Task 3: Energy Loss Measurement using ALiBaVa

(of Track 1: Silicon Sensors)

Introduction

In this small experiment the energy loss, here observed as charge deposition, of impinging particles in a thin silicon layer is measured. A silicon strip sensor attached to an analog readout system (ALiBaVa) is used to get a direct measure of the charge. As particle source a Sr90 source is being used. The task entails getting acquainted with the system, a calibration and to measure the Sr-spectrum.

Bethe Bloch and Landau

The principle of solid-state detectors is based on the energy loss of traversing particles. Traversing charged particles generate free electron-hole pairs, which move towards opposite electrodes under the influence of an electric field. The energy loss of heavy particles in the matter was described by H.A. Bethe and F. Bloch [ref].

(1
)

$$-\frac{dE}{dx} = 4\pi N_A r_e^2 m_e c^2 z^2 \frac{Z}{A} \cdot \frac{1}{\beta^2} \cdot [\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 T_{\max}}{I^2} - \beta^2 - \frac{\delta}{2} - \frac{C}{Z}]$$

With:

$T_{\max}$ Maximum kinetic energy which can be transferred to the electron in a single collision

I^2 Excitation energy

$\frac{\delta}{2}$ Density term due to polarisation: leads to saturation at higher energies

$\frac{C}{Z}$ Shell correction term, only relevant at lower energies

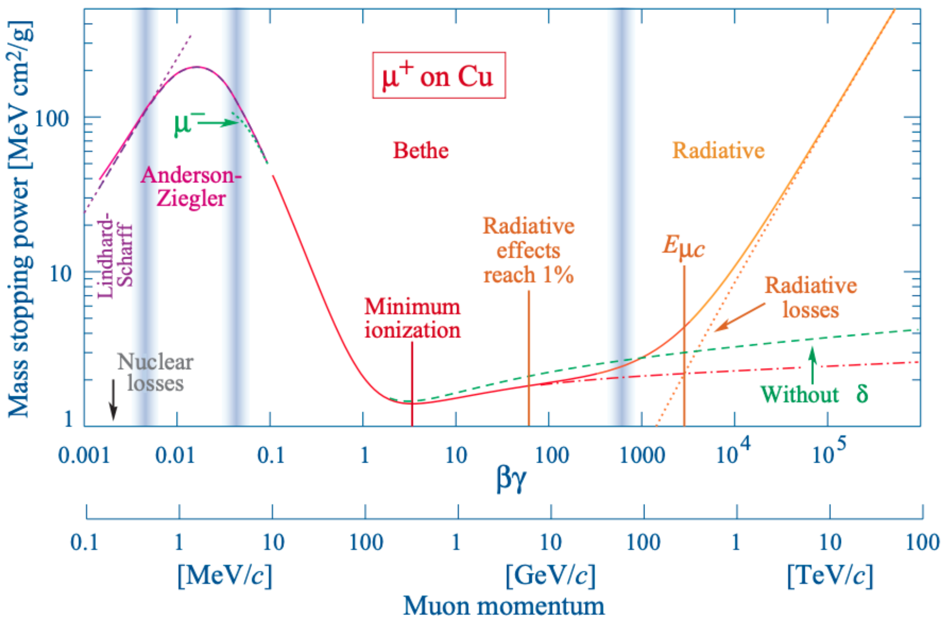


Figure 1: Mass stopping power (= dE/dx) for positive muons in copper as a function of = p/Mc over nine orders of magnitude in momentum (12 orders of magnitude in kinetic energy). Solid curves indicate the total stopping power. Data below the break at 0.1 are taken from ICRU 49, and data at higher energies are from Ref. 5. Vertical bands indicate boundaries between different approximations discussed in the text. The short dotted lines labeled "μ " illustrate the "Barkas effect," the dependence of stopping power on projectile charge at very low energies. dE/dx in the radiative region is not simply a function of [Source: Particle Data Group].

Minimum ionizing particles: Particles with minimal energy loss due to their energy (see figure above).

