Desiderata for the WG on top BSM matters

James Ferrando, *Glasgow (ATLAS)*
Justin Pilot, *UC Davis (CMS)*
on behalf of ATLAS and CMS

TOPLHC Working Group Meeting
23 May 2014

Introduction

- Aim to summarise answers to three main questions:
  - What would you like to learn with more precision about top dynamics, in order to improve searches and search tools?
  - What bread-and-butter top measurements can be used to address the points above?
  - What searches activities do you think could in the long run benefit from having a combination activity where feedback/involvement of the TOPLHCWG would be important?
- Answers given primarily with a top/exotics focus but some SUSY/Higgs related topics also addressed

Top Dynamics and Jet Substructure

Top Dynamics

- Direct searches probe a variety of top final states:

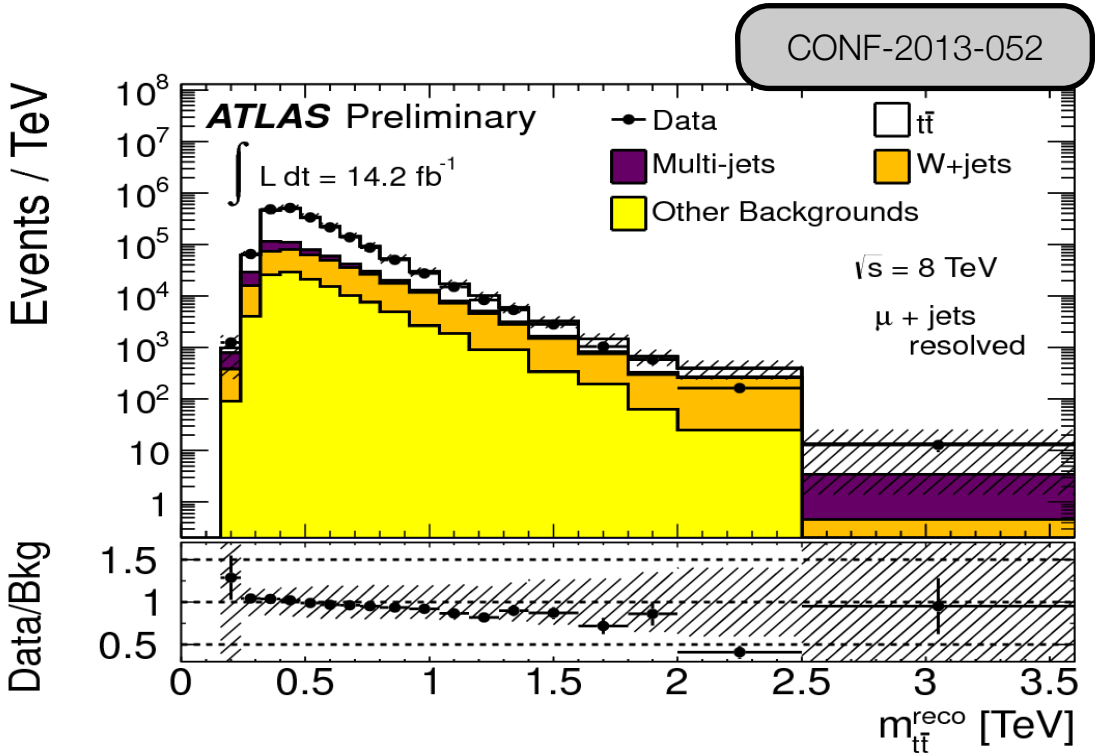
- **Top-Pair:**
  - Searches in the tails of e.g. top-pair invariant mass, top transverse momentum
  - Searches for e.g. stealth stops lying close to the top-quark mass

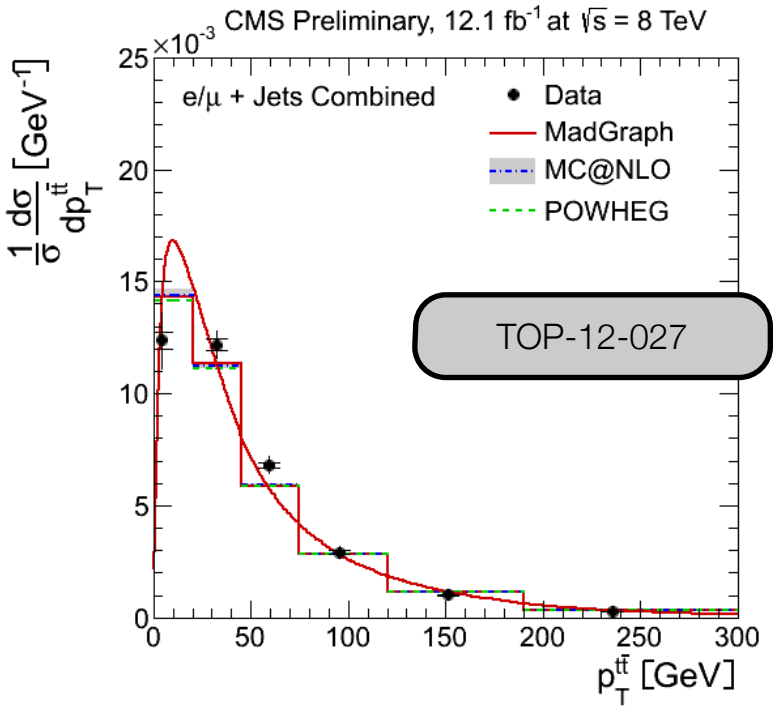
- **Top-pair +X:**
  - Searches for Vector-like quarks (VLQs) – extra heavy bosons
  - Searches for ttH, tH^+ - extra heavy quarks, extra jets
  - Searches for stops/ 3G leptoquarks – extra invisibles

- **Single-top (+X):**
  - Tail searches: in top+bottom mass or top/bottom transverse momentum
  - Single VLQ production – forward jets, heavy bosons, and top
  - Mono-top – single top + invisibles

- **Boosted top**
  - Use single-jet mass, jet substructure etc.

Top Dynamics

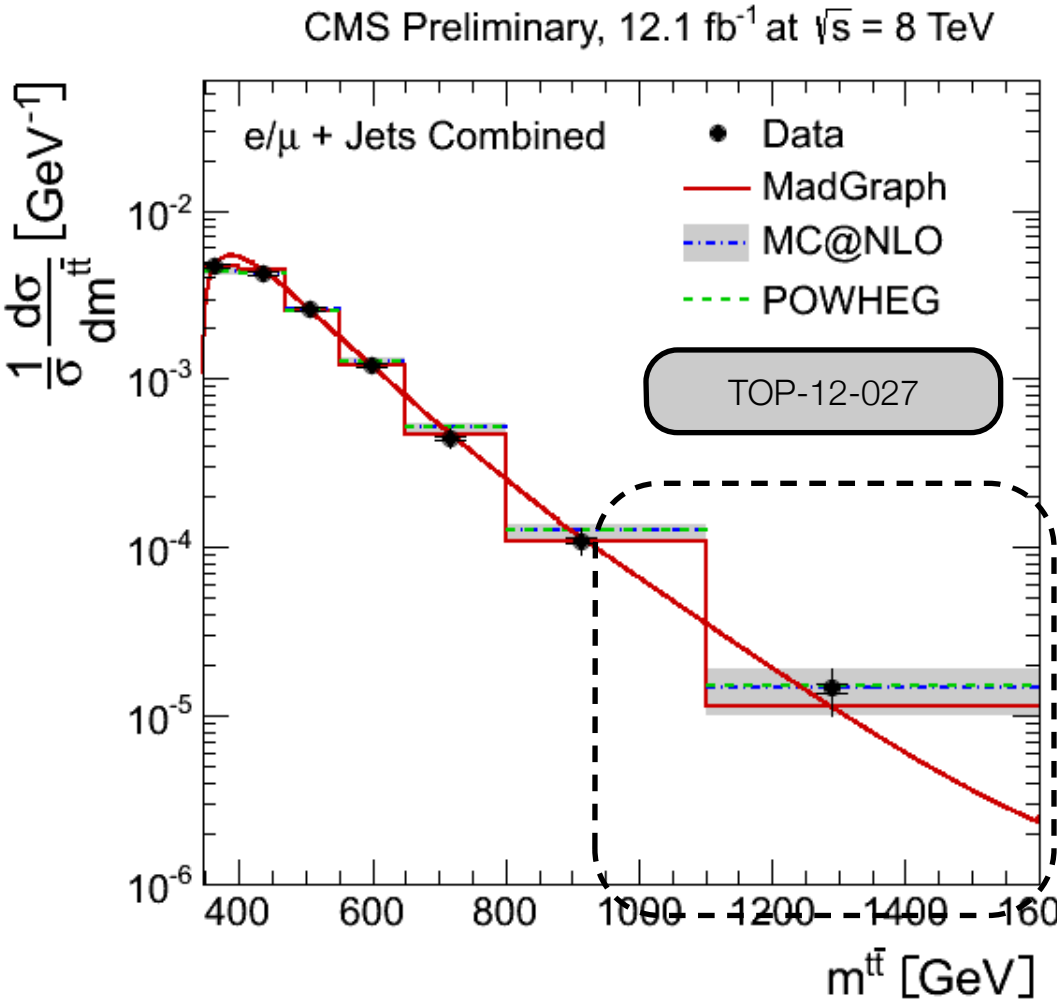


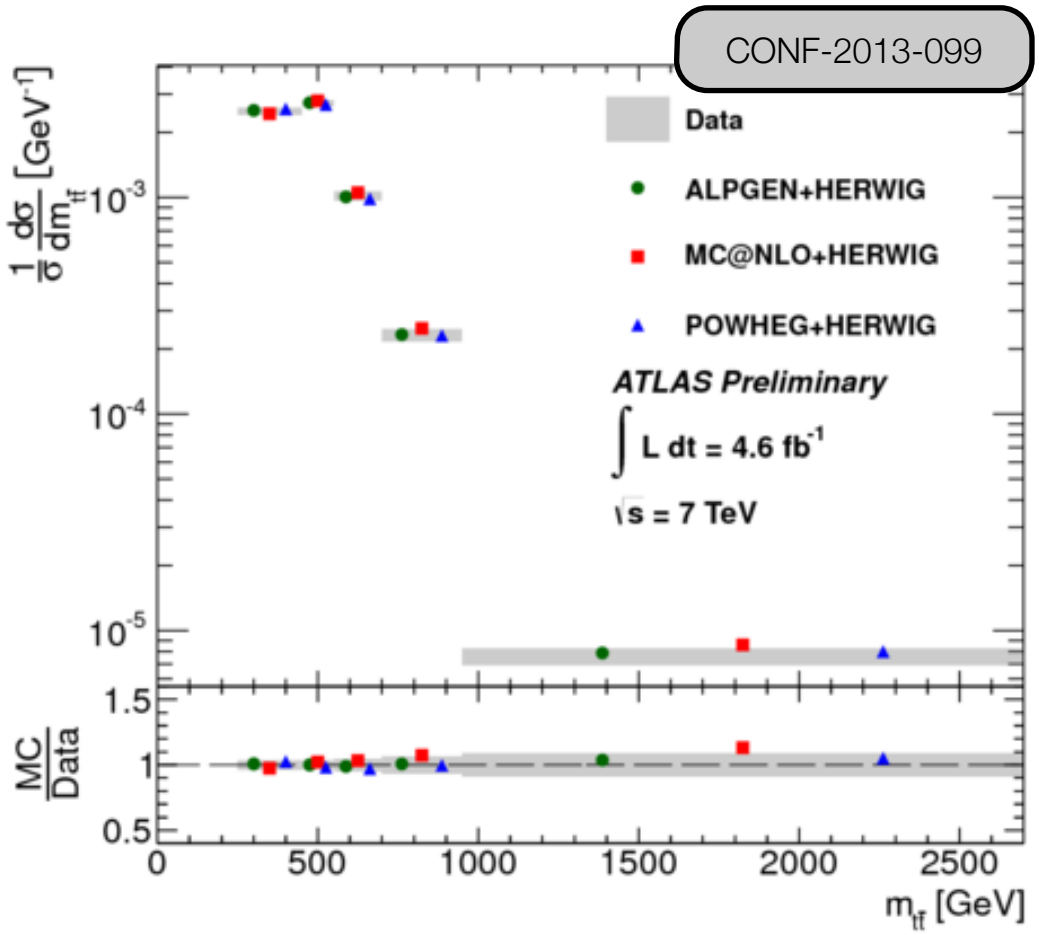


- Exotics searches often probing high top-anti-top mass
- Large uncertainties including a sizeable theoretical component (PDF/scale uncertainties, EW corrections etc.)
- Disagreements with theory visible in unfolded measurements too
- Control of these uncertainties would help searches

Differential Cross Section

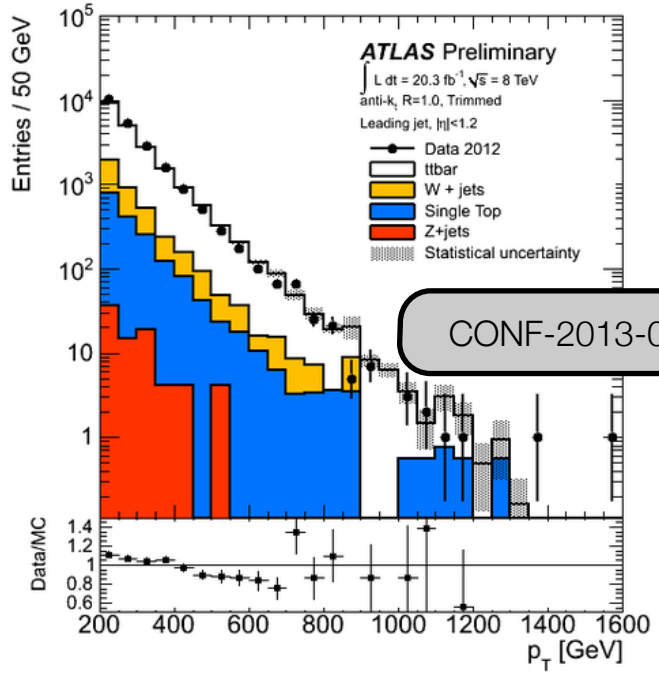
- For the boosted analyses, we would like to have a more accurate prediction of the cross section for high-pT top pair production
  - Currently one of biggest systematic uncertainties
  - Boosted top cross section under preparation



