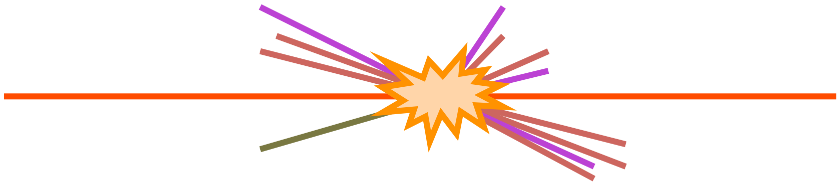
W/Z/ttbar+jets

LHC & Tevatron



W. H. Bell

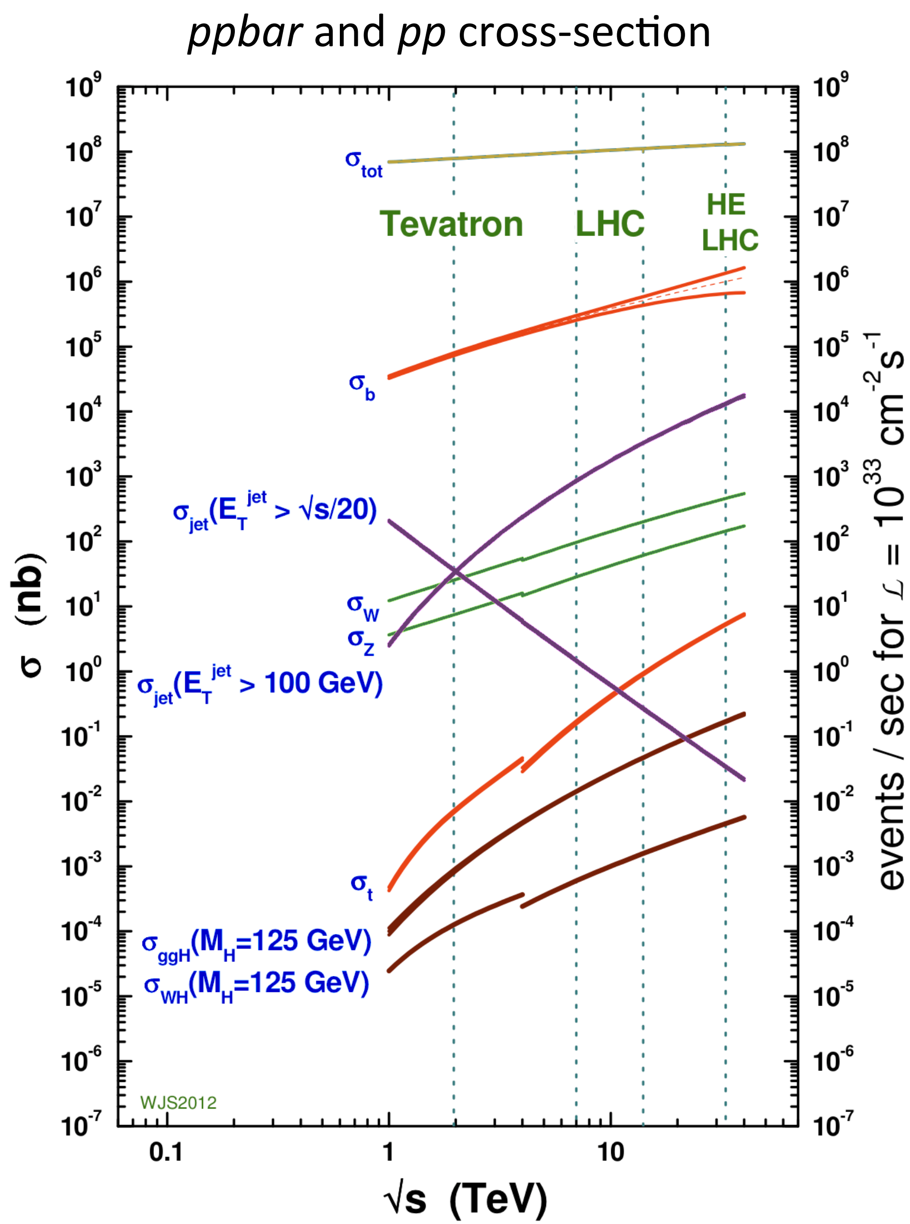
Université de Genève

Outline

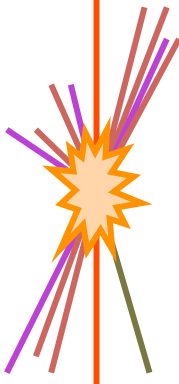
- Motivation
- MC models
- Types of measurements
- Selected results from LHC and Tevatron
  - Z+jets
  - W+jets
  - Ttbar+jets
- Conclusions

Motivation

- Test pQCD predictions
  - PDFs - probe region of high Q^2 and low x.
    - Test flavour fractions with associated HF production
    - LHC probes gluons and sea quarks
  - Difficult to provide NLO predictions at higher multiplicities
  - Fixed order matrix element and parton shower matching more difficult with NLO predictions.
- Constrain background processes, needed for:
  - Ttbar, single top, VBF, WW-scattering
  - Higgs studies
  - BSM searches



W/Z/ttbar+jet analyses



- Analyses performed at Tevatron and LHC
  - LHC – much higher cross-sections
- Additional jet production significantly higher at LHC.
  - Differential spectra available with respect to kinematic variables.

MC models

- Two approaches
  - Fixed order generators e.g. NLO(Np=0), LO(Np=1), LL(Np>=2)
    - PS (LL) jet p_T spectrum can be too soft or hard depending on the scheme applied.
    - *Examples:* MC@NLO, POWHEG, MCFM (Np<=2), BlackHat+SHERPA (Np<=4)
  - Multi-leg generators e.g. LO(Np<=5), LL(>5).
    - Require tuning, since sensitive to scale choice
    - Ratio of Np/Np+1 tuned (uncertainties of ~10%)
    - *Examples:* ALPGEN LO(Np<=5), LL(>5), MadGraph LO(Np<=5), LL(>5), Pythia LO(Np<=1), LL(>1), SHERPA (Comix)
- QCD ISR/FSR uncertainties remain significant for ttbar processes.
  - Tune multi-leg generators ME and PS scales.
  - Tune radiation parameters in NLO generators, e.g. h_{damp} in POWHEG.

