Tagging Quark/Gluon Initiated Jets at ATLAS

Boston Jets 2014

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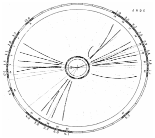
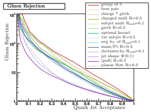
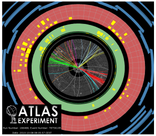
History and Motivation

- Quark-initiated and gluon initiated jets have long been known to have different properties
  - Well measured at PETRA, SLAC, LEP, others
- Two papers from Schwartz and Gallicchio in 2011, along with previous efforts in ATLAS, led to a push for creating and commissioning a quark-gluon tagger at ATLAS
  - Theory paper (here) investigated the best variables to use to train a tagger, in parallel to our own efforts
- Many potential applications in searches for new physics and standard model measurements
  - Separate hadronically decaying bosons from gluon dominated backgrounds (diboson searches, Higgs, etc.), improve discrimination in dijet searches, monojet characterization, many more







Today's Talk

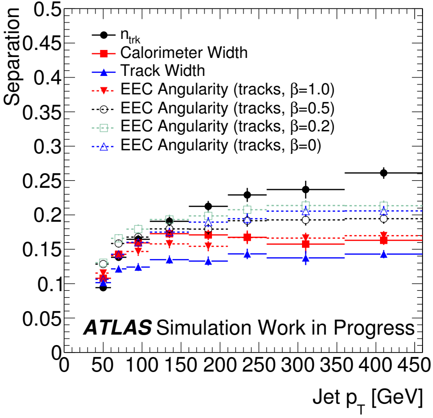
- Today, we are showing for the first time the full results of the 2011 ATLAS q/g tagger
- Results not yet publicly available: will be published in a paper (very) soon

1. Constructing of a Tagger
   - Variable Selection
   - Purified Samples
   - Defining the Likelihood
2. Tagging Performance
   - Systematic Uncertainties
   - Overview of Performance
   - Angularities

Constructing a Tagger

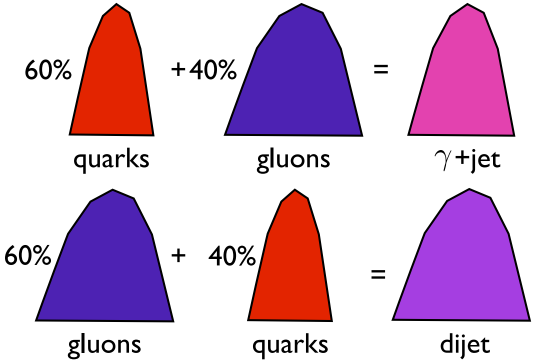
Variable Selection

- Important to choose pileup robust variables: **use only tracking**
- Need strong performance across wide range of p_T: n_{trk} has best performance at highest, track width better at low
- EEC variables have good separation as well– but have systematic issues we will describe later
- We use a **likelihood** combining n_{trk} and track width



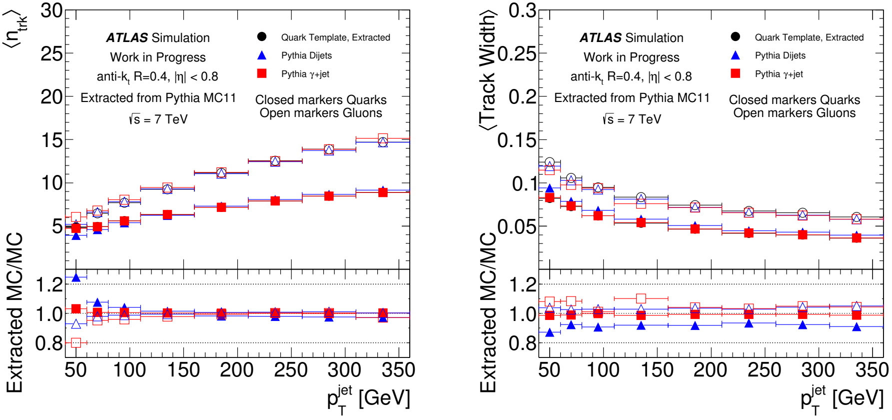
Template Methods

- Significant data/MC disagreement for the input variables required the use of a data-driven template technique



