A Self-Triggering Silicon-Tracking Telescope for Spectator Proton Detection

R. Schleichert, T. Krings, S. Merzliakov, A. Mussgiller, and D. Protic

***Abstract*—With the ANKE spectrometer at the COoler SYnchrotron COSY Juelich the mesonic structure of the nucleon will be studied in polarized proton–proton and proton–deuteron collisions. The identification and tracking of low energy protons permits using deuterium as an effective neutron target. For this purpose, modular self-triggering tracking telescopes built up by double-sided silicon strip detectors inside the accelerator ultra-high vacuum have been developed. Their basic features are $\Delta E/E$ proton identification from 2.5–40 MeV and particle tracking over a wide dynamic range, either 2.5 MeV spectator protons or minimum ionizing particles. By the use of self-triggering read-out chips, the telescopes identify a particle passage within 100 ns and therefore allow the possibility of a fast hit pattern recognition. In combination with a read-out pitch of $\sim$200 μm, they provide a high rate capability. The recent development of very thick ($\geq$5 mm) double-sided microstructured Si(Li) and very thin ($\leq$65 μm) double-sided Si-detectors provides the use of the telescopes over a wide range of particle energies.**

I. Introduction

THE ANKE spectrometer is an internal experiment at the COoler SYnchrotron COSY Juelich [1]. COSY provides (polarized) protons and deuterons in a momentum range from 300 MeV/c to 3600 MeV/c. Together with the polarized atomic beam source (ABS) of the ANKE spectrometer polarized proton-proton and proton-deuteron collisions can be studied. The identification and tracking of low energy protons allows us to use the polarized deuteron gas of the ABS as a polarized neutron target and, e.g., to study reactions of the type $pn \rightarrow pnX$ or $pn \rightarrow pdX$.

For this purpose a vertex detector based on double-sided silicon strip detectors inside the ultra high vacuum of the COSY ring is under development [2]. Its layout is based on modular self-triggering tracking telescopes that provide the following.

1) $\Delta E/E$ proton identification from 2.5 up to 40 MeV. The telescope structure of 65/300/300/5500 μm thick double-sided Si-strip detectors, read out by high dynamic range chips [3], allows $\Delta E/E$ particle identification over a wide dynamic range.
2) Self-triggering capabilities. The telescopes identify a particle passage within $\leq$100 ns and provide in combination with the self-triggering chips a fast hit pattern recognition.

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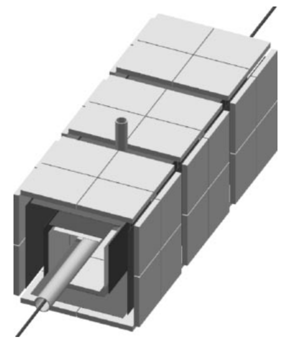

Fig. 1. Twelve telescopes are arranged around the 40 cm long storage cell of the polarized atomic beam source.

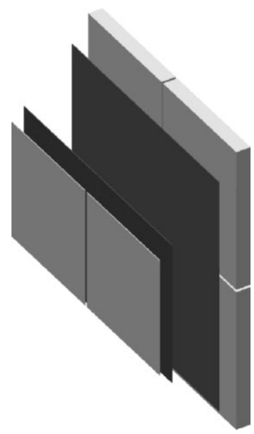

Fig. 2. Telescope arrangement of double-sided silicon strip detectors: two 65 μm thick detectors as inner layer, two and four 300 μm thick detectors as middle layers, and four 5500 μm thick Si(Li) detectors as outer layer. Protons will be tracked and identified from 2.5 MeV up to 40 MeV.

3) Particle tracking over a wide range of energies, either 2.5 MeV spectator protons or minimum ionizing particles.
4) High rate capability.

The recent development of very thick ($>$5 mm) double-sided microstructured Si(Li) [4] and very thin (65 μm) double-sided Si-detectors provides the use of the telescopes over a wide range of particle energies. Fig. 1 shows a possible arrangement of 12 telescopes around a 40 cm long ABS storage cell.

