Prospects for Emerging Jets in Run 3

Roy F. Cruz[1] on behalf of the CMS Collaboration
[1]University of Wisconsin-Madison; work conducted at the University of Puerto Rico Mayagüez

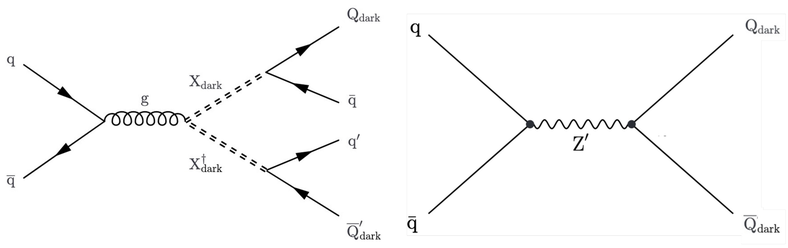
Background

- Astronomical evidence indicates dark matter.
- Hidden Valley models propose a dark QCD sector coupled to the SM via a mediator.
- Model of interest: Energy of jets produced in dark sector gradually emerge into SM through the decay of long-lived dark mesons (π_{dark}, ρ_{dark}) into quarks producing an *emerging jet* (EJ).
- Previous CMS search [1] looked for EJs inside the CMS tracker produced through the pair production of bi-fundamental scalar mediator (Figure 1a).
- Next iteration will incorporate other models:
  - Longer lived π_{dark}
  - Z' mediator models (Figure 1b)
- Goal: **Study the performance of novel L1 triggers for new EJ production mechanism and models with higher $c\tau_{\pi_{\text{dark}}}$.**

Sample Production

- Development of Z' mediator model Pythia MC production code and integrated into existing codebase from previous analysis.
- Production of a set of comprehensive samples for trigger studies for both Z' and bi-fundamental scalar mediator models.

EJ Model Parameters	
Model parameter	List of values
m_{med} [GeV]	100, 250, 500, 750, 1000, 1500, 2000
$m_{\pi_{\text{dark}}}$ [GeV]	10, 20
$c\tau_{\pi_{\text{dark}}}$ [mm]	1, 100, **1000, 1500, 2000**



a) Pair production of bifundamental scalar mediator

b) Z' mediator

Figure 1: Feynman diagram of the two production mechanism studied

Novel L1 Triggers

- Previous search used triggers which cut on

$$H_T = \sum_i p_{T,jet_i}$$

- Novel triggers in Run 3 could offer potential opportunities for increased sensitivity for newer models.
- New triggers of interest:
  - Machine learning based anomaly detection (AD) triggers (CICADA & AXOL1TL) [2]
  - HCAL displaced jet long-lived particle (LLP) triggers [3]
  - Cathode Strip Chambers High Multiplicity Trigger (CSC HMT) [4]

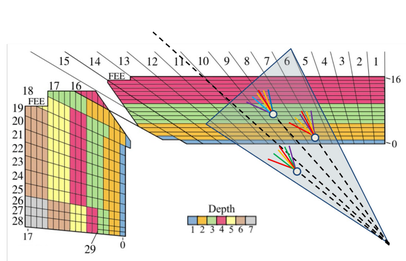


Figure 2: Ilustration of the decay of a particular long-lived π_{dark} that is part of an EJ inside the HCAL, leading to a displaced sub-jet which the HCAL displaced jet trigger can target [3]

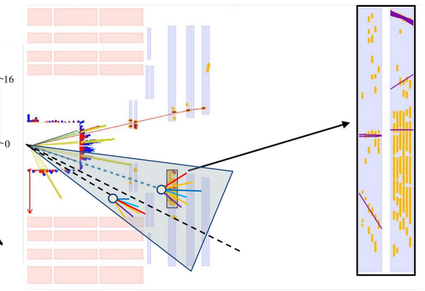


Figure 3: Ilustration of the decay of a particular long-lived π_{dark} that is part of an EJ inside the CSC, producing a shower which the CSC HMT targets [4]

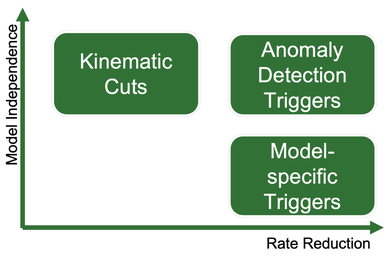


Figure 4: Schematic figure showing how each type of trigger, including AD triggers, are characterized by their mode independence and rate reduction [2]

