New emerging jet models and trigger strategies

Dark shower workshop presentation

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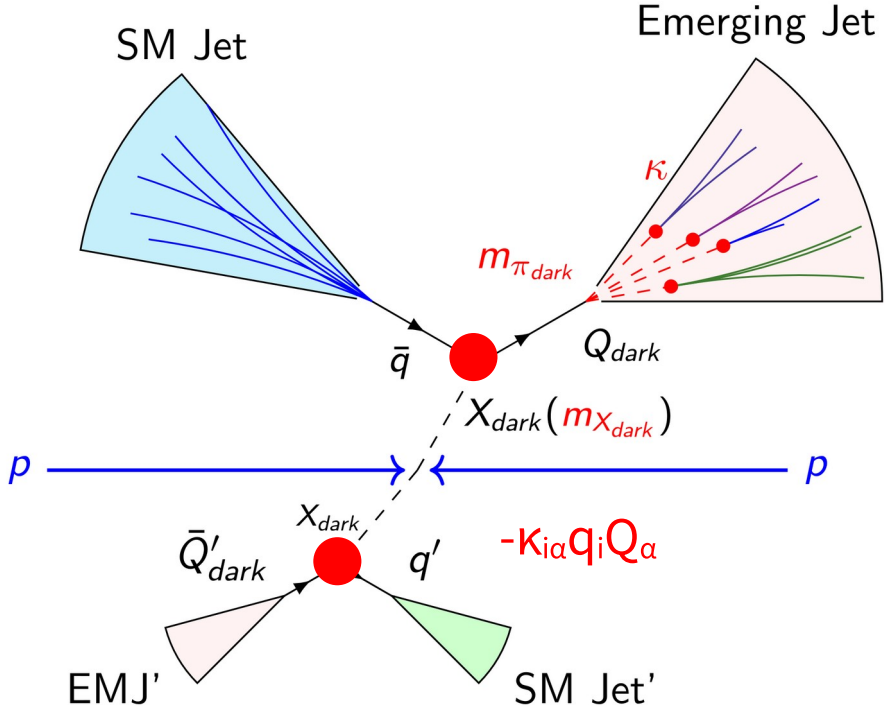
Overview of emerging jets at CMS



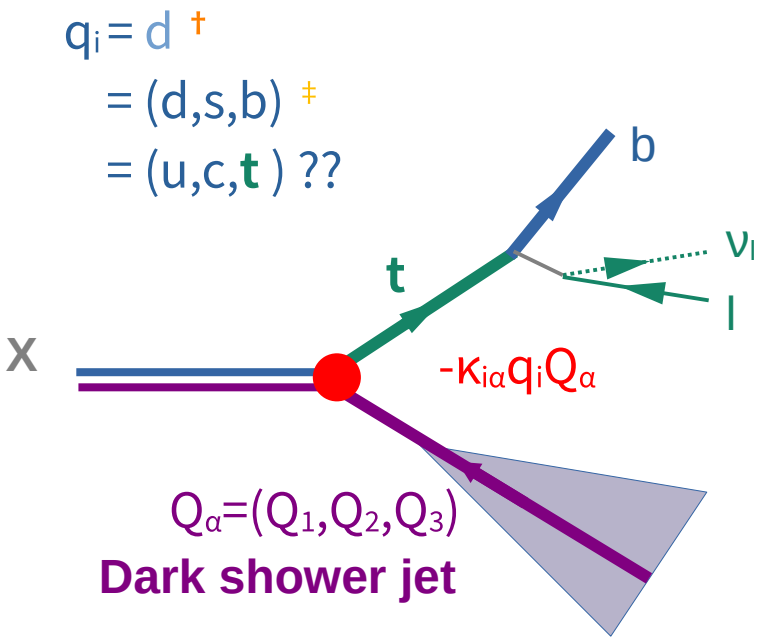
Pair production of SM-dark sector (DS) bifundemental mediator (X) decribed by new Yukawa coupling term

- SM jet guarantees “nominal” trigger path
- DS shower generates jets with multiple displaced vertices/tracks, “emerging jets”
- Accompanying SM jet can either be:
  - Mono-flavored: (CMS-EXO-18-001[1])
  - Any SM down-type: (CMS-EXO-22-015[2])

What can be done beyond higher luminosity?