II. Detection Concept

The basic detection concept of a telescope is to combine proton identification and particle tracking over a wide energy range. The tracking of particles is accomplished by the use of double-sided silicon strip detectors. Measuring the energy

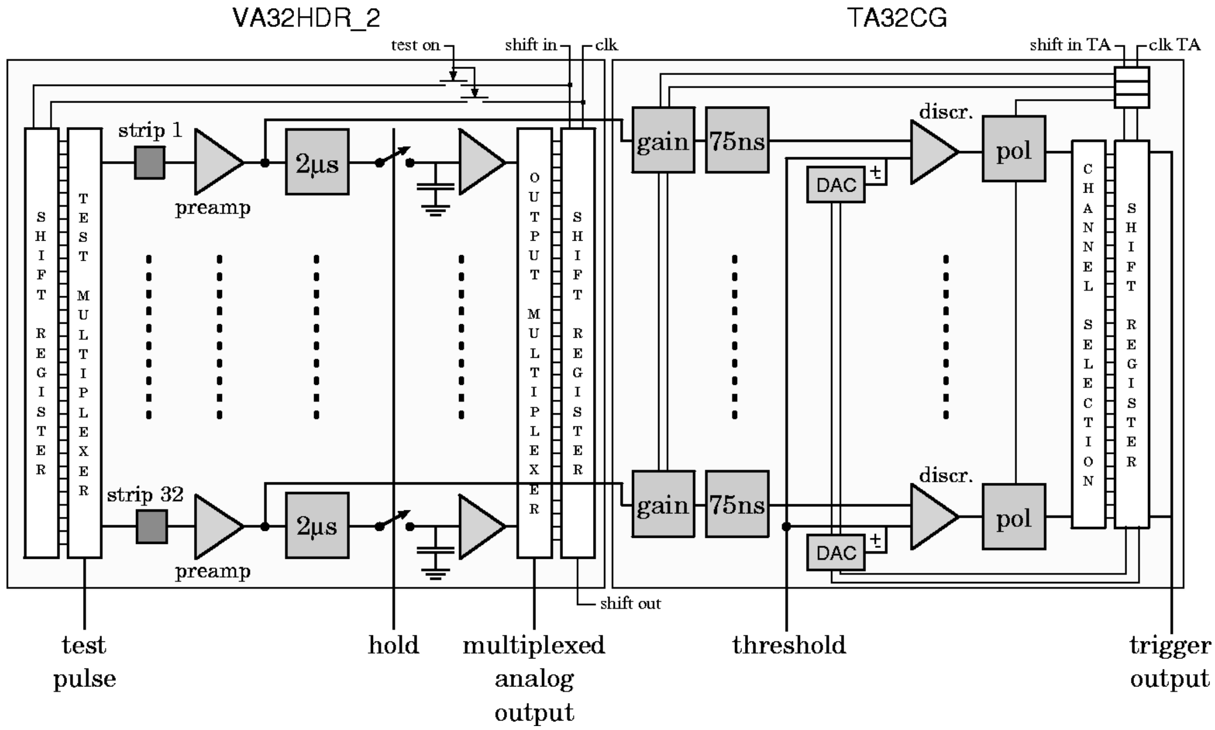

Fig. 3. Block diagram of the VA32HDR_2 and the TA32CG chips. The individual preamplifier outputs of the VA32HDR_2 are directly bonded to the inputs of the TA32CG. In the simplest trigger configuration the trigger output of the TA32CG directly serves to generate a hold signal for the VA32HDR_2.

losses in the individual layers of the telescope allows the identification of stopped particles by the $\Delta E/E$ method. The minimum energy of a proton to be tracked is given by the thickness of the most inner layer. It will be detected as soon as it passes through the inner layer and is stopped in the second layer. The maximum energy of protons to be identified is given by the range within the telescope and therefore by the total thickness of all detection layers. The self-triggering capability of all detectors introduces the options to start a read-out on a particle passage and to set fast timing coincidences with other detector components of the ANKE spectrometer. Fig. 2 shows the principle arrangement of 4 layers of detectors[1] within a single telescope.

III. Detectors

A first setup has been arranged to check the performance of the chosen detectors. Three individual double-sided position sensitive detectors are assembled as a prototype of a silicon tracking-telescope.

The actual inner layer is a 65 μm thick detector ($40 \cdot 40$ mm^2 active area, 40 strips on each side, Micron Semiconductors BB1 design). It sets the detection threshold for protons to about 2.5 MeV.

