W/Z + jets in ATLAS

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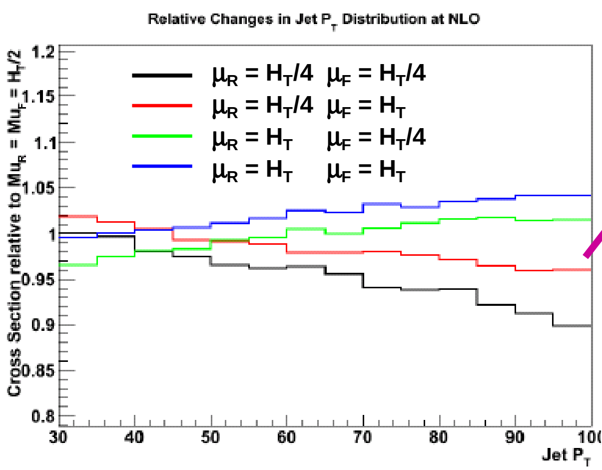
Scope of the presentation

- Level of precision needed on W/Z+jets measurements for sensitivity to improvement in theoretical understanding of these processes
- State where W/Z+jets ATLAS measurements stand and show data to MC comparison of various observables
- Give a quick overview of how we tackle down some of the important systematics affecting W/Z+jets analyses
- Bring to your attention some issues we are facing in order to start useful discussions
  - Bring feed-back to the collaboration
  - Hopefully reach some consensus among the wide HEP community

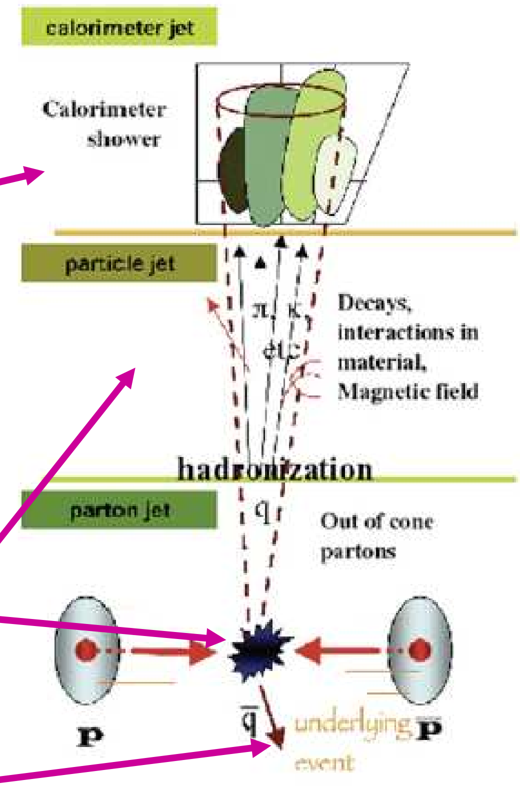
W/Z+jets measurements

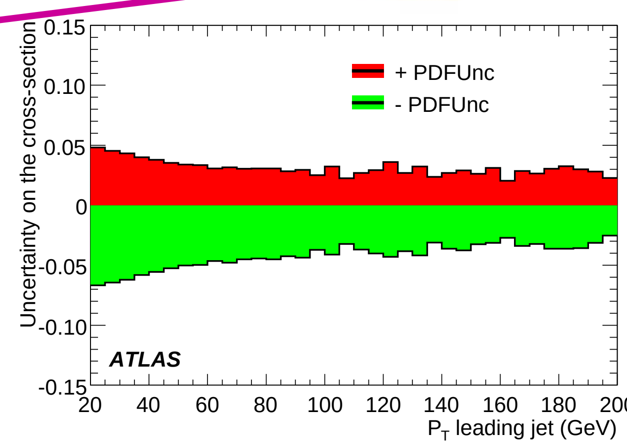
- ATLAS is in commissioning period:
  - Jet & E_T^{miss} resolution and calibration
  - Leptons energy scale and resolution
  - Trigger, Pile-up and Luminosity
- Crucial to study W/Z+jets events to understand our detector and tools
  - First priority with 2010 data



Perturbative QCD

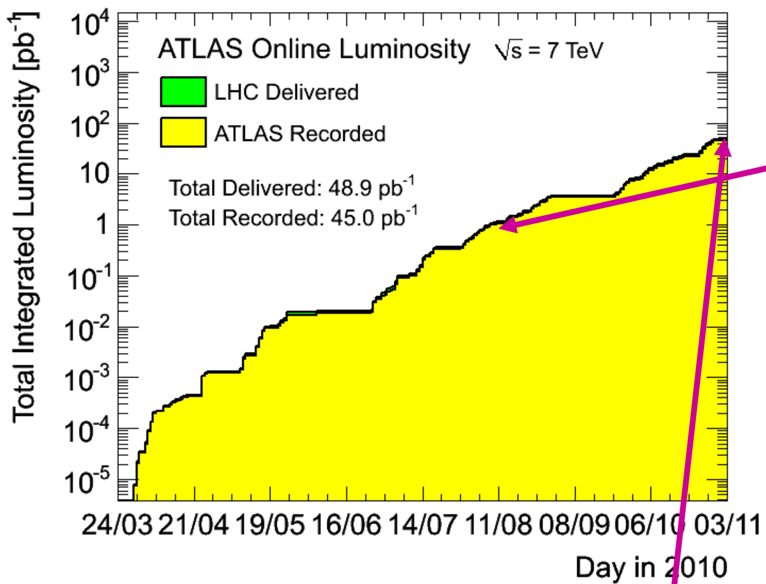
Fragmentation
Hadronization
Underlying events





The key to reach a better understanding of the Standard Model is:
to keep systematic uncertainties low

Status of W/Z+jets analyses



- We studied W+jets and Z+jets with 1pb^{-1}
  - Absolute cross sections
  - Relative to inclusive cross sections
  - All possible ratios

  Uncertainty on W+jets already dominated by systematic uncertainty
  - MC-based or simplify correction factors
  - Mostly conservative estimate of systematic uncertainties
  - Paper under internal review

- Z+jets uncertainty : Δstats $\approx$ Δsyst
  - Public note under internal review

- Provide Comparison to LO and NLO (MCFM) calculations
- Update with 2010 full 45pb^{-1} recorded dataset
  - Use more data-driven corrections

FIRST LOOK AT W/Z+JETS ATLAS DATA

Data vs MC

- Use 35 to 42 pb^{-1} (±11%) of data in the following distributions
  - Collected from 6 GeV to 15 GeV thresholds electron and muon triggers

- MC used in the following distributions
    - ALPGEN+HERWIG+JIMMY with CTEQ6L1 PDF for W/Z+jets events
    - Pythia dijet events (P_T > 15 GeV) with MRST2007LO* PDF for QCD
    - Use POWHEG with CTEQ6L1 PDF for ttbar
    - Added <N>=2 pile-up events, reweighted to primary vertices observed in data
    - ATLAS MC09 tune are used