[1] “Search for new particles decaying to a jet and an emerging jet”, JHEP 02 (2019) 179
[2] “Search for dark QCD with emerging jets in proton-proton collisions at $\sqrt{s}$ = 13 TeV”, JHEP 07 (2024) 142

Model extension – Isospin +½ coupling



Existing search effort for the mono-flavored model † and flavored model ‡ only includes coupling to isospin – ½ **SM** quark, a natural modification would be to have the **bifundemental** couple to isopin +½ **SM** quark, in particular, **Top quark** production allows for alternate lepton/EW-like trigger paths:

- Lower **mediator** mass can be probed
- Associated **top quark** reconstruction can be used to suppress other SM backgrounds.
- Preliminary studies show that these models are not excluded by $t\bar{t}$+MET/t+MET search efforts!

† "Emerging Jets", JHEP 05 (2015) 059
‡ "A flavoured dark sector", JHEP 08 (2018) 052

Sensitivity projection (@140fb^{-1})

- Benchmark **signal model**: Follows existing reference model[‡] with identity coupling to all 3 isospin + ½ SM quarks. M_X = 1 TeV, cτ=45mm
- **Emerging jets signature tagging**: Estimated CMS Run 2 search result[¶]
- **Top** selection and **EW** background suppression: CMS Run 2 t+X/t$\bar{t}$+X results[§]

From GEN study | Extrapolate Ref § | Extrapolate Ref ¶

	Lepton (~30GeV) + 4 Jets (~80GeV)	**Top reco.** (+SM jet selection)	**dark shower** tag
SM Multijet	~150K	<10	<< 1
t$\bar{t}$ + jets	~200M	200K	**100-500**
Dark shower (mono-flavored)	~1	<< 1	<<1
Dark shower (top-coupled)	2000	200-500	**50-200**

Rough estimated number of events after major event selection cuts (~140fb^{-1})

[‡] "A flavoured dark sector", JHEP 08 (2018) 052

[¶] "Search for dark QCD with emerging jets in proton-proton collisions at $\sqrt{s}$ = 13 TeV", JHEP 07 (2024) 142

[§] "Search for dark matter produced in association with a single top quark or a top quark pair in proton-proton collisions at $\sqrt{s}$=13 TeVs", CMS-PAS-EXO-22-014

Dark shower signals - modification

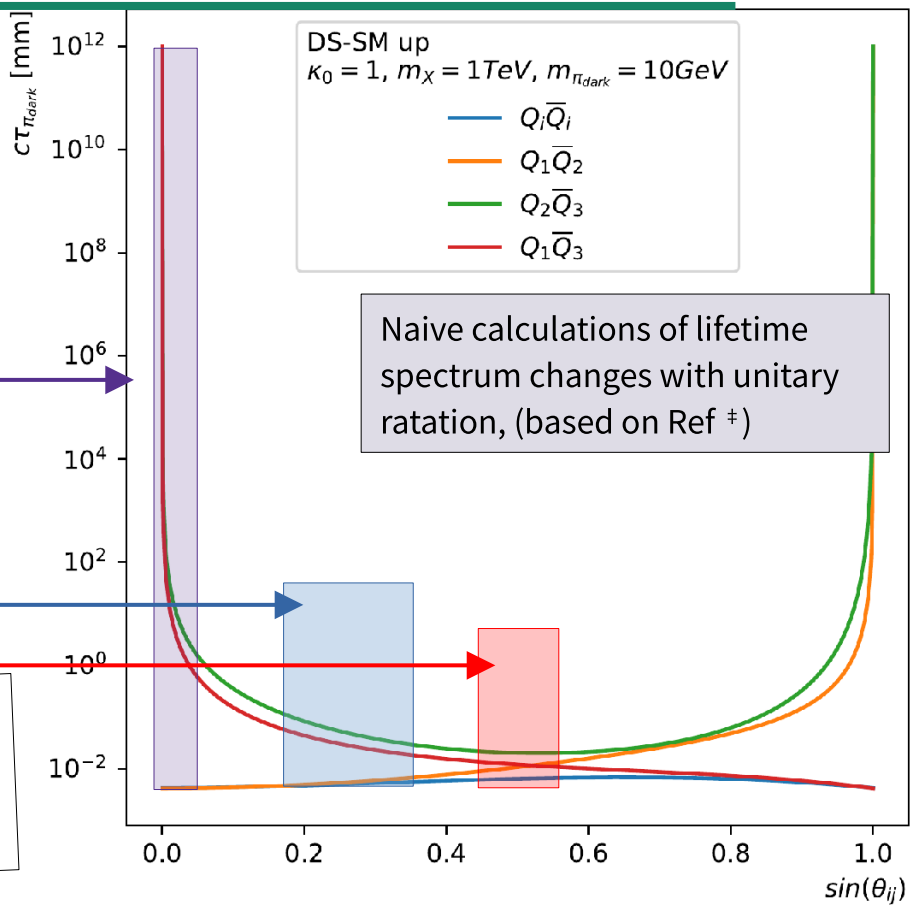
The flavored model in Ref [‡] introduces a spectrum of lifetime depending on **DS-SM** Yukawa coupling. Further modifications can be made by unitary rotations:

- **"semi-visible"–like**: ***new*** to top-coupled model (keep Yukawa matrix "identity-like")
  - **dark meson** cannot decay to **top quark**
  - Mixture of *stable* **DS** mesons + LLP DS mesons
- **Prompt+displaced** (CMS Run 2 search)
- **Uni-lifetime models** (CMS 2018 search)

Top + **existing** EMJ tagging strategy

or

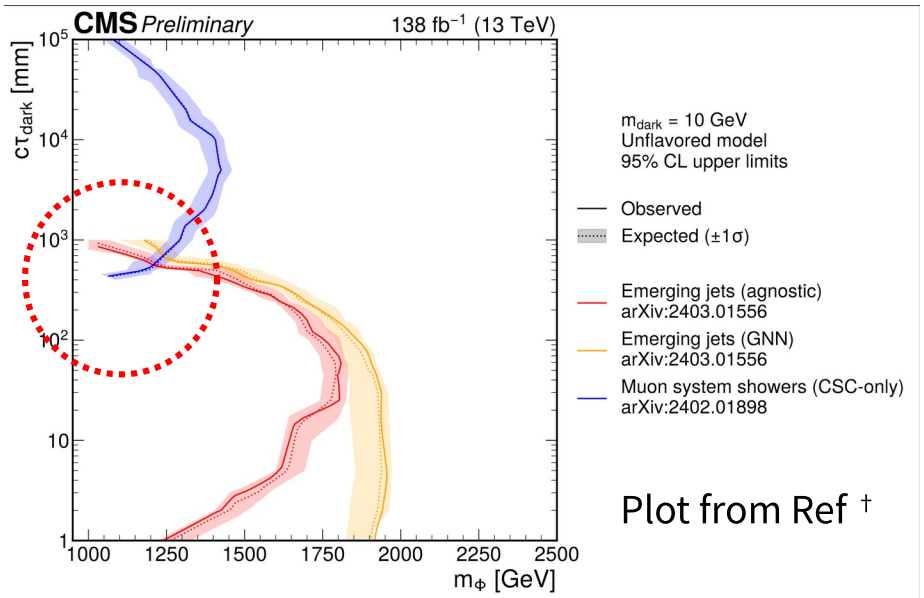
Completely new tagging strategy?



[‡] "A flavoured dark sector", JHEP 08 (2018) 052

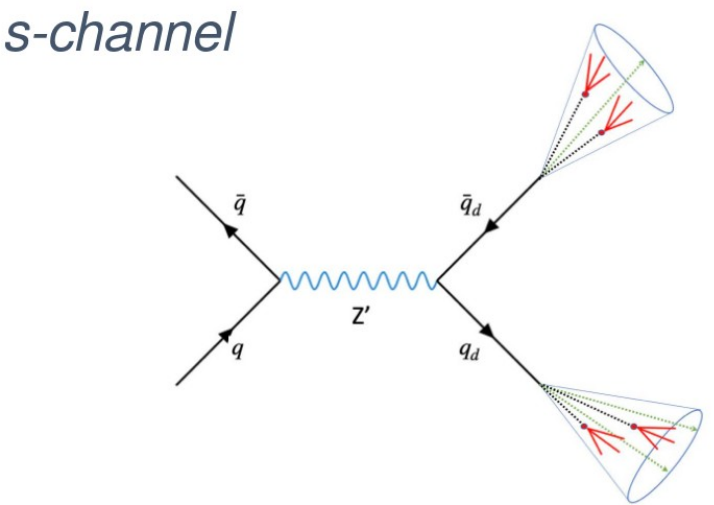
New probes available in CMS Run 3 data

Can we bridge the sensitivity gap at beyond the tracking system? Calorimeter triggers [‡] / dedicated Muon system triggers [¶]?



Plot from Ref [†]

Can we reliably trigger on the anomalous dark shower itself [§ *]? Directly probing alternate dark shower production topologies!



