Jet Tagging with Deep Sets of Subjets

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BASED ON WORK IN PROGRESS WITH:

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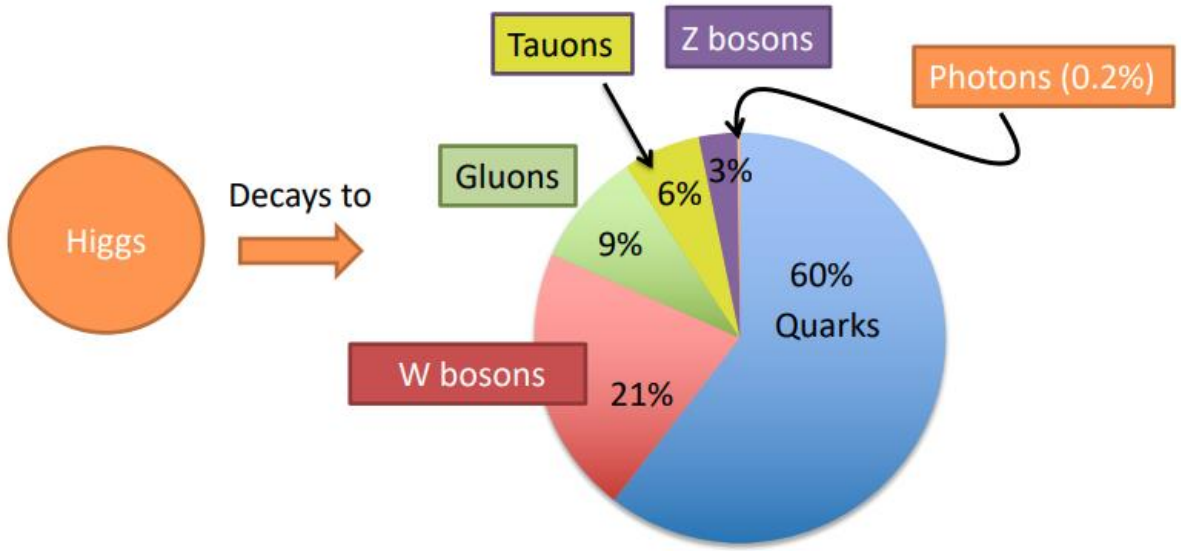
Overview

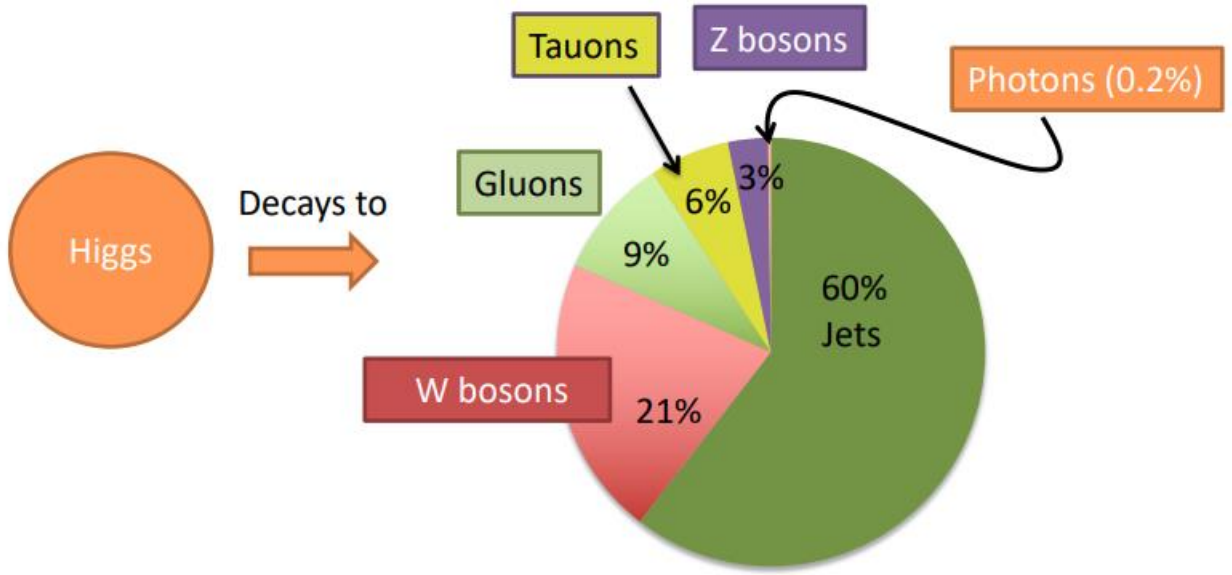
- Traditional Jet Classification Architectures
- Jet Flow Network (JFN)
- Minimal Information
- Connection to Graph Theory