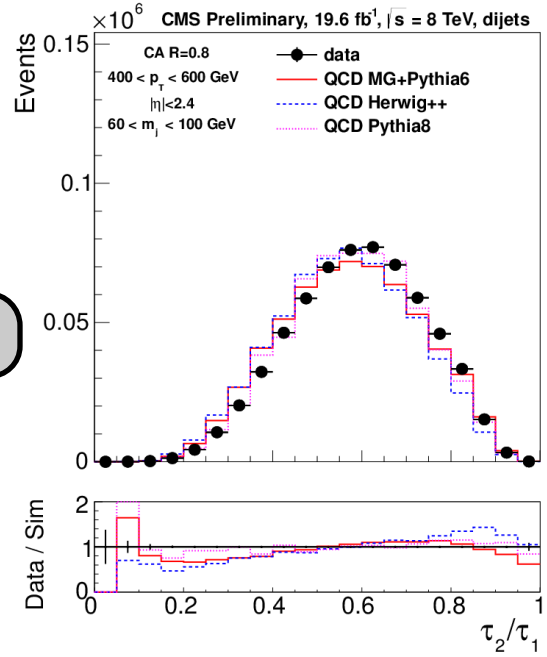


Substructure Algorithms

- Again MC tuning or better modeling could improve searches

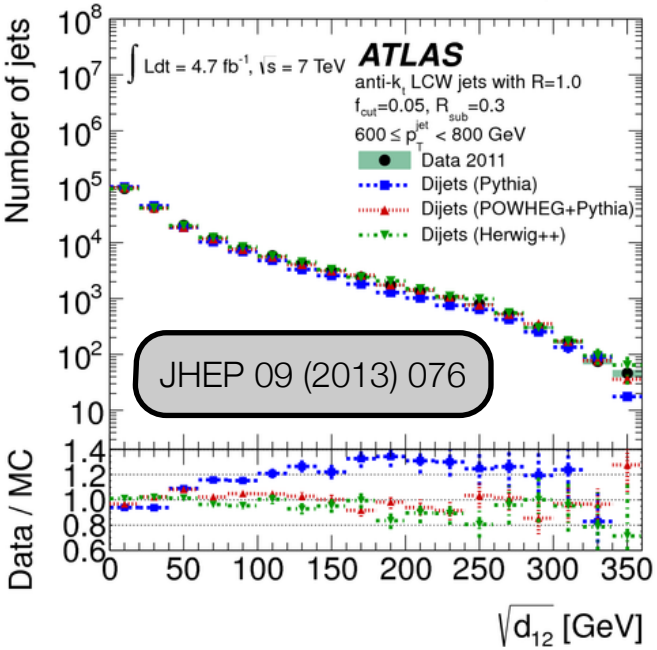


CONF-2013-084

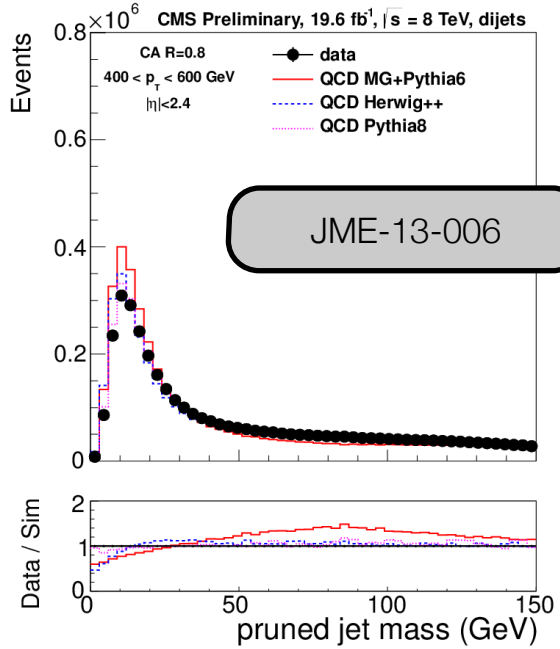


Pythia8 and Herwig++ perform better relative to Pythia6

Should we make this a "default" recommendation when we have the choice of generators?



JHEP 09 (2013) 076



JME-13-006

Should we measure top pair cross section with various groomed jets?

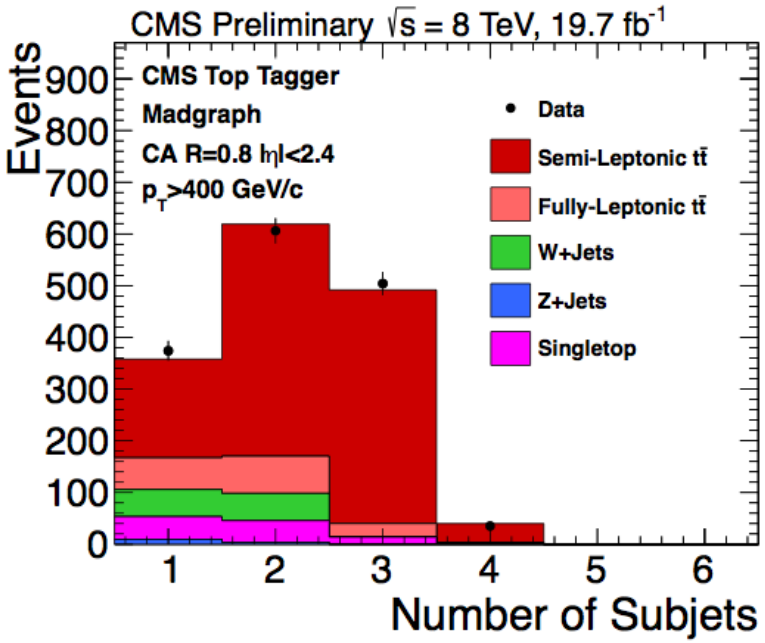
Is there any extra information to gain?

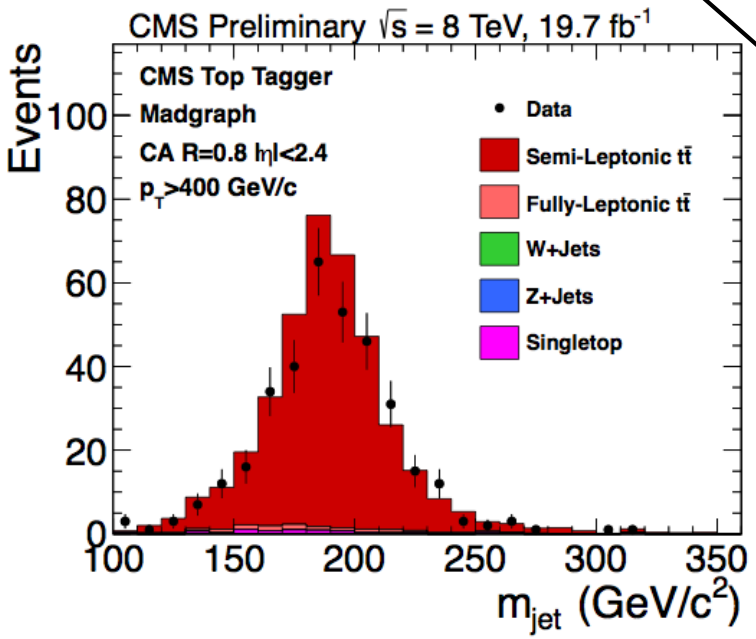
CMS Top Tagger

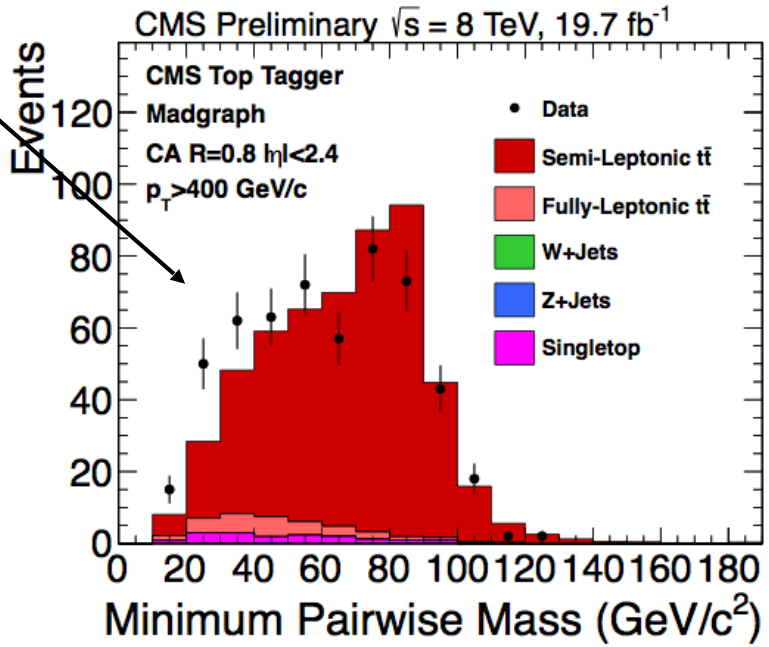
JME-13-007

- Three quantities used to identify top jets
  - Jet mass (in [140, 250] GeV)
  - Minimum pairwise subjet mass (> 50 GeV)
  - Number of subjets (>= 3)

- Can check modeling of observables in lepton + single jet events
  - Some disagreement seen in minimum pairwise subjet mass





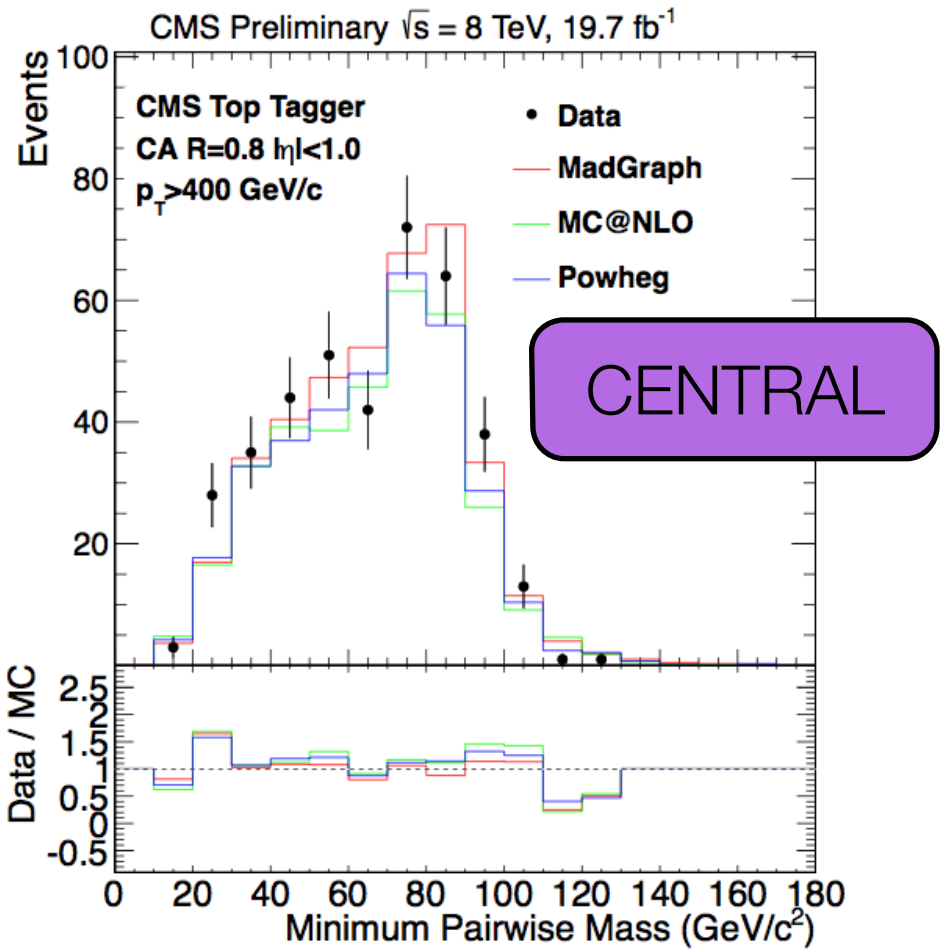


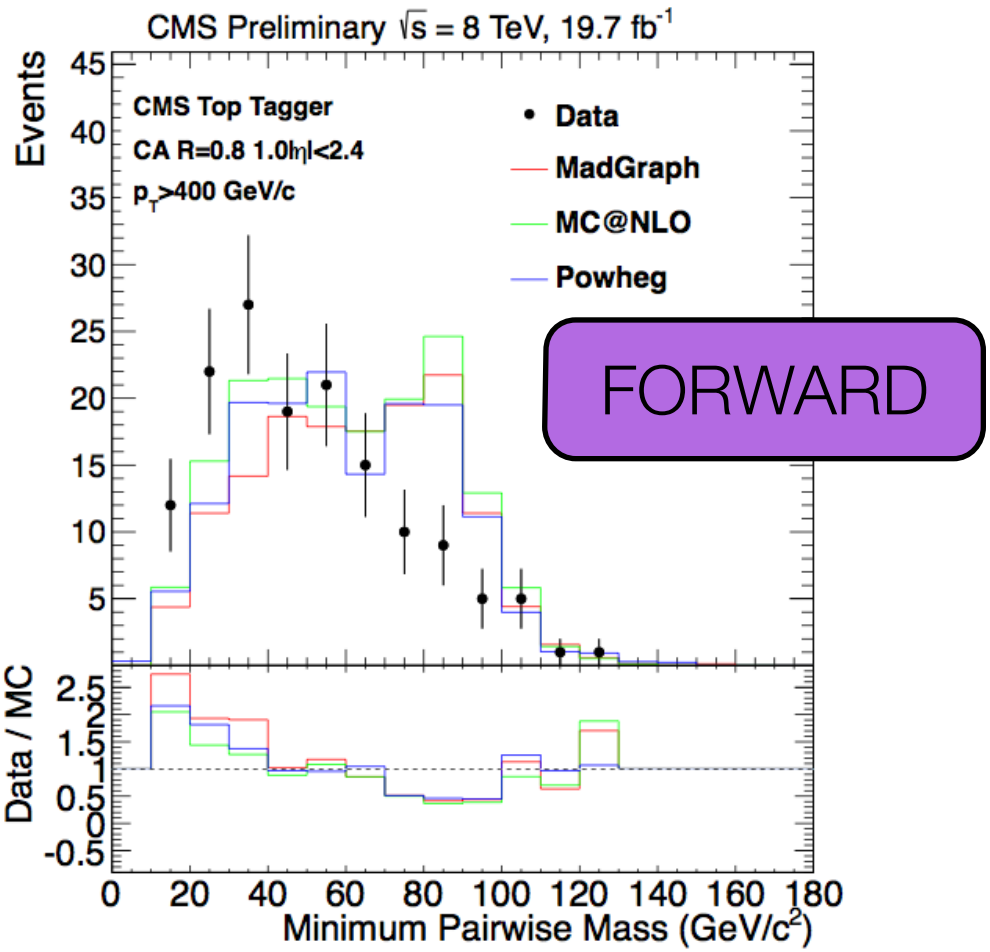
Comparing Generators

JME-13-007

- Significant disagreement seen in forward region
  - High η → high momentum to pass p_T cut
  - FSR may be an issue here and may not be modeled properly?

