Chapter 5

Central Preshower Detector

5.1 Introduction

The CDF collaboration proposes to replace the Central Preshower (CPR) and Central Crack (CCR) detectors with an integrated scintillator detector. This would happen at the time the silicon detector is replaced for Run IIb. There are many reasons for this replacement: 1) The CPR is a slow wire chamber that integrates over several crossings and has relatively poor segmentation. This combination will lead to very high occupancies in Run IIb, crippling electron and photon identification. 2) Even with the modest occupancies in Run IIa, the current CPR segmentation makes it difficult to use in more sophisticated analyses such as improving jet resolutions. 3) With 10 fb^{-1} the CPR is expected to have collected 0.1 C/cm, where wire aging has typically caused significant degradation in performance, sometimes beginning with much smaller doses. 4) The thin gas layers of the CPR and CCR have much worse pulse height resolution than a scintillator detector. This is important for both electron identification and improving resolutions with a dead material correction. 5) We have an opportunity to build a much better detector for a relatively small cost. This is possible because we intend to reuse the Run IIa electronics and perhaps use Minos scintillator and other components for the detector.

5.2 Run I Physics Using the CPR and CCR

There are four potential uses for preshower detectors such as the CPR: 1) improving electron identification, 2) separating single photons from meson backgrounds, 3) improving electron and photon resolutions by correcting for dead material, and 4) estimating the energy deposited in the EM calorimeter by charged hadrons. The CPR has been used extensively in electron identification in CDF. It provides about a factor of two to three more rejection of charged pions that pass all other cuts using tracking, calorimetry, and shower maximum information. This extra rejection has been crucial in soft electron ID for b jet tagging, as was shown in the first top evidence paper and displayed in Figure 5.1.

Secondly, the CPR has been used in numerous publications involving photon identification. The shower maximum detectors cannot resolve single photons from meson decays above 35 GeV since the angular separation between the two photons is too small. The CPR uses photon conversion rates which are energy independent. It was used initially to extend the QCD measurement of direct photons by more than 100 GeV in photon p_T, as shown in Figure 5.2. More recently the CPR has been used to estimate backgrounds to signals of exotic physics that include photons. New physics is expected to come at higher p_T, in a region where the shower maximum detector has no discriminatory power. It is crucial to maintain this photon identification capability for possible new signals in Run II. As the next section will show, with the luminosities possible in Run IIb, the occupancy of the current detector will be too large for photon identification.

The third possible use for a preshower detector is to improve electron and photon energy resolutions by correcting for dead material losses. This has not been implemented in CDF to date due to the relatively poor energy resolution of a thin gas detector. The ZEUS experiment has used their scintillator preshower detector to correct for soft photon energy losses in jets, and has seen an improvement in their jet resolution by an impressive 17%[1]. As is well known, improving jet energy resolution will be important in finding various new physics signals such as the Higgs.

Finally, a preshower detector can be used in other ways to improve jet resolutions in algorithms incorporating charged tracking. Since the tracking resolution is so much better than the calorimeter, the main challenge is to estimate the remaining electromagnetic (and neutral hadron) component of the jet. Charged tracks complicate this since they shower in the EM calorimeter, whereas preshower detectors can be used to estimate this contribution to the EM energy. The current CPR detector makes this difficult since a single cell spans five calorimeter towers, possibly collecting showers from other particles in the jet. A preshower detector where each cell is confined to a single calorimeter tower, such as the one in this proposal, is desirable for this purpose.

The current CDF central crack chambers (CCR) have not been directly involved in a CDF publication, but they have been checked for large pulse heights in all of the rare events CDF has observed. Their non-utilization has been due more to a lack of software tools than to their intrinsic usefulness. This has been recently illustrated by a search for a Z peak in dielectron events, where one electron passed into a crack[2]. Figure 5.3 shows a comparison of the Z peak measured when using the electron + track 4-vector and when one uses the electron + crack energy 4-vector. This indicates the capability of tagging high energy photons in the crack region in events which may contain new physics. The crack covers about 8% of the central detector, and in events with multiple EM objects such as the famous $ee\gamma\gamma Met$ event the possibility of one object hitting the crack is quite high. If we are lucky enough to get a sample of such events then doing measurements of this physics will require crack tagging of photons. Irrespective of the source of this single event, if SUSY is producing signals with photons as some suggest, there will be a large variety of new physics with photons and missing E_T and other objects. Crack tagging of high-energy photons will become even more important. The current crack chamber is a very thin gas layer that would be much improved with a scintillator replacement, integrated with the new preshower detector.

