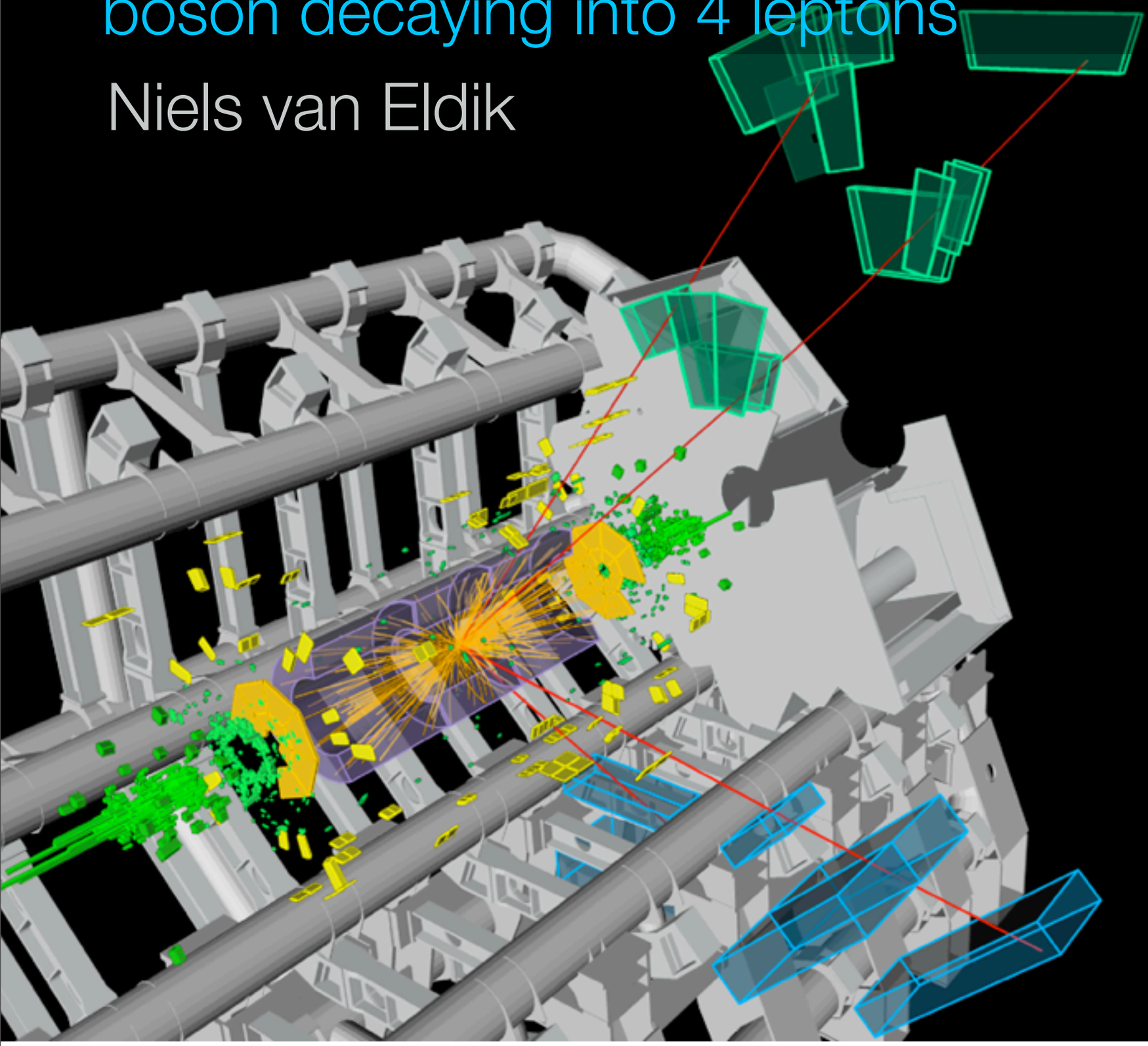
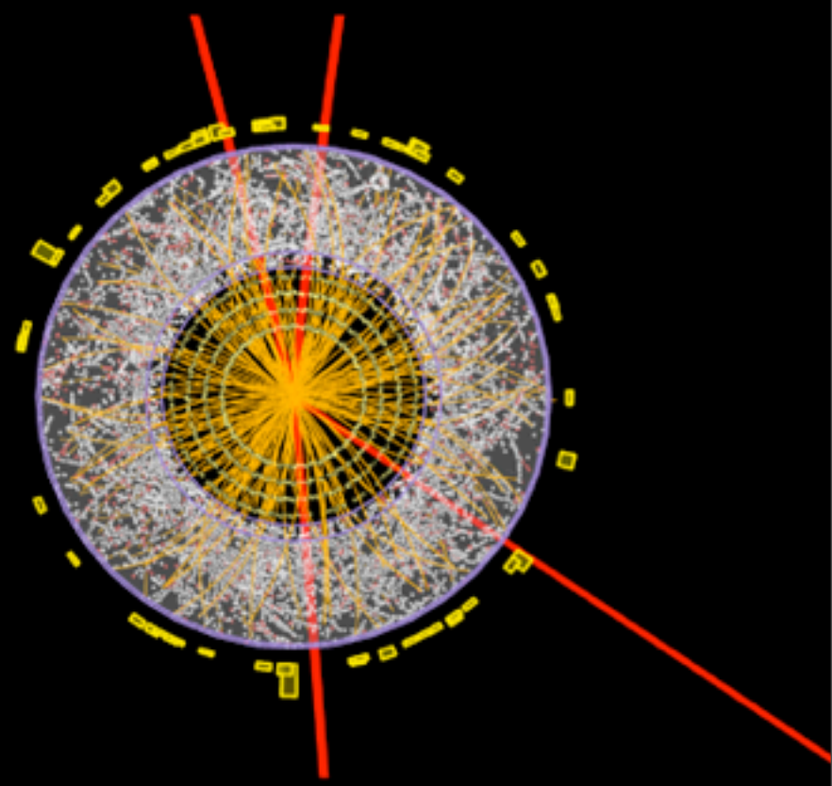
Measurement of the properties of a Higgs like boson decaying into 4 leptons

Niels van Eldik

ATLAS EXPERIMENT
http://atlas.ch





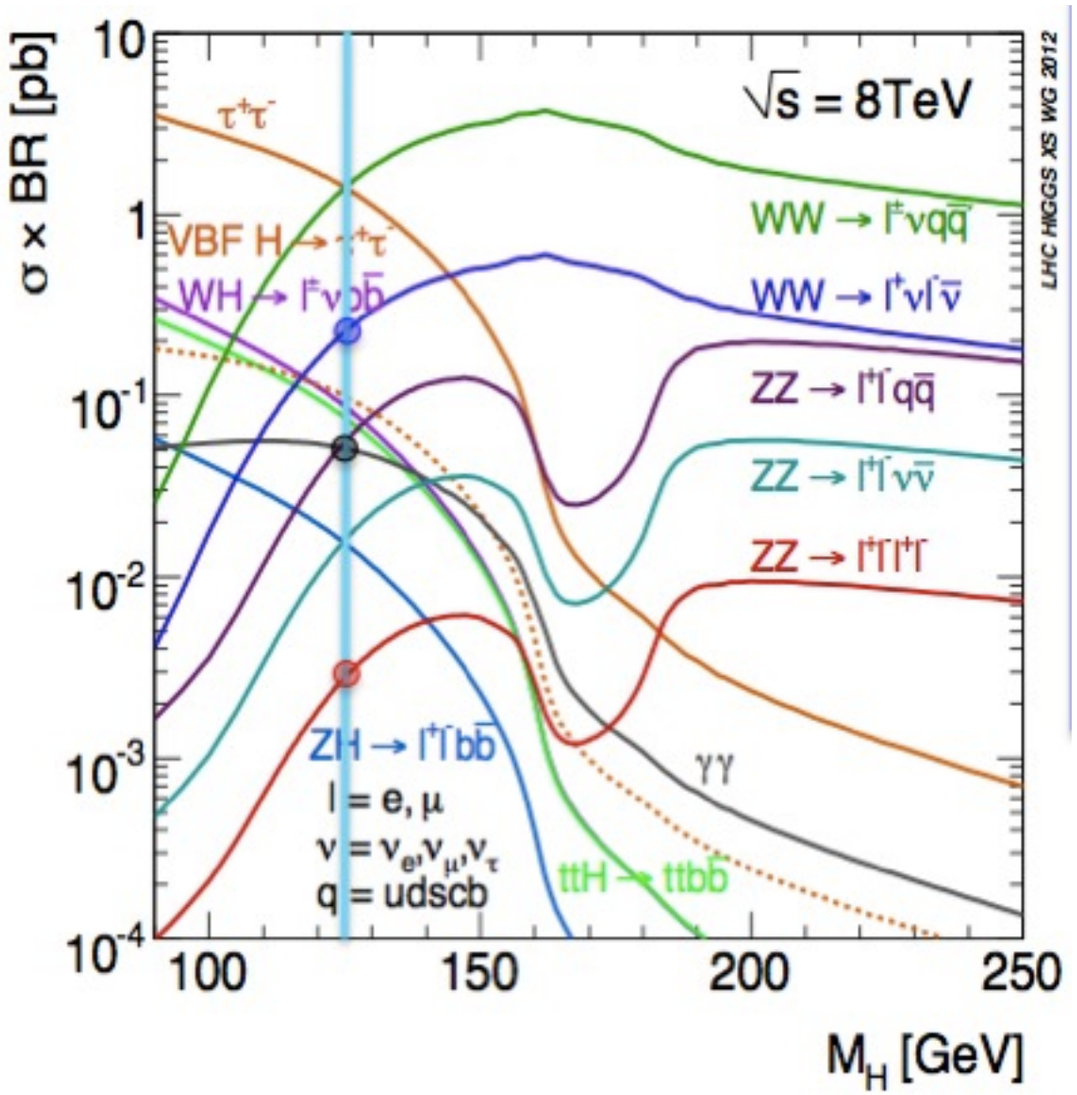
CERN

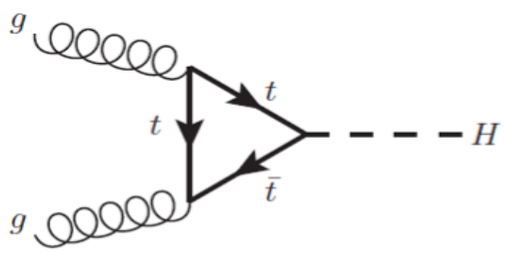
Introduction

- Talk covers
  - overview of the main analysis
  - mass measurement
  - spin-parity measurements
- Full 2011 - 2012 ATLAS dataset:
  - 4.6 fb^{-1} @ 7 TeV
  - 20.7 fb^{-1} @ 8 TeV
- Reference publications:
  - Measurements of the properties of the Higgs-like boson in the four lepton decay channel with the ATLAS detector using 25 fb-1 of proton-proton collision data (ATLAS-CONF-2013-013)
  - Evidence for the spin-0 nature of the Higgs boson using ATLAS data (arXiv:1307.1432)
  - Measurements of Higgs boson production and couplings in diboson final states with the ATLAS (arXiv:1307.1427)

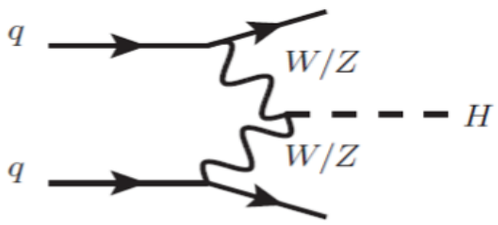
The golden channel:
H -> ZZ -> 4l

- Events can be fully reconstructed with high efficiency and purity
  - allows mass, spin-parity measurement
- Signal/background ratio ~ 1
- However: low σ*BR

