Future Circular Colliders

Michael Benedikt, Frank Zimmermann

gratefully acknowledging input from FCC coordination group, global design study team and all international contributors

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

http://cern.ch/fcc
• Motivation for Future Circular Colliders
• FCC Study Scope & Time Line
• Machine Design, Physics, Detectors
• Technologies
• FCC Organisation & Collaboration
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,....”

• U.S. strategy and 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....”

• ICFA statement 2014:
  ”.... ICFA supports studies of energy frontier circular colliders and encourages global coordination.....”
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 \(\to O(10)\) in \(E_{\text{cms}}\)
International FCC collaboration (CERN as host lab) to study:

- **\(pp\)-collider \(O(100) \, \text{TeV} \) (FCC-\(hh\))
  - main emphasis, defining infrastructure requirements
  - \(~16 \, \text{T} \Rightarrow 100 \, \text{TeV} \, pp\) 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
CepC/SppC study (CAS-IHEP) 54 km (baseline)  
e^+e^− collisions ~2028; pp collisions ~2042

Qinhuangdao (秦皇岛)

CepC, SppC

100 km

50 km

easy access
300 km east
from Beijing
3 h by car
1 h by train

Yifang Wang

Chinese Toscana
Previous studies in Italy (ELOISATRON 300km), USA (SSC 87km, VLHC 233km), Japan (TRISTAN-II 94km)

**ex. ELOISATRON**

Supercolliders
Superdetectors: Proceedings of the 19th and 25th Workshops of the INFN

Eloisatron

**ex. SSC**

**ex. TRISTAN II**

Many aspects of machine design and R&D non-site specific.
→ Exploit synergies with other projects and prev. studies

**ex. VLHC**

VLHC Design Study Group Collaboration
SLAC-R-591, SLAC-R-0591, SLAC-591, SLAC-0591, FERMILAB-TM-2149

http://www.vlhc.org/

F. Takasaki

Tristan-II option 1
FCC-hh: 100 TeV pp collider as long-term goal → defines infrastructure needs
FCC-ee: e⁺e⁻ collider, potential intermediate step
HE-LHC: based on FCC-hh technology

**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

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

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

overall cost model;
**cost scenarios** for collider options
including infrastructure and injectors;
**implementation and governance** models
Now is the right time to plan for the period 2035 – 2040
Goal of phase 1: CDR by end 2018 for next update of European Strategy
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Michael Benedikt, Frank Zimmermann
The University of Tokyo, 23. May 2016

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
Progress on site investigations

- Tunnel optimization tool developed by FCC with industry.
- Now also used for ILC site studies.
- Excellent example for synergy between the projects.
More detailed studies launched on
- CE: single vs. double tunnels
- CE: caverns, shafts, underground layout
- technical infrastructures
- safety, access
- transport, integration, installation
- operation aspects
FCC-hh injector studies

Injector options:

- SPS $\rightarrow$ LHC $\rightarrow$ FCC
- SPS/SPS_{upgrade} $\rightarrow$ FCC
- SPS $\rightarrow$ FCC booster $\rightarrow$ FCC

Current baseline is to fully re-use the existing CERN accelerator complex

- injection energy 3.3 TeV from LHC
## Hadron collider parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FCC-hh</th>
<th>HE-LHC*</th>
<th>(HL) LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision energy cms [TeV]</td>
<td>100</td>
<td>&gt;25</td>
<td>14</td>
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<tr>
<td>Dipole field [T]</td>
<td>16</td>
<td>16</td>
<td>8.3</td>
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<tr>
<td>Circumference [km]</td>
<td>100</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td># IP</td>
<td>2 main &amp; 2</td>
<td>2 &amp; 2</td>
<td>2 &amp; 2</td>
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<tr>
<td>Beam current [A]</td>
<td>0.5</td>
<td>1.27</td>
<td>(1.12) 0.58</td>
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<tr>
<td>Bunch intensity $[10^{11}]$</td>
<td>1</td>
<td>1 (0.2)</td>
<td>(2.2) 1.15</td>
</tr>
<tr>
<td>Bunch spacing [ns]</td>
<td>25</td>
<td>25 (5)</td>
<td>25</td>
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<tr>
<td>Beta* [m]</td>
<td>1.1</td>
<td>0.3</td>
<td>(0.15) 0.55</td>
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<tr>
<td>Luminosity/IP $[10^{34} \text{ cm}^{-2}\text{s}^{-1}]$</td>
<td>5</td>
<td>20 - 30</td>
<td>(5) 1</td>
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<tr>
<td>Events/bunch crossing</td>
<td>170</td>
<td>&lt;1020 (204)</td>
<td>&gt;850 (135) 27</td>
</tr>
<tr>
<td>Stored energy/beam [GJ]</td>
<td>8.4</td>
<td>1.4</td>
<td>(0.7) 0.36</td>
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<tr>
<td>Synchrotron rad. [W/m/beam]</td>
<td>30</td>
<td>4.1</td>
<td>(0.35) 0.18</td>
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</table>
FCC-hh luminosity phases

