Single sided μ-strip detector with backplane readout for fast trigger applications

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Abstract

Motivated by a project to trigger on-line on the charged decay of neutral strange particles, a single sided Si-μ-strip vertex detector (SVX) has been placed in vacuum close to the liquid hydrogen target of the Crystal Barrel meson spectrometer at LEAR (CERN). An event is accepted if the multiplicity of charged tracks outside the SVX increases by 2 or more. For this purpose the signals from the detector backplane are read out by electronics specially adapted to the problems of speed, high detector capacitance and high leakage current. This provides a fast first level trigger (0.5 μs), gives an additional energy deposit measurement and helps in pile up recognition. The exact event multiplicity for a second level trigger can be determined from discriminators in the strip signal ADCs during the serial readout (26 μs), using a CAMAC based multiplicity encoder. If no digital control signals are applied to the SVX, the signal to noise ratio for minimum ionising particles (MIPs) on the backplane has been measured to be around 12. This is in good agreement with noise calculations, where noise cross-talk between the two preamp systems is neglected. The backplane signal can further on be used to trigger the readout of the strip side, which allows the detection of events in the detector itself (e.g. X-rays).

1   Introduction

As a spectrometer for the study of hadronic resonances the Crystal Barrel Detector [1] was designed for a complete reconstruction of $\overline{\text{p}}$p and $\overline{\text{p}}$d annihilation events. The final state particles are mainly pions, kaons and γ's in typical momentum ranges between $0.1 \ldots 1$ GeV/c. Whilst detection of all neutral events works excellently with the 1380 CsI crystals of the electromagnetic calorimeter, the charged tracking in the 1.5 T magnetic field is substantially improved by means of the new Si-μ-strip vertex detector, which covers about the same solid angle as the outer Jet Drift Chamber (JDC). The SVX was mainly proposed [2] for on-line triggering on events with K_S^0 Mesons in the final state, which is equivalent to strangeness production in the final state.

High statistics studies of rare channels demand the application of on-line triggers, through which an event rate of typically 10 kHz is to be reduced to a DAQ recording speed of about 50 Hz. First level trigger decisions are to be taken within 4 μs after the event, the maximum drift time in the JDC. To introduce a minimal bias in the momentum distribution of the triggered events, the inner multiplicity should be measured as close as possible to the primary vertex, which is, in our case, limited by the spatial extension of the liquid hydrogen target.

2   The Si-Vertex detector (SVX)

The SVX is constructed in a modular architecture permitting redundancy at the trigger level. Fifteen independent elements are arranged in a windmill configuration, at a radial distance of 13 mm, around the target. The overlap provides complete coverage of the detector's solid angle in the radial direction. Each element consists of the readout chip (VIKING [3]) and some passive electronics placed on a small ceramic hybrid, which is mounted at an angle of $35°$ to the Si detector. This unusual structure was

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required by the target geometry. The 130 bonds from detector to hybrid had therefore to be bent on a flexible vacuum holder before the parts could be glued to their support on a special alignment table.
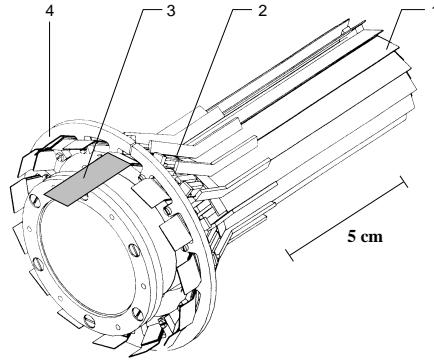

Figure 1: 3 D view of the Si-vertex-detector. 1: Si-μ-strip detectors, 2: Hybrid, 3: Active electronics and flat band cables, 4: Cooling ring.

The backplane trigger and the high strip readout rate (5 MHz) made it necessary to allocate some active electronics a few centimetres behind each element on a small double sided PCB (size: 45 mm x 10 mm). Serving also as a holder for micro connectors, it houses the differential line drivers for the analogue output signals of the chip as well as a charge integrating preamp (folded cascode design) with a shaper and line driver for the backplane signal.

