Top Trigger Efficiency Measurements
and the top_trigger package


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This notes is divided into to parts. The first part contains a detailed description of the method used to measure the trigger efficiency for the Top physics analyses. The results of all the different trigger efficiency turn-on curves needed to calculate the efficiency of an event to pass one of the Top physics triggers are presented. The second part of the note describes the implementation of the trigger efficiency calculations contained in a CVS package called top_trigger.
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This note is divided into two distinct parts. In the first part, the approach used to measure the Top trigger efficiencies based on single object turn-on curves is described in details. The method used to measure each object trigger turn-on curves and the formula used to combined those turn-on curves are presented. The second part of the note contains a description of the top_trigger package; a code that implements the formula and trigger efficiency turn-on curves presented in the previous part of the note. The code was designed in order to facilitate the application of trigger efficiencies to Monte Carlo events.

I. TRIGGER EFFICIENCY MEASUREMENTS

This part of the note describes the approach used by the Top Physics group to measure the trigger efficiency for each analysis.

A. The DØ Experiment Trigger System

Potentially interesting events are selected online using the DØ three-tiered trigger system. The trigger system is designed to filter events at a rate of 50 Hz based on information from various subdetector systems received at an input rate of 7.5 MHz. The trigger requirements relevant for the event selections described in this document are based on information from the calorimeter, muon and luminosity detectors.

The first level of the trigger is a purely hardware-based system. At Level 1, individual detector systems send a list of trigger primitives to the Level 1 trigger framework. The L1 trigger framework examines the subdetector trigger primitives and reject events that do not meet some predefined conditions. The Level 1 calorimeter trigger information is based on the electromagnetic or total energy deposited in units of trigger towers of size $\Delta \eta \times \Delta \phi = 0.2 \times 0.2$. The coverage of the calorimeter trigger system was increased in March 2003 from $|\eta| < 2.4$ to $|\eta| < 3.2$. Level 1 calorimeter trigger criteria consist of requiring one or more trigger towers to be above a certain predefined threshold. The muon trigger system identifies predefined hit patterns based on information from the scintillator detectors and proportional drift tubes.

The second level of the trigger system is a two-stage hardware/software hybrid system. In the first stage, pre-processor units analyse the information from individual subdetectors and identify physics objects. The list of physics objects from each subdetector is then sent to the global processor where correlations between physics objects from individual subdetectors can be identified. Events that satisfy one of the Level 2 criteria defined in the trigger menu are then analyzed by the Level 3 trigger system.

The Level 3 trigger is a software-based system running a speed optimized version of the DØ offline reconstruction software. The precision readout information from the entire detector is available at this stage and used to identify physics objects such as electrons, muons, jets, missing energy, etc. Events that satisfy one of the many possible Level 3 filters are then saved to tape for offline reconstruction and analysis.

a. Trigger Requirements Vocabulary

Level 1 trigger requirements based on information from the calorimeter are identified using the notation $\text{CEM}(n,x)$ and $\text{CJT}(n,x)$. The terms $\text{CEM}(n,x)$ ( $\text{CJT}(n,x)$ ) require an event to contain at least $n$ trigger towers with a minimum amount of electromagnetic (electromagnetic + hadronic) energy of $x$ GeV. The acronym mu1ptxatxx (mu2ptxatxx) is used to describe the coincidence between at least two layers.
of muon scintillators within the entire trigger acceptance compatible with the presence of one (two) muons. Level 2 and Level 3 conditions follow a similar notation where the two arguments of an acronym refer to the number of objects and energy threshold required. For example, the L3 condition ELE_SHT(1,15) is the short-hand notation for requiring at least one electron, identified using a shower shape algorithm, above an energy threshold of 15 GeV.

A complete description of each trigger requirement can be obtained by querying the trigger list database at http://d0db.fnal.gov/trigdb/cgi/trigdb_main.py.

B. Introduction to Measuring Trigger Efficiencies

In many data analyses, it is necessary to estimate accurately the efficiency of one or many triggers for the signal of interest. The trigger efficiency can be measured in two different ways; either simulate the trigger requirements on Monte Carlo simulated events using the program TrigSim, or fold into Monte Carlo simulated events the per-electron, per-muon and per-jet efficiency of satisfying individual trigger conditions at Level 1, Level 2 and Level 3. The probability of a single object (electron, muon, jet) to satisfy a particular trigger requirement is measured in data.

Although correlations and overlap between triggers are automatically taken into account using the first method, in general, the Monte Carlo modeling of trigger objects and trigger quantities is not adequate to be used for precision measurements of the trigger efficiency. The Top physics working group has therefore instead chosen to use the second method based on probabilities derived from data.

C. Probability Combination

The approach used to combine single object trigger efficiencies to calculate the probability of an event to satisfy a specific trigger is also described in [1]. The method used to combine single-object turn-on curves is summarized below.

The total event probability \( P(L_1, L_2, L_3) \) is calculated as the product of the probabilities for the event to satisfy the trigger conditions at each triggering level,

\[
P(L_1, L_2, L_3) = P(L_1) \cdot P(L_2|L_1) \cdot P(L_3|L_1, L_2)
\]

where \( P(L_2|L_1) \) and \( P(L_3|L_1, L_2) \) represent the conditional probability for an event to satisfy a set of criteria given it has already passed the requirements imposed at the previous triggering level(s).

The total probability of an event to satisfy a set of trigger requirements is obtained assuming that the probability for a single object to satisfy a specific trigger condition is independent of the presence of other objects in the event. Under this assumption, the contributions from different types of objects to the total event probability can be factored out such that

\[
P(object_1, object_2) = P(object_1) \cdot P(object_2).
\]

Furthermore, under this assumption, the probability \( P \) for at least one object to satisfy a particular trigger condition, out of a total of \( N \) objects present in an event, is given by
\[ P = 1 - \prod_{i=1}^{N} (1 - P_i) \]  

where \( P_i \) represents the single object probability. It can be shown that the probability of at least two objects to satisfy a particular trigger condition, out of a total of \( N \) objects present in an event, is obtained using

\[ P = 1 - \prod_{i=1}^{N} (1 - P_i) - \sum_{i=1}^{N} P_i \prod_{j=1, j \neq i}^{N} (1 - P_j). \]  

D. The Top Physics Triggers

The menu of trigger requirements that are used during data taking to identify Top-like events has evolved with time. The data sample analysed ([2]) was collected using five different trigger list versions: v8 to v12. The total trigger efficiency is calculated as the luminosity weighted average of the event probability associated to the trigger requirements contained in each individual trigger list.

Tables I and II summarise the triggers in trigger list v8 to v12 used to identify Top-like events of different final states.

E. Single Object Trigger Efficiency

The probability of a single object to satisfy a particular trigger requirement is measured using the following general procedure. The first step consists of identifying a sample of events unbiased with respect to the trigger requirement under study. Offline reconstructed objects are then identified in the events. The efficiency is obtained by calculating the fraction of these offline reconstructed objects that satisfy the trigger condition under study. Single object efficiencies are in general parameterised as a function of the kinematic variables \( p_t, \eta \) and \( \phi \) of the offline reconstructed objects.

The data analysed in the Top Physics group analyses were recorded based on five different trigger list versions (v8 to v12). In order to take into account major changes in the trigger system and study the trigger response as function of trigger list, many single object trigger efficiencies were measured separately for different trigger lists. Data recorded using different trigger lists for which no changes to a particular subdetector and associated trigger system occurred are combined.