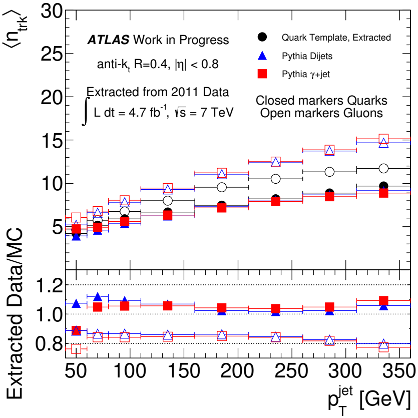
- Take percentages from MC, measure γ+jet and dijet in data: solve for quark and gluon distributions in data
- More information on method in backup

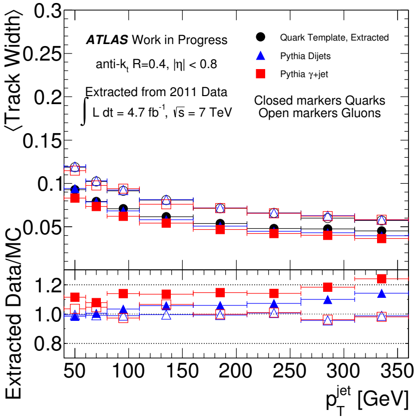
Testing Method in MC



- MC-labeled distributions in γ+jet and dijets agree very well with templates derived in MC
  - Disagreeement at low p_T will be discussed at length soon
- Gives us confidence that the algorithm is doing something sensible

Templates with Data



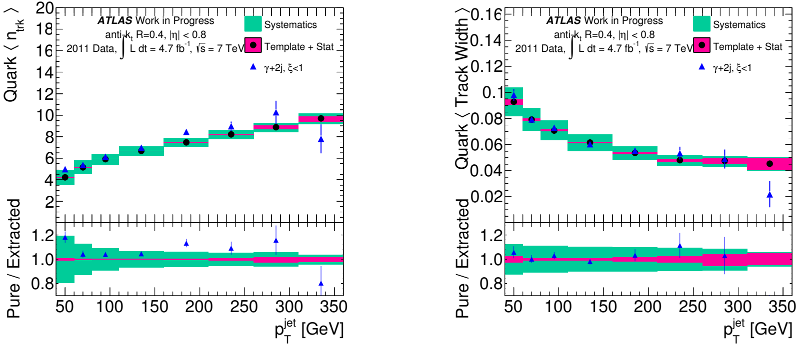


- But data disagrees with Pythia in n_{trk}, leading to worse separation than expected
- Track Width has better agreement, though not good at high p_T

Purified Samples

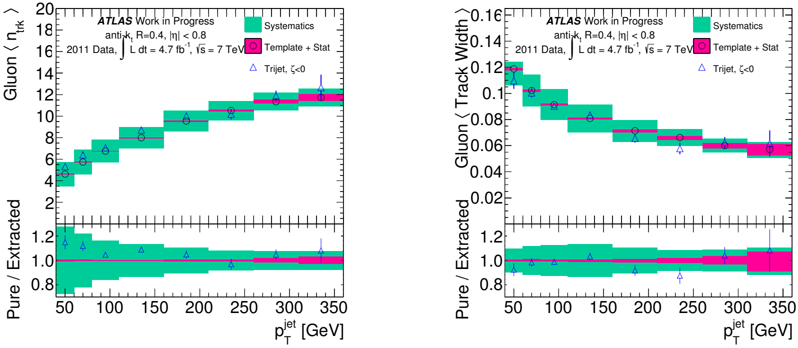
- Are the data templates correct? How can we test these derived shapes?
- Define **topological/kinematic regions** where jets are more likely to be quark-initiated or gluon-initiated
  - Trijet sample, with $\zeta = |\eta_3| - |\eta_1| - |\eta_2| < 0$ is gluon-like
  - γ+2jet sample, with $\xi = \eta_{jet1} \times \eta_\gamma + \Delta R(jet2, \gamma) < 1$ is quark-like
  - See arXiv:1104.1175 for more details
- These regions have purity of $\sim 90\%$– good regions for **validation of templates**!
  - Not enough statistics to derive 2D templates, but enough to be useful for validation

Pure Shapes: Quarks



- Shapes from topologically purified samples **generally agree** with extracted templates to 1 σ

Pure Shapes: Gluons

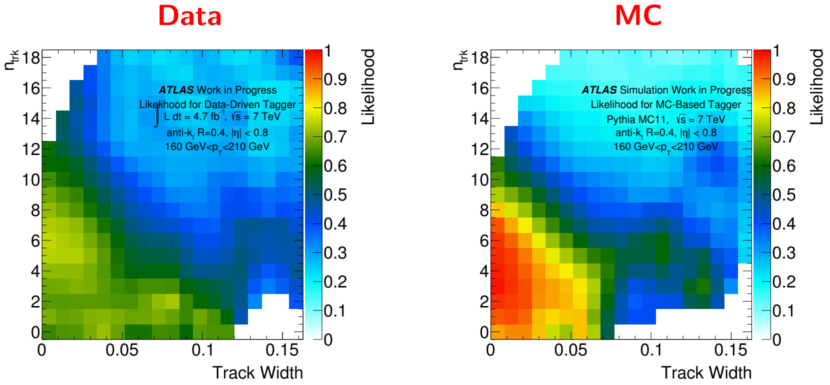


- **Similar levels of agreement** with gluon shapes
- **Completely independent** data samples verify our template shapes

Likelihood

SLAC

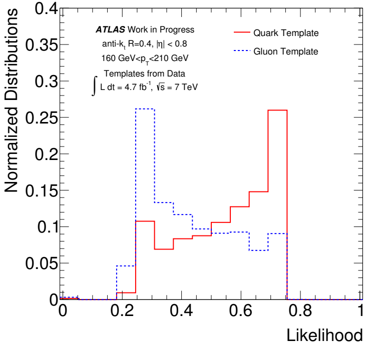
- Define $L = q/(q+g)$ separately in data and MC



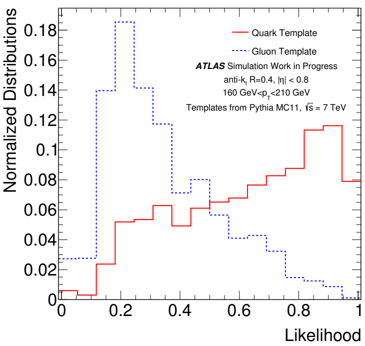
- Immediately can see that while **shapes are similar**, performance is **much worse** in data

Likelihood Output

Data



MC



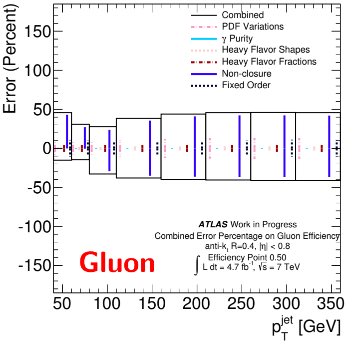
- **Significantly reduced** performance in data
  - But enough to still make something useful!
- We will define a tagger at **4 operating points**: 0.3, 0.5, 0.7, and 0.9 quark efficiency

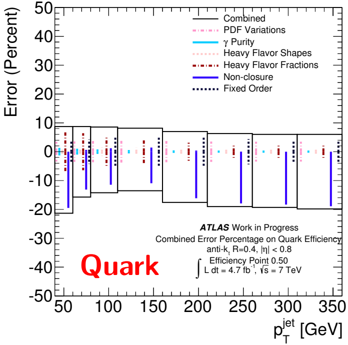
Tagging Performance

Systematic Uncertainties

- Many different sources of error considered for the tagger:
  1. PDF variations– affect q/g fractions
  2. γ purity– affects data input
  3. Heavy flavor shapes/fraction– affects MC inputs
  4. Madgraph/Pythia fraction differences– affect q/g fractions
  5. Non-closure/ sample dependence– affects data inputs

Systematics Summary





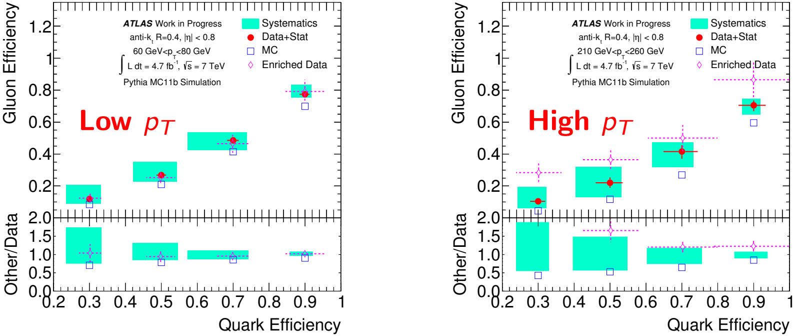
- Here, show **breakdown of systematics** for 50% quark-like o.p.
- **Sample dependence** is by far the largest effect
  - Quarks/gluons from γ+jet do not look exactly like quarks/gluons from dijets (in both Pythia and Herwig)
  - Need to understand this effect to apply this tagger to other topologies
- More operating points, and details on non-closure, in ▸ backup

Overview of Performance

SLAC

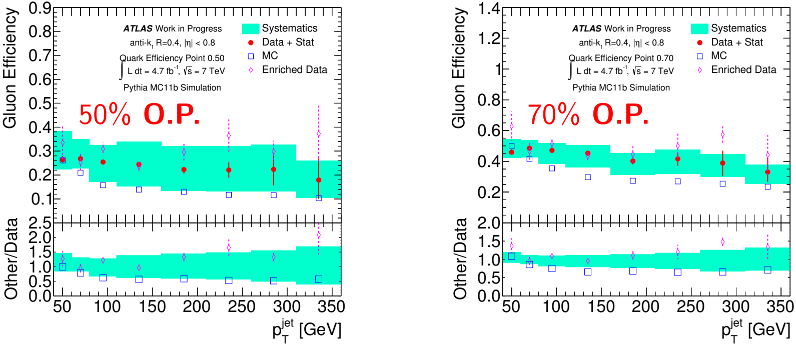
- For measuring performance, we will show several different tests together:
  - Red points indicate performance of data tagger, tested on data templates
    - Red lines on those points indicate statistical uncertainties
  - Teal band indicates systematic uncertainties
  - Blue points indicate performance of pythia tagger, tested on pythia templates
  - Magenta points indicate performance of data tagger, tested on **pure data samples**

Gluon Efficiency vs. Quark Efficiency



- Purified samples show slightly worse gluon efficiency than data, but **agreement within 1σ**
- Data shows worse performance than MC– **generally greater than 1σ disagreement**

Performance vs. Jet p_T



- Left shows 50% quark point, right shows 70%
- Results are consistent across p_T: purified samples measurement **generally agree** with data, but **MC significantly overestimates performance**
- Other operating points in backup

