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ACCURACY OF ELECTROMAGNETIC SHOWER POSITION DETERMINATION BY A WIDE-GAP DRIFT CHAMBER

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I. Introduction

To increase spatial resolution of homogeneous electromagnetic calorimeters, one may use an additional coordinate detector placed behind an active converter [1-3]. A high accuracy of the electromagnetic (e.m.) shower position measurement is required in many experiments, first of all, at high energy reactions where γ-quanta appear with small angles. The improvement of spatial resolution of the e.m. calorimeters is the aim of many scientific groups (e.g. [1-4]).

It turns out that the best spatial resolution can be achieved by wide-gap drift chambers (WDC) [1,4]. Therefore, for a lead glass Čerenkov shower detector (SD) with an aperture ~ 1x2 m^2 consisted of lead glass blocks 100x100x350 mm^2 which is part of the spectrometer "Hyperon" [5] built by JINR-IHEP we are constracting an active converter 1x2 m^2 and large wide-gap drift chambers with sensitive area 1 m^2, that overlap the SD aperture.

This paper presents the results of measurements on a smaller SD with aperture 0.2 m^2 in the 3 GeV positron beam. We have used two different types of electronics with WDC: a) a flash analog-to-digital converter (FADC) [6], b) a multi-hit time-to-digital converter (MHTDC) [9].

In this paper the spatial resolution obtained by the MHTDC method is compared with that obtained by various algorithms of data processing in the FADC method.

We also present here the radial charge distribution in the e.m. shower for various depths in lead glass obtained by WDC.

II. Experimental set-up

The experiment was carried out at channel No. 18 of the IHEP (Serpukhov) accelerator. The scheme of the set-up is shown in Fig. 1. The trigger was obtained by means of three scintillation counters $S_1S_2S_3$ and threshold Čerenkov counters $C_1C_2C_3$ selecting positrons with momentum 3 GeV/c. The extra scintillation counters S_4 and S_5 1 mm wide form a narrow beam; they have been adjusted with an accuracy 0.1 mm.

The experimental set-up includes: an electrodeless drift chamber [7] DC-2 placed behind (at 1cm) the active converter (AC)

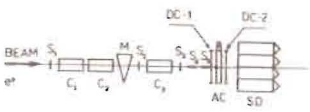

Fig. 1. Experimental set-up. M-electromagnet.

made of lead glass blocks TF-1-000 (radiation length X_0 = 2.5 cm), an electromagnetic calorimeter (SD) consisting of 12 elements of the same lead glass blocks (10x10x35 cm^3). An electrode drift chamber /8/ DC-1 (20x30x2 cm^3) with one sense wire 0.02 mm in diameter, the drift length 10 cm, has been used for measurement of the beam positron coordinate. The converter thickness in measurements varied within 1,2,3 and 4 radiation lengths. Information on the energy E_{SD} deposited in SD and E_{AC} in AC was used to control if the incident particle is a positron. The required energy $E_{SD}+E_{AC}$ should be equal (within the resolution of SD $\Delta E/E \sim 6\%$) to the initial positron energy $\sim$ 3 GeV.

The "electrodeless" drift chamber DC-2 (20x30x2 cm^3) with one sense wire 0.03 mm in diameter, drift length 10 cm was used for determining the coordinate of e.m. shower axis. The shower detector was also used to remove the left-right ambiguity of coordinates measured by the drift chambers. The wires of DC-1 and DC-2 were put vertically, one after another, parallel to the boundary of SD blocks. The coordinate sign is defined by a higher energy deposite on the right or left side of the SD.

Mixture of 82% argon and 18% isobutane was used in the drift chambers. In this mixture the saturation of the drift velocity is achieved at the electric field $\sim$ 500-700 V/cm. A potential U = 7 kV was applied to DC-2 (the drift length l = 10 cm), while in DC-1 a potential +1.5 kV on sense wire and -6 kV on the cathode was used.

In Fig. 2 the block-diagram of electronics for DC-2 is shown. When e.m. shower passed DC-2, signals from the anode wire come within 2 μs to the amplifier A (with an amplification 0.16 V/pC). After that the signals are formed in the "Gaussian" filter (GF) with a time constant $\tau \sim 70$ ns. Therefore the signals from close electrons and positrons inside the shower are integrated into one signal with a large amplitude. Further the signal was devided and fed into two different electronic blocks.

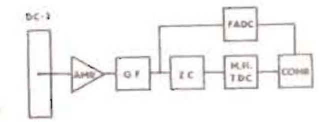

Fig. 2. Block-diagram of the electronics: AMP - amplifier, GF - Gaussian filter, ZC - zero crosser.

