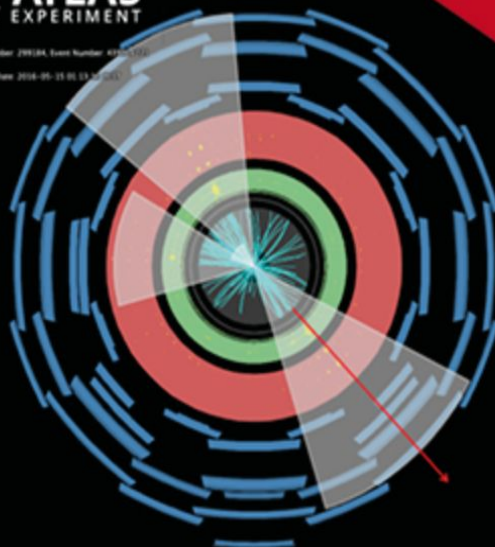




Summary of



Run Number: 293124, Event Number: 4220-2712  
Date: 2018-01-15 01:13:12 (UTC)



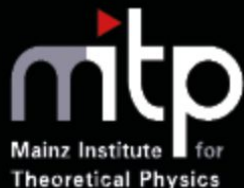
# Colours in Darkness:

Towards Improved Modelling of Strongly Interacting Dark-Sector Showers

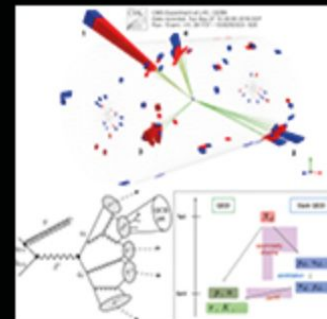
October 17 – 20, 2023



<https://indico.mitp.uni-mainz.de/event/377>



[Link: https://indico.mitp.uni-mainz.de/event/377/](https://indico.mitp.uni-mainz.de/event/377/)



**Sukanya Sinha**

University of Manchester

LHC DMWG Meeting

30/11/2023

MANCHESTER  
1824

The University of Manchester



European Research Council  
Established by the European Commission

# The big picture!

**We have not found any concrete sign of new physics ... yet!**

Looking at unusual topologies and hidden corners of the phase space

→ signature based searches, using benchmark models.

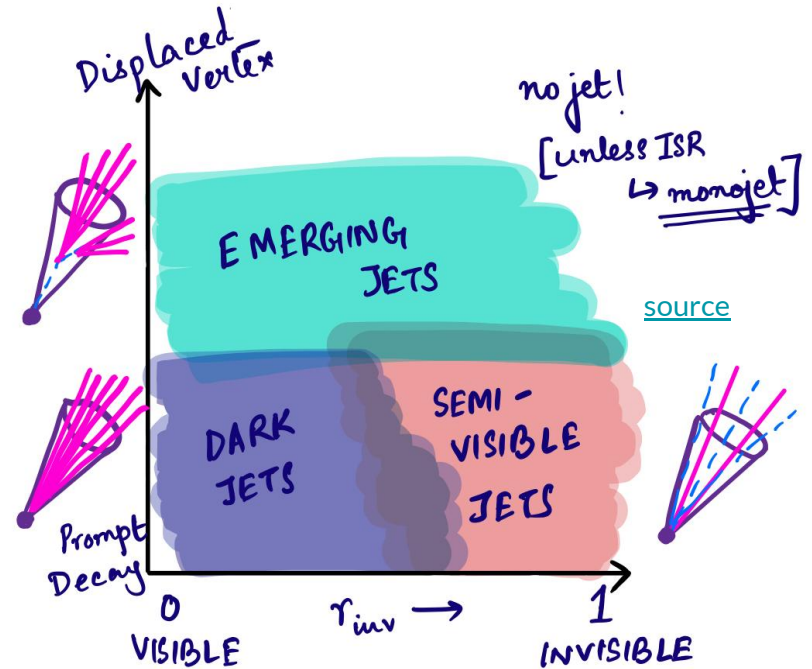
Dark hadrons decaying PROMPTLY in a QCD-like fashion, fully (dark jets)

or partially back to visible sector (semi-visible jets)

Dark hadrons undergoing DISPLACED decays in a QCD-like fashion (emerging jets)



(Courtesy: Jorge Cham)

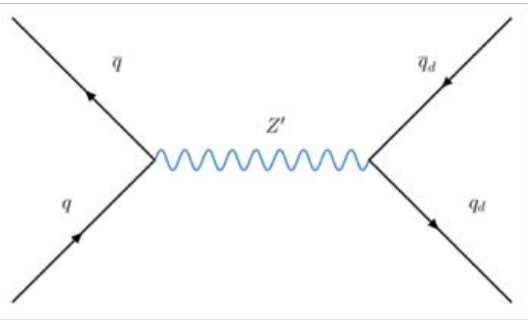


# Scope of the workshop

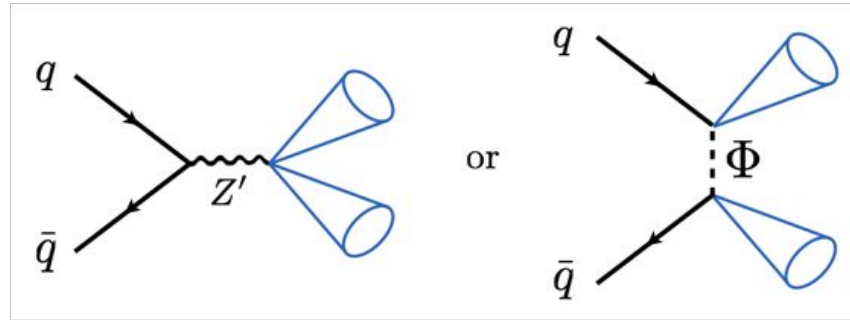
All pictures are taken from workshop talks unless stated otherwise

Aim to build collaboration and motivate cross-talk between the experimental and theory community dedicated towards developing and understanding the strongly interacting dark sector.

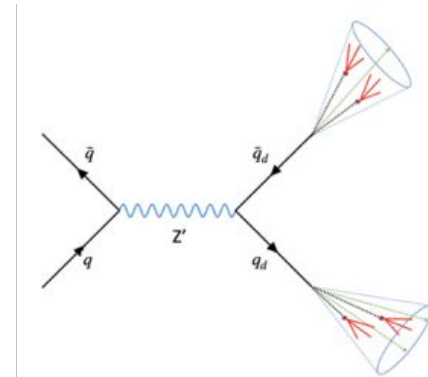
→ understanding the current status of the dark showering module within Monte Carlo generators like Pythia and Herwig, as well as identifying benchmark models that can drive future search strategies.



Dark jets



Semi-visible jets



Emerging jets

# Programme of the Workshop

Day1: Dark showers: Theory and Generator perspective

Day2: Dark showers: Experimental perspective (Run-2 results, lessons learnt, tools/analysis techniques developed)

Day3: Dark showers: Reinterpretability/reproducibility of experimental results, and new final-state signatures

Day4: Plans for ways forward: summary report

**Dedicated ECS sessions, focussing on individual topics**

# Programme of the Workshop

summary report on arXiv [[arXiv:2311.16330](https://arxiv.org/abs/2311.16330)]

Day1: Dark showers: Theory and **Speaker List**

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Day2: Dark showers: Experiment  
tools/analysis techniques develop

Day3: Dark showers: Reinterpretation  
final-state signatures

Day4: Plans for ways forward: summary

1. **Pedro Schwaller** [Emerging jets Phenomenology]
2. **Tim Cohen** [Semi-visible jets Phenomenology]
3. **Deepak Kar** [Semi-visible jets ATLAS result]
4. **Dilia Maria Portillo Quintero** [Dark jet resonances ATLAS result]
5. **Louie Dartmoor Corpe** [Reinterpretation tools]
6. **Aran Garcia-Bellido** [Semi-visible jets CMS result]
7. **Jannicke Pearkes** [Emerging jets CMS result]
8. **Suchita Kulkarni** [Pythia8 Hidden Valley module]
9. **Nishita Desai** [Alternative Hidden Valley configurations]
10. **Dominic Stafford** [Herwig7 dark shower module]
11. **Matt Strassler** [Dark showers: theory paradigm]
12. **Jon Butterworth** [Constraints on new theories using RIVET]
13. **Mark Goodsell** [Dark matter and dark sector complementarity]

**Dedicated ECS sessions, for**



# Images for dark showers



modern



design



contemporary



custom



beautiful

## Day 1: Summary and action items

- Main challenge on the theory frontier
  - capturing the vast range of possible signatures while taking into account the limits of theoretical knowledge
  - availability of simulation tools → currently HV is only Pythia8, HV in Herwig is WIP
  - finite number of phenomenological studies and experimental searches that can be done in practice

Progress on simulation tools (talk), and simplified phenomenological models and simple but complete benchmark models reported throughout the day looks promising and shows potential for shorter term standalone feasibility studies.



# Day 2: Summary and action items



- Discussion session focused on the existing experimental results and possible benchmark signal choices as well as alternate analysis approaches
- Model-dependence can arise at different stages: from dark quarks production going to dark showering, dark hadronization and decays.
  - fixing the portal and assuming QCD-like hidden sector [choosing certain number of dark colours/flavours] gives an handle on perturbative steps of the process
- Compromise has to be struck between theoretically sound models and experimentally searchable models focusing on uncovered phase space.
  - Independent tests are needed to gain more confidence in the different classes of theories that can be studied using this approach

# Day 2: Summary and action items (contd)

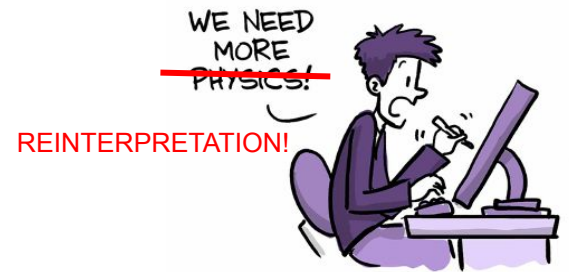


Discussions on the definition of  $r_{inv}$ :

- If  $r_{inv}$  is forced as an input parameter → can be taken at face value, and easier to understand for theorists
- If  $r_{inv}$  is made an output parameter → accurate branching ratios should be taken into account
  - a. downside to this approach is that the  $r_{inv}$  becomes much more model-dependent and difficult to reinterpret.
- Invisible fraction of total energy for a given model is preferred, especially when multiple flavours of dark quarks is involved



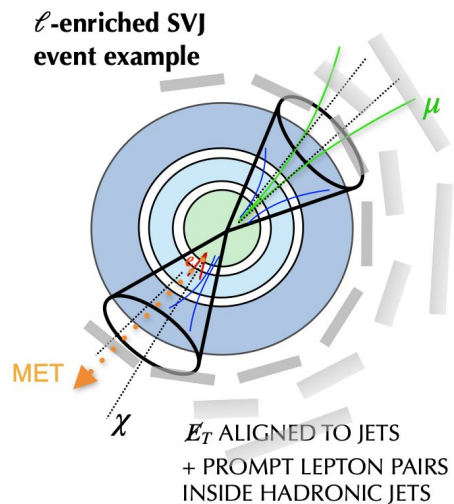
# Day 3: Summary and action items



- **Wishlist for more things to be added to reinterpretation?**
  - Full likelihoods → additional information coming from covariance matrices & explicitly spelling out intermediate steps in the analysis chain with descriptive object definitions]
  - Efficiency maps tend to be model dependent → difficult to reinterpret
  - Providing validated SimpleAnalysis routines, or REANA implementations of full analysis workflow, or using the detector smearing available within Rivet
  - CutfloWS need to be documented for searches properly
  - Wishlist for HEPData: cross-sections of signals should be included, ML info needs to be shared (at least features obtained from classifiers)
- To gain semi-quantitative estimate of phase space/parameter gaps: simpler analyses that are easily recastable are useful
- Reinterpretation of the CMS emerging jet search for exotic decays of the SM Higgs boson presented

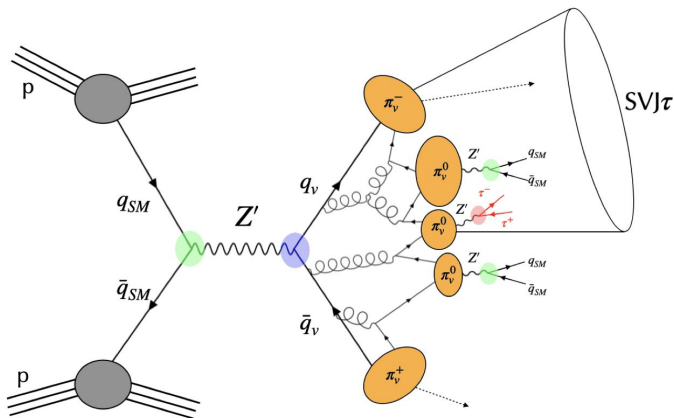
# Day 3: Summary and action items (contd...)

New signatures:



Two approaches for e/ $\mu$  enriched SVJ production presented

**Tau-enriched SVJ**

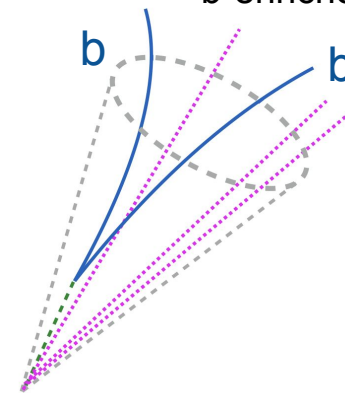


$Z' \leftrightarrow e, \mu$  coupling suppressed

→ Avoids existing constraints from di-lepton searches

→ Leaves possibility of  $\tau$  in jets

**b-enriched SVJ**



Explicitly producing just b-hadrons in the visible showering step

Additional handle on tagging SVJ

Reduces multijet BG

# Conclusions

- Several avenues of strongly interacting dark sector open for exploration
- General idea evolving around the need of more signature based searches
- First bounds set on these kind of signatures from CMS/ATLAS (many more to come)
- Can probe unusual collider phase-space corners by exploiting existing wealth of jet substructure observables or alternate search strategies (Partial Event Building + TLA and/or delayed stream)
- There is a buzzing ecosystem of re-interpretation
- **All discussions summarised in report, now on arXiv [arXiv:2311.16330]**

arXiv:2311.16330v1 [hep-ph] 27 Nov 2023

## MITP Colours in Darkness workshop summary report

Jon Butterworth<sup>a</sup>, Cesare Cazzaniga<sup>b</sup>, Aran Garcia-Bellido<sup>c</sup>, Deepak Kar<sup>d</sup>, Suchita Kulkarni<sup>e</sup>, Pedro Schwaller<sup>f</sup>, Sukanya Sinha<sup>g</sup>, Danielle Wilson-Edwards<sup>g</sup> and Jose Zurita<sup>h</sup>

<sup>a</sup>Department of Physics & Astronomy, University College London, London, United Kingdom

<sup>b</sup>ETH Zürich, Institute for Particle Physics and Astrophysics, 8093 Zurich, Switzerland

<sup>c</sup>Department of Physics and Astronomy, University of Rochester, Rochester NY, USA

<sup>d</sup>School of Physics, University of Witwatersrand, Johannesburg, South Africa

<sup>e</sup>Institute of Physics, NAWI Graz, University of Graz, Graz, Austria

<sup>f</sup>PRISMA+ Cluster of Excellence and Mainz Institute for Theoretical Physics, Johannes Gutenberg-Universität Mainz, Mainz, Germany

<sup>g</sup>School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom

<sup>h</sup>Instituto de Física Corpuscular, CSIC-Universitat de València, Paterna, Spain

\*Corresponding author(s): **Sukanya Sinha**\*

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### ABSTRACT

This report summarises the talks and discussions that took place over the course of the MITP Youngst@rs Colours in Darkness workshop 2023. All talks can be found at this URL: <https://indico.mitp.uni-mainz.de/event/377/>.

## 1 Introduction

In recent years, there has been an increase in the number of search programmes exploring the possibility of a “dark sector” beyond the Standard Model (BSM) using LHC data. To date, dark matter (DM) searches at the Large Hadron Collider (LHC) have usually focused on WIMPs (Weakly Interacting Massive Particles), but since the standard signatures have found no compelling evidence, several recent phenomenology papers have explored the possibility of accessing the dark sector with unique collider topologies. If dark mesons exist, their evolution and hadronization procedure are currently little constrained. They could

\*sukanya.sinha@cern.ch