SM Higgs Searches in ATLAS

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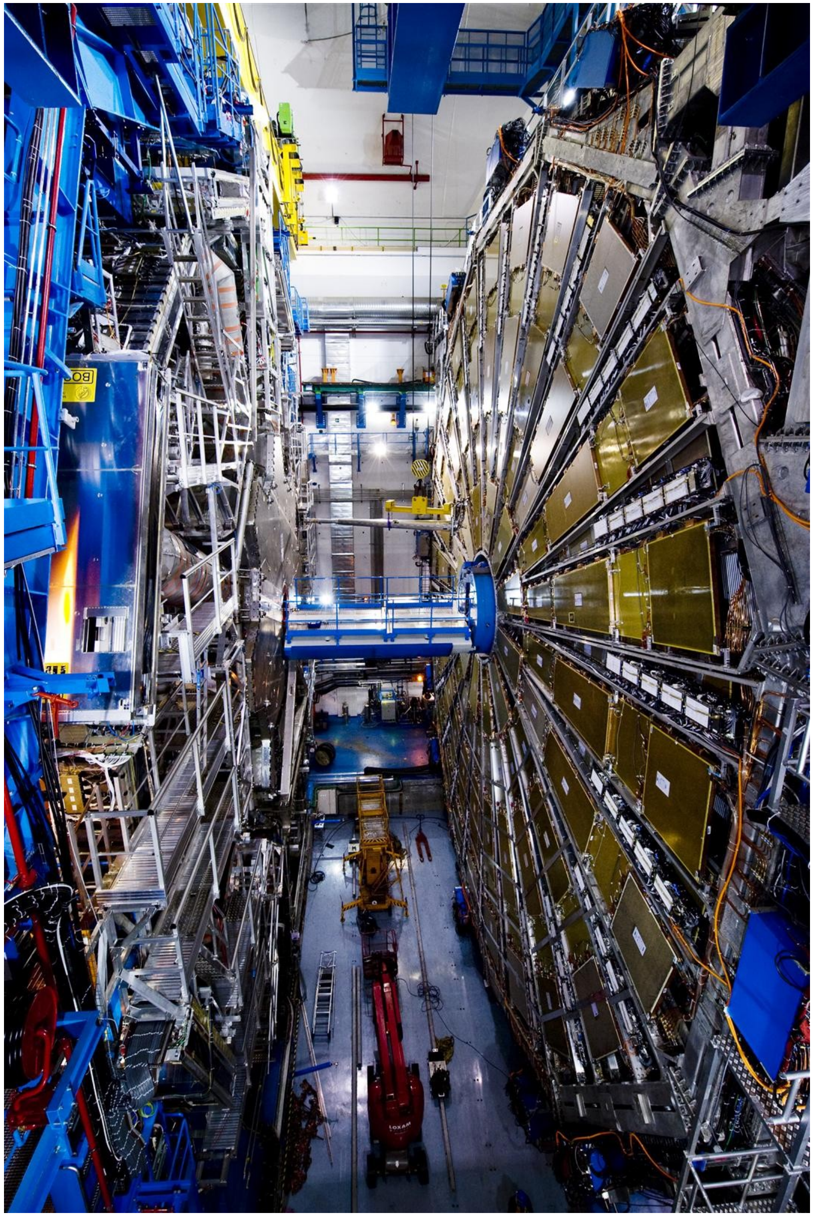
On behalf of the ATLAS Collaboration

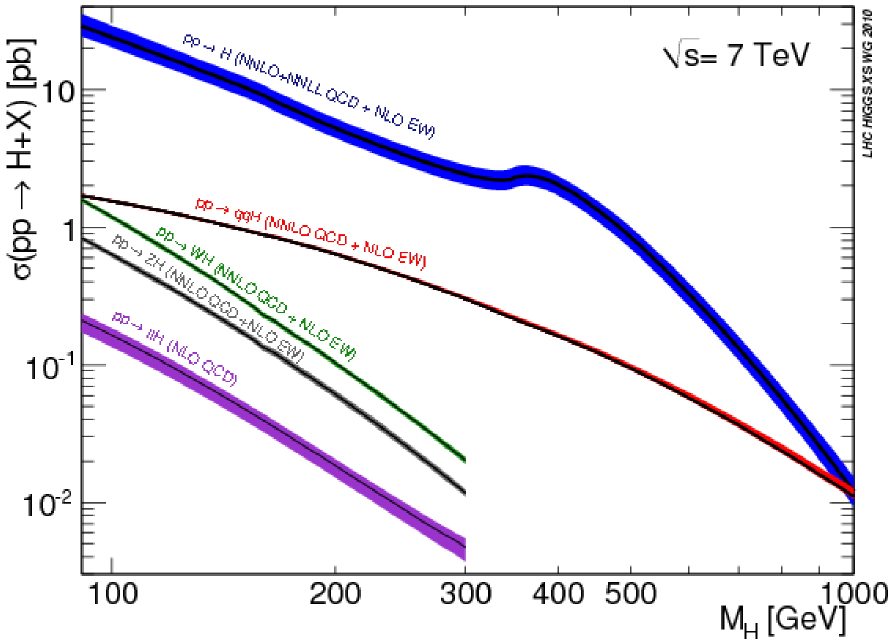
Outline

- Introduction
- SM Higgs at the LHC
- The ATLAS Detector
- Higgs Decay Channels discussed here
    - $H \rightarrow bb$
    - $H \rightarrow \tau\tau$
    - $H \rightarrow \gamma\gamma$
    - $H \rightarrow WW$
    - $H \rightarrow ZZ$
- Conclusion and outlook

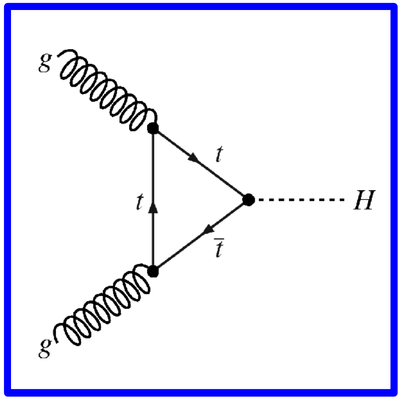


Higgs Production at the LHC

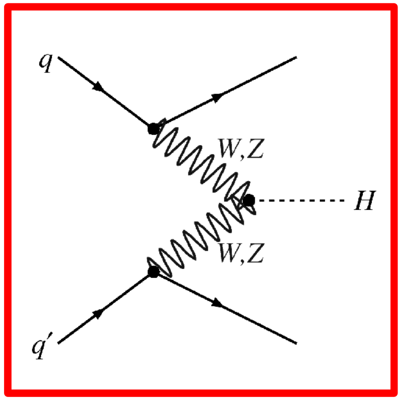
- gg-Fusion dominating at LHC
  - VBF, VH, ttH easier to trigger
- Reach up to masses of 1TeV
  - Here concentrating on low values
- Slopes slightly different at $\sqrt{s}$=8TeV
  - General picture remains unchanged



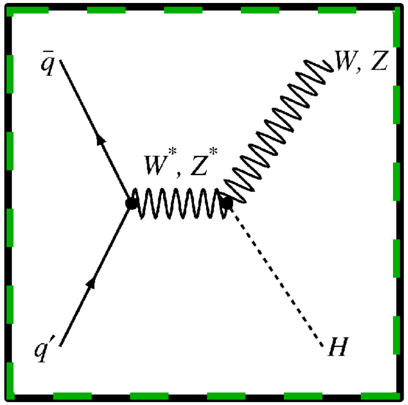
gg-Fusion



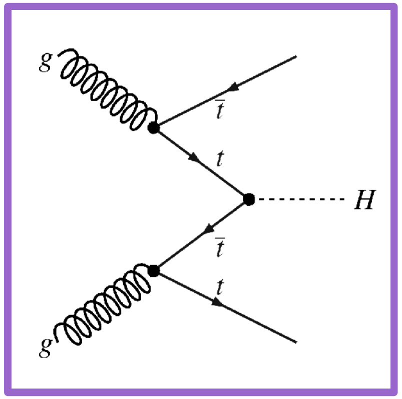
VBF



VH

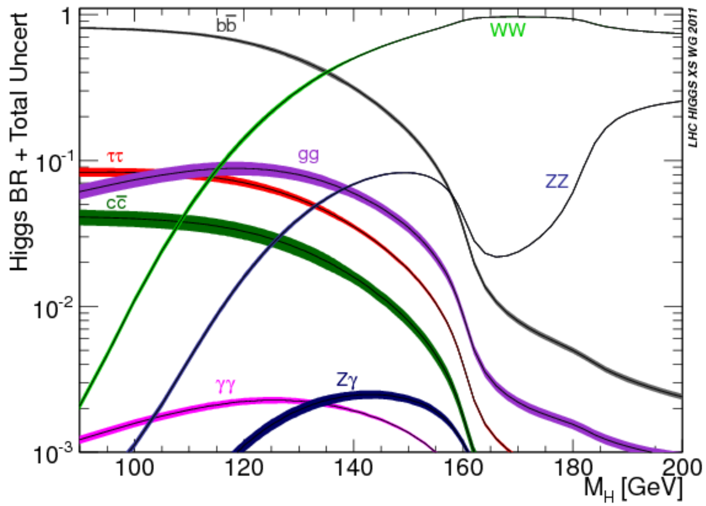


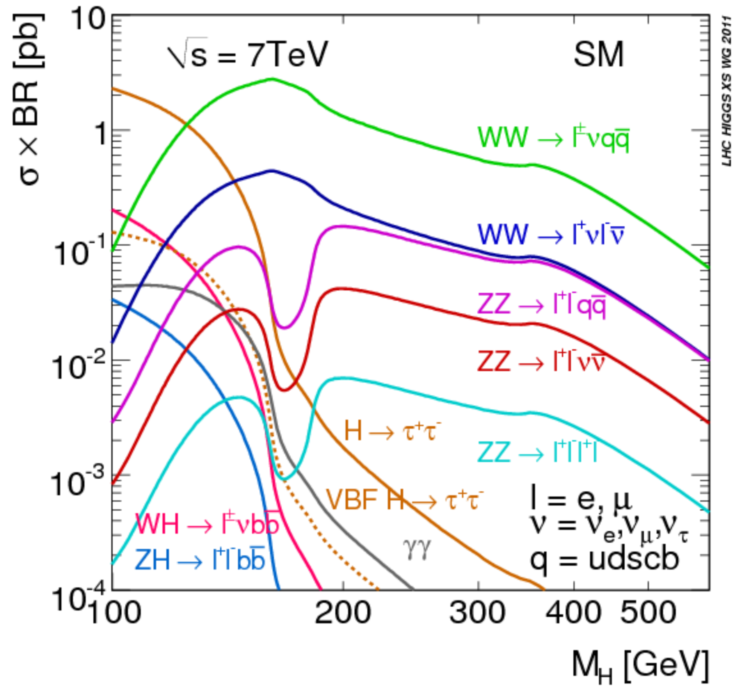
$t\bar{t}H$



Higgs Decay Modes

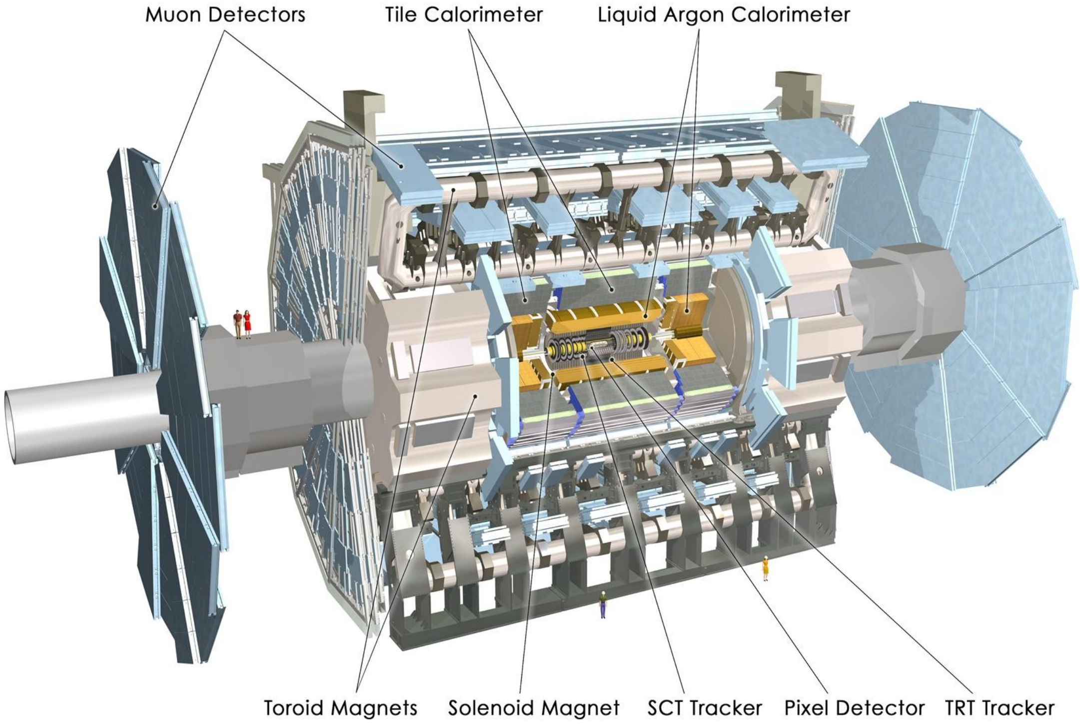
- Several decay modes accessible
  - Importance depends on m_H
- At low Higgs masses
  - $H \rightarrow b\bar{b}$ dominating
- At higher masses
  - WW and ZZ have higher BR
- To find experimental importance
  - Combine crosssection and BR
  - Take final states into account
  - Analyse background processes





The ATLAS Detector

- General Info
  - Length ~46m
  - Diameter ~25m
  - Weight ~7000t
  - Under ground ~92m



ATLAS Collaboration JINST 3 (2008) S08003

- Magnets
  - Solenoid: 2T
  - Toroid (barrel): 0.5T
  - Toroid (endcap): 1T
- Tracker
  - $\sigma(p_T)/p_T \approx 0.05\%\ p_T \oplus 1\%$
- ECAL
  - $\sigma(E)/E \approx 10\% / \sqrt{E} \oplus 0.7\%$
- HCAL
  - $\sigma(E)/E \approx 50\% / \sqrt{E} \oplus 3\%$
- Muon Spectrometer
  - $\sigma(p_T)/p_T \approx$ 2% @ 50GeV
  - $\sigma(p_T)/p_T \approx$ 10% @ 1TeV
- Trigger
  - 3 Levels: 40MHz → 200Hz

Higgs Searches in ATLAS

- Many analyses
  - Too much to present today
- All results online
  - Some examples presented now

Summary of latest results in all channels

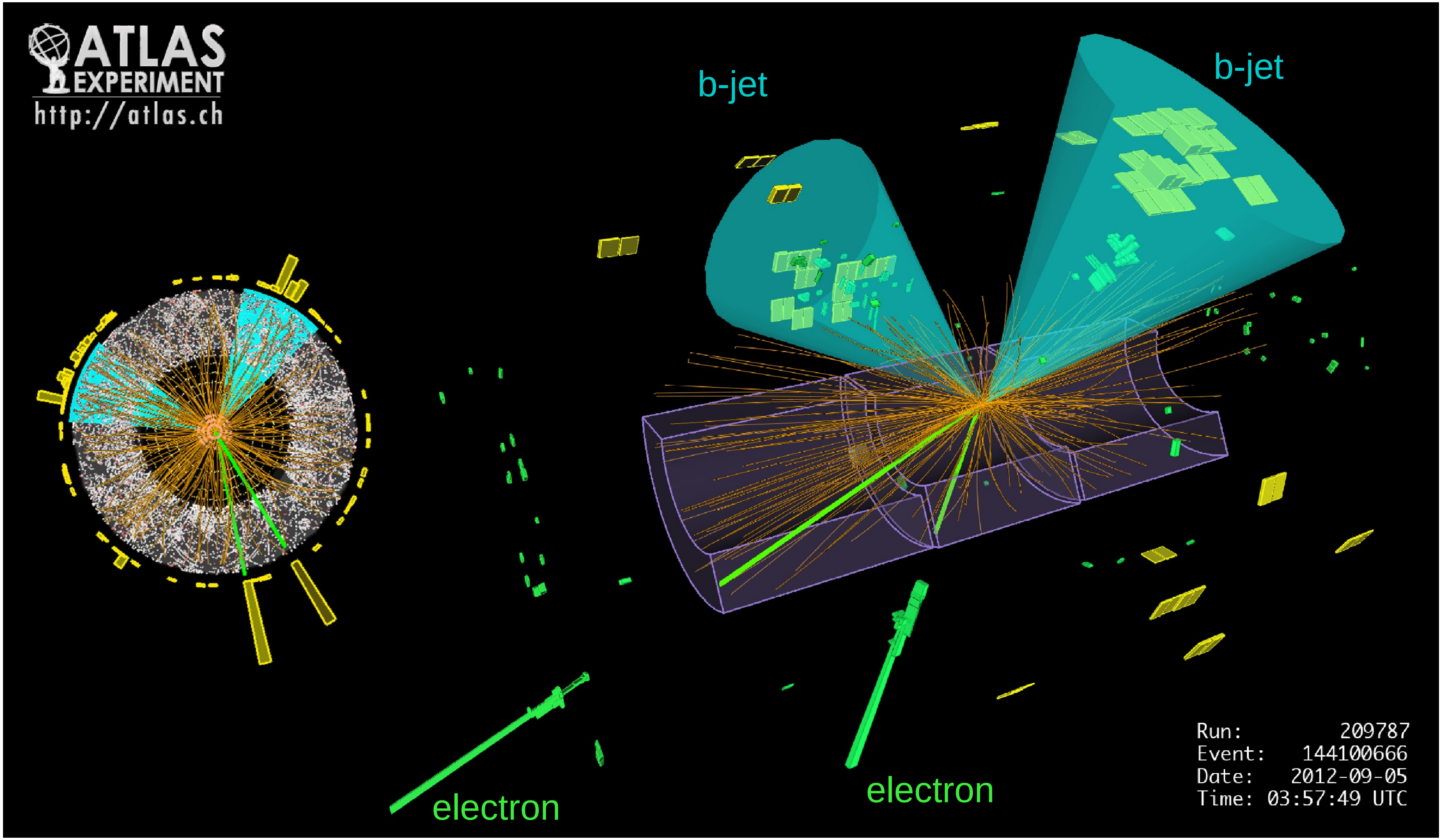
Channel		Conference note	L (fb^{-1})	Date		Publication	L (fb^{-1})	Date
SM H combination		ATLAS-CONF-2012-170	4.9+13.0	Dec 2012		arXiv:1207.7214	4.9+5.9	Jul 2012
SM H to ZZ(*) to 4l		ATLAS-CONF-2012-169	4.8+13.0	Dec 2012		arXiv:1202.1415	4.8	Feb 2012
SM H to diphoton		ATLAS-CONF-2012-168	4.9+13.0	Dec 2012		arXiv:1202.1414	4.9	Feb 2012
LFV Charged Higgs		-	4.7	Dec 2012		Paper	4.6	Feb 2012
SM H couplings		ATLAS-CONF-2012-127	4.9+5.9	Sep 2012		-	-	-
SM H combination		ATLAS-CONF-2012-162	4.9+13.0	Nov 2012		arXiv:1207.7214	4.9+5.9	Jul 2012
SM H to diphoton		ATLAS-CONF-2012-091	4.9+5.9	Jul 2012		arXiv:1202.1414	4.9	Feb 2012
SM H to ZZ(*) to 4l		ATLAS-CONF-2012-092	4.8+5.8	Jul 2012		arXiv:1202.1415	4.8	Feb 2012
SM H to WW to lvlv SM H to WW to lvlv (MVA)		ATLAS-CONF-2012-158 ATLAS-CONF-2012-060	4.7+13.0 4.7	Nov 2012 Jun 2012		arXiv:1206.0756	4.7	Jun 2012
SM WH, H to WW		ATLAS-CONF-2012-078	4.7	Jul 2012		-	-	-
SM H to tautau		ATLAS-CONF-2012-160	4.7+13.0	Nov 2012		arXiv:1206.5971	4.7	Jun 2012
SM VH, H to bb		ATLAS-CONF-2012-161	4.7+13.0	Nov 2012		arXiv:1207.0210	4.7	Jun 2012
SM ttH, H to bb		ATLAS-CONF-2012-135	4.7	Sep 2012		-	-	-
SM H to ZZ to llvv		ATLAS-CONF-2012-016	4.7	Mar 2012		arXiv:1205.6744	4.7	May 2012
SM H to ZZ to llqq		ATLAS-CONF-2012-017	4.7	Mar 2012		arXiv:1206.2443	4.7	Jun 2012
SM H to ZZ to llqq Low Mas		ATLAS-CONF-2012-163	4.7	Nov 2012		-	-	-
SM H to WW to lvqq		ATLAS-CONF-2012-018	4.7	Mar 2012		arXiv:1206.6074	4.7	Jun 2012
Higgs in SM with 4th fermion generation		ATLAS-CONF-2011-135	1.0-2.3	Aug 2011		-	-	-
Fermiophobic H to diphoton		ATLAS-CONF-2012-013	4.9	Mar 2012		arXiv:1205.0701	4.9	May 2012
MSSM neutral H		ATLAS-CONF-2012-094	4.7	Jul 2012		arXiv:1107.5003	0.036	Jul 2011
MSSM H+ to taunu		ATLAS-CONF-2012-011	4.7	Mar 2012		arXiv:1204.2760	4.6	Apr 2012
MSSM H+ to csbar		ATLAS-CONF-2011-094	0.035	Jul 2011		-	-	-
NMSSM a1 to mumu		ATLAS-CONF-2011-020	0.037	Mar 2011		-	-	-
NMSSM H to a0a0 to 4photons		ATLAS-CONF-2012-079	4.9	Jul 2012		-	-	-

