Run II Trigger Performance For $e\mu$ Triggers

CMS Collaboration

Abstract

This note reports the trigger efficiencies for the $e\mu$ cross triggers for the entire Run II. The efficiencies for 2016, 2017 and 2018 are compared.
Run II Trigger Performance for eμ triggers

On behalf of CMS Collaboration

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The trigger efficiency for cross triggers has been measured using the Tag and Probe method by acquiring dilepton events having same flavour and opposite charge such that the invariant mass of the combination (tag and probe lepton) is consistent with the Z mass, in a dilepton mass window of 60-120 GeV.

An isolated muon candidate (Tag) is required to have $p_T > 30$ GeV at the trigger level (entire Run II) and $|\eta| < 2.4$, whereas an electron candidate (Tag) is required to have $p_T > 35$ GeV and 40 GeV for 2016, 2017-2018 respectively with $|\eta| < 2.5$.

The Tag candidate (muon/electron) required to pass the tight ISO/ID and single lepton trigger. For electron candidate, multivariate identification with isolation with working point corresponding to 90% signal efficiency is applied, whereas for muon candidate tight selection for identification and isolation is applied with working point corresponding to 80% signal efficiency.

The Probe candidate is required to satisfy the same lepton selection as that of the Tag candidate and also to pass the trigger, ensured by geometrical matching of probe lepton with corresponding physics object at trigger level within $\Delta R < 0.1$, where $\Delta R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2}$. 

Introduction
The trigger efficiency (L1+HLT) is calculated by taking the ratio of events with the Probe passing the trigger in question, to all Probes, where all probe is defined as those lepton pairs which passes the lepton selection only.

\[
\text{Trigger efficiency} = \frac{\text{Passing probe}}{\text{All probe}}
\]

Trigger efficiencies are measured and compared within full 2016, 2017 and 2018 dataset.

Even though these are cross lepton triggers, we still use tag and probe method with same flavour dilepton events. We achieved this by using the closest dilepton trigger leg to each leg of eμ trigger and apply the remaining selection by hand. Specific L1T seed is also required to pass.

As an example, for the efficiency of muon leg of HLT_Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL_DZ, we have used Mu8 leg of HLT_Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ. In addition to it, \(p_T\) threshold and quality cuts have been applied i.e. (L1Mu20 OR L1Mu23) and (L1MuQual>=12 AND L1MuQual<=15) for HLTMu23 (L1Mu5 OR L1Mu7 for HLTMu12). OR of the L1 thresholds take care of all the L1 seeds of respective trigger. The efficiency of electron leg of HLT_Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL_DZ and HLT_Mu12_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ triggers has been measured from the HLT_Ele23_Ele12_CaloIdL_TrackIdL_IsoVL_DZ.

We used this method, as Tag and Probe is a more standard method and we also gain in statistics with usage of dilepton events from Z boson candidates.
HLT_Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL_DZ : electron Leg
Electron trigger efficiency as a function of the reconstructed electron transverse momentum ($p_T$) in the full Run II dataset corresponding to an integrated luminosity of 138 fb$^{-1}$ collected at $\sqrt{s}=13$ TeV. The efficiency is measured by tag-and-probe method (in $Z\rightarrow ee$ event) with respect to mva-based tight electron identification. The reconstructed electron pseudorapidity is restricted to the acceptance of the trigger path that is $\text{abs}(\eta)<2.5$ unless specified. The plotted uncertainties are statistical only. The last bin includes the overflow, i.e. also probes with $p_T>200$ GeV.

HLT_Ele12_CaloIdL_TrackIdL_IsoVL is the electron leg of the lowest threshold unprescaled cross-lepton trigger HLT_Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL_DZ that requires $E_T>12$ GeV for the electron. The “DZ” requirement on the distance of closest approach in Z direction between the two electron tracks is $\sim 99.5\%$ efficient. Electron triggers are seeded via a logical OR of various level-1 trigger items. At the highest instantaneous luminosities, the level-1 $E_T$ threshold was higher than the HLT threshold contributing to the delayed turn-on of the efficiency as a function of $p_T$. The efficiency is better in 2016 as the tracker alignment was much better in 2016 and also issues with new pixel detector were there in 2017 and 2018.
HLT_Mu12_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ : electron leg

CMS Preliminary

36 fb$^{-1}$ + 42 fb$^{-1}$ + 60 fb$^{-1}$ (13 TeV)

Efficiency

Electron $p_T$ (GeV)

