# Estimation of Top Background to SUSY Searches from Data

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## Abstract

**The Standard Model process of $t\bar{t}$ production is one of the most important background to searches for Supersymmetry (SUSY) at the Large Hadron Collider (LHC) at CERN. We describe the methods to estimate the contributions of $t\bar{t}$ decay with one and two leptons in SUSY searches with zero, one or two isolated leptons, multi-jets and large missing transverse energy with the first data of the ATLAS experiment. The performance has been evaluated with simulated data.**

## Motivations

- **SUSY early search strategy: Search for deviations from SM**
  - **Missing transverse energy $E_T^{miss}$ is key SUSY signature**
- **The discovery of new physics can only be claimed when SM backgrounds are well understood and under control**
- **Background should be estimated from data (using data-driven methods) because of limited knowledge of :**

| | |
|---|---|
| Underlying Event | Parton Showering |
| Cross-sections | Parton Distribution Functions |
| Detector Calibration (jets, $E_T^{miss}$) | Limited Monte Carlo statistics |



## Data-Driven Methods

***One approach*** **is to use a pair of uncorrelated variables with signal versus background separation power and to *extrapolate* the background from a background-dominated control region into the signal region.**

**"ABCD" Method**

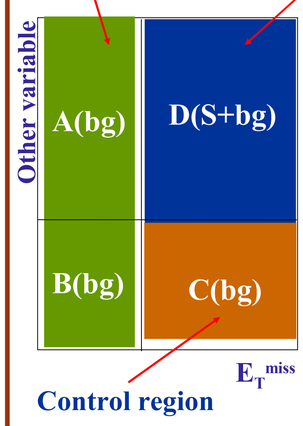
$N_{bg}$ **in signal region D =** $(N_A/N_B)*N_C$

Normalization factor

Control sample

Normalization region

Signal region

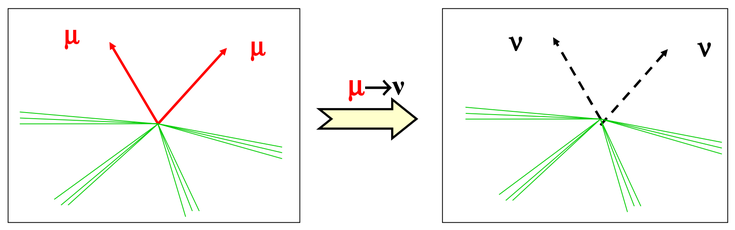



**Key points:**

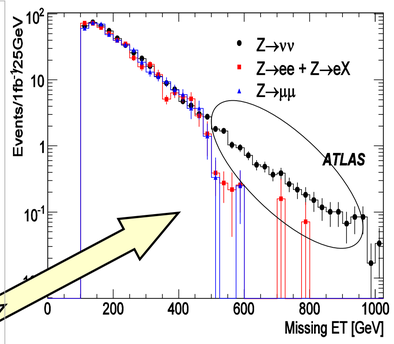
- **The two variables should have good signal discriminating power and small correlation**
- **Control Sample:** enough statistics; small SUSY contamination; provide unbiased estimation of SM background
- **Normalization region selection:** enough statistics; small SUSY contamination; ratio $(N_A/N_B)$ independent of $E_T^{miss}$

**Replacement Method**

**Example: Estimate Z→νν background from Z→ll**




- **Seed Sample: reconstructed Z→ee or Z→μμ events**
- **Replacement: replace charged leptons by neutrinos**
  ($E_T^{miss}$ **is estimated by** $p_T^{(Z)}$ )
- **Apply corrections for:**
  - **lepton efficiency (from data)**
  - **acceptance (from MC)**
- **Derive Z→νν $E_T^{miss}$ distribution:**
  **obtain shape in low statistics region by extrapolation or MC simulation**



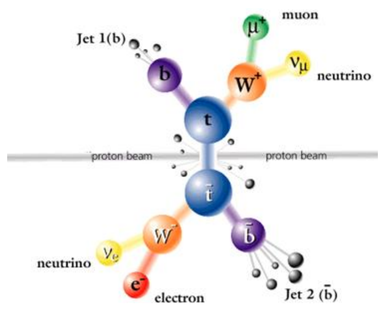



## Method of Top Background Estimation

### Di-leptonic top background in two-lepton SUSY search mode

- **Apply standard 2 lepton SUSY selection cuts**
- **Select b-jet pair candidates from the permutations of 4 leading jets**
- **Apply the kinematic constraints:**

$$m_W^2 = (p_{l1} + p_{\nu 1})^2$$
$$m_W^2 = (p_{l2} + p_{\nu 2})^2$$
$$m_t^2 = (p_{l1} + p_{\nu 1} + p_{b1})^2$$
$$m_t^2 = (p_{l2} + p_{\nu 2} + p_{b2})^2$$
$$E_x^{miss} = p_{(\nu 1)x} + p_{(\nu 2)x}$$
$$E_y^{miss} = p_{(\nu 1)y} + p_{(\nu 2)y}$$

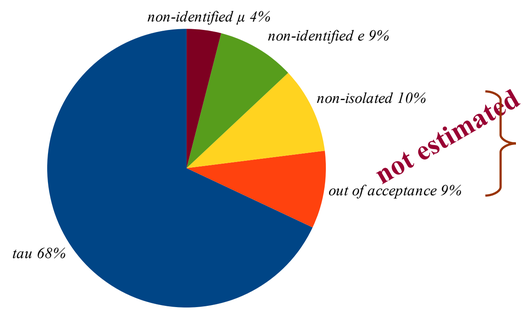


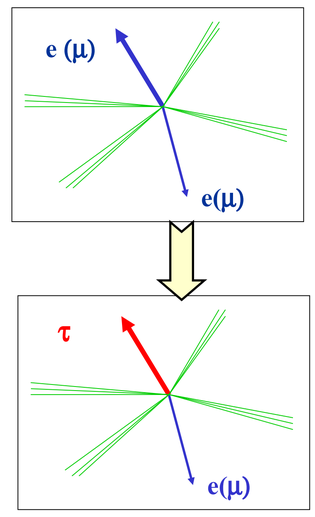

- **Control sample: events with at least one b-jet pair fulfilling the system of equations**
- **Apply "ABCD" method**
- **The result is very similar to the one-lepton mode result**



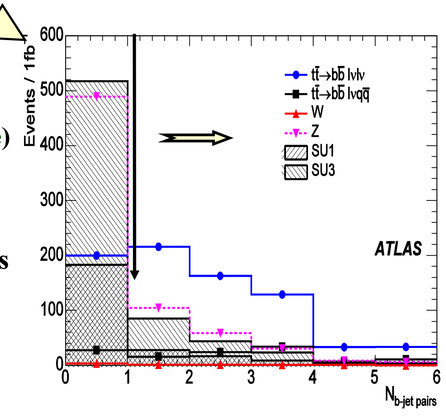
### Di-leptonic top background in one-lepton SUSY search mode

**One lepton can be missing in di-leptonic $t\bar{t}$ :**




- **Select seed events (pure di-leptonic $t\bar{t}$ ):**
  - **Require 2 leptons and n-1 jets [1]**
  - **Require at least one b-jet pair**
- **Estimate di-leptonic top by:**
  - **Replace the reconstructed lepton by**
    - **τ(tau contribution)**
    - **or by an electronic jet (non-identified e)**
    - **or remove muon (non-identified μ )**
  - **Apply efficiency correction**
  - **Recalculate all discrimination variables ($E_T^{miss}$, $M_{eff}$ [2], $N_{jets}$, …)**
  - **Apply one-lepton mode cuts (4 jets, 1 lepton, $E_T^{miss}$, $m_T$ [3], $S_T$ [4], …)**




