HIGGS SEARCH IN THE $H \to b\bar{b}$ CHANNEL IN ATLAS

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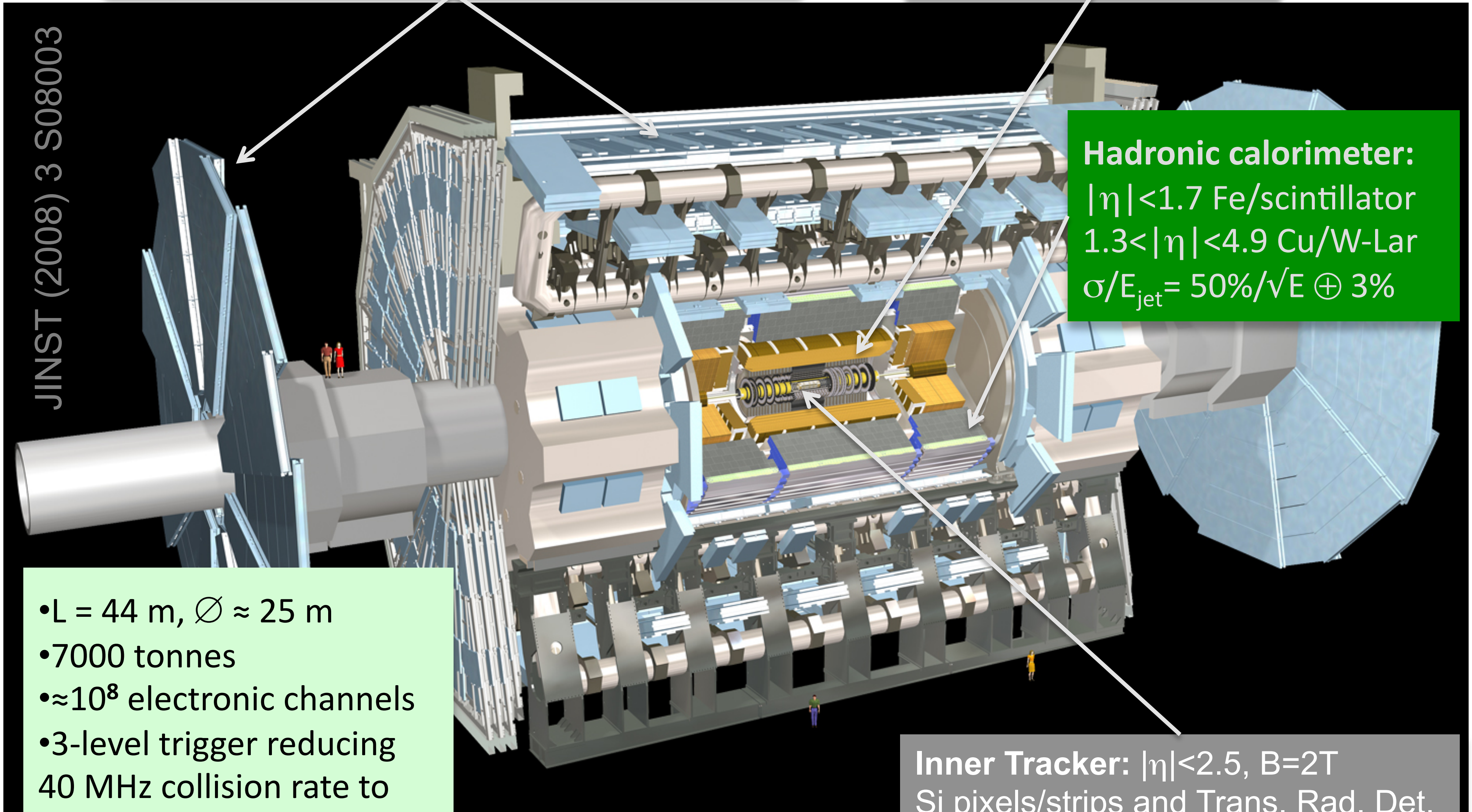
Outline

- ATLAS and the LHC
- Higgs physics at the LHC
- ZH/WH $H \rightarrow bb$ in ATLAS
  - Event selection
  - Backgrounds
  - Systematic errors
  - Results
- Boosted VH
- Summary and Outlook

ATLAS and the LHC

Muon Spectrometer: $|\eta|<2.7$
Air-core toroids and gas-based muon chambers
σ/p_T = 2% @ 50GeV to 10% @ 1TeV (ID+MS)

EM calorimeter: $|\eta|<3.2$
Pb-LAr Accordion
$\sigma/E = 10\%/\sqrt{E} \oplus 0.7\%$

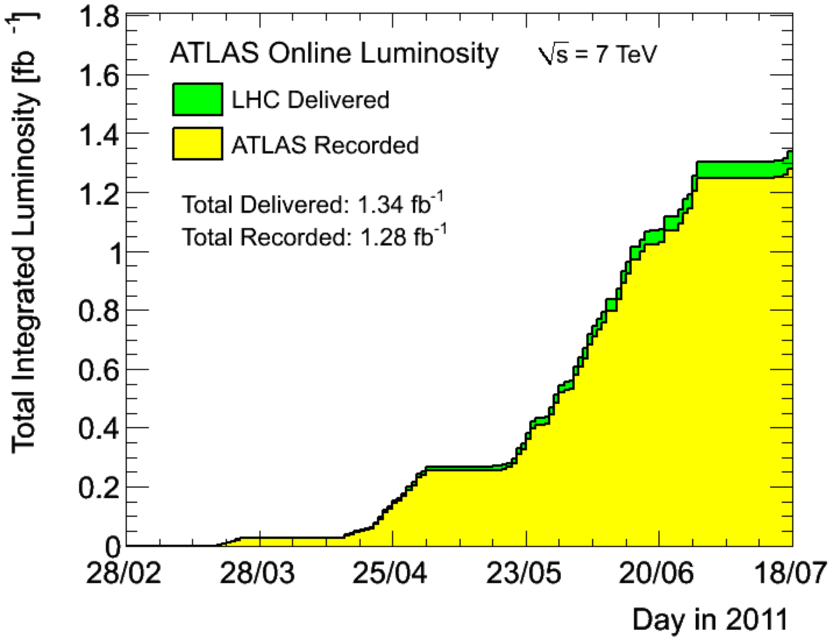


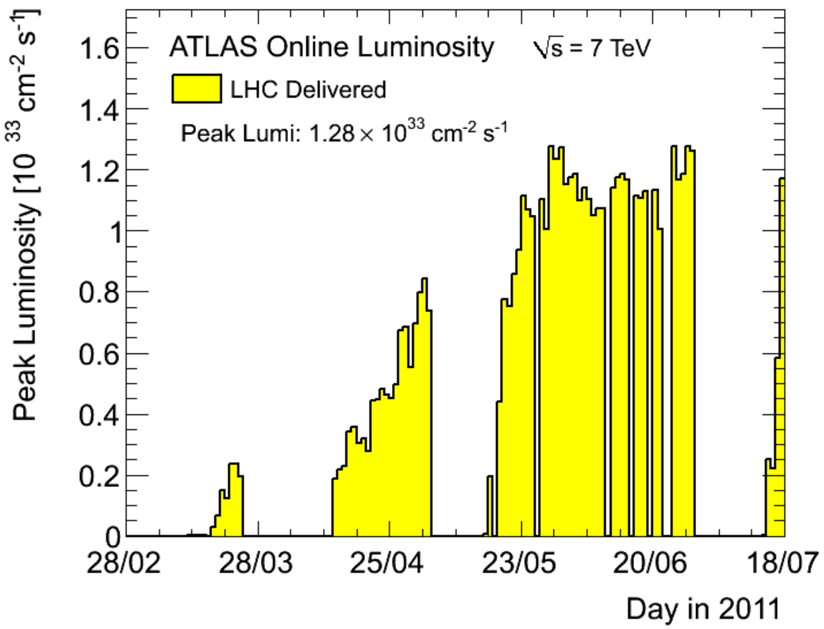
Hadronic calorimeter:
$|\eta|<1.7$ Fe/scintillator
$1.3<|\eta|<4.9$ Cu/W-Lar
$\sigma/E_{jet} = 50\%/\sqrt{E} \oplus 3\%$

- L = 44 m, ∅ ≈ 25 m
- 7000 tonnes
- ≈10^8 electronic channels
- 3-level trigger reducing 40 MHz collision rate to 200 Hz of events to tape

Inner Tracker: $|\eta|<2.5$, B=2T
Si pixels/strips and Trans. Rad. Det.
$\sigma/p_T = 0.05\%\ p_T\,(\mathrm{GeV}) \oplus 1\%$

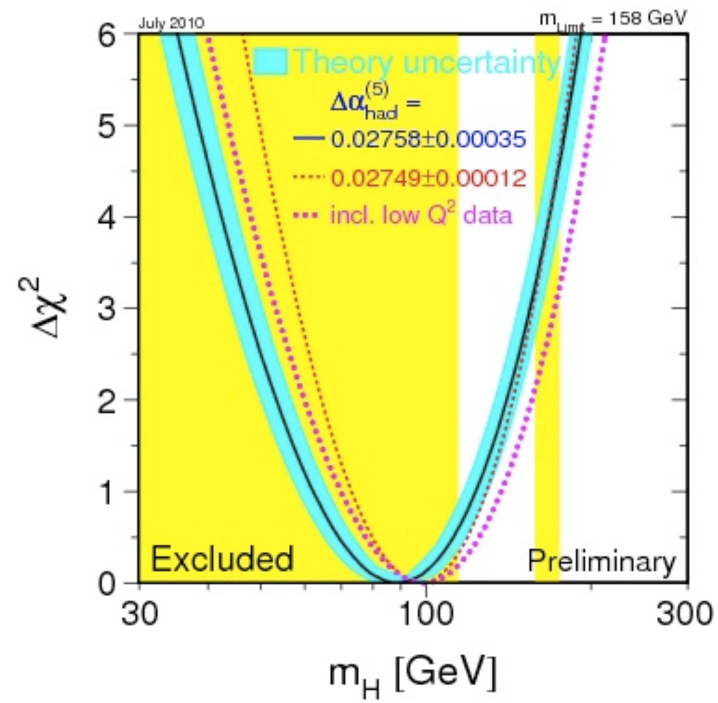
- Very successful operation in 2011!
- Running @ $\sqrt{s}$ = 7TeV and 50ns bunch crossing
- Peak instantaneous luminosity $1.28 \times 10^{33} cm^{-2} s^{-1}$
- Average pileup <μ> ≈ 6 but peak up to 14
- Collected 20 – 60 pb^{-1} per day before tech. stop
- Continue run until end of 2012
- Then shutdown and upgrade to higher $\sqrt{s}$





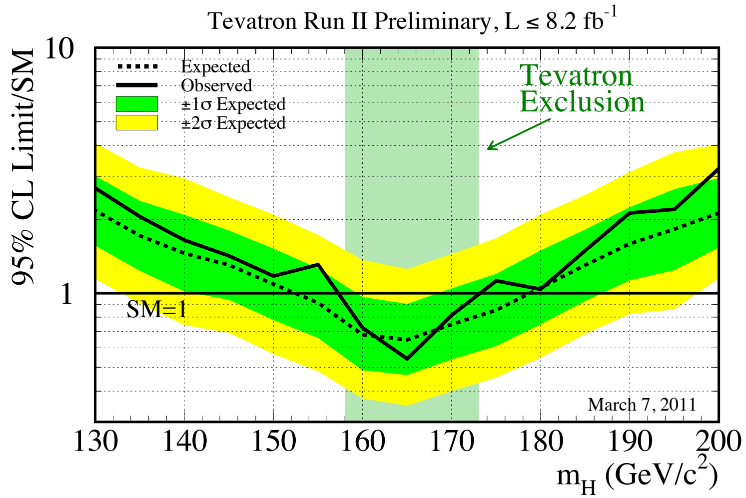
Higgs Physics at the LHC

- The **simplest model** of electroweak symmetry breaking predicts one **Higgs scalar**
  - The Higgs boson mass is the only free parameter
- Current mass limits:
  - LEP **excluded** mass range below **114.4 GeV/c²**
  - EW fit: m_H = **89^{+35}_{-26} GeV/c²** (July 2010)
  - Including LEP: m_H < **185 GeV/c²** (July 2010)
  - Tevatron **excluded** range of **158 – 173 GeV/c²**



