Timing with grazing diamond detector

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The Lecce group in August 2012 proposed to the ATLAS Forward Physics (AFP) collaboration to replace the QUARTIC timing detector with Diamond detectors to solve two main limitations: photodetector radiation damage and large detector size.

Diamond detectors produced by Chemical Vapor Deposition (CVD) have a potential for high temporal resolution due to the intrinsic fast response to ionizing radiation (less than 100 ps rise time). The diamond detectors are successfully used in measurements of time-of-flight in nuclear physics for medium-heavy ions, where the signal intensity is high, obtaining temporal resolution of about 28 ps.

Assuming a readout electronics chain capable to correct for time walk error and with a negligible time digitization error (employing for example very fast constant fraction discriminators and TDCs, for on-line corrections, or very fast waveform digitizers, for off-line corrections) we can estimate the achievable time resolution using the formula:

$$\Delta t = \frac{t_{rise}}{S/N}, \tag{1}$$

where t_{rise} is the signal rise time, approximately given by the maximum between the charge collection time and the electronics rise-time, S is the collected charge in diamond due to a crossing ionizing particle, and N is the electronic noise, which for diamond is just due to the front-end noise, because the leakage current is negligible. In order to improve the time resolution is necessary to act on one of the following conditions: decrease the signal rise time, decrease the noise and increase the signal. Such goals require the developing of low-noise and high-speed front-end electronics and the use of innovative geometrical and circuital configurations for the diamond sensors.

In our application the limiting factor is the collected charge in diamond for a minimum ionizing particle which is quite small. In fact, we expect about 3600 e^- signal in diamond for a charge collection distance of about 100 μm. It is worth to mention that the relativistic rise in energy loss for 7 TeV proton with respect to 1 GeV proton should give an additional 30% increase. Considering a diamond sensor having 300 μm of charge collection distance, we have a signal of about 10800 e^- and a collection time of about 3 ns (the drift velocity for both free charge carriers is about 100 μm/1ns in saturated conditions). Assuming an electronics noise of about 500 e^- and an electronic rise-time negligible with respect to the sensor collection time, we can estimate by the Formula 1 a time resolution of about 138 ps. This is typically the time resolution report in the literature for minimum ionizing particle detection with diamond.

Several improvements are possible with respect to the results reported in literature which should allow us to reach the goal of 30 ps resolution per plane. The exploration of these ideas are strongly pursued by the different groups and any progress in any direction, when available, is going to be included in our baseline design presented below. In fact, to have a diamond detector solution competitive with the QUARTIC detector for run III we have to reach better performance in a cost effective manner .

We proposed a conservative approach that could be built with the existing technology. The idea is to boost strongly the signal, without affecting the noise and the collection time, by placing several diamond layers parallel to the tracks, one on top of each other. The planar geometry allows easily to work with both free charge carriers in saturation conditions (electric field higher than $1V/1\mu$) and be less sensitive to charge fluctuations intrinsic to the ionization process. Such a configuration can be built with diamond sensors because the electrodes thickness is not bigger than few hundred nm, than resulting in a negligible dead area.

We began to study experimentally the time resolution limit achievable with the grazing diamond concept by carrying out two testbeams.

The first one was done at the DESY along the beam line named TB 22, which provided electrons with energies of about 5 GeV with small divergence. The second one was done at the CERN, along the beam line named H6, which provided pions with energies of about 120 GeV. The exper-

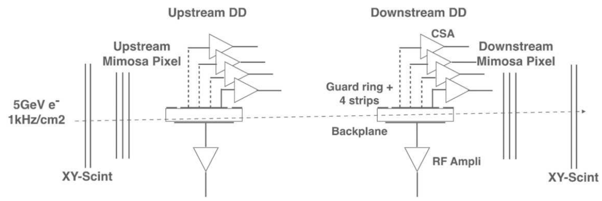

Figure 1. Experimental setup used to measure the time-of-flight between two diamond detectors placed parallel to a 5 GeV electron beam at DESY. A similar setup was used in a testbeam with 120 GeV pion beam at CERN.

imental setup was similar in both cases and it is shown in Figure 1 for the DESY testbeam. The main test consisted in the measurement of the time-of-flight of particles with two polycrystalline diamond detectors parallel to the beam and extract the time resolution for a MIP-like particle crossing the sensor along the long dimension.

