V+jets Experimental Issues

Monica Dunford

May 21st, 2012

LHC EW Working Group

Outline

- Main points of focus
  - Review of 2010 results
  - Overview of theory predictions for 2011 results
  - Phase space and observables for 2011/2012 results
  - Combinations of phase space and additional considerations

2010 Results

- ATLAS and CMS 2010 V+jets results are largely complementary
  - CMS has W^+, W^- and W/Z ratio results for several jet multiplicities
  - ATLAS measures many jet-based observables
- Links to publications from 2010
  - CMS:
    - W, Z, R+jets: JHEP 01 (2012) 010
  - ATLAS:
    - W+jets: Phys. Rev. D85 (2012) 092002
    - Z+jets: Phys. Rev. D85 (2012) 032009
    - R+jets: Phys. Lett. B708 (2012) 221-240

Phase Space for 2010

- Fiducial cross sections definitions are already quite similar, but different in many ways

ATLAS

- Leptons
  - Lepton $p_T > 20$ GeV
  - Lepton $|\eta| < 2.5$
  - Lepton dressed
- Jets
  - Anti-K_T, R=0.4
  - $p_T > 30$ GeV (20 GeV also in W+jets)
  - $|\eta| < 4.4$
  - ΔR (jet-lepton) > 0.5

CMS

- Leptons
  - Lepton $p_T > 20$ GeV
  - Electron $|\eta| < 2.5$, not $1.4442 < |\eta| < 1.566$
  - Muon $|\eta| < 2.1$
  - Lepton at born-level
- Jets
  - Anti-K_T, R=0.5
  - $E_T > 30$ GeV
  - $|\eta| < 2.4$
  - ΔR (jet-electron) > 0.3

Phase Space for 2010

- Fiducial cross sections definitions for W and Z selection

ATLAS	CMS

• Z+jets
  • Second lepton $p_T > 20$ GeV
  • 66 GeV < M_{ll} < 116 GeV
• W+jets
  • Neutrino $p_T > 25$ GeV
  • Transverse Mass: $M_T >$ 40 GeV
	• Z+jets
	  • Second lepton $p_T > 10$ GeV
	  • 60 GeV < M_{ll} < 120 GeV
	• W+jets
	  • Transverse Mass: $M_T >$ 50 GeV (no cut at particle-level)

ATLAS R+jets measurement has some differences, see paper

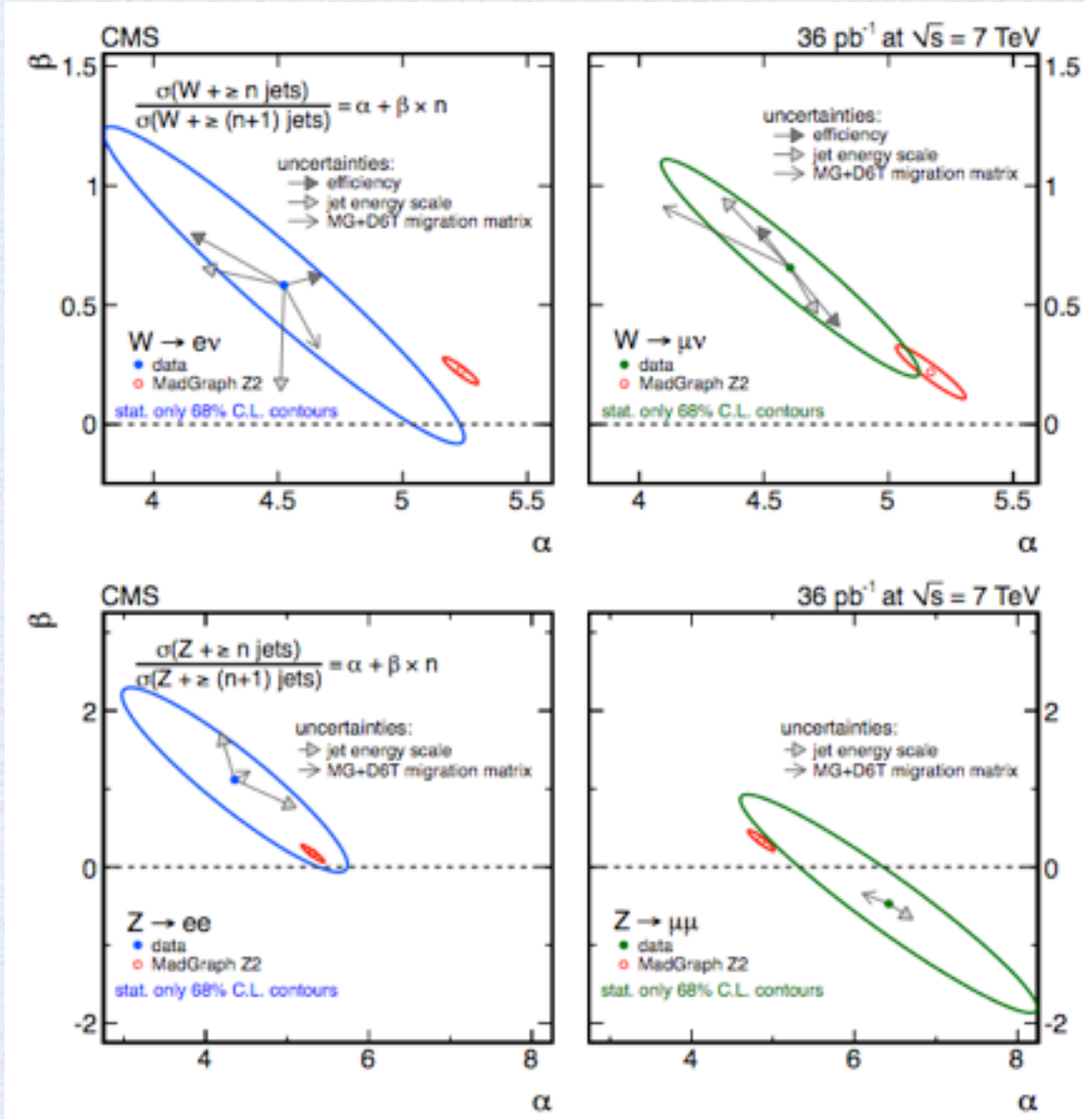
V+jets in CMS

- CMS results include
  - W, Z cross sections for $N_{jets} \geq 1\text{-}4$
  - Ratios of W/Z cross section for $N_{jets} \geq 1\text{-}4$
  - W^+ and W^- cross section for $N_{jets} \geq 1\text{-}4$
  - Test of 'staircase scaling'

$$C_n \equiv \frac{\sigma_n}{\sigma_{n+1}} = \alpha\,,$$

$$C_n = \alpha + \beta\, n.$$

$\frac{\sigma(V+\geq n_{jets})}{\sigma(V)}\ (V = W, Z)$	$n_{jets} \geq 1-4$
$\frac{\sigma(V+\geq n_{jets})}{\sigma(V+\geq n_{jets})}\ (V = W, Z)$	$n_{jets} \geq 1-4$
$\frac{\sigma(W+\geq n_{jets})\sigma(Z)}{\sigma(Z+\geq n_{jets})\sigma(W)}$	$n_{jets} \geq 1-4$
$\frac{\sigma(W^+)-\sigma(W^-)}{\sigma(W)}(+ \geq n_{jets})$	$n_{jets} \geq 1-4$



Results from 2010: ATLAS

- Using the full 2010 data set, ATLAS focused on numerous jet-based
- Cross section listed here for W+jets, but similar distributions were also shown for Z +jets

- For precision tests of scale used in α_s calculations
  - Inclusive jet multiplicities and ratio

$$\sigma(W+ \geq N \text{ jets}) \cdot Br(W \to l\nu) \qquad \frac{\sigma(W+ \geq N \text{ jets})}{\sigma(W+ \geq N-1 \text{ jets})}$$

  - Differential cross sections as a function of Nth jet p_T

$$\frac{d\sigma(W+ \geq K \text{ jets}) \cdot Br(W \to l\nu)}{dp_T(N^{\text{th}} \text{ jet})} \qquad K = 1\text{-}4, N \leq K$$

  - Differential cross sections as a function of H_T (scalar sum of lepton, jet p_T and missing E_T)

$$\frac{d\sigma(W+ \geq N \text{ jets}) \cdot Br(W \to l\nu)}{dH_T}$$

  - Differential cross sections as a function of the invariant mass of the first N-jets

$$\frac{d\sigma(W+ \geq N \text{ jets}) \cdot Br(W \to l\nu)}{dM_{\text{inv}}(N - \text{jets})}$$

