W/Z production associated with a H or a Z boson decaying to a $b\bar{b}$ pair

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8th-10th April 2013 - IoP HEPP and APP Meeting - Liverpool
Latest public results on the production of a vector boson decaying leptonically produced in association with a Z or a H boson decaying to a b\bar{b} pair.

✧ Motivation
✧ Event selection and analysis strategy
  ✧ Signal and background modeling
✧ Statistical treatment
  ✧ Higgs fit ingredients
  ✧ Validation on VZ(Z\rightarrow b\bar{b})
  ✧ VH(H\rightarrow b\bar{b}) results
✧ Summary and conclusions

Analysis performed on datasets:
✧ 13.0 fb\(^{-1}\) for \(\sqrt{s}=8\) TeV
✧ 4.7 fb\(^{-1}\) for \(\sqrt{s}=7\) TeV
Motivation

Higgs mechanism explains **EW Symmetry breaking**
In SM coupling to the **scalar** Higgs field, vector bosons and fermions acquire mass

**Several Production channels:**

Other production mechanisms cannot be exploited because of QCD background ≈9 order of magnitudes larger

**Method** used in $H\rightarrow b\bar{b}$ searches, look for associated production with:

- $W/Z$ and exploit **leptonic** vector bosons decays
- Exploit distinct signature in the detector.

$H\rightarrow b\bar{b}$ observation → test of direct coupling with fermions.
Event selection strategy

Three separate channels exploiting all possible leptonic V decays
(naming convention: lepton = charged lepton):

\[ ZH \rightarrow v\bar{v}b\bar{b} \text{ - “0 lepton”} \]
\[ WH \rightarrow lvb\bar{b} \text{ - “1 lepton”} \]
\[ ZH \rightarrow l^+l^-b\bar{b} \text{ - “2 lepton”} \]

0-lepton channel has significant contribution from lvb\bar{b} events with undetected charged leptons

Tag signature via V→leptons

- **0-lepton** → high \( E_t^{miss} \)
- **1-lepton** → identify W:
  - 1 high-\( p_T \) lepton + \( E_t^{miss} \) + W \( m_T \) cut
- **2-lepton** → identify Z:
  - 2 high \( p_T \) leptons + Z mass cut

\[ H \rightarrow b\bar{b} \text{ - jet selection} \]

- 2 or 3 jets final states
- 2 b-tagged jets
- b-tagging 70% efficient with 1% fake rate
WH candidate

a WH→μνb̄b event candidate

Run: 207620
Event: 101402870
Date: 2012-07-29
Time: 00:05:11 UTC
Analysis strategy

Strategy:
look for excess in $m_{b\bar{b}}$ (di-b-jet system invariant mass) distribution

- Exploit growth of $S/\sqrt{B}$ as a function of recoiling $Vp_t$
Analysis strategy

Strategy:
look for excess in $m_{b\bar{b}}$
(di-$b$-jet system invariant mass) distribution

△ Exploit growth of $S/\sqrt{B}$ as a function of recoiling $V \ p_t$
⇒ divide $m_{b\bar{b}}$ in bins of $p_t^V$

Chiara Debenedetti - ATLAS VH($H\rightarrow bb$), VZ($Z\rightarrow bb$) - 09.04.2013 - IoP meeting, Liverpool
Signals and backgrounds

Background-dominated analysis
Rely on different techniques to estimate shape and normalisation

- QCD multijet → data-driven
- Diboson → MC prediction
- V+I/c → shape from MC and normalisation from data (template fit to extract V+jets flavor fraction)
- V+b,top → shape from MC and normalisation from data (profile likelihood fit)

Examples of background composition

0 lepton - W+jets, Z+jets, top
1 lepton - W+jets, top
2 lepton - Z+jets
Statistical treatment - definitions

- **Profile likelihood fit** gives interpretation of result
- **Aim**: understand how much the data (dis)agree with the proposed model
- **Hypothesis testing**: signal+background hp vs null (background only) hp
Statistical treatment - definitions