2016 HLT_Ele23
2017 HLT_Ele23
2018 HLT_Ele23
Electron trigger efficiency as a function of the reconstructed electron transverse momentum ($p_T$) in the full Run II dataset corresponding to an integrated luminosity 138 fb$^{-1}$ collected at $\sqrt{s}=13$ TeV. The efficiency is measured by tag-and-probe method (in $Z\rightarrow ee$ event) with respect to mva-based tight electron identification. The plotted uncertainties are statistical only. The reconstructed electron pseudorapidity is restricted to the acceptance of the trigger path that is $\text{abs}(\eta)<2.5$ unless specified. The last bin includes the overflow, i.e. also probes with $p_T>200$ GeV.

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CMS Preliminary

36 fb⁻¹ + 42 fb⁻¹ + 60 fb⁻¹ (13 TeV)

Electron $p_T >$ HLT Threshold + 2 GeV

- 2016 HLT_Ele12
- 2017 HLT_Ele12
- 2018 HLT_Ele12
Electron trigger efficiency as a function of the reconstructed electron pseudo rapidity ($\eta$) in the full Run II dataset corresponding to an integrated luminosity $138 \text{ fb}^{-1}$ collected at $\sqrt{s}=13 \text{ TeV}$. The efficiency is measured by tag-and-probe method (in $Z\rightarrow ee$ event) with respect to mva-based tight electron identification. It is required that the reconstructed electron transverse momentum ($p_T$) is at least 2 GeV higher than the trigger threshold to show the behavior with typical analysis cuts. The reconstructed electron pseudorapidity is restricted to the acceptance of the trigger path that is $\text{abs}(\eta)<2.5$ unless specified. The plotted uncertainties are statistical only.

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HLT_Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL_DZ : electron leg

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36 fb$^{-1} + 42$ fb$^{-1} + 60$ fb$^{-1}$ (13 TeV)

Efficiency

Electron $p_T > 50$ GeV

- 2016 HLT_Ele12
- 2017 HLT_Ele12
- 2018 HLT_Ele12
Electron trigger efficiency as a function of the reconstructed electron pseudo rapidity ($\eta$) in the full Run II dataset corresponding to an integrated luminosity 138 fb$^{-1}$ collected at $\sqrt{s}=13$ TeV. The efficiency is measured by tag-and-probe method (in $Z\rightarrow ee$ event) with respect to mva-based tight electron identification. It is required that the reconstructed electron transverse momentum ($p_T$) is at least 50 GeV to show the behaviour on the efficiency plateau in $p_T$. The reconstructed electron pseudorapidity is restricted to the acceptance of the trigger path that is $\text{abs}(\eta)<2.5$ unless specified. The plotted uncertainties are statistical only.

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**CMS Preliminary**

36 fb$^{-1}$ + 42 fb$^{-1}$ + 60 fb$^{-1}$ (13 TeV)

![Graph showing electron efficiency as a function of number of vertices](image)

- Electron $p_T >$ HLT Threshold + 2 GeV
- 2016 HLT_Ele12
- 2017 HLT_Ele12
- 2018 HLT_Ele12
Electron trigger efficiency as a function of the number of reconstructed vertices - that is used to estimate the amount of pile-up in the event in the full Run II dataset corresponding to an integrated luminosity 138 fb\(^{-1}\) collected at \(\sqrt{s}=13\) TeV. The efficiency is measured by tag-and-probe method (in Z\(\rightarrow\)ee event) with respect to mva-based tight electron identification. It is required that the reconstructed electron transverse momentum (\(p_T\)) is at least 2 GeV higher than the trigger threshold to show the behavior with typical analysis cuts. The reconstructed electron pseudorapidity is restricted to the acceptance of the trigger path that is \(\text{abs}(\eta) < 2.5\) unless specified. The plotted uncertainties are statistical only.

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CMS Preliminary

36 fb\(^{-1}\) + 42 fb\(^{-1}\) + 60 fb\(^{-1}\) (13 TeV)

Electron p_{T} > 50 GeV

- 2016 HLT_Ele12
- 2017 HLT_Ele12
- 2018 HLT_Ele12
Electron trigger efficiency as a function of the number of reconstructed vertices - that is used to estimate the amount of pile-up in the full Run II dataset corresponding to an integrated luminosity 138 fb$^{-1}$ collected at $\sqrt{s}=13$ TeV. The efficiency is measured by tag-and-probe method (in $Z \rightarrow ee$ event) with respect to mva-based tight electron identification. It is required that the reconstructed electron transverse momentum ($p_T$) is at least 50 GeV to show the behaviour on the efficiency plateau in $p_T$. The reconstructed electron pseudorapidity is restricted to the acceptance of the trigger path that is $\text{abs}(\eta)<2.5$ unless specified. The plotted uncertainties are statistical only.