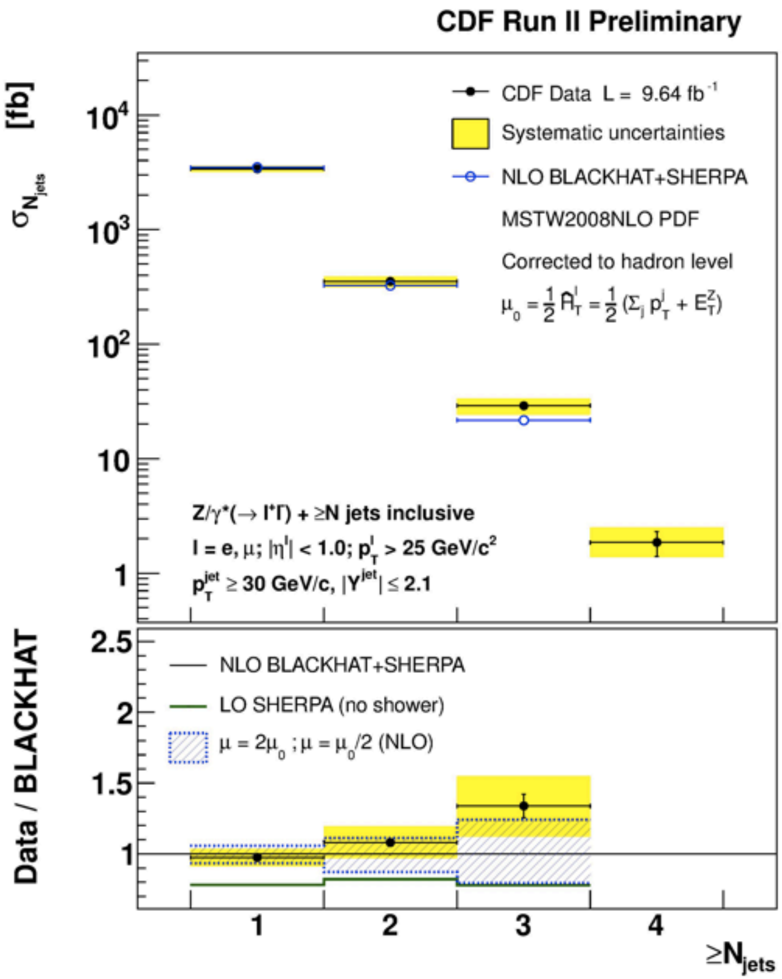
Presenting measurements

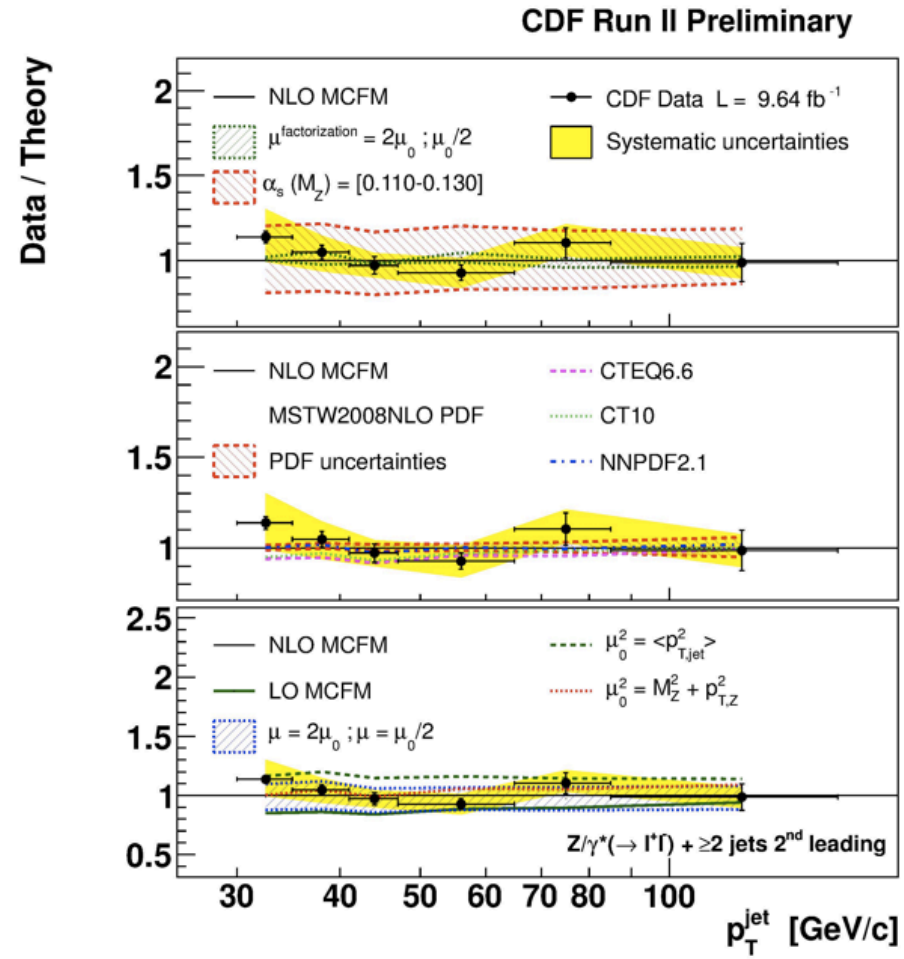
- Corrected for all detector effects
- Avoid correction back to parton multiplicities
  - Additional parton jet multiplicity smeared across several jet multiplicity bins
  - Additional parton jet multiplicities – function of p_T cut on partons, large variations for different MC
- Correct to jets of stable particles
  - After the removal of leptons (e,μ,ν) from W and Z decays
  - Correct fixed order NLO generators for non-pQCD effects (fragmentation & underlying event)

Z+jets – CDF

NLO BlackHat+Sherpa in agreement with data.

Scale and α_s variations important across range.
Separate PDF error sets – small shifts.

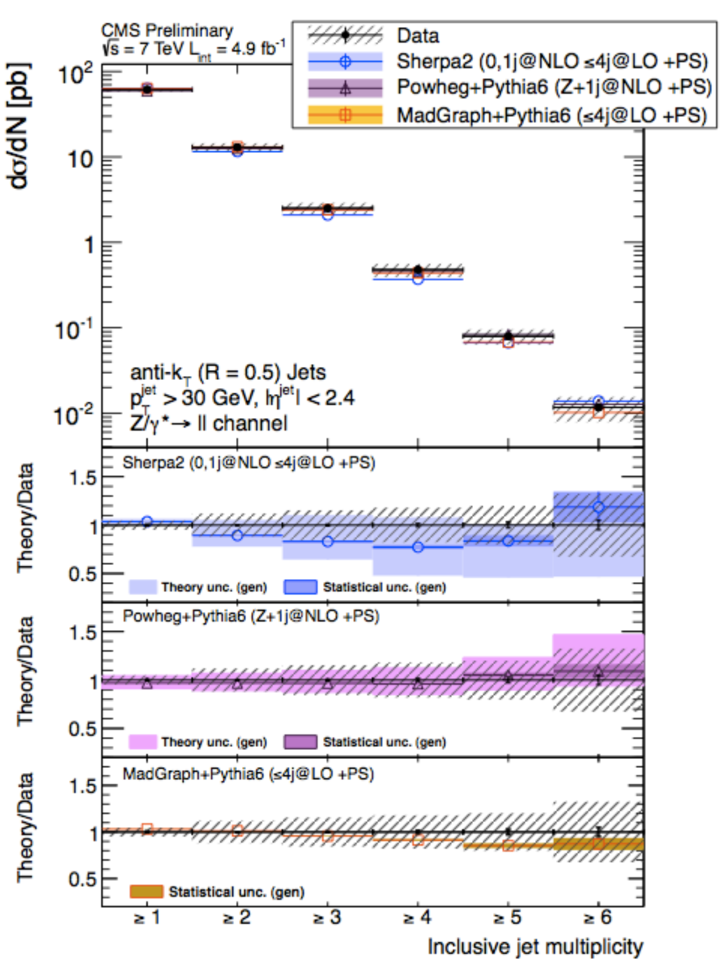


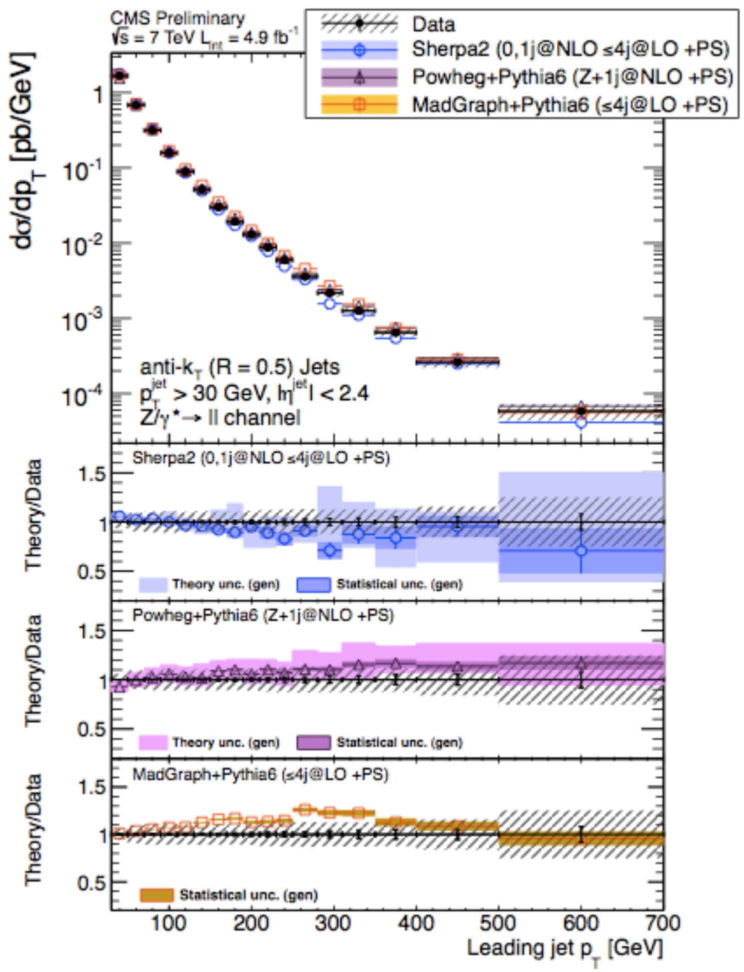


Z+jets – CMS

FO NLO and LO multi-leg ME+PS consistent with jet multiplicity

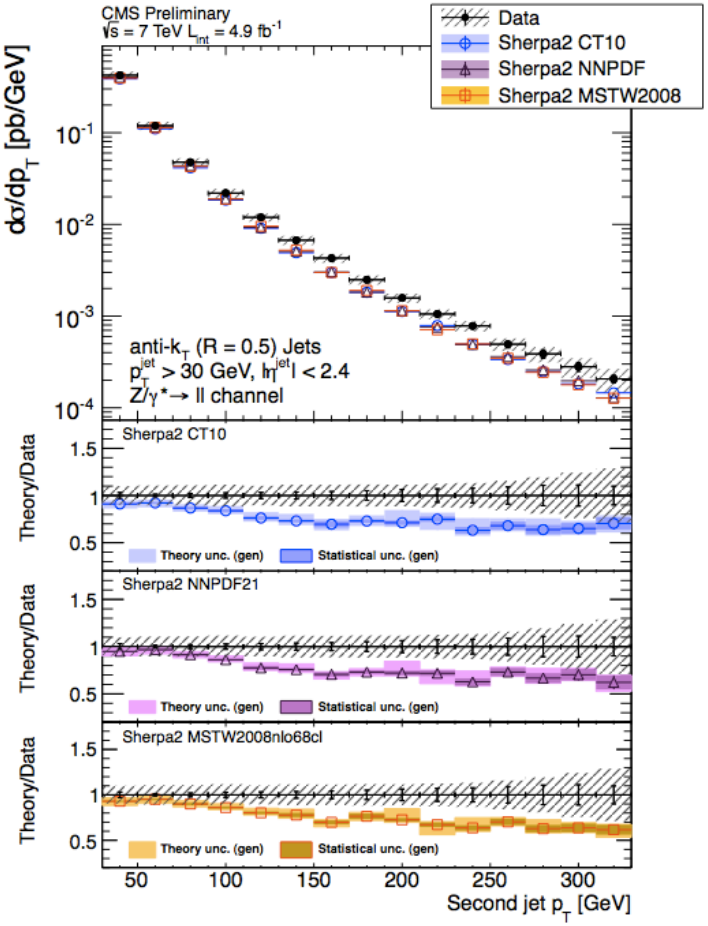
MadGraph produces harder p_T spectrum. NLO predictions differ from data central values.



