Conceptual Design Report
on
the Belle Inner Tracker Upgrade

Inner Tracker Upgrade Task Force

Ver.1.00

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Abstract

The necessity to upgrade the cathode part of the CDC is explained, emphasizing the importance of the upgrade study of the SVD and CDC jointly. An overview of the new inner tracker, which consists of the enlarged SVD with 5 layers of double-sided silicon strip detectors and two layers of small-cell drift chamber, are described. The expected performance of the inner tracker is also shown in terms of the trigger, low-momentum tracking, and the vertex resolution.

Contents

Chapter 1

Overview

1.1 Movivation for the upgrade

Although the Belle detector[1] is working fine for the moment, we have noticed that some parts of the detector are starting to suffer from the high beam backgrounds and may need to be upgraded. In particular, the Silicon Vertex Detector (SVD) and the inner part of the Central Drift Chamber (CDC) are showing the effects of high rates. Since we foresee even higher beam current in future machine runs, there is an urgent need to think about detector upgrades.

An upgrade plan for the SVD has been worked out, and has been reviewed by external committees[2]. The plan is to install the new radiation-hard SVD (called SVD2.0) in 2002, replacing the present one (called SVD1.4 for a historical reason). On the other hand, an upgrade plan of the CDC[3]. has not been thought out. Therefore we decided to set up a task force to study the possible detector upgrade of the SVD and the CDC jointly. A consideration behind this is that the replacement of the inner part of the CDC is closely coupled to the upgrade plan of the SVD in two ways: 1) one possiblity is to replace the inner portion of the CDC with an expanded SVD; and 2) if we do so, we have to examine various technical feasiblity and also re-optimization of the SVD design may be needed.

The task force first assessed the expected lifetime of the current CDC using reasonable assumptions regarding the increase of luminosity and backgrounds. We considered both hard failures (e.g., HV instability due to aging) and soft degradation of performance over time, as explained in later sections. Based on that study, we concluded that we need to replace the cathode part of the CDC.

We believe that one of the primary roles of the new inner tracker should be to improve the low-momentum track reconstruction which has the direct impact on physics analyses. It will be beneficial to any mode that requires the detection of slow pions from D^*. The effective efficiency of the flavor tagging is also expected to be increased. One solution to this end is to add another layer of silicon ladders so that we can reconstruct low momentum tracks with the new 5-layer SVD alone.[1] This also seems to be a good solution considering

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[1] Although we should demonstrate the superiority of 5-layer SVD to 4-layer design by ourselves which is in progress, we can here refer to a study done by BaBar group[4] to know how 5-layer SVT improves the track reconstruction for $Pt < 90 MeV/c$ compared with the 4-layer design.

the expertise and infrastructure in hand for the upgrade. It is also possible to re-design the whole SVD with five layers that would give the better performance. Note that adding two more ladders (six-layer SVD !) seems to be beyond the capability of the present SVD group and the gain in physics analyses is questionable. We also need to remember that adding more material in general results in more photon conversions, losing the sensitivity to some of very important rare processes such as radiative B-meson decays and modes that include π^0 in the final states.

Along this line we compiled a list of upgrade options, in each listing the pro's and con's, as well as estimation of the approximate cost and time required to complete the upgrade. Further narrowing down the options, the task force finally came up with a proposal to replace the cathode part with the 5th SVD layer and two layers of small-cell drift chamber. As we emphasize the importance of reinforcing the low momentum tracking and tracking trigger as well, the new design is often called the Inner Tracker (IT). The outline of this report is as follows: the motivation, requirements and an overview of the upgrade are given in this chapter. We describe some detail of the new trigger system and the small-cell drift chamber in Chapters 2 and 3. Then we explain the expected performance of the new IT in terms of the low momentum track finding and impact parameter resolutions in Chapter 4, before we summarize the report in Chapter 5. Note that the detail of the new SVD design is found elsewhere[2]. The technical detail of the proposed SVD trigger system is also found in the same reference.

1.2 CDC lifetime

In the following, first we discuss the expected lifetime of the CDC (Section 1.2) which was the original motivation of the upgrade study, showing the consensus we obtained throughout the study.

Before continuing, we define the nomenclature on the CDC structure used in the following discussion. Fig.1.1 diplays the super-layer structure of the CDC. As shown in the figure, the layer 0, 1 and 2 correspond to the cathode part, the part for layers 3 to 13 has the conical shape when viewed in the r-z plane and is called the inner part (i.e. note that the inner part does not include the cathode part), and the layers 14 to 49 form the main part.

By the increase of the beam currents, one can think of the following three problems:

- gain drop,
- large dead time due to high hit rate and
- instable operation (trips, frequent transition to the current-limit mode).

In the following we look into each issue in turn.

1.2.1 Gain drop

So far there is no gain drop observed even in the layer 1 as shown in Fig.1.2. The total

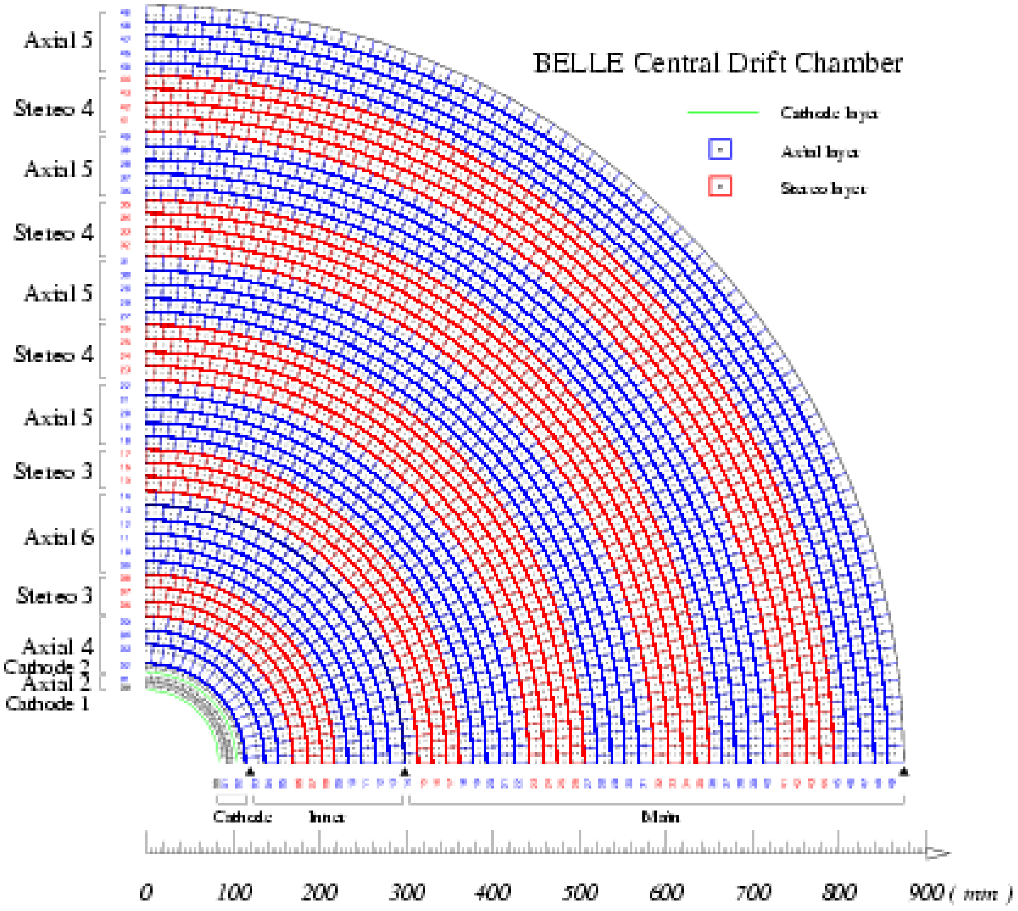

Figure 1.1: The super-layer structure of the CDC in the $r\phi$ view.

