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Addendum to Proposal P238:

FURTHER COMMENTS ON COLLIDER TEST OF SILICON MICROVERTEX DETECTOR

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ABSTRACT

In P238Add.2 we requested a Collider test run for the proposed silicon micro-vertex detector. In the present document we describe details of the preparation for this run, give a time schedule for preparation of the various components and explain how the proposed silicon test detector will furnish the necessary information to plan for the full scale experiment. In an Appendix, we explain how the Forward Beauty Detector might be used at LHC and what modifications and additions to the detector would be necessary. We make a very preliminary estimate of the resulting increase in reconstructed B-meson event yields.

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*) Spokesman
[1]) At this time, commitment is for silicon test run
[2]) Pending approval of the Laboratory and IN2P3
[3]) Pending approval of INFN
[4]) Pending approval of CEN-Saclay
[5]) Pending approval of IHEP & SCUAE

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1. Introduction

In P238Add.2 we requested an SPS collider run for silicon trigger tests for the proposed Forward Beauty Detector (FBD). We outlined the purpose of the proposed test and described a suitable test detector. In the present document, we provide more details concerning this run and its preparation, including a detailed time schedule.

A key innovation of Proposal P238 is its efficient trigger on beauty production which exploits information from a silicon micro-vertex detector which has essentially a fixed-target geometry (detector planes perpendicular to the beam line). This constitutes a new and untried approach to the experimental study of B physics at hadron colliders. If the trigger proves successful, it will afford an abundant and relatively cheap source of tagged and reconstructed B hadrons. Furthermore, although our detailed studies have thus far been limited to the SPS Collider, preliminary studies for the LHC lead us to conclude that the FBD, suitably modified and augmented, could also be used at higher energies, where increased event yields will allow quality CP-violation studies to be performed in B decay.

In Chapter 2, we review the P238 trigger algorithm and explain how the use of a single-view silicon detector does not compromise the goals of the test run.

Chapters 3 and 4 contain summaries of the preparation work for the silicon detectors and support/positioning mechanisms, respectively. A detailed planning schedule for all major components is given in Chapter 5. Our conclusion is that, with an immediate approval from CERN, we can be ready for a collider run which begins in September 1990.

Chapter 6 contains two sections on data analysis. Section 6.1 explains how the Monte-Carlo simulated data samples in P238 will be compared with the data recorded in this test run. In Section 6.2, we discuss the possibilities of obtaining a sample of heavy flavor events from a topology study of the silicon data and show examples of the types of events that should be visible.

Finally, the discussion of the Forward Beauty Detector at LHC is in Appendix A.

2. Discussion of Silicon Detector Test Version

Aside from bringing a silicon detector of the type proposed into operation in the collider environment, the main goal of the proposed test is to show that acquired data are well described by our Monte-Carlo simulated data (this may or may not require tuning the Monte-Carlo program, as discussed below in Section 6.1). In this chapter and in Section 6.1, we show how the 6-plane silicon detector described in P238Add.2, and shown here again in Fig. 1, will provide the data necessary for this work. The geometry of the test detector does not differ in any fundamental way, other than scale, from that proposed for the complete experiment.

We remind the reader of some of the key elements of the P238 trigger algorithm which influence the design of the silicon system:

- Tracks are found which have points in at least three consecutive detector planes in x-z and/or y-z views.

- No x-y matching is performed in the online trigger calculations. Thus, only the x-z and y-z projections of tracks and their impact parameters are used in the trigger calculations and no attempt is made to decide if a given track is found in both views or only one.

- The χ^2 is formed using, independently, the x-z and/or y-z projected impact parameters of the tracks.

