Observation of a Higgs-like Boson at CMS

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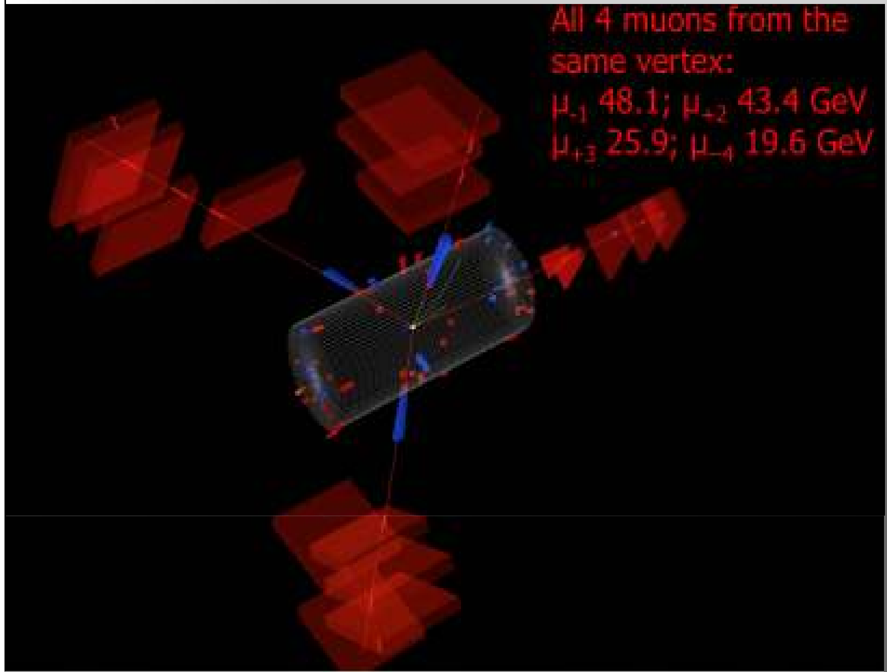
14 September 2012

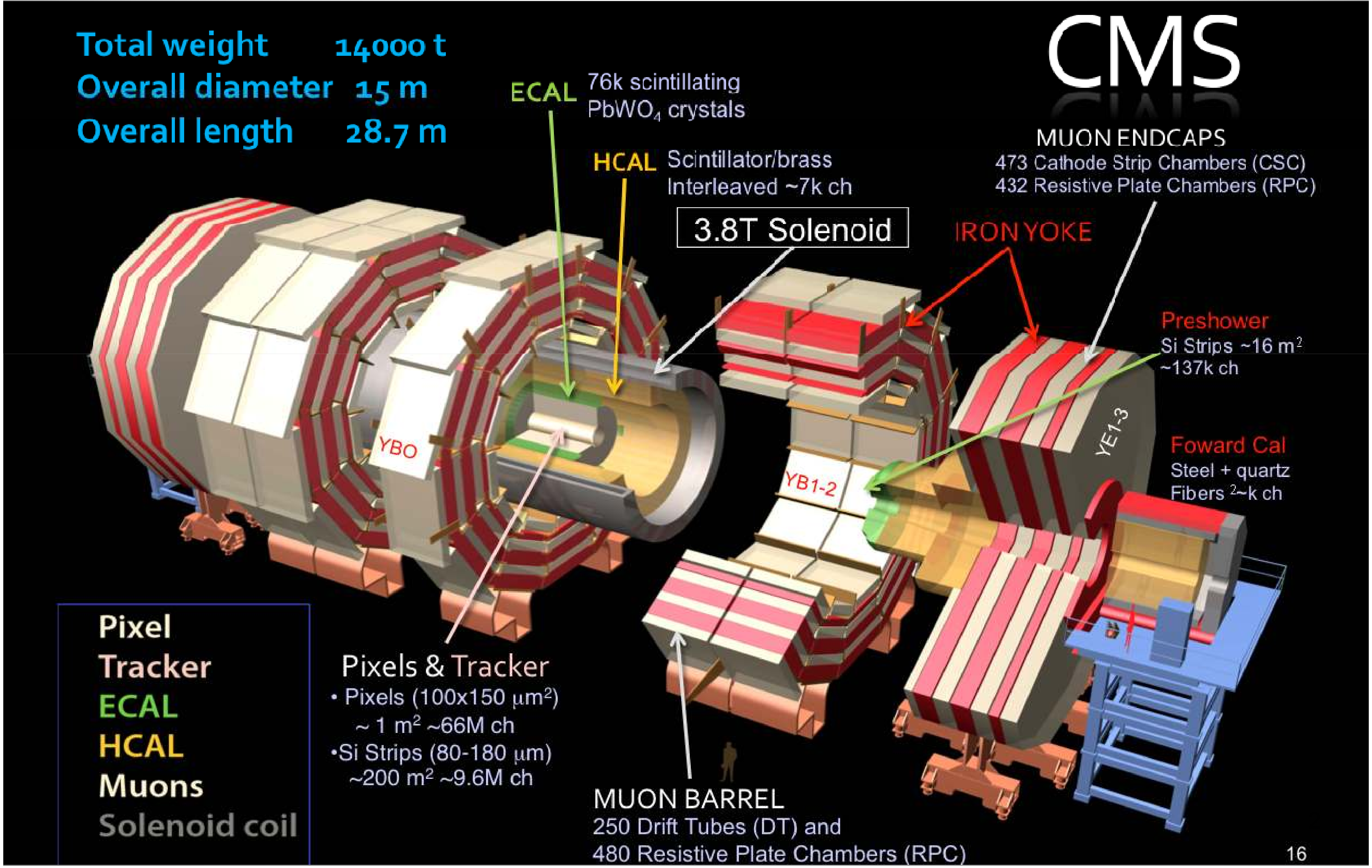
Outline



The first pp -> ZZ event
seen at the LHC in 2010
4-μmass ~ 200 GeV

- Introduction:
- Summer/Fall 2011: the first LHC exclusion wave
- December 2011: first sightings of a bump
- Summer 2012
  - The observation of a new particle at 125 GeV
- The next steps/Future
- Summary

The CMS Detector



July 4th 2012   17:00 Melbourne

- Official announcement of the observation of a Higgs-like particle with mass of 125-126 GeV by CMS and ATLAS.
- Historic seminar at CERN with simultaneous transmission and live link at the large particle physics conference of 2012 in Melbourne, Australia

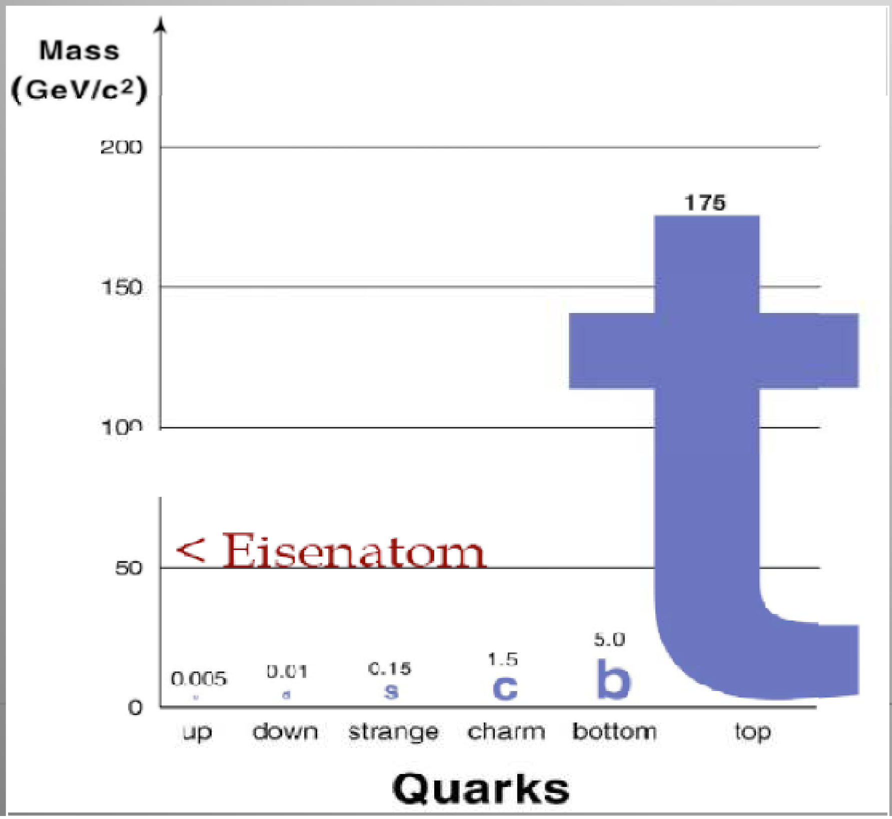
Melbourne

The Origin of Particle Masses

A most basic question is why particles have masses
…and so different masses

Peter Higgs

The mass mystery could be solved with the ‘Higgs mechanism’ which predicts the existence of a new elementary particle, the ‘Higgs’ particle (theory 1964, P. Higgs, R. Brout and F. Englert)



The Higgs (H) particle has been searched for since decades at accelerators, but was not found…

The LHC will have sufficient energy to produce it for sure, if it exists

Francois Englert

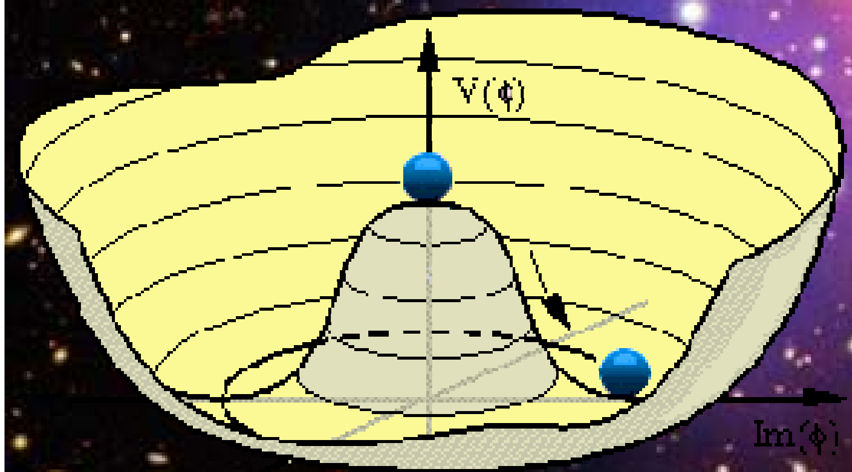
The Hunt for the Higgs

Where do the masses of elementary particles come from?

The key question: Where is the Higgs?

Massless particles move at the speed of light -> no atom formation!!

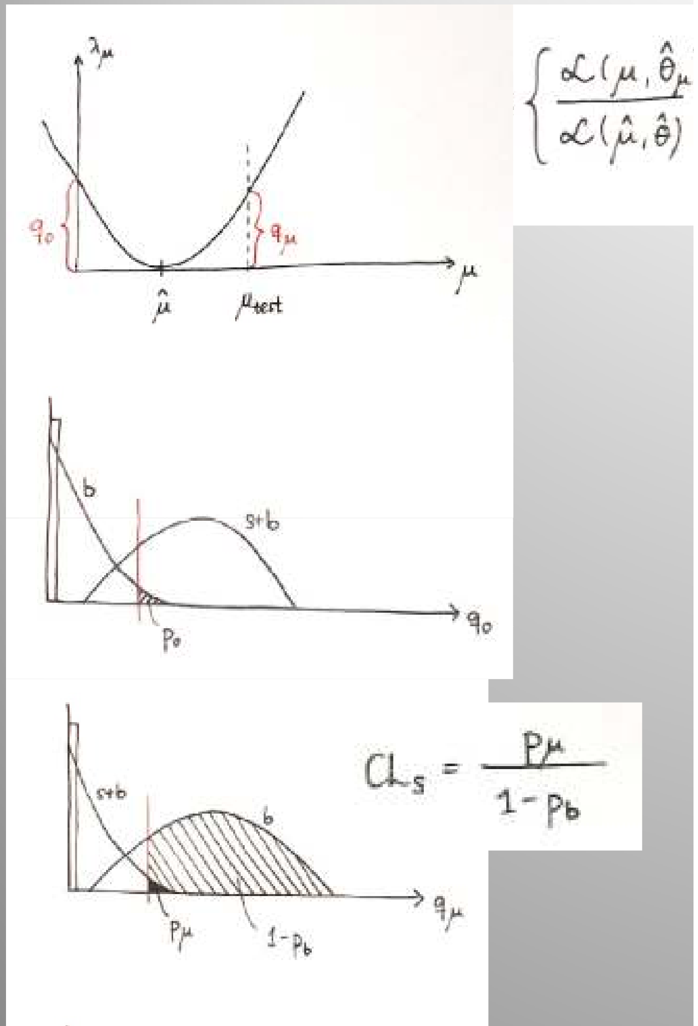
We do not know the mass of the Higgs Boson



Scalar field with at least one scalar particle

It could be anywhere from 114 to 700 GeV

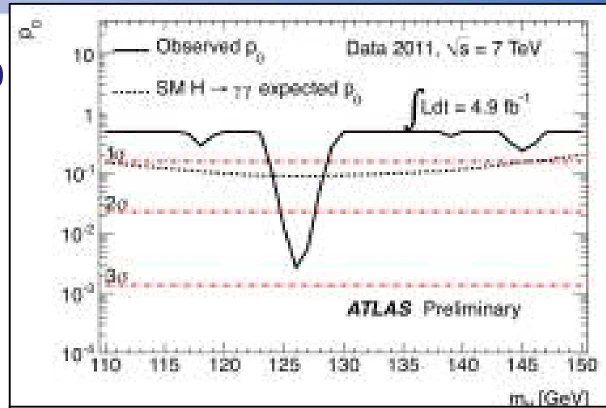
Aside: Profile likelihood Ratio, p_0 and CL_s

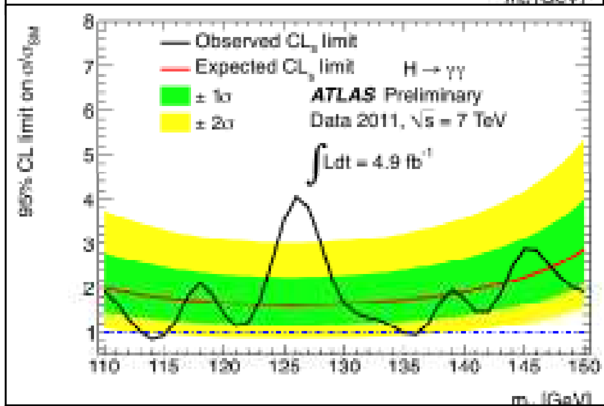


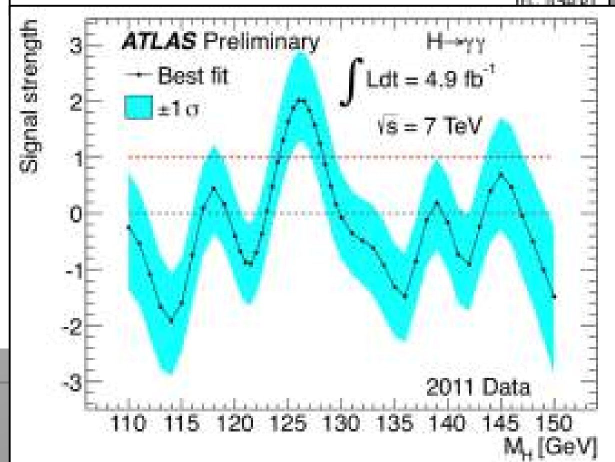
- Local significance p_0 to test background hypothesis

- $CL_s = CL_{s+b}/CL_b$ (log-likelihood ratio) to test signal hypothesis

- $\hat{\mu}$ to estimate signal strength (relative to expectation)

