Special Losses

D. Mirarchi

On behalf of many colleagues from:

BE-ABP, BE-BI, BE-OP, BE-RF, EN-SMM, EN-STI, TE-CRG, TE-MPE, TE-VSC


9th Evian Workshop, 31st January 2019
Outline

I. UFO
II. ULO
III. 16L2
IV. 10Hz
V. Conclusions
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Introduction

There are UFOs and UFOs...

- Unidentified Falling Object:
  1. Dust particles falling into the beam (tens of μm)
  2. Inelastic proton-UFO collisions
  3. Hadronic showers and energy deposition on magnets coil
  4. Quench

Very fast failure! Few turns!
**UFO detection**

- **UFO detection** based on **Beam Loss Monitor**

- **Several studies** during the years and **changes on BLM threshold**

**Initial strategy:**
BLM threshold set to avoid quenches

**Spurious dump** on UFO that won’t lead to a quench

Downtime quenches < spurious dumps

Let’s increase thresholds!

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**Graphical Representation:**

- **2015**
  - 22 events (700h SB)
  - **2016**
    - 21 events (1780h SB)

**Quench Levels:**
- **Quenches arc/DS**
- **BLM dumps arc/DS (w/o quench)**
- **BLM dumps LSS (w/o quench)**
- **BCM dumps experiments**

**Notes:**
- *2015 events do not include dumps and quenches in cell 15R8 (ULO location)*
- **2017/18 events do not include dumps and quenches in cell 16L2**

**Event Breakdown:**
- **2015**
  - **2016**
    - 4 events as of 23/10 (1780h SB)
    - 2 events (1750h SB)
    - 2 events (750h SB)

**Optimization:**
- Arc/DS at 3 x quench level
- LSS at quench level
- Opt. at TCLs/TCTs/XRPs
Quench level and BLM threshold

Tight connection between quench level, BLM threshold and energy deposition simulations

- **Main lessons learnt:**
  - **Similar losses** in all quenches (within a factor of 2)
  - **Inelastic collision** in the range of $6\times10^7$-$1.2\times10^8$
  - **UFO radius** in the range of 40-100 µm

**Experimental validation of quench level models!**
UFO rate evolution

**UFO rates in the arc (cells ≥12) in stable beams**

- **Clear de-conditioning** during LS1 and **re-conditioning** during Run 2
- **Similar UFO rate** as end of Run 1 achieved after about 1.5-2 years
What to expect after LS2

Any redistribution of UFOs?

No significant changes due to LS1

Any difference between 6.5 TeV and 7 TeV?

Smaller UFOs can lead to a quench!

Any influence of magnet exchange?

- Exchange of some magnets created hot spot
- No correlation quench – hot spot

X = quench
down = magnet exchange in LS1/EYETS
**Introduction**

- **Significant UFO activity in cell 15R8** during commissioning in 2015 (14 dump, 3 quench)
- **First actions taken:**
  - Energy deposition simulations
  - Located vertex of hadronic showers at **MB.C15R8.B2 centre ±1m**
  - Local aperture measurements
  - Revealed presence of an **Unidentified Lying Object**
**ULO measurements**

**Measurement procedure:**

1. **Beam shaped with IR7-TCPs:** 2/4σ in H/V
2. **Local aperture probed** systematically:
   - H/V bump steps of **3/0.5mm**
3. **Max bump** excursion:
   - in **H ~ ±14mm** (losses at Q15)
   - in **V ~ ±8mm** (losses at Q14 and Q16)
ULO evolution and mitigation

- **Mitigation strategy:**
  Orbit bump to bypass it, while ensuring $10\sigma$ at injection

- **Constant monitoring during Run 2**
  ULO scan during commissioning to deploy optimal bump

  *Limitation successfully removed!*

  *Access planned mid-April, let’s see what it is!*

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CERN

LHC Collimation Project

Manchester 1824

The University of Manchester
I. UFO
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Introduction

- Sudden increase of losses in the half-cell 16L2 represented “The” machine limitation in 2017. 67 dumps induced: only two at injection, one quench induced at high energy.

- Three stages of loss rate:
  1. Steady loss in 16L2 arising during the ramp along the entire fill (~ few 1e-6 Gy/s)
  2. Sharp rise of losses in 16L2 “UFO-like” (1e-3 ÷ 1e-2 Gy/s)
  3. Very fast rise of losses at collimators triggering a dump (few ms)

FFT BLM: Revolution frequency in 16L2
dBLM: Vertical losses from all bunches

Something touched at every turn

Beams undergo betatron oscillations
Scattered particles reach primary collimators
Localization of the source

- **Energy deposition simulations** to identify longitudinal location of hadronic showers vertex

- **Estimated position:**

  \[ 2630.7 \text{ m} \leftrightarrow 2632.0 \text{ m} \]
Main correlations and mitigations

Clear correlation between losses and MCB current

Process sensitive to few mT!