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults

$H \to bb$

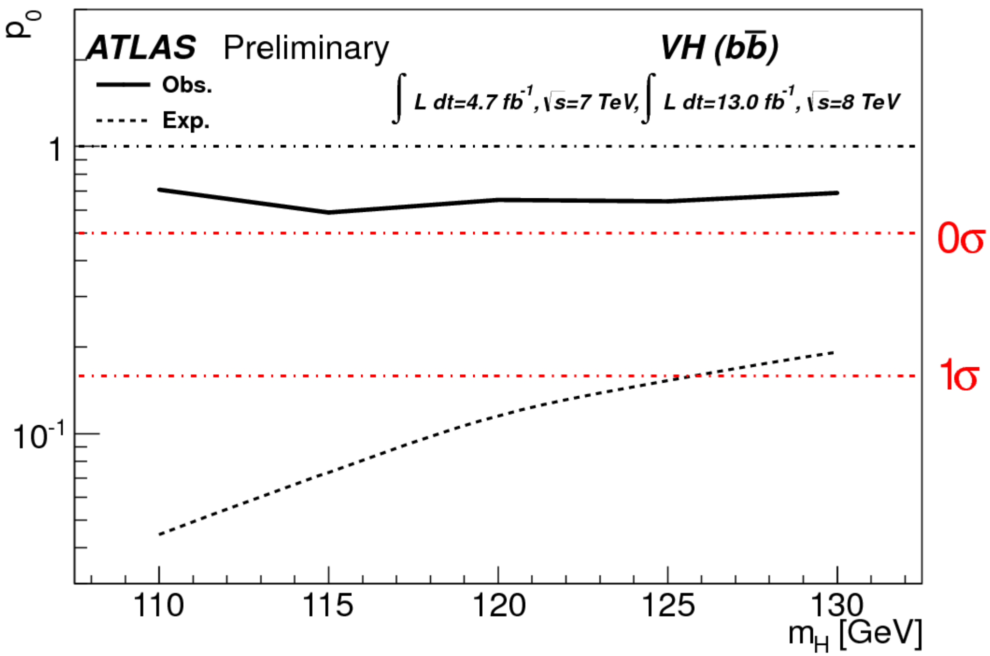
- Highest branching ratio at low masses m_H
- Associated production ttH and VH
  - Lower cross section than ggF, but easier to reject backgrounds
- Very challenging jet backgrounds
  - Several orders of magnitude bigger
  - Biggest contributions from top, W+jets and Z+jets
- Event selection (Focusing on VH analysis)
  - Three categories based on number of leptons
    - 0 leptons: $ZH \to \nu\nu bb$
    - 1 lepton: $WH \to l\nu bb$
    - 2 leptons: $ZH \to llbb$
  - No additional leptons
  - Some missing energy in case of ν in final state
  - Two b-tags: 70% efficiency per tag (mistag ~1%)
- Categories further split
  - Depending on vector boson momentum and number of jets
- Data presented here
  - 2011 $\sqrt{s}=7TeV$ $\int Ldt = 4.7fb^{-1}$
  - 2012 $\sqrt{s}=8TeV$ $\int Ldt = 13fb^{-1}$

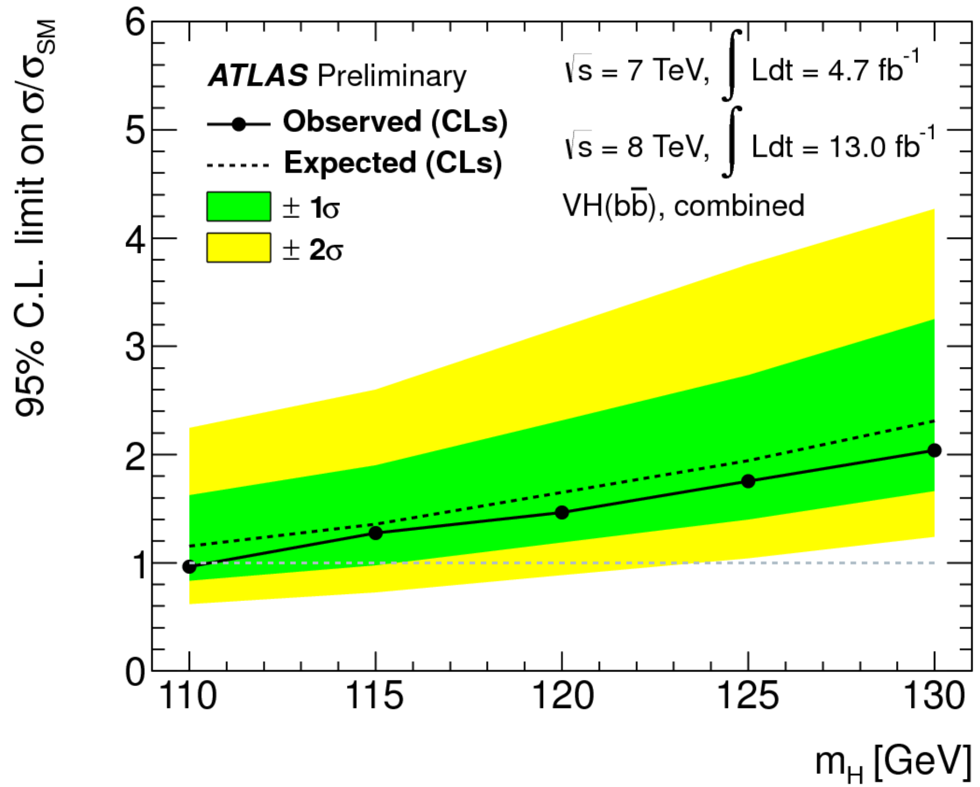
ZH → eebb



Currently ~50 signal candidates for VH(bb)

H → bb

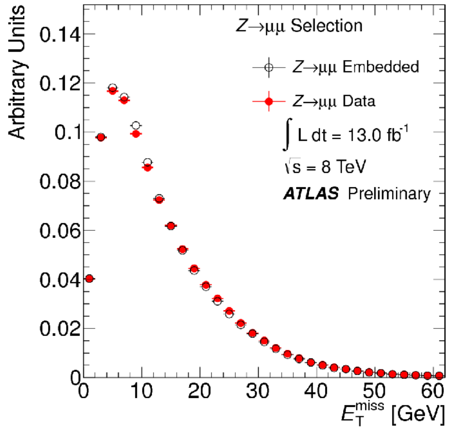




- Consistency of observed data with background-only hypothesis
  - local $p_0(m_H$=125GeV) = 0.64 (corresponding to 1σ)
- Exclusion limits
  - SM Higgs excluded at 95%CL for m_H=110 GeV

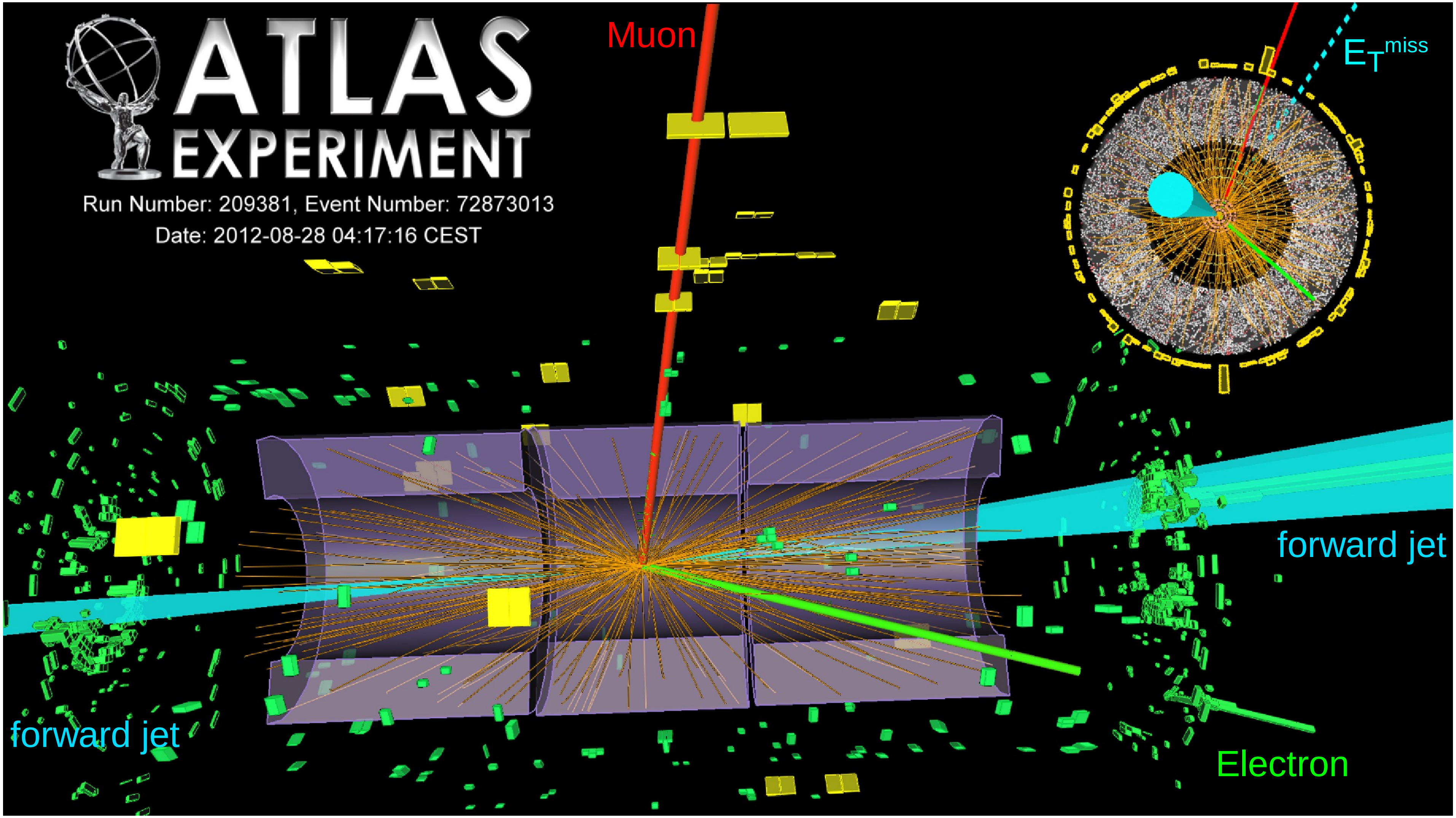
H → ττ

- Three decay modes exclusively defined by number of leptons
  - $H \rightarrow \tau_\ell \tau_\ell$ (~12%)
  - $H \rightarrow \tau_\ell \tau_h$ (~46%)
  - $H \rightarrow \tau_h \tau_h$ (~42%)
- Many exclusively defined categories
  - Based on jet multiplicity, kinematics and H production mode
- Signature
  - τ-pair from resonance
  - Missing E_T
    - Poor mass resolution
- Background understanding crutial
  - The most important irreducible Background is $Z \rightarrow \tau\tau$
  - Modelled using real $Z \rightarrow \mu\mu$ events and replacing μ by simulated τ



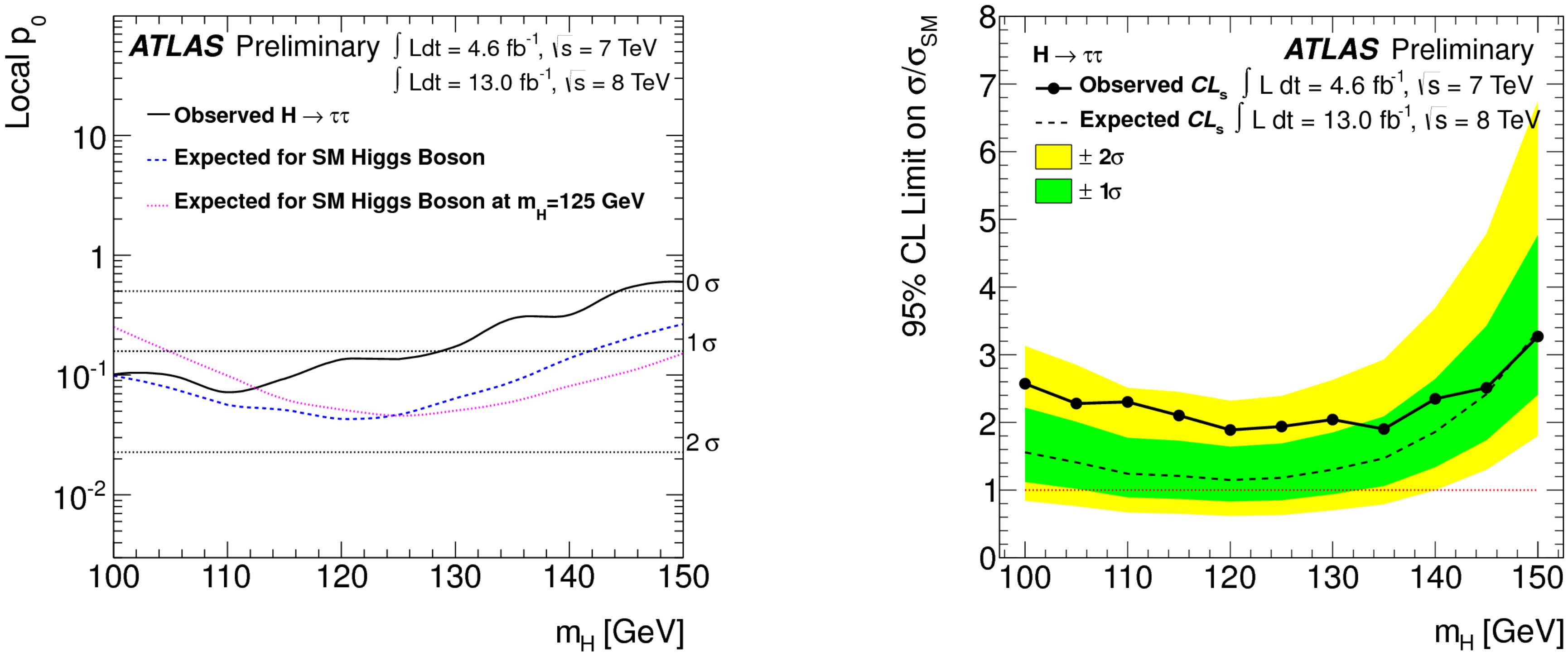
- Data presented here
  - 2011 $\sqrt{s}$=7TeV $\int Ldt = 4.6 fb^{-1}$
  - 2012 $\sqrt{s}$=8TeV $\int Ldt = 13 fb^{-1}$