- Profile likelihood fit gives interpretation of result
- Aim: understand how much the data (dis)agree with the proposed model
- Hypothesis testing: signal+background hp vs null (background only) hp

Each bin can be represented by a Poisson likelihood:

\[ L(\mu) = \frac{(\mu s + b)^n}{n!} e^{-(\mu s + b)} \]

**Useful definitions:**

- Parameter of interest \((\mu)\) - specifies difference between null \((\mu=0)\) and test hypothesis \((\mu=1)\)
Statistical treatment - definitions

- **Profile likelihood fit** gives interpretation of result
- **Aim**: understand how much the data (dis)agree with the proposed model
- **Hypothesis testing**: signal+background hp vs null (background only) hp

\[
L(\mu, \theta) = \prod_{i=1}^{N} \frac{(\mu s_i + b_i)^{n_i}}{n_i!} e^{-(\mu s_i + b_i)}
\]

- **Profile likelihood fit**
- **Aim**: understand how much the data (dis)agree with the proposed model
- **Hypothesis testing**: signal+background hp vs null (background only) hp

**Useful definitions:**
- **Parameter of interest** \((\mu)\) - specifies difference between null \((\mu=0)\) and test hypothesis \((\mu=1)\)
- **Nuisance parameters** \((\theta)\) - all additional parameters the model depends on (systematic errors)
Profile likelihood ratio

\[ \lambda(\mu) = \frac{L(\mu, \hat{\theta})}{L(\hat{\mu}, \hat{\theta})} \]

\( \lambda \geq 0 \leq 1 \)

- Numerator: **conditional** fit (\( \mu \) is not determined by the fit - fixed)
- Denominator: **unconditional** fit (\( \mu \) is a parameter of the ML fit)

Nuisance parameters for conditional and unconditional fit
Profile likelihood ratio

\[ \lambda(\mu) = \frac{L(\mu, \hat{\theta})}{L(\hat{\mu}, \hat{\theta})} \]

- Numerator: conditional fit (\( \mu \) is not determined by the fit - fixed)
- Denominator: unconditional fit (\( \mu \) is a parameter of the ML fit)

Define test statistic: \[ t_\mu = -2 \ln \lambda(\mu) \] (Log Likelihood Ratio)

Evaluated for 3 cases:
- \( n_i \) = background hp \( \rightarrow \) distribution of \( t_\mu \)
- \( n_i \) = signal + background hp \( \rightarrow \) distribution of \( t_\mu \)
- \( n_i \) = observed data \( \rightarrow \) one value

\[ L(\mu, \theta) = \prod_{i=1}^{N} \frac{(\mu s_i + b_i)^{n_i}}{n_i!} e^{-(\mu s_i + b_i)} \]
Profile likelihood ratio

\[ \lambda(\mu) = \frac{L(\mu, \hat{\theta})}{L(\hat{\mu}, \hat{\theta})} \]

\( \text{NB: } 0 \leq \lambda \leq 1 \)

- Numerator: conditional fit (\( \mu \) is not determined by the fit - fixed)
- Denominator: unconditional fit (\( \mu \) is a parameter of the ML fit)

Define test statistic: \( t_\mu = -2 \ln \lambda(\mu) \) (Log Likelihood Ratio)

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- \( n_i = \text{observed data} \rightarrow \text{one value} \)

\[ L(\mu, \theta) = \prod_{i=1}^{N} \frac{(\mu s_i + b_i)^{n_i}}{n_i!} e^{-(\mu s_i + b_i)} \]

P-value: probability for a test to find a more background-like result than the observed data

\( \text{CL}_S = p_{S+B}/(1-p_B) \)

Confidence interval for limit calculation
Exclusion and discovery

Exclusion (at 95% CL)
aka how to obtain the “brazilian band” plot:

- **expected** limit: calculate CLS using median of null hypothesis (B)
- **observed** limit: CLS calculated using measured data
- CLS < 0.05 => reject test hypothesis at 95% confidence Level
- to calculate limit, \( \mu \) is varied to satisfy CLS = 0.05
Exclusion and discovery

