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A DOUBLET OF 3" CYLINDRICAL SILICON DRIFT DETECTORS IN THE CERES/NA45 EXPERIMENT

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Abstract

We report on the performance of a doublet of 3" cylindrical silicon drift detectors installed as an upgrade of the CERES/NA45 electron pair spectrometer for the Pb-beam at the CERN SPS. The silicon detectors provide external particle tracking and background rejection of conversions and close Dalitz pairs. Results on vertex reconstruction and rejection from a Pb test-run in 1994 are presented.

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Introduction

Electron pairs (e^+e^-) are considered a unique probe of the hot and dense matter produced in ultra-relativistic A-A collisions. Of electromagnetic origin, they obey the Stefan-Boltzmann law for the emission rate and leave the interaction zone freely. However, they are also extremely rare compared to the enormous number of hadrons produced in the fireball ($e^+e^-/\pi^\circ \approx 10^{-5}$). Moreover, there is a huge background of pairs only slightly opened, originating from late decays of free hadrons, from π° Dalitz decays as well as from conversions of ubiquitous photons ($\pi^\circ \rightarrow 2\gamma$) in the target and detector material.

The CERES/NA45 experiment has succeeded to measure low-mass electron pairs in proton and sulphur induced collisions at the CERN SPS [1] with a double ring-imaging Cherenkov (RICH) spectrometer. For S-Au collisions, with a charged particle density of $dn_{ch}/dy \approx 160$ in central collisions, the signal-to-background ratio was marginal. Elaborate algorithms for finding the Cherenkov rings and for rejection of close pairs had to be supplemented by the powerful ability of a silicon-drift detector (SSD) to reject those pairs not recognized in the RICHes as well as fictitious pairs of electron tracks not originating from a common vertex.

For our future experiments at the 160 GeV/u Pb beam, characterized by central charged particle densities of $dn_{ch}/dy \approx 500$, the addition of an external particle tracking is absolutely mandatory to reduce the much higher background arising from combinations of electron tracks belonging to close but unrecognized pairs. Furthermore the SDD-doublet increases the ring finding efficiency by pointing at ring center candidates in the first RICH detector.

As a major upgrade of the CERES spectrometer, a doublet of improved SDD's has been implemented to serve as a stand-alone vertex detector. Here, we report on a first successful test with Pb beam in fall 1994 [2].

Silicon Drift Detectors in the CERES Experiment

The detector principle is known since long [3]. As truly two-dimensional devices with excellent spatial resolution, SDDs are free of ambiguities in hit location even when exposed to the extreme particle densities encountered in ultra-relativistic heavy-ion collisions. Compared to pixel devices, their high-end competitors, they allow fast readout with modest electronics.

CERES by now has accumulated five years of pioneering experience in the design and production of cylindrical drift detectors [4] and in operating them in the environment of a large-scale experiment [5]. Cylindrical symmetry was chosen to comply with that of the RICH detectors; it brings the benefit to apply the high voltages for the drift field without a guard structure. The first generation of detectors, which was used during the proton and sulphur runs, was highly successful. It's main design features were 360 n^+-implanted charge collecting anodes on the outer periphery of a 3" wafer, intrinsic voltage dividers p^+-implanted on each side of the wafer, and the collection of surface leakage currents in sink anodes.

However, in the first generation of detectors the azimuthal resolution was deteriorated by deviations from a strictly *radial* geometry of the 'field cage'. Due to layout constraints the field rings had to be approximated by concentric regular polygons on both surfaces of the detector with sides that span 3°. This 120-fold symmetry of the field resulted in a higher charge collection to one third of the anodes, those in the center of a 3° segment, the remaining two thirds, those at the segment edges, received a substantially smaller portion [6]. For the second generation of 3"-detectors[1], which were installed for the lead beam in 1994, this was overcome by rotating the front lithography masks by 1.5° with respect to the back lithographies, resulting now in a well approximated radial drift field inside the depleted silicon, where the generated charge moves towards the anodes.

