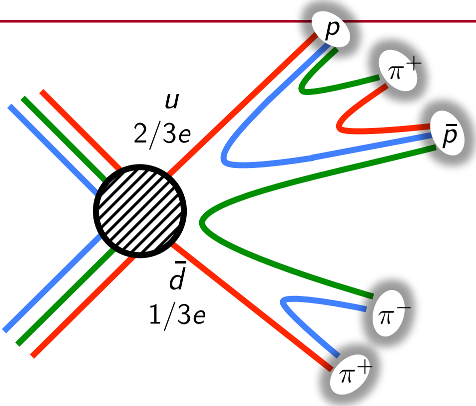
New SUSY and Jet Analyses at ATLAS

Maximilian Swiatlowski



Challenges and Opportunities in Run I

- SLAC has been involved in many SUSY and jet analyses in Run I
- Just a selection of the most recent, and ongoing, results today:
  1. Quark/gluon discrimination
  2. Measuring, and using, jet charge
  3. Measuring color flow in $t\bar{t}$
  4. Search for direct stop production in the 1-lepton channel
  5. Search for gluino production with hadronic RPV decays

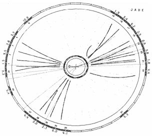
Quark/Gluon Discrimination

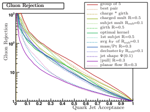
hep-ex:1405.6583

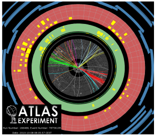
M. Swiatlowski, A. Schwartzman

History and Motivation

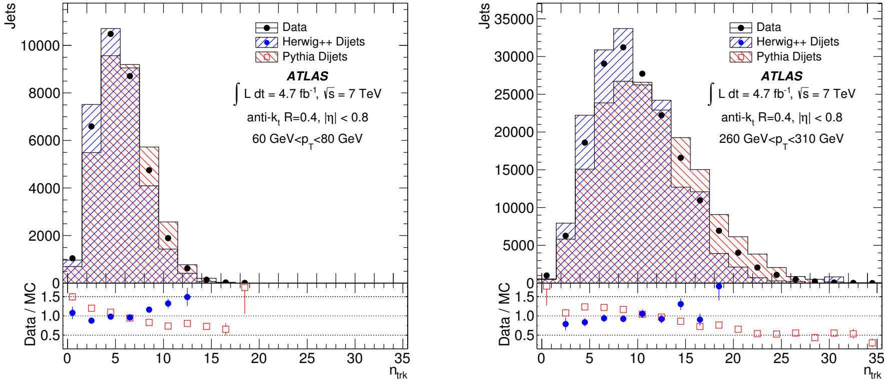
- Quark-initiated and gluon initiated jets have long been known to have different properties
    - Well measured at PETRA, SLAC, LEP, others
- Fantastic theoretical playground: many different variables and approaches are possible
    - ATLAS uses some of the simplest variables– n_{trk} and track width
- Many potential applications in searches for new physics and standard model measurements
    - Separate (resolved) hadronically decaying bosons from gluon dominated backgrounds (diboson searches, Higgs, etc.), improve discrimination in dijet searches, monojet characterization, many more





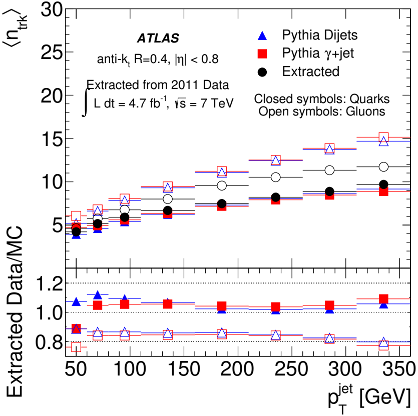


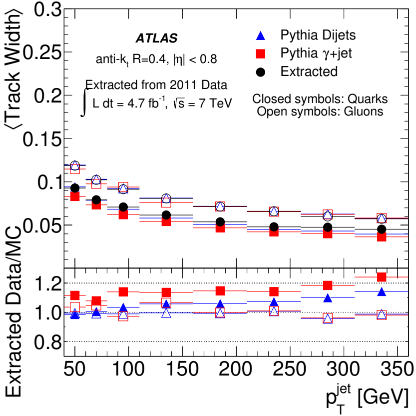
Data/MC (Dis)Agreement



- **Significant disagreement between data and MC!**
- Pythia performs very poorly, but Herwig++ is slightly better

