Progress with FCC-eh IR design and SR load

R. Martin

Electrons for the LHC Workshop
June 28, 2018

Thanks to:
E. Cruz-Alaniz, B. Holzer, P. Kostka, B. Parker, R. Tomás
Progress with FCC-eh IR design and SR load

LHeC

R. Martin

Electrons for the LHC Workshop
June 28, 2018

Thanks to:
E. Cruz-Alaniz, B. Holzer, P. Kostka, B. Parker, R. Tomás
Why new IR for LHeC?

- Final focus magnet design of 2012 CDR was mainly concerned with field free region

- Result: poor field quality of the quadrupole field

- B. Parker: “The MSQ design for Q1 given in the LHeC CDR is really not suitable for its intended usage.” LHeC and FCC-eh workshop, Sept. 2017

- Meeting in May 2018 to come up with new magnet designs that satisfy beam optics need and are realistic

- Update of LHeC CDR by October 2018: need for fast results ⇒ start with less ambitious $\beta^* = 10$ cm baseline option
# New Magnets

<table>
<thead>
<tr>
<th>Magnet</th>
<th>Gradient [T/m]</th>
<th>Aperture radius [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1a</td>
<td>252</td>
<td>20</td>
</tr>
<tr>
<td>Q1b</td>
<td>164</td>
<td>32</td>
</tr>
<tr>
<td>Q2</td>
<td>186</td>
<td>40</td>
</tr>
<tr>
<td>Q3</td>
<td>175</td>
<td>45</td>
</tr>
</tbody>
</table>

- Larger beam separation in Q1a ⇒ Synchrotron radiation increases
- Increase $L^*$ to 15 m to keep Synchrotron radiation low

Magnet designs for Q1a and Q1b by B. Parker. See talk this afternoon.
$P_{\text{synch}} = 27 \, \text{kW}, \quad E_{\text{crit}} = 513 \, \text{keV} \quad \text{at 60 GeV}$
Beam optics: colliding beam with $\beta^* = 10$ cm

- Integrated in HL-LHC (V1.0) lattice
- Chromaticity correction and dynamic aperture studies presented by E. Cruz-Alaniz
- Quadrupole strengths according to HL-LHC requirements, except for some tuning quadrupoles
- Recombination dipoles below 5.6 T
- Assumed beam stay clear of 12.3 $\sigma$ will require local protection and specific phase advances in the ring
Beam optics: non-colliding beam

- Optics for injection and collision energy exist
- Aperture bottleneck in matching quadrupoles can probably be mitigated
- Quadrupole strengths according to HL-LHC requirements
- Dipoles like colliding beam
Beam optics: non-colliding beam

- Optics for injection and collision energy exist
- Aperture bottleneck in matching quadrupoles can probably be mitigated
- Quadrupole strengths according to HL-LHC requirements
- Dipoles like colliding beam
Beam optics: electron beam?

- Many open questions
- Where do we put the final focus system?
- Need input from (NC-) magnet experts
- Basic IR design exists, becomes more challenging if chromaticity correction is necessary
- Integration in full ERL lattice?

PhD student starting to work on electron beam in September.
Beam optics: electron beam?

- Many open questions
- Where do we put the final focus system?
- Need input from (NC-) magnet experts
- Basic IR design exists, becomes more challenging if chromaticity correction is necessary
- Integration in full ERL lattice?

PhD student starting to in September to work on electron beam
Lower $\beta^*$?

- $L^*$ cannot be reduced due to synchrotron radiation
- The magnets were designed to accommodate a beam with $\beta^* = 10\, \text{cm}$
- Lower $\beta^*$ $\Rightarrow$ Larger aperture needed $\Rightarrow$ lower gradients, potentially larger separation ($\Rightarrow$ Radiation)

$\Rightarrow$ Need to get everything out of available space
Lower $\beta^*$?
Lower $\beta^*$?

- Dipoles
- Triplet

Distance from IP $s$ [m]

0 0.3
0 0.2
0 0.1
0 0.0
0 −0.1
0 −0.2
0 −0.3

$x$ [m]

0 5 10 15 20 25 30
Lower $\beta^*$?

Progress with FCC-eh IR design and SR load
Lower $\beta^*$?
\[ \beta^* = 5 \text{ cm?} \]

<table>
<thead>
<tr>
<th>Magnet</th>
<th>Gradient [T/m]</th>
<th>Aperture radius [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q0 (nc)</td>
<td>50</td>
<td>20</td>
</tr>
<tr>
<td>Q1a</td>
<td>110</td>
<td>27</td>
</tr>
<tr>
<td>Q1b</td>
<td>162</td>
<td>37</td>
</tr>
<tr>
<td>Q2</td>
<td>123</td>
<td>62</td>
</tr>
<tr>
<td>Q3</td>
<td>123</td>
<td>62</td>
</tr>
</tbody>
</table>

- Might be possible BUT:
  - needs NC septum design
  - SC quadrupole parameters to be approved
  - only realistic once integrated in ring
  - Chromaticity correction for \( \beta^* = 5 \text{ cm} \) very challenging, maybe impossible

\[ \Rightarrow \text{Many IFs} \]
FCC week 2018: presented first IR design based on some LHeC magnets and some educated guesses.

Interaction region layout for $\beta^* = 0.3$ m

Note: $\beta_e^*$ naively scaled to have $\beta_e^* \cdot \epsilon_e = \beta_p^* \cdot \epsilon_p$

In most cases we do not want to use LHeC magnets because we need smaller aperture but higher gradients.

However, if new LHeC magnet designs are somewhat representative, we can make some “guesstimates”...
Beam separation in first quadrupole septum will be similar to LHeC ⇒ proton crossing angle almost doubled from first LHeC guess (from 27 mrad to 51 mrad)

Consequently we need more bending strength in recombination dipoles

Magnetic field already capped at 10 T ⇒ need more space

First calculations show that we will use up almost all reserve space we still had in first design

... even though beam separation increased to 250 mm
First quadrupole magnet becomes stronger than expected

Unfortunately Q2 and Q3 will probably become 15% to 20% weaker than initially guessed

⇒ Need more space (which is scarce)

FCC-eh design becomes challenging

We need to iterate **FCC-eh specific** magnet designs ↔ optics calculations from the start

We need to squeeze out every bit of space we can get (e.g. from redesign of injection section?)

**Guess**: We will end up somewhere around $\beta^* = 30\,\text{cm}$. 
First quadrupole magnet becomes stronger than expected

Unfortunately Q2 and Q3 will probably become 15 % to 20 % weaker than initially guessed

⇒ Need more space (which is scarce)

FCC-eh design becomes challenging

We need to iterate FCC-eh specific magnet designs ↔ optics calculations from the start

We need to squeeze out every bit of space we can get (e.g. from redesign of injection section?)

Guess: We will end up somewhere around $\beta^* = 30 \text{ cm}$.

Possible improvement: save space by redesigning entire injection system of FCC-hh to inject closer to detector, like in LHC
We have optics for $\beta^* = 10$ cm option in LHeC
- magnet parameters realistic
- integrated in ring
- chromaticity and dynamic aperture are being studied
- minor issues to be addressed

We have ideas on how to get lower $\beta^*$ but they need a lot of work (Magnets!)

Electron IR needs a lot of questions addressed

New magnet designs require also lots of rework on FCC-eh

FCC-eh IR is challenging due to limited space, $\beta^*$ around 30 cm looks possible

If we can rework the entire injection system, lower $\beta^*$ might be possible in FCC-eh