# SIFT-ing for Dark Shower Signals

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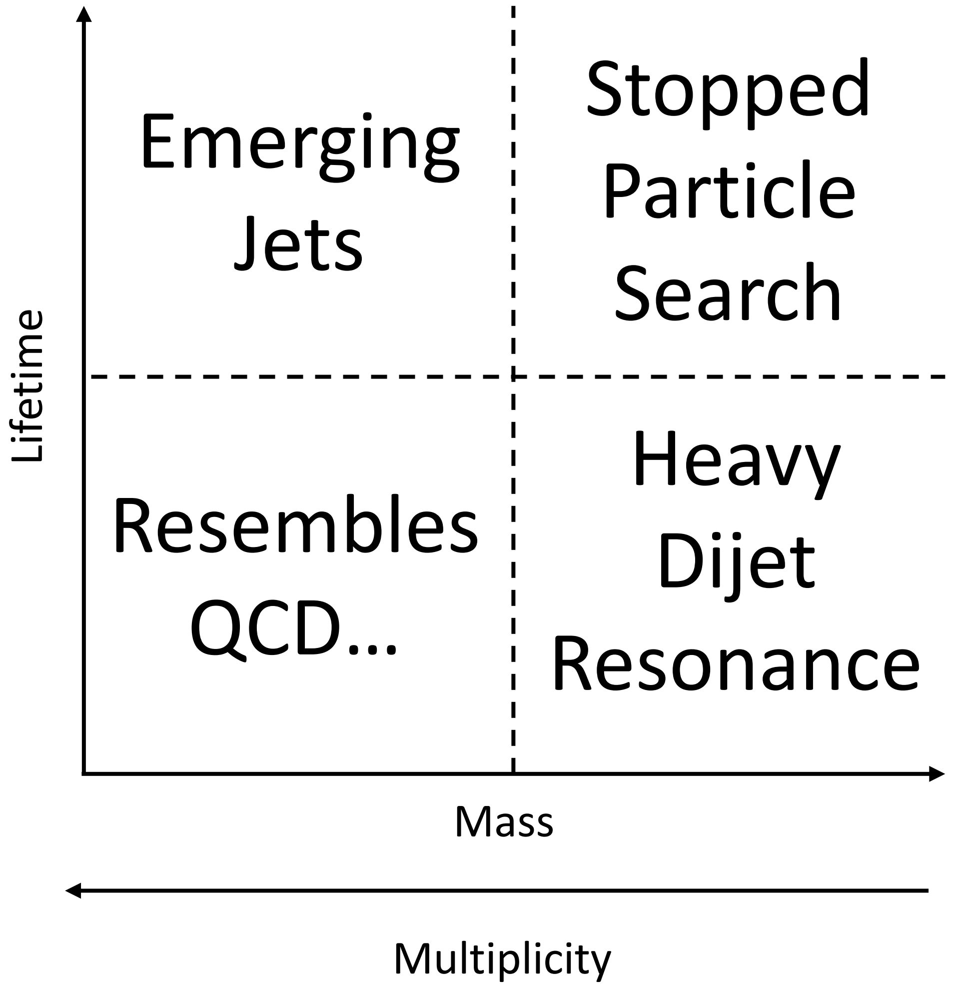
# Dark Shower Signatures



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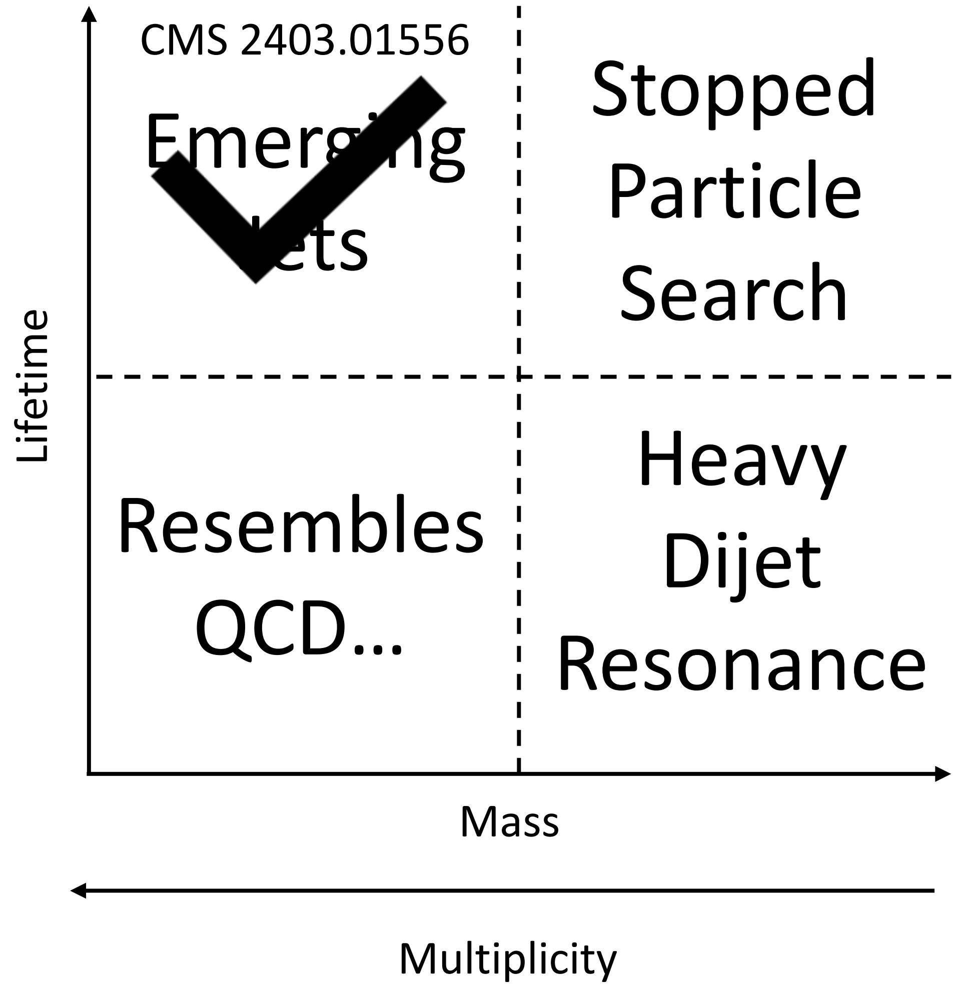


