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A High Multiplicity Trigger for RunII

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Abstract

We propose a trigger to collect in RunII an unbiased sample of events characterized by the presence of many associated particles in the COT. Also soft tracks with p_T as low as 400 MeV/c should be included.

This note exploits the possibility of using the calorimeter trigger at level 1 and 2, together with a global reconstruction at level 3. We try to keep trigger requirements as simple as possible, compatibly with very low trigger rates ($<$ 1% of total bandwidth).

1 Introduction

This note present a study of feasibility for a high multiplicity trigger for RunII. The topology of event we want to select is characterized by many tracks in the COT associated to the same event vertex, including tracks with transverse momentum as low as the offline code can reconstruct (400 MeV/c). For we can not make use of XFT or SVT and we are led to a trigger path that exploits the calorimeter data at level 1 and 2. At level 3 we assume that a global reconstruction of COT tracks will be done, at least for a small sample. We aim to use no more than 1% of the total bandwidth at each trigger level, and in particular no more than 0.25 Hz at L3.

Since a many-track event can be easily faked by a multiple interaction crossing, we suggest as an initial constrain that the trigger be dynamically prescaled so to collect events only at low instantaneous luminosities ($\mathcal{L}$). How low the luminosity should be will depend on the Tevatron run conditions; we assume that with $\mathcal{L} < 1.0 \cdot 10^{32} cm^{-2} s^{-1}$ we are going to collect enough events for our analysis purposes. This limit correspond to an average number of inelastic interactions per crossing of about two when the Tevatron is operated with 36 bunches. This strategy should match with the necessity of other triggers to run rather at high instantaneous luminosity.

2 Physics motivations

In our Min-Bias studies, events with charged multiplicity as high as 30 and no significant jet activity are found. As shown in CDF note 5399, events with no energy clusters of $E_T > 1.1\ GeV$ in the calorimeter are more than 50% of the whole sample. Their properties seem to be independent of the `c.m.s.` energy and, in particular, the correlation of the average track p_T versus the charged multiplicity. On the other hand, in the full Min-Bias sample, the shape of this correlation, not described by any model, is likely to be strongly connected to the different behavior of the soft and the jet-like components. The structure of the curve, rather well determined at lower multiplicities, is still basically unknown in the high multiplicity region for obvious statistical reasons (figure 1): only just about 1% of the events after offline selection has multiplicity ≥ 18.

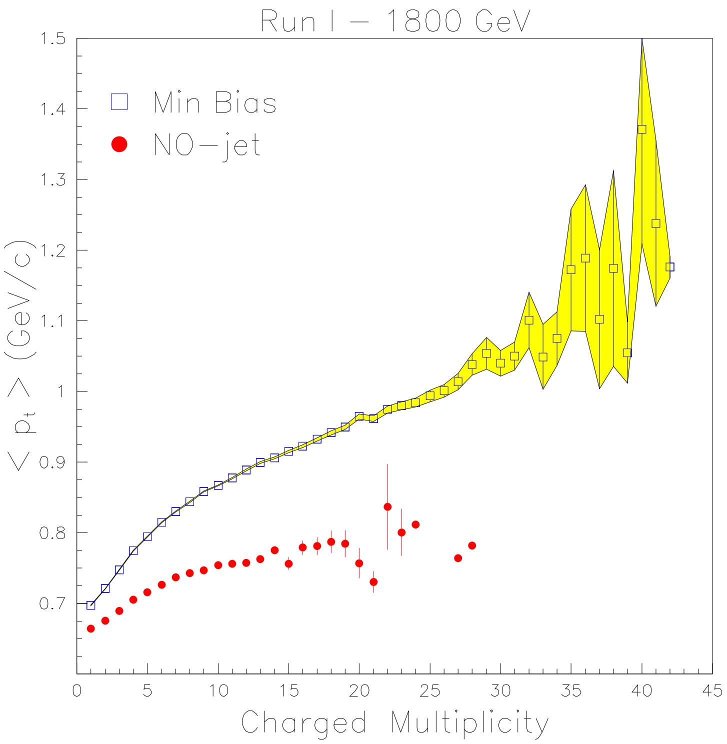

Figure 1: The correlation between average track p_T and the charged multiplicity.