The second layer consists of a single 300 μm thick detector ($66.18 \cdot 51.13$ mm^2 active area, 631 + 1023 strips, Micron Semiconductors Babar IV design), which can stop protons of kinetic energies up to 6.3 MeV. On the *n-side* of the detector there are 631 strips (316 strips, 315 floating strips) with a pitch of 105 μm. Already on the detector they are bonded to 315 groups of two strips plus one single strip. Therefore 316 groups of strips (pitch 210 μm) are bonded to a Kapton pitch-adapter that furthermore joins the groups to 40 channels: 38 channels in the center, each joining eight groups, two channels at the border, each joining six groups. These 40 channels have been equipped with dedicated fast preamplifiers for timing measurements, which are not presented here. On the *p-side* there are 1023 strips (512 strips, 511 floating strips) with a pitch of 50 μm. On the detector they are bonded together to 256 groups (pitch 200 μm): 255 groups of 4 strips, 1 group with 3 strips. These 256 groups are bonded to a pitch-adapter foil. It joins the groups to the $7 \cdot 32 = 224$ readout-channels of the flexible printed circuit described below: 192 single-group channels in the center, $2 \cdot 16$ channels at the borders, each joining two groups.

The last layer is a 5500 μm thick single-sided Si(Li) detector with 200 strips and an active area of $47 \cdot 23$ mm^2 [5]. It stops protons up to 40 MeV and therefore covers most of the dynamic range of the telescope.

[1]The third layer is optionally to guaranty redundancy in the case of multiple track events.

IV. Chip Electronics

The high dynamic range for the energy measurements together with the requirement of self-triggering electronics leads to the chip combination VA32HDR_2 and TA32CG of the Norwegian company *IDEAS* [3]. The VA32HDR_2 houses 32 preamplifiers and 32 slow shaper amplifiers whereas the TA32CG provides 32 corresponding fast shaper amplifiers and discriminators to get timing and trigger signals (Fig. 3).

The 32 slow shaper amplifiers provide charge integration with a peaking time of 2 μs. The peak-amplitude is sampled by applying a hold signal, which has to be supplied externally with the appropriate timing. The read-out is done over a $<$5 MHz multiplexed analog output. Fig. 4 shows the ADC output versus the

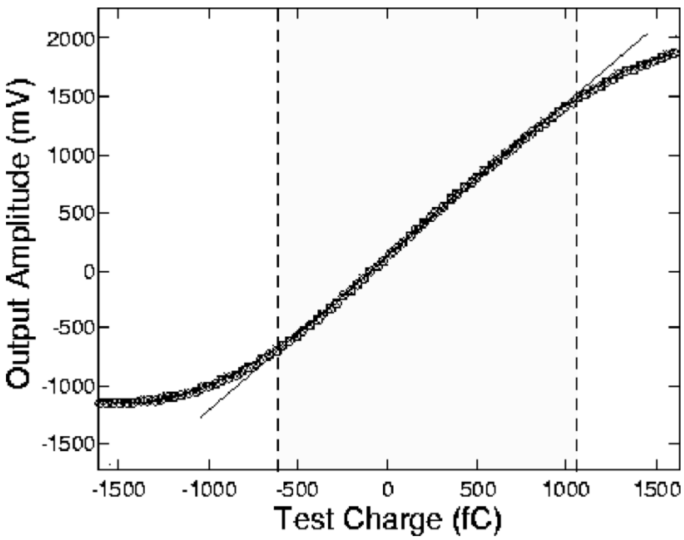

Fig. 4. Test charge applied to the test-pulse input of the VA32_HDR2 versus the ADC response for a single channel.

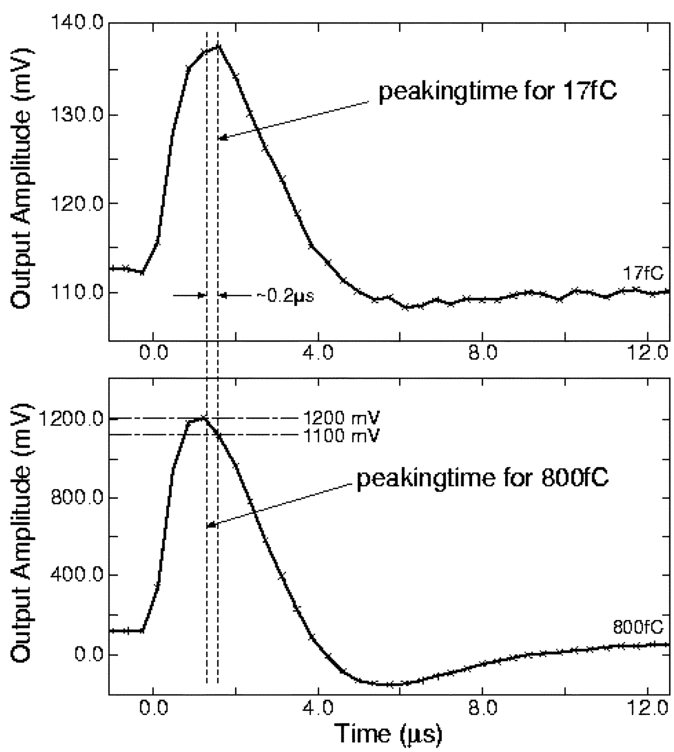

Fig. 5. Peaking time varies with the amplitude of the input charge.