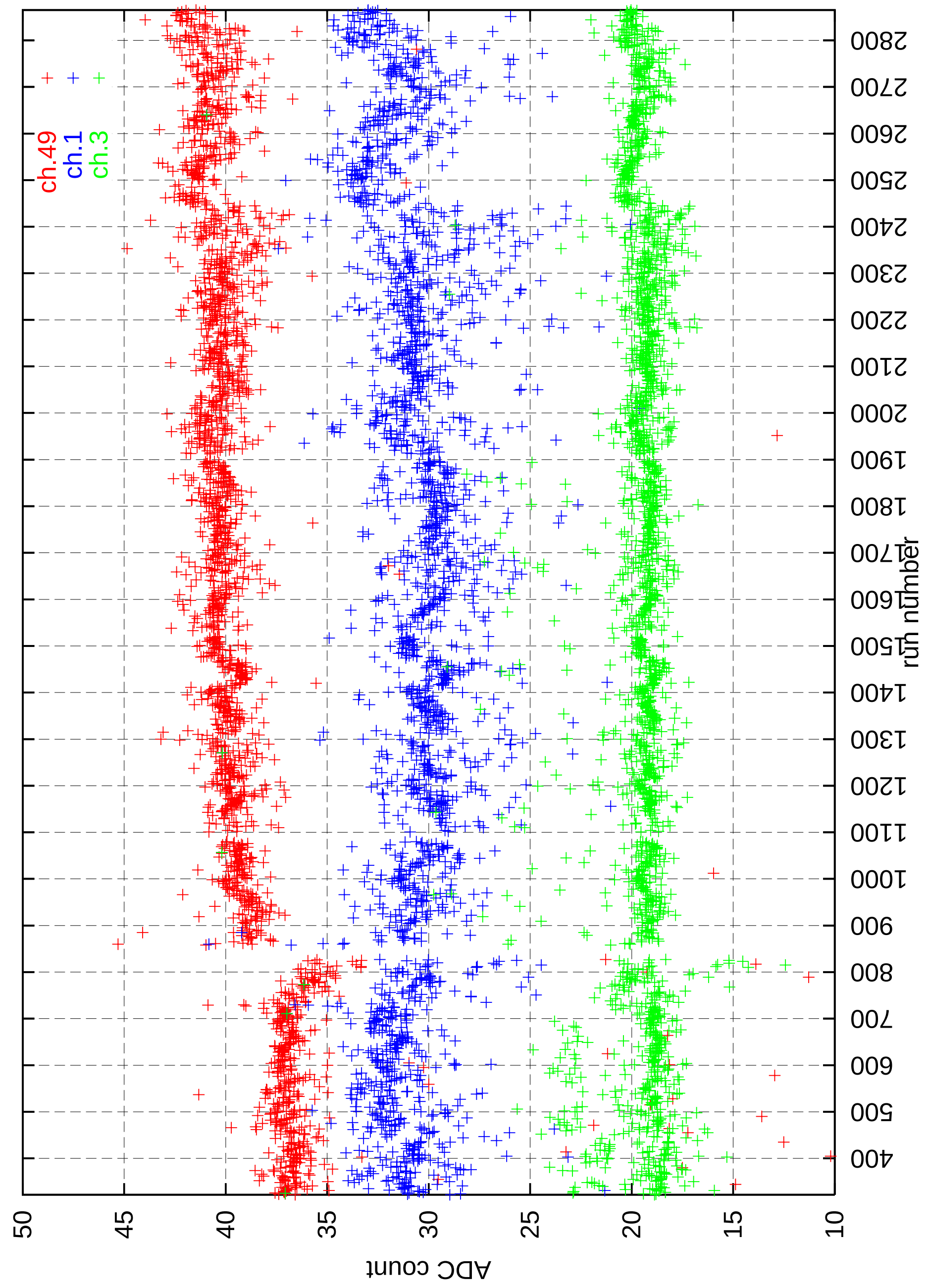

Figure 1.2: The gains of the CDC layers 1, 3 and 49 vs. run numbers.

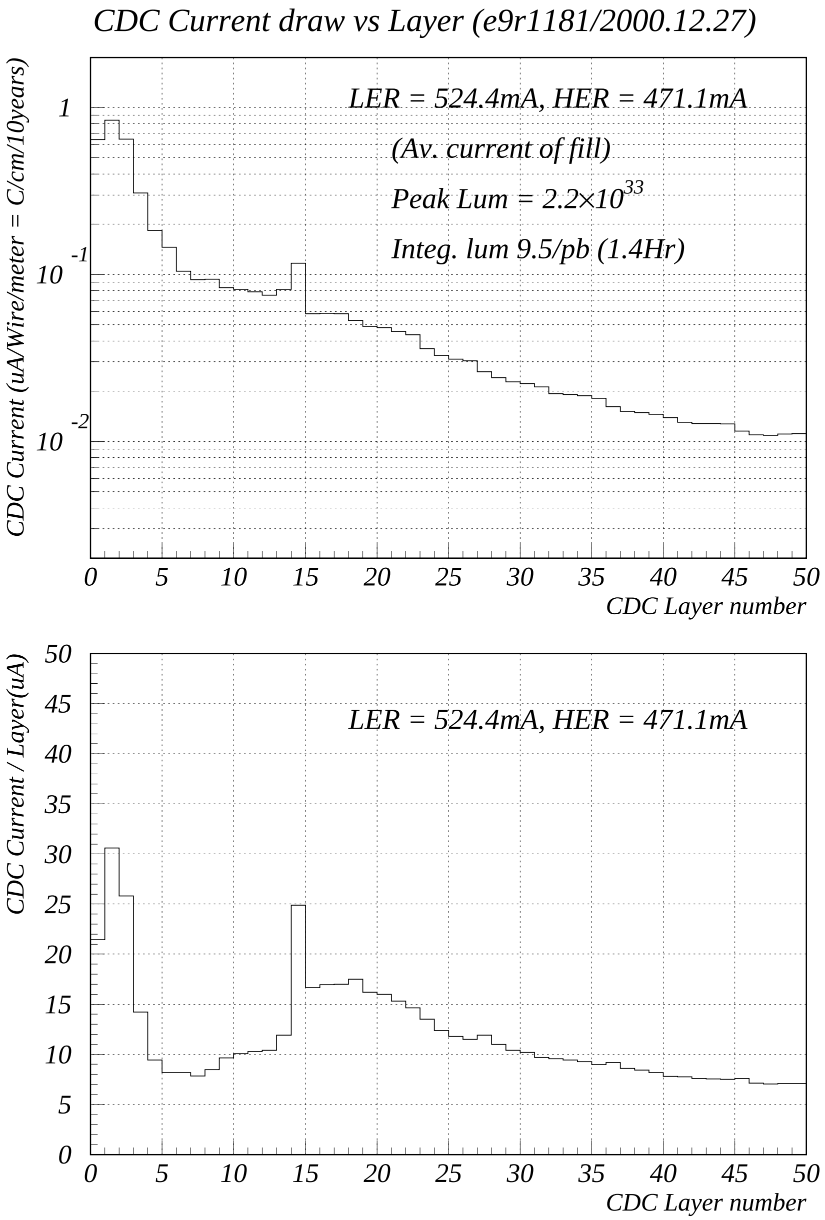

Figure 1.3: The CDC current draw in each layer.

charge on the sense wires of the first layer, however, already exceeded around 0.1C/cm. According to the test results obtained 5 years ago, expected gain drop with this amount of total charge is 1-10% depending on the number of days before getting irradiation. Thus even if we can keep the present level of the annual accumulated charge, the total amount of charge after 5 years of operation can be 0.5C/cm and there is no guarantee for the good performance in this case. Therefore it would be desirable to replace the cathode part with this reason.

The next question is if we need to replace the inner (conical) part of the CDC. Given the fact that we have not seen any gain drop yet, we can not predict the lifetime by extrapolating the gain curve. However we can make some arguments based on the difference in the current draw among wires in different layers. As shown in Fig.1.3, the current draw per wire in the layer 4 is about five times as small as that in the layer 1. Assuming that the current draw is kept at about the same level, the expected total charge on each wire in the layer 4 will be 0.1C/cm after five years of operation. As we do not see any gain drop in the layer 1 with this level of total charge, in this case we expect the stable gain in the layer 4 for next five years. In addition, based on the result of the gain drop measurement done as a part of the R&D of the CDC, an increase of current draw by a factor of about three will probably be tolerable before we start seeing deterioration in the performance.

On the other hand, assuming the linear increase of current draw as a function of beam current, for example, the layer 4 loses any margin at the full beam current and will be just OK for five years of operation. The beampipe with the smaller radius, which is planned to be introduced for SVD2.0, may cause more particles hitting near the IP (the IP masks mostly) and may result in the larger background in the CDC. Thus one of the key questions is how much we can reduce the background at the full beam current. The present best estimation is that the hit rate will increase typically by a factor of five which seems acceptable, although not much margin with it, for the CDC. The detail of such studies is given in the IR section of the SVD2.0 TDR[2].

1.2.2 Hit rate

According to the investigation before the summer shutdown in 2000, the back-scattered high-energy (about 30keV) X-ray from the High Energy Ring (HER, i.e. the electron ring) was the dominant source of the CDC background except for the four innermost layers. Thanks to various modifications made during the shutdown such as the reshaped copper chamber, the thick gold layer inside the IP chamber, the larger tungsten mask on the IP chamber, the hit rate was reduced successfully by a factor of five. Thus it is expected that we will be able to operate the CDC with the design HER current which is about twice as large as the value in the runs before the summer 2000 shutdown.

As for the Low Energy Ring (LER, i.e. the positron ring), the background was also reduced by a factor of two compared with the situation before the summer 2000 shutdown with the new usable masks, further scrubbing and the new tungsten mask on the QCS-R chamber. The present hit rate of ∼0.5kHz at 400mA in the layer 4 would be scaled to ∼21kHz at 2600mA conservatively assuming quadratic dependence on the beam current. This is still smaller than the hit rate of the layer 0 in runs during Jan.-July 2000 which was typically 130kHz/wire with the maximum beam currents (I_LER=700mA, I_HER=500mA) that we achieved. The inefficiency in this case was about 10% in the layer 0. Therefore as far as the hit rate is concerned, the present CDC (except layers 0 to 3) will probably survive the full current operation. We would like to point out, however, that the hit rate can further be reduced by modifying the CDC read-out electronics, for example by reducing the deadtime in MQTs. As the new beampipe with the smaller radius may cause unexpectedly high background rate, it will be quite important to reduce the deadtime in the CDC read-out electronics. We will discuss this issue and show our plan in Chapter3.

1.2.3 Stability

There is a threshold on the current draw in each layer of the CDC. If the current on the wire exceeds the threshold, the layer goes into "the current limit mode" in which the HV is lowered automatically. In this mode the entire Belle DAQ is paused. The deadtime from the "current limit mode" is typically less than 1% except at the beginning of bad fills. In this condition, we had a safety margin of a factor of about three before getting into trouble. As the current in the layer 4 is typically five times as small as that in the first layer, the relative deadtime caused by the layer 4 is also about a fifth, i.e. we have another factor of five. The "trip"s of the CDC are less frequent. Thus we will not make a special effort to reduce it. However one has to remember that it is difficult to raise the present trip level.[2]

1.2.4 Summary

Considering what was described in the previous sections, we came into the following consensus:

- If the background level does not go up compared with the present level, there is no urgent need to replace the most of the inner part (layers 4-13) of the CDC, probably until 2005. The layer 3 seems to be marginal. Also no urgent need to replace the main part (layers 14-49). Therefore a replacement of the entire CDC is not an attractive scenario considering the required person power and the very tight schedule. A partial replacement of the inner (conical) part is also unrealistic.

- We need to make efforts to reduce background level by all means so that the above assumption on the background level is realized. Although we already have fairly good understanding and prediction of the hit rate and radiation dose (see the SVD2.0 TDR for detail), we should continue investigating how much additional background we will have by the new beampipe with the smaller radius.

