Finding dark showers at the LHC

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based on

[arXiv:1907.04346]
[arXiv:2006.08639]
and work in progress

with Thorben Finke, Felix Kahlhoefer, Michael Krämer,

Alexander Mück, Patrick Tunney

TRR 257 - Particle Physics Phenomenology
after the Higgs Discovery

Institute for Theoretical Particle Physics and Cosmology

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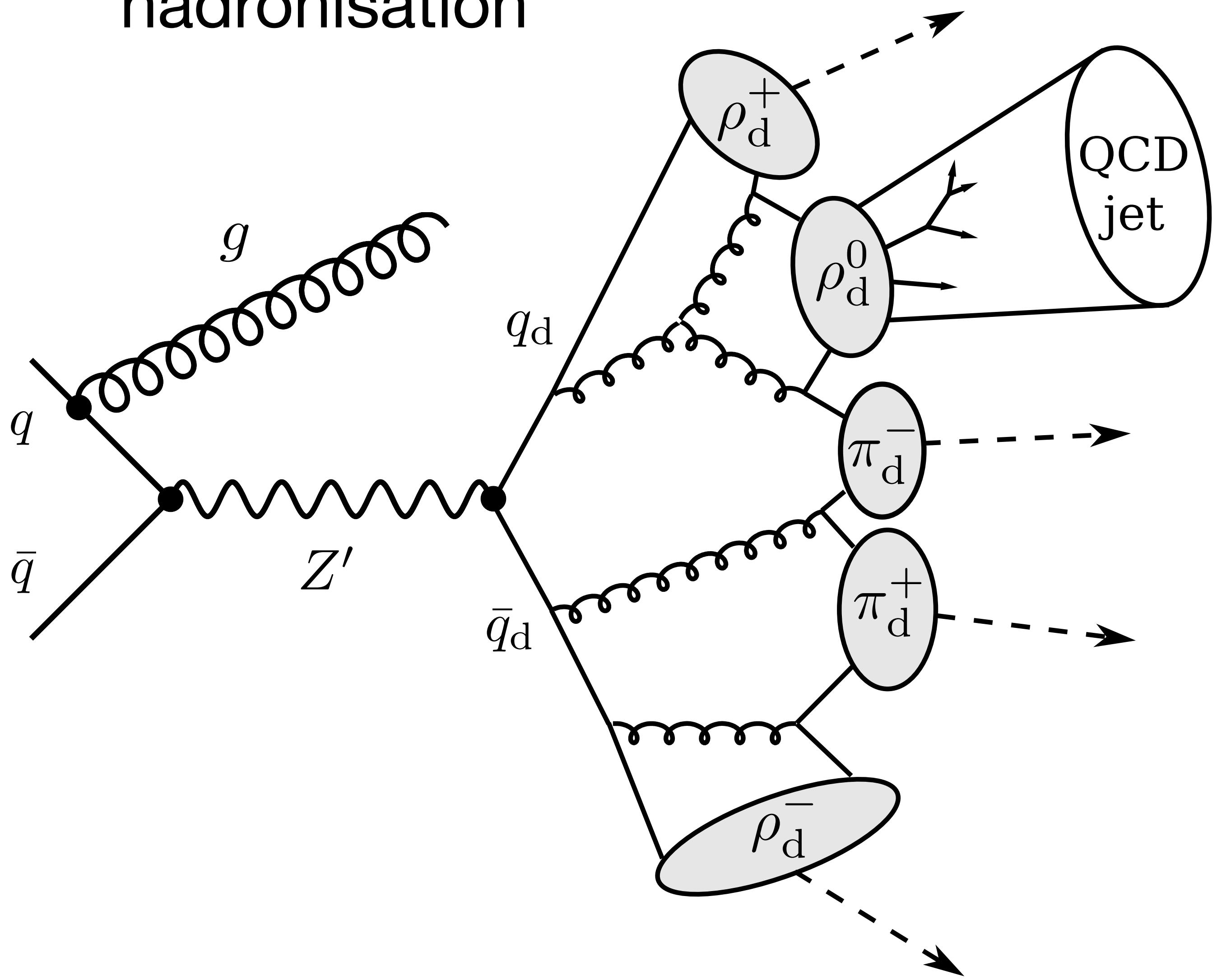
Dark showers at the LHC

