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Status Report of the Fermilab B Collider Study Group[1]

Participating Institutions[2]

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Abstract

The motivation, size and scope of a B-$\bar{B}$ CP-violation experiment, called here the Bottom Collider Detector, at an upgraded Tevatron Collider is indicated. Preliminary results from detector and event simulation studies by the Bottom Collider Study Group are presented. No detector design details are discussed though some overviews are given. Where appropriate, discussions on what further study is required is given. The need for an upgraded Tevatron is absolutely clear. A factor of 200 increase over the present design luminosity of 1×10^{30} cm^{-2}sec^{-1} is highly desirable. This report is not intended as a proposal nor as a finished study but merely represents the status of our thinking at this time: the Bottom Collider Detector is challenging but doable; it is the most agressive pursuit of CP-violation physics possible in the near future, and would be a vital step in the development of the high-rate, 4π instrumentation needed for the SSC era.

Introduction

The goal of the Bottom Collider Detector is to produce 10^{11} B-$\bar{B}$ events for which an efficient single-lepton trigger tags one B and permits detailed study of the few-particle decay modes of the other B. The trigger efficiency should be at least 5%, and the combined acceptance and vertex reconstruction efficiency for the other B should be above 20%, so that a sample of 100,000 reconstructed events would be obtained for a mode with a 10^{-4} branching fraction. A sample of this size in each of several few-body decay channels will permit a detailed study of CP nonconservation in the B-$\bar{B}$ system. A decay mode with a 10^{-8} branching fraction would still yield 10 events, so the study of rare processes is an obvious byproduct.

The very large B-$\bar{B}$ cross section at 2 TeV (~ 45 μb),[3] the relatively favorable ratio of bottom to total cross section ($\sim 10^{-3}$), combined with an average luminosity of 10^{32} cm^{-2}sec^{-1} makes the upgraded Tevatron Collider a unique B facility that will produce important and fundamental physics results on a time scale of approximately 5 years from now.

Similar ambitious physics goals are being considered in the e^+e^- community; the B-$\bar{B}$ cross section at the $\Upsilon(4S)$ is about 1 nb, while the trigger efficiency might be close to 100%. No credible plan exists for a new e^+e^- machine that could reach the luminosity of 10^{34} cm^{-2}sec^{-1} with asymmetric beam energies as needed to compete with the hadron-collider option.

The Bottom Collider Study Group was formed to follow up on ideas developed at the Workshop on High Sensitivity Beauty Physics at Fermilab, Nov. 1987, which in turn was prompted by two letters of intent submitted to Fermilab for consideration in 1987.[4,5] The group has taken a very broad and ambitious approach to defining the experimental goals and parameters associated with performing a high-statistics B experiment in the upgraded Tevatron collider. The organization set up for studying the issues was to divide the study group into several sections, each addressing one aspect of the experimental design, and then meeting roughly once a month to present the work to date.

The starting design parameters used as guidelines are listed below:

- pp or $\bar{p}p$ collisions at $\sqrt{s} = 2$ TeV;
- An average luminosity of about 10^{32} cm^{-2}sec^{-1} ;
- Interaction rate of 5 MHz ($\sigma_t = 50$ mb);
- $\sigma_{BB} = 45$ μb, or 4500 B-$\bar{B}$ events/sec;
- An average event multiplicity of 60 charged pions and 30 π^0's;
- A magnetic detector with acceptance from 2° to 178°, or roughly ±4 units of rapidity;
- A semileptonic trigger efficient for electrons of 1 GeV/c P_T and above;

- At a hadron collider the B-decay modes useful for study of CP violation are those which permit reconstruction of the B mass;
- Charged tracks from B decay are fully reconstructed including a μ-vertex measurement and particle identification;
- A B-mass resolution of 25 MeV/c^2 is needed to suppress combinatoric backgrounds, and to separate B_d from B_s;
- Only B-decay modes containing all charged tracks will be reconstructed; π^0 reconstruction is not required;
- An hermetic hadron calorimeter is not required as missing-E_T is not an important quantity for B-$\bar{B}$ physics.

The main issues are discussed in the following sections:

1. Bottom Physics Goals

The major physics goal of this experiment is to observe and study CP nonconservation in the neutral and charged bottom-meson systems. The B-$\bar{B}$ system provides a detailed test of the standard model in that the parameters of the K-M matrix may be overdetermined by measurement of CP violation in several different modes. The opportunity for systematic study is much greater than in the K-$\bar{K}$ or D-$\bar{D}$ systems, with the corresponding prospect for greatly increased understanding of the quark mass matrix. Deviations from present expectations would give important clues about the Higgs sector and possible new generations of quarks. Exploration of the B-$\bar{B}$ system is vital for a better understanding of the sources of CP violation beyond the parametrization that we have now.[6]

The proposed experiment is concerned with the systematic investigation of CP violation in several channels of B-$\bar{B}$ decay, rather than merely providing low-statistics evidence that CP violation exists. The technique which appears of most general utility in a collider experiment is a search for asymmetries of the type

$$A = \frac{\Gamma(B \to f) - \Gamma(\bar{B} \to \bar{f})}{\Gamma(B \to f) + \Gamma(\bar{B} \to \bar{f})}.$$

When final state f is the same as $\bar{f}$, as in many potentially favorable cases, the decaying B must be identified as a B or $\bar{B}$ (which is complicated in an interesting manner by bottom oscillations). This identification is made by determining the flavor of the other B of the B-$\bar{B}$ pair. In a hadron-collider experiment this is necessary anyway for trigger purposes, in that the sign of the electron in the triggering decay $B \to eX$ identifies the flavor. Decay modes of the B^0 such as $D^+\pi^-$ are 'self tagging' and would not require a trigger on the other B. Likewise, analysis of asymmetries of charged-B decays does not require flavor identification of the other B. While these modes will be explored in the Bottom Collider Detector we are unlikely to profit from the freedom to ignore the second B.

We would concentrate on few-particle final states f such as $\pi^+\pi^-$, K^+K^-, $p\bar{p}$, $D^+\pi^-$, ψK_S, $\psi\pi^+\pi^-$, *etc.*, which yield only charged particles in the detector. Estimates of the asymmetry parameter A for such decays are of order 0.1, while the branching fractions are expected to lie in the range 10^{-4}-10^{-5}.

To reach a statistical significance of S standard deviations in a measurement of asymmetry A the total number N of tagged and reconstructed decays required is

$$N = \left(\frac{1}{A^2} - 1\right) S^2 \sim \frac{S^2}{A^2}.$$

Thus a 5σ signal requires $N = 2500$ for $A = 0.1$, but $N = 250{,}000$ for $A = 0.01$. Clearly the experiment must have the flexibility to profit from those decay modes with $A \sim 0.1$, but it is not known at present which modes these are.

It may well be a tradeoff of Nature that modes with large asymmetries, A, have small branching fractions. If we then take 10^{-5} as the more likely branching fraction for the interesting modes with $A \sim 0.1$, we would need 2.5×10^8 tagged B's for a significant study.

Supposing the tagging efficiency (times reconstruction efficiency) can be maintained at 1% in the hadron-collider environment, a total of 2.5×10^{10} B-$\bar{B}$ pairs is required for a serious investigation. This sets the scale of effort required in the proposed experiment.

2. Detector Overview

The physics goals of the B-$\bar{B}$ experiment at a hadron collider mandate two major capabilities of the detector:

- Tagging of one member of a B-$\bar{B}$ pair;
- Full reconstruction of charged decay modes of the other B.

Geometric Coverage: $2° < \theta < 178°$

An initial sense of the geometry of the B-$\bar{B}$ events can be gained from fig. 1 which shows the pseudorapidity, $\eta = -\ln \tan \theta/2$, for pions for the decay $B_d^0 \to \pi^+\pi^-$ for B's produced in $p\bar{p}$ collsions at $\sqrt{s} = 2$ TeV. This is taken from a simulation[7] using the Monte Carlo program *PYTHIA*.[8] About 95% of the tracks from a B decay lie within the range $-4 < \eta < 4$ corresponding to angles of $2° < \theta < 178°$ with respect to the beam axis. We then desire particle detection at all azimuthal angles over this range in polar angles.

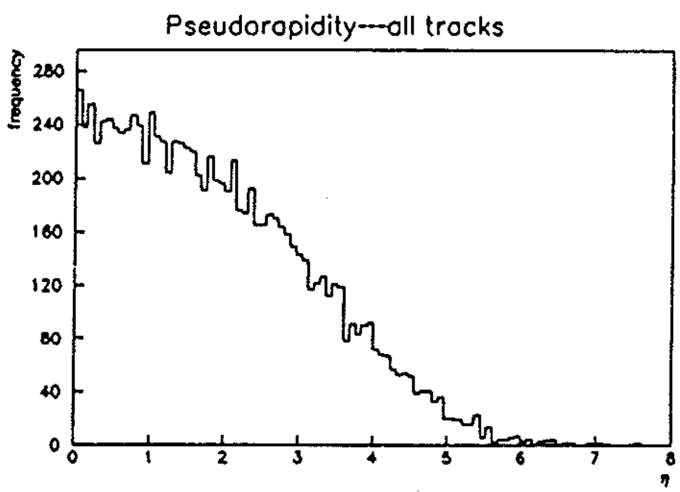

Fig. 1. Pseudorapidity distribution for decay products from $B_d^0 \to \pi^+\pi^-$ from a *PYTHIA* simulation at $\sqrt{s} = 2$ TeV.[7]

The basic character of the detector should thus be 'central,' but with greater emphasis on the angular region $2° < \theta < 30°$ than in present detectors designed for W and Z physics.