Data Driven Templates



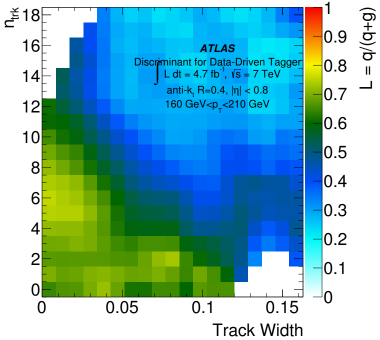


- Need **data-driven technique** to extract quark and gluon shapes
- Significant disagreement in n_{trk} observed
- Track Width has better agreement, though not good at high p_T

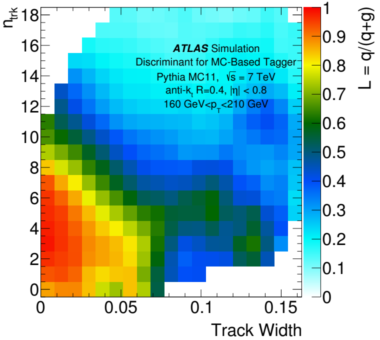
Likelihood

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

Data

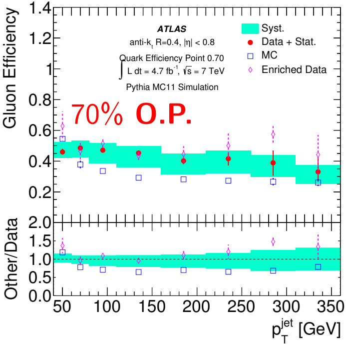


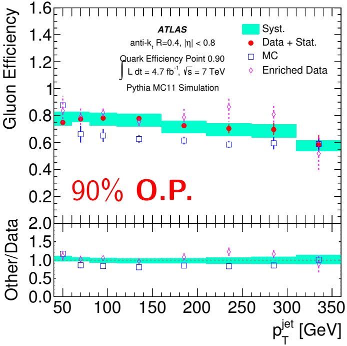
MC



- **Shapes are similar**, but performance is **much worse** in data
    - Still enough to be useful: tagger defined at several operating points

Performance vs. Jet p_T





- Results are consistent across p_T: purified samples measurement **generally agree** with data, but **MC significantly overestimates performance**
- Unexpected result: unfolded measurements will be critical for tuning

Jet Charge

ATLAS-CONF-2013-086

B. Nachman, A. Schwartzman

Definition of Jet Charge

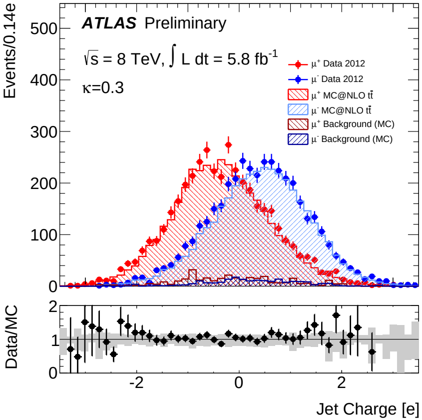
- For a jet j with transverse momentum $(p_T)_j$, let Tr be the set of *ghost associated* tracks.
- Each track in Tr has momentum p_T^i and charge (determined from the curvature) q_i.

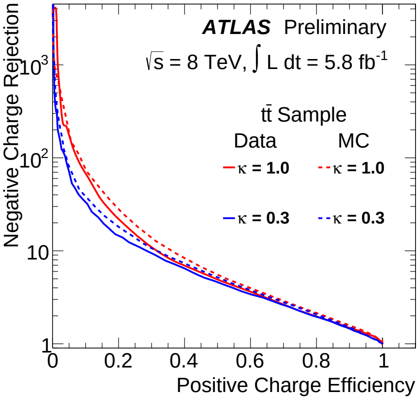
For a weighting factor $\kappa \in \mathbb{R}$, define the jet charge of j:

$$Q_j = \frac{1}{(p_{Tj})^\kappa} \sum_{i \in \mathrm{Tr}} q_i \times (p_T^i)^\kappa, \qquad (1)$$

- This is not the only way charge has been defined in the past - there are variants of the denominator & the track momentum.