- MC@NLO and Powheg seem to model slightly better





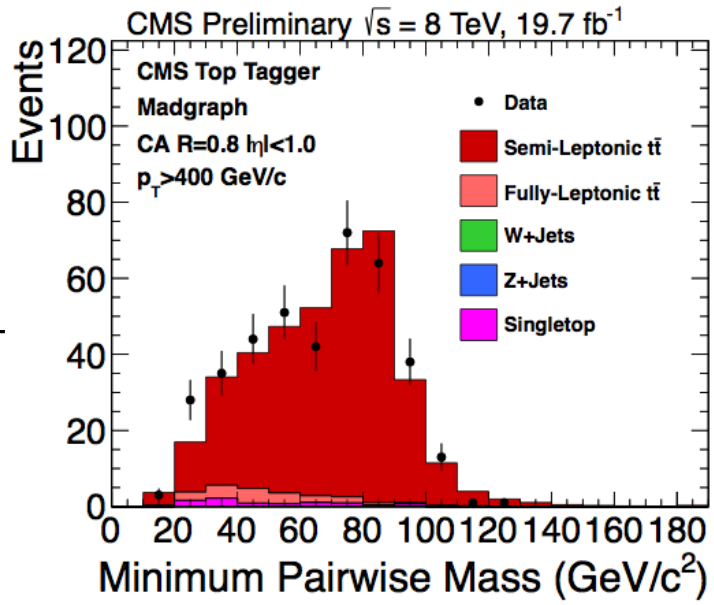
Comparing Generators

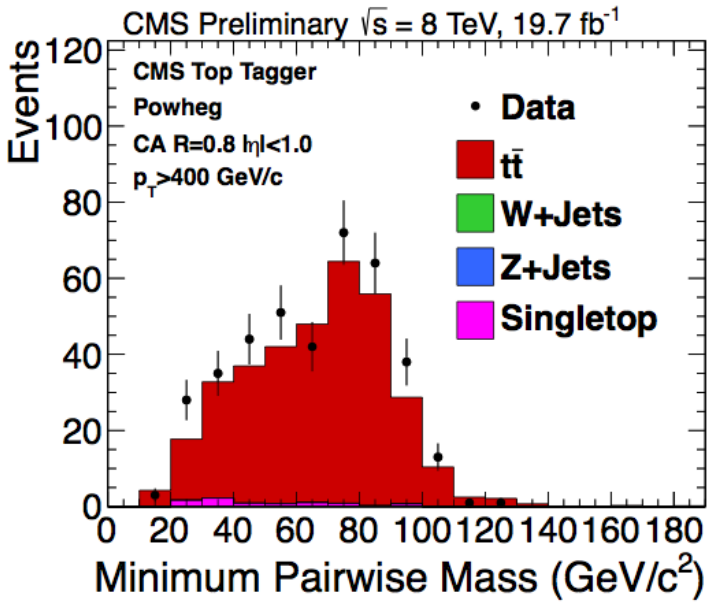
JME-13-007

MadGraph

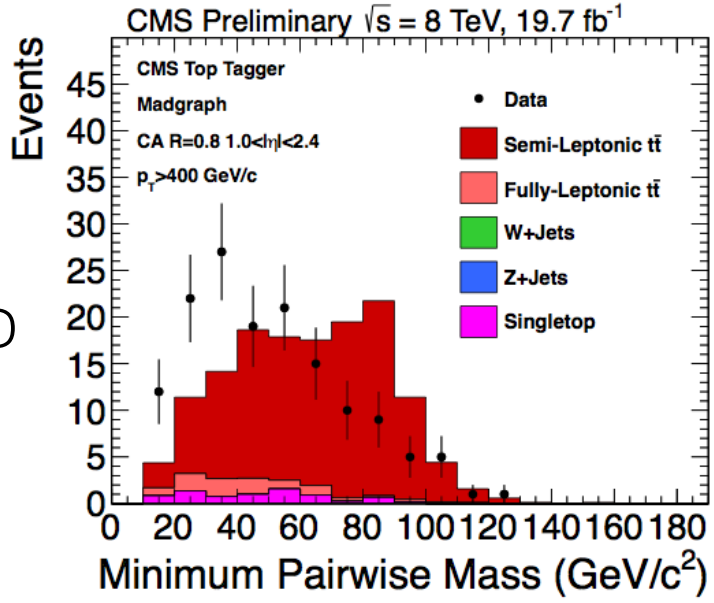
Powheg

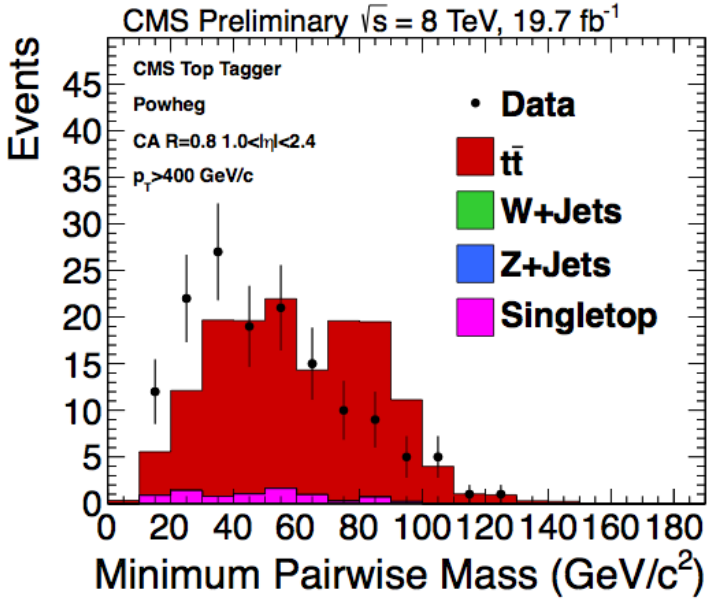
CENTRAL





FORWARD

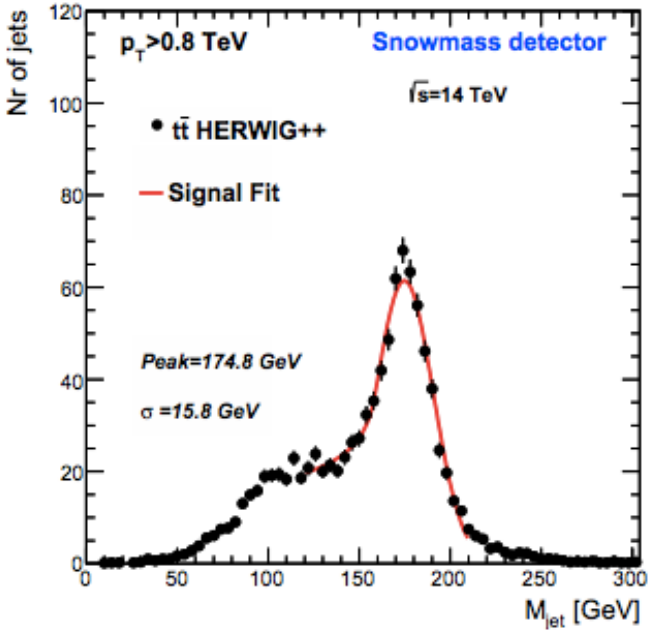


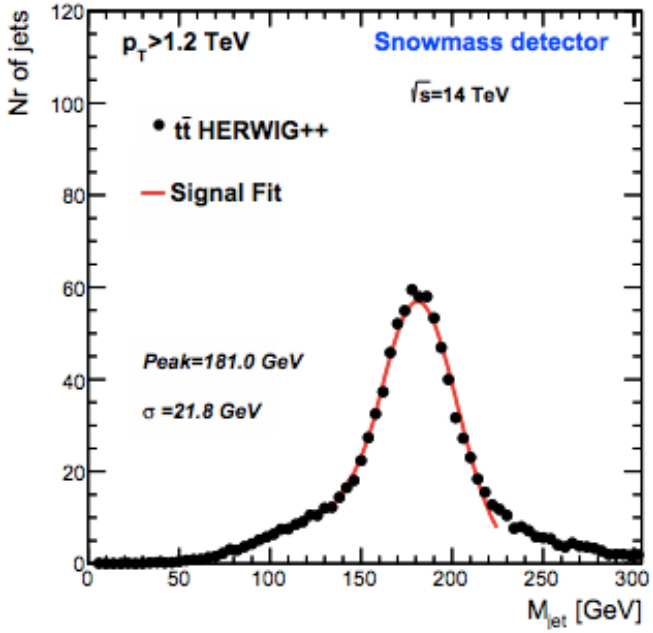


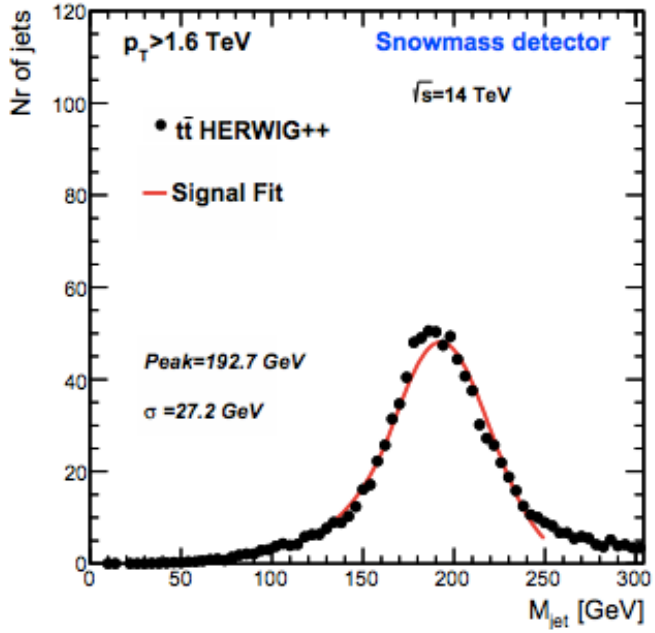
Jet Mass Resolution

- With higher energy, jet mass resolution is expected to degrade
  - What can we do to maintain performance?
  - Work underway to study specialized jet algorithms
    - Many already in use

  - Input from theory useful to determine which are calculable and effective



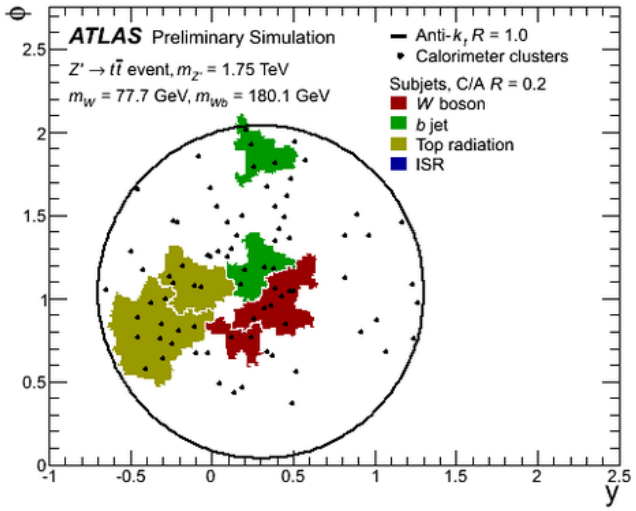


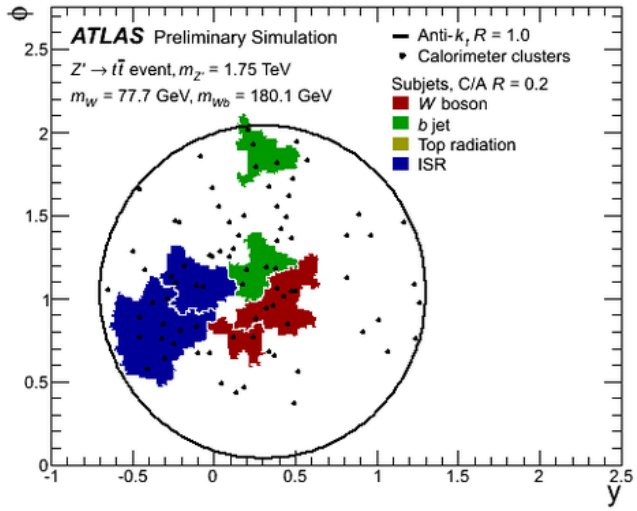


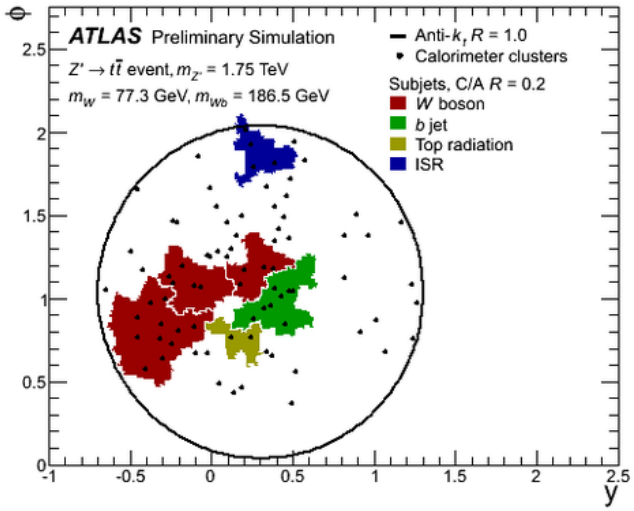
Shower Deconstruction

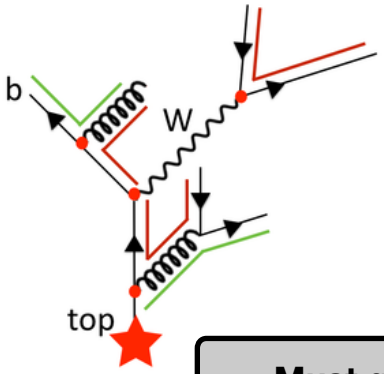
CONF-2014-003

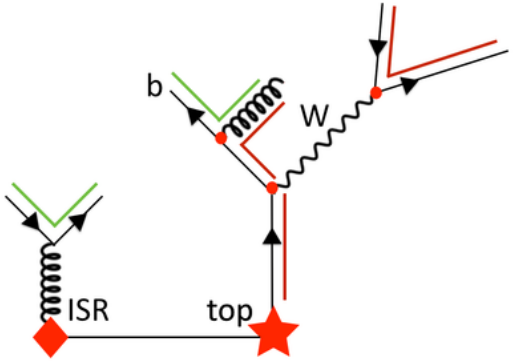
- Tools such as shower deconstruction can account for the extra radiation
  - Construct many different shower hypotheses (O(1k)) for each event
  - Determine consistency of jet with boosted top quark decay

