W boson production in association with jets at ATLAS

Maria Fiascaris
University of Oxford

IOP 2010
March 30th 2010

Aim & Outline

Goal:

- Feasibility study for the measurement of the W(eν)+jets cross-section at the LHC with early data:
  - Assume 100 pb^{-1} of integrated luminosity, $\sqrt{s}$ = 10 TeV
  - Develop techniques for W+jets measurement, emphasis on data-driven methods
  - Focus on jet multiplicities Njets = 1 , 2
  - Robust measurements for early data: ratio W+jets / Z+jets

→ All based on Monte Carlo simulations

Why W + Jets?

1) **Test of perturbative QCD**:
   - Broad kinematic acceptance of LHC: can explore unknown regions
   - Large QCD background

➔ **Crucial to understand QCD!**

Why W + Jets?

1) **Test of perturbative QCD**:
   - Broad kinematic acceptance of LHC: can explore unknown regions
   - Large QCD background

→ **Crucial to understand QCD!**

2) **Background to SM and Beyond the SM processes:**
   Top
   Higgs
   SUSY

Why W + Jets?

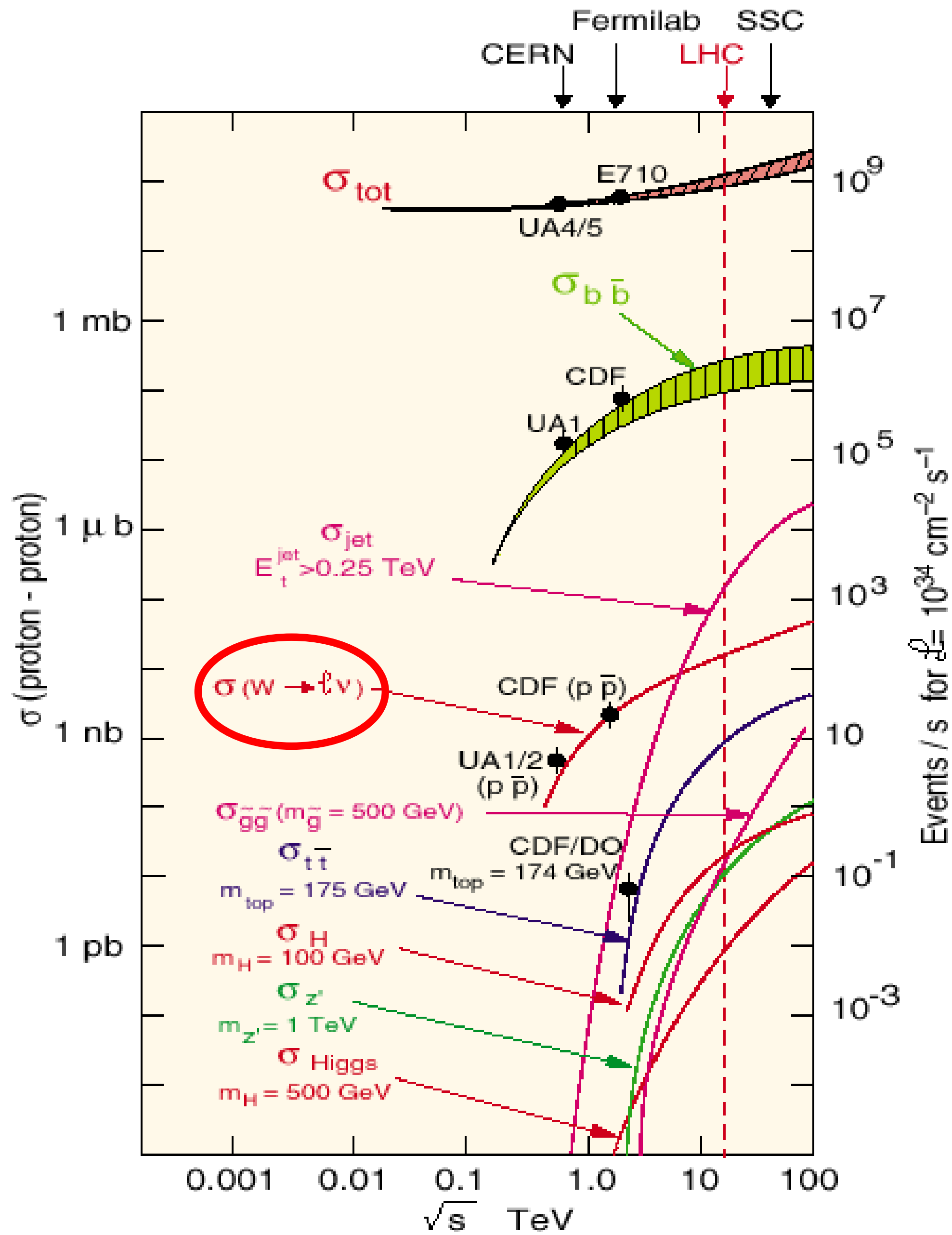
1) **Test of perturbative QCD**:
- Broad kinematic acceptance of LHC: can explore unknown regions
- Large QCD background

➜ **Crucial to understand QCD!**

2) **Background to SM and Beyond the SM processes:**

Top
Higgs
SUSY

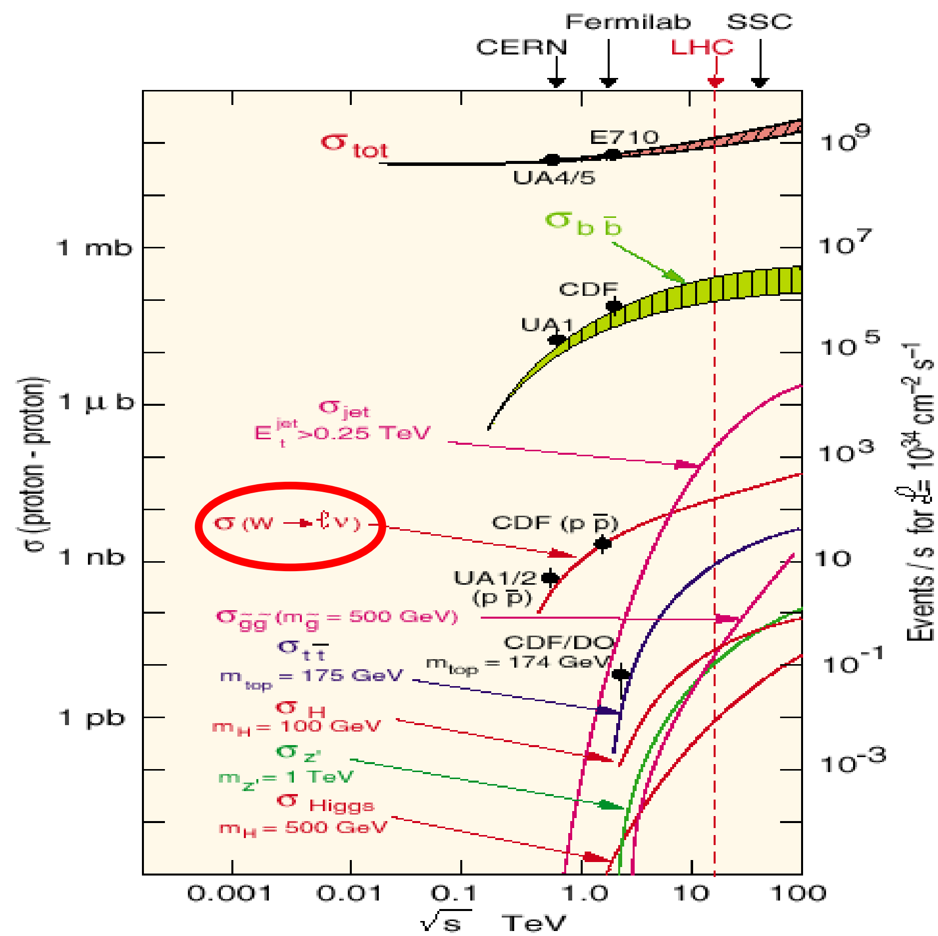
To make **new discoveries** we need to **understand the SM** first!



