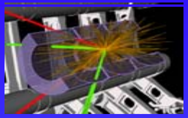


The Higgs Boson : Latest Measurements and Perspectives

Thomas Muller (KIT), on behalf of the ATLAS and CMS Collaborations

Outline:

- Introduction
- Bosonic decay channels ($\gamma\gamma$, ZZ, WW)
- Fermionic decays ($\tau\tau$, bb)
- Properties: Mass, Couplings, Spin/Parity
- Expectations for 300 fb^{-1} and 3000 fb^{-1}

Summary

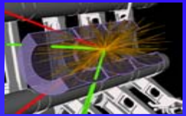
No details on:

- Object reconstruction, event selection
- Background estimation and systematics
- Statistical analyses

I leave out:

- $H\rightarrow Z\gamma$, $H\rightarrow\mu\mu$
- ttH

} Very nice new results on limits



Presentations on this *Tagung*

PV V Plenarvortrag: Entdeckung eines Higgs-artigen Teilchens am LHC — •Karl Jakobs

PV VIII Abendvortrag: Das Higgs-Boson: Sind alle Rätsel gelöst? - Neues vom Teilchenbeschleuniger LHC — •Arno Straessner

T 5.1 Hauptvortrag: Die Entdeckung des Higgs-Bosons: aktuelle Ergebnisse und Perspektiven — •Thomas Müller

T 7.5 Eingeladener Vortrag: Search for Higgs and other bosons in beyond standard model physics with CMS — •Adrian Perieanu

T 8.3 Eingeladener Vortrag: Suche nach dem Higgs-Boson des Standard-Modells im Zerfall $H \to \tau\tau$ mit ATLAS — •Stanley Lai

T 8.5 Eingeladener Vortrag: Messungen der Higgs-Boson-Eigenschaften mit dem ATLAS Experiment — •Johannes Elmsheuser

T 9.1 Preisträgervortrag: Observation and study of the Higgs boson candidate in the diphoton decay channel with the ATLAS detector — •Kerstin Tackmann

T 44.1 Suche nach geladenen Higgs-Bosonen im Zerfall $H^+ \to \tau\nu$ mit dem ATLAS-Experiment — Martin Flechl, •Anna Kopp und Markus Schumacher

T 44.2 Neutral MSSM Higgs search in the $\Phi \to \tau\tau$ decay channel — •Felix Frensch, Martin Niegel, Stefan Wayand, Fedor Ratnikov, Florian Weiser, Artur Speiser, Christian Lüdtke, Roger Wolf, Wim de Boer, and Dimitri Kazakov

T 44.3 Studien zum Entdeckungspotential für das Higgs-Boson im Zerfall $H \to \tau\tau \to ll + 4\nu$ — Michael Böhler, Martin Flechl, Michel Janus, Stan Lai, •Julian Maluck und Markus Schumacher

T 44.4 Untersuchung von Higgs-Boson-Zerfällen in ττ-Endzuständen am CMS-Experiment des LHC — •Thomas Müller, Günter Quast, Manuel Zeise, Raphael Friese, Frensch Felix, Alexei Raspereza, Agni Bethani und Armin Burgmeier

T 44.5 Suche nach neutralen Higgs-Bosonen im MSSM im Kanal $h/H/A \to \tau\tau \to lh$ bei ATLAS — •Felix Friedrich, Arno Straessner und Wolfgang Mader

T 44.6 Suche nach neutralen MSSM-Higgsbosonen im Zerfallskanal $h/H/A \to \tau^+\tau^- \to lh$ bei ATLAS — •Tan Wang, Jürgen Kroseberg und Jochen Dingfelder

T 44.7 Theoretische Unsicherheiten bei der Suche nach neutralen MSSM Higgs-Bosonen mit ATLAS — •Lorenz Hauswald, Felix Friedrich, Sebastian Wahrmund, Marcus Morgenstern, Christian Rudolph, Wolfgang Mader und Arno Straessner

T 44.8 Untersuchung des Higgs-Sektors des NMSSM am LHC — •Florian Weiser, Wim de Boer, Fedor Ratnikov, Stefan Wayand, Felix Frensch, Conny Beskidt, Christian Lüdtke, Artur Speiser, Martin Niegel und Daniel Tröndle

T 45.1 Suche nach schweren neutralen MSSM Higgs Boson Zerfällen im voll-hadronischen ττ Kanal — •Marcus Morgenstern, Dirk Duschinger, Wolfgang Mader, Arno Straessner und Sebastian Wahrmund

T 45.2 Search for the neutral MSSM Higgs bosons in the final state with hadronically decaying τ pairs at the ATLAS experiment — •Federico Scutti, Jochen Dingfelder, and Will Davey

T 45.3 $Z \to \tau\tau$ Embedding Studies for the $H \to \tau\tau$ Search at the CMS experiment — •Armin Burgmeier, Manuel Zeise, and Christian Veelken

T 45.4 Modellierung von $Z \to \tau\tau$ Untergrund im Rahmen der Higgssuche in ATLAS — •Jessica Liebal, Thomas Schwindt, Jürgen Kroseberg und Norbert Wermes

T 45.5 Suche nach neutralen Higgs-Bosonen im Zerfallskanal $H \to \tau\tau \to ll4\nu$ mit dem ATLAS-Detektor — •Christian Schillo, Michel Janus, Michel Böhler, Dirk Sammel, Stan Lai und Markus Schumacher

T 45.6 Optimierungsstudien zur Suche nach dem SM Higgs-Boson im VBF-Kanal $qq(H) \to \tau_{lep}\tau_{lep}$ mit ATLAS — •Eric Drechsler, Katharina Bierwagen, Ulla Blumenschein und Arnulf Quadt

T 45.7 Suche nach dem Higgs-Boson des Standardmodells mit multivariaten Methoden im Endzustand $H \to \tau\tau \to ll+4\nu$ mit dem ATLAS-Detektor — •Dirk Sammel, Michael Böhler, Michel Janus, Stan Lai und Markus Schumacher

45.8 Multivariate Techniken zur Identifikation von $H \to \tau\tau \to \mu\mu$-Zerfällen — •Raphael Friese, Thomas Müller, Manuel Zeise und Günter Quast

45.9 Search for the Higgs particle decaying into Tau leptons in the Electron-Electron channel with the CMS Experiment — •Jakob Salfeld and Alexei Raspereza

T 46.1 Multivariate Suche nach dem Standardmodell Higgs-Boson im Zerfallskanal $H \to \tau^+\tau^- \to l\nu\nu$ had ν mit dem ATLAS-Experiment — Karl Jakobs, Romain Madar und •Helge Hass

T 46.2 Suche nach dem Standardmodell Higgs-Boson im Zerfallskanal $H \to \tau^+\tau^- \to l\nu\nu_\tau$ had ν_τ mit dem ATLAS-Experiment — •Nils Ruthmann, Karl Jakobs und Romain Madar

T 46.3 Suche nach dem Standardmodell Higgs-Boson im Zerfall $H \to \tau_{lep}\tau_{had}$ — •Jana Kraus, Thomas Schwindt, Jessica Liebal, Jürgen Kroseberg und Norbert Wermes

T 46.4 Suche nach Higgs-Ereignissen mit zwei hadronisch zerfallenden Tau-Leptonen bei CMS — Vladimir Cherepanov, Günter Flügge, •Bastian Kargoll, Alexander Nehrkorn, Ian M. Nugent, Lars Perchalla und Achim Stahl

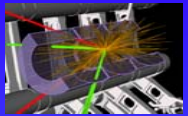
T 46.5 Search for the SM Higgs boson in the fully hadronic di-tau final state with the ATLAS experiment at the LHC — •Daniele Zanzi, Johanna Bronner, Sandra Kortner, Alessandro Manfredini, Rikard Sandström, and Sebastian Stern

T 46.6 Studien zur Suche nach $H \to \mu^+\mu^-$ Zerfällen beim ATLAS Experiment am LHC — •Friedrich Hönig, Johannes Elmsheuser und Dorothee Schaile

T 46.7 Acceptance Systematics from Theory uncertainties in the $H \to \mu\mu$ analysis at ATLAS — •Christian Rudolph, Wolfgang Mader, and Michael Kobel

T 46.8 Untersuchung des myonischen Zerfallskanals des Higgs Bosons im Kontext des Standard Modells und seiner minimal supersymmetrischen Erweiterung — •Hendrik Weber und Adrian Perieanu

T 46.9 Suche nach neutralen MSSM Higgsbosonen im Zerfallskanal $h/H/A \to \mu^+\mu^-$ mit dem ATLAS Detektor — Johanna Bronner, Sandra Kortner, Alessandro Manfredini, Rikard Sandstroem, •Sebastian Stern und Daniele Zanzi



T 47.1 Studien zu $H \to W^+W^-$ Zerfällen beim ATLAS Experiment am LHC — •Christian Meineck, Bonnie Chow, Philipp Heimpel, Johannes Elmsheuser und Dorothee Schaile

T 47.2 Boosted decision tree studies in $H \to WW$ searche ATLAS — •Bonnie Chow, Johannes Elmsheuser, Phi Heimpel, Christian Meineck, and Dorothee Schaile

T 47.3 Suche nach dem Higgs-Boson in $H \to W^+W^-$ Zerfällen mit Boosted Decision Trees beim ATLAS Experiment am LHC — •Philipp Heimpel, Bonnie Ch Christian Meineck, Johannes Elmsheuser und Doro Schaile

T 47.4 Analyse des SM Higgs-Zerfalls im Kanal $H \to WW$ ν μ ν mit dem ATLAS-Detektor — •Sebastian Mori Olivier Arnaez, Volker Büscher, Frank Fiedler, Pai-hsien Jennifer Hsu, Johannes Mattmann, Christi Schmitt und Natalie Wieseotte

T 47.5 SM $H \to WW \to \ell\nu\ell\nu$ analysis with the ATLAS detecto the LHC — •Pai-hsien Jennifer Hsu, Olivier Arnaez, Volker Büscher, Frank Fiedler, Johannes Mattmann, Sebastian Moritz, Christian Schmitt, and Natalie Wieseotte

T 47.6 Suche nach dem Higgs-Boson in VBF-Produktion Zerfallskanal $H \to WW \to \ell\nu\ell\nu$ mit dem ATLAS-Detektor — •Johanna Bronner, Sandra Kortner, Hubert Kroha, Sebastian Stern, Daniele Zanzi und Alessandro Manfredini

T 47.7 Untersuchung der Kopplungsstärken des Higgs-Bosons im $H \to WW \to l\nu\ l\nu$ Zerfallskanal mit Hilfe von neuronalen Netzen mit dem ATLAS Experiment — •Gunar Ernis, Dominic Hirschbühl, Simon Köhlmann und Wolgang Wagner

T 47.8 Suche nach dem Higgs-Boson im Zerfall $H \to WW^*$ - $\ell\ \nu\ \ell'\ \nu'$ mithilfe von multivariaten Analysemethoden mit dem CMS-Experiment — Ulrich Husemann, Patricia Lobelle und •Jan Müller

T 47.9 Suche nach einem weiteren Higgs-Boson im $H \to WW \to \ell\ \nu\ \ell\ \nu$ Zerfallskanal mit dem ATLAS Experiment — Gunar Ernis, Dominic Hirschbühl, •Simon Köhlmann und Wolfgang Wagner

T 47.10 Untersuchung der Spin- und CP-Eigenschaften des neu entdeckten Bosons im Zerfall in zwei Photonen produziert in Vektorbosonfusion mit dem ATLAS Detektor — •Florian Kiss, Martin Flechl und Markus Schumacher

T 47.11 Bestimmung der totalen Higgs-Zerfallsbreite durch WW-Fusion am ILC — •Claude Dürig, Klaus Desch und Philip Bechtle

T 48.1 Suche nach $H \longrightarrow b\bar{b}$ Zerfällen in assoziierter Produktion mit einem Z-Boson beim ATLAS Experiment am LHC — •Thomas Maier, Michiel Sanders, Dorothee Schaile, Dan Vladoiu und Jonas Will

T 48.2 Multivariate Analysen zur Suche nach Standardmodell Higgs-Zerfällen in b-Quarks mit ATLAS — •Stephan Hageböck, Götz Gaycken, Jan Therhaag, Eckhard von Toerne und Norbert Wermes

T 48.3 Suche nach dem Standardmodell Higgs-Boson im Zerfallskanal $H \to b\ \bar{b}$ mit dem ATLAS-Experiment und multivariaten Methoden — Karl Jakobs, Christian Weiser, Georges Aad und •Daniel Büscher

T 48.4 Suche nach dem Standardmodell Higgs-Boson im Kanal $t\bar{t}H$, $H \to b\bar{b}$ mit dem CMS Experiment am LHC — •Tobias Verlage

T 48.5 Suche nach Higgs-Boson-Produktion in Assoziation mit einem Top-Quark-Paar am CMS-Experiment — Olaf Böcker, Alexis Descroix, Ulrich Husemann, Patricia Lobelle und •Hannes Mildner

T 48.6 Search for MSSM $H \to bb$ — Joerg Behr, Wolfgang Lohmann, Rainer Mankel, •Ihar Marfin, Alexei Raspereza, Alexander Spiridonov, and Roberval Walsh

T 48.7 Suche nach ttH Ereignissen mit der Matrix Element Method am ATLAS Experiment — •Olaf Nackenhorst, Elizaveta Shabalina, Kevin Kröninger, Arnulf Quadt und Leonid Serkin

T 48.8 MC modelling uncertainty studies of the $t\bar{t}H$ process — •Steffen Henkelmann, Elizaveta Shabalina, Kevin Kröninger, and Arnulf Quadt

T 48.9 Optimization of multivariate techniques for searches of $t\bar{t}H$ events in ATLAS at the LHC — Kevin Kröninger, Arnulf Quadt, •Leonid Serkin, and Elizaveta Shabalina

T 48.10 Search for Light NMSSM Higgs Boson Production in bb Final States with the CMS Experiment — •Gregor Hellwig, Rainer Mankel, Alexei Raspereza, and Roberval Walsh

T 49.1 Discovery of a new Higgs-like particle in the diphoton decay channel with ATLAS — •Jana Schaarschmidt and Louis Fayard

T 49.2 Suche nach dem Higgs-Boson im Kanal $pp \to H \to ZZ^* \to 4\ell$ und Massenmessung mit dem ATLAS-Detektor — •Katharina Ecker, Maximilian Goblirsch-Kolb, Oliver Kortner, Sandra Kortner und Hubert Kroha

T 49.3 Search for $H \to WW \to \ell\nu\ qq$ decays in ATLAS — •Rikard Sandström, Johanna Bronner, Daniele Zanzi, Sandra Kortner, Alessandro Manfredini, and Sebastian Stern

T 49.4 Optimierung bei der Suche nach dem durch Vektorbosonfusion erzeugten SM Higgs-Boson im Zerfallskanal $H \to WW \to \ell\nu\ell\nu$ — •Natalie Wieseotte, Olivier Arnaez, Volker Büscher, Frank Fiedler, Pai-hsien Jennifer Hsu, Johannes Mattmann, Sebastian Moritz und Christian Schmitt

T 49.5 Search for the Standard Model Higgs boson production via vector-boson fusion in the $H \to W^{\pm}W^{\mp(*)} \to \ell^{+}\nu\ell'^{-}\bar{\nu}'$ channel — Karl Jakobs, Tuan Vu Anh, and •Andreas Walz

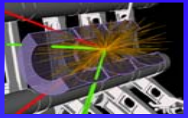
T 49.6 Studien zu einem Higgs-artigen Boson im Zerfallskanal $WH \to \ell\nu bb$ mit dem CMS-Experiment — •Christian Böser, Thorsten Chwalek, Simon Fink, Hauke Held, Benedikt Maier, Thomas Müller, Philipp Schieferdecker, Frank-Peter Schilling und Jeannine Wagner-Kuhr

T 49.7 Suche nach $H \to \tau_{lep}\tau_{had}$ Zerfällen mit multi-variaten Methoden in ATLAS — •Thomas Schwindt, Jana Kraus, Jessica Liebal, Jürgen Kroseberg und Norbert Wermes

T 49.8 Untersuchung von Spin und CP-Eigenwert des Higgs-Boson-Kandidaten im Zerfallskanal $H \to WW \to e\ \nu_e\ \mu\ \nu_\mu$ bei ATLAS — •Johannes Mattmann, Olivier Arnaez, Volker Büscher, Frank Fiedler, Pai-hsien Jennifer Hsu, Sebastian Moritz, Christian Schmitt und Natalie Wieseotte

T 49.9 Study of the spin and CP of the Higgs-like resonance through a multivariate analysis in the $H \to WW^{(*)} \to \ell\ \nu\ \ell'\ \nu'$ channel with the ATLAS Detector — •Manuela Venturi, Karl Jakobs, and Tuan Vu-Anh

Also: recent summary talks by K. Tackmann, S. Dittmeier at the 6th Ann. Workshop of the Helmholtz-Alliance TERA in Dec. 2012



Recent Public Infomations from ATLAS and CMS

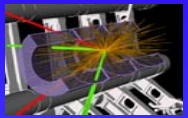
Channel	Conference note	L (fb^{-1})	Date	Publication	L (fb^{-1})	Date
SM H combination	ATLAS-CONF-2012-170	4.9+13.0	Dec 2012	arXiv:1207.7214	4.9+5.9	Jul 2012
SM H to ZZ(*) to 4l	ATLAS-CONF-2012-169	4.8+13.0	Dec 2012	arXiv:1202.1415	4.8	Feb 2012
SM H to diphoton	ATLAS-CONF-2012-168	4.9+13.0	Dec 2012	arXiv:1202.1414	4.9	Feb 2012
Lepton Universality Violation 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

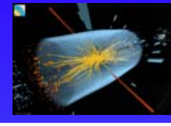
Nov-2012	**2011/2 (HCP) data**: H -> ZZ -> 4l	TWiki, PAS
Nov-2012	**2011/2 (HCP) data**: H -> WW -> 2l2nu	TWiki, PAS
Nov-2012	**2011/2 (HCP) data**: H -> tau tau	TWiki, PAS
Nov-2012	**2011/2 (HCP) data**: H -> tau tau (MSSM)	TWiki, PAS
Nov-2012	**2011/2 (HCP) data**: VH -> V tau tau	TWiki, PAS
Nov-2012	**2011/2 (HCP) data**: VH -> V bb	TWiki, PAS
Nov-2012	**2011/2 (HCP) data**: H -> WW -> lnujj	TWiki, PAS
Nov-2012	**2011/2 (ICHEP) data**: WH -> 3l3nu	TWiki, PAS
Nov-2012	**2011/2 (HCP) data**: Combination	TWiki, PAS
Nov-2012	**2011/2 (ICHEP) data**: bbH->bbbb (MSSM) sl+h	TWiki, PAS
May-2012	**2011 data**: phi -> mu mu	TWiki, PAS
Jul-2012	**2011/2 data: H -> gamma gamma**	TWiki, PAS
Jul-2012	**2011/2 data: H -> ZZ -> 4l**	TWiki, PAS
Jul-2012	**2011/2 data**: H -> WW -> 2l2nu	TWiki, PAS
Jul-2012	**2011/2 data**: H -> WW -> 2l2nu, shape	TWiki, PAS
Jul-2012	**2011/2 data**: H -> tau tau	TWiki, PAS
Jul-2012	**2011/2 data**: VH -> V bb	TWiki, PAS
Jul-2012	**2011/2 data**: H -> ZZ -> 2l2nu	TWiki, PAS
Jul-2012	**2011/2 data**: H -> WW -> lnujj	TWiki, PAS
Jul-2012	**2011 data**: ttH -> tt bb	TWiki, PAS
Jul-2012	**2011/2 data: Observation: ~125 GeV**	TWiki, PAS
Jul-2012	**2011/2 data**: H -> gamma gamma, FP	TWiki, PAS
Jul-2012	**2011 data**: bbH all hadronic	TWiki, PAS
Jul-2012	**2011 data**: bbH semileptonic	TWiki, PAS

Plus „Moriond-Publications“ 2013

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

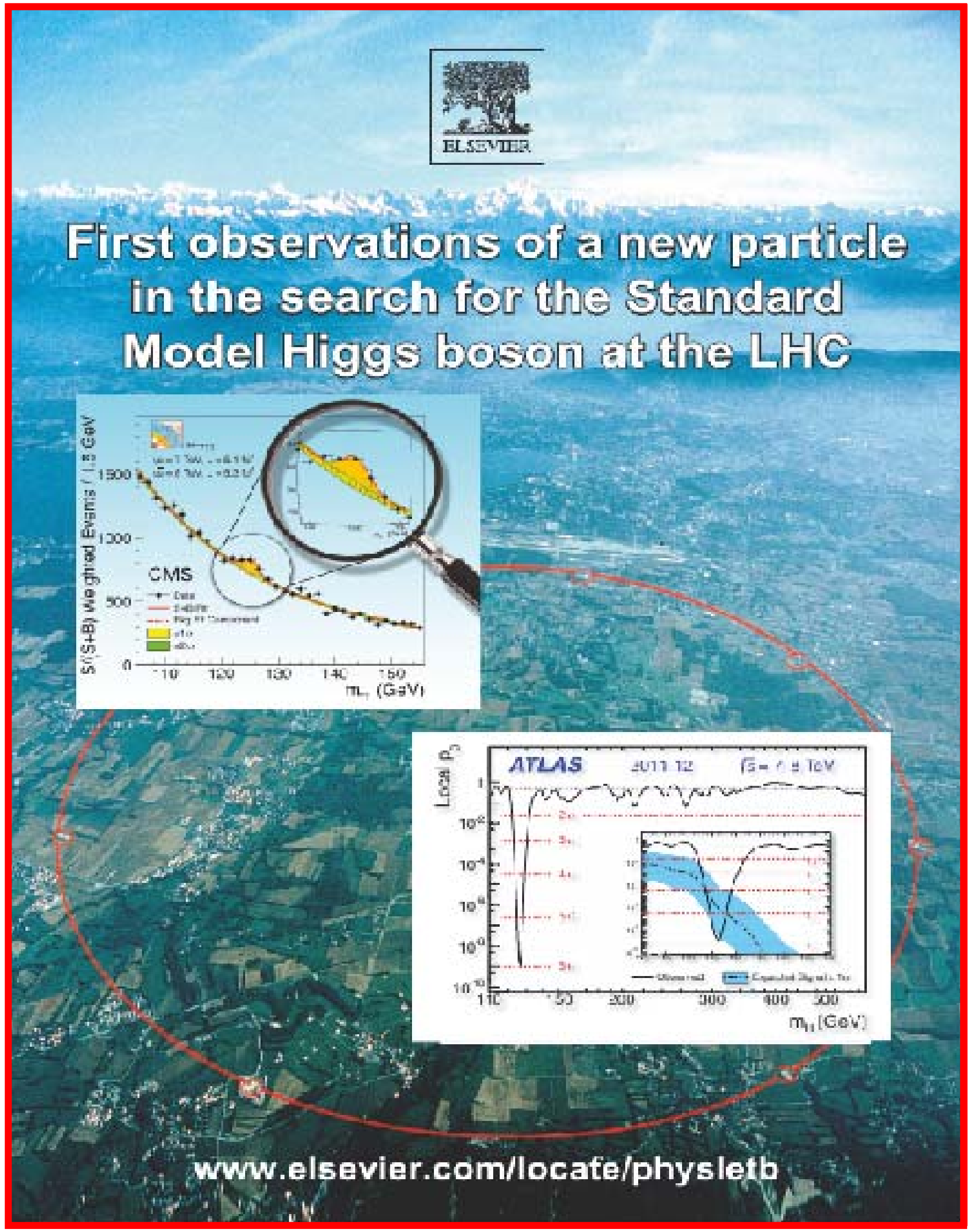
http://cms.web.cern.ch/org/cms-higgs-results





A. Introduction

The Discovery July 4, 2012



[Phys. Lett. B 716 (2012)]

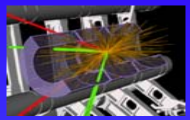
Significant excess of events in both ATLAS and CMS in

$H \rightarrow ZZ$ and $H \rightarrow \gamma\gamma$

(the most significant channels)

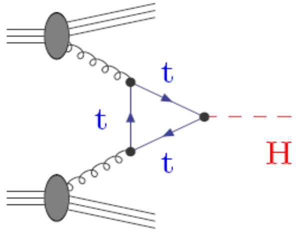
Is it „Higgs“ ?