VBF H → $\tau_e\tau_\mu$



Currently ~330 signal candidates for H → ττ

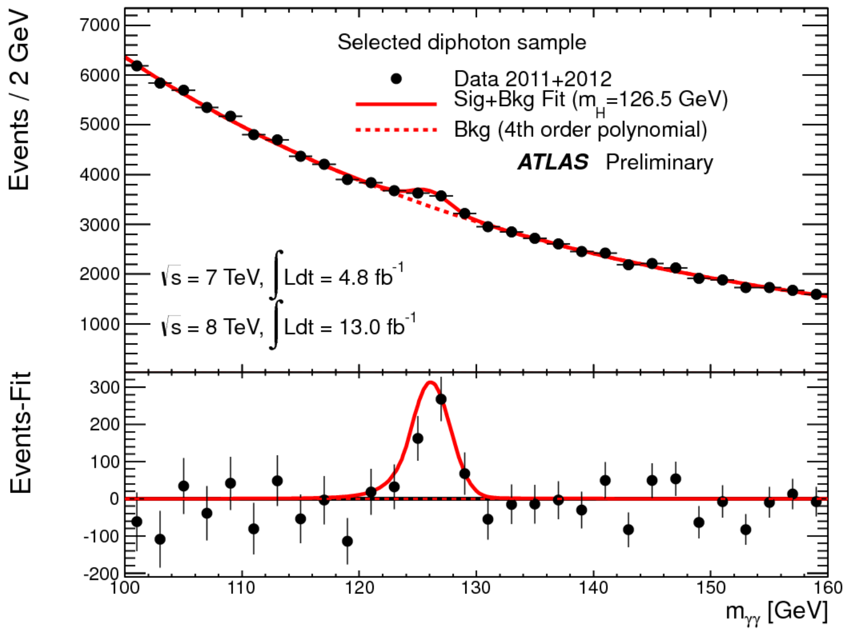
H → ττ



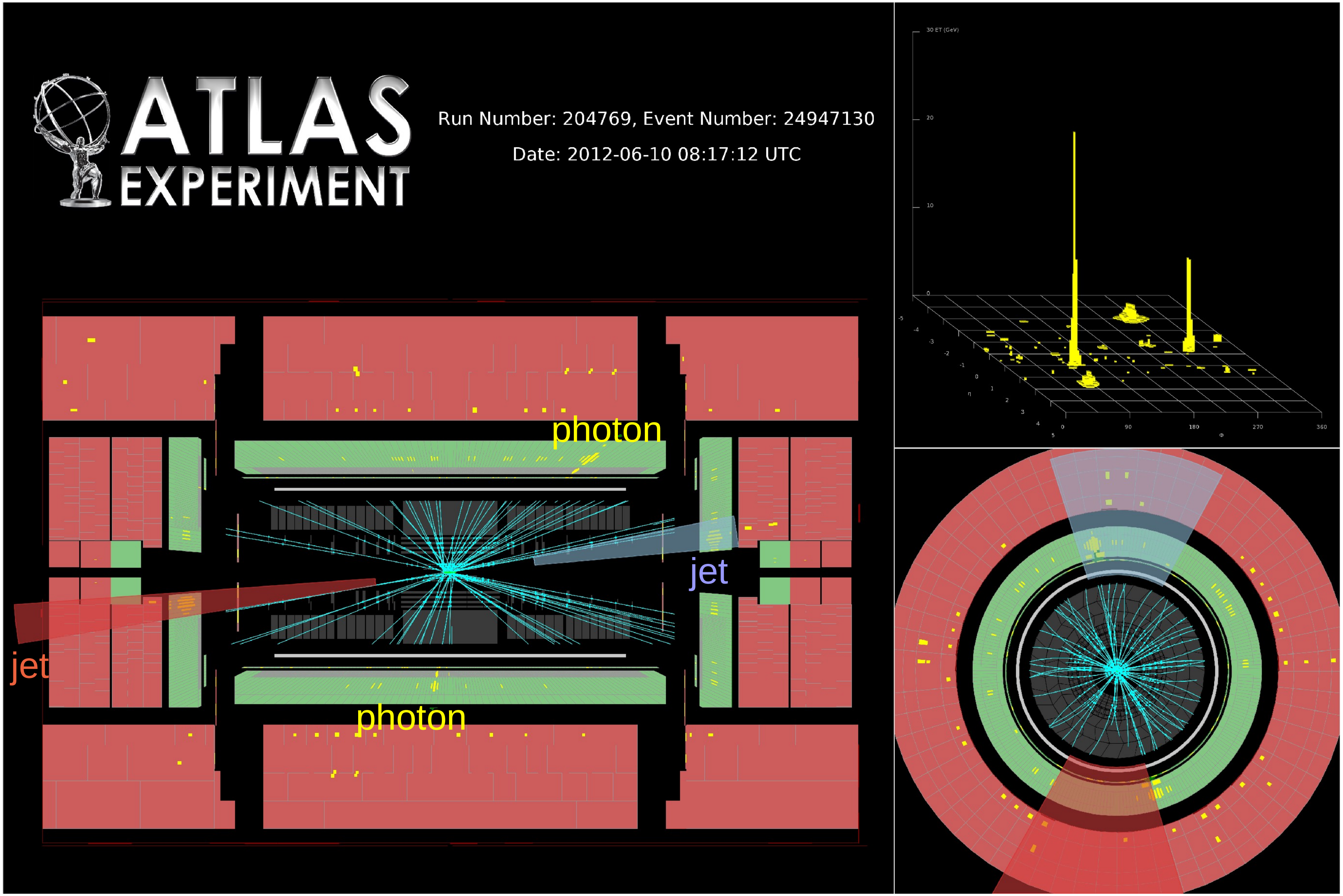
- Consistency of observed data with background-only hypothesis
  - local $p_0(m_H=125\text{GeV})$ = 13.5% (corresponding to 1.1σ)
- Exclusion limits
  - No range of SM Higgs masses excluded at 95%CL

$H \rightarrow \gamma\gamma$

- Very small branching ratio (~0.2%)
  - But clean signature
- Full reconstruction of H decay
  - Good mass resolution ~1.5% at best
- Signature
  - Two energetic isolated photons
  - Peak in diphoton mass spectrum
- Large background, but smoothly varying
  - Determined from sidebands
  - Composition measured in data
- Good mass resolution requires
  - Good photon energy calibration
  - Good photon direction
  - Good understanding of γ-conversion
- Increased sensitivity by dividing events into categories
  - Based on signal-to-background ratio and mass resolution
- Data presented here
  - 2011 $\sqrt{s}$=7TeV $\int Ldt = 4.8fb^{-1}$
  - 2012 $\sqrt{s}$=8TeV $\int Ldt = 13fb^{-1}$

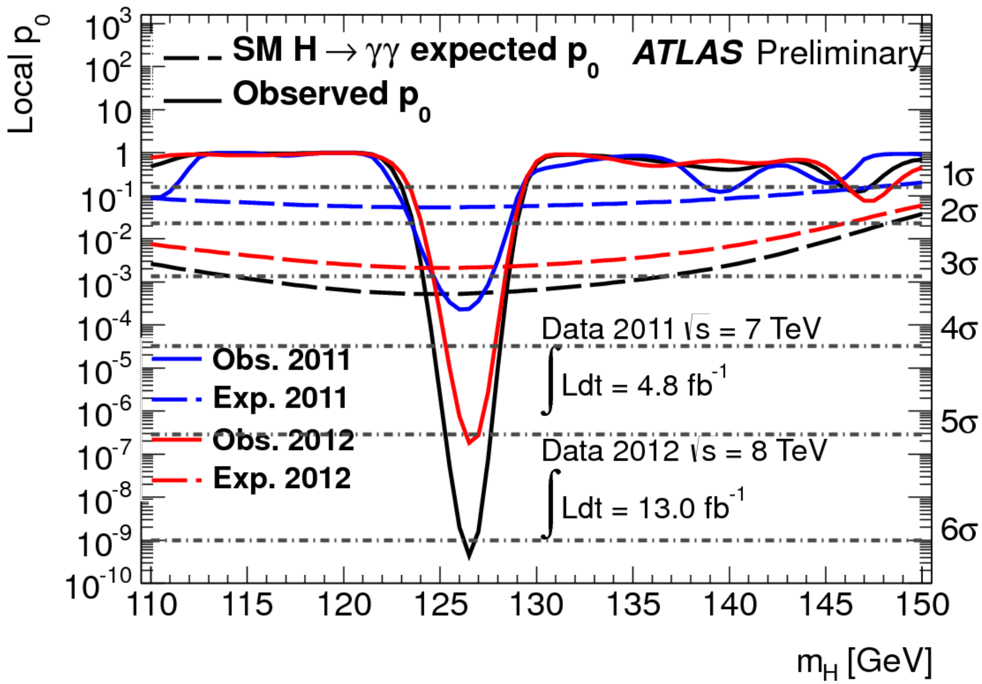


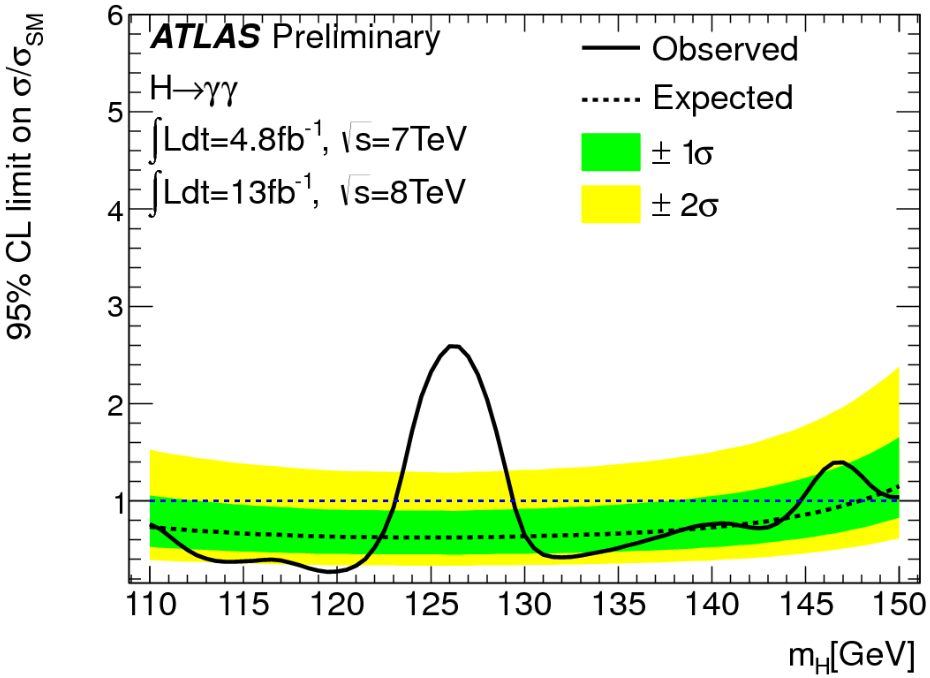
H → γγ



Currently ~330 signal candidates for H → γγ

H → γγ

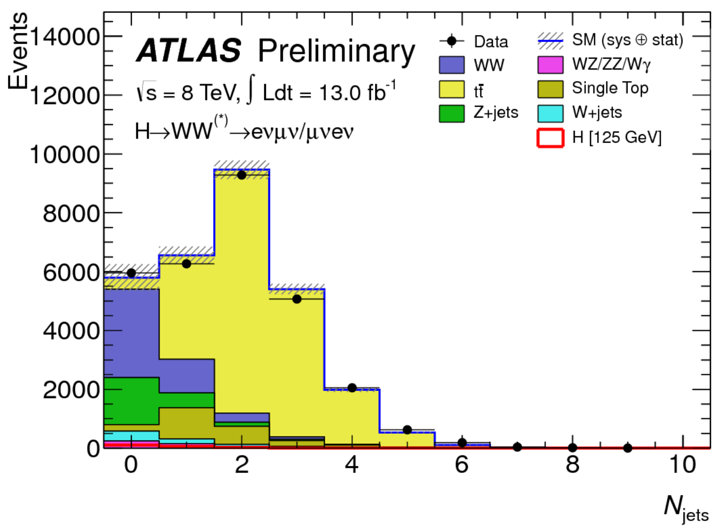




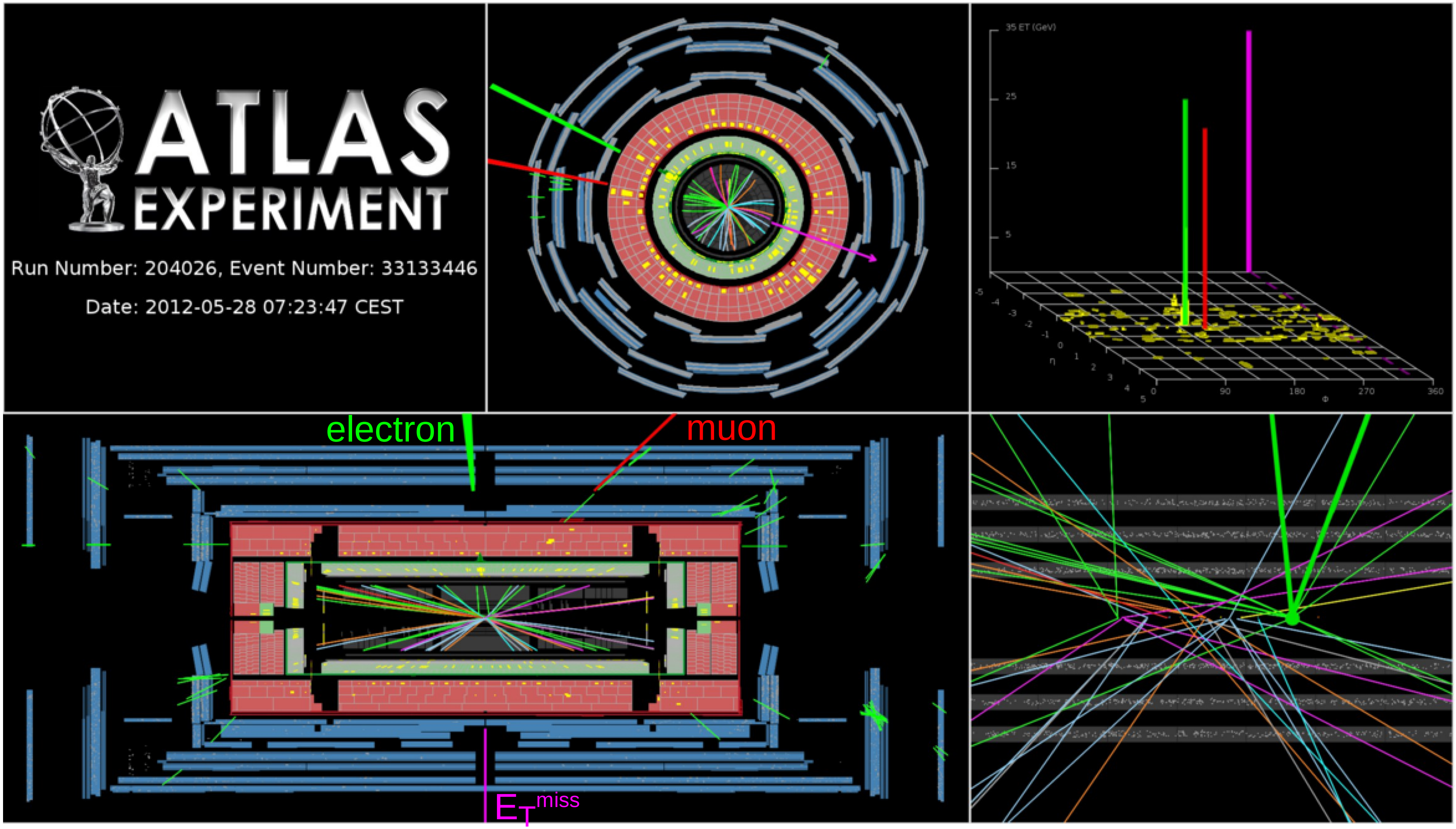
- Consistency of observed data with background-only hypothesis
  - Excess observed around m_H=126.5 GeV
  - local $p_0 = 4.4 \times 10^{-10}$ (corresponding to 6.1σ) **single channel discovery!**
  - global $p_0 = 2.8 \times 10^{-8}$ (corresponding to 5.4σ)
- Exclusion limits
  - SM Higgs excluded at 95%CL in ranges 110-122.5 GeV and 129.5-144.5 GeV

$H \to WW^* \to \ell\nu\ell\nu$

- Large branching ratio which peaks around $2M_W < m_H < 2M_Z$
  - Provides information about production rate and H coupling to W
  - Dominated by gg-Fusion production mode
    - To enhance different production modes use jet multiplicity
- Contains 2 neutrinos
  - Poor mass resolution
  - Look for excess above background
- Signal
  - 2 isolated high p_T leptons with opposite charge + missing ET
  - Use different flavour leptons to reduce background
- Correlated W spins
  - Leptons go preferentially in same direction
- Background depends on jet multiplicity
  - Reducible: tt, diboson, W+jets, Drell-Yan
  - Irreducible: WW
- Data presented here
  - 2012 $\sqrt{s}$=8TeV $\int$Ldt = 13fb^{-1}

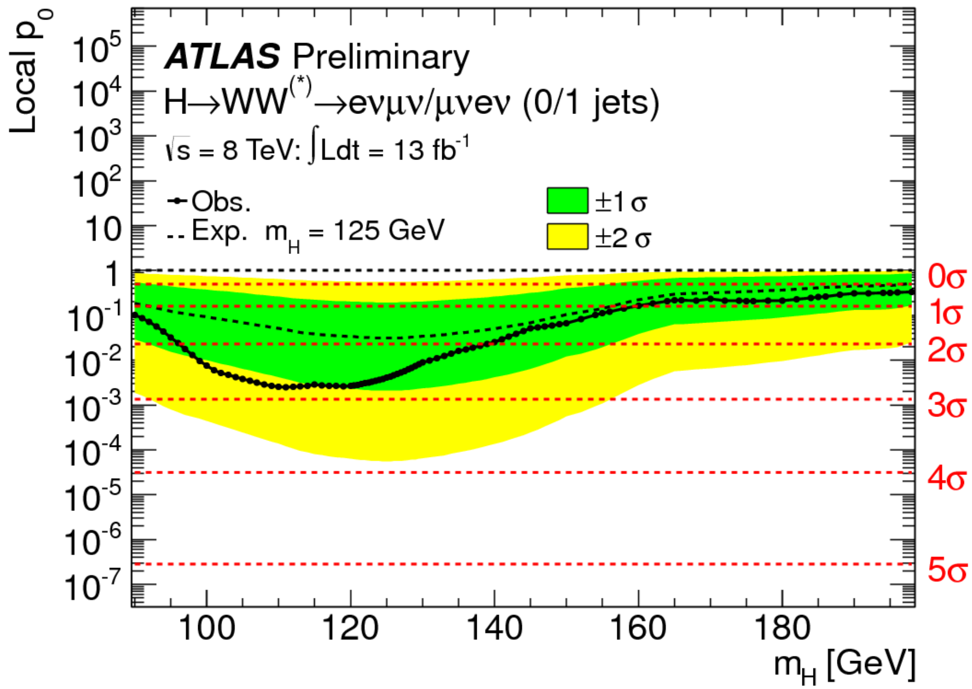


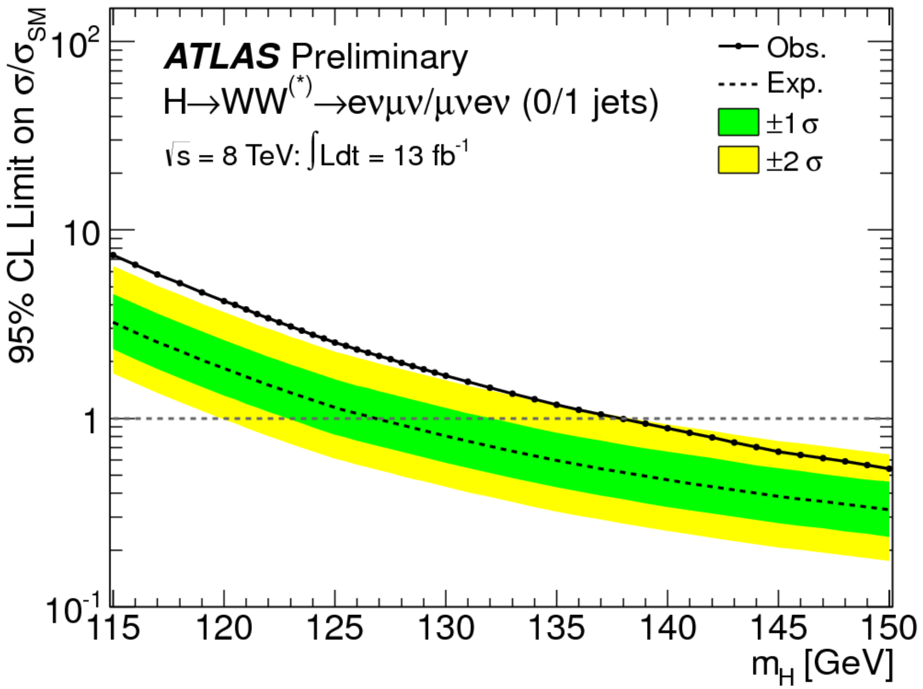
$H \rightarrow WW^* \rightarrow e\nu\mu\nu$



