Results on QCD jet production at ATLAS and CMS

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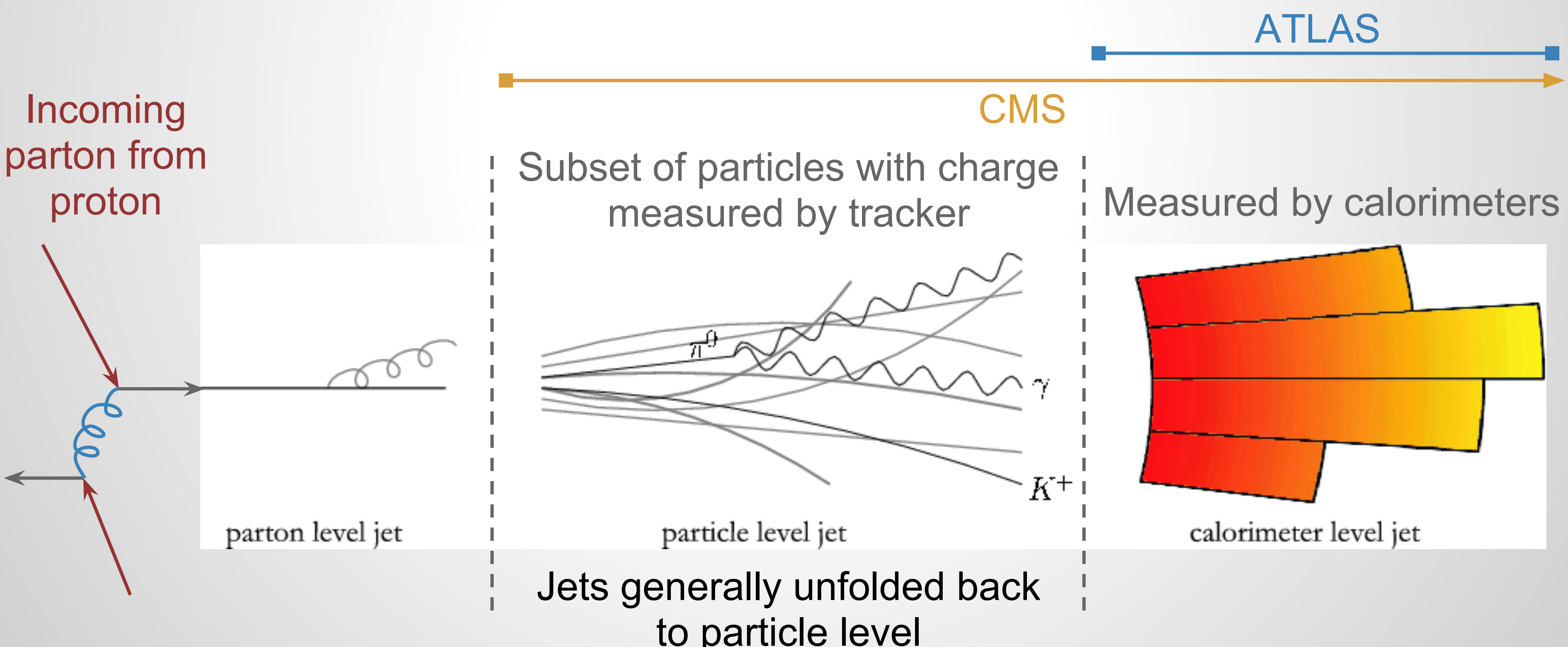
Jets at the LHC

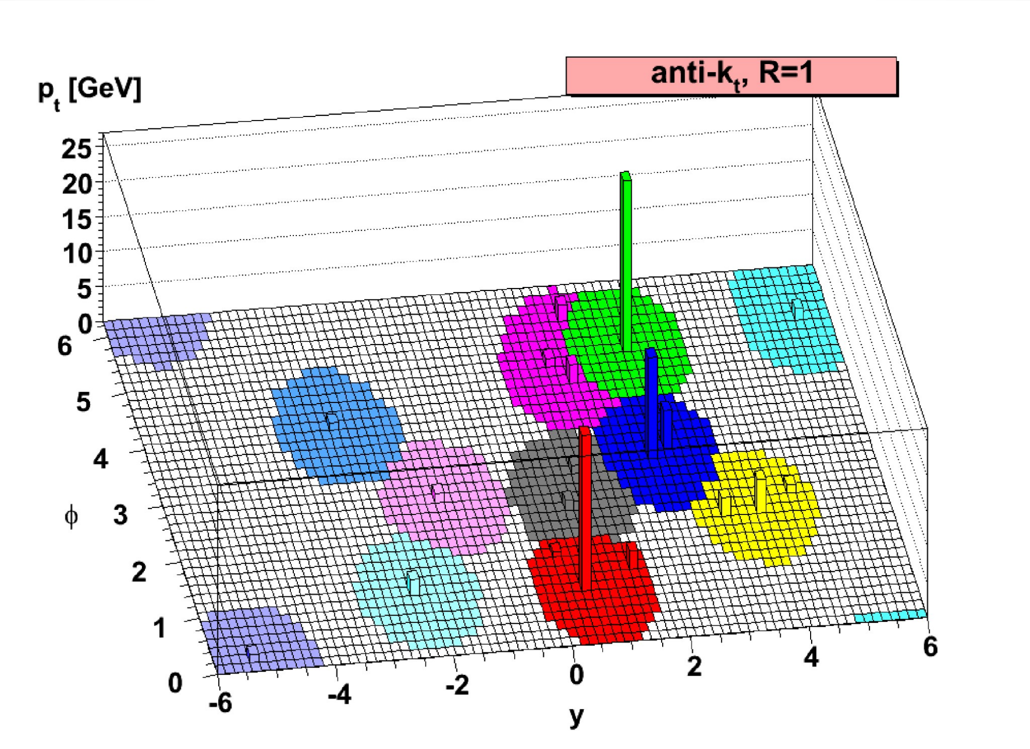
- Jets serve as proxy to final state partons
  - ATLAS uses a calorimeter with fine longitudinal segmentation, building jets from calorimeter clusters
  - CMS uses particle flow, building jets out of particles composed of information from several subdetectors



[Image by D. Gillber]

Jets at the LHC

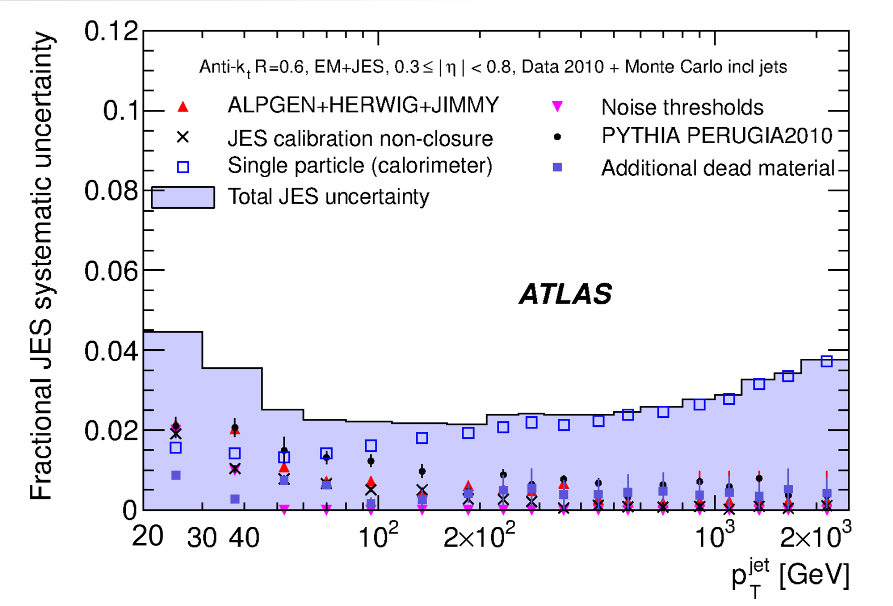
- Most measurements use the anti-k_T clustering algorithm
  - Infrared safe, idealized cone algorithm
  - Radius parameter R determines size of jet
    - $0.4 \leq R \leq 0.7$ used in most analyses
    - $R \geq 1.0$ used for jet substructure, boosted objects



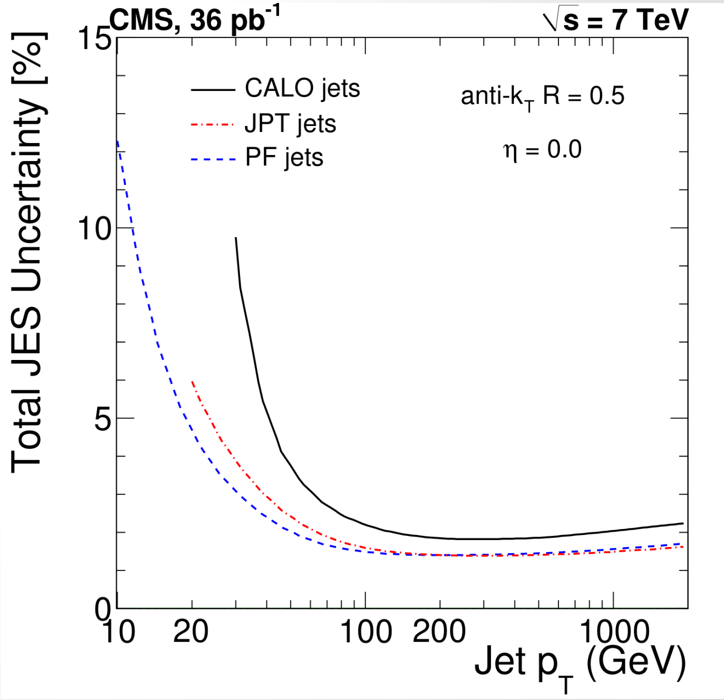
[JHEP 0804:063,2008]

Jet performance

- Jet energy calibration for 2010 derived using Monte Carlo simulation
  - Checked using data driven (jet-jet, photon-jet, etc...) techniques
- Uncertainty on jet energy calibration often dominates measurements
  - Increases as rapidity *y* increases
- 2011 uncertainty will show large decrease (expected soon)



