CMOS Pixel Sensors with on-chip Neural Network

R. Zhao[1,2], A. Besson[1,2], C. Hu-Guo[1], A. Perez Perez[1], K. Jaaskelainen[1], M. Goffe[1], Y. Hu[1,2], M. Winter[1]

Contact Email: Ruiguang.ZHAO@iphc.cnrs.fr

[1]Institut Pluridisciplinaire Hubert CURIEN (IPHC), F-67000 Strasbourg, France

[2]Université de Strasbourg, F-67000 Strasbourg, France

PROJECT INTRODUCTION

MOTIVATION

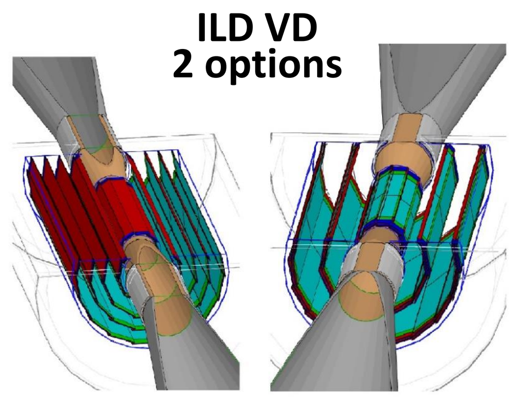
There are large lots of hits that are generated by particles that come from the beam background affecting the tracking efficiency and reducing the system bandwidth.

Features of particles coming from the background:

- Low momentum (larger incident angle on sensors)
- Enlarged cluster size (elongated shape)

Target: to tag and remove hits from the beam background versus hits from physics signals

Program: using on-chip Neural Network algorithm to classify these two kinds of hits through their charges distribution and cluster shapes [1][2]



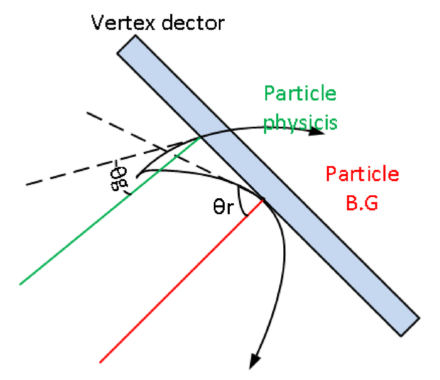


Fig.1 Hits tracking on detector

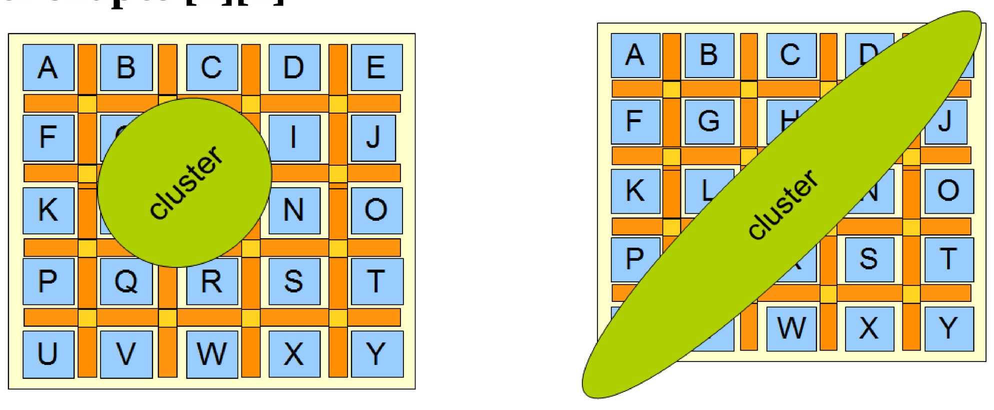
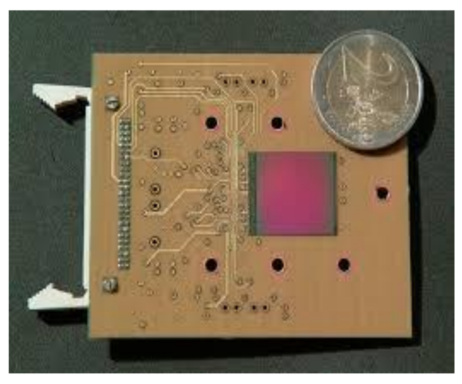


