UFOs in the LHC

Tobias Baer

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1. Introduction to LHC Machine Protection System
2. Fast Loss Events (UFOs)
3. Outlook and Mitigation
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Challenge: Stored Energy

- SPS incident in June 2008:
  400 GeV beam with 2 MJ  
  \[(J. Wenninger, CERN-BE-2009-003-OP)\]

- LHC stored beam energy:
  \[\text{Nominal intensity: } 3.2 \cdot 10^{14} \text{ protons.}\]
  \[\text{(2808 bunches)}\]
  \[\text{Nominal beam energy: } 7 \text{ TeV}\]
  \[\text{Nominal stored energy (beam): } 362 \text{ MJ}\]

- Stored energy in magnets (nominal): over 10 GJ

- Damage threshold: \(\approx 10 \text{ kJ}\) (5% of single bunch). \((R. Schmidt, \text{ PAC07})\)

- Quench limit: few mJ/cm³

- Now 3.5 TeV, 35 MJ. In 2011 up to 100 MJ.
Beam Collimation

- Three stage collimation system (≈100 collimators and absorbers)
  
  *primary (5.7σ): deflection*
  
  *secondary (8.5σ): absorption*
  
  *tertiary (15σ): triplet protection*
  
  *special dump and injection protection collimators*

1.2 m Collimator Opening
Beam Dump System

Length: about 8 m

Beam absorber (graphite)

Concrete shielding

up to 800°C
Beam Interlock System

• Over 200 systems can request a beam dump:
  
  * Power converter
  * BPMs
  * Collimators
  * Software Interlock System
  * Vacuum
  * Access system

**BLMs**

• ≈ 4000 BLMs

• 12 different integration times
  (40µs – 83.8s)
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Unconventional loss pattern:
Loss location often in the arc, timescale: 10 turns.
Until now: 20 emergency beam dumps due to fast loss events.

Fast loss event rate proportional to intensity
Fast Loss Event Rate

- After the increase of the BLM Threshold by a factor of 3 there were about **4.1 times less beam dumps** due to fast loss events.
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• 113 events below threshold found in 2010. *(E. Nebot)*

• **UFO rate**: proportional to beam intensity.
Events Below Threshold

- **Average signal**: no clear dependence on intensity

- **Loss duration**: tendency to decrease with intensity

*courtesy of E. B. Holzer and E. Nebot*
UFOs Detection in 2011

• Online UFO detection from live BLM data.
  
  *Losses (RS 4) of two BLMs in 40m are above 1E-4 Gy/s.*
  
  \[ RS_2 / RS_1 > 0.55 \text{ (UFO average: 0.89).} \]
  
  \[ RS_3 / RS_2 > 0.45 \text{ (UFO average: 0.79).} \]

• **Over 4000 triggers** so far.

  • From subset of 230 manually verified triggers:
    
    *About 70% are UFOs, 10% ambiguous cases, 20% are false triggers.*

  • For most analysis additional cut. E.g.:
    
    *Only flat top UFOs, loss of UFO BLM (RS05) > 5 \cdot 10^{-4} \text{ Gy/s (≈ 5 \% of threshold).}*

    *53 events remain of subset, of which 51 are clear UFOs (96\%) and 2 are ambiguous cases.*
Most events are much below threshold.
Spatial UFO Distribution

The UFOs are distributed all around the machine.

**38 candidate UFOs at injection kicker magnet for Beam 2.**

Mainly UFOs at injection kicker magnets.
UFO rate

On average: **10 UFOs/hour**

1978 candidate UFOs at 3.5 TeV. Data scaled with 0.7669 (detection efficiency from reference data)
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Dump of BLMQI.04L2.B1E20_MQY on 320µs, 640µs and 2.5ms integration time
• From fit to losses
  \textit{Amplitude: 0.63 Gy/s}
  \textit{Width: 0.29 ms}
UFOs at MKIs

- Since 08.04.2011 in total **460** fast loss events around MKIs. (**104** around MKI in IP2, **336** around MKI in IP8).

