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Update on UFO Dynamics Studies

Simulations and Run 2 events analysis

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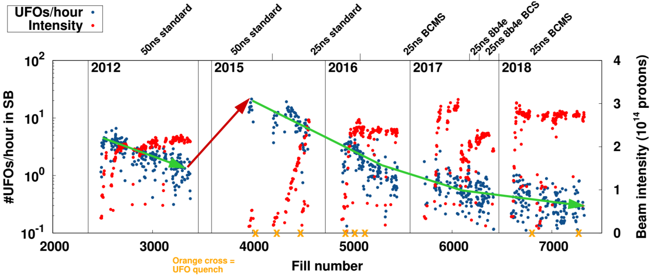
A word on UFOs

From A. Lechner : "Update about (non-16L2) UFOs" (2018)



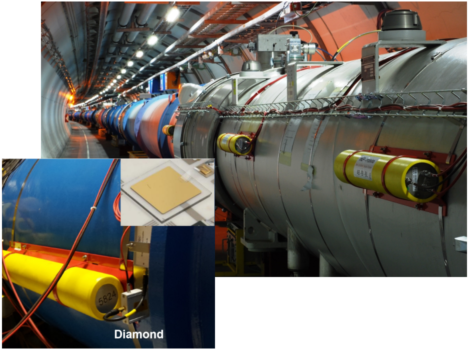
Why do we care?

- Beam dumps? Yes, 115 during Run 2
- Magnet quenches? Yes, 8 during Run 2
- Intensity drop? No, negligible during p-p physics (not an electron machine)

Data Collection

Instruments

- Beam Loss Monitors (BLM)
- Diamond BLMs (dBLM)



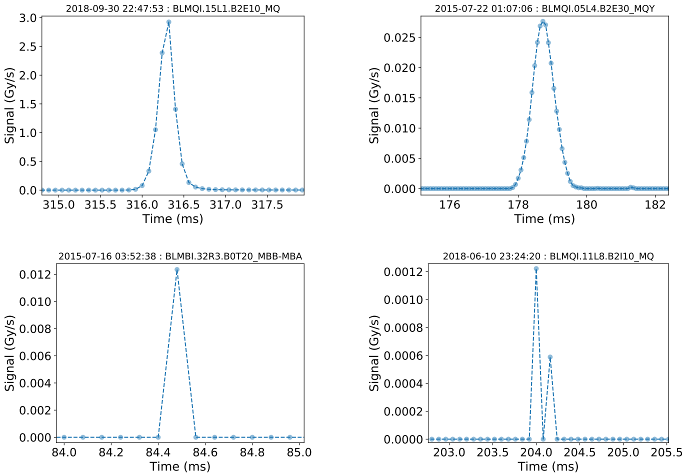
Databases

- UFO Buster :
  - Beam parameters
  - Triggers Capture Buffer : 80 μs resolution BLM signal
- Post-Mortem database : 40 μs resolution BLM signal
- dBLM database : 1.6 ns resolution diamond BLMs signal

Time profile examples

Some events with signal

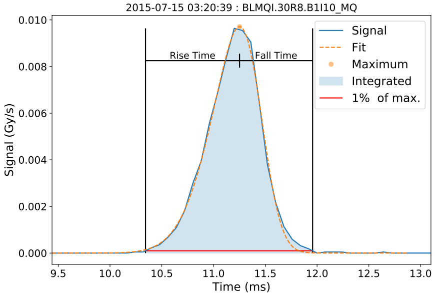
And some with not much information...



Time profile examples - Measurements

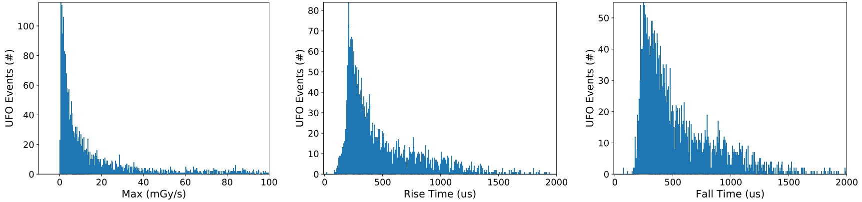
Source	Number of events
UFO Buster	337,217
Matching Capture Buffer	57,262
→ Filter 1 (SNR > threshold)	32,137
→ Filter 2 (min. 5 points signal)	3,035

Following slides: (Filter 2 row)



Measurements overview

Parameter		Min.	-	Max.
Maximum Losses	(Gy/s)	9.05×10^{-5}	-	3.16
Integrated Signal	(Gy)	2.90×10^{-8}	-	2.02×10^{-3}
Rise Time	(μs)	91	-	4241
Fall Time	(μs)	109	-	3876
Full length	(μs)	317	-	7118

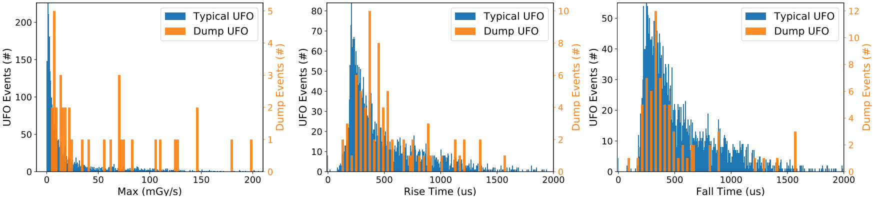


Normal UFOs v.s. Dump UFOs

Dump UFOs seem to have :

- Higher losses
- Longer rise time
- Shorter fall time

However, not a lot of statistics... In-depth analysis of the dump UFOs is still to be done.

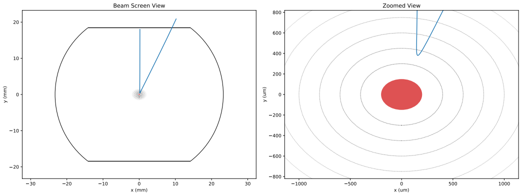


Dynamics Simulation Tool

Tool developed (starting in 2010, F. Zimmermann, B. Auchmann *et al.*) to simulate UFO dynamics :

1. UFO begins to fall and/or be attracted toward the proton beam
2. UFO-beam interaction knocks-off electrons in the UFO (ionization) and lead to proton losses
3. The charged UFO is repelled by the beam

Recently translated in Python by R. Schmidt, and under continuous development

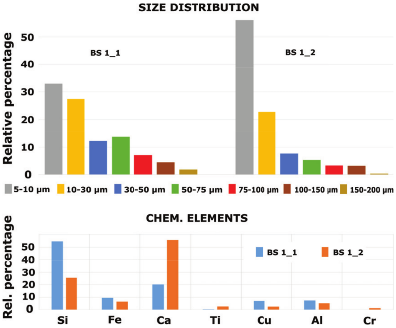


Simulations - Parameter scan

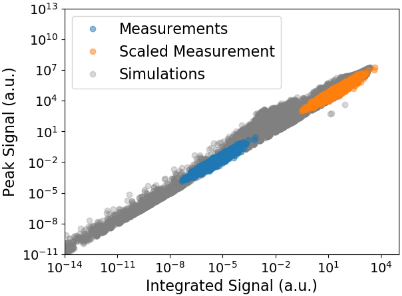
- Range of parameters is based on past studies:
  - FLUKA simulations (A. Lechner)
  - Dust collection in the beam pipe (L. Grob)

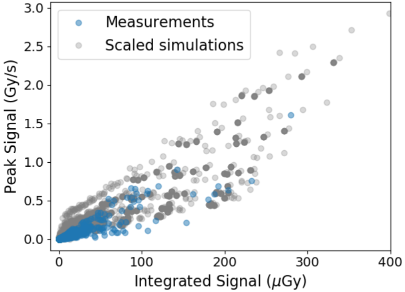
Parameter	Values
UFO Charge	$0 - 10^8 \cdot (-e)$
UFO Position	Top of beam screen
UFO Radius	$1\ \mu m - 50\ \mu m$
UFO Material	Cu, Si, Al
Beam Energy	6.5 TeV
Beam Intensity	$3 \times 10^{10} - 3 \times 10^{14}$
Beam σ_x	$50\ \mu m - 500\ \mu m$
Beam σ_y	$50\ \mu m - 500\ \mu m$

