THE DIAMOND PROJECT AT GSI - PERSPECTIVES

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CVD-diamond detectors operational in various heavy-ion experiments at GSI are described. The results shown demonstrate convincingly the suitability of such detectors for a variety of tasks, where classical well known detectors fail. New applications are introduced, which are being recently developed for the use in measurements of minimum-ionizing particles.

1 Introduction

Heavy-ion experiments at GSI cover nuclear and atomic physics, related basic and applied research in plasma physics and material science as well as biophysics including tumor therapy with carbon ions. After low-energy sections, the heavy-ion synchrotron (SIS) provides pulsed, cooled ion beams up to 2 GeV/amu of beam intensities up to 10^{11} ions/spill. All kind of ions from protons with Z=1 to ^{238}U ions with Z=92 are available. Detector and trigger systems have to cope with a signal ratio of 1:9000, a variable beam intensity from a few ions to about 10^{11} ions/s and a time structure from 100 ns to 10 s. Whereas the high-energetic ions from the SIS traverse nearly undisturbed the detectors, in the low-energy domain of the accelerator facility the ion range in solid state material is in the order of 1 μm. Severe radiation damage is observed.

The most remarkable properties of CVD-diamond detectors implemented in heavy-ion measurements at GSI are radiation hardness, intrinsic time resolution well below 50 ps and a single-particle count-rate capability ranging from 1 to 10^9 ions/s [1]. However, due to the inhomogeneous charge collection inside the polycrystalline diamond bulk, even a rough particle identification based on pulse-height resolution is excluded [2].

2 CVD-Diamond Heavy-Ion Detectors

Contrary to high-energy physics, where polished highest-quality diamond material and low noise charge-sensitive integrating electronics is needed, the highly-ionizing heavy ions allow the use of thin 'as grown' material, which is characterized by a short carrier lifetime. In order to take advantage of the fast collection of charge (∼100 ps) low-impedance broad-band amplifiers (DBA) are used [3]. The diamond samples are connected via 50 Ω micro-strip lines to the amplifiers. This type of amplifier can be driven also, if connected after some meters of impedance-matched transmission lines, without disturbing the signal performance.

2.1 Diamond Detectors in Physics of Dense Matter (W. Koenig et al.)

A beautiful example which demonstrates the variability and power of CVD-diamond detectors in heavy-ion experiments is the HADES spectrometer. [4]

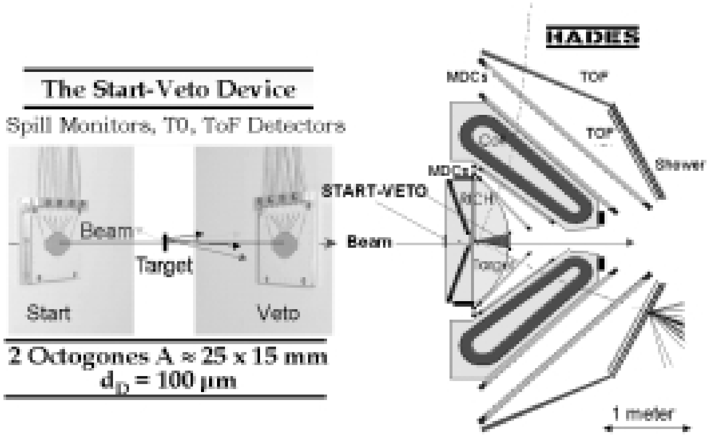

Figure 1. The Start-Veto device (left) of the HADES spectrometer (right).

The High-Acceptance Di-Electron Spectrometer is designed for studies of hadronic properties in nuclear matter. Theoretical models predict a shift in the mass and resonance width of vector mesons like ρ, ω and ϕ, if they are produced inside the nucleus. Lepton pairs obtained from the decay of the mesons are excellent probes for such investigations. A mass resolution better than 1% is required to distinguish ρ and ω.

Fig. 1 shows a schematic view of HADES (right) and a zoomed explosion view of the Start-Veto device (left). A pair of identical diamond strip detectors located 75 cm upstream and downstream the target is used to determine the START for the ToF (Time-of-Flight) measurements. The lepton candidates are selected by position correlations of hits in the RICH (Ring Imaging Cerencov Hodoscope) and in the segmented plastic-scintillator wall (TOF).