The CDF preshower and crack detectors are expected to play important roles in Run II physics such as soft electron tagging of b jets, photon identification in SUSY events or other new physics, and improving jet resolutions for mass bump searches such as the Higgs. The next section will explain why the CPR in particular will be severely degraded or completely useless in the high-luminosity Run IIb era.

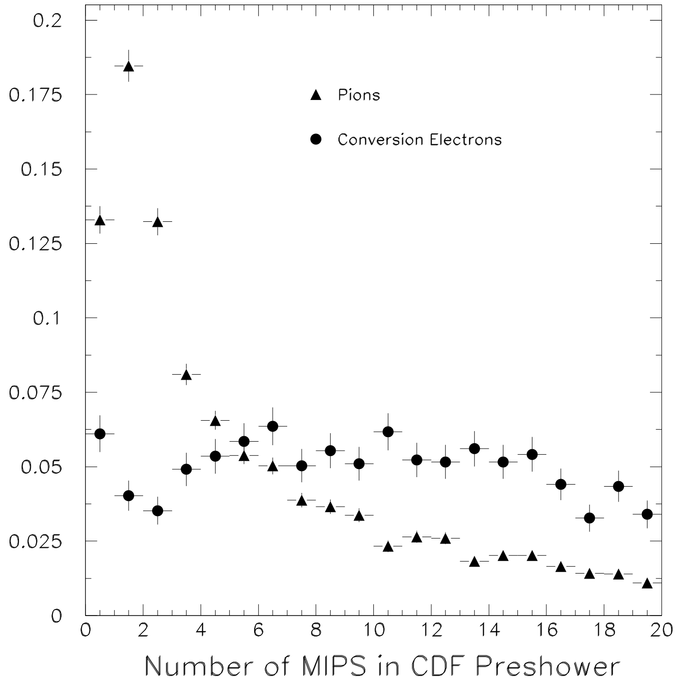

Figure 5.1: CPR response to electrons and charged pions as shown in the top "evidence" PRD.

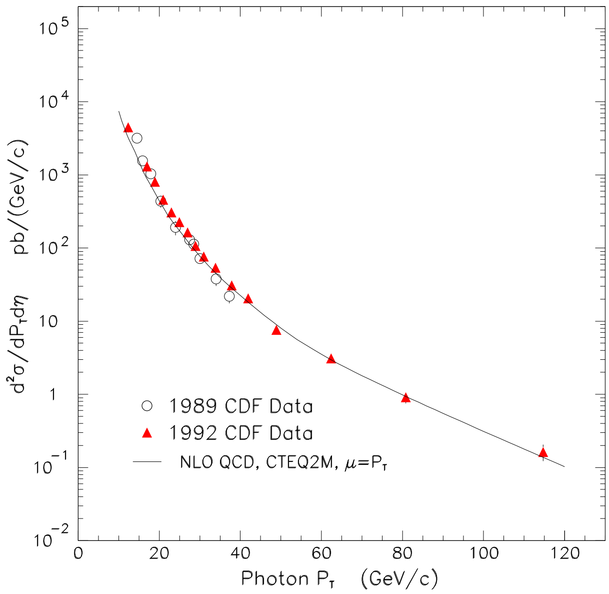

Figure 5.2: Direct photon cross section from 1989 (before CPR installation) and from 1992 using the CPR. The cross section was extended by almost 100 GeV in photon Pt.

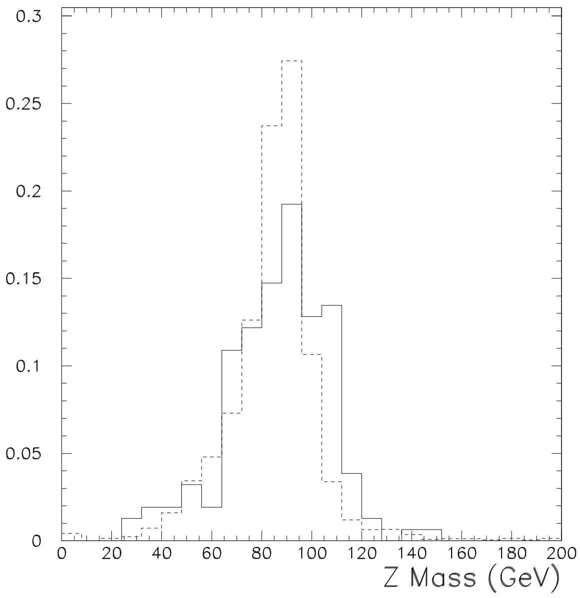

Figure 5.3: Dashed line is Z peak using electron + track, the solid line is electron plus Crack Chamber pulse height for electrons that went into the ϕ crack.