Results from 2010: ATLAS

- For tests which are sensitive to PDFs
  - Rapidity of the leading jet $\frac{d\sigma(W+ \geq 1 \text{ jets}) \cdot Br(W \to l\nu)}{dy(\text{First Jet})}$
  - Rapidity difference and sum between lepton and jet $\frac{d\sigma(W+ \geq 1 \text{ jets}) \cdot Br(W \to l\nu)}{d(y(\text{Lepton}) - y(\text{First Jet}))}$ $\frac{d\sigma(W+ \geq 1 \text{ jets}) \cdot Br(W \to l\nu)}{d(y(\text{Lepton}) + y(\text{First Jet}))}$
- For tests of hard parton radiation at large angles and ME to PS matching schemes
  - Rapidity difference between first and second jet $\frac{d\sigma(W+ \geq 2 \text{ jets}) \cdot Br(W \to l\nu)}{d(y(\text{First Jet}) - y(\text{Second Jet}))}$
  - Angular separation between first and second jet $\frac{d\sigma(W+ \geq 2 \text{ jets}) \cdot Br(W \to l\nu)}{d|\phi(\text{First Jet}) - \phi(\text{Second Jet})|}$
  - Distance in ΔR between first and second jet $\frac{d\sigma(W+ \geq 2 \text{ jets}) \cdot Br(W \to l\nu)}{dR_{JJ}}$

2010 R+jets Measurement

- Both CMS and ATLAS presented measurements of R +jets in 2010
  - CMS: Measured ratio for $N_{jets} \geq 1$-4
  - ATLAS: Measured ratio for Njets ≥ 1, but as a function of jet threshold
- Measurement significantly reduces main systematic uncertainties
  - R+jets: JES is 1.7% at 100 GeV (ATLAS)
  - W+jets: JES is 10% at 100 GeV (ATLAS)

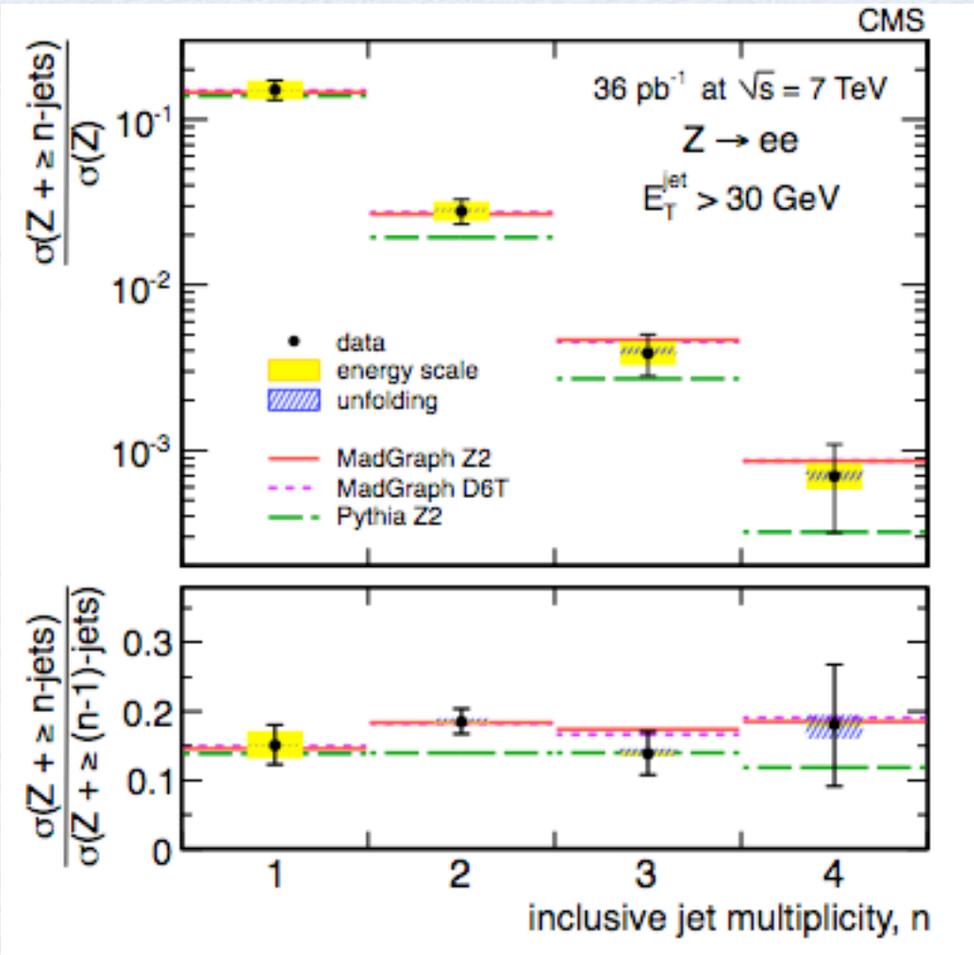
Key Measurement that we would like to expand using 2011 data

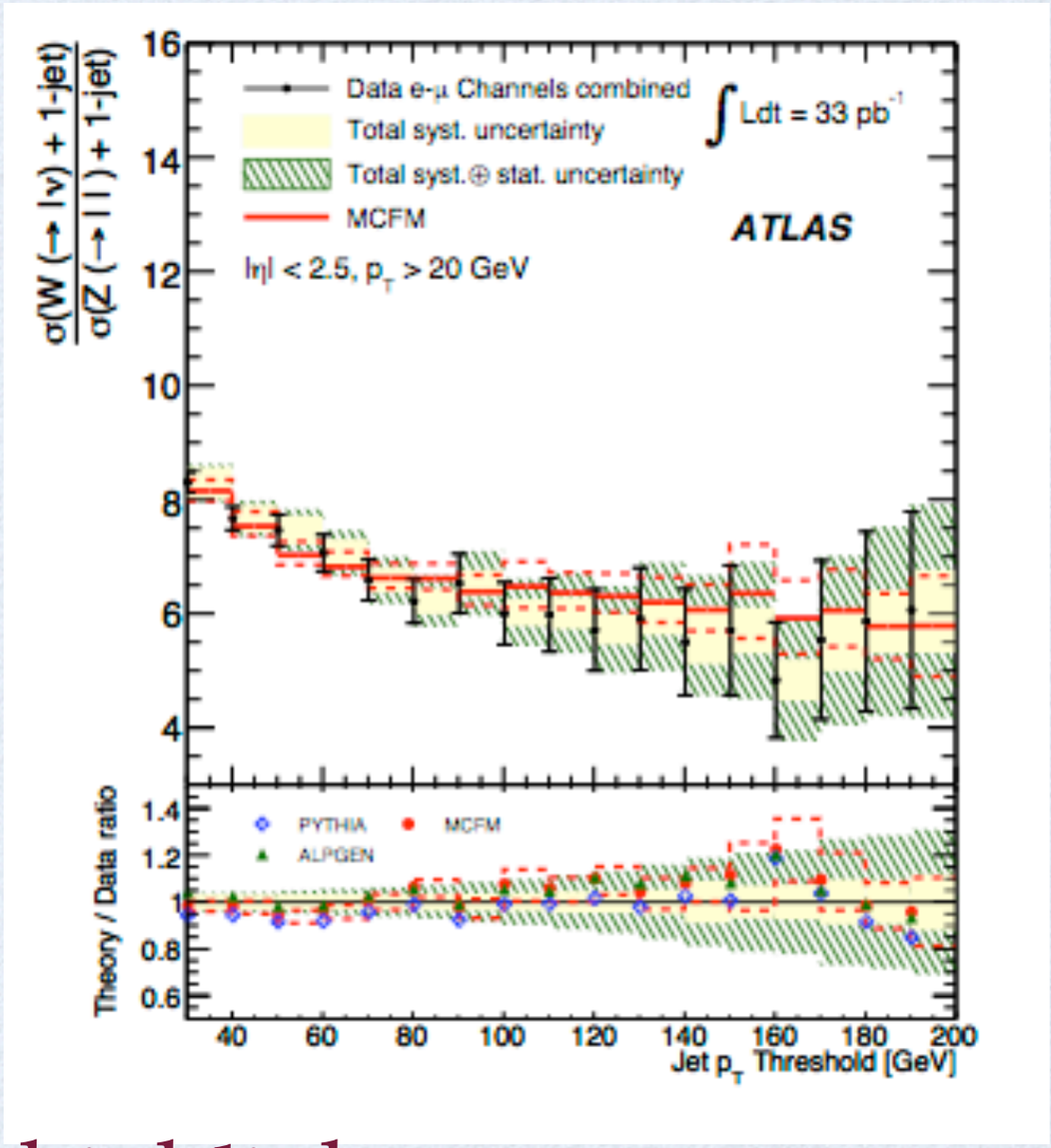
Predictions Used for 2010

- ALPGEN v2.13
  - Interfaced to HERWIG v6.510 + JIMMY v4.31 AUET1 tune
  - CTEQ61L PDF, MLM matching scale 20 GeV
- SHERPA v1.2.3
  - MT scale, CTEQ6.6 PDF, CKKW matching scale 30 GeV
- Blackhat+Sherpa
  - Scale HT/2, PDF CTEQ6.6
- MadGraph 4.4.13
  - Interfaced to PYTHIA 6.422
  - MT scale, KtMLM matching scale 20 GeV
  - PDF CTEQ6L1

Summary for Results

- In 2010, in general the data for both CMS and ATLAS agree well with the predictions

