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CDF Triggers for Run IIb

Fermilab will remain at the energy frontier through run IIb of the Tevatron Collider. This provides an opportunity for CDF to explore high mass phenomena with unprecedented sensitivity. But to reach this goal the accelerator must deliver very large instantaneous luminosity. For CDF to collect close to 10 fb^{-1} during run II, the Tevatron will have to run either at $2 \times 10^{32}\ cm^{-2} - sec^{-1}$ with luminosity leveling or start each store at $4 \times 10^{32}\ cm^{-2} - sec^{-1}$ with the usual exponential decay. Since we have to extrapolate current conditions up by an order of magnitude in instantaneous luminosity, and there will be a new silicon tracker, contingency must be built into our assessment of run IIb conditions. Our experience with run IIa, in which the drift chamber occupancy is a factor of two larger than predicted, shows that such contingency is extremely important. If there is luminosity leveling, we should have a factor of two margin in our planned capability. Without luminosity leveling, the contingency becomes inefficiency at the beginning of each store. In either case, the goal is a system that is designed to reach a peak instantaneous luminosity of $4 \times 10^{32}\ cm^{-2} - sec^{-1}$, which corresponds to 10 interactions per crossing for a 396 nsec accelerator bunch separation. This is the assumption made in the remainder of this document.

We have been asked to use the search for the Higgs boson as the benchmark for assessing needed detector upgrades. But it must be remembered that the discovery of the Higgs is by no means assured. It is imperative that CDF carry out a broad program of high-P_T physics, including detailed study of the properties of the top quark and searches for other possible new phenomena such as supersymmetry, technicolor, large extra dimensions, high mass gauge bosons, compositeness, and additional fermion generations. Following the discussion of the Higgs search, we consider additional triggers that will address the other physics goals of run IIb.

1 Higgs Boson

The search for a low mass Higgs Boson ($M_H < 135\ GeV$) focuses on associated production of the Higgs with a W or Z. The dominant decay mode of the Higgs in this mass region is expected to be $b\bar{b}$, with $\tau\tau$ possible at large $tan\beta$. The trigger requirements depend on how the W or Z decays. If it decays to $q\bar{q}$, resulting in a 4-jet final state, two of which are b jets, the background is severe. Techniques have been developed to extract the signal, but the contribution to the overall Higgs sensitivity is not large. Consequently in this document we ignore that channel.

1.1 Decay of the W or Z into e or μ; all Higgs decay modes

This channel provides approximately two-thirds of the Higgs sensitivity. The trigger selects a high P_T electron or muon, with thresholds set by the W and Z decay spectra. The table below gives the trigger cross sections at level 1, level 2, and level 3, extrapolated to $4 \times 10^{32}\ cm^{-2} - sec^{-1}$ using our best estimate of the effect of multiple interactions. We have used both run I and run IIa data, as shown in figures 1 and 2. In the case of the level-3 electron trigger, we will apply cuts that are close to those used in the offline analysis in order to reduce the trigger rate by an additional factor of two beyond those used at present (figure 1). A prescaled trigger with looser criteria can be used to study backgrounds. The muon level-2 and level-3 rates are more uncertain because the run IIa level-2 muon trigger is not yet operational (at present we use levels 1 and 3 only), and there is not yet sufficient data taken with the CMX detector.

Trigger	σ_{L1} (nb)	σ_{L2} (nb)	σ_{L3} (nb)
High E_T central electron	1,500	170	30
Plug electron + $\not{E}_t$	771	55	10
High P_T muon (CMUP)	1,773	200	8
High P_T muon (CMX)	1,773	200	8
Total	5,817	625	56
Total rates at 4×10^{32}	2,327 Hz	250 Hz	22 Hz

1.2 Decay of the Z into $\nu\bar{\nu}$ and H into $b\bar{b}$ or $\tau\bar{\tau}$

This channel provides approximately one-third of the Higgs sensitivity. We employ two triggers: large $\not{E}_t$ plus two jets (for both $b\bar{b}$ and $\tau\bar{\tau}$), and two identified b-jets (to cover intermediate $\not{E}_t$ for $H \to b\bar{b}$). The former has a $\not{E}_t$ threshold of 35 GeV, which is high since it is at the peak of the ZH $\not{E}_t$ spectrum. Since the level-2 trigger rate increases rapidly at high luminosity as this threshold is reduced, we cover the lower $\not{E}_t$ region instead with the high-P_T b-jet trigger.