Fig.2 Cluster generated by particles from experiment versus background

Feasibility study

Use an existing sensor (Mimosa18) and a FPGA device to validate the idea of reconstructing hits' incident angles by combining the CPS and NN

CMOS Pixel sensor



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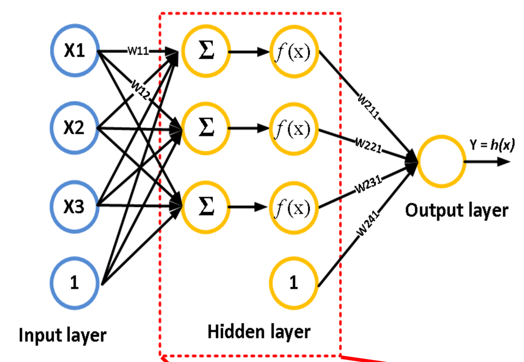
Neural Network(NN)



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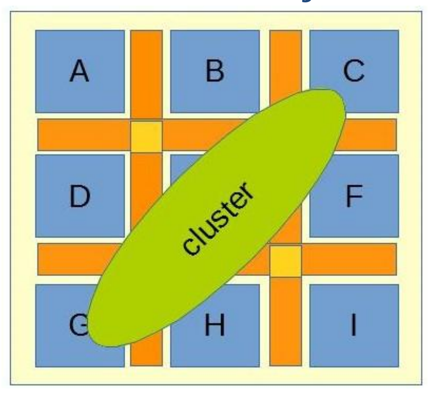
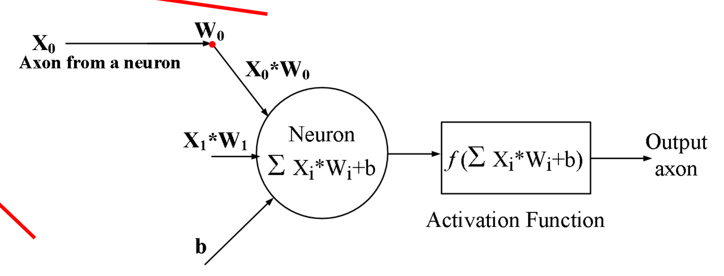
Identified object





CMOS Pixel Sensor:

- To detect charged particles,
- To identify hits' shapes & charges

Neural Network (NN):

- To reconstruct the particle incident angle
- To classify hits from background according to their specific shapes & charges

TRAINING PROCEDURE (OFFLINE)

Using the raw data and the incident angle θ to train connection weights of the neural network, to define the whole structure of the neural network (by TMVA software)[3].

Step1: Collect raw data from the output of Mimosa18 under different incident angle θ

Step2: Train connection weights of the Neural Network by using raw data and incident angle θ

1. Collect Raw Data

Collect sensor output raw data under β (^{90}Sr) source with different incident angles.

