Designing the interaction regions of the upgrades of the LHC

Emilia Cruz

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Guadalajara, Mexico
About me

- **Bachelors degree:**
  National Autonomous University of Mexico, Science Faculty.

- **Academic Stays:**

- **Project:**
  Studied resolution of the Cherenkov Camera of the CREAM (Cosmic Rays Energetics and Mass).

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About me

• Master’s degree:
  National Autonomous University of Mexico, Institute of Physics.

• Academic Stays:

• Project:
  Study of two different resonances $\rho$ and $\varphi$ in proton-proton collisions.
About me

• PhD/ Marie Curie Fellowship

• Academic Stays:

• Project:
  Effects of high luminosity collisions in the upgrades of the large hadron collider.
About me

- **Postdoc**
  University of Oxford, JAI

- **Project:**
  Contribute to the design of the IR optics for the FCC-hh project.
The LHC has been providing hadron collisions since 2009 taking particle physics to a new era of Energy and Luminosity.

What are the next stages?
Increase Luminosity ($5 \times 10^{34}$ cm$^{-2}$s$^{-1}$) in IP1 (ATLAS) and IP5 (CMS)
The LHeC aims to implement a new ERL to circulate electrons and collide them with one of the proton beams of the LHC.

Increase Luminosity \(5 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}\) in IP1 (ATLAS) and IP5 (CMS)
The FCC-hh project aims to construct a new 100 km tunnel and use the LHC as injector to have pp collisions with a **center-of-mass energy up to 100 TeV**.
Designing an interaction region is an important part of the design of any particle collider. Beams are brought to a focus with small beam sizes and restrictions are given from both the accelerator and the detector.
Challenges in IR designs

Designing an interaction region is an important and challenging objective in the development of any particle collider. Beams are brought to a focus with small beam sizes and restrictions are given from both the accelerator and the detector.

Established design
High Beta functions in the IT
Do fringe fields have a bigger effect?
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New design in an IR design for a different type of collisions and range of energy.
Can we increase the luminosity? Reduce the SR?
Chromaticity Correction?
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Flexibility in a design, find the best option.
Unprecedented energies
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Increasing Luminosity

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FOCUSING. QUADRUPOLES. Implementation of new inner triplet Q1-Q3

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SEVERE LIMITATIONS
1. Quadrupole apertures
2. Quadrupole strengths
3. Efficiency of the chromatic correction
Achromatic Telescopic Squeezing Scheme (ATS) HL-LHC

\[ \beta^* = 0.55\ m \rightarrow 0.15\ m \]

Increases Beta function in location of sextupoles in arc

\[ \xi_{x,y}^S = -\frac{1}{4\pi} \int \beta_{x,y}(s)S(s)D_x(s)ds \]
Integration of Fringe Fields

Challenges

- Previous studies have not taken into account the fringe fields. In particular dynamic aperture studies have been done with a thin version of the lattice.
- New quadrupoles have higher gradients and higher apertures. Fringe fields effects are expected to be more significant.
Integration of Fringe Fields

Fringe Field Studies:

1. Model Fringe Fields.
2. Obtain Transfer Maps
3. Implement fringe field element using SAMM code
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Results of fringe fields: change in dynamics for particles with large dynamic aperture, but no reduction in dynamic aperture (stable zone).
Focus one of the proton beams and collide it with the electron beam while the other proton beam bypasses the interaction.

Non-focused proton beam through free field aperture of (new) inner triplet. Focus proton beam 2 $\rightarrow$ minimize $\beta^*$ (current value in IR2 10 m)
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\[ L = \frac{1}{4\pi e} \frac{N_{b, i}}{\varepsilon_p} \frac{1}{\beta_p^*} \cdot \int_{-H_D}^{H_{hg}} I_e H_{hg} H_D \]

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Repeat procedure of HL.
* New dipoles
* Magnets with free-field aperture
Achromatic Telescopic Squeezing Scheme (ATS)
HL-LHC+LHeC

HL-LHC

IP1/IP5
β*=15 cm

IP2
β*=10 m
Achromatic Telescopic Squeezing Scheme (ATS) HL-LHC+LHeC

HL-LHC

IP1/IP5
\( \beta^* = 15 \text{ cm} \)

IP2
\( \beta^* = 10 \text{ m} \)

HL-LHC + LHeC

IP1/IP5
\( \beta^* = 15 \text{ cm} \)

IP2
\( \beta^* = 10 \text{ cm} \)

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# Flexibility of the Design

<table>
<thead>
<tr>
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<th>Disadvantages</th>
<th>Advantages</th>
<th>Cases found</th>
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</thead>
<tbody>
<tr>
<td>Minimize $\beta^*$</td>
<td>Increase Chromatic Aberrations</td>
<td>Increase Luminosity</td>
<td>$L^<em>=10-20 \text{ m}$ With $\beta^</em>$ fixed at 10 cm</td>
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</table>

**Challenges**
Find the right balance between competing criteria. Where is the compromise?

Further studies, chromatic correction, synchrotron radiation, tracking studies.
Results in LHeC

- Optical Designs. $L^* = 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20$
  $\beta^* = 5, 6, 7, 8, 9, 10, 20$
- Chromatic Correction
- Require nominal Luminosity
- Tracking studies
- SR and magnet design
Results in LHeC

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  - $L^* = 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20$
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\(\beta^*=10\text{ cm}\)
\(L^*=14-15\text{ m}\)
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\[ \beta^* = 10 \text{ cm} \]
\[ L^* = 14-15 \text{ m} \]
Choose parameters:

Options \( L^* = 36, 45 \) and \( 61 \) m. \( L^* = 45 \) good compromise between detector requirements and keeping inner triplet “short”.

Options \( \beta^* = 1.1 \) m (Baseline – not an issue), 0.3 m (Ultimate, reachable), 0.05 m limited by beam stay clear limitations.

Radiation load in the quadrupoles is the main driver. Shielding required inside the quadrupole reduces \( \beta^* \) reach.
Objectives of the correct Scheme:
Control possible misalignments of the quadruples, field/tilt errors of the interaction region (in particular the IT, D1 and D2) while maintaining the crossing angle.
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**FCC Correction Scheme**

1. Calculate maximum orbit deviation in IR after correction.
2. Repeat for 500 seeds
3. Calculate value of the maximum orbit deviation for which 90% of the seeds are included ($x_{90}$)
Conclusions

• Designing an interaction region is an important objective of any new accelerator and often compromises must be made.
• The upgrades of the large hadron collider comes with further challenges, mainly driven by the unprecedented ranges of energy and luminosity.
  - Fringe Fields in the HL-LHC.
  - LHeC IR accommodated in previous IR2.
  - Correction Scheme for FCC.
Thank you!

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