At the SSC, with $\sqrt{s} = 40$ TeV, the corresponding range of pseudorapidity for B-decay products is about $-6 < \eta < 6$. The angular range corresponding to $|\eta| > 4$ is at very small angles to the beams, and would require detectors[9] resembling those in fixed-target experiments.[10] The present Bottom Collider Detector is, however, a prototype of that needed to cover the central rapidity range at the SSC.

The typical transverse momentum of the B-decay products is 1 GeV/c, corresponding to total momenta in the range of 1-50 GeV/c, at $\sqrt{s} = 2$ TeV (see fig. 2). The exciting B physics occurs in rather 'soft' events at collider energies.

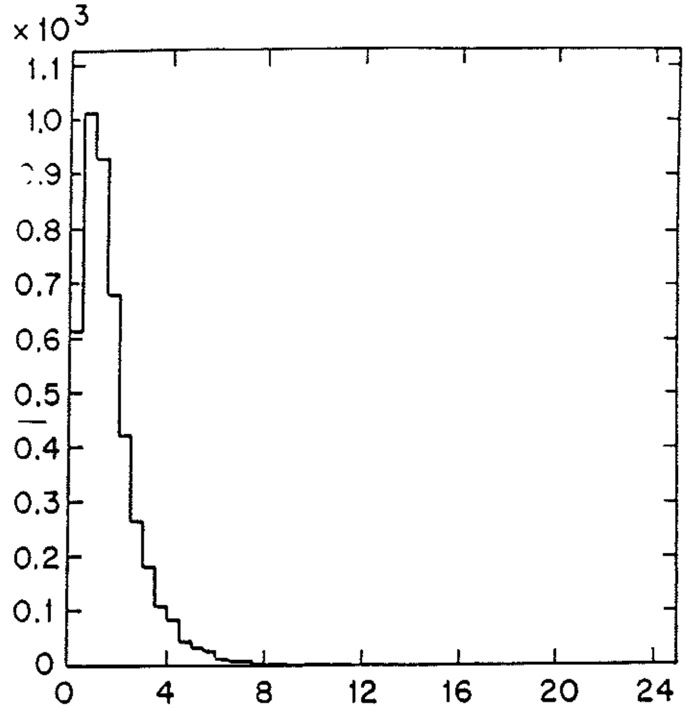

Fig. 2. The P_T spectrum in GeV/c for electrons from the decay $B \to eX$ at $\sqrt{s} = 2$ TeV.

Use of a Dipole Magnet

Complete analysis of the charged tracks from B decay will require a magnetic field in the central region. In the approximation that interesting tracks from B decay are distributed uniformly in pseudorapidity, the track density varies as

$$\frac{dN}{d\theta} \sim \frac{1}{\theta},$$

so the detector must emphasize tracking at small angles to the beam The solenoidal field of typical collider detectors is somewhat unfavorable for B-collider physics at $\sqrt{s} = 2$ TeV in that the momentum resolution is quite limited for small-angle tracks which exit the end of the solenoid. Instead we prefer a dipole magnet with magnetic field transverse to e beam. This affords good momentum resolution at small angles where the track density is high, and a very limited region in azimuth for $\theta \sim 90°$ with poor momentum resolution, but where the track density is low (see fig. 3). Some 95% of all particles from B decay have transverse momenta less than 3 GeV/c (fig. 2), which permits rather accurate momentum measurements even for directions near $(\theta = 90°, \phi = 90°)$.

A single large dipole magnet can provide excellent momentum resolution for the entire geometrical region of B decays at $\sqrt{s} = 2$ TeV, which lends itself to a unified detector concept. While such a magnet might have to be newly built we note that the Chicago Cyclotron Magnet would be very suitable if its gap were enlarged to 3 m.

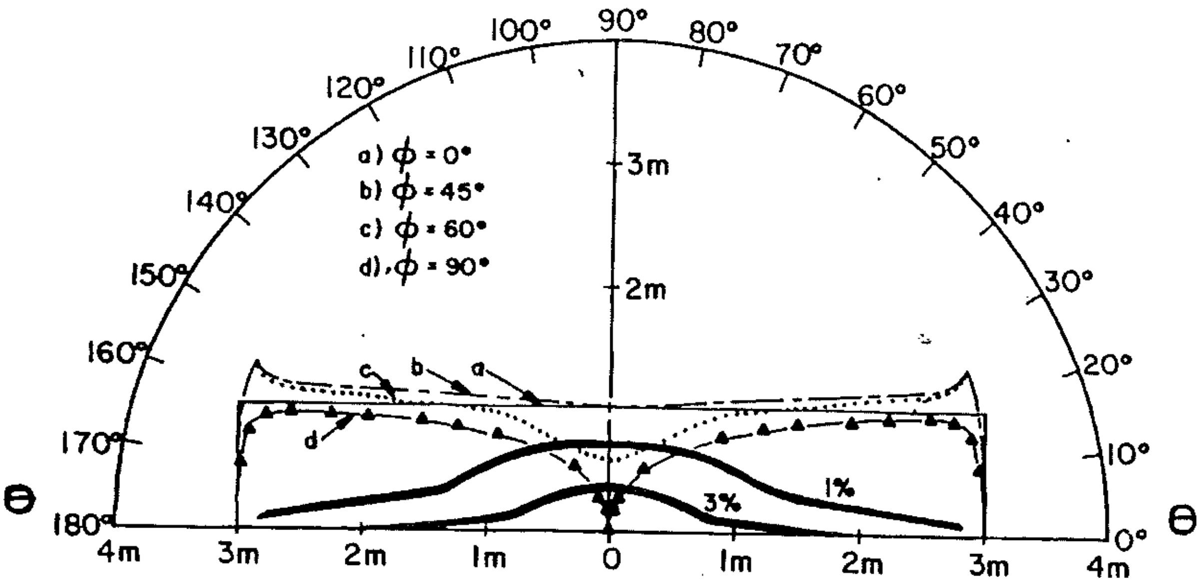

Fig. 3. The Reay plot illustrating the momentum resolution attainable with a 1-Tesla dipole magnet in the Bottom Collider Detector. The interaction point is at the origin and the beams lie along the horizontal (z) axis. The magnetic field is perpendicular to the paper (x-z plane) and is taken to be uniform within the rectangle which represents the top view of one half of the 2 m × 2 m × 6 m field volume. The curves labelled a) through d) show the path length, projected onto the x-z plane, of a track emerging from the origin with a given (θ, ϕ) direction. This path length is represented as the distance from the origin of the plot. The momentum resolution of the detector varies as Bl^2 where l is the path length shown on the plot. The countours labelled 1% and 3% show the required path length to achieve a momentum resolution of 1% and 3%, respectively, for tracks of transverse-momentum $P_T = 3.5$ GeV/c, supposing the measurement accuracy in the sagitta is 40 μm. For example, at $\phi = 90°$ a momentum resolution of better than 3% can be obtained at all polar angles except $75° < \theta < 105°$. For $\phi < 55°$ a momentum resolution of better than 1% is obtained at all polar angles.

Broad Requirements for Tracking and Particle Identification

To accomplish a full reconstruction of charged tracks from B decays in a high-multiplicity environment we shall need

- A 3D microvertex detector with a worst-case impact-parameter resolution of 20-μm.
- A magnetic field integral of 2-3 Tesla-m for small-angle tracks.
- A tracking chamber with 50-100 of samples per track for pattern recognition and momentum measurement of accuracy $\Delta P/P = 0.01$ for tracks with $P_T < 3$ GeV/c;
- Identification of π, K, p, e, and if possible μ. However, reconstruction of $\pi^0 \to \gamma\gamma$ and hadron calorimetry may not be necessary.

Figures 4 and 5 sketch a detector which incorporates these features. We briefly introduce the various detector elements in the remainder of this section, from the intersection regions outwards. Greater detail is presented in the subsequent sections.

