LEPTONIC FAKE RATES FROM JETS AT ATLAS

Gemma Wooden
University of Oxford for the ATLAS collaboration

Berkeley workshop on physics opportunities with early LHC data

6th – 8th May 2009

Overview

- Motivation
- Expected electron fake rates from simulation:
  - Cut-based method
  - Multivariate techniques
- Expected muon fake rates from simulation
- Background estimates using data-driven method:
  - In $W \rightarrow e\nu$ events
- Conclusions

Motivation

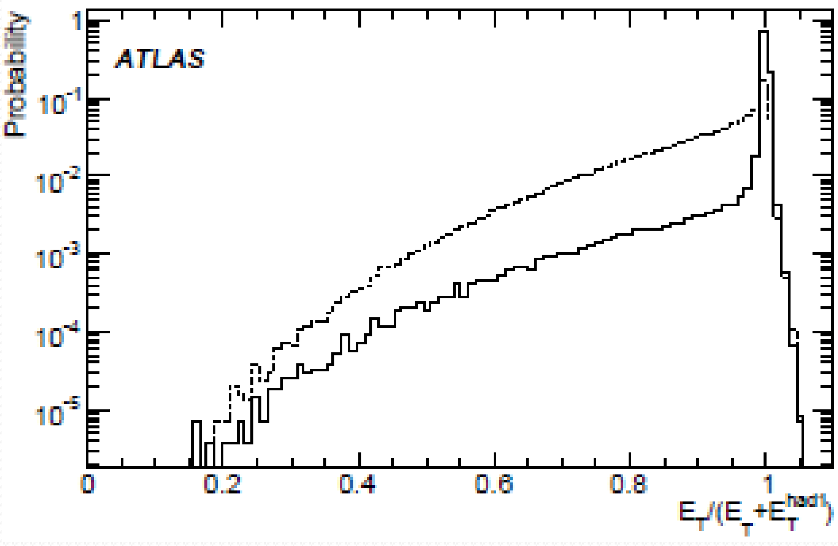
- Important to measure leptonic fake rates since they will affect many interesting physics results:
  - Electroweak measurements
    - Top & W mass
  - Diboson studies
    - Anomalous triple gauge couplings would enhance production cross-sections
    - Could find evidence for new physics
  - Higgs searches
    - Fake leptons will be an important background to $H \rightarrow WW$ and $H \rightarrow ZZ$ channels

Sources of background to leptons

- Electrons are split into 4 categories:
  - Isolated – e from Z, W, t, τ or μ
  - Non-isolated – e from J/ψ, b- or c-hadron decays
  - Background – e from photon conversions, π^0/e Dalitz decays or $u/d/s$-hadron decays
  - Non-electron – charged hadrons, muons
- Muons are categorised into 2 types:
  - Direct – no quarks in their ancestry
  - Indirect – ancestry includes a heavy quark but not a tau
- There may also be fake muons where charged hadrons are falsely reconstructed as muons
- At design luminosity, there will also be a significant background in the muon chambers from low-energy photons and neutrons (cavern background)

Introduction to cut-based method for electrons

- The PYTHIA event generator was used to generate a large jet sample (8.2 million events)
- This sample, referred to as filtered di-jets, contains all hard-scattering QCD processes with $E_T > 15$ GeV as well as other interesting physics processes, e.g. single W/Z production
- Three standard sets of ATLAS selection cuts for electrons have been used: loose, medium and tight, with cuts on various discriminating variables
- The plot below illustrates one such variable



Ratio of E_T of electron candidate to sum of E_T and E_T in first layer of hadronic calorimeter

Solid line: $Z \longrightarrow ee$ sample
Dotted line: Filtered di-jets sample

Multivariate techniques & comparison with cut-based method

- Several multivariate methods have been investigated as well as the simple cut-based method
- The jet rejection and efficiency has been calculated for one of these, a likelihood discriminant
- The efficiency achieved with the likelihood discriminant method with the rejection fixed at that achieved by the cut-based method for a given electron selection (& vice versa for the rejection) allows a comparison:

Cuts	Cut-based method		Likelihood method	
	Efficiency ε_e (%)	Rejection R_j	Efficiency (%) at fixed R_j	Rejection at fixed ε_e
Loose	87.97 ± 0.05	567 ± 1	89.11 ± 0.05	2767 ± 17
Medium	77.29 ± 0.06	2184 ± 7	88.26 ± 0.05	$(3.77 \pm 0.08) \times 10^4$
Tight (isol)	64.22 ± 0.07	$(9.9 \pm 0.2) \times 10^4$	67.53 ± 0.06	$(1.26 \pm 0.05) \times 10^5$
Tight (TRT)	61.66 ± 0.07	$(8.9 \pm 0.2) \times 10^4$	68.71 ± 0.06	$(1.46 \pm 0.06) \times 10^5$

This gives a **fake rate** of the order **10^{-4}** or better

This table shows that multivariate methods may improve jet rejection BUT they are only suitable once the detector is well understood – cut-based method will be used for first data!

Muon fake rates from simulation

- An inclusive ttbar sample with one lepton in the final state was produced using the generator MC@NLO
- Also used PYTHIA to generate low- and high-P_T muon samples
- Used standard ATLAS combined muon algorithm (Staco), which statistically combines muon spectrometer tracks with inner detector tracks
- The table shows the efficiency for all found muons (found) & for those which match a true muon (good) as well as the fake rates

Sample	Efficiency		Fakes/(1000 events) above p_T limit (GeV/c)			
	found	good	3	10	20	50
Staco						
$t\bar{t}$ direct	0.943 (1)	0.875 (1)	22.0 (3)	9.6 (2)	3.4 (1)	0.62 (4)
$t\bar{t}$ indirect	0.933 (1)	0.767 (2)				
$t\bar{t}$ direct cut	0.924 (1)	0.865 (1)	14.8 (2)	3.1 (1)	0.39 (3)	0.01 (1)
hi-$\mathscr{L}$ $t\bar{t}$ direct	0.941 (2)	0.871 (3)	25.9 (7)	11.2 (4)	4.3 (3)	0.7 (1)
Z'	0.910 (2)	0.824 (3)	14 (1)	8.4 (9)	5.2 (7)	3.4 (6)
J/ψ	0.943 (3)	0.873 (4)	0.9 (2)	0.24 (8)	0.11 (5)	0.0 (0)

This gives a **fake rate** of the order 10^{-3} or even better in the high P_T region

It's likely that isolation requirements would improve this

Introduction to data-based background estimation

- Fake electrons from jets provide an important background to W in electron channel:

Selection	$W \to e\nu$	jets	$W \to \tau\nu$	$Z \to ee$
Trigger	37.01 ± 0.09	835 ± 18	1.73 ± 0.02	6.07 ± 0.01
$E_T > 25$ GeV, $\lvert\eta\rvert < 2.4$	30.84 ± 0.09	383 ± 12	1.03 ± 0.01	3.23 ± 0.01
Electron ID	26.77 ± 0.09	110 ± 6	0.91 ± 0.01	2.95 ± 0.01
$\not{E}_T > 25$ GeV	22.06 ± 0.09	4.6 ± 0.7	0.55 ± 0.01	0.06 ± 0.01
$M_T > 40$ GeV	21.71 ± 0.08	1.5 ± 0.4	0.43 ± 0.01	0.04 ± 0.01

