Heat load estimates for the experimental vacuum chambers and potential limitations

74th HiLumi WP2 Meeting
August 16th 2016
Experimental vacuum chambers in LHC

- ALICE
  - Beam pipe
- ATLAS
  - Beam pipe
  - ATLAS-ALFA Roman pots
- CMS
  - Beam pipe
  - CT-PPS Roman pots
- LHCb
  - Beam pipe
  - VELO and wakefield suppressor
- TOTEM
Experimental vacuum chambers in HiLumi LHC

• ALICE
  • Beam pipe (modified)
• ATLAS
  • Beam pipe (modified)
  • ATLAS-ALFA Roman pots
• CMS
  • Beam pipe (modified, design still under way)
  • CT-PPS Roman pots
• LHCb
  • Beam pipe (modified)
  • VELO and wakefield suppressor (strongly modified, design still under way)
• TOTEM Roman pots
Main modifications

• Reduction of diameter for the pipe immediately around the IP
  • ALICE (for LS2, 29 mm inner radius to 18 mm inner radius), approved at TREX provided it is ok for the 0
  • ATLAS (reduction from 58 mm to 47 mm, already done during LS1)
  • CMS (reduction from 58 mm to 43.4 mm, already done during LS1)
  • LHCb (5.5 mm to 3.5 mm during LS2)

• Modification of the geometry away from the IP
  • ATLAS
  • CMS
  • LHCb (change of material → copper to Aluminium)
ALICE

• Plan for diameter reduction during LS2
• Discussed at TREX meetings in June 2014 and July 2014
• Reduction of inner radius from 29 mm to 18 mm
• Recommended for approval at TREX provided:
  • the 0.8 mm thick Beryllium pipe at 18 mm can sustain the 5 to 6 W/m expected from resistive wall
  • The stainless steel (resp. Al) at 20.1 mm radius should cope with 20 W/m (resp. 4 W/m)
• At this occasion, note that large low frequency modes are due to the large cone
  • Asked if temperature monitoring is possible
  • Turned out one could re-use the probes used for the bake out
  • Was implemented during 2015 (many thanks to ALICE colleagues: Andre Augustinus, Arturo Tauro, Werner Riegler)
ALICE: worry for resonant modes

Power from resonant modes for ALICE

Modes from R. Wanzenberg and O. Zagorodnova, DESY

Significant increase of power loss with HL-LHC parameters (here with 1.2 ns)
→ even the modes at higher frequencies are significant (of the order of 20 to 50 W)
→ Similar case for CMS and LHCb
Observations of ALICE temperatures

- Temperature probes reasonably close to the stainless steel chamber
- Sensors 8 and 9 (TC5 and TC6) are close to the cone
- Visible beam induced temperature increase, but small (1 to 3 C).
- Scaling to HL-LHC beam parameters still does not seem too problematic for 3 mm chamber.
ALICE beam pipe
ALICE beam pipe

→ Interesting behaviour with bunch length (due to longitudinal stability or blow up)
Black – RB26 4-5
(lower patch panel)
TC3 – patch 07
TC4 – patch 08
TC5 – patch 09
TC6 – patch 10
TC7 – patch 11
TC10 (spare) – patch 14
ATLAS

• No particular worry for the beam pipe (change already made in LS1)
• No official forward physics request (yet?)
New CMS pipe
Main changes with respect to study by Rainer Wanzenberg (ats_note_2013_018)

Change of cone:
- Reduction of maximum radius from ~157 mm to ~110 mm
- Change of material from Stainless steel to Aluminium
Main changes with respect to study by Rainer Wanzenberg (ats_note_2013_018)

Change of cone:
- Reduction of maximum radius from ~157 mm to ~110 mm
- Change of material from Stainless steel to Aluminium

<table>
<thead>
<tr>
<th>Picked Elements</th>
<th>(in mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1(X,Y,Z)</td>
<td>0, 157.200000, -10528</td>
</tr>
<tr>
<td>P2(X,Y,Z)</td>
<td>0, 109.640189, -10854</td>
</tr>
<tr>
<td>P2 - P1</td>
<td>0, -47.559811, -326</td>
</tr>
<tr>
<td></td>
<td>P2 - P1</td>
</tr>
</tbody>
</table>

→ Modes at higher frequency
→ Higher shunt impedance
CMS: first 10 modes

→ very significant reduction at the beginning of the fill (where it matters the most)
→ The factor 5 increase due to the better conductor should not make things worse.
→ There is NEG coating: impact? (skin depth at 1 GHz: 15 micron).
CMS pipe: Power loss for 1 ns

- Less power loss expected with the new beam pipe
- With less probability to hit the mode due to the high Q
LHCb VELO

- Very complex geometry around the beam
- New geometry even more complex
- Design underway (especially the wake field suppressor)
- Other impedance contributions also increase significantly → we thought there was margin in collisions for transverse and for longitudinal.
- It will be difficult to perform measurements as no spare tank
- No showstopper yet but it seems a risky move.
- Risk could be mitigated if VELO position could be changed in case of problems
non-trivial detail: wakefield suppressors

connection for WF-suppressors

WF-suppressors after installation
Current box => upgrade box (prototype)