Fig.3 Test bench for gathering raw data

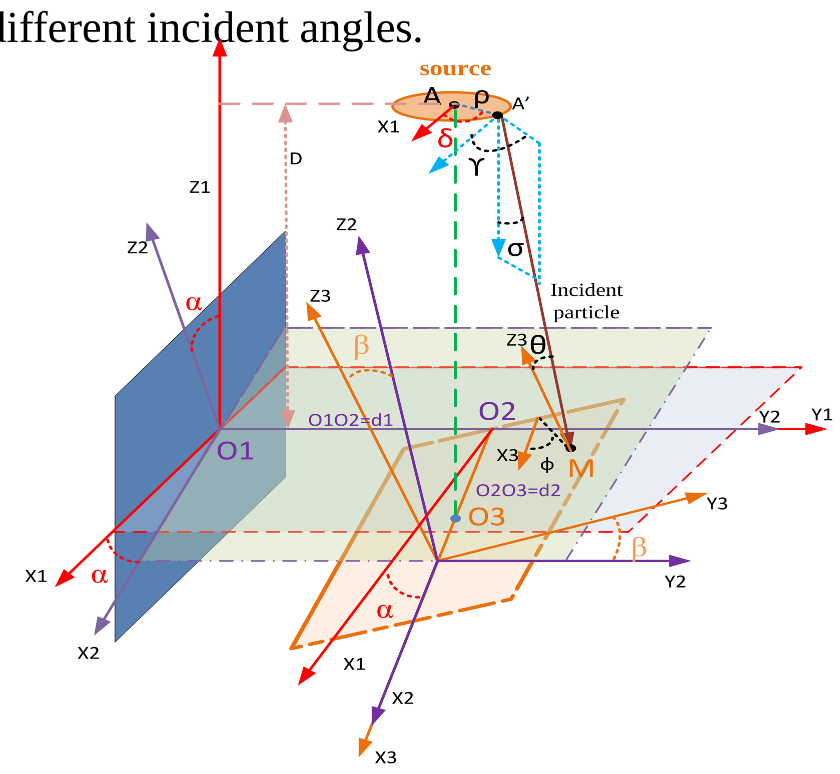


Fig.4 The principle of the 2 angle rotation support

- θ, φ : represent information of one incident particle. They are angles between the incident particle direction and the Z3 axis and X3 axis respectively.
  Can not be controlled
- α, β, : represent the positions of the sensor. They are angles between the sensor direction and the X1 axis and Y1 axis respectively. (3D information in the test bench)
  Can be changed by rotating DUT in 2 axes
- The relationship between α, β, θ, φ is shown in the fig.5.
  We can change the value of θ and φ by changing value of α, β.
  Calculate angle φ by Main Component Analysis.

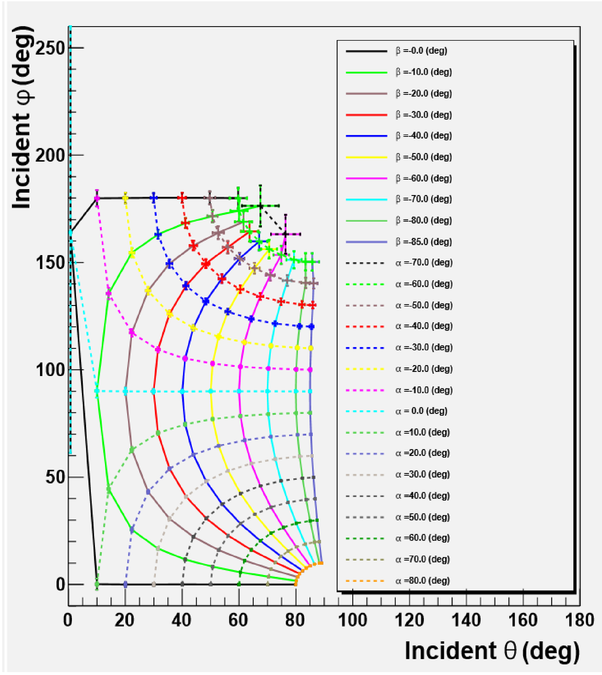


Fig.5 The relationship between α, β, and θ, φ

$$
\begin{cases}
\cos\varphi = \dfrac{-\left|\overrightarrow{vecMA'X3}\right|}{\sqrt{vecMA'X3^2 + vecMA'Y3^2}} \\
\sin\varphi = \dfrac{-\left|\overrightarrow{vecMA'Y3}\right|}{\sqrt{vecMA'X3^2 + vecMA'Y3^2}}
\end{cases}
\qquad
\cos\theta = \frac{\overrightarrow{vecMA'Z3}}{|MA'|}
$$

2. Train Connection Weights

1. Initialization

- Inputs and correct outputs are known.
- Structure and activation function are fixed.
- Initial weights are chosen randomly.

2. Training

- Neural networks is an iterative learning
- Calculate outputs by initial connection weights
- Errors are then propagated back, adjust connection weights.

3. End

- Neural network is used to regress output until tolerable error .

