CHAPTER 6: PREVIOUS APPLICATIONS OF SILICON DRIFT DETECTORS

6.1 Introduction

The Silicon Drift Detector is a new type of charged particle detection device. The low number of readout channels per active area and the high position resolution achievable makes this technology attractive for high-energy experiments. Depending on the experimental setup, Silicon Drift Detectors are used for different purposes. In a configuration with only one layer, drift detectors serve as hit multiplicity counters, covering a large area with high granularity that allows precise multiplicity measurements in high hit density environments. By using two or more layers, Silicon Drift Detectors can be assembled as tracking or vertex reconstruction detectors. In all applications, an additional advantage of the Silicon Drift Detector is the thin active layer that reduces the probability of multiple scattering and production of background radiation (δ-electrons).

Two relativistic heavy-ion experiments at CERN, NA45 [ref. 6.1, 6.2] and WA98 [ref. 6.3], have utilized Silicon Drift Detectors. Both experiments run in a fixed target configuration, in which circular geometry drift detectors were applied primarily as hit multiplicity detectors, located downstream of the target. In fixed target experiments, the circular geometry is better suited for multiplicity measurements due to its 360° coverage in azimuthal direction around the beam. In a more recent experiment, BNL-AGS/E896, an array of linear Silicon Drift Detectors was used as a tracking device placed inside a high magnetic field to measure the momentum of charged particles. This was the first experiment in which Silicon Drift Detectors were configured as an actual tracking detector.

In this chapter, a brief description of the two CERN experiments will be presented. In the following chapter, experiment E896 and its use of the STAR/SVT Silicon Drift Detectors will be described in more detail, along with results from the beam time and discussion of the detector performance.

6.2 Experiment NA45

6.2.1 Experiment overview

CERES/NA45 is a fixed target heavy ion experiment at the CERN SPS. It is an experiment studying the dilepton pair production (e^+e^-) in relativistic nuclear collisions to probe the possibility of a phase transition in nuclear matter, which might lead to the formation of a new state of matter.

In relativistic heavy-ion collisions, the interaction can be divided into three main stages. First, as the nuclei start to overlap, hard scattering processes between the partons take place redistributing the original beam energy into the internal degrees of freedom. This leads to a system of heated and compressed excited matter. In the second stage, if the temperature and density are sufficiently high, a phase transition occurs and a deconfined system of quarks and gluons can be formed called the Quark-Gluon Plasma (QGP) [ref. 6.4, 6.5, 6.6]. QCD lattice gauge theory [ref. 6.7, 6.8] calculations predict a critical temperature for de-confinement of $T_c \approx 200$ MeV. If the phase transition is not reached a gas of hadrons with high density and temperature is formed, usually referred to as "fireball". In the last stage, assuming Quark-Gluon Plasma formation, cooling of the system leads to the hadronization of quarks and gluons. In the case of the fireball, the hadron gas cools down until its constituents decouple and do not interact anymore. Lepton pairs are produced during all stages of the space-time evolution. Because of their electromagnetic character, they will leave the collision region without undergoing final state interactions, thus probing the very early stages of deconfinement. In addition, lepton pairs created in the interaction region, through the decay of vector mesons will carry the intrinsic characteristics of the medium, which makes lepton measurements a useful tool to study the initial conditions of the reaction.

Low-mass electron pair production in high-energy hadronic collisions has been studied in several experiments. Most of the recent experiments observed a lepton pair yield above the contribution expected from hadronic sources, in certain region of the reconstructed di-lepton mass spectrum. These results triggered intense theoretical activity to explain the unexpected yield. Some of the measured yield has quantitatively been explained as resulting from $\pi\pi$-annihilation, but the most interesting approach considers a broadening of mass peaks in the dilepton spectrum due to the decrease of meson masses, in particular of the ρ-meson, in hot and dense matter as a precursor for the phase transition [ref. 6.9, 6.10]. Lately, theory predicted that some of the excess yield of the dilepton could be accounted for by decays of neutral mesons produced in the reaction. It was shown that part of the apparent enhancement of the dilepton yield, deduced from early experiments, was due to underestimation of the relevant hadron production cross sections, in particular the cross section of the η-meson. Therefore, in order to increase the sensitivity of the dilepton spectrum for possible deviations from conventional sources, experiment NA45 has proposed to study the electron-pair production together with the hadron production to account for the background.

