Z+jets cross section measurement at ATLAS

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KET LHC-D workshop, 3.-4.6.2008, Zuerich

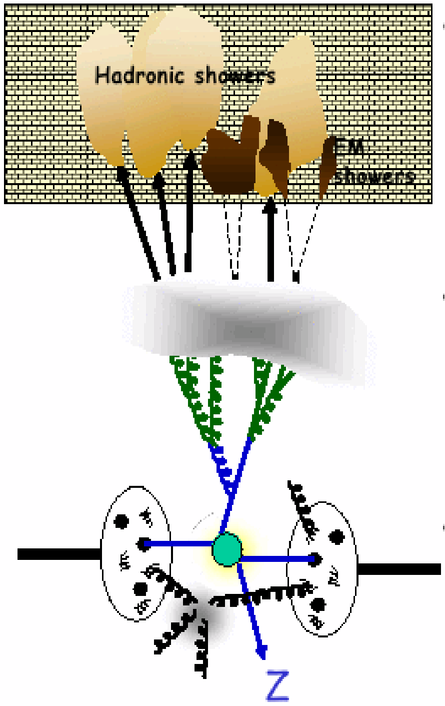
Introduction

- Measurement of the inclusive Z+jets cross section and comparison with QCD predictions
  -> stringent test of perturbative QCD
  -> important backgrounds for searches in ATLAS (Higgs, SUSY, ...)
  Observables: Inclusive jets cross section (Z+ >=N jets)
  Differential cross section (jet PT)

- MC event generator validation (Pythia, Alpgen, Sherpa ...)

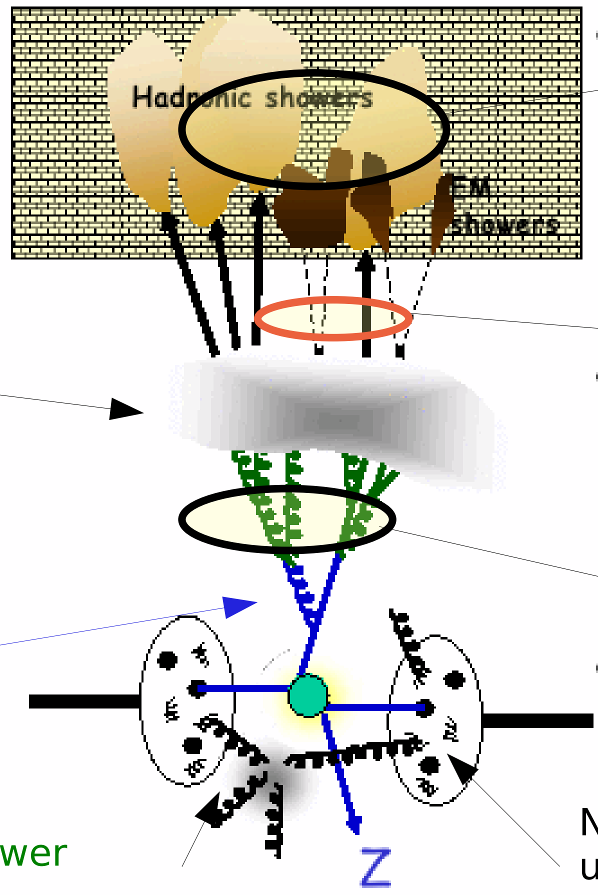
- What can we do now:
  - Generator study: compare predictions of different event generato
    with theoretical predictions
  - Feasability study: use generated signal and background events as
    pseudo data in order to simulate the measurement
    -> Expected precission of the measurement

- Channels: Z->ee+jets, Z->mumu+jets
  More details for Z->ee in this presentation



Comparison of data and MCFM predictions

In order to compare the measured jet cross section with theoretical predictions, both are corrected to the hadron level



Reconstructed objects

Unfold detector effects

hadron(particle)-level)

Correct for non-perturbative effects

Parton Level (~MCFM)

Non-perturbative:
Fragmentation/
Hadronisation:
phenomenological models

Perturbative QCD:
- Hard interaction:
  matrix element
- ISR/FSR:
  - MCFM: full NLO correction
  - Event generator: parton shower

Non-perturbative but universal: PDF measured at HERA etc

Signal and background samples Z->ee

Signal

Signal: > 500 pb-1

- Alpgen+Herwig Z->ee, VBF loose filter

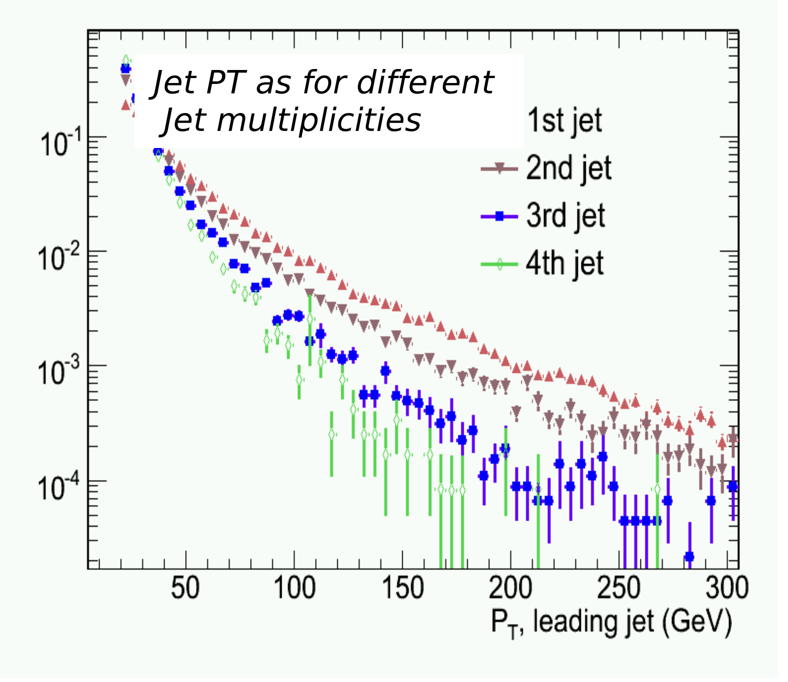
8130:	ZeeNp0,	80000 evts	537 pb-1
8131:	ZeeNp1,	98800 evts	716 pb-1
8132:	ZeeNp2,	96200 evts	1905 pb-1
8133:	ZeeNp3,	49000 evts	3025 pb-1
8134:	ZeeNp4,	46250 evts	10120 pb-1
8135:	ZeeNp5,	16950 evts	10030 pb-1

VBF loose cut:
>=1 Cone04 jet
PT>20GeV, |eta|<5
(only for fullsim)

- 5144: Pythia Z->ee inclusive, 172900 evts, 121pb-1

Background

5568,	Pythia Ttbar,	500000 evts,	625 pb-1
5200,	McatNLO: lep+jets	45650 evts	100 pb-1
5104,	Pythia W->enu,	179900 evts,	16.5 pb-1
5146,	Pythia Z->tautau,	170000 evts,	2208 pb-1
5802,	Pythia JF17: Filtered Dijets,	3012000 evts,	0.004 pb-1



Lepton and Jet ID

Electrons

- Track and Shower-shape requirement ("IsEM medium")
- trigger-level isolation for at least one electron
- PT>25 GeV
- |eta| <2.4, cracks excluded: [1.37-1.52]

Muons

- Inner detector and Muon chambers ("Staco" algorithm)
- Isolation: cone20, E_T< 15GeV
- 0.1<|eta|<1.2, 1.3<|eta|<2.4
- P_T > 15 GeV

Jet selection

- Z->ee: Tower jet, Seeded Cone 0.4
  Z->mumu: Cluster jet, Seeded Cone 0.4
- Lepton veto (ΔR < 0.4)
- P_T > 40 GeV
- |eta| < 3.0

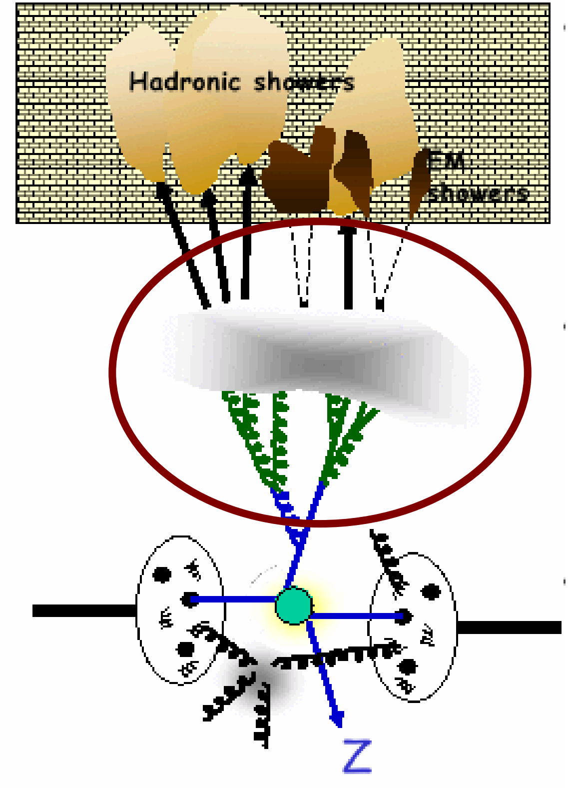
Z event selection

- Invariant mass [91+- 10]GeV
- ΔR(electrons) > 0.2
- Z->ee: Event passes OR of e25i and 2e15i trigger

I: From Parton to Hadron level

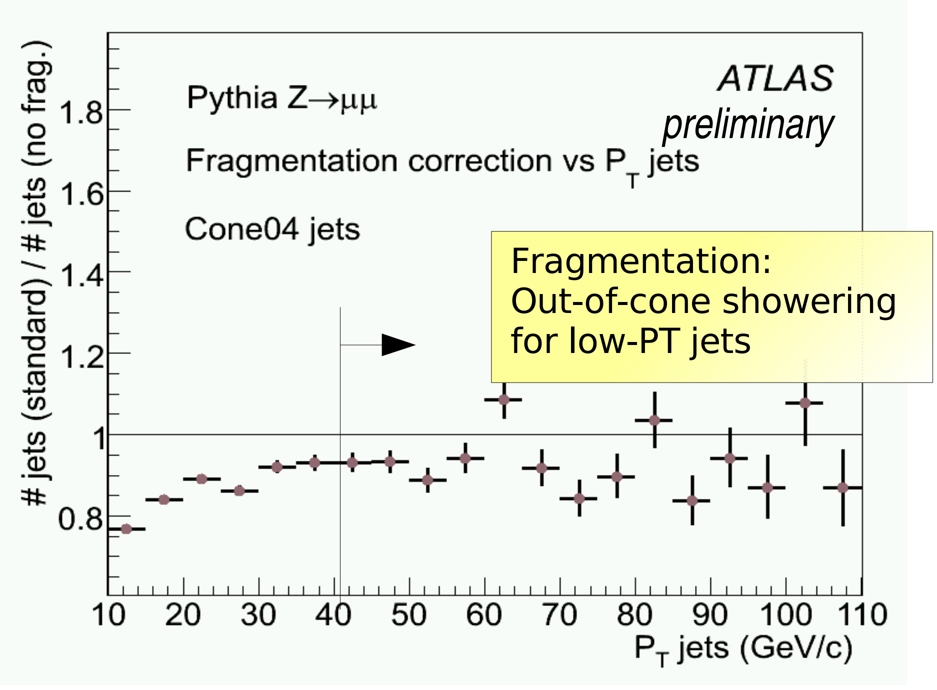
Non-perturbative processes:

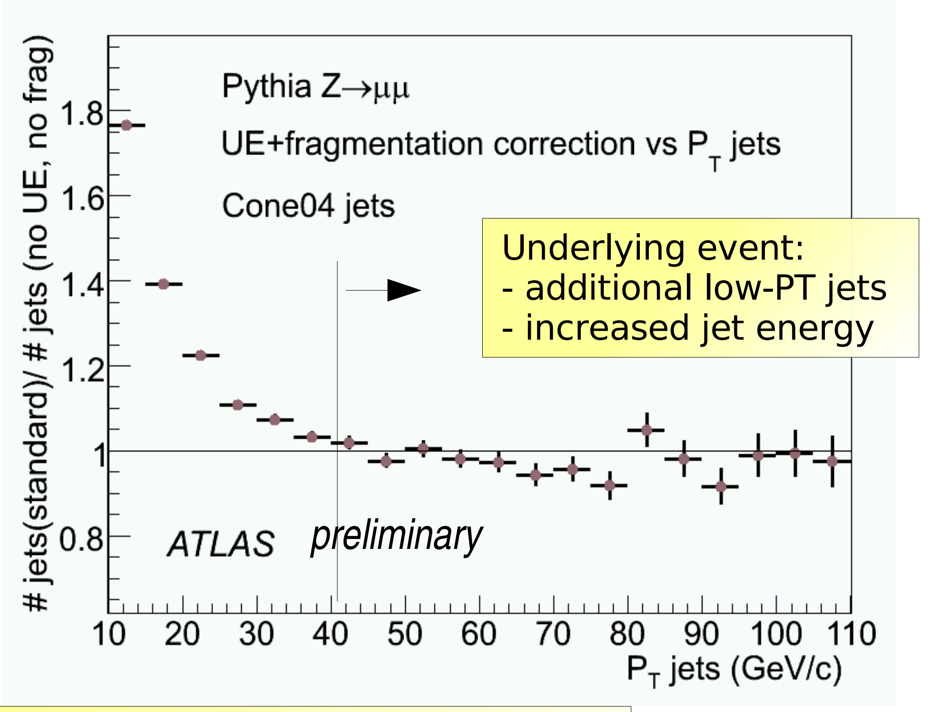
- Fragmentation
- Underlying event



Corrections for fragmentation and UE+frag

- Generated Z->mumu:
  (1) standard UE tuning (ATLAS tune, similar to Tune A), Pythia 6.403
  (2) “ No UE”: MultipleParticle Interactions switched off (MSTP 81 = 20)
  (3) “ no Fragmentation”: Fragmentation master switch (MSTJ(1)=0 in pydat1)