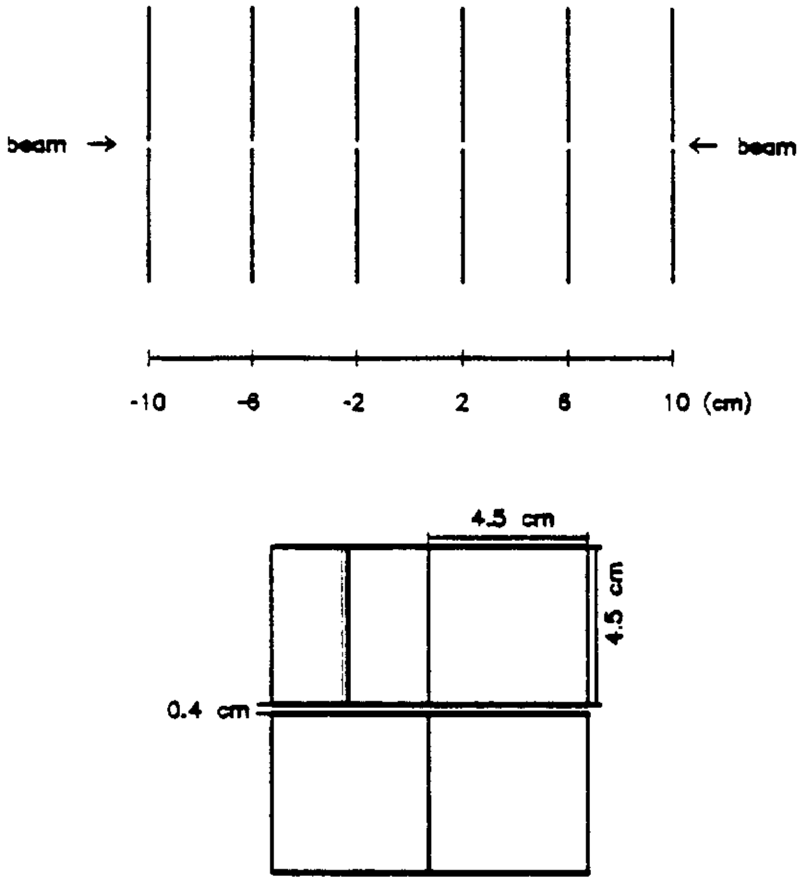

Figure 1: Proposed 6-plane silicon detector system for collider test run. Side view shows the 4 cm spacing between planes and the independent upper and lower detector assemblies. The beams pass through the 4 mm gap between these assemblies. The front view shows how the upper and lower assemblies each contain two silicon detectors side by side. As discussed in Chapter 3, the silicon detectors are 4.5 cm squares with 50 μm pitch.

- There is an iteration procedure in the trigger algorithm in which as many as three of the tracks which have the largest contributions to the χ^2 are excluded from the χ^2 and a new fit performed. The word "tracks" here refers independently to the x-z or y-z projections. Thus, a track may be excluded (and often is) from the χ^2 in one view, while its corresponding projection in the other view is not removed.

The consequence of the above is that the identical trigger algorithm can be implemented in one view alone. The only effect of not implementing a second view is a decrease in the number of terms in the χ^2. Thus we argue that, since there is no essential modification to the mathematics of the algorithm, agreement between predictions and measurements using a one-view detector will allow a reliable estimate of the performance of a 2-view detector.

In order to demonstrate the properties of such a one-view trigger, we have implemented a version of our trigger algorithm which assumes a 6-plane one-view silicon detector and tested it with Monte-Carlo data. The results are given in Table 1 for samples of minimum bias events and (inclusive)

$b\bar{b}$ events. For the minimum bias events, these numbers constitute predictions which will be compared with the data obtained in the run. These predictions assume that no adjustments will be needed for the Monte-Carlo, as discussed in Section 6.1. If such adjustments prove to be necessary, new predictions may be made.

Table 1: *Efficiencies for a One-View Silicon Detector*$^{(a,b,c)}$

	Min.Bias.Sample		$b\bar{b}$ Sample		Ratio
	Events	ϵ_{mb}	Events	ϵ_{bb}	$\epsilon_{bb}/\epsilon_{mb}$
Initial No. Events	1700		850		
Events before χ^2 Minimization	1246		612		
Events after χ^2 Minimiz, χ^2 cut	192	.11	449	.53	4.7
Same after 1 track rejected	36	.021	248	.29	14
Same after 2 tracks rejected	6	.0035	96	.11	31
Same after 3 tracks rejected	2	.0012	54	.054	45

(a) This table is not intended to be used in data acquisition, but rather as predictions to be compared with the results from an offline analysis of data.

(b) ϵ_{mb} and ϵ_{bb} are the fraction of events which remain after each step.

(c) The procedures are identical to those used in P238. After each minimization step, there is a cut made at χ^2/degree of freedom > 30.

