Triggering with the Forward Proton Detector

Andrew Brandt

November 16, 1998

Abstract

Details of triggering with the Forward Proton Detector (FPD) are discussed.

1 Introduction

The FPD will be comprised of small scintillating fiber detectors installed in a series of Roman pots to measure the (x, y) coordinates of the proton or anti-proton track, thus allowing the determination of the track momentum and angle.

Each Roman pot will contain the position detector and trigger scintillator. The trigger scintillator consists of a 2×2 cm plastic scintillator connected to a PMT. The coincidence formed by the trigger scintillators in each spectrometer can be used in the Level 1 trigger, both for triggering and rejecting early time hits from halo. Existing scintillator and phototubes could be used for these small counters.

The position detectors are six-plane scintillating fiber detectors comprised of stacked ribbons of four fibers oriented such that the scattered proton (or anti-proton) would pass through all four fibers to maximize the light output. The detectors will use multi-channel photomultiplier tubes which will be interfaced with modified Central Fiber Tracker trigger boards, resulting in DØ standard data structure and triggering.

This document discusses issues related to the triggering with the FPD, expanding on some of the topics discussed in the original FPD proposal [1].

2 Fiber Readout

The scintillating fibers are connected to clear fibers that are bundled together in groups of four and connected to one channel of the MAPMT as shown in Fig. 1. Four fibers per channel will give about 10 photoelectrons and fit comfortably within the pixel size of the MAPMT. There will be 112 channels per pot, so seven 16 channel tubes will be required for each pot (126 phototubes in all). The upper right side of Fig. 1 shows a front view of the 16 channel HAMAMATSU H6568 MAPMT. This MAPMT presents good gain uniformity among its 16 anodes with negligible cross-talk and has a pitch of 4.5 mm. The lower right part of the figure shows how the four fiber arrangement interfaces with an anode.

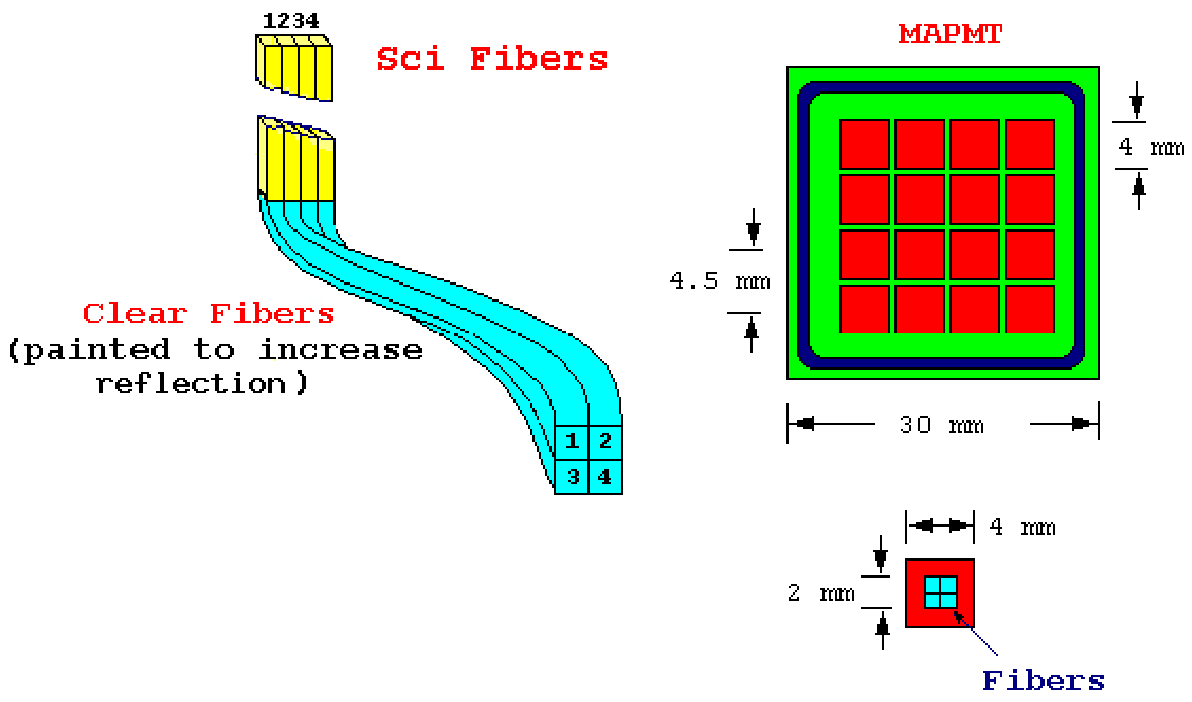

Figure 1: The interface of clear and scintillating fibers and the MAPMT.

Each phototube output will then be amplified[1] in the tunnel and passed

[1] the amplifier needs to be developed

Spectrometer Label	Detector One	Detector Two	Trigger Tag Number
PU	P1U	P2U	1
PD	P1D	P2D	2
PI	P1I	P2I	3
PO	P1O	P2O	4
AU	A1U	A2U	5
AD	A1D	A2D	6
AI	A1I	A2I	7
AO	A1O	A2O	8
DI	D1I	D2I	9

Table 1: Spectrometer Labeling and Level 1 Trigger Tag Number.

through a 16 channel flat cable[2]. The signals can be read out by a standard Central Fiber Tracker (CFT) trigger board, although a new connector has to be developed and the capacitor values need to be set appropriately for the SIFT chip.