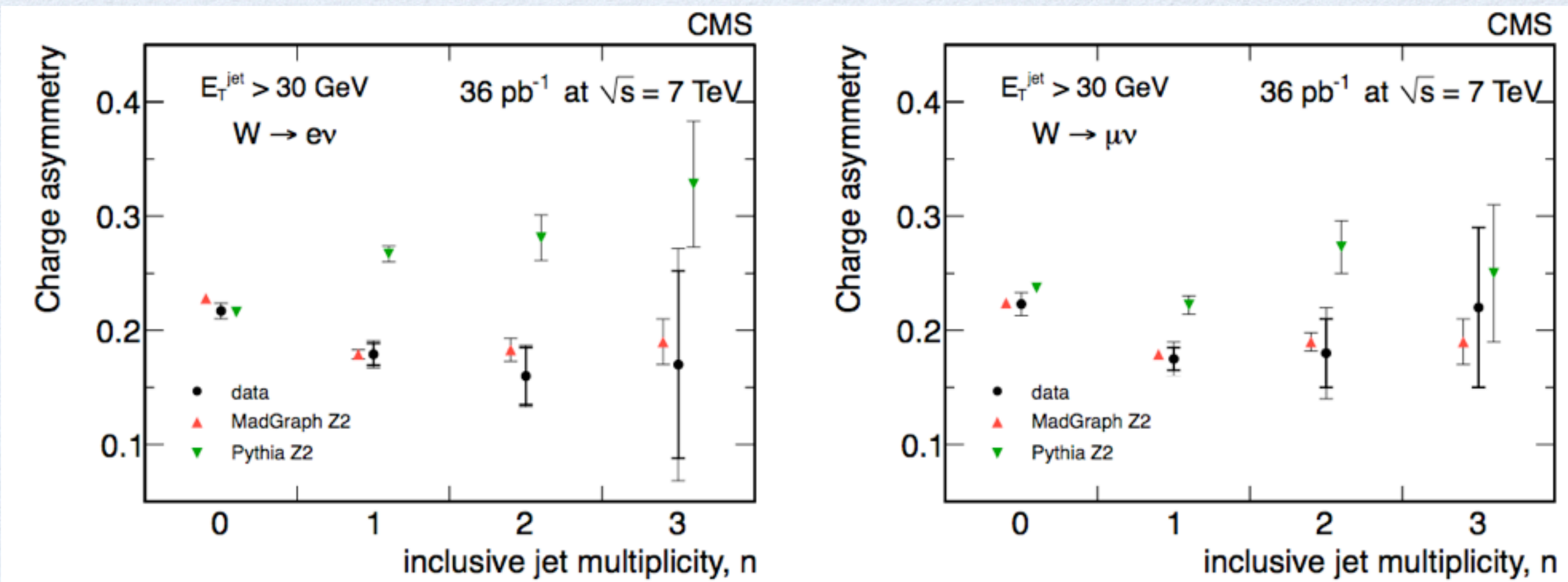




In next slides will only highlight some distributions with 'tension'

Charge Asymmetry

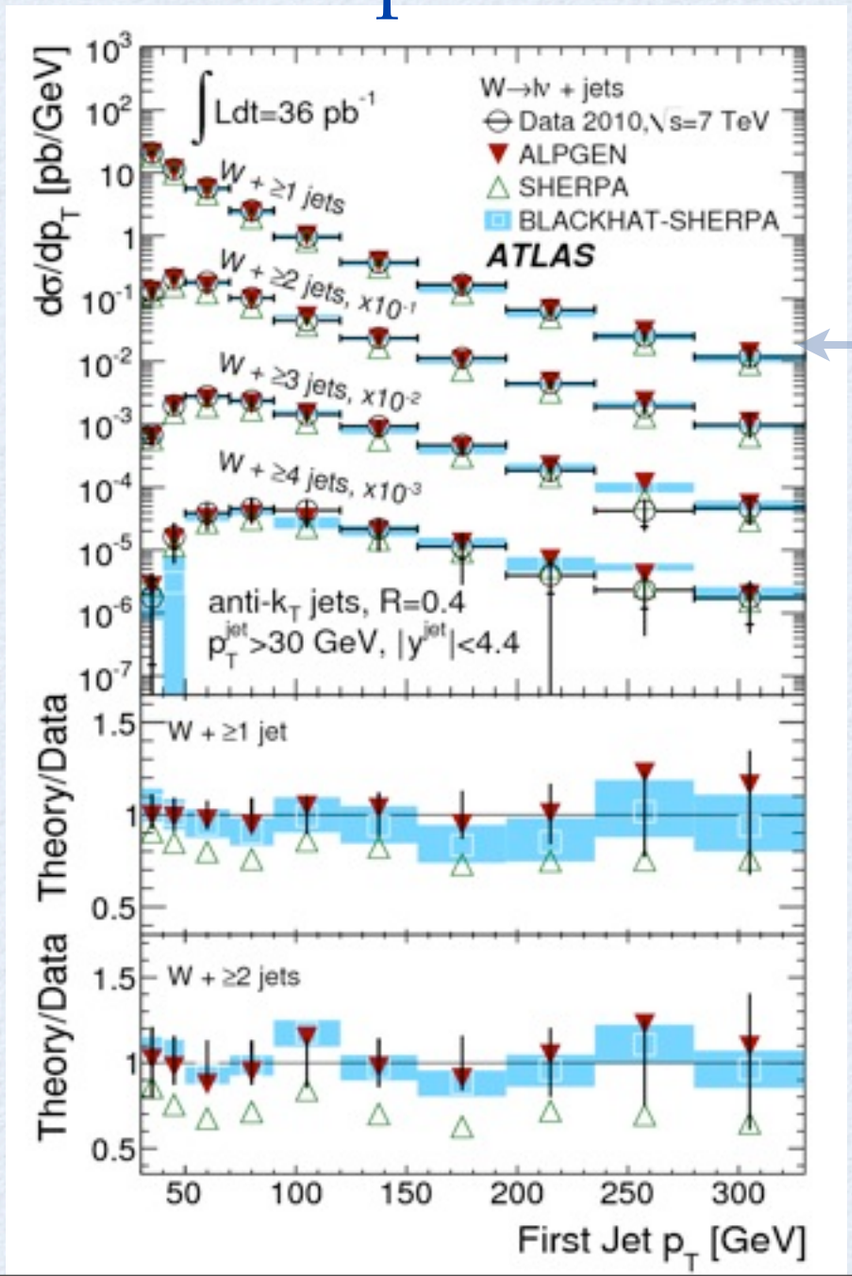
- Pythia results disagree for W plus 1-jet
- Appears that matching works well for the inclusive measurement but not separately for W^+ and W^-