- It is desirable to replace the cathode part (layers 0-2). The replacement in 2002 will be ideal, although careful consideration of schedule is required.

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[2] It is also difficult to predict the likely case at the full beam current as the trip rate depends on many factors.

- We need to look into new electronics for the CDC that has the smaller deadtime.

1.3 Requirements on trigger

As will be explained in the next chapter, the estimated the Level-1 (L1) hardware trigger rate at the design current could be about 1.4kHz which is far beyond the limit of the bandwidth of the DAQ system.[3] Although this estimation has rather large ambiguity, we should be prepared for this case and the rate reduction before the online computing farm (or in other words before the L2 trigger) seems mandatory. Therefore we do need to pursue the SVD trigger.

The primary role of the present CDC cathode layers is to provide the L1 trigger signal. Until now, the CDC cathode Z trigger has been providing the typical rate reduction of 0.8. In other words, the rate would go up from 150∼250Hz, which was the typical L1 rate, to 200∼300Hz without the cathode trigger.

Axial layers in the cathode part are also used in the innermost Trigger Segment Finder (TSF) for the $r\phi$ trigger. Thus the quality of the L1 $r\phi$ track trigger will be also degraded. Using data dedicated for beam background studies, it is estimated that we will see about 40% increase in the trigger rate with the present logic, if we take out the innermost TSF.

It is apparently desirable for the new inner tracker to have some trigger capability at least to compensate for the loss by taking out the cathode part. Therefore the question here is if we have matured technology to provide the SVD trigger, and if it is effective enough. As for the front-end VLSI technology, there is a commercially available chip called VA-TA (from IDE AS, Norway)[5] which is compatible with VA. R&D projects have been in progress to fabricate the VA-TA with $0.35\mu m$ technology which guarantees sufficient radiation tolerance.

The SVD L1 trigger with VATA is not the only possible solution to solve this L1 rate problem. In the Belle DAQ system, it is possible to abort the data taking in the read-out phase after a receipt of the L1 trigger. This abort scheme has not been used in the data taking so far, but it was implemented to cope with the situation where we encounter unexpectedly-large backgrounds. Thus one can implement somewhat better trigger logic with a longer latency to use this abort scheme. Such a trigger is called the Level 1.5 trigger (L1.5). As SVD FADCs do online cluster finding for sparcification, the SVD L1.5 can be implemented together with the existing readout system without VATA. Although the L1.5 trigger does not reduce the L1 dead time, it can solve the DAQ bottle-neck problem which is more serious at Belle. One technical necessity is to reduce the readout deadtime of the SVD which will be about 100μsec in case no improvement is made. In this case, the SVD L1.5 latency is also at least 100μsec (called "slow L1.5") and the L1 deadtime at the L1 rate of 1.5kHz will be 15% which is rather large. To reduce the deadtime we need to double the number of multiplexed readout channels of the SVD. This requires modifications of the repeater system. As the latency of 50μsec (called "fast L1.5") will be possible if this is done, the deadtime at 1.5kHz L1 rate will be 7.5% which

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[3] Even after the upgrade of the DAQ system, it is desirable to keep the input rate to the Level-2 (L2) software trigger below 500Hz.

is acceptable. Therefore even if VATA development will have some troubles, the SVD can solve the DAQ bottle-neck problem. Thus whether we need VATA or not is not a key question anymore. Note that it is still worth trying to implement VATA which is useful to reduce the L1 trigger deadtime. There is also potential possibility to use VATA outputs for the L0 trigger which is necessary to generate the hold signal to the VA readout circuitry.

For the SVD trigger it is certainly better to increase the number of DSSD layers. Thus a 5-layer SVD is superior to the 4-layer configuration. Remaining worries were possible degradation of the impact parameter resolution and the efficiency of the low momentum tracking due to the additional material in case of the 5-layer SVD. As will be explained in Chapter 4, however, that both results are better with the 5-layer SVD than the 4-layer case. Hence we conclude that we should pursue the 5-layer configuration as the default option.

1.4 Other types of detectors

Before showing an overview of our proposal, here we briefly mention other detector technologies. In a spirit of making a thorough investigation, we also considered silicon pads, SCIFI and straw tubes as alternative options. The cell size of the Si-PAD can well be below 1mm to guarantee the resolution of a few hundred microns. The front-end electronics is not easy, however, and it will be questionable if we will be able to develop and install something sufficient in 2002. Although SCIFI can provide the typical resolution of 1mm with the 1mm diameter and it is thin enough, we do not know how and where we have the optical connections. Also we will face the difficulty in the mechanical support for the light-guides or PMTs in the limited space. We also considered costs, radiation hardness, R&D issues etc., but the bottom line is that for us to accomplish the Belle upgrade in 2002, we could not find any advantages of SCIFI except trigger purpose with TOF counter information.

Straw tubes made of 50um-thick Kapton can also give the resolution of about 200um with the cell size of 4mm. One of the general advantages of the straw tubes is that they are quite light and therefore the multiple Coulomb scattering can be reduced. In our case, however, the CFRP inner cylinder is anyway necessary. Since the small-cell chamber will be a part of the CDC as will be explained in Chapter3, no additional thick structure is needed. Thus we could not find any advantage of straw tubes compared with the small-cell drift chamber.

To summarize, the 5th SVD layer together with additional axial layers with a small cell size seems to be best solution among all we have considered.

1.5 Inner Tracker Design Overview

Based on the discussion given so far, we propose to install the 5-layer SVD by removing the cathode part of the CDC. The new design will be beneficial to low-momentum tracking, as well as the L1 and/or L1.5 trigger. We will also be able to have larger clearance for SVD hybrids and cables which makes the design of the mechanical structure easier. Figure 1.4 is an rϕ view of the inner tracker which consists of the enlarged SVD and two layers of drift chamber with each cell size of 5mm.

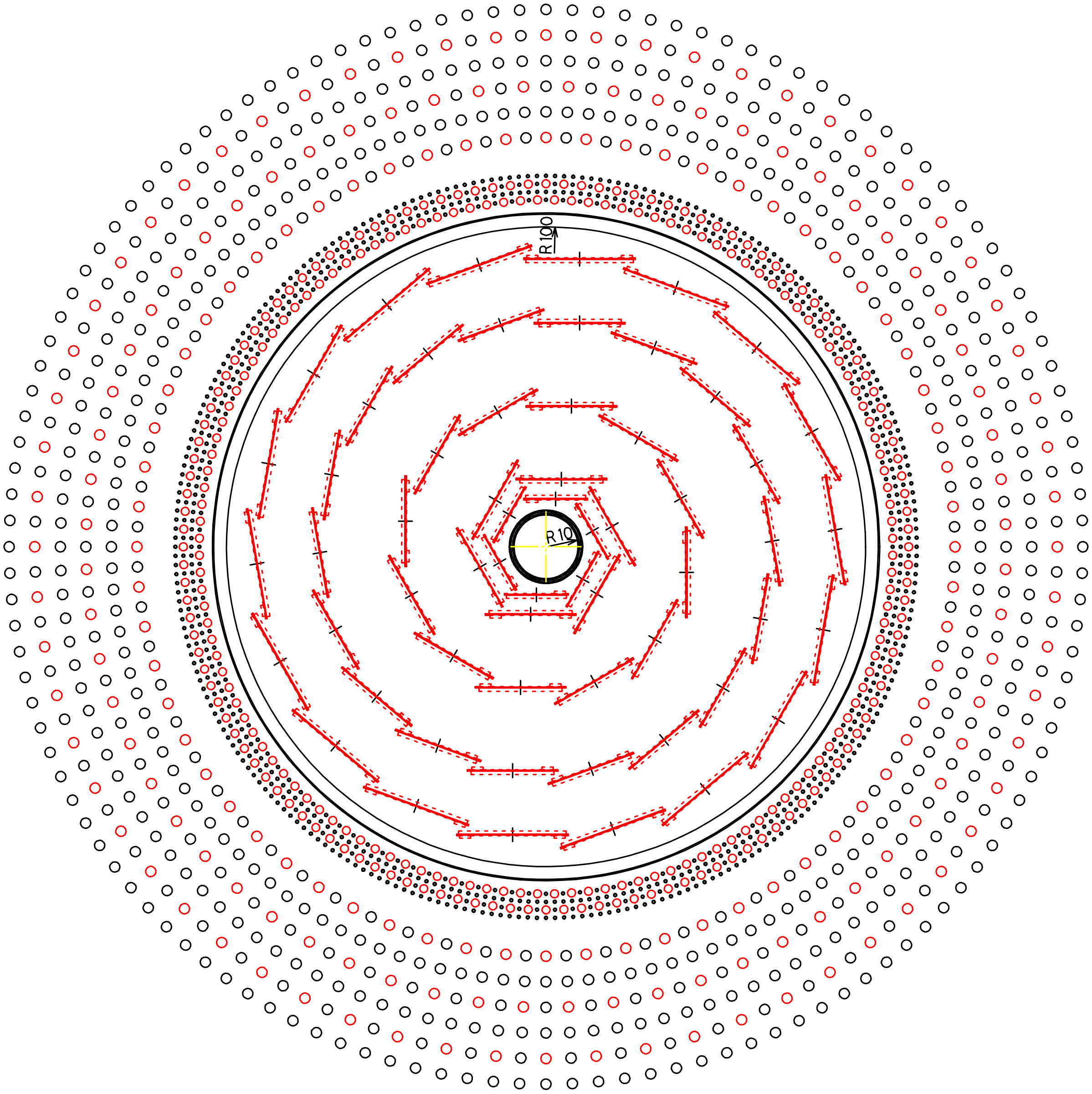

Figure 1.4: An rϕ view of the new inner tracker.

1.5.1 Enlarged SVD

The proposal by the SVD group which was also supported by the task force is as follows (for all three cases the SVD group plans the installtion in the summer 2002):

1. The SVD group pursues the 5-layer SVD with VATA as the "agressive" default option. As VATA includes on-chip DAC to provide bias voltages and currents, we can reduce the number of components in the repeater system and it is straightforward to implement the fast L1.5. Note that this option also requires new hybrids and the repeater system.