The total number of channels needed per spectrometer is 224 (112 per pot), which is less than half the trigger board limit of 500-600 channels. Five boards will be required, one for PU and PD (proton up and down), one for PI and PO (proton in and out), one for AU and AD (anti-proton up and down), one for AI and AO, and one for DI (dipole spectrometer). The spectrometer labelling is shown in Table 1, which is extracted from Ref. [2].

A schematic of the trigger board as applied to the outputs for the PU spectrometer is shown in Fig. 2. The signal from the MAPMT will likely have to be attenuated by at least a factor of ten since the gain expected from the MAPMT is much greater than that of the VLPC, for which the boards were designed. This attenuation could be easily done on the board by using a different capacitor, but a more desirable option would be to add this attenuation to an adapter cable which will connect the flat cables to the front end board (this will allow the boards to be identical copies of the CDF boards). The signals will be passed through the existing front-end chip (SIFT). These boards were designed to allow for different input signals since they are being used by the central and forward preshower detectors in addition to the central fiber tracker. The SIFT chip outputs signals to the SVX-II chip for digitization. The SVX-II chip will then store the information

[2]the flat cable was used in Run I in the tracking system

from the fiber hits in the standard event data block. The SIFT chip also outputs a TTL signal for use in the trigger logic.

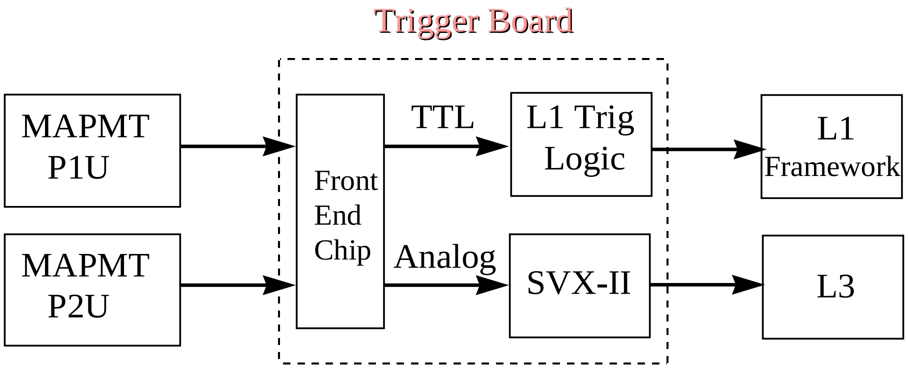

Figure 2: A schematic diagram of the readout of the scintillating fiber detectors.

3 FPD Trigger Overview

The FPD is designed to be a sub-detector of DØ and will be well-integrated into the DØ trigger framework. Due to the relatively small number of channels (about 2000 compared to hundreds of thousands for other sub-detectors), this detector will have a negligible effect on the event size. It should be read out on every event since any standard type of physics process below mass threshold can be produced diffractively.

It will also be necessary to have a few dedicated triggers which demand tracks at the trigger level. Dedicated triggers will be required for

- Diffractive jet production. The low E_T jet cross section is too large to have an unprescaled diffractive jet trigger unless a track requirement is explicitly included. A diffractive jet trigger would combine a low E_T cluster with a track in a p or $\overline{p}$ spectrometer.

- Double pomeron exchange. This will require tracks in p and $\overline{p}$ spectrometers, as well as an E_T cluster for the hard double pomeron exchange case.

- Inclusive single diffraction. This prescaled trigger will be necessary to understand the operation of the FPD, as well as for soft single diffraction studies and ratios of diffractive jet to inclusive diffraction, which allows for the cancellation of many systematic uncertainties.

- Elastic scattering. This requires tracks in diagonally opposite spectrometers. A sample of elastic events should be accumulated each run for alignment purposes and luminosity monitoring. These events should be quiet in all the other detectors and could be written at a high rate without requiring much bandwidth.

To minimize the bandwidth for these dedicated triggers, the capability to cut on ξ (fractional momentum loss of the proton, which is equivalent to the momentum fraction carried by the pomeron) at Level 1 is essential. This allows the different triggers to only accept tracks in the kinematic range of interest. In addition to the requirement of a p or $\overline{p}$ (or both in some cases jets), the dedicated triggers must include elements to reject multiple interaction and halo backgrounds, which will be discussed in subsequent sections.

Although the bulk of data taking will be done during typical collider running conditions, it may be advantageous to take occasional low luminosity runs or special runs for systematic studies. It will be useful to map out the acceptance contours and a few dedicated runs are typically optimal for high cross section and alignment studies.

3.1 Level 1 Trigger Operation

Details of the electronics and trigger operation are discussed in the FPD TDR [3]. The Level 1 trigger logic is formed in gate array chips which combine the hit plane information along with a table-lookup incorporating the transport matrix equations to give the ξ and $|t|$ (momentum transfer $|t| \sim \theta^2$) of the track. A study of the number of tracking equations necessary to specify a typical ξ and $|t|$ range is in progress, but is expected to be well below the 8000 equations available on the trigger board. The total time required for the FPD Level 1 decision is expected to be well within the 4.2 μsec time allowed for a Level 1 decision. The Level 1 framework will automatically synchronize the FPD decision with all other Level 1 decisions, so timing will not be a problem.

The FPD trigger cards will transmit their trigger decisions to the FPD trigger manager. The manager will combine these independent trigger decisions into L1 "AND-OR" terms for the L1 Framework. The FPD trigger manager will be a smaller version of the CFT and Muon L1 trigger managers and will not require additional design or engineering.

