Update on R2E and Heat Load Simulations

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EN/STI-BMI and the Infrastructure and Operations Working Group
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Introduction

- **FCC-hh arc cell beam-gas interaction**
  - Impact of secondary showers on magnets and electronics.

- Beam lifetime, $\tau$, considering losses due to nuclear scattering with residual gas:
  \[ \tau = \frac{1}{\sigma_g cn_g} > 100 \text{ h} \]
  Where:
  - $\sigma_g$ nuclear scattering cross section (86.4 mb),
  - $n_g$ molecular gas density
  - Gives $n_g = 1 \times 10^{15}$ atoms/m$^3$

- Update on previous work carried out by A. Infantino
  - FCC week 2017: “FLUKA Montecarlo modelling of the FCC arc cell: radiation environment and energy deposition due to beam-gas interactions”
  - FCC week 2018: “Radiation environment assessment in the FCChh and FCCee machines”
FLUKA Model

FCC-hh arc FODO cell

- Lattice based on latest optics, MAD-X TWISS file (R. Martin)
- 214 m in length

Simulation Parameters:
- >200,000 primaries per beam
- Boundary condition
- CPU Time ~120 – 130 seconds per primary

MB x 6 x 2
L = 14.2 m
θ = 1.3 mrad

MQ x 2
L = 6.4 m
**Updates**

**Gas Profile**

- Average gas density unchanged (1e9 atoms/cm³)
- Shorter photon absorber (previously absorbing ~x2 more power than now which led to higher outgassing.)
- Optimised interconnect region geometry, increasing the conductance of the region.

**Beam Screen**

- New scheme for dealing with synchrotron radiation effects
- Better vacuum quality and lower electron cloud density

I. Bellafont: “Study on the beam induced vacuum effects in the FCC-hh beam vacuum chamber”, this conference, Wednesday, 8:30 am
Lattice Element Updates

Previous
Radius [cm] | Updated Radius [cm]
-------------|-------------------
MB Cold mass  | 45                | 37                
MQ Cold mass  | 32.37             | 24.87             
MB Coil       | 8.1               | 8.1               
MQ Coil       | 5.672             | 5.922             

Additional increase in beam – beam separation: 20 -> 25 cm

$R_{Coil} = 8.1$ cm

$R_{CM} = 45$ cm

$R_{CM} = 37$ cm
Energy Deposition on Coils

Power density: steady state losses (as opposed to transient losses)
Energy Deposition on Coils

Centre of ring

Beam

Power density [$\text{mW cm}^{-3}$]
Secondary Trajectories

xAxis = 0.01*zAxis

xAxis = 0.1*zAxis
Secondary Trajectories

xAxis = 0.01*zAxis

Neutral particles

Peak Power Density [mW cm⁻³]

s [m]
Secondary Trajectories

Split into inner- and outer- ring scoring

\[ x\text{Axis} = 0.01 \times z\text{Axis} \]
Secondary Trajectories

Peak Power Density [mW cm\(^{-3}\)]

Periodic lattice

Periodic lattice

beam

D1  D2  D3  D4  D5  D6  Q1

x > 0
x < 0
Secondary Trajectories

Periodic lattice

Peak Power Density [mW cm⁻³]

s [m]

D5, D6, Q1, D7, D8

beam

x > 0
x < 0
Secondary Trajectories

![Diagram showing secondary trajectories through D5, D6, Q1, D7, and D8.]
Energy deposition on coils

Comparison with previous study

Peak Power Density [mW cm\(^{-3}\)]

![Graph showing energy deposition on coils with a comparison to previous study.](image-url)
Energy deposition on coils
Energy deposition on coils

Peak power density in coils: 1.6 mW/cm³

Corresponding to a dose of: 4.1 MGy y⁻¹

Pessimistic gas density, 200x density achieved currently in LHC
Power Per Element (Cold Mass)

- Updated design of beam screen provides less shielding for coils and cold mass:
  - Each beam screen now absorbing ~5% of power loss density as opposed to 16% previously.
  - 86% absorbed by cold mass, 73% previously.

- Average losses along arc cell: 414 mW/m (2 beams)
- Maximum heat load on most impacted dipole is 476 mW/m on cold mass (2 beams)

### Two Beams Power per Element [W]

<table>
<thead>
<tr>
<th>Element</th>
<th>Beam Screen (W)</th>
<th>Cold Mass (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB1</td>
<td>0.140</td>
<td>5.52</td>
</tr>
<tr>
<td>MB2</td>
<td>0.212</td>
<td>6.51</td>
</tr>
<tr>
<td>MB3</td>
<td>0.164</td>
<td>5.84</td>
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<tr>
<td>MB4</td>
<td>0.162</td>
<td>5.87</td>
</tr>
<tr>
<td>MB5</td>
<td>0.161</td>
<td>6.76</td>
</tr>
<tr>
<td>MB6</td>
<td>0.160</td>
<td>5.67</td>
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<tr>
<td>MQ1</td>
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<td>MB7</td>
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<tr>
<td>MB8</td>
<td>0.211</td>
<td>6.41</td>
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<tr>
<td>MB9</td>
<td>0.160</td>
<td>5.68</td>
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<tr>
<td>MB10</td>
<td>0.159</td>
<td>5.71</td>
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<td>MB11</td>
<td>0.157</td>
<td>6.57</td>
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<td>MB12</td>
<td>0.156</td>
<td>5.36</td>
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<tr>
<td>MQ1</td>
<td>0.121</td>
<td>2.14</td>
</tr>
</tbody>
</table>

(Current per beam: 0.5 A)
Radiation to Electronics

• Scoring mesh in location of power converters/electronics
  • Direct comparison with previous results
• Normalised to $10^7$ s
  • ~1 year beam operation

• Total ionizing dose
  • Cumulative effects, long-term radiation damage
• High-energy hadron fluence (HEH):
  • proportional to number of single event upsets (SEUs)
Dose on Electronics

Dose mostly photons & electrons, easily blocked by cold mass

Maximum: 341 Gy yr\(^{-1}\)

Maximum: 244 Gy yr\(^{-1}\)

158 Gy yr\(^{-1}\)
For R2E it is important to consider 2 simultaneous beams.
Dose on Electronics: Combined Beams

Based on pessimistic gas density, 200x lower density achieved currently in LHC

Maximum: 400 Gy yr⁻¹
R2E impact - HEH

Some increase due to reduced radius of cold mass in dipoles and quadrupoles

Neutron dominated

[Graph showing neutron fluence with labels for D5, D6, Q1, D7, D8, D9]
Again, based on pessimistic gas density, 200x density achieved currently in LHC.
Summary

• New beam screen design has impacted energy deposition on coils and cold mass
  • Now only 5% on beam screen with 86% on cold mass
  • Higher peak power density 1.6 mW/cm³ on coils

• R2E outcome: an increase in radiation to electronics under beamline
  • Maximum dose: 400 Gy yr⁻¹
  • Maximum high energy hadron fluence: 1.2e11 cm⁻² yr⁻¹
  • However, the gas density used ~200x greater than achieved currently in the LHC
Thanks for listening

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Special thanks to
I. Bellafont