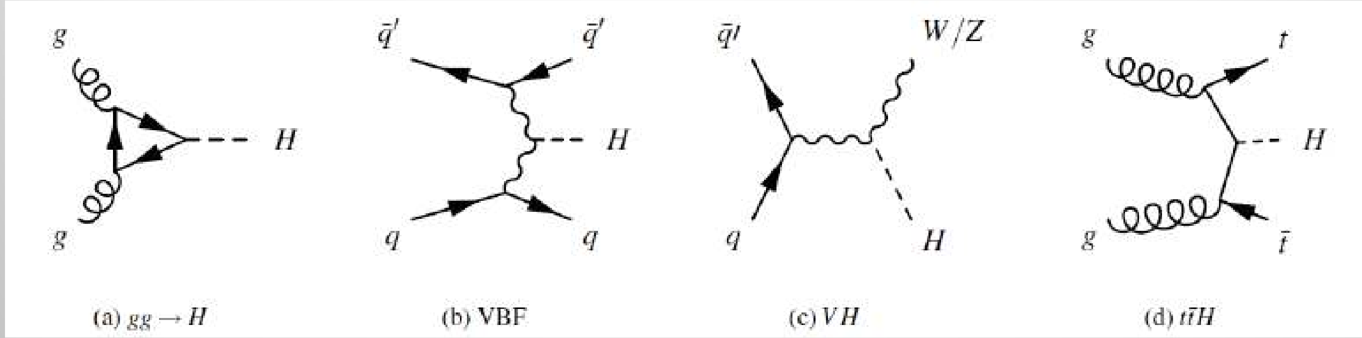






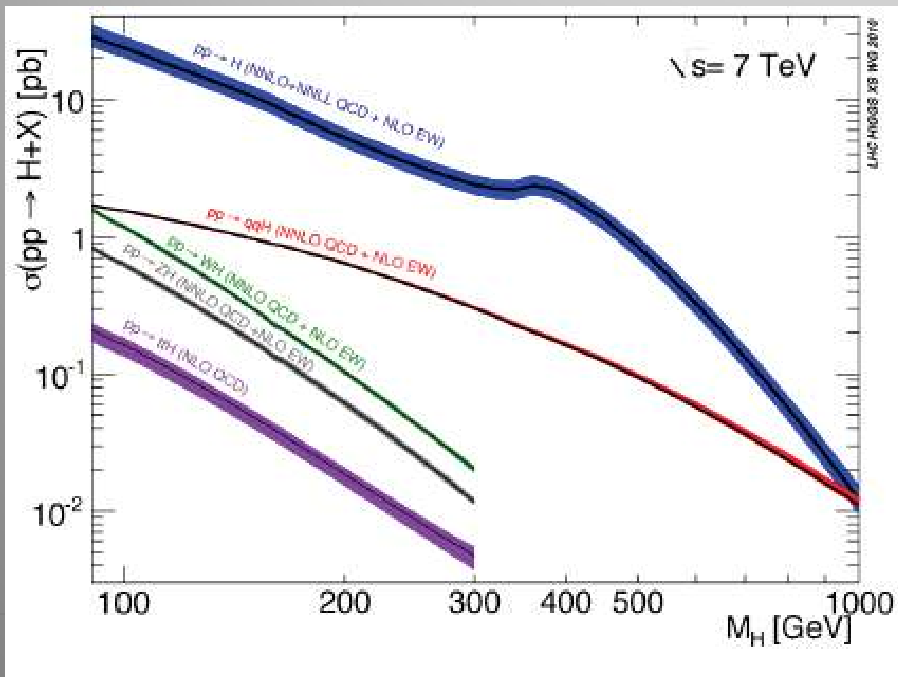
Follow LHCHCG Combination Procedures

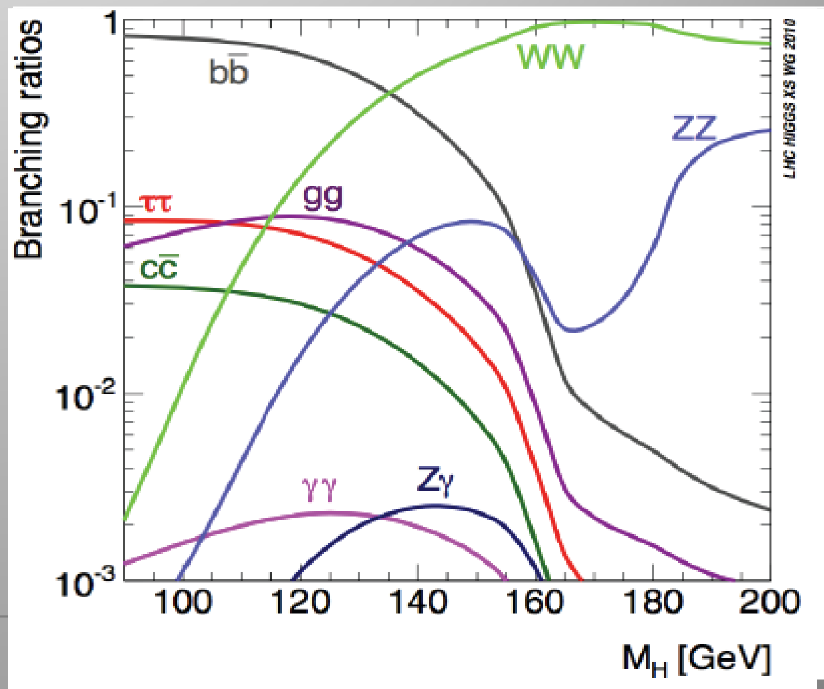
Higgs Searches



Production: gg fusion, VBF and VH, (ttH)

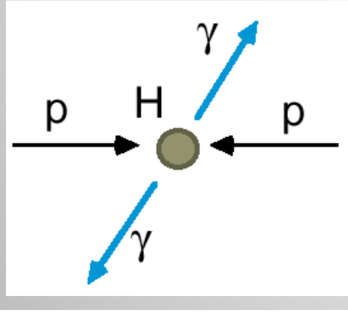
Decay: γγ, ZZ, WW, tautau, bb,…

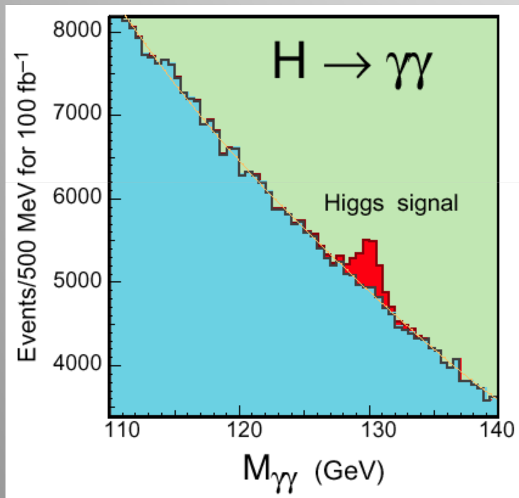


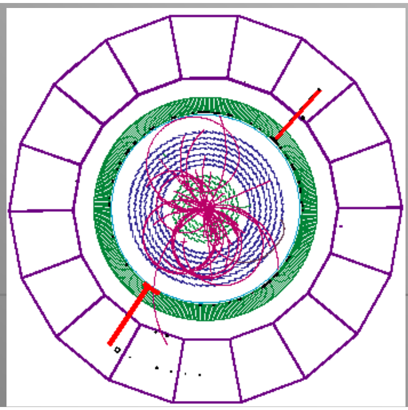


Higgs Boson Searches

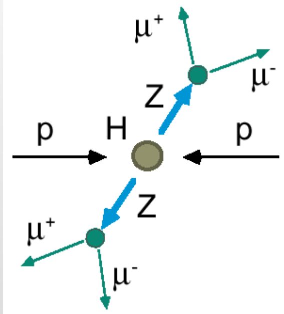
Low $M_H < 140$ GeV/c²

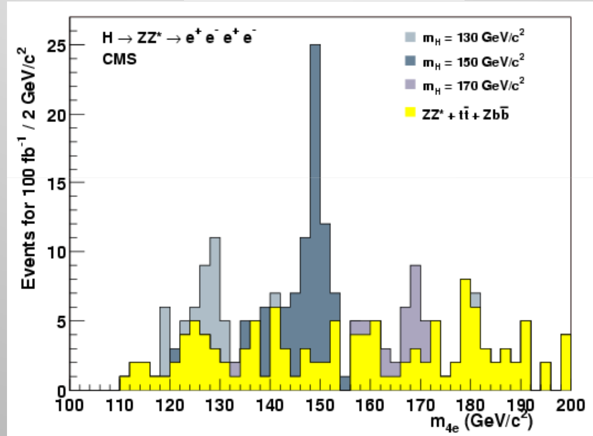


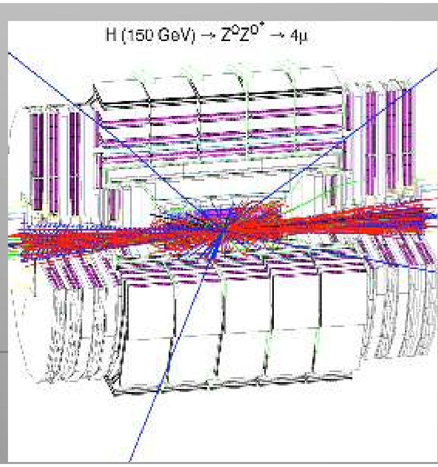




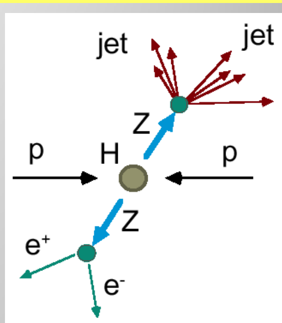
Medium $130<M_H<500$ GeV/c²

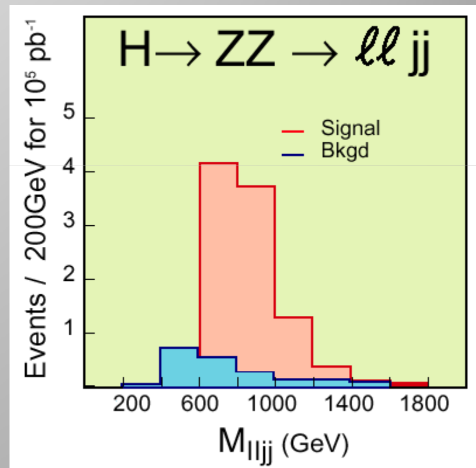


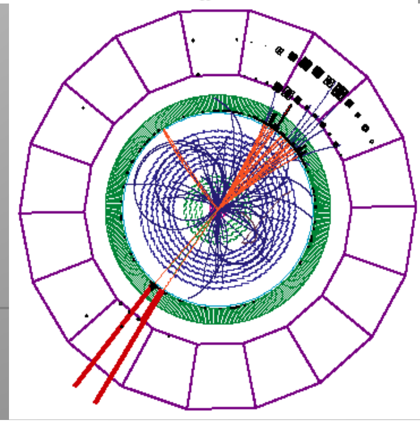




High $M_H >$ ~500 GeV/c²







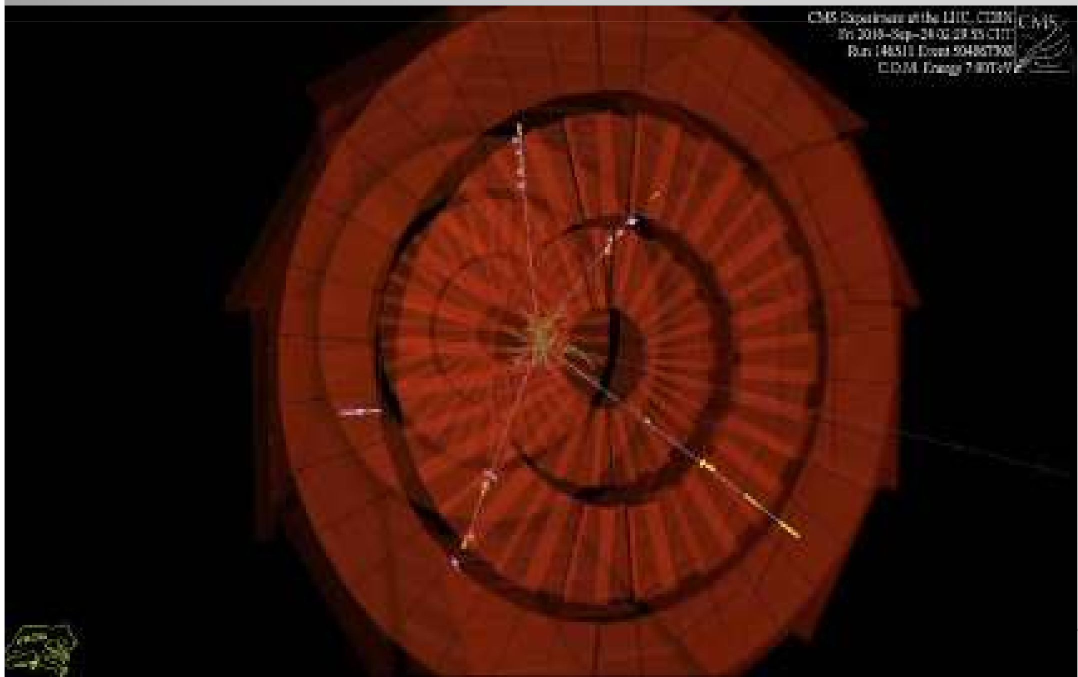
Searches for the Higgs Particle

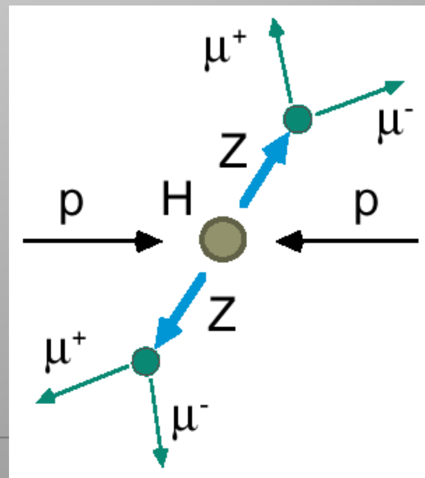
A Higgs particle will decay immediately, eg in two heavy quarks or two heavy (W,Z) bosons

Example: Higgs(?) decays into ZZ and each Z boson decays into μμ

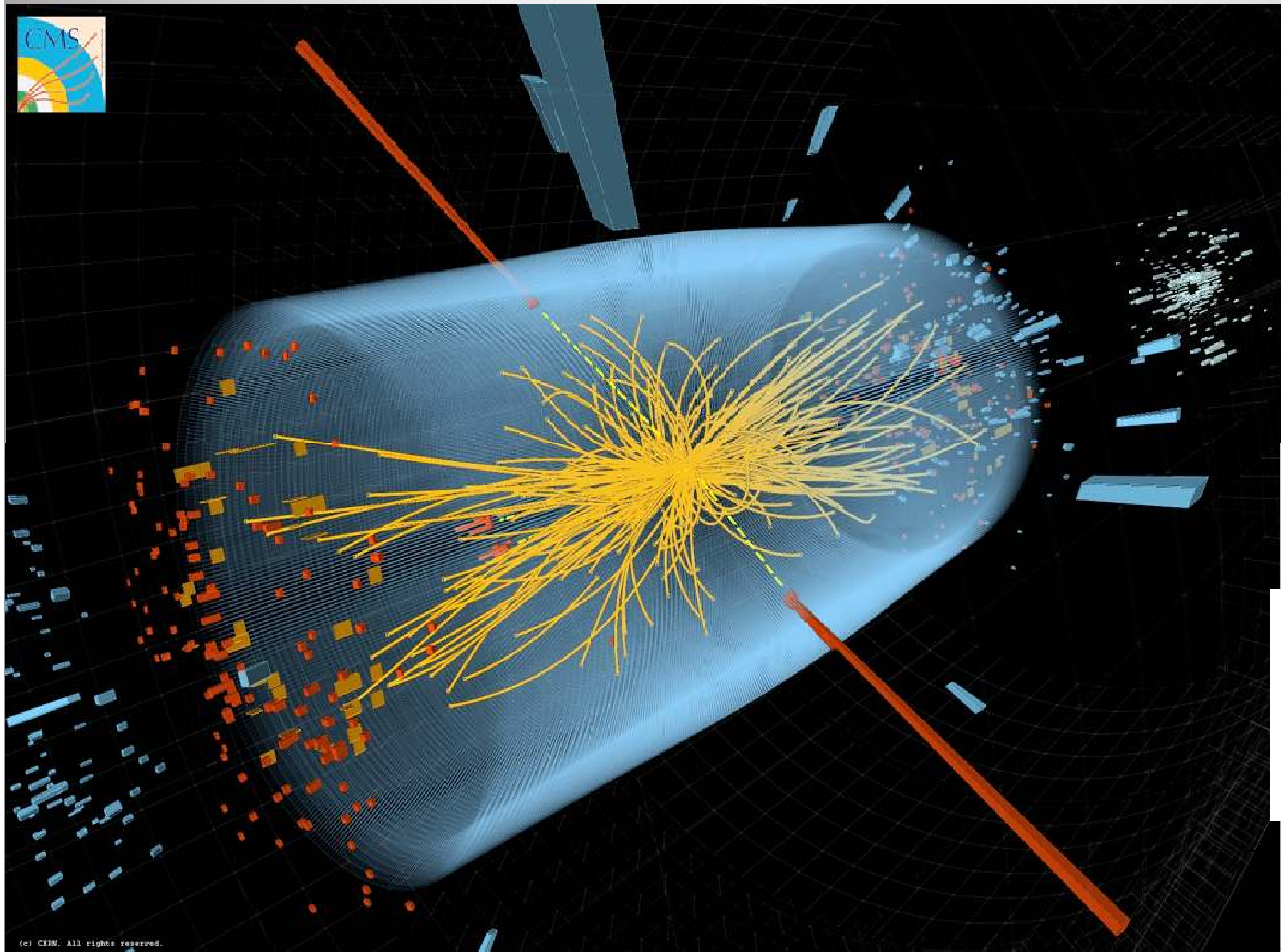
So we look for 4 muons in the detector

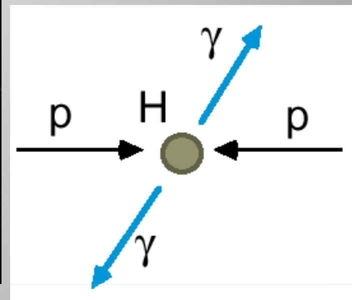
But two Z bosons can also be produced in LHC collisions, without involving a Higgs!
We cannot say for on event by event (we can use the total invariant mass of the 4 muons)