1. Electron

The efficiency for an offline electron to pass a specific trigger requirement is obtained based on a sample of \( Z \to ee \) events, using the “tag-and-probe” method. Events triggered by one of the single electron triggers in each of the trigger list version considered were further selected by requiring the presence of two offline electrons. Electrons are identified in this sample of events using the offline selection criteria of the Top Physics group defined in section [2]. The invariant mass of the two offline electrons was required to be within a small window around the \( Z \) mass. One electron was randomly chosen (“tag”) and required
<table>
<thead>
<tr>
<th>Final State</th>
<th>Trigger List</th>
<th>Trigger Name</th>
<th>L1</th>
<th>L2</th>
<th>L3</th>
</tr>
</thead>
<tbody>
<tr>
<td>di-em</td>
<td>v12</td>
<td>E1,2L20</td>
<td>CEM(1,11)</td>
<td>__________</td>
<td>ELE_NLV(2,20)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E2,2L20</td>
<td>CEM(2,6)</td>
<td>__________</td>
<td>ELE_NLV(2,20)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E3,2L20</td>
<td>CEM(2,3)CEM(1,9)</td>
<td>__________</td>
<td>ELE_NLV(2,20)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E1,2L15_SH15</td>
<td>CEM(1,11)</td>
<td>__________</td>
<td>ELE_NLV(2,15)ELE_SH(1,15)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E2,2L15_SH15</td>
<td>CEM(2,6)</td>
<td>__________</td>
<td>ELE_NLV(2,15)ELE_SH(1,15)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>E3,2L15_SH15</td>
<td>CEM(2,3)CEM(1,9)</td>
<td>__________</td>
<td>ELE_NLV(2,15)ELE_SH(1,15)</td>
</tr>
<tr>
<td></td>
<td>v11</td>
<td>2EM_HI</td>
<td>CEM(2,10)</td>
<td>__________</td>
<td>ELE_LOOSE(1,20)</td>
</tr>
<tr>
<td></td>
<td>v10</td>
<td>2EM_HI</td>
<td>CEM(2,10)</td>
<td>__________</td>
<td>ELE_LOOSE(1,20)</td>
</tr>
<tr>
<td></td>
<td>v9</td>
<td>2EM_HI</td>
<td>CEM(2,10)</td>
<td>__________</td>
<td>ELE_LOOSE(1,20)</td>
</tr>
<tr>
<td></td>
<td>v8</td>
<td>2EM_HI</td>
<td>CEM(2,10)</td>
<td>__________</td>
<td>ELE_LOOSE(1,20)</td>
</tr>
<tr>
<td>di-muon</td>
<td>v12</td>
<td>2MU_A,L2M0_TRK5</td>
<td>mu2ptxatxx</td>
<td>MUON(1,med)</td>
<td>TRK(1,5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2MU_A,L2M0_L3L6</td>
<td>mu2ptxatxx</td>
<td>MUON(1,med)</td>
<td>MUON(1,6,loose)</td>
</tr>
<tr>
<td></td>
<td>v11</td>
<td>2MU_A,L2M0_TRK10</td>
<td>mu2ptxatxx</td>
<td>MUON(1,med)</td>
<td>TRK(1,10)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2MU_A,L2M0_L3L15</td>
<td>mu2ptxatxx</td>
<td>MUON(1,med)</td>
<td>MUON(1,15,loose)</td>
</tr>
<tr>
<td></td>
<td>v10</td>
<td>2MU_A,L2M0</td>
<td>mu2ptxatxx</td>
<td>MUON(1,med)</td>
<td>__________</td>
</tr>
<tr>
<td></td>
<td>v9</td>
<td>2MU_A,L2M0</td>
<td>mu2ptxatxx</td>
<td>MUON(1,med)</td>
<td>__________</td>
</tr>
<tr>
<td></td>
<td>v8</td>
<td>2MU_A,L2M0</td>
<td>mu2ptxatxx</td>
<td>MUON(1,med)</td>
<td>__________</td>
</tr>
</tbody>
</table>

TABLE I: Summary of triggers used to identify events containing two electrons or two muons in different trigger list version.
<table>
<thead>
<tr>
<th>Final State</th>
<th>Trigger List</th>
<th>Trigger Name</th>
<th>L1</th>
<th>L2</th>
<th>L3</th>
</tr>
</thead>
<tbody>
<tr>
<td>e+jets</td>
<td>v12 MATX_EM6,L12</td>
<td>mu1ptxatxx,CEM(1,6)</td>
<td>________</td>
<td>________</td>
<td>ELE_NLV(1,12)</td>
</tr>
<tr>
<td></td>
<td>v11 MU_A_EM10</td>
<td>mu1ptxatxx,CEM(1,5)</td>
<td>________</td>
<td>________</td>
<td>ELE_LOOSE(1,10)</td>
</tr>
<tr>
<td></td>
<td>v10 MU_A_EM10</td>
<td>mu1ptxatxx,CEM(1,5)</td>
<td>________</td>
<td>________</td>
<td>ELE_LOOSE(1,10)</td>
</tr>
<tr>
<td></td>
<td>v9 MU_A_EM10</td>
<td>mu1ptxatxx,CEM(1,5)</td>
<td>________</td>
<td>________</td>
<td>ELE_LOOSE(1,10)</td>
</tr>
<tr>
<td></td>
<td>≥ v8.2 MU_W_EM10</td>
<td>mu1ptxwtxx,CEM(1,5)</td>
<td>________</td>
<td>________</td>
<td>ELE_LOOSE(1,10)</td>
</tr>
<tr>
<td>µ+jets</td>
<td>v12 EM15_2JT15</td>
<td>CEM(1,10)</td>
<td>CJT(2,5)</td>
<td>________</td>
<td>ELE_LOOSE_SH_T(1,15),JET(2,15)</td>
</tr>
<tr>
<td></td>
<td>v11 EM15_2JT15</td>
<td>CEM(1,10),CJT(2,5)</td>
<td>EM(0.85,10),JET(2,10)</td>
<td>________</td>
<td>ELE_LOOSE_SH_T(1,15),JET(2,15)</td>
</tr>
<tr>
<td></td>
<td>v10 EM15_2JT15</td>
<td>CEM(1,10),CJT(2,5)</td>
<td>EM(0.85,10),JET(2,10)</td>
<td>________</td>
<td>ELE_LOOSE_SH_T(1,15),JET(2,15)</td>
</tr>
<tr>
<td></td>
<td>v9 EM15_2JT15</td>
<td>CEM(1,10),CJT(2,5)</td>
<td>EM(0.85,10),JET(2,10)</td>
<td>________</td>
<td>ELE_LOOSE_SH_T(1,15),JET(2,15)</td>
</tr>
<tr>
<td></td>
<td>≥ v8.2 EM15_2JT15</td>
<td>CEM(1,10),CJT(2,5)</td>
<td>EM(0.85,10),JET(2,10)</td>
<td>________</td>
<td>ELE_LOOSE_SH_T(1,15),JET(2,15)</td>
</tr>
<tr>
<td>all-jets</td>
<td>v12 4JT12</td>
<td>CJT(3,5)</td>
<td>JET(3,8),HT(50)</td>
<td>JET(4,12),JET(3,15),JET(2,25)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>v11 4JT10</td>
<td>CJT(4,5)</td>
<td>JET(3,8),HT(90)</td>
<td>JET(4,10),JET(2,20)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>v10 4JT10</td>
<td>CJT(4,5)</td>
<td>JET(3,8),HT(90)</td>
<td>JET(4,10),JET(2,20)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>v9 4JT10</td>
<td>CJT(4,5)</td>
<td>JET(3,8),HT(90)</td>
<td>JET(4,10),JET(2,20)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>v8 4JT10</td>
<td>CJT(4,5)</td>
<td>JET(3,8)</td>
<td>JET(4,10)</td>
<td></td>
</tr>
</tbody>
</table>

**TABLE II:** Summary of triggers used to identify different final state events in trigger list v8 to v12.
to satisfy one of the L1 single electron trigger requirement. The second offline electron ("probe") was then used to calculate the efficiency of a particular trigger criteria.

a. **Level 1** The trigger efficiency for the following Level 1 conditions are measured: CEM(1,11), CEM(1,6), the combined OR (CEM,OR) of three conditions [ CEM(1,11) OR CEM(2,6) OR CEM(2,3)CEM(1,9) ] for trigger list version 12, and CEM(1,10), CEM(1,5) for trigger list versions 8 to 11.

The single electron efficiency is found to be constant as function of \( \eta \) in the region of interest and of \( \phi \) and is therefore only parameterised as function of the offline reconstructed electron \( p_T \). The trigger efficiency in general reaches a maximum constant value for electrons with \( p_T \) about twice that of the L1 energy threshold. Figures 1 and 2 show the turn-on curves obtained for the L1 criteria in the v12 and v8-v11 trigger list, respectively. Since all the rootuple prepared with the program top-analyze for the Top group only contained offline electrons with \( p_T > 15 \) GeV, it was not possible to obtain data points for the lower \( p_T \) region in order to accurately estimate the efficiency there. For trigger thresholds where the turn-on region is below a \( p_T \) of 15 GeV, the trigger efficiency was treated as constant. For trigger thresholds above 15 GeV, the turn-on curves where fitted to a function that assumes a sharply rising efficiency value around each trigger energy threshold. The lack of data points at low \( p_T \) results in a large statistical uncertainty in this low \( p_T \) region which gets taken into account in the uncertainty calculation described later. The function used to parameterise the Level 1 electron trigger efficiency is

\[
f(p_T) = 0.5 \cdot A_2 \cdot \left(1 + \text{erf} \left( \frac{p_T - A_0}{\sqrt{2} \cdot A_1} \right) \right)
\]  

where A0, A1 and A2 are parameters that can be respectively interpreted as the \( p_T \) value at which the efficiency reaches half its maximum value, the slope of the turn-on curve and the maximum efficiency in the plateau region.

Table III summarizes the values of the fitted parameters and their errors obtained from a fit to the data.