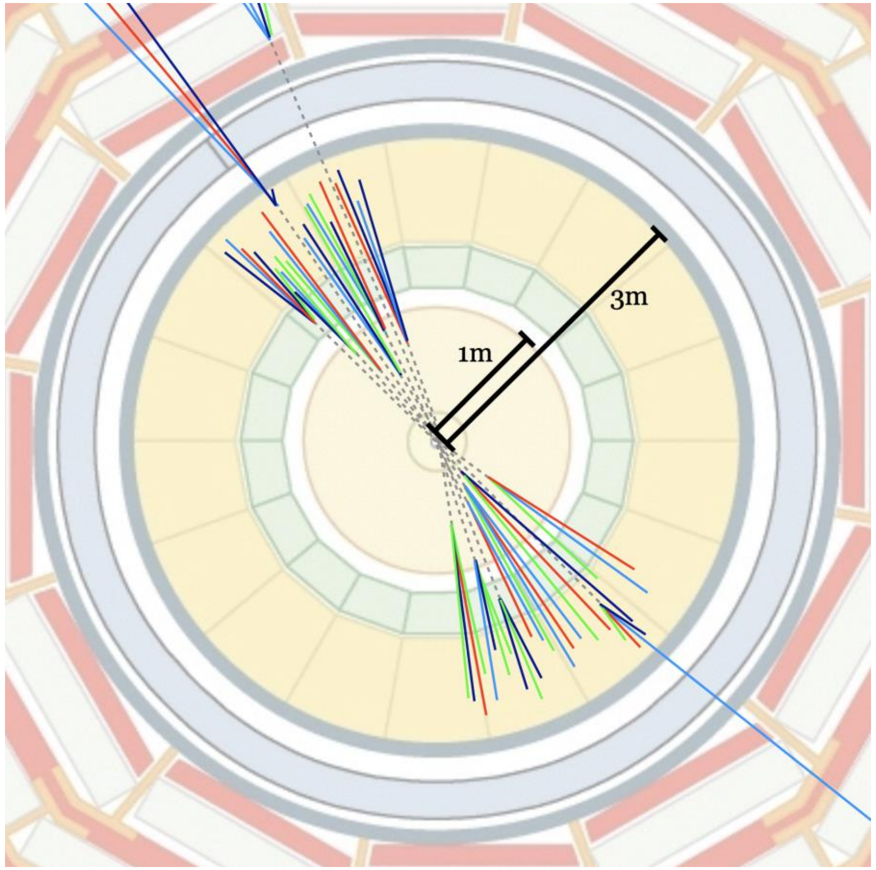

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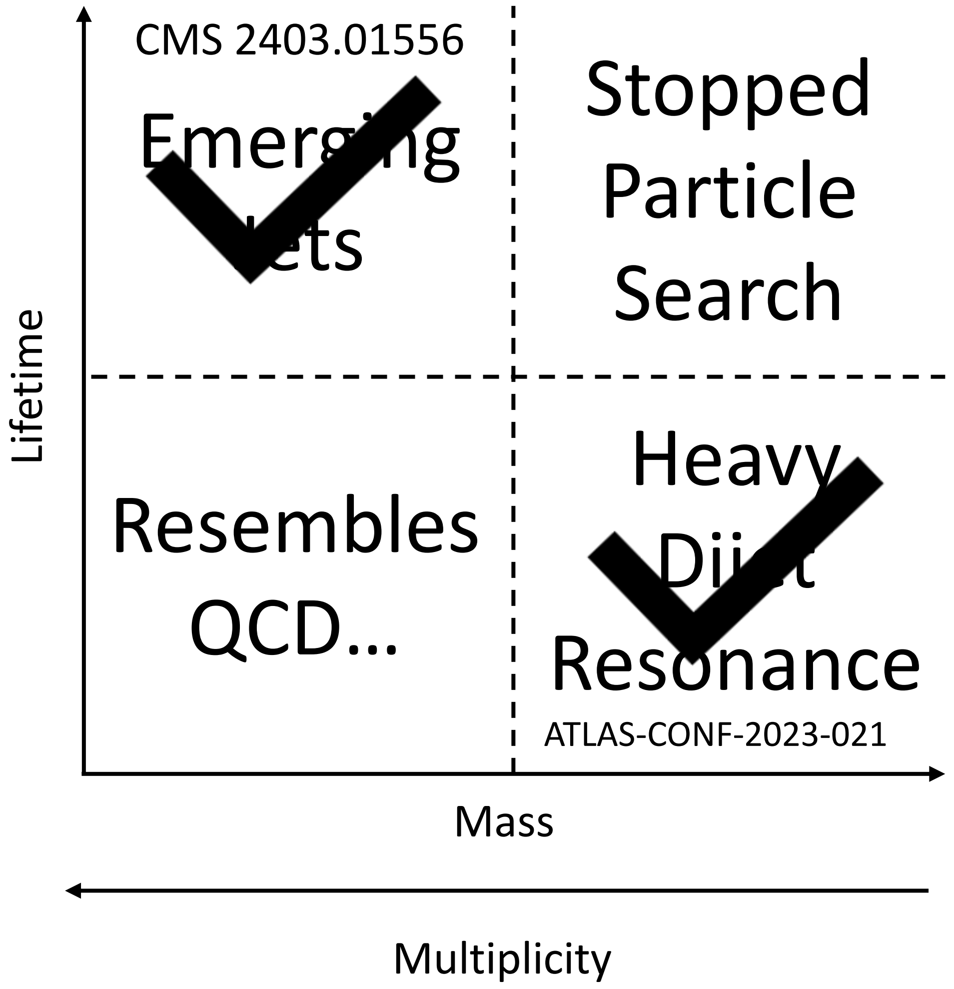