From R = 5.5mm to 3.5mm
Non zero real longitudinal impedance at low frequency due to “global step out”

Clear presence of longitudinal modes above 400 MHz, but less linked to the geometry of the box than to the connections between the boxes and the outside tank
Updated resistive power loss as a function of distance to the box

Resistive power loss vs distance of flat pipe (NEG (1 \(\mu\)m)/AlMg4.5(150 \(\mu\)m)/Torlon)

- \(N_b=1.15\times10^{11}\) p/b
- \(M=2748\) bunches
- Bunch length=1 ns
Prediction for HL-LHC parameters

- \( N_b = 2.2 \times 10^{11} \ \text{p/b} \)
- \( M = 2748 \ \text{bunches} \)
- Bunch length = 1.08 ns
Summary

• ALICE
  • Beam pipe (modified) ➔ no worry so far

• ATLAS
  • Beam pipe (modified) ➔ no worry so far
  • ATLAS–ALFA Roman pots

• CMS
  • Beam pipe (modified, design still under way) ➔ no worry so far
  • CT–PPS Roman pots

• LHCb
  • Beam pipe (modified) ➔ no worry so far
  • VELO and wakefield suppressor (strongly modified, design still under way) ➔ no showstopper yet but seems very risky, being followed up with Massimiliano Ferro Luzzi.

• TOTEM Roman pots
Increase in heat load only from intensity increase

<table>
<thead>
<tr>
<th>Factor from situation before LS1</th>
<th>2016</th>
<th>HL-LHC (25 ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M (\times) Nb(^2)</td>
<td>1</td>
<td>4.5</td>
</tr>
<tr>
<td>Broadband (M(\times)Nb(^2))</td>
<td>1</td>
<td>2.2</td>
</tr>
<tr>
<td>Narrow band (M(\times)Nb(^2))</td>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>

*Narrow band is a worst case scenario assuming that the resonance stands exactly at a multiple of 40 MHz

Significant increase in heat load from impedance with HL-LHC intensity (factor 4 to 7)
New LHCb design

Length : ~ 0.5 m and very small change. Looked at worst case scenario.
<table>
<thead>
<tr>
<th>Energy</th>
<th>Inner radius</th>
<th>Bunch length (4σₜ)</th>
<th>( \text{Im}(Z_{\text{eff}}) ) [Ω/m] resistive part</th>
<th>( \text{Im}(Z_{\text{eff}}) ) [Ω/m] geom. part</th>
<th>( \text{Im}(Z_{\text{eff}}) ) [MΩ/m] total (LHC ring)</th>
</tr>
</thead>
<tbody>
<tr>
<td>450 GeV</td>
<td>25 mm</td>
<td>1.3 ns</td>
<td>20</td>
<td>600</td>
<td>~2.4</td>
</tr>
<tr>
<td>450 GeV</td>
<td>20 mm</td>
<td>1.3 ns</td>
<td>38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 TeV</td>
<td>25 mm</td>
<td>1 ns (nominal)</td>
<td>17</td>
<td>600</td>
<td>~25</td>
</tr>
<tr>
<td>7 TeV</td>
<td>20 mm</td>
<td>1 ns (nominal)</td>
<td>33</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy</th>
<th>Inner radius</th>
<th>Bunch length (4σₜ)</th>
<th>( (Z_{|/n})_{\text{eff}} ) [Ω] resistive part</th>
<th>( (Z_{|/n})_{\text{eff}} ) [Ω] total (LHC ring)</th>
<th>Power loss in W (2 beams)</th>
</tr>
</thead>
<tbody>
<tr>
<td>450 GeV</td>
<td>25 mm</td>
<td>1.4 ns (MD)</td>
<td>( j \times 0.09 \times 10^{-5} )</td>
<td>( j \times 0.09 )</td>
<td>1.2</td>
</tr>
<tr>
<td>450 GeV</td>
<td>20 mm</td>
<td>1.4 ns (MD)</td>
<td>( j \times 0.1 \times 10^{-5} )</td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td>7 TeV</td>
<td>25 mm</td>
<td>1 ns (nominal)</td>
<td>( j \times 0.06 \times 10^{-5} )</td>
<td>( j \times 0.085 )</td>
<td>1.1</td>
</tr>
<tr>
<td>7 TeV</td>
<td>20 mm</td>
<td>1 ns (nominal)</td>
<td>( j \times 0.07 \times 10^{-5} )</td>
<td></td>
<td>1.4</td>
</tr>
</tbody>
</table>

→ small increase of impedance with the new geometry. However, it remains tiny compared to the total LHC impedance. Is a 25% increase in power loss ok?

Also: geometric \( \text{Im}(Z/n)=1.5 \times 10^{-4} \) Ohm