New Experimental Techniques for Dark Sectors

Semi-visible Jets and Emerging Jets with Partial Event Building
(CERN Summer School Project)

Angelica Aira Ayalin
University of the Philippines Diliman

Supervisors: Sukanya Sinha (University of Manchester) & Christopher Young (CERN)

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?

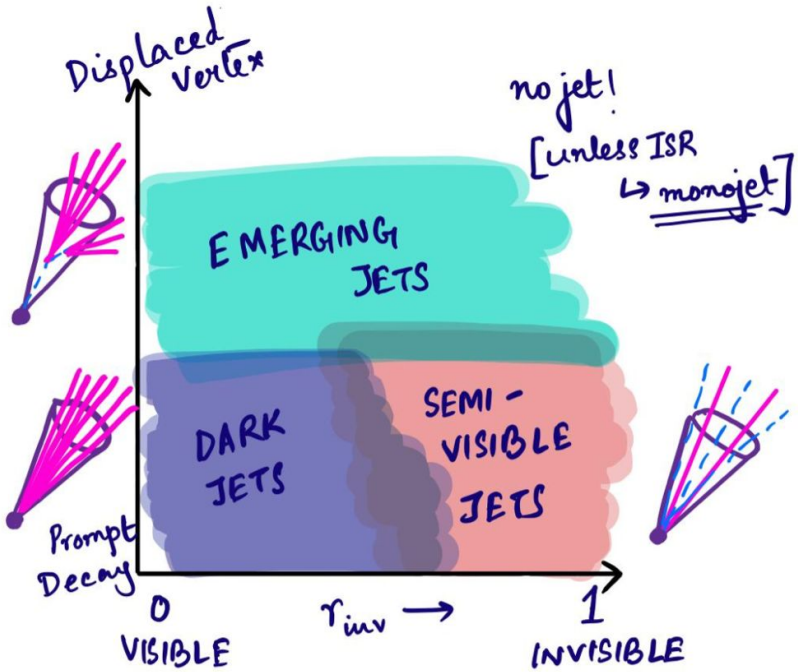
If we produce a dark sector quark it will fragment and hadronize into dark sector hadrons which will then decay giving unusual topologies in our detector.

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

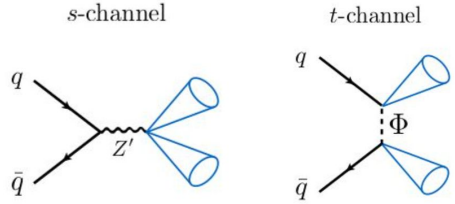
❗ challenging event signature



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



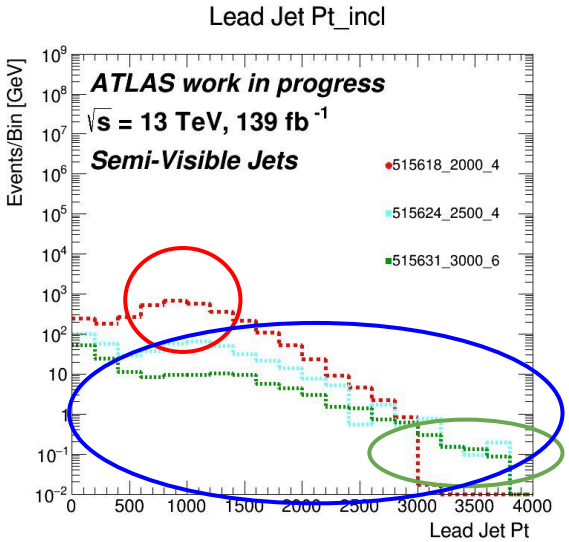
↑ high pT jets

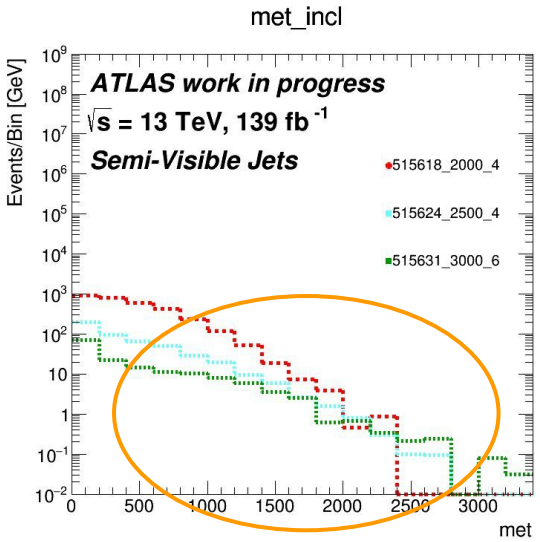
↓ lower mediator masses peak from s-channel resonance