Is it „The Higgs“?

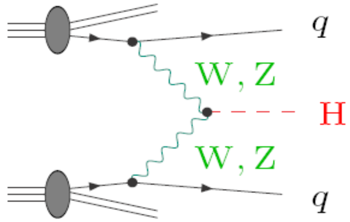


Higgs Boson Production

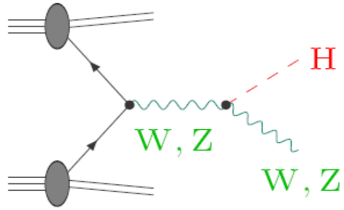
Gluon fusion
Selection of Higgs at large p_T enhances S/B



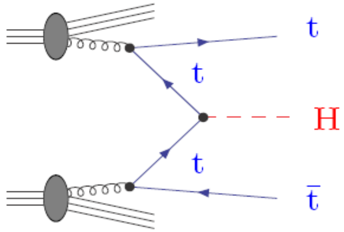
Vector boson fusion (VBF)
Two forward jets with large |y|



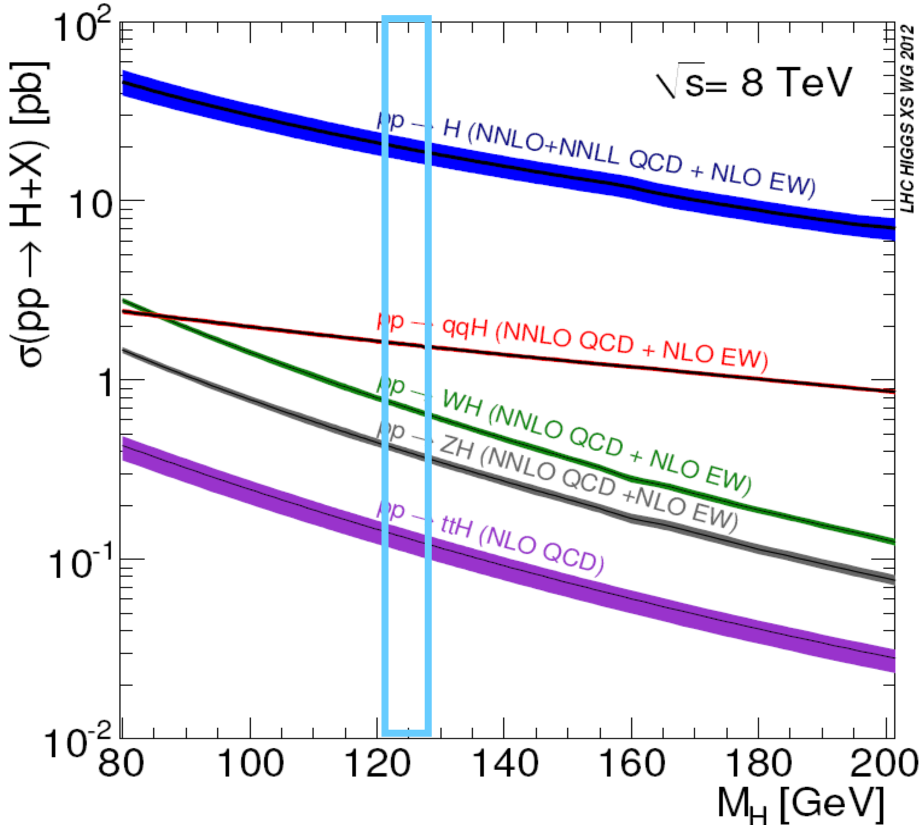
Associated production
Selection of Higgs at large p_T enhances S/B



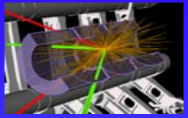
ttH production
Dominant diagram t-t fusion



Note: EWK corrections are ~5%



	Uncertainties scale	Uncertainties PDF4LHC	NLO/NNLO/NNLO+ QCD	EW
ggF	6–14%	7%	>100%	5%
VBF	1%	3–4%	5%	5%
WH	1%	3–4%	30%	5–10%
ZH	2–4%	3–4%	45%	5%
ttH	10%	9%	15–20%	?



Higgs Boson Decay Modes

Higgs Boson decay into:

Bosons → first observations

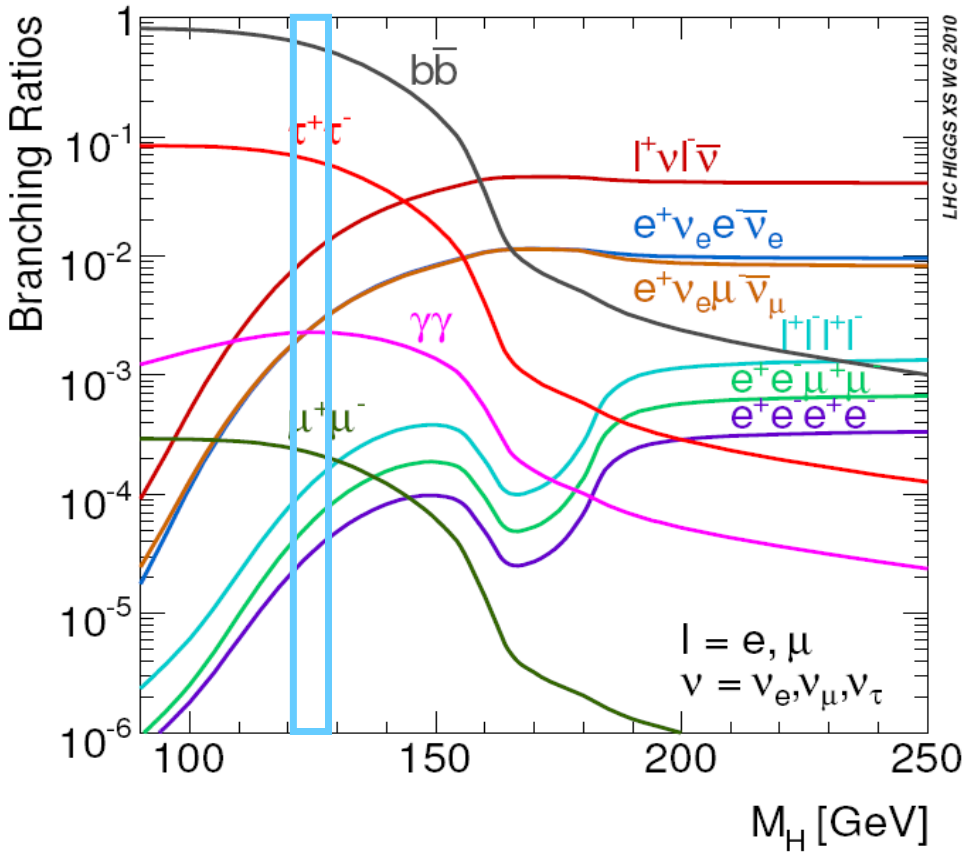
- $\gamma\gamma$: Excellent mass resolution
- ZZ* → 4l: Low background
- WW* → 2l2ν: High statistics, poor mass resolution

Fermions of the third generation:

- bb: Only in associated production
- $\tau\tau$: Leptonic and hadronic decay

Fermions of the second generation:

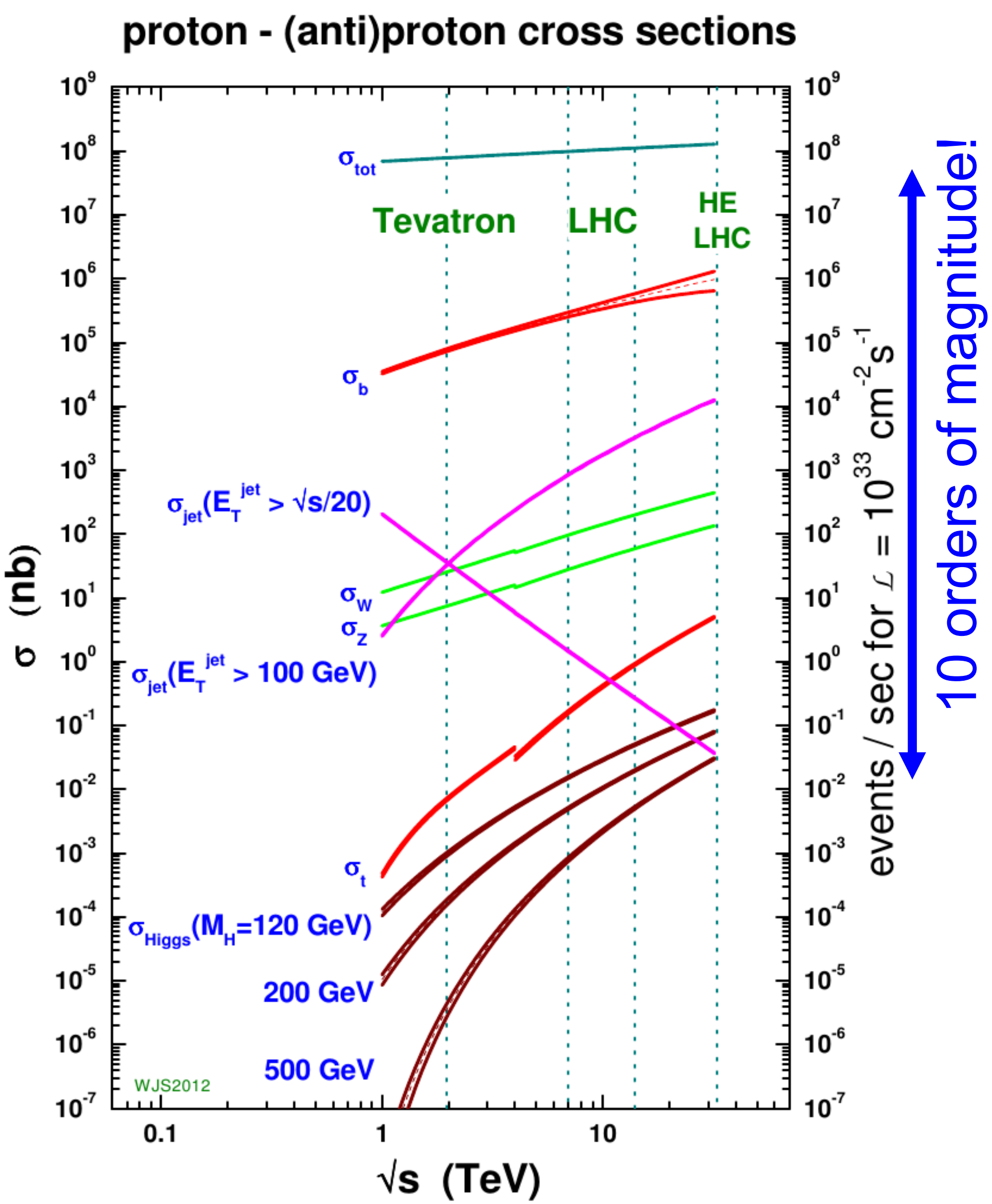
- cc, $\mu\mu$: very hard but necessary!

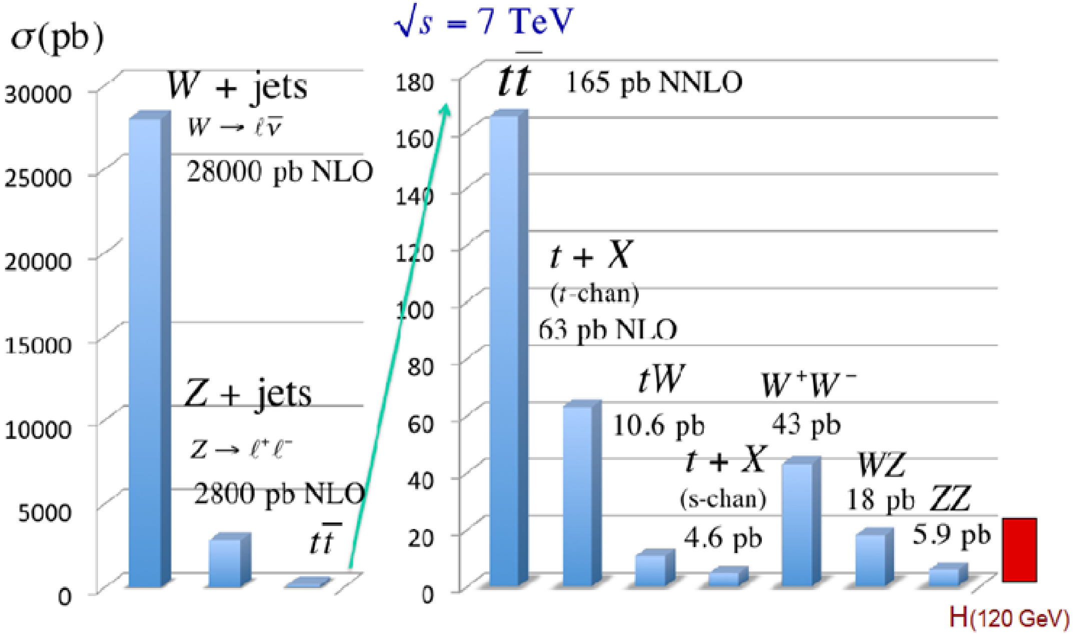


Parametric + theoretical uncertainty of BRs: LHC Higgs XS WG 2011

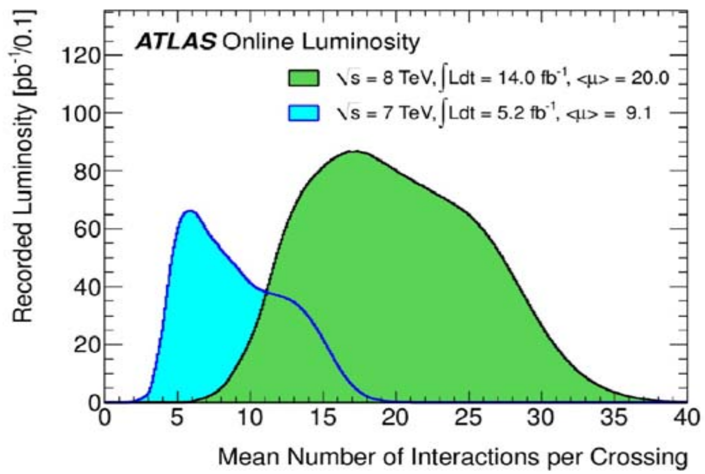
M_H[GeV]	H →	$b\bar{b}$	$\tau^+\tau^-$	$c\bar{c}$	gg	$\gamma\gamma$	WW	ZZ
120		3%	6%	12%	10%	5%	5%	5%
150		4%	3%	10%	8%	2%	1%	1%

Experimental Challenges



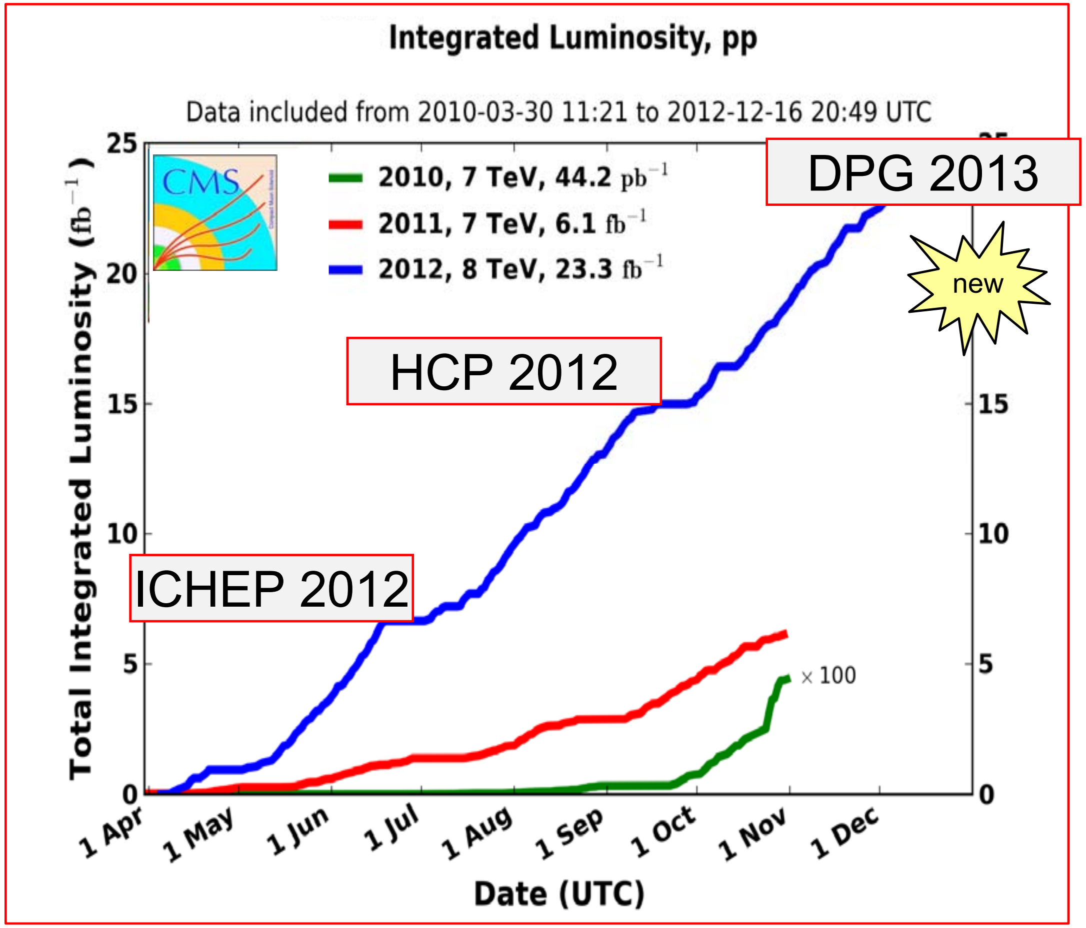


Relevant Background Processes



Pileup

Data taken at the LHC



ATLAS and CMS each collected $5\ fb^{-1}$@ 7TeV and $20\ fb^{-1}$@ 8TeV

Results shown here based on $5\ fb^{-1}$ data at 7TeV and up to $20\ fb^{-1}$ of data at 8TeV

Taken with 50 ns bunch spacing and typically 20 interactions/bunch crossing

Max. instantaneous luminosity $7.5\ 10^{33}/cm^2s$

Until end 2012:

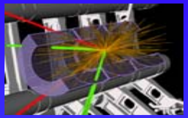
~ $2.5\ 10^{15}$ pp collisions (inel. + el.)