**Exclusion (at 95% CL)**

*aka how to obtain the “brazilian band” plot:*

- **expected** limit: calculate $\text{CL}_S$ using median of null hypothesis (B)
- **observed** limit: $\text{CL}_S$ calculated using measured data
- $\text{CL}_S < 0.05$ => reject test hypothesis at 95% confidence Level
- to calculate limit, $\mu$ is varied to satisfy $\text{CL}_S = 0.05$
**Exclusion and discovery**

**Exclusion (at 95% CL)**

aka how to obtain the “brazilian band” plot:

- **expected** limit: calculate CL_s using median of null hypothesis (B)
- **observed** limit: CL_s calculated using measured data
- CL_s<0.05 => reject test hypothesis at 95% confidence Level
- to calculate limit, μ is varied to satisfy CL_s=0.05

---

**Discovery p_0(=p_B) and gaussian significance (σ):**

- **expected** p_0 calculated using median of test hypothesis
- **observed** p_0 using observed data
- nσ=distance from median of null hypothesis
  - 3σ → evidence
  - 5σ → discovery
**Higgs fit ingredients**

**Input** to VH(bb) profile likelihood fit: \(m_{bb}\) distributions split into **categories**

**Discriminant variables:**
- number of leptons
- number of jets
- \(V p_T\) intervals

**Different regions of \(S/\sqrt{B}\)**

**Total:** 16 categories + control regions
\[\Rightarrow\] complex fit

**Validation needed!!**

Use known signal to cross-check:
\[VZ(Z\rightarrow bb)\]
VZ(b\bar{b}) observation

- Similar signature to VH(b\bar{b}) and ~5 times larger cross section
- Excellent way to validate background estimate and Higgs search strategy
- Performed profile likelihood fit with a mixture of WZ(b\bar{b}) and ZZ(b\bar{b}) as signal
- WH and ZH with m_H=125 GeV considered as backgrounds

Observed VZ(b\bar{b}) signal with

\[ \hat{\mu} = 1.09 \pm 0.20\text{(stat)} \pm 0.22\text{(syst)} \]

and 4\sigma significance
\textbf{VH(H→b\bar{b}) results}

- Observed limit at $m_H=125$ GeV: $1.8 \times \text{SM}$ (expected 1.9)
- Signal strength $\hat{\mu}=-0.4\pm0.7\,(\text{stat})\pm0.8\,(\text{syst})$
- Observed $\rho_0$: $0.64$ (expected 0.15)
- Excluded a Higgs of mass $\sim 110$ GeV

Reached sensitivity more than 2 times that of previous publication (Phys. Lett. B 718 (2012) 369-390) $1.8$ vs $4.6$ obs at $m_H=125$ GeV
Summary and conclusions

✦ Looking for the Higgs in difficult $H \rightarrow b\bar{b}$ topology
  ↓
  highest BR for $m_H \approx 125\text{GeV}$

✦ Exploit **associated production with a vector boson**
  $\rightarrow$ tag on leptonic final states

✦ Perform complicated **profile likelihood fit** to test signal+background hp

✦ Search method validated on $VZ(Z \rightarrow b\bar{b}) \Rightarrow 4\sigma$ observation
Summary and conclusions

- Looking for the Higgs in difficult $H \rightarrow b \bar{b}$ topology
  - highest BR for $m_H \approx 125\text{GeV}$

- Exploit associated production with a vector boson
  → tag on leptonic final states

- Perform complicated profile likelihood fit to test signal+background hp

- Search method validated on $VZ(Z \rightarrow b \bar{b}) \Rightarrow 4\sigma$ observation

- Excluded a Higgs of $m=110\text{GeV}$

- Observed (expected) a 95% CL limit of $1.8\times 1.9 \times \text{SM}$
..thanks a lot for your attention!!
Backup
The ATLAS detector