The trigger operation is best illustrated with a simple example. Consider a single diffractive interaction trigger which requires a coincidence of trigger scintillator hits along with a track in any one of the nine spectrometers. First, each spectrometer will transmit the MAPMT signals to the trigger logic. The hits in each pair of pots are compared to an equation list in order to determine if they are consistent with a valid trajectory, and the ξ and $|t|$ values for that trajectory. A track list is then created in the receiver and concentrator boards, which combine the information from the nine spectrometers. The track list is sent to the trigger manager. The trigger scintillators will be read out by the luminosity monitor boards, which will be capable of accurate time resolution on the order of 200 psec. These board will supply information about the timing of scintillator hits to the trigger manager, including the coincidence of the pair of scintillators in a spectrometer, and the presence of early time hits. The trigger manager then polls all spectrometers to see if any one of the spectrometers has a valid trigger: ξ and $|t|$ values within a specified range, a scintillator confirm, and no halo veto. It then provides a logical OR of the results to the L1 Framework. Double pomeron exchange or elastic triggers would be generated by requiring pairs of spectrometers to trigger. The FPD will require 16 of the 256 Level 1 "AND-OR" terms as discussed in Sec. 3.2.1.

This readout system has the great advantage of using existing DØ trigger boards such that the data storage and triggering are completely DØ standard.

3.2 FPD trigger terms

The basic FPD trigger unit is a "Track", which demands hits in both Roman pot detectors comprising a given spectrometer. The type of track will be specifiable as well as the momentum (x) range and momentum transfer (t) range. Currently there are six types of tracks foreseen comprised of combinations of four x and two t ranges

1. Elas$\equiv 0.99 < x$, all t

2. Full$\equiv 0.95 < x$, all t

3. Med$\equiv 0.97 < x < 0.996$, all t

4. High$\equiv 0.95 < x < 0.99$, all t
5. Hi-t$\equiv 0.95 < x$, $|t| > 1$ GeV^2
6. EHi-t$\equiv 0.99 < x$, $|t| > 1$ GeV^2

The exact minimum and maximum values will, of course, be determined experimentally to optimize the useful data. It may be desirable to put an upper x cut on the "Full" range to avoid spurious tracks. The upper edge of the "Med" range (medium mass) will be determined based on actual resolution to cut out the low mass diffractive peak. The "High" mass range might be extended to lower values of $x = 0.9$, in order to allow very massive systems and understand non-diffractive background. For each of these terms a full t range will likely be allowed. A special "Hi-t" trigger will also be used to give full acceptance for the rare large momentum transfer events.

In addition to the different kinematic ranges associated with the "Track" term, it will also be useful to have different kind of tracks. "DTrack" will refer to spectrometer 9, the dipole spectrometer. "QTrack" will refer to spectrometers 1–8, the quadrupole spectrometers. It will be necessary to treat these separately since the rate for the dipole spectrometer will be much larger due to the larger acceptance for small $|t|$ where the cross section is large. It may be desirable to be able to trigger on "ATrack" ($\overline{p}$) or "Ptrack" (p) separately.

Certain triggers will require combinations of tracks. "OTrack", for over-constrained would be the coincidence of "DTrack" and "ATrack", that is, tracks which pass through both the dipole and a quadrupole spectrometer on the outgoing $\overline{p}$ side. The allowed "OTrack" combinations are 5-9, 6-9, 7-9, and 8-9. "Elastic" triggers would require diagonally opposite spectrometers (1-6, 2-5, 3-8, 4-7) and $x \approx 1$. A "Hi-t Elastic" trigger would also be useful–perhaps even an intermediate $|t|$ trigger would be useful, depending on the rates. Hard double pomeron (HDP) triggers would require any combination of a "PTrack" and and "ATrack": each of spectrometers 1–4 can be paired with spectrometers 5–9. An inclusive double pomeron (IDP) trigger might in addition veto on elastic combinations in order to avoid possible background from elastic events.

These trigger terms can also include a veto on adjacent spectrometers to avoid backgrounds from sprays of particles, thus there should be no tracks in 2–4 if there is a track in spectrometer 1. The adjacent spectrometer veto would have to be monitored as a function of luminosity, since for high luminosity some good events would be rejected to to additional single diffractive

AND-OR Term	Name	x range	$\|t\|$ range	Spec ID
1	Track-Full	$0.95 < x$	all t	1–9
2	Track-Med	$0.97 < x < 0.996$	all t	1–9
3	Track-High	$0.95 < x < 0.99$	all t	1–9
4	Track-HiT	$0.95 < x$	$\|t\| > 1$ GeV^2	1–9
5	PTrack-Full	$0.95 < x$	all t	1–4
6	PTrack-Med	$0.97 < x < 0.996$	all t	1–4
7	PTrack-High	$0.95 < x < 0.99$	all t	1–4
8	PTrack-HiT	$0.95 < x$	$\|t\| > 1$ GeV^2	1–4
9	AorDTrack-Full	$0.95 < x$	all t	5–9
10	AorDTrack-Med	$0.97 < x < 0.996$	all t	5–9
11	AorDTrack-High	$0.95 < x < 0.99$	all t	5–9
12	AorDTrack-HiT	$0.95 < x$	$\|t\| > 1$ GeV^2	5–9
13	Elastic	$0.99 < x$	all t	1-6, 2-5, 3-8, 4-7
14	Elastic-HiT	$0.99 < x$	$\|t\| > 1$ GeV^2	1-6, 2-5, 3-8, 4-7
15	OC	$0.95 < x$	all t	5-9, 6-9, 7-9, 8-9
16	OC-HiT	$0.95 < x$	$\|t\| > 1$ GeV^2	5-9, 6-9, 7-9, 8-9

Table 2: AND-OR term definitions.

interactions. The trigger scintillator could be used to generalize this to hits in adjacent spectrometers and also to veto on halo in the diagonally opposite spectrometer.

