Utilizing Modern Machine Learning Techniques to Understand the Origin of Mass

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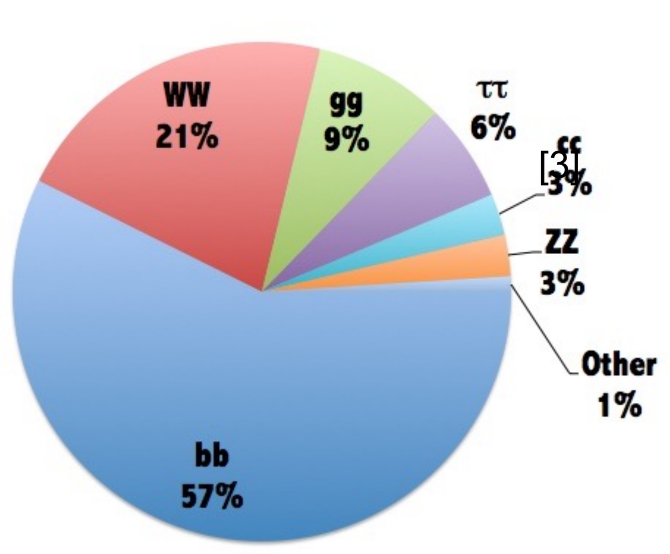
1. Understanding the Origin of Mass

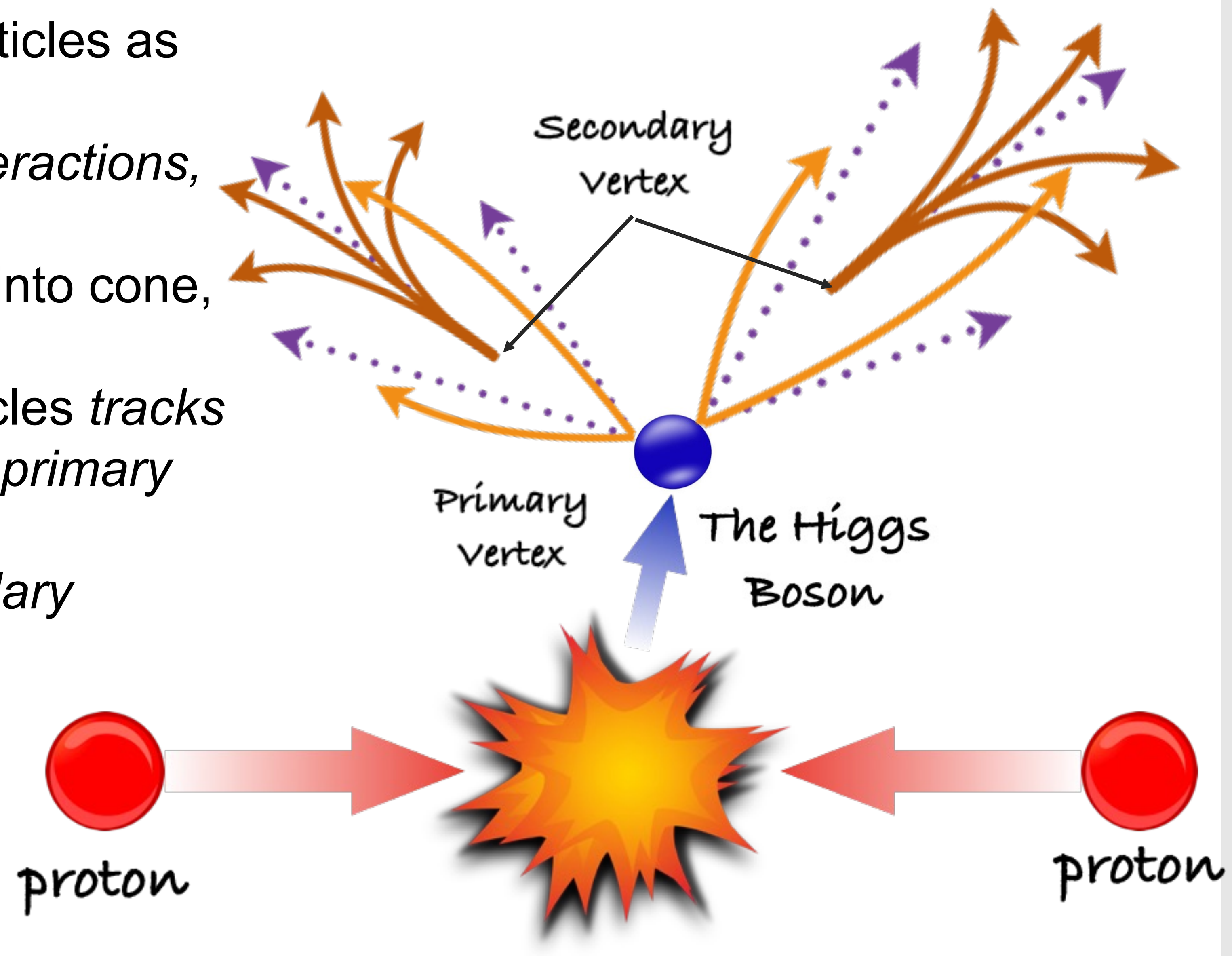
Particles get mass from the Higgs field
 The Higgs boson, was discovered at CERN by the ATLAS and CMS experiments in 2012 [1,2]
Many questions remain
 Is the Higgs linked to dark matter?
Accurate measurements required to answer such questions
Higgs, and other interesting particles, often decay to particles called *b-quarks*
 Detection of *b-quarks* is vitally important
 Must discriminate against main backgrounds, *c-quarks,* and *light-quarks*