Higgs Boson decay modes



Taken from M. Schwartz 's talk at ML4Jets 2017

Higgs Boson decay modes



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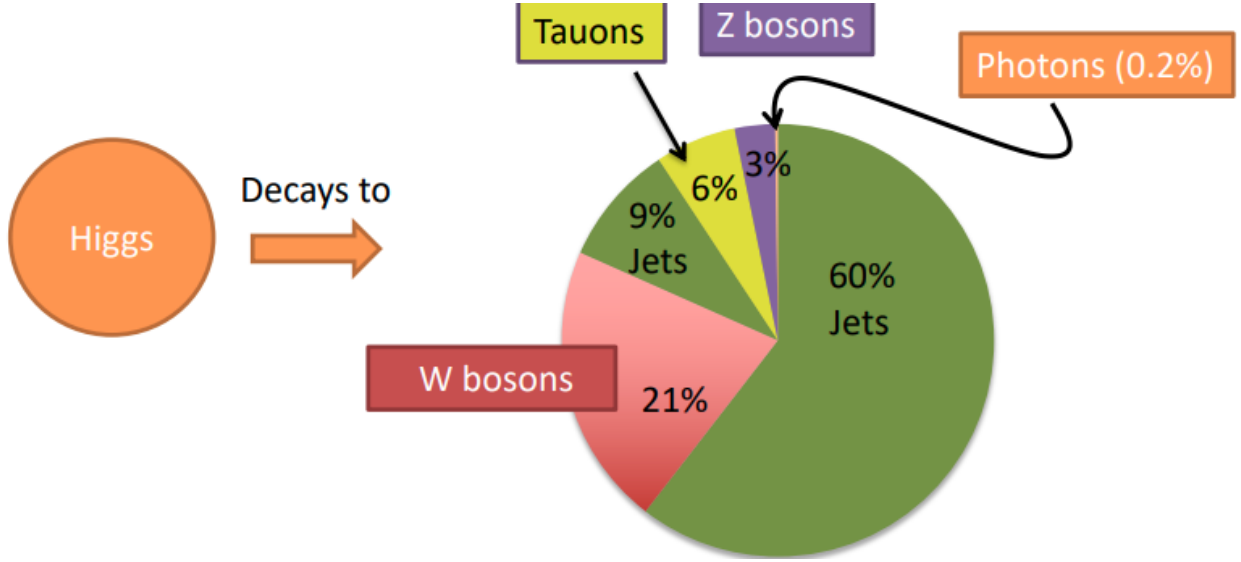

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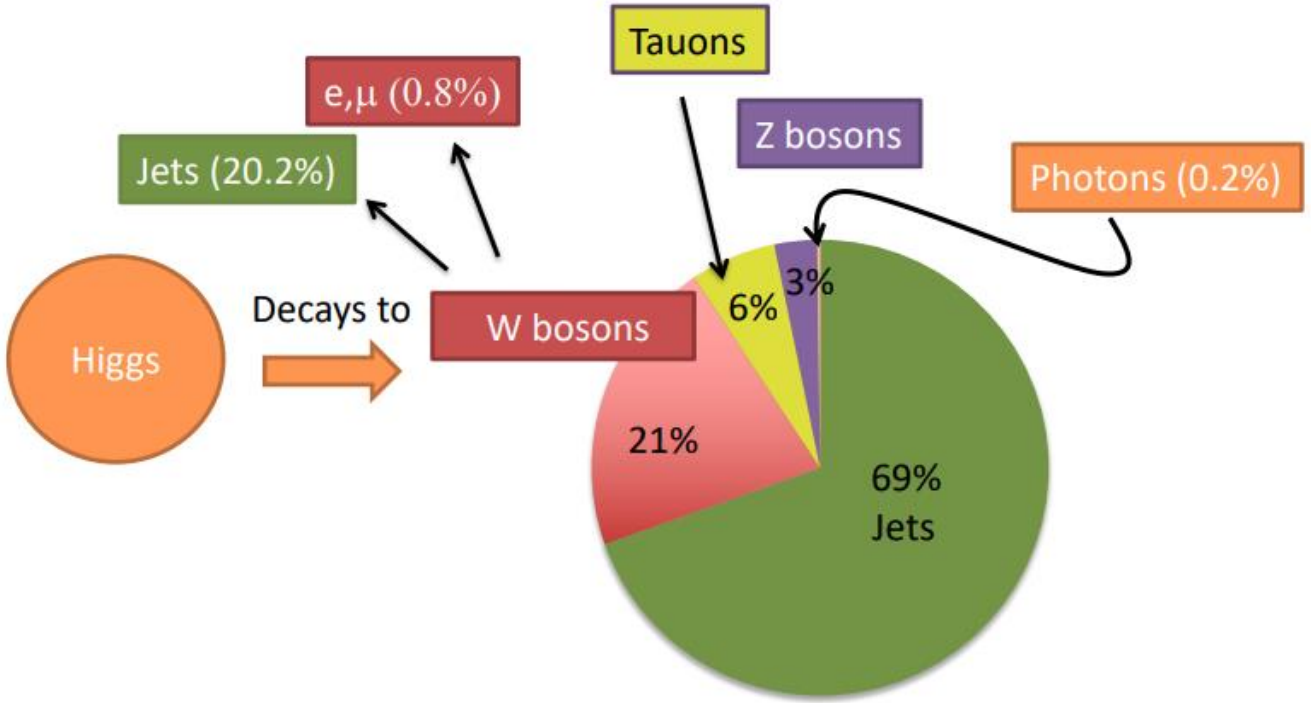