2. If some problems on VATA grow, we turn to conventional VA circuitry and implement the fast L1.5. This requires the new hybrids (to have two analog outputs per hybrid) and the repeater system.

3. If we also find that the fast L1.5 will not be in time for the installation in the summer 2002, we will go to the slow L1.5 option as a backup. In this case we just use frontend electronics components developed already. Yet we need some modification on the SVD FADCs (HALNYs) to provide L1.5 trigger information.

One of the virtues of this scenario is that there is no mechanical difference in these three options. Only the electronics is different. Although new DSSDs and relevant ladder assembly jigs have to be developed in any case, this will be feasible. Whether we can go to the agressive default with VATA or not will be determined in April 2001 after we evaluate the performance of VATA.

1.5.2 Small-cell drift chamber

The CDC group has proposed to add two axial layers with small cell size. The main movitation is to reinforce the L1 rϕ trigger. By adding two layers, each with 5mm-cell, the innermost TSF can be made of five axial layers. This configuration is expected to be robust enough in terms of the purity of the TSF hits. It can also be potentially useful to improve low-momentum tracking.

Note that such extension with a cell size of 5mm can live together with the 5-layer SVD. As shown in Table 1.5.2, whether we introduce such additional CDC layers or not does not cause much difference in the lever arm of the SVD.

	a) SVD(4 layer) + cathode	b) SVD(5 layer) + CDC inner cylinder	c) SVD(5 layer) + additional CDC layers
SVD outermost layer	60	90±2	85±2
outer radius of outer cover	74	105±2	100±2
used for CDC and/or SVD support	(min.) 77 (max.) 116	(min.) 107±2 (max.) 116	(min.) 102±2 (max.) 116
	(mm)	(mm)	(mm)

Table 1.1: Geometries in the radial direction for a) the present SVD, b) the new SVD without additional CDC layers and c) the new SVD with additional CDC layers.

Chapter 2

Trigger system

2.1 Level-1 trigger rate estimation

Assuming that we have neither the cathode nor SVD trigger, we have estimated the trigger rate at the design current, extrapolating the present condition and keeping the present trigger logic, where the present logic is realized as the logical "OR" of the following sub-triggers:

- Two-track trigger
- Energy trigger
- pre-scaled Bhabha trigger
- other miscellaneous trigger

The basic idea behind it is to keep the logic loose enough to take all the physics modes of interest with very high (∼100%) efficiency, where such modes include not only B decays but decays of τ and two-photon processes.

Based on the background study made on July 5, 2000 (LER/HER single beams), as shown in Fig.2.1, the trigger rate will be ∼630Hz from LER at 2.6A, and ∼310Hz from HER at 1.1A assuming quadratic increase with the beam current. Without the cathode z trigger we will have 20% increase in the trigger rate. Thus the estimated trigger rate from single beams will be (630Hz + 310Hz) x 1.2 = 1130Hz (assuming that the performance of the $r\phi$ track trigger remains the same thanks to two layers of 5mm-cell chamber). The physics rates (proportional to the luminosity) will be ∼225Hz at $L = 10^{34} cm^{-2} s^{-1}$. See the following table: For the high-current operation we also need to consider some beam-beam effects but there is no quantitative estimation. Adding all, the total trigger rate will be ∼1355Hz + (beam-beam). Fig.2.2 shows the relation between the measured trigger rate and expected rate calculated ignoring the beam-beam effect, which shows a good agreement. The rate of $\sim 1.4kHz$ is beyond the capability of the Belle DAQ system. According to the DAQ upgrade proposal[6], the input rate to the L2 trigger should be below 700Hz. Taking some margin for safety, our goal will be to reduce it to 500Hz.

Physics	40Hz/10^{33}	225Hz/$10^{34}cm^{-2}s^{-1}$
$B\bar{B}$ + continuum	4	40
$\mu^+\mu^-$ + $\tau^+\tau^-$	2	20
two-photon	15	150
Bhabha + $\gamma\gamma$	15 (prescalable)	15

Table 2.1: Expected trigger rates for various physics processes at at the design beam current and luminosity.

It can be reduced to 515Hz + (beam-beam) with a tight logic in which the two-track trigger is prescaled and three-track trigger is introduced. With a very tight logic requiring the logical "AND" of the track trigger and the energy trigger, it can be ∼285Hz + (beam-beam). In this case the efficiency for the hadron events (i.e. B decays and continuum events which are called "HadronC" sample) is estimated to be 92%. Although the precise estimation of the efficiency is ongoing, we should accept a considerable loss of τ and two-photon events in this case. Thus SVD trigger will certainly provide an important safety margin in the data aquisition at the very large beam current.

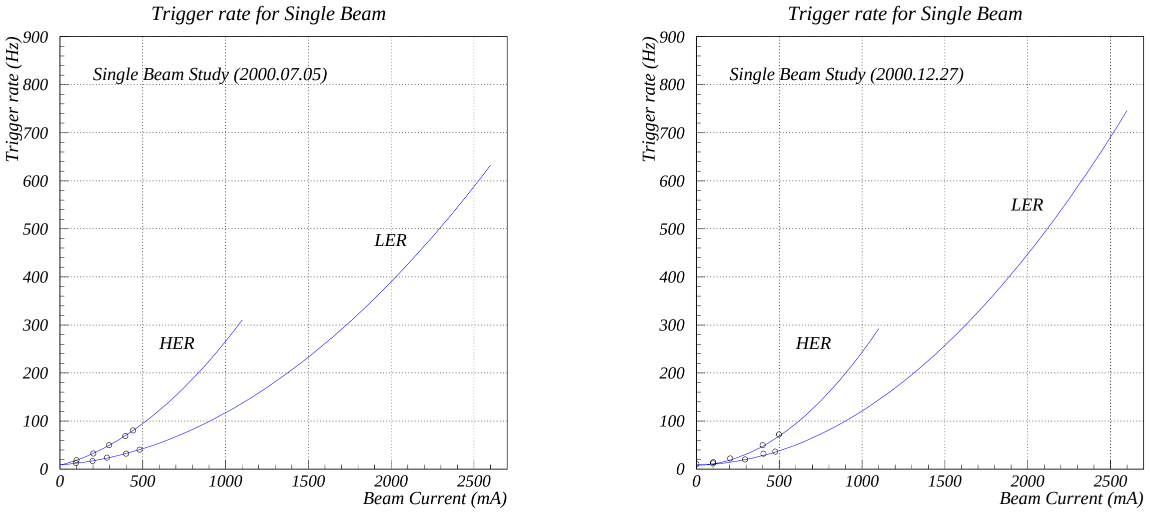

Figure 2.1: Trigger rates obtained with single-beam test runs taken in July 2000 (left) and December 2000 (right).

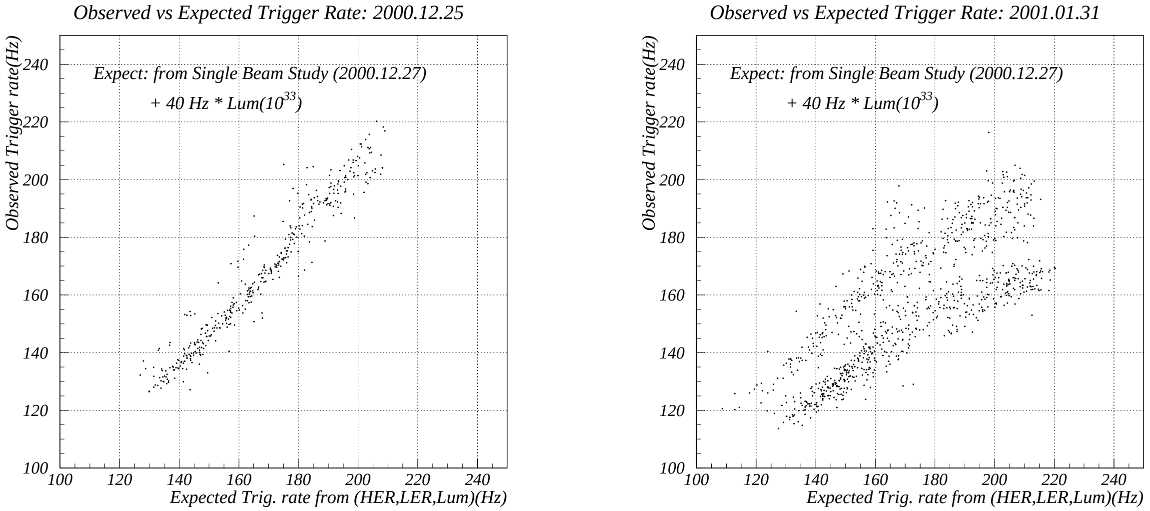

Figure 2.2: Observed trigger rate vs. expected rate calculated from the results of the single-beam test runs. The left figure is made with the data taken on Dec.25, 2000 when the best daily integrated luminosity of $135pb^{-1}/day$ is recorded. The right figure is for data on Jan.31, 2001 when $112pb^{-1}/day$, the best in Jan 2001, is recorded. Two bands seen in the plot are due to the fact that the trigger rate decreased in the middle of the day by some mask adjustment.

2.2 CDC level-1 trigger

2.2.1 Impact on taking out the level-1 cathode trigger

Using present data we studied the effect of taking out the innermost three layers from the L1 track trigger. As shown in Fig.2.3, the loss of innermost 3 layers from the innermost TSF certainly restricts the pattern recognition flexibility inside the TSF. Here worries are increased random TSF hit rates by wire hits induced by any background/noise as well as the degraded impact parameter resolution. Data were taken on Nov.20, 2000. Some different MLU logics were tested in order to mimic the case without the inner-most layers. Compared to the present trigger logic, the clear increase of the tail in the impact parameter distribution was observed (Fig.2.4). This will correspond to the trigger rate increase of ∼40%. Thus it clearly indicates the necessity to introduce the small-cell drift chamber.

