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First Results of the ITC/TPC Alignment from the 1991 Cosmics Run

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Abstract

This note presents the first results on the relative alignment of TPC and ITC measured with cosmic events recorded in March 1991. The results for the position of the ITC are in good agreement with this year's survey, while the imperfections of the TPC agree with the 1989 measurement.

1 Introduction

From 31789 cosmic events recorded in March 1991, 1334 tracks crossing the inner tracking chamber (ITC) and the time projection chamber (TPC) were used to determine the relative alignment constants for these detectors. Additionally imperfections inside the TPC were measured. The results for the alignment are in good agreement with this years survey [FO 91], while the imperfections of the TPC agree with previous measurement [RO 89].

The geometrical alignment of ITC and TPC by mechanical means is known to a few 100 μm. We reach a higher precision in the r-ϕ plane by using tracks from cosmics crossing both detectors due to a better position resolution of 180 μm for the TPC and 150 μm for the ITC [AL 91]. As the resolution in the r-z plane of the ITC is in the order of cm, no improvement can be made there.

The numbers from the alignment with cosmics are used for the 1991 reconstruction in JULIA.

2 Alignment

The fundamental equations and the method for aligning ITC and TPC are described in detail in previous notes [FO 87,RO 88].

Assuming only small deviations from perfectly aligned bodies, the relative positions between two rigid bodies can be described in a cartesian coordinate system by six parameters: three linear offsets along the axes δX, δY, δZ and three rotation angles $\delta\Psi$, $\delta\Omega$, $\delta\Phi$, respectively.

To determine misalignment, track parameters are measured independently in ITC and TPC. These parameters are D_0, the distance of closest approach of a track to the primary vertex in the r-ϕ plane and the angle Φ_0 of a track with respect to the x-axis at D_0 (the TASSO convention is used). The differences between these values as measured in ITC and TPC can be expressed in terms of the alignment parameters [FO 87],

$$\Delta D_0 = (\delta X + Z_0 \delta\Omega) \cdot \sin\Phi_0 - (\delta Y - Z_0 \delta\Psi) \cdot \cos\Phi_0 \qquad (1)$$

and

$$\delta\Phi = \Phi_0^{TPC} - \Phi_0^{ITC} + \tan\lambda \cdot (\delta\Omega \sin\Phi_0 - \delta\Psi \cos\Phi_0) \,, \qquad (2)$$

where λ is the angle of a track with respect to the vertical measured in the r-z plane (dip angle). Z_0 and Φ_0 are taken from TPC measurements, since the TPC has a better z resolution and a longer lever arm than the ITC.

Equation (1) yields four alignment parameters, the two offsets δX, δY and the angles $\delta\Psi$, $\delta\Omega$. The remaining fifth parameter $\delta\Phi$ is given by equation (2). Both equations are nearly decoupled.

In the above only the geometrical misalignment between ITC and TPC was taken into account; the detectors themselves were regarded as perfect. However, at least two effects are known which distort the measurement in the TPC: (1) transverse components of the drift velocity $\vec{v}$, parametrized by $\Psi_x \equiv v_x/v_z$ and $\Psi_y \equiv v_y/v_z$, which can arise from a non-zero angle between $\vec{E}$- and $\vec{B}$-field; (2) a relative rotation of the two TPC halves about z, described by the twist angle Φ^T. These imperfections which are linear in z can be measured by a procedure described in [RO 88]. In aligning ITC and TPC we actually split the TPC in two, and treat both sides independently. Thus we have to determine 2 × 5 parameters, which taking the ITC as a unit, allows us to measure the known imperfections and distortions of the TPC mentioned above.