Why W + Jets?

1) **Test of perturbative QCD**:
- Broad kinematic acceptance of LHC: can explore unknown regions
- Large QCD background

➜ **Crucial to understand QCD!**



2) **Background to SM and Beyond the SM processes:**

Top
Higgs
SUSY

To make **new discoveries** we need to **understand the SM** first!

3) **W (and Z) bosons copiously produced at LHC**
➜abundant statistics for detector performance studies:

Jet algorithms
Lepton reconstruction & missing transverse energy in high jet multiplicity environment

W + jets production @ LHC

- W cross-sections at LHC are **10 times larger** than at the Tevatron
- Production in association with multi-jets also enhanced

$\sigma \cdot \mathrm{BR}$ **(W→eν) [pb]** (from M.Mangano)

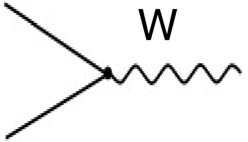
N Jets →	1	2	3	4	5
Tevatron	230	37	5.7	0.75	0.08
LHC	3400	1130	340	100	28

Et(jet)>20 GeV, $|\eta|<2.5$, ΔR=0.7, $\sqrt{s}$ = 14 TeV

W+0 partons **(LO)→ need q, qbar:**

valence-valence process at Tevatron

valence-sea, sea-sea process at LHC

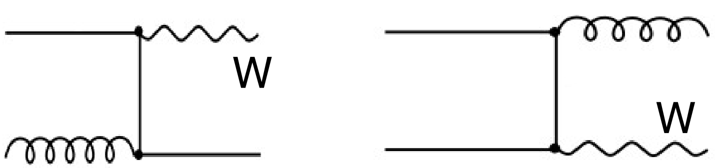


$\sigma(N_{jet}=0) \propto \alpha \cdot \mathrm{Lum}(q\ qbar)$

W+1 partons:

q qbar → W g (Tevatron)

q g→ W q' (LHC)



$\sigma(N_{jet}=1) \propto \alpha\ \alpha_s\ \mathrm{Lum}(q\ qbar / qg)$

Different at Tevatron and LHC!

→ At LHC W + jets is enhanced:

large contribution from **gluon**

large phase space available for **additional jets**

W + jets Event Selection

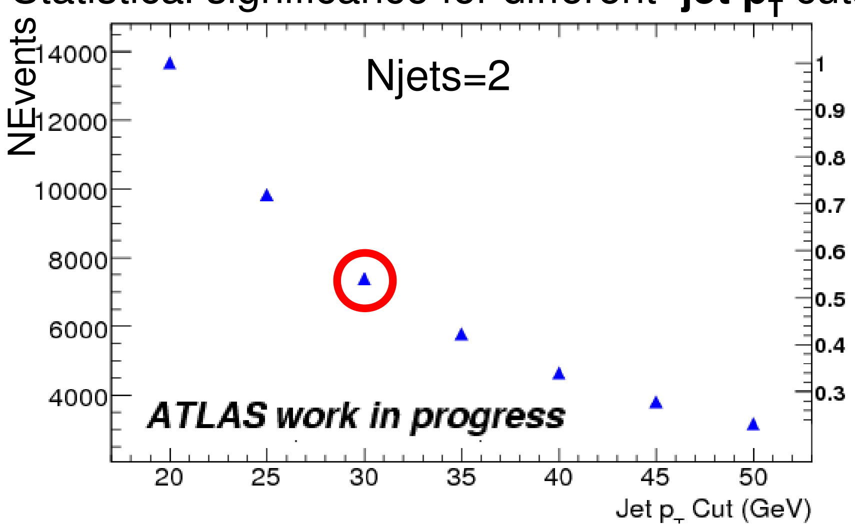
W(eν) + jets cross-section

- Electron p_T > 25 GeV, |η|< 2.5
- Neutrino p_T > 25 GeV
- Jets
  - Algorithm Anti-K_T with R=0.4
  - p_T > 30 GeV, |eta| < 3.1

W Offline selection

- Single isolated electron trigger
- N_{ele} =1 in acceptance + particle identification
- Missing Transverse Energy > 25 GeV

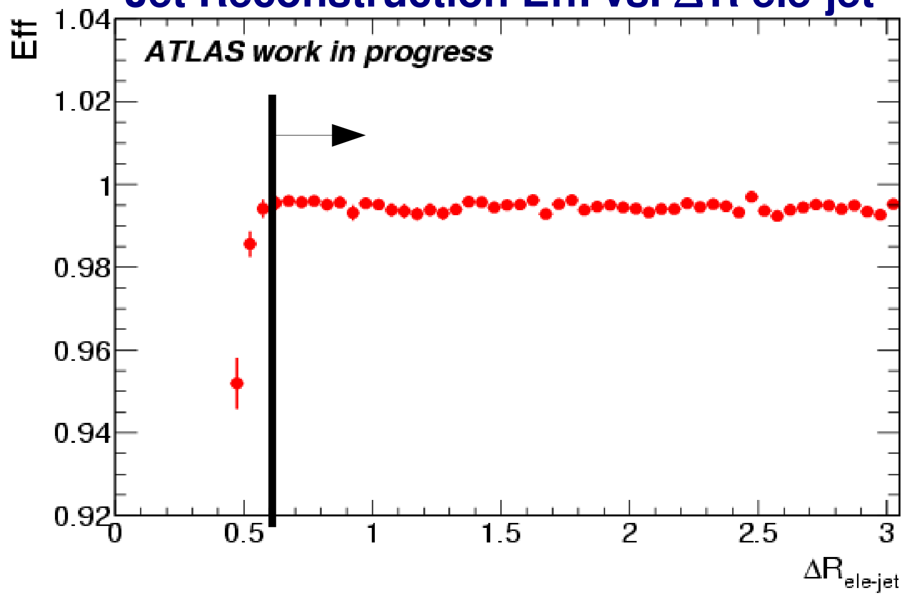
Statistical significance for different **jet p_T** cuts