6.2.2 NA45 experimental setup

Figure 6.1 shows a schematic view of the NA45 experimental setup. The experiments main detector, the CERES spectrometer (Cerenkov Ring Electron Spectrometer), is devoted to the measurement of electron pairs. It consists of two

Ring Imaging Cerenkov detectors (RICH) separated by a solenoid superconducting magnet. Two Silicon Drift Detectors were incorporated into the experiment to measure the charged particle distribution and to analyze the event azimuthal anisotropies. In combination with a Pad Chamber detector, located behind the magnetic field, the momentum distribution of the charged particles was obtained, for a pseudo-rapidity range of 2.1 to 2.6, by measuring the azimuthal deflection due to the magnetic field.

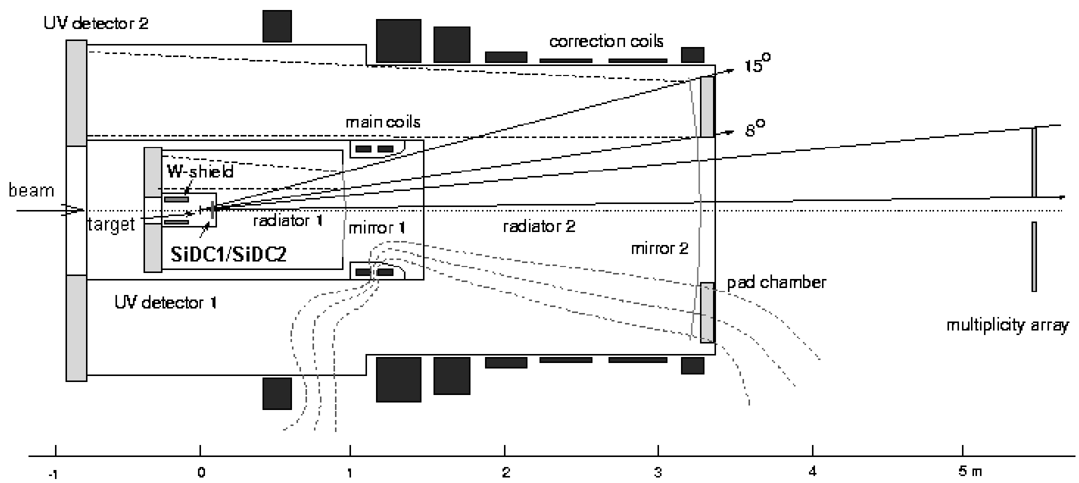

Figure 6.1: *Schematic view of the NA45 experimental setup.*

6.2.3 Silicon Drift Detectors in NA45

A pair of circular Silicon Drift Detectors was used to measure the multiplicity of charged particles and to reconstruct the reaction vertex. The pair of detectors was placed at a distance of approximately *10 cm*, closely spaced, down-stream of the target. A small hole in the center of the detector (*6 mm* diameter) allowed the passage of the non-interacting particle beam. Each detector provided unambiguous position information in radial (r) and azimutal (ϕ) coordinates.

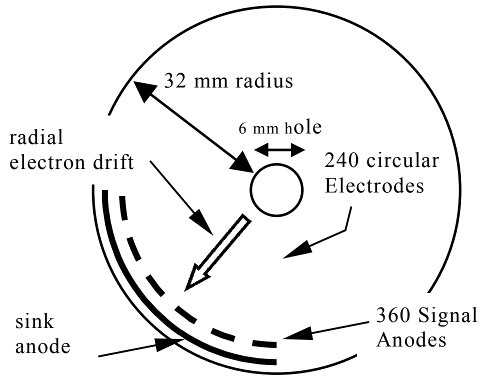

Figure 6.2: *Schematic view of a cylindrical drift detector.*

Figure 6.2 shows a schematic view of a typical cylindrical drift detector design, similar to the detectors used in the NA45 experiment. Electrons created in the detector by traversing charged particles drift radially outward towards an array of 360 anodes located at the periphery of the detector. The drift time determines the radial coordinate (r) and charge sharing between contiguous anodes measures the azimuthal coordinate (ϕ). The basic operation is very similar to a linear drift detector. However in circular drift detectors the charge diffusion in the azimuthal direction is increased by a defocusing component caused by the radial divergence of the drift field. That increases the charge spreading across the anodes by a factor up to three times more than in the case of linear drift detectors. In principle, this effect would improve the position resolution in the azimuthal direction, but at the same time, the total integrated charge collected by each individual anode is smaller, and for low signals it can cause considerable inefficiencies.

