Search for the Standard Model Higgs boson in the $H \to ZZ^{(*)} \to 4\ell$ channel with the ATLAS detector

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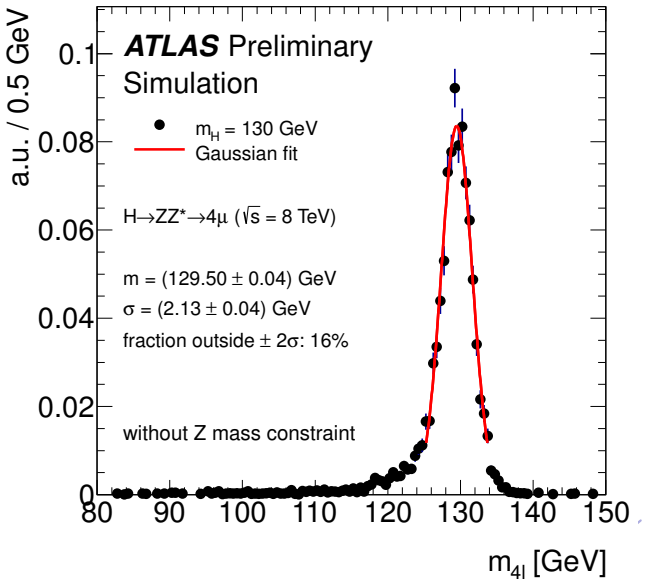
Outline

Introduction

- $H \to ZZ^{(*)} \to 4\ell(\ell = e, \mu)$
  1. Clean signature, 4 leptons, $\frac{S}{B} \sim 1$
  2. Narrow peak, mass fully reconstructed.
  3. Benefits from excellent electron and muon resolution
- Backgrounds
  1. Irreducible: $ZZ^{(*)}$, same final state, isolated leptons
  2. Reducible: $Zb\bar{b}$, Z+jets , $t\bar{t}$
- Data
  1. 7 TeV data sample, 4.8 fb^{-1}
  2. 8 TeV data sample, 5.8 fb^{-1}



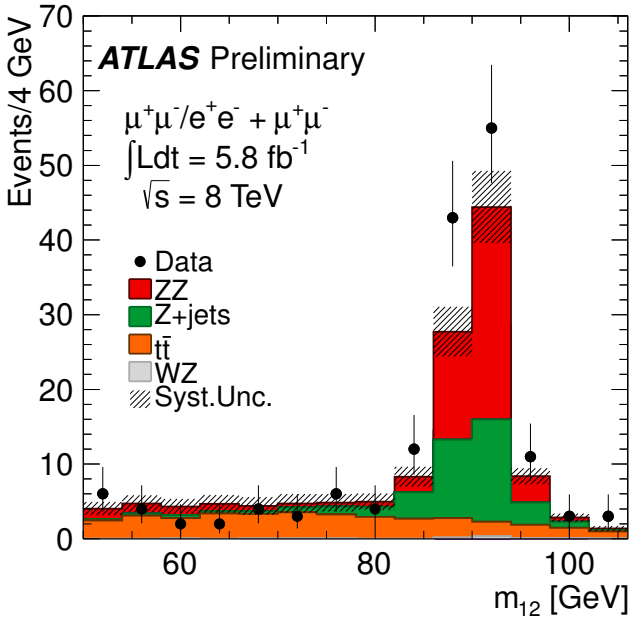
Event Selection

- Optimized phase space to enhance low mass sensitivity
  1. $p_T^{1,2,3,4} > 20, 15, 10, 7$ GeV (6 GeV for μ)
  2. Leading di-lepton mass : $50 < m_{12} < 106 GeV$
  3. Sub-leading di-lepton mass : $m_{thr}(m_{4l}) < m_{34} < 115 GeV, m_{thr} = 17.5 - 50 GeV$
- Additional requirements to reduce background
  1. calorimeter isolation
  2. track isolation
  3. impact parameter significance
- Z mass constraint of leading Z

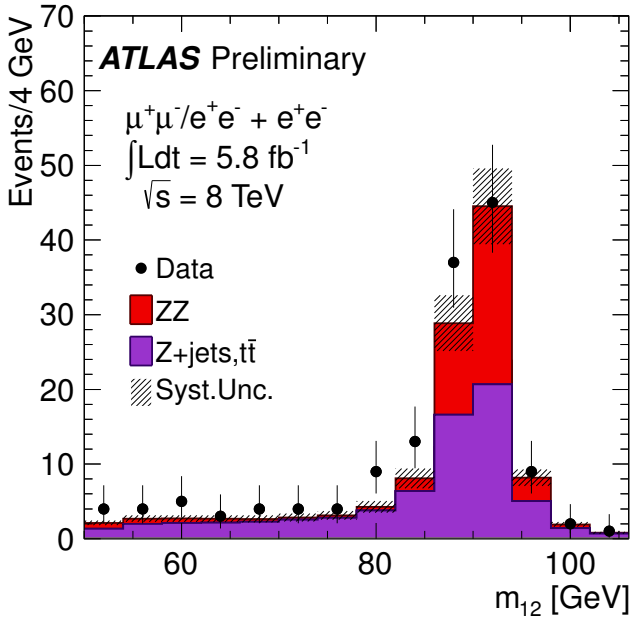
Control region

Control region is defined by removing isolation/impact parameter requirements.

