Classifying Quark and Gluon Jets for ATLAS at CERN

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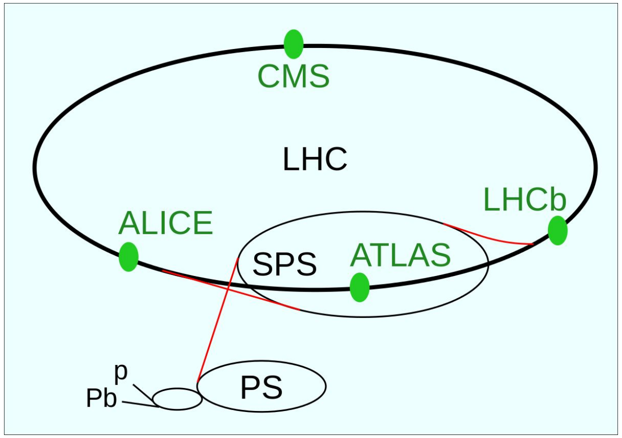
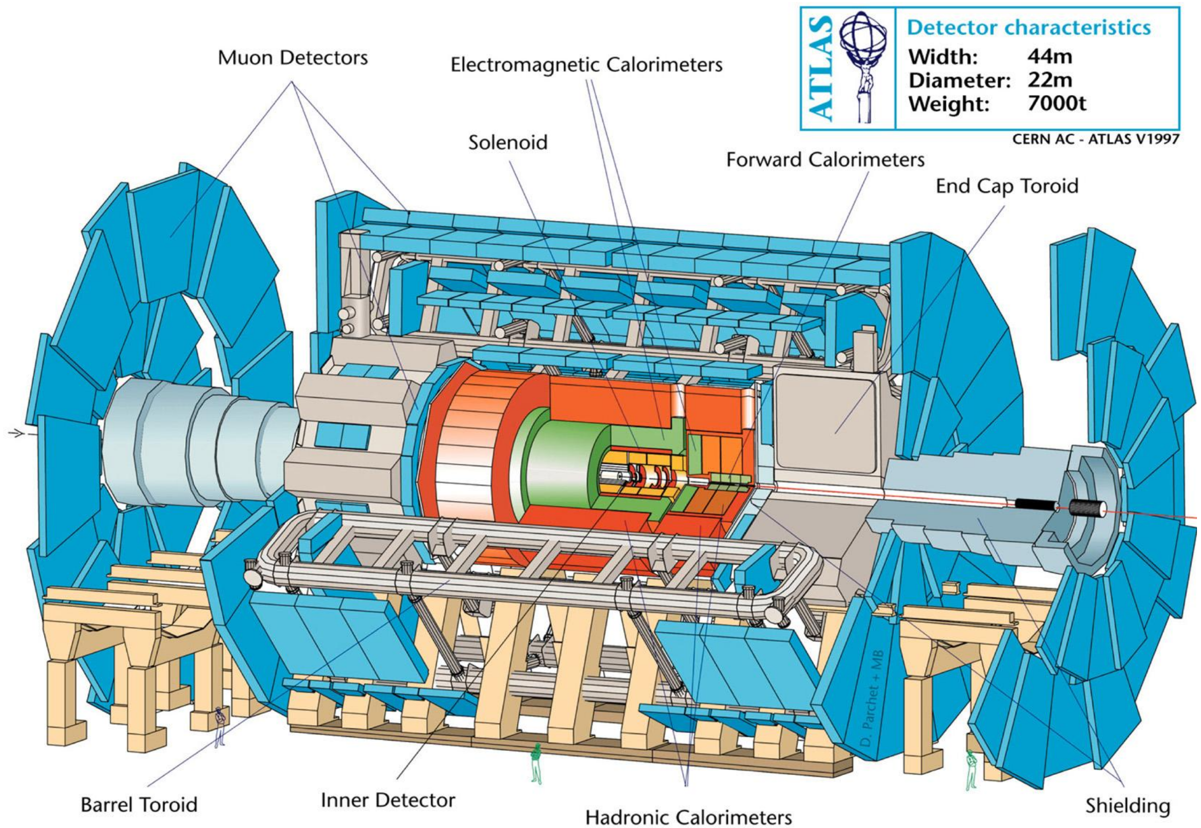
Carleton Student Presentations

The ATLAS experiment





- The ATLAS experiment is a general purpose experiment at the LHC.
- It is used to study proton-proton collisions at 13 TeV.

What is a jet?

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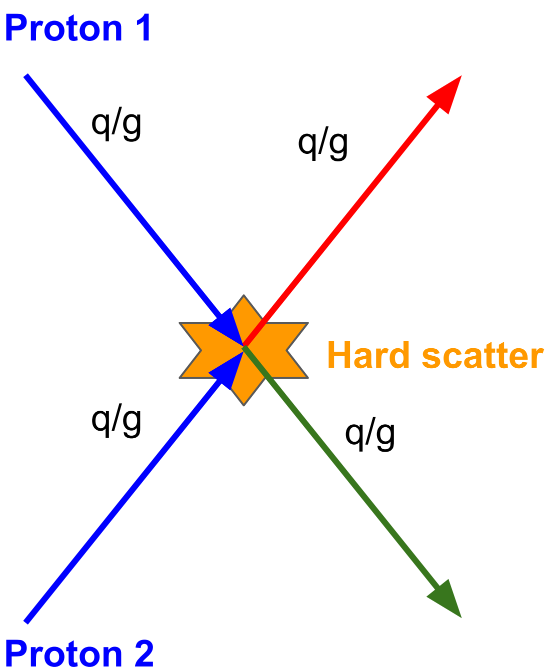

<u>Matrix element level</u>

Collision between two partons in LHC. Results in two partons at first order.

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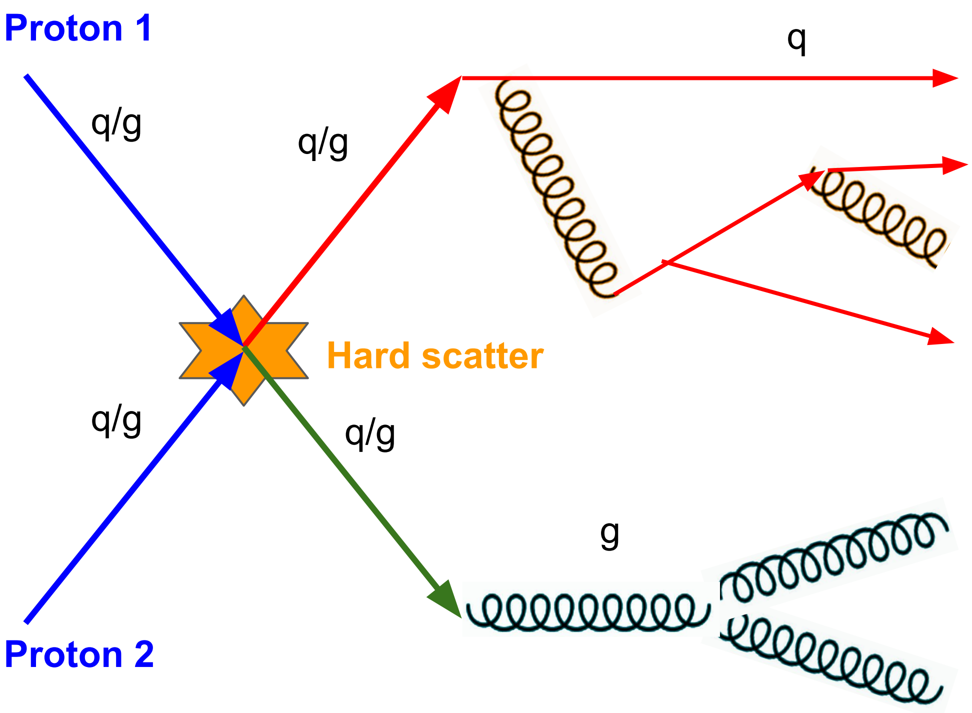

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<u>Parton shower level</u>

Partons undergo QCD interactions and create “parton jets”.

