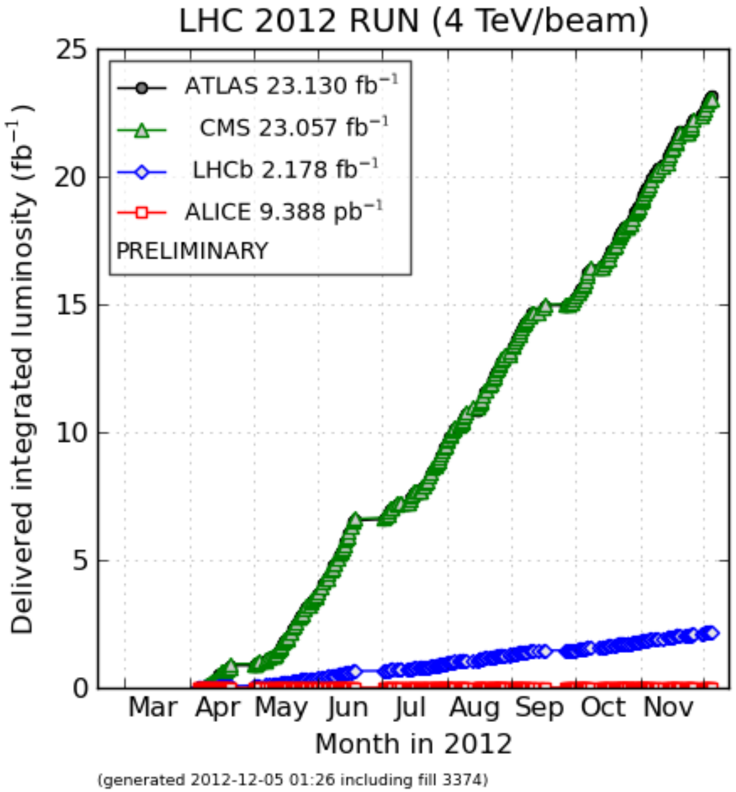
LHC Higgs Cross Section WG
- Introduction -

C. Mariotti, G. Passarino,
S. Heinemeyer and R. Tanaka

Dec. 5-6, 2012, CERN

Higgs Discovery on July 4th, 2012 !

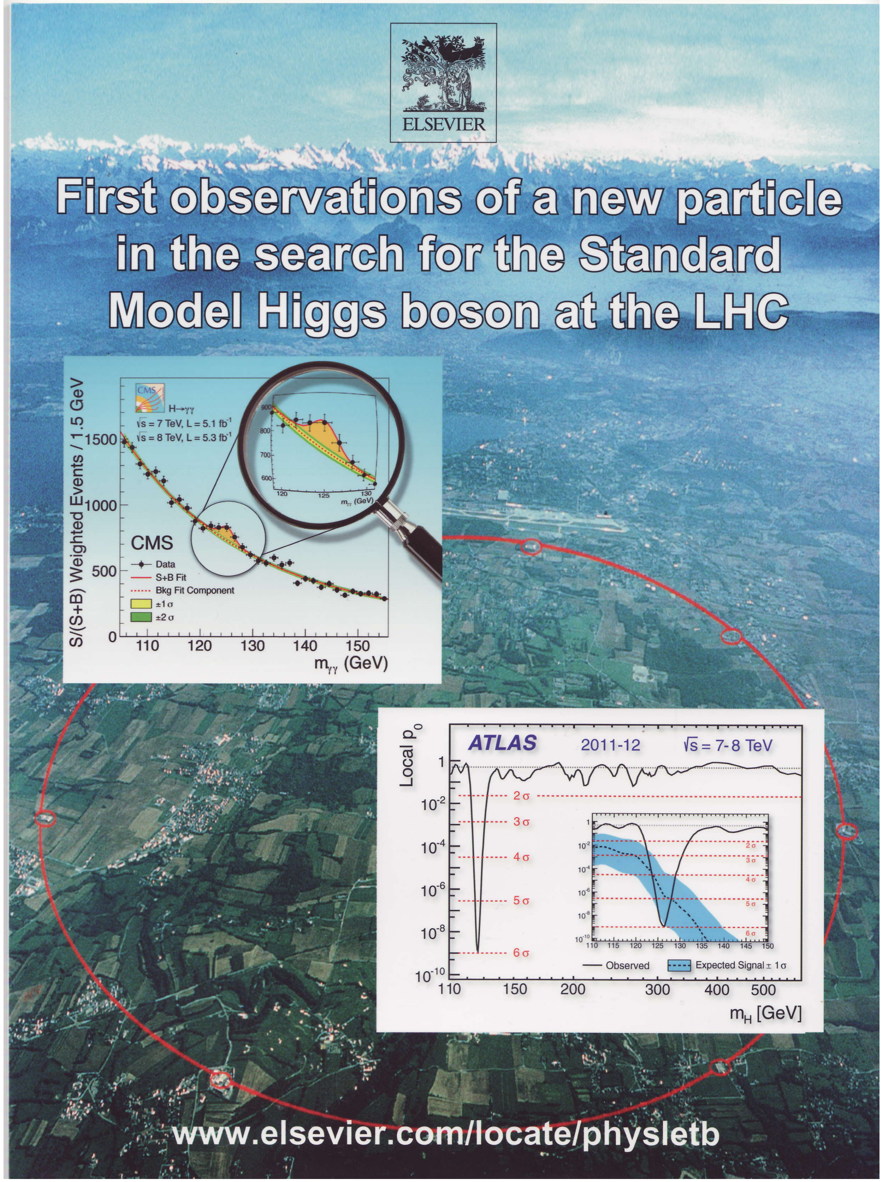
Fantastic LHC run in 2011-2012 !



