Higgs searches: validation and assessment of the simulation tools

The Zurich phenomenology workshop:

Higgs search confronts theory

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- **I focus here on a (likely incomplete) review of the status and prospects of validation against data**

For a thorough discussion of TH predictions and systematics, see the new forthcoming report:

Handbook of LHC Higgs cross sections:

2. Differential Distributions

Report of the LHC Higgs Cross Section Working Group

Editors: S. Dittmaier
C. Mariotti
G. Passarino
R. Tanaka

Validation: general remarks

- **Signal modeling:**
  - Validation of signal-specific features can only be done once the signal is available: for the Higgs, this is still a bit premature, alas!
  - General features of final states, relevant to the proper simulation of signal events, can however be partly assessed using "signal control samples", namely SM processes probing specific dynamical properties, such as:
    - initial-state radiation (Higgs pt spectrum, associated jet multiplicity, VBF jet-veto survival)
- **Background modeling:**
  - Higgs searches are sensitive to a broad and diverse set of SM bg processes: DY, ttbar, V+jets (V=W, Z, γ), V+hvq's, VV, etc.
  - By and large, LHC/Tevatron data have shown good agreement with theory for most processes.
    - In many cases, data-driven bg estimates are also usable and **are** used.
    - In both cases, however, one needs to confirm the validity of the transfer of the bg estimate from the control region to the Higgs signal region
  - Open issues however remain. E.g.
    - Wbb, Zbb
    - VBF-like final states never tested at the Tevatron, still poorly tested at LHC
    - ....

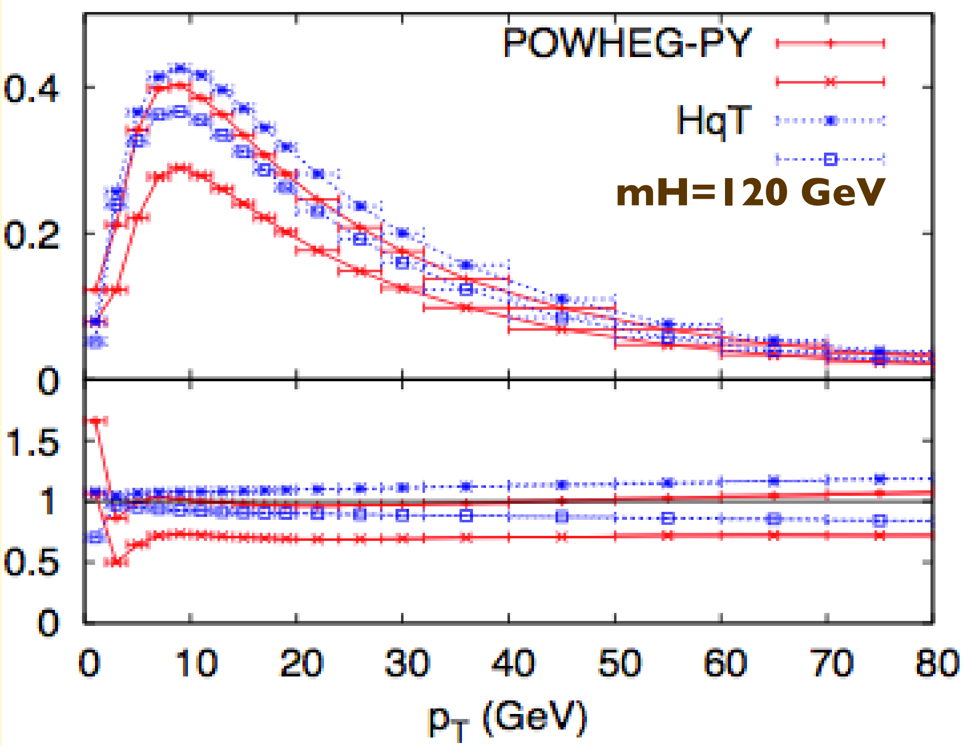
Side remark

- Validation of Higgs-specific tools gives valuable information on tools' performance, which can then be applied in other contexts
- It is therefore useful to consider turning some of the studies done in the context of Higgs searches into actual measurements (e.g. cross sections corrected and unfolded to the hadron level) or data vs MC comparisons
  - Several examples already exist, e.g. VV (V=W, Z, γ) cross section's and will be discussed in the following

H → γγ

- Signal observation doesn't rely heavily on MC modeling of either S or B. Just fit the sidebands ....
- Limit setting (or cross-section determination) relies directly on signal modeling. Typical strategy:
  - NLO POWHEG for gg→H, VBF
  - LO MC for VH, ttH, etc
  - rescale total rates of individual procs to (N)NLO
  - reweight events to match pt(H) distribution at NNLL (e.g. HqT, DeFlorian et al, JHEP 1111 (2011) 064)

pt_H spectrum



From the HWG, vol 2 prelim draft

[8]K. Hamilton, F. Maltoni, P. Nason and P. Torrielli.

ATLAS-CONF-2011-161

Table 6: Summary of systematic uncertainties on the expected signal.

Type and source	Uncertainty
Event yield	
Photon reconstruction and identification	±11%
Effect of pileup on photon identification	±4%
Isolation cut efficiency	±5%
Trigger efficiency	±1%
Higgs boson cross section	+15% / −11%
Higgs boson p_T modeling	±1%
Luminosity	±3.9%
Mass resolution	
Calorimeter energy resolution	±12%
Photon energy calibration	±6%
Effect of pileup on energy resolution	±3%
Photon angular resolution	±1%
Migration	
Higgs boson p_T modeling	±8%
Conversion reconstruction	±4.5%

- Only indirect validation checks can be made, as no adequate control sample exists for comparison. E.g.
  - pt_{DY} is driven by qqbar initial state (rather than gg)
  - $pt_{t\text{-}tbar}$ is mostly in color-octet (and $\sqrt{s}$ >> O(120 GeV))

ISR validation/tuning in qqbar→DY at the LHC

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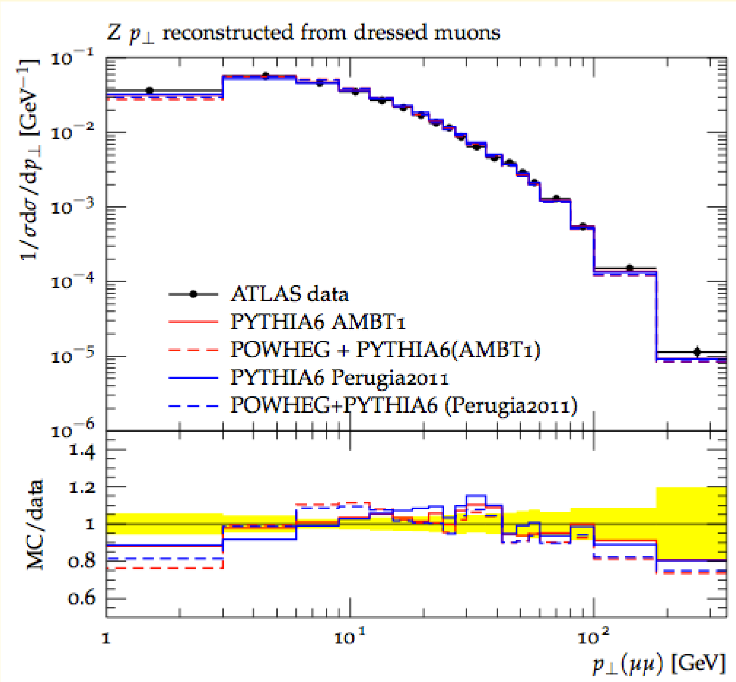
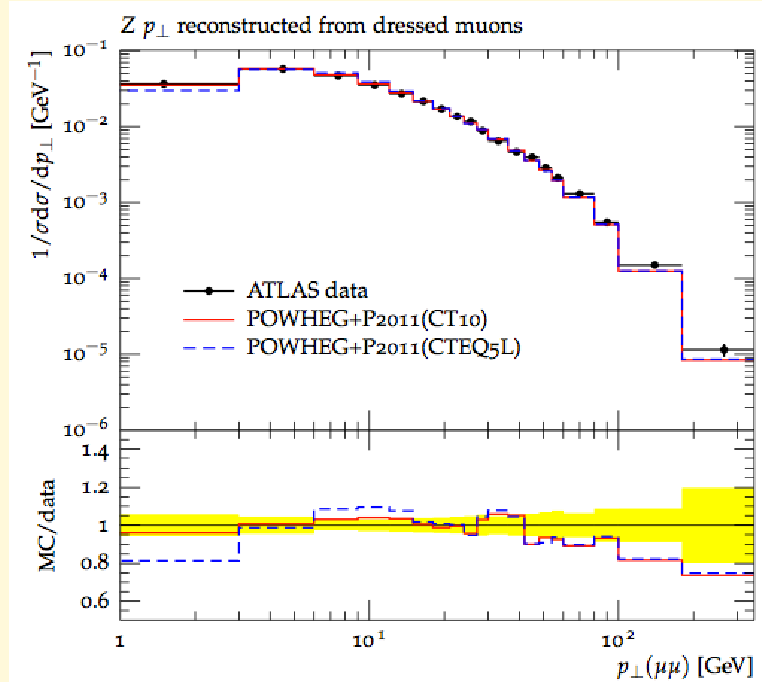
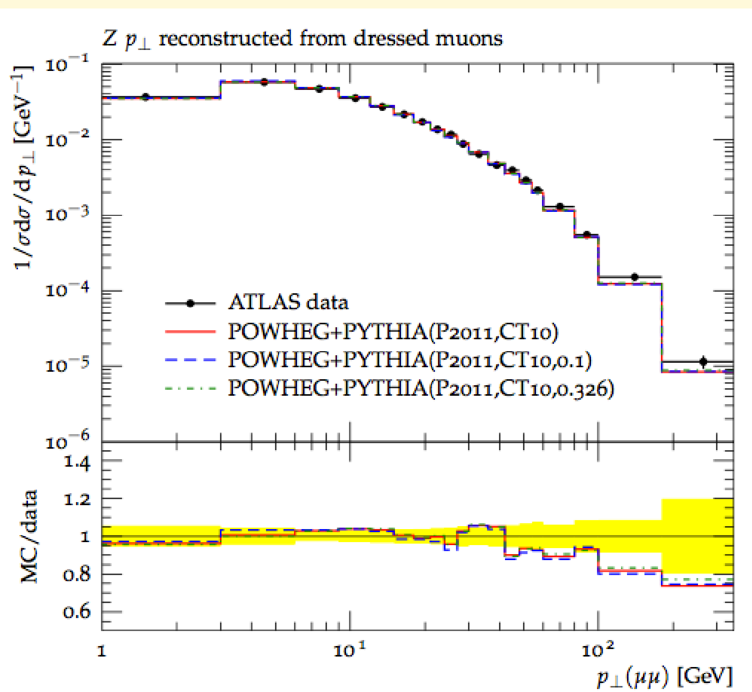
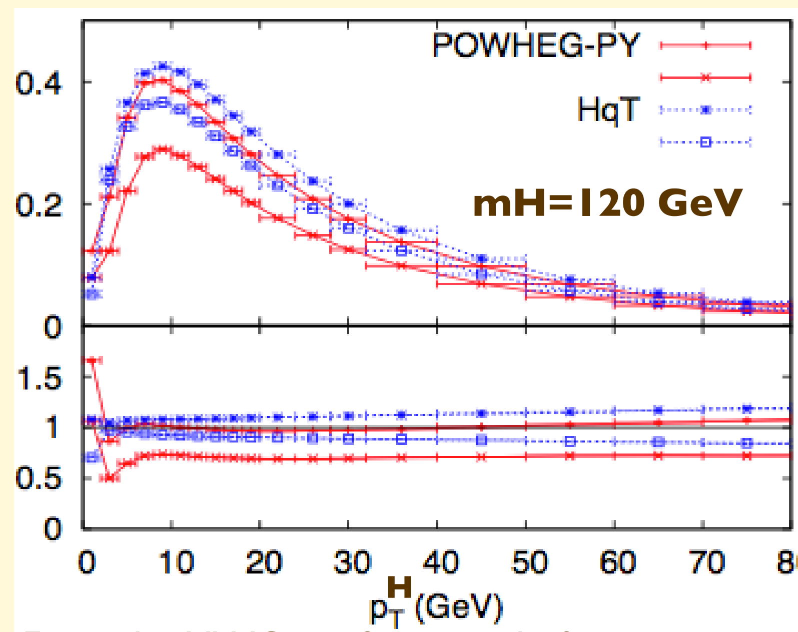