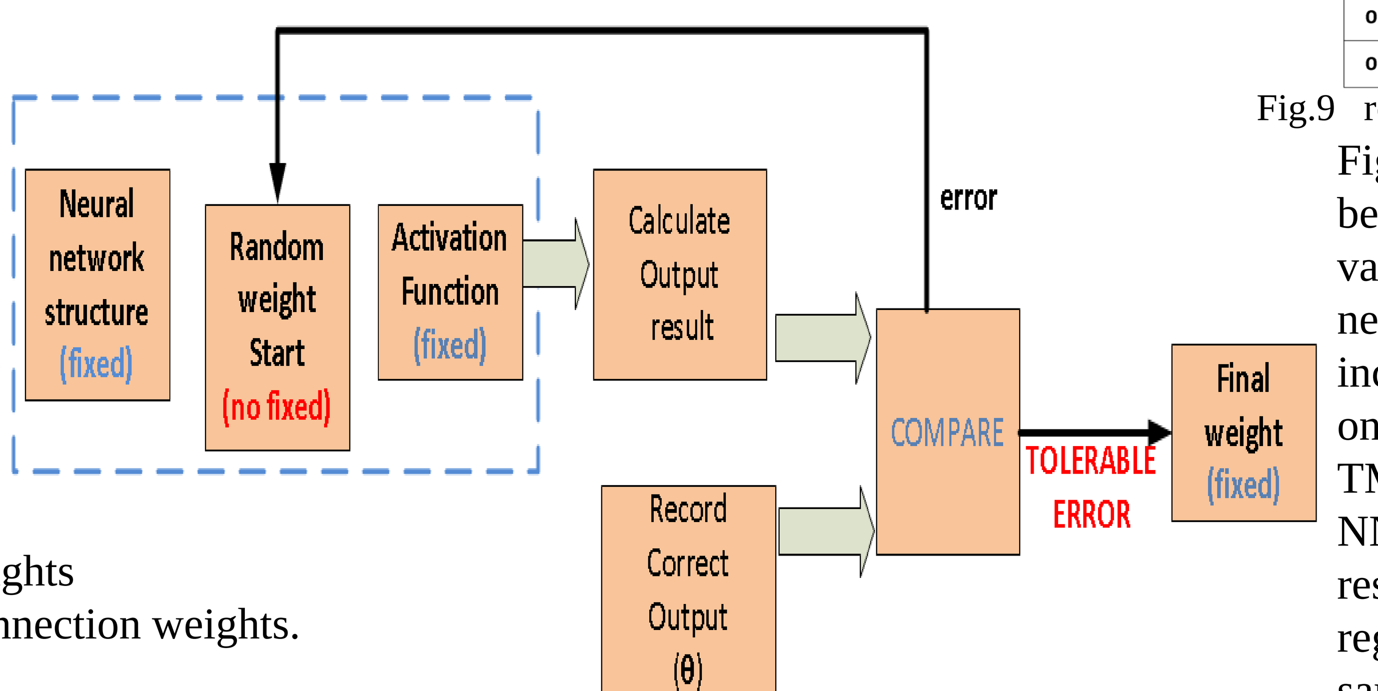


Fig. 6 Principle of calculating weights

REGRESSION PROCEDURE (OFFLINE)

Using the raw data and neural network to reconstruct the incident angle θ (implemented in a FPGA device by us).

Step1: Collect raw data from outputs of Mimosa18

Step2: Reconstruct the incident angle θ by neural network and raw data

1. Collect Raw Data

Test data is a part of data which is used in training procedure

2. Calculate incident angles

- Cluster search: search cluster in raw data matrix, store input parameter of ANN, SeedCharge and TotCharge;
- Main Component Analysis (MCA): Find main direction of each cluster, calculate input parameter of ANN, RMSX_MaxStd and RMSY_MinStd
  - **Shape of a cluster**
    - Maximum/Minimum standard deviation (MaxStd/MinStd) related to θ
    - Orientation of the main direction related to φ (calculate by MCA)
  - **Charge of a cluster**
    - Seed charge (SeedCharge ADC) of cluster related to θ
    - Total charge (TotCharge ADC) of cluster related to θ

