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SOLENOIDAL DETECTOR NOTES

SOME MERITS OF A Z COORDINATE MEASUREMENT IN SILICON VERTEX DETECTORS

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1. Introduction.

The questions of the importance and efficiency of the z coordinate measurement in Silicon Vertex Detectors are topical now, since there are proposals to use double-sided (and pixel) silicon detectors both in an upgraded CDF and in SDC. Some simulation results are presented in this note. In Section 2 the influence of a z coordinate measurement in SVX of CDF is considered. The results for a simplified model of the STS proposed for SDC at SSC are presented in Section 3. In Section 4 the rates of B meson loss in large p_T b- and t - jets at Tevatron and SSC energies, if z coordinate measurement is not made, is estimated. The main results are summarized in Section 5.

2. Track fit updating with z coordinate measurement in the SVX of CDF.

The method of track reconstruction in the SVX of CDF was described in Ref.[1]. The track equation giving z as a function of the distance R from the beam is given by the formula

$$Z(R) = Z_0 + \frac{Cot\theta}{C} Sin^{-1}\left(\frac{C^2R^2 - C^2D^2}{1+2CD}\right)^{\frac{1}{2}}, \tag{1}$$

where R is a radial coordinate in the transverse plane, Z_0 is z coordinate at the point of closest approach of a trajectory to the beam axis, C=$1/2\rho$ (ρ - track radius of curvature), D - impact parameter, θ - production polar angle.

It was assumed in this study that a z coordinate measurement is made, with some error σ_z, at each layer of SVX, in additional to the x coordinate measurement. In the simulation, the z coordinate were taken from the LISP bank in order to account for multiple scattering.

The fit result was calculated as

$$\vec{P_1} = \vec{P_0} + \left((V_0)^{-1} + A\right)^{-1} \frac{\delta z}{\delta p} \frac{z_1 - z_0}{{\sigma_z}^2}, \tag{2}$$

where $\vec{P_1}$ - calculated values of the parameters Z_0, C, D, Cotθ, ϕ_0 (azimusal angle at D) on layer 1,

$\vec{P_0}, V_0$ - parameters and covariance matrix, using measurement on layer 0,

z_1 - coordinate on layer 1,

z_0 - coordinate, extropolated to layer 1 with the parameters $\vec{P_0}$.

The A matrix is defined from (1) as

$$A = \frac{1}{{\sigma_z}^2} \frac{\delta z}{\delta p_i} \frac{\delta z}{\delta p_j}.$$

Using layer 1 informaition, the new covariance matrix iz given by

$$V_1 = \left((V_0)^{-1} + A\right)^{-1}.$$

To calculate these values, suitable changes were made in SVXREC, UPFIT and DERIV routines of the SVX simulation program. The results were checked with one track

events. A large two-jet event sample was generated with ISAJET [2] (ver. 6.38) with $p_T \geq 20\ GeV/C$ and $|\eta| \leq 2$ (for jets) at an energy of $\sqrt{s} = 1.8$ TeV. The tracks of the charged particles with transverse momenta $p_T \geq 1\ GeV/C$ were included in the fit.

Figures 1 and 2 show distributions of the differences between fitted parameters, D(fit), Z_0(fit) and generated ones, D(gen) and Z_0(gen), when z is measured only in the CTC (Central Tracking Chamber). The resolution is about 30 μm in D and 6 mm in Z_0.

The resolution σ_z of SVX depends on a number of factors: pitch size, architecture, clustering algorithm. For example, the resolution of double-sided silicon detectors depends on the size of the stereo angle. Bisides, σ_z will depend on occupancy because of pattern recognition problems in projective strip detector.

The value $\sigma_z = 100\ \mu$m has been chosen. Such a resolution corresponds, for example, to pixels with pitch of $\sim 300\ \mu$m ($\sigma_z \simeq$ pitch/ $\sqrt{12}$), or to strips of 20 μm pitch whith 12° stereo angle.

Figure 3 shows the result for the Z_0 parameter with the procedure described above. The same Z_0 distributions, but for resolutions $\sigma_z = 20\ \mu$m and $\sigma_z = 50\ \mu$m are shown in Fig. 4 and 5 respectively. Table 1 presentes the results of gaussian fits (sigmas) for all distributions considered above (in column 5). It is seen from Table 1 that the z coordinate measurement leads to an improvement on Z_0 resolution by approximately 60 times for $\sigma_z = 100\ \mu$m. The influence of multiple scattering leads to a more modest resolution in Z_0 as compared to z resolution, σ_z, at smaller values (20 and 50 μm) of σ_z.