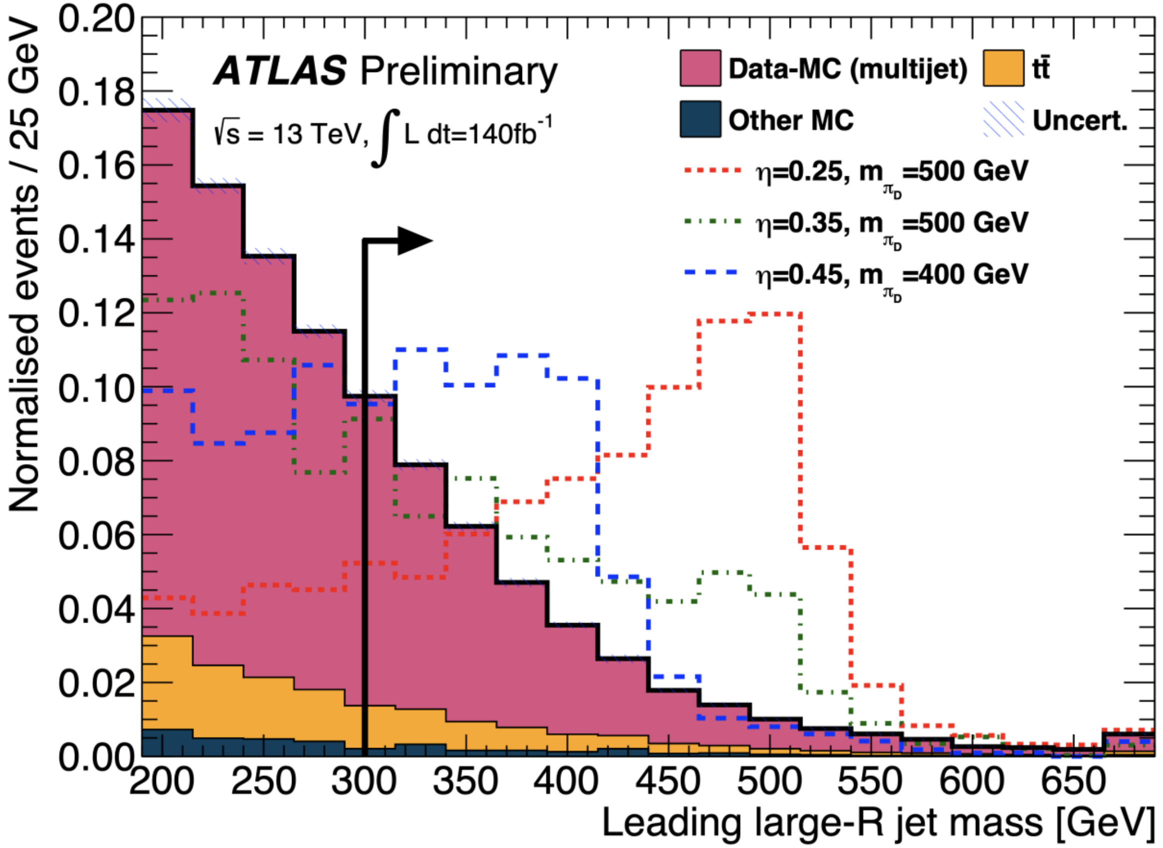

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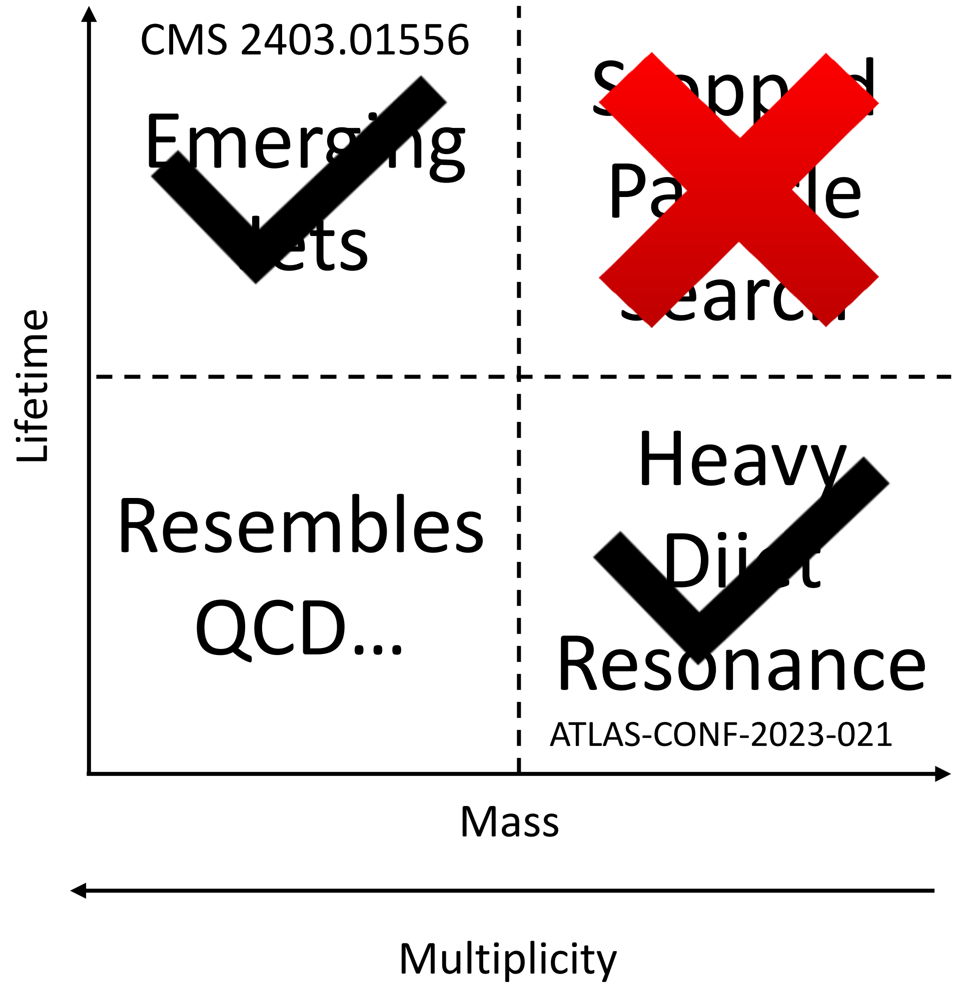
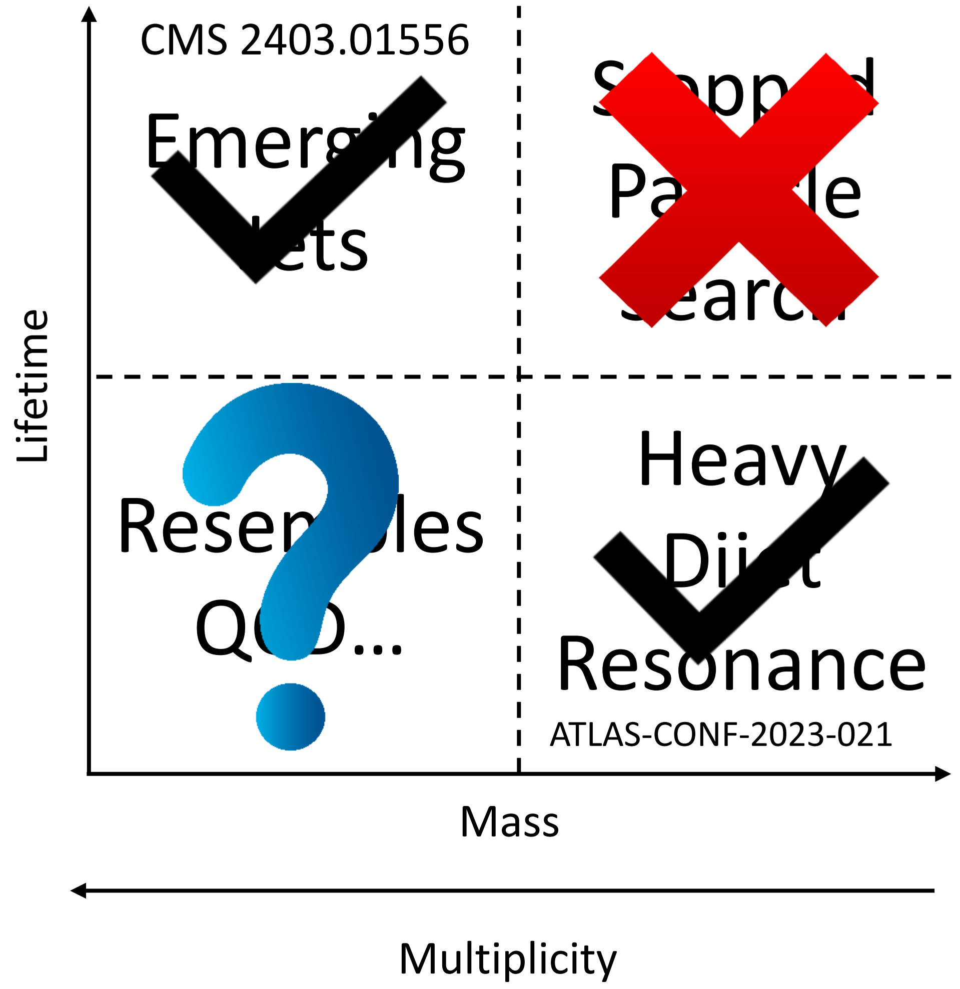



- ❑ Large mass with long lifetime means very small couplings
- ❑ Negligible particle production at LHC