- MC events normalized to observed data candidates before jet selections
  - Relative normalization of MC samples to NLO cross sections except QCD

Selections

- Lepton kinematic:
  - Electron $E_T^{clus} > 20$ GeV and muon combined track $P_T > 20$ GeV with $P_T^{MS} > 10$ GeV
- Eta coverage:
  - $|\eta_{ele}|<2.47$ excluding barrel to end-cap transition region ($1.37<|\eta_{ele}|<1.56$), $|\eta_{muo}|<2.4$
- Lepton quality requirements:
  - Tight requirements on electron cluster shape, track quality and matching
  - Muon cone 4 track isolation $\Sigma P_T^{ID}/P_T < 0.2$ and $|P_T^{ID} - P_T^{MS}| < 15$ GeV
- Jet selections:
  - AntiKt4 jets with $P_T > 20$ GeV and $|\eta| < 2.8$
- ETmiss selections
  - $E_T^{miss} > 25$ GeV, computed from calibrated topoclusters and out-of-cluster energy
- ATLAS standard clean-up cuts are applied

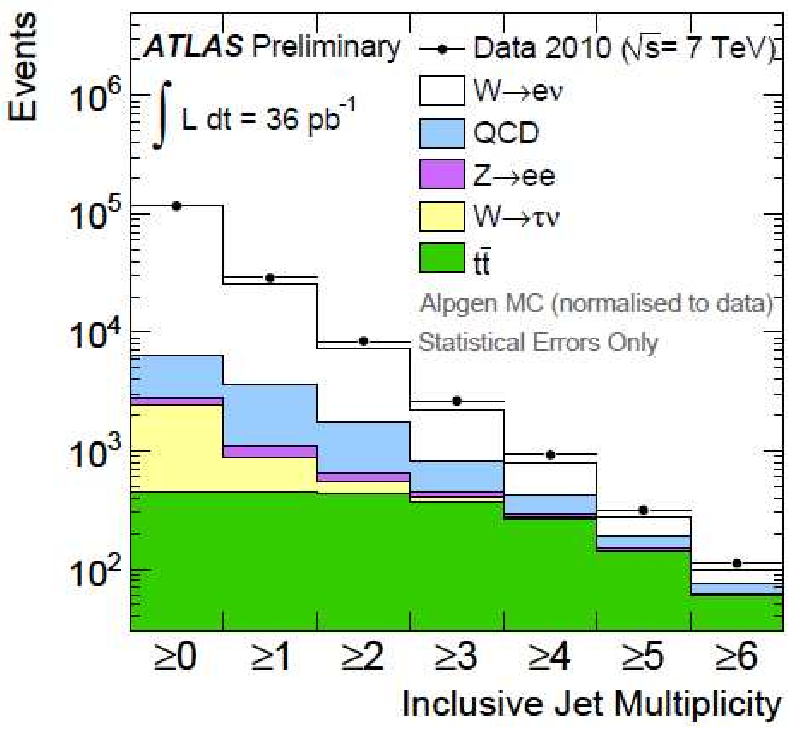
Jet Multiplicity

- QCD and top backgrounds significantly increase with the number of jets
  - Bigger effect at higher centre of mass energy

    $\Rightarrow$ Need to estimate these backgrounds precisely from data

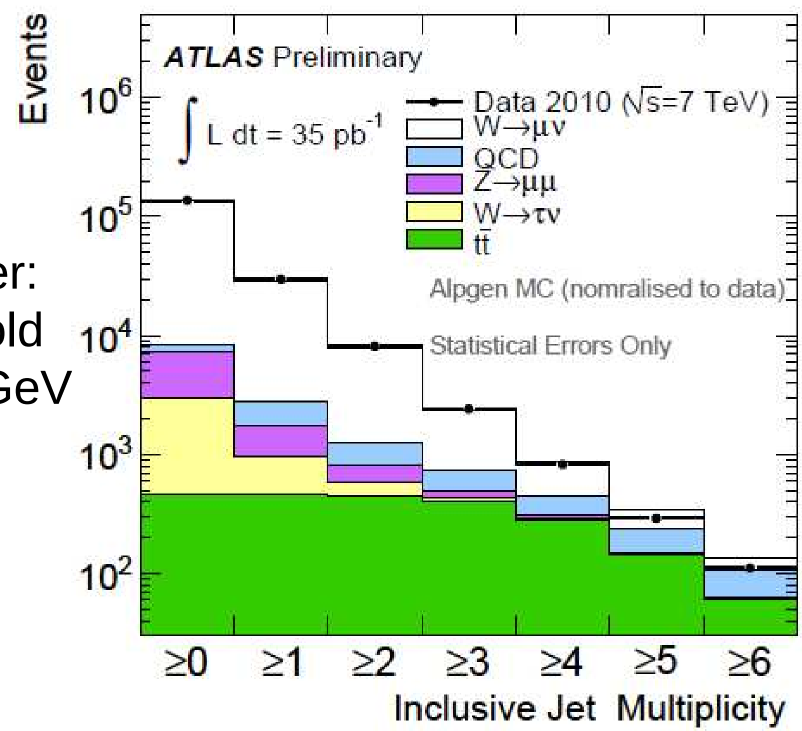
- Other electroweak backgrounds can be estimated using MC ratios