- Central idea: **dark sector may resemble QCD**

benchmark model and cosmology in EB et al., 1907.04346

- LHC production of dark quarks leads to **dark shower** and hadronisation



- Large number of dark mesons in an event (order 10)
- Most escape the detector as $\not{E}_T$
- The ρ_{d}^{0} mesons decay and gives rise to QCD jets
- Jets aligned with missing energy

➡ **Semi-visible jets**

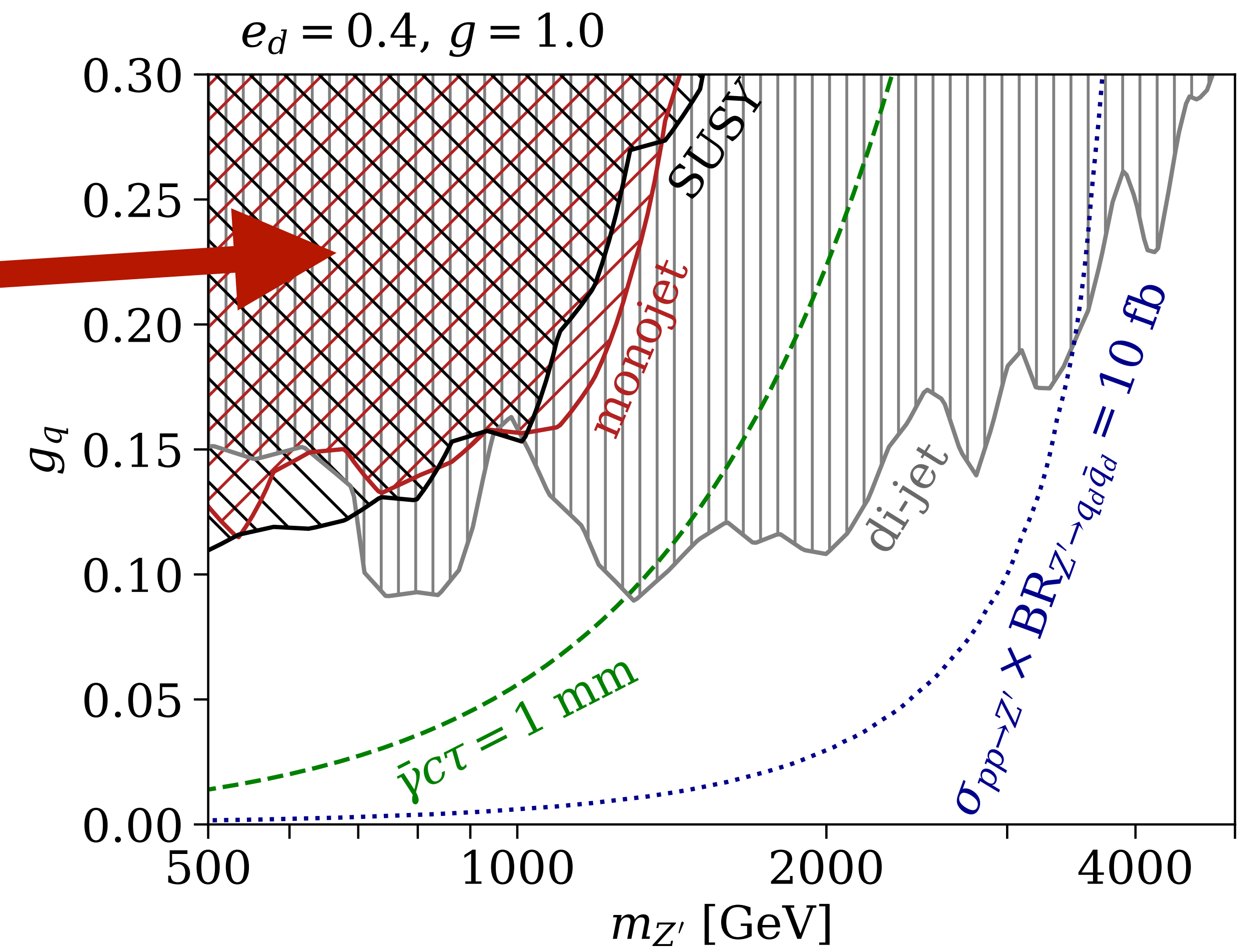
Cohen et al, 1503.00009

- Exciting new signatures, but difficult to detect

Limits from existing searches

Standard searches for missing energy are sensitive to events where **one dark shower remains fully invisible**