Currently ~110 signal candidates for ggH(WW)

H → WW* → ℓνℓν

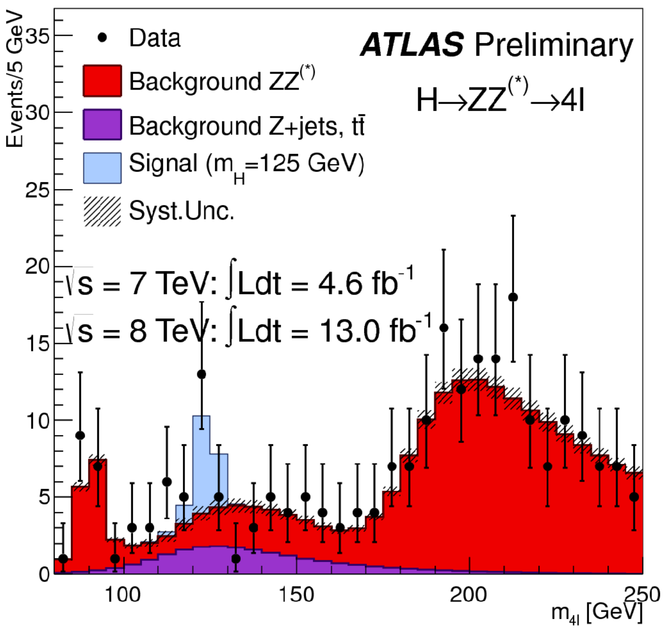




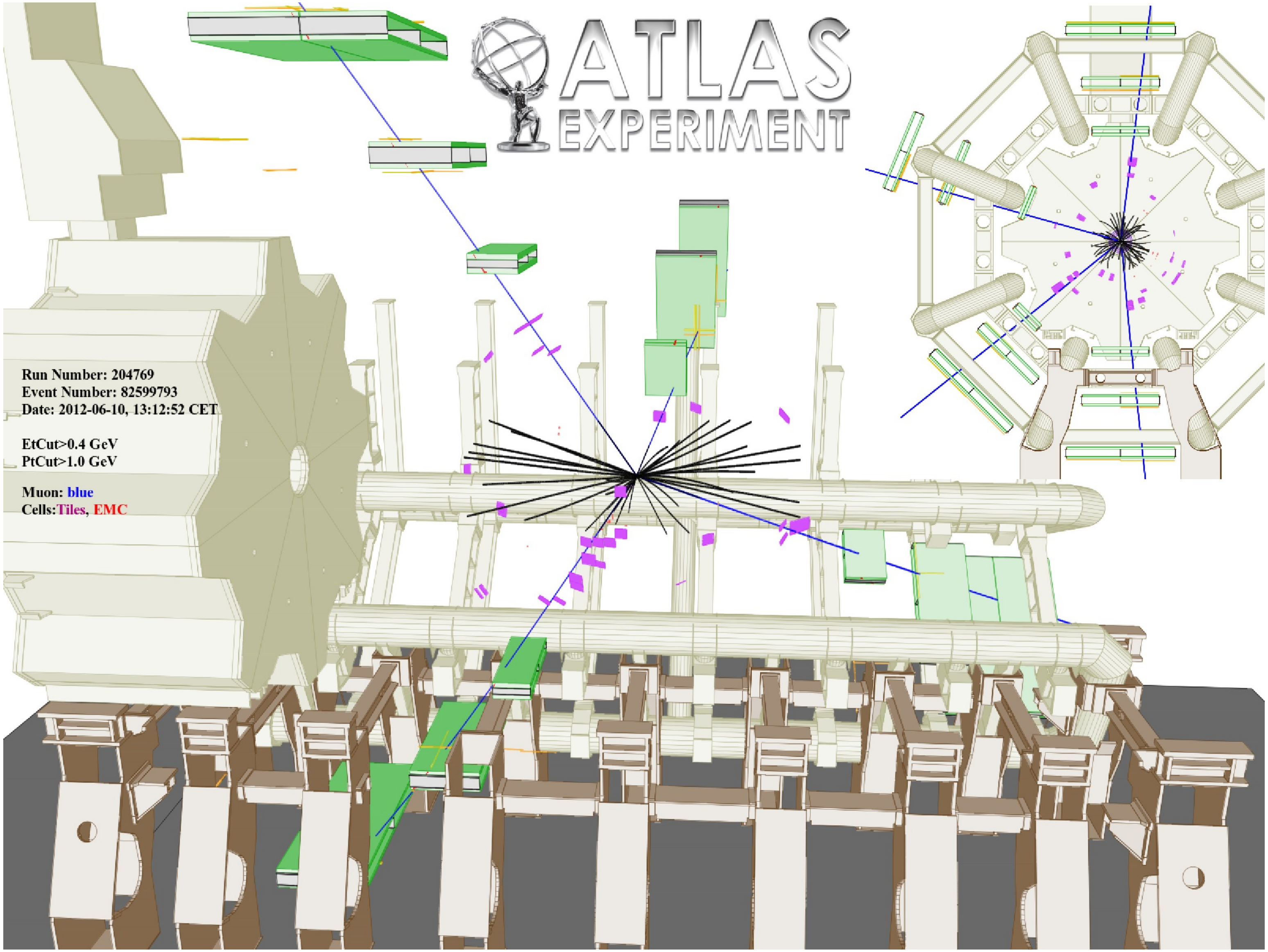
- Consistency of observed data with background-only hypothesis
  - local $p_0(m_H=125\text{GeV}) = 4 \times 10^{-3}$ (corresponding to 2.6σ)
- Exclusion limits
  - SM Higgs excluded at 95%CL in ranges 139-200 GeV

H → ZZ* → ℓℓℓℓ

- „Golden Channel"
  - Small branching ratio, but high S/B
  - Full reconstruction… good mass resolution
    - $\sigma/m \approx$ 1-2% at low masses
- Clean signature
  - Two $\ell^+\ell^-$ pairs forming Z (one maybe off-shell)
  - Energetic, isolated leptons
  - Leptons from primary vertex
- Background
  - Reducible: Z+jets, Zbb, tt
  - Irreducible: ZZ
- Requirements
  - Good single lepton reconstruction and trigger efficiency: $\varepsilon_{4\ell} \sim \varepsilon_\ell^4$
  - Well understood Lepton energy resolution
- Data presented here
  - 2011 $\sqrt{s}$=7TeV $\int Ldt$ = 4.8fb^{-1}
  - 2012 $\sqrt{s}$=8TeV $\int Ldt$ = 13fb^{-1}



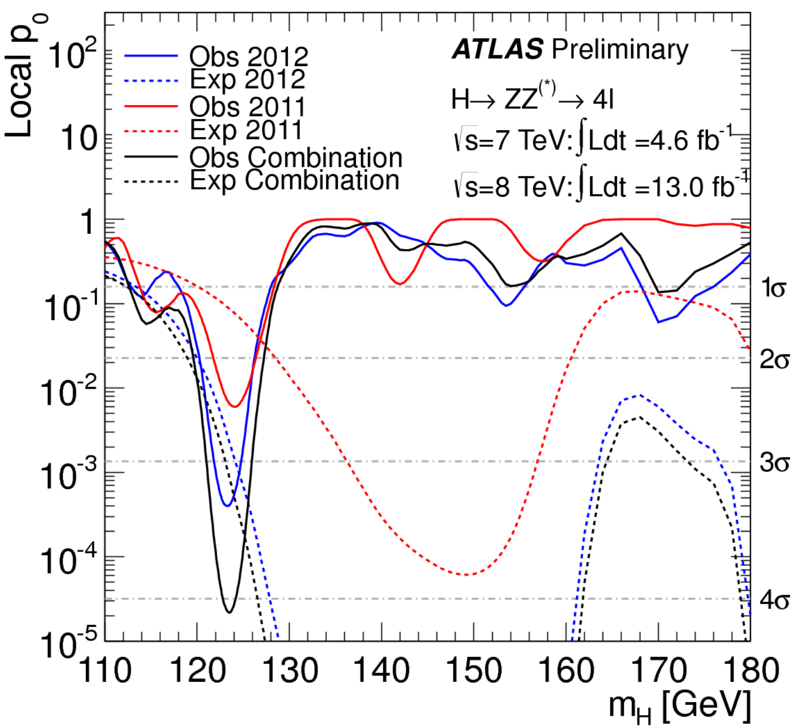
H → 4μ

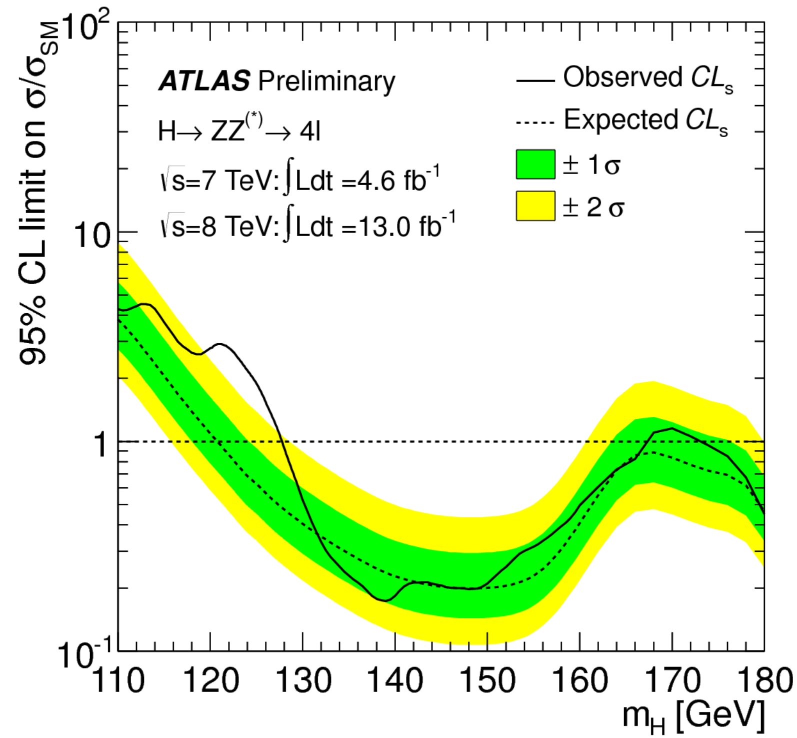


Currently ~10 signal candidates for H→4ℓ

$H \rightarrow ZZ^* \rightarrow \ell\ell\ell\ell$

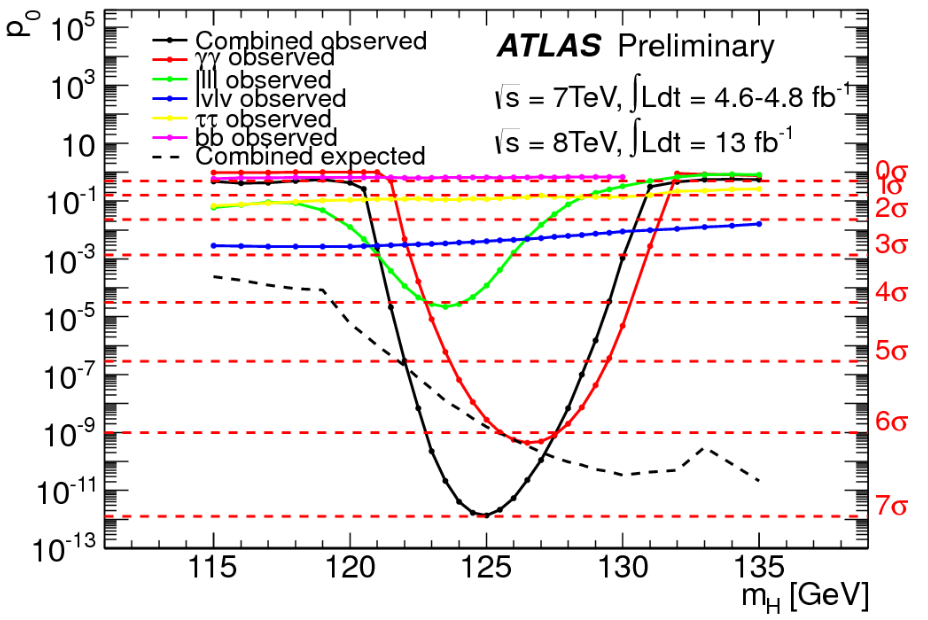
- Consistency of observed data with background-only hypothesis
  - Excess observed around m_H=123.5 GeV
  - local $p_0 = 2.1 \times 10^{-5}$ (corresponding to 4.1σ)
- Exclusion limits
  - SM Higgs excluded at 95%CL in ranges 128-168 GeV and 174-580 GeV

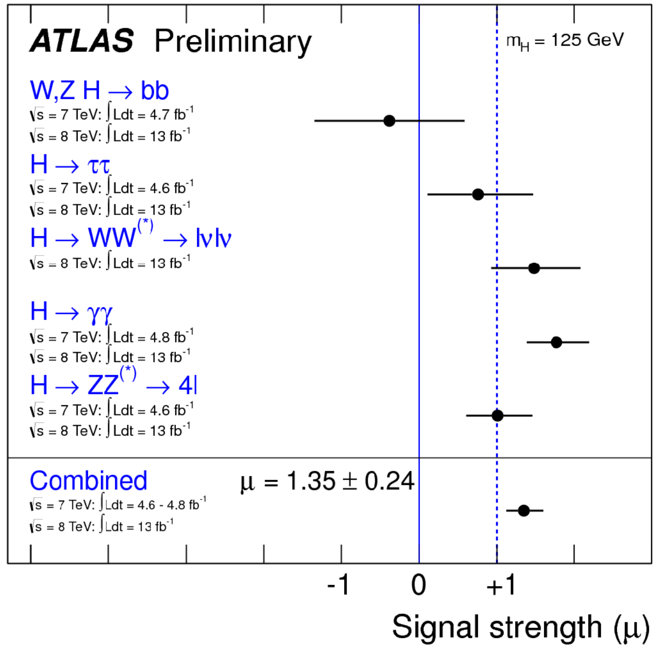




Combination

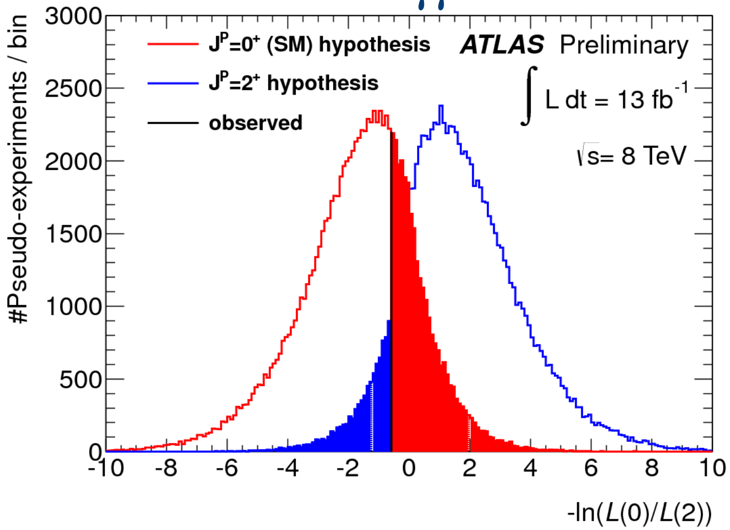
- Consistency of observed data with background-only hypothesis
  - Excess observed at m_H=125.2 ±0.3(stat) ±0.6(sys) GeV
  - local $p_0 = 10^{-12}$ (corresponding to 7.0σ)
- Signal strength
  - $\hat{\mu}(m_H=125)$ = 1.35±0.19 (stat)±0.15(sys)



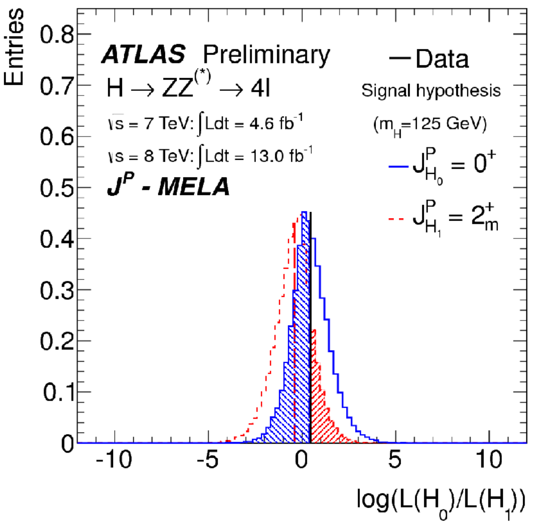


Analysis of Spin and Parity

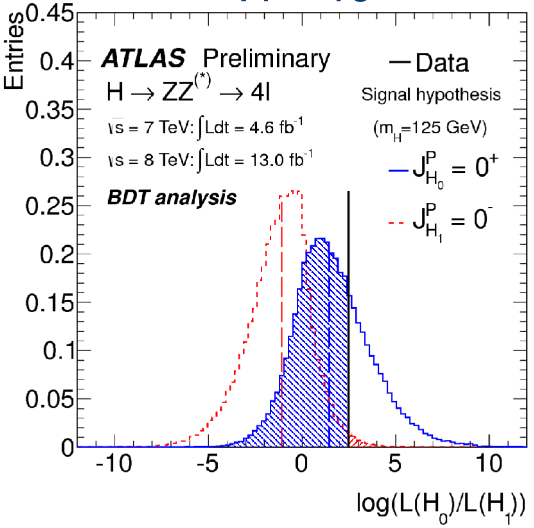
$H \rightarrow \gamma\gamma$



$H \rightarrow 4\ell$



$H \rightarrow 4\ell$



- Spin 2^+ hypothesis
  - Excluded at 91% CL in $H \rightarrow \gamma\gamma$
  - Excluded at 85% CL in $H \rightarrow 4\ell$
- Spin 0^- hypothesis
  - Excluded at 99% CL in $H \rightarrow 4\ell$
- Spin 0 hypothesis
  - Observation fully compatible

Conclusions & Outlook

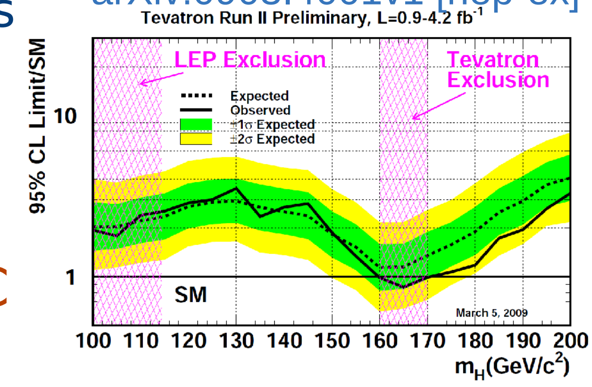
- The ATLAS detector has now collected following pp-data
  - 2011: at $\sqrt{s}$=7TeV $\int L dt$ = 4.8fb^{-1}
  - 2012: at $\sqrt{s}$=8TeV $\int L dt$ = 21.7fb^{-1}
- Results presented here
  - Used all 2011 data and 13fb^{-1} of the 2012 data
- Updated results confirm earlier observations based on lower statistics
  - Excess observed at m_H=125.2 ±0.3(stat) ±0.6(sys) GeV
  - local $p_0 = 10^{-12}$ (corresponding to 7.0σ)
- Further updates using the full 2011+2012 datasets expected soon
  - Observation of „Higgs-like“ particle done
  - Measurements of the couplings become more interesting
- Beginning of 2013 the LHC will continue with heavy ion collisions
  - Afterwards a long shutdown of about two years
  - Accelerator and experiments will prepare for 14 TeV

