Large Area Silicon Drift Detector Prototypes for Experiment ALICE

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Linear Silicon Drift detectors with an active area of $33.5\ cm^2$*, and having total dead regions of* $9\ \%$*, were designed as a joint effort of the SDD group of NPI Řež and the Instrumentation Division of BNL. The detectors were fabricated on 4" diameter, Neutron Transmutation Doped (NTD) wafers of n-type resistivity of* $3.5k\Omega \cdot cm$ *at the ICM Prague and at the TESLA SEZAM, Czech Republic. Detectors have a hexagonal shape with two rectangular active regions, each having a maximal drift length of* $33.5mm$*. Signals are collected on 200 anodes at each end of the active regions, resulting in an anode pitch of* $250\mu m$*. To calibrate the drift velocity two structures were implemented. i) MOS charge injection structures and ii) precise openings in metalization for laser-induced charge injection. Auxiliary anodes around the guard zone allow for a leakage current study in this region. Details of the detector design, together with the first results of detector calibration and tests in the secondary beam of* $348GeV/c\ \pi^-$ *at the SPS accelerator, are discussed.*

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1 Introduction

The inner tracking system (ITS) of the ALICE experiment consists of six cylindrical layers of position sensitive silicon detectors. The two innermost layers are equipped with silicon pixel detectors, followed by the next two layers which incorporates Silicon drift detectors (SDD). The two outermost layers consist of Silicon Strip Detectors.

The main purpose of the ITS is detection of secondary vertices (hyperon and charm) track finding of low p_t charged particles, improvement of momentum resolution at large momenta and dE/dx identification and momentum reconstruction of low energy particles.

The two layers of silicon drift detectors are segmented to 36 ladders. The inner SDD layer consists of 12 ladders equipped with 6 detectors per ladder. The outer SDD layer contains 24 ladders, equipped with 8 detectors per ladder [2]. Linear SDD prototypes described in this paper have been designed for the inner SDD layer.

2 Detector Operation and Structure

Silicon drift detectors are two–dimensional position sensitive detectors of charged particles and X–rays.The principle of the silicon drift detector was first described and implemented by Gatti and Rehak [1]. The full depletion of the detector is accomplished by a suitable choice of reversed voltages applied on P-N junctions created on both sides of the detector.

When an ionizing particle crosses the detector, electron-hole pairs are generated along the passage of the particle. A fast charged particle at the minimum of ionization (MIP), crossing a $280\mu m$ thick silicon detector, produces about 25000 electron–hole pairs. In the electric field created in the volume of the detector by a combination of applied voltages on the surface junctions, and the effect of ionized impurities in the silicon bulk, the holes move to the nearest P-N junction on the detector surface. The electrons move in an opposite direction towards the central plane of the detector, and within this plane drift toward an array of collecting anodes which can be up to $35mm$ away. The distance of the particle crossing from the anode array is given by the measurement of the electron drift time. The second coordinate of the particle crossing is determined from the partition of the generated charge among segmented anodes. Since the anode capacitance is very low ($\approx$ 400 fF), the introduced noise essential for high detector sensitivity is very low.

For the central collision in ALICE, the particle density in SDD layers can reach $\approx 5cm^{-2}$. This density is rather low compared to conditions on SPS [3] where the SDDs were used up to now. Thus the requirements on double particle resolution is less strict for the ALICE experiment than for the heavy ion experiments running at the SPS. The detector design has to be robust to ensure the high production yield. The detector has to be equipped by calibration charge injectors which are used to correct the temperature variation of the drift velocity. A linear SDD prototype has been designed according to following specifications:

- Rectangular active region 50 x 67 mm
- 9% of dead region
- Simplified charge collection region
- Implanted P+ resistor HV divider
- Drift length 2 x 33.5 mm
- 200 anodes on each side of the detector (anode pitch 250 μm)
- 3 lines of MOS and N+ charge injection structures
- Precise openings in metalization for laser-induced charge injection