Number of events x 10^4 for an integrated luminosity of 50 pb^{-1}

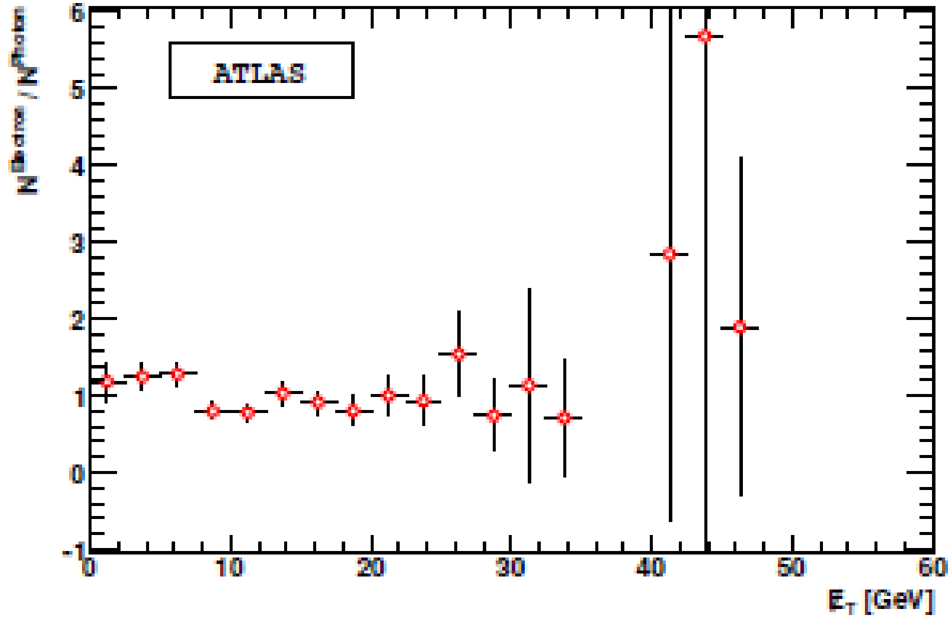
- Jet production cross-section and fragmentation properties aren't well known at the LHC
- This introduces significant uncertainty on jet background => can't rely on Monte Carlo
- Data-driven method desirable
- Idea: Measure normalisation & shape of jet background before missing E_T cut
  - Find signal-free jet sample with M_T distribution & jet multiplicity similar to that of jet background to $W \longrightarrow e\nu$
  - Use this sample to measure rejection of missing E_T cut to estimate jet background in W event selection

W and jet event selections

- Search for events with signature suggestive of W signal:
  - Look for an EM object with a matched track passing a single electron trigger
- Signal sample:
  - Select events with one electron candidate which satisfies medium selection criteria and passes E_T and η cuts described on the previous slide
  - Remove events with a second high P_T electromagnetic cluster which, with the first electron, gives an invariant mass close to Z peak
- Jet background control sample:
  - Use single photon trigger with $E_T > 20$ GeV
  - Look for photon cluster satisfying same kinematic & calorimetric cuts as electron candidate
  - To reject events with true electrons, require that there is no inner detector track matching cluster

Ratio of the missing E_T distributions in jet background events and in the control sample

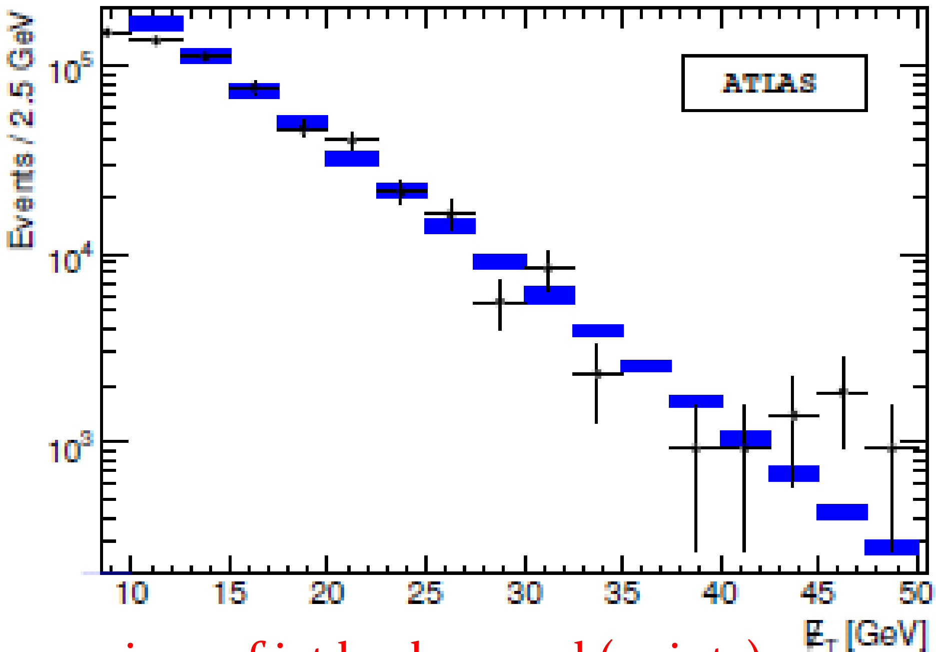
- Simulation indicates that the missing E_T distribution of jet background events is identical (within statistics) to that of the jet background control sample