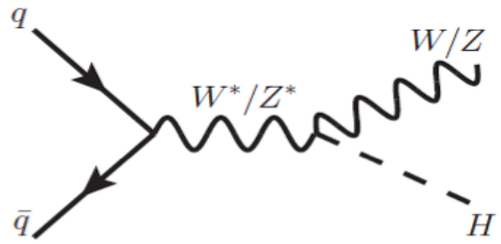




ggF



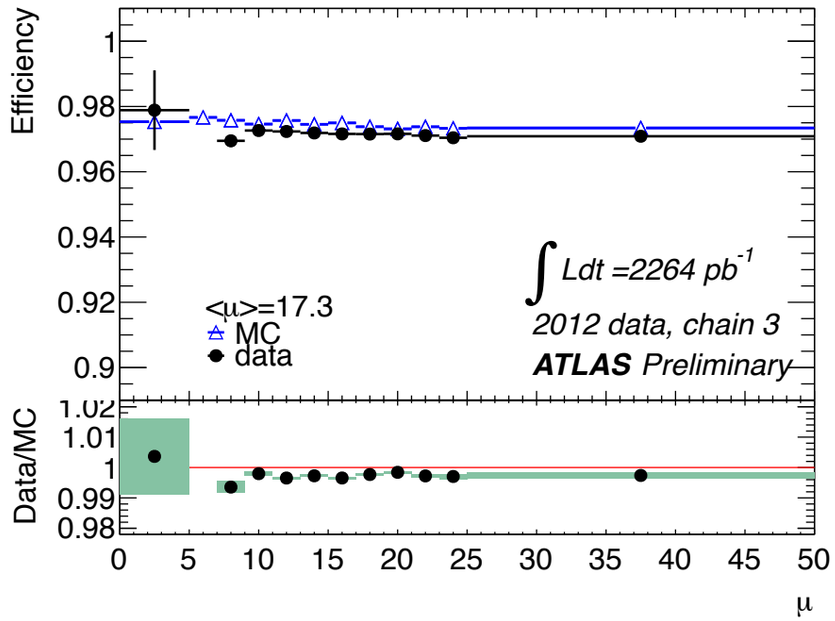
VBF

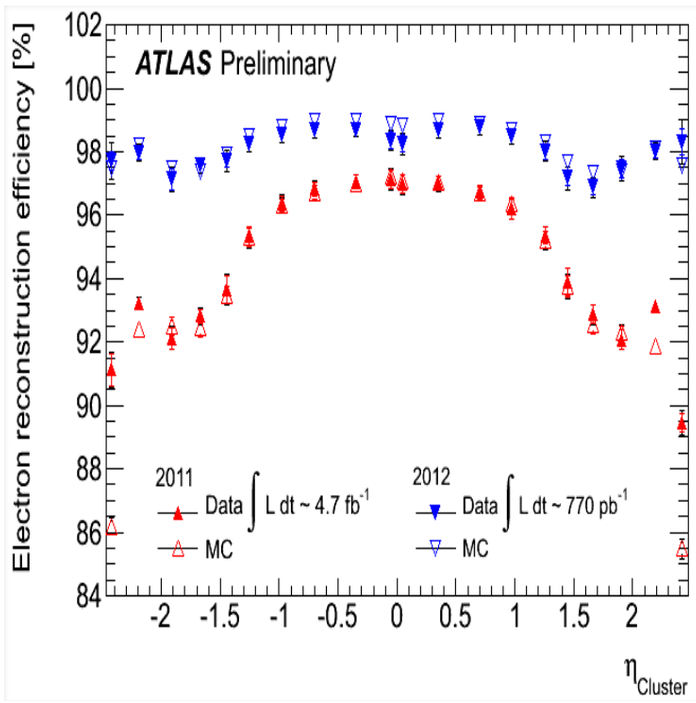


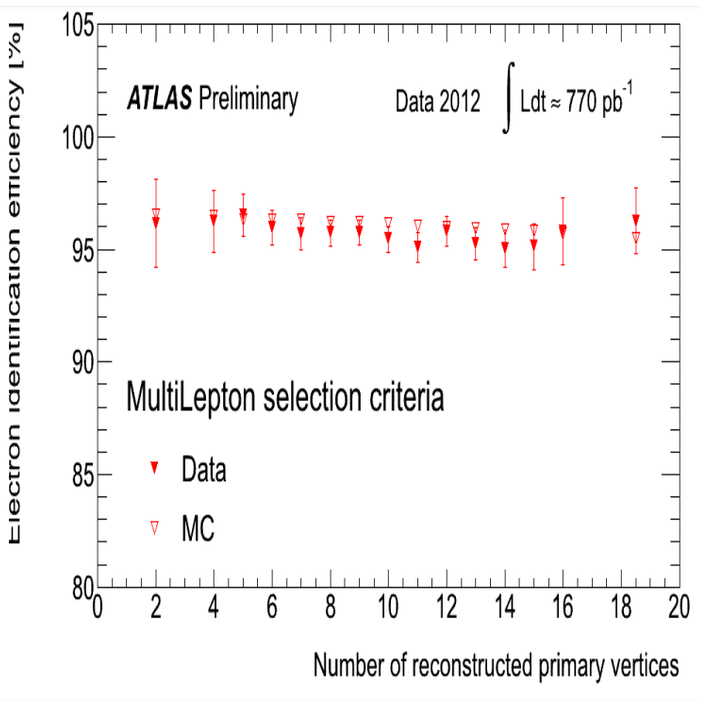
VH

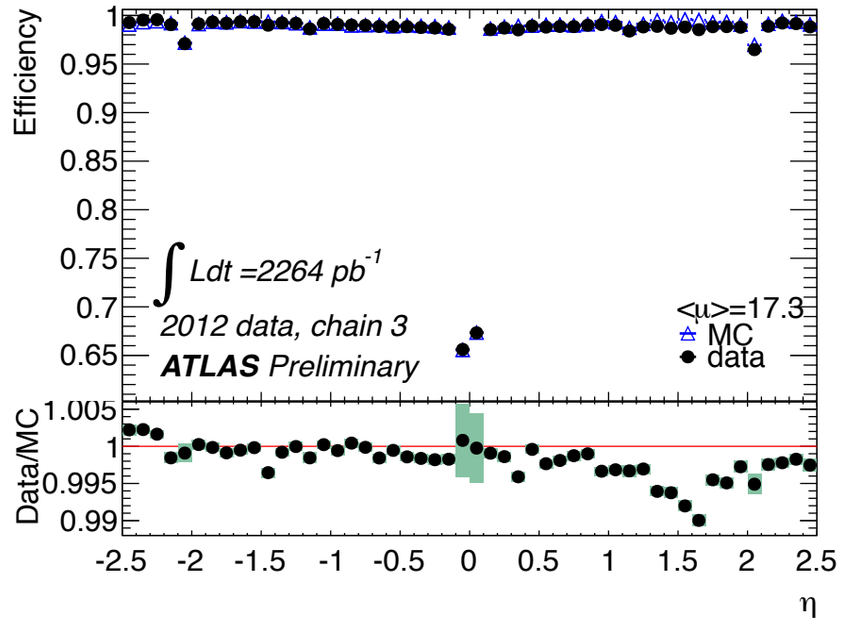
Reconstruction performance: efficiencies

- Significant improvements of the electron reconstruction efficiency for the 2012 dataset
- Muon reconstruction efficiency close to the geometrical acceptance
- Very good data/MC agreement for both muons and electrons