3. Preparation of Silicon Detectors & Readout

The Si strip detectors to be used for this test experiment will be built at the Central Institute for Industrial Research (S.I.) in Oslo. They are similar to those fabricated for the DELPHI experiment. The detectors use the principle of capacitive coupling of the p strip via a 200 nm thick oxide to the readout metal strip [see: M. Caccia et al., NIM A260 (87)124]. Each diode in this design has its own polysilicon bias resistor. The value of the resistance of the poly lines can be tailored to the specific experimental requirements, such as particle occupancy of strips and speed of amplifier. In the case of the collider test, using the SVX readout chip from Berkeley, we estimate that an appropriate value would be 500 KΩ.

The detectors built for the DELPHI micro-vertex detector are fully functional and are now being installed. Much experience has been obtained with these detectors,[1] which have very high yield of good strips (between 99% and 100%) and excellent leakage current behaviour (in the range of 50 pA/strip to 1 nA/strip average).

S.I. presently uses 3" wafers for detector production. This allows them to furnish us with high quality detectors with dimensions 44.8×44.8 mm^2 and thickness 250 μm. The spatial resolution of similar detectors with a diode pitch of 25 μm and a readout pitch of 50 μm has been measured to be $\sigma = 5\mu$m (we plan to read out ADC information during the test run).

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[1] It is of interest to note here that first beam tests of double-sided readout detectors produced by S.I. Oslo, using the same technology, show very promising results. It can therefore be envisaged to use x-y readout on one, 200 μm thick, detector plane in the complete experiment, as assumed in the original P238 trigger studies.

We have an offer from S.I. to fabricate the necessary 24 (+ spares) detectors on the time scale, shown on the planning schedule in Chapter 5. We plan to initiate the order immediately and can thus be in possession of the detectors by 1 February 1990.

Since each of the 24 detectors will be equipped with seven 128 channel SVX chips, a total of 168 SVX chips (+ spares) will be necessary. According to the LBL SVX group, fabrication time for the CMOS SVX chips is typically six weeks (C Haber, private communication). Moreover, from their experience, it is estimated that design and fabrication of the thick-film ceramic readout hybrid that we need will take a total of 3 months. These times are shown accordingly on the planning schedule in Chapter 5.

The silicon detectors will be mounted with chips and put on a mechanical support structure, including high precision alignment, in P. Weilhammer's laboratory at CERN. All detector assemblies will be fully electrically tested and the response of each strip at two positions will be automatically logged in a data base. The facilities for this testing already exist in the lab. We estimate that the assembly work can be done within 6 weeks. Laboratory tests of the full detector system will require a further 4 weeks. This total 10 week period carries us from mid-february until end-april on the planning schedule.

As explained in P238Add.2, we already have the complete SVX readout electronics system and relevant software operational at CERN. This system is interfaced to the MicroVax computer which we will use for data acquisition.

We note that the final silicon detectors for the complete experiment will differ in the following ways from those to be used in this test run (these differences are all minor, as far as the validity of our test is concerned).

- The final detectors will be 50 x 50 mm^2.
- The final pitch will be about 35 μm (this is somewhat larger than the 25 μm assumed in P238, but should have little effect on the performance).
- We will use a new simpler and faster version of the SVX chip packaged for 35 μm pitch, which is under development by the Nygren group at LBL.
- We will use double-sided silicon detectors with 200 μm thickness.

4. Preparation of Silicon Support/Positioning Mechanism

The silicon support and positioning mechanism consists of two sub-assemblies which may be designed and built in parallel. These are:

1. The detector box which includes components such as the RF/vacuum shielding, the precision mounting plate which holds the silicon and readout electronics, the vacuum feed-throughs for signals to and from the detector and the cooling for the readout electronics, which are in the vacuum.
2. The positioning mechanism (including control electronics and computer interface) which moves the detectors to ±2mm from the beam for data taking and retracts them to a safe distance during beam manipulations.