In summary, we can separate the transformations between two of the three detector components into a global geometrical part, describing the misalignment between TPC and ITC, and into a part due to the imperfections of the TPC. The resulting transformations are[1],

$$
\begin{aligned}
\delta X_{A/B} &= \delta X \pm \Psi_x z_{end} \\
\delta Y_{A/B} &= \delta Y \pm \Psi_y z_{end} \\
\delta \Omega_{A/B} &= \delta \Omega - \Psi_x \\
\delta \Psi_{A/B} &= \delta \Psi + \Psi_y \\
\delta \Phi_{A/B} &= \delta \Phi + \frac{z - |z|}{2} \Phi^T ,
\end{aligned}
\tag{3}
$$

where the choice of the + sign in the first two corresponds to side A.

We first correct for a T_0 offset in the TPC. For this, we use tracks which cross both TPC halves and determine the difference in those crossing points with the z-axis.

With this overall offset we then reconstruct the tracks. We perform track fits only on the TPC side with the most associated hits. For each track, the parameters D_0 and Φ_0 are measured in both TPC and ITC, while Z_0 and λ are taken from the TPC (see section [CO 91] for details). We then make a χ^2 fit to eq (1) using the Minuit package (the errors are calculated by Minos). The fit parameters $\delta X_{A/B}$, $\delta Y_{A/B}$, $\delta \Omega_{A/B}$ and $\delta \Psi_{A/B}$ are used then to compute $\delta \Phi_{A/B}$ (eq (2)) for each track. From the mean and width of this distribution we determine $\delta \Phi_{A/B}$ and the associated statistical error.

3 Results

Assuming that no other distortions invalidate eq (3), it can be inverted to give δX, δY, $\delta\Omega$, $\delta\Psi$, $\delta\Phi$ and Ψ_x, Ψ_y and Φ^T. For the final results we demand $D_0 < 15$ cm, a track momentum greater than 6 GeV, and a χ^2/NDF < 3 on the ITC iteration process. The distribution of the differences ΔD_0 and $\Delta \Phi_0$ between the TPC and ITC measurement (which are the input parameters for the fitting procedure) are shown in figure 1. Respectively for side A

[1]The index 'A' refers to the TPC side where $Z_0 > 0$.

and B we find $< D_0 > = 68$ μm, -882 μm with RMS of 660 μm, 581 μm and $< \Phi_0 > = 331$ μrad, 183 μrad with RMS of 885 μrad or 847 μrad. The mean values are of the order of a few 100 μm as expected from the mechanical alignment. The RMS are in good agreement with the combined extrapolation uncertainties in D_0 from TPC and ITC [AL 91].

Using these values the fit for the alignment parameters was carried out. The final results are listed in table 1.

4 Systematic Effects

In order to check if the results given in table 1 are biased by the chosen cuts, the cut parameters D_0, track momentum and χ^2/NDF in the ITC iteration process were varied.

- By demanding a minimum track momentum of 3, 6 or 9 GeV the influence of multiple scattering in the beam pipe and the ITC is tested. Multiple scattering causes additional uncertainties in the extrapolation of a track to the primary vertex not corrected for in cosmic events. The width of the distribution of the track residuals decreases with increasing momentum and becomes flat for momenta greater than 6 GeV (see fig 2). The cuts are chosen in the sensitive part of the momentum vs. residual width spectrum.

- By varying D_0 we change the quality of the track reconstruction. The TPC reconstruction algorithms in JULIA expect tracks coming from the vertex. Tracks with large D_0 do not cross the pad row radially which leads to a larger χ^2 in the track fit. We chose D_0 cuts of 5, 10, and 15 cm. The D_0 distribution, fig 3, is almost flat.

- To test the effects of the ITC iteration procedure, we loosened the χ^2/NDF cut from 3 to 4.

Since all these cuts affect the track reconstruction ideally we expect variations in the width of the D_0 and Φ_0 distributions, but unaltered mean values. Figure 4 illustrates the effect of varying the D_0 cut. (The track momentum was 6 GeV and a χ^2/NDF cut of 3 in the ITC iteration process was used.) Table 2 summarizes the variation of the momentum and of D_0. Comparing the different results, we see that variations in the track momenta have the greatest impact on the results and the χ^2 of the fit (this remains unchanged even if the χ^2/NDF of 4 in the ITC iteration process is included).