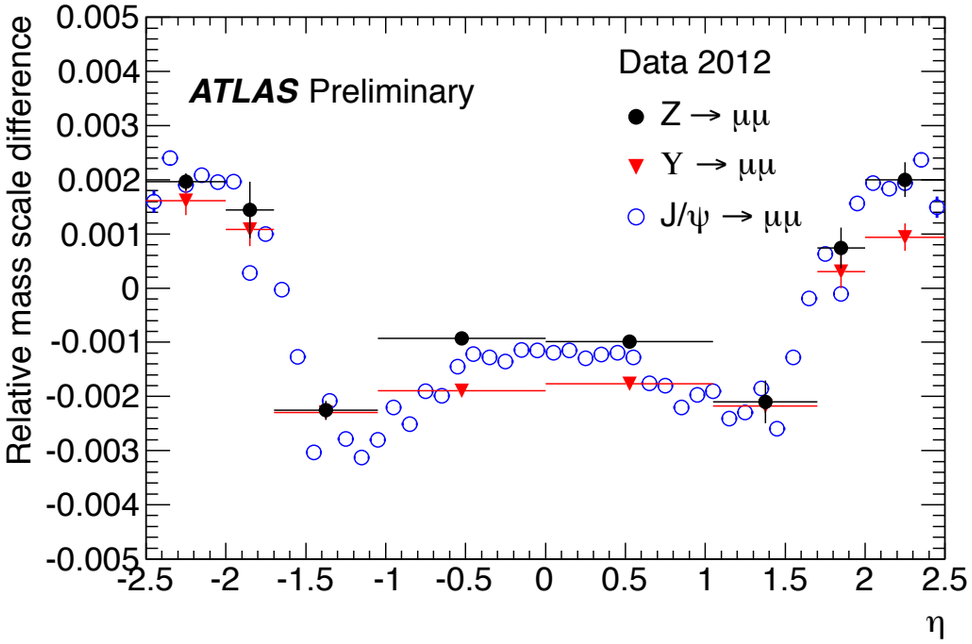


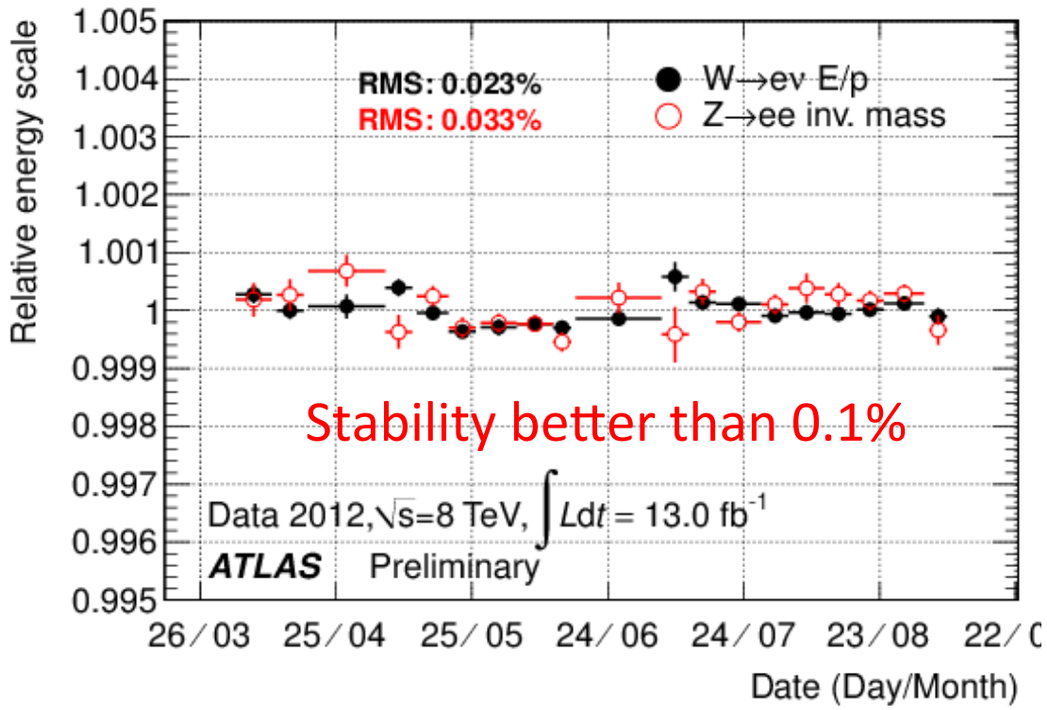


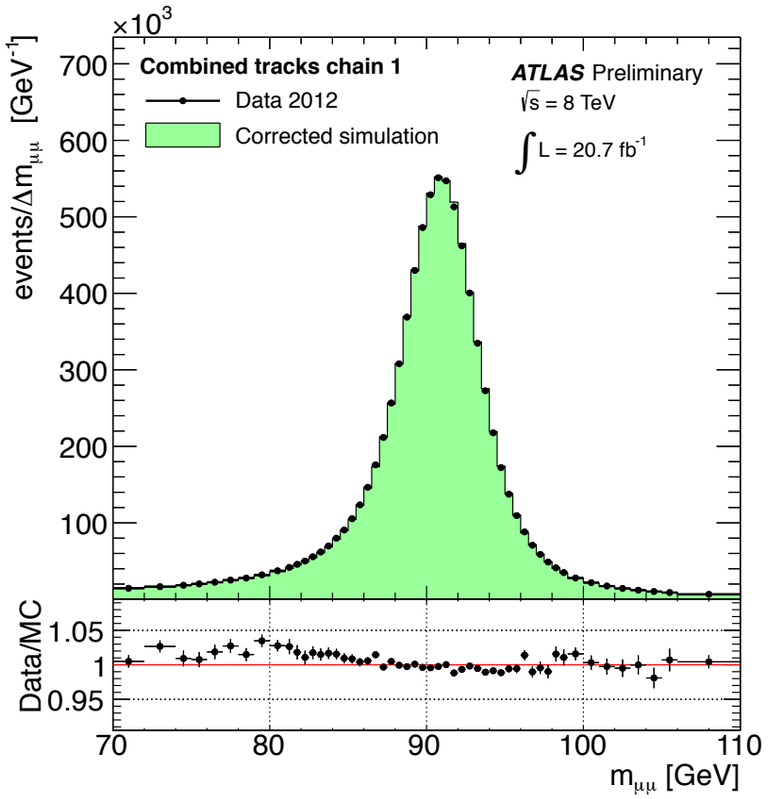


Reconstruction performance: energy scale

- Very detailed cross-checks performed
  - results very stable in time and under pile-up
  - both for electrons and muons
- Different input objects (Z/W/Upsilon/J/Psi) give comparable results
- Very good agreement with Monte-Carlo: better than 0.1%







Event selection

- Object selection:
  - Electrons: $E_T > 7$ GeV, $|\eta| < 2.47$, $GSF_{bremfit}$
  - Muons: $p_T > 6$ GeV, $|\eta| < 2.7$, FSR recovery
  - Jets (anti-k_T, R=0.4): pT > 25 GeV for $|\eta| < 2.4$, $p_T > 30$ for $2.4<|\eta|<4.5$
  - Object overlap removal: e-e, e-μ, μ-μ, e-jet
- Additional lepton selection:
  - relative track isolation in a cone of $\Delta R<0.2$: $I_{track} < 0.15$
  - relative calo isolation in a cone of $\Delta R<0.2$: typically $I_{calo} < 0.3$
  - $|d_0/\sigma_{d0}| < 3.5$ (6.5) for muons (electrons)
- Four lepton selection:
  - 2 SF-OS lepton pairs with $p_{T,l1} > 20$ GeV, $p_{T,l2} > 15$ GeV, $p_{T,l3} > 10$ GeV
  - Matched to single and di-lepton trigger
  - Quadruplet: SF-OS pairs with masses closest (Z_1) and next-closest (Z_2) to m_Z
  - Leading pair (Z_1): 50 GeV < m_{12} < 106 GeV
  - Subleading pair (Z_2): $m_{min} < m_{12} < 106$ GeV, m_{min} = 12 (50) GeV for m_{4l} <140 (>190) GeV

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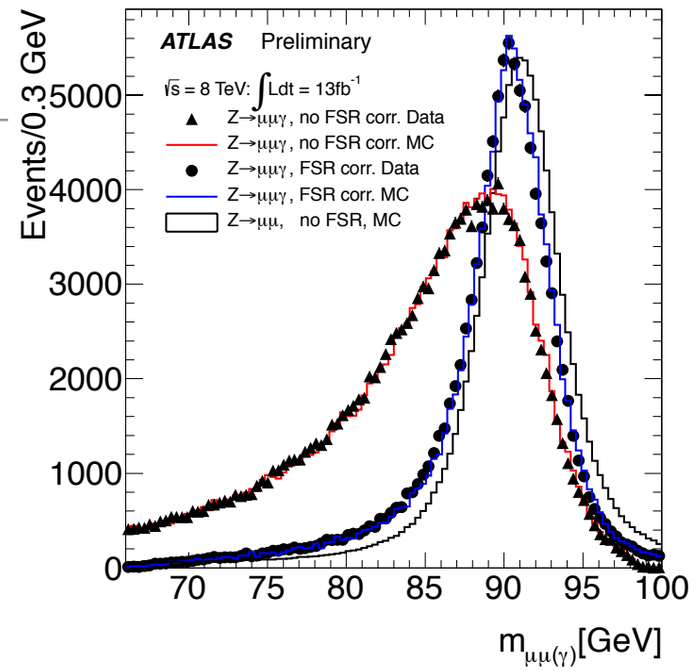
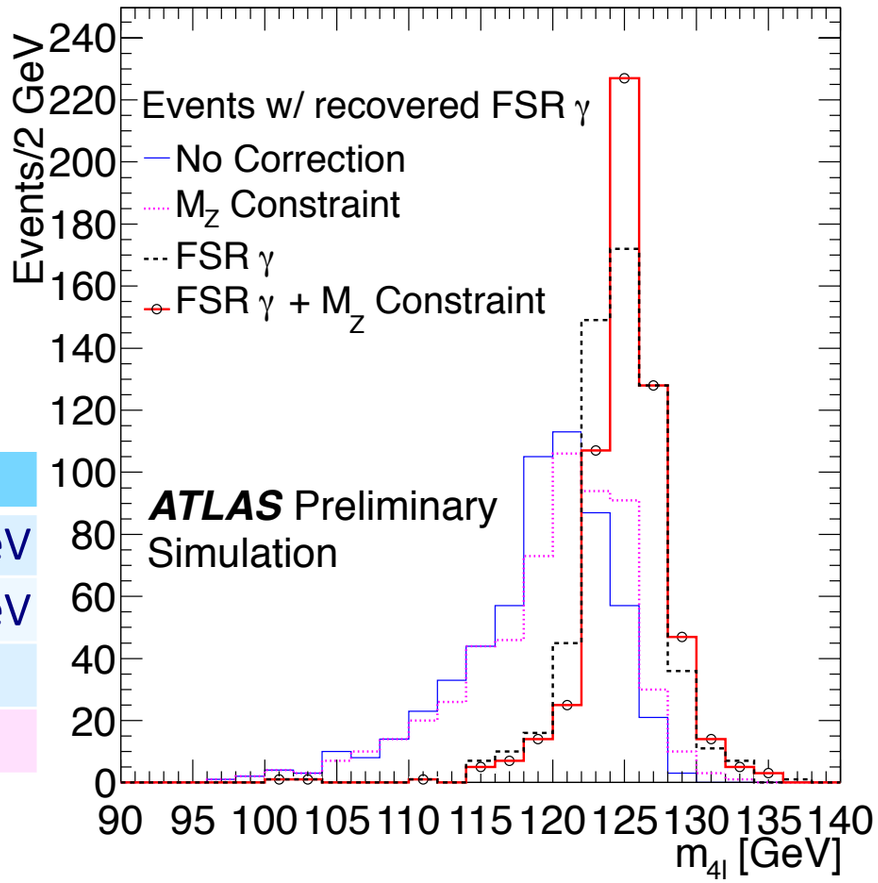
Overall acceptance
m_H = 125 GeV:
- 4μ 39%
- 2e2μ 26%
- 4e 19%
Mispairing <10%

Improving the mass reconstruction

- FSR correction for muons
  - Correct momentum of muon if photon with $E_T > 1.3$ GeV and $\Delta R_{cluster,\mu} < 0.15$
  - Only applied on leading muons with 66 GeV<$m_{\mu\mu}$<89 GeV and $m_{\mu\mu\gamma}$<100.0 GeV
  - FSR finding efficiency 70%, purity 85%
  - Affects 4% of the events
- Z-mass constraint on the leading lepton pair; for m_{4l}>190 GeV also on the subleading

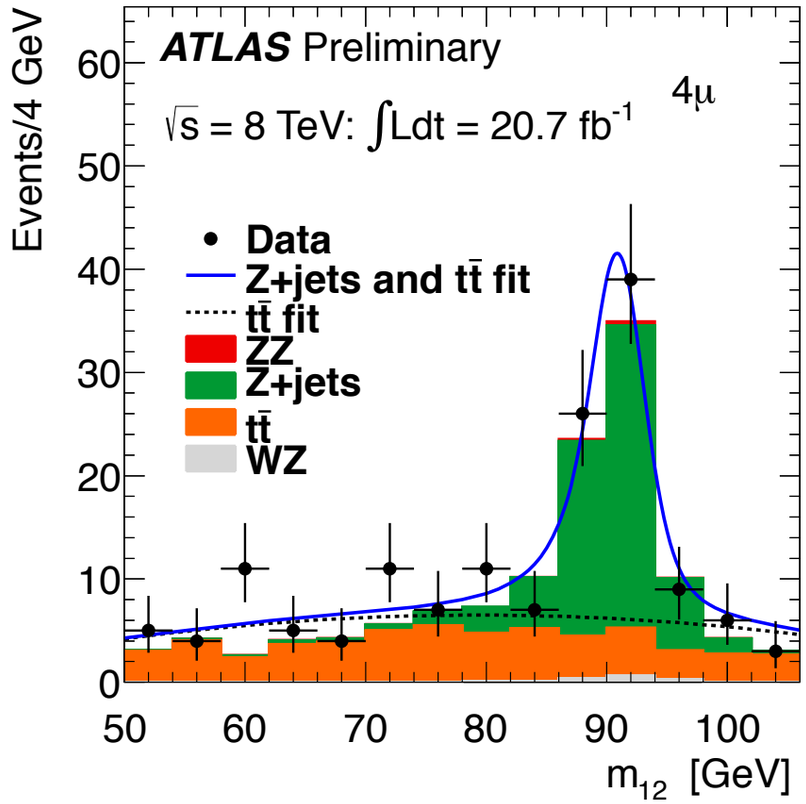


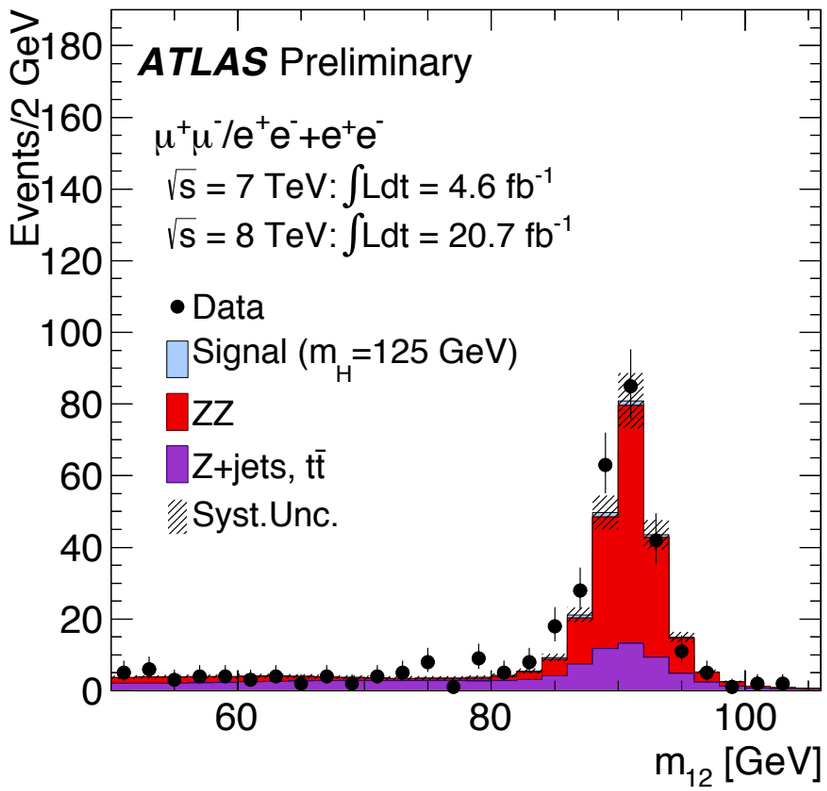
m_H=125 GeV	4μ	2μ2e / 2e2μ	4e
Gaussian mean	124.88±0.02 GeV	124.39±0.02 GeV	123.71±0.05 GeV
Gaussian width	1.62±0.02 GeV	1.90±0.02 GeV	2.40±0.05 GeV
Tails (outside 2σ)	16%	22%	21%
Improvement on σ	19%	16%	12%



