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**Performance of the Silicon Ring Counters
for the HELIOS Experiment at CERN**

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ABSTRACT

The construction and operation of silicon ring counters designed to measure multiplicity and pseudorapidity distributions of charged tracks in a high multiplicity environment, are described.

The detectors operated successfully in the HELIOS experiment during the CERN-SPS relativistic ion runs with ^{16}O projectiles in 1986 and with ^{32}S in 1987. They also provided a multiplicity trigger for the experiment.

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1. INTRODUCTION

The NA34/2 (HELIOS) experiment [1] is devoted to the study of states of nuclear matter at high density produced via high-energy nucleus-nucleus collisions. The fundamental motivation for such studies is the possibility, according to predictions by lattice quantum chromodynamics, of observing a phase transition towards a new state of deconfined quarks and gluons. In this context, a detailed knowledge of the charged particle yields and angular distributions is essential to evaluate thermodynamical variables such as the energy density, and to detect possible collective effects [2]. This implies an accurate measurement of charged-particle distributions combining good resolution in pseudorapidity (η) with high-rate capability.

The HELIOS silicon ring counters (fig. 1) meet both these requirements, being fast and highly segmented (384 pads each) ¹. The detector design is presented in section 2.

The signal from each detecting element is sent both to ADC's and discriminators, whose outputs enter a fast summing logic which provides a set of multiplicity triggers. The electronic chain is described in section 3, and the multiplicity trigger logic in section 4. In section 5, results on the performances of the detectors and the associated electronics are presented.

2. DETECTORS AND SUPPORTS

To minimize production costs and time scales, we decided to use a well-established silicon technology, i.e. 3 in. wafers with ion-implanted diode structures (pads), and a modular design, with identical detectors at different distances from the target along the beam line (fig. 2). Each detector covers approximately 2 units of pseudorapidity.

The segmentation of the detectors has been chosen in such a way as to measure the multiplicity directly in η intervals, i.e. concentric rings, subdivided in azimuthal sectors. The width of the rings increases with increasing radii to ensure a quasi-constant η step, of less than 0.1 units of η . Each detector has a total of 384 pads (a multiple of 24, which is the modularity of the electronic chain) arranged into 32 rings and 12 angular sectors.

Figure 3 shows a schematic view of one counter. Its geometrical characteristics are summarized in table 1.

The pads are connected to the preamplifiers via a multi-step fanout: the silicon is glued to a ceramic overlay [4], which is then attached to a printed circuit board (PCB), which in turn is connected to the preamplifier boards via flexible jumpers. The leads on the overlay are connected, on one side to the detector and on the other to the leads on the PCB, via thermosonic gold bondings. The jumpers allow fast interchange of detectors and ensure mechanical decoupling between the detector and the heavy cables.

¹ The concept of these detectors was first put forward in the P213 proposal to the SPSC [3], which later merged with HELIOS.

Micron Semiconductor Ltd. fabricated the implantation masks and the detectors and performed mounting and bonding to the overlay and the PCB.

The overlay and the PCB were designed using a software package, developed at CERN [5], to generate a coded tape for the EMMA-80 photo-plotter of the Surface Treatment Laboratory.

The ceramic overlay has 16 slots, 1.3 mm wide, which allow bonding from both edges to the underlying silicon. Four holes on the outside are cut for alignment purposes, and a central one to let the beam through (fig. 4).

The layout of the slots is optimized to keep a sensible modularity for the multiplicity trigger: each connector groups 24 pads belonging to the innermost or to the outermost 16 rings of a given quadrant. In this way it is possible to form discriminator sums over either half of a detector (i.e. about 1 unit of η) without further rearrangement of the channels.

A gold paste was deposited on the 600 μm thick ceramic by serigraphic method, then the desired pattern was etched chemically; the slots and the outline (70 by 70 mm^2) were cut by laser. Thinner (250 μm) ceramic or 300 μm G30 were unsuitable, essentially because of robustness and rigidity requirements imposed by the bondings to the silicon.