In order to analyse the structure of the curve, the 0-bias sample that we are going to collect in RunII is not going to supply a sufficient number of events (only about twice the statistics than in RunI will be collected). We propose to collect a sample of events, not biased against low p_T tracks, large enough to increase the statistic of in the tail of the multiplicity distribution ($mult \gtrsim 16$) of a factor ≈ 20.

3 Data set

We have simulated the trigger path at all levels with the RunIB Min-Bias data (stream XMBB_5F). The simulation and the choice of the trigger thresholds were done assuming that during RunII the trigger will be active only at instantaneous luminosities smaller than 10^{32} $cm^{-2}s^{-1}$ (36 bunches) with average luminosity of $0.7 \cdot 10^{32}$ $cm^{-2}s^{-1}$. This limit on $\mathcal{L}$ should supply enough statistics if it will be satisfied for about half of the running time [1]. Conditions for RunIB were chosen so that the average number of inelastic interactions per crossing at the average luminosity be the same as in RunII. [1]. This roughly coincide with the whole RunIB Min-Bias sample: we selected 1474850 events after rejecting in-time cosmics and bad runs.

4 Rates (before trigger)

In RunII only the RF will start the trigger ("0-bias"). The trigger rate can than be expressed as:

$$R = \epsilon \cdot \frac{1 - e^{-\mu}}{\mu} \cdot \sigma_{\overline{p}p} \cdot \mathcal{L} = \epsilon \cdot \frac{1 - e^{-\mu}}{\Delta t} \tag{1}$$

being $\mu = \sigma_{\overline{p}p} \cdot \mathcal{L} \cdot \Delta t$, where ϵ is the trigger efficiency, $\sigma_{\overline{p}p}$ the total cross section, $\mathcal{L}$ the instantaneous luminosity, μ the average number of $\overline{p}p$ interactions per crossing and Δt the time interval between crossings.

Since we do not want to bias our analysis by excluding any high multiplicity event, we need to keep the trigger efficiency ϵ up to 1 for multiplicities greater than 15. This limit is chosen so to be low enough to nicely connect to the 0-bias sample and high enough to supply a statistically significant set of events in the tail of the multiplicity distribution (multiplicity $\gtrsim 20$).

In our low luminosity scenario we expect a 0-bias rate of about 2.4 MHz and an inelastic rate of about 2.3 MHz. If we assume that the average luminosity of events with $\mathcal{L} < 10^{32}$ $cm^{-2}s^{-1}$ will be $0.7 \cdot 10^{32}$ $cm^{-2}s^{-1}$, the average number of inelastic collisions per crossing is $\mu \simeq 1.9$ and we can compute a total rate of $R_{\overline{p}p} \simeq 2.3$ MHz and an inelastic rate of $R_{inelastic} \simeq 2.1$ MHz (see Appendix).

5 Level 1 simulation

In order to reject crossings with no interactions and make sure that at least some tracks are present in the COT, as first approach we require at L1 the presence of at least one trigger-tower above $E_T = 0.5$ GeV in the central calorimeter (10

[1] All calculations in this note refer to run conditions with 36 bunches and Δt between crossings 396 ns. Number of events are computed assuming a 2 years run time with duty factor of 50%. The total $\overline{p}p$ cross section has been assumed to be 82 mb at 1800 GeV and 84 mb at 2000 GeV. The inelastic cross sections to be 56 mb and 57.5 mb respectively.

centralmost trigger-towers). The tower energy threshold being the value of the least significant bit (LSB) of the energy word at L1 [2].

The correlation between the number of trigger-towers above threshold and the charged multiplicity (as counted by offline reconstruction code) is very rough and does not allow a higher cut on the number of towers if we want to keep $\epsilon = 1$. In figure 2 only events selected by the offline reconstruction code are present: 886542 events passed the following cuts:

- at least 1 vertex of class > 5 is present
- multiple interactions closer than 60 cm were rejected (we select primary vertices as those of class 11 or 12. If only vertices of class ≤ 10 are present in the VTVZ bank, only the first one is assumed to be primary).
- $|Z_{vertex}| < 60$ cm

This subsample was used to place the threshold on the number of towers. In order to estimate the trigger rates and cross sections, all events of the sample were used.