# Dark Shower Signatures



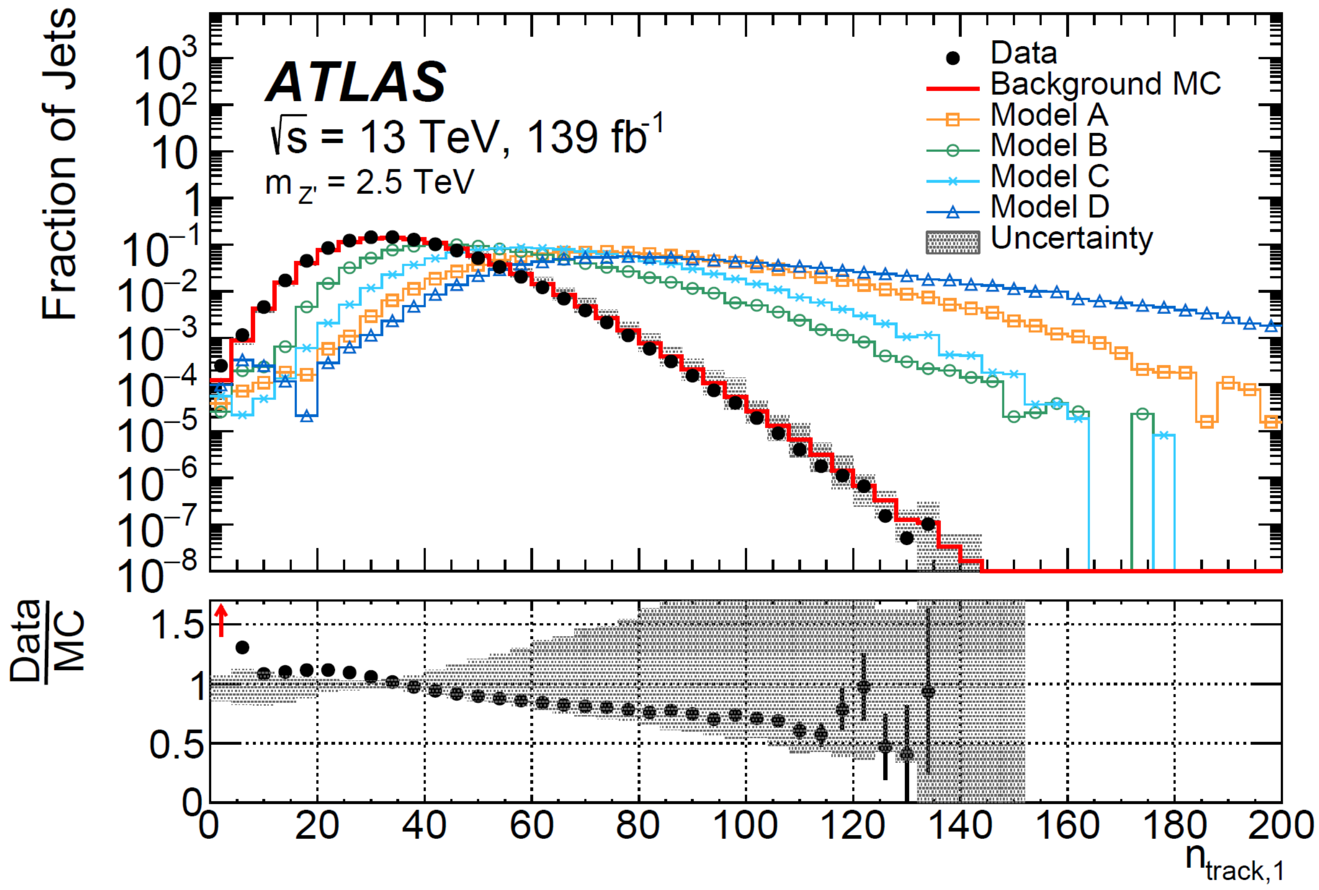

## What we want to focus on

- ❑ Resembles QCD -
  - This explains the absence of any searches in this area so far.
  - Our goal is to discern just how closely it resembles QCD and distinguish it
- ❑ Combinatoric background –
  - Due to the large number of possible pairings, reconstructing the physical dark pion mass is very challenging

# ATLAS Search for Dark Jets

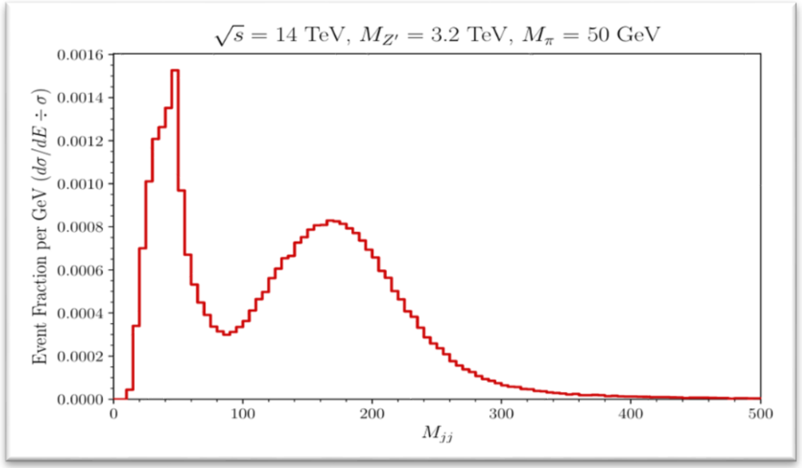
- Search for Z-prime production with decays into 'dark quarks' at ATLAS
- Selects signal events by anomalously large number of tracks in jets at a given $P_T$
- Aims to reconstruct Z' mass, but not to see the dark pions directly