As a consequence of the modular structure, 300 vacuum feedthroughs in a high density array were necessary. A double layer PCB was therefore glued into an aluminum flange, holding also the 15 connectors for the cables (3m) to power supplies and ADC's.

The DC coupled Si-detectors, which were broken out of the wafers, have a length of 74 mm and a width of 8.4 mm. A border of 1 mm around the strips is occupied by the 10 fold guard ring structure. The 128 strips, laid down with a 50 μm pitch, are oriented along the beam and magnetic field and allow an $r\phi$ measurement of the charged tracks.

From the size and thickness (370 μm), a theoretical backplane capacitance of 180 pF was estimated; the total leakage currents were measured to be about 1 μA per detector at a bias voltage of 50 V. A n-channel junction-FET (IF 450L) was chosen for the backplane preamp input stage. For a clean backplane signal, much effort had to be put into a proper ground- and RF- design, which had the additional effect of almost completely eliminating the common mode noise of the strip readout.
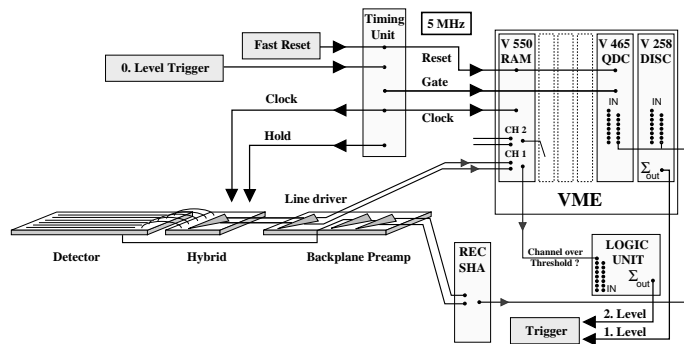
Figure 2: SVX Block diagram for one of the 15 elements

Digitising of the 15 analogue multiplexed signals from the VIKING chips is done in 8 two-channel VME FADC Modules (CAEN V550) synchronised to the readout clock. The built-in hardware zero suppression was disabled in favour of a logic output for triggering. This creates a short pulse (20 ns) during the conversion of each channel (200 ns) if the converted value lies above a downloaded threshold.

Noisy strips, as well as overlapping regions between two neighbouring detectors, can be masked out by setting the corresponding thresholds to the maximum.

The backplane signals are fed into a custom made receiver and second shaper unit (NIM), from where they are split to a 16 channel threshold discriminator (VME: CAEN V258B) and two 8-channel charge integrating ADC's (VME: CAEN V465).

3 Trigger conditions

The combination of the separately measured multiplicities from the backplanes (0.5 μs after the event) and the cluster logic (26 μs after the event) is done in different levels of the hardware trigger. Due to segmentation and overlap of the 15 detector elements, trigger setups are chosen for the physics program with the following considerations. Tracks from the primary vertex have a probability of about 25 % of hitting two backplanes and creating a backplane multiplicity of two. Furthermore the same backplane can be hit by two or more[1] tracks, depending on event topologies. A strip readout is not needed if only charged tracks from secondary vertices outside the SVX are considered. This case is shown in the first row of Table 1. The last type, $1 \to 3$, is used for $\overline{p}n$ annihilations in deuterium.

Trigger type	SVX Backplane	Tracks	SVX Strips
$0 \to \geq 2$	0	$2 \ldots 4$	-
$2 \to 4$	$1 \ldots 3$	4	2
$1 \to 3$	$1 \ldots 2$	3	1
Trigger level	1.	1.	2.

Table 1: Hardware trigger conditions for back- and stripside.