The short intrinsic dead time of ∼ 1-2 ns [1] is the most important advantage of the diamond detectors in this experiment. The required high collision rates of $\sim 10^8$ ions/spill can therefore be accepted. Beam particles not reacting in the target produce a signal in the downstream detector, which is used as a veto for the upstream detector. This provides a START signal with a rate below 10^7 ions/spill. The veto efficiency of 90% has still to be improved.

In Fig. 2 ToF spectra measured in a commissioning run with ^{52}Cr ions on ^{27}Al are shown. The distance between the START counter and the segmented plastic-scintillator wall (TOF) is 2.1 m.

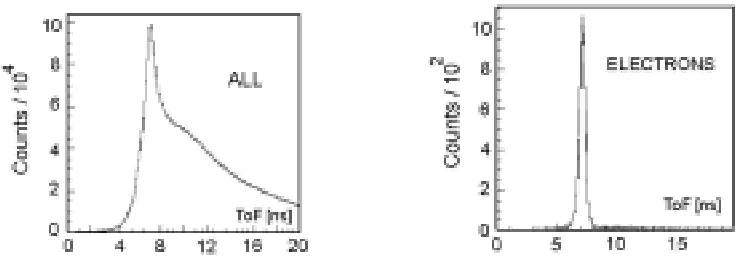

Figure 2. Left: ToF spectrum of all particles detected. Right: ToF spectrum of electron candidates, as selected by means of a position correlation between RICH and TOF hits. Data were taken without magnetic field.

The data from all 384 TOF segments are included in both spectra. In the left plot the ToF spectrum of all particles arriving within 20 ns at TOF is shown. By means of an angular correlation between RICH and TOF, leptons are selected, and the ToF spectrum of those candidates is shown on the right plot. The intrinsic time resolution of the Start-Veto device amounts to $\sigma = \pm$ 29 ps [1]. The ToF resolution of σ=233 ps is determined by the TOF detector and is affected from the calibration of all TOF segments.

2.2 Focal Plane Detectors of Magnetic Spectrometers (S. Toleikis et al.)

A large area (60 mm x 40 mm) CVD-diamond detector of a thickness of 200 μm has been implemented as the focal plane detector of a magnetic spectrometer used for beam-foil spectroscopy. Since August 2000 the experimental setup shown in Fig. 3 (left) is in operation.

Hydrogenlike ions passing through a target foil produce different excited charge states by electron capture. The γ radiation of the subsequent decay of

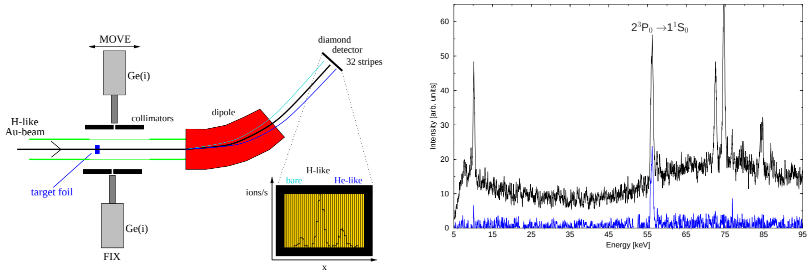

Figure 3. Left: The experimental setup in the atomic physics cave. Right: X-ray spectra of helium-like Au atoms with (lower curve) and without coincidence (upper curve) to the corresponding diamond strips.

the excited states is detected with two Ge(i) detectors, one of them movable. The different ionic charge states are deflected by the magnetic field on different diamond strips. High-resolution spectroscopy and lifetime measurements are performed up to the heaviest ions. Fig. 3 (right) demonstrates the background suppression in X-ray spectra of heliumlike ^{197}Au ions if the Ge(i) detector is readout in coincidence with the corresponding diamond strips (low spectrum).

2.3 Diamond Detectors in Accelerator Beam-Diagnostics

Beam intensities up to 10^{11} ions/spill are particularly challenging for detectors to be used in accelerator beam diagnostics. However, this is the top application of CVD-diamond detectors. It is not just they fulfill the tasks excellent but also, there exists nearly no alternative detector material. A variety of beam-intensity- and beam-profile monitors as well as beam-loss monitors outside the beamlines is installed. Optionally, each of the diamond detectors can be used for high-resolution spill- and bunch-structure investigations.

