SILICON DETECTORS IN PARTICLE PHYSICS

Pavel Jiroušek, pavel.jirousek.jr@gmail.com, Na Hvížďalce 23, Praha 5, 155 00
Jan Brandejs, honza.brandejs1@gmail.com, Kpt. Jaroše 942, Holice, 534 01

INTRODUCTION

One of the largest physical experiments currently operating in LHC in CERN is the ATLAS experiment. LHC and ATLAS were designed to operate at luminosity of 1 – 2 x 10^{34} $cm^{-2}s^{-1}$. After this luminosity is reached, LHC will undergo the High Luminosity Upgrade, which will increase the performance by factor of 10. Closest to the Interaction point is the inner detector, more accurately the “tracker” (Pixel, SCT, TRT), which is a system of silicon detectors. The current silicon detectors are not designed to withstand such radiation, therefore they have to be replaced.

The base principle of detection of charged particles in semiconductor detectors is knocking out electrons from their position in silicon monocrystalline. These electrons are then collected on the detection electrodes (strips). From the charge measured on the strips, we can retrieve data about the detected particle.

Before the detectors are installed in the tracker, they have to pass a series of tests, which examine their performance and only the ones which meet the set criteria can be used. Besides excluding malfunctioning modules, tests are also carried out to determine the accuracy and other parameters of the detectors and calibrate them to operate most effectively. In order to handle large number of modules, the testing apertures have to be well prepared and automated. All of these tests have to be conducted in a strict dust-free environment. One of these clean laboratories where the modules are going to be examined is at the Faculty of Mathematics and Physics at Charles University in Prague under the supervision of doc. RNDr. Zdeněk Doležal, Dr.

ABCN CHIPS AND STRIPS

When two beams of particles collide in ATLAS, the amount of data produced by the detectors is too large to store it in its raw form. In order to reduce it, the analogue signal is transformed into binary by the ABCn (Analogue to Binary Chip next) before it is processed by other systems in ATLAS. Like most electronic devices, detectors suffer from noise, however at accuracy that is required this distortion becomes a problem. To cut off the false signal, ABCn chips have a threshold set. When the analogue data is transformed, all amplitudes lower than the value of the threshold are ignored. The question now is, what is the optimal value of the threshold. If we would measure a reference signal from the detector and progressively increased the value of the threshold, it would eventually overgrow the amplitude of the signal. If we would plot this measurement, we would expect a step function as a result. However the real signal is distorted by noise to a typical S-curve.

The used value of threshold is the mean value of the S-curve. For this particular calibration, we used a specialised software based on ROOT, written for this particular purpose. The same program is also used for testing the functionality of the strips and their corresponding channels.

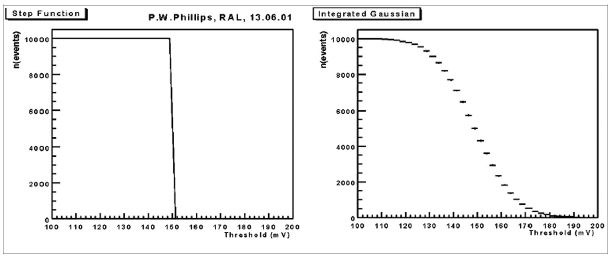


Fig. 1. Step function and S-curve [1]

DETECTOR'S CHARGE COLLECTION CAPABILITY

When a charged particle comes to rest inside a silicon detector, its charge is added to the system and contributes to the noise. In order to determine its intensity, we measured charge collection capability of the detectors. This is done by irradiating the module with ß$^-$ source (^{207}Bi) and measuring the amount of particles passed through the detector.

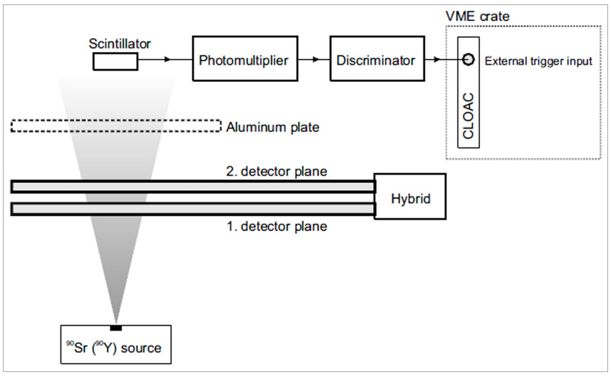


Fig. 2. Measurement setup [2]

Particles with different energies have different probability of being absorbed. The lower the energy, the higher the probability. Therefore if we are to draw correct conclusions from our measurements, we have to know the energy spectrum and the activity of the source. We have determined it by similar procedure as in the chip threshold calibration. We used a scintillator connected to discriminator with an adjustable threshold and measured the amount of particles. Different energies of the particle lead to different amplitudes of the signal. By increasing the threshold, we cut off particles of certain energies. So by differentiating the data collected, we obtain an unscaled energy spectrum (Fig. 3).