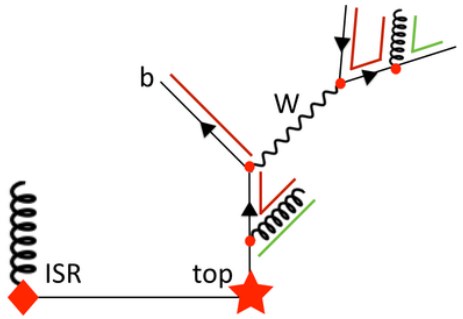










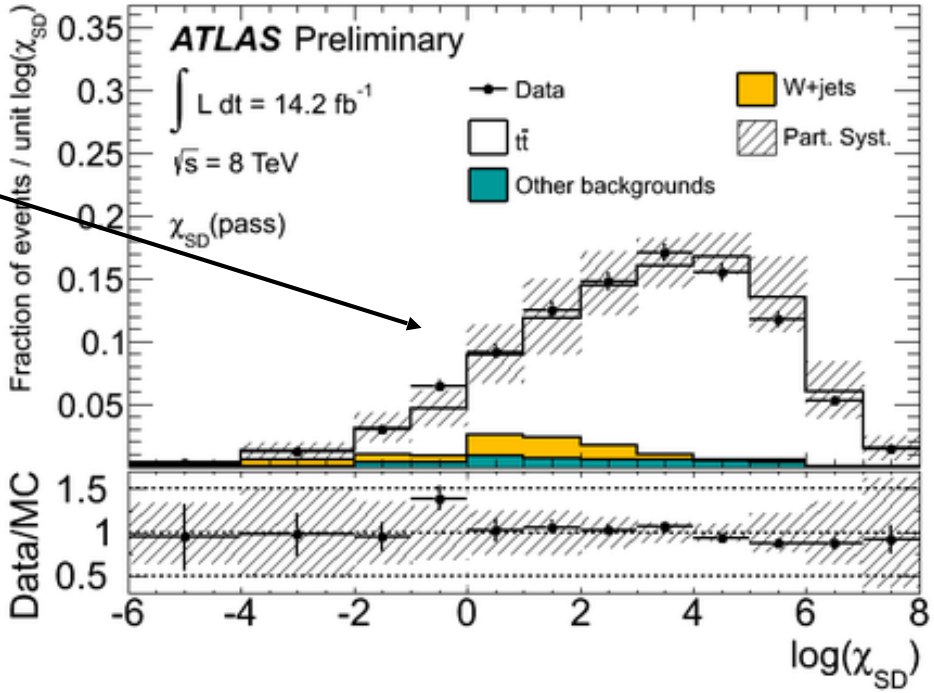


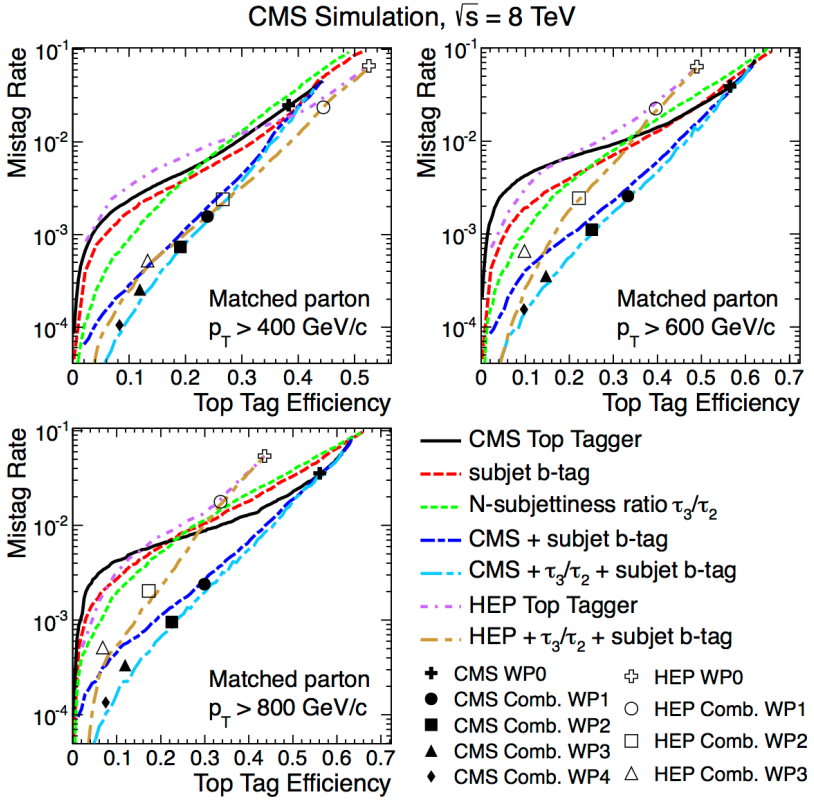
Must get shower model correct for good performance

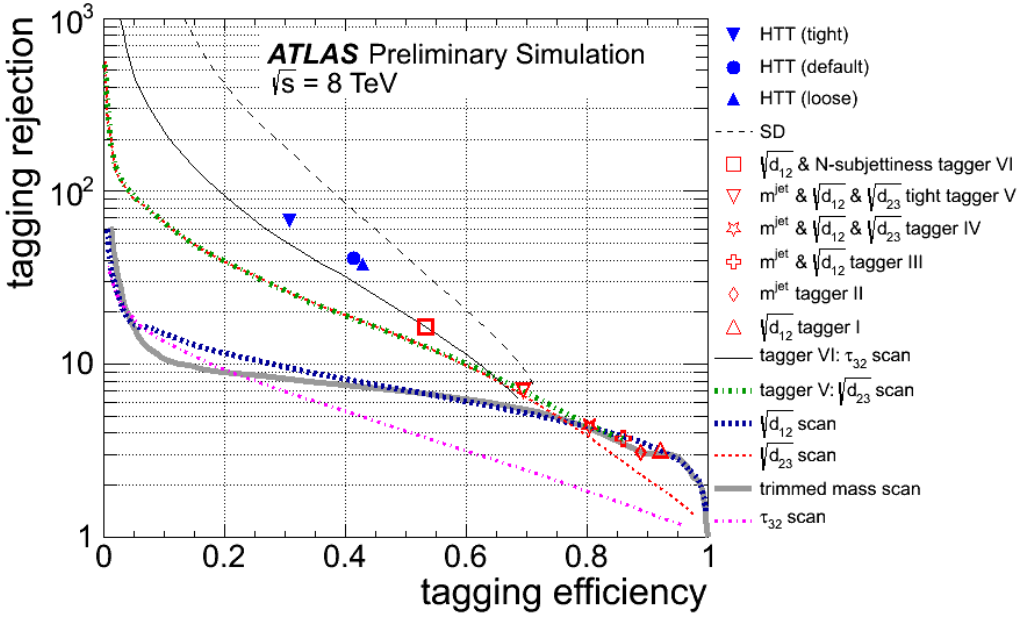
Shower Deconstruction

CONF-2014-003

- Construct likelihood ratio based on shower probabilities to isolate top events
- Better performance than HEPTopTagger and others
- Reliable signal efficiencies depend on substructure modeling

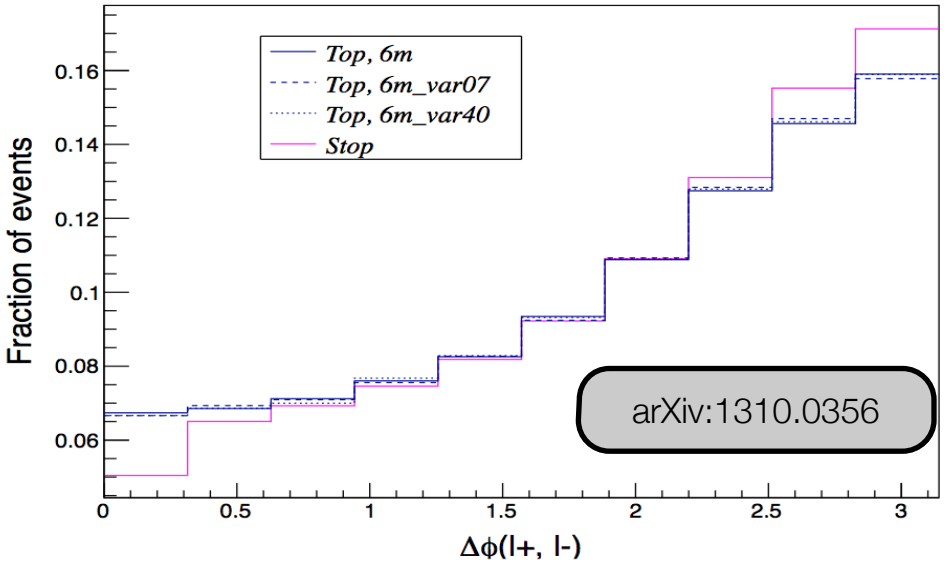


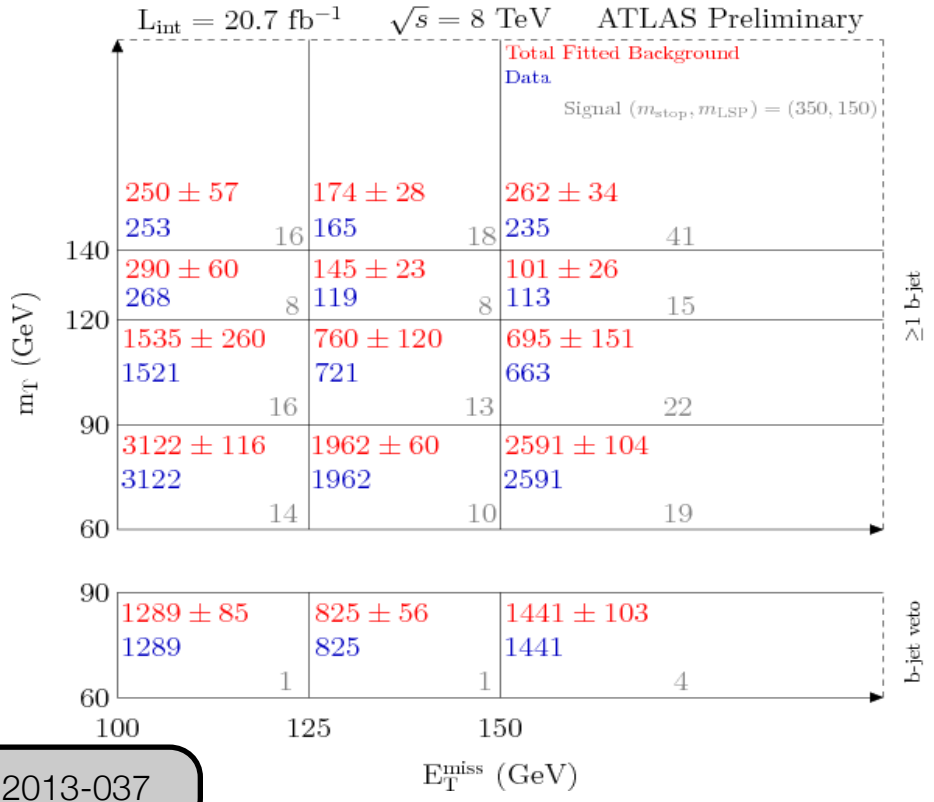




Top Dynamics

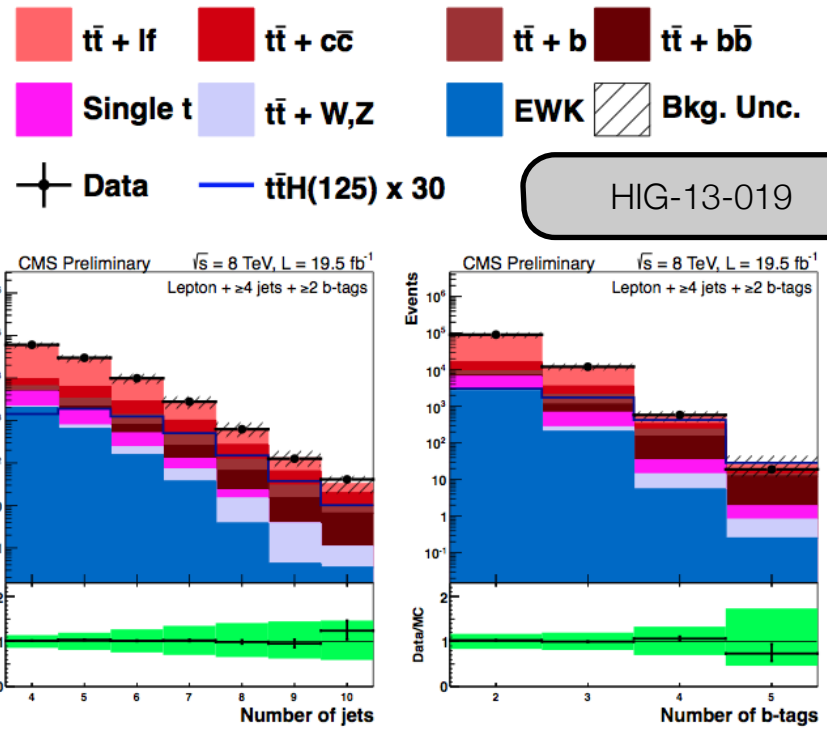
- Two top dynamics issues of particular interest to SUSY searches:
  - **Spin correlations:**
    - Can exploit spin-correlations to separate top and stealth stop
    - Requires precise modelling of spin correlations in MC
  - **Transverse Mass line-shape:**
    - Often used for CR->SR extrapolation
    - precise modelling of the transverse W mass line shape, thus needed e.g. leptonic tau decays need to be precisely modelled

