The artificial retina for track reconstruction at the LHC crossing rate

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We present the first implementation of a real-time 3D tracking system in a realistic LHC detector able to perform a full tracking reconstruction of complex events at 40 MHz, with existing electronic component.

Retina Algorithm

The retina algorithm is a biological-inspired high-parallel algorithm [1].

The leap of the algorithm is the continuos response of the pre-calculated patterns, which allows a coarser grid saving patterns. How the retina algorithm works can be summarized as follows:

✓ discretize track parameters space in *cells*;

✓ each *cell* corresponds to a track that intersects the detector layers in *receptors*;

✓ in each detector layer, the distance **s** between the **real hit** and the **pre-calculated receptor** is used to compute the contribution to the excitation level R_{ij}, of the considered hit;

✓ tracks are identified by a local excitation-cluster;
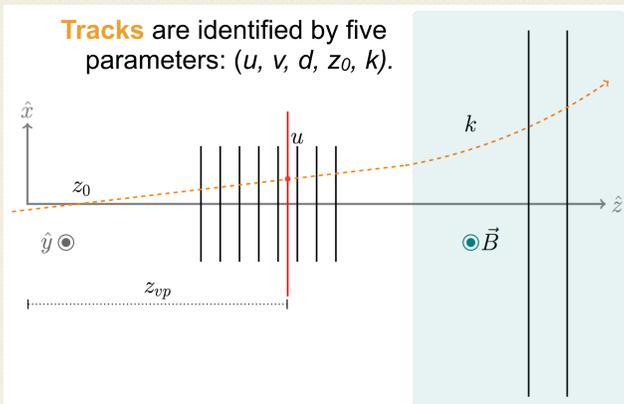
✓ parameters are determined interpolating nearby cells.

$$s = (x - x(m_i, q_j))$$

$$R_{ij} = \sum_{kr} \exp\left(-\frac{s_{kr}^2}{2\sigma^2}\right)$$
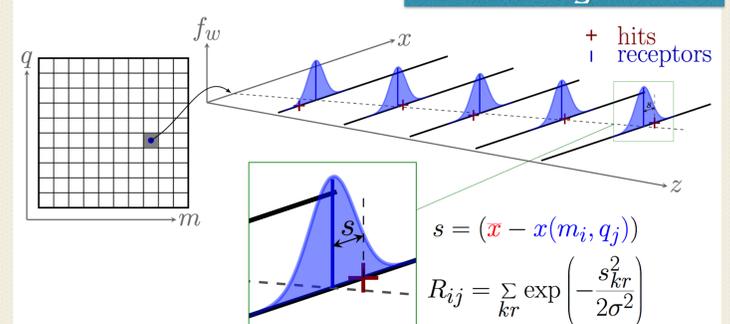
Tracker geometry

A complex detector can be schematized as an array of tracking detectors immersed in a generic magnetic field.

Tracks are identified by five parameters: (u, v, d, z_0, k).

Geometry directly impact algorithm implementation. Tracking in a volume with weak magnetic field **B** allows:

✓ approximation of tracks to straight lines originating from a single point;

  ▸ this identify a primary 2D-plane to perform pattern recognition;

✓ treating track momentum and track origin as perturbations of main parameters (u,v).
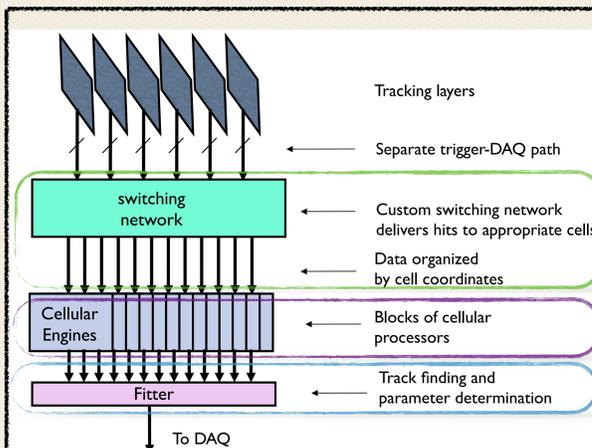
Track finding

A simple 2D example to visualize how the retina algorithm works:

▸ n parallel single-coordinate layers,

▸ no magnetic field, straight line tracks identified by two parameters (m,q).