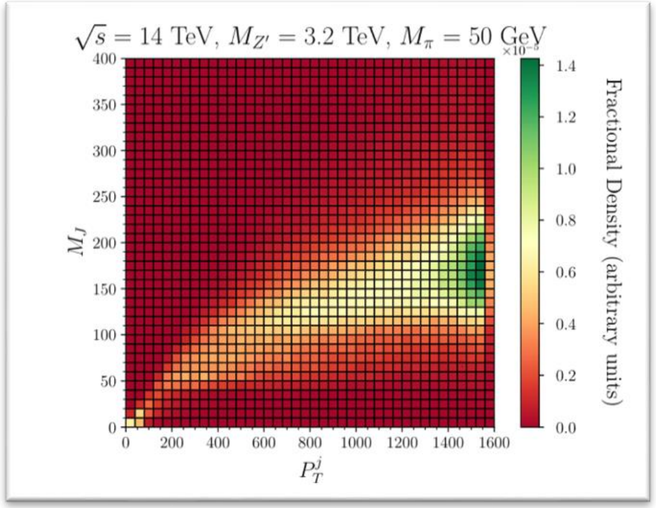
arXiv:2311.03944

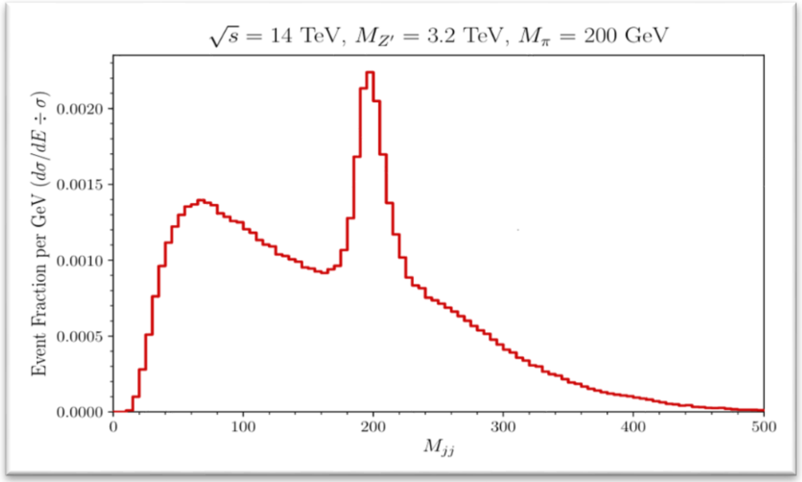


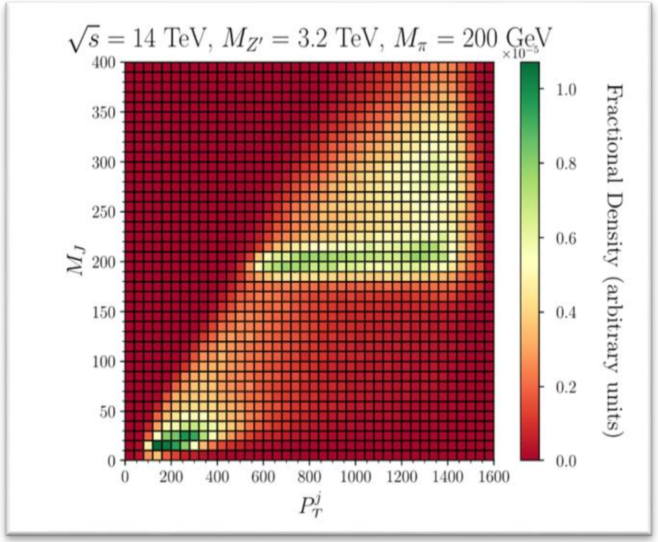
# $\pi_d$ Reconstruction Techniques

*A la* Strassler arXiv:0806.2385



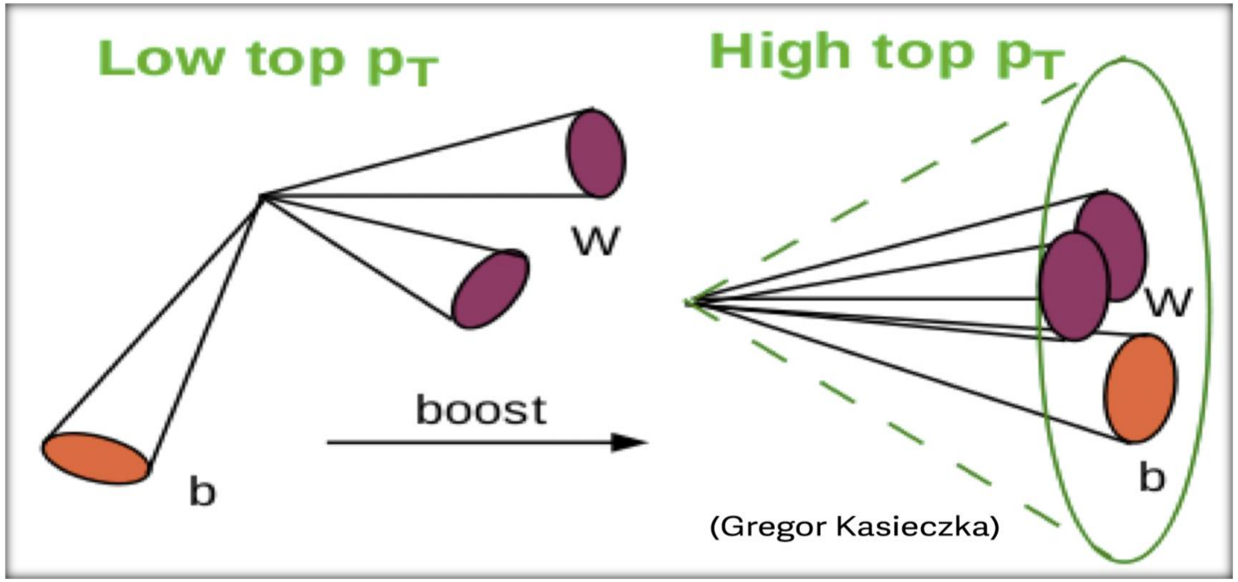



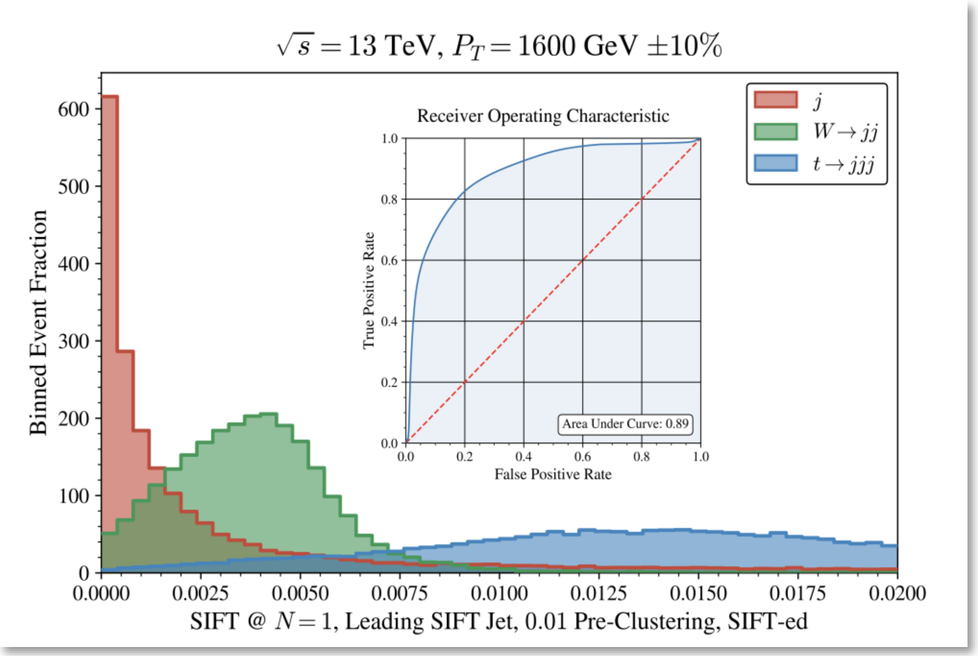

- Assumed that dark pions decay into bottom quarks
  - Effectively background free
- Reconstructed resonances in dijet masses or monojet masses
- This reconstruction works much better for higher masses

# SIFT: Scale-Invariant Filtered Tree




- A radius-free jet clustering algorithm
- Mutually hard prongs cluster last
- Tags substructure while clustering
- Well-defined combinatoric slice
- One method for low & high boost

$$\delta_{AB} \equiv \frac{\Delta M_{AB}^2}{E_{\mathrm{T}A}^2 + E_{\mathrm{T}B}^2}$$