3.2.1 AND-OR terms

In order to implement the trigger terms described above 16 AND-OR terms are required as shown in Table 2.

These terms are generated by the trigger manager and will include a halo veto from the diagonally opposite spectrometer and perhaps an adjacent spectrometer veto. Combinations of terms 5–8 and 9–12 can be used for double pomeron triggers.

3.3 Multiple Interactions and Background

A serious concern about triggering on hard diffraction is the frequency of multiple $p\overline{p}$ interactions in the same bunch crossing. There are two types of multiple interactions that are of concern:

1. The superposition of a hard single diffractive event with a minimum bias event.

2. The superposition of a standard single diffractive event with a hard scattering event (pile-up background).

Unlike pile-up (discussed in Sec. 3.3.1), the occurrence of an extra minimum bias interaction in a hard diffractive event is not a background. It does, however, obscure some of the properties of the diffractive events by changing the multiplicity distribution (filling in the rapidity gap) and biasing the energy flow of the event. For high cross section processes we have the luxury of rejecting these events online, and can obtain a good sample of single interaction events in order to properly study the diffractive final states. This can be achieved with single interaction triggers using the upgraded Level Ø detector (luminosity monitor or LM) in a similar manner as in Run I. We would pass the event if there were

- No hits on the side of the LM beam hodoscope scintillators where the p ($\overline{p}$) track is detected. This is the typical configuration for low to intermediate mass single diffractive events.

- LM hits on both sides, but with a timing consistent with a single interaction hypothesis. [3] Higher mass diffractive events or diffractive events where the interacting parton from the pomeron carries a large fraction of the pomeron momentum will often give hits on both North and South counters.

This single interaction requirement can be implemented at Level 1, so these multiple interaction events will have minimal impact on the bandwidth. The residual multiple interaction contamination in this sample should be small (about 10% from Run I studies) and can be cleaned up further at Level 3 or offline (see Sec. 3.3.1 for details) with an expected residual contamination of $< 1\%$.

[3] A new algorithm will be employed which cuts on the time difference (δt) between the earliest time hit and the 'latest minus two' hit (the latest hit is not used since occasionally a slow particle from the interaction will hit the LM counters). For a single interaction event there will be a fairly small spread in the time distribution, so this difference will not be large. For a multiple interaction event, there will be a much larger δt since the events typically do not occur at the same time. Note that this algorithm is also effective for the pile-up of a diffractive and minimum bias event as δt will again be large due to the different time of the two interactions. events.

Lum ($cm^{-2}s^{-1}$)	Min Bias $\sigma = 47$ mb P($n=0$)	SD $\sigma = 10$ mb P($n=0$)	SD($\xi > 0.004$) $\sigma = 2$ mb P($n=0$)	SD($\xi > 0.01$) $\sigma = 1$ mb P($n=0$)	P($n \geq 2$)
2E31	0.58	0.89	0.98	0.99	0.000067
4E31	0.34	0.79	0.95	0.98	0.00027
6E31	0.19	0.71	0.93	0.97	0.00060
8E31	0.11	0.63	0.91	0.95	0.0010

Table 3: Single interaction fraction P($n = 0$) versus instantaneous luminosity for minimum bias and single diffractive (SD) cross sections, assuming 36 bunches. The probability of two or more extra interactions P($n \geq 2$) is also given for $\sigma = 1$ mb.

The probability P($n = 0$) of no extra interaction in addition to a hard scattering is easily calculated using the following equations, which give the average number of extra interactions $\overline{n}$ in terms of the cross section σ, instantaneous luminosity $\mathcal{L}$, period T, and number of bunches N_B.

$$\overline{n} = \sigma \cdot \mathcal{L} \cdot T/N_B \tag{1}$$

$$P(n = 0) = \mathrm{e}^{-\overline{n}} \tag{2}$$

The second column in Table 3 (labelled Min Bias) shows the probability of no extra minimum bias interactions as a function of luminosity using a minimum bias cross section of $\sigma = 47$ mb, $T = 2.094 \times 10^{-5}$ s, and 36 bunches. The single interaction fraction is seen to be quite appreciable at lower luminosities, but falls quickly with luminosity.

For rare processes such as diffractive W production it would be undesirable to impose a single interaction requirement at the trigger level, due to the loss in statistics. It is more sensible to read out the detectors for all events and just impose single interaction requirements on the higher cross section processes. It will be difficult to separate the diffractive component from the pileup component, since a non-diffractive W event overlayed with a low mass diffractive event will appear quite similar to a diffractive W event overlayed with a minimum bias event. The principal difference will be the ξ distributions, which will peak sharply at $\xi = 0$ for the fake background, but at higher ξ for diffractive W's. [4]

[4] It should be noted that a fraction of real hard diffractive events ($1 - \mathrm{P_{SD}}(\mathrm{n} = 0)$) will have an extra diffractive event overlayed, and this effect must be considered at high luminosity.