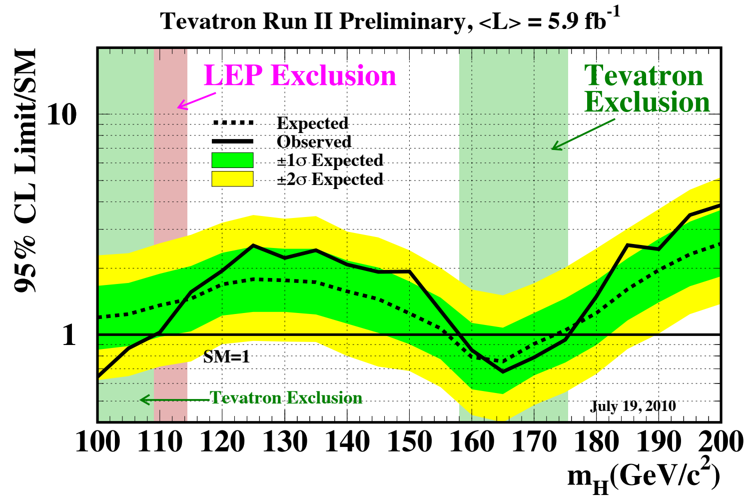
http://lepewwg.web.cern.ch/LEPEWWG/

March 2011



http://tevnphwg.fnal.gov/

July 2010



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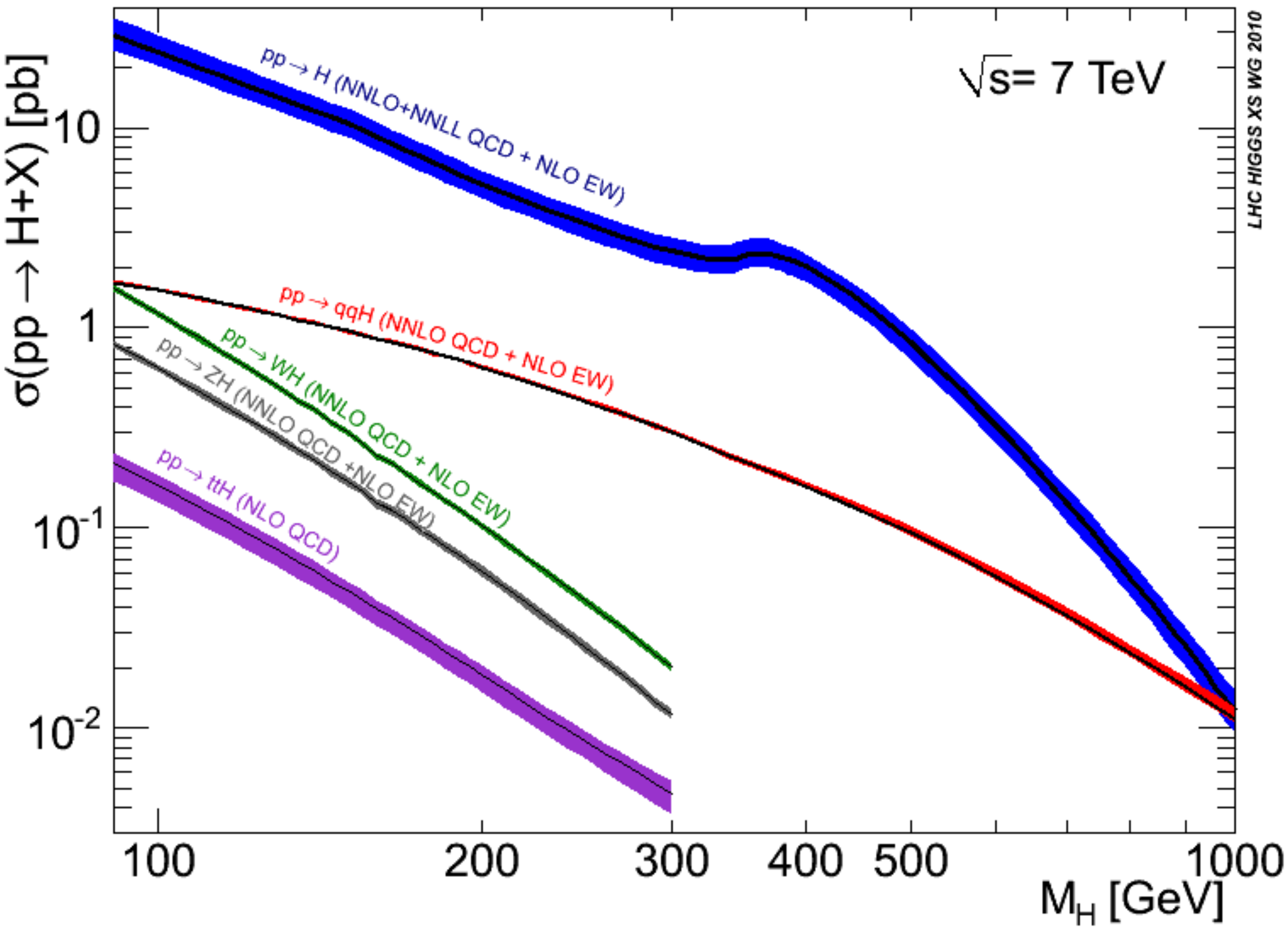
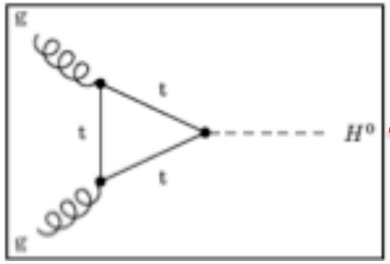
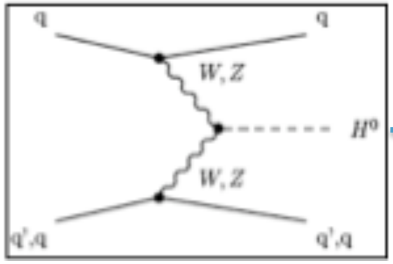
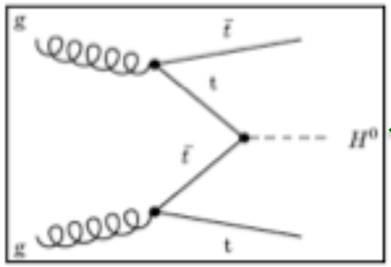
CERN-2011-002; arXiv:1101.0593









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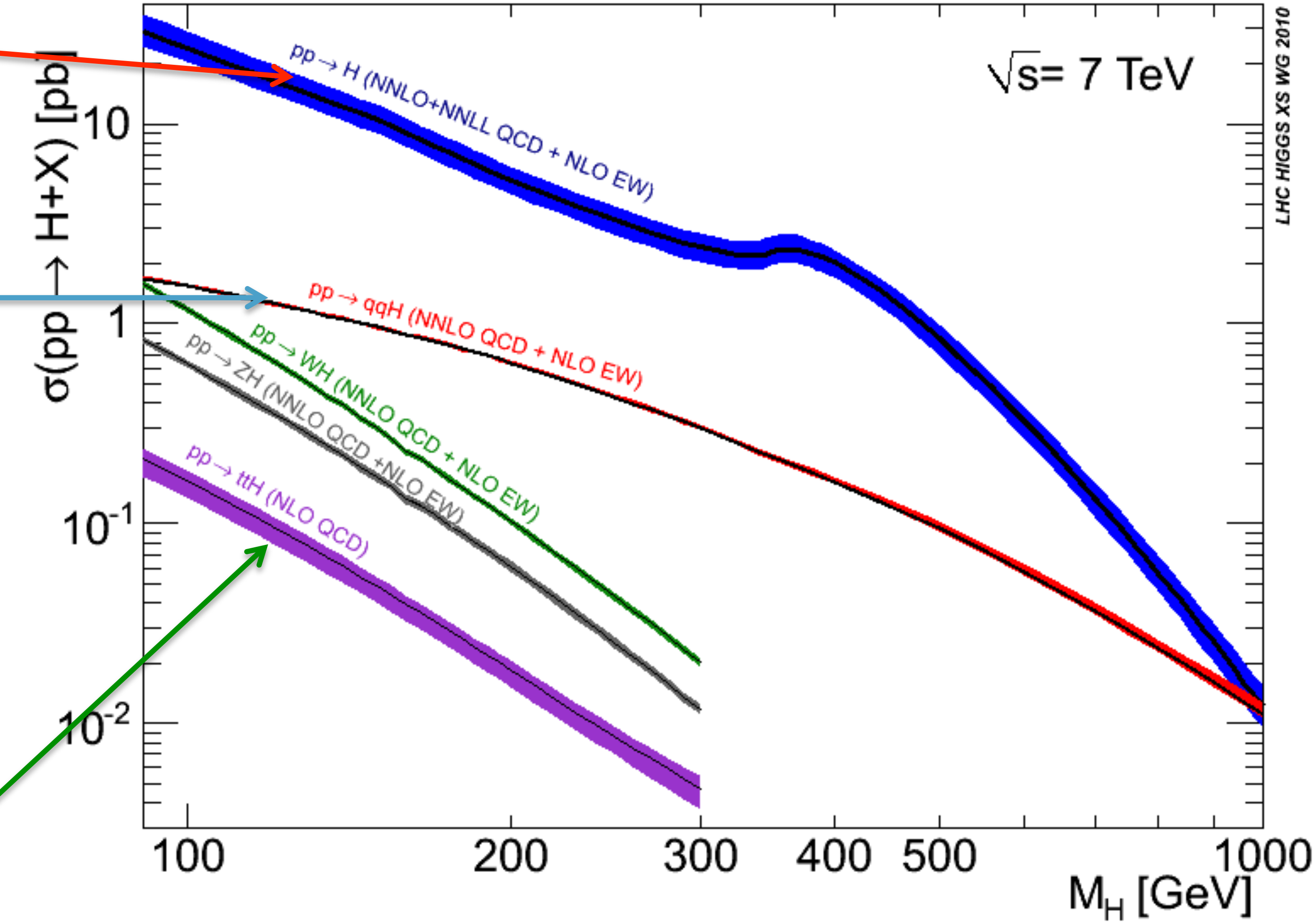