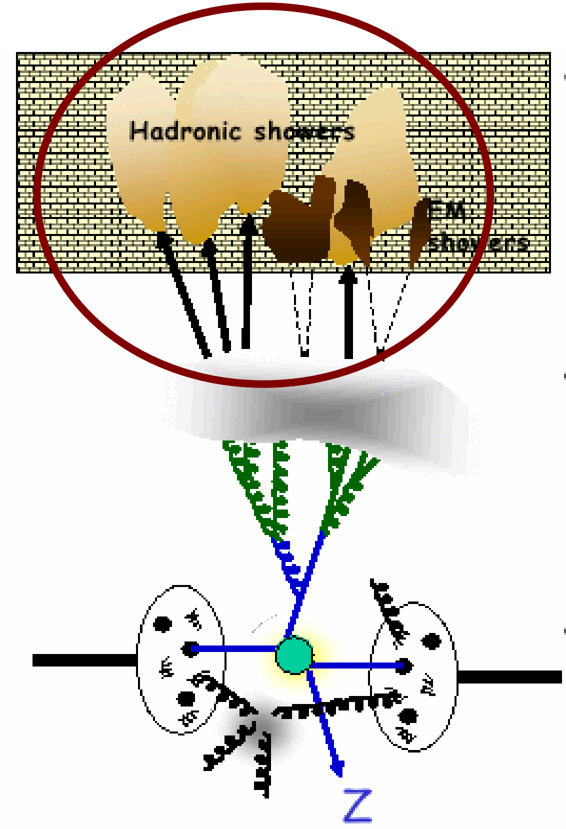
-> Corrections small for jet P_T > 40 GeV
-> from lack of statistics: apply global residual correction for P_T > 40 GeV
as a function of the jet multiplicity

II: Reconstructed data: unfolding to hadron level

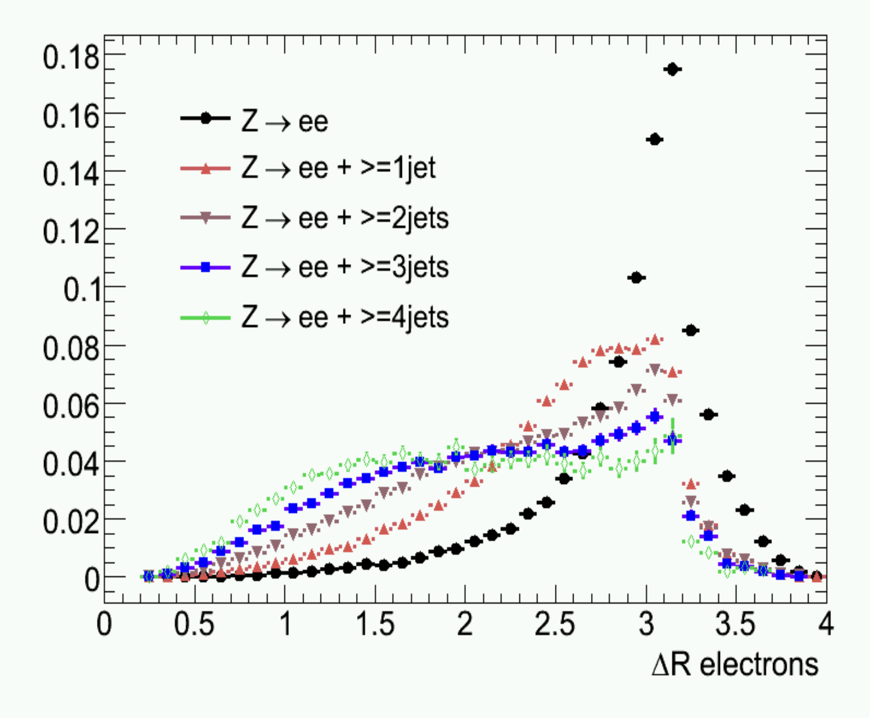
<u>Unfolding corrections:</u>

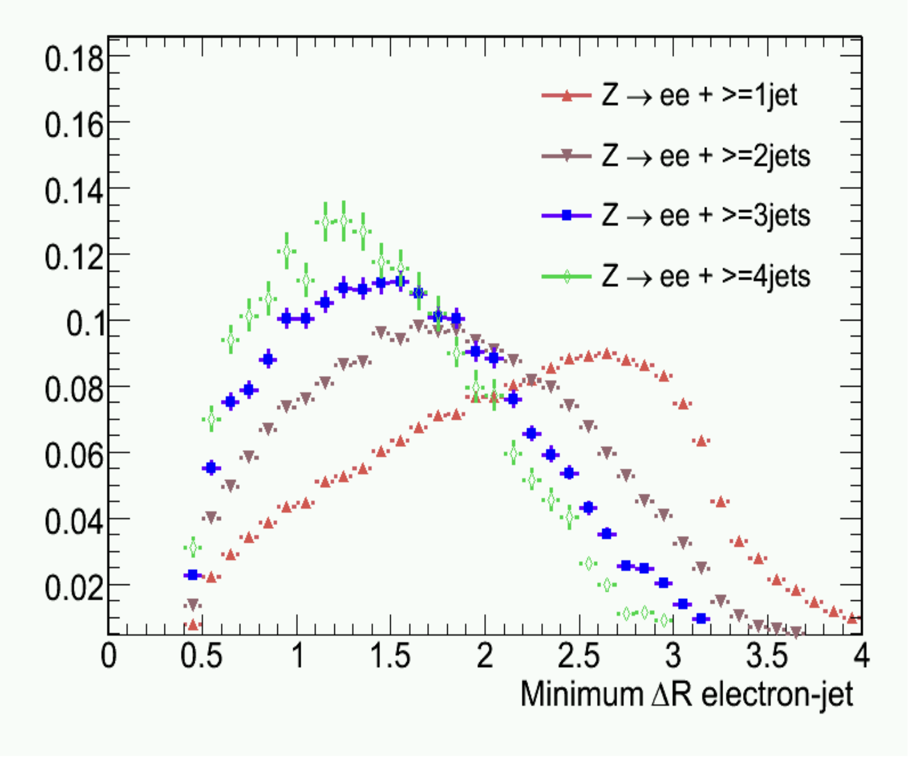
- Discarding the cracks
- Background fraction, in particular QCD
- Electron reco efficiency
- Electron resolution

- Jet reco efficiency
- Jet energy scale
- Jet resolution



Electron reconstruction in high-multiplicity events

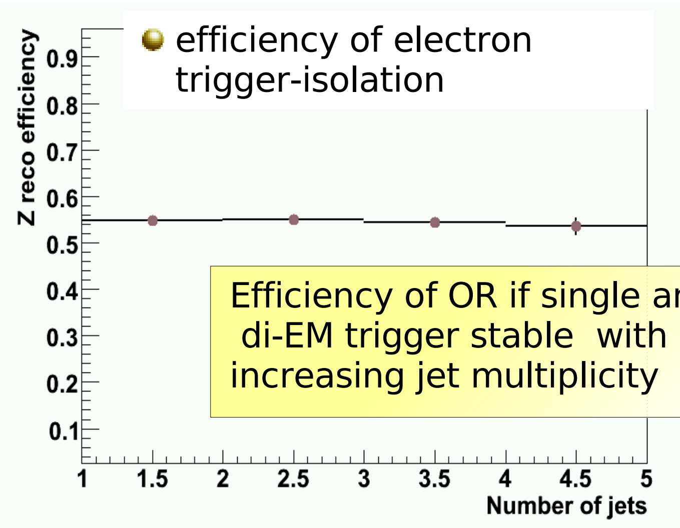




DR between electrons and between electrons and jets becomes smaller with increasing jet multiplicity
-> bias in trigger and reco efficiency ?

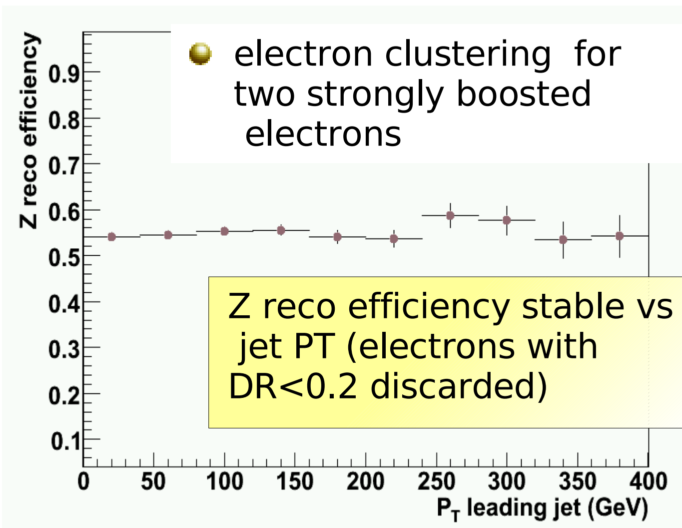
Isolation and shower shape in high-multiplicity events

- efficiency of electron trigger-isolation



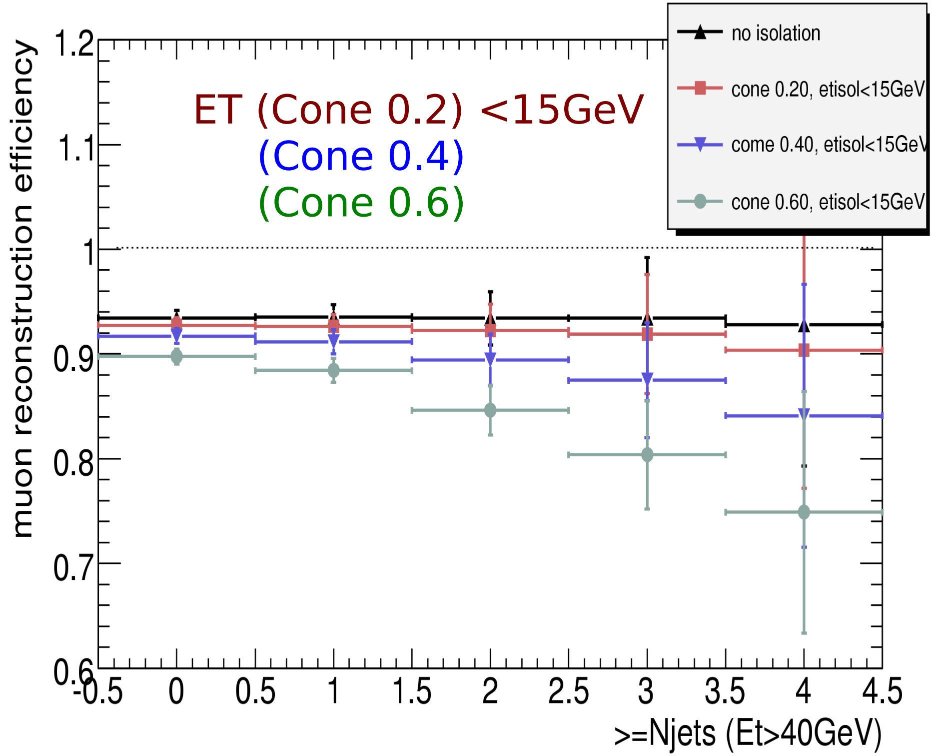
Efficiency of OR if single and di-EM trigger stable with increasing jet multiplicity

- electron clustering for two strongly boosted electrons



Z reco efficiency stable vs jet PT (electrons with DR<0.2 discarded)

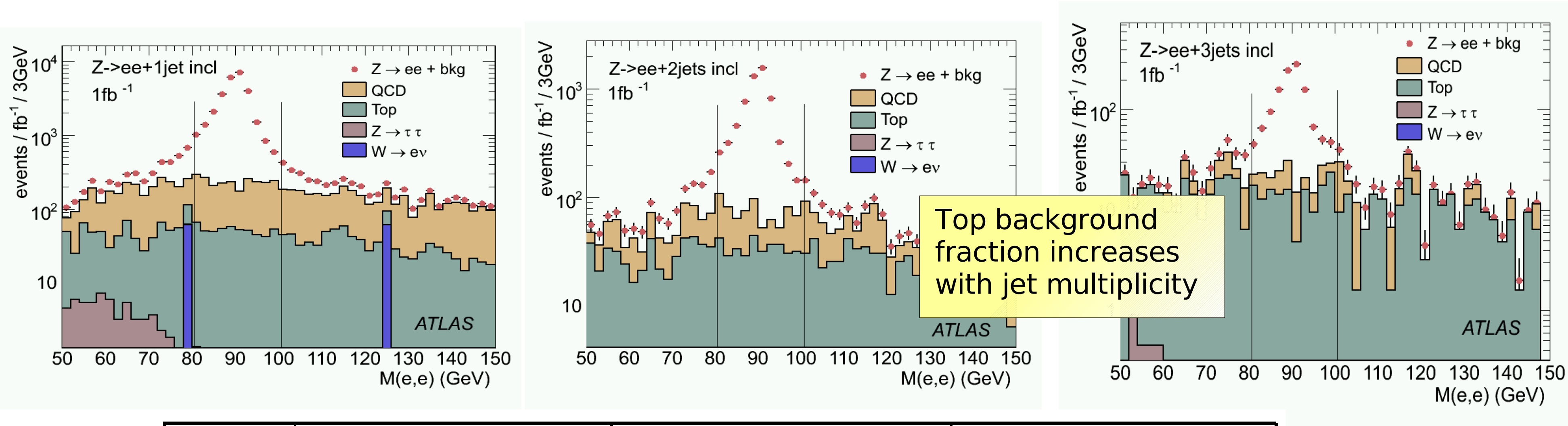
- Muon reco efficiency vs jet multiplicity for different isolation criteria



Efficiency for Muon Calorimeter Isolation in Cone 0.2 is stable

Z->ee: Signal and background for 1 fb-1

- ID: isEM medium + trigger, Alpgen, official normalization , LO cross sections



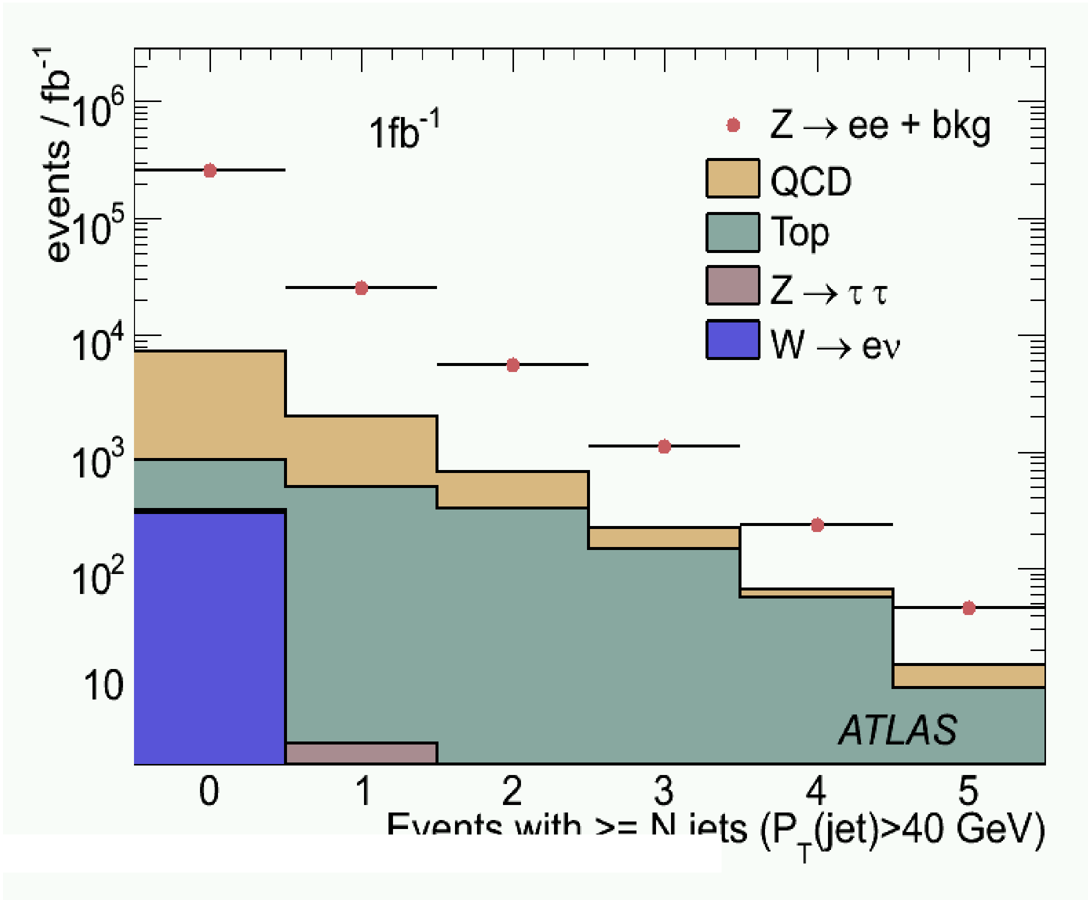
Top background fraction increases with jet multiplicity

Process	$Z \to ee + \geq 1$jet xsec $[fb]$	$Z \to ee + \geq 1$jet fraction $[\%]$	$Z \to ee + \geq 2$jets xsec $[fb]$	$Z \to ee + \geq 2$jets fraction $[\%]$	$Z \to ee + \geq 3$jets xsec $[fb]$	$Z \to ee + \geq 3$jets fraction $[\%]$
$Z \to ee$	23520±145	91.9±0.8	4894±45	87.9±1.3	900±15	80.0±2.4
QCD jets	1545±89	6.0±0.4	336±42	6.0±0.8	78±20	6.9±1.8
$t\bar{t}$	496±28	1.9±0.1	333±23	6.0±0.4	146±15	13.0±1.4
$Z \to \tau\tau$	3.2±1.2	0.01±0.005	(0.67±0.25)	(0.01±0.005)	(0.1±0.05)	(0.01±0.005)
$W \to e\nu$	(28±13)	(0.1±0.05)	(5.9±2.6)	(0.1±0.05)	(1.1±0.5)	(0.1±0.05)

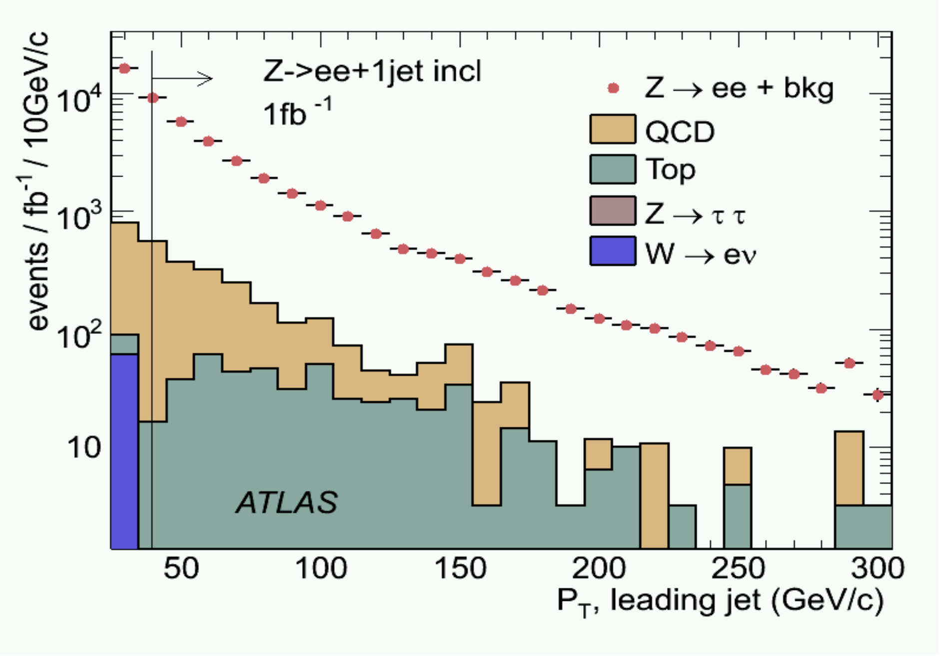
Efficiency of Z->ee reconstruction ~33% for all jet multiplicities considered

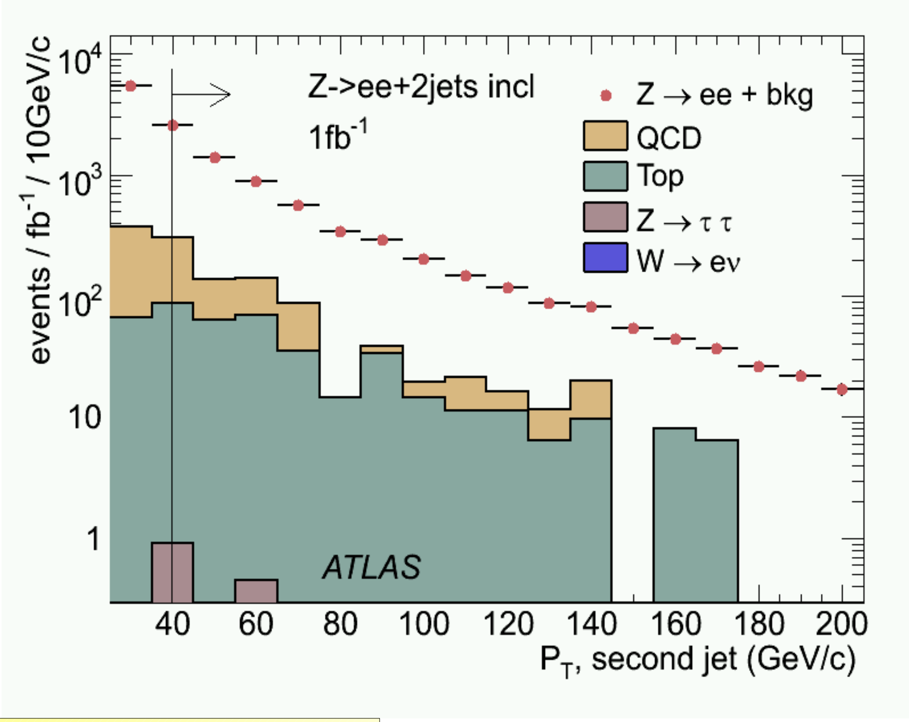
Z->ee: Observables (all selection cuts applied)

- Use Pythia sample for inclusive cross section, Alpgen samples for Z+ >= 1 jet



Z->ee: Observables (all selection cuts applied)





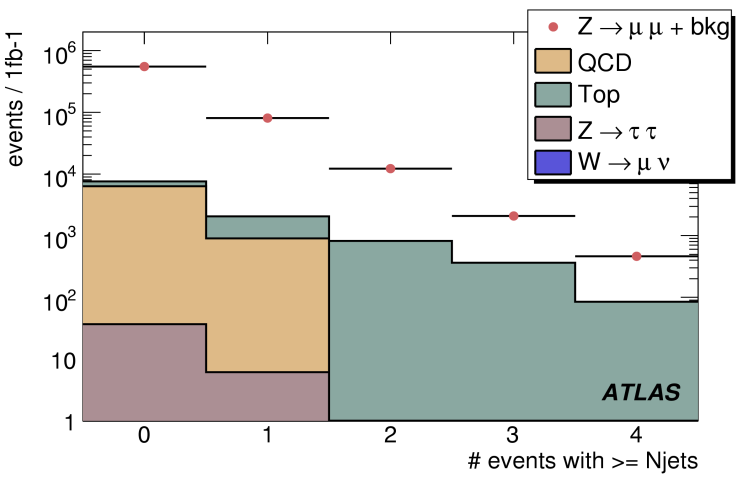
Ttbar distributions different from signal distributions -> Important to understand Top production at ATLAS

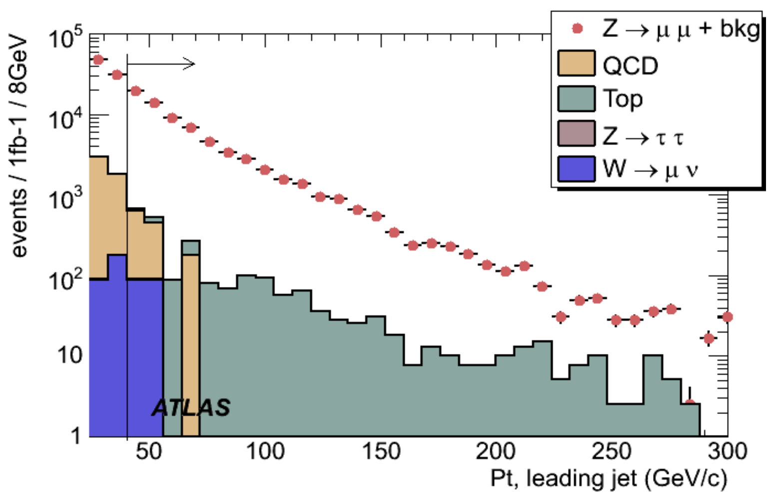
Signal-free regions:

- e+mu events
- events with large Missing ET

Z->$\mu\mu$: Signal and background: Pythia vs. Alpgen

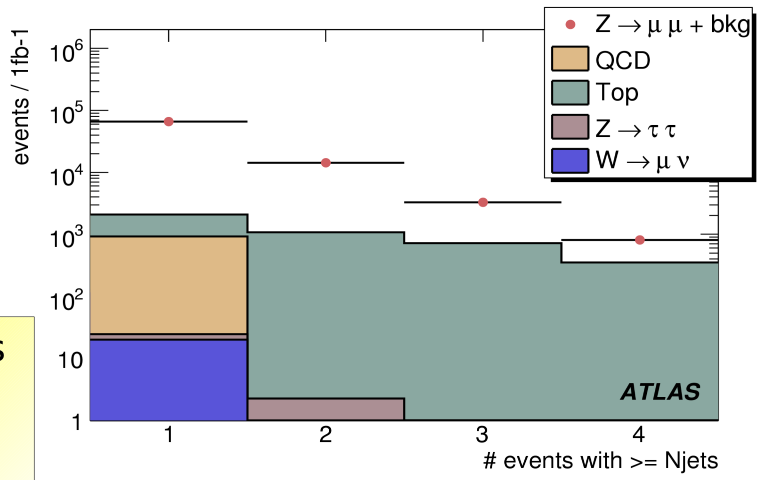
- **Pythia**

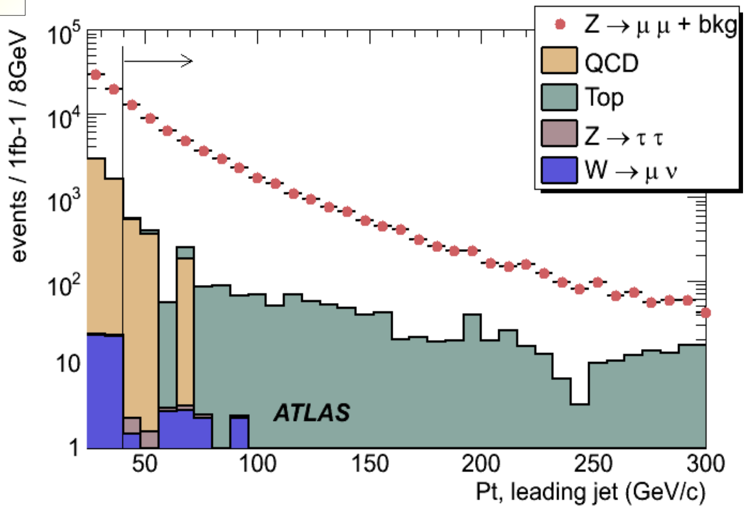




Alpgen predicts more Ttbar background then Pythia for Z + >= 3 jets

- **Alpgen**



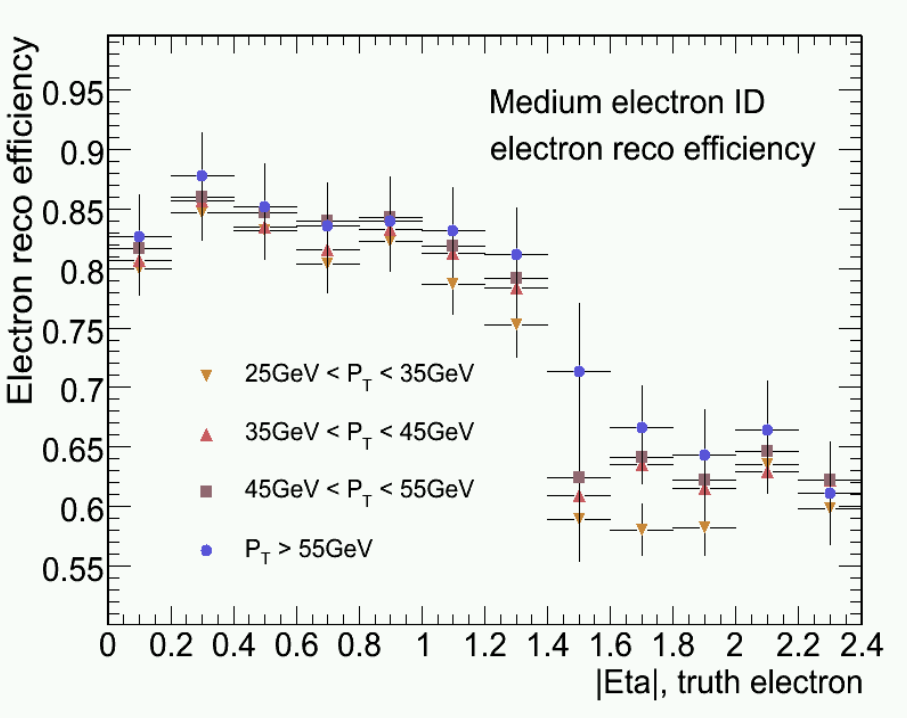


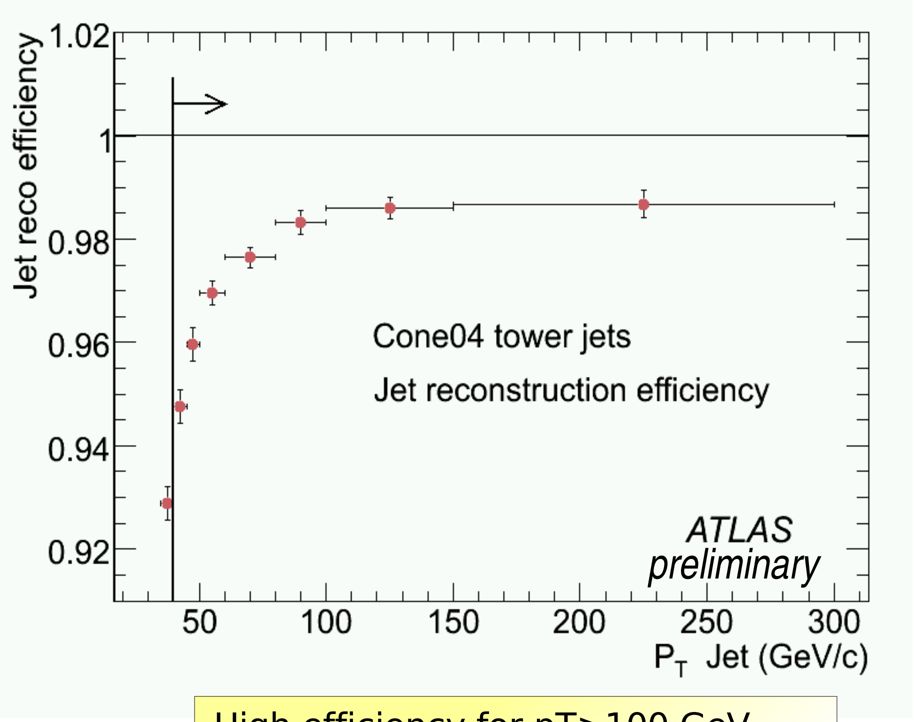
Unfolding to the truth level

Unfolding

- Electron reco efficiency as a function of Eta for different PT

- Jet reco efficiency as a function of PT



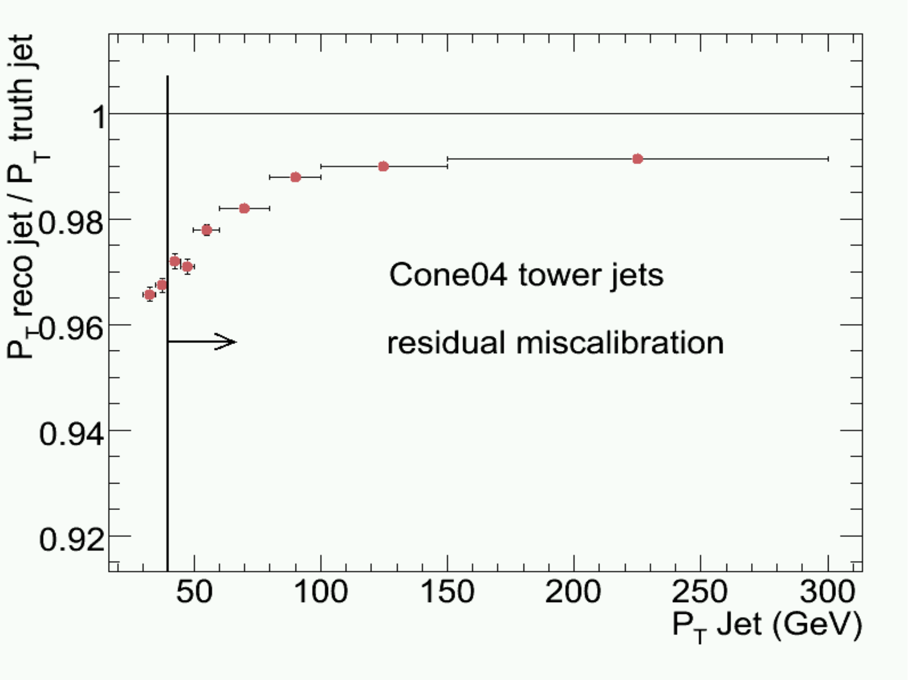


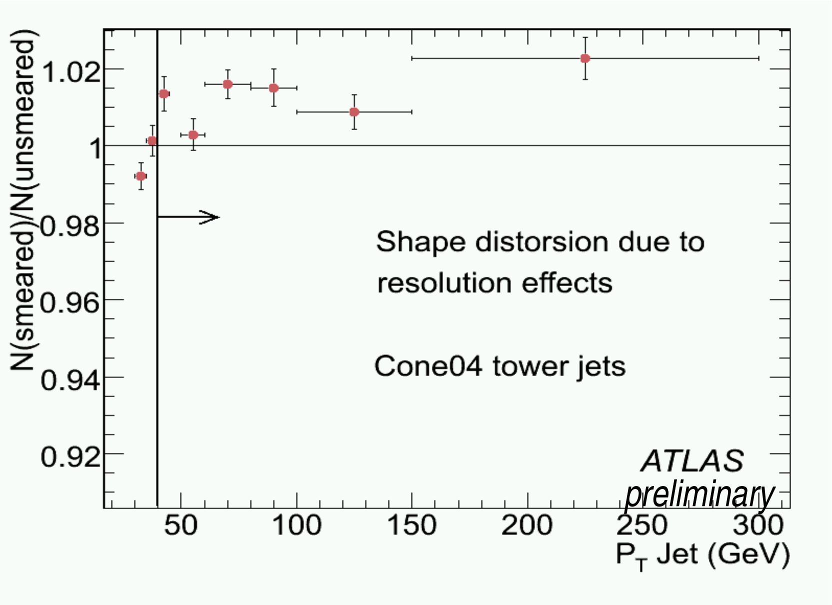
High efficiency for pT>100 GeV

- + overall trigger efficiency vs offline: Z->ee: 99.63+- 0.11%

JES and Jet reco efficiency: Cone04 tower jets

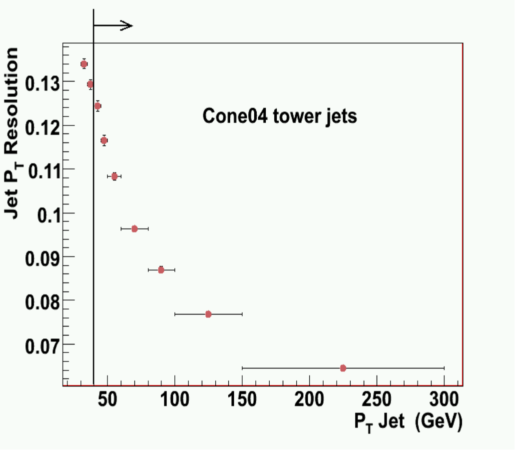
- Calculate Non-linearity and Resolution from PT(reco)/PT(truth) of matched jets
- Use 10 bins in PT with similar number of events





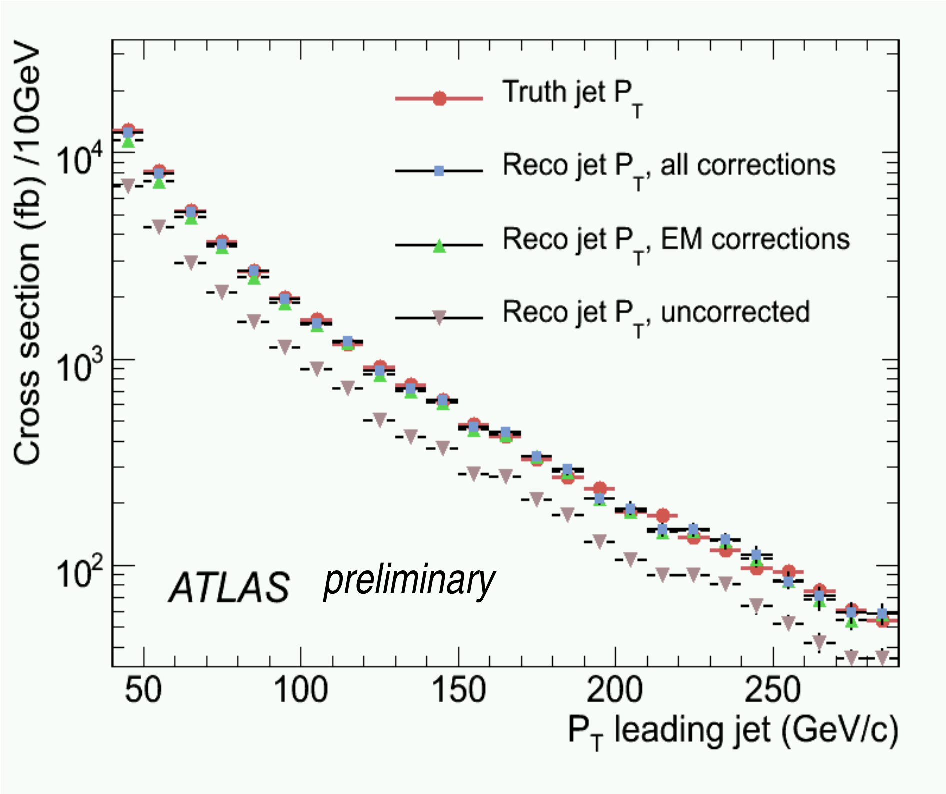
JES: Non-linearity at low PT(jet):
out-of-cone showering
up to 3% correction.

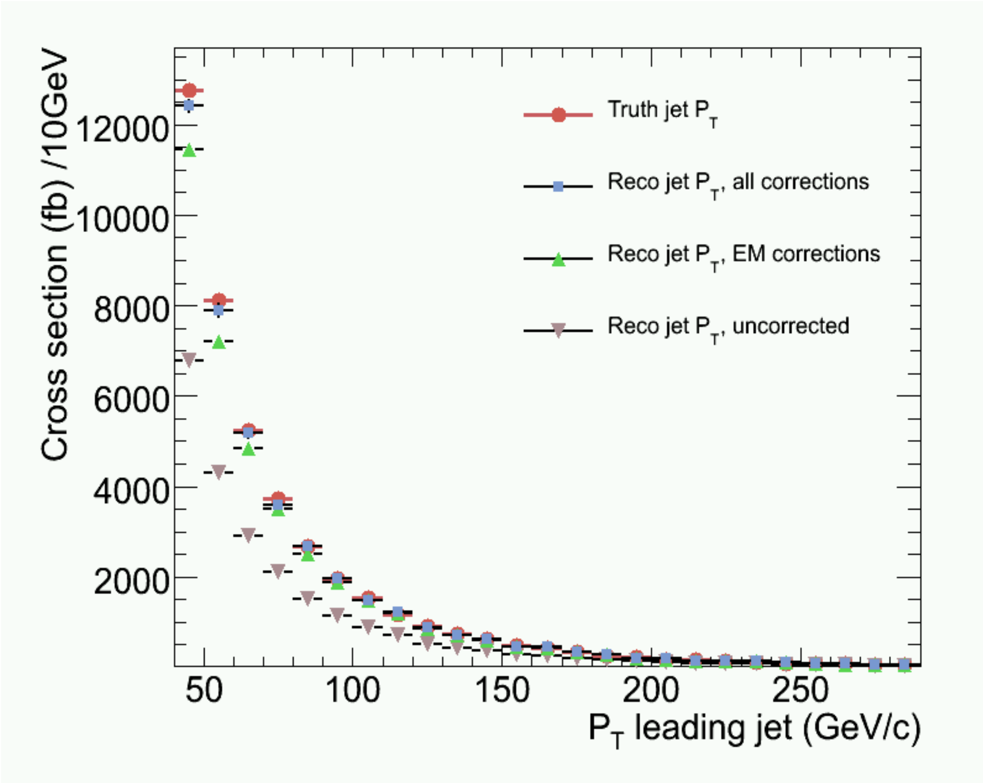
Increased number of jets by 1-2% (large statistical error)



- uncertainty on the PT distribution: < 1.5% error on the cross section
- uncertainty on the resolution: < 2-4% error on the cross section.

