LHC aperture and ULO restrictions: are they a possible limitation in 2016?

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Evian, 15th December 2015
Introduction

• Available **machine aperture crucial** parameter for the **LHC operations**:
  
  ➢ At **450 GeV**: historical concerns on **tight aperture** design in superconductive magnets
  
  ➢ At **6.5 TeV**: reach in $\beta^*$ strongly connected with triplet aperture

• Precise knowledge of available aperture crucial to **push machine performance**

• Adequate **protection of bottleneck** has to be ensured at any time by the collimation system

  **Margins on collimation hierarchy** rescaled to ensure the best cleaning and machine protection performances (see Roderik’s talk on Thursday)

**Thus:**

✓ **Aperture measurements** performed every year during machine **commissioning (and MD)**

✓ Significant **UFO activity** in cell **15R8** triggered various studies that revealed the presence of an **unexpected restriction**: Unidentified Lying Object
Outline

- **ULO:**
  - ULO evolution in 2015
  - Where are we now?
  - How can we deal with it in 2016?
  - UFO at the ULO feature, activity and monitoring

- **Overview of 2015 aperture:**
  - 450 GeV
  - Proton physics: 80cm and 40cm $\beta^*$
  - Ions configuration

- **Conclusions**
UO:

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Conclusions
Motivations

✓ Significant UFO activity in cell 15R8 during machine commissioning (14 dump, 3 quench)


✓ Several *scans of local aperture* performed (12 between April and May)

Revealed presence of an *Unidentified Lying Object*

✓ *Investigations* on beam loss at the ULO location rely on three *main observables*:

  • Dedicated *local aperture measurements*
  
  • Analysis of *UFOs at the ULO* location
  
  • *Parasitic monitoring* of beam losses during standard cycles
Measurement procedure

4 correctors bump in V plane
3 correctors bump in H plane

Main measurement features:

- Beam shaped with IR7-TCPs: 4σ in V and 2σ in H
- Local aperture probed systematically:
  - Steps of 0.5mm at 450 GeV and 0.2mm at 6.5 TeV
- Max bump excursion:
  - in H ~ ±14mm (losses on Q15)
  - in V ~ ±8mm (losses on Q14 and Q16)

Beam screen
No losses at B15
1st losses at B15
Local aperture scan

• **Was it there** from the beginning of RunII?

  Initial though: *something frozen* on the top of the beam pipe *fallen due to warm up*

  **Answer:** *YES, it was there on the bottom but seems grown after the first warm up*

---

**Scan toward the top**

(13/4 First scan at ULO)
Local aperture scan

- **Was it there** from the beginning of RunII?
  
  Initial thought: *something frozen* on the top of the beam pipe *fallen due to warm up*
  
  Answer: **YES**, it was there on the bottom but seems grown after the first warm up
Local aperture scan

- **Was it there** from the beginning of RunII?

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  **Answer:** **YES, it was there on the bottom but seems grown after the first warm up**

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Scan **toward the top**

(13/4 First scan at ULO)

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**IR8**

**BLMBI.15R8.B0T20_MBA-MBB**

**Bump shape observed:**

**Nothing on the top!**
Was it there from the beginning of RunII?

Initial though: something frozen on the top of the beam pipe fallen due to warm up

Answer: YES, it was there on the bottom but seems grown after the first warm up
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Scan **toward the bottom**

(23/4 First scan after warm up)
Local aperture scan

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  **Scan toward the bottom**
  (23/4 First scan after warm up)

  Hard to say from RunI: different BLM positions

  IR8  BLMBI.15R8.B0T20_MBA-MBB
  Much clearer signature!
**ULO restriction in May 2015**

**Vertical** restriction **not constant**: typically 13-14 $\sigma$ at injection, but in a few cases less than 8 $\sigma$.

**Horizontal** position of ULO **stable**: *deployed local orbit bumps*

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No obvious limitations in operations (losses, collimation cleaning) **after bumps** were deployed.

Checked correlations with: intensity, energy, present and previous machine mode.

No clear correlation found!
ULO restriction now?

- Local aperture scan repeated with protons (15/11) and lead beams (10/12)
  - Consistent results obtained: **vertical dimension increased**

- What if it keep **growing is 2016**?
  - Still room to have at least 10σ in both planes (@ 450 GeV)
  - Possible best **new bump** to be decided based on **actual situation**

- Fixed bump of:
  - H = -3mm
  - V = +1mm

- ~5-6 σ\(_y\) (@ 450 GeV)

- Edge of the object

- Maximum shifts:
  - H = -6mm
  - V = +3.5mm

15/12/15
Daniele Mirarchi, Evian 2015
UFO at the ULO

Fixed bump deployed

Quench

Dump limit

25 ns (1) 25 ns (2)

50 ns

UFO at the ULO

Beam screen warm up to 70 K — 80 K

Very quiet period, considering the total intensity

Note: removed UFOs on beam1 and those originated at the quadrupole.