**Inner detector**
- for $\eta=0$, track has typically 3 Pixel, 8 SCT and 30 TRT hits
- magnetic field (~2 T) produced by solenoid
- coverage: $|\eta|<2.5$ (2.0 for TRT)
- resolution: $\sigma(p_t)/p_t=0.05\%\oplus1\%$

**Calorimeters**
- Pb/LAr accordion structure for EM
- provides e/$\gamma$ energy measurement with $\sigma/E\sim10%/\sqrt{E}$(GeV)$\oplus0.7\%$
- Iron scintillator tiles for hadronic
- provides jet and $E_{t}^{\text{miss}}$ measurement with $\sigma/E\sim50%/\sqrt{E}$ (GeV)$\oplus3\%$
- Forward calorimeter: FCAL covers up to $|\eta|<4.9$

**Muon spectrometer**
- coverage: $|\eta|<2.7$
- magnetic field (~0.5 T) produced by toroids
- $\sigma(p_t)/p_t=10\%$ for $p_t=1$TeV
Higgs $\sigma \times BR @ 8\text{TeV}$

$\sqrt{s} = 8\text{TeV}$

$\sigma \times BR [\text{pb}]$

$M_H [\text{GeV}]$

100 150 200 250

10

10^{-1}

10^{-2}

10^{-3}

10^{-4}

$\tau^+ \tau^-$

$VBF H \rightarrow \tau^+ \tau^-$

$WH \rightarrow \ell^+ \nu p\bar{p}$

$WW \rightarrow \ell^+ \nu q\bar{q}$

$WW \rightarrow \ell^+ \ell^- \nu \nu$

$ZZ \rightarrow \ell^+ \ell^- q\bar{q}$

$ZZ \rightarrow \ell^+ \ell^- \nu\nu$

$ZZ \rightarrow \ell^+ \ell^- \ell^+ \ell^-$

$ZH \rightarrow \ell^+ \nu b\bar{b}$

$\ell = e, \mu$

$\nu = \nu_e, \nu_\mu, \nu_\tau$

$q = \text{udscb}$

$ttH \rightarrow ttbb$
Jet clustering anti-kt algorithm

From topoclusters to jets
\{t_i\} \rightarrow \text{reconstruction algorithm} \rightarrow \{j_k\}

\textbf{Anti-kt algorithm}

- default for ATLAS jet reconstruction
- recursive algorithm - combines sequentially pairs of constituents
- combination dependent on $p_t$, ($\eta, \phi$) distance
- clustering starts from most energetic constituents
- advantage: high-$p_t$ anti-kt jets have regular shapes guaranteeing stability against pile-up
b-tagging in ATLAS

- Algorithms to identify heavy flavour content in reconstructed jets
- Impact parameter of tracks in jet
  - **IP3D** uses track weights based on longitudinal and transverse IP significance
- Displaced secondary vertex
  - **SV1** reconstructs inclusive displaced vertex
  - **JetFitter** reconstructs multiple vertices along implied b-hadron line of flight
    - Cascade decay topologies
- Advanced NN based algorithms
  - **JetFitterCombNN**: IP3D+JetFitter
  - **MV1**: IP3D+JetFitterCombNN+SV1

MC calibration results illustrated with **MV1 @ 70% b-jet efficiency**

Credits to: Mark Tibbets
b-tagging in ATLAS - c mistag rate

**ATLAS Preliminary**

- MV1
- JetFitterCombNN
- JetFitterCombNNc
- IP3D+SV1
- SV0

Calibrated on $t\bar{t}$ events at 7 TeV

$t\bar{t}$ simulation, $\sqrt{s}$=7 TeV

$p_T^{\text{jet}} > 15$ GeV, $|\eta^{\text{jet}}| < 2.5$
Flavour fit

- Maximum likelihood fit for jet flavour fraction evaluation in V+jets background
- Aim: calculation of W/Z+l/c scale factors for normalisation
- Performed on 12 regions (with different Vjets composition and top enriched)

\[ V\text{jets} = \alpha_1 \times Wl + \alpha_2 \times Wc + \alpha_3 \times Wb + \beta_1 \times Zl + \beta_2 \times Zc + \beta_3 \times Zb \]

