Updates on LHC external dump (TDE)
Evian 2021 workshop

M. Calviani on behalf of SY-STI

23rd November 2021
Outlook

- Introduction to LHC dump
- Challenges and behavior during beam impact
- Dump upgrades during LS2
- Questions on core behavior following beam impact
- Work ahead & Conclusions
Acknowledgments

SY/STI, BE/CEM, EN/MME, TE/VSC, EN/HE, SY/ABT, BE/OP, IPT, EN/ACE, EN/EL, NTNU, external industrial partners
**LHC beam kinetic energy reaching several hundreds of MJ**

- This energy is sufficient to melt more than 2.5 tons of Cu

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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>$E_{\text{prot}}$ (TeV)</td>
<td>4</td>
<td>6.5</td>
<td>6.8</td>
<td>7</td>
</tr>
<tr>
<td>$\Delta t_b$ (ns)</td>
<td>50</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>$N_b$</td>
<td>1380</td>
<td>2556</td>
<td>2748</td>
<td>2760</td>
</tr>
<tr>
<td>$I_b$ (p)</td>
<td>$1.7 \times 10^{11}$</td>
<td>$1.2 \times 10^{11}$</td>
<td>$1.8 \times 10^{11}$</td>
<td>$2.2 \times 10^{11}$</td>
</tr>
<tr>
<td>$E_{\text{beam}}$ (MJ)</td>
<td>150</td>
<td>320</td>
<td>539</td>
<td>680</td>
</tr>
<tr>
<td>$\varepsilon_n$ (μm rad)</td>
<td>$\approx 2.5$</td>
<td>$\approx 2$</td>
<td>1.8–2.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Where do we safely dispose of these beams without damaging sensitive equipment?
Large Hadron Collider beam dump

Point 6

LHC tunnel

TD6X connection line

UD6X dump caverns

750 m
LHC beam dump

- The LHC TDE (Target Dump External) is a beam dump constituted by a graphite (low and high density) absorber of roughly 8.5 m length and 700 mm diameter – no active cooling.

- It is installed inside a 12 mm thick tube of 316LN duplex stainless-steel alloy and filled with nitrogen gas slightly above atmospheric pressure.

\[ \lambda \approx 15 \]

\( >99.9999\% \) of 6.5 TeV particles have an inelastic collision in the core.

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What the challenges?

<table>
<thead>
<tr>
<th></th>
<th>Fraction of beam energy</th>
<th>Energy deposition (MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dump:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphite</td>
<td>73.6%</td>
<td>397</td>
</tr>
<tr>
<td>Shell</td>
<td>4.2%</td>
<td>23</td>
</tr>
<tr>
<td>Windows, flanges etc.</td>
<td>0.04%</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>77.9%</td>
<td>420</td>
</tr>
<tr>
<td><strong>Environment:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shielding</td>
<td>17.4%</td>
<td>94</td>
</tr>
<tr>
<td>Air</td>
<td>0.015%</td>
<td>0.08</td>
</tr>
<tr>
<td>Cavern</td>
<td>0.12%</td>
<td>0.6</td>
</tr>
<tr>
<td>Molasse, rock, etc.</td>
<td>0.04%</td>
<td>0.2</td>
</tr>
</tbody>
</table>
| **Total**      | 17.6%                   | 95                     

**Absorbed energy**
(worst case Run 2):
- Dump: $\sim 250$ MJ
- Shielding: $\sim 56$ MJ

**Rest:**
- Cavern: $\sim 0.1\%$
- Rock, molasse, etc.: $\sim 0.05\%$
- Air: $\sim 0.02\%$
- Shielding: $\sim 17\%$

Note: dump core is inside shielding.
Dumped energy

\[ \text{Dumped energy} = \text{proton energy} \times \text{beam intensity} \text{ at the moment of beam extraction} \]

**Good day:**

Courtesy A. Lechner, from LHC TDE autopsy review (Nov 2021)

**Bad day:**

120 MJ

(4.5x smaller than in Run3)

\[ \pm 200 \text{ GJ were dumped so far (60 GJ in Run 1 and 140 GJ in Run 2)} \]
Dumped energy

Operational challenges in the dump started to appear

Courtesy A. Lechner, from LHC TDE autopsy review (Nov 2021)
What did we see?

- Starting from end of 2015 (ramp up in intensity), we observed several problems associated with $N_2$ leaks and physical movements.

- What do we saw with instrumentation?

Time scale of 100 ms

- Beam direction

Horizontal displacement of the Dump (in the beam direction)

- 5-6 mm

- Time scale of >10 hours (!)
Simulation package appears to be in good agreement with data.
Dump slow response

Simulation package appears to be in good agreement with data
During Long Shutdown 2, a large effort has been devoted to provide a Run 3 compatible beam dump system.

- NB: Cannot remove the physical origin of the vibration – must work on mitigating the effects of vibration.

Endorsement at January 2020 TDE review and ensuing LMCs (LMC 417, 402, 399, 394, 390).

- LS2 upgrades focused on
  - Vibration effects mitigation (N₂ leaks)
  - Dump Windows upgrade
Short summary of LS2 modifications

- **Run1-2**

- Original *spares* were modified and employed as **new operational dumps**
- **No spares currently available** – under production and at the moment expected for **mid 2023**
- **Modifications avoids dump-induced leaks in the UHV beam line**

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Dump configuration
Upgraded dump support system

- Based on **two steel wire rope loops** that suspend the dump block inside a frame
- Freedom to **accommodate vibrations**
- Avoids any accumulative movement of the dump over repeated expansion and retraction cycles
Dump windows

- Provide **robust enclosures** at the extremities of the stainless-steel dump block vessel (TiGr2 → TiGr5)

- **Contain the internal N₂ atmosphere** while withstanding the beam-induced thermo-mechanical and dynamic loads
Dump windows

Beam effects:

- Dump upstream window
  - $T_{\text{max}} = 64 \degree C$, 43 MPa VM (17 m s$^{-1}$)
  - Tails of stress waves that are generated by the beam impact following the sweep pattern

- Dump downstream window
  - $T_{\text{max}} = 155 \degree C$, 141 MPa VM (32 m s$^{-1}$)
  - Due to the developed particle shower generated along the 8 meters long dump core

230 MPa induced by vibration (!) >> beam loading
Updates on instrumentation – what’s installed

HD camera picture

Pt100’s

LVDT

LDV head

Optical microphone

Data acquisition rack

Thanks to BE/CEM and EN/MME

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Some early results from 2021 test run

Gafchromic foil installed on both dumps

Inspector interface (under construction)

UD62 Dump on 26/10/2021 at 00:02:03, $3.4 \times 10^{11}$ dumped intensity (few bunches)
Are there any open points in view of Run3?

Broken extruded graphite from UD68 dump (summer 2020)

Sigraflex® sample (March 2020)
What are we doing to understand whether Run 3 operational conditions?

- Autopsy of the highly radioactive UD68 dump to assess core status (Run 2 parameters)
  - Technical Review November 2021 [https://indico.cern.ch/event/1072664/](https://indico.cern.ch/event/1072664/)
  - Execution in Jan/Feb 2022, results to follow in the weeks/months

- Execution of HRMT56 and subsequent PIE
  - Experiment completed and results to be available starting from January 2022

- Ongoing CERN-NTNU collaboration (Sigraflex®)
Conclusions

- Despite challenging timeline and scope, LS2 upgrades of LHC dumps have been **successfully implemented**

- **Vessel and windows ready to accept Run3** beam parameters

- Open questions related to **core behaviour** will be hopefully be **clarified during 2022** in view of Run3 (as well as spares & HL-LHC dump)