Validation of jet unfolding

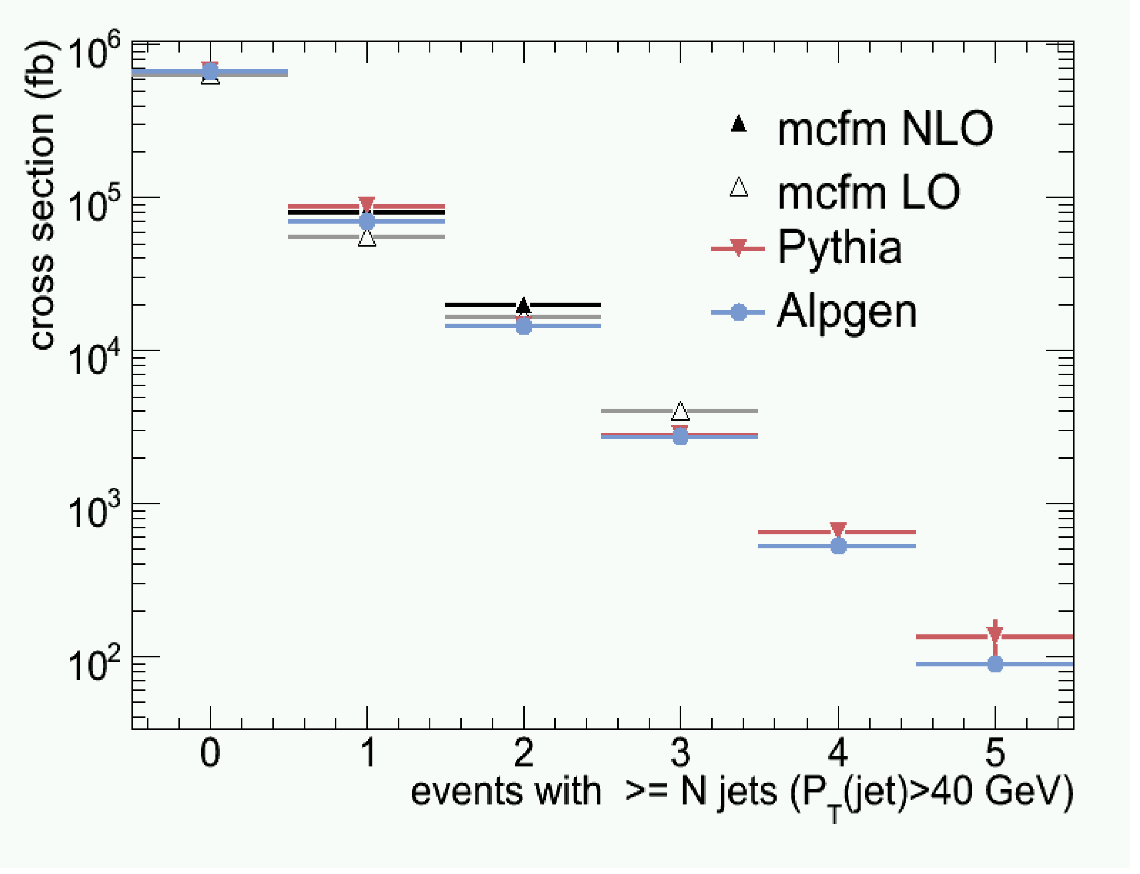




Dominant correction from Elecron reco efficiency
Jet corrections at Low PT(jet)

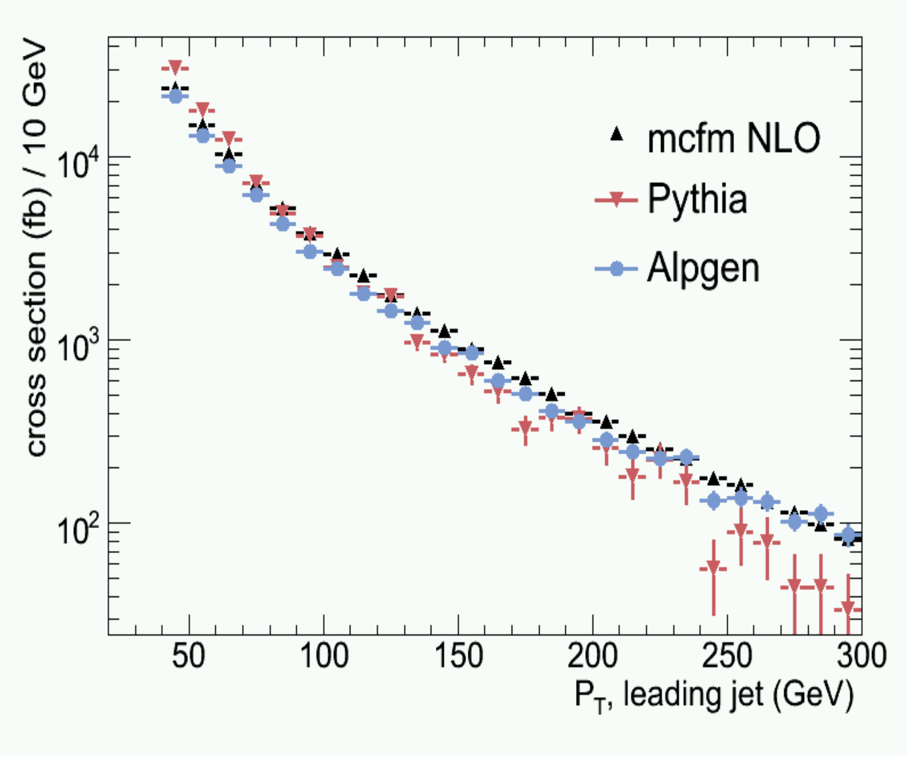
Comparison of Alpgen/Pythia and MCFM

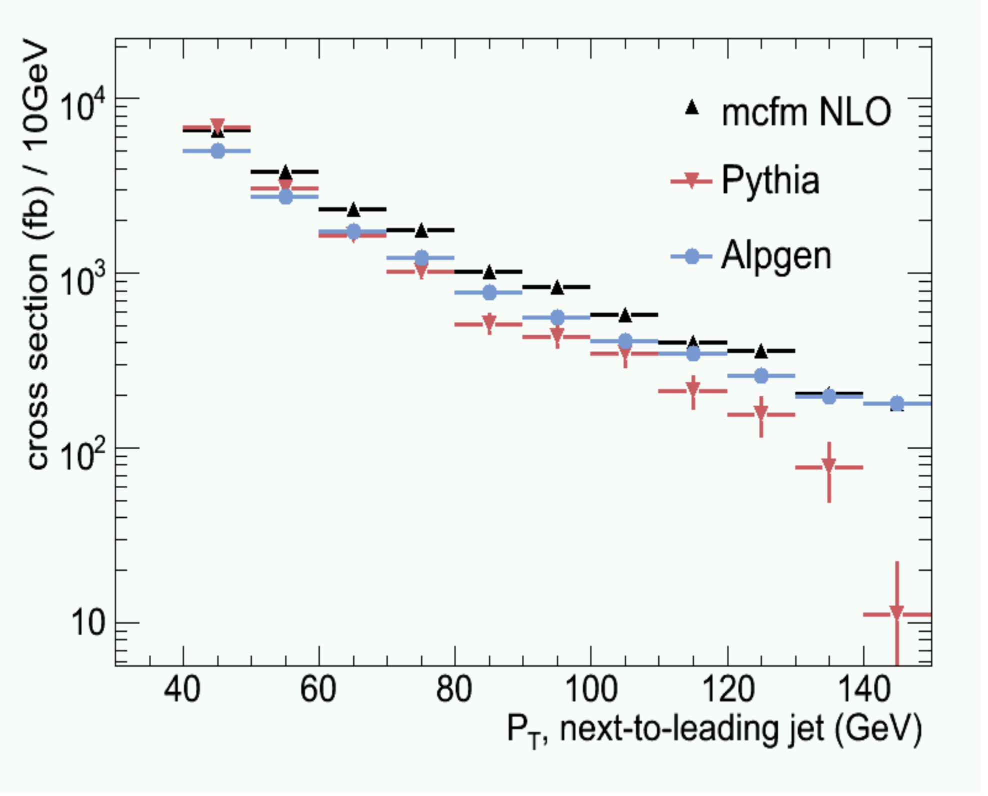
- Compare Generators at hadron level with MCFM corrected to hadron level
- Global normalization of Pythia and Alpgen data to the NLO inclusive cross section
- Pythia/Alpgen: statistical errors
- MCFM: PDF, residual fragmentation



Both Pythia and Alpgen predict lower jet multiplicities than even LO MCFM

Comparison of Alpgen/Pythia and MCFM

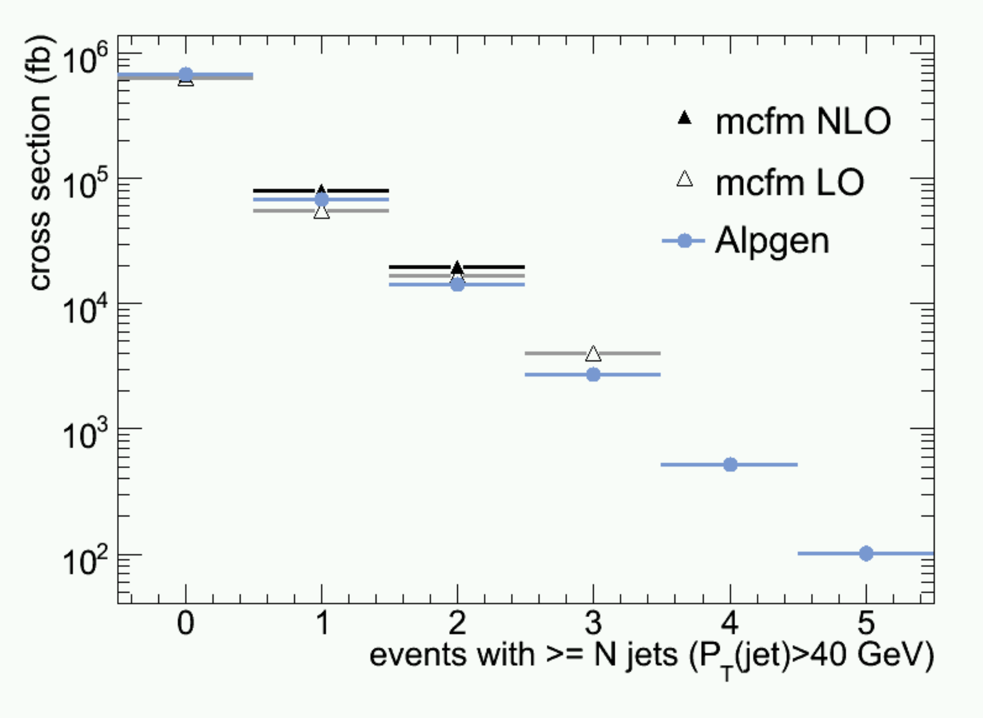


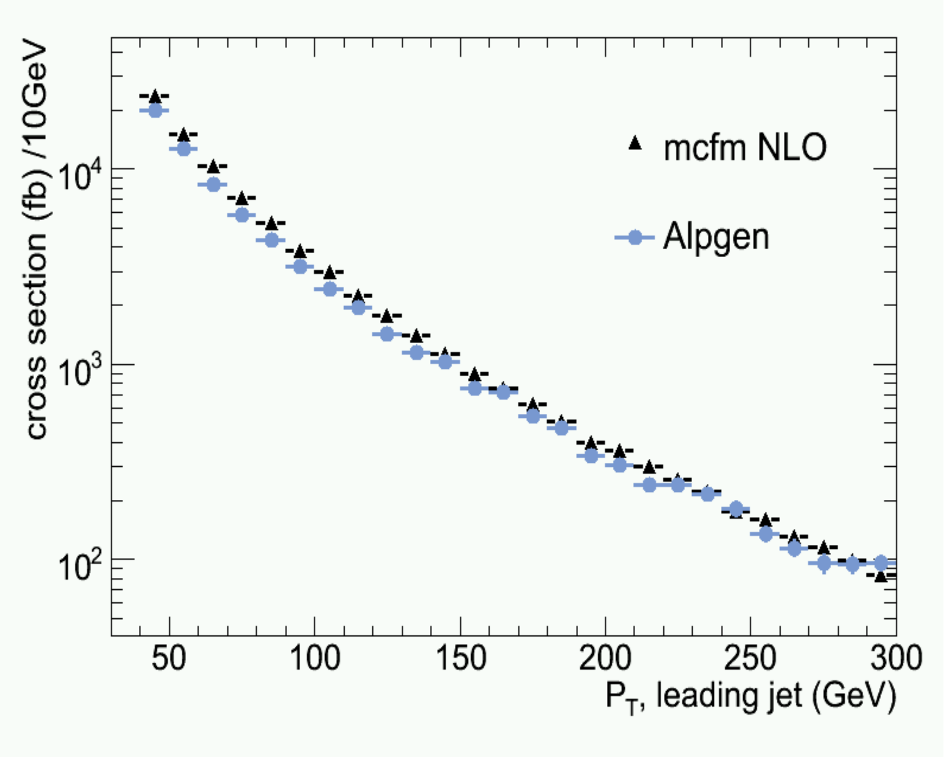


Pythia Parton Shower jets are softer than
Alpgen Matrix Element jets, as expected

Comparison of Reco and MCFM

- All corrections applied to reconstruced signal
- global normalization of Alpgen
- Compare jet observables with MCFM predictions
- Errors scaled to uncertainty expected from data (1fb-1): Statistics, background subtraction, JES uncertainty (3%) etc. (see next slide)