The first method. Signals from GF were fed to FADC /6/ that every 64 ns measures the input charge and records

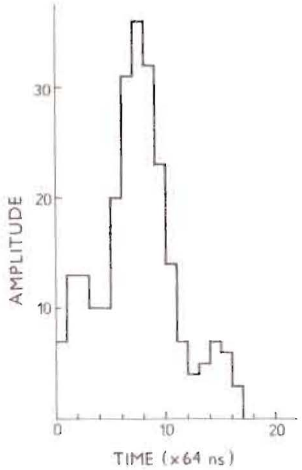

Fig. 3. Spectrum of a typical radial charge distribution of e.m. shower in DC-2 obtained by FADC.

it in the buffer memory. In this way, we get a charge distribution histogram of the shower in DC-2 with the 64 ns steps (which corresponds to 3 mm in space). A typical shower charge distribution in DC-2 obtained by FADC is plotted in Fig. 3. Here the shower axis coordinate was at a distance $\sim$ 2.5 cm from the DC-2 wire. In Fig. 3 one can see a central part of the e.m. shower formed by a dense jet of conversion electrons and also a peripheral component of the shower.

The second method. Signals from GF went to a zero crosser (ZC) which determind the time of the maximum of the input signal. Further, the MHTDC with the 64 ns dead time measured the position of those maxima with an accuracy $\sim$ 1 ns.

III. Spatial resolution

Spatial resolution of the e.m. shower coordinate measurement was determined from distributions of quantities $\Delta X = X_1 - X_2$, where X_1 is the coordinate of a beam positron measured by DC-1, and X_2 is the coordinate of the shower axis calculated from the charge spectrum of DC-2.

Let us discuss the methods of shower coordinate determination. Most authors take, as the shower coordinate, the position of the center of gravity of a transversal charge distribution (Cobb et al. /2/, Rameika et al. /3/, Akopdjanov et al. /10/). Others /10/, taking into account the exponential fall-off of the transversal charge distribution, approximate the shower transversal profile by exponents and as the shower coordinate they take the position of maximum of the charge distribution.

In our case X_2 was obtained by four different methods.

Method TDC /1/. Information about all maxima (above the threshold) of charge distribution across the shower came from MHTDC (see the preceding section, method 2). When only one signal came from MHTDC it was just used for determining the shower axis coordinate. But if two or more signals came from MHTDC, as the shower coordinate we took the coordinate nearest to the one determined from the energy distribution in SD.

Method ADC-center of gravity. Information on the shower profile came from FADC (see the preceding section, the first method), the shower coordinate was counted as the center of gravity of charge distribution in ADC:

$$X_2 = \sum_i A_i X_i \Big/ \sum_i A_i \,, \qquad (1)$$

where A_i is the amplitude of the signal in the i-th time interval of FADC (i = 1,2,...,256), and X_i is the coordinate in DC-2 corresponding to the interval i.

Method ADC-maximum. Information on the shower came from FADC. Shower coordinate was taken as FADC channel X_i with the maximum value of A_i.

Method ADC-weighted maximum. The coordinate X_i corresponding to the maximum value of ADC spectrum A_i was found. The shower coordinate was found as:

$$X_2 = \sum_{i-2}^{i+2} A_i X_i \Big/ \sum_{i-2}^{i+2} A_i \,. \qquad (2)$$

When showers went throughout the whole chamber area spatial resolutions were found from distributions of values $\Delta X = X_1 - X_2$. These distributions are shown in Fig. 4 for all the above-listed methods, obtained at the converter thickness $4X_0$. Each distribution is approximated by a Gaussian with a FWHM equal to its experimental value. Note that ADC - w.m., ADC - max., TDC methods give a similar resolution as they are based on the determination of the charge distribution maximum in DC. The space resolutions presented in this paper do not take account of the beam angular divergence and the in-

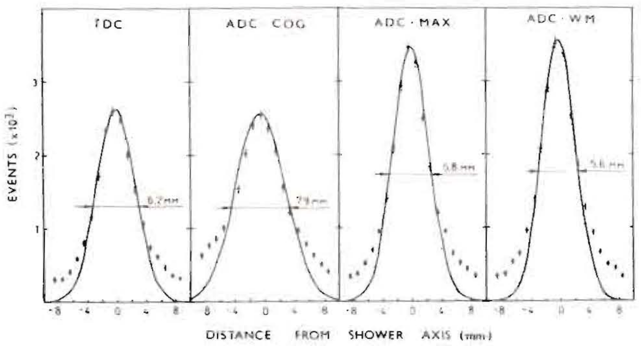

Fig. 4. Distributions of ΔX found by different methods at the converter thickness $4X_0$.