We used two polycrystalline diamond detectors: the first one provided a start signal and the second one the stop signal. The diamond detectors consisted of 10x10x0.5 mm^3 sensors with four metalized strips on the front-side, 6.5 mm long and with 1.5 mm pitch, a square guard ring of 8 mm side length and a metalized pad on the back-side. The strip electrodes and the back-side pads were connected to SMA connectors and the signal directly amplified by fast charge amplifiers of 100 MHz bandwidth and 8 mV/fC gain (CIVIDEC C6) or by broadband amplifiers of 2 GHz bandwidth, voltage gain 100 and input terminated at 50 Ω (CIVIDEC C2). The high voltage was applied by the amplifiers connected to the back-side pad. The analog signals were digitized by a 17 channels digitizer having a 12 bit ADC resolution and a 20GS/s sampling rate (CAEN DT5742) and analyzed off-line. Two signals from the detectors were discriminated by two constant fraction discriminators and put in temporal coincidence.

In the DESY testbeam the 5 GeV electron tracks are expected to undergo a significant multiple scattering because they have to cross about 2 cm of diamond material and 5 mm of detector cases aluminium. In addition, scattered electrons from material not aligned with the sensors, but near by, could create fake trigger coincidences, which are of course correlated in time but worsening the time resolution, due to path length different from the most straight ones. In order to mitigate these effects we used the pixel telescope to reconstruct tracks to clean up the events. The pixel telescope was fully provided and supported by DESY and it was made by two stations of three planes of MIMOSA monolithic pixel sensors.

The time resolution estimates improve accordingly to the expectations [1]. In fact, stronger are the requirements on tracks to be straight with respect to the two diamonds, better is the achieved time resolution. In addition, a mild dependency of the time-of-flight measurements with respect to the vertical distance between tracks and collecting electrodes was observed. After correcting for this systematic effect, we obtain a time-of-flight distribution between the two sensors as depicted in Figure 2a), which corresponds to a time resolution of 92.7$\pm$24 ps, measured by the standard deviation of the time-of-flight distribution divided by $\sqrt{2}$, because the time spread of the two diamond detectors are assumed to be equal.

In the CERN testbeam the 120 GeV pion tracks are basically straight but secondary particles are expected to be produced for a not negligible fraction of events and an external tracker detector was not available to measure track multiplicity and track entrance point. The time-of-flight distribution is shown in Figure 2b) for events leaving signals in all four channels for both detectors, In order to select tracks almost parallel to the sensors. The distribution has two narrow peaks clearly visible but they origin is still not understood. Nevertheless, using again the standard deviation of the distribution divide by $\sqrt{2}$ we estimate a time resolution of about 61ps.

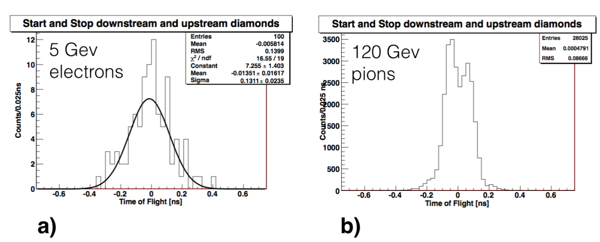

Figure 2. Distribution of the time-of-flight between two polycrystalline diamond detectors placed parallel to a 5 GeV electron beam, after correcting for track entrance point vertical dependency (a), and placed parallel to a 120 GeV pion beam (b). The high voltage value was -350 V and 500V, respectively.

REFERENCES

1. G. Chiodini, G. Fiore, R. Perrino, C. Pinto, and S. Spagnolo, “MINIMUM IONIZING PARTICLE TIMING WITH GRAZING DIAMOND”, *Acta. Phys. Pol. B Proc. Suppl.* No. 4 Vol. 7 (2014).