6.6 A Novel Particle Detector for UA2: The Power of Silicon

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In 1983 — the UA1 and UA2 collaborations had just discovered the W and Z bosons — the UA2 collaboration decided to upgrade its tracking detector by replacing part of the existing detector with a silicon detector [33]. It represented a major step forward in silicon detector technology, replacing the conventional strip-geometry of the detector elements [Highlight 5.9] with a novel checkerboard or "pad" configuration, providing improved track reconstruction. This detector worked very well. It encouraged the collaboration in 1986 [34] to push this concept further and to develop a second Silicon Pad Detector (SPD) with finer pad segmentation to be placed directly around the collision interaction beam pipe.

The layout of the new inner SPD matched the detector geometry of the outer silicon detector in order to optimize track reconstruction. The detector was built as a cylinder surrounding closely the beam pipe in the available radial thickness of 9 mm, with almost no dead space. The size of the pads was 17.3 × 33.5 mm^2; they provided 3072 channels. It was the first incarnation of a silicon tracker with a detector geometry adapted to a collider experiment, an ancestor of the present silicon vertex detectors.

The project presented several challenges: the barrel detector had to fit into the available radial space of less than 1 cm, including silicon sensors, electronics and associated circuit boards. Miniaturization of the detector was mandatory and was achieved with at that time two brand new technologies, the silicon sensor [35] and an Application Specific Integrated Circuit (ASIC), representing totally new approaches in particle physics experimentation. At that time tracking technology was based on gaseous detectors (MWPC) [Highlight 4.8] and discrete electronics comprising miniaturized components with hybrid electronic technology.

Fig. 6.15. ASIC AMPLEX, a 16 channel readout system developed for the Inner Silicon Pad Detector.

Developing the readout electronic system scaled to the miniaturized dimensions of the SPD represented probably the biggest challenge. Existing electronics was too bulky — incompatible with the required thickness and the channel density of the UA2 Silicon Pad Detector. It required the development of a novel ASIC tailored to the UA2 silicon sensors and experimental requirements. Figure 6.15 shows the device mounted in a 10 × 10 mm^2 package. All 16 electronics channels, providing the readout of 16 pads, were contained in a silicon die of 4 × 4 mm^2.

The ASIC, called AMPLEX [36], was fabricated in a 3 μm gate length CMOS technology. Stringent requirements were placed on the electronic noise, because a relatively tiny charge of about 24 000 electrons (4 fC) is produced by a minimum ionizing particle in 300 μm thick silicon. The typical noise figure obtained with the AMPLEX input amplifier stage was the equivalent of 1200 e$^-$ r.m.s. resulting in an excellent signal-to-noise ratio of 20. Power consumption per channel was 1.5 mW.

The second feature of the AMPLEX circuit was the readout technique. The CERN proton–antiproton collider had a machine cycle of 3.8 μs. Therefore, the signal had to be available within 2–3 μs for a possible "readout decision" within the machine cycle prior to the serialized readout of the analogue signals of all channels. An appropriate signal shaping circuit was implemented, a proven electronic design for nuclear instrumentation, followed by a sample-hold circuit.

One further critical step in the construction was the assembly of the silicon detectors and electronics. A stave-like long multilayer-board, 3.5 mm thick, carried on the outer side all the AMPLEX-ASICs (plus a few capacitors) and on

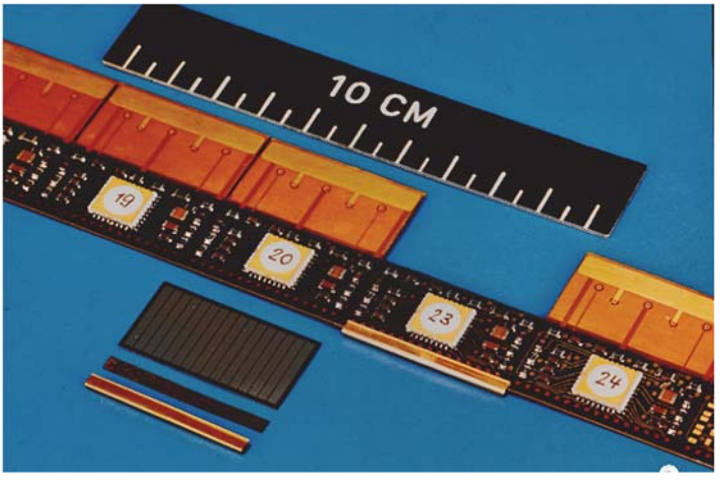

Fig. 6.16. Assembly of the silicon pad sensor and AMPLEX ASIC's on the stave.

the inner side the silicon sensors. The electric contact from the sensor to the multilayer-board was established by a strip of vertically conductive rubber under mechanical pressure of an elastic clip. A similar approach has been later used for the construction of the silicon tracker and vertex of ATLAS and CMS [Highlight 8.6].

The assembled and tested detector boards were positioned on a carbon fibre support, prior to insertion into the UA2 detector (Fig. 6.17). The insertion of the detector was assumed to be a trivial task, until it was realized that the detector diameter was 0.3 mm bigger than the available space of 9 mm. As always, the devil is in the details. The problem was solved by replacing certain capacitors which were out of specification and the Inner UA2 Silicon Pad Detector was successfully installed.

Both UA2 Silicon Pad Detectors performed very reliably during the data-taking from 1987 up to the end of operation at the p–p̄ collider in 1991. The unambiguous two-dimensional tracking information was instrumental for the pattern recognition of the many secondary tracks produced in these p–p̄ collisions. The AMPLEX chip was the first complex readout chip operating inside the sensitive volume of an inner detector and in the direct vicinity of the interaction point.

Fig. 6.17. Insertion of the inner silicon pad detector into the UA2 detector.