Figure 3 shows two selected $\overline{p}d$ events from the CB event display, triggered under the conditions $2 \to 4$. The backplane amplitude corresponds to the distance of the second bar parallel to the detector. The position on the strip side is marked by a dot.
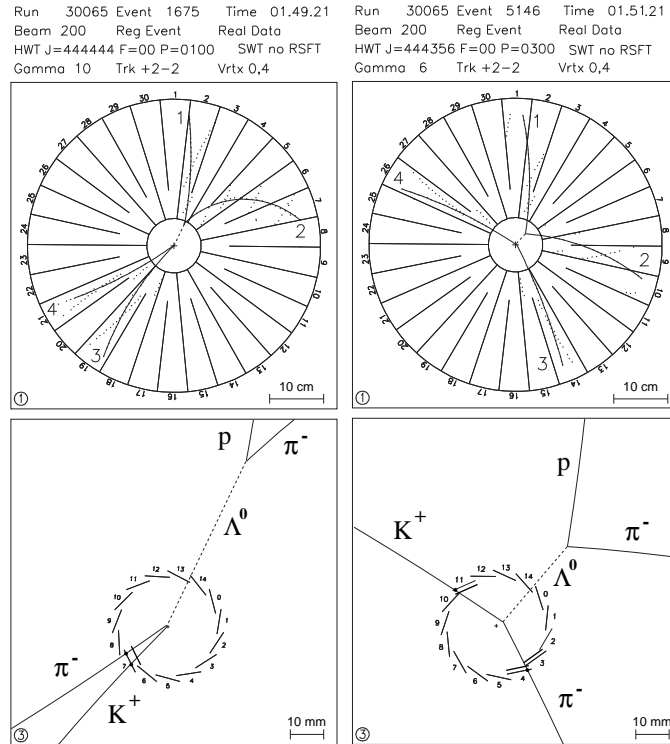

Figure 3: $r\phi$ projection of the charged tracks of two $\overline{p}d$ events with a Λ decaying into $p\pi^-$.

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[1]improbable, due to a average multiplicity of ≈ 2.5 charged tracks per event

4 Backplane readout

This section will briefly[2] outline the key points of the backplane readout of single sided position sensitive Si-detectors. The problems will be discussed under the assumption of long integration times in the preamps relative to carrier collection times in the detector, which is less then 20 ns in 300 μm Silicon.

4.1 Charge is measured twice

To understand how the signal of the detector can be measured at the same time in two readout systems with one not hindering the other, the working principle of a standard charge sensitive preamplifier (QSA) will be reviewed. It should be kept in mind that, in principle, the measured quantities are currents.

Due to its low input impedance and high open loop amplification, a QSA will reflect the input current into a small internal feedback capacitor, which works as an integrator. The voltage on this capacitor corresponds to the amount of charge which is virtually flown over the preamp input to ground.
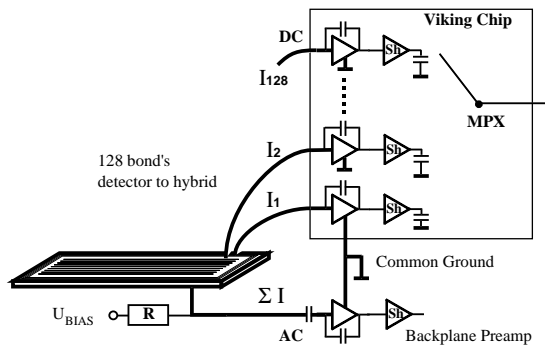

Figure 4: Schematic diagram indicating the discharge currents

For considerations of the total electronic circuit connected to the detector, a QSA can be replaced in first approximation by a capacitor with the size of its feedback capacitor multiplied by the open loop gain. The flow of the charge, which was liberated in the detector, can so be quantitatively estimated, employing the values of detector, coupling and stray capacitances. Figure 4 shows the circuit diagram for the detector discharge current, where the charge splits to different surface contacts and returns over the one backplane contact. The same charge passes the two readout systems and is thereby measured twice.