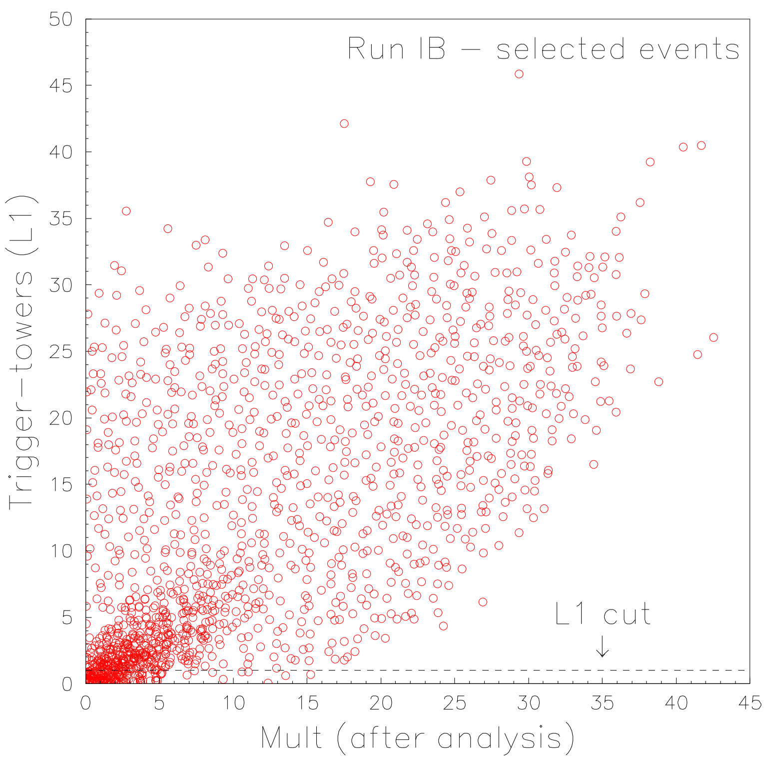

Figure 2: The correlation between the number of trigger-towers at L1 and the charged multiplicity as selected by offline analysis.

Both here as at L2 the tower transverse energy is computed with respect to the nominal interaction point.

The threshold chosen allows to select about 83% of the inelastic cross section. If one considers also empty crossings, elastic and diffractive events, about 70% of all crossings passes the trigger selection. A prescale will be needed since this rate is too high. Our guess is to set a prescaling factor of 300000, but this number is subject to change depending on the Tevatron running conditions.

We plot the efficiency of level 1 versus the number of trigger-towers (figure 3). The efficiency is computed as the ratio of the number of "high-multiplicity " events (multiplicity ≥18) selected by the trigger to the total number of such events in the sample. For the threshold selected the efficiency is one down to multiplicity about 12.

The fraction of events of high multiplicity to the number of events selected ("purity") is about 1.9%.

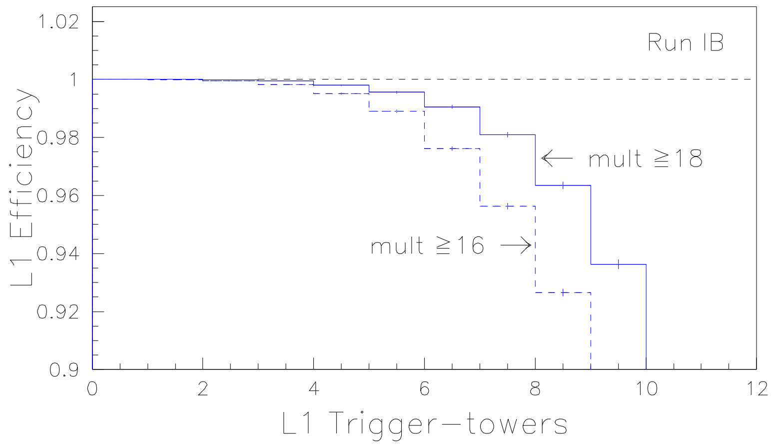

Figure 3: The L1 trigger efficiency versus the threshold.

6 Level 2

The trigger strategy at L2 resemble that of L1: a threshold is set on the number of trigger-towers with EM transverse energy above 125 MeV in the central calorimeter. The resolution of the information on tower energy at L2 is much higher than at L1 and allows a more stringent event selection.