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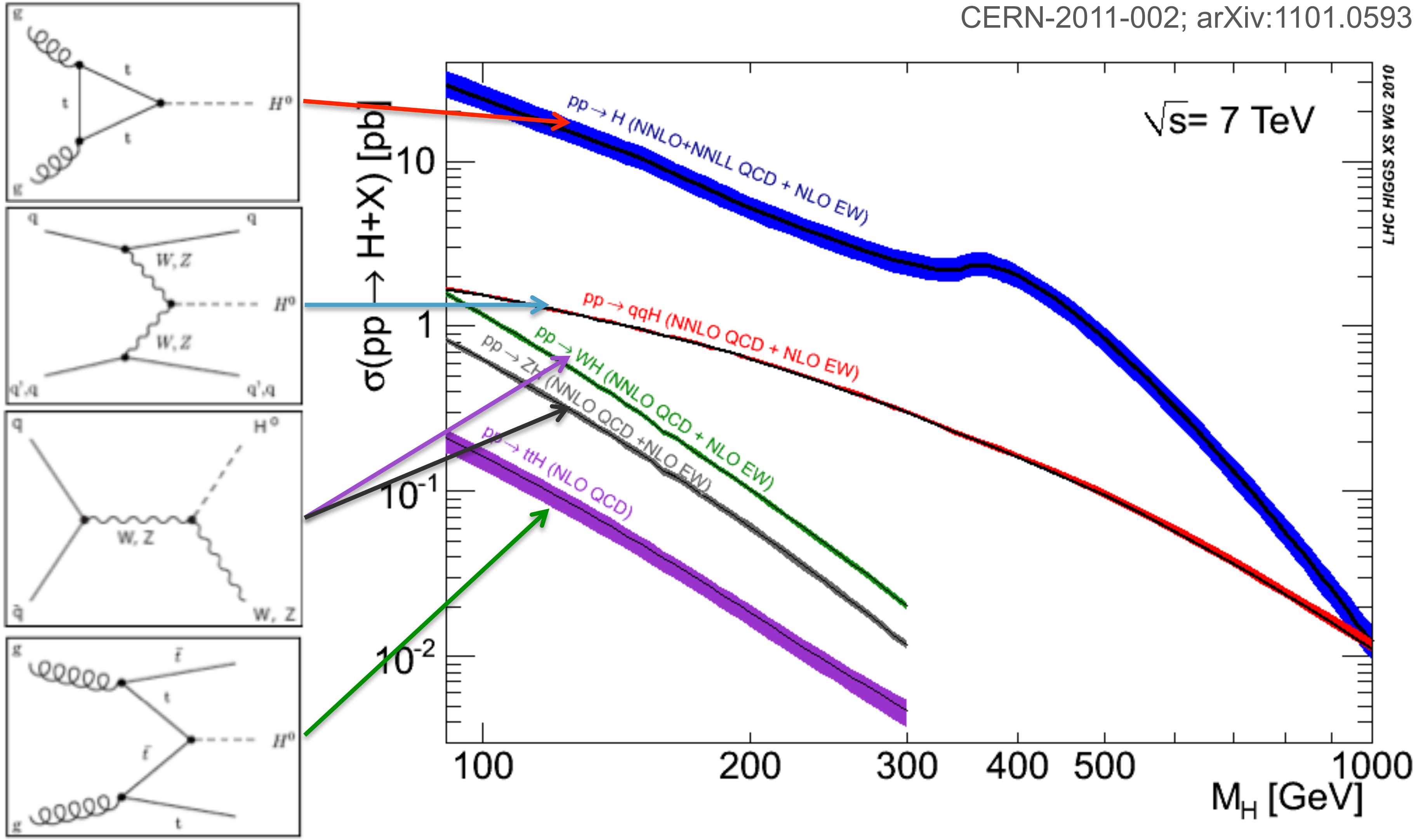

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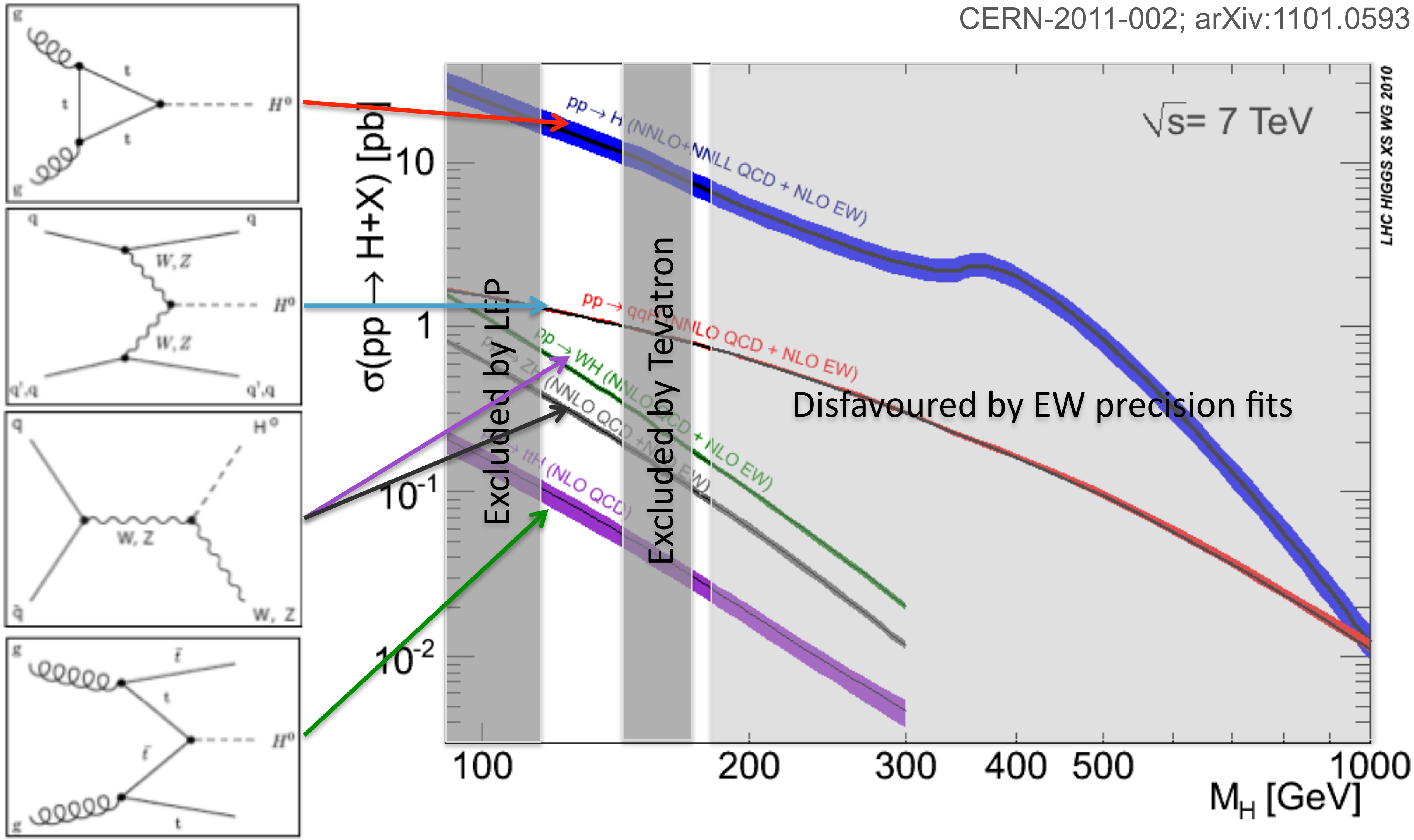
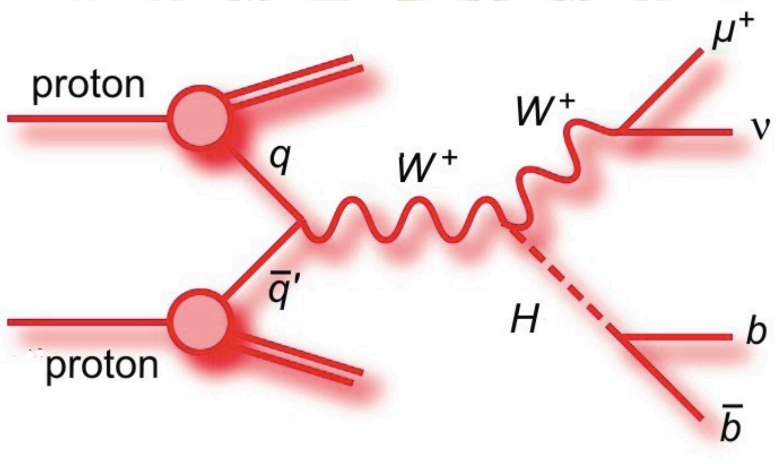
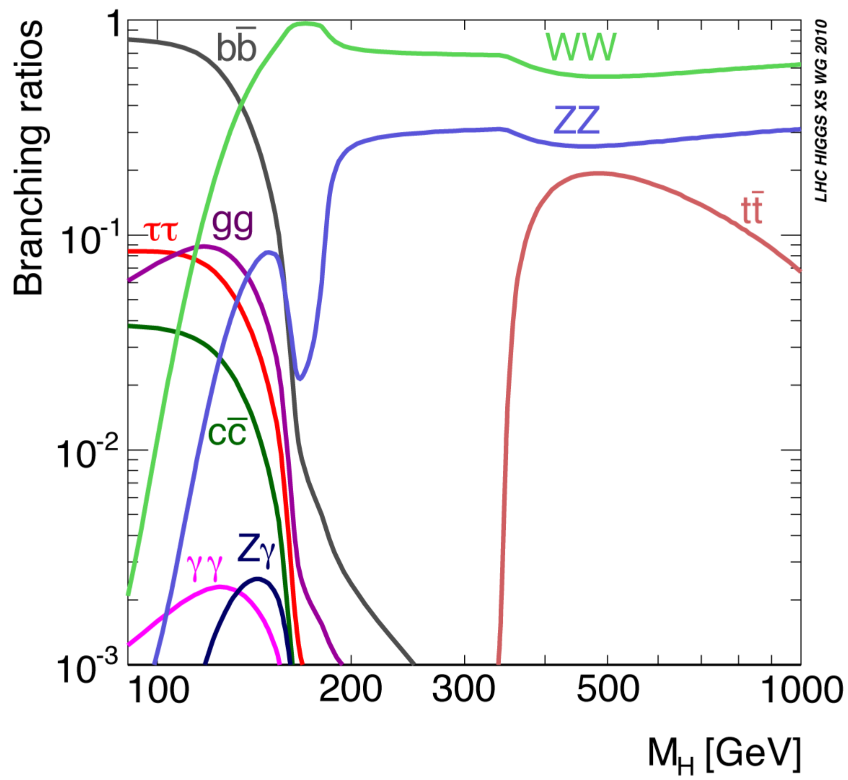


H→bb Searches in ZH/WH production



- This talk: ZH→llbb and WH→lνbb
  - 1.04 fb^{-1} analyzed
- H->bb dominant at low mass
  - WH cross section factor ≈2x higher than ZH, but important top background
  - ZH less affected by top background
- Simple, robust cut-based analysis for first LHC direct search for H→bb(*)
  - Select Z or W and search for 2 additional b jets
  - Search Higgs in m_{bb} spectrum

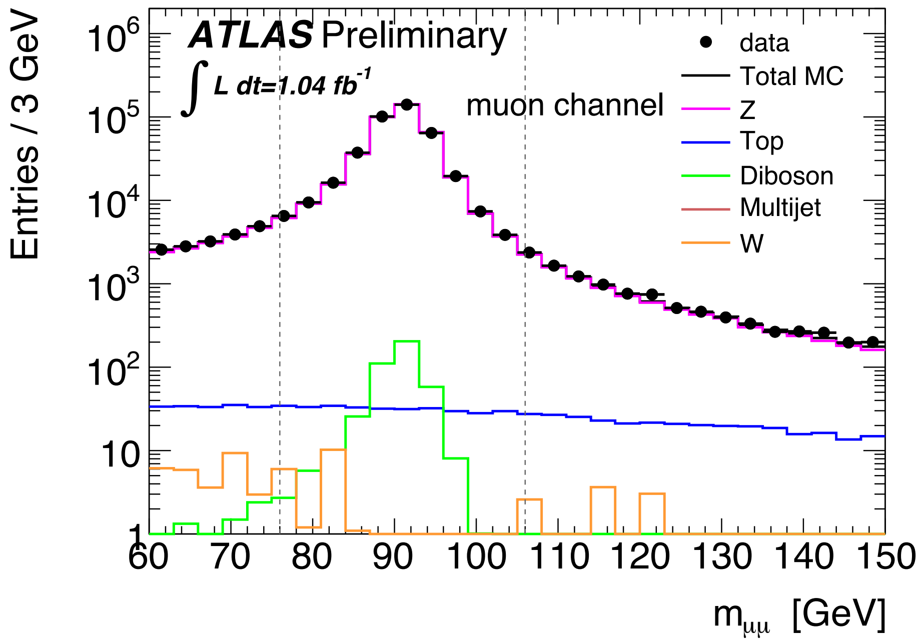
(*) Using newly commissioned advanced taggers. See posters by Kirika Uchida and Nicolas Bousson on b-tagging