Electron channel



Remember: jet threshold is $E_T > 20$ GeV

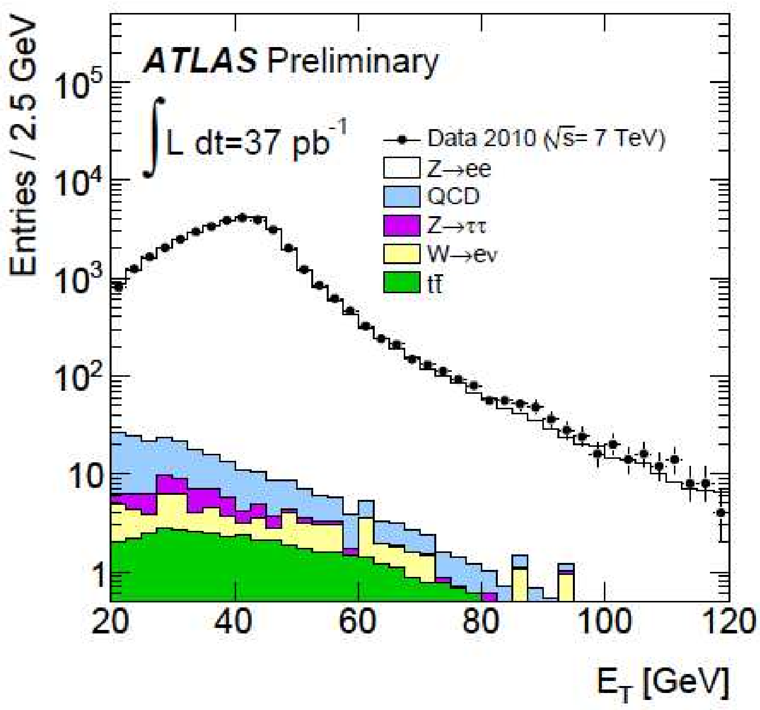
Muon channel



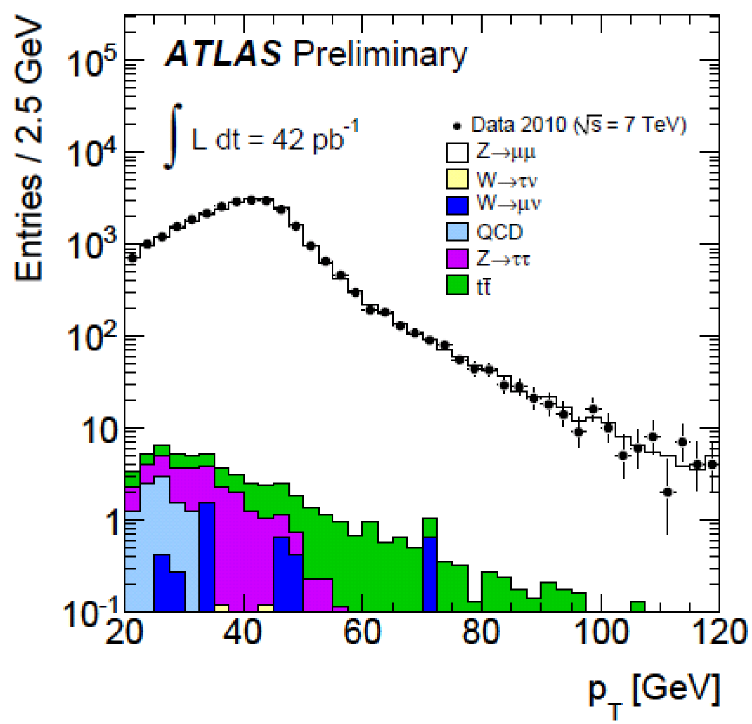
Lepton Transverse Momentum

- MC describes well the detector effects on lepton reconstruction and resolution
- Can use MC to estimate electron and muon resolution effects on acceptance
  - For better precision, measure resolution in data before correction.

Electron channel



Muon channel

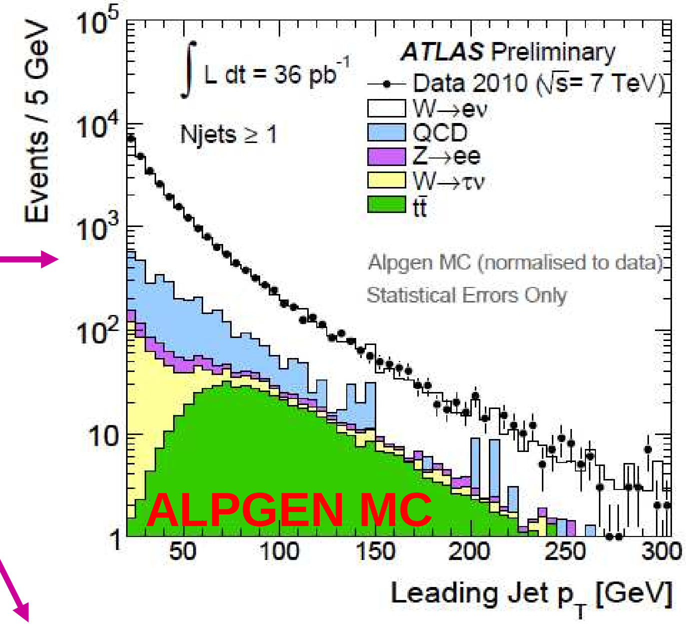


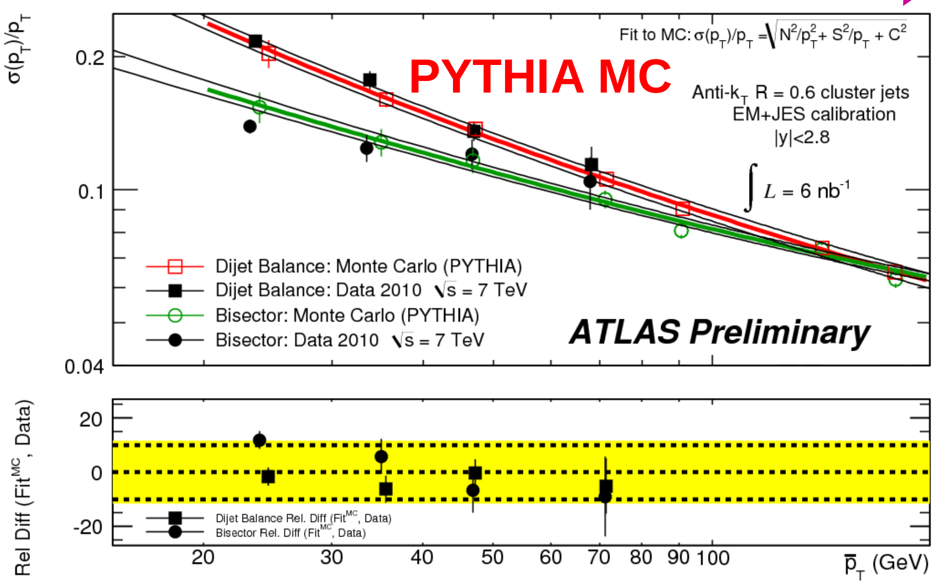
Jet Transverse Momentum

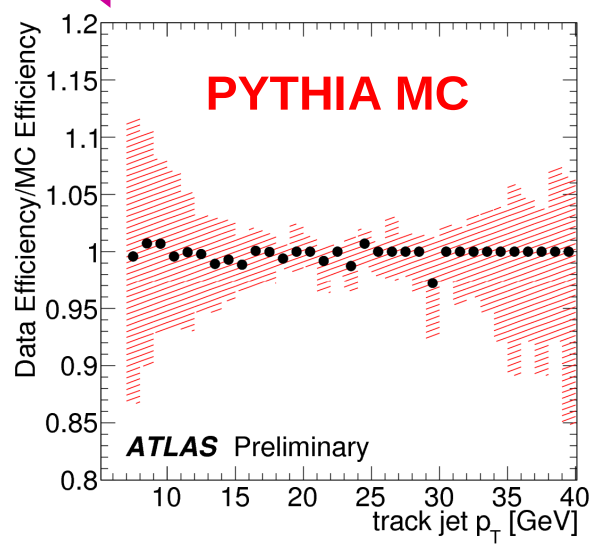
- Simulation are used to unfold detector effects in W/Z+jets measurements
- ATLAS data well modelled by simulation:
  - Jet transverse momentum in W+jets events
  - reconstruction efficiency in QCD dijet events
  - jet energy resolution in QCD dijet events

