FCC-eh Machine Configuration and Performance

Configuration:

Modular design elements:

- 60 GeV ERL configuration for the ‘e’ beam documented in the LHeC CDR → varied sizes;
  applicable to LHC, HE-LHC and FCC
- IR configuration with head-on collisions
  → without Crab Cavities (vs EI in US)!
  → SR acceptance in detector and beam separation
  → Dipole integrated into detector
  → ‘Sweetspot’ IR magnet design
- 800MHz SRF: synergy with FCC-ee and FCC-hh
60GeV ERL Baseline Configuration:

Super Conducting Recirculating Linac with Energy Recovery

Operation in parallel with LHC/HE-LHC/FCC-hh
- TeV scale collision energy
  ➔ 50-150 GeV beam energy
- power consumption < 100 MW
  ➔ 60 GeV beam energy
- int. luminosity > 100 * HERA
- peak luminosity $L > 10^{34} \text{ cm}^{-2}\text{s}^{-1}$

➔ 944 cavities; 59 cryo modules per linac
➔ ca. 9 km underground tunnel installation
➔ more than 4500 magnets

courtesy H.Burkhardt, BE-ABP CERN (layout scaled!)

Peter Kostka

* LHeC CDR, arXiv:1206.2913
Various options on the table with solutions at hand! 
Design work on the ‘Sweet Spot’ magnet is still ongoing! 
Final implementation strongly depends on actual IR choice and 
FCC-hh optics configuration!!!
FCC-eh Configuration: Layout & Civil Engineering

Configuration:

Different Size Variations: e.g. LHeC

Independent FCC-he
Point L, F, H or B

LHeC / FCC-he
LHC P8 & FCC PB

C. Cook @ FCC week in Rome
FCC Layout Changes

Rome 2016 Layout

Jo Stanyard

Updates since Rome 2016 layout:

- Reduced depth below surface level.
- Reduced length of straight sections at J and D.
- Increased tunnel length from A-L, A-B and G-F, G-H.
- Avoids Jura Limestone and Pre-Alps region.
- Reduced Total Tunnel Length.
FCC Layout Changes (profile)

Rome 2016 Layout

Berlin 2017 Layout

Reduced Depth & alignment change; area surrounding L no longer in limestone.

Jo Stanyard
Detector Considerations from the LHeC to the FCC

- **Interaction region:**
  - Assume similar interaction region as for LHeC
    - FCC-hh bunch spacing? 25 ns no showstopper,
    - 5 ns, 12.5 ns to be looked at → stronger dipole field?
  - Dipole field across the whole detector
  - $e^\pm$ syn radiation → elliptical beam-pipe

- **Detector:**
  - Higher momenta/energies → Larger BL$^2$
  - Larger transverse calorimetry (up to 12 $\lambda$ in the fwd region)
  - Large acceptance over $\eta$
  - Bunch spacing (25 ns → 12.5 ns → 5 ns)
  - Pile-up no problem in ep than for LHC/FCC-hh

- **Beam Pipe Design**
  - Low $X_0$, $\lambda$ material (Be), stable, capable for 1$^\circ$ tracks
  - Allowing low $p_T$ particle measurement

- **Magnets**
  - Use the solenoid option as proposed for FCC-hh + balanced conical solenoid.
  - Strong field in the fwd/bwd region to allow for tracking over a wide range of $\eta$ - down 1$^\circ$ $\theta$-angle.
  - The concept is attractive and could be adjusted.

Pictures W.Riegler on Monday
talk of Herman ten Kate, Matthias Mentink
https://indico.cern.ch/event/556692/contributions/2465157/

New Reference Design FCC-hh

Peter Kostka
FCC-he Detector Layout - Inner Dipoles and Solenoid

3 beams:
\( e^\pm + \text{proton}1 + \text{proton}2 \)
(or heavy ions A)

Dipole magnets to guide the e-beam in and out, for making electrons to collide head-on with p-beam1;
0.3 T dipoles (transverse) field along 2 x 9 m (internal shown only)

Central Tracker
- circular-elliptical beam pipe
- 4 layers Si-pixel (ALICE+ type)
- 5 layers Si-strixel

(length see Table of Detector Dimensions/Parameters)
Machine Study Goals:
- High current, multi-turn (3) ERL concept with 802MHz SRF
- Beam Breakup intensity limit and filling patterns,
- ERL efficiency,
- beam size evolution etc.
- SRF LLRF feedback and control
- Failure scenarios
- Beam Halo formation and dump line acceptance
- Beam Instrumentation
- Build up operational experience
- Source and injector
FCC-eh Physics Motivation

Five Major Themes for eh Physics:

- Cleanest high-resolution microscope
- Joint eh and hh physics
- High precision Higgs exploration
- Discovery Beyond the Standard Model
- Unique Nuclear Physics Facility

→ high precision PDFs open door for high precision pp physics
Gluon PDF with FCC-eh data

**Gluon PDF**
- Most important parton for most SM and BSM scenarios
- Precise knowledge at all scales and x-values is imminent

**Low-x**
- Important for boosted topologies at FCC-eh
- Currently no data at $x<10^{-4}$
- Uncertainty only from 'extrapolation' but

**High-x**
- poorly constrained because of limited statistics

**FCC-eh**
- Explore region of $x$ down to $x \sim 10^{-7}$
- Small-$x$ phenomenology:
  - BFKL or saturation effects may show up
  -$\rightarrow$ Physics topics on their own
High precision determination of strong coupling constant $\alpha_s$ to 0.1%

FCC-eh prospects

- Highest precision expected incl. PDF uncert.

