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# Study of the Trigger Rates and Signal Efficiencies for updated SUSY dilepton trigger paths

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**Abstract**

We present an reviewed proposal for the SUSY dilepton trigger paths, estimate their cross sections at L2 and L3 and evaluate the acceptances for several representative SUSY signals.

# 1 Introduction

We propose to re-implement the SUSY dilepton trigger paths. This set of triggers is crucial for a wide variety of exotic physics searches. It is the workhorse trigger for the Tevatron's "golden" SUSY mode (trileptons, $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$) and many other SUSY searches such as $\tilde{g}\tilde{q}$ and the light top squark. We have three general trigger sets:

1. a high-momentum inclusive trigger with $p_T(E_T) \geq 12$ GeV for muons (electron.) Specifically, we propose CEM_12, CMUP_12, CMX_12. (We refer to this trigger simply as "12" in this note.)

2. a medium-momentum lepton+track trigger with $p_T(E_T) \geq 8$ GeV for the muon (electron) and $p_T > 8$ GeV for the track. An exhaustive list would be CEM8_TRK8, CMU8_TRK8, CMX8_TRK8; we would like to include in addition BMU?_TRK8 and PEM8_TRK8 but have not determined the appropriate thresholds yet or if the appropriate L1 triggers are feasible. (We refer to this trigger as "8" in this note.)

3. a low-momentum dilepton trigger with $p_T(E_T) \geq 4$ GeV for the muon (electron), where we designate a *primary* lepton (CEM, CMUP, CMX) and a *secondary* lepton (same plus PEM, CMU and BMU). A full list of triggers is CEM4_CEM4, CEM4_CMU4, CEM4_CMX4, CEM4_PEM8, CMUP4_PEM8, CMX4_PEM8, CMUP4_CMX4, CMUP4_CMU4. (We refer to this trigger as "4" in this note.)

The inclusive trigger is conceptually simple and sensitive to many SUSY scenarios where large mass differences among the gauginos results in relatively stiff leptons. The lepton plus track trigger path allows the selection of CMIO muons for the second lepton as well as trilepton selections where the second and third lepton are only identified as isolated tracks and the first lepton is somewhat softer. The low-momentum dilepton trigger is sensitive to those SUSY scenarios where either cascade decays, small gaugino mass differences, or the $R$-parity violation result in many low-momentum leptons.

In the list above, the leptons can be either CMU(P) or CMX muons, CEM primary and additionally PEM secondary leptons. The track is just an XFT track at L2 above the designated momentum. The triggers are very similar to what is currently implemented; one major change is that we now plan to have the L3 triggers implement the same requirements as the L2 triggers. [1]

In this note, we estimate the cross sections at L2 and L3 for these revised SUSY dilepton paths. We use an unbiased selection of events passing L2 and L3, the `L2DecisionMaker` package to emulate L2 trigger decisions, and an emulation of the L3 executable for L3. In Sec. 2 we discuss the estimated trigger cross sections while Sec. 3 shows an estimate of how much acceptance we gain from each path and makes a recommendation about which paths to drop for an eventual high-luminosity trigger table.

We will need to think some more whether there are any additional backup triggers that are needed but this will depend obviously on the exact implementation we decide on.

Finally, as an aside, the high-momentum inclusive trigger mentioned above obviously has a large overlap with the inclusive lepton trigger used by the EWK and top groups (CEM16, CMUP16, CMX16.) In discussing the trigger cross sections and signal efficiencies, we will highlight what happens if we replace the inclusive 12 GeV trigger mentioned above with the equivalent higher-momentum trigger from the EWK/top groups.

# 2 Trigger Cross sections

In this Section we list the expected trigger cross sections at L2 and L3 for the proposed paths. The trigger cross sections as a function of instantaneous luminosity for the input trigger paths can be seen in Appendix A.

[1] Currently, the L3 triggers always request some combination of 4 GeV lepton objects regardless of the requirements at L2.

| Trigger | L2 incl. (nb) | L2 exclu. (nb) |
|---|---|---|
| CMUP4+$\ell$ | $69.8 \pm 2.6$ | $50.1 \pm 2.2$ |
| CMUP4_CMU4 | $41.6 \pm 2.0$ | |
| CMUP4_CMX4 | $1.3 \pm 0.4$ | |
| CMUP4_PEM8 | $11.8 \pm 1.1$ | |
| CMUP4_CEM4 | $19.5 \pm 1.4$ | |
| CMUP8_TRK8 | $38.8 \pm 2.0$ | $11.1 \pm 1.1$ |
| CMUP12 | $81.4 \pm 2.8$ | $52.0 \pm 2.3$ |
| CMUP8 | $194.9 \pm 4.2$ | |
| CMUP16 | $37.9 \pm 1.9$ | |
| baseline | $146.1 \pm 3.7$ | |
| $12 \rightarrow 16$ | $116.3 \pm 3.3$ | |

Table 1: Inclusive Level 2 trigger cross sections for the CMUP SUSY_DILEPTON trigger paths. CMUP4+$\ell$ is the sum of the following four triggers. The CMUP8 L2 trigger is shown as a cross-check; it feeds the CMUP16 trigger at L3 in the current physics trigger table (PHYSICS_2_05-v9). The exclusive cross sections do not include the triggers where no entry is included.

## 2.1 CMUP

We consider the following CMUP-based paths here. They are:

1. CMUP4_CMU4 - a 4 GeV CMUP muon and a 4 GeV CMU muon;
2. CMUP4_CMX4 - a 4 GeV CMUP and 4 GeV CMX muon;
3. CMUP4_PEM8 - a 4 GeV CMUP and 8 GeV PEM cluster;
4. CMUP4_CEM4 - a 4 GeV CMUP and 4 GeV CEM electron with RECES;
5. CMUP8_TRK8 - one 8 GeV CMUP muon and a second track with $p_T > 8$ GeV;
6. CMUP12 - at least one muon with $p_T > 12$ GeV.
7. CMUP16 - at least one muon with $p_T > 16$ GeV.

We also list the CMUP8 L2 trigger, which feeds the inclusive CMUP16 trigger at L3, as a cross-check. The number we derive for this trigger agrees well with the directly measured numbers. The corresponding L2 and L3 cross sections are shown in Table 1. We use the "Muon" and "Dimuon" classes for the L2 decision for the primary leptons, the "XFTTrack" with $n_{\text{track}} \geq 2$, for the track requirement. For the electrons, we use the "RecesElectron" class for CEM4 and the "PhotonReces" class for PEM8.

We use the MUON_PS1000_L1_CMUP6_PT4 path as our source for unbiased L2/L3 CMUP4 muons. We use a sample of 10,000 events.

For the exclusive L2 trigger cross sections, we consider the case where the CMUP8 trigger, which feeds the high $p_T$ inclusive CMUP16 trigger paths, is present in its current form and absent.

If it is present:

- the exclusive cross section for the CMUP12 and CMUP8_TRK8 triggers is zero (trivially);
- the exclusive cross section for the CMUP4_CMU4 trigger is $25.8 \pm 1.6$ nb;
- the exclusive cross section for the CMUP8 trigger is $96.2 \pm 3.1$ nb.