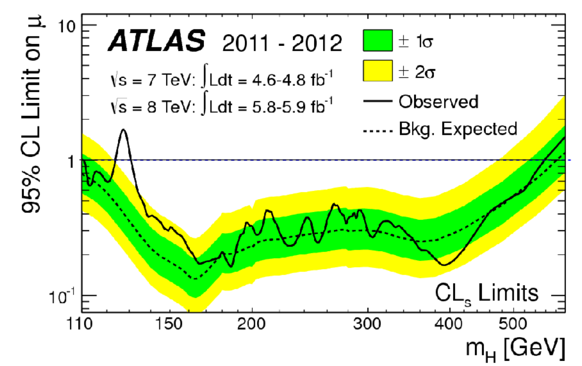
Additional Slides

Introduction

- Higgs is missing keystone in the Standard Model
  - Higgs mechanism predicts boson, but not it's mass
- Results of direct searches before LHC:
  - LEP: excluded (@95%CL) m_H<114GeV
  - Tevatron: excluded(@95%CL) 160<m_H<170GeV
- Higgs discovery is one of the main goals for the LHC
  - Not the only one, but that's a different story...
- Observation of a new particle with a mass of about 125 GeV
  - ATLAS and CMS announced a discovery
  - „Higgs-like particle“… is it the Higgs?
- Change in the analyses
  - Away from purely discovery search
  - Towards measurements of properties
- pp-collision mode stopped at LHC for upgrade
  - All analyses will be updated using the full statistics avilable

arXiv:0903.4001v1 [hep-ex]





The Large Hadron Collider

- (design) CM energy: 14 TeV
- (2012) 8 TeV
- (design) Luminosity: $10^{34} cm^{-2}s^{-1}$
- (2012) $7.7 \times 10^{33} cm^{-2}s^{-1}$
- (design)Bunch crossing: 25 ns
- (2012) 50 ns
- Protons per bunch: $\sim 10^{11}$
- Beam radius: 16.7 μm

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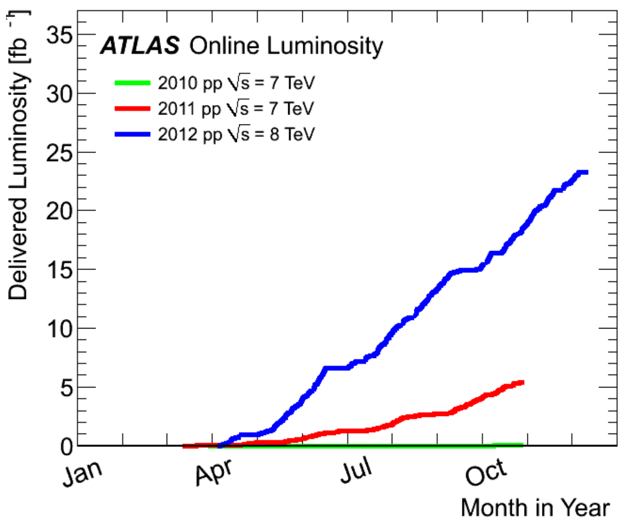
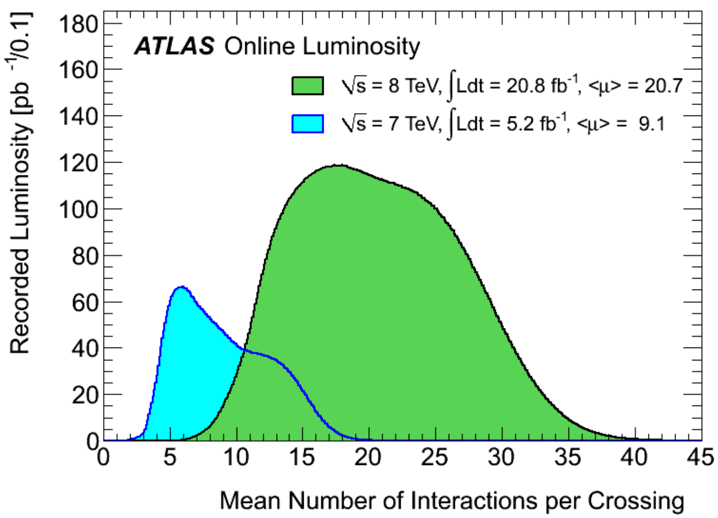
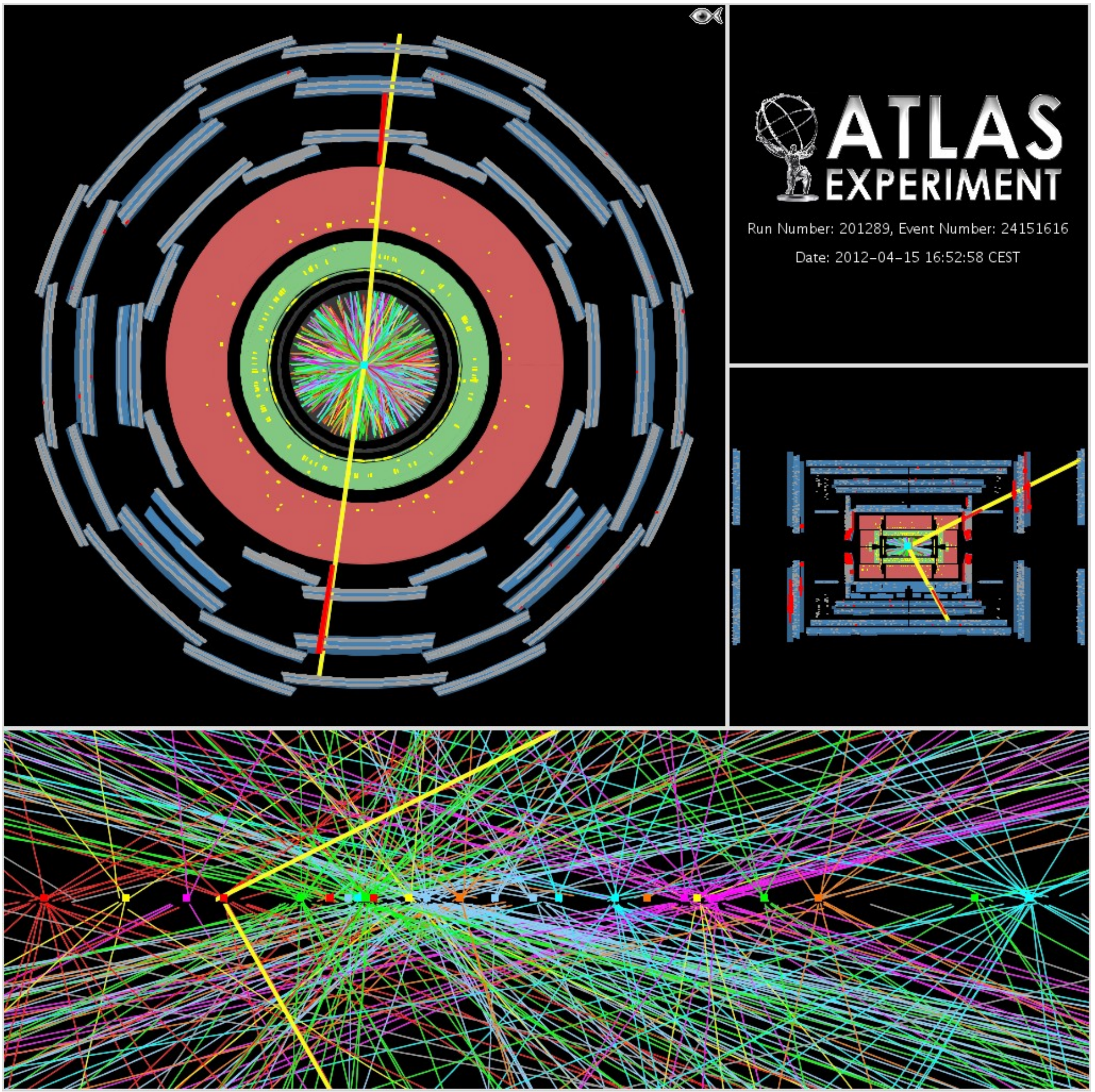
The ATLAS Data

- Results presented here correspond to
  - 2011 data taking
    - Centre-of-mass energy $\sqrt{s}$ = 7TeV
    - Integrated luminosity ~4.8fb^{-1}
    - Pileup $<\mu> \approx 9$
  - 2012 data taking
    - Centre-of-mass energy $\sqrt{s}$ = 8TeV
    - Integrated luminosity up to 13fb^{-1}
    - Pileup $<\mu> \approx 20$
- More to come
  - 2012 data taking
    - Integrated luminosity up tp 21.7fb^{-1}
  - In preparation for Moriond conference



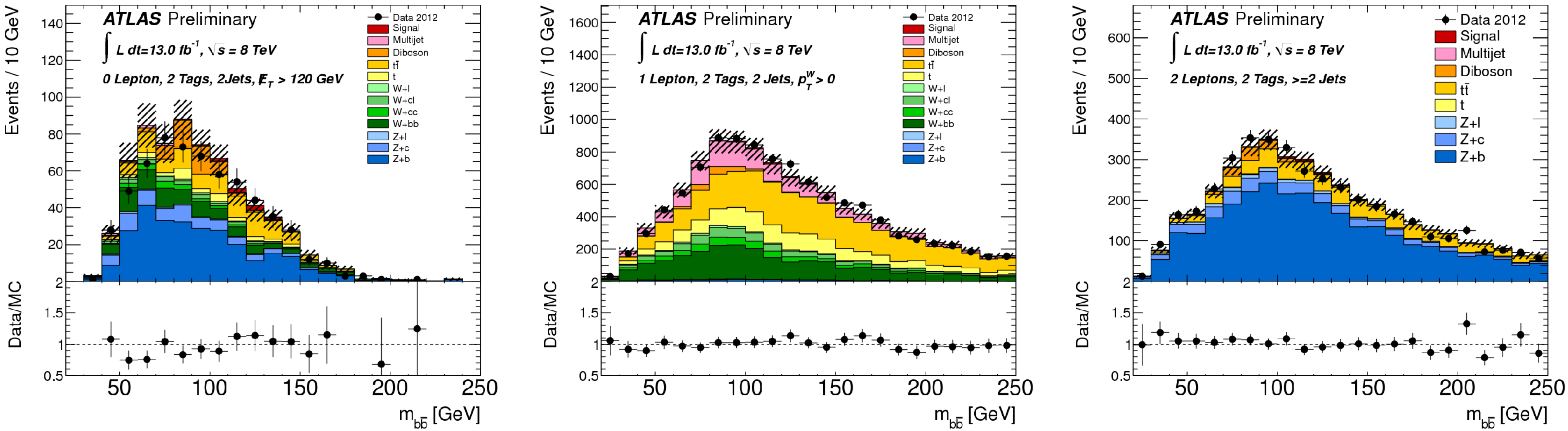


High Pile-up



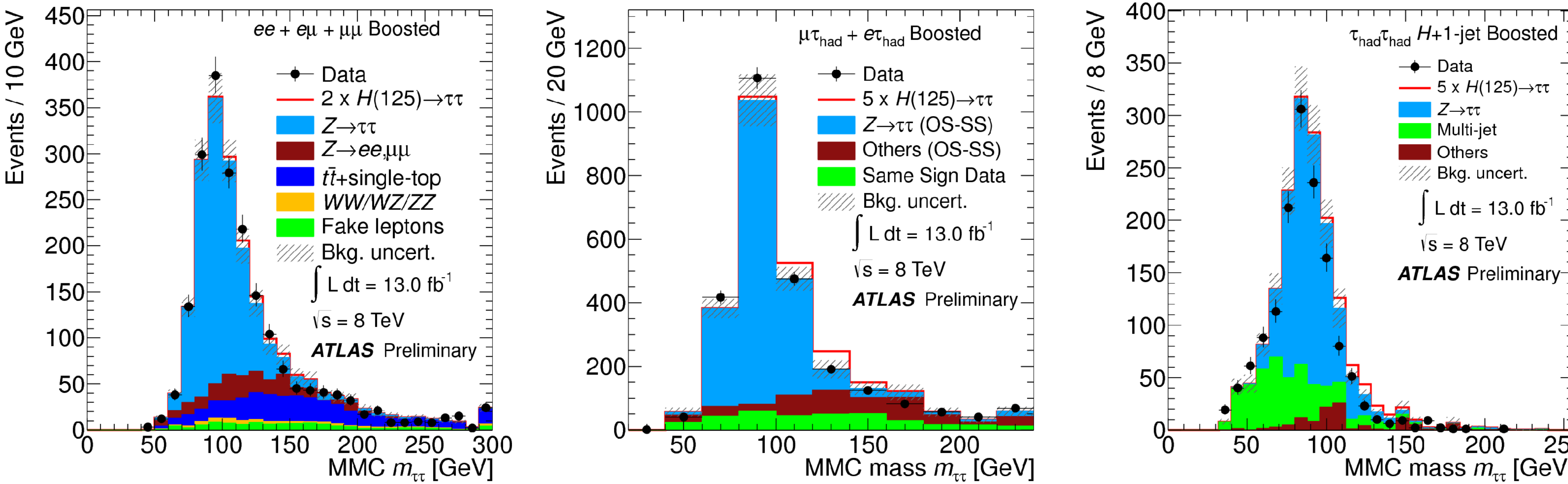
- Event
  - Z→μμ
- Verteces
  - 25 reconstructed
- Tracks
  - Only displayed if p_T>0.4GeV

H → bb



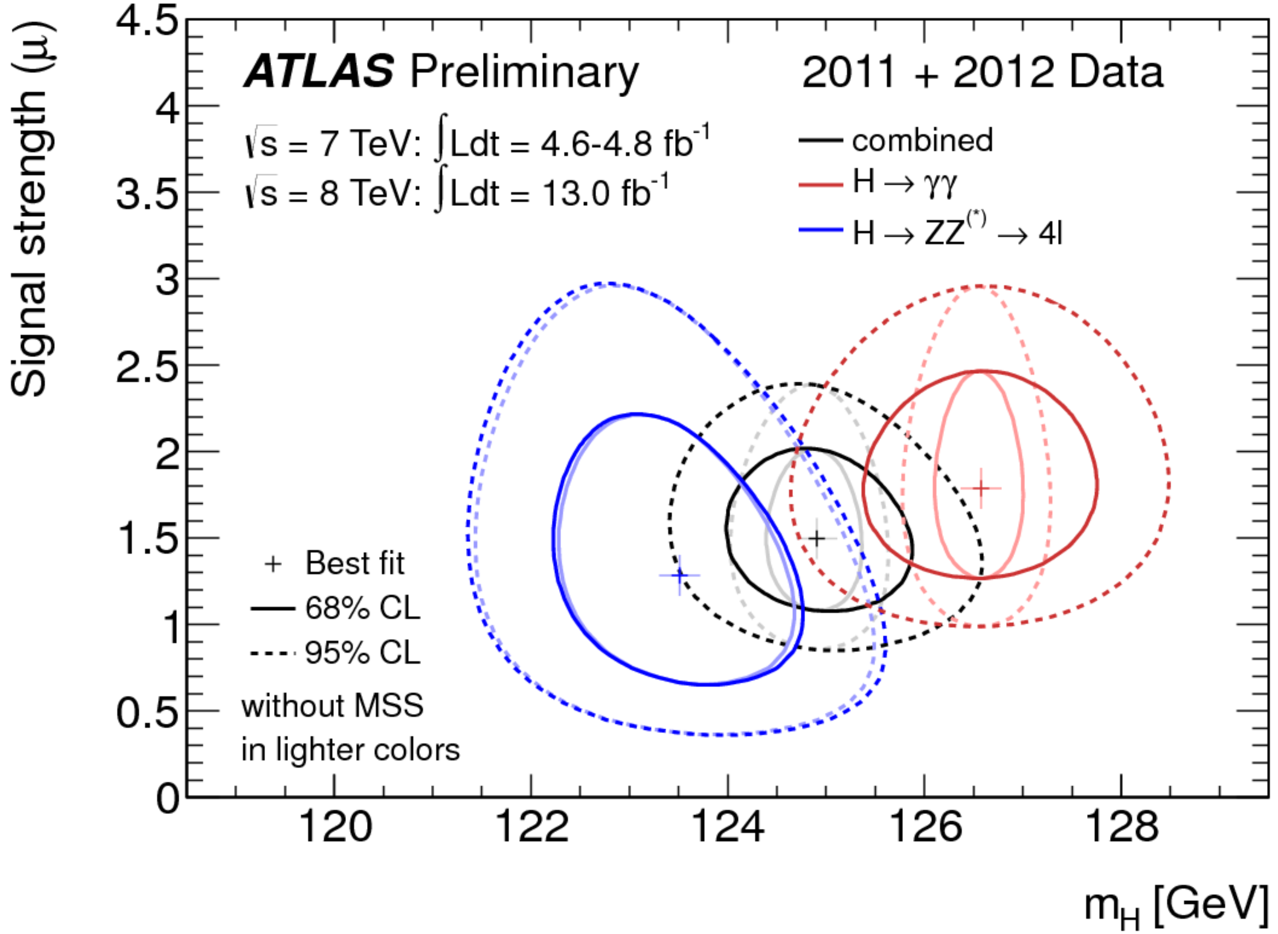
- Examples of the m_{bb} distributions for the 0, 1 and 2-lepton category
  - Overall good description of data by MC
- Background composition depends on category
  - Description uses combination of MC and data-driven estimate
    - Multijet purely data-driven estimation
    - Diboson purely MC based
    - All others take shape from MC and normalisation from data

Boosted H → ττ



- Example showing boosted Higgs analysis in the three ττ decay channels
  - General agreement between data and MC good
  - Note: the signal contribution in MC has been scaled for visibility
- MMC mass = missing mass calculator to reconstruct $m_{\tau\tau}$
  - Efficiency > 99%
  - Mass resolution 13-20%

Mass Measurements



Best fit signal strength

$\mu(m_H=125) = 1.35 \pm 0.19$ (stat) ± 0.15 (sys)

Combined mass measurement

$m_H = 125.2 \pm 0.3$ (stat) ± 0.6 (sys) GeV

Individual measurements

Results in agreement with 2.7σ assuming Gaussian pdfs for systematic uncertainties