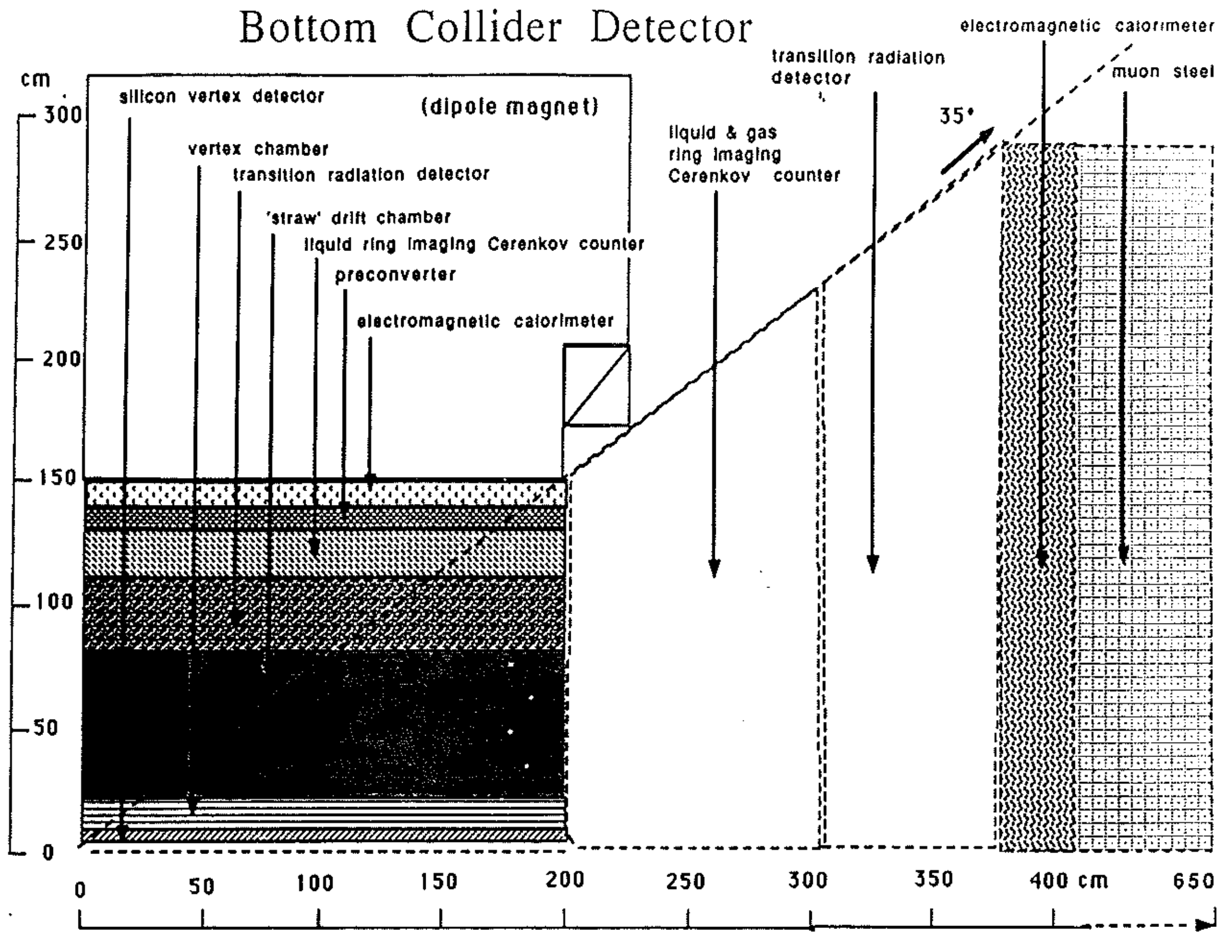

Fig. 4. View of the detector with the beam (z) axis horizontal and the dipole magnetic field along the vertical (y) axis.

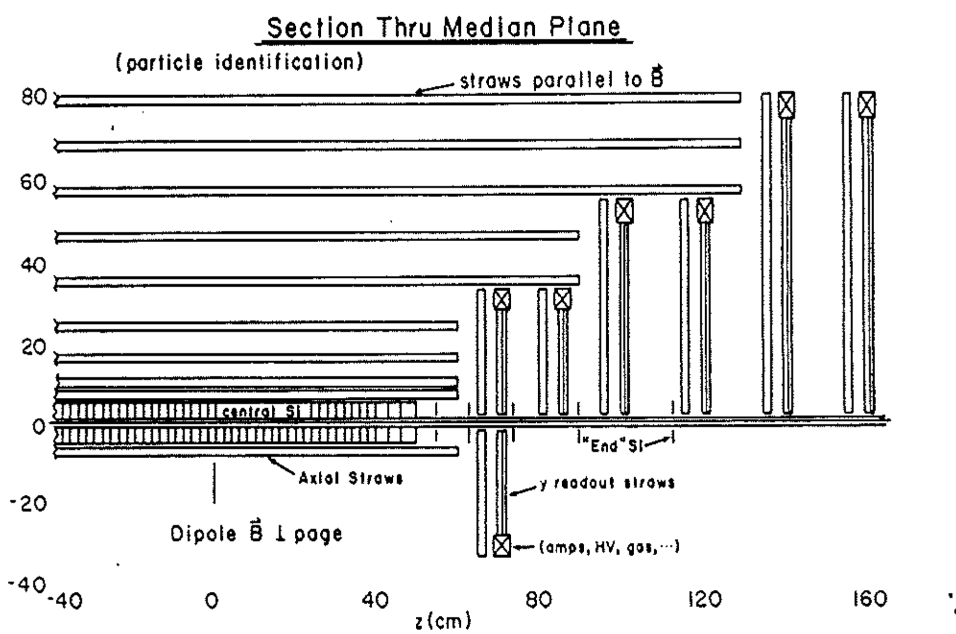

Fig. 5. A section through the median (x-z) plane of the silicon vertex detector and the straw tracking chamber.

Beam Pipe

The beam pipe must not only be thin to minimize secondary particle interactions but also must have a very small radius to permit high accuracy in the vertex reconstruction. We propose to use a beryllium pipe about 1 inch in diameter with a 400-μm-thick wall.

Microvertex detector

The lifetime, $c\tau$, of bottom mesons is about 360 μm. Secondary vertices must be reconstructable when their separation from the primary vertex is of this scale. We propose a microvertex detector based on silicon-strip detectors. Alternative vertex detectors utilizing pixel devices are also under consideration.

The novel difficulty for precision vertexing in a collider experiment is that the secondary tracks emerge into the full 4π laboratory solid angle (see fig. 6) At present, tracking with silicon-strip detectors has been implemented only in geometries with near-normal-incidence tracks. However, because the interaction region in a hadron collider is spatially extended there is no plausible geometrical arrangement of silicon planes which does not have some tracks at 45° incidence.

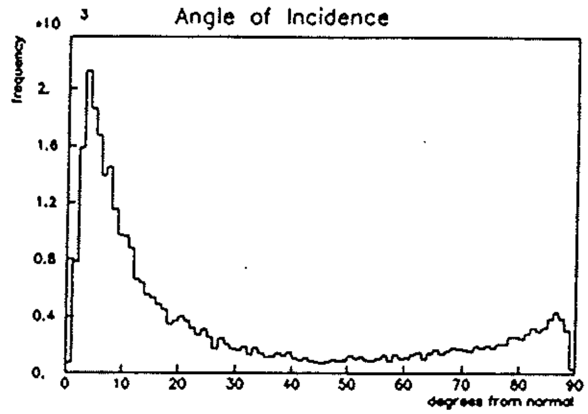

Fig. 6. Angle of incidence (degrees from normal) on the silicon vertex detector for decay products of bottom mesons.

We anticipate that development of silicon detector technology will permit its use for 45°-incident tracks. We plan to use 50-μm strip width, so that a 45° track would cross 70 μm of silicon per strip. The signal is then 70 μm $\times$ 80 electron-hole pairs/μm = 5600 electrons. It appears likely that VLSI readout chips for the silicon-strip detectors will achieve noise figures of 1000 electrons, which is entirely adequate. Indeed, if this noise level can be maintained even with $\sim$ 0° incidence should be detectable, as these would yield about 4000 electrons.

Multiple scattering of charged particles and conversion of photons in the silicon detectors is a non-neglible problem. As a consequence we plan to use 200-μm-thick silicon, with double-sided readout.

The number of channels required in the vertex detector is very large. If the interaction region is roughly 1-m long, as in the present $p\bar{p}$ running at the Tevatron, approximately 10^6 strips are needed. Furthermore, there must be an inner 'barrel' of silicon 1-m long and concentric with the beam pipe in order to collect the large-angle tracks which emerge along the entire interaction region. This places considerable material just after the beam pipe which will be traversed by most small-angle tracks, leading to severe backgrounds of converted photons.

It would be much more favorable if a short interaction region were available, of order 10 cm. The inner barrel need only extend the length of the interaction region, so the number of silicon channels could be reduced by a factor of four, and γ-conversions would be greatly reduced. For this reason the Bottom Collider Detector is much more suited to a *pp* machine with a finite beam-crossing angle and correspondingly short interaction region.

Tracking Chamber

The silicon vertex chamber will provide typically only two measurements per track (in each of two coordinates) as the cost of, and multiple scattering in, additional planes is prohibitive. Therefore the inner vertex chamber must be surrounded by a tracking chamber capable of excellent pattern recognition in high-multiplicity events. The position resolution of and material traversed in crossing this chamber should permit a 25-MeV/c^2 resolution at the B-meson mass to distiguish B_d from B_s.

As we also wish particle identification for tracks in all 4π solid angle it is useful to have a tracking chamber which does not have massive end plates. The self-supporting 'straw' chambers are very appealing for this reason. In addition they offer high-rate capability and rather good position resolution.

A straw chamber for the Bottom Collider Detector might have about 10^5 channels of 3-mm-diameter tubes operating at 3-atmospheres pressure. Each track would cross approximately 80 tubes. The resolution transverse to the wire would be about 40 μm. Charge-division, or a pad readout, could be used to measure the longitudinal coordinate to a few mm accuracy. Development work is needed on thin-wall tubes to minimize the multiple scattering in the chamber.

RICH Counters

Separation of π, K and p will be accomplished with Ring Imaging Čerenkov Counters, with a liquid radiator for production angles above 30° and liquid plus gaseous radiators at smaller angles. Time-of-flight counters in the central region will help identify very soft tracks.

Transition Radiation Counters (TRD's)

Separation of e's from charged pions will be aided by multiple layers of TRD's, about 20 cm each. The combination of tracking information with the transition radiation signal should permit a pion rejection factor of 20 in the TRD. The utility of the TRD's at small production angles needs further study.[11]

Electromagnetic Calorimeter

The calorimeter functions primarily to aid in electron identification, rather than providing a precision energy measurement. As such position resolution is more critical. We thus have the option to use a sampling calorimeter (as opposed to total absorption in BGO or lead glass, *etc.*), with a tracking chamber after two radiation lengths. The first two radiation lengths can then serve as a preconverter to aid in rejection of $\pi^{\mp} \rightarrow \pi^0$ charge exchange. The particular form of the electromagnetic calorimeter is not specified at this time.

