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Real-time tracking system based on artificial retina algorithm. Testbeam results and future developments for application at HL-LHC.

Abstract: we present the testbeam results of a real-time tracking system[1] based on artificial retina[2], a highly parallelized algorithm for particle pattern recognition and track reconstruction. The system is a practical demonstrator designed in the context of the INFN-RETINA project, whose aim is to develop a fast track finding system capable to operate at 40 MHz event rate with several tracks per event in the high-luminosity LHC (HL-LHC) experiments. The prototype has been tested using a 180 GeV/c proton beam at the CERN Super Proton Synchrotron (SPS), reconstructing tracks in real time with sub-microsecond latencies and with track parameter resolutions comparable with the offline results. The next target is the implementation of the artificial retina for a 4D tracking system including the time information of the hits, that is particularly important to better associate the tracks to the correct proton-proton production vertex in case of high pile up as in the HL-LHC experiments.

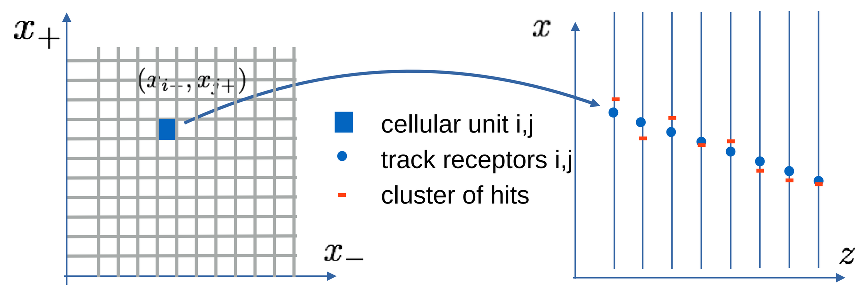
Artificial retina algorithm

The algorithm is based on a pool of cellular units that evaluate in parallel a response based on the proximity of the input hits to specific precomputed tracks.

Track candidates are identified by local maxima of the cells' response and the track parameters are recovered by interpolation of the response values near the maximum.

The algorithm is highly parallelized and well suitable for implementation in FPGA and application to high energy physics experiments.

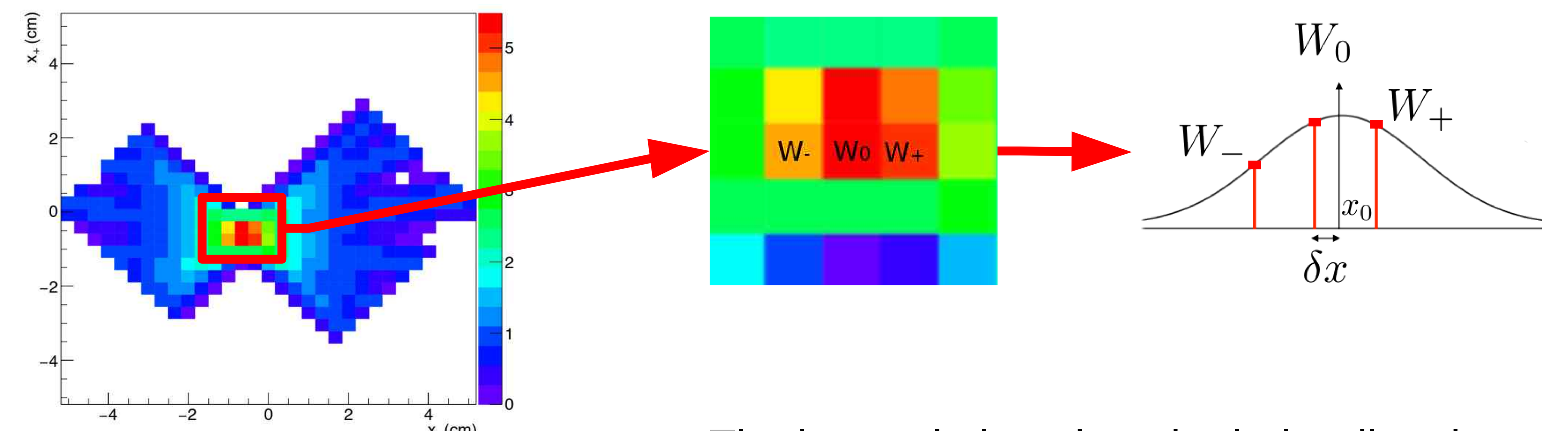
Artificial retina algorithm for a 2D tracking system



A grid of cellular units covers the space of track parameters. Each cell is associated to a set of track receptors corresponding to the intersections of the track with the tracking planes.
The response of the (i,j)th cellular unit is a function of the hit-receptor distances s_{ijk}.