The Bethe-Bloch formula describes only the average energy loss of charged particles when traveling through matter for a large energy range. In case of thin detectors the variation width within the energy transfer of the reactions leads to a large variation of the energy loss:

- A broad maximum: collisions with little energy loss
- A long-tail towards higher energy loss: few collisions with large energy loss $T_{\max}$, delta-electrons.

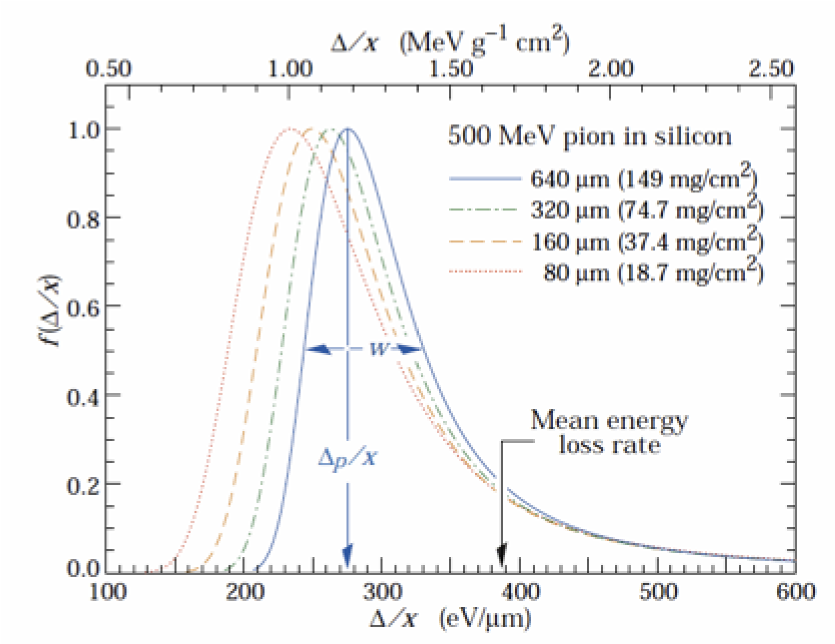


Figure 2: Examples for 500 MeV pions incident on thin silicon detectors.

The Landau distribution is used in physics to describe the fluctuations in the energy loss of a charged particle passing through a thin layer of matter. Here thin can be defined over the energy loss and the maximum kinetic energy which can be transferred in a single collision: $dE < 10 \cdot T_{\max}$. A typical silicon sensor is 300μm thin and can be considered as thin in this context.

The ALiBaVa Setup

The ALiBaVa is a small laboratory system for the characterization of silicon strip sensors. The front-end electronics are based on a low noise chip with 128 input channels and a clock speed of 40MHz which was developed for the LHC experiments to read out microstrip detectors. The system is typically used to test microstrip sensors with variable interstrip distance by laser, radioactive source or particle beam. At DESY we use it for the sensor development work of the CMS and ATLAS groups studying, for example, the analog signal size before and after irradiation.

The ALiBaVa system hardware has two main parts: a **daughterboard** hosting the readout and a **motherboard** (see Figure 1). The first one contains two readout chips (Beetle) and has fan-ins and sensor support to interface the sensors. The last one is intended to process the analog data that comes from the readout chips and from external trigger signals, to control the whole system and to communicate with a PC via USB. There is provision for an external trigger input (a silicon trigger board is available) and a 'synchronized' trigger output for pulsing an external excitation source (e.g. laser system). In this system, the readout is triggered by a scintillator with PMT readout placed directly underneath the sensor

The sensor in the EDIT School setup is an ATLAS ITK strip sensor. Details below.