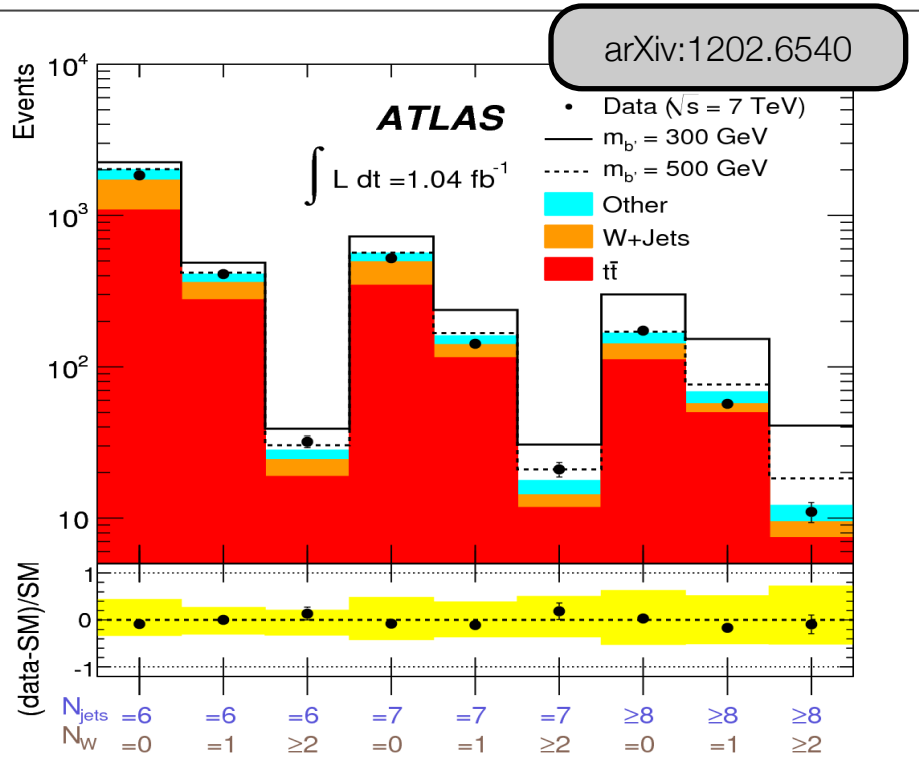




CONF-2013-037

Top Dynamics





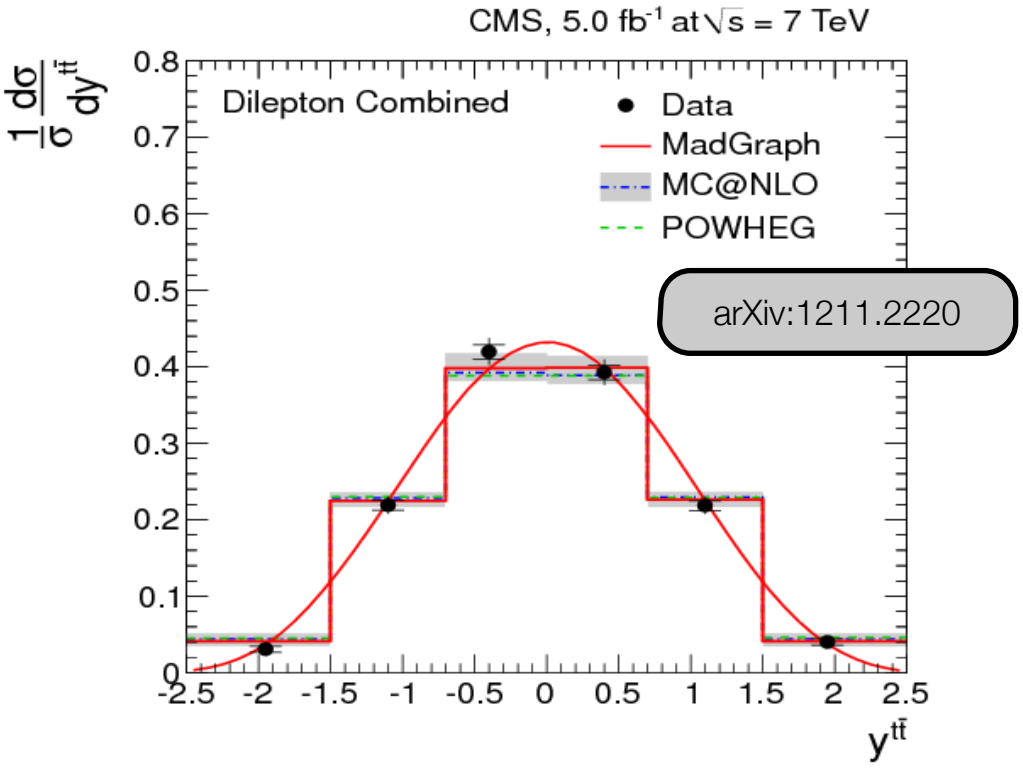
- tt+X final states also of significant interest:
  - ttH etc. needs accurate predictions for ttbar plus extra jets and ttbar plus extra heavy flavour jets
  - Heavy quark searches also depend on this (and ttbar plus extra bosons)

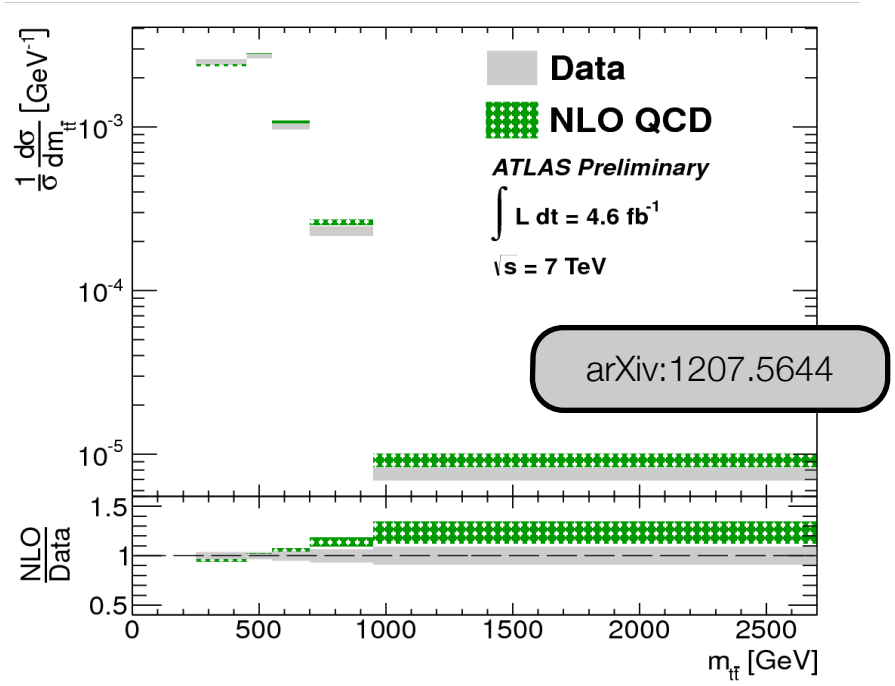
- Searches need good control of these, and of summed momentum of objects (H_T), often used to discriminate against backgrounds

Measurements

Measurements

- More of top-antitop system measurements would be useful to constrain the gluon in PDF fits:
  - Also boosted and double-differential if possible
  - Help reduce theory uncertainties in the tails



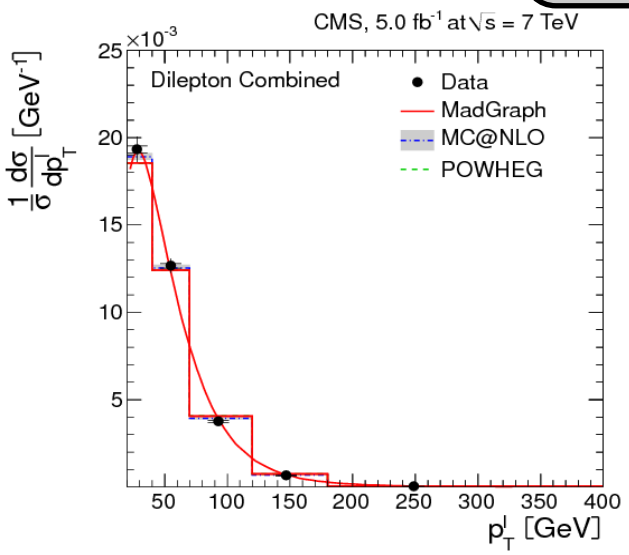


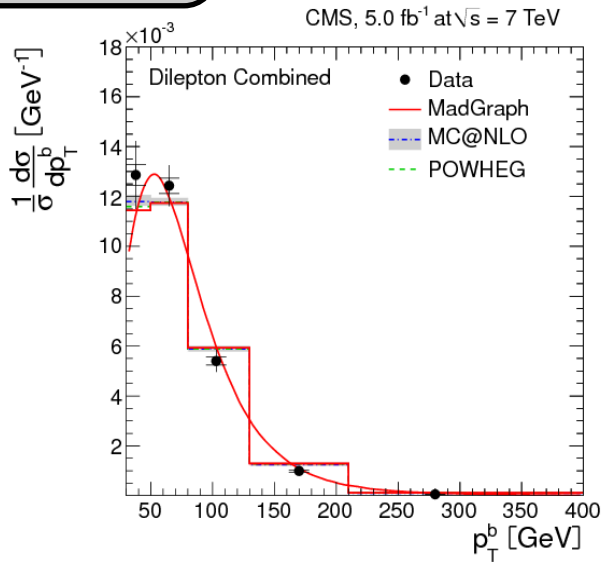
- We also need **particle-level** measurements if we want to tune our MC

Measurements

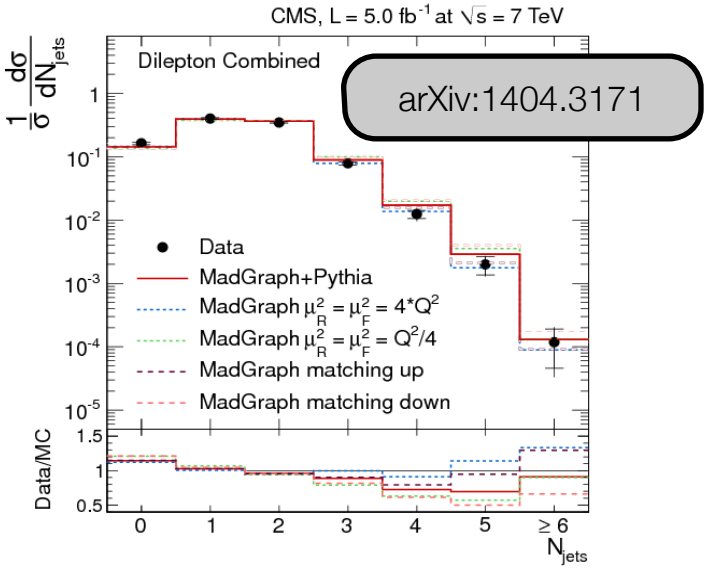
- CMS measurements of particle-level quantities in ttbar (and +jets):

arXiv:1211.2220





arXiv:1404.3171

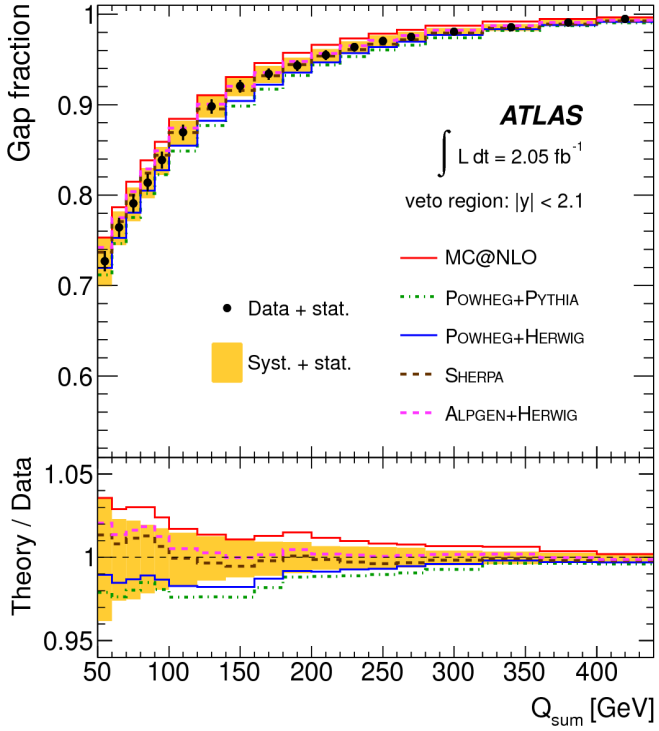


- Very nice measurements but:
  - Hepdata entry still in preparation
  - Rivet routine still in preparation
- Having both would make it much more useful for tuning hard QCD behaviour in Monte Carlos
- CR/UE tuning subtleties related to Pedro's talk generally less significant for BSM searches
- For ttH, a particle-level measurement of tt+HF is highly desirable