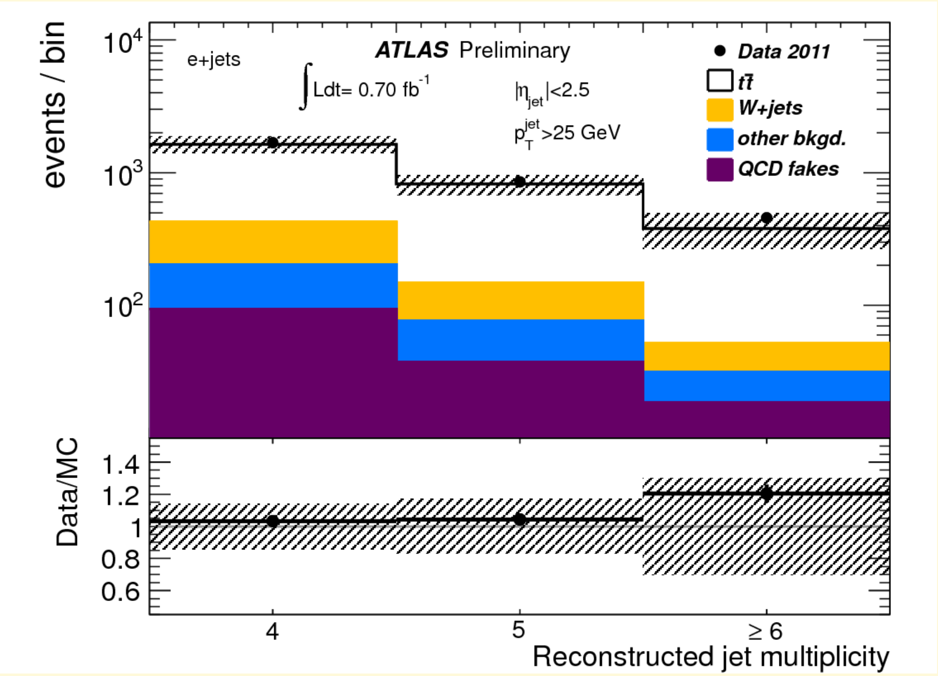
cfr expected TH systematics for gg→H

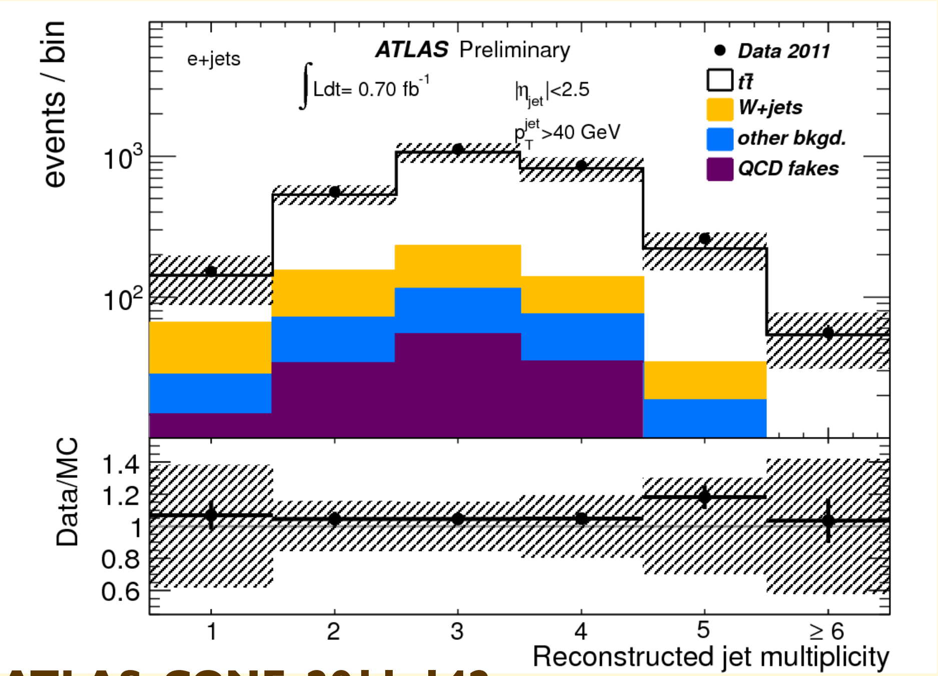


From the HWG, vol 2 prelim draft

[8] K. Hamilton, F. Maltoni, P. Nason and P. Torrielli.

Indirect ISR validation in gg→tt at the LHC





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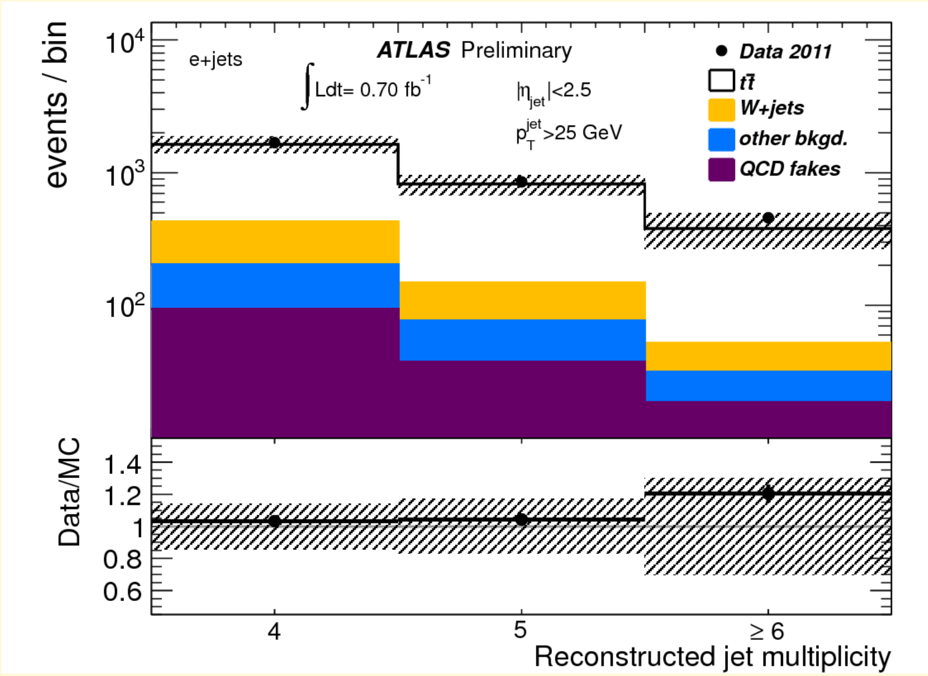
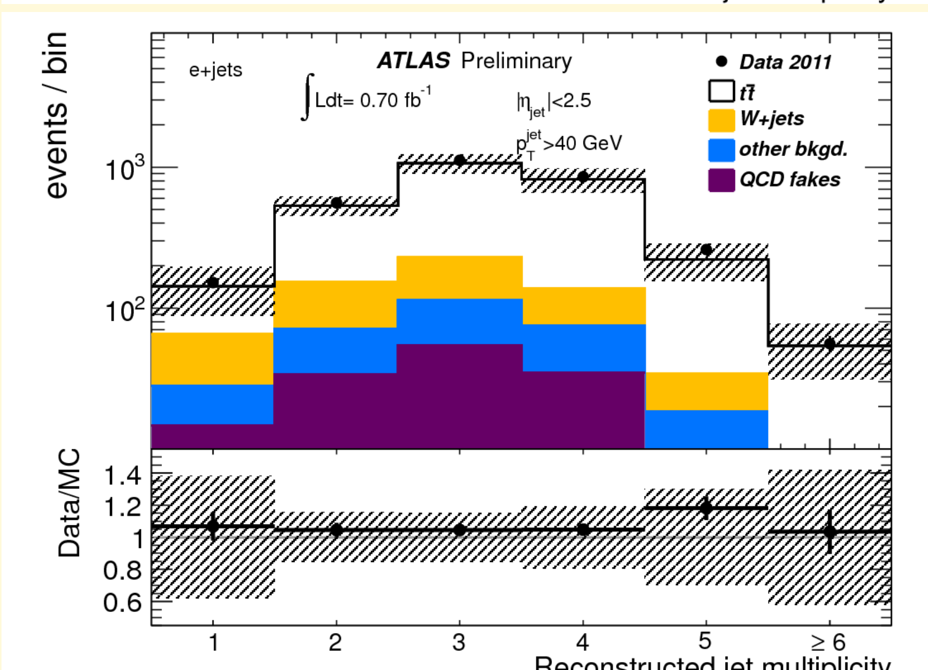
Indirect ISR validation in gg→tt at the LHC





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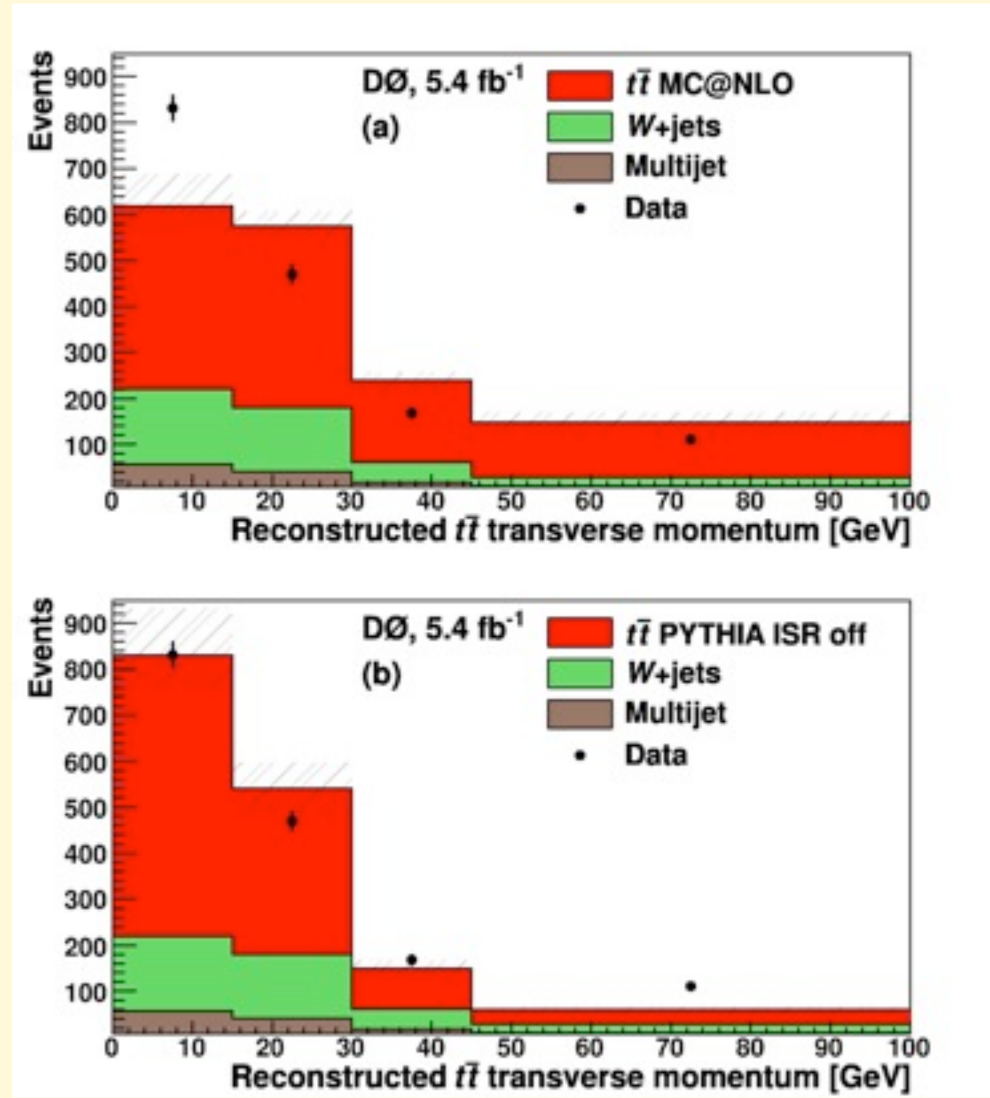
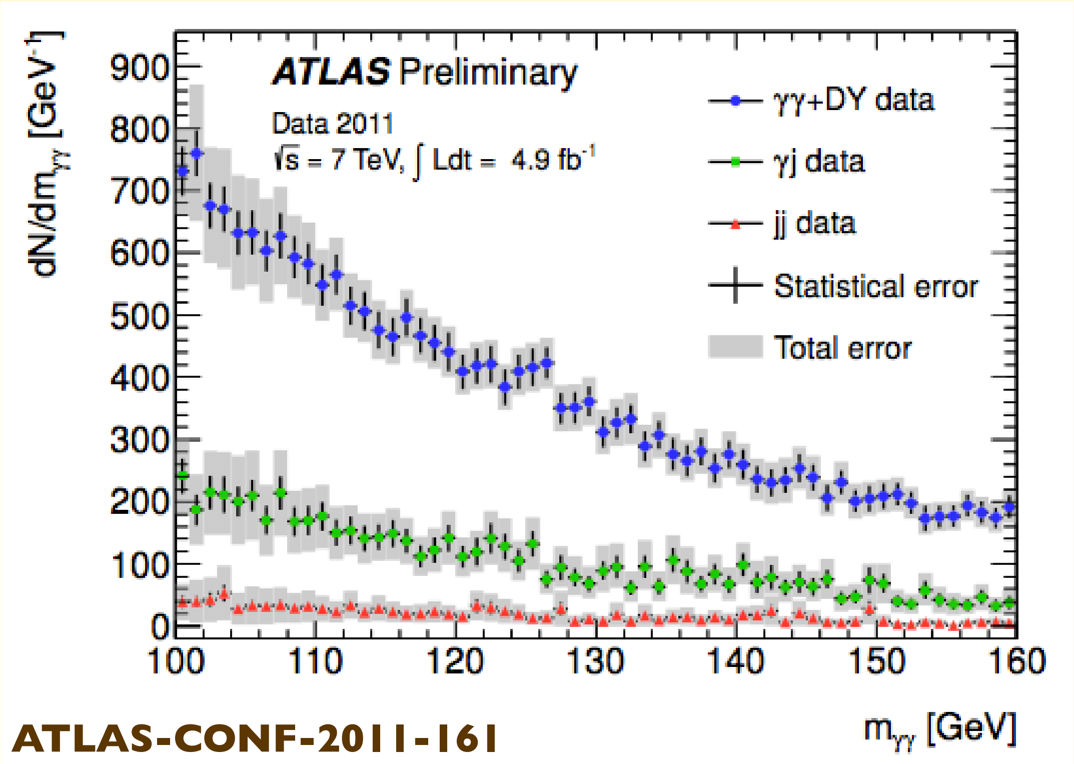
ISR validation in qqbar→tt at the Tevatron

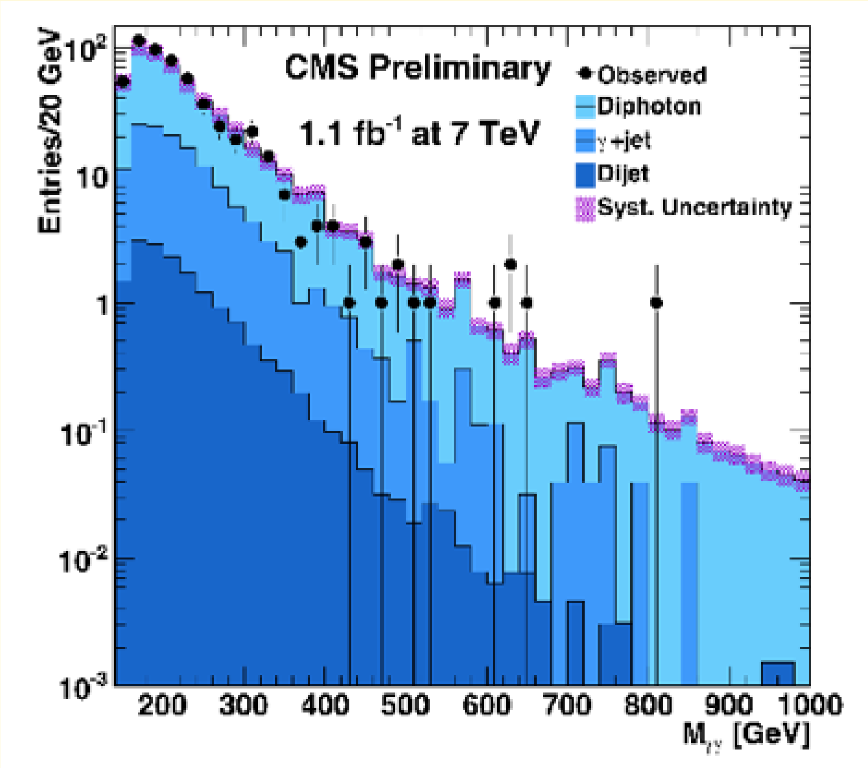


DØ, Phys. Rev. D 84, 112005 (2011)