A sensitive measure of the deviations from radial symmetry is the transverse electric field, deflecting the electron cloud sideways. Using the program of Castoldi and Gatti, applying a closed-form solution of the 3-D Poisson equation presented at this Conference [7], we have calculated the tangential fields for one sector, as shown in Fig. 1, for the detectors with and without rotation. The maximum transverse electrical field of $6{\cdot}10^{-2}$ V/μm ($\approx$ 1% of the longitudinal drift field) is reduced by a factor of 6 due to the rotation (Fig. 1). Laser tests indeed show uniform charge collection on all anodes.

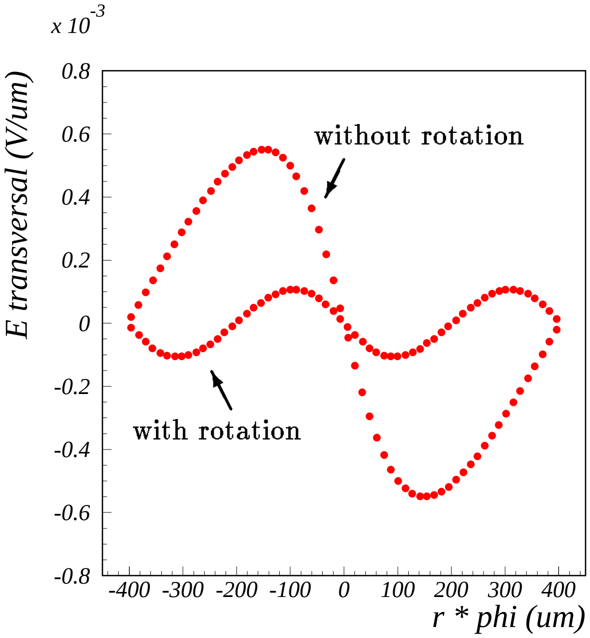

Figure 1: Transverse electrical field plotted vs the transverse coordinate ($\pm 400\mu$m $\equiv \pm 1.5°$, zero corresponds to the border of two neighbouring 3°-sectors) at radius r = 15.4 mm. Due to the 1.5° rotation of front vs back lithographies, the transverse field is reduced from $6{\cdot}10^{-2}$ to $1{\cdot}10^{-2}$V/μm.

Experiment at the Pb Beam

The target used for the Pb beam is segmented into 8 individual disks of 600 μm diameter and 25μm thickness, separated along the beam direction by 2.9 mm. This way, a high interaction length is maintained, while the radiation length for photons entering the spectrometer acceptance is kept low ($X/X_\circ$= 0.37%). The SDD doublet is situated in the inner part of the spectrometer, about 9 cm behind the segmented target, and covers the full spectrometer acceptance of 8° to 15° for all target disks. Both SDDs are traversed by about 600 minimum ionizing particles in central Pb-Pb collisions. The detector setup within the spectrometer is shown in Fig. 2. The spacing between the two detectors was chosen to compromise between a sufficiently long lever arm to point to the vertex and a sufficiently low confusion of tracks due to multiple scattering in the first detector.

Electrical pickup was a severe problem of the old setup, which required a high detection threshold resulting in a loss of efficiency. We have employed the 32-channel bipolar

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[1] produced by SINTEF, 0134 Oslo 3, Norway

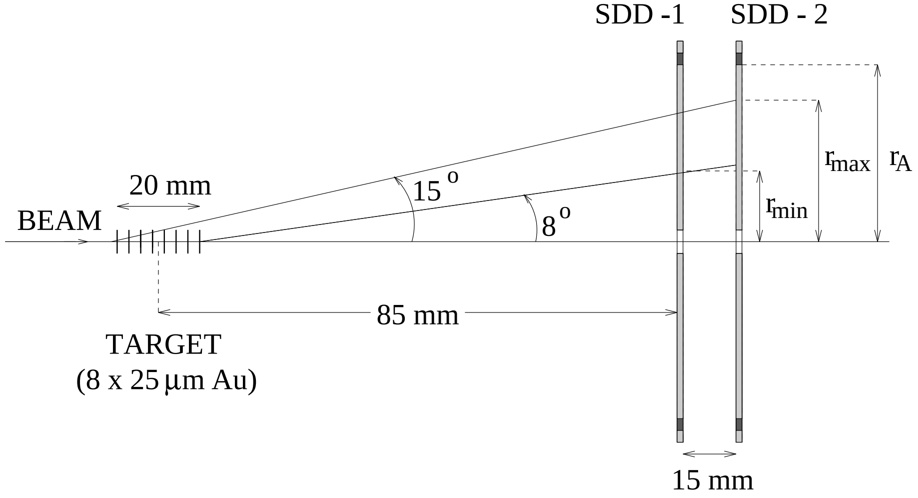

Figure 2: Schematic drawing of the cylindrical SDD doublet covering the full acceptance of the Ring Imaging CHerenkov (RICH) counters (to the right, not shown), setup 1994.