Ion beams from the SIS are extracted either 'slow', distributed over a time interval 0.5 s to 10 s or 'fast' in a bunch of about 100 ns. When monitoring slow extracted beams up to a beam intensity of 10^9 ions/s the detectors are used in a single-particle mode. An integrated current pulse is obtained from fast extracted bunches. Due to the short intrinsic dead time of the detectors, it was possible for the first time to observe the unexpected internal time structure of the bunches. Fig. 4 shows two ^{58}Ni bunches of quite different time structure, which were extracted consecutively. Whereas on the left picture the 4 pre-

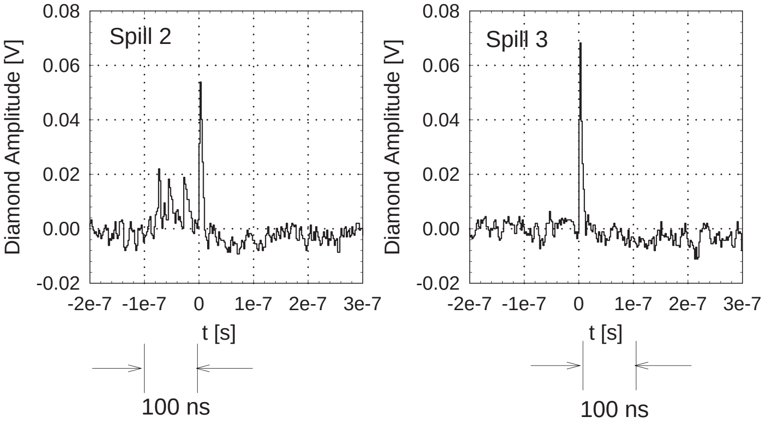

Figure 4. Two consecutively extracted nickel bunches.

bunched beam strings are still visible on the right one a bunch compression of about 20 ns seems to be achieved.

2.4 Position-Sensitive Carbon-Ion Dosimeter

More than hundred patients have been already treated at GSI. ^{12}C beams of an energy between 100 MeV/amu and 400 MeV/amu and an intensity of 10^8 ions/spill are scanned over the tumor volume. The results are impressive. In order to check the presently used ionisation chambers and to have an independent determination of the applied dose, single-particle counting is proposed. A prototype large-area position-sensitive carbon dosimeter was developed and first beam tests were performed recently. The 20 x 20 mm^2 CVD-diamond pad detector of a thickness of 100 μm contains 16 pads which are glued with conductive silver on a doubble-sided ceramic board. Each pad is connected to a broad-band amplifier. The dosimeter operates as a beam-profile monitor measuring precisely the total fluence F in ions/cm^2. The dose D applied on each pad can then be calculated taking into account the energy loss ΔE of a single ^{12}C ion in matter with density ϱ and thickness d according to D=(ΔE/ion)*(F/dϱ). The similarity of carbon with human tissue is of particular advantage.

3 ToF Detectors for MIPs (M. Petrovici, NINPE Bucharest)

The use of CVD-diamond detectors for fast timing of Minimum-Ionizing Particles (MIPs) has been investigated. First tests using ^{90}Sr electrons have been performed. Two polished diamond detectors with a collection distance of 210 μm and a thickness of 500 μm were triggered by a plastic scintillator behind the diamonds. DBA amplifiers and low-threshold discriminators were used. The time-difference distribution fitted to a gaussian gives a time resolution of σ=95 ps assuming equal contribution of both detectors. However, due to an equivalent noise charge of 12000 e of the DBA, the detection efficiency obtained was only 3%. New type of amplifiers based on High Electron Mobility Transistors (HEMT) are under construction striving for both, a significantly improved signal-to-noise ratio and a time performance of the present DBA generation.

4 Concluding Remarks

The use of CVD-diamond detectors at GSI has been established. Various CVD-diamond applications in the framework of the tumor therapy are under investigation. We proceed with the study of polished CVD-diamond samples for timing detectors for MIPs. Recently, a joint venture with the Wits University of Johannesburg, Southafrica has been started, aiming to investigate the suitability of HPHT (High Pressure High Temperature) single-crystal diamond for electronic devices and for radiation hard detectors which combine both, the timing properties of CVD diamond and the energy-resolution of silicon detectors.

Acknowledgments

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