CHARGE COLLECTION EFFICIENCY (CCE) SETUP AUTOMATIZATION

DESY Summer Student Programme 2014

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ABSTRACT

This paper depicts the background, the concept, the process and the result of CCE setup upgrade in order to study artificial diamond's properties. The Report includes information about the properties of the artificial diamonds, the location of the diamond detectors in LHC experiment, description of the physical principles underlying in the diamond detectors operation. The description of the measuring devices which are used in the install are presented. The results of test-diamond measurements before and after upgrade are reported.

1. INTRODUCTION

1.1 Synthetic Diamonds

The earliest successes in growing synthetic diamonds were reported by James Ballantyne Hannay[1]in 1879 and by Ferdinand Frederic Henri Moissan[2] in 1893. Their method involved heating charcoal at up to 3500 °C with iron inside a carbon crucible in a furnace.

Nowadays artificial diamonds are mostly produced using two the technologies: the High-Pressure High-Temperature (HPHT) and the Chemical Vapor Deposition (CVD) Crystal Formation methods. For detector diamonds these methods are combined – CVD method is used to produce the seed of CVD for the diamond and by the HPHT method other diamond is formed. Figure 1 demonstrates surface of a sCVD diamond with high definition made by Electron micrograph after CVD process.

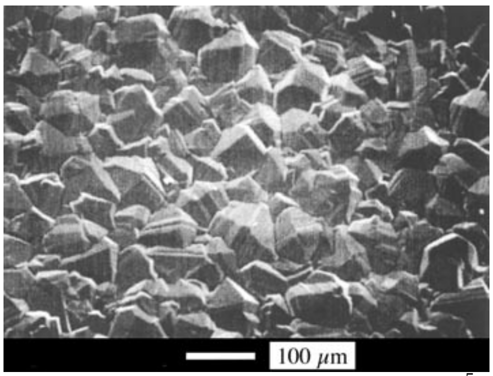


Fig.1 Electron micrographs of a CVD[5]

The main properties of diamonds for particle detection are radiation resistance of a material, temperature independent, no need of forced cooling, nanosecond time resolution, big energy gap (radiation tolerance).

1.2 Applications of diamond detectors in HEP

In terms of applications of diamond at experimental particle physics, it should be mentioned that diamond is a very promising material in detectors technologies. As it was stated above, the diamonds are radiation tolerant, they are not temperature dependent even under radiation.

These properties allow to use detectors based on the diamonds under a high level of radiation. One of detectors is the Fast Beam Conditions Monitoring (BCM1F)[3] buildup at Compact muon solenoid (CMS) experiment of the Large Hadron Collider (LHC) at CERN[4].

BCM1F is an online monitor providing real time information about flux that is essential feedback for the LHC beam operation. Also it is used as a luminosity[5] monitoring system which is based on bunch-by-bunch measurements of LHC beam and collision products inside the beam pipe. BCM1F is located inside the CMS detector. It is one of the monitoring systems with the highest time resolution(1 μs), and able to monitor bunch and single particle actions.

Such detector units are installed perpendicular to the trajectory of the beam inside the CMS detector ±1.8m from the beams interaction point. The location of the BCM1F detectors is shown at figure 2.

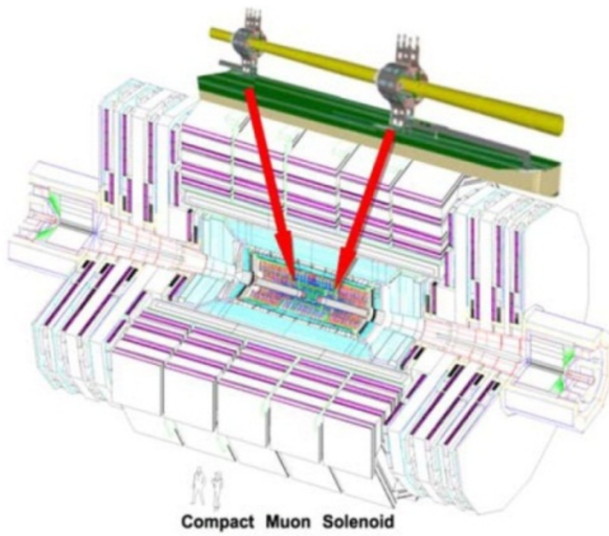


Fig.2 BCM1F locations

An upgrade of BCM1F[6] system foresees the install 24 non-irradiated sCVD sensors with the split electrode. The plan is shown at figure 3.