charge applied to the test-pulse input of the chip.[2] The chips show an approximately linear response from -500 fC up to $+1000$ fC.

The main contribution to the integral nonlinearity is the peaking time variation with amplitude. As shown in Fig. 5, with the same timing of the hold signal the difference in amplitude is about 9%. This systematic effect can be corrected by a careful calibration of each channel.

[2]The measurements have been performed with the VADAQ system of *IDEAS*/Normal and an evaluation board with the chips.

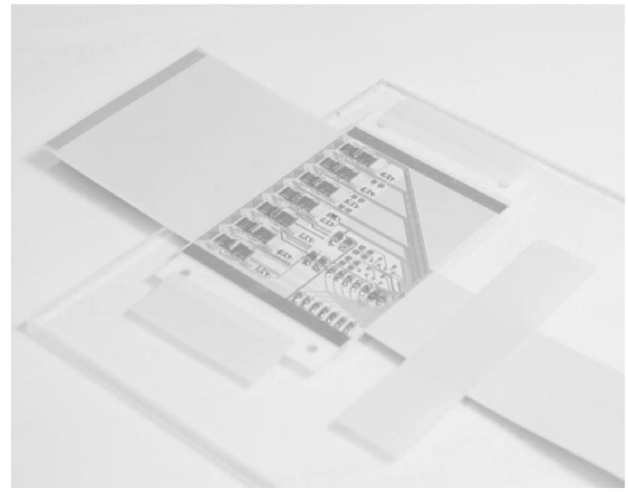

Fig. 6. Y-Flex flexible printed board with seven chip-pairs glued on it. To the left side the foil is directly glued to the detector. Right side interfaces to the vacuum feed-through.

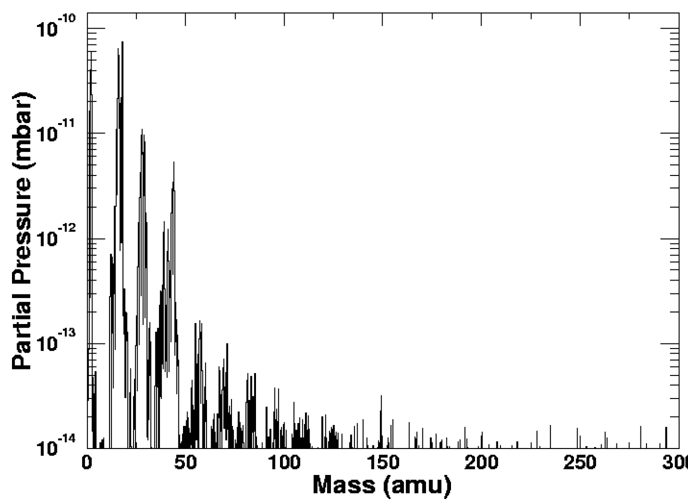

Fig. 7. Residual-gas spectrum of the Y-Flex flexible printed board. Total pressure at which the spectrum has been taken is $1.6 \cdot 10^{-9}$ mbar. Total assembly shows up to be fully UHV compatible.

V. Flexible Printed Circuit Board

The in-vacuum assembly of the chips is based on the use of flexible printed circuit boards, so-called Y-Flex [6] (Fig. 6). The material [(liquid crystal polymer (LCP)] has been chosen for two reasons. First, it is not magnetic or electrically conductive, which is important in the 1.6 T environment of the ANKE spectrometer magnet. Second, it is designed to incorporate a minimum amount of water. This feature is extremely attractive to minimize the pumping time to reach ultra high vacuum conditions.

In the prototype assembly seven chip-pairs are glued and some resistors and capacitors are soldered on the flexible printed board. Before bonding the chips, the foil is glued on a simple 0.635 mm Al_2O_3 ceramic plate to have a rigid support in the region of the chips.