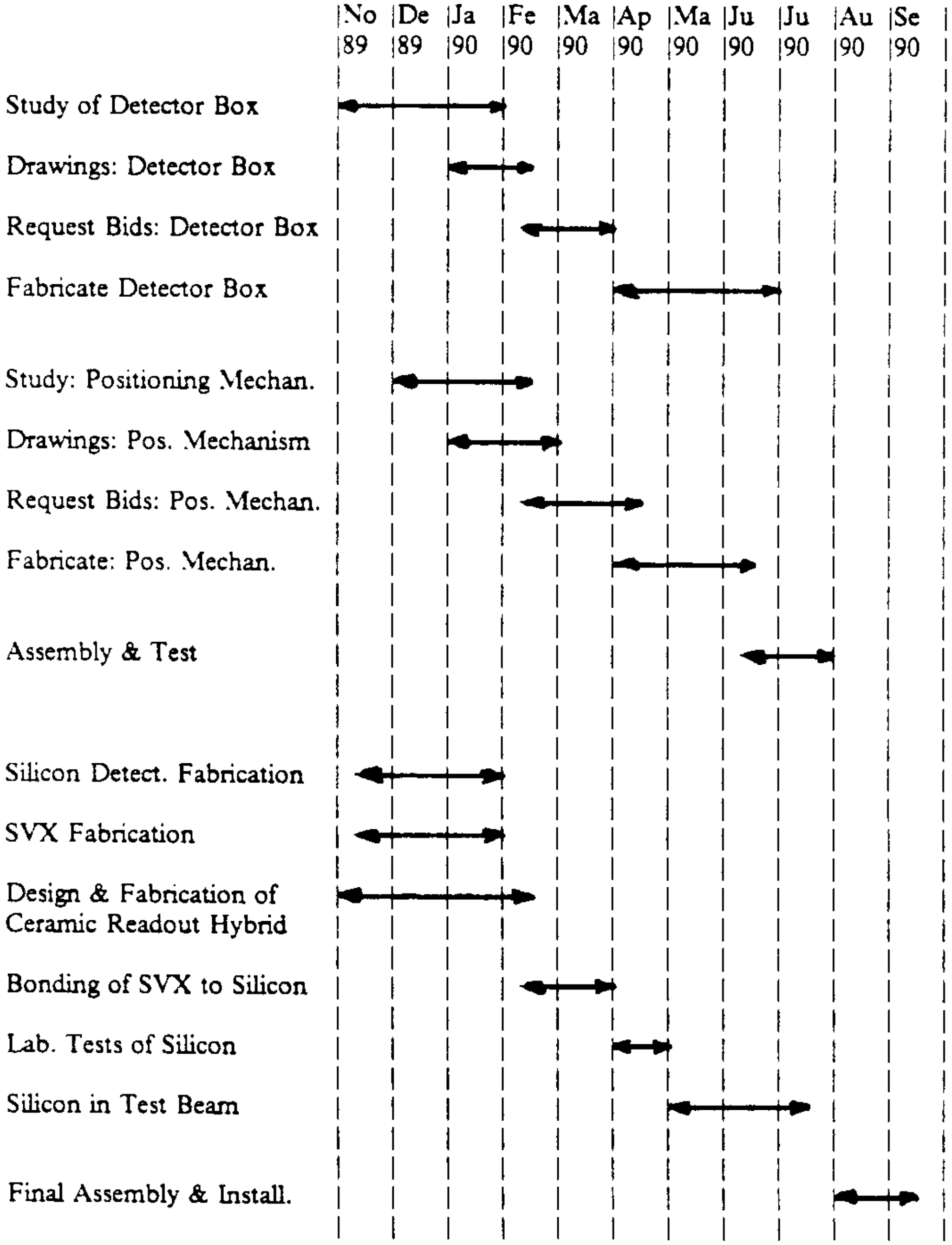
A schedule for the construction of this apparatus, shown in Chapter 5, was developed by G. Engelmann & H. Wahl (SPS Division). The schedule shows that, if work in the SPS Division is begun by 1 November 1990, the device would be available for installation of the silicon detectors by 31 July

1990. The complete silicon micro-vertex detector assembly can then be installed in the Collider and ready for collisions in September 1990.

All study and design work should be completed by mid February, at which time requests for tenders will be issued for those components which require fabrication outside of CERN. All fabrication will take place during April, May and June 1990. Final assembly is scheduled to begin in mid-June and will be completed by end-July.

The RF shielding tests mentioned in P238Add.2 will be used to determine the amount of shielding needed to protect the detector from RF pickup due to the beam passage. This work will be carried out by our group in collaboration with the SPS Division at the same time as the design work of the mechanics system is taking place. We have decided that we can use aluminum for RF shielding instead of Beryllium, as suggested in P238.