**Seed sample:** 2 leptons, (n-1) jets, ≥1 bjet pair → Replace lepton by tau / Replace lepton by jet or remove muon → Apply one-lepton mode cuts → **Control Sample** → Normalize in low $E_T^{miss}$ of 80-120 GeV → **Signal Sample**

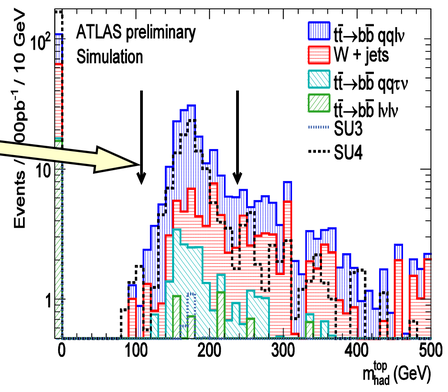
1) n is number of jets required in the SUSY search
2) $M_{eff}$ is defined as: $M_{eff} = E_T^{miss} + \sum_{jets} E_T^{(j)} + \sum_{leptons} E_T^{(l)}$
3) $m_T$ is defined as: $m_T^2 = 2(|p_T^l| |E_T^{miss}| - p_T^l \cdot p_T^{miss})$
4) $S_T$ is transverse sphericity

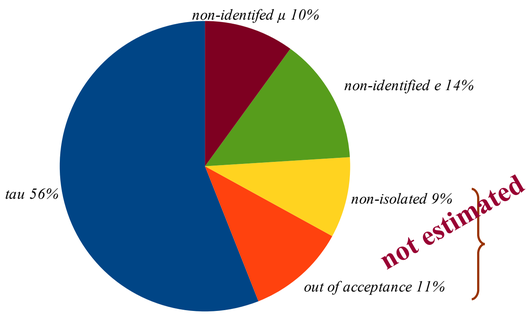


### Semi-leptonic top background in no-lepton SUSY search mode

**One lepton can be missing in semi-leptonic $t\bar{t}$:**

- **Select seed events (pure semi-leptonic $t\bar{t}$):**
  - **Require 1 lepton and n-1 jets**
  - **Apply mass cut of hadronic top decay**
- **Estimate semi-leptonic top by:**
  - **Replace the reconstructed lepton**
    - **by τ (tau contribution)**
    - **or by an electronic-jet (non-identified e)**
    - **or remove muon (non-identified μ)**
  - **Apply efficiency correction**
  - **Recalculate all discrimination variables ($E_T^{miss}$, $M_{eff}$, $N_{jets}$, …)**
  - **Apply no-lepton mode cuts (4 jets, no lepton, $E_T^{miss}$, $S_T$, …)**



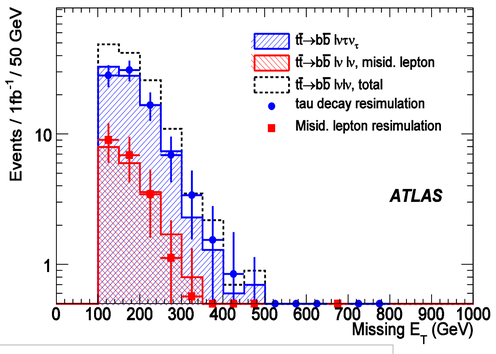




**Seed sample:** 1 lepton, (n-1) jets, hadronic top mass cut → Replace lepton by tau / Replace lepton by jet or remove muon → Apply no-lepton mode cuts → **Control Sample** → Normalize in low $E_T^{miss}$ of 80-120 GeV → **Signal Sample**