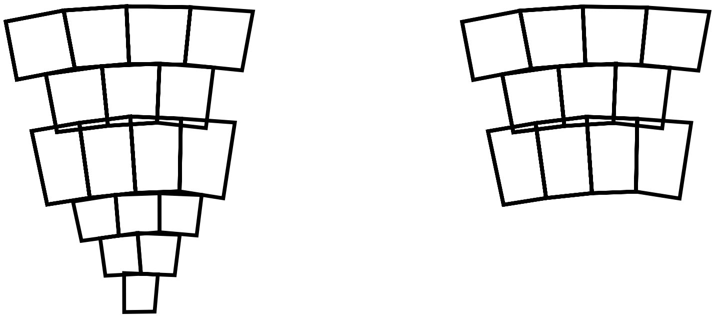

Figure 2.3: The shape of TSF with (left) and without (right) the cathode part of CDC.

2.3 SVD level-1 and level-1.5 trigger

2.3.1 Lessons learnt from the old studies

We have just started evaluating the performance of the SVD trigger with simulation studies in detail. Here we summarize a similar study the SVD group made three years ago[7] for the old SVD that consisted of four layers of DSSDs. As we are pursuing the similar detector configuration for the upgrade, the outcome of the old study includes useful information. In the following we briefly summarize it:

The SVD trigger track was found in z and r-phi separately, but with the similar logic that requires three-fold coincidence out of four layers imposing the IP constraint. The efficiency of the single track was above 95% for $p_t > 0.3$GeV/c. A slight charge asymmetry was seen because of the windmill structure. The trigger efficiencies for $B \to J/\psi Ks$ and $B \to \pi^+\pi^-$ were above 99% assuming 3% dead channel for each side of DSSD. The estimated background rate (at the full beam current) was (169±11) Hz with the CDC trigger only, and (32±5) Hz with the CDC and SVD trigger combined. Further reduction

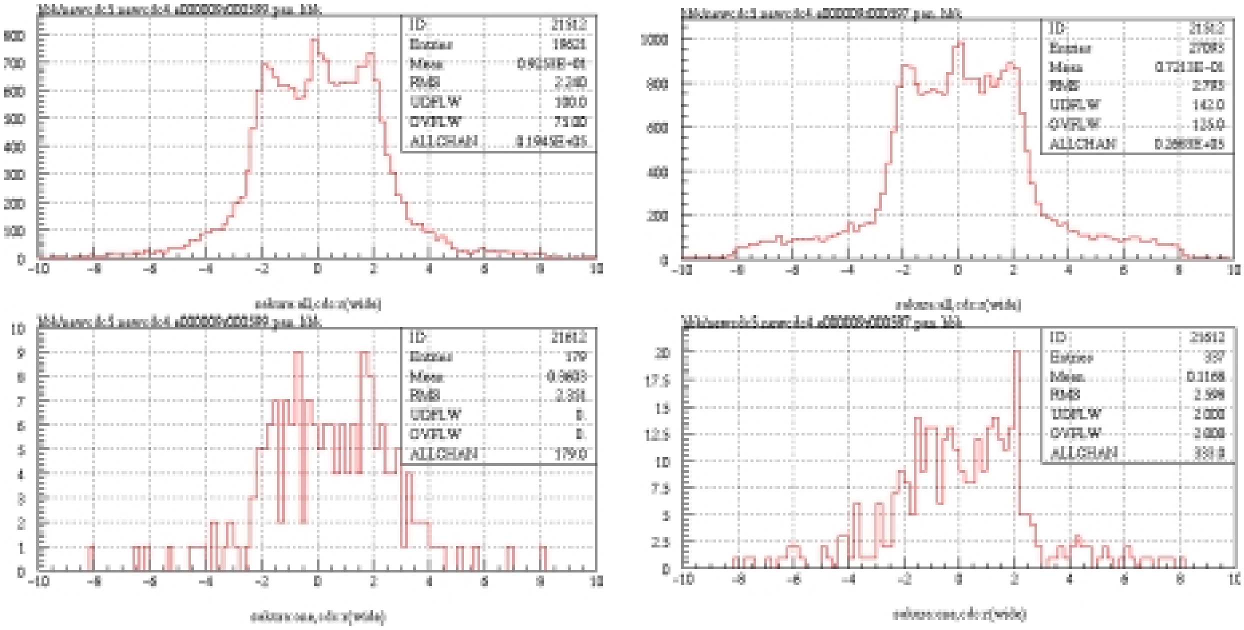

Figure 2.4: Track rϕ impact parameter distribution with the present TSF shape (left) and TSF without the innermost three layers (right). A clear increase of fake tracks is seen in the right figure.

was possible by requiring regional matching between the CDC and the SVD. As for the SVD trigger in the new design, we are doing this kind of study again to evaluate its performance. Judging from the old study described here, however, it will be certainly useful if we can provide trigger signals from four SVD layers out of five.

2.3.2 SVD hit occupancy

SVD occupancy in real data is an important input to the SVD trigger study where the key question is what the occupancy (or the single-strip hit rate) at the design beam current will be. The average number of clusters (dE/dx > 8000e-) in data taken with the random trigger is typically ~150 in runs taken after September 2000, where the typical beam parameters (taken in run418) were $I_{HER} \simeq 500.0mA$, $I_{LER} \simeq 630mA$, $Lumi(peak) \simeq 1.8e33cm^{-2}s^{-1}$ and $L1rate \simeq 150Hz$. As almost no track could be reconstructed for these events, we can crudely assume that this number can be used as the input to the trigger simulation study. As the number of clusters with the same definition is 16 which is much smaller, the clusters observed in the randomly-triggered events during the collision runs are mostly originated from the beam activity. Then the trigger bit occupancy was estimated assuming that we take OR of 32 consecutive strips. If we keep the present level of the background, the trigger bit occupancy will be 3.2% for L1.5. In case of VATA, shorter peaking time for trigger signal might help reduce this rate, whereas estimation at this stage will be difficult as we do not know the quality of the trigger signal from VATA.

2.3.3 Simulation with simplified condition

We made a toy MC program to study basic features of the SVD trigger. The studies are quite similar to what was done five years ago which is mentioned in Section2.3.1. The trigger logic is rather simple and is summarized as follows:

- IP size is restricted to be $|z| < 3cm$.
- Combine 32 consecutive z strips to make a trigger segment.
- For each trigger segment in the outermost layer, define a trapezoid with the segment and the IP.
- In each layer make ORs of trigger segments inside the trapezoid.
- Require coincidence among trigger segments in different layers where it is allowed to miss one layer; i.e. 4-fold coincidence in case we have 5 trigger layers, 3-fold for 4 layers and 2-fold for 3 layers.
- Check all of such SVD local tracks.
- Do the same thing for r-phi as well, but in r-phi the SVD is divided into sextants only (This should be modified).

The SVD trigger is fired if at least one SVD local track is found. With this logic we investigated the effect of noist hits. Assuming 500nsec trigger gate width and scaling the measured occupancy shown in the previous section, we estimate that the trigger-bit occupancy is 3.2%. With this condition we obtain the probability that one track fires the trigger. The result is shown in Fig.2.5. It clearly shows that “4 out of 5” logic is superior to the case with 3 layers. Our major conclusions are as follows:

- The SVD z trigger can define IP with the accuracy of a few mm.
- The ”4 out of 5” trigger logic is much more robust than the ”2 out of 3” case against noise hits. At this point we can not conclude if ”3 out of 4” is acceptable. The answer depends on the SVD noise hit rate.
- The length of IP should be optimized.

Our plan includes detailed SVD trigger simulation using a Geant-based program with photo-nuclear interactions implemented (with GELHAD package) to optimize the trigger logic and granularity.

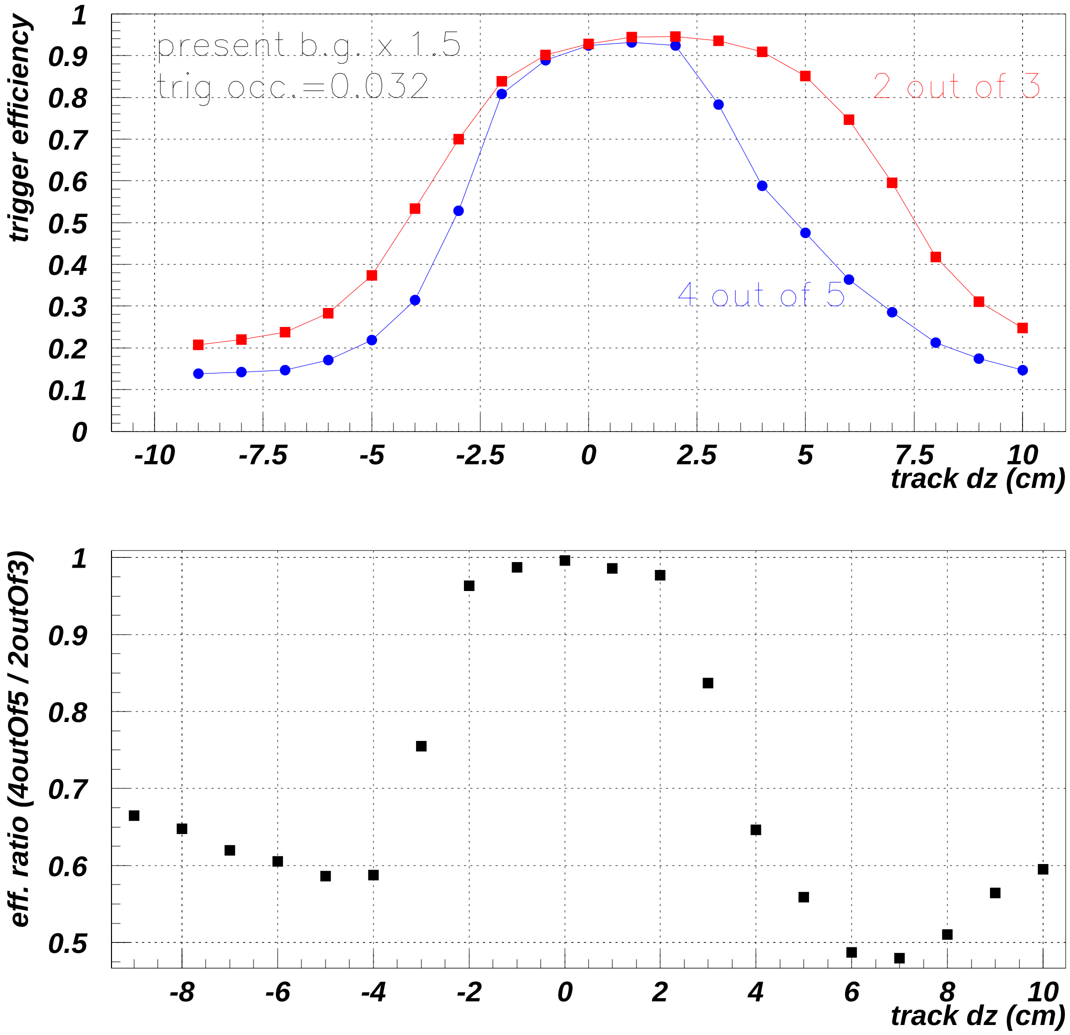

Figure 2.5: Track finding efficiency as a function of the track impact parameter resolution in z direction (up), and the ratio of the efficiency between the 4-out-of-5 logic and 2-out-of-3 logic (bottom).

