FPGA-based algorithms for the new trigger system for the phase 2 Upgrade of the CMS Drift Tubes detector

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Introduction

The LHC upgrade and its associated luminosity increment is a challenge for all the detectors, that, accordingly, have to upgrade many of their subsystems in order to cope with the new expected particle's flux rate.

One of the affected CMS subsystems is the ***Drift Tube Chambers (DTs)***, which read-out electronics need to be replaced. This forces, as well, the change of the muon track-reconstruction mechanism that it is used for the first stage of the trigger system ***(L1A)***.

In the present work, we have developed a software algorithm, initially written in C++ programming language, but designed with its portability to a FPGA VHDL code in mind. It's based on the ***mean-timer paradigm***, and should be able to rebuild muon trajectories and reject spurious signals, and coping, at the same time, with the requirements of processing speed imposed by the detector upgrade.

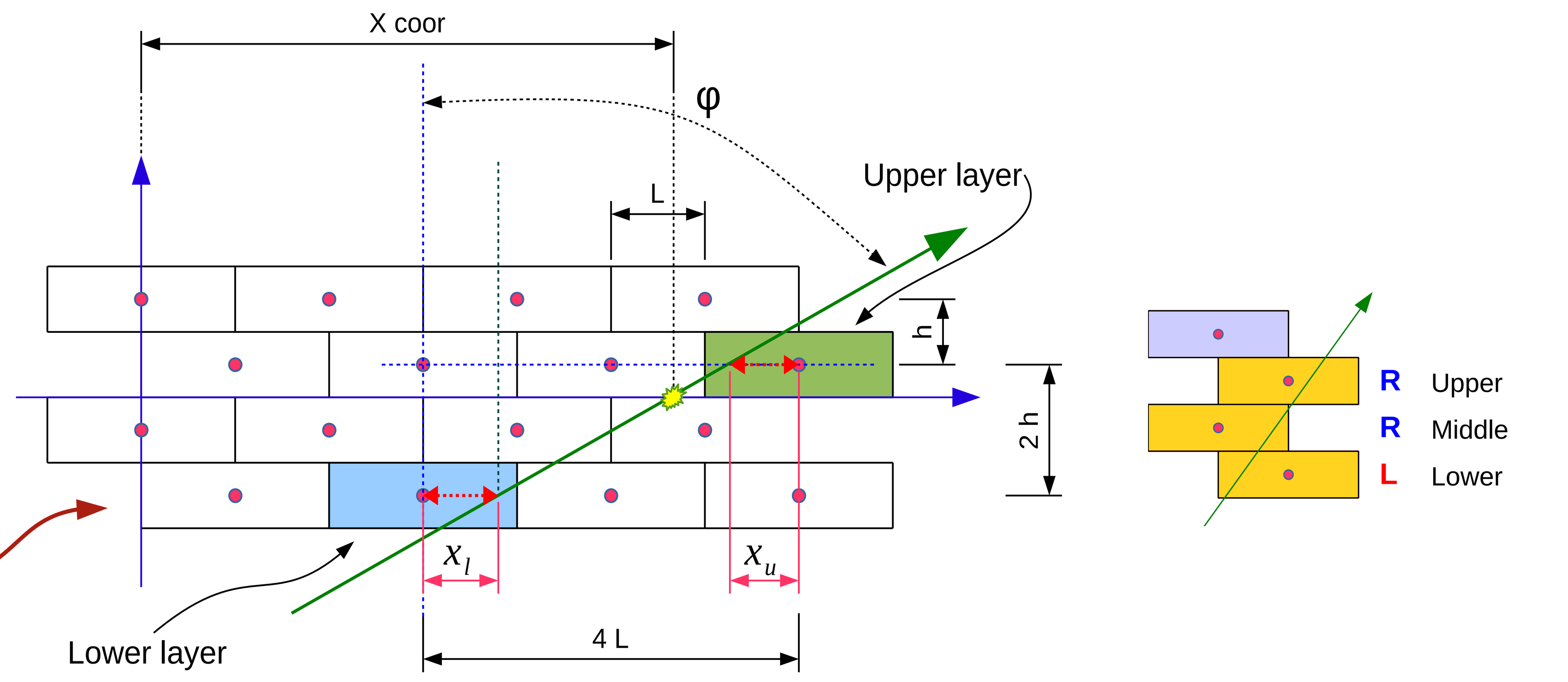
Principles and methods (I)

In the new scenario, pure ***DT*** cell chamber signals ("***hits***") –available for the former ***BTI ASIC***– are no longer useful. Instead, the particle's drift-time value from each chamber's cell should be used.

A variation of the original ***mean-timer*** method has been applied to convert 4 cells 32-bit TDC time values into muon trajectory's position and slope.

We start from a simple straight line equation, ***applying it to a couple*** of arbitrary ***DT*** chamber cells, and considering the 4 combinations of cell-wire sides where the particles could travel, because drift time gives no information about that. This ***LEFT – RIGHT ambiguity*** must be resolved.

$$y_u - y_l = cotg(\phi)\cdot(x_u - x_l)$$



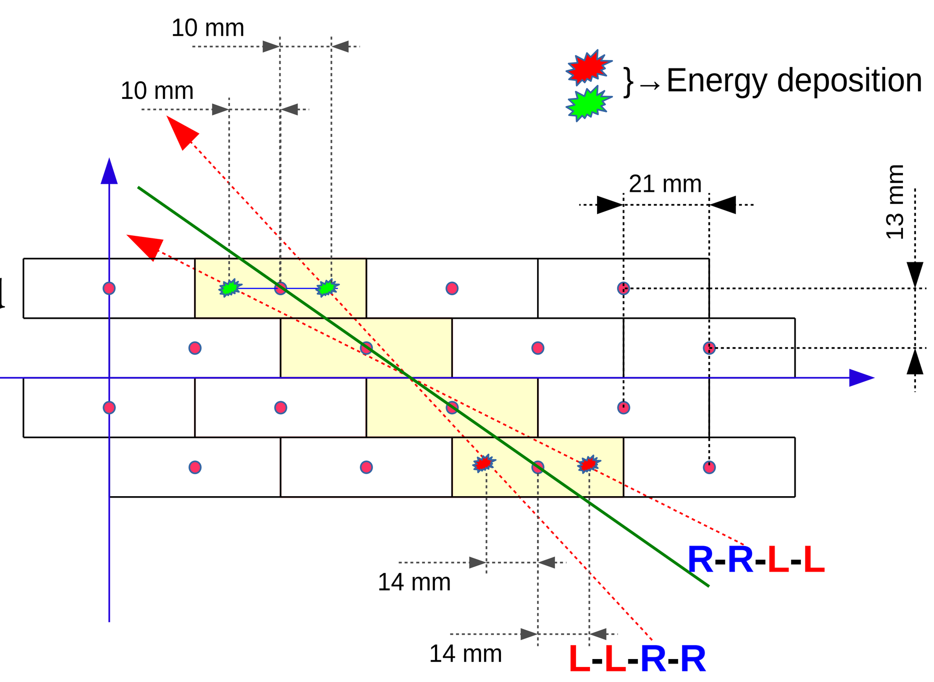
A set of spatial chamber-geometry-dependant equations are obtained after considering all cases, which differ only in a pair of signs from each other. This group of signs represent a ***laterality combination***.

$$L_{low}L_{up} \rightarrow H_{ul}\cdot L - x_u + x_l = V_{ul}\cdot h\cdot tg(\phi)$$
$$R_{low}R_{up} \rightarrow H_{ul}\cdot L + x_u - x_l = V_{ul}\cdot h\cdot tg(\phi)$$
$$L_{low}R_{up} \rightarrow H_{ul}\cdot L + x_u + x_l = V_{ul}\cdot h\cdot tg(\phi)$$
$$R_{low}L_{up} \rightarrow H_{ul}\cdot L - x_u - x_l = V_{ul}\cdot h\cdot tg(\phi)$$

Principles and methods (II)

It's not only necessary to accept or reject a group of hit's time-stamps as a particle candidate, but also to associate them with its ***bunch crossing (BX)*** value, as well as, at the same time, to resolve the ***lateral ambiguity***.

To achieve all of this, previous equations are applied to any group of cells, two by two, and are converted into a new unique time-dependant-form equation. Thus, it is established a condition to accept a group candidate, based on the existence of a ***BX*** valid time value: ***denominator's equation not null***, and resulting ***BX time-value positive***.



$$Bx_t = \frac{V_{um}\cdot(H_{ml}\cdot T + a\tau_m + b\tau_l) - V_{ml}\cdot(H_{um}\cdot T + c\tau_u + d\tau_m)}{V_{um}\cdot(a+b) - V_{ml}\cdot(c+d)}$$

BX acceptance condition

$$\tau'_i = \tau_i - Bx_t$$

$$V_{um}\cdot(H_{ml}\cdot T + a\tau'_m + b\tau'_l) - V_{ml}\cdot(H_{um}\cdot T + c\tau'_u + d\tau'_m) \le \Delta$$