A Collision with two Photons



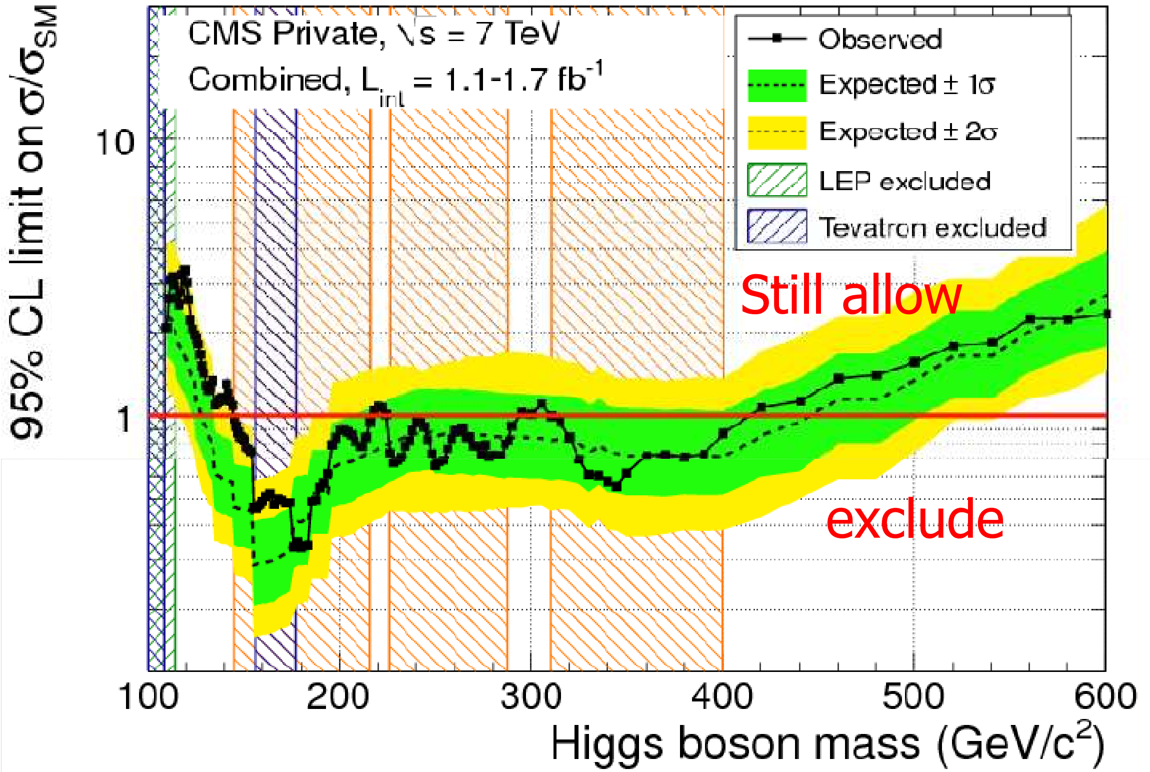


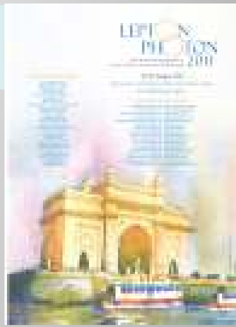
A Higgs or
a 'background'
process without
a Higgs?

Summer-Fall 2011

Where is the Standard Model Higgs Boson?

Summary of the results shown at the Lepton-Photon conference





No Higgs found yet!

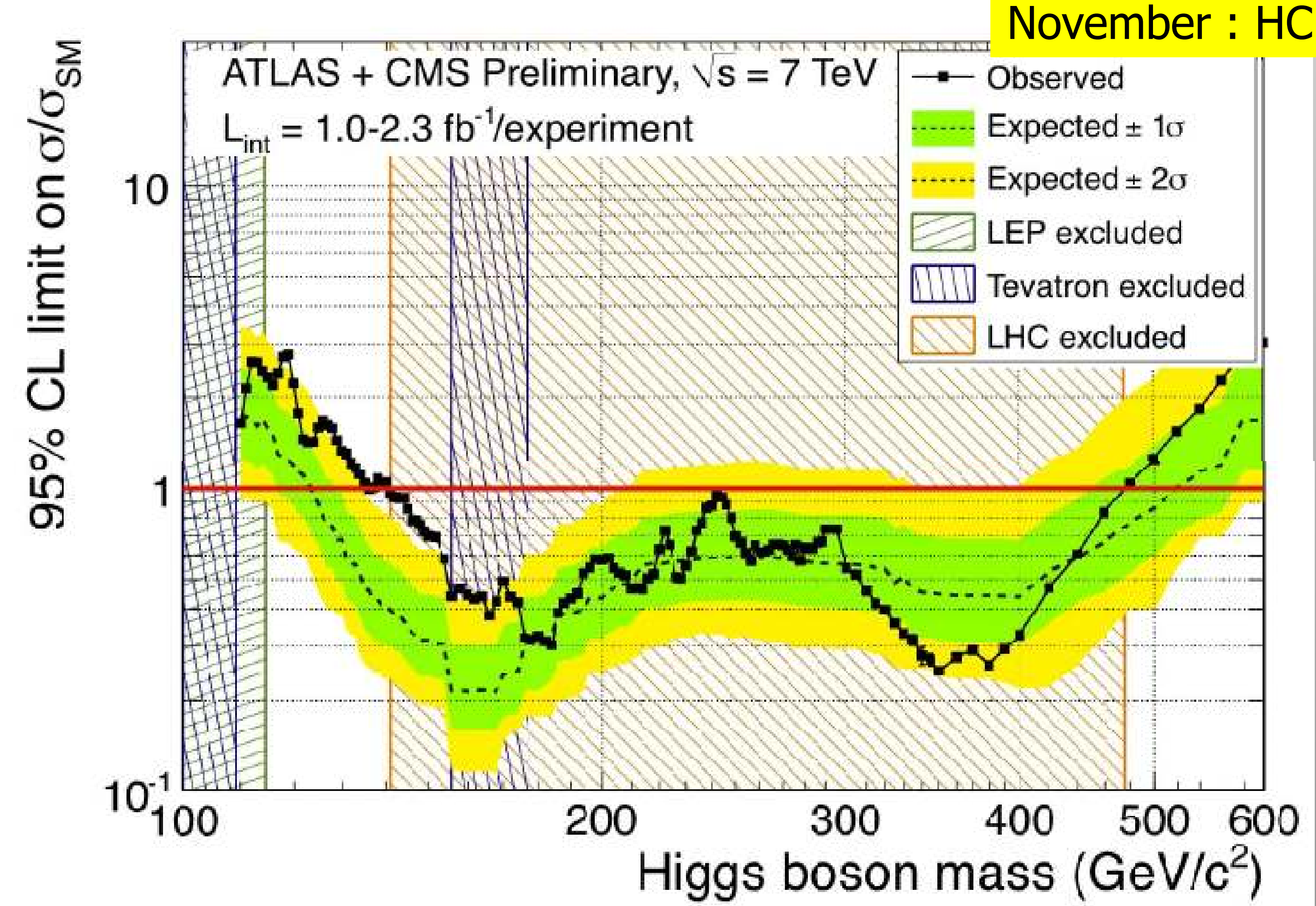
- Experiments sensitive to a Higgs Boson with mass 130-440 GeV so far
- Exclude the mass region 145-400 GeV

If we would exclude the Higgs in the full range, this would be a major discovery!!!

New Phenomena are expected to be observed ~1 TeV @ LHC

ATLAS+CMS Higgs Combination

November : HCP Paris



Observed 95% CL exclusion mass range: 141-476 GeV

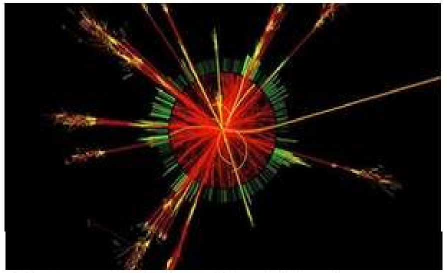
Higgs can live only in the interval 114.4 -141 GeV or above 476 GeV

News in the Press…

Higgs boson range narrows at European collider

By Pallab Ghosh
Science correspondent, BBC News

Scientists at the Large Hadron Collider say a signal that suggested they might have seen "hints" of the long-sought Higgs boson particle has weakened.



Data from sub-atomic particle collisions has more than doubled in the space of just three weeks

New results to be presented this week at a conference in India all but eliminate the mid-range where the Higgs - if it exists - might be found.

Physicists will now search for the boson at lower and higher energy ranges.

Higgs signal sinks from view

Early hints of the boson grow weaker with fresh data.

Geoff Brumfie

The Higgs boson, the most sought-after particle in all of physics, is proving tougher to find than physicists had hoped.

Higgs boson signals fade at Large Hadron Collider

Cern scientist says he sees 'no striking evidence of anything that could resemble a discovery' in hunt for Higgs boson

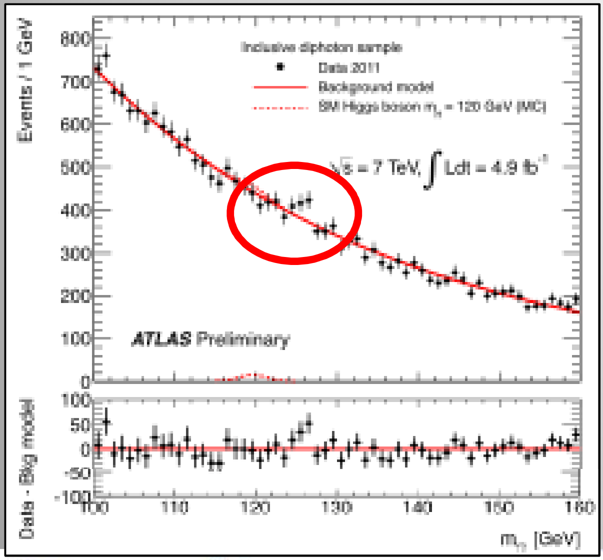
Ian Sample
guardian.co.uk, Monday 22 August 2011 17.10 BST
Article history

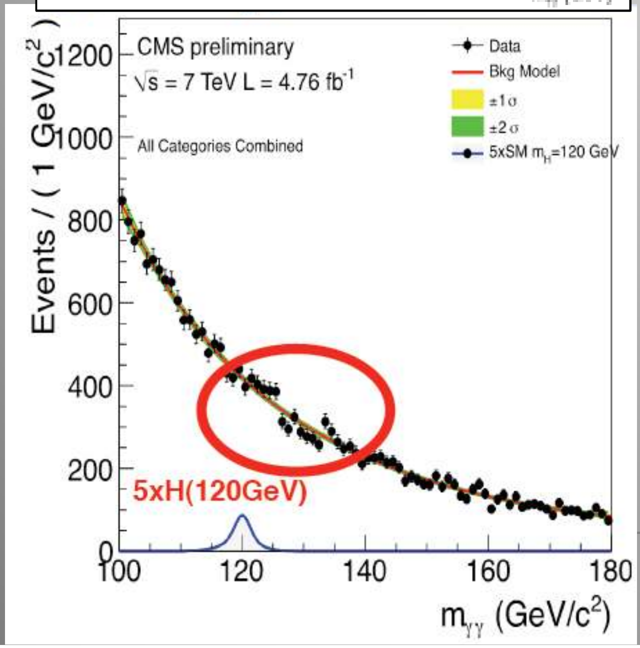
Screens show data from a collision at the Large Hadron Collider. Photograph: Denis Balibouse/Reuters

December 13 2011

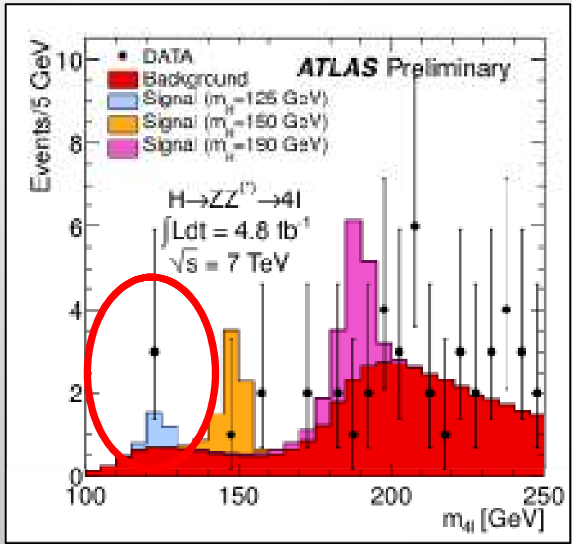
Results from the Experiments

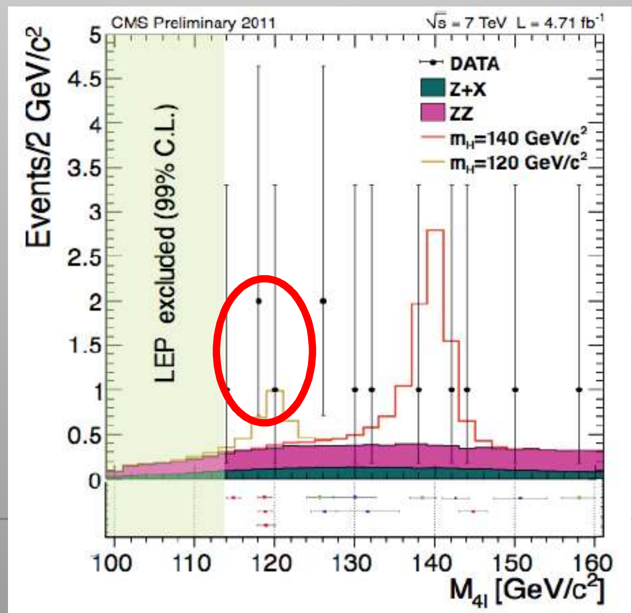
Higgs → 2 photons??





Higgs → 2 Z →4 leptons??





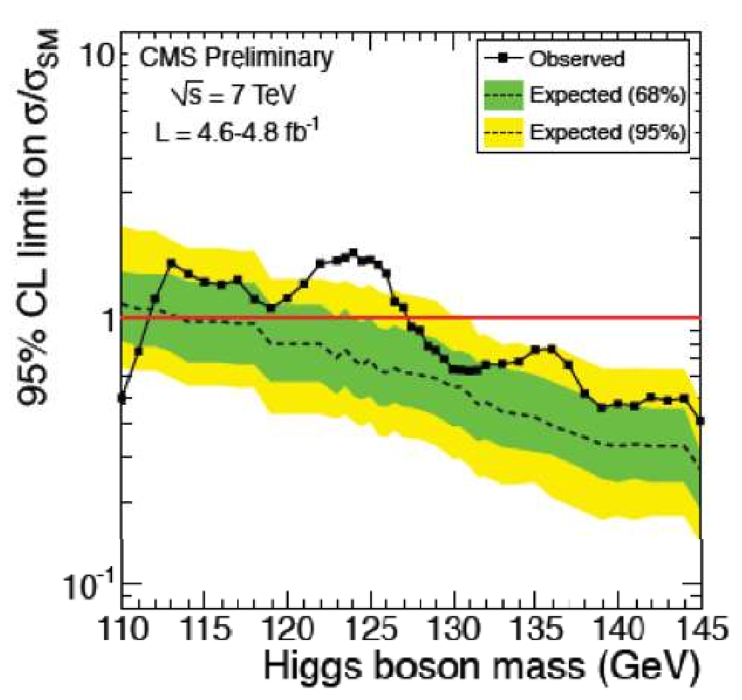
Some "excess" of events seen in both experiments within a mass range of 5-6 GeV. Low statistics.

