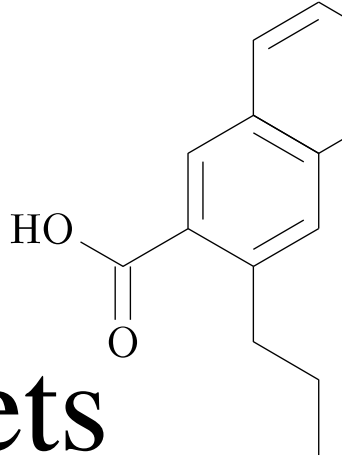
Spectral Analysis of Color Charges in Two-Prong Jets with Neural Networks



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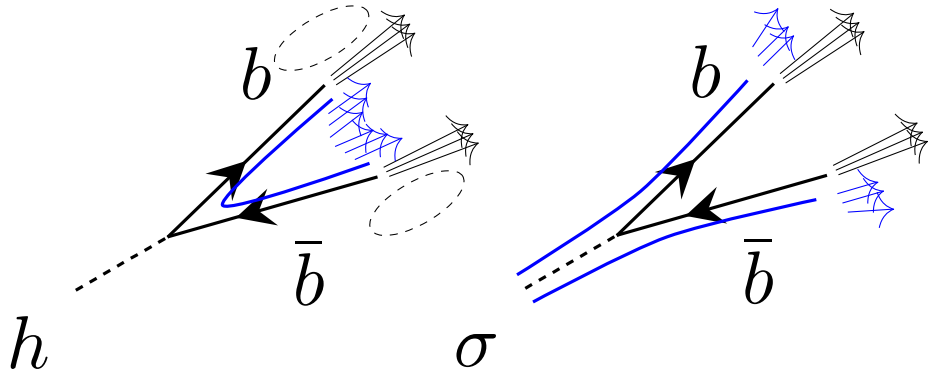
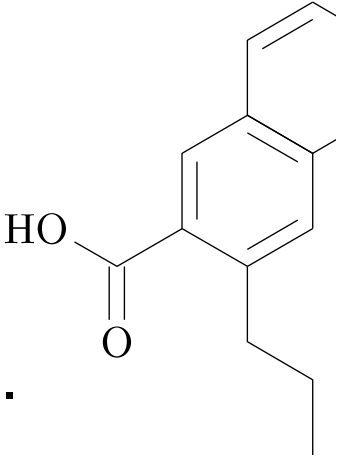
KEK-PH 2018 Winter

KEK, Tsukuba, Ibaraki, Japan
Dec. 2018

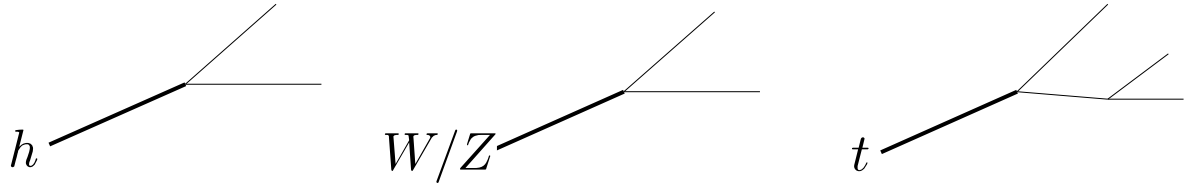


based on **S. H. Lim**, M. M. Nojiri, arXiv:1807.03312, JHEP10(2018)181.
A. Chakraborty, **S. H. Lim**, M. M. Nojiri, will appear on arXiv soon.

Introduction

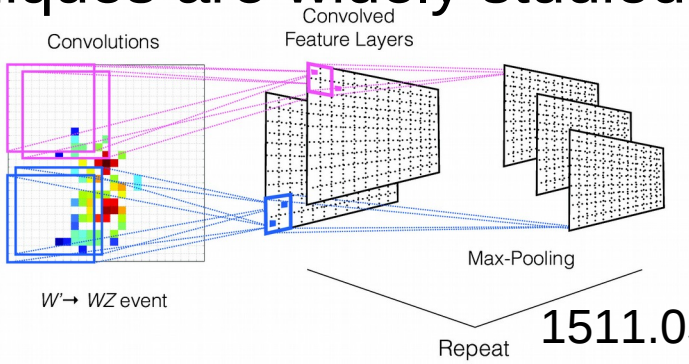


As LHC stacked many multi-TeV $\sqrt{\hat{s}}$ events,
we observed many boosted heavy particles producing jets.



To analyze these kinds of complex objects, machine learning techniques are widely studied nowadays.

CNN



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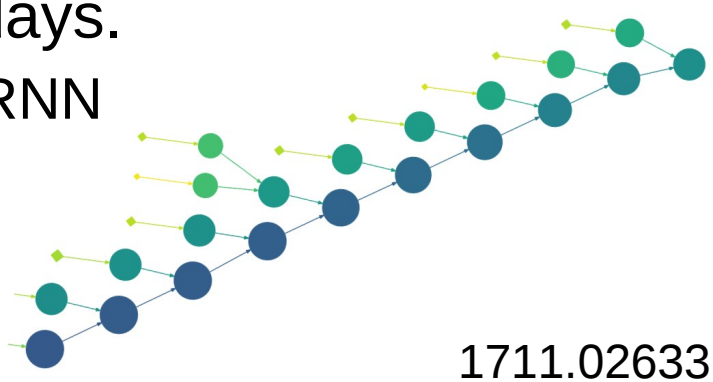
RNN



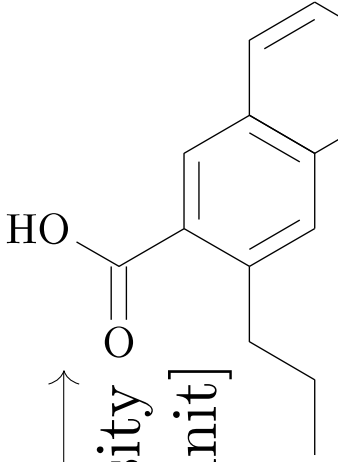
1711.02633

I introduce a new deep learning based analysis that

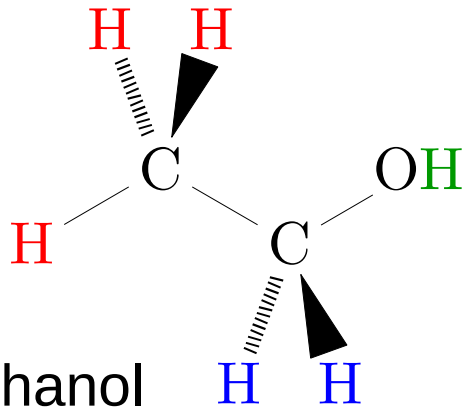
- has **visual** representation of jet substructure
- has **verifiable** predictions from neural network