phase 1: $\beta^*=1.1 \text{ m}, \Delta Q_{\text{tot}}=0.01, t_{ta}=5 \text{ h}, 250 \text{ fb}^{-1} / \text{ year}$

phase 2: $\beta^*=0.3 \text{ m}, \Delta Q_{\text{tot}}=0.03, t_{ta}=4 \text{ h}, 1 \text{ ab}^{-1} / \text{ year}$

radiation damping: $\tau \sim 1 \text{ h}$

Total integrated luminosity over 25 years operation $O(20) \text{ ab}^{-1}$

consistent with physics goals

PRST-AB 18, 101002 (2015)
Physics at the FCC-hh

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/FutureHadroncollider

- Volume 1: SM processes (238 pages)
- Volume 2: Higgs and EW symmetry breaking studies (175 pages)
- Volume 3: beyond the Standard Model phenomena (189 pages)
- Volume 4: physics with heavy ions (56 pages)
- Volume 5: physics opportunities with the FCC-hh injectors (14 pages)
### Huge Production Rates at 100 TeV

<table>
<thead>
<tr>
<th>Process</th>
<th>( N_{100} )</th>
<th>( N_{100}/N_8 )</th>
<th>( N_{100}/N_{14} )</th>
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<tr>
<td>( gg \to H )</td>
<td>( 16 \times 10^9 )</td>
<td>( 4 \times 10^4 )</td>
<td>( 110 )</td>
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<tr>
<td>VBF</td>
<td>( 1.6 \times 10^9 )</td>
<td>( 5 \times 10^4 )</td>
<td>( 120 )</td>
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<tr>
<td>( WH )</td>
<td>( 3.2 \times 10^8 )</td>
<td>( 2 \times 10^4 )</td>
<td>( 65 )</td>
</tr>
<tr>
<td>( ZH )</td>
<td>( 2.2 \times 10^8 )</td>
<td>( 3 \times 10^4 )</td>
<td>( 85 )</td>
</tr>
<tr>
<td>( t\bar{t}H )</td>
<td>( 7.6 \times 10^8 )</td>
<td>( 3 \times 10^5 )</td>
<td>( 420 )</td>
</tr>
</tbody>
</table>

### Implications
- Can afford reducing statistics, with tighter kinematical cuts that reduce backgrounds and systematics.
- Explore new dynamical regimes, with novel tests of the SM and EWSB.
LHC results: need for higher energy

Dec 2011

Dec 2015

G. Giudice
FCC-hh physics perspectives

Collider Limits
- 100 TeV
- 14 TeV

- wino
- higgsino
- mixed ($\tilde{B}/\tilde{H}$)
- mixed ($\tilde{B}/\tilde{W}$)
- gluino coan.
- stop coan.
- squark coan.

$\chi$ [TeV]
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The University of Tokyo, 23. May 2016

FCC-hh full-ring optics design

full ring optics design available as basis for:

• beam dynamics studies
• optimisation of each insertion
• definition of system specifications (apertures, etc.)
• improvement of baseline optics and layout
**FCC-hh MDI studies**

**design of interaction region**
- consistent for machine and detector
  - $L^* = 45$ m
  - integrated spectrometer and compensation dipoles
- optics with long triplet with large aperture
  - helps distributing collision debris
  - more beam stay clear
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protecting triplet from debris

total power of background events
100-500 kW per experiment
- car or truck engine

already limit in LHC and HL-LHC
- magnet lifetime, heat load

study of 3000 fb\(^{-1}\) in older FCC-hh detector design

goal: survive at least 5000 fb\(^{-1}\)
- one 5-year run

dose for 3000 fb\(^{-1}\)

30 MGy = present limit

M. I. Besana, F. Cerutti, et al.
Some design challenges:

- large $\eta$ acceptance
- radiation levels of $>50 \times$ LHC Phase II
- pileup of $\sim 1000$

R&D for FCC detectors is a natural continuation of the R&D for LHC Phase II upgrade

A B=6 T, R=6 m solenoid with shielding coil and 2 dipoles has been engineered in detail. Alternative magnet systems are being studied.