preamplifier/shaper (OLA chip) developed for future silicon drift detector applications in the ALICE experiment [8]. The readout is fully based on complementary signals, which completely removes electrical pickup and allows to set a low detection threshold. The power consumption of this new front end chip is only about 2.3 mW/channel, a factor of 10 less compared to the former hybrid electronics. However, the operation of the full system with 1.8 m of 60 Ohm terminated flat cables was accompanied by a lack of stability. In order to suppress oscillations, we had to choose a mode, which caused some deterioration of the dynamic range as well as the pulse shape.

The time constant of the semi-Gaussian shaper was measured to be $\sigma^t_{elec} = 42$ ns, about twice the design value foreseen as an optimal compromise between the competing requirements of good double-pulse resolution and low ballistic deficit. By the latter we describe the loss of signal amplitude at the output of the shaper with increasing drift time, due to the diffusive broadening of the charge cloud.

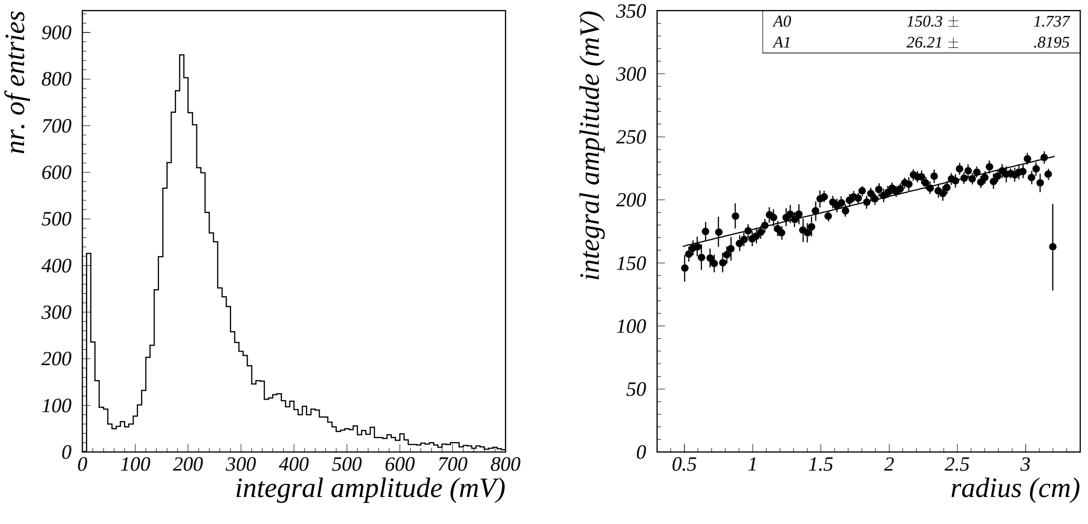

Figure 3: Left: Amplitude (Landau) distribution of hits in SDD-1 with radius > 1.5 cm. Right: Amplitude of hits vs. the radial position (ballistic deficit).

An amplitude distribution of minimum-ionizing particles reconstructed in SDD-1 – mostly pions – is depicted in Fig. 3 (left). Hits of low amplitude are due to soft X rays. The ballistic deficit with the new amplifier was reduced to less than 30%, over the full range of radial drift (Fig. 3 right). The small ballistic deficit guarantees high detection efficiency also for hits in the inner part of the detector.

Figure 4 demonstrates the quality in the reconstruction of interaction vertices using all charged particle tracks without recourse to any sophisticated hit algorithms: the positions of the 8 disks of the segmented Au target are perfectly resolved along the beam line (Fig. 4 left). The lateral xy-position distribution of the reconstructed vertices (right side) reflects the folding of the beam profile with the extension of the target disks (600 μm diameter), indicated by the circle. The vertex reconstruction efficiency is very high; more than 98% of the target interactions have a reconstructed vertex.

