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Future Circular Collider Study

Frank Zimmermann

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

LHC SPS PS FCC

http://cern.ch/fcc

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J. Wenninger
colliders and discoveries

powerful instruments for discovery and precision measurement
International FCC collaboration (CERN as host lab) to study:

- **pp-collider** (*FCC-hh*)
  - main emphasis, defining infrastructure requirements
  - \(\sim 16 \text{ T} \Rightarrow 100 \text{ TeV } pp \text{ in } 100 \text{ km}\)

- **80-100 km tunnel infrastructure** in Geneva area, site specific

- **e^+e^- collider** (*FCC-ee*), as potential first step

- **p-e** (*FCC-he*) option, integration one IP, FCC-hh & ERL

- **HE-LHC** with *FCC-hh* technology
FCC-hh: 100 TeV pp collider as long-term goal → defines infrastructure needs
FCC-ee: $\text{e}^+\text{e}^-$ collider, potential intermediate step
HE-LHC: based on FCC-hh technology

key enabling technologies
pushed in dedicated R&D programmes, e.g.
16 Tesla magnet program, cryogenics,
SRF technologies and RF power sources

tunnel infrastructure in Geneva area, linked to CERN accelerator complex;
site-specific, as requested by European Strategy
elaborate and document
- physics opportunities
- discovery potentials

**experiment concepts** for hh, ee and he
Machine Detector Interface (MDI) studies
R&D needs for **detector technologies**

overall **cost model for collider scenarios**
including infrastructure and injectors

develop **realization concepts**
forge **partnerships with industry**
must advance fast now to be ready for the period 2035 – 2040; goal of phase 1: CDR by end 2018 for next update of European Strategy
site investigations

C. Cook, J. Osborne

Future Circular Collider Study
Frank Zimmermann
Conf12 Workshop, 4 September 2016
• 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 tunnel layout

‘baseline’ layout

- 100 km tunnel 6 m inner diameter
- 4 large experimental caverns
- 8 service caverns for infrastructure
- 12 & 4 vertical shafts (3 km integral)
- 2 transfer tunnels (10 km)
- 2 beam dump tunnels (4 km)
<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>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>
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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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<td>1 (0.2)</td>
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<tr>
<td>bunch spacing [ns]</td>
<td>25 (5)</td>
<td>25 (5)</td>
<td>25</td>
</tr>
<tr>
<td>IP $\beta^*_x,y$ [m]</td>
<td>1.1</td>
<td>0.3</td>
<td>0.25</td>
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<tr>
<td>luminosity/IP [$10^{34}$ cm$^{-2}$s$^{-1}$]</td>
<td>5</td>
<td>30</td>
<td>34</td>
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<td>peak #events/bunch crossing</td>
<td>170</td>
<td>1020 (204)</td>
<td>1070 (214)</td>
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<td>stored energy/beam [GJ]</td>
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<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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<td>transv. emit. damping time [h]</td>
<td>1.1</td>
<td>4.5</td>
<td>25.8</td>
</tr>
<tr>
<td>initial proton burn off time [h]</td>
<td>17.0</td>
<td>3.4</td>
<td>2.3</td>
</tr>
</tbody>
</table>

*tentative
pp/p-pbar in the $L-E$ plane
phase 1: $\beta^* = 1.1 \text{ m, } \Delta Q_{tot} = 0.01, t_{ta} = 5 \text{ h, } 250 \text{ fb}^{-1} / \text{ year}$

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

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

Total integrated luminosity over 25 years operation $O(20) \text{ ab}^{-1}$ consistent with physics goals
FCC-hh - 100 TeV c.m., 25 ns

- Burn off slower than emittance damping → emittance control
HE-LHC - 25 TeV c.m., 25 ns

- Luminosity ($10^{34} \text{ cm}^2\text{s}^{-1}$)
  - $\beta^*$ = 25 cm or 15 cm

- Bunch population ($10^{11}$)
  - Ultimate $\beta^*$
  - Baseline

- Normalized emittance [$\mu$m]
  - Ultimate $\beta^*$
  - Baseline

- Total tune shift
  - Baseline
  - Ultimate $\beta^*$

- Burn off faster than emittance shrinkage → tune shift decreases during fill
integrated lattice exists;

recent designs:
  - energy collimation
  - extraction
  - experiment
  - betatron collimation
  - injection

first results on:
  - dynamic aperture
  - tolerances and alignment
  - detailed magnet specifications
FCC-hh full-ring optics

full ring lattice permits:

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

D. Schulte, B. Holzer, R. Haerer, A. Seryi, et al.
key technologies for FCC-hh

16 T arc dipole magnets based on $Nb_3Sn$

- conductor development, magnet design
- highest priority! (talk by Gijs de Rijk)

arc beam screen
cryogenics system
SC septa
SC detector magnets
R&D on superconducting septa

need extraction system for safely removing beam from collider;
hybrid system: short overall length with high robustness & availability

SuShi concept:
SC shield creates field-free region inside strong dipole field

3 candidate technologies:
(1) NbTi/Nb/Cu multilayer sheet
(2) HTS tape
(3) Bulk MgB$_2$
high synchrotron radiation load of proton beams @ 50 TeV:

- ~30 W/m/beam (@16 T) (LHC <0.2W/m)
- 5 MW total in arcs (@1.9 K!!)

new beam screen with ante-chamber

- absorption of synchrotron radiation at 50 K to reduce cryogenic power
- factor 50! reduction of cryo power
**goals:**
- drastically lower FCC-hh beam impedance
- allow for (even) higher beam-screen temperature

**candidate materials:**

**TI-1223** (promising performance, opens up >100 K temperature window, scalable coating, R&D with CNR-SPIN and TU-Vienna)

**YBCO** (proven performance, requires forming technology, R&D with ICMAB-ALBA-IAFE)

HTS can have surface resistance lower than Cu at $T < 77$ K and $f < 10$ GHz
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

H. ten Kate, W. Riegler et al.
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

proton losses in dispersion suppressor are an issue

dose for 3000 fb$^{-1}$

$30$ MGy = present limit

i. triplet shielding
- 5mm
- 10mm
- 15mm
- 20mm

radation dose for final quadrupoles

I. Besana, F. Cerutti, A. Seryi, et al.
aperture model of machine exists; system design developed; first efficiency studies
  • high losses in dispersion suppressor
  • heat load on primary collimators close to the limit

upcoming:
  • study load on secondary collimators
  • shower simulations
  • operational robustness improvements:
    - crystal collimation?
    - hollow electron lens?
  • impact of 5 ns operation on design

M. Fiascaris, J. Molson, S. Redaelli, D. Schulte
injector options:

- SPS $\rightarrow$ LHC $\rightarrow$ FCC
- SPS/SPS\text{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

Injection from SPS tunnel means lower injection energy $\sim$1.5 TeV
lower injection energy (1.5 TeV)?

beam studies proposed at LHC (injection at 225 GeV instead of 450 GeV) and at RHIC ($p$ inj. at 7.3 GeV)
### FCC-hh as A-A collider

<table>
<thead>
<tr>
<th></th>
<th>Pb-Pb</th>
<th>Pb-p</th>
</tr>
</thead>
<tbody>
<tr>
<td>beam energy [TeV]</td>
<td>4100</td>
<td>50</td>
</tr>
<tr>
<td>c.m. energy/nucleon pair [TeV]</td>
<td>39.4</td>
<td>62.8</td>
</tr>
<tr>
<td>no. bunches / beam</td>
<td>2072</td>
<td>2072</td>
</tr>
<tr>
<td>IP beta function [m]</td>
<td>1.1</td>
<td>1.1</td>
</tr>
<tr>
<td>long. emit. rad. damping time [h]</td>
<td>0.24</td>
<td>0.5</td>
</tr>
<tr>
<td>init. luminosity [10^{27} cm^{-2}s^{-1}]</td>
<td>24.5</td>
<td>2052</td>
</tr>
<tr>
<td>peak luminosity [10^{27} cm^{-2}s^{-1}]</td>
<td>57.8</td>
<td>9918</td>
</tr>
</tbody>
</table>

Based on existing LHC complex; fast radiation damping; secondary beams from IP require dedicated collimators,…


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)

- Being published as CERN yellow report

M. Mangano et al.
FCC-hh physics perspectives

Collider Limits

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

$m_{\tilde{\chi}}$ [TeV]