<table>
<thead>
<tr>
<th></th>
<th>A0</th>
<th>A1</th>
<th>A2</th>
</tr>
</thead>
<tbody>
<tr>
<td>v12</td>
<td>CEM(1,6)</td>
<td>14 ± 9</td>
<td>0.9914 ± 0.0009</td>
</tr>
<tr>
<td></td>
<td>CEM(1,11)</td>
<td>15 ± 4</td>
<td>0.9952 ± 0.0006</td>
</tr>
<tr>
<td></td>
<td>CEM,OR</td>
<td>1 ± 11</td>
<td>0.9962 ± 0.0006</td>
</tr>
<tr>
<td>v8-v11</td>
<td>CEM(1,5)</td>
<td>3 ± 15</td>
<td>0.983 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>CEM(1,10)</td>
<td>4 ± 11</td>
<td>0.978 ± 0.001</td>
</tr>
</tbody>
</table>

**Table III**: Fitted values of the parameters introduced in Equation 5 used to parameterise the Level 1 electron trigger efficiencies. The trigger efficiency of the conditions CEM(1,6) (for trigger list v12) and CEM(1,5) (for trigger list v8-v11) were measured to be constant for offline reconstructed electron with \( p_T > 15 \) GeV.

The uncertainty on the measured trigger efficiencies (\( \Delta f \)) as function of \( p_T \) is obtained by error propagation of the statistical uncertainty of each fitted parameters.

\[
\Delta f^2 = \left( \frac{\delta f}{\delta A_0} \right)^2 \cdot \Delta A_0^2 + \left( \frac{\delta f}{\delta A_1} \right)^2 \cdot \Delta A_1^2 + \left( \frac{\delta f}{\delta A_2} \right)^2 \cdot \Delta A_2^2
\]  

\[
\Delta f^2 = \left[ \frac{A_2}{\sqrt{2\pi} \cdot A_1} \cdot \exp \left( -1 \cdot \left( \frac{p_T - A_0}{\sqrt{2} \cdot A_1} \right)^2 \right) \right]^2 (\Delta A_0)^2 +
\]
FIG. 1: Trigger efficiency as function of $p_T$ for an offline electron to satisfy the following Level 1 trigger requirements used in trigger list v12: CEM(1,6) (top left), CEM(1,11) (top right) and [CEM(1,11).or.CEM(2,6).or.CEM(2,3)CEM(1,9)] (bottom).

FIG. 2: Trigger efficiency as function of $p_T$ for an offline electron to satisfy the following Level 1 trigger requirements used in trigger list v8 to v11: CEM(1,5) (left) and CEM(1,10) (right).

\[
\frac{A_2 \cdot (p_T - A_0)}{\sqrt{2\pi} A_1^2} \cdot \exp \left(-1 \cdot \left(\frac{p_T - A_0}{\sqrt{2} \cdot A_1}\right)^2\right) (\Delta A_1)^2 + \\
0.5 \cdot (1 + \text{erf} \left(\frac{p_T - A_0}{\sqrt{2} \cdot A_1}\right))^2 (\Delta A_2)^2
\]

(7)

where the symbols $\Delta A_0$, $\Delta A_1$ and $\Delta A_2$ represent the statistical uncertainty on each fitted parameters $A_0$, $A_1$ and $A_2$. 

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b. **Level 2** The single electron efficiency for the L2 condition requiring one electron with an EM fraction greater than 0.85 and $p_T > 10$ GeV for electrons that have satisfied the CEM(1,10) condition has been shown to be fully efficient [3].

c. **Level 3** The efficiency for an offline electron to satisfy the following Level 3 trigger requirements was measured: ELE\_NLV(1,12), ELE\_NLV(1,15), ELE\_SH(1,15), ELE\_NLV(1,20) for data recorded with the v12 trigger list and ELE\_LOOSE(1,10) for data recorded with the v8 to v11 trigger list. The trigger efficiency for each Level 3 requirement was measured separately for offline electrons in the endcap and barrel region.

Samples of events available at the time of the study unfortunately contained only offline electrons with $p_T > 15$ GeV. Details of the method used to obtain an estimate of the L3 electron trigger efficiency for $p_T$ down to 10 GeV can be found in [4] and is summarised below.

The trigger efficiency for an electron to satisfy one of the Level 3 requirement with energy threshold below 15 GeV was measured using the following procedure. The trigger efficiency for each Level 3 requirement was measured and parameterised, using Equation 5, at different trigger energy thresholds above 15 GeV. The value of the fitted parameters were then extrapolated down to the required lower $p_T$ threshold.

The efficiency of an offline electron to satisfy each Level 3 requirement listed above for trigger thresholds of 20, 25, 30 and 35 GeV are shown in Appendix A. Results of the fits to Equation 5 are superimposed on those plots.

The parameter describing the slope of the turn-on curve ($A_1$) and the maximum efficiency in the plateau region ($A_2$) are constant as function of different $p_T$ threshold within statistical errors. The extrapoleted value of these parameters for trigger requirements with lower $p_T$ threshold are therefore taken to be the weighted average of the fitted parameter values obtained for the higher $p_T$ threshold. The value of the parameter describing the $p_T$ at which the efficiency reaches half its maximum ($A_0$), on the other hand, does obviously vary with the $p_T$ trigger threshold considered. The value of this parameter for a trigger condition with a $p_T$ threshold lower than 20 GeV is found by extrapolation to the given lower $p_T$ threshold the value of the fitted parameters at higher $p_T$ threshold. Figures 3 and 4 shows the linear parameterisation of the fitted parameter values found at a higher $p_T$ threshold value for each Level 3 condition considered.

Finally, Table IV summarises the extrapolated value of each parameter used to describe the trigger efficiency of the Level 3 condition relevant of the Top triggers.

As described above, the uncertainty on the Level 3 trigger efficiency estimate is obtained using Equation 6.

Some L3 electron trigger requirements depend on the shower shape of the electron candidate. Electrons which are triggered with or without such shower shape requirements are expected to have different loose-to-tight offline ID efficiencies, since the offline selection likelihood is also, amongst other quantities, based on shower shape information. However, first indication show that this effect is small.

2. **Muon**

Offline muons are defined using the offline selection criteria defined in [2]. The Level 1 and Level 2 trigger conditions and implementation have not changed in the period of data
FIG. 3: Parameterisation of the fitted parameter A0 ($p_T$ value at which the efficiency reaches half its maximum value) as function of trigger $p_T$ threshold for offline electrons in the barrel (left) and endcap (right) region of the calorimeter for each Level 3 trigger requirement considered in the trigger list v12: ELE_NLV(1,x) (top row), ELE_SH(1,x) (middle row) and ELE_SHT(1,x) (bottom row).
<table>
<thead>
<tr>
<th></th>
<th>Barrel (CC)</th>
<th>Endcap (EC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A0</td>
<td>A1</td>
</tr>
<tr>
<td>v12 ELE_NLV(1,12)</td>
<td>13.6 ± 0.5</td>
<td>1.57 ± 0.07</td>
</tr>
<tr>
<td>ELE_NLV(1,15)</td>
<td>16.7±0.5</td>
<td>1.57±0.07</td>
</tr>
<tr>
<td>ELE_NLV(1,20)</td>
<td>21.9±0.5</td>
<td>1.57±0.07</td>
</tr>
<tr>
<td>ELE_SH(1,15)</td>
<td>16.8±0.6</td>
<td>1.47±0.06</td>
</tr>
<tr>
<td>ELE_SH(1,15)</td>
<td>16.8±0.5</td>
<td>1.42±0.07</td>
</tr>
<tr>
<td>v8-v11 ELE_LOOSE(1,10)</td>
<td>13.8±0.7</td>
<td>2.7±0.1</td>
</tr>
<tr>
<td>ELE_LOOSE(1,20)</td>
<td>24.0±0.7</td>
<td>2.7±0.1</td>
</tr>
<tr>
<td>ELE_LOOSE_SH_T(1,15)</td>
<td>19±1</td>
<td>2.9±0.2</td>
</tr>
</tbody>
</table>

TABLE IV: Parameter values of equation 5 used to estimate the trigger efficiency of each Level 3 requirements considered.
FIG. 4: Parameterisation of the fitted parameter $A_0$ ($p_T$ value at which the efficiency reaches half its maximum value) as function of trigger $p_T$ threshold for offline electrons in the barrel (left) and endcap (right) region of the calorimeter for each Level 3 trigger requirement considered in the trigger list v8 to v11: ELE\_LOOSE(1,x) (top row) and ELE\_LOOSE\_SH\_T(1,x) (bottom row).

taking using the trigger list v8 to v12. The same efficiency parameterisations are therefore used for the trigger efficiency calculations in all trigger list versions.

The highest statistics event sample used to obtain the muon trigger efficiencies consists of $Z \rightarrow \mu\mu$ events. The “tag-and-probe” method is then used to calculate the fraction of offline muons that pass the trigger requirement under study.

Figure 5 shows the probability of an offline muon to satisfy the Level 1 requirement mu1ptxatxx (a) and the Level 2 requirement MUON(1,med) given it has fired the Level 1 condition (b) as a function of the offline muon $|\eta|$. For muon with $p_T > 15$ GeV, the Level 1 and Level 2 trigger efficiencies were found to be constant as function of $p_T$. The function used to parameterise the $\eta$ dependence is given by

$$f(\eta) = A_3 + A_0 \cdot \exp \left( - A_1 \cdot (\eta^2 - A_2^2) \right) \sin \left( \eta^2 - A_2^2 \right)$$  \hspace{1cm} (8)
FIG. 5: Muon trigger efficiency as function of offline muon $|\eta|$ for the Level 1 condition mu1ptxatxx (a) and for the Level 2 condition MUON(1,med) given that the muon already satisfies the Level 1 condition.

<table>
<thead>
<tr>
<th></th>
<th>A0</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>-0.8±0.2</td>
<td>2.8±0.5</td>
<td>0.1±0.1</td>
<td>0.99±0.01</td>
</tr>
<tr>
<td>L2</td>
<td>0±0</td>
<td>8.7±7.0</td>
<td>1.779±0.006</td>
<td>0.981±0.007</td>
</tr>
</tbody>
</table>

TABLE V: Fit results for the Level 1 and Level 2 muon trigger efficiencies for data recorded with trigger list v8 to v12. The function used to fit the $\eta$ dependence is given in Equation 8.

Results of the fit are summarised in Table V.

In order to check for any possible geometrical biases associated to the use of back-to-back muons, both Level 1 and Level 2 muon trigger efficiencies were also calculated using a sample of $W \rightarrow \mu\nu$ events. This sample of events was selected using the following criteria

- require at least one isolated medium muon with a track matched and $p_T > 20$ GeV.
- $\Delta R(\mu, \text{jet}) \geq 0.5$
- Primary vertex reconstructed with at least 3 tracks, $|z_{PV}| < 60$ cm
- $\sigma_{dca} < 3$
- MET $< 20$ GeV

The muon trigger efficiency for the trigger requirements L1 mu1ptxatxx and L2M0 were found to be similar to those obtained using $Z \rightarrow \mu\mu$ events.

The uncertainty on the measured trigger efficiencies as function of muon $p_T$ is obtained using error propagation and is given by

$$\Delta f^2 = \left[ \exp \left( -A1 \cdot (\eta^2 - A2) \right) \cdot \sin(\eta^2 - A2) \right]^2 \cdot (\Delta A0)^2 + \left[ \exp(-A1 \cdot (\eta^2 - A2)) \cdot \sin(\eta^2 - A2) \cdot A0 \cdot (\eta^2 - A2) \right]^2 \cdot (\Delta A1)^2 + \left[ \exp \left( -A1 \cdot (\eta^2 - A2) \right) \cdot \sin(\eta^2 - A2) \cdot A0 \cdot A1 -$$
\[
\exp \left( -A_1 \cdot (\eta^2 - A_2) \right) \cos(\eta^2 - A_2) \cdot A_0 \right] \cdot (\Delta A_2)^2 + 
(\Delta A_3)^2 \]

(9)

where the symbols \(\Delta A_0\), \(\Delta A_1\), \(\Delta A_2\) and \(\Delta A_3\) represent the statistical uncertainty on each fitted parameters \(A_0\), \(A_1\), \(A_2\) and \(A_3\).

The last piece of information needed to calculated the probability of an event to pass the di-\(\mu\) triggers is the probability for offline reconstructed muons to satisfy one of the two requirements:

\[
\text{v12} : \ TRK(1,5) \ \text{or} \ MUON(1,6,\text{loose}) \\
\text{v11} : \ TRK(1,10) \ \text{or} \ MUON(1,15,\text{loose})
\]

(10)

The trigger efficiency in both cases was measured to be 100

3. Jet

Jets are defined using the offline selection criteria defined in section [2]. The jet trigger efficiencies are parameterised as function of jet \(p_T\) in three regions of the calorimeter: CC (\(|\eta| < 0.8\)), ICR (0.8 \(\leq |\eta| < 1.5\)) and EC (\(|\eta| \geq 1.5\)).

In order to check for the possible presence of bias associated with a particular event selection, two different methods were used to calculate the jet trigger efficiencies. The first approach consisted of measuring the jet trigger efficiency on a sample of events that passed at least one of the many muon triggers present in the trigger list version of interest. This method has the advantage of not depending on the calorimeter trigger response. The second approach consisted of measuring the jet trigger efficiencies using a sample of events that satisfied any one of the single electron triggers present in the different trigger lists considered. In order to reduce the contamination of electrons and therefore obtain a pure sample of jets, only events that contain exactly one offline reconstructed electron that matches to both a Level 1 and Level 2 electron in the event are considered. Figure 6 shows the electromagnetic energy fraction for all jets in events before and after requiring the offline electron to be matched to L2 EM object. Both methods were found to give identical results as shown in Figure 7.

a. Uncertainties on efficiency measurements

The uncertainty on the jet trigger efficiency turn-on curves is taken to be the sum in quadrature of the statistical and systematic components. As described above, the statistical component of the uncertainty on the trigger efficiency is obtained using Equation 6. The jet turn-on curves were measured with a large data sample which results in a small statistical uncertainty on the trigger efficiency measurements. Possible systematic effects associated to the method used for measuring the trigger efficiencies could however be of the same size or even larger than the statistical uncertainties. In order to quantify possible effects due to the jet quality used in measuring the efficiencies, all the trigger turn-on curves were re-measured requiring, this time, a track-match for every jet and thereby improving the purity of the jet samples. Figures 23 to 34 in Appendix B show the relative difference, as function of \(p_T\), between the efficiencies measured requiring and not requiring a track-match as part of the jet definition.

b. Jet probability of satisfying an EM-type trigger

In addition to the turn-on curves measured above, the probability of a jet to satisfy EM-type trigger requirements was also measured.
| Trigger List | Trigger condition | $|\eta| < 0.8$ | $0.8 \leq |\eta| < 1.5$ | $|\eta| \geq 1.5$ |
|--------------|------------------|-------------|----------------|----------------|
| v12          | L1 CJT(1,3)      | $A_0 = 14.03 \pm 0.07$ | $A_0 = 19.14 \pm 0.05$ | $A_0 = 13.38 \pm 0.05$ |
|              |                  | $A_1 = 2.51 \pm 0.02$  | $A_1 = 3.24 \pm 0.03$  | $A_1 = 2.55 \pm 0.02$  |
|              |                  | $A_2 = 0.9981 \pm 0.0009$ | $A_2 = 0.991 \pm 0.004$ | $A_2 = 0.9993 \pm 0.0007$ |
|              | L2 JET(1,10)     | $A_0 = 12.74 \pm 0.09$ | $A_0 = 16.65 \pm 0.09$ | $A_0 = 8.7 \pm 0.1$ |
|              |                  | $A_1 = 2.40 \pm 0.03$  | $A_1 = 3.12 \pm 0.06$  | $A_1 = 2.69 \pm 0.03$  |
|              |                  | $A_2 = 0.9986 \pm 0.0008$ | $A_2 = 0.991 \pm 0.004$ | $A_2 = 0.9999 \pm 0.001$ |
|              | L3 JET(1,20)     | $A_0 = 22.04 \pm 0.05$ | $A_0 = 32.2 \pm 0.05$  | $A_0 = 22 \pm 2$  |
|              |                  | $A_1 = 0.87 \pm 0.01$  | $A_1 = 1.9 \pm 0.1$  | $A_1 = 2.3 \pm 0.2$  |
|              |                  | $A_2 = 0.985 \pm 0.005$ | $A_2 = 0.989 \pm 0.005$ | $A_2 = 0.994 \pm 0.002$ |
|              | L3 JET(1,25)     | $A_0 = 36.69 \pm 0.07$ | $A_0 = 42.4 \pm 0.2$  | $A_0 = 36.7 \pm 0.1$  |
|              |                  | $A_1 = 0.77 \pm 0.01$  | $A_1 = 1.12 \pm 0.04$  | $A_1 = 1.09 \pm 0.05$  |
|              |                  | $A_2 = 0.985 \pm 0.005$ | $A_2 = 0.982 \pm 0.006$ | $A_2 = 0.978 \pm 0.004$ |
| v9-v11       | L1 CJT(1,5)      | $A_0 = 21.33 \pm 0.07$ | $A_0 = 30.4 \pm 0.02$  | $A_0 = 22.84 \pm 0.07$ |
|              |                  | $A_1 = 1.9 \pm 0.1$  | $A_1 = 2.3 \pm 0.2$  |
|              | L2 JET(1,10)     | $A_0 = 24.67 \pm 0.06$ | $A_0 = 28.31 \pm 0.08$ | $A_0 = 25.39 \pm 0.06$ |
|              |                  | $A_1 = 1.10 \pm 0.02$  | $A_1 = 1.59 \pm 0.03$  | $A_1 = 1.36 \pm 0.02$  |
|              |                  | $A_2 = 0.961 \pm 0.001$ | $A_2 = 0.969 \pm 0.002$ | $A_2 = 0.974 \pm 0.001$ |
|              | L3 JET(1,20)     | $A_0 = 23.39 \pm 0.06$ | $A_0 = 32.32 \pm 0.06$ |
|              |                  | $A_1 = 1.36 \pm 0.05$  | $A_1 = 1.47 \pm 0.02$  |
|              |                  | $A_2 = 0.98 \pm 0.01$  | $A_2 = 0.988 \pm 0.009$ | $A_2 = 0.978 \pm 0.002$ |