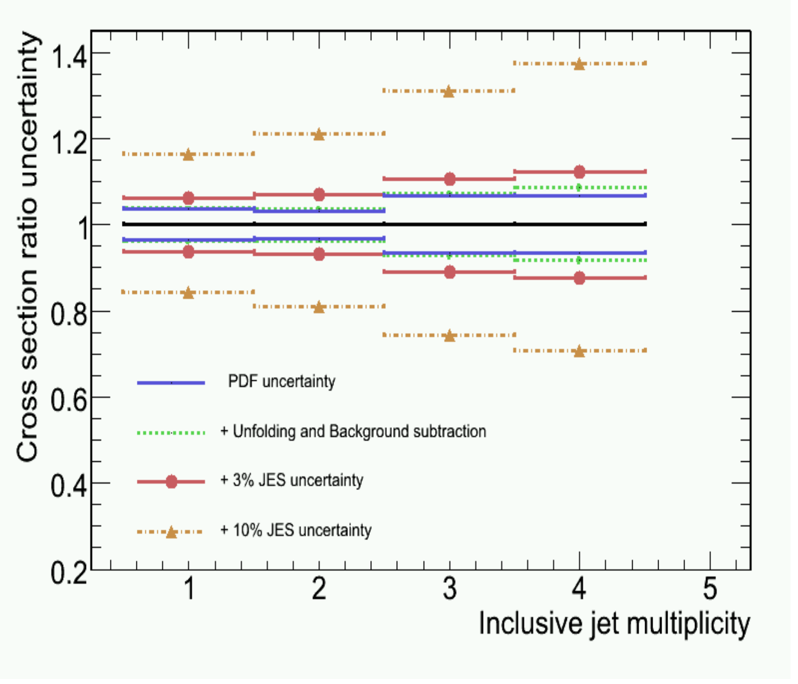


Expected uncertainties for data/Theory

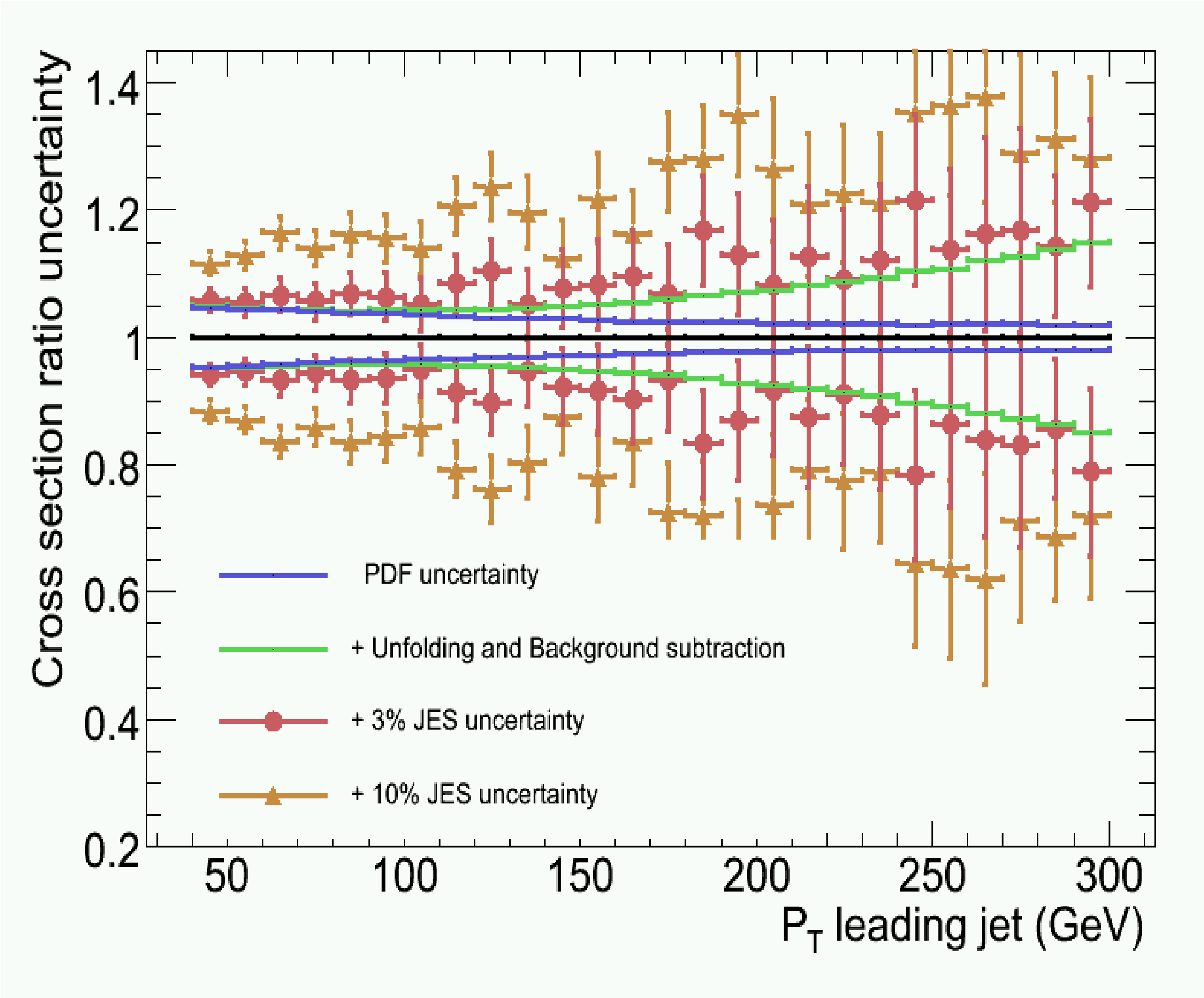
- **Error on JES:** largest contribution: compare 1% - 3% - 10%, see plots
- **PDF uncertainties:** contributions from complete set of error functions
- **QCD background:** assume 20% uncertainty: Z->ee+jets: 1-2% error on the cross section
- **Electron reco efficiency:** 1% (not relevant if relating to the inclusive cross section)
- **Statistical error:** only relevant for large PT/jets) and large jet multiplicities

<u>Not included in the plot:</u>

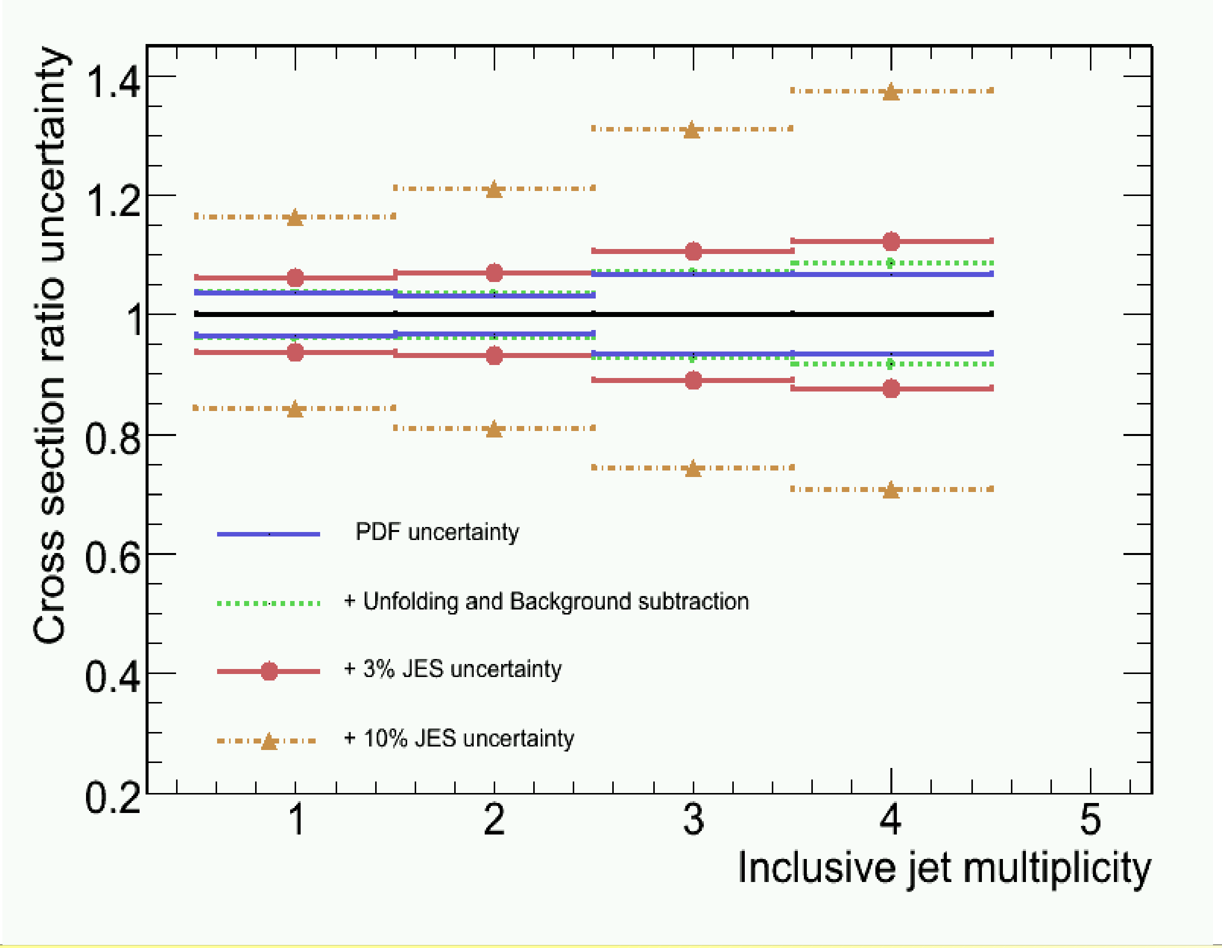
- Error from uncertainty on the **PT distribution** (percentage level)
- Error from uncertainty on the **jet resolution** (percentage level)
- Uncertainty on the **Ttbar background**: developing data driven methods
- **Integrated luminosity**: not relevant if relating to inclusive cross section



Expected uncertainties for data/Theory: PT leading jet



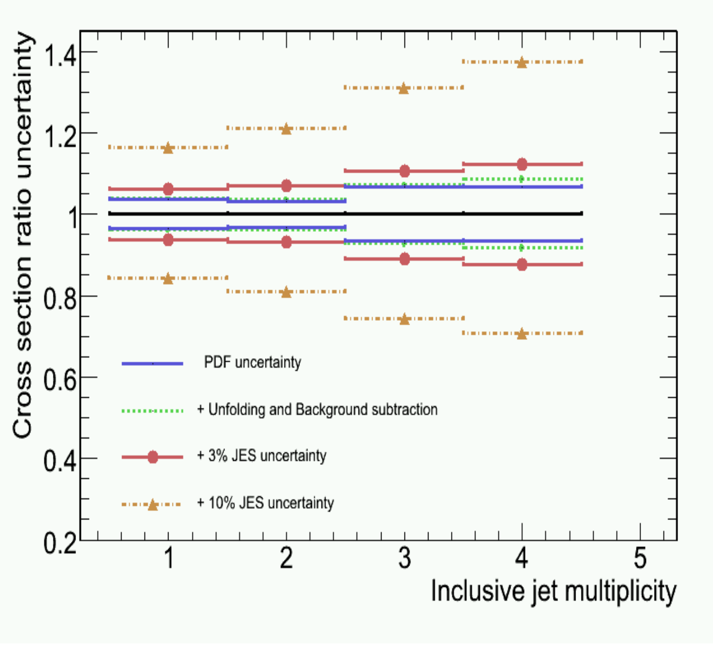
Expected uncertainties for data/Theory: PT leading jet



With an error of 3% (10%) on the JES scale we expect an uncertainty of 5-10% (20-30%) on the cross section measurements
-> with 10% JES scale uncertainty we cannot even distinguish between LO and NLO predictions

Summary

- Using fully simulated MC for Signal and background processes we have performed a feasibility study for the measurement of the Z+jets inclusive and differential cross section at ATLAS with data corresponding to 1fb-1
- The expected total uncertainty is at the level of 5-10% (20-30%) for Jet Energy Scale uncertainties of 3% (10%)
- Differences in the predictions from Pythia, Alpgen and Theory predictions specified: Pythia and Alpgen predictions have to be validated (and retuned) with the data
- Developing data driven methods to assess the most important background sources: Multi-jet and Top production



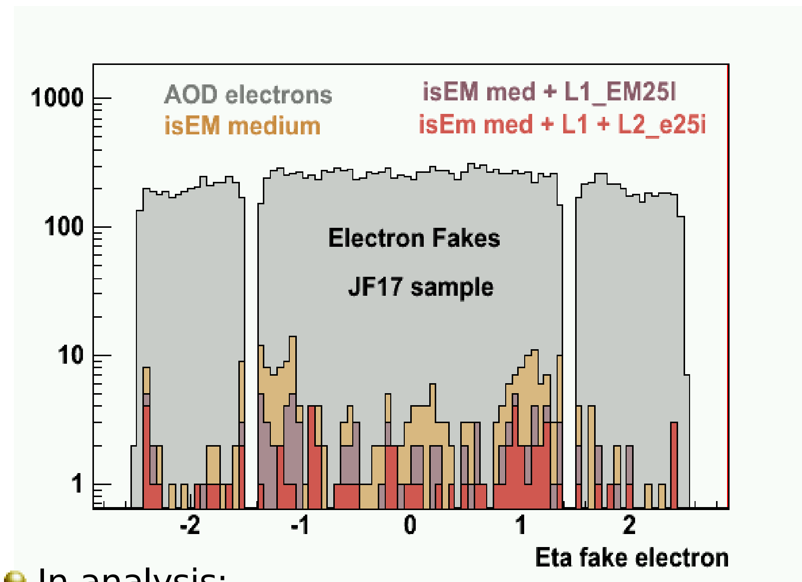
backup

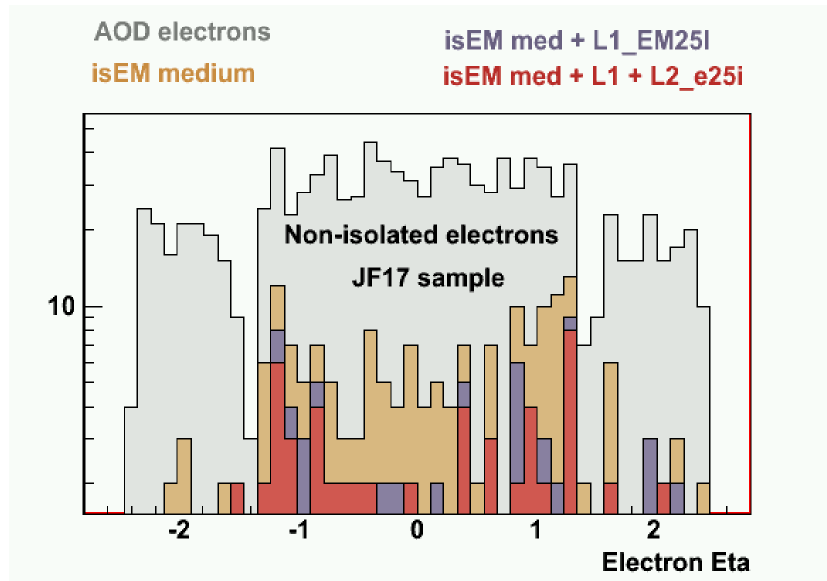
Simulating QCD background for Z->ee+jets

- Sample JF17: filtered Pythia dijets: 3Mio evts

  trig1_misal1_mc12_V1.005802.JF17_pythia_jet_filter.recon.AOD.v12000601
  - discard events with W,Z or Ttbar
  - subsamples:
    - 1) discard reco electrons matched with truth electrons
    - 2) select reco electrons matched with truth electrons
  - Select events with one AOD electron, PT>25, fiducial eta region
  - consider only leading fake electron: apply electron ID and trigger cuts (use single-electron trigger to calculate efficiency for di-electron trigger)

- ...In Collisions: estimate QCD background from data:
  - fit mass shape
  - invert ID cuts

