PROCEEDINGS OF SCIENCE

Search for long-lived particles decaying to a pair of muons in proton-proton collisions at $\sqrt{s}$ = 13.6 TeV with 2022 data

Rubén López Ruiz[a,1,*]

[a] *Universidad de Cantabria, Av. Los Castros S/N, Santander, Spain*

E-mail: rlopezru@cern.ch

Presented here is an inclusive search for long-lived particles decaying to a pair of displaced muons. This search analyzes data collected in 2022 by the CMS experiment at the CERN LHC in proton-proton collisions at $\sqrt{s}$=13.6 TeV, adding up to an integrated luminosity of 36.6 fb^{-1}. The experimental signature is a pair of oppositely charged muons originating from a common secondary vertex spatially separated from the pp interaction (displaced dimuons), considering distances that go from several hundred micrometers to several meters. The results of the analysis are interpreted in the frameworks of two simplified models: the hidden Abelian Higgs model, in which the Higgs boson decays to a pair of long-lived dark photons, and R-parity violating supersymmetry model, in which long-lived neutralinos decay to a pair of muons and a neutrino. The results here presented substantially improve the ones in the previous analysis performed using data taken at $\sqrt{s}$=13 TeV. The key to these improvements, particularly significant at low masses and long lifetimes, is the improved triggers for displaced muons and the offline analysis refinements.

12th Large Hadron Collider Physics Conference (LHCP2024)
3-7 June 2024
Boston, USA

[1] on behalf of The CMS Collaboration
[*] Speaker

https://pos.sissa.it/

PoS(LHCP2024)265

1. Introduction

Long lived particles (LLPs) are predicted by many extensions of the standard model (SM), and present challenging signatures that may be underlooked at the LHC. This analysis [1] is an inclusive search for exotic massive LLPs decaying to a pair of oppositely charged muons (displaced dimuon) that originate from a common vertex that is displaced from the pp interaction point.

The search is performed using 36.6 fb^{-1} of data collected by the CMS experiment [2] in 2022, at $\sqrt{s}$ = 13.6 TeV. It is an extension of the equivalent search [3] performed with Run2 data from 2016 and 2018 at $\sqrt{s}$ = 13 TeV.

The search probes masses of the LLP greater than 10 GeV and vertex displacements ranging between several hundred micrometers to several meters. The results are interpreted in two different signal models: a Hidden Abelian Higgs Model (HAHM) and an R-Parity Violating (RPV) SUSY model with long lived neutralinos.

2. Improved trigger algorithms

The key to obtaining improved exclusion limits with approximately 2.5 times less luminosity than in Run 2 is the use of new, dedicated triggers in the Run3 data taking. First, a new set of level 1 seeds with very low p_T threshold are used. Additional level 1 seeds are added that benefit from a new track-finding procedure in the barrel without beamspot constraint. The p_T thresholds of the level 2 and level 3 trigger paths are also lowered.

These new triggers used in combination with the old Run 2 triggers improve the efficiency over a wide range of the LLP lifetime (Figure 1).

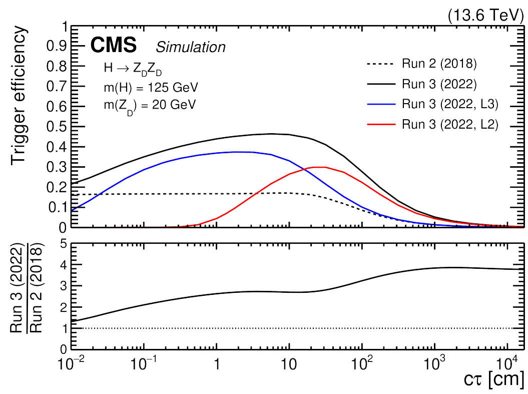

Figure 1: Efficiencies of the Run 2 and Run 3 displaced dimuon triggers as a function of $c\tau$ for the HAHM signal events with $m(Z_D)$ = 20 GeV.

3. Muon reconstruction and analysis strategy

This analysis uses two muon reconstruction algorithms:

1. Global/tracker muon algorithms (TMS): they use and combine information from the CMS tracker and the muon system. They offer the best spatial and momentum resolution for the muons, but their efficiency decreases rapidly with displacement.

2. Standalone muon algorithms (STA): they use only information from the muon system. They allow reconstructing muons up to several meters of displacement, but they offer a poorer spatial and momentum resolution.

For the analysis strategy, dimuon events are classified into three mutually exclusive categories, each of which benefits of a different selection and background evaluation.

1. TMS-TMS category: both muons are reconstructed using the tracker and the muon system.
2. STA-STA category: both muons are reconstructed using only the muon system information.
3. STA-TMS category: this is a mixed category, where one muon is STA and the other TMS.