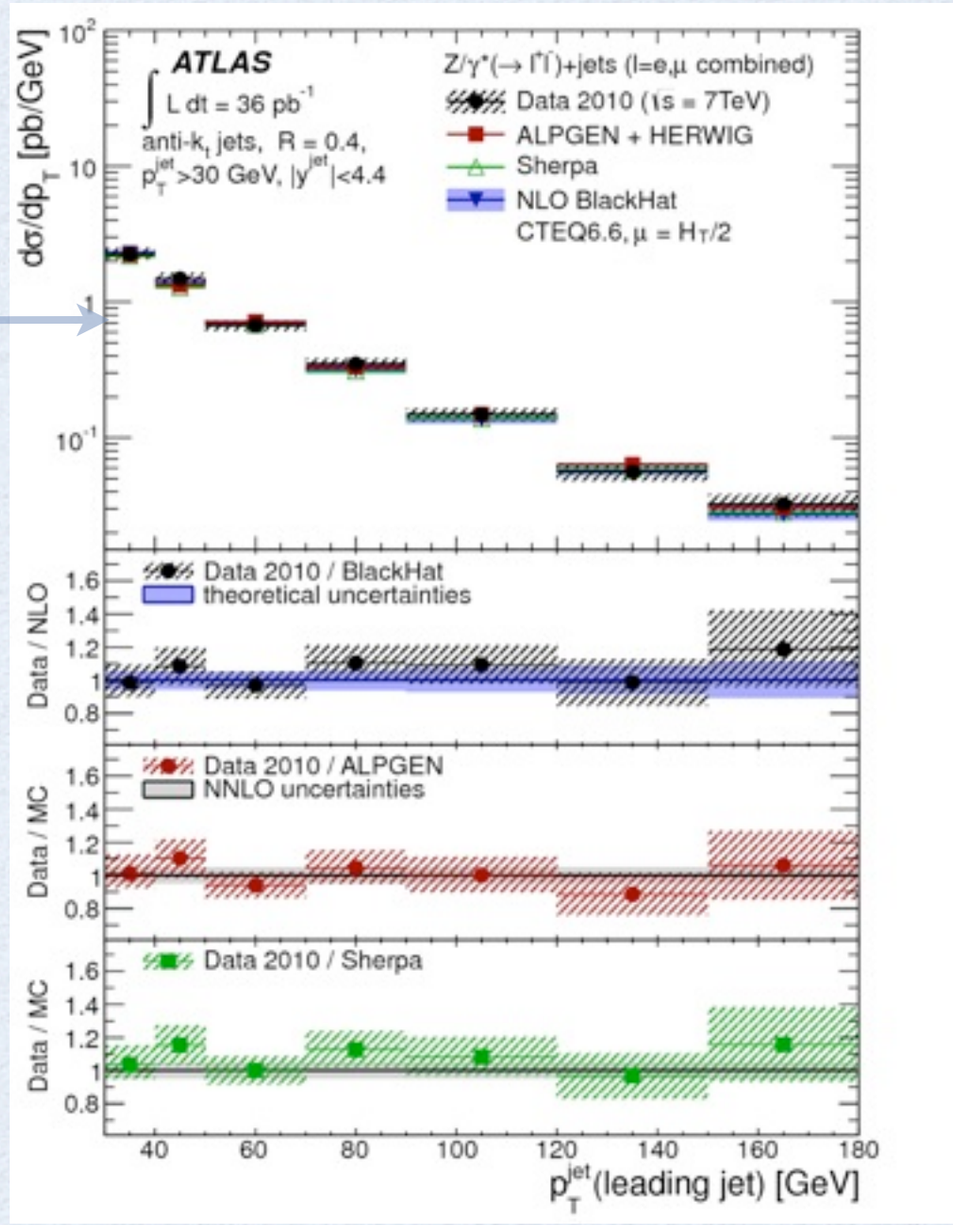
Leading Jet P_Ts

Test of scales used in calculation of α_s

- Blackhat, Alpgen better describes data
- Sherpa differences could be due to different choice of scale



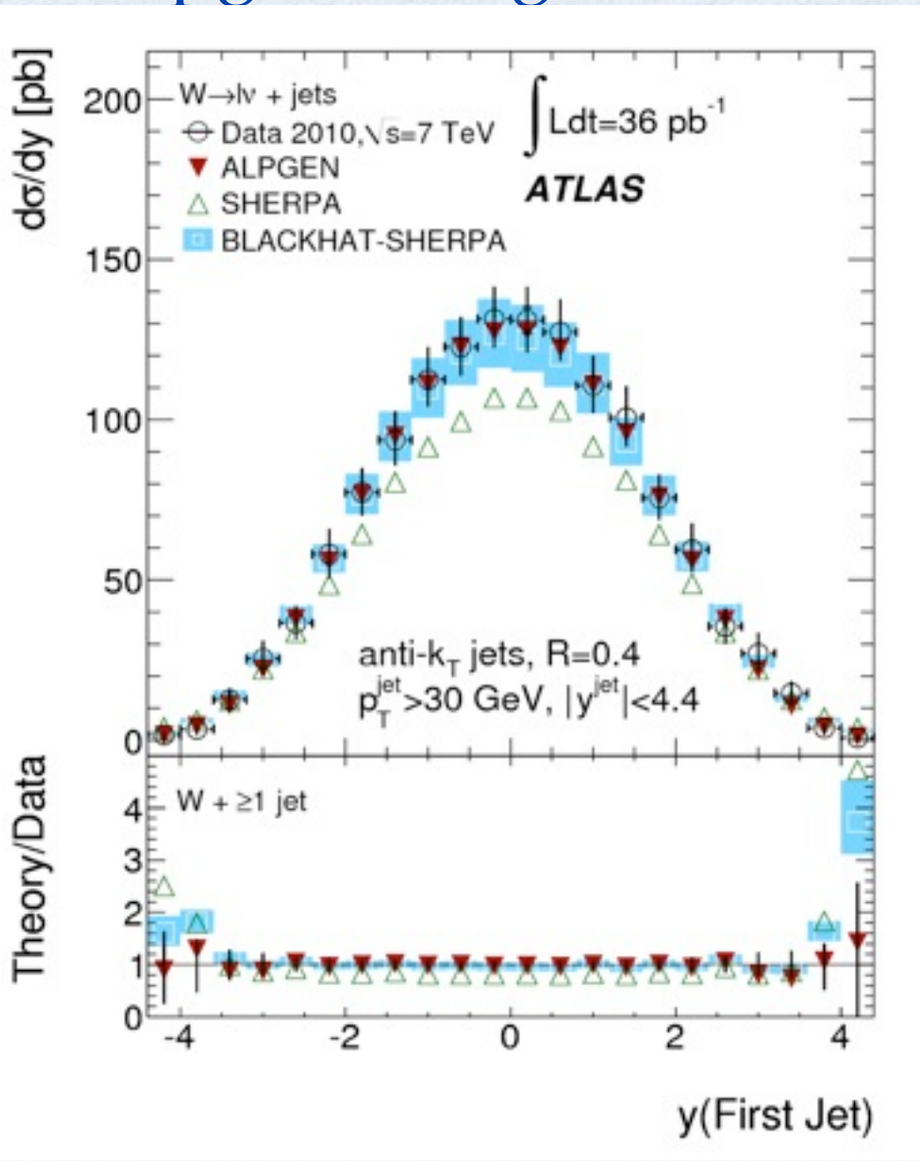
ALPGEN, Sherpa normalized to NNLO

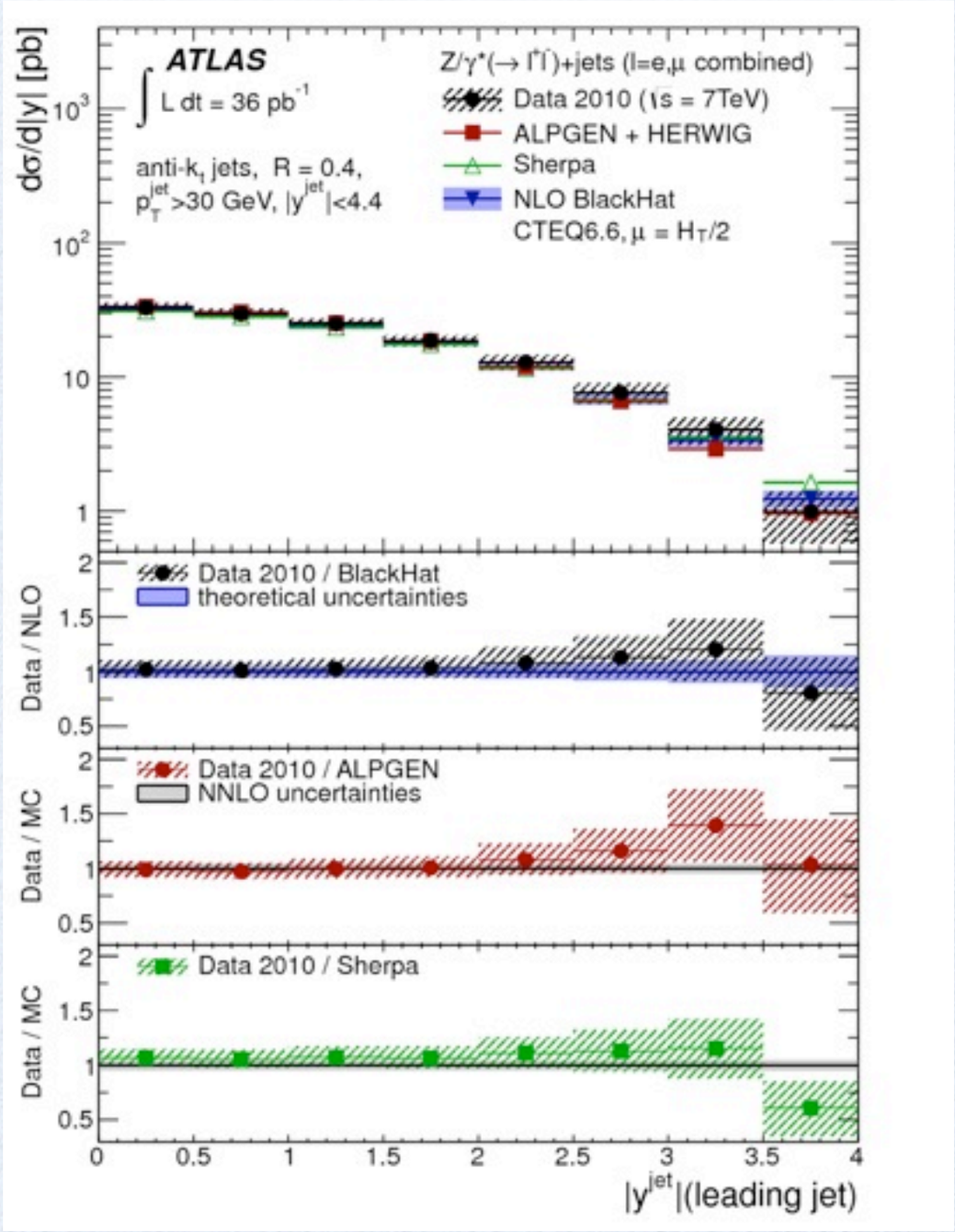


Rapidity of Leading Jet

PDF Sensitivities

- Sherpa tends to predict high cross section at larger rapidities
- Sherpa, Blackhat using NLO PDFs
- Alpgen using LO PDFs

