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SOLENOIDAL DETECTOR NOTES

THE EFFECT OF MATERIAL IN THE TRACKING VOLUME - E/ρ AND POSITION MATCHING -

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The effect of material in the tracking volume - E/p and position matching -

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Abstract

Efficiency-losses caused by bremsstrahlung were systematically evaluated for the baseline design of the central tracker of the SDC detector for electrons of 20 GeV. The geometry, in which a total material of 18% of unit radiation length(X_0) was at 90°, was modeled in the EGS4 as collected materials in front of the trackers and as distributed. The efficiency-losses were found smaller in the distributed case than collected ones; the best result was obtained when only the inner tracker was used. The distributed material was approximately equivalent to half as much total material in front of the tracking volume. Using the inner tracker, the loss was 5% for the cut of $0.5<E/p<1.5$. In the track-EM shower position matching, Δ_ϕ^{SM}, the bremsstrahlung up stream or down stream was mitigated by taking either narrow or wide calorimeter area utilizing the fine-sampling shower-max (SM) detector. The overall loss was 11% for the cut of $0.5<E/p<1.5$ and $|\Delta_\phi^{SM}|<15$mm. Over the transverse momentum range of 10-400 GeV/c, the loss for the cut of $0.5<E/p<1.5$ varied 5-9% and the overall loss 7-12% for the cut of $0.5<E/p<1.5$ and $|\Delta_\phi^{SM}|<15$mm, by using either the inner tracker or the full tracker.

Introduction:--

Because of the high density of charged tracks in the vicinity of jets and the large dynamic range of momentum to be measured with the SDC tracker, from several GeV/c to several TeV/c, the SDC tracker is designed to have great precision in point measurement in a large tracking volume in a strong magnetic field. The engineering baseline design[1] of the SDC tracker, shown in Fig. 1, consists of the inner tracking system based on Silicon strips and Silicon pixels and the outer system based on the superlayers of bunched scintillating fibers and/or straw chambers, with a superconducting solenoid magnet outside the tracker and in front of the EM calorimeter, which provides a magnetic field of 2 Tesla. The number of hit points and the point-resolutions in the $r\phi$ direction are 18 points and 15 μm in the inner tracking system and 7 points and 60 μm in the outer system, as summarized in Table I.

Inherent to a tracking system of this high precision is the amount of material, to which electrons are most vulnerable[2]. The material of the baseline design is, in the radiation length unit (X_0), 18.3% at 90 degrees(°)[3] including internal bremsstrahlung of 2.5% equivalent in the $W^{\pm}\rightarrow e^{\pm}\nu$ decay and a gas in the tracking volume of 1.1%. The material is followed by the superconducting coil of 120% in front of the calorimeter. However, the situation of the SDC is different from the existing trackers, such as that of the CDF: most of the material is attached to the location of the measurement, instead of in front of the chamber.

The direct consequence of the material to the electrons is the electron bremsstrahlung. To assess the issue, one approach in simulation, using EGS or GEANT, is to collect the materials in front of the tracking system (totally or separately for the inner and the outer systems) followed by the seemingly massless tracking volume; the other is to distribute the material as it is. In the first approach one can use the exiting momentum after the collected material as the momentum measured with the tracking system. In the second approach one requires fitting to obtain the momentum but this approach is more realistic and desirable since electrons experience the material gradually and other processes such as multiple scattering and measurement errors can be convoluted.

The idea to identify electrons is to see the matching of quantities measured with the tracking system and those with the calorimeter. Usually, two variables are to be used: energy-momentum matching, so-called E/p, and track-shower position matching, say Δ. For example, CDF has required $E/p<1.5$ and $|\Delta|<15$-30 mm[4]. There were number of studies on the issue for the SDC. However, because of the definitions of "E", "p", collected or distributed materials, the E/p efficiencies were different study by study. These makes it difficult to understand the issue/effect. This study was intended to sort out the differences and to understand the issue consistently.

Simulations:--

The baseline tracking geometry of the SDC was modelled with the materials of the elements such as Silicon for the inner tracking system and Polystyrene for the scintillating fiber, or with the radiation-length equivalent of solid Aluminum, together with the coil with solid Aluminum,and the EM calorimeter with solid Lead, in the EGS4 system[5]. Since it is important whether we can reproduce existing data/study[6], both approaches, collected and distributed materials, were simulated for the tracking geometry.

In both approaches, electron/positron tracks, including secondary tracks if primary electrons showered in the material in the tracking volume, were swum in the magnetic field and traced in the whole tracking volume. No bremsstrahlung identification was attempted in order not to introduce further ambiguity[7]. The electron/positrons from the tracking volume were showered in the coil and showered in the EM calorimeter. Tower size of the SDC calorimeter is $\Delta\eta\times\Delta\phi=0.05\times0.05$, which has a cross section of 100mm×100mm at r=2 m; there are Shower-Max (SM) detectors (20 mm wide strips) at the shower maximum to provide fine lateral profiles and positions of the showers. EM showers were developed only in the first part of the EM calorimeter, i.e. in front of the SM detector, modeled with 6 X_0 solid lead and showers were stopped when they passed through the SM detector, in order to shorten up the computing time.

Momentum p:-- The hit points in the sensitive layers were smeared with the point measurement errors, and then, the momentum of the track was obtained by fitting a circle to the hits in the r-ϕ (x-y) plane and a straight line in the s-z plane where s is the path length in the r-ϕ (x-y) plane. The track with the fitted highest momentum was chosen as the original electron with its measured momentum, p. This is the definition of p in this study.

Energy E:-- The energy measured with the calorimeter, the energy resolution of the calorimeter, and the shower spread at the SM detectors were evaluated as follows. First, calculated was the fraction of the energy-deposit of the charged tracks of the EM shower in the SM detector, which distances of the energy-deposits in the $r\phi$- and z-directions, ($\Delta_i=\sqrt{(\Delta_{\phi i})^2+(\Delta_{zi})^2}$), were within a radius of 150 mm from the extrapolated track from the original electron, to the total energy-deposit of all the charged tracks in the SM detector[8]. Second, the total energy entering the calorimeter was scaled with this fraction to give the energy entering the calorimeter within a radius of 150 mm around the original electron. Third, the scaled energy was smeared with an energy resolution of

$$\sigma_E/E=15\%/\sqrt{E}\oplus 0.5\% \text{ (added in quadrature).}$$

Fourth, this smeared energy was re-scaled to give the initial energy of E_0 at its peak. This smeared and re-scaled energy is the definition of E in this study.