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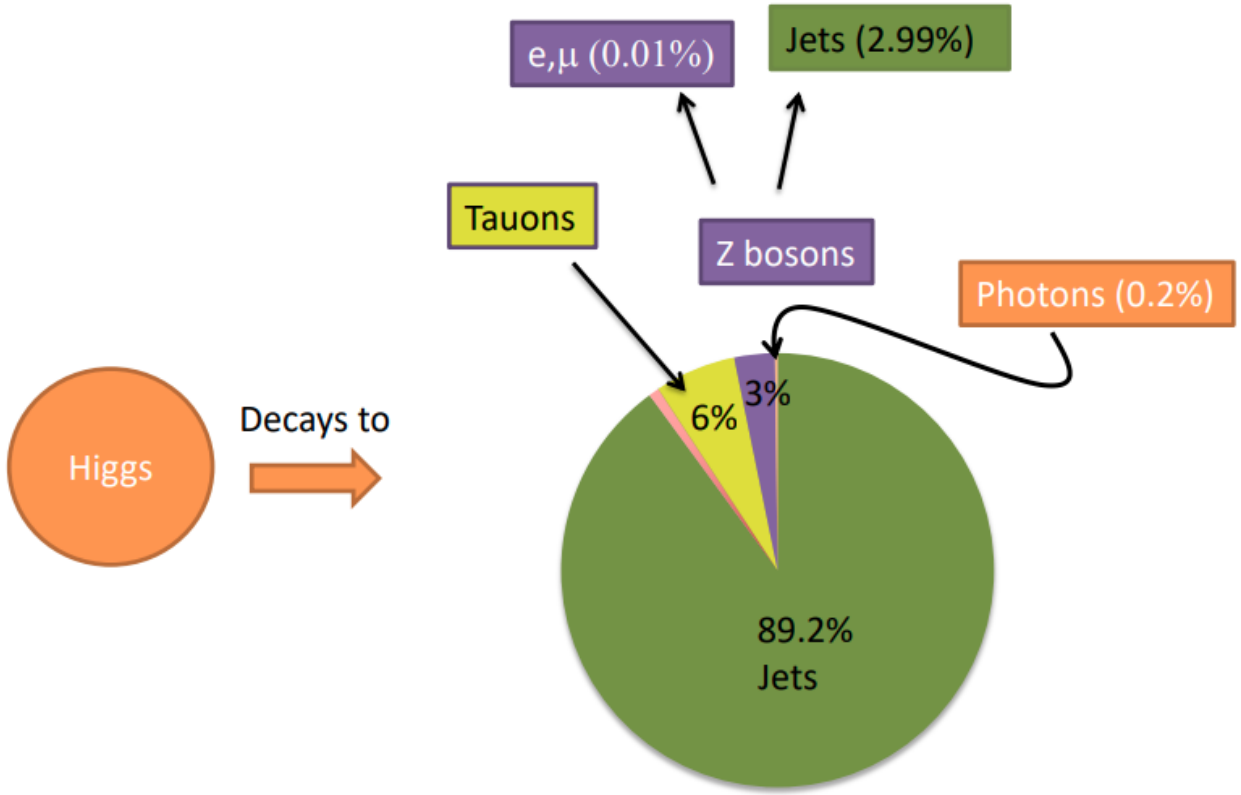

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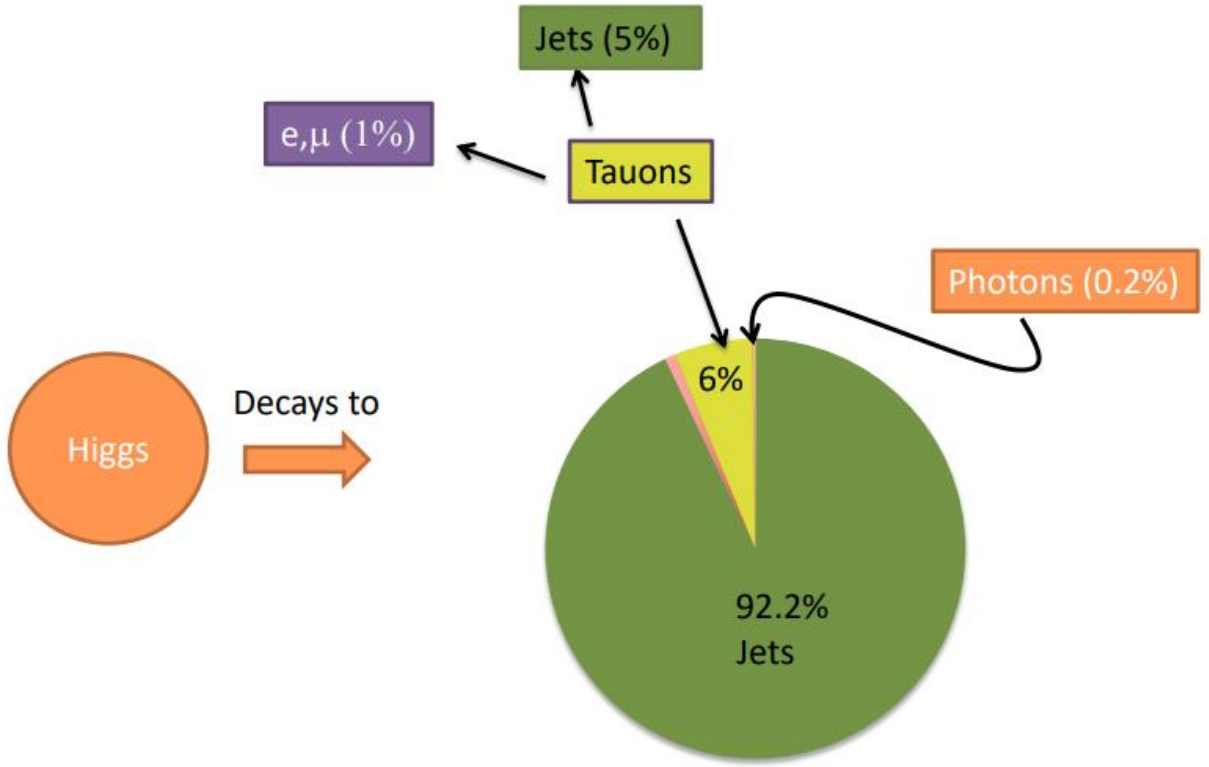