From L. Grob : "Dust Analysis From LHC Vacuum System to Identify the Source of Macro Particle-Beam-Interactions" (2019)



Simulations - Results





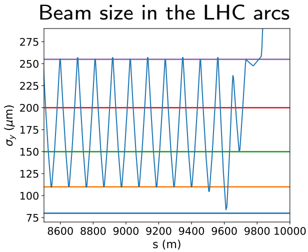
Log-Log axis

- Expected "calibration" constant (BLM response to incoming particles)
- Can be calculated with FLUKA
- Scaled measurements move along the simulated line : compatible with the need for this BLM calibration

Regular axis

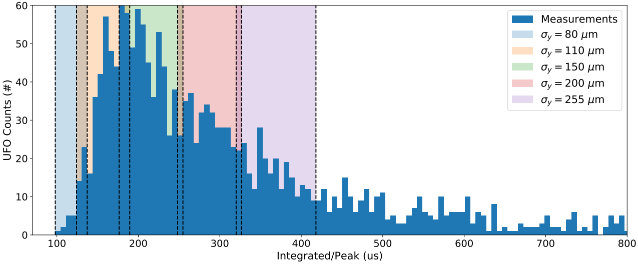
- Range of σ_y influences the thickness of the simulation band (left figure) and the slope (right figure)
- Coverage is compatible with measurements for same σ_y range

Simulations - Beam size



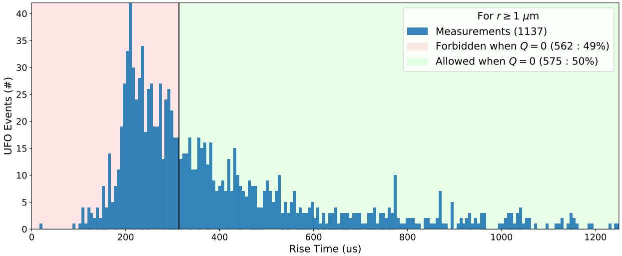
Let's look at the ratio (Integrated signal)/(Peak Signal)

- Units of seconds
- Independent of the BLM calibration
- Equivalent to time spent in the beam by the UFO
- From previous slide : highly dependant on σ_y



Simulations - UFO Charge

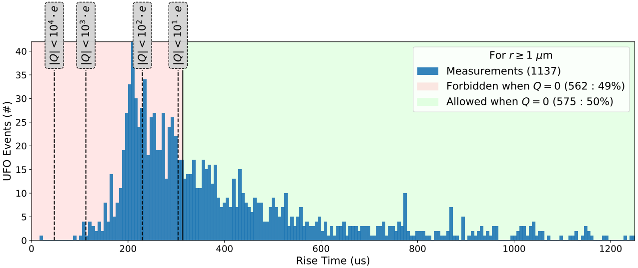
- Since 2010, it is hypothesized that the fall of UFOs is not only driven by gravity
- We can verify this hypothesis by fixing $Q = 0$ (no UFO charge) and scanning through all the other parameters



UFO dynamics driven by gravity alone is incompatible with measurements!

Simulations - UFO Charge

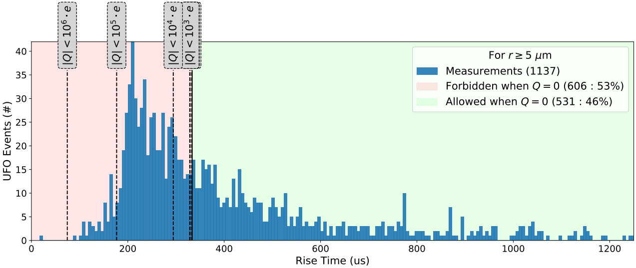
- Next logical step : what is the minimum charge which allows to explain the measurements?