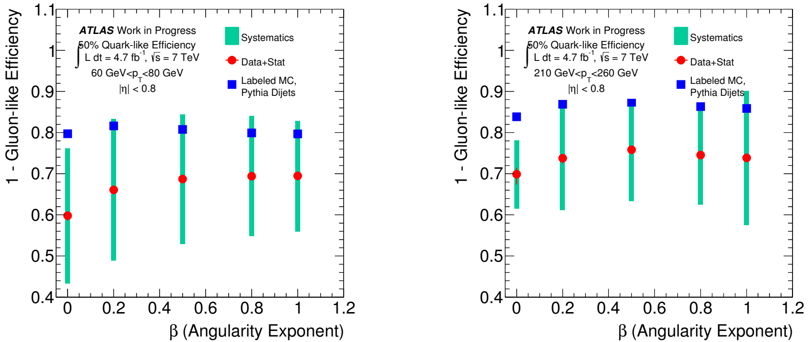
Angularities

- New class of variables, called "Energy Correlation Angularities," described in arXiv:1305.0007
- Interestingly: possible to show that these variables contain **maximum** discriminatory power between q/g
- Defined with free parameter β:

$$Ang = \frac{\sum_i \sum_j p_{T,i} p_{T,j} (\Delta R(i,j))^\beta}{(\sum p_{T,i})^2} \quad (1)$$

- How does gluon efficiency change with β, and how large are the systematics?

Angularity Performance



- **NB**: 1 - Gluon Efficiency shown
- **Significant differences** between data and MC performance, and **systematics are larger** than for the likelihood
  - Sample dependence is **very large** for angularities, at least with $\beta < 1$
- $\beta = 0.2$ is slightly optimal in MC, but difficult to tell trend in data

Conclusions

Summary

- Much effort has gone into studying the properties of quark and gluon initiated jets (see existing conf note, ATLAS-CONF-2012-138)
- Since then, work has focused on deriving a tagger, calibrating it to data, and determining the systematics
- Data/MC disagreements make tagger derivation difficult– use **templates from data**
- Systematics need to be carefully assessed– **large sample dependencies observed**
  - Angularities in particular seem sensitive to these effects
- Final paper, with all these results and more, should be out soon!

Thank You For Your Attention!

Backup

Defining Quark/Gluon Initiated Jets

- Need to use a consistent definition across generators for defining a quark/gluon iniiated jet
- We use: “a jet is defined by the flavor of the highest energy parton inside the jet”
    - This labelling is studied in Madgraph to determine how often it matches the Matrix Element: $95 - 99\%$ of the time

Extracting Templates

SLAC

- Goal: to better understand quark/gluon shapes in data, extrapolate **data** to 100% purity with fractions from MC
- Ideally, solve for q/g on bin-per-bin basis from:

$$h^{\gamma+j} = P_Q^{\gamma+j} q + P_G^{\gamma+j} g$$
$$h^{dijet} = P_Q^{dijet} q + P_G^{dijet} g$$

P_Q = percentage quark
h = histogram value
q/g = templates
$(\gamma + jet)/(dijet)$ = different sample

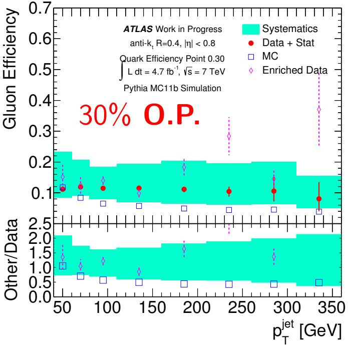
- But, need to account for b and c fractions (for now, taken from MC):

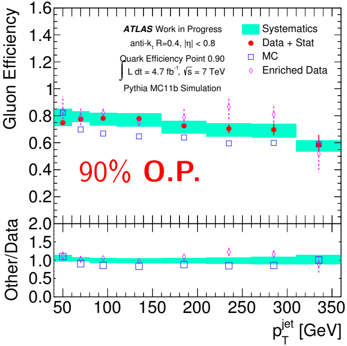
$$h^{\gamma+jet} = P_Q^{\gamma+jet} q + P_G^{\gamma+jet} g + P_B^{\gamma+jet} b + P_C^{\gamma+jet} c$$
$$h^{dijet} = P_Q^{dijet} q + P_G^{dijet} g + P_B^{dijet} b + P_C^{dijet} c$$