leading to large $\Delta\phi = \min_j \Delta\phi(j, \not{E}_T)$

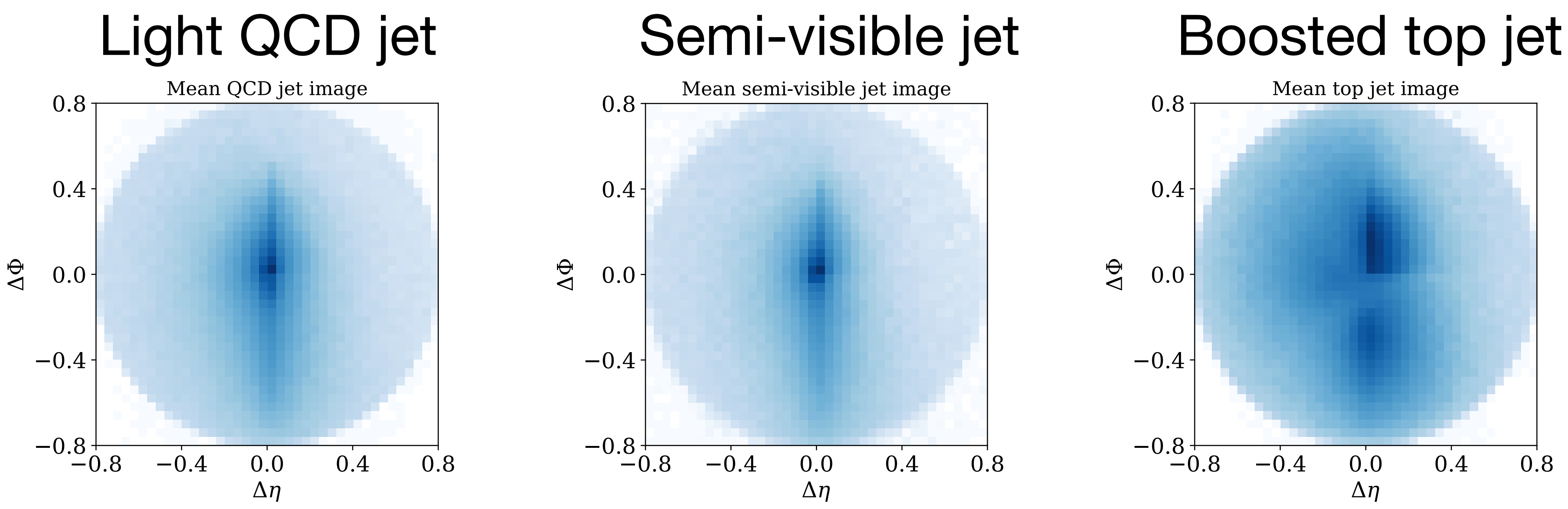


For small $\Delta\phi$: no dedicated analysis yet. CMS analysis in progress.

Can we improve the sensitivity for dark showers with machine learning?

Can we do better with machine learning?