4.2 Noise crosstalk between the two readout systems

Noise in a charge sensitive readout system is commonly referred to a equivalent noise charge (ENC) on its input. This corresponds to a effective noise voltage (U_{rms}^{input}) on the preamp input. The contribution from the preamp itself to this noise voltage[3] does not depend on the total input capacitance, causing the linear increase of the noise charge with the size of the input capacitance.

The noise voltage at the inputs of the preamp systems will be used to estimate a noise crosstalk from the backplane to a strip readout channel and in the reverse direction.

To handle a high input capacitance, the noise of a backplane preamp will typically lie below $1\ nV/\sqrt{Hz}$, which corresponds to an noise voltage of roughly 1 μV over the total bandwidth (for 1 μs shaping). With the strip to backplane capacitances of typical 300 μm Si-devices (see figure 5) the noise crosstalk to a strip is in most cases very small. In the case for the SVX, taking 3 pF, something like 25 e_{rms}^- is estimated. As an incoherent contribution to the 850 e_{rms}^- noise from interstrip capacitance and leakage current, it is not relevant.

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[2]a more detailed publication describing the backplane readout is in preparation

[3]mostly of the type of 1/f and series white noise

Figure 5: Capacitance network for the readout system. The following numbers are estimated for the SVX. Typical values for 300 μm strip detectors are in brackets:

C_I: Interstrip capacitance $\approx$ 15 pF (typ. $1\ldots2\ pF/cm$)
C_B: Strip to Backplane capacitance $\approx$ 3 pF (typ. $0.4\ pF/cm$)
I_B: Leakage current per strip $\approx$ 10 nA

Noise from the stripside readout introduced into the backplane is higher for two reasons. The strip readout preamps are designed for smaller load capacitances and have therefore a higher input noise voltage. In addition is the value for a single crosstalk multiplied by a factor square root of the number of strip channels.

Measurements on strip detectors with low leakage current and many readout channels indeed show an increase of backplane noise when switching the strip readout on, or introducing more parallel noise on the strip side of smaller bias resistors. Thereby care has to be taken to distinguish effects from change in the capacitiv load for the backplane preamp, induced by change in the depletion depth or not working feedback in the strip preamps, when they are switched off.

For the SVX, additional noise on the backplane generated from the readout chip is in the order of $500\ e^-_{rms}$. Due to the unusual high parallel noise of the leakage current ($\approx$ 1 μA) it is, however, negligible.

4.3   Backplane readout noise

It is a good approach for most 300 μm Si-devices to neglect additional noise on the backplanes induced from the strip readout preamps. Besides the often dominating parallel noise of the total leakage current, there are other noise sources, which can significantly contribute to the backplane noise; e.g.: a bad ohmic contact into the Si-bulk or lattice defects on the borders where the detector was cut[4]. The spectral behaviour of these noise sources is similar to that of 1/f or parallel noise. The total noise on one backplane can be described by incoherently adding of ideal parallel, series and 1/f contributions, i.e.:

$$ENC^2_{Total} \;\; = \;\; ENC^2_{Par} \; + \; ENC^2_{Ser} \; + \; ENC^2_{1/f} \tag{1}$$

Figure 6 shows measurements on one of the detectors for the input FET IF 450 L with a forward transconductance of about 50 mS and a gate capacitance of 60 pF. The signal is processed in the same way as in the SVX readout electronics, by a 6th order semi gaussian shaper.

Figure 6: backplane noise versus shaping time in number of electrons rms.

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[4]mostly there is no guardring around the backplane contact

5   Measurements

The following plots show measurements on one of the SVX elements. The signal on the strip side is derived from the common mode corrected sum over the fired strips. The backplane signal is directly taken from a integrating ADC, which is gated to the event trigger.
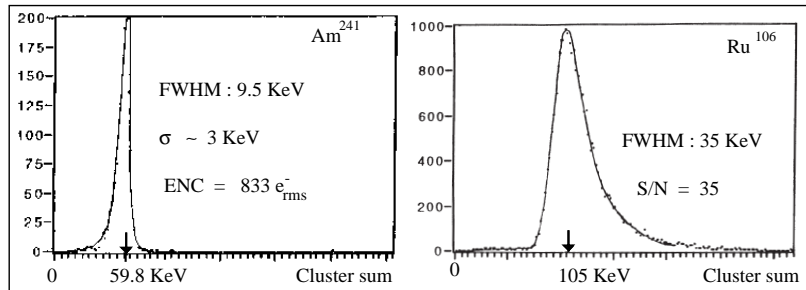
5.1   Energy spectra of strip signals