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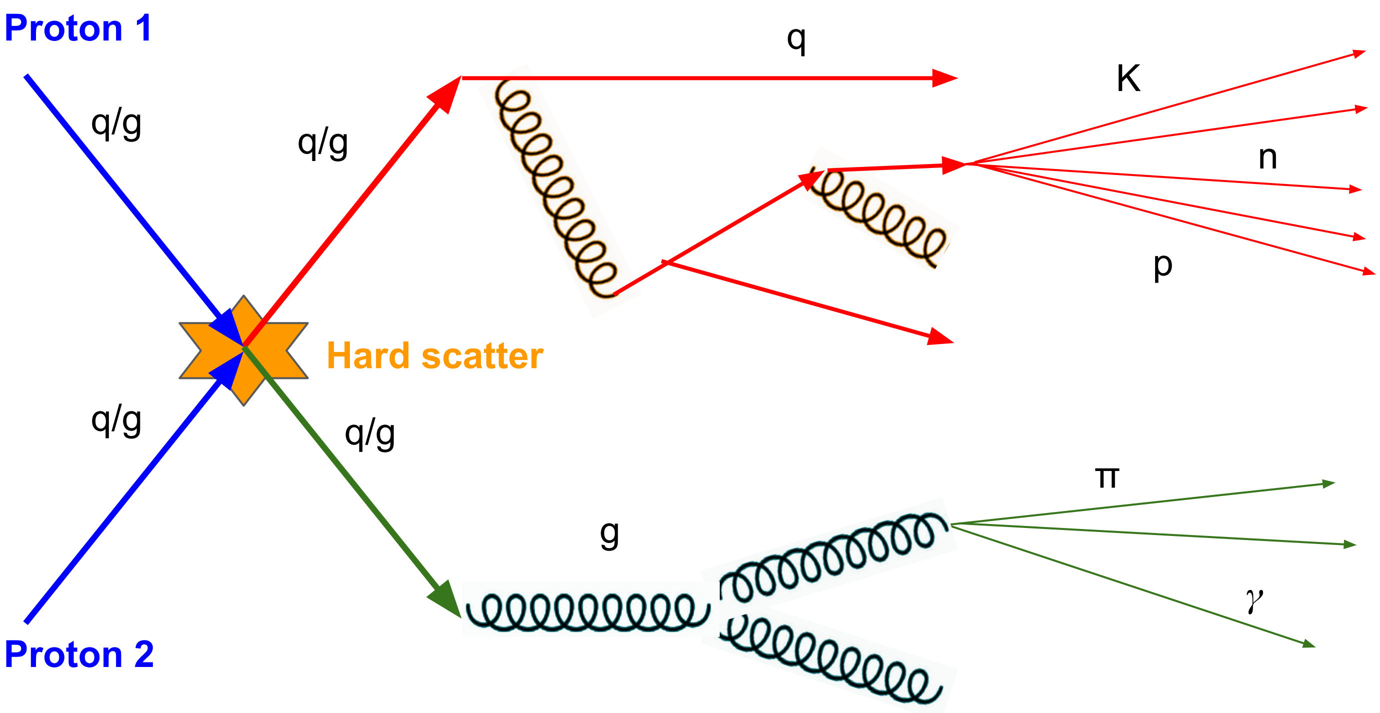

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<u>Hadron level</u>

Partons hadronize into stable particles. Particles grouped into “hadron jets”.

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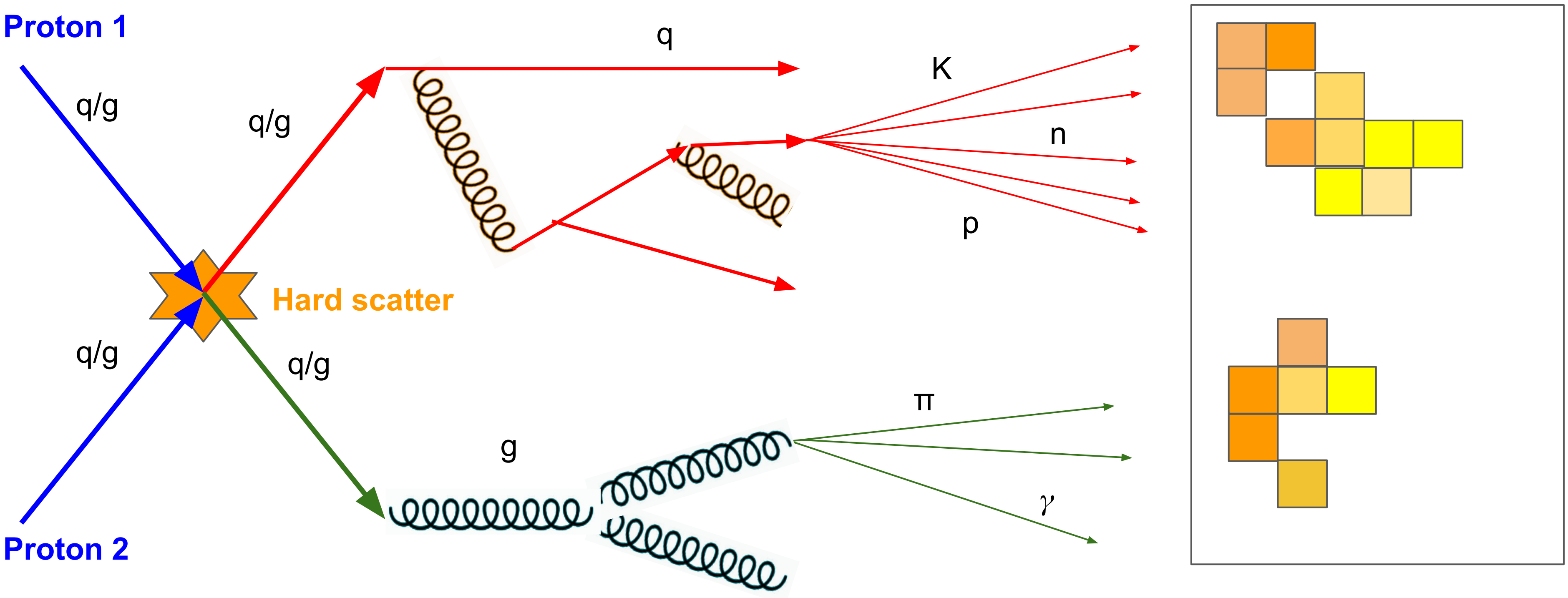

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Energy depositions in calorimeters simulated and grouped into “reconstructed jets”.

