Power deposition in DS magnets due to ion collision debris (BFPP1) in IR1/5 and IR2

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ColUSM

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1 Introduction

2 Validation against BLM measurements (IR5)

3 Power deposition by $^{208}\text{Pb}^{81+}$ ions in DS dipole

4 Effectiveness of DS collimators (in IR1/2/5)

5 Loosing the $^{208}\text{Pb}^{81+}$ ions in the connection cryostat (in IR1/5)

6 Conclusions
This presentation: validation of BLM simulations against 2011 data and summary of power deposition results for IR1/5 and IR2

We only consider bound-free pair production (BFPP1, see [1]) → secondary $^{208}\text{Pb}^{81+}$ beam

Studied options to reduce power density:

- TCLD ($\text{Cu 50 cm vs W 100 cm}$)
- Orbit bump (IR1/5 only)

Impact distributions from SixTrack by M. Schaumann and R. Bruce ([1] and [2])

All results presented in following are for an instantaneous luminosity of $1 \times 10^{27} \text{cm}^{-2} \text{s}^{-1}$

- One can however easily scale to other luminosities, e.g. to $6 \times 10^{27} \text{cm}^{-2} \text{s}^{-1}$ (=ALICE HL-LHC performance goal [2])

Power densities in magnet coils are always radially averaged over the cable (see figure on the right)

- Note that Refs [1-4] referred to the peak power density at the inner edge of the coils

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Validation against BLM measurements (IR5)

DS next to IR5 (2011, Pb@1.38 TeV/u): validation of calculated BLM signals

- Measurement data:
  - BLM signals (RS12) time-integrated over fills (stable beams only) and normalized with the number of BFPP (using the measured lumi)
  - Note: measured signals are not (yet) offset corrected (can affect the lower signals)
- Assumed loss location ($s \approx 13747$ m from IP1, 417.7 m from IP2) yields a good agreement with measurement:
  - Largest BLM signals agree within $\sim 25\%$ (very sensitive to impact location!)
  - Pattern very well reproduced (note that statistical error is still large for BLMs upstream of loss location)

**Figure:** Absolute comparison of sim. and measured BLM signals around MB.B11R5, LEGR.11R5 and MQ.11R5. Only BLMs on B1 considered. Signals are expressed per BFPP1. Assumed BFPP cross section is 250 b (thanks to R. Bruce and J. Jowett for providing the cross section). Impact distribution courtesy of M. Schaumann.
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DS next to IR2 (Pb@2.76 TeV/u): power density in coils

- Maximum power density in MB coils (radially averaged over cable and per $1 \times 10^{27} \text{cm}^{-2} \text{sec}^{-1}$):
  - 7.3 mW/cm$^3$
- Recent estimates of the steady-state quench limit of MB cables (for 7 TeV operation) range from 25 mW/cm$^3$ [4] to 49 mW/cm$^3$ [5].

For more details see [1–3] (note the different normalization)

Figure: Peak power density in MB.B10R2 magnet coils (radially averaged over cable). Results normalized to an instantaneous luminosity of $1 \times 10^{27} \text{cm}^{-2} \text{sec}^{-1}$. Assumed BFPP cross section is 281 b.

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Effectiveness of DS collimators (in IR1/2/5)

Layout with TCLDs

Analogous for IR1/5, but in cell 11
DS next to IR2 (Pb@2.76 TeV/u): power density in presence of TCLD (A10R2)

- Maximum power density in 11T magnet coils (radially averaged over cable and per $1 \times 10^{27} \text{ cm}^{-2} \text{ sec}^{-1}$):
  - 0.5 m Cu jaws:
    * $\sim 0.5 \text{ mW/cm}^3$
  - 1 m W jaws:
    * $\sim 0.12 \text{ mW/cm}^3$
- Quench limit of the Nb3Sn-based 11T magnets is around $110 \text{ mW/cm}^3$ according to first estimates [3]


For more details see [1,2] (note the different normalization)

Note: we assumed a mean impact parameter of 2 mm

**Figure:** Peak power density in 11T magnet coils (radially averaged over cable). Results normalized to an instantaneous luminosity of $1 \times 10^{27} \text{ cm}^{-2} \text{ sec}^{-1}$. Assumed BFPP cross section is 281 b.
$^{208}\text{Pb}^{81+}$ impact distribution on TCLD (2.76 TeV/u): IR2 (A10R2) vs IR1 (B9R1)

**Figure:** Phase space distribution of $^{208}\text{Pb}^{81+}$ ions at the front phase of the TCLD in the DS next to IR2 (left) and IR1 (right). Distributions are normalized to an inst. luminosity of $1 \times 10^{27}$ cm$^{-1}$ s$^{-1}$.

**Data courtesy of M. Schaumann.**

- The results shown on the previous slide were based on the left distribution (IR2)
- Considering the impact distributions, one can expect similar results for IR1
Effectiveness of DS collimators (in IR1/2/5)

$^{208}\text{Pb}^{81+}$ impact distribution on TCLD (2.76 TeV/u): IR2 (A10R2) vs IR5 (B9R5)

**Figure:** Phase space distribution of $^{208}\text{Pb}^{81+}$ ions at the front phase of the TCLD in the DS next to IR2 (left) and IR5 (right). Distributions are normalized to an inst. luminosity of $1 \times 10^{27}$ cm$^{-1}$ s$^{-1}$. Data courtesy of M. Schaumann.