**TABLE VI:** Trigger efficiency for an offline reconstructed jet to satisfy different trigger conditions. Each fitted value is quoted with its associated statistical uncertainty. The function used to fit the data is given in equation 5.
FIG. 6: Electromagnetic energy fraction of jets before (a) and after (b) requiring that the offline electron be matched to a L2 EM object.

This additional piece of information makes it possible to take into account the probability that a jet can also satisfy the EM-type requirements. Events recorded based on having fired one of the single muon triggers were used for this study. The standard jet reconstruction described in [2] is then applied and each jet found in the event is in turn considered as to whether it satisfies the trigger requirement under study.

Figures 8 and 9 show the probability for an offline reconstructed jet to satisfy the v8 to v12 EM-type requirements.

The following two equations are used to parameterise the efficiency as function of the offline jet $p_T$.

$$f(p_T) = (A2 + A3 \cdot p_T) \cdot (1 + erf \left( \frac{p_T - A0}{\sqrt{p_T} \cdot A1 + A4} \right))$$  \hspace{1cm} (11)$$

and

$$f(p_T) = (A2 + A3 \cdot p_T) \cdot (1 + erf \left( \frac{p_T - A0 + A4 \cdot p_T}{\sqrt{p_T} \cdot A1} \right))$$  \hspace{1cm} (12)$$

Results of the various fit to data are summarize in Table VII.

The probability of a jet to satisfy a Level 3 EM-type requirement is expected to be much smaller. While at Level 1 only the number and energy in calorimeter trigger towers are used to built trigger conditions, at Level 3, the entire precision readout of the detector and more detailed algorithms, such as shower shape algorithms, are available. To test this hypothesis, the probability of a jet to satisfy the loosest Level 3 requirements used in trigger list v12 and v8-v11 was also measured. Figure 10 show the probability of a jet to satisfy the ELE_NLV(1,12) and ELE_LOOSE(1,10) requirements as function of $p_T$. The efficiency is indeed significantly lower is therefore neglected.

F. Top Trigger Efficiency Measurements

The formula used to combined the various turn-on curves in order to estimate the total trigger efficiency of the Top physics triggers are presented here. In general, the probability
<table>
<thead>
<tr>
<th>Equation</th>
<th>A0</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
</tr>
</thead>
<tbody>
<tr>
<td>v12 CEM(1,6)</td>
<td>66.8±0.5</td>
<td>8.50±0.07</td>
<td>11±1</td>
<td>0.56±0.02</td>
<td>-1.85±0.01</td>
</tr>
<tr>
<td>CEM(1,11)</td>
<td>89±4</td>
<td>6.4±0.4</td>
<td>6.62±0.06</td>
<td>-0.0019±0.0003</td>
<td>2.75±0.5</td>
</tr>
<tr>
<td>CEM OR</td>
<td>72.03±0.04</td>
<td>5.84±0.02</td>
<td>0.75±0.03</td>
<td>-0.0023±0.0002</td>
<td>-0.12±0.01</td>
</tr>
<tr>
<td>v8-v11 CEM(1,5)</td>
<td>68.60±0.4</td>
<td>10.485±0.009</td>
<td>3.9±0.5</td>
<td>0.318±0.006</td>
<td>-2.001±0.006</td>
</tr>
<tr>
<td>CEM(1,10)</td>
<td>(666±3)E+05</td>
<td>(538±3)E+04</td>
<td>12.9±0.2</td>
<td>-0.050±0.001</td>
<td>(19±1)E+05</td>
</tr>
</tbody>
</table>

TABLE VII: Fit results for the jet probability of satisfying one of the Level 1 trigger requirements used in trigger list v8 to v12.
of an event to satisfy a class of triggers is obtained by calculating the luminosity weighted average of the event probability for each trigger list version.

1. di-em triggers

The probability for an event to satisfy the di-em triggers presented in Table I is obtained by multiplying the probability of the event to satisfy the Level 1 condition and the probability of the event to satisfy the the Level 3 condition (there are no Level 2 conditions applied for these triggers),

$$P_{\text{diem}} = P_{\text{L1}} \cdot P_{\text{L3}} \tag{13}$$

In order to take into account the probability of a jet to satisfy the Level 1 conditions, the Level 1 event probability is obtained as the 'OR' of the electron and jet probabilities to fulfill the trigger requirement, i.e.

$$P_{\text{L1}} = P_{(\text{e}|L1)} + P_{(\text{jet}|L1)} - P_{(\text{e}|L1)} \cdot P_{(\text{jet}|L1)} \tag{14}$$
where the symbols \( P_{e|L1} \) and \( P_{\text{jet}|L1} \) represent the probability that electrons and jets in the event satisfy the Level 1 condition.

Using Equations 3 and 4, the probabilities \( P_{e|L1} \) and \( P_{\text{jet}|L1} \) are given by

\[
\text{v12: } P_{e|L1} = 1 - \prod_{i=1}^{N} \left(1 - P_{i(e|\text{CEM}_{\text{OR}})} \right)
\]

\[
P_{\text{jet}|L1} = 1 - \prod_{i=1}^{N} \left(1 - P_{i(\text{jet}|\text{CEM}_{\text{OR}})} \right)
\]

\[
\text{v8 – v11 } P_{e|L1} = 1 - \prod_{i=1}^{N} \left(1 - P_{i(e|\text{CEM(1,10)})} \right) - \\
\sum_{i=1}^{N} P_{i(e|\text{CEM(1,10)})} \prod_{j=1,j\neq i}^{N} \left(1 - P_{j(e|\text{CEM(1,10)})} \right)
\]

\[
P_{\text{jet}|L1} = 1 - \prod_{i=1}^{N} \left(1 - P_{i(\text{jet}|\text{CEM(1,10)})} \right) - \\
\sum_{i=1}^{N} P_{i(\text{jet}|\text{CEM(1,10)})} \prod_{j=1,j\neq i}^{N} \left(1 - P_{j(\text{jet}|\text{CEM(1,10)})} \right)
\]
FIG. 9: Probability for a jet to satisfy the EM-type conditions used in trigger list v8 to v11: CEM(1,5) (left) and CEM(1,10) (right). The points are the data and the solid line shows the result of a fit to the data using Equation 11 to describe CEM(1,5) and Equation 12 for CEM(1,10).

\[ \chi^2_{\text{ndf}} = 112.8/78 \]
\[ \text{Prob} = 0.006056 \]
\[ p_0 = 1.219 \times 10^{11} \pm 1.469 \times 10^{11} \]
\[ p_1 = 1.235 \times 10^{11} \pm 1.512 \times 10^{11} \]
\[ p_2 = 0.003889 \pm 0.07765 \]
\[ p_3 = 3.194 \times 10^{-5} \pm 0.000407 \]
\[ p_4 = 4.495 \times 10^{11} \pm 5.504 \times 10^{11} \]

FIG. 10: Probability for a jet to satisfy the Level 3 EM-type conditions ELE_NLV(1,12) (top) and ELE_LOOSE(1,10) (bottom) used in trigger lists v12 and v8-v11, respectively. The points are the data and the solid line shows the result of a fit to the data using Equation 12.

\[ \chi^2_{\text{ndf}} = 413.4/84 \]
\[ \text{Prob} = 0 \]
\[ p_0 = 10.67 \pm 49.31 \]
\[ p_1 = 6.296 \pm 17.7 \]
\[ p_2 = 0.01206 \pm 0.06622 \]
\[ p_3 = 6.686 \times 10^{-5} \pm 0.0003144 \]
\[ p_4 = 20.48 \pm 54.79 \]

The probability of an event to satisfy the Level 3 conditions is obtained following the same reasoning. In the v12 trigger list, the di-em triggers consist of two distinct Level 3 conditions: ELE_NLV(2,20) and ELE_NLV(1,15)ELE_SH(1,15). At Level 3, the probability of a jet to satisfy a Level 3 condition is significantly smaller than at Level 1 as shown in Section I E 1 and is therefore ignored.