In measuring the energy, one should take care of the following two points to have good E/p ratios:

(1) Calorimeter area should be narrow enough not to collect the bremsstrahlung photons if they were emitted up stream in the tracking volume;
(2) Calorimeter area should be wide enough to collect the bremsstrahlung photons if they are emitted down stream in the tracking volume.

In Fig. 2, circumferential differences at the radius of r_0=2100 mm between the photons (straight tangential line) and the bent secondary chareged tracks (circle) are shown as a function of the energy of the secondary charged track under the 2 Tesla magnetic field when bremsstrahlung occurs at a radius of r. If bremsstrahlung occurs at the origin (r=0) and the secondary momentum is 8 GeV/c, the distance is more than 150 mm at r_0=2100 mm. Since the bremsstrahlung occurs at the origin, a perfect tracker measures the momentum to be 8 GeV/c. If we limit the calorimeter area within 150 mm, we do not see the photon energy and the calorimeter energy is 8 GeV; E/p=1. On the other hand, if we have a wide calorimeter area, e.g. within 200 mm, we have the original energy, say 20 GeV; $E/p \geq 2$. Which is better is depend on physics goals. The tower size is quantized in reality. The radius of 150 mm is chosen to cover three towers.

Track-Shower position matching, min.Δ_ϕ^{SM}:-- The same caution as for the calorimeter area in the energy measurement should be taken here, too. However, we have a fine lateral sampling with the SM detector. Two position matching values were calculated for a shower to accommodate the two cases noted above: in the SM detector, distances of the energy-deposits in the $r\phi$- and z-directions of each charged tracks, ($\Delta_i=\sqrt{(\Delta_{\phi i})^2+(\Delta_{zi})^2}$), were calculated from the extrapolated track from the original electron; energy-weighted average distances of an event, the Track-Shower position matching: Δ_ϕ^{SM} in the $r\phi$-direction and Δ_z^{SM} in the z-direction, were calculated from the energy-deposits which Δ_i's are within 150 mm or within 40 mm; the minimum of the two was taken as the Track-Shower position matching, e.g. $min.\Delta_\phi^{SM}$ in the $r\phi$ plane. The 150 mm and 40 mm were taken considering the tower size and the strip width. No optimization for the sizes was tried.

Positrons with a transverse energy of E_{t_0}=20 GeV were generated at η=0.5 (thus the thickening factor is $1/\sin\theta$=1.13) considering the following factors: the effect of material is worse for lower energy electrons; the electrons from the $W^{\pm}\rightarrow e^{\pm}\nu$ decay make a peak around the transverse energy of 40 GeV and populate more the lower energy side than the higher side (see ref. 6); at 90°(η=0), the amount of the material is the least but electrons in an event will emerge in wide η regions.

When generating electrons at the interaction points, there are several common contributions in the material budget: internal bremsstrahlung of 2.5% X_0 equivalent in the decay of $W^{\pm}\rightarrow e^{\pm}\nu$, a beam pipe of Beryllium of 1.27mm, i.e. 0.36% X_0 in front of the tracking volume, and a gas filling the tracking volume which amounts to be 1.1% X_0 assuming Air. These, totaling 4.0% X_0 at 90°, were included in the following cases. The material budget in the different modeling described below are summarized in Table II.

CDF*: *approximation of the CDF design.* To simulate the CDF design in the SDC geometry, in which the material is almost concentrated in front of the central tracking chamber (CTC; only CTC is used to get the momentum), 3.2% X_0 Aluminum was placed at r=180 mm and 9 "CTC" superlayers were set between r=200 mm and 1600 mm using the locations of two outer most Si-strips, the Scifi's, and the Straws of the baseline geometry. To have comparable resolving power of BL^2, the magnetic field, B, was reduced to 1.0 *Tesla* (for L=1.4m) instead of 1.5 *Tesla* (for L=0.9m) of the CDF. The position resolution of a superlayer was taken to be σ_{axial}=100 μm and σ_{stereo}=2.0 mm. The material included: 2.9% for internal bremsstrahlung and the beam pipe, 3.2% for other materials before the CTC, and 1.1% for the gas in the CTC, totaling 7.2% at 90°.

SDC-I: *collected material of the SDC baseline design.* To see a direct comparison with the above CDF design, the material in the SDC(set to 14.1% X_0) was collected at the location of r=180 mm, and σ_{axial}=60 μm and B=2.0 *Tesla* were set. In this case the material included: 2.9% for internal bremsstrahlung and the beam pipe, 14.1% for the material in the SDC tracking volume, and 1.1% for the gas, totaling 18.1% at 90°.

SDC-II: *collected material of the SDC baseline design.* Because the tracking system of the SDC can be separated naturally into the inner tracker with the Silicon and the outer tracker with the Scifi/Straw, the materials were collected at two locations: the first layer of pixel for the Silicon system (6.8% X_0), and the first layer of Scifi for the Scifi/Straw system (8.6% X_0). The reason for the splitting is the vast difference of the point resolutions and the number of hits of the inner and the outer trackers: 15 μm and 18 points, and

60 μm and 7 points, respectively. Within the SDC-II condition the following cases were studied:

(a) All the elements of the tracking system were turned on for the track fitting.

(b) Following a suggestion to use only the outer tracker for the momentum measurement as in the CDF, in which the VTPC or the SVX is not included in the measurement yet, the outer tracker was turned on and the inner tracker was turned off. Note that even though the inner tracker was turned off, the material was there.

(c) As mentioned above the SDC inner tracking system has a superior resolution and number of hits; the Silicon system is not only a vertex detector in the SDC design but also a tracker for momentum measurement. With this respect the inner tracking system is a different concept from the CDF and may be sufficient for the low-momentum track measurement. The inner tracking system was turned on and the the outer tracking system was turned off.

SDC-III: ***distributed material of the SDC baseline design.*** A bunched material in front of the measurement is always the worst. The most realistic simulation is to simulate the material as it is distributed. The geometry of the SDC baseline design were constructed layer by layer. As in the SDC-II, three cases were generated:

a) All the tracking element was turned on.

b) A direct comparison with the SDC-IIb simulation: the outer tracker was turned on and the inner tracker was turned off.

c) A direct comparison with the SDC-IIc simulation: the outer tracker was turned off and the inner tracker was turned on.

Results:--

The quantities of the bremsstrahlung tails are shown in the E/p distributions in Fig. 3 for CDF*, and in Fig. 4 for SDC-IIIa, IIIb and IIIc. Bremsstrahlung tails are observable in the larger E/p values. To make a systematic comparison, first, qualities of the tracking systems are summarized in Table III: momentum resolutions (Gaussian fit), peaks and resolutions of the Track-Shower matching (Gaussian fit). Secondly, two variables were selected and efficiency-losses were summarized in Table IV: E/p and E_0/p. The E_0 is the energy at the origin and the E is the re-scaled or "calibrated"

energy which gives the peak at E_0 but has a spread due to the bremsstrahlung and the calorimeter resolution.

