TRIUMF

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Progress report : UFO Dynamics studies

(From the collaboration on UFO studies between TRIUMF and CERN HL-LHC)

Context

Unidentified Falling Objects (UFOs) present in the LHC beam pipe have been under continuous study since the start of LHC operation. While there are still a lot of unknowns related to UFOs, they are believed to be micrometer-sized dust particles falling into the LHC beam and causing protons losses which can sometimes lead to protective beam dumps or even magnet quenches.

Initial Task Description

The agreement between the two parties stipulates that "TRIUMF shall contribute to the investigation of the origin, the generation mechanism and dynamics of UFOs and their criticality for the operation of LHC at 7 TeV as well as with increased beam intensities in the HL-LHC era". The project is divided into three main objectives :

1. Analysis of UFO loss data recorded during standard beam operation and dedicated beam experiments

2. Modelling of the UFO movement dynamics

3. Simulation of beam particle interactions and their impact on accelerator equipment like superconducting magnets

Work performed

Upgrade of the UFO Dynamics Simulation Tool

The code (in Python) from the existing UFO Dynamics Simulation Tool was updated in order to facilitate the implementation of new physics and to allow testing different new hypotheses in the future. A crosscheck between the simulation tool and the paper describing the underlying physics was performed, revealing some small bugs. Moreover, a new module able to simulate multiple events in batch was implemented, allowing to study the effect of different parameters sequentially and preparing for future Monte-Carlo simulations.

While working on the simulation tool, the assumptions regarding the calculation of the electric field from the LHC beam were tested. It was found that neglecting the beam screen (as it was done in the past) accounts for a large error in the electric field, tens of sigmas away from the center of the beam. In order to simulate the dynamics of charged UFOs, an accurate description of the electric field is necessary everywhere around the beam. Hence, a numerical method to accurately calculate this field was developed and implemented in the simulation tool. The findings were reported in a note on the subject (*Generalizing the Method of Images for Complex Boundary Conditions : Application on the LHC Beam Screen*, url : `https://arxiv.org/abs/1905.03405`).

Development of new methods of analysis in the study of UFO bunch-by-bunch signals

New methods making use of the different bunch parameters (bunch-by-bunch emittance and intensity) were developed to be used with the diamond beam loss monitors measurements (bunch-by-bunch losses). Those methods are still under development, as described below:

UFO True Range Multilateration (TRM): In principle, combining losses from a pair of bunches and knowing their emittance and intensity, we can restrain the UFO position at a given time to a curve in real space (either an ellipse or an hyperbola). Looking at multiple pairs of bunches within a narrow time frame, we would expect those curves to agree upon the actual position of the UFO. A proof of principle using simulated UFO trajectories showed the validity of the method. However, applying it to the measured data revealed limitations which are currently under study.

UFO Angular Position: Generally, we expect to see a correlation between the bunch sizes and the UFO losses coming from those bunches. Hence, for a given UFO angular position, the correlation coefficient between the bunch losses and the bunch sizes should be maximal when the bunch sizes are measured along the corresponding angle. The strategy applied in this method is to look for the angle which maximises this correlation coefficient in order to get a measurement of the UFO angular position at a given time. This method is still under study and requires a proof of principle before being applied to the measurement data.

Data Collection

UFO-related losses have been recorded by 2 different beam loss monitors during Run 2 : Ionization Chamber BLMs (ICBLMs) and Diamond BLMs (dBLMs). The majority of the time profiles collected during Run 2 were recorded by the UFO Buster, a tool designed to detect UFO events and trigger the recording of the ICBLM signals with a 80 μs resolution. Likewise, the Post-Mortem system records the ICBLM signals with a 40 μs resolution whenever a protective beam dump is triggered. The corresponding database contains the UFO time profiles for all beam dumps caused by UFOs. Finally, the dBLMs recording is triggered by an independent algorithm, which saves a 1.6 ns resolution bunch-by-bunch signal when a certain threshold is exceeded.

As a first step in the gathering of all available UFO data, the UFO Buster database was studied. From the 337,217 events recorded by the UFO Buster during Run 2, only 57,262 ICBLM time profiles were recorded. From there, filters were applied (signal to noise ratio and event length), which narrowed down the list of events to 3,035. The filters were chosen to keep only the time profiles on which it is possible to make meaningful analysis. The range of different important quantities found in those time profiles is reported in table 1. Those quantities were chosen to describe the time profiles as they can be measured without prior knowledge of the real underlying signal shape (avoid bias) and because they can be directly used to compare the simulations with the measurements.

Table 1: Range of important quantities observed in the UFO time profiles from Run 2

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

Data Analysis and Simulations

Using a wide range of reasonable UFO event parameters (radius, mass, material, beam energy, beam intensity, beam size) based on previous work on the subject, some 100,000 events were simulated. The key parameters from the simulated time profiles were then compared to the measured ones (see table 1). Overall, there is a good qualitative agreement between the simulations and the measured data, as it is possible to explain all the measured key parameters with the simulations. The main conclusions are presented below.

UFO Charge

Since 2010, it is hypothesized that the fall of UFOs is not only driven by gravity and that UFOs must carry an initial negative charge to explain some of the observations. In light of all the measurement from Run 2, this hypothesis can be tested. As shown on figure 1, simulations with an initially neutral UFO are incompatible with the measurements, as 49% of the observed rise times fall below the minimum rise time obtained in simulations. This result gives a strong indication that **UFOs are generally negatively charged before they interact with the beam**. From there, the initial UFO charge needed to explain the range of rise times observed in the measurements was studied. By iteratively repeating the simulations with increasing UFO charge, its was found that **UFOs generally carry an initial charge $|Q| > 10^6 \cdot e$ (or 1.6×10^{-13} C) before interacting with the beam**.

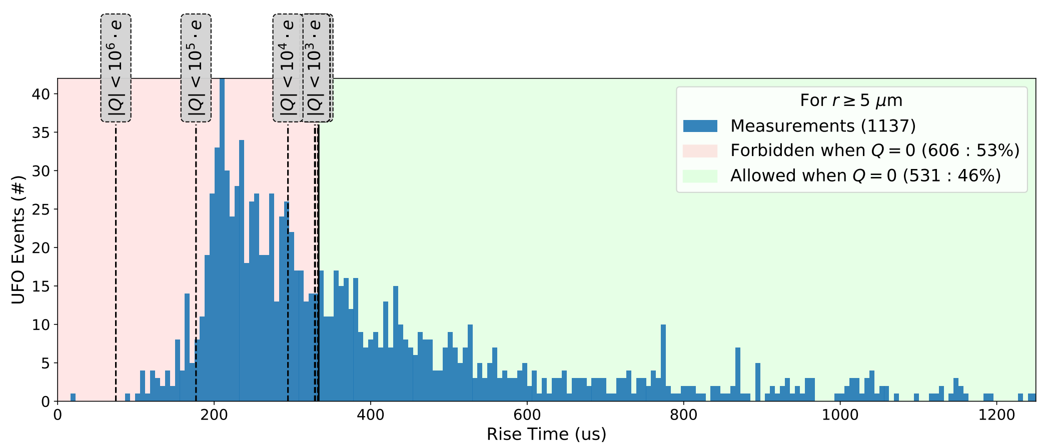

Figure 1: Distribution of rise time observed in the UFO measurements. The range of possible rise times found in the simulations assuming a neutral UFO is shown by the green region. The lower bound is shown for different initial UFO charge (Q) by the dashed lines.

Beam Size

Since the start of UFO studies, different methods were used to estimate the location of UFO events within standard LHC arc cells. It has been shown that FLUKA simulations can be used to make such estimations on a case-by-case basis. However, due to the complexity of the analysis, only a few events were analysed. In the analysis of the simulated time profiles, it was observed that the integrated signal to peak signal ratio is strongly correlated to the vertical beam size (σ_y). The ratios obtained from the measurements are shown on figure 2. Since the evolution of the beam size in the LHC is a well known quantity, it can be used to estimate the location of UFO events within a standard LHC arc cell.

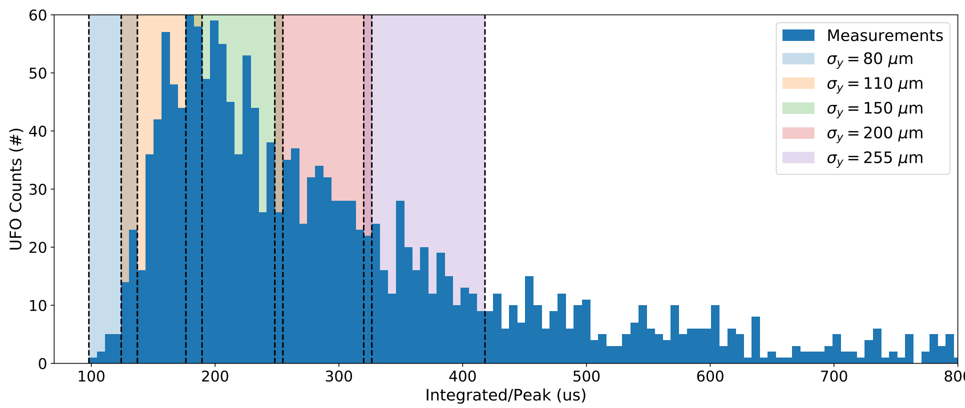

Figure 2: Distribution of integrated signal to peak signal ratio observed in the UFO measurements. The colored areas indicate the range corresponding to different vertical beam sizes in the simulations.

The integrated signal to peak signal ratio has some interesting properties : it is independent of the BLM response (calibration factor), and has units of seconds. It is equivalent to the time spent in the beam by the UFO. The results presented here are still under study, but a comparison between the measurements and the simulations suggests that the vertical beam size at the UFO interaction locations generally falls between 110 μm and 255 μm (β_y between 33 m and 180 m), as expected for standard arc cells. For reference, the evolution of the vertical beam size in a standard arc cell is shown on figure 3.

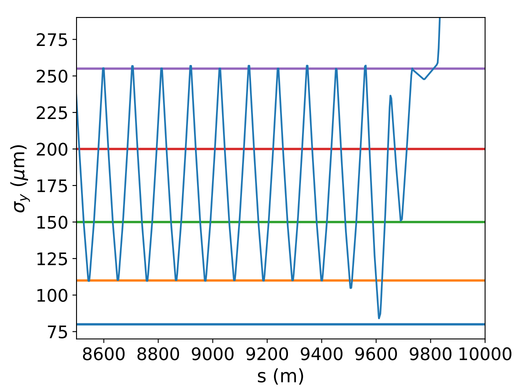

Figure 3: Evolution of the vertical beam size in a standard LHC arc cell assuming an emittance of 2.5 mm·mrad. The colored lines represent the beam sizes shown on figure 2.