It is important to note that these triggers serve other important purposes as well: the $\not{E}_t$ + 2 jet trigger is a prime trigger for SUSY and large extra dimensions; the two b-jet trigger is a critical calibration trigger for determining the b-jet energy scale and resolution through $Z \to b\bar{b}$. The level-1 cross section for the two b-jet trigger is shown in figure 3. The large reduction in the cross section between levels 2 and 3 comes from our ability to do offline-quality secondary vertex finding in level 3. The two b-jet trigger is also an important cross-check trigger for the Higgs search. Since it triggers on $H \to b\bar{b}$, it covers all of the W and Z decay modes. Since it also triggers on $Z \to b\bar{b}$, for that channel it covers all of the Higgs decay modes.

Trigger	σ_{L1} (nb)	σ_{L2} (nb)	σ_{L3} (nb)
2 High P_T b-jets	10,840	200	10
$\not{E}_t$ + 2 jets	163	126	13
Total	11,003	326	23
Total rates at 4×10^{32}	4,401 Hz	130 Hz	9 Hz

1.3 Calibration and Cross-check Triggers

In order to understand the efficiency and background rates for the Higgs search, it is critical to measure the energy scales, resolutions, and backgrounds for b-jets, electrons, muons, and $\not\!\!E_t$. This requires a number of calibration data sets taken at a variety of instantaneous luminosities. These triggers have thresholds and prescales adjusted to limit the trigger rates.

Trigger	σ_{L1} (nb)	σ_{L2} (nb)	σ_{L3} (nb)
$Z \to bb$	included in section 1.2 above		
Jets	6,500	42	12
$\not\!\!E_t$	(overlap)	163	3
Photons	(overlap)	50	15
$J/\psi \to \mu\mu$	850	38	10
Total	7,350	293	40
Total rates at 4×10^{32}	2,940 Hz	117 Hz	16 Hz

1.4 Total Higgs Search Trigger Rates

Trigger	Rates at 4×10^{32}		
	L1	L2	L3
e/μ	2,327 Hz	250 Hz	22 Hz
ν	4,401 Hz	130 Hz	9 Hz
calibration	2,940 Hz	117 Hz	16 Hz
Total	9,668 Hz	497 Hz	47 Hz

1.5 High Mass Higgs Search

For Higgs mass above 135 GeV, the WW and ZZ decay modes start to dominate. The trigger then depends on the decay modes of the daughter vector bosons. If both decay hadronically, the backgrounds are huge and there won't be much contribution to the Higgs sensitivity. When a W or Z decays into an electron or muon final state, the single lepton trigger mentioned above is appropriate. If a Z decays into $\nu\bar{\nu}$, the $\not\!\!E_t$ plus jets trigger discussed above works well. If a W or Z decays into tau leptons, the tau triggers listed in the next section are used.

2 Other High-P_T Searches

The following triggers are needed to carry out the broad physics program at the energy frontier that was mentioned at the beginning of this note. Thresholds have been set based on studies of the top quark, SUSY, and other exotic searches.

Trigger	σ_{L1} (nb)	σ_{L2} (nb)	σ_{L3} (nb)
High-P_T jets	19,000	60	17
$t\bar{t}$	(overlap)	50	5
$\tau\bar{\tau}$	5,000	50	4
$\not{E}_t + \tau$	(overlap)	50	4
High-E_T photons	13,500	110	21
di-leptons, tri-leptons	1,000	190	45
Total	38,500	660	96
Total rates at 4×10^{32}	15,400 Hz	264 Hz	38 Hz

3 Total Trigger Rates

The total trigger rates at a luminosity of 4×10^{32} are approximately 25 KHz at level 1, which is within our current capability, 750 Hz at level 2, which can be handled with our planned run IIb upgrade, and 85 Hz at level 3, which is at the limit of our current capability.