Tracks are peaking structures (over-a-threshold).
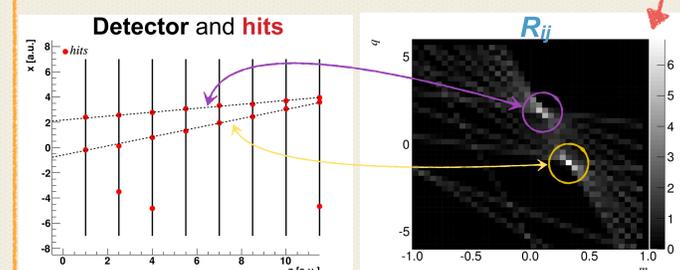
Hardware implementation

✓ Hits need to be delivered **fast** and in **parallel** to all the necessary engines.

✓ Custom switching network has been developed, on high-bandwidth FPGA.

✓ Array of track parameter cells are mapped onto an array of cellular engines (implemented as an independent block of logic).

✓ Each engine has the task to evaluate the weight of a single (u,v) cell.

✓ Local maximum are found in parallel in, via horizontal exchange of information between adjacent engine.

✓ Coordinates and intensity of the local maxima and the intensities of their nearest neighbors, are used to extract track parameters.

All the system has been programmed in VHDL, simulated and placed on the Altera's Stratix V (model `5SGXEA7N2F45C2ES`). The system is capable of running at frequencies ≥ 350 MHz

Task	Latency (cycles)
Switching network	21
Engine processing	70
Clustering	55
Data output	10
Total	$\simeq 150$

At 350 MHz, latency is less than 0.5μs. Practically tracks are provided immediately, as an additional detector that outputs tracks.

Performances in a Real HEP case

As physics case we applied the retina algorithm on LHCb upgraded experiment, where realtime tracking plays an important role. The first part of the tracking sequence (VELO + UT) has been implemented:

▸ 8 pixel layers from upgraded LHCb VELO [3];

▸ 2 silicon-strip detector from the UT [4] (sink into the fringe field of the magnet).

Performances of the retina are evaluated with a detailed `C++` simulation, accepting hits from the full LHCb-MC.

Retina efficiency results very close to the full reconstruction algorithm. The same holds for the uniformity in response of all measurement of track parameters
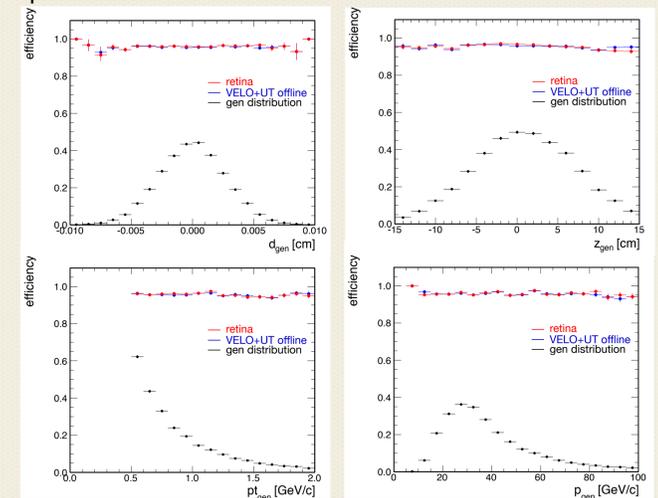
Comparable resolutions, on track parameters, to the full reconstruction algorithm are obtained.

We demonstrated that high-quality track reconstruction in large LHC detector is feasible at 40MHz event rate, with sub-μs latencies, using parallel algorithms in conjuction with current high-bandwidth FPGA (more details in ref. [2])

R&D project by: ([1]INFN-Pisa/University/SNS, [2]INFN-Milano/Politecnico, [3]CERN, [4]Fermilab)

A. Abba[2], F. Bedeschi[1], F. Caponio[2], M. Citterio[2], A. Cusimano[2], A. Geraci[2], P. Marino[1], M. Morello[1], N. Neri[2], D. Ninci[1], M. Petruzzo[2], A. Piucci[1], G. Punzi[1], L. Ristori[1,4], F. Spinella[1], S. Stracka[1], D. Tonelli[3].

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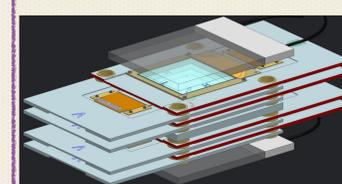
A first prototype of tracking system based on the retina algorithm has being implemented today, using Stratix III FPGAs to be mounted on TEL62 [5]. Functionality tests using cosmic rays or test beam.