The improved Z_0 measurement will carry along an improved θ measurements, i.e., for example, improved effective mass resolution in charged prong decay of unstable particles. Secondary vertex searches will become possible also in the longitudinal plane. A study of the merits of the method in terms of these additional parameter and physics studies will be subject of further work.

3. The case of the Silicon Tracking System of SDC.

We consider the central barrel of the Silicon Tracking System of SDC[3,4] with the two innermost layers made out of pixel detectors at radii less then 10 cm, and strip detectors outside these radii. The pixel size is $50\times250\mu$m in the x and z directions respectively.[4]

We were not in the condition to simulate the performances of the STS of SDC properly. The best we could do was to modify the SVX tracking program of CDF somehow and address some significant specific questions for SDC. At present, the basic desing of STS has a z-information provided by a 10 mrad stereo angle of 50 μm pitch strips on all detectors, which amounts to a 1500 μm resolution in z and provides a vertexing accuracy of the same order. Therefore, we address to following question: how would the Z_0 resolution improve if the pixel version with pixel size $50\times250\ \mu m^2$ was adopted for the two innermost detectors? We found an approximate answer to this question by the following procedure.

The following changes have been made to the SVX simulation program:

- Two layers only were included in the detector with radii $R_1 \simeq 6.0\ cm$ and $R_2 \simeq 8.0\ cm$.
- The pitch size was decreased to 50 μm (from 60 μm).
- The assumed resolution was $\sigma_z = 75\ \mu$m (approximately $250/\sqrt{12}\ \mu$m).

- In order to simulate the reconstruction accuracy of the outer STS detector, the values of the CTC fit parameters and covariance matrix were scaled as shown in the first two colums of Tabel 2 (these Z_0 values are very reasonable in the considered rapidity region [4]).

The simulation was made for ISAJET events at SSC energy ($\sqrt{s} = 40$ TeV) with jets of $p_T \geq 30\ GeV/c$ and $|\eta| \leq 2.5$.

The results of the simulation are presented in Table 2, wich shows the sigmas of the distributions of D(fit)-D(gen) and Z_0(fit)-Z_0(gen) for the cases without and with the inside pixel layers and, also, for different sets of the input pixel fit parameters and covariance matrix (Sim. 1 and 2 in Table 2). These preliminary results give a hint on how to define more precisely the optimum characteristics of the strip and pixel detectors. For example, it is seen from Table 2 that the results with pixel layers are very similer for Sim.1 and Sim.2, which make different assumptions for the outside detector.

4. Usefulness of a z coordinate measurement in SVX(STS) to select B mesons.

It is clear that a fraction of B mesons with long enough path length in the transverse plane can be selected with the measurement of the x and y coordinates only. Such a possibility relies on a good enough reconstruction accuracy for the primary event vertex and for the B decays point in the transverse plane. The z coordinate measurement can be an important complement. To make some estimates for this problem, ISAJET was used to generate two-jet events. To simulate some tipical tasks involvin b - quark direct production in a hadron collider experiments, jets for b - quarks of $p_T \geq 20\ GeV/c$ and $|\eta| \leq 2$ were generated. Besides, t - quark jets with different minimum p_T cuts were also generated to address b - quark production from t decays. The generation was done for $p\bar{p}$ interactions at $\sqrt{s} = 1.8$ TeV and for pp interactions at $\sqrt{s} = 40$ TeV. The cut on polar angle, $20^o \leq \theta \leq 160^o$ (for all charged particles) was included in addition, according to the geometries of the SVX and STS barrel part. Next, the transverse and longitudinal path lengths (l_i) of B mesons were generated in proportion to $exp\ (-l_i/l_0)$, where $l_0 = c\tau p_B^i/m_B$ ($c\tau = 0.035$ cm, p_B^i and m_B are transverse/longitudinal momenta and mass of B mesons).

Mean values of B transverse and longitudinal momenta for the different processes are presented in Table 3 for comparison. The t - jets have been generated at $p_T \geq 20\ GeV/C$ and $m_t = 150$ GeV. It is seen from Table 3 that the B transverse and longitudinal momenta depend little on $\sqrt{s}$. This means that the transverse and longitudinal path lengths are also similar.