I want to introduce an analogy from
[1]H-NMR analysis in Organic Chemistry

Analogy from ^{1}H-NMR in Organic Chemistry

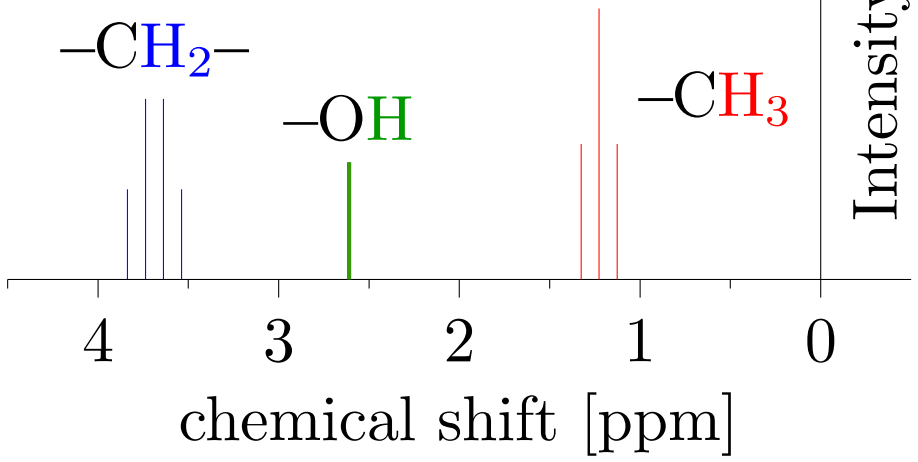


Chemists use ^{1}H-NMR spectrum
to identify molecular substructures.

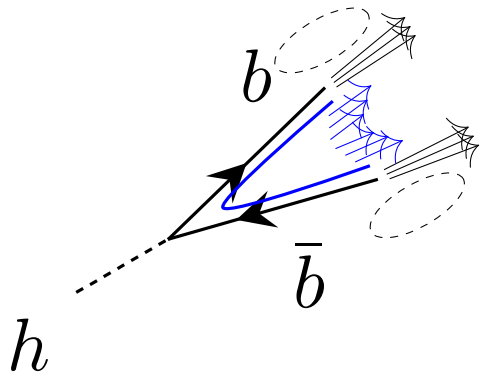


Encode

Decode



Can we build a similar analysis framework for jet substructure?

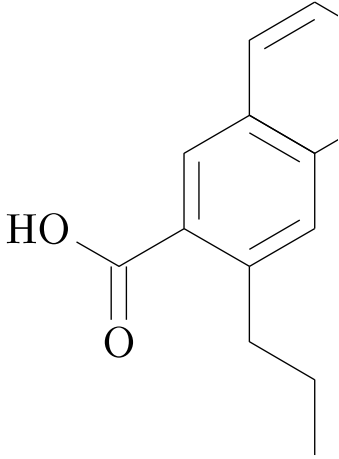


Encode

Decode

?

Two-Point Correlation Spectrum



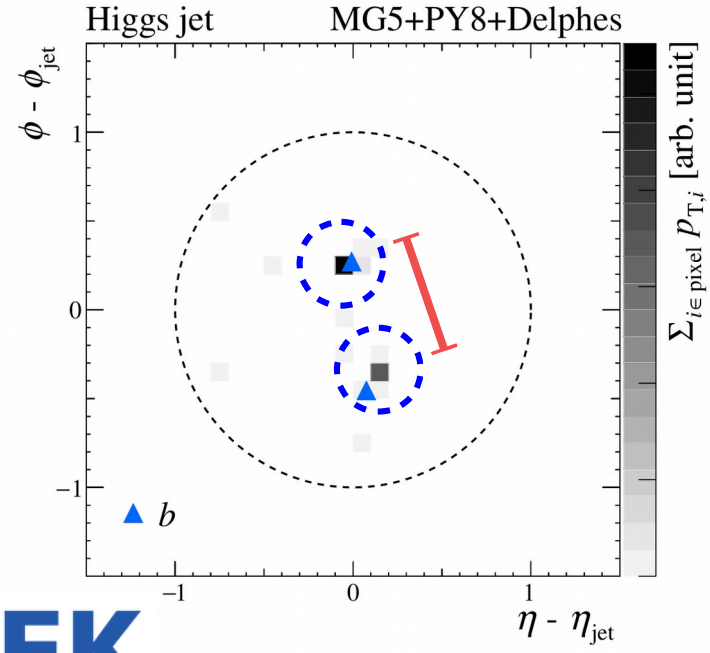
We introduce an IRC safe (binned) spectral function:

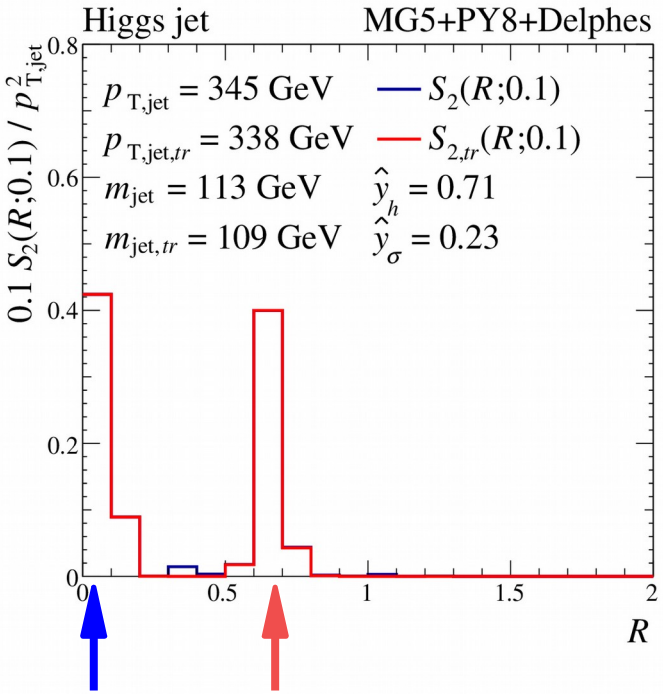
$$S_2(R;\Delta R) = \frac{1}{\Delta R} \sum_{\substack{i,j\in\text{jet} \\ R_{ij}\in[R,R+\Delta R]}} p_{T,i}p_{T,j}$$

