LHC Dark Showers Workshop

Monday 27 October 2025 - Thursday 30 October 2025

CERN

Book of Abstracts

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A Novel Beam Dump Experiment for Dark Sector Searches Using the CMS Detector

Author: Hyunyong Kim[1]

[1] *Seoul National University (KR)*

We propose a novel scheme for performing a beam-dump-like experiment with the general-purpose detectors (ATLAS and CMS) at the LHC. Collisions of high-energy protons result in jets containing a number of energetic hadrons and electromagnetic objects that are essentially "dumped"to hadronic and electromagnetic calorimeters, respectively, and induce the production of secondary hadrons, electrons, and photons in calorimetric showers. We envision a situation where new physics particles are produced by the interactions of these secondary particles inside the calorimeters. For proof of principles, we consider the axion-like particles (ALPs) produced via the Primakoff process in the presence of their interaction with photons at CMS. We argue that the drift tube chambers and the ME0 module of the muon system can serve as detectors to record the photons from the ALP decay, demonstrating that assuming the background level can be controlled as discussed in this work, the resulting sensitivity reach is competitive due to their close proximity to the signal source points. We further show that the LHC does not suffer from a barrier, dubbed beam-dump "ceiling", that typical beam-dump experiments hardly surpass. This gives the LHC great potential to explore a wide range of parameter space. This analysis can be extended to investigate various types of light mediators with couplings to the Standard Model leptons and quarks.

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Surveying the Hidden Valley landscape

Author: Joshua Lockyer[None]

Co-authors: Suchita Kulkarni [1]; Wei Liu [2]; Wei Liu [2]

[1] *University of Graz*

[2] *Nanjing University of Science and Technology*

The confining and asymptotically free nature of confining Hidden Valleys (HVs) naturally give rise to long-lived mesons and to "dark showers". Due to the vast theory space inherent to HV theories, we seek to reinterpret existing collider searches by keeping the mediator properties fixed while varying parameters of the HV theory itself. Such an endeavour necessitates accurate modelling of the simulation properties dependence on their fundamental theory parameters.

We specifically focus on theories with very long-lived mesons where we need to reinterpret existing CMS searches targeting long-lived particle decays in the muon system. By using this model-agnostic approach, we show that this existing CMS search is sensitive to the fundamental parameters of the confining DS itself and present model dependent exclusions on its parameter space.

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Semi-visible Emerging Jet

Authors: Joshua Lockyer[None]; José Francisco Zurita[1]; Juliana Carrasco[None]; Suchita Kulkarni[2]; Wei Liu[3]

[1] *IFIC, CSIC-UV*

[2] *University of Graz*

[3] *Nanjing University of Science and Technology*

The dark shower collider phenomenology splits the signatures into the "semi-visible"and "emerging-jets", corresponding to seemingly orthogonal simplified models (s-channel vs t-channel). However, those are not exclusive signatures, and hence I will discuss how to hunt for dark showers that give visible and invisible displaced signatures. These Semi-Visible Emerging Jets (SVEJ) have striking signatures at the LHC, and I will show a proof-of-concept on the LHC sensitivity to these signatures, and then non-trivial interplay with the CalRatio ATLAS search.

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s-channel semivisible jet - emerging jet interplay

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Probing the Higgs Portal to a Hidden Valley at FCCee

Authors: Andrea Siddharta Maria[1]; Annapaola De Cosa[1]; Cesare Tiziano Cazzaniga[1]; Emre Sitti[1]; Felix Kahlhoefer[2]

[1] *ETH Zurich (CH)*

[2] *Karlsruhe Institute of Technology*

Within the Hidden Valley (HV) scenario, for a QCD-like dark sector, novel experimental signatures emerge, characterized by sprays of particles resembling hadronic jets containing stable dark bound states. The resulting signature is characterised by missing momentum aligned with one of the jets, and is known as semi-visible jets (SVJs). We investigate the potential role of the Higgs boson as a portal to HV, specifically leading to SVJ signatures at the FCC-ee. We present new simplified models allowing the decays of the unstable dark bound states to photons, leptons and quarks. We investigate also scenarios with different fractions of invisible states and introduce efficient analysis strategies to probe them. The presented model and signature can be extended also in the context of the LHC, and provide a further benchmark to probe new SVJ signatures also at hadron colliders via the Higgs boson.