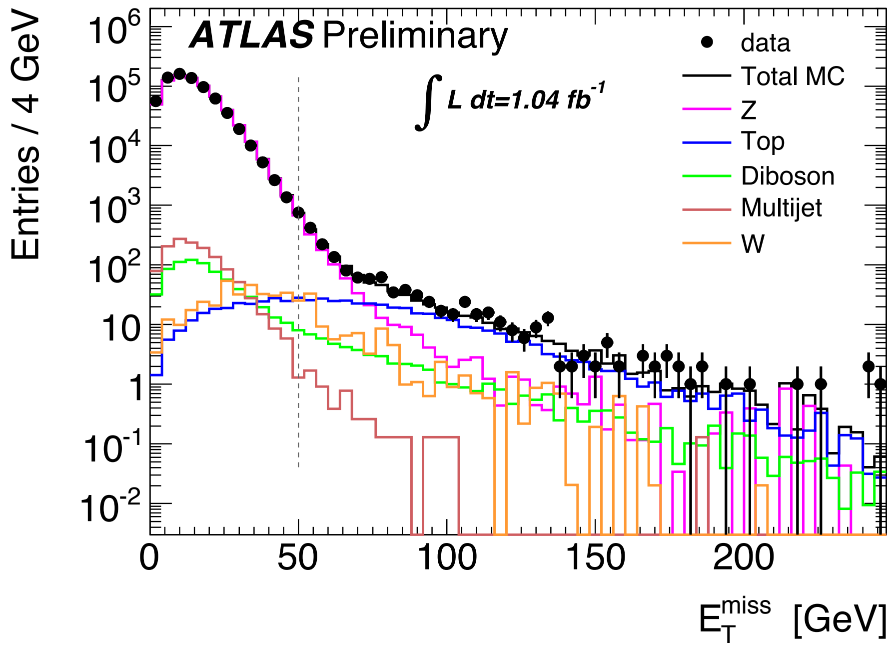


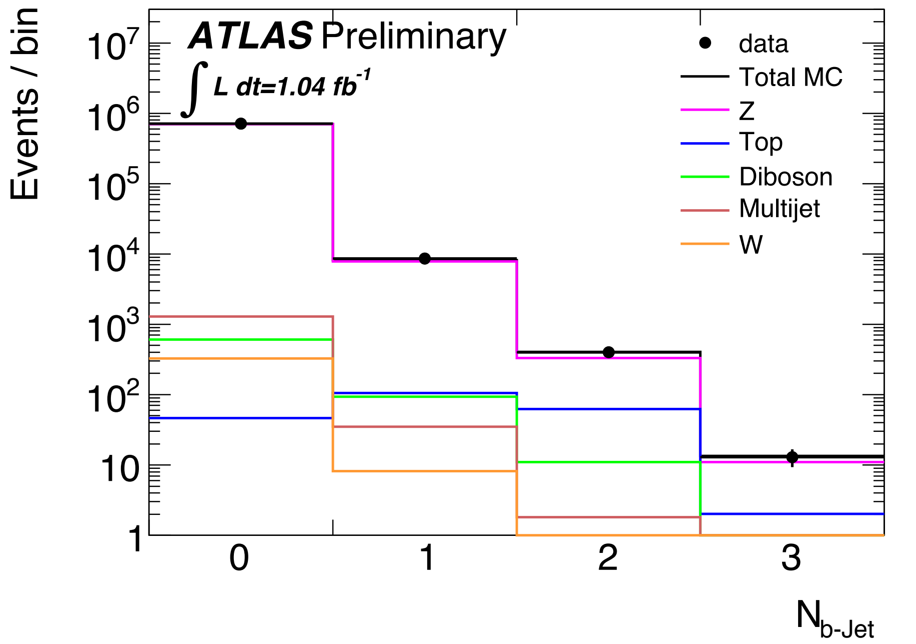
m_H (GeV)	$\sigma(WH)$ (pb)	$\sigma(ZH)$ (pb)	Branching Ratios $H \to b\bar{b}$
110	0.8754	0.4721	0.745
115	0.7546	0.3598	0.705
120	0.6561	0.3158	0.649
125	0.5729	0.2778	0.578
130	0.5008	0.2453	0.494

ZH→llbb Selection

- Trigger:
  - e (p_T^e>20GeV) or μ (p_T^μ>18GeV)
  - 2e/2μ trigger (p_T>12GeV)
- Exactly 2 leptons p_T > 20GeV
  - Opposite charge for μ
- Z mass cut: 76 < m_{ll} < 106 GeV
- E_T^{miss} < 50GeV
- Two leading jets b tagged

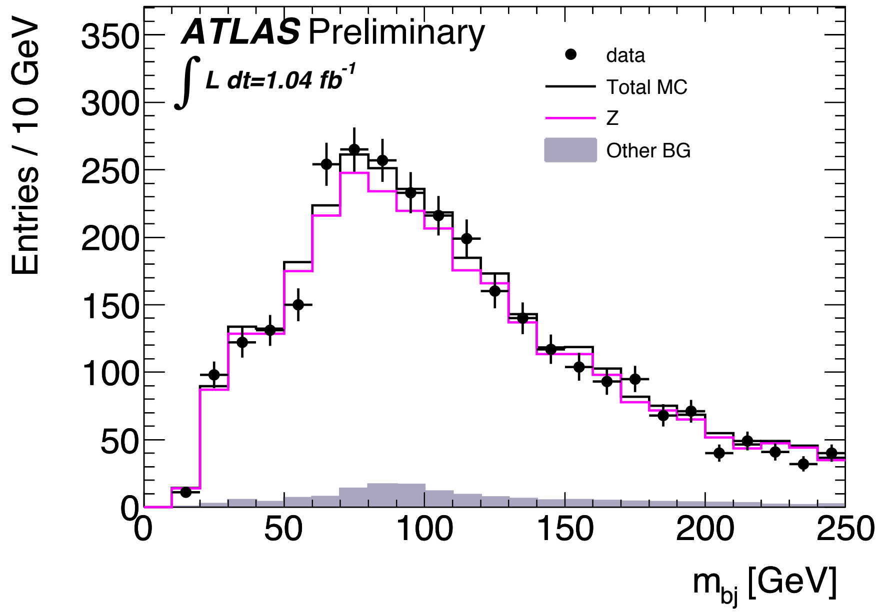


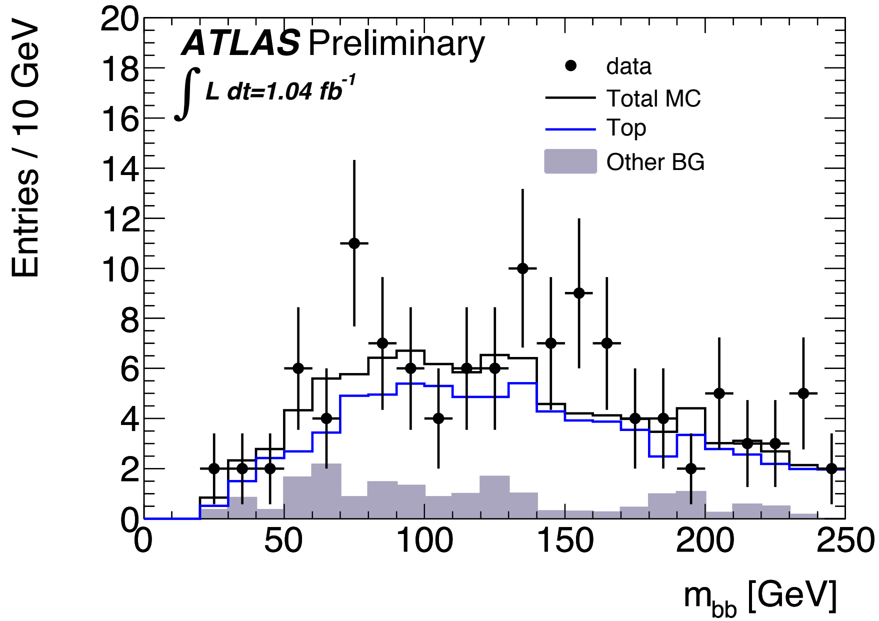




ZH→llbb Backgrounds

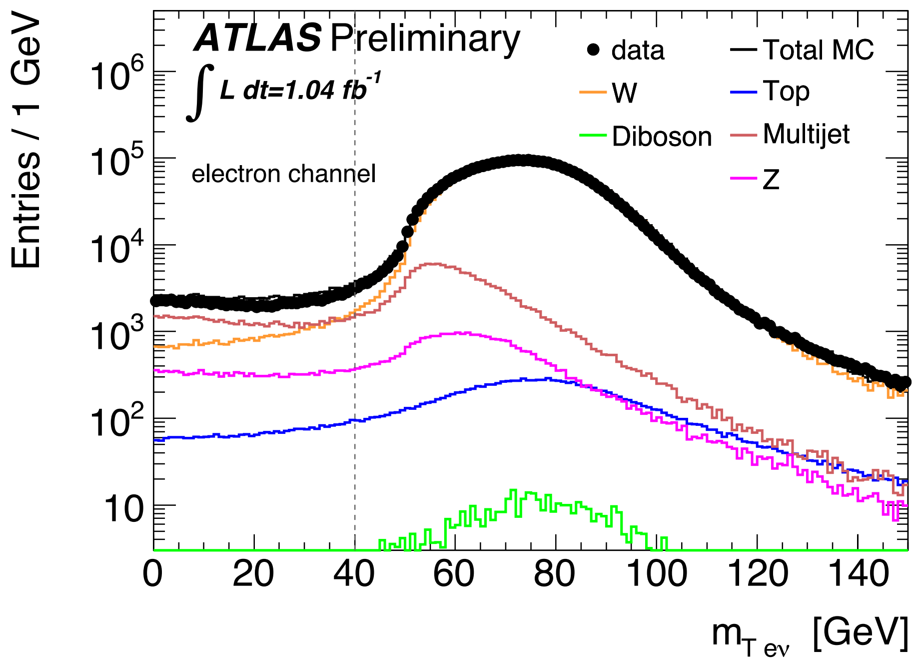
- $Z + b(b\bar{b})$ dominates:
  - Shape from MC
  - Normalization from sideband (m_{bb} < 80GeV);
  - Cross check in single-b control region m_{bj}
- Top:
  - From MC
  - Cross check in m_{ll} control regions: [60GeV, 76GeV] or [106GeV, 150GeV]
- Multijet:
  - e channel: multijet sample from reverting electron quality cuts
  - μ channel: negligible (from MC)
- Diboson ZZ, WZ: from MC