A parametrized detector performance model (DELPHES) is available and integrated in FCC software framework for physics simulations.

https://twiki.cern.ch/twiki/bin/view/FCC/FccPythiaDelphes
parametrized detector performance (DELPHES) is integrated in the FCC software framework and ready to use. https://twiki.cern.ch/twiki/bin/view/FCC/FccPythiaDelphes

full simulation functional
reconstruction and fast simulation are very advanced

lots of effort on updating documentation and infrastructure
single entry point for all information: http://fccsw.web.cern.ch/fccsw/

calorimeter resolution, containment studies

muon system performance studies and requirements
FCC study continues effort on **high-field collider in LHC tunnel**

2010 EuCARD Workshop Malta; Yellow Report CERN-2011-1

- based on 16-T dipoles developed for FCC-hh
- extrapolation of other parts from the present (HL-)LHC and from FCC developments

HE-LHC - 25 TeV c.m.

$\beta^* = 25$ cm or $15$ cm

Very preliminary
HE-LHC: pile up & performance

with 160 days of physics, 70% availability, 3 h turnaround time

$\beta^*=25 \text{ cm}: 920 \text{ fb}^{-1}/\text{year}$
$\beta^*=15 \text{ cm}: 1100 \text{ fb}^{-1}/\text{year}$

very preliminary

pile up of 1000 or shorter (e.g. 5 ns) bunch spacing – what is easier?

M. Benedikt, S. Fartoukh, F. Zimmermann
FCC–ee: physics requirements

- physics programs / energies:
  - \( Z (45.5 \text{ GeV}) \) \( Z \) pole, ‘TeraZ’ and high precision \( M_Z \) & \( \Gamma_Z \)
  - \( W (80 \text{ GeV}) \) \( W \) pair production threshold, high precision \( M_W \)
  - \( H (120 \text{ GeV}) \) \( ZH \) production (maximum rate of \( H \)'s)
  - \( t (175 \text{ GeV}) \): \( tt \) threshold, \( H \) studies

- beam energy range from 35 GeV to \( \approx 200 \) GeV

- highest possible luminosities at all working points

- possibly \( H (63 \text{ GeV}) \) direct s-channel production with monochromatization

- some polarization up to \( \geq 80 \) GeV for precise beam energy calibration (<100 keV)
# lepton collider parameters

<table>
<thead>
<tr>
<th>parameter</th>
<th>FCC-ee (400 MHz)</th>
<th>LEP2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physics working point</td>
<td>Z</td>
<td>WW</td>
</tr>
<tr>
<td>energy/beam [GeV]</td>
<td>45.6</td>
<td>80</td>
</tr>
<tr>
<td>bunches/beam</td>
<td>30180</td>
<td>91500</td>
</tr>
<tr>
<td>bunch spacing [ns]</td>
<td>7.5</td>
<td>2.5</td>
</tr>
<tr>
<td>bunch population [10^{11}]</td>
<td>1.0</td>
<td>0.33</td>
</tr>
<tr>
<td>beam current [mA]</td>
<td>1450</td>
<td>1450</td>
</tr>
<tr>
<td>luminosity/IP x 10^{34}cm^{-2}s^{-1}</td>
<td>210</td>
<td>90</td>
</tr>
<tr>
<td>energy loss/turn [GeV]</td>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>synchrotron power [MW]</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>RF voltage [GV]</td>
<td>0.4</td>
<td>0.2</td>
</tr>
</tbody>
</table>

identical FCC-ee baseline optics for all energies

FCC-ee: 2 separate rings  
LEP: single beam pipe
FCC-ee exploits lessons & recipes from past $e^+e^-$ and $pp$ colliders

combining successful ingredients of recent colliders $\rightarrow$ 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 $\beta_y^*$

KEKB: $e^+$ source

HERA, LEP, RHIC: spin gymnastics
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FCC-ee luminosity per IP

Further increase with squeeze to
$\beta_y^*=1\text{ mm},\ \beta_x^*=0.5\text{ m}$

new baseline
crab waist with 2 IPs
$\beta_y^*=2\text{ mm},\ \beta_x^*=1\text{ m}$

solid baseline with functioning optics, space for improvement, esp. at Z and W
• 2 main IPs in A, G for both machines
• asymmetric IR optic/geometry for ee to limit synchrotron radiation to detector
FCC-ee optics design

optics design for all working points achieving baseline performance
interaction region: asymmetric optics design