Jet Charge Tag and Probe in $t\bar{t}$

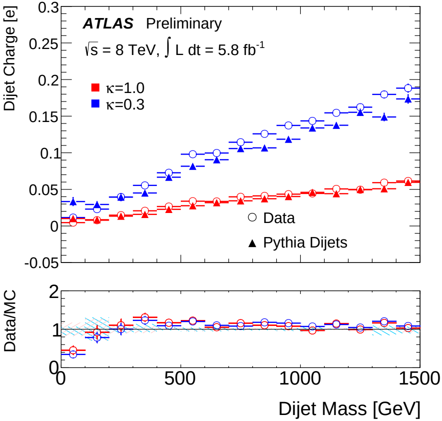




- Test the charge tagging capabilities of jet charge in semi-leptonic $t\bar{t}$
  - Charge of the lepton determines the charge of the the $W \to qq'$
- Ongoing work to use jet charge for tagging the properties of $V \to qq'$

Jet Charge vs Energy Scale

- The average jet charge increases because the valence up quark dominates the PDF at high momentum fraction
- Potential differences between data and MC are under investigation as we unfold the distribution
- One can further remove the impact of PDFs and extract the energy dependance of the average jet charge per flavour.
  - Compare to NLO calculations of this scale violation



Color Flow and Jet Pull

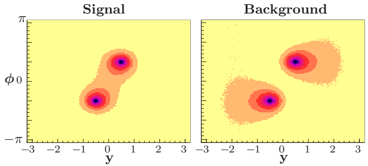
ATLAS-CONF-2014-048

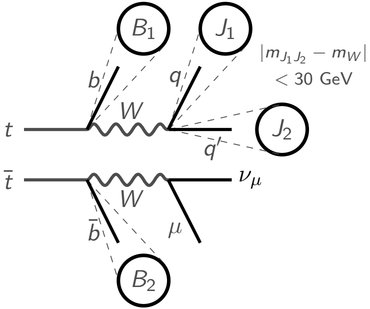
B. Nachman, M. Swiatlowski, A. Schwartzman

Overview

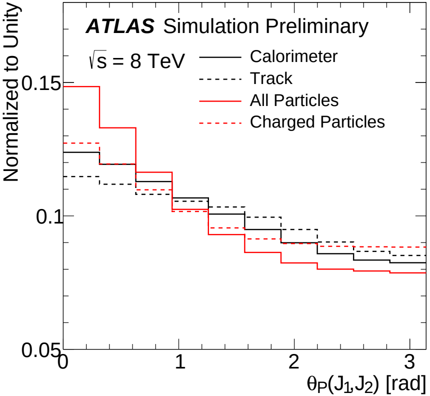
- Jet pull is sensitive to the **superstructure** of the event: the color connection *between jets*
  - Combines substructure information of one jet, with the full topology of the event
- Can we measure the orientation of the energy in one jet relative to another?
  - D0 had a measurement in 2011, but ATLAS (and CMS) have many more events, and potentially more sensitive detectors
- Not just an interesting measurement of the Standard Model:
  - Can be used for searches ($H \to b\bar{b}$)
  - Can measure color charge of any new hadronic measurement