Background estimates

- Main irreducible background: ZZ*
  - estimated from MC: POWHEG, gg2ZZ, SHERPA
  - normalized to MCFM cross-section
- Reducible background: Z + jets, ttbar:
  - data-driven using control regions with relaxed or inverted selection
  - transfer factors from data or MC (cross-checked with data)
  - redundant set of methods for cross-checks





Background estimates: reducible background

method	estimate at $\sqrt{s} = 8$ TeV	estimate at $\sqrt{s} = 7$ TeV
	4μ	4μ
m_{12} fit: Z + jets contribution	$2.4 \pm 0.5 \pm 0.6^{\dagger}$	$0.22 \pm 0.07 \pm 0.02^{\dagger}$
m_{12} fit: $t\bar{t}$ contribution	$0.14 \pm 0.03 \pm 0.03^{\dagger}$	$0.03 \pm 0.01 \pm 0.01^{\dagger}$
$t\bar{t}$ from $e\mu + \mu\mu$	$0.10 \pm 0.05 \pm 0.004$	-
	$2e2\mu$	$2e2\mu$
m_{12} fit: Z + jets contribution	$2.5 \pm 0.5 \pm 0.6^{\dagger}$	$0.19 \pm 0.06 \pm 0.02^{\dagger}$
m_{12} fit: $t\bar{t}$ contribution	$0.10 \pm 0.02 \pm 0.02^{\dagger}$	$0.03 \pm 0.01 \pm 0.01^{\dagger}$
$t\bar{t}$ from $e\mu + \mu\mu$	$0.12 \pm 0.07 \pm 0.005$	-
	$2\mu 2e$	$2\mu 2e$
$\ell\ell + e^{\pm}e^{\mp}$ relaxed cuts	$5.2 \pm 0.4 \pm 0.5^{\dagger}$	$1.8 \pm 0.3 \pm 0.4$
$\ell\ell + e^{\pm}e^{\mp}$ inverted cuts	$3.9 \pm 0.4 \pm 0.6$	-
$3\ell + \ell$ (same-sign)	$4.3 \pm 0.6 \pm 0.5$	$2.8 \pm 0.4 \pm 0.5^{\dagger}$
sub-leading same sign full analysis events	4	0
	$4e$	$4e$
$\ell\ell + e^{\pm}e^{\mp}$ relaxed cuts	$3.2 \pm 0.5 \pm 0.4^{\dagger}$	$1.4 \pm 0.3 \pm 0.4$
$\ell\ell + e^{\pm}e^{\mp}$ inverted cuts	$3.6 \pm 0.6 \pm 0.6$	-
$3\ell + \ell$ (same-sign)	$4.2 \pm 0.5 \pm 0.5$	$2.5 \pm 0.3 \pm 0.5^{\dagger}$
sub-leading same sign full analysis events	3	2

4.6 fb^{-1} @ 7 TeV

20.7 fb^{-1} @ 8 TeV

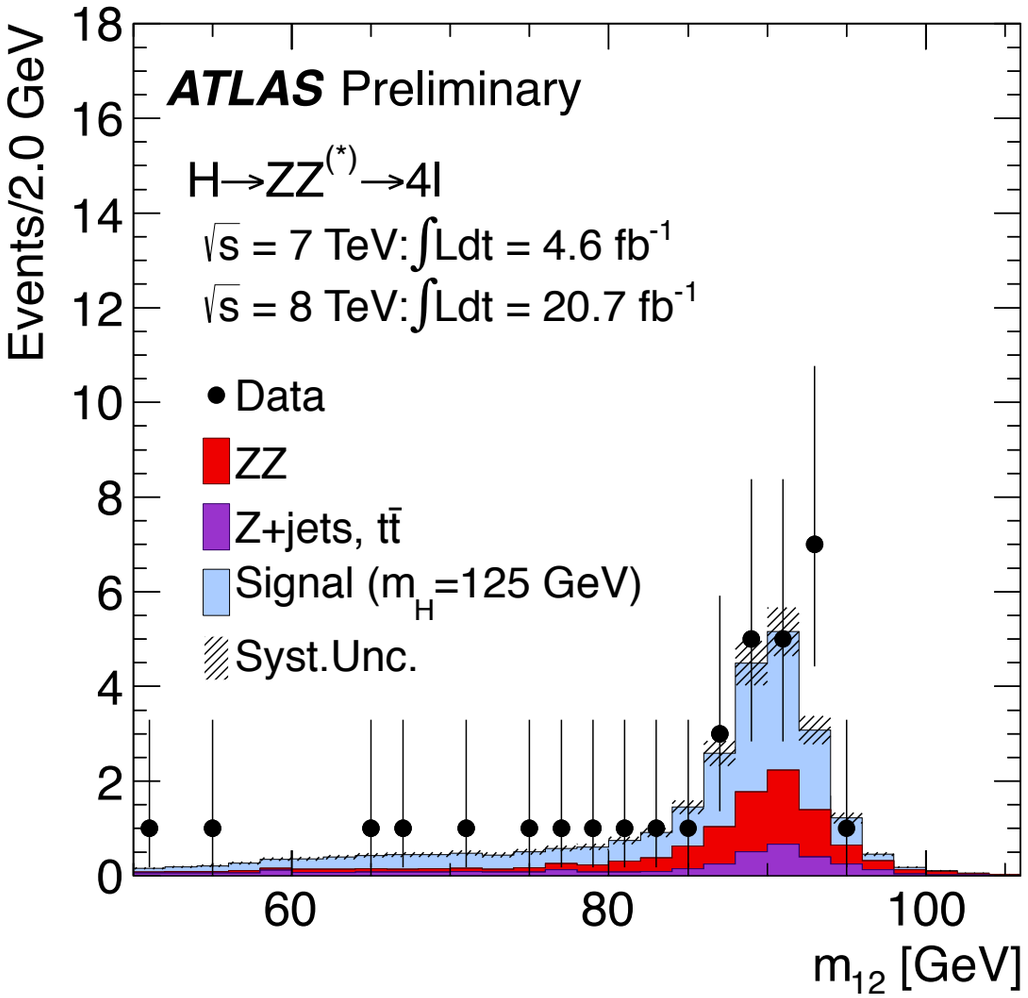
Systematics

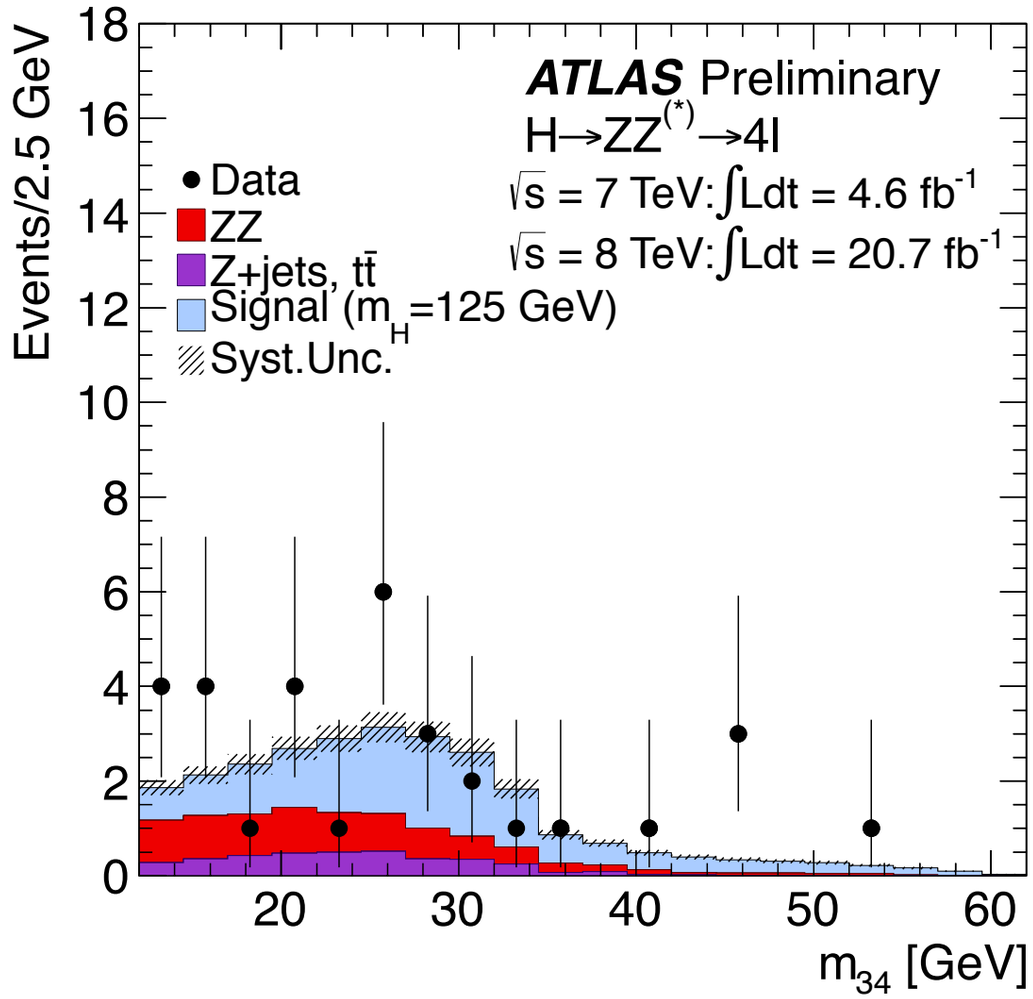
Signal rate	
Luminosity	1.8% (2011), 3.6% (2012)
Signal cross-section – scale	+7/-8% (ggF), 1% (VBF, VH)
– PDF	8% (gg), 4% (qq)
ggF p_T-reweighting	1%
$ZZ^{(*)}$ cross-section & shape – scale	5%
– PDF, α_s	8% (gg), 4% (qq)
Reducible background rate & shape	~30% (Z+μμ), ~20% (Z+ee)
Electron identification – signal @ m_H=125 GeV)	9.4% (4e), 8.7% (2μ2e), 2.4% (2e2μ)
– signal @ m_H=1 TeV)	2.4% (4e), 1.8% (2μ2e), 1.6% (2e2μ)
Muon identification	0.8% (4μ), 0.4% (2μ2e), 0.4% (2e2μ)
Mass measurement	
Electron energy scale and resolution	0.4% (4e), 0.2% (2e2μ)
Low-E_T electrons, QED FSR, background	<0.1%
Muon momentum scale and resolution	0.2% (4μ), 0.1% (2μ2e)

Electron and photon energy scale systematics fully correlated (from Z→ee based calibration)

Additional theoretical and experimental uncertainties for VBF-like and VH-like categories!