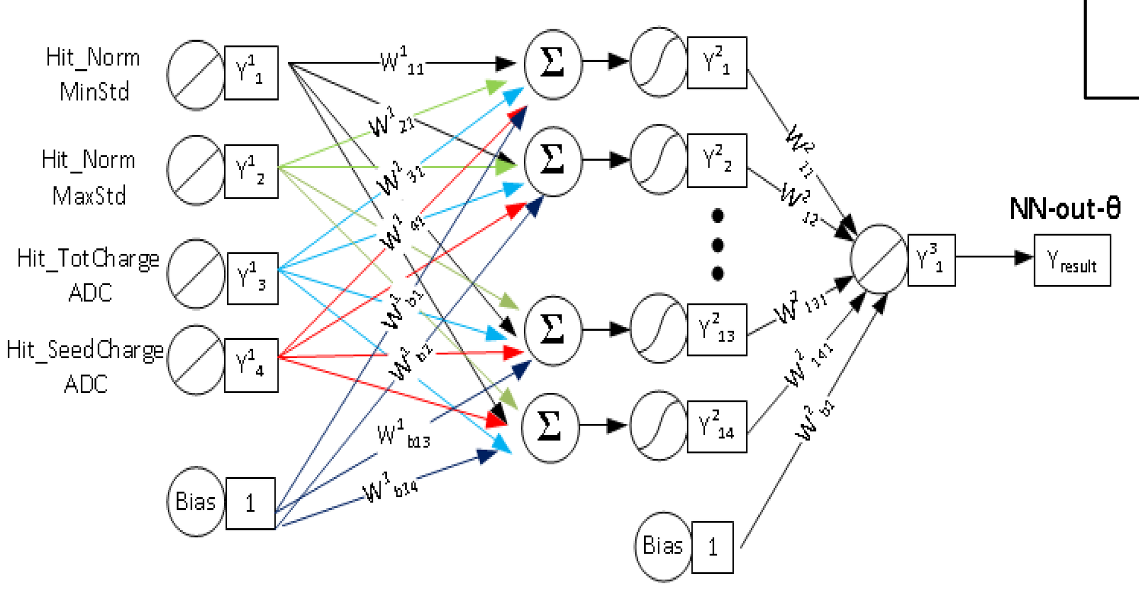


Fig.7 Structure of the neural network

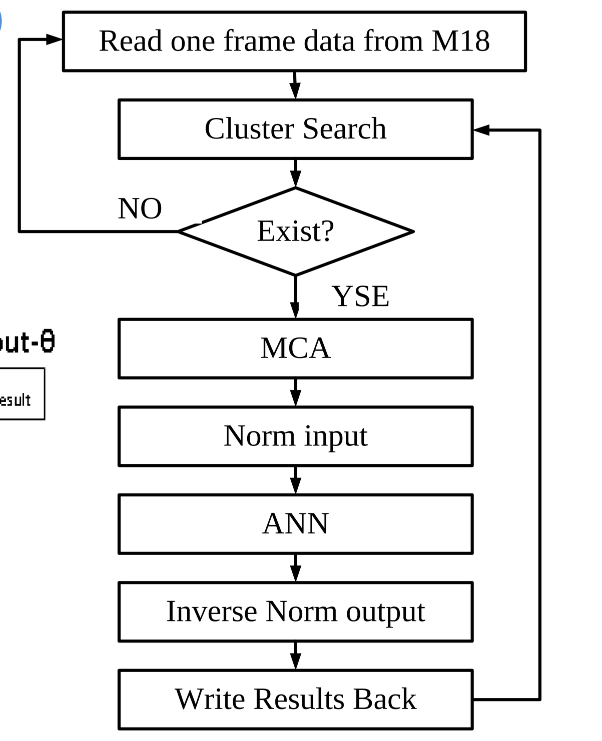


Fig.8 Control flow of regression procedure

RESULT ANALYSIS

0	0	0	0	0	0	0
0	7	0	0	0	0	0
0	0	13	14	0	0	0
0	0	34	257	10	0	0
0	0	13	21	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

Fig.9 regression example by FPGA

Fig.9 shows an example of clusters that is searched by FPGA device. The regression incident angle of this cluster is 43.75 degree. Frame number of this cluster is 4500, seed pixel charge is 257 ADC unit. There is the same cluster information in regression result by TMVA software.