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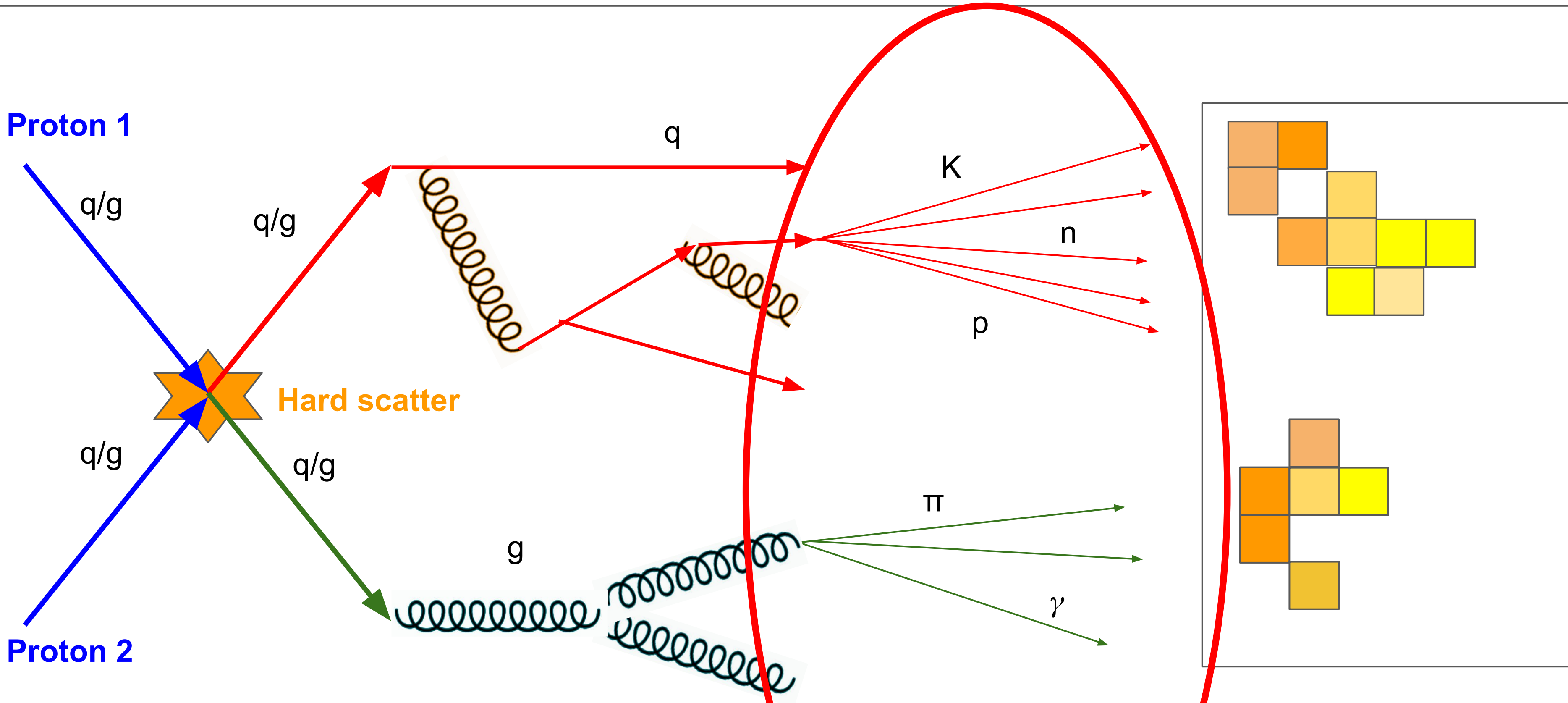

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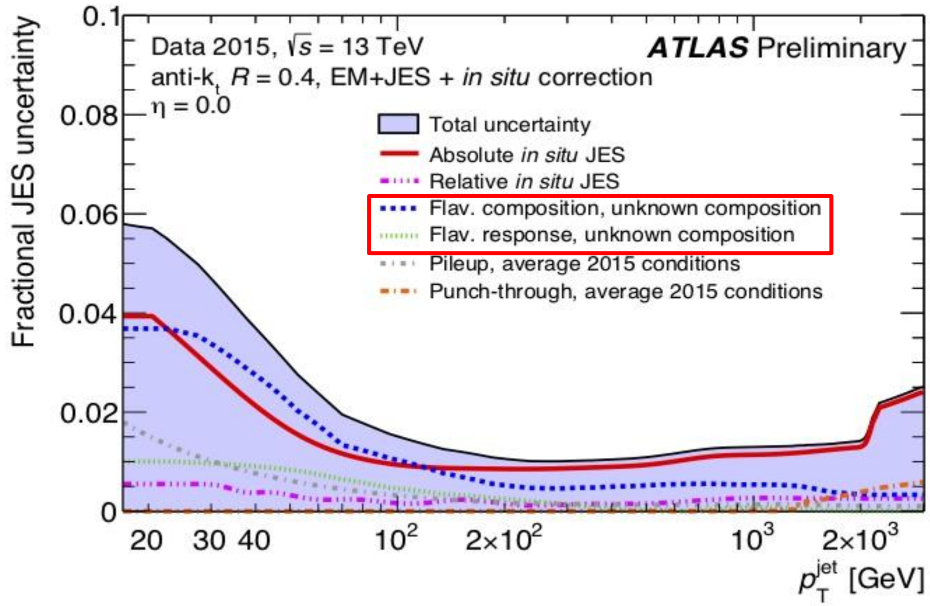
Why do we want a jet classifier?

- Interested in calorimeter **response**, aka Jet Energy Scale (**JES**).

  Ratio of transverse momentum at reco level and hadron level.

$$R = p_{\mathrm{T}}^{\mathrm{reco}} / p_{\mathrm{T}}^{\mathrm{hadron}}$$

- Response depends on flavour of jet (initiated by quark or gluon).
- For many analyses, *Jet Energy Scale uncertainty* is a dominant uncertainty.
- Knowing the flavour of each jet will reduce the *flavour composition* component of this uncertainty.



Why do we want a hadron-level jet classifier?

- Jets are currently tagged as quark or gluon jets by looking at the highest p_T parton at parton shower level.
- Parton showering is modelled by a Monte Carlo generator such as Pythia, Herwig, Sherpa.
- Partons are unphysical, so the parton level is handled differently by each generator.
- Using partons to label jets introduces a dependence on the generator used. Instead we should define quark and gluon jets by their ***physical properties at hadron level***. This is the focus of my work.

How can we distinguish quark/gluon hadron jets?