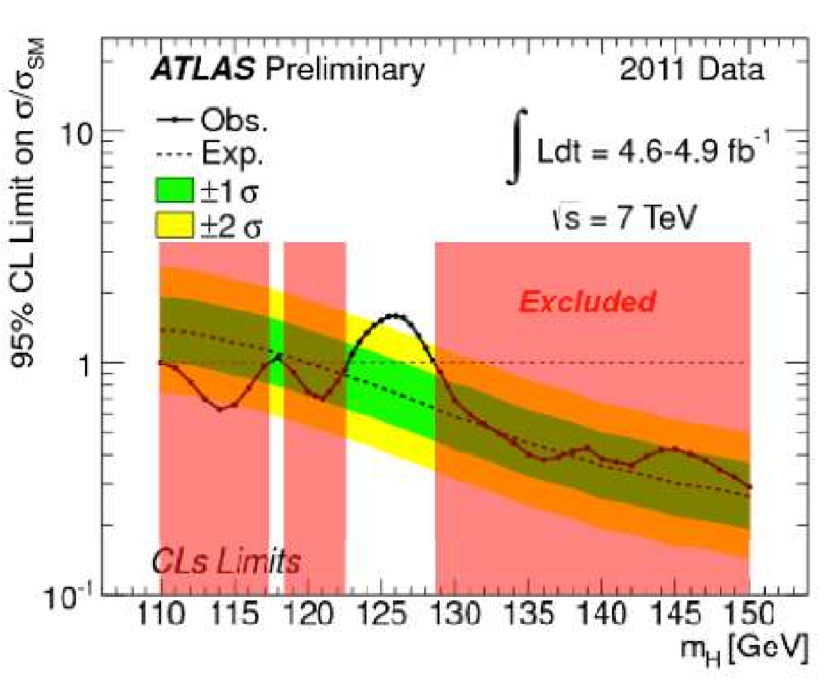
Is this significant? Not by eye!

But sophisticated Statistical Methods have used to fully analyse this.

And the result is…→

The Results of the Higgs Search 2011





Results

1) The mass region where Higgs particle can possibly live has been reduced to very small mass range of 115-130 GeV (95% CL)
2) We see an excess of events in that region over expectation from pure background. Cool!
   Is this the first sign of the 'growing Higgs signal?
   Is it a statistical fluctuation in the background? We can't say for sure.

→These questions will be answered with the 2012 data (4 x 2011 data)

So Where is the Higgs Boson?

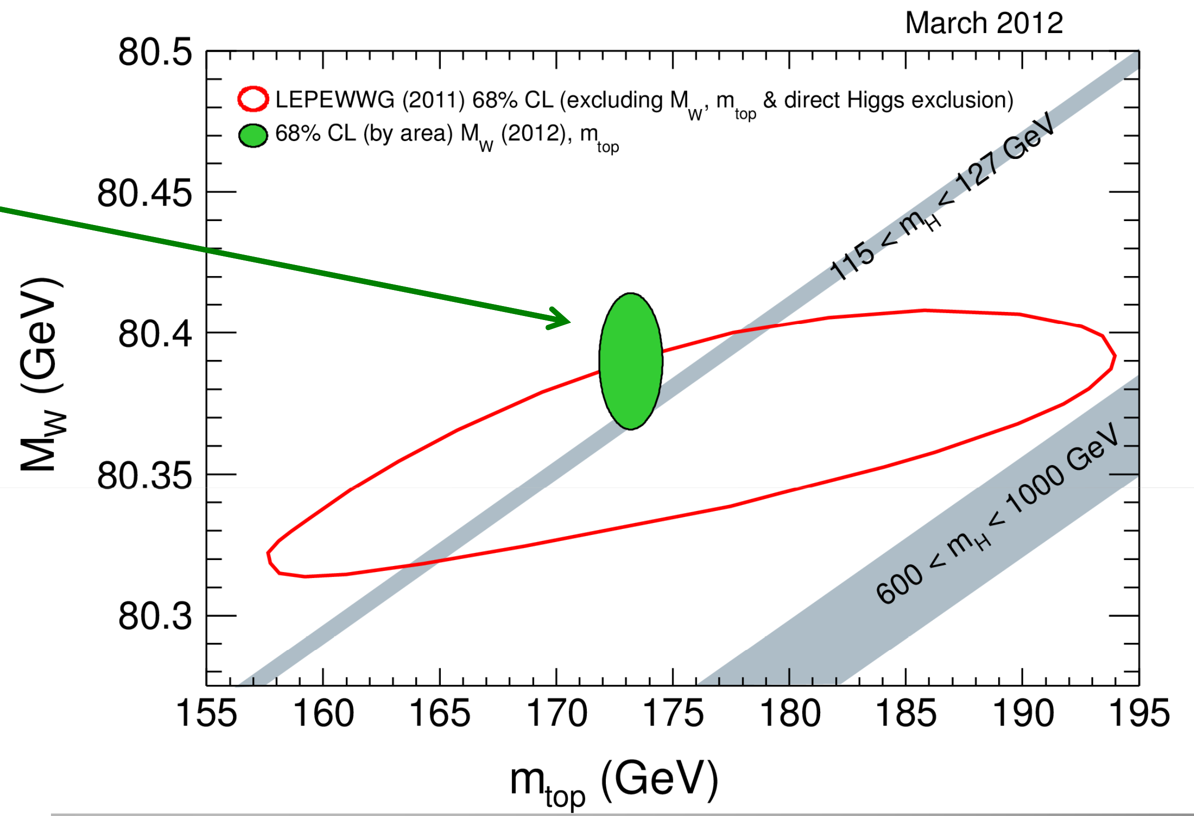
- The experiments analysed the new data, for the full year of 2011
- They can exclude an even larger range, and restrict the region for the Higgs to 115-130 GeV
- But.. they see a tantalizing excess in the “Higgs” mass range of 120-126 GeV. This is exciting!
- The significance of this excess is still far too low to claim a discovery, but a Higgs signal could just start to be seen just like that. The excess could still go away with more data.
- The LHC 2012 data will be the referee…These data were highly awaited for by the community…

  Maybe this was the first sign of life of the Higgs boson?

Summer 2012

Higgs Situation in Early 2012

Exquisitely precise measurement of M_W driven mainly by the Tevatron.



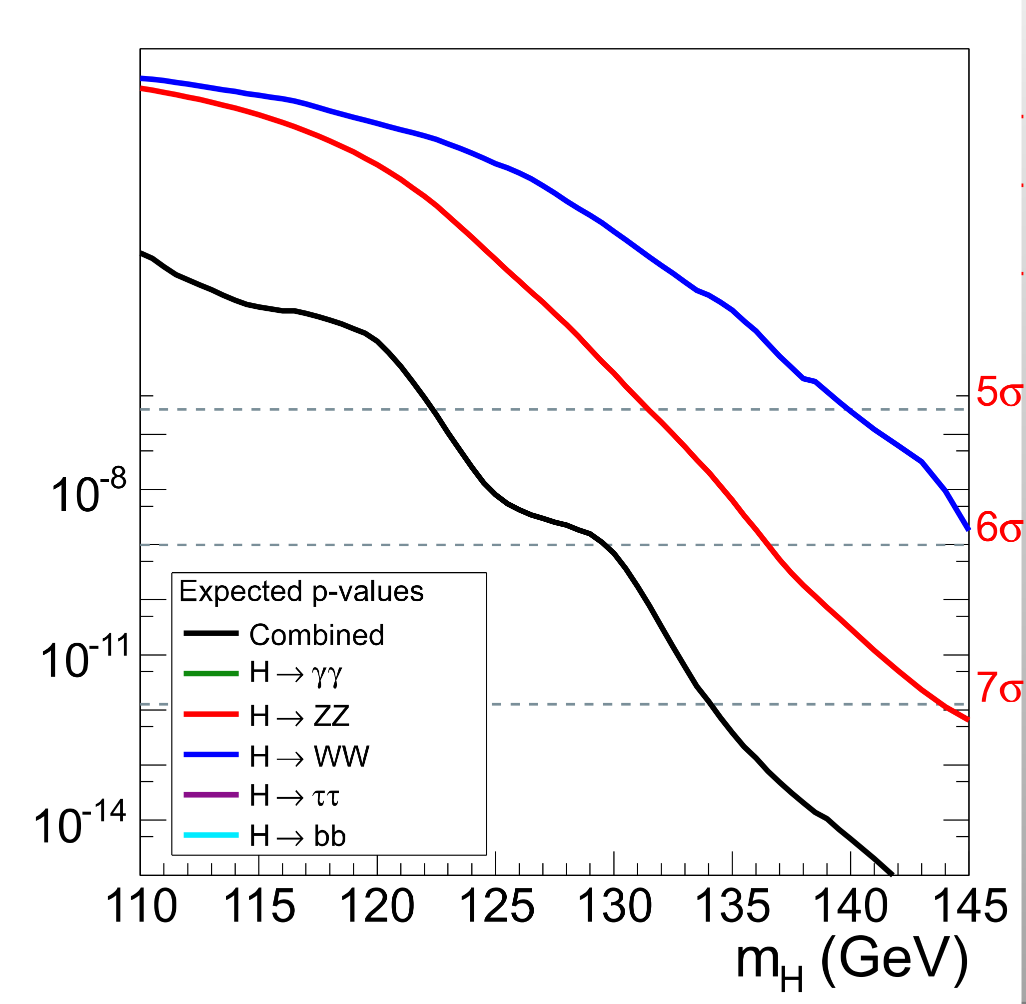
Much of the SM Higgs range has been ruled out by 2011 LHC running.

Exclusions of M_H:

- LEP < 114.4 GeV (arXiv:0602042v1)
- Tevatron [156,177] GeV (arXiv:1107.5518)
- LHC [~127, 600] GeV arXiv:1202.1408 (ATLAS); arXiv:1202.1488 (CMS)

Sensitivity vs Higgs Decay

Summer 2012: 5.1 fb-1 @ 7TeV and 5.3 fb-1 at 8 TeV



Most of the heavy lifting is done by γγ and ZZ, since those modes exploit the excellent mass resolution (~1%) of CMS.

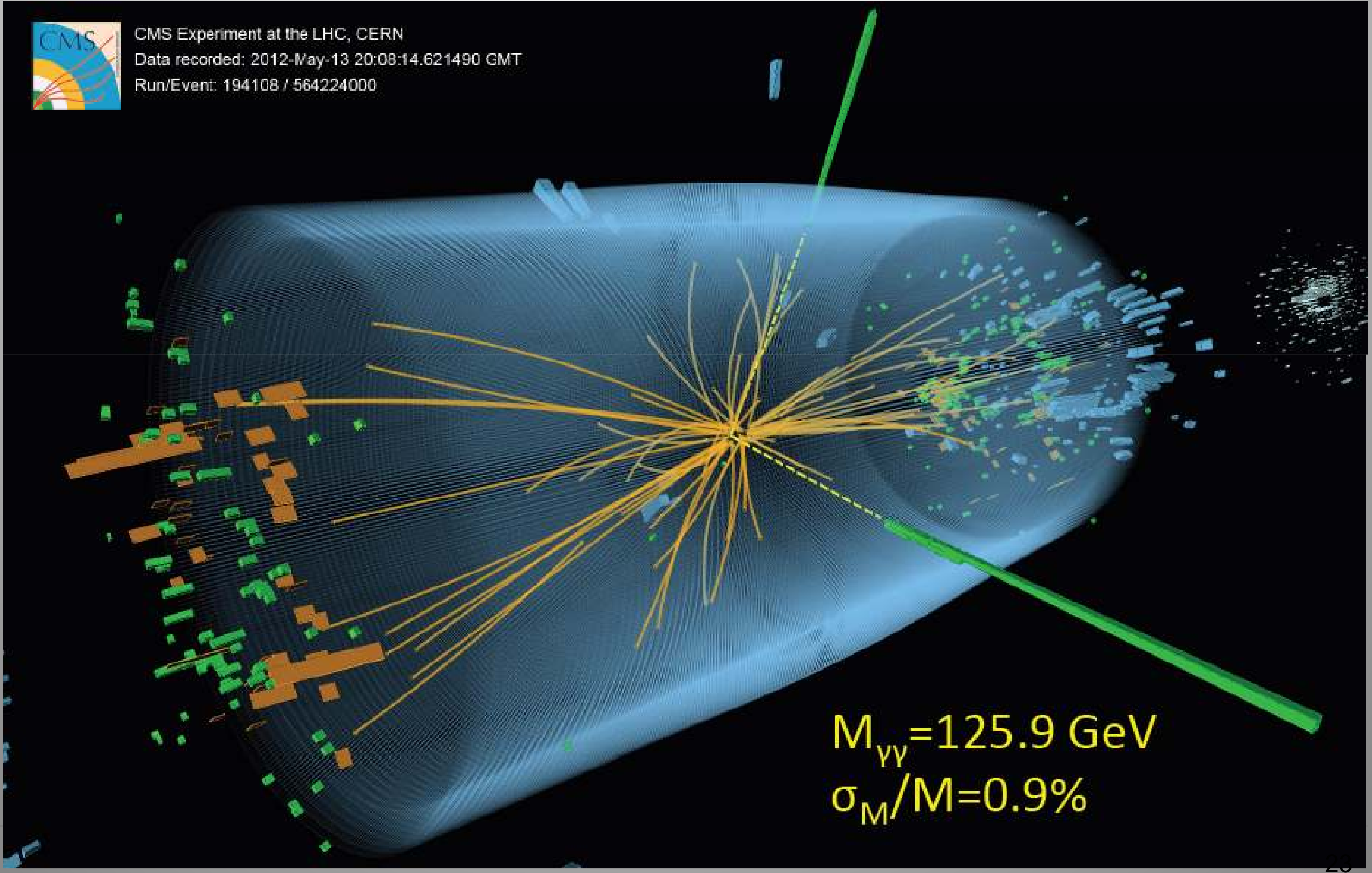
A discovery is possible!

Blinding the Data

Not to have a bias in the analysis we decided to analyse the 2012 data blinded
The unblinding in CMS was on June 15th
About 700 participants (400 persons in a room for 250 people, rest by video)

That day CMS knew whether they had a discovery or not…

H→γγ Channel


CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000
$M_{\gamma\gamma}$=125.9 GeV
σ_M/M=0.9%

H→2 Photons Analysis Strategy

- Multi-Variate Analysis (MVA) for photon ID and event classification
  - Divide events into non-overlapping samples of varying S/B based on properties of the reconstructed photons and presence of di-jets from VBF process
- Cross check with cut-based analysis
  - MVA and cut-based results consistent
  - MVA gives 15% better sensitivity
- Primary vertex selection, which is needed for $M_{\gamma\gamma}$ calculation, is based on consistency with di-photon kinematics (p_T balance etc.)
- Background fitted on the Mass spectrum with polynomial (3th to 5th order depending on the case)
- No Monte Carlo used, except for training

Higgs → 2 Photons

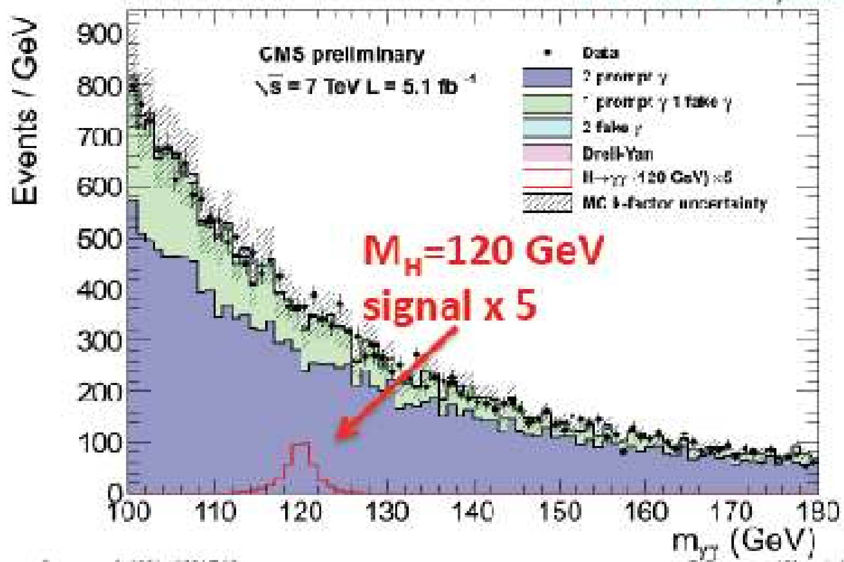
- Small BR: ~2x10^{-3}
- Two isolated high E_t photons
- VBF channel has two additional jets from outgoing quarks **(treated separately)**
- **Narrow mass peak**
  - very good mass resolution ~1%