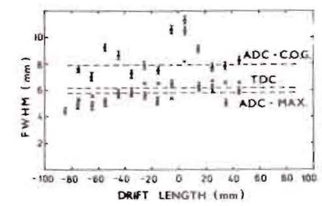

Fig. 5. Spatial resolutions σ for e.m. showers in 1 cm intervals of DC-2. o – method ADC-c.o.g., x – method TDC, • – method ADC-max.

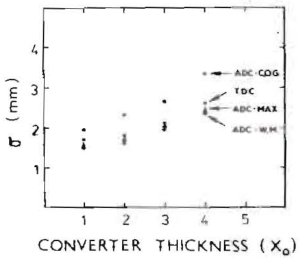

Fig. 6. Dependence of the spatial resolution δ on the converter thickness.

trinsic resolution of DC-1 and DC-2 ($\delta_x \sim 0.3$ mm for single particles /7,8/).

In Fig. 5 spatial resolutions σ are shown (FWHM from Fig. 4) obtained by TDC, ADC - c.o.g. and ADC - max. methods in 1 cm intervals of DC-2; measurements were done with a wide positron beam (~15 cm). Despite some fluctuations it may be noted that the best resolution is achieved by ADC-max.method, while the worse by ADC-c.o.g.

The resolutions σ (see Fig. 5) in parts near the chamber wire are worse than the mean value over the chamber. Its origin is in an incorrect determination of the coordinate sign for particles passing near the wire. This sign is defined by means of SD. Thus, if a shower passed near the wire, then e^+e^- of the e.m. shower will with a large probability pass both to the left and to the right of the DC-2 wire. However, we will put all the tracks into one side of the DC-2. In the processing this will shift X_2.

The space resolutions $\delta = \sigma/2.36$ for the whole chamber area (except for the interval (-5,15) mm near the wire) are shown in Fig.6 as a function of the converter thickness. From Fig. 6 it is seen that the resolution obtained by ADC - w.m., ADC - max. and TDC methods are similar and noticeably differ from those obtained by ADC - c.o.g. method. Consequently, the experiment shows that the determination of the shower axis coordinate from the charge distribution maximum is more accurate than that by the center of gravity. Similar results were published by the IHEP group /10/ who obtained the resolution $\delta \sim 3$ mm by the center of gravity method, while taking into account the exponential fall-off across the e.m. shower they got $\delta \sim 2$ mm at an electron energy ~ 25 GeV. These data point to strong correlations between the direction of motion of an initial particle and that of a central jet of conversion electrons and positrons with high particle density.

Table I. Spatial resolution at the converter thickness $3X_0$:

Method	Resolution δ , mm
ADC - w.max.	1.9 ± 0.1
ADC - max.	2.0 ± 0.1
TDC	2.1 ± 0.1
ADC - c.o.g.	2.6 ± 0.1

It should be mentioned that the presented values of δ are not corrected for angular divergence of the beam. To our estimate the corresponding correction will improve the values of δ by 0.2-0.3mm.

It is seen that a simpler TDC method provides a resolution that is practically as good as the one obtained by ADC. We stress, however, that the methods based on ADC do not require an additional determination of the coordinate in SD and allow the measurement of coordinates of two close showers registered by one wire of the drift chamber. By our estimate the two-shower resolution is not worse than 3 cm.

IV. <u>Radial charge distribution at different shower depths</u>

Figure 7 shows the transverse charge distribution of the e.m. shower at the converter depth 1,2,3 and 4 X_0 obtained by DC-2. It is seen that the distributions can be described by a sum of two exponents:

$$Y(x,t) = c_1 \exp[-|x - x_a|/\lambda_1(t)] + c_2 \exp[-|x - x_a|/\lambda_2(t)] . \qquad (3)$$

where x_a is the coordinate of the shower axis, λ_1 and λ_2 are the attenuation lengths for the central and peripheral parts of the e.m. shower respectively, t is the shower depth (in radiation lengths X_0).

The radial charge distribution of the shower via two exponents is described by various authors - Iwata /11/ and Akopdjanov /10/. The attenuation length λ_1 (for the central component of the shower) is mainly due to the narrow angular distribution and also to subsequent multiple scattering of electrons and positrons in the shower, while λ_2 (for the peripheral component) is due to the isotropic propagation of photons with a minimal absorbtion cross section. On the other hand, the groups from IHEP /12/ and FNAL /3/ described the e.m. shower profile only by one exponent.

In measurements of radial charge distributions at different shower depth we would like to exclude all systematic effects caused by the drift chamber. We have already spoken about distortions of signals near the DC-2 wire. Because of that we exclude the interval ± 40 mm around the wire. Besides, it is also necessary to exclude the showers detected near the walls, as part of these showers is beyond the chamber. We accepted for shower profile calculations only the showers from the interval [40, 75] mm.