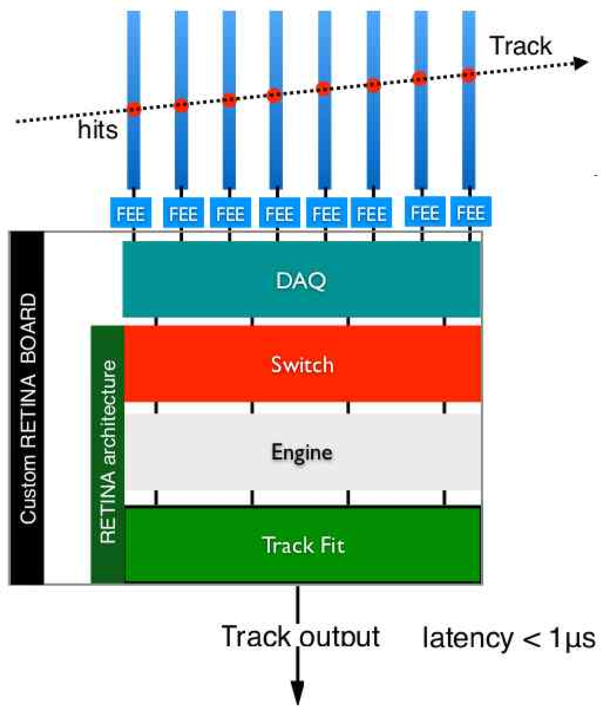
$$W_{ij} = \sum_k \exp\left(-\frac{s_{ijk}^2}{2\sigma^2}\right)$$

Retina response for a single track event



The interpolation along both the directions provides the track parameters with offline-like quality even using a coarse grid

Architecture



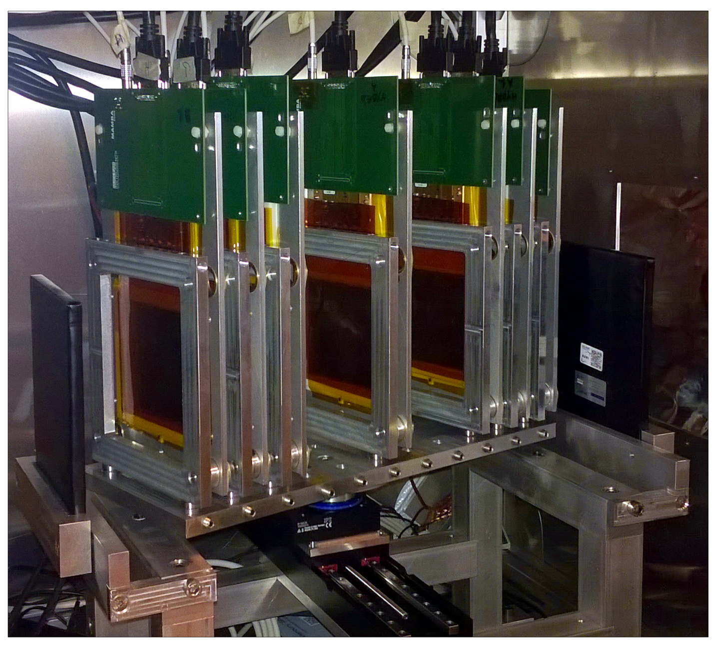
The switch delivers in parallel the hits from the telescope to the cellular units

512 cellular units (engines), evaluate the retina response

The track fitter finds the local maxima and evaluate the track parameters via interpolation.