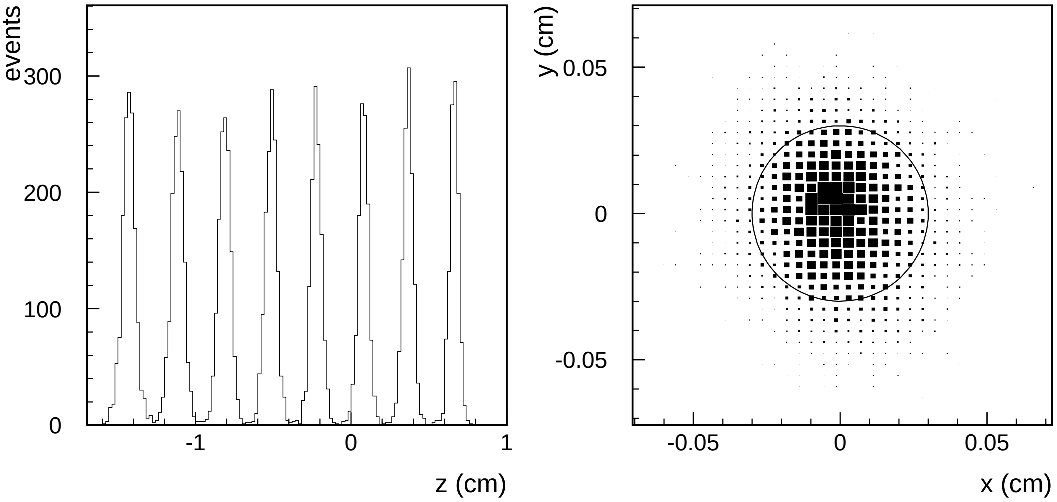

Figure 4: Determination of the interaction vertices with the doublet of silicon drift chambers: distribution of reconstructed vertex positions *along* the beam axis showing the resolved 8 Au target disks of 25 μm thickness each (left), and the distribution of the *lateral* xy-position of the reconstructed vertices (right), reflecting the beam profile folded with the target disks of 600 μm diameter (marked as a circle) and the reconstruction resolution.

The position resolution measured with charged particle tracks is displayed in Fig. 5. The values quoted in the figure represent the dispersion in SDD-1 for tracks defined by the interaction vertex and a hit in SDD-2. They result from the combined effect of the intrinsic resolution of the detectors, the accuracy in vertex reconstruction and multiple scattering. We notice the very good azimuthal resolution, considering the 17 mrad pitch of the anode structure, which results from charge sharing of single hits among several anodes due to diffusion. Laser tests showed excellent position resolution of better than 2 mrad in the azimuthal direction, and of 20 μm in the radial direction.

Rejection of close e^+e^- pairs from photon conversions and π° Dalitz decays is the major task for the silicon drift detector telescope. Their signature is a double-d$E/$dx signal or a close double hit. For the rejection the correlated information of both detectors is used. Figure 6 illustrates some first results. The left side shows the correlation of the analog signals measured in the two silicon drift detectors from identified tracks; these are mainly single tracks with measured signal amplitudes that correspond to minimum ionizing particles; they must not be rejected. The right-hand side of Fig. 6 shows the same