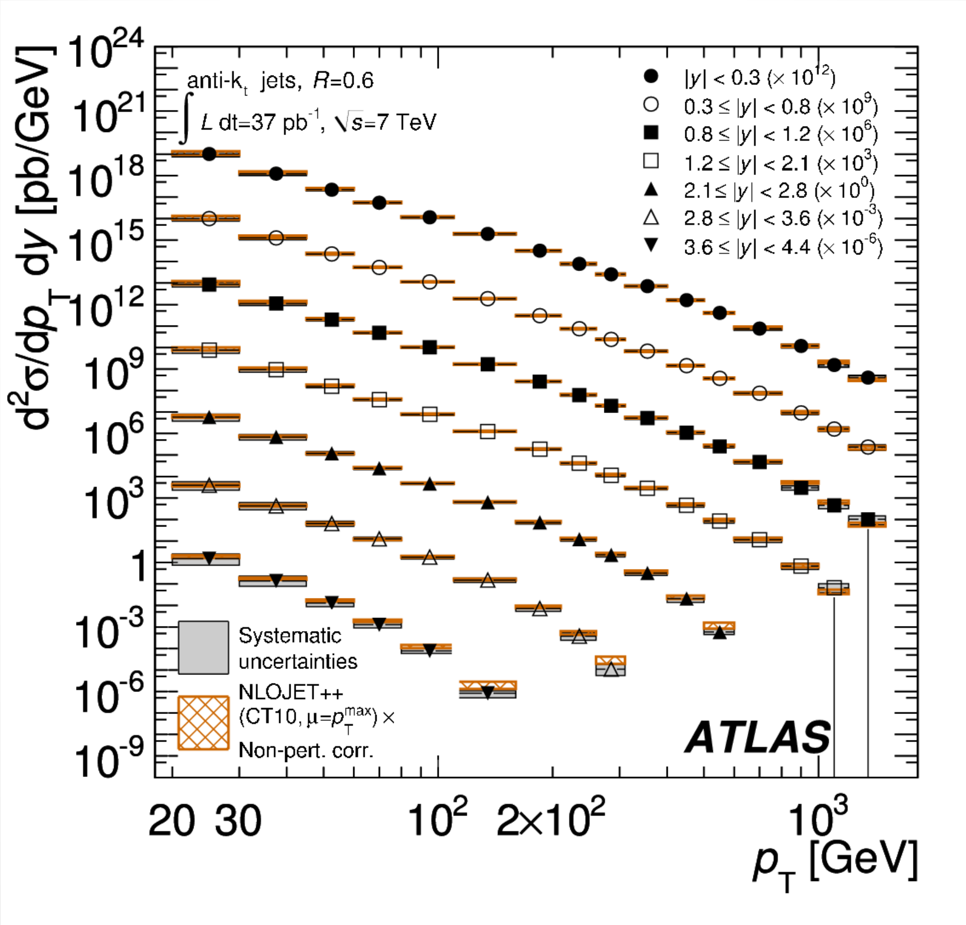
[arXiv:1112.6426v1]



[JINST 6 (2011) 11002]

Inclusive jet p_T cross section

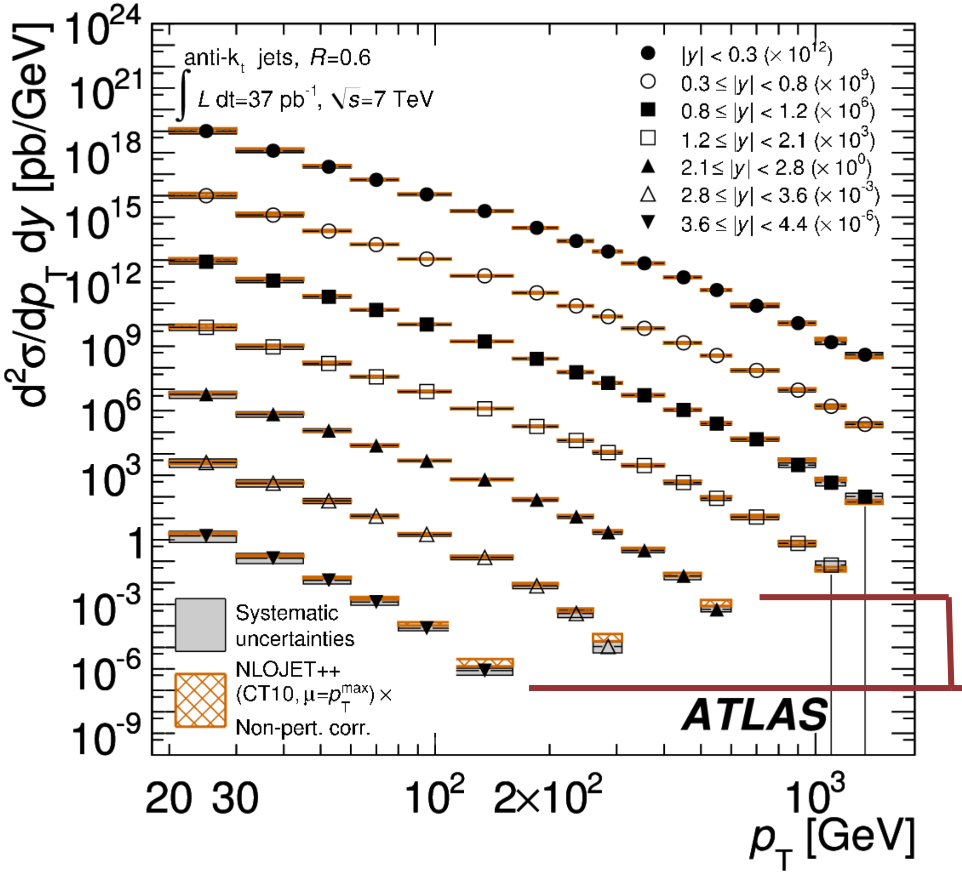
- Measure inclusive jet p_T spectra in bins of $|y|$
- 2010 measured jets with $20 < p_T < 1500$ GeV and $|y| < 4.4$

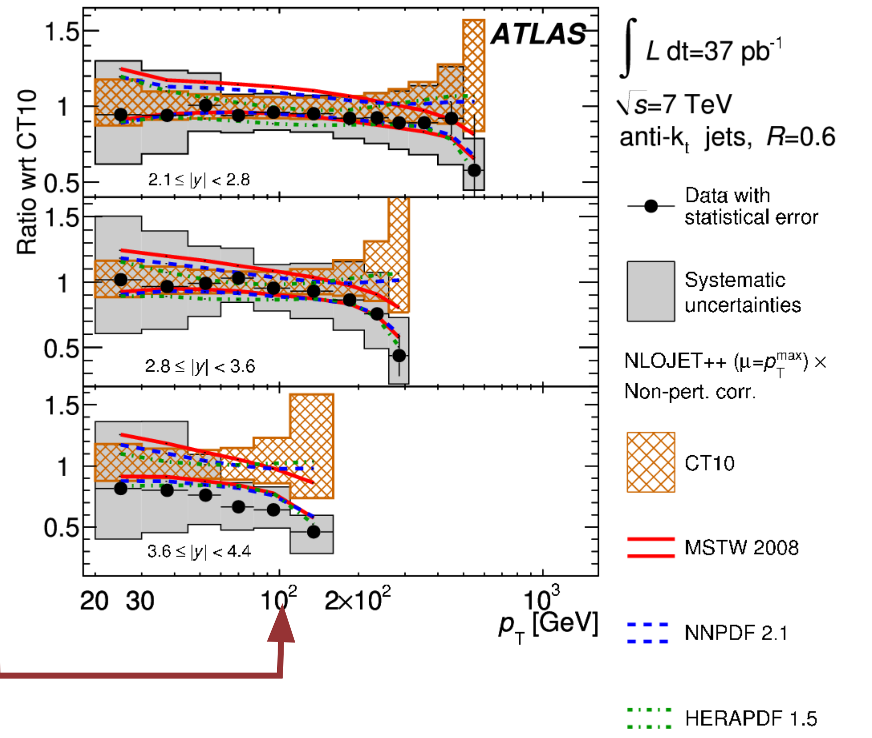


[arXiv:1112.6297v2]

Inclusive jet p_T cross section

- Generally good agreement seen
- Looking at $|y| > 2.1$ see tension between data, theory

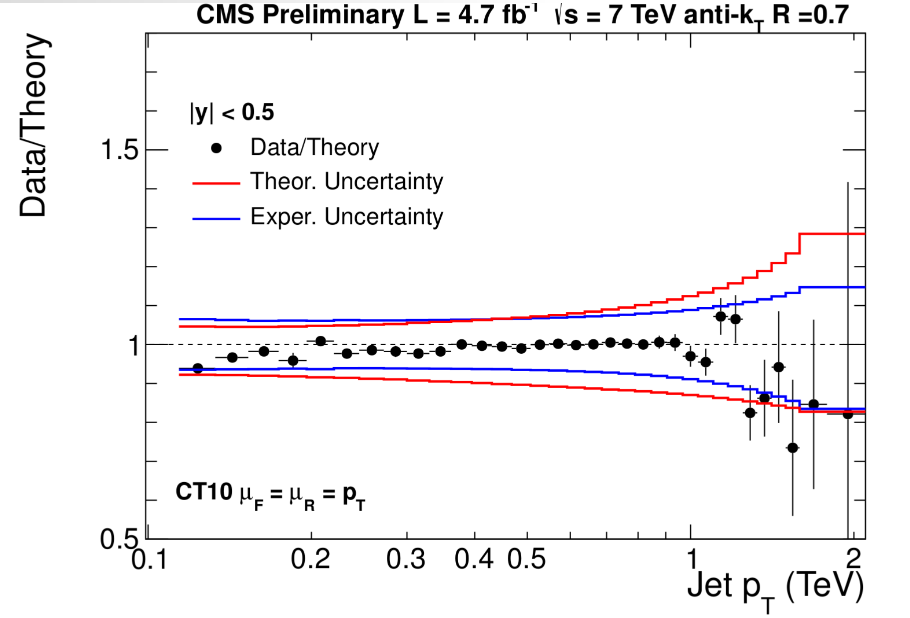


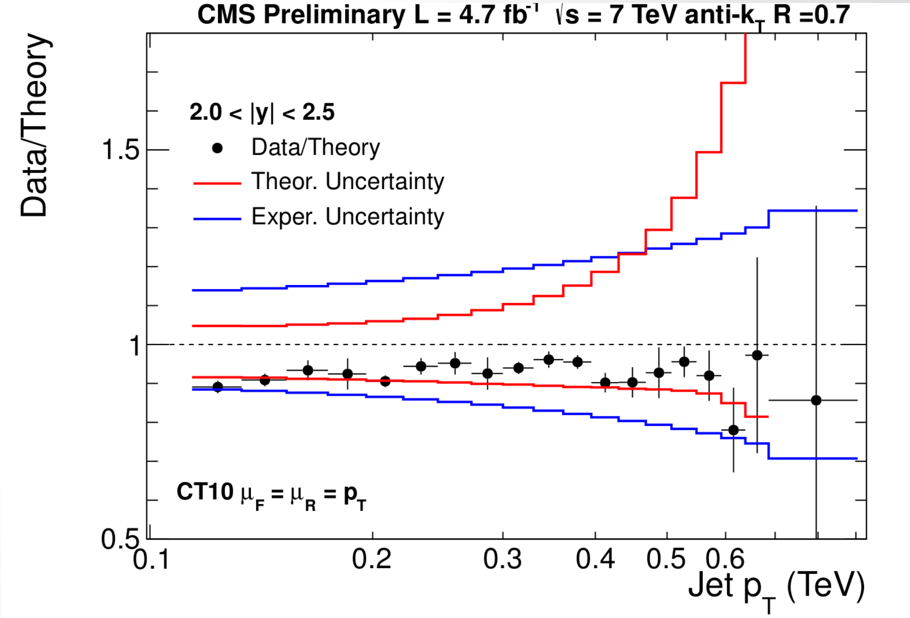


[arXiv:1112.6297v2]

Inclusive jet p_T cross section

- 2011 increased luminosity, measured out to *p_T ~ 2 TeV*
- Ratio with NLOJET++ theory calculation shown below
- Good agreement seen across large kinematic range
- Theory uncertainty dominated by PDF at large *p_T*