http://lpc.web.cern.ch/lpc/

→ talk by Jan Uythoven (CERN TE-ABT)

Physics Letters B 716 (2012) 1-61



Physics Letters B 716 (2012) 1–29

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Physics Letters B

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Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC ☆

ATLAS Collaboration *

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

A R T I C L E I N F O

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A B S T R A C T

A search for the Standard Model Higgs boson in proton–proton collisions with the ATLAS detector at the LHC is presented. The datasets used correspond to integrated luminosities of approximately 4.8 fb^{-1} collected at $\sqrt{s}=7$ TeV in 2011 and 5.8 fb^{-1} at $\sqrt{s}=8$ TeV in 2012. Individual searches in the channels $H\to ZZ^{(*)}\to 4\ell$, $H\to\gamma\gamma$ and $H\to WW^{(*)}\to e\nu\mu\nu$ in the 8 TeV data are combined with previously published results of searches for $H\to ZZ^{(*)}$, $WW^{(*)}$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from improved analyses of the $H\to ZZ^{(*)}\to 4\ell$ and $H\to\gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of $126.0\pm0.4\,(\text{stat})\pm0.4\,(\text{sys})$ GeV is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9}, is compatible with the production and decay of the Standard Model Higgs boson.

1. Introduction

The Standard Model (SM) of particle physics [1–4] has been tested by many experiments over the last four decades and has been shown to successfully describe high energy particle interactions. However, the mechanism that breaks electroweak symmetry in the SM has not been verified experimentally. This mechanism [5–10], which gives mass to massive elementary particles, implies the existence of a scalar particle, the SM Higgs boson. The search for the Higgs boson, the only elementary particle in the SM that has not yet been observed, is one of the highlights of the Large Hadron Collider [11] (LHC) physics programme.

Indirect limits on the SM Higgs boson mass of $m_H<158$ GeV at 95% confidence level (CL) have been set using global fits to precision electroweak results [12]. Direct searches at LEP [13], the Tevatron [14–16] and the LHC [17,18] have previously excluded, at 95% CL, a SM Higgs boson with mass below 600 GeV, apart from some mass regions between 116 GeV and 127 GeV.

Both the ATLAS and CMS Collaborations reported excesses of events in their 2011 datasets of proton–proton (pp) collisions at centre-of-mass energy $\sqrt{s}=7$ TeV at the LHC, which were compatible with SM Higgs boson production and decay in the mass region 124–126 GeV, with significances of 2.9 and 3.1 standard deviations (σ), respectively [17,18]. The CDF and DØ experiments at the Tevatron have also recently reported a broad excess in the mass region 120–135 GeV; using the existing LHC constraints, the observed local significances for $m_H=125$ GeV are 2.7σ for CDF [14], 1.1σ for DØ [15] and 2.8σ for their combination [16].

The previous ATLAS searches in 4.6–4.8 fb^{-1} of data at $\sqrt{s}=7$ TeV are combined here with new searches for $H\to ZZ^{(*)}\to 4\ell$,[1] $H\to\gamma\gamma$ and $H\to WW^{(*)}\to e\nu\mu\nu$ in the 5.8–5.9 fb^{-1} of pp collision data taken at $\sqrt{s}=8$ TeV between April and June 2012.

The data were recorded with instantaneous luminosities up to 6.8×10^{33} $\text{cm}^{-2}\,\text{s}^{-1}$; they are therefore affected by multiple pp collisions occurring in the same or neighbouring bunch crossings (pile-up). In the 7 TeV data, the average number of interactions per bunch crossing was approximately 10; the average increased to approximately 20 in the 8 TeV data. The reconstruction, identification and isolation criteria used for electrons and photons in the 8 TeV data are improved, making the $H\to ZZ^{(*)}\to 4\ell$ and $H\to\gamma\gamma$ searches more robust against the increased pile-up. These analyses were re-optimised with simulation and frozen before looking at the 8 TeV data.

In the $H\to WW^{(*)}\to\ell\nu\ell\nu$ channel, the increased pile-up deteriorates the event missing transverse momentum, E_T^{miss}, resolution, which results in significantly larger Drell–Yan background in the same-flavour final states. Since the $e\mu$ channel provides most of the sensitivity of the search, only this final state is used in the analysis of the 8 TeV data. The kinematic region in which a SM Higgs boson with a mass between 110 GeV and 140 GeV is

* *E-mail address:* atlas.publications@cern.ch.