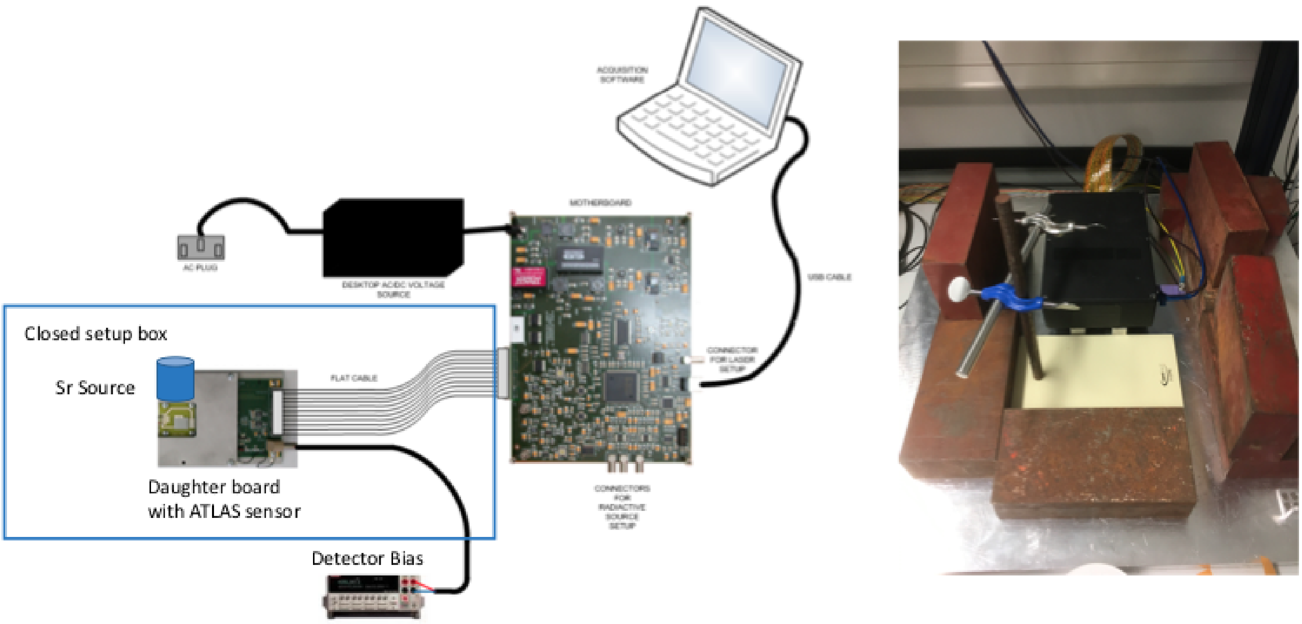


Figure 3: Schematic of the laboratory setup for measuring charge deposition (left) and a look inside the closed setup box (right).

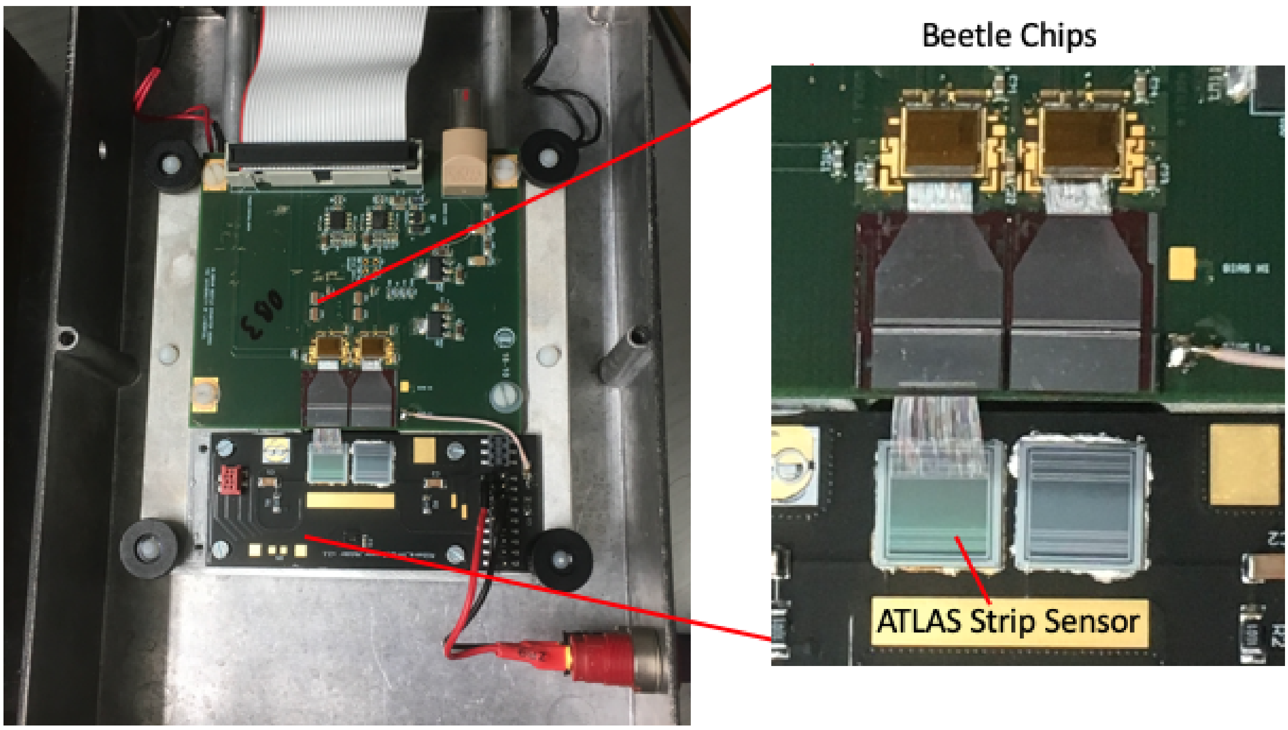


Figure 4: Top view of the EDIT2020 Landau setup inside the closed setup box with a zoom-in onto the daughterboard housing the beetle chip and the ATLAS strip mini sensor.

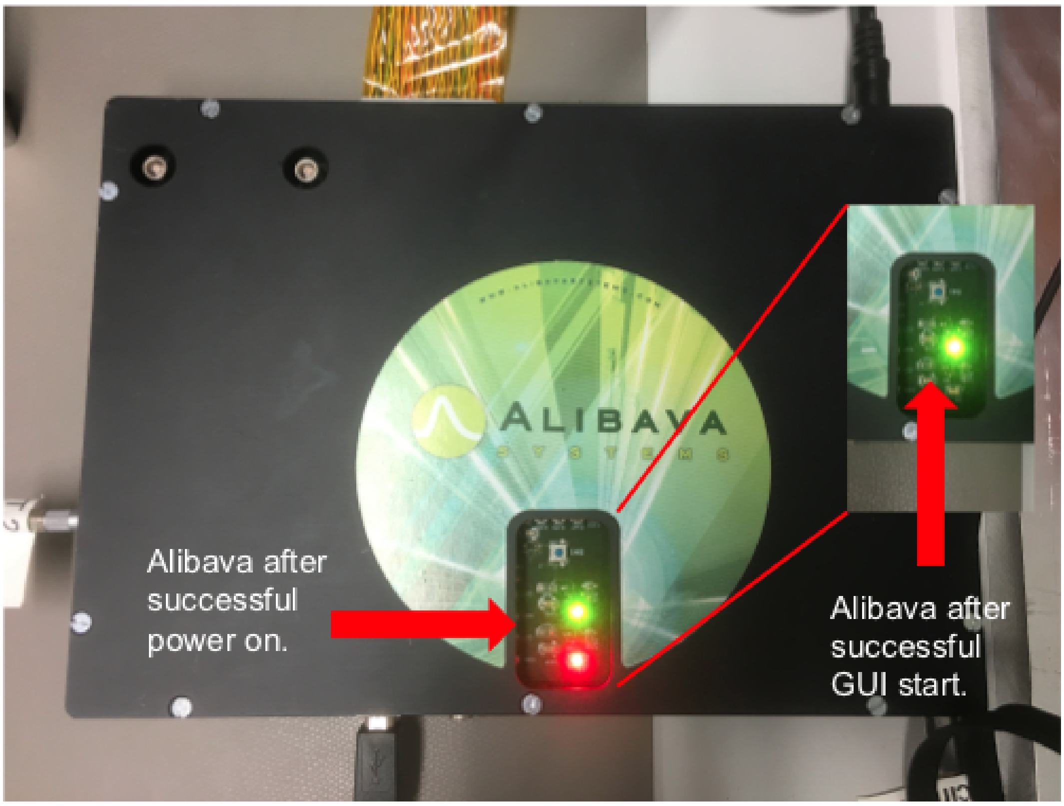


Figure 5: Top view of the box housing the Alibava motherboard with the initialization lights.

PMT power supply Strip sensor bias voltage

Figure 6: Power supplies for the PMTs and the strip sensors.

AliBava GUI

alibava-gui is a graphical user interface that controls the ALiBaVa card. It is able to configure the device, receive the data that the card sends via the USB bus and store it in a file for further analysis. The alibava-gui also monitors the data while in acquisition mode so that the user can detect problems or just find the proper parameters to run the system in an optimal way.

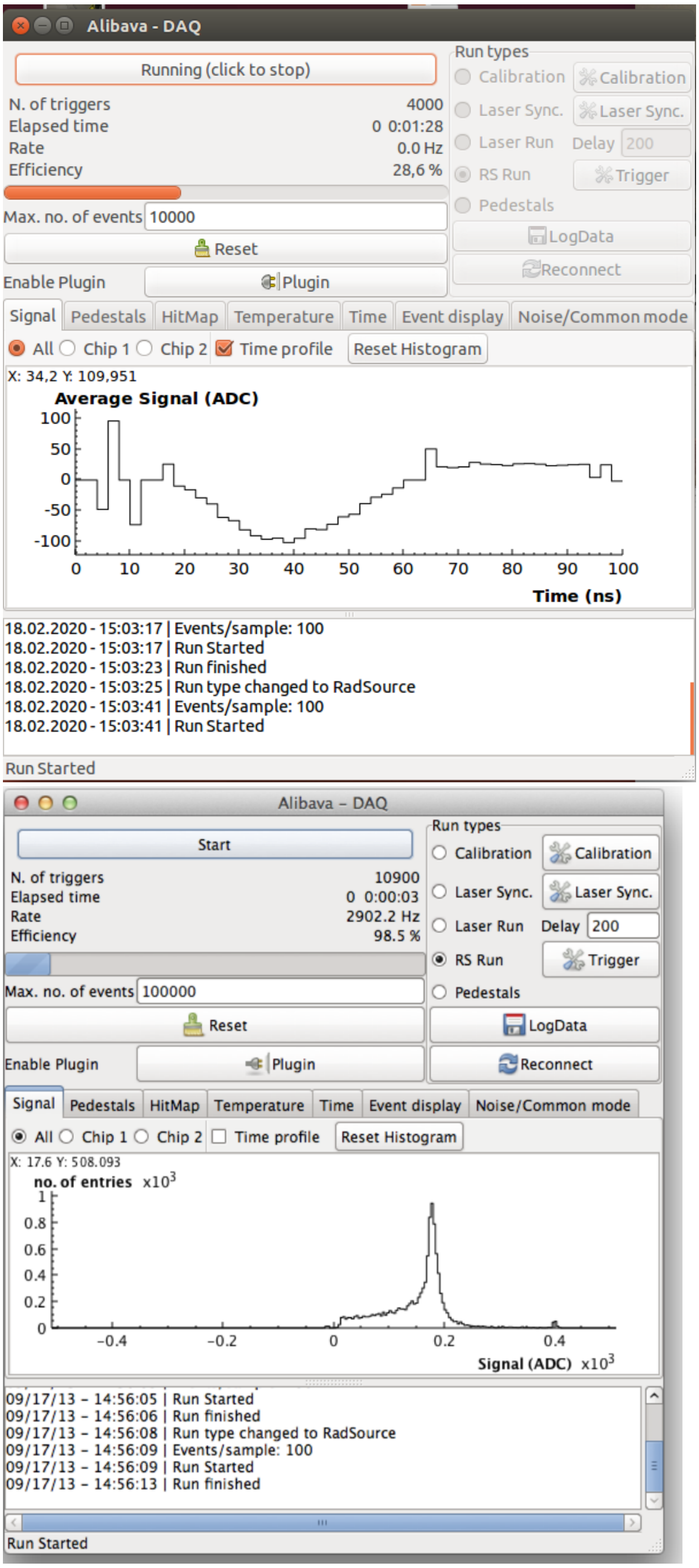


Figure 7: Screenshots of the Alibava GUI. Right Main menu with the full signal, left the time profile.