Taking the results from the different measurements, we made a χ^2-test for their compatibitity within statistics, taking into account that the event samples are correlated. A deviation of the reduced χ^2 from 1 was translated into an estimate for the systematic error (for details see [SC 91]). These are the errors quoted in table 1. All systematic uncertainties are smaller than 3 times the statistical ones, i.e., the results of the different samples are not dominated by their systematic errors.

5 Conclusion

Table 1 gives the final values for the geometrical alignment constants, the constants which take into account a nonzero angle between electric and magnetic field inside the TPC (Ψ_x and Ψ_y) and a tilt between both sides (Φ^T). The rotation angles $\delta\Phi$, $\delta\Psi$ and $\delta\Omega$ are used to calculate the Euler angles α, β and γ, which also are listed in table 1. Since the cosmics follow a $\cos^2(\lambda)$ distribution, with λ the angle of the tracks to the vertical, we need high statistics to measure the small linear offset δY. This is reflected in the corresponding results in table 1. The results of this year with 1334 tracks from cosmics are compared to the results from the 1989 alignment where only about 120 tracks were used. We see no difference for Ψ_x, Ψ_y, and Φ^T relative to the last cosmic run. This was expected, because the position of the TPC inside the solenoid has not changed. However, we find different constants for the relative ITC-TPC alignment. The reason for the shift is due to the removal of the ITC during shutdown. The results of this year's survey are given as well. The survey measures only a geometrical misalignment; it cannot take into account systematic effects inside the detectors (like field distortions and transverse drift velocity). Therefore the alignment constants relevant for the reconstruction of tracks have to be determined with data, using the same reconstruction program (JULIA) for the measurement as well as for the application of these constants. As table 1 reveals, the systematic effects inside the detectors influence mainly the values for the rotation angles given by the survey, whereas the values for the linear offsets are in good agreement for both measurements.

6 Tables

	cosmics 1991	cosmics 1989	survey 1991
$\Psi_x \cdot 10^{-6}$	-407 ± 10 ± 7	-440 ± 40	
$\Psi_y \cdot 10^{-6}$	390 ± 30 ± 18	344 ± 85	
δX_{Off} [μm]	520 ± 20 ± 16	1044 ± 100	450 ± 100
δY_{Off} [μm]	-10 ± 20 ± 63	- 579 ± 200	0 ± 50
$\delta\Omega_{Off}$ [μrad]	340 ± 30 ± 56	100 ± 180	20 ± 50
$\delta\Psi_{Off}$ [μrad]	-180 ± 40 ± 52	-30 ± 360	0 ± 20
$\delta\Phi_{Off}$ [μrad]	-320 ± 20 ± 54	-320 ± 140	0 ± 330
Φ_T [μrad]	-70 ± 40 ± 152		
α [rad]	0.51029		
β [rad]	0.000390		
γ [rad]	-0.51062		

Table 1: *Results of the 1989 and 1991 alignment using cosmic data. The results from this years survey are given in the third column.*

	D_0=15 cm p=6 GeV N=1131 χ^2/NDF=1.6	D_0=10 cm p=6 GeV N=1012 χ^2/NDF=1.6	D_0=5 cm p=6 GeV N=628 χ^2/NDF=1.6	D_0=15 cm p=3 GeV N=1150 χ^2/NDF=1.9	D_0=15 cm p=9 GeV N=1120 χ^2/NDF=1.7
$\Psi_x \cdot 10^{-6}$	-408 $\pm$ 7	-408 $\pm$ 7	-411 $\pm$ 9	-410 $\pm$ 7	-407 $\pm$ 6
$\Psi_y \cdot 10^{-6}$	392 $\pm$ 10	388 $\pm$ 11	382 $\pm$ 14	391 $\pm$ 10	392 $\pm$ 10
δX_{Off} [μm]	525 $\pm$ 15	509 $\pm$ 17	528 $\pm$ 21	520 $\pm$ 15	523 $\pm$ 10
δY_{Off} [μm]	-20 $\pm$ 22	-7 $\pm$ 23	-13 $\pm$ 30	-2 $\pm$ 15	-6 $\pm$ 22
$\delta\Omega_{Off}$ [μrad]	343 $\pm$ 27	338 $\pm$29	366 $\pm$ 33	352 $\pm$ 27	354 $\pm$ 27
$\delta\Psi_{Off}$ [μrad]	-173 $\pm$ 40	-178 $\pm$ 43	-157 $\pm$ 55	-177 $\pm$ 40	-172 $\pm$ 40
$\delta\Phi_{Off}$ [μrad]	-340 $\pm$ 26	-325 $\pm$ 25	-308 $\pm$ 27	-346 $\pm$ 27	-345 $\pm$ 26
Φ^T [μrad]	-86 $\pm$ 38	-76 $\pm$ 36	-93 $\pm$ 40	-64 $\pm$ 38	-66 $\pm$ 38