[1] The symbol ℓ stands for electron or muon.

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Physics Letters B

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Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC ☆

CMS Collaboration *

CERN, Switzerland

This paper is dedicated to the memory of our colleagues who worked on CMS but have since passed away. In recognition of their many contributions to the achievement of this observation.

A R T I C L E I N F O

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CMS
Physics
Higgs

A B S T R A C T

Results are presented from searches for the standard model Higgs boson in proton–proton collisions at $\sqrt{s}=7$ and 8 TeV in the Compact Muon Solenoid experiment at the LHC, using data samples corresponding to integrated luminosities of up to 5.1 fb^{-1} at 7 TeV and 5.3 fb^{-1} at 8 TeV. The search is performed in five decay modes: $\gamma\gamma$, ZZ, W^+W^-, $\tau^+\tau^-$, and $\text{b}\bar{\text{b}}$. An excess of events is observed above the expected background, with a local significance of 5.0 standard deviations, at a mass near 125 GeV, signalling the production of a new particle. The expected significance for a standard model Higgs boson of that mass is 5.8 standard deviations. The excess is most significant in the two decay modes with the best mass resolution, $\gamma\gamma$ and ZZ; a fit to these signals gives a mass of $125.3\pm0.4(\text{stat.})\pm0.5(\text{syst.})$ GeV. The decay to two photons indicates that the new particle is a boson with spin different from one.

1. Introduction

The standard model of elementary particles provides a remarkably accurate description of results from many accelerator and non-accelerator based experiments. The SM comprises quarks and leptons as the building blocks of matter, and describes their interactions through the exchange of force carriers: the photon for electromagnetic interactions, the W and Z bosons for weak interactions, and the gluons for strong interactions. The electromagnetic and weak interactions are unified in the electroweak theory. Although the predictions of the SM have been extensively confirmed, the question of how the W and Z gauge bosons acquire mass whilst the photon remains massless is still open.

Nearly fifty years ago it was proposed [1–6] that spontaneous symmetry breaking in gauge theories could be achieved through the introduction of a scalar field. Applying this mechanism to the electroweak theory [7–9] through a complex scalar doublet field leads to the generation of the W and Z masses, and to the prediction of the existence of the SM Higgs boson (H). The scalar field also gives mass to the fundamental fermions through the Yukawa interaction. The mass m_{H} of the SM Higgs boson is not predicted by theory. However, general considerations [10–13] suggest that m_{H} should be smaller than $\sim$1 TeV, while precision electroweak measurements imply that $m_{\text{H}}<152$ GeV at 95% confidence level (CL) [14]. Over the past twenty years, direct searches for the Higgs boson have been carried out at the LEP collider, leading to a lower bound of $m_{\text{H}}>114.4$ GeV at 95% CL [15], and at the Tevatron proton–antiproton collider, excluding the mass range 162–166 GeV at 95% CL [16] and detecting an excess of events, recently reported in [17–19], in the range 120–135 GeV.

The discovery or exclusion of the SM Higgs boson is one of the primary scientific goals of the Large Hadron Collider (LHC) [20]. Previous direct searches at the LHC were based on data from proton–proton collisions corresponding to an integrated luminosity of 5 fb^{-1} collected at a centre-of-mass energy $\sqrt{s}=7$ TeV. The CMS experiment excluded at 95% CL a range of masses from 127 to 600 GeV [21]. The ATLAS experiment excluded at 95% CL the ranges 111.4–116.6, 119.4–122.1 and 129.2–541 GeV [22]. Within the remaining allowed mass region, an excess of events near 125 GeV was reported by both experiments. In 2012 the proton–proton centre-of-mass energy was increased to 8 TeV and by the end of June an additional integrated luminosity of more than 5 fb^{-1} had been recorded by each of these experiments, thereby enhancing significantly the sensitivity of the search for the Higgs boson.

This Letter reports the results of a search for the SM Higgs boson using samples collected by the CMS experiment, comprising data recorded at $\sqrt{s}=7$ and 8 TeV. The search is performed in

* *E-mail address:* cms-publication-committee-chair@cern.ch.