Chapter 3

Small cell drift chamber

3.1 Structure

We prefer that a basic design of the small cell drift chamber is similar to the cathode part of the present CDC. It means that the chamber consists of a thin inner cylinder made of CFRP and two aluminum endplates that support the whole wire tension. The gas volume is common to the our part of CDC since we do not plan to use any additional outer cylinder to minimize the material inside the acceptance. Major parameters of the new chamber are listed in table 3.1. The thickness of the inner cylinder, which is the same as the value right now and is 0.4mm, is chosen to be thick enough to keep the precise cylindrical shape, at the same time thin enough to minimize the background hits produced by a photon conversion.

The aluminum endplates will be machined at the KEK machine shop. A test drilling for a small piece was already done without any serious problems, in spite of the fact that many small holes with 0.8mm diameter had to be drilled.

The present cathode part was installed with a small bar which was set inside the cathode part temporarily. The same method is applicable to remove the cathode part and to install the new small cell drift chamber. The installation bar was supported by the wire stringing jig at the installation of the cathode part. This part has to be re-designed.

3.2 Wire configuration

The small cell drift chamber has two cylindrical layers. Each layer contains 128 drift cells, which have around 2.5mm maximum drift distance. It is a half of the cell size of the present cathode part. We think this is almost minimum cell size for a drift chamber using feedthroughs and aluminum endplates. The wire configuration was shown in Fig. 3.1.

The number of total sense wires and field wires are 256 and 768, respectively. The same wires (gold-plated tungsten wires with 30μm diameter for the sense wires and aluminum wires with 126μm diameter for the field wires) will be used. Feedthroughs with 2.5mm diameter will be used to hold the sense wires. These are slightly thinner than the present ones (3.2mm diameter) to match the small cell. It is impossible to apply the new

Table 3.1: Major parameters for the small cell drift chamber

Inner radius	102 mm
Radius of 1st sense wire	108.5 mm
Radius of 2nd sense wire	113.5 mm
Wire length	711 mm
Number of cells per layer	128
Number of total sense wires	256
Number of total field wires	768
Thickness of inner cylinder	0.4 mm
Thickness of endplates	10 mm

feedthroughs for the field wires due to limited space. Since the crimping pins with 1mm diameter will be inserted into aluminum endplates directly, no additional connection to the ground is necessary. But, it is impossible to measure the tension for each field wires after the wire stringing. The field wire with a very low tension can be found using an air blow. We think it is enough for the field wires. Even if some troubles happen in the field wires after supplying a high voltage, the field wires can easily be replaced before the installation.

One thing we have to develop is a new crimping tool to match the small cell structure. Some R&D works were started.

3.3 Readout electronics

The electronics we are using at present is basically usable for the new chamber. The preamplifiers and the TDC modules are common to anode and cathode readouts. Therefore we can use the same modules for the new chamber. Although the shaper Q/T modules are different, the number of readout channels for anode wires is larger by only 64 and enough spare modules are available.

In order to cope with the expected harsh background condition, however, it is desirable to develop a new shaper Q/T module which is capable of treating the higher hit rate. The maximum rate of the present shaper Q/T modules is limited by a gate width (0.6μsec) to integrate the signal charge and a conversion time (2.2μsec) from charge to time which is essential to provide good dE/dx measurement. However the precise measurement of the signal charge for the small cell drift chamber is not necessary because only two additional samples with a shorter pass length do not help improve the dE/dx resolution. Also the precise measurement of dE/dx under a high background rate is anyway questionable. Thus for the new shaper Q/T module we want the shorter gate width (0.1μsec) and a shorter conversion time (0.15μsec) to improve the rate capability.[1] In this case the hit

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[1] Note that the new shaper Q/T modules should also provide the output signal with the present 0.6μsec gate width for the CDC r-ϕ trigger, even though a gate width for the Q/T chips itself becomes shorter.

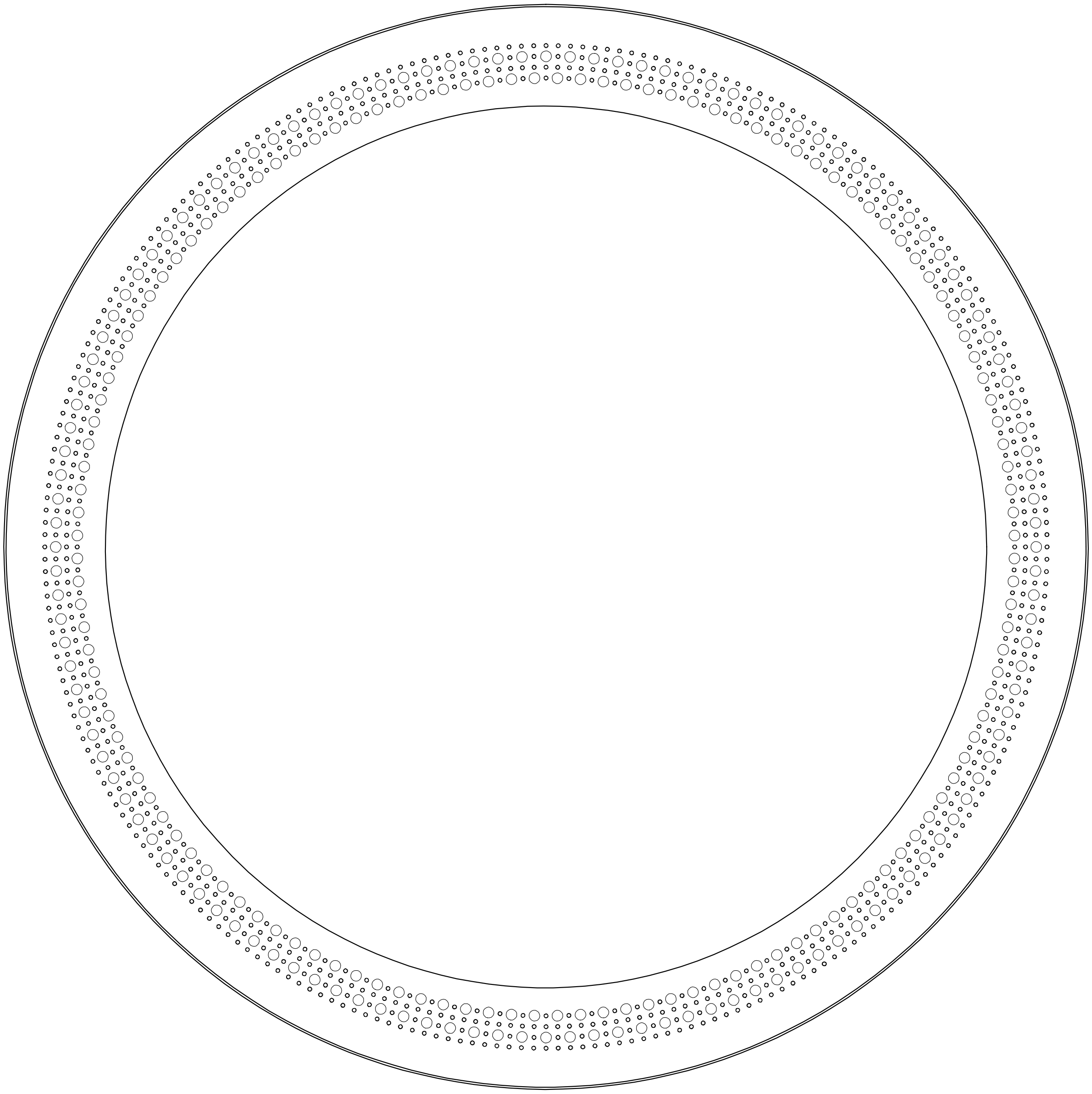

Figure 3.1: Wire configuration of the small cell drift chamber. The large and small circles represent feedthrough holes for sense and field wires, respectively.

rate up to 400kHz is manageable with the inefficiency coming from the electronics less than 10%. This is comfortably higher than the hit rate per wire for the innermost layer of 100kHz at present with the maximum beam current (LER=700mA and HER=560mA). With the new chamber the number of cells becomes double (thus the hit rate per wire is a half), resulting in the large safety margin of a factor of eight. Although the measurement of signal charge is not essential, the new modules will be capable of doing it because a crude pulse height information is still very useful to reduce the noise hits and to know the radiation damage of the chamber.