The total assembly of a single flexible printed board has been checked for its ultra high vacuum compatibility. Fig. 7 shows the residual-gas spectrum. The remaining gas components are no severe distortion to the COSY vacuum and can easily be pumped.

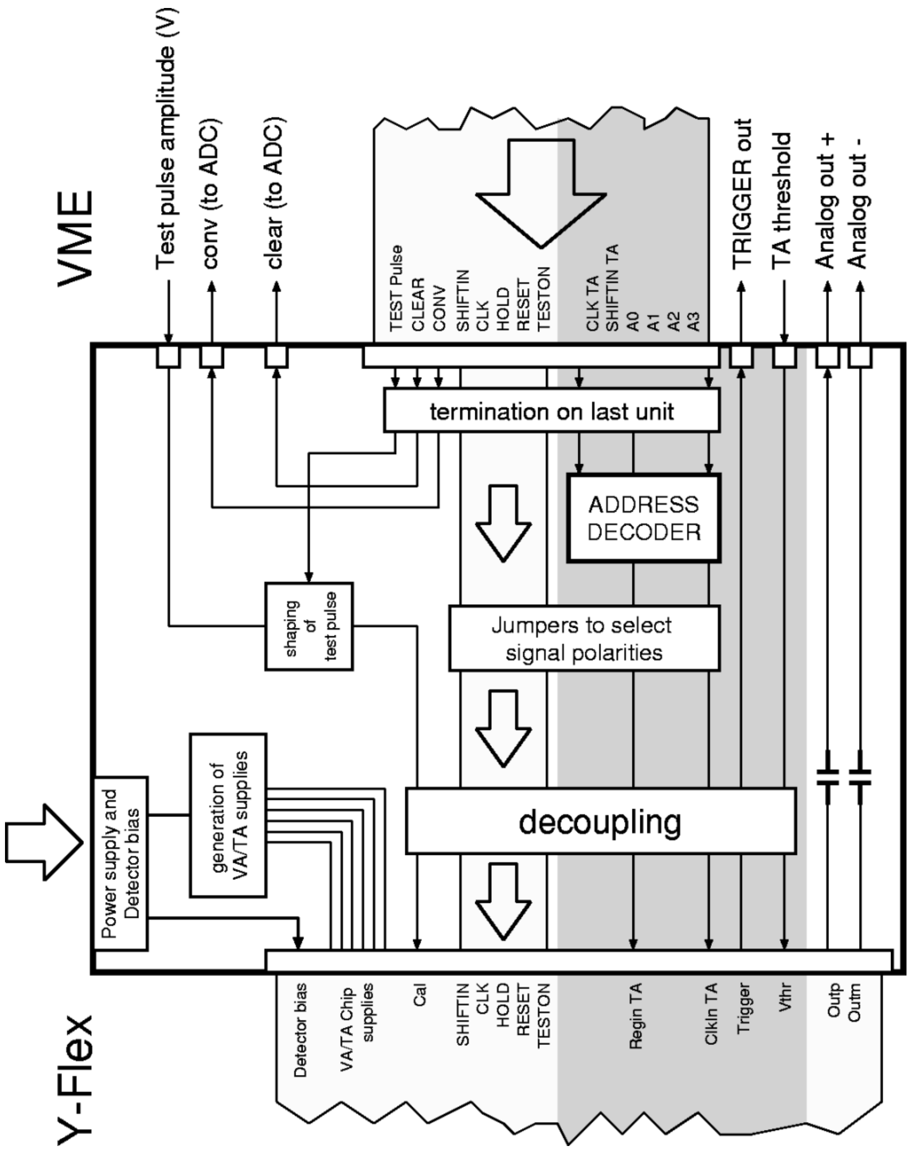

Fig. 8. RCard block scheme. Y-Flex part coming from the detector is electrically fully decoupled from the VME control part.

VI. VME Read Out System

Fig. 8 shows the block scheme of the interface electronics between VME and the Y-Flex flexible printed board, the so-called RCard. Its main purpose is to decouple all bias and control lines of the chips on the Y-Flex boards that are operated at detector biases up to 1.5 kV. One card is needed for each side of a detector.