The ξ distribution for multiple interaction W events tagged by the FPD will thus consist of two components, which can both be measured independently: the inclusive ξ distribution can be measured in inclusive single diffractive events, and the diffractive W ξ distribution can be measured in single interaction diffractive W events. A fit to the observed ξ distribution of these tagged MI W events will yield the fraction of these events that are diffractive W's (after correction for the FPD acceptance). The diffractive W fraction can more easily be obtained from single interaction events, of course, but with much lower statistics.

Of course, there will be an appreciable fraction of rare events with a single interaction that can be studied in more detail.

3.3.1 Pile-up Background

Pile-up, the background due to the superposition of a low mass diffractive event with a hard scattering event, is a more serious concern since this combination can fake a hard diffractive signal. Using the two-arm (p and $\overline{p}$) single diffractive (SD) cross section of $\sigma = 10$ mb, we see that there will be an appreciable pile-up background for the quadrupole spectrometers (the fake background for the dipole spectrometer is relatively less important due to the acceptance being weighted towards higher ξ where the fake background is negligible). For example, from the third column of Table 3 at 4E31 luminosity 21% of all events ($1-\mathrm{P}(n=0)$) will have at least one extra single diffractive event. Fortunately, this background is dominated by very low mass diffraction which could not produce jets and can easily be rejected at Level 1 by a cut such as $\xi > 0.004$, which will reduce the effective cross section to about 2 mb [4]. Applying this cut reduces the overlap of diffractive events with dijet events to a few percent (5% at 4E31). The aforementioned single interaction requirement will reduce this background by about a factor of 10 based on Run I experience. Note that virtually all single diffractive events with $\xi > 0.004$ ($M_X > 126$ GeV/c^2) will give enough hits in the LM counters for this requirement to be effective. With these simple cuts the fake background is reduced to about 0.5% of dijet events, which is on the order of the expected 0.3–1% hard diffractive dijet signal [5, 6]. As shown in Sec. 3.4, the Level 1 rates implied by this level of background are acceptable after the proton acceptance is taken into account. At Level 3 this background can be reduced to near zero as discussed below.

The hard double pomeron background, due to the pile-up of two opposite side single diffractive events with a dijet event, is also manageable. A tighter cut requiring that $\xi > 0.01$ would likely be used for double pomeron events. Since only about $M_X = \sqrt{\xi_1 \cdot \xi_2}\sqrt{s}$ is available for jet production (for $\xi_1 = \xi_2 = 0.01$ this gives an $M_X = 20$ GeV/c^2), there will be no contribution to jet cross sections from lower ξ values, but a large contribution to the pile-up background. The column in Table 3 labelled P$(n \geq 2)$ shows the probability of having two or more single diffractive events for a diffractive cross section of 1 mb is 0.00027. This gives a background more than an order of magnitude greater than the expected signal for hard double pomeron exchange, which is likely to be a few millionths of the dijet cross section [5]. Although this absolute rate is already small and additional cuts are not strictly necessary, we would likely still apply a single interaction requirement to reduce the contamination at Level 1 to the same order as the signal and keep the E_T threshold as low as possible. The same arguments apply to background from two soft single diffractive events plus a dijet event or one hard single diffractive dijet event and one soft single diffractive event. [5]

At Level 3 (or offline in the case of diffractive W bosons) there will be other tools available for identifying pile-up background which will be combined into a single interaction algorithm or tool:

- The new silicon tracking detector will be very efficient at finding vertices with $|z| < 30$ cm at Level 3 and up to 40 cm offline with a resolution of about 20(200) μm for $|z| < 30(40)$ cm. The multiple interaction rejection will thus be very efficient for events with reasonably central vertices and tracks with $\eta < 2.5$. The ξ cuts suggested above will already ensure that the events will typically have several central tracks. The silicon will not help reject events with one central and one non-central vertex or two non-central vertices, but the first case will give a good separation in Luminosity Monitor event times and be rejected, and the second case is very rare.

- The event interaction time from the trigger scintillators can be compared to the interaction time from the LM to determine whether the times are consistent with coming from the same interaction. With a single tube resolution of 240 ps, we expect a 170 ps time resolution for the two trigger counters. The LM counters typically will have several counters hit and are expected to give a resolution of 100 ps. Convoluting these distributions with the time distribution of the event (about

[5]The soft diffractive event will still typically hit one side of the LM due to the $\xi > 0.01$ cut.

1 nsec) and demanding a two sigma separation gives a rejection factor of three. This cut would be particularly useful for rejecting diffractive events where the diffractive system is produced at small angles $\eta > 2.5$ for which the multiple vertex cut is ineffective.

- Conservation of longitudinal momentum can be imposed by requiring that the sum of the momentum of the trigger proton and the longitudinal energy in the DØ calorimeter on the trigger side is less than the initial 1 TeV beam momentum (within resolution). This is a very effective cut, particularly for low ξ (for example with $\xi = 0.01$ the proton alone contributes 990 GeV/c to the longitudinal momentum). Essentially, this makes use of the fact that a pile-up event will have a beam remnant and a diffractive event will have none to reject pile-up events. An equivalent cut for the UA8 collaboration was very successful and the FPD momentum resolution and DØ energy resolution are greatly superior.

