Observation of $Z \rightarrow \tau\tau \rightarrow e\mu$ with $35.2\,\mathrm{pb}^{-}1$ at ATLAS

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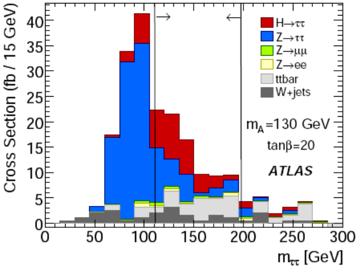
Introduction

- Observation of $Z \to \tau\tau \to e\mu$ with first LHC data recorded by ATLAS detector.
- Measure its cross section, $pp \to Z$, at center of mass energy $\sqrt{s} = 7\,\mathrm{TeV}$.
- Important background to SM and SUSY Higgs decays to two tau leptons.



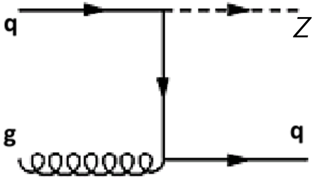
G. Aad et al., Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics CERN-OPEN-2008-020

Remark

- For Higgs hypothesis with low masses $Z \to \tau\tau$ is an irreducible and dominant background because of its similar event topology.

Introduction

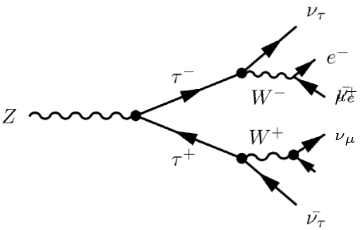
- $Z \longrightarrow \tau\tau$ should be well understood as a background.
- Techniques for invariant mass reconstruction can be tested with $Z \longrightarrow \tau\tau$.



Introduction

Why the leptonic final state?

- branching fraction of $\tau \rightarrow \ell$ only 17.5%
- but di-lepton final state gives high suppression of multijet background
- same flavour lepton final state (ee, $\mu\mu$) suffers from γ^*/Z background
- concentration on different flavour final state $\mathbf{Z} \rightarrow \boldsymbol{\tau\tau} \rightarrow \mathbf{e}\boldsymbol{\mu}$



Event Signature

- Two leptons in the final state.
- Undetectable energy from neutrinos; but noticable as missing transverse energy (negative sum of all transverse energies in the calorimeter).

Backgrounds of $Z \to \tau\tau \to e\mu$

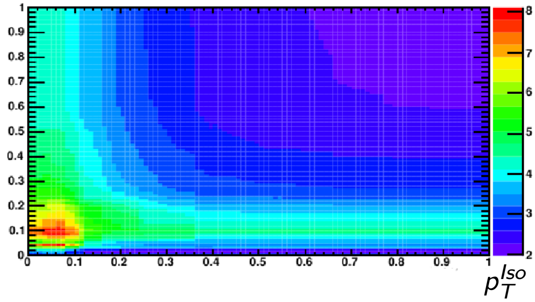
- **QCD multijet** processes with quarks and gluons at matrix level
  - leptons may come from heavy flavour quark decays from jets
  - leptons may imitated by charged hadrons
  - occurance of two leptons of opp. charge is seldom, but cross section is large
- $\boldsymbol{\gamma^*/\mathrm{Z} \to \mathrm{ee}, \mu\mu}$ production of two leptons of opp. charge and same flavour
  - additional jets in the event may produce or fake an additional lepton
- $\boldsymbol{\mathrm{W} \to \ell\nu}$ additional leptons may come from jets in the event
- $\boldsymbol{\mathrm{t\bar{t}}}$ direct background if decay is fully leptonic
  - when decaying semi-leptoni or full-hadronic leptons may come from jets
- **single Top and Di-boson processes** were found to be negligible

Event selection applied to data and Monte Carlo simulation, multijet background estimated from data.
Search for excess in data over background with compatible expectation from MC.