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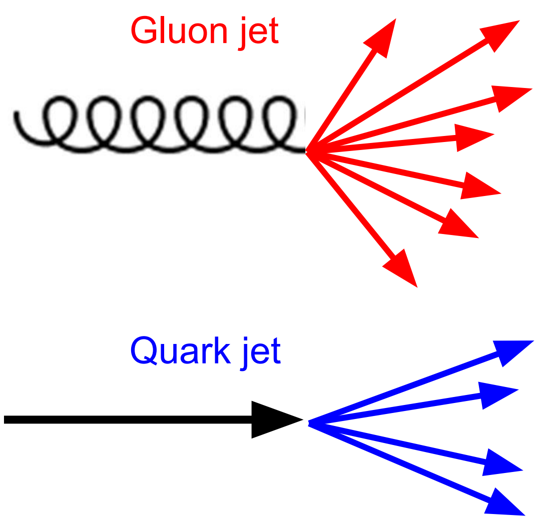
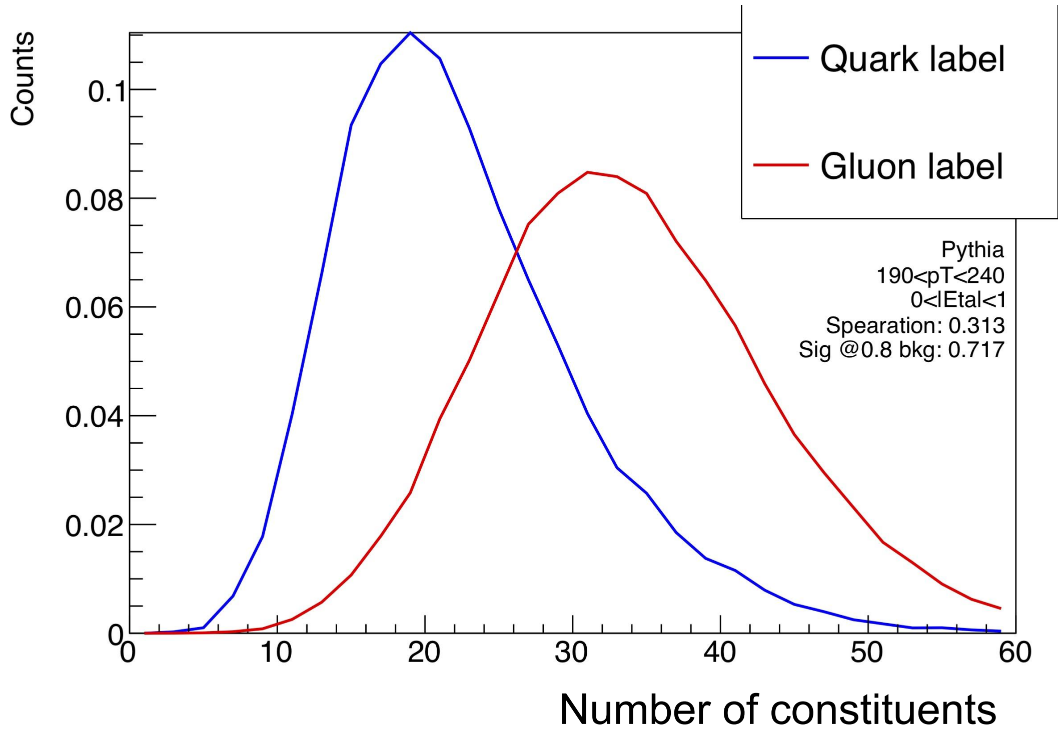
- Number of constituents:
  On average, gluon jets have more constituent particles.

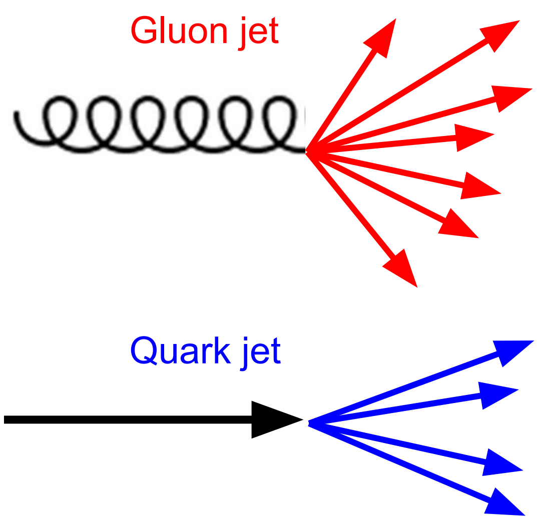


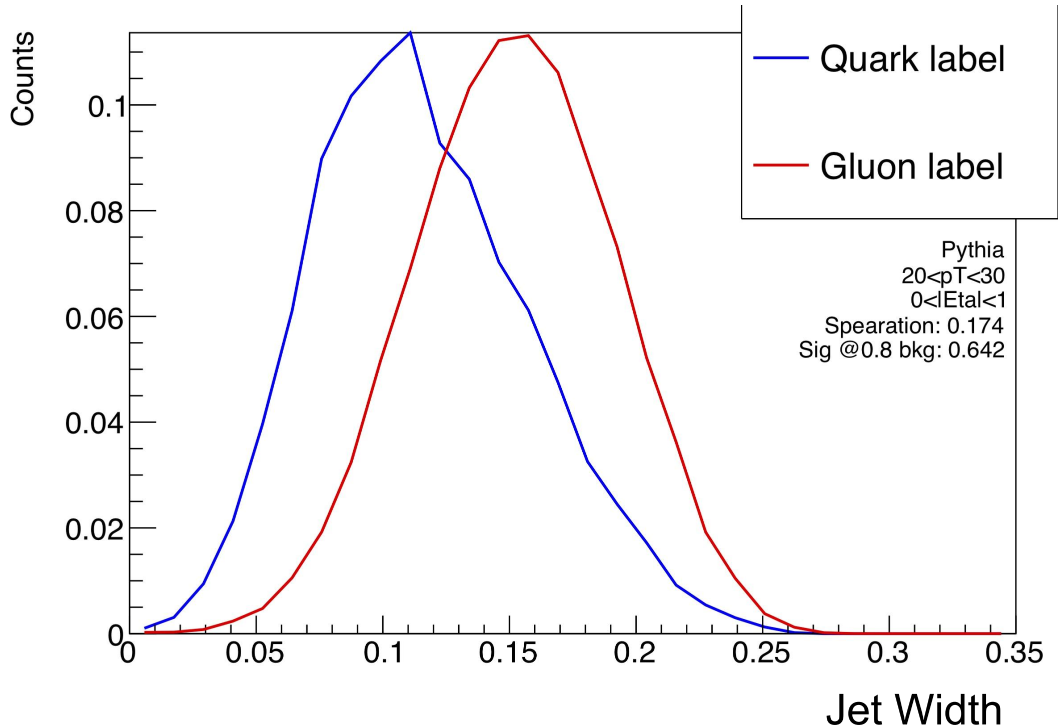


How can we distinguish quark/gluon hadron jets?