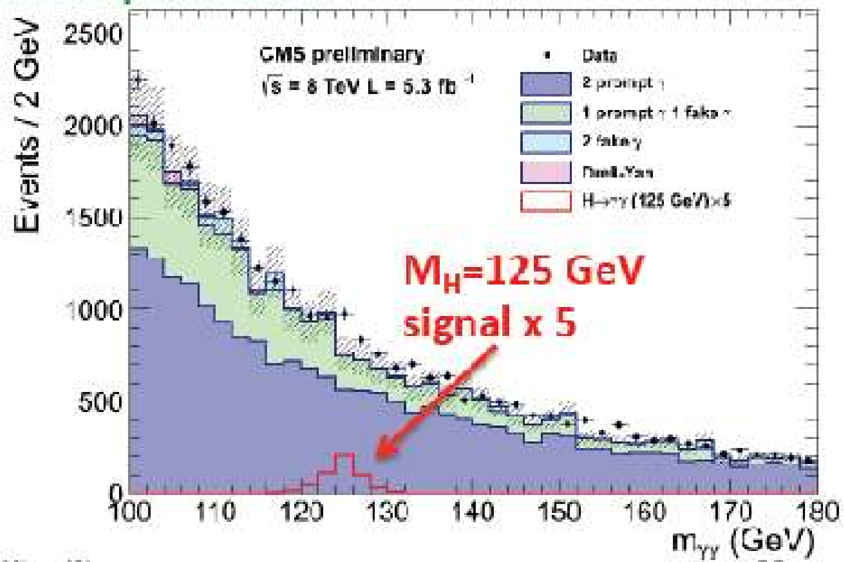
- Signature: small mass peak over large smoothly decreasing background
  - Irreducible: 2γ QCD production
  - Reducible: γ+jet with 1 additional fake photon, DY with electrons faking photons
- Studied mass range: 110-150 GeV

7 TeV dataset

BG MC only used for optimization

8 TeV dataset

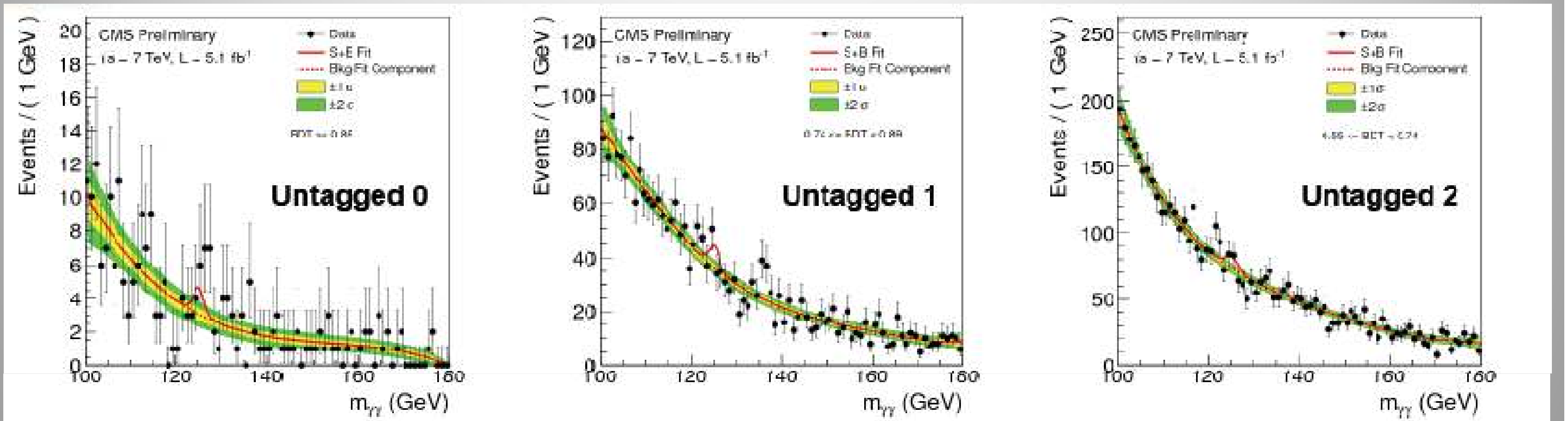


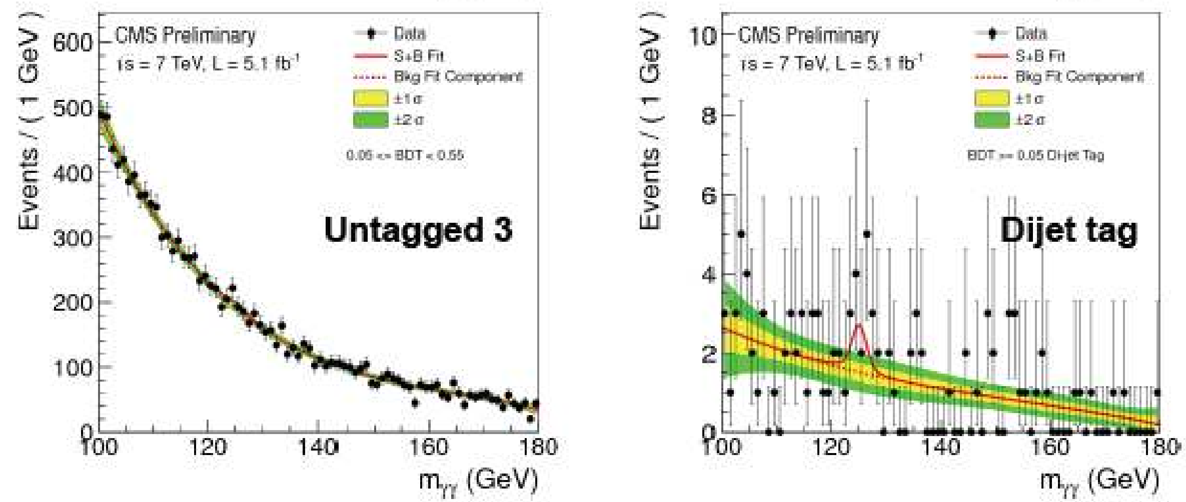


Photon/Jet Selection (2012)

- Photons
  - $|\eta_\gamma| < 2.5$ and not in $1.44 < |\eta_\gamma| < 1.57$
  - Leading photon $p_T > M_{\gamma\gamma}/3$
  - Other photon $p_T > M_{\gamma\gamma}/4$
  - Leading photon in di-jet case $p_T > M_{\gamma\gamma}/2$
- Jets
  - $|\eta_{jet}| < 4.7$
  - Leading jet $p_T > 30$ GeV, other jet $p_T > 20$ GeV
  - $\Delta\eta > 3.5$
  - $M_{jj} > 250$ GeV @ 8 TeV

Higgs → 2 photons: Categories

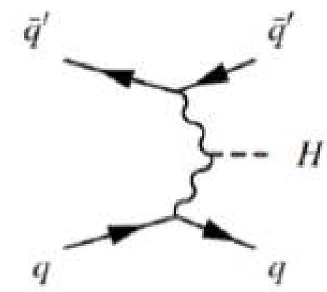


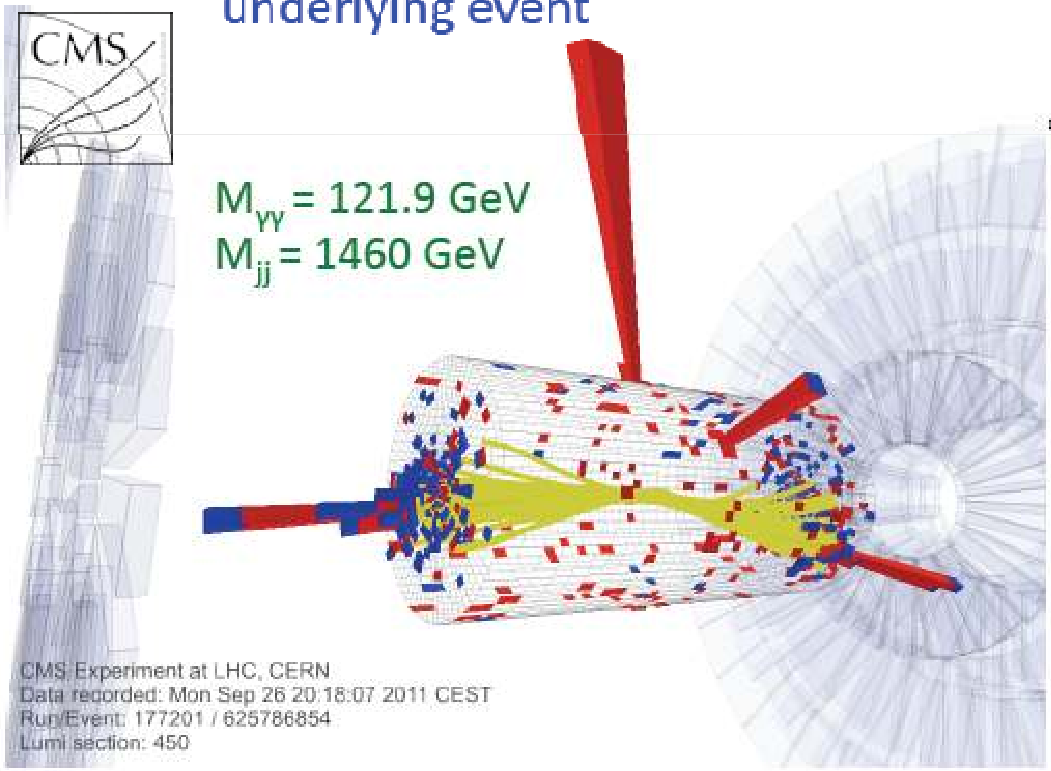


- Background model is entirely from data.
- Fit to mass distribution in each category with polynomial functions (3rd to 5th degree)
  - keep bias below 20% of fit error.
  - causes some loss of performance due to number of parameters in fit function.

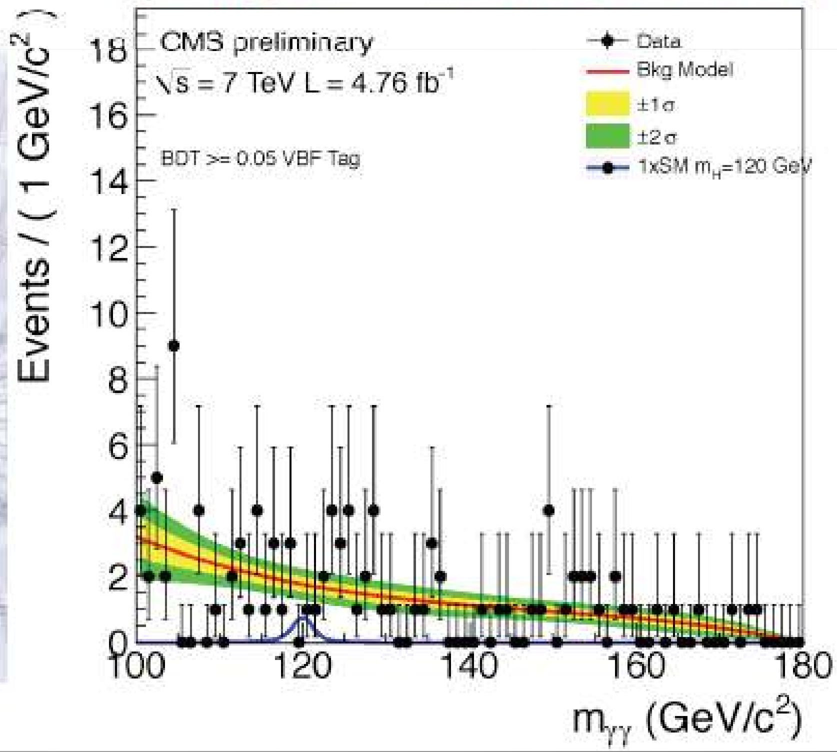
$H \rightarrow \gamma\gamma$: Vector Boson Fusion Analysis

- Exclusive dijet tag improves sensitivity by ~10%
- Photon identification is the same
  - tighter lead photon E_t cut (E_t lead/$M_{\gamma\gamma}$ > 55/120)
- Dijet tag selection on dijet variables
  - exploits two additional VBF high p_T jets at large rapidity
- Contamination of gg-fusion ~25%, syst error 50-70% dominated by underlying event