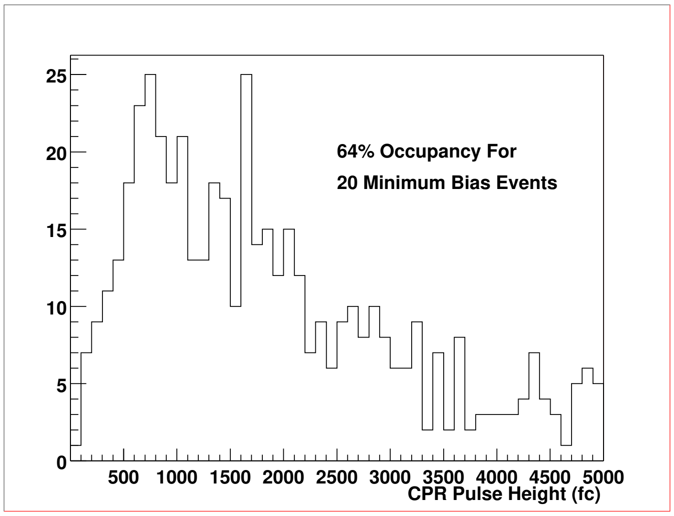

Figure 5.4: CPR run IIa pulse height for 20 overlapping minimum bias events. This background occupancy is 64%, for comparison the conversion frequency for a single photon is between 60% and 65%. The photon cross section is derived from counting the fraction in the zero bin. The occupancy of the estimated underlying event will make this very difficult.

5.3 Occupancy Issues

The occupancy and segmentation issues discussed in this section are only relevant for the preshower detector. The current crack chambers are not sensitive to MIPS or soft photons like the CPR and the proposed crack chambers have the same segmentation as the previous ones. The CPR is a slow wire chamber and, based on early results from Run II, it appears that integrating over four crossings will be necessary to collect a significant fraction of the charge. One concrete example of a problematic scenario is if the peak Run IIb luminosities reach 6x10^{32}, with 108 bunches and 132 ns spacing. This will give rise to 5 minimum bias events per crossing. With the CPR integrating over 4 crossings, the detector will have to deal with over 20 minimum bias events! A second concrete example is the TDR situation of luminosities reaching 2x10^{32}, but with 36 bunches and 396 ns spacing. This results in 6 minimum bias events per crossing. With the CPR integrating over only two crossings in this case, a total of 12 minimum bias events are present in the CPR. With these two examples it is possible to extrapolate to any other possibility. We present Figure 5.4 as evidence of the serious difficulties the CPR could have in Run IIb. The figure shows the Run II CPR pulse height distribution in the case of overlapping 20 minimum bias events, it has an occupancy of 64%. The technique to identify photons at high p_T is to count the fraction of events in the zero bin, since single photons convert less often than multiple photons. The conversion frequency for a single photon is between 60% and 65background occupancy from minimum bias events that discrimination will not be possible. Similar difficulties arise for electron identification. Obviously there is a continuous degradation of performance with increasing luminosities; here we have only mapped out one possibility. But this discussion indicates that the occupancy problems in Run IIb are real. The proposed detector design will reduce the occupancy from overlapping minimum bias events by more than x10. This is accomplished by improving the detector speed with a scintillator replacement, as well as improving the detector segmentation.

5.4 Upgraded Detector Design for Run IIb

The relatively limited budget available for the Run IIb upgrades necessitates a limited budget for the CPR upgrade. In this spirit, we plan to re-use the existing electronics channels currently employed in the read-out of the existing CPR and CCR detectors, thus removing one of the largest components of the cost for any new detector system. At the time that the present CPR was constructed, the technology did not exist for the convenient design of a scintillator-based device to fulfill the same purpose. In the intervening years, advances in the production of wavelength-shifting (WLS) and clear plastic optical fibers have allowed for the design of scintillator detectors with WLS fiber readout with almost arbitrary segmentation and essentially complete hermeticity. Such a design has already been implemented in CDF in the plug electromagnetic and hadronic calorimeters and in the plug preshower detectors, as well as in many other experiments such as CMS and MINOS.