Ratio of missing E_T in jet background events to control sample as a function of missing E_T for an integrated luminosity of 50 pb^{-1}

W event results

- Comparison indicates that the estimated jet background from the control sample agrees well with the actual background to W from jet events:



Comparison of jet background (points) to fitted background for an integrated luminosity of 50 pb^{-1}

- The estimated background may then be subtracted from the signal sample
- This data-driven method gives a jet background fraction of (0+4-0)% with an uncertainty of $\Delta B = 0.92 \times 10^4$ events
- => significant reduction!
- Further cuts requiring large missing E_T & large M_T may then be applied in order to further select the W signal and remove other sources of background

Conclusions

- Lepton fakes will be a significant contribution to backgrounds to some of the most interesting physics that the LHC hopes to investigate
- Therefore very important to understand and be able to reduce
- Results from Monte Carlo suggest fake rates to be of the order 10^{-4} for electrons and 10^{-3} for muons
- Can use data-driven techniques to understand fake rates as well as multivariate techniques once detector is well understood
- Data-driven methods have been investigated in the context of a W cross-section measurement & initial studies indicate that they accurately predict background from jets faking leptons in simulation
- More work to do – will be able to start trying to understand & characterise jet events with first data

Backup slides

Samples used for data-driven method

- W sample generated using PYTHIA
- Diboson & ttbar samples generated with MC@NLO

Channel	$\sigma(\times B_r)$	ε_{filter}	N_{evt} $(\times 10^3)$	$\mathscr{L}$ (pb^{-1})
$W \rightarrow e\nu$	20510 pb	0.63	140	11
$\gamma/Z \rightarrow ee, \sqrt{\hat{s}} > 60$ GeV	2015 pb	0.86	399	230
$\gamma/Z \rightarrow ee, \sqrt{\hat{s}} < 60$ GeV	9220 pb	0.022	197	969
$W \rightarrow \tau\nu_\tau$	20510 pb	0.20	32	8
$Z \rightarrow \tau\tau$	2015 pb	0.05	13	129
$t\bar{t}$	833 pb	0.54	382	850
Inclusive jets (p_T >6 GeV)	70 mb	0.058	2480	0.0006
Inclusive jets (p_T >17 GeV)	2333 μb	0.09	3725	0.02
WW$\rightarrow$ $(e\nu)(e\nu)$	1.275 pb	1.	20	15608
ZZ	14.8 pb	1.	43	2922
WZ	29.4 pb	1.	50	1699

Contribution and origin of electron candidates before selection cuts

- From the di-jets sample:

Isolated	Non-isolated	Background
W – 75.0%	b-hadrons – 38.7%	γ-conv. – 97.8%
Z – 20.9%	c-hadrons – 60.6%	Dalitz decays – 1.8%
t – < 0.1%	J/ψ – 0.7%	$u/d/s$-hadrons – 0.4%
τ – 4.1%		

ATLAS electron & muon selection criteria

- Electrons must have $|\eta| < 1.37$ or $1.52 < |\eta| < 2.4$ to avoid crack regions in the detector
- There are three standard sets of identification criteria:
  - Loose: simple shower-shape cuts
  - Medium: further cuts on shower-shape & track quality
  - Tight: tighter cut on track-matching as well as requirements on hits in different regions of the inner detector
  - Tight (isol) applies an additional cut on the isolation energy of the electron
  - Tight (TRT) doesn't include any explicit cut on isolation energy but applies tighter cuts on the TRT (Transition Radiation Tracker) information
- In W events, require one electron with $P_T > 25$ GeV/c satisfying medium criteria
- Muons must have $|\eta| < 2.5$
- Low P_T muon sample requires two muons with $P_T > 25$ GeV/c
- High P_T muon sample has an average muon $P_T = 500$ GeV/c, with a Z' mass of 2 TeV