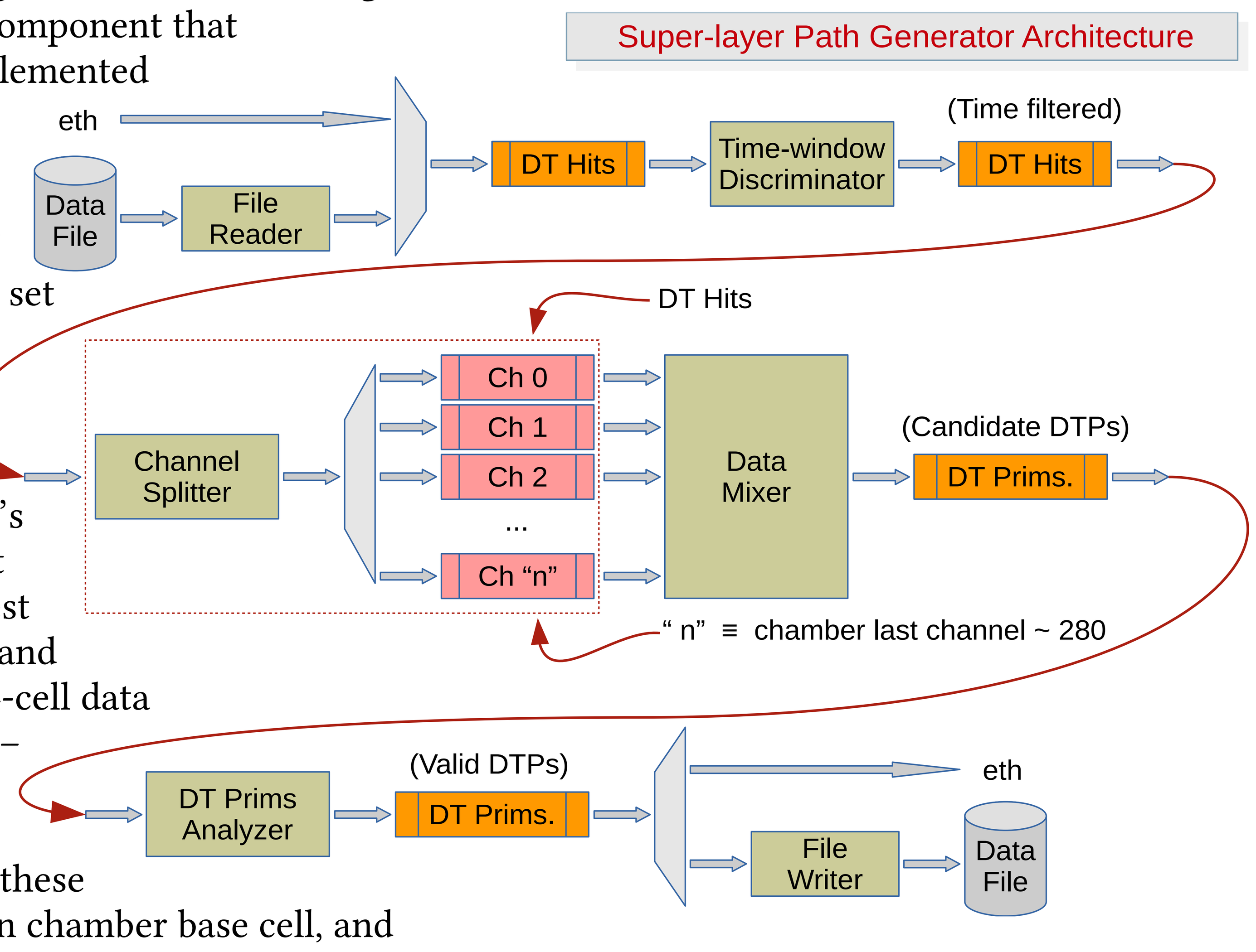
Aditional tolerance condition

Algorithm architecture

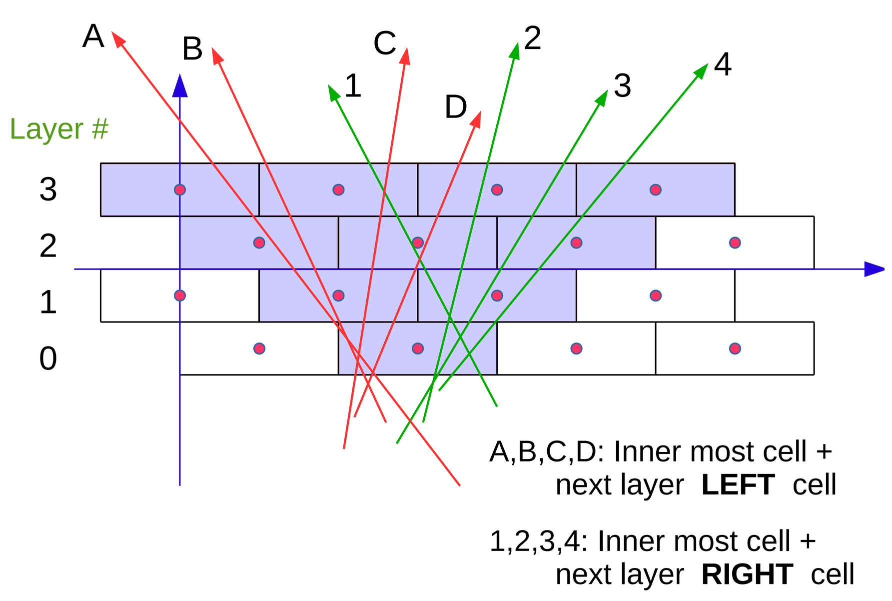
The algorithm is designed in multi-threading modular form, with component that will be able to be implemented into a FPGA.

It works over a pre-selected group of cells, and a simplified set of possible muon trajectories.

It gets TDC-time-stamps hit's data from the tadout electronics –on the test version, from a file–, and combines them into 4-cell data package –a candidate– according with a preselected group of possible paths. All of these paths share a common chamber base cell, and cover 10 chamber cells.