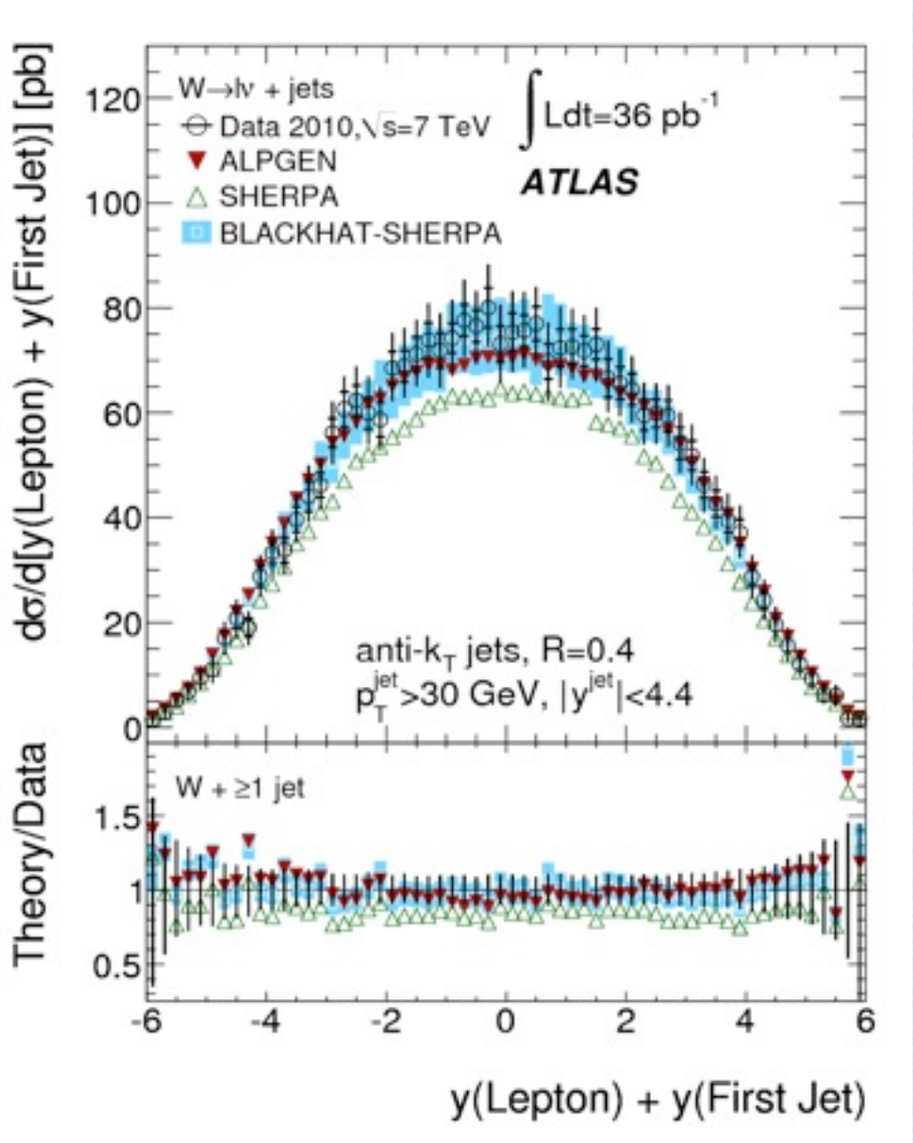


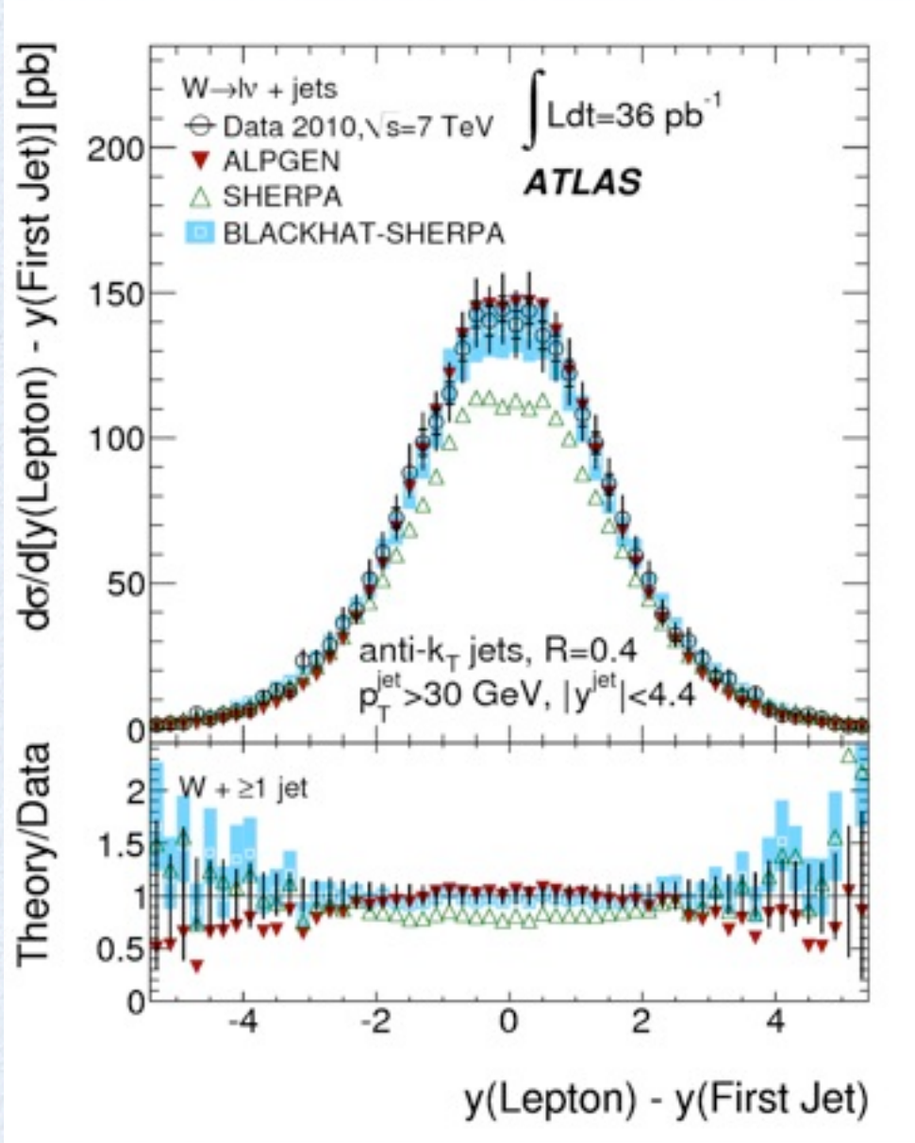


Lepton/Jet Differences

PDF Sensitivities

- Shape is similar for Blackhat, Sherpa with respect to the data
- Deviations at high rapidity might be due to insufficient knowledge of gluon PDFs at high x