Want to evaluate \( \alpha_i \) and \( \beta_i \), \( \alpha_3 \) and \( \beta_3 \) will be re-calculated in the profile likelihood fit

Example input regions

\( \int L \, dt = 13.0 \, fb^{-1}, \sqrt{s} = 8 \, \text{TeV} \)
1 Lepton, Pre-Tag, 2 Jets, \( p_T > 0 \)

Top enriched region →

1 b-tag region ←
**$p_t^V$ dependence and final fit**

- Steeper fall for background in $p_t^V$ distribution in data than MC ⇒ good news!
- Need to correct for this in the MC. Affects both $V$+jets and top.

**Corrections applied per $p_t^V$ bin:**
- $V$+jets ranging between 5 and 10%
- top ~15%

**In final fit 16 signal region categories and top control regions**

- Profile likelihood fit $L(\mu, \theta)$ to signal strength $\mu = \sigma/\sigma_{SM}$
- $\theta$ represent statistical and systematic nuisance parameters
- $W/Z+b$ and top normalisations left floating in the fit

**Floating backgrounds scale factors:**

<table>
<thead>
<tr>
<th></th>
<th>$\sqrt{s} = 7$ TeV</th>
<th>$\sqrt{s} = 8$ TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>$1.10 \pm 0.14$</td>
<td>$1.29 \pm 0.16$</td>
</tr>
<tr>
<td>$Z+b$</td>
<td>$1.22 \pm 0.20$</td>
<td>$1.11 \pm 0.15$</td>
</tr>
<tr>
<td>$W+b$</td>
<td>$1.19 \pm 0.23$</td>
<td>$0.79 \pm 0.20$</td>
</tr>
</tbody>
</table>
Systematic errors = nuisance parameters $\Theta$

Different type of systematic $\Rightarrow$ different statistical treatment

**Shape systematic**
Gaussian distributed
Systematic variation is different for each bin of $m_{b\bar{b}}$ distribution but is correlated $\Rightarrow$ if one bin varies, the others vary as well

**Normalisation systematic**
Log-normal distributed
Systematic variation is the same for each bin of $m_{b\bar{b}}$ distribution and is correlated $\Rightarrow$ if one bin varies, the others vary as well

**Floating normalisation**
No prior
Normalisation in bin left free to float within very loose constraints. Allows to calculate normalisations for top and W$b\bar{b}$ backgrounds

**Statistical parameters**
Poisson distributed
MC statistical uncertainty per bin. Bin-by-bin uncorrelated. Mean of Poisson is number of events per bin - less than 5% statistical uncertainty per bin $\rightarrow$ 400 events $\rightarrow$ gaussian
### Systematic uncertainties

- Enter in the fit as nuisance parameters both for signal and backgrounds
- Shrunken considerably by profile likelihood fit
- Illustrate **values after cuts** in tables

**Background**

<table>
<thead>
<tr>
<th>Uncertainty [%]</th>
<th>0 lepton</th>
<th>1 lepton</th>
<th>2 lepton</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b$-tagging</td>
<td>6.5</td>
<td>6.0</td>
<td>6.9</td>
</tr>
<tr>
<td>$c$-tagging</td>
<td>7.3</td>
<td>6.4</td>
<td>3.6</td>
</tr>
<tr>
<td>Light tagging</td>
<td>2.1</td>
<td>2.2</td>
<td>2.8</td>
</tr>
<tr>
<td>Jet/Pile-up/$E_T^{miss}$</td>
<td>20</td>
<td>7.0</td>
<td>5.4</td>
</tr>
<tr>
<td>Lepton</td>
<td>0.0</td>
<td>2.1</td>
<td>1.8</td>
</tr>
<tr>
<td>Top modelling</td>
<td>2.7</td>
<td>4.1</td>
<td>0.5</td>
</tr>
<tr>
<td>$W$ modelling</td>
<td>1.8</td>
<td>5.4</td>
<td>0.0</td>
</tr>
<tr>
<td>$Z$ modelling</td>
<td>2.8</td>
<td>0.1</td>
<td>4.7</td>
</tr>
<tr>
<td>Diboson</td>
<td>0.8</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Multijet</td>
<td>0.6</td>
<td>2.6</td>
<td>0.0</td>
</tr>
<tr>
<td>Luminosity</td>
<td>3.6</td>
<td>3.6</td>
<td>3.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>8.3</td>
<td>3.6</td>
<td>6.6</td>
</tr>
</tbody>
</table>