SVD group requires to use the trigger signal from the small cell drift chamber in order to reduce the rate and the latency for the L0 trigger which is now made with TOF signals alone. Maximum drift time is expected to be very short, less than 100nsec. However, the latency is not so small using the current electronics system and the new shaper Q/T module. In order to reduce the latency, the additional modules and the shorter cables are necessary. We have just started a discussion among CDC, SVD and TOF groups. In a case with the shortest latency, the modules should be located at the detector surface, where the electronics of CsI and KLM are located. The signal should be divided into two in that place. One is sent to the electronics hut for the CDC readout, and the other used for the L0 trigger at that place. Also TOF electronics should be modified. If the moderate latency is acceptable for SVD, the CDC group prefers to send the signals to the electronics hut with shorter cables. In this case the trigger signal will be provided with the new shaper Q/T modules. The difference of a cable length in these two cases is only 5m or so.

3.4 Schedule and cost

There are not any critical R&D items for the construction of the small cell drift chamber. One test chamber is still necessary to check the construction technique. The test chamber will be constructed by the end of March 2001. The final design will be fixed in spring of 2001. The drilling of aluminum endplates at the KEK machine shop will be scheduled in July 2001. The wire stringing will be done in fall 2001. It will take one month. After that, we have enough time to check the real chamber before the installation in summer 2002.

The new shaper Q/T module will be designed and one or two modules will be fabricated in 2001. After several tests, all modules will be ordered and will be available before the installation of the chamber.

The estimated cost is listed in the table 3.2. There are no expensive items.

Table 3.2: Cost for small cell drift chamber

Items	kYen
Inner CFRP cylinder	2000
Endplates	500
Feedthrough	1000
Crimping tool	500
Wire stringing	2000
Installation jig	1000
New shaper/QT	3000
Electronics for new L0	2000
Total	12000

Chapter 4

Expected performance on tracking and vertexing

4.1 Low momentum track finding

Let us start with two basic limitations in the low momentum tracking. One is the effect of the energy loss. Because of large dE/dx in the beampipe and the SVD, tracks with Pt<60MeV/c do not enter the CDC. The other is based on a simple geometrical fact: Tracks with Pt<40MeV/c can not reach the first stereo superlayer of the CDC. Although we envisage the improvement of the track reconstruction for P_t below 200MeV/c or so, certainly we can not gain much for $P_t < 40 \sim 50 MeV/c$.

What we need to know is traking efficiency of slow pions in 5-layer SVD and in 4-layer SVD for comparision. As a simple and quick study, we made a comparision with a simple coincidence logic rather than with a track reconstruction algorithm. Single pion events were generated where the momentum distribution is taken from $B \to D^* \ell \nu$. The average pt is about 87MeV/c. As for the hit counting, hits created by secondaries (hadron interaction, decay-in-flight) or by curling-back segments were not counted. To select the track, we imposed the following selection criteria:

- a) For 5-layer SVD : hits in SVD ≥ 5 (i.e. in both $r\phi$ and z hits)
- b) For 4-layer SVD : (hits in SVD ≥ 5) .or. (hits in SVD ≥ 4 and hits found in the CDC first axial layer)
- c) For 4-layer SVD : (hits in SVD ≥ 5) .or. (hits in SVD ≥ 4 and hits found in the CDC first stereo layer)

The results are as follows:

a) 5-layer SVD : efficiency $= 76.8 \pm 0.4\%$
b) 4-layer SVD : efficiency $= 71.4 \pm 0.5\%$
c) 4-layer SVD : efficiency $= 69.0 \pm 0.5\%$

The ratio of $(4 - layerSVD)/(5 - layerSVD) = 93$ 90% is obtained (N.B. the efficiencies include the anglular acceptance). Thus in spite of the fact the 5-layer SVD has more meterial, it gives us the higher efficiency. Considering the large background hit rate, it is clear that the 5-layer SVD is much more robust aginst the noise hits. Hence this study indicates the superiority of 5-layer SVD in terms of low momentum tracking. In any case, the upgrade with 4 or 5 layers of SVD substantially improves the tracking efficiency in low momentum region compared with the present 3-layer SVD. Fig.4.1 shows the expected efficiency obtained with the same study together with the case with the present 3-layer SVD. It is expected that the reconstruction efficiency for $B \to D^*\ell\nu$ could be improved by ∼50%.

4.2 Impact parameter resolution

By introducing the 5th layer, the total amount of material in the SVD increases. Therefore one might ask that the thicker material results in the worse impact parameter resolution. Table 4.2 summarizes the material budget of the present SVD and that of one of possible 5-layer configurations which will be explained in the next section. The total thickness of the present SVD and the CDC cathode part is 2.60% X0 whereas it becomes 3.37% X0 (30% increase) in the 5-layer option. Fig.4.2 shows the impact parameter resolutions for these cases estimated with TRACKERR. Table4.2 also lists typical resolutions for the three cases. As shown in the figure and the table, there is very little difference in the impact parameter resolutions between 4-layer and 5-layer options. The z resolution is dominated by the radial distance of the first layer from the beam line (1.5 cm in the both cases) and there is no sizable degradation by introducing the 5th layer. Actually it becomes slightly better probably because of the larger lever arm. Therefore we conclude that the 5-layer configuration is not harmful for the precise vertex reconstruction.

Note that what is discussed above is the comparison between two cases, with or without the 5th layer. This should not be confused with the other comparision which is with or without the innermost layer. In case we abandon the smaller (i.e. r=1cm) beampipe and thus abandon introducing the innermost layer with r=1.5cm, the SVD2.0 will have a 4-layer configuation **WITH** the 5th layer installed. In this case, the difference in the impact parameter resolution is larger as shown in Fig.4.3, although we still see a good improvement compared with SVD1.2 (or SVD1.4). If we install the 5-layer SVD, the improvement in the impact parameter resolution will be 40-50%, while in case without the innermost layer it will be 20-30%.

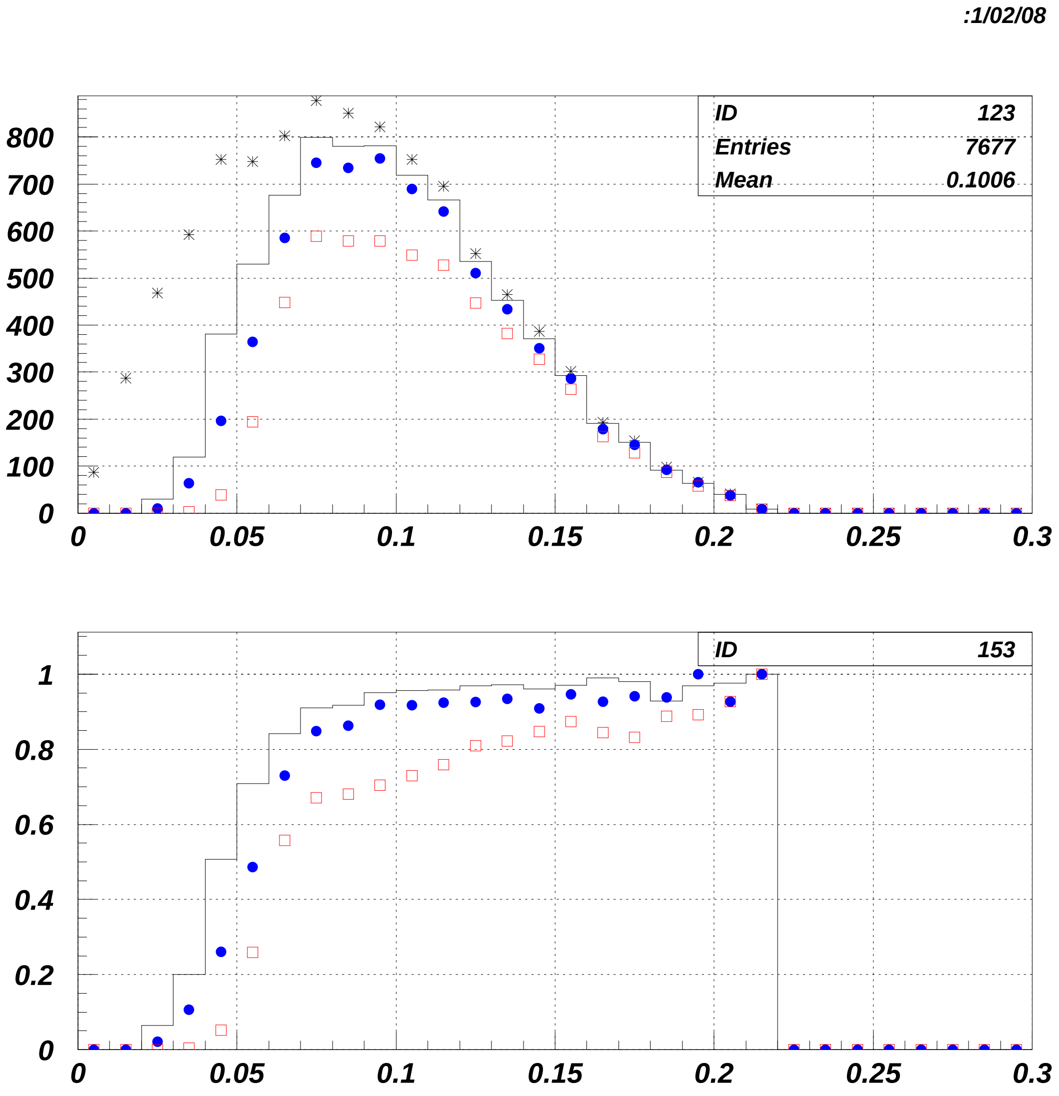

Figure 4.1: Transverse momentum distribution (top) and tracking efficiency (efficiency) of slow pions from $B \to D^*\ell\nu$, $D^* \to D\pi$ in SVD1.2 (blank square), SVD2.0 with 5 layers (histogram) and SVD2.0 without the 5th layer (circle). The p_t at the generator level is also shown with $*$ in the top figure.