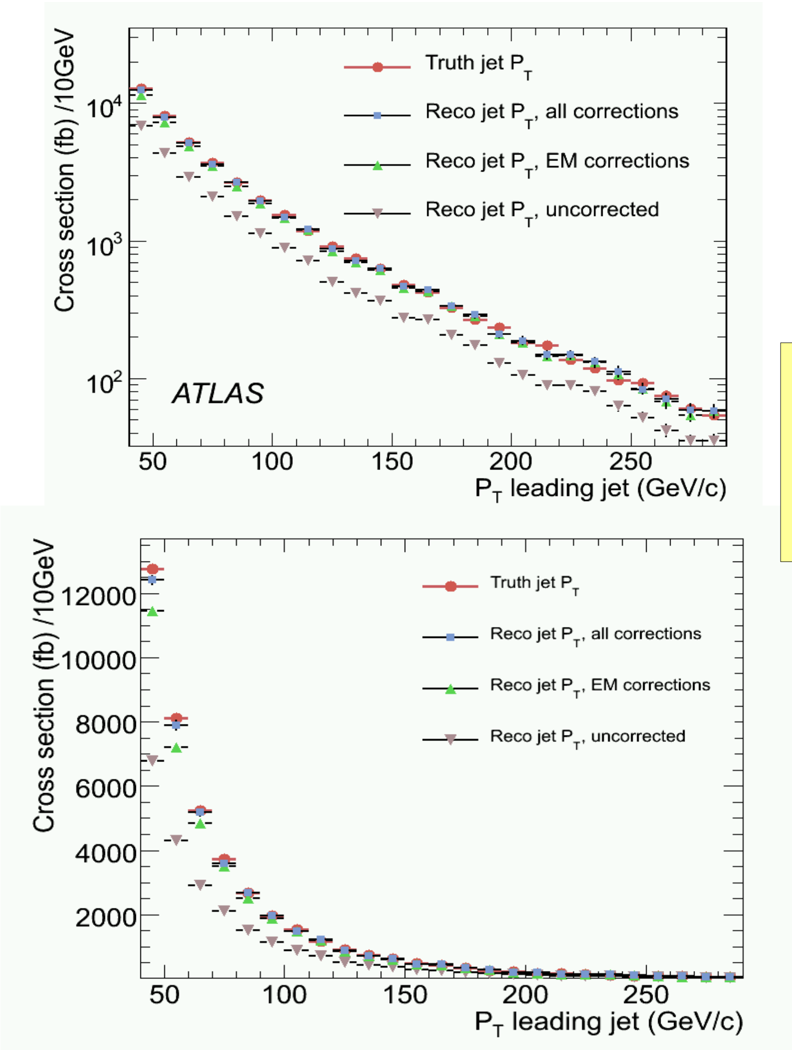




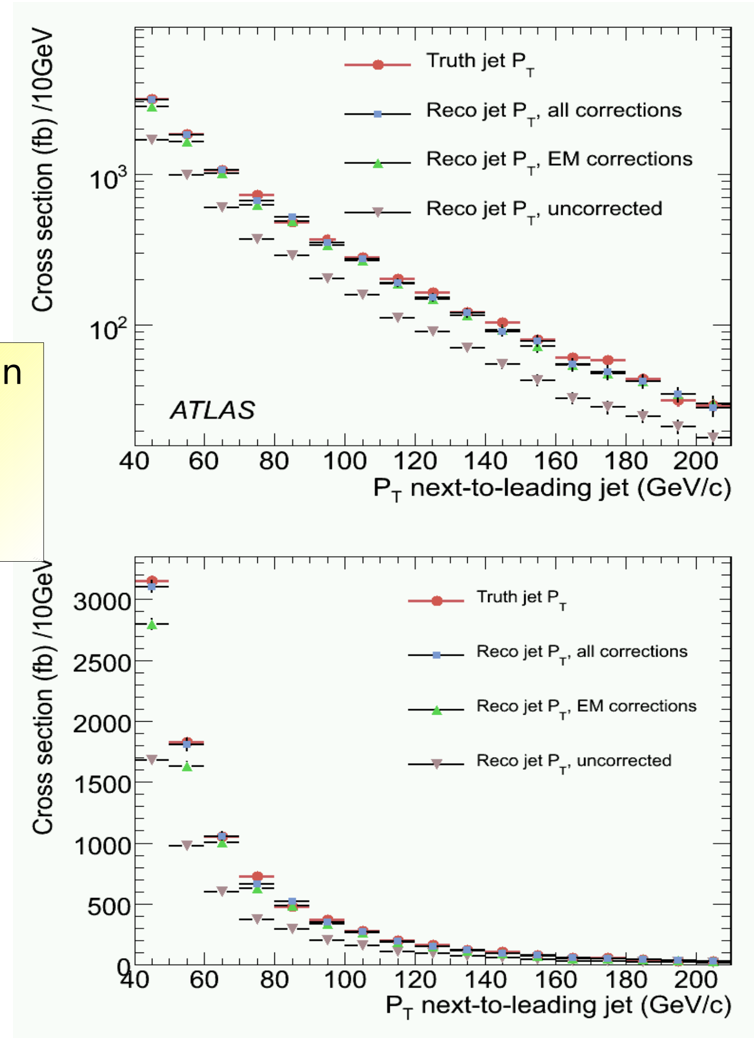
- In analysis:
  - Use all events with two AOD electron fakes
  - require the events to pass only the kinematic cuts
  - weight both electrons with ID/trigger rejection from single electrons

Validation of jet unfolding

PT leading jet



PT next-to-leading jet



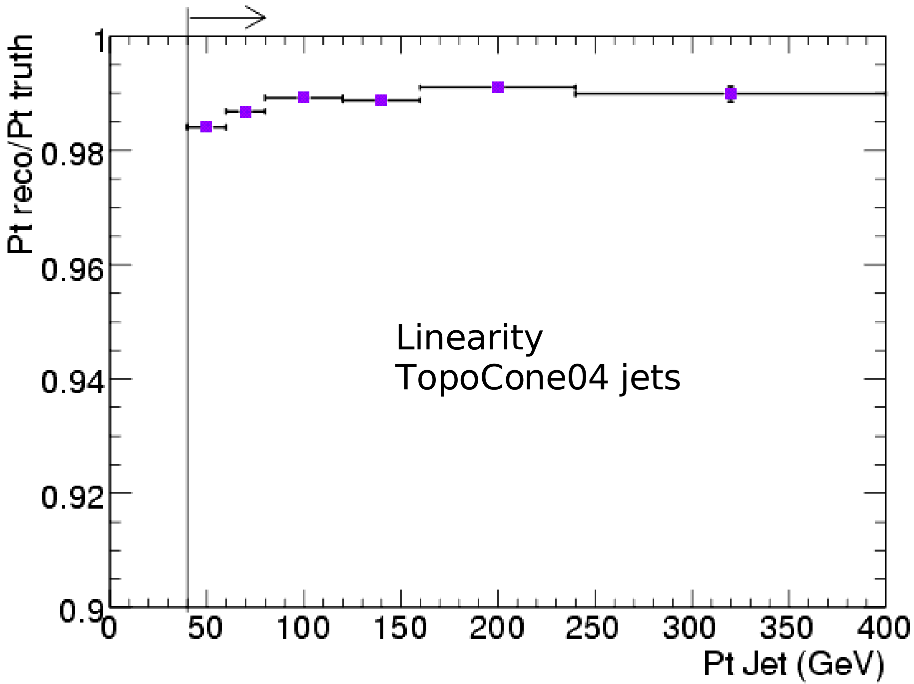
Dominant correction from Elecron reco efficiency
Jet corrections at Low PT(jet)

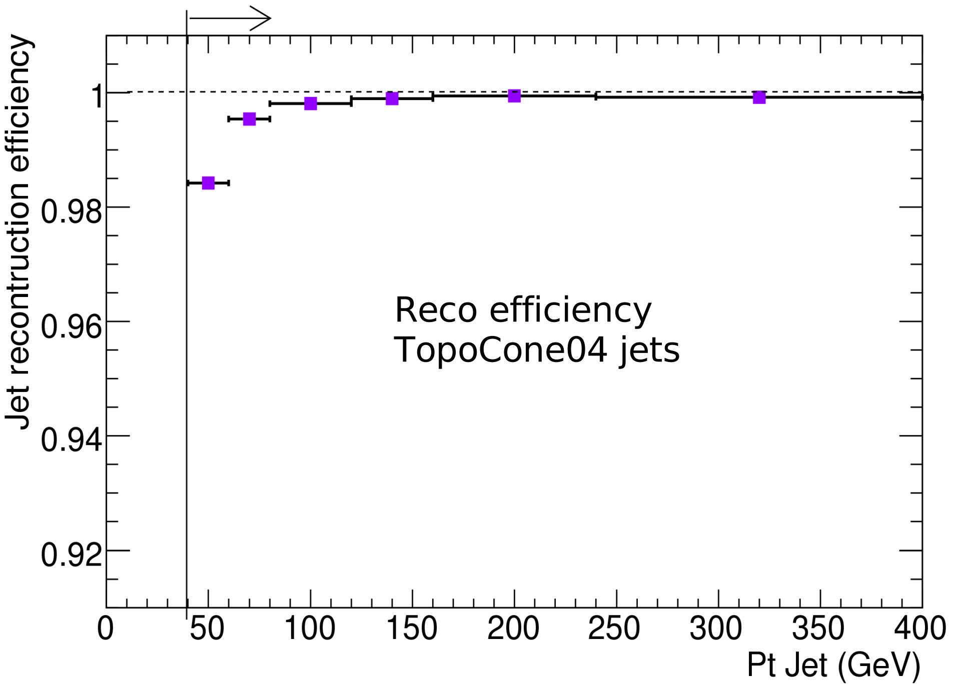
Signal and background samples Z->mumu

Sample	Process	events	$\int L dt$	generation	reconstruction
Pythia					
5145	$Z \to \mu\mu$	160000	120	11.0.4	12.0.6.1
5105	$W \to \mu\nu$	45000	5.5	11.0.4	12.0.6.1
17506	$QCD(bb(\mu\mu))$	123000	1.1	12.0.3	12.0.6.2
5568	$t\bar{t}$	75000	94	12.0.3	12.0.7.1
5904	$Z \to \tau\tau$	38000	9800	11.0.5	12.0.6.1
Alpgen+Herwig					
8142	$Z \to \mu\mu$ + 0partons	26000	525	12.0.5	12.0.6.4
8143	$Z \to \mu\mu$ + 1partons	50000	360	12.0.5	12.0.6.4
8144	$Z \to \mu\mu$ + 2partons	21000	400	12.0.5	12.0.6.4
8145	$Z \to \mu\mu$ + 3partons	18000	1200	12.0.5	12.0.6.4
8146	$Z \to \mu\mu$ + 4partons	7000	1500	12.0.5	12.0.6.4
8147	$Z \to \mu\mu$ + 5partons	5000	3000	12.0.5	12.0.6.4
6108	$W \to \mu\nu$ + 1partons	45000	28	12.0.5	12.0.6.5
6109	$W \to \mu\nu$ + 2partons	35000	60	12.0.5	12.0.6.5
6110	$W \to \mu\nu$ + 3partons	46000	270	12.0.5	12.0.6.5
6111	$W \to \mu\nu$ + 4partons	32000	630	12.0.5	12.0.6.5
6112	$W \to \mu\nu$ + 5partons	10000	500	12.0.5	12.0.6.5
6370	$t\bar{t}$ + 0partons	5000	100	12.0.5	12.0.6.4
6371	$t\bar{t}$ + 1partons	5000	65	12.0.5	12.0.6.4
6372	$t\bar{t}$ + 2partons	2500	24	12.0.5	12.0.6.4
8154	$Z \to \tau\tau$ + 0partons	10000	200	12.0.5	12.0.6.1
8155	$Z \to \tau\tau$ + 1partons	9500	170	12.0.5	12.0.6.1
8156	$Z \to \tau\tau$ + 2partons	9500	450	12.0.5	12.0.6.1
8157	$Z \to \tau\tau$ + 3partons	5000	700	12.0.5	12.0.6.1
8158	$Z \to \tau\tau$ + 4partons	5000	2500	12.0.5	12.0.6.1
8159	$Z \to \tau\tau$ + 5partons	4000	1800	12.0.5	12.0.6.1

Two +- complete signal+background sets
1) Pythia
2) Alpgen+herwig

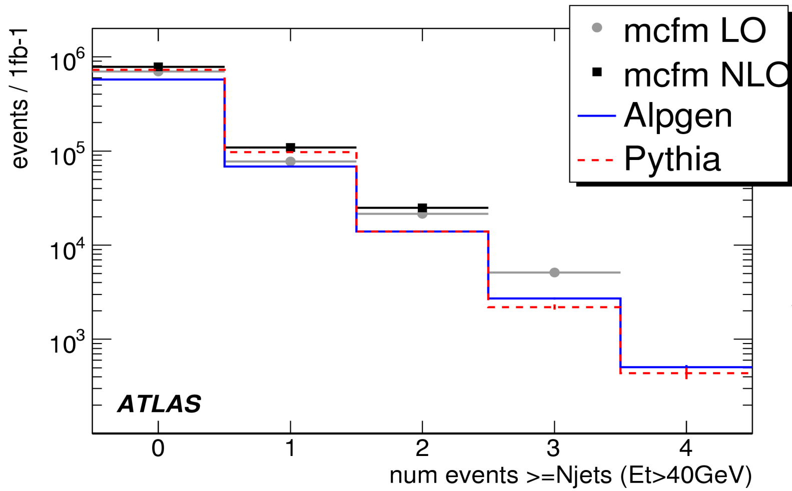
JES and Jet reco efficiency: Cone 4 Topo jets