If we assume the 8 GeV inclusive CMUP trigger disappears and look exclusively at the SUSY dilepton triggers:

| Trigger | L2 incl. (nb) | L2 excl (nb) |
|---|---|---|
| CMX8_TRK8 | $41.5 \pm 4.3$ | $12.2 \pm 2.5$ |
| CMX12 | $101.8 \pm 5.5$ | $71.9 \pm 5.2$ |
| CMX10 | $157.1 \pm 5.0$ | |
| CMX16 | $62.0 \pm 5.0$ | |
| baseline | $115.6 \pm 5.5$ | |
| $12 \to 16$ | $82.4 \pm 5.4$ | |

Table 2: Inclusive and exclusive Level 2 trigger cross sections for the CMX SUSY_DILEPTON trigger paths. CMX10 is listed as a cross-check for our ability to reproduce the L2 processor decisions off-line. It currently feeds the high-momentum CMX trigger. CMX16 is a possible replacement for it where we cut at 16 GeV in L2.

- the exclusive L2 trigger cross sections for the CMUP12, CMUP8_TRK8 and CMUP4_CMU4 triggers are $54.0 \pm 2.3$ nb, $11.8 \pm 1.1$ nb and $28.4 \pm 1.7$ nb, respectively.
- in other words, the overlap are
  - 4 and 8 GeV triggers: overlap is $14.5 \pm 1.2$ nb;
  - 8 and 12 GeV triggers: overlap is $24.2 \pm 1.6$ nb.
  - 4 and 12 GeV triggers: overlap is $16.2 \pm 1.3$ nb.

and the total trigger cross section for the CMUP section of the proposal is $146.1 \pm 3.7$ nb.

## 2.2 CMX

We consider the two primary CMX-based paths here. They are:

1. CMX8_TRK8 - one 8 GeV CMX muon and a second track with $p_T > 8$ GeV;
2. CMX12 - at least one 12 GeV muon in the CMX.

We have not yet included the CMX_CMX or CMX_PEM triggers in our emulation tools. As a cross-check, we calculate the cross-section for L2_CMX6_PT10, which feeds the CMX16 trigger @ L3. For this trigger, our calculated cross section agrees well with the directly measured cross-section.

For the CMX triggers, we use the MONITOR_PS200_L3TAG data set to get an unbiased set of L2 triggers. From the monitor data set, we select the L1_CMX6_PT8_CSX triggers.

The L2 and L3 cross sections are shown in Table 1. As with CMUP, we use the "Muon" class for the L2 decision for the primary leptons and the "XFTTrack" with $n_{\text{track}} \geq 2$ for the track requirement. The CMX10 path is a 10 GeV muon at L2 (L2_CMX6_PT10), and it is somewhat surprising that the trigger rate drop so quickly between 10-12 GeV. Fig. 1 shows that the $p_T$ spectrum drops very sharply for those events passing this path at L2, explaining the apparent decrease in the trigger cross section. However, the shape of the $p_T$ spectrum is somewhat worrisome. It has been suggested that this effect could be due to a combination of limited statistics and fakes [1].

The exclusive CMX L2 trigger cross sections are $71.9 \pm 5.2$ nb for CMX12 and $12.2 \pm 2.5$ for the CMX8_TRK8 triggers, respectively, ignoring the CMX6_PT10 trigger that feeds the high pt single inclusive CMX paths. The total cross section of the CMX-paths (8||12) is $115.6 \pm 5.5$ nb. If we replace the 12 GeV path with a 16 GeV path in L2, the trigger cross section at L2 drops to $82.4 \pm 5.4$ nb.

## 2.3 Central Electron

We consider the following CEM-based paths here.

- CEM4-based paths:

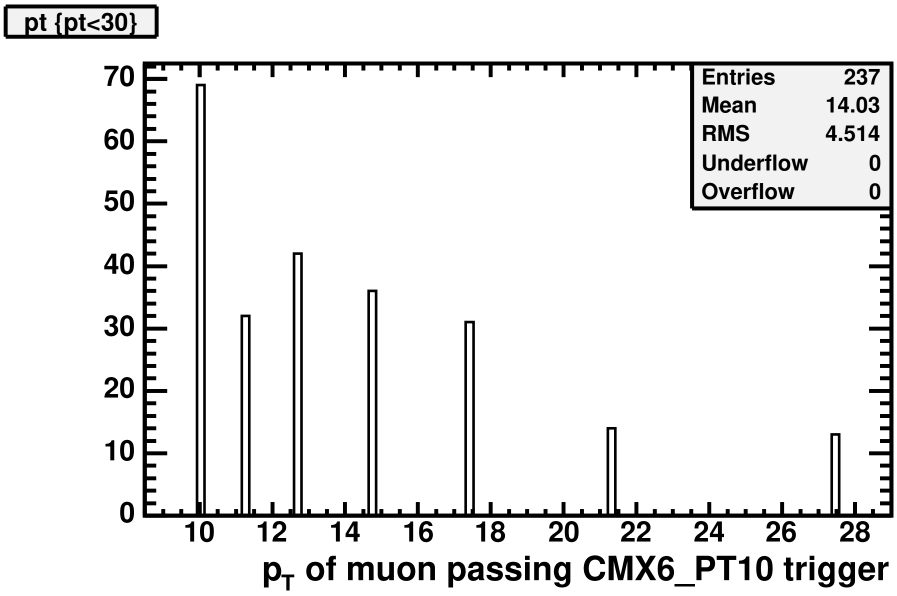


Figure 1: $p_T$ spectrum of those CMX muons in the monitoring sample that have $p_T > 10$ GeV. It has been suggested that this effect could be due to a combination of limited statistics and fakes [1].

  - CEM4_CEM4 - two 4 GeV CEM electrons
  - CEM4_PEM8 - one 4 GeV CEM electron and one 8 GeV PEM electron
  - CEM4_CMU4 - one 4 GeV CEM electron and one 4 GeV CMU muon
  - CEM4_CMX4 - one 4 GeV CEM electron and one 4 GeV CMX muon

- CEM8_TRK8 - one 8 GeV CEM electron and a second track with $p_T > 8$. Due to the large cross section here, we also consider the adding the following cuts to reduce the contribution from XFT "split tracks":
  - $\Delta\phi \geq 2^o$
  - $\Delta\phi \geq 10^o$
- CEM12 paths. We consider several options as this path has a rather large cross-section:
  - CEM12 - at least one 12 GeV electron
  - CEM12_RECES - at least one 12 GeV electron, with a CES requirement in L2. Here We use the "RecesElectron" L2 trigger with high threshold, $E_T > 3$ GeV. This is our baseline option for this trigger.
  - CEM12_ISO3 - at least one 12 GeV electron and $< 3$ GeV or $< 15\%$ iso energy

For the CEM4 and CEM8 triggers we use the L2 algorithm "RecesElectron". For the PEM8 trigger, we use the L2 algorithm "PhotonReces." For CEM12 and CEM16 we use "InclusiveElectron" except as noted. The corresponding L2 and L3 cross cross sections for these triggers are shown in Table 3. For comparison, we also show CEM16, which feeds the EWK/top inclusive high momentum lepton triggers at L3.

For the CEM triggers, we use the ELECTRON_CENTRAL_PS5K_L1_CEM4_PT4 path. It has no requirements at L2 or L3 but is prescaled by a factor of 12,500. The unprescaled cross section is about 20 $\mu$b.