From Data
From MC
Solving for This

- Then, compare pure data shapes to pure MC shapes (used for training tagger)

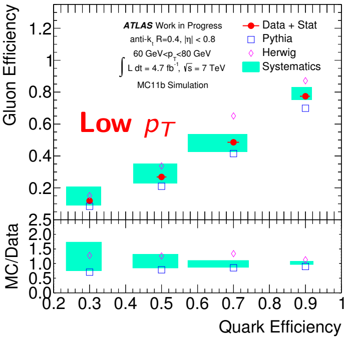
Performance vs. Jet p_T

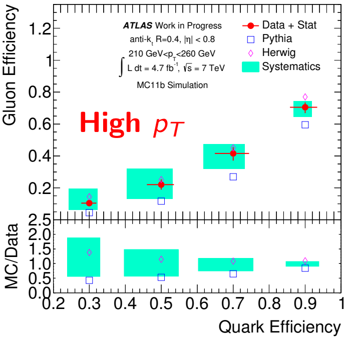




- Results are consistent across p_T: purified samples measurement **generally agree** with data, but **MC significantly overestimates performance**

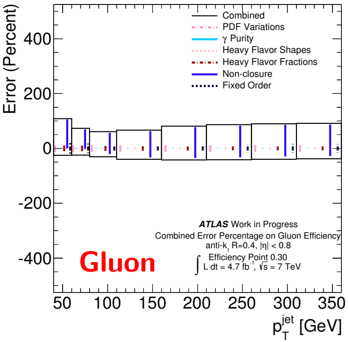
Gluon Efficiency vs. Quark Efficiency, with Herwig++

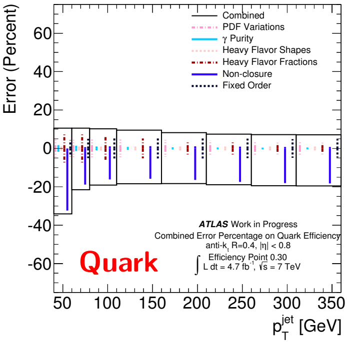




- Herwig++ generally agrees with data better: sometimes even under-predicts performance

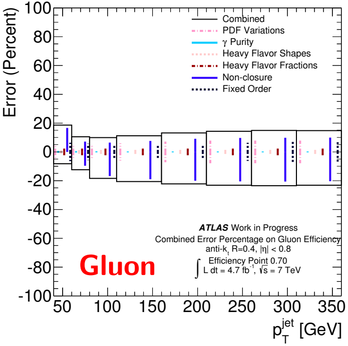
Systematics Summary: 30% Operating Point

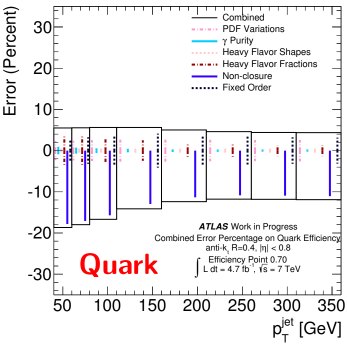




- Similar effects as at other operating points: largest here at low efficiency

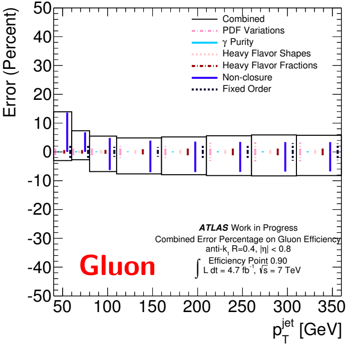
Systematics Summary: 70% Operating Point