Then, each candidate is validated or rejected using the ***BX acceptance equation*** together with the ***tolerance condition***.



To achieve all of this, the following set of tasks are performed:

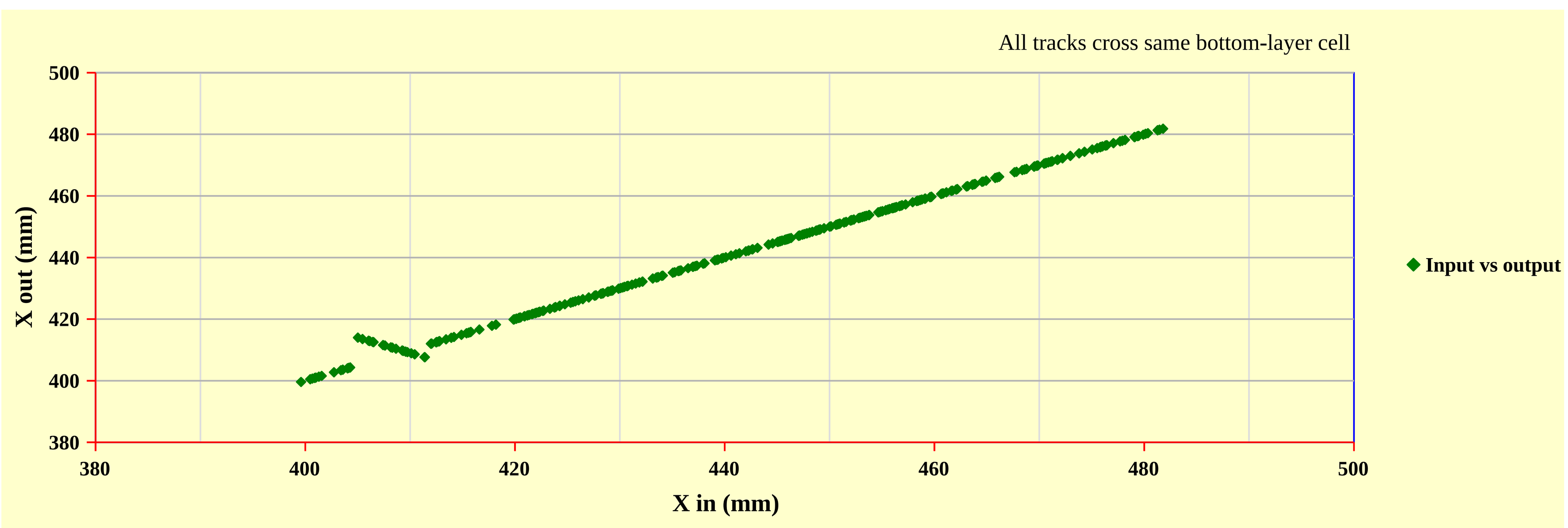
- Rejects data from noisy channels –***cells***–.
- Separates data –***hits***– from different channels into different buffers.
- For each base cell in the chamber, it mixes splitted hits accordingly to the correspondent preselected trajectories, and builds 4-cell candidate packages.
- Each candidate is analyzed taking into account every group of 3 cells and their ***laterality combinations***.
- Valid candidates are accepted and they are labeled with a quality level.