Additional Event Selection Cuts

- Jet / electron performance deterioration
- Minimum electron-jet separation:
  ΔR ele-jet > 0.6
- Minimum jet-jet separation
  ΔR jet-jet > 0.6

Jet Reconstruction Eff. vs. ΔR ele-jet

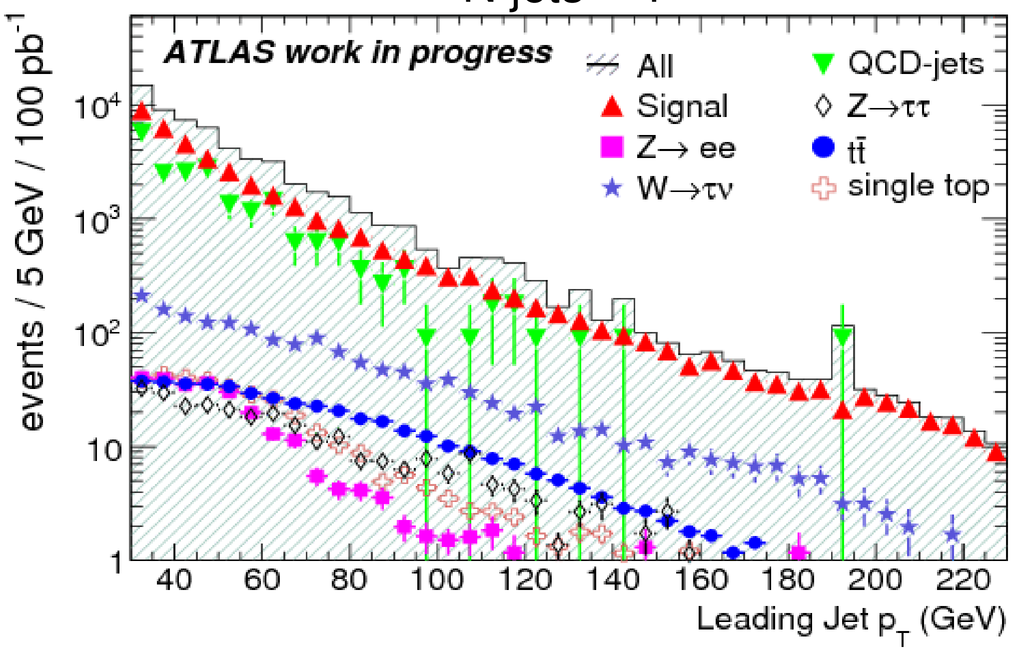


→ Expected statistics for **100 pb^{-1}** at **√s=10 TeV**:
- ~ **36 k** events **N jets=1**
- ~ **8k** events **N jets=2**

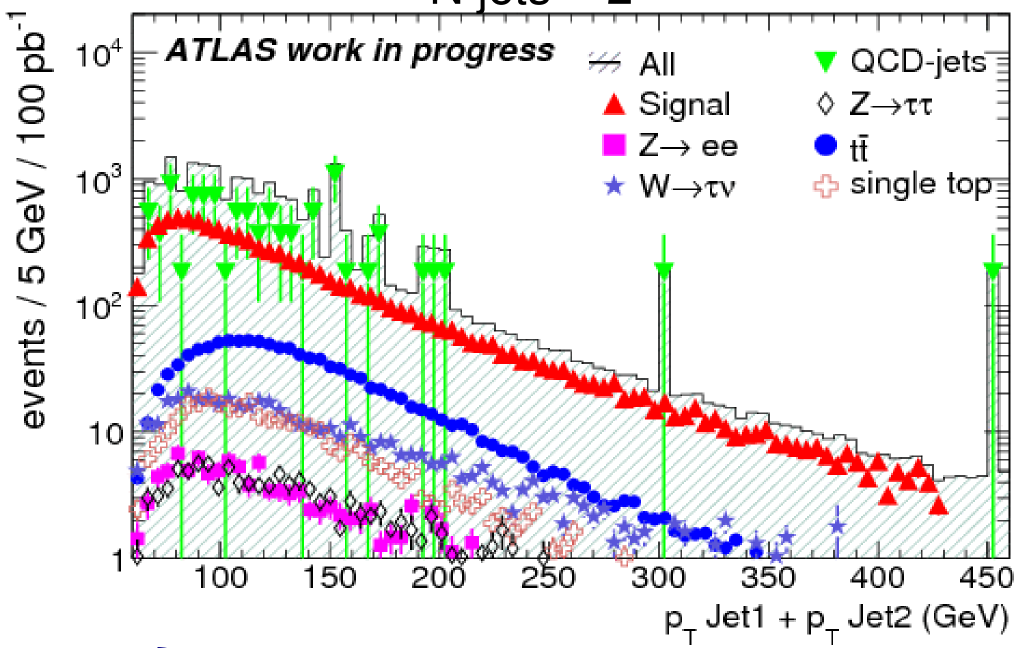
*(~30% less for √s=7 TeV)

Signal and Backgrounds

N jets = 1



N jets = 2



- **QCD-jets:** dominant background, but also the least known:
  - Limited MC statistics + large uncertainties on prod. rate
  - Jet faking an electron + fake missing E_T
- **Single top and top pair production** important at high multiplicity (> 15% for 2 jets)
  - Contain real W from t → Wb
  - For 1-2 jets, ttbar fully-leptonic signature dominates: tt → W(eν) W(lν) bb

→ Data-driven background estimation using cut reversal
- QCD: track/cluster requirements
- Ttbar: btagging

- **Z(ll), W($\tau\nu$)** non negligible backgrounds
  - W($\tau\nu$) important (~5%) and difficult to estimate