Where space permits the electromagnetic calorimeter should be followed by a post-calorimeter of 1-2 hadron interaction lengths to help identify hadron showers which simulate electrons in the earlier detectors. The post-calorimeters could be located in the forward and backward detectors, and to the sides of the magnet aperture.

3. Accelerator Issues, Collision Hall, and Magnet

General Characteristics of the Detector and Collision Hall

The accelerator-related requirements for the Bottom Collider Detector are derived from the performance needed to achieve the physics goals sketched above in sec. 1. In order to study CP violation in the B-$\bar{B}$ system, the experiment should produce about 10^{11} bottom events per running year. The detector (see figs. 4 and 5 of sec. 2 above) will cover nearly 4π steradians. The central detector has a dipole magnet with a 1-Tesla field transverse to the beam axis, and a field volume of (at least) three by three square meters by four meters along the beam axis. Compensation must be made for the transverse deflection of the beams by the dipole magnet.

The detection of the B-$\bar{B}$ decay products requires that a sophisticated solid-state vertex detector, which may be prone to radiation damage, be located within 1/2″ of the beamline. There will also be a forward/backward detector that extends several meters up- and downstream from the central detector.

The space required in an experimental hall is roughly determined by the overall dimensions of the detector. As presently envisioned, the detector occupies a volume of about six meters square in cross section and 12 meters in length. The dimensions of the spectrometer magnet will be comparable to those of the Chicago Cyclotron Magnet.

Beam Energy

The present detector is designed for the 1×1 TeV beams of the Tevatron. The B-$\bar{B}$ production cross section varies approximately linearly with collider beam energy so an accelerator with 500-GeV beams is still a serious contender for the B-physics experiment. For beam energies considerably above 1 Tev a substantial fraction of B-decay products emerge at extremely small angles to the beam, which likely requires a detector with multiple magnets. The Tevatron energy is perhaps the largest for which a detector based on a single central magnet will suffice.

Luminosity

As discussed in section 1, systematic exploration of CP violation in the B-$\bar{B}$ system becomes possible for luminosities of order 10^{32} cm^{-2}sec^{-1} . The large investment in the Bottom Collider Detector would be problematic if the average luminosity were only 10^{31} cm^{-2}sec^{-1} . We recommend an average luminosity of 10^{32} cm^{-2}sec^{-1} be the accelerator goal. The higher luminosity and greater reliability of a pp collider make this option extremely desirable for B physics.

Length of the Interaction Region

The length of the interaction region determines the length of the vertex detector. At the present Tevatron the interaction region has a σ of 35 cm. A vertex detector for this region would have to be at least one meter long, with 10^6 readout channels and unwanted material close to the beam pipe. Current discussions for a Tevatron Upgrade include the possibility of a shorter interaction region with a σ of 10 cm. The reduction in σ would greatly simplify the vertex detector design.

Although all current versions of the Upgrade make provision for a reduced interaction-region length, the *pp* option offers the greatest flexibility in that a crossing angle is part of the machine design. By increasing the size of the crossing angle, the length of the interaction region can be proportionately reduced at the expense of luminosity. Because high luminosity can best be achieved in the *pp* option, the experiment would have the best chance of achieving an intersection-region length of about 5 cm at a luminosity of 10^{32} $cm^{-2}sec^{-1}$.

Beam Size

A small transverse beam size is desirable for several reasons. An important signature of B decays is the detection of their decay vertex some few-hundred μm from the primary interaction point. If the beam size is small compared to 100 μm then we gain the considerable advantage of regarding the beam as 1-dimensional. The diameter of the beam pipe, and therefore the vertex detector, is determined by the beam size. The motion of the beams within the beam pipe when the spectrometer dipole is turned on, which also affects the size of the beam pipe, is minimized when the beam size is smallest. And, of course, one achieves higher luminosity with a smaller beam cross section as well.

Beam Pipe

Conversions of photons in the beam pipe and multiple Coulomb scattering must be minimized in this experiment. A suitable beam pipe could be made of 400-μm-thick beryllium and should be roughly 1/2″ in radius.

Beam Halo

Halo associated with the beams will contribute to the radiation exposure of the vertex detector and thereby shorten its lifetime. Present data indicate that the silicon detector can survive 10^5 rads and the micro-electronics withstand about 10^4 rads. It is clear that catastrophic beam loss must not occur near the detector. The beam-loss level for abort may need to be lowered compared to present operation.

The Spectrometer Dipole Magnet

The dipole magnet should be rather like the Chicago Cyclotron Magnet, but with its gap increased to 3 m in height. Such a magnet will weigh about 2500 tons, and will determine the transverse size of the detector hall. The cost of powering conventional coils for such a large magnet favors the use of superconducting coils. The cost of construction of a new magnet might be \$1.25M for the steel at \$500/ton, plus \$1M for the superconducting coils, plus cryogenics, plus installation.

A Comparison of Existing Magnets

A comparison has been made with existing magnets that might be available on a time scale adequate for the Bottom Collider Detector. The magnets that have been studied are the CCM (Chicago Cyclotron Magnet), the NFTF (Nuclear Fusion Test Facility), the Fifteen Foot Bubble Chamber Magnet, and the Berkeley 184" Cyclotron magnet.

The CCM would be an ideal magnet for the B Collider, if its gap were opened from the present 1 m to the needed 3 m. It will be tied up in the muon program for several years. If it should become available, the cost of moving it to a new facility would be around $750,000.

The NFTF has been turned on only once so this is a virtually new magnet. Only the superconducting coils of the NFTF magnet would be of use at the Bottom Collider Detector. The project would have to pay the cost of building the magnet yoke. A rough design shows that four of the existing ten coils could be used to achieve a 1-Tesla field. The cost of transport and installation are not known.

The Fifteen Foot Bubble Chamber Magnet has not been considered seriously for this project because it is being sought for an experiment at Gran Sasso. As for the NFTF magnet, a steel yoke would have to be built to incorporate the existing coils. No cost estimates are available.

An attempt had been made to acquire the Berkeley 184" Cyclotron Magnet for the Bottom Collider Detector. This was not possible because the magnet plates are only two inches thick (too many plates, too much rigging cost), they are mildly radioactive, and they are welded together into a yoke that also supports the crane at the Berkeley Cyclotron Building. The estimated costs of the procurement of this steel exceeds $1M, and was considered excessive. The magnet coils from the cyclotron are not considered useful because they are oil cooled and radioactive.

Compensation for the Dipole Field

The presence of a spectrometer dipole in the Tevatron would alter the beam trajectory unless compensating measures are taken. The scheme that has been chosen for compensation uses two dogleg bends, one at each end of the straight section and each 20 feet from the center of the interaction region, just downstream of the low-beta quads. The two magnets are both of opposite polarity relative to the spectrometer dipole, and run in series with it (that is, the currents run up together). The spectrometer dipole and compensating magnets are energized only after coasting beam has been established. The beams at the crossing region then move laterally a few mm as the magnets are energized.

The Detector Hall and Support Facilities

The Detector Hall required for this facility will be comparable in size to that at D0. The detector itself will fill about one half the space available in a straight section at the Tevatron. The compensating dipoles are placed at the outer ends of the straight section. The need for electron detection and calorimetry will require the use of special gasses and liquids. The detector may use ethane, TMAE, TEA, or liquid argon. The detector will require a substantial signal processing area. The Detector Building must also provide for a control room, office and technician space and shop support.

Summary and Status of Accelerator Issues

The broadest issues associated with the accelerator have been successfully worked out. The installation of the spectrometer dipole magnet in the Tevatron seems eminently feasible. The detector size (except perhaps for the magnet yoke) is relatively modest compared to present collider detectors. The magnet parameters are well understood. The location of a vertex detector around the beam pipe is a main feature of this detector and presents special considerations for the accelerator.

The issues that remain to be solved are those that interface with the accelerator beam optics. While the field nonuniformity of the spectrometer dipole is not thought to pose a serious problem it must be studied in more detail. Methods must be developed to insure that a catastrophic loss of beam into the vertex detector does not occur.

4. Silicon Vertex Detector

Overview

During the past year, the B Collider Study Group has specified the basic geometrical layout of a silicon-microstrip vertex detector suitable for the long interaction region of the present Fermilab $p\bar{p}$ collider.† In brief, this design consists of mosaics of silicon wafers of 200-μm thickness and 50-μm strip width, and double-sided readout arranged as in fig. 7 to form:

1) 2 cylindrical shells around the beam pipe with length 80 cm and radii of 1.5 and 5 cm, and
2) 27 annular disks of radius 10 cm oriented perpendicular to the beam and outside the beam pipe, with a total extent of 210 cm along the beam.