Table 2: *Results for the alignment constants after variation of the D_0 and momentum cut. On the ITC iteration process a χ^2/NDF cut of 3 was used.*

7 Figures

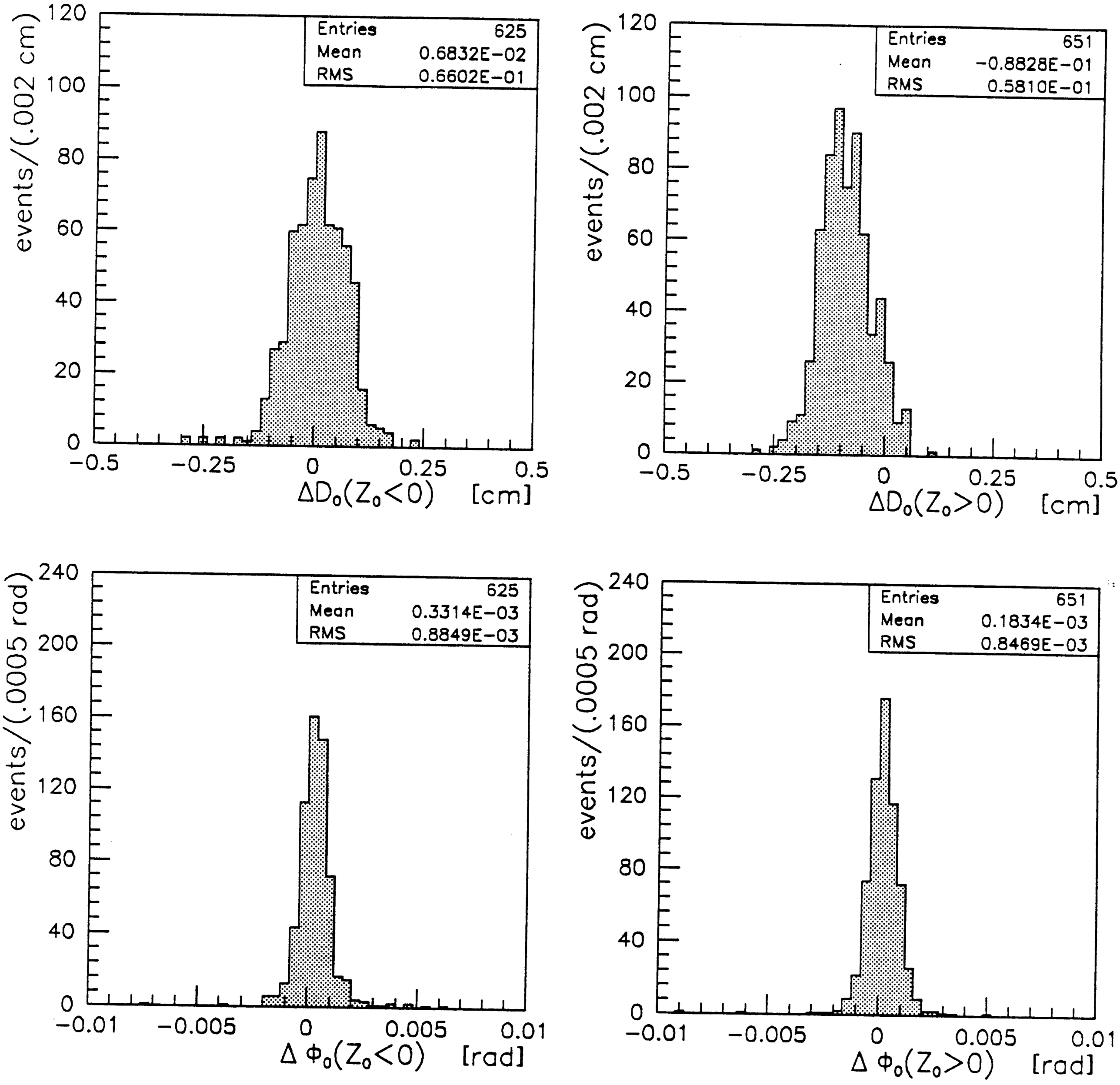

Figure 1: *Distribution of the differences* $\Delta D_0 = Q \cdot D_0$*(ITC-TPC) and* $\Delta\Phi_0 = \Phi_0$*(ITC-TPC).*