Selected events





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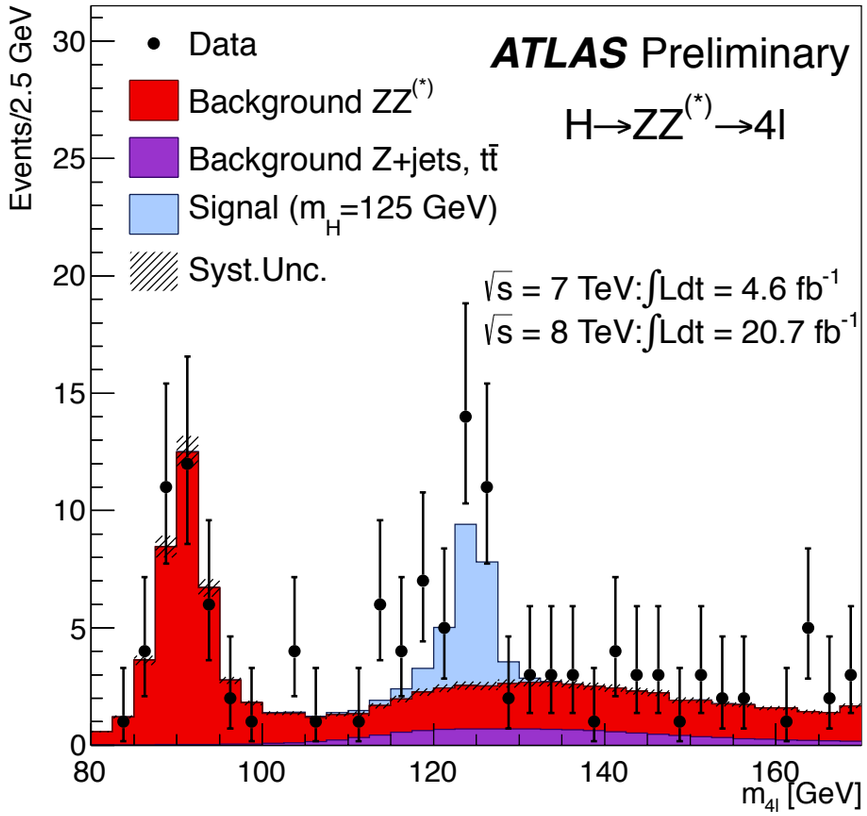
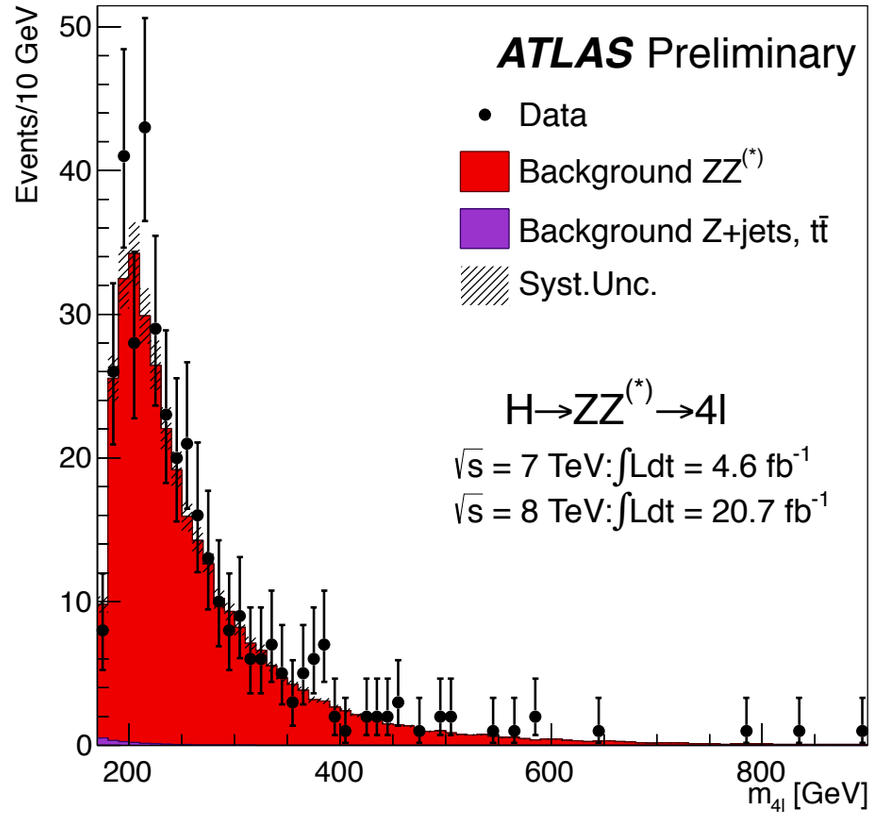
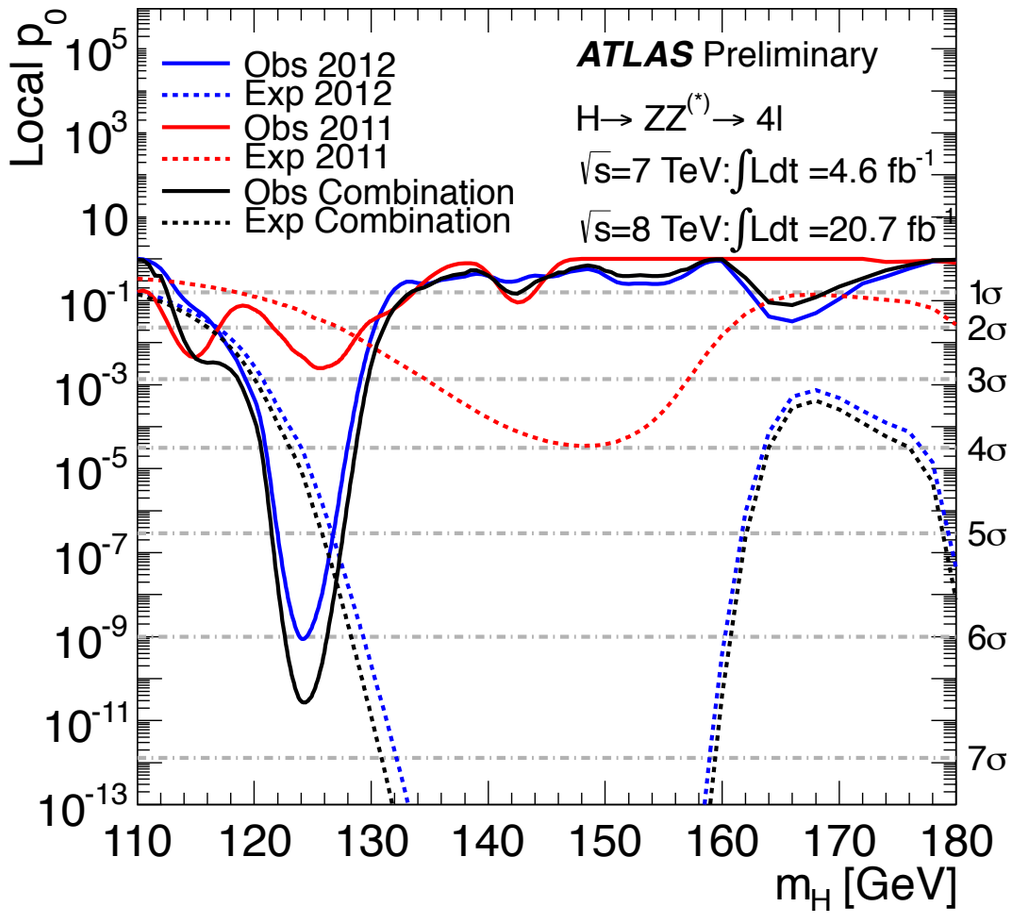




	4μ		$2\mu 2e/2e2\mu$		$4e$	
	low mass	high mass	low mass	high mass	low mass	high mass
$\sqrt{s} = 8$ TeV integrated luminosity 20.7 fb^{-1}						
$ZZ^{(*)}$	12.4 ± 0.6	92.6 ± 6.7	14.7 ± 0.9	144 ± 11	5.4 ± 0.5	55.9 ± 4.5
Z, $Zb\bar{b}$, and $t\bar{t}$	1.9 ± 0.6	0.5 ± 0.2	6.1 ± 1.5	1.5 ± 0.4	2.5 ± 0.6	0.6 ± 0.2
total background	14.3 ± 0.8	93.1 ± 6.7	20.8 ± 1.8	145 ± 11	8.0 ± 0.8	56.5 ± 4.5
data	27	93	28	169	13	55
$m_H = 125$ GeV	5.8 ± 0.7		7.0 ± 0.9		2.9 ± 0.4	

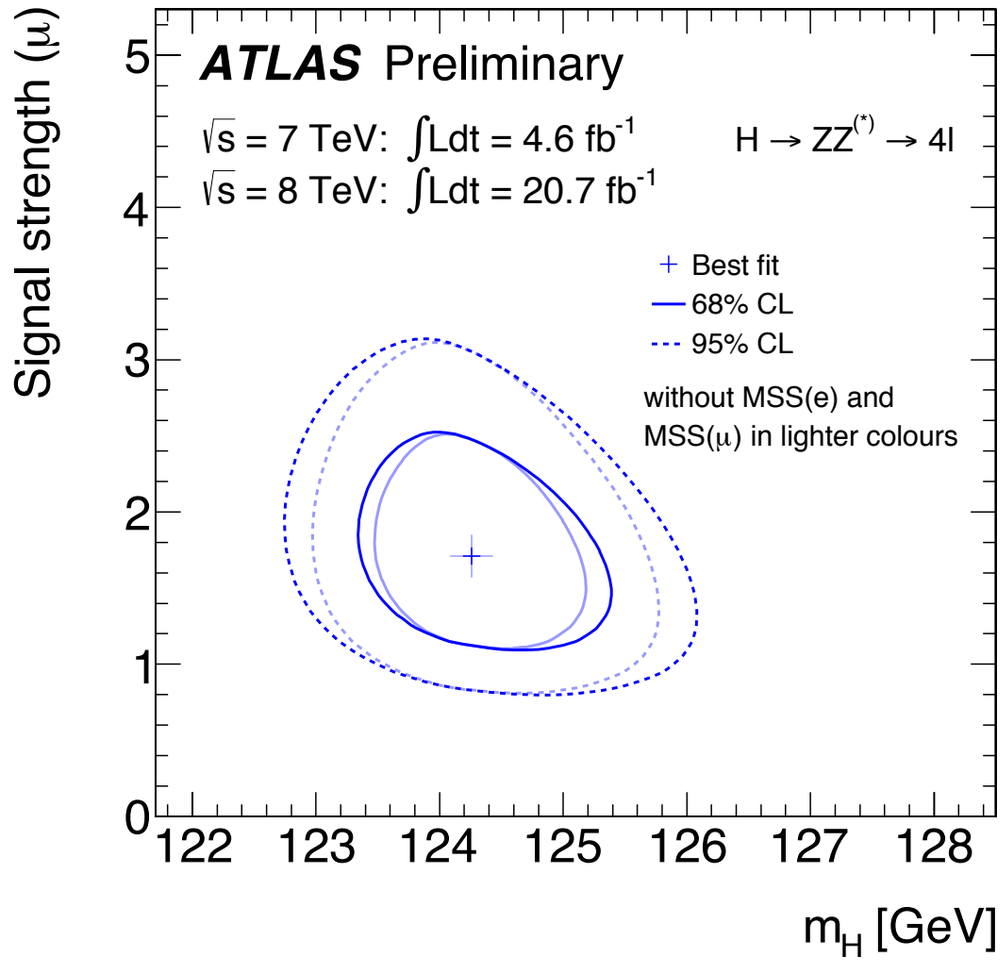
Higgs search result



H->ZZ*->4l

single channel discovery:

6.6 sigma



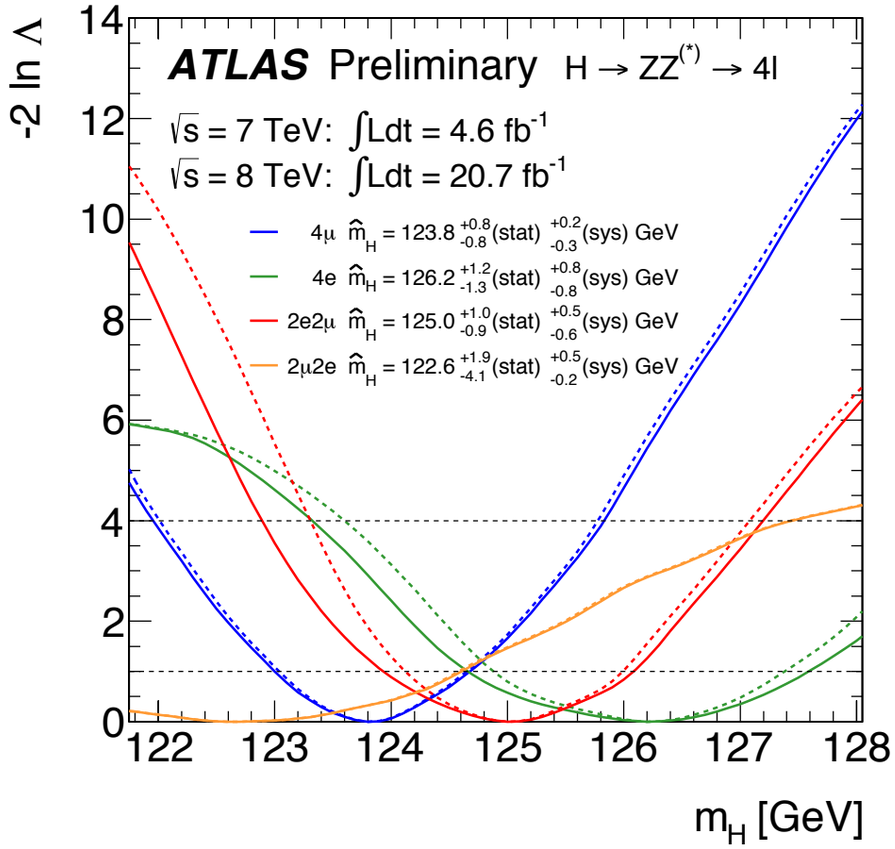
Signal strength

$\mu = 1.7\ ^{+0.5}_{-0.4}$ for $m_H = 124.3$ GeV

$\mu = 1.5 \pm 0.4$ for $m_H = 125.5$ GeV

Mass measurements

- The mass distributions are described as smooth unbinned estimates of the probability density functions obtained from simulation
- A Z mass constraint is used for m_{12} to improve the resolution
- The four channels are treated separately in the fit
- The 4μ and 2e2μ channels have the best mass resolution



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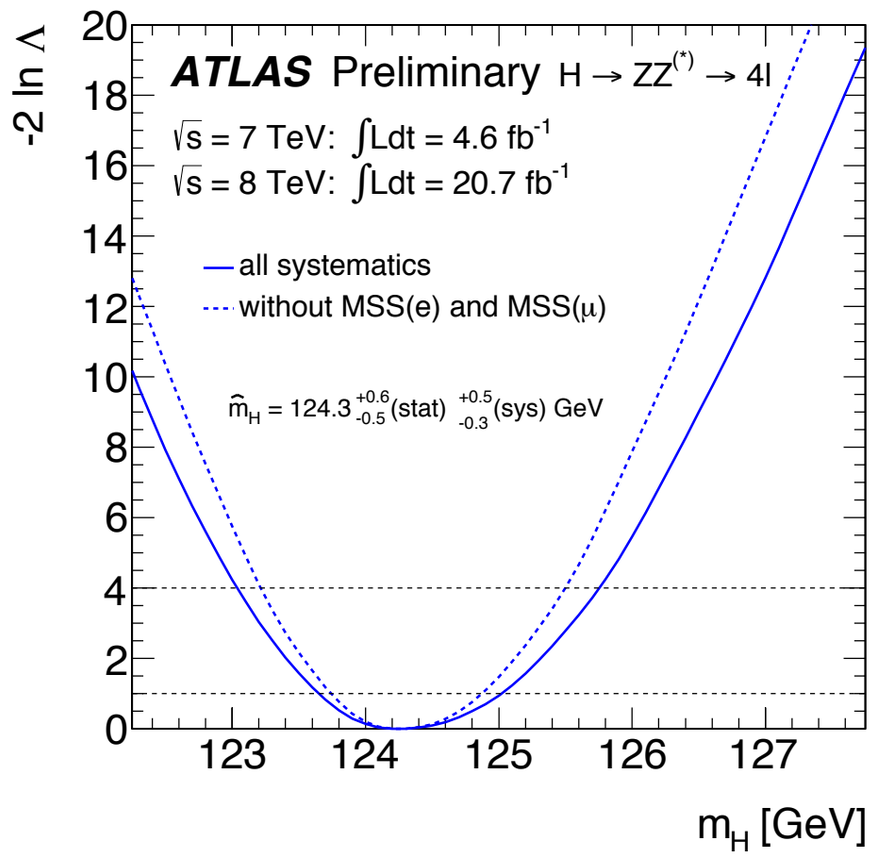
- A Z mass constraint is used for m_{12} to improve the resolution
- The four channels are treated separately in the fit
- The 4μ and 2e2μ channels have the best mass resolution
- Statistical uncertainties still larger than systematic uncertainties
- Systematic uncertainties dominated by energy and momentum scale uncertainties

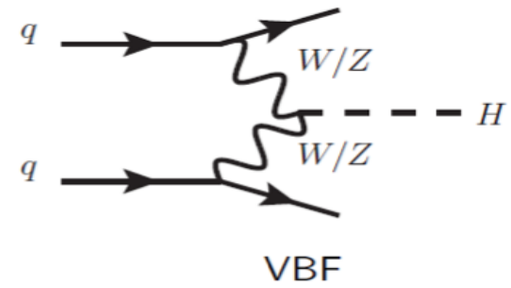


m_H =124.3 $^{+0.6}_{-0.5}$ (stat) $^{+0.5}_{-0.3}$ (syst) GeV

Event categorization

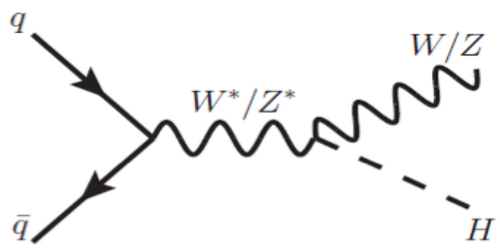
H -> 4l selection

VBF selection
$N_{jet}>1$, $|\eta_{j1}-\eta_{j2}|>3$, $m_{jj}>350$ GeV

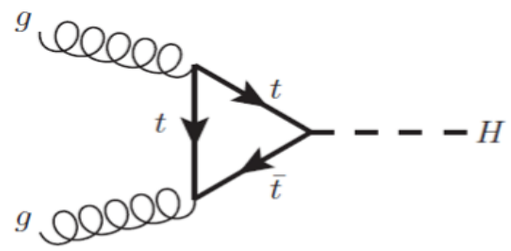


VBF

VH selection
Additional lepton with $p_T>8$ GeV



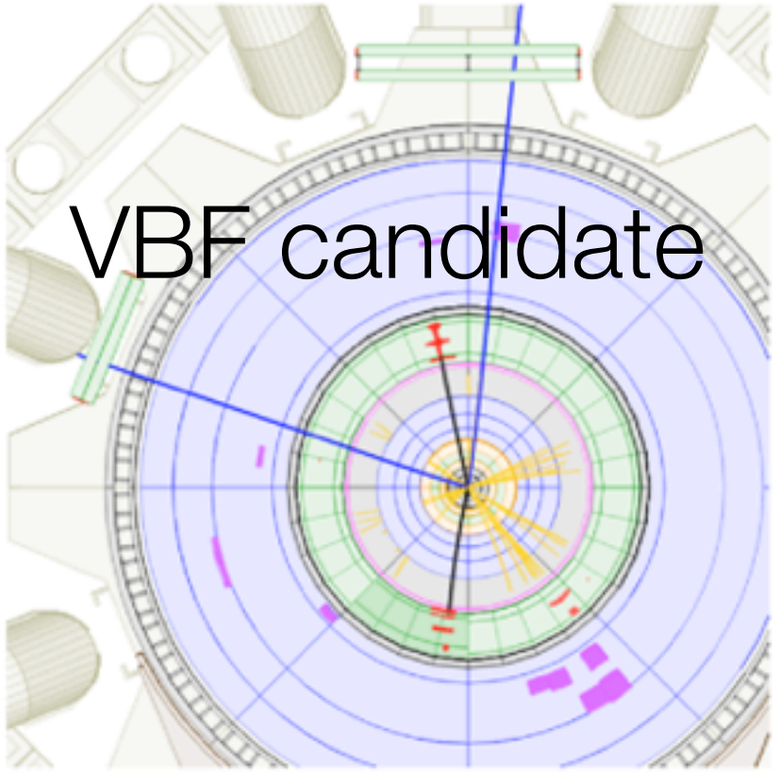
VH



ggF

category	$gg \to H, q\bar{q}/gg \to t\bar{t}H$	$qq' \to Hqq'$	$q\bar{q} \to W/ZH$
		$\sqrt{s} = 8$ TeV	
ggF-like	13.5	0.79	0.65
VBF-like	0.28	0.43	0.01
VH-like	0.06	-	0.14

VBF candidate



Run Number: 209109
Event Number: 76170653
Date: 2012-08-24, 08:31:00 CET

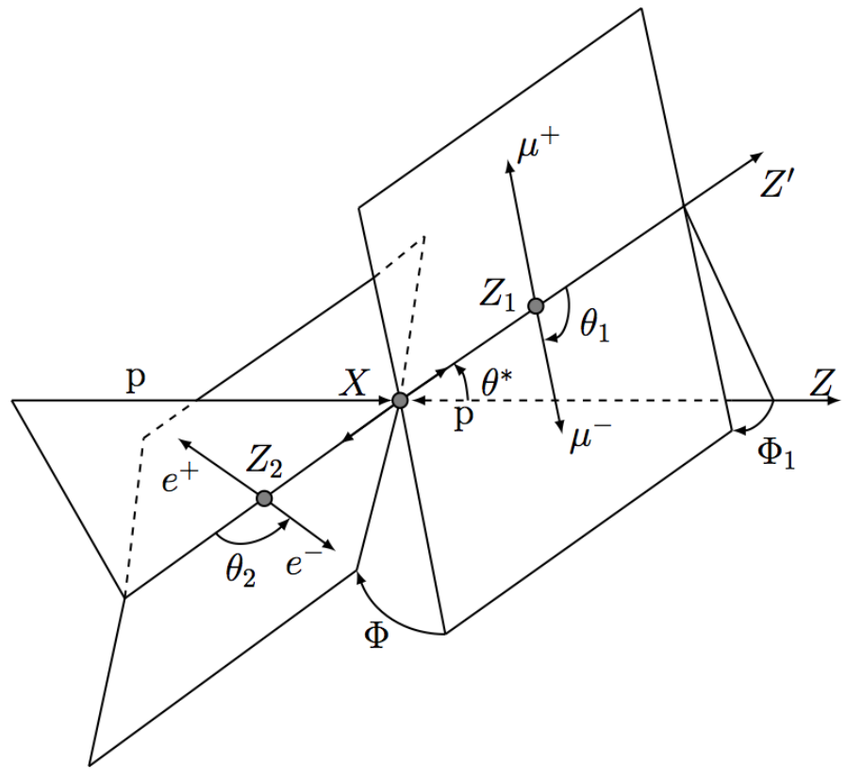
EtCut > 1.0 GeV
PtCut > 0.4 GeV
Muon: blue
Electron: black
Cells: Tiles, EMC