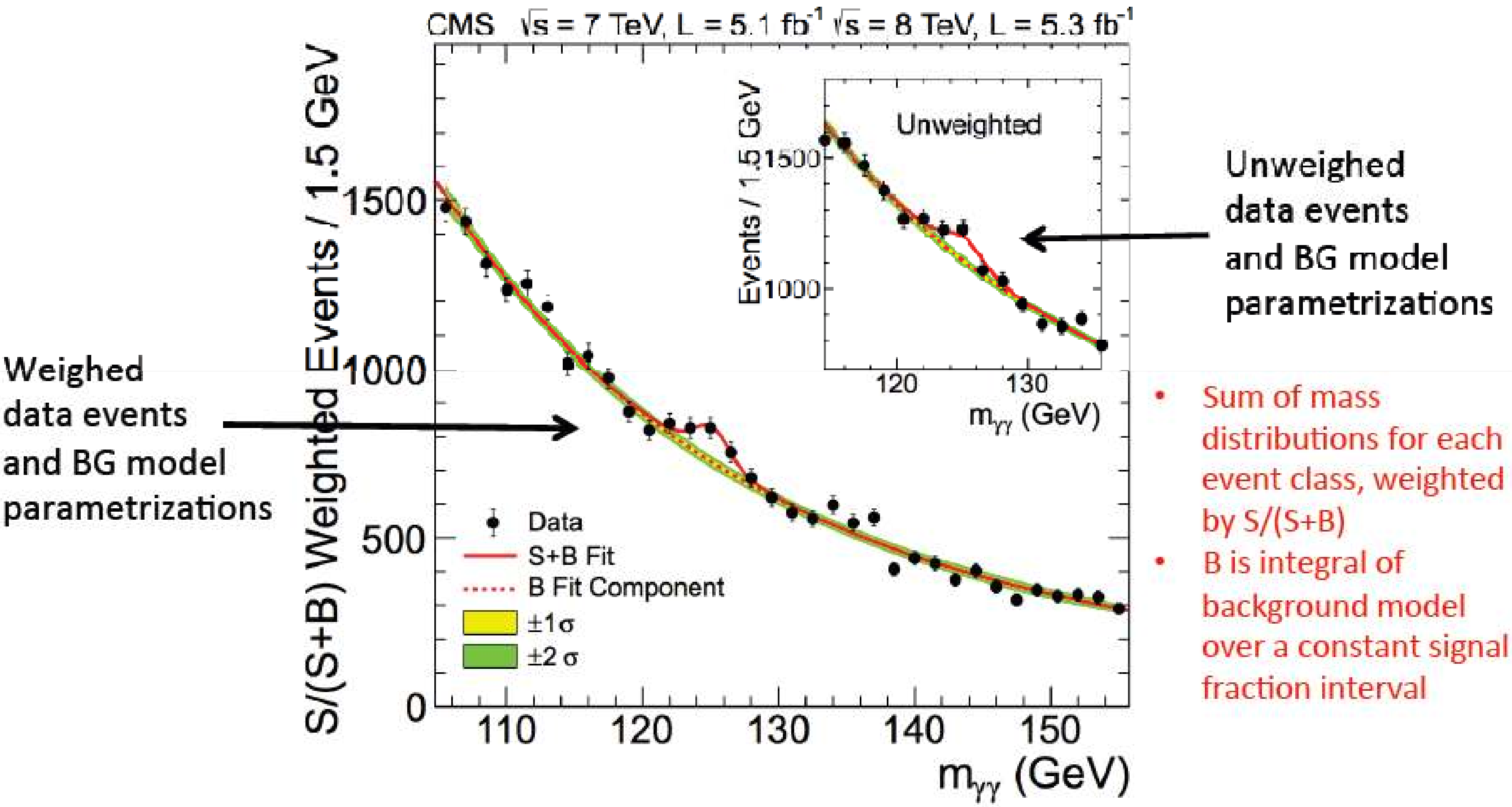




Dijet tag selection has high s/b, ~1/3



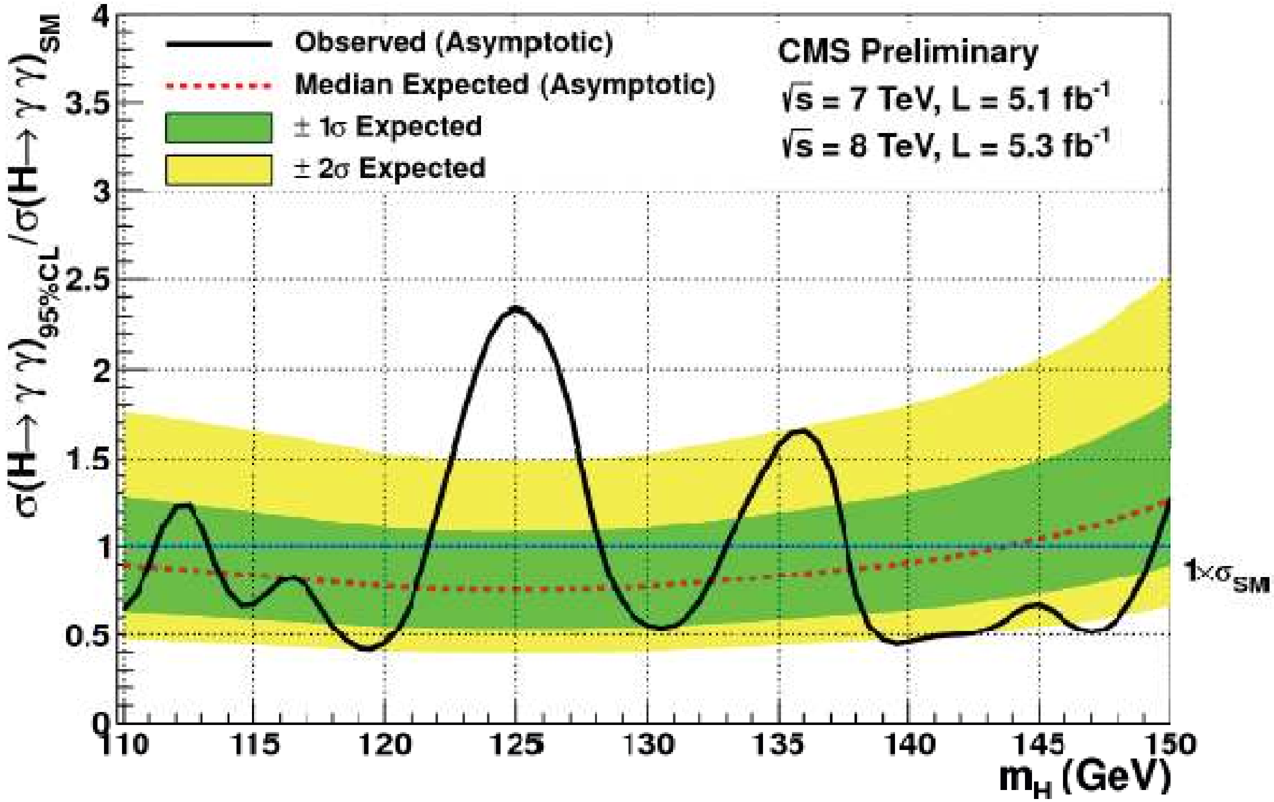
H→γγ: Combined Mass Spectrum



- Sum of mass distributions for each event class, weighted by S/(S+B)
- B is integral of background model over a constant signal fraction interval

- This plot is not used in the analysis and it is for illustration only, it adds all event classes together

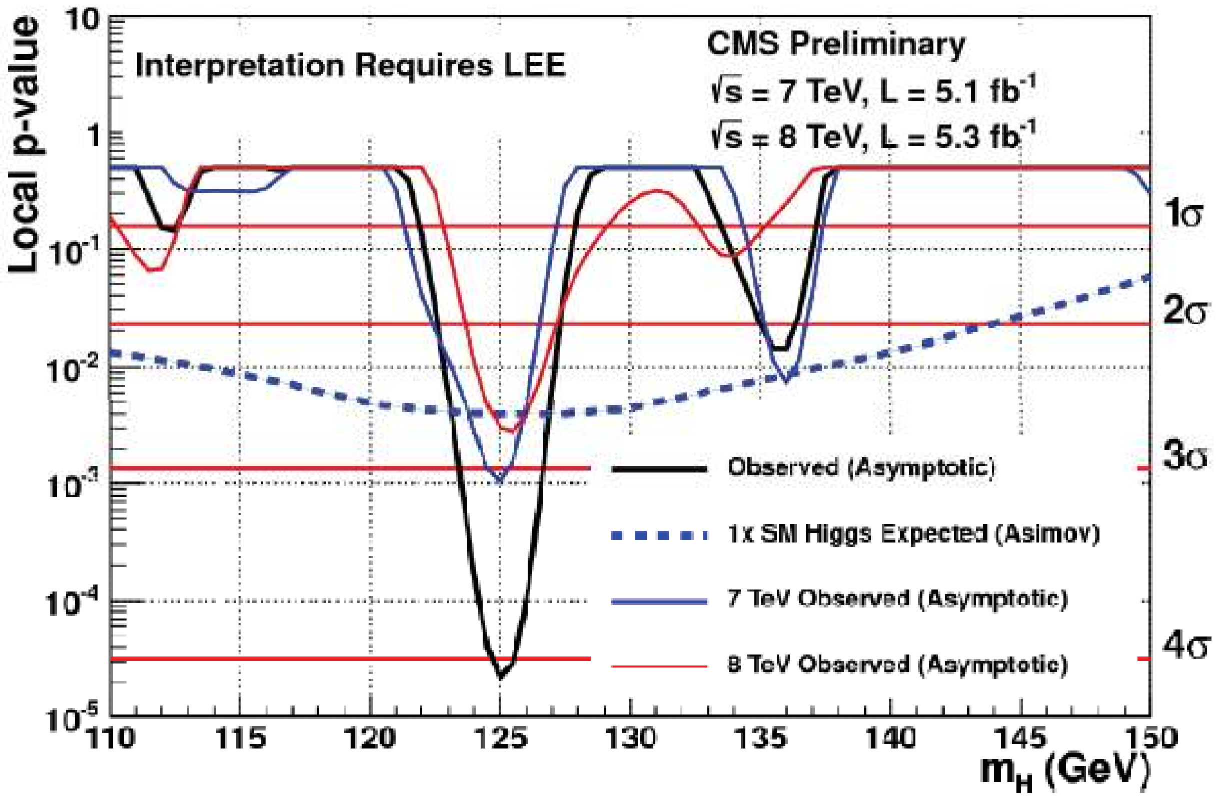
H→2 Photons Results: Exclusion



- Expected 95% CL exclusion: 0.76 x SM at 125 GeV
- Excluded at 95% CL:
  110.0-111.0, 113-123, 129-132, 138-149 GeV

$H \rightarrow \gamma\gamma$ Results: P-values

How (in)compatible is the data with the background only hypothesis ??

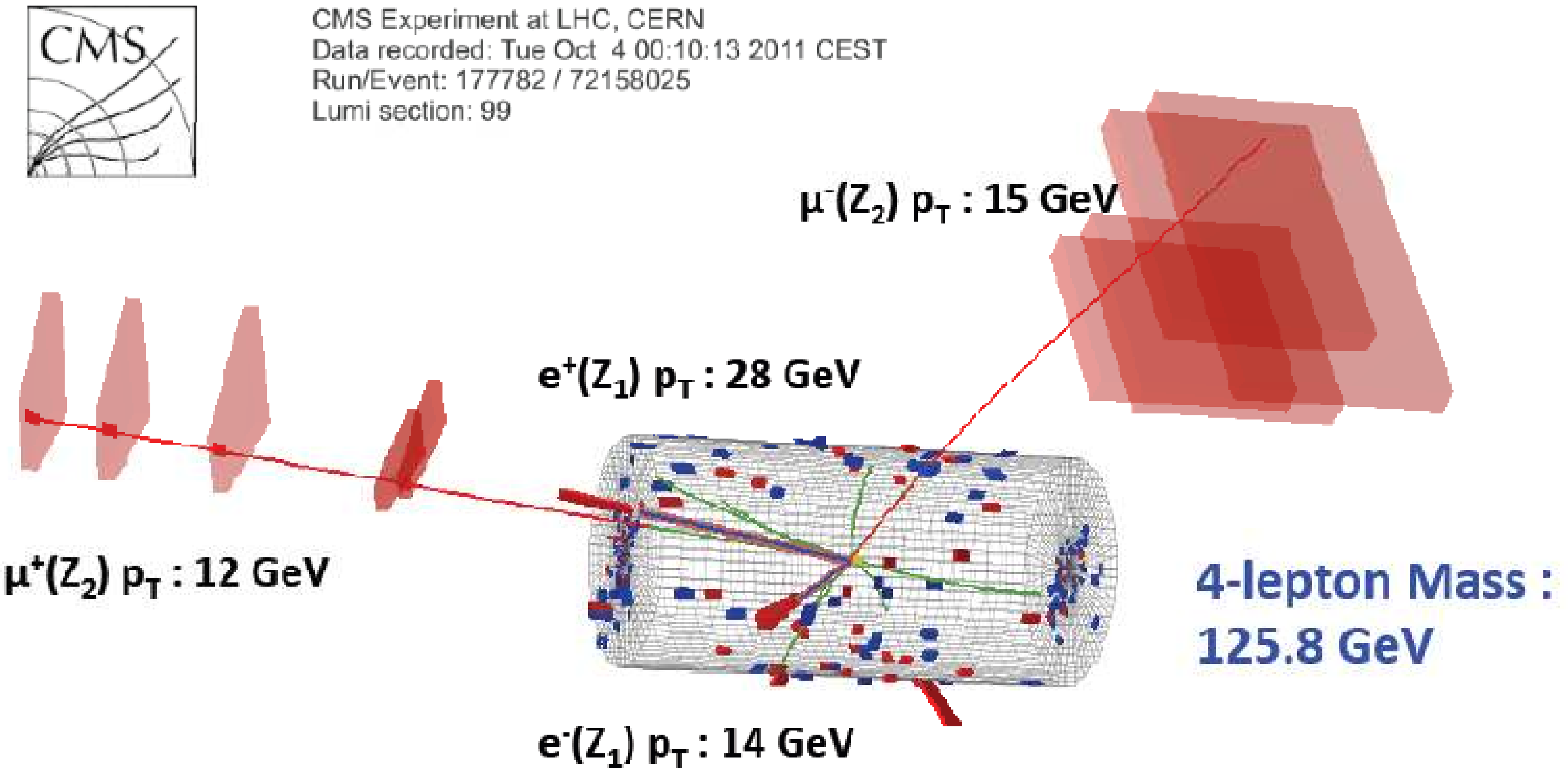


Similar Results from cut based And cross check MVA analysis (3.7 and 4.6 σ)

- Largest excess around 125 GeV
  - Local significance 4.1 σ
  - Global significance in 110-150 GeV 3.2 σ
  - Fitted σ/σ_{SM} at 125: 1.6 ± 0.5

H→ZZ→4 Charged Lepton Analysis

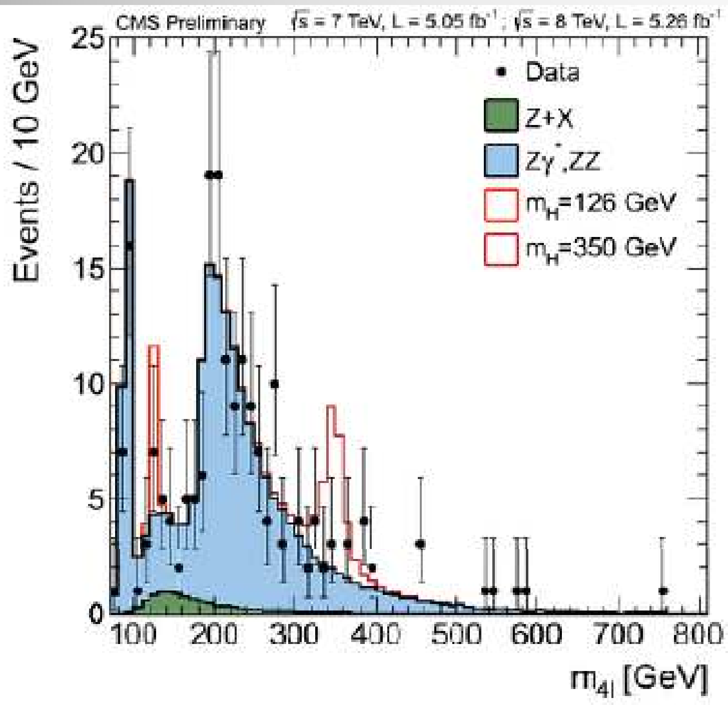
- Clean channel: 2 high mass pairs of opposite sign isolated electrons or muons coming from PV
- **Narrow mass peak**
  - Very good mass resolution 1-2 %
- Background
  - irreducible: ZZ
  - reducible: Z+jets, Zbb, tt, WZ
- Very small BR ~10^{-4} at 125 GeV

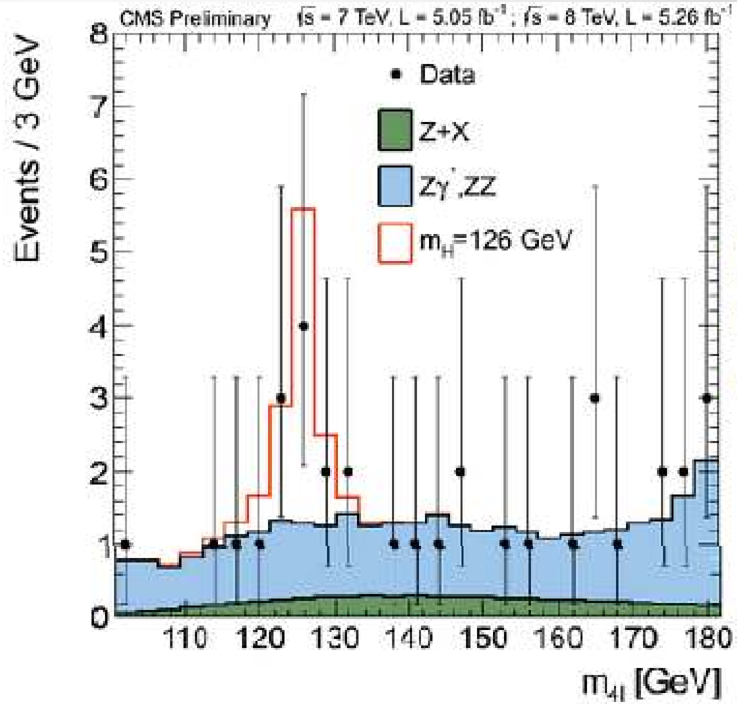


H→ZZ Selection

- 4e, 4μ, 2e2μ cases handled separately
- Backgrounds
  - Direct ZZ production (irreducible)
  - Z+bb, Z+tt (real leptons)
  - Z+jets, WZ+jets (jet misID as lepton)
- Final state radiation (FSR) recovery
- Lepton requirements
  - Electrons: p_T > 7 GeV, $|\eta|<2.5$
  - Muons: p_T > 5 GeV, $|\eta|<2.4$
  - Isolation for both e's and μ's
  - Leptons must come from common vertex
- Di-lepton mass
  - Closest match: $40 < M_{ll} < 120$ GeV
  - Other pair: $12 < M_{ll} < 120$ GeV

H→ZZ→4 Charged Lepton Analysis

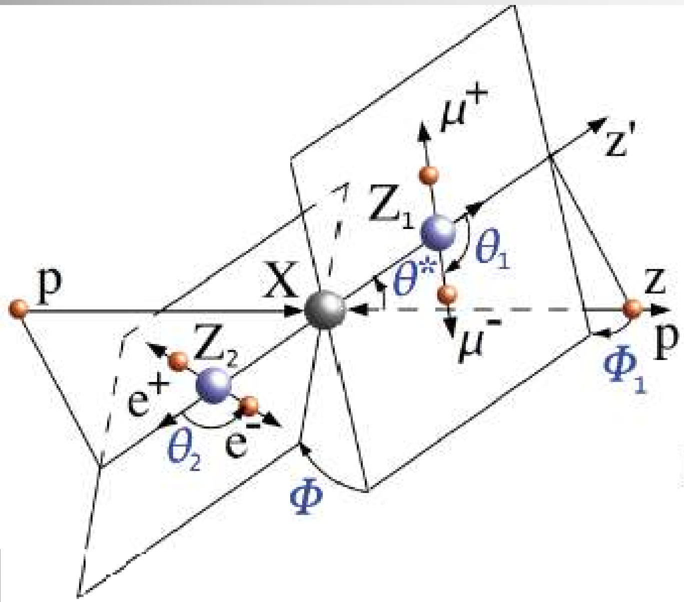




In 110-160 GeV
BG exp.: 20 ± 3
H(125): 7.6 ± 1.1
data: 21

Channel	4e	4μ	$2e2\mu$	4ℓ
ZZ background	2.7 ± 0.3	5.7 ± 0.6	7.2 ± 0.8	15.6 ± 1.4
Z + X	$1.2^{+1.1}_{-0.8}$	$0.9^{+0.7}_{-0.6}$	$2.3^{+1.8}_{-1.4}$	$4.4^{+2.2}_{-1.7}$
All backgrounds ($110 < m_{4\ell} < 160$ GeV)	$3.9^{+1.1}_{-0.8}$	$6.6^{+0.9}_{-0.8}$	$9.5^{+2.0}_{-1.6}$	$20.0^{+3.2}_{-2.6}$
Observed ($110 < m_{4\ell} < 160$ GeV)	6	6	9	21
Signal ($m_H = 125$ GeV)	1.37 ± 0.44	2.75 ± 0.56	3.44 ± 0.81	7.56 ± 1.08
All backgrounds (signal region)	$0.71^{+0.20}_{-0.15}$	$1.25^{+0.15}_{-0.13}$	$1.83^{+0.36}_{-0.28}$	$3.79^{+0.47}_{-0.45}$
Observed (signal region)	1	3	5	9