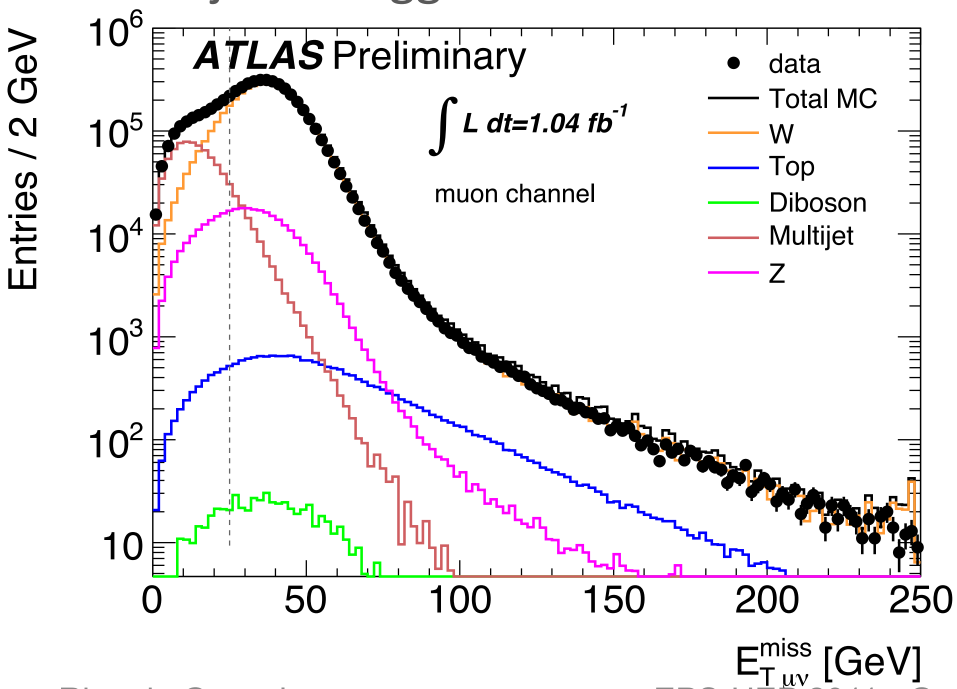


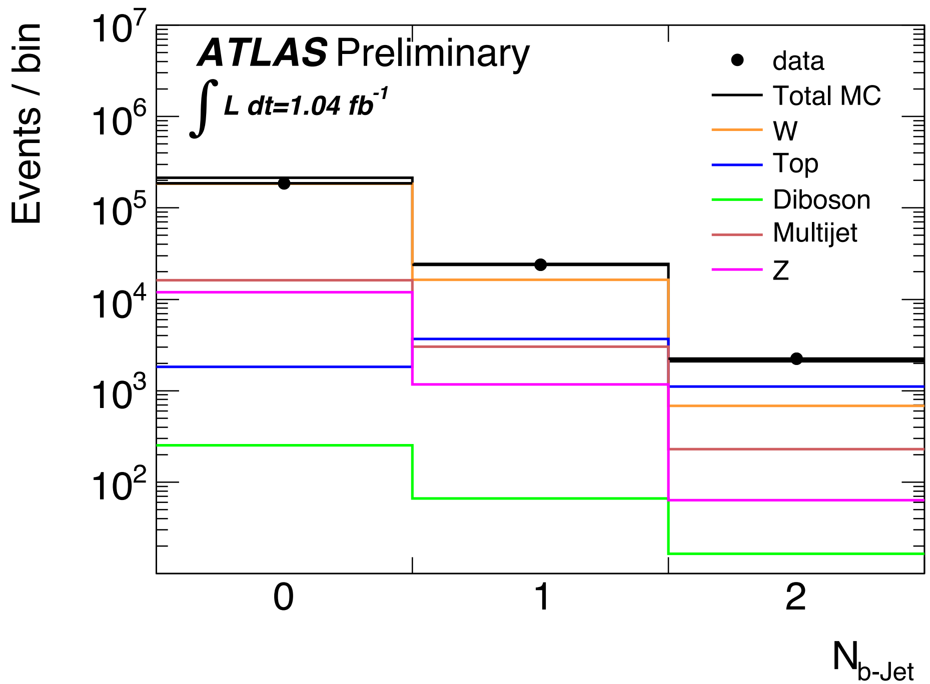


WH→lνbb Selection

- Trigger: e (p_T^e>20GeV) or μ (p_T^μ>18GeV)
- Exactly 1 lepton – p_T > 25GeV
- $M_T = \sqrt{2 p_T^l p_T^\nu (1 - \cos \Delta\phi_{l\nu})}$ > 40 GeV
- E_T^{miss} > 25GeV
- Exactly 2 jets (anti-k_T 0.4; E_T > 25GeV) to reduce top background
- Both jets b tagged

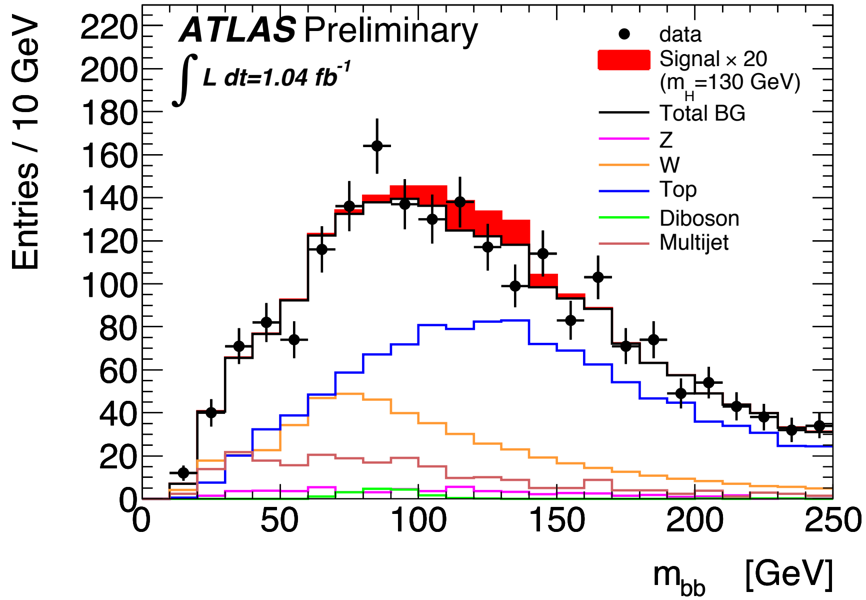


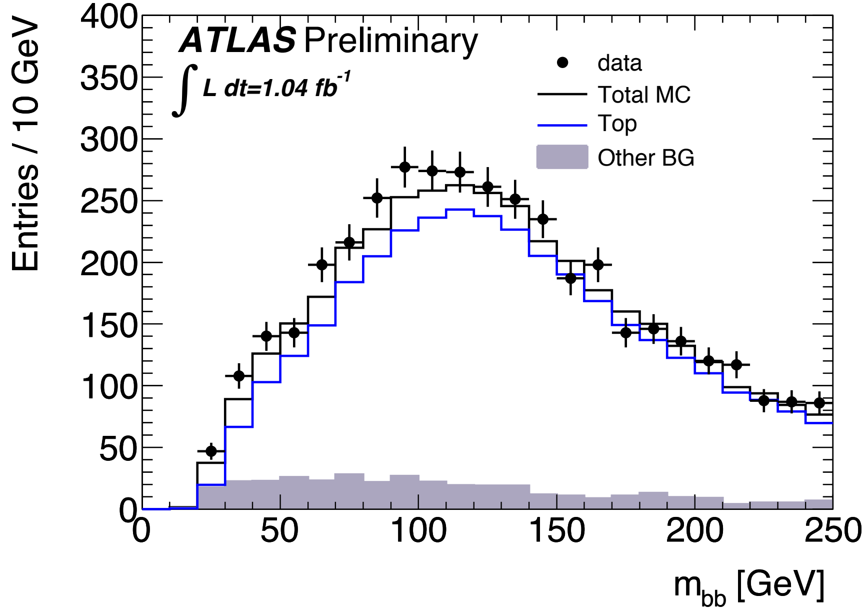




WH→lνbb Backgrounds

- W+jets and top dominant:
  - W+jets important at low m_{bb}:
    - Use m_{jj} from data as template
  - Top dominant at high m_{bb}:
    - Describe shape with MC
    - Cross check m_{bb} in 3-jet bin
  - Normalisation from m_{bb} sidebands [40GeV, 80 GeV] and [140GeV, 250GeV]
- Z+jets: use same normalisation of MC as measured in ZH
- Multijet Data templates from QCD enhanced samples (anti-isolation)
- Diboson WW , WZ from Monte Carlo





Systematic Uncertainties

- Dominant systematic errors from b-tagging efficiency in both analyses
- Followed by jet energy scale
- Points at the next things things to improve!

ZH→llbb

Source of Uncertainty	Effect on the signal $m_H = 115$ GeV	Effect on the signal $m_H = 130$ GeV
Electron Energy Scale	$< 1\%$	$< 1\%$
Electron Energy Resolution	$< 1\%$	$< 1\%$
Muon Momentum Resolution	1%	3%
Jet Energy	9%	7%
Jet Energy Resolution	$< 1\%$	$< 1\%$
Missing Transverse Energy	2%	2%
b-tagging Efficiency	16%	17%
b-tagging Mis-tag Rate	$< 1\%$	$< 1\%$
Electron Efficiency	1%	1%
Muon Efficiency	1%	1%
Luminosity	4%	4%
Higgs Cross-section	5%	5%

WH→lνbb

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b-tagging Mis-tag Fraction	3%	3%
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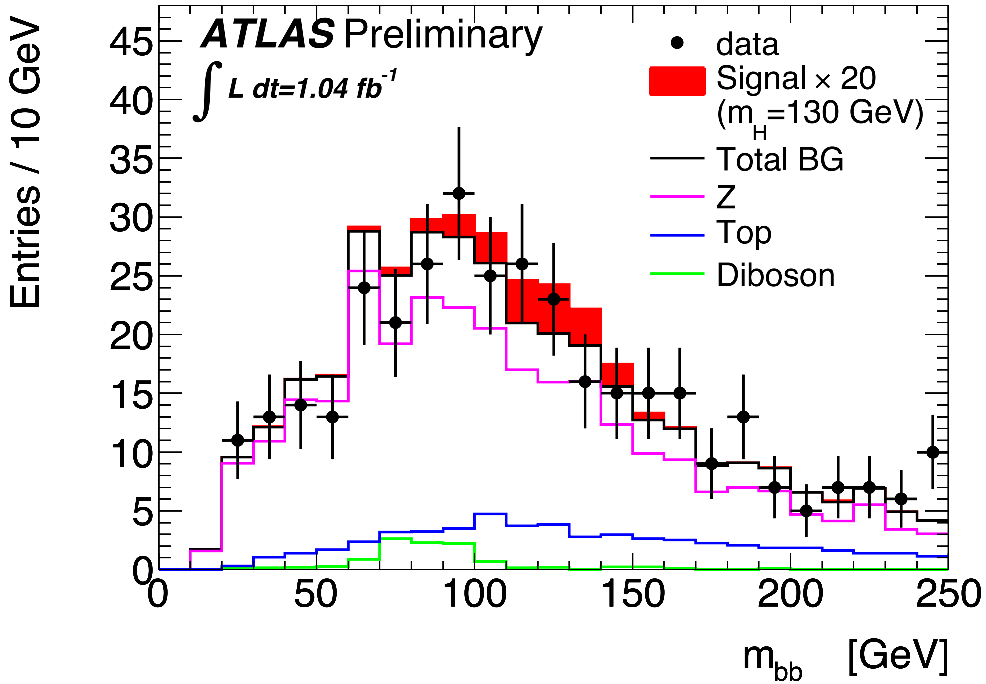
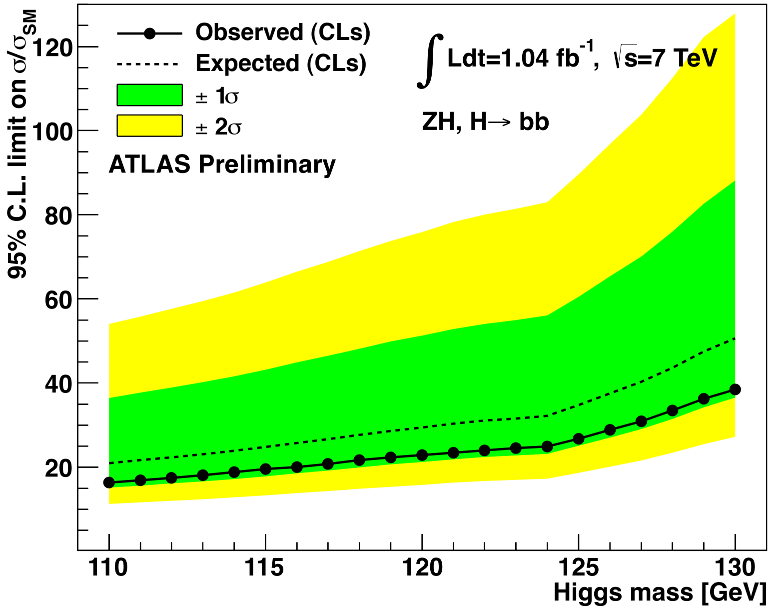
H→bb Analysis Results

