions to high-field magnets and SRF**, e.g. through structure like LARP
- US holding **FCC physics workshops at SLAC, FNAL, Aspen**, ….

- FCC study **proposal to include two US representatives in global study steering group** (which could play a role in this critical formation phase) still **waiting for DOE approval**

FCC - China Status

- **IHEP/CAS project of CepC/SppC** similar to FCC-ee/FCC-hh
- **Numerous CepC workshops and events in China**;
- **Invited visits by many international accelerator experts** (SLAC, KEK, Cornell, FNAL, BINP, ANL, Korea, …)
- **More aggressive time schedule:** CepC CDR end of 2014; first e^+e^- collisions in 2028; first *pp* collisions in 2042
- **Attractive location** (1 h from Beijing by TGV, "Chinese Toscana", "best beach of China")
- Present project proposal based on **54 km circumference** (2x LHC)
- **Optimized for Higgs factory mode** (240 GeV c.m.)
- **Fruitful collaboration & competition with FCC** (joint meetings)

Proposal for study timeline

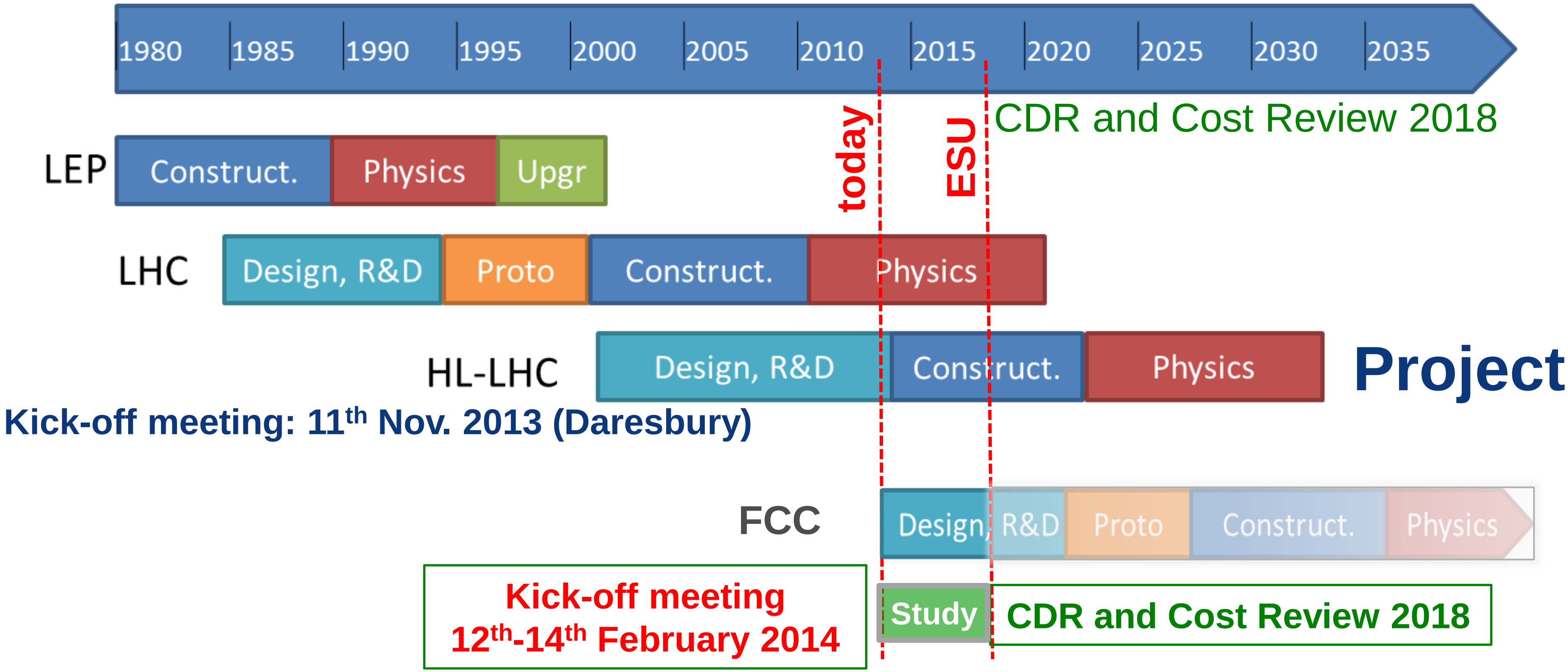


FCC work plan study phase 1

Explore options, now – spring 2015:

- Investigate **different options** in all technical areas, **taking a broad view**
- **Deliverables: description and comparison of options with relative merits/cost, Develop schedules, understand relative impact of options on overall schedule (physics operation time, machine installation time, etc.)**
- **FCC workshop to converge to common baseline with small number of options**
- **Proposed WS date 23 – 27 March 2015** (presently no known collisions…)
- Followed by review ~2 months later, begin June 2015

FCC study milestones



Summary

- There are strongly rising activities in energy-frontier circular colliders worldwide. CERN is setting-up an international study for the design of Future Circular Colliders (FCC).
- Worldwide collaboration in all areas, i.e. physics, experiments and accelerators will be important for the field of HE physics in general and to reach the demanding goal of a CDR by 2018.
- The FCC kick-off meeting was very well attended, with balanced international participation and with very constructive and encouraging atmosphere, explicitly remarked by many participants.
- There was a broad consensus on study organisation, contents, timeline and the proposed collaboration process.


great interest & fascination
around the world!
Riesiger Teilch
Nachfolger
CERN、大型円形加速器の建設を検討 出力はLHCの7倍
AFP＝時事 2月9日(日)18時4分配信
re powerful collider
Frankfurter Allgemeine
Wissen
Sciences
Discussions sur un nouvel
accélérateur de particules géant


UNIVERSITÉ DE GENÈVE
FCC Kick-Off 2014
Future Circular Collider (FCC) Study
FCC
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Future Circular Collider Study
FCC Kick-Off 2014
R-D Heuer, CERN
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maticity correction similar to SuperKEKB,
tum acceptance will be similar, about ±1.4%.


FCC-ee
FCC-hh
Power Limitation
Synchrotron radiation
Beam power given by RF
Limits the total beam current I
For example, E0=120 GeV, ρ=2.6 km, U0=6.97 GeV, I=7.2 mA, lead to Pb=50 MW in our design.
Ring Layout
Deep Inelastic Scattering [eh → e'X]
FCC-he

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