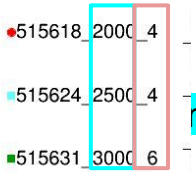
↓ higher mediator masses dominated by t-channel production

↑ high MET

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







r_inv: rate of stable dark hadrons / total dark hadrons
mediator mass: the mass of the ϕ in the production diagram

Triggers

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

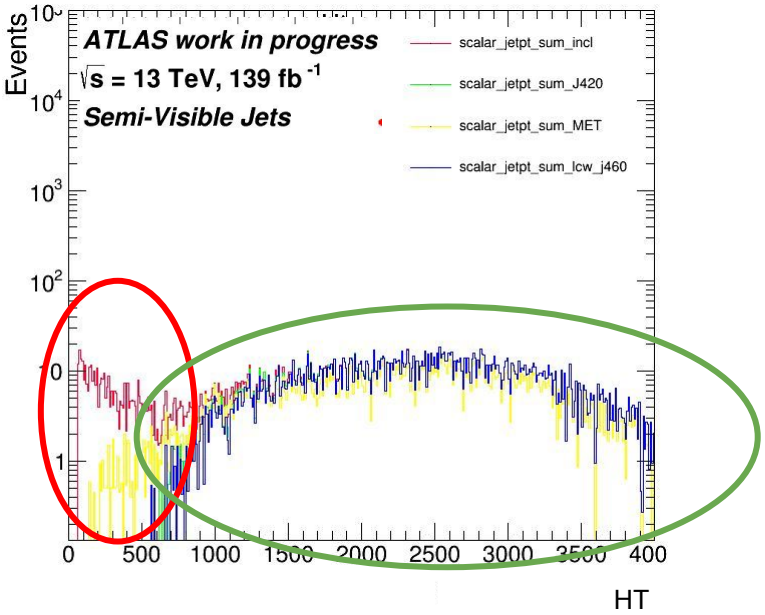
- Collisions in the LHC happen every 25 ns → 40 MHz rate of collisions → impossible to read-out or record data at that rate in ATLAS
- **Trigger** selects which events we want to keep for analysis → based on having high transverse momentum objects (e.g. jets, electrons, muons, etc.)
- Rate of data recorded 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** → 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

Signal 1: r_inv = 0.4, mediator mass = 2000 GeV



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

Partial Event Building

Triggers can only do 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

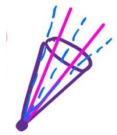
Feasibility Check of Partial Event Building

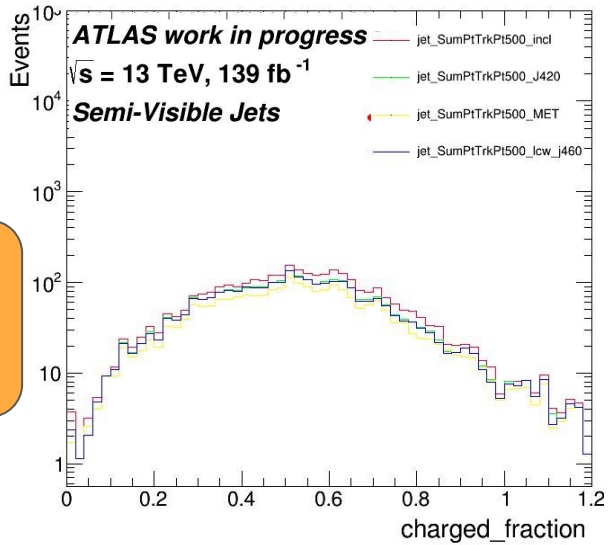
$$chf = \frac{\sum pT^{trk}_{PV}}{jetpT}$$