ZH→llbb

- Good description of the background
- No excess observed
- Single-channel exclusion of ≈20x Standard Model





Source	expected events		(stat.)		(sys.)
Z+jets	261.0	±	7.8	±	24.6
Top-quark	52.0	±	1.3	±	10.6
Multijet	1.4	±	0.4	±	1.4
ZZ	9.2	±	1.1	±	2.3
WZ	1.1	±	0.3	±	0.3
Total background	324.8	±	8.0	±	27.9
Data	329				
Signal m_H = 110 GeV	2.22	±	0.09	±	0.43
Signal m_H = 115 GeV	1.91	±	0.07	±	0.38
Signal m_H = 120 GeV	1.58	±	0.06	±	0.32
Signal m_H = 125 GeV	1.44	±	0.05	±	0.28
Signal m_H = 130 GeV	1.02	±	0.04	±	0.20

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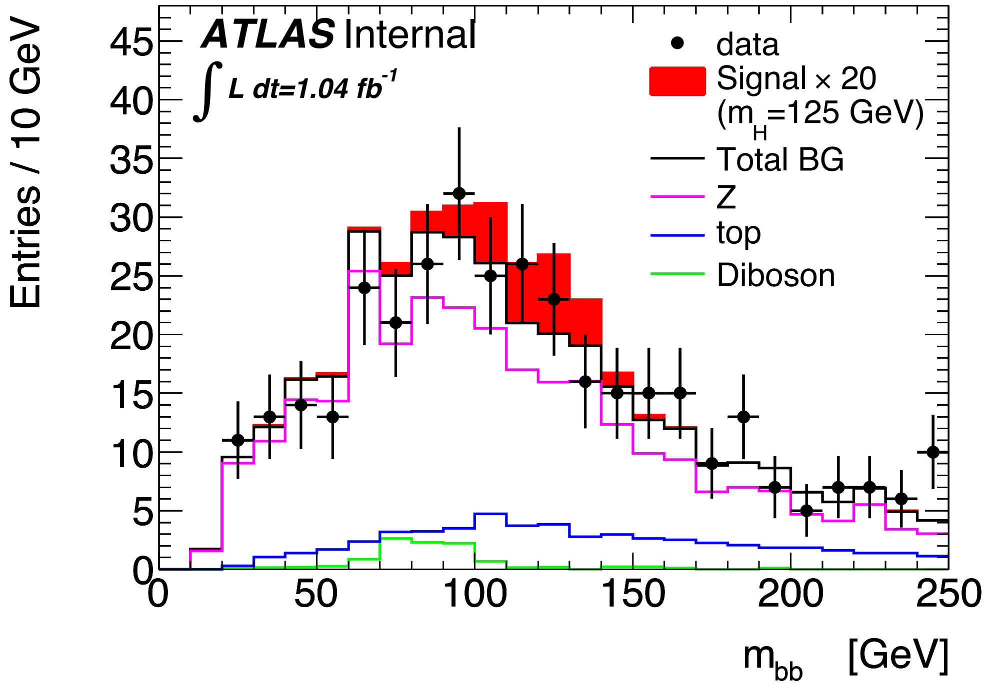

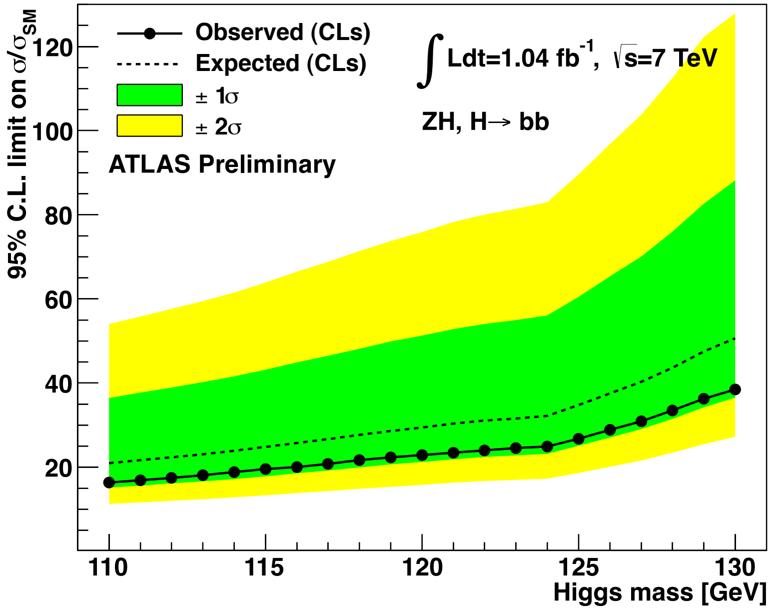

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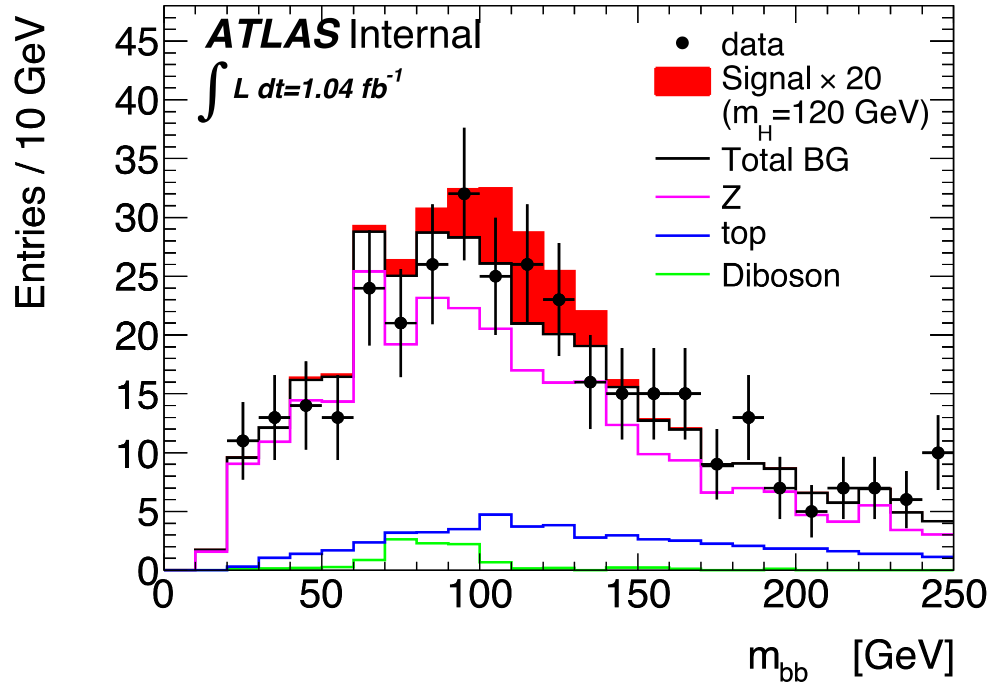

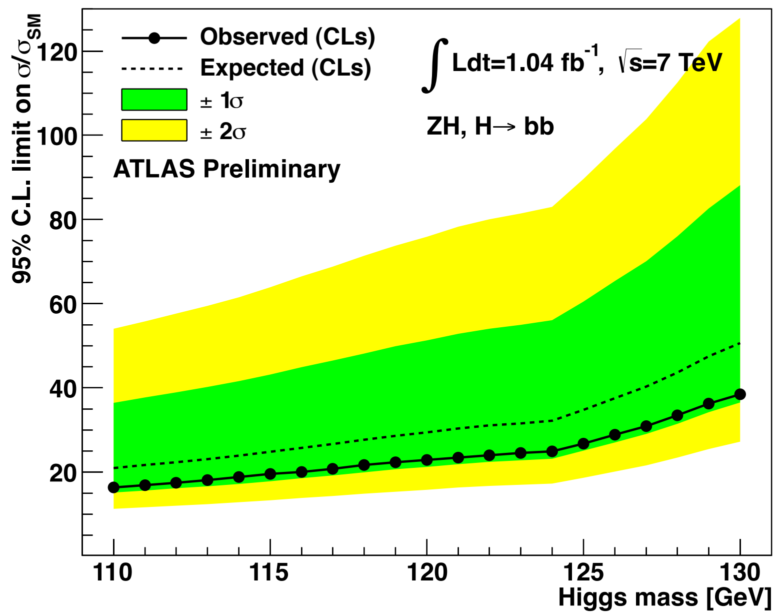

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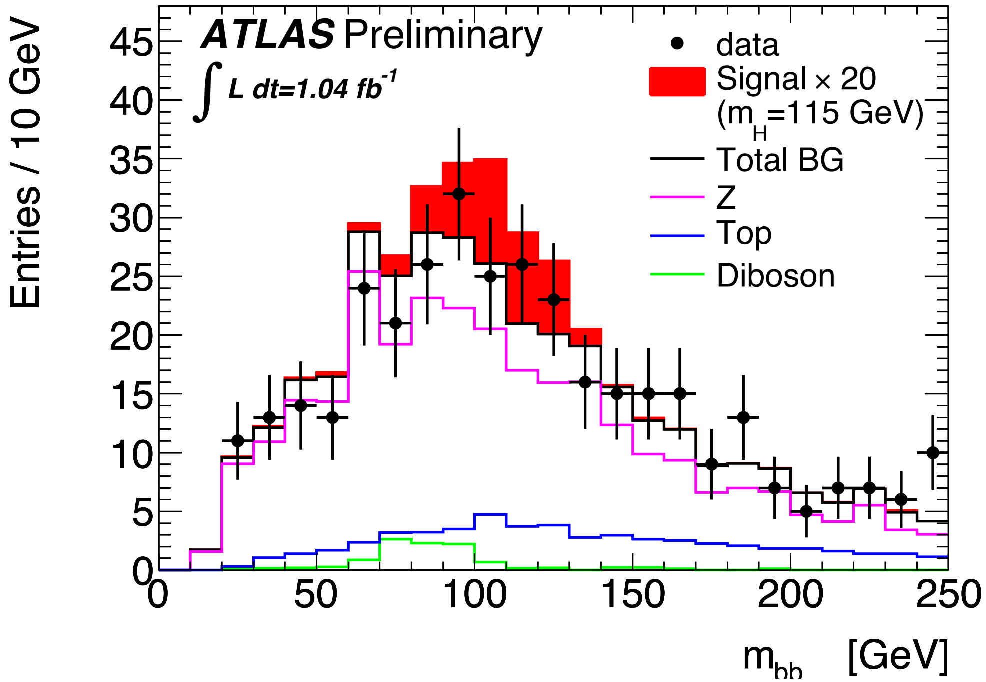