Expected VBF-like signal (m_{4l}=120-130 GeV):
0.71±0.10 events, S_H/B: 5
VBF purity: 60%
VBF signal: 0.4 events
$S_{VBF}/(S_{ggF}+B)$: 1

VBF candidates (m_{4l}>160 GeV): 6
SM ZZ: 3.8±1.3 events

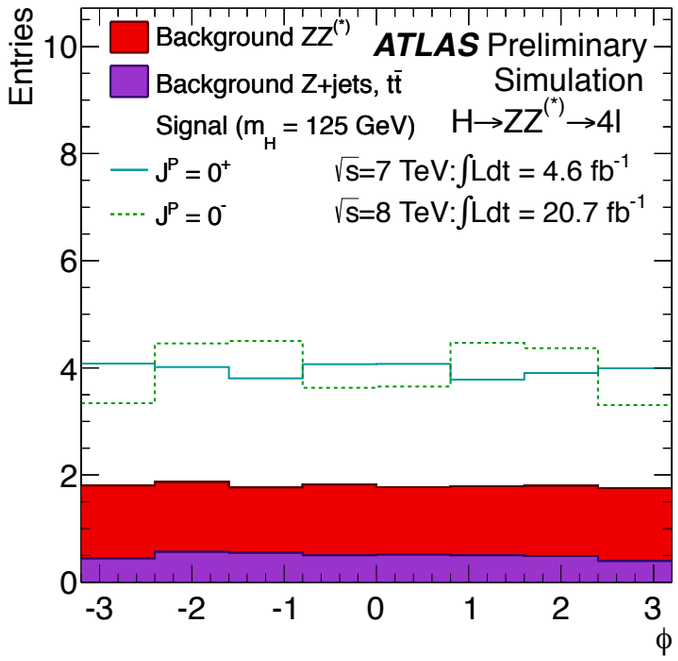
Spin-Parity analysis

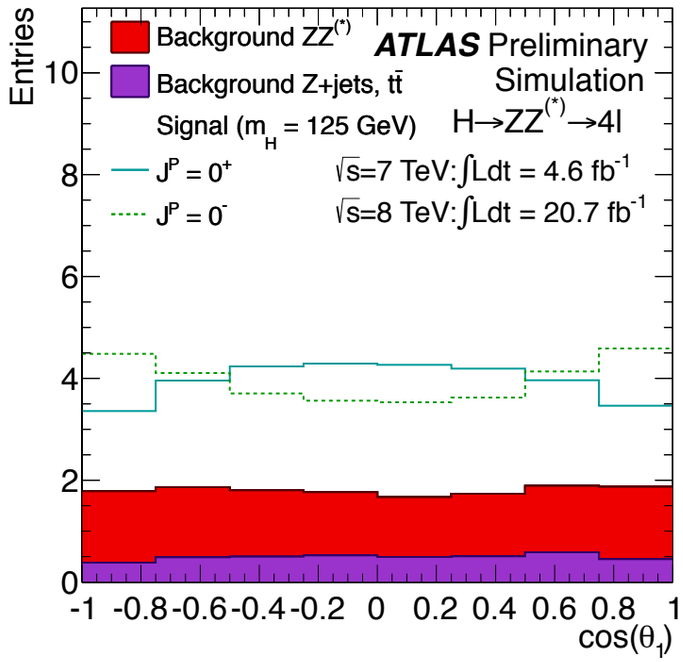
- Same event selection as for the main analysis
- Restrict mass-region to 115-130 GeV
  - two regions (improves sensitivity by ~5%)
    - high S/B: 121-127 GeV
    - low S/B: 115-121 and 127-130 GeV
- Events generated with JHU LO, re-weighted to match the POWHEG p_T spectrum
- Different spin–parity states generated via ggF production:
  - 0^+, 0^-, 1^+, 1^-, 2_m^+
- Seven sensitive variables
  - the masses of the two Z bosons
  - the angle between the two decay planes of the four leptons
  - the decay angles of the negative leptons θ_1, θ_2
  - the production angle θ^*
  - the decay angle of the first Z: Φ_1

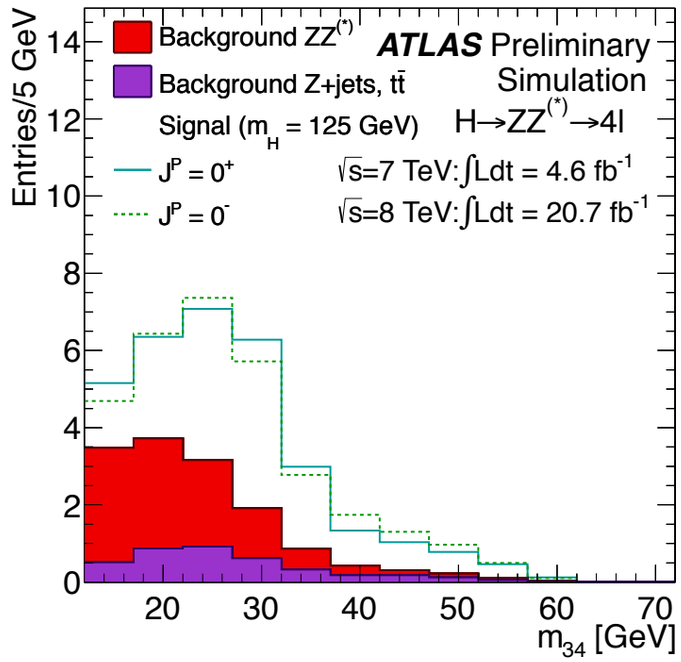


Spin-Parity analysis

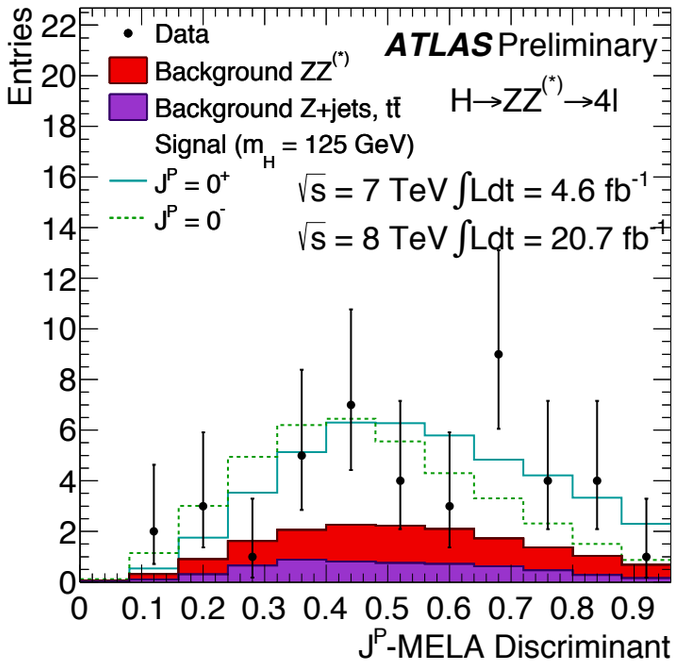
- Strategy: demonstrate consistency with 0^+ and falsify other hypothesis
- Combine the seven variables: multivariate analysis
  - boosted decision tree (BDT) for each spin-parity hypothesis pair
    - for 0^+ - 0^- separation: exclude θ^* and Φ_1
    - for all other separations: use all variables
  - matrix element based likelihood ratio (MELA)
    - calculate probability that an event comes from a particular spin-parity state
    - correct for detector acceptance, analysis selection and mispairing using full MC