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Electroweak Portal Dark Shower

Author: LINGFENG LI[1]

[1] *Brown U.*

We present the phenomenology of the electroweak portal dark shower. The talk will include a brief introduction to the UV theory. We will also present model-independent experimental bounds from current LHC data and future projections.

Progress report area:

s-channel semivisible jet - emerging jet interplay

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Search for Strongly-Coupled Dark Matter via t-channel Production of Semi-Visible Jets

Author: Akshat Shrivastava[1]

Co-authors: Annapaola De Cosa [2]; Aran Garcia-Bellido [3]; Chin Lung Tan [4]; Christopher Madrid [1]; Emily Ann Smith [5]; Kevin Pedro [5]; Nukulsinh Parmar [3]; Roberto Seidita [2]

[1] *Texas Tech University (US)*

[2] *ETH Zurich (CH)*

[3] *University of Rochester (US)*

[4] *Purdue University (US)*

[5] *Fermi National Accelerator Lab. (US)*

We present a search for strongly coupled dark matter in the form of semi-visible jets (SVJs) using the full Run˜2 CMS dataset. SVJs arise in Hidden Valley models with a confining dark QCD sector, where dark quarks produced via \textit{t}-channel scalar exchange hadronize into dark hadrons—some decaying to Standard Model particles and others escaping detection. This results in jets with both visible and invisible components, and missing transverse momentum (p_T^{miss}) that is aligned with a jet rather than isotropic. After a set of event preselection requirements, an event-level deep neural network (DNN) trained with a Lagrange multiplier to ensure independence from p_T^{miss} is applied to select candidate events. This DNN output is used to define the ABCD plane for data-driven background estimation. Within each selected event, individual jets are tagged using both supervised and unsupervised SVJ taggers. The ABCD method is used to estimate Standard Model backgrounds and validate closure directly in data using low-signal control regions, ensuring reliable background predictions in the presence of semi-visible signals.

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Reinterpretation of the early Run-3 displaced-jets search at CMS for emerging-jets signatures

Author: Jingyu Luo[1]

[1] *Brown University (US)*

In this talk, I will present the reinterpretation of the early Run-3 displaced-jets search at CMS \[Rep. Prog. Phys. 88 (2025) 037801\] for emerging-jets signatures. The search analyzes a data sample of proton-proton collisions at a center-of-mass energy of 13.6 TeV, corresponding to an integrated luminosity of 34.7 fb^{-1}, collected with the CMS detector at the CERN LHC in 2022. Novel techniques in trigger, reconstruction, and machine learning have been developed for and employed in this search, leading to significant improvements in sensitivities to displaced-jets signatures arising from long-lived particle decays.

We further interpret this search for emerging-jets signatures. Models with a dark sector having a new confining gauge group are considered. New dark quarks are charged under the gauge group, and can undergo parton shower and hadronization within the dark sector, producing long-lived dark hadrons that can subsequently decay into standard model particles. We examine the cases where the dark quarks are pair produced from the decays of a new heavy vector boson Z' or the Higgs boson. For the model where a Z' boson decays to a pair of dark quarks, production cross sections larger than 6.5 fb can be excluded for Z' boson masses larger than 600 GeV. For the models where the Higgs boson decay to a pair of dark quarks, the lowest limits on the branching fraction of the Higgs boson to dark quarks reach below 1% for dark hadron proper decay lengths smaller than $1\ \mathrm{m}$. These are the most stringent limits to date on these models.

