

Dark Showers Workshop

Tuesday 21 January 2025 - Thursday 23 January 2025

Book of Abstracts

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Flash Talks / 3**Exploring Dark Showers with Radiations****Authors:** Bingxuan Liu¹; Kevin Pedro²¹ *Sun Yat-Sen University (CN)*² *Fermi National Accelerator Lab. (US)***Corresponding Authors:** pedrok@cern.ch, bingxuan.liu@cern.ch

e investigate the potential to search for semi-visible jets (SVJs) at the Large Hadron Collider (LHC) using initial-state radiation (ISR). Both photon ISR and jet ISR channels are considered, using a benchmark signal model with the decay of a leptophobic Z' mediator forming two SVJs. We compare and extend several techniques to decompose the missing transverse momentum into per-jet contributions, in order to reconstruct the mediator mass and to define a new observable measuring the fraction of invisible dark hadrons. The presence of ISR facilitates the identification of the SVJs, and the resulting boost improves the resolution of the observables, especially for models with high invisible fractions. We combine the two observables to propose a complete search strategy and discuss an extension of the strategy to probe the whole model parameter space.

Are you happy to have the meeting recorded?:

Yes

Extended Talks / 4**Dark showers from sneaky dark matter****Author:** Pedro Schwaller^{None}**Corresponding Author:** pedro.schwaller@uni-mainz.de

We present a minimal composite dark matter model, based on a $SU(N_d)$ dark sector with n_f dark quarks and a heavy t-channel mediator. For $n_f \geq 4$, the dark flavor symmetry guarantees the stability of a subset of the dark pions, which serve as our dark matter candidates. Their relic abundance is determined by co-scattering or co-annihilation with the remaining dark pions, which are unstable and decay. Due to their degenerate masses, the annihilation cross section is suppressed at low temperatures, thereby avoiding stringent constraints from indirect detection and opening up the GeV mass window. The decaying dark pions are naturally long lived. We obtain limits on the model from semi-visible or emerging jet searches and estimate the reach of future probes.

Are you happy to have the meeting recorded?:

Yes

Flash Talks / 5**Probing photons-enriched signatures for Semi-visible jets at the LHC****Author:** Cesare Tiziano Cazzaniga¹**Co-authors:** Alessandro Russo ; Annapaola De Cosa ¹; Emre Sitti ¹

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The Hidden Valley scenario consists of a set of models where the Standard Model is accompanied by a Hidden Sector and connected with it via a heavy mediator or a weak coupling. If realised in nature, the Hidden Valley scenario may result in unusual and little-studied phenomena at the LHC. Under the assumption of a QCD-like confining dark sector, novel experimental signatures emerge, characterized by sprays of particles resembling hadronic jets containing stable invisible dark matter bound states. The resulting signature is characterised by missing momentum aligned with one of the jets, defining an orthogonal phase-space compared to traditional WIMPs searches. These semi-visible jets have been studied theoretically and experimentally in the fully hadronic signature, and more recently including also leptonic final states. We present new simplified models allowing the decays of the unstable dark bound states to photons via a pseudo-scalar portal, such as an axion-like particle. The new resulting signatures are semi-visible jets characterised by an enhanced presence of non-isolated photons, coming directly from dark bound states decays. We show that these exotic jets evade the phase space probed by current LHC searches exploiting jets or photons due to the expected high jet neutral electromagnetic fraction and photons candidates non-isolation, respectively. Moreover, we show that by leveraging the distinguishing features of the substructure of the final state BSM jets compared to SM ones, it is possible to develop identification criteria that can be used in real analyses at the LHC to enhance the sensitivity to these novel signatures.

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Yes

Flash Talks / 6

Constraints on resonant and non-resonant production modes of SVJs

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We look at the constraints we get from SM measurements on resonant and non-resonant production modes of semi-visible jets by running CONTUR. By varying several parameters in both channels, we can investigate the kinematics behind the exclusions and see the merit in using reinterpretation tools in developing search strategies/phenomenological studies.