The ALiBaVa firmware provides **five-run modes** (but you will not use all of them)

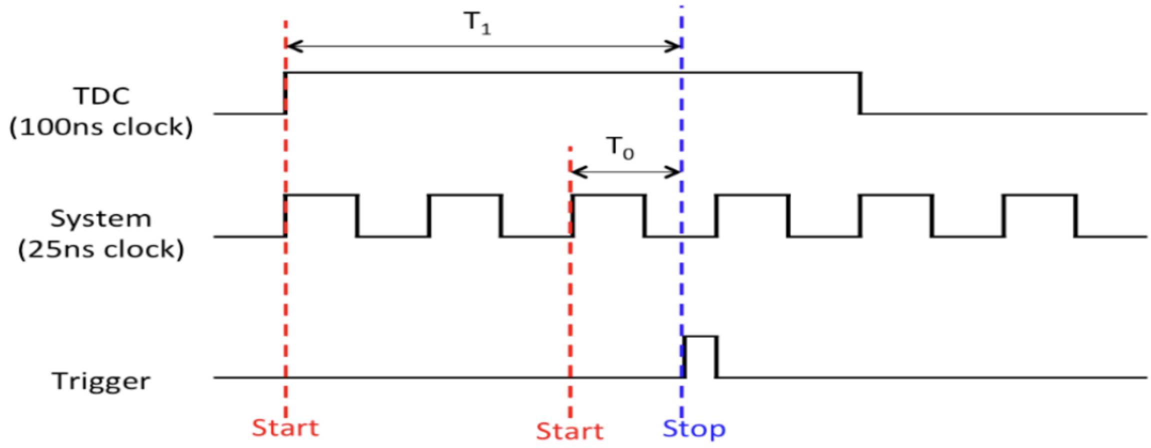
- Pedestals: makes a pedestal run. ALiBaVa generates an internal trigger that will allow computing the baseline or pedestals and its variation (the noise)
- Calibration: makes a calibration run. the system programs the Beetle chips to inject calibration pulses to all the channels in order to characterize the electrical behavior of the ASICs.
- Laser synchronization: Alibava is able to send a pulse that can be used to trigger a laser system. This run mode scans the delay between the pulse
  sent by alibava and the acquisition so that the system will sample at the maximum of the signal produced by the laser (not used during EDIT school).

- Laser:makes a laser run. One needs to run the in laser synchronization mode before in order to read back the optimal signal produced by the laser (not used during EDIT school).
- Source: makes a run in which the acquisition is triggered by signals above the threshold in the input connectors. In the EDIT setup, this signal comes from a scintillator with PMT.

More on setting up the system see printout or https://www.alibavasystems.com/images/Catalogo/alibava-startup-guide.pdf

Pulse shape reconstruction a simple explanation is as follows, for details, please look into the alibava manual page 11.

The internal system clock of the alibava is a 25 ns clock (40MHz). When a trigger comes in, it records time T_0, and plots the Time Profile “time vs average ADC” . However, the time of each signal we will get is constrained in the 25 ns window. If we enable the pulse shape reconstruction on the GUI (Settings->DAQ->click pulse shape rec box), it would open a window of 100 ns.



The time Profile plot on the GUI has an average charge plotted in the y-axis so you can see that the charge of the signal decreases off-peak.

The physical reason for checking the Time profile and perform a time cut is that you have an electron go through the sensor and knocks off charge, the charge gets collected on the strips due to the bias voltage, and that charge goes into an amplifier on the Beetle chip and then disappears. So there is only a short window in time where you can see the charge from the hit. If you look too early in time you'll just see the first few electrons that made it to the amplifier, and if you look too late you'll see most of the charge has left the amplifier so you have to look the right period of time (the time cut) where you see all the charge from the hit.

