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Diamonds as timing detectors for minimum-ionizing particles: The HADES proton-beam monitor and START signal detectors for time of flight measurements

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ABSTRACT

This paper gives an overview on a recent development of measuring Time-Of-Flight (TOF) of minimum-ionizing particles (MIP) with mono-crystalline diamond detectors. The application in the HADES spectrometer as well as test results obtained with proton beams are discussed.

1. Introduction

Diamond detectors are well known for their radiation hardness and high drift velocity of both electrons and holes, making them ideal not only as TOF detectors placed in the beam [1,2] but also as luminosity monitors [3]. However, due to the large effective energy needed to create electron–hole pairs (13 eV) the charge created by minimum-ionizing particles (MIP) traversing the diamond is marginal (14,000 pairs for a 300 μm thick diamond) [4]. Internal effects in the widely used poly-crystalline (PC) diamond material produced by Chemical Vapor Deposition (CVD) method leads to significant losses of collected charge in this type of sensors. Therefore, these sensors cannot be used for a TOF measurement of MIPs because signals are too small to be registered by state-of-the-art electronics. Instead, the recently developed technology of producing a mono-crystalline diamond material, which is almost free of structural defects and chemical impurities and thus provides very high charge collection efficiency, allows for building detectors for MIP based on single-crystalline diamond material.

In the following, a dedicated, low-noise readout scheme is described as well as its application as a TOF detector for proton beams in the HADES experiment [5].

2. Diamond readout

Mono-crystalline diamonds[1] with two different detector sizes of $3.5\times3.5\,mm^2$ (4 pixel) and $4.7\times4.7\ mm^2$ (8 pixel) with thicknesses of 300 and 500 μm, respectively, were used during the test. The base plate containing a diamond ($4.7\times4.7\,mm^2$) surrounded by eight amplifiers is shown in Fig. 1. The PC board material is Rogers 4003C TM, utilizing a low dielectric constant of 3.4. The segmentation of the metallization is shown in Fig. 2. For both our detectors a capacitance of a single segment was 0.25 pF, and was defined by the geometry of the segment. A data acquisition system of the test setup (see Fig. 3) was built based on the TRB [6], a stand-alone DAQ board, which employs the HPTDC [7] chips for time measurement. The analog signal from the detector, after amplification (two stages), was sent to the

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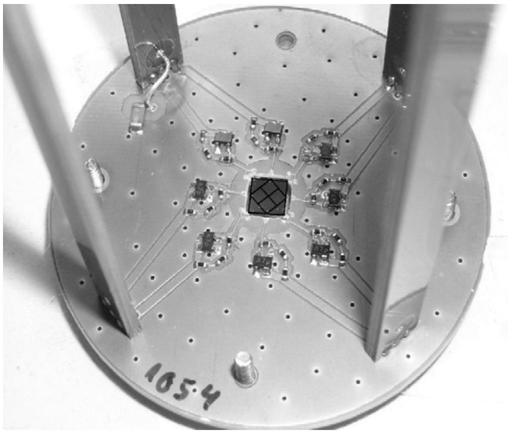

Fig. 1. PC board ($\phi = 50$ mm) with the diamond ($4.7 \times 4.7\,mm^2$) in the centre surrounded by eight amplifiers (1st stage of amplification).

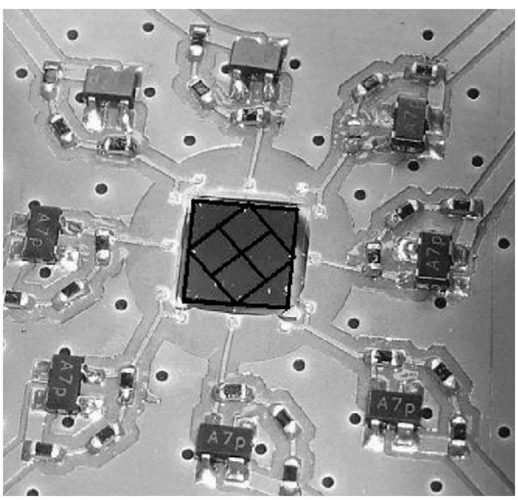

Fig. 2. Segmentation of the metal surface on the diamond detector. Eight diamond segments connected with the amplifiers located on the PCB. The bonding wires used to provide electrical contact are not visible in the photo.

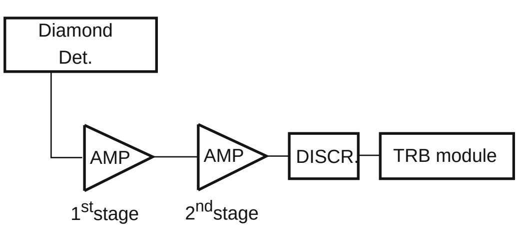

Fig. 3. A readout system used during the diamond detector test. Two stages of amplification followed by a discriminator and the TRB [6] module measure leading edge of the pulse and pulse-width of the signal from a single segment of the detector.

signal discrimination circuit with the signal integration functionality. The integrated signal was converted into pulse width of the timing output of the discriminator which allowed for pulse-width measurement.