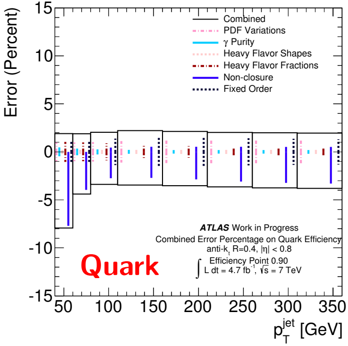




- Similar effects as at other operating points

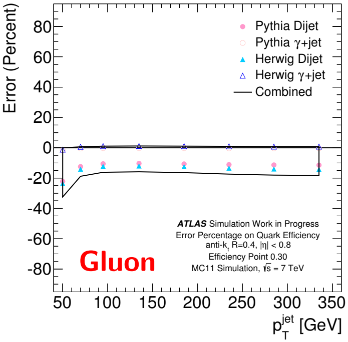
Systematics Summary: 90% Operating Point

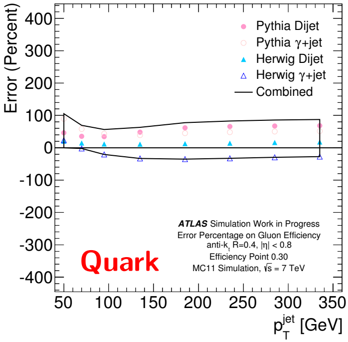




- Similar effects as at other operating points

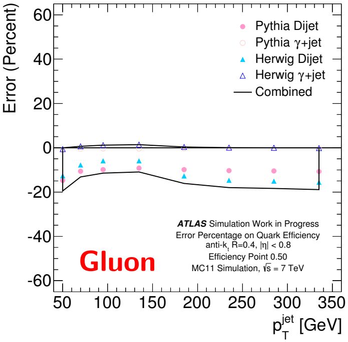
Nonclosure: 30% Operating Point

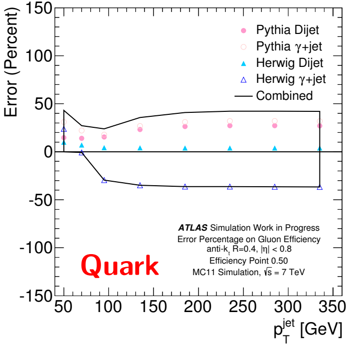




- Breakdown of Pythia/Herwig++ disagreements with their respective templates

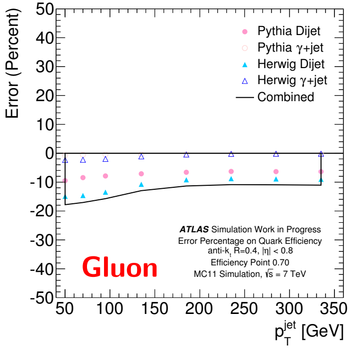
Nonclosure: 50% Operating Point





- Breakdown of Pythia/Herwig++ disagreements with their respective templates

Nonclosure: 70% Operating Point



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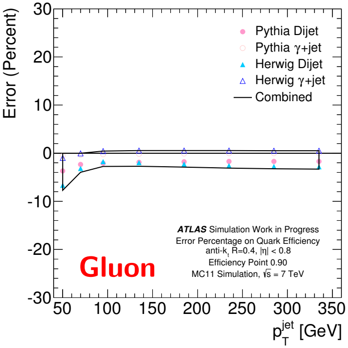
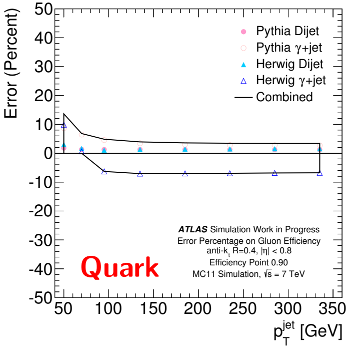
Nonclosure: 90% Operating Point





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