Task Description

1. Familiarize yourself with the Setup and the connections (see Figures above for reference) :
    - ALiBaVa daughter board + Atlas12 strip sensors in the black box
    - ALiBaVa motherboard
    - Scintillator and PMT
    - DC power supply for the PMT
    - High voltage power supply for the sensor
    - Sr90 source (is in the box behind radiation screening for safety reasons)
2. Apply +/- 1V to the sensor.**Q: Is the sensor is an n or p bulk?**
3. Apply the bias voltage of 400V to the silicon sensor in steps of 1V. Please check if the compliance is set to be 105 µA before starting.
4. Apply 13.7 V to the PMT for the scintillator (see Figure 6). It should be set already. Please press the output button.
5. Plug in the power cable of the ALiBaVa (backside), the red and green light on the motherboard should be on. If not in, unplug and plug again (see Figure 5).
6. Open the Alibava GUI (icon located on the Desktop), the red light on the Motherboard should disappear if the system is programmed correctly(see Figure 5).
   If not, quit the GUI and disconnect the power cable and redo step 3 and 4.
7. Load config file (.ini) on the Alibava GUI.
   (File->OpenDesktopEDIT.ini)
8. Set the bias voltage to 400V. Check if the pulse shape reconstruction is turned on in the GUI. (Settings->DAQ->Pulse Shape Rec)
   Q: What is a pulse shape reconstruction?
9. Perform a trigger latency scan using RS run function. (To change the latency: SettingsLatencyApply) The suggested range between 110 - 140. Start with larger steps and then refine.
   If the latency is correctly set, the hit map should look somehow like Figure 7 right.
   Q: What is a trigger latency and why do you need to scan this ?
   Q: What is the optimal value ? Please note it down.
10. Do a scan of the bias voltage for the silicon sensor using the RS run function in the GUI. For now, unable the pulse shape reconstruction (Settings->DAQclick the pulse shape Rec. box). Scan the voltage from 100 to 400 V, by changing the voltage on KEITHLEY.
    (To check the mean of the signal from the GUI: right-click the mouse on the signal plot -> show stats)

Q: At what Voltage is the sensor starting to be fully depleted?

11. Set to the trigger latency as noted above and bias voltage and start taking different run types. Now enable the Pulse Shape Reconstruction.

    REMEMBER TO CREATE THE DATAFILE BEFORE TAKING DATA. Save the file in the Folder on the Desktop/EDIT2020/AlibavaData/ To save the file: before taking data,
    Settings->Data Format->HDF5;
    LogData"filename_Ped.hdf" (see note below)

    a. Pedestal Run with 10k events.
       Alibava generates an internal trigger that will allow computing the baseline or pedestals and the noise.
       Derive the pedestal value and noise.

    b. Calibration Run (with 100 samples per run): Alibava programs the Beetle chips to inject calibration pulses to all the channels in order to characterize the electrical behavior of the ASICs.
       i. A delay scan to determine the delay time set the charge to be 24500 e- (Calibrations Pop up menu Select Scan type to Delay)
          Why do we choose 24500 e- ?
          Why do we need to do a delay scan?
       ii. Set the delay time to the obtained value and do a charge scan (see pop-menu Select Scan type to Charge).

    c. Radiation Source Run (RS)
       i. Set this threshold value in the GUI (settings trigger Trigger Pulse IN). Since we only have one scintillator, select "trigger pulse In" with the logic "OR", and set the threshold to -200mV and 0mV.
       ii. Take data - decide how many events are reasonable.

**** [Note] Data file name should be saved as the following structure:**

"file prefix name" _ "bias voltage" V_Ped/Cal/Sr90.hdf

for example: Pedestal data file of the run at -100V,

Test_-100V_Ped.hdf

Important:

This setup is using a Sr-Source – please be careful and follow all safety instructions! Do not open the setup box by yourself. Always as Ginger or Surabhi if the source needs to be moved.

Strontium-90 (^{90}Sr)
is a radioactive isotope of strontium produced by nuclear fission, with a half-life of 28.8 years. It undergoes decay into yttrium-90, with decay energy of 0.546 MeV. Strontium-90 has applications in medicine and industry and is an isotope of concern in the fallout from nuclear weapons and nuclear accidents.