- synchrotron radiation from upstream dipoles <100 keV up to 450 m from IP
- dynamic aperture & momentum acceptance requirements fulfilled at all WPs
FCC-ee full-ring optics design

dynamic aperture and momentum acceptance requirements fulfilled

175 GeV, $\beta^{*}_{x,y} = (1 \text{ m}, 2 \text{ mm})$

45.6 GeV, $\beta^{*}_{x,y} = (0.5 \text{ m}, 1 \text{ mm})$

K. Oide
SuperKEKB: FCC-ee demonstrator

\[ I_{e^+} = 3.6 \, \text{A}, \ I_{e^-} = 2.6 \, \text{A} \]

\[ P_{SR} \sim 13 \, \text{MW} \]

\[ C = 3 \, \text{km} \]

beam commissioning started this year

top up injection at high current
\[ \beta_y^\ast = 300 \, \mu\text{m} \) (FCC-ee: 1 mm) \]

lifetime 5 min (FCC-ee: \geq 20 \, \text{min})

\[ \frac{\varepsilon_y}{\varepsilon_x} = 0.25\% \) (similar to FCC-ee) \]

off momentum acceptance
\[ (\pm 1.5\%, \) similar to FCC-ee) \]

\[ e^+ \text{ production rate} \) (2.5x10^{12}/\text{s,} \]
\[ \text{FCC-ee:} < 1.5x10^{12}/\text{s} \) (Z cr.waist) \]

SuperKEKB goes beyond FCC-ee, testing all concept
MDI work focused on optimization of:

- $I^*$, IR quadrupole design
- compensation & shielding solenoid
- SR masking and chamber layout

"envelope" for the shielding solenoid (yellow):  
- $z_{\text{start}} = 2.2$ m (front face)

Compensating solenoid (green):  
- $z_{\text{start}} = 1.3$ m, $z_{\text{end}} = 2.2$ m  
- $B = 4.9$ T

CERN model of CCT IR quadrupole
- width = 20 cm i.e. $z_{\text{start}} \sim 1.1$ m
- Si/W calorimeter

BINP prototype IR quadr.  
- 2 cm aperture, 100 T/m
the combination of FCC-ee and FCC-hh is «invincible»
synchrotron radiation/beam screen

handling of 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 FCC-hh beam screen prototype testing 2017 at ANKA facility in Germany
Cryo power for cooling of SR heat

Overall optimisation of cryo-power, vacuum and impedance
Temperature ranges: <20, 40K-60K, 100K-120K

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**Multi-bunch instability growth time:**

- 100MW: 25 turns
- 200MW: 9 turns
- 300MW: 

(ΔQ=0.5)
CERN & EuroCirCol 16T programs

Field records

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

Magnets with bore

CERN RMC

LBNL HD1

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superconductor performance

$J_c$ in kA/mm$^2$

$B$ in T

$Nb3Sn \ T = 4.5 \ K$

LHC at 1.9 K

Critical surface FCC

HL-LHC

5400 mm$^2$

~10% margin

HL-LHC

3150 mm$^2$

~10% margin

FCC ultimate

Nb-Ti

Not possible

Different technology

~1.7 times less SC
**Nb₃Sn conductor program**

**Nb₃Sn conductor is one of the major cost and performance factors for FCC-hh and must be given highest attention**

- **Goals:** $J_c$ increase (16 T, 4.2 K) > 1500 A/mm², significant cost reduction
- **Actions ongoing and planned (in addition to activities at CERN):**
  - Purchase of wires in Europe, US
  - Industrial R&D in Europe
  - **Collaboration agreements with KEK**, Russia, Korea (in preparation), to stipulate conductor development with regional industry
  - Collaborations with several European Universities and Research Centres
  - **U.S. Magnet Development Program with conductor R&D program and focused on 16 T cos theta dipole model magnet.**
RF system requirements

Very large range of operation parameters

<table>
<thead>
<tr>
<th></th>
<th>$V_{total}$ GV</th>
<th>$n_{bunches}$</th>
<th>$I_{beam}$ mA</th>
<th>$\Delta E$/turn GeV</th>
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<tr>
<td>hh</td>
<td>0.032</td>
<td>30000/90000</td>
<td>500</td>
<td>0.034</td>
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<tr>
<td>Z</td>
<td>0.4/0.2</td>
<td>5162</td>
<td>152</td>
<td>0.33</td>
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<tr>
<td>W</td>
<td>0.8</td>
<td>770</td>
<td>30</td>
<td>1.67</td>
</tr>
<tr>
<td>H</td>
<td>5.5</td>
<td>78</td>
<td>6.6</td>
<td>7.55</td>
</tr>
<tr>
<td>t</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