→ Lepton vetos
→ Estimation from MC

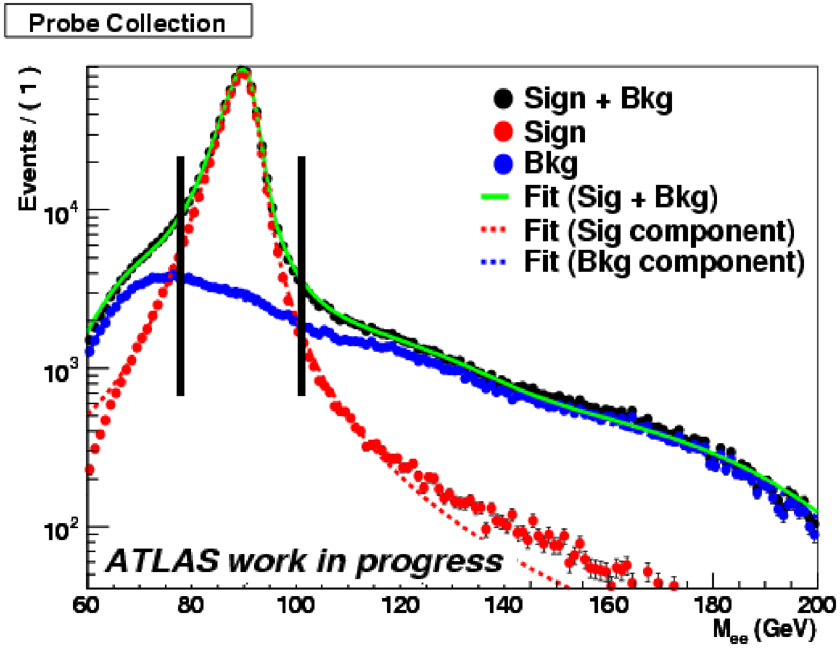
Electron Efficiencies

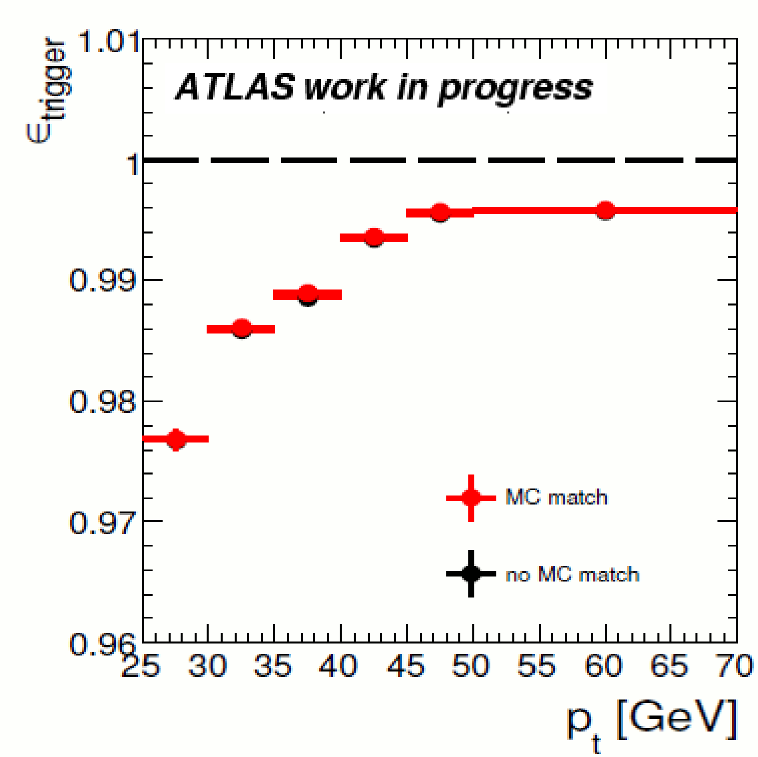
Electron Trigger/Reconstruction efficiencies can be determined using a **data-driven method** on Z→ee:

Tag and Probe (T&P)

- One electron passes tight selection (**Tag**)
- Measure efficiency on 2nd lepton from Z (**Probe**)
- Invariant mass cut to reject background

$$\text{Eff} = \frac{\text{N T\&P pairs (probe passing cuts)}}{\text{N pairs}}$$





- Main **background** from **QCD-jets**
  Background subtraction needed (global fit of S+B)
- Efficiency calculated in steps:

$$\epsilon = \epsilon_{Reco}\ \epsilon_{PID}\ \epsilon_{Trig}$$

ϵ_{Reco} = reconstruction eff

ϵ_{PID} = particle identification eff (wrt reco)

ϵ_{Trig} = trigger eff (wrt PID)

Electron Efficiencies

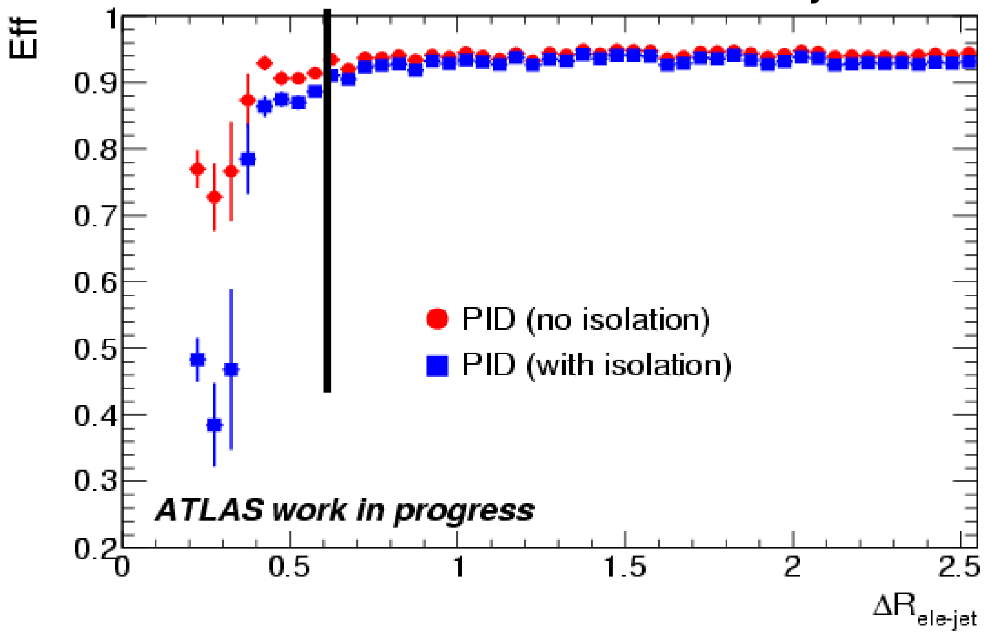
Efficiency dependence on **hadronic activity**

- Strong dependence on **ΔRele-jet** → event selection ΔRele-jet > 0.6 helps!
- Negligible dependence on **jet multiplicity** up to Njets=3 (no isolation)
- For Njets=1, 2 can neglect efficiency dependence on jet variables!
- Need parametrization in electron kinematic variables (**η- p_T**)