100 TeV
14 TeV

G. Giudice
FCC-ee physics requirements

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

- beam energy range from 35 GeV to $\approx 200$ GeV
- highest possible luminosities at all working points
- possibly $H$ (63 GeV) direct s-channel production with monochromatization
  (c.m. energy spread $<6$ MeV, presentation at IPAC’16)
- beam polarization up to $\geq 80$ GeV for beam energy calibration
# Lepton Collider Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FCC-ee (400 MHz)</th>
<th>CEPC</th>
<th>LEP2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physics working point</td>
<td>Z</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>energy/beam [GeV]</td>
<td>45.6</td>
<td>120</td>
<td>105</td>
</tr>
<tr>
<td>bunches/beam</td>
<td>30180</td>
<td>50</td>
<td>4</td>
</tr>
<tr>
<td>bunch spacing [ns]</td>
<td>7.5</td>
<td>50</td>
<td>22000</td>
</tr>
<tr>
<td>bunch population ([10^{11}])</td>
<td>1.0</td>
<td>3.8</td>
<td>4.2</td>
</tr>
<tr>
<td>beam current [mA]</td>
<td>1450</td>
<td>16.6</td>
<td>3</td>
</tr>
<tr>
<td>luminosity/IP (x 10^{34} \text{cm}^{-2}\text{s}^{-1})</td>
<td>210</td>
<td>2.0</td>
<td>0.0012</td>
</tr>
<tr>
<td>energy loss/turn [GeV]</td>
<td>0.03</td>
<td>3.1</td>
<td>3.34</td>
</tr>
<tr>
<td>synchrotron power [MW]</td>
<td>100</td>
<td>103</td>
<td>22</td>
</tr>
<tr>
<td>RF voltage [GV]</td>
<td>0.4</td>
<td>6.9</td>
<td>3.5</td>
</tr>
</tbody>
</table>

**Identical FCC-ee baseline optics for all energies**

- FCC-ee: 2 separate rings
- CEPC, LEP: single beam pipe
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 $\beta_y^*$

**KEKB:** $e^+$ source

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

further increase with squeeze to
\( \beta_y^* = 1 \text{ mm}, \beta_x^* = 0.5 \text{ m} \)

new baseline 2016,
crab waist w 2 IPs
\( \beta_y^* = 2 \text{ mm}, \beta_x^* = 1 \text{ m} \)

mono-

chromati-
zation?

\( \alpha_{\text{QED}} \)

Z

H?

WW

HZ

t\bar{t}

conservative baseline with functioning optics,
space for improvement, esp. at Z and W

c.m. energy [GeV]
beside the collider ring(s), a full-energy booster of the same size (same tunnel) must provide beams for top-up injection to sustain the extremely high luminosity

- same size of RF system, but low power (~ MW)
- top up frequency ≈0.1 Hz
- booster injection energy ≈5-20 GeV
- bypass around the experiments
• 2 main IPs in A, G for both machines
• asymmetric IR optic/geometry for ee to limit synchrotron radiation to detector

Lepton beams must cross over through the common RF to enter the IP from inside. Only a half of each ring is filled with bunches.

Max. separation of 3(4) rings is about 12 m: wider tunnel or two tunnels are necessary around the IPs, for ±1.2 km.

transverse emittances

in good company with modern light sources

LHC MD proposed!
final-focus 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
SuperKEKB will pave the way towards $\beta^* \leq 2$ mm
SuperKEKB: ultra-low $\beta^*$

$I_{e+} = 3.6$ A, $I_{e-} = 2.6$ A

$P_{SR} \sim 13$ MW

$C = 3$ km

beam commissioning started this year

K. Oide et al.

SuperKEKB goes beyond FCC-ee, testing all concept

top up injection at high current

$\beta_y^* = 300$ $\mu$m (FCC-ee: 1 mm)

lifetime 5 min (FCC-ee: $\geq 20$ min)

$\varepsilon_y / \varepsilon_x = 0.25\%$ (similar to FCC-ee)

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

$e^+$ production rate ($2.5 \times 10^{12}$/s, FCC-ee: $< 1.5 \times 10^{12}$/s (Z cr.waist)
key technologies for FCC-ee

SC radiofrequency system
efficient RF power sources
vacuum chamber with photon stops and discrete shielding
low-power low-field arc magnets
final IR quadrupoles
**SRF system requirements**

**very large range of operation parameters**

<table>
<thead>
<tr>
<th>“Ampere-class” machines</th>
<th>“high gradient” machines</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{total}$ (GV)</td>
<td>$n_{bunches}$</td>
</tr>
<tr>
<td>hh</td>
<td>0.032</td>
</tr>
<tr>
<td>Z</td>
<td>0.4/0.2</td>
</tr>
<tr>
<td>W</td>
<td>0.8</td>
</tr>
<tr>
<td>H</td>
<td>5.5</td>
</tr>
<tr>
<td>t</td>
<td>10</td>
</tr>
</tbody>
</table>

**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
SRF 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
future circular collider study

Frank Zimmermann

Conf12 Workshop, 4 September 2016

Dotted lines – only changing P drive
Solid lines – changing P drive and Voltage

η=90%!