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)
- 📊 Plot leading jet charged fraction

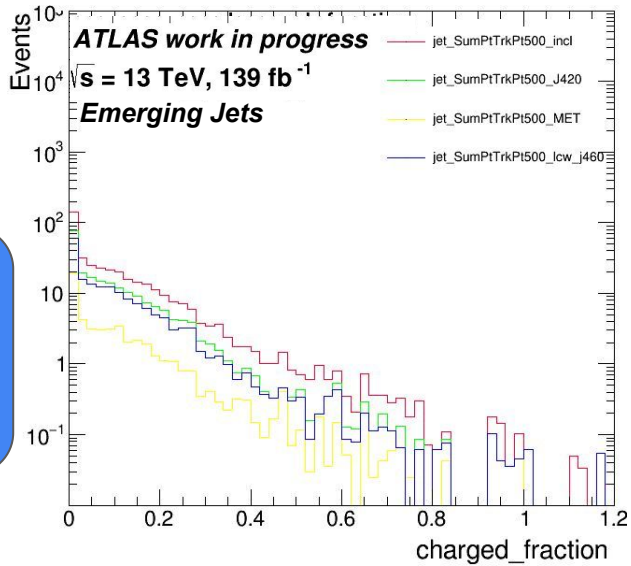
r_inv = 0.4, mediator mass = 2000 GeV





this looks like normal QCD jets with peak around 60%

mediator mass = 1500 GeV, lifetime 10 mm



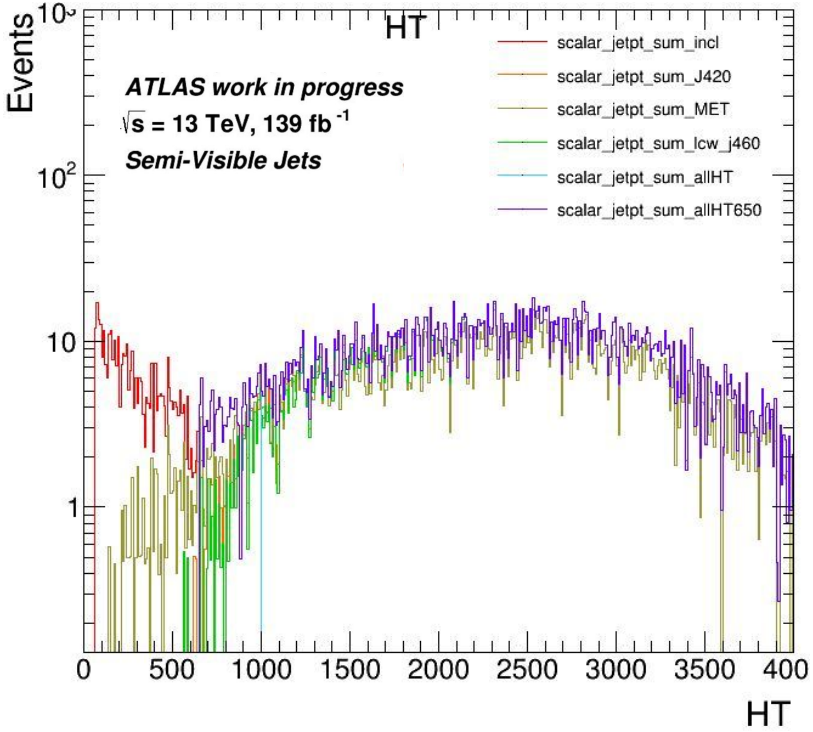
we see lack of tracks (~0 chf) showing ✨special ✨ nature of EJ

Next step for the project: Emulate whole PEB selection

New Trigger Choice for SVJ

- New triggers tried:
  - **allHT trigger** → scalar jet pt sum>1000 GeV
  - **allHT650 trigger** → scalar jet pt sum>650 GeV
- allHT650 trigger:
  - ✔ records highest HT energy events for SVJ