Table 4-7 presents the B rates in different regions of transverse (l_T) and longitudinal (l_z) path length for the ISAJET events mentioned above. It is seen from these Tables that, if the fiducial regions in transverse and longitudinal vertex reconstruction is taken to be $3\sigma_T \times 3\sigma_z = 100 \times 300\mu$m, an amount of (5-10)% of B is lost without z coordinate measurement. But one may assume more realistically that $3\sigma_T = 200$-$300\ \mu$m because of reconstruction problems for b decay vertex. The primary vertex can be reconstructed in SVX, for example, with the accuracy of $\sigma_T = 12\ \mu$m for t - jet events (at $m_t = 150$ GeV) and of $\sigma_T = 35\ \mu$m for b - jet events.[5] Under these assumptions, the rates of B loss can increase to up of (15-20)%. The reason why the B - loss, after all, is not so large is the

relative large polar angle of the SVX(STS) detection regions. It was shown also in Ref.[6] for t jet simulation that a z coordinate measurement in SVX improves B tagging efficiency by approximately 10% only.

In order to check the influence of the different Montecarlo models to the presented results, a run was also made with the PYTHIA Montecarlo (ver. 5.3).[7] Very similar results to the ones presented in Tables 4-7 were obtained.

5. Conclusions.

- Simulation was made of the Z_0 resolution attainable if a z coordinate measurement is performed in SVX(CDF).

The case of STS(SDC) was also considered, in very simplified approach. A z coordinate measurement in the SVX with a resolution of $\sigma_z = 100$ (μm) would improve the accuracy on Z_0 by approximately 60 times.

An improvement by about one order of magnitude is estimated for STS, if pixels are adopted for the two innermost layers (with $\sigma_z = 75\mu$m for each layer).

- Tagged B rates are reduced by $\leq$ (15-20)% without z coordinate measurement in SVX(STS), if transverse and longitudinal resolution of vertex reconstruction are $\leq$ 100 μm.

The results are very much the same using both ISAJET and PYTHIA Montecarlo generation.

6. Acknowledgements.

I would like to thank F. Bedeschi, G. Bellettini, D. Bisello, G. Busetto, L. Pescara for continous support and carefull reading of the manuskript.

References

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[7] H. U. Bengtsson, T. Sjostrand, The Lund Monte Carlo Programs. PYTHIA, version 5.3. CERN, 1989.

Table 1: Fit accuracies of D and Z_0 track parameters in CTC and CTC + SVX of CDF.

z coordinate measurement	Parameter	Detectors	σ_z (cm)	Sigma (cm)
without	D	CTC		0.055
		CTC+SVX		0.003
	Z_0	CTC		0.630
		CTC+SVX		0.600
with	Z_0	CTC+SVX	0.010	0.011
			0.002	0.004
			0.005	0.007

Table 2: Fit accuracies of D and Z_0 track parameters in the STS of SDC.

Sim.	Without pixels		With two pixel layers	
	D - sigma (cm)	Z_0 - sigma (cm)	D - sigma (cm)	Z_0 - sigma (cm)
1	0.005	0.07	0.005	0.007
2	0.008	0.1	0.005	0.008

Table 3: Mean values of transverse (p_T) and longitudinal (p_z) B meson momenta for the different processes.

Energy (TeV)	Type of quark-jets	Mean p_T (GeV/C) of B meson	Mean p_z (GeV/C) of B meson
1.8	b-jets	19.7±0.3	19.3±0.6
	t-jets	34.8±1.3	24.0±0.8
40	b-jets	22.2±0.5	23.8±1.0
	t-jets	37.6±1.9	37.7±1.4

Table 4: Rates of B mesons (%) in different regions of transverse (l_T) and longitudinal (l_z) B path length for ISAJET events with two b jet production in $p\bar{p}$ interactions at $\sqrt{s} = 1.8$ TeV.

Δl_T μm	Any l_z	$l_z \geq 300\mu$m	$l_z \geq 600\mu$m
0-100	8.6 ±1.0	5.4 ±0.8	4.1 ±0.7
0-200	17.1 ±1.4	11.3 ±1.2	8.4 ±1.0
0-300	24.8 ±1.7	15.5 ±1.4	10.8 ±1.1
0-400	30.8 ±1.9	18.8 ±1.5	13.6 ±1.3
0-500	37.0 ±2.1	23.5 ±1.7	16.8 ±1.4

Table 5: The same as in Table 4, but for two t jets produced in $p\bar{p}$ interactions at $\sqrt{s} = 1.8$ TeV.