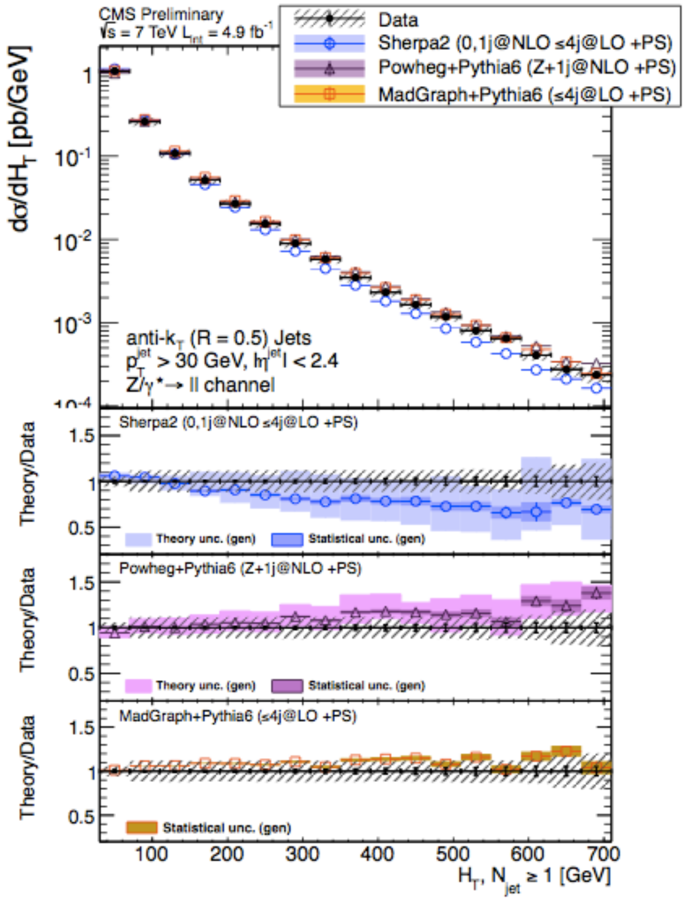


Z+jets – CMS

All Sherpa predictions @NLO are too soft, for all PDFs considered



Powheg+Pythia6 (NLO ME+PS) and MadGraph (LO multi-leg+PS) have higher H_T



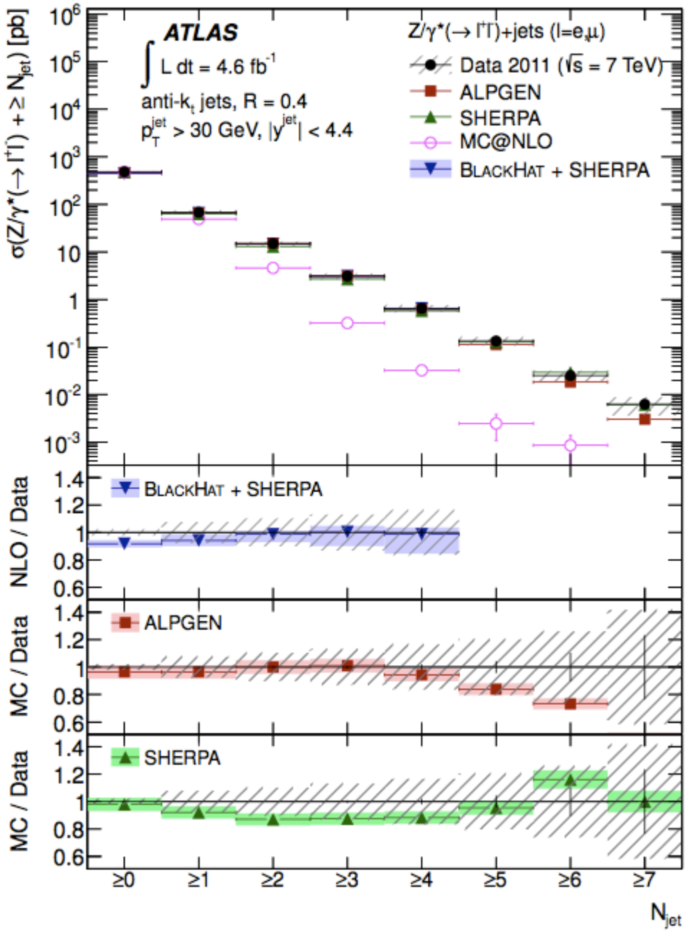
JHEP07 (2013) 032

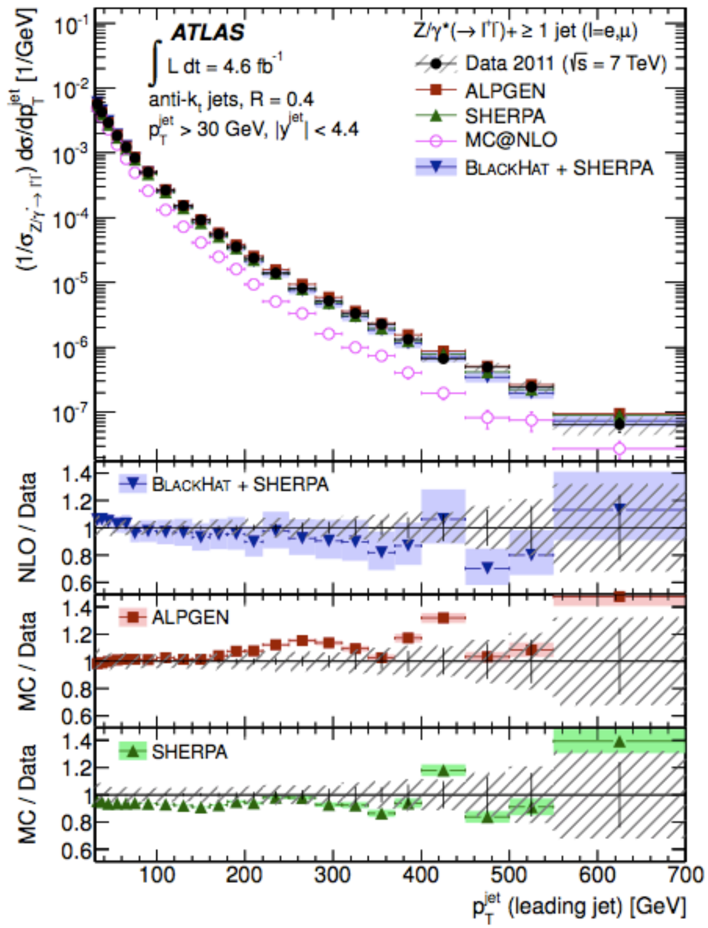
Z+jets $\sigma(n_{jets})$, $\sigma(p_T^{jet})$ – ATLAS