Significant contribution by e-cloud on losses and Q shift along the train

- **Mitigation strategy:**
  - Dipolar field of MCBs
  - 8b4e filling pattern
  - Solenoid in the field free region of the interconnection
  - BCM production scheme

Dipolar field of MCBs
8b4e filling pattern
Solenoid in the field free region of the interconnection
BCM production scheme

1357 b, 1.10e11 ppb, 25 ns

1284 b, 1.04e11 ppb, 50 ns

10% increase of ppb in 2017
Mitigation at inj. in 2018

Prevent “UFO-like” events suppressing multipacting

Brighter beams
Lessons learnt and actions taken

- **Team work made the difference:**
  - Many people involved and actions also discussed in a dedicated Task Force
  - Additional hardware installed with impressive schedule

- Most probable scenario: **Accidental air venting** during the removal of the mobile group for the final pinch-off (EYETS 2016-2017)
  - Upgraded pumping ports design
  - New pumping scheme and procedure integrated into a dedicated QA and checklist

- Temperature up to **80-90 K and analysis of gas** released (YETS 2017-2018)
  - Compromise between risks associated to bring a sector to room temperature and vacuum quality reached

- Few dump events in **2018** with gradual **conditioning along the year**
  - Mitigated with few hours in SB with 900 bunches
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• **8 dumps** with similar signature in 2018:
  1. during the p-p run
  2. during the Pb-Pb run (out of 48 physics fills)

1. **Hor. trajectory oscillation at 8-12 Hz**

![Image of oscillation](image)

2. **Increasing losses at the TCPs**

![Image of losses](image)

3. **Dump on losses**

![Image of losses](image)

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**Limiting locations:**
- TCSG.A5L7.B1
- MQ.13R7.B1
- TCTPH.4L1.B1

*Losses above BLM threshold (set at quench level)*
Present understanding

• Where is the origin of these oscillations?

Kink and orbit displacement of both beams compatible with horizontal movement of MQ

• At which point of the cycle do they start?
  ADT and 100Hz BLM at TCPs show that are always present

• No ITR2 cryostat movement measured by survey team
  Internal vibration? Origin at Q4-Q5?

• First time that IP2 squeezed to 50 cm during Pb-Pb run: induced displacement amplified
  Why 21L4 during p-p run (β_x=180m)?
Possible actions and mitigations

- Crucial **better understanding** of the events:
  - ✓ **What is the trigger** of sudden amplitude increase?
  - ✓ **Will the amplitude keep increasing**?

- **Present studies** based on dump events and **PM data**:
  - ✓ **More observations needed** and study events not leading to dump
  - ✓ **T-b-T BPM acquisition** triggered when these oscillation are detected?
  - ✓ **Accelerometer on cryostat** of suspected MQs?

- Dump triggered by **losses** due to **beam halo** intercepted by TCPs: **possible mitigations**?

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**Improved cleaning**

- Measured margin of a factor >10 with **crystal collimation**

**Active halo control**

- Estimated orbit displacement \(~0.5\sigma\)
- Installation of **TCLD** in IR7-DS planned in LS2
- **Hollow electron lens** could efficiently deplete it (Run 4?)
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Conclusions

• **Unidentified Falling Object:**
  Experimental validation of quench level models and improved BLM threshold strategy
  Hard to predict UFO rate right after LS2: in the range 2012-2015, if equivalent to LS1

• **Unidentified Lying Object:**
  Successfully mitigated during Run 2 by means of local orbit bump
  Access mid-April: if something found, remove it. If nothing found, replace magnet?

• **16L2:**
  Significant limitation in 2017, successfully mitigated and target integrated lumi reached
  Most probable cause identified and actions taken to avoid repetition
  Should literally “evaporate” during LS2 with warm up to room temperature

• **10Hz:**
  Sound explanation found for events during 2018 Pb run
  Still more to understand on the trigger and dump during p run (improved diagnostic?)
  Possible loss mitigation: crystal collimation and TCLD (Run 3?), hollow e-lens (Run 4?)