The Level 2 cross secrtions are shown in Table 3. We conclude:

- the cross section for our proposed set of triggers is 450 nb ("baseline");

| Trigger | incl. (nb) | excl. (nb) |
|---|---|---|
| CEM4+$\ell$ | $220 \pm 10$ | $180 \pm 11$ |
| CEM4_CEM4 | $96 \pm 6$ | $71 \pm 2$ |
| CEM4_CMUP4 | $22 \pm 3$ | $20 \pm 1$ |
| CEM4_CMU4 | $92 \pm 6$ | N/A |
| CEM4_PEM8 | $89 \pm 6$ | $77 \pm 3$ |
| CEM4_CMX4 | $14 \pm 2$ | $12 \pm 1$ |
| CEM8_TRK8 | | |
| baseline | $152 \pm 8$ | $69 \pm 2$ |
| +linkerchip | $128 \pm 8$ | N/A |
| CEM12 | | |
| baseline | $190 \pm 9$ | $101 \pm 4$ |
| -RECES | $254 \pm 10$ | N/A |
| +ISO3 | $70 \pm 5$ | N/A |

| Trigger | Level 2 (nb) |
|---|---|
| Total | |
| baseline | 450 |
| drop RECES | 510 |
| drop CMP | 500 |
| drop RECES, drop CMP | 560 |
| $12 \rightarrow 16$ | 390 |
| drop RECES, $12 \rightarrow 16$ | 425 |
| drop TRK8 | 380 |
| drop TRK8, $12 \rightarrow 16$ | 330 |
| Crosscheck: CEM16 | |
| baseline | $90 \pm 10$ |
| drop RECES | $144 \pm 10$ |

Table 3: Inclusive and exclusive Level 2 trigger cross sections for the CEM SUSY_DILEPTON trigger paths, including our baseline proposal and various alternatives. The exclusive cross sections are only given for our "baseline" proposal.

- requiring RECES reduces the rate by about 60 nb. Reequiring CMUP instead of CMU reduces the rate by another 50 nb. This is the scenario implemented in (PHYSICS_2_05_v9).
- raising the CEM threshold from 12 to 16 GeV would reduces the rate by another 60 nb;
- vetoing tracks which are in adjacent linker chips in teh CEM8_TRK8 trigger reduces the cross section by 20 nb.
- dropping the CEM8_TRK8 trigger would reduces the rate by another 60 nb.

The cross section for those triggers in the currently implemented table (PHYSICS_2_05_v11) is 480 nb.

# 3 Signal Efficiencies

The interest for triggering on low $p_T$ leptons arises mostly from SUSY. We evaluate the efficiencies of the triggers on three signal samples:

- $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ production: this is the classic "trilepton analysis" which probes SUSY beyond the LEP2 results. Depending on the mass difference between the $\tilde{\chi}_1^\pm$ (or $\tilde{\chi}_2^0$) and the $\tilde{\chi}_1^0$ the lepton $p_T$ spectra change. Also, at high $\tan\beta$ the final states with $\tau$-leptons are most significant because the $\tilde{\tau}_L$ has then a relatively low mass. We thus also investigate a point at $\tan\beta = 30$. In this scenario the lepton+track and single lepton triggers are expected to play a bigger role since they are more sensitive to hadronic $\tau$-decays. There are also dedicated lepton+track and $\tau$ triggers for the $\tau$ physics programme [4].
- $\tilde{q}\tilde{g}$: the squarks and gluinos may undergo a cascade decay resulting in like-sign low $p_T$ leptons in the final state.
- $\tilde{t}_1\bar{\tilde{t}}_1$ production followed by $\tilde{t}_1 \rightarrow \ell b \tilde{\nu}$ decay is another very interesting signal that relies on these triggers.

All these are well motivated by theoretical SUSY models and in fact amongst the most promising discovery channels at the Tevatron. The trilepton analysis is sensitive to the parameter space which is most consistent with the Dark Matter density observed by WMAP [5]. Squarks and gluino decays into leptons are also uniquely sensitive to an interesting part of the MSSM parameter space. Stop quarks are thought to be the lightest amongst all squarks due to the large top mass. In particular a consistency of the world's data with baryogenesis can only be achieved in mSUGRA if the stop quark is light.

Instead of running the full trigger simulation we have emulated the trigger by looking at the offline quantities and cutting similar to the Level 3 trigger. We consider the following objects to fire the triggers:

- electrons:
  - CEM4: a central electron with $E_T > 6$ GeV and $p_T > 4$ GeV
  - CEM8: a central electron with $E_T > 12$ GeV and $p_T > 8$ GeV
  - CEM12: a central electron with $E_T > 16$ GeV and $p_T > 8$ GeV
  - CEM16: a central electron with $E_T > 20$ GeV and $p_T > 10$ GeV
  - PEM8: a plug electron with $E_T > 12$ GeV ($\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ only)
- CMUP and CMX muons:
  - CMUP(X)4: a muon with a CMUP(X) stub in the same wedge with $p_T > 4$ GeV
  - CMUP(X)8: a muon with a CMUP(X) stub in the same wedge with $p_T > 8$ GeV
  - CMUP(X)12: a muon with a CMUP(X) stub in the same wedge with $p_T > 12$ GeV
  - CMUP(X)16: a muon with a CMUP(X) stub in the same wedge with $p_T > 18$ GeV
- tracks
  - TRK8: a track with COT hits in all four axial superlayers and $p_T > 8$ GeV

The electron $E_T$ thresholds are chosen such to roughly reflect the trigger turn-on. We have also evaluated the efficiency when asking for (CMU || CMP) instead of CMUP.

#### 3.0.1 Notation

We use a shorthand when referring to the triggers: "4" corresponds to a trigger requiring two leptons with $p_T, E_T > 4$ GeV. "8" corresponds to a trigger requiring a lepton with $p_T, E_T > 8$ GeV and an additional TRK8 object as defined above. "12" ("16") correspond to inclusive triggers for single leptons with a threshold of 12 (16) GeV.

### 3.1 Trilepton analysis ($\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$)

The acceptances due to the different trigger options are shown in Table 4 for four points in SUSY parameter space:

- $m_0 = 100$, $m_{1/2} = 180$, $\tan\beta = 5$: the corresponding mass of the charginos and neutralinos are: $m(\chi_1^{\pm}) = 116$ GeV, $m(\chi_2^0) = 117$ GeV and $m(\chi_1^0) = 63$ GeV;
- $m_0 = 74$, $m_{1/2} = 168$, $\tan\beta = 5$: the corresponding mass of the charginos and neutralinos are: $m(\chi_1^{\pm}) = 107$ GeV, $m(\chi_2^0) = 109$ GeV and $m(\chi_1^0) = 58$ GeV;
- $m_0 = 175$, $m_{1/2} = 230$, $\tan\beta = 5$: the corresponding mass of the charginos and neutralinos are: $m(\chi_1^{\pm}) = 160$ GeV, $m(\chi_2^0) = 161$ GeV and $m(\chi_1^0) = 86$ GeV;

| lepton | $m_0$ | $m_{1/2}$ | $\tan\beta$ | 4\|\|8\|\|12 | 4\|\|12 | 8\|\|12 | 4\|\|8 | 4\|\|8\|\|16 | 4\|\|16 | 8\|\|\|16 | 16 | 2_05_v11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $e,\mu$ | 100 | 180 | 5 | 76.0 | −1.1 | −4.9 | −9.6 | −2.8 | −7.8 | −9.4 | −18.2 | −8.3 |
| | 74 | 168 | 3 | 67.5 | −0.7 | −5.0 | −12.7 | −2.0 | −5.6 | −8.7 | −14.8 | −10.4 |
| | 175 | 230 | 5 | 78.0 | −1.6 | −5.2 | −8.1 | −0.6 | −4.2 | −6.5 | −12.0 | −8.1 |
| | 120 | 160 | 30 | 45.3 | −0.7 | −7.4 | −10.0 | −4.9 | −9.4 | −15.2 | −26.5 | −5.7 |
| $e,\mu,\tau$ | 100 | 180 | 5 | 62.7 | −1.1 | −4.4 | −11.2 | −2.9 | −8.2 | −8.6 | −16.8 | −9.7 |
| | 74 | 168 | 3 | 63.6 | −0.7 | −4.9 | −14.1 | −2.2 | −5.6 | −8.6 | −14.1 | −11.4 |
| | 175 | 230 | 5 | 60.1 | −1.3 | −4.0 | −9.4 | −1.7 | −6.9 | −6.5 | −13.0 | −8.5 |
| | 120 | 160 | 30 | 14.3 | −0.6 | −1.5 | −5.6 | −2.8 | −5.5 | −4.7 | −8.1 | −3.8 |