For the PC board (motherboard) we used G30 material, which has better compatibility of thermal properties with the ceramic than G10. Two rows of single-in-line connectors are mounted on three edges of the PCB, to allow the connection with the jumpers (fig. 5). A circuit mounted on the lower part of the motherboard provides bias and pulsing to the detector.

The motherboard is fixed to a base plate via a U-shaped aluminium frame. The detector is aligned under the microscope with its center line parallel to the surface of the base plate within 0.5 mrad. From this procedure, the position relative to the baseline is known to better than 15 μm .

The detectors are then mounted onto a platform in the HELIOS target zone, and alignment is checked with an optical telescope, by viewing the edges of the beam hole. The measured offsets were up to 100 μm , with a measurement accuracy of 10 μm .

3. READOUT ELECTRONICS

The readout chain (fig. 6) includes a charge sensitive preamplifier and an intermediate amplifier followed by a shaper and a peak-sensing ADC [6].

The preamplifiers ² [7] feature 3 channels on each hybrid, to allow short fan-out leads (fig. 7). The specifications of the preamplifiers are listed in table 2. The hybrids are mounted onto PC boards (fig. 1) from which a set of 5 m long, 24 channel, shielded twisted pair cables takes the signals to the intermediate amplifiers.

The intermediate amplifiers provide amplification (by a factor 4) and differentiation of the signals ($\tau = 18$ ns), and drive the 65 m long, 24 channel flat coaxial cables to the counting room.

² BNL type IO456-2-3

There, the signals are fed into shaping amplifiers³ which give further amplification and provide a bipolar signal.

A magnetic splitter is mounted after the shaper, providing the direct signal to the peak-sensing ADC⁴ and the inverted signal to the discriminator, used in the multiplicity trigger logic. The linearity of the chain was found to be preserved by the insertion of the splitters, while the signal at the ADC input was reduced by a factor of about 2.3.

4. MULTIPLICITY TRIGGER ELECTRONICS

The trigger is designed to allow a fast selection of the events based either on their total charged multiplicity or on the multiplicity in selected pseudorapidity intervals. The trigger treats each detector as divided into an inner and an outer region, of 192 pads, each corresponding to about one unit of η . Sums of fired discriminators are computed separately for each region of the two detectors, and compared with programmable digital thresholds, providing triggers to the Very Fast Bus (VFB), a fast trigger processing and selection system [8]. For each selection of η ranges, two independent threshold levels were allowed, so that, through downscaling of the lower-threshold triggers, one could select a balanced mix of medium and high multiplicity events.

A block diagram of the multiplicity trigger is shown in fig. 8. The analogue signals are presented to the inputs of ECL discriminators (fig. 9a). The setting of the discriminator thresholds is done in two steps: the coarse value for the 24 channels in a discriminator module is provided by an external d.c. level, while the fine setting is done via individual trimmers, allowing the suppression of noisy channels. A CAMAC module provides the programmable d.c. level for 16 discriminator modules. The 24 discriminated signals inside one module are summed using a compact encoder, made with 2 EPROMs plus a standard half-adder. This stage provides a 5-bit sum over 24 channels (fig. 9b). The 32 5-bit words (Σ in fig. 8) are summed using a cascade of half-adders (74LS283), giving four 8-bit words, each corresponding to the sum over 192 channels. The partial sums are combined to form a sum Σ_T over the total η coverage and a variable sum Σ_V over a selected η coverage. Finally, Σ_T and Σ_V are compared with two different thresholds for each of them. Then the four comparator outputs, strobed by the synchronization logic, are sent to the VFB. The four thresholds are CAMAC programmable and can also be readout, as well as Σ_T , Σ_V and the partial sums. A separate functional block contains the synchronization logic (see the timing diagram in fig. 10). The start signal is obtained from the pretrigger of the experiment (which essentially requires a valid interaction), delayed to match the timing of the analogue signals. Three latch-enable signals are then generated, to hold the logical signals at the discriminator outputs, the partial sum terms, and the final sums Σ_T and Σ_V , respectively. The reset signal comes from the ADC clear provided by the general trigger system.

