Low energy nuclei detection with ALPIDE detector

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IPRD19
The HEPD-01 detector

HEPD-01 is installed on CSES satellite, successfully launched on February 2nd, 2018 from Jiuquan Satellite Launch Center in the Gobi desert. Mission is devoted to the observation of Earth from space.

ENERGY RANGE:
Electrons: 3 – 100 MeV
Protons and nuclei: 30 – 300 MeV/nucleon

ANGULAR RESOLUTION: <8° @ 5 MeV
ENERGY RESOLUTION: < 10% @ 5 MeV
PARTICLE IDENTIFICATION: >90%

POWER CONSUMPTION: < 27 W (assigned power budget <43 MeV)

LIFE SPAN: >5 years
HEPD-02 tracker

From microstrips to MAPS:

**ADVANTAGES**
- Low fake hit rates
- Low cost
- Better resolution
- Thin detector

**LIMITS**
- High power consumption
- Digital only readout
- Increasing number of channels
- 5 years and ~5M for development
The ALPIDE sensor

- Designed by ALICE collaboration for their Inner Tracker Upgrade;
- Readout realised using 180 nm CMOS technology;
- 512x1024 pixel in 1.5x3 cm²;
- 100 µm thick (50 µm also available);
- Deep p-well allow **p-MOS transistor implantation** on chip without reducing collection efficiency.
- Charge collection by **diffusion**.
- Designed for and widely tested with MIPs.
Towards a cluster generator

Energy deposited
GEANT4

Charge collection probability of electrodes
TCAD

Epitaxial thickness
Noise
Threshold
Measurements

Cluster Generator

Simulated clusters:
Cluster Size Structures

MIP cluster size measurement VS impact position
Cluster recorded with 62 MeV/a.m.u. helium nucleus

https://doi.org/10.1016/j.nima.2015.09.057
Test beam measurements: The experimental setup

- The experimental setup was composed by a **ALPIDE sensor** and two **EJ200** plastic scintillator bars (2x30x150 mm$^3$) used to give a trigger signal;
- The scintillators were **read by two PMTs** for each bar;
- The signal of the PMTs was processed by a CAEN DT5725 digitizer, that saved the waveforms and gave the trigger signal to the MOSAIC board used to control ALPIDE;
- Waveforms from PMTs were also collected by a Lecroy oscilloscope.
- The **energy** of the beam was **62 MeV/amu** and we tested the sensor with **protons, He, C and O** in Catania @ LNS.
- We used the same setup with **20 MeV to 220 MeV protons** in Trento @ APSS Proton Therapy centre.
The analysis is applied to protons acquired with the beam perpendicular to the detector. Calculation of mean and RMS along x and y for all the events. Selection of single cluster events: events with RMS>2 are rejected.

For all the selected events, subtraction of the mean from pixel coordinates and stacking on a 2D histogram. Normalisation of the histogram. Calculation of mean and RMS from the 2D histogram. Integral of 2D histogram corresponds to average cluster size. Clusters show a circular symmetry.

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The stacked analysis can be applied to the data sets with inclined tracks.

Inclination of the detector distributes the cluster along more detector columns.

From the plots, realised with 220 MeV proton data, it is clear that the shape depends on the angle between the beam and the detector.

The effect is clear if we focus on the more populated centre of the distribution.

The cluster assume an elliptic shape.

It is possible to build a model to describe this behaviour.
The model we propose to describe the cluster size evolution is really simple;

There are two parameters to be determined by the fit

The IC parameter quantifies the intrinsic cluster size produced by the nucleus on the silicon;

The intrinsic cluster size is expected to increase with Z, since the charge produced inside epitaxial layer increases

The second parameter T is the effective thickness of the epitaxial layer.