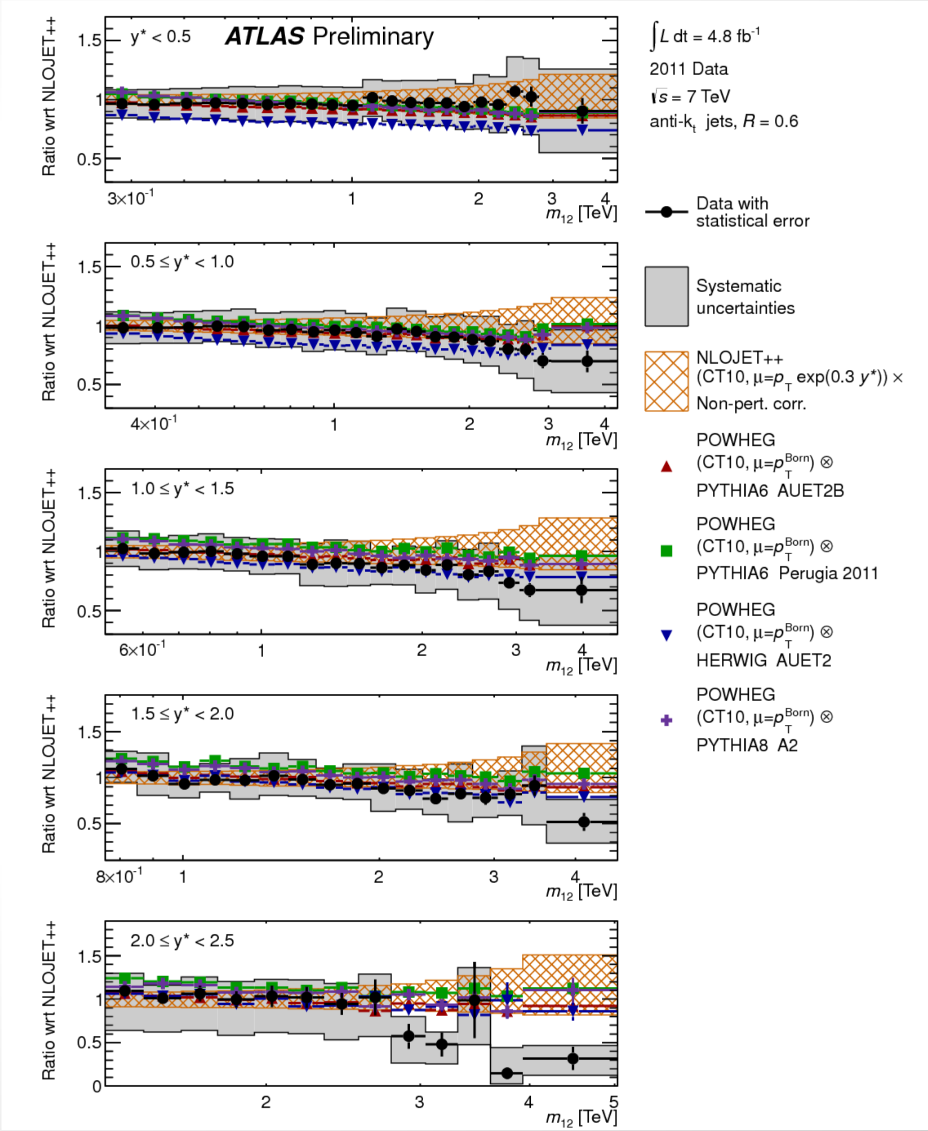




[CMS-PAS-QCD-11-004]

Dijet mass cross section

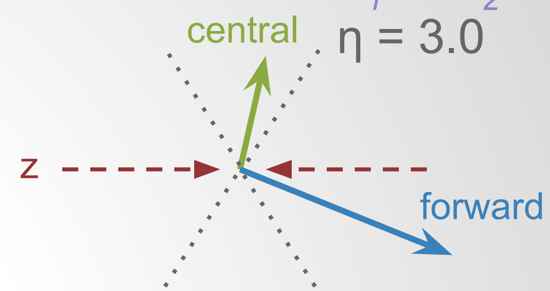
- Dijet mass m_{12} measurement in bins of $y^* = |y_1 - y_2|/2$
- Ratio with NLOJET++ theory calculation
- POWHEG (NLO matrix element + parton shower)
- Negative trend in data emerging at high m_{12}, large y^*
  - NLOJET++ larger than data
  - POWHEG+PYTHIA shows best shape agreement

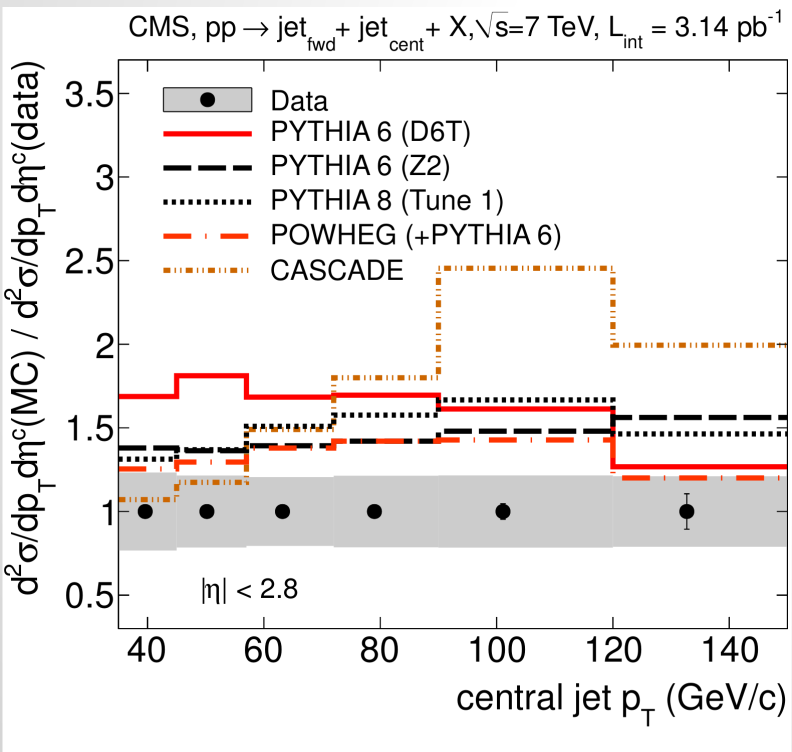


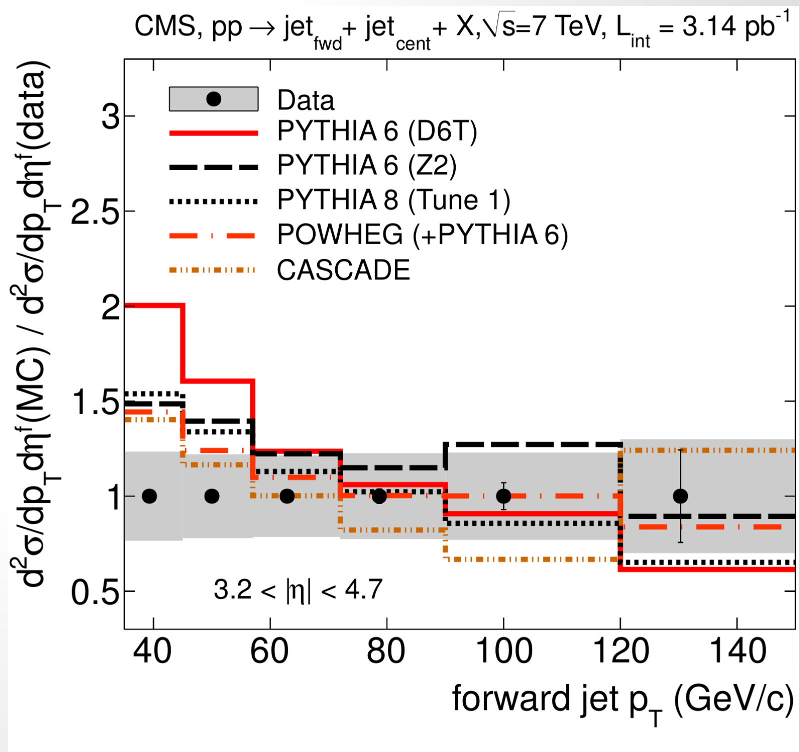
[ATLAS-CONF-2012-021]

Central + forward dijet systems

- Probe QCD for incoming partons with different momentum fraction $x_1 \ll x_2$
- Require one central jet ($|\eta| < 2.8$), one forward jet ($3.2 < |\eta| < 4.7$)
- Use highest p_T jet in each region for dijet system
- Ratio of jet p_T spectra, PYTHIA / data



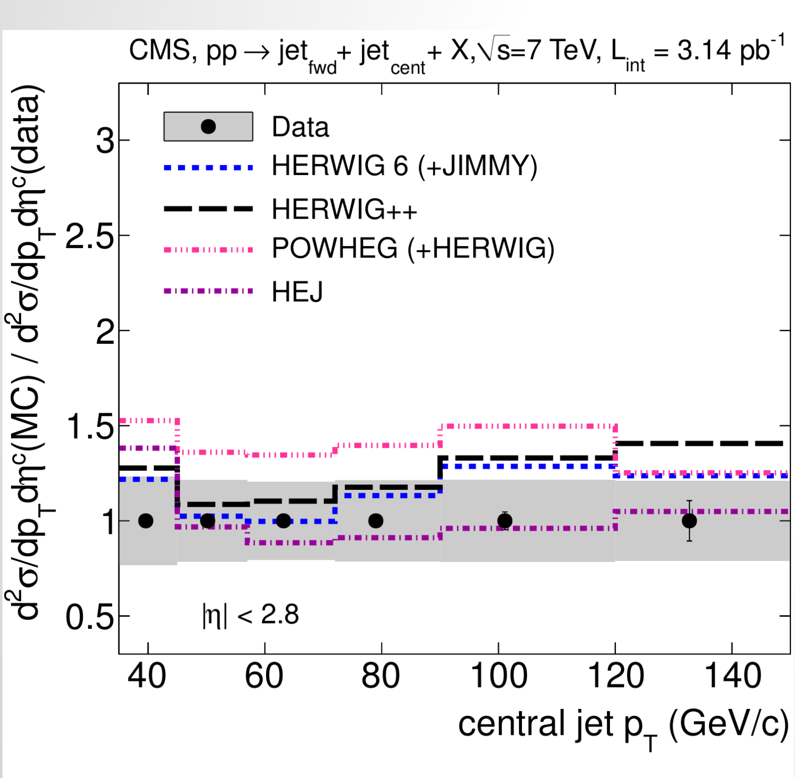


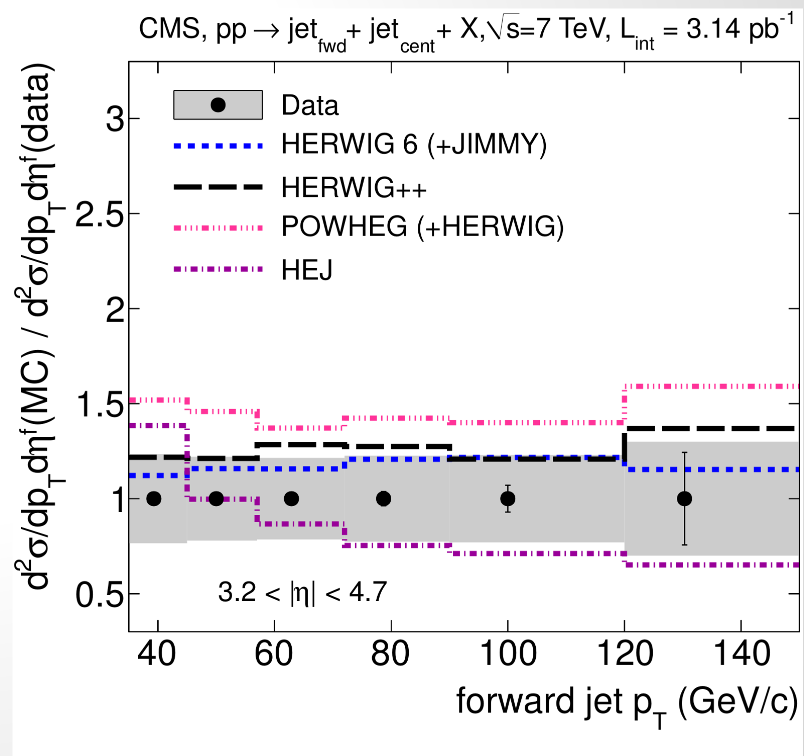


[arXiv:1202.0704v1]