The new CPR will be placed in the space currently occupied by the old CPR and CCR. The basic design of the new CPR involves scintillator strips, segmented in η and in ϕ, read out by WLS fibers embedded in a groove in one surface of the scintillator. The scintillator for each wedge will be assembled into a mechanical structure ("pizza pan") similar to that used in the endplug calorimeter upgrade. After exiting the strips, the WLS fibers will be routed through grooves in a plastic layer underneath the scintillator to the high eta edge of each wedge, where they will be glued into a number of plastic shell optical connectors. The WLS fibers will be doped with a UV suppressant in order to reduce any cross-talk induced by Cerenkov light as the fibers cross the adjacent towers. The light signals will be routed from these optical connectors through the gap between the central and endwall calorimeters to the back of each wedge of the central calorimeter. There the light signals from each fiber will be coupled to the pixels of the MAPMT's.

Reusing the electronics for CPR/CCR implies two SMD cards per wedge or 64 channels. Note that modification of central SMQIE/SQUID electronics is not required. A possible design would be to retain ten CCR channels and allocate six channels to each of the nine fiducial calorimeter towers. With this segmentation, tower-based information could be used in the optimized jet resolution algorithm. If the six panels per tower were overlapped, one could reach eleven ϕ bins per wedge, but at the expense of a larger occupancy. These tradeoffs of position resolution versus occupancy will be studied early in Run IIa before the CPR2 design is finalized.

Figure 5.5 (top) shows a possible layout, with no overlapping tiles to reduce occupancy as much as possible. The manner in which the existing MINOS extrusions would be used is indicated. Each segment in $\eta - \phi$ would be read out by 3 WLS fibers. We have maintained the full ten towers in the cracks since the greatest hermeticity possible is mandated for missing energy studies. On the other hand, the tenth tower has never been used in CDF for electron and photon measurements due to poor energy measurement. For this reason we have only instrumented the first nine towers for the preshower section of the detector. The segmentation shown is 2X3 ($\Delta\eta X \Delta\phi$) per calorimeter tower. The bottom figure shows the side view, displaying the embedded fibers and fiber bundles.

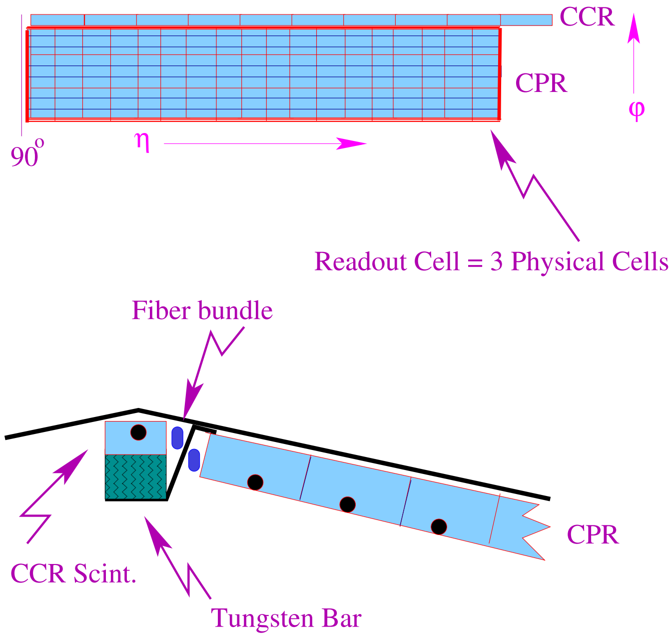

Figure 5.5: CPR2 layout including crack region. In this design non-overlapping panels (top figure) are used to reduce occupancy. Black circles show the embedded fibers in the bottom figure.

5.4.1 Scintillator

The amount of scintillator needed for the new CPR is relatively modest, of the order of 50 m^2. The maximum thickness of the scintillator in the crack region is 0.7 cm due to spacial constraints, while in the rest of the detector the scintillator will be at least 1 cm thick to improve light yield. We are currently exploring several options for the procurement of the scintillator needed, with an eye to optimize both the performance and the cost. The three options are: 1) MINOS scintillator, 2) ITEP Group scintillator, and 3) Bicron scintillator.