Listed in the Table IV are the fraction of events lost for the E/p or E_0/p cut being $0.5<E/p<2.0$, $0.5<E/p<1.5$, and $0.5<E/p<1.3$, to quantify the bremsstrahlung tail. The lower cut were imposed to reject the ill-fitted momentum, i.e. nearly straight lines which were observable when only the inner tracker was turned on; when this cut was not imposed, SDC-IIc and SDC-IIIc gave rather small losses. This lower cut correlates to the cut to the ratio of the HADRON calorimeter response to the EM calorimeter response to reject the fakes of overlapping of low-energy π^0's and high-energy $\pi^{\pm}$'s.

The Track-Shower position matching in the $r\phi$-direction, $min.\Delta_{\phi}^{SM}$, is shown for CDF* in Fig. 1(b) and for SDC-IIIc in Fig. 5. In the figures, the positive side is the bremsstrahlung side. In the Fig. 5, there is small tail in the positive side; large tail in the negative side. This is because the position matching was OR-ed with the wide(Δ_i<150 mm) or narrow(Δ_i<40 mm) calorimeter areas. Bremsstrahlung photons from up stream were discarded; shower position estimation was imperfect for the split energies of the bremsstrahlung photons and the electrons when the bremsstrahlung occurred down stream of or after the active tracker. For CDF*, the matching was calculated only for Δ_i<150 mm.

A cut on Track-Shower position matching, $|min.\Delta_{\phi}^{SM}| < 15$ mm in the $r\phi$-direction, was imposed in addition to the E/p cut for CDF*, SDC-IIIa, SDC-IIIb, and SDC-IIIc. As seen in the Fig. 5 and summarized in the Table III, the peaks were not located exactly zero because of imperfect accounting of bremsstrahlung in the track fitting and/or shower position estimation. The distances were calculated from the non-zero peaks. The efficiency-losses for the cuts are listed in Table IV. No cut was required in the z-direction because the resolutions were too good to cut at 15-30 mm and there was almost no effect of bremsstrahlung in this direction; in real analysis a cut in this direction will be placed to reduce background. Care should be taken: the z-resolution is not too good with the inner tracker only and usage of the full tracker is needed for the z matching.

Energy dependence of the losses were calculated for SDC-IIIa and -IIIc, and are plotted in Fig. 6. The Track-Shower position matching becomes more difficult in the lower momentum region. The inner tracker, or even the full tracker, has a long lever arm to the calorimeter and the materials in the arm degrade the matching, A further optimization for the calorimeter area might improve the position matching. Using either the inner or the full tracker, the efficiency-losses for the E/p cut ($0.5<E/p<1.5$) were 4-9% over the momentum range of 10 GeV/c $<p_t<$ 400 GeV/c. Together with the cut for the position

matching ($|min.\Delta_{\phi}^{SM}|$<15mm), the losses were increased to 7-12% over the momentum range.

Discussions on the numbers in the Table IV:--

The rows of CDF* in the Table IV are the same quantities as calculated by A.B.Wicklund in the ref. 6 (and SDC-I or SDC-IIb might correspond to his SDC calculation; only E/p was listed in the ref.); the E/p distributions shown in Fig. 3-4 have a Gaussian σ of about 5%. These values are consistent with his calculations. The losses in the distributed cases (SDC-III) are consistent with those of the collected cases (SDC-II), and actually better by 1-2% because a track is being sampled before it passes through the total material. Thus, existing data were reproduced and consistency between the distributed and collected cases were checked; the EGS calculations were verified to be correctly done.

The scaling factor, E/E_o, has peaks about 0.98 in CDF* and SDC's. This means that the peak-loss was mainly caused by the coil of 1.2 X_0; material in the tracking volume contributed very small perturbation other than the tail. In SDC's, the losses in E/p's were better by 2-5% than in E_o/p's. In a first glance, the fact that E/p is better than E_o/p is strange because E_o is a δ function while E is convoluted with the calorimeter resolution. The main reason for this was the finite calorimeter area of 150 mm. Large bremsstrahlung from up stream tends to miss this area so that the E is reduced and, hence, E/p becomes closer to unity. In CDF*, the losses in E/p's were as good as in E_o/p's. The amount of material of CDF (7.2% X_0) was much less than that of SDC (18.3% X_0), in addition to the difference of the resolving power, BL^2.

When the dead materials were in front of the active tracking volume (SDC-I, SDC-IIb, SDC-IIIb), the losses were very large (15-22% for $0.5<E/p<1.5$-1.3) compared with the case when materials were in the active volume (SDC-IIa, SDC-IIIa) (8-14%). Early sampling of the track helps to reduce the effect of bremsstrahlung; distributed materials in the tracking volume is approximately equivalent to half as much total materials collected in front of the tracking volume. The best result was obtained with the inner tracker only. By using only the inner tracker(SDC-IIc and SDC-IIIc), the momentum resolution was comparable with CDF and the losses for the E/p cut (5-7%) were comparable or better than CDF (6-9%). Even the absolute momentum was comparable as seen for the E_o/p cut. The materials in the inner tracker (6.8%; effective material being about 3.4%), was comparable with that of CDF (4.2%).

Care must be taken when an additional selection for Track-Shower position matching is introduced. As seen in the Table IV, when the Track-Shower matching cut, $|min.\Delta_{\phi}^{SM}|$<15 mm, was imposed in addition to the E/p

cut, the losses (10.8-10.7% in SDC-IIIa, -IIIc) were worse than that of CDF*(7.4%). As seen in Fig. 5, the tail in SDC-IIIc is in the opposite direction to the bremsstrahlung tail in CDF* in Fig. 3(b); the bremsstrahlung down stream caused more losses than upper stream.

Summary:--

The effect of material in the tracking volume in the baseline design of the SDC tracking system has been evaluated by constructing various cases with the EGS4 simulation. A major difference of the SDC tracking system from the conventional system is that the material is located at the measurement location/layer, rather than in front of the tracking system. Two types of simulations were made: collected in front of the tracking volume and as it is distributed. In both cases, electrons were swum in the magnetic field, showered in the material, and momentum of a track was fitted convoluting the measurement errors in the whole tracker, the outer only, or the inner tracker only. No bremsstrahlung identification was attempted. The effect of the electron bremsstrahlung in the various cases were compared for the positrons of E_{t0}=20 GeV and at η=0.5.