The probability of an event to satisfy the ‘OR’ of the two conditions used in trigger list v12 is

\[ v12 : P_{L3} = P_{(e|\text{ELE_NLV}(2,20))}P_{(e|\text{ELE_NLV}(1,15)\text{ELE_SH}(1,15))} - P_{(e|\text{ELE_NLV}(2,20))} \cdot P_{(e|\text{ELE_NLV}(2,15)\text{ELE_SH}(1,15))} \]  

and once again using Equation 4

\[ v12 : P_{(e|\text{ELE_NLV}(2,20))} = 1 - \prod_{i=1}^{N}(1 - P_{(e|\text{ELE_NLV}(1,20))}) - \]
The probability of an event to satisfy the combined requirement ELE\_NL\_V(2,15) ELE\_SH(1,15) can be written as
\[ v_{12} = P(e | \text{ELE\_NL\_V}(2,15) \text{ELE\_SH}(1,15)) \] (17)
where the symbol \( P(e | \text{ELE\_SH}(1,15) | \text{ELE\_NL\_V}(1,15)) \) represents the conditional probability of an electron to satisfy \( \text{ELE\_SH}(1,15) \) given that it satisfies the condition \( \text{ELE\_NL\_V}(1,15) \). It has been shown [5] that, within statistical uncertainties, this conditional is equal to the probability of an electron to satisfy \( \text{ELE\_SH}(1,15) \), independent of whether that electron also satisfies \( \text{ELE\_NL\_V}(1,15) \).

The value of \( P(e | \text{ELE\_NL\_V}(2,15)) \) and \( P(e | \text{ELE\_SH}(1,15)) \) are obtained using Equation 4 and 3.

Finally, for trigger lists v8 to v11, the probability of an event to satisfy the Level 3 requirement ELE\_LOOSE(1,10) and ELE\_LOOSE(1,20) is calculated using Equation 3.

2. \( \text{di-}\mu \) triggers

The probability for an event to satisfy the \( \text{di-}\mu \) triggers presented in Table I is obtained by multiplying the probability of the event to satisfy the Level 1, Level 2 and Level 3 conditions.

\[ P_{\text{di-}\mu} = P_{L1} \cdot P_{L2} \cdot P_{L3} \] (18)

Following the same reasoning as in the previous section, the probability of an event to satisfy the Level 1 and Level 2 requirements can be directly calculated, for each trigger list version, using Equations 4 and 3, respectively. For trigger list version 11 and 12, two Level 3 conditions were used. The trigger efficiency for an offline muon to satisfy the ‘OR’ of the two conditions was measured and presented in Section I E 2.

3. \( \text{e-}\mu \) triggers

The probability for an event to satisfy the \( \text{e-}\mu \) triggers presented in Table II is calculated based on the assumption that the probability of each type of object to satisfy their respective trigger requirements is independent, i.e.

\[ P_{\text{e-}\mu} = P_{\text{EM}} \cdot P_{\text{MU}} \] (19)

where \( P_{\text{EM}} \) (\( P_{\text{MU}} \)) represents the probability for the event to satisfy the electrons-type (muon-type) conditions. These probabilities can be further sub-divided into individual trigger requirements (note there are no Level 2 conditions applied in the triggers considered)

\[ P_{\text{EM}} = P_{(e | L1)} \cdot P_{(e | L3)} P_{\text{MU}} = P_{(\mu | L1)} \cdot \] (20)

Following the discussion presented in Section IF 1, the probability for an event to satisfy the Level 1 EM requirement, taking into account the jet contribution, is

\[ P_{L1} = P_{(e | L1)} + P_{(\text{jet} | L1)} - P_{(e | L1)} \cdot P_{(\text{jet} | L1)} \] (21)

while the quantity \( P_{(e | L3)} \) is calculated using Equation 3.

Similarly, the probability \( P_{(\mu | L1)} \) is also obtained directly using Equation 3.
Due to the shortcomings of the method used to calculate the trigger efficiencies, in the case of the e+jets suite of triggers, not all the correlations can be directly taken into account. Although correlations between electrons firing jet-type trigger requirements and vice-versa exist, it has been shown, for example in Section 1E1, that many of these correlations are small and it is therefore still possible to obtain a meaningful estimate of the trigger efficiency for the e+jets triggers.

The probability for an event to satisfy the e+jets triggers presented in Table I is obtained by multiplying the probability of the event to satisfy the conditions at each triggering Level,

\[ P_{\text{e+jets}} = P_{L1} \cdot P_{L2} \cdot P_{L3} \]  

(22)

In order to take into account some correlations between electron and jet probabilities at Level 1, if an event contains at least one electron with \( p_T > 10 \) GeV, it is assumed that this particular object would satisfy both the CEM(1,10) and CJT(1,5) condition. Thus, the probability of an event to satisfy the Level 1 condition is calculated as

\[
\begin{align*}
    \text{if } & \geq 1 \text{ electron with } p_T > 10 \text{ GeV : } P_{L1} = P_{(e|\text{CEM(1,10)})} \cdot P_{(\text{jet}|\text{CJT(1,5)})} \\
    \text{else : } & P_{L1} = P_{(e|\text{CEM(1,10)})} \cdot P_{(\text{jet}|\text{CJT(2,5)})}
\end{align*}
\]

(23)

The same approach is used in order to calculate the probability for an event to satisfy the Level 2 conditions, i.e.

\[
\begin{align*}
    \text{if } & \geq 1 \text{ electron with } p_T > 10 \text{ GeV : } P_{L2} = P_{(e|\text{EM(1,10)})} \cdot P_{(\text{jet}|\text{JET(1,10)})} \\
    \text{else : } & P_{L2} = P_{(e|\text{EM(1,10)})} \cdot P_{(\text{jet}|\text{JET(2,10)})}
\end{align*}
\]

(24)

and also for the Level 3 event probability,

\[
\begin{align*}
    \text{if } & \geq 1 \text{ electron with } p_T > 15 \text{ GeV : } P_{L3} = P_{(e|\text{ELE2_OSE_SH(1,15)}) \cdot P_{(\text{jet}|\text{JET(1,15)})} \\
    \text{else : } & P_{L3} = P_{(e|\text{ELE2_OSE_SH(1,15)}) \cdot P_{(\text{jet}|\text{JET(2,15)})}
\end{align*}
\]

(25)

Note that for trigger list v12, the \( p_T \) threshold to be used in deciding which formula to use is 20 GeV instead of 15 GeV (see Table II).

5. \( \mu+jets \) triggers

The probability of an event to satisfy the \( \mu+jets \) triggers is obtained based on the same assumptions made so far.

\[ P_{\mu+jets} = P_{\text{MU}} \cdot P_{\text{JET}} \]  

(26)

where \( P_{\text{MU}} \) (\( P_{\text{JET}} \)) represents the probability for the event to satisfy the muon-type (jet-type) conditions. These probabilities can be further sub-divided into individual trigger requirements such that,

\[ v12 : P_{\text{MU}} = P_{(\mu|\text{mu1ptxaxx})} \cdot P_{(\mu|\text{MUON(1,med)})} \]
II. THE TOP_TRIGGER PACKAGE

The top_trigger package was designed to facilitate the trigger efficiency measurements for the various data analyses performed within the Top Physics group. Although the main purpose of the package is to calculate trigger weight for Monte Carlo events based on single-object turn-on curves previously measured, it also provides additional utilities that many analyzers will find useful.

A. Introduction

The top_trigger only implements at the moment the suite of triggers used in the Top Physics analyses. It could however easily be modified to accommodate any type of triggers. The package contains two main classes; the TriggerEfficiency and the TriggerDQManager classes, each described below.

B. How to obtain a copy of the code

The top_trigger package is a CVS package and can therefore easily be obtained with the following commands on the clued0 computer system:

```
> setup D0RunII pxx,xx,xx
> newrel -t my_work_directory pxx.xx.xx
> cd my_work_directory
> setup d0cvs
> kinit -f
> addpkg top_trigger Stradivarius_ichep04_br04
```

Different versions of the code exist, corresponding to the different datasets and object identification cuts used within the Top Physics group at different point in time. The most up-to-date version numbers and potential code changes, improvements and bug fixes can be found on the DØ CVS web browser[6].

C. Package Structure

The top_trigger package follow the DØ convention for framework packages. The header files are stored in top_trigger/top_trigger/ directory and the source files, in the top_trigger/src/ directory.

The parameterisations of each trigger turn-on curve needed for the trigger efficiency calculations are stored in the file top_trigger/parameters/fit.txt. The information is formatted as follow:
trigger object function Parameters and Errors

<table>
<thead>
<tr>
<th>list</th>
<th>level</th>
<th>type</th>
<th>condition</th>
<th>A0</th>
<th>ΔA0</th>
<th>A1</th>
<th>ΔA1</th>
<th>A2</th>
<th>ΔA2</th>
<th>A3</th>
<th>ΔA3</th>
<th>A4</th>
<th>ΔA4</th>
<th>A5</th>
<th>ΔA5</th>
</tr>
</thead>
<tbody>
<tr>
<td>v12</td>
<td>L1</td>
<td>EM</td>
<td>CEM(1,11)</td>
<td>f1</td>
<td>15</td>
<td>9</td>
<td>3</td>
<td>15</td>
<td>0.9914</td>
<td>0.0009</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>v12</td>
<td>L3</td>
<td>EM</td>
<td>ELE(1,12)</td>
<td>f2</td>
<td>13.6</td>
<td>0.5</td>
<td>1.57</td>
<td>0.07</td>
<td>0.974</td>
<td>0.002</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13.65</td>
<td>0.08</td>
<td>1.4</td>
<td>0.1</td>
<td>0.998</td>
<td>0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

...etc...

All the turn-on curve functions can be found in the file `top_trigger/src/TriggerEfficiency.cpp`.

A similar format is used for the text file containing the parameterisations of the jet systematic uncertainties contained in the file `top_trigger/parameters/systematics.txt`.

The directory `top_trigger/doc/` contains documentation about the package and its usage. In addition, plots of the various turn-on curves used in the package and the fitting results are stored in the directory `top_trigger/doc/turn-on`.

### D. The TriggerEfficiency Class

The combination of different efficiency turn-on curves is done within the `TriggerEfficiency` class. The following non-exhaustive list of methods are available in the `TriggerEfficiency` class. Most methods are overloaded such that you have a choice of different input parameters for maximal flexibility and ease of use. Details of implementation of each method can be found in `top_trigger/top_trigger/TriggerEfficiency.hpp`.

```cpp
float EventWeight(...) // This method returns a weight (between 0-1) for each event for which this method is called. If no trigger list version is passed to the method, the event weight returned is the luminosity averaged weight for each trigger list version. This method can be called more than once per events. Just change the key input parameter in order to separately store internally the results of each different call to the EventWeight method.
```
vector<float>
EventWeightSigma(...) Returns a vector of event weights corresponding to the
weight obtained by varying individual turn-on curves
by ± 1 sigma. The vector elements correspond to the
following variations:

\[
\text{vector \ which \ turn-on \ sigma \ element \ curve \ is \ varied \ variation}
\]

\[
[0] \ EM \ L1 \ +1.
[1] \ EM \ L2 \ +1.
[2] \ EM \ L3 \ +1.
[3] \ MU \ L1 \ +1.
[4] \ MU \ L2 \ +1.
[5] \ MU \ L3 \ +1.
[6] \ JET \ L1 \ +1.
[7] \ JET \ L2 \ +1.
[8] \ JET \ L3 \ +1.
[9] \ EM \ L1 \ -1.
[10] \ EM \ L2 \ -1.
[11] \ EM \ L3 \ -1.
[12] \ MU \ L1 \ -1.
[13] \ MU \ L2 \ -1.
[14] \ MU \ L3 \ -1.
[15] \ JET \ L1 \ -1.
[16] \ JET \ L2 \ -1.
[17] \ JET \ L3 \ -1.
\]

float GetTriggerEfficiency(...) After looping over all the events, a call to this method
will return the total average event weight. You can
specify a trigger list version if you only want the
average event weight of this sample for a particular
trigger list only. If you called the method EventWeight
more than once in your event loop, you can access the
total average weight corresponding to each different
call by passing the appropriate key. This key identifies
which internal counters should be read.

bool hasEventFired(...) This method simply calls internally the EventWeight
method and then generate a random number to decide
whether this event should have passed the trigger
requirements or not. Not that a call to this method
does not increment the internal counters of the
TriggerEfficiency class and therefore you cannot call at
the end of your event loop the GetTriggerEfficiency
method (it will simply return 0).
float MuonDetEta(...) Method provided to help calculate the muon detector eta.

1. Code Example

If you use a MakeClass framework running over top_analyzed rootuple, then at the beginning of your code, you need to create an object of type Trigger Efficiency:

```cpp
bool debug = false; /* debug information is printed or not

// lumi for (v12,v11,v10,v9,v8-part1,v8-part2)

TriggerEfficiency *t = new TriggerEfficiency("top_trigger",debug,lumi);
```

Then, in the event loop, call the EventWeight and EventWeightSigma methods with the appropriate inputs:

```cpp
// Loop over all the events
for (int ievent=0; ievent < Nevt; ievent++){
    .... bla...bla...bla...

    // For muon without a track match, use local muon
    // information.
    //
    // if muon is MTC, reject
    //
    // For muon with a track match, remember to
    // transform muon PHYSICS eta into DETECTOR eta
    //
    float* MUpt = new float[Nmuons];
    float* MUeta = new float[Nmuons];
    float* MUphi = new float[Nmuons];

    for (int i=0;i< Nmuons;i++) {
        if (MuonArray_hascentral[i]==1) {
            MUpt[i] = MuonArray_pt[i];
            MUeta[i] = t->MuonDetEta(MuonArray_eta[i],
                                      MuonArray_phi[i],
                                      MuonArray_z0[i]);
            MUphi[i] = MuonArray_phi[i];
        }
    }
```
else {
    if (MuonArray_qptloc[i] != 0.) MUpt[i] = fabs( 1./MuonArray_qptloc[i] );
    else continue;
    MUeta[i] = MuonArray_etaloc[i];
    MUphi[i] = MuonArray_philoc[i];
}

//
// Correct the energy of mu-tagged jets to use
// the light quark JES
//
float* JETpt = new float[Njets];
for (int i =0; i< Njets; i++){
    if (JetArray_muotag[i]) {
    }
    else JETpt[i] = JetArray_pt[i];
}

//
// Calculate the trigger weight of this particular events
//
float evtw_ejets = t->TriggerEfficiency::EventWeight("ejets",
    Nems, EMArray_pt, EMArray_caldetectoreta, EMArray_phi,
    Nmuons, MUpt, MUeta, MUphi, Njets,JETpt, JetArray_detEta, JetArray_phi,
    cal_met,"key1");

//
// Get a vector of trigger weight calculated by varying
// individually each type of turn on curves
//
std::vector< float > weight_syst =
    t->TriggerEfficiency::EventWeightSigma("ejets",
        Nems, EMArray_pt,
        EMArray_caldetectoreta, EMArray_phi,
        Nmuons, MUpt, MUeta, MUphi, Njets,JETpt, JetArray_detEta, JetArray_phi,
        cal_met,"key1");
JetArray_phi,
cal_met);
...
}

At the end of your event loop, you can then call:

    // Returns the average weight of all the events
    float total_weight = t->TriggerEfficiency::GetTriggerEfficiency("ejets","key1");

E. The TriggerDQManager Class

This class provides an interface to easily check whether an event is valid for a particular
stop analysis. The code can be found in top_trigger/src/TriggerDQManager.cpp and
stop_trigger/top_trigger/TriggerDQManager.hpp.

The class TriggerDQManager has been designed to check the L1/L2 bits for you in order to
protect against bugs in the scriptrunner code that were present for a few months a resulted
in events being recorded even though they had not satisfied all the trigger requirements. In
addition, it also automatically check for bad luminosity blocks and good run numbers (it
internally calls the top_dq package). Basically, it does it all for you and return a boolean
value as to whether or not a particular event is valid for your analysis.

At the beginning of your code, create a new object of type TriggerDQManager:

    TriggerDQManager *_myEventManager =
        new TriggerDQManager("mujets","top_dq","top_trigger")

or, equivalently,

    TriggerDQManager *_myEventManager =
        new TriggerDQManager("MUQCD","top_dq","top_trigger")

Then, in your event loop, simply call:

    bool eventOK =
        _myEventManager->isEventValidForAnalysis(run,lbn,L1Name,L2Name,L3Name)

where

    run = run number
    lbn = luminosity block number
    L1Name = vector of string containing L1 bit names fired by this event
    L2Name = vector of string containing L2 bit names fired by this event
    L3Name = vector of string containing L3 bit names fired by this event

The following basic methods are available:
bool isEventValidForAnalysis(...) Main method. Checks Good run list, bad luminosity block list and whether the event fired the right trigger for a particular top analysis. It checks, as a fix to a bug in scriptrunner for the data taking period April-November 2002, that the right L1/L2 bits were also fired.

TriggerEfficiency *eff() Returns a pointer to the default TriggerEfficiency object that was internally created. This pointer can then be used to call any method associated with the TriggerEfficiency class.

analysis_dataquality *adq() Returns a pointer to the analysis_dataquality object (see top_dq package) internally created. This pointer can then be used to call any methods associated with analysis_dataquality objects.

1. Code Example

If you are using the MakeClass framework, in order to be able to decode the trigger bit names, you will need to first include the utils.cpp and utils.hpp files in the directory where you want to run the root macro from. These files are part of the top_analyze tarball and can be found in the directories top_tree/src/ and top_tree/top_tree/.

```
TriggerDQManager _mymanager;
_mymanager("mujets","top_dq","top_trigger");

std::vector<string> L1Name, L2Name, L3Name;

for (int iname=0; iname<l1name_n; ++iname) {
    std::string trigname =
        IString(L1NameArray_l1name[iname]).get_string();
    L1Name.push_back(trigname);
}  // L1 names

for (int iname=0; iname<l2name_n; ++iname) {
    std::string trigname =
        IString(L2NameArray_l2name[iname]).get_string();
    L2Name.push_back(trigname);
}  // L2 names

for (int iname=0; iname<l3name_n; ++iname) {
    std::string trigname =
        IString(L3NameArray_l3name[iname]).get_string();
    L3Name.push_back(trigname);
}  // L3 names
```
bool trig = _mymanager->isEventValidForAnalysis(runnum,
  lumblk,
  L1Name,
  L2Name,
  L3Name);

If you are instead using the topd0root framework:

TriggerDQManager _mymanager;
_mymanager("mujets","top_dq","top_trigger");

int runNumber = event()->GetRunNumber();
int lbn = event()->GetLumblk();

// L1Name
std::vector<std::string> L1Names;
TClonesArray* L1NameArray = event()->GetL1Names();
for (unsigned int i=0; i<L1NameArray->GetEntries(); i++) {
  TheL1NameClass* L1name = (TheL1NameClass*)L1NameArray->At(i);
  std::string s((L1name->L1Name()).Data());
  L1Names.push_back(s);
}

// L2Name
std::vector<std::string> L2Names;
TClonesArray* L2NameArray = event()->GetL2Names();
for (unsigned int i=0; i<L2NameArray->GetEntries(); i++) {
  TheL2NameClass* L2name = (TheL2NameClass*)L2NameArray->At(i);
  std::string s((L2name->L2Name()).Data());
  L2Names.push_back(s);
}

// L3Name
std::vector<std::string> L3Names;
TClonesArray* L3NameArray = event()->GetL3Names();
for (unsigned int i=0; i<L3NameArray->GetEntries(); i++) {
  TheL3NameClass* L3name = (TheL3NameClass*)L3NameArray->At(i);
  std::string s((L3name->L3Name()).Data());
  L3Names.push_back(s);
}

bool isOK = _mymanager.isEventValidForAnalysis(runNumber,
  lbn,
  L1Names,
  L2Names,
  L3Names);
Note that the `TriggerDQManager` class instantiates internally both a `TriggerEfficiency` and `analysis_dataquality` object. It takes care of both the data quality and the trigger requirements. You can use those objects with a call like:

```c++
_mymanager->eff()->EventWeight("mujets", nEM, EMpt, ...);
```
APPENDIX A: LEVEL 3 ELECTRON TURN-ON CURVES

All the Level 3 electron turn-on curves for the different trigger thresholds considered are shown in this section (Figure 11 to 22). On all Figures, the point represent data and the solid line shows the results of a fit to the data using Equation 5. In order to obtain a parameterisation of the Level 3 condition for trigger threshold lower than 15 GeV, the fitted values of parameters obtained at different trigger $p_T$ threshold are extrapolated to the value of trigger threshold needed.
FIG. 12: Trigger efficiency as function of $p_T$ for an offline electron in the barrel (left) and endcap (right) calorimeter for the Level 3 requirement ELE_NLV(1,25) used in trigger list v12.

FIG. 13: Trigger efficiency as function of $p_T$ for an offline electron in the barrel (left) and endcap (right) calorimeter for the Level 3 requirement ELE_NLV(1,30) used in trigger list v12.
FIG. 14: Trigger efficiency as function of $p_T$ for an offline electron in the barrel (left) and endcap (right) calorimeter for the Level 3 requirement ELE\_NLV(1,35) used in trigger list v12.

FIG. 15: Trigger efficiency as function of $p_T$ for an offline electron in the barrel (left) and endcap (right) calorimeter for the Level 3 requirements ELE\_SH(1,20) (top) and ELE\_SHT(1,20) (bottom) used in trigger list v12.
FIG. 16: Trigger efficiency as function of $p_T$ for an offline electron in the barrel (left) and endcap (right) calorimeter for the Level 3 requirements ELE$_{SH}(1,25)$ (top) and ELE$_{SHT}(1,25)$ (bottom) used in trigger list v12.

FIG. 17: Trigger efficiency as function of $p_T$ for an offline electron in the barrel (left) and endcap (right) calorimeter for the Level 3 requirements ELE$_{SH}(1,30)$ (top) and ELE$_{SHT}(1,30)$ (bottom) used in trigger list v12.
FIG. 18: Trigger efficiency as function of $p_T$ for an offline electron in the barrel (left) and endcap (right) calorimeter for the Level 3 requirements ELE_SH(1,35) (top) and ELE_SHT(1,35) (bottom) used in trigger list v12.

FIG. 19: Trigger efficiency as function of $p_T$ for an offline electron in the barrel (left) and endcap (right) calorimeter for the Level 3 requirements ELE_LOOSE(1,20) (top) and ELE_LOOSE_SH_T(1,20) (bottom) used in trigger list v8 to v11.
FIG. 20: Trigger efficiency as function of $p_T$ for an offline electron in the barrel (left) and endcap (right) calorimeter for the Level 3 requirements ELE_LOOSE(1,25) (top) and ELE_LOOSE_SH_T(1,25) (bottom) used in trigger list v8 to v11.

FIG. 21: Trigger efficiency as function of $p_T$ for an offline electron in the barrel (left) and endcap (right) calorimeter for the Level 3 requirements ELE_LOOSE(1,30) (top) and ELE_LOOSE_SH_T(1,30) (bottom) used in trigger list v8 to v11.
FIG. 22: Trigger efficiency as function of $p_T$ for an offline electron in the barrel (left) and endcap (right) calorimeter for the Level 3 requirements ELE\_LOOSE(1,35) (top) and ELE\_LOOSE\_SH,T(1,35) (bottom) used in trigger list v8 to v11.
FIG. 23: Relative differences between the L1 trigger efficiencies from trigger list v12 measured with and without requiring a track-match for the jets.

APPENDIX B: LEVEL 3 JET EFFICIENCY SYSTEMATICS

This section shows all the plots of the relative difference in the measured jet trigger efficiencies between efficiencies obtained with and without requiring a track-match for the jet definition. This relative difference as function of jet $p_T$ is taken as a systematic uncertainty on the jet trigger efficiency turn-on curves.
FIG. 24: Relative differences between the L2 trigger efficiencies from trigger list v12 measured with and without requiring a track-match for the jets.

FIG. 25: Relative differences between the L3 trigger efficiencies (JET(1,25)) from trigger list v12 measured with and without requiring a track-match for the jets.
FIG. 26: Relative differences between the L1 trigger efficiencies from trigger list v11 measured with and without requiring a track-match for the jets.

FIG. 27: Relative differences between the L2 trigger efficiencies from trigger list v11 measured with and without requiring a track-match for the jets.
FIG. 28: Relative differences between the L3 trigger efficiencies (JET(1,20)) from trigger list v11 measured with and without requiring a track-match for the jets.

FIG. 29: Relative differences between the L1 trigger efficiencies from trigger list v10 measured with and without requiring a track-match for the jets.
FIG. 30: Relative differences between the L2 trigger efficiencies from trigger list v10 measured with and without requiring a track-match for the jets.

FIG. 31: Relative differences between the L3 trigger efficiencies (JET(1,25)) from trigger list v10 measured with and without requiring a track-match for the jets.
FIG. 32: Relative differences between the L1 trigger efficiencies from trigger list v9 measured with and without requiring a track-match for the jets.

FIG. 33: Relative differences between the L2 trigger efficiencies from trigger list v9 measured with and without requiring a track-match for the jets.
FIG. 34: Relative differences between the L3 trigger efficiencies (JET(1,20)) from trigger list v9 measured with and without requiring a track-match for the jets.