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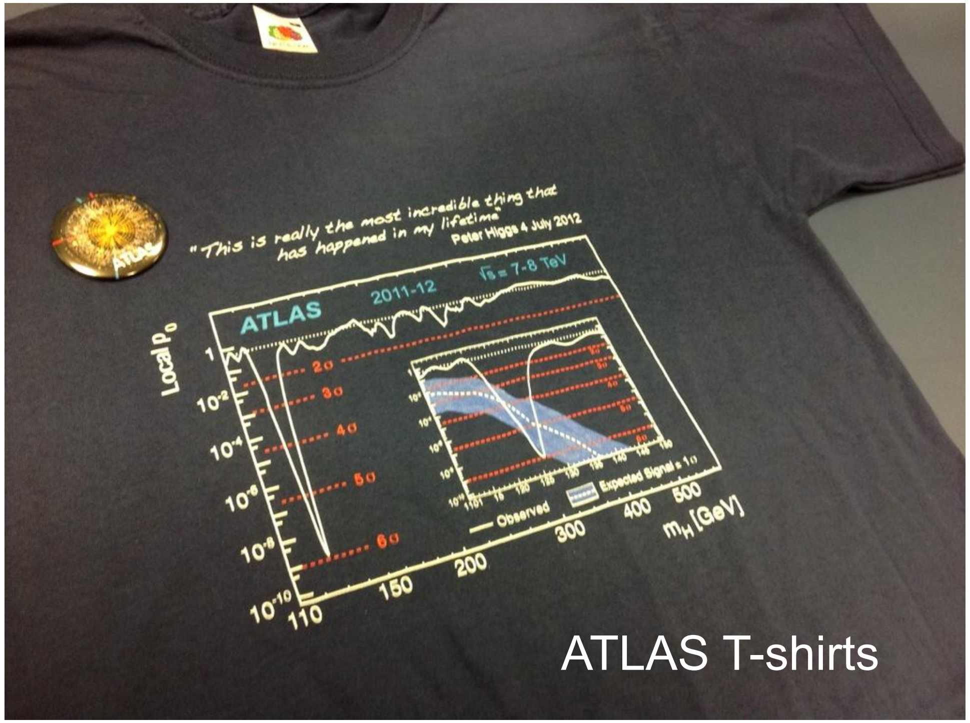
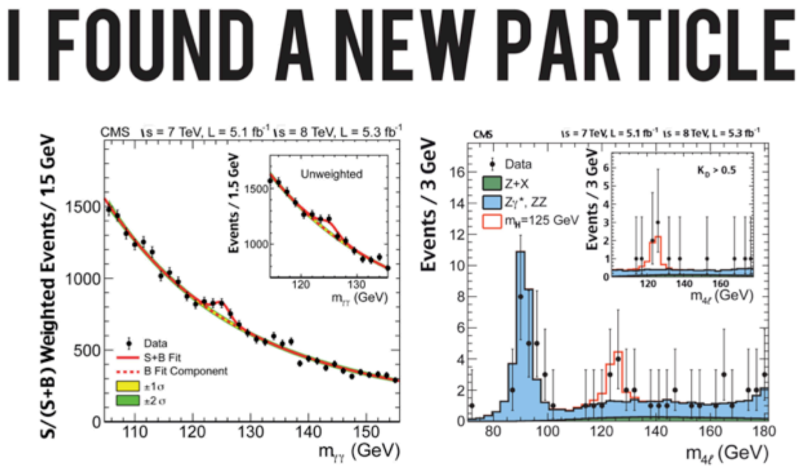
http://dx.doi.org/10.1016/j.physletb.2012.08.021

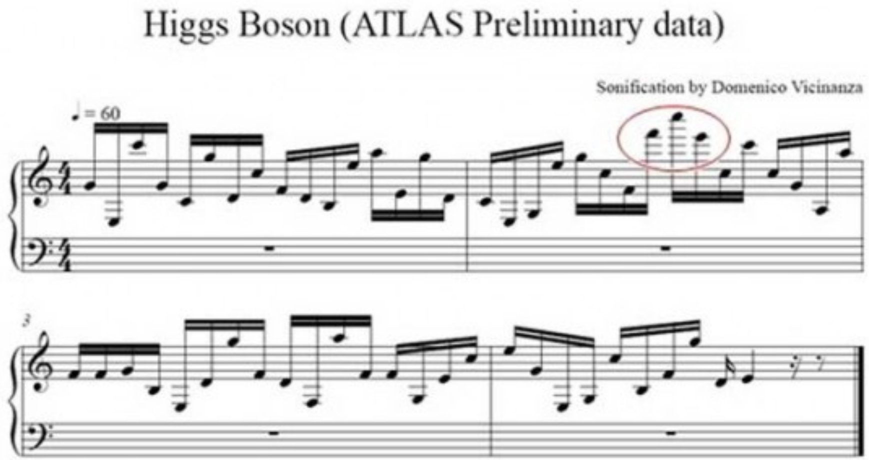
Higgs Discovery on July 4^{th}, 2012 !



ATLAS T-shirts



CMS T-shirts



http://www.geekosystem.com/higgs-boson-song/

→ talks by Fabio Cerutti (ATLAS)
and by Andre Tinoco Mendes (CMS)

LHC Higgs Cross Section Working Group

ATLAS ⊕ CMS ⊗ Theory

SM XS TF
MC Group

Statistics
Forum

Creation announced in January 2010.
Kickoff meeting on February 3, 2010.