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Electron $p_T > $ HLT Threshold + 2 GeV

- 2016 HLT_Ele23
- 2017 HLT_Ele23
- 2018 HLT_Ele23
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36 fb\(^{-1}\) + 42 fb\(^{-1}\) + 60 fb\(^{-1}\) (13 TeV)

Electron \(p_T > 50\) GeV

- 2016 HLT_Ele23
- 2017 HLT_Ele23
- 2018 HLT_Ele23
Electron trigger efficiency as a function of the number of reconstructed vertices - that is used to estimate the amount of pile-up in the full Run II dataset corresponding to an integrated luminosity 138 fb$^{-1}$ collected at $\sqrt{s}=13$ TeV. The efficiency is measured by tag-and-probe method (in Z→ee event) with respect to mva-based tight electron identification. It is required that the reconstructed electron transverse momentum ($p_T$) is at least 50 GeV to show the behaviour on the efficiency plateau in $p_T$. The reconstructed electron pseudorapidity is restricted to the acceptance of the trigger path that is $|\eta|<2.5$ unless specified. The plotted uncertainties are statistical only.

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Muon trigger efficiency as a function of the reconstructed muon transverse momentum ($p_T$) in the full Run II dataset corresponding to an integrated luminosity $138 \text{ fb}^{-1}$ collected at $\sqrt{s}=13 \text{ TeV}$. The efficiency is measured by tag-and-probe method (in $Z\rightarrow\mu\mu$ event) with respect to cut-based tight muon identification and tight isolation. The reconstructed muon pseudorapidity is restricted to the acceptance of the trigger path that is $\text{abs}(\eta)<2.4$ unless specified. The plotted uncertainties are statistical only. The last bin includes the overflow, i.e. also probes with $p_T>200 \text{ GeV}$.

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HLT_Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL_DZ: muon leg

CMS Preliminary

36 fb$^{-1}$ + 42 fb$^{-1}$ + 60 fb$^{-1}$ (13 TeV)

Efficiency vs. Muon $p_T$ (GeV)

- 2016 HLT_Mu23
- 2017 HLT_Mu23
- 2018 HLT_Mu23
Muon trigger efficiency as a function of the reconstructed muon transverse momentum ($p_T$) in the full Run II dataset corresponding to an integrated luminosity 138 fb$^{-1}$ collected at $\sqrt{s}=13$ TeV. The efficiency is measured by tag-and-probe method (in $Z\rightarrow\mu\mu$ event) with respect to cut-based tight muon identification and tight isolation. The reconstructed muon pseudorapidity is restricted to the acceptance of the trigger path that is $|\eta|<2.4$ unless specified. The plotted uncertainties are statistical only. The last bin includes the overflow, i.e. also probes with $p_T>200$ GeV.

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CMS Preliminary

36 fb^{-1} + 42 fb^{-1} + 60 fb^{-1} (13 TeV)

Efficiency

Muon p_{T} > HLT Threshold + 2 GeV

- 2016 HLT_Mu12
- 2017 HLT_Mu12
- 2018 HLT_Mu12
Muon trigger efficiency as a function of the reconstructed muon pseudo rapidity ($\eta$) in the full Run II dataset corresponding to an integrated luminosity 138 fb$^{-1}$ collected at $\sqrt{s}=13$ TeV. The efficiency is measured by tag-and-probe method (in $Z\rightarrow\mu\mu$ event) with respect to cut-based tight muon identification and tight isolation. The reconstructed muon pseudorapidity is restricted to the acceptance of the trigger path that is $\text{abs}(\eta)<2.4$ unless specified. It is required that the reconstructed muon transverse momentum ($p_T$) is at least 2 GeV higher than the trigger threshold to show the behavior with typical analysis cuts. The plotted uncertainties are statistical only.