SVJ Signal 1: r_inv = 0.4, mediator mass = 2000 GeV



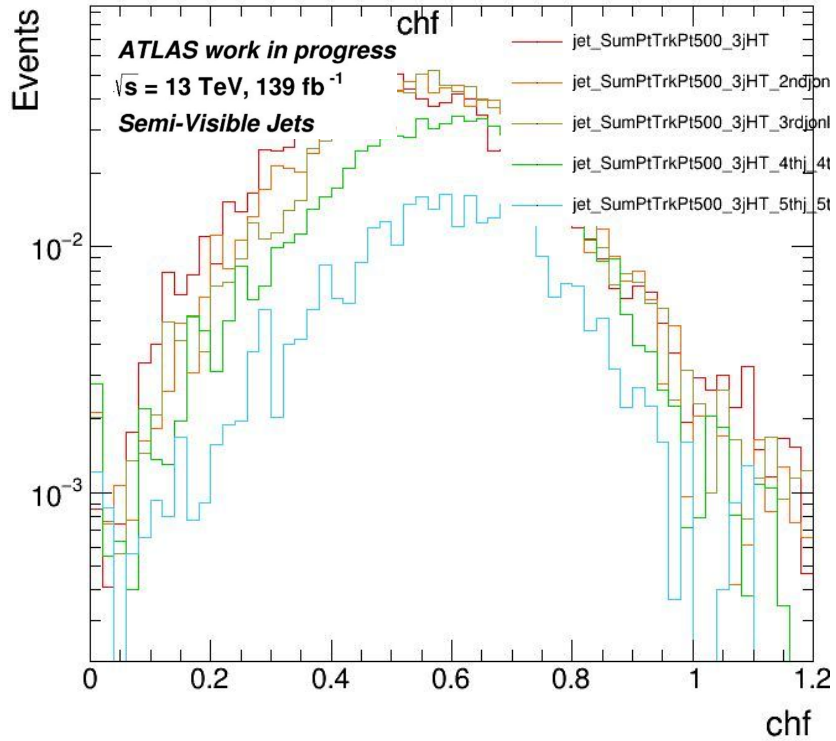
New Trigger Efficiencies for SVJ Signals

With allHT and allHT650

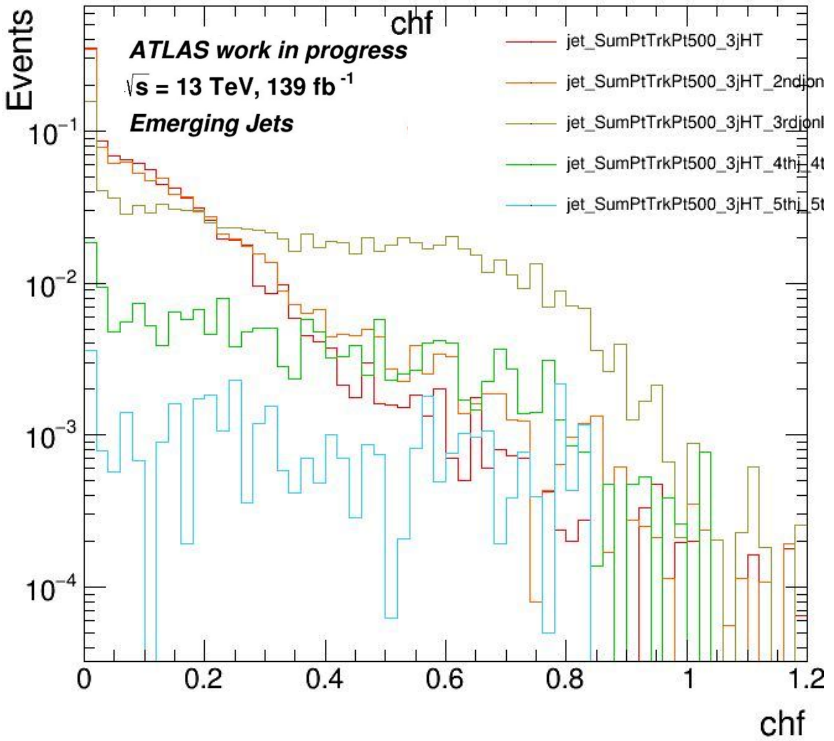
	Semi-visible Jet Signals		
event/signal	**515618**	**515624**	**515631**
mediator mass	2000	2500	3000
r_inv	4	4	6
efficiency_J420	84.73%	62.56%	44.22%
efficiency_MET	70.86%	56.12%	49.85%
efficiency_lcw_j460	83.03%	61.04%	42.01%
efficiency_allHT	84.14%	61.56%	40.65%
efficiency_allHT650	88.64%	67.89%	48.03%
Comparison vs allHT650			
allHT650 and J420	4.42%	7.86%	7.93%
allHT650 and allHT	6.33%	10.09%	12.55%

How many regions of interest are required?