Central + forward dijet systems

- HERWIG describes this observable better
  - Uses an angular ordering for parton showering
  - POWHEG+HERWIG shows normalization difference similar to POWHEG+PYTHIA

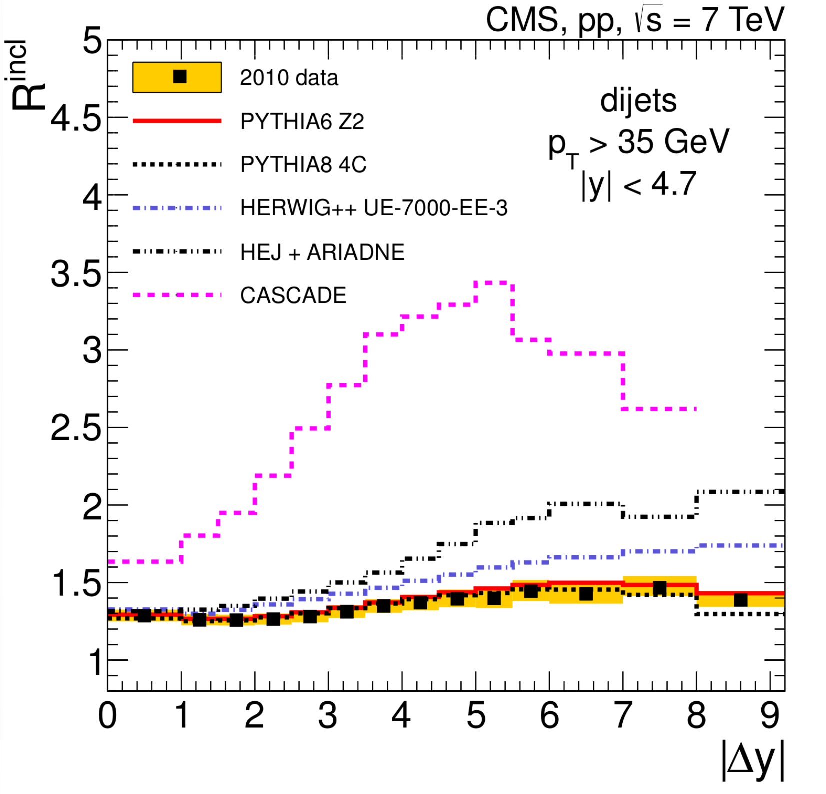


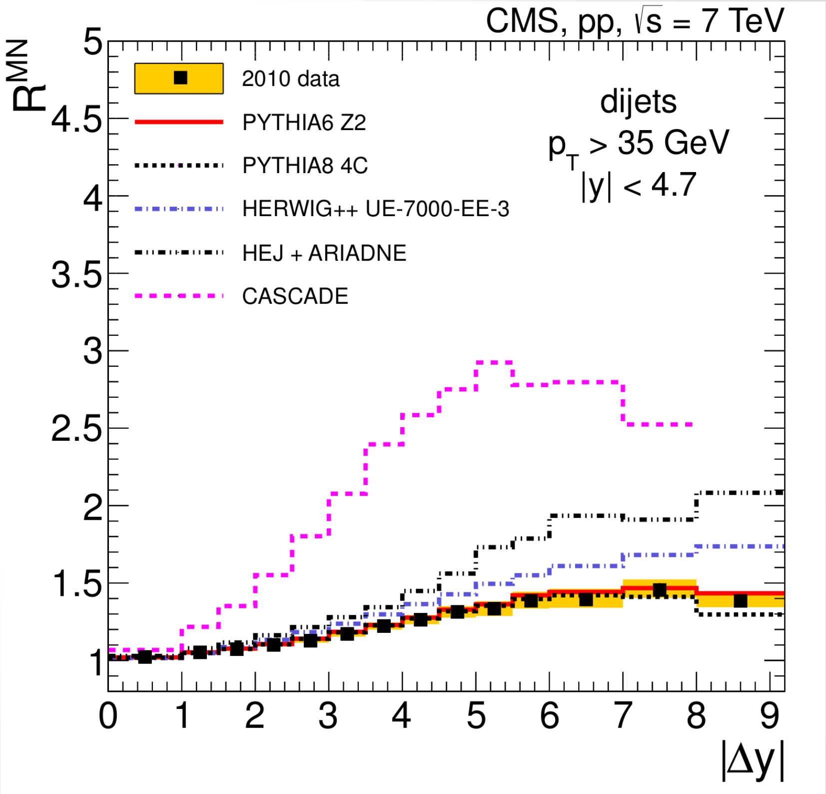


[arXiv:1202.0704v1]

Inclusive / exclusive dijet samples

- Sensitive to resummation of large *log(1/x)* terms (BFKL evolution)
- R^{incl} = inclusive ($N \geq 2$ jets, all combinations) / exclusive ($N = 2$ jets)
- R^{MN} = most forward backward pair ($N \geq 2$ jets) / exclusive ($N = 2$ jets)
- PYTHIA gives best description of data

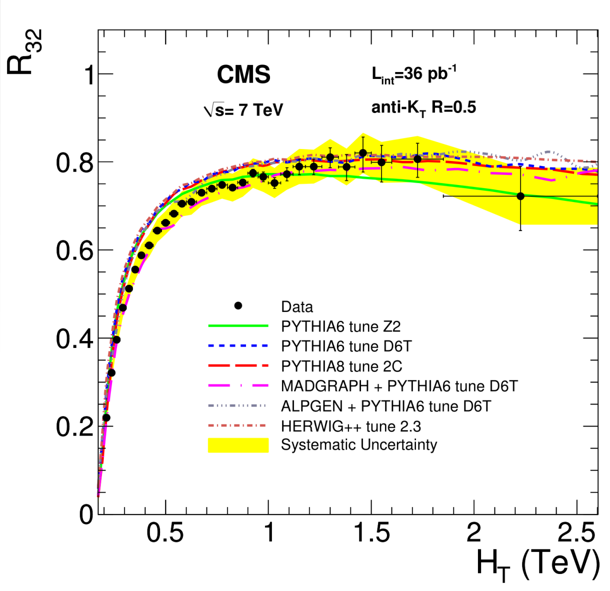


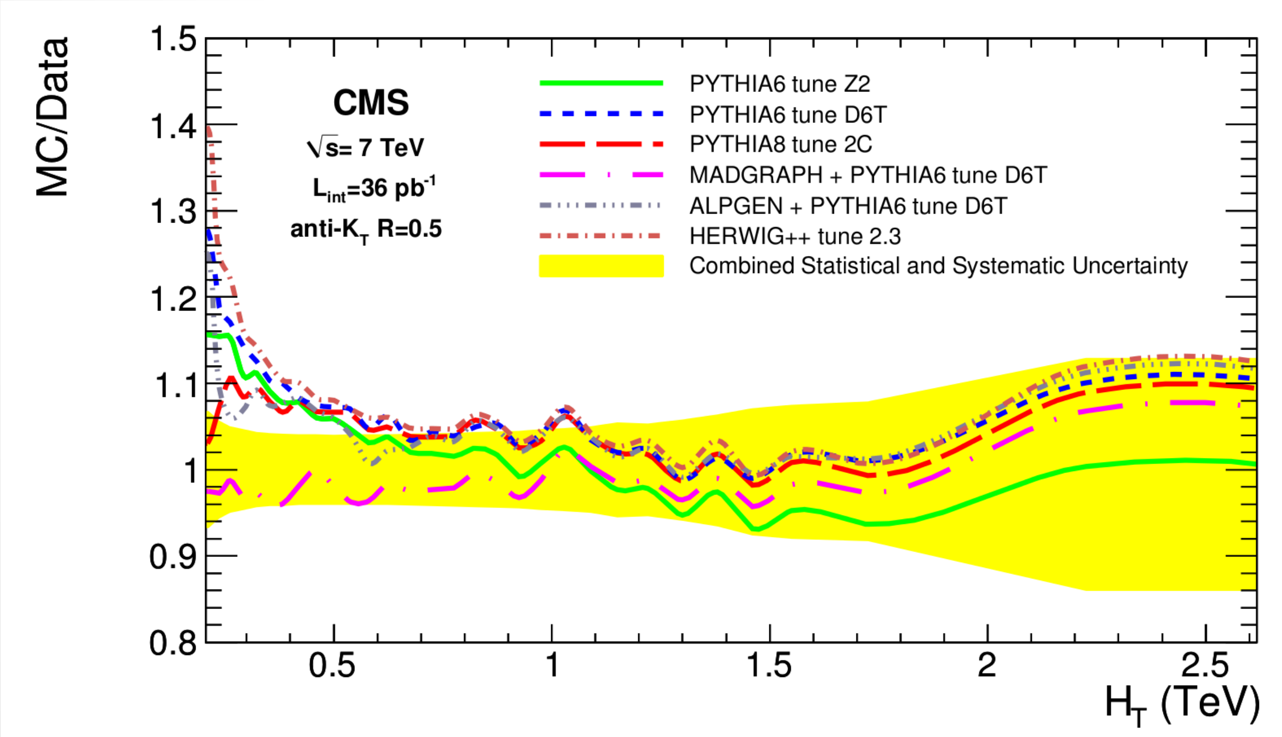


[arXiv:1112.6426v1]

3 jet / 2 jet ratio

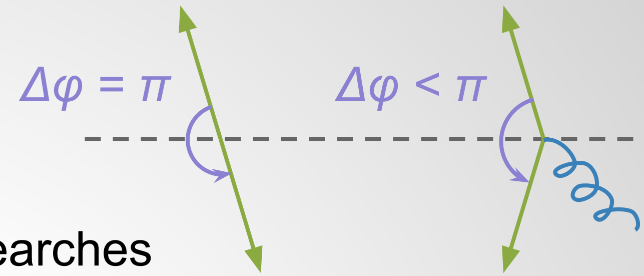
- Probe of next-to-leading order effects
- Ratio of events with $N \geq 3$ jets / $N \geq 2$ jets
- Measured vs. $H_T = \Sigma\ jet\ p_T$
- Good agreement above $H_T = 500$ GeV