5. Time Schedule



6. Data Analysis

6.1 Adjustment of Monte-Carlo Generator

In Appendix A of Proposal P238, we have shown that PYTHIA 4.8 correctly reproduces minimum bias (UA5) data in areas which could affect the performance of the trigger, such as the charged particle multiplicity and pseudo-rapidity distributions and the K^0 pseudo-rapidity distribution. While we are thus reasonably confident that PYTHIA is not a major source of uncertainty in the evaluation of minimum bias event suppression by our trigger, we would use the test data to check quantities which are of more direct relevance to the trigger performance such as raw silicon hit distributions and track χ^2 distributions.

The first analysis step (after the usual track finding and vertex finding) will be to isolate tracks coming from sources other than beam-beam interactions. Beam halo tracks should be easily recognizable since they travel roughly parallel to the beam line. We will be able to measure their distribution in the x-z plane. A reasonable guess can be made for the full three dimensional distribution given the x-z distribution and the known properties of the beam. Tracks entering the detector from beam-gas interactions should also be easily identifiable. The distribution of these tracks may reasonably assumed to not depend on the azimuthal coordinate.

After these event-unrelated sources have been measured, they will be added to the PYTHIA-generated events. The next step is a detailed comparison of real data with the Monte-Carlo events, passed through GEANT to simulate the silicon data. Quantities to be compared include the raw silicon hit distributions, track residual distribution, impact parameter distribution and single-view vertex χ^2 distribution. If discrepancies are found (such as extra silicon hits from some unknown source) the Monte-Carlo software will be modified to bring data and simulation into agreement. At this point, it will be verified that the Monte-Carlo software reproduces the observed behavior of the vertex χ^2 distribution, as tracks giving large χ^2 contributions are discarded.

We believe that Monte-Carlo software which reproduces the above distributions can be relied on to correctly model the full three dimensional structure of minimum bias events. It can therefore be used, in conjunction with the processor emulator which is now under development, to give an accurate assessment of the performance of the trigger.

6.2 Topology Studies of Heavy Flavor Production

It should be possible to perform an offline topology study of the 1-view silicon data and isolate clear examples of heavy flavor production. In order to understand the potential yield of such a study, we have carried out a (preliminary) analysis of Monte-Carlo data samples for minimum bias and $b\bar{b}$ events. We search for heavy flavor topologies (a primary vertex together with at least one secondary vertex of at least 4 tracks which occurs more than 1.5 mm downstream) in order to estimate how many $b\bar{b}$ events we can expect to isolate and what will be the minimum bias background.

Is is important to note that the offline topology study in one view that we consider here is quite different and much simplified in character from the elaborate analysis precedures discussed in P238, where the analysis was done in three dimensions and the momentum and mass identification of each track was assumed to be known. Nonetheless, as is shown below, useful topology information can be extracted from the silicon data we will obtain.

Reconstruction software was developed to isolate events with primary and secondary vertices in simulated data from the 6-plane silicon detector (generated using PYTHIA & GEANT). and applied to a sample of 1700 minimum bias events and 850 inclusive $b\bar{b}$ production events whose primary vertices occur between the third and fourth planes of the 6-plane detector. In lieu of using more sophisticated software, which will be written later, displays of the resulting multiple vertex events were then scanned to arrive at estimates for the efficiencies of $b\bar{b}$ events and minimum bias events surviving this selection.

An average of eight 3-point tracks were found per minimum bias event using the same track-finding software as in P238. These tracks are used to find a first vertex estimate using the histogramming procedure described in P238. This vertex point was then used as a constraint for finding 2-point tracks (i.e., those smaller angle tracks which traverse only the outer two silicon planes of the detector). An average of four such tracks is found per event. We have checked that this procedure gives clean tracks by comparing them with the generated Monte-Carlo tracks.

Starting with the "first vertex estimate", all tracks are used to set up a χ^2 (as in the online procedure) and the χ^2 then minimized to find an improved vertex position. Tracks, which are statistically incompatible with this found vertex, are removed and a new minimization performed. When an acceptable χ^2 is found, the excluded tracks are checked to determine if they form a common vertex (as in the offline procedure used in P238). This procedure is repeated until all tracks are utilized.

All vertices which contain at least four tracks, of which at least two are in each of the forward/backward hemispheres, are termed "primary" vertices. For events with exactly one primary vertex, other vertices are termed "secondary" if they contain at least four tracks in one hemisphere. Finally, to compensate for present inadequacies in the software, we have scanned those events which contain at least one secondary vertex separated from the primary vertex by more than 1.5 mm (along the beam direction). Events are eliminated, which do not have the correct topology (e.g. tracks of a "secondary" vertex point in the wrong hemisphere, etc.). The results of this study are summarized in table 2.