~10^{10} pp collisions recorded

$25 \cdot 10^6$ Z → μμ decays produced

Expected number of H decays in data:

~ 1000 H → γγ
~ 50 H → ZZ → 4 ℓ
~ 5000 H → WW → ℓν ℓν



B. Signals: Bosonic Decay Channels

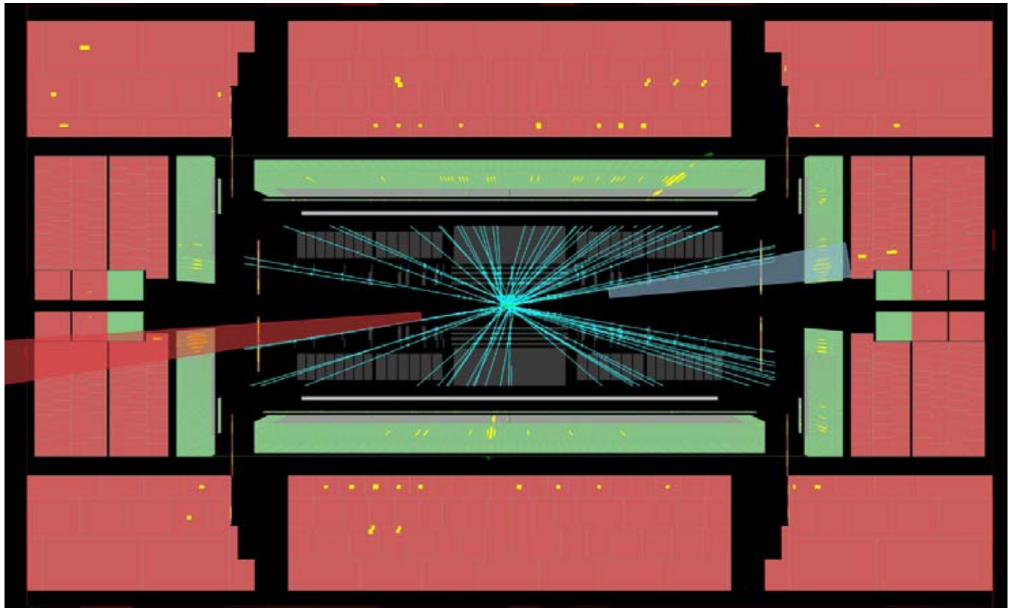
1. H → $\gamma\gamma$

- Clean final state with 2 isolated photons
- Narrow mass peak on continuum
- Background shape extracted from data
- Fits in subcategories with distinct resolution and S/B improves total sensitivity

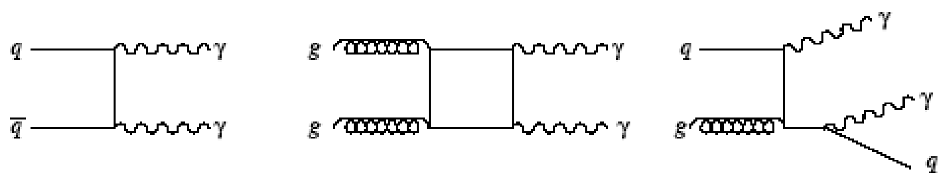
•To fight pile-up:

ATLAS: Longitudinal segmentation of EM Cal. to determine photon polar angle →determines Vertex

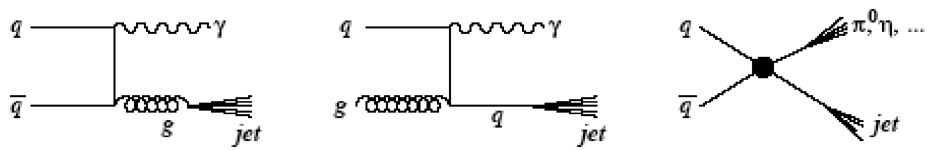
CMS: algorithmus based on Σp_T^2 of tracks and $p_T^{\gamma\gamma}$ balance chooses right vertex in 80% of cases



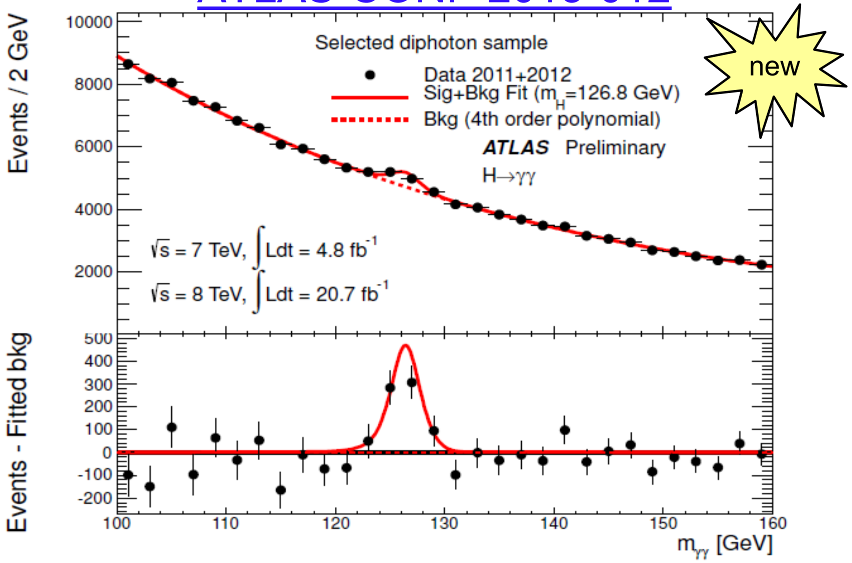
Irreducible background: pp→$\gamma\gamma$+X ~75%



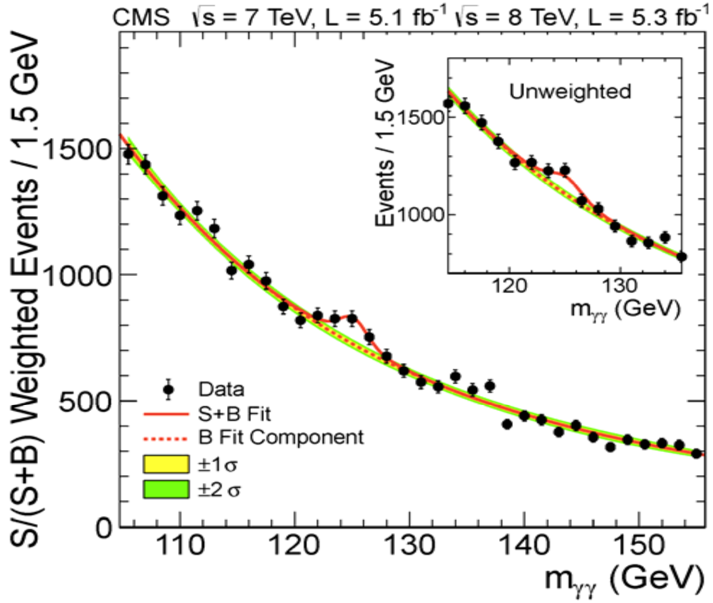
Reducible background: pp→$\gamma\gamma$+jets, Drell Yan+jets

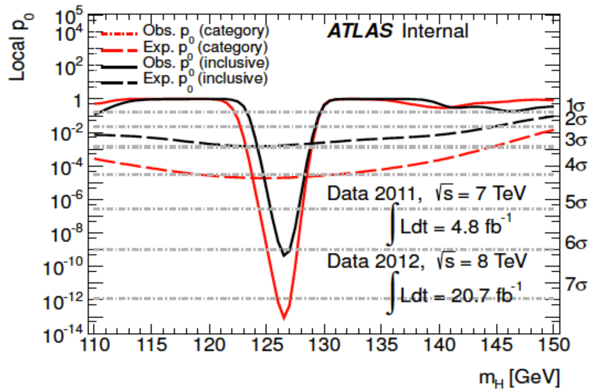


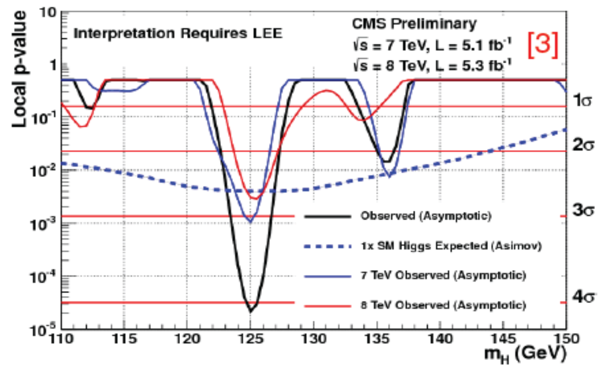
[ATLAS-CONF-2013-012](#)



[arXiv:1207.7235](#)







ATLAS: $\mu = 1.65 \pm 0.24(\text{stat.})\ ^{+0.25}_{-0.18}(\text{sys.})$ at 7.4σ (exp. 4.1σ) **!**

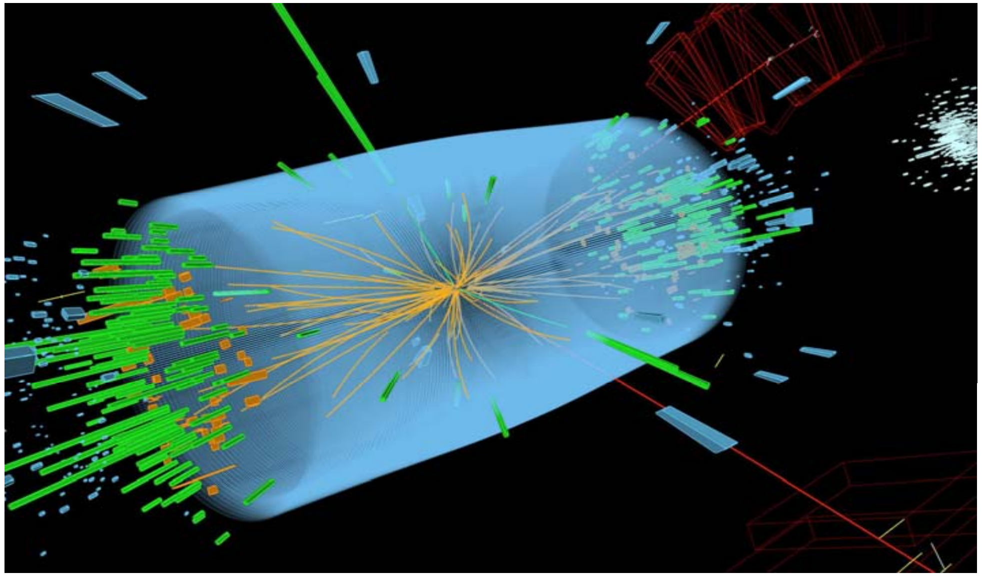
Mass 126.8 ± 0.2(stat.) ± 0.7(sys.) GeV

CMS: $\mu = 1.56 \pm 0.43(\text{stat.})$ at 4.1σ

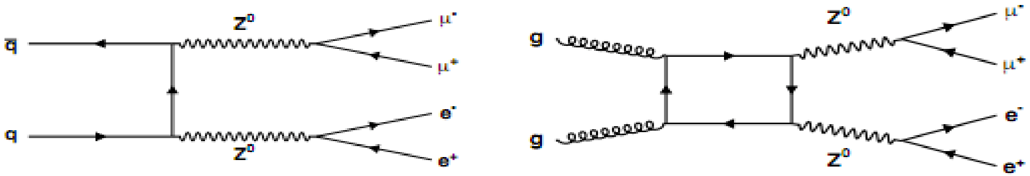
Mass 125.1 ± 0.4(stat.) ± 0.6(sys.) GeV

} New results next week !

2. H → ZZ* → 4 leptons

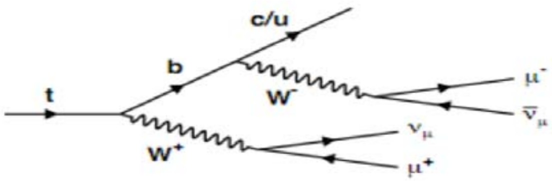


- High lepton reconstruction efficiencies for m(4l) > 100 GeV
- Standard reference candle: single-resonant Z→4l
- Used for Measurement of mass, spin&parity



Irreducible background

Irreducible background:
- ZZ continuum, Zγ* – use kinematics to separate signal

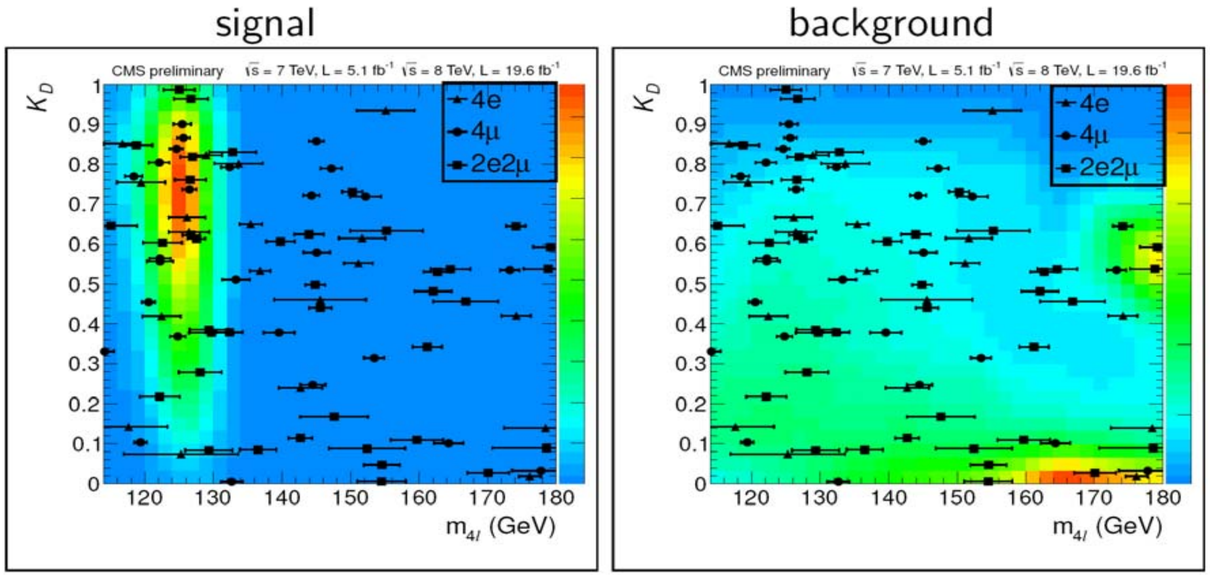


Reducible background

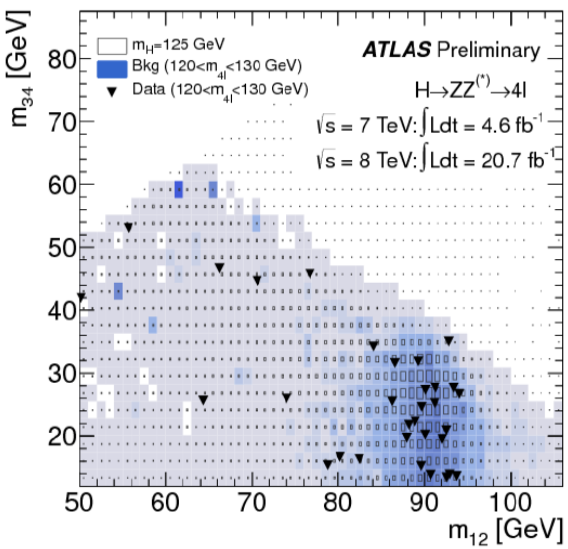
Reducible background:
- Z + jets, Zbb & tt – use lepton isolation and impact parameter to reject b ->lX decays

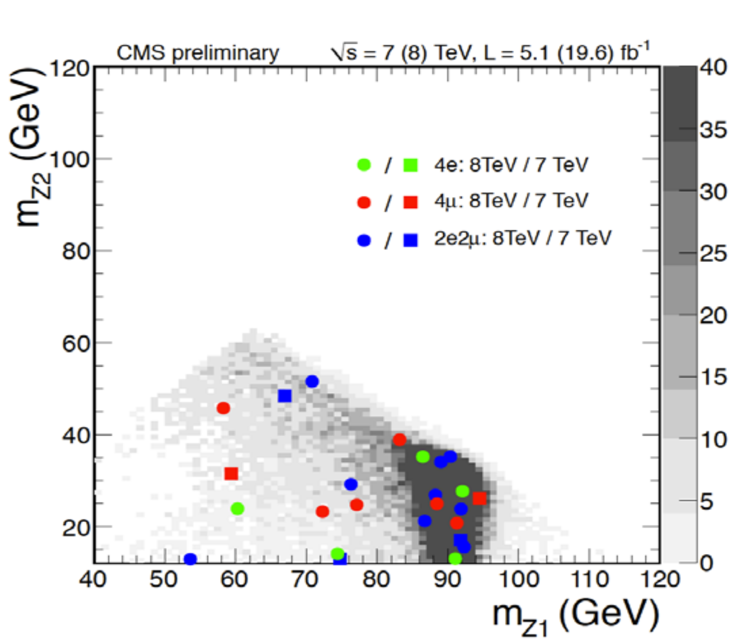
CMS:
Matrix Element Likelihood Analysis:
uses kinematic variables, angles for signal to background discrimination (MELA)

ATLAS:
Boosted Decision Trees
MELA

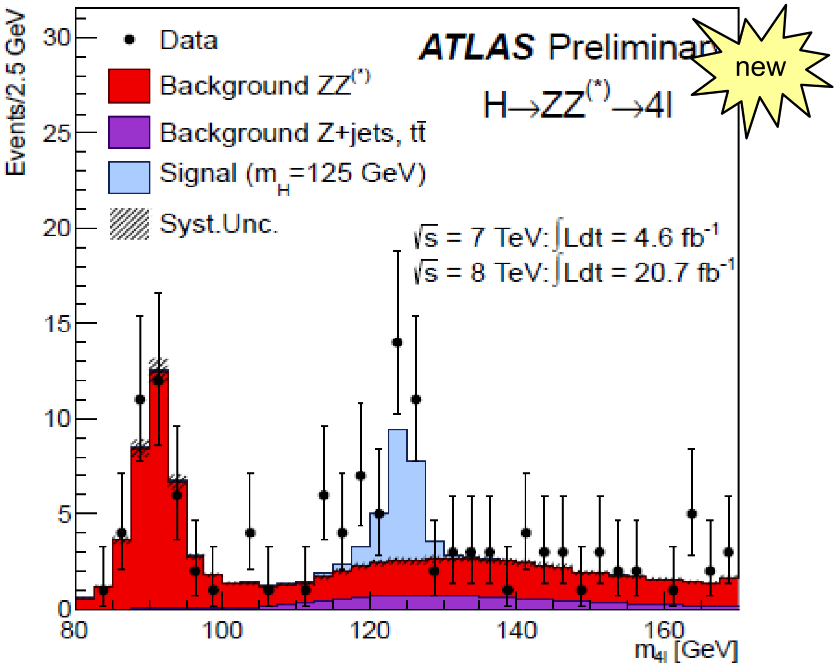


$$1/K_D = 1 + \frac{P_{background}(m_1, m_2, \theta_1, \theta_2, \Psi, \Phi, \theta^*)}{P_{signal}(m_1, m_2, \theta_1, \theta_2, \Psi, \Phi, \theta^*)}$$

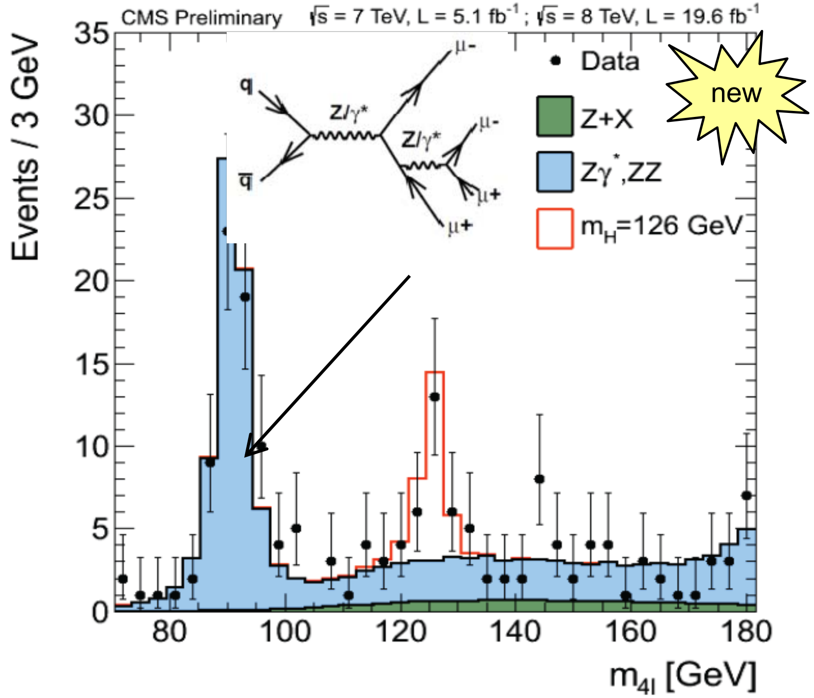




ATLAS-CONF-2013-013



CMS-PAS-HIG-13-002



ATLAS: $\mu = 1.7 \pm 0.5$ at 6.6σ (expected 4.4σ)

Mass $124.3\ ^{+0.6}_{-0.5}$ (stat.) $^{+0.5}_{-0.3}$ (syst.) GeV

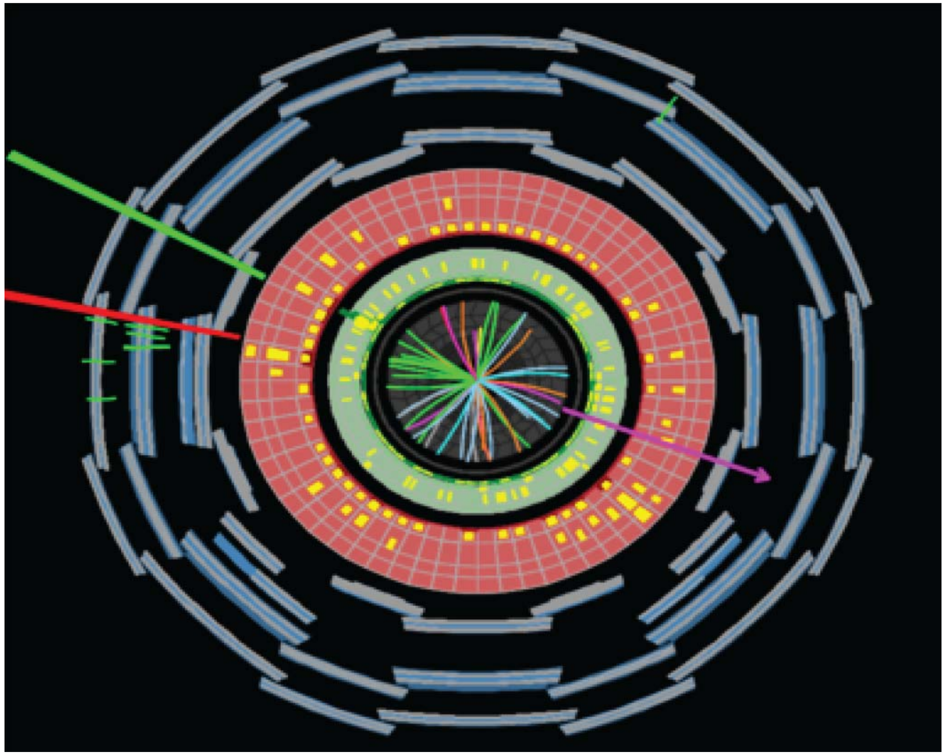
CMS: $\mu = 0.91^{+0.30}_{-0.24}$ at 6.7σ