Example: spectrum of a two-prong jet with two constituents

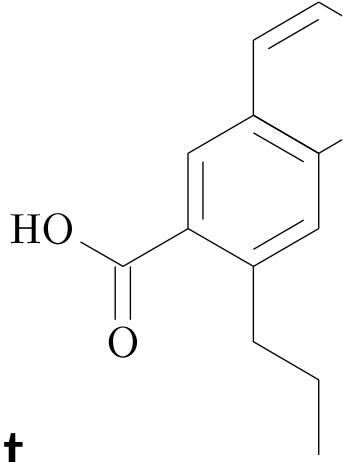
$$S_2(R) = (p_{T,b}^2 + p_{T,\bar{b}}^2)\cdot\delta(R) + 2p_{T,b}p_{T,\bar{b}}\cdot\delta(R - R_{b\bar{b}})$$

Autocorrelation Cross-Correlation



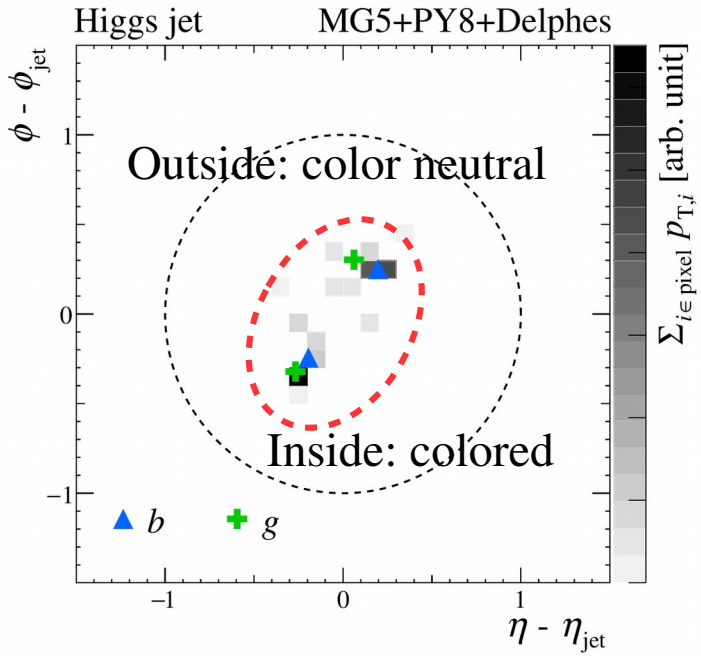


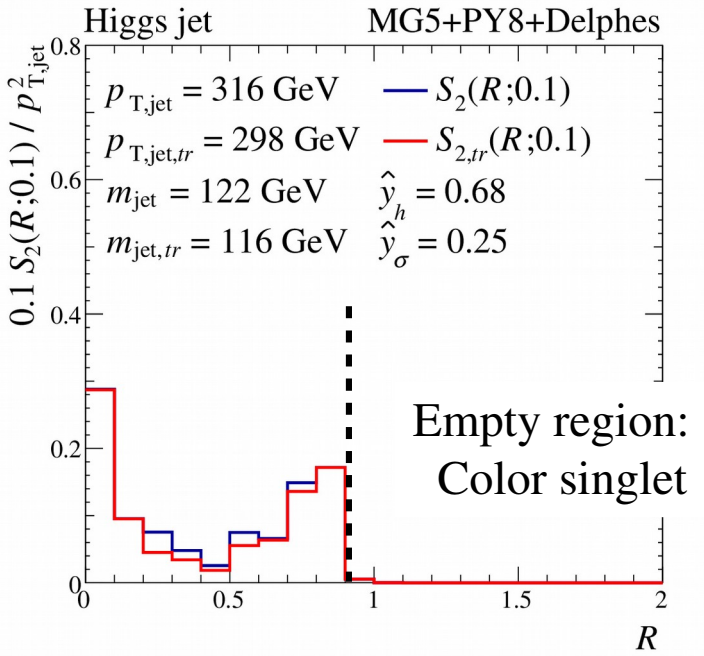
Higgs Jet (+ radiation)



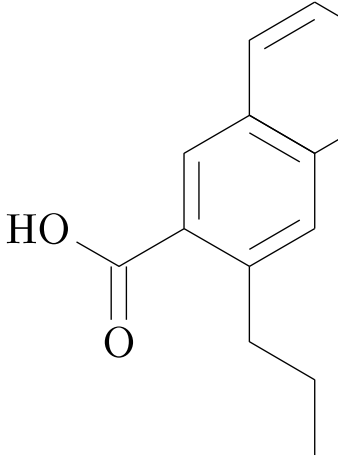
- Higgs boson is color singlet.
  - Radiation beyond $R_{b\bar{b}}$ is small → color singlet
  - Radiation from two b's is inward.

(U-shaped spectrum)