*Team work: many people involved, many ideas, many actions taken and mitigations found!*
Thanks for your attention!
Outline

BACKUP
Outline

UFO...
BLM dumps and quenches: regular UFOs vs ULO/16L2

Includes 12 quenches:
- 8x UFOs
- 3x ULO
- 1x 16L2

A. Lechner

*ULO data from B. Auchmann
Cumulative number of UFOs (cells $ \geq 12$) in stable beams (2015-2018)

$\Rightarrow$ more relevant for the likelihood of a quench $\Rightarrow$ # of UFO events accumulated over time

<table>
<thead>
<tr>
<th>Year</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative # of UFOs in SB</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Orange cross = UFO quench

2 quenches

Cumulative hours in SB (fills with $>100$ bunches only)

Only fills with $>100b$ per beam, includes triggers on all Run 2 standard BLMs (RS04 detection threshold: $2 \times 10^{-4}$ Gy/sec)
Arc UFO rate (cells ≥12) vs beam intensity

2012 intensity ramp-up

4 TeV, 50 ns
(Fills 2482-2536)

#UFOs/hour in SB

Beam intensity (10^{14} protons)

0 0.5 1 1.5 2

2016 intensity ramp-up

6.5 TeV, 25 ns
(Fills 4895-4990)

#UFOs/hour in SB

0 0.5 1 1.5 2 2.5

Only fills with ≥ 1 h in STABLE and with > 100b per beam.

A. Lechner
Normalized fill-by-fill arc UFO rates (cells ≥12) in stable beams (2012-2018)

UFO rate (cells ≥12) in stable beams, normalized to beam intensity:

Only fills with ≥1 h in STABLE and with >100b per beam, only BLMs common to Run 1 and Run 2.
Can we compare Run 1 and Run 2 UFO rates?

Yes (at least to a good approximation), if ...

... we use different detection thresholds to account for the different beam energy
... we focus on a subset of BLMs common to both runs

Run 1 BLM layout:

Run 2 BLM layout:
ULO...
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!

First beams of RunII

First inj. of 36b trains

2 dumps following ap. meas.

500Hz LM

Bump in 15R8 (29/4)
Beneficial!

Beams lost in ramp during snapback

Scrubbing for 50ns phys.

Scrubbing for 25ns phys.

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
UFO at the ULO

Fixed bump deployed

Quench

Dump limit

25 ns (1)

25 ns (2)

50 ns

Ratio BLM signal / thresholds

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

14

0.01$

0.1$

1$

10$

100$

1000$

01/04$ 21/05$ 10/07$ 29/08$ 18/10$

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Outline

16L2...
Overview of 2017 run

Main mitigation steps of the year:

- Change of 16L2 orbit corrector (MCB) current
- Change to 8b4e filling scheme
- Installation of solenoid

Day with ≥ 1 dump by 16L2

29/01/2018 LHC Performance Workshop, D. Mirarchi
First dump by 16L2

- First dump event: **First fill with 72b trains** during Scrubbing run (1236b)

  **Fill 5725, 29th of May**

- **First action taken right after this event:**
  - ✔ Local aperture measurements  ➡️ No evident aperture restriction found

- **First hints on the source of this event:**
  - ✔ Clear signature of losses from both beams  ➡️ Both beams interacting with nuclei
Mitigation using MCB field

- Action taken the 20\textsuperscript{th} of July:
  - Operational bump to set $I_{MCB} > 2.5$ A
  - MCB removed from orbit feedback

  \textit{Smooth 25 ns operations restored!}

$I_{MCB}$ set to $\sim 0$ A after $\sim 2$ h in Stable Beams:

Beams dumped by 16L2 event about 6 min after $I_{MCB} \sim 0$ A
Beam screen to 80K

- Two warm up of the beam screen only, performed between 10th and 13th of August

  Abnormal increase of pressure observed by additional gauges installed (up to 2e-3 mbar!)

- Main effects:
  - Change of $I_{MCB}$ no longer sufficient
  - Steady losses reduced but significant spikes
  - Clear correlation between spikes and dumps
  - Reduced intensity to get to Stable Beams

- Possible explanation:
  1. Accidental air venting during at the end of EYETS
  2. Part of the evaporated gas condensed in cold spots in the interconnection area during beam screen thermal regeneration
Change to 8b4e plus solenoid

- **Significant contribution by e-cloud** on losses from tests with 50 ns beams and Q shift along the train observable in the post-mortem of the dump occurring as a result of the instability

- Change to 8b4e filling pattern to reduce multipacting
  - Loss spikes reduced significantly and smooth operations restored!
  - 16L2 events occurred when ppb > 1.17e11

- Installation of solenoid and change to BCS production scheme to increase bunch brightness
  - Multipacting reduced also in the field free region of the interconnection
  - 16L2 events occurred when ppb > 1.3e11!