Mass 125.8 ± 0.5(stat.) $\pm$ 0.2(sys.) GeV

3. $H \to WW \to 2l2\nu$ (6 channels)

Higgs boson signal:

- Two isolated opposite sign Leptons (e or μ) and MET
- Dilepton invariant mass and $\Delta\varphi$ are small in standard Model



Exclusive analysis in bins of jet multiplicities:

0-jet: optimized for gluon-fusion, purest channels, least affected by top BG

1-jet: more affected by top BG

Event classes:

- ee, μμ
- eμ

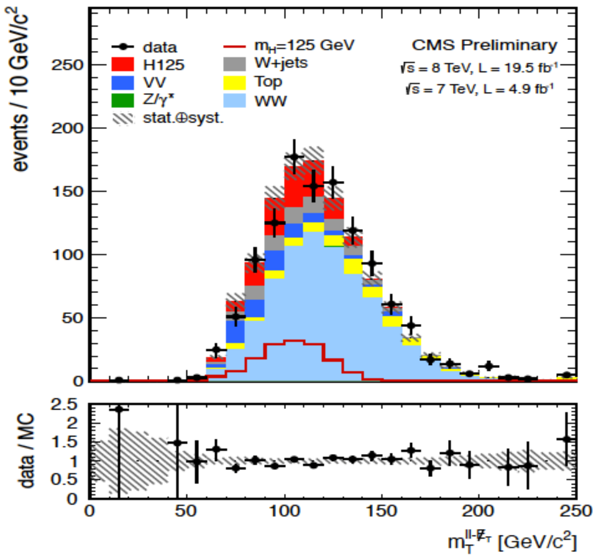
Irreducible background:

- Standard model diboson decays to two leptons and MET

Reducible background:

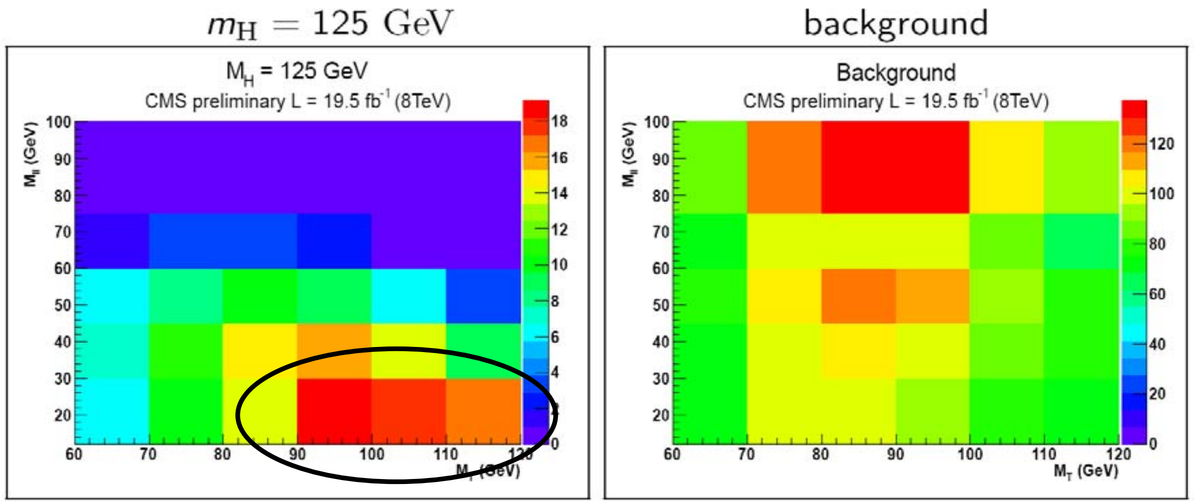
- $Z \to ll$+(jets→fake MET)
- $W \to l\nu$+(jets→fake lepton)
- tW and ttbar production

CMS-PAS-HIG-13-003

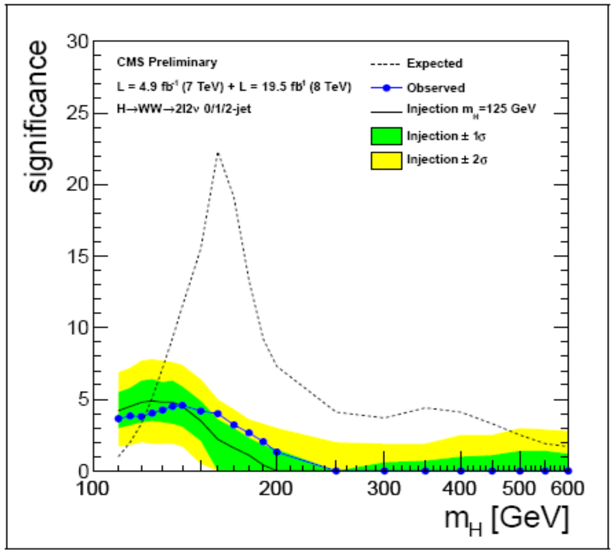


Counting analysis

new

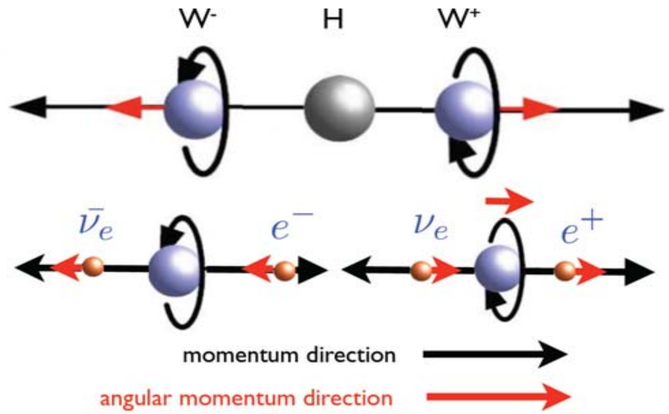


2D(MT,Mll) analysis

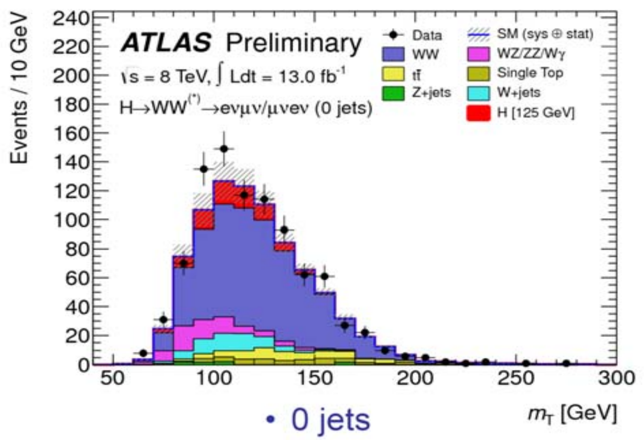


- $\sim 4.0(5.1)\ \sigma$ observed (expected) significance at $m_{\rm H} \sim 125$ GeV

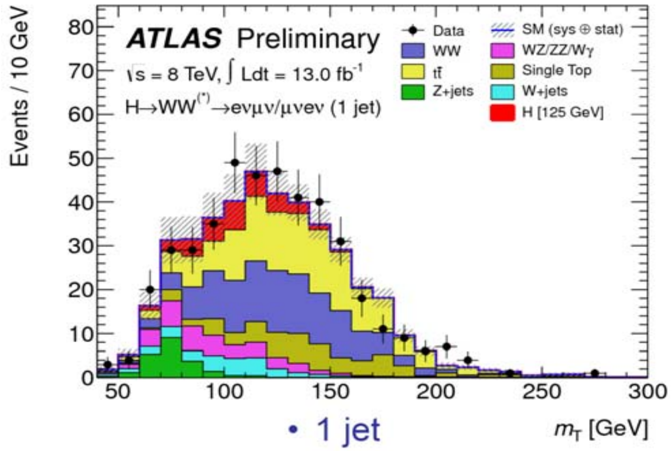
Significance at mH = 125 GeV



$$m_T^{\,2} = (E_T^{ll} + \not{E}_T)^2 - \left|\vec{p}_T^{\,ll} + \vec{p}_T^{\,miss}\right|^2$$

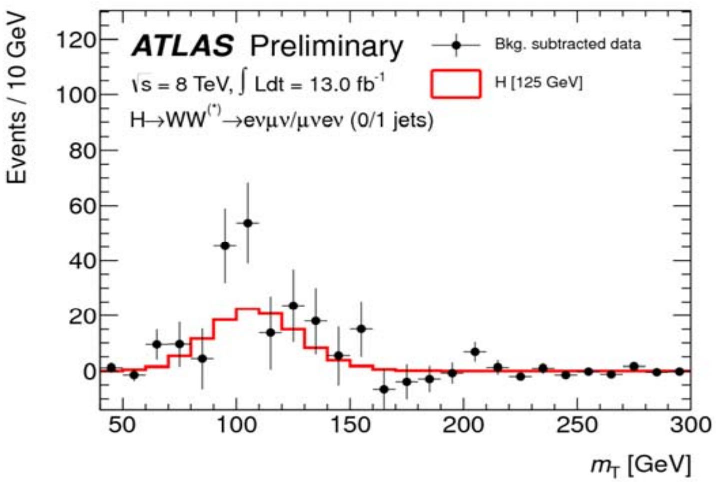


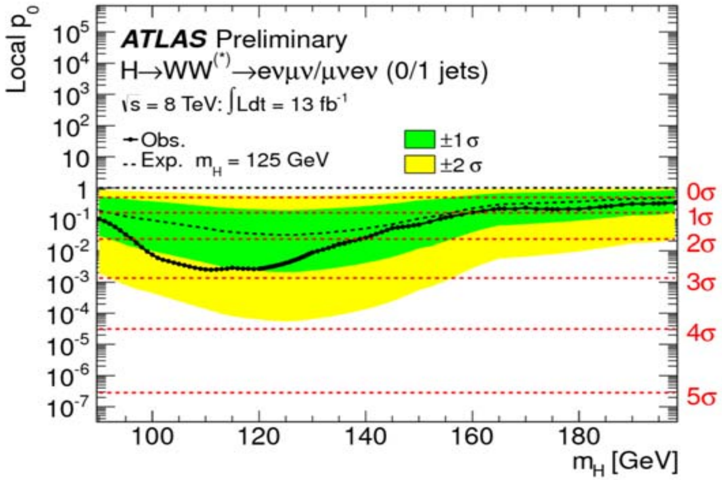
• 0 jets



• 1 jet

ATLAS-CONF-2012-158

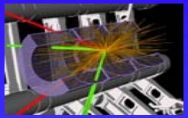




Signal strength:

ATLAS: $\mu = 1.5 \pm 0.6$ at 2.6σ (1.9σ expected)

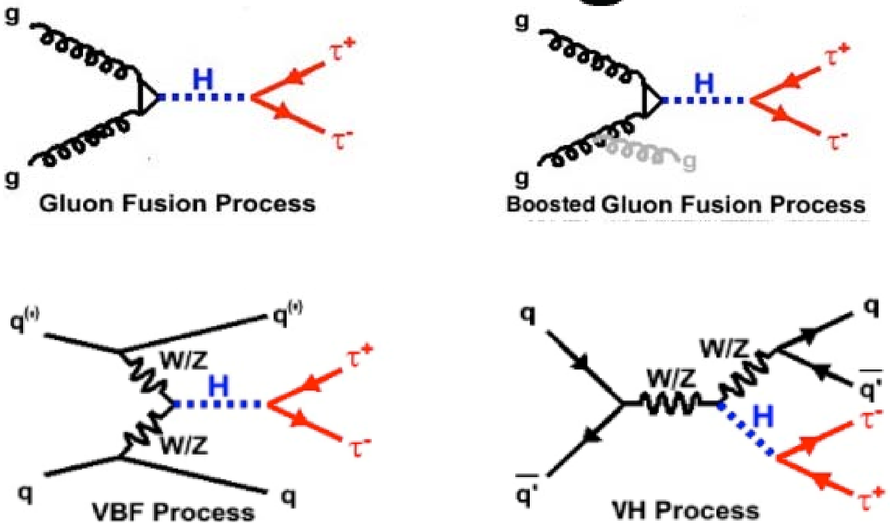
CMS: $\mu = 0.76 \pm 0.21$ at 4.0σ (5.1σ expected)

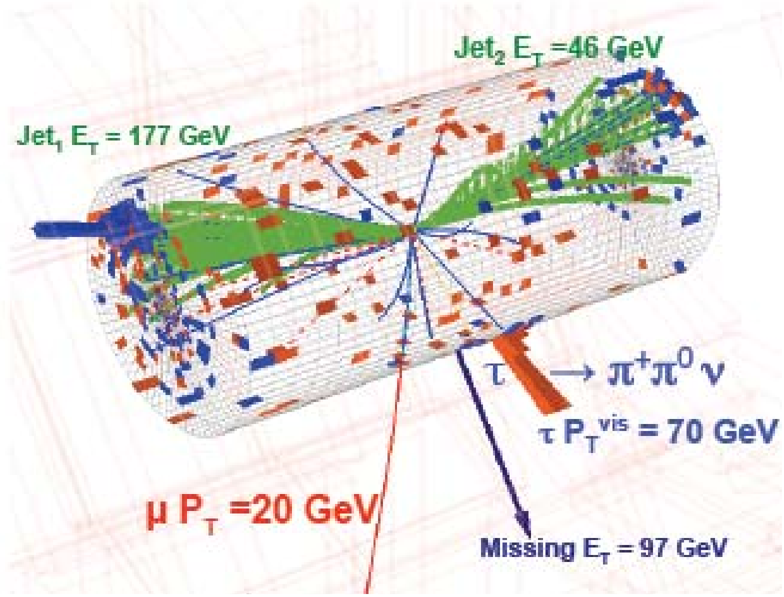


C. Signals: Fermionic Decay Channels

4. Higgs → $\tau^+ \tau^-$

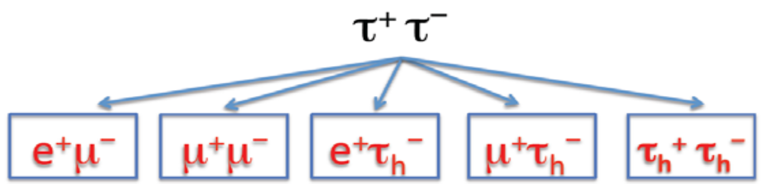
Event Categories



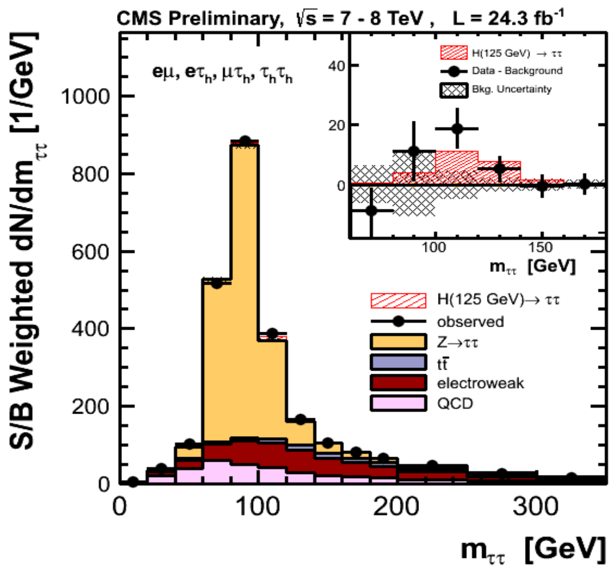


Strategy:

- Select isolated, well-identified leptons, τ_h
- Topological cuts (e.g. m_T in $l\tau_h$, $p_T(H)$ in $\tau_h\tau_h$) to suppress background
- Categorize events based on number of jets, τ p_T
- Template fit to $m_{\tau\tau}$ shape

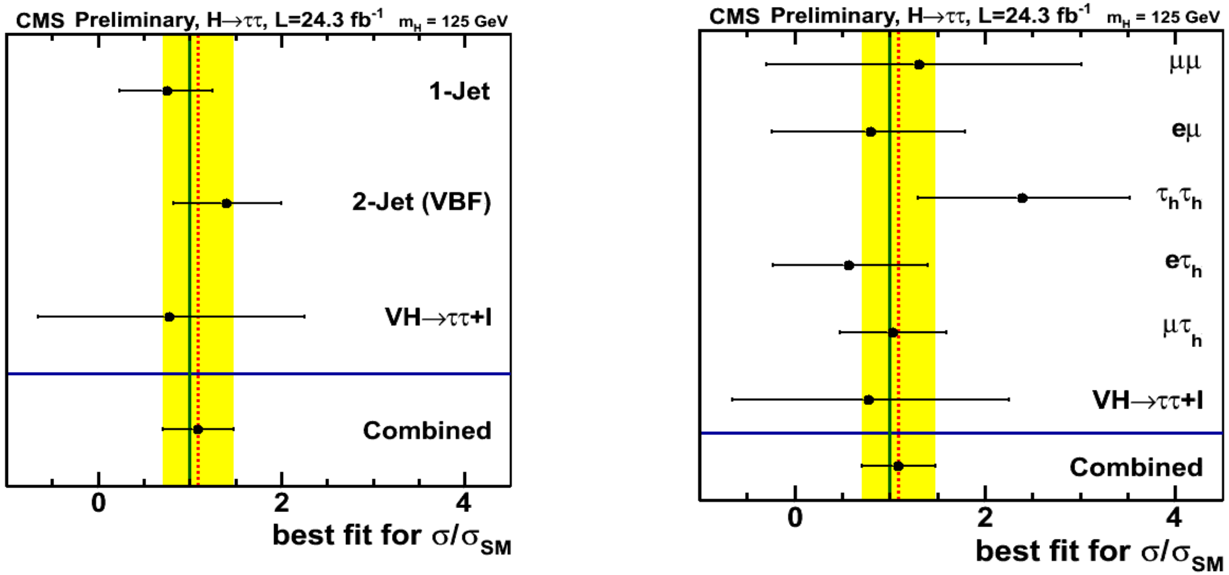


new



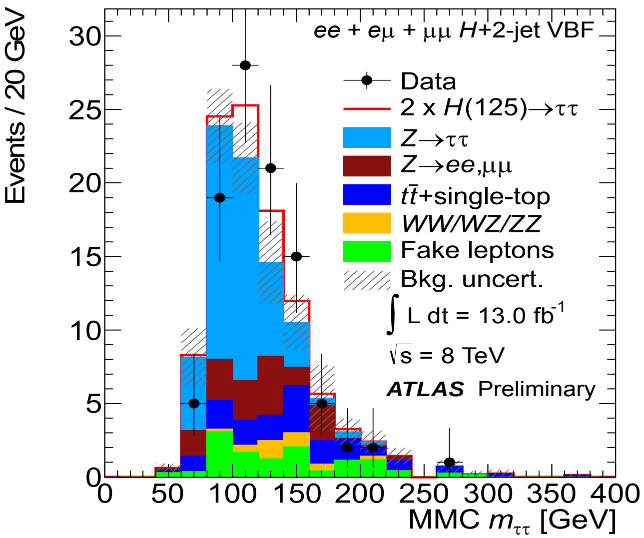
Combined 1-jet and VBF

[CMS-PAS-HIG-13-004]



Fitted signal strength per category

[ATLAS-CONF-2012-160]

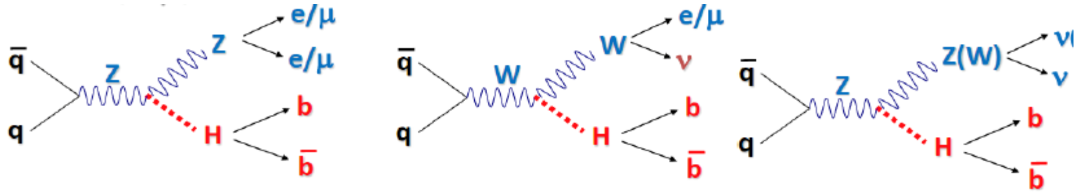


Signal strength:

ATLAS: $\mu = 0.7 \pm 0.7$

CMS: $\mu = 1.1 \pm 0.4$ at 2.9σ (2.6σ expected)

Event Categories



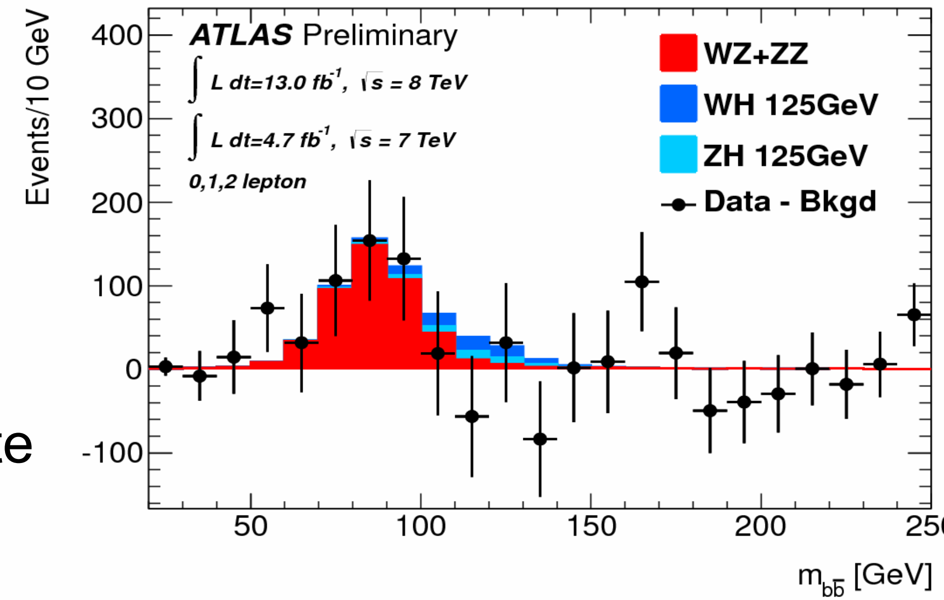
- H→*bb* has largest BR but very high background
- Search for associated production with W or Z (W→*lν*, Z→*ll*, Z→*νν*)
- Final states with leptons, $E_T$miss and b-jets