At present, the information regarding the total number of trigger towers with some energy content is not available in any of the L2 triggers. Yet, such datum can be computed by the L2 cluster finder (L2CAL) with a few changes that we describe qualitatively in next paragraph.

6.1 The L2CAL

The main task of the L2 calorimeter trigger is to clusterize the energy deposited in the calorimeter towers at each L1 Accept. The L2CAL can perform four different "passes" over every event [3], each pass characterized by a different set of thresholds. A different threshold can be set for every trigger tower, both over the total transverse energy (THR_SUM) or over the electromagnetic energy only (THR_EM). One of these passes is unoccupied at the moment and can be user for our purposes.

The energy of the event arrives from DIRAC to L2 as a 10 bit word (125 MeV LSB, 128 GeV full scale) for each of the 576 trigger towers ($24\eta \times 24\phi$). The first step of the clustering algorithm is implemented in a FPGA chip inside a DCAS (Digital Cluster and Sum) board. There is one of these programmable chips ("cluster cell") for each trigger tower. As it is now, the chip's algorithm performs a comparison of the tower energy with its threshold and outputs the energy of those towers that are decided to be a "seed" or a "shoulder" for a cluster. Then the cluster is expanded until no towers adjacent to the cluster have energy above the shoulder threshold [4]. The total cluster energy is summed outside the chip.

Our proposal is to force this algorithm to clusterize all the towers in the central region, independently of their energy content. The modification should apply to one of the four passes only (pass number three). One cluster of 576 towers is then found in every event. The number of towers with a minimum energy content can be obtained from the cluster energy word if the same value is output by every cluster cell (every trigger-tower) to the cluster energy adder.

All this is possible, thanks to the efforts of Monica Tecchio, with a few modifications to the cluster cell algorithm.

6.2 L2 timing

Fortunately there are no timing problems. Assuming there are 10 μs available for a L2 decision, each of the four passes should be done in 2.5 μs.

To begin with, the clustering algorithm has a 1.4 μs overhead time for finding the cluster seed and other calculations. Than the four towers adjacent to the seed are joined to the cluster in a 30 ns time, according to first tests during commissioning run [5]. Since we want to check only the central calorimeter, our region of interest is a "grid" of $10\eta \times 24\phi = 240$ trigger-towers. In the worst case the seed will be in one of the corners of the grid and it will take 32 expansion steps to join all towers into the cluster. The total time employed is:

$$1.4\mu s + (32 \times 30ns) = 2.36\mu s \tag{2}$$

6.3 L2 simulation

The correlation between the number of EM trigger towers and the event charged multiplicity is shown in figure 4. We decided to use only the EM component of the tower energy because it results in a higher rejection factor than the total (EM+HAD) transverse energy.