- Dominant background is different in case of sub-leading pair flavor.
- Background estimation is separated into $\ell\ell + \mu\mu$ and $\ell\ell + ee$.
  1. $\ell\ell + \mu\mu$: main background $Zb\bar{b}$ and $t\bar{t}$, from semi-leptonic b-decays
  2. $\ell\ell + ee$: main background Z+jets and $Zb\bar{b}$, from conversions and mis-identified hadrons



(a) $\ell\ell + \mu\mu$

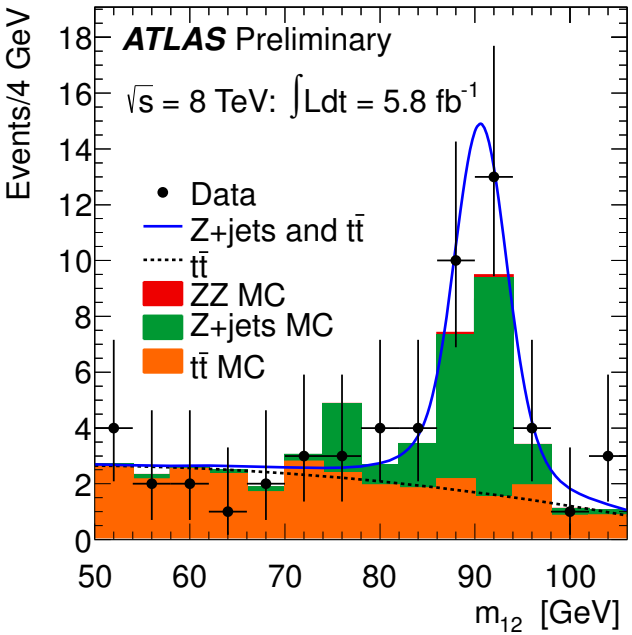


(b) $\ell\ell + ee$

$\ell\ell + \mu\mu$ final state

Baseline method

- Control region: sub-leading pair fails impact parameter requirement
- m_{12} is clearly separated for the 2 main background, $Zb\bar{b}$ and $t\bar{t}$.
- Fitting m_{12} to get yields from the 2 components.
- Extrapolation to signal region using transfer factor from MC



- Systematic error of transfer factor is obtained by comparing MC and data efficiency in Z+μ control region
- Result compatible with cross check methods

$\ell\ell + ee$ final state

- Fake e sources
  1. Hadrons (F)
  2. Conversions (C/γ)
  3. Semi-leptonic decays of heavy flavor/ electron-like (E/Q)
- To distinguish these sources, use
  1. TRT ratio: the fraction of high threshold hits in the Transition Radiation Tracker
  2. B-layer hits: number of hits in the innermost layer of the Pixel Detector barrel region
  3. f1: Fraction of energy in first sampling of e/m calorimeter

Baseline method

- Relax identification in sub-leading di-electron, and categorize events.
- Use categorization to check MC description
- Extrapolate yields in each category to the signal region

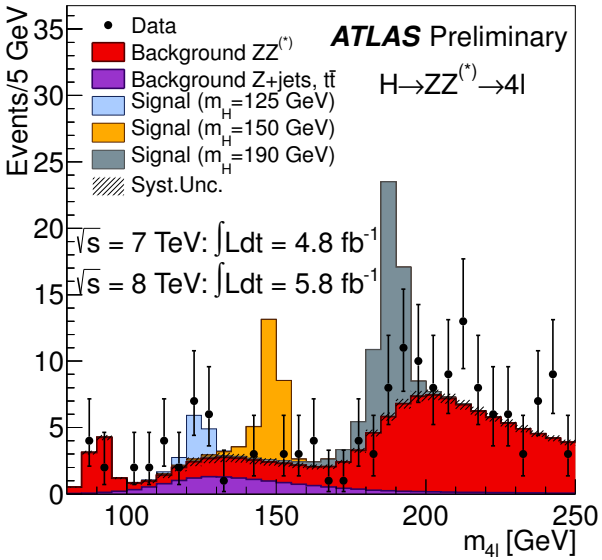
	$4e$		$2\mu 2e$	
	Data	MC	Data	MC
EE	32	22.7±4.8	31	24.9±5.0
EC	6	6.0±2.5	2	1.9±1.4
EF	18	19.0±4.4	26	15.3±3.9
CE	4	8.8±3.0	6	5.1±2.3
CC	1	5.3±2.3	6	4.2±2.0
CF	12	8.8±3.0	15	15.3±3.9
FE	16	5.7±2.4	12	8.4±2.9
FC	6	6.5±2.6	7	4.3±2.1
FF	12	17.4±4.2	16	33.6±5.8
Total	107	100±10	121	113±11