Fig. 10 shows the difference between the obtained mean values of θ from neural network and the real incident angles θ. The blue one is obtained from NN by TMVA and the red one from NN by FPGA device. The results of the FPGA regression are basically the same as the software (TMVA) regression results.

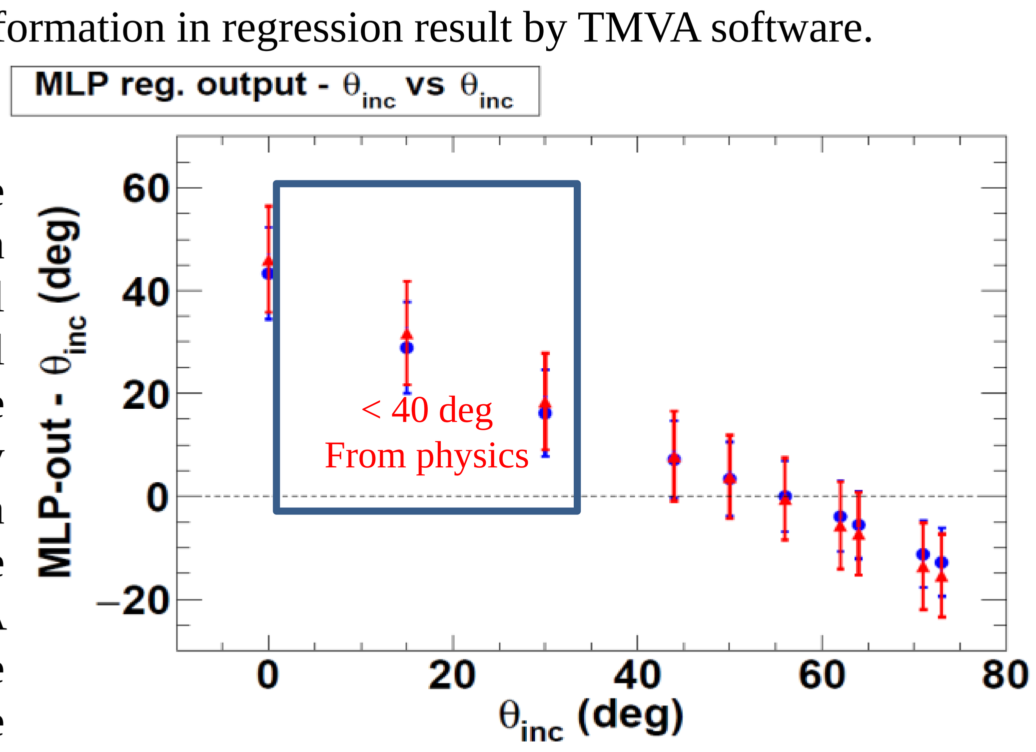


Fig.10 Neural Network regression result by FPGA

CONCLUSIONS

- Training the neural network through raw data from Mimosa18 sensor and incident angle θ.
- Regress the predict incident angle θ by neural network implemented in a FPGA device.
- The regression result form FPGA are basically the same as the software (TMVA) regression result, validating the regression procedure by FPGA

PERSPECTIVES

- Based on the system, gather more data, train accurate weights value of the neural network.
- Design new feature extract algorithm to represent cluster information.
- Design an algorithm of on-chip cluster search.
- Optimize the power consumption and size of the design.

REFERENCES

[1] A. Besson ; Towards low occupancy ILD VTX detector in CMOS technology adapted for tracking and vertexing, International Workshop on Future Linear Colliders LCWS2016, Morioka, Japan, 5-9 December 2016.

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[3] ArXiv:physics/0703039 [Data Analysis, Statistics and Probability] , CERN-OPEN-2007-007, TMVA version 4.2.0 , October 4, 2013, http:// tmva.sourceforge.net