Future Circular Collider (FCC) Study

Michael Benedikt

LAL Orsay, 7. May 2014
Outline

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

CLIC CDR and cost study (2012)

- 3 volumes CDR: physics & detectors, accelerator complex, strategy, cost & schedule
- Collaborative effort: 40+ institutes worldwide
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$_3$Sn 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
  - $\sim 16 \, \text{T} \Rightarrow 100 \, \text{TeV} \, pp$ in 100 km
  - $\sim 20 \, \text{T} \Rightarrow 100 \, \text{TeV} \, pp$ 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 \textit{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!)
  \begin{itemize}
  \item \textcolor{red}{Must start studying now to be ready for 2035/2040}
  \end{itemize}

Lepton collider \textit{FCC-ee} as potential intermediate step

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

Lepton-hadron collider \textit{FCC-he} as option

- High precision \textbf{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)**: $1 \times 10^{11}$ p
- **#bunches**: 10500
- **Stored beam energy**: 8.2 GJ/beam
- **Emittance normalised**: $2.15 \times 10^{-6}$ m, normalised
- **Luminosity**: $5 \times 10^{34}$ cm$^{-2}$s$^{-1}$
- **$\beta^*$**: 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 $16T \text{Nb}_3\text{Sn}$ technology for $\sim100$ TeV c.m. in $\sim100$ km

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

Develop $\text{Nb}_3\text{Sn}$-based $16$ T dipole technology,

- with sufficient aperture ($\sim40$ 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 (Nb$_3$Sn)

<table>
<thead>
<tr>
<th>Program</th>
<th>Goals</th>
<th>Main partners</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>US-base program</td>
<td>High field Nb$_3$Sn dipoles as technology demonstrators</td>
<td>DOE (BNL, FNAL, LBNL)</td>
<td>D20 reached 13.5 T (50 mm) in 1997, HD1 reached 16 T (0 mm) in 2004. LD1 shell and conductor procured</td>
</tr>
<tr>
<td>EuCARD</td>
<td>13 T (100 mm) Nb$_3$Sn dipole</td>
<td>EuCARD collaboration (CEA, CERN)</td>
<td>SMC reached 13.5 T (0 mm) in 2013, RMC in construction, FReSCa2 structure procured and tested at CERN, coils in fabrication at CEA</td>
</tr>
<tr>
<td>FReSCa2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>US-LARP</td>
<td>140 T/m (150 mm) Nb$_3$Sn quadrupoles for the LHC IR upgrade</td>
<td>DOE US-LARP (BNL, FNAL, LBNL, CERN)</td>
<td>Short HQ models (120 mm), long LQ prototype (90 mm) tested, QXF (150 mm) models in production (US-LARP and CERN)</td>
</tr>
<tr>
<td>11 T</td>
<td>11 T (60 mm) Nb$_3$Sn dipoles for the LHC DS collimators</td>
<td>FNAL, CERN</td>
<td>2 short models tested, 1 mirror in test at FNAL, first model in production at CERN</td>
</tr>
</tbody>
</table>

**NOTE:** program at TAMU not reported
# Running programs – HTS

<table>
<thead>
<tr>
<th>Program</th>
<th>Goals</th>
<th>Main partners</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>US-base program</td>
<td>High field HTS small models as technology demonstrators</td>
<td>DOE (BNL, FNAL, LBNL)</td>
<td>BSCCO racetracks produced and tested (self field) at LBNL. CCT design and prototyping work, first model (NbTi) reached 2.5 T in 2013</td>
</tr>
<tr>
<td>EuCARD HTS insert</td>
<td>6 T (0 mm) HTS dipole insert for FReSCa2 (19 T)</td>
<td>EuCARD collaboration (INPG, CEA)</td>
<td>Short racetrack coils in test at INPG</td>
</tr>
<tr>
<td>EuCARD2</td>
<td>5 T (40 mm) HTS short dipole (also as insert for FReSCa2 (18 T)</td>
<td>EuCARD2 collaboration (CERN, CEA), S-Innovation, US-BSSCo</td>
<td>Superconductor material studies in progress, conceptual designs</td>
</tr>
<tr>
<td>US-BSSCo</td>
<td>Increase $J_e$ of BSCCO-2212 to 600 A/mm² for high B physics (30 T all SC user facility)</td>
<td>DOE (BNL, FNAL, LBNL), NHMFL</td>
<td>BSCCO-2212 production restarted at OST in collaboration with CERN, OPHT furnaces, cabling R&amp;D</td>
</tr>
<tr>
<td>S-Innovation</td>
<td>HTS-based compact accelerator systems</td>
<td>Kyoto University, KEK</td>
<td>Conceptual design studies, test of a racetrack HTS at 77 K (self field) to determine field quality</td>
</tr>
</tbody>
</table>