ATLAS-CONF-2012-161

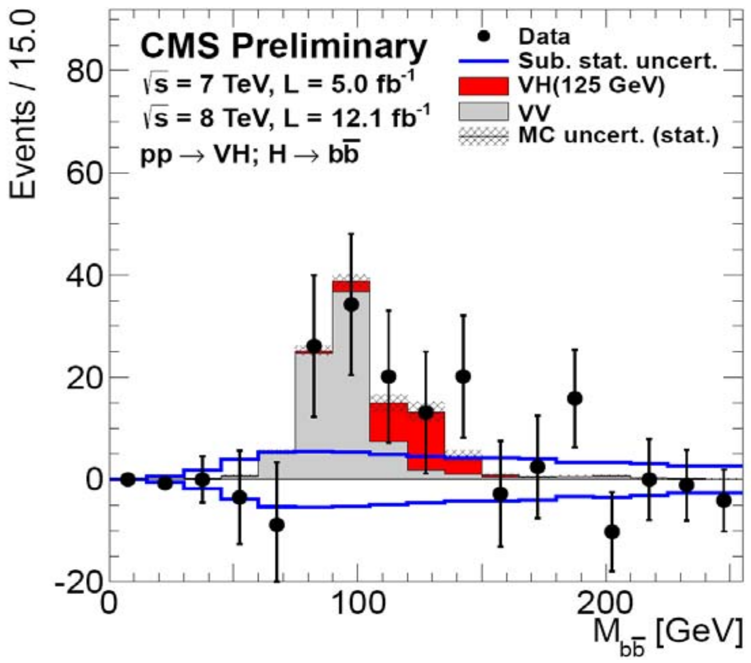
ATLAS-CONF-2012-170

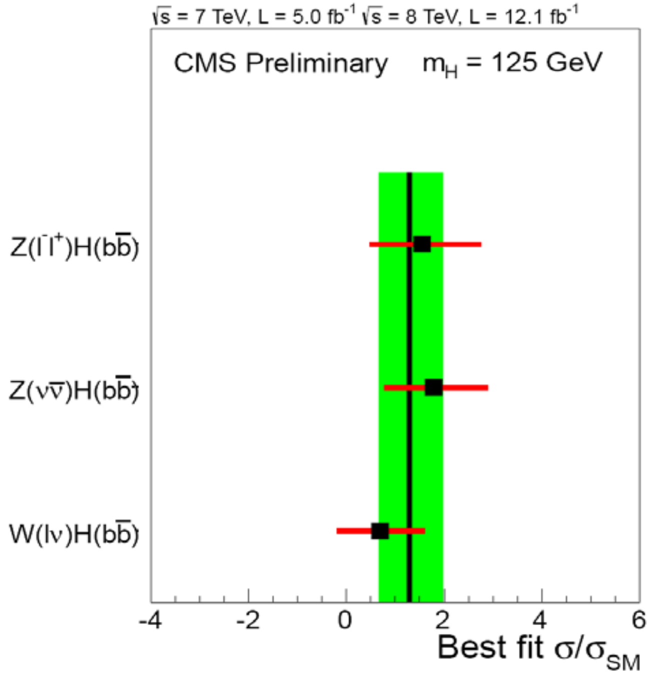
- Main background: W/Z + jets, top

  Normalized from control regions in data



- Analysis strategy:
  Divide in categories high and low p_T of boson
- Further discriminate from Bkd using multivariate techniques



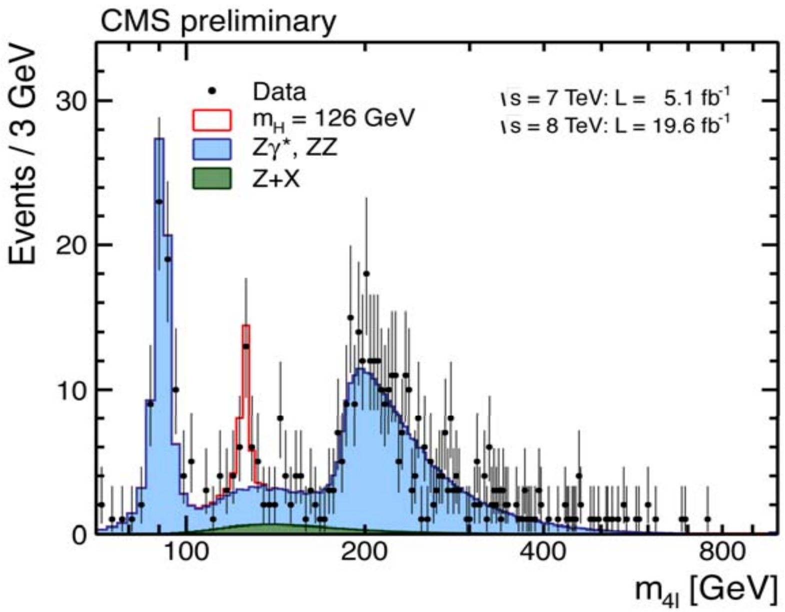


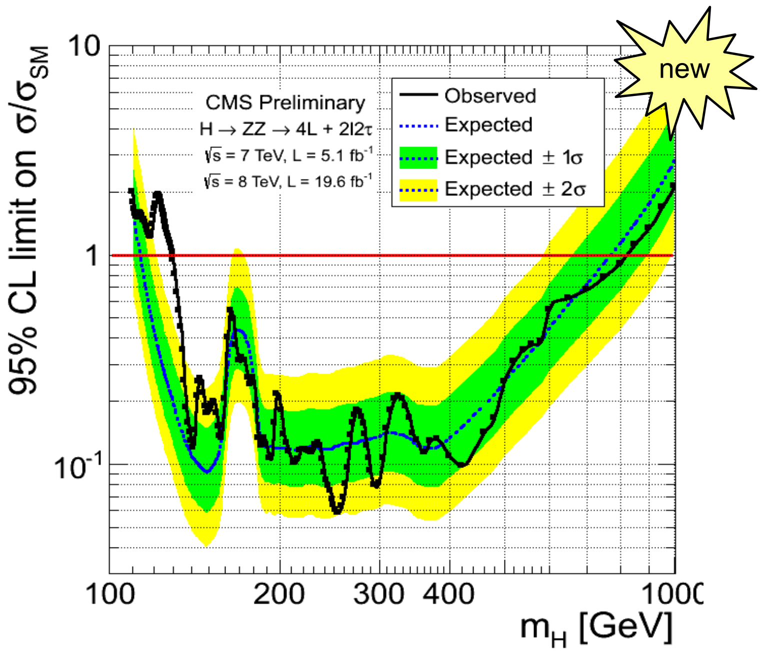
Signal strength:

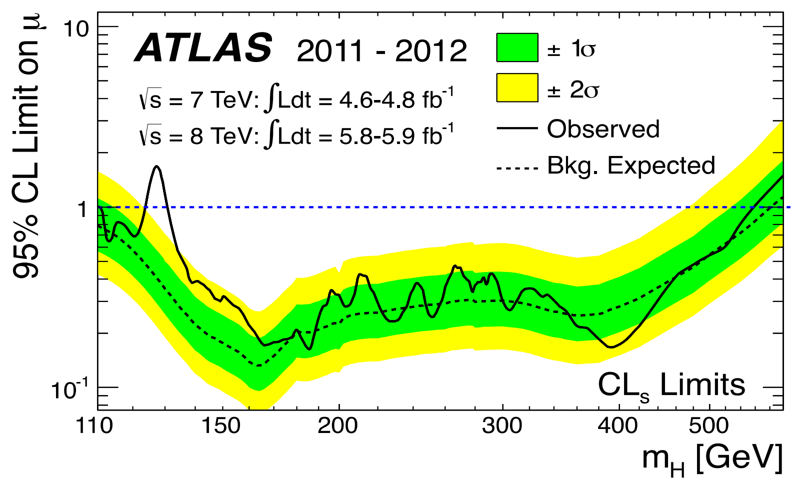
ATLAS: $\mu = -0.4 \pm 1.0$

CMS: $\mu = 1.3^{+0.7}_{-0.6}$

6. Search for a second "SM" Higgs

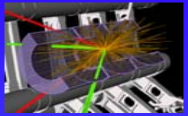






130-827 GeV exclusion at 95% C.L.

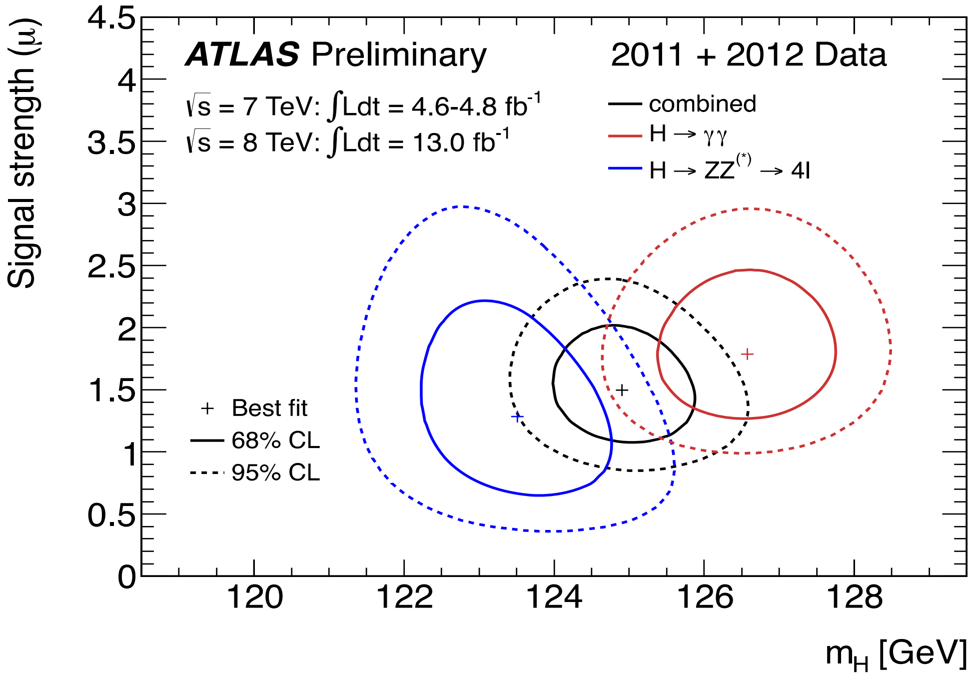
C. PROPERTIES OF THE FOUND PARTICLE



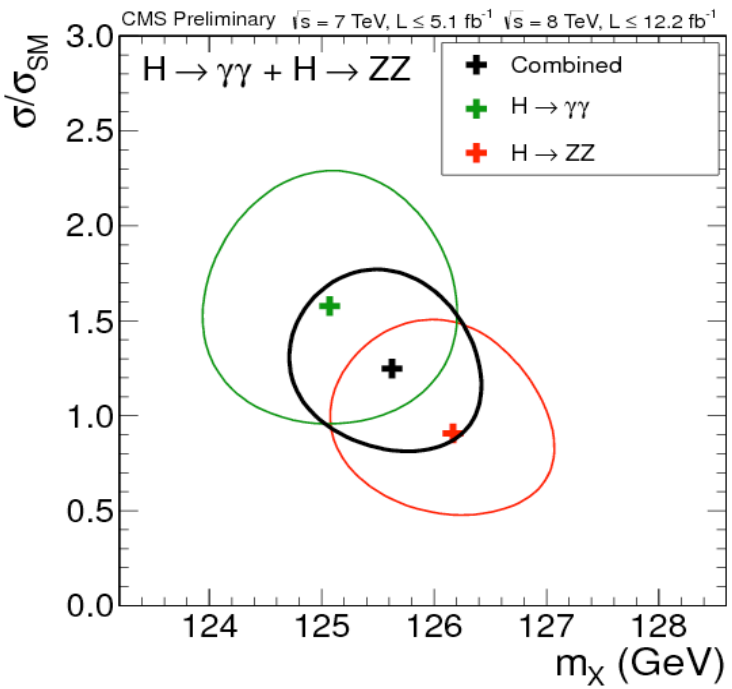
1. Mass

- The energy scale of leptons is measured using J/Ψ and Z
- Precision: 0.2% - 0.5%
- The photon energy scale is derived from Z->ee, knowing the shower shapes in the Electromagnetic Calorimeter

ATLAS: CONF-2012-162

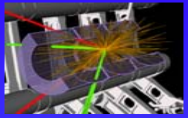


CMS-PAS-HIG-12-045



CMS m_H = 125.8 ± 0.4 (stat.) ± 0.4 (syst.) GeV

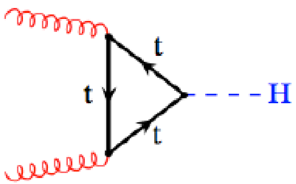
ATLAS m_H = 125.5 ± 0.2 (stat.) ± 0.5 (syst.) GeV

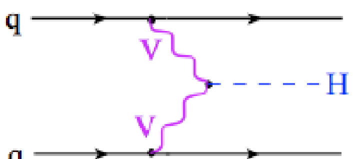


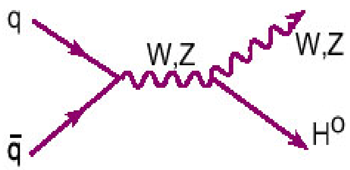
2. Higgs Signal Strength and Couplings

Table 1: Numerator scaling factors for different production×decay channels. Four coupling constant modifiers can be identified: c_V, c_b, c_τ, c_t. Denominator scaling factor is common and proportional to Γ_{TOT}

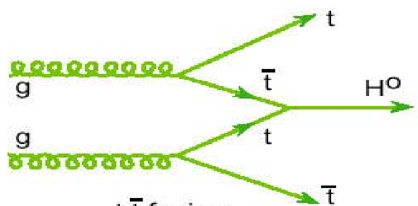
	$gg \to H$	VBF	VH	ttH
$H \to \gamma\gamma$	$c_t^2 \cdot \lvert\alpha c_V + \beta c_t\rvert^2$	$c_V^2 \cdot \lvert\alpha c_V + \beta c_t\rvert^2$	$(c_V^2 \cdot \lvert\alpha c_V + \beta c_t\rvert^2)$	$(c_t^2 \cdot \lvert\alpha c_V + \beta c_t\rvert^2)$
$H \to bb$	$(c_t^2 c_b^2)$	$(c_V^2 \cdot c_b^2)$	$c_V^2 \cdot c_b^2$	$c_t^2 \cdot c_b^2$
$H \to \tau\tau$	$c_t^2 \cdot c_\tau^2$	$c_V^2 \cdot c_\tau^2$	$c_V^2 \cdot c_\tau^2$	$(c_t^2 \cdot c_\tau^2)$
$H \to WW$	$c_t^2 \cdot c_V^2$	$c_V^2 \cdot c_V^2$	$c_V^2 \cdot c_V^2$	$(c_t^2 \cdot c_V^2)$
$H \to ZZ$	$c_t^2 \cdot c_V^2$	$(c_V^2 \cdot c_V^2)$	$(c_V^2 \cdot c_V^2)$	$(c_t^2 \cdot c_V^2)$



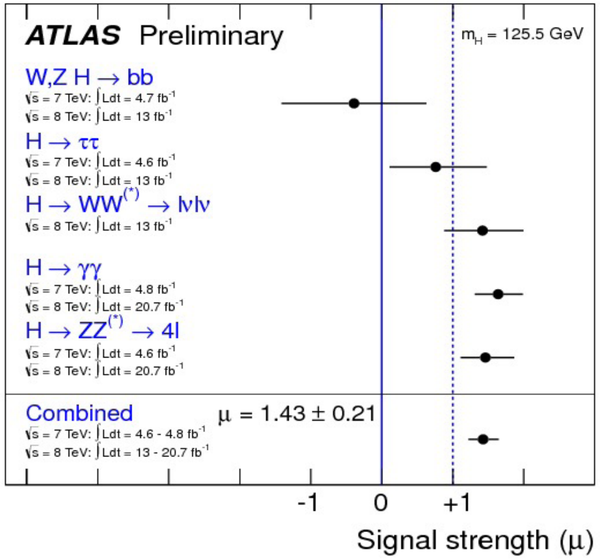




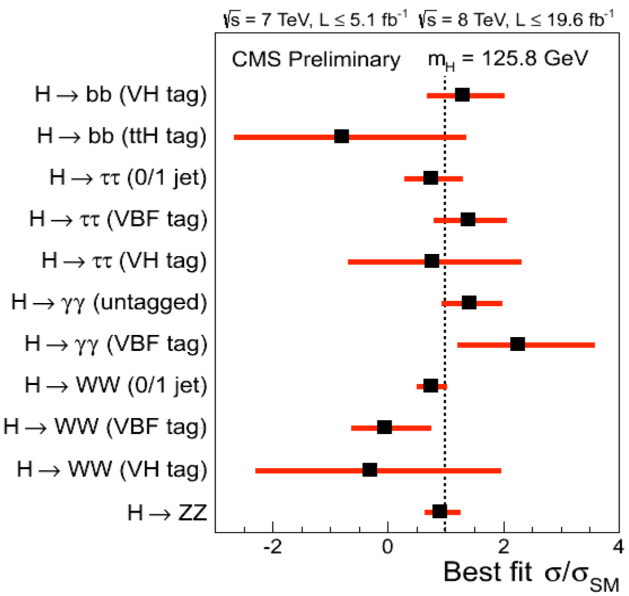
W, Z bremsstrahlung

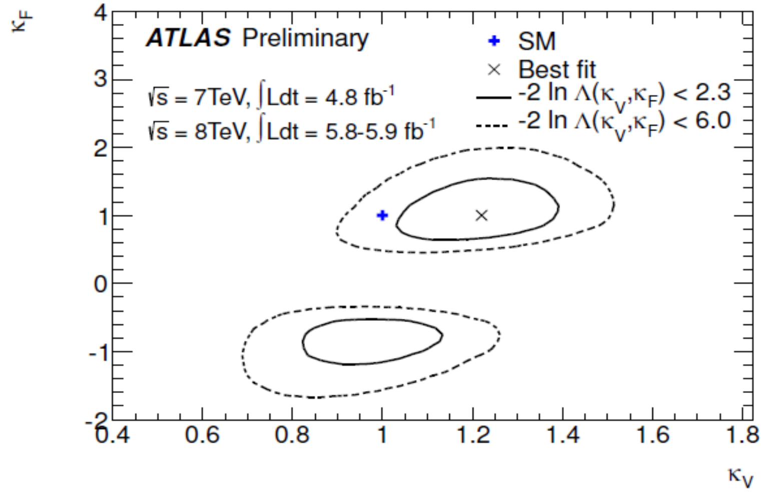


$t\,\bar{t}$ fusion

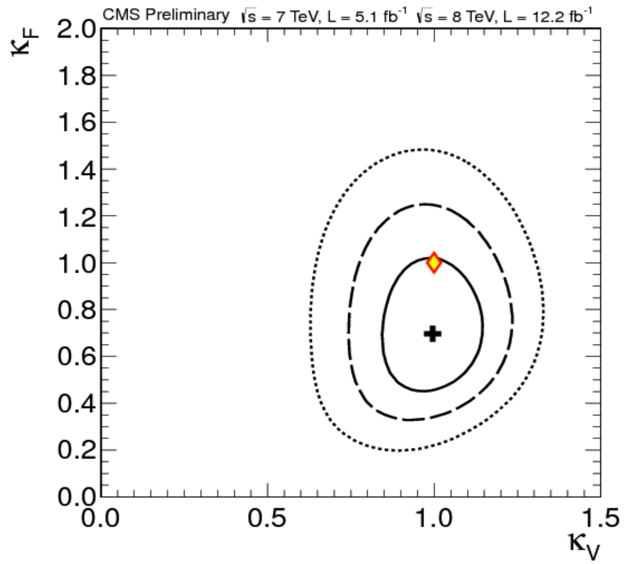


μ = 1.43 ± 0.16 (stat) ± 0.14 (sys)



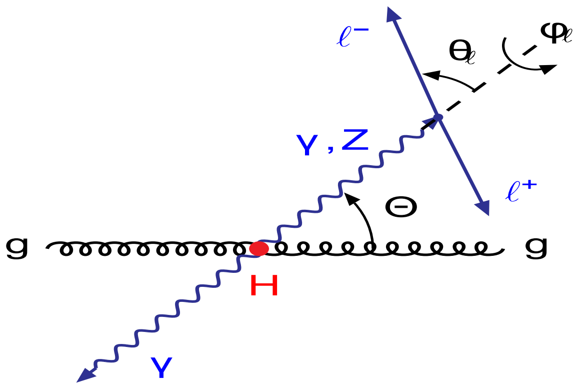


- Assume:
- gg → H and H → γγ only through SM particles
- $\kappa_V = \kappa_W = \kappa_Z$; $\kappa_F = \kappa_t = \kappa_b = \kappa_\tau$