The result obtained for the case in which all the materials were collected in front of the active inner and outer tracking volume was the worst (SDC-I). Distributing the materials and including the inner tracker reduced the losses (SDC-IIb → SDC-IIa → SDC-IIc and SDC-IIIb → SDC-IIIa → SDC-IIIc); the best result was obtained by using only the inner tracker. This is understood in that early sampling and track-fitting mitigates the bremsstrahlung in the material. The inner tracker provided comparable or better efficiency in E/p (5% loss for $0.5<E/p<1.5$) and comparable momentum resolution to CDF.

A caution should be taken for the Track-Shower position matching. The SDC condition: larger resolving power, BL^2, and more material in the tracking volume than CDF, makes the shower position estimation more difficult. To match the momentum measurement, the calorimeter area should be either narrow enough if bremsstrahlung occurs up stream or wide enough if bremsstrahlung occurs down stream. The position matching distance was calculated for the energy-deposit either within 150 mm or 40 mm in the Shower-Max detector and the minimum was taken for the event. By narrowing the calorimeter area, the bremsstrahlung up stream was mitigated and the materials down stream or after the active tracker degraded the efficiency and gave the limit (the loss was 10.7% for $0.5<E/p<1.5$ and $|min.\Delta_{\phi}^{SM}|<15$ mm).

Over the momentum range of 10 GeV/c < p_t < 400 GeV/c, using either the inner or the whole tracker, the efficiency-losses for the E/p cut, $0.5<E/p<1.5$, varied 4-9%; the losses were increased to 7-12% together with the Track-Shower position matching cut($|min.\Delta_{\phi}^{SM}|<15$mm).

To take full advantage of the SDC tracking system, the inner tracker should be a momentum measurement device for low momentum tracks (in addition to the capabilities of pattern recognition in the vicinity of jets, vertexing, and momentum measurement of the TeV/c muons together with the outer tracker) with the minimum material in the outer tracker. The engineering baseline design has not been optimized for either physics nor cost; the Si system has been "re-designed" to cost[9]; a task force has been formed to evaluate the tracking system[10]. With change of the geometry, the above numbers must be re-evaluated. Vis-a-vis, the evaluation must lead to an optimized design of the SDC tracker.

References

[1] R. Amendolia et al., Report of the Task Force on R&D Directions for Tracking, SDC-91-00055, April, 1991

[2] A task force has been formed in the SDC collaboration to assess the issue. Studies have been reported in the collaboration meetings at SSCL (June, 1991) and at LBL (Aug., 1991) chaired by John Matthews.

[3] In the ref. 1, the material is about 15% at 90°, and adding the internal bremsstrahlung of 2.5% and the air in the volume of 1.1% results in 18.6% which is close to my own estimation of 18.3%.

[4] F. Abe et al., CDF collaboration, Phys. Rev. D43(1991)664, Phys. Rev. D43(1991)2070

[5] W.R. Nelson, H. Hirayama, D.W.O. Rogers, The EGS4 code system, SLAC-265

[6] A.B.Wicklund, "*E/p* Issues for SDC", June 17, 1991

[7] There are several ways to identify the bremsstrahlung: χ^2 cut, Momentum/Energy change of more than half, etc. in the track reconstruction/fitting. In this note, no bremsstrahlung identification was attempted in order not to introduce ambiguity with the identification.

[8] This process was invented to account for the shower spread in the calorimeter and to collect charged tracks in the shower (at the shower max detector) within 150 mm from the extrapolated track from the tracker. Neutrals were discarded. The number of charged tracks was large enough not to introduce further fluctuation; σ_E/E were 3.3-3.4% for all the models at 20 GeV.

[9] Y. Unno and A. Seiden, SDC-91-134

[10] Chairperson: T. Kondo, Tracking Evaluation Committee, formed Nov. 1991; report due by Feb., 1992.

Table Captions

Table I. Number of hits or super-layers and resolutions of the hits or the super-layers in the baseline design of the SDC tracking system and of the CDF.

Table II. Summary of material thicknesses in the studied cases. The baseline design of the SDC tracking system consists of the inner with the Si system and of the outer with the Scifi and Straw system.

Table III. Summary of qualities of the tracking system of the studied cases for the baseline design of the SDC tracking system: Momentum resolution, Track-Shower matching in the ϕ and z directions at the shower max. detector (SM). Values are for the Gaussian sigmas and its peaks.

Table IV. Event-loss fractions for the E/p and E_0/p cut in the simulated cases of the SDC tracking system for positrons of E_{t0}=20GeV and at η=0.5. The cases with an additional cut for the Track-Shower position matching are also appended.

Figure Captions

Fig. 1 The baseline design of the SDC tracking system.

Fig. 2 The distances between the photons and the secondary electrons at the radius of r_o=2100 mm for the bremsstrahlung at a radius r in the magnetic field of 2 Tesla.

Fig. 3 Distributions from the CDF* simulation: (a) E/p, and (b) Track-Shower position matching in the $r\phi$ direction, $min.\Delta_{\phi}^{SM}$. Bremsstrahlung tail is seen on the positive side.

Fig. 4 E/p distributions from the SDC-III simulations: (a) SDC-IIIa (the full tracker), (b) SDC-IIIb (the outer tracker), and (c) SDC-IIIc (the inner tracker)

Fig. 5 Distribution of the Track-Shower position matching in the $r\phi$ direction, $min.\Delta_{\phi}^{SM}$ from the SDC-IIIc simulation. A larger tail is seen on the negative side caused by the bremsstrahlung down stream.

Fig. 6 Transverse momentum dependence of the efficiency-losses for the E/p cut and for the combined cut of the E/p and the Track-Shower position matching, $min.\Delta_{\phi}^{SM}$, by using the inner tracker or the full tracker (inner+outer) of the SDC tracking system.

Table I. Number of hits or super-layers and resolutions of the hits or the super-layers in the baseline design of the SDC tracking system and of the CDF.

Tracking system	Components	#hits	$r\phi$-resolution	z-resolution
SDC:				
Inner	Si (Pixels + strips[a])	2+2×8=16	15 μm	3.0 mm
Outer	Scifi + Straw superlayers	3+4=7[b]	60 μm	1.2 mm
CDF:				
Central(CTC)	Jet super layer	9	100 μm	2.0 mm

[a] Si-strips are double-sided and have two hits per layer.
b One hit represents a superlayer with a combined resolution.

Table II. Summary of material thicknesses in the studied cases. The baseline design of the SDC tracking system consists of the inner with the Si system and of the outer with the Scifi and Straw system.

