GEORG-AUGUST-UNIVERSITÄT
GÖTTINGEN

Z+jets cross section measurement with first data

Despoina Evangelakou

In discussion with: K. Bierwagen, U. Blumenschein, A. Quadt

2nd Institute of Physics, Georg-August-University Göttingen

PHYSICS AT THE TERA SCALE
Helmholtz Alliance

FSP 101
ATLAS

Bundesministerium
für Bildung
und Forschung

Introduction

Plan:

- Measurement of the inclusive and differential Z+jets cross-section and comparison with theory
- Validate and tune generators with first data

Preparation:

- Feasibility study with fully-simulated data for 100 pb^{-1} at 10 TeV
    - Study statistical and systematic limitations
    - Establish necessary methods
        - Background estimation
        - Correction for detector effects
        - Correction for UE and fragmentation
- Generator comparison

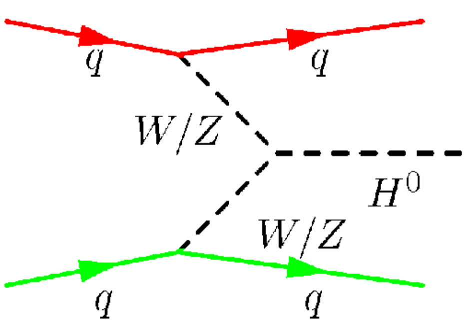
Difference to CSC study

See ATLAS CSC book:
http://cdsweb.cern.ch/record/1125884
and the presentation at the 2nd annual workshop:
https://indico.desy.de/contributionDisplay.py?contribId=24&sessionId=15&confId=1158

- CMS energy: 10 TeV
- Include Z+jets as background to VBF $H \to \tau^+\tau^-$
  - Consider third jet, η distributions
  - Consider also jets with 20 GeV< p_T <40 GeV
- Comparison of several methods for correcting detector effects

VB F $H \to \tau^+\tau^-$:

- Presence of two high-p_T jets
  - Very forward
  - Well separated in η
- Central Jet veto



Monte Carlo Samples

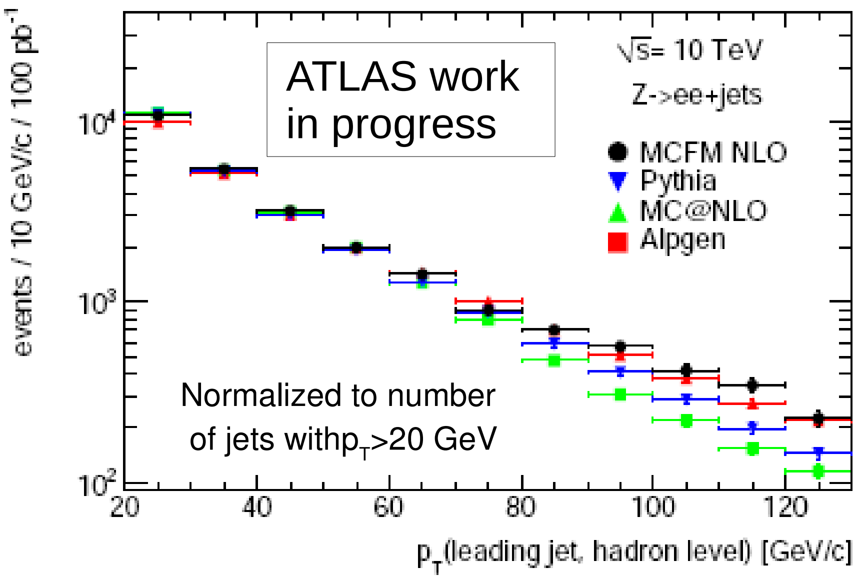
- $\sqrt{s}$ = 10 TeV
- Fully simulated data:
  - Signal:
    - (Z-> ee)+jets: Alpgen+Jimmy, Pythia, MCatNLO
  - Backgrounds:
    - ttbar: MCatNLO+Jimmy
    - QCD: Pythia
    - Z->tautau: Alpgen+Jimmy
    - W->ev: Alpgen+Jimmy
  - Integrated luminosity > 300 pb^{-1} (except QCD)

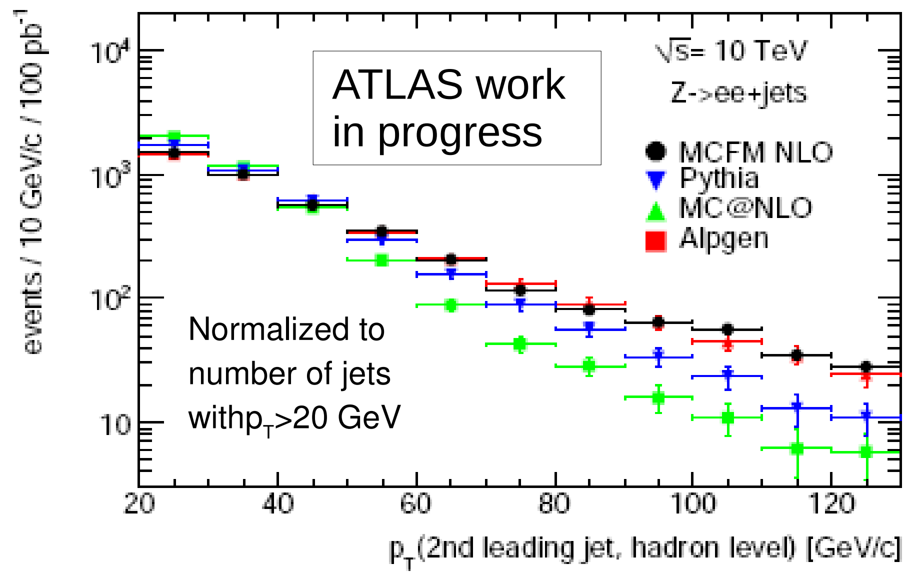
- MCFM:
  - NLO for $N_{partons}$ = 0, 1, 2
  - LO for $N_{partons}$ = 3

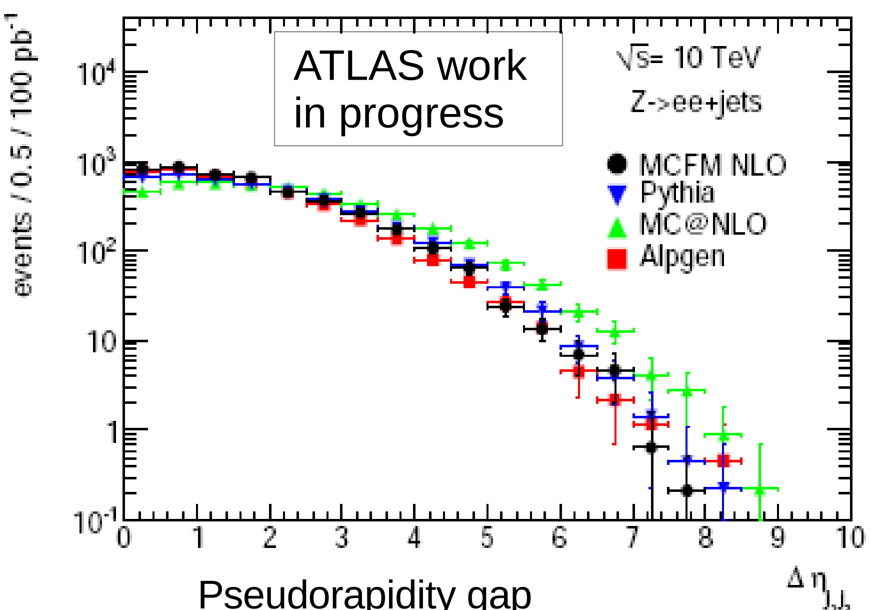
Outline

- Comparison of the MC generators used in ATLAS
- Signal and backgrounds
- Unfolding to the hadron level
  - Corrections parton level -> hadron level
  - Corrections detector level -> hadron level
- Statistical and systematic limitations

Comparison of the MC generators







- Alpgen predicts harder jets and larger jet multiplicity than Pythia and MCatNLO, better agreement with MCFM predictions
- McatNLO predicts broader η distribution

Side remark: Corrections on MCFM for UE and fragmentation are included

Outline

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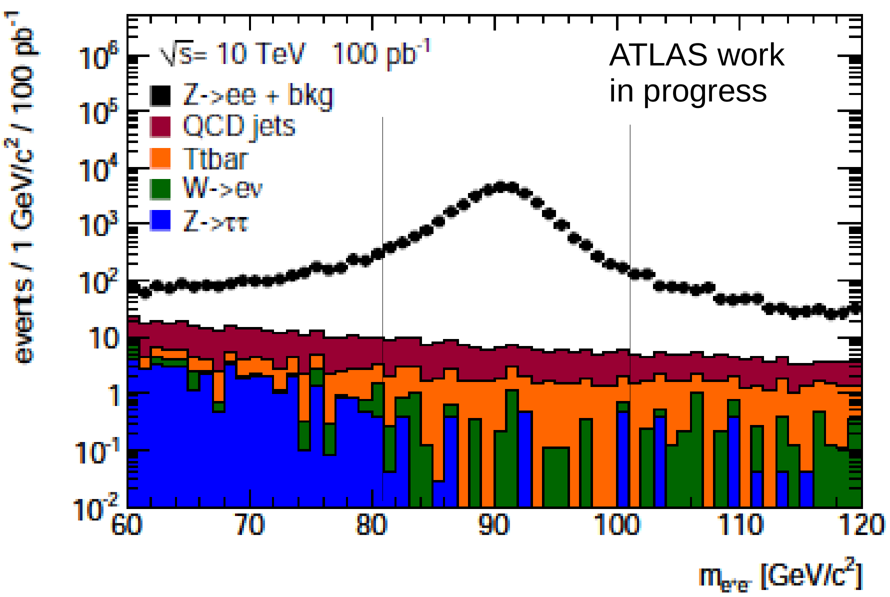
Z → ee +jets selection

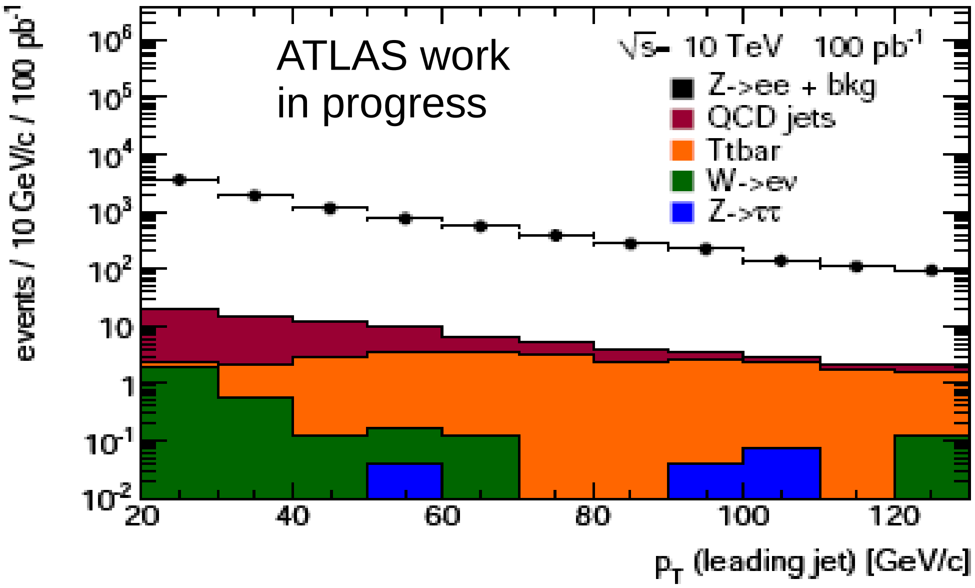
- Signal selection:
  - Select at least two electrons
    - p_T>15 GeV,
    - $\Delta R(e,e) > 0.2$,
    - mass window (m_{ee} ±10 GeV)

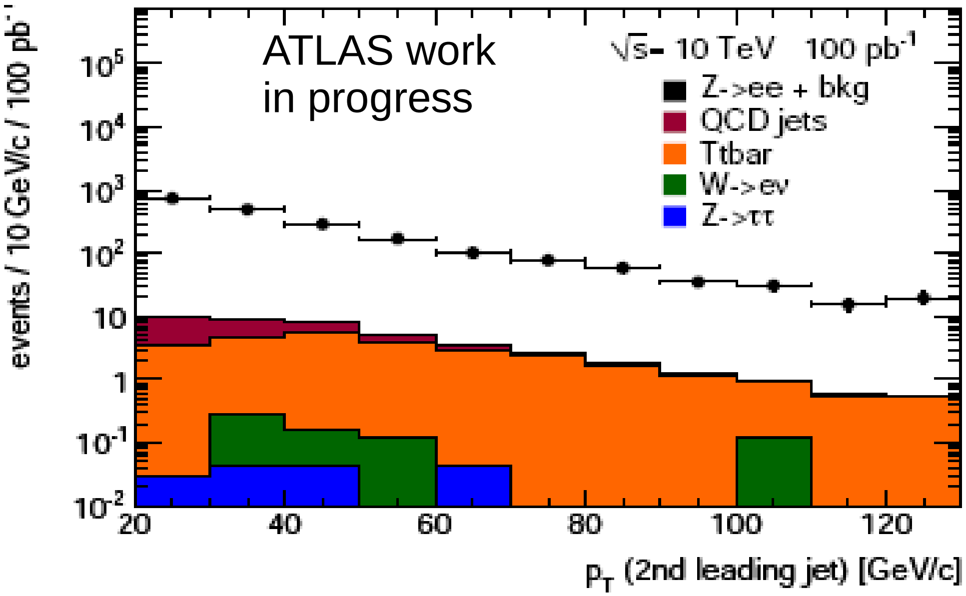
- Main backgrounds:
  - QCD jets (no electron ID cuts, but scale with rejection)
  - ttbar
  - Z -> tautau
  - W -> enu



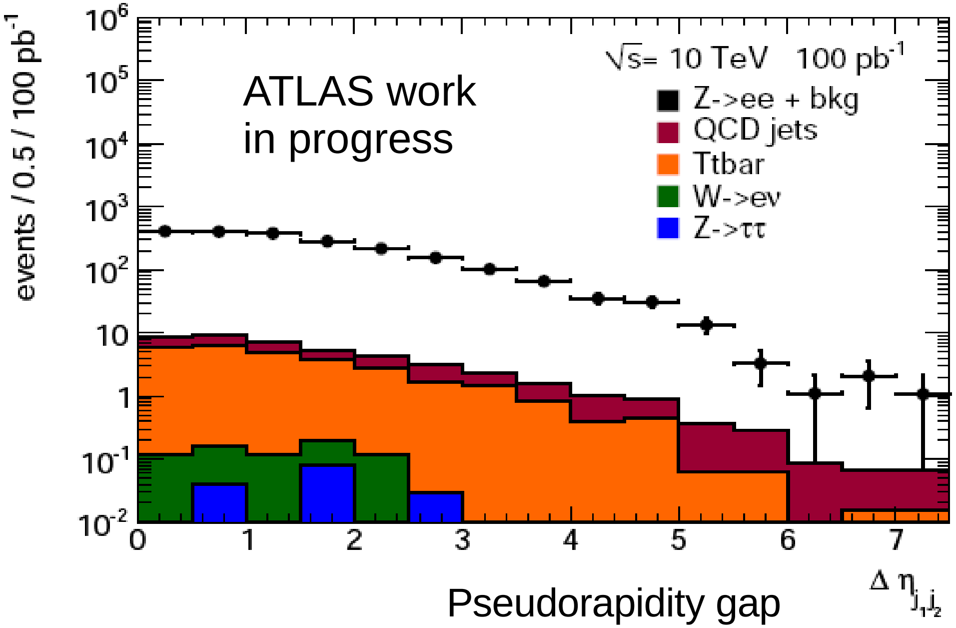
	(Z->ee)+1jet Fraction [%]	(Z->ee)+2jets Fraction [%]	(Z->ee)+3jets fraction[%]
Z->ee	98.81±1.56	97.68±3.37	95.91±7.81
QCD dijets	0.61±0.13	0.52±0.25	0.46±0.55
Ttbar	0.55±0.12	1.75±0.46	3.55±1.51
W->eν	0.02±0.03	0.04±0.07	0.07±0.22
Z->$\tau\tau$	0.004±0.01	0.01±0.04	0.00±0.00
All bkg	1.19±0.18	2.32±0.52	4.09±1.62

Differential Z+jets cross section





- Harder Jets in TTbar
- QCD background in events with forward jets

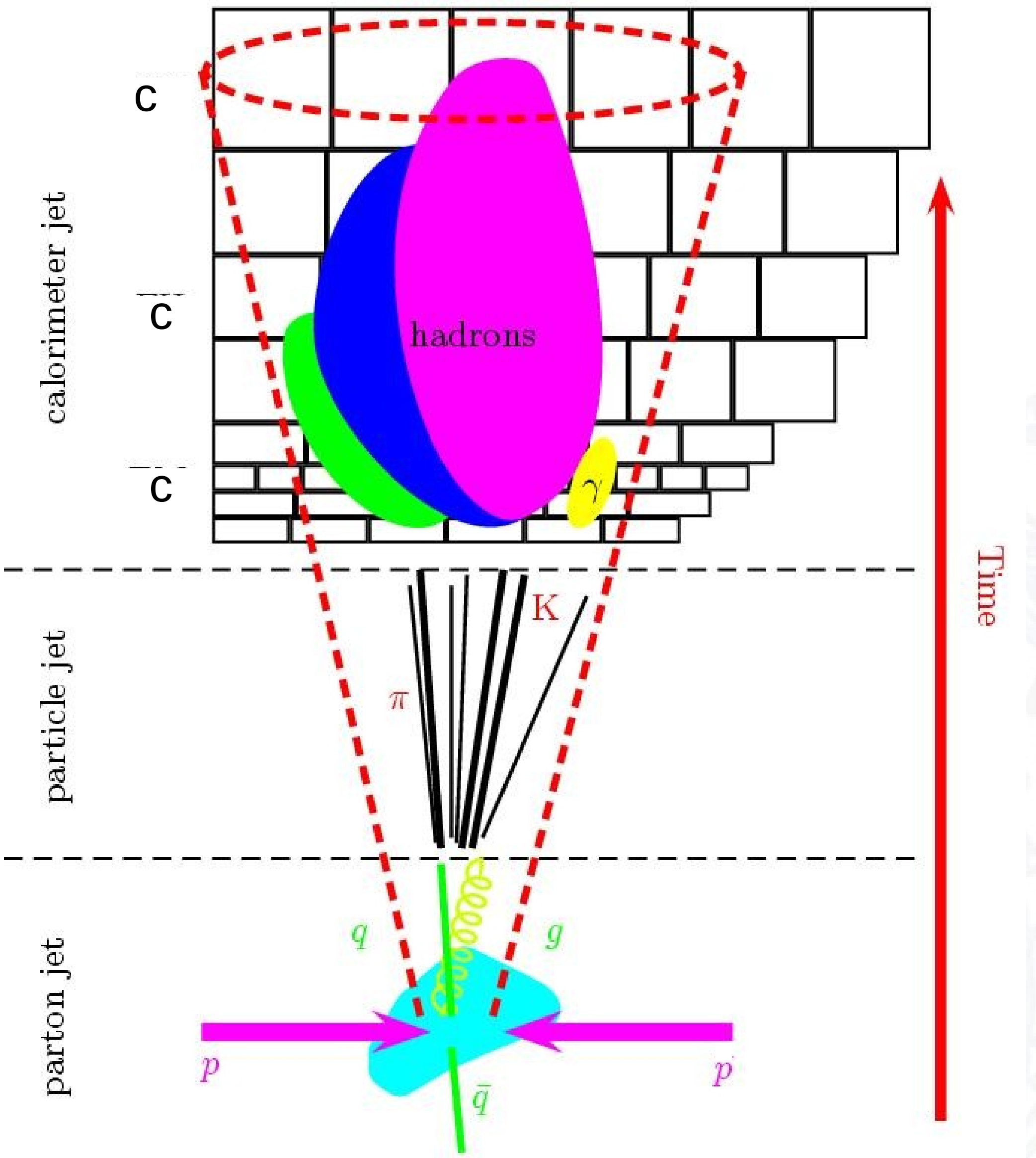


Z+jets cross section measurement

Comparison data and theory (similar for generator validation)

Uncertanties

Statistics	Detector level (real data)
JES, Detector Unfolding	↓
	Hadron level
Non-perturbative effects (UE, fragmentation)	↑
PDF	Parton level (MCFM)



Outline

- Comparison of the MC generators used in ATLAS
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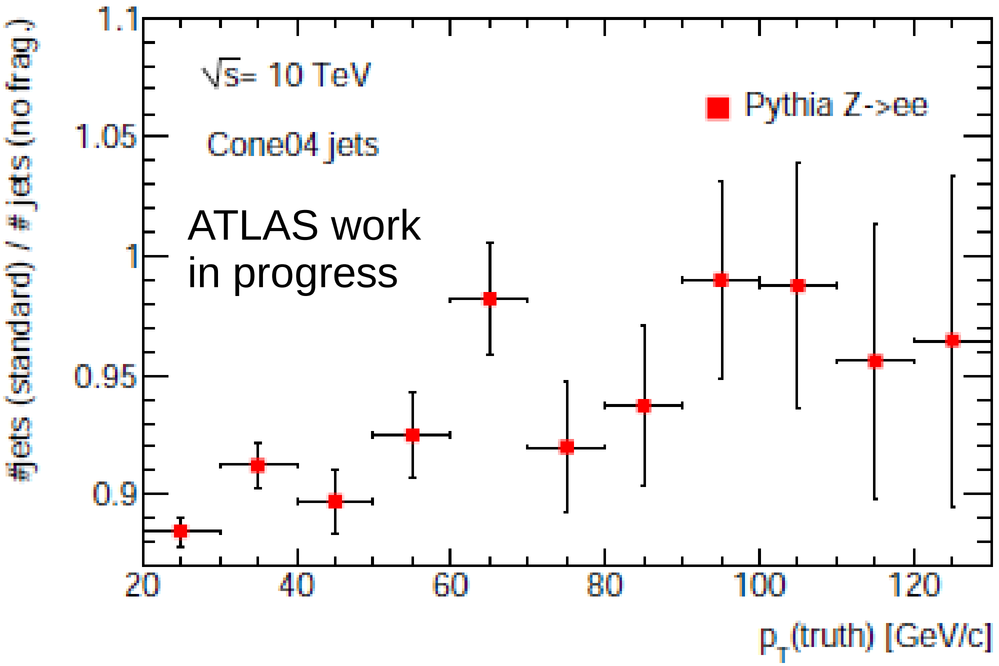
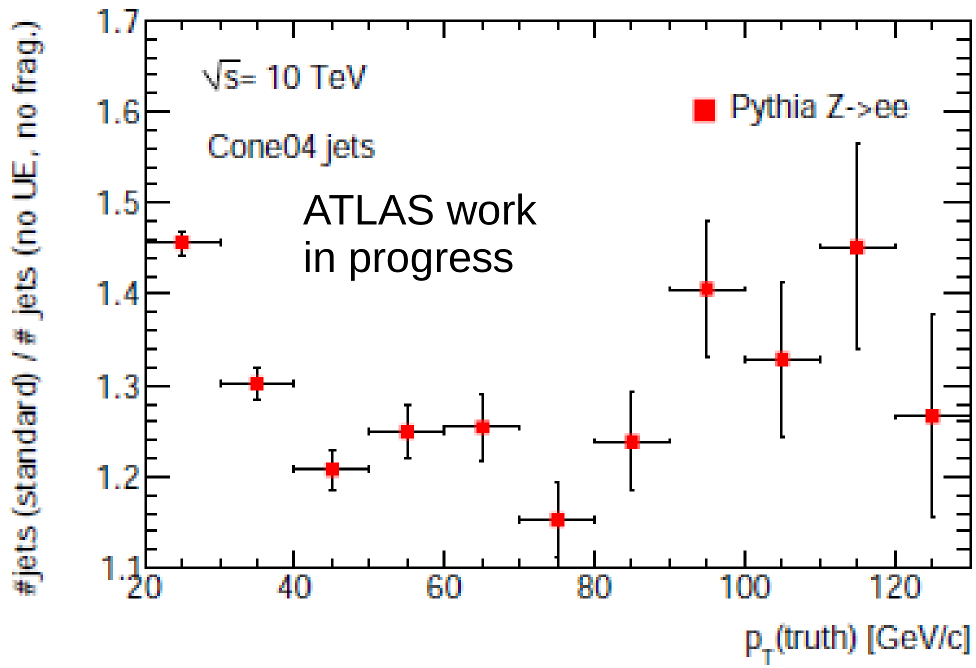
  - Corrections parton level -> hadron level
  - Corrections detector level -> hadron level
- Statistical and systematic limitations

Corrections parton → hadron level

Generate Pythia Z -> ee samples:

1. ATLAS standard — hadron level
2. No fragmentation
3. No fragmentation and no UE — parton level





Fragmentation → out-of-cone energy loss at low p_T

UE → additional energy deposition, order 1 GeV

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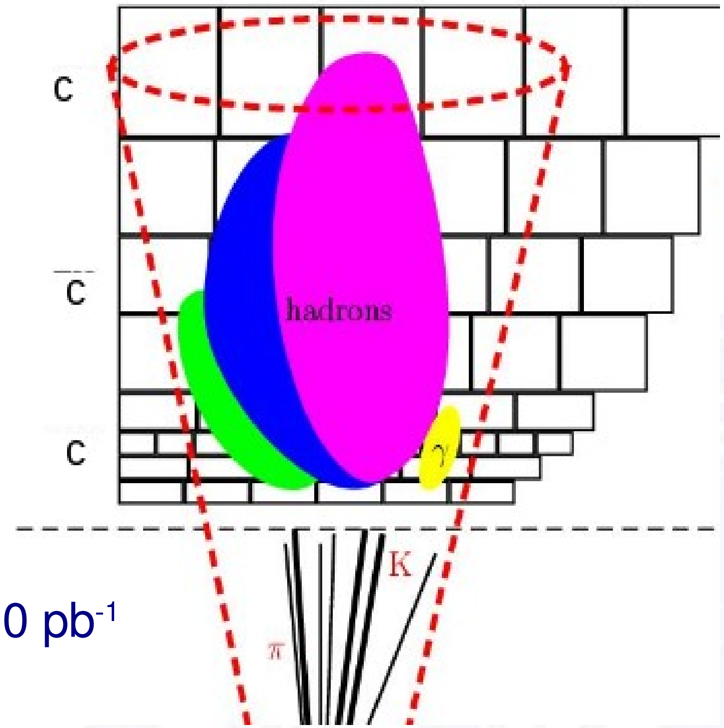
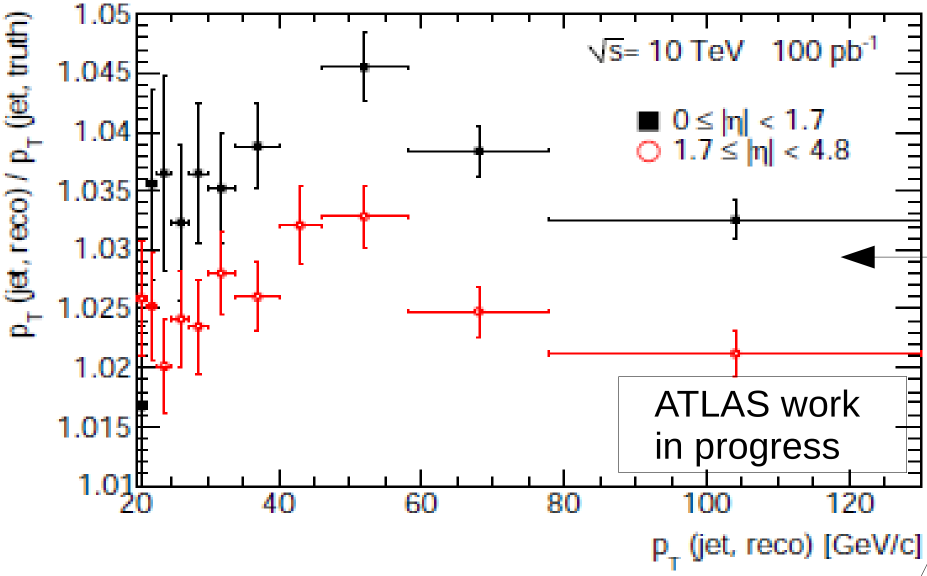
Corrections for detector effects

- 4 different corrections
  1. Factorized corrections
  2. Matrix unfolding
     1. Inversion w/o regularization
     2. Interative (Bayes) method
  3. Bin-by-bin method



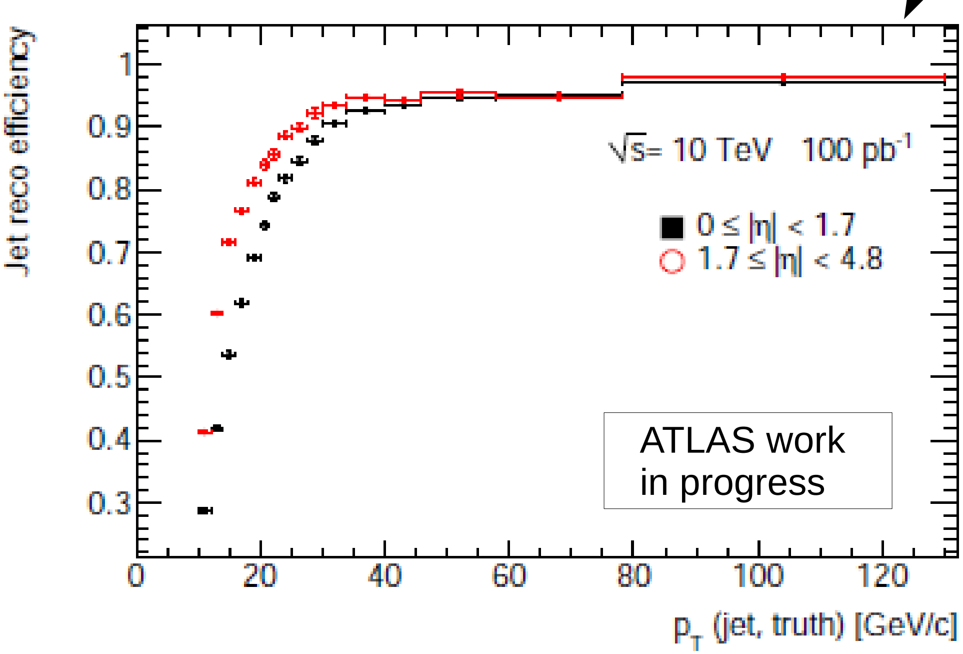
- Use two statistically independend MC sets of 100 pb^{-1}
  - Training sample
  - Test Sample
- Study impact of different shape by correcting Alpgen with corrections derived from Alpgen and corrections derived from Pythia (full MC statistics)

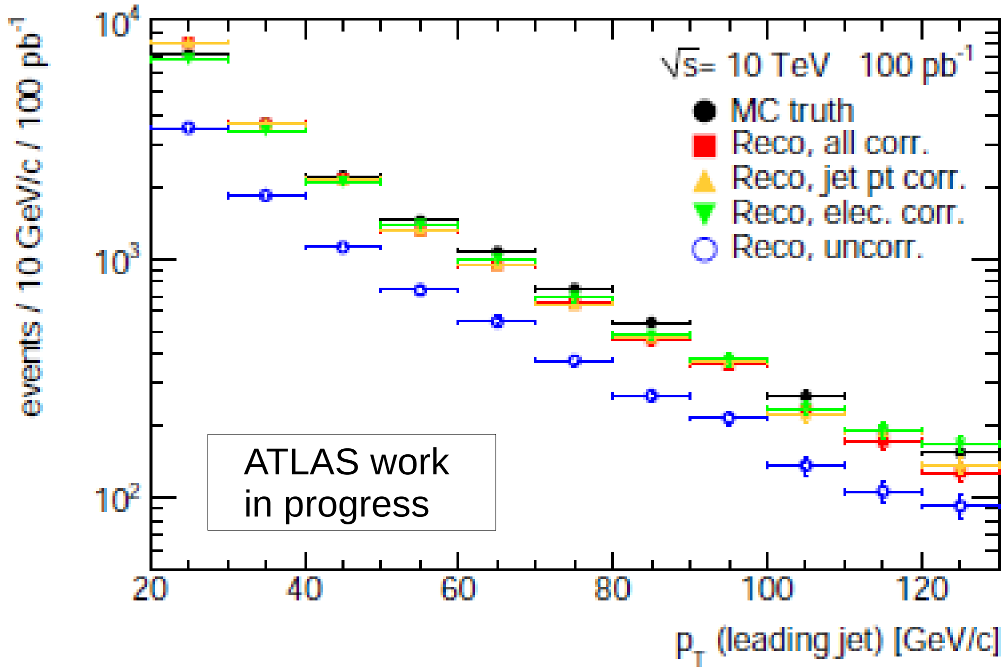
Factorized Corrections



Corrections assumed to factorize:

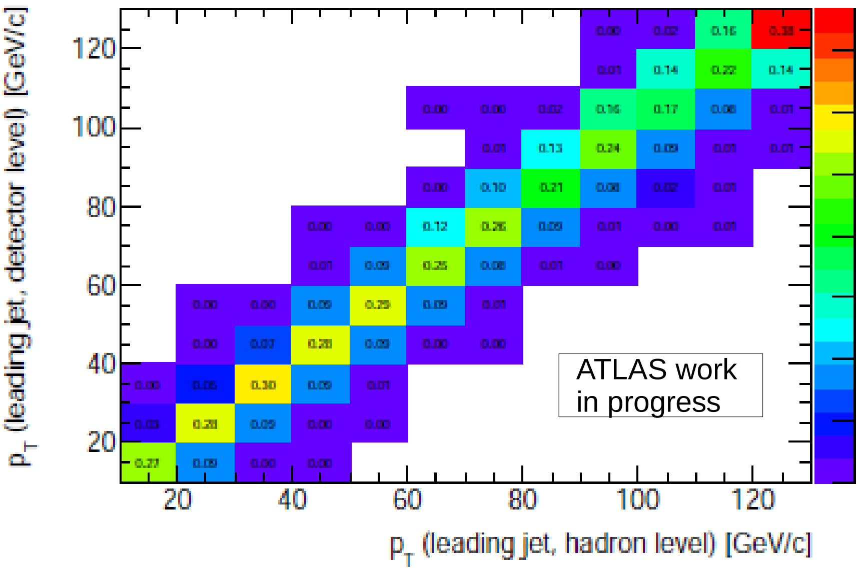
- Electron ID and reco efficiency (large but global)
- Electron non-linearity and resolution (small, global)
- JES → non-linearity at low p_T (real correction)
- Jet reco efficiency (event re-weighting)
- Jet resolution → distortion of p_T shape (ebent re-weighting)

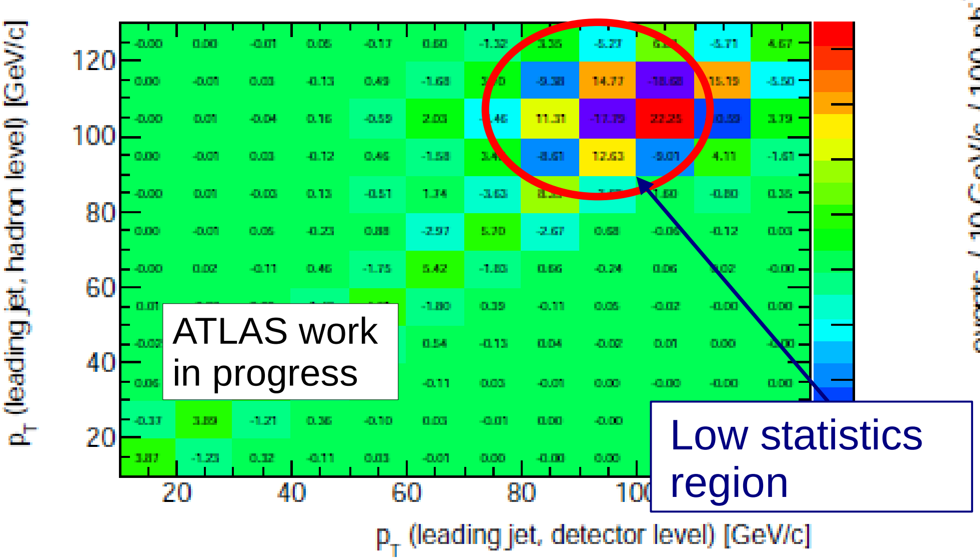


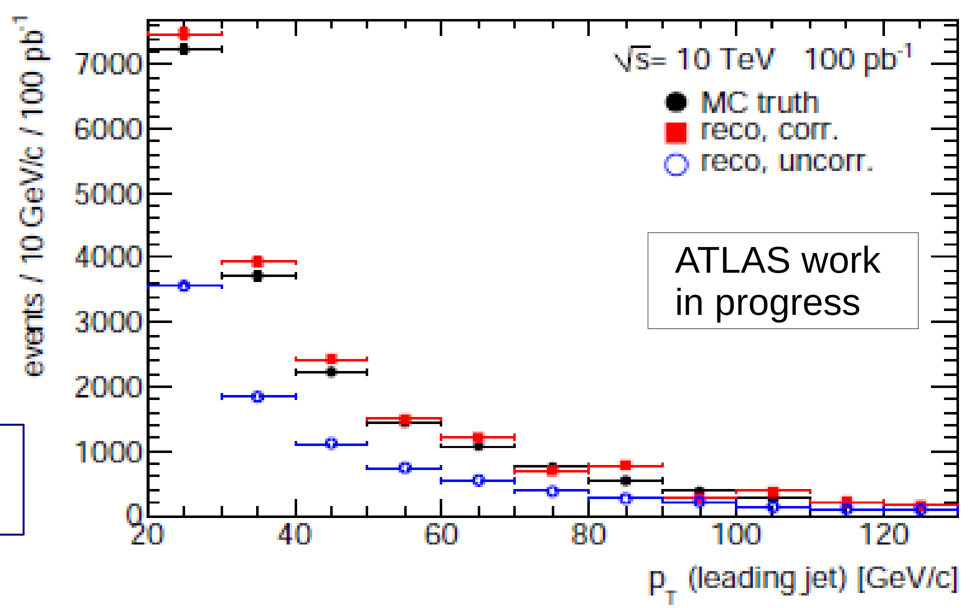


Matrix Method – w/o regularization

- Create migration Matrix M_{ij} ($d=M\cdot h$) with the training sample
- Normalize with reco efficiency
- Invert normalized Matrix
- Apply to test sample: $h=M^{-1}\cdot d$

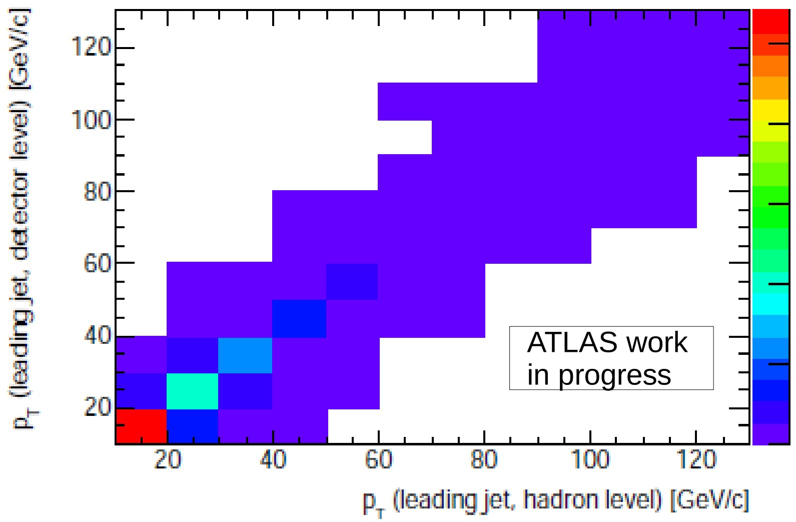






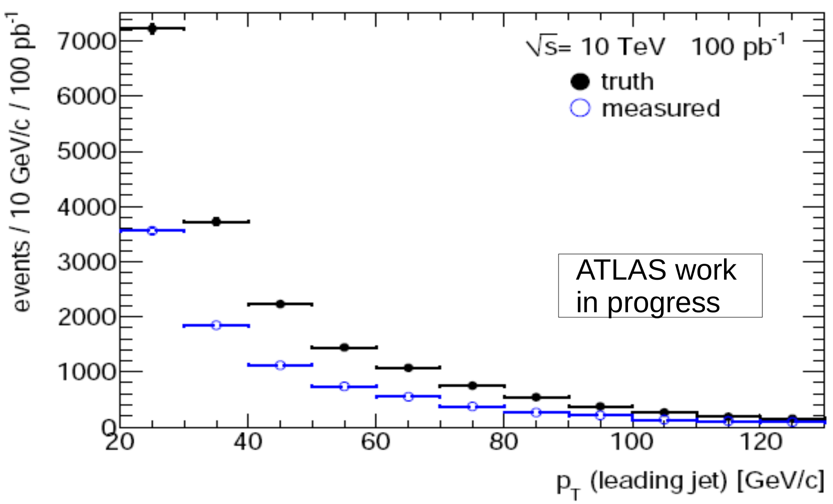
Bayes method, Bin-by-Bin method

- Bayes Method:



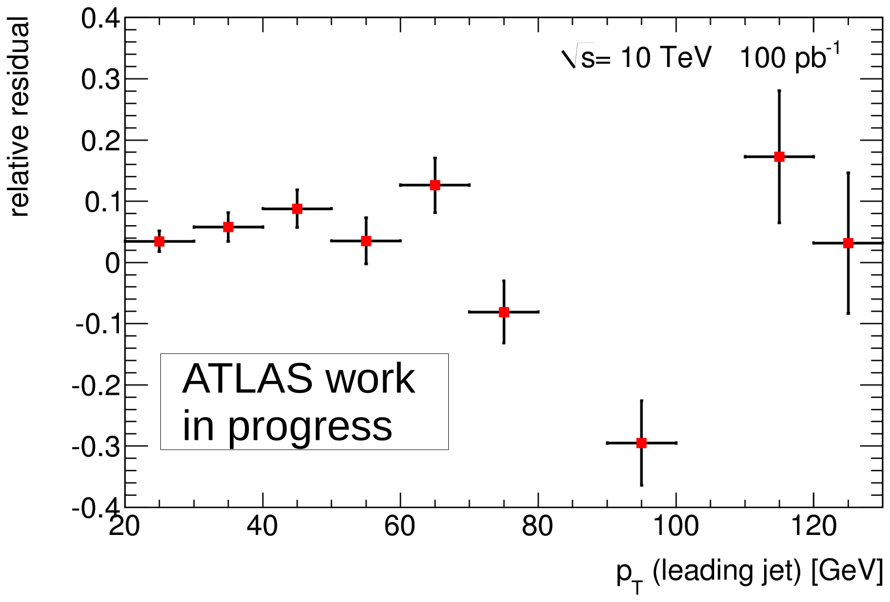
- Input: truth distribution, migration matrix R_{ji}
- Recalculate improved truth distribution μ_i from the measured distribution n_j by using the Bayes theorem $$\hat{\mu}_i = \frac{1}{\varepsilon_i} \sum_{j=1}^{N} \frac{R_{ji} p_i}{\sum_k R_{jk} p_k} n_j$$

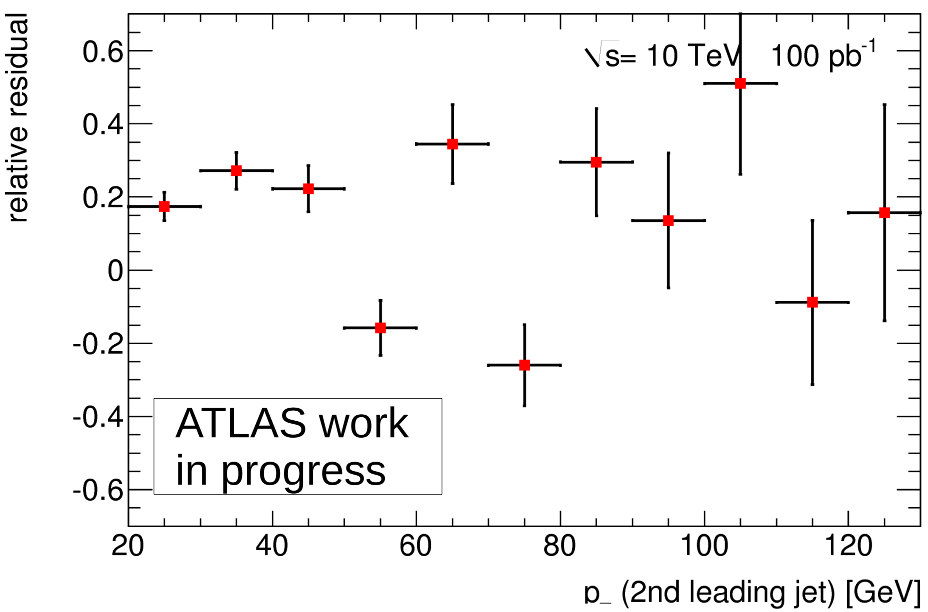
- Bin-by-Bin Method:



- Correction = measured / truth distribution (training sample)
- Expected to be viable for small migration (migration matrix ≈ diagonal, bin size larger than resolution)

Residuals (1) Matrix inversion





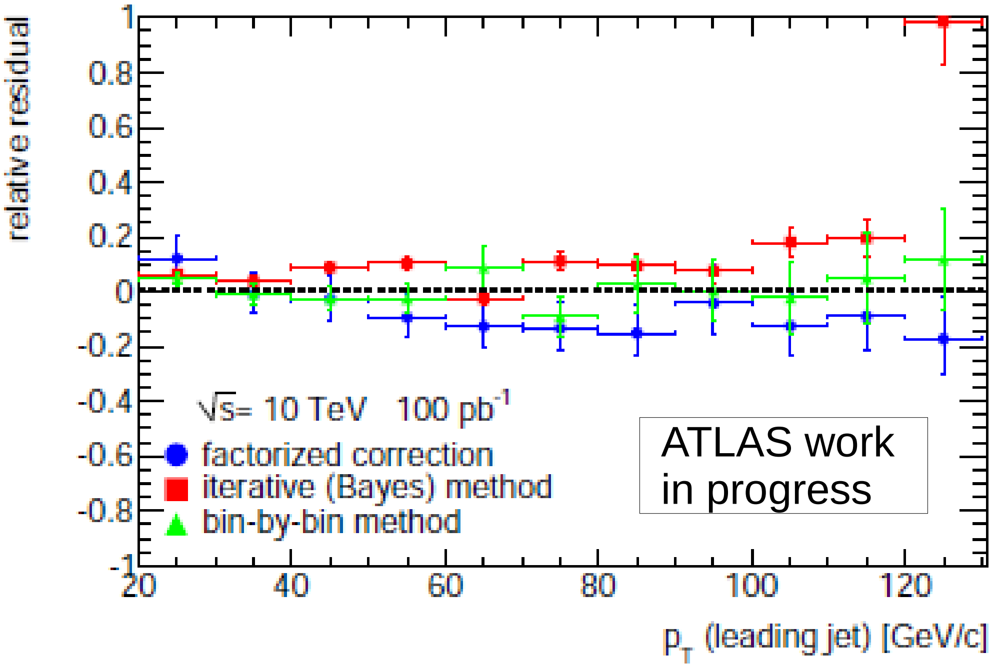
Rel residual = (reco_corrected - truth)/truth

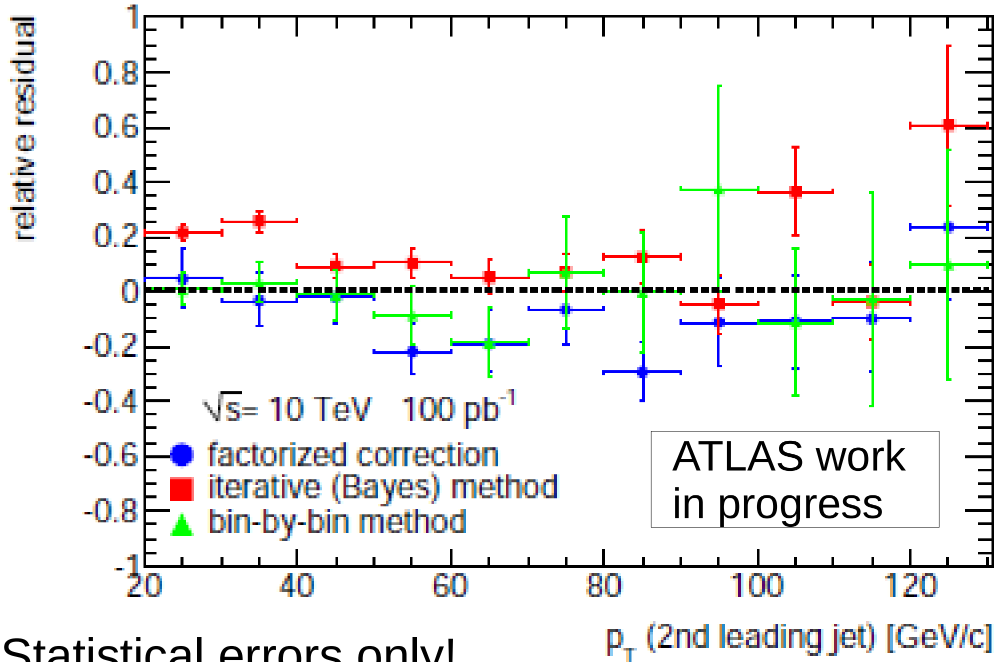
- Good performance in high statistics regions
- Problems in low statistics regions (typical fluctuations)

→

- Increase statistics
- Adapt binning
- Use regularization

Residuals (2) Other methods

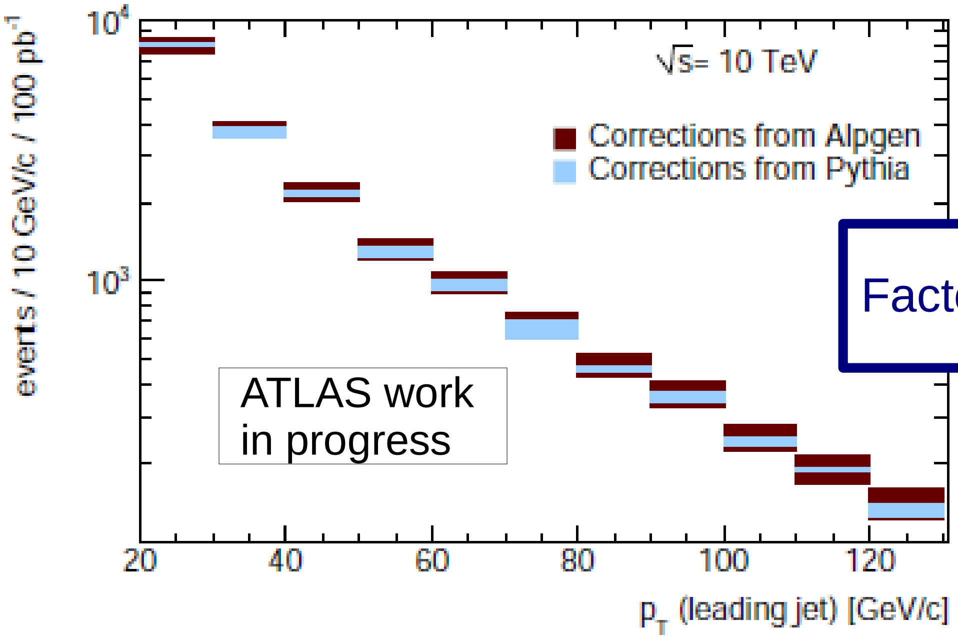




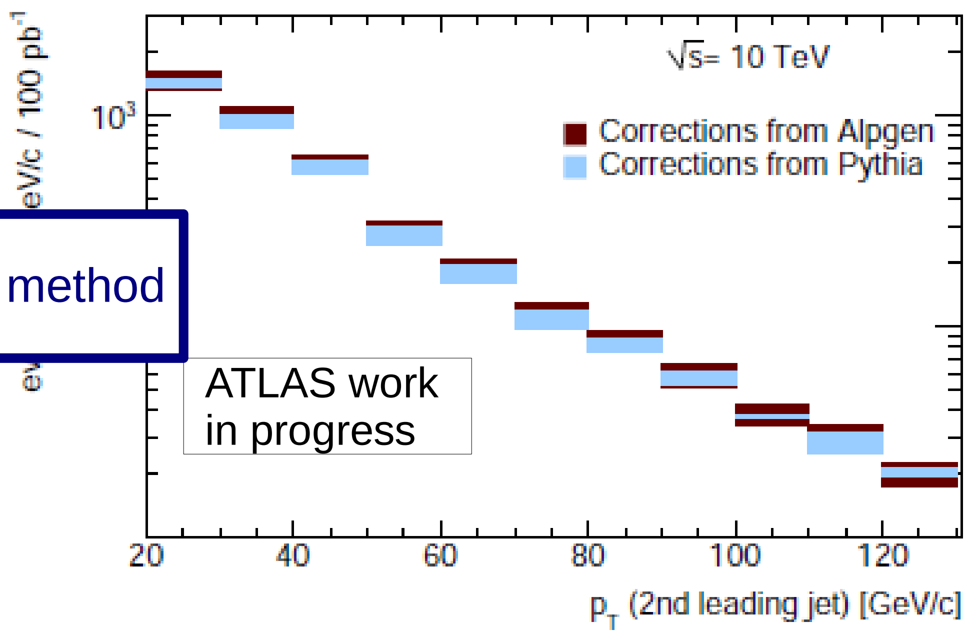
Statistical errors only!

- Factorized corrections, Bayes unfolding: Fake jets not taken into account, Migration from very low-PT jets only partially covered -> Bias of 10-30% -> to be fine tuned
- Bin-by-Bin method good agreement, shape dependence to be checked

Shape of the training sample



Factorized method

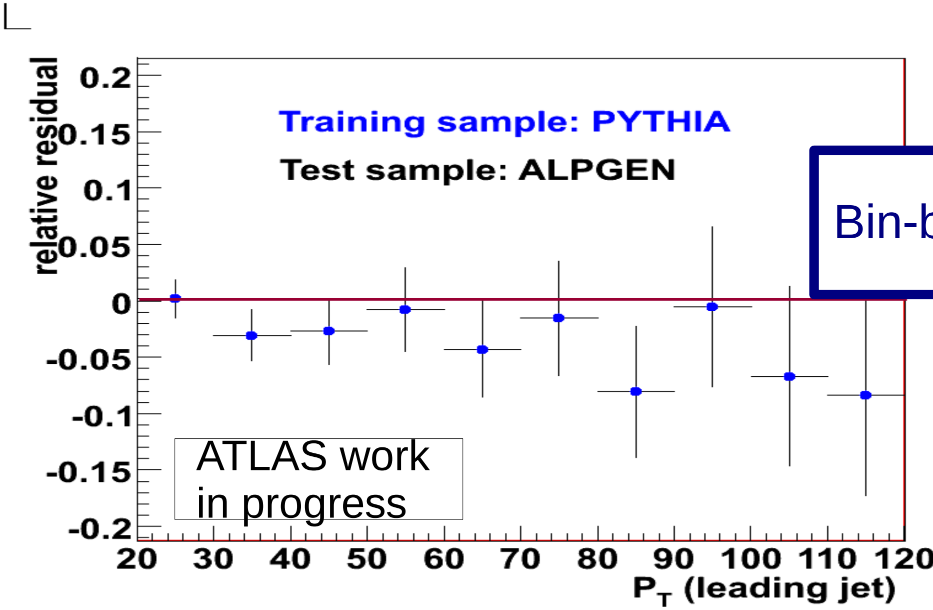


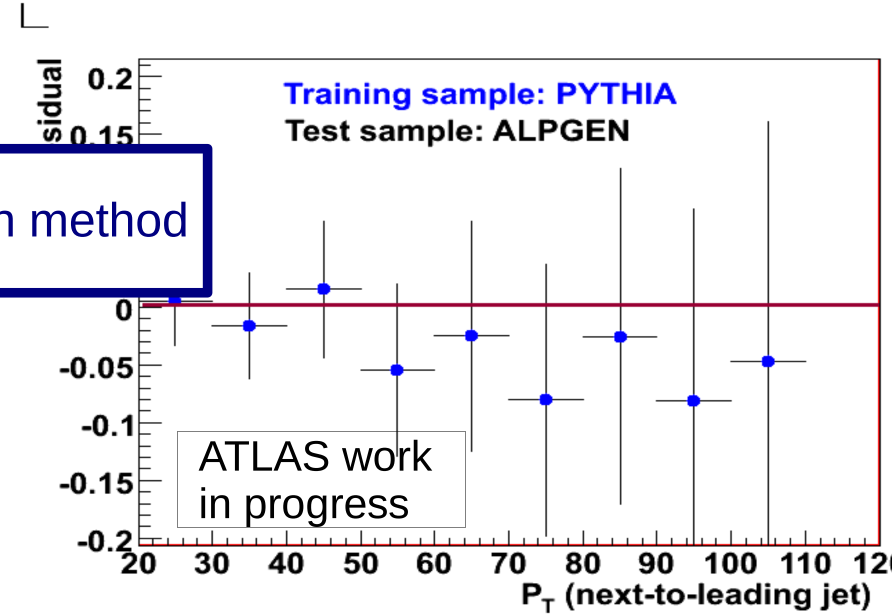
- Derive corrections from two training samples:
  1) Training sample: PYTHIA
  2) Training sample: ALPGEN
- Correct ALPGEN reco distributions with both corrections and compare the corrected distributions

- Bias by different shape of training sample small compared to statistical uncertainty

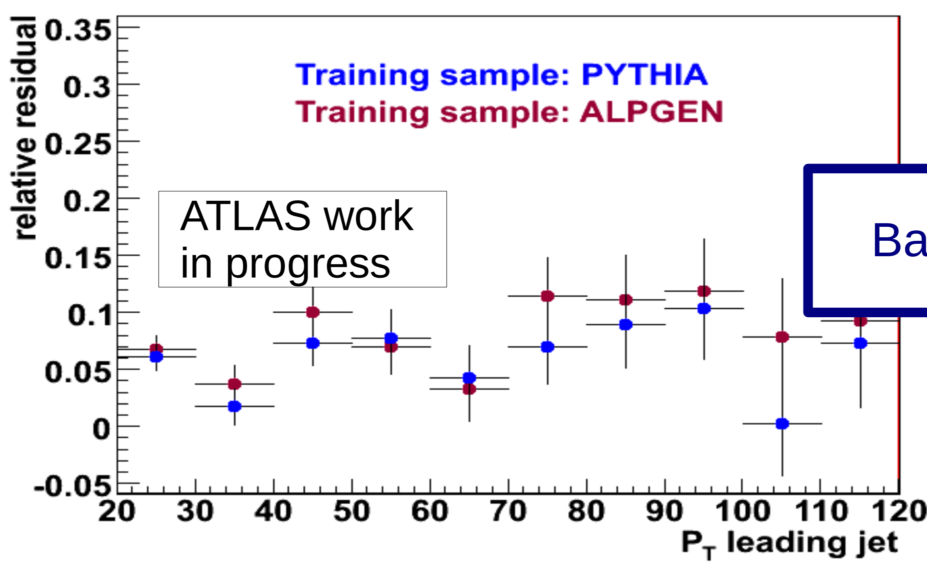
Shape of the training sample

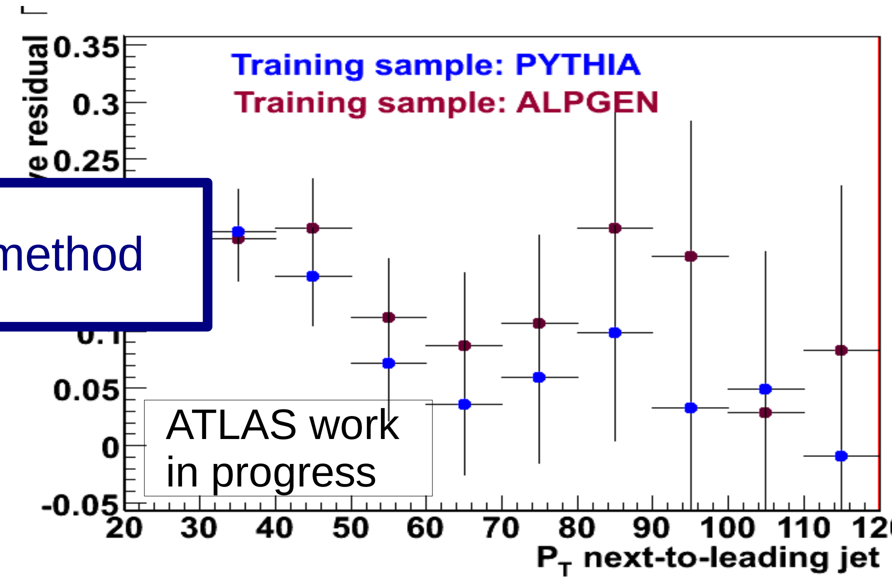
Bin-by-Bin method





Bayes method





- Bias by different shape of training sample small compared to statistical uncertainty

Outline

- Comparison of the MC generators used in ATLAS
- Signal and backgrounds
- Unfolding to the hadron level
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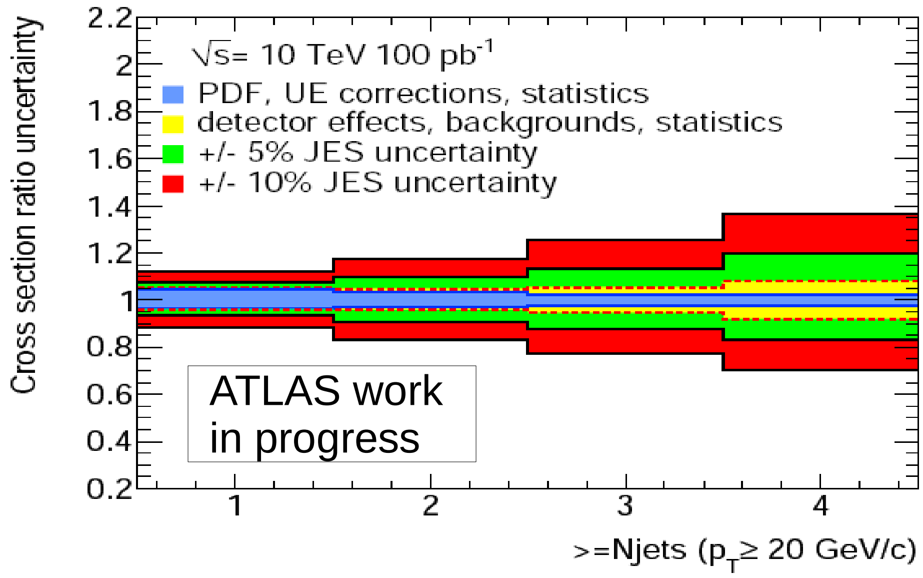
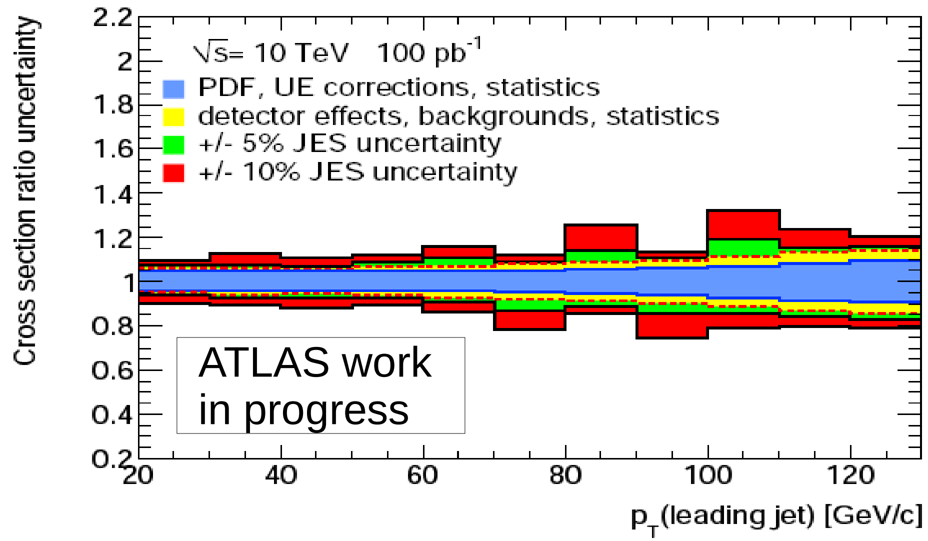
  - Corrections detector level -> hadron level
- Combined statistical and systematic limitations

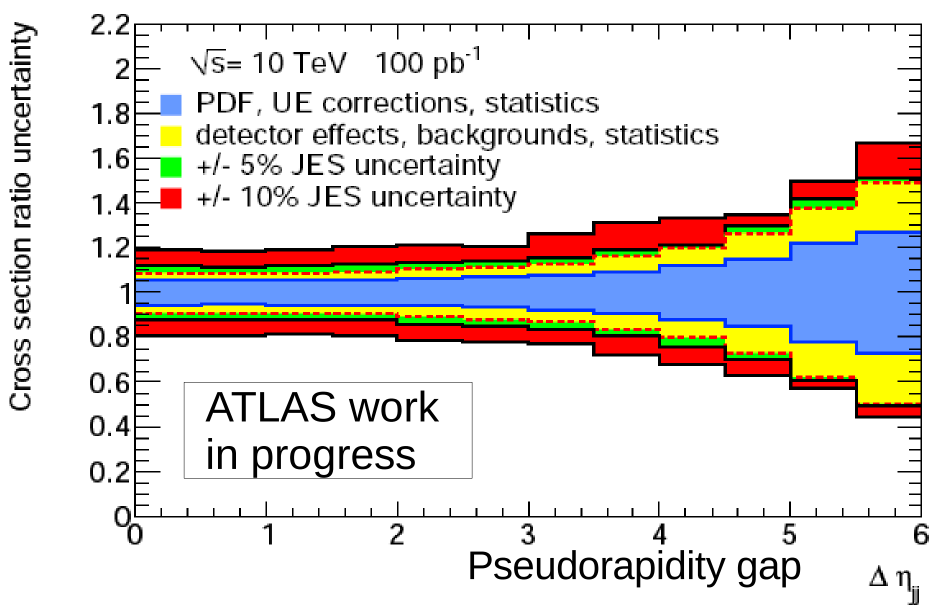
Derived for factorized corrections, but expect similar results for other methods

Ratio data to theory (set to 1)

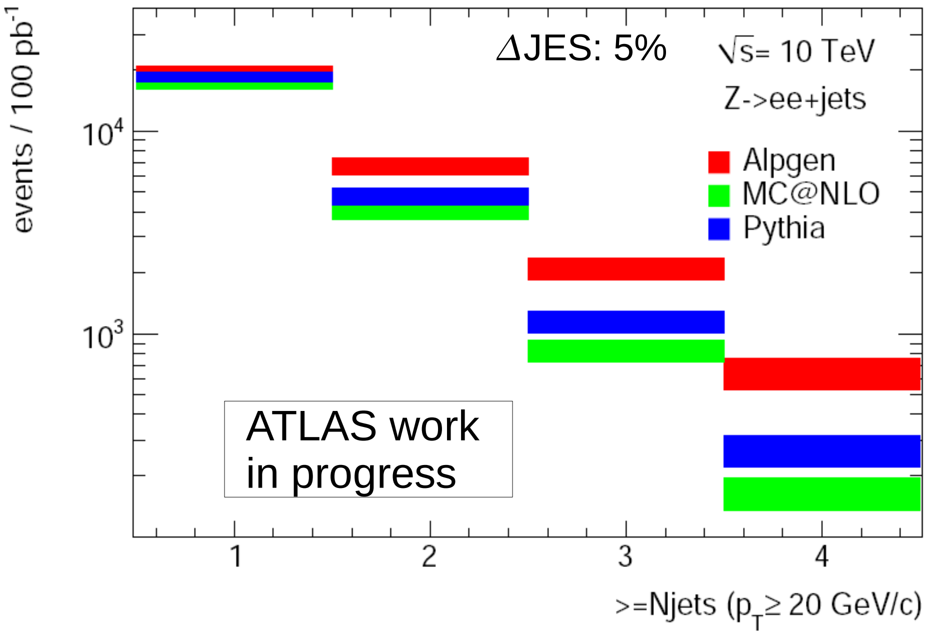


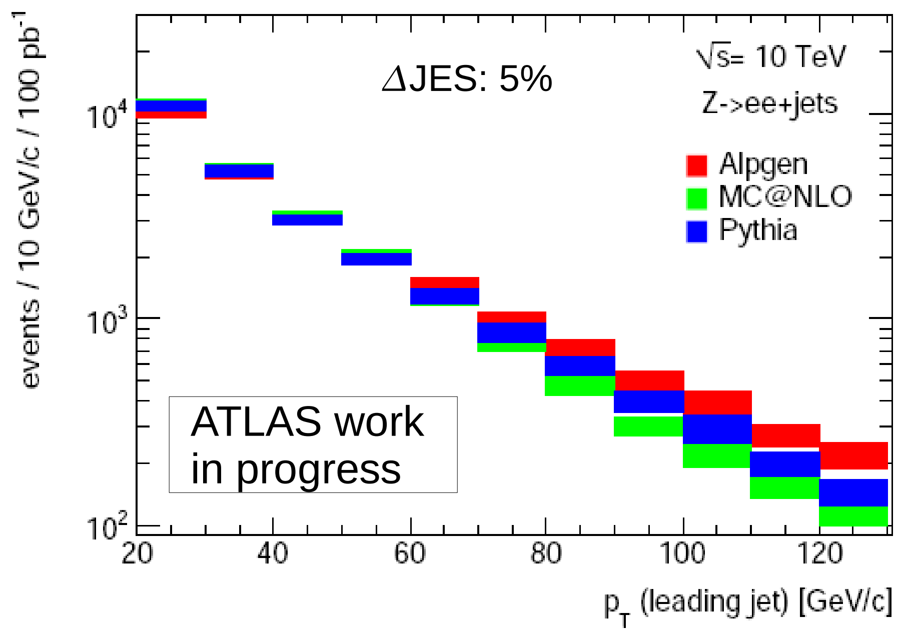


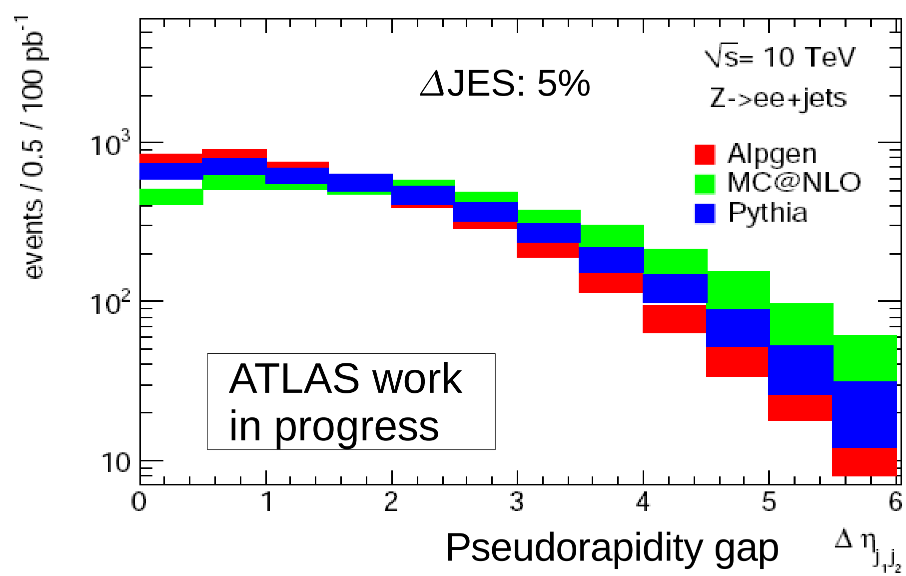
- Contribution from JES dominates
- Z+1jet: PDFs and parton level corrections
- VBF quantities: statistics
- Total additional uncertainty for Z+1-3 jets
  - 6% -12% (JES uncert. 5%)
  - 13% -25% (JES uncert. 10%)



MC generators comparison







- Differentiation between generators difficult but possible if the complete distribution is taken into account

Summary and Outlook

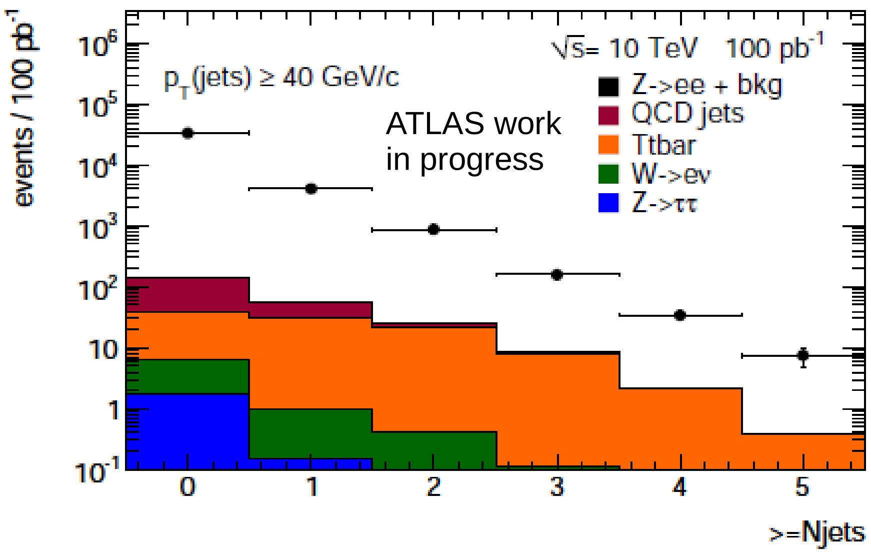
- Investigated jet multiplicity, P_T distribution and VBF Higgs key quantities in (Z->ee)+jets events
- Compared prediction of various MC generators
- Investigated backgrounds, in particuler Ttbar, QCD
- Method to correct theory predictions from parton to hadron level
- Implementation and comparison of 4 methods for correcting for detector effects
- Comprehensive study of statistical and systematic errors

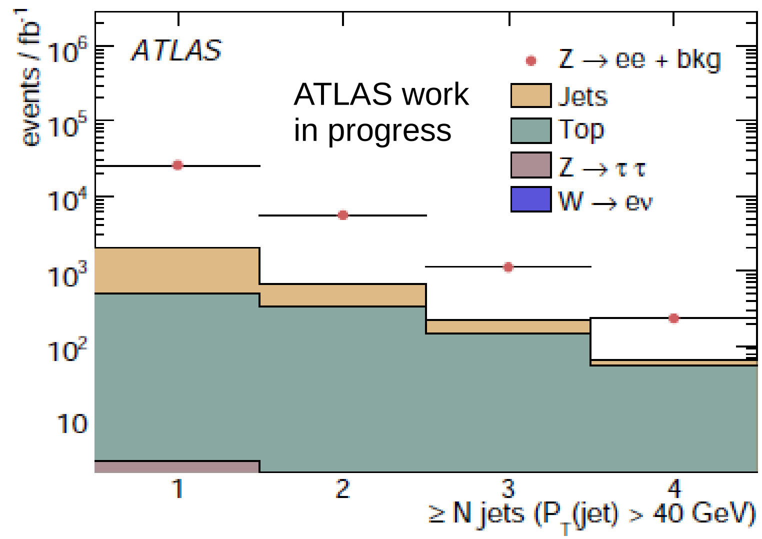
ToDo (as long as there is no data):

- Theory: Investigate scale dependence
- Parton->hadron level: compare corrections for different UE predictions
- Optimize corrections for detector effects, study regularization methods
- Study data-driven methods to extract the background

Back-Up Slides

Background estimation

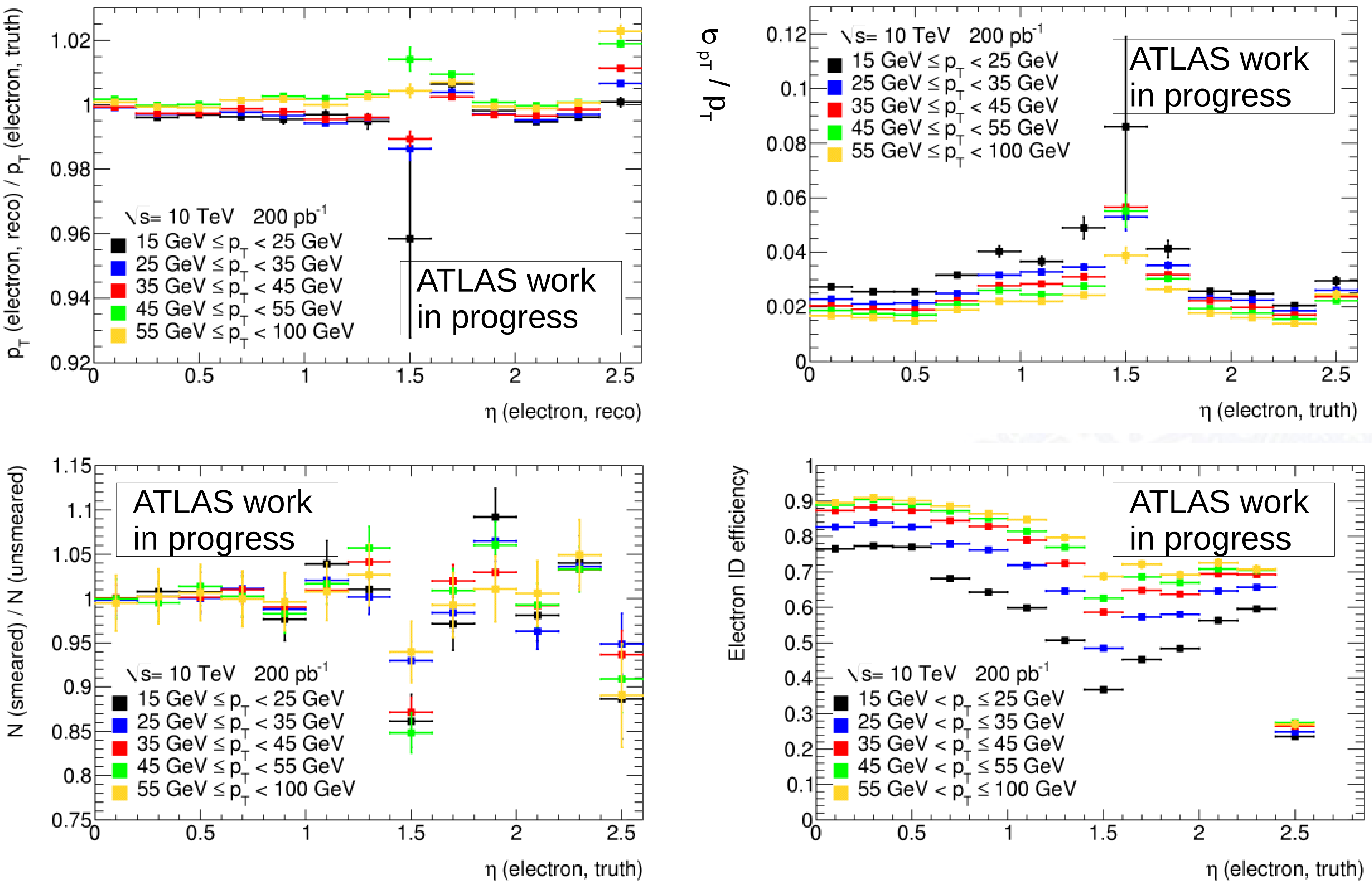




Process	$Z \to e^+e^- + \geq 1jet$ fraction [%]	$Z \to e^+e^- + \geq 2jets$ fraction [%]	$Z \to e^+e^- + \geq 3jets$ fraction [%]
10 TeV			
$Z \to e^+e^-$	98.81 ± 1.56	97.68 ± 3.37	95.91 ± 7.81
$QCDjets$	0.61 ± 0.13	0.52 ± 0.25	0.46 ± 0.55
$t\bar{t}$	0.55 ± 0.12	1.75 ± 0.46	3.55 ± 1.51
$W \to e\nu$	0.02 ± 0.03	0.04 ± 0.07	0.07 ± 0.22
$Z \to \tau^+\tau^-$	0.004 ± 0.01	0.01 ± 0.04	0.00 ± 0.00
total background/all events	1.19 ± 0.18	2.32 ± 0.52	4.09 ± 1.62
14 TeV			
$Z \to e^+e^-$	91.9 ± 0.8	87.9 ± 1.3	80.0 ± 2.4
$QCDjets$	6.0 ± 0.4	6.0 ± 0.8	6.9 ± 1.8
$t\bar{t}$	1.9 ± 0.1	6.0 ± 0.4	13.0 ± 1.4
$W \to e\nu$	0.1 ± 0.05	0.1 ± 0.05	0.05 ± 0.1
$Z \to \tau^+\tau^-$	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01
total background/all events	8.0 ± 0.6	12.1 ± 0.9	20.0 ± 2.3