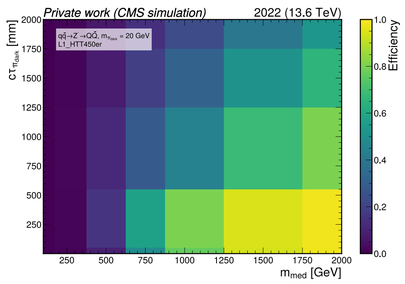


Figure 5: Trigger efficiency of the $H_T > 450$ GeV trigger for the simulated parameter space. This illustrates the baseline efficiencies expected if the trigger used in the previous search was reutilized.

Efficiency Results

Trigger Efficiency Results Summary for Z' Mediator	
Trigger(s)	Performance Summary
AD Triggers	Do not specifically target models with higher $c\tau_{\pi_{\text{dark}}}$. However, they do offer some non-negligible increase in efficiency, particularly for AXOL1TL, at the current allocated rates (150 Hz for CICADA, 200 Hz for AXOL1TL).
HCAL LLP	As expected by their design, these target models with higher $c\tau_{\pi_{\text{dark}}}$. The increase in the efficiency peaks around models with higher π_{dark} lifetimes, and lower m_{med}, which corresponds to the area in parameter space that is hardest to trigger on. Increase peaks at 1.11×.
CSC HMT	This targets models with higher $c\tau_{\pi_{\text{dark}}}$, which is also expected by their design. Peak in efficiency increase is around lowest m_{med} and highest $c\tau_{\pi_{\text{dark}}}$ simulated. Increase peaks at 4.47×.

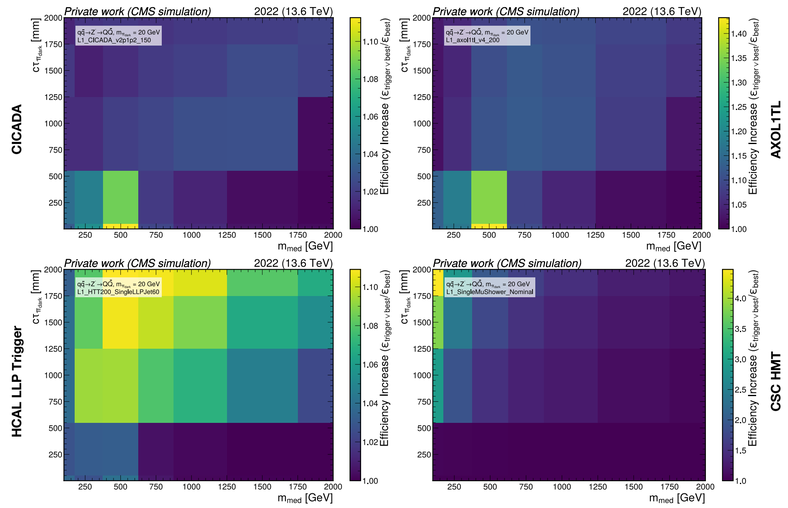


Figure 6: Efficiency increase of using each novel trigger with the best conventional trigger, i.e. $\frac{\varepsilon_{\text{trigger} \vee \text{best}}}{\varepsilon_{\text{best}}}$, for EJ models with a Z' mediator. Best trigger refers to the conventional trigger with highest efficiency for a given set of model parameter values.

Conclusions

- Novel L1Ts enhance sensitivity to EJs from Z' mediators and larger $c\tau_{\pi_{\text{dark}}}$.
- CSC HMT shows the largest efficiency gain (4.47×), though absolute increase is small due to low sensitivity at low m_{med}.
- HCAL LLP triggers, especially the single LLP trigger, provide modest gains ($\leq 1.11\times$) across broader regions with longer lifetimes.
- AD triggers shows promise, but future versions must also be tested. Moreover, the results depend on how much data is collected with these novel triggers.

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Bibliography

[1] arXiv:1502.05409v3
[2] arXiv:2411.19506
[3] CMS DP-2024/058
[4] CMS DP-2022/062