“Amper-class” machines

“High gradient” machines

Naive scale up from an hh system

- Voltage and beam current ranges span more than factor $> 10^2$
- No well-adapted single RF system solution satisfying requirements
RF system R&D lines

400 MHz single-cell cavities preferred for hh and ee-Z (few MeV/m)
- Baseline Nb/Cu @4.5 K, development with synergies to HL-LHC, HE-LHC
- R&D: power coupling 1 MW/cell, HOM power handling (damper, cryomodule)

400 or 800 MHz multi-cell cavities preferred for ee-H, ee-tt and ee-W
- Baseline options 400 MHz Nb/Cu @4.5 K, 800 MHz bulk Nb system @2K
- R&D: High Q₀ cavities, coating, long-term: Nb₃Sn like components
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
• 75 institutes
• 26 countries + EC

Status: April, 2016
### FCC Collaboration Status

75 collaboration members & CERN as host institute, April 2016

| ALBA/CELLS, Spain | UT Enschede, Netherlands | KIT Karlsruhe, Germany |
| Ankara U., Turkey | U Geneva, Switzerland | KU, Seoul, Korea |
| U Belgrade, Serbia | Goethe U Frankfurt, Germany | Korea U Sejong, Korea |
| U Bern, Switzerland | GSI, Germany | U. Liverpool, UK |
| BINP, Russia | GWNU, Korea | U. Lund, Sweden |
| CASE (SUNY/BNL), USA | U. Guanajuato, Mexico | MAX IV, Lund, Sweden |
| CBPF, Brazil | Hellenic Open U, Greece | MEPHi, Russia |
| CEA Grenoble, France | HEPHY, Austria | UNIMI, Milan, Italy |
| CEA Saclay, France | U Houston, USA | MIT, USA |
| CIEMAT, Spain | IIT Kanpur, India | Northern Illinois U, USA |
| Cinvestav, Mexico | IFJ PAN Krakow, Poland | NC PHEP Minsk, Belarus |
| CNRS, France | INFN, Italy | U Oxford, UK |
| CNR-SPIN, Italy | INP Minsk, Belarus | PSI, Switzerland |
| Cockcroft Institute, UK | U Iowa, USA | U. Rostock, Germany |
| U Colima, Mexico | IPM, Iran | RTU, Riga, Latvia |
| UCPH Copenhagen, Denmark | UC Irvine, USA | UC Santa Barbara, USA |
| CSIC/IFIC, Spain | Istanbul Aydin U., Turkey | Sapienza/Roma, Italy |
| TU Darmstadt, Germany | JAI, UK | U Siegen, Germany |
| TU Delft, Netherlands | JINR Dubna, Russia | U Silesia, Poland |
| DESY, Germany | Jefferson LAB, USA | TU Tampere, Finland |
| DOE, Washington, USA | FZ Jülich, Germany | TOBB, Turkey |
| ESS, Lund, Sweden | KAIST, Korea | U Twente, Netherlands |
| TU Dresden, Germany | KEK, Japan | TU Vienna, Austria |
| Duke U, USA | KIAS, Korea | Wigner RCP, Budapest, Hungary |
| EPFL, Switzerland | King’s College London, UK | Wroclaw UT, Poland |
European Union contributes with funding to FCC-hh study

- Supports and makes essential contributions to the FCC-hh work packages:
  - Arc & IR optics design, 16 T dipole design, cryogenic beam vacuum system
  - Recognition of FCC Study by European Commission.

**EuroCirCol EU Horizon 2020 Grant**

**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.
<table>
<thead>
<tr>
<th>Organization</th>
<th>Country</th>
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<td>CERN</td>
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Consortium Beneficiaries, signing the Grant Agreement
First FCC Week
Conference
Washington DC
23 - 27 March 2015
http://cern.ch/fccw2015

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Participants 468
Institutes 168
Countries 24
Conclusions

• There is a strong, rising interest in Future Circular Colliders and a community is forming to study these machines

• International collaboration is needed to advance with this study on all of its challenging subjects

• Japanese expertise and participation in accelerators, experiments & physics are essential and most welcome!

• Consolidated parameter sets for both machines FCC-hh and FCC-ee have been established. Work on all areas, accelerator physics, technologies, infrastructures, detectors and physics is advancing well.

• Next milestone is a study review at FCC Week 2017, to define contents of the Conceptual Design Report.