Δl_T μm	Any l_z	$l_z \geq 300\mu$m	$l_z \geq 600\mu$m
0-100	5.7 ±0.9	3.5 ±0.7	2.5 ±0.6
0-200	11.9 ±1.2	6.9 ±0.9	5.2 ±0.8
0-300	15.6 ±1.4	9.3 ±1.1	6.9 ±0.9
0-400	19.9 ±1.6	12.0 ±1.3	9.1 ±1.1
0-500	25.0 ±1.8	15.8 ±1.4	11.7 ±1.2

Table 6: The same as in Table 4, but for two b jets produced in pp interactions at $\sqrt{s} = 40$ TeV.

Δl_T μm	Any l_z	$l_z \geq 300\mu$m	$l_z \geq 600\mu$m
0-100	9.7 ±1.7	6.1 ±1.3	4.7 ±1.2
0-200	16.2 ±2.4	10.8 ±1.9	8.3 ±1.7
0-300	23.8 ±2.9	16.2 ±2.3	11.9 ±1.9
0-400	29.6 ±3.2	20.6 ±2.6	14.8 ±2.2
0-500	34.7 ±3.5	23.1 ±2.9	17.0 ±2.4

Table 7: The same as in Table 4, but for two t jets produced in pp interactions at $\sqrt{s} = 40$ TeV.

Δl_T μm	Any l_z	$l_z \geq 300\mu$m	$l_z \geq 600\mu$m
0-100	5.6 $\pm$1.5	4.3 $\pm$1.2	3.6 $\pm$1.0
0-200	11.0 $\pm$2.0	8.3 $\pm$1.5	8.0 $\pm$1.3
0-300	16.5 $\pm$2.4	12.6 $\pm$1.8	11.3 $\pm$1.5
0-400	22.2 $\pm$2.7	15.3 $\pm$2.4	13.3 $\pm$1.9
0-500	25.5 $\pm$3.1	17.6 $\pm$2.6	15.0 $\pm$2.0