UFOs are generally charged with $|Q| > 1000 \cdot e$ $(-1.6 \times 10^{-16}$ C)

Simulations - UFO Charge

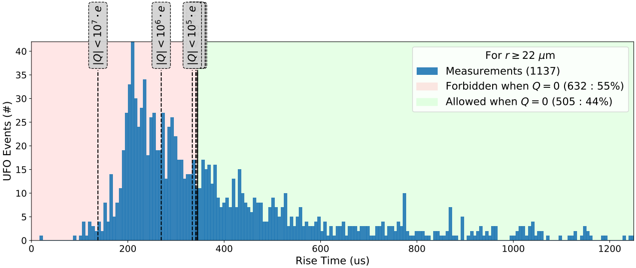
- With increasing UFO radius, more and more charges are needed to explain the measurements



UFOs with $r \geq 5\ \mu$m are generally charged with $|Q| > 10^6 \cdot e$ $(-1.6 \times 10^{-13}$ C)

Simulations - UFO Charge

- With increasing UFO radius, more and more charges are needed to explain the measurements



UFOs with $r \geq 22\ \mu$m are generally charged with $|Q| > 10^7 \cdot e$ $(-1.6 \times 10^{-12}$ C)

Conclusion

- For the first time, time profiles from the UFO Buster were investigated. Only 1% of the events contain appreciable signal on which we can make measurements.
- Studied UFO time profiles in a systematic way
  - First measurements of key parameters in UFO time profiles
  - First comparison between dump UFOs and UFO Buster UFOs
- Validation of the accepted UFO parameters against dynamics simulations.
- Studied the effect of the beam size on UFO time profiles.
- Showed that gravity alone can't explain Run 2 measurements.
- Established a lower bound of 10^6 electrons as the initial UFO charge for radius above 5 μm in order to explain all measurements.
- Overall : gathered important statistics which could help understand release mechanism!

Outlook

- In-depth comparison of dump UFOs with UFO Buster events is needed in order to validate our understanding.
- Comparison of the UFO rate from confirmed UFO events against all UFO Buster triggers.
- Systematic categorization of UFOs into families is needed
  - Comparison of statistics from confirmed UFO events against all UFO Buster triggers
  - Comparison of known UFO types (16L2, ULO, MKI) against all other events
- Incorporating the BLM calibration factor from FLUKA simulations in the analysis is vital in order to solidify our understanding and come to new conclusions.
- Monte-Carlo simulations with appropriate distributions for the input parameters of the dynamics simulation is needed to further our understanding.

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Summary of work done

Since January 2019 :

- Literature review of previous UFO studies.
- Development of a more accurate description of the electric field around the LHC proton beam.
- Upgrade of the UFO Dynamics Simulation Tool
- Development of new methods of analysis for studying UFO bunch-by-bunch signals.
- Gathering of all available data from standard beam operation between 2015 and 2018. First look and direct conclusions.
- Started an in-depth analysis of the data mentioned above.

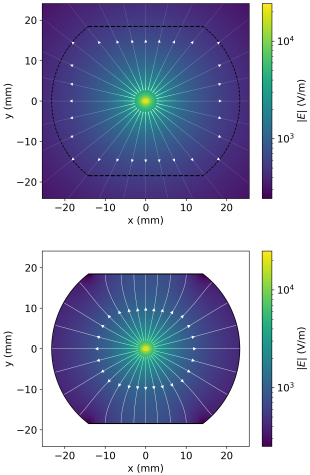
E-field around the LHC proton beam

- Original approximation considered the Houssais E-field in free space (i.e. no beam screen)

- A new method to solve Laplace's equation for complex boundary conditions was developed and allowed to find a more accurate description of the E-field

Bélanger, P. (2019). Generalizing the Method of Images for Complex Boundary Conditions : Application on the LHC Beam Screen.

https://arxiv.org/abs/1905.03405



E-field around the LHC proton beam

Conclusion : ignoring the beam screen accounts for an error of 1% in the E-field at 1σ from the center of the beam and 10% at 30σ

The method developed can also be used for off-centered beam, at really low computing cost.