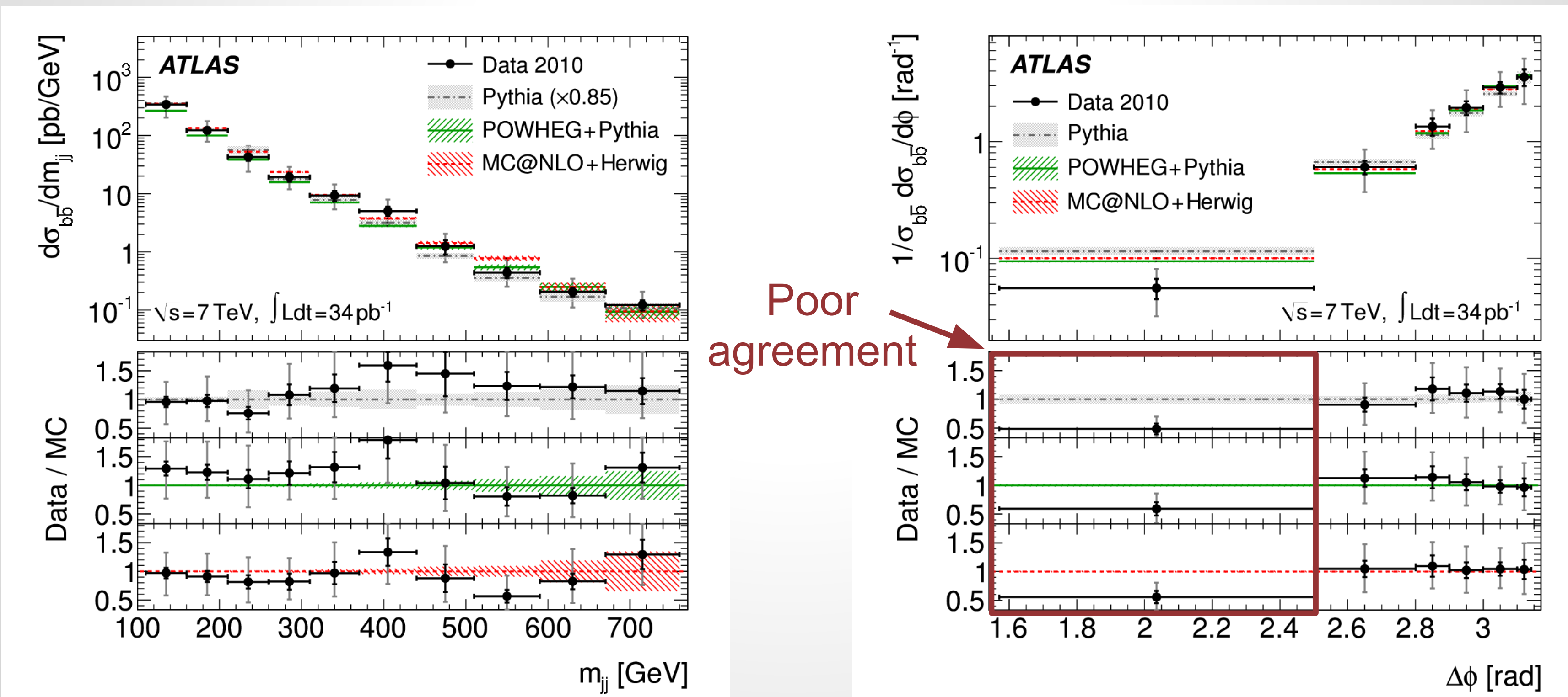


[Phys. Lett. B 702 (2011) 336-354]

b-jet production



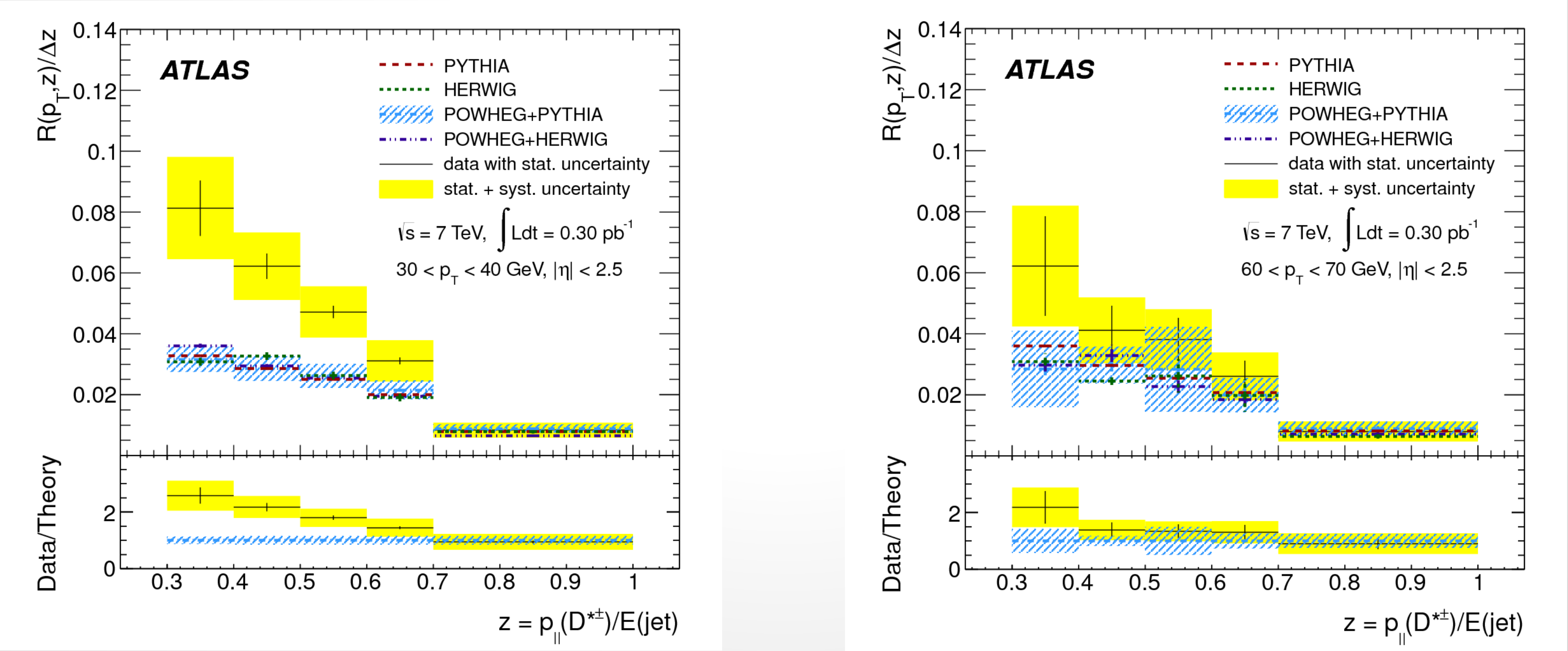
- Production of jets from b-hadrons
  - Important background for new physics searches
- Dijet mass m_{jj} shows agreement with NLO theory
- $\Delta\varphi$ dominated by back to back systems
  - Poor agreement seen for systems with radiation (smaller $\Delta\varphi$)



[Eur.Phys.J.C 71 (2011) 1846]

$D^{*\pm}$ production in jets

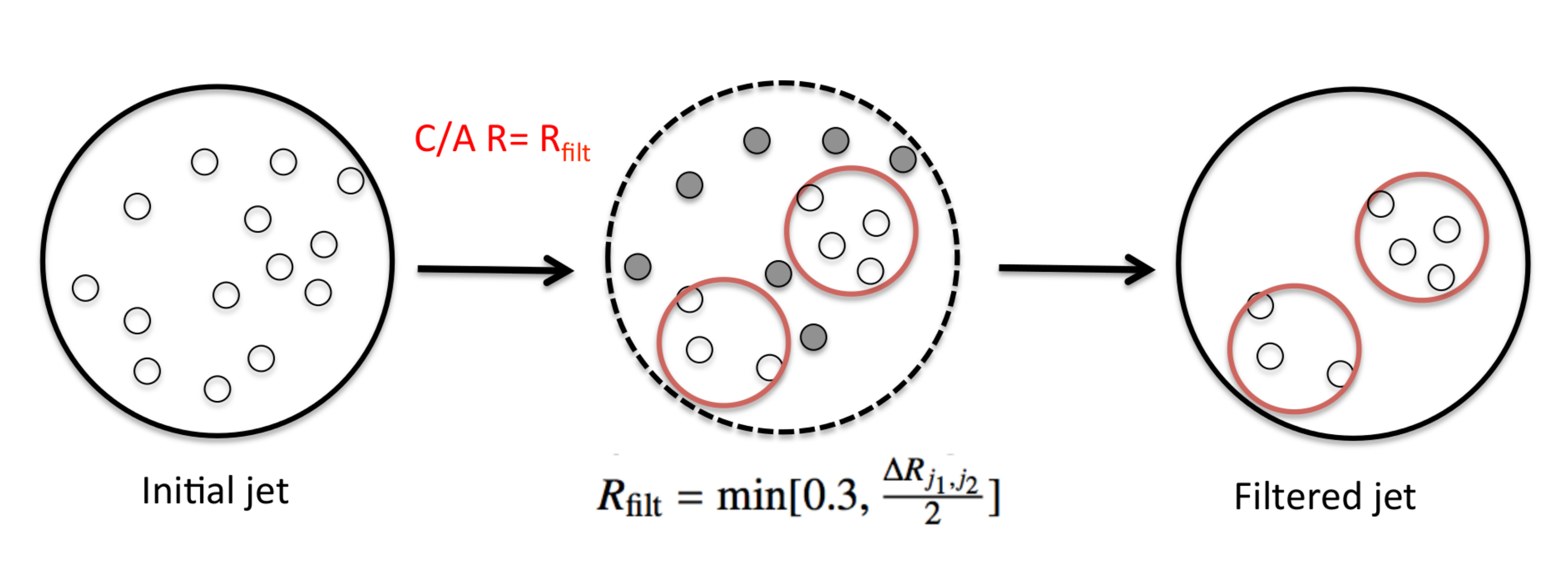
- Production of $D^{*\pm}$ mesons in jets tests MC hadronization description
    - Important for understanding backgrounds for new physics
- Plotted vs. z = ($D^{*\pm}$ momentum along jet axis) / (jet energy)
- Best agreement seen at large $D^{*\pm}$ momentum fraction z
- Theory shows large discrepancy with data at low jet p_T



[Phys. Rev. D85 (2012) 052005]

Jet substructure

- Useful for identifying hadronic decays of boosted heavy particles
  - Important to check parton-shower modelling in Monte Carlo
- Splitting / filtering with Cambridge-Aachen *R = 1.2* jets
  - Undo clustering of jet until large mass drop observed
- Robust against the effects of muliple proton-proton interactions