MC@NLO (Z+1j NLO +PS) prediction is too soft

Alpgen and Sherpa v1.4.1 (multi-leg ME+PS) are in agreement with data

BlackHat+Sherpa in best agreement with data central values

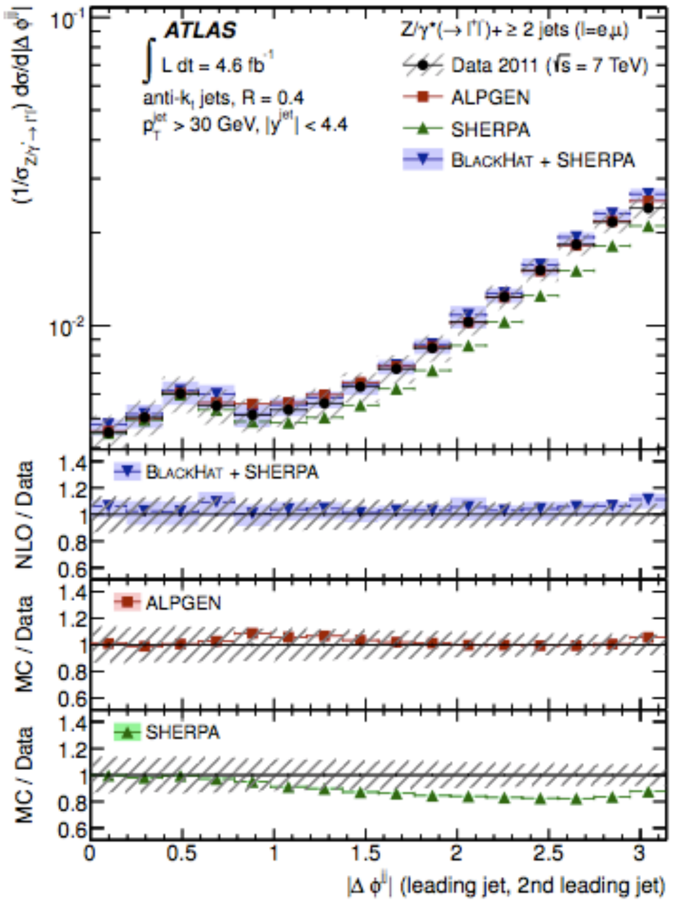


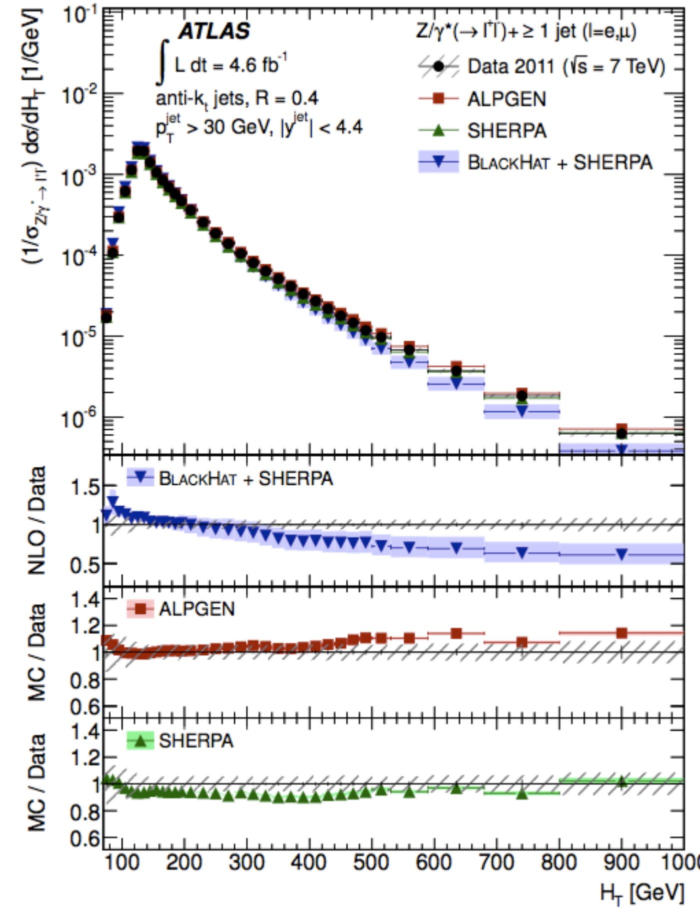


JHEP07 (2013) 032

Z+jets σ(Δϕ(j_1,j_2)), σ(H_T) – ATLAS

Sherpa v1.4.1 predicts too few large angle jet parts – hard emissions.
BlackHat+Sherpa does not describe the H_T distribution at high values, (missing higher orders)
ALPGEN agrees with the data for both variables.

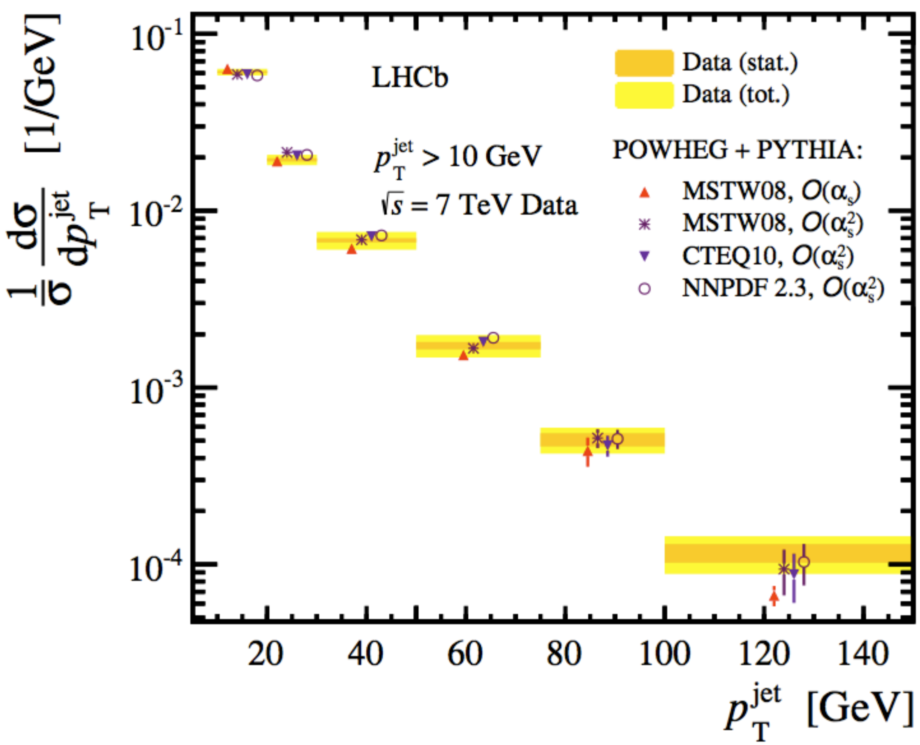


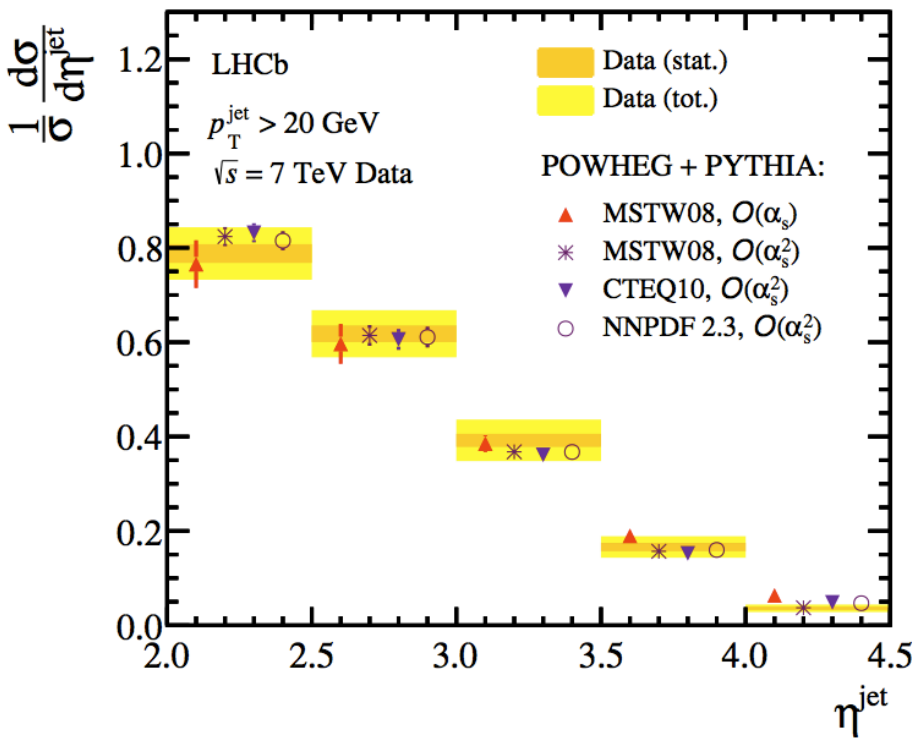


Z+jets, forward region – LHCb

POWHEG+PYTHIA (NLO ME+PS) predictions in reasonable agreement with forward region data

MSTW08 LO PDF predicts a lower jet p_T and more forward jet eta distribution



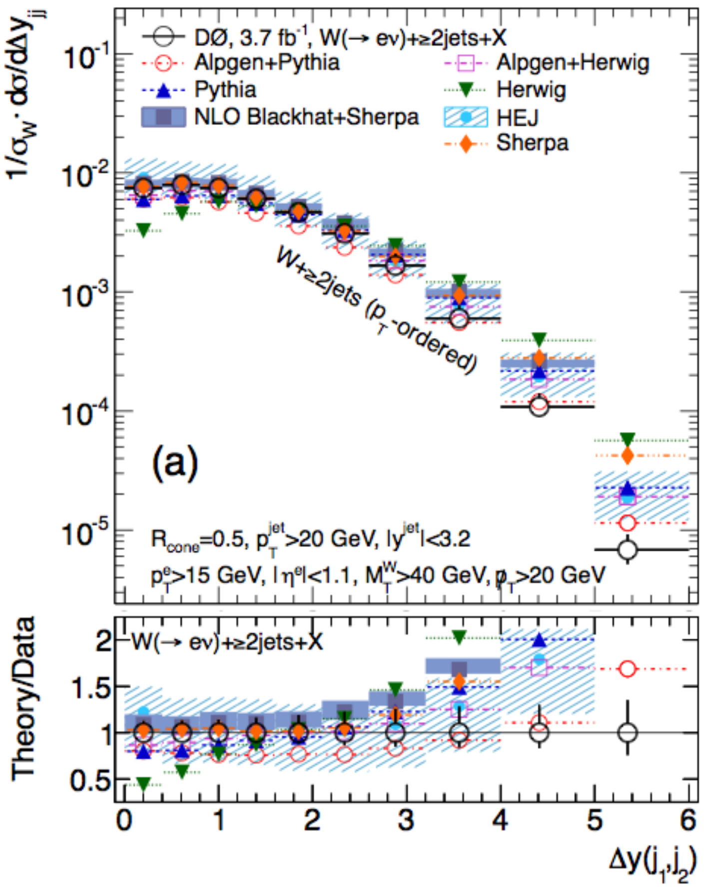


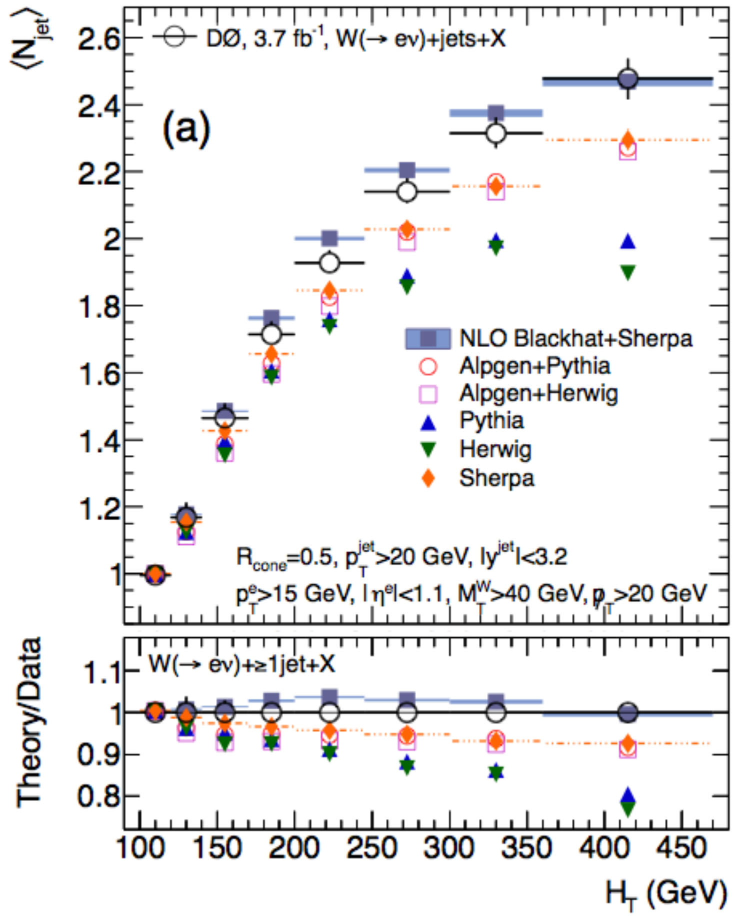
Phys.Rev. D88 (2013) 092001

W+jets $\Delta y(j_1,j_2)$, H_T vs $<N_{jet}>$ – D0

Alpgen+Pythia: best description of large angle emission.