H→ZZ→4 Charged Lepton Analysis

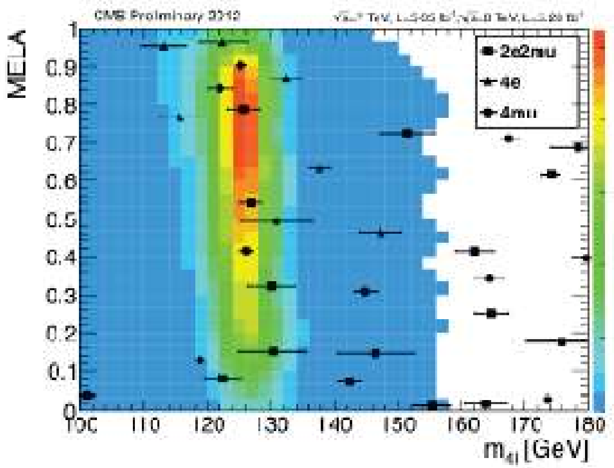


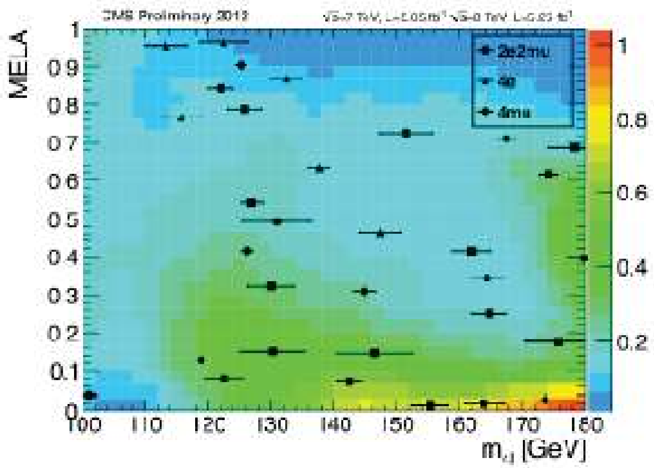
MELA: Matrix Element Likelihood Analysis:
uses kinematic inputs for
signal to ZZ background discrimination
$\{m_1, m_2, \theta_1, \theta_2, \theta^*, \Phi, \Phi_1\}$

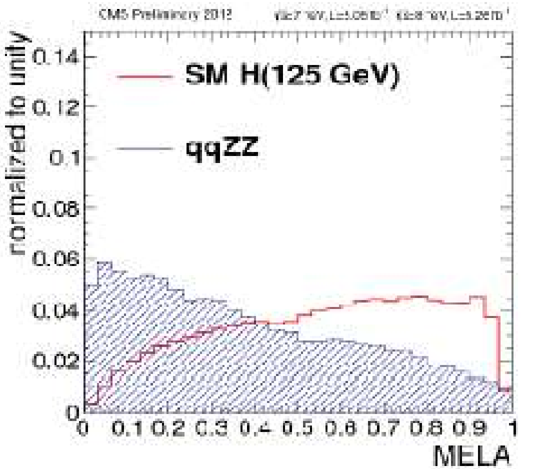
$$\mathrm{MELA} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$

arXiv:1208.4018

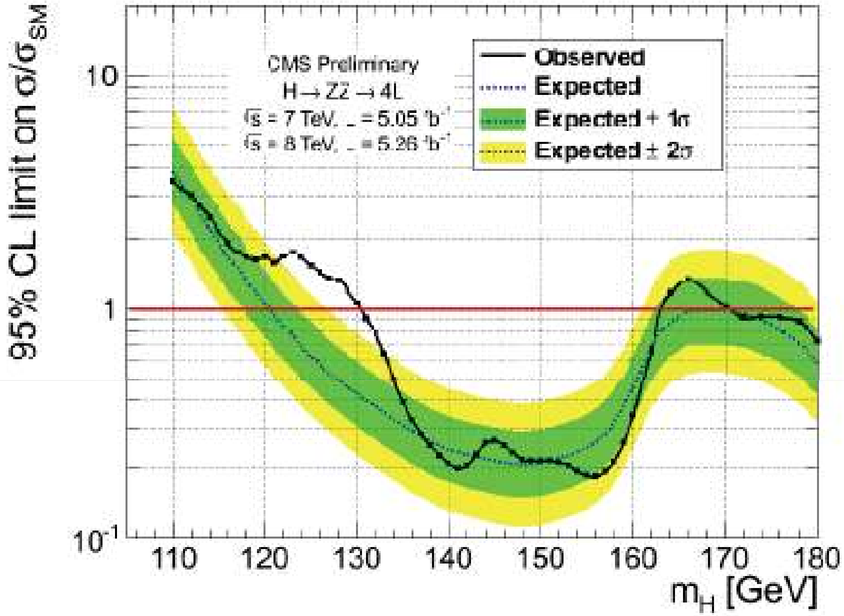
MELA Improves the sensitivity by ~30%
Compared to using the mass alone

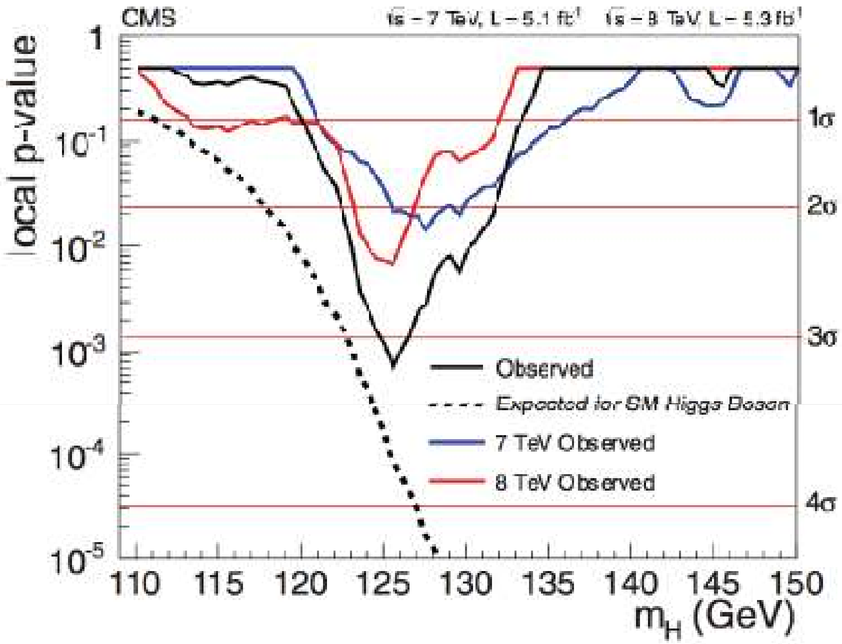






H→ZZ→4 Charged Lepton Analysis





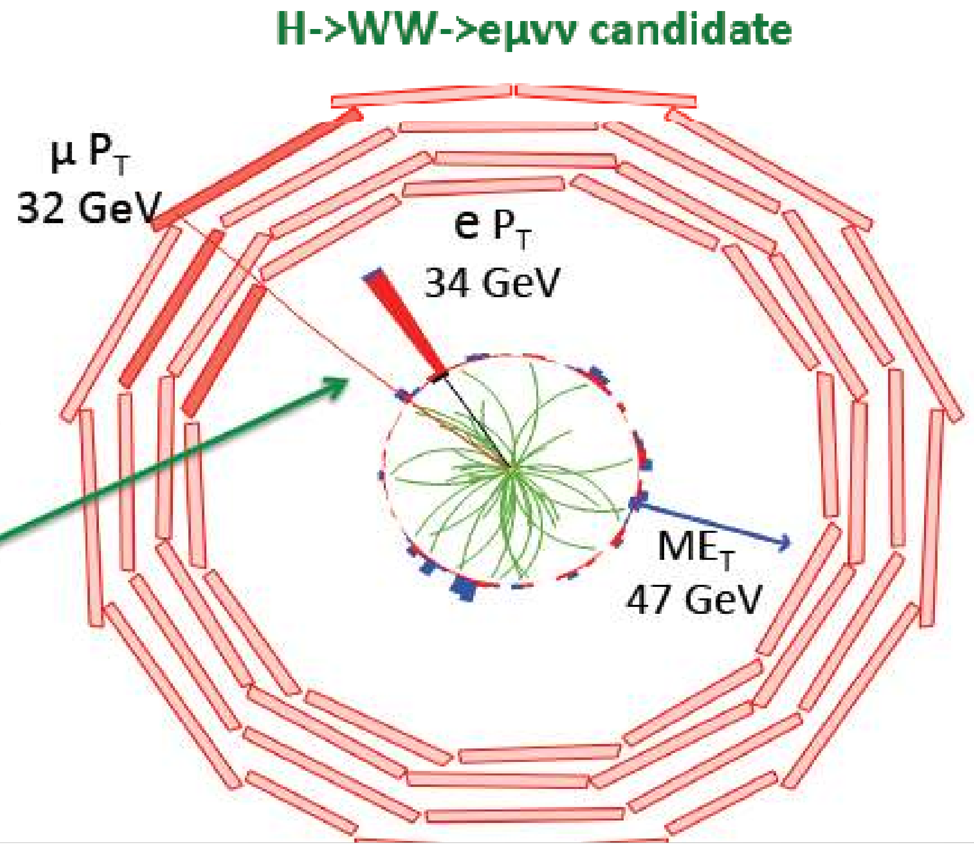
- Excess of events at 125.5 GeV
  - expected significance: 3.8 σ
  - observed significance: 3.2 σ

H→WW→2l2ν

- Most sensitive channel around ~ twice M_W
- $125<M_H<200$ GeV
- No narrow mass peak (mass resolution ~ 20%)
- Search: Two isolated leptons with $p_T>20/10$ GeV + MET>~40 GeV

- Main backgrounds
  - WW (irreducible)
  - Z+jets, WZ, ZZ, tt, W + jets
- BG estimation crucial
  - Main BG estimated from data

The scalar Higgs boson and the V-A structure of the W decay favors a small opening angle between the two charged leptons

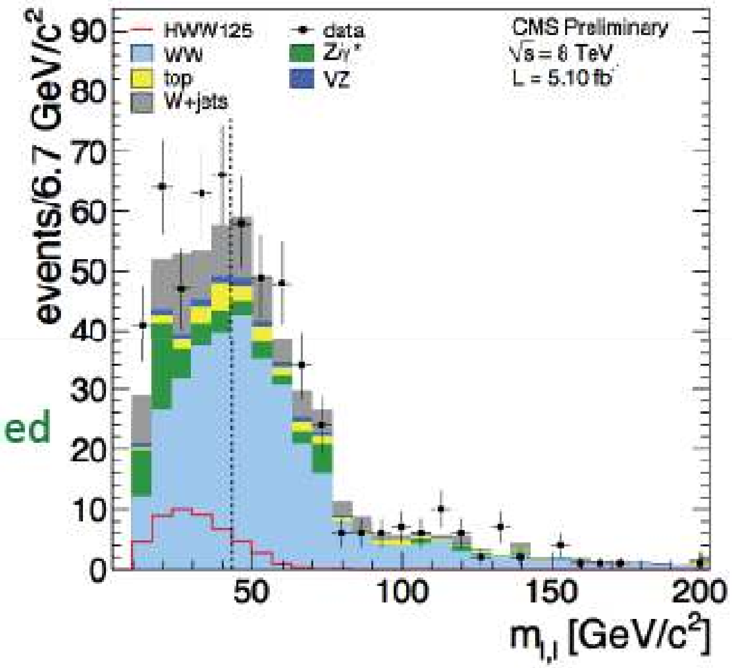


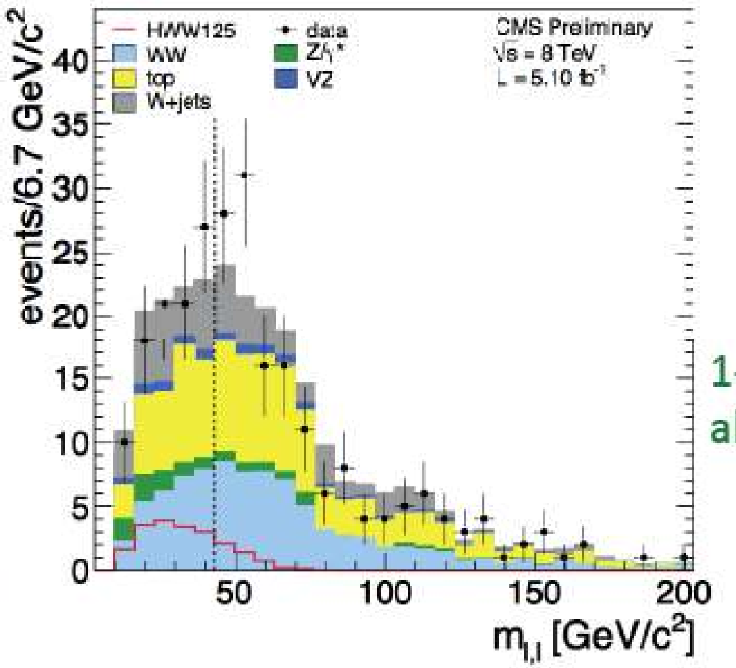
H→WW→2l2v: Analysis Strategy

- The analysis is performed in exclusive jet multiplicities (0, 1, 2-jet bins) and different flavours (ee,μμ,eμ)
  - WW background contributes more to the 0-jet bin
  - tt background contributes more to the 1 and 2-jet bin
  - Z+jets and ZZ contribute more to the same flavour channel (ee/μμ)
- 2-jet bin corresponds to the VBF channel (di-jet tag)
- Two different analysis:
  - Cut and count in 0, 1 and 2-jet analysis
  - Multi-variate in the 0 and 1-jet bin