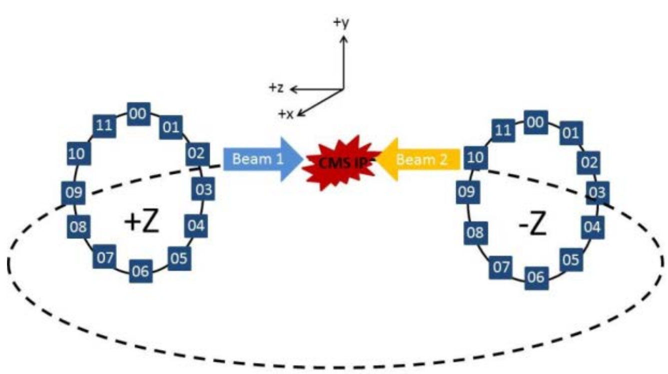


Fig.3 BCM1F upgrade plan[7]

In order to find the best diamonds, characterization of more then 50 sCVD diamonds were measured. The characterization contains in measuring the current versus voltage (IV), current stability over time (I-t) and the charge collection efficiency (CCE). This report focuses on the CCE measurements, the modifications and improvements of the CCE measurement setup, that was created in the laboratory at DESY.

1.3 Basic principles of detectors operation.

The basis of the system is a physical process that takes place within a sCVD diamond. The signal in the external circuit is generated merely by the movement of particle through the diamond. In the absence of an externally applied electric field, the electrons and holes (produced by ionization), which are both able to move within the diamond lattice, would normally recombine quickly. Under the action of the external electrical field pairs separates and travel to the electrodes and the movement of free charges generates a signal, which is amplified and later analyzed. If the external field is not enough electrons and holes recombine and signal does not generates. You can see the process at figure 4.

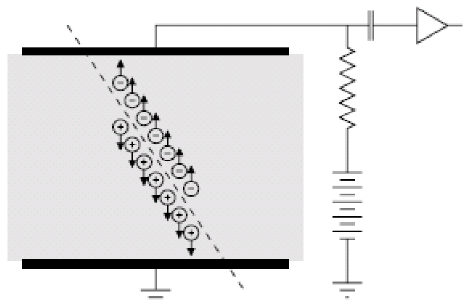


Fig.4 Generation of a signal in a diamond detector

If charges $+q$ and $-q$ move apart a distance x in a uniform electric field $E$the work done by the power source maintaining the field is $E \times q$. If the width of the gap is l and the applied potential difference is V the electric field is $E = \frac{V}{l}$ and the work can be written as $\frac{E \times q}{l}$. In order to deliver this amount of energy to the detector a transient current passes around the circuit, and the time integral of this current, i.e. the total charge which flows, say Q, is given by dividing by V[8].

$$Q = \frac{qx}{l}$$

Real sCVD diamond for BCM1F upgrade is shown on figure 5. Picture was made by the laser microscope at DESY. The dimension of diamonds the with 2 pads are about 5×5 mm. The thickness of the diamond is about 500μm.

Fig.5 Picture of a two pad diamond sCVD

2. SETUP DESCRIPTION

The Charge Collection Efficiency Setup consists of 2 main blocks. First is a unit which is directly related to the diamond. It consists of a source of radiation, a sample stage for diamonds, a needle, a preamplifier and two scintillators. All listed equipment is inside the box, which is grounded. The Second block is a transmitting-analyzing unit. It consists of a high voltage source, an amplifier, a low threshold discriminator, a coincidence unit, a fan in fan out, an advanced direct connect, a dual timer. The general diagram of all equipment in CCE measuring setup is shown if Figure 7. More detailed description is in Appendix 1.

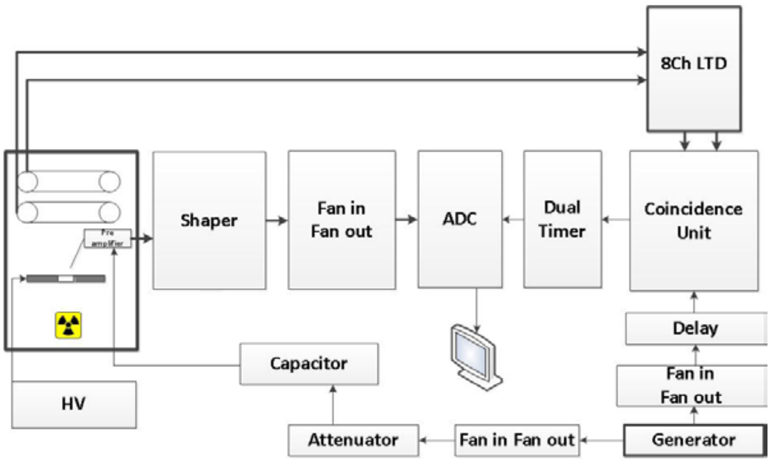


Fig.7 general diagram the setup

3. READOUT ANALYSIS

For the proper analysis of the diamonds CCE characterizations two mesuarments must be done. Both use the same equipment and are very similar. The distinction between signal and pedestal measurements is that in one case we measure charge from diamond at exact time of ionization (signal) and in other average in time (pedestal). First show the charge generated inside the diamond by particle ionization second shows the level of background radiation.