Workshops in Torino (Nov. 2009), Freiburg (April 2010), CERN (July 2010), Bari (Nov. 2010), BNL (May 2011), Paris (Nov. 2011), CERN (May 2012)

Task: **SM and MSSM Higgs Cross Section and BRs**

- Uncertainty estimation (scale, α_s, PDF, etc.)
- Monte Carlo at NLO for signal and bkg.
- **Higgs Property Measurements**
- **BSM Higgs Scenarios**

11 Working Subgroups:
ggF, VBF, WH/ZH, ttH, MSSM
Light Mass Higgs, Heavy Higgs/BSM
BR, Jets, NLO MC, PDF

PDF4LHC
WG

LHC Higgs
Combination
WG

LHC Higgs XS WG CERN Report

CERN–2011–002
17 February 2011

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Handbook of LHC Higgs cross sections:
1. Inclusive observables

Report of the LHC Higgs Cross Section Working Group

S. Dittmaier
C. Mariotti
G. Passarino
R. Tanaka

GENEVA
2011

CERN–2012–002
15 January 2012

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Handbook of LHC Higgs cross sections:
2. Differential Distributions

Report of the LHC Higgs Cross Section Working Group

Editors: S. Dittmaier
C. Mariotti
G. Passarino
R. Tanaka

GENEVA
2012

CERN Report 1 went out before the 1st Higgs results of LHC !
(very much appreciated by the collaborations)

64 authors
151 pages
370 references

# of citations = 200 as of Dec. 5, 2012

120 authors
275 pages
456 references

# of citations = 107 as of Dec. 5, 2012

Higgs Physics Theoretical Issues

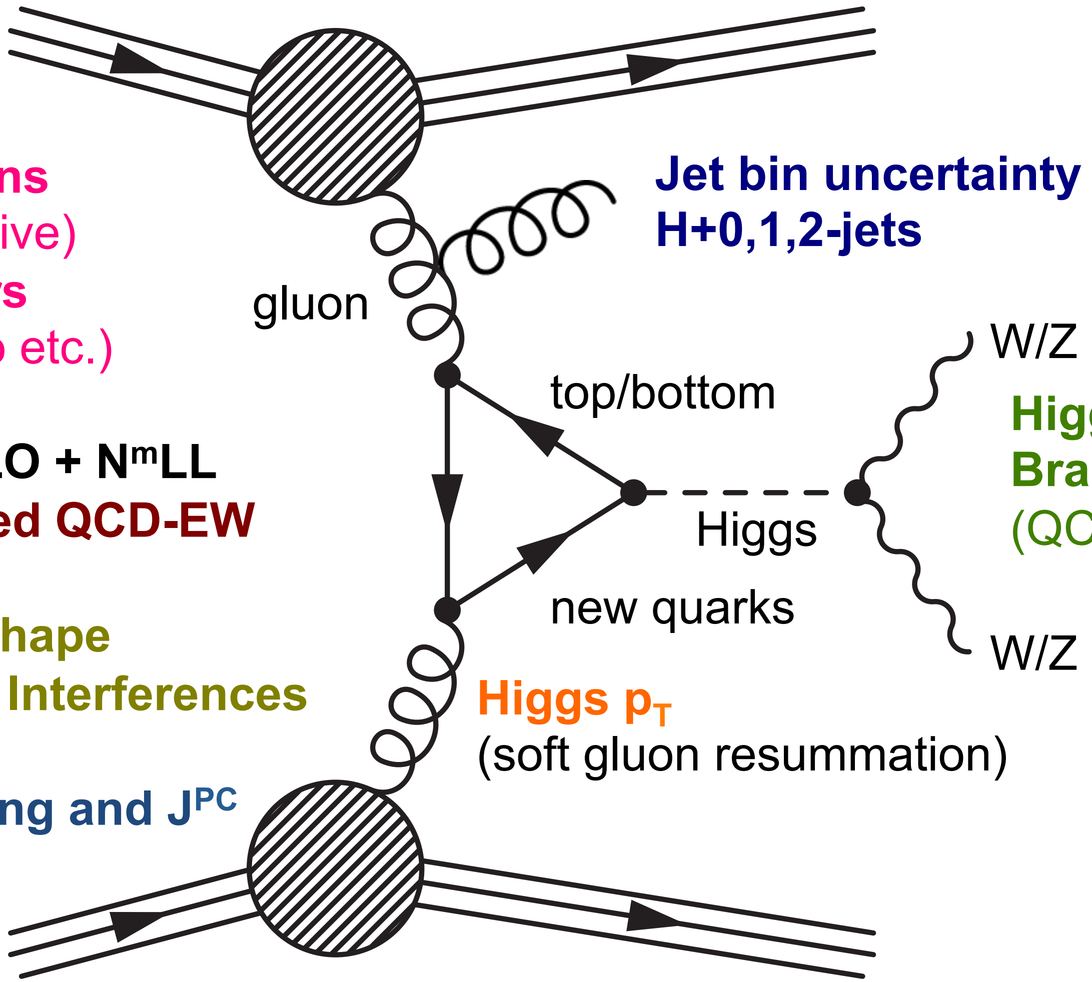
ggF, VBF, WH/ZH, ttH, BSM Higgs

Higgs Cross Sections
(inclusive/exclusive)
Differential K-factors
(effect of jet-veto etc.)