As the noise to signal ratio of the system is proportional to the input capacitance of the preamplifier the design of the front-end electronics has been optimized to assure the lowest possible input capacitance and relatively short shaping constant which is important for TOF measurements.

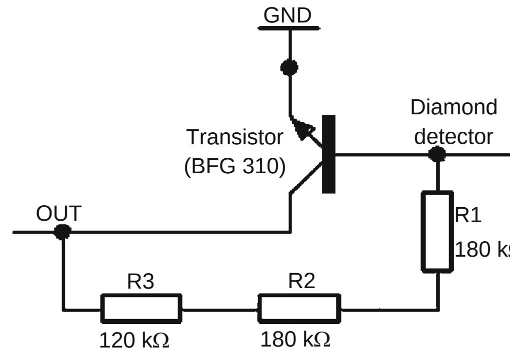

Fig. 4. Schematic of the 1st-stage front-end amplifier of a single diamond detector segment.

The crucial part of the readout system is a set of two amplification stages characterized as follows:

1. The 1st-stage amplifier is mounted as close as possible to the detector in order to reduce capacitance from cables. This amplifier was coupled directly to the single detector segment via bond-wires (dc-coupling), see Figs. 1 and 2. The single channel of 1st-stage amplifier is based on an RF transistor with small input capacitance (0.2 pF) and is shown in Fig. 4. The bias current of the 1st-stage amplifiers was reduced to an extremely small value leading to a relatively large input impedance of about 2 kΩ. For our application the 1st-stage amplifiers, mounted on a PC board, were installed inside the beam line in vacuum.
2. The 2nd-stage amplifier, booster amplifier, located outside of the beam line, performed actual signal amplification and also provided proper termination of the signal line as well as final shaping of the signal resulting in rise-times[2] of 1.2 ns (300 μm) and 1.35 ns (500 μm), respectively. The booster amplifier provided also the bias voltage for the 1st-stage amplifier via a 56 Ω pull-up resistor connected to 5 V. It is worth to be mentioned that the design of the booster amplifier is not critical. Two versions, one based on discrete transistor (BFG425) and a second one based on low noise monolithic amplifier (Gali-S55) were tested and gave the same results.

It should be mentioned that for such a front-end design (TOF measurement purposes) it is necessary to keep the stray capacitances at a minimum [8]. In our case this was realized by providing the bias current via three resistors in series in order to reduce their capacitive coupling below 0.1 pF. The power consumption of a single amplifier amounts to slightly less than 5 mW at a 5 V supply, allowing for operation in vacuum which is an important issue for the foreseen application as a beam detector.

3. Results

The diamond test experiment was performed in the experimental setup of the High Acceptance Di-Electron Spectrometer HADES [5] at GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt, Germany. Two diamond detectors were installed inside the HADES beam line 20 and 50 cm upstream of the HADES nominal focal point, respectively. The beam focus was optimized in such a way that the beam spots on both detectors were smaller

[2] The time it takes for the pulse to rise from 10 to 90% of its full amplitude.

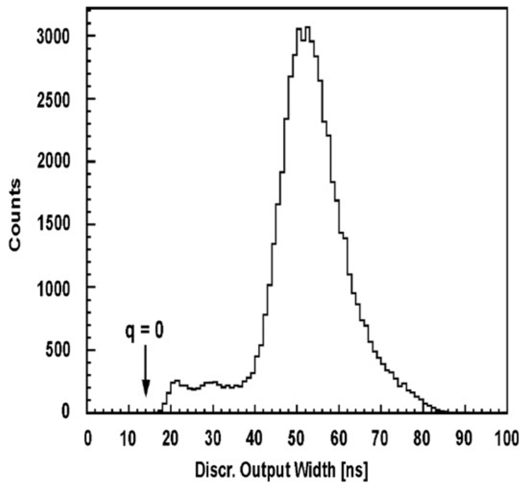

Fig. 5. Pulse-charge distribution measured via charge to pulse-width conversion for 1.8 GeV protons traversing a mono-crystalline diamond of 500 μm thickness.

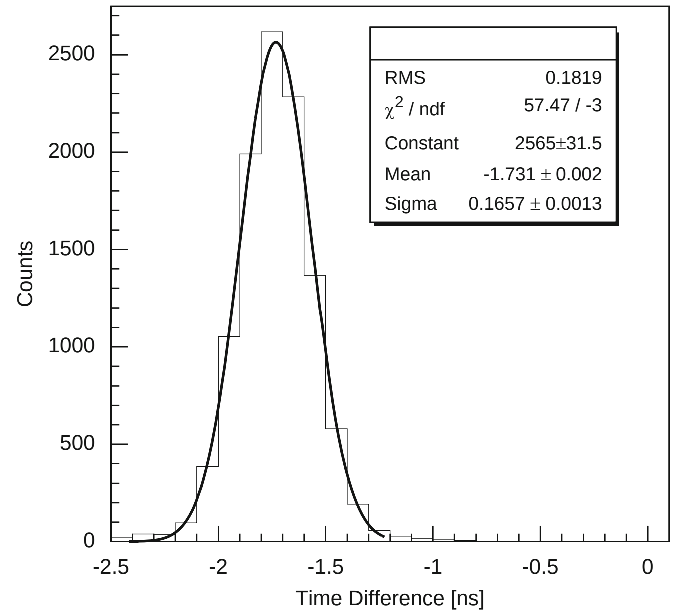

Fig. 6. Time resolution for 1.8 GeV protons between two mono-crystalline diamonds without any correction.