The results of the TMS-TMS and STA-STA categories are statistically combined. The hybrid category (STA-TMS) provides the lowest sensitivity of the three and was not included in this result.

4. Event selection

The basic selection requires events with 1 or more primary vertices, matching between the trigger level reconstructed muons and STA muons, and less than 4 nearly parallel STA muons. Additional muon and dimuon selections are collected in Table 1.

Muon sel.	STA	TMS	**Dimuon sel.**	STA-STA	TMS-TMS
STA-TMS assoc.	Not matched	Matched to STA	DCA	< 15 cm	< 15 cm
N(CSC+DT hits)	> 12	> 12 (for assoc. STA)	χ^2_{vertex}	< 10	< 10
N(DT hits) barrel	> 18	-	ΔN (pixel hits)	-	< 3
Tracker muon	-	yes	N(DT hits)	> 24 if $\lvert\Delta\eta\rvert < 0.1$	-
Matched μ segm.	-	> 1	$\sigma(L_{xy})$	> 20 cm	-
p_T	> 10 GeV	> 10 GeV	$\cos(\alpha)$	> −0.9	> −0.99
$\sigma(p_T)/p_T$	< 1.0	< 1.0	No b2b mu with $\lvert\Delta t\rvert > 20$ ns	yes	-
χ^2_{trk}/dof	> 2.5	-	N(dimuon segm.)	> 4 (> 5 if $\lvert\Delta\eta\rvert < 0.1$)	-
$I^{\text{rel}}_{\text{trk}}$	< 0.15	< 0.075	Dimuon mass	> 10 GeV	> 10 GeV
$\lvert\Delta t\rvert$	< 12 ns	-	p_T leading muon	-	> 25 GeV
$d_0/\sigma(d_0)$	-	> 6	$L_{xy}/\sigma(L_{xy})$	> 6	> 6
			$\lvert\Delta\phi\rvert$ (H→$Z_D Z_D$)	$< \pi/10$	$< \pi/30$
			$\lvert\Delta\phi\rvert$ (SUSY)	$< \pi/4$	$< \pi/4$
			+ Common vertex fit converged and opposite sign muons		

Table 1: Selection criteria applied to muons and dimuons.

5. Background estimation and signal scale factors

The background evaluation method in this search is data driven, based on control regions with one or more of the above selection criteria inverted.

For the case of Drell-Yan and other prompt backgrounds, the number of background events is evaluated in the $|\Delta\phi|$-symmetric control region as:

$$N^i(\text{DY,SR}) = N^i(\text{DY,CR}) \times R^i_{\text{DY}},$$

where R^i_{DY} is a transfer factor accounting for the possible asymmetry, and found to be 0.75 (30% sys. unc.) for STA-STA and 1 (15% sys. unc.) for TMS-TMS. For the case of QCD backgrounds, the number of events is evaluated in the control regions obtained by selecting same sign dimuons and inverting the isolation cut. In the STA-STA category, $N_{\text{QCD}}(\text{SR}) = N_{\text{noniso}} \times R_{\text{QCD}}$, with R_{QCD} evaluated in the same-sign control region. For the TMS-TMS category, $N_{\text{QCD}}(\text{SR}) = N_{\text{SS}} \times R_{\text{QCD}}$, with R_{QCD} obtained from the ratio of OS/SS dimuons in the nonisolated control region. Signal scale factors are applied due to muon identification, reconstruction and trigger efficiencies. Their values range from 0.75 – 1 for STA-STA and from 0.83 – 1 for TMS-TMS (with uncertainty of 5-15%).

6. Results and interpretation

Figures 2 and 3 display the observed number of events and predicted backgrounds for the two dimuon categories as a function of $m_{\mu\mu}$ and $m^{\text{corr}}_{\mu\mu}$. The corrected mass is defined as

$$m^{\text{corr}}_{\mu\mu} = \sqrt{m^2_{\mu\mu} + p^2_{\mu\mu} \sin^2\theta} + p_{\mu\mu} \sin\theta,$$

and is used to improve the mass resolution in the RPV SUSY model.

No significant excess of events is observed with respect to the Standard Model prediction. Therefore, these yields are used to set upper limits on the branching ratio of the decay for the HAHM model, and on the product of the cross section and the branching ratio for the RPV SUSY model. Masses of the LLP probed range from 10 GeV to 60 GeV for the HAHM model and from 125 GeV to 1.6 TeV for the RPV SUSY model. For a comprehensive review of results see [1].