As shown in the plot, the model perfectly describes the results obtained from GEANT4 simulation of the setup, where diffusion is not included.

\[ f(x) = IC \cdot (1 + 2 \cdot \frac{1}{IC \cdot \pi} \cdot \frac{100 \mu m}{T} \cdot \tan x) \]
Measurements with different angles: 

**Results**

- 62 MeV/a.m.u. nuclei @ Catania LNS
- Cluster size obtained from **gaussian fit** on the cumulative distributions
- As expected, **cluster size increases with Z.**
- Saturation of intrinsic cluster size for Z ≥6

- 20 MeV protons @ Trento APSS Proton therapy centre, different back bias values
- The results of the best fits give a **epitaxial thickness of about 25 µm**, but uncertainties are large.
- The nominal value is quoted between 19 µm and 40 µm [1]
- When the back bias is applied, the charge collection is more efficient and the cluster size decreases.

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[1] CERN-THESIS-2016-033
Towards a cluster generator

Energy deposited

GEANT4

Charge collection probability of electrodes

TCAD
Simulations

- Two different simulation tools have been used for simulations.
  - **GEANT4:**
    - Setup simulation with test beam conditions
    - Energy of the beam reconstruction
    - Energy deposited inside the detectors
    - Number of hit pixels
  - **TCAD:**
    - Simulation of a small region of the ALPIDE
    - Electric field structure
    - Charge collection
    - Cluster size

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The TCAD simulation aims to **reproduce** the **cluster size results**.

Because of the **high computing power required** by the simulation, we use the symmetry of the system to explore larger domains.

**Heavy Ion model** is used to simulate the energy deposition on silicon.

The charge diffusion is followed for **2 µs** after the charge release.

**Three different domains** are used to explore the effects of particles hitting different pixel positions.

Only **vertical hits** are simulated.

**Three thicknesses** of epitaxial have been simulated.
• The simulation must be tuned to provide cluster size results compatible with the experimental results.

• In particular we varied the following parameters:
  - Doping profile
  - Mesh
  - Electrode shape
  - Epitaxial thickness

• The charge collected on electrodes at different distances from the hit position have a defined behaviour

Two different behaviours

Different curves give information on the same regime behavior.
Hit on electrode

- When particle hits a electrode, the charge collection efficiency is higher, in particular on the first 3-4 µm of thickness (region 1).

- Then there is a second region, up to 15 µm, in which the charge diffuse, but most of it is collected by the hit electrode (region 2).

- Then the rest of charge produced on epitaxial layer is shared by all the neighbour electrodes (region 3).

- The region of high collection efficiency has a radius of about 3 µm around the electrode.

- The double behaviour can be corrected by defining the regions where the two curves have to be applied using the position on the pixel surface as reference.
• Simulation tool is tuned with a single TCAD simulation with energy deposition comparable to the 20 MeV proton release.

• The results obtained at low energies have a good agreement with data.

• At higher energy the discrepancy is about 30%.

• The reason of the discrepancy is probably due to different behaviour of electrons when charge density is lower.

• TCAD calculation of MIP energy deposition has been run and is under analysis. A update of the simulation tool will be ready soon.

Reference energy: TCAD is tuned at this energy.
Conclusions

• We started to explore the operability of ALPIDE for highly ionizing nuclei.

• The diffusive charge collected allows to provide hints on energy deposition in silicon based on cluster size. This feature could become an important input for particle identification algorithms.

• The response obtained with test beams have been studied by comparing it with GEANT4 and TCAD simulations.

• A tool to reproduce cluster size based on charge deposition in silicon is under construction.

• Results show that ALPIDE provides good quality information from the interaction with particles widely far from the design target.

• Tracking capabilities (not dealt with in this presentation but independently checked to be as good as for MIPs) will profit from cluster tagging, improving the angular resolution and feeding the full Deep Learning-based reconstruction algorithm of HEPD-02.
BACKUP
Cluster finding algorithm: DBSCAN library

- The stacked analysis gives us information on cluster shapes and dimensions. We can use the results to tune a cluster finding algorithm that can work on more complex data samples.
- DBSCAN is a **python library** devoted to cluster finding. We selected this for our analysis because it does not need to know in advance the number of clusters in a frame.
- The main input parameters are:
  - **Minimum number of pixel** for each cluster, set to 2
  - **Maximum distance** of a pixel from the others to be considered as cluster element, set to 2
  - We don’t impose any form of continuity between the pixels of a cluster

The agreement is good!
Discrepancies on the lower energies have to be further investigated.