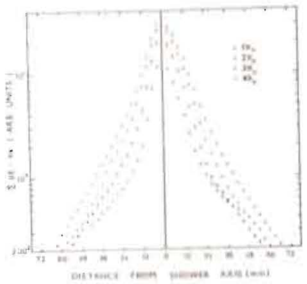

Fig. 7. Radial charge distribution of e.m. showers in DC-2, E=3 GeV, at the lead glass depth $1,2,3,4X_0$.

Note that the distributions shown in Fig. 7 are asymmetric, which is due to the shape of the output signal from the amplifier whose leading edge is more steep than the fall-off. This effect was also observed by the CERN group /4/.

So, the left parts of the charge distributions (see Fig. 7) will be considered undistorted by systematic errors, and they will be employed for determination of the constants in (3). The left parts of transverse charge distributions of the e.m. shower in DC-2 from the interval [40, 75] mm are drawn in Fig. 8. Solid curves were computed according to formula 3. The values of parameters $\lambda_1(t)$ and $\lambda_2(t)$ are shown in Table II.

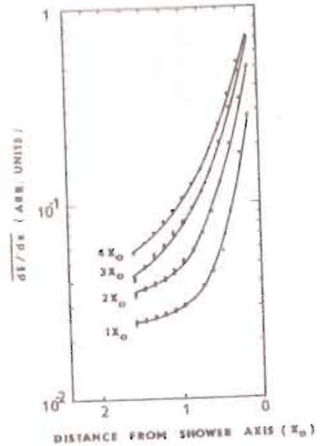

Fig. 8. Radial charge distributions of e.m. showers with E=3 GeV at the lead glass depth $1,2,3,4X_0$.

Table II.

$t(X_0)$	λ_1(mm)	λ_2 (mm)
1	4.4 ± 0.3	218 ± 36
2	5.6 ± 0.3	177 ± 77
3	6.2 ± 0.5	44 ± 5
4	6.9 ± 0.5	48 ± 3

The function $\lambda_1(t)$ is plotted in Fig.9 and is compared with $\lambda_1(t)$ obtained in /12/ for showers from 32 GeV electrons in lead and with λ_1 and λ_2 found in /10/ for showers from 25 GeV electrons in lead glass TF-1.

From Fig. 8 and Table II it is seen that the two-exponent description of the transverse charge distribution evolves

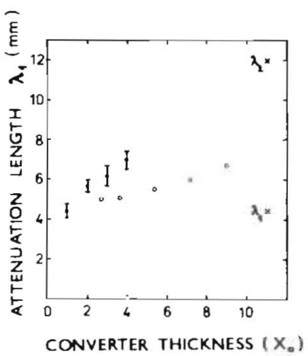

Fig. 9. Attenuation length λ_1 as a function of the converter thickness: Ī – the present paper, o – Bushnin /12/, x – Akopdjanov /10/.

to the one-exponent description with the increase of the converter thickness.

Conclusion

1. By using a wide-gap drift chambers high spatial resolutions δ have been achieved in determining the shower coordinates for the positron energy 3 GeV and the converter thickness $3X_0$. Without account for the beam angular divergence the spatial resolution δ is:

δ = 1.9 ± 0.1 mm with the use of FADC

δ = 2.1 ± 0.1 mm with the use of MHTDC

2. Resolutions δ found with the use of e.m. shower maxima exceed those obtained by the center of gravity method.

3. Transverse charge distributions of the e.m. showers for $t = 1,2,3,4X_0$ in lead-glass were measured with the use of a wide-gap DC. They could be described by two exponents.

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Улучшение точности определения координат электромагнитных ливней с помощью широкозазорной дрейфовой камеры

С помощью широкозазорной дрейфовой камеры, размещенной после активного конвертера, определялись координаты электромагнитных ливней с энергией 3 ГэВ. Сравниваются различные методы обработки с помощью ВЦП с малым мертвым временем и с помощью модуля квантования сигналов с быстродействующими АЦП. Достигнуто пространственное разрешение 1,9 мм /с.к.о./ при толщине конвертера $3X_0$. Приведено поперечное распределение заряда э.м. ливня на разных глубинах его развития в свинцовом стекле.

Работа выполнена в Лаборатории ядерных проблем ОИЯИ.

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Accuracy of Electromagnetic Shower Position Determination by a Wide-Gap Drift Chamber

The electromagnetic shower position was measured by a wide-gap drift chamber placed behind an active converter. Different methods for the shower-position determination based on MHTDC and flash ADC were used. Spatial resolution 1.9 mm /r.m.s./ at an energy 3 GeV and converter thickness $3X_0$ was achieved. Transversal charge distribution at different depths of the e.m. shower in the lead glass was measured.

The investigation has been performed at the Laboratory of Nuclear Problems, JINR.

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