**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/mm² 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.
• **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).

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

• 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, $\beta^* \sim 1$ 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 $\leftrightarrow$ ILC, B-factories, SLAC, BNL

• Transverse Polarization $\leftrightarrow$ RHIC, SLC:
  • Polarization optimization, snakes for physics with polarized beams.
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 $4 \times 10^{11}$ 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 $\rightarrow$ 2 MV and ~250 kW per cavity, (8 cavities per beam)
  - Lepton collider ~600 cavities 20 MV / 180 kW RF $\rightarrow$ 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$_3$Sn coating on Nb at Cornell, 800 ºC ÷ 1400 ºC 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.
### Main areas for design study

<table>
<thead>
<tr>
<th>Machines and infrastructure conceptual designs</th>
<th>Technologies R&amp;D activities Planning</th>
<th>Physics experiments detectors</th>
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<tbody>
<tr>
<td>Infrastructure</td>
<td>High-field magnets</td>
<td>Hadron physics experiments interface, integration</td>
</tr>
<tr>
<td>Hadron collider conceptual design</td>
<td>Superconducting RF systems</td>
<td>e+ e- coll. physics experiments interface, integration</td>
</tr>
<tr>
<td>Hadron injectors</td>
<td>Cryogenics</td>
<td></td>
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<tr>
<td>Lepton collider conceptual design</td>
<td>Specific technologies</td>
<td>e- - p physics, experiments, integration aspects</td>
</tr>
<tr>
<td>Safety, operation, energy management environmental aspects</td>
<td>Planning</td>
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**Future Circular Collider Study**  
Michael Benedikt  
LAL Orsay, 7th May 2014
Proposal for FCC WBS top level

Preliminary

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

Future Circular Collider Study
Michael Benedikt
LAL Orsay, 7th May 2014
### Future Circular Colliders - Conceptual Design Study

Study coordination, **M. Benedikt, F. Zimmermann**

<table>
<thead>
<tr>
<th>Hadron collider</th>
<th>Hadron injectors</th>
<th>e+ e- collider and injectors</th>
<th>Infrastructure, cost estimates</th>
<th>Technology</th>
<th>Physics and experiments</th>
</tr>
</thead>
<tbody>
<tr>
<td>D. Schulte</td>
<td>B. Goddard</td>
<td>J. Wenninger</td>
<td>P. Lebrun</td>
<td>High Field Magnets</td>
<td>Hadrons</td>
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<td></td>
<td>L. Bottura</td>
<td>A. Ball, F. Gianotti, M. Mangano</td>
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<td></td>
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<td>Superconducting RF</td>
<td>e+ e-</td>
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<td></td>
<td></td>
<td>E. Jensen</td>
<td>A. Blondel</td>
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<td>Cryogenics</td>
<td>J. Ellis, P. Janot</td>
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<td>L. Tavian</td>
<td>e- p</td>
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<td>Specific Technologies</td>
<td>M. Klein</td>
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<td>JM. Jimenez</td>
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</tbody>
</table>

**e- p option**

Integration aspects **O. Brüning**

**Operation aspects,**

energy efficiency, safety, environment **P. Collier**

**Planning (Implementation roadmap, financial planning, reporting)**

**F. Sonnemann, J. Gutleber**
Future Circular Collider Study
Kick-off Meeting

12-15 February 2014,
University of Geneva, Switzerland

LOCAL ORGANIZING COMMITTEE
University of Geneva
C. Blanchard, A. Blondel,
C. Doglioni, G. Iacobucci,
M. Koratzinos
CERN
M. Benedikt, E. Delucinge,
J. Gutleber, D. Hudson,
C. Potter, F. Zimmermann

SCIENTIFIC ORGANIZING COMMITTEE
FCC Coordination Group
A. Ball, M. Benedikt, A. Blondel,
F. Bordry, L. Bottura, O. Brüning,
P. Collier, J. Ellis, F. Gianotti,
B. Goddard, P. Janot, E. Jensen,
J. M. Jimenez, M. Klein, P. Lebrun,
M. Mangano, D. Schulte,
F. Sonnemann, L. Tavian,
J. Wenninger, F. Zimmermann

http://indico.cern.ch/e/fcc-kickoff
FCC Kick-off Meeting

Kick-off Meeting of the Future Circular Colliders Design Study
12 - 15 February 2014, University of Geneva / Switzerland
341 registered participants
### FCC Kick-off participants

341 registered participants - geographical distribution

<table>
<thead>
<tr>
<th>Region</th>
<th>Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Americas (37)</td>
<td></td>
</tr>
<tr>
<td>Canada: 1</td>
<td></td>
</tr>
<tr>
<td>Mexico: 2</td>
<td></td>
</tr>
<tr>
<td><strong>US</strong>: 34</td>
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<tr>
<td>Asia (19)</td>
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</tr>
<tr>
<td>China: 9</td>
<td></td>
</tr>
<tr>
<td>Japan: 9</td>
<td></td>
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<tr>
<td>Republic of Korea: 1</td>
<td></td>
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<tr>
<td>Africa (1)</td>
<td></td>
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<tr>
<td>South Africa: 1</td>
<td></td>
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</tbody>
</table>

| 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     |              |

<table>
<thead>
<tr>
<th>Additional Countries</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Serbia: 1</td>
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<tr>
<td><strong>Spain</strong>: 11</td>
<td></td>
</tr>
<tr>
<td>Sweden: 1</td>
<td></td>
</tr>
<tr>
<td><strong>Switzerland</strong>: 19</td>
<td>(w/o CERN)</td>
</tr>
<tr>
<td>UK: 25</td>
<td></td>
</tr>
</tbody>
</table>

Well-balanced world-wide attendance
Workshop Goals

- 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
### Session 1a - Opening (Chaired by Giuseppe IACOBUCCI/Alain BLONDEL - University of Geneva) - MR380 (13:30-15:00)

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>13:30</td>
<td>Welcome</td>
<td>VASSALLI, Jean-Dominique</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BLONDEL, Alain</td>
</tr>
<tr>
<td>13:40</td>
<td>Opening &amp; Introduction</td>
<td>HEUER, Rolf</td>
</tr>
<tr>
<td>14:00</td>
<td>Energy frontier after the Higgs discovery</td>
<td>ARKANI-HAMED, Nima</td>
</tr>
<tr>
<td>14:30</td>
<td>Precision frontier at high energies</td>
<td>GROJEAN, Christophe</td>
</tr>
</tbody>
</table>

### Session 1b - Opening (Chaired by Alex MUELLER - CNRS/IN2P3) - MR380 (15:30-17:45)

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>15:30</td>
<td>CERN roadmap</td>
<td>BORDRY, Frédérick</td>
</tr>
<tr>
<td>15:50</td>
<td>FCC study</td>
<td>BENEDIKT, Michael</td>
</tr>
<tr>
<td>16:20</td>
<td>Chinese activities for circular colliders</td>
<td>WANG, Yifang</td>
</tr>
<tr>
<td>16:40</td>
<td>US activities related to circular colliders studies</td>
<td>HENDERSON, Stuart</td>
</tr>
<tr>
<td>17:00</td>
<td>Cultural, economical and societal impact of big science projects</td>
<td>WOMERSLEY, John William</td>
</tr>
</tbody>
</table>

**Public Lecture: Le boson de Higgs et le seigneur des anneaux** - U600 (19:00-21:00)

- Presenters: SPIRO, Michel
### Workshop programme (ii)