SVJ Signal 1: r_inv = 0.4, mediator mass = 2000 GeV

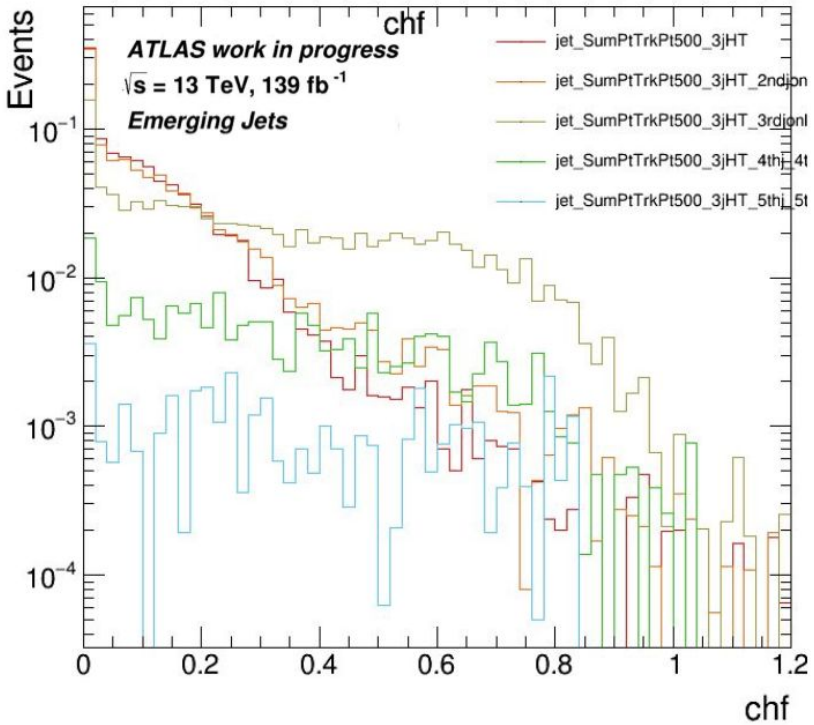


EJ Signal 2: mediator mass = 1500 GeV, lifetime 10 mm



chf of lead jet and next 4 jets

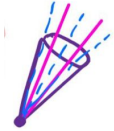
How many regions of interest are required?



event/signal	801928
dark confinement scale (Λ_dark)	1.6
Z prime mass [GeV]	1500
Dark pion mass [GeV]	0.8
Dark rho mass [GeV]	3.2
Lifetime [mm]	10
leadjet_2bins	44%
2ndjet_2bins	42%
3rdjet_2bins	20%
4thjet_2bins	3%
5thjet_2bins	0%

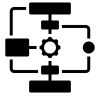
Charged fraction of first 5 jets for EJ signal 2 (Z' mass = 1500 GeV, lifetime = 10 mm)

Conclusion



- Semi-visible jet signals → high jet pT and high MET

- Emerging jet signals → no tracks reconstructed from PV, particles produced are displaced from hard scatter



- Triggering on SVJ: large-R triggers perform well, allHT650 performs best

- Partial Event Building: promising way of increasing signal that we can record

- For PEB, 3rd jet has to be included to determine special nature of EJ signals
- Thanks to ATLAS, CERN, and CERN & Society!