Landau Setup Data Analysis

Please log into lxplus.cern.ch with one of your CERN accounts. If no one has a CERN account, the tutor will log into a prepared account.

On lxplus create a folder for EDIT2020 or go to the prepared EDIT2020 folder. And scp -r he directory of the files which is on the desktop of the computer there: EDIT2020/

On your own lxplus, please edit the lines in these files (in EDIT2020/Analysis/):

1. in runinfo.txt: line 2,4 the path should be set as the description in the file
2. in Stream.py: line 13 the path of the runinfo.txt should be "your_lxplus/EDIT2020/Analysis/"
3. in dolandau.py: line 7, 10 the path of the runinfo.txt and LandauFit.C should be "your_lxplus/EDIT2020/Analysis/"

1. Change to the bash shell script for convenience:

   ```
   exec /bin/bash
   ```

2. Setup computing environment:

   ```
   source setup_Alibava.sh
   ```

3. Edit the runinfo.txt (use your favorite editor, vim would be one option), Please look into the parameters and discuss them:

   - file prefix, directory of the data file, directory of the output root file
   - chip number the beetle chip that is connected to the sensor is **chip 0**
   - start and end of the bonded strip no. since the sensor is only connected to chip 0, only the first two numbers have to be modified. Set to **0, 127**, run the code first and determine the final bonded region from "HitMap" in rootfile afterward (see below).
   - Time profile cut Only entries in this time window are taken into account to avoid truncated signals. Set to **0, 100**, run the code first and obtain the time window from "TimeProfile" in rootfile afterward (see below).
   - Seed cut if the signal is greater than **cut*noise**, it will be considered a hit. Set it to **0**

- Neighbor cut if the signal of the neighbor strip is greater than **nbrcut*noise**, it will be added to the cluster

4. Run the python code :

```
python3 stream.py -s (Bias voltage)
python3 stream.py -s -100
```

5. Start root

6. Start TBrowser e (the letter is arbitrarily chosen)

7. Look into the _hd.root file:
 strip_charge (signal without pedestal subtraction)
Q: **What do you see ? What needs to be done to get an optimal Landau ?**

8. Look into the root file, all signals here are pedestal subtracted already :
 HitMap
 TimeProfile
 Chip0Signal_100bins
Modify the parameters in runinfo.txt (see above) to improve the analysis; the description is as step 3.

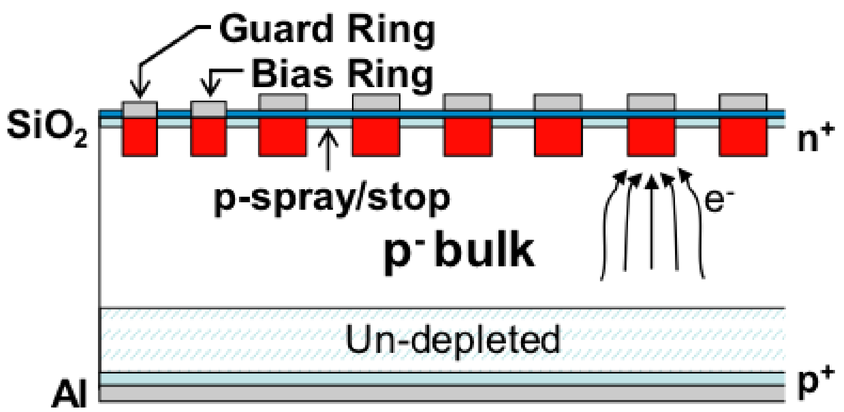
9. Re-run the python code stream.py (in step 4.) until you are satisfied with the distributions.
Q: What are the best settings?

10. Do a Landau Gaussian fit:

```
python3 dolandau.py -s (Bias Voltage)
python3 dolandau.py -s -100
```

11. Start TBrowser again, and recheck the Hitmap, TimeProfile and Chip0Signal_100bins
Print the MPV value of each fitting curve.
 Seed_MPVPrint()
 Cluster_MPV->Print()
Q: What can you correlate with the thickness of the sensor?

Information on ATLAS12 mini sensors



Thickness: 310 um +/- 20 um

Strip pitch: 74 um