H → γγ, backgrounds

- Specific study of signal (e.g. γγ angular correlations), may require more detailed understanding of background's properties, because of huge B/S ratio





- The contamination rate from γj/jj depends on both physics processes and experimental effects (detector+event selection). The physics aspects touch on difficult-to-model hadronization issues (e.g. z→1 fragmentation). It would be interesting to know whether these direct determinations of the relative γγ/γj/jj fractions agree with MC estimates

Example

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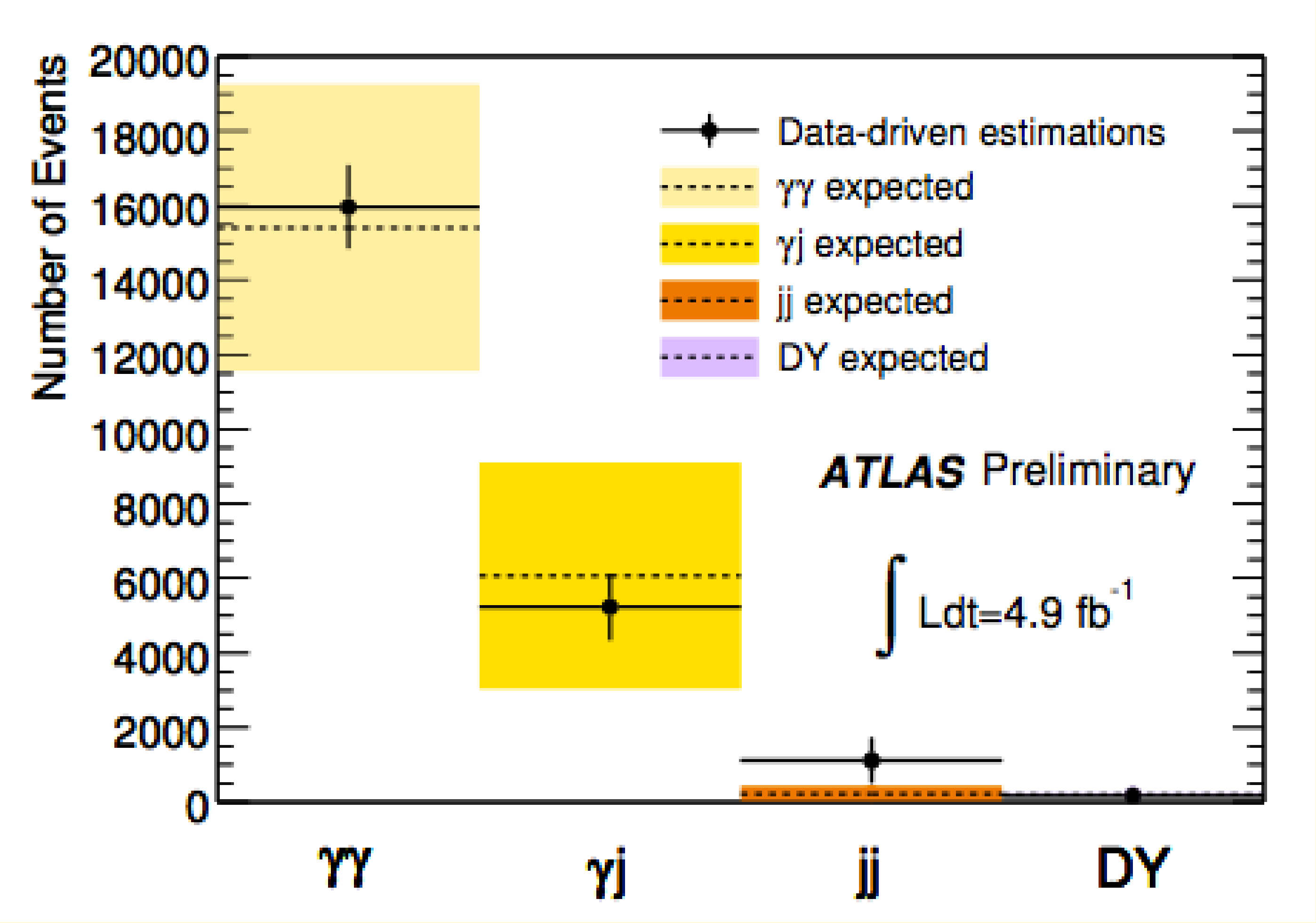
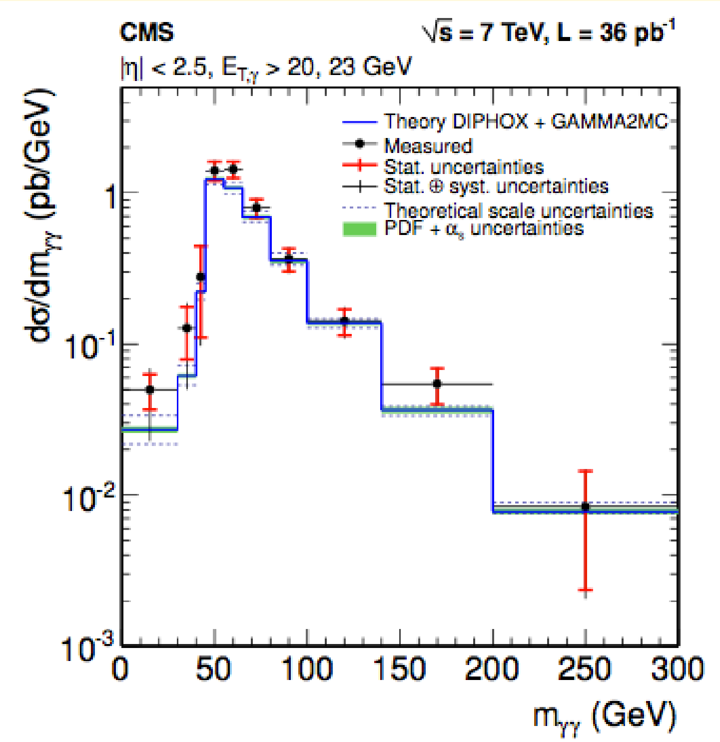
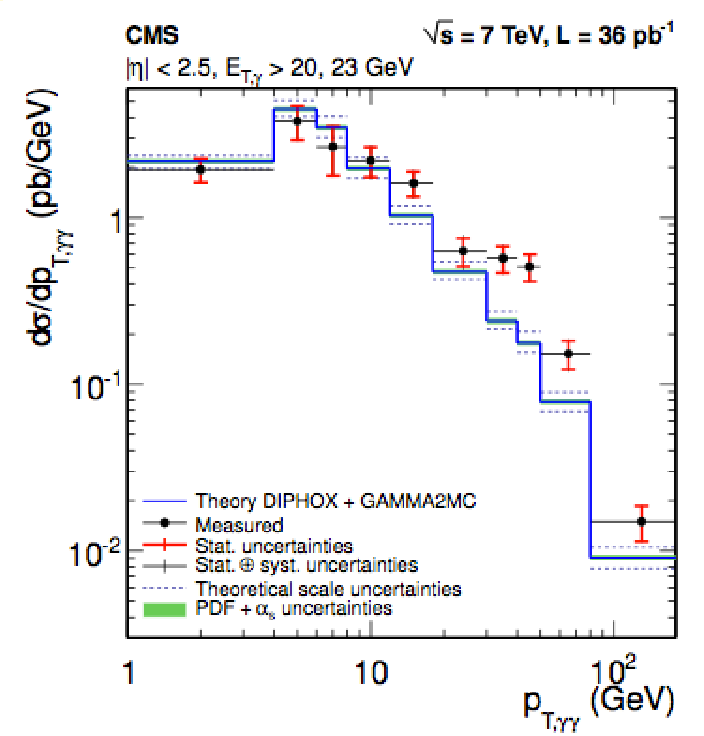
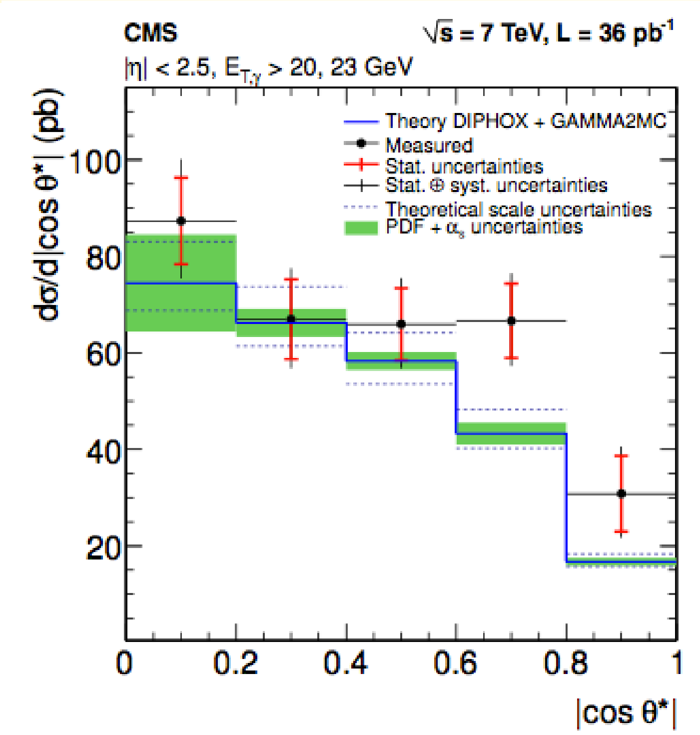
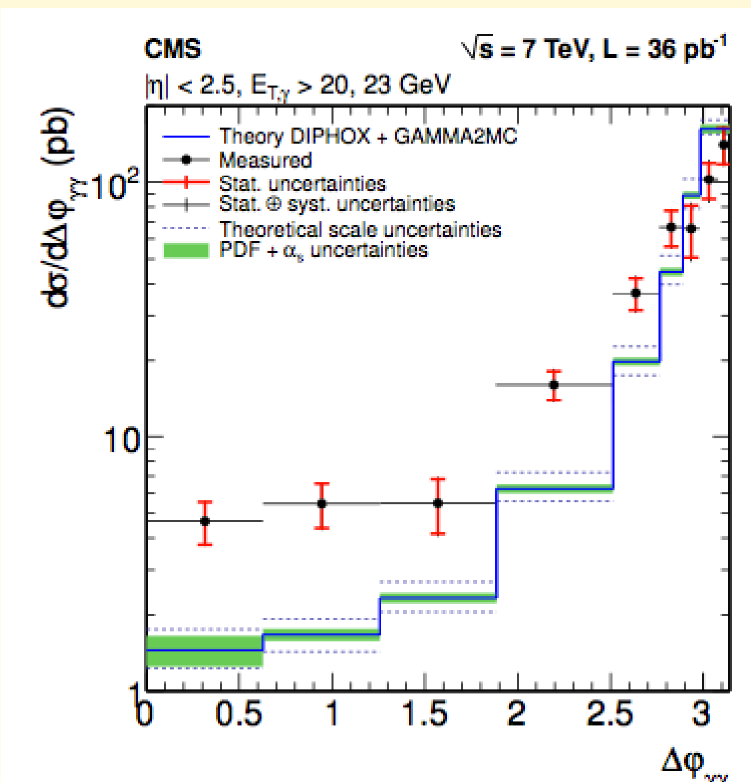


$pp \to \gamma\gamma$ production, CMS, arXiv:1110.6461v1

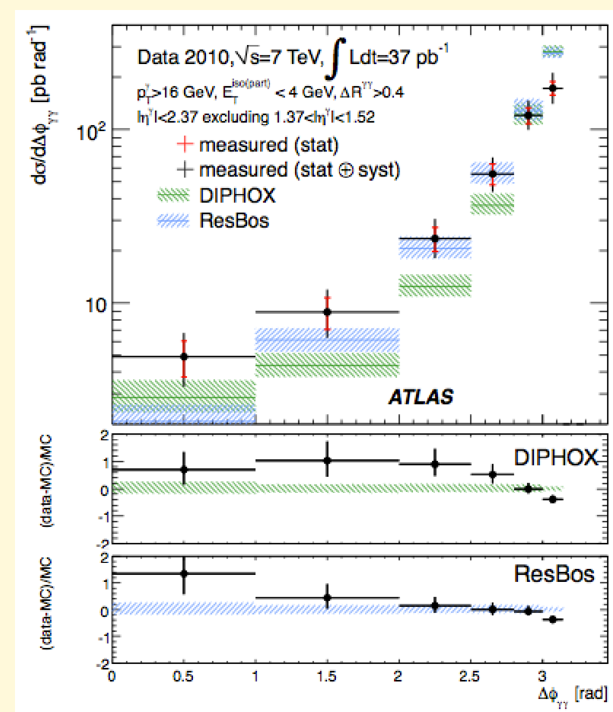








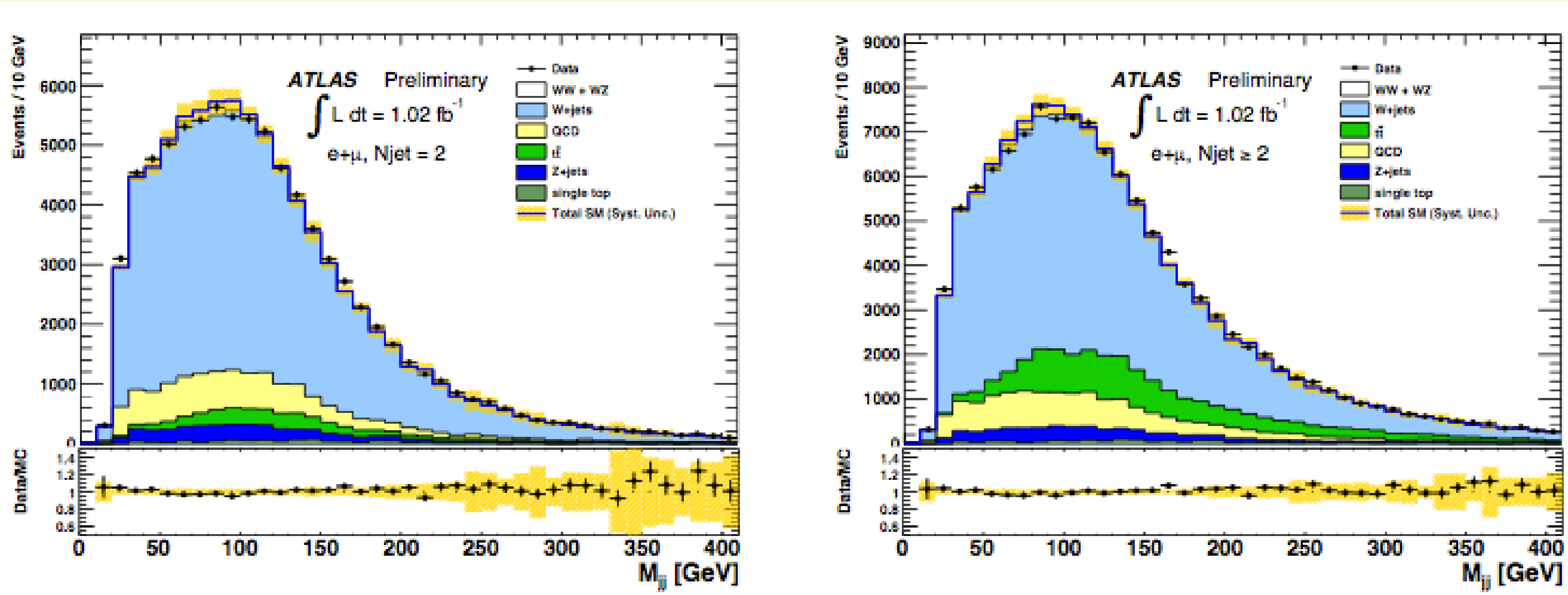
cfr ATLAS, arxiv:1107.0581 :



Question: is the $\gamma\gamma/\gamma j/jj$ separation done for each bin in each distribution, or is it done globally for the full sample?
Could the discrepancies be due to the different spectra of $\gamma\gamma/\gamma j/jj$, and the different composition across bins?