- Deep neural networks have shown excellent performance in tagging boosted top jets. Kasieczka et al., 1902.09914
- Example: Convolutional Neural Network to classify jet images

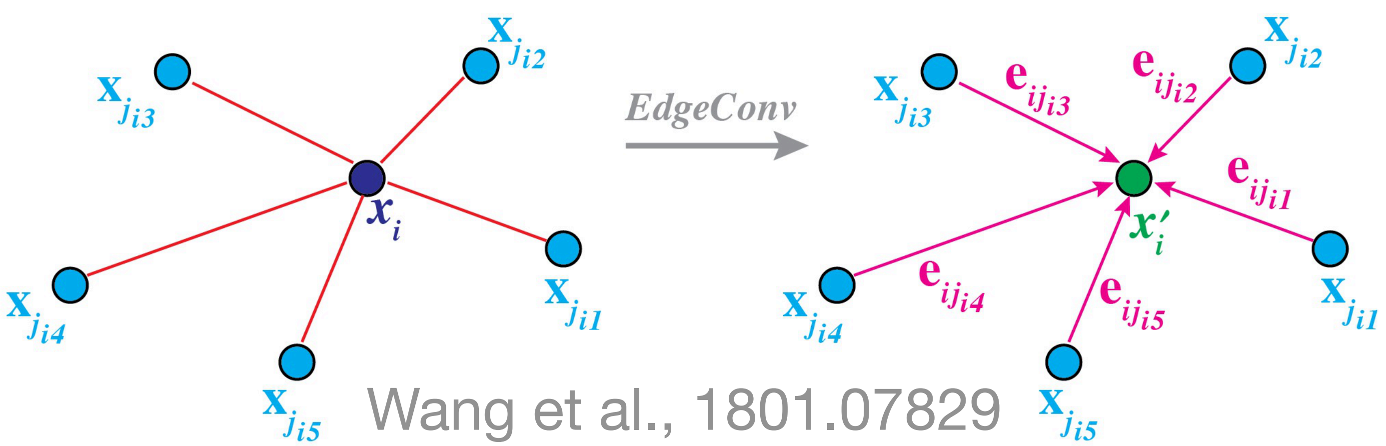


- While top jets can be distinguished from light QCD by eye, semi-visible jets are much more similar to QCD
- Diminished performance of standard neural network architectures

Casting a graph net to catch dark showers

- **New approach: dynamic graph convolutional neural networks** representing jets as unordered point clouds and re-arranging them in feature space

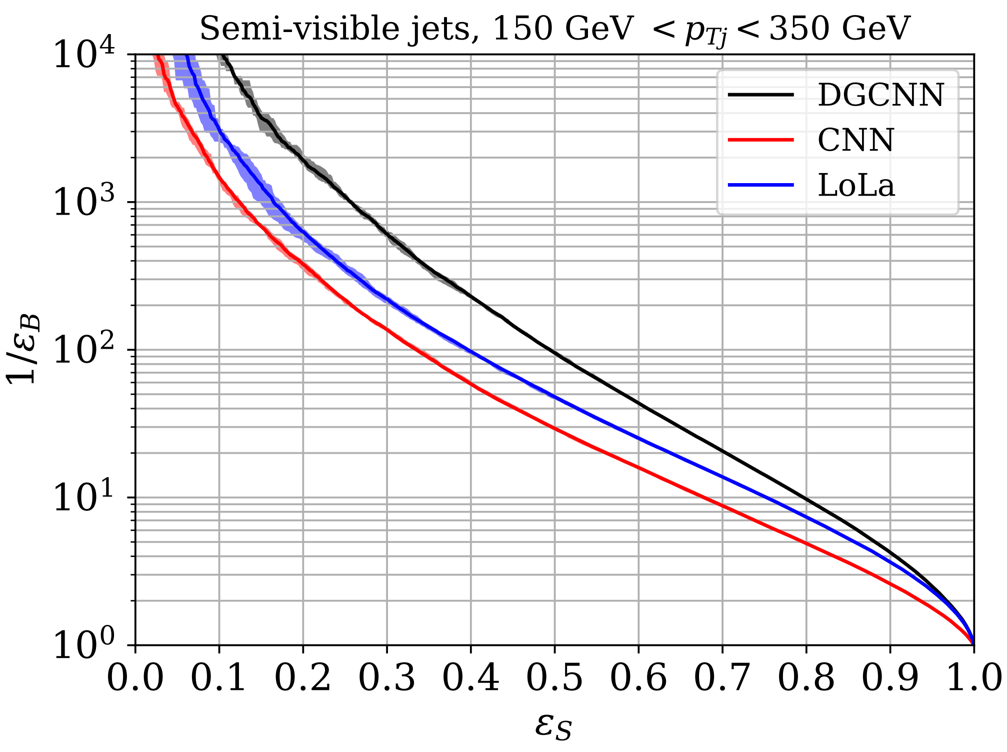
Qu, Gouskos, 1902.08570



Wang et al., 1801.07829

- **DGCNN significantly outperforms** other architectures in dark shower tagging
- So far require supervised training on MC samples
- Dependence on dark shower parameters can be alleviated by mixed training samples
- Working on unsupervised anomaly detection with dark showers as use case