A loose rapidity gap requirement could also be implemented. From studies of the forward multiplicity distribution [7], a cut on a small number of calorimeter towers above threshold would provide a rejection factor of about 100 on fake background events while preserving a large fraction of rapidity gap (diffractive) events. We would be reluctant to adopt a tight rapidity gap cut online in the hard diffractive triggers except in the unlikely event that it proves absolutely necessary to control the rates, since there would potentially be some biases to the physics. For inclusive double pomeron exchange, loose rapidity gap requirements likely will be used due to higher backgrounds and less concern about biases.

Although lower luminosity is optimal for dedicated hard diffractive triggers, there is still an appreciable single interaction cross section at very high luminosity and there are many handles for rejecting pile-up background.

3.3.2 Halo Background

A preliminary study of the correlation of halo hits was performed to determine the background from halo [1]. It was found that $> 98\%$ of tracks had early time hits in both pots of the diagonally opposite spectrometer and could thus be rejected.

Trigger	L1 Terms	L3 Terms
Hard Diffraction	Track($0.97 < x < 0.996$)$\cdot$Two 2 GeV Towers $\cdot$ Halo Veto$\cdot$LM Single Interaction	1 Jet $E_T > 15$ GeV$\cdot$ Single Interaction Tool
Hard Double Pomeron	Track(p,$\overline{p}$,$0.95 < x < 0.99$)$\cdot$Two 2 GeV Towers $\cdot$ Halo Veto$\cdot$LM Single Interaction	1 Jet $E_T > 10$ GeV$\cdot$ Single Interaction Tool
Double Pomeron	Tk(p,$\overline{p}$,$0.97 < x < 0.996$)$\cdot$Halo Veto$\cdot$LM Veto	X$\cdot$SI Tool

Table 4: Details of primary dedicated triggers.

3.4 Triggering and Event Samples

Examples of the trigger terms for the primary physics topics that require dedicated triggers are given in Table 4. These terms are described in detail below:

- "Track" refers to a track required with a certain momentum fraction. For the hard diffraction trigger the track can be in any spectrometer, for the double pomeron triggers both p and $\overline{p}$ tracks are required.
- "Halo Veto" refers to the veto on early hits in the diagonal opposite spectrometer
- "LM Single Interaction" is the requirement that the LM counters yield a timing consistent with a single event hypothesis.
- "Tower" refers to a trigger tower which is 0.2×0.2 in $\eta \times \phi$.
- "LM Veto" demands that there are no hits in either side of the luminosity monitor (rapidity gap requirement).
- "Single Interaction Tool" is a Level 3 routine that uses the full detector information to reject multiple interactions as discussed in the previous section.
- "X" refers to some level of activity in the detector, such as a central fiber track, some number of hits in the silicon vertex detector, etc.

In addition to these triggers, prescaled elastic and single diffractive triggers will be taken to monitor the FPD performance.

	Trigger Rates (Hz)				
Trigger	L1 Physics	L1 Bkgd	L3 Physics	L3 Bkgd	Events/fb^{-1}
Hard SD	4.0	2.2	0.08	0.0005	500,000
Hard DP	0.002	0.001	0.0004	0.000002	2,500
Inclusive DP	0.07	0.07	0.001	≈ 0	6,000

Table 5: Trigger rates (Hz), backgrounds, and number of events for hard single diffraction, hard double pomeron, and inclusive double pomeron exchange.

3.4.1 Trigger Rates

The trigger rates for hard diffraction, hard double pomeron exchange, and inclusive double pomeron exchange are discussed in this section. Each topic has a detailed estimate of the physics and background rates showing the effect of each trigger term. There is a table summarizing each topic. A global summary of the rates and expected number of events is given in Table 5 for a typical 4E31 luminosity.

The Level 1 rates in Hz are given by the following expression:

$$\mathrm{L1} = \sigma \cdot \mathrm{A} \cdot \mathrm{SI} \cdot \mathcal{L} \tag{3}$$

where σ is the L1 cross section, A is the spectrometer acceptance, SI is the single interaction acceptance factor (which ranges from 1 at low luminosity to 0.1 at high luminosity), and $\mathcal{L}$ is the luminosity in units of 10^{30} cm$^{-2}s^{-1}$.

- Hard Diffraction. The summary of this section is given by Table 6. The details are discussed below. The cross section for two trigger towers with $E_T > 2$ GeV was measured in Run I to be about 1000 μb. Assuming 0.3% of these events are diffractive gives a cross section of 3 μb. A cut of $\xi < 0.03$ is imposed to ensure that the data sample is dominated by pomeron exchange (some data would be taken with a relaxed cut in order to understand the non-diffractive background). The acceptance is about 1% for the quadrupole spectrometers and 20% for the dipole spectrometer over this range. Since only $\overline{p}$'s are accepted by the dipole spectrometer, the average acceptance is about 10%. A luminosity of $4 \cdot 10^{31}$ cm$^{-2}s^{-1}$ gives SI = 0.34 (from Table 3), which combined with A = 10%, yields $\mathrm{L1_{HSD}} = 4.0$ Hz.

  The multiple interaction fake rate can also be evaluated using Eq. 3, with different values of σ and A. In this case $\sigma = 5$ μb (0.5% of the dijet cross section including the LM cut as discussed in the previous section). The acceptance for quadrupole spectrometers is the same for signal and fake background, but the dipole acceptance for fake background is much lower due to the increased acceptance for higher ξ which has lower background. An overall acceptance A = 3% is assumed, giving $\mathrm{L1}_{\mathrm{MI}} = 2.0$ Hz. The same SI factor still applies, since it refers to the overlap of an extra minimum bias event, which would cause the rejection of fake background that would have otherwise passed the single interaction cut.