- Also for IR5, one can expect similar results as for IR2
- Hence, no dedicated simulations were carried out for IR1 and IR5
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DS next to IR5 (2011, Pb@1.38 TeV/u, with orbit bump): validation of BLM signals

- Measurement data (BLM RS09) from 24/11/2011 at 17:12:26
  - Inst. lumi = $0.108 \times 10^{27} \text{cm}^{-2} \text{sec}^{-1}$
- Assumed loss location ($s \approx 13752$ m) maybe slightly downstream of real loss location:
  - real loss locations certainly between BLMs at $s = 13749.4$ m and $s = 13756.27$ m

**Figure:** Absolute comparison of sim. and measured BLM signals around MB.B11R5, LEGR.11R5 and MQ.11R5. Only BLMS on B1 considered. Signals are expressed per BFPP1. Assumed BFPP cross section is 250 b.
DS next to IR5 (2011, Pb@1.38 TeV/u, with/without orbit bump): power density in coils

- Maximum power density in coils (radially averaged over cable and per $1 \times 10^{27} \text{cm}^{-2} \text{sec}^{-1}$):
  - No bump:
    * MB: 2.1 mW/cm$^3$
    * MQ: 0.023 mW/cm$^3$
  - With bump:
    * MB: <0.01 mW/cm$^3$
    * MQ: 0.038 mW/cm$^3$

**Figure:** Peak power density in magnet coils (radially averaged over cable). Results normalized to an instantaneous luminosity of $1 \times 10^{27} \text{cm}^{-2} \text{sec}^{-1}$
DS next to IR5 (2015, Pb@2.56 TeV/u, without orbit bump): power density in coils

- With the 2015 optics, the loss location is predicted to lie within LEGR.11R5, even without orbit bump
- Maximum power density in coils (radially averaged over cable and per $1 \times 10^{27} \text{cm}^{-2} \text{sec}^{-1}$):
  - MB: $<0.01 \text{mW/cm}^3$
  - MQ: 0.067 mW/cm$^3$

**Figure:** Peak power density in magnet coils (radially averaged over cable). Results normalized to an instantaneous luminosity of $1 \times 10^{27} \text{cm}^{-2} \text{sec}^{-1}$
DS next to IR5 (2015, Pb@2.56 TeV/u, without orbit bump): power to LEGR

- Debris-induced power per $1 \times 10^{27} \text{cm}^{-2}\text{sec}^{-1}$:

<table>
<thead>
<tr>
<th>Component</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEG.11R5 Beam screen (B1)</td>
<td>2.3</td>
</tr>
<tr>
<td>Vacuum chamber (B1)</td>
<td>2.0</td>
</tr>
<tr>
<td>Tube around vacuum chamber (B1)</td>
<td>1.7</td>
</tr>
<tr>
<td>Pb shielding</td>
<td>6.3</td>
</tr>
<tr>
<td>Cold mass shell</td>
<td>0.5</td>
</tr>
<tr>
<td>Cryostat</td>
<td>0.7</td>
</tr>
<tr>
<td>Other components:</td>
<td>~1</td>
</tr>
<tr>
<td>Total</td>
<td>14.4</td>
</tr>
<tr>
<td>Concrete walls</td>
<td>3.9</td>
</tr>
<tr>
<td>MQ.11R5</td>
<td>1.5</td>
</tr>
<tr>
<td>MB.B11R5</td>
<td>≤0.01</td>
</tr>
</tbody>
</table>

Rest leaves simulation geometry or is spent in nuclear interactions.

Figure: Illustration of the connection cryostat model used in the FLUKA calculations. green=cryostat, gray=Pb box, violet=cold mass shell, end cap, beam pipes, beam screen, M-lines etc, yellow=helium, orange=bus bars
Introduction

Validation against BLM measurements (IR5)

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- BLM signals measured during 2011 heavy ion run can be well reproduced with FLUKA
  - Confirms also the loss location predicted by tracking studies
- For IR1/R5, the simulation suggests that no TCLD is needed if $^{208}\text{Pb}^{81+}$ losses can be shifted into connection cryostat
  - Acceptable power load in connection cryostat should however be checked
- As already previously shown, for IR2 the estimated peak power density (averaged over cable width) in the MB is $N \times 7.3 \text{mW/cm}^3$ for an instantaneous luminosity of $N \times 10^{27} \text{cm}^{-2}\text{s}^{-1}$
  - For ALICE HL goal of $6 \times 10^{27} \text{cm}^{-2}\text{s}^{-1}$ one gets 44 mW/cm$^3$, which has to be compared to an estimated quench limit of 25-49 mW/cm$^3$
  - With TCLDs the power density can be effectively reduced, no risk of quench even for short jaws of 50 cm (if one can find TCLD settings which allow for a mean impact parameter of the order of $\sim \text{mm}$)