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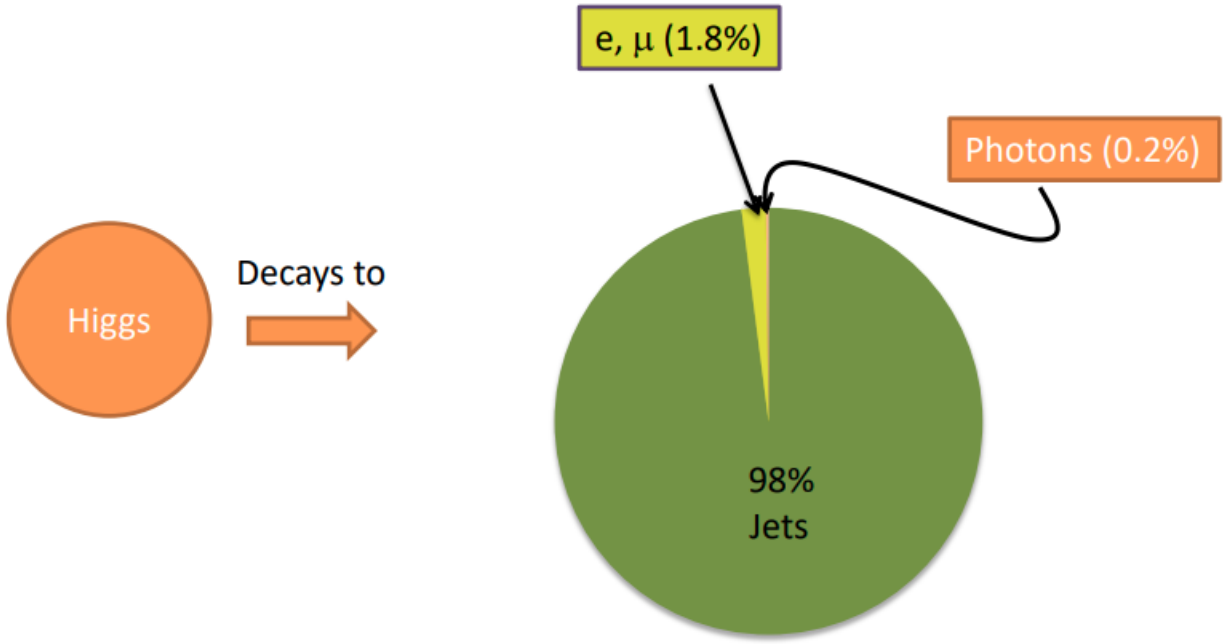
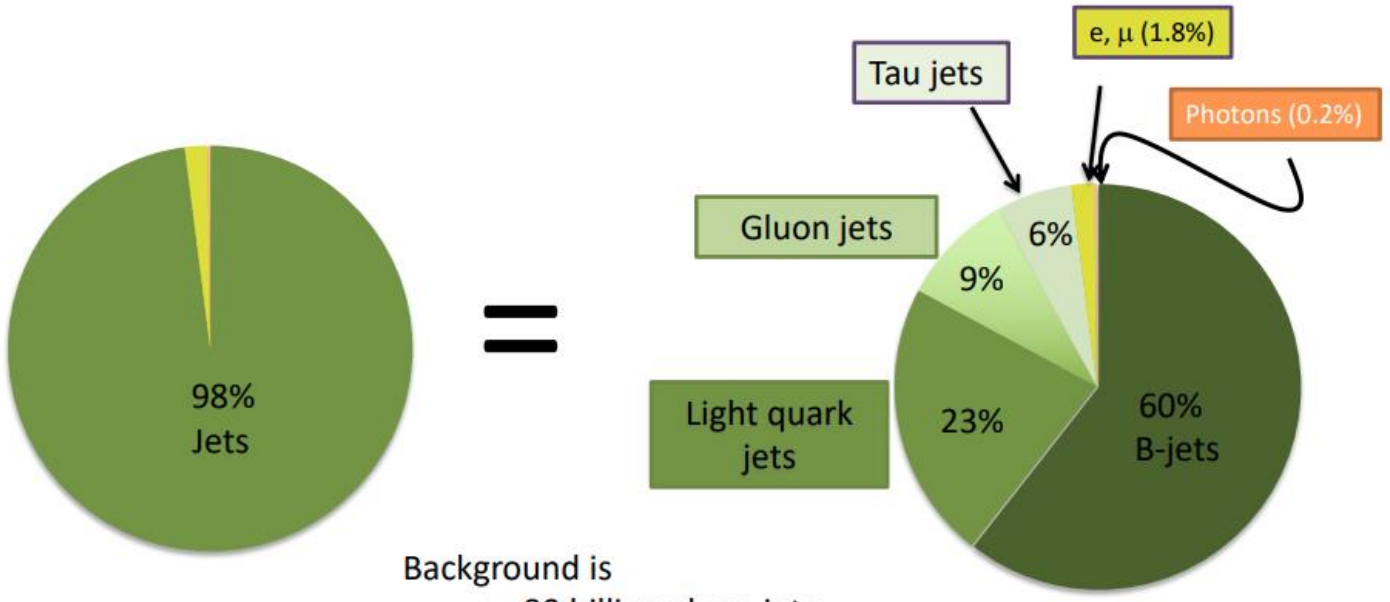


- Higgs discovery involved just these special decays

Taken from M. Schwartz's talk at ML4Jets 2017

Not all Jets are created equal



Background is
- 80 billion gluon jets
- 10 billion light quark jets

How can we tell all these different jet types apart?