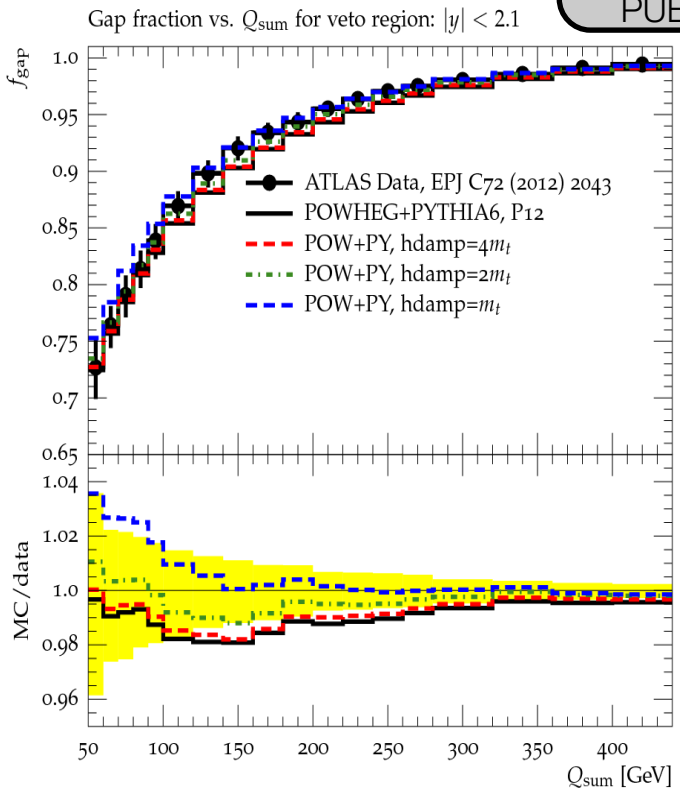
Measurements

- Need more measurements like ATLAS gap fraction:

arXiv:1203.5015



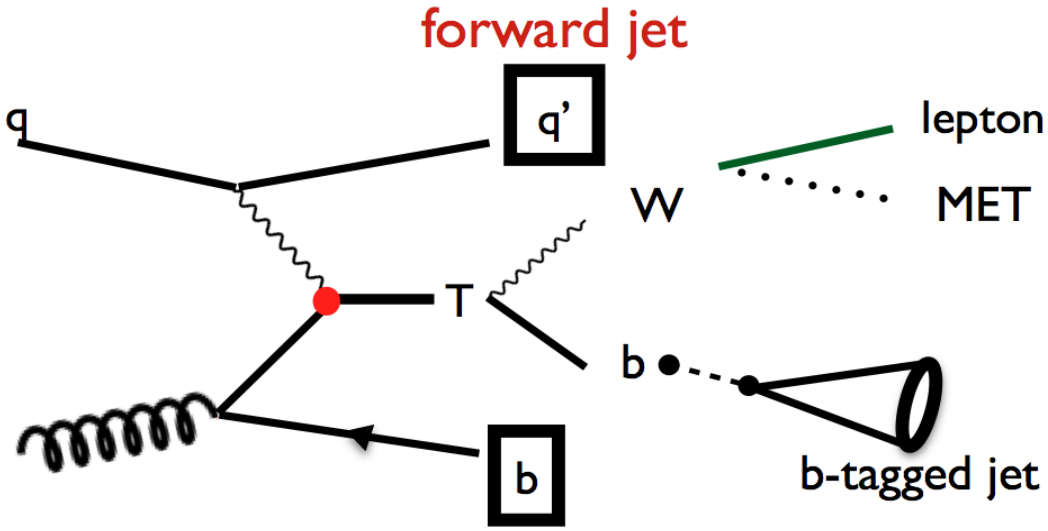
ATLAS-PHYS-PUB-2014-005

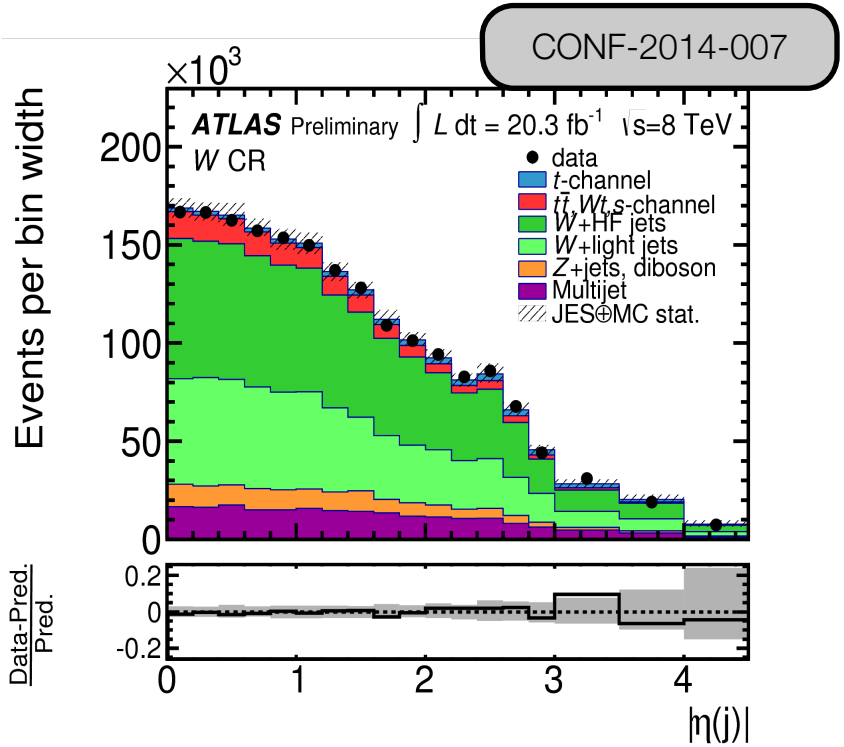


- Nice measurement and:
  - Has a Hepdata entry
  - Has a Rivet routine
- Can thus be used to justify/determine I/FSR uncertainty choices in MC (and has been so used)

Measurements

- Single top fiducial measurements are also of interest in helping us with single VLQ searches:
  - t-channel production mechanism very similar to single VLQ production
  - Forward jet a key object for these searches
  - Combination of 4FS and 5FS calculations and scale choices can change forward jet kinematics
  - Measurements of forward jet and extra b In t-channel single top can help understand which is the best choice for our signals



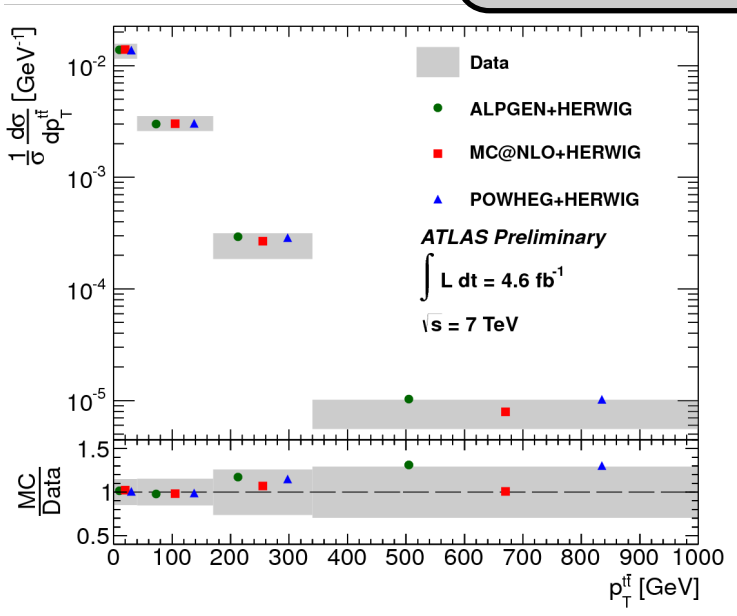


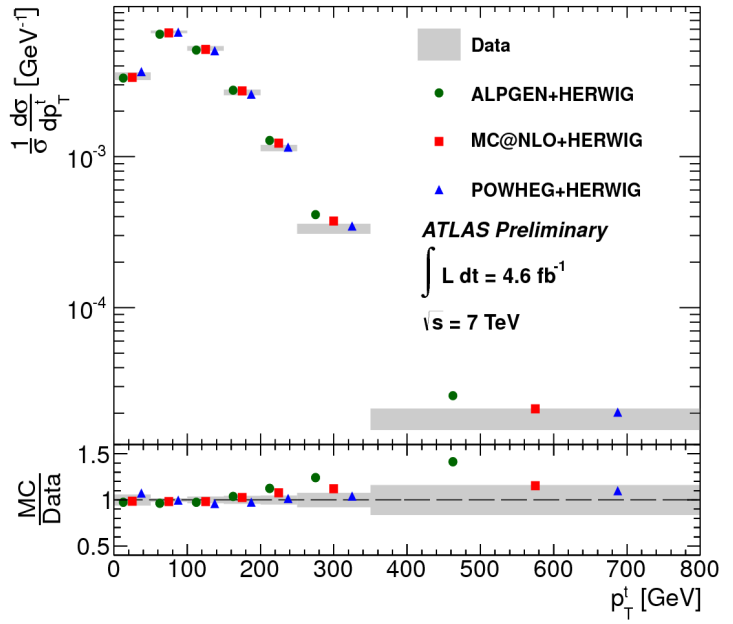
Measurements

CONF-2013-099

- Parton-level measurements can still be useful
  - Disagreement in top and ttbar kinematics already discussed in this meeting
  - Measurements can be used to derive corrections for searches

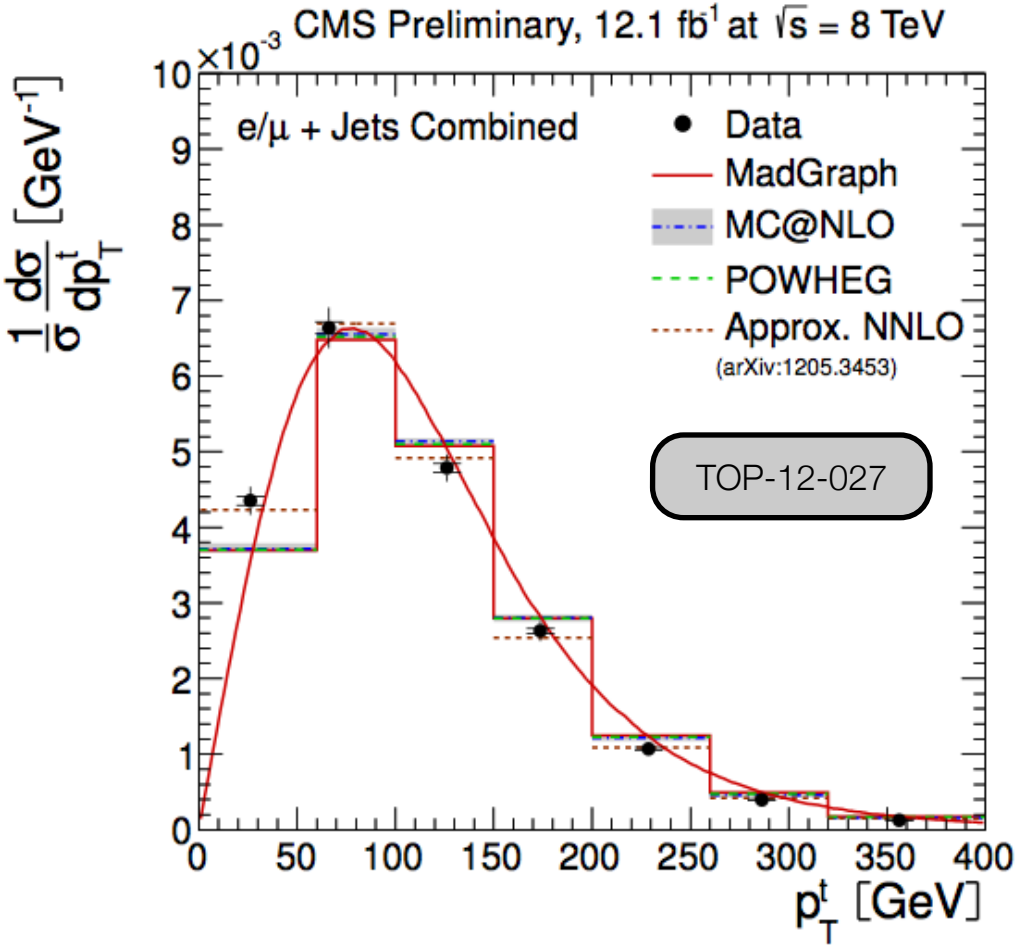
- ATLAS procedure (so far only used for ttH CONF note) – sequential reweighting:
  - Reweight (at truth-level) using distribution of ttbar transverse momentum
  - Then reweight using distribution of top transverse momentum
  - Factors derived from 7 TeV measurements are currently used
  - (ATLAS-CONF-2013-099)