On the VME side the board provides a flat cable connector for all digital control signals of the board and the front-end electronics. Up to 16 RCards can be connected and addressed on a single common bus. All necessary control signals to read out the amplifier chips and to set the trigger pattern of the addressed RCard are provided over this flat-cable connection. Since the timing of the hold-signal for one VA32HDR_2 read-out chain is crucial for good performance, an adjustable delay is provided for this signal on each RCard. Two voltage inputs are provided which allow controlling the TA32CG threshold and the calibration pulse amplitude. The block scheme of the complete setup with all VME components is shown in Fig. 9.

For the generation of the TA32CG trigger thresholds on the RCards external 16-bit DACs are used [7]. Each threshold can be controlled individually. The ADCs have 10 bit resolution and are especially designed for the read-out of multiplexed analog signals from silicon-strip detectors [8]. A dedicated sequencer generates the timing and control sequence [9]. This unit has 16 outputs, eight inputs and a programmable sequencer memory of 4096 data words, which can be clocked with up to 40 MHz. The differential analog outputs of the RCards are connected to the corresponding inputs of the ADC units, and the control bus is connected to each RCard via the above-mentioned flat cable. Since the common mode of the system is under investigation, the internal zero suppression of the ADC unit is not used. Thus every channel has to be read out, which decreases the performance seriously. For the given setup with two ADC units and a total number of 504 individual strips, approximately 220 events can be read out per second. By using the zero-suppression the read-out speed can be increased immediately to more then 1000 events per second.