³ CERN type N273

⁴ LRS model 2281

The maximum time needed for the multiplicity processor is 900 ns after the delayed pretrigger (fig. 10). For a beam of $\approx 10^6$ ppb and a target of $\approx 10\%$ of an interaction length, giving a pretrigger rate of 10 kHz, this represents a dead time $< 1\%$. This time could be reduced by use of faster logic elements.

5. PERFORMANCE

The detectors were first tested in the laboratory, both by pulsing the preamplifiers or the backplane, and with a ^{106}Ru source. The full depletion voltage was found to be typically 20–35 V, with a current of about 20 μA drawn for the whole detector, mostly due to a few bad pads, while the good ones were drawing less than 10 nA each. The signal-to-noise ratio was satisfactory, as it was the overall performance of the electronic chain. This can be seen from the quality of a typical pulse-height spectrum (taken during the ^{32}S run), shown in fig. 11 together with the noise curve. Such quality is sufficient to allow an estimation, via a fit of the pulse height distribution, of the contribution due to multiple charged particles hitting the same pad [9].

The distribution of the ratio signal/r.m.s. noise for all the pads is shown in fig. 12, with its mean around 30. The typical noise figure is 800 r.m.s. electrons. In fig. 13 is shown the dependence of the signal-to-noise ratio upon the area, and thus the capacitance, of the pads: the modest decrease with increasing area indicates that the capacitance of the connections and fan-out leads dominates over the one of the detector diodes, even for the largest pads.

The high multiplicity of the events and the fine segmentation of the counters allowed also to correct for the missing pads. During the 1986 and 1987 periods, those represented a relatively high fraction of the total, varying from 10% to 18%, mainly because of bad diodes and missing bondings, but also because of noisy electronic channels, broken cables and so on.

The detectors and trigger system were used during the whole NA34/2 data taking period, with different geometrical configurations depending on the type of target used. The targets were alternatively thin passive targets, a wire chamber type active target, and emulsions. In the latter case, together with an independent measurement of multiplicity vs. η distributions, the counters provided a means of selecting events to be measured in the emulsion and to verify the identification of the events found in order to correlate them with the measurements in the electronic part of the apparatus. Data were taken using as a projectile 200 A GeV ^{16}O ions in 1986, 200 A GeV ^{32}S ions in 1987, and 200 GeV protons in 1988. Radiation damage effects did not produce any observable deterioration of the performance of the counters.

The off-line analysis of the data is now in an advanced stage [9].

The performance of the trigger electronics was very satisfactory. This is shown by the on-line correlation plots between ADC multiplicity (defined by a cut at 12 standard deviations above pedestal) and digital multiplicity, in each of the trigger regions (fig. 14a and 14b).

The trigger on high multiplicity events was found to be essentially free from the upstream interactions contamination: the empty target rate was basically zero. This is due to the silicon detectors having a good geometrical acceptance for tracks coming from the target, as opposed to those coming from upstream sources. Actually, the information from the counters is used in the off-line analysis to discriminate against off-target interactions [10]: in fig. 15 is shown the correlation between transverse energy and multiplicity for target-in (15a) and target-out (15b) runs. At least for the interesting region of relatively high multiplicities, the two sources appear clearly separated.

6. SUMMARY

We have built and tested a new silicon detector with true bidimensional read-out, using an overlay technique. ADC readout, as well as discriminator information, is available.

We also developed a multiplicity processor providing a set of four different triggers with variable thresholds and η -coverage.

Both the detectors and the trigger system have been successfully operated in the very high multiplicity environment of ultra-relativistic heavy-ion collisions, allowing fast extraction of high statistics total multiplicity and $dN/d\eta$ distributions.