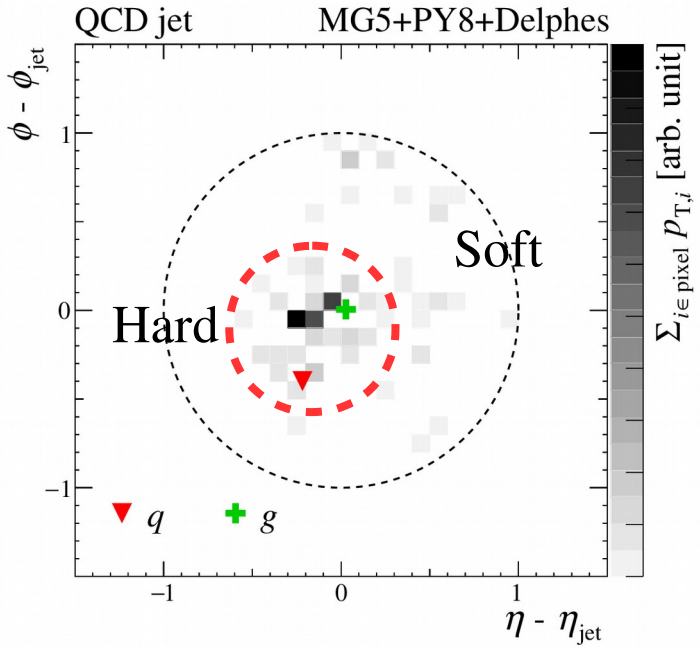


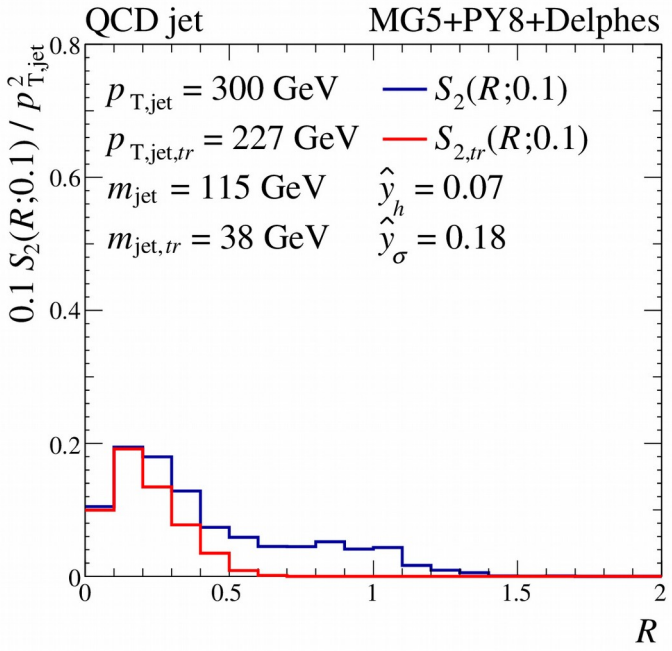


QCD jet



- QCD jets are mostly one-prong jets with surrounding soft particles.
- Its spectrum has a smoothly falling behavior.

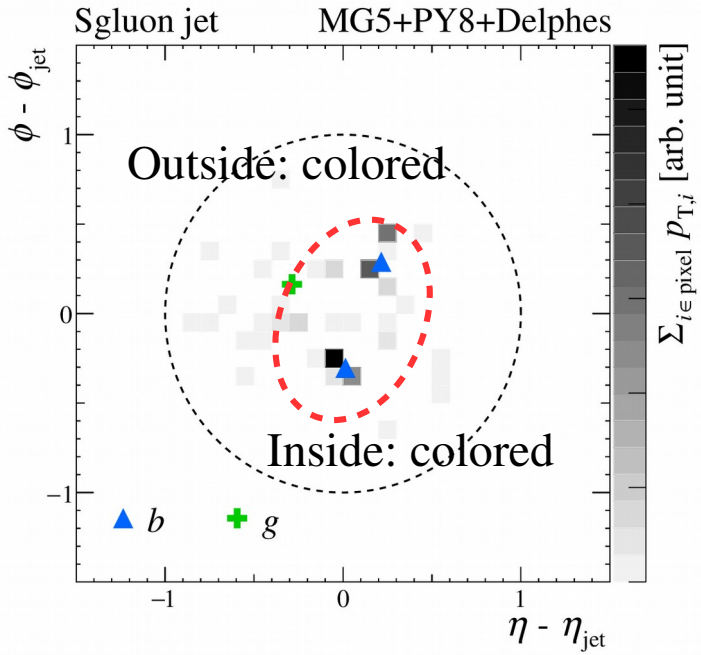


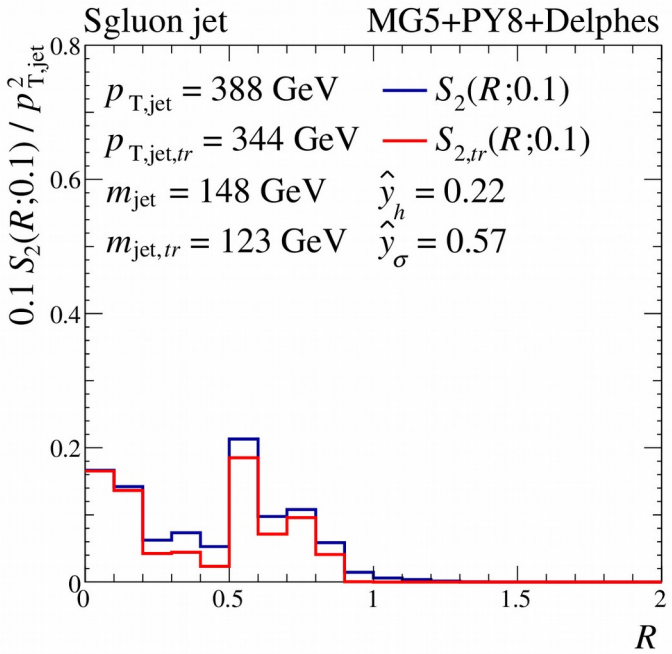


Sgluon Jet

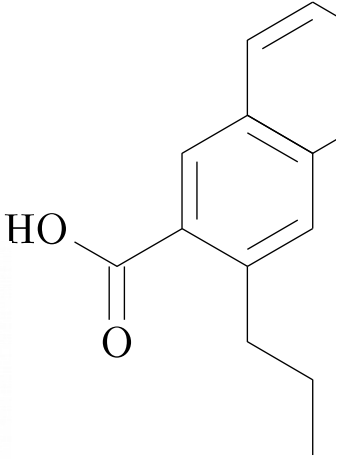
Preliminary

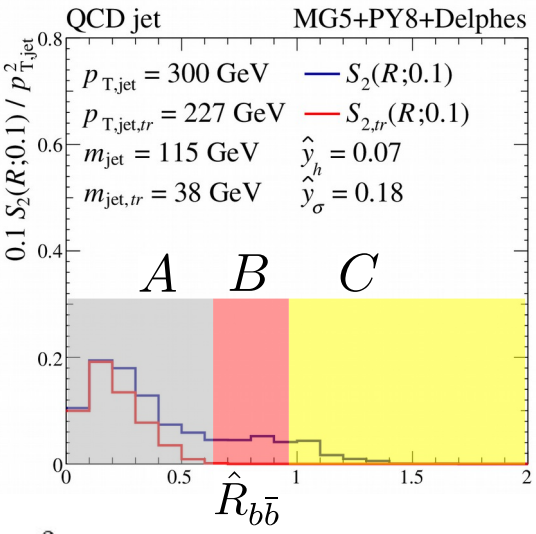
- Sgluon is color octet.
  - Radiation beyond $R_{b\bar{b}}$ is large.
  - Radiation from two b's is outward.
    (sawtooth-shaped spectrum)