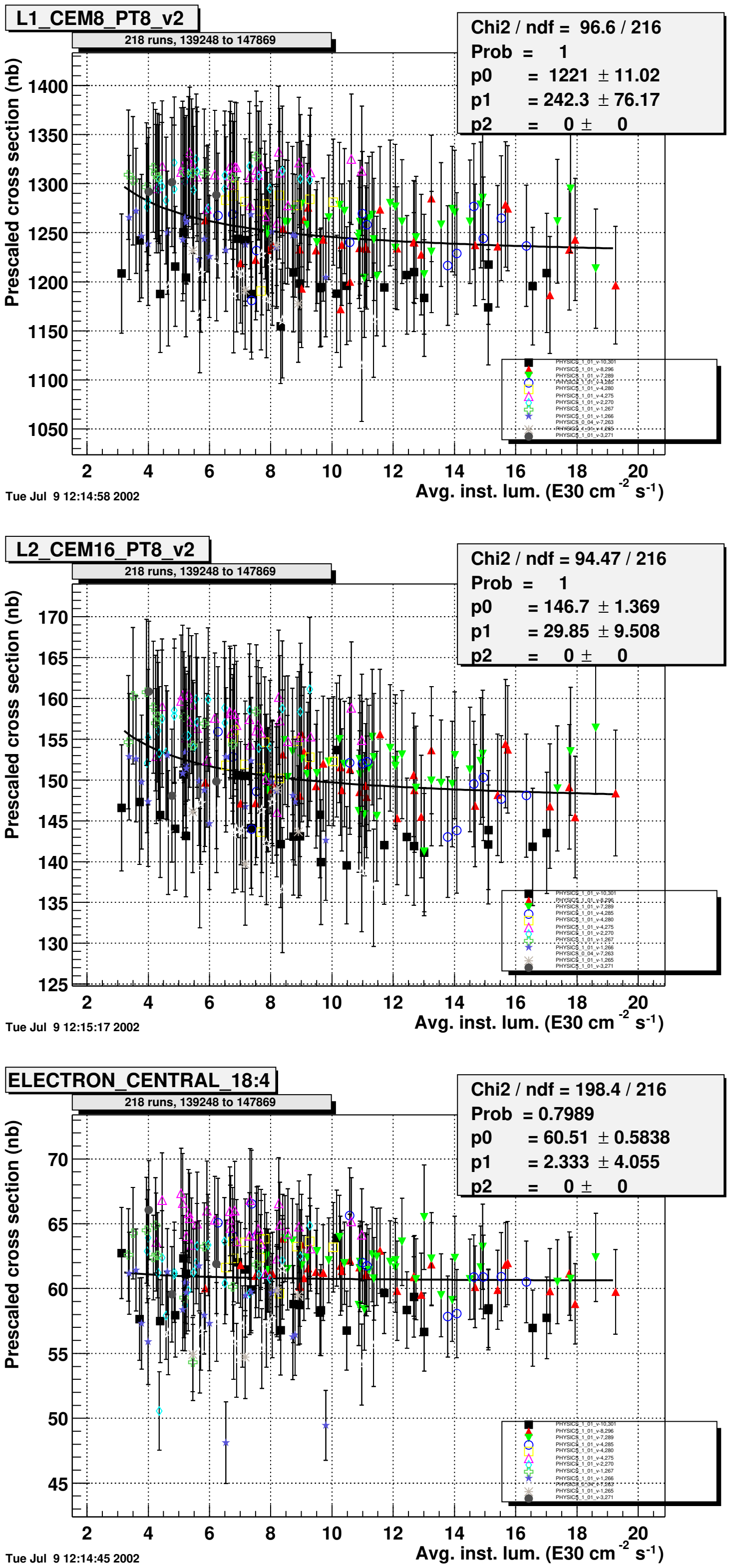

Figure 1: Level-1, 2, and 3 cross sections (nb) for inclusive electron triggers as a function of instantaneous luminosity (10^{30} cm^{-2} s^{-1}).