The circular drift detector designed for NA45 [ref. 6.11] was expected to have a position resolution better than *40 μm* in each direction. The maximum drift distance was about *3 cm*, and the nominal value of the drift field was *500 V/cm*, resulting in a maximum drift time of *4 μs*. A special feature of this detector was the system designed to drain away surface currents. Leakage currents arising from electrons thermally generated at the Si-SiO_2 interface contribute to the increase of the anode noise. A path for electrons was provided at the detector surface through p+ field electrodes. These electrodes guide the generated electrons from the inner part of the detector to an outer area, where a sink anode is placed. This design feature has proven to reduce the anode leakage current and therefore improves the efficiency and energy resolution of this detector.

Preliminary data analysis from this experiment shows a position resolution of $120\ \mu m$ in the drift direction and $20\ \mu m$ on the azimuthal direction. Anode leakage currents were measured to be below $10\ nA/cm^2$ on average, sufficiently low to yield a good signal to noise ratio.

The circular drift detector performed satisfactory in the NA45 experiment, resolving all charged particles in high multiplicity events with a limited number of readout channels. The pair of detectors allowed vertex reconstruction of more than 98% of all primary interactions. Further detailed information on the performance of the circular drift detectors in this experiment can be found in [ref. 6.12].

6.3 Experiment WA98

6.3.1 Experiment overview

WA98 [ref. 6.3] is a fixed target relativistic heavy-ion experiment at the CERN SPS accelerator, studying collisions of $^{208}Pb+^{208}Pb$ at energies up to $158\ A{\cdot}GeV$. It has a large acceptance for photons and hadrons with the ability to measure several different global observables on an event-by-event basis. Its aim is to sample high statistics of photons, neutral hadrons and charged particles and study their correlation.

Measurements of the inclusive transverse momentum distribution of produced particles and their relative production cross section is known to be a valuable tool in the study of high-energy hadronic interactions. Moreover, since photons interact with particles in the collision region only through electromagnetic interactions, the mean-free path of the photon is expected to be quite large and consequently photons may not suffer collisions after their production. Photon rates and momentum distributions depend on the momentum distribution of the particles in the collision region, therefore, photons carry information on the thermodynamical state of the medium at the time of their production (very similar to the di-lepton probes measured by NA45 described in the previous section). On the other hand, hadrons decouple much later due to the strong interactions and therefore, only provide information about the freeze-out phase of the reaction. By combining information from photons or leptons and from hadrons and comparing with data from proton-proton interactions it is hoped that the development of the heavy-ion system can be reconstructed from the initial state of high density and temperature through the freeze-out phase.

The neutral particle detection in WA98 is focused on identifying π^0 and η-mesons with high precision over an extended transverse momentum range via the two photon decay channel [ref. 6.13]. Due to the high sensitivity for charged and neutral pion production, another interesting topic pursued in this experiment is the search for Disoriented Chiral Condensates (DCC) [ref. 6.14]. The chiral symmetry of the QCD vacuum is believed to be spontaneously broken in nature by the formation of isoscalar quark condensates, when passing from the QCD vacuum into normal vacuum. It was postulated that under certain conditions, it is possible to create small pockets (domains) in the normal vacuum where the chiral symmetry is briefly restored. For example, in high-energy hadronic collisions, a hot shell, expanding at the speed of light, could shield the cool interior from the influence of the normal vacuum outside, allowing an inner core of DCC to form ("Baked Alaska" model) [ref. 6.15]. The DCC has special properties that would allow identification of its formation in high-energy collisions. One characteristic is that the binomial partitioning between the number of charged pions and neutral pions (conservation of isospin) is not preserved because the condensation leads to a preferred direction in the specific vacum domain. This effect manifests itself in an isospin preference for the ground state of matter, namely the pion. In other words, the ratio $N(\pi^0)/[N(\pi^0)+N(\pi^+)+N(\pi^-)]$ will deviate from 1/3 [ref. 6.16].