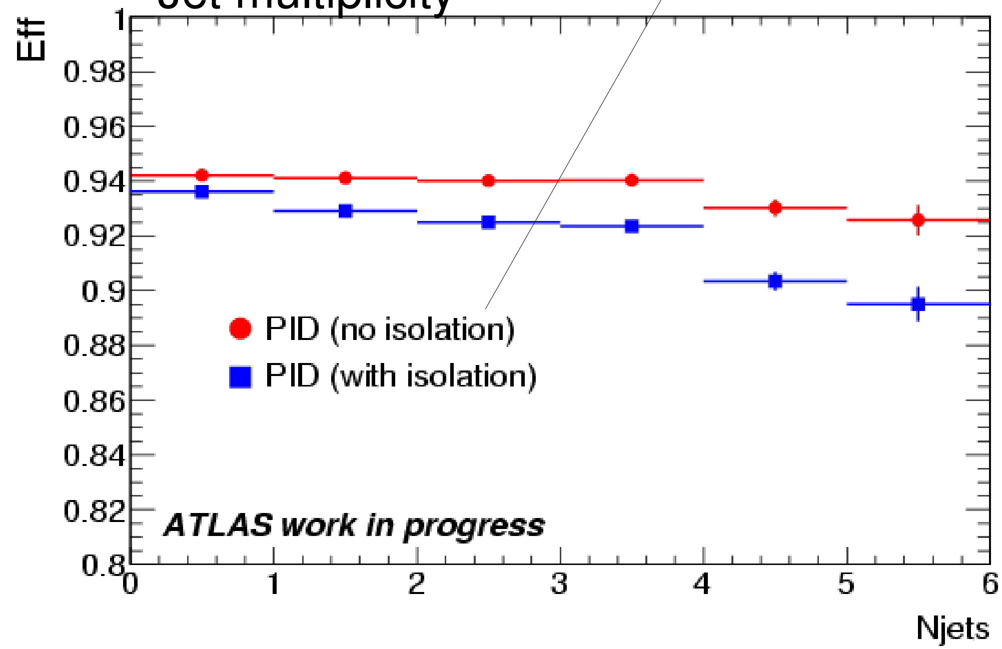
Isolation:

$$\frac{e_T(R < 0.2 \text{ around Ele})}{e_T\,(\text{Cluster})}$$

Distance between electron and jet



Jet multiplicity



Extrapolation of efficiencies form Z to W non-trivial:

- Parametrize efficiencies in η- p_T, (charge due to W asymmetry)
- For **100 pb^{-1}** and **1%** statistical uncertainty few η - p_T bins possible (barrel-endcaps, 4 p_T bins)
- Assess systematic uncertainties on W +jets cross-section from using T&P eff.