**Signal**

<table>
<thead>
<tr>
<th>Uncertainty [%]</th>
<th>0 lepton</th>
<th>1 lepton</th>
<th>2 lepton</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b$-tagging</td>
<td>8.9</td>
<td>9.0</td>
<td>8.8</td>
</tr>
<tr>
<td>Jet/Pile-up/$E_T^{miss}$</td>
<td>19</td>
<td>25</td>
<td>6.7</td>
</tr>
<tr>
<td>Lepton</td>
<td>0.0</td>
<td>0.0</td>
<td>2.1</td>
</tr>
<tr>
<td>$H \rightarrow bb$ BR</td>
<td>3.3</td>
<td>3.3</td>
<td>3.3</td>
</tr>
<tr>
<td>$VH p_T$-dependence</td>
<td>5.3</td>
<td>8.1</td>
<td>7.6</td>
</tr>
<tr>
<td>$VH$ theory PDF</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>$VH$ theory scale</td>
<td>1.6</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Statistical</td>
<td>4.9</td>
<td>18</td>
<td>4.1</td>
</tr>
<tr>
<td>Luminosity</td>
<td>3.6</td>
<td>3.6</td>
<td>3.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>24</td>
<td>34</td>
<td>16</td>
</tr>
</tbody>
</table>
Final plots - 0 lepton
Final plots - 1 lepton

ATLAS Preliminary

\[ \int L \, dt = 13.0 \, fb^{-1}, \ (\sqrt{s} = 8 \, TeV) \]
1 Lepton 2 Jets, \( p_T^W < 50 \, GeV \)

ATLAS Preliminary

\[ \int L \, dt = 13.0 \, fb^{-1}, \ (\sqrt{s} = 8 \, TeV) \]
1 Lepton 2 Jets, \( 50 < p_T^W < 100 \, GeV \)

ATLAS Preliminary

\[ \int L \, dt = 13.0 \, fb^{-1}, \ (\sqrt{s} = 8 \, TeV) \]
1 Lepton 2 Jets, \( 100 < p_T^W < 150 \, GeV \)

ATLAS Preliminary

\[ \int L \, dt = 13.0 \, fb^{-1}, \ (\sqrt{s} = 8 \, TeV) \]
1 Lepton 2 Jets, \( p_T^W > 200 \, GeV \)

ATLAS Preliminary

\[ \int L \, dt = 13.0 \, fb^{-1}, \ (\sqrt{s} = 8 \, TeV) \]
1 Lepton 2 Jets, \( 150 < p_T^W < 200 \, GeV \)
Final plots - 2 lepton
### Final event yields

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0-lepton, 2 jet</td>
<td>0.8 0.2 0.2 2.9 2.6</td>
<td>0.3 0.4 0.1 1.1 1.1</td>
<td>0.0 0.0 0.0 4.7 6.8</td>
</tr>
<tr>
<td>0-lepton, 3 jet</td>
<td>0.8 0.2 0.2 1.1 1.1</td>
<td>0.4 0.1 0.1 3.6 3.6</td>
<td>0.0 0.0 0.0 4.0 1.5</td>
</tr>
<tr>
<td>1-lepton</td>
<td>10.6 12.9 7.5 3.6 3.6</td>
<td>3.6 3.6 3.6 3.6 3.6</td>
<td>3.6 3.6 3.6 3.6 3.6</td>
</tr>
<tr>
<td>2-lepton</td>
<td>4.7 6.8 4.0 1.5 1.4</td>
<td>4.0 1.5 1.4 4.0 1.5</td>
<td>4.0 1.5 1.4 4.0 1.5</td>
</tr>
</tbody>
</table>