Cases	Materials	Total [X_0]
CDF*	2.5%(IB)+0.36%(BP)+3.2%(Al@r=180mm)+1.1%(Air)	7.2%
(CDF[a]	2.5%(IB)+4.6%	7.1%)
SDC-I	2.5%(IB)+0.36%(BP)+14.1%(Al@r=180mm)+1.1%(Air)	18.1%
SDC-II	2.5%(IB)+0.36%(BP)+6.6%(Al@r=50mm) +8.2%(Al@r=700mm)+0.6%[b](Air)	18.2%
SDC-III	2.5%(IB)+0.36%(BP)+6.8%(Si)[c] +8.6%(Scifi+Straw)[c]	18.3%

IB: internal bremsstrahlung, BP: beam pipe, Al: aluminum, Air: the air

[a]Ref. 6,

[b]The amount happened to be the value due to the simulation technicality

[c]The material includes sensors, supports, and gas/air in the volume.

Table III. Summary of qualities of the tracking system of the studied cases for the baseline design of the SDC tracking system: Momentum resolution, Track-Shower matching in the ϕ and z directions at the shower max. detector (SM). Values are for the Gaussian sigmas and its peaks.

Cases	$1/p_t$ σ_{p_t}/p_t [GeV/c^{-1}]	$\langle\Delta_\phi^{SM}\rangle$ [mm]	$\sigma_{\Delta_\phi}^{SM}$ [mm]	$\langle\Delta_z^{SM}\rangle$ [mm]	$\sigma_{\Delta_z}^{SM}$ [mm]
CDF*	0.0016	1.0	1.5	0.0	2.1
(CDF[a]	0.002	-	~2.1	-	~4.6)
SDC-I	0.0006	1.9	1.5	0.0	1.6
SDC-IIa	0.0005	-	-	-	-
SDC-IIb	0.0012	-	-	-	-
SDC-IIc	0.0013	-	-	-	-
SDC-IIIa	0.0005	1.4	1.6	0.0	1.6
SDC-IIIb	0.0014	1.2	2.0	0.0	1.9
SDC-IIIc	0.0016	-2.6	2.7	0.0	12.5

[a]Ref. 4. The widths of the Track-Shower matching were obtained by eyeball-fitting for the distributions which passed through E/p cut.

Table IV. Event-loss fractions for the E/p and E_0/p cut in the simulated cases of the SDC tracking system for positrons of E_{t0}=20GeV and at η=0.5. The cases with an additional cut for the Track-Shower position matching are also appended.

Cases	E/p [a] cut 0.5< and <2.0	<1.5	<1.3	E_0/p [a] cut <0.5 and <2.0	<1.5	<1.3	E/E_0 peak[b]
CDF*	4.1%	6.8%	9.6%	4.4%	7.1%	9.9%	0.9843
	3.3%[c]	6.1%[c]	9.0%[c]	-	-	-	
(CDF[d]	3.3%[c]	5.8%[c]	8.3%[c]	-	-	-	-)
SDC-I	7.0%	14.6%	21.9%	12.6%	19.9%	26.7%	0.9804
SDC-IIa	3.4%	7.7%	13.6%	6.4%	10.4%	16.4%	0.9816
SDC-IIb	8.3%	15.7%	22.3%	12.0%	19.4%	25.9%	0.9816
SDC-IIc	3.1%	6.6%	9.5%	5.5%	8.6%	11.4%	0.9816
SDC-IIIa	3.9%	8.5%	12.5%	6.3%	10.6%	14.9%	0.9808
SDC-IIIb	7.3%	13.0%	19.6%	9.8%	15.2%	20.7%	0.9808
SDC-IIIc	2.6%	5.0%	7.1%	3.9%	6.4%	8.5%	0.9808
Imposing an additional cut: $\lvert min.\Delta_{\phi}^{SM} \rvert$<15 mm							
CDF*	5.0%	7.4%	9.9%				
SDC-IIIa	6.7%	10.8%	14.4%	-	-	-	
SDC-IIIb	8.4%	14.3%	19.3%	-	-	-	
SDC-IIIc	9.0%	10.7%	12.7%	-	-	-	

[a] The values are based on about 4000 Monte Carlo events and typical statistical error is ±0.5% at 10% loss.

[b] Typical statistical error is ±0.0006.

[c] Losses are for E/p or E_0/p cut <2.0, <1.5, and <1.3; E/p or E_0/p cut >0.5 was not imposed.

[d] Ref. 6.

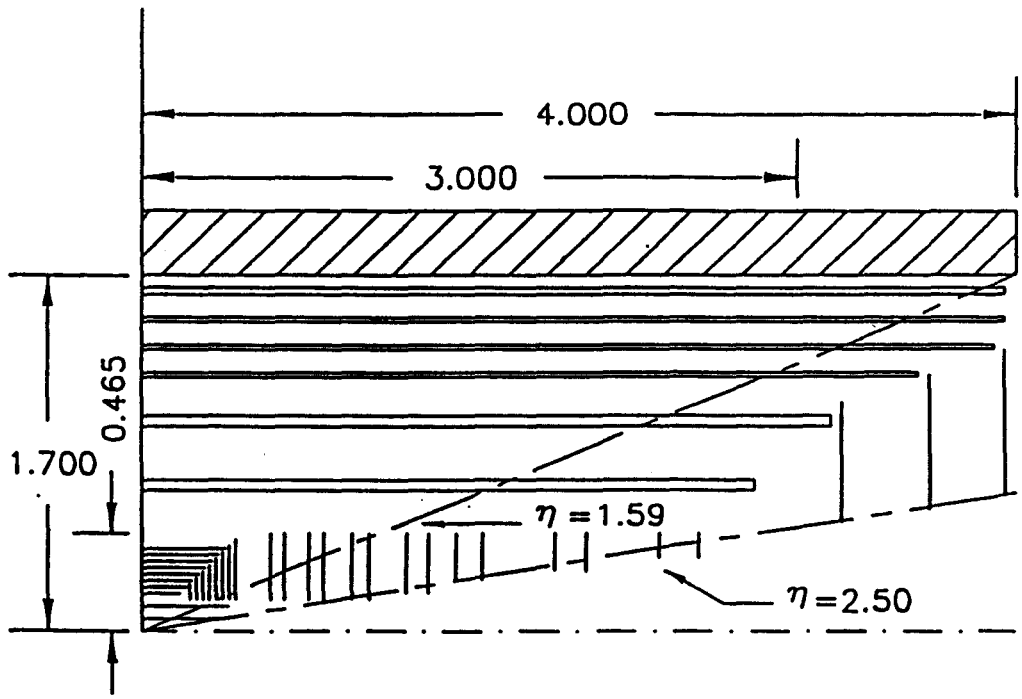

Fig. 1 The baseline design of the SDC tracking system.