The pipelined architecture allows sub-μs latencies

Telescope system at SPS



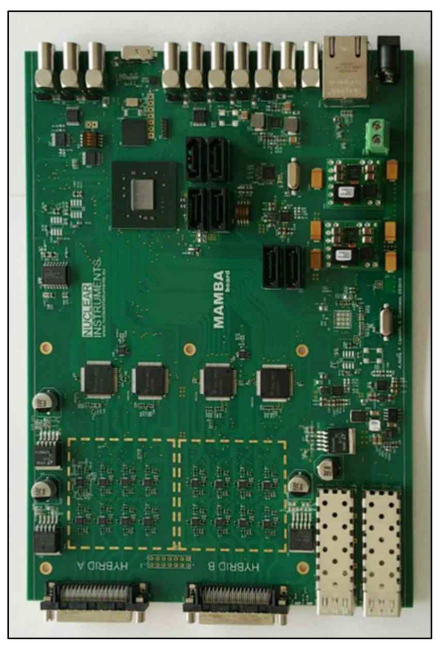
7 single-sided silicon strip (STM OB2) sensors:

- ~10x10cm² active area
- 512 strips
- 183μm pitch
- 500μm thickness

Two plastic scintillators providing the trigger

Linear and rotation stages

DAQ and Retina board



MAMBA board:
Milano **A**dvanced **M**ulti **B**eetle **A**cquisition board

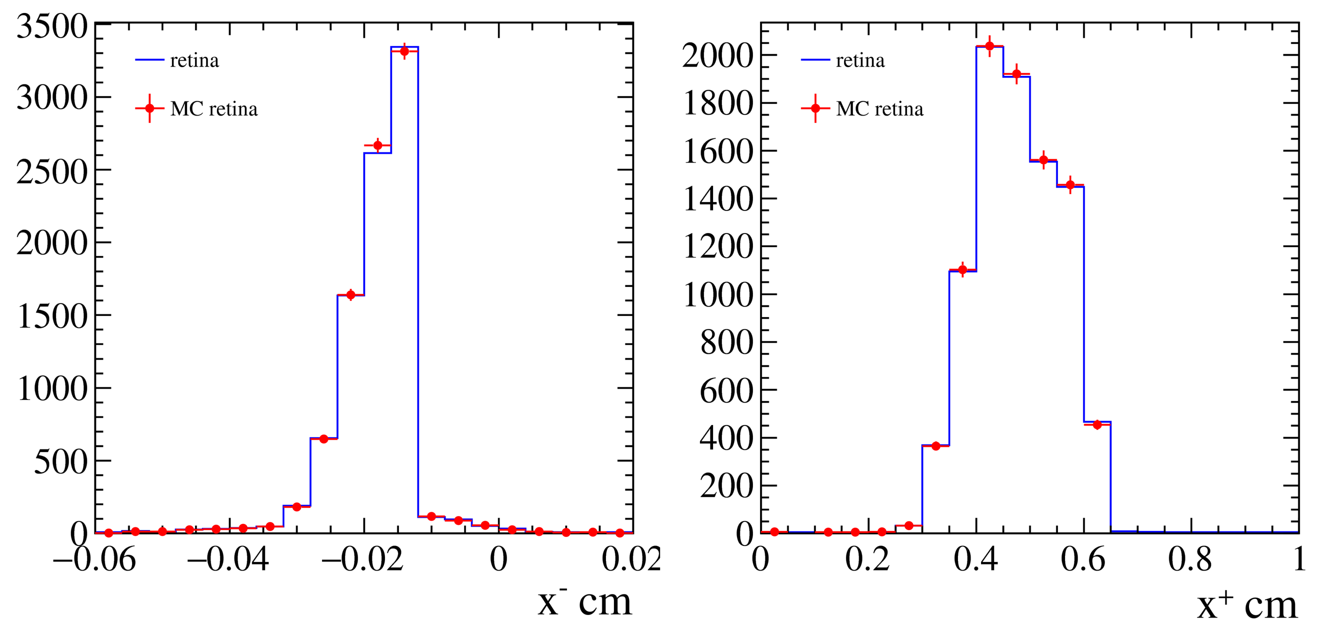
Custom design based on Xilinx Kintex 7 FPGA.