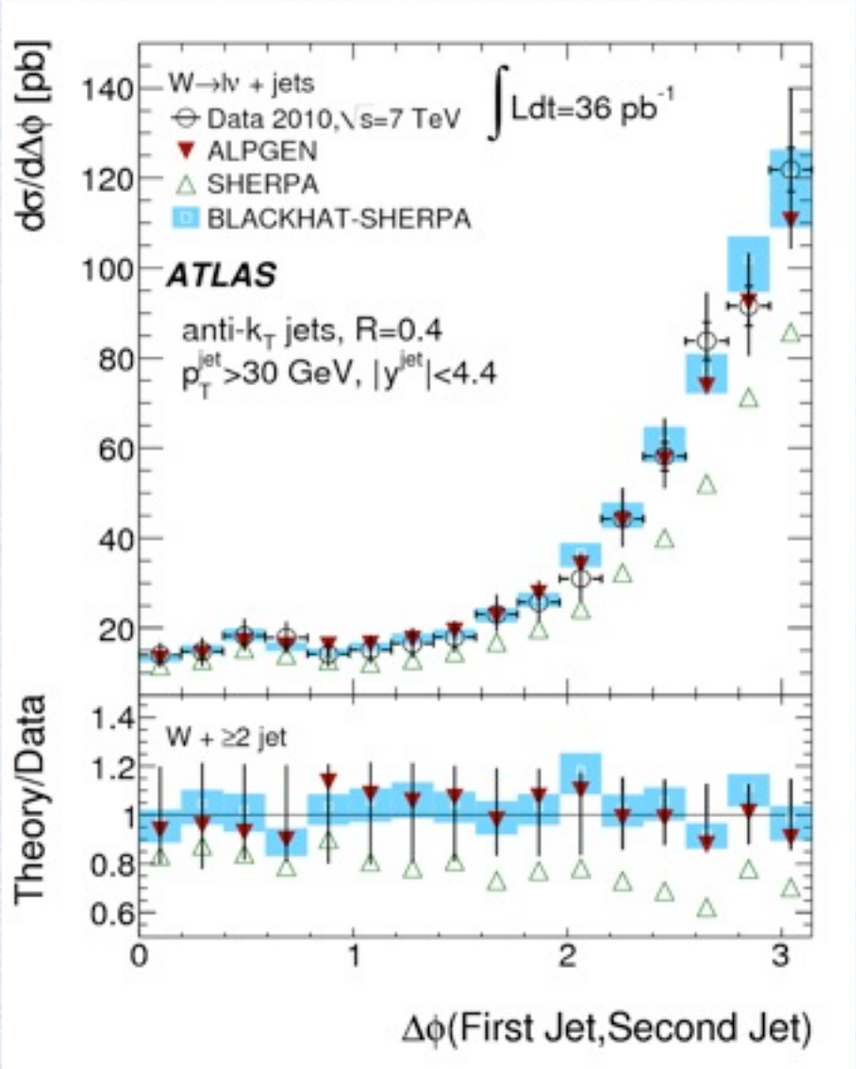


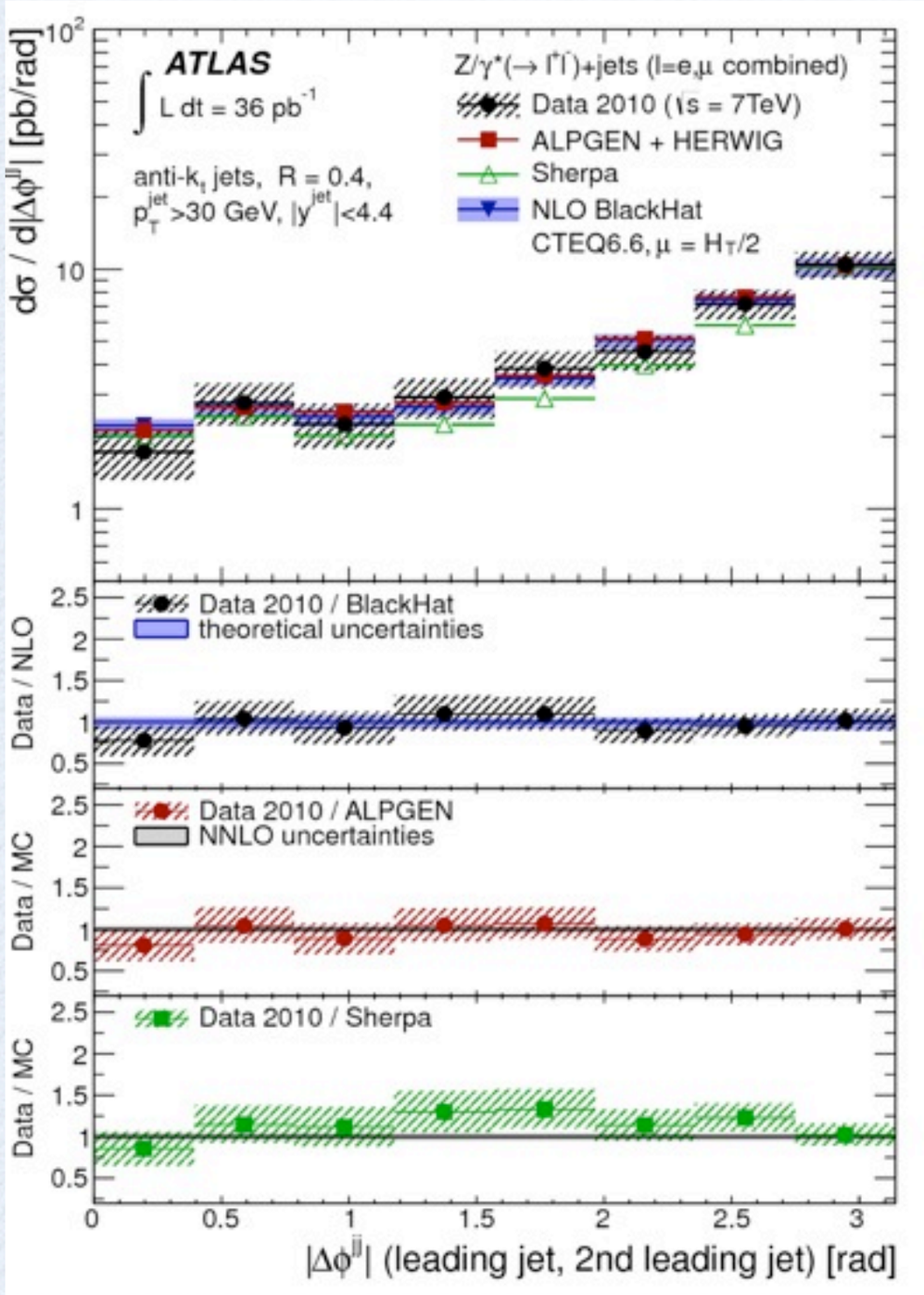


Differences in phi

Tests of large angles

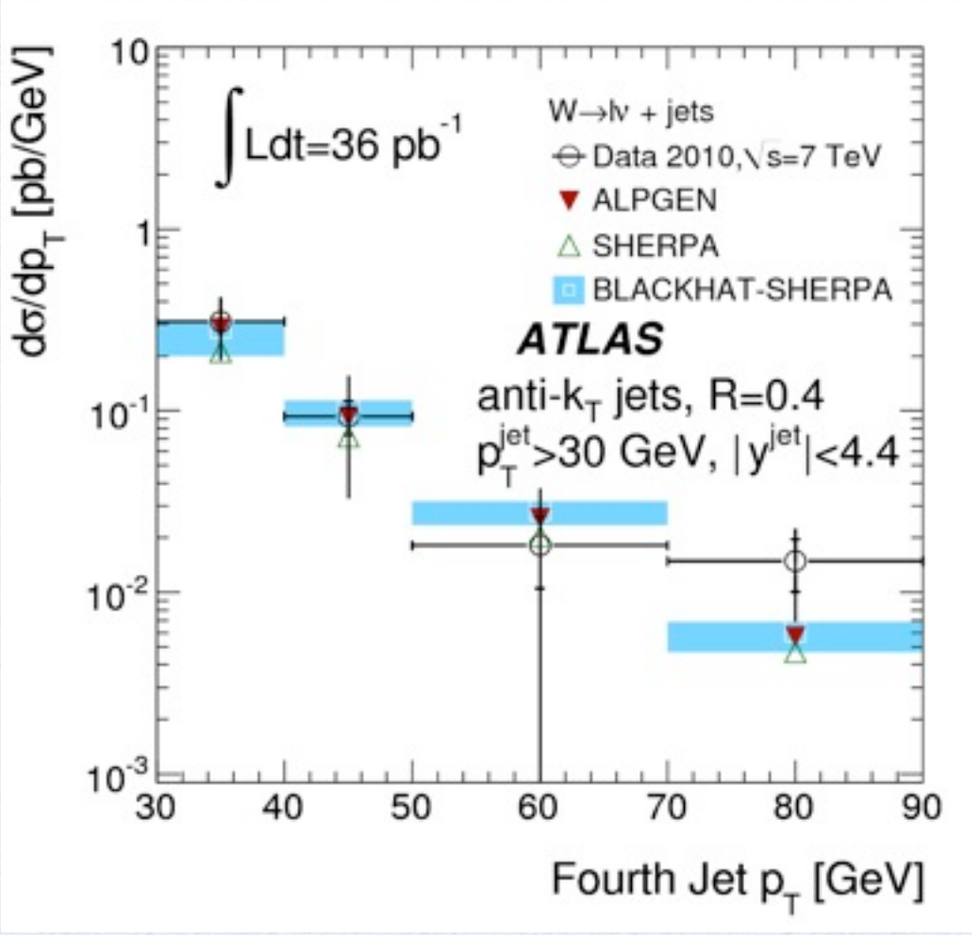
- Small angular separation produced mainly from parton shower
- Large separation from ME
- Deviations in Sherpa stronger in W+jets