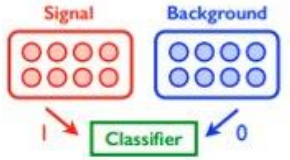
Taken from M. Schwartz's talk at ML4Jets 2017

One of the biggest challenges of collider phenomenology is

Jet Classification

E.g. Quark/Gluon Classification

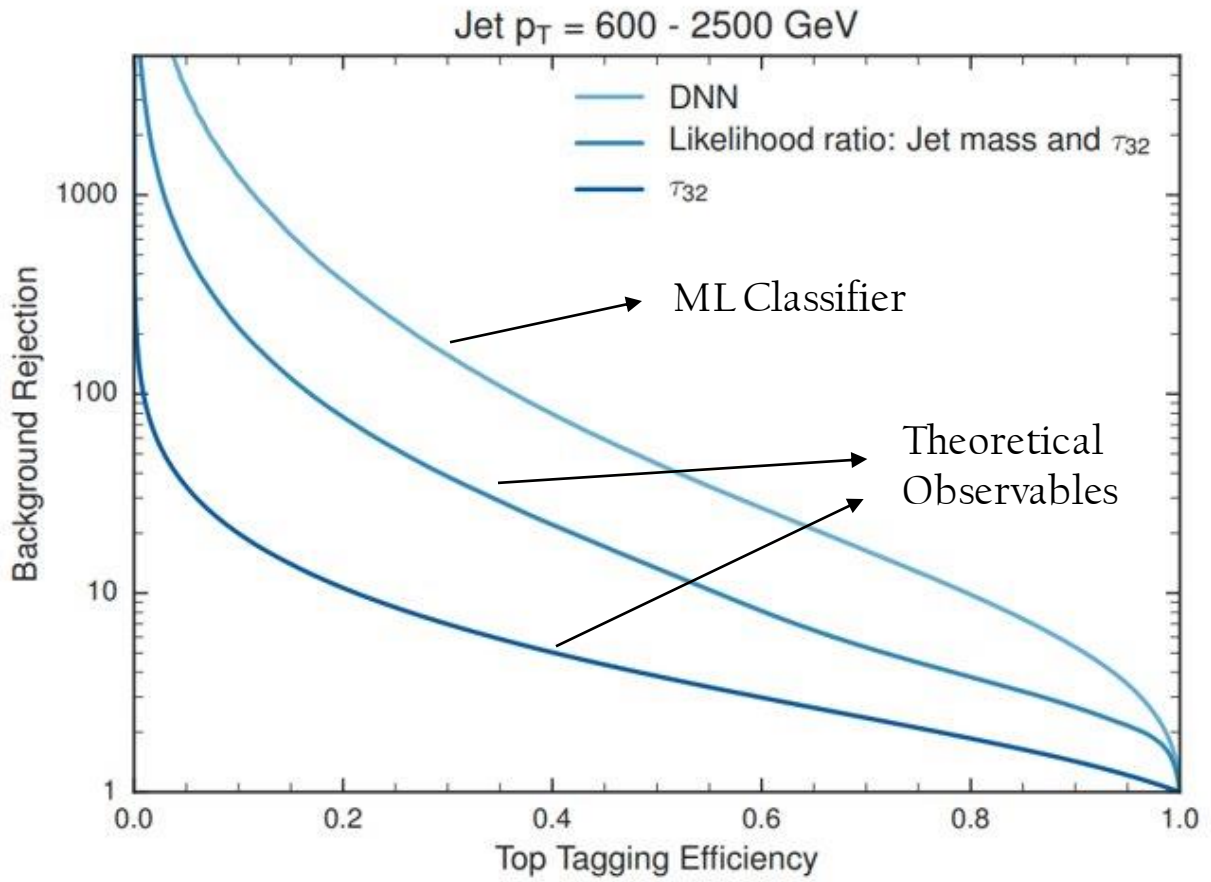
"Hello, World!" of Jet Physics



e.g.  Quark $C_q = 4/3$ vs.  Gluon $C_g = 3 = 9/3$

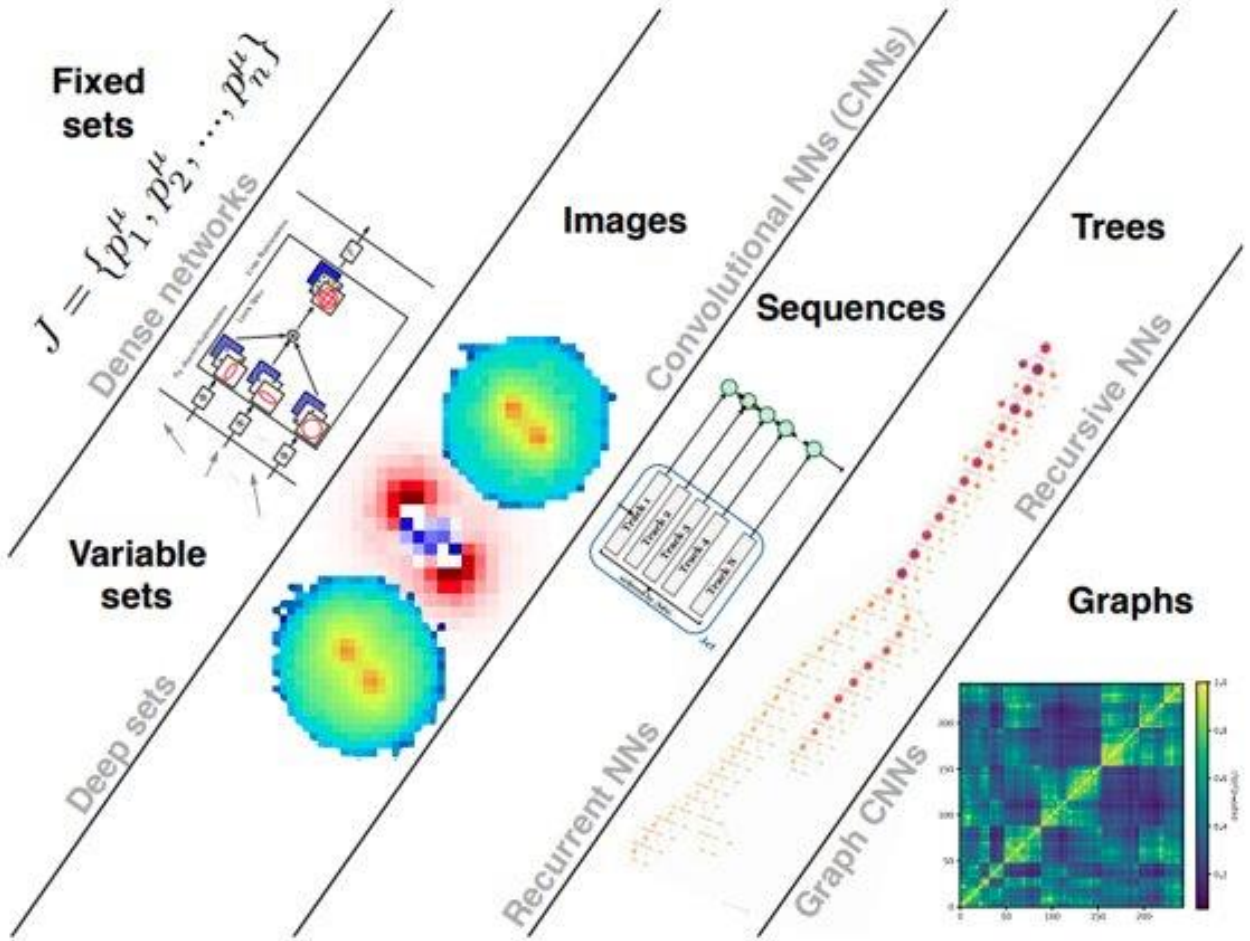
Find $h\left(\quad\right)$  such that $h(\text{Quark}) = 1$, $h(\text{Gluon}) = 0$