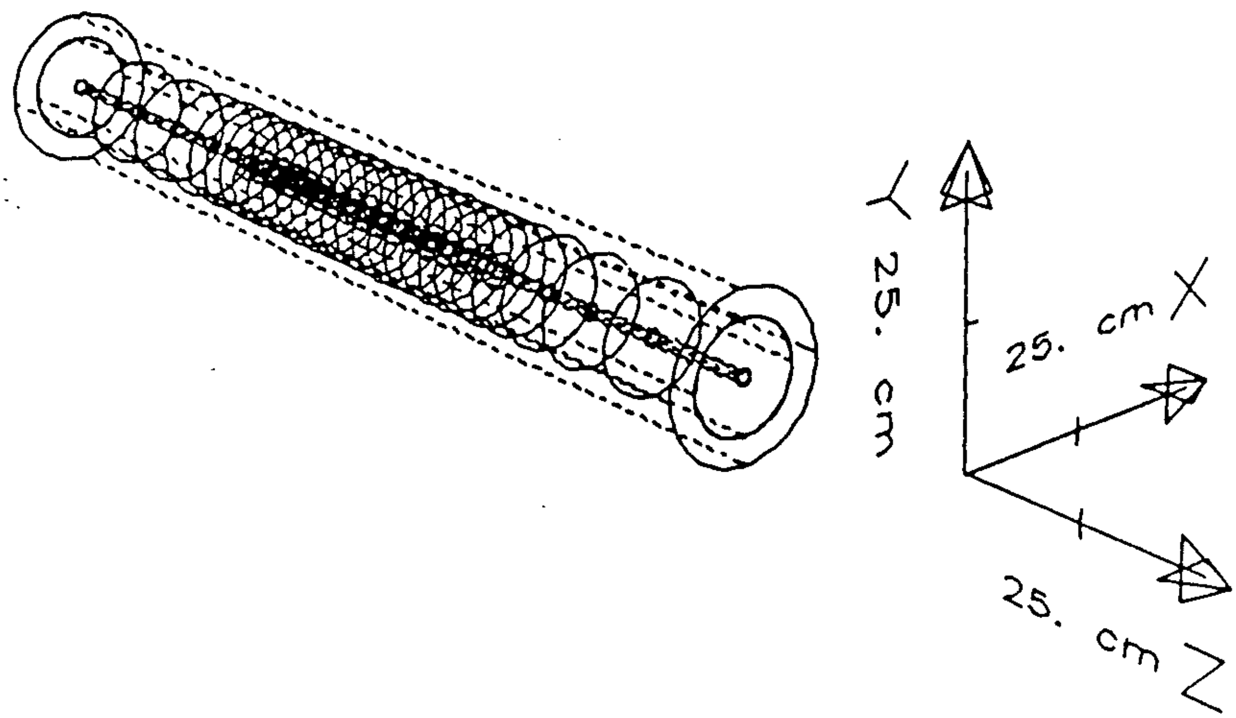

Fig. 7. Layout of the silicon vertex detector

This design is described in detail in ref. 7 along with a description of a Monte Carlo simulation of the decays $B \rightarrow \pi^+\pi^-$ and $B \rightarrow \psi K_S$, ($\psi \rightarrow e^+e^-$). The simulation shows that efficiencies (per B-decay) of 45% are possible with a vertex cut of $S/\Delta S > 5$ (see fig. 8), where S is the distance from the primary interaction vertex to the measured secondary

† As noted in sec. 2 it is extremely advantageous to have an interaction region of < 10 cm to simplify the vertex detector. The vertex reconstruction efficiencies associated with a short interaction region are, however, only slightly larger than those reported here.

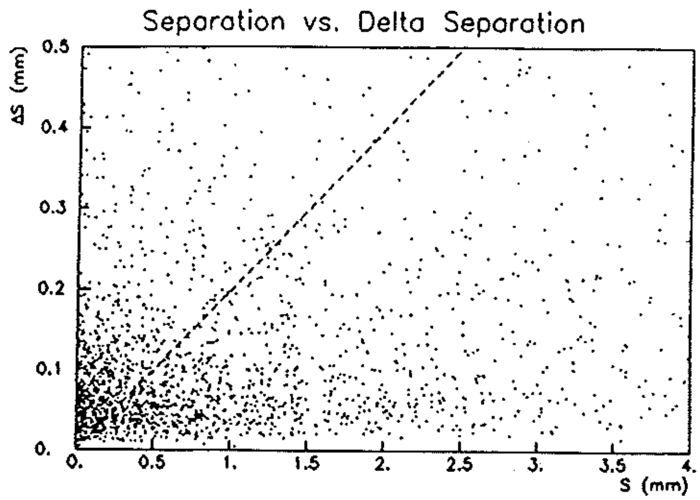

Fig. 8. Scatterplot of separation S vs delta separation ΔS for simulated $B \to \psi K_S$ events. The region below the dashed line contains events that satisfy the cut $S/\Delta S > 5$. Events with small S are predominantly produced in the central region, where the lower B momentum leads to a lower fraction of events surviving the cut.

vertex, and ΔS is the error in S (taken here as the distance between the reconstructed decay vertex and the Monte-Carlo-generated decay vertex).

Hardware Development

Although some optimization of plane spacings and sizes is no doubt possible, it would be prudent to assess the realization of this design in actual hardware devices. Fortunately, the basic hardware devices already exist. Double-sided silicon wafers have been successfully fabricated and low-power CMOS readout chips ("microplex chips") have been developed.[12]

However, a number of crucial operating parameters remain to be established:

a) The amount of material in mechanical mounting, cooling, and signal fanout. The simulation, so far, has included only the effects of the 200-μm-thick silicon-detector wafers and the 400-μm-thick Be beam pipe. The additional material must be included.
b) The noise rate for a given detection efficiency and the effect of efficiency and noise on pattern recognition. So far, the simulation has not considered the efficiency of detectors or the effects of errors in pattern recognition.
c) The detection efficiency for large angle of incidence, above 45°. Silicon detectors have not been used in the past to detect particles at large angle of incidence.
d) The effect of radiation damage in a hadron environment for *specific* devices. Devices could be tested in fixed-target beams or near the beam pipe of the collider. It is well known that radiation tolerance varies with manufacturing techniques.

To address these problems, members of the B Collider Study Group have expressed interest in a number of future projects. We will obtain and evaluate a double-sided silicon wafer from a commercial vendor (MBB-Messerschmidt, FRG) and study the large angle of incidence problem, and other characteristics of these devices. This work, and construction of a mechanical model of the silicon mosaic will be pursued at the U. of Oklahoma.

Physicists from Yale U. will obtain a variety of available microplex chips and evaluate the efficiency and noise as a function of gating time. Simulation efforts, building on the existing work, will focus on the effects of realistic material estimates, pattern recognition problems, and more sophisticated vertex fitting.

Detector Geometry

The silicon vertex detector under consideration is logically segmented into two regions. The central region covers most of the interaction region with a combined geometry of equally-spaced silicon planes and two segmented barrels. The rapidity-spaced region covers the outer limits of the interaction region with silicon planes at equal density in pseudorapidity. All silicon elements lie outside the beryllium beam pipe. Figure 7 presents a *GEANT3*[13] picture of the detector geometry.

The beryllium beam pipe has radius 1.3 cm and thickness 400 μm. All (double-sided) silicon elements are of 200-μm thickness and have a strip pitch of 50 μm. Each disk has an inner radius of 1.5 cm and an outer radius of 10 cm. The detector consists of 27 parallel silicon disks and two segmented silicon barrels. The barrels have strips in z and ϕ directions, while the planes have strips in the x and y directions. The total length of the vertex detector is approximately 210 cm.

The central region of the vertex detector contains 17 planes with an interdisk spacing of 5 cm. The barrel segments are placed in the interdisk volumes and extend to the disk edges of the neighboring planes. The inner barrel radius is 1.5 cm; the outer silicon barrel radius is 5.0 cm. The central region extends from the center of the interaction region to $z = \pm 40$ cm.

The rapidity-spaced region is abutted to the central region and covers the outer limits of the interaction region. Silicon planes are placed every one-third unit of pseudorapidity, with the $\eta = 3$ planes equivalenced to the outer planes of the central region. Five rapidity-spaced planes extend from the ends of the central region.

This detector combines the features of the planar and barrel silicon geometries. Planes provide effective detector surfaces for particles traveling into the forward and backward regions, while barrels provide effective detector surfaces for radially moving particles. The outer radius of the silicon planes has been chosen to be twice the interplane distance to guarantee two hits for all particles in the central region. The silicon thickness has been adjusted to 200 μm to guarantee satisfaction of the cluster cut parameter for tracks incident on detectors up to 45° from normal incidence. Since the planes and barrels present relatively perpendicular surfaces to the particle tracks, this provides that all tracks that pass through the body of the detector will have two acceptable hits.

Event Simulation

PYTHIA 4.8 was used as the event generator for this simulation. Bottom-meson events were generated for a $p\bar{p}$ collider with 2-TeV center-of-mass energy. The minimum invariant mass of the hard-scattering parton subsystem was set at 10.5 GeV; the minimum allowed transverse momentum was 0.2 GeV/c. Decays of secondary particles were prohibited in the *PYTHIA* event generation—all particle decays were handled by *GEANT3*.

Bottom mesons only were selected from among the full *PYTHIA*-generated event for entry into *GEANT3*. Our objective was to determine whether reconstruction of bottom mesons would be possible using this vertex detector—one should first check that reconstruction is possible without any extraneous particles. Simulations were run using one of two decay modes: $B_d^0 \rightarrow \pi^+\pi^-$ and $B_d^0 \rightarrow \psi K_S$, ($\psi \rightarrow e^+e^-$). No magnetic field was present in the simulations, this being a preliminary design study. (Current Bottom Collider Detector designs include a 1.0-1.5 Tesla dipole field.)

Analysis was performed using *GEANT3*'s knowledge of the particle decay. No pattern recognition was used; the *GEANT3* particle decay chain was followed to identify descendants of each bottom meson. Both of the chosen decay modes allow a simple trigger—both provide two prompt, charged particles. Bottom meson events were accepted if both charged particle tracks had at least two hits in the silicon detectors.