Table 2: Summary of vertex finding(a)

Cuts	Minimum Bias	$b\bar{b}$
Total event sample	1700	850
Exactly one primary vertex	945	556
At least one secondary vertex	21	58
$z_{sec} - z_{prim} > 1.5$ mm	1	28
Valid secondary vertex from scan	0	19

(a) The events in each row include the cuts from the previous row.

All but one of the minimum bias events are eliminated by the topology software. The remaining event is visually inconsistent with heavy flavor production and is rejected. This results in an upper limit for the minimum bias efficiency of 1/1700 = 0.00059. This is an upper limit, because further software improvements are possible and larger sample sizes can be generated. More suppression is possible here than in Chapter 2 because of the more elaborate offline analysis. There is a significant difference between the trigger algorithm, discussed in Chapter 2, which simply tests the hypothesis that all tracks come from a single vertex, and actually finding secondary vertices.

28 of the original 850 $b\bar{b}$ event sample survive all cuts and an additional 9 events are rejected in the event scan, resulting in a 0.022 net detection efficiency for $b\bar{b}$ events. Fig. 2 displays two events which survive the scan.

Assumed values of 50 mb and 15 μb for total inelastic and $b\bar{b}$ cross sections, respectively, lead to an upper limit of 89 minimum bias events per $b\bar{b}$ event, which survive the above selection criteria. Although we are unable at the present time to firmly conclude that $b\bar{b}$ events can be cleanly separated from minimum bias background, we are encouraged by the clean nature of the $b\bar{b}$ events which survive the scan (see Fig. 2), and expect that the suppression of minimum bias events will be considerably larger. Some of the B events will, of course, display both B and D decay vertices. We have not yet studied the contribution from direct charm production, although B events with high multiplicity and long decay distance should be uniquely identifiable.

The cross sections assumed in the previous paragraph, together with a $b\bar{b}$ detection efficiency of 0.022 and a probability of about 10% for the primary vertex to be between detector planes 3 and 4, yield 6.6×10^{-7} observed $b\bar{b}$ events per minimum bias event recorded on tape. Since our running (LBL) silicon readout system should allow us to record data at a 100 Hz rate, we expect about 3.6 identified $b\bar{b}$ events per day (assuming 15 hours of running per day). Thus, in the complete Fall 1990 run, we may obtain several hundred such $b\bar{b}$ events. This number can be increased in a number of ways, which we are presently contemplating. An increase from six to eight detector planes would yield a factor of three. Availability of a faster silicon readout system and/or a relatively simple version of our online trigger processor could yield further (larger) increases in sample size.