MINOS has adopted the technology of (polystyrene-based) scintillator strips read out by WLS fibers for both their near and far detectors. Because of the large volume of scintillator needed, they have chosen the technology of extruding their scintillator into strips of width 4.1 cm and thickness 1 cm with a groove for a 1.2 mm diameter fiber running along one of the large surfaces of the strip. Each strip is coextruded with a TiO2 coating which serves both to trap the light inside the scintillator as well as allowing for much greater durability and ease of handling. The brightness of the extruded scintillator is comparable to Bicron BC404. MINOS will produce a total of 700,000 m of extruded scintillator of this type. Our requirements will be less than 0.2% of this total. The strip width being used for MINOS may not be optimal for the CPR. A change of extrusion size is easily possible with the production of a new die. If the extrusion width is less than the segmentation size, several WLS fibers from different extrusions in the same readout segment can be coupled to the same MAPMT pixel.

The Russian ITEP group on CDF has the ability to produce 1 cm thick scintillator either by the processes of extrusion or injection molding. The scintillator brightness typically is on the order of 70% of that of Bicron BC404. The cost for production is not currently available but should be cheaper than Bicron.

The third scintillator option is to purchase 1 cm thick scintillator sheets from Bicron of approximate size 0.75 X 2.5 m^2 and then to cut and polish the scintillator strips using the existing facilities in Lab 8. At the same time, a groove for the WLS fiber would be machined. This option would also require the most handling, but is still a viable option if the other two options do not work out. The primary choice is the MINOS scintillator extrusion due to its low cost, light yield, durability and ease of handling. As will be discussed later, a prototype is being constructed using this scintillator.

5.4.2 Phototubes

The readout of the detector would be by the use of multi-anode PMT's (MAMPT's). The current choice would be to use the R5900 tube manufactured by Hamamatsu, which is the same tube used for the endplug shower maximum detector. This is a 16 channel device with pixel size of 4.5X4.5 mm^2. With one detector channel per pixel, each wedge of the CPR would require 4 MAPMT's, for a total of 192. If we allow for approximately 5% spares, then the total need would be for approximately 200 MAPMT's. We are also exploring the option of using a 64 channel MAPMT produced by Hamamatsu, which has the advantage of leading to only one PMT per wedge.

5.4.3 Performance

The new CPR should be sensitive to minimum ionizing particles (MIPS). A yield of 5 photoelectrons per MIP should be sufficient for this purpose. MINOS has achieved a light yield using their standard extrusions of the order of 10 photoelectrons per MIP. This has been achieved through the readout of both ends of the WLS fibers, but also with greater fiber lengths than will be necessary for CDF. The new CPR will read out only one end of the fiber but much of the light transmitted in the other direction will be recovered by mirroring that end of the fiber. The process of depositing an aluminized mirror on a polished fiber end (and then applying a protective coating) was developed for CDF and has become routine in the facility located in the Fermilab village.

The CCR scintillator is forced to be thinner, on the order of 6 mm, than that used for the CPR. This will result in less light but the yield should still be sufficient for the CCR functionality. MINOS uses WLS fibers of diameter 1.2 mm for their detector readout. It may be easiest for the same diameter fibers to be used for the CPR2, but this matter is currently under investigation. Due to its location in the central rapidity region and at a relatively large radius, there should be little impact from radiation damage on the performance of the CPR2, even at the highest foreseen luminosities.

5.4.4 R&D/Prototyping

We plan on pursuing a relatively aggressive R&D/prototyping schedule in order to finalize the design parameters. An initial 4-tower prototype has been built at ANL, making use of scintillator extrusion and wavelength-shifting fiber obtained from MINOS, as well as components left over from the endplug upgrade project. Several design issues arose in the construction of this prototype, such as the firm placement of the fibers in the groove in the scintillator at the point of exiting the scintillator. These issues will be further investigated as the chamber performance is evaluated with a source mapping. It is anticipated that a second 4-tower prototype will be built before a full-size prototype is constructed.

Since each current CPR chamber covers half of a wedge, it may be possible for us to replace a CPR chamber (in the higher η section of a wedge) by a prototype upgrade module. The installation of a prototype detector would enable us to test its performance during the early part of Run II. This could happen in the summer 2002 shutdown.

Bibliography

[1] S. Magill/ZEUS talk at CALOR2000

[2] CDFNote 4798