Will be measured on Z+jets events

Electron channel

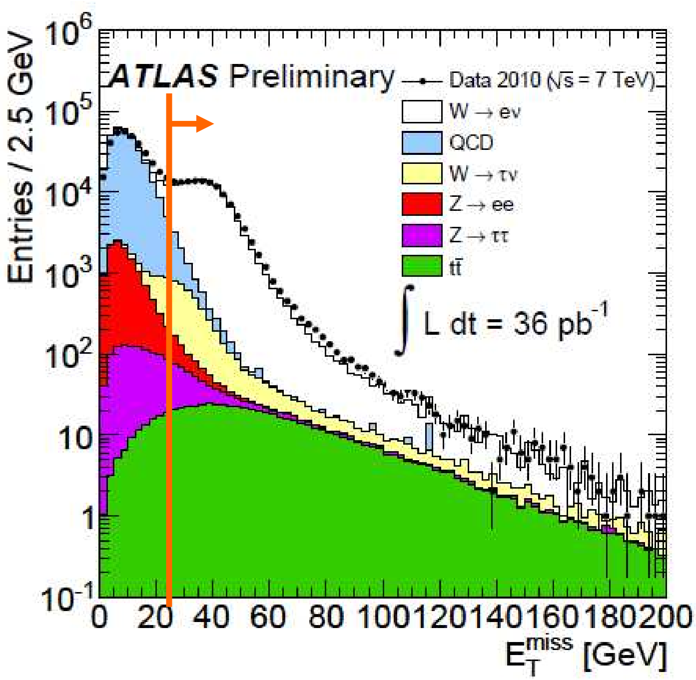






Missing E_T

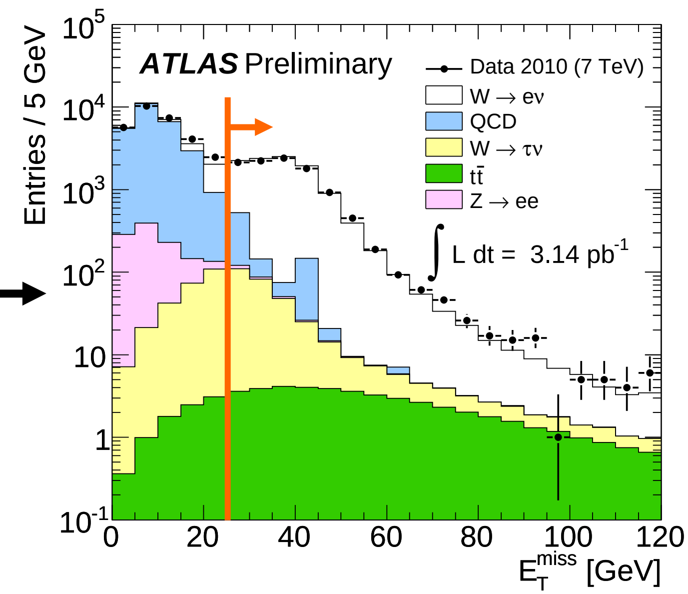
- Reasonably good agreement between data and MC in the bulk of the signal region
  - some care must be made with missing E_T model
    - pile-up effects
- Use data to estimate:
  - Missing E_T selection acceptance correction
  - QCD background prediction



Electron channel

Low pile-up

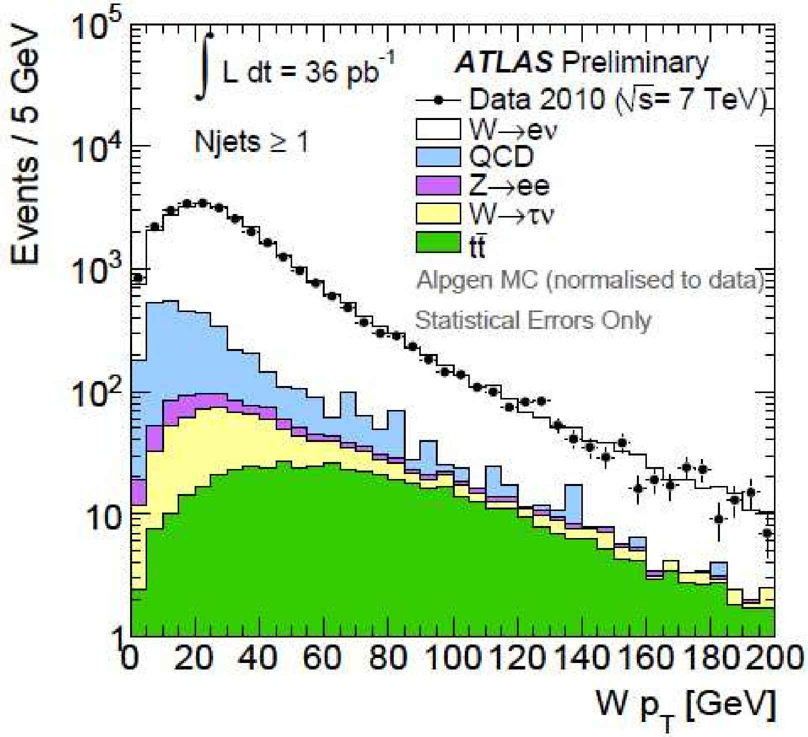
Higher pile-up



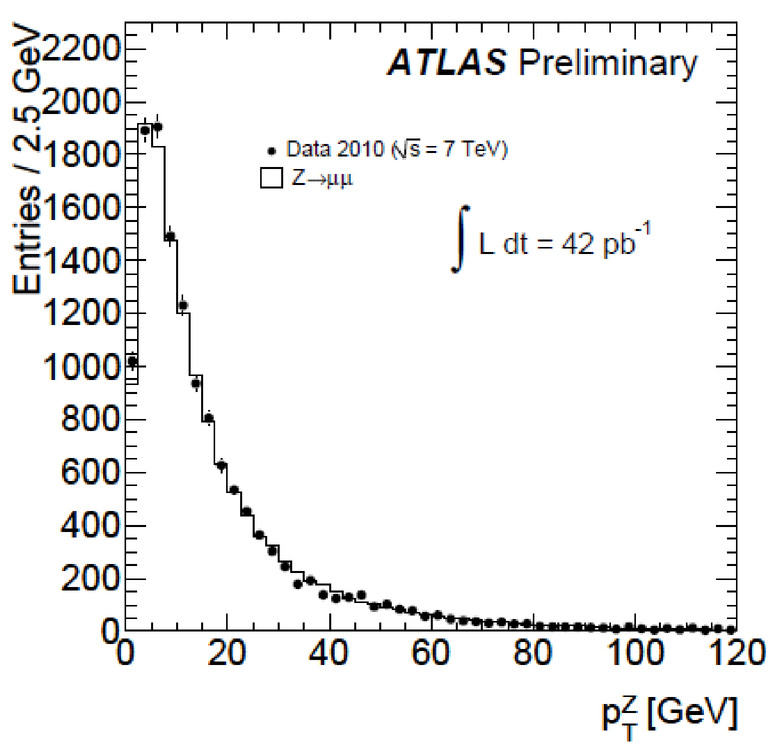
W/Z Transverse Momentum

- Good understanding of vector boson transverse momentum reconstructed from leptons over wide range of kinematics
  - Will be used to calibrate jets in W/Z+jets events
  - Useful to tune soft QCD effects in MC