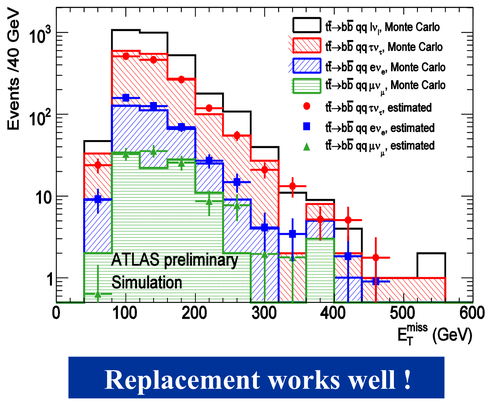


## How well does the method work?

### Di-leptonic top background in one-lepton SUSY search mode




### Semi-leptonic top background in no-lepton SUSY search mode

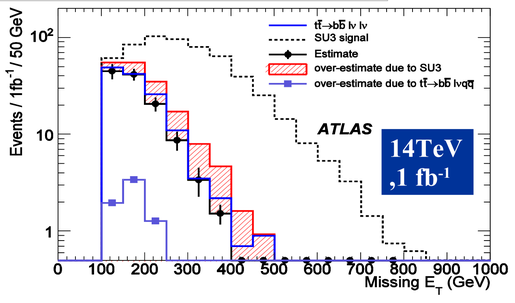


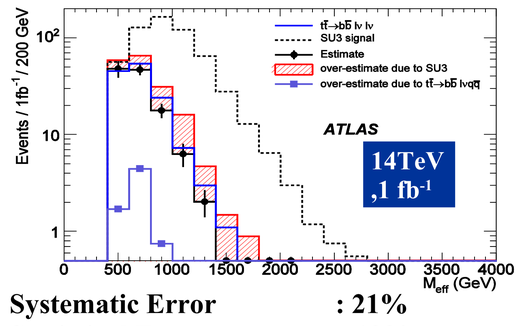

**Replacement works well !**



## Results

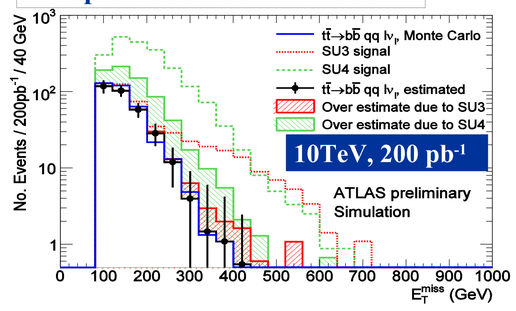
### Di-leptonic top background in one-lepton SUSY search mode

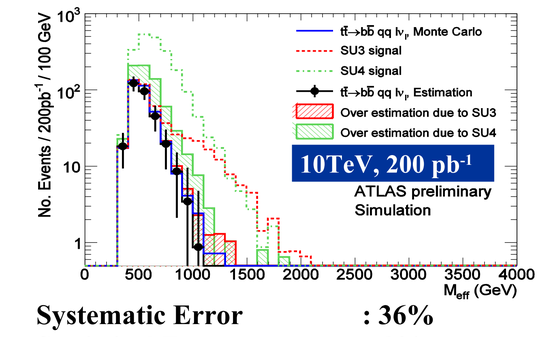



**Systematic Error : 21%**
**Statistical Error : 12%**
**Over-estimate due to SU3 [5] : 41%**

### Semi-leptonic top background in no-lepton SUSY search mode




**Systematic Error : 36%**
**Statistical Error : 8%**
**Over-estimate due to SU3 : 4%**
**Over-estimate due to SU4 [6] : 110%**

**The shaded areas show background over-estimation due to SUSY contamination**

5) SU3 is mSUGRA ATLAS Benchmark point with SUSY scale 600 GeV
6) SU4 is mSUGRA ATLAS Benchmark point with SUSY scale 400 GeV



## Summary

- **Data-driven methods for top background estimation in the no, one and two-lepton SUSY search modes have been developed and tested with the Monte Carlo simulation**
- **Systematic uncertainties for three different channels have been studied in details**
- **Further information**
  - **ATL-PHYS-PUB-2009-083**
  - **CERN-OPEN-2008-020**
- **Several complementary methods of background estimation are an important ingredient of claims of SUSY discovery**



Poster presented at "Lepton-Photon 2009 -LP09", Hamburg, Germany