Table 4: Trigger efficiencies for the trilepton signal for different choices of SUSY parameters and different trigger options. See the text for a full description and Sec. 3.0.1 for a description of the notation we use. The first (4||8||12) gives our "baseline" trigger efficiency. All the other ones are relative to that, i.e. the trigger efficiency for the other trigger scenarios is lower by the amount shown (in absolute value). We consider the case where there are only electrons and muons in the final state $(e, \mu)$ which can either be produced directly or result from the $\tau$-decay. We consider also the case where in addition the hadronic $\tau$-decays are included in the denominator $(e, \mu, \tau)$. The number of denominator events is about 2200, 4200, 300 and 800 for the four cases from top to bottom for the first four rows. For the 2nd four rows it is 3900, 5500, 700 and 70,000.

- $m_0 = 120$, $m_{1/2} = 160$, $\tan\beta = 30$: the corresponding mass of the charginos and neutralinos are: $m(\chi_1^\pm) = 101$ GeV, $m(\chi_2^0) = 103$ GeV and $m(\chi_1^0) = 55$ GeV. In this scenario 94.5% of the events contain three $\tau$-leptons in the final state.

In all cases we chose $A_0 = 0$ and $\mu > 0$. Note that the fourth point ($m_{1/2} = 160$ GeV) is just excluded by the LEPII chargino searches but the other three probe virgin parameter space. For the denominator we require at least three leptons at generator level with $p_T > 3.5$ and $|\eta| < 2.5$. The results are presented separately for only electrons and muons (either from prompt production of $\tau$-decays) and for the case where hadronic $\tau$'s are included. For the high $\tan\beta$ scenario we also include the case where all three leptons are $\tau$-leptons. The entries to the left of the double line are for our default scenario, while those to the right consider the case where we drop the 12 GeV inclusive trigger and replace it with the high-$p_T$ inclusive trigger used by the EWK and top groups.

At low $\tan\beta$ we find :

- when including all the triggers, the total efficiency is between 70% and 79% for these three points in SUSY parameter space ("4||8||12") for $l = e, \mu, \tau$ at low $\tan\beta$. At high $\tan\beta$ it is about 15%;
- dropping the 12 GeV triggers in favor of the 16 GeV triggers ("4||8||16") reduces the efficiencies by about 3% at low and 6% at high $\tan\beta$;
- dropping the 8 GeV triggers but keeping the 12 GeV trigger ("4||12") reduces the efficiencies by about 1%. Note that 1% absolute change for the $e, \mu, \tau$ case at high $\tan\beta$ means 7% relative change;
- all the other scenarios we evaluated result in a significant efficiency loss of about 5-14% absolute or 10-30% relative.
- currently the 4 GeV trigger uses CMU4 rather than CMUP4 as assumed for this study. Using CMU4 increases the total efficiency by 2% and that of the 4 GeV triggers alone by 6%.
- the efficiencies of the currently (PHYSICS_2_05_v11) and previously (PHYSICS_2_05_v9) implemented trigger setups are also given. The efficiency of the current implementation is up to 10% worse and the previously implemented one is about 3% worse.

Similar conclusions hold even if we exclude hadronic $\tau$-decays but since the total efficiency is higher the relative drop in efficiency is a bit smaller. For the high $\tan\beta$ scenario the efficiency is significantly

| Scenario | $m_{\tilde{g}}$ | $m_{\tilde{q}}$ | $m_{\tilde{\chi}_1^0}$ | $m_{\tilde{\chi}_1^\pm}$ |
|---|---|---|---|---|
| A | 260 | 300 | 36 | 80 |
| B | 177 | 410 | 24 | 54 |
| C | 217 | 470 | 30 | 65 |

Table 5: Mass parameters for three $\tilde{g}\tilde{q}$ scenarios.

lower and the relative changes in trigger efficiency are thus more pronounced. E.g. dropping the 16 GeV triggers reduced the efficiency from 15.1% to 12.3 %, i.e. results in a 20% reduction of the efficiency. We have also studied samples generated by John Zhou which have $\tan\beta = 3$ and are preselected to contain three central leptons. They cover the entire parameter space in which we have sensitivity in the mSUGRA model. The efficiency of all triggers for these samples is presented in Figure 2 as function on $m_0$ and $m_{1/2}$.

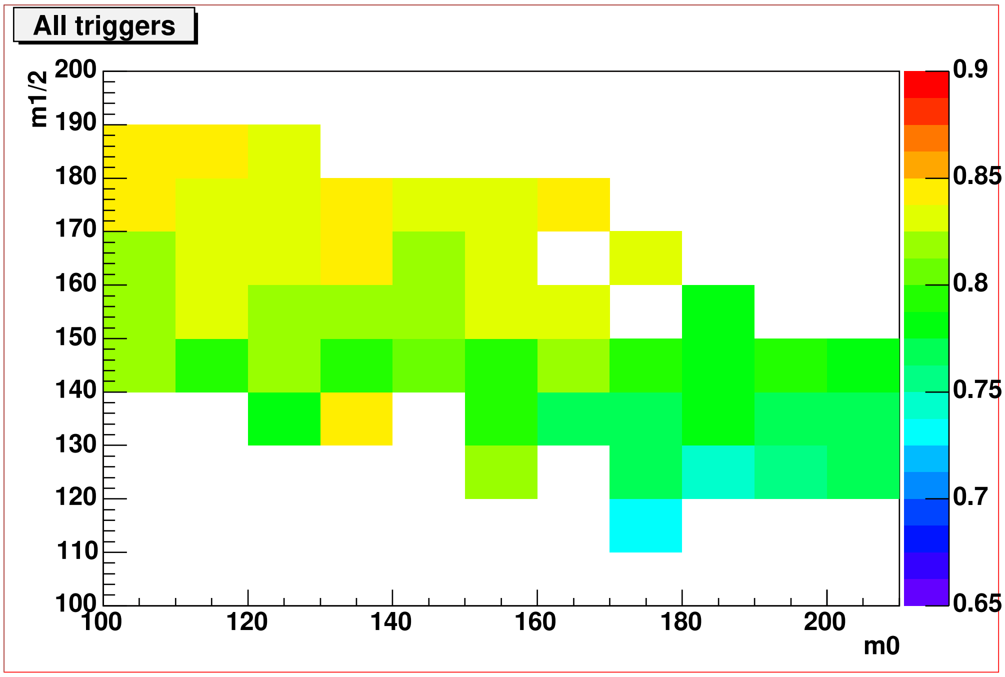


Figure 2: Absolute efficiency of triggering events with three central leptons ($\eta < 1.4$) as function of $m_0$ and $m_{1/2}$ for $\tan\beta = 3$ for the combination of all triggers: 4, 8, 12 and 16 GeV.