#### Table 6: The expected numbers of signal and background events for the 8 TeV data after the region in Table 6.

- **ZH**: 2.9 2.1 2.6 0.8 0.8 1.1 0.3 0.4 0.1 0.0 0.0 4.7 6.8 4.0 1.5 1.4
- **WH**: 0.8 0.4 0.4 0.2 0.2 0.2 10.6 12.9 7.5 3.6 3.6 0.0 0.0 0.0 0.0 0.0

#### Calculation of Cross Sections

The expected number of signal and background events in each bin are from Table 6. The test statistic $T$ is then constructed according to the profile likelihood: $T = \frac{1}{2} (\hat{\theta} - \theta^0)^T \Sigma^{-1} (\hat{\theta} - \theta^0)$, where $\hat{\theta}$ is the estimated parameter, $\theta^0$ is the true parameter, and $\Sigma$ is the covariance matrix.

The total expected background and its uncertainty is included. The resulting scale factors from the fit are shown in Table 6.

#### Calculated in range 0<m_{bb}/GeV<250

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0-lepton, 2 jet</td>
<td>0.8 0.2 0.2 2.9 2.6</td>
<td>0.3 0.4 0.1 1.1 1.1</td>
<td>0.0 0.0 0.0 4.7 6.8</td>
</tr>
<tr>
<td>0-lepton, 3 jet</td>
<td>0.8 0.2 0.2 1.1 1.1</td>
<td>0.4 0.1 0.1 3.6 3.6</td>
<td>0.0 0.0 0.0 4.0 1.5</td>
</tr>
<tr>
<td>1-lepton</td>
<td>10.6 12.9 7.5 3.6 3.6</td>
<td>3.6 3.6 3.6 3.6 3.6</td>
<td>3.6 3.6 3.6 3.6 3.6</td>
</tr>
<tr>
<td>2-lepton</td>
<td>4.7 6.8 4.0 1.5 1.4</td>
<td>4.0 1.5 1.4 4.0 1.5</td>
<td>4.0 1.5 1.4 4.0 1.5</td>
</tr>
</tbody>
</table>

#### Data

- **Total Bkg.**: 361 127 98 164 63 42 3810 4310 1730 297 138 1500 1770 665 97 72
- **Data**: 342 131 90 175 65 32 3821 4301 1697 297 132 1485 1773 657 100 69

Chiara Debenedetti - ATLAS VH(H→bb), VZ(Z→bb) - 09.04.2013 - IoP meeting, Liverpool
Results for 7 and 8 TeV datasets

Result of profile likelihood fit for 7 and 8 TeV dataset separately

$\bar{s} = 7$ TeV, $\int L dt = 4.7$ fb$^{-1}$

$\bar{s} = 8$ TeV, $\int L dt = 13.0$ fb$^{-1}$

$\mu_{\text{hat}} = -2.7 \pm 1.1$ (stat) $\pm 1.1$ (syst)

$\mu_{\text{hat}} = 1.0 \pm 0.9$ (stat) $\pm 1.1$ (syst)
VZ(\(b\bar{b}\)) - 8TeV channel breakdown

ATLAS Preliminary

Two Lepton

- WZ+ZZ
- ZH 125 GeV
- Bkgd Uncert.
- Data - Bkgd

One Lepton

- WZ+ZZ
- WH 125 GeV
- ZH 125 GeV
- Bkgd Uncert.
- Data - Bkgd

Zero Lepton

- WZ+ZZ
- WH 125 GeV
- ZH 125 GeV
- Bkgd Uncert.
- Data - Bkgd