3.1 Signal measurements

Figure 8 shows a schematic diagram of Signal measurements.

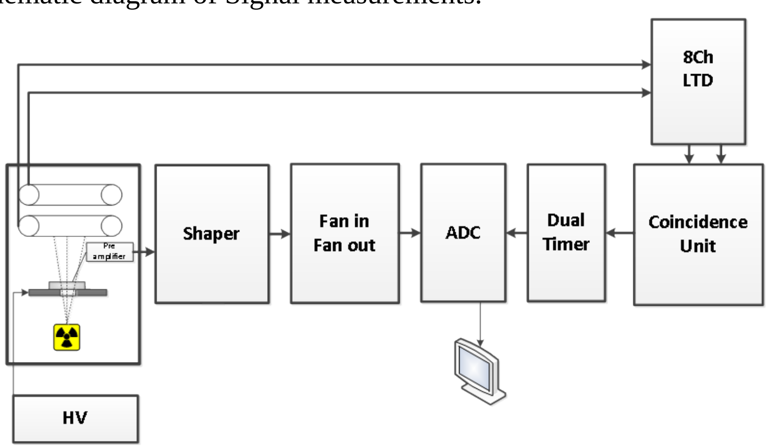


Fig.8 schematic diagram of Signal measurements.

Particles from Sr-90 go straight through the diamond and produce the ionization. Inside the diamond lattices free electrons and holes are borne and due to the external electrical field go to the eletrodes. It is the way how the signal is born. The needle contacts with the diamond and transports signal to the pre-amplifier. After the per-amplifier the signal is very short and the shaper helps to form wider signal. It must be observed that all signal is value, and after the shaper the signal gets a small positive part, so it goes to the Fan-In-Fan-Out, which biases signal down on -21 mVolts without changing the shape and timing of the signal. After that the signal goes to the Dual timer unit to create a longer time Gate for the ADC. Also between scintillators and Coincidence unit there is a LTD. It helps to separate the background noise and measuring signals.

The particles that produced ionization inside the diamond goes futer. Thery are registered by the two scintillators on the top of the box. The signal from the scintillators are discriminated and sent to the Coincidence unit. If both signal come at the same time, coincidence unit will pass the signal trough. This signal becomes a Gate signal for the ADC. The ADC senses the signal just during the open Gate.

3.2 Pedestal (background) measurement

The signal from the diamond comes the same way, but in that sort of measurements scintillators are not used. Instead of it source of impulses are applied. It sent impulses to Coincident Unit periodically in time independent to passing radiation flux through the scintillators. In that way averaging out other time can be achieved. Figure 9 shows a schematic diagram of pedestal measurements.

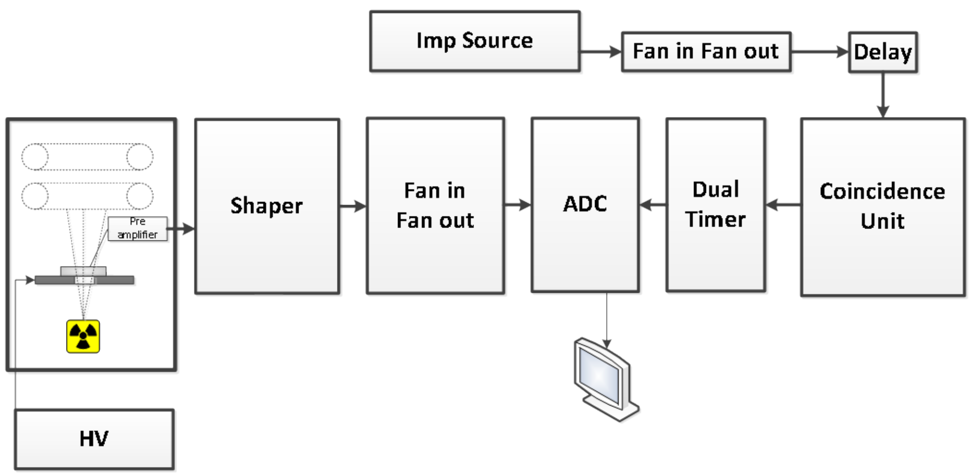


Fig.9 Pedestal measurement

3.3 ADC data

The transmited analog signal, after Shaper, is correlated to the charge generated inside the diamond. ADC converts the analog signal to a digital one. It is clearly seen two spectums peaks. Lower one is a pedestal, higher histogram is Signal. Figure 10 shows the output data from ADC on computer.