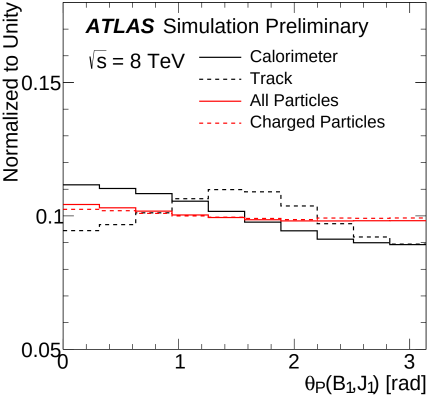
1001.5027





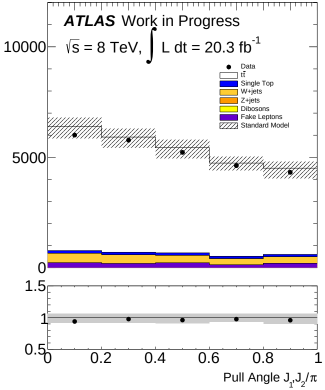
W-jets vs. b-jets

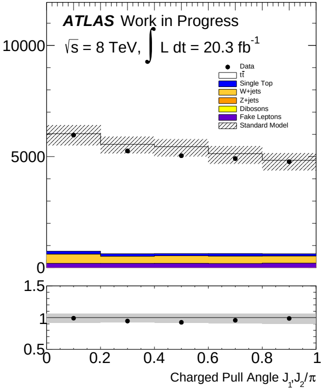




- Large difference between the two topologies, and **very large** shift from truth to reconstructed
- **A large caveat**: kinematics and topology are very important

Data/MC Agreement

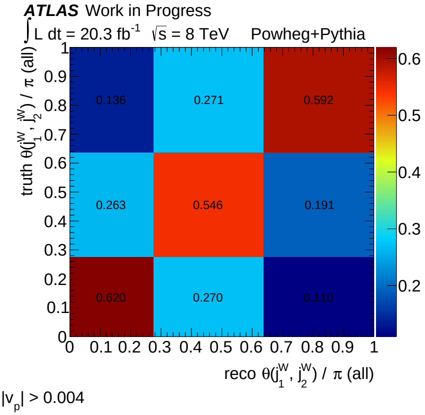




- Very good data/MC agreement observed in both calorimeter and track measurement
  - Powheg+Pythia (shown here) and MC@NLO+Jimmy both model the color flow very well

Unfolding

- Working now on **unfolding** the pull distribution
  - Example unfolding matrix shown here: substantial off-diagonal terms mean that understanding **pull resolution** is critical for the measurement
- Will compare nominal color flow to "flipped" scenario (where W acts as an octet)
  - Aim to **conclusively** demonstrate that data is consistent with SM color flow

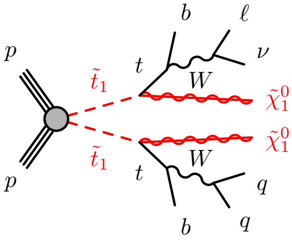


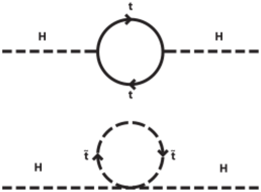
Direct Stop in the 1-lepton Channel

hep-ex:1407.0583

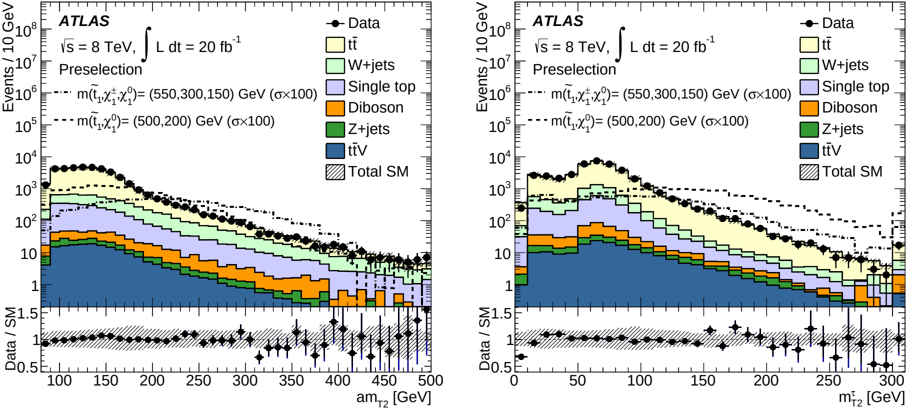
T. Eifert, P. Grenier, B. Nachman, Q. Zeng

- Motivation for stops is very clear: scalar top partners **regulate the leading contribution** to the quantum corrections to the Higgs mass
- 1-lepton channel provides **best balance** between clean signal and branching fraction
- Clever variable choices and experimental optimization are key to sensitivity
- See also the very complete recent seminar from Ben!