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36 fb$^{-1}$ + 42 fb$^{-1}$ + 60 fb$^{-1}$ (13 TeV)

Efficiency vs Muon $\eta$

Muon $p_T > 50$ GeV

- 2016 HLT_Mu12
- 2017 HLT_Mu12
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36 fb\(^{-1}\) + 42 fb\(^{-1}\) + 60 fb\(^{-1}\) (13 TeV)

![Efficiency Plot](image)

Muon p_{T} > HLT Threshold + 2 GeV

- 2016 HLT_Mu23
- 2017 HLT_Mu23
- 2018 HLT_Mu23
Muon trigger efficiency as a function of the reconstructed muon pseudo rapidity ($\eta$) in the full Run II dataset corresponding to an integrated luminosity 138 $fb^{-1}$ collected at $\sqrt{s}=13$ TeV. The efficiency is measured by tag-and-probe method (in $Z\rightarrow\mu\mu$ event) with respect to cut-based tight muon identification and tight isolation. The reconstructed muon pseudorapidity is restricted to the acceptance of the trigger path that is $|\eta|<2.4$ unless specified. It is required that the reconstructed muon transverse momentum ($p_T$) is at least 2 GeV higher than the trigger threshold to show the behavior with typical analysis cuts. The plotted uncertainties are statistical only.

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36 fb⁻¹ + 42 fb⁻¹ + 60 fb⁻¹ (13 TeV)

Efficiency

Muon $p_T > 50$ GeV

- 2016  HLT_Mu23
- 2017  HLT_Mu23
- 2018  HLT_Mu23

Muon $\eta$
Muon trigger efficiency as a function of the reconstructed muon pseudo rapidity ($\eta$) in the full Run II dataset corresponding to an integrated luminosity 138 fb$^{-1}$ collected at $\sqrt{s}=13$ TeV. The efficiency is measured by tag-and-probe method (in $Z\rightarrow\mu\mu$ event) with respect to cut-based tight muon identification and tight isolation. The reconstructed muon pseudorapidity is restricted to the acceptance of the trigger path that is $\text{abs}(\eta)<2.4$ unless specified. It is required that the reconstructed electron transverse momentum ($p_T$) is at least 50 GeV to show the behaviour on the efficiency plateau in $p_T$. The plotted uncertainties are statistical only.

HLT_Mu23_TrkIsoVVL_CaloIdL_TrackIdL_IsoVL is the muon leg of the lowest threshold unprescaled cross-lepton trigger HLT_Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL_DZ that requires $E_T>23$ GeV for the muon. The “DZ” requirement on the distance of closest approach in Z direction between the two muon tracks is $\sim 99.5\%$ efficient. Muon triggers are seeded via a logical OR of various level-1 trigger items. At the highest instantaneous luminosities, the level-1 $E_T$ threshold was higher than the HLT threshold contributing to the delayed turn-on of the efficiency as a function of $p_T$. The efficiency is better in 2018 as compared to 2016 and 2017 due to better muon reconstruction performance in 2018 and phase-I pixel performance was much better in 2018 than 2017. As 2017 suffered from DCDC converter issues and extended commissioning period in the beginning of 2017.
HLT_Mu12_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ : muon leg

CMS Preliminary

36 fb$^{-1}$ + 42 fb$^{-1}$ + 60 fb$^{-1}$ (13 TeV)

Efficiency

Muon $p_T >$ HLT Threshold + 2 GeV

- 2016 HLT_Mu12
- 2017 HLT_Mu12
- 2018 HLT_Mu12

Number of Vertices
Muon trigger efficiency as a function of the number of reconstructed vertices - that is used to estimate the amount of pile-up in the full Run II dataset corresponding to an integrated luminosity 138 fb$^{-1}$ collected at $\sqrt{s}=13$ TeV. The efficiency is measured by tag-and-probe method (in Z→μμ event) with respect to cut-based tight muon identification and tight isolation. The reconstructed muon pseudorapidity is restricted to the acceptance of the trigger path that is $|\eta|<2.4$ unless specified. It is required that the reconstructed muon transverse momentum ($p_T$) is at least 2 GeV higher than the trigger threshold to show the behavior with typical analysis cuts. The plotted uncertainties are statistical only.