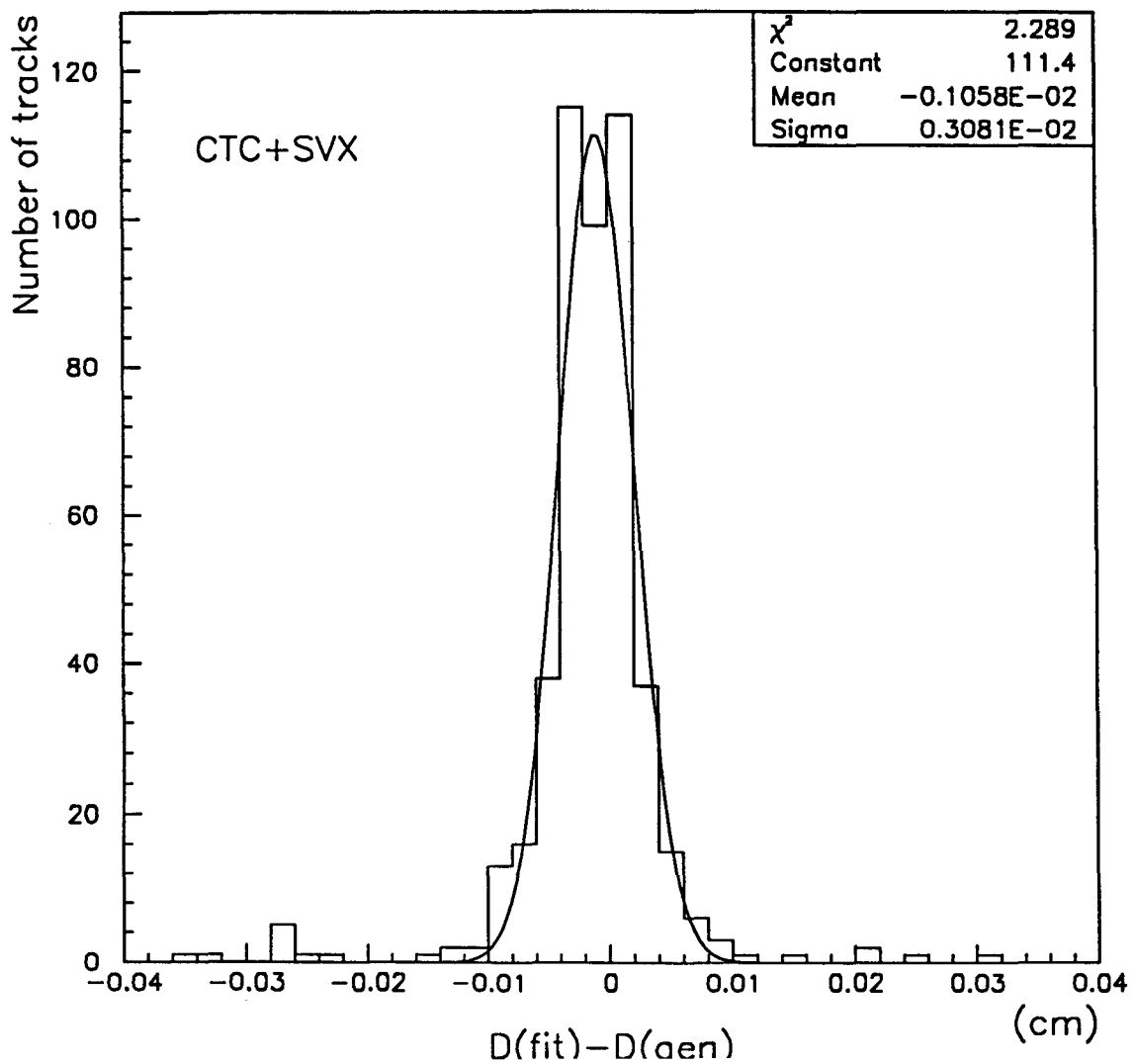

Figure 1: Distribution of the difference between fitted and generated values of impact parameter, D, for the tracks reconstructed in the CTC + SVX detectors (this parameter is insensitive to a z - measurement).