LO ME (Np<=1)+PS models produce much smaller H_T. Multi-leg generators are closer to the data, but also produce lower H_T. The H_T distribution is best described by BlackHat+Sherpa

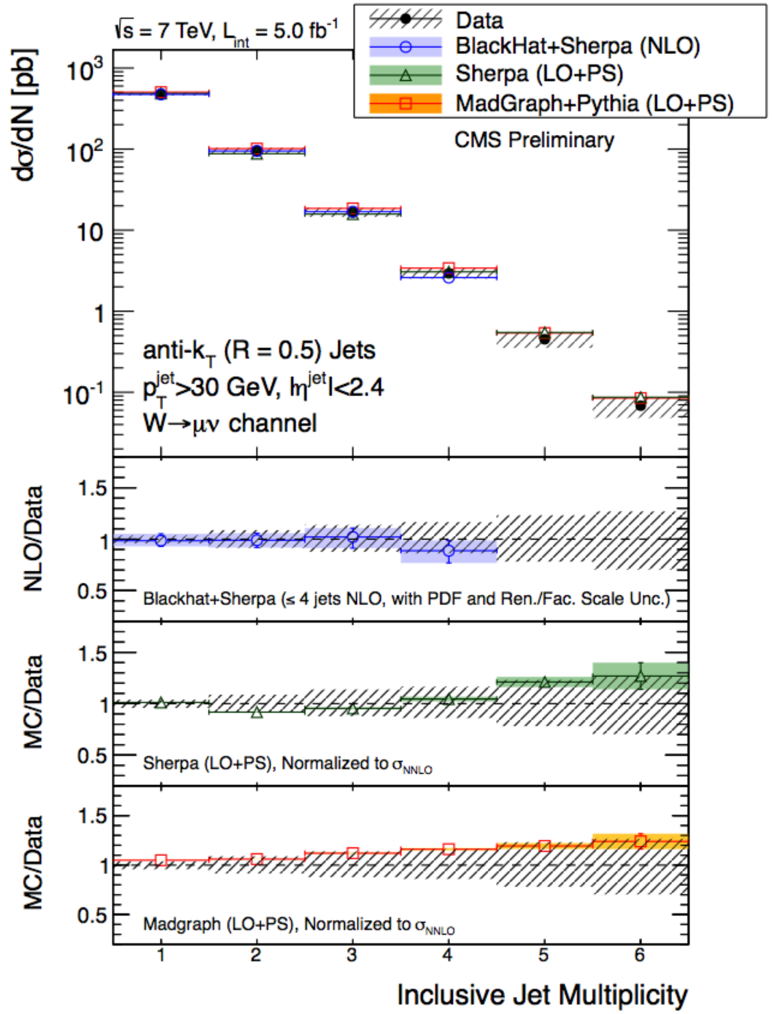


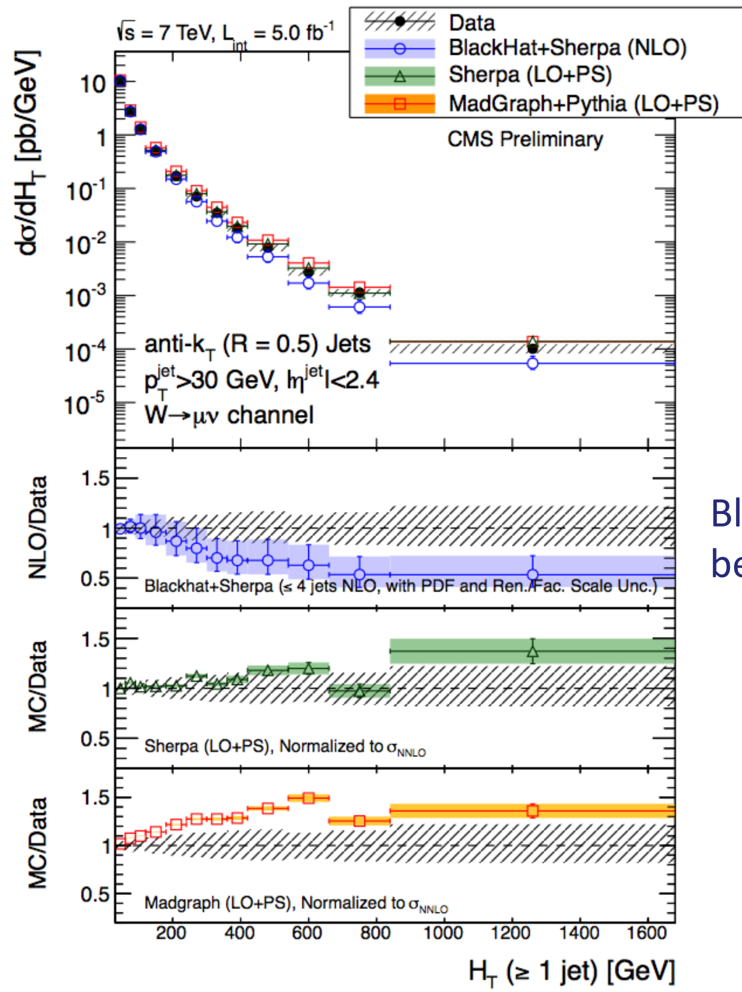


W+jets $\sigma(n_{jets})$, $\sigma(H_T)$ – CMS

MadGraph predicts too many jets and higher H_T

Largest differences observed in inclusive >=1 selection



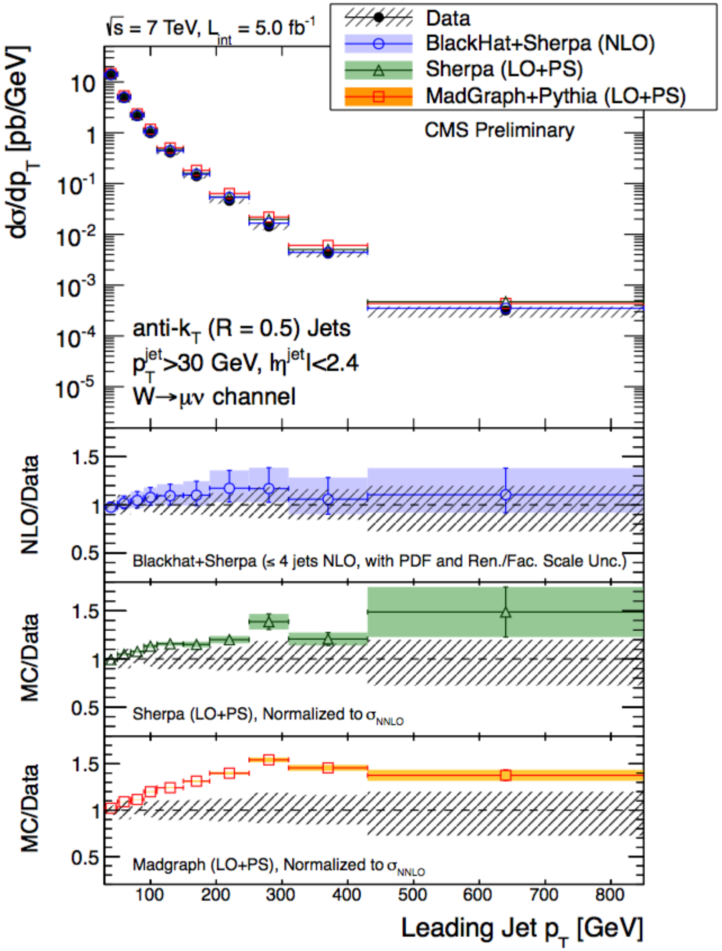


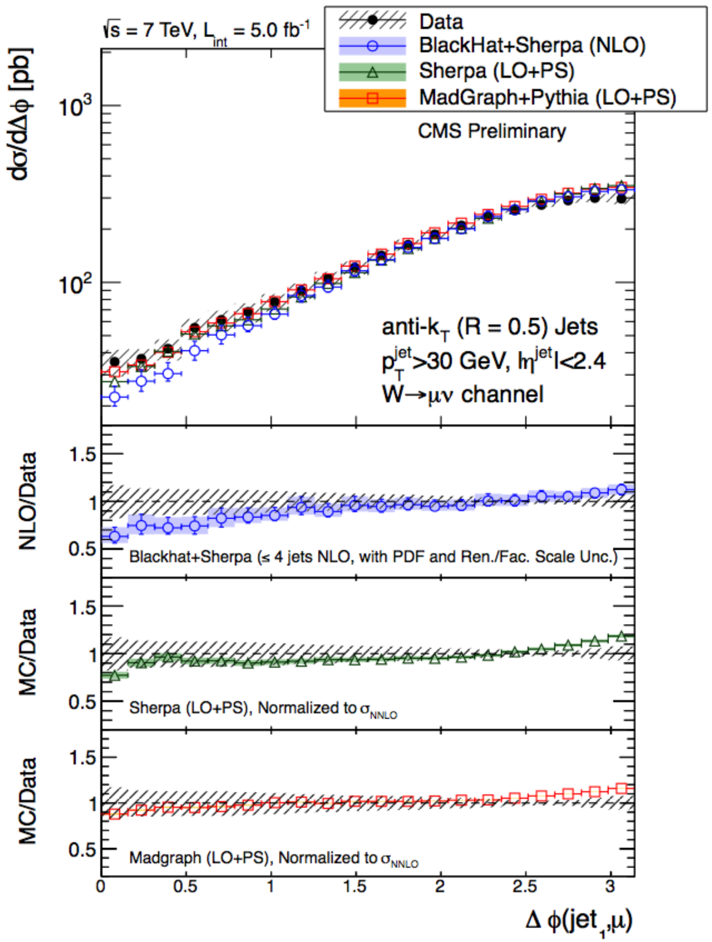
BlackHat+Sherpa below data

W+jets σ(p_T^{jet}), σ(Δϕ(jet_1,μ)) – CMS

MadGraph predicts a p_T spectrum that is too hard.
Other generators are higher than data central values.