- Number of constituents.
- Width:
  On average, gluon jets are wider.

$$w = \frac{\sum_i p_{\mathrm{T},i} \times \Delta R(i, \mathrm{jet})}{\sum_i p_{\mathrm{T},i}}$$



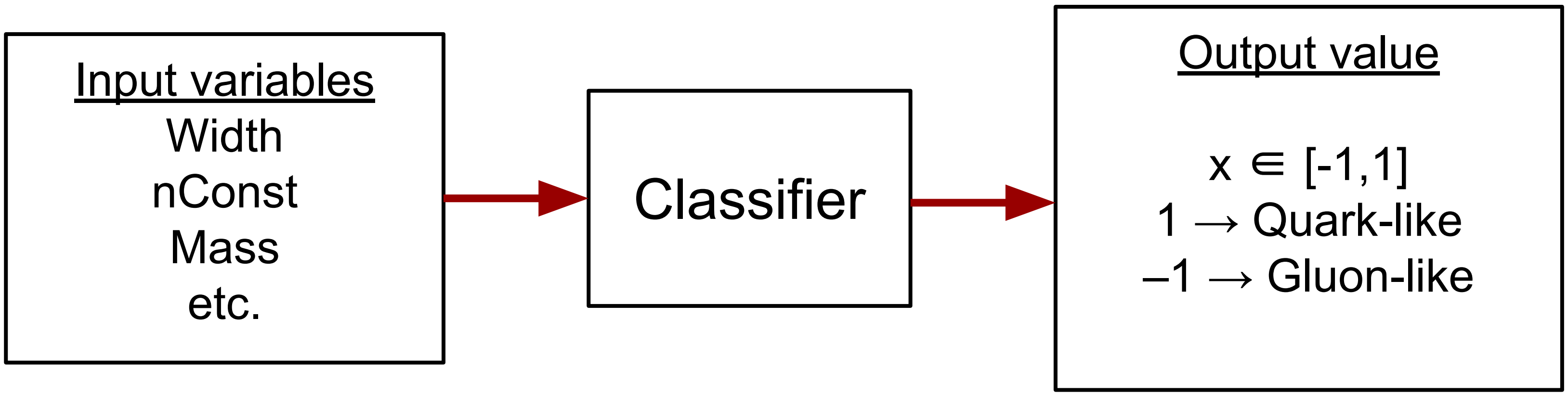


How can we distinguish quark/gluon hadron jets?

- Number of constituents.
- Width.
- ...

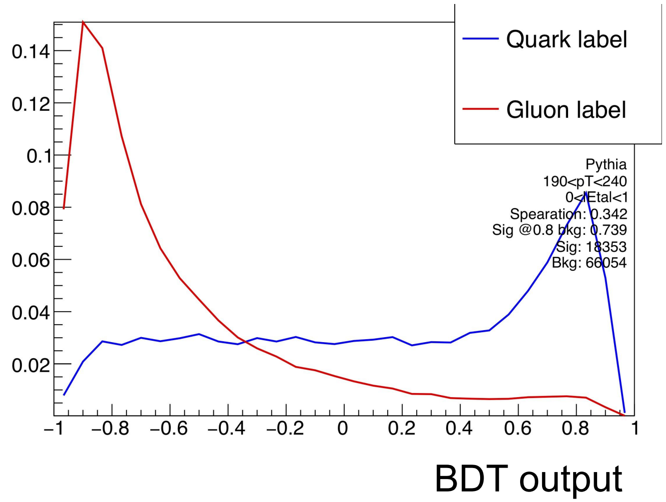
Total of 13 input variables

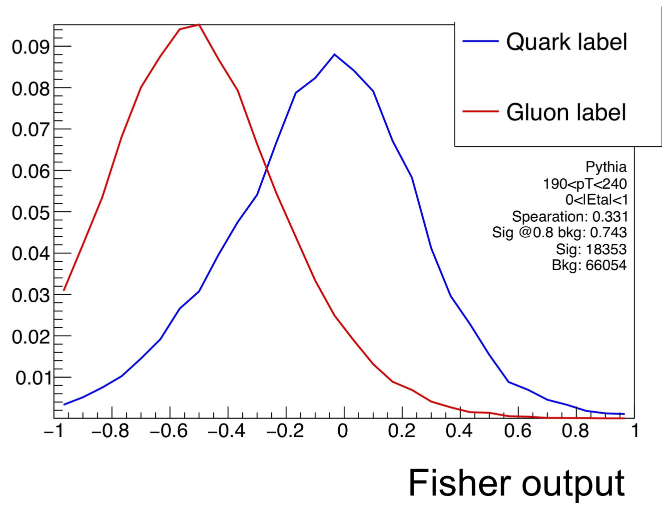
Training a classifier using TMVA



- Classifier trained to distinguish two classes of data: quark and gluon jets (as labelled using parton information).
- Gives each jet a value on [-1,1] depending if it is “quark-like” or “gluon-like”.

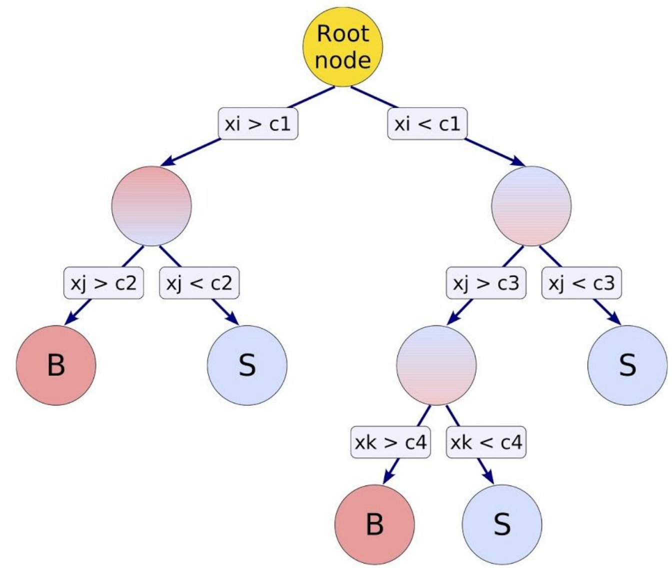
Two MVA methods used





← Gluon-like   Quark-like →

Boosted Decision Trees



Fisher

- Linear discriminant.
- Training data used to determine coefficients.