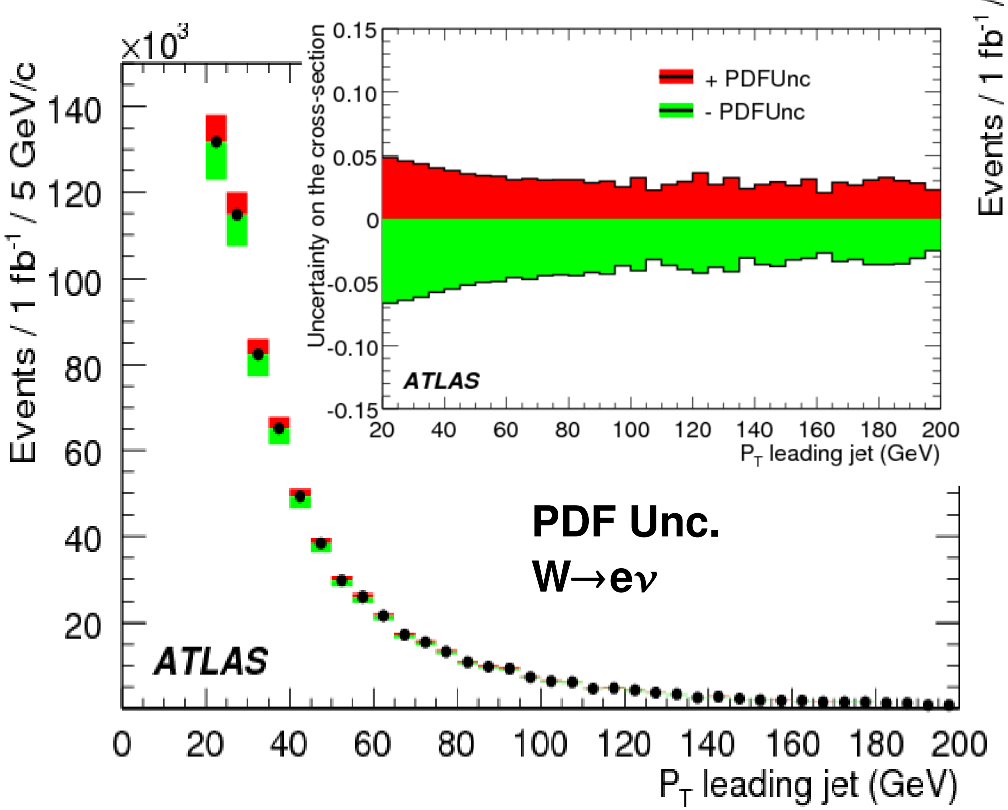
Systematic Uncertainties

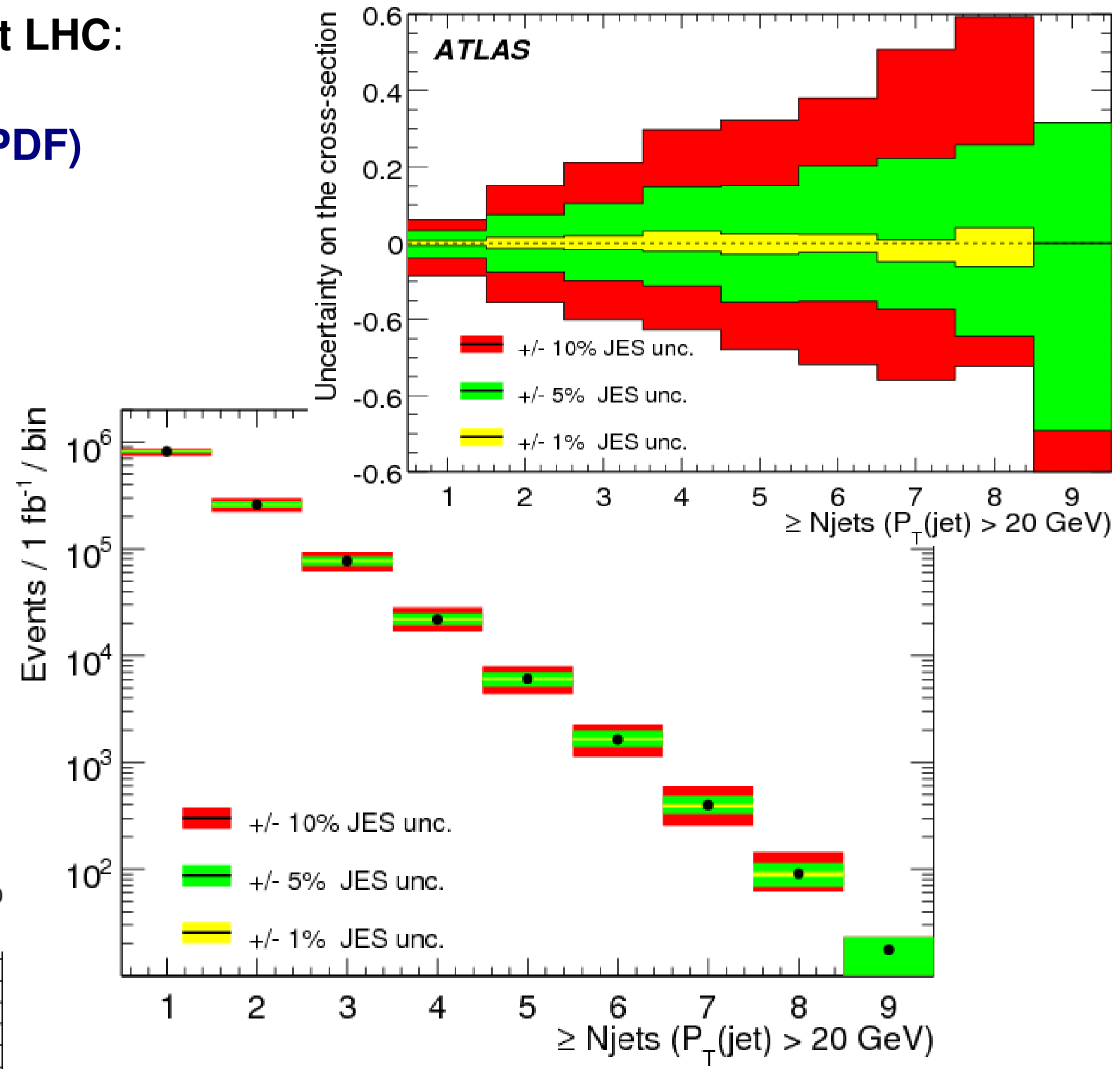
Largest sources of **systematics uncertainties at LHC**:

- Experimental: **Jet Energy Scale (JES)**
- Theoretical: **Parton Distribution Functions (PDF)**

PDF Uncertainties

- Affect every cross-section calculation at LHC
- Evaluated with CTEQ6M
- Effect on cross-section < 5% (low Njets)





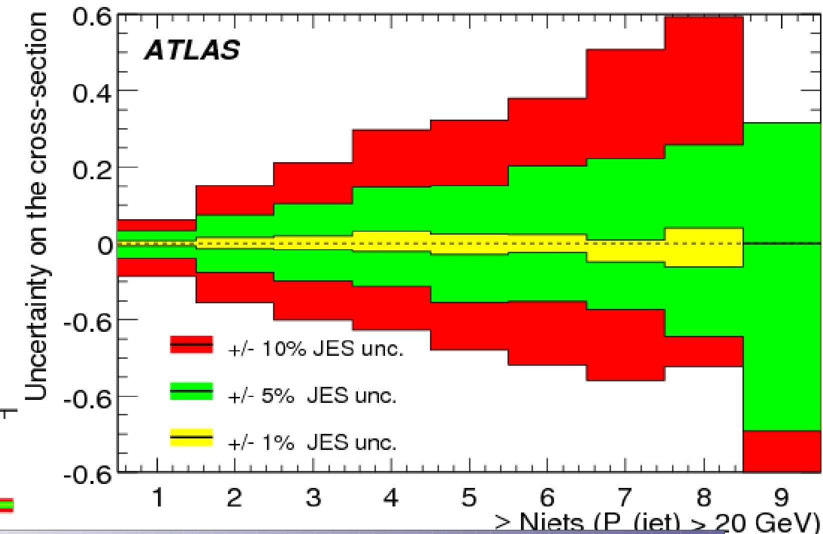
JES Uncertainties

- ATLAS goal: reduce JES uncertainty to 1-2%
- Expectation with early data ~ 5-10%
- Effect on cross-section: 10-20% (JES unc= 5%)

Systematic Uncertainties

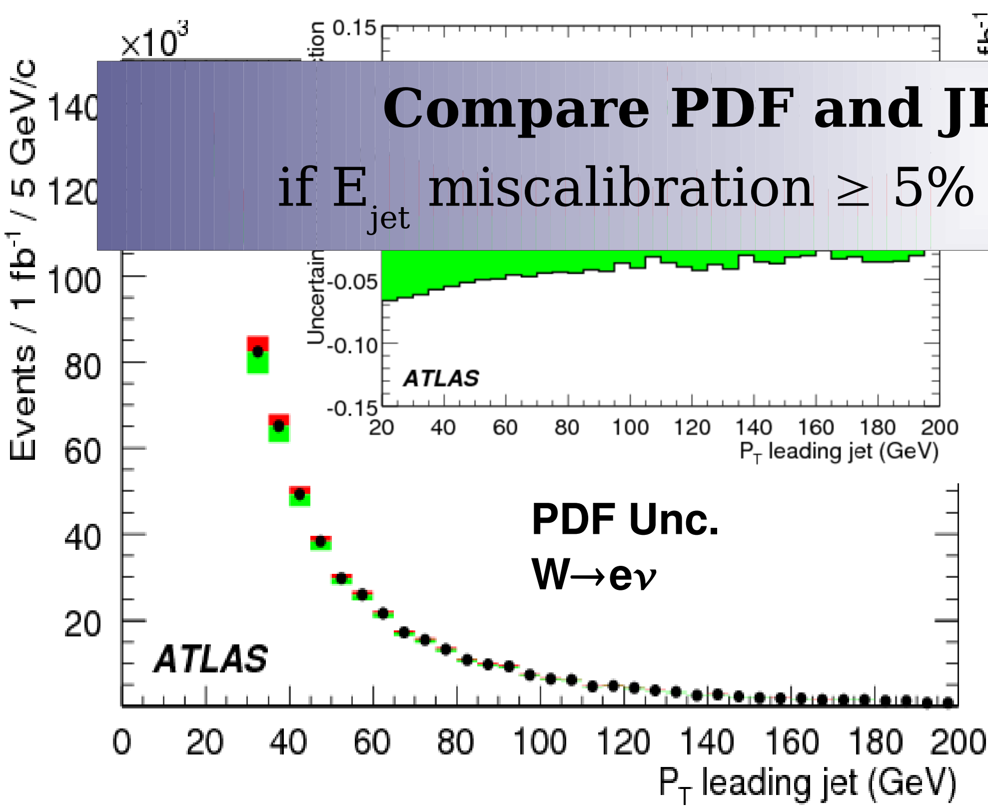
Largest sources of **systematics uncertainties at LHC**:

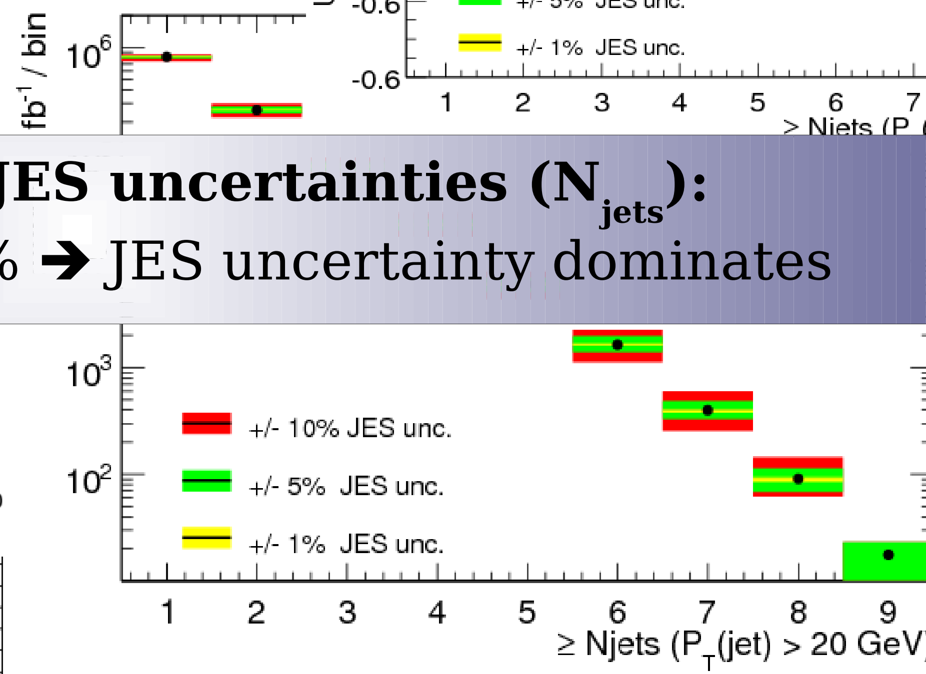
- Experimental: **Jet Energy Scale (JES)**
- Theoretical: **Parton Distribution Functions (PDF)**



PDF Uncertainties

- Affect every cross-section calculation at LHC
- Evaluated with CTEQ6M
- Effect on cross-section < 5% (low Njets)





Compare PDF and JES uncertainties (N_{jets}):

if E_{jet} miscalibration ≥ 5% ➔ JES uncertainty dominates

JES Uncertainties

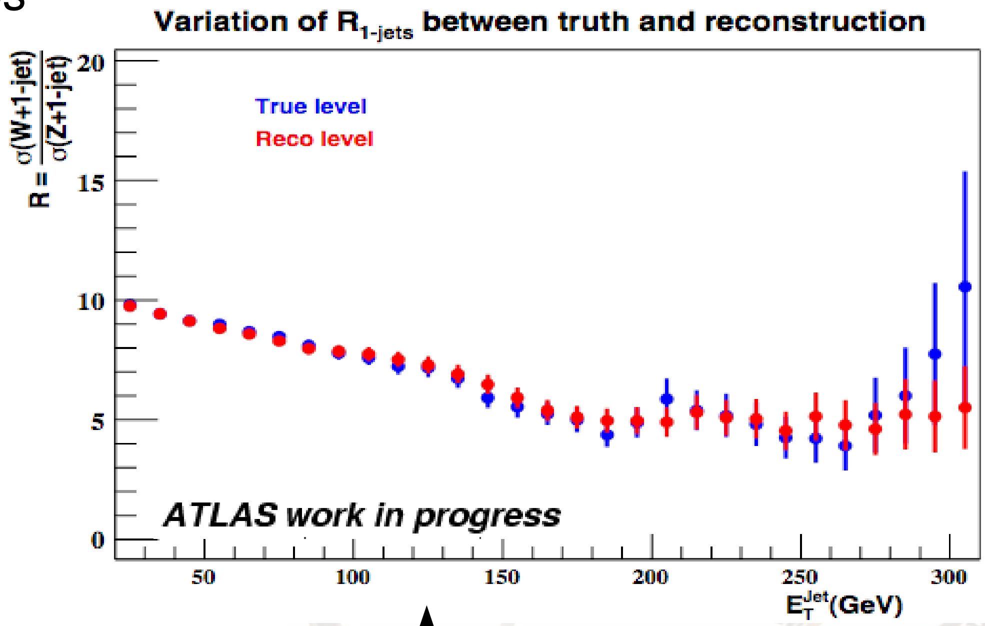
- ATLAS goal: reduce JES uncertainty to 1-2%
- Expectation with early data ~ 5-10%
- Effect on cross-section: 10-20% (JES unc= 5%)

Early data measurement

- Measurement of W+jets cross-section dominated by **systematic uncertainties on jets**
- Robust measurements for early data are ratios

W + jets / Z + jets ratio

- Jet effects cancel (uncert., eff.)
- Luminosity uncertainty cancels
- Need good understanding of:
  - Electron efficiencies
  - Acceptances
  - Backgrounds
- Statistically limited by Z



	W+ 2 jets	Ratio (2 jets)
Jet energy resolution	**5.0%**	**0.4%**
Jet energy scale	**15.0%**	**0.5%**
Lepton energy resolution*	**0.2%**	**0.3%**
Lepton energy scale*	**1.0%**	**0.2%**
Missing Et Resolution*	**<4.5%**	**<4.5%**

* evaluated in μ channel

Cross-section Ratio for Jets :

- Algorithm Anti-K_T, R=0.4
- $p_T > 30$ GeV, $|\eta| < 3.1$
- No cuts on leptons

Statistical uncertainty on R (2 jets) ~ **2.4%** (jet $p_T > 30$ GeV, 100 pb^{-1})

Conclusions

- W + jets is an interesting process on its own (test QCD) and it is crucial for new physics discoveries
- Investigated techniques for measuring W(eν)+jets with focus on:
  - Event selection
  - Backgrounds
  - Efficiencies
- Measurement limited by uncertainties on jets:
  - For early data plan to measure ratio **W+n jets / Z + n jets**
  - Focused on **100 pb^{-1}** of data, but plan to perform first ratio measurement with **10 pb^{-1}** (stat. error 6% for 1 jet bin, 11% for 2 jets)