Event Selection

- **Preselection**
  - Selection of data with good quality of needed detector parts
  - Data has to be triggered by an electron with $p_T > 10\,\mathrm{GeV}$ and a muon with $p_T > 6\,\mathrm{GeV}$
- **Electron selection**
  - object has to pass geometrical detector cut, with $p_T > 15\,\mathrm{GeV}$
  - pass identification selection criteria built of calorimeter and track variables
- **Muon selection**
  - object has to pass geometrical detector cut, with $p_T > 10\,\mathrm{GeV}$
  - additional quality requirements of variables from inner detector and muon chambers
- **Dilepton selection** - exactly one electron and muon with opposite charge, passing the lepton requirements, have to be found

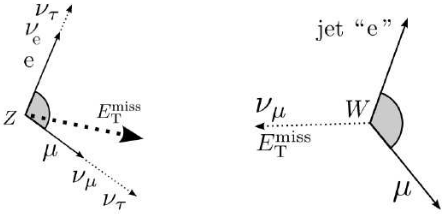
- **Lepton isolation** - multijet suppression
  - in contrast to multijet events, leptons from EW boson decays are isolated in the calorimeter
  - two variables found to give highest background suppression and signal efficiency
    1. sum over p_T of tracks within a cone around lepton divided by lepton p_T, p_T^{Iso}
    2. sum over E_T of of charged and neutral particles in the calorimeter within a cone around lepton divided by lepton p_T, E_T^{Iso}



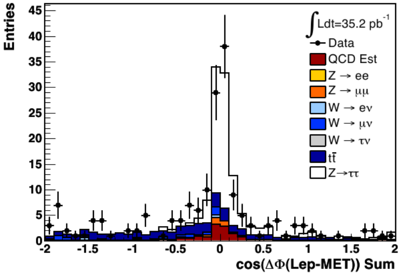
Significance $S/\sqrt{S+B}$ in two-dimensional isolation phase-space of electrons

Event Selection

- **W + Jets suppression**
  - Because of large mass of Z boson w.r.t decay products, τ leptons are boosted.
  - *tau* decay products are approximately collinear
  - E_T^{miss} vector should lie between leptons in transversal plane
  - For W events the second lepton comes from a jet, Jet/"Lepton", neutrino and lepton are balanced.
  - E_T^{miss} vector will not lie in opening angle of leptons.
  - $\sum \cos\Delta\phi = \cos(\phi(e) - \phi(E_T^{miss})) + \cos(\phi(\mu) - \phi(E_T^{miss})) > -0.15$

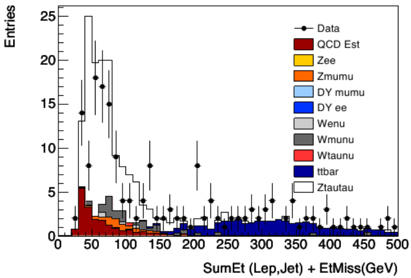


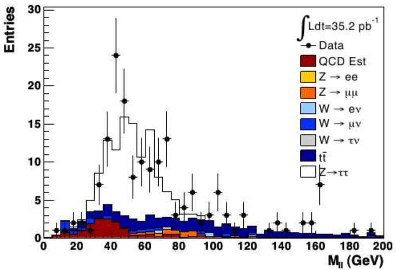
(a) $Z \to \tau\tau \to \mu\nu\nu\, e\nu\nu$ (b) $W \to \mu\nu$



Event Selection

- **$t\bar{t}$ suppression**
  - $t\bar{t}$ events have a topology with high p_T jets, leptons and high E_T^{miss}
  - $E_{T,jets} + E_{T,e} + E_{T,\mu} + E_T^{miss} < 150\,\mathrm{GeV}$
- **Invariant lepton mass**
  - Invariant Di-lepton mass is chosen to be within $25\,\mathrm{GeV} < m_{e\mu} < 80\,\mathrm{GeV}$





Estimation of Background Processes

Normalisation of W background

- Shape and normalisation taken from MC and cross section @NNLO.
- Normalisation checked with data by selecting a $W \rightarrow \ell\nu$ enriched control sample in data.
- Selection of one muon and electron, one of them isolated, and $60\,\mathrm{GeV} < m_T < 100\,\mathrm{GeV}$

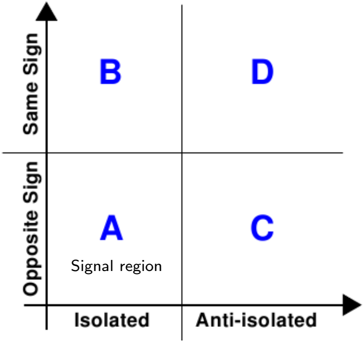
isol. e, antiisol. μ		isol. μ, antiisol. e	
Data	6	Data	17
$W \rightarrow e\nu$	3.11 ± 1.22	$W \rightarrow \mu\nu$	12.0 ± 2.17
Sum MC	3.95 ± 1.23	Sum MC	15.11 ± 2.24

- normalisation of W MC is acceptable

Estimation of Background Processes

Estimation of multijet background

- Because of large cross section simulated samples correspond to low luminosities.
- Kinematic distribution and normalisation have to be gained from data.
- Split data into four regions after cut on one electron and muon.