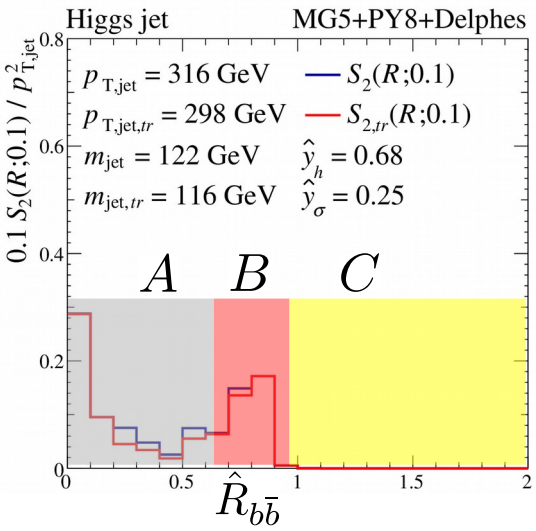


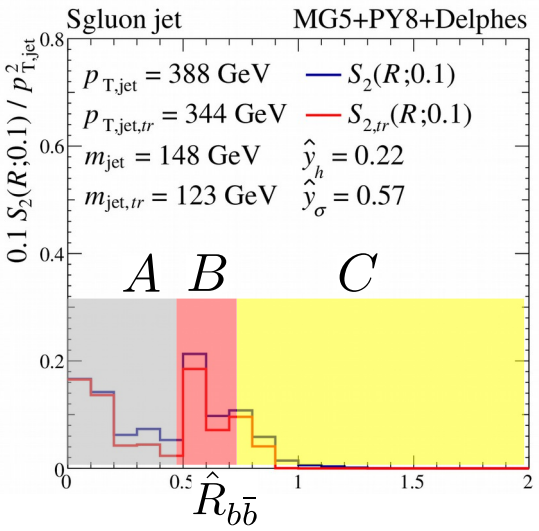


Quick Classifiers

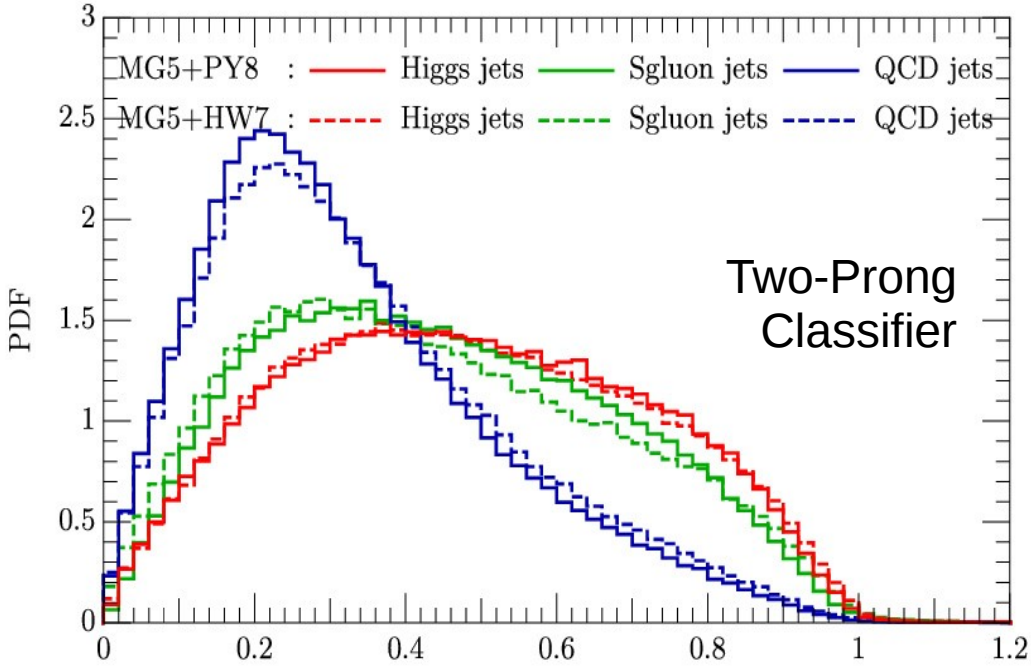




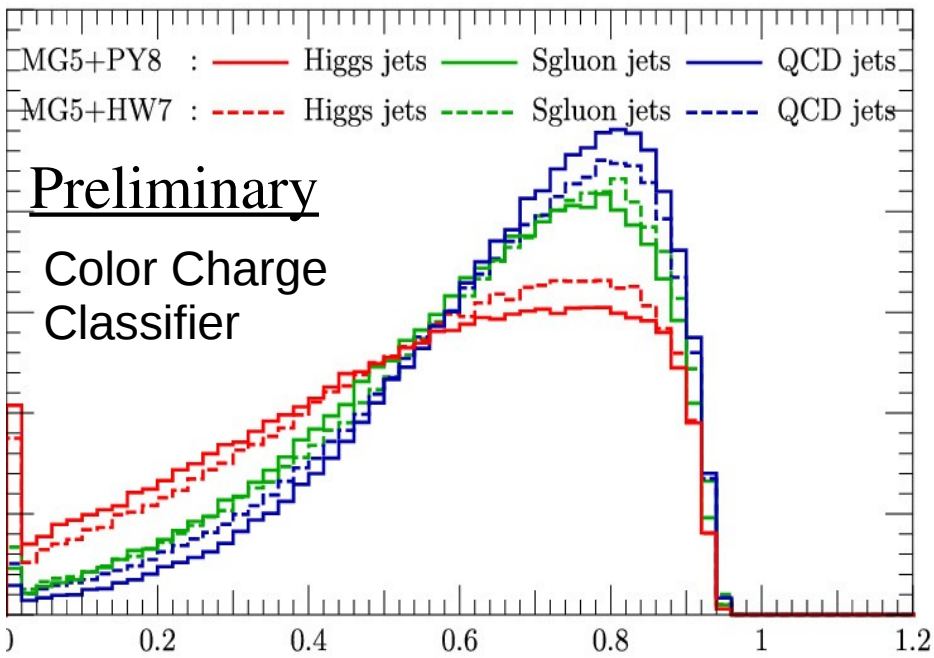




$$\hat{R}_{b\bar{b}} = \frac{2m_h}{p_{T,\mathrm{jet}}}$$



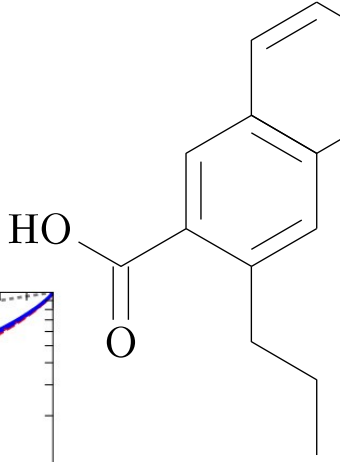