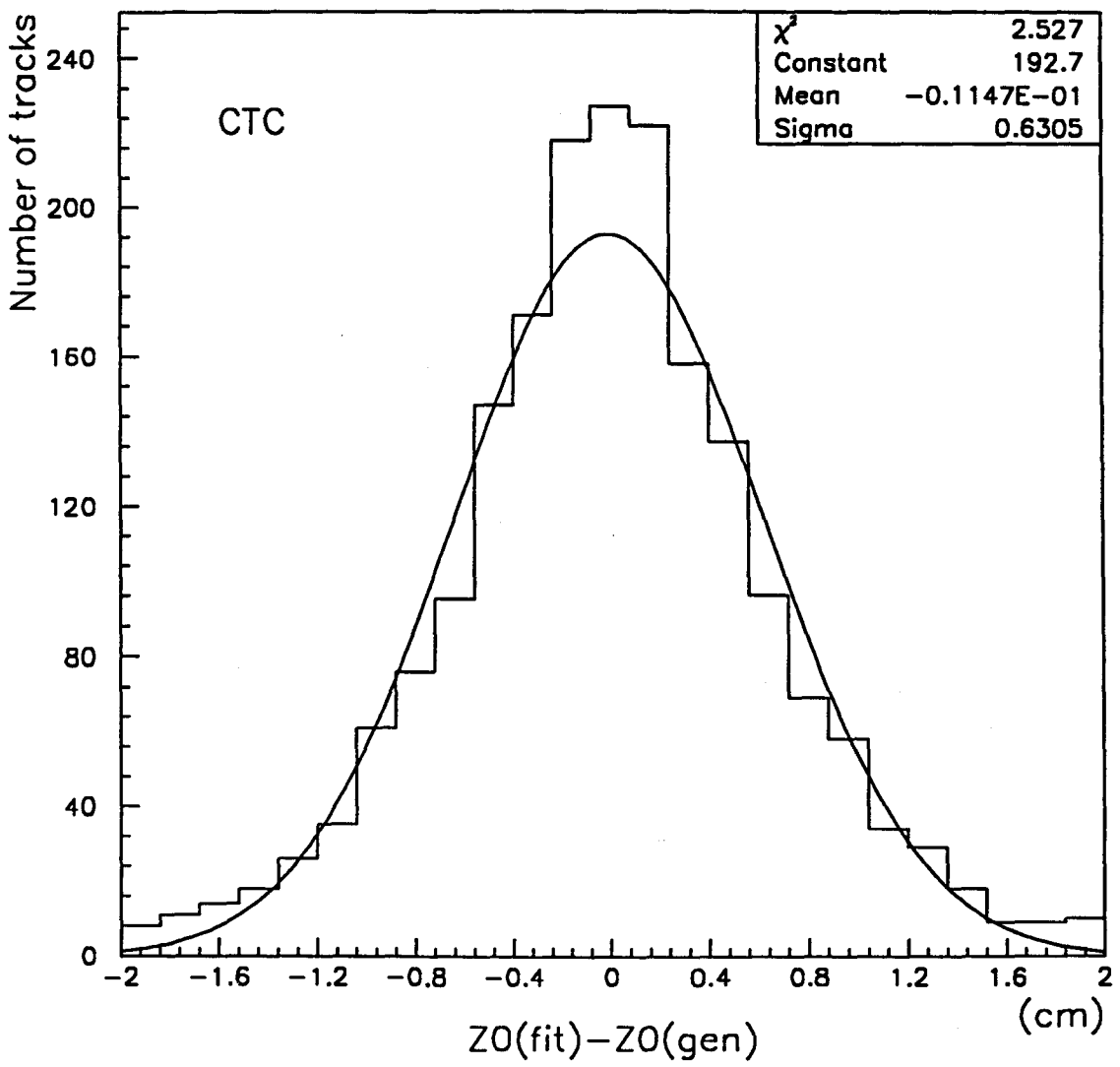

Figure 2: Distribution of the difference between fitted and generated values of track parameter Z_0 when z is not measured in the SVX.

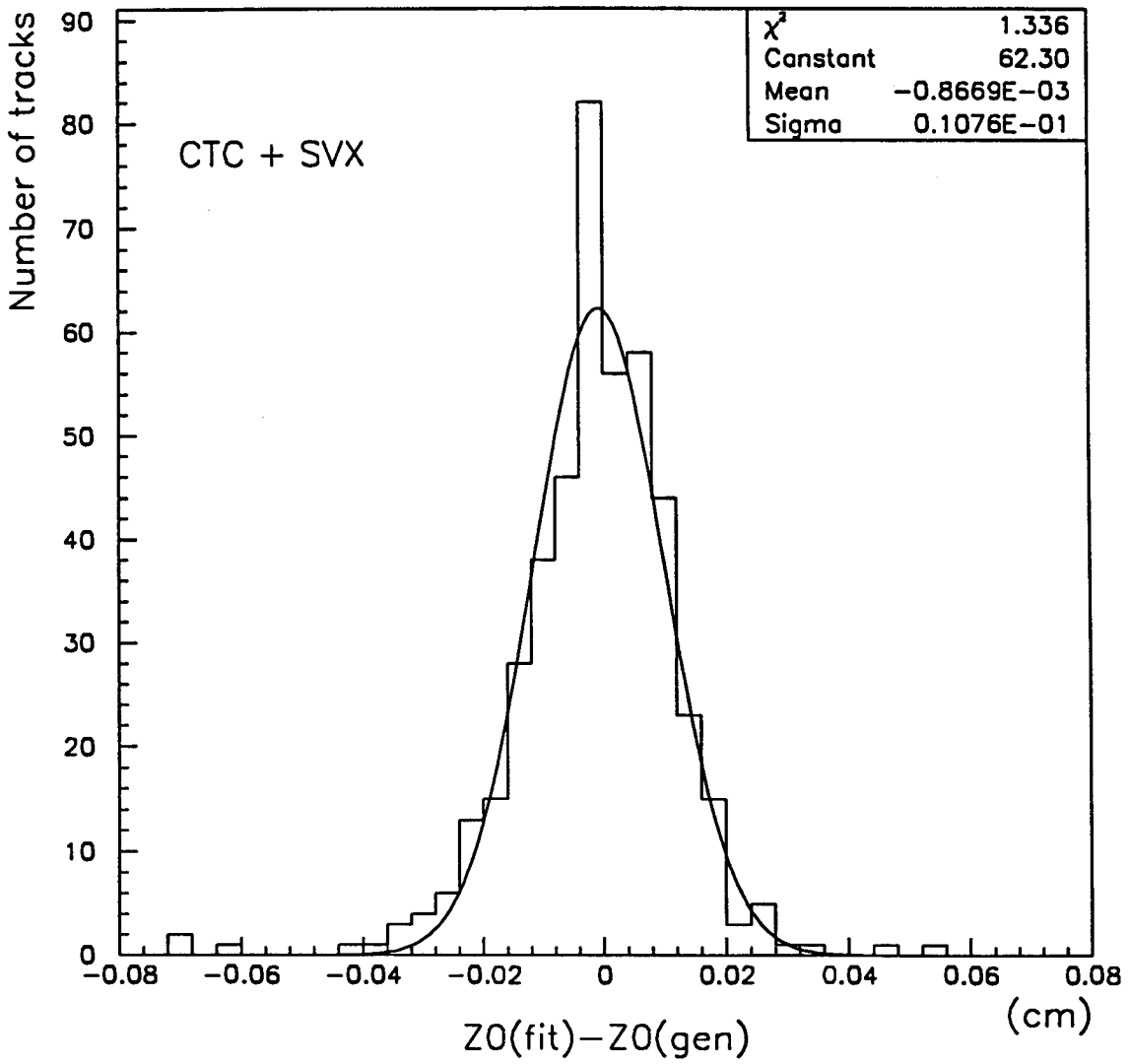

Figure 3: Distribution of the difference between fitted and generated values of track parameter Z_0 with z coordinate measurement in the SVX (z resolution $\sigma_z = 100\ \mu$m).