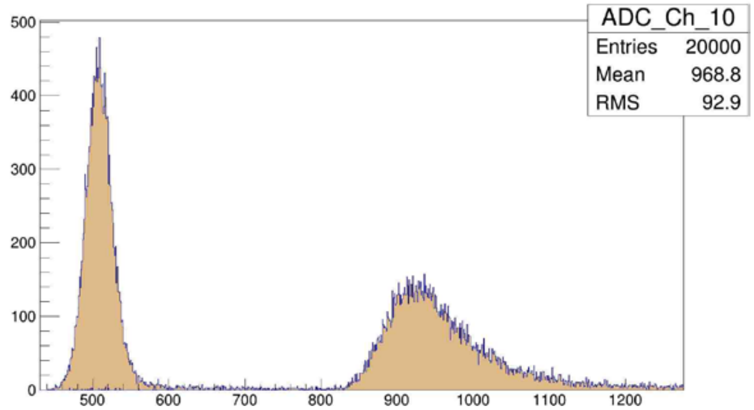


Fig.10 output data from ADC on computer

Since the nature of the processes is different, so they are characterized by different probability distributions. Pedestal, as a background noise, has a classical natural distrebution. That is shown on the figure 11.

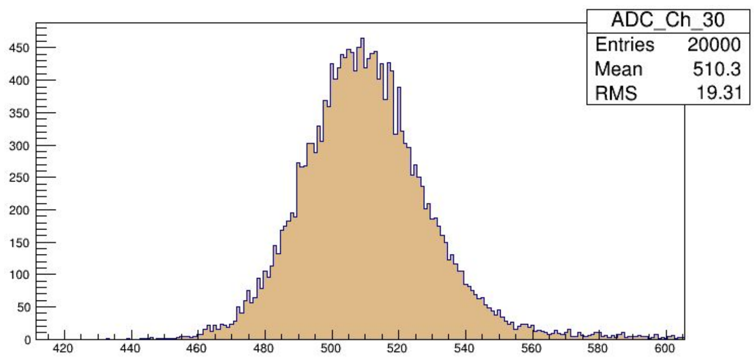


Fig.11 Pedestal ADC histograms

The signal from the diamond, see figure 12, has Landau distribution, with a significantly slower decline on the tail chart.

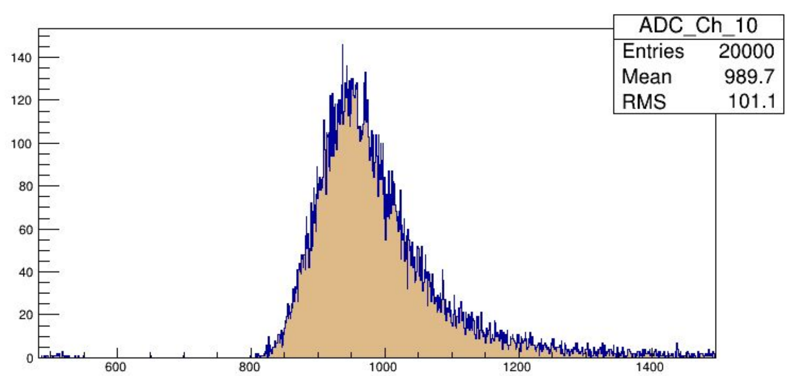


Fig.12 Signal ADC histograms

It is explained by the thicknes of the detector. R.J. Tapper[8] interprets it this way – for thinner detectors a treatment is required that deals properly with the high-energy tail of the distribution, that is contributed by collisions with atomic electrons. during this case the utmost energy transfer is little enough to form the distinction vital, whereas for the high-energy beams like minimum-ionizing pions the utmost energy transfer is incredibly giant compared with the common, and therefore the original variety of the Landau distribution is suitable.

3.4 Range of a Problem at the manual switching

One of the weak spots of this setup was the manual switching. Usually one session of CCE-measurement at one HV-level takes at least 5 minutes. There are 14 HV points which must be mesuared in each CCE session. Simply calculation shows that it is 70 minutes per each side of the diamond. This timing doesn't include install calibration, primary data processing, changing the diamond samples. In general it takes atleast 2 hours to measure one diamond. Such result are to slow from many points.

Other problem of manual switching is the systematic error during the measurements. When the manual switching is used, timing between the pedestal and signal measurements is not stable, so the system error increase.

As a result of discussion, it was decided to make an upgrade of CCE measuring setup.

4. AUTOMATIZATION OF THE CCE SETUP

Automatization of coincident unit looks like a standard decision in such upgrade. In that case pedestal and signal measurements are done consistently with a strictly fixed time interval. But more original and profitable solution was suggested. Instead of a coincident unit upgrade, put a delay line between FIFO and ADC input (see figure 13).