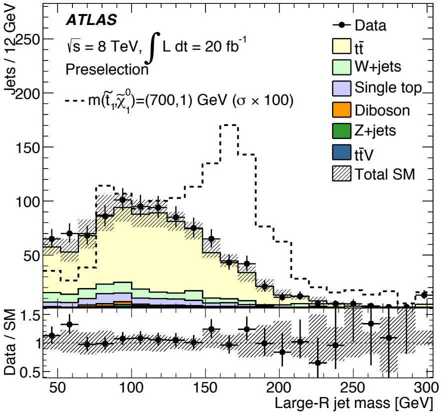
Variable Development



- Main background is dileptonic top with a missed lepton
- Several different versions of m_{T2} variable are constructed to target these backgrounds: lost leptons and hadronic τ decays

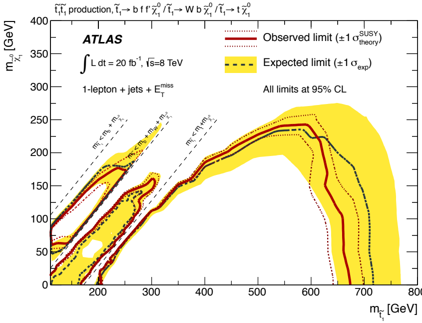
Boosted Top Identification

- High mass stops– $m_{\tilde{t}} \gtrsim 700$ GeV– start to merge and form 'top jets'
  - Can reconstruct this using anti-k_t R=1.0 trimmed jets
- Most backgrounds are di-leptonic top: should not contain any hadronic tops
- Significant discrimination is possible for high mass stops!



Limits

- Dozens of interpretations are available– showing only one here!
- Significant regions of phase space have been ruled out
    - m_{T2} and **top tagging** help at high $m_{\tilde{t}}$
    - E_T^{miss} triggers and **shape fit** help at low $m_{\tilde{t}}$
- A very complete result, but room for stops remain
    - Compressed scenarios along the diagonal are not completely excluded
    - "Natural" SUSY may have heavier stops



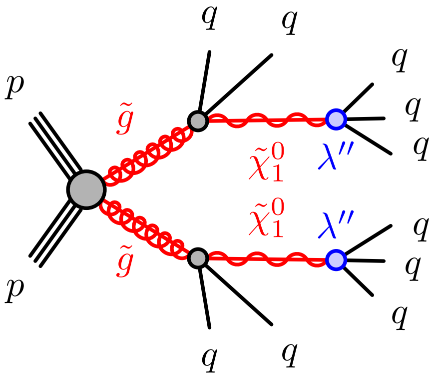
All-Hadronic RPV Gluino

Work in Progress

M. Swiatlowski, A. Schwartzman

High Multiplicity RPV Signatures

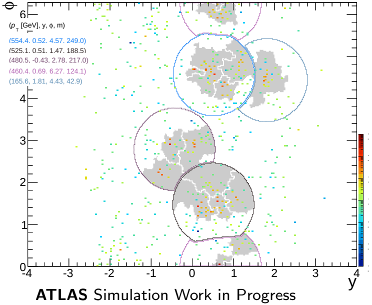
- We are considering $\tilde{g}$ pair production, decaying with $\tilde{g} \rightarrow \tilde{q}q$, $\tilde{q} \rightarrow \tilde{\chi}_0 q$, $\tilde{\chi}_0 \rightarrow 3q$



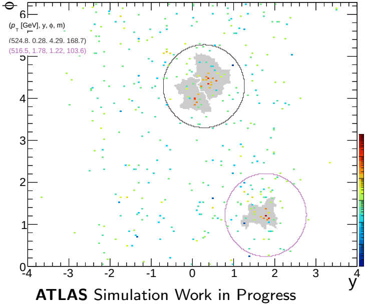
- A natural, UDD RPV model: final state characterized by many partons
  - Between **10** (light quarks) and **22** (tops) partons in final state
  - In the all-hadronic channel, no E_T^{miss}: need other discrimination handles
  - **Extremely difficult background estimation:** high-mass extremes of QCD are difficult to model
- In the absence of light gluinos, can RPV be hiding SUSY?