Figure 7: Left: Cluster size spectrum of 60 KeV γ's, triggered with the backplane signal. Right: Cluster size spectrum of MIPs of an electron source with the same settings as in the left.

Figure 7 shows on the left γ events, where the backplane signal is used to trigger the strip readout. The broadening of the γ line to its left is due to events in the border region around the strips or to the escaping of converted electrons. The noise is deduced from the right tail of the curve assuming a gaussian pulse height distribution. The plot on the right shows the landau like spectrum of minimal ionising electrons of a Ru^{106} source. It is taken under the same conditions as before, allowing to determine the absolute value of the most probable energy deposit in the detector. From this number the thickness of the sensitive detector volume, the depletion zone, was estimated to be about $360 \mu m$.
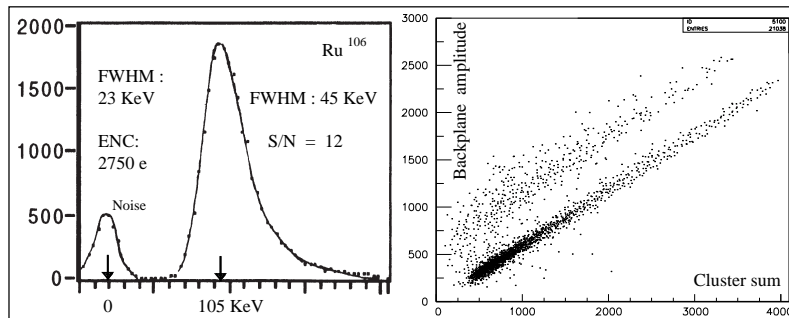
5.2   Energy spectra of backplane signals

Figure 8: Left: Backplane signals of the MIP events from above. Right: Correlation plot from MIPs in experimental data between the signal on the backplane and the cluster size.

The plot on the left shows the backplane signals of the same events of the electron source as above, plotted together with some pedestal events. The clear separation of the two peaks gives a high efficiency for charged track recognition. The noise is determined from the width of the pedestal distribution. The plot on the right shows the backplane signals from minimal ionising pions in $\overline{p}p$ annihilations against the strip side signal, demanding there exactly one cluster. The band over the main diagonal corresponds to events with two charged tracks in the detector, where one track goes through the guardring region or areas from dead strips.

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5.3 Spatial resolution

The improvement in spatial resolution by using the hits in the SVX is demonstrated in the following plots. They show the difference between the two impact parameters of the charged tracks in $\overline{p}p \rightarrow \pi^+\pi^-$ collinear events.
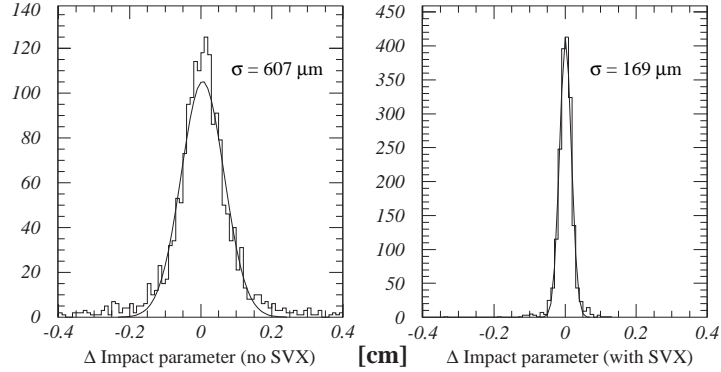

Figure 9: The distribution on the left is for tracks not incorporating SVX hits, the one on the right for tracks where the hits have been included.