background: QCD jets

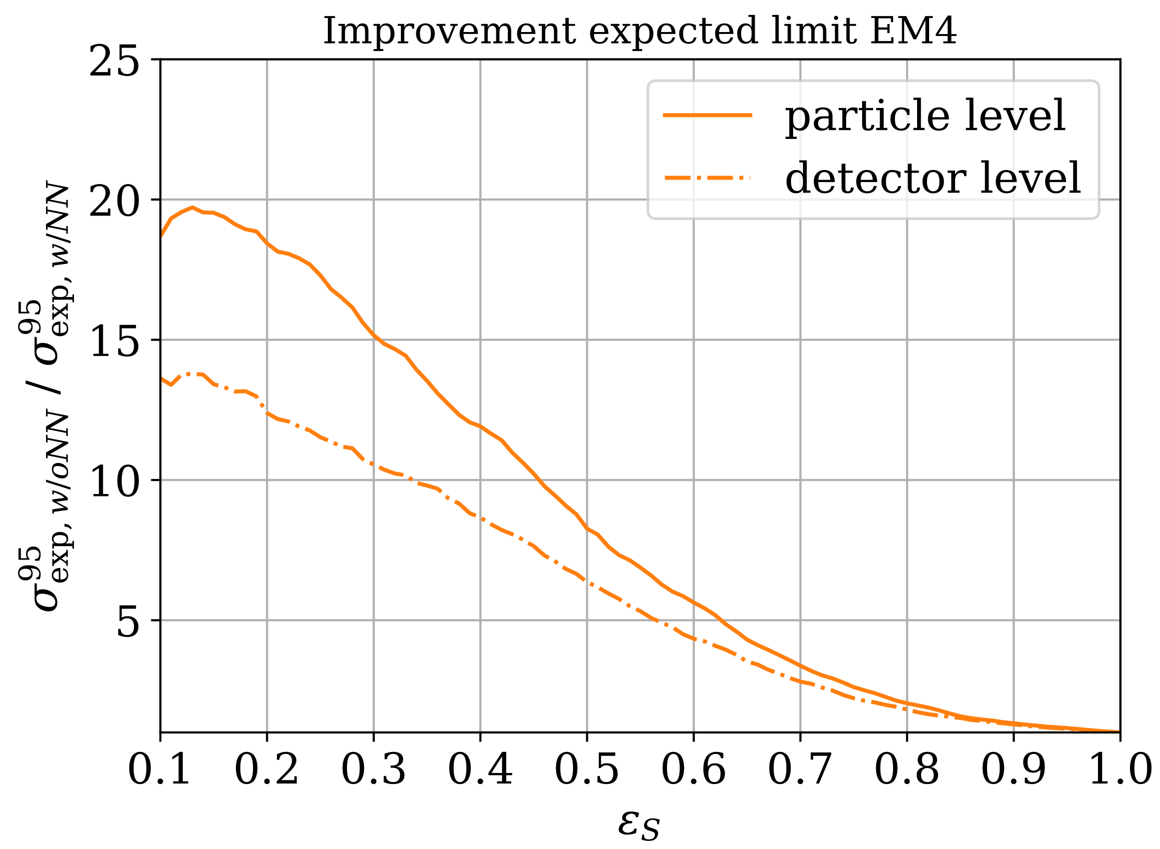


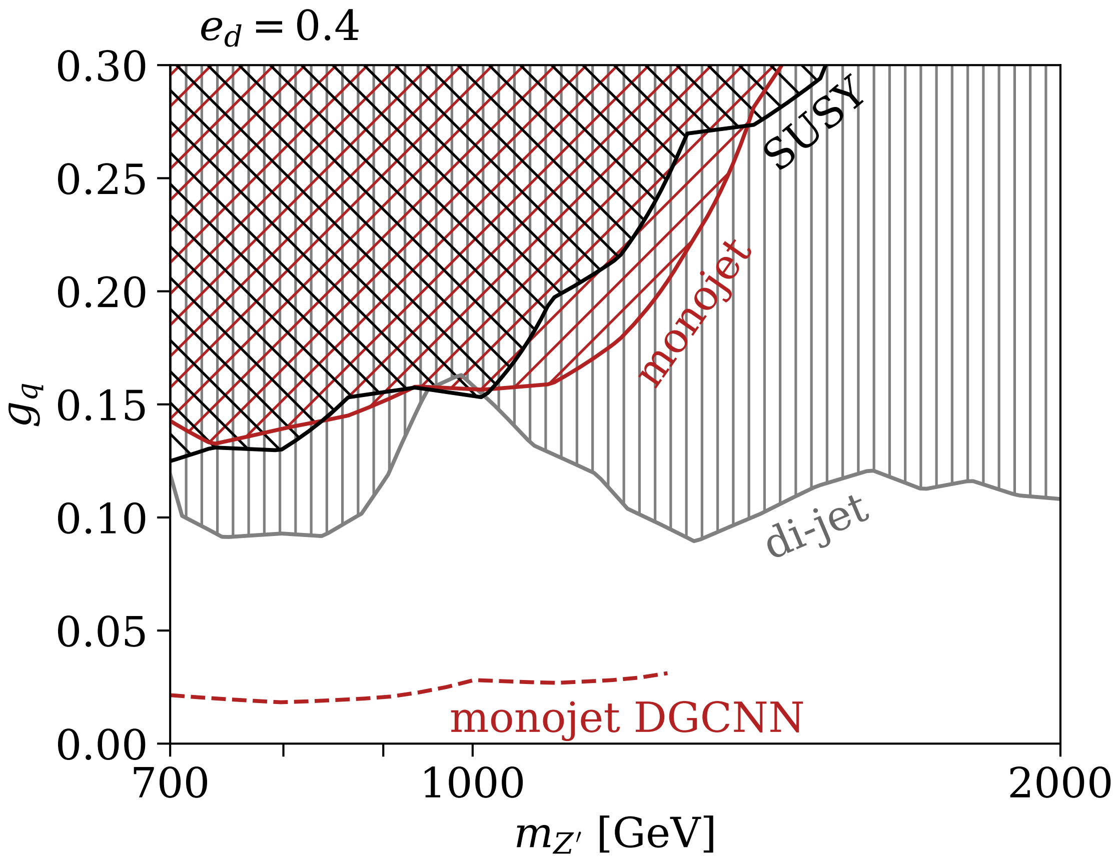
Signal: semi-visible jets

Enhancing LHC sensitivity for dark showers

- By how much can we improve an analysis with our dark shower tagger? ➡ **Monojet search as example** ATLAS, 1711.03301
- Train on dark showers and dominant background (Z + jets)
- Require at least on tagged jet after standard monojet cuts