**Session 2a - Hadron machine (Chaired by Akira Yamamoto - KEK) - MR380 (08:30-10:30)**

<table>
<thead>
<tr>
<th>time</th>
<th>title</th>
<th>presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>08:30</td>
<td>Hadron collider overview</td>
<td>SCHULTE, Daniel</td>
</tr>
<tr>
<td>09:00</td>
<td>Synchrotron radiation &amp; vacuum concepts</td>
<td>KERSEVAN, Roberto</td>
</tr>
<tr>
<td>09:30</td>
<td>Hadron injector options</td>
<td>HERR, Werner</td>
</tr>
<tr>
<td>10:00</td>
<td>R&amp;D roadmap towards 16 T Nb3Sn dipole magnets ready for industrial production</td>
<td>STRAUSS, Bruce</td>
</tr>
</tbody>
</table>

**Session 2b - Hadron physics (Chaired by Tejinder VIRDEE - Imperial College) - MR380 (11:00-12:30)**

<table>
<thead>
<tr>
<th>time</th>
<th>title</th>
<th>presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>11:00</td>
<td>Hadron collider experiments and physics: introduction</td>
<td>GIANOTTI, Fabiola</td>
</tr>
<tr>
<td>11:25</td>
<td>Experimental challenges and first ideas about detector layouts</td>
<td>FOURNIER, Daniel</td>
</tr>
<tr>
<td>11:50</td>
<td>The physics landscape and opportunities</td>
<td>MANGANO, Michelangelo</td>
</tr>
<tr>
<td>12:15</td>
<td>Open discussion</td>
<td></td>
</tr>
</tbody>
</table>
### Session 3a - Lepton machine (Chaired by Eugene LEVICHEV - BINP) - MR380 (14:00-16:00)

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:00</td>
<td>Lepton collider overview</td>
<td>WENNINGER, Jorg</td>
</tr>
<tr>
<td>14:30</td>
<td>Optics challenges</td>
<td>HOLZER, Bernhard</td>
</tr>
<tr>
<td>14:50</td>
<td>Final focus + injector concepts based on SuperKEKB</td>
<td>OIDE, Katsunobu</td>
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<tr>
<td>15:10</td>
<td>Lepton injector options</td>
<td>PAPAPHILIPPOU, Yannis</td>
</tr>
<tr>
<td>15:30</td>
<td>100-MW RF system at different beam energies and intensities</td>
<td>JENSEN, Erk</td>
</tr>
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</table>

### Session 3b - Lepton physics (Chaired by Michel SPIRO - CEA) - MR380 (16:30-18:00)

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
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<tbody>
<tr>
<td>16:30</td>
<td>Lepton physics</td>
<td>ELLIS, Jonathan R.</td>
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<tr>
<td>17:00</td>
<td>Lepton experiments &amp; detectors</td>
<td>ROLANDI, Gigi</td>
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<tr>
<td>17:30</td>
<td>Lepton-Hadron Physics, Experiments, Detectors</td>
<td>D'ONOFRIO, Monica</td>
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</tbody>
</table>
**Session 4a - Infrastructure & operation - (Chaired by Thomas ROSER - BNL) - MR380 (08:30-11:00)**

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
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<tbody>
<tr>
<td>08:30</td>
<td>Unconventional issues in conventional facilities</td>
<td>LEBRUN, Philippe</td>
</tr>
<tr>
<td>09:00</td>
<td>Cryogenics</td>
<td>TAVIAN, Laurent Jean</td>
</tr>
<tr>
<td>09:30</td>
<td>Availability, energy, operation</td>
<td>COLLIER, Paul</td>
</tr>
<tr>
<td>10:00</td>
<td>Gotthard tunnel project</td>
<td>AMBERG, Felix</td>
</tr>
<tr>
<td>10:30</td>
<td>Geology and civil engineering</td>
<td>OSBORNE, John Andrew</td>
</tr>
</tbody>
</table>