QCD correction $N^kLO + N^mLL$
EW correction, Mixed QCD-EW

Heavy Higgs Line Shape
SM Backgrounds & Interferences

Higgs Mass, Coupling and J^{PC}



Jet bin uncertainty
H+0,1,2-jets

Higgs decay
Branching ratios
(QCD/EW corr.)

Higgs p_T
(soft gluon resummation)

PDF+α_s uncertainties
Renormalization/Factorization scale dependence

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 (NNLO QCD)
ggh@NNLO (NNLO QCD)

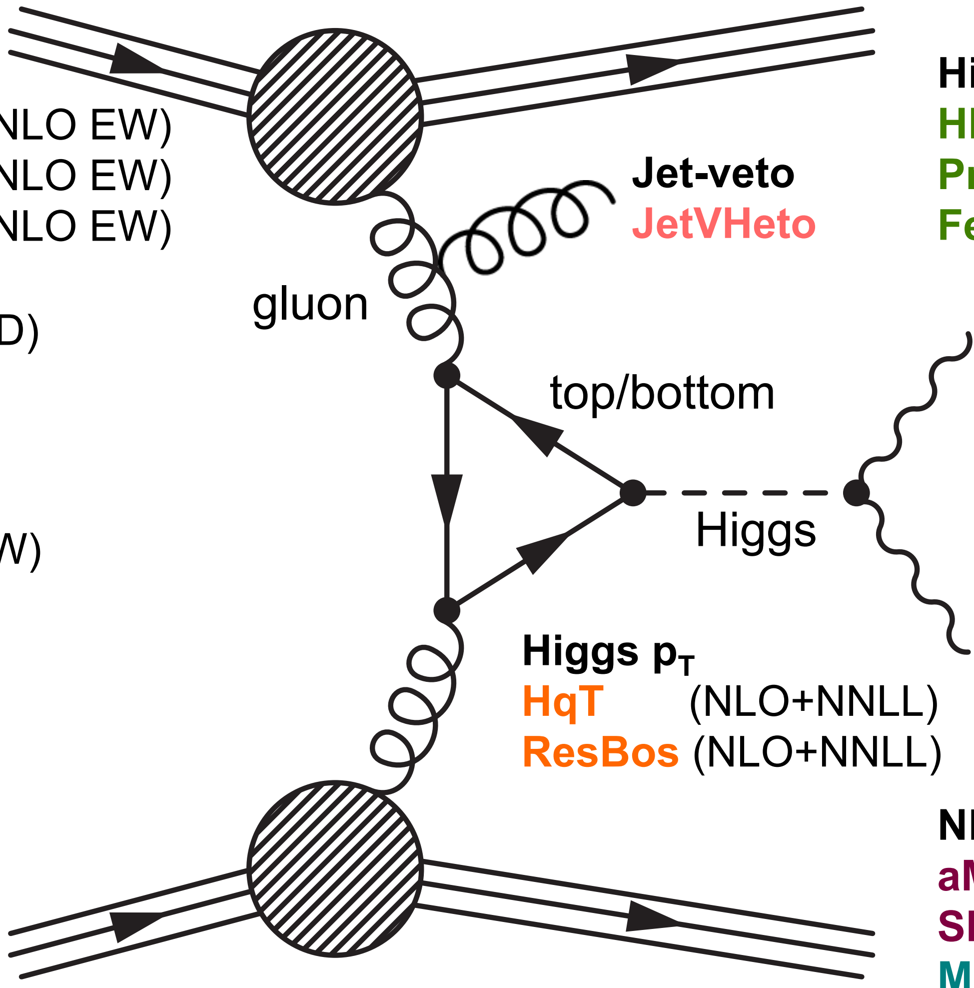
VBF
VV2H (NLO QCD)
VBFNLO (NLO QCD)
HAWK (NLO QCD+EW)
VBF@NNLO (NNLO)

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

ttH
HQQ (LO QCD)

bbH
bbH@NNLO (NNLO QCD)

+ private codes.