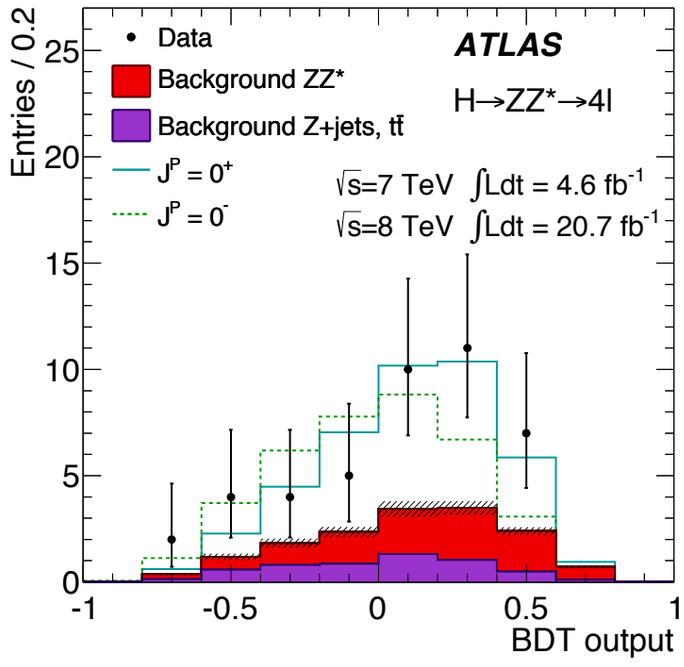


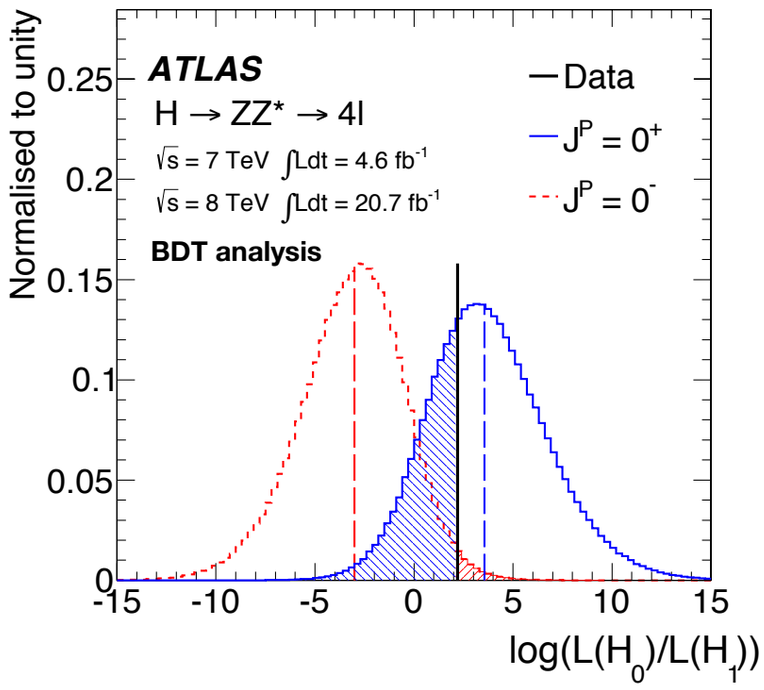




Spin-Parity analysis: 0^+ vs 0^-

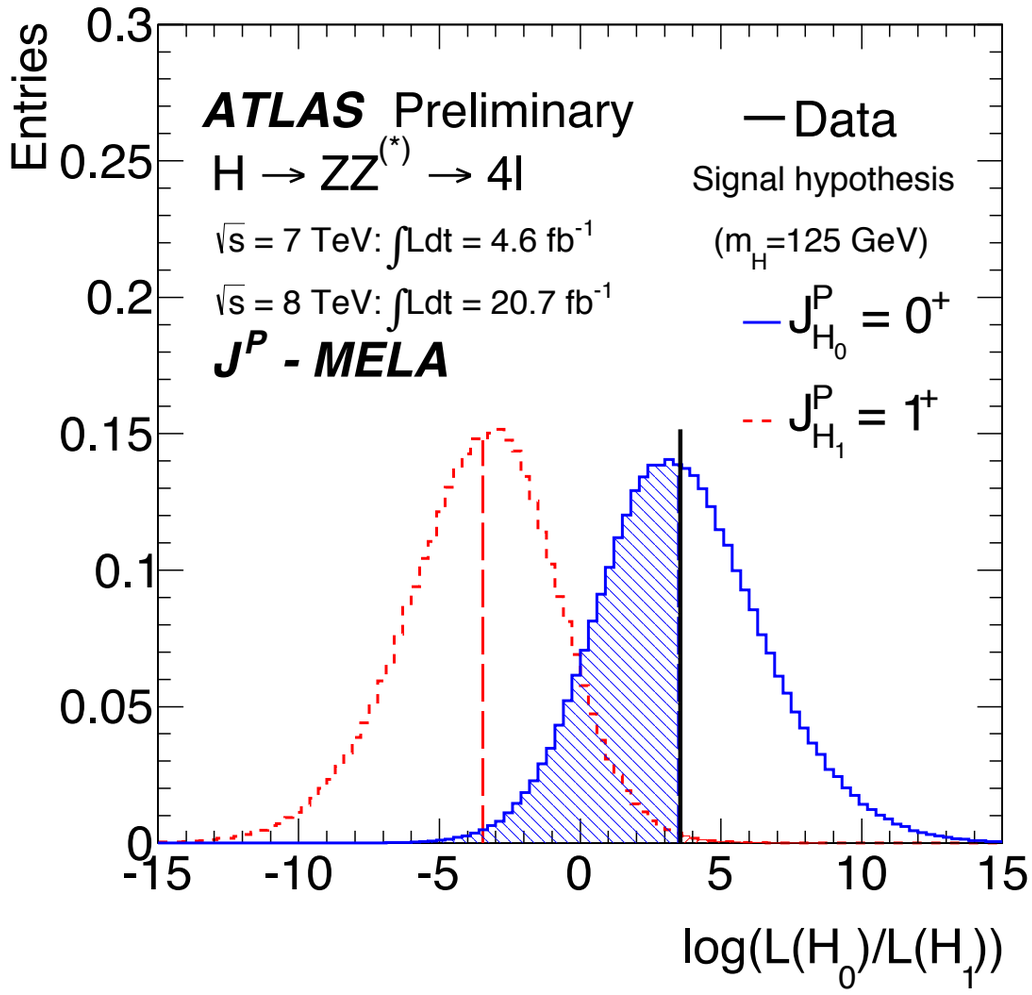


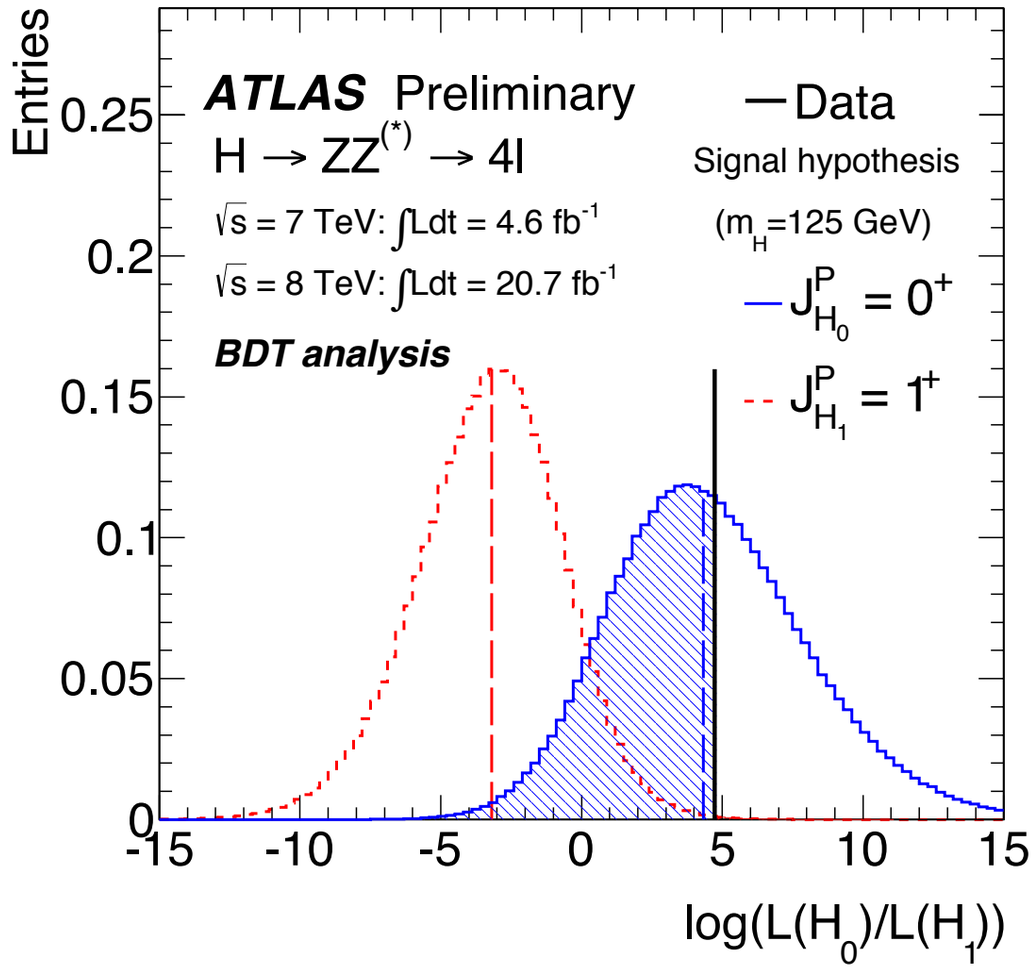




Both analysis have similar sensitivity
Exclude $J^P=0^-$ (vs. 0^+) with 97.8% CL

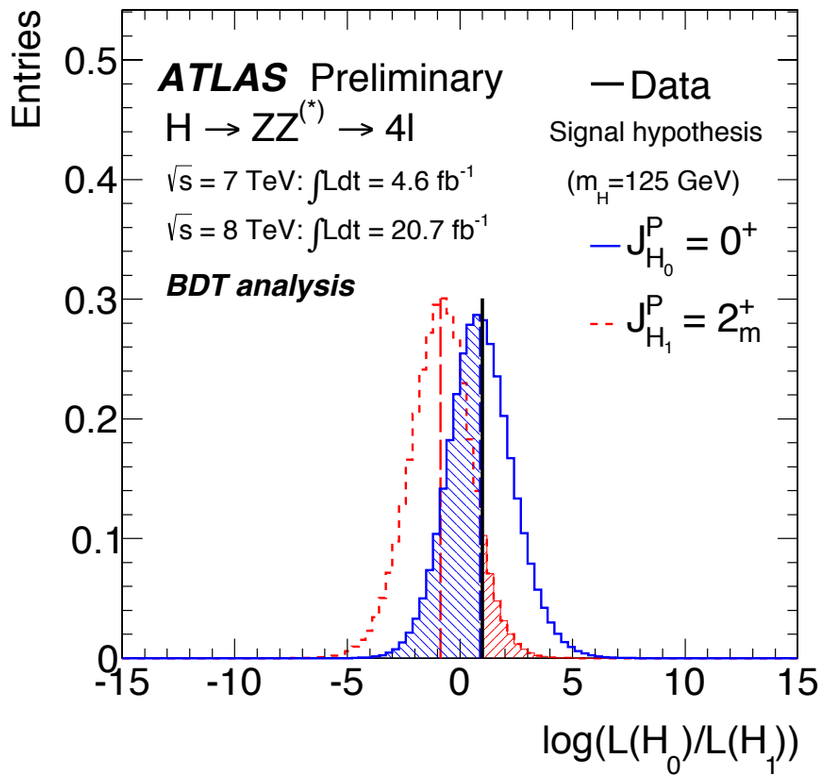
Spin-Parity analysis: 0^+ vs $1^{-,+}$

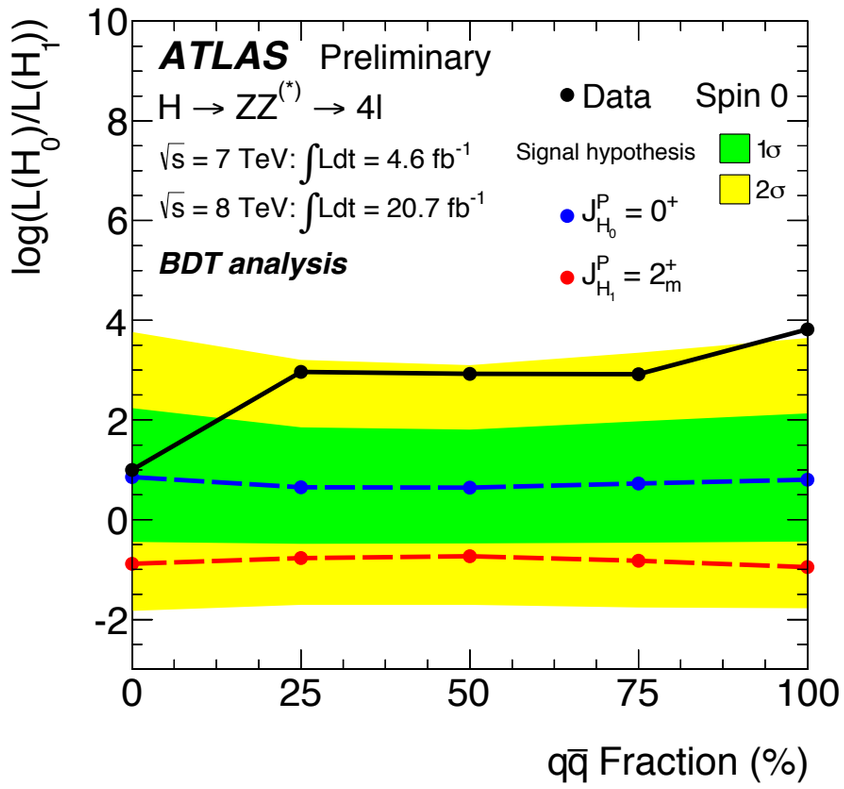




BDT analysis excludes:
$J^P=1^-$ with 94% CL
$J^P=1^+$ with 99.8% CL

Spin-Parity analysis: 0^+ vs 2_m^+





Spin 2: graviton-like tensor with minimal couplings to SM particles

equivalent to a Kaluza-Klein graviton (Y. Gao et al, Phys. Rev. D81 (2010) 075022)

Production via gg-fusion and qq annihilation possible: studies are preformed as function of the qq-fraction

Observed exclusion: 83.2% CL (100% ggF)

Conclusions

- Results presented using the full 2011 (4.6 fb^{-1}) and 2012 (20.7 fb^{-1}) data set
- Inclusive analysis
  - observation of a 6.6 σ excess over background
  - the best fitted mass is $124.3\ ^{+0.6}_{-0.5}\ (stat)^{+0.5}_{-0.3}\ (syst)$ GeV
  - the signal strength is $1.7\ ^{+0.5}_{-0.4}$
- Events divided into three categories: ggF-, VBF-, VH-like
  - one VBF-like event with m_H=123.5 GeV observed, where 0.5 VBF signal events expected with S/B~1(when counting ggF signal as background)
- BDT and J^p-mela analysis testing several spin-parity states: 0^+, 0^-, 1^+, 1^-, 2_m^+
  - the new boson compatible with SM 0^+ Higgs hypothesis when comparing pair-wise with 0^-, 1^+, 1^-, 2_m^+
  - 0^-, 1^+ hypothesis excluded at 97.8% CL or higher in favor of 0^+