**Session 4b - Closing (Chaired by Tord EKELOF - Uppsala University) - MR380 (11:30-13:00)**

<table>
<thead>
<tr>
<th>Time</th>
<th>Title</th>
<th>Presenter</th>
</tr>
</thead>
<tbody>
<tr>
<td>11:30</td>
<td>Health, safety and environment</td>
<td>TRANT, Ralf</td>
</tr>
<tr>
<td>12:00</td>
<td>Closing remarks &amp; outlook</td>
<td>HEUER, Rolf</td>
</tr>
</tbody>
</table>
### FCC Kick-Off Parallel Sessions (Friday afternoon)

<table>
<thead>
<tr>
<th>Session</th>
<th># Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical infrastructure and civil engineering</td>
<td>47</td>
</tr>
<tr>
<td>Hadron collider design (+ SC magnets + injectors)</td>
<td>75</td>
</tr>
<tr>
<td>Lepton collider design (+ SC RF + injectors)</td>
<td>62</td>
</tr>
<tr>
<td>Hadron Physics, Experiments, Detectors</td>
<td>93</td>
</tr>
<tr>
<td>Lepton Physics, Experiments, Detectors</td>
<td>54</td>
</tr>
<tr>
<td>e-p Option</td>
<td>18</td>
</tr>
<tr>
<td>Overall physics and phenomenology</td>
<td>63</td>
</tr>
</tbody>
</table>
How (the study should be organised)

- Exploitation of all options for such a project (hh – ee – ep) within one study
- Global Collaboration for the Study of Future Circular Colliders (similar to the CLIC collaboration)
- Hosted by CERN
Proposed international organization structure

- Collaboration Board
  1 person/inst.

- Steering Committee
  2-3 persons/region

- Advisory Committee
  1-2 experts/field

- FCC Study Coordination

- Hadron Collider Physics Experiments
- Lepton Collider Physics Experiments
- e-p Physics Experiments
- Hadron Injectors
- Hadron Collider
- Lepton Injectors
- Lepton Collider
- Accelerator R&D Technologies
- Infrastructures Operation
- Costing Planning

Rolf Heuer Opening talk
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

March  April  May  June  July  August  September 2014
**FCC EU Design Study Proposal**

Horizon2020 call – design study, **deadline 02.09.2014**
Prepare proposal parallel to FCC collaboration setup

**Goals for 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)

**Timeline**

- **Kick-off event discussions**
- **Input from interested partners, end of May**
- **Complete draft proposal, end of June**
- **Iteration, agreements, signatures**
- **Submission of EU FCC DS proposal, 2 Sept.**

**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)
- 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
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

| Year | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 | Q1 | Q2 | Q3 | Q4 |
|------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 2014 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 2015 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 2016 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 2017 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| 2018 |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |

**Study plan, scope definition**

- Explore options “weak interaction”

**Workshop & Review:** identification of baseline

- Conceptual study of baseline “strong interact.”

**Workshop & Review, cost model, LHC results → study re-scoping?**

**Elaboration, consolidation**

**Workshop & Review → contents of CDR**

**Report**

**Release CDR**
## FCC work plan study phase 1

<table>
<thead>
<tr>
<th>2014</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
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<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
</tbody>
</table>

### Prepare

Kick-off, collaboration forming, study plan and organisation

### Phase 1: Explore options “weak interaction”

- 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


LEP
- Construct.
- Physics
- Upgr

LHC
- Design, R&D
- Proto
- Construct.
- Physics

HL-LHC
- Design, R&D
- Construct.
- Physics

FCC
- Design, R&D
- Proto
- Construct.
- Physics

Project

Kick-off meeting: 11th Nov. 2013 (Daresbury)

Kick-off meeting 12th-14th February 2014

CDR and Cost Review 2018
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 the world! & fascination.
Future Circular Collider (FCC) Study
Power Limitation

- Synchrotron radiation
  \[ P_s = \frac{4}{3} \pi \rho m c r \]
- Beam power given by RF
  \[ P_b = U_b I / e \]
- Limits the total beam current

For example, \( E_p = 120 \text{ GeV}, r = 3.6 \text{ km}, U_b = 6.97 \text{ GeV}, l = 7.2 \text{ mA}, \) lead to \( P_b = 5.3 \text{ MW} \) in our design.