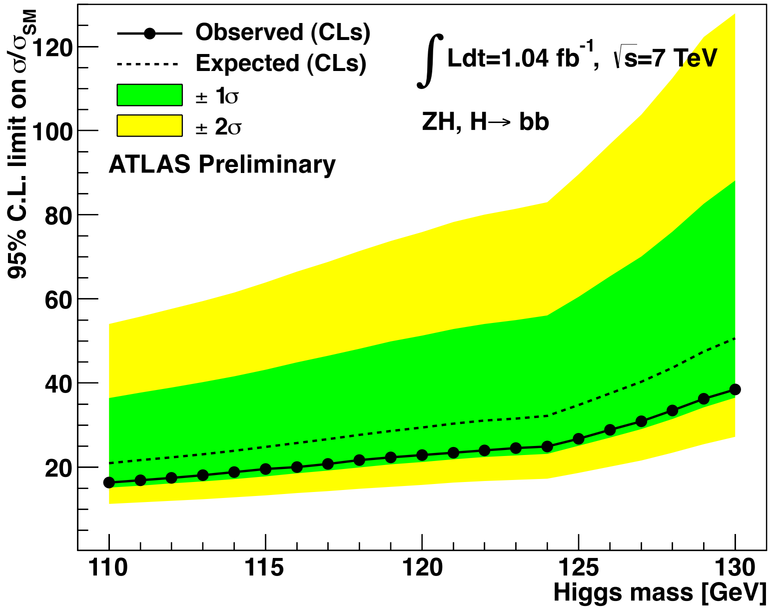

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WH→lνbb

- Good description of the background
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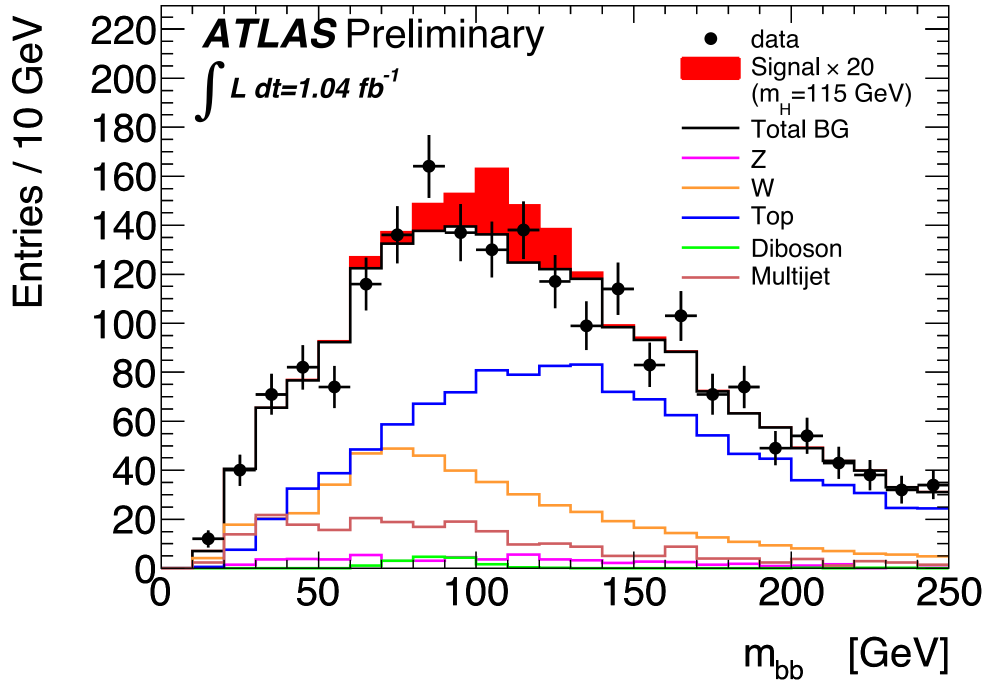
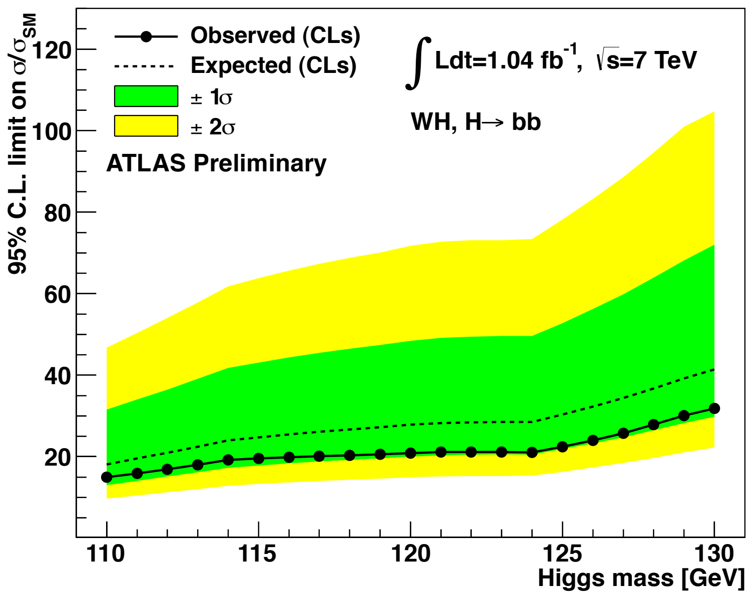
- Single-channel exclusion of ≈20-30x Standard Model

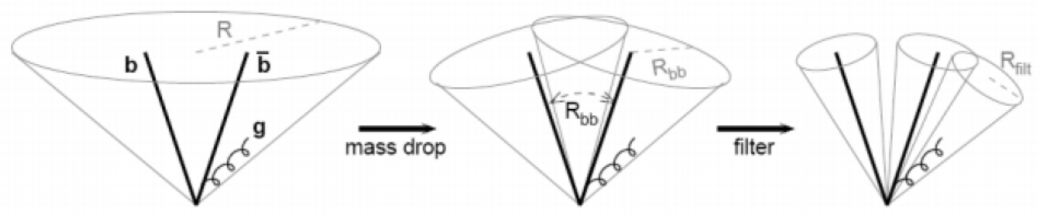


Source	expected events		(stat.)		(sys.)
Z+jets	54.4	±	3.9	±	12.3
W+jets	466.7	±	1.4	±	67.1
Top-quark	1141.8	±	8.8	±	81.2
Multijet	193.0	±	9.4	±	96.5
WZ	16.1	±	2.2	±	3.5
WW	4.8	±	1.1	±	1.4
Total background	1876.6	±	13.7	±	150.7
Data	1888				
Signal m_H = 110 GeV	6.72	±	0.31	±	1.20
Signal m_H = 115 GeV	5.25	±	0.30	±	0.97
Signal m_H = 120 GeV	4.54	±	0.25	±	0.83
Signal m_H = 125 GeV	4.08	±	0.21	±	0.77
Signal m_H = 130 GeV	3.28	±	0.17	±	0.62

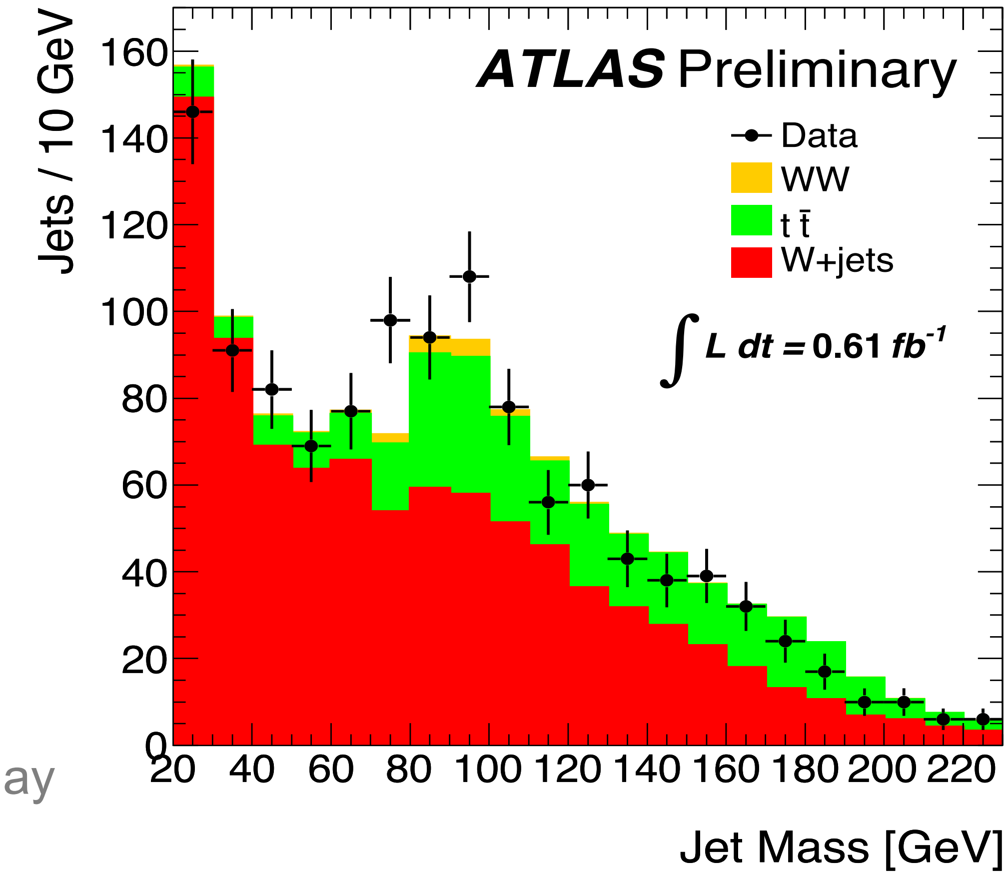


Boosted VH with $H \rightarrow bb$

- Alternative to inclusive channels: search for high-pT Higgs to bb:
  - J. M. Butterworth, A. R. Davison, M. Rubin, and G. P. Salam, Phys. Rev. Lett. 100 (2008) 242001, arXiv:0802.2470 [hep-ph]
- p_T^H > 200GeV ≈ 5% of inclusive cross section but improved significance



- Select W→lν events and search for a H→bb jet
  1. Search for high-p_T jet (Cambridge-Aachen algorithm, R=1.2)
  2. Search jet clustering history in reverse and look for large mass drop
  3. Re-cluster with small R parameter to find sub jets