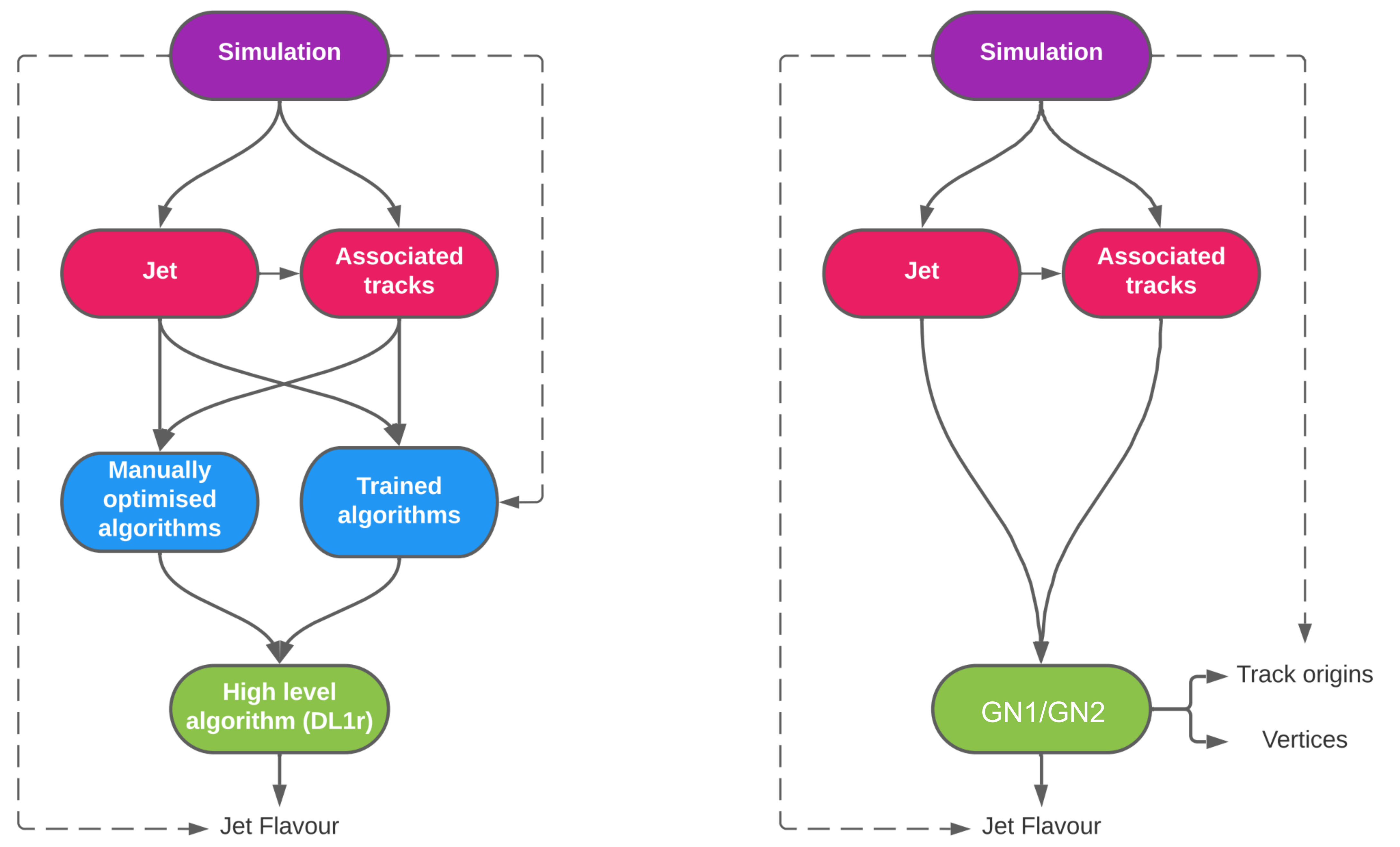
Higgs decays at m_H=125GeV



2. Anatomy of a b-jet

b-quarks produce more particles as they travel in the detector
 Hadronization, matter interactions, decays
Particles grouped together into cone, called a *jet*
Jets contain details of particles *tracks*
Particles originate from the *primary vertex*
 Further decays at *secondary* and *tertiary vertices*