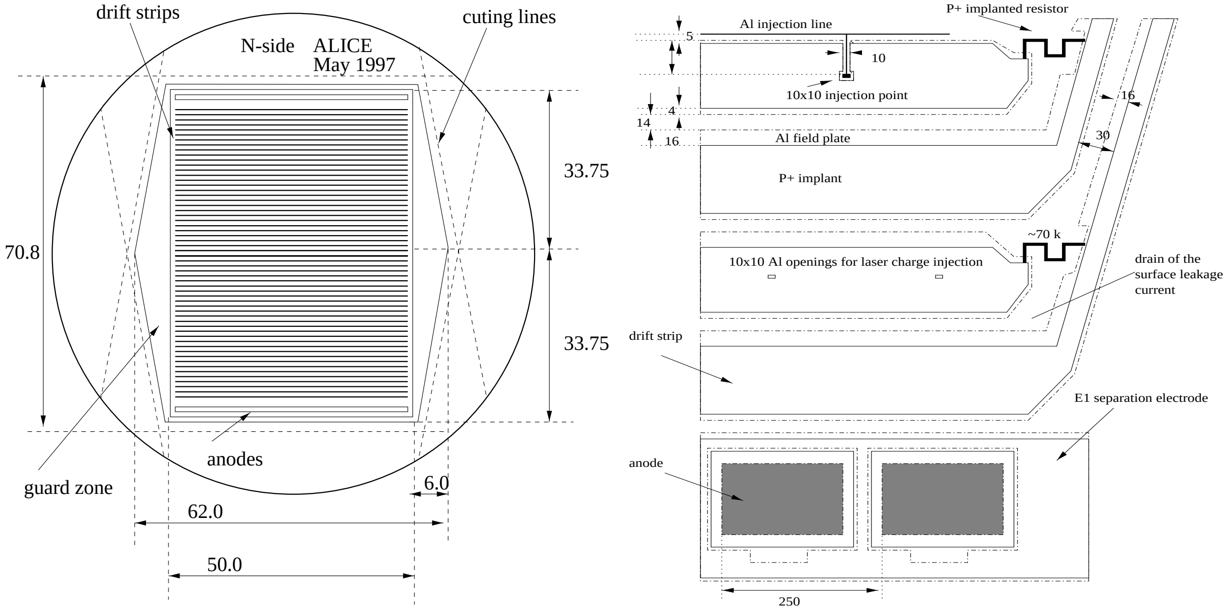

Figure 1: a) Layout of the 4" wafer with ALICE Linear SDD prototype, b) Details of the ALICE Linear SDD design

- Anode structures around the guard zone permitting allows study of the leakage currents in this region
- Detector fabricated on $3.5k\Omega/cm$ NTD N-type Si wafer.

The hexagonal shape of the detector and a rectangular active region allow a simple alignment of detectors on the ladder. A schematic view of the 4" Si wafer is in Fig.1a.

In order to obtain the required performance, it was necessary to simulate the behavior of several detector structures. For simulation of the electric field the 2-D simulator Posibin was used. The gap between two drift electrodes, the extension of aluminum field plates and the separation of guard strips were optimized for the operation of the detector at the drift field of $76V/mm$. The leakage current generated at the $Si - SiO_2$ interface between adjacent drift electrodes is drained along the interface toward the sides of the detection area. Here, the surface current enters the main drift potential minimum and is directed toward the guard zone. Distribution of the leakage current can be measured on anode structures around the guard zone.

The MOS injector structures, with injection point near the center of the drift strip, ensure the point–like charge injection from the well defined surface structures. For test purposes we have implemented also N+ injectors. Details of the detector design are shown on Fig.1b.

3 Detector Fabrication

The detector has been designed for fabrication on 4" diameter wafers. It required the double-sided technology of the smallest feature of $1\mu m$. The detector was designed in the

CADENCE design environment. Masks were generated on the optical mask generator at TESLA SEZAM using the data prepared in ASICentrum Prague. Detector wafers were fabricated at ICM Prague and TESLA SEZAM.

Detector wafers were cut by a diamond saw (6 pieces) and by laser (12 pieces). ¿From the set of 6 detectors cut by the diamond saw, we selected a detector for the first beam test held in July 1998.