→ **Looking forward to seeing first Ws and Zs in ATLAS!**

EXTRAS

Anti-Kt Algorithm

- ATLAS default algorithm: sequential recombination algorithm Anti-Kt
- Standard Kt algorithm:
  - $d_{ij} = \min(k_{T\,i}^2, k_{T\,j}^2)\,\Delta R^2_{ij}/D^2$

    *dij is the minimal transverse momenta of one jet wrt to the other

    $\Delta R^2_{ij} = (y_i - y_j)^2 + (\varphi_i - \varphi_j)^2$, i and j can be particle, pre-clusters

    k_T is the object transverse momentum

    D is a parameter of the jet algorithm (~size)
  - $d_i = k_{T\,i}^2$
  - Find smallest distance:
    - if it is d_{ij} : recombine objects i and j
    - If it is d_i: call i a jet and remove it from list of objects
    - Recalculate distances and re-iterate until no objects are left
- Anti-Kt is a generalization:
  - $d_{ij} = \min(k_{T\,i}^{2p}, k_{T\,j}^{2p})\,\Delta R^2_{ij}/D^2$
  - $d_i = k_{T\,i}^{2p}$

    p=-1

➔ Algorithm is infra-red and collinear safe
➔ Generate circular hard jets

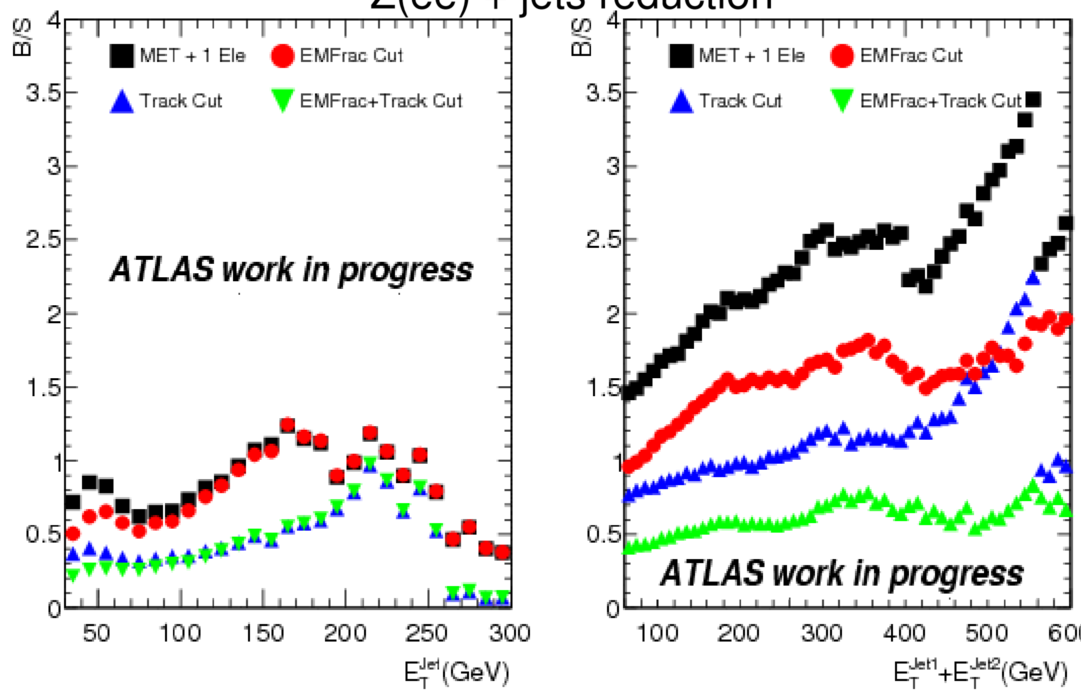
Lepton Vetos

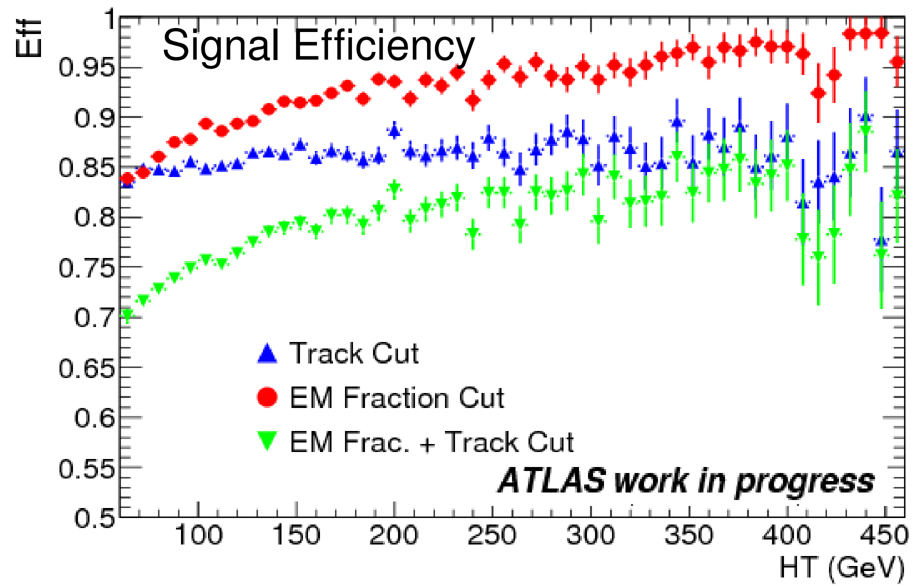
Backgrounds with at least two leptons that can be reduced with a lepton veto:
Z(→ee), **Z(→ττ)**, **ttbar, dibosons (WW, ZZ,WZ)**

Vetos

- **Jets with high EM fraction:**
  - EMFrac = $E_{EM} / (E_{EM}+E_{HAD})$
  - Effective on additional electrons
- **Isolated tracks:**
  - IsoFrac = $\sum_i (p_T^i - p_T^{lept})/p_T^{lept}$
    i=good quality tracks in R=0.4 cone around lepton
  - Effective against electrons and muons

Z(ee) + jets reduction





- Jet EM fraction veto only effective on Z(ee) background
- Isolated track veto reduces also other backgrounds
- Other considerations: signal efficiency, loss in statistics, systematic uncertainties (more later)

Background estimations

➔ **Data-driven techniques** whenever possible to minimize dependence on MC
➔ Different **independent methods** for cross-checking predictions

- **Z(ee), Z($\tau\tau$), dibosons backgrounds**: small and well understood → lepton vetos + estimate from MC
- **W($\tau\nu$)**: important background and difficult to reduce → study additional τ veto?
- **Ttbar production and QCD**: important backgrounds, data-driven methods

Data-driven background estimation

- Define background **control region** by reversing some cuts
  - Extract background **shape**
  - Background shape must not be biased by cut reversal!
  - QCD-jets: reverse cluster/track requirements
  - Ttbar: use b-tagging
- Extract **normalization** from signal region

ttbar background extraction