[†] "Exotic searches by CMS", 58th Rencontres de Moriond on Electroweak Interactions and Unified Theories,
[‡] "A Novel Timing Trigger with the CMS Hadron Calorimeter", CMS detector note CMS-DN-2023-022
[¶] "High Multiplicity Trigger for Long-Lived Particles in CMS Detector in 2022 and 2023", CMS detector note CMS-DP-2024-099
[§] "Level-1 Trigger Calorimeter Image Convolutional Anomaly Detection Algorithm", CMS detector note CMS-DP-2023-086
[*] "2024 Data Collected with AXOL1TL Anomaly Detection at the CMS Level-1 Trigger", CMS detector note CMS-DP-2024-059

Summary

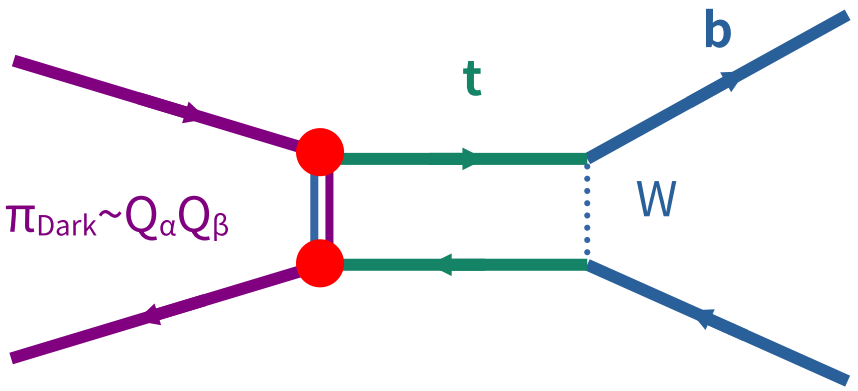
Many interesting paths can exist for emerging jets search efforts!

- Modifications to DS-SM modles
  - Different SM triggers are available with top production
  - Alternate emerging jets signature depending of coupling
    Many models not covered by existing CMS searches!

- **New tools** at CMS that can be used to probe models!
  - LLP based triggers in tracking/calo/muon systems
  - Anomally trigger to directly trigger on dark shower signature!

Backup

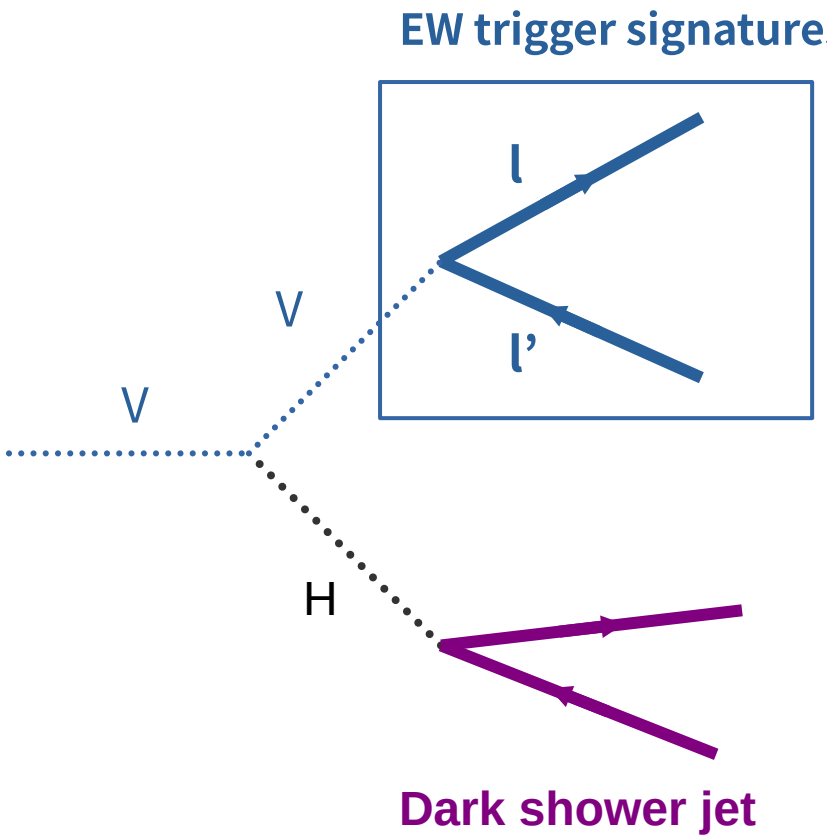
Alternate top-only coupling



Can we include just the SM **top** in the **DS-SM Yukawa** coupling matrix?

- **Dark sector meson** decay is now only possible at loop level (enforces long lifetime)
- Production of dark shower will always be associated with at least 1 top quark (can boost lepton-based trigger sensitivity)
- *Does this violate any known flavor physics limits?*

Even more possibilities with EW triggers



If we are looking at EW triggers, are there other production paths that was previously uncovered/insensitive to?

- Associated Higgs/EW production?