HLT_Mu12_TrkIsoVVL_CaloIdL_TrackIdL_IsoVL is the muon leg of the lowest threshold unprescaled cross-lepton trigger HLT_Mu12_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ that requires $E_T>12$ GeV for the muon. The “DZ” requirement on the distance of closest approach in Z direction between the two muon tracks is $\sim 99.5\%$ efficient. Muon triggers are seeded via a logical OR of various level-1 trigger items. At the highest instantaneous luminosities, the level-1 $E_T$ threshold was higher than the HLT threshold contributing to the delayed turn-on of the efficiency as a function of $p_T$. The efficiency is better in 2018 as compared to 2016 and 2017 due to better muon reconstruction performance in 2018 and phase-I pixel performance was much better in 2018 than 2017. As 2017 suffered from DCDC converter issues and extended commissioning period in the beginning of 2017.
HLT_Mu12_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ: muon leg

CMS Preliminary

36 fb$^{-1}$ + 42 fb$^{-1}$ + 60 fb$^{-1}$ (13 TeV)

Efficiency vs. Number of Vertices

Muon $p_T > 50$ GeV

- 2016 HLT_Mu12
- 2017 HLT_Mu12
- 2018 HLT_Mu12

Number of Vertices
Muon trigger efficiency as a function of the number of reconstructed vertices - that is used to estimate the amount of pile-up in the full Run II dataset corresponding to an integrated luminosity 138 fb$^{-1}$ collected at $\sqrt{s}=13$ TeV. The efficiency is measured by tag-and-probe method (in $Z\rightarrow\mu\mu$ event) with respect to cut-based tight muon identification and tight isolation. The reconstructed muon pseudorapidity is restricted to the acceptance of the trigger path that is $\text{abs}(\eta)<2.4$ unless specified. It is required that the reconstructed electron transverse momentum ($p_T$) is at least 50 GeV to show the behaviour on the efficiency plateau in $p_T$.

HLT_Mu12_TrkIsoVVL_CaloIdL_TrackIdL_IsoVL is the muon leg of the lowest threshold unprescaled cross-lepton trigger HLT_Mu12_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ that requires $E_T>12$ GeV for the muon. The “DZ” requirement on the distance of closest approach in Z direction between the two muon tracks is $\sim 99.5\%$ efficient. Muon triggers are seeded via a logical OR of various level-1 trigger items. At the highest instantaneous luminosities, the level-1 $E_T$ threshold was higher than the HLT threshold contributing to the delayed turn-on of the efficiency as a function of $p_T$. The efficiency is better in 2018 as compared to 2016 and 2017 due to better muon reconstruction performance in 2018 and phase-I pixel performance was much better in 2018 than 2017. As 2017 suffered from DCDC converter issues and extended commissioning period in the beginning of 2017.
HLT_Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL_DZ: muon leg

CMS Preliminary

36 fb$^{-1}$ + 42 fb$^{-1}$ + 60 fb$^{-1}$ (13 TeV)

Efficiency vs. Number of Vertices

Muon $p_T >$ HLT Threshold + 2 GeV

- 2016 HLT_Mu23
- 2017 HLT_Mu23
- 2018 HLT_Mu23
Muon trigger efficiency as a function of the number of reconstructed vertices - that is used to estimate the amount of pile-up in the full Run II dataset corresponding to an integrated luminosity 138 fb$^{-1}$ collected at $\sqrt{s}=13$ TeV. The efficiency is measured by tag-and-probe method (in $Z\rightarrow\mu\mu$ event) with respect to cut-based tight muon identification and tight isolation. The reconstructed muon pseudorapidity is restricted to the acceptance of the trigger path that is $\text{abs}(\eta)<2.4$ unless specified. It is required that the reconstructed muon transverse momentum ($p_T$) is at least 2 GeV higher than the trigger threshold to show the behavior with typical analysis cuts. The plotted uncertainties are statistical only.

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HLT_Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL_DZ: muon leg

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Efficiency vs Number of Vertices

Muon $p_T > 50$ GeV

- 2016 HLT_Mu23
- 2017 HLT_Mu23
- 2018 HLT_Mu23
Muon trigger efficiency as a function of the number of reconstructed vertices - that is used to estimate the amount of pile-up in the full Run II dataset corresponding to an integrated luminosity 138 fb$^{-1}$ collected at $\sqrt{s}=13$ TeV. The efficiency is measured by tag-and-probe method (in $Z\rightarrow\mu\mu$ event) with respect to cut-based tight muon identification and tight isolation. The reconstructed muon pseudorapidity is restricted to the acceptance of the trigger path that is $\text{abs}(\eta)<2.4$ unless specified. It is required that the reconstructed electron transverse momentum ($p_T$) is at least 50 GeV to show the behaviour on the efficiency plateau in $p_T$. The plotted uncertainties are statistical only.

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