ML Classifiers > Theoretical Observables



J. Pearkes et al 1704.02124

Many ways to represent a Jet



Taken from A. Larkoski et al. 1709.04464

IRC safe vs IRC unsafe architectures

Permutation-invariant neural networks based on deep sets

Zaheer et al. 1703.06114
Wagstaff et al. 1901.09006
Bloem-Reddy, Teh JMLR 21 90 (2020)

Unordered, variable-length sets of particles as input

Komiske, Metodiev, Thaler JHEP 01 (2019) 121

Particle Flow Network (PFN)

$$f(p_1, \ldots, p_M) = F\left(\sum_{i=1}^{M} \Phi\left(p_i\right)\right)$$

latent space $d = 256$

Classifier

DNNs

Includes IRC-unsafe information

Energy Flow Network (EFN)

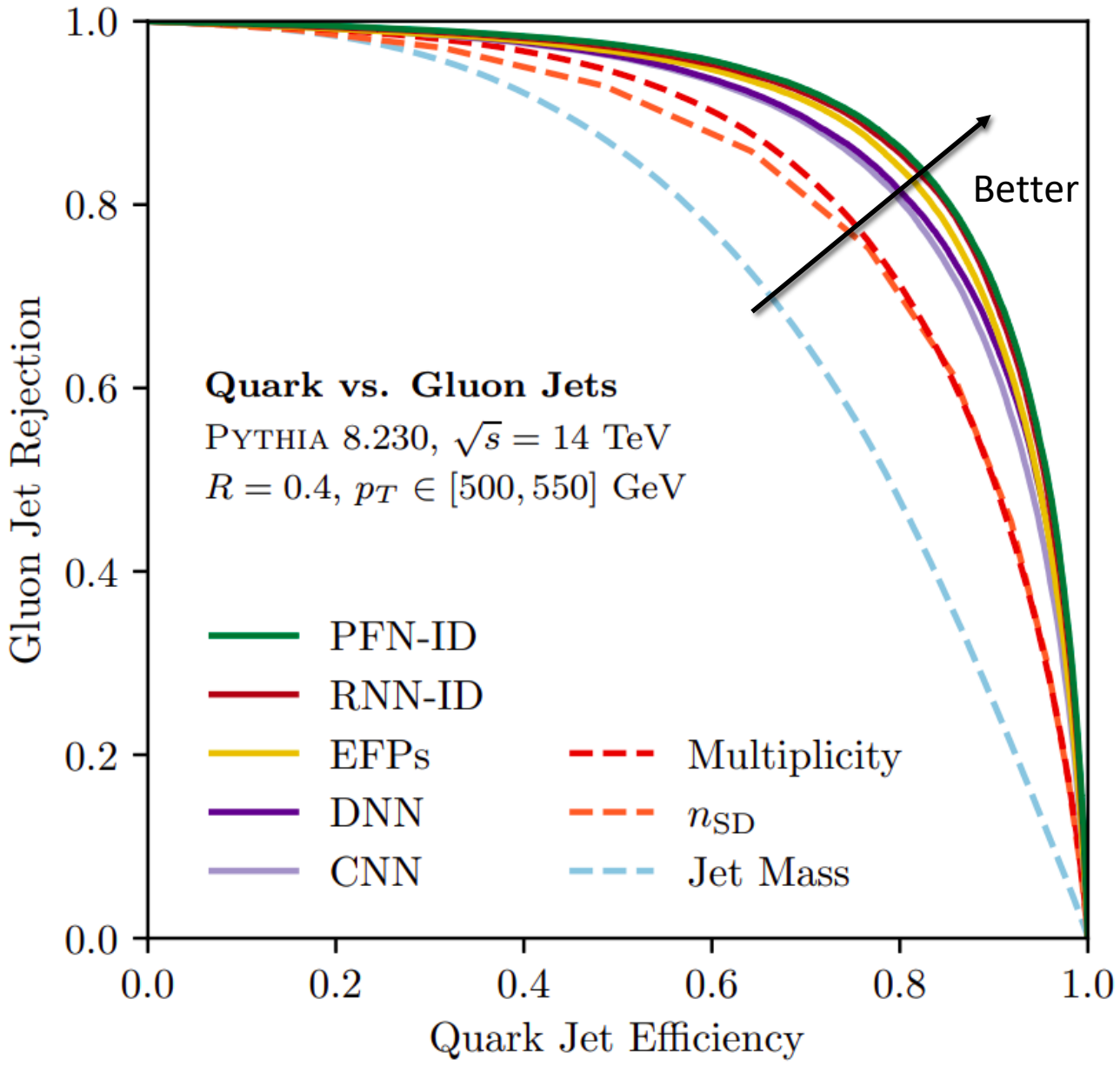
$$f(p_1, \ldots, p_M) = F\left(\sum_{i=1}^{M} z_i \Phi\left(\hat{p}_i\right)\right)$$