ATLAS EXPERIMENT

CERN

CERN & Society Foundation

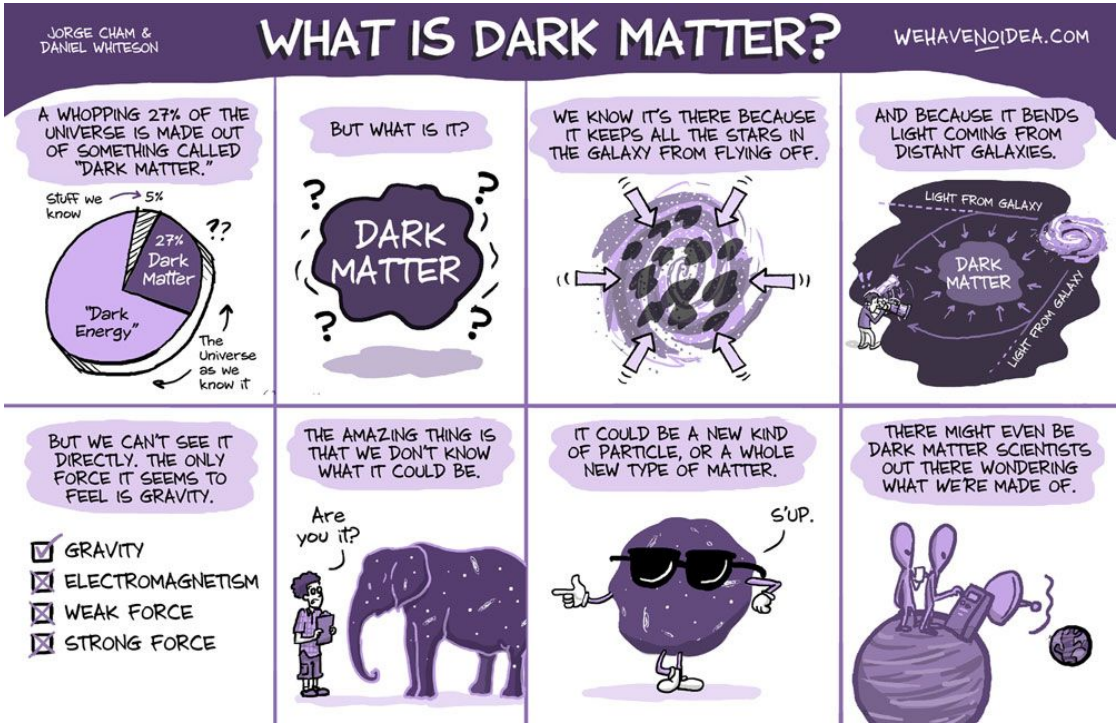
Trigger Efficiencies for SVJ Signals

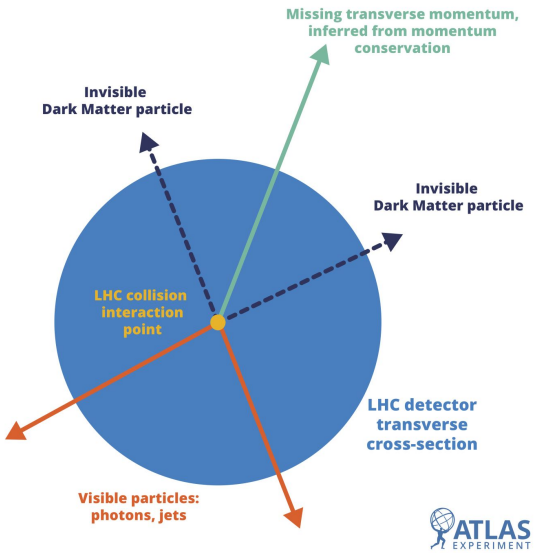
How much is each trigger capturing?

	small		
event/signal	**515618**	**515624**	**515631**
mediator mass	2000	2500	3000
r_inv	4	4	6
efficiency_J420	84.73%	62.56%	44.22%
efficiency_MET	70.86%	56.12%	49.85%
	large		
efficiency_lcw_j460	91.00%	79.00%	66.50%

- 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)