Results

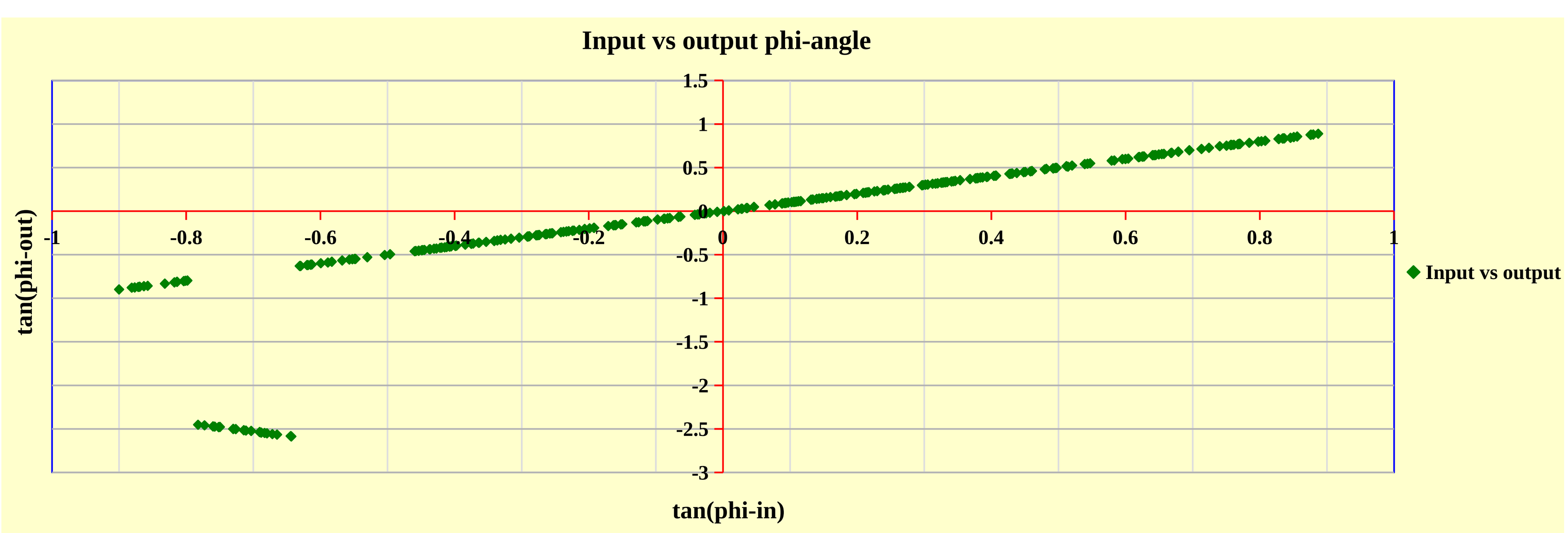
The algorithm has been tested using a prepared set of good muon trajectories. With the resulting data, two graphs have been depicted to compare input and reconstructed data, evaluating the performance of the algorithm's subprocedure in charge of ***DT primitive candidates*** analysis.

In both cases the agreement is good.

Comparison between generated and reconstructed chamber position



Comparison between generated and reconstructed trajectory slope



Conclusions

- Results point out that this algorithm is able to determine trajectories –using ***DT hits*** time measurements, referred to the ***BX = 0***, as starting point–, and that is a good candidate to face ***L1A*** upgrade plans.
- It solves, using a fast procedure, ***L-R cell ambiguity***, and also it's able to label with different quality levels those detected DT primitives valid candidates.
- Due to multithreading software architectural approach, translation to FPGA should be straight forward enough.
- It's pending to determine if timing requirements could be achieve, but it could only be done after FPGA implementation.
- Next step is to proceed with the characterisation of the restrictions to be applied in the hit rate, dead time, etc..., depending on the FPGA resources to be used, and to optimize the algorithm procedure in charge of creating primitives.

References

- **BTI Reference Manual.** – L. Castellani, M. Cavicchi, M. de Giorgi, R. Martinelli, A. J. da Ponte Sancho, P. Zotto
- **Diseño, construcción y validación del sistema de adquisición de datos de las cámaras de deriva del experimento CMS.** – C. F. Bedoya – Ph.D. Thesis. Universidad Complutense de Madrid: Spain.