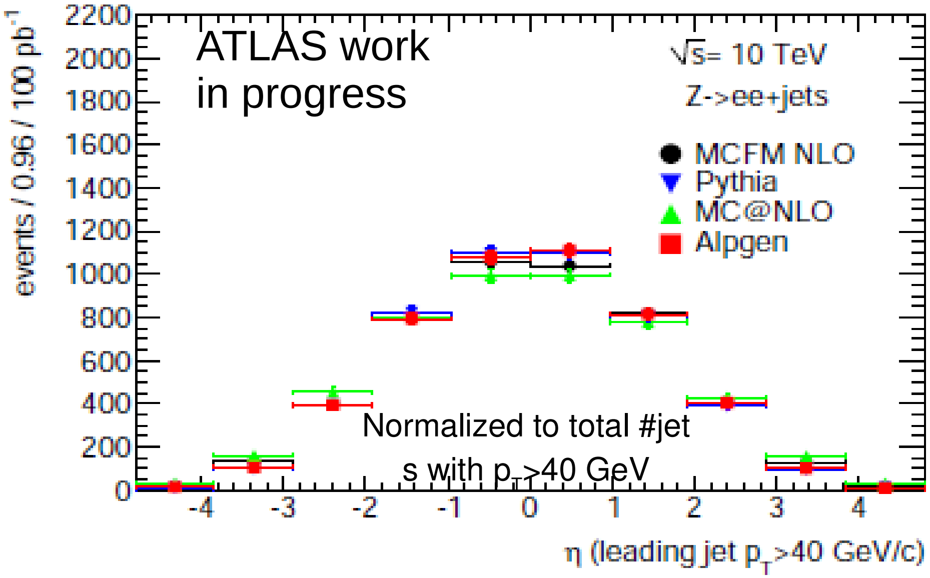
- More QCD background at √s = 14 TeV because of missing isolation
- σ(ttbar)/ σ(Z) is smaller at √s = 10 TeV.

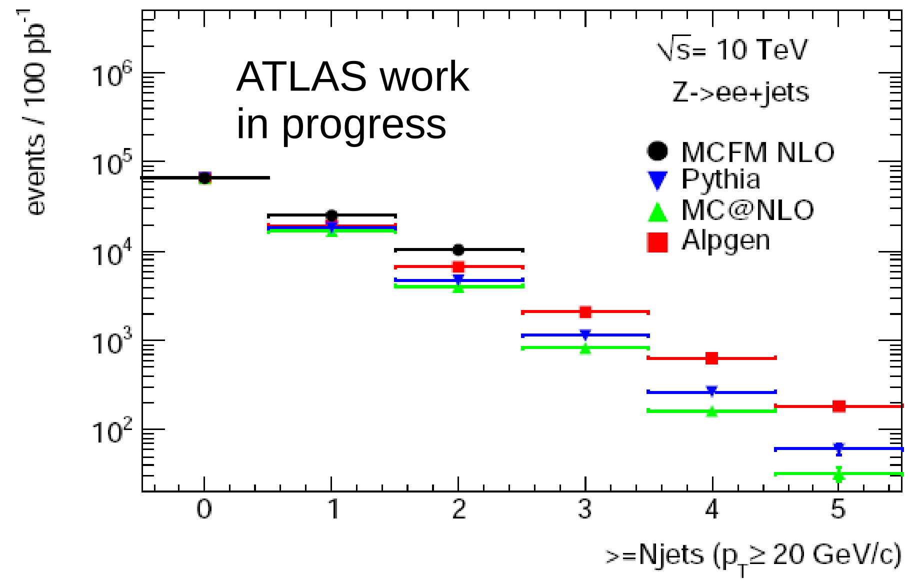
Factorized corrections - electron

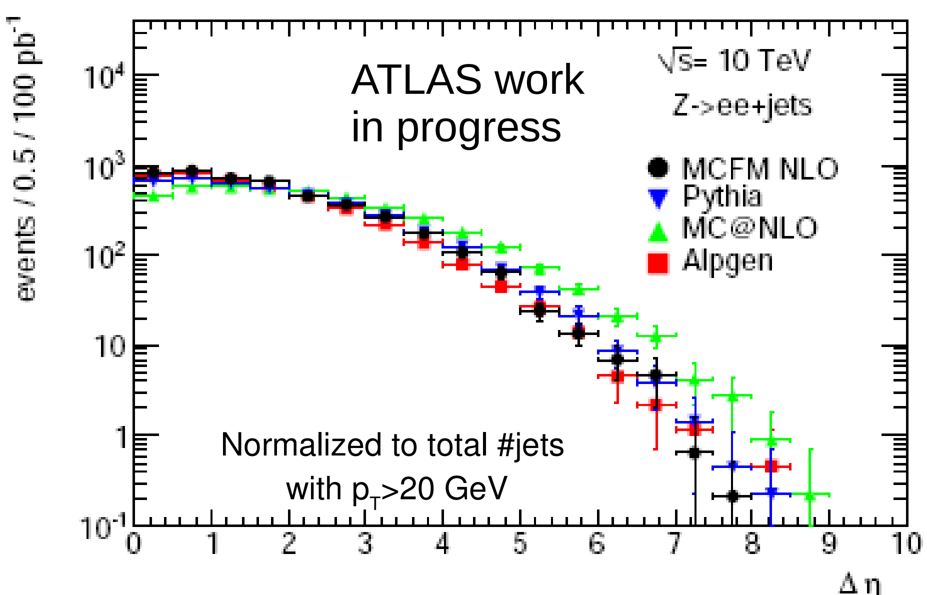


El-ID: el_medium_ no-iso + calo-iso

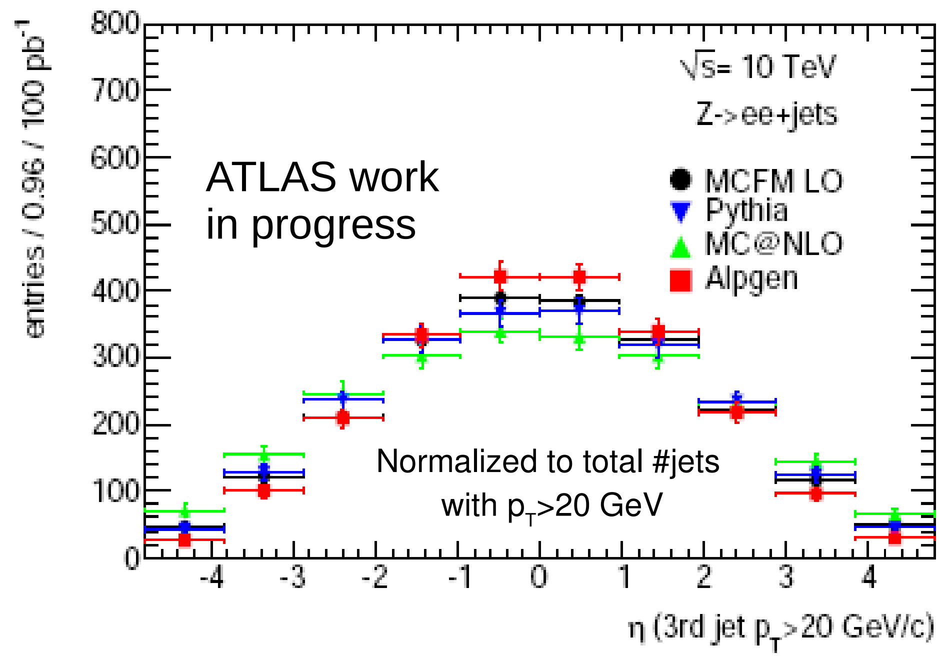
Comparison of the MC generators



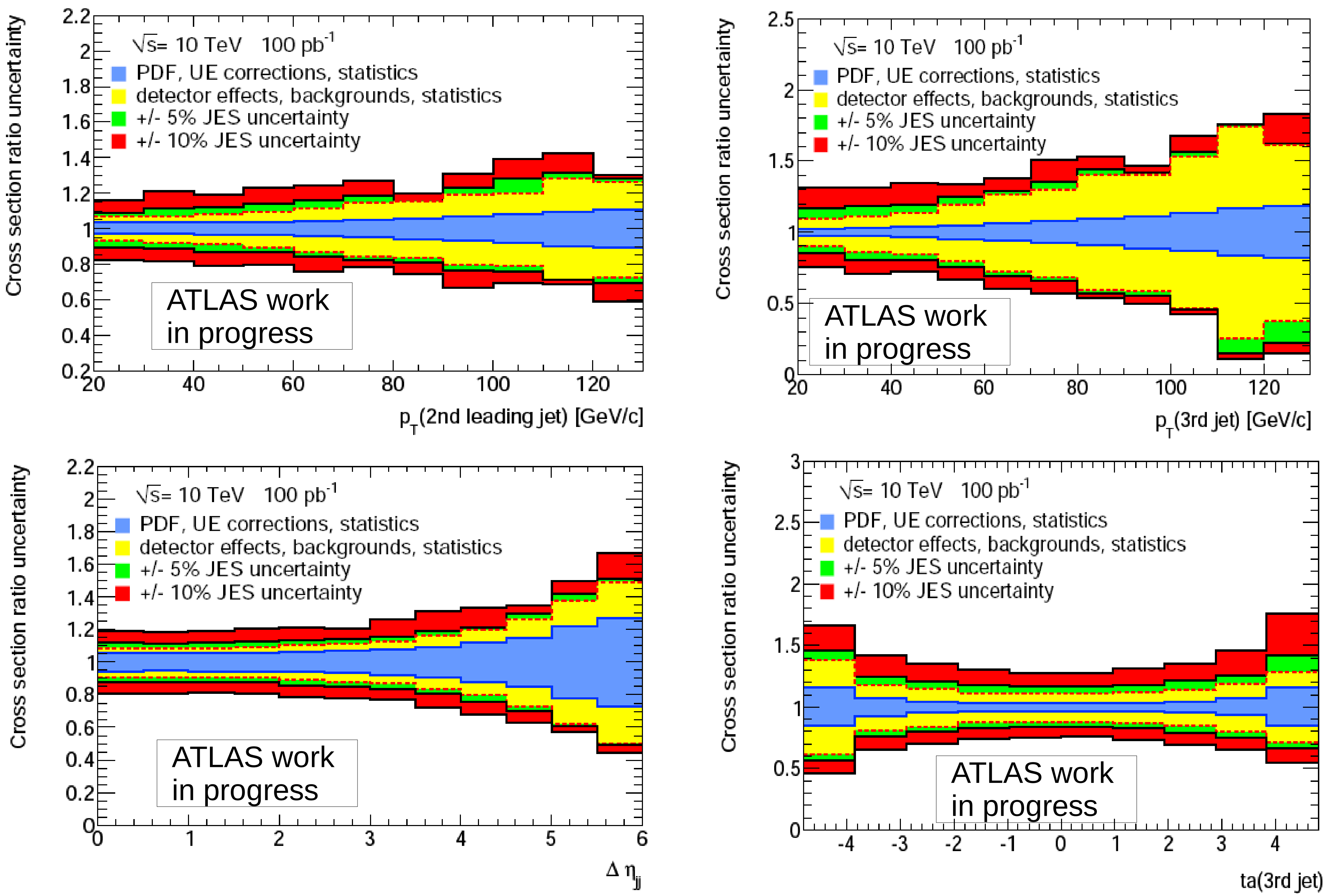




Pseudorapidity gap between tagged jets



Combined Uncertanties



MC generators comparison