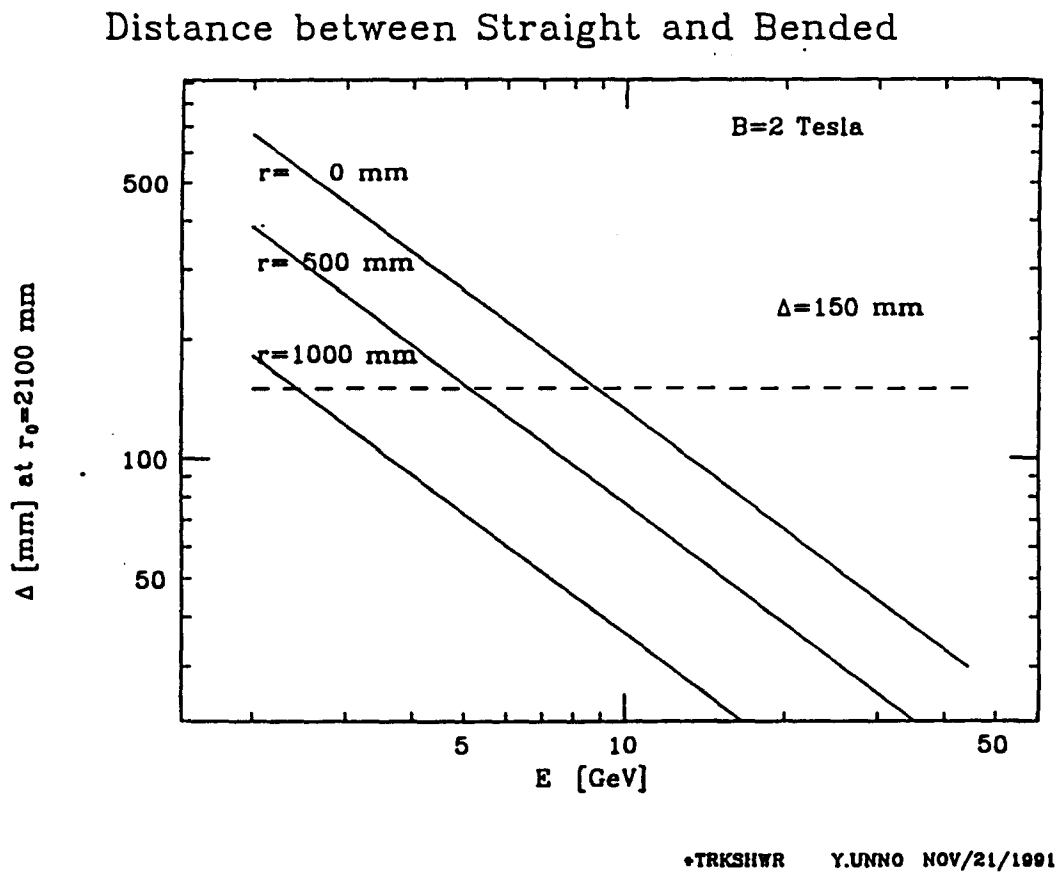

Fig. 2 The distances between the photons and the secondary electrons at the radius of r_0=2100 mm for the bremsstrahlung at a radius r in the magnetic field of 2 Tesla.

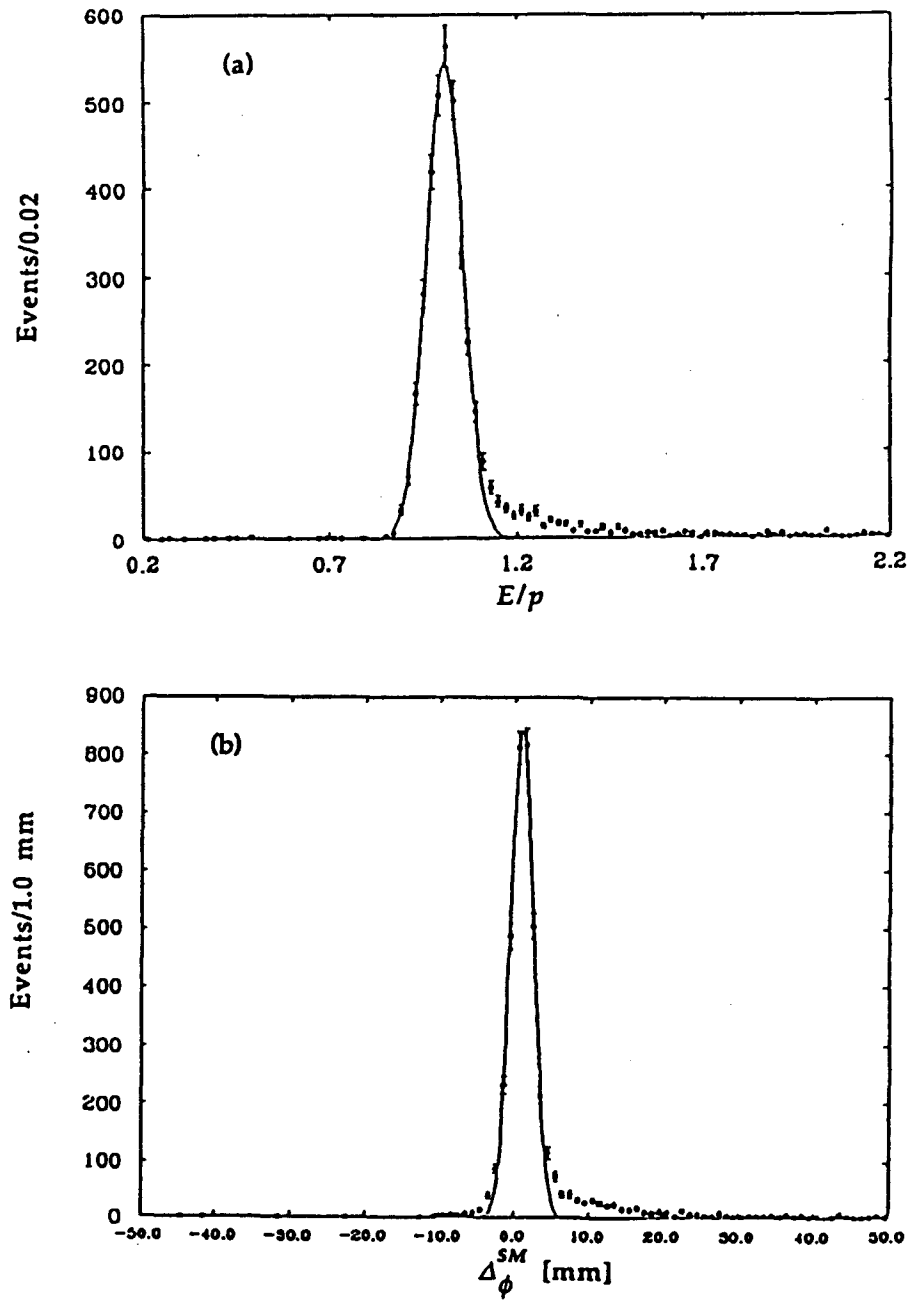

Fig. 3 Distributions from the CDF* simulation: (a) E/p, and (b) Track-Shower position matching in the $r\phi$ direction, $min.\Delta_{\phi}^{SM}$. Bremsstrahlung tail is seen on the positive side.