Daniel Britzger
High precision couplings: up quark-Z boson

High precision test of electroweak sector of the Standard Model

Daniel Britzger

- precision EW physics in ep is not limited by PDFs or QCD
- precision QCD physics in ep is not limited by EW corrections
Higgs Couplings at pp + ep
running concurrently

ATLAS Simulation Preliminary

\[ Y_i = \frac{y_{F_i}}{\sqrt{\kappa_F}} \]

\[ b \quad \tau \quad \mu \]

\[ \int L dt = 300 \text{ fb}^{-1} \]
\[ \int L dt = 3000 \text{ fb}^{-1} \]

\[ \text{Ratio to SM} \]

LHeC @1ab^{-1}
results in 2038 ...
concurrent with HL-LHC end

use ep as the ‘near’
detector for pp to beat \( \alpha_s \)
and PDF uncertainties to
<~0.5%, \( \delta m_b \) to 10 MeV,
\( \delta m_{\text{charm}} \) to 3 MeV

[Image of a diagram showing particle interactions and production]

charm!
Higgs Couplings at pp + ep

**High precision determination of α_s to 0.1%**

**LHeC**
- (E_p = 7 TeV)
- √s ~ 1.3 TeV

<table>
<thead>
<tr>
<th></th>
<th>LHeC</th>
<th>DLHC</th>
<th>FCC ep</th>
</tr>
</thead>
<tbody>
<tr>
<td>k (Hbb)</td>
<td>0.5%</td>
<td>0.3%</td>
<td>0.2%</td>
</tr>
<tr>
<td>k (Hcc)</td>
<td>4%</td>
<td>2.8%</td>
<td>1.8%</td>
</tr>
</tbody>
</table>

**Ratio to SM**
- pp: PDF + α_s errors 0.5% with new ep input!
- FCC ep detector for pp to beat α_s and PDF uncertainties to <~0.5%, δm_b to 10 MeV, δm_charm to 3 MeV

**LHeC @1ab**
- results in 2038 ...
- concurrent with HL-LHC end
Higgs Portal to New Physics: exotic Higgs decay

Very promising first results to discover an exotic Higgs decay into two new light scalars at FCC-eh down to a BR of 1% for 1 ab$^{-1}$. A BR of 10% could be discovered within 1 year (100 fb$^{-1}$).

$m_{\phi} = 20$ GeV

Many more, often published studies on BSM Higgs physics, e.g. Higgs into Dark Matter charged Higgs bosons and Higgs self coupling $H \rightarrow HH$
Precision Top Physics in ep

Orhan Cakir

$V_{tb}$ to 0.5% with 0.1 ab$^{-1}$

- Electric and magnetic dipole moments to O(5%) precision LHeC, better at FCC-eh

- Top physics a strong area of study
- More results coming for the CDR
BSM Physics in ep

★ Indirect impact from improved PDF

★ Direct Searches
  ♦ Leptoquarks: limits, quantum # & couplings
  ♦ Contact interactions: $\eta \eta q q$
  ♦ Anomalous gauge couplings: $\sigma \sigma$
  ♦ Vector boson scattering
  ♦ BSM in the top sector
  ♦ RPC SUSY: DM, sleptons
  ♦ RPV SUSY: neutralinos, squarks
  ♦ BSM Higgs: exotic (invisible) decay, $H^+$, $H^{++}$
  ♦ Sterile neutrinos

Kechen Wang

Dedicated studies still underway, use clean final state and high luminosity. Many new ideas
New Physics in eA

Example: diffractive scattering

Search for new physics at high densities through huge extension of range and unique property of eA collision: LHC showed p is collective projectile much as A

High precision exploration of parton dynamics in nuclei and extension of QCD.

Guilherme Milhano
Main eh Tasks for Completion of CDR

4 areas of activity

Accelerator: Update of the eh IR design for LHC/HE-LHC/FCC at $10^{34}$

PERLE: Technical design and fabrication+test of an 802 MHz cavity

Detector: Update detector technology choice (collaboration with hh)

Physics: Update wrt LHC results and integration with hh+ee

Contributions to 4 FCC CDR Books (see M Benedikt today)

B1: Physics with the FCC (hh-he-ee)

B2: Summary of FCC-hh with integrated FCC-eh

B3: Details to B2

B6: HE LHC with eh (based on LHeC CDR Update B0)

a total of ~300 FCC pages
End
FCC Layout Changes

Jo Stanyard

Highlights:
- Avoids Jura and Pre-Alps limestone.
- Only one sector containing limestone.
- Significantly reduced total shaft length.
- Experimental Site at Point A on existing CERN land.
- Avoids extremely large overburden.
Based on the LHeC design; figure shows the version using a single solenoid system; Solenoid&Dipoles between Electromagnetic Calorimeter and Hadronic Calorimeter.
ERL SRF: PERLE @ Orsay

PERLE: 150, 450, 900 MeV
Frequency: 801.58 MHz
Voltage: 18.7 MV/cavity

High current, multi-turn (3) ERL concept with 802MHz SRF to be tested at PERLE facility in LAL in Orsay!!!

Key questions to be addressed: BB limit, ERL efficiency, beam size evolution etc.

FCC-eh: 60 GeV, ERL
1km SRF linac; 944 cavities; 59 cryo modules / linac
Number of passes: 6
Beam current: 6.6-25.6 mA

Basic unit: 5-cell cavity into 4-cavity module