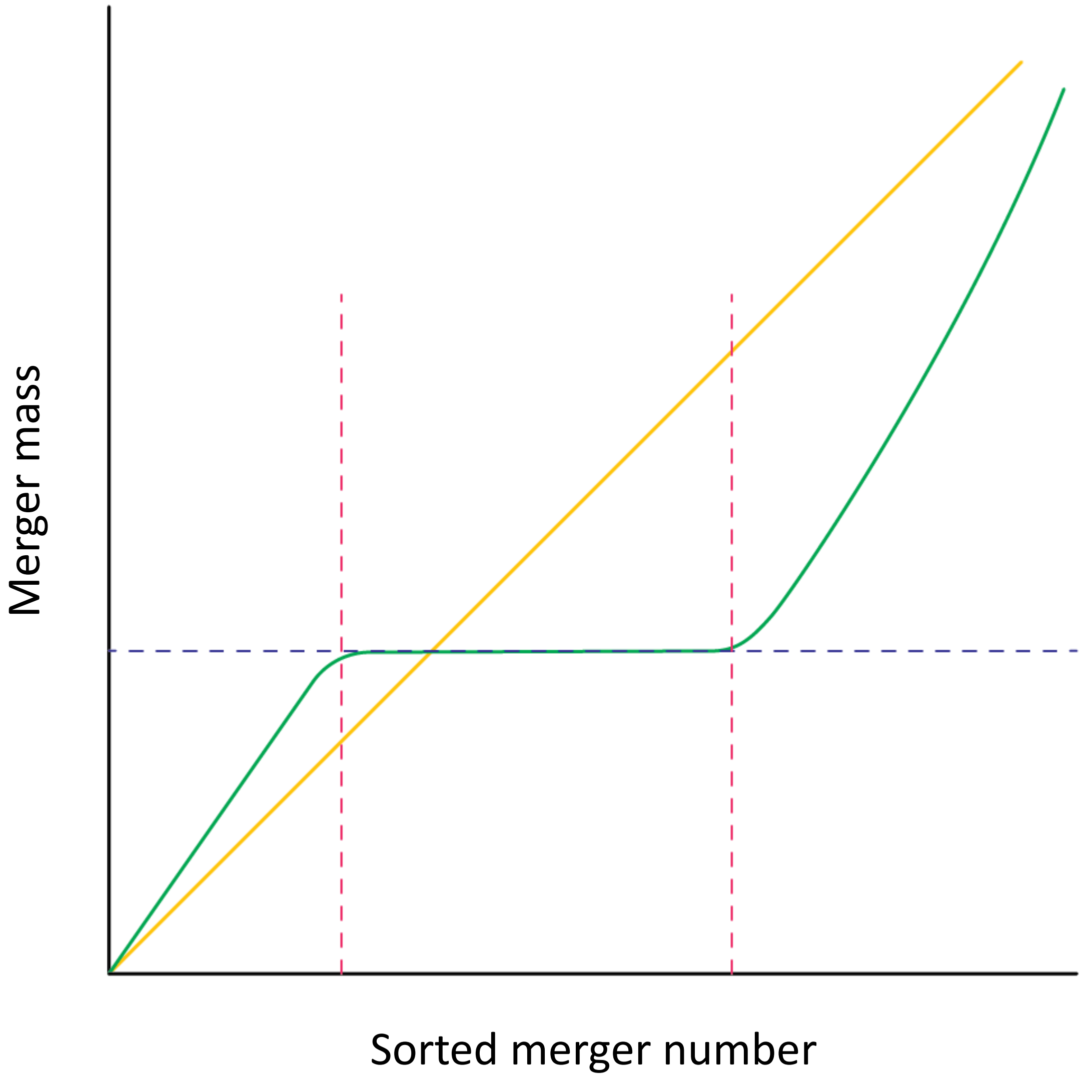



arXiv:2302.08609

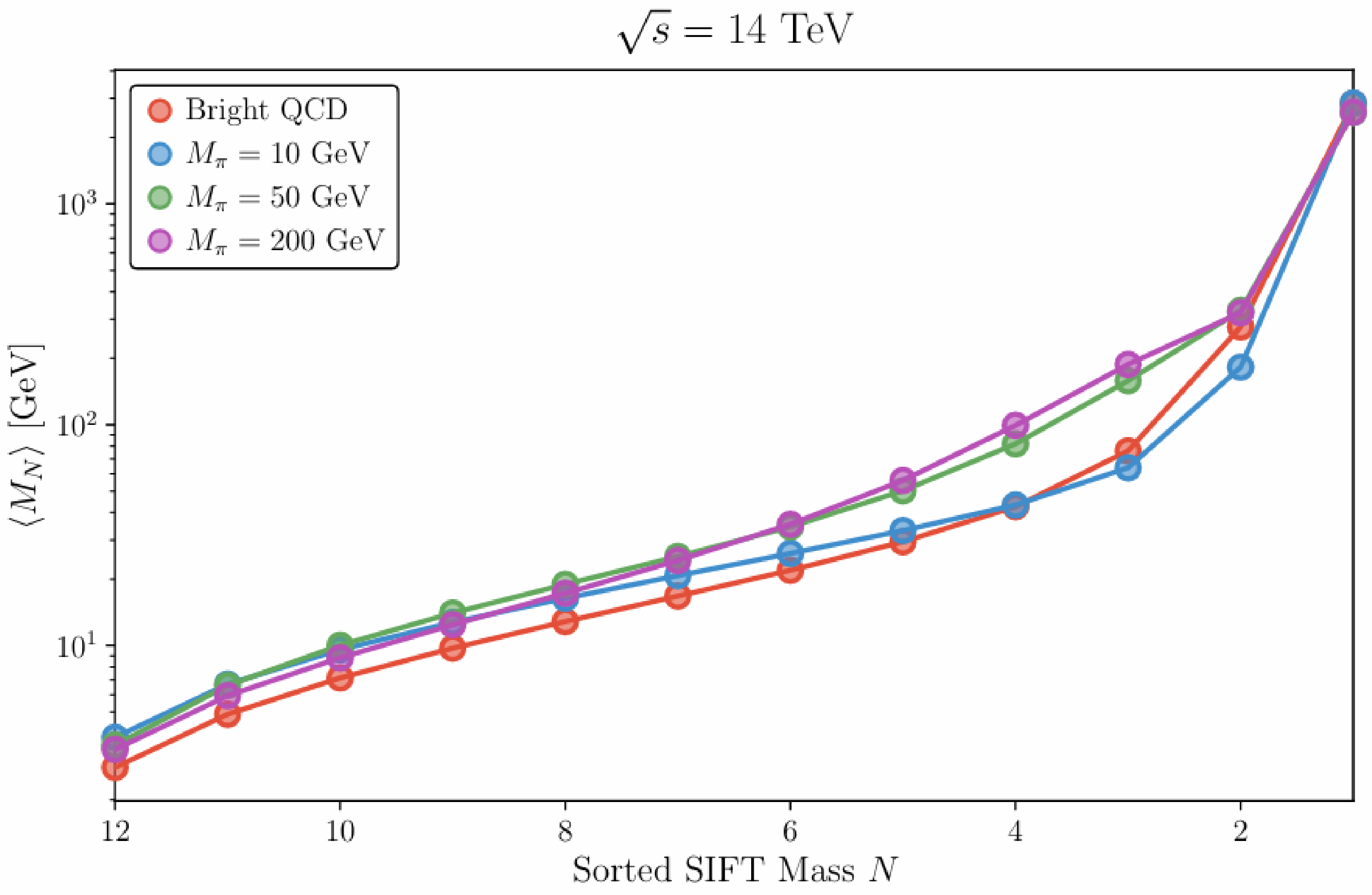
# Plateau Investigation Of New Scales: PIONS

- Cartoon of a log plot of jet algorithm merger masses, sorted by mass

- **Yellow** line shows a typical QCD showering
- **Green** shows a Dark QCD event
- **Red** upright lines are separated by the hypothetical plateau length $N$
  - This length is a parameter defining the variable
- Slope of the **Blue** line is the variable we want to search in
  - We calculate the rms of discretized derivatives between mergers to yield the variable $\Pi_N$