A cluster size cut was imposed on the particle hits in the silicon detectors. The cluster size is defined to be the number of adjacent silicon strips which are fired by the passage of a single particle track. Large cluster sizes present possible problems with signal size, hit location and pattern recognition. Hits with cluster sizes greater than four strips were rejected in this class of simulations.

Particle tracks were defined by the first two (valid) hits on the track. Cuts on the vertex resolution were imposed on the quantity $S/\Delta S$, where S represents the distance of flight of the bottom meson and ΔS represents the three-dimensional distance between the reconstructed decay vertex and the true (Monte Carlo) decay vertex. $S/\Delta S > 5$ was the imposed cut.

Results

Simulations were performed using a realistic model of the Tevatron interaction region—a normal (Gaussian) distribution of events with $\sigma = 35\,\text{cm}$. Vertex detector acceptance as a function of the applied cuts can be seen in Table 1 below. Results are shown for both of the decay modes $B_d \rightarrow \pi^+\pi^-$ and $B_d \rightarrow \psi K_S^0$. Application of cuts is cumulative down through the rows of the table.

Table 1. Vertex-detector acceptance for an interaction region with a normal (Gaussian) distribution, $\sigma_z = 35\,\text{cm}$, of primary vertices.

cuts	$B_d \rightarrow \pi^+\pi^-$	$B_d \rightarrow \psi K_S$
geometry cut	0.768	0.775
cluster cut	0.751	0.763
vertex cut	0.466	0.449

Figure 9 presents the accepted pseudorapidity distribution for bottom mesons in the BCD silicon vertex detector. All cuts (geometry, cluster size, and vertex) have been imposed on this distribution. The distribution is for the decay mode $B_d \rightarrow \pi^+\pi^-$; the distribution for the decay mode $B_d \rightarrow \psi K_S$ is virtually identical.

Computer simulations of the vertex chamber are presently being extended to include the problems of pattern recognition in the presence of non-B-decay tracks, noise hits, δ-rays, sampling fluctuations, and the curvature of low-momentum tracks.

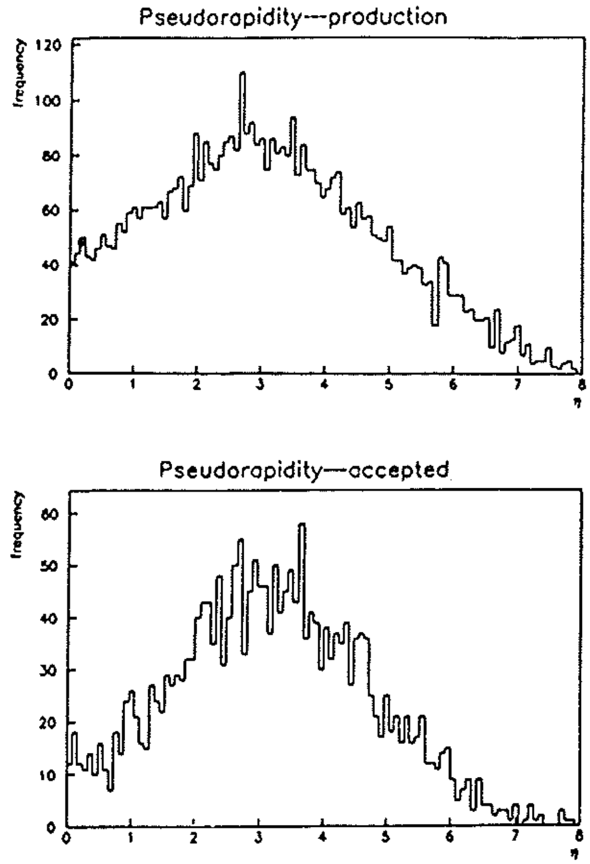

Fig. 9. Pseudorapidity distribution of generated B mesons (top) and accepted B mesons (bottom).

5. Tracking

Tracking Requirements

Multiple scattering and instrumentation costs in the silicon microstrip vertex detectors do not allow a sufficient number of planes to reconstruct tracks in three-dimensional space. The vertex detector must therefore be regarded as a precise vernier to improve the pointing accuracy of tracks reconstructed in three dimensions by an outer tracking system of wire chambers.

The outer tracking system must also measure the momentum of tracks with $P_T <$ 3 GeV/c to an accuracy of $\Delta P/P < \pm 1\%$ in the dipole magnetic field, and be able to reconstruct curved tracks coming from anywhere along the interaction region. This reconstruction problem is more difficult than that for detectors having a solenoidal field, in which the tracks in the azimuthal view are circles coming from a well-defined point (the beam intersection). The outer tracking system must operate at interaction rates of 5–10 MHz, and cannot have massive support structures such as end plates which would interfere with the 4π electron trigger which will surround it.

General Approach

There are two traditional approaches to tracking. One such approach (commonly used in collider experiments) is to have one strong view with 50 to 200 sampling points in the magnetic bend plane, and a weaker orthogonal view with subsidiary information such as small-angle stereo or resistive charge division to resolve the stereo ambiguity. The opposite approach (commonly used in fixed-target experiments) is to have at least three independent views with approximately the same number of samples in each view. This is necessary when the track density is high, as it will be at small angles in this experiment, and when resolving the stereo ambiguities is not trivial. If the total number of samples is limited (by multiple scattering considerations, for example) this means fewer samples per view.

The Bottom Collider Detector must have higher quality tracking at small angles to the beam than in most present collider experiments. Therefore we are pursuing a tracking configuration with precision measurements in both x and y, and with the large number of samples required for pattern recognition in high-multiplicity events. The proposed tracking chamber is based on 'straw-tube' technology.

Straw Tubes

Tracking chambers based on straw tubes have several advantages for this experiment:

- no massive mechanical supports are required;
- the small drift distance allows high rates;
- resolutions of better than 40 μm can be achieved with pressurized straws;
- the damage due to a broken wire is confined to its own tube.

However, the support for the wire tension is distributed in the walls of the straws, which are a potentially large source of multiple scattering. The wall thickness must be reduced substantially below that now in common use. For example, one published design[14] uses one-atmosphere straws 7.0 mm in diameter with 85-μm aluminized-mylar walls. The multiple scattering from a double row of such tubes is approximately equivalent to that from a silicon wafer, and 40 such double rows (0.08 radiation lengths) uniformly distributed in 0.75 m of 10-kG field would degrade momentum resolution to greater than 1%.

DeSalvo[15] has proposed a design for an SSC central-tracking detector which is based on a large number of straws of 3.0-mm diameter and 30-μm wall thickness, pressurized to 3–4 atm. In addition to improving the resolution of the straws to 30–40 μm, the pressurization adds to the rigidity and allows the reduction in diameter which leads to thinner walls. A "superlayer" of 8 rows of such tubes (fig. 10) contains only 3.4×10^{-3} radiation lengths, resolves left-right ambiguities locally, and provides both a vector with 2-mrad pointing accuracy and an estimate of curvature. Eight such superlayers in 0.75 m of 10-kG field contribute only 0.6% to the momentum resolution due to multiple scattering.

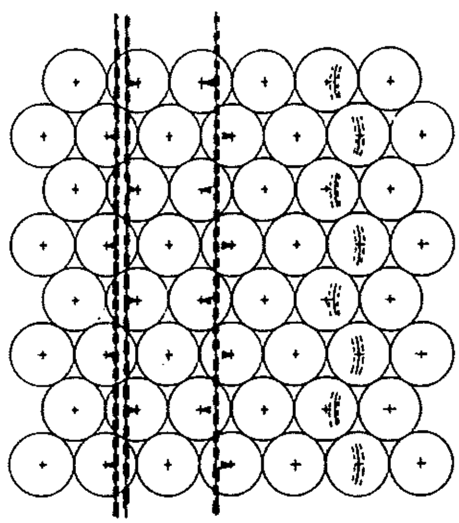

Fig. 10. A 'superlayer' of 8 rows of straw tubes.