A 40-beam prototype “BAC” klystron has been built and successfully tested at VDBT, Moscow, this year!

I. Syratchev

comparing simulated performances of MBIOT and HEKCW MBK

eta = 90%!
Efficient 2-in-1 arc magnets

dipole based on twin aperture yoke and single busbars as coils

Twin 2-in-1 quadrupole

The novel arrangements of the magnetic circuit allow for considerable savings in Ampere-turns and power consumption, less units to manufacture, transport, install, align, remove,…
MDI work started with optimization of:
- $I^*$, IR quadrupole design
- compensation & shielding solenoid
- SR masking and chamber layout

“envelope” for the shielding solenoid (yellow):
- z_start = 2.2 m (front face)

Compensating solenoid (green):
- z_start = 1.3 m, z_end = 2.2 m
- $B = 4.9 \, T$

CERN model of CCT IR quadrupole
- width = 20 cm i.e. z_start ~ 1.1 m
- Si/W calorimeter

BINP prototype IR quadr.
- 2 cm aperture, 100 T/m
Future Circular Collider Study
Frank Zimmermann
Conf12 Workshop, 4 September 2016

**polarization & energy calibration**

**accurate energy calibration** using resonant depolarization ⇒ measurement of $M_Z, \Gamma_Z, M_W - \delta M_Z, \delta \Gamma_Z \sim 0.1 \text{ MeV}, \delta M_W \sim 0.3 \text{ MeV}

**physics with longitudinally polarized beams** - transverse polarization must be rotated into the longitudinal plane using spin rotators (see e.g. HERA)

**scaling from LEP observations**:

**polarization expected up to the WW threshold**!

**simulations for FCC-ee**: high polarization with harmonic spin matching

**polarimetry extrapolated from ELSA to FCC-ee**: $\Delta P \sim 0.1\%$ turn by turn and bunch by bunch using conventional high-power laser

First Look at the Physics Case of TLEP

The TLEP Design Study Working Group
(See next pages for the list of authors)


OPEN ACCESS
lepton-hadron collider FCC-he

FCC-he collides e- from ERL with FCC-hh protons

(same concept as proposed for LHeC; same ERL?)

see LHeC presentation by D. Pellegrini
### lepton-hadron ($p$) parameters

<table>
<thead>
<tr>
<th>Parameter [Unit]</th>
<th>LHeC CDR</th>
<th>ep at HL-LHC</th>
<th>ep at HE-LHC</th>
<th>FCC-he</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_p$ [TeV]</td>
<td>7</td>
<td>7</td>
<td>15</td>
<td>50</td>
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<tr>
<td>$E_e$ [GeV]</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
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<tr>
<td>$\sqrt{s}$ [TeV]</td>
<td>1.3</td>
<td>1.3</td>
<td>1.9</td>
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<td>Bunch spacing [ns]</td>
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<tr>
<td>$p$/bunch [$10^{11}$]</td>
<td>1.7</td>
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<td>1</td>
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<tr>
<td>$\varepsilon_p$ [$\mu$m]</td>
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<td>2</td>
<td>2</td>
<td>2.2</td>
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<tr>
<td>$\epsilon$/$bunch$ [$10^9$]</td>
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<td>2.3</td>
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<tr>
<td>$\epsilon^-$ current [mA]</td>
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<td>15</td>
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<tr>
<td>$\beta_p^*$ [cm]</td>
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<td>7</td>
<td>10</td>
<td>15</td>
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<tr>
<td>Hourglass factor</td>
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<tr>
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<td>1.3</td>
<td>1.2</td>
<td>1.3</td>
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<tr>
<td>Luminosity [$10^{33}$ cm$^{-2}$s$^{-1}$]</td>
<td>1.3</td>
<td>10.1</td>
<td>15.1</td>
<td>9.2</td>
</tr>
</tbody>
</table>

O. Bruning, M. Klein, D. Schulte, F. Zimmermann
FCC-he site studies

FCC Long Straight Section H

Tunnel Geology
- Molasse rock (sandstone).