Classifier

DNNs

Includes only IRC-safe information

PFN performs amazingly well

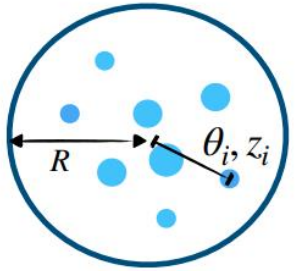


J. Thaler et al, 2111.14589

Jet Observables and IRC safety

We are free to construct any observable from the jet's constituents

e.g. $\lambda_\alpha^\kappa = \sum_{i \in \text{jet}} z_i^\kappa \theta_i^\alpha$

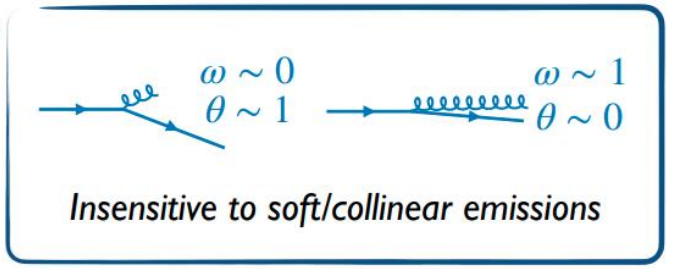


$$\theta_i = \frac{\sqrt{\Delta y^2 + \Delta \varphi^2}}{R}$$

$$z_i = \frac{p_{\mathrm{T},i}}{p_{\mathrm{T,jet}}}$$

However, usually only those combinations that obey **infrared-collinear (IRC) safety** are calculable in perturbative QCD

e.g. $\lambda_{\alpha>0}^{\kappa=1} = \sum_{i \in \text{jet}} z_i \theta_i^\alpha$



Interpretability

PFN is IRC unsafe, sensitive to non perturbative physics and it has 3N variables where N is the number of hadrons

Increase interpretability by connecting it to Sudakov/IRC safe observables and cutting down the size of the input

Jet Flow Network (JFN)

Instead of hadrons, we work with subjets

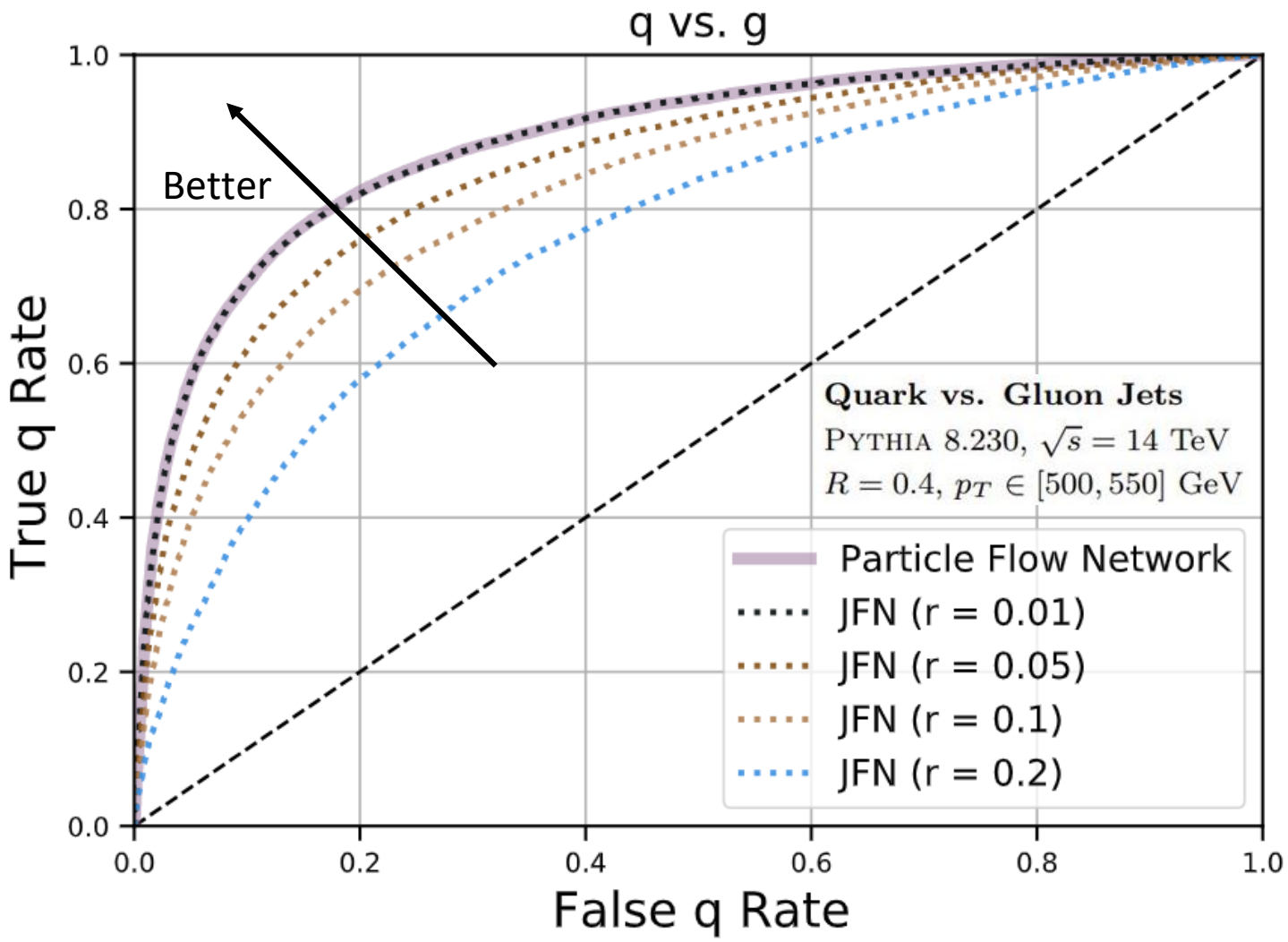
For a non-zero subjet radius r the classifier is IRC safe