$B/(A+C)$



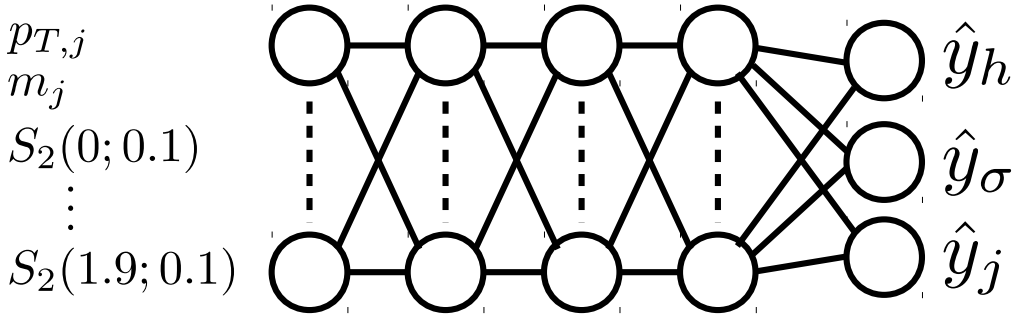
$40C/(A+B+40C)$

KEK

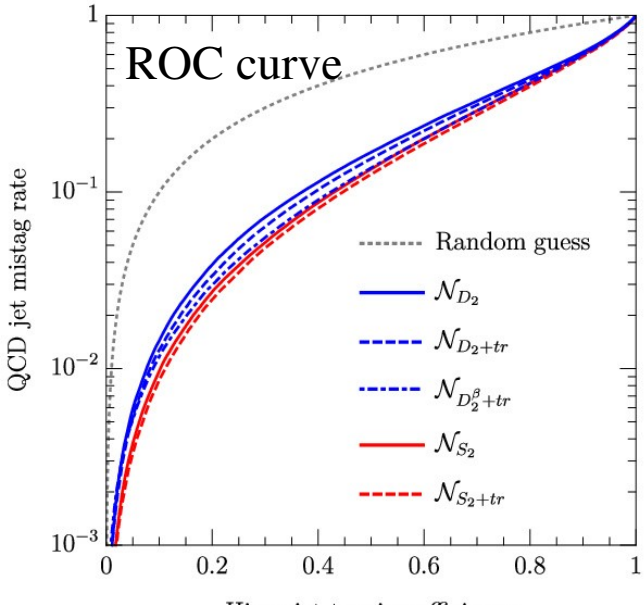
Classification with $S_2(R)$ and NN



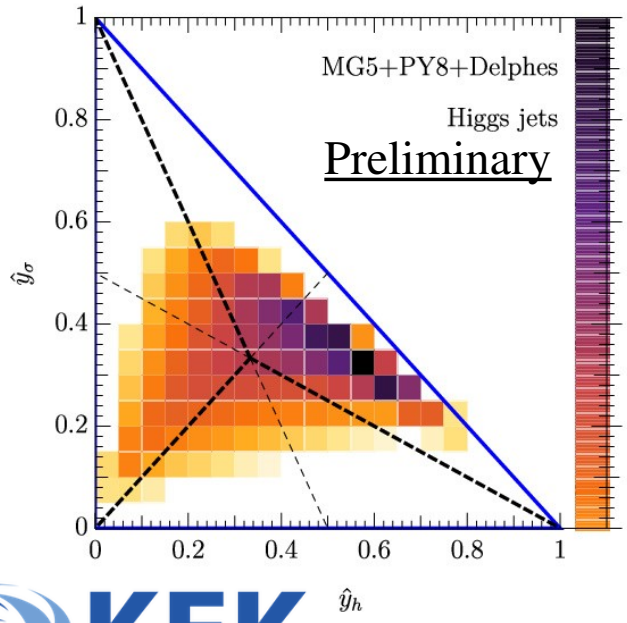
Use dense neural network classifiers

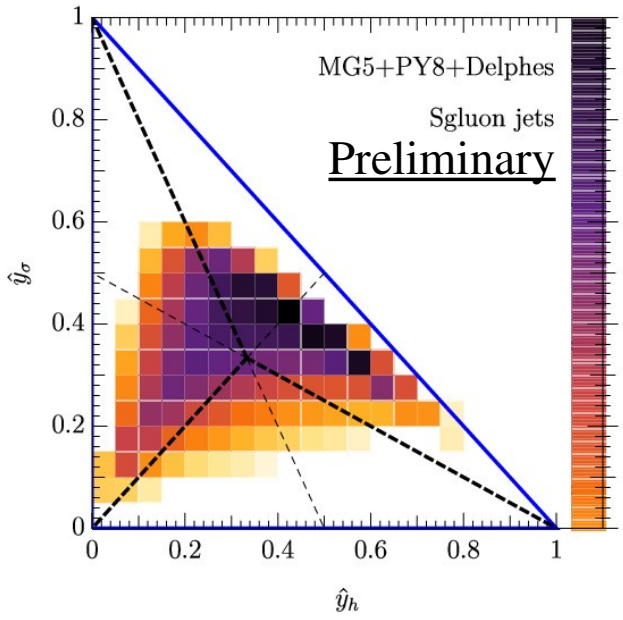