VH, H→bb

- **Signal modeling:** NLO MC+shower, rescale to NNLO, no big issues expected
- **Bg's**
  - V+jets
  - V+QQ
- Key issue: m_{jj} spectrum for bg peaks close to 100 GeV, due to kin cuts. Thus data-driven interpolation from the sidebands of bg spectrum is less robust for light Higgs than, e.g., in the H→ γγ case



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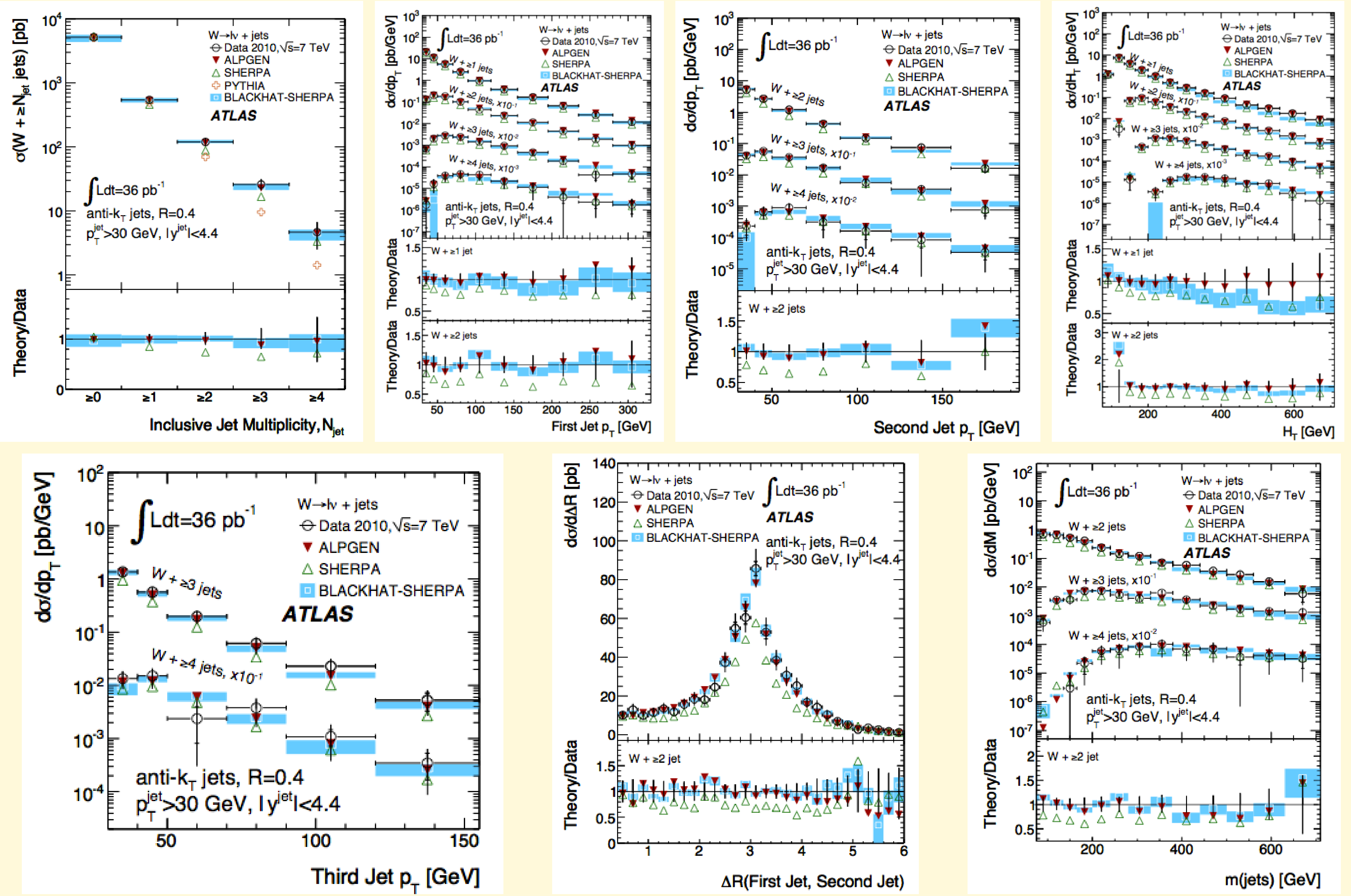
W+jets validation

ATLAS, arXiv:1201.1276

Alpgen Sherpa and Pythia σ_{tot} normalized to $\sigma_{NNLO}(W)$



W+b-jet
CDF analysis

- $p_{T\ lepton} > 20$ GeV , $|\eta_{lepton}| < 1.1$ MET>25 GeV
- $p_{T\ jet} > 20$ GeV , $|\eta_{\ jet}| < 2$, R=0.4

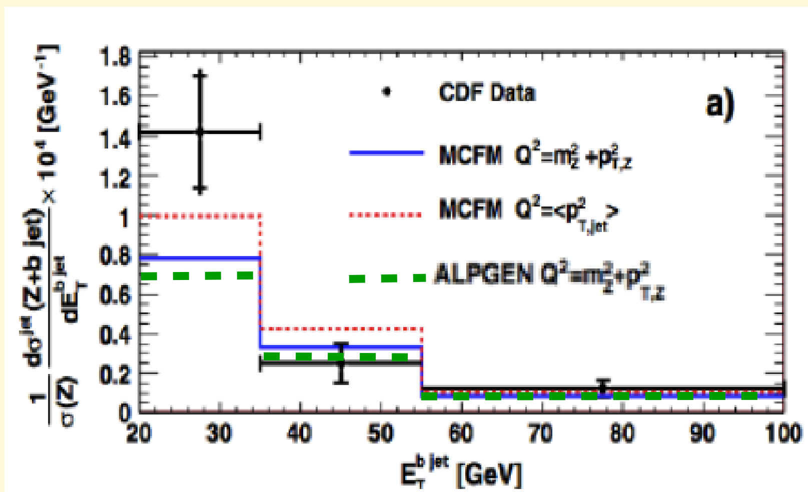
	$\sigma_{Wb} \times$ BR(W→e nu) [pb]
CDF	2.74 ± 0.27 (stat) ± 0.42 (syst)
MCFM	1.22 ± 0.14
Wbb+ Wbb1jet MLM matching with Herwig	$[0.504]_{Wbb} + [0.126]_{Wbbj} = 0.73$

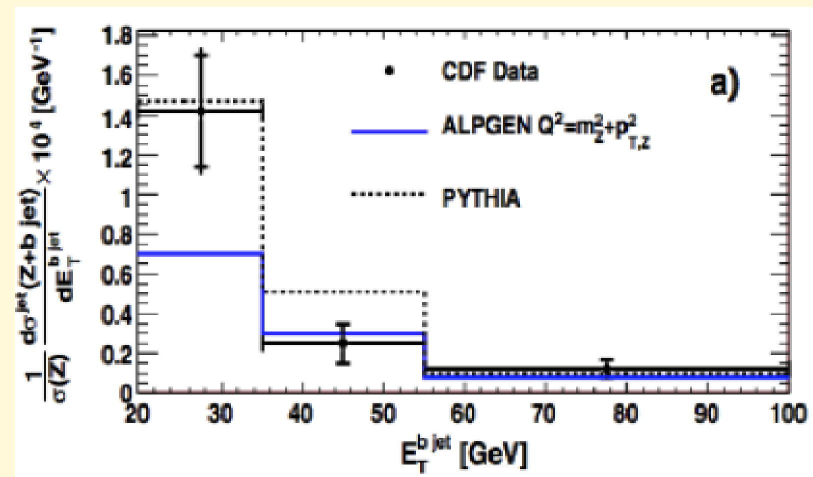
Data/NLO > 2 !!

Data/Alpgen > 3 !!

Z+b-jet
CDF analysis

- $E_{T\ jet} > 20$ GeV
- $|\eta_{\ jet}| < 1.5$ R=0.7



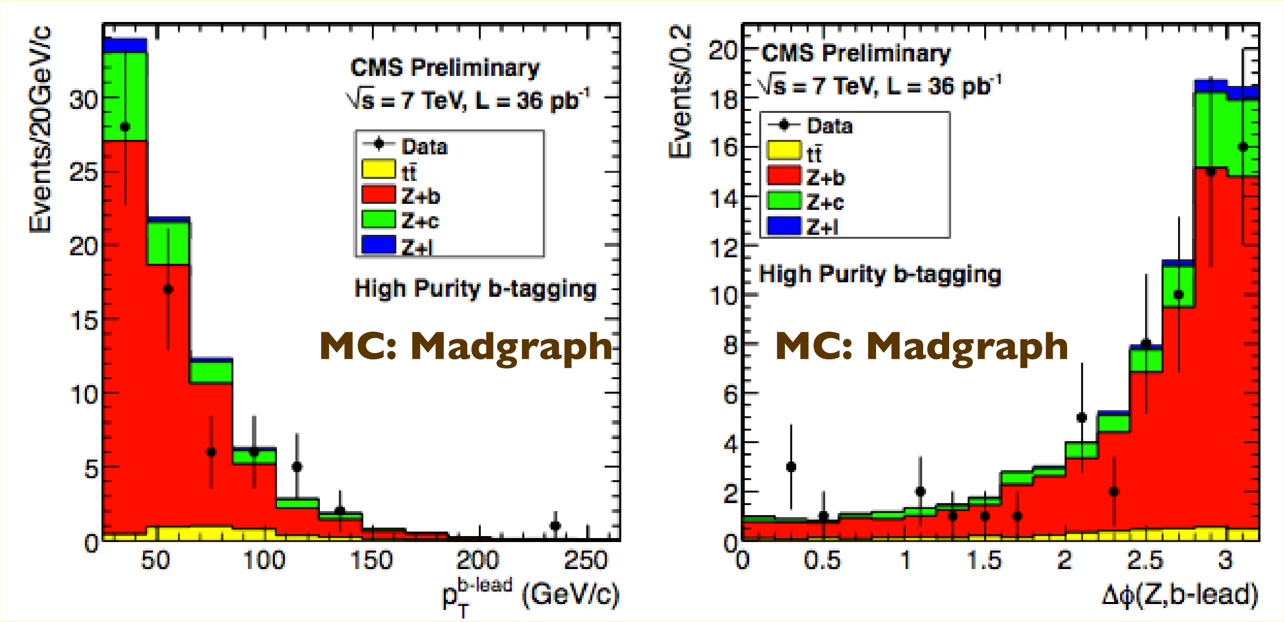


	CDF	MCFM $Q^2=M^2+p_T^2$	MCFM $Q^2 = \langle p_T^2 \rangle$	ALP $Q^2=M^2+p_T^2$	ALP $Q^2 = \langle p_T^2 \rangle$
σ[Z+b-jet] / σ[Z+jet]	2.1 ± 0.4 %	1.8%	2.2%	1.6%	2.3%
σ[Z+b-jet] / σ[Z]	0.33 ±0.07%	0.23%	0.28%	0.21%	0.3%

CMS

Z production in association with b jets

- CMS-PAS-EWK-10-015



	Sample	$\frac{pp\to ee+b+X}{pp\to ee+j+X}$ (%) $p_T^e > 25$ GeV, $\lvert\eta^e\rvert < 2.5$	$\frac{pp\to \mu\mu+b+X}{pp\to \mu\mu+j+X}$ (%) $p_T^\mu > 20$ GeV, $\lvert\eta^\mu\rvert < 2.1$
(1)	Data SSVHE	$4.3 \pm 0.6(stat) \pm 1.1(syst)$	$5.1 \pm 0.6(stat) \pm 1.3(syst)$
(2)	Data SSVHP	$5.4 \pm 1.0(stat) \pm 1.2(syst)$	$4.6 \pm 0.8(stat) \pm 1.1(syst)$
	MADGRAPH	$5.1 \pm 0.2(stat) \pm 0.2(syst) \pm 0.6(theory)$	$5.3 \pm 0.1(stat) \pm 0.2(syst) \pm 0.6(theory)$
	MCFM	$4.3 \pm 0.5(theory)$	$4.7 \pm 0.5(theory)$