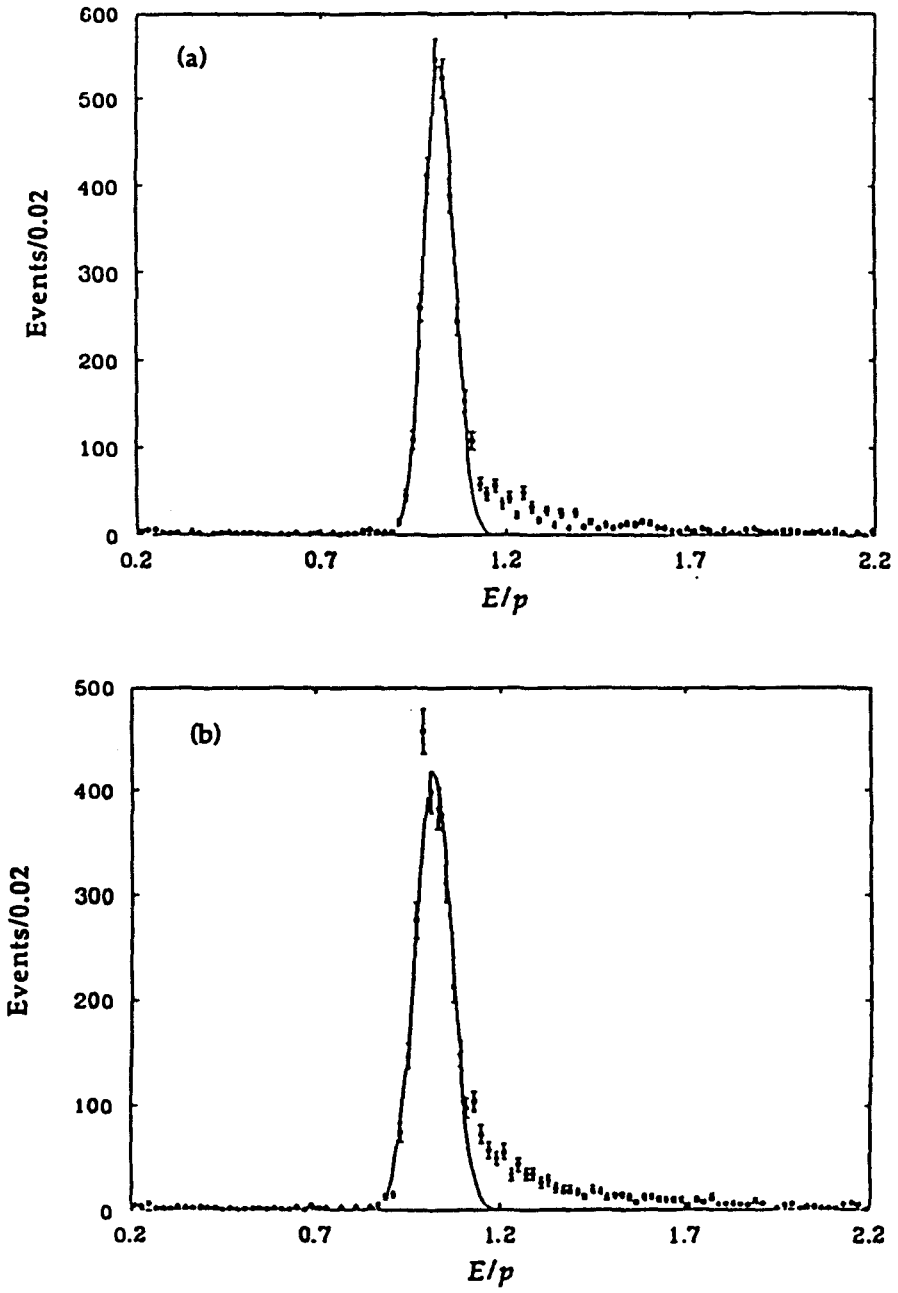

Fig. 4 E/p distributions from the SDC-III simulations: (a) SDC-IIIa (the full tracker), (b) SDC-IIIb (the outer tracker), and (c) SDC-IIIc (the inner tracker)