**Distribution of first BLM which sees the loss:**

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**Left of IP2**

**Right of IP8**
MKI UFOs During Scrubbing

- Typical scenario for MKI UFOs during scrubbing: Loss spikes occur in first few minutes after an injection and go away then.

Timeseries Chart between 2011-04-06 14:00:00.000 and 2011-04-06 16:00:00.000 (LOCAL_TIME)

2 hours
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Two extreme cases:

- UFO much larger than beam: the beam is imaging the UFO.
- UFO much smaller than beam: the UFO is imaging the beam.

Most UFO shapes are Gaussian, thus most UFOs are expected to be smaller than the beam.

From FLUKA simulations: size $\approx 1 \, \mu m$.

(cf. M. Sapinski, F. Zimmermann at Chamonix 2011)

courtesy of J. Wenninger (cf. MPP 25.03.2011)
UFO Speed

- UFO speed:
  \[ v_U = \frac{\sqrt{\sigma_b^2 + \sigma_U^2}}{\sigma_T} > \frac{\sigma_b}{\sigma_T} \]

  \[ v_U, \sigma_b, \sigma_U, \sigma_T: \text{UFO speed, transverse beam size, UFO size, temporal width of loss.} \]

- From free fall:
  \[ v_U = \sqrt{2 \cdot g \cdot h} = 0.63 \text{ m/s} \]

The UFO speed corresponds to the expected speed for a free fall from the aperture.
Correlation with Wire Scanner

From wire scans: linear dependency of BLM signal on beam energy
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Next Steps and Mitigation

- **Next Steps:**
  - Improve diagnostics *(acquisition of turn-by-turn data)*
  - Better localization of UFOs at injection kicker magnets *(simulations, additional BLMs)*
  - Determine real quench limit.

- **Mitigation Strategy:**
  - Increase BLM thresholds further *(For higher energies thresholds need to be decreased)*
Summary

• **20 emergency beam dumps** due to UFOs so far.

• **Over 4000 candidate UFOs** detected in 2011 so far.
  
  2 UFOs were dumping the beam.
  
  Most events at 3.5 TeV.
  
  Increased UFO rate around injection kicker magnets.

• UFOs are prospectively micrometer sized dust particles.

• Next step: improve the diagnostics.
  
  Acquisition of turn-by-turn BLM data.
  
  Installation of additional BLMs.
Thank you
for your Attention

Further information:

- M. Sapinski, “Is the BLM system ready to go to higher intensities?”, Workshop on LHC Performance, Chamonix, Jan. 2011.

Tobias Baer
CERN BE/OP
Tobias.Baer@cern.ch
Office: +41 22 76 75379
Backup slides
Known Dust Particle Sources

- Distributed ion pumps (PF-AR, HERA).
- Electrical Discharges (PF-AR).
- Movable Devices. (LHC)
- Particles frozen or condensed at cold elements. (ANKA)
Loss Time

- **Definition of $T_{loss}$**:

![Graph showing signal, noise level, and threshold over time](image)
Example: Loss at MKI for B1

- Loss starts at BLMEI.05L2.B1E20_MKI.C5L2.B1
- BLMQI.04L2.B1E20_MQY at 98% of dump threshold (RS5)
- At 3.5 TeV stable beams.
Example: UFOs at MKI R8


UFO at 1424 GeV, 768 bunches. Loss starts at BLMQI.04R8.B1I30_MQY.
Loss ratio for MKI UFOs B1

104 candidate UFOs around MKI for B1, no cuts.
Loss ratio for MKI UFOs B2

336 candidate UFOs around MKI for B2, no cuts.
From **simulations**:

- Dust particle will be positively ionized and be repelled from the beam.

  *Beam intensity: $2.3 \cdot 10^{12}$ protons, Al object.*

- Loss duration of a few ms.

  *Losses become shorter for larger beam intensities.*
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