Assumptions

Electric charge and isolation are uncorrelated.
Event yields in multijet events have same contribution in SS and OS.
Subtract other MC contribution in regions.

Estimation of Background Processes

Estimation of multijet background

From assumption

$$\frac{N_A^{multijet}}{N_B^{multijet}} = \frac{N_C^{multijet}}{N_D^{multijet}}$$

one gets multijet background in signal region A after

- isolation cut $N_A^{multijet} = 16.4 \pm 8.6$ (stat.) ± 3.5 (sys.)
- visible mass $N_A^{multijet} = 3.4 \pm 3.7$ (stat.) ± 0.7 (sys.)

Kinematic distributions are taken from multijet pure region C (Anti-isolated and OS).

Systematics

Theoretical uncertainties

- Cross Section
  - uncertainties estimated at NNLO by varying the factorisation and renormalisation scale, the uncertainty eigenvector of the parton density functions and the strong coupling constant
  - overall uncertainty of 5% on the cross-section of W and Z production, 6% for $t\bar{t}$ is considered

Experimental uncertainties

- Luminosity - uncertainty comes from the beam-scan measurements, estimated to be 11%
- Lepton reconstruction efficiency
  - scale factors applied to MC in order to match refficiency in data
  - factors estimated by tag and probe methods with Z decays

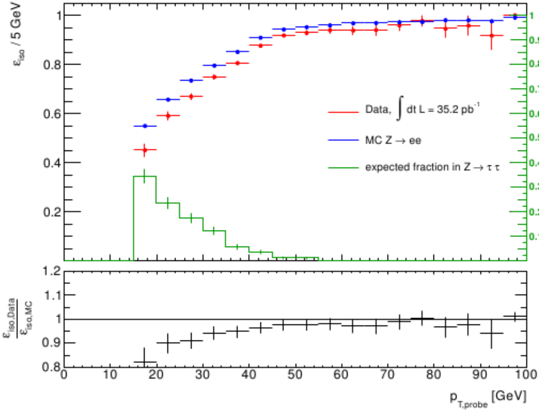
Systematics

Experimental uncertainties

- Lepton energy scale and resolution
  - calorimeter dependent energy and momentum variables shifted by 3% for electrons and by $\approx 1\%$ for muons
  - further energy and momentum variables smeared by Gaussian to evaluate resolution for electrons and muons
- Lepton isolation efficiciency
  - Z decays are selected with tag and probe method - tag lepton has to pass isolation - derive isolation efficiency by asking whether probe lepton passes isolation

Experimental uncertainties

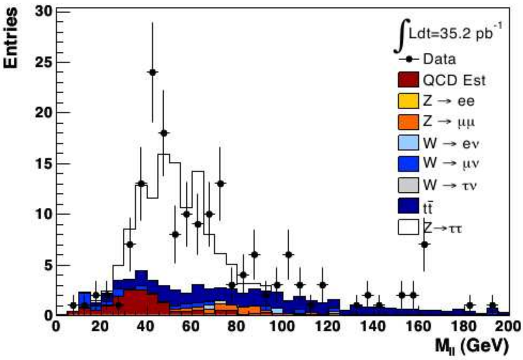
- Lepton isolation eficiciency



Systematics

- largest systematics on $Z \to \tau\tau$ signal MC sample give
    1. electron isolation efficiency 15.5%
    2. luminosity 11%
    3. electron energy resolution 5.8%
    4. other contributions are less than 5%

Observation of $Z \rightarrow \tau\tau \rightarrow e\mu$



Multijet contribution and kinematic distribution estimated from data.

Clear excess of signal over background with compatible MC expectation.

Observation of $Z \rightarrow \tau\tau \rightarrow e\mu$

Samples	Number of candidates
Data	75
$Z \rightarrow \tau\tau$	69.3 ± 5.1 (stat.) ± 15.1 (sys.)
$Z \rightarrow \ell\ell$, W, $t\bar{t}$	3 ± 0.7 (stat.) ± 0.7 (sys.)
multijet background (data)	3.4 ± 3.7 (stat.) ± 0.6 (sys.)
total background	6.4 ± 3.8 (stat.) ± 0.9 (sys.)
Data (after background subtraction)	68.6 ± 3.8 (stat.) ± 0.9 (sys.)