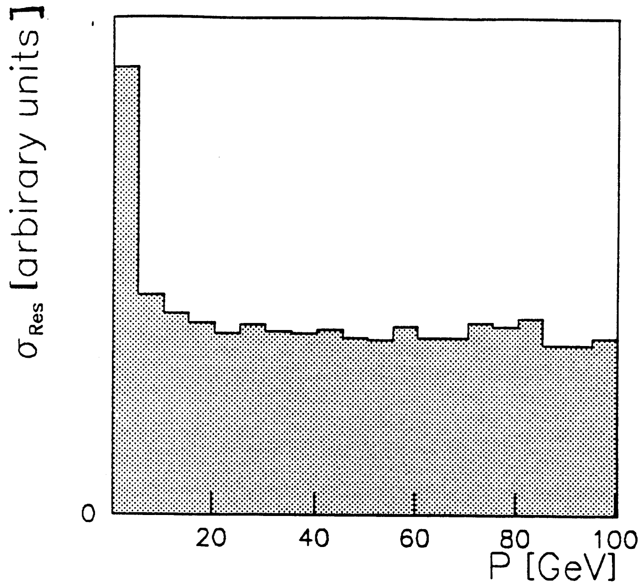

Figure 2: *Dependence of the track residuals σ_{Res} on the track momentum P.*

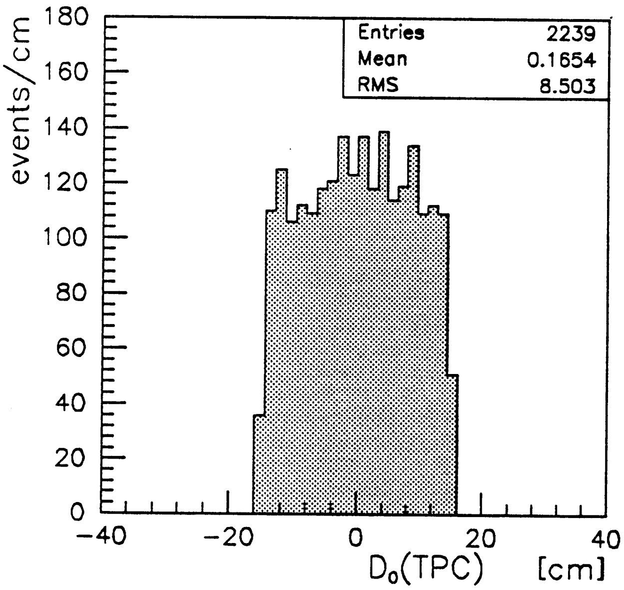

Figure 3: *Distribution of D_0 as measured in ITC and TPC for z>0. A flat distribution is expected for cosmics.*