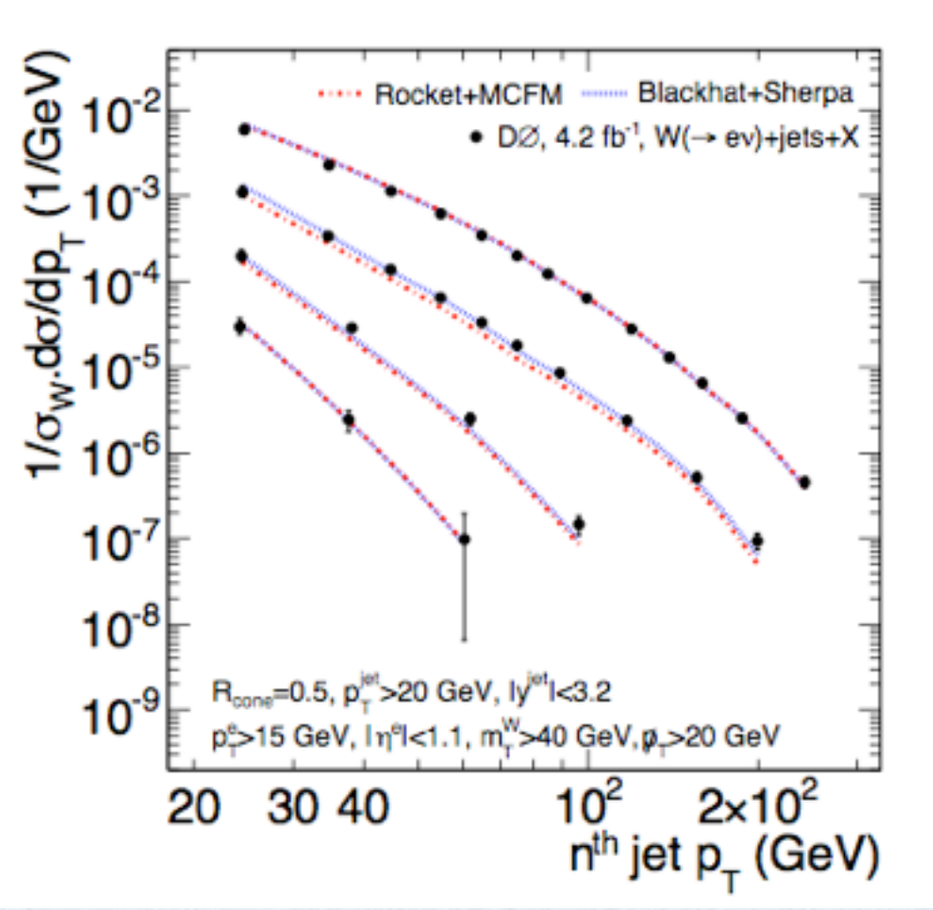




For comparison to Tevatron

- A comments on 2010 data: the statistical uncertainties and kinematic reach are similar to those of the Tevatron
  - ATLAS: W+jets ≥ 4 10% statistical
  - D0: W+jets = 4 jets 5% statistical
- 2011 data will truly go beyond





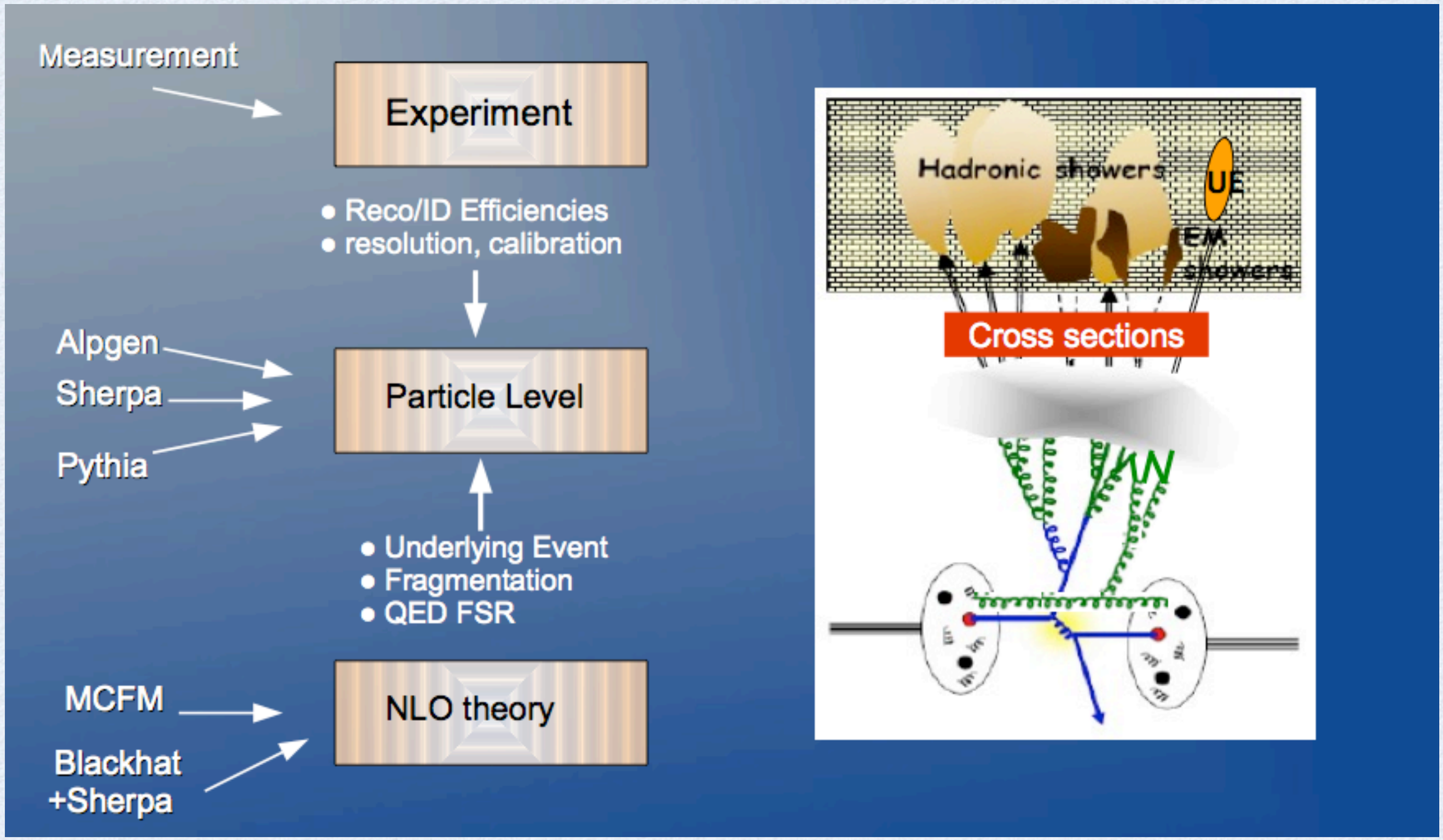
The NLO 'Revolution'

- MCs planned for 2011
  - Alpgen
  - Sherpa
  - Pythia
  - MadGraph
  - MCFM
  - Blackhat+Sherpa
    - Njets = 4 (2010)
    - Njets = 5 (2012)

	3+ years ago	today
W/Z	NNLO	NNLO
V+1j	NLO	NLO+PS
V+2j	NLO	NLO
V+3j	LO	NLO
V+4j	LO	NLO
V+5j	LO	NLO soon

Comparing Data and Theory

- Point of comparison is the particle level

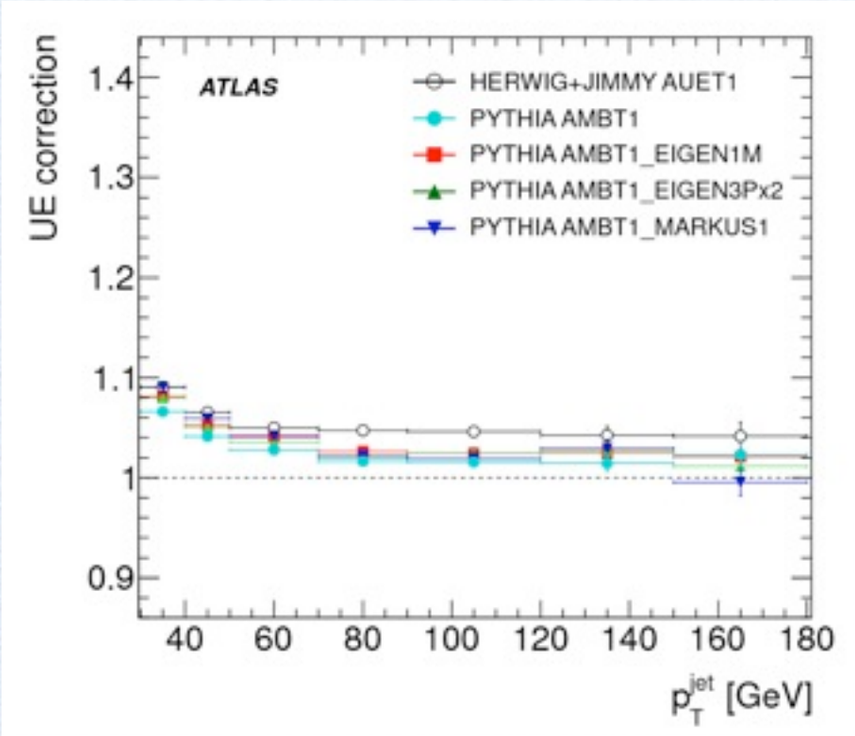


From U. Blumenshein's LHC EW talk

Theory Predictions

- Need to identify a common approach for both the prediction's central value and systematic uncertainties