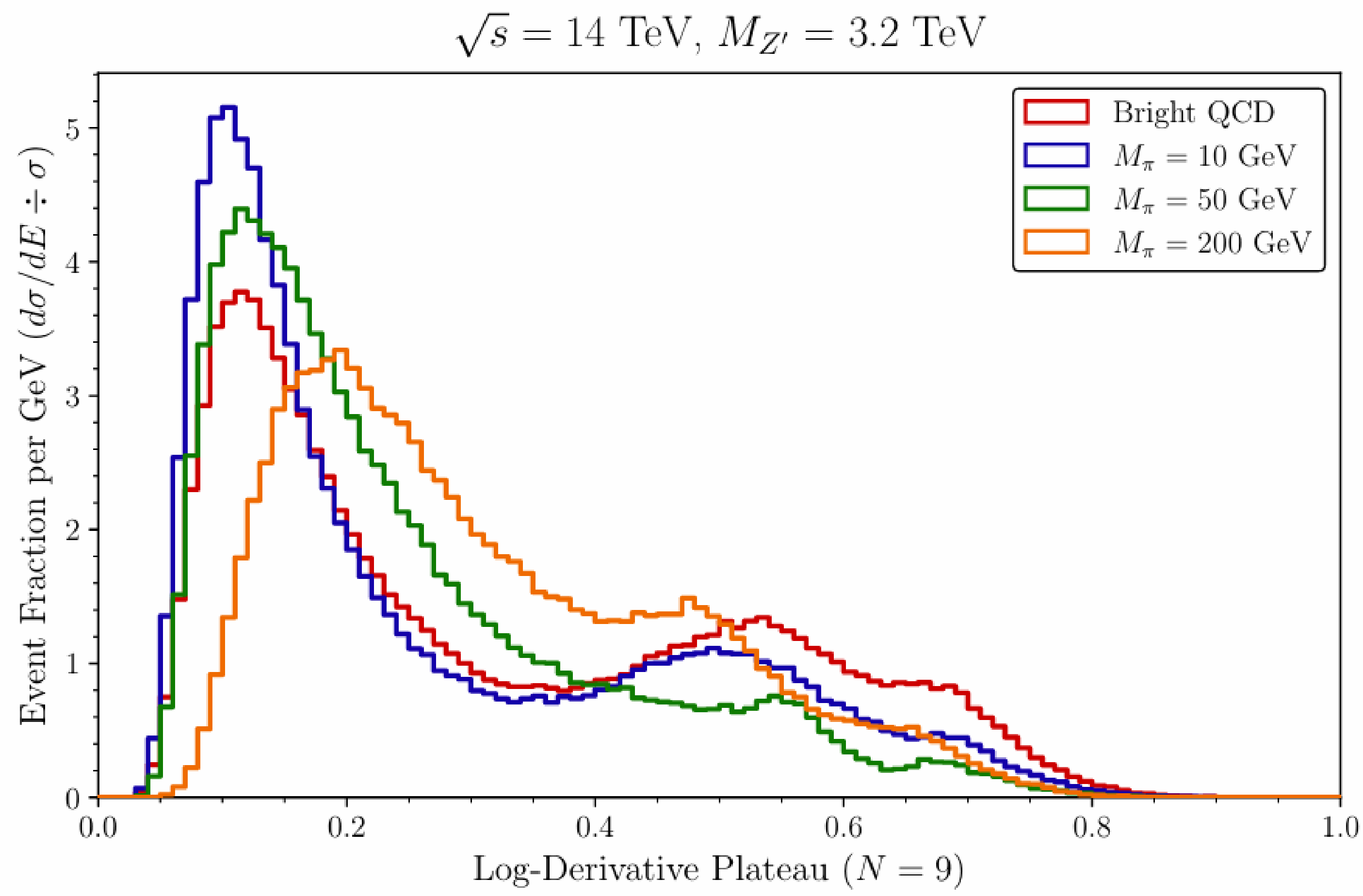
# Exploring Merger Masses in Simulation




- This is the sorted merger mass plot averaged over a large number of events.
- Note flattening in blue curve relative to red

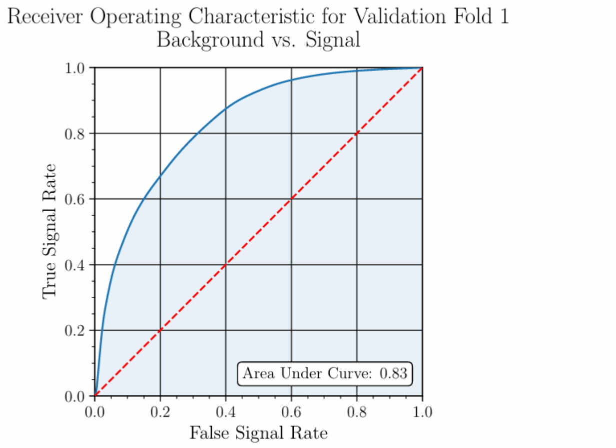
# PIONS distribution

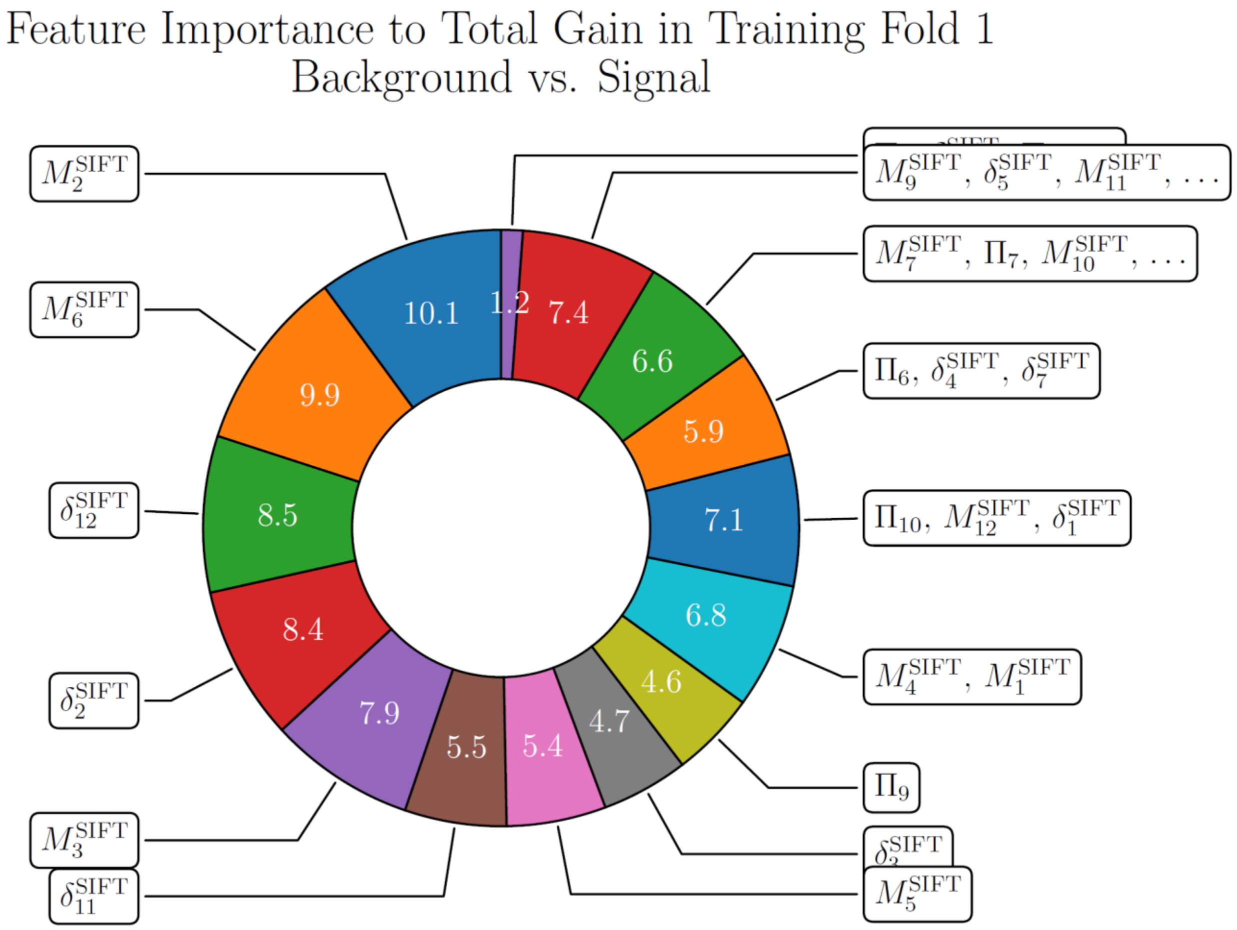
- Event-by-event $\Pi_9$ for different showering hypotheses
- A flat plateau of length $N$ in the merger mass plot gives low values of $\Pi_N$