BlackHat+Sherpa does not predict enough collinear radiation.

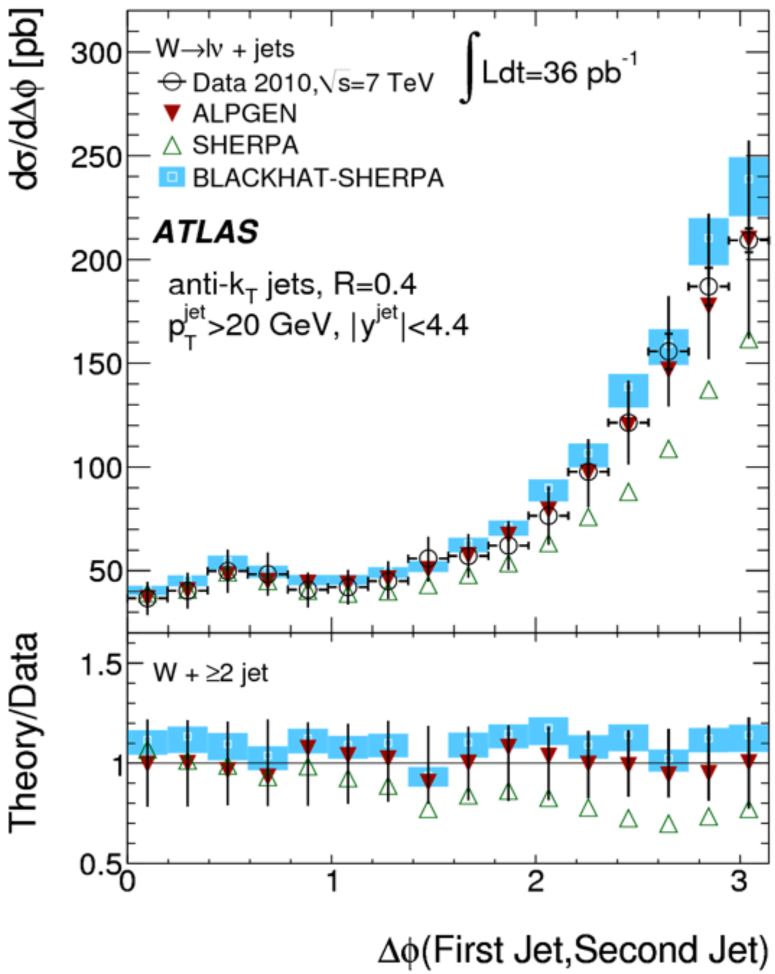




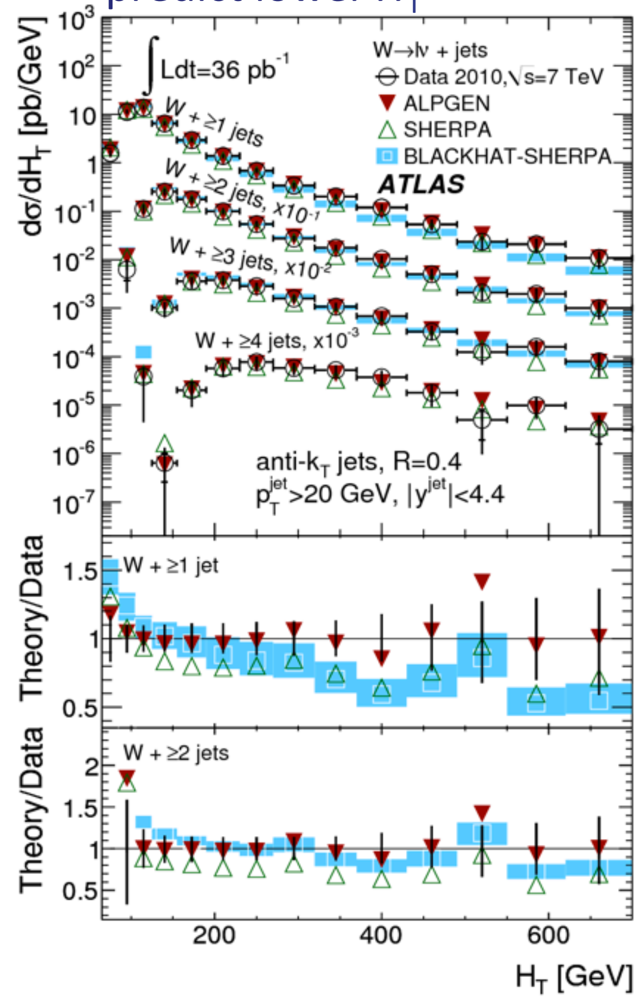
Phys. Rev. D85 (2012) 092002

W+jets $\sigma(\Delta\phi(j_1,j_2))$, $\sigma(H_T)$ – ATLAS

Sherpa multi-leg has lower large angle emission.
ALPGEN multi-leg agrees with data.



Sherpa and BlackHat+Sherpa predict lower H_T

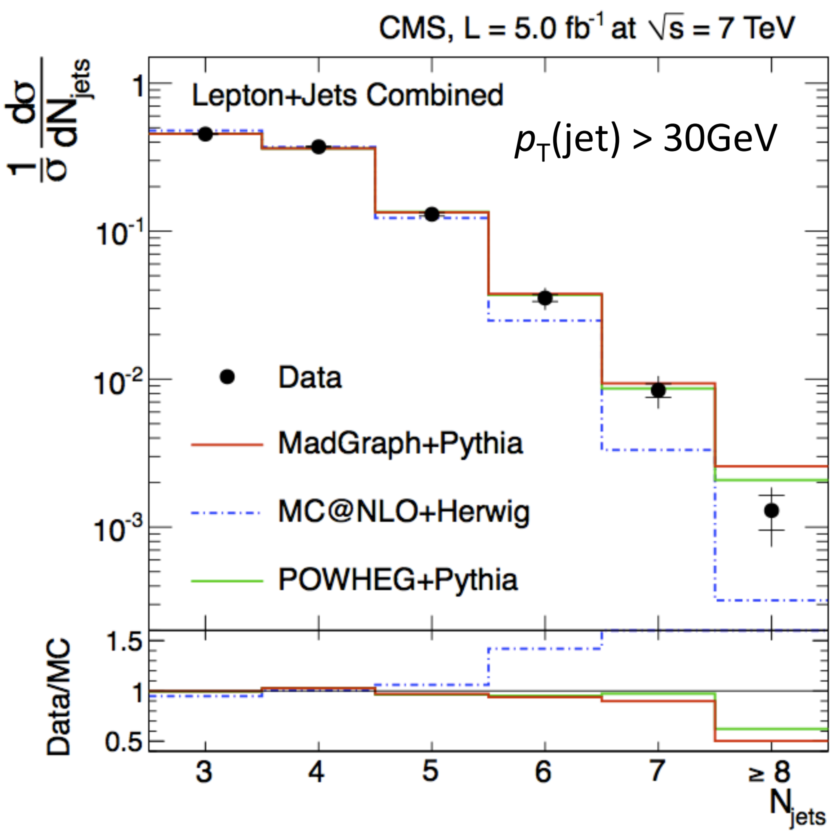


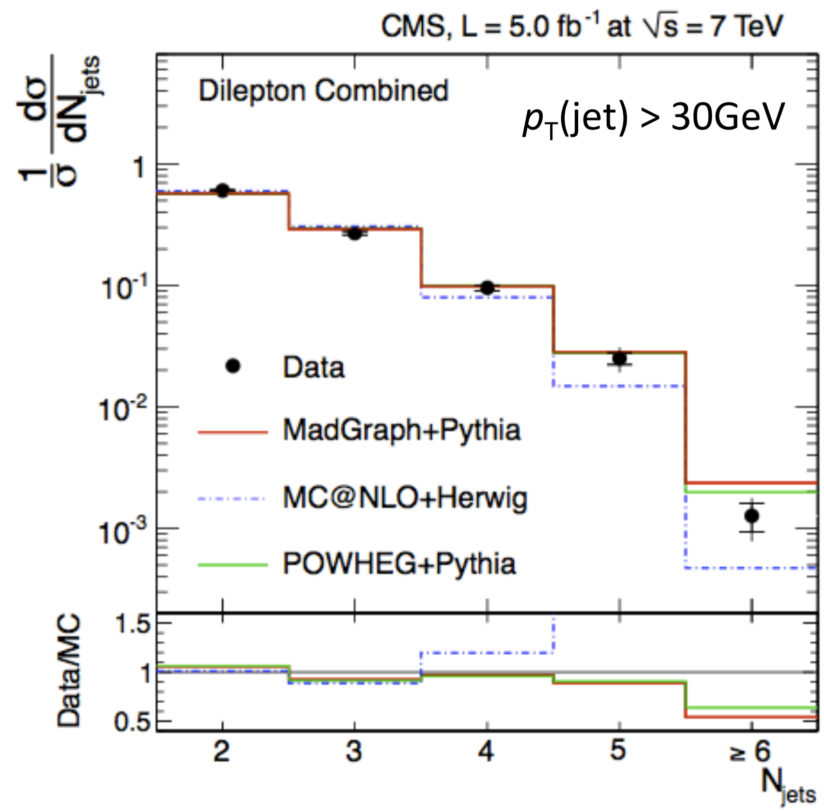
arXiv:1404.3171 [hep-ex]

ttbar+jets σ(n_{jets}) – CMS

At higher jet multiplicities only LL precision.
Different ME+PS matching scheme affects jet multiplicity distribution.