4 Measurement

Signals from the detector were amplified by the OLA preamplifier-shaper. MAXIM 435 differential boosters were used to drive cables with the Struck FADCs at the other end. The FADC system was running at 30 MHz scanning frequency. The drift field of $71 V/mm$ was applied on the detector which resulted in a mean electron drift velocity of $7.9 mm/\mu s$.

4.1 Laser calibration

The detector had been calibrated using the laser-induced charge injection. The detector was mounted on the PC-controlled micro positioning X-Y table Merkhauser. The table allowed positioning of any chosen position at the surface of the detector at the focal point of the laser beam. A pulsed 905 nm laser light of a diameter of $< 100 \mu m$ at given point injected charge corresponding to $\approx 1 MIP$. This charge, after the drift time, was detected on the anode. The measurement of the drift time for several distances from the laser focal point has been carried on. The inverse of this measured function have been used for the position reconstruction from the drift time measurement.

4.2 Beam test

The test was performed in a secondary beam having 348 GeV/c π^- from the H4 extraction line of the SPS accelerator. The beam intensity was adjusted to avoid pile-up of signals in the SDD. The detector was mounted into the Silicon Strip Detector (SSD) telescope, consisting of 10 layers of SSD with active area 2x2 cm and strip pitch $50 \mu m$. Data acquisition was triggered by coincidence in two crosses of plastic scintillators placed in front and after the SSD telescope. During the test, we encountered serious problems with the preamplifier-shaper OLA chip. The output stage of the chip was partially damaged and the gain of the chip had decreased. The observed detector signal, shown in Fig.2a, was so low that the system was sensitive to the noise of the subsequent stages.

In spite this problem, it was possible, after careful noise cut-off, to analyze data from the whole SSD - SDD telescope and determine the beam profile and SDD resolution.

We had instrumented only 15 readout anode channels and the beam profile could be determined only in the drift direction (horizontal coordinate). In the vertical coordinate only the SDD geometrical acceptance can be observed. The comparison of the position distributions predicted from projection of the reconstructed track into the SDD plane and the real SDD data is shown on Fig.2b.

Only tracks consisting of more than 2 points in each coordinate of the SSD telescope were accepted for the track reconstruction. Residuals of the particle locations in different

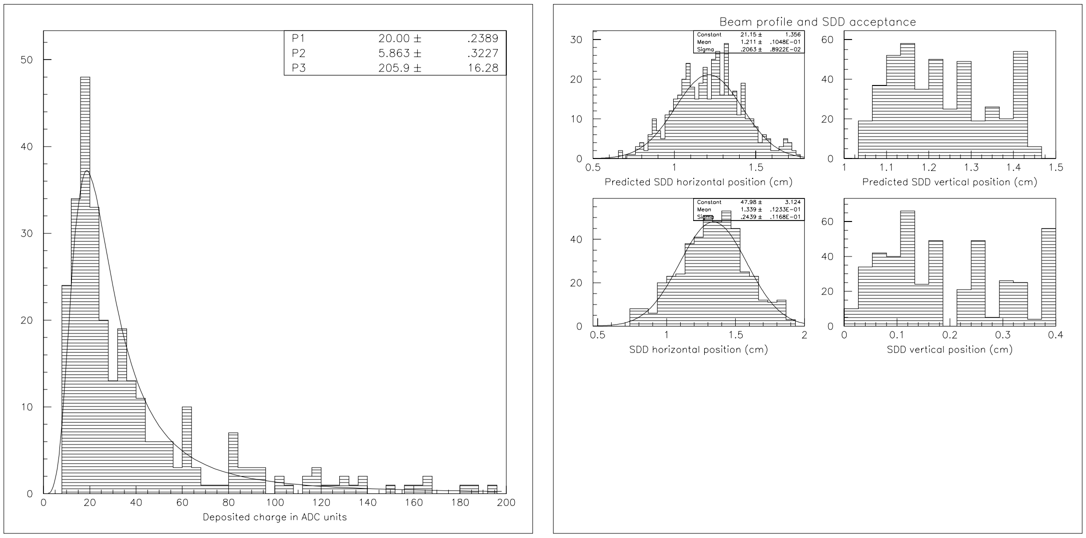

Figure 2: a) Charge deposited by the particle (ADC counts), b) Beam profile in the SDD plane, as predicted from the track reconstruction and from SDD data.