b-jets have more vertices further from the primary vertex





Large volumes of particle decays are simulated at ATLAS
Allows for complex metrics associated with each jet to be utilised at *truth* level

3. Classical b-tagging at ATLAS

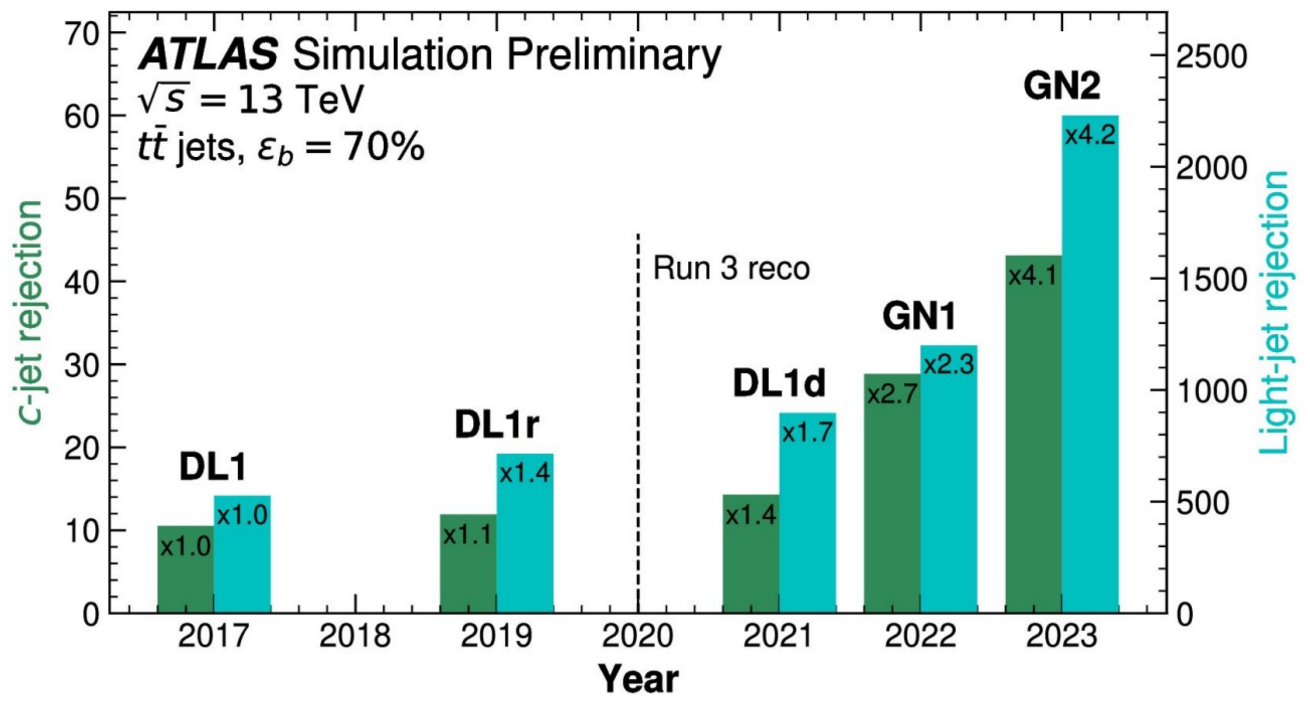
Task of tagging b-jets, *b-tagging*, has always relied heavily on statistical techniques