More conservative treatment of uncertainties yields 2.3σ

Mass scale systematic (MSS) uncertainties

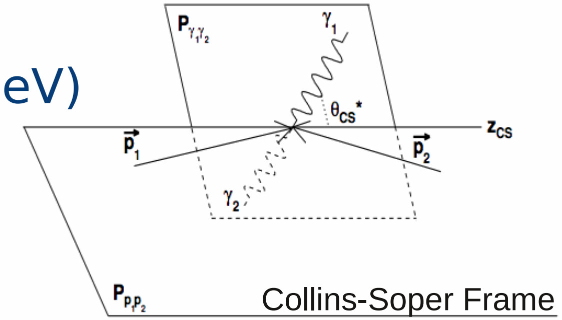
e Energy scale from $Z \to ee$

Material upstream from EM calo

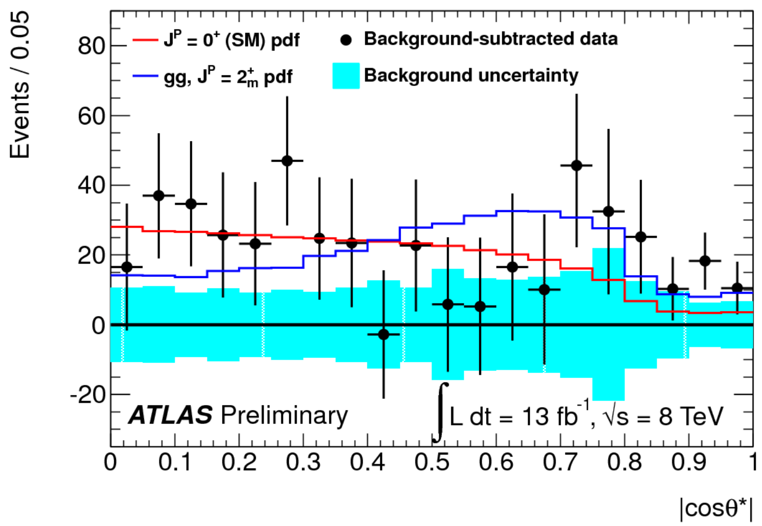
Energy scale of presampler

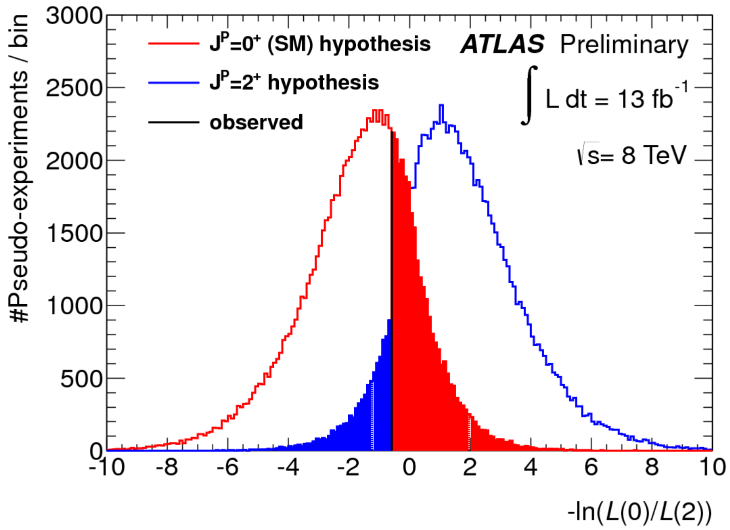
Spin Analysis in H→γγ

- Using inclusive analysis
  - Sensitive variable is diphoton cos θ* distribution
  - Use events within 1.5σ of the peak (m_H=126.5 GeV)



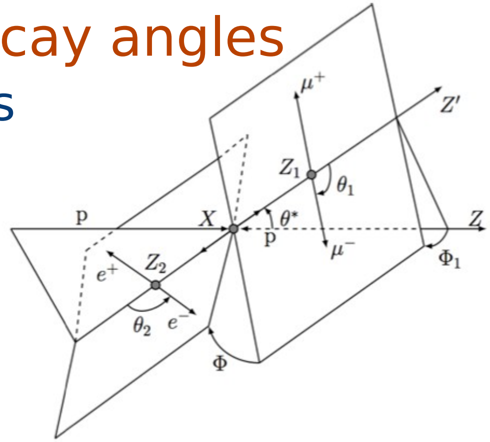
- Spin hypotheses
  - Expected sensitivity: exclusion of spin 2^+ hypothesis at the 97% CL
  - Observed exclusion of spin 2^+ hypothesis at the 91% CL
  - Observation fully compatible with spin 0 (within 0.5σ)



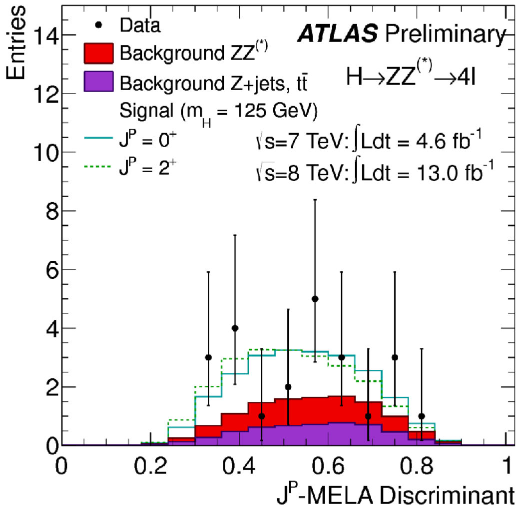


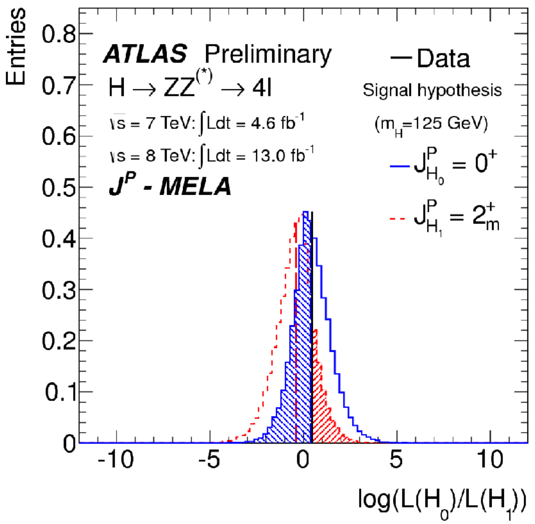
Spin Analysis in H→4ℓ

- Two methods using distribution of 5 production and decay angles
  - Boosted decision tree (BDT) in a multivariate analysis
  - Matrix element based likelihood ratio (MELA)



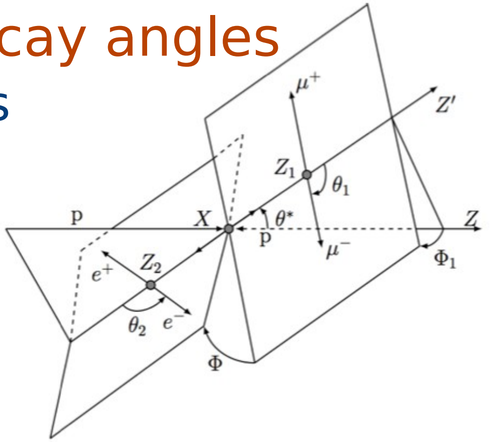
- Spin hypotheses
  - Expected sensitivity: exclusion of spin 2^+ hypothesis at the 80% CL
  - Observed exclusion of spin 2^+ hypothesis at the 85% CL
  - Observation fully compatible with spin 0 (within 0.18σ)



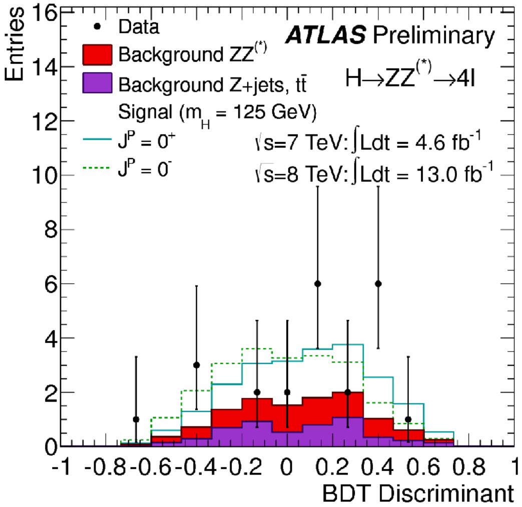


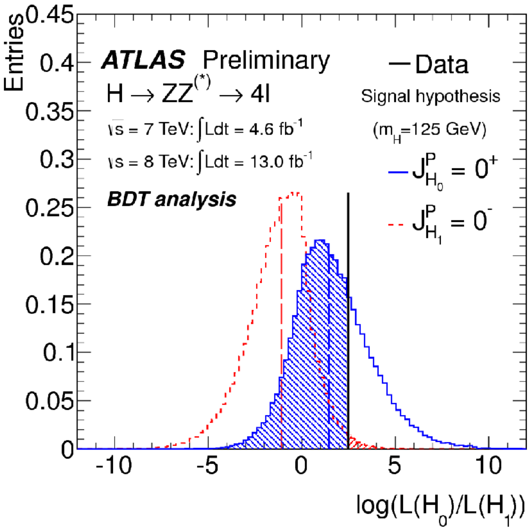
Parity Analysis in H→4ℓ

- Two methods using distribution of 5 production and decay angles
  - Boosted decision tree (BDT) in a multivariate analysis
  - Matrix element based likelihood ratio (MELA)



- Parity hypotheses
  - Expected sensitivity: exclusion of the 0^- hypothesis at the 96% CL
  - Observed exclusion of the 0^- hypothesis at the 99% CL
  - Observation fully compatible with spin 0 (within 0.5σ)





Cracow Epiphany Conference 7^{th}–9^{th} January 2013

SM Higgs Searches in ATLAS

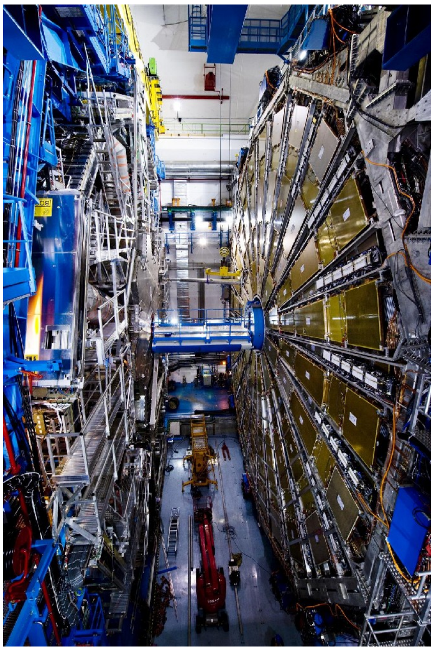
Philipp Fleischmann
Universität Würzburg

On behalf of the ATLAS Collaboration

Julius-Maximilians-
UNIVERSITÄT
WÜRZBURG

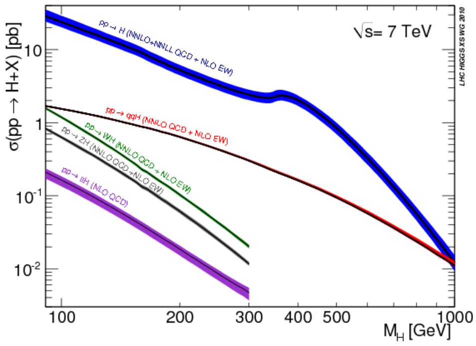
Outline

- Introduction
- SM Higgs at the LHC
- The ATLAS Detector
- Higgs Decay Channels discussed here
  - $H \rightarrow bb$
  - $H \rightarrow \tau\tau$
  - $H \rightarrow \gamma\gamma$
  - $H \rightarrow WW$
  - $H \rightarrow ZZ$
- Conclusion and outlook

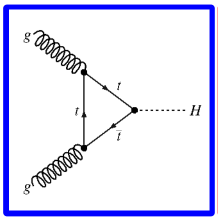


Higgs Production at the LHC

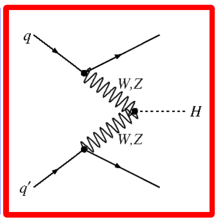
- gg-Fusion dominating at LHC
  - VBF, VH, ttH easier to trigger
- Reach up to masses of 1TeV
  - Here concentrating on low values
- Slopes slightly different at $\sqrt{s}$=8TeV
  - General picture remains unchanged



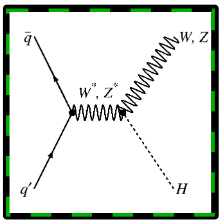
gg-Fusion



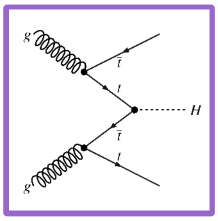
VBF



VH

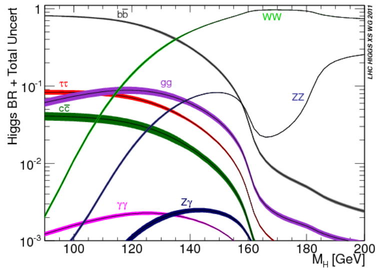


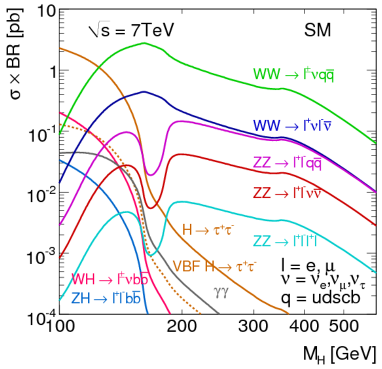
$t\bar{t}$H



Higgs Decay Modes

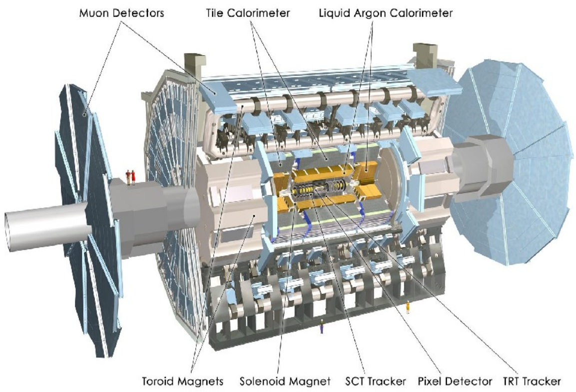
- Several decay modes accessible
  - Importance depends on m_H
- At low Higgs masses
  - $H \rightarrow b\bar{b}$ dominating
- At higher masses
  - WW and ZZ have higher BR
- To find experimental importance
  - Combine crosssection and BR
  - Take final states into account
  - Analyse background processes





The ATLAS Detector

- General Info
  - Length ~46m
  - Diameter ~25m
  - Weight ~7000t
  - Under ground ~92m



ATLAS Collaboration JINST 3 (2008) S08003

- Magnets
  - Solenoid: 2T
  - Toroid (barrel): 0.5T
  - Toroid (endcap): 1T
- Tracker
  - $\sigma(p_T)/p_T \approx 0.05\%\ p_T \oplus 1\%$
- ECAL
  - $\sigma(E)/E \approx 10\% / \sqrt{E} \oplus 0.7\%$
- HCAL
  - $\sigma(E)/E \approx 50\% / \sqrt{E} \oplus 3\%$
- Muon Spectrometer
  - $\sigma(p_T)/p_T \approx$ 2% @ 50GeV
  - $\sigma(p_T)/p_T \approx$ 10% @ 1TeV
- Trigger
  - 3 Levels: 40MHz → 200Hz

Higgs Searches in ATLAS

- Many analyses
  - Too much to present today
- All results online
  - Some examples presented now

Summary of latest results in all channels

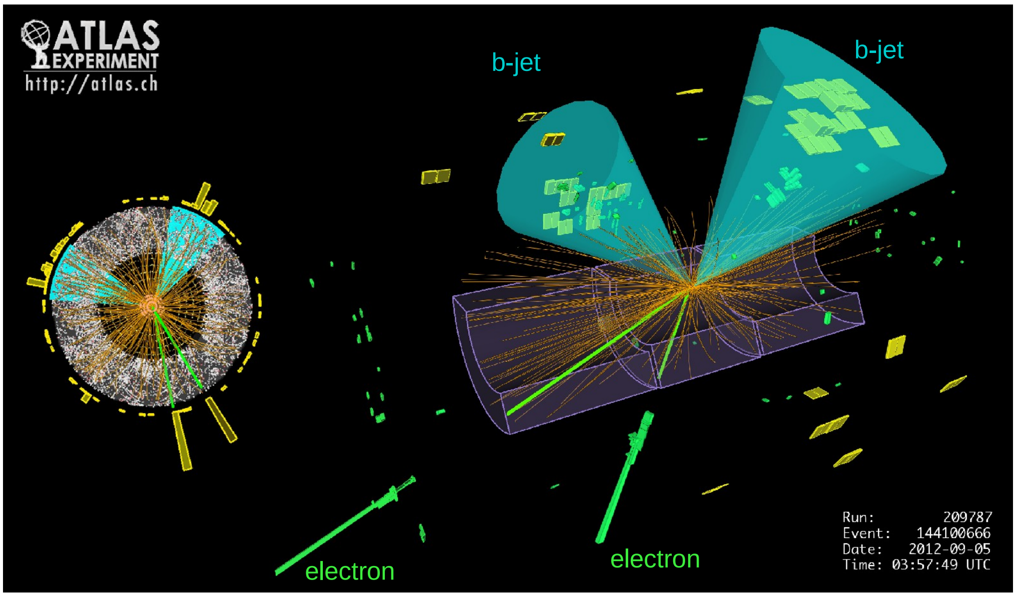
Channel	Conference note	L (fb^{-1})	Date	Publication	L (fb^{-1})	Date
SM H combination	ATLAS-CONF-2012-170	4.9+13.0	Dec 2012	arXiv:1207.7214	4.9+5.9	Jul 2012
SM H to ZZ(*) to 4l	ATLAS-CONF-2012-169	4.8+13.0	Dec 2012	arXiv:1202.1415	4.8	Feb 2012
SM H to diphoton	ATLAS-CONF-2012-168	4.9+13.0	Dec 2012	arXiv:1202.1414	4.9	Feb 2012
LFV Charged Higgs	-	4.7	Dec 2012	Paper	4.6	Feb 2012
SM H couplings	ATLAS-CONF-2012-127	4.9+5.9	Sep 2012	-	-	-
SM H combination	ATLAS-CONF-2012-162	4.9+13.0	Nov 2012	arXiv:1207.7214	4.9+5.9	Jul 2012
SM H to diphoton	ATLAS-CONF-2012-091	4.9+5.9	Jul 2012	arXiv:1202.1414	4.9	Feb 2012
SM H to ZZ(*) to 4l	ATLAS-CONF-2012-092	4.8+5.8	Jul 2012	arXiv:1202.1415	4.8	Feb 2012
SM H to WW to lvlv SM H to WW to lvlv (MVA)	ATLAS-CONF-2012-158 ATLAS-CONF-2012-060	4.7+13.0 4.7	Nov 2012 Jun 2012	arXiv:1206.0756	4.7	Jun 2012
SM WH, H to WW	ATLAS-CONF-2012-078	4.7	Jul 2012	-	-	-
SM H to tautau	ATLAS-CONF-2012-160	4.7+13.0	Nov 2012	arXiv:1206.5971	4.7	Jun 2012
SM VH, H to bb	ATLAS-CONF-2012-161	4.7+13.0	Nov 2012	arXiv:1207.0210	4.7	Jun 2012
SM ttH, H to bb	ATLAS-CONF-2012-135	4.7	Sep 2012	-	-	-
SM H to ZZ to llvv	ATLAS-CONF-2012-016	4.7	Mar 2012	arXiv:1205.6744	4.7	May 2012
SM H to ZZ to llqq	ATLAS-CONF-2012-017	4.7	Mar 2012	arXiv:1206.2443	4.7	Jun 2012
SM H to ZZ to llqq Low Mas	ATLAS-CONF-2012-163	4.7	Nov 2012	-	-	-
SM H to WW to lvqq	ATLAS-CONF-2012-018	4.7	Mar 2012	arXiv:1206.6074	4.7	Jun 2012
Higgs in SM with 4th fermion generation	ATLAS-CONF-2011-135	1.0-2.3	Aug 2011	-	-	-
Fermiophobic H to diphoton	ATLAS-CONF-2012-013	4.9	Mar 2012	arXiv:1205.0701	4.9	May 2012
MSSM neutral H	ATLAS-CONF-2012-094	4.7	Jul 2012	arXiv:1107.5003	0.036	Jul 2011
MSSM H+ to taunu	ATLAS-CONF-2012-011	4.7	Mar 2012	arXiv:1204.2760	4.6	Apr 2012
MSSM H+ to csbar	ATLAS-CONF-2011-094	0.035	Jul 2011	-	-	-
NMSSM a1 to mumu	ATLAS-CONF-2011-020	0.037	Mar 2011	-	-	-
NMSSM H to a0a0 to 4photons	ATLAS-CONF-2012-079	4.9	Jul 2012	-	-	-

