PROCEEDINGS OF SCIENCE

LLP results from CMS

Ang Li on behalf of the CMS Collaboration*

Institute of High Energy Physics (HEPHY), Austrian Academy of Sciences (ÖAW), Nikolsdorfer Gasse 18, 1050 Vienna, Austria

E-mail: ang.li@cern.ch

Searches for long-lived particles are theoretically well-motivated and involve special signatures in the detector. A few latest results about searches for long-lived particles from the CMS experiment are presented. With the novel ideas of targeted signatures and new technologies, those searches set stringent limits to many new physics models.

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*Speaker

1. Introduction

Many physics models beyond the standard model (SM) predict the existence of long-lived particles (LLPs). Those particles travel a measurable distance before they decay, leaving unique signatures in a detector, which are generally challenging to reconstruct and can remove most of the SM background events. In recent years, many searches [1] have been conducted in the CMS experiment [2] to explore different long-lived signatures with novel reconstruction technologies. This work introduces searches conducted in the CMS experiment that target signatures generated by LLPs.

2. Search for inelastic dark matter

This search [3] is the first dedicated collider search that targets inelastic dark matter. In the signal model, two states of dark matter (χ_1 and χ_2) have a small mass difference and are coupled with the dark photon (A'). The heavier state χ_2 is long-lived and decays to the lighter state χ_1 and an off-shell dark photon, which then decays to a pair of fermions. This search considers the case where the dark photon decays to a pair of soft muons. The targeted signature includes a pair of soft and displaced muons, significant missing transverse momentum, and an energetic recoiling jet. To be sensitive to signal events with larger displacement, the search uses a dedicated displaced muon reconstruction, which only uses information from the muon system, to reconstruct muons. Compared with the standard muon reconstruction, whose reconstruction efficiency drops from 95% to 0% in the displacement range of 1–100 cm, the displaced muon reconstruction provides an efficiency of around 95% for displacement from 1 to 300 cm. Since no information from the tracking system is used for displaced muon reconstruction, the displaced muons have worse resolution on the transverse momentum and transverse impact parameter. To recover the resolution for muons with smaller displacement, a match between displaced muons and standard muons is performed based on ΔR, and the number of matched muons is used to categorize the events (0-, 1-, or 2-matches). Data-driven background estimation based on the ABCD method is performed individually on events in different categories. The observation in data is consistent with the background estimation. The limits are set on the interaction strength (y) and the mass of the lighter dark matter state (m_1), as shown in Figure 1 (left).

3. Search for LLPs using out-of-time trackless jets

This search [4] targets gauge-mediated supersymmetry breaking signal model. In this model, neutralinos ($\tilde{\chi}$) are long-lived and decay to a nearly massless gravitino and a Higgs or Z boson. The Higgs or Z boson decays hadronically into a pair of quarks. $\tilde{\chi}$ that decays in the outer regions of the tracking system or inside the calorimeter will result in jets that include less number of tracks, which contributes to the trackless feature. Also, such jets arrive later at the electromagnetic calorimeter compared with those generated promptly in the interaction point, making the signal jets out of time. The targeted signature includes missing transverse momentum resulting from the gravitinos and out-of-time and trackless jets caused by long-lived $\tilde{\chi}$ decay. Time and energy information from the electromagnetic calorimeter is used to determine the jet time. To increase the selection efficiency for signal jets, a jet tagger based on a deep neural network that combines the timing information with track information is applied. A signal efficiency of 82% is achieved with a background rejection rate of 4×10^{-4}. The signal region is defined to include events with at least two tagged jets. The number of background events in the signal region is estimated using the mistag rate, which is measured using events with a lepton and a jet. No excess is observed in data. The upper limits are set as a function of $\tilde{\chi}$ mass ($m_{\tilde{\chi}}$) and proper decay length ($c\tau_{\tilde{\chi}}$), as shown in Figure 1 (right). The search excludes $\tilde{\chi}$ with masses up to 1.18 TeV (990 GeV) at $c\tau_{\tilde{\chi}}$ of 0.5 (3.0) m.

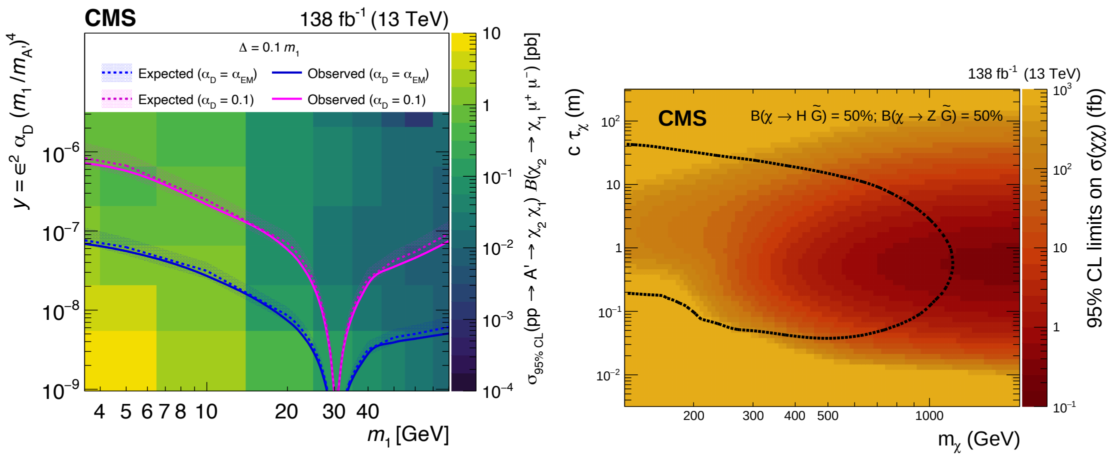

Figure 1: Search for inelastic dark matter [3] (left): Limits on the product of the production cross section of the dark matter and the branching ratio to a muon pair as a function of m_1 and y for a given mass difference Δ. Search for LLPs using out-of-time trackless jets [4] (right): Limits on the production cross section of $\tilde{\chi}$ for a given branching ratio to Higgs and Z boson as a function of $m_{\tilde{\chi}}$ and $c\tau_{\tilde{\chi}}$.