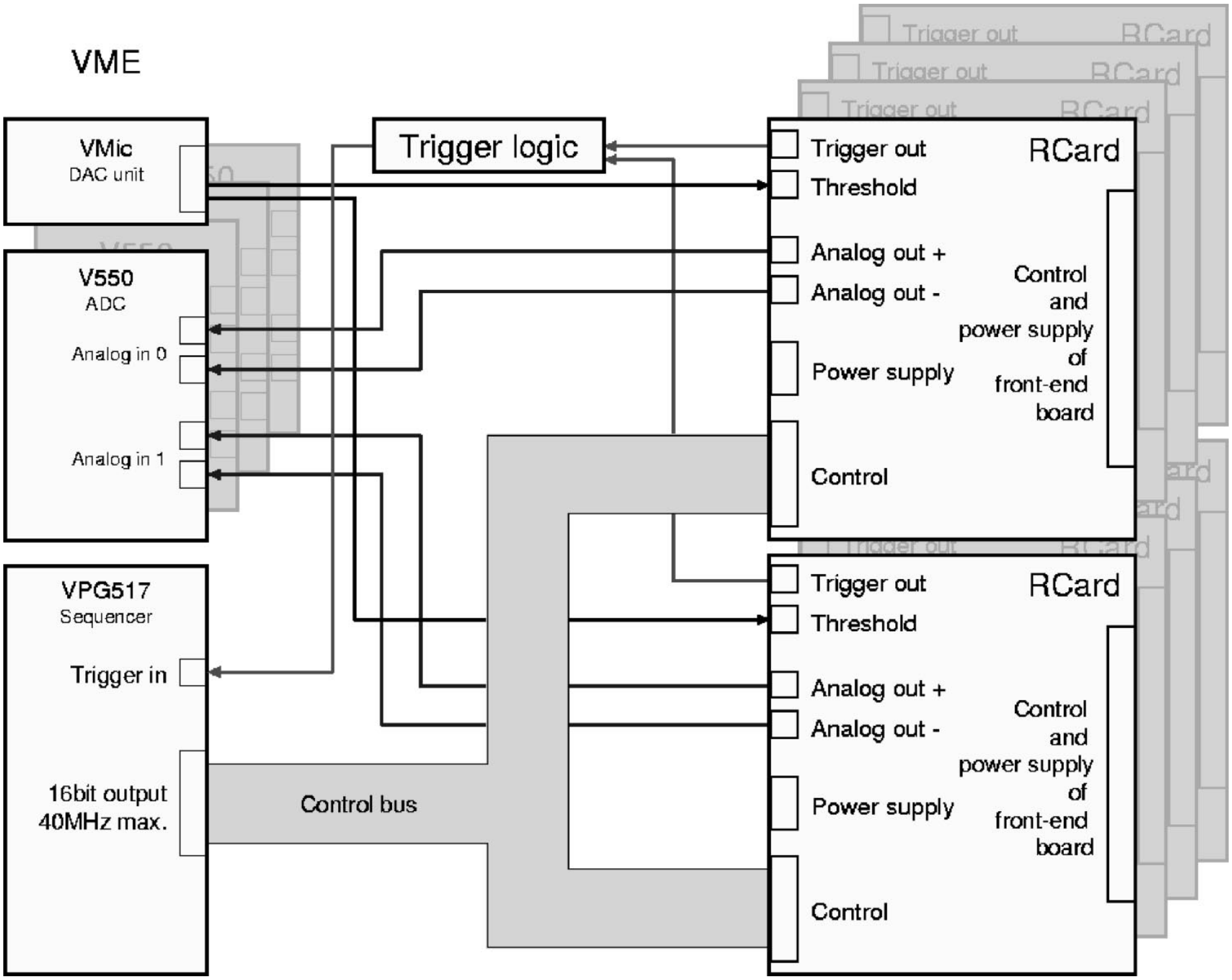

Fig. 9. Block diagram of the VME read out scheme. Two RCards are foreseen to read one double-sided silicon strip detector.

VII. Experimental Results

The complete setup with three detectors has been installed and included into the common ANKE read-out system during beam-time in September 2001. At a COSY energy of $T_p = 500$ MeV data has been taken for the reaction $pd \to pX$. Fig. 10 shows a typical pedestal distribution in the experimental environment. Without any correction the width is about 53 keV full-width at half-maximum (FWHM). Applying an offline common-mode correction the width of the pedestal distribution can be reduced to about 33 keV FWHM.

Fig. 11 shows the energy loss in the first 65 μm thin layer versus the energy loss in the second 300 μm thick layer together with the expected energy losses for protons and deuterons which have been calculated by the SRIM software [10]. All channels have been energy calibrated by a simple linear approximation taking the pedestal value as zero energy loss and the full energy limits for protons in the detectors (2.2 MeV in 65 μm and 6.3 MeV in 300 μm silicon). The 40 channels of the 65 μm (p-side) and the 224 channels of the 300 μm (p-side) are summed in the spectrum.

Even with this simple calibration, not taking into account the nonlinearity of the electronic chips, a single narrow proton band appears. The minimum detected proton energy can be extracted to be about 2.5 MeV. No deuterons show up because the telescope is installed in the backward hemisphere of the target. So with a proton beam impinging on a deuteron target there can be no scattered deuterons. Nevertheless the proton-deuteron

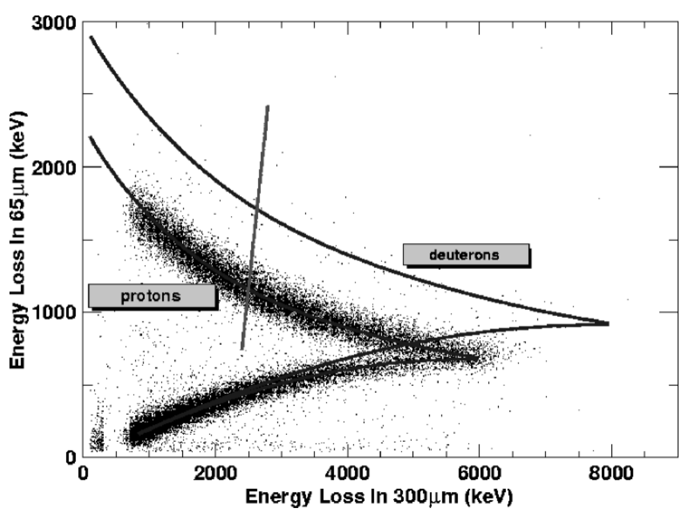

Fig. 11. Energy loss in the 65 μm versus the energy loss in the 300 μm thick detector. Only the band from the proton is seen. Deuterons cannot be seen here because the detectors are placed in the backward hemisphere of the target. In addition to the experimental data the SRIM calculations [10] for the energy losses of protons and deuterons are drawn. Fig. 12 shows the energy resolution along the indicated slice orthogonal to the proton band.

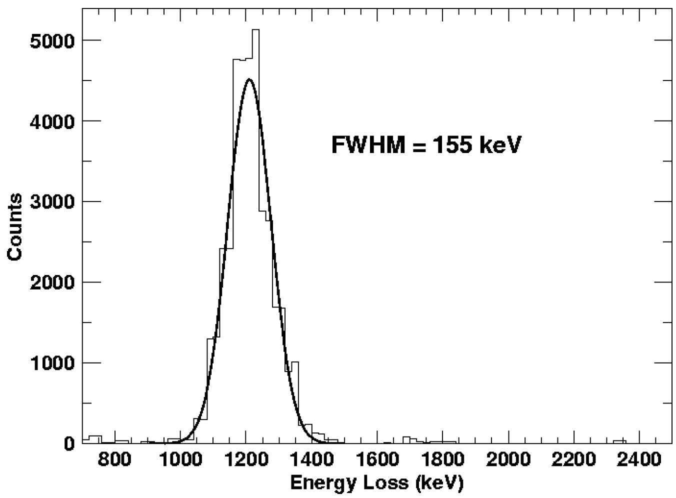

Fig. 12. Projection on the slice indicated in Fig. 11 results in an energy resolution of about 160 keV FWHM.