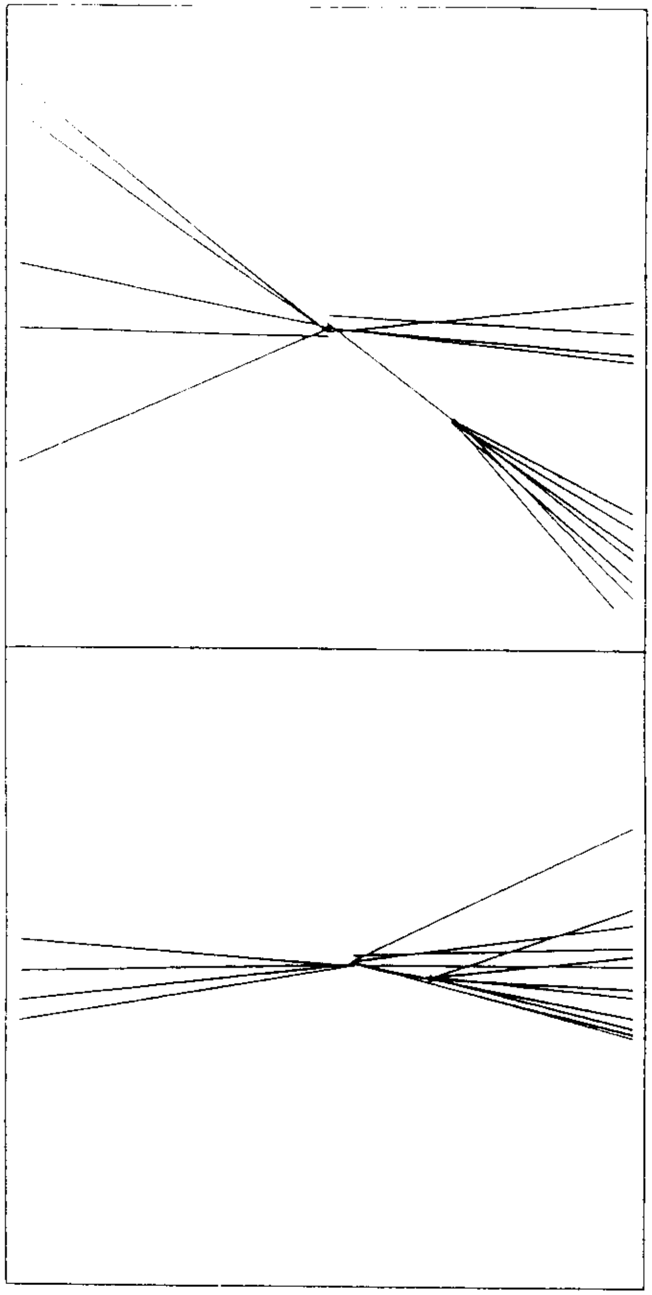


Figure 2: Beauty Events Which Survive All Cuts. On each display, the horizontal scale is ± 1 cm and the vertical scale is ± 3 mm. In each case there are tracks (2 on the upper event, 1 on the lower) that appear not to come from the primary vertex. These are examples of either tracks from V decays, multiply scattered low momentum tracks or "ghost" tracks.

7. Budget

Table 3: Cost Estimates (in SF)

Device	Total(kSF)
Si Detectors (total costs)	170
Readout Electronics (in hand)	
Support/Positioning Assembly	250
Online Computer (in hand)	
Total	420

APPENDIX A: Use of Forward Beauty Detector at LHC

We have noted that the production of B-Mesons from gluon-gluon fusion is markedly polar in laboratory production angle at high energies and becomes increasingly so as the energy increases. Fig. 3 (from ISAJET) shows the expected laboratory angular distribution of B-Meson decay products at the LHC.

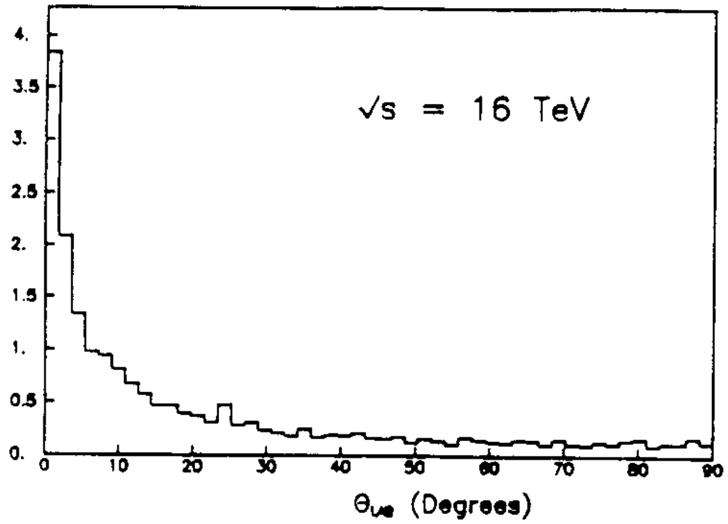


Figure 3: Angular Distribution of B-Meson Decay Tracks at LHC The angular distribution is shown for decay tracks from all B-mesons which have been generated via parton-parton fusion at a cm energy of 16 TeV using the program ISAJET.

Extrapolation of the proposed SPS experiment to the LHC involves three important considerations:

- **Minimum Angle Acceptance:** The proposed P238 detector with θ_{min} = 10 mrad and total length of ±11 meters would have to be supplemented by an additional spectrometer, with length about 10 m, in order to extend coverage down to smaller θ_{min}. Our preliminary estimate (using ISAJET) is that the addition of a third spectrometer, which would cover the smaller angles from 2 to 10 mrad, would result in less than a 10% loss of B-mesons at LHC due to small angle particles lost in the beam pipe.