Really Old
 Log likelihood analysis of track features

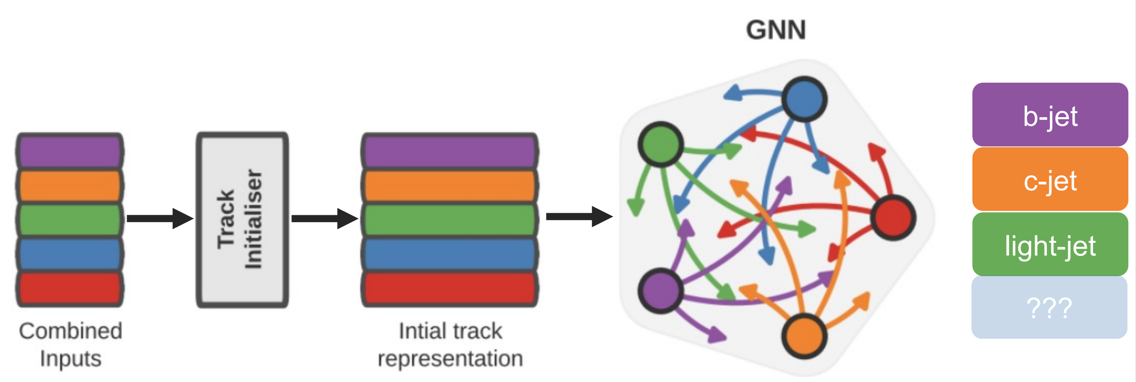
Somewhat Old
 Hand craft algorithms that find the secondary and further vertices: *high-level features*
 Likelihood ratio test on these

A Little Bit Old
 Deep learning on track and high-level features

Recent
 Treat jets as graphs, use *Graph Neural Network* to perform vertex-finding and b-tagging in unison [3] : *GN1/GN2*



4. GN2 as a Multi-Class Predictor



Output is model probability of jet origin
➔ Readily extendible to more classes
➔ Better able to discern other backgrounds
➔ Allows GN2 to be *generic* jet-tagger

Early adoption at ATLAS suggests
$4 - 15 \times$ improvement!

5. Conclusion

Study of particle physics allows us to understand the universe at its most fundamental level
Requires correctly measuring particles produced at the ATLAS detector
Recent improvements to b-tagging of up to 4 times per b-jet
 Up to **16 times** improvement for most common Higgs decay

Machine learning paving the way for advancements in physics understanding at ATLAS

References
[1] Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC – The ATLAS Collaboration (2012)
[2] Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC – The CMS Collaboration (2012)
[3] *Graph Neural Network Jet Flavour Tagging with the ATLAS Detector* – The ATLAS Collaboration (2022)

Contacts

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