Data consistent with $\kappa_V = \kappa_F = 1$

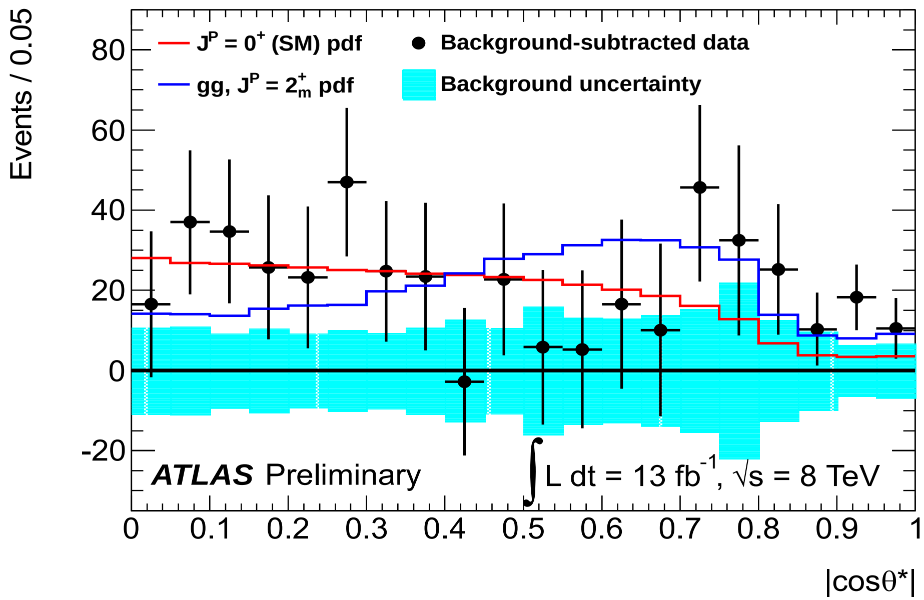
3. Spin of Higgs

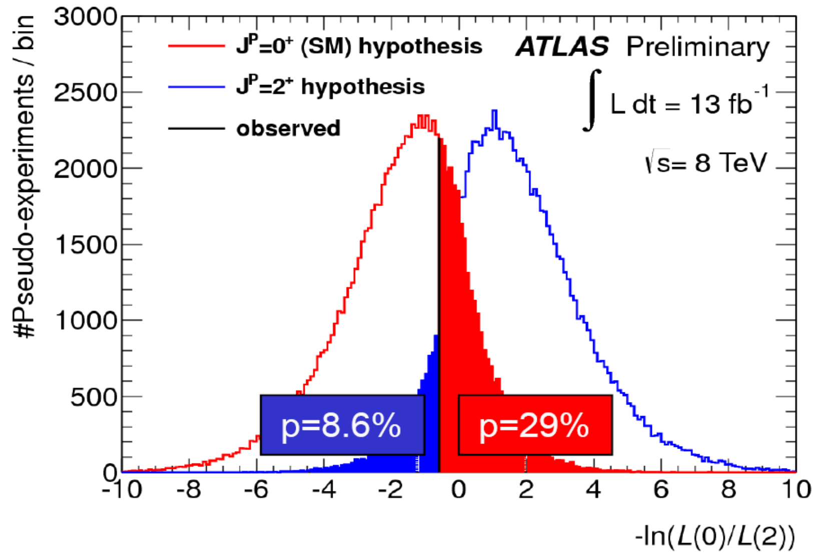


Decay angle in the Higgs boson rest frame (Collins-Soper frame)

Compare dN/d|cosθ*| for:

- spin-0+ hypothesis: flat before cuts
- spin-2+ hypothesis: ~ 1+6cos2θ* +cos4θ*

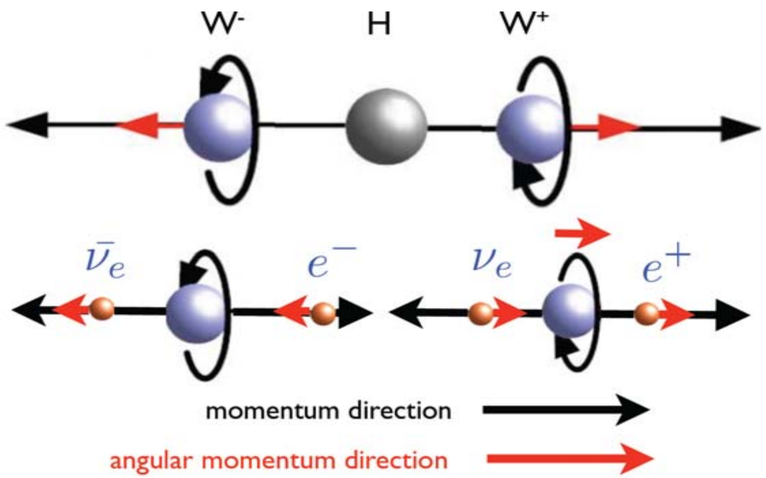


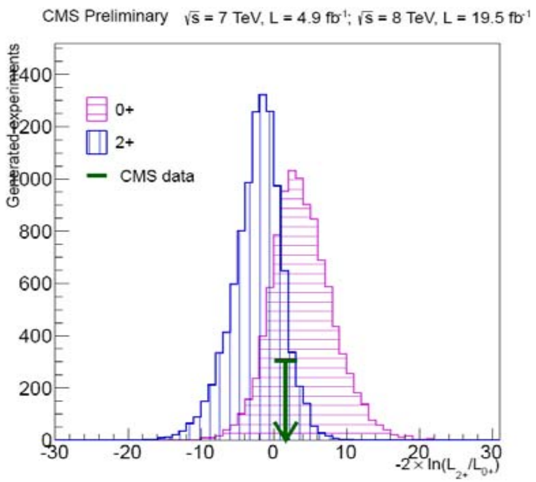


Likelihood hypothesis test of spin 0 versus spin 2:

Data favour spin 0,
exclude spin 2 at 93% Cl.

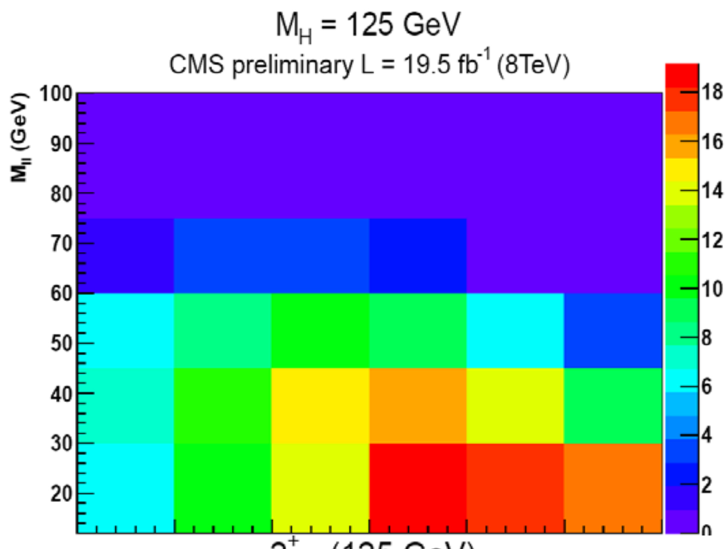
Kinematics of final state leptons sensitive to spin structure of resonance



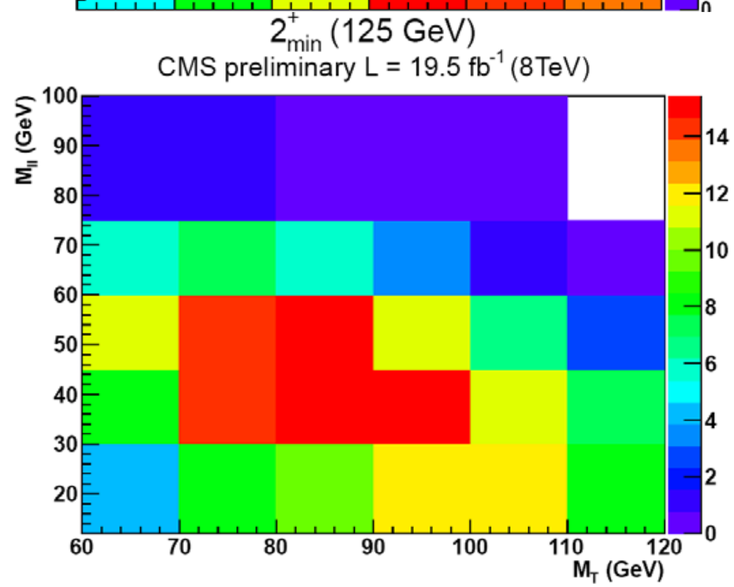


new

SM ($J^P=0^+$)



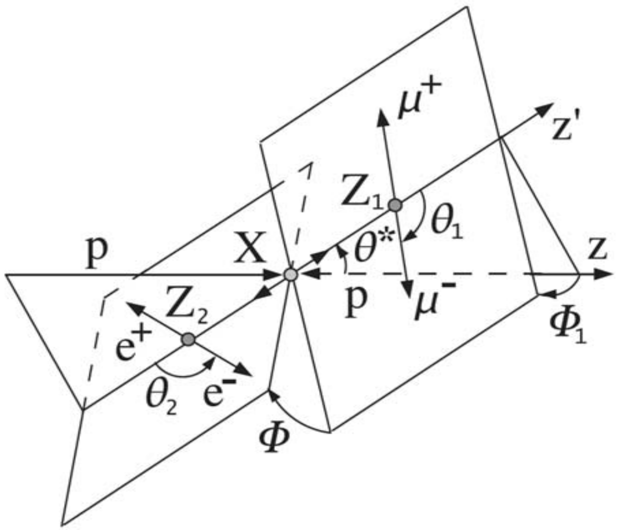
$J^P=2^+$



Likelihood hypothesis test of spin-0 versus spin 2:

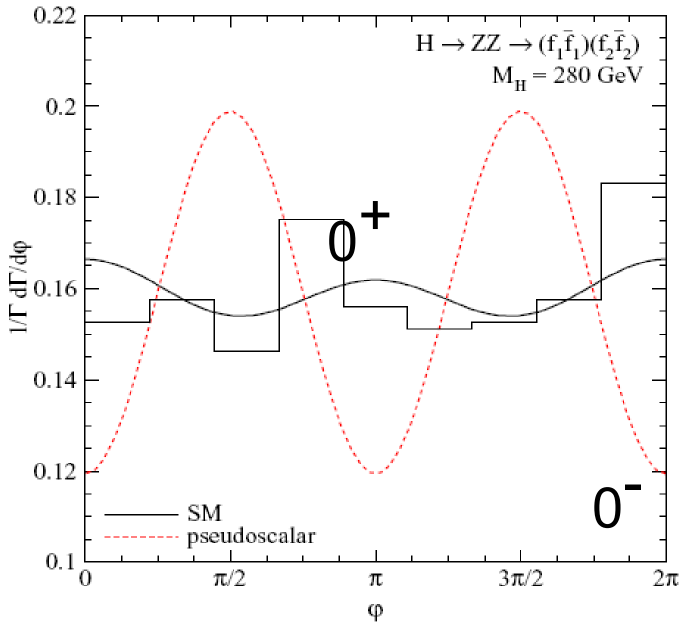
Data favour spin 0,
exclude spin 2 with 1.3σ (expected 1.9σ)

Angular distributions in H→ZZ*→4l sensitive to J P



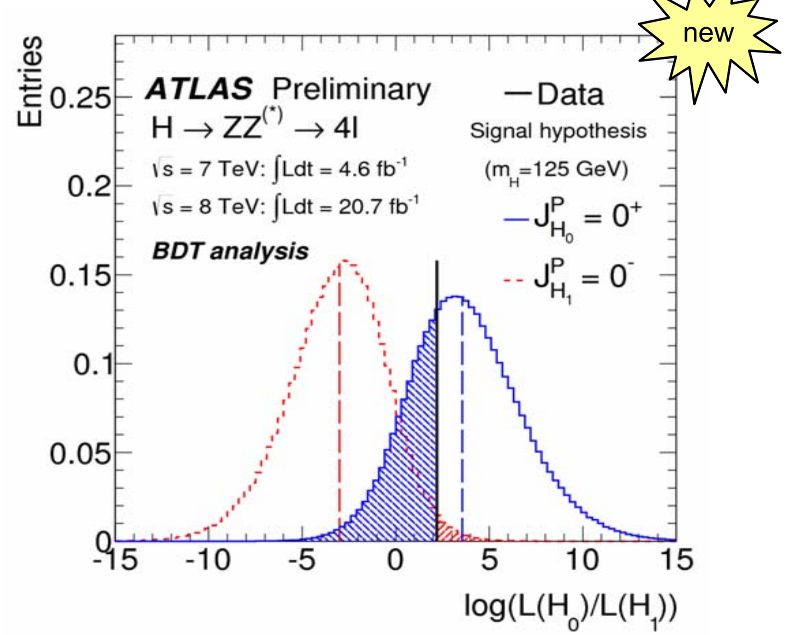
Angle between Z decay planes:

Choi, Miller, Mühlleitner, Zerwas '02

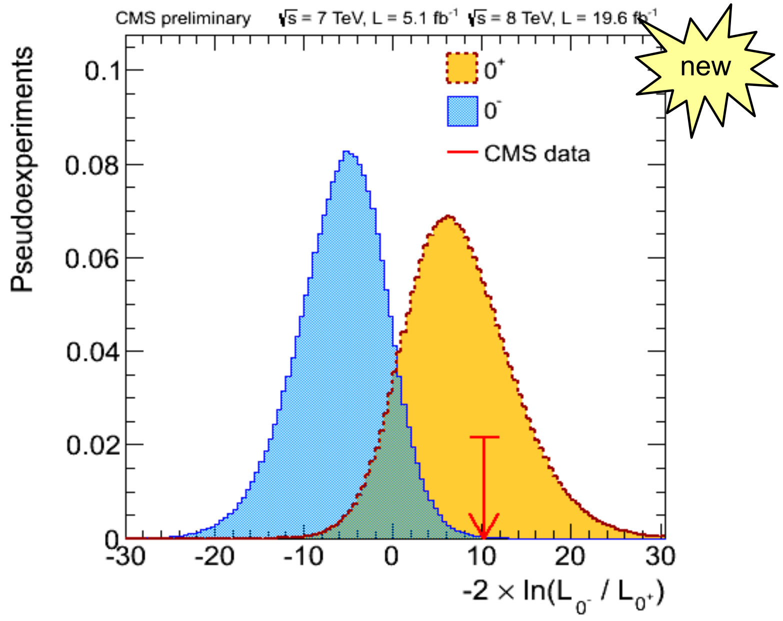


- **Spin 0 ⇒ two S=1 particles ⇒ angular correlations.**
- **Positive parity ⇒ decay planes aligned.**
- **Negative parity ⇒ decay planes orthogonal**

[ATLAS-CONF-2013-013](#)



[CMS PAS HIG-13-002](#)



Spin-Parity summary

$J^P = 0^+$ vs. $J^P = 0^-$ — 2.8σ (ATLAS), 2.5σ (CMS)

$J^P = 0^+$ vs. $J^P = 2^+_m$ — 1.2σ (ATLAS), 1.3σ (CMS)

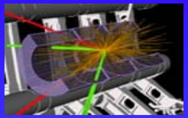
Data favour $J^P = 0^+$ w.r.t. other J^P configurations (including 0^-, 1^-, 1^+, 2^+)

ATLAS

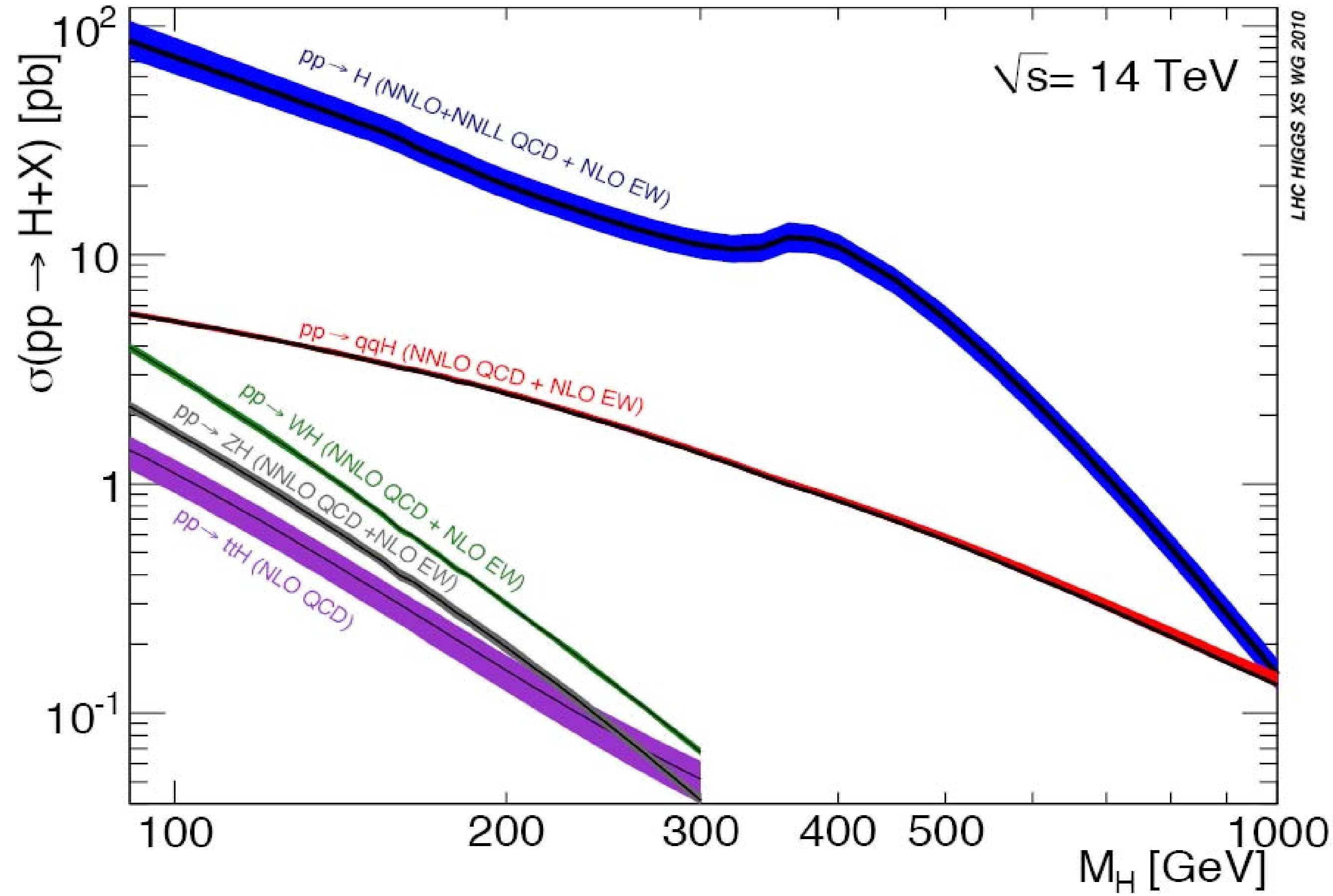
		BDT analysis			
		tested J^P for an assumed 0^+		tested 0^+ for an assumed J^P	$\mathrm{CL_S}$
		expected	observed	observed*	
0^-	p_0	0.0037	0.015	0.31	0.022
1^+	p_0	0.0016	0.001	0.55	0.002
1^-	p_0	0.0038	0.051	0.15	0.060
2^+_m	p_0	0.092	0.079	0.53	0.168
2^-	p_0	0.0053	0.25	0.034	0.258

CMS

J^P	production	comment	expect (μ=1)	obs. 0^+	obs. J^P	CL_s
0^-	$gg \to X$	pseudoscalar	2.6σ (2.8σ)	0.5σ	3.3σ	0.16%
0^+_h	$gg \to X$	higher dim operators	1.7σ (1.8σ)	0.0σ	1.7σ	8.1%
2^+_{mgg}	$gg \to X$	minimal couplings	1.8σ (1.9σ)	0.8σ	2.7σ	1.5%
$2^+_{mq\bar{q}}$	$q\bar{q} \to X$	minimal couplings	1.7σ (1.9σ)	1.8σ	4.0σ	$<0.1\%$
1^-	$q\bar{q} \to X$	exotic vector	2.8σ (3.1σ)	1.4σ	$>4.0\sigma$	$<0.1\%$
1^+	$q\bar{q} \to X$	exotic pseudovector	2.3σ (2.6σ)	1.7σ	$>4.0\sigma$	$<0.1\%$

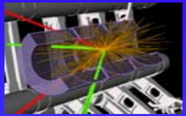


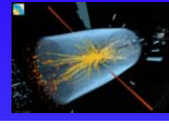
D. Perspectives



Good summary of studies:

Paolo Giacomelli (INFN Bologna),
Bill Murray (STFC/RAL)
Presented at Plenary ECFA meeting
Friday, November 23rd, 2012





With LHC 7-8 TeV data:

- First characterization of Higgs-like boson
- spin/parity at 3-4 sigma level
- combined signal strength, $\mu=\sigma/\sigma_{SM}$, with ~15% precision

With LHC 13/14 TeV data until ~2022 (~300 fb^{-1}):

- measure Higgs boson properties
- individual couplings at 5-10% precision

With HL-LHC 13/14 TeV data until ~2032 (~3000 fb^{-1}):