Up to 8 telescope planes readout at 300KHz, limited by the front-end electronics

On-board Retina algorithm

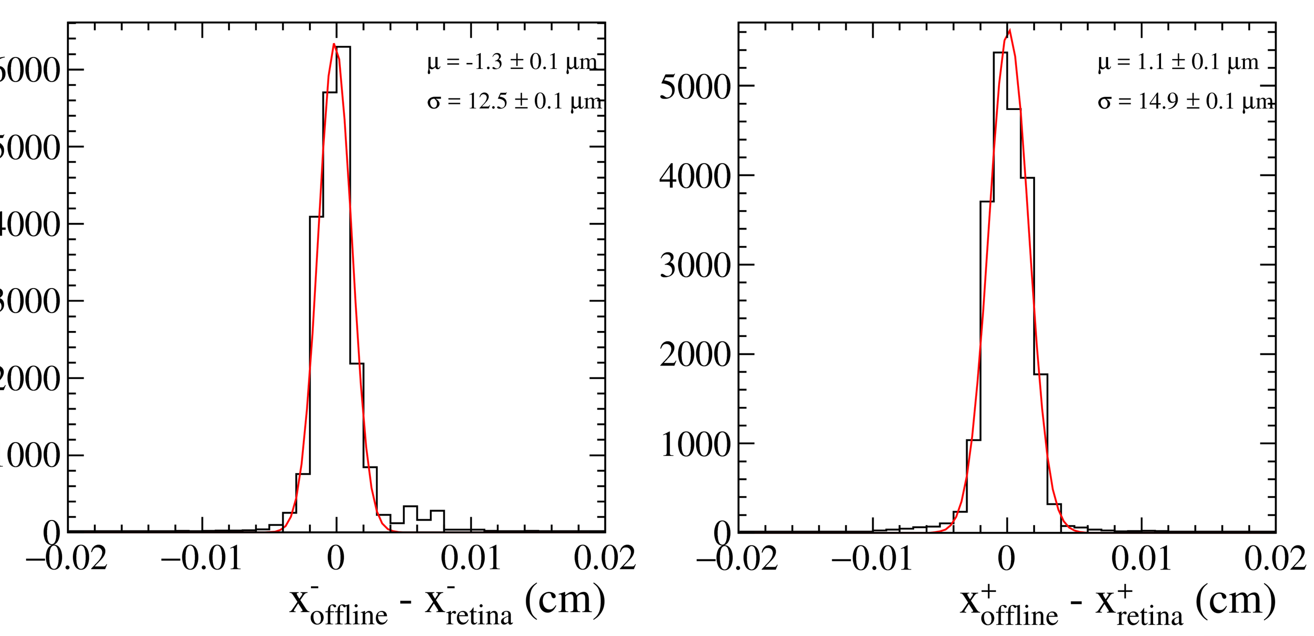
Testbeam at CERN SPS - Results

The system has been tested with beam at the CERN SPS using 180 Gev/c protons. The maximum track reconstruction rate is 300KHz, limited by the maximum readout rate of the front-end electronics. The results are in agreement with the ones obtained from offline analysis and with the high-level simulations of the retina response to real testbeam data.



Track parameters distribution determined by the artificial retina.

Testbeam data processed by the MAMBA board (retina) and verified using the artificial retina simulated response (MC retina).



Distribution of the residuals for the track parameters evaluated using a simple χ² minimization algorithm (offline) and track parameters from the artificial retina algorithm

Application at HL-LHC

The high luminosity phase of LHC will start after 2025 and aims to increase the instantaneous luminosity up to $L = 5 \cdot 10^{34}$ cm^{-2} s^{-1}.

The inclusion of tracking information in the first stage of the trigger chain is crucial to handle the higher pile-up and number of tracks per event.

We propose an implementation of the artificial retina to a 4D tracking system including precise space and time information of the hits.