Figure 3 shows the ratio of the efficiency in any given scenario to the scenario where all proposed triggers are kept. By design it is 1 for the all triggers (4||8||12) option. The plot is rather busy and contains a lot of information and can only be made sense of in color. The main features are:

## 3.2 Gluino-squark ($\tilde{g}\tilde{q}$) production

One way of searching for squarks and gluinos is via appearance of like-sign events, which can occur, for instance, via the decay $\tilde{g} \to \tilde{\chi}_1^\pm qq'$ in the case of $\tilde{g}\tilde{g}$ production due to the Majorana nature of gluinos. We use several signal samples of $\sim 10$ k gluino-squark decays with the masses shown in Tab. 5.

We assume four degenerate squarks. Table 6 shows the acceptance for a squark-gluino search using like-sign dileptons. Unlike the chargino-neutralino section described above, we do not use plug electrons here as the charge determination is not that great in the forward region. We use for our denominator in the efficiencies those events with two generator-level leptons with $p_T > 3.5$ and $|\eta| < 2.5$. For the 8 GeV lepton + track trigger, we force the track to match to a HEPG muon or

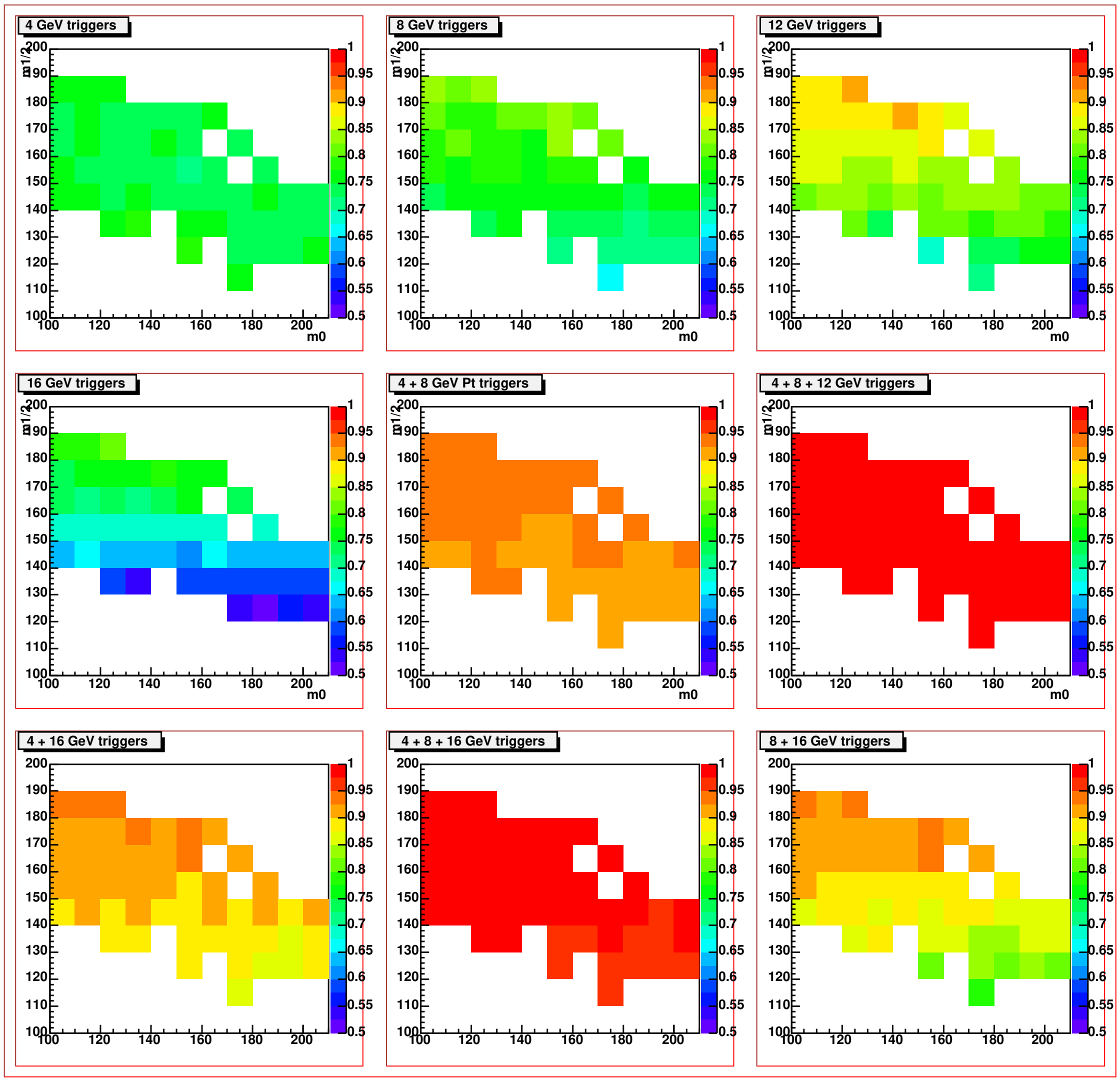


Figure 3: Efficiency of several trigger options relative to the total efficiency as function of $m_0$ and $m_{1/2}$. The different triggers are shown, e.g "$4 + 16$ GeV triggers" shows the OR of the 4 and 16 GeV triggers.

electron as in this channel, the jet-like environment makes the trigger appear unrealistically efficient if one just requires a track in a way that would not be reflected in the actual analysis.

| Scenario | 4‖8‖12 | 4‖12 | 8‖12 | 4‖8 | 4‖8‖16 | 4‖16 | 8‖16 | 16 |
|---|---|---|---|---|---|---|---|---|
| A | 42.3% | -2.5% | -1.8% | -14.6% | -1.7% | -6.6% | -4.0% | |
| B | 41.0% | -3.2% | -4.1% | -10.8% | -3.0% | -8.6% | -8.2% | -40.9% |
| C | 43.2% | -4.0% | -2.9% | -10.8% | -2.6% | -9.6% | -6.6% | -37.1% |

Table 6: Signal acceptance for gluino-squark production followed by decay into dileptons for various trigger scenarios. The denominator has events with two or more HEPG electrons or muons with $p_T > 3.5$, $|\eta| < 2.5$ ($n \simeq 1700$.) All entries are absolute efficiency differences relative to the first column (4‖8‖12.) The entries to the left of the double line are for our default scenario, while those to the right consider the case where we drop the 12 GeV inclusive trigger and replace it with the high-$p_T$ inclusive trigger used by the EWK and top groups. See Sec. 3.0.1 for a description of the notation we use.

If we assume that the high momentum triggers will remain unchanged, we can conclude that for the $\tilde{g}\tilde{q}$ into leptons analysis that:

- the overall trigger efficiency with all triggers is $\sim 42\%$ (4‖8‖12);
- dropping the 12 GeV inclusive trigger has minimal impact if the high $p_T$ path is maintained ((4‖8‖12) vs 4‖8‖16 ). Otherwise, for just the 4‖8 scenario the acceptance drops to $\sim 28\%$;
- dropping the lepton + track triggers causes a decrease of 2.5% of the acceptance (4‖8‖12 vs 4‖12);
- dropping the low $p_T$ dilepton trigger causes a decrease of 2-4% percent (8‖12 vs 4‖8‖12).

### 3.3 Top squark ($\tilde{t}_1\bar{\tilde{t}}_1$) production

The third generation squarks play a special role in Supersymmetry. Due to the large Yukawa coupling of the top quark, large mass splitting can occur in the third generation, leading to the case where the top squark $\tilde{t}_1$ is the lightest squark, possibly lighter than standard-model top. As such the top squark presents a opportunity for CDF to discover Supersymmetry before the turn-on of LHC.