- measure couplings with ultimate precision
- Study WW scattering

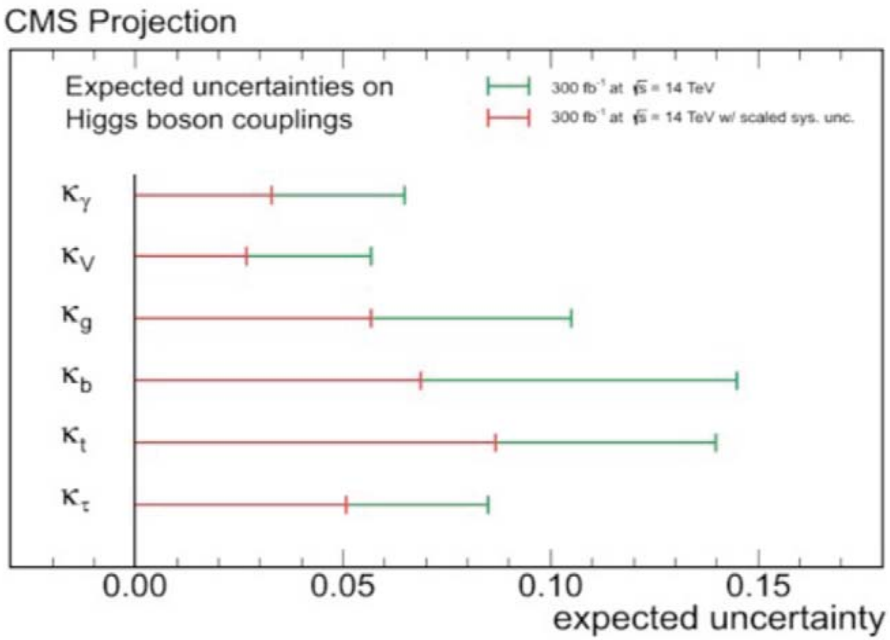
- Need detectors and trigger with high performances from low to high energy scales
  - 125 GeV Higgs-like measurements
  - Multi-TeV new physics searches

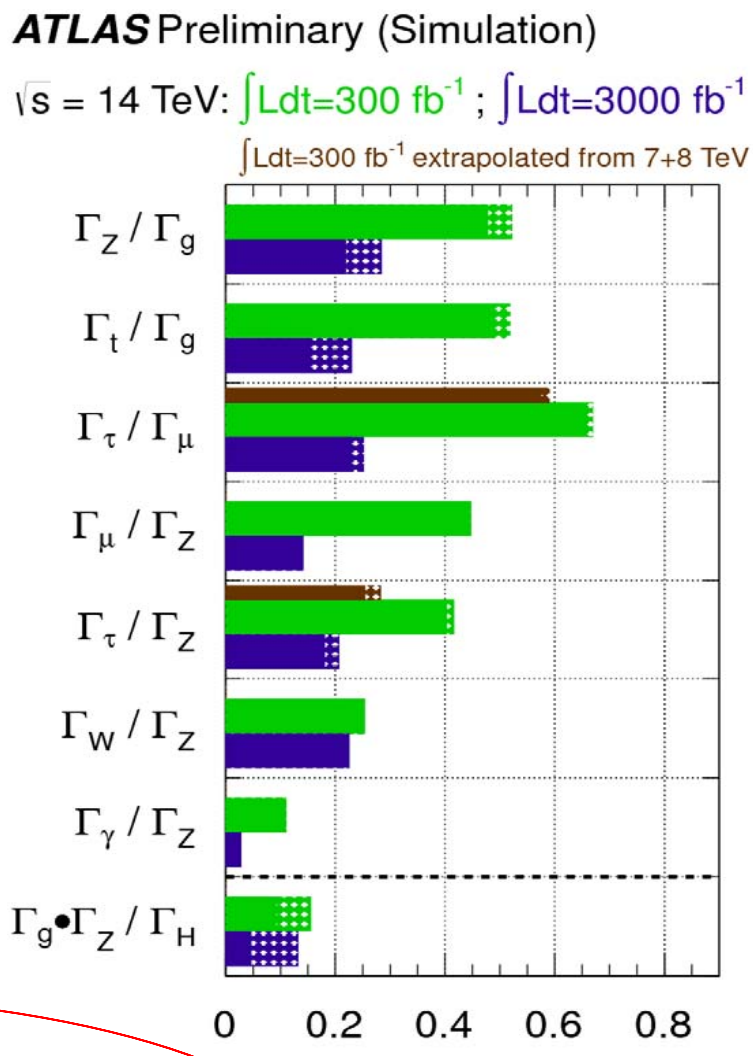
- Phase 1 Upgrade: twice LHC design luminosity
  - Event pileup reaches 50 collisions per beam crossing (@ 25 ns)
  - Factor 5 increase of trigger rates relative to 2012 run

- Phase 2 Upgrade: 5x LHC design luminosity
  - Event pileup reaches 125 collisions per beam crossing (@ 25 ns)
  - Need solutions to cope with very high rates, radiation and pileup

1. Higgs couplings (300-3000 fb^{-1})

- Scale signal and background cross sections
- Systematic uncertainties unchanged
- Dashed line: no theoretical uncertainty

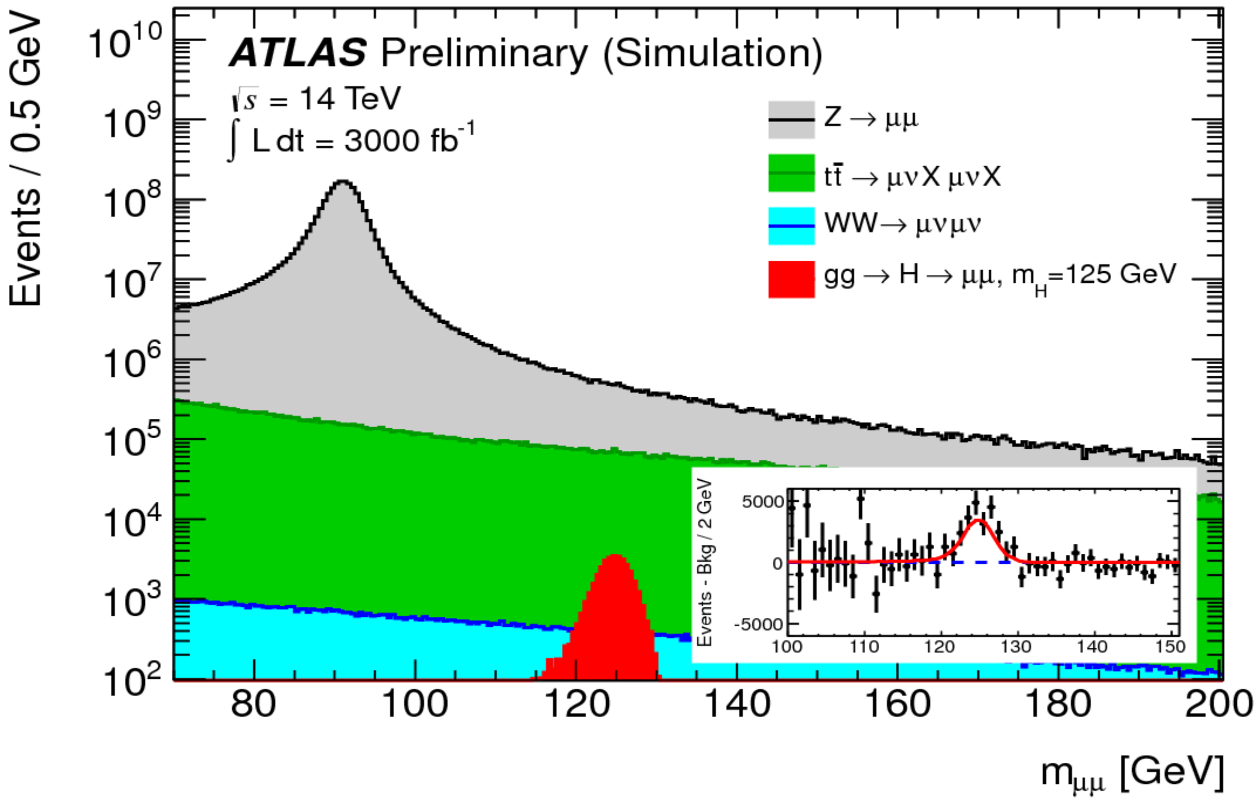




$$\frac{\Delta(\Gamma_X/\Gamma_Y)}{\Gamma_X/\Gamma_Y} \sim 2\frac{\Delta(\kappa_X/\kappa_Y)}{\kappa_X/\kappa_Y}$$

	300 fb^{-1}	3000 fb^{-1}
κ_V	3.0% (5.6%)	1.9% (4.5%)
κ_F	8.9% (10%)	3.6% (5.9%)

2. New modes at HL-LHC (3000 fb^{-1})



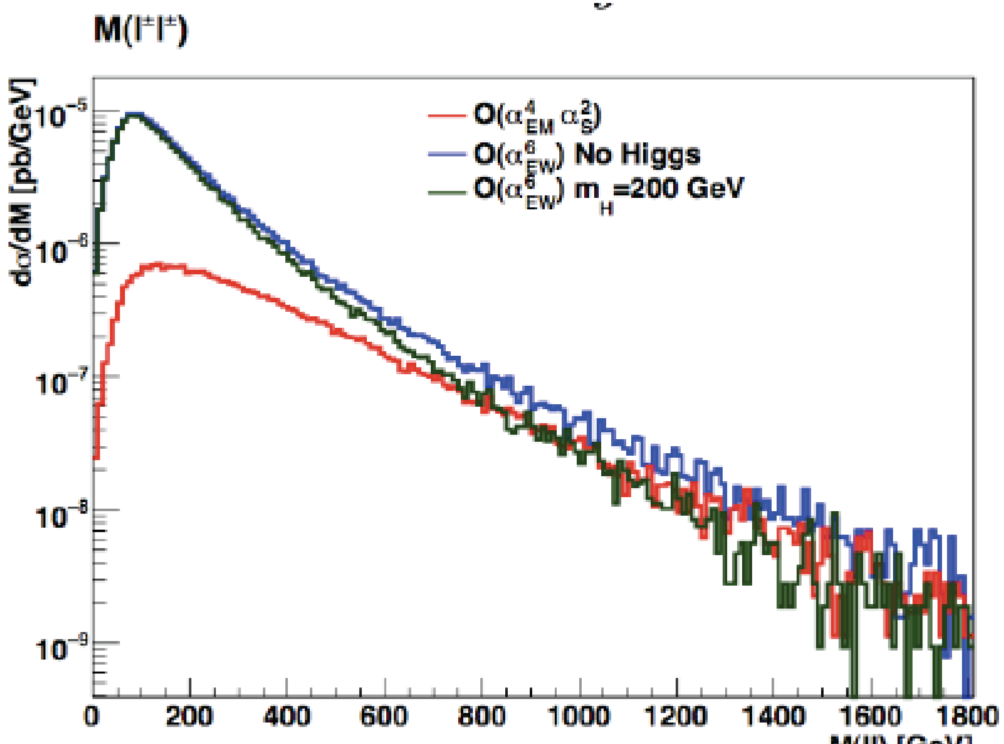
H→μμ
allows direct study of coupling to two different generations

3. Longitudinal Boson-Boson Scattering (3000 fb^{-1})

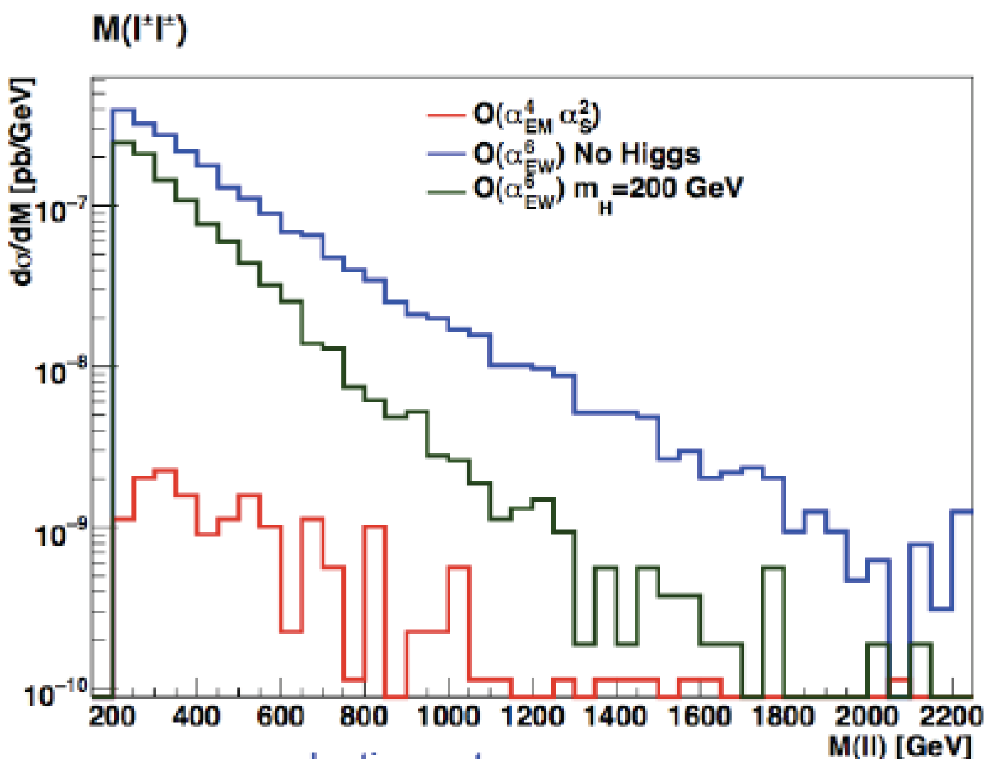
In no Higgs case: increasing of xsec at high VV is suppressed by

- PDF
- offshell bosons
- unpolarized bosons

→ small difference between SM and violation of unitarity



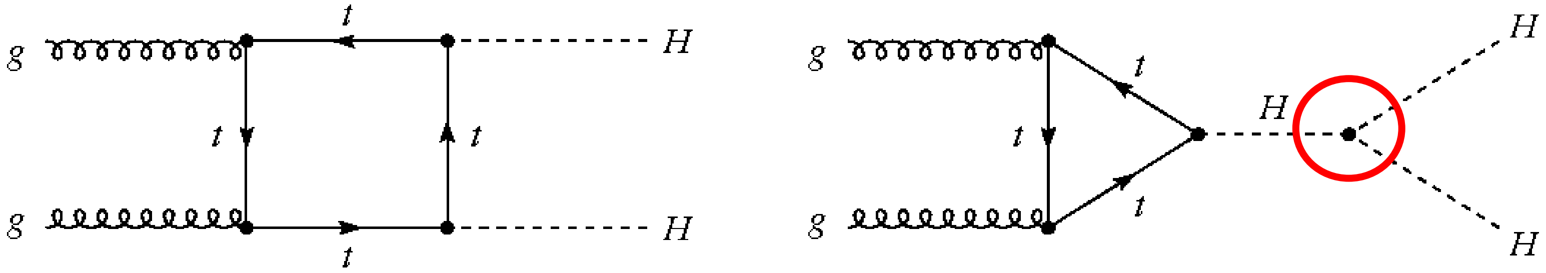
acceptance cuts



selection cuts

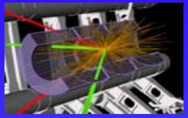
→ with proper cut (eg Δηjets) can be enhanced -> selection of the longitudinal W

4. Higgs Self coupling (3000 fb^{-1})



Needs observation of Higgs pairs:
Extemely difficult at LHC !
But it is not enough
– Need to prove triple Higgs involved
– negative interference

bb$\gamma\gamma$ allows 3σ HH observation
– 2 experiments, more channels, may give 3σ coupling measurement



Conclusion

„I think we have it“

Rolf Heuer, at the end of the presentations on July 4th, 2012

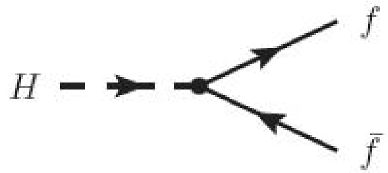
- Analysis of 7 TeV and 8 TeV data soon complete – interesting new results presented this week
- ATLAS and CMS have established the existence of the boson
- Measurements of mass, cross section times ranching ratios, with increasing precision
- First direct evidence for Youkawa couplings to fermions!
- Determination of spin-parity
- SM values are favored: it is quite likely THE SM HIGGS ! (We think)
- Interesting outlook for 14 TeV run at high and at very high luminosities


DAS LETZTE, DAS ICH VERSTANDEN HABE, WAR "HEUREKA"!
H
OH

APPENDIX

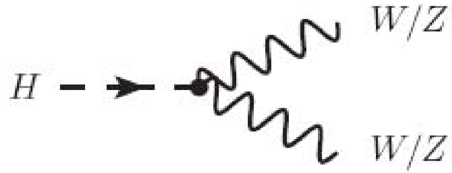
- Zerfälle in Fermionen, Z- und W-Paare:

$$\Gamma(H \to f\bar{f}) = N_C \frac{G_F}{4\sqrt{2}\pi} m_f^2(m_H)\, m_H$$



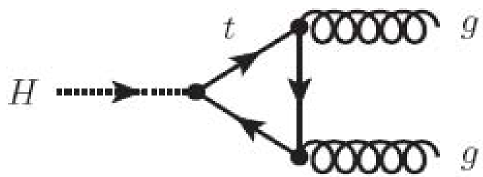
$$\Gamma(H \to ZZ) = \frac{G_F}{16\sqrt{2}\pi} m_H^3 (1 - 4x + 12x^2)\, \beta_Z, \quad x = M_Z^2 / m_H^2$$

$$\Gamma(H \to WW) = 2\frac{G_F}{16\sqrt{2}\pi} m_H^3 (1 - 4x + 12x^2)\, \beta_W, \quad x = M_W^2 / m_H^2$$

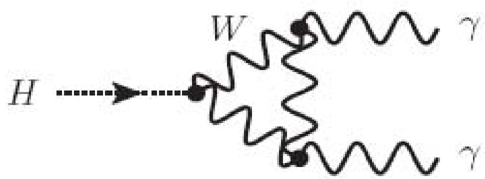


- Zerfall in Gluonen und Photonen

$$\Gamma(H \to gg) \quad = \quad \frac{G_F\, \alpha_S^2(m_H^2)}{36\sqrt{2}\pi^3} m_H^3 \left[1 + \left(\frac{94}{4} - \frac{7N_f}{6}\right)\frac{\alpha_S}{\pi}\right]$$



$$\Gamma(H \to \gamma\gamma) \quad = \quad \frac{G_F\, \alpha^2}{128\sqrt{2}\pi^3} m_H^3 \left[\frac{4}{3} N_C q_t^2 - 7\right]^2$$



- Einzige Unbekannte: Higgs-Masse

ggF, VBF, WH/ZH, ttH, MSSM Higgs

Cross Section

ggF
- HIGLU (NNLO QCD+NLO EW)
- iHixs (NNLO QCD+NLO EW)
- FeHiPro (NNLO QCD+NLO EW)
- HNNLO/HqT/HRes (NNLO+NNLL QCD)
- ggh@NNLO (NNLO QCD)

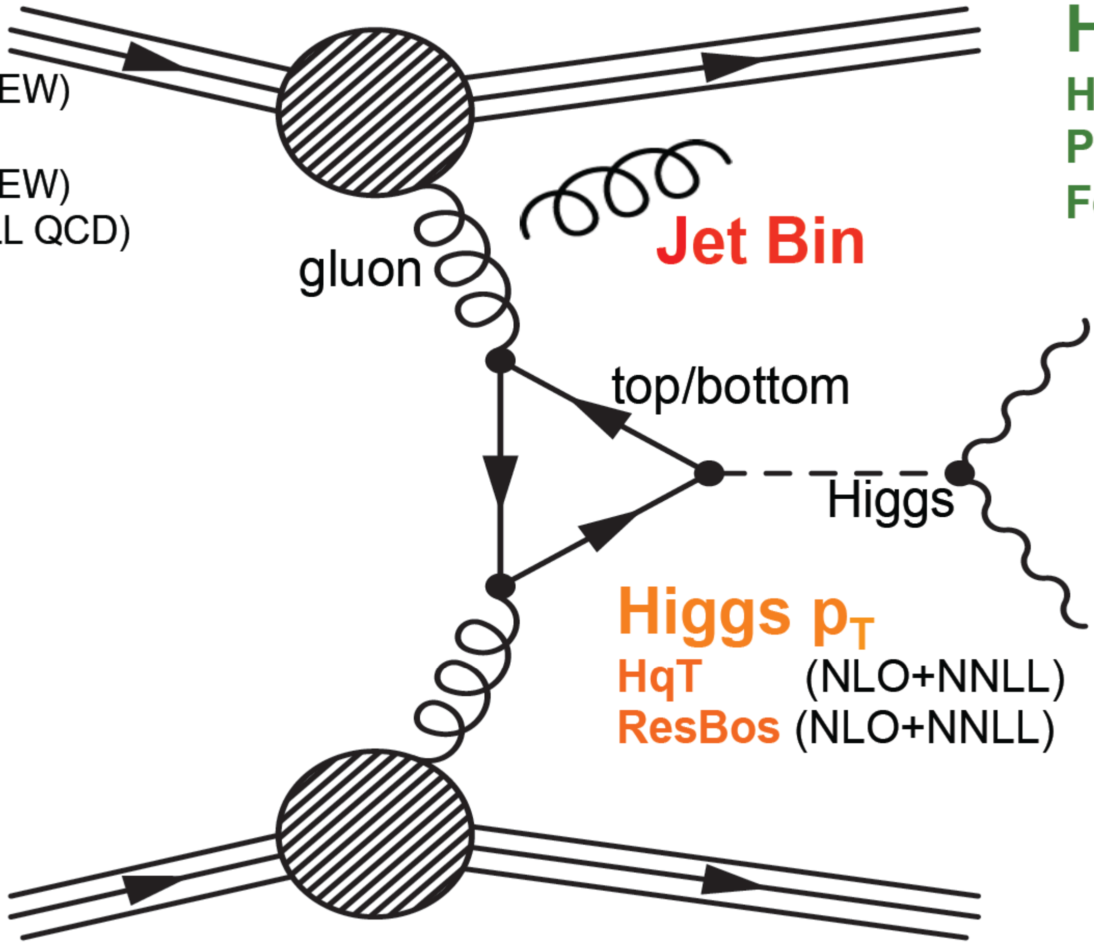
VBF
- VV2H (NLO QCD)
- VBFNLO (NLO QCD+EW)
- HAWK (NLO QCD+EW)
- VBF@NNLO (NNLO)

WH/ZH
- V2HV (NLO QCD)
- VH@NNLO (NNLO)

ttH
- HQQ (LO QCD)

bbH
- bbH@NNLO (NNLO QCD)

+ private codes.