[arXiv:1203.4606v1]

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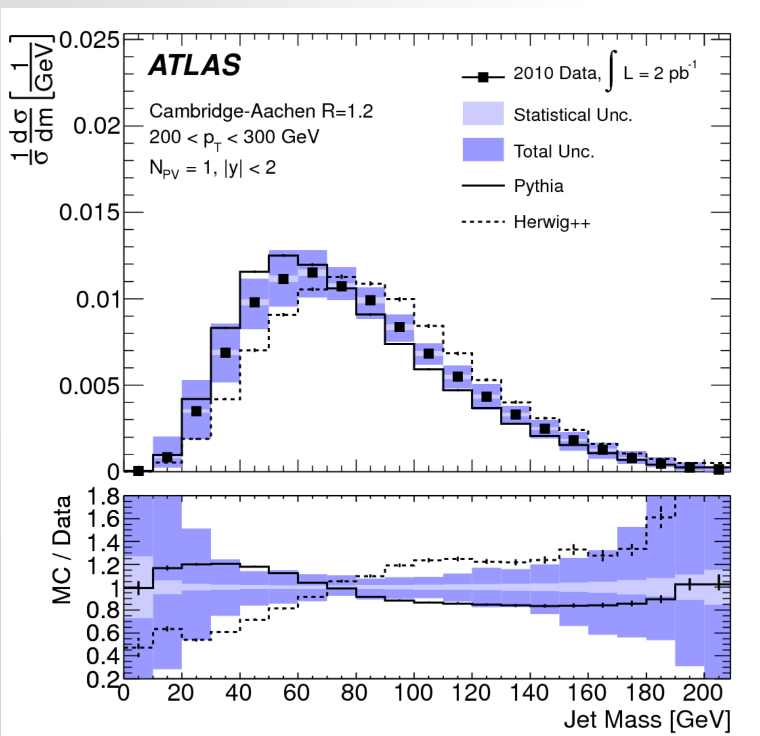
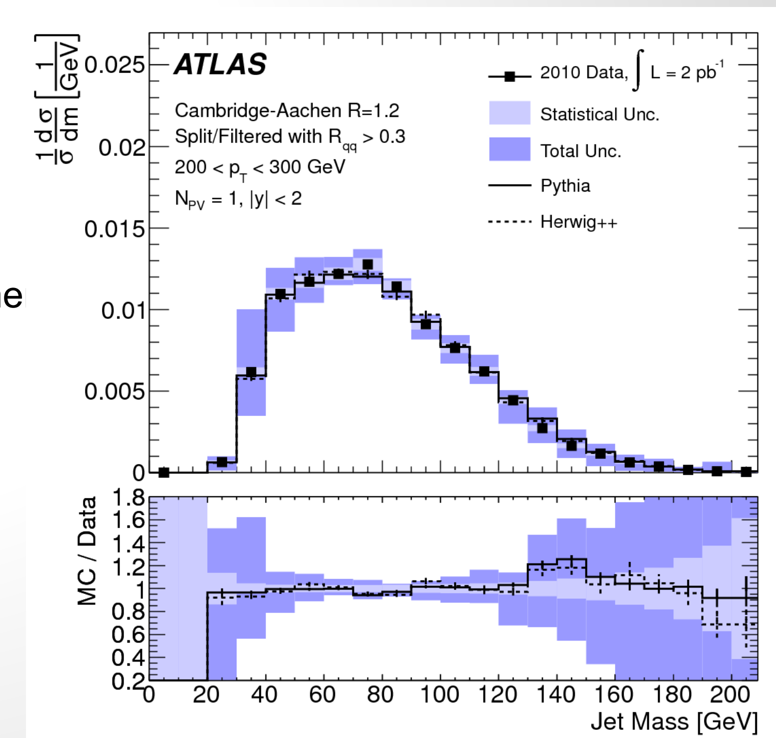


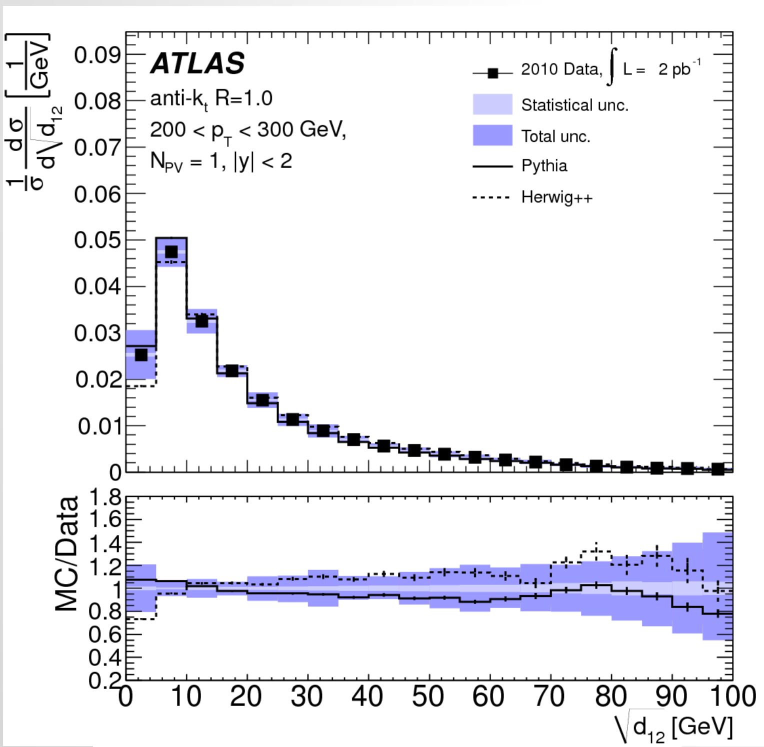
mproved agreeme
after splitting /
filtering

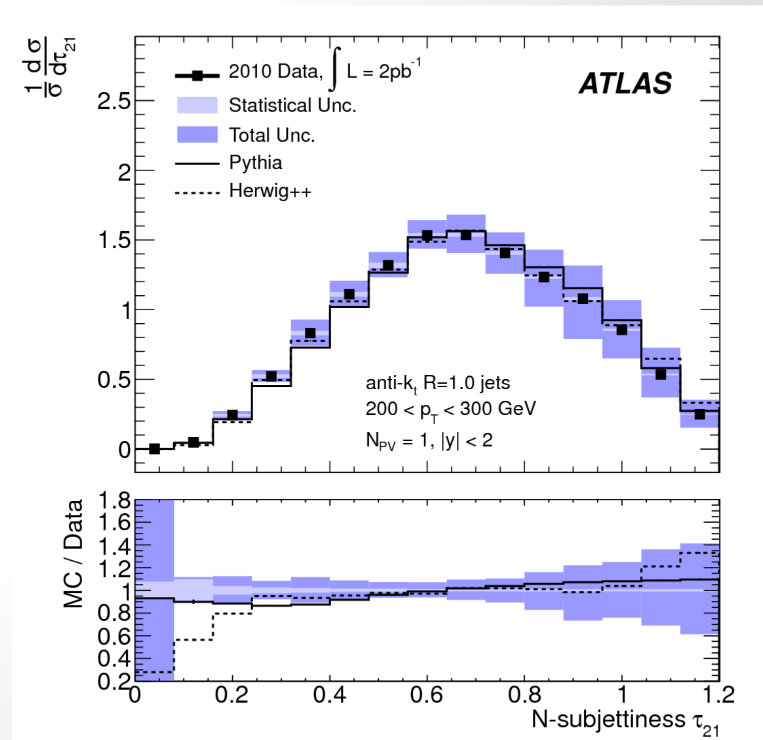


[arXiv:1203.4606v1]

Jet substructure

- k_t splitting scale $\sqrt{d_{ij}}$: kinematic threshold for breaking jets into subjets
- N-subjettiness: "How much does this jet look like N different subjets?"
- Monte Carlo prediction describes data well





$$\sqrt{d_{12}} = \min(p_{Tj1}, p_{Tj2}) \times \delta R_{j1,j2},$$

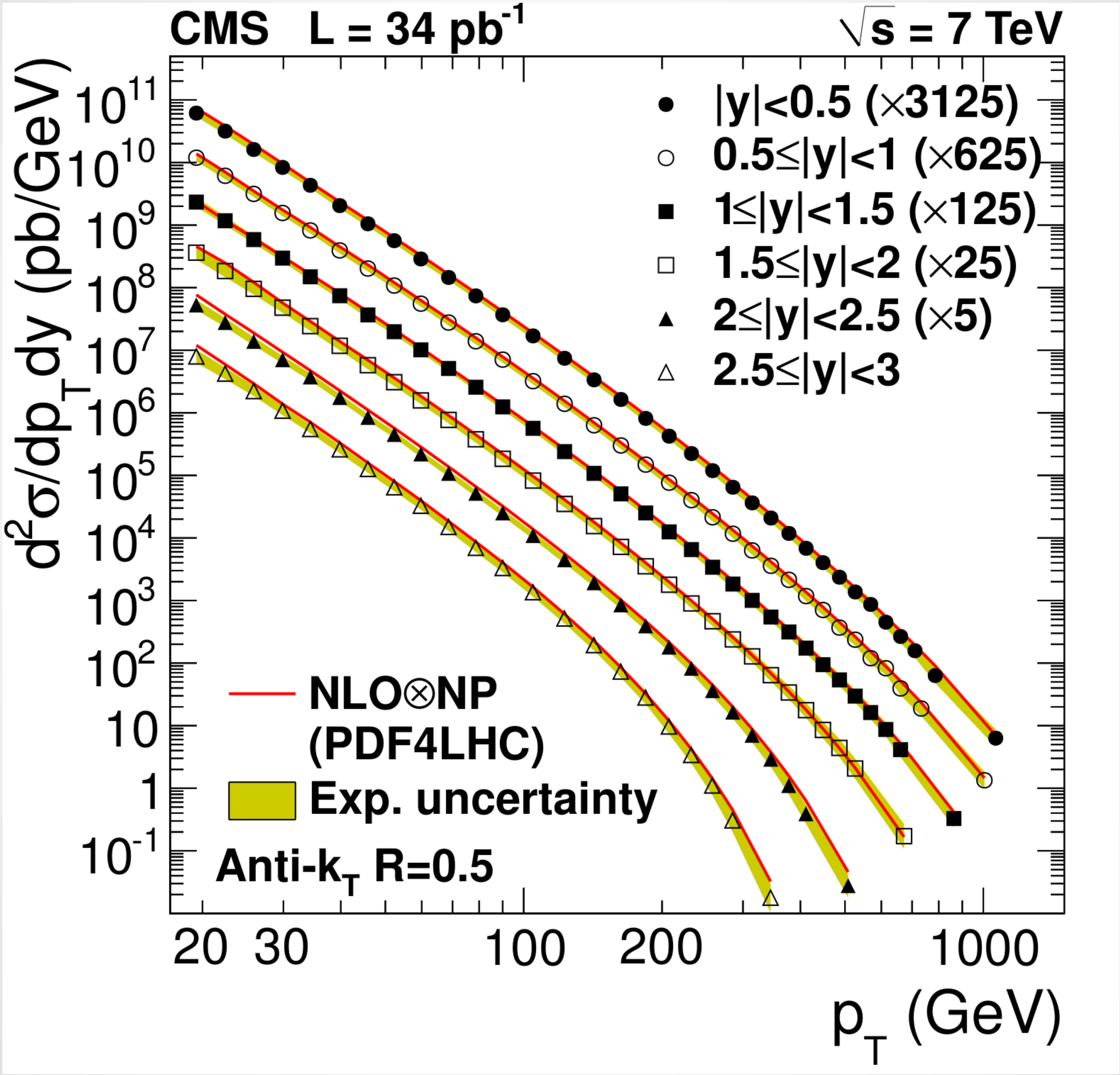
[arXiv:1203.4606v1]