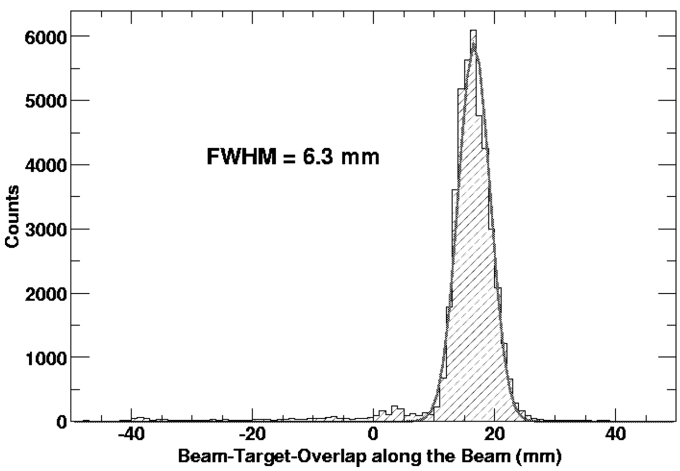

Fig. 13. Target density distribution along the beam-axis is of gaussian shape with a width of 6.3 mm.

separation by their energy losses in the first two layers under forward angles of the telescope can be expected to be pretty good as deduced from Fig. 12. The energy resolution along the slice which is indicated in Fig. 11 is shown to be ~160 KeV FWHM, which proves the good performance of the 65 μm thick detector.

With the use of the first and the second layer of the telescope straight-line tracks have been reconstructed. Intersecting these tracks with the plane in the beam-axis, parallel to the detectors results in the target density distribution along the beam which is shown in Fig. 13.

VIII. Conclusion and Outlook

The prototype assembly of a single Silicon Tracking Telescope has been evaluated. The 65 μm and 300 μm thick detectors together with their chip electronics provide already low energy proton identification and tracking. A modified Babar IV detector design with 200 μm pitch is in preparation.

The 5500 μm thick single-sided Si(Li) detector will be exchanged by a double-sided one, which then will provide tracking and particle identification over the full dynamic range.

The UHV compatibility has been shown. Due to the choice of LCP as flexible printed circuit the pumping times to get ultra

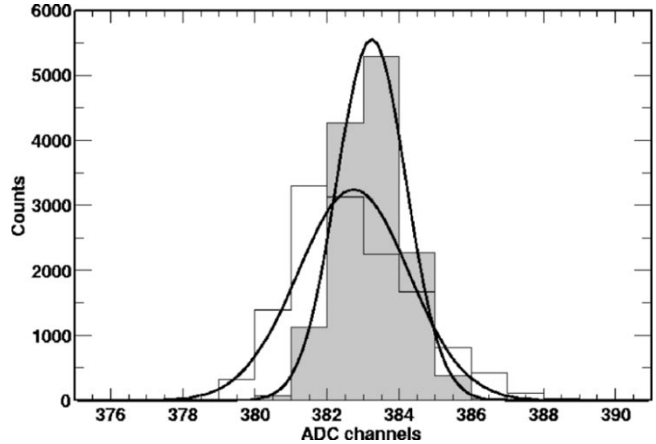

Fig. 10. Typical pedestal distributions measured in ADC channels. In the raw data the width is $\sigma = 1.54$ ADC-channels. It can improved by a common-mode correction to a more narrow distribution of $\sigma = 0.96$ ADC-channels, where one ADC channel corresponds to 15 keV.

high vacuum conditions can be kept short also for an extended setup of telescopes.

The VA32HDR_2 and TA32CG have a sufficient performance for higher energy losses ($>$3.6 fC). In a redesign the two chips are going to be joined into a one-die VA32TA2. The new chip which will also be designed to have improved trigger capabilities for minimum ionizing particles in the 300 μm thick detectors.

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