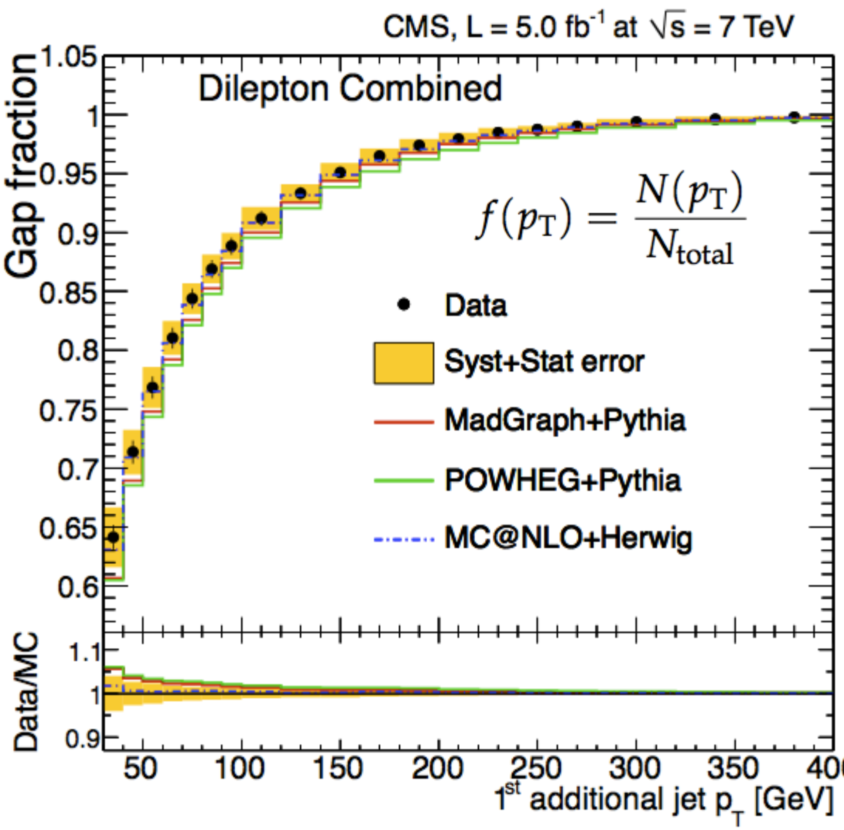
MC@NLO underestimates the n_{jet} distribution from 4(5) jets onwards.
Other generators are slightly higher that data for highest jet multiplicities.

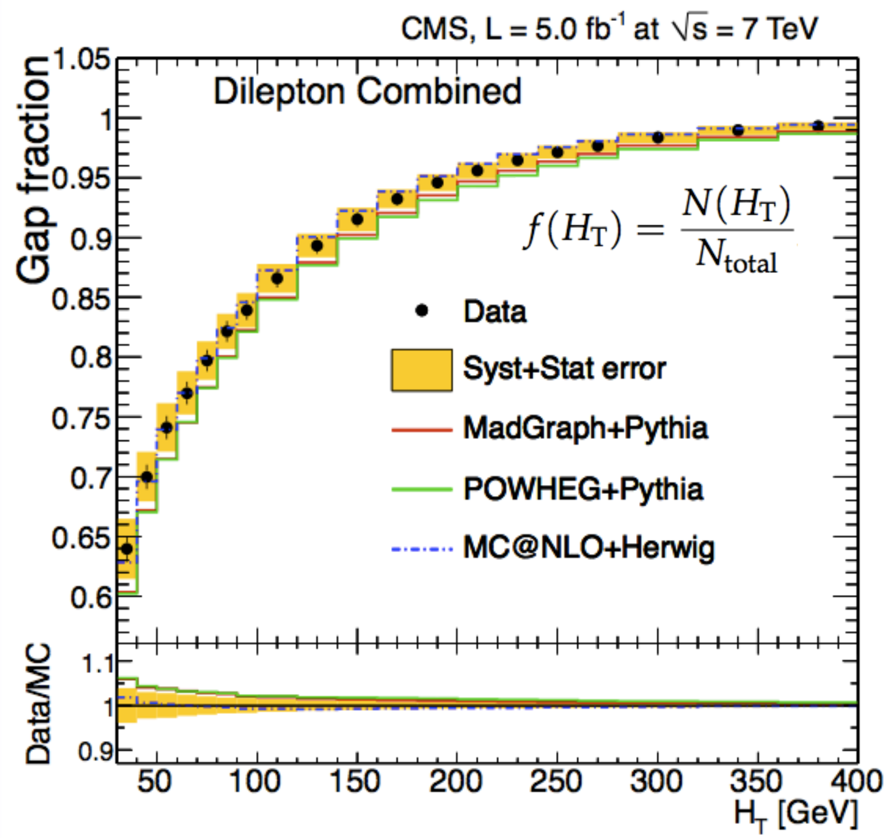




ttbar+jets, gap fraction – CMS

MC@NLO is slightly favoured by the data.
POWHEG+Pythia and MadGraph are below the data for both observables.