This search sets the most stringent limits in the HAHM model for lifetime values corresponding to decay lengths smaller than 0.1 cm and larger than 10 cm. Additionally, for the RPV SUSY model

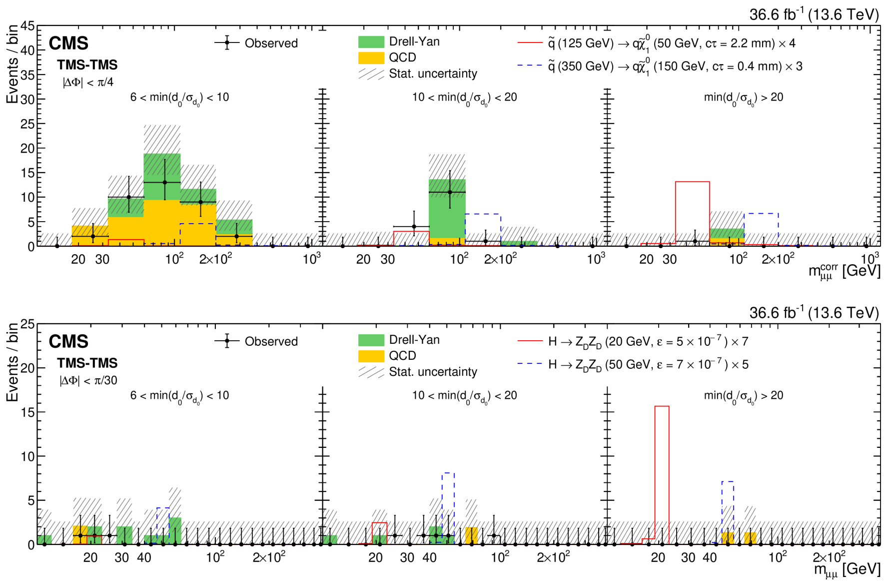

Figure 2: Comparison of observed and expected numbers of events in the TMS-TMS dimuon category.

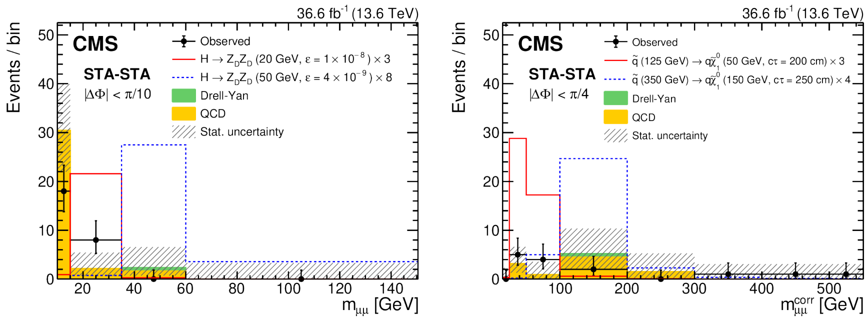

Figure 3: Comparison of observed and expected numbers of events in the STA-STA dimuon category.

it sets tighter limits than the CMS Run 1 search [4] and ATLAS Run 2 search [5] for lifetimes smaller than 1 cm and larger than 1 m.

7. Conclusions

A search for displaced muons has been performed using Run 3 data with the CMS detector. No excess of data with respect to the Standard Model background has been observed. Upper limits on the production cross section have been derived. Even if the sample is 2.5 times smaller than in the previous search based on Run 2 data, the limits are comparable or even tighter in some regions of the parameter space. The new displaced muon triggers engineered for Run 3 are the main reason for this improvement.

References

[1] CMS Collaboration, Search for long-lived particles decaying to final states with a pair of muons in proton-proton collisions at $\sqrt{s}$=13.6 TeV, JHEP 05 (2024) 47, doi:10.1007/JHEP05(2024)047

[2] CMS Collaboration, The CMS experiment at the CERN LHC, JINST 3 (2008) S08004, doi:10.1088/1748-0221/3/08/S08004

[3] CMS Collaboration, Search for long-lived particles decaying to a pair of muons in proton-proton collisions at $\sqrt{s}$ = 13 TeV, JHEP 05 (2023) 228, doi:10.1007/JHEP05(2023)228, arXiv:2205.08582

[4] CMS Collaboration, Search for long-lived particles that decay into final states containing two electrons or two muons in proton-proton collisions at $\sqrt{s}$ = 8 TeV, Phys. Rev. D 91 (2015) 052012, doi:10.1103/PhysRevD.91.052012, arXiv:1411.6977

[5] ATLAS Collaboration, Search for long-lived particles in final states with displaced dimuon vertices in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector, Phys. Rev. D 99 (2019) 012001, doi:10.1103/PhysRevD.99.012001, arXiv:1808.03057

[6] CMS Collaboration, Development of the CMS detector for the CERN LHC Run 3, JINST 19 (2024) P05064