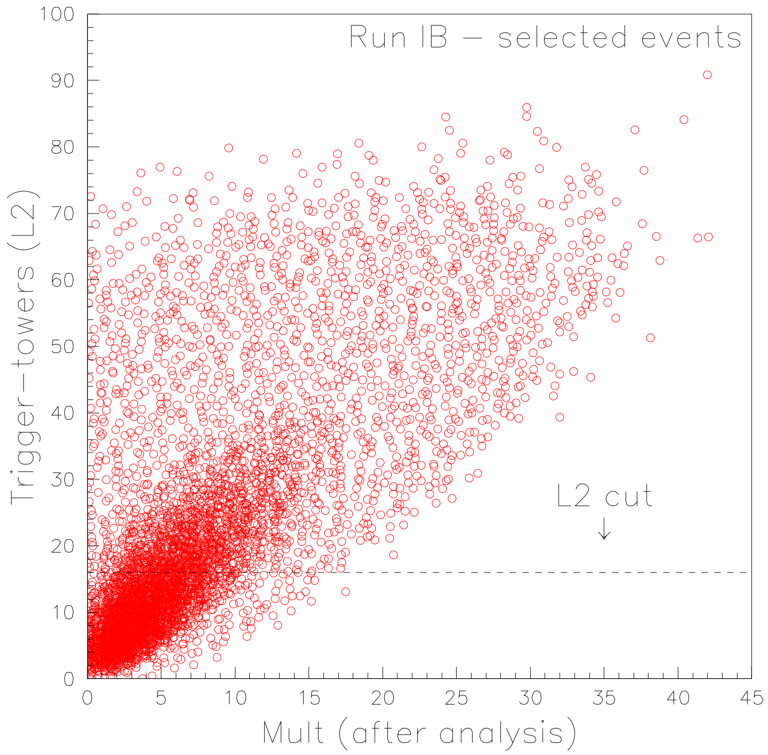

Figure 4: The correlation between the number of trigger-towers at L2 and the charged multiplicity as selected by offline analysis.

By requiring to have at least 16 towers above $125MeV$ we select about 55% of the events accepted by L1. This cut ensures full efficiency ($\epsilon = 1$) for multiplicities ≥ 18 (figure 5).

The purity of the selected sample is about 3.4%.

7 Level 3

As mentioned in the introduction, we have assumed that at level 3 a global reconstruction of the COT will be possible, at least for a small part of the bandwidth. This assumption is quite necessary since the reduction factor of the combined

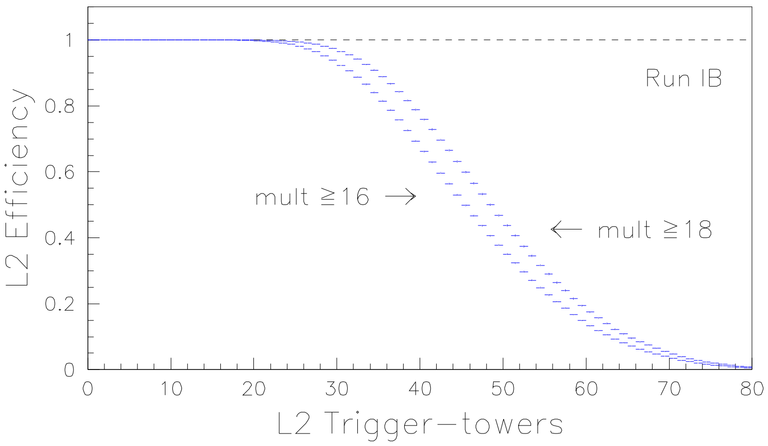

Figure 5: The combined L1+L2 trigger efficiency versus the threshold.

level 1 and 2 is only about 60% and we need now to apply a very stringent selection on the number of tracks associated with the primary vertex.

In order to do this, a good reconstruction of the event vertex Z position is also highly desirable since it would allow to have a good rejection of secondary particles. We have therefore assumed that the primary vertex package (PV) speed will be improved before the run begins and that it will be running online.

A coarse simulation of the L3 tracking can be applied to the RunIB data by simply taking the tracks reconstructed offline without requiring the usual track quality cut (CTCSEL). We have than computed the number of tracks that pass the following cuts:

- track impact parameter $D_0 < 0.5\ cm$
- track z matching $|Z_0 - Z_{vertex}| < 5\ cm$
- track $p_T > 0.4\ GeV/c$
- track $|\eta| < 1.0$

The correlation between the number of tracks counted this way and the fully selected offline multiplicity is very tight [2] (figure 6).

In the reliability limit of this approach, we can place a cut on events with more than 15 L3-tracks and select 6.9% of the events accepted by L2. The final purity of the selected sample is almost 90%.

In the case that the PV package will not be available to run online, a rough estimate of the primary vertex position along the Z axis with a resolution in the

[2] In fact, the number of tracks found in the complete offline selection is just a subsample of the tracks that we select at L3. In other words, there are no events with offline multiplicity greater than the number of tracks selected here.