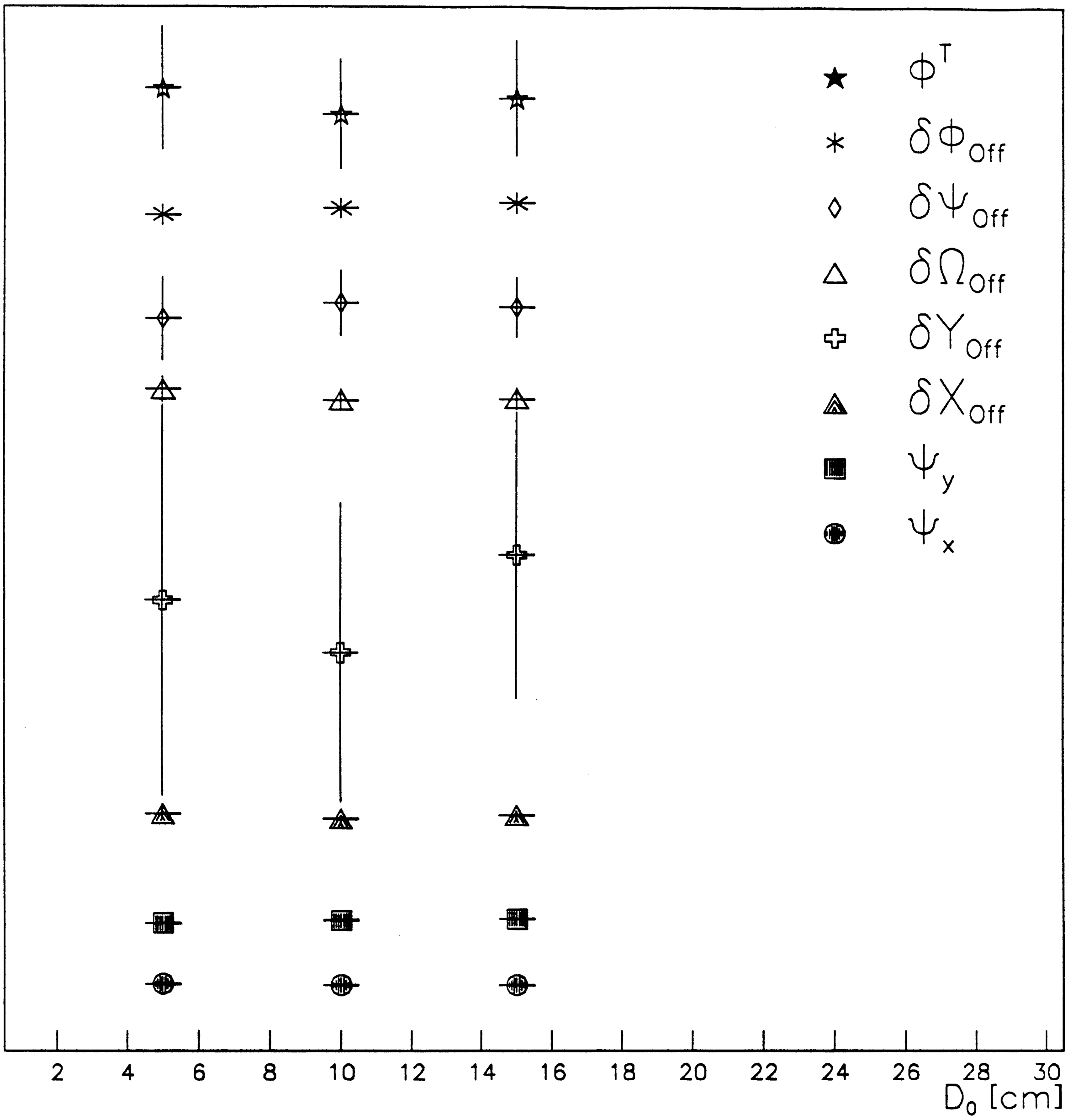

Figure 4: *Dependence of the fit results on the parameter D_0. The values given are normalized to those used for the final results (D_0=15, p = 6 GeV).*

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