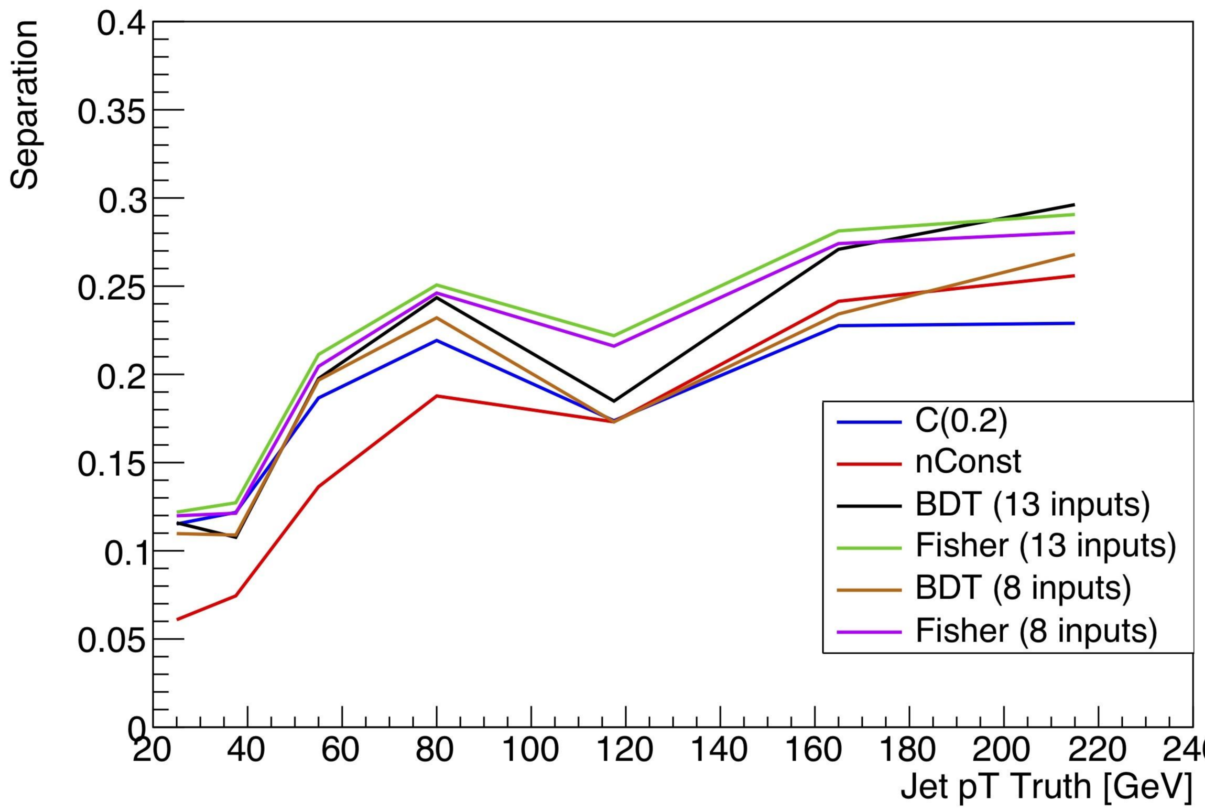
$$y_F(i) = F_0 + \sum_{k=1}^{n_{\text{var}}} F_k x_k(i)$$

How effective are the classifiers?

A good metric is the separation between quark and gluon distributions.

$$\langle S^2 \rangle = \frac{1}{2} \int \frac{(\hat{y}_S(y) - \hat{y}_B(y))^2}{\hat{y}_S(y) + \hat{y}_B(y)} dy$$

- Is 1 for two distributions with no overlap, and 0 for two identical distributions.
- Trained classifiers are stronger than the strongest input variable.
- Fisher is as good as or better than Boosted Decision Trees.



Response of “quark-like” and “gluon-like” jets

- Quark jets have a higher average response than gluon jets.
- We would hope that the more “quark-like” a jet is, as defined by our classifier, the higher the response.

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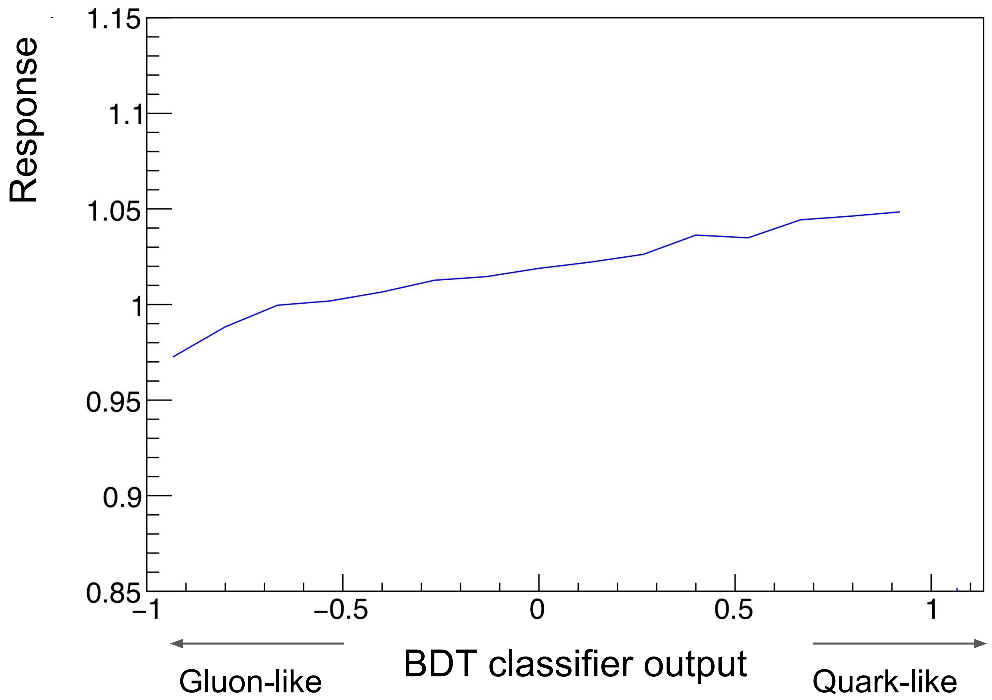
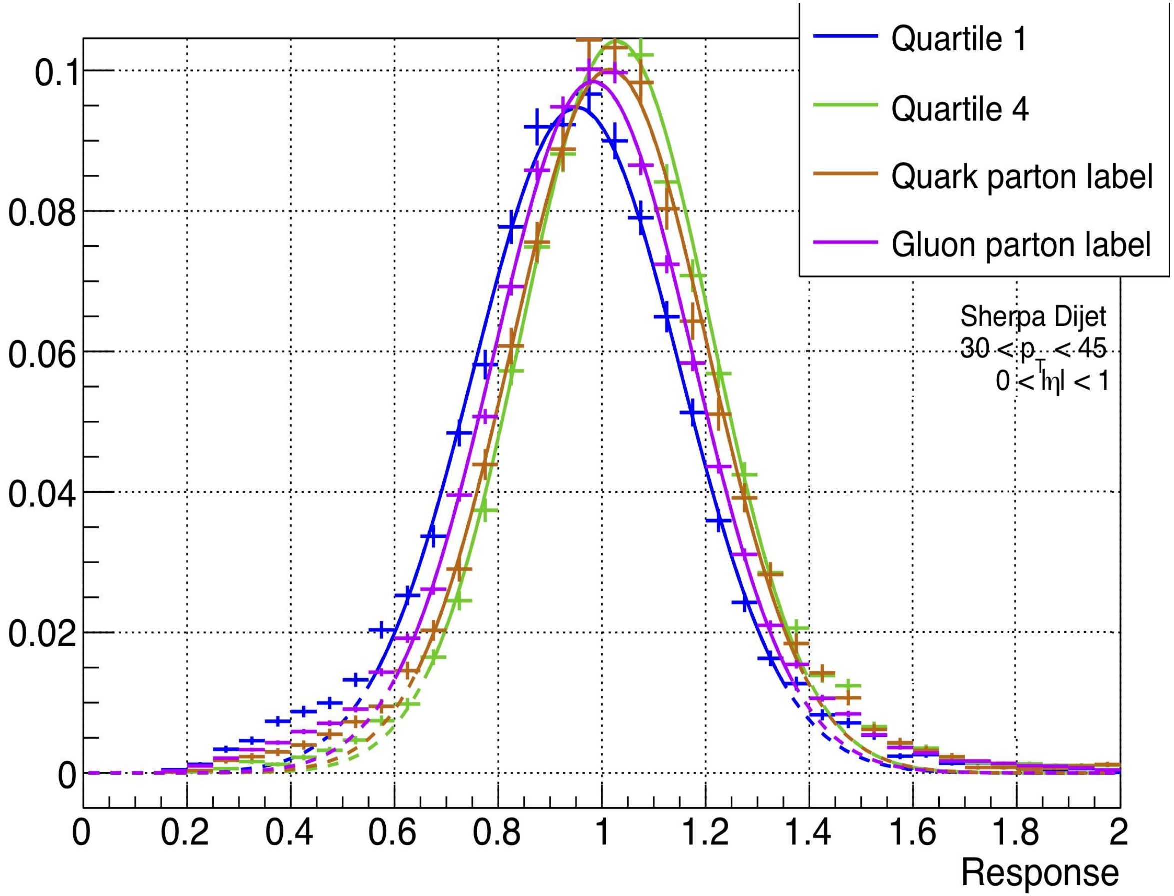