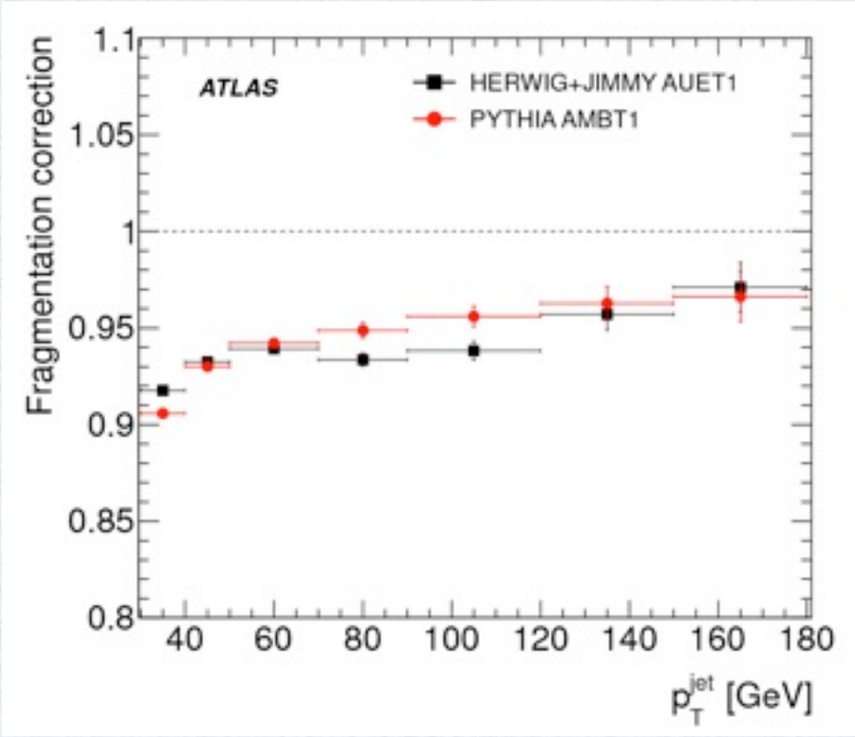
UE



Points to consider

- PDFs
- Renormalization/factorization scales
- Matching procedure and scale
- Underlying event model
- Fragmentation
- Hadronization
- Decay tables

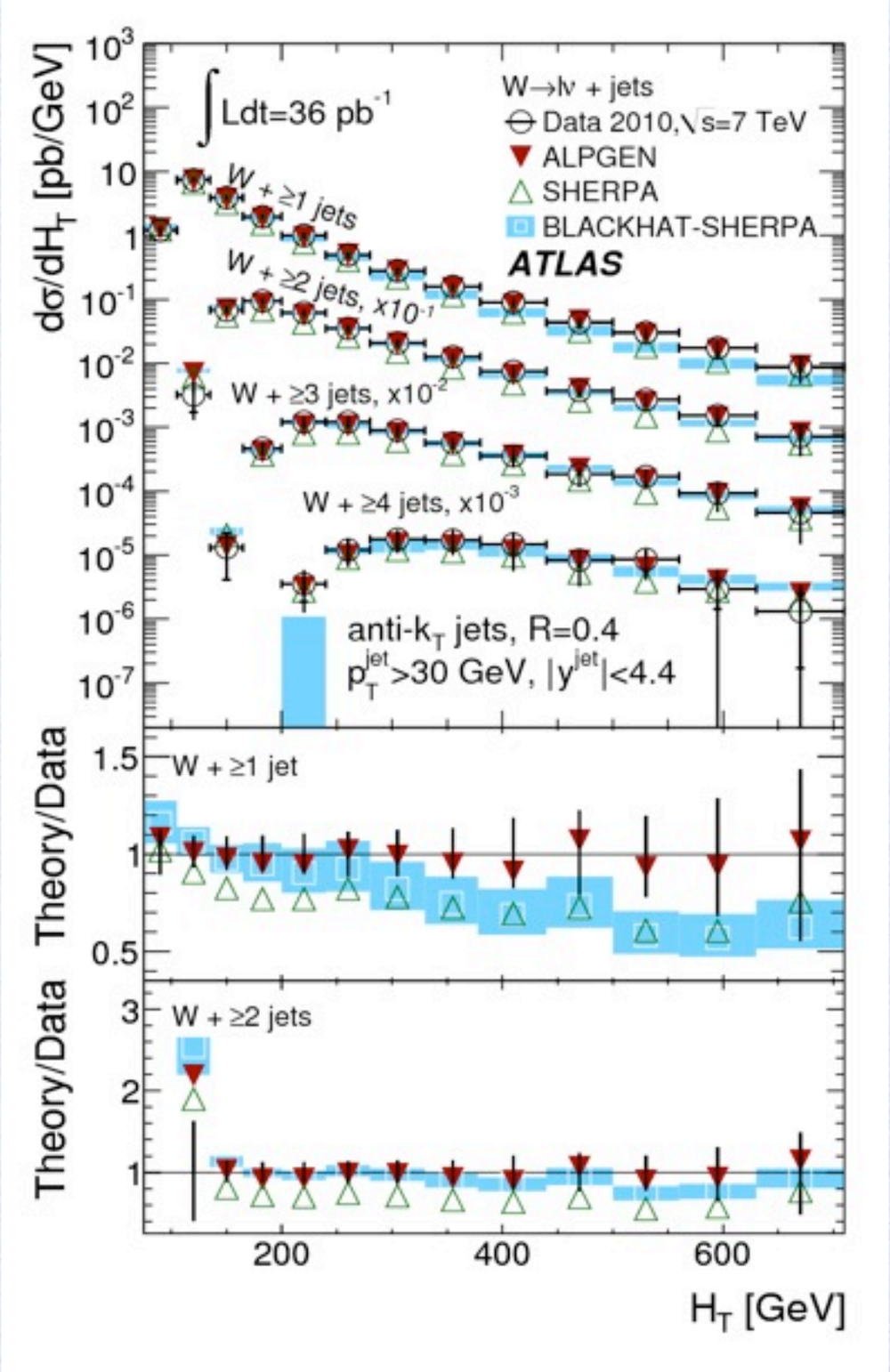
Fragmentation



Some Considerations for NLO

- Some questions to address
  - How to produce prediction for inclusive quantities (i.e. H_T)

Inability of fixed-order calculations to model inclusive quantities such as H_T → improved by exclusive sums of NLO calculations



Observables for 2011

- Possible observables for comparison/combination
  - Properties of individual jets: Jet p_T
  - Angular relations between the two leading jets: y, Δy
  - W/Z cross sections: vs. N_{jets}, N_{jets}/N_{jets}-1
  - Event observables: H_T
- Need to define the details
  - Inclusive or exclusive N_{jets}
  - Normalization to inclusive W/Z cross section
  - Binning

A Common Phase Space: Leptons

ATLAS	2011	CMS

• Leptons
  • W: Lepton $p_T > 25$ GeV
  • Z: Lepton $p_T > 20$ GeV
  • Lepton $\lvert\eta\rvert < 2.5$
  • Lepton dressed
		• Leptons
		  • W: Lepton $p_T > 35$ GeV, $M_T > 55$GeV
		  • Z: Lepton $p_T > 20$ GeV
		  • Electron $\lvert\eta\rvert < 2.5$
		  • Muon $\lvert\eta\rvert < 2.4$
		  • Lepton at bare-level (after FSR)

- Some changes to the lepton selection in 2011 due to trigger requirements
- For common phase space, will be following the recommendations from the W/Z inclusive groups

A Common Phase Space: Jets

ATLAS	2011	CMS

• Jets
  • Anti-K_T, R=0.4
  • p_T > 30 GeV (20 GeV also in W+jets)
  • $\lvert\eta\rvert < 4.4$
  • ΔR (jet-lepton) > 0.5
		• Jets
		  • Anti-K_T, R=0.5
		  • E_T > 30 GeV
		  • $\lvert\eta\rvert < 2.4$
		  • ΔR (jet-electron) > 0.3

- Both ATLAS and CMS uses anti-kT algorithm, but with different cone size
  - It is not easy for either experiment to change this
- ATLAS also using a larger rapidity range
- Before the jet clustering
  - CMS removes all neutrinos and muons
  - ATLAS removing neutrinos and leptons from vector boson

Jet Radius

- How to find a common phase space between the two jet radii?
  - Correct to parton-level: Not preferred!
    - The corrections to parton-level would have large uncertainties and strong model dependence
  - Apply a R=0.4 ↔ R=0.5 correction
    - This can be done together with corrections to common phase space
    - Relatively safe and simple
    - Uncertainties of particle level correction such UE are small, since correction in the annulus (between 0.4<R<0.5) is small
    - See slides from V. Ciulli and A. Tropiano
- Want to develop a common tool (possibly a RIVET routine) to extrapolate to fiducial volume between the experiments

Conclusions

- ATLAS and CMS have published results for W, Z, and R+jets
  - Overall the predictions agree well with the data
  - Some tension exists at large jet p_Ts and rapidities
- Have several new observables planned for 2011 measurements
- A definition of a combined phase space is being worked on