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsPublicResults

H → bb

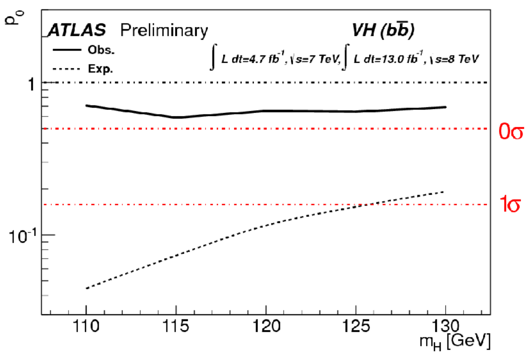
- Highest branching ratio at low masses m_H
- Associated production ttH and VH
    - Lower cross section than ggF, but easier to reject backgrounds
- Very challenging jet backgrounds
    - Several orders of magnitude bigger
    - Biggest contributions from top, W+jets and Z+jets
- Event selection (Focusing on VH analysis)
    - Three categories based on number of leptons
        - 0 leptons: $ZH \rightarrow \nu\nu bb$
        - 1 lepton: $WH \rightarrow l\nu bb$
        - 2 leptons: $ZH \rightarrow llbb$
    - No additional leptons
    - Some missing energy in case of ν in final state
    - Two b-tags: 70% efficiency per tag (mistag ~1%)
- Categories further split
    - Depending on vector boson momentum and number of jets
- Data presented here
    - 2011 $\sqrt{s}$=7TeV $\int L dt$ = 4.7fb^{-1}
    - 2012 $\sqrt{s}$=8TeV $\int L dt$ = 13fb^{-1}

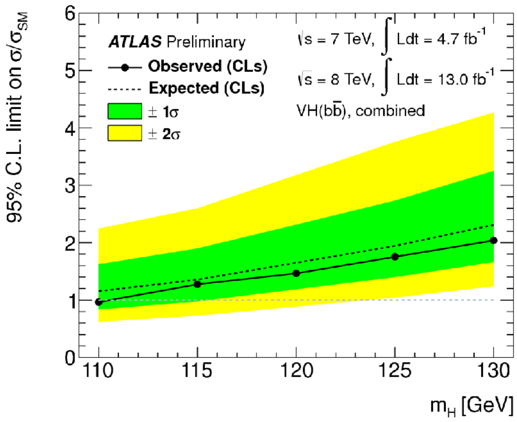
ZH → eebb



Currently ~50 signal candidates for VH(bb)

H → bb

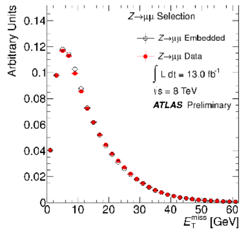




- Consistency of observed data with background-only hypothesis
  - local $p_0(m_H=125GeV) = 0.64$ (corresponding to 1σ)
- Exclusion limits
  - SM Higgs excluded at 95%CL for m_H=110 GeV

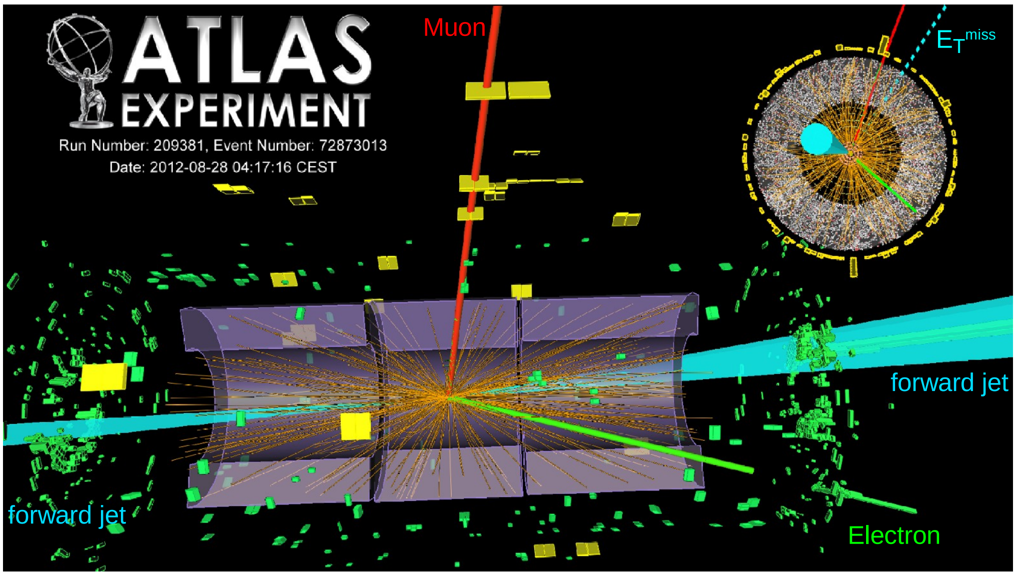
$H \rightarrow \tau\tau$

- Three decay modes exclusively defined by number of leptons
  - $H \rightarrow \tau_\ell \tau_\ell$ (~12%)
  - $H \rightarrow \tau_\ell \tau_h$ (~46%)
  - $H \rightarrow \tau_h \tau_h$ (~42%)
- Many exclusively defined categories
  - Based on jet multiplicity, kinematics and H production mode
- Signature
  - τ-pair from resonance
  - Missing E_T
    - Poor mass resolution



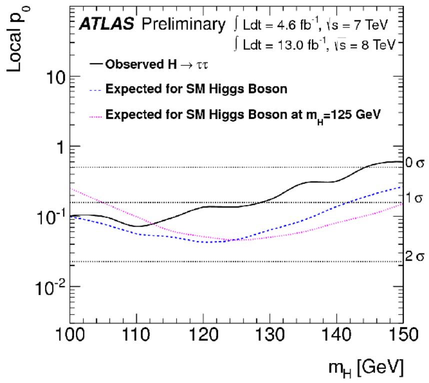
- Background understanding crutial
  - The most important irreducible Background is $Z\rightarrow\tau\tau$
  - Modelled using real $Z\rightarrow\mu\mu$ events and replacing μ by simulated τ
- Data presented here
  - 2011 $\sqrt{s}$=7TeV $\int Ldt = 4.6 fb^{-1}$
  - 2012 $\sqrt{s}$=8TeV $\int Ldt = 13 fb^{-1}$

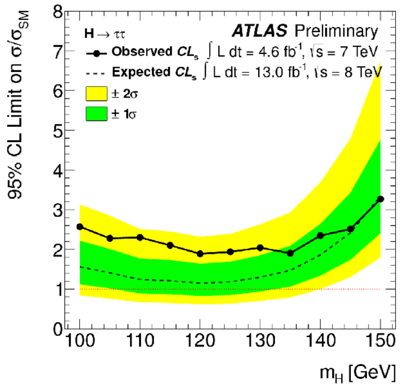
VBF H → $\tau_e\tau_\mu$



Currently ~330 signal candidates for H→ττ

H → ττ

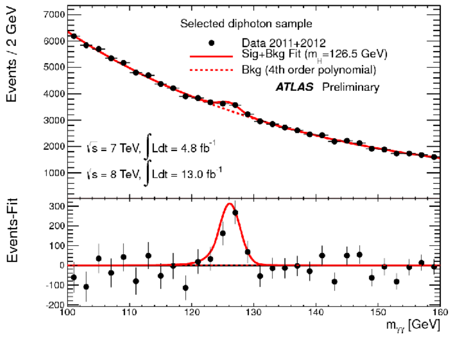




- Consistency of observed data with background-only hypothesis
  - local $p_0(m_H=125GeV) = 13.5\%$ (corresponding to 1.1σ)
- Exclusion limits
  - No range of SM Higgs masses excluded at 95%CL

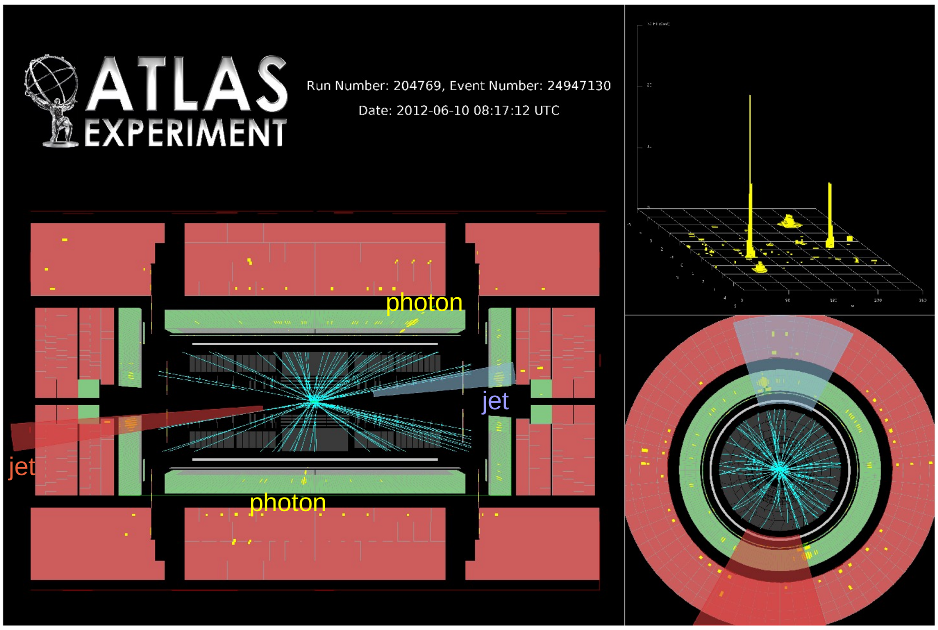
$H \rightarrow \gamma\gamma$

- Very small branching ratio (~0.2%)
  - But clean signature
- Full reconstruction of H decay
  - Good mass resolution ~1.5% at best
- Signature
  - Two energetic isolated photons
  - Peak in diphoton mass spectrum
- Large background, but smoothly varying
  - Determined from sidebands
  - Composition measured in data
- Good mass resolution requires
  - Good photon energy calibration
  - Good photon direction
  - Good understanding of γ-conversion



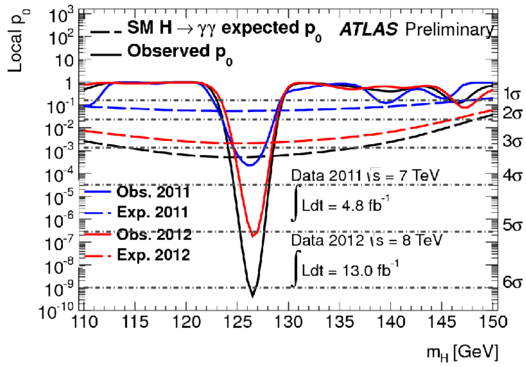
- Increased sensitivity by dividing events into categories
  - Based on signal-to-background ratio and mass resolution
- Data presented here
  - 2011 $\sqrt{s}$=7TeV $\int Ldt = 4.8 fb^{-1}$
  - 2012 $\sqrt{s}$=8TeV $\int Ldt = 13 fb^{-1}$

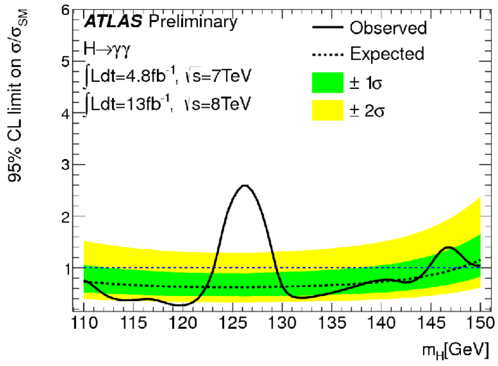
H → γγ



Currently ~330 signal candidates for H→γγ

H → γγ

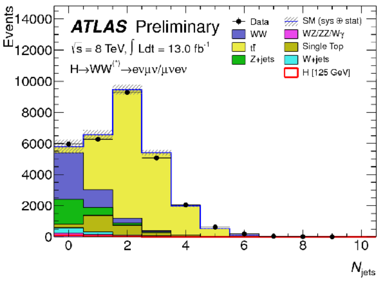




- Consistency of observed data with background-only hypothesis
  - Excess observed around m_H=126.5 GeV
  - local $p_0 = 4.4 \times 10^{-10}$ (corresponding to 6.1σ) **single channel discovery!**
  - global $p_0 = 2.8 \times 10^{-8}$ (corresponding to 5.4σ)
- Exclusion limits
  - SM Higgs excluded at 95%CL in ranges 110-122.5 GeV and 129.5-144.5 GeV

$H \rightarrow WW^* \rightarrow \ell\nu\ell\nu$

- Large branching ratio which peaks around $2M_W < m_H < 2M_Z$
  - Provides information about production rate and H coupling to W
  - Dominated by gg-Fusion production mode
    - To enhance different production modes use jet multiplicity
- Contains 2 neutrinos
  - Poor mass resolution
  - Look for excess above background
- Signal
  - 2 isolated high p_T leptons with opposite charge + missing ET
  - Use different flavour leptons to reduce background
- Correlated W spins
  - Leptons go preferentially in same direction
- Background depends on jet multiplicity
  - Reducible: tt, diboson, W+jets, Drell-Yan
  - Irreducible: WW
- Data presented here
  - 2012 $\sqrt{s}$=8TeV $\int Ldt = 13fb^{-1}$



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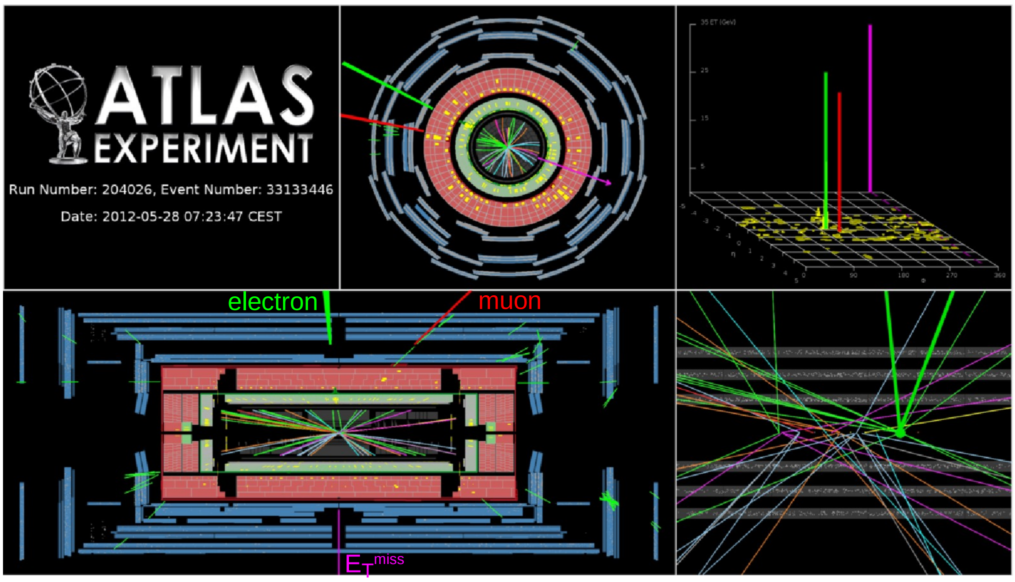
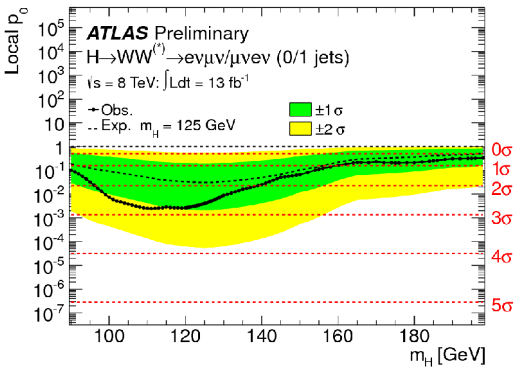
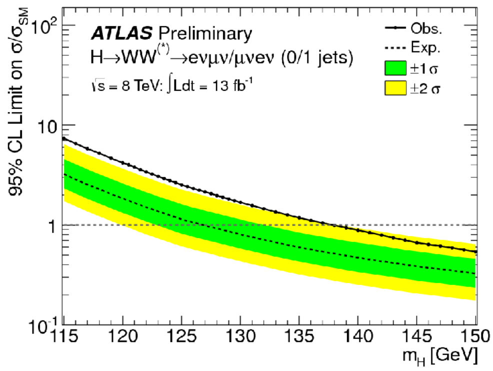
H → WW* → eνμν



Currently ~110 signal candidates for ggH(WW)

H → WW* → ℓνℓν

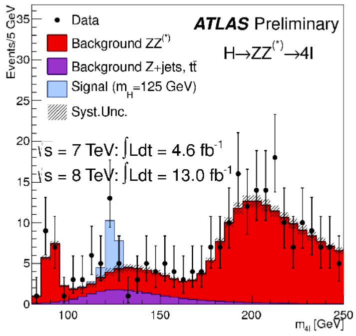




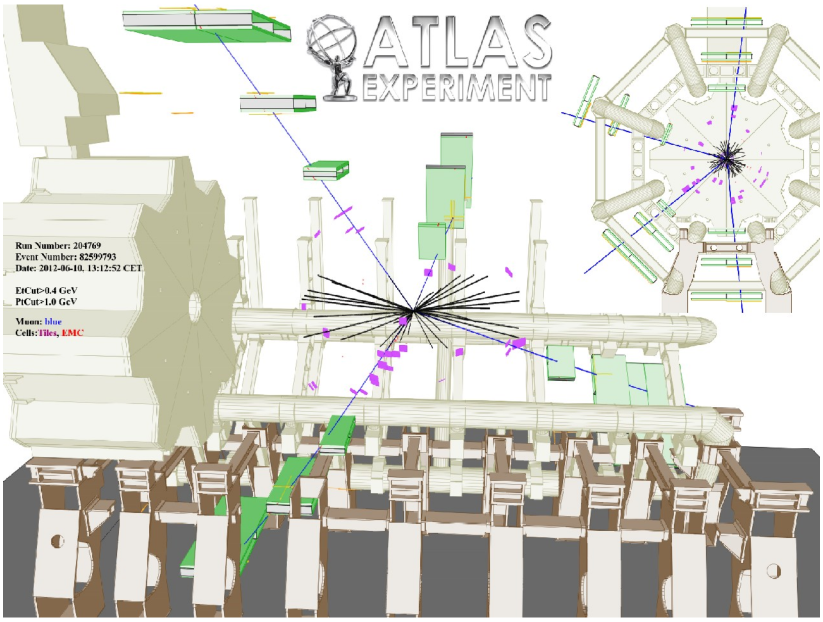
- Consistency of observed data with background-only hypothesis
  - local $p_0(m_H=125GeV) = 4 \times 10^{-3}$ (corresponding to 2.6σ)
- Exclusion limits
  - SM Higgs excluded at 95%CL in ranges 139-200 GeV