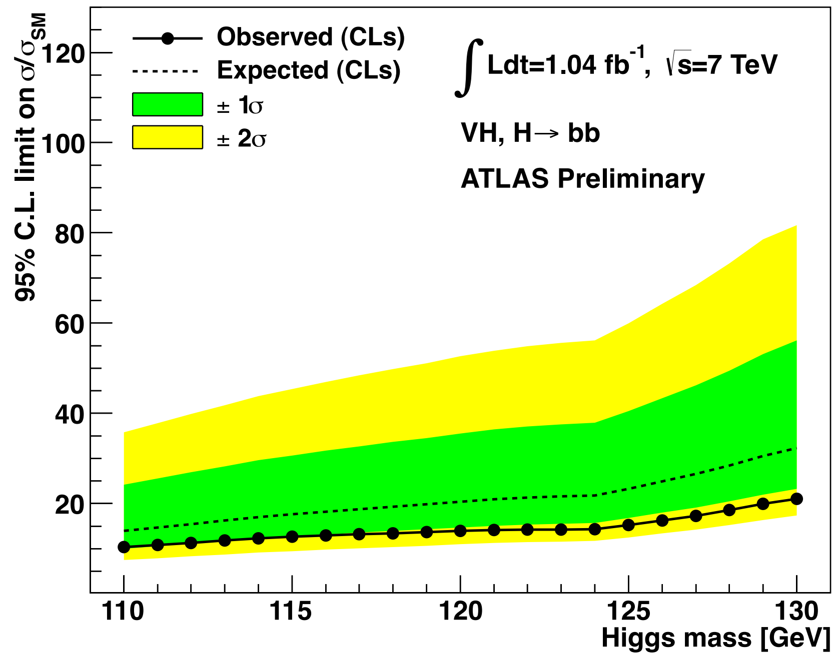
- Peak consistent with W→jj in tt events
- Proof of principle for future analysis

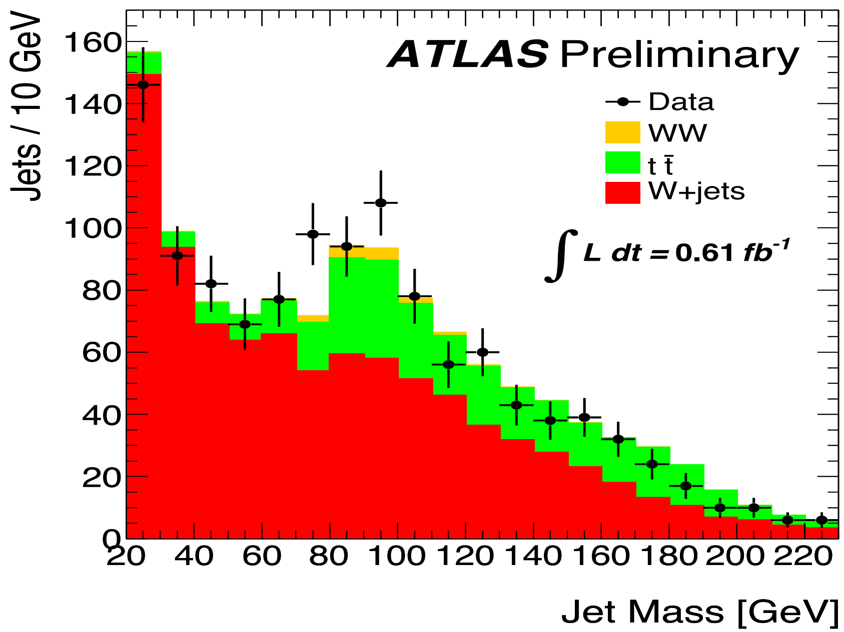
See talk by D.Miller in QCD yesterday

Conclusions & Outlook

- First direct search for H→bb at the LHC in WH and ZH channels
- Combined sensitivity to ≈10-20x Standard Model
- Room for improvement!
  - Reduce systematics
  - New channels to explore
  - Multivariate analyses
  - Lots of data expected!
- Proof of principle for boosted Higgs analysis
- **Watch this space!**

Ref.: ATLAS-CONF-2011-103



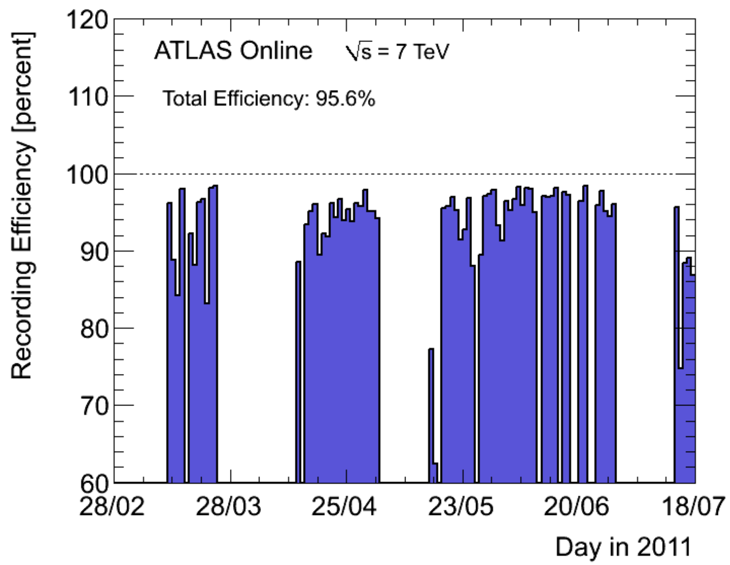


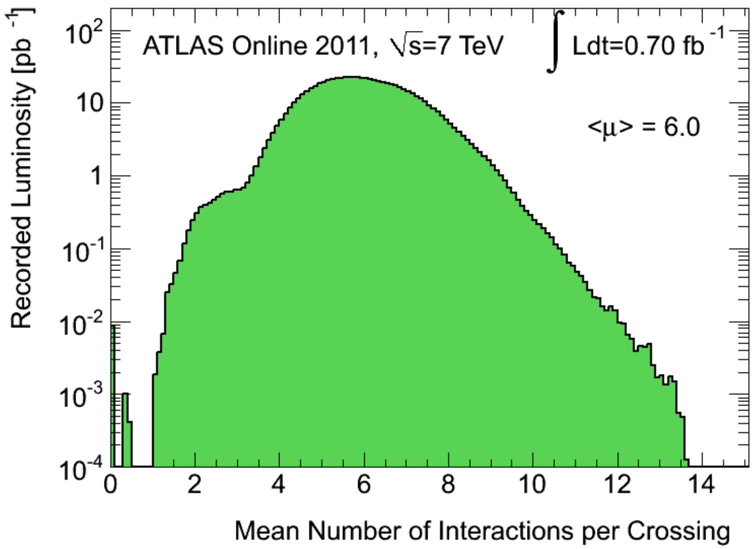
BACKUP

ATLAS & LHC: Efficiency and Pileup

- **Very good ATLAS performance**
  - **Data-taking efficiency above 95%**
- **Luminosity-weighted distribution of the mean number of interactions per crossing for 2011**
- **Calculated from the instantaneous luminosity as:**

  $\mu = L \times \sigma_{inel} / (n_{bunch} \times f_r)$
  - **L: instantaneous luminosity**
  - **σ_{inel} : inelastic cross section (71.5 mb)**
  - **n_{bunch}: number of colliding bunches**
  - **f_r: LHC revolution frequency**
- **Entries at $\mu \approx 0$ from pilot bunches**
- **See: arXiv:1101.2185**





Monte Carlo Samples

Process	Generator	$\sigma \times BR$
WH	PYTHIA	See Tab. 1
ZH	PYTHIA	See Tab. 1
$W \to \ell\nu$	ALPGEN	10.46 nb [36, 37]
$Z/\gamma* \to \ell\ell$	ALPGEN, PYTHIA	
$m_{\ell\ell} > 40$ GeV		1.07nb [36, 38]
$m_{\ell\ell} > 60$ GeV		0.989 nb [36, 38]
WW	MC@NLO+gg2WW	46.23 pb [32, 33]
$WW \to l\nu qq$	HERWIG	46.23 pb [32, 33]
WZ	MC@NLO	
$66 < m_{\ell\ell} < 116$ GeV		18.0 pb [33]
ZZ	MC@NLO, PYTHIA	
$66 < m_{\ell\ell} < 116$ GeV		5.96 pb [33]
Top quark		
$t\bar{t}$	MC@NLO	164.6 pb [39]
$t-$channel	MC@NLO	58.7 pb [33]
$s-$channel	MC@NLO	3.94 pb [33]
$Wt-$channel	MC@NLO	13.1 pb [33]
$b\bar{b} \to \mu\mu$	PYTHIA	73.9 nb
$c\bar{c} \to \mu\mu$	PYTHIA	28.4 nb

Table 2: Monte Carlo programs used for modeling signal and background processes and the cross-sections times branching ratio (BR) used to normalize the different processes. Branching ratios correspond to the decays shown. Where two generators are given the second is used to estimate systematic uncertainties.

- Common event selection:

	$ZH \rightarrow \ell\ell b\bar{b}$	$WH \rightarrow \ell\nu b\bar{b}$
Trigger	single/dilepton	single lepton
Primary vertex	primary vertex with > 3 tracks	
Number of leptons	exactly two	exactly one
Invariant/transverse mass	$76 < m_{ll} < 106$ GeV	$m_T > 40$ GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$	$E_{\mathrm{T}}^{\mathrm{miss}} < 50$ GeV	$E_{\mathrm{T}}^{\mathrm{miss}} > 25$ GeV
Jets	at least two	exactly two
b-tagged jets	exactly two	exactly two

- Lepton Identification:

	$ZH \rightarrow \ell\ell b\bar{b}$		$WH \rightarrow \ell\nu b\bar{b}$	
	e **channel**	μ **channel**	e **channel**	μ **channel**
Kinematic cuts	$E_T^e > 20$ GeV $\lvert\eta^e_{cluster}\rvert < 2.47$	$P_T^\mu > 20$ GeV $\lvert\eta^\mu\rvert < 2.5$	$E_T^e > 25$ GeV $\lvert\eta^e_{cluster}\rvert < 2.47$	$P_T^\mu > 25$ GeV $\lvert\eta^\mu\rvert < 2.4$
impact parameter	$\lvert d_0\rvert < 1$ mm $\lvert z_0\rvert < 10$ mm		$\lvert d_0\rvert < 0.1$ mm $\lvert z_0\rvert < 10$ mm	
Track isolation	$\sum_{tracks} P_T^{track}(\Delta R < 0.2)/p_T^\mu < 0.1$			

- Jet reconstruction:

Constituents	Topological jets
Identification	Anti-K_T $R = 0.4$
Kinematic cuts	$P_T^{jet} > 25$ GeV $\lvert\eta^{jet}\rvert < 2.5$
Pile-Up conditions	$\lvert JVF\rvert > 0.75$

Detector related uncertainties

Source of Uncertainty	Treatment in analysis
Jet Energy Scale (JES) [61]	2 – 7% as a function of p_T and η
Jet Pile-up Uncertainty	2 – 7% as a function of p_T and η
b-quark Energy Scale	2.5%
Jet Energy Resolution [62]	5 – 12%
Electron Selection Efficiency	0.7 – 3% as a function of p_T, 0.4 – 6% as a function of η
Electron Trigger Efficiency	0.4 – 1% as a function of η
Electron Reconstruction Efficiency	0.7 – 1.8% as a function of η
Electron Energy Scale	0.1 – 6% as a function of η, pileup, material effects etc.
Electron Energy Resolution	Sampling term 20%, a small constant term has a large variation with η
Muon Selection Efficiency	0.2 – 3% as a function of p_T
Muon Trigger Efficiency	$< 1\%$
Muon Momentum Scale	2 – 16% η-dependent systematic on scale
Muon Momentum Resolution	p_T and η-dependent resolution smearing functions, systematic $\leq 1\%$
b-tagging Efficiency	5 – 14% as a function of p_T
b-tagging Mis-tag Fraction	8 – 12% as a function of p_T and η
Missing Transverse Energy	Add/subtract object uncertainties in E_T^{miss}

Normalization Systematic Uncertainties

Source of Uncertainty	Treatment in analysis	
	ZH	*WH*
Luminosity	3.7%	3.7%
Higgs cross-section	5%	5%
Background norm. and shape:		
Top	9%	6%
Z+jets	11% plus shape	11%
W+jets	negligible	14% plus shapes
ZZ	11%	negligible
WZ	11%	11%
WW	negligible	11%
QCD multijets	100%	50%