For halo, $\sigma \cdot \mathrm{A} = 0.000016 \cdot 1000\ \mu$b as discussed earlier (the 0.000016 already includes the acceptance for halo tracks), so $\mathrm{L1}_{\mathrm{HALO}} = 0.2$ Hz.

Unlike most DØ triggers there will be little luminosity dependence of the rates, since the rate increase from the increased luminosity is roughly cancelled by the SI acceptance factor which decreases with increasing luminosity.

From Run I the $E_T > 15$ GeV jet cut gave a reduction of about 50, giving a Level 3 physics cross section of 2 nb, corresponding to a rate of 0.08 Hz. From the single interaction tool, we expect a rejection of greater than 100 for fake background and greater than 40 for halo background (in addition to the jet rejection which applies equally to all these samples), giving a final background rate of less than 0.0005 Hz (about 20% coming from halo).

- Hard Double Pomeron. We now apply Eq. 3 to the hard double pomeron case. This section is summarized by Table 7. A reasonable guess for the hard double pomeron cross section is about 1% of the hard diffractive cross section, or 0.03 μb. The acceptance is now the product of the p and $\overline{p}$ acceptance. The $\overline{p}$ acceptance averaged over the range $0.01 < \xi < 0.05$ is about 50%. Combining this with the 1% p acceptance yields a total acceptance of about 0.5%. Applying the luminosity and SI factor gives a L1 physics rate of 0.002 Hz.

  The background to hard double pomeron exchange is dominated by the overlap of two inclusive diffractive interactions and a dijet event. At 4E31, the probability of two single diffractive events with $\xi > 0.01$ is $3 \cdot 10^{-4}$, and one-half of these cases give a p and a $\overline{p}$. Assuming that 10% of these events survive the Level 1 single interaction cut gives $1.5 \cdot 10^{-5}$ of the dijet cross section or 0.015 μb. Applying the same acceptance and SI factors as for the signal gives 0.001 Hz. Other fake combinations

	$\sigma(\mu\text{b})$	Rate(Hz)@4×10^{31}
Hard Diffraction $\sigma_{L1}(p\overline{p}\rightarrow jj)$	1000	40000
$\sigma_{L1}(\text{SD}\rightarrow p+jj)$	3	120
$\sigma_{L1}(\text{SD}\rightarrow p+jj)\cdot\text{A}$	0.3	12
$\sigma_{L1}(\text{SD}\rightarrow p+jj)\cdot\text{A}\cdot\text{SI}$	0.1	4.0
$\sigma_{L3}(\text{SD}\rightarrow p+jj)\cdot E_T>15$	0.002	0.08
MI Fake $\sigma_{L1}(p\overline{p}\rightarrow jj)$	1000	40000
$\sigma_{L1}(\text{MI}\rightarrow p+jj)$	50	2000
$\sigma_{L1}(\text{MI}\rightarrow p+jj)\cdot\text{LM}$	5	200
$\sigma_{L1}(\text{MI}\rightarrow p+jj)\cdot\text{LM}\cdot\text{A}$	0.15	6
$\sigma_{L1}(\text{MI}\rightarrow p+jj)\cdot\text{LM}\cdot\text{A}\cdot\text{SI}$	0.05	2.0
$\sigma_{L3}(\text{MI}\rightarrow p+jj)\cdot E_T>15$	0.001	0.04
$\sigma_{L3}(\text{MI}\rightarrow p+jj)\cdot E_T>15\cdot$ L3 SI Tool($\approx$100)	0.00001	0.0004
Halo Fake $\sigma_{L1}(p\overline{p}\rightarrow jj)$	1000	40000
$\sigma_{L1}(\text{Halo}\rightarrow p+jj)\cdot\text{A}$	0.016	0.6
$\sigma_{L1}(\text{Halo}\rightarrow p+jj)\cdot\text{A}\cdot\text{SI}$	0.005	0.2
$\sigma_{L3}(\text{Halo}\rightarrow p+jj)\cdot E_T>15$	0.0001	0.004
$\sigma_{L3}(\text{Halo}\rightarrow p+jj)\cdot E_T>15\cdot$ L3 SI Tool($\approx$40)	0.000002	0.0001

Table 6: Cross sections and trigger rates for hard single diffraction (SD$\rightarrow$ $p+jj$) and fake backgrounds to hard single diffraction from multiple interactions (MI) and halo. The expression $p+jj$ also include the charge conjugate $\overline{p}+jj$.

	$\sigma(\mu$b)	Rate(Hz)@4$\times 10^{31}$
Hard Double Pomeron σ_{L1}(DP$\rightarrow p\overline{p}+jj$)	0.03	1.2
σ_{L1}(DP$\rightarrow p\overline{p}+jj$)$\cdot$A	0.00015	0.006
σ_{L1}(DP$\rightarrow p\overline{p}+jj$)$\cdot$A$\cdot$SI	0.00005	0.002
σ_{L3}(DP$\rightarrow p\overline{p}+jj$)$\cdot E_T > 10$	0.00001	0.0004
MI Fake σ_{L1}(MI$\rightarrow p\overline{p}+jj$)	0.15	6.0
σ_{L1}(MI$\rightarrow p\overline{p}+jj$)$\cdot$LM	0.015	0.6
σ_{L1}(MI$\rightarrow p\overline{p}+jj$)$\cdot$LM$\cdot$A$\cdot$SI	0.000025	0.001
σ_{L3}(MI$\rightarrow p\overline{p}+jj$)$\cdot E_T > 10$	0.000005	0.0002
σ_{L3}(MI$\rightarrow p\overline{p}+jj$)$\cdot E_T > 10\cdot$ L3 SI Tool($\approx$100)	≈ 0	0.000002
Halo Fake σ_{L1}(Halo$\rightarrow p\overline{p}+jj$)$\cdot$A	≈ 0	≈ 0
σ_{L3}(Halo$\rightarrow p\overline{p}+jj$)	≈ 0	≈ 0