4. Search for fractionally charged particles

This search [5] targets fractionally charged particles that are produced in pairs in Drell-Yan-like events. According to the Bethe relation, when a charged particle passes through a material, the energy deposit per travel distance is proportional to the square of its charge. As a result, fractionally charged particles are more likely to generate hits with low-energy deposits in the tracking system. The search explores the signature of tracks with a large number of low-energy hits. Events with one or two tracks that have an invariant mass below 80 GeV or above 100 GeV are included in the signal region. Events with an invariant mass between 80 and 100 GeV are dominated by Z boson candidates, and thus are used as the control region to estimate background in the signal region by fitting the number of low-energy hits distribution. No significant excess is observed in data. The limits are presented as a function of charge and mass of the fractionally charged particles, as shown in Figure 2. Those are the best limits on the signature in the considered phase space.

5. Search for LLPs decaying to a pair of muons

This search [6] focuses on the signature of a pair of displaced muons. The search is sensitive to several models, one of them is the exotic Higgs boson (ϕ) decaying to two long-lived scalar bosons (X), and at least one of the scalar bosons decays to a pair of muons. A customized trigger, which looks for two muons with moderate transverse momentum, is designed to increase the signal efficiency. To be sensitive to muons with larger displacements, the search uses muons based on the tracking system and muons based on the muon system. Background events, which result from instrumental and reconstruction mistakes, are estimated using a data-driven ABCD method. No excess is observed in data. The search sets limits on the product of the LLP production cross section and the branching ratio to muon pairs for various exotic Higgs masses, LLP masses, and LLP proper decay lengths ($c\tau$), as shown in Figure 2. The search is sensitive to a broad range of $c\tau$ from 30 μm to more than 1 km.

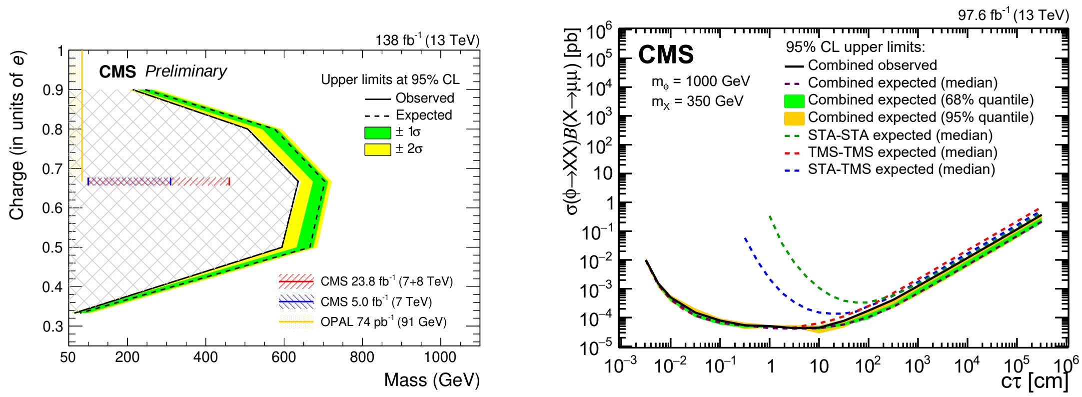

Figure 2: Search for fractionally charged particles [5] (left): Exclusion region of fractionally charged particles as a function of its mass and charge. It is compared with previous CMS and OPAL results. Search for LLPs decaying to a pair of muons [6] (right): Upper limits on the product of the production cross section of X and branching ratio to muons pairs, as a function of $c\tau$.

6. Summary

This work presents several CMS searches that target a variety of long-lived signatures, which are theoretically well-motivated and technically challenging to search for. With the special signatures, the most stringent limit of many new physics models and final states is set by CMS. Although no significant excess is observed, there are still many opportunities to explore, such as new triggers, new signatures, and new data taken in Run-3, which could provide insights into the new physics.

References

[1] M. Darwish, *Searches for displaced jets at the LHC*, in *Proceedings of The Tenth Annual Conference on Large Hadron Collider Physics — PoS(LHCP2022)*, vol. 422, p. 084, 2023, DOI.

[2] CMS collaboration, *The CMS experiment at the CERN LHC*, *JINST* **3** (2008) S08004.

[3] CMS collaboration, *Search for inelastic dark matter in events with two displaced muons and missing transverse momentum in proton-proton collisions at $\sqrt{s}$ = 13 TeV*, 2305.11649.

[4] CMS collaboration, *Search for long-lived particles using out-of-time trackless jets in proton-proton collisions at* $\sqrt{s} = 13$ *TeV*, *JHEP* **07** (2023) 210 [2212.06695].

[5] CMS collaboration, *Search for fractionally charged particles in pp collisions at* $\sqrt{s} = 13$ *TeV*, Tech. Rep. CMS-PAS-EXO-19-006, CERN, Geneva (2022).

[6] 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 [2205.08582].