The whole area of the module has to be tested, however the test can be conducted at one place at a time. To do this effectively with large number of modules, the process needed to be automated. For this we used a pair of computer controlled scroll bars and designed a program based on ROOT that operates them and collects and processes data from the reference scintillator.

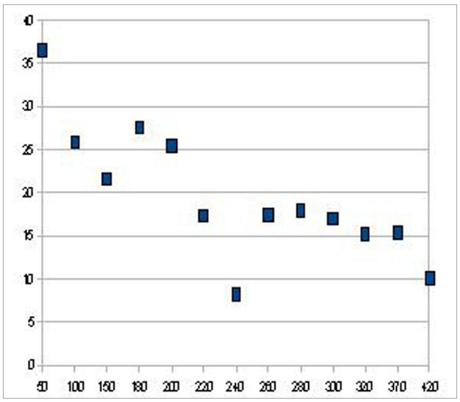
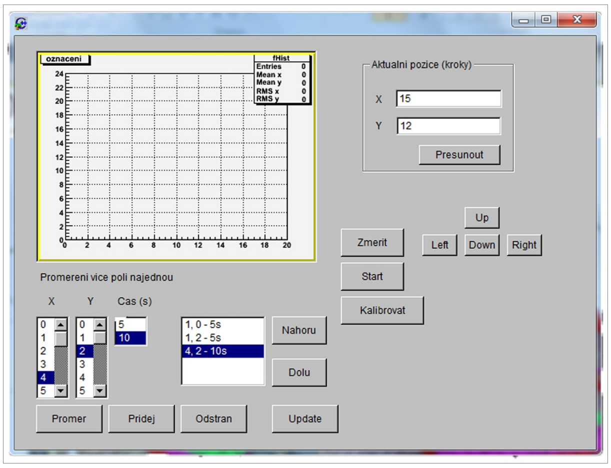


Fig. 3. Energy spectrum of ^{207}Bi



Aktualni pozice (kroky)

X 15

Y 12

Promereni vice poli najednou

X	Y	Cas (s)
0	0	5
1	1	10
2	2	
3	3	
4	4	
5	5	

1, 0 - 5s
1, 2 - 5s
4, 2 - 10s

Fig. 4. User interface

POSITION ACCURACY

When a charge is collected on aluminium strips, it is not concentrated on a single strip, but usually most of it is distributed among two of them. However the particle did not pass through two places at the same time, but somewhere in between. We can calculate the exact position of the particle from the following formula.

$$x = \frac{S_2}{S_1 + S_2} d \qquad (1)$$

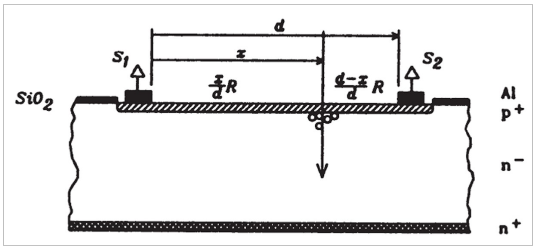


Fig. 5. Cross-section of the detector [3]

The amplitude of the signal is not accurate due to the noise. This inaccuracy depends on the distance between strips and noise signal ratio.

$$\sigma_x \approx \frac{d}{S/N} \qquad (2)$$

The position accuracy is also measured experimentally by sending a beam through an array of tested detectors, while measuring it's real trajectory by four precise analogue telescopes and comparing data from both. Data have to be processed in order to remove the effects of the inaccuracy of position of tested modules in light-tight box.

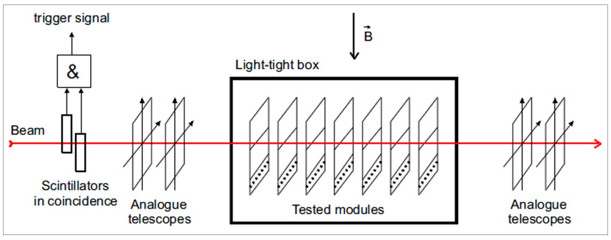


Fig. 6. Position accuracy test [2]

CONCLUSIONS

We learned about application of silicon detectors in particle physics and their testing, which needs to be carried out before their installation. A series of tests have been conducted, including the chip and strip testing and calibration, as well as the analysis of the data from the position accuracy tests. We also made preparations for future measurements of detector's charge collection capability, which required determining an energy spectrum of Bismut and designing a specialised program based on ROOT.

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REFERENCES

1. Pavel Řezníček: Tests of semiconductor microstrip detectors of ATLAS detector, diploma thesis (MFF UK, Prague – 2003)
2. Zdeněk Doležal: Křemíkový stripový dráhový detektor, poster (MFF UK, Prague – 2008)
3. Zdeněk Doležal: Polovodičové detektory v jaderné a subjaderné fyzice, text for lecture JSF101p1a (MFF UK, Prague – 2007)