W+≥1-jet
Electron channel



Z+≥0-jet
Muon channel

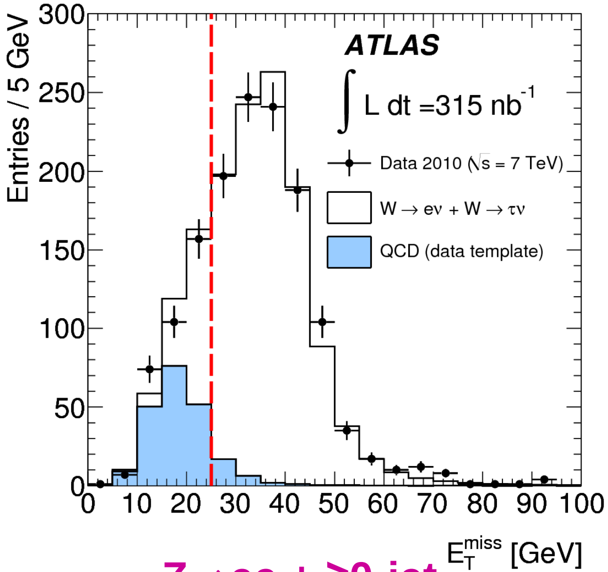


TOWARD PRECISE W/Z+JETS MEASUREMENTS

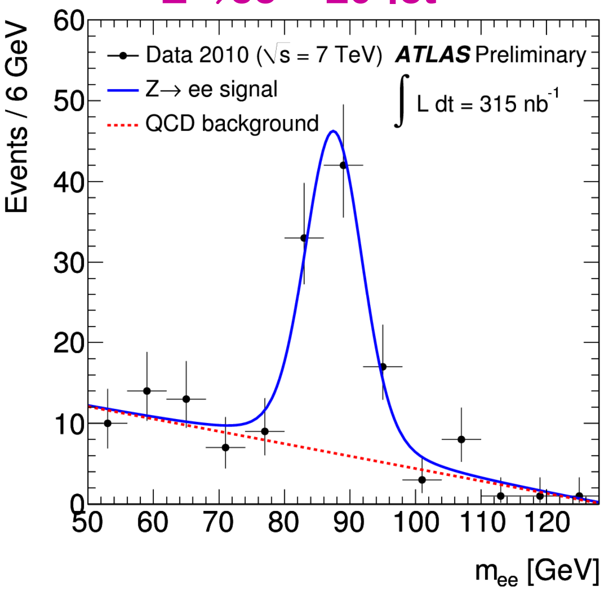
Systematic: QCD background

- QCD bkg predictions proceed from the opposition of two big numbers
  - Dijet cross section
  - Fake rejection
  - ⇒ Hard to estimate from MC
- Template method ($W \to e\nu$):
  - QCD E_T^{miss} from reversed electron selections, W E_T^{miss} from MC
  - Fit both templates to data
  - Integrate normalized QCD in signal region
  - ▶ $f_{QCD}(W+\geq 1\text{-jet}) \sim 12\%$, $\Delta f_{QCD}/f_{QCD} \sim 30\%$
- $Z \to ee$ QCD background estimate:
  - Direct fit to invariant mass
  - Number of same sign leptons under Z peak
  - ▶ $f_{QCD}(Z+\geq 1\text{-jet}) \sim 3\%$, $\Delta f_{QCD}/f_{QCD} \sim 30\%$

W→eν + ≥0-jet

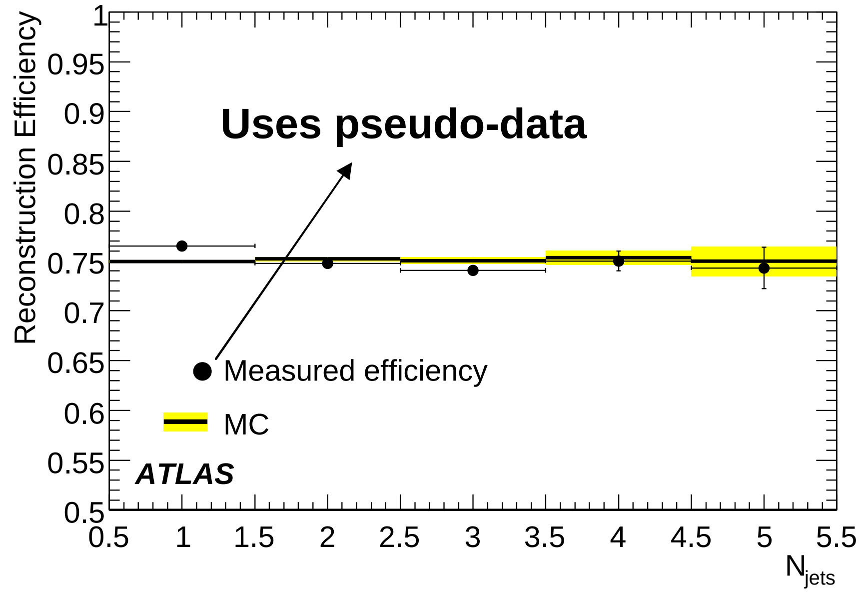


Z→ee + ≥0-jet



Lepton efficiency

- Lepton efficiencies don't depend on the recoiling jet activity
  - Can use precise estimates from inclusive data samples
- Efficiencies are measured from MC in first 2010 analyses
  - Tag & Probe method and E_T^{miss} preselected events already show promising results



- Trigger fully efficient in 2010 data

$$C_W = \varepsilon^W_{\mathrm{event}} \cdot \alpha^W_{\mathrm{reco}} \cdot \varepsilon^W_{\mathrm{lep}} \cdot \varepsilon^W_{\mathrm{trig}}$$

$$C_Z = \varepsilon^Z_{\mathrm{event}} \cdot \alpha^Z_{\mathrm{reco}} \cdot (\varepsilon^Z_{\mathrm{lep}})^2 \cdot [1-(1-\varepsilon^Z_{\mathrm{trig}})^2]$$