A conceptual design for the outer tracking chamber using such superlayers of straws is shown in figs. 5 (sec. 2) and 11. The silicon vertex detector is immediately surrounded by a superlayer of straws aligned parallel to the beam (z) axis. In the central region (in which the track density is relatively low) nearly all straws are parallel to the magnetic field, taken to be along the y axis. The coordinate (y) in the non-bend plane is obtained from the superlayer of axial straws surrounding the silicon detector, and from resistive charge division in the wires. It is likely that at least one additional superlayer of straws measuring the coordinate in the non-bend plane will be required to ensure unambiguous extrapolation into the silicon vertex detector. In the forward and backward directions (where track densities are higher) there are alternating superlayers measuring coordinates in the bend (x-z) and nonbend (y-z) planes. Resolution of the stereo ambiguity would

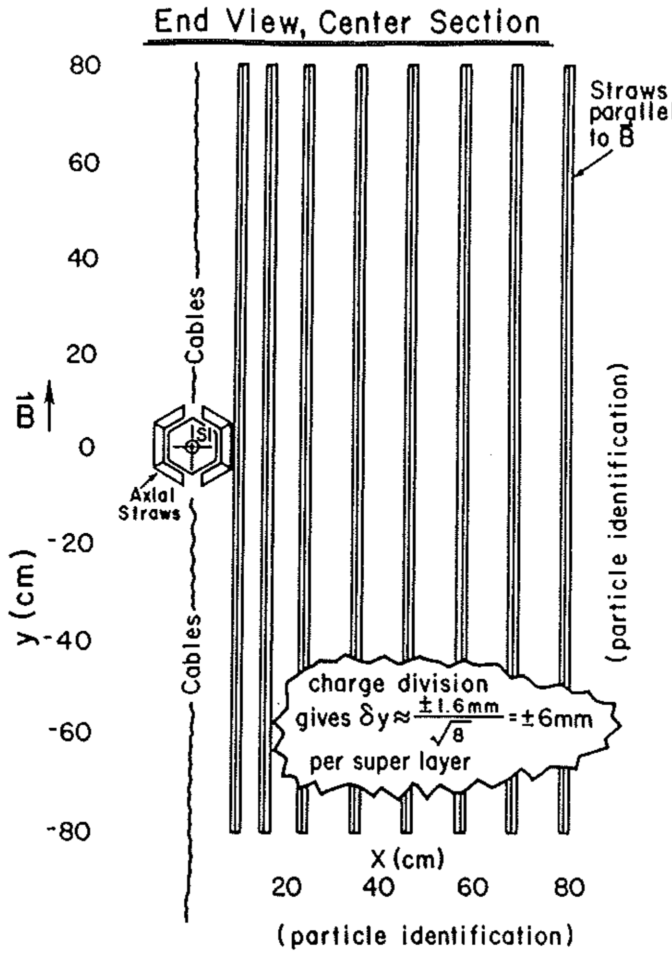

Fig. 11. View along the beam through the center section of the straw-tube tracking system.

be accomplished by rotating a few of the non-bend superlayers to an intermediate stereo angle.

Tracking Simulation

The next step in designing the tracking system is to confront realistic simulated events in the detector with an actual track-finding algorithm. We must determine the number of samples and the number and kind of stereo information needed to establish unambiguous three-dimensional tracks, and to extrapolate reliably into the silicon vertex detector. Work on such a "generic" trackfinder is underway at Ohio State, and will form the basis for studies at Snowmass. This program is designed to deal with configurations of N superlayers of M samples each, provided only that all detectors in a view are in the same rectangular coordinate system; it can find tracks of uniform curvature from an unspecified origin. On a longer timescale, a prototyping effort must be established to show that these very delicate straws can actually be built with the expected mechanical and electrical properties.

6. Trigger

Goals

The signature of a B meson which appears most suitable as a trigger for the Bottom Collider Detector is a moderate-transverse-momentum electron from a semileptonic decay. As indicated in fig. 12 (based on an *ISAJET*[16] calculation) about 50% of semileptonic B decays yield an electron with $P_T > 1$ GeV/c. The semileptonic branching fraction is 12%, and either B of a B-$\bar{B}$ pair is suitable for triggering. Thus a trigger cut of $P_T > 1$ on electrons could yield a 12% triggering efficiency for B-$\bar{B}$ pairs. If the efficiency of electron identification, including eventual offline reconstruction of a secondary vertex for the $B \rightarrow eX$ decay, is 40% an overall trigger efficiency of 5% could be achieved.

This is a formidable goal, as the electrons must be identified amidst a 5-MHz interaction rate yielding a 500-MHz total rate of particles in the detector. The triggering scheme will be implemented in a multilevel processor. If we anticipate a trigger rate as high as 1 kHz the dead-time associated with the highest level should not be much more that 10 μs. The difficulty in achieving this suggests that, as an alternative, B-candidate events be pipelined for the duration of the highest-level processor.

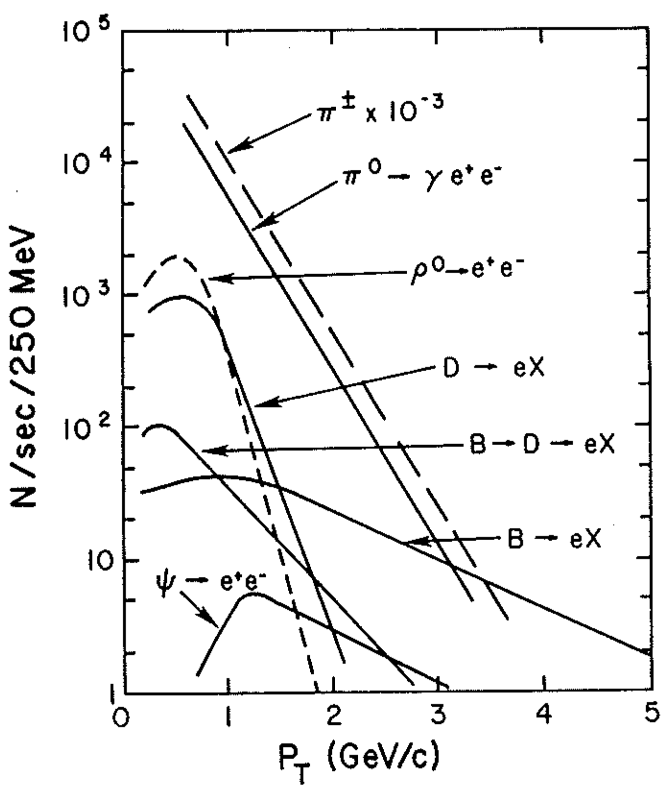

Fig. 12. The rate of electrons per 250-MeV/c bin from various sources in $p\bar{p}$ collisions at $\sqrt{s} = 2$ TeV and luminosity 10^{32} cm^{-2}sec^{-1} .

Sources of Electrons

A summary of the rate of electrons from various sources as a function of transverse momentum is given in fig. 12. Prompt electrons derive from direct electronic bottom and charm decay, e^+e^- decays of vector mesons, and Dalitz decays of pseudoscalar mesons. Fake electron triggers will derive from misidentified $\pi^\pm$'s, including $\pi^\pm$-π^0 overlaps. A hint of the severity of the fake-electron problem is given by the spectrum for $\pi^\pm$, also sketched in fig. 12.

The present philosophy is to pass all prompt electrons to the software-event-processing stage (supposing the fake electron triggers can be sufficiently suppressed). With a trigger cut of $P_T > 1$ GeV/c a substantial fraction of the prompt electrons are from B decay, and there is no need to distinguish among the various sources of prompt electrons in the trigger.

Misidentified Hadrons

The rate of charged π's into the detector is about 300 MHz: 60 charged pions per event times the 5-MHz interaction rate. Of these about 15 MHz have transverse momentum above 1 GeV/c and so are potential fake triggers if misidentified as electrons. The online π-e rejection must be greater than 10^4 to reduce fake electron triggers to a 'mere' 1 kHz. Such rejection factors have been achieved in offline analyses but not yet at the trigger level.

Three types of detectors will contribute to π-e separation: the transition radiation detectors, the RICH counters, and the electromagnetic calorimeter. We suppose that a two-layer system of tracking TRD's can yield a rejection factor of 20 online, and that the RICH counter yields a factor of 5.

The electromagnetic calorimeter is configured with its first two radiation lengths as an active preconverter, in which a 'shower' of three charged particles must be detected for an electron candidate. If the calorimeter is made with tungsten plates the two radiation lengths correspond to 0.04 of an interaction length, providing an immediate rejection factor of 25. A comparison of the shower energy with the charged-track's momentum will be made; only interactions leading to $\pi^\pm$-π^0 charge exchange will survive this E/P cut. As such interactions comprise less than 5% of the total, the overall rejection factor from the electromagnetic calorimeter is greater than 500.

The combined rejection factor from the three detector will then be 5×10^4, corresponding to a trigger rate of 300/sec from misidentified hadrons. As mentioned above, the difficulty is to obtain this rejection factor online.

Overlaps of $\pi^\pm$ and γ's from π^0's

A fake electron trigger is generated if the momentum of a charged pion matches the energy of a π^0 whose shower overlaps the charged-pion track in the electron calorimeter. The TRD and RICH detector still provide rejection of the charged pion, so the rate of dangerous charged pions is 0.01×15 MHz $= 150$ kHz. Further rejection is obtained by spatially resolving the charged track from the π^0 shower in the electron calorimeter.

A study of the overlap problem was made with the *ISAJET* Monte Carlo program. Initially, an 'overlap' was defined as a charged pion whose separation from a neutral pion was $|\Delta\eta| < 0.1$ and $|\Delta\phi| < 0.2$. It was found that about 7% of charged pions with $P_T > 1$ GeV/c had such an overlap. These overlaps are dangerous only if the E/P cut is also satisfied. Assuming the electron calorimeter has energy resolution for photons of $\sigma_E = 0.15\sqrt{E}$ the statistical significance of the E/P cut in standard deviations is

$$S.D. = \frac{|E - P|}{0.15\sqrt{E}}.$$

A cut requiring a 2σ separation of E of the π^0 from the P of the $\pi^\pm$ yields a rejection factor of 15. The rate of overlaps satisfying the combined trigger cuts is then less than 1 kHz.

The definition of overlap used above is satisfied by a pair of pions whose separation is less than 10 cm at 1-m radius from the beamline. However, two particles should be resolvable in the electron calorimeter if their separation is only 1 cm, which would provide an extra rejection factor of 100. In this case the rate of fake electron triggers from overlaps would drop to only 10 Hz.

Dalitz decays and γ-Conversions in Matter

The branching fraction for the decay $\pi^0 \rightarrow \gamma e^+ e^-$ is 0.015, as if the vacuum is 0.007 of a radiation length thick. Electrons from conversions of γ's in material will be more numerous than those from Dalitz decay if the photon has traversed more than 0.007 radiation lengths. For example, with a beam pipe whose wall is 400-μm-thick Be, or 0.001 of a radiation length, photons at angles of less than 1/7 to the beam are more likely to convert in the pipe than during the π^0 decay.