4D retina simulation and implementation

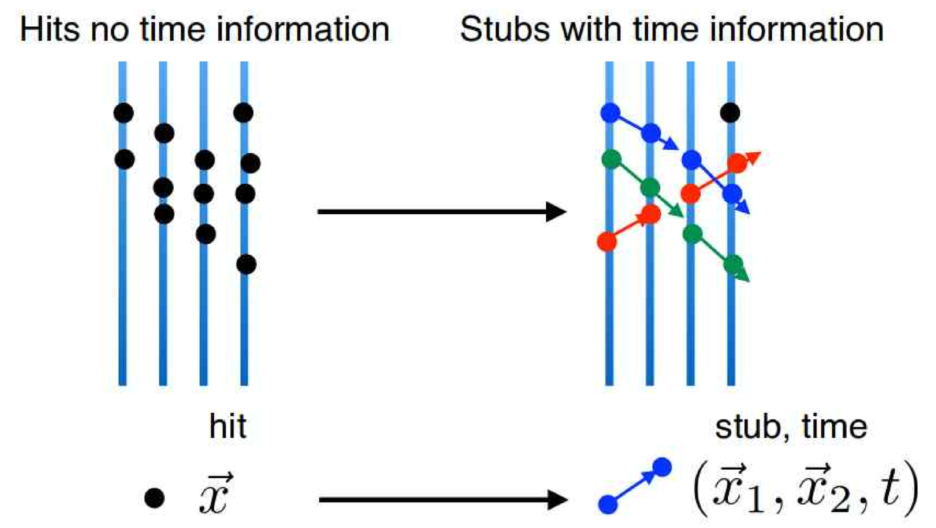
High-level C++ simulations of the 4D artificial retina algorithm have been performed for a VELO(LHCb)-like tracker with 1200 tracks/event in the forward region.

The reconstruction efficiency is ~99% and the purity improves from ~60% to >80% when including the time information while the track quality is comparable with the quality from offline analysis.

The algorithm is being implemented on a custom board with multiple Xilinx Virtex UltraScale devices.

The system will be feeded with simulated data from the LHCb VELO tracker to demonstrate the tracking performance and evaluate the maximum input rate.

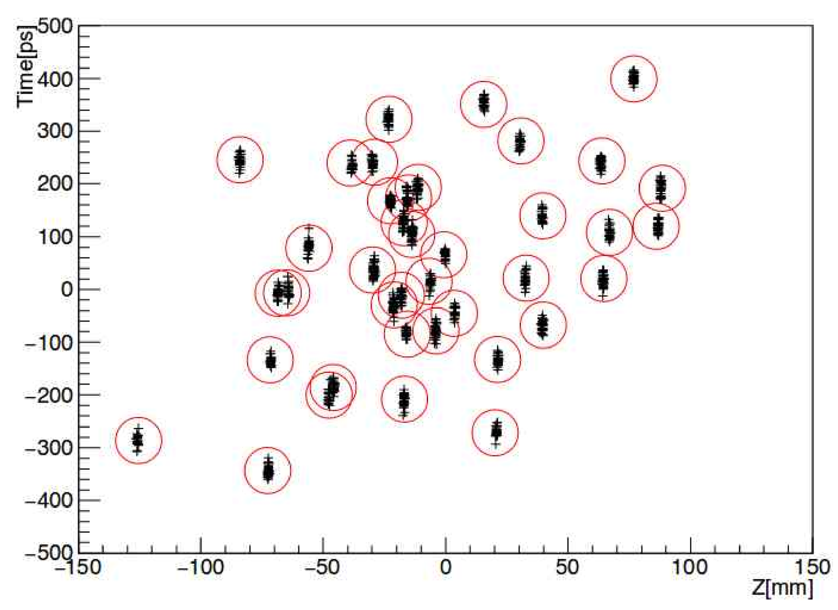
4D artificial retina with stubs and time information



Track segments (stubs) are identified from couples of 4D (space+time) hits in adjacent planes and filtered according to geometric and time cuts to remove fake combinations.

The cellular units are distributed in a sub-space of the track parameters in which track candidates are identified. The track parameters are obtained both via interpolation and averaging the stub contributions.

The use of the time information of the hits allows to measure the time of the track to reduce the mis-association of tracks to the primary vertexes.



Typical distribution of the track origins in an HL-LHC event with ~40 primary vertexes. The time of the tracks helps in discriminating vertexes with similar spatial coordinate.

Conclusions and next tasks

The first real-time tracking system based on the artificial retina algorithm has been designed, implemented and tested on beam at SPS for a 2D tracking telescope.

Testbeam results from the artificial retina are in agreement with both the results from the offline analysis and from the high-level simulatuions of the retina response.

The implementation of the 4D artificial retina algorithm in the latest generation FPGAs is ongoing.

The architecture will be tested at 10-40 MHz event rate with simulated data of the LHCb tracking system to verify the possibility of application of the artificial retina to the current detector and to a future upgrade at high luminosity.

References:
[1] N. Neri et al., POS(TIPP2014)19
[2] L. Ristori, NIM A 453 (2000) 425-42