(1) High-tagging efficiency sample

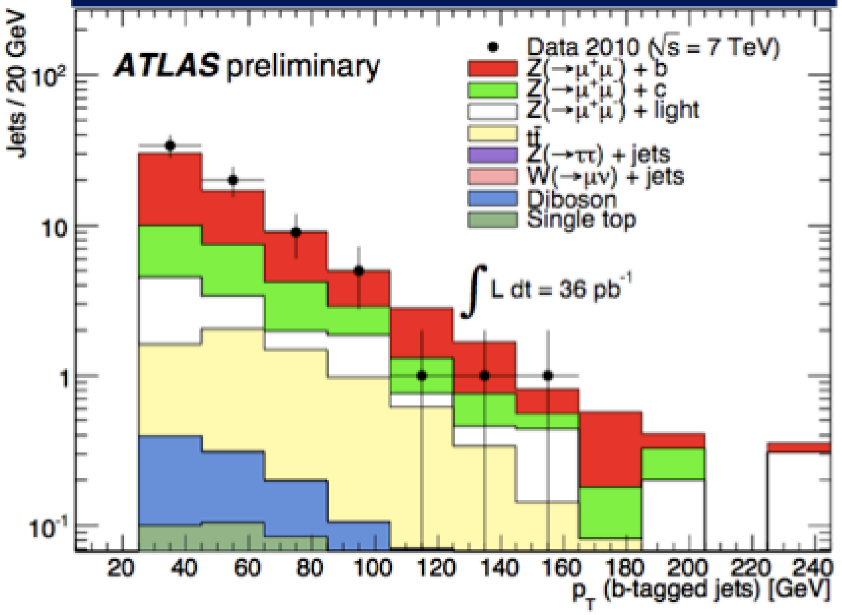
(2) High-tagging purity sample

Z + b-jets results

$$\sigma = \frac{N_b}{C_e \times \mathcal{L}_e + C_\mu \times \mathcal{L}_\mu}$$

- Inclusive b-jet production cross section in association with a Z boson
- Jet fitted yield is corrected for all detector effects with MC LO matched prediction for Zjet (including heavy flavour) from ALPGEN and SHERPA
- uncertainty: ≈ 20% stat. and ≈23% syst.
- dominant systematics:
  - b-tagging & SV mass template ≈10%
  - Z+b-jet modeling ≈10%
  - Jet + bjet energy scale ≈4%
- MCFM in good agreement with data within uncertainty

Z+b uncorrected b-jet spectrum



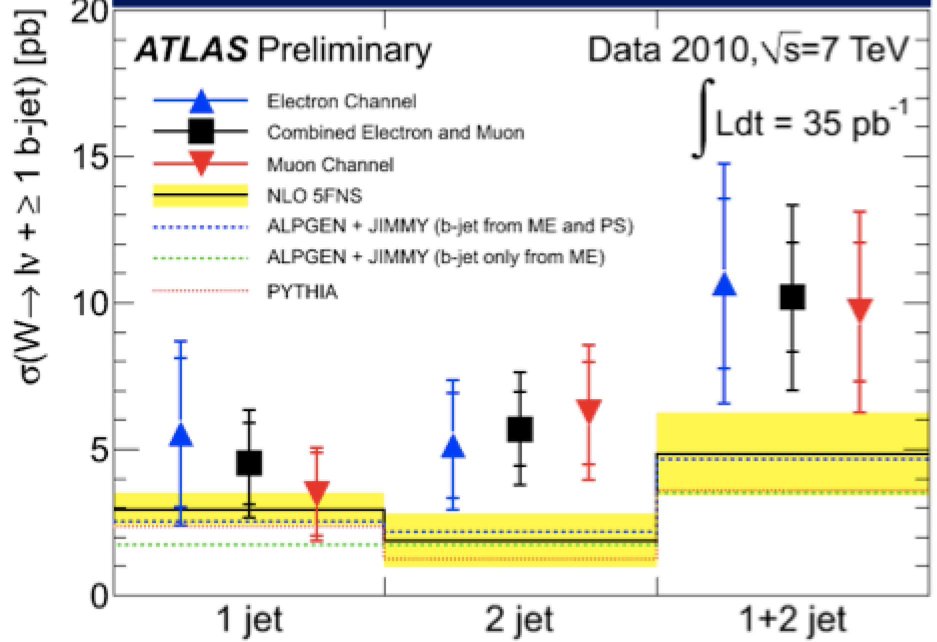
Experiment	$3.55^{+0.82}_{-0.74}$(stat)$^{+0.73}_{-0.55}$(syst) ± 0.12(lumi) pb
MCFM	3.40 ± 0.44 pb
ALPGEN	2.23 ± 0.01(stat only)pb
SHERPA	3.33 ± 0.04(stat only) pb

W + b-jets results

$$\sigma_{W+b-\text{jet}} \times \mathcal{B}(W \to \ell\nu) = \frac{n^{\text{tag}} \cdot f_{W+b-\text{jet}}}{\int Ldt \cdot \mathcal{U}}$$

- W+b-jet cross section (event level)
- First measurement in exclusive jet bins
- event fitted yield is corrected for all detector effects with MC LO matched prediction for Wjet (including heavy flavour) from ALPGEN
- uncertainty: ≈ 20% stat. and ≈25% syst.
- dominant systematics:
  - b-tagging & SV mass template ≈16%
  - top background ≈12%
  - QCD background ≈7%
  - W+b-jet modeling ≈10%
  - Jet + bjet energy scale ≈7%

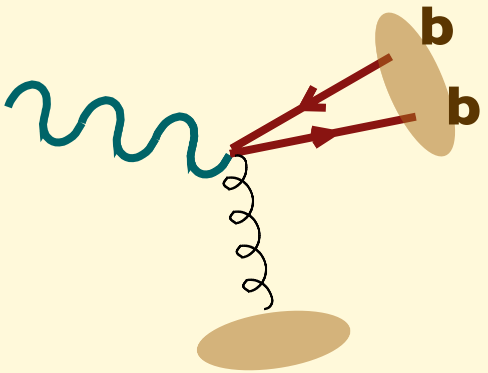
W+b-jet cross sections



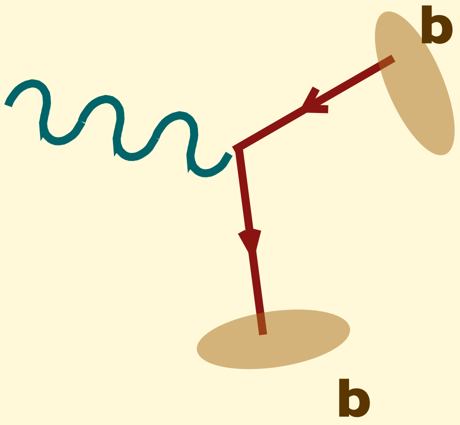
- NLO prediction obtained in the 5 flavour number scheme [F. Caola *et al.* arXiv:1107.3714]
- NLO agrees within 1.5σ with the measurements

	σ_{vis} [pb]
1 jet	$2.9^{+0.40}_{-0.36}$ (scale) $^{+0.18}_{-0.02}$ (PDF) $^{+0.19}_{-0.10}$ (m_b) $\pm$ 0.20 (non-pert)
2 jet	$1.9^{+0.81}_{-0.37}$ (scale) $^{+0.14}_{-0.02}$ (PDF) $^{+0.06}_{-0.05}$ (m_b) $\pm$ 0.13 (non-pert.)
1+2 jet	$4.8^{+1.20}_{-0.73}$ (scale) $^{+0.32}_{-0.03}$ (PDF) $^{+0.25}_{-0.15}$ (m_b) $\pm$ 0.34 (non-pert.)

For the applications to VH→Vbb searches, it is crucial to parameterize possible discrepancies or K-factors in the data/theory comparison of VQQ final states w.r.t. the multiplicity of heavy quark jets



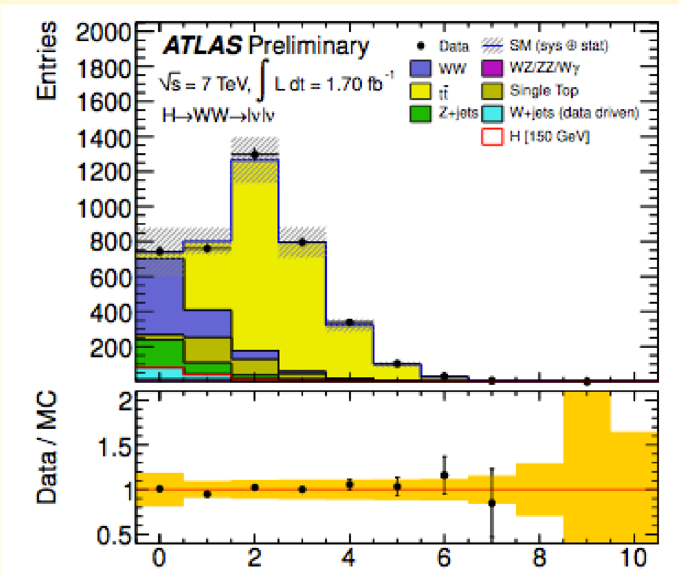
This does not contribute to H→bb bg



This contributes to H→bb bg

H→WW→ℓℓνν

Large top leakage at low Njet



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Hard to validate *directly*
modeling of tt→WW+(0,1) jets!

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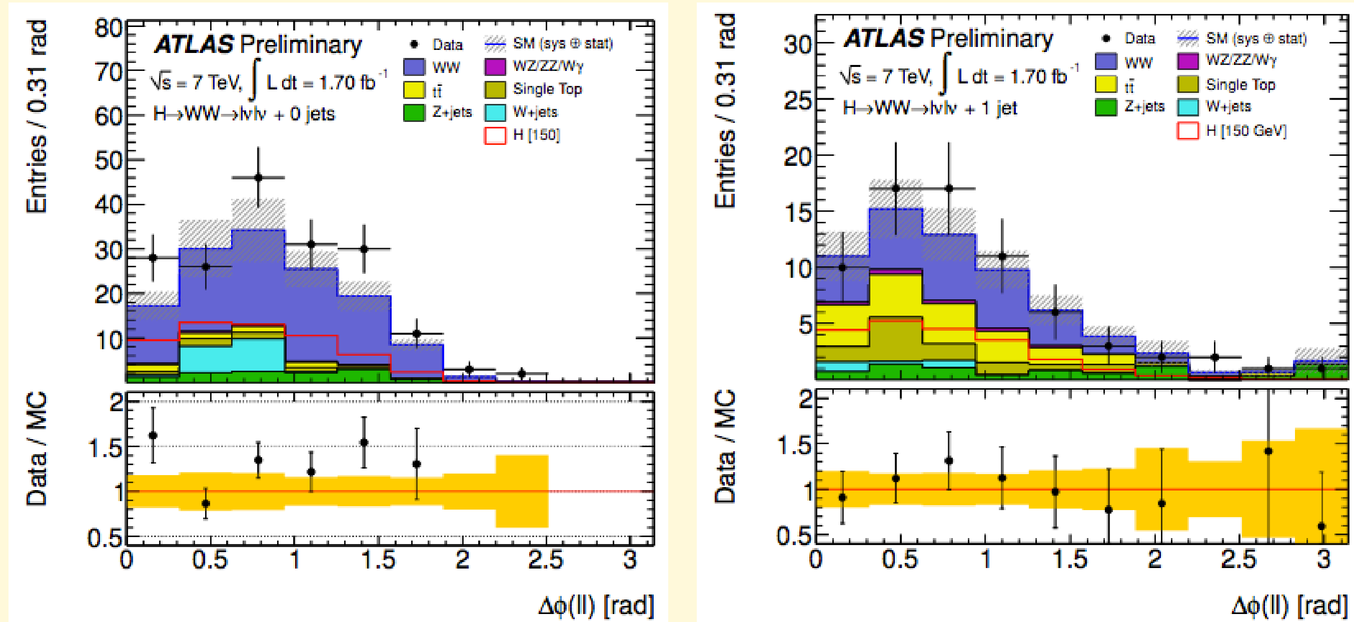
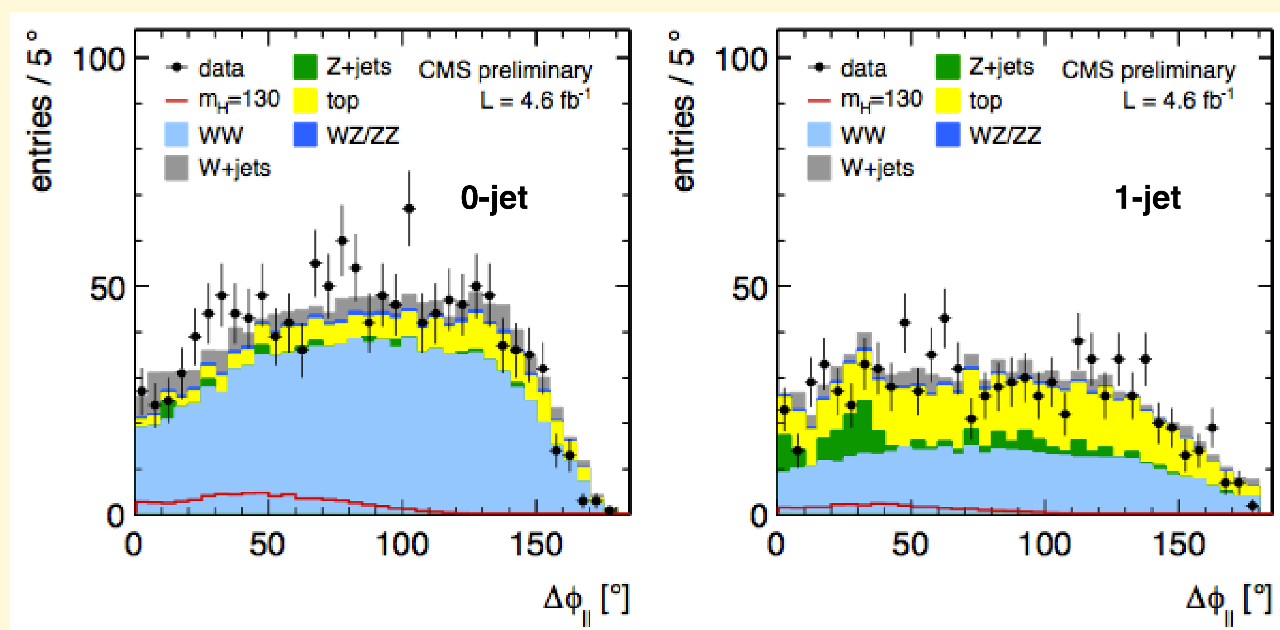
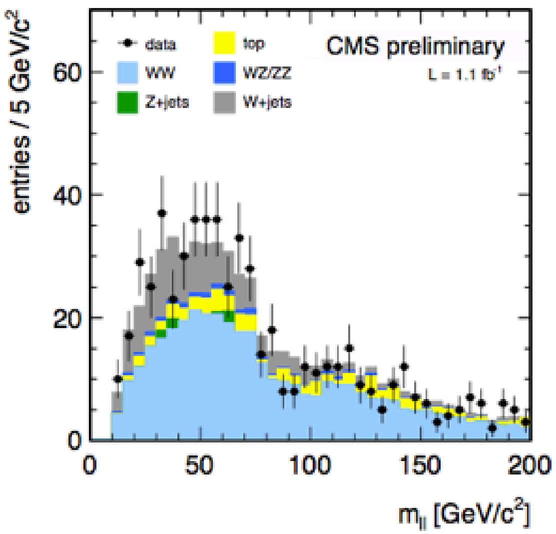


CMS PAS HIG-11-024



$WW(\rightarrow l l \nu \nu)$



Event yields

Sample	Yield
$qq \to W^+W^-$	349.7 ± 30.3
$gg \to W^+W^-$	17.2 ± 1.6
$W + \text{jets}$	106.9 ± 38.9
$t\bar{t} + tW$	63.8 ± 15.9
$Z/\gamma^* \to \ell\ell + WZ + ZZ$	12.2 ± 5.3
$Z/\gamma^* \to \tau\tau$	1.6 ± 0.4
WZ/ZZ not in $Z/\gamma^* \to \ell\ell$	8.5 ± 0.9
$W + \gamma$	8.7 ± 1.7
signal + background	568.6 ± 52.2
Data	626

Measured cross section for $\sigma(W^+W^-)$:

2011 data with 1.1 fb^{-1} 55.3±3.3(stat)±6.9(syst)±3.3(lumi) pb

2010 data with 36 pb^{-1} 41.1±15.3(stat)±5.8(syst)±4.5(lumi) pb

NLO prediction: 43.0±2.1 pb ($qq \rightarrow WW$) + 1.46 pb ($gg \rightarrow WW$)

7

This is the WW Xsect study, not the Higgs search

Comment:

Data – (S+B) = 58±52
where $52 = 39_{W+jets} \oplus 16_{Wt+tt} \oplus 5_{DY+WW+ZZ}$
thus the only reasonable origin of the discrepancy is the systematics in the W +jets channel, or the statistics in the signal (±30 => ~2σ)

ATLAS

- $N_{obs} = 414$
  $N_{Bkg} = 169.8 \pm 6.4 \pm 27.1$

$$\sigma_{WW}^{tot} = 48.2 \pm 4.0(\text{stat}) \pm 6.4(\text{syst}) \pm 1.8(\text{lumi})\ \text{pb}$$

$$\sigma_{Theory(NLO)}^{tot} = 46 \pm 3\ pb$$

Michael Kagan LHC Electroweak Working Group Meeting -

Vector-boson fusion processes

- **Potential issues**
  - $VV \to H \to X$ Signal:
    - jet-veto efficiency (no suitable data as yet for validation)
  - $pp \to Xjj$ backgrounds:
    - jet-veto rejection (data available for tests with X=0)
  - $gg \to H \to X$ background:
    - jet-veto rejection

VBF total rates

From the HWG, vol 2 prelim draft

A. Denner, S. Farrington, C. Hackstein, C. Oleari, D. Rebuzzi (eds.); S. Dittmaier, A. Mück, S. Palmer and W. Quayle.

Table 14: Higgs-boson NLO cross sections at 7 TeV with VBF cuts and CTEQ6.6 PDF set with and without EW corrections, relative EW corrections and theoretical uncertainties from PDF and scale variations.

	w/ EW corr		w/o EW corr		EW corr	uncert.	
M_{H} [GeV]	HAWK [fb]	VBFNLO [fb]	HAWK [fb]	VBFNLO [fb]	HAWK [%]	PDF [%]	scale [%]
120	261.18 ± 0.43	258.27 ± 0.41	283.91 ± 0.42	282.80 ± 0.19	-8.0 ± 0.2	± 3.5	$+0.5 - 0.5$
150	218.40 ± 0.36	216.84 ± 0.40	236.75 ± 0.35	236.68 ± 0.14	-7.8 ± 0.2	± 3.5	$+1.0 - 0.5$
200	165.22 ± 0.24	163.50 ± 0.24	176.46 ± 0.24	176.89 ± 0.10	-6.4 ± 0.2	± 3.6	$+0.6 - 0.6$
250	123.81 ± 0.17	122.67 ± 0.17	133.13 ± 0.16	133.15 ± 0.07	-7.0 ± 0.2	± 3.8	$+0.6 - 0.5$
500	38.10 ± 0.07	37.31 ± 0.08	38.38 ± 0.07	38.41 ± 0.02	-0.7 ± 0.3	± 4.3	$+0.4 - 0.4$
600	26.34 ± 0.12	25.46 ± 0.07	25.70 ± 0.11	25.55 ± 0.01	2.5 ± 0.7	± 4.4	$+0.7 - 0.6$

$p_{\mathrm{T}j} > 20\,\mathrm{GeV}, \qquad |y_j| < 4.5$

$|y_{j_1} - y_{j_2}| > 4\,, \qquad m_{jj} > 600\,\mathrm{GeV}.$

Table 15: POWHEG Higgs-boson NLO QCD cross sections at 7 TeV with VBF cuts and CTEQ6.6 PDF set: fixed NLO results, POWHEG showered by PYTHIA (PY) and by HERWIG (HW).

M_{H} [GeV]	POWHEG NLO [fb]	POWHEG + PY [fb]	POWHEG + HW [fb]
120	282.87 ± 0.75	262.96 ± 0.99	262.04 ± 0.99
150	237.30 ± 0.57	221.54 ± 0.79	219.95 ± 0.79
200	177.05 ± 0.38	164.55 ± 0.55	163.83 ± 0.55
250	132.93 ± 0.26	124.19 ± 0.40	123.65 ± 0.40
500	34.04 ± 0.07	31.92 ± 0.09	31.78 ± 0.10
600	20.56 ± 0.03	19.47 ± 0.06	19.30 ± 0.06

Table 18: NLO QCD cross sections and efficiencies from VBFNLO for the full VBF selection including the jet veto cut of 20 GeV and the corresponding relative uncertainties from the QCD scale and PDFs.

M_{H}	Cross section			Efficiency		
[GeV]	[fb]	[%]	[%]	[%]	[%]	[%]
120	261.64	± 3.76	± 4.91	0.200	± 3.485	± 1.468
150	218.69	± 3.59	± 4.66	0.221	± 3.376	± 1.196
200	163.34	± 3.92	± 4.66	0.252	± 3.829	± 1.490
250	123.06	± 4.16	± 5.11	0.279	± 4.145	± 1.493
500	33.55	± 4.37	± 5.43	0.365	± 4.766	± 1.227
600	20.82	± 4.44	± 5.58	0.384	± 4.958	± 1.002

Summary assessment:

Low mass:

Δ(shower/PL)= –8%

Δ(EW/noEW)= –8%

High mass:

POWHEG: Δ(shower/PL) = –5%

Δ(POWHEG NLO/VBFNLO)= –20% *

Δ(EW/noEW)= +2.5%

* diff due to different BW implementation

PDF:

±3-4% CTEQ6.6

±5-6% MSTW2008NLO

(central values consistent within syst)

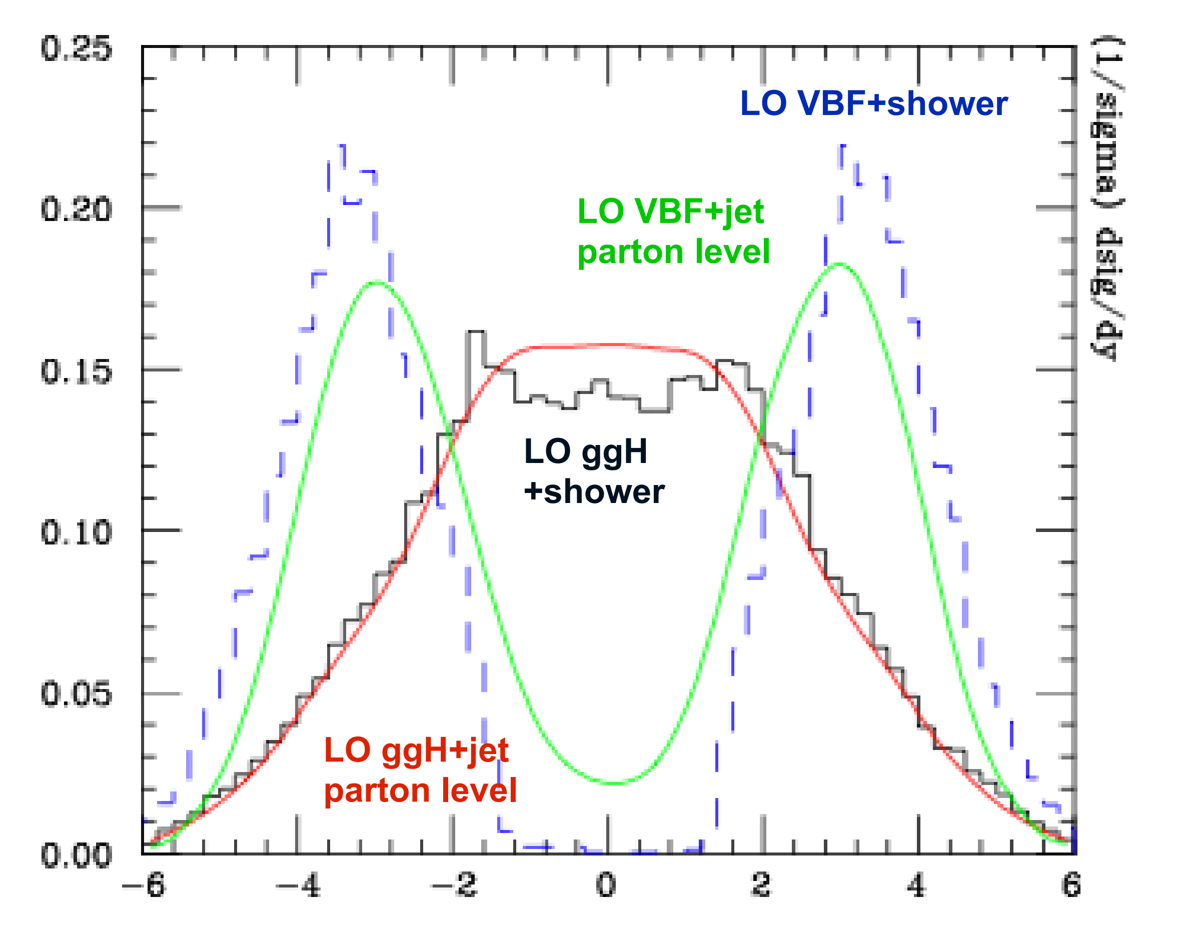
X-section after jet veto:

± 4% from scale variation (VBFNLO)

± 5% from PDF (VBFNLO)

3rd-jet rates and spectra in Hjj production

Del Duca et al, JHEP 0610 (2006) 016



ggH: ——— ~ ———   **VBF:** ——— ≠ ———

need to incorporate higher-order MEs for proper simulation of central jet activity (and thus veto survival rate) in VBF H production

POWHEG study of 3rd-jet emission in VBF Hjj production at NLO, Nason and Oleari, JHEP 1002 (2010) 037

$$y_{j_3}^{\mathrm{rel}} = y_{j_3} - \frac{y_{j_1} + y_{j_2}}{2}$$

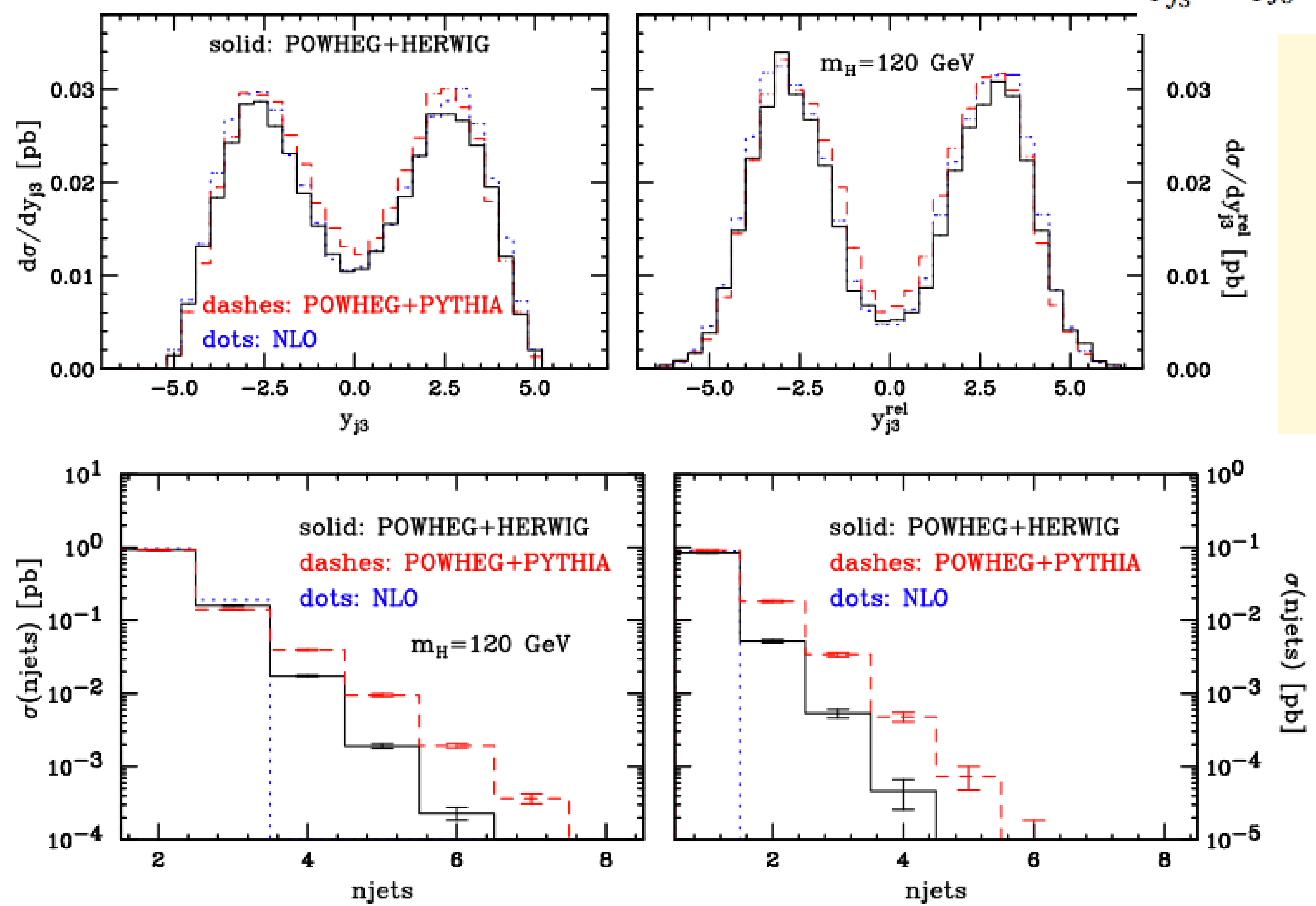
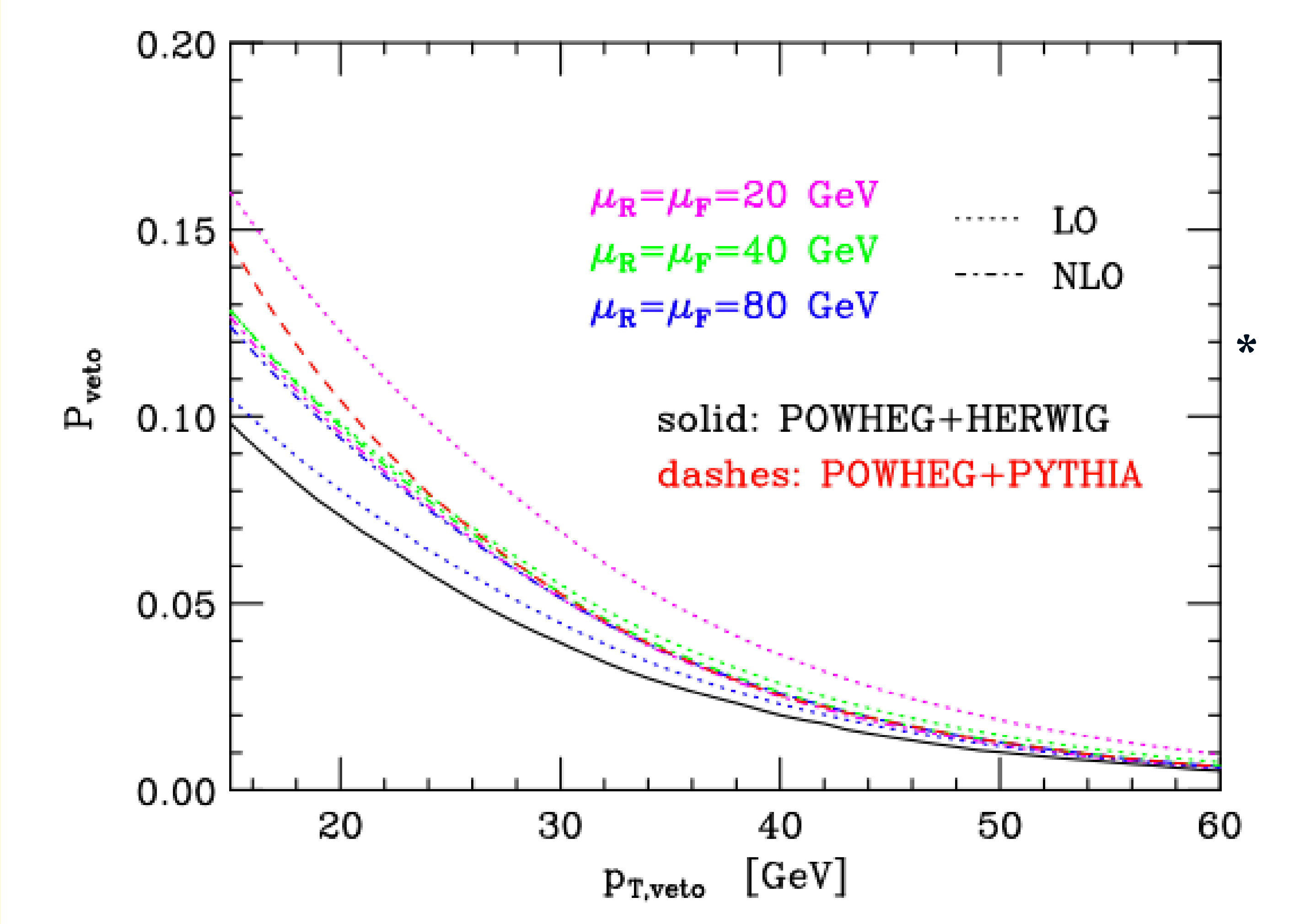


Figure 8: Jet-multiplicity distribution for jets that pass the cuts of eqs. (3.3) and (3.4) (left panel) and those that fall within the rapidity interval of the two tagging jets, $\min(y_{j_1}, y_{j_2}) < y_j < \max(y_{j_1}, y_{j_2})$ (right panel).

POWHEG study of 3rd-jet emission in VBF Hjj production at NLO, Nason and Oleari, JHEP 1002 (2010) 037

Veto inefficiency for VBF signal:



*

=> syst's ~±5% for signal efficiency

Proper validation would require study of, e.g., VBF production of Zjj

* NLO: T. Figy, V. Hankele, and D. Zeppenfeld, *Next-to-leading order QCD corrections to Higgs plus three jet production in vector-boson fusion*, *JHEP* **02** (2008) 076, [0710.5621].

Studies of jet activity in final states with dijets at large Δy

ATLAS, JHEP 1109 (2011) 053

indirect validation of jet-veto suppression efficiency for bgs

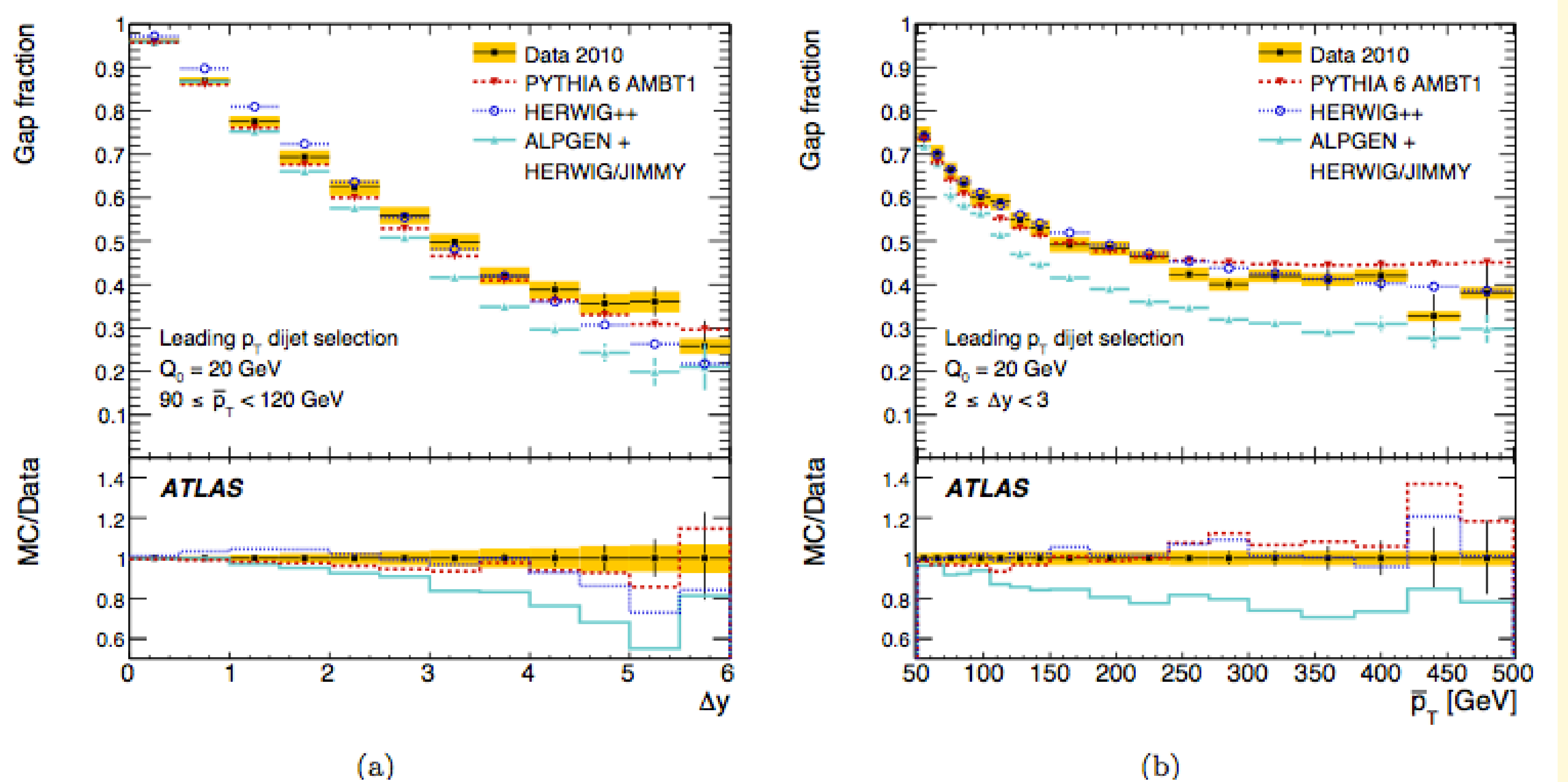


Figure 2. Gap fraction as a function of Δy, given that the dijet system is defined as the leading-p_T jets in the event and satisfies $90 \leq \bar{p}_T < 120$ GeV (a). Gap fraction as a function of $\bar{p}_T$ given that the rapidity interval is $2 \leq \Delta y < 3$ (b). The (corrected) data are the black points, with error bars representing the statistical uncertainty. The total systematic uncertainty on the measurement is represented by the solid (yellow) band. The dashed (red) points represents the PYTHIA prediction (tune AMBT1), the dot-dashed (blue) points represents the HERWIG++ prediction (tune LHC-UE7-1) and the solid (cyan) points represents the ALPGEN prediction (tune AUET1).