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References

1. H. Gordon *et al.*, Proposal P203 to the SPSC, CERN-SPSC/84-43 (1984)
2. M. Jacob and H. Satz, eds., Quark matter formation and heavy ion collisions, Proc. Bielefeld Workshop, 1982 (World Scientific, Singapore, 1982);
T.W. Ludlam and H.E. Wegner, eds., Quark matter 1983, Brookhaven, Nucl. Phys. **A418** (1984);
M. Gyulassy, ed., Quark matter 1986, Nucl.Phys. **A461** (1987).
3. N. Armenise *et al.*, Proposal P213 to the SPSC, CERN/SPSC/85-24.
4. R.H. Beuttenmuller *et al.*, Nucl. Instrum. Methods in Phys. Res. **A252** (1986) 471.
5. W. Dahme, private communication.
6. R.H. Beuttenmuller *et al.*, Nucl. Instrum. Methods in Phys. Res. **A253** (1987) 500.
7. V. Radeka and D. Stephani, private communication.
8. D. Cockerill *et al.*, The AFS trigger system at the CERN ISR, Proc. Int. Conf. on Experimentation at LEP, Uppsala, Sweden, 16-20 June 1980;
C.W. Fabjan, High- p_T event trigger and processor for the ISR Axial Field Spectrometer, Int. Conf. on High-Energy Physics, Madison, Wisc., USA, 17-23 July 1980;
L. Rosselet, A calorimeter trigger system for the ISR Axial Field Spectrometer, Topical Conf. on the Application of Microprocessors to High-Energy Physics Experiments, CERN, Geneva, Switzerland, 4-6 May 1981.
9. HELIOS Collaboration, T.Åkesson *et al.*, Measurement of the multiplicity in Oxygen-nucleus collisions at 60 and 200 GeV per nucleon, in preparation.
10. HELIOS Collaboration, T.Åkesson *et al.*, Zeit. Phys. **C38** (1988) 383.

Table 1
Specifications of the ring counter

Active outer diameter	60 mm
Active inner diameter	7 mm
Physical hole diameter	2 mm
Number of concentric rings	32
Number of 30° sectors	12
Number of pads	384
Minimum radial pitch	270 μm
Maximum radial pitch	1200 μm
Minimum area of a pad	0.51 mm ²
Maximum area of a pad	18.5 mm ²
Wafer thickness (silicon)	300 μm
Overlay thickness (ceramic)	600 μm
Motherboard thickness (G30)	1600 μm

Table 2
Specifications of the electronic chain

Preamplifier sensitivity	3 mV/fC
Intermediate Amplifier gain	4
Shaping Amplifier gain	12.5
ADC sensitivity	1 count/mV
ADC counts for 1 mip (no splitter)	535 mV
ADC counts for 1 mip (splitter)	210 mV

Figure captions

- Fig. 1 Ring counter with preamplifiers (Photo CERN X-657.10.86).
- Fig. 2 Set-up for the 1987 run, thin target configuration.
- Fig. 3 Layout of the silicon ring counter.
- Fig. 4 Layout of the ceramic overlay (Photo CERN 441.04.86).
- Fig. 5 Layout of the PC board.
- Fig. 6 Overall scheme of the electronic chain.
- Fig. 7 Layout of a preamplifier hybrid (courtesy of Instrumentation Division, BNL, Upton, NY).
- Fig. 8 Block diagram of the multiplicity trigger chain.
- Fig. 9 (a) Circuit diagram of one ECL discriminator. (b) Circuit diagram of the EPROM coding stage for 24 discriminator channels.
- Fig. 10 Timing diagram of the multiplicity trigger.
- Fig. 11 A typical pulse-height spectrum with the associated noise spectrum.
- Fig. 12 Distribution of the signal-to-noise (r.m.s.) ratio for all the pads.
- Fig. 13 Dependence of the signal-to-noise ratio upon the area and capacitance of the pads.
- Fig. 14 On-line ADC multiplicity versus digital multiplicity for two η regions.
- Fig. 15 Correlation between transverse energy and multiplicity for target-in (a) and target-out (b) runs.

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15