Summary

- Theory predictions describe data well over large kinematic region
- Discrepancies seen for:
  - High p_T, m_{12}, and large y
  - Radiation (NLO, NNLO effects)
  - Heavy flavor fragmentation functions
- Many ongoing analyses probing these effects
  - 2010/2011 used to tune theory in previously unexplored regime
  - 2012 will bring exciting new results

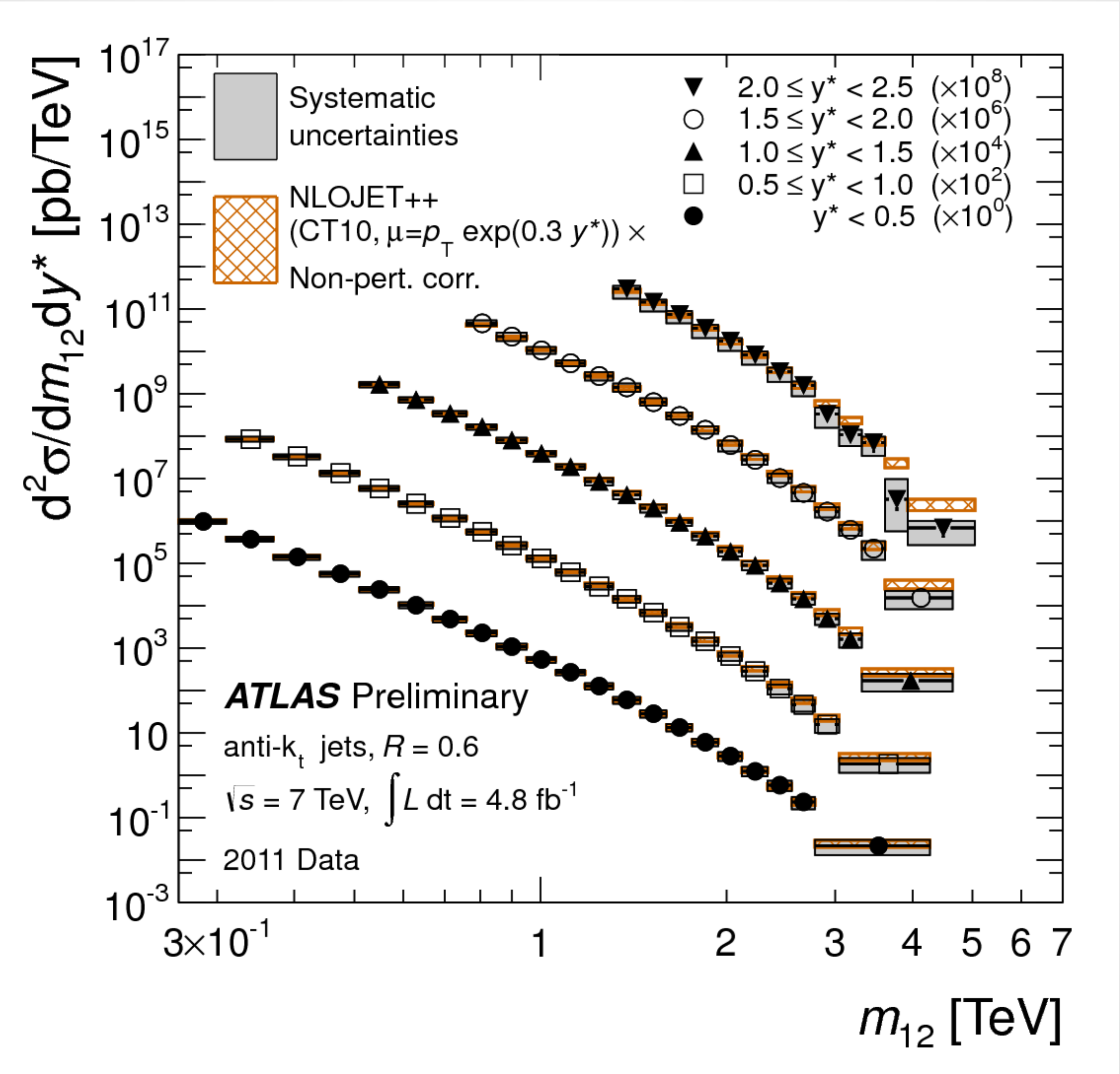
Backup material

Inclusive jet cross section



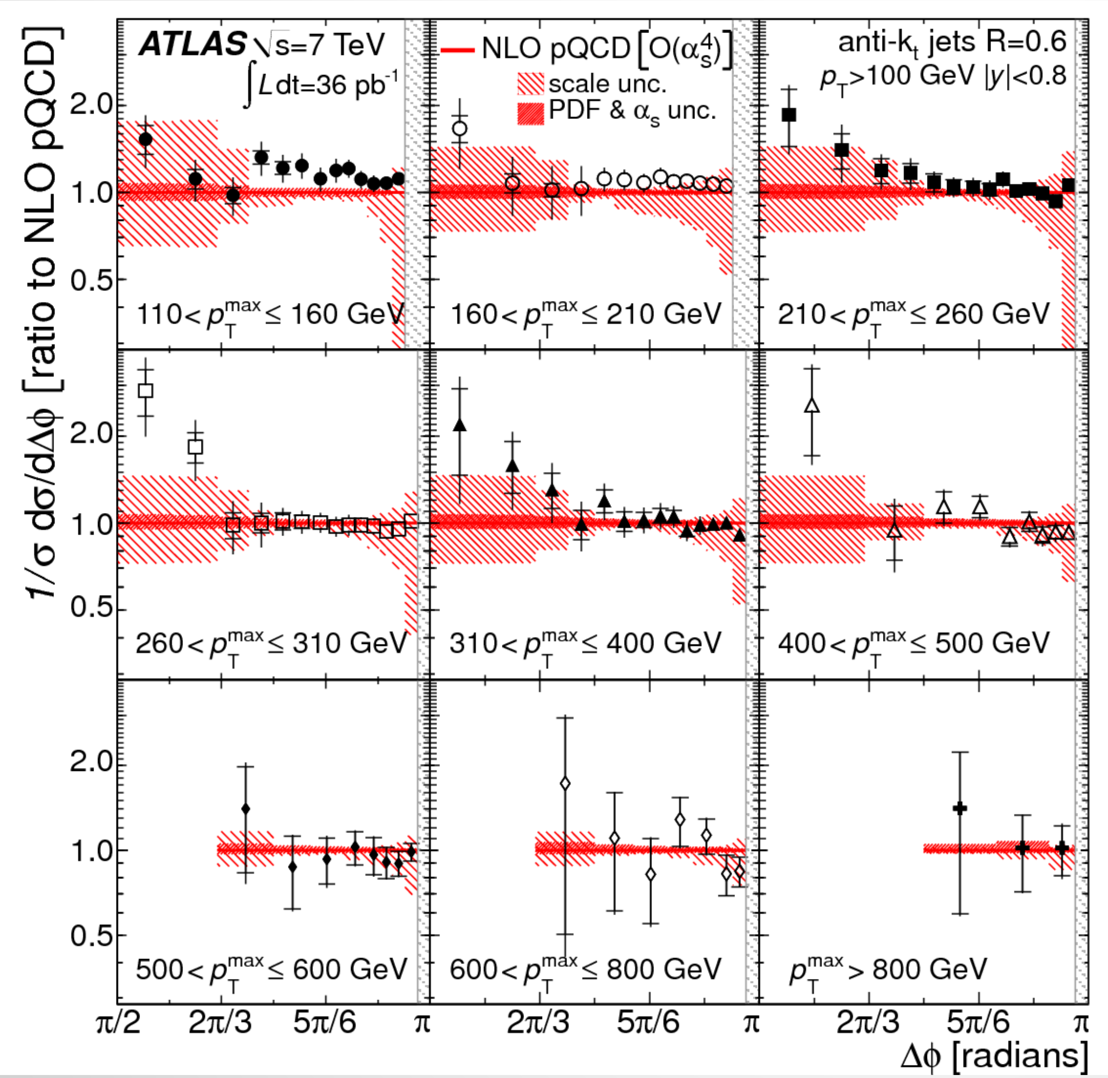
[Phys.Rev.Lett.107:132001,2011]

Inclusive jet cross section



[ATLAS-CONF-2012-021]