H → ZZ* → ℓℓℓℓ

- „Golden Channel"
  - Small branching ratio, but high S/B
  - Full reconstruction... good mass resolution
    - σ/m ≈ 1-2% at low masses
- Clean signature
  - Two $\ell^+\ell^-$ pairs forming Z (one maybe off-shell)
  - Energetic, isolated leptons
  - Leptons from primary vertex
- Background
  - Reducible: Z+jets, Zbb, tt
  - Irreducible: ZZ
- Requirements
  - Good single lepton reconstruction and trigger efficiency: $\varepsilon_{4\ell} \sim \varepsilon_{\ell}^4$
  - Well understood Lepton energy resolution
- Data presented here
  - 2011 $\sqrt{s}$=7TeV $\int L dt$ = 4.8fb^{-1}
  - 2012 $\sqrt{s}$=8TeV $\int L dt$ = 13fb^{-1}



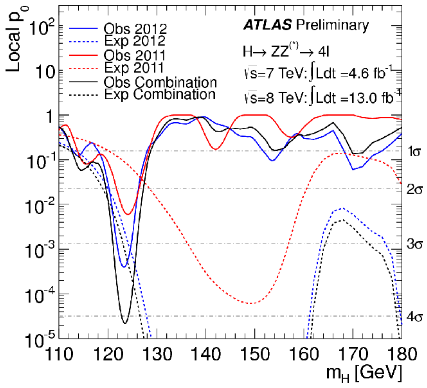
H → 4μ

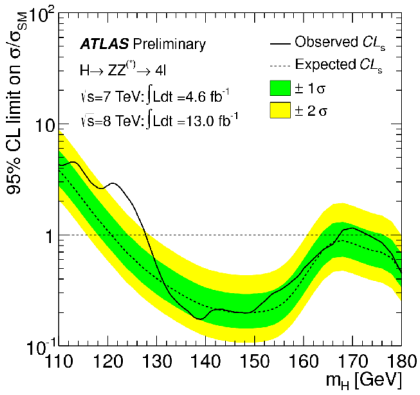


Currently ~10 signal candidates for H→4ℓ

H → ZZ* → ℓℓℓℓ

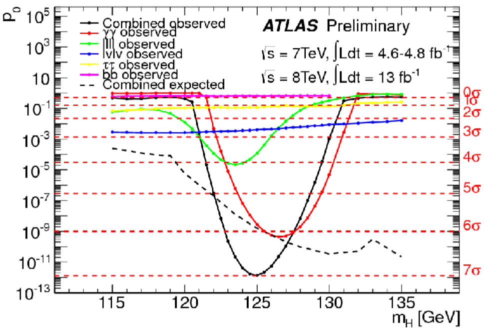
- Consistency of observed data with background-only hypothesis
  - Excess observed around m_H=123.5 GeV
  - local $p_0 = 2.1 \times 10^{-5}$ (corresponding to 4.1σ)
- Exclusion limits
  - SM Higgs excluded at 95%CL in ranges 128-168 GeV and 174-580 GeV

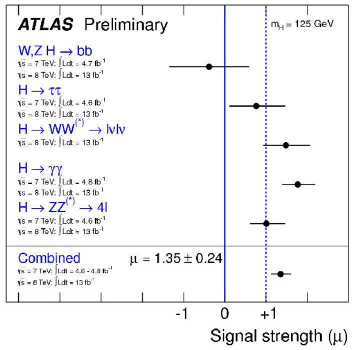




Combination

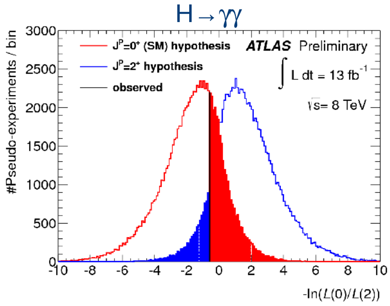
- Consistency of observed data with background-only hypothesis
  - Excess observed at m_H=125.2 ±0.3(stat) ±0.6(sys) GeV
  - local p_0 = 10^{-12} (corresponding to 7.0σ)
- Signal strength
  - $\hat{\mu}(m_H=125)$ = 1.35±0.19 (stat)±0.15(sys)



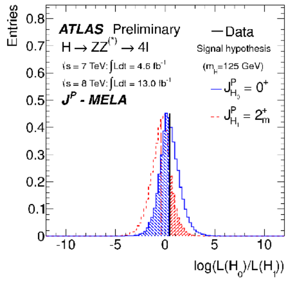


Analysis of Spin and Parity

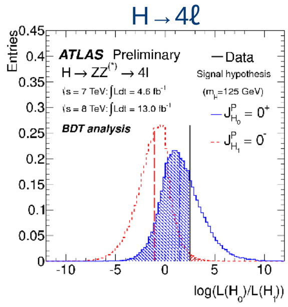
H→γγ



H→4ℓ



H→4ℓ



- Spin 2^+ hypothesis
  - Excluded at 91% CL in H→γγ
  - Excluded at 85% CL in H→4ℓ
- Spin 0^- hypothesis
  - Excluded at 99% CL in H→4ℓ
- Spin 0 hypothesis
  - Observation fully compatible

Conclusions & Outlook

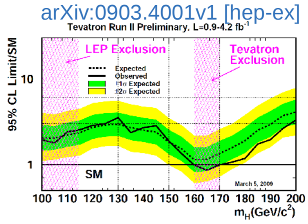
- The ATLAS detector has now collected following pp-data
  - 2011: at $\sqrt{s}$=7TeV $\int Ldt$ = 4.8fb^{-1}
  - 2012: at $\sqrt{s}$=8TeV $\int Ldt$ = 21.7fb^{-1}
- Results presented here
  - Used all 2011 data and 13fb^{-1} of the 2012 data
- Updated results confirm earlier observations based on lower statistics
  - Excess observed at m_H=125.2 ±0.3(stat) ±0.6(sys) GeV
  - local $p_0 = 10^{-12}$ (corresponding to 7.0σ)
- Further updates using the full 2011+2012 datasets expected soon
  - Observation of „Higgs-like“ particle done
  - Measurements of the couplings become more interesting
- Beginning of 2013 the LHC will continue with heavy ion collisions
  - Afterwards a long shutdown of about two years
  - Accelerator and experiments will prepare for 14 TeV

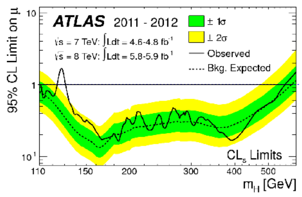
Additional Slides

Introduction

- Higgs is missing keystone in the Standard Model
  - Higgs mechanism predicts boson, but not it's mass
- Results of direct searches before LHC:
  - LEP: excluded (@95%CL) m_H<114GeV
  - Tevatron: excluded(@95%CL) 160<m_H<170GeV
- Higgs discovery is one of the main goals for the LHC
  - Not the only one, but that's a different story...
- Observation of a new particle with a mass of about 125 GeV
  - ATLAS and CMS announced a discovery
  - „Higgs-like particle“… is it the Higgs?
- Change in the analyses
  - Away from purely discovery search
  - Towards measurements of properties
- pp-collision mode stopped at LHC for upgrade
  - All analyses will be updated using the full statistics avilable

arXiv:0903.4001v1 [hep-ex]



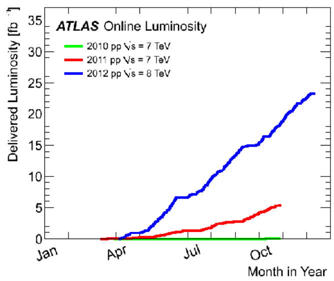


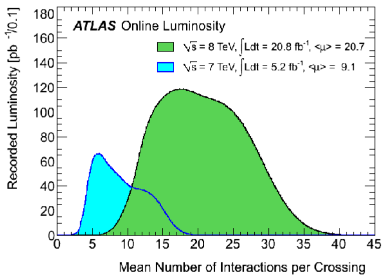
The Large Hadron Collider

- (design) CM energy: 14 TeV
- (2012) 8 TeV
- (design) Luminosity: $10^{34}cm^{-2}s^{-1}$
- (2012) $7.7 \times 10^{33}cm^{-2}s^{-1}$
- (design)Bunch crossing: 25 ns
- (2012) 50 ns
- Protons per bunch: $\sim 10^{11}$
- Beam radius: 16.7 μm

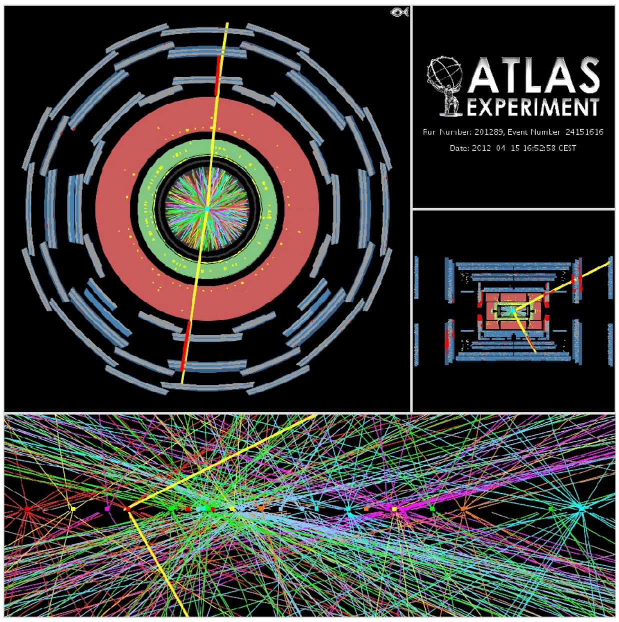
The ATLAS Data

- Results presented here correspond to
  - 2011 data taking
    - Centre-of-mass energy $\sqrt{s}$ = 7TeV
    - Integrated luminosity ~4.8fb^{-1}
    - Pileup $<\mu> \approx 9$
  - 2012 data taking
    - Centre-of-mass energy $\sqrt{s}$ = 8TeV
    - Integrated luminosity up to 13fb^{-1}
    - Pileup $<\mu> \approx 20$
- More to come
  - 2012 data taking
    - Integrated luminosity up tp 21.7fb^{-1}
  - In preparation for Moriond conference



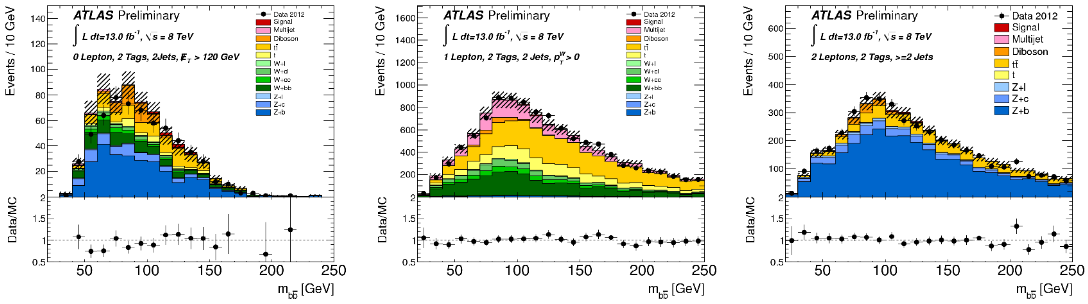


High Pile-up



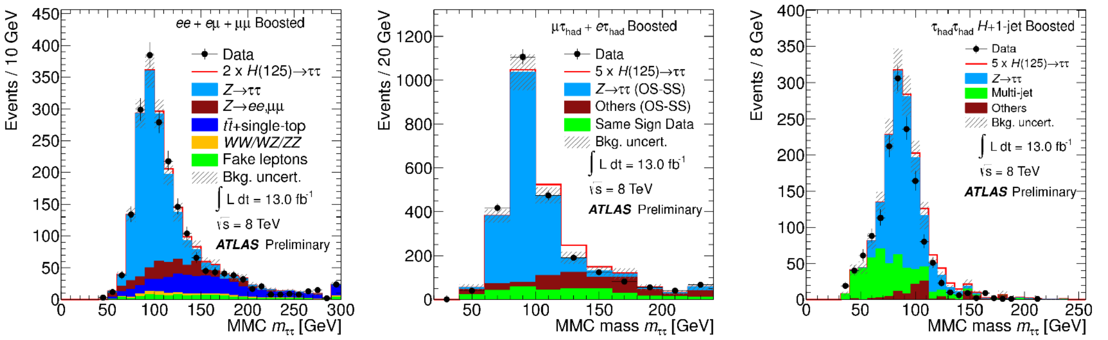
- Event
  - $Z \rightarrow \mu\mu$
- Verteces
  - 25 reconstructed
- Tracks
  - Only displayed if $p_T > 0.4 GeV$

H → bb



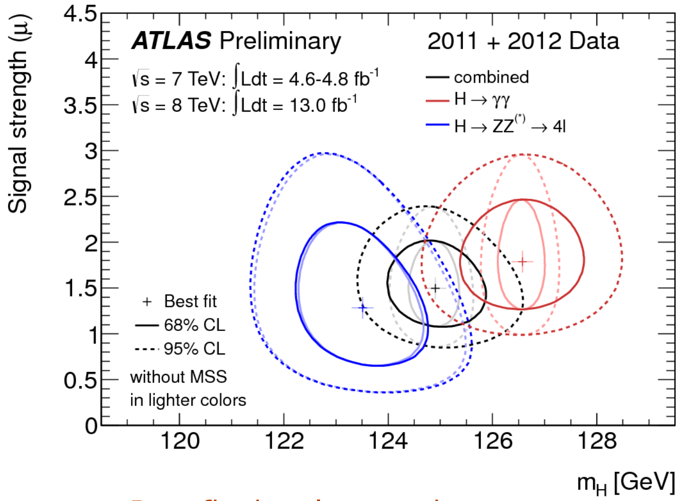
- Examples of the m_{bb} distributions for the 0, 1 and 2-lepton category
  - Overall good description of data by MC
- Background composition depends on category
  - Description uses combination of MC and data-driven estimate
    - Multijet purely data-driven estimation
    - Diboson purely MC based
    - All others take shape from MC and normalisation from data

Boosted H → ττ



- Example showing boosted Higgs analysis in the three ττ decay channels
  - General agreement between data and MC good
  - Note: the signal contribution in MC has been scaled for visibility
- MMC mass = missing mass calculator to reconstruct $m_{\tau\tau}$
  - Efficiency > 99%
  - Mass resolution 13-20%

Mass Measurements



Best fit signal strength

$\mu(m_H=125)$ = 1.35±0.19 (stat)±0.15(sys)

Combined mass measurement

m_H=125.2 ±0.3(stat) ±0.6(sys) GeV

Individual measurements

Results in agreement with 2.7σ assuming Gaussian pdfs for systematic uncertainties

More conservative treatment of uncertainties yields 2.3σ

Mass scale systematic (MSS) uncertainties

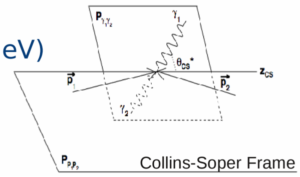
e Energy scale from $Z \rightarrow ee$

Material upstream from EM calo

Energy scale of presampler

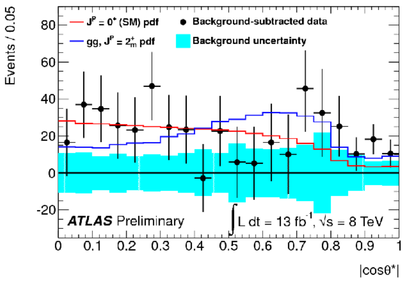
Spin Analysis in H→γγ

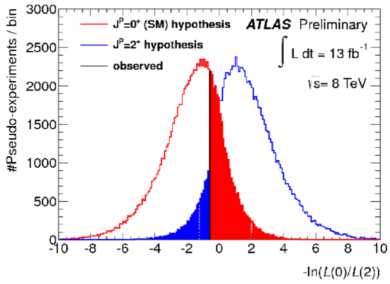
- Using inclusive analysis
  - Sensitive variable is diphoton cos θ* distribution
  - Use events within 1.5σ of the peak (m_H=126.5 GeV)



Collins-Soper Frame

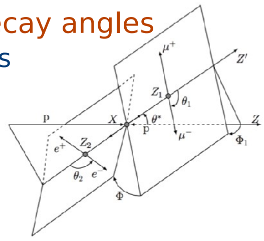
- Spin hypotheses
  - Expected sensitivity: exclusion of spin 2^+ hypothesis at the 97% CL
  - Observed exclusion of spin 2^+ hypothesis at the 91% CL
  - Observation fully compatible with spin 0 (within 0.5σ)



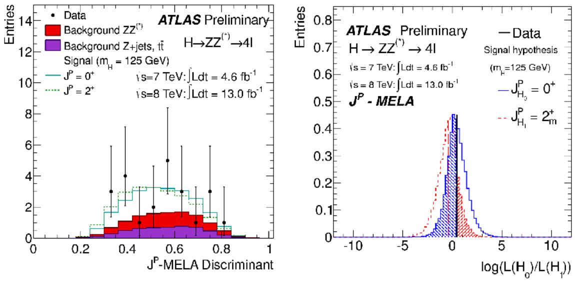


Spin Analysis in H→4ℓ

- Two methods using distribution of 5 production and decay angles
  - Boosted decision tree (BDT) in a multivariate analysis
  - Matrix element based likelihood ratio (MELA)

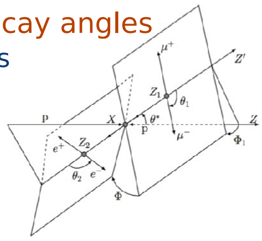


- Spin hypotheses
  - Expected sensitivity: exclusion of spin 2^+ hypothesis at the 80% CL
  - Observed exclusion of spin 2^+ hypothesis at the 85% CL
  - Observation fully compatible with spin 0 (within 0.18σ)



Parity Analysis in H→4ℓ

- Two methods using distribution of 5 production and decay angles
  - Boosted decision tree (BDT) in a multivariate analysis
  - Matrix element based likelihood ratio (MELA)



- Parity hypotheses
  - Expected sensitivity: exclusion of the 0^- hypothesis at the 96% CL
  - Observed exclusion of the 0^- hypothesis at the 99% CL
  - Observation fully compatible with spin 0 (within 0.5σ)