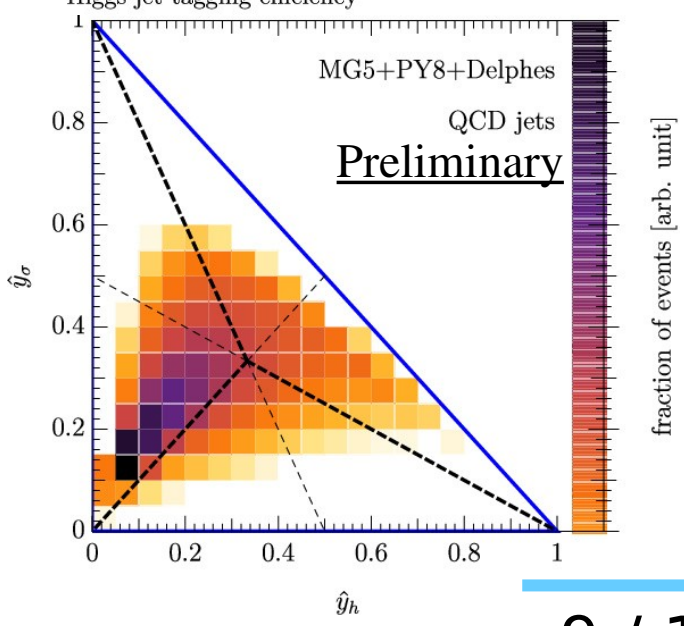
For Higgs vs QCD →



For Higgs vs Sgluon vs QCD ↓



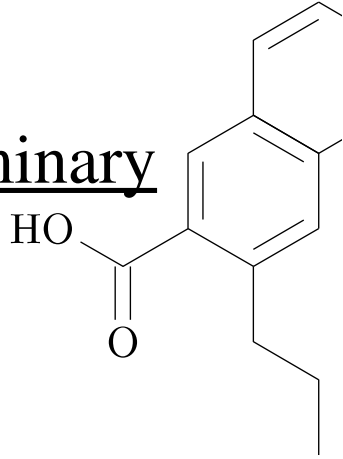




KEK

Interpretable NN architecture

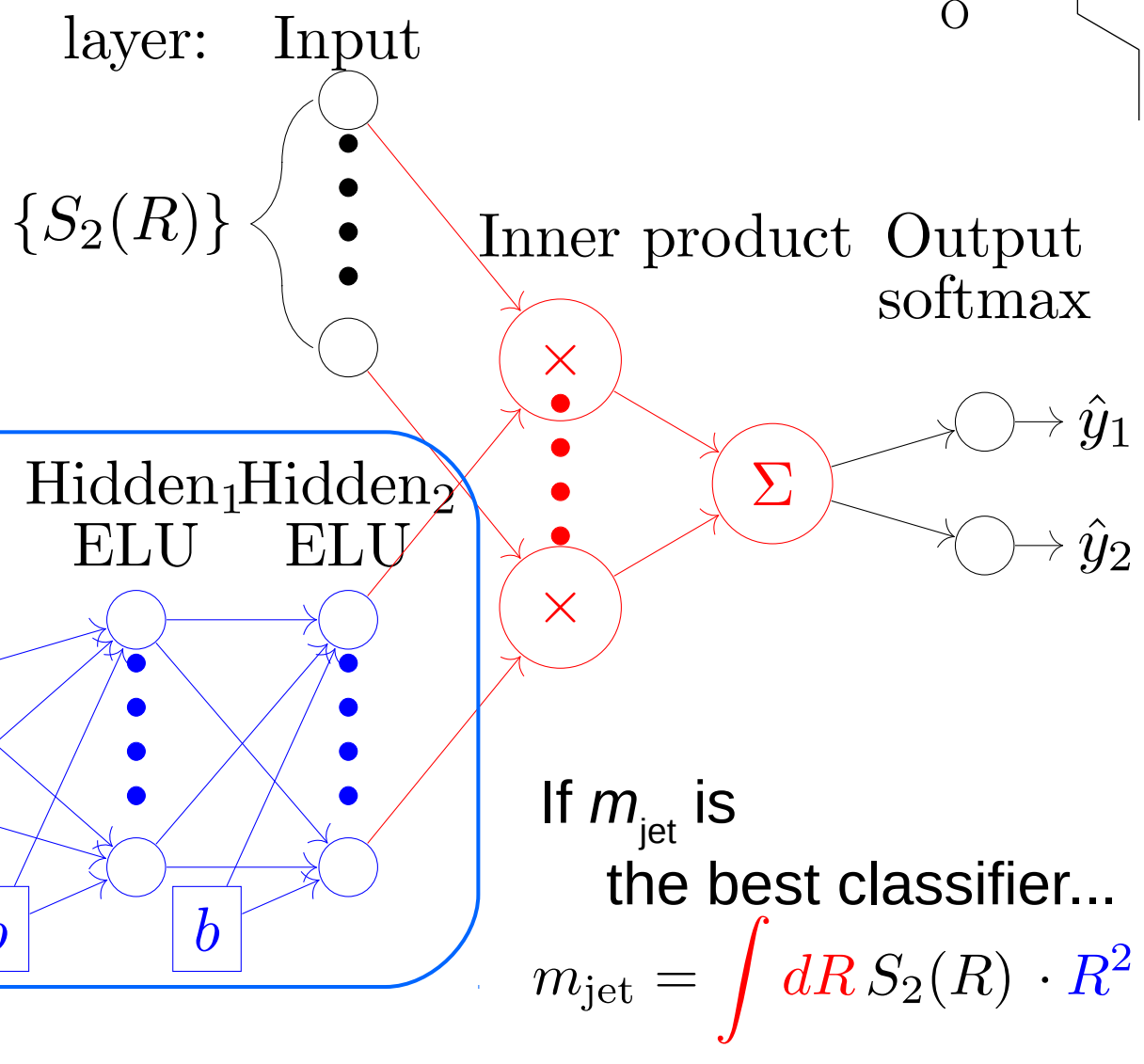
Preliminary



- $S_2(R)$ is a basis of two-point correlation functions.