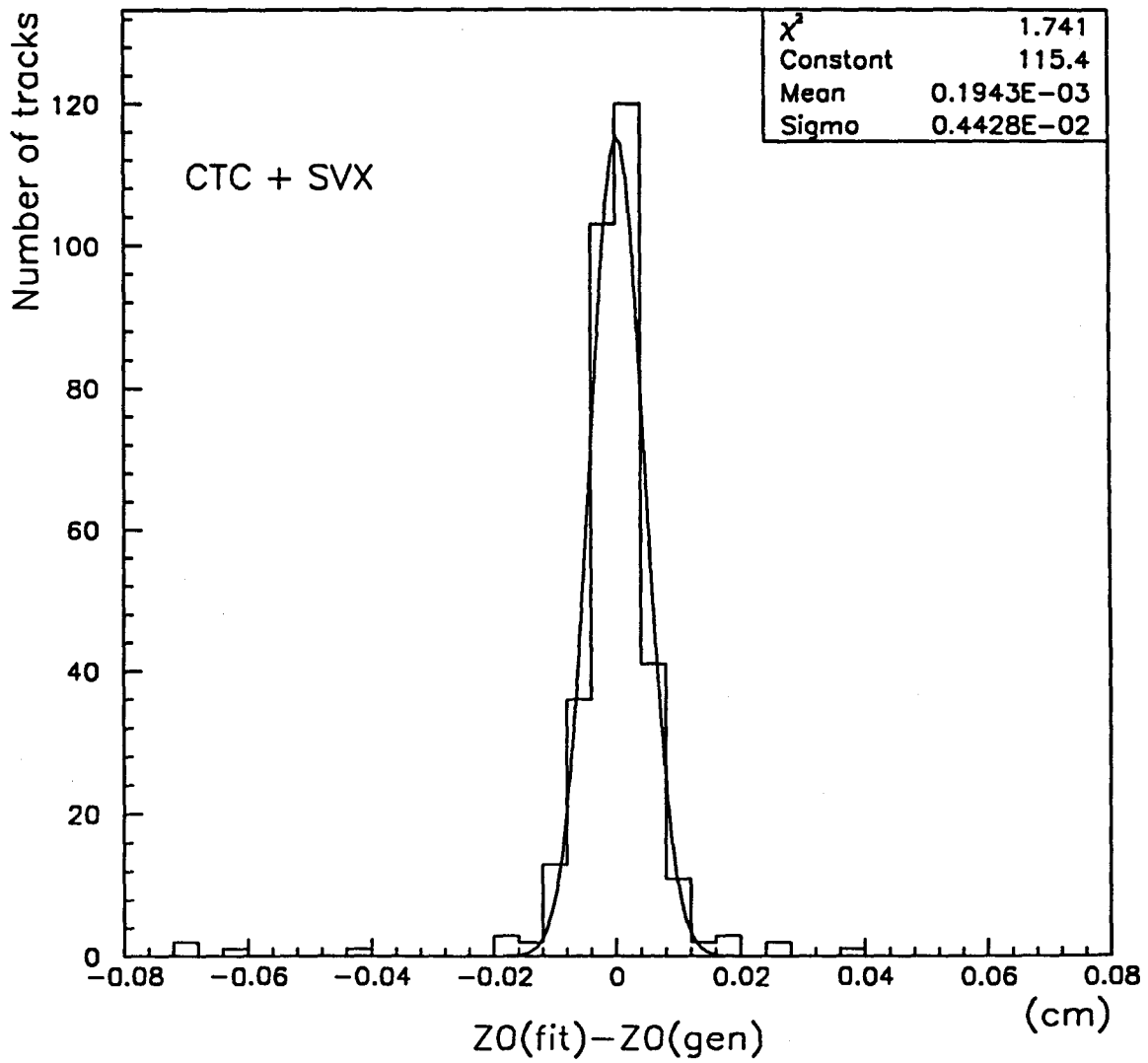

Figure 4: The same distribution as in Fig.3, but at the $\sigma_z = 20\ \mu$m.