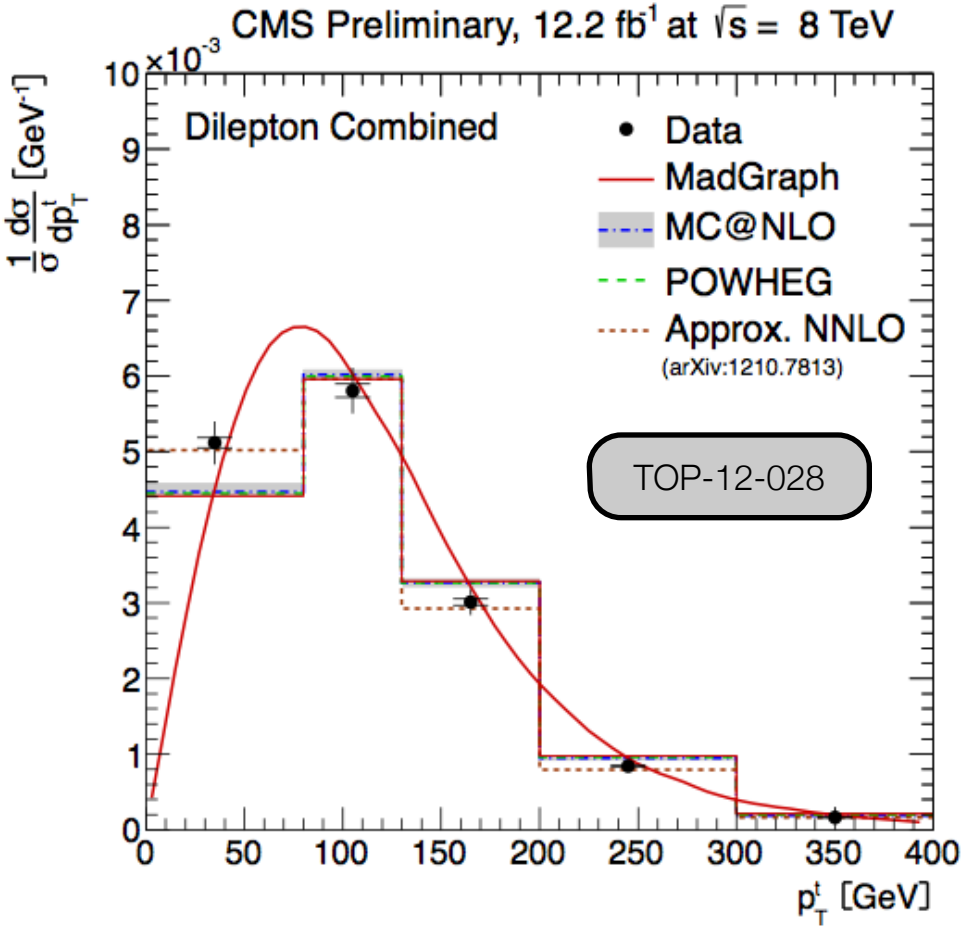




Top pT Reweighting (CMS)

- Top p_T spectrum in data softer than predicted by various MC generators
- Scale factors derived to account for observed shape differences





Top pT Reweighting (CMS)

- Compute SFs for various p_T bins with all contributing analyses
  - Lepton + jets
  - Dilepton
  - 7 TeV and 8 TeV done independently
  - Good agreement between analyses and datasets

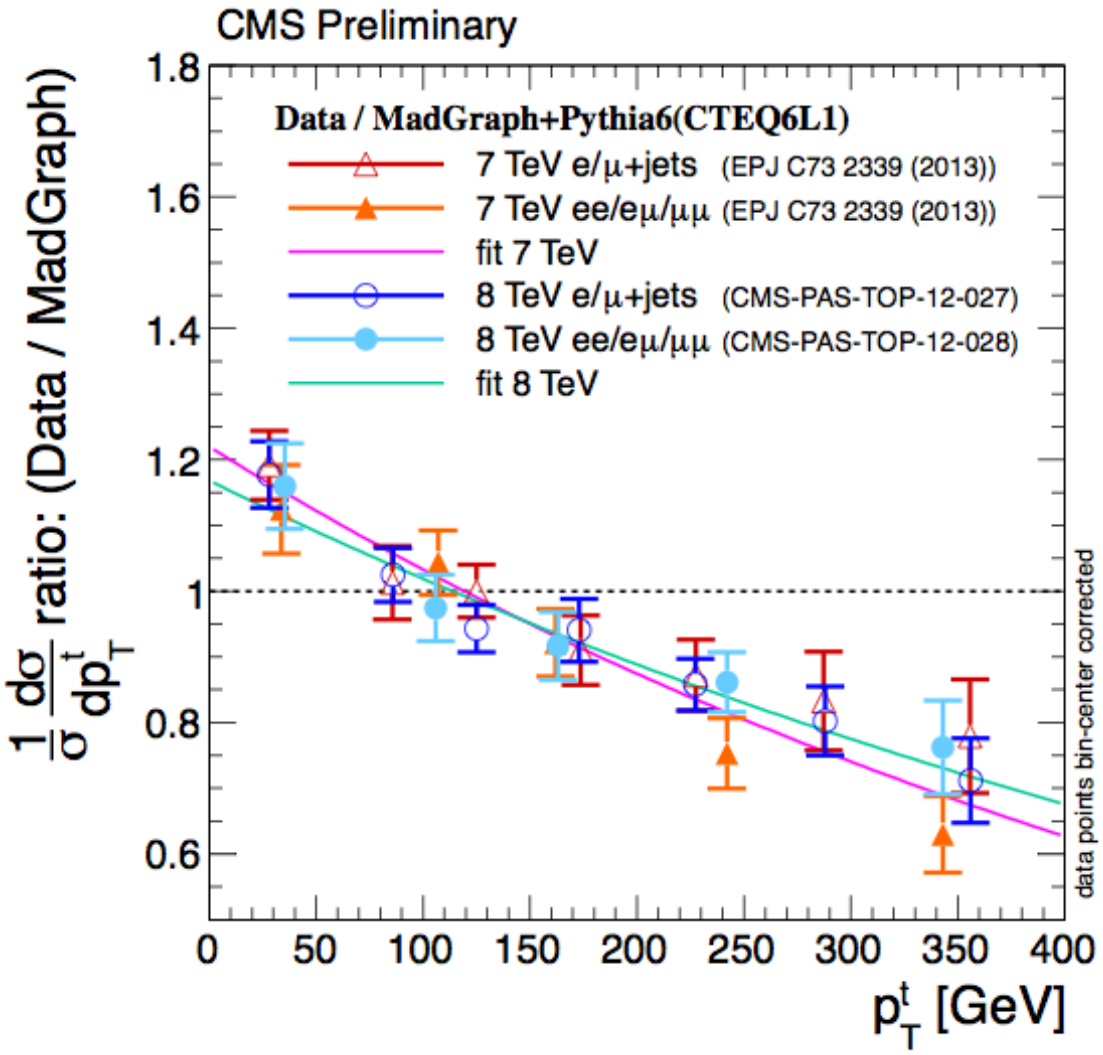
- Fit an exponential to the SF points to interpolate to all pT values

- Use event weights derived as

$$\sqrt{f_t \cdot f_{\bar{t}}}$$

- Prescription valid up to 400 GeV
  - Need better understanding of boosted regime

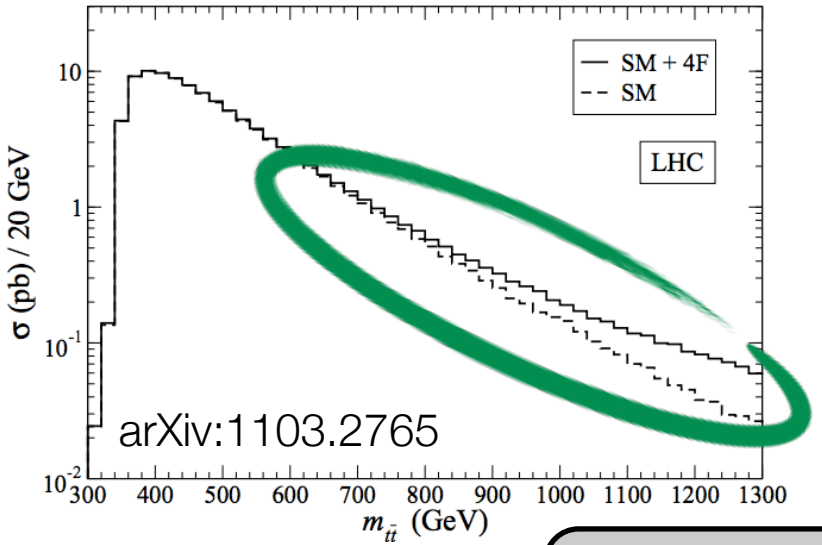
- Systematics determined by applying no weight or weight^2



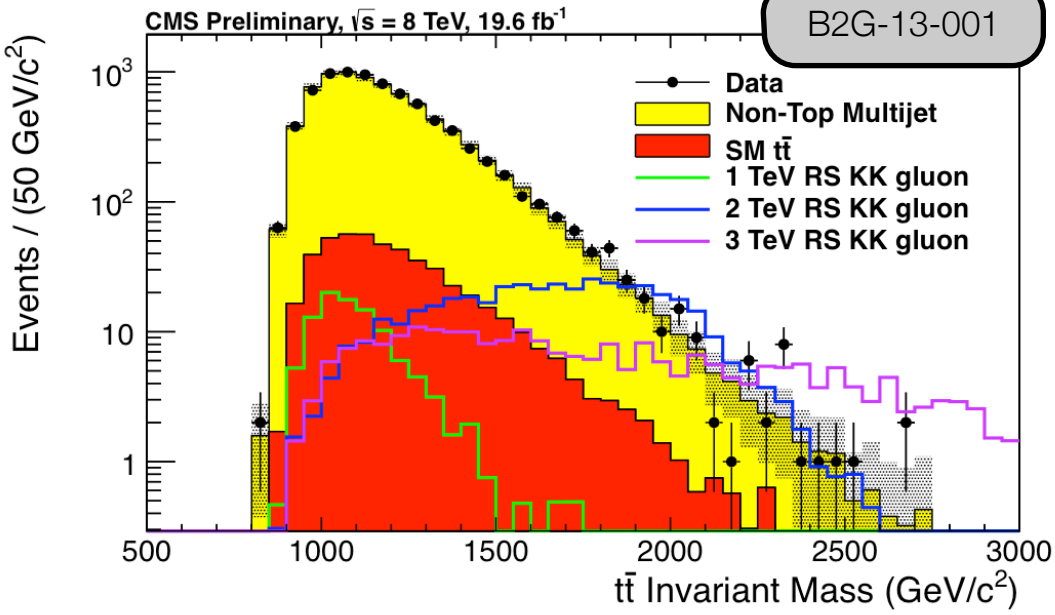
Non-Resonant Enhancements

- What would be best observable to use for non-resonant searches

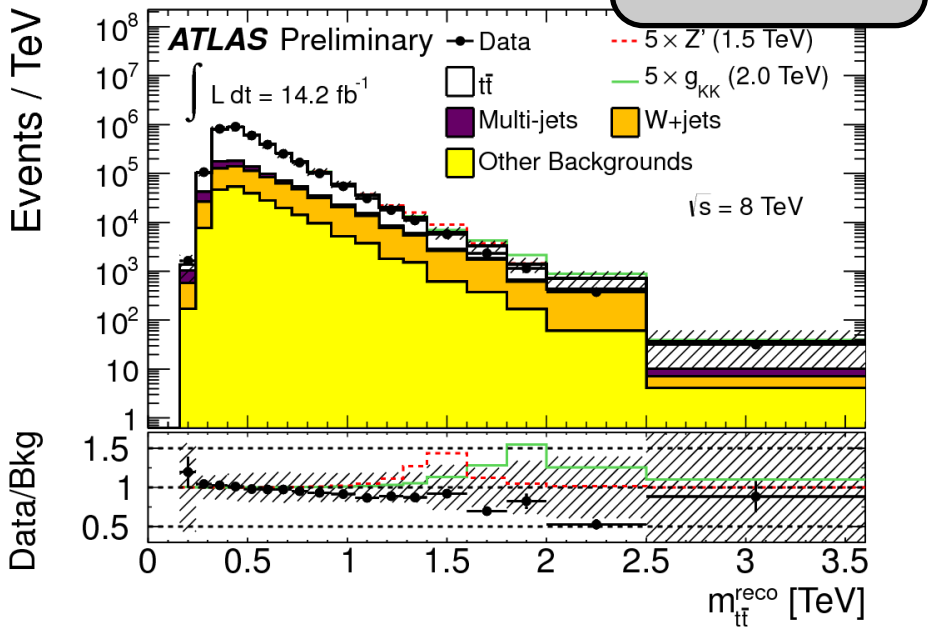
- Currently use the top pair invariant mass spectrum
  - Could be candidate for ATLAS+CMS combination?
  - Reduce statistical fluctuation in tails