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**Diagram:**

- Day with ≥ 1 dump by 16L2

- ppb threshold w/o solenoid
- ppb threshold with solenoid

**Legend:**

- TS2 + MD3
- BCS production scheme
- Solenoid installation
Latest events

- **Operational bump to change of $I_{MCB}$ not incorporated in the 2.5 TeV cycle**
  - $I_{MCB}$ of Beam 2 at $\sim 0$ A
  - Dumps occurred in Beam 2
  - Confirmation impossible to run with $I_{MCB} \sim 0$ A

- **Limited time during MD4** to perform systematic tests on the effect of the solenoid:
  - Single fill with physics beams but solenoid OFF (8b4e BCS, 1868b, 1.25e11 ppb)
  - Dump during ramp confirmed beneficial effect of solenoid on intensity threshold
YETS plans

- **Initial plan:** bring all sector 12 to **room temperature**

- **First action:** temperature increased up to **80-90 K (including cold mass)** and analysis of the gas released

  - **Confirmed contamination by atmospheric air**

  ![Composition of Atmospheric Air](image)

  - **Estimated air entered:** 7 bar l per beam pipe $>$ 99.96% pumped $+$ Amount of gas reduced by $10^5$

  - **Estimated amount of water vapor:** 0.1 g per beam pipe $+$ Condensed on the pumping lines

- **Warm up stopped:**
  
  *Compromise between risks associated to bring a sector to room temperature and vacuum quality reached*
Avoid repetition

- **Most probable scenario:**
  
  Accidental air venting, 
  during the removal of the mobile group for the final pinch-off

- **New pumping scheme:** All the pump groups installed in positions equipped with vacuum gauges

  Detection of air entering during mechanical activities

- **Removal of pumping groups before cool down:**

  Quick re-pumping in case of air leak, 
  no need of magnet warm up
Intensity Ramp up 2018

Average bunch intensity taken at Injection.
Intensity Ramp up 2018 (normalized)

Average bunch intensity taken at Injection.

Very early activity w.r.t. 2017 but clear conditioning after scrubbing

D. Mirarchi
Average bunch intensity taken at Injection.

- ppb (× 1e11)
- Spikes B1
- Spikes B2
- Dump B1
- Dump B2

3 dump events in B1 followed by 4 “thunderstorm”
Cured after fill 6746 with 900b recovery fill

D. Mirarchi
From TS1 to MD2 (2018)

Average bunch intensity taken at Injection.

Two dump events in B1 without following dumps due to “thunderstorm”

D. Mirarchi
One dump event in B1 without following dumps due to "thunderstorm"
From TS2 to end of Run2 p-p run (2018)

No dump events, only one single spike in B1

D. Mirarchi
• **Very early activity w.r.t. 2017** observed during intensity ramp up (first observation in 2017 during scrubbing run, in 2018 already visible with 75b)

• **Clear conditioning** after scrubbing and intensity ramp up

• **Still 7 dumps caused between end on intensity ramp up and TS1** (4 dumps caused by following “thunderstorm”)

• **Mitigation strategy** of the “thunderstorm” of recovery fill with 900b worked from fill 6746

• **Two dump events in B1 between TS1 and MD2** without following dumps due to “thunderstorm”

• **One dump event in B1 between MD2 and TS2** without following dumps due to “thunderstorm”

• **No dump and only one single spike in B1 from TS2 to end of Run 2 p-p run**
10Hz...
• Extreme peak-to-peak trajectory on B1 and B2, ratio B1/B2 ~2.4.
  • A kink is visible @ 21L4 for B1.
  • MICADO points to cell 21L4 for both B1 and B2, kick ~ 1 μrad @ MQ (on p2p traj excursion), consistent between B1 and B2 (also sign !).
Fill 7235 / pp kink

- Kink @ 21L4 clearly visible on normalized position of B1 and B2.
• Time evolution: estimate period ~1300 turns ~ 9 Hz.

- Ratio B1/B2 ~ 2.44, matches the ratio of $\sqrt{\beta_{x1}}/\sqrt{\beta_{x2}}$ for the H plane of cell 21L4.
- Consistent with a horizontal movement of the MQ in cell 21L4.
- Kick of 1 µrad $\rightarrow$ 37 µm quad displacement (p2p).
  - ~20 µm oscillation amplitude.

J. Wenninger
• Triplet modes at ~8, 11 and 12 Hz in horizontal plane.
• Fits rather well the observed frequencies...
Raw Oscillation

(a) Ion fill 7442

(b) Ion fill 7447

Figure: Horizontal beam displacement observed in all cases

X. Buffat and A. Oeftiger
BPM Spectrum

Ions 50cm

- Lines around 10Hz are **visible in the horizontal spectrum**
- **no lines** can be found in the **vertical spectrum**
- often two lines at around **10Hz and 12Hz**
- the **12Hz line** has usually **higher amplitude**
- sometimes only one line around 11Hz
- these lines are **visible for both**, Ions and Protons
- they are **more distinct for Ion optics**, especially in **Beam 2**
- **Injection does not show** clear lines.

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Figure: Beam 1 Frequency Spectrum of horizontal BPMs.

Figure: Beam 2 Frequency Spectrum of horizontal BPMs.

*J. Dilly*
100Hz BLM FFT

G. Trad
Heat Load VS Losses...
25 ns

Normalized losses

$10^{-1}$

The University of Manchester