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A Strangely Stable Dark Sector

Author: Emily Ann Smith[1]

Co-authors: Kevin Pedro [1]; Matthew James Strassler [2]

[1] *Fermi National Accelerator Lab. (US)*

[2] *Harvard University*

We investigate new classes of models that can produce a wide range of r_inv values. The model parameter ranges are chosen to occupy phase space regions that are well-understood from perturbative and lattice QCD results. Different parameter variations can change r_inv while preserving similar showering behavior or produce different showers with degenerate or near-degenerate r_inv values. We present the first exploration of these variations to quantify their impact on observables such as jet substructure, in order to ensure both the breadth and physical reality of proposed simplified benchmark models.

Progress report area:

Different rinv values

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Are SVJs hidden from the Lund Plane?

Authors: Ahmed Hammad[1]; Claire Shepherd-Themistocleous[None]; Miguel Angel Avendano Bernal[2]; Srinandan Dasmahapatra[None]; Stefano Moretti[3]

[1] *KEK, Japan*

[2] *University of Southampton*

[3] *Science and Technology Facilities Council STFC (GB)*

In the context of Dark Matter detection at colliders, several new signatures have emerged that bridge experimental data with the theoretical models. Among these, Semi-Visible Jets (SVJs) represent a novel promising signature, particularly those mediated by a resonant Z′ boson that enables the production of heavy dark hadrons. In such a scenario, jets consist of both visible SM particles and invisible dark matter components, resulting in missing transverse energy that is aligned with the jet axis. This feature disrupts conventional LHC search strategies, which typically rely on large angular separations between jets and MET. Consequently, SVJ events closely mimic QCD backgrounds, complicating their discrimination. The complexity is further heightened since the poorly constrained nature of the dark sector; factors such as the dark confinement scale, dark meson masses and the fraction of the invisible DM hadrons. Our study consider different topologies, including heavy gauge boson Z′, resulting in different kinematic features for the produced SVJ from the QCD ones. Traditional SVJ searches have relied either on global kinematic observables or on jet substructure features such as energy correlation functions that highlight differences between SVJ and QCD jets. In this work, we propose a multimodal Transformer-based network with cross-attention, designed to jointly analyse both sources of information. By combining kinematic observables with local jet-level features (encoded in the jet constituents), the model achieves a more effective separation between signal and background. In addition, the adoption of a cross-attention mechanism serves to establish a conditional correlation between the global kinematic variables of the event and the corresponding features within the SVJ that arise from dark hadron dynamics. To reduce the network dependence on specific theoretical assumptions, we train it on mixed datasets generated with different values of the theoretical parameters. Furthermore, we analyze the latent space representations learned by the network to quantify the impact of each theoretical parameter
on the embedded data distribution.

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Studying CKKWL merging/matching scheme for t-channel generation

Author: Deepak Kar[1]

[1] *University of the Witwatersrand (ZA)*

Comparison of currently used MLM matching scheme and more well motivated CKKWL scheme for t-channel SVJ production will be presented.

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t-channel generation

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How invisible is it?

Co-author: Bingxuan Liu [1]

[1] *Sun Yat-Sen University (CN)*

Semi-visible jet signatures have rich phenomenology for experiments to explore. While the details of the dark shower parameters are being studied carefully, the community has identified a critical parameter, r_{inv}, to capture the main characteristics of such signatures. It is the fraction of invisible dark hadron decays. r_{inv} is correlated with key observables in the analyses, such as the transverse missing energy. It is of great interest to reconstruct this quantity at the analysis level, to help with designing more powerful search strategies and directly probe the nature of the excess in case of a discovery. In a previous work1, we investigated the possibility of reconstructing r_{inv} in the boosted regime using a simple decomposition method, which gave us promising results. In this ongoing work, we attempt to apply a ML-based technique to regress r_{inv}, achieving a much better resolution.

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