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Yes

Flash Talks / 7

Bridging the Higgs Portal to the Dark Sector: From FCCee to LHC

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Dark showers arising from the Higgs coupling to a strongly confined dark sector present a unique avenue for exploring new physics signatures. Within the FCC-ee framework, this model is being studied, highlighting the production of semi-visible jets (SVJs) enriched with photons and leptons. These signatures, featuring displaced decays and complex jet structures, demand tailored reconstruction techniques and novel targeted analyses.

We aim to adapt this model for the LHC, leveraging vector boson fusion production of the Higgs, which couples to dark quarks and subsequently hadronizes into dark mesons. Standard jet identification at the LHC may fail to capture such photon-enriched and lepton-enriched SVJs, necessitating the development of new algorithms relying on jet substructure.

Key challenges include understanding how Standard Model (SM) analyses, such as those targeting the Higgs-to-b-quark decay channel, overlap with or constrain these novel signatures. While $H \rightarrow bb$ acts as a background, assessing the sensitivity of SM analyses to dark sector scenarios or highlighting their limitations in identifying photon- and lepton-enriched SVJs is central to our exploration.

This work will focus on developing new analysis strategies tailored to the LHC environment, where existing detector capabilities and triggers may already offer opportunities to probe this signature. By uncovering an unexplored parameter space, particularly in the low-mass regime around the Higgs scale, we aim to refine the methods for identifying dark sector signatures and enhance sensitivity to new physics within Higgs portal frameworks.

Are you happy to have the meeting recorded?:

Yes

Flash Talks / 8

Reinterpreting LHC Dark QCD results

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In this contribution, we will present our recent studies on the recasting of the different LHC darkQCD analyses using MadAnalysis5. The reinterpretation was done in the context of dark shower models focussing on semi-visible jet resonances.

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Yes

Flash Talks / 9**Semivisible Jets from Dark Glueballs****Authors:** Deepak Kar¹; Zofia Borowska^{None}¹ *University of the Witwatersrand (ZA)***Corresponding Authors:** zofia.anna.borowska@gmail.com, deepak.kar@cern.ch

We explored a darkQCD model of the hadronization of dark gluons into dark glueballs to generate semi-visible jet signature. We considered two portal particles, a Higgs and a Z' . Trying to generate the SVJ signature with the Higgs mediator, we found the expected signature, but with an extremely low cross-section, to the order of 10^{-9} pb. It was not possible to generate the signature with the Z' portal due to technical issues in the MG5 event generation and a Pythia shower.

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Yes

Extended Talks / 10**Signals of Pure-Glue and Many-Species Dark Sectors****Author:** Austin Batz¹¹ *University of Oregon***Corresponding Author:** abatz@uoregon.edu

The pure-gluon limit of confining dark sectors reveals new insights into dark shower phenomenology. When the dark quark masses and the scale of a collider's hard interactions that produce the dark sector are significantly larger than the dark confinement scale, there is a dark gluon shower that produces only dark glueballs. These glueballs can then decay to the Standard Model with lifetimes that vary greatly depending on the glueball species and the parameters that set the strength of the portal interaction. This hierarchy of lifetimes leads to different potential signals, including semivisible and emerging jets. In fact, the difference in lifetimes between different species reveals an overlap in the semivisible and emerging jet regimes, motivating search strategies that leverage observables from both signals for any dark shower model with several dark hadron species.

Are you happy to have the meeting recorded?:

Yes

Flash Talks / 11**Search for top-coupled dark sector with emerging jets signatures****Authors:** Benedikt Maier¹; Jannicke Pearkes²; Kevin Pedro³; Kevin Stenson²; Markus Klute⁴; Richa Sharma⁵; Roy Cruz Candelaria⁶; Yi-Mu Chen⁷

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Current search efforts for flavored dark sectors that couple to multiple SM quarks flavors has only included the coupling to isospin $-\frac{1}{2}$ SM quarks using the emerging jet signature. A natural extension to such models would be to change the coupling to isospin $+\frac{1}{2}$ SM quark. In particular, the coupling to SM top quarks allows for electroweak-like event selection and triggers to be used, opening the possibility to explore a wider region in the dark sector phase spaces. The accompanying dark sector shower also means that such model may not be fully excluded by existing $t + X$ or $t\bar{t} + X$ search efforts at the LHC. This talk aim to present the projection of the potential sensitivity of CMS to such models at Run 3, as well as exploring additional information available in Run 3 data that can further boost sensitivity to dark show signals.

Are you happy to have the meeting recorded?:

Yes

Extended Talks / 12

Hidden valleys in CMS muon endcap detector

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We demonstrate the sensitivity of the CMS search at the high luminosity LHC run for long-lived particles for Hidden Valley scenarios. We use a theoretically consistent parametrisation of the Hidden Valley parameters to establish our simulation setup. We also adopt a hybrid strategy and establish upper limits on the Hidden Valley production cross section as a function of the model parameters for a model independent interpretation of the search results. Our results demonstrate that the CMS search for long-lived particle decays in the CMS muon endcap is highly sensitive to the underlying theory parameter and it has a capacity to constrain overall scale as well as the ratio of the pion mass to this scale. Furthermore we demonstrate that the search is comparatively less sensitive to the Hidden Valley number of colors or the flavours.

Are you happy to have the meeting recorded?:

Yes

Flash Talks / 13

A multi-boson door into compositeness

Author: Abhishek Iyer¹

Co-authors: Abhishek Kumar Singh²; Aldo Deandrea³; Giacomo Cacciapaglia⁴; Suchita Kulkarni⁵

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We consider the prospect of the SM as a composite of a new fundamental fermionic sector (q_{TC}). Such scenarios can be considered as QCD-like, where the hadronization scale $\Lambda_{TC} \sim \text{few TeV}$. The study of $q\bar{q} \rightarrow q_{TC}\bar{q}_{TC}$ at 100 TeV at FCC-hh has a direct analogue to the study of $e^+e^- \rightarrow q\bar{q}$ at around few GeV at LEP. While the latter considered the production of few-pion final states formed due to the fragmentation and eventual hadronization of the SM quarks, we will consider the production of few scalars (TC-mesons) that are formed out of the new quarks q_{TC} . In its simplest manifestation, these scalars are identified as the Higgs and the longitudinal components of the gauge bosons. The resulting multi-TC-meson final state is an artefact of the underlying QCD-like dynamics. Using the Lund string model for producing these TC mesons, we use simple kinematic discriminants to establish a proof of concept for such an analysis to be a near undisputed sign of compositeness and, hence, a need for FCC-hh.

Are you happy to have the meeting recorded?:

Yes

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Long-lived glueballs as a test of early matter domination

Author: Filippo Sala¹

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I will show how collider searches for long-lived particles (LLPs) can test the dynamics responsible for matter domination in the early universe. In particular I will focus on long-lived glueballs from a GeV-scale confining dark sector, of relevance for this workshop. After a summary of their cosmology, I will prove that searches of glueballs, from decays of the Higgs or other particles, test increasing values of dilution at ATLAS and CMS, CODEX-b, ANUBIS and MATHUSLA. These results provide a quantitative physics motivation to test longer lifetimes.

Are you happy to have the meeting recorded?:

Yes

Extended Talks / 15

Dark Showers in Herwig 7

Authors: Dominic William Stafford¹; Simon Platzer²; Suchita Kulkarni³

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We present the new implementation of Dark Showers in the Herwig 7 generator. This implementation features for the first time an angular ordered dark shower and dark hadronisation implemented via the cluster hadronisation model. This talk will cover the scale hierarchies involved in dark shower models, and how to pick sensible values for generator parameters based on these scales. Secondly, the talk will explore the impact of hadronisation. This has not yet been much discussed in the context of dark showers, but is potentially a large effect since current event generators use semi-empirical hadronisation models tuned to SM data. A method for estimating the size of this effect on the current cluster hadronisation model will be presented and on-going work to move to more theoretically motivated models with fewer tunable parameters discussed.

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Yes

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Comparisons of Dark Showers between Herwig and Pythia

Authors: Annapaola De Cosa¹; Cesare Tiziano Cazzaniga¹; Deepak Kar²; Dominic William Stafford³; Simon Platzer⁴; Suchita Kulkarni⁵; Sukanya Sinha⁶

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We present an ongoing effort to compare the new Herwig Dark Showers code with the existing Pythia Hidden Valley module. In addition to the physical parameters of the model, an event generator requires a number of semi-empirical settings to be tuned, particularly in the hadronisation. Since no dark showers have yet been observed, the best choices for these parameters can only be estimated using intuition from QCD. The aim of these studies is to determine which observables are consistent between generators and for variations of the tunable parameters, and hence are more reliable for use in future analyses, and identify pitfalls for parameter setting. This talk will introduce the theoretically motivated benchmarks proposed in the Snowmass white paper on dark showers, which are used in this study, and present initial lessons learnt from attempting consistent parameter setting between generators.

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Yes

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the initiative for Dark Matter in Europe and beyond (iDMEu) and the ESCAPE DM Science Project

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With this talk, we would like to introduce the initiative for Dark Matter in Europe and beyond (iDMEu) and the ESCAPE Dark Matter Science Project. iDMEu is an initiative hosted by JENA (Joint ECFA, NuPECC and APPEC), and takes shape as a collective effort by a group of particle and astroparticle physicists to set up an online resource meta-repository, a common discussion platform and a series of meetings on topics concerning Dark Matter. The Dark Matter Science Project is a set of analyses / reinterpretations from different experiments (including one on dark showers) that have been implemented on a virtual research environment.

We would like to hear suggestions on how these initiatives and their connection to different communities (including those providing computing/tools) can help the dark showers benchmarking effort.

Acronyms, because this is needed by the author as well:

- ECFA (the European Committee for Future Accelerators)
- NuPECC (the Nuclear Physics European Collaboration Committee)
- APPEC (the Astroparticle Physics European Consortium)
- JENAA/JENAS (Joint ECFA, APPEC and NuPECC Activities/Seminar)
- ESCAPE (The European Science Cluster of Astronomy & Particle Physics ESFRI Research Infrastructures)
- ESFRI (European Strategy Forum on Research Infrastructures)

Are you happy to have the meeting recorded?:

Yes

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Joint ATLAS and CMS HepMC: dark showers benchmarks as a pilot

Author: Caterina Doglioni¹

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With this talk, we would like to introduce the idea of using the dark showers HepMC files produced in this effort as a test case to exercise the (distributed) computing machinery that would allow ATLAS and CMS to share HepMC files.

If this works and there are no drawbacks to implementation even for large-scale samples, there are the following benefits:

1. ATLAS and CMS are able to compare results more easily if they start from the same HepMC

2. theorists who want to reinterpret results can look at shared generation cards (rather than emailing each collaboration to find out what they are using)
3. we save storage space (which also has an environmental cost)

Are you happy to have the meeting recorded?:

Yes

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Cosmic ray antihelium in the Galaxy

Author: Pedro De la Torre Luque¹

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The creation of anti-nuclei in the Galaxy has been discussed as a possible signal of exotic production mechanisms such as primordial black hole evaporation or dark matter decay/annihilation in addition to the more conventional production from cosmic-ray interactions. Tentative observations of cosmic-ray antideuteron and antihelium by the AMS-02 collaboration have re-energized the quest to use antinuclei to search for physics beyond the standard model.

In this talk, we show state-of-art predictions of the antinuclei flux from both astrophysical and standard dark matter annihilation models from combined fits to high-precision antiproton data as well as cosmic-ray nuclei measurements. Astrophysical mechanisms can explain the amount of antideuteron events detected by AMS-02, while their antihelium production lies far below the sensitivity of this experiment. In turn, standard dark matter models could potentially produce the detected antideuteron and antihelium-3 events, but the production of any detectable antihelium-4 flux would require more novel dark matter model building. As one of the few proposed ways to explain the detection of antihelium-4 events, we discuss that the annihilation/decay of a QCD-like dark sector could potentially explain the preliminary observations of AMS-02.

Are you happy to have the meeting recorded?: