Constraining QCD modelling uncertainties in ttbar events at ATLAS

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IOP HEPP Meeting, 8th-10th Apr 2013, Liverpool

Outline
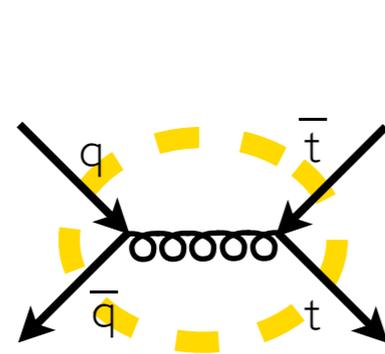
- MC generators used for ttbar
- Measurements constraining uncertainties
- Alternative uncertainty prescriptions
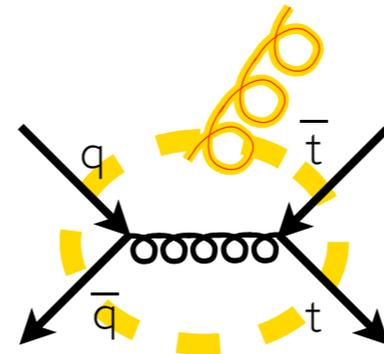- Summary

ATLAS

MC Generators used for ttbar

- The Monte Carlo event generators currently used for ttbar can be split into two categories:

  - **Next-to-leading order** + parton shower. E.g. **MC@NLO/Powheg + Herwig/Pythia**

ttbar @ NLO   ttbar**+1 jet** @ LO   More jets from parton shower   ''NLO+PS''

MC Generators used for ttbar
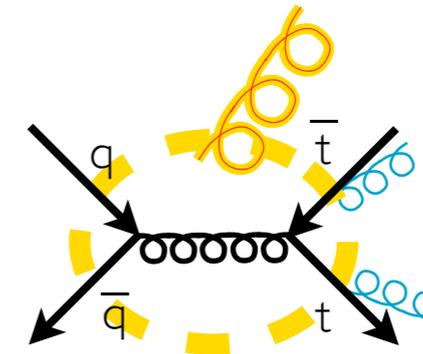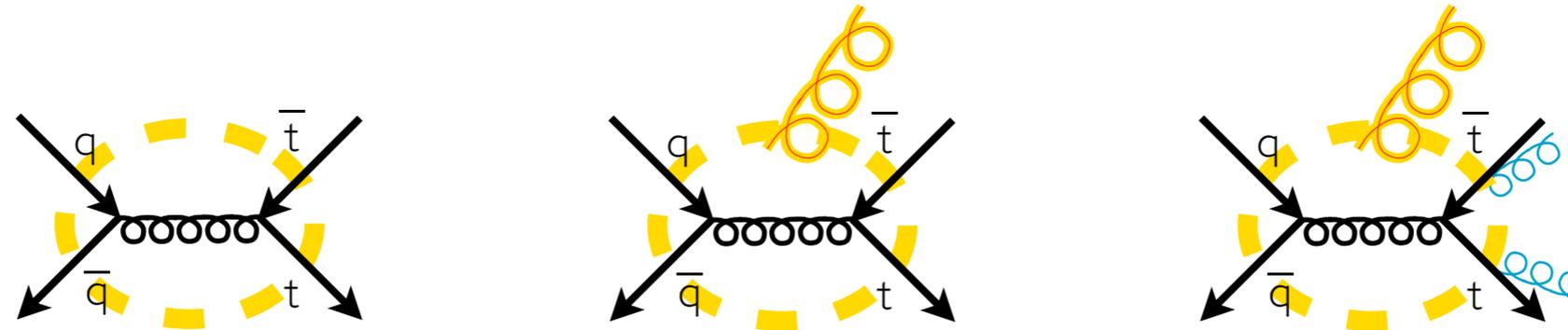
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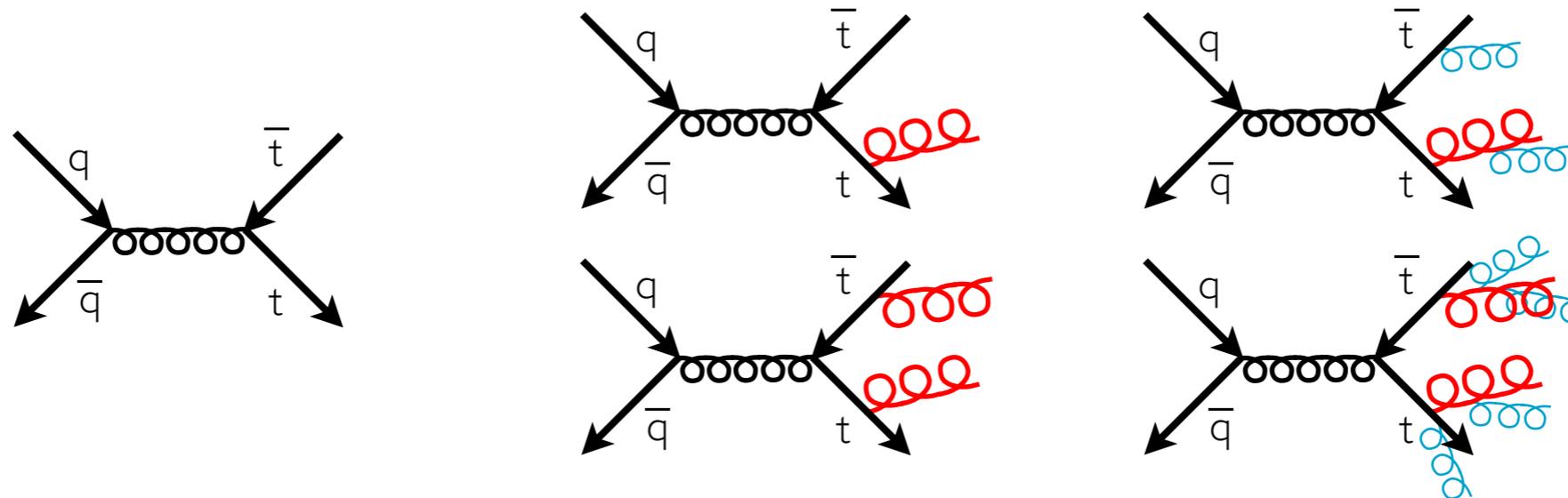

ttbar @ NLO   ttbar+1 jet @ LO   More jets from parton shower

"NLO+PS"

  - Multi-leg leading order + parton shower. E.g. Alpgen + Herwig/Pythia, Sherpa.
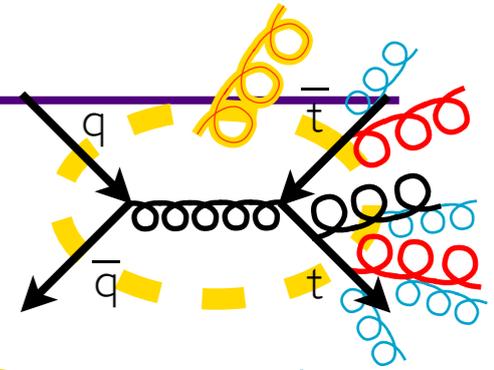

ttbar @ LO   ttbar+1/2/3/4j @ LO   More jets from parton shower

"ME+PS"

MC Generators used for ttbar

- Future generators:

  - aMC@NLO + Herwig++/Pythia8, released recently, will provide **ttbar+**1j @ NLO, + parton shower.

  - Sherpa 2.0, hopefully released 'soon', will provide **ttbar+**1j @ NLO, +2/3/4 @ LO + parton shower.

    ("MEPS@NLO")

- Lots of nice tools for generating events.

  - Important not to just blindly accept that what the generator gives us is the whole truth.

  - Always uncertainties associated with the MC predictions.

- Scales can be varied by a factor 2.

  - Factorization, renormalization, resummation scales.

- Parameters controlling ME+PS matching - MLM, CKKW.

- Parton shower-specific uncertainty - AcerMC (LO+PS). Increase/decrease parton shower activity.

Measurements constraining uncertainties

Measurement of $t\bar{t}$ production with a veto on additional central jet activity in pp collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector

Eur.Phys.J. C72 (2012) 2043

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1824

Measurements constraining uncertainties
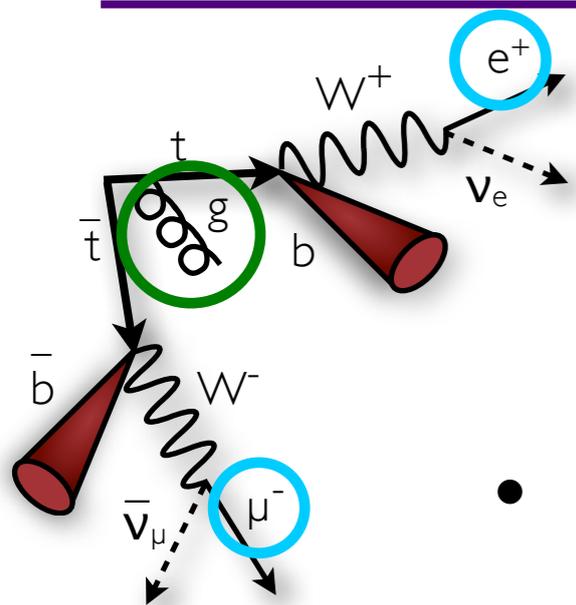
- Study the fraction of ttbar events which do **not** contain an additional jet, in a central rapidity region, with $p_T > Q_0$.

$$f_{gap}(Q_0) = \frac{n_{gap}(Q_0)}{N_{t\bar{t}}}$$

- Alternatively take the sum of the p_T of jets falling into each rapidity region and define:

$$f_{gap}(Q_{sum}) = \frac{n_{gap}(Q_{sum})}{N_{t\bar{t}}}$$

- Use dilepton-channel events with two tagged b-jets, to easily identify any additional jet(s).

ϕ |y| < 2.1

b-jets
leptons
additional jet

-2.1   -1.5   -0.8   0   0.8   1.5   2.1   y
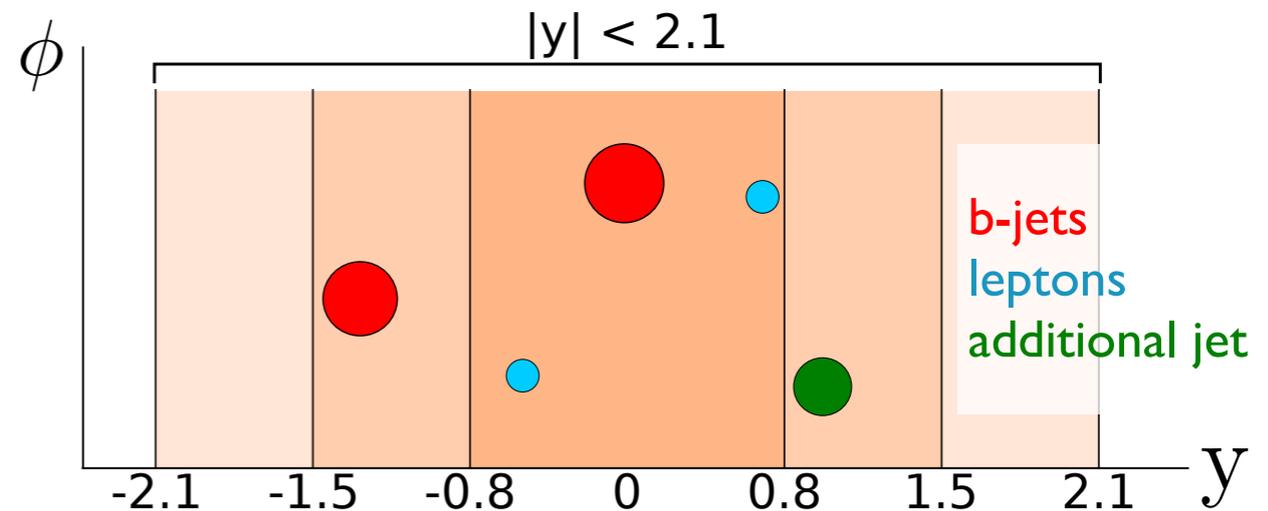
- Four rapidity regions: |y| < 0.8,   0.8 ≤ |y| < 1.5,   1.5 ≤ |y| < 2.1, |y| < 2.1

- Measurement corrected for detector effects and presented in a well-defined fiducial region.

Measurements constraining uncertainties

- The gap fraction can be expressed in terms of a ratio of cross-sections:

$$f_{\mathrm{gap}}(Q_0) = \frac{n_{\mathrm{gap}}(Q_0)}{N_{\mathrm{t\bar{t}}}} = \frac{\sigma^f_{\mathrm{t\bar{t}}+0\,\mathrm{j}}}{\sigma^f_{\mathrm{t\bar{t}}}} = 1 - \frac{\sigma^f_{\mathrm{t\bar{t}}+\geq 1\,\mathrm{j}}}{\sigma^f_{\mathrm{t\bar{t}}}}$$

- Where:

$$\sigma^f_{\mathrm{t\bar{t}}} =$$ Fiducial cross-section for dilepton ttbar events

$$\sigma^f_{\mathrm{t\bar{t}}+0\,\mathrm{j}} =$$ Fiducial cross-section for dilepton ttbar events with **no** additional jet with p_T > Q_0 GeV.
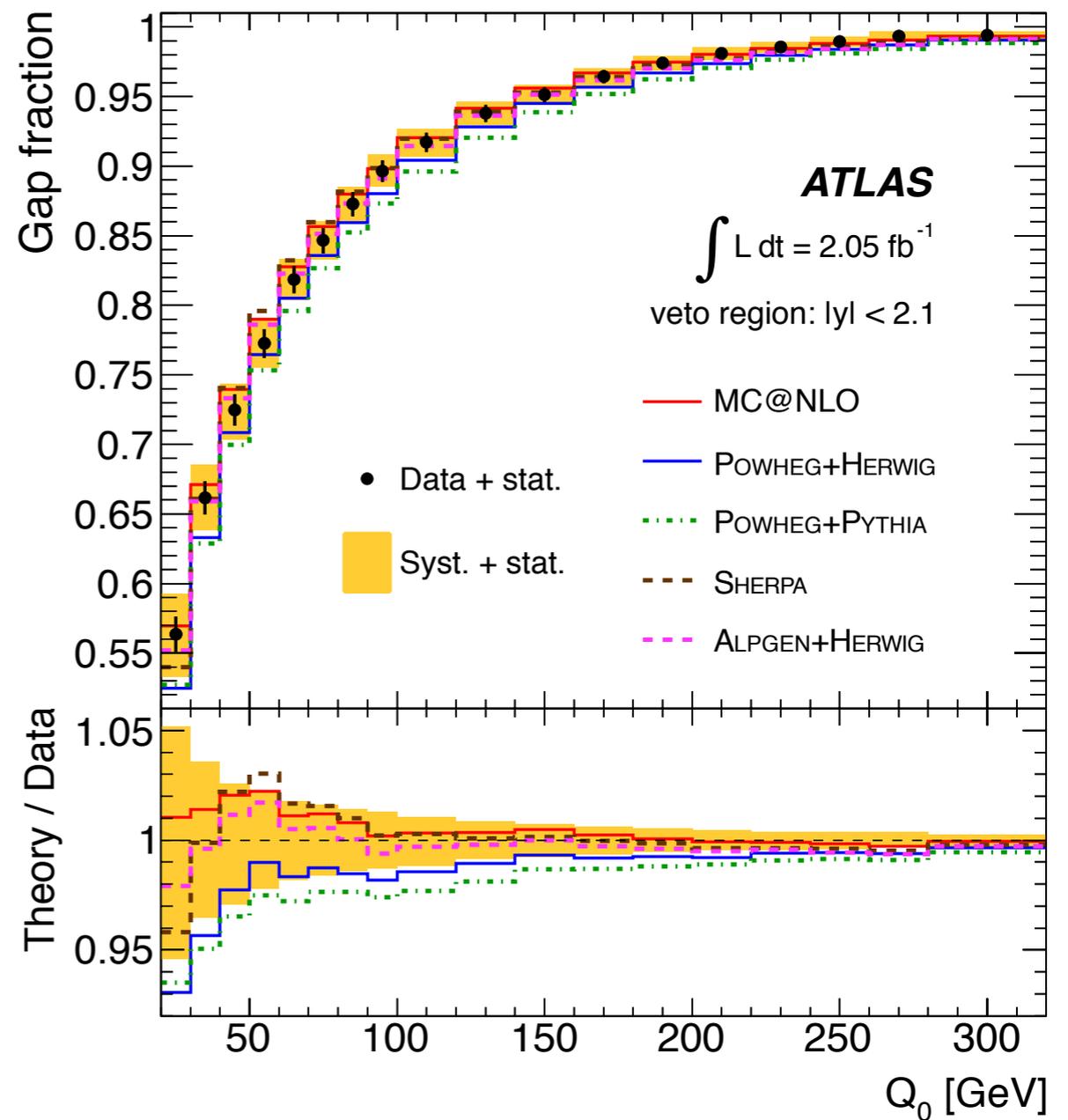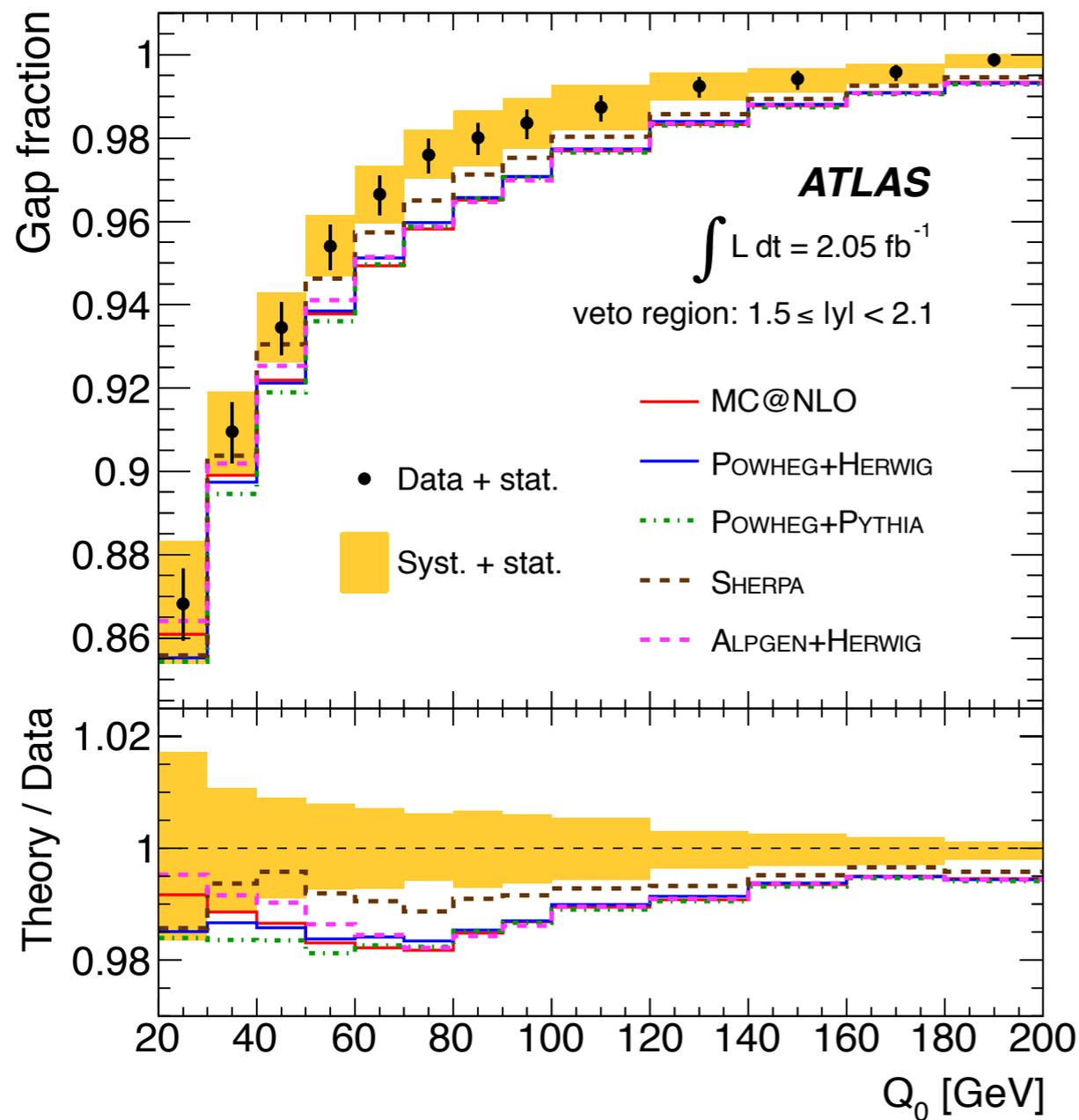
$$\sigma^f_{\mathrm{t\bar{t}}+\geq 1\,\mathrm{j}} =$$ Fiducial cross-section for dilepton ttbar events with **at least** one additional jet with p_T > Q_0 GeV.