Given the LEP limits on the mass of the lightest chargino ($\tilde{\chi}_1^{\pm}$), a promising channel for low-mass stop quark is the decay to a lepton, sneutrino and b-quark. This decay is most relevant for stop masses between 130 and 160 GeV. We generate MC with $m_{\tilde{t}} = 130$ GeV/c$^2$ and $m_{\tilde{\nu}} = 75$ GeV/$c^2$ and $m(\tilde{\chi}^+) = 45$ GeV/$c^2$.

| lepton | 4‖8‖12 | 4‖12 | 8‖12 | 4‖8 | 4‖8‖16 | 4‖16 | 8‖‖16 | 16 | 2_05_v11 |
|---|---|---|---|---|---|---|---|---|---|
| $e, \mu$ | 57.8 | $-0.8$ | $-2.5$ | $-10.4$ | $-2.4$ | $-7.5$ | $-5.9$ | $-14.5$ | $-7.2$ |
| $e, \mu, \tau$ | 47.0 | $-0.9$ | $-2.5$ | $-9.6$ | $-2.1$ | $-7.3$ | $-5.3$ | $-12.9$ | $-7.3$ |

Table 7: Signal acceptance for stop pair production decaying to dileptons for various trigger scenarios. The denominator consists of events with two or more HEPG electrons or muons with $p_T > 3.5$, $|\eta| < 2.5$. See Sec. 3.0.1 for a description of the notation we use. The table is setup exactly like Table 4. The denominator is about 630 events in the top row and 1000 events in the bottom row.

For the top squark analysis, we can conclude that

- our baseline efficiency is $\sim 49\%$ (4‖8‖12) for $l = e, \mu, \tau$;
- dropping all high momentum triggers causes a $\sim 10\%$ drop in absolute efficiency (4‖8‖12 vs 4‖8), or 17% relative to the baseline cuts;
- dropping the 12 GeV triggers in favor of the 16 GeV triggers ("4‖8‖16") reduces the efficiencies by about 2% in relative or 4% in absolute terms;

- dropping the 8 GeV triggers but keeping the 12 GeV trigger ("4||12") reduces the efficiencies by about 1.5% in relative or 3% in absolute terms. 7% relative change;
- all the other scenarios we evaluated result in a significant efficiency loss of about 3-10%
- the efficiencies of the currently (PHYSICS_2_05_v11) and previously (PHYSICS_2_05_v11) implemented trigger setups are also given. The efficiency of the current implementation is 7% worse and the previously implemented one is about 3% worse.

# 4 Overlap of SUSY_DILEPTON Triggers with other CDF triggers

An independent study conducted on $\sim 46\,\mathrm{pb}^{-1}$ of the MONITOR_L3TAG_PS200 dataset was aimed at understanding the impact of the SUSY_DILEPTON trigger as a whole on the global Level 2 bandwidth; the two most representative trigger configurations (corresponding to trigger tables PHYSICS_2_05_v9 and PHYSICS_2_05_v11) have been considered. For each trigger path two quantities have been evaluated: the total cross-section, which has been observed to match the corresponding TrigMon value, and the exclusive cross-section, which is defined as the portion of the total cross-section collected by the considered trigger path only. The results of this study have been summarized in Table 8, where the total and exclusive cross-sections computed for the entire set of paths has been reported.

| **PATH** | $\sigma_{tot}$ **[nb]** | $\sigma_{excl}$ **[nb]** |
|---|---|---|
| L2_TWO_CEM4_PT4_CES3 | 70 | 35 |
| L2_CEM4_PT4_CES3_&_CMU6_PT4 | 80 | 50 |
| L2_CEM4_PT4_CES3_&_CMX1.5_PT4_CSX | 20 | 10 |
| L2_CEM4_PT4_CES3_&_PEM8 | 75 | 50 |
| L2_TWO_CMU6_PT4 | 50 | 10 |
| L2_CMU6_PT4_&_CMX1.5_PT4_CSX | 10 | 3 |
| L2_PEM8_&_CMU6_PT4 | 45 | 30 |
| L2_PEM8_&_CMX1.5_PT4_CSX | 10 | 5 |
| L2_CMUP6_PT8_&_TRK8<br>L2_CMUP6_PT12 | $\leq 180$ | $\leq 140$ |
| L2_CEM8_PT8_CES3_&_TRK8 | 130 | 20 |
| L2_CEM12_PT8 | 280 | 90 |
| ALL | 750 | 300 |

Table 8: Total and exclusive cross-sections for proposed Level 2 primitives. Estimations are based upon PHYSICS_2_05_v9 and PHYSICS_2_05_v11 data collected in the MONITOR_L3TAG_PS200 dataset. Estimated total cross-section values are in agreement with TrigMon; exclusive cross-section evaluations rely on the specified trigger setups. Contributions of L2_CMUP6_PT8_&_TRK8 and L2_CMUP6_PT12 are here overestimated by considering the total and exclusive cross-sections of the more inclusive L2_CMUP6_PT8 primitive. In general, all numbers depend from instantaneous luminosity; the reported values correspond to $\mathcal{L} \sim 7.5 \times 10^{31}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ [2].

Contrary to the total cross-section evaluations, which depend only on the definition of the primitive to which they refer, exclusive cross-section numbers reported in Table 8 need to be taken *cum grano salis*, since there is an intrinsic dependency from the definition of all competing primitives, or, equivalently, from the considered trigger table. This dependency was reduced by considering different periods of data-taking, each corresponding to a different trigger table, and by monitoring trigger overlaps[2]. At the same time, in order to keep cross-section growth factors under control, all quantities were studied

[2] Even if each trigger is an independent from the others, it is crucial to maintain a global view in order to exploit the full capabilities of the trigger system; in this respect, it is clear that arguments based uniquely on total cross-sections cannot constitute the bottom line.

with respect to instantaneous luminosity. L2_CMX6_PT8_&_TRK8 and L2_CMX6_PT12 were not included in this study because of lack of simulation tools.

There are two main issues that need particular attention: the first one concerns the inclusive 12 GeV lepton paths, while the other one deals with the lepton+track paths. In both cases, due to non-negligible total cross-sections, it is of crucial importance to understand the reliablity of the quoted exclusive contributions. The problem seems to affect more the electron paths; therefore, the following discussion will be focused on L2_CEM12_PT8 and L2_CEM8_PT8_CES3_&_TRK8 only.

For what concerns L2_CEM12_PT8, the major overlap source is due to L2_CEM16_PT8: a steady 50% overlap[3] has been observed up to instantaneous luminosities of $\sim 7 \times 10^{31}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$. Therefore, assuming L2_CEM16_PT8 is not removed from future trigger tables[4], the exclusive cross-section of L2_CEM12_PT8 has an upper bound at $\sim 140$ nb (without considering any other overlap).

Switching to L2_CEM8_PT8_CES3_&_TRK8, the major overlap sources[5] are due to L2_CEM8_PT8_CES3_&_TRK5_DPHI10 (75%), followed by L2_CEM12_PT8 (60%) and by L2_CEM16_PT8 (40%). Incidentally, the exclusive cross-section of L2_CEM8_PT8_CES3_&_TRK8 is tiny (never exceeding 20 nb up to $\mathcal{L} \sim 7.5 \times 10^{31}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$) and therefore its contribution to the global Level 2 bandwidth is unlikely to become relevant. However, this needs to be reevaluated when the L2_CEM8_PT8_CES3_&_TRK5_DPHI10 trigger is changed to an ELECTRON_TAU trigger as recently proposed by Alexei Safonov *et al.*.