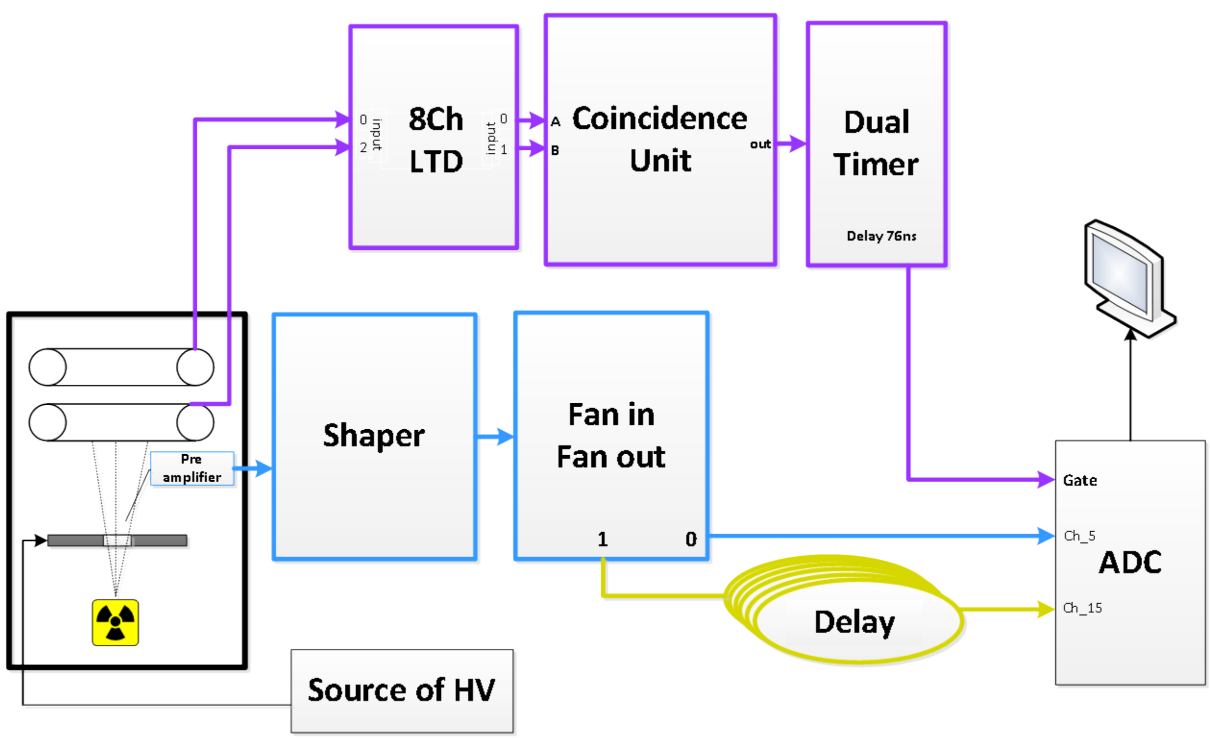


Fig.13 Principal scheme of CCE setup

FAN-in-FAN-out duplicates the same signal as arrived on its input and transmit it to delay cable. Signal in delay line will come much later and will not be processed by ADC. Time delay between signals is 375ns.

That time is enough to allow only noise in the gate window for the pedestal measurements. At the moment when the normal signal will receive permission from the coincident unit to pass through and go to the ADC. Computer star to collect data from channel with normal signal and from other channel with delay. Figure 13 show the arrival and Gate time during which ADC collects the date from the install.

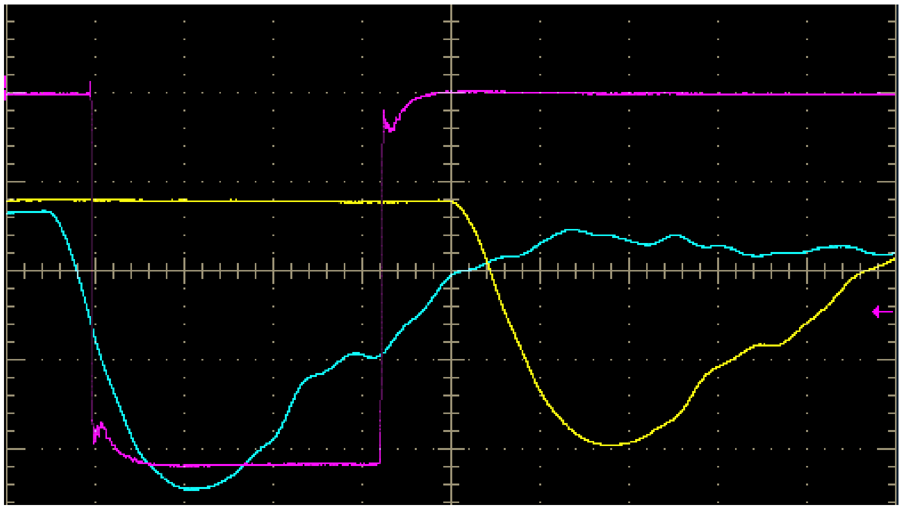


Fig. 14 Arrival time

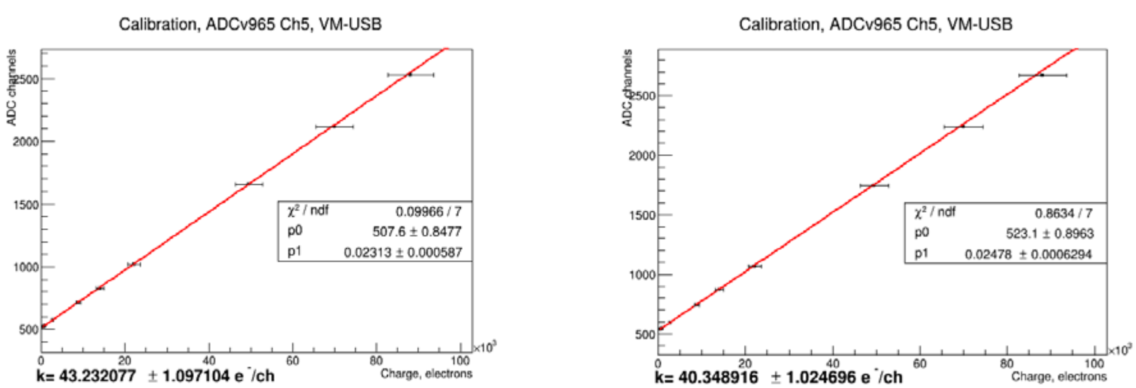
As it is shown on the figure 14 at the gate time one channel provides information about the signal and from the other channel information about the background (pedestal). Such solution allowed getting a signal and pedestaling measurements simultaneously, which is much better.

5. TESTING OF AUTOMATED SETUP

To affirm the reliability of the results, it was determined to perform a series of tests.

5.1 Calibration result comparison

Figure 15 show the calibration characteristic of signal channel before and after the upgrade.



Before upgrade After upgrade

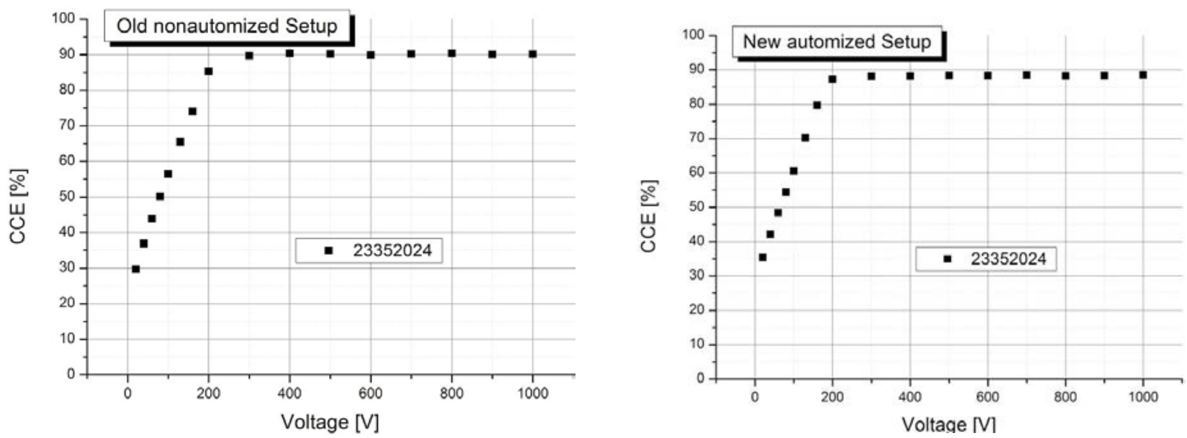
Fig. 15 calibration characteristic of signal channel (5)

The calibration factor has not changed much. It shows that there are no new leakages on the apparatus.

5.2 SCVD diamond test result comparison

For the test a one- pad sCVD diamond was taken. It is one of the best in the entire series that was available at the moment. First characteristics were measured before the upgrade and then after.

Also CCE measurements shown in the Figure 16 were done on the test sCVD diamond before and after the upgrade.



Before upgrade After upgrade

Fig. 16 CCE measurements of the test sCVD diamond (23352024)

5.3 Pedestal test result comparison

The results of pedestal measurements are presented in Figure17.

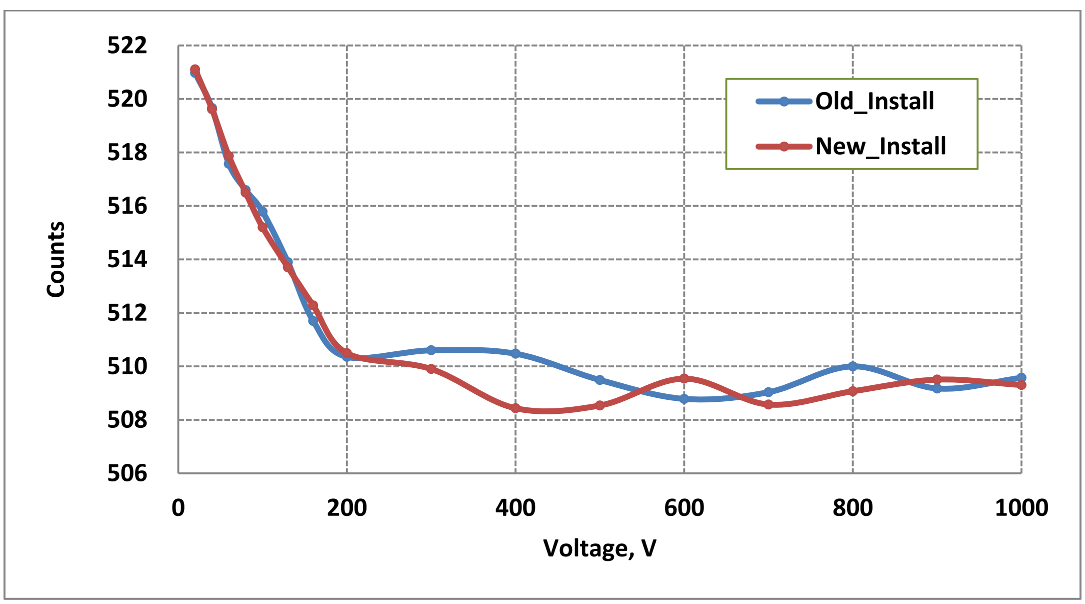


Fig. 17 Pedestal measurements

The values obtained are similar and placed in error. It can be concluded that the results of the measurements and calculations are similar.

5.4 Standard deviation result comparison

Also standard deviation (sigma) was measured. Sigma is a common measure of dispersion values of the random variable versus to its mathematical expectation. The results are shown in Figure 18.

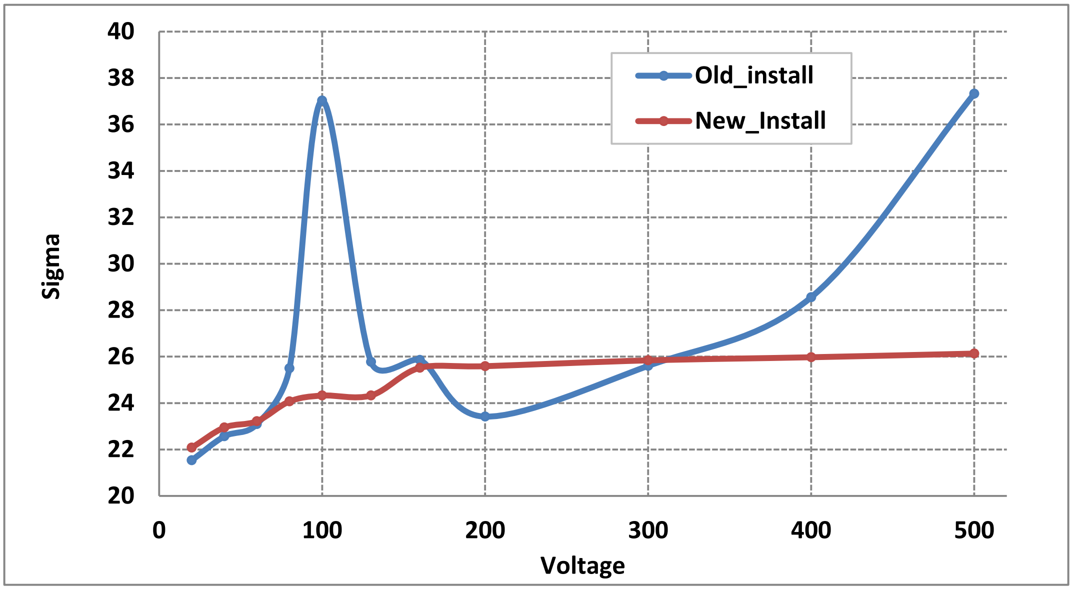


Fig .18 Sigma measurements

After the upgrade sigma's values become less fluctuation, which means better sampling results during the measurements. It can be can be described by setting strict periodicity between pedestal and signal measurements.

5.5 Time measurement comparison.

Time spent on a diamond significantly decreased. Now it is above 10 minutes (versus 70 min before) on one side of the diamond. Chance of mistakes made by the user is minimized. Also, there is a new option of a strict time delay between changing the HV point and measurements. Which gives a new aspects of measurements.