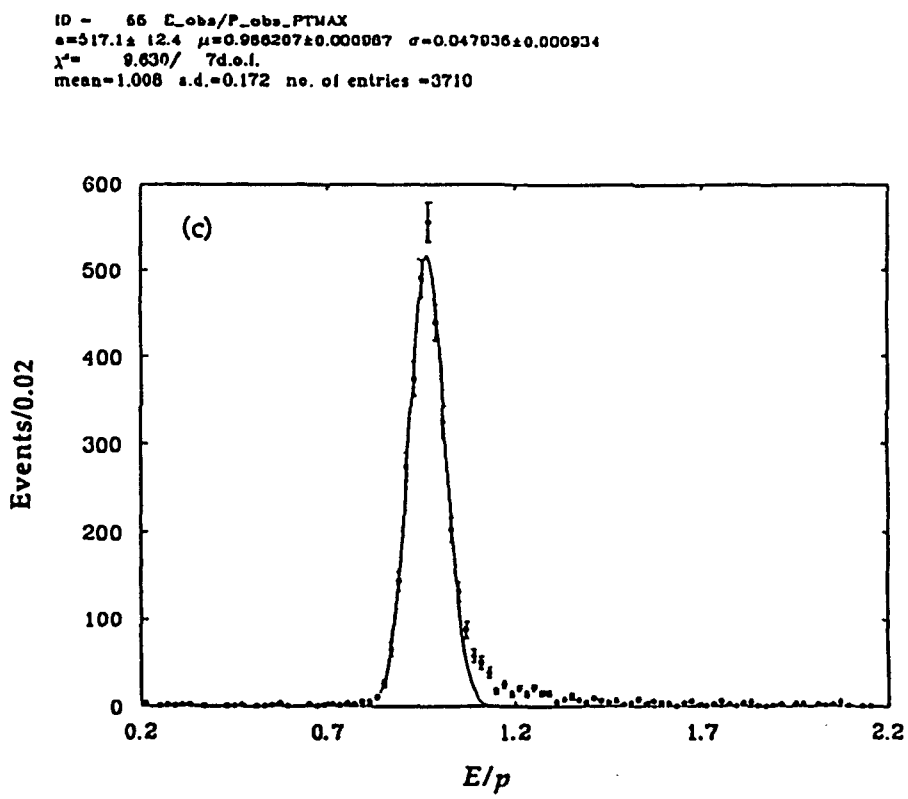

Fig. 4 Continued

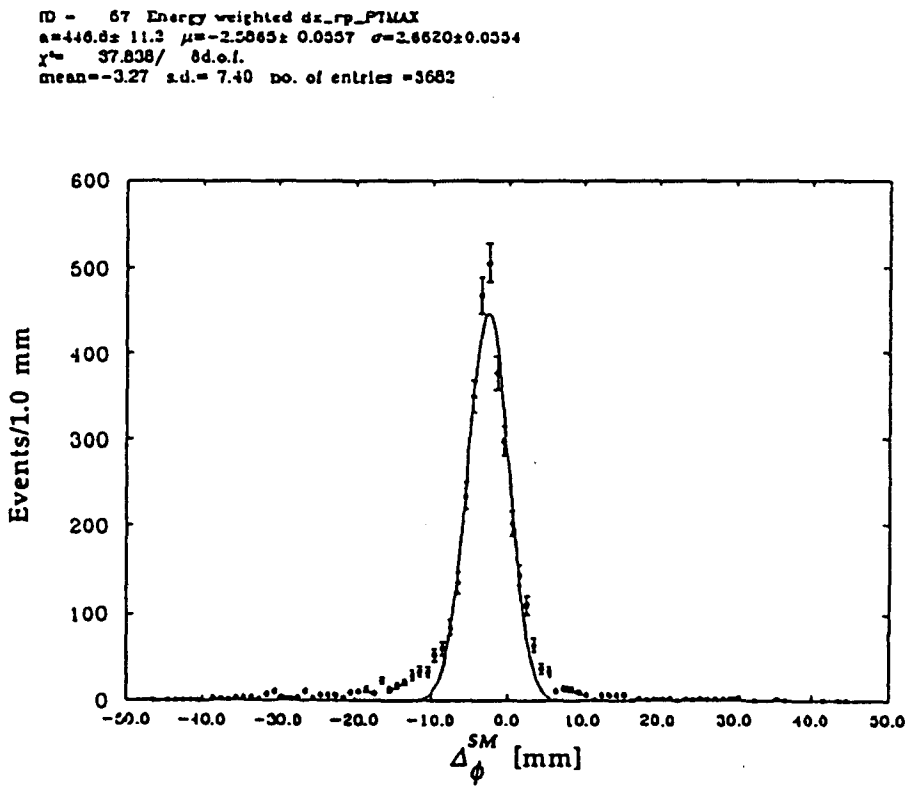

Fig. 5 Distribution of the Track-Shower position matching in the $r\phi$ direction, $min.\Delta_\phi^{SM}$ from the SDC-IIIc simulation. A larger tail is seen on the negative side caused by the bremsstrahlung down stream.

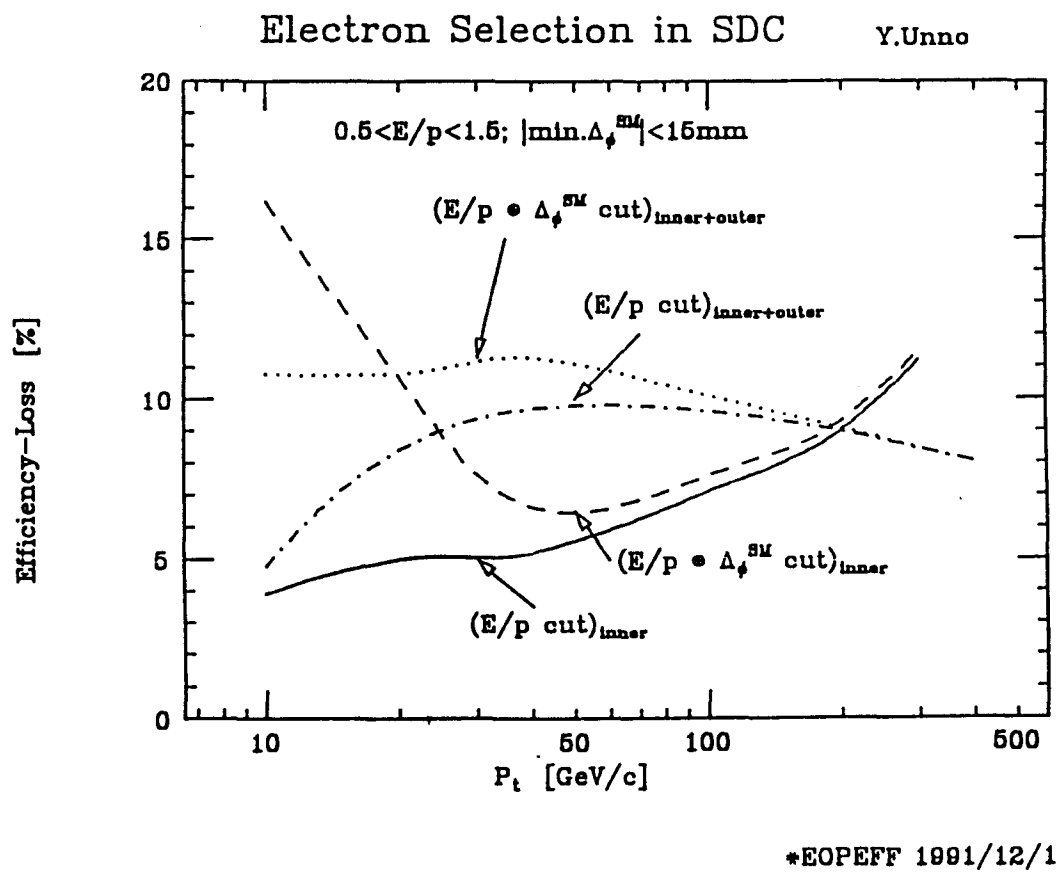

Fig. 6 Transverse momentum dependence of the efficiency-losses for the E/p cut and for the combined cut of the E/p and the Track-Shower position matching, $min.\Delta_{\phi}^{SM}$, by using the inner tracker or the full tracker (inner+outer) of the SDC tracking system.