A separate comment is deserved by the analysis of trigger cross-section growth factors: these have been observed particularly in paths that rely on the XFT tracking (inclusive muon[6] and lepton+track paths); it is generally believed that the XFT fake rate is among the major causes of trigger growth factors. Recently, a recipe has been proposed for reducing the XFT fake rate; we will therefore reconsider this issue after the suggested modifications are implemented on the XFT algorithm.

# 5 Summary

Table 9 summarises the L2 trigger cross sections for several scenarios.

**CEM**

| Description | $\sigma$(nb) |
|---|---|
| baseline | 450 |
| $12 \rightarrow 16$ | -60 |
| drop TRK8 | -70 |
| drop TRK8, $12 \rightarrow 16$ | -120 |

**CMX**

| Description | $\sigma$(nb) |
|---|---|
| baseline | 116 |
| $12 \rightarrow 16$ | -34 |

**SUSY Dilepton**

| Description | $\sigma$(nb) |
|---|---|
| baseline | 711 |

**CMUP**

| Description | $\sigma$(nb) |
|---|---|
| baseline | 146 |
| $12 \rightarrow 16$ | -30 |

Table 9: L2 trigger cross sections for the baseline and several alternative proposals. The baseline here is the full 4||8||12 as discussed in the previous sections, except in the CMX case where it is just 8||12. The measured overlap between these sections via the lepton + track triggers is negligible.

Note, again, that these L2 trigger cross sections here are an upper limit. Except in Sec. 4, we have not considered any overlaps with triggers outside the SUSY dilepton proposal, *e.g.*, with the $B$, $\tau$ triggers or EWK triggers. From the previous section we anticipate that about 50% of the cross

[3] Approximately 50% of the events collected by L2_CEM12_PT8 fulfil the L2_CEM16_PT8 requirements.

[4] We believe this assumption is pretty safe, since the removal of the high-$p_T$ inclusive leptons would endanger many primary physics programs of the experiment.

[5] Overlaps are expressed here as fractions of the total L2_CEM8_PT8_CES3_&_TRK8 cross-section.

[6] No growth factor has been observed for the L2_CEM12_PT8 path.

section is overlap. Also, we expect the CEM8_TRK8, the CEM12 and the CMX trigger rates to reduce substantially when the new XFT code is running.

| Description | Efficiency (%) | | | Trigger |
|---|---|---|---|---|
| | $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ | $\tilde{g}\tilde{q}$ | $\tilde{t}_1\tilde{t}_1$ | Cross Section |
| baseline | 100 | 100 | 100 | 710 nb |
| 12 → 16 | -3.6 | -4.0 | -4.0 | 586 nb |
| drop TRK8 | -1.0 | -2.3 | -5.9 | 640 nb |
| drop TRK8, 12 → 16 | -8.5 | -12.4 | -15.6 | 526 nb |

Table 10: Summary of change in signal efficiency for various alternatives. The efficiency changes are relative to the baseline scenario. For the $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ signal, we use the top line of Table 4. For $\tilde{g}\tilde{q}$ we use scenario A.

The baseline of our proposal has a total L2 trigger cross section of up to 711 nb. The true reduction, considering all the overlaps with the other CDF triggers can only be measured in a test run. We will do this as soon as this is available.

# 6 Conclusion and Proposal

The results of the signal studies presented in this note support the idea, originally proposed in [3], of a SUSY_DILEPTON trigger organized in three classes, as highlighted in Table 11.

We have evaluated the cross sections and example signal efficienies for the SUSY_DILEPTON triggers. These triggers are crucial for the SUSY discovery potential at the Tevatron. Particularly the "golden" trilepton channel suffers from little background and benefits from large lepton acceptance both in the analysis and at trigger level. In particular the 8 and 12 GeV triggers should not be seen as "backup" paths but as signal triggers since they provide a substantial gain in cases of CMIO muons or plug electrons. For this reason, even a decrease in acceptance of a few percentage points is not desirable. In order to pursue acceptance maximization, we propose the following (see Table 11 and 12):

| | SUSY_DILEPTON PATHS | | |
|---|---|---|---|
| | **DILEPTON** | **LEPTON+TRACK** | **INCLUSIVE LEPTON** |
| L2 & L3 LAYOUT | CEM4_CEM4<br>CEM4_CMUP4<br>CEM4_CMX4<br>CEM4_PEM8<br>CMUP4_CMU4<br>CMUP4_CMX4<br>CMUP4_PEM8<br>CMX4_PEM8 | CEM8_TRK8<br>CMUP8_TRK8<br>CMX8_TRK8 | CEM12<br>CMUP12<br>CMX12 |

Table 11: Proposed layout for the SUSY_DILEPTON trigger.

- re-install the inclusive electron path (L2_CEM12_PT8), which was removed after trigger table PHYSICS_2_05_v9 but add a RECES requirement of 3 GeV at L2;
- add the L2_CEM16, L2_CMUP16 and L2_CMX16 triggers to the SUSY_DILEPTON data set;
- split the current L2_CMUP6_PT8 primitive in the less inclusive L2_CMUP6_PT8_&_TRK8 and L2_CMUP6_PT12;

- abandon the common Level 3 dilepton filter in favour of a structure that, according to the feeding Level 2 path, requires either a low-$p_T$ dilepton pair or a lepton+track or an inclusive lepton, so to confirm the Level 2 requirements.

Additionally, the results obtained in the previous sections seem to discourage the use of Level 2 filtering based upon cluster isolation and track-cluster separation; from our studies, the effect of these requirements on the total SUSY_DILEPTON cross-section is limited to $5\div 10\%$. On the other hand, the introduction of topological selections would imply undesired biases in our data.

| **LEVEL 1** | **LEVEL 2** | **LEVEL 3** |
|---|---|---|
| L1_TWO_CEM4_PT4 | L2_TWO_CEM4_PT4_CES3 | CEM4_CEM4 |
| L1_CEM4_PT4_&_CMU1.5_PT1.5 | L2_CEM4_PT4_CES3_&_CMU6_PT4 | CEM4_CMU4 |
| L1_CEM4_PT4_&_CMX1.5_PT2_CSX | L2_CEM4_PT4_CES3_&_CMX1.5_PT4_CSX | CEM4_CMX4 |
| L1_EM8 | L2_CEM4_PT4_CES3_&_PEM8 | CEM4_PEM8 |
| L1_TWO_CMU1.5_PT1.5 | L2_TWO_CMU6_PT4 | CMU4_CMU4 |
| L1_CMU1.5_PT1.5_&_CMX1.5_PT2_CSX | L2_CMU6_PT4_&_CMX1.5_PT4_CSX | CMU4_CMX4 |
| L1_CMU1.5_PT1.5_&_EM8 | L2_PEM8_&_CMU6_PT4 | CMU4_PEM8 |
| L1_CMX1.5_PT2_CSX_&_EM8 | L2_PEM8_&_CMX1.5_PT4_CSX | CMX4_PEM8 |
| L1_CEM8_PT8 | L2_CEM8_PT8_CES3_&_TRK8 | CEM8_TRK8 |
| L1_CMUP6_PT4 | L2_CMUP8_PT8_&_TRK8 | CMUP8_TRK8 |
| L1_CMX6_PT8_CSX | L2_CMX6_PT8_CSX_&_TRK8 | CMX8_TRK8 |
| L1_CEM8_PT8 | L2_CEM12_PT8(_CES3) | CEM12 |
| L1_CMUP6_PT4 | L2_CMUP12_PT8 | CMUP12 |
| L1_CMX6_PT8_CSX | L2_CMX6_PT12_CSX | CMX12 |

Table 12: Detail of the proposed layout for the SUSY_DILEPTON trigger.