As we lower r, we smoothly transition to the non-perturbative regime

Properties of **inclusive subjets** are **known to NLL** *(L. Dai et al 1606.07411, F.Ringer et al 1705.05375, 2103.16573)*

As we lower r JFN converges to PFN

Think of r as a parameter that allows us to trade performance for insensitivity to nonperturbative effects



Does JFN completely and minimally span the phase space ?

- *For a jet with M subjets, the phase space is 3M-3 dimensional*

- See earlier work using N-subjettiness observables.

  (A. Larkoski 1704.08249, F. Ringer et al 2111.14589 for Heavy Ion Jets)

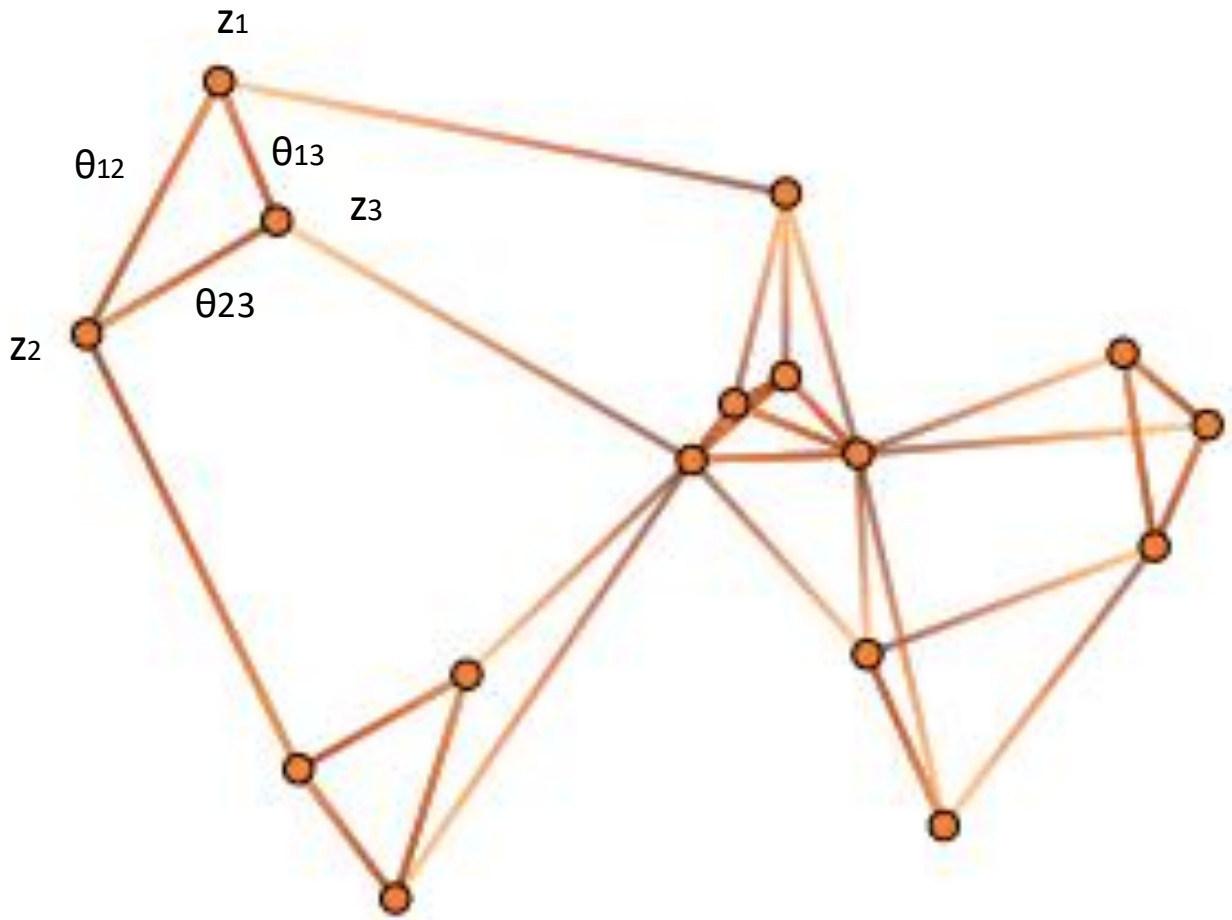
- *We can split the phase space to* M *transverse momenta* $+ 2M-3$ *relative angles (Euclidean Distances)* ***between the subjets on the*** (η,φ) ***plane***

  (see A. Larkoski, T. Melia 2008.06508 for a geometric picture in terms of Manifolds)

Can we interpret the relative angles as edges on a graph ?

Yes -> Connection with Graph Theory

(still working on the results)



THANK YOU