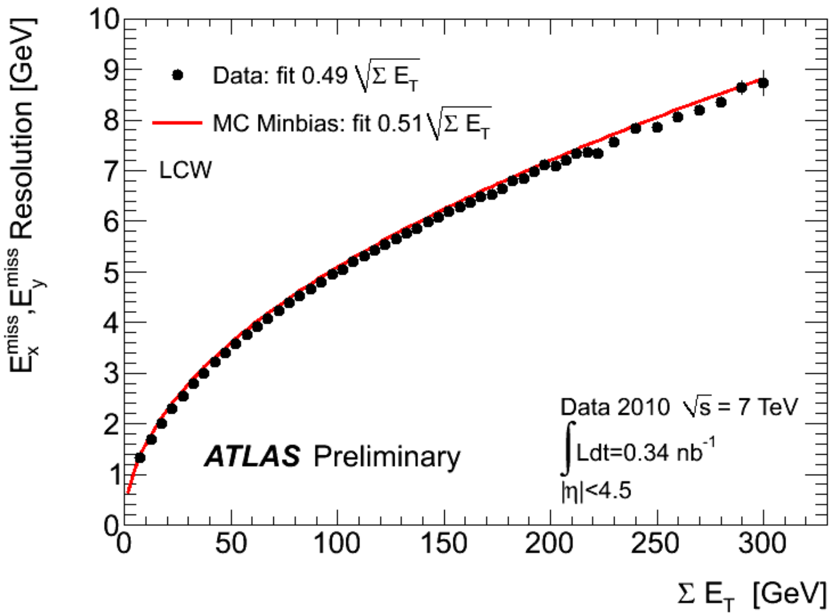
Parameter	$\delta C_W/C_W(\%)$	$\delta C_Z/C_Z(\%)$
Trigger efficiency	<0.2	<0.2
Material effects, reconstruction and identification	5.6	8.8
Energy scale and resolution	3.3	1.9
E_T^{miss} scale and resolution	2.0	-
Problematic regions in the calorimeter	1.4	2.7
Pile-up	0.5	0.2
Charge misidentification	0.5	0.5
FSR modelling	0.3	0.3
Theoretical uncertainty (PDFs)	0.3	0.3
Total uncertainty	7.0	9.4

Eliminated from data-driven estimate of efficiencies

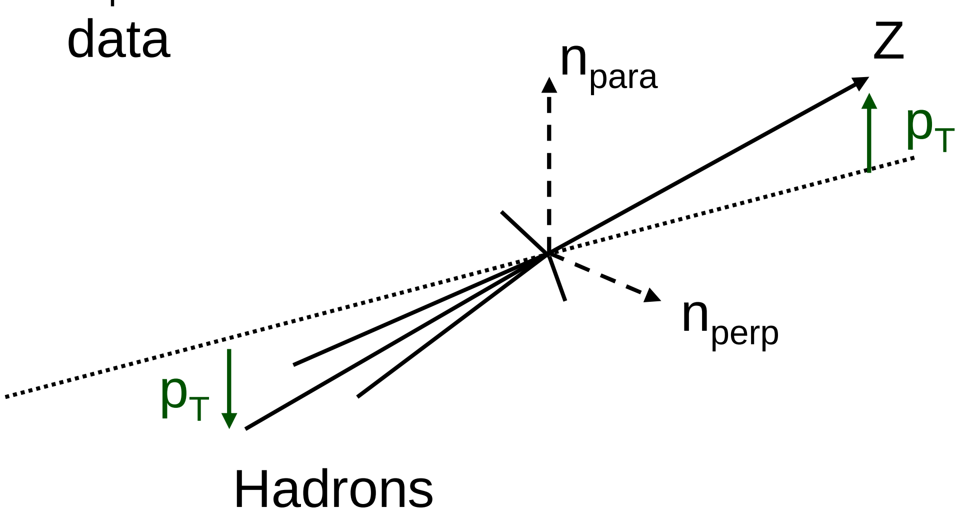
Systematics: E_T^{miss}

- Need to correct for detector effects on E_T^{miss} selection acceptance
- Non-trivial systematic uncertainty
  - Jet energy scale and resolution
  - Pile-up
  - Material modelling
  - Non-cluster energy

  $\Rightarrow \Delta A_{reco}$ ~2-4% from MC estimate



- E_T^{miss} resolution can be measured in data



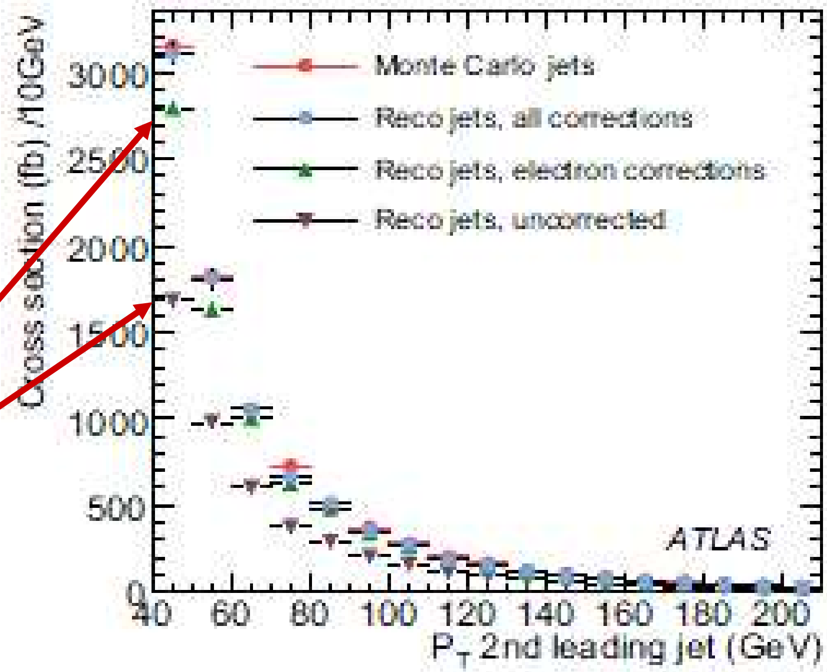
Data-driven estimate of correction factor to E_T^{miss} acceptance

- Select Z+jets events
- Measure $\sigma(E_T^{miss})$ along n_{perp}
- Measure $\mu(E_T^{miss})$ along n_{para}
- Apply gaussian smearing to true P_T^{ν}

Systematics: detector unfolding

- Jet energy resolution and reconstruction well modelled in MC.
- To correct measurement up to hadron level, need to solve the reverse problem (unfolding)
  - involve other sources of uncertainties
  - Many different techniques on the market

  $\rightarrow$ More complicated problem
- Smaller than lepton efficiency correction
  - Not a dominant source of systematics in 2010 measurements
  - Used simple bin-by-bin corrections
- Need to adopt:
  - good unfolding method,
  - generate high MC statistics,
  - identify all sources of systematics