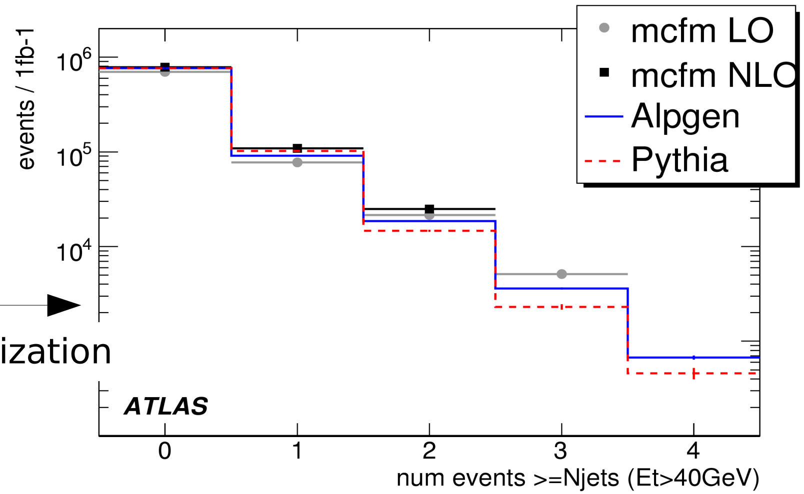


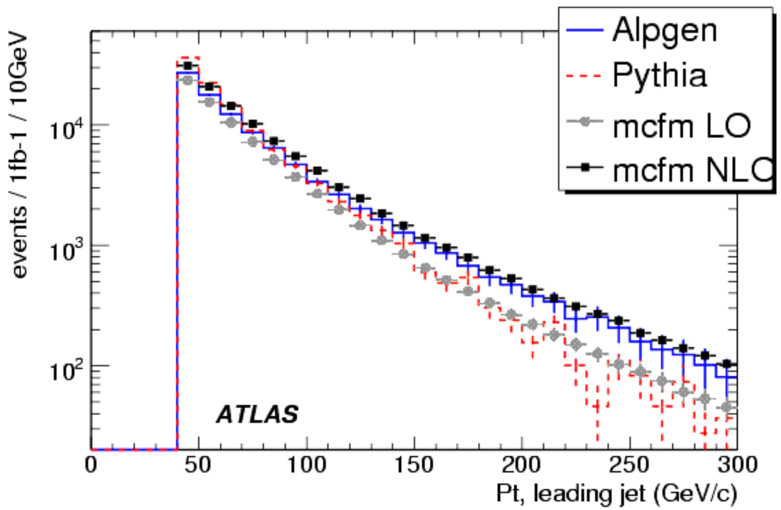
Corrections for cluster jets
lower than for tower jets

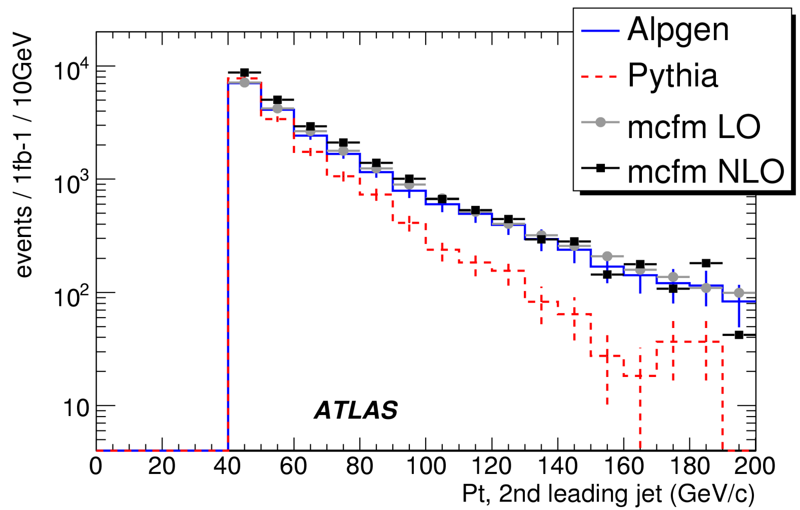
Z->mumu: Truth Observables



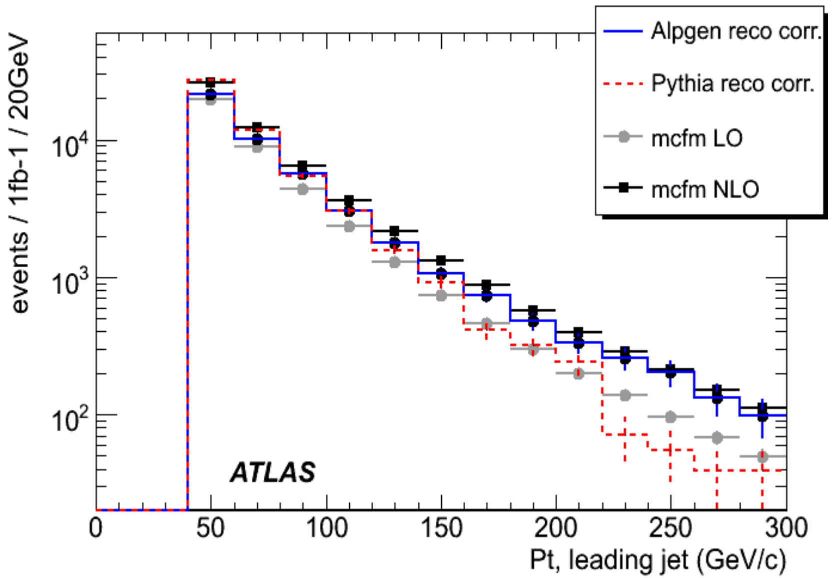
Global normalization

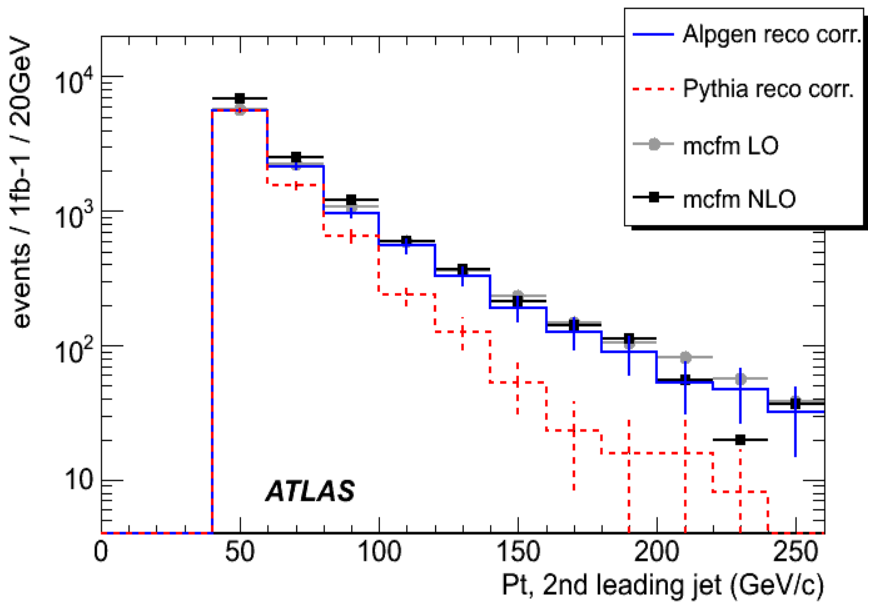




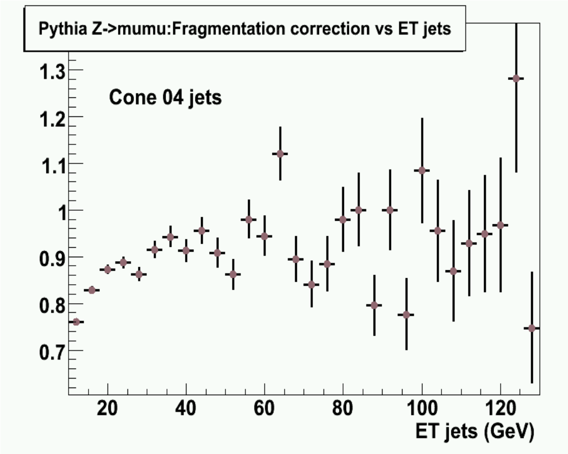


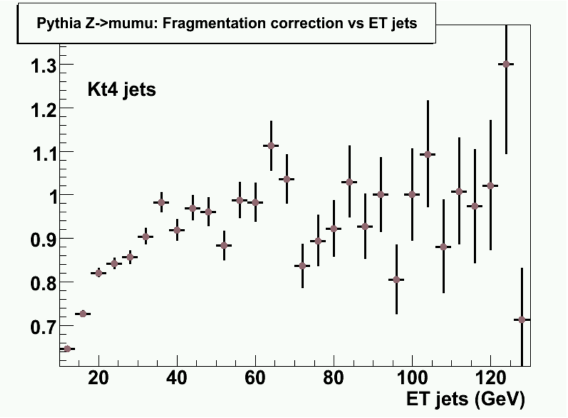
Z->mumu: Observables after unfolding

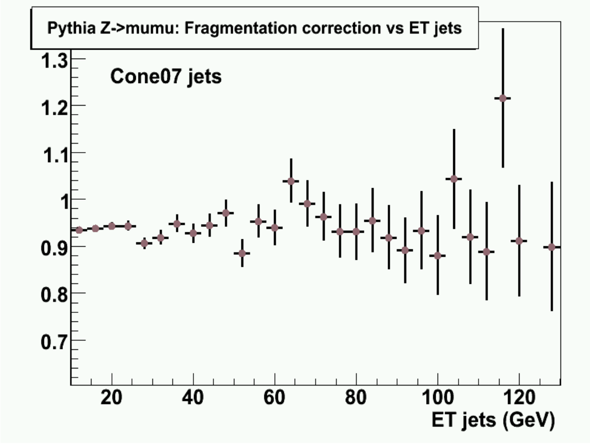


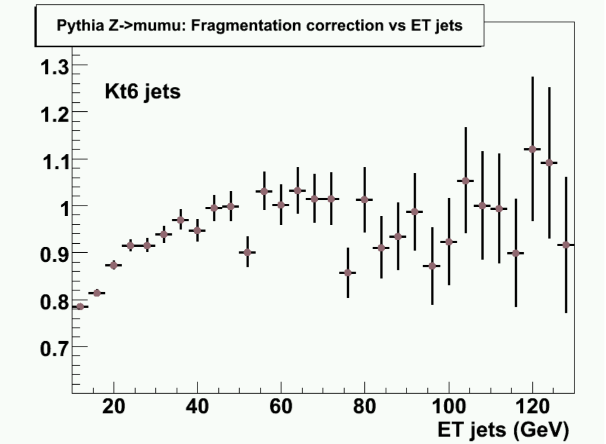


Fragmentation corrections: all CSC jet algorithms



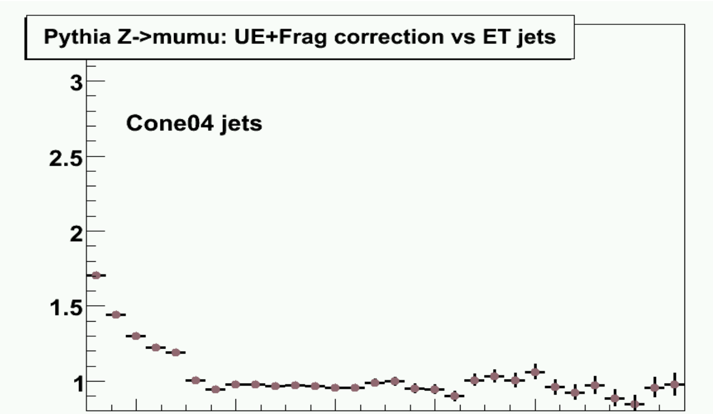


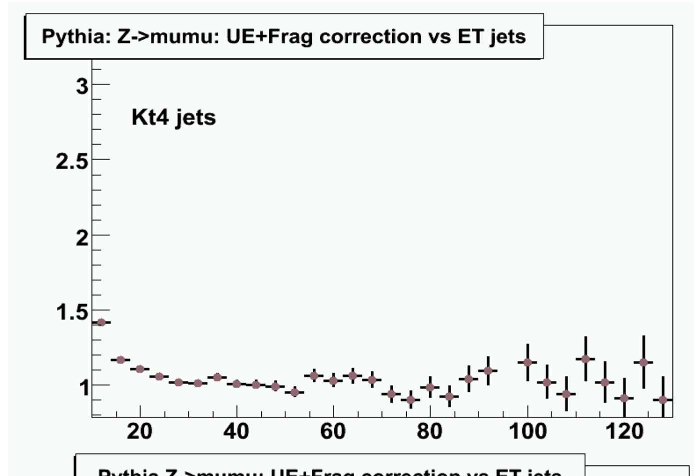


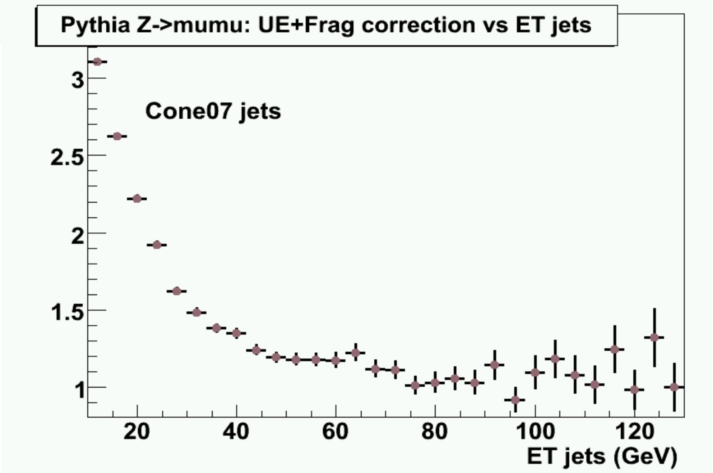


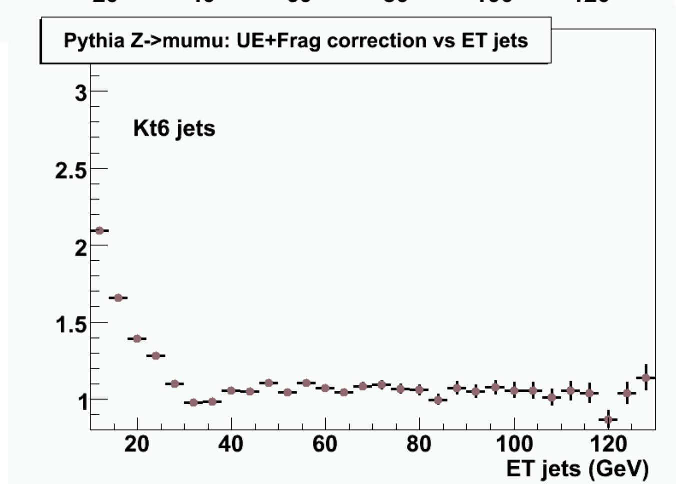
-> As expected, Cone07 shows the smallest loss of energy due to out-of-cone showering , Kt4 has the largest energy loss, Kt6 and Cone04 perform somewhat better than Kt4
-> The loss of energy diminishes with increasing ET of the jets: roughly similar performance for all algorithms at ET>40 GeV

All non-perturbative corrections









-> The combined corrections for underlying event and fragmentation are large for Cone07 jets, smallest for Kt4.

-> Remaining corrections negligible for ET>40 GeV for Kt4, C4 and Kt6
Negligible for Cone07 only for ET> 80 GeV