➡ Sensitivity improved by factor ~ 20



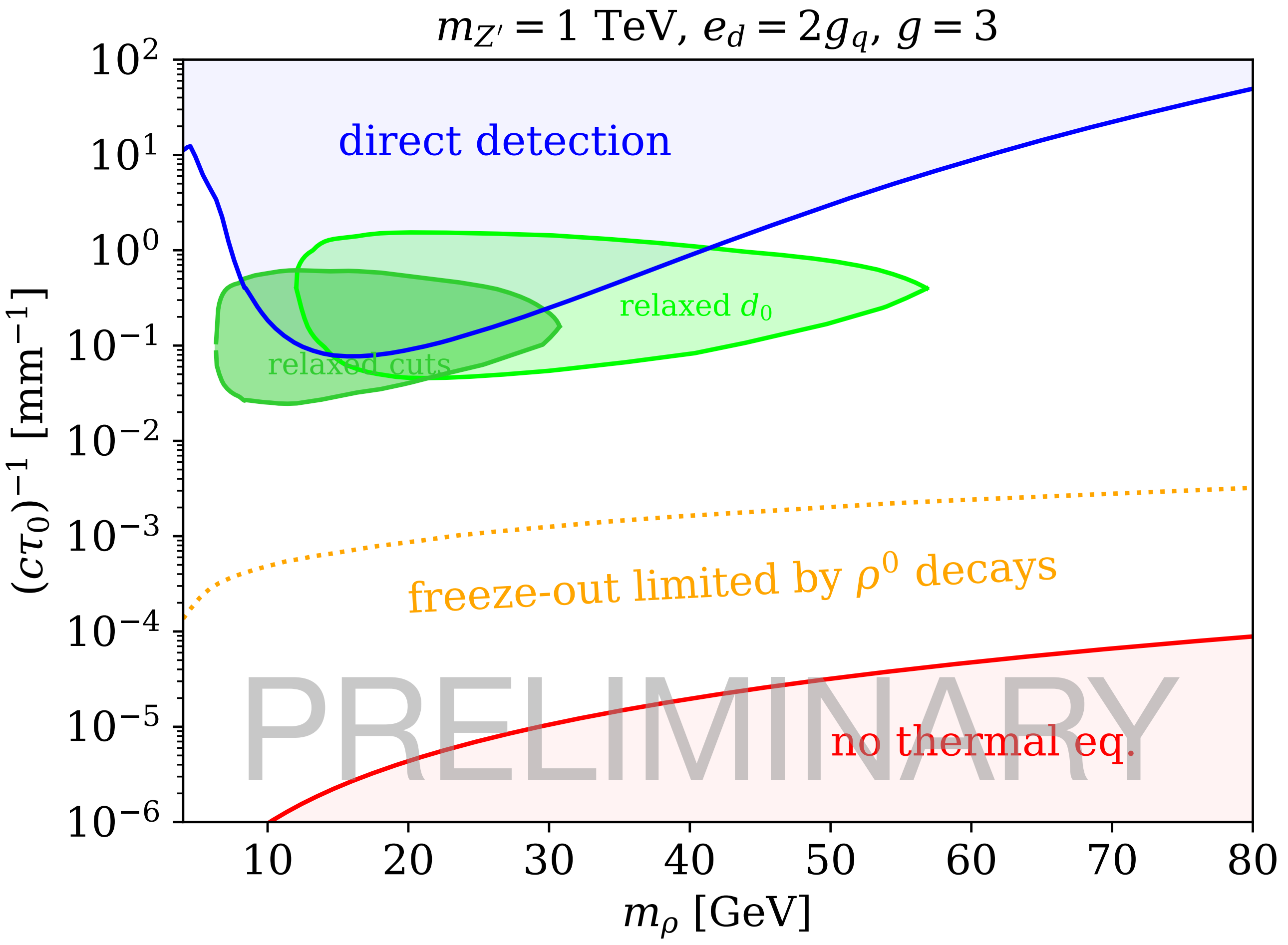


Displaced vertices from dark showers

- Long-lived particles are a generic prediction in strongly interacting dark sectors
- For small coupling, the ρ_d decay length is on the order of mm to cm

➡ displaced vertices + MET from dark showers

- Requiring large impact parameter for all tracks biases vertex mass to small values
- New analysis strategy: crucial to include some tracks with small impact parameter



Conclusions

- Dark pions are well-motivated dark matter candidates.
- Strongly interacting dark sectors are cosmologically viable.
- Dark showers give rise to exciting new LHC signatures, in particular semi-visible jets.
- However, they are difficult to find with conventional methods

  → Great opportunity for machine learning
- Graph networks are particularly well suited for this
- Model dependence can be mitigated, e.g. with mixed training
- Can increase sensitivity of a monojet search by more than an order of magnitude even when all other cuts remain the same
- Large parts of the dark shower parameter space gives rise to displaced vertices → important to increase sensitivity