Azimuthal decorrelations

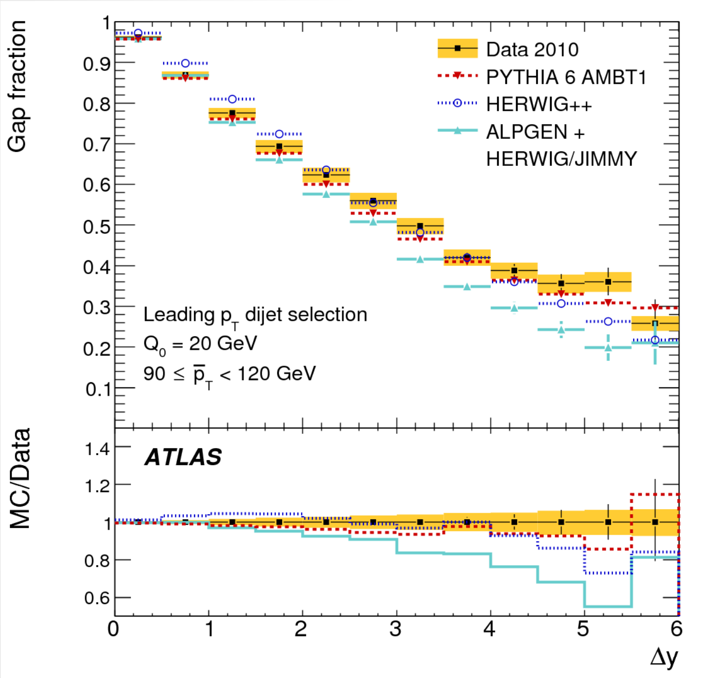


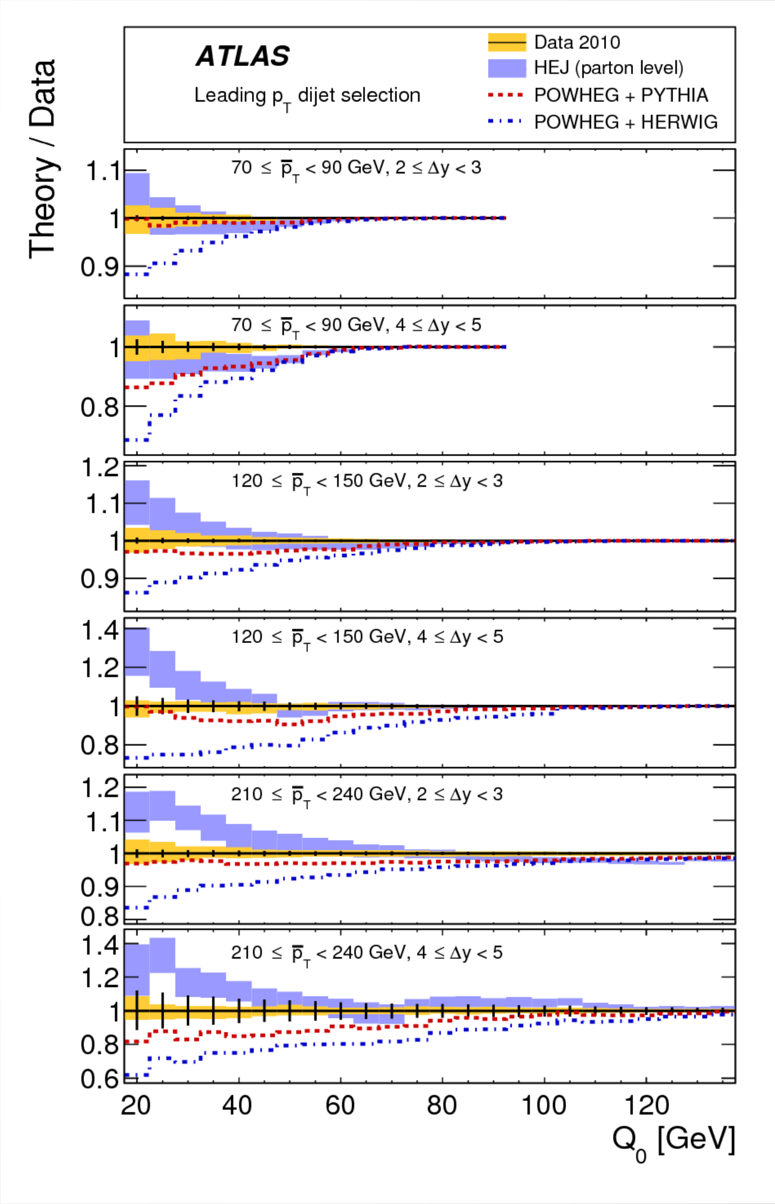
- Measure $\Delta\varphi$ between highest p_T jets
- Probe of third jet activity without measuring third jet
- Data poorly described at low p_T, large $\Delta\varphi$

[Phys. Rev. Lett. 106 (2011) 172002]

Rapidity gap measurement

- Gap fraction: events with no jet activity above with $p_T > Q_0$ inside dijet Δy
- POWHEG + PYTHIA describes data best
- Low Q_0 shows larger disagreement (poor modelling of soft gluon emission)

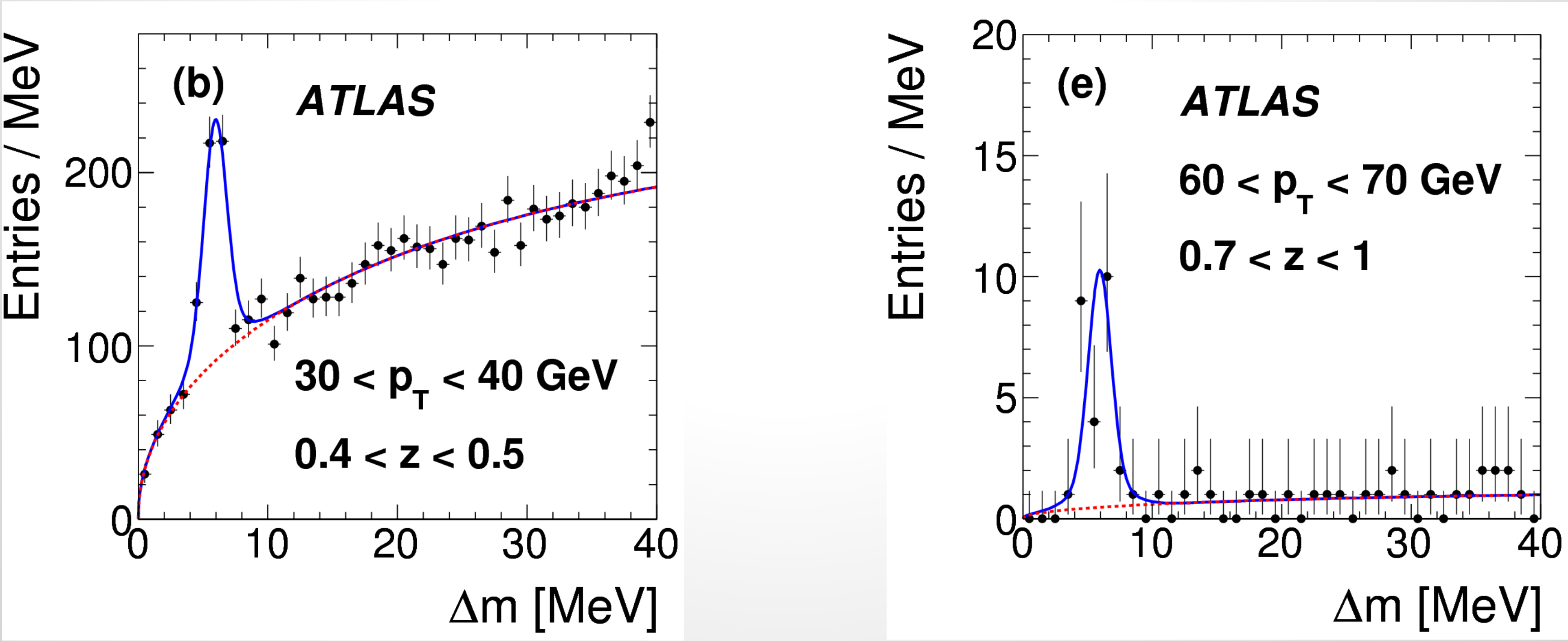




[JHEP 1109 (2011) 053]

$D^{*\pm}$ production in jets

- Production of $D^{*\pm}$ mesons inside jets
  - D^{*+} □ $D^0\,\pi^+$ □ $(K^-\,\pi^+)\,\pi^+$ (and charge conugate)
- Test of fragmentation function description in generators
- Plotted by z = ($D^{*\pm}$ momentum along jet axis) / (jet energy)
- Yield extracted from mass distribution Δm
  - $\Delta m = m(K^-\,\pi^+\,\pi^+) - m(K^-\,\pi^+) - m(\pi^+)$



[Phys. Rev. D85 (2012) 052005]

Splitting and filtering procedure

Each stage in the clustering combines two objects j_1 and j_2 to make another object j. Use definitions $v = \frac{\min(p_{Tj1}^2, p_{Tj2}^2)}{m_j^2} \delta R_{j1,j2}^2$ and $\delta R_{j1,j2} = \sqrt{\delta y_{j1,j2}^2 + \delta \phi_{j1,j2}^2}$, where δy and $\delta \phi$ are the differences in rapidities and azimuthal angles respectively. The procedure takes a jet to be the object j and applies the following:

1. Undo the last clustering step of j to get j_1 and j_2. These are ordered such that their mass has the property $m_{j1} > m_{j2}$. If j cannot be unclustered (i.e. it is a single particle) or $\delta R_{j1,j2} < 0.3$ then it is not a suitable candidate, so discard this jet.

2. If the splitting has $m_{j1}/m_j < \mu$ (large change in jet mass) and $v > v_{\mathrm{cut}}$ (fairly symmetric) then continue, otherwise redefine j as j_1 and go back to step 1. Both μ and v are parameters of the algorithm.

3. Recluster the constituents of the jet with the Cambridge-Aachen algorithm with an R-parameter of $R_{filt} = \min(0.3, \delta R_{j1,j2}/2)$ finding n new subjets s_1, $s_2 \ldots s_n$ ordered in descending p_{T}.

4. Redefine the jet as the sum of subjet four-momenta $\sum_{i=1}^{\min(n,3)} s_i$.

The algorithm parameters μ and v_{cut} are taken as 0.67 and 0.09 respectively [19].

[arXiv:1203.4606v1]

Jet substructure

k_t **splitting scales**: prior to final clustering of j_1 and j_2 of the jet:

$$\sqrt{d_{12}} = \min(p_{Tj1}, p_{Tj2}) \times \delta R_{j1,j2},$$

N-subjettiness: Sum over all constituents k of the jet:

$$\tau_N = \frac{1}{d_0} \sum_k p_{T,k} \times \min(\delta R_{1,k}, \delta R_{2,k}, \ldots, \delta R_{N,k})$$

$$d_0 = \sum_k p_{T,k} R,$$

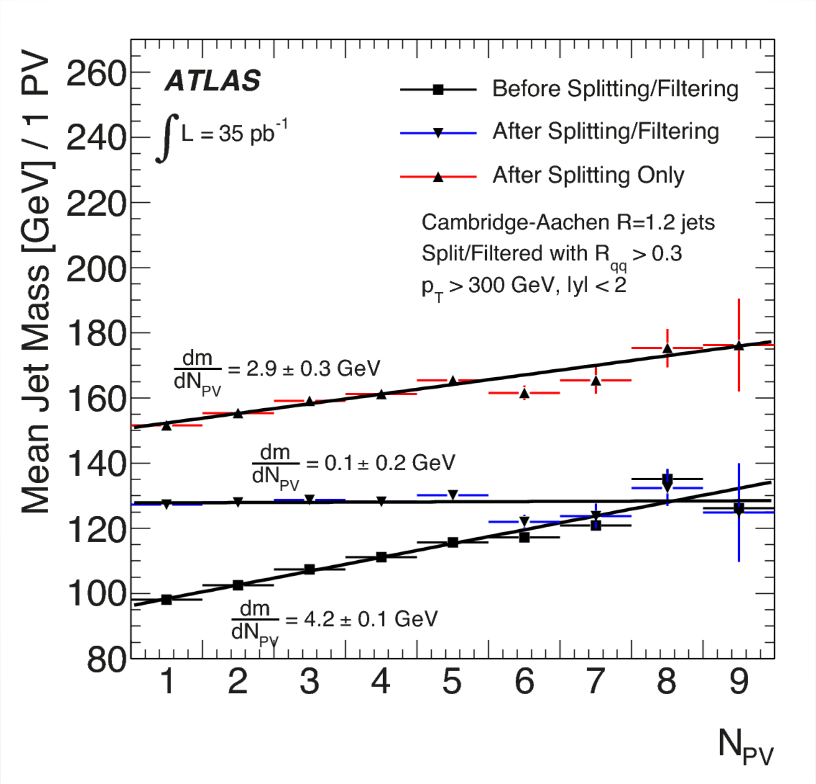
$$T_{21} = T_2 / T_1$$

"How much does this jet look like N different subjets?"

[arXiv:1203.4606v1]

Jet substructure

- Splitting / filtering with Cambridge-Aachen *R = 1.2* jets
  - Undo clustering of jet until large mass drop observed
- Robust against the effects of muliple proton-proton interactions



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