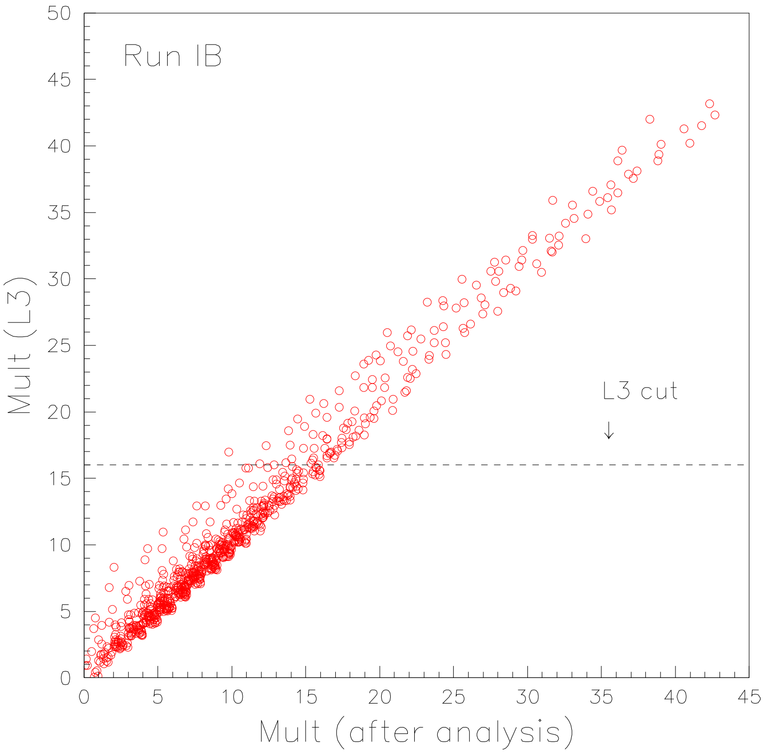

Figure 6: The correlation between the number of tracks at L3 and the multiplicity selected offline.

order of 3 cm will probably be at hand at L3. This condition was simulated by applying a less strict condition on the tracks z matching to the event vertex. By requiring $|Z_0 - Z_{vertex}| < 8\ cm$ our cut selects about 8.1% of the events and the final sample purity drops to about 75%.

If no conditions on vertex Z matching are required, L3 selects about 21% of the events and the purity drops to about 28%.

8 Summary

We report in table 1 the rates expected for the trigger and relative number of events. All calculations are based on a 2 years run with 50% on-time. We have also assumed that the instantaneous luminosity will be lower than our threshold for about half of the time and that the average luminosity in this period will be $\mathcal{L} = 0.7\ cm^{-2}s^{-1}$.

All numbers may be subject to change depending on the effective run conditions, on the needs of other triggers and suggestions by the collaboration, as long as a large enough sample can be collected.

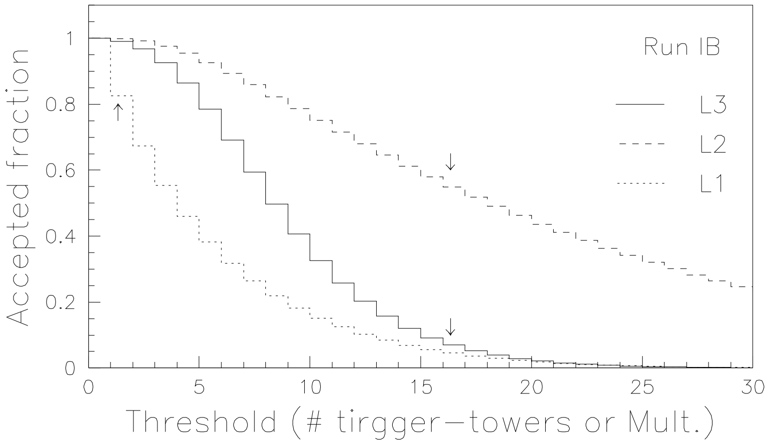

Figure 7: The trigger acceptance factors at all levels.

	N. events	bandwidth (Hz)	$\mathcal{L}_{int.}$ (nb^{-1})	N. events (mult.$\geq$ 16)	bandwidth (Hz)
crossings	$3.8 \cdot 10^{13}$	$2.52 \cdot 10^6$	$36 \cdot 10^3$	$0.36 \cdot 10^{12}$	$2.4 \cdot 10^4$
PS (L1) (1/300000)	$126 \cdot 10^6$	8.4	120	$1.2 \cdot 10^6$	0.08
L1(*) (84%)	$106 \cdot 10^6$	7.1	100	$1.2 \cdot 10^6$	0.08
L1 (83%)	$88 \cdot 10^6$	5.9	84	$1.2 \cdot 10^6$	0.08
L2 (55%)	$49 \cdot 10^6$	3.2	4.6	$1.2 \cdot 10^6$	0.08
L3 (6.9%)	$3.4 \cdot 10^6$	0.22	3.2	$1.2 \cdot 10^6$	0.08
Analysis (40%)	$1.3 \cdot 10^6$	0.09	1.3	$1.2 \cdot 10^6$	0.08

(*) rejects empty crossings and elastic or diffractive events

Table 1: Summary of trigger rates. All rates refer to the output rate of their level. PS means "prescale": suggested prescaling factors are reported. The number of events is computed assuming that the trigger will be taking data for about half of the total running time.