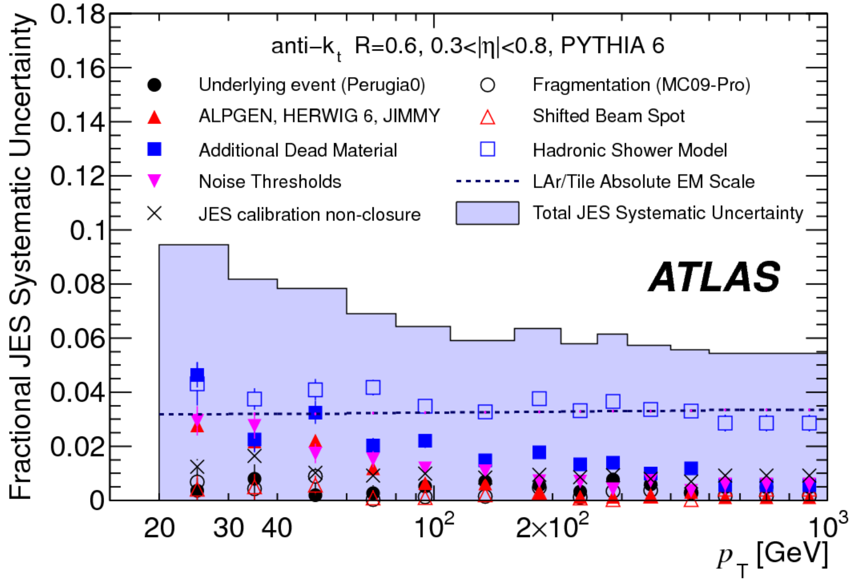
Unfolding workshop at CERN

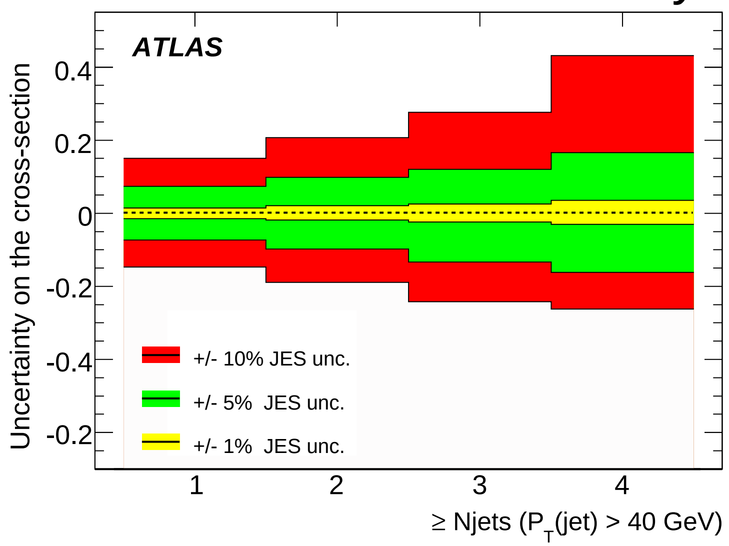
on 20/01/2011

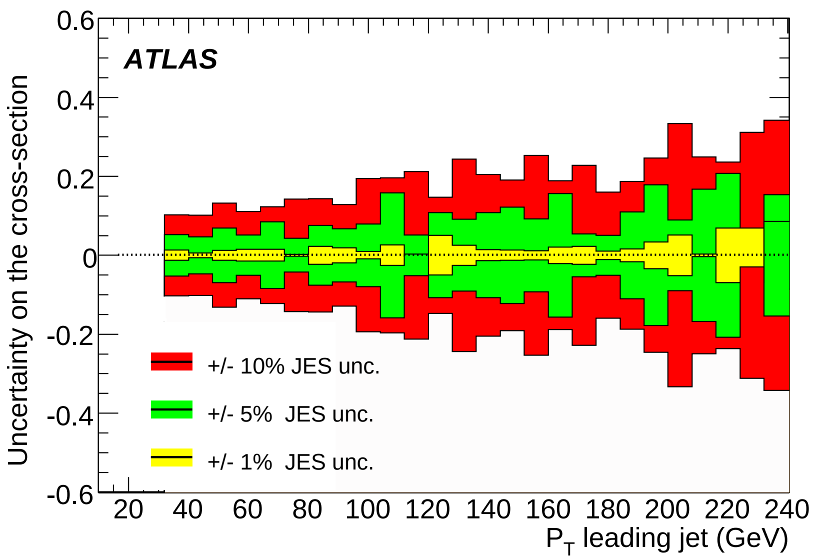
http://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=107747

Systematics: Jet Energy Scale

- ATLAS jets are calibrated from MC
  - Conservative uncertainty estimate
- Large impact of Jet Energy Scale uncertainty on cross sections
  - ΔJES = 5% $\rightarrow$ $\Delta\sigma_{tot}$ ~ 7%
  - Remove statistical effects in $\Delta\sigma$
  - Smaller effects on ratios
- Single particle measurement will constrain ΔJES in 2011 analyses







Systematics: summary and outlook

- Dominant systematic uncertainties on W/Z+1-jet ~$1pb^{-1}$ analysis

Sources of systematics	$\Delta\sigma$(W+jets) 1 pb^{-1}	$\Delta\sigma$(Z+jets) 1 pb^{-1}	target for $45pb^{-1}$ analyses
Jet Energy Scale	10%	10%	6-7%
Lepton A_{det} and ε	7%	10%	4-5%
Unfolding + jet E_T resolution	3%	5%	3%
QCD background	6%	2%	1-3%
E_T^{miss} A_{det}	3%	-	1-2%
Luminosity	11%	11%	5%

- Total of ~14/15% systematic uncertainty (excluding luminosity) compared to 3/11% statistical uncertainty
  - Already systematic dominated with ~$1pb^{-1}$ of data
  - Factor of ~2 reduction on systematic and luminosity uncertainties with full dataset

$\Rightarrow$ Sensitivity to NLO effects

$\Rightarrow$ Will soon start to get sensitivity beyond theoretical precision

Effects which were small and neglected must now be treated properly

$\Rightarrow$ Induce some discussions

DISCUSSION

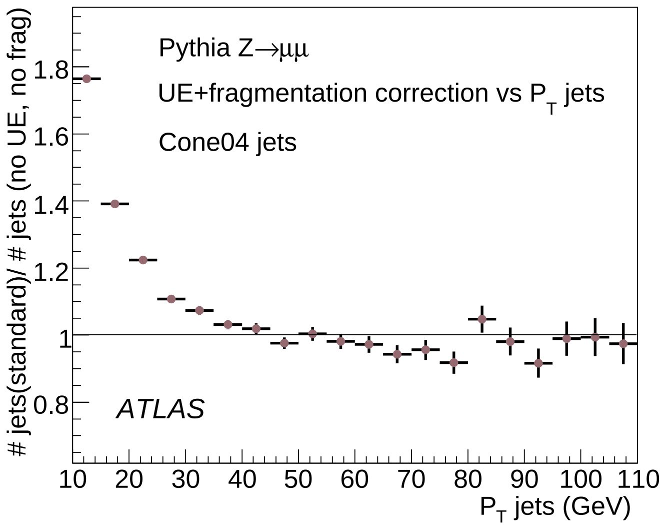
Jet Energy Threshold

- Experimental criteria favour jet P_T thresholds above 30 GeV:
  - Calibration below 20 GeV affected by jet reconstruction threshold
  - Jet energy scale uncertainty and pile-up dramatically increase below 30 GeV
  - Jet reconstruction efficiency quickly decreases below 30 GeV