SSD planes are plotted on Fig.3a. There are no apparent signs of systematic widening of the residual distributions due to the multiple scattering.

The predicted position of a particle from the SSD telescope correlates well with the position measurement from the tested SDD in both in the anode and in the drift direction. This correlation, together with distribution of residuals in SDD, is shown on Fig.3b.

Distribution of the SDD residuals is much wider than expected. This is due mainly to i) decreased S/N ratio, resulting from the low gain of the the damaged preamplifiers and and ii) the low sampling frequency of the DAQ (30 Mhz), resulting in under-sampling of the shaper waveform. The presented results are intended to show the functionality of the produced linear SDD rather than a report on its position resolution.

5 Conclusions

The ALICE compatible Linear SDD prototype has been designed at BNL and ASICentrum Prague and fabricated in Czech companies ICM Prague and TESLA SEZAM. The detector is equipped with several features for easy integration into a large system (rectangular active zone, simple charge collection region, n+ and MOS calibration injectors) and for study of detector performance (precise aluminum openings in strip metalization for laser-induced charge injection, anode structures around the guard zone). Functionality of the detector has been proven in the beam test. The detector resolution and the other features of its performance are still being studied.

In the next phase the detector will be tested together with SCA readout electronics and new CESIPA preamplifier-shaper chips and MOS injectors will be used for on-line calibration of the mean drift velocity.

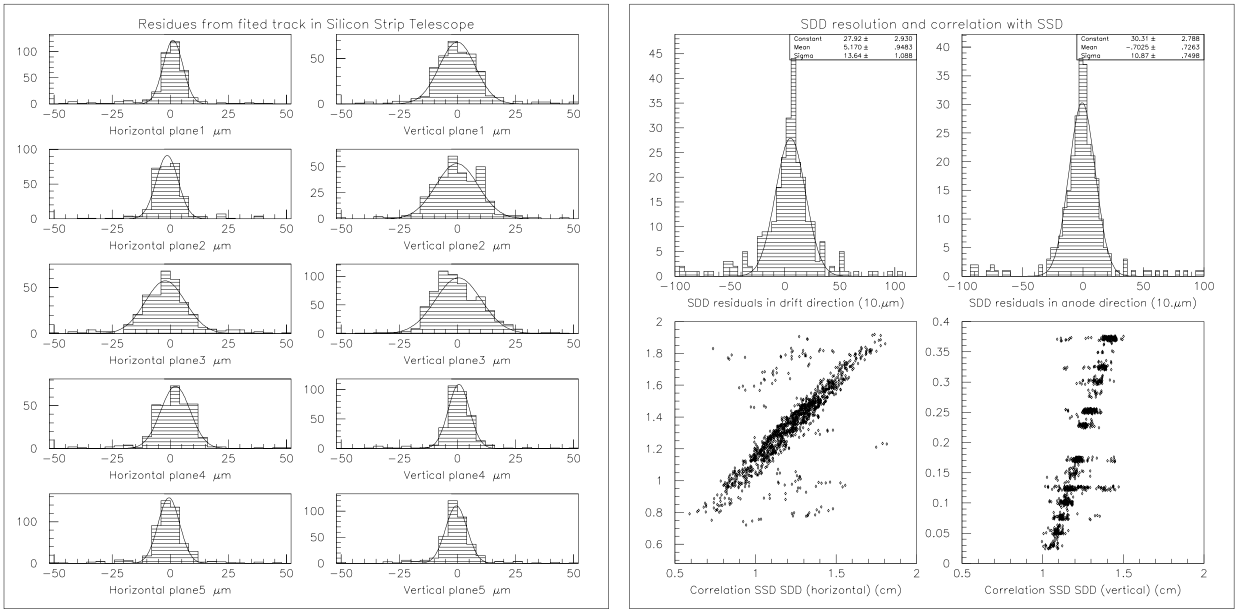

Figure 3: a) Residuals of the particle hit position in different SSD planes, b) Correlation of SSD and SDD signals and SDD resolution

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