Component	a) SVD1.4 + cathode	b) SVD(5layer) + small-cell chamber
beampipe		
gold	0.29	0.29
inner pipe	0.14	0.14
coolant	-	0.10
outer pipe	0.14	0.09
beampipe total	0.57	0.62
SVD		
inner cover	0.04	-
layer 1 DSSD	0.32	0.32
layer 1 rib	0.17	0.25
layer 2 DSSD	0.32	0.32
layer 2 rib	0.14	-
layer 3 DSSD	0.32	0.32
layer 3 rib	0.15	0.17
layer 4 DSSD	-	0.32
layer 4 rib	-	0.16
layer 5 DSSD	-	0.32
layer 5 rib	-	0.17
outer cover	0.23	0.23
SVD total	1.69	2.58
CDC ($r < 116mm$)		
inner cylinder	0.17	0.17
cathode layer 2	0.17	-
CDC($r < 116mm$) total	0.34	0.17
Grand total	2.60	3.37
	(% X0)	(% X0)

Table 4.1: Material budget of a) SVD1.2 + cathode and b) SVD(5layer) + small-cell chamber.

	P (GeV/c)	4	1	0.5
dz	(SVD1.2)	26.19	46.95	83.36
dz	(SVD2.0, w/o 5th layer)	14.24	25.54	44.89
dz	(SVD2.0, 5layers)	13.95	25.36	44.82
dρ	(SVD1.2)	15.75	41.75	79.46
dρ	(SVD2.0, w/o 5th layer)	9.08	22.77	41.90
dρ	(SVD2.0, 5layers)	8.79	22.74	41.83

Table 4.2: Impact parameter resolutions (μm) for tracks with $\theta = 90^o$.

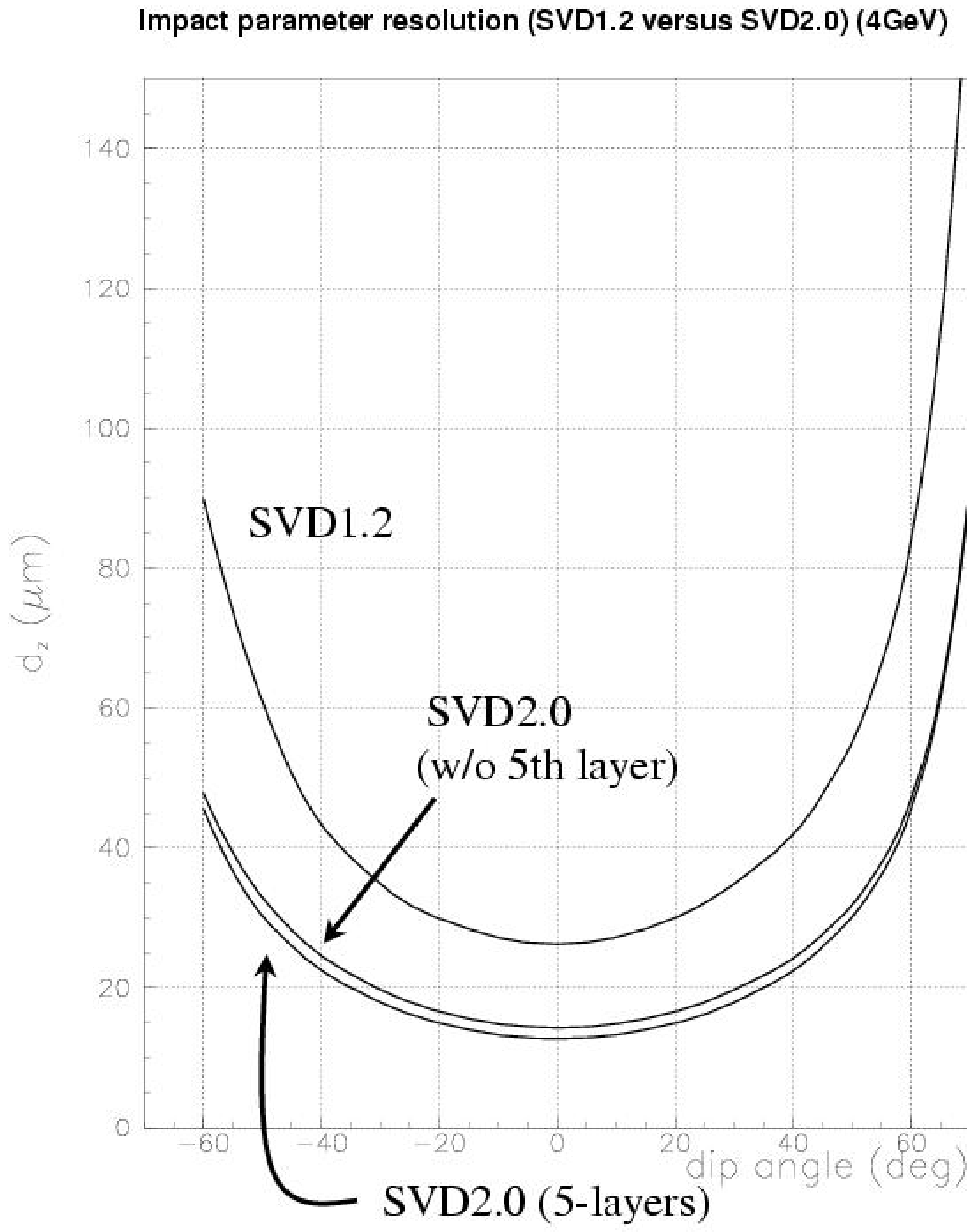

Figure 4.2: Z impact parameter resolutions for SVD1.2, SVD2 with four layers, and SVD2 with five layers. The latter two cases show quite similar results whereas the SVD1.2 is worst.

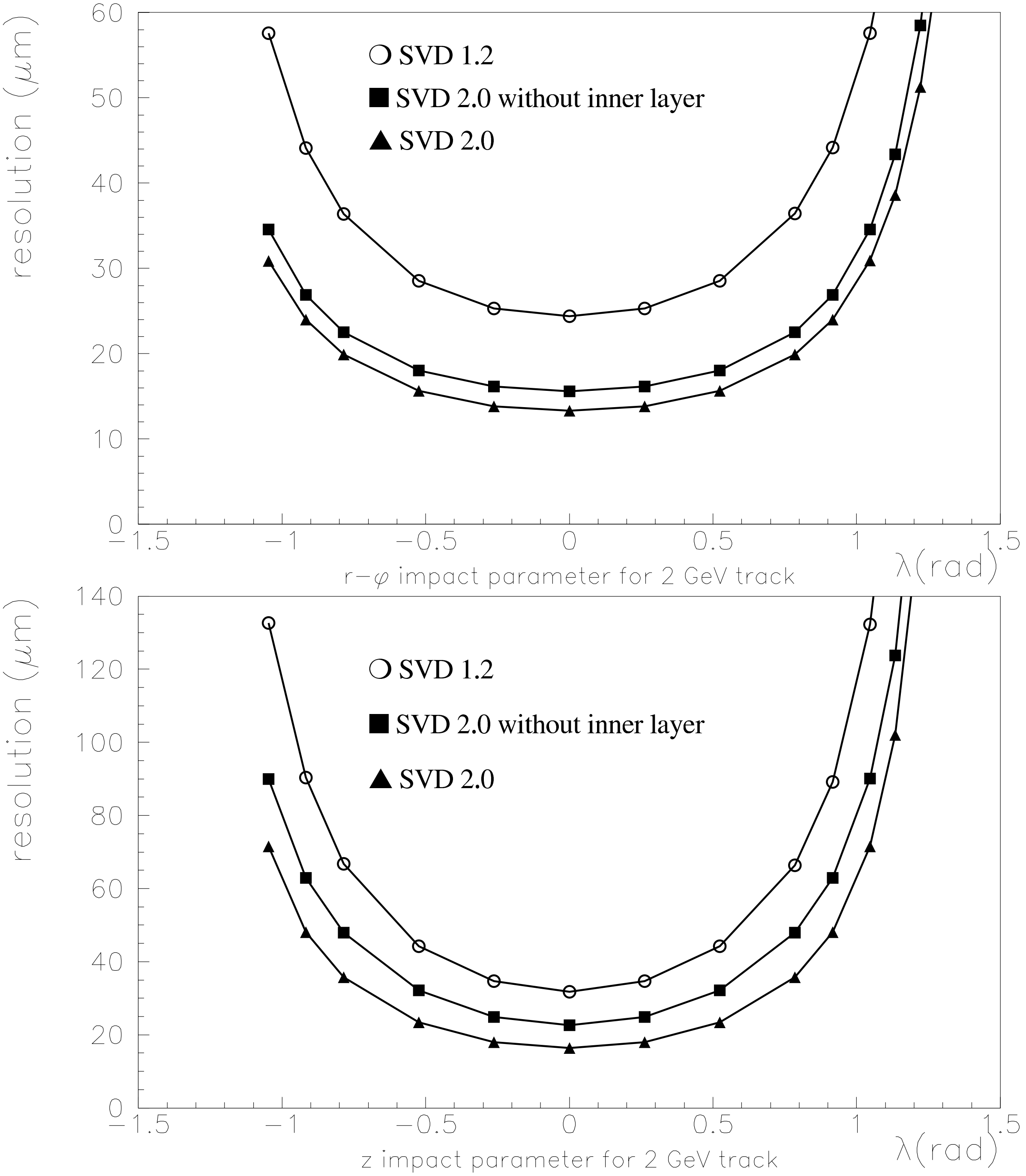

Figure 4.3: Impact parameter resolutions with SVD1.2 and SVD2.0 with or without the innermost layer obtained with the TRACKERR program.

Chapter 5

Summary

Assuming that the background level does not go up compared with the present level, there is no urgent need to replace the CDC except the cathode part for next 5 years. The CDC cathode part should be replaced. The best time will be summer 2002. One of the primary roles of the new inner tracker should be to improve low momentum track finding. It is also desirable to provide L1 and L1.5 trigger information at least to compensate for the loss of the CDC cathode z trigger. Possible upgrade options were surveyed and we conclude that the option with 5-layer SVD plus two-layer 5mm-cell chamber is most suitable among detector technologies we had considered.

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