9 Rates vs luminosity

We have checked the effects of instantaneous luminosity on the trigger rates. RunIB data was divided into four intervals: $\mathcal{L} < 5$, $5 \leq \mathcal{L} < 10$, $10 \leq \mathcal{L} < 15$, $\mathcal{L} \geq 15$ where the numbers are in units of $10^{30}\ cm^{-2}s^{-1}$. We then plotted the number of trigger towers versus the charged multiplicity for each subsample and computed the number of events that passed the cuts (table 2).

Both at L1 and L2 the fraction of accepted events increases significantly if the trigger threshold remains fixed (≥ 1 tower at L1 and > 16 towers at L2).

Because of this increase, it seems not advisable to raise our luminosity limit for running the trigger. In case that the Tevatron will steadily run at very high

$\mathcal{L}$ ($10^{30}\ cm^{-2}s^{-1}$)	$\langle\mathcal{L}\rangle_{IB}$ ($10^{30}\ cm^{-2}s^{-1}$)	$\mathcal{L}_{II}$ ($10^{32}\ cm^{-2}s^{-1}$)	R (L1)	R (L2)
$\mathcal{L} < 5$	2.9	$\mathcal{L} < 0.4$	73%	45%
$5 \leq \mathcal{L} < 10$	7.6	$0.4 \leq \mathcal{L} < 0.9$	80%	58%
$10 \leq \mathcal{L} < 15$	12.5	$0.9 \leq \mathcal{L} < 1.3$	86%	71%
$\mathcal{L} \geq 15$	15.8	$\mathcal{L} \geq 1.3$	91%	82%

Table 2: Trigger rates at L1 and L2 for various luminosity intervals.

luminosity we suggest instead to increase the trigger bandwidth. Should the $\mathcal{L}$ at the beginning of each store be in the order of $1.5 \cdot 10^{30}\ cm^{-2}s^{-1}$, it would take about six hours before it drops to $10^{30}\ cm^{-2}s^{-1}$ [1]. The increase in bandwidth will then depend on the store duration. Although the store length cannot be foreseen at the moment, in table 3 we propose an alternative scenario based on the hypothesis that the trigger will be taking data only for about one fifth of the total running time. To collect a sufficient statistics the bandwidth grows at L2 up to about 3% of total.

	N. events	bandwidth (Hz)	$\mathcal{L}_{int.}$ (nb^{-1})	N. events (mult.$\geq$ 16)	bandwidth (Hz)
crossings	$3.8 \cdot 10^{13}$	$2.52 \cdot 10^{6}$	$36 \cdot 10^{3}$	$0.36 \cdot 10^{12}$	$2.9 \cdot 10^{4}$
PS (L1) (1/100000)	$0.15 \cdot 10^{9}$	25	35	$1.4 \cdot 10^{6}$	0.29
L1(*) (84%)	$0.13 \cdot 10^{9}$	21	30	$1.4 \cdot 10^{6}$	0.24
L1 (83%)	$0.1 \cdot 10^{9}$	17	24	$1.4 \cdot 10^{6}$	0.24
L2 (55%)	$58 \cdot 10^{6}$	9.7	14	$1.4 \cdot 10^{6}$	0.24
L3 (6.8%)	$4.0 \cdot 10^{6}$	0.67	1.0	$1.4 \cdot 10^{6}$	0.24
Analysis (40%)	$1.6 \cdot 10^{6}$	0.27	0.4	$1.4 \cdot 10^{6}$	0.24

(*) rejects empty crossings and elastic or diffractive events

Table 3: Summary of trigger rates. All rates refer to the output rate of their level. PS means "prescale": suggested prescaling factors are reported. The number of events is computed assuming that the trigger will be taking data for about one fifth of the total running time.