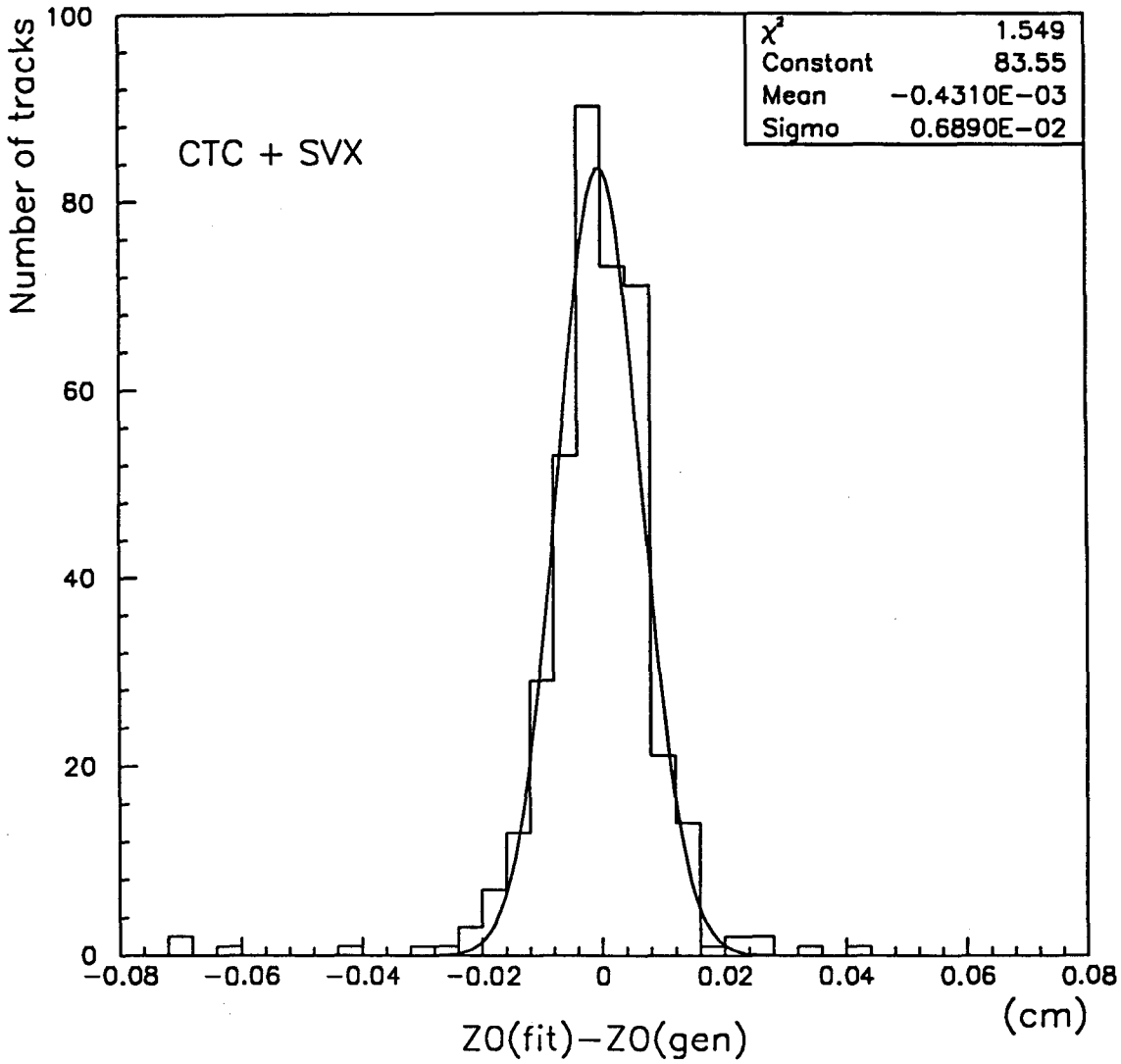

Figure 5: The same distribution as in Fig.3, but at the $\sigma_z = 50\ \mu$m.

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Abstract

Simulation was made of a track fitting in an upgraded Silicon Vertex Detector(SVX) of CDF with z coordinate measurement. The special case of the Silicon Tracking System(STS) of the Solenoidal Detector Collaboration (SDC, at the SSC) was also studied. The improvement added by a z coordinate measurement to select B mesons, was estimated with the aid of the ISAJET and PYTHIA Montecarlo models.

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1. Introduction.

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