By comparing the ratio of the production of charged particles and neutral particles on an event-by-event basis, WA98 was the first CERN experiment to perform a DCC search. No events with large fluctuation in the charged-neutral ratio were observed. These results are in accordance with the MINIMAX experiment at FERMILAB [ref. 6.17]. Comparing the data to a model calculation, WA98 has set a 90% confidence level upper limit on the frequency of the DCC production as a function of its size.

6.3.2 WA98 experimental setup

Figure 6.3 shows the experimental set-up used in WA98. Neutral mesons (π^0 and η-meson) are measured through the photon decay channels, using the Photon Multiplicity detector (PMD). Charged particles are measured with a combination of Silicon Drift Detectors and Silicon Pad Detectors (SPMD).

The Photon Multiplicity Detector (PMD) situated 21.5 m downstream from the target, is composed of several module boxes each with a matrix of 50 × 38 photon detection pads. Photons impinging on the detector are converted in a 3.34 X_0 thick lead and iron converter and the secondaries are detected in a *3mm*-thick plastic scintillator. Each detection pad is connected through fiber optic to an image intensifier and a CCD camera for signal readout. Hadrons that hit the PMD detector create an undesirable background, however photons and hadrons interact differently in the PMD pads, which allows us to distinguish photon hits from hadron hits. In addition, the photon energy is measured in a finely segmented electromagnetic Lead Glass spectrometer downstream of the PMD. The combined system yields high precision data on π^0 and η-mesons at mid-rapidity in a large range of transverse momentum.

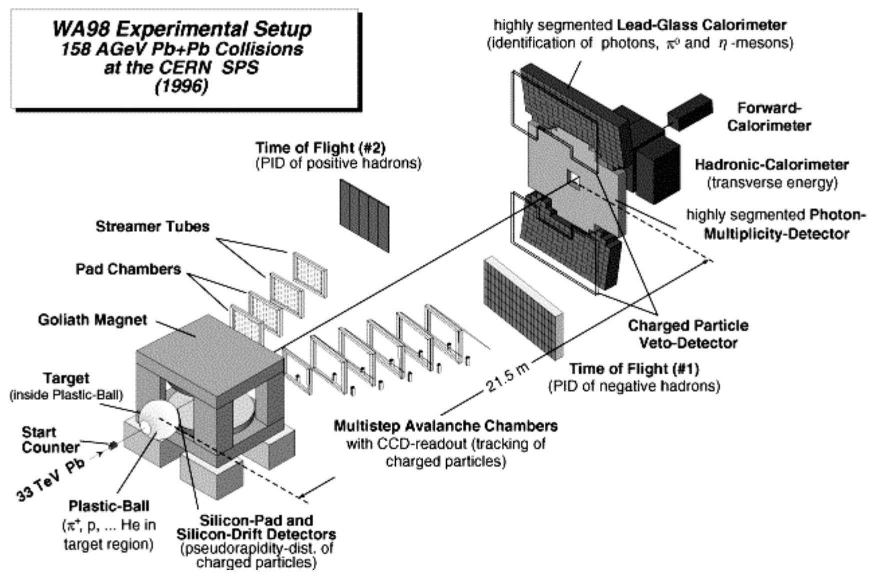

Figure 6.3: *Experimental set-up of WA98 at CERN SPS. Silicon Drift Detectors and pad detectors were used for multiplicity measurements.*

The charged particle multiplicity is measured by Silicon Drift Detectors and Silicon pad detectors placed just downstream from the target. The momentum of each charged particle is measured by two spectrometers placed behind the silicon detectors, on each side of the beam; a multi-step Avalanche Chamber tracking system and a Pad Chamber/Streamer Tube tracking system. The silicon detectors improve the overall charged particle tracking. A Time-of-Flight system is used for particle identification.

The Silicon Drift Detectors used in this experiment had the same geometry and specifications than the Silicon Drift Detectors used in the experiment NA45. Further information about WA98 can be found in reference 6.3 and 6.18.