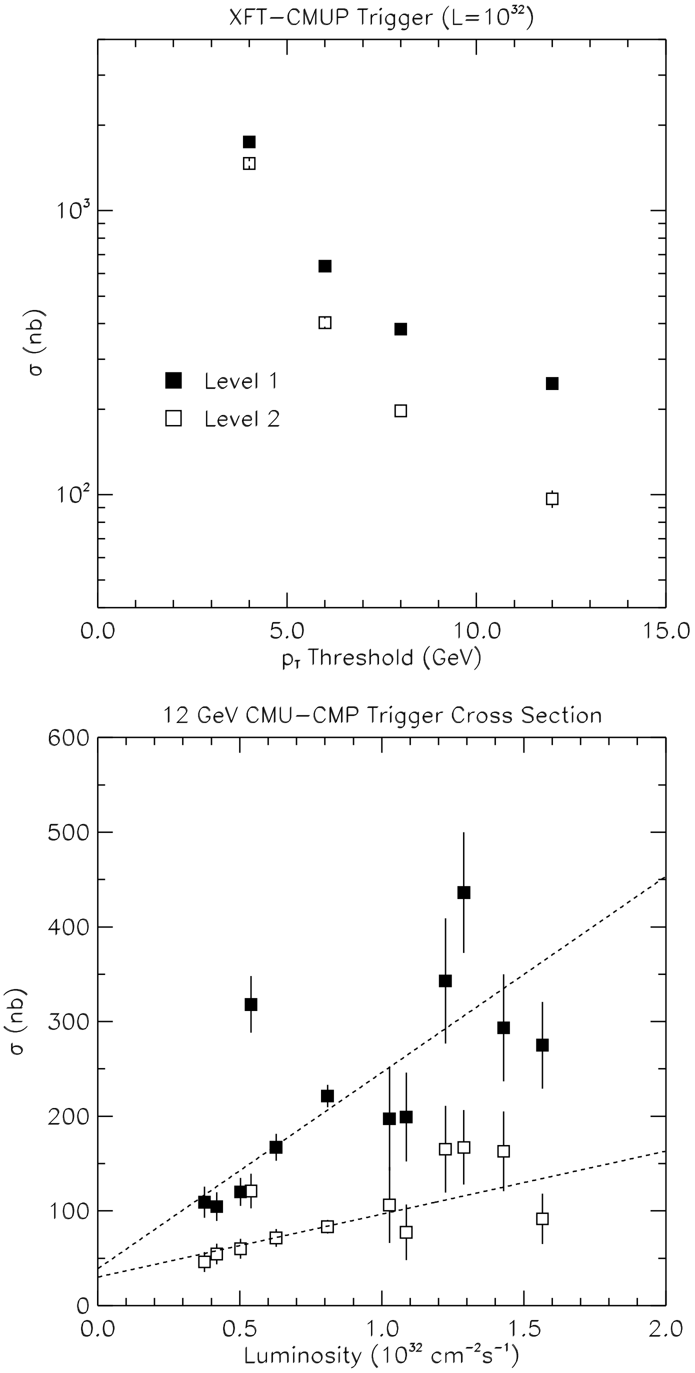

Figure 2: Level-1 and Level-2 cross sections (nb) as a function of track P_T (GeV) (top) and instantaneous luminosity with $P_T > 12$ GeV. The studies were done with Run I data.

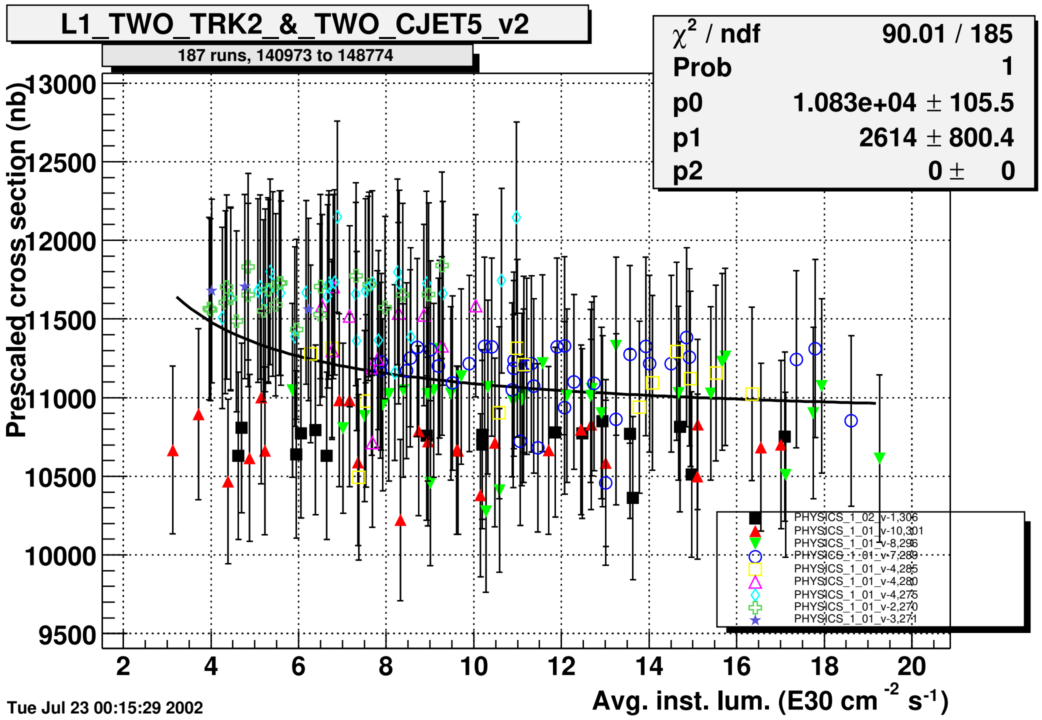

Figure 3: Level-1 cross section (nb) for the two b-jet trigger as a function of instantaneous luminosity (10^{30} cm^{-2} s^{-1}).