High precision multi-hit time-of-flight measurements at R^3B*

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Introduction

The kinematically complete reaction measurements at the upcoming R^3B set-up require the identification and separation of heavy, relativistic reaction fragments. This requires a precise measurement of the time-of-flight in order to calculate the momentum of the particles with the necessary resolution of $\delta p/p = 10^{-3}$. Depending on the length of the flight path and the energy of the ions, this translates into a required time resolution of about 15 ps for ions with $A \gtrsim 150$ [1].

To reach this goal, two new detectors based on plastic scintillators have been developed for the time-of-flight measurement: An optimized start counter and a multi-layer time-of-flight wall [2] which will provide energy loss and position information as well.

The signals of the photomultipliers will be readout by a new multichannel front-end electronic card (TAMEX). This card has been designed by the GSI CSEE group for high-resolution time and charge measurements and is a combination of the existing LAND TACQUILA FEE and a FPGA TDC from the VFTX module.

Electronics

The VFTX module [3] provides a time resolution of less than 15 ps RMS over a long time range. This is achieved by a combination of a FPGA, a TDC and an external clock signal. The TDC measures the times of the rising and the falling edges of the detector signal with respect to the external 200 MHz clock signal, see Figure 1. The FPGA stores this TDC value together with the timestamp (cycle number) of the clock signal. This way, times can be measured with respect to the arbitrary origin of the clock.

In order to measure detector times with respect to a common start or trigger signal, the common start signal has to be connected to any free VFTX input channel as well. Since the external clock signal can be applied to multiple VFTX boards, the time reference for all VFTX channels is guarantied to remain synchronized over the whole period of the experiment.

In addition, the VFTX is able to record multiple hits per event (trigger) and channel which is not only useful for experiments with high beam intensities but also in cases where several secondary particles need to be detected, e.g. from the neutron shower in the Neuland detector [4] or if the incident particle breaks up in multiple fragments.

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Measuring the times of both, rising and falling edge of the signal, provides the length of the signal which can - if properly shaped - be considered as a measure for the energy integral of the signal. For several detectors, a second electronics branch to measure the energy is therefore not necessary. For a precise charge measurement with the time-of-flight wall however, a more accurate energy measurement is necessary and will be available on the TAMEX card.

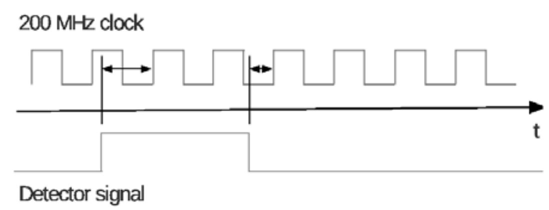

Figure 1: Measurement of rising and falling edge of a detector signal by the VFTX card.

While the TAMEX cards are not yet available, the circuit for the time measurement is already available in the VFTX modules and hence the time resolution of the whole chain detector / data acquisition / data analysis could already be tested.

Software

The current LAND/R^3B analysis software land02 has been adopted to analyse VFTX data. This required the handling of multiple times per event and channel, the introduction of calibration routines and the conversion of rising and falling time signals into an energy value.

While the external 200 MHz clock signal is assumed to be sufficiently stable, the TDCs need a bin-wise calibration in order to reach the designed time resolution. The calibration is performed by recording TDC times of random input signals. The resulting histogram of raw TDC times (without considering the clock cycle) should ideally resemble a perfect rectangle with 5ns width. The calibration routine calculates the width of each time bin such, that this goal is reached, see Figure 2.

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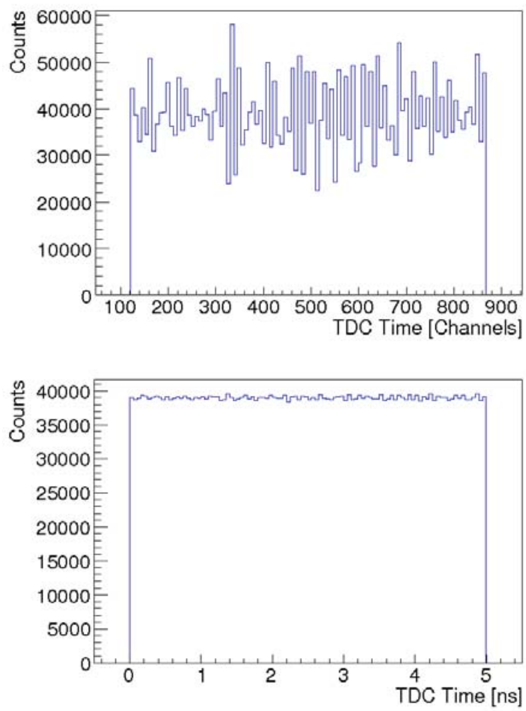

Figure 2: Top: Raw times (in channels) from random input signals. The variation of the bin contents reflects the non-linearity of the TDC. Bottom: The events are equally distributed after the calibration.

Test measurements

The new start counter consists of a square plastic scintillator of 5.5x5.5 cm^2 size and 0.5 mm thickness. The scintillator is read out on all four sides to improve the time resolution by averaging the four measurements. In order to reduce uncertainties from reflections of the scintillation light to an absolute minimum, the photomultipliers have been coupled to the scintillator material without any light guide.

The energy deposition of heavy ions was simulated by illuminating a small area (2mm diameter) with a Nitrogen UV laser (337 nm wave length). The time measurement was calibrated and analyzed using the updated land02 analysis software. The time resolution can be estimated by analysing the time difference of signals from opposite photomultipliers, see Figure 3. The resulting peak shows a width (σ) of 13 ps indicating a time resolution for an average of all four photomulipliers of well below 15 ps.

Summary

On the example of the optimized start detector it could be shown that time measurements with an uncertainty of less than 15 ps are feasible. The second time for the time-of-flight measurement will be measured by the multi-layer time-of-flight wall where up to 6 individual time measurements can be averaged. This will result in a similarly precise time information.

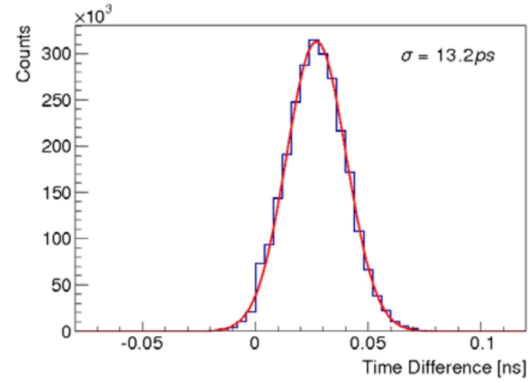

Figure 3: Time difference between left and right readout from a square 5.5x5.5cm ^{2} scintillator bar. The peak shows a width (σ) of 13 ps indicating a time resolution for the average of all four signals of well below 15 ps.

References

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