Measurements of the HLT performance of displaced muons using Cosmics data

CMS Collaboration

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This note presents the performance of a dedicated displaced standalone muon reconstruction at the High Level Trigger in cosmics data recorded with the CMS detector in 2016. The results are presented as a function of the impact parameter of the offline reconstructed muon. A double muon trigger based on this muon reconstruction has been developed for the search of long-lived particles decaying into dimuons with 2018 data. The trigger relies only on information from the muon detectors to allow sensitivity to decays beyond the inner tracking detector.
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Abstract

This note presents the performance of a dedicated displaced standalone muon reconstruction at the High Level Trigger in cosmics data recorded with the CMS detector in 2016. The results are presented as a function of the impact parameter of the offline reconstructed muon. A double muon trigger based on this muon reconstruction has been developed for the search of long-lived particles decaying into dimuons with 2018 data. The trigger relies only on information from the muon detectors to allow sensitivity to decays beyond the inner tracking detector.
Introduction

The presented performance studies are carried out in the context of a generic search for long-lived particles decaying into displaced dimuons. The studied objects are muons reconstructed using only the muon detectors, in order to be sensitive to decays beyond the inner detector (“displaced standalone” muon reconstruction, dSA).

In 2018, double muon triggers with a $p_T$ threshold of 23 GeV were developed. The presented performance studies focus on their components, i.e., single muon triggers with online $p_T$ thresholds of 23 GeV. The performance is also shown for a $p_T$ threshold of 28 GeV to illustrate the dependence of the turn-on on the threshold.

Datasets: All measurements are carried out using data recorded by a highly performant (\textsuperscript{*}) L1 trigger without $p_T$ thresholds (“SingleMuOpen” trigger), thus removing L1 effects and allowing for the evaluation of pure-HLT efficiencies.

- Cosmics data taken with a SingleMuOpen L1 trigger in 2016. Each event is required to have two offline reconstructed back-to-back dSA muons.
- Simulated signal samples using the process $h_{BSM} \rightarrow XX$, $X \rightarrow \mu^+\mu^-$, with $m_h = (125, 200)$ GeV, $m_X = (20, 50)$ GeV, and three $c_\tau_X$ samples covering typical displacements of $\langle L_{xy} \rangle = 3, 30, 300$ cm, respectively, and with the same trigger configuration as in the Cosmics data.

\textsuperscript{*} The absolute SingleMuOpen efficiency has been measured in simulation and found to be greater than 98% for muons with $p_T^{(gen)} > 5$ GeV and $|\eta| < 1.2$. 
Event display of a typical cosmic muon recorded in CMS

A cosmic muon is reconstructed as two offline back-to-back dSA muons in CMS.

$\phi$-$\phi$ plane

$\phi$-$z$ plane
Efficiency of the reference path
HLT_L2Mu10_NoVertex_CosmicSeed

Part I
Reference path efficiencies: Event & muon selection, definition of efficiency

Reference trigger: event triggered by a SingleMuOpen L1 trigger in the lower hemisphere

Offline dSA muon in event recorded by the reference trigger having:
- nStations > 1, nHits(CSC+DT) > 18, $\sigma_{p_T}/p_T < 1.0$, $\chi^2/\text{ndof} < 2.5$
- $p_T > 25$ GeV, $|\eta| < 1.2$
- $|d_z| < 200$ cm

Trigger efficiencies are defined as follows:

Efficiency = $rac{\text{offline dSA muon that passes the offline selection in an event triggered by SingleMuOpen at L1}}{\text{muon in the denominator if HLT_L2Mu10_NoVertex_CosmicSeed also fired}}$
Efficiency of the trigger HLT_L2Mu10_NoVertex_CosmicSeed for displaced muons

Figure: HLT_L2Mu10_NoVertex_CosmicSeed reconstruction efficiency for offline displaced standalone (dSA) muons measured in Cosmics data as a function of the transverse impact parameter $d_0$. Efficiencies are computed w.r.t. events with lower-leg offline dSA muons with $p_T > 25$ GeV selected with a SingleMuOpen L1 trigger. For all results, $|\eta| < 1.2$ is applied.
HLT_L2Mu[23|28]_NoVertex_CosmicSeed turn-on efficiencies

Part II
Turn-on efficiencies: Event & muon selection, definition of trigger efficiencies

**Reference HLT:** event triggered by HLT_L2Mu10_NoVertex in the lower hemisphere

**Offline dSA muon in event recorded by the reference HLT having:**
- ID: \( n\text{Stations} > 1, \ n\text{Hits(CSC+DT)} > 18, \sigma p_T/p_T < 1.0 \)
- \( |\eta| < 1.2 \)
- additional requirements for Cosmics data:
  - select the muon pair with the largest 3D opening angle \( \alpha(\mu,\mu) \) between its muon legs
  - \( \alpha(\mu,\mu) > 2.9 \)
  - require opposite detector hemispheres for the two muon legs

**Trigger efficiencies** are defined as follows:

Efficiency = \[
\frac{\text{offline dSA muon with offline } p_T > 10 \text{ GeV in event triggered by HLT_L2Mu10_NoVertex}}{\text{muon in the denominator if HLT_L2Mu[23|28]_NoVertex also fired}}
\]
Figure: Trigger turn-on efficiencies for HLT_L2Mu23_NoVertex_CosmicSeed as a function of the transverse momentum $p_T$ of offline displaced standalone (dSA) muons in different bins of the transverse impact parameter $d_0$. Efficiencies are measured w.r.t. events recorded with HLT_L2Mu10_NoVertex_CosmicSeed with a SingleMuOpen seeding at L1 that triggered in the lower detector hemisphere. Measurements with cosmic ray muons (blue) are compared to ones with MC signal samples (orange). For all results, $|\eta| < 1.2$ is applied.
Figure: Trigger turn-on efficiencies for HLT_L2Mu28_NoVertex_CosmicSeed as a function of the transverse momentum $p_T$ of offline displaced standalone (dSA) muons in different bins of the transverse impact parameter $d_0$. Efficiencies are measured w.r.t. events recorded with HLT_L2Mu10_NoVertex_CosmicSeed with a SingleMuOpen seeding at L1 that triggered in the lower detector hemisphere. Measurements with cosmic ray muons (blue) are compared to ones with MC signal samples (orange). For all results, $|\eta| < 1.2$ is applied.