B2G-13-001



CONF-2013-052

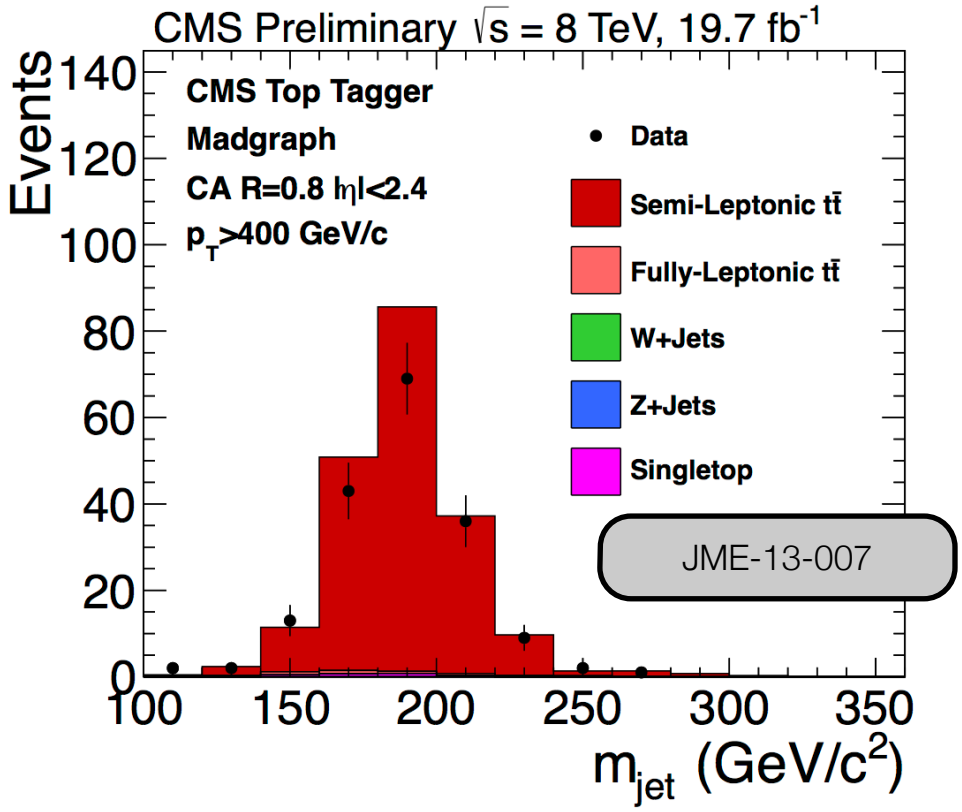


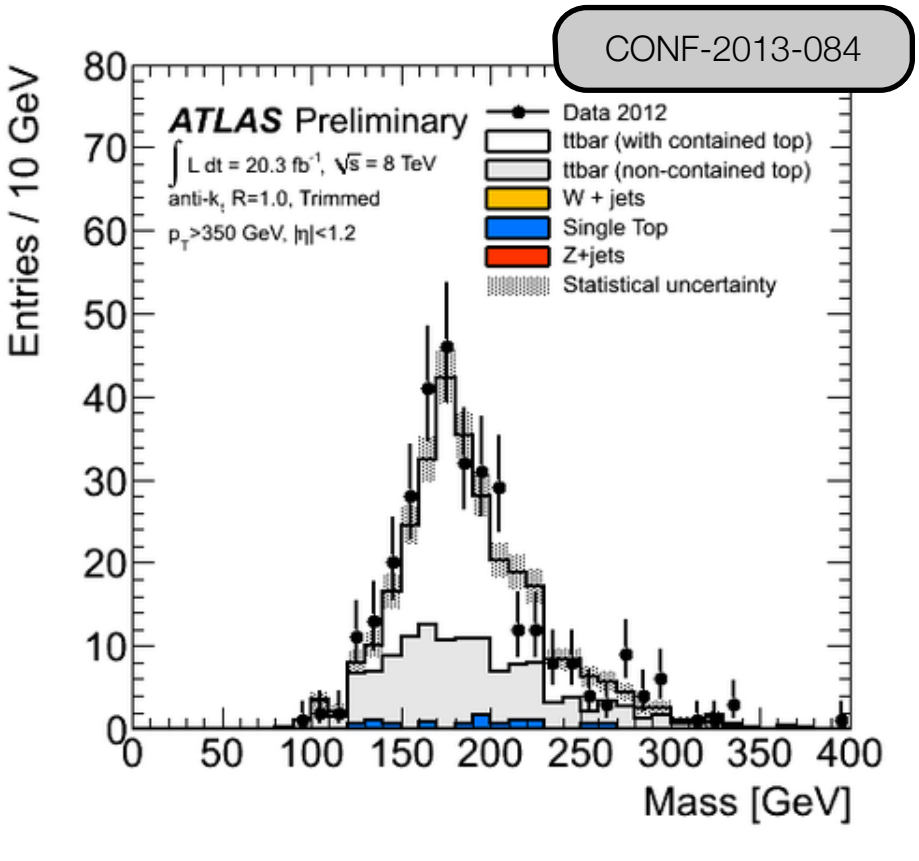
Single-jet Top Mass?

- What are the prospects for single- (or double-) jet top mass measurements?
  - Is this feasible in the next run?

- May be the only way to measure at high pile-up?
  - Large uncertainties on jet corrections due to pile-up subtraction algorithms
  - Makes resolved scenario difficult

- Can get pure sample of ttbar events with top-tagging algorithms
  - Currently low statistics — combination of ATLAS+CMS useful?





Combinations

- Three ways that direct searches can profit from ATLAS-CMS combinations/ combination work:
  - Establishing common benchmarks for common searches. **TopLHCWG could be a suitable forum for this.**
    - e.g. tt resonances, benchmarks/ k-factors not the same
  - If the searches are systematically limited and uncertainties are not correlated between experiments. **Expertise from other topLHCWG combinations would really help here.**
    - Examples: low mass region of ttbar and tb resonances, combination can push coupling limits down
  - Statistically limited searches. **Combination here only seem to make sense at the end of a run, during a shutdown.**

Conclusions

- Quite a few topics in top physics relevant for BSM searches
- Issues/interests often in common with those discussed elsewhere in this meeting
  - top-quark pT
  - single-top fiducial
  - MC uncertainties
- Scope for top BSM combination activities with the working group, especially where we can benefit from expertise from SM top combinations

Backup Material

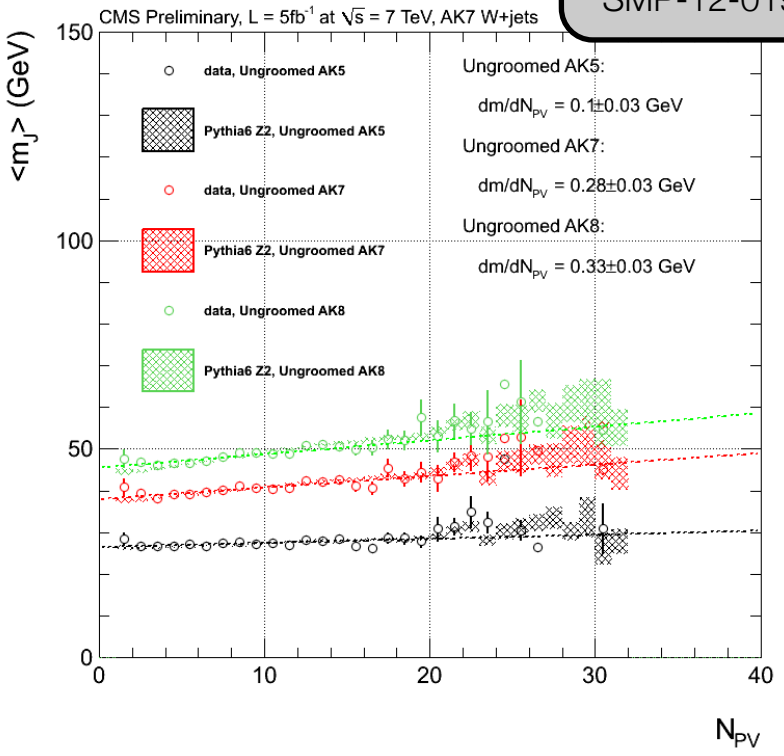
Pileup Mitigation

Tagging selection	Efficiency (%) vs. N_{vtx} slope	Mistag rate (%) vs. N_{vtx} slope
CMS Tagger WP0	-0.031 ± 0.034	0.095 ± 0.006
$\tau_3/\tau_2 < 0.55$ (R=0.8)	-0.429 ± 0.031	-0.031 ± 0.001
Subjet b-tag CSV-medium	-0.049 ± 0.033	0.006 ± 0.002
CMS Combined Tagger WP3	-0.213 ± 0.024	-0.002 ± 0.0002
HEP Tagger WP2	-0.180 ± 0.028	-0.010 ± 0.006
HEP Combined Tagger WP3	-0.463 ± 0.0236	-0.001 ± 0.002

JME-13-007

- Efficiency of algorithms degrades with high pileup
  - Generally due to mass resolution
  - Events fall outside of top mass window
- Additional algorithms can stabilize the mass
  - Jet trimming for example
- How to use these algorithms simultaneously with measurement of top mass?
  - Correction for trimmed portion of jet?

SMP-12-019



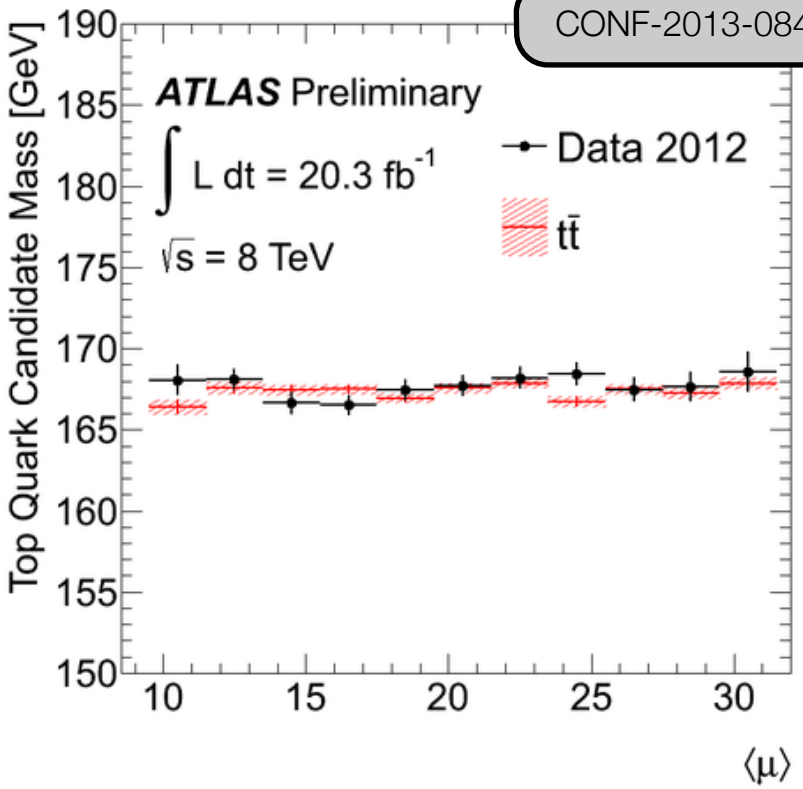
Pileup Mitigation

Tagging selection	Efficiency (%) vs. N_{vtx} slope	Mistag rate (%) vs. N_{vtx} slope
CMS Tagger WP0	-0.031 ± 0.034	0.095 ± 0.006
$\tau_3/\tau_2 < 0.55$ (R=0.8)	-0.429 ± 0.031	-0.031 ± 0.001
Subjet b-tag CSV-medium	-0.049 ± 0.033	0.006 ± 0.002
CMS Combined Tagger WP3	-0.213 ± 0.024	-0.002 ± 0.0002
HEP Tagger WP2	-0.180 ± 0.028	-0.010 ± 0.006
HEP Combined Tagger WP3	-0.463 ± 0.0236	-0.001 ± 0.002

JME-13-007

- Efficiency of algorithms degrades with high pileup
  - Generally due to mass resolution
  - Events fall outside of top mass window
- Additional algorithms can stabilize the mass
  - Jet trimming for example
- How to use these algorithms simultaneously with measurement of top mass?
  - Correction for trimmed portion of jet?

CONF-2013-084



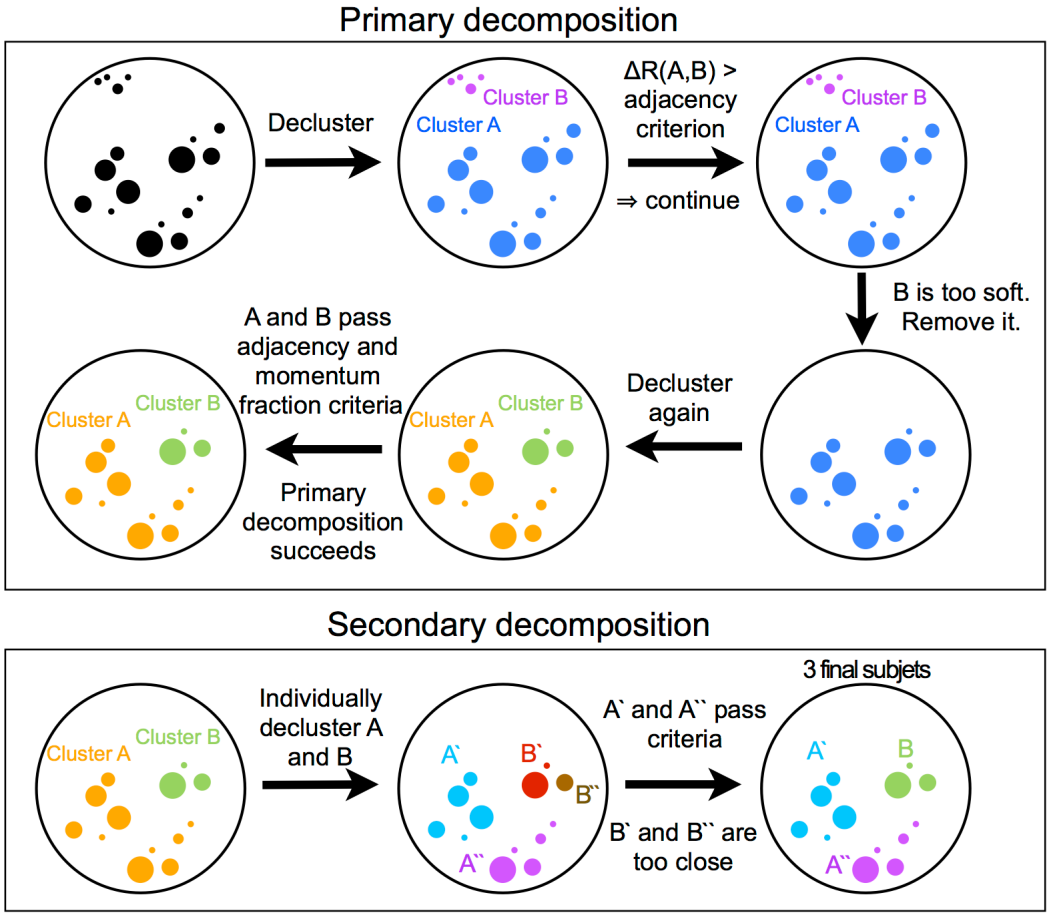
Top-Tagging Algorithms

JME-13-007

- Currently CMS uses two top-tagging algorithms
  - CMS Top Tagger (high pT > 400 GeV)
  - HEP Top Tagger (medium pT > 200 GeV)

- CMS Top Tagger aims to decompose jet into up to 4 subjets
  - Removes soft and large-angle radiation from the jet

Example: CMS Top Tagger decomposition



CMS Top Tagger Flowchart