Dark Matter Searches: Semi-visible Jets and Emerging Jets with Partial Event Building

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What is Dark Matter? Why have we not found it yet?

 mono-X searches:
 X - SM object
 mono - DM recoiling in opposite direction

... but what if we should look at unusual final states?
The Dark Sector: Semi-visible Jets (SVJ) and Emerging Jets (EJ)

What if there's not 1 DM particle but a whole sector of invisible particles that interact with each other?

If we produce a dark sector quark it will fragment and hadronize into dark sector hadrons which will then decay giving unusual topologies in our detector.

Different parameters, different jet phenomenologies. For example:

**Semi-visible Jets (SVJ):** produced when dark quarks decay partly to SM quarks and partly to stable dark hadrons (which are invisible) → missing transverse energy

**Emerging Jets (EJ):** dark hadrons undergoing displaced decays → displaced objects

❗ challenging event signature

**displaced vertex:** charged tracks originating from a displaced point

**r_inv:** rate of stable dark hadrons / total dark hadrons
Properties of the SVJ signal

Lead jet pt (transverse momentum of leading jet in pT): momentum of most transversely energetic jet.

MET (missing transverse momentum): event momentum imbalance in x-y plane.

Plotting the lead jet pT and the MET in the event:

- \( r_{inv} \): rate of stable dark hadrons / total dark hadrons
- \( \text{mediator mass} \): the mass of the \( \phi \) in the production diagram.
Triggers

How do we choose interesting events that we want to keep and study? We use triggers!

- Collisions in the LHC happen every 25 ns → 40 MHz rate of collisions → impossible to read-out or record data at that rate in ATLAS
- **Trigger** selects which events we want to keep for analysis → based on having high transverse momentum objects (e.g. jets, electrons, muons, etc.)
- Rate of data recorded needs to be shared between the different physics objects
- We record **all** events with high pT jets and also events with high MET
- But our signals have both of these properties - which trigger is best to record the most data?
-💡 Look at efficiency of recording the data using different triggers
Semi-visible jets - trigger choice

What are the current triggers in ATLAS?

- ATLAS records all events satisfying any of:
  - **J420 trigger** \( r=0.4 \) (small-R) jet w/ offline pT>450 GeV
  - **lcw_j460 trigger** \( r=1.0 \) (large-R) jet w/ offline pT>500 GeV
  - **MET trigger** \( \rightarrow \) offline MET>200 GeV

- All 3 triggers:
  - ✔ record highest HT energy events
  - ✗ miss low HT signal

-💡 Find highest efficiency by computing integrals of the plots

**ATLAS work in progress**

\( \mathcal{S} = 13 \text{ TeV, } 139 \text{ fb}^{-1} \)

**Semi-Visible Jets**

HT: scalar jet pt sum, hadronic transverse energy
incl: inclusive with 2-jet pre-selection, no triggers applied yet
Trigger Efficiencies for SVJ Signals

*How much is each trigger capturing?*

<table>
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<th>event/signal</th>
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<th>515624</th>
<th>515631</th>
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<td>mediator mass</td>
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<td>6</td>
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<tr>
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<tr>
<td>efficiency_lcw_j460</td>
<td>91.00%</td>
<td>79.00%</td>
<td>66.50%</td>
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</tbody>
</table>

- Current ATLAS analysis: uses **MET trigger** (met > 200 GeV) (simplest to use)
- But we see that slightly more signal events are recorded by the **large-R trigger** (r=1.0)
- For Run 3 analysis, we can revisit this strategy to recover some signal efficiency!
- I have also studied the efficiencies for emerging jet signals (internal)
Partial Event Building

Triggers can only so much... so how can we save more events?

- We record only ~1-2 kHz of full ATLAS events split between trigger signatures
- Possibility of recording more events if we record only PART of the detector and trigger information!

💡 Partial Event Building principle

- Find efficient triggers more signal events than existing triggers
- Record enough information to distinguish them from background

Emerging jets appear displaced in the detector Recording these special jets Separate new physics from SM jets

💡 Study what triggers for dark sector signals + retain enough information to distinguish against QCD
Feasibility Check of Partial Event Building

*PEB for the dark sector is brand new… feasibility check first!*

- Record information in region(s) around leading jet(s) with Partial Event Building → check that these contain “special” jets
- **charged fraction (chf)** - fraction of pT of the lead jet carried by primary vertex (PV) tracks (trk)
  \[
  chf = \frac{\sum pT_{trk}}{jetpT}
  \]
- Plot leading jet charged fraction

**ATLAS work in progress**

\(s = 13 \text{ TeV}, 139 \text{ fb}^{-1}\)

**Semi-Visible Jets**

- this looks like normal QCD jets with peak around 60%

**Emerging Jets**

we see lack of tracks (~0 chf) showing ✨special ✨nature of EJ

Next step for the project: Emulate whole PEB selection
Conclusion

- Semi-visible jet signals → high jet pT and high MET
- Emerging jet signals → no tracks reconstructed from primary vertex, particles produced are displaced from hard scatter
- Triggering on SVJ: large-R triggers perform well
- Partial Event Building: promising way of increasing signal that we can record
- Learning more about ATLAS search analyses and triggers
- Thanks to ATLAS, CERN, and CERN & Society!