than 2 mm in diameter. The detectors were exposed to proton beams with kinetic energies from 1.2 to 3.5 GeV and rates of up to 3×10^6/s. Several detector samples with different metallizations were tested to achieve stable operation of the detector at high beam intensities. As a result the high-rate capability could be reached only after applying a metallization procedure which includes passivation in an oxygen plasma, "baking" at 500 °C in an Ar atmosphere and depositing a 50 nm Cr layer followed by a 150 nm Au layer. Otherwise, a constantly increasing leakage current appeared at intensities above several 10^5/s which finally resulted in a rapid discharge. The data acquisition system of the test setup, shown in Fig. 3, measured the leading-edge and the pulse-width of the signals. Fig. 5 shows the signal charge distribution of a single segment measured for 1.8 GeV protons (MIP). Zero charge results in a minimum width of 14 ns (arrow in Fig. 5). The visible tail at small signal charges (small signal widths) is dominated by cases where the beam particle hits the detector at the edge of the segment and in this case charge is shared between neighboring segments of the diamond.

To determine the time resolution of the detectors, two diamonds were put into the proton beam with a distance of 30 cm between them. The pulse-width distributions were used to remove signals where charge sharing between segments occurred. The applied condition was: 42.0 ns $<$ (pulse-width) $<$ 70.0 ns. As shown in Fig. 6, the time resolution measured with leading edge discriminators between two segments of diamond is about 165 ps. This gives a single segment time resolution of 117 ps. Based on the signal to RMS-noise[3] ratio of about 23 (300 μm) and 27 (500 μm) one expects an intrinsic time resolution of about 65 ps for both detector thicknesses, which indicates a significant contribution from the diamonds themselves [9].

The detection efficiency of the device was measured with a well focused proton beam centered in the middle of the diamond detector. The diameter of the beam spot at the focal point (center of the diamond) was less than 2 mm and the halo of proton beams is typically below 1%. As a reference, a plastic, segmented detector, located 7 m downstream, where the beam was defocused (beam spot diameter of about 30 mm), was used. By comparing the rates measured in the reference detector with the rates seen by the diamond detector, the diamond detection efficiency was determined to be $\geq 95\%$.

[3] RMS-noise is defined as the average voltage noise level appearing at the output of the device, expressed in RMS value of the measured voltage distribution.

4. Outlook

Due to continuous progress in the development of low-noise transistors, the signal to RMS-noise ratio, as seen from the simulation, can be improved by nearly 50% at 10% shorter rise-time based on up to date SiGe:C technology. In particular, tiny housings of the newly developed transistors provide less stray capacitance (e.g. BFR705L3RH) which will improve the signal to RMS-noise ratio. On the basis of the data sheets of the state-of-the-art transistors the power consumption per channel can be reduced to below 2.5 mW and the total area of all components of such an amplifier amounts to only 2 mm^2. Preliminary results with a Sr^{90} source confirmed these improvements [9], but no in-beam tests were performed so far.

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References

[1] W. Adam, et al.The RD42 Collaboration, NIMA 511 (2003) 124.
[2] C. Mer, et al., Diamond and Related Materials 13 (2004) 791.
[3] E. Bartz et al., JINST 4 P04015 2009.
[4] Single-crystal CVD diamond detectors for hadron physics, M. Pomorski et al, in: Proceedings of the Ninth Conference on Astroparticle, Particle and Space Physics, Detectors and Medical Physics Applications, Villa Olmo, Como, Italy, 17–21 October 2005, p. 92, DOI No: 10.1142/9789812773678_0016.
[5] G. Agakichiev, et al., (HADES), Eur. Phys. J. A 41 (2009) 243.
[6] M. Traxler, 128 channel high resolution TDC with integrated DAQ-system, GSI Scientific Report (2005) 281.
[7] 〈http://tdc.web.cern.ch/tdc/hptdc/docs/hptdc_manual_ver2.2.pdf〉, HPTDC, J. Christiansen, Digital Microelec. Group, CERN.
[8] The 4th NoRHDia Workshop, GSI, Darmstadt June 8–June 10, 2008 〈http://www-norhdia.gsi.de/talks/4th/W_Koenig.pdf〉, 〈http://www-norhdia.gsi.de/talks/4th/A_Schuettauf.pdf〉.
[9] W. Koenig, Talk given on 1st CARAT Workshop at GSI, Darmstadt, December 13-15, 2009 〈http://www-norhdia.gsi.de/CARAT01/CARAT01Talks/Koenig.pdf〉.