5.4 Data

In a data sample[5] consisting of $\overline{p}$ annihilations in liquid deuterium, the following plots show the invariant mass peaks of different strange particles.
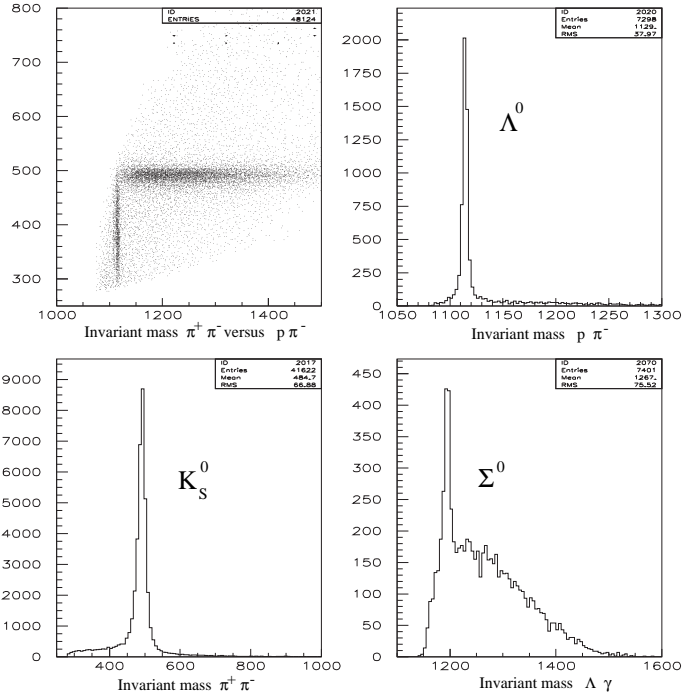

Figure 10: Invariant mass spectra $[MeV/c^2]$ of different hypotheses for the secondary particles observed in the decay of neutral particles in $\overline{p}d$ annihilations.

The events were selected by demanding exactly two charged tracks with a secondary vertex outside the SVX. Events with γ conversions or back scatters from the electromagnetic calorimeter are filtered out.

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[5]accumulated in August 95 by 9 days of running the K_S^0 trigger

6   Further considerations

Up to momenta of about 0.4 GeV/c particle identification by dE/dx can be done in the JDC, where the truncated mean of an average of 10 points is evaluated. Path length corrected plots for the energy deposit in the SVX versus particle momenta, show bands, which correspond to pions, kaons and protons. Investigations are in progress to determine the degree to which particle identification can be improved by implementing the energy loss in the SVX into the global tracking.

In a further project, the relation between cluster size and track angle in the SVX has been found to be quite useful for matching tracks to SVX hits. Due to the small pitch to thickness ratio of the detectors, 3 or more strips fire for angles larger than 25 degrees.

7   Conclusions

The dead time for trigger decisions on the backplanes is about $1\mu s$, for a strip readout $100\mu s$. The S/N from MIP's has been measured to be 35 for signals on the strip side, and 12 for those on the backplane. With the additional coordinate from the SVX, the momentum resolution for charged tracks (at 928 MeV/c) is improved from 61 to 35 MeV/c. The vertex resolution drops from around 0.7 mm to about 0.1 mm.

Since the upgrade of the Crystal Barrel Detector with the SVX, which took place in spring 95, more than 150 million triggered data have been taken in about 22 weeks of beam time. The enrichment factor for events with K_S^0 mesons in the final state could this year be raised to 250 compared to minimum bias data samples. With this data, the statistics available in rare channels is now of the same order of magnitude, as that accumulated in the more dominant channels in $\overline{p}p$ annihilations.

References

[1] E. Aker et al., Nucl. Instr. and Meth. A 321 (1992) 69.

[2] M. Doser et al., Cern SPSLC 93-23/M 522 (1993).

[3] O. Toker et al., Nucl. Instr. and Meth. A 340 (1994) 572.