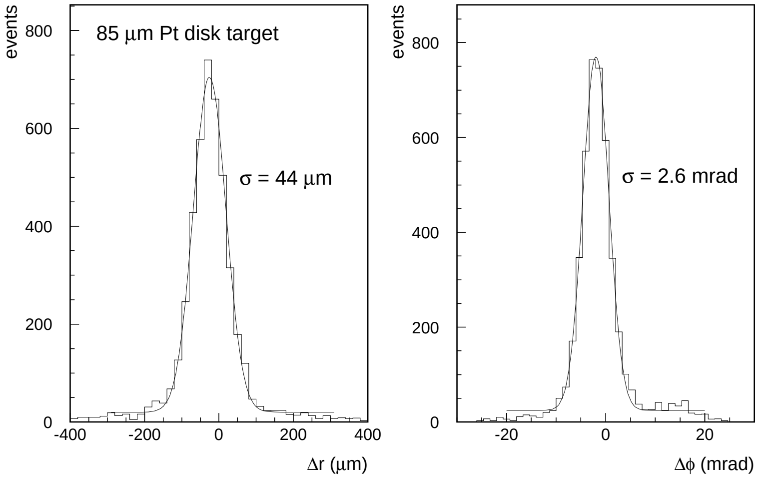

Figure 5: Position resolution of the silicon drift chambers: radial and azimuthal residuals in SDD-1 for tracks defined by the interaction vertex and a hit in SDD-2 for a 85μm single disk Platinum target.

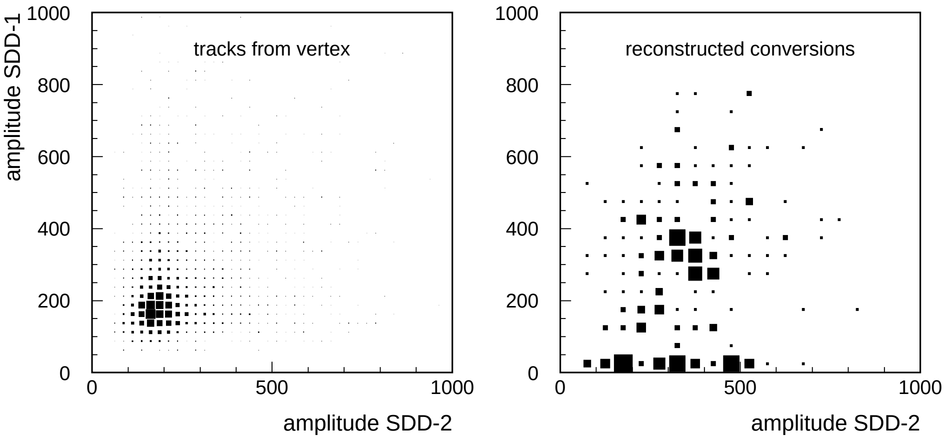

Figure 6: Distributions of dE/dx in SDD-1 vs. SDD-2 for all tracks pointing to the vertex (left), and for a sample of reconstructed conversions (right), exhibiting double-dE/dx.

correlation for a sample of conversions identified in the RICHes.

A large number of hits with double-dE/dx signals in both silicon detectors are clearly visible. One also observes a second class of events with no signal in SDD-1 and a large amplitude spread in SDD-2, corresponding to conversions in material between the SDDs and within the second detector. Late conversions behind SDD-2 (not shown) can be rejected by the absence of hits in both detectors. These figures demonstrate only part of the rejection power; an additional double-hit recognition will further improve it.

Conclusion

CERES expanded its use of Cylindrical Silicon Drift Detectors (SDD) in order to maintain its ability to measure rare electron pairs in the hadron-dense environment of Pb-Au collisions. A doublet of 3" SDDs replaced the single 3" SDD used in the proton/sulphur era and acts as a vertex detector for external tracking at the entrance of the CERES spectrometer. New integrated readout chips were implemented. Clean signals free of pickup and a low detection threshold together with moderate ballistic deficit assure high detection efficiency. The observed instabilities of the chips will be cured by a new design of the preamp/shaper unit with enhanced driving capability at the expense of lower gain.

The strategy at production stage, to engineer a better radial symmetry of the drift potential by rotating front vs. back lithographies, succeeded in uniform charge collection, and improved the azimuthal hit resolution considerably. First results from a 160 GeV/u Pb-Au test run in 1994 prove an excellent vertex finding efficiency with the expected longitudinal and lateral resolution and the capability to reject close electron pairs.

A new generation of 4" detectors uses a novel interlaced anode structure, which forces charge division among several anodes also for short drift times in order to improve the azimuthal resolution for the outer part of the detector. The design of the new SDD uses 360-fold symmetry for the field structure; front lithographies are rotated by 0.5° with respect to the back lithographies. Both measures will reduce the transverse electrical field by two order of magnitudes compared to the original 3" design. The novel 4"-detectors, presently in a new production, are the subject of a contribution by P. Rehak to this conference [9].

Acknowledgements

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