Table 7: Cross sections and trigger rates for hard double pomeron exchange (DP$\rightarrow p\overline{p}+jj$) and fake backgrounds from multiple interactions (MI) and halo.

such as a diffractive interaction with a hard single diffractive one are at least a factor of five smaller. Fake background involving halo requires either two independent halo tracks superimposed with a dijet event, or one halo track combined with a diffractive interaction and a dijet event. In either case the small acceptance combined with $\xi > 0.01$ renders this background negligible.

At Level 3, the rejection is only expected to be about a factor of 5 due to the lower E_T threshold. Multiple interaction background rates should be an additional factor of 100 smaller and can safely be ignored. The total Level 3 physics cross section is thus about 10 pb.

- Inclusive Double Pomeron. This section is summarized by Table 8. The estimate for the inclusive double pomeron cross section is in the range of 10–100 μb [8]. Assume a cross section of 5 μb after applying the $\xi > 0.004$ cut. Applying a total acceptance of 0.1%, luminosity, and SI factors gives a rate of 0.07 Hz.

  The multiple interaction background requires two single diffractive

	$\sigma(\mu$b)	Rate(Hz)@4×10^{31}
Inclusive Double Pomeron σ_{L1}(DP$\rightarrow p\overline{p}+X$)	5.0	200
σ_{L1}(DP$\rightarrow p\overline{p}+X$)$\cdot$A	0.005	0.2
σ_{L1}(DP$\rightarrow p\overline{p}+X$)$\cdot$A$\cdot$SI	0.0017	0.07
σ_{L3}(DP$\rightarrow p\overline{p}+X$)$\cdot$ Physics	0.000025	0.001
MI Fake σ_{L1}(MI$\rightarrow p\overline{p}+X$)	50	2000
σ_{L1}(MI$\rightarrow p\overline{p}+X$)$\cdot$LM	5	200
σ_{L1}(MI$\rightarrow p\overline{p}+X$)$\cdot$LM$\cdot$ A $\cdot$SI	0.0017	0.07
σ_{L3}(MI$\rightarrow p\overline{p}+X$)$\cdot$ Rap. Gap($\approx$10,000)	≈ 0	≈ 0
Halo Fake σ_{L1}(Halo$\rightarrow p\overline{p}+X$)$\cdot$A	≈ 0	≈ 0
σ_{L3}(Halo$\rightarrow p\overline{p}+X$)	≈ 0	≈ 0

Table 8: Cross sections and trigger rates for inclusive double pomeron (DP$\rightarrow p\overline{p}+X$) and fake backgrounds.

events on opposite sides, which has a cross section of 50 μb (2.5% of the 2 mb cross section has a second diffractive event on the opposite side). Applying the LM, acceptance, luminosity, and SI factors give a small L1 rate of 0.07 Hz, which will be completely obliterated by the rapidity gap cut on both sides (rejection of 10,000). Fake background involving halo is negligible as in the hard double pomeron case.

The addition of a cut on "X" (some physics activity such as tracks, energy, or muons), since we will want to measure something in the event, will lower the physics L3 rate to an insignificant level, perhaps 0.001 Hz.

The background (Bkgd) rates are dominated by multiple interactions (see Sec. 3.3) and are seen to be small compared to the signal. While there are large uncertainties in these numbers due to the limited data on these subjects, we clearly expect to obtain large samples to carry out these analyses.

References

[1] "Proposal for a Forward Proton Detector at DØ", Proposal P-900 submitted to the Fermilab PAC, Oct. 1998; A. Brandt *et al*, FERMILAB PUB–97-377.

[2] M. Martens, "Coordinate System and Naming Conventions for the FPD Roman Pots", http://www-d0.fnal.gov/ ˜brandta/fpg/DØ_private /fpg.html (under Subgroups/ Accelerator Interface).

[3] A. Brandt, C. Savioli, M. Vaz, "Forward Proton Detector Electronics", http://www-d0.fnal.gov/ ˜brandta/fpg/DØ_private /fpg.html (under Subgroups/ Trigger/TDR).

[4] F. Abe *et al.* (CDF Collaboration), Phys. Rev. D **50**, 5535 (1994).

[5] A. Brandt (DØ Collaboration) *Proceedings of the 11th Topical Workshop on Proton-Antiproton Collider Physics*, Abano Terme, Italy, 1996.

[6] F. Abe *et al.* (CDF Collaboration), Phys. Rev. Lett. **78**, 2698 (1997).

[7] A. Brandt, K. Maruitz (DØ Collaboration) *Proceedings of the LAFEX International School of High ENergy Physics (LISHEP '98)*, Rio de Janeiro, Brazil 1998.

[8] K.H. Streng, Phys. Lett. B **166**, 443 (1986).