S. Redaelli, LMC, 18-11-2015

UFOs at ULO

0.01$

0.1$

1$

10$

100$

1000$

01/04$

21/05$

10/07$

29/08$

18/10$

Daniele Mirarchi, Evian 2015

S. Redaelli
Parasitic monitoring of beam losses

- Clear **loss spikes** (i.e. exp. decay and peak > 1e-6 Gy/s) looking at **1.3s BLM running sum**

  *Most of them synchronised with injection or inj. cleaning*

  Beam screen warm up: **No clear effect on loss rate!**

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- 14/11: Loss during setting up async. dump.
- 20/11: Synchro loop unstable when injecting 12 bunches
- 21/11: Emittances too high (tune problem at inj.)
- 23/11: Loss inj. cleaning
- 6/12: Wrong trim of tune

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- Bump in 15R8 (29/4) **Beneficial!**
- First inj. of 36b trains
- 2 dumps following ap. meas.
- 500Hz LM
- Beams lost in ramp during snapback
- Scrubbing for 50ns phys.
- Scrubbing for 25ns phys.
- OMC MD
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Global aperture at 450 GeV

Global aperture measurements allows to **identify machine bottleneck:**

- Only **TCP in place and opened** in steps of 0.5σ
- Gentle **ADT blow up** at each step, until **losses on aperture** are observed

**Example of continuous TCP scan and ADT blow up**
Global aperture measurements allows to **identify machine bottleneck**:

- Only **TCP in place and opened** in steps of 0.5σ
- Gentle **ADT blow up** at each step, **until losses on aperture** are observed

**Example of continuous TCP scan and ADT blow up**
Local aperture measurements are performed at bottleneck found with global measurements:

- Beam are shaped with TCPs at 4σ and available aperture probed with local bumps

Summary of bottleneck combining smallest global and local aperture measurements:

<table>
<thead>
<tr>
<th>Year</th>
<th>Element</th>
<th>Aperture [σ]</th>
<th>Year</th>
<th>Element</th>
<th>Aperture [σ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>B1H</td>
<td>11.6</td>
<td>2015</td>
<td>Q6R2</td>
<td>11.5</td>
</tr>
<tr>
<td></td>
<td>B1V</td>
<td>12.4</td>
<td></td>
<td>Q4L6</td>
<td>12.0</td>
</tr>
<tr>
<td></td>
<td>B2H</td>
<td>13.0</td>
<td></td>
<td>Q5R6</td>
<td>12.5</td>
</tr>
<tr>
<td></td>
<td>B2V</td>
<td>12.7</td>
<td></td>
<td>Q4R6</td>
<td>12.5</td>
</tr>
</tbody>
</table>

\[ A_{\text{bottleneck}} = A_{\text{bump}} + 4\sigma \]
MQX aperture at 6.5 TeV

- Measurements performed with squeezed and colliding beams, 80cm and 40cm $\beta^*$, p and Pb

- Similar approach of global aperture at Injection:
  - Only TCTs in place and opened in steps of 0.5$\sigma$
  - Gentle ADT blow up at each step, until losses moved from TCT to MQX

Summary of triplets aperture measurements with squeezed beams:

<table>
<thead>
<tr>
<th>Protons</th>
<th>Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\beta^*$ = 80cm</td>
</tr>
<tr>
<td></td>
<td>Xing = 145 $\mu$rad</td>
</tr>
<tr>
<td>B1H</td>
<td>16.7</td>
</tr>
<tr>
<td>B1V</td>
<td>15.7</td>
</tr>
<tr>
<td>B2H</td>
<td>&gt;18.7</td>
</tr>
<tr>
<td>B2V</td>
<td>15.7</td>
</tr>
</tbody>
</table>

Good agreement with predictions: 15.9$\sigma$ with 80cm $\beta^*$, 9.5 with 40cm $\beta^*$ (R. Bruce, Chamonix ‘14)
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Conclusions

• Unidentified Lying Object:
  ✓ Present since beginning of 2015 and maybe earlier (different BLM positions in RunI)
  ✓ Although initial concerns (14 dump, 3 quench) it was not a main limitation in 2015
  ✓ Fixed bump to “by-pass” the object beneficial on UFO rate and beam loss
  ✓ Hard to predict situation in 2016: lack understanding the nature of the ULO
  ✓ Still room to increase fixed orbit bump to get a least 10σ at 450 GeV in worst scenarios

  Crucial to perform local scan during 2016 commissioning to set optimum orbit bump, plus periodic beam loss monitoring and ULO scans to avoid any limitation to LHC operations

• Available machine aperture:
  ✓ At 450 GeV: 11.5σ for B1V
  ✓ At 6.5 TeV: 15.7σ with 80cm β*, 9.5σ with 40cm β*, for both beams in V
  ✓ With lead beams: 14σ for both beams in V

  Required aperture measurements in 2016 commissioning to check bottleneck evolution and to avoid any limitation to LHC operations
**UFO at the ULO**

*Is there any particular feature of UFOs in C15R8 w.r.t. UFOs in the rest of the ring?*

**Comparative analysis** between:

- All the dumps due to **UFOs at the ULO, UFOs in the machine, and programmed dump**

**FFT** of BLM that detected the UFO using **PM data**

**Characteristic FFT: UFOs in cell 15R8 generated by repeated passage of the beam on the ULO**
Stored energy in the machine

UFO limitations
more severe
with very low
intensities in the
LHC.

50 ns

25 ns (1)

25 ns (2)

100 ns
($\beta^*=90m$)

S. Redaelli
Example of multiple UFO at the ULO

16.04.2015 00:03:47

Monitor Losses versus Time

BLMB.15R8.BOT20.MBA-MBB

Total Losses = 4.2387 [Gray/s]
No obvious activity seen in C15R8
The most weird measurement...

Seems that we touched something with very small shift...but....