Measurements constraining uncertainties
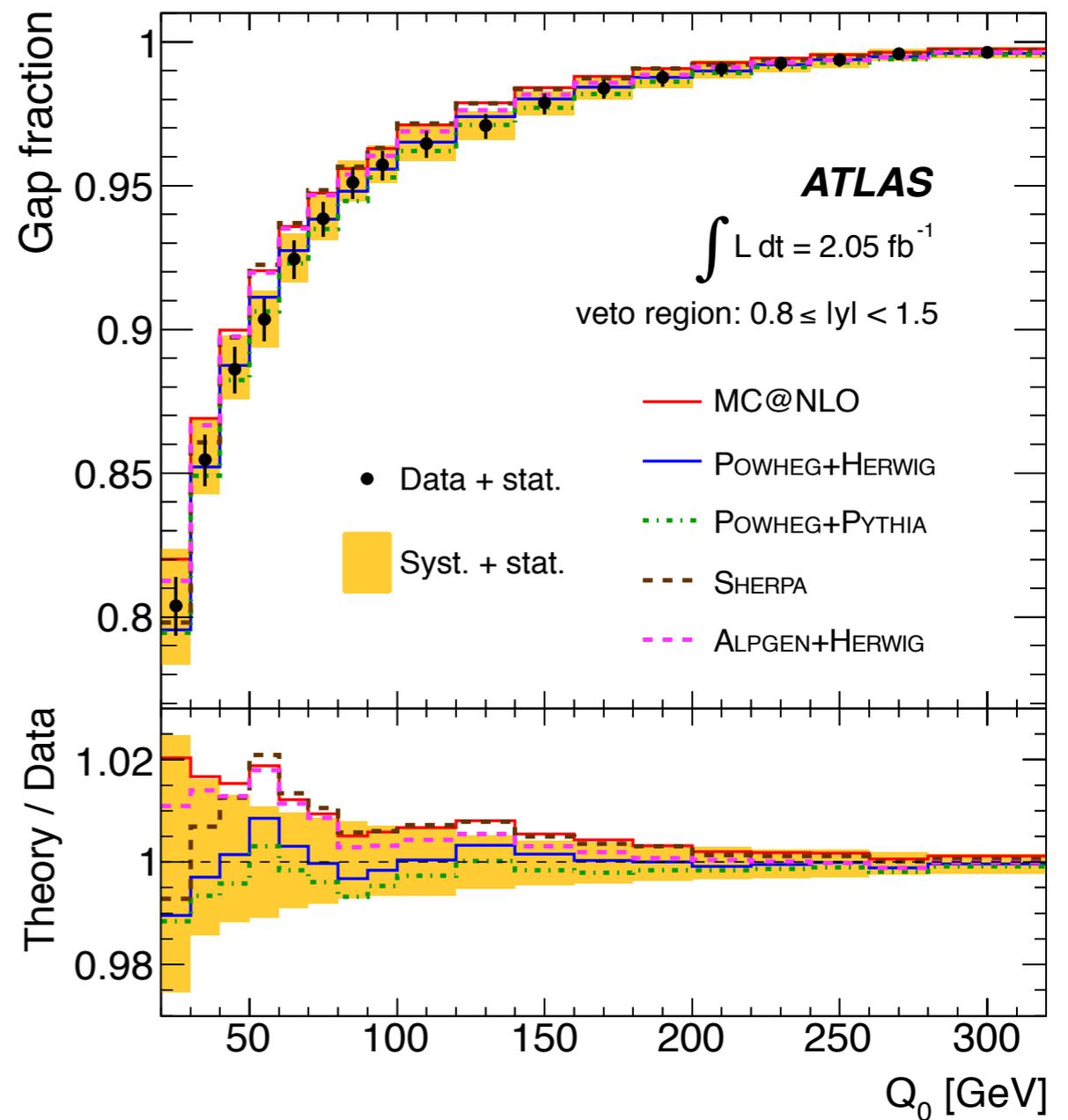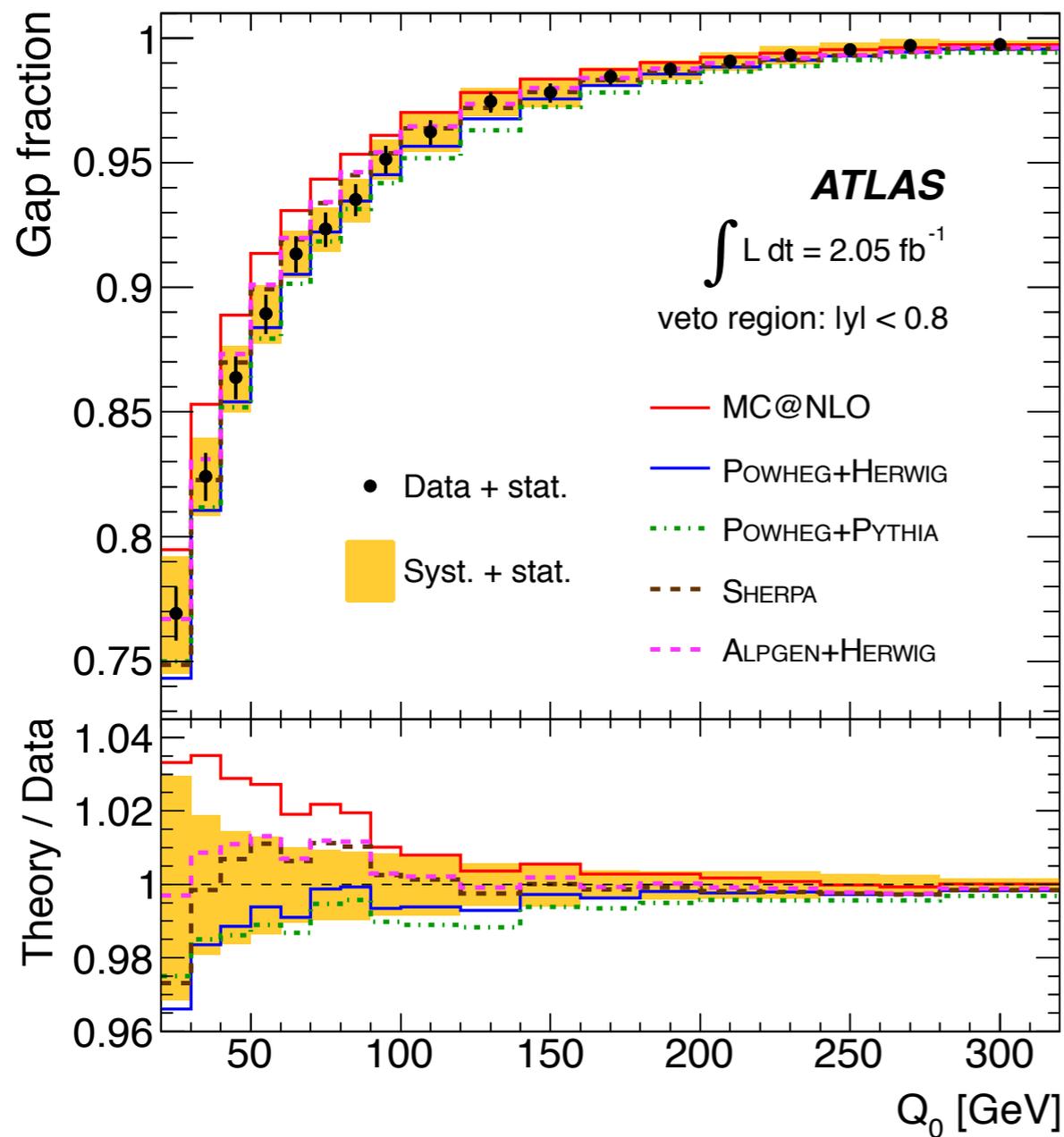
- In general, both the NLO+PS and ME+PS generators give a good description of the data.

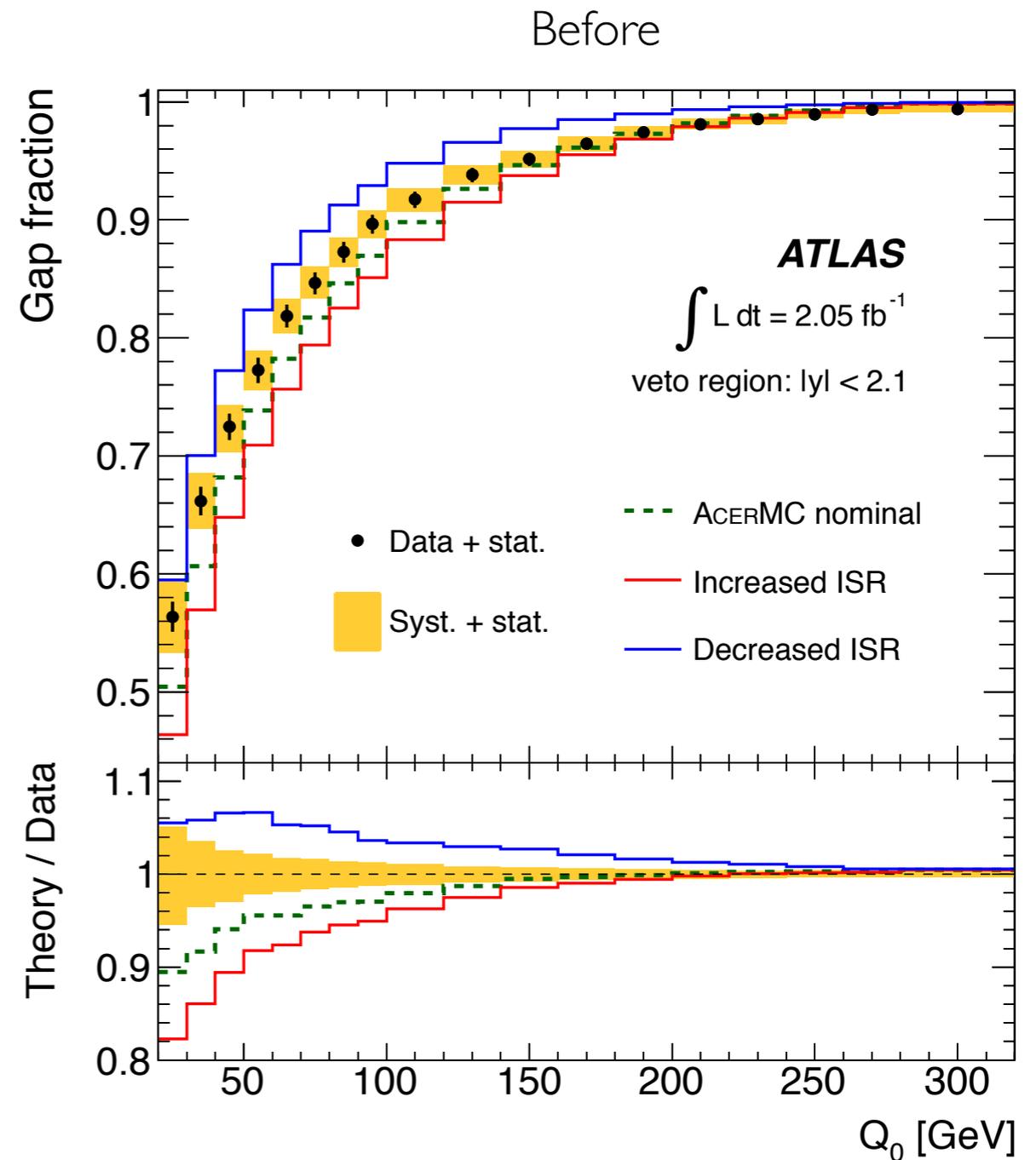- MC@NLO overshoots the data in the most central (|y| < 0.8) region (not enough radiation).

Measurements constraining uncertainties

- All generators predict too much radiation into the region $1.5 \leq |y| < 2.1$

- Best overall description given by Sherpa.

Measurements constraining uncertainties

- Nominal AcerMC curve not consistent with the data.

  - Spread of increased/decreased ISR curves much larger than the total experimental uncertainty.

- This was one of the dominant uncertainties in many Top group analyses.

- These variations have since been 're-tuned' to be more consistent with the data uncertainty.

  - Difference between more & less PS approx. the same as expt. uncertainty.

  - Parton shower-related uncertainty is now smaller. (by approx. factor of 2).

Before

ATLAS

$\int L\ dt = 2.05\ fb^{-1}$

veto region: $|y| < 2.1$

- - - AcerMC nominal
- Data + stat.
- Increased ISR
- Syst. + stat.
- Decreased ISR
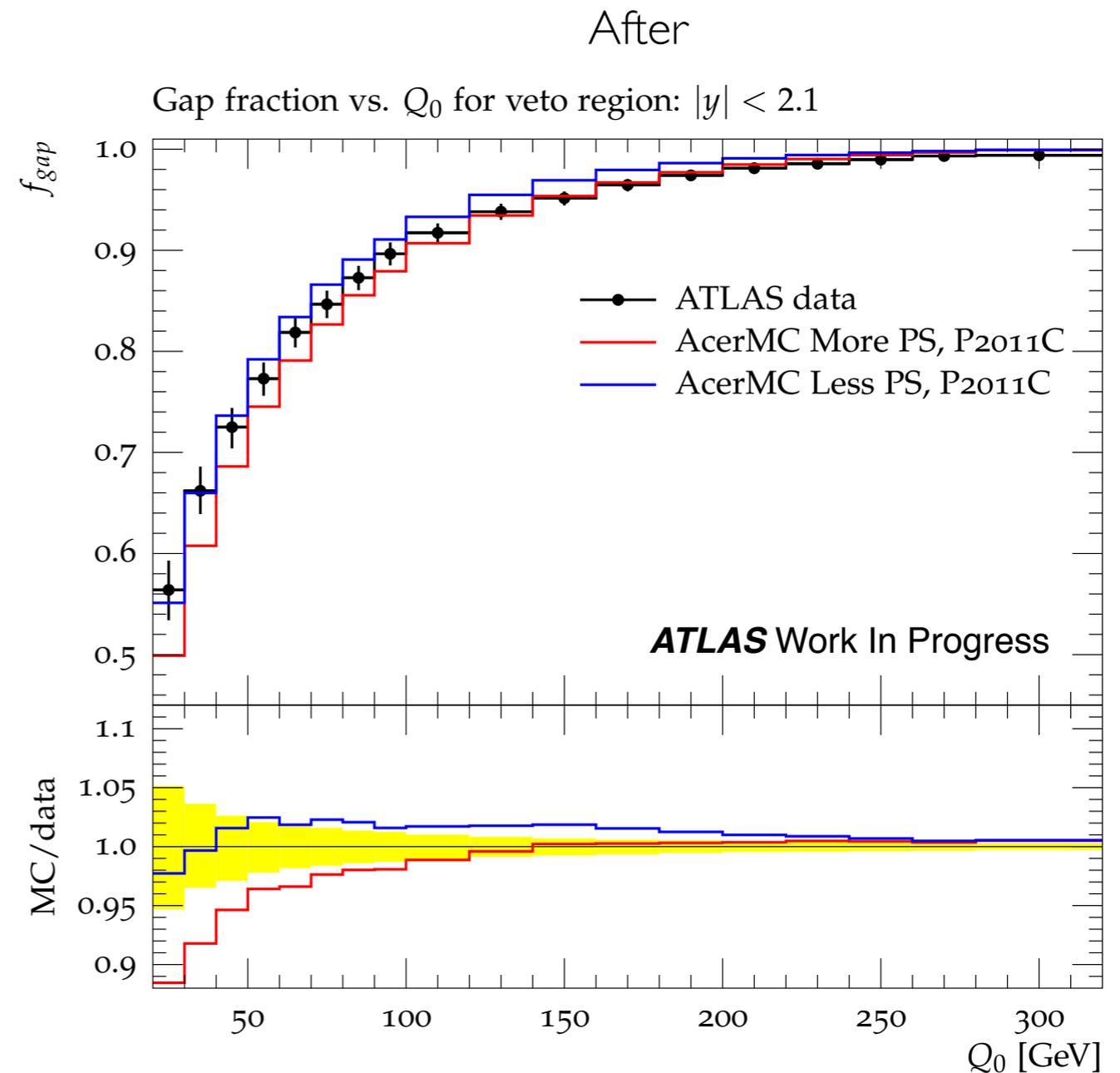
Gap fraction

Theory / Data

Q_0 [GeV]

Measurements constraining uncertainties

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After

Gap fraction vs. Q_0 for veto region: $|y| < 2.1$

- ATLAS data
- AcerMC More PS, P2011C
- AcerMC Less PS, P2011C

ATLAS Work In Progress

Alternative uncertainty prescriptions

- Work is ongoing to produce an alternative estimate of this additional radiation uncertainty.

  - Varying scales in Alpgen+Pythia.

- Parameter: `ktfac`

  - *"...a prefactor directly on the renormalization scale argument of α_s..."*

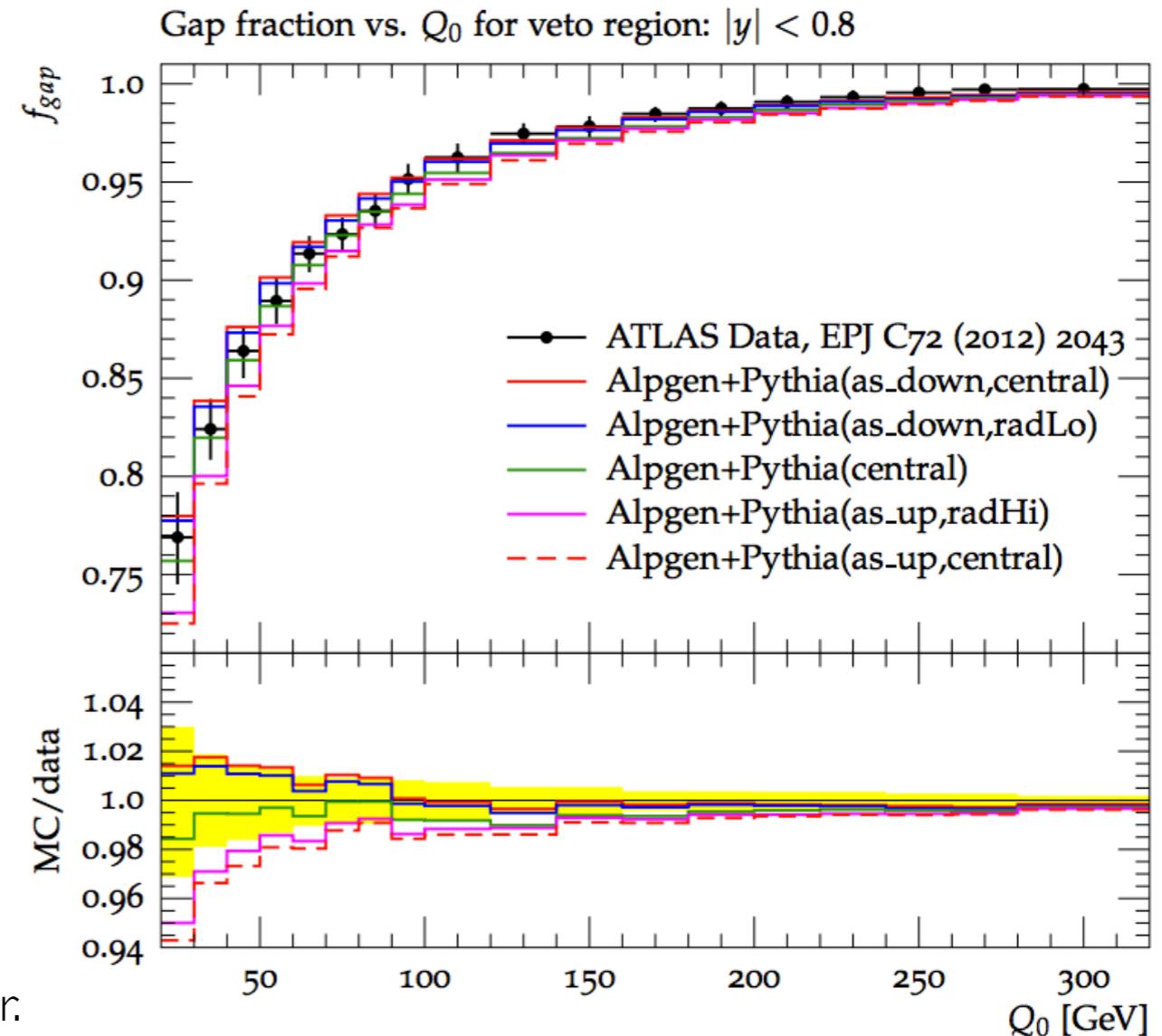$$\alpha_s(k\mu^2) \overset{1-\text{loop}}{=} \frac{1}{b_0 \ln(k\mu^2/\Lambda^2)}$$

    Cooper et. al. **Eur.Phys.J. C72 (2012) 2078**

- Some care must be taken to make sure the scale is varied consistently on either side of the 'matching-boundary'

  - I.e. in the matrix element **and** parton shower.

- Alpgen samples with varied α_s give a reasonable envelope.

  - Samples with increased α_s not consistent with data. (Consistent picture between gap fraction and jet multiplicity.)

Gap fraction vs. Q_0 for veto region: $|y| < 0.8$

Legend:
- ATLAS Data, EPJ C72 (2012) 2043
- Alpgen+Pythia(as_down,central)
- Alpgen+Pythia(as_down,radLo)
- Alpgen+Pythia(central)
- Alpgen+Pythia(as_up,radHi)
- Alpgen+Pythia(as_up,central)

ATL-PHYS-PUB-2013-005

Alternative uncertainty prescriptions

- Work is ongoing to produce an alternative
  estimate of this additional radiation uncertainty.

  - Varying scales

- Parameter: ktfac

  - "...a prefactor
    scale argument

    $\alpha_s \, (k)^2$

    Cooper et. al. **Eu**

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  scale is varied cons
  the 'matching-boun

  - I.e. in the matri

- Alpgen samples wi

  - Samples with increas
    (Consistent picture between gap fraction and jet multiplicity.)

Gap fraction vs. Q_0 for veto region: $|y| < 2.1$
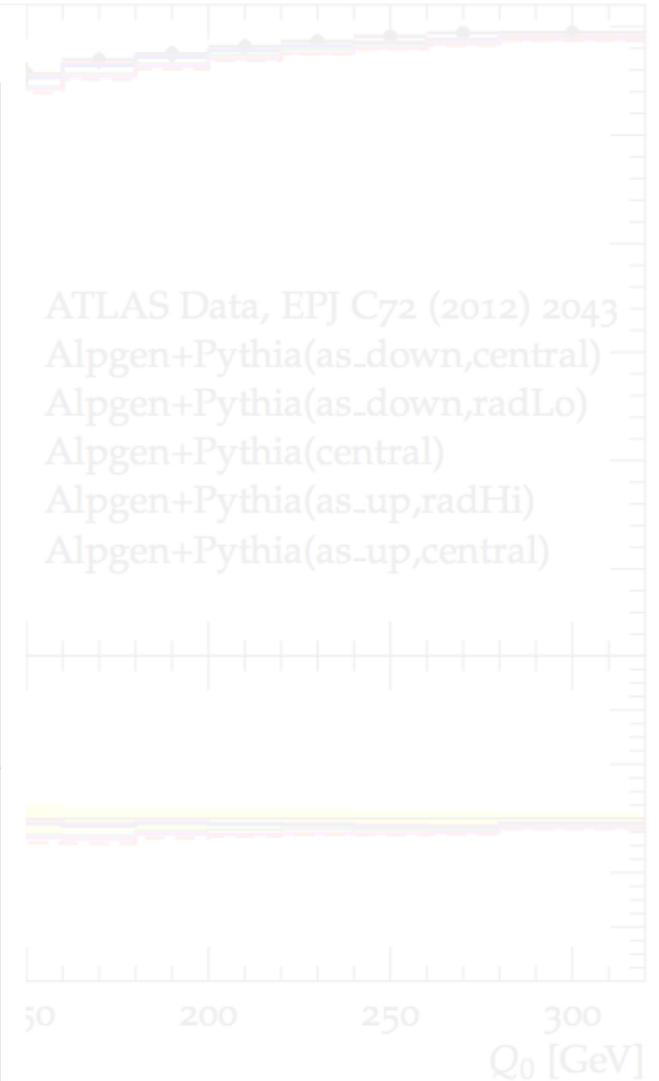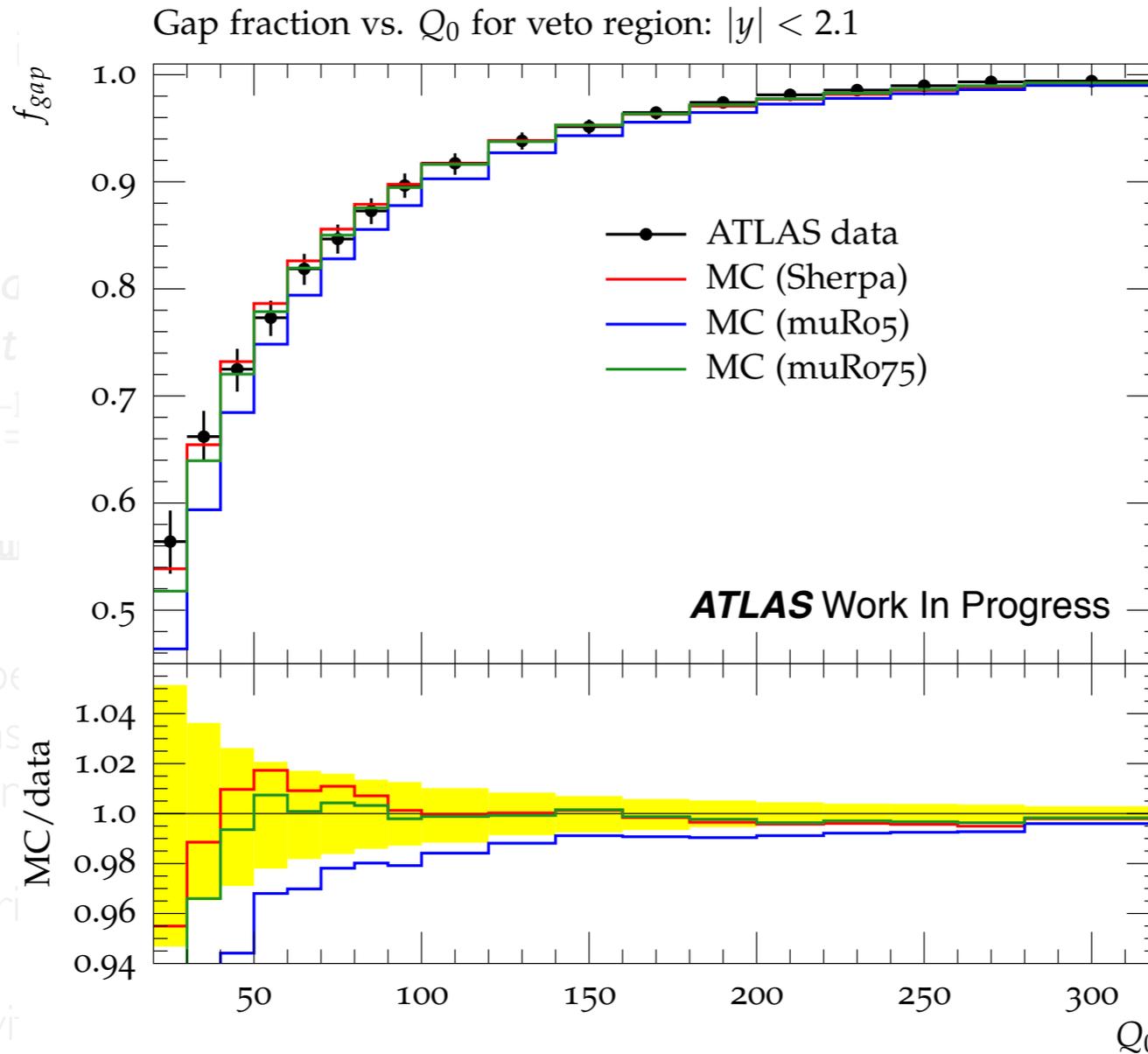
Scale variation studies w/ Sherpa also ongoing.
E.g. Renormalization scale varied by x0.5 and x0.75.

Summary

- Many MCs used to generate ttbar events. Each with their associated uncertainties.

- Size of some uncertainties can be constrained by the data.

  - Ttbar + jet veto analysis constrained ISR/FSR systematic.

  - Reduced uncertainties for many other analyses.

- Alternative systematics prescription under investigation by varying scales in Alpgen & Sherpa

 - Should eventually replace AcerMC variations.

Backup slides

The University
of Manchester

ttbar + jet veto - analysis cuts

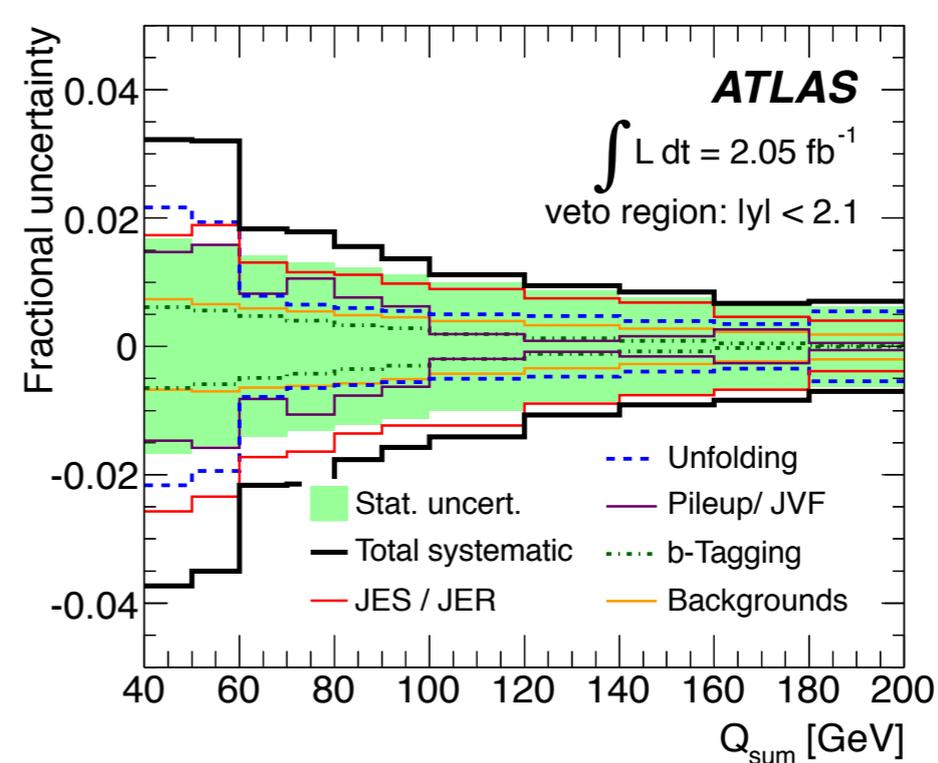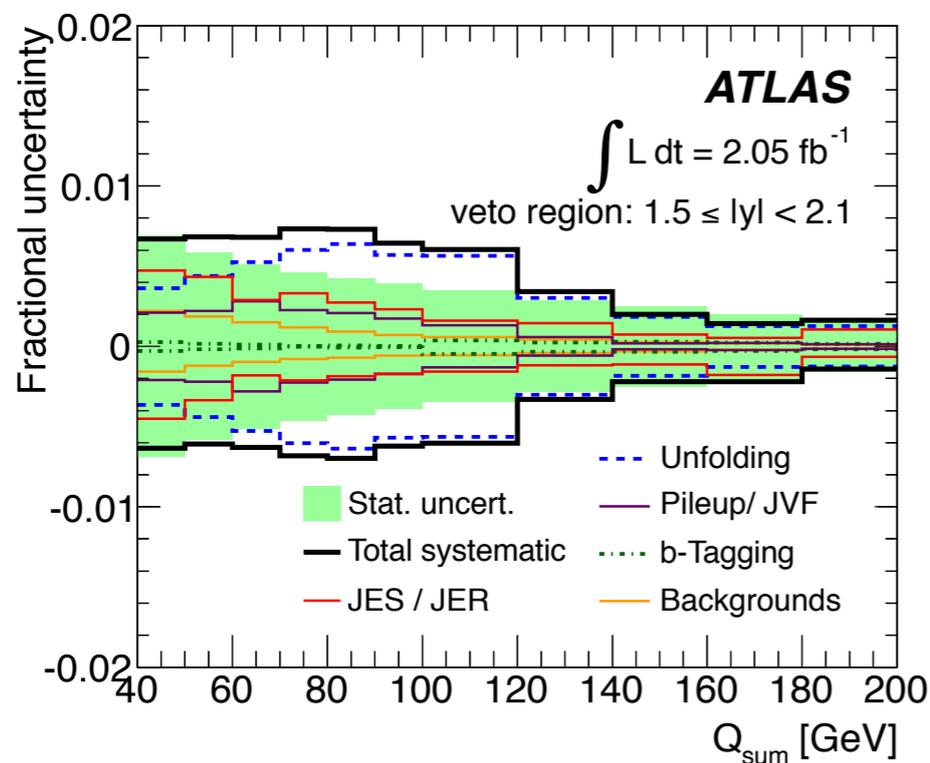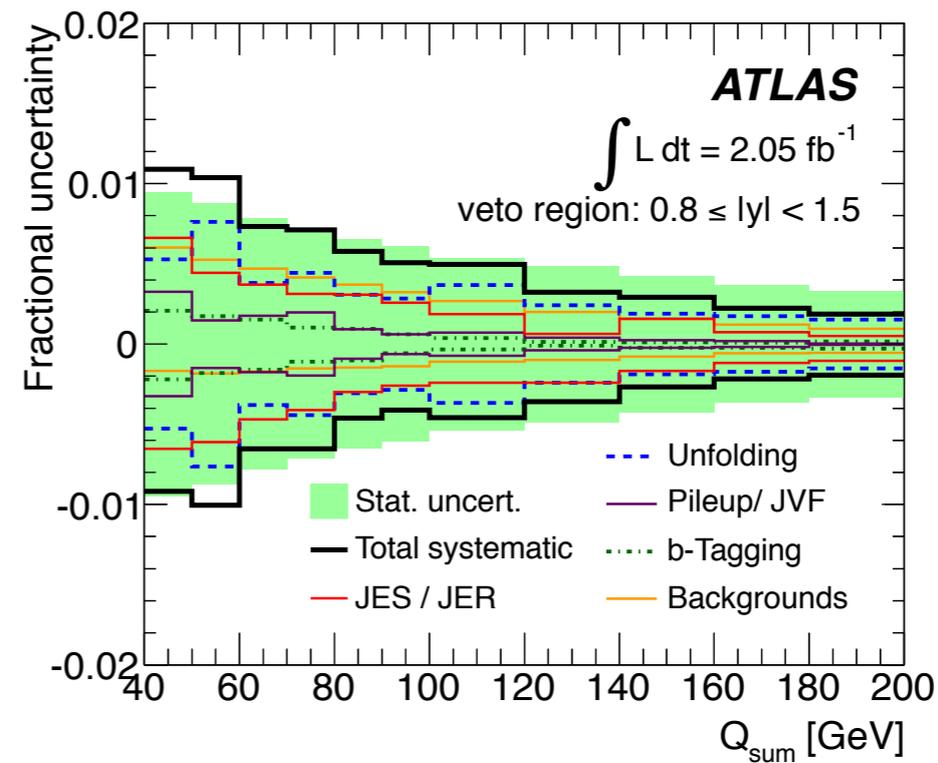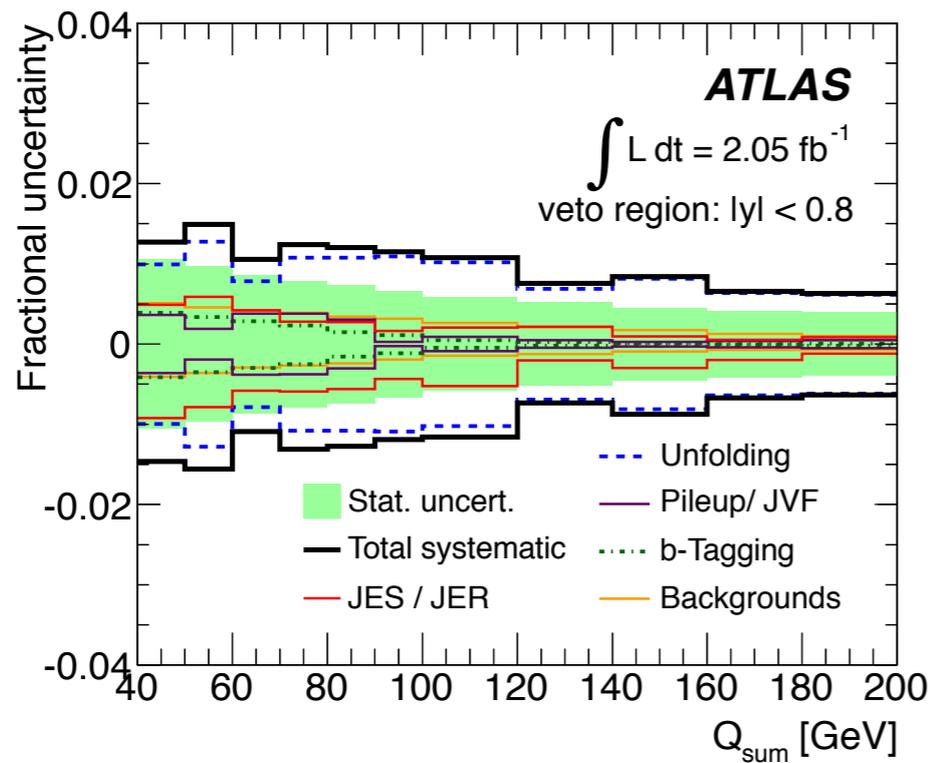| Selection	Channel		
	ee	$\mu\mu$	$e\mu$
Electrons	2 with $E_{\mathrm{T}} > 25$ GeV, $|\eta| < 2.47$	$-$	1 with $E_{\mathrm{T}} > 25$ GeV, $|\eta| < 2.47$
Muons	$-$	2 with $p_{\mathrm{T}} > 20$ GeV, $|\eta| < 2.5$	1 with $p_{\mathrm{T}} > 20$ GeV, $|\eta| < 2.5$
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 40 GeV	> 40 GeV	$-$
H_T	$-$	$-$	> 130 GeV
$m_{\ell\ell}$	> 15 GeV $\quad$ $|m_{\ell\ell} - 91\,\mathrm{GeV}| > 10$ GeV	> 15 GeV $\quad$ $|m_{\ell\ell} - 91\,\mathrm{GeV}| > 10$ GeV	$-$
b-tagged jets	At least 2 with $p_{\mathrm{T}} > 25$ GeV, $|y| < 2.4$, $\Delta R(j, \ell) > 0.4$		

Gap fraction vs. Q_0 - Systematic uncertainties
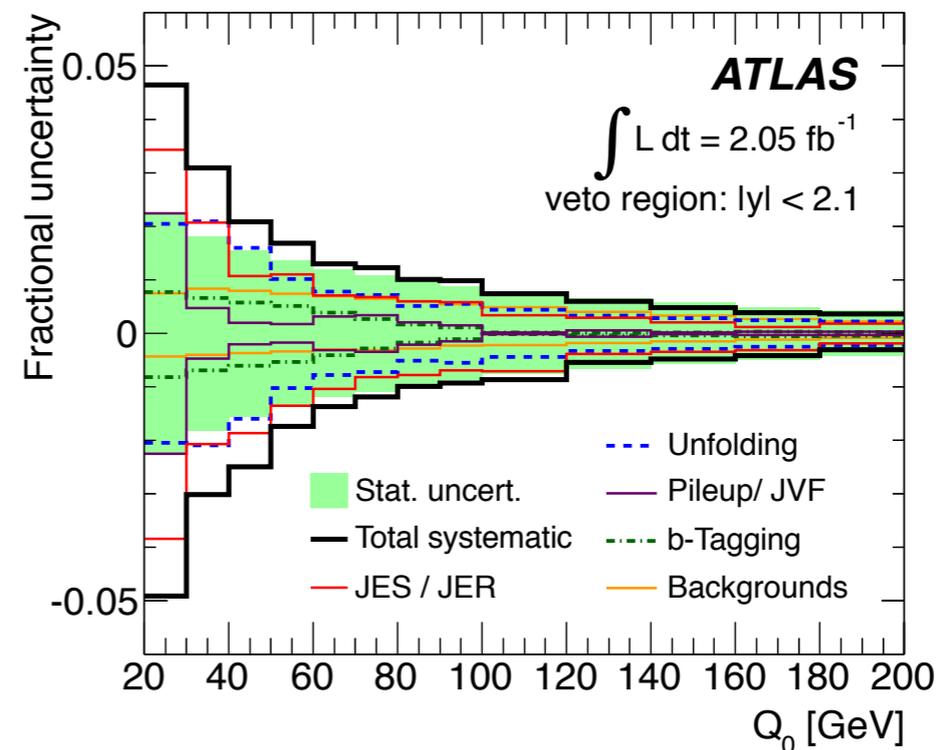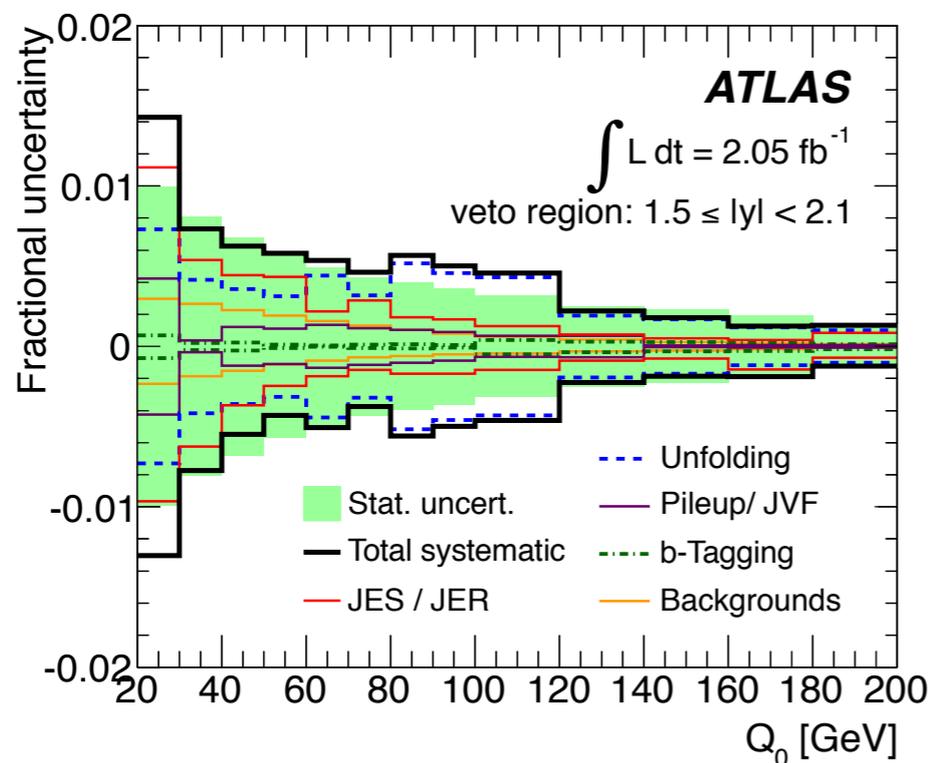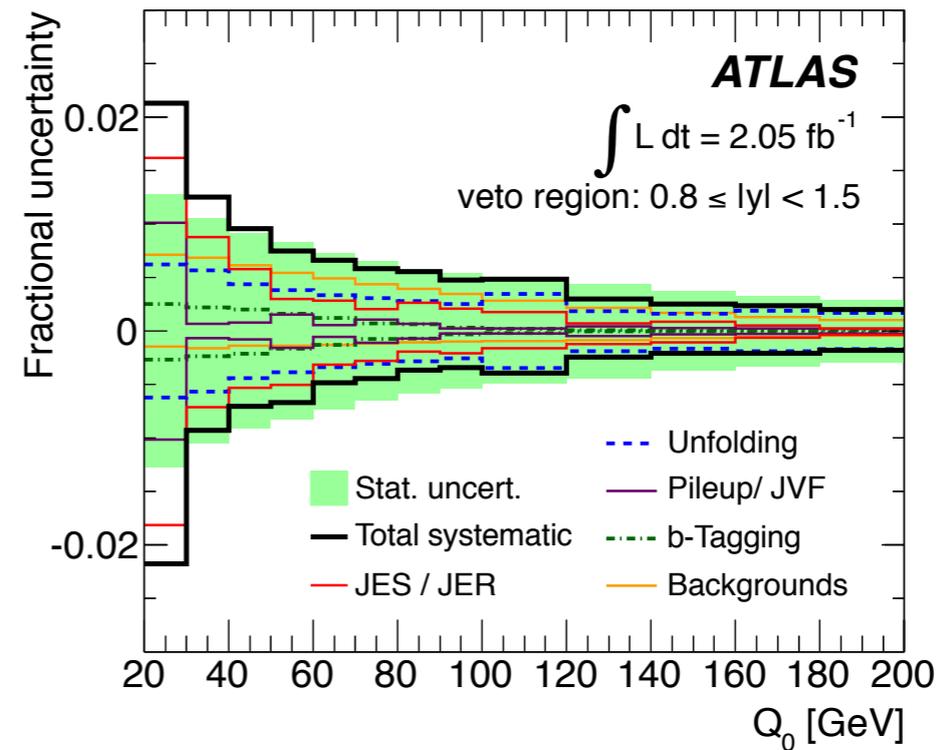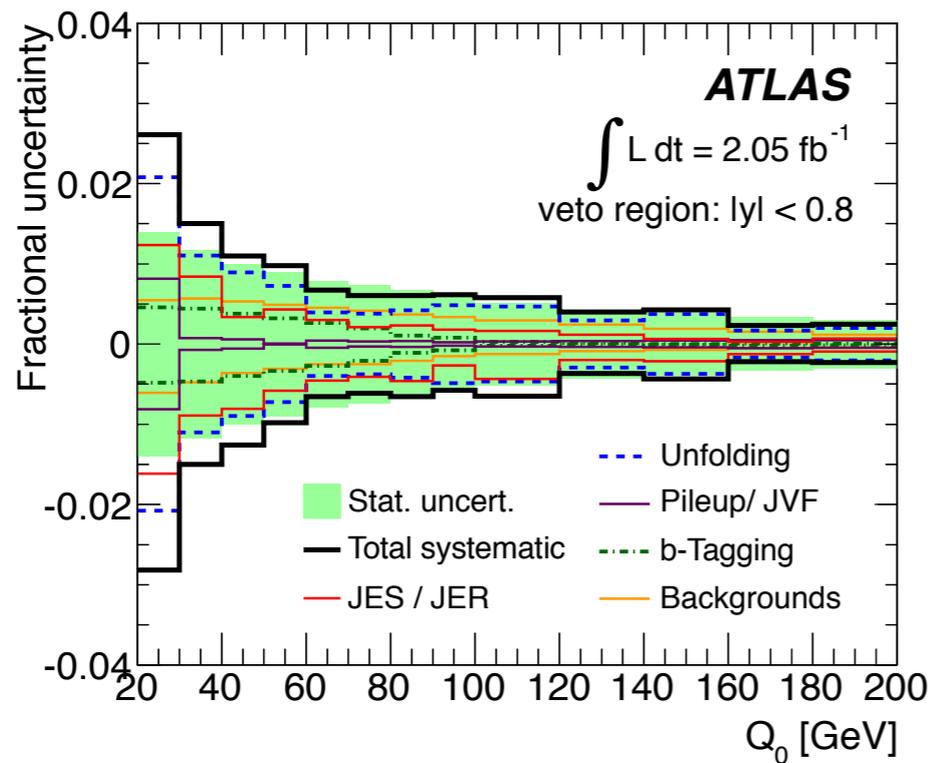
Gap fraction vs. Q~sum~
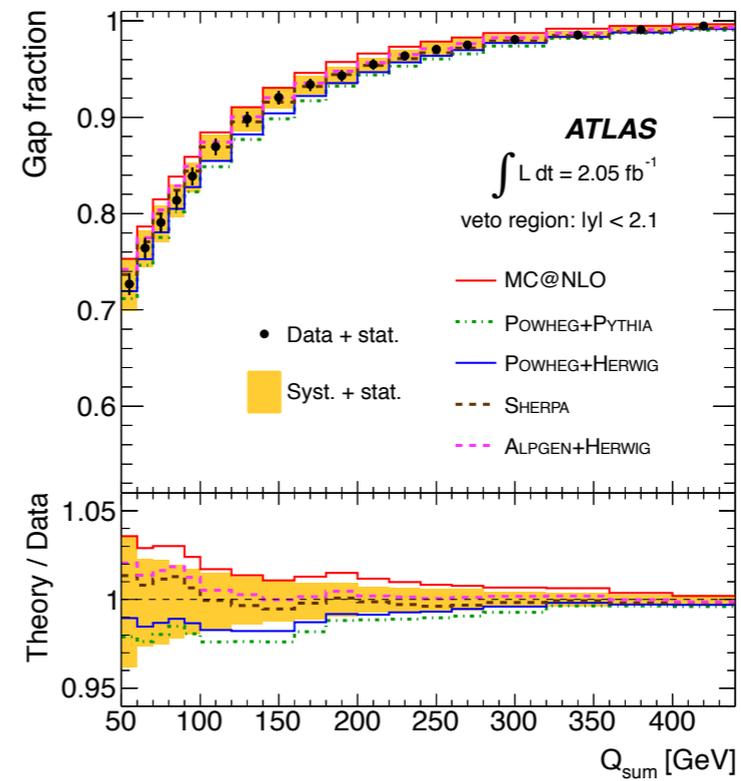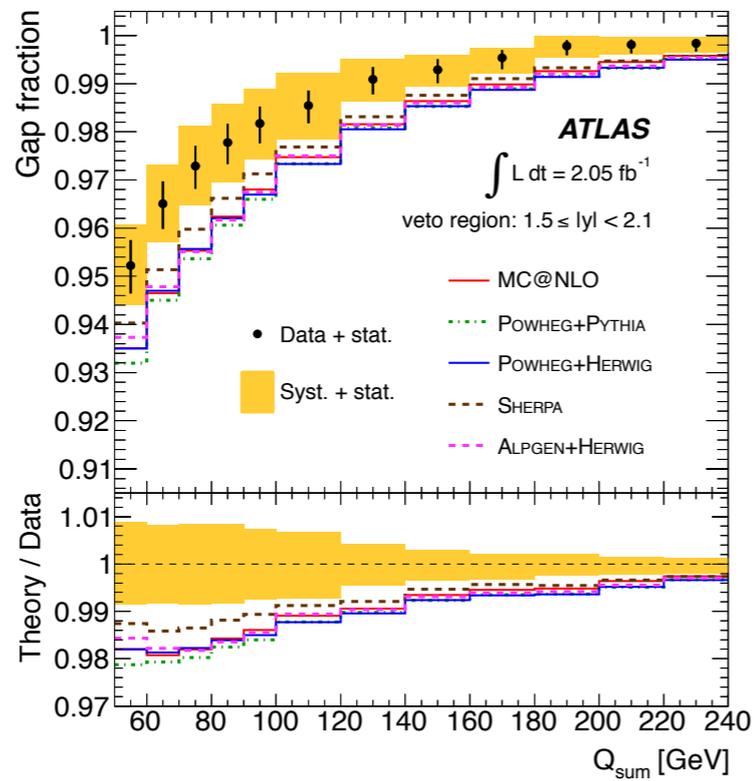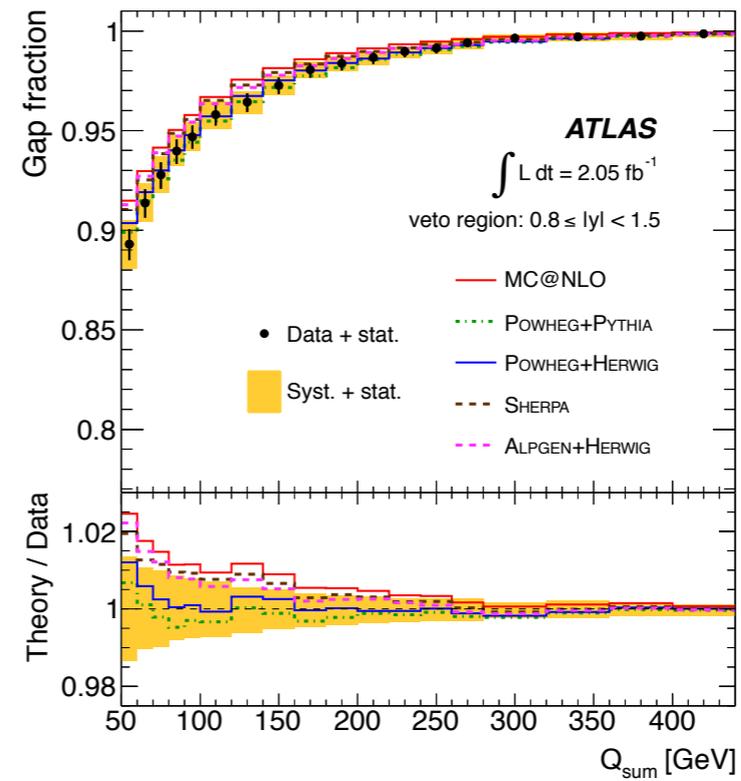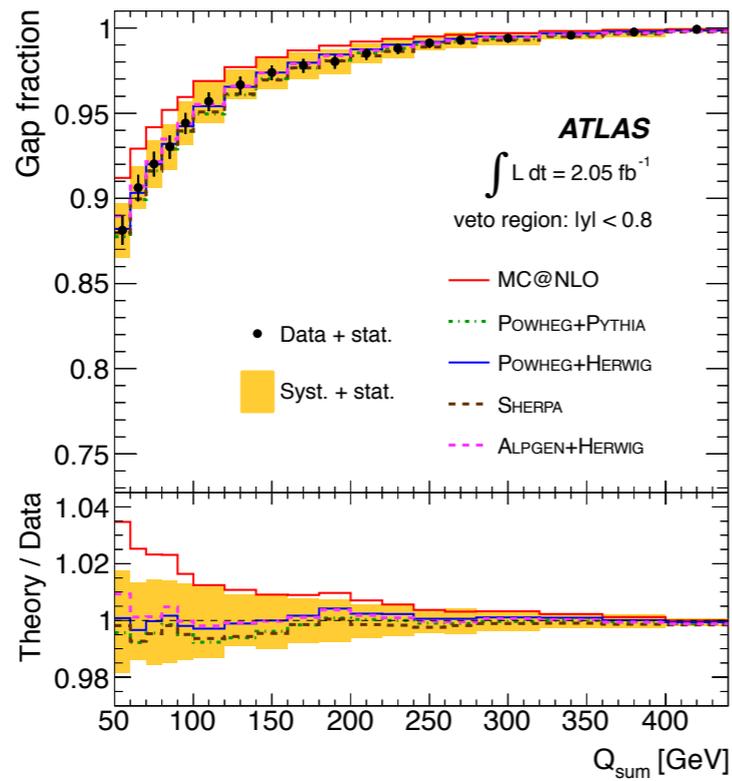
Gap fraction vs. Q_{sum} - systematic uncertainties

AcerMC parameter variations

```
- PARP(67): controls high-pt ISR branchings phase-space;
             ISR branchings with pTevol > m_dip/2 * PARP(67) are
             power suppressed by a factor (m_dip/(2pTevol))**2


- PARP(64): multiplicative factor of the mom. scale^2 in running
             alpha_s used in ISR


- PARP(72): multiplicative factor of the lam_QCD in
             running alpha_s used in FSR central param. setting is
             motivated by ATLAS FSR QCD jet shapes,
             variations correspond to *1/2 and *1.5 central value


- PARJ(82): FSR low-pt cutoff
```

- Defaults: PARP(67) = 4,   PARP(64) = 1
- ISR Down: PARP(67) = 0.5,   PARP(64) = 4
- ISR Up: PARP(67) = 6,   PARP(64) = 0.25

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ATLAS-CONF-2012-155

ATLAS Preliminary
- Data
- ALPGEN+PYTHIA
- ALPGEN+PYTHIA (α_s Up)
- ALPGEN+PYTHIA (α_s Down)

$\int L\, dt = 4.7\ \text{fb}^{-1}$

$\sqrt{s} = 7$ TeV

anti k_t R=0.4
$|\eta| < 2.5$
$p_T > 40$ GeV
e+jets