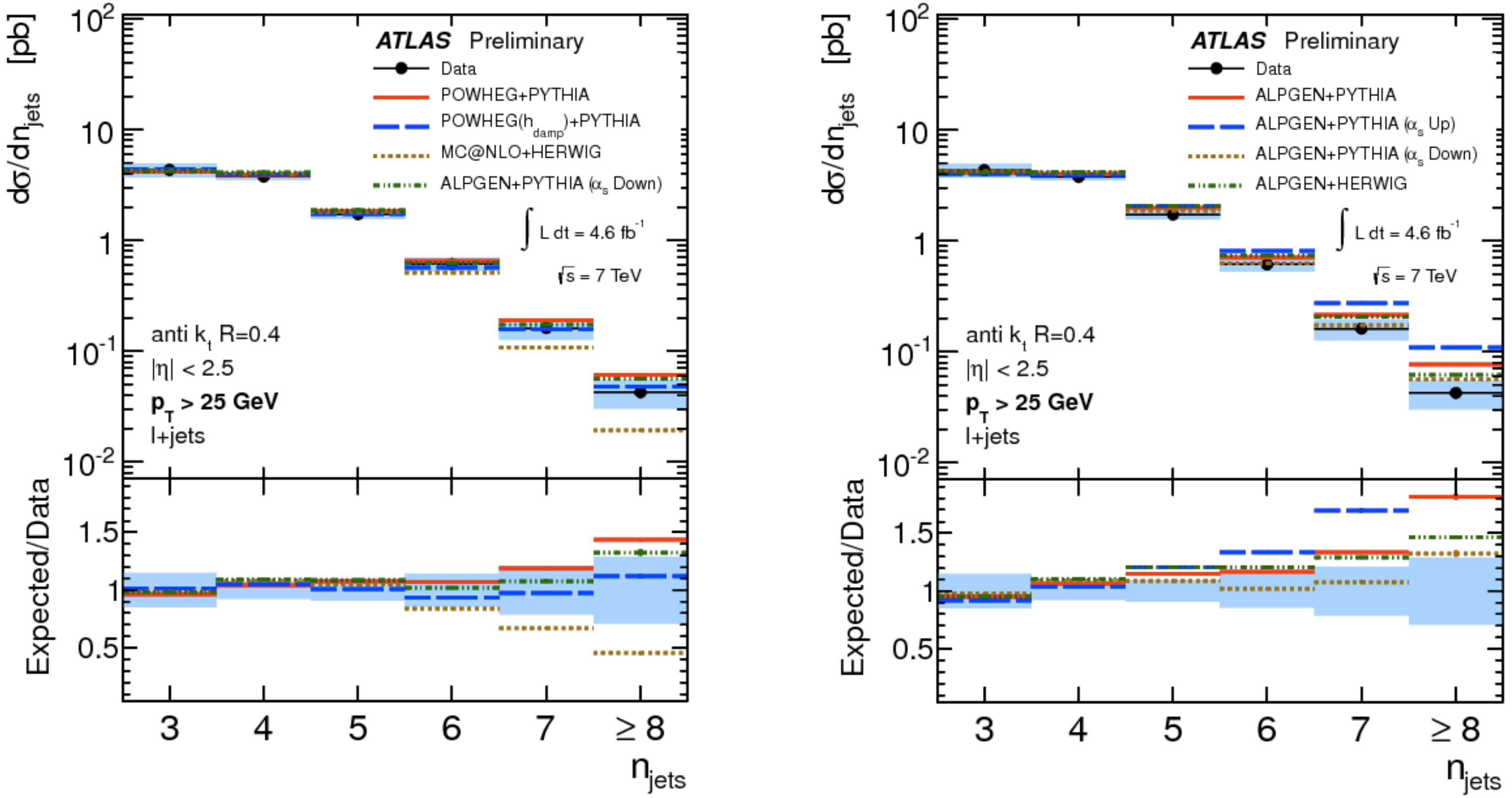




In submission process

ttbar+jets : σ(n_{jets}) – ATLAS

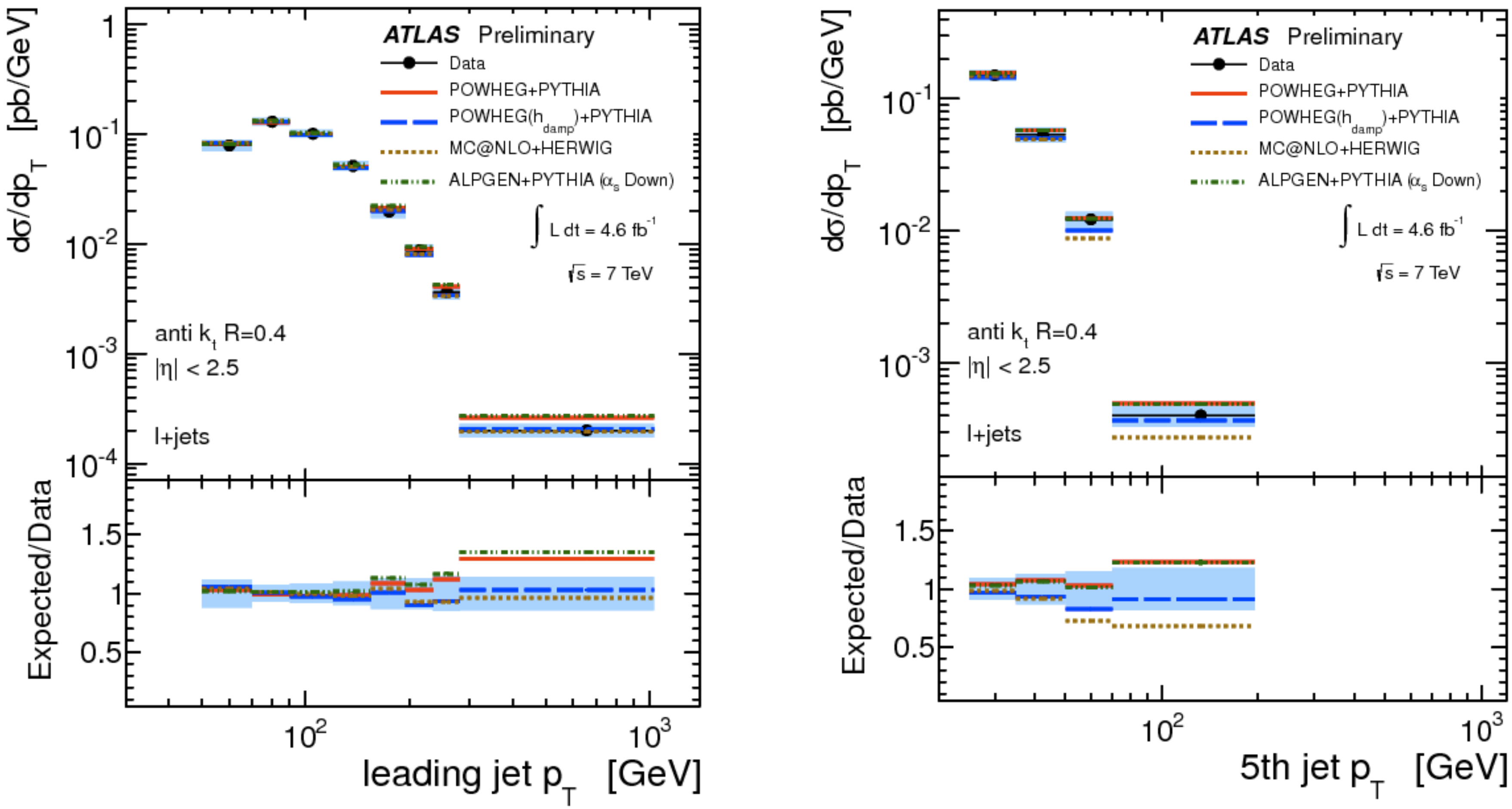
ATLAS analysis probes FO ME and multi-leg generators, as well as ISR/FSR variations.
MC@NLO seen to predict a jet multiplicity that is too low.
h_{damp} and scale choices for multi-leg generators show improvements.



In submission process

ttbar+jets : $\sigma(p_T^{jet})$ – ATLAS

MC@NLO leading jet prediction close to data, 5th jet is too soft.
Best agreement seen with POWHEG h_{damp} tune.
Default POWHEG settings and best ALPGEN+PYTHIA tune – too hard leading jet.

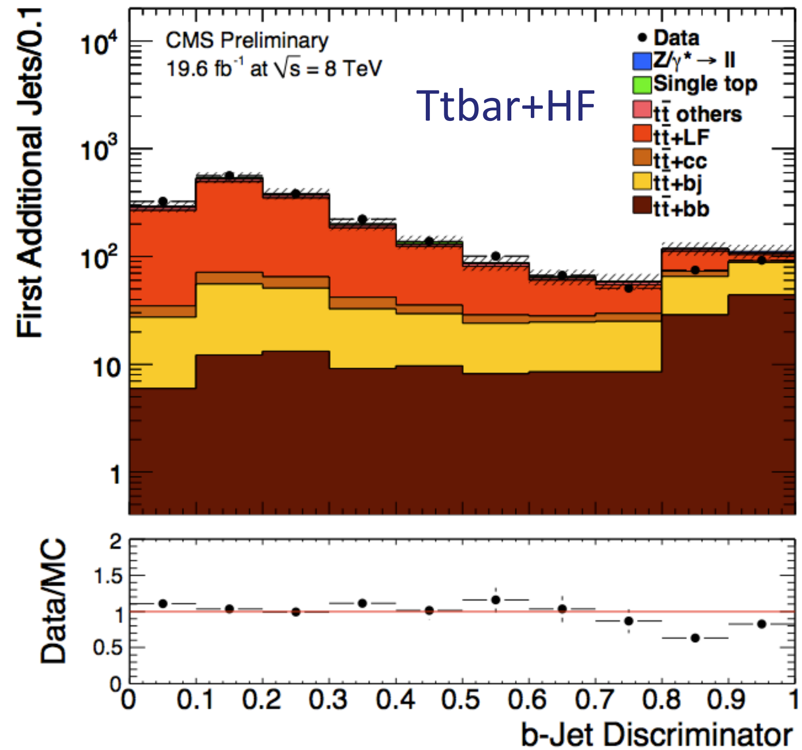


Phys. Rev. D 89, 072012 (2014) Ttbar+HF *ATLAS*

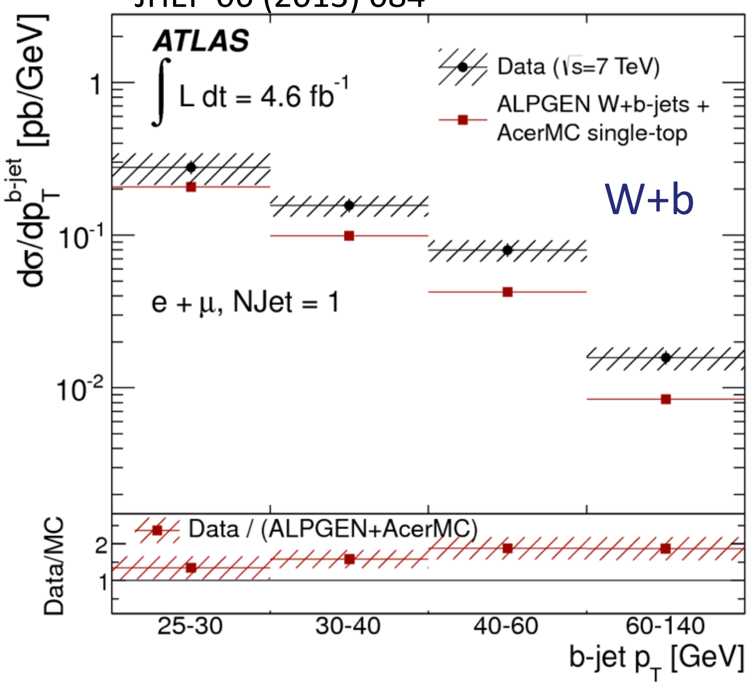
HF production

Type of b-tag, fractions	Data fit	MC expectation
Additional LF jets, %	8 ± 4	20
Additional b-jets, %	-2 ± 7	9
Additional c-jets, %	26 ± 8	3.5
b-jets from $t \to Wb$, %	65	–
b-jets from other sources, %	2.5	–

TOP-13-010



JHEP 06 (2013) 084



Multi-leg (ALPGEN) with FO single top-quark is too soft

Result for $\sigma(t\bar{t}b\bar{b})/\sigma(t\bar{t}jj)$ & p_T > 20GeV

$$0.023 \pm 0.003(\text{stat.}) \pm 0.005(\text{syst.})$$

MadGraph: 0.016 ± 0.002
POWHEG: 0.017 ± 0.002

Conclusions

- Agreement between FO(NLO/LO) ME+PS and multi-leg (LO)+PS generators and data in many kinematic distributions
  - Need to choose scale wisely
  - Tune parameters such as h_{damp} for better performance.
  - Expect to test next generation of NLO generators for higher jet multiplicity processes.
- Measurements are affected by JES, ISR/FSR and fragmentation modelling uncertainties
  - PDF uncertainties are smaller, but still important
  - Need improved MC modelling uncertainties for more precise probes of pQCD
- Expect more measurements of associated HF production