$$\Sigma = \int dR\, S_2(R) \cdot f_2(R)$$

$$= \sum_{i,j \in \text{jet}} p_{T,i} p_{T,j} f_2(R_{ij})$$



NN representation of kernel $f_2(R)$

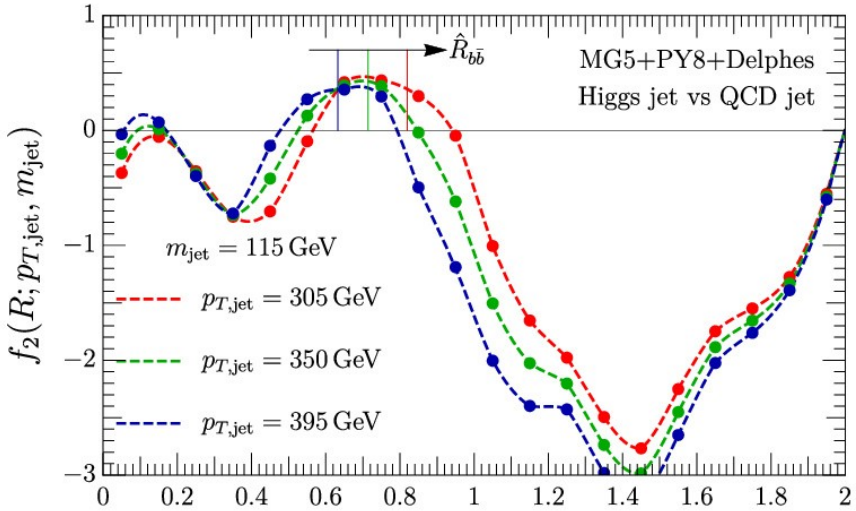
→ **interpretable**

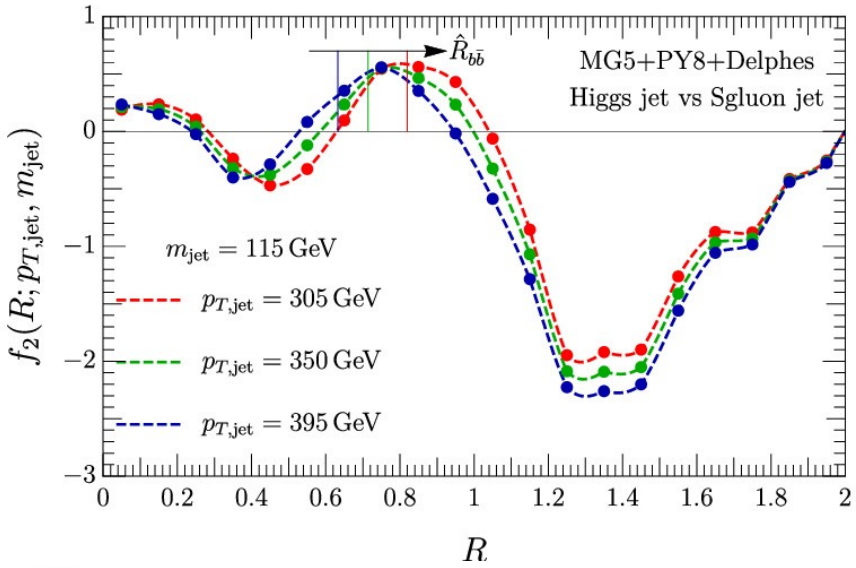
If m_{jet} is the best classifier...

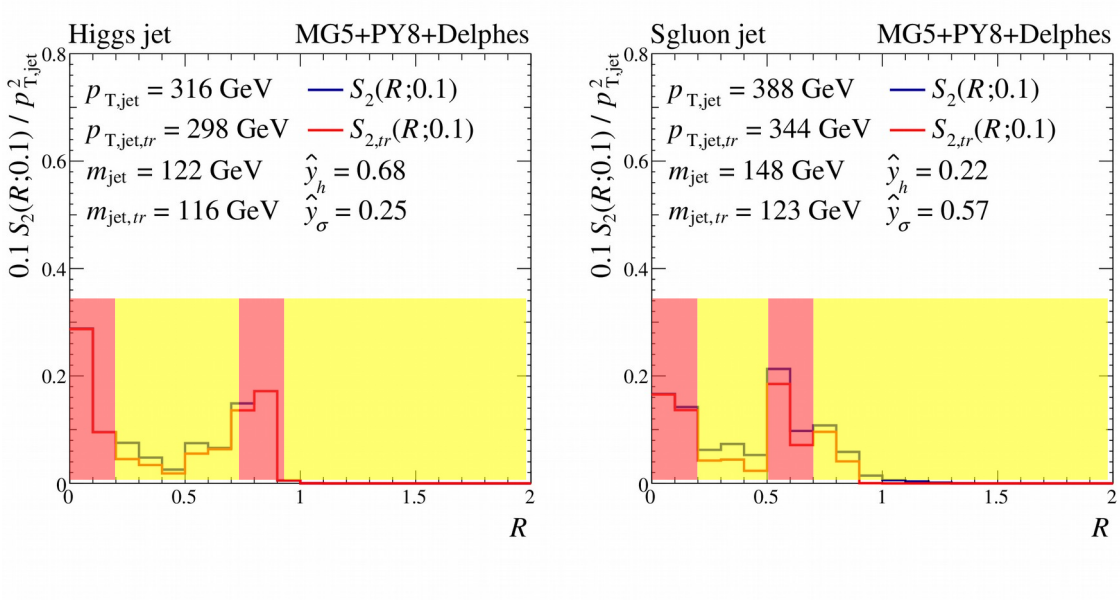
$$m_{\text{jet}} = \int dR\, S_2(R) \cdot R^2$$

Kernels found by Machine Learning

Preliminary

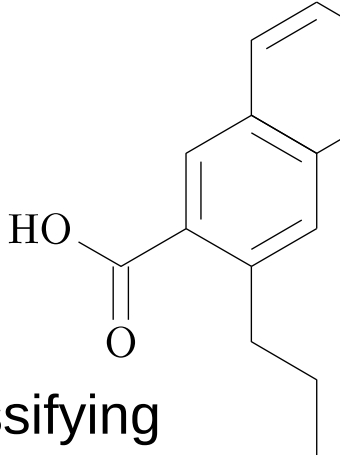






The network compares correlation at R=0 and R_{bb}, and that of surrounding.

Summary



- We have introduced a spectral analysis of jet substructure for classifying Higgs jets, Sgluon jets and QCD jets.
- The spetrum $S_2(R)$ is highly visual and useful in describing jet substructure with large angular scale.
- The spectral function $S_2(R)$ provide us a systematical framework for investigating jet substructure over various angular scale.
- For example, $S_2(R)$ can be used for understanding a color charge of boosted jets.
- Furthermore, we can build a neural network with interpretable weights. This will help us managing the network architecture itself and we could do more interesting works.
- There are more applications will be coming out soon, so please stay tuned!