# BDT Results $M_\pi = 10$ GeV – Our Variables

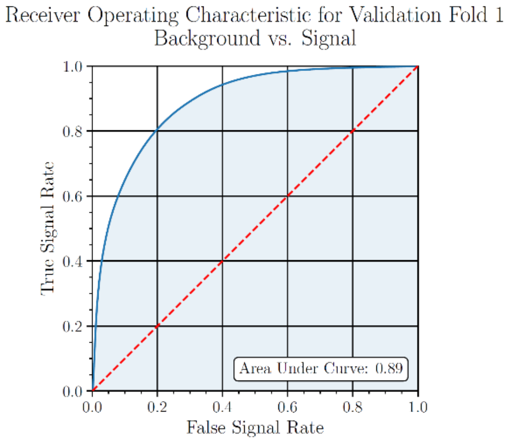
- Merger masses, SIFT measures, and $\Pi_N$ variables all contribute to QCD vs Dark QCD discrimination power
- Both late and early merger variables are important to the analysis
- AUROC score of 83% using only these SIFTy variables

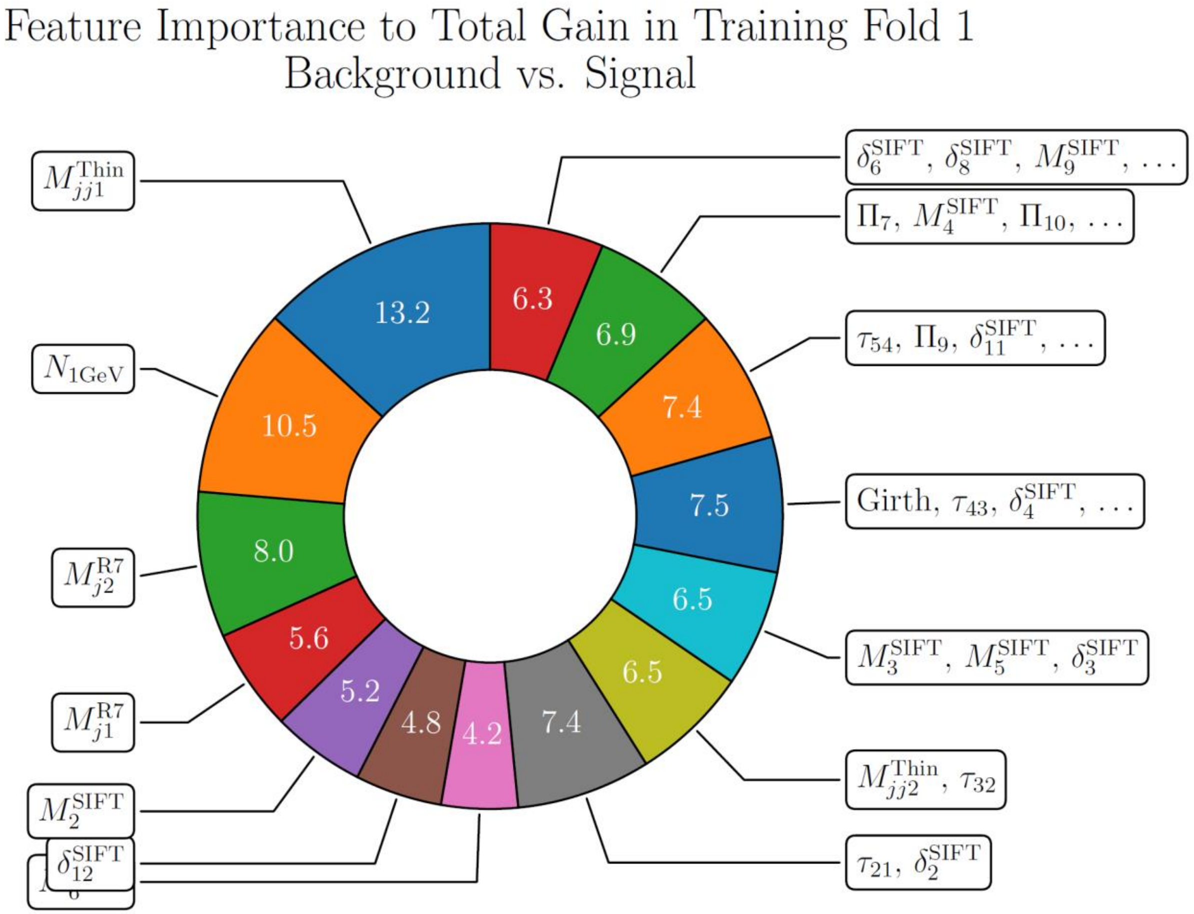


# BDT Results $M_\pi = 10$ GeV – All Variables

- A kitchen-sink analysis utilizes dijet masses, monojet masses, particle counts, and SIFTy variables
- Uses information very similar to ATLAS analysis, improved by addition of the two other approaches
- AUROC score of 89%



# Classifier scores

| $M_\pi$ | Strassler All | SIFT All | Classic QCD | Kitchen Sink |
|---|---|---|---|---|
| 10 | 79 | 83 | 77 | 89 |
| 25 | 89 | 94 | 87 | 96 |
| 50 | 95 | 98 | 91 | 99 |
| 120 | 98 | 99 | 93 | 100 |
| 200 | 99 | 99 | 92 | 100 |
| 500 | 96 | 99 | 73 | 99 |

- SIFTy technique alone is outcompeting dijet resonance techniques of Strassler and broadly-classified QCD variables alone
- Putting it all together, we have strong classification power throughout the explored parameter space
  - Makes explicit the complementarity of these approaches

# Conclusion

- We can achieve this level of discrimination between QCD showers and new dark QCD showers with prompt decays
- We can do that in this regime, where it seems other techniques do not work as well
  - Information from these techniques is complimentary
- This is a valuable expansion of the reach of the LHC into the Dark QCD parameter space

# Exploring Further

- Explore using this as a potential discovery tool rather than a discrimination tool
- Broaden our parameter space away from the fixed Z' mass
- Cross train machine learning against each individual mass

# Thank You

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