Jet Bin

Higgs Decay
- HDECAY (NLO)
- Prophecy4f (NLO)
- FeynHiggs, CPSuperH

Heavy Higgs
- Lineshape (HTO)
- Inerference (gg2VV)

Higgs p_T
- HqT (NLO+NNLL)
- ResBos (NLO+NNLL)

NLO MC
aMC@NLO, POWHEG, SHERPA, HERWIG++

NLO code MCFM

PDF: CTEQ, MSTW, NNPDF, etc. (NNLO)

Couplings

Production modes

$$\frac{\sigma_{ggH}}{\sigma_{ggH}^{SM}} = \begin{cases} \kappa_g^2(\kappa_b, \kappa_t, m_H) \\ \kappa_g^2 \end{cases}$$

$$\frac{\sigma_{VBF}}{\sigma_{VBF}^{SM}} = \kappa_{VBF}^2(\kappa_W, \kappa_Z, m_H)$$

$$\frac{\sigma_{WH}}{\sigma_{WH}^{SM}} = \kappa_W^2$$

$$\frac{\sigma_{ZH}}{\sigma_{ZH}^{SM}} = \kappa_Z^2$$

$$\frac{\sigma_{t\bar{t}H}}{\sigma_{t\bar{t}H}^{SM}} = \kappa_t^2$$

Detectable decay modes

$$\frac{\Gamma_{WW^{(*)}}}{\Gamma_{WW^{(*)}}^{SM}} = \kappa_W^2$$

$$\frac{\Gamma_{ZZ^{(*)}}}{\Gamma_{ZZ^{(*)}}^{SM}} = \kappa_Z^2$$

$$\frac{\Gamma_{b\bar{b}}}{\Gamma_{b\bar{b}}^{SM}} = \kappa_b^2$$

$$\frac{\Gamma_{\tau^-\tau^+}}{\Gamma_{\tau^-\tau^+}^{SM}} = \kappa_\tau^2$$

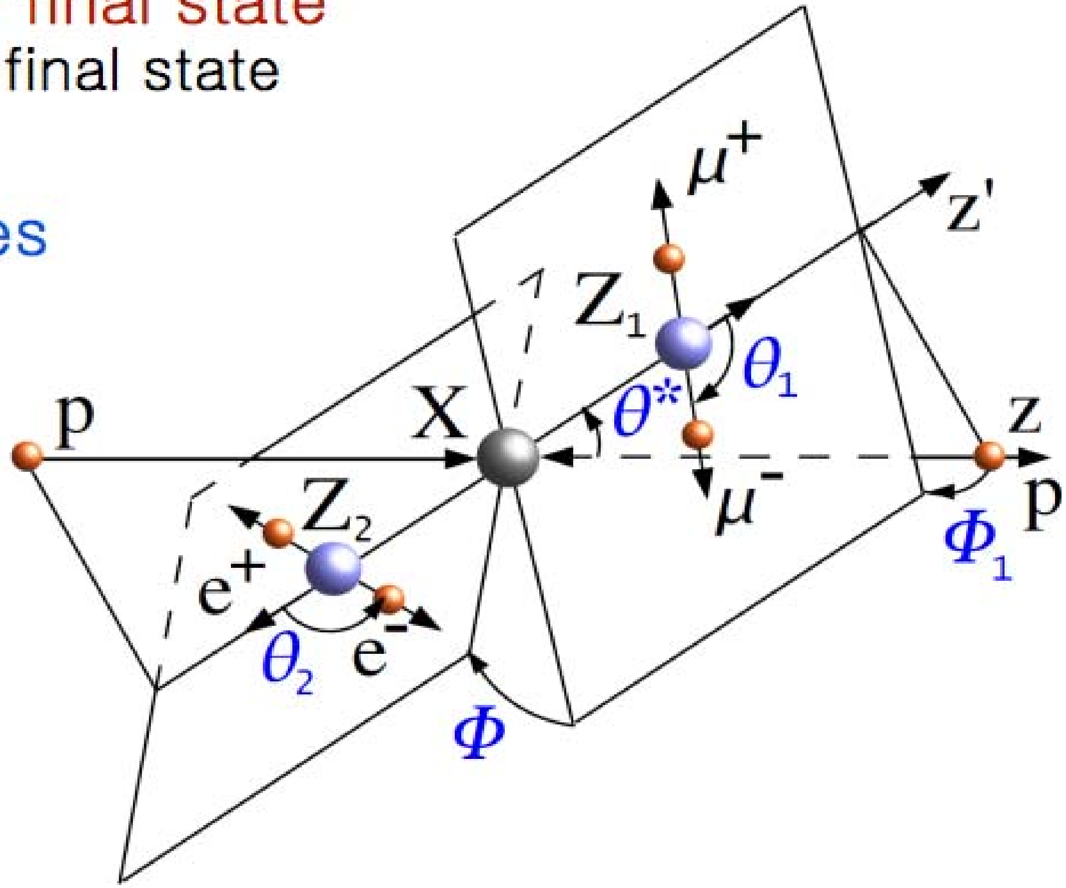
$$\frac{\Gamma_{\gamma\gamma}}{\Gamma_{\gamma\gamma}^{SM}} = \begin{cases} \kappa_\gamma^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_\gamma^2 \end{cases}$$

$$\frac{\Gamma_{Z\gamma}}{\Gamma_{Z\gamma}^{SM}} = \begin{cases} \kappa_{(Z\gamma)}^2(\kappa_b, \kappa_t, \kappa_\tau, \kappa_W, m_H) \\ \kappa_{(Z\gamma)}^2 \end{cases}$$

Let us consider the X→VV→4f final state
– more information in four-body final state

Θ_1, Θ_2, Φ: helicity (decay) angles
Θ^*, Φ_1: production angles

Θ^*, Φ_1 uncorrelated with spin 0 kinematics (flat), used in separation from background



full event kinematics described by:

$\{m_{4l}, m_1, m_2, \Theta_1, \Theta_2, \Phi, \Theta^*, \Phi_1, Y_H, pT_H\}$

** pT_H from NLO effects, Y_H from parton distribution functions

Angular distributions parametrised by hel. amplitudes

$$\begin{aligned}
F^J_{00}(\theta^*) \times \Big\{ & 4\, f_{00} \sin^2\theta_1 \sin^2\theta_2 + (f_{++} + f_{--}) \left((1+\cos^2\theta_1)(1+\cos^2\theta_2) + 4R_1R_2\cos\theta_1\cos\theta_2 \right) \\
& - 2\,(f_{++} - f_{--})\,\left(R_1\cos\theta_1(1+\cos^2\theta_2) + R_2(1+\cos^2\theta_1)\cos\theta_2 \right) \\
& + 4\sqrt{f_{++}f_{00}}\,(R_1 - \cos\theta_1)\sin\theta_1(R_2 - \cos\theta_2)\sin\theta_2\cos(\Phi + \phi_{++}) \\
& + 4\sqrt{f_{--}f_{00}}\,(R_1 + \cos\theta_1)\sin\theta_1(R_2 + \cos\theta_2)\sin\theta_2\cos(\Phi - \phi_{--}) \\
& + 2\sqrt{f_{++}f_{--}}\sin^2\theta_1\sin^2\theta_2\cos(2\Phi + \phi_{++} - \phi_{--}) \Big\}
\end{aligned}$$

$J_z = 0$

$$\begin{aligned}
+4F^J_{11}(\theta^*) \times \Big\{ & (f_{+0} + f_{0-})(1 - \cos^2\theta_1\cos^2\theta_2) - (f_{+0} - f_{0-})(R_1\cos\theta_1\sin^2\theta_2 + R_2\sin^2\theta_1\cos\theta_2) \\
& + 2\sqrt{f_{+0}f_{0-}}\sin\theta_1\sin\theta_2(R_1R_2 - \cos\theta_1\cos\theta_2)\cos(\Phi + \phi_{+0} - \phi_{0-}) \Big\} \\
+(-1)^J \times 4F^J_{-11}(\theta^*) \times \Big\{ & (f_{+0} + f_{0-})(R_1R_2 + \cos\theta_1\cos\theta_2) - (f_{+0} - f_{0-})(R_1\cos\theta_2 + R_2\cos\theta_1) \\
& + 2\sqrt{f_{+0}f_{0-}}\sin\theta_1\sin\theta_2\cos(\Phi + \phi_{+0} - \phi_{0-}) \Big\} \sin\theta_1\sin\theta_2\cos(2\Psi)
\end{aligned}$$

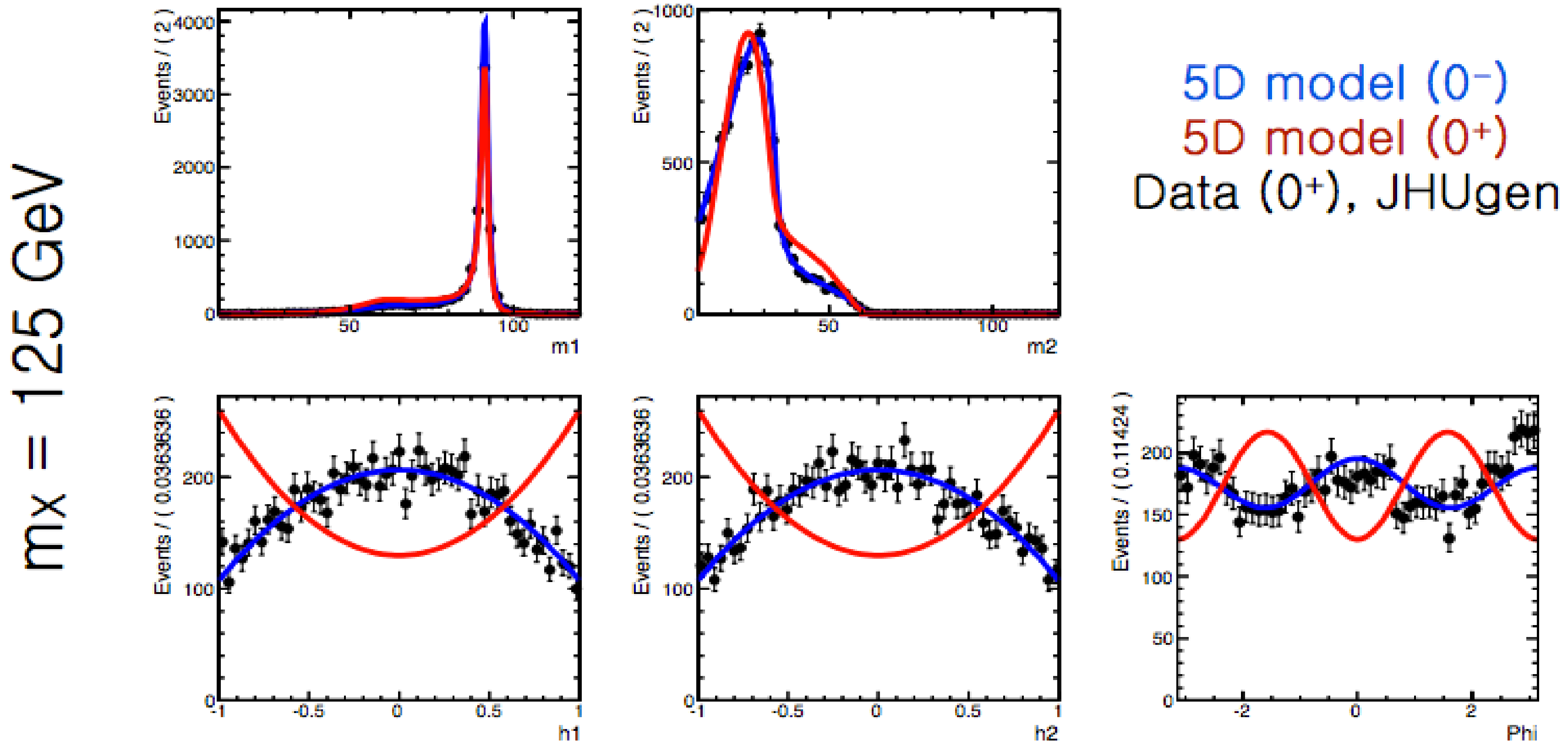
$J_z = \pm 1$

$$\begin{aligned}
& +2F^J_{22}(\theta^*) \times f_{+-}\Big\{ (1+\cos^2\theta_1)(1+\cos^2\theta_2) - 4R_1R_2\cos\theta_1\cos\theta_2 \Big\} \\
& +(-1)^J \times 2F^J_{-22}(\theta^*) \times f_{+-}\sin^2\theta_1\sin^2\theta_2\cos(4\Psi)
\end{aligned}$$

$J_z = \pm 2$

+ interference terms

- Signal model is fully correlated analytic 8-d model $\{m_{ZZ}, m_1, m_2, \Theta_1, \Theta_2, \Phi, \Theta^*, \Phi_1\}$
  - Model takes as inputs directly spin-0 couplings a_1, a_2, a_3
  - N.B. production angles Θ^*, Φ_1 are uncorrelated and flat



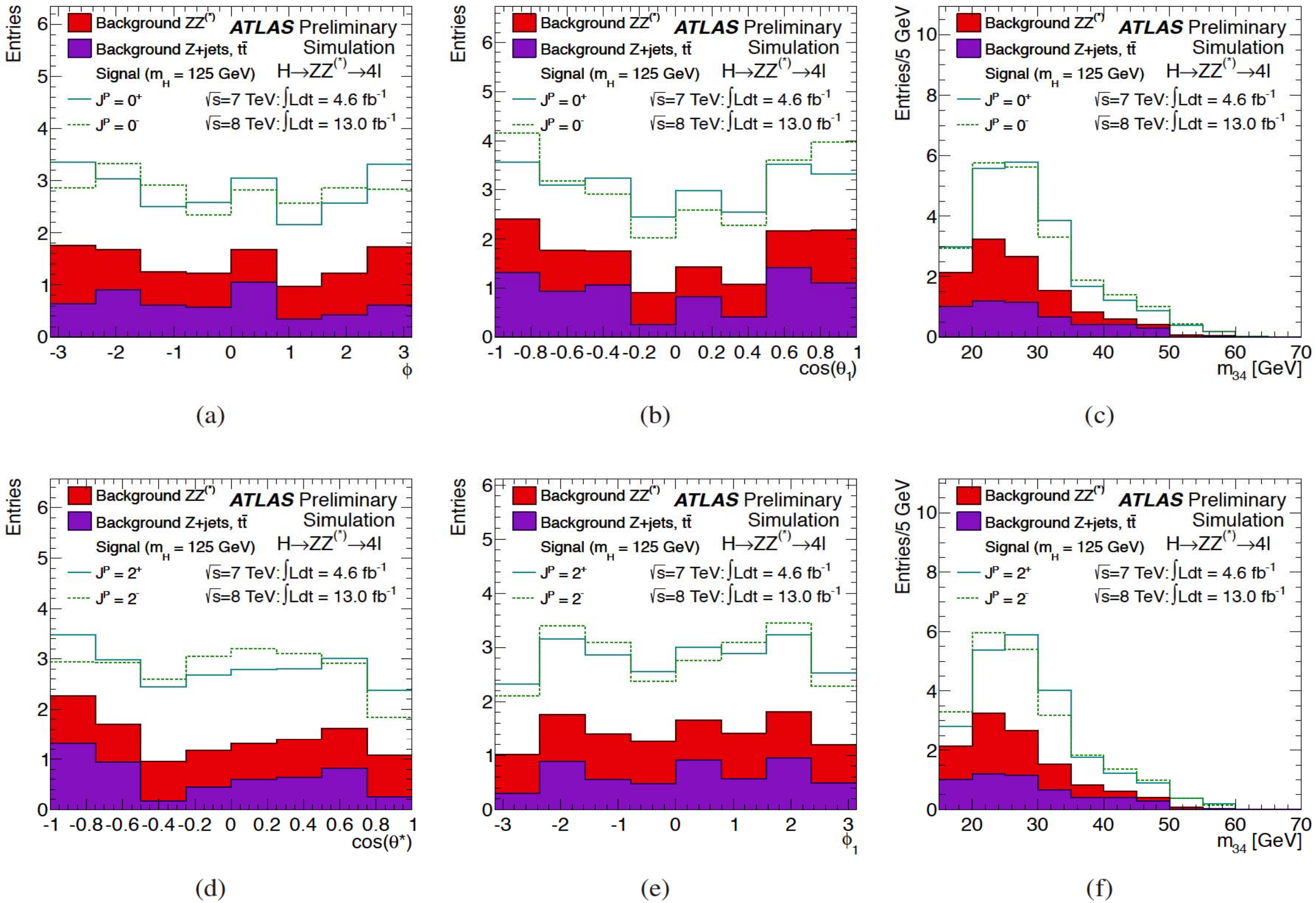
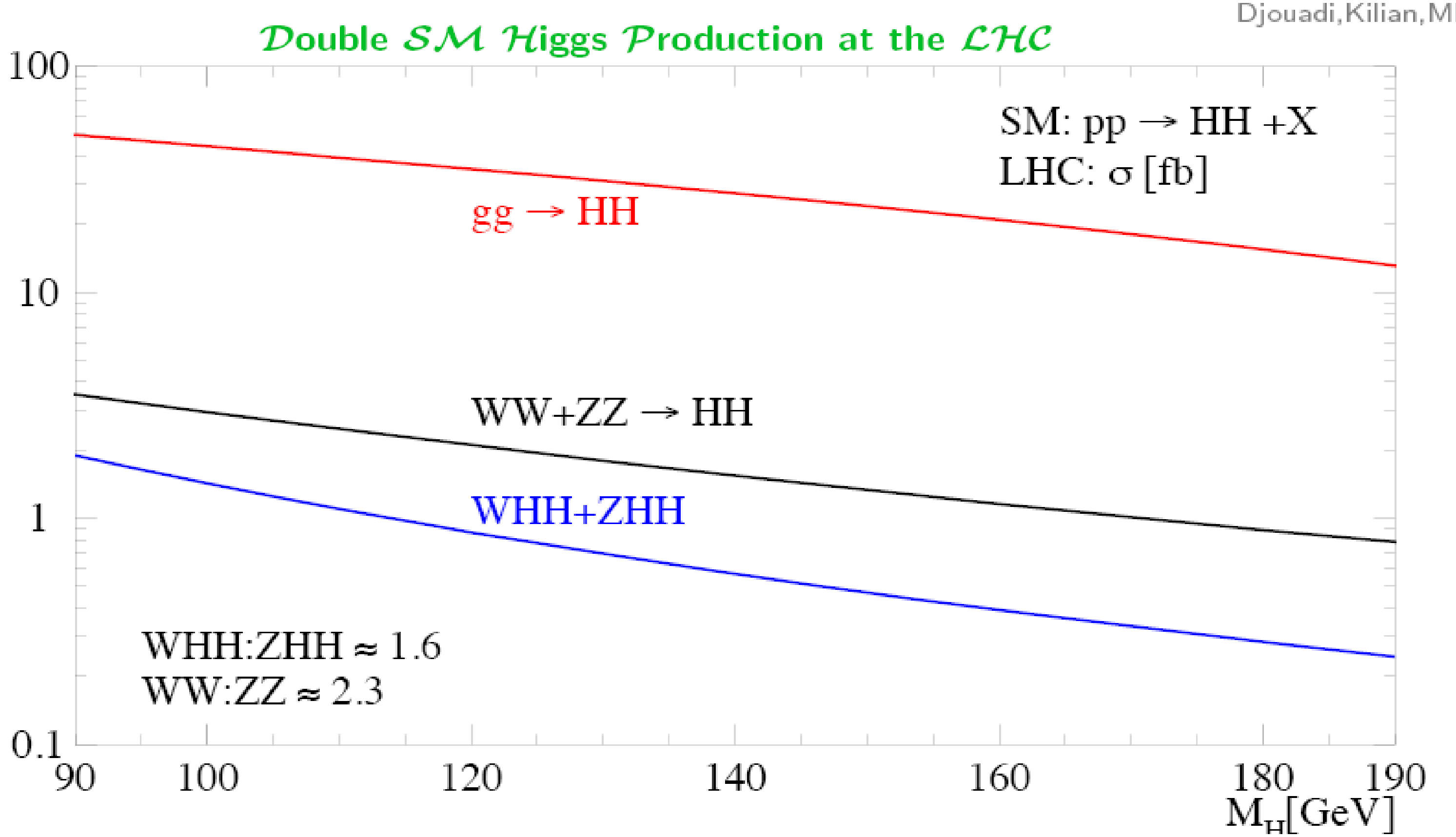


Figure 6: Expected distributions for $\sqrt{s}$ = 7 TeV and $\sqrt{s}$ = 8 TeV for $m_{4\ell}$ = 125 GeV including backgrounds in the mass range 115 GeV $< m_{4\ell} <$ 130 GeV comparing two pairs of spin/parity J^P states. Comparison of 0^+ versus 0^- hypotheses: (a) Φ, (b) $\cos\theta_1$, and (c) m_{34}, and comparison of 2^+_m versus 2^- hypotheses: (d) $\cos\theta^*$, (e) Φ_1, and (f) m_{34}.

Higgs Self coupling

Djouadi,Kilian,MMM,Zerwas



Gianotti et al.;Blondel,Clark,Mazzucato
Baur,Plehn,Rainwater
Dahlhoff

$M_H > 140$ GeV: $gg \to HH \to W^+W^-W^+W^-$:

- LHC [$\int \mathcal{L} = 300$ fb^{-1}]:
  $150 \lesssim M_H \lesssim 200$ GeV: $\lambda_{HHH} = 0$ exclusion at 95% CL
- SLHC [$\int \mathcal{L} = 3$ ab^{-1}]:
  $150 < M_H < 200$ GeV $\delta\lambda_{HHH}/\lambda_{HHH} = 20 - 30\%$ at 1 σ