Digluon Tagging using $\sqrt{s} = 13$ TeV pp Collisions in the ATLAS Detector

**Physics Motivation**
A variety of beyond Standard Model (BSM) theories predict new bosons with two-prong decays at masses other than the W, Z, and Higgs bosons. Light (pseudo) scalar particles (a bosons) from extended Higgs sectors or axion-like particle models could result in Lorentz-boosted digluon jets ($a \rightarrow gg$). The decay $a \rightarrow gg$ can be dominant in certain two-Higgs doublet models via quantum loop-induced processes [1]. There could be a new heavy vector-like fermion that couples to $a$ and allows for $a \rightarrow \gamma \gamma$ or $a \rightarrow gg$ decays. Also, in models without a diphoton component, like models with warped extra dimensions that can have only Quantum Chromodynamics (QCD) extended in the bulk, the correspondingradiation would decay predominantly to gluons [2].

**Signal Digluon Jets vs Background QCD Quark / Gluon Jets**
In the intermediate a mass ($m_a$) regime, the a is light and has a significant Lorentz boost in the laboratory frame such that its decay products are collimated into a single jet with radius $\leq 0.4$. The main background comes from generic QCD quark and gluon jets. Jet substructure variables (shown below) can help us discriminate signal and background jets. The radiation patterns shown in the averaged jet ($\eta$-$\phi$) images (shown on the right side) made using associated track $p_T$ in one jet $p_T$ bin highlight this further.

**Classifier Architecture**
Comprised of two main components:
1. Jet level tagger that accepts variable length track inputs from each jet (shown in dashed box on the left)
2. Event level fully connected module

**Training & Performance**
Loss function has a distance correlation term to decorrelate the output and $m_a$ for ABCD background estimation [4].

The background events are reweighted using a MC - Data classifier with the same architecture to ensure matching of event & substructure observables for better digluon tagging (see below).

**Conclusions & Outlook**
- A novel method to tag $a \rightarrow gg$ digluon jets from prompt decays of light BSM scalars which can couple to SM Higgs boson is presented.
- The tagger learns the unique radiation pattern from single jets.
- A novel variable high dimensional MC weighting technique is shown.
- The tagging method can be extended to boosted object searches such as $a \rightarrow qq$ ($u,d,s$) or $cc$ which are also well motivated for BSM physics.

**Schematic & Innovations**
Background $Z \rightarrow \mu \mu + QCD$ jets
- Reweight w/ data using new technique. Matches event, jet, and substructure observables
- Signal ($Z \rightarrow \mu \mu$) $H \rightarrow aa \rightarrow 4g$
- Innovative classifier w/ jet and event level info. DisCo [3] loss to decorrelate output with $m_a$
- Digluon vs QCD jet classifier from jet tagger latent space output embedding
- $H \rightarrow aa \rightarrow 4g$ event classifier

**Classificer Architecture**
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1. Jet level tagger that accepts variable length track inputs from each jet (shown in dashed box on the left)
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Tracks in jets used as variable length inputs (features: $p_T$, distance from jet axis) and processed w/ deep sets implemented as particle flow network. The network embeds each track into a latent space then sums all latent space vectors together before returning the final 2D latent space vector for each jet.

The event level module combines the embeddings of both leading jets, and info from the jet and 2 boson 4-vectors.

A single probability score for each event is returned. Separate taggers are trained for each of the mass points that are tested. Note that the jet level tagger is generic, but the event level tagger is specific to the signal channel targeted and adaptable for other cases.

**Reweighting**
Reweighting is done in sidebands outside the blue lines in the $m_a$ plot.

The digluon jet tagger evaluated by training a dense network on the 2D output. ROC curves for digluon vs QCD jets are shown below for one jet $p_T$ bin.

High QCD jet rejection achieved for low scalar masses, w/ tagger degrading at higher masses; consistent w/ plots above that show resemblance to QCD jets. Better gluon jet rejection illustrates the constraints from the singlet initiated digluon decay versus gluon jets.

For high $m_a$ the tagger from $a \rightarrow gg$ is extended to $a \rightarrow quq$ ($u,d,s$) or $cc$. The tagging method can be extended to boosted object searches such as $a \rightarrow qq$ ($u,d,s$) or $cc$ which are also well motivated for BSM physics.

**Bibliography**

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