- Theoretical prediction less robust for lower jet E_T:
  - Low P_T jets are more sensitive to soft QCD effects
  - Lower P_T jet thresholds imply higher scale uncertainty for theoretical predictions

Q: Prefer to reach as low jet P_T thresholds as possible (input to theorists) or keep thresholds higher (more robust comparisons)?

Q: What would be desirable jet thresholds in W/Z+jets physics?



Detector acceptance

- Lepton acceptance corrections depend on theoretical input (generators)
  - True level lepton P_T and η cuts, E_T^{miss} cut, mass selections, etc

$\Rightarrow$ Acceptance correction in measurements make it difficult for theorist to disentangle these effects to test potential improvements in their models

- Correcting for detector acceptance is needed to:
  - Combine or compare measurements made in muon and electron channels
  - Compare results from various experiments (detector independent results)

Q: Prefer to see publication with visible cross sections only or correct for a full acceptance cross sections?

Q: How isolation should be treated?

So far, in ATLAS, we are working out both numbers, but publication preferences still on analysis to analysis basis.

QED Final State Radiation

- QED radiation, especially from FSR is:
  - different for electrons and muons
  - simulated with varying accuracy in different MC programs and kinematic regions

- Theory accuracy at the few-per-mille level for inclusive cross section,

  ► this is *not true* in general for differential or exclusive distributions.

Final state electron	**Pythia status code 1**	**Well defined physics final state**	**Input to unfolding is theory dependent**
Electron at production vertex	**Pythia status code 3**	**Compare electrons and muons**	**Measurement can't profit from new theory**
"Dressed" electron	**Final state + photon in cone around it**	**Physics final state close to vertex electron**	**Cone size is arbitrary**

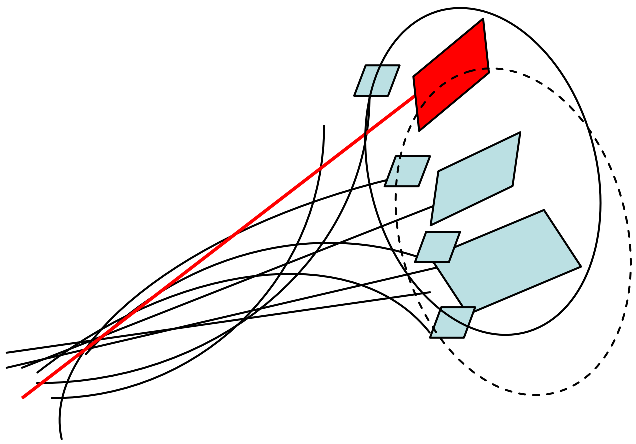
Q: what exactly should we measure and how should we confront it with theory? Correction before or after radiations? Both?

Q: How to assign reasonable systematic uncertainty on such effect?

Q: Should QED radiation be included in true jet clustering?

Jet-Electron overlap

- Electrons are reconstructed as jets in the calorimeter
  - Affect the energy response and reconstruction efficiency of close-by jets
- No ideal way to experimentally deal with this
  - Remove jets using ΔR matching
    - Small cone (~0.2)
    - Large cone (~0.5)
    - Small cone + event veto
  - Remove electron cluster from calorimeter and rerun jet algorithm
  - 4-vector subtraction



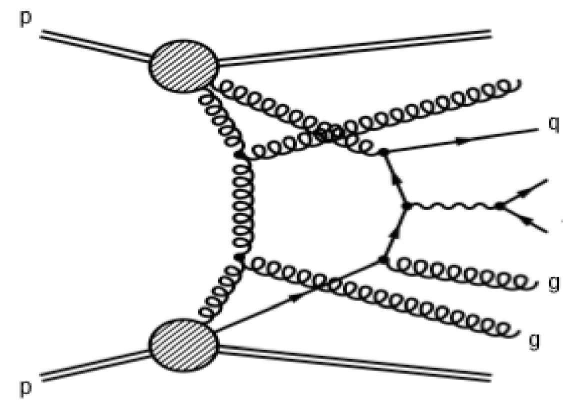
Q: Which is the best approach for comparison to theory and with other experiments?

Q: When a ΔR approach is used, should the decay products of vector boson be included in true jet clustering?

Correction to Parton level MC

- Unfolding brings jets from detector level to hadron level
- NLO fixed order calculation programs like MCFM don't include non-perturbative QCD effects for W/Z+parton(s) processes
  - Hadronization, underlying event

    $\Rightarrow$ No hadron level…



- K-factors obtained from NLO/LO MCFM prediction can't be applied to predictions involving parton shower

Q: Should we compute hadronization + underlying event correction factor from PYTHIA or HERWIG and apply them to MCFM predictions or it is preferable to leave predictions as they are?

Conclusion

- W/Z+jets physics allow to:
  - Study detector performance and validate measurement tools
    - ⇒ Improve systematic uncertainty on calibrations, efficiencies, unfolding, etc
  - Better understanding of higher order QCD corrections
    - ⇐ Require small systematic uncertainty on the measurements

Provide crucial understanding of major background to many new physics searches

- ATLAS performed 1 pb^{-1} W/Z+jets measurements
  - Good data to MC agreement
  - Set the ground for more precise future measurements
- Small effects will become important as the precision increases

► Need already discussions with theorist and other experiments on how to provide the best handle on these effects

  - Eg: QED FSR, jet energy threshold, jet-electron overlap removal, etc
- Using the 2010 full dataset and the yet to come 2011 data:
  - improve jet, E_T^{miss} and lepton performances using Z+jets events
  - Start to study Heavy flavour

Some references

- First Z+jets MC study:
  - CSC book: **arXiv:0901.0512** [hep-ex]
- Paper on the W/Z inclusive measurement
  - CERN-PH-EP-2010-037, **arXiv:1010.2130** [hep-ex]
- Jet energy resolution and reconstruction efficiency studies
  - ATLAS-CONF-2010-054
- Jet energy scale uncertainty estimate
  - ATLAS-CONF-2010-056
- ETmiss performance studies
  - ATLAS-CONF-2010-057