Figure 12 shows that the rate of electrons from Dalitz decay with $P_T > 1$ GeV/c is about 10 kHz at a luminosity of 10^{32} cm^{-2}sec^{-1}. The rate of electrons from γ-conversions in matter will be higher. Thus a rejection factor of order 100 is needed against these conversions.

More study is needed as to how this rejection will be achieved. Conversions outside the beam pipe can be suppressed by fast tracking all the way to the first silicon plane. Conversions in the pipe and Dalitz decays could be suppresed by a dE/dx measurement in the first silicon plane, but very large numbers of channels are involved.

Electron Detection Efficiency

The process of electron identification inevitably causes some real electrons to be lost. Rough estimates of the various detection efficiencies are:

- Fast tracking: 0.95
- Preconvertor cut at 2 radiation lengths: 0.90
- E/P cut: 0.95
- TRD cut: 0.90
- RICH counter cut: 0.95
- electron shower overlapped by another particle: 0.95

The overall efficiency of electron identification might then be 0.62. Great care will be needed to achieve an efficiency this high!

7. Signal to Noise

Here we consider three issues related to signal strength: flavor tagging, combinatoric backgrounds, and reconstruction efficiency

Flavor Tagging

Even when the electron trigger has successfully identified a B-$\bar{B}$ event there remains the question as to whether the flavor of the B's can be properly determined. This is critical when the 'other' B decays to a mode accessible both to a B and $\bar{B}$, as the flavor of the 'trigger' B must be identified before the 'other' B can be used in the measurement of the CP-violating asymmetry, as discussed in sec. 1.

If the trigger electron is from a direct decay of the form $B \to eX$ the sign of the electron determines the flavor of the B. But if the electron is from a D decay in the cascade $B \to DX$, $D \to eY$, the sign of the electron anticorrelates with the flavor of the B. In the direct decays, $B \to eX$, X includes a D or D^* most of the time. Hence the question of flavor tagging of the 'trigger' B is largely equivalent to that of associating the trigger electron with the secondary B-decay vertex or with the tertiary D-decay vertex. We estimate that the electron can be properly associated with its vertex only 40% of the time, based on the studies described in sec. 5. This factor has been included in the estimates of overall trigger efficiency given elsewhere in this report.

In the case of the 'self-tagging' modes, $B \to f$, where $f \neq \bar{f}$, the trigger efficiency will thus be 2.5 times higher.

Combinatoric Backgrounds

A B-mass peak could not be identified against the continuum due to combinatoric backgrounds without the requirement that B-decay products have a significantly nonzero impact parameter with respect to the primary vertex. However, a small fraction of non-B-decay tracks will appear to come from secondary vertices due to measurement errors. This problem is certainly most severe when attempting to find the decay $B^0 \to \pi^+\pi^-$.

A study of minimum-bias events collected by CDF at $\sqrt{s} = 1.8$ TeV indicates that the number of events in the $\pi^+\pi^-$ continuum mass spectrum in a 120-MeV/c^2 interval around the B mass is roughly 10^3 times the number of $B \to \pi^+\pi^-$ decays, assuming a branching fraction of 10^{-4} for this decay. Thus to obtain a 10:1 signal to noise in the mass spectrum after applying the impact parameter cut, each pion track must have less than 0.01 probability of being wrongly associated with a secondary vertex. Existing fixed-target experiments have achieved better rejection of tracks from the primary vertex than this. We anticipate that the demonstrated noise rejection of the silicon vertex detector will be available to the Bottom Collider Detector.

Reconstruction Efficiency

- Geometrical acceptance = 0.9
- Track reconstruction efficiency = 0.95
- Vertex reconstruction efficiency = 0.4
- Particle identification efficiency = 0.9

- Overall B-decay reconstruction efficiency = 0.32

8. Data Acquisition

Overview

In order to harvest the 10^{11} B-$\bar{B}$ pairs produced in the Bottom Collider Detector all events that satisfy the electron trigger should continue through the data acquisition system for further analysis. System architectures appropriate for data acquisition in this experiment have been considered in detail at the Workshop on High Sensitivity Beauty Physics at Fermilab.[17,18]

We anticipate an event size commensurate with the size and complexity of this detector. Due to the large number of detector elements and channels, zero suppression will be required and thus the recording of addresses as well as hit information will be necessary. An estimate of the event record size is 10^5 bytes per event, supposing each of the 100 particles per typical event is sampled by 100 detector element with 10 bytes of information per sample. The total trigger rate of events emerging from the online processors is about 1-2 kHz, including the expected rate of 500 B-$\bar{B}$ pairs per second and about 1 kHz from other prompt electron sources. This gives a net information transfer rate of up to 200 Mbytes per second.

Recording Devices

Contemporary data-acquisition systems using parallel transfer to multiple video cassettes, such as that proposed in E-791 at Fermilab, will record about 8 Mbytes/sec to this permanent medium. Based on this, recording 100-200 Mbytes/sec to a permanent storage medium is not an unreasonable goal for an experiment planned for 5 years from now. Steve Bracker has pointed out that tape systems developed and in use by the Haystack Observatory of the astronomy department at MIT presently record 100 MBytes/sec. This custom system is several years from being useful for high-energy-physics experiments but nevertheless indicates the state of the art. In addition, we are considering the viability of rejecting the other sources of prompt electrons using software filters as a further reduction in rate to permanent storage.

For the near future, it will be necessary for this group to become involved with laboratory efforts to develop high-rate data-acquisition systems. Discussions with such experts as E. Barsotti, C. Swoboda, and S. Bracker are underway. We anticipate that this experiment will benefit greatly from the rapid evolution presently occuring in data-acquistion technology. In addition, the introduction of RISC processors suggest that large increases in online computing can be expected in the next several years.

We conclude that although the needs of the Bottom Collider Detector are very demanding, the data-acquisition system can be designed and built in the next few years.

9. Summary

We summarize here the accomplishments of the B Collider Study Group towards a realistic proposal for an experiment to study CP violation in the B-$\bar{B}$ system at a hadron collider, and sketch the directions for continuing study.

Accomplishments

- Merging of the two earlier proposals for B collider detectors[4,5] into a single concept based on a central dipole magnet.
- Setting of overall goals of the experiment:
  - Production of 10^{11} B-$\bar{B}$ pairs;
  - Reconstruction and particle identification only of charged tracks from B decay;
  - 10^5 reconstructed decays for charged-particle modes with a branching fraction of 10^{-4};
  - 5σ evidence for a CP-violating asymmetry of 0.1 in such a decay mode.
- Identification of accelerator performance goals vital to the success of the B-collider experiment:
  - An average luminosity of order 10^{32} cm^{-2}sec^{-1} ;
  - A short ($<$ 10 cm) interaction region;
  - Compensation magnets to counteract the effect of the dipole magnet on the beams.
- Specification of the overall architecture of the experiment;
  - Central detector inside the gap of the dipole magnet, plus forward and backward arms for tracks below 35°
  - Silicon vertex chamber
  - Straw-tube tracking system
  - Particle identification via liquid and gas RICH counters, TRD's and electron calorimetry, with muon identification in the forward/backward arms
- Identification of performance goals for a silicon vertex chamber:
  - Innermost detector elements at a radius of 1.5 cm from the beam;
  - Use of double-side, 200-μm-thick silicon to minimize multiple scattering;
  - Need to measure tracks with 45° incidence to the detector plane;
  - Need for reliable noise performance of 1000 electrons.
- Scenario of a tracking chamber system based on straw-tube technology.
- Statement of a triggering scheme based on electrons of $P_T > 1$ GeV/c from the decay $B \rightarrow eX$.

Work to Do

Topics which will be under consideration at the Snowmass Workshop include:

- Experimental Signal
  - Flavor tagging
  - Self tagged modes
  - Time development of mixing
- Accelerator Liaison
- Design of the dipole magnet
- Simulation of the vertex detector
  - Effect of high event multiplicity
  - Use of large clusters of hits
  - Effects of noise, signal fluctuations, δ-rays
- Hardware design of the vertex detector
  - Silicon-strip architecture
  - Readout electronics, cabling
  - Alternatives based on pixel devices
- Design of the central tracking system
  - Charge division vs pad readout
  - Development of very thin-wall tubes
  - Effect of scattering in the tube-end material
- Pattern recognition in the tracking system
  - Vertex-finding
  - Track-finding
  - Overlapping events
  - Fast tracking algorithm at trigger level
- RICH counters, liquid vs solid
  - π-K-p separation offline
  - e-π separation online
- Transition radiation detectors
  - 3D tracking in the trigger
  - backgrounds at small angles
- Electromagnetic calorimeter
  - Type: warm vs cold; total absorption vs sampling
  - Segmentation: preconverter, post-calorimeter
- Forward muon detection
- Triggering
  - Electron trigger scenario, efficiency, background, hardware implementation
  - Other triggers: μ, K, secondary vertex, *etc.*
- Front-end electronics
- Data acquisition
- Online processing
- Staging and time scale of the experiment

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K.T. McDonald, *Princeton U.*;
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Invited speakers include J.D. Bjorken *Fermilab*; S. Palestini *INFN Torino*, R. Van Berg *U. Pennsylvania*. Minutes of the meetings can be obtained from R. Stefanski, *Fermilab*.
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