It works very well!

Response of “quark-like” and “gluon-like” jets



Gluon jets labelled using parton information.

Quark jets labelled using parton information.

25% most “gluon-like” jets using classifier.

25% most “quark-like” jets using classifier.

Classifier can describe the response difference between quark and gluon jets just as well as the parton information can!

Conclusions

- I have trained quark/gluon jet classifiers using hadron level inputs.
  - Obtain ~70% quark-jet efficiency at 80% gluon-jet rejection
- A simple Fisher discriminant is as effective as using Boosted Decision Trees.
- The “quark-iness” or “gluon-iness” of a jet is linearly related to its calorimeter response.
  - Can hence be used to parameterize JES uncertainty!

My CERN experience

- IPP/CERN summer student program.
- ~300 summer students from ~100 countries.
- 5 week lecture series.
- Experiment tours.
- Europe travel.

- Presenting to and getting feedback from other groups.
- ROOT, machine learning, data.
- Working independently on a research project.
- Time management between work and fun.

Many thanks to:

My supervisor Dag Gillberg!
Ben Nachman and the q/g tagging group
The JES/JER group

Future work

- Create a software tool to decorate jets with a hadron level quark/gluon label.
- Use this tool as part of ATLAS jet reconstruction so all jets are labelled.
- Use this label in JES uncertainty parameterization.

How can we distinguish quark/gluon hadron jets?

- Number of constituents.
- Width.
- Mass.
- Fraction of jet p_T carried by:
  - Charged hadrons
  - Photons
  - The highest-p_T hadron
- Total jet charge, weighted by $p_T^{0.5}$.
- Number of constituents carrying 90% of jet p_T.

- Effective number of constituents:

$$N_{\text{const}}^{\text{eff}} = \frac{(\sum_i p_{\mathrm{T},i})^2}{\sum_i p_{\mathrm{T},i}^2}$$

- Jet energy sharing value:

$$p_{\mathrm{T}}D = \frac{\sqrt{\sum_i p_{\mathrm{T},i}^2}}{\sum_i p_{\mathrm{T},i}}$$

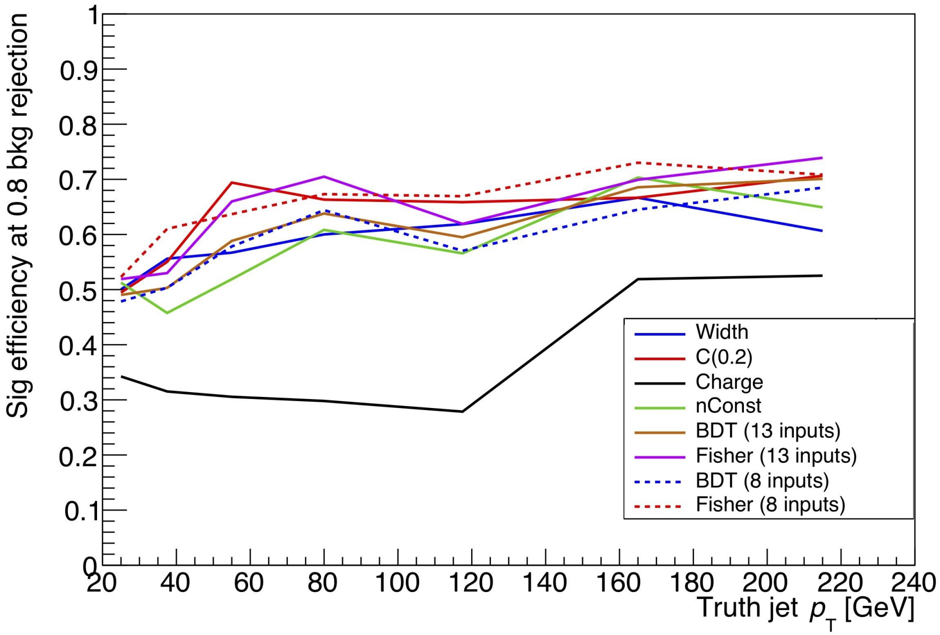
- Energy-energy-correlation angularity with β = 0.2, 1.0, 2.0.

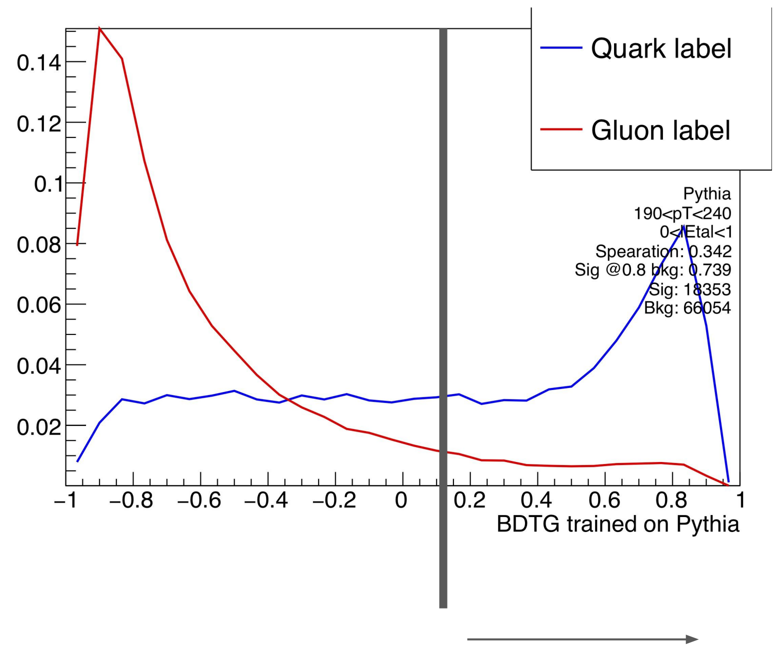
$$C(\beta) = \frac{\sum_i \sum_j p_{\mathrm{T},i} \times p_{\mathrm{T},j} \times (\Delta R(i,j))^\beta}{(\sum_i p_{\mathrm{T},i})^2}$$

How effective are the classifiers?