Construction
- Tunnel Boring Machine (TBM) in straight sections
- Roadheader in arcs

Civil Engineering challenges
- Low geological risk
- Interaction with main FCC tunnel(s)

C. Cook, M. Klein
FCC-he physics

similar to, and better than LHeC

LHeC CDR: About 200 experimentalists and theorists from 69 institutes working for 5 years based on series of yearly workshops since 2008

LHeC and FCC-eh
High-energy frontier e-p and e-A colliders to follow HERA with factor 1000 higher luminosity running simultaneously with HL-LHC / FCC-hh.

M. Klein, U. Klein

http://cern.ch/lhec
unravelling QCD at the FCC

(1) QCD coupling $\alpha_s$ (FCC-ee, FCC-he)

(2) parton densities (FCC-he)

(3) beyond DGLAP (FCC-he)

(4) many-body QCD (FCC-hh, HE-LHC)

numerous synergies between the various FCC colliders!

D. d’Enterria, QCD at Future Facilities, QCD@LHC, Zurich, August 2016
QCD coupling $\alpha_S$

- determines strength of strong interaction between quarks & gluons.
- single free parameter in QCD in the $m_q \rightarrow 0$ limit
- determined at a ref. scale ($Q=m_Z$)

FCC-he: $\alpha_S$ from proton structure function $\rightarrow \delta\alpha_S < 0.3\%$

FCC-ee: $\alpha_S$ from e$^+$e$^-$ jet event shapes & rates $\rightarrow \delta\alpha_S < 1\%$

$\alpha_S$ from hadronic Z decays $\rightarrow \delta\alpha_S < 0.3\%$

$\alpha_S$ from hadronic W decays $\rightarrow \delta\alpha_S < 0.3\%$

~0.3% $\alpha_S$ precision from high-lumi e$^+$e$^-$ measurements
parton kinematics: \((x, Q^2)\)

**FCC-he**

\(pe\)

**FCC-hh**

\(pp\)

D. d’Enterria, M. Klein

Future Circular Collider Study
Frank Zimmermann
Conf12 Workshop, 4 September 2016
parton kinematics: \((x, Q^2) - 2\)

FCC-he (Ae)

FCC-hh (AA)

D. d’Enterria
FCC-pp: ~10% PDF uncertainty at $H, Z$ scales

FCC-he lowers FCC-pp PDF uncertainty to <1% at $H, Z$ scales and strongly reduces parton uncertainties between 10 GeV and 10 TeV, for all flavors

<1% PDF precision at FCC-hh from high-energy e-p collider (FCC-he)

few % nuclear PDF precision from high-energy e-A collider (FCC-he)
beyond DGLAP

non-linear evolution at low $x$, gluon splitting, gluon recombination multiparton interactions, ...

FCC-he ($pe, Ae$) will probe nonlinear QCD
many-body QCD

FCC-hh (AA) studying QGP at TeV/fm$^3$
what will FCC do for QCD?

(1) permil $\alpha_s$ precision (FCC-ee, FCC-he)
(2) sub-% PDF precision (FCC-he)
(3) nonlinear QCD limit (FCC-he)
(4) TeV/fm$^3$ QCD thermodynamics (FCC-hh, HE-LHC)

FCC = the perfect accelerator complex to reveal the QCD secrets

D. d’Enterria
FCC International Collaboration

- 87 institutes
- 28 countries + EC

Status: August, 2016
**FCC Collaboration Status**

87 collaboration members + EC + CERN as host

<table>
<thead>
<tr>
<th>Collaboration</th>
<th>Country</th>
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*status 29 August 2016*
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

Resources provided by research institutes and universities with H2020 grant support.

Resources provided and work carried out by worldwide collaboration.
Summary

- FCCs’ ee/pp/AA/pe/Ap/Ae collisions will explore uncharted regions in energy, luminosity, polarization, $x$ and $Q^2$
  - novel challenges and new opportunities
  - innovative technological approaches
- FCC Study aims at cost-effective design with maximum performance
- rapidly growing global FCC collaboration (now nearly 100 institutes), more contributors welcome - especially from Greece!
- Next milestone: FCC Week 2017