Analysis Strategy: Accidental Substructure

Cohen, Izaguirre, Lisanti, Lou arXiv:1212.1456



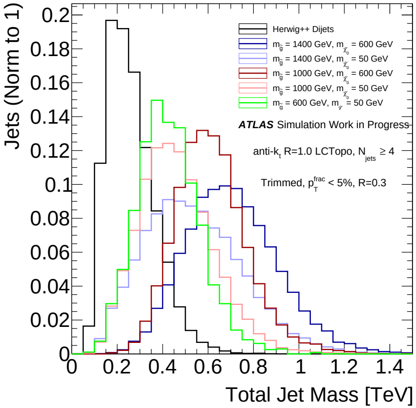
Signal: = 1 TeV, = 100 GeV



Background: Herwig++ dijet

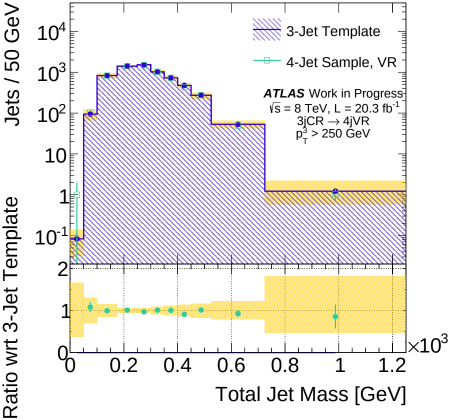
- Even without boost, **high multiplicity** events can still display substructure inside of large-R jets
  - $\rightarrow$ Large-R jets from signal will have **mass**, even though we do not reconstruct $\tilde{g}$ or $\tilde{\chi}_0$
- Use total jet mass (M_J^{Σ}) and $\Delta\eta$ between leading jets

- Broad range of signal points is **very sensitive** to M_J^{Σ} variable
  - Shows significantly better discrimination than H_T or others
- Herwig++ used here as a stand-in: actual backgrounds need to be estimated **from data**



Background Estimation

- Use **jet substructure templates** to estimate backgrounds
  - Wacker et al., 1402.0516
- Measure **jet mass** in low-multiplicity QCD control region
- Extrapolate to **several control and validation regions** with high multiplicity
- **Very good agreement seen!**
- Expect to set limits at $m_{\tilde{g}} \gtrsim 1000$ GeV



Conclusions

Summary

- SLAC has a broad involvement in SUSY searches and Standard Model measurements which use state-of-the-art jet substructure techniques:
  1. Published the **first quark/gluon tagger** at a hadron collider
  2. Performing the **first unfolded measurement** of jet charge
  3. Measuring Standard Model **color flow with jet pull**
  4. Set **strong limits on stop production** with m_{T2} and boosted jets
  5. Analyzing **all-hadronic, no MET, SUSY signals** and setting new, strong limits
- Many places to go with this experience at 13 TeV: where to?

Thank You For Your Attention!

Backup

Defining Quark/Gluon Initiated Jets

- Need to use a consistent definition across generators for defining a quark/gluon initiated 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

- 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:

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

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

- 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

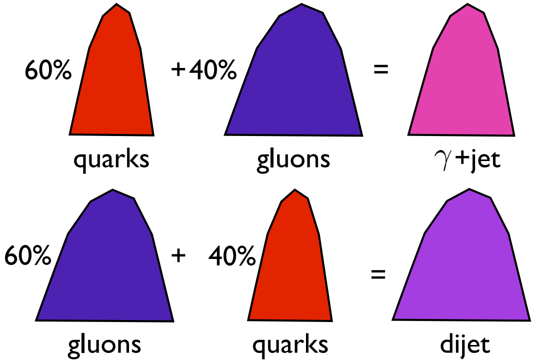
From MC

Solving for This

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

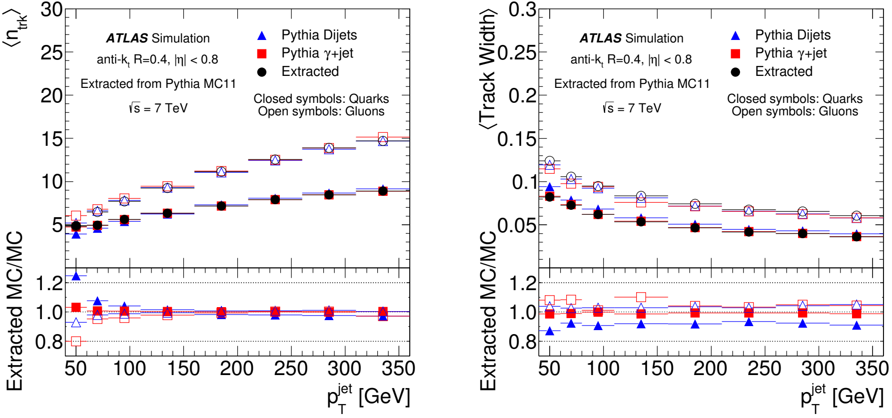
Template Methods

- 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

Templates with MC

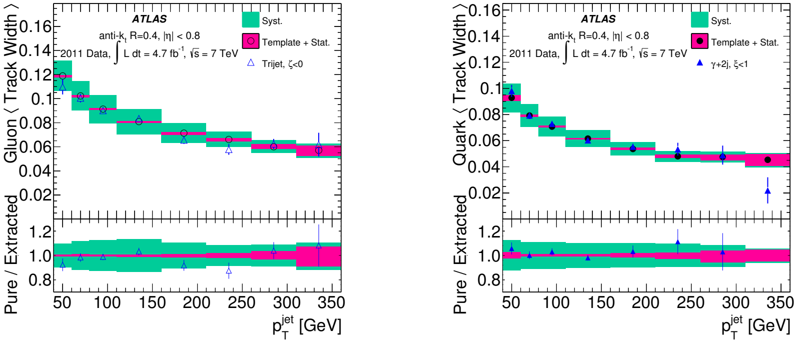


- Extraction technique shows very good closure in MC!
- Differences will later be taken as a systematic

Purified Samples

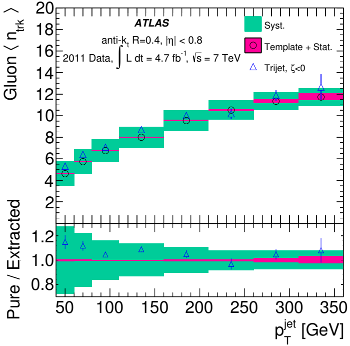
- Are the data templates correct? How can we test these derived shapes?
- Define **topological/kinematic regions** where jets are more likely to be quark-initiated or gluon-initiated
  - Trijet sample, with $\zeta = |\eta_3| - |\eta_1| - |\eta_2| < 0$ is gluon-like
  - γ+2jet sample, with $\xi = \eta_{jet1} \times \eta_\gamma + \Delta R(jet2, \gamma) < 1$ 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

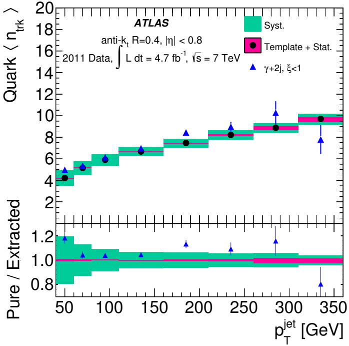
Pure Shapes: Track Width



- Shapes from topologically purified samples **generally agree** with extracted templates to 1 σ
- **Independent sample** confirms difference between data and MC

Pure Shapes: n_{trk}





- Shapes from topologically purified samples **generally agree** with extracted templates to 1 σ
  - Shapes also agree for Track Width
- **Independent sample** confirms difference between data and MC