One metric is the quark-jet efficiency at 80% gluon-jet rejection.

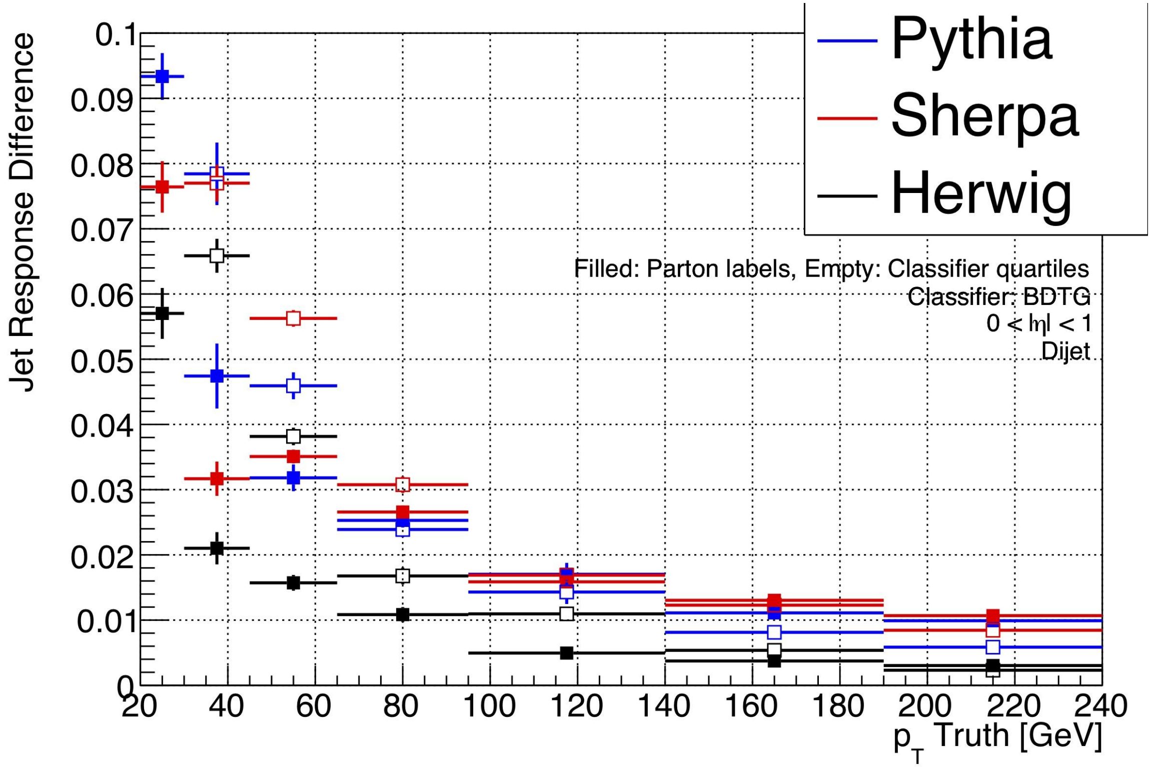
1. Make a cut so that 80% of the gluon jets are excluded.
2. What fraction of quark jets survive?

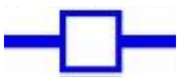




80% gluon-jets rejected
60% quark-jets remaining

Have we avoided generator dependance?





Distance between classifier peaks on previous slide

Distance between parton label peaks on previous slide

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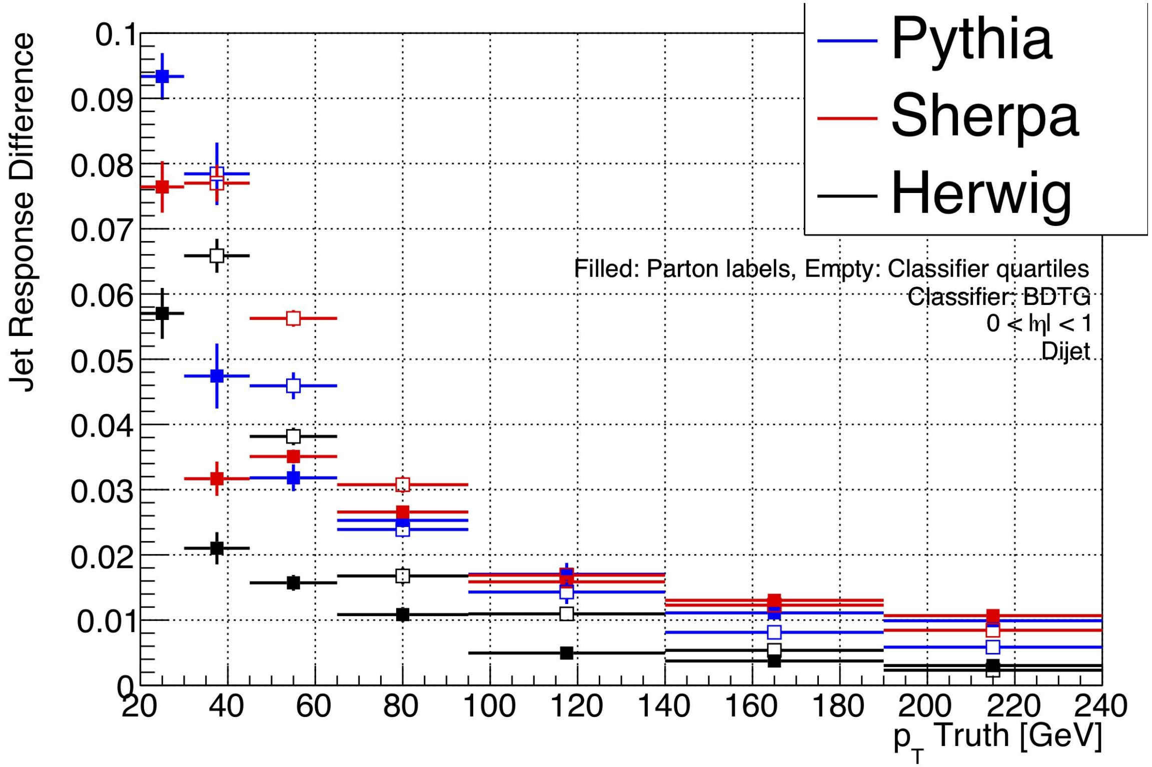

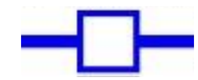

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Distance between parton label peaks on previous slide

Not yet

- Preliminary results: still a spread between empty bubbles of different colours. More work is needed.
- Generator-dependent parton information was still used for training – might need a new approach to see improvement.