10 Options for high luminosity

In the so called "High Luminosity" scenario the average number of interactions per crossing should decrease, in spite of the increased instantaneous luminosity.

With 108 bunches and $\Delta t = 132\ ns$ we compute an average number of inelastic interactions per crossing $\mu_{inel.} \approx 1.9$, very close to what we had before under the restriction that $\mathcal{L} < 10^{32}\ cm^{-2}s^{-1}$.

It results that the rates already computed (see table 1) still apply with no modifications. The trigger bandwidth will increase of a factor ≈ 2.5 since Δt changes.

11 Acknowledgements

We wish to thank Chiara Zampolli for her work on the trigger simulation and Pedro Amaral for his helpful suggestions and comments. A very special thank to Monica Tecchio for making available and clear to us the electronics of L2 and for her generous help and suggestions.

References

[1] M.Martens and P. Bagley, *Luminosity Distribution During Collider Run II*, http://www-ap.fnal.gov/ martens/luminosity/lum_dist.ps

[2] J. Wahl and P. Amaral, CDF notes n. 4225 and 4231.

[3] M. Tecchio, *LOCOS specifications*, http://umaxp1.physics.lsa.umich.edu/cdf/document/locos_specifications.htm

[4] CDF Technical Design Report.

[5] Monica Tecchio, private communication.

Appendix: how we compute the event rate

If for every beam crossing we always had one and only one $\overline{p}p$ interaction, the total $\overline{p}p$ rate would be simply $1/\Delta t$ where Δt is the time interval between crossings.

But in some cases two bunches cross with no interactions and in some other with more than one. The distribution of the number of interactions is Poissonian with mean μ so that $\epsilon^{-\mu}$ is the probability of having no interactions in a beam crossing. We can then write the rate ($R_{\overline{p}p}$) as:

$$R_{\overline{p}p} = \frac{1 - \epsilon^{-\mu}}{\Delta t} \tag{3}$$

with $\mu = \sigma_{\overline{p}p} \cdot \mathcal{L} \cdot \Delta t$. $R_{\overline{p}p}$ includes elastic and diffractive events as well as inelastic ones. How to compute an "inelstic" rate $R_{inel.}$? We note that elastic events can be mixed with inelastic ones in the same crossings; our rate will be given by the number of beam crossing that contains *at least* one inelastic event. It's easy to compute the probability of crossings with only elastic or diffractive events:

$$\begin{aligned} P_{EL} = \quad & P(1\ event) \cdot P(of\ being\ elastic) + \\ & P(2\ events) \cdot P(of\ being\ both\ elastic) + \\ & P(3\ events) \cdot P(of\ being\ all\ elastic) + ... \end{aligned} \tag{4}$$

the probability to have 1,2,3... interactions is Poissonian. The probability that a single interaction is elastic is given by the ratio of the cross sections:

$$P(elastic\ or\ diffractive) = 1 - \left(\frac{\sigma_{inel.}}{\sigma_{tot.}}\right) = 1 - \frac{56\ mb}{82\ mb} \simeq 32\% \tag{5}$$

We assume that events are independent so the probability that two events in the same crossing are both elastic factorizes. Then our probability is a function of μ which is a function of the luminosity and has to be subtracted to the total $R_{\overline{p}p}$ in order to have the inelastic rate. In our case, $P_{EL} \simeq 4.0\%$ at $\mathcal{L} = 10^{32}\ cm^{-2}s^{-1}$ and $P_{EL} \simeq 6.5\%$ at $\mathcal{L} = 0.7 \cdot 10^{32}\ cm^{-2}s^{-1}$.

It is possible now to compute also the average number of inelastic interactions ($\mu_{inel.}$) as:

$$\mu_{inel.} = \frac{\sigma_{inel.} \cdot \mathcal{L}}{R_{inel.}} \tag{6}$$

For RunII its value is about $\mu_{inel.} = 2.5$ at $\mathcal{L} = 10^{32}$ and $\mu_{inel.} = 1.9$ at $\mathcal{L} = 0.7 \cdot 10^{32} cm^{-2}s^{-1}$.