Jet-veto
JetVHeto

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

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

Higgs Properties
MELA/JHUGen
MadGraph5

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

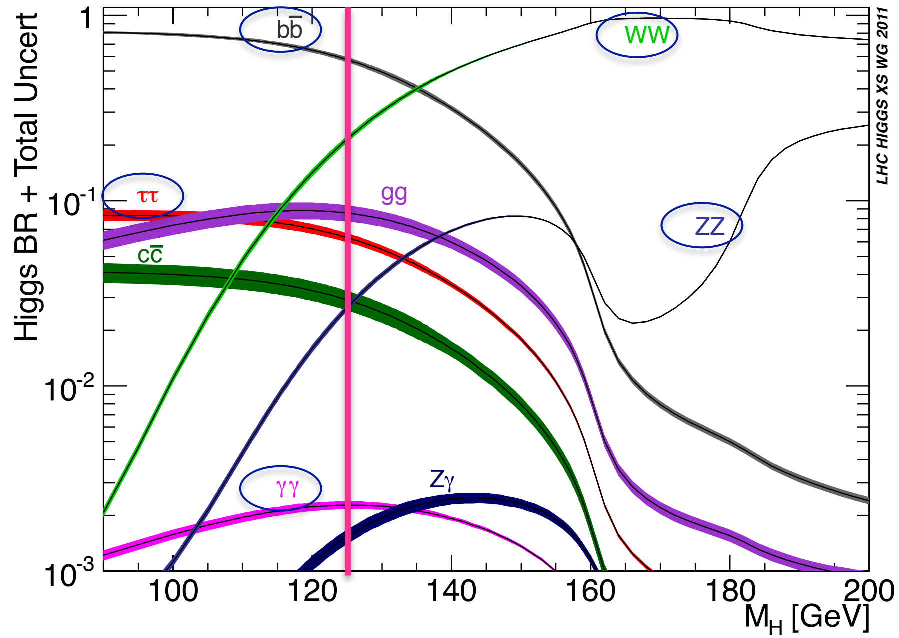
PDF: MSTW2008, CT10, NNPDF2.1, etc.

Higgs Property Measurements

- Main question now: is Higgs signal at M_H=126GeV SM like ?
  → Higgs mass, coupling and J^{PC}.

- Precision Higgs Physics
  - HCP2012: declaration that hadron collider machine can do precision physics !
  - Theory uncertainty is becoming more and more important than ever before !
  - Any improvements are welcome !

- Experimental Challenges
  - Clear separation of ggF, VBF, WH/ZH and ttH
  - Improve Higgs mass measurements (FSR etc.)
  - Other decay modes than big 5: H→μμ, Zγ, invisible, HH, etc.
  - SM Higgs as background ?
  - How to carry out BSM/Heavy Higgs ?



Higgs Property Measurements

Q1) What could be the target for near future improvements ?

- Higher-order calculations (ex. NNNLO in ggF, scale uncertainty < 5%?)
- PDF measurements with LHC data (gg parton luminosity < 5%?)
- Better prediction on the differential distributions in Higgs and SM bkg.
- Reduction of jet-bin uncertainty, ggF in 2-jet bin (VBF) category & fat jets.
- Interference effects between Higgs and SM continuum, ex. γγ, WW, ZZ.

→ talks by ALL subgroups

Q2) Which tools do experimental collaborations need ?

- Tools for Higgs property measurements, ex. MELA/JHUGen, MadGraph5
- NLO MC's for Higgs and SM backgrounds, ex. H+jj

→ talks by Light Mass Higgs, Jets and NLO MC subgroups

BSM Higgs

- Finding the hint of BSM physics is one of the most important issue !

Q3) What is the implication of 126GeV Higgs for MSSM scenario ?

- MSSM, NMSSM, BMSSM, pMSSM, …

→ talk by MSSM subgroup

Q4) What could be the benchmark process for BSM Higgs searches ?

- Singlet, 2HDM, Dilaton, Composite, …
- But BSM Higgs world is too vast (for me) ! What is the optimal strategy ?

→ talk by BSM subgroup

Q5) Prescription for heavy Higgs search up to M_H=1TeV ?

- Interference effects in gg→(H)→WW/ZZ.
- Strategy for $V_L V_L$ scattering study.

→ talk by Heavy Higgs subgroup

Organization Matter

- Currently 11 subgroups
  - Higgs Productions: ggF, VBF, WH/ZH and ttH
  - Common Issues: BR, Jets, NLO MC and PDF
  - Light Mass Higgs (Higgs coupling and J^{PC})
  - MSSM
  - Heavy Higgs / BSM

Q6) Could there be better organization or new subgroup ?

- Reinforce Light Mass Higgs and BSM subgroups ?

Q7) How to involve more theorists and experimentalists ?

- From Asia and America in particular.

CERN Report 3 and Future Activities

- CERN Report 3 “Higgs Property Measurements”
  - Initial target is to publish before Moriond 2013 for full 2012 data analyses.

Prescription of the Higgs X-section WG
A.David et al, arXiv:1209.0040
Let’s agree to make them de-facto standard for communication between experiments and the theoretical community (the keepers of the ‘physics’ content being the Higgs X-section WG)