- **Improved Momentum Resolution:** The increased track momenta from B-meson decay at LHC require that appropriate precautions be taken in the detectors to avoid degradation of momentum resolution. Fig. 4 shows the average momentum of B-meson decay tracks vs. laboratory angle at the SPS and at LHC. In the angular range of the first spectrometer (100-600 mrad), the track momenta at SPS and LHC are nearly the same. Thus the first spectrometer requires no changes. In the second spectrometer (10-100 mrad), tracks at LHC have somewhat higher momenta. These can be accomodated if the normal dipole magnet is replaced by a superconducting dipole. In the third spectrometer (2-10 mrad), which is added for the transition to higher energy, a superconducting dipole magnet with opposing field (to provide beam compensation) would be used together with silicon tracking (maximum size can probably be limited to about 20 x 20 cm^2).

- **Luminosity:** There is a natural limit to the useable luminosity which is determined by pileup considerations, complicated by the need for real-time pipelined calculations, and also by radiation damage to the silicon detectors due to the beam-beam interaction rate. We are currently studying this question for the LHC. We think that, for this type of experiment with elaborate silicon systems close to the beams and in which exclusive final states are reconstructed, one probably will not want to run with luminosities larger than 10^{31} $cm^{-2}s^{-1}$. We believe that one interaction region could be run with such a low luminosity without compromising high luminosity operation in the other regions.

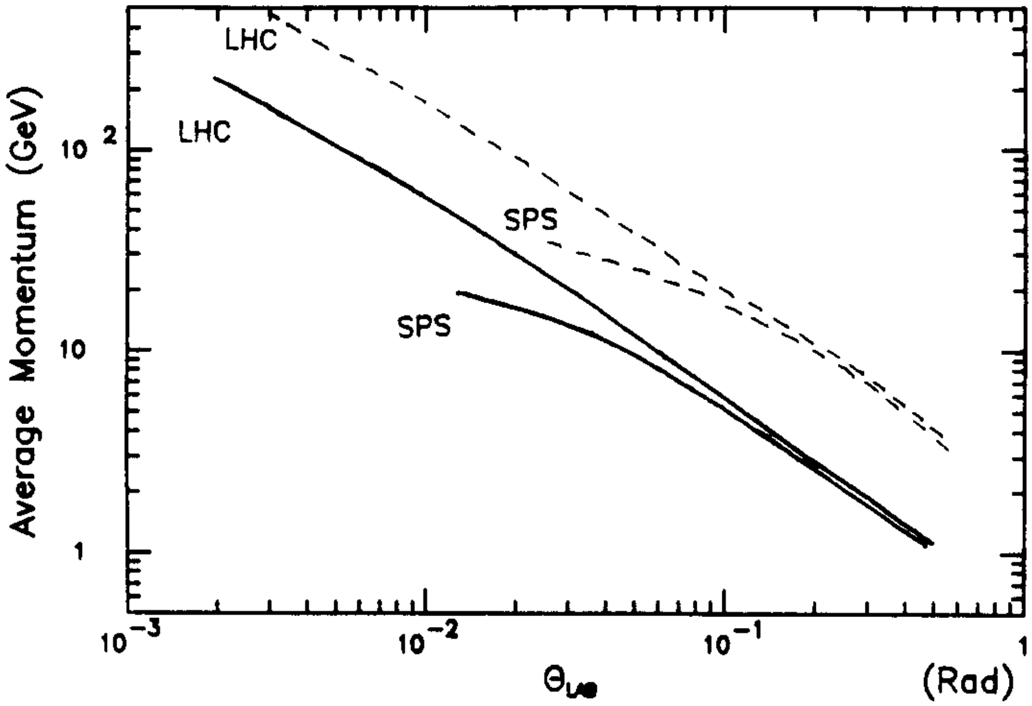


Figure 4: Mean B Decay Track Momentum vs. Laboratory Angle The mean momentum is evaluated for decay tracks of B-mesons which are generated at the two cm energies using the program ISAJET. and whose decay tracks are fully accepted in the 600 mrad aperture of the detector. The dashed curves are those momenta, below which 95% of all tracks occur.

We estimate that, due to a number of reasons (mainly: larger B cross section, σ_B/σ_{total} ratio, available luminosity and forward collimation of B decay products), a factor of at least 500 times larger event samples should be obtainable at the LHC than at the SPS-Collider. This should place such an experiment well over the threshold to perform quality CP-violation studies in B decay. Thus our beauty program starting at the SPS-Collider would evolve to a more powerful CP-Violation experiment at the LHC.