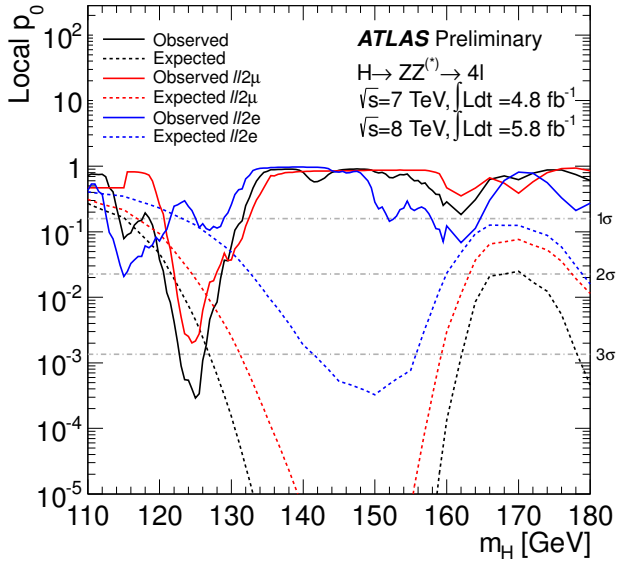
Background Estimation result at 8 TeV

Method	Estimated number of events
4μ	
m_{12} fit: $Z+\text{jets}$ contribution	$0.51\pm 0.13 \pm 0.16^{\dagger}$
m_{12} fit: $t\bar{t}$ contribution	$0.044\pm 0.015\pm 0.015^{\dagger}$
$t\bar{t}$ from $e^{\pm}\mu^{\mp}+\mu^{\pm}\mu^{\mp}$	$0.058\pm 0.015\pm 0.019$
$2e2\mu$	
m_{12} fit: $Z+\text{jets}$ contribution	$0.41\pm 0.10 \pm 0.13^{\dagger}$
m_{12} fit: $t\bar{t}$ contribution	$0.040\pm 0.013\pm 0.013^{\dagger}$
$t\bar{t}$ from $e^{\pm}\mu^{\mp}+\mu^{\pm}\mu^{\mp}$	$0.051\pm 0.013\pm 0.017$
$2\mu 2e$	
$\ell\ell+e^{\pm}e^{\mp}$	$4.9\pm 0.8 \pm 0.7^{\dagger}$
$\ell\ell+e^{\pm}e^{\pm}$	$4.1\pm 0.6 \pm 0.8$
$3\ell+\ell$ (same-sign)	$3.5\pm 0.5 \pm 0.5$
$4e$	
$\ell\ell+e^{\pm}e^{\mp}$	$3.9\pm 0.7 \pm 0.8^{\dagger}$
$\ell\ell+e^{\pm}e^{\pm}$	$3.1\pm 0.5 \pm 0.6$
$3\ell+\ell$ (same-sign)	$3.0\pm 0.4 \pm 0.4$

The †' symbol indicates the estimated number of events used for the background normalization, the others being cross-checks.

Combined results with 7 TeV and 8 TeV data





- Combining datasets, observe 3.4σ excess at $m_H = 125\,GeV$
- Becomes 2.5σ when accounting for the look-elsewhere effect
- Best-fit value for $m_H = 125\,GeV$: $\mu = 1.3 \pm 0.6$

Summary

- Presented search for $H \to ZZ \to 4\ell$
  1. Optimized 2011 7 TeV data (4.8 fb^{-1})
  2. New added 2012 8 TeV data (5.8 fb^{-1})
- Developing robust background estimation methods
- Observe 3.4σ excess at $m_H = 125 GeV$, 2.5σ after look-elsewhere effect
- Best signal strength $\mu = 1.3 \pm 0.6$
- More details will be given in Luis's talk.

BackUp

$\ell\ell + \mu\mu$ final state

- Alternative method for $t\bar{t}$ estimation
  1. Analysis selection, but $e\mu$ leading di-lepton and $Z \to \ell\ell$ veto
  2. Extrapolation to signal region
  3. compatible results with m_{12} fit

$\ell\ell + ee$ final state

Alternative method

- Require sub-leading pair same sign
- Relax the electron identification of the last energetic one
- Composition from maximum likelihood fit
  1. Simultaneous fit of b-layer hits and TRT ratio
  2. Template from Z+X MC
  3. Less sensitive to Q component, fix from MC
- Efficiency from Z+X MC