T. Camporesi, HC2012, Tokyo

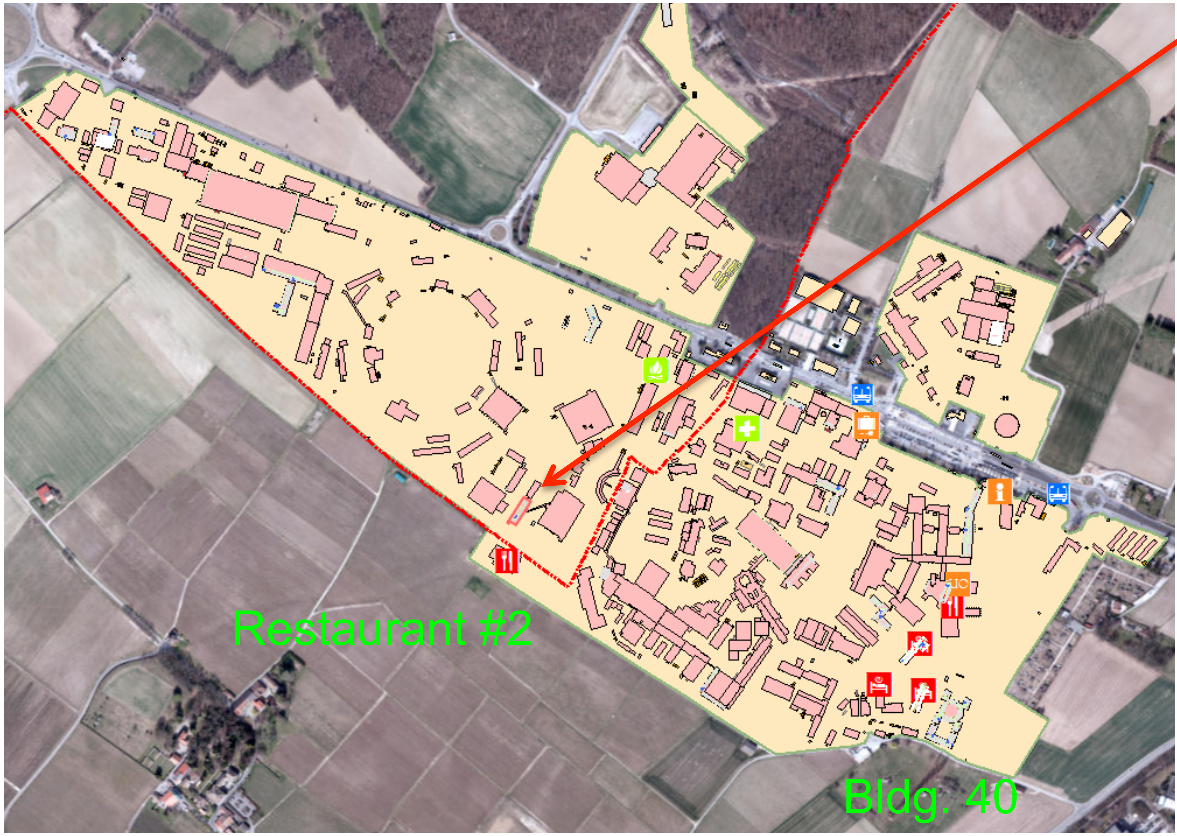
- LHC long shutdown 2013-2014
  - Now time to start thinking about what to do during the shutdown.

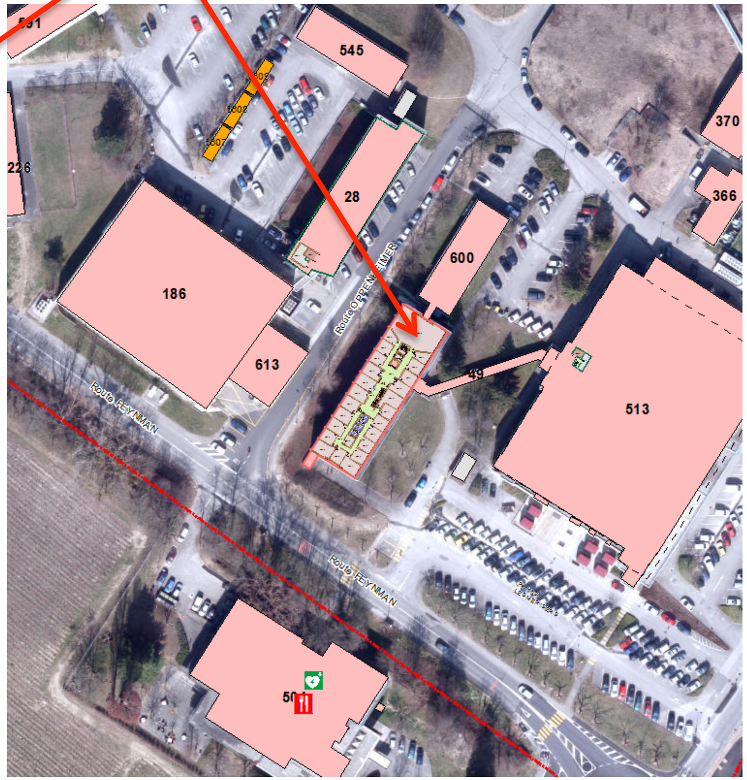
- European Strategy Report
  - So far for HL-LHC (14 TeV, 3 ab^{-1} by ~2030) on Higgs coupling, including the Higgs self-coupling.
  - Further study for HE-LHC (33 TeV or above?).

Let’s discuss in the closing session !

Logistics

- No social dinner this time …
  - Find your friends for dinner tonight !
- Tomorrow afternoon session at IT-division Auditorium (Bldg. 31-3-004)





Restaurant #2