6. CONCLUSION

In order to upgrade BCM1F detectors it has become necessary to increase the measurement speed of diamonds. To accomplish this required CCE install upgrade was produced. As a result of this work were obtained new calibration parameters, removed the time characteristics of the signals were made, CCE measurements of the test-diamond were made, comparative tests of the pedestal level were done, measurement error (sigma) was improved.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

1. Hannay, J. B. (1879). "On the Artificial Formation of the Diamond". Proc. R. Soc. Lond. 30 (200–205): 450–461.
2. C. Royère (1999). "The electric furnace of Henri Moissan at one hundred years: connection with the electric furnace, the solar furnace, the plasma furnace". Annales pharmaceutiques françaises 57 (2): 116–300.
3. A.Belletal. “Fast Beam Conditions Monitor BCM1F for the CMS Experiment”. Nucl. Instrument and Methods A614, 433(2010)
4. CMS Collaboration, “ The CMS experiment at the CERN LHC ”, 2008 JINST 3 S08004.
5. N. Odell. “Measurements of luminosity and normalized beam-induced background using the CMS Fast Beam Condition Monitor”, PoS ICHEP2012: 526
6. J. Leonard. “Fast Beam Condition Monitor for CMS: performance and upgrade”, Nuclear Instruments & Methods in Physics Research A (2014)
7. M. Hempel. “Performance Of Detectors Using Diamond Sensors At The Lhc And CMS”, Proceedings of IBIC (2013)
8. R J Tapper. “Diamond detectors”, Rep. Prog. Phys. (2000)

Appendix 1
DESCRIPTION OF THE CCE SETUP UNITS

Radiation Source

As the source of radiation Strontium-90 is used. It undergoes β^- decay into yttrium-90, with a decay energy of 0.546 MeV, with a half-life time of 28.8 years. Source is placed under the stage in a protective lead holder on a movable carriage.

Amplifier system

First block is pre-amplifier, which read out the signal from the diamond. Pre-amplifier (Amptek A250F Charge Sensitive Preamplifier) is based on field-effect transistor(FET) to match detector characteristics. It amplifies signal from the needle, which has contact with the diamond. It's very sensitive to the static electrical field. So in case of any manipulation with the diamond or safe box of pre-amplifier, the power supply of pre-amplifier must be switched off. After the pre-amplifier signal is too short for measurements. Signal goes to the shaper, where gets time modulation.

Scintillation detectors

Two plastic scintillator BC-408 are used as the main detector of charged particles. Each of them registers γ-rays in range of 100 keV to 5 MeV. This photons are generated by the interaction of charged particles from the radiation source, passing through the detector material. The γ-rays from both scintillators are readout by multianode photomultiplier.

High Voltage Source (Keithley 2410 SourceMaster)

The power supply gives a high voltage to the one side of the measured diamond through the position table. The power supply provides precision measurements of voltage and current, which can be shown on display. That power source characteristics include low noise, precision, and readback. High Voltage consumes 20W. It may provides voltage in the range from ±5μV (source) to ±1.1kV and current from ±10pA to ±1A. One of the advantages of this source is the possibility of remote control. This option was used in new setup.

Low Threshold Discriminator (CAEN Low Threshold Discriminator Model N844)

Low Threshold Discriminator has 8 Channel. For the needs of the CCE installation 2 channels has been involved. Each discriminator thresholds is customizable in a range from -1 mV to -255 mV with 1 mV step. The pulse forming stage of the discriminator produces an output pulse whose width is adjustable in a range from 6 to 95 ns. LT-Discriminator separates low background signal from each of scintillation detectors.

Coincidence unit (LRS Model 466)

The coincidence unit (CU) contains three independent high-speed general-purpose coincidence units. Each channel has four coincidence inputs and a separate veto that which accept standard negative NIM logic levels. The logic inputs may be individually enabled or disabled without altering input cabling or termination by means of front-panel push button switches. Each channel has four coincidence inputs and a separate veto input which accept standard logic levels. The logic inputs may be individually enabled or disabled without altering input cabling or termination by means of front-panel push button switches. Coincidence Unit Generates a time gap. If signals from both scintillation detectors (after LTD) are registered during the time gap from CU, the signal pass through.

FAN in FAN out (Quad Linear FAN-IN FAN-OUT model N625)

The Mod. N625 is a 1-unit NIM module which houses four 4 Input + 4 Output Fan in/Fan out sections and a Single Channel Discriminator. Each Fan in/Fan out section produces on all its output connectors, the sum of the signals fed to the inputs, eventually inverted. Both input and output signals are DC coupled. Maximum input amplitude is ±1.6 V. Fan in Fan out Duplicates signal from input without form and time changing.

Advanced Direct Connect (Analog-to-Digital Converter Model V965)

Sixteen Analog -to-Digital Conversion channels with current integrating negative inputs. For each channel, the input charge is converted to a voltage level by a QAC (Charge to Amplitude Conversion) section. Unit converts an analog signal from all install to digital by integrating current over time when Gate is open. That integrated signal goes to computer.

Dual timer (Dual Timer CAEN Model N93B)

The module produces NIM and ECL pulses whose width ranges from 50 ns to 10 s when triggered. Output pulses are provided normal and complementary. Timers can be re-triggered with the pulse end marker signal. The trigger START can be provided either via an external signal or manually via a front panel switch. The step between is 40ns long and the Input Output Delay is 13ns long. So the full Delay of this unit is 76ns long.