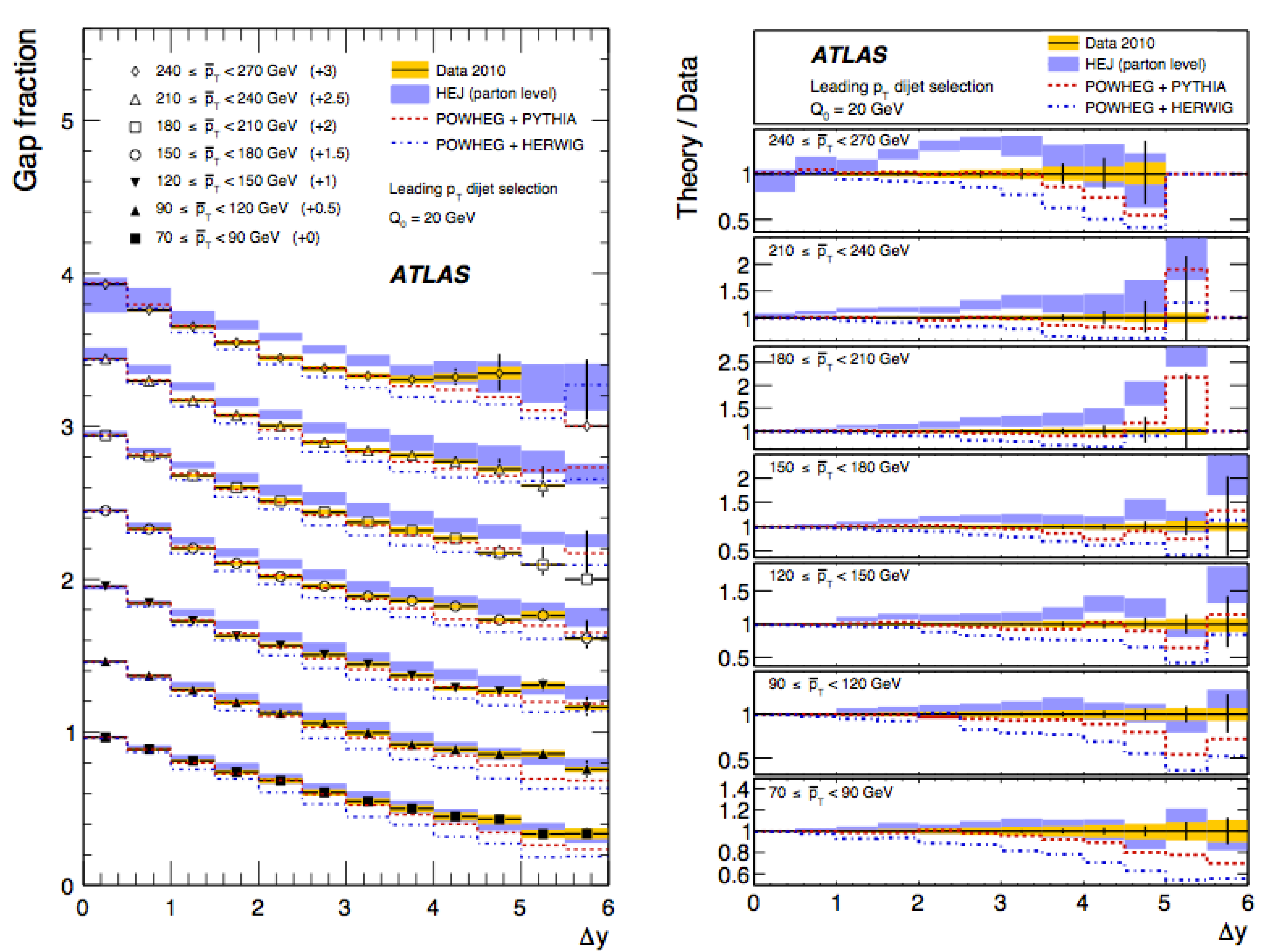
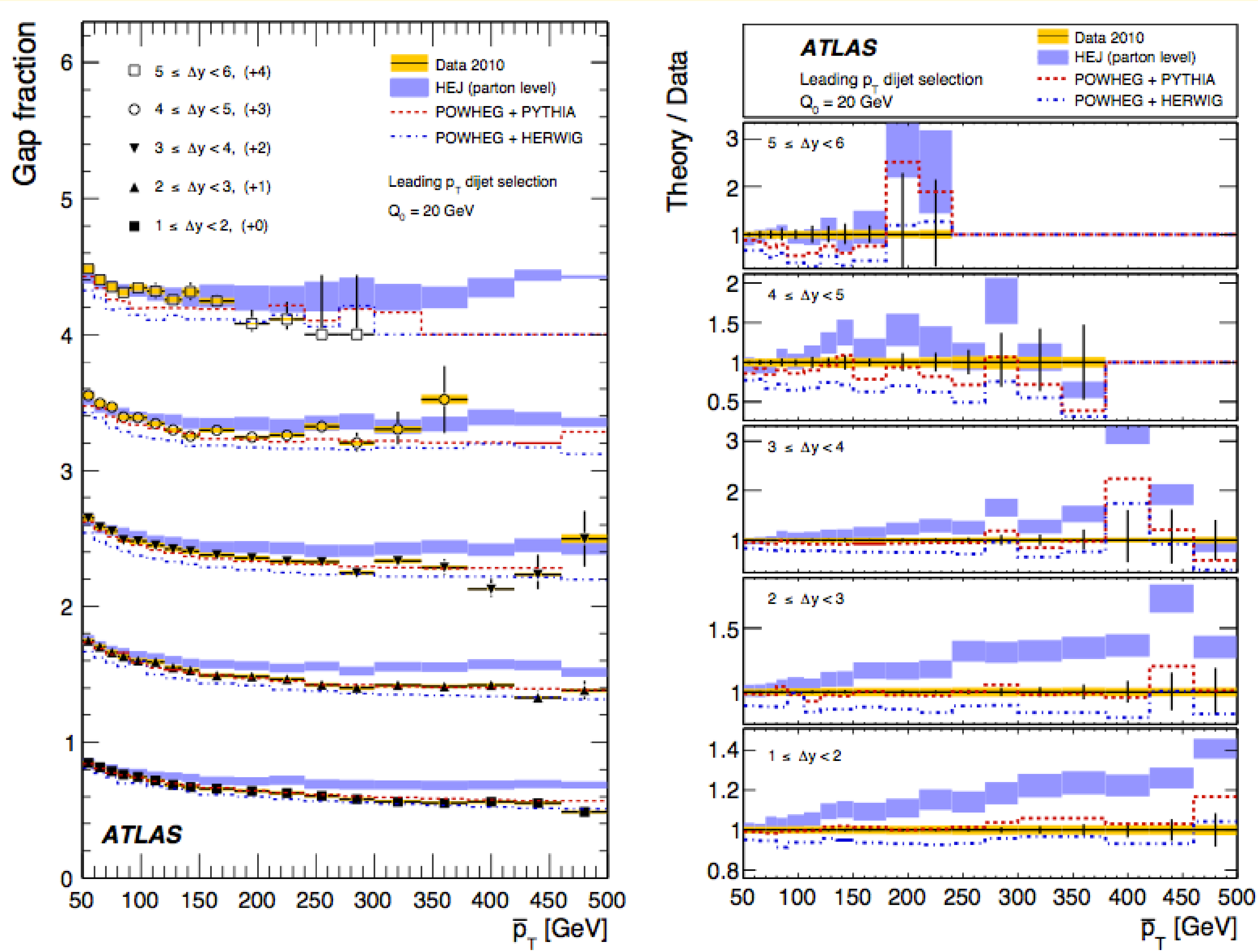
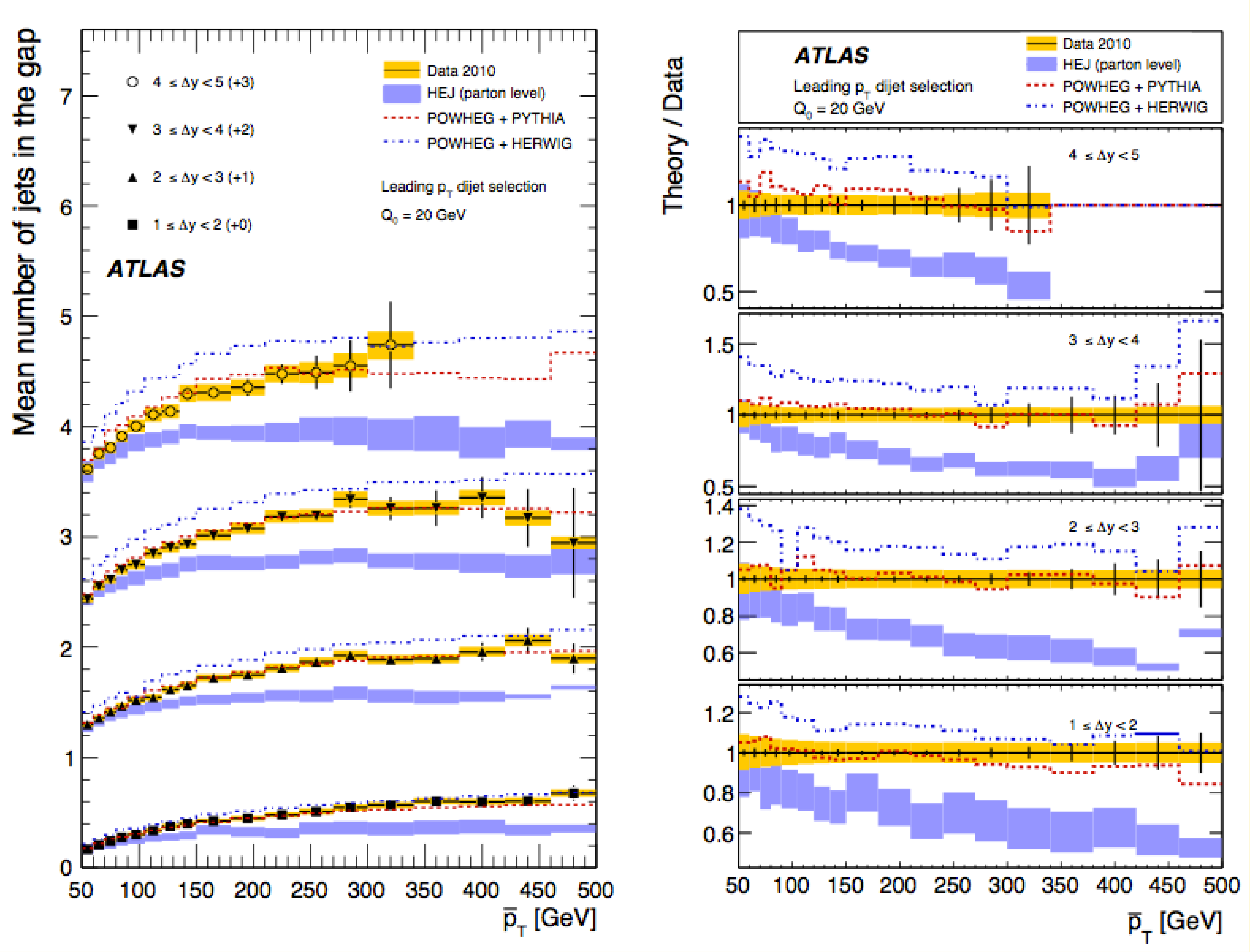


Figure 3. Gap fraction as a function of Δy for various $\bar{p}_T$ slices. The dijet system is defined as the two leading-p_T jets in the event. The data are compared to the HEJ and POWHEG predictions in (a). The ratio of these theory predictions to the data are shown in (b). The (unfolded) data are the black points, with error bars representing the statistical uncertainty and a solid (yellow) band representing the total systematic uncertainty. The darker (blue) band represents the theoretical uncertainty in the HEJ calculation from variation of the PDF and renormalisation/factorisation scales. The dashed (red) and dot-dashed (blue) curves represent the POWHEG predictions after showering, hadronisation and underlying event simulation with PYTHIA (tune AMBT1) and HERWIG/JIMMY (tune AUET1), respectively.

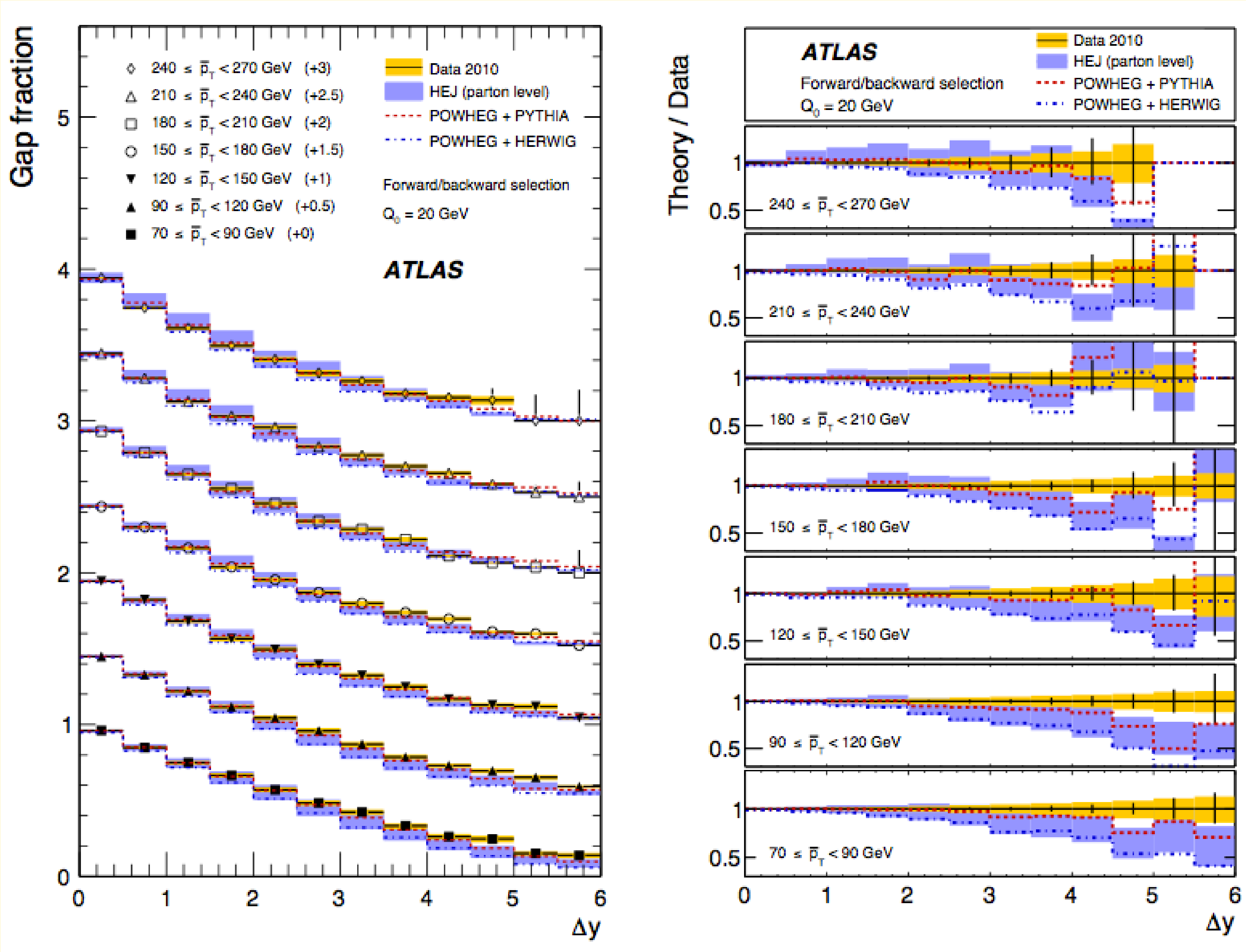
At large Δy (VBF region) POWHEG +Herwig has more jet activity than data (up to x2) and more than POWHEG+Pythia

=> syst's ~±50% for bg suppression


Gap fraction
5 ≤ Δy < 6, (+4)
4 ≤ Δy < 5, (+3)
3 ≤ Δy < 4, (+2)
2 ≤ Δy < 3, (+1)
1 ≤ Δy < 2, (+0)
Data 2010
HEJ (parton level)
POWHEG + PYTHIA
POWHEG + HERWIG
Leading p_T dijet selection
Q_0 = 20 GeV
ATLAS
$\bar{p}_T$ [GeV]
Theory / Data
ATLAS
Leading p_T dijet selection
Q_0 = 20 GeV
Data 2010
HEJ (parton level)
POWHEG + PYTHIA
POWHEG + HERWIG
5 ≤ Δy < 6
4 ≤ Δy < 5
3 ≤ Δy < 4
2 ≤ Δy < 3
1 ≤ Δy < 2
$\bar{p}_T$ [GeV]



Mean number of jets in the gap
4 ≤ Δy < 5 (+3)
3 ≤ Δy < 4 (+2)
2 ≤ Δy < 3 (+1)
1 ≤ Δy < 2 (+0)
Data 2010
HEJ (parton level)
POWHEG + PYTHIA
POWHEG + HERWIG
Leading p_T dijet selection
Q_0 = 20 GeV
ATLAS
p̄_T [GeV]
Theory / Data
4 ≤ Δy < 5
3 ≤ Δy < 4
2 ≤ Δy < 3
1 ≤ Δy < 2


Gap fraction
240 ≤ $\bar{p}_T$ < 270 GeV (+3)
210 ≤ $\bar{p}_T$ < 240 GeV (+2.5)
180 ≤ $\bar{p}_T$ < 210 GeV (+2)
150 ≤ $\bar{p}_T$ < 180 GeV (+1.5)
120 ≤ $\bar{p}_T$ < 150 GeV (+1)
90 ≤ $\bar{p}_T$ < 120 GeV (+0.5)
70 ≤ $\bar{p}_T$ < 90 GeV (+0)
Data 2010
HEJ (parton level)
POWHEG + PYTHIA
POWHEG + HERWIG
Forward/backward selection
Q_0 = 20 GeV
ATLAS
Δy
Theory / Data
ATLAS
Forward/backward selection
Q_0 = 20 GeV
Data 2010
HEJ (parton level)
POWHEG + PYTHIA
POWHEG + HERWIG
240 ≤ $\bar{p}_T$ < 270 GeV
210 ≤ $\bar{p}_T$ < 240 GeV
180 ≤ $\bar{p}_T$ < 210 GeV
150 ≤ $\bar{p}_T$ < 180 GeV
120 ≤ $\bar{p}_T$ < 150 GeV
90 ≤ $\bar{p}_T$ < 120 GeV
70 ≤ $\bar{p}_T$ < 90 GeV
Δy

Final remarks

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- Thanks to the sophisticated and thorough use of data-driven techniques, the (un)suitability of theoretical MC generation tools is not standing on the way of the Higgs discovery
- Independently of this, explicit comparisons, checks and validations show that tools appear to be in rather good shape and up to the task of discovery
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Final remarks

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- Independently of this, explicit comparisons, checks and validations show that tools appear to be in rather good shape and up to the task of discovery
- Nevertheless, some aspects of the simulation of Higgs production are still poorly tested (e.g. VBF)
- Higgs-search studies are bringing in valuable information for the validation and further improvement of the tools, and further efforts should be made, alongside the discovery race, to fully exploit the potential of these data, to benefit improved tools, and further applications to studies of the Higgs once found, or other BSM searches