Higgs → WW→lνlν: Data

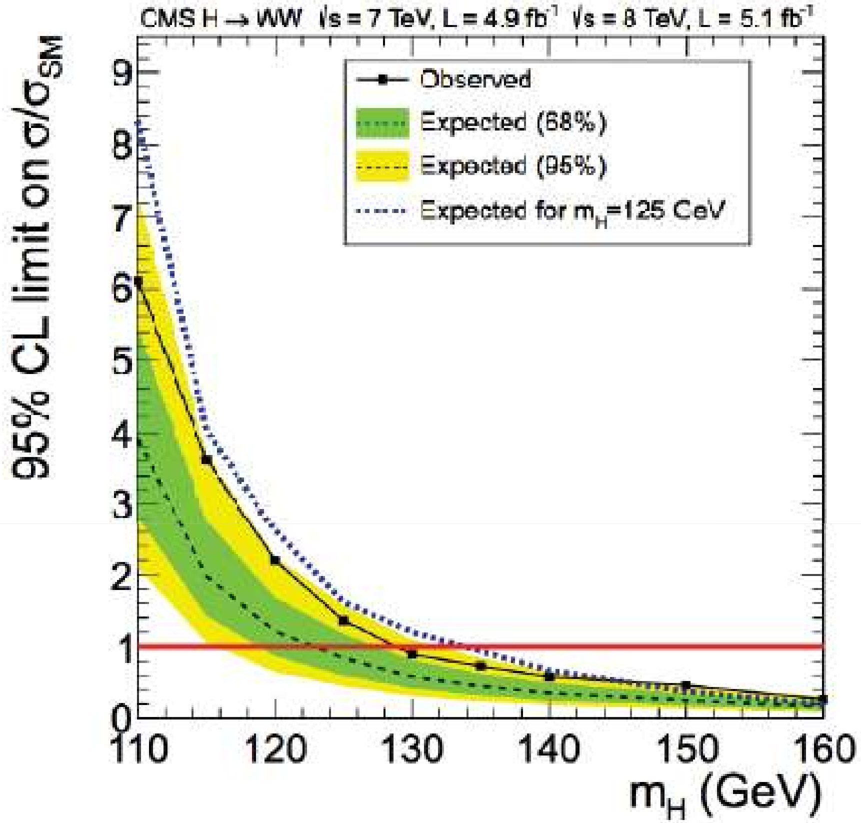
0-jet bin
all combined





1-jet bin
all combined

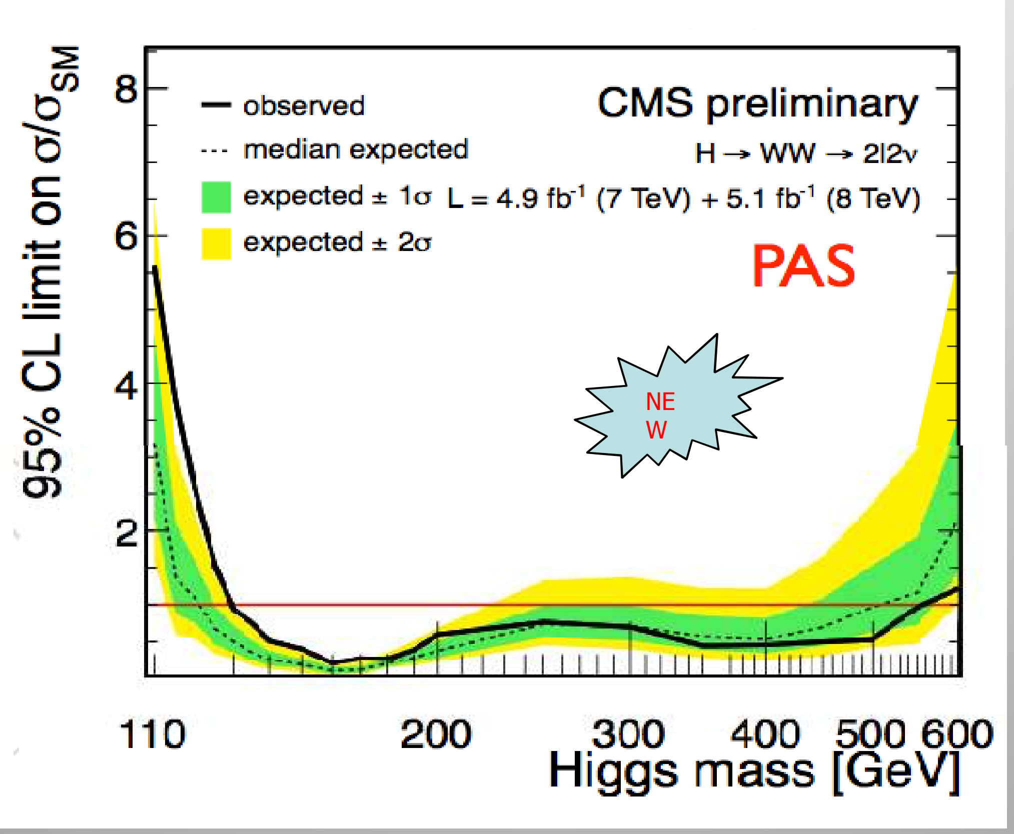
Higgs → WW→lνlν: Result



- Broad excess, as expected from resolution, between 110 and 140 GeV
- P-value at 125 GeV
  - expected 2.4 σ
  - observed 1.6 σ

The excess spread over a large range as we cannot reconstruct the mass in this channel

Higgs → WW→lvlv: Result

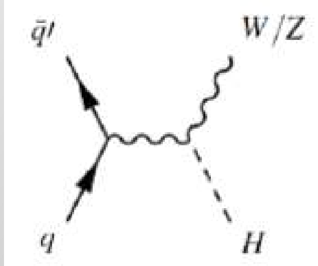


Deviation at 125 GeV: 2σ

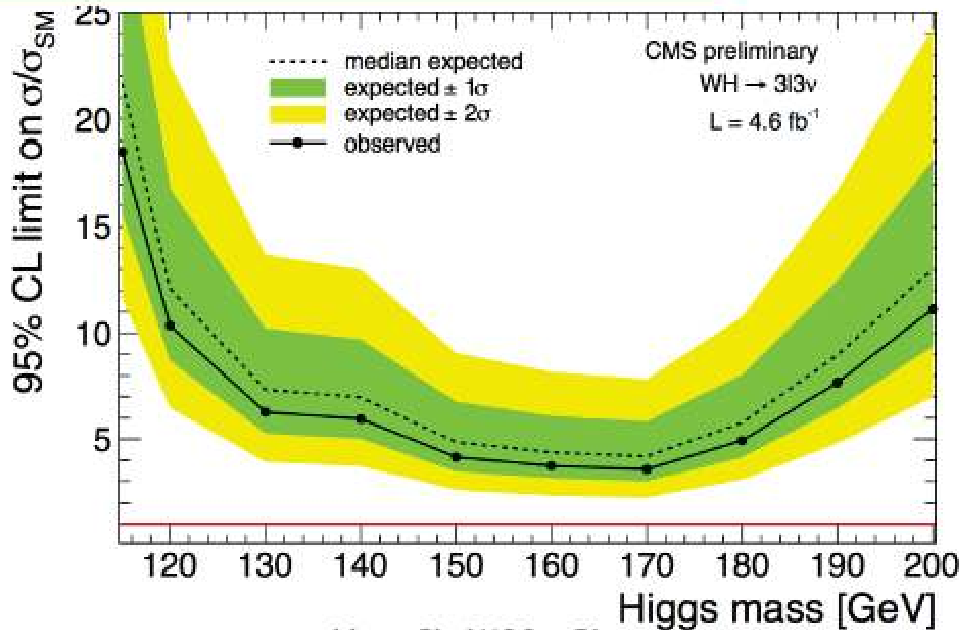
New analysis using shape dependence.
Increased sensitivity!

Associated Production: HW→ WWW

Similar to the inclusive WW analysis (leptonic decays)
-Cut and count analysis with mass independent selection
-Main backgrounds estimated from data.



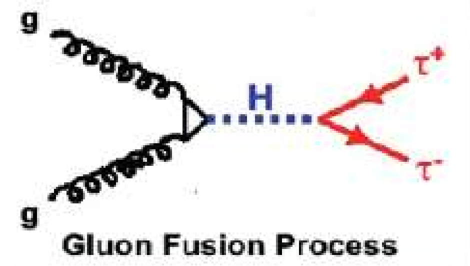
stage	WH (120) $H \to \tau\tau$	WH (120) $H \to WW$	data	all bkg.	WZ $\to 3\ell\nu$	ZZ $\to 4\ell$	top+Z/γ^*
3-lepton preselection	2.1 ± 0.0	3.5 ± 0.1	950	968.3 ± 11.9	482.9 ± 1.8	78.4 ± 0.9	348.0 ± 9.7
min-MET > 40 GeV	1.0 ± 0.0	1.8 ± 0.1	244	270.5 ± 4.4	208.2 ± 1.1	7.9 ± 0.3	54.5 ± 4.3
Z removal	0.4 ± 0.0	1.0 ± 0.1	40	47.9 ± 3.1	15.9 ± 0.4	0.7 ± 0.1	31.3 ± 3.1
top veto	0.1 ± 0.0	0.6 ± 0.1	12	14.2 ± 1.3	8.8 ± 0.4	0.4 ± 0.1	4.9 ± 1.3
$\Delta R_{\ell^+\ell^-}$ & $m_{\ell\ell}$	0.1 ± 0.0	0.5 ± 0.1	7	8.4 ± 0.9	5.7 ± 0.2	0.3 ± 0.1	2.6 ± 0.9

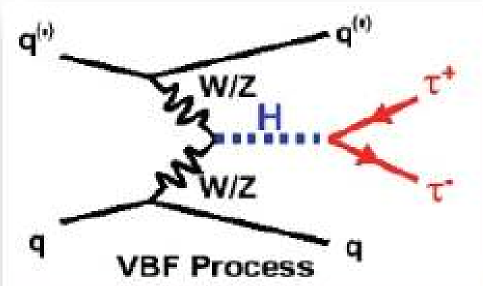


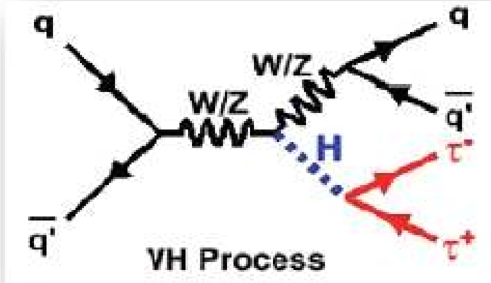
2011 data only

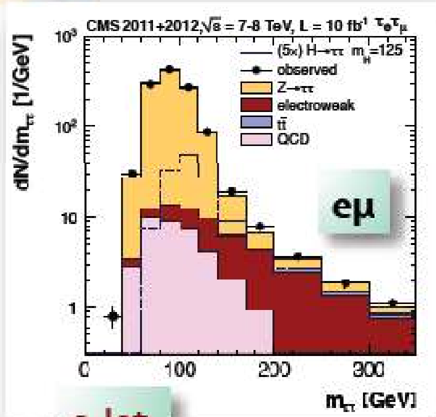
CMS document HIG-11-034

Higgs → tau tau



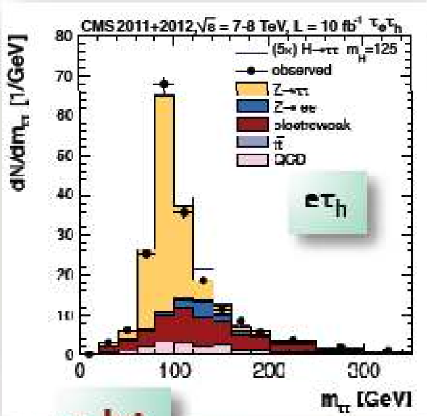






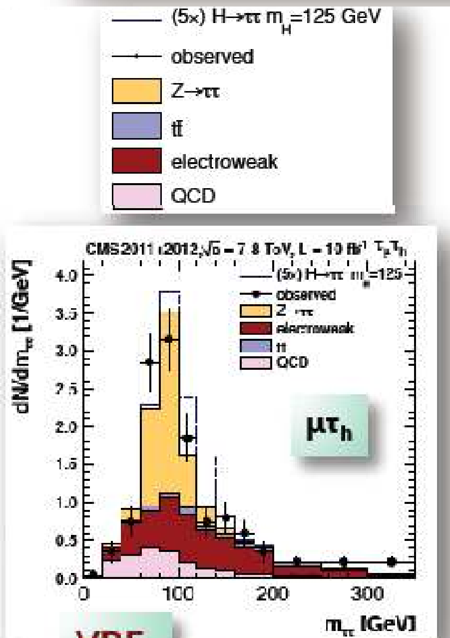
0 Jet

- Constrains energy scales and efficiencies
  - Large Drell-Yan background
  - Sensitivity boosted by low/high p_T split



1 Jet

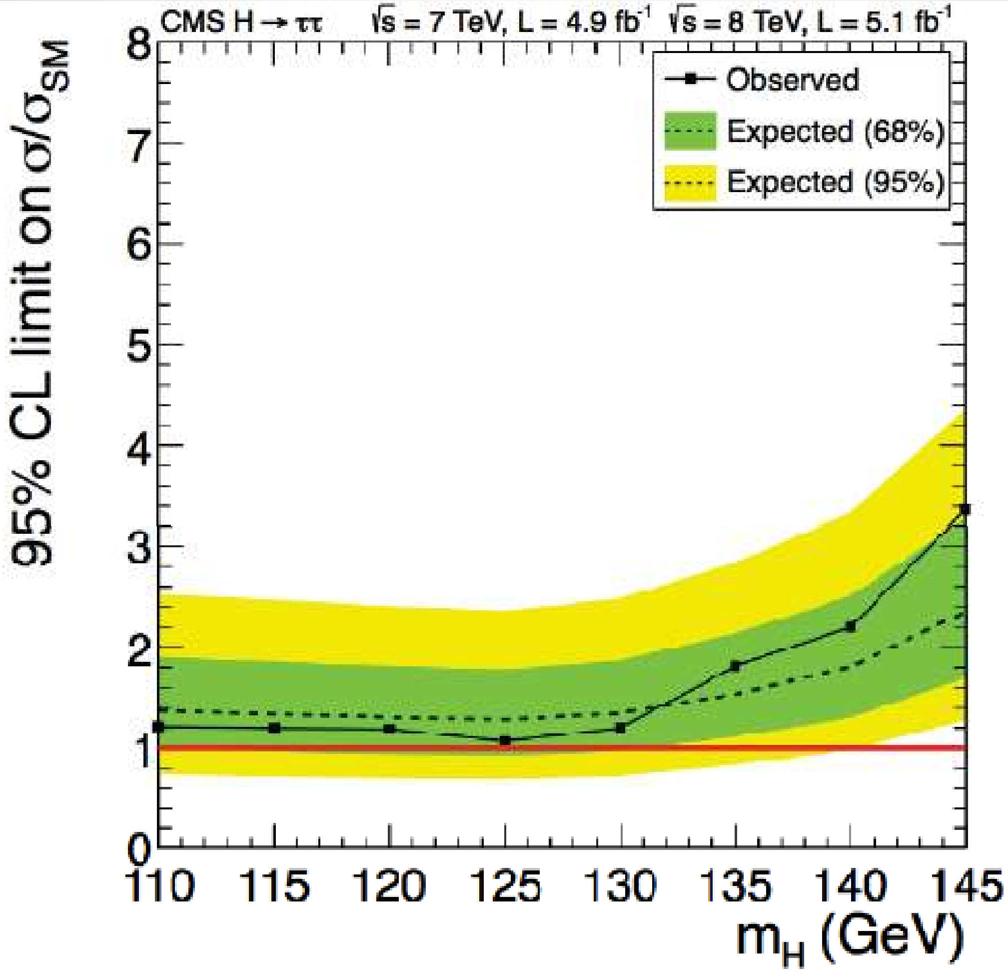
- Enhanced sensitivity to gluon fusion
  - Improved mass resolution
  - Increased sensitivity by splitting into low and high p_T categories



VBF

- Enhanced sensitivity to VBF production
  - Highest sensitivity for $m_H < 130$ GeV

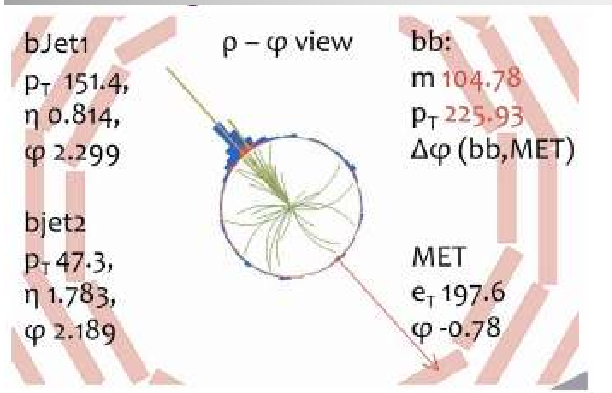
Higgs → Tau Tau: Results



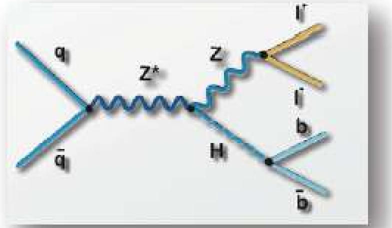
- No excess at 125 GeV:
  - Expected 1.4σ
  - Measured a slightly negative value of μ

Somewhat surprising!!

H → bb



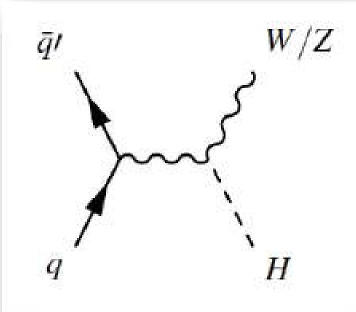
Associated Production
=> final states with
leptons, MET and b-jets

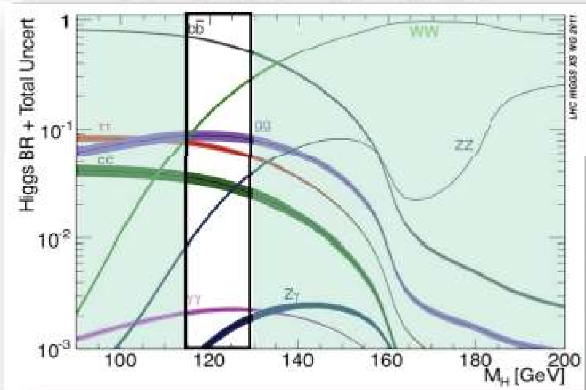