If any compromises (e.g. at the highest luminosities) need to be made we would suggest:

- Drop (or prescale) the 12 GeV trigger during "high luminosity". This reduces the efficiency for the signal by $3-4\%$ and the total cross section of the electron based SUSY dilepton triggers by 140 nb, considering CEM12, CMUP12 and CMX12 and assuming the absence of an unprescaled CMUP8 trigger. Ideally we would prefer the CEM16 trigger to have the RECES requirement since this reduces the rate of that trigger by about 50 nb with no efficiency loss. Such a change, however, needs to be discussed amongst all the high $P_t$ physics groups.
- Change from CMU to CMUP requirement. We have not yet evaluated the gain in bandwidth for all our triggers but for the ones where we have we find reductions of up to a factor of five on the individual cross sections.

# A Input trigger cross sections

Figures 4,5,6 show the trigger cross sections of the paths used as inputs in these studies. The CEM and CMUP trigger inputs show small luminosity growth terms. The CMX has a more sizeable growth term, which should be alleviated by the XFT firmware changes currently being implemented.

We use the MUON_PS1000_L1_CMUP6_PT4 path as our source for unbiased L2/L3 CMUP4 muons. The complete trigger path is shown below. We use as a baseline for the trigger rate estimates a cross section of 8 $\mu b$ at $\mathcal{L} = 90 \times 10^{30}\text{cm}^{-2}\text{s}^{-1}$.

1. L1_CMUP6_PT4
2. L2_PS250_L1_CMUP6_PT4 - auto-accept with a prescale of 250
3. L3_NULL - auto-accept with a prescale of four.

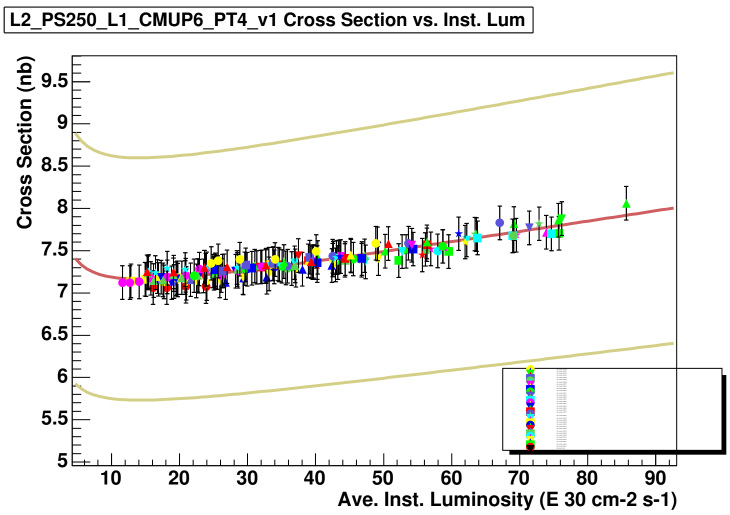


Figure 4: Xmon cross section for the MUON_PS1000_L1_CMUP6_PT4 trigger, which we use for the CMUP trigger studies.

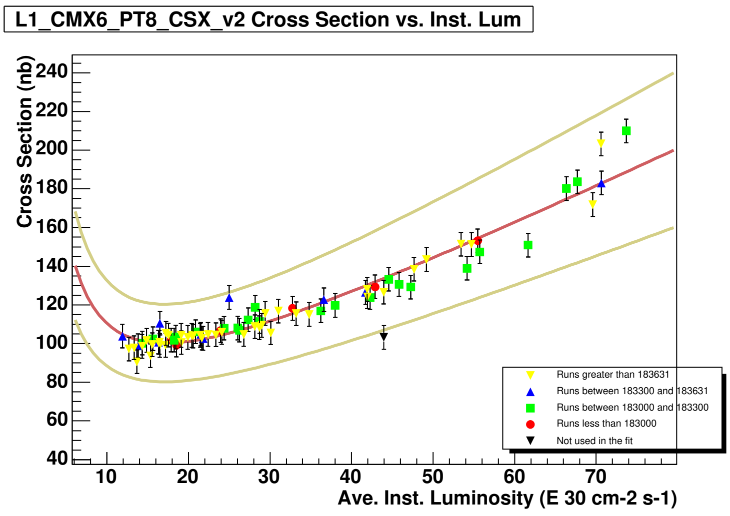


Figure 5: Xmon cross section for the L1_CMX6_PT8_CSX trigger, which we use for the CMX trigger studies.

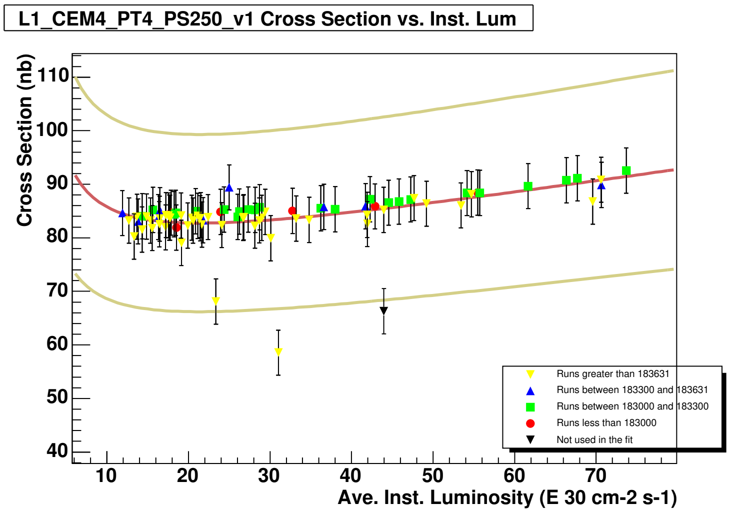


Figure 6: Xmon cross section for the ELECTRON_CENTRAL_PS5K-_L1_CEM4_PT4 trigger at L1 (L1_CEM4_PT4_PS250), which we use for the CEM studies.

# B Monitor and Backup Triggers

We need the following monitor triggers for measuring the trigger efficiencies:

- CENTRAL_ELECTRON_4 and CENTRAL_ELECTRON_8 with the standard L1 and L3 but no L2 requirements
- CMUP_4 with the standard L1 and L3 but no L2 requirements
- CMX_4 with the standard L1 and L3 but no L2 requirements

We can the use Drell-Yan, J/$\psi$ and $\Upsilon$ events to measure the L2 trigger (particularly RECES) efficiencies, the XFT efficiency (from DY and J/$\psi$ ee samples), the CMUP and CMX L1 requirements (from J/$\psi \to \mu\mu$).

# References

[1] Jonathan D. Lewis, private communication.

[2] Refer to the web page *http://fcdfhome.fnal.gov/usr/melisa/cross.html* for more details and plots.

[3] M. P. Giordani and S. Lammel, *"Dilepton Triggers for Exotic Searches at CDF II"*, CDF internal note 6074, August 2002.

[4] A. Anastassov et al., "Selection of Tau Laptons with the CDF Run 2 Trigger System", CDF note 6499; S. Baroiant et al.,"Update on the Lepton + Track Trigger in Run II - Definition and Physics Goasl", CDF note 6325

[5] WMAP collaboration, D. N. Spengel et al., Astrophy. J. Suppl. x48 175 (2003)