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



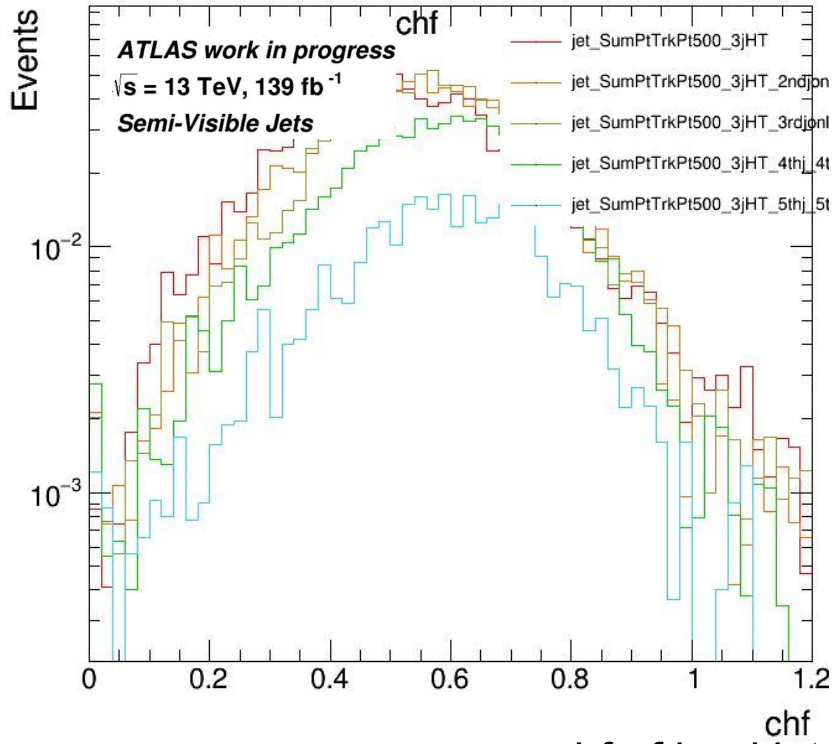


mono-X searches:
X - SM object

… but what if we should look at unusual final states?

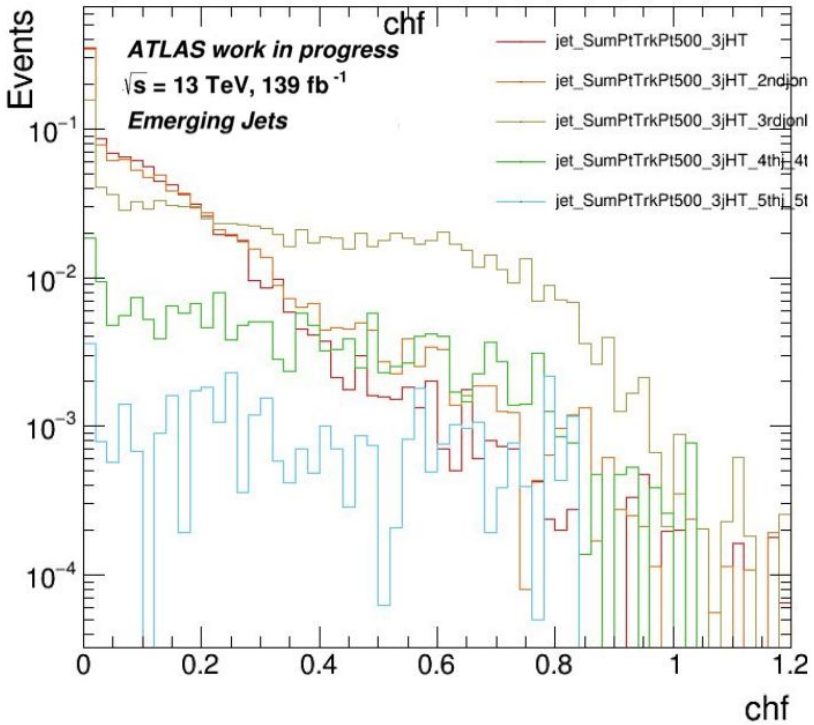
How many regions of interest are required?

SVJ Signal 1: r_inv = 0.4, mediator mass = 2000 GeV



chf of lead jet and next 4 jets

How many regions of interest are required?



event/signal	801928
dark confinement scale (Λ_dark)	1.6
Z prime mass [GeV]	1500
Dark pion mass [GeV]	0.8
Dark rho mass [GeV]	3.2
Lifetime [mm]	10
leadjet_2bins	44%
2ndjet_2bins	42%
3rdjet_2bins	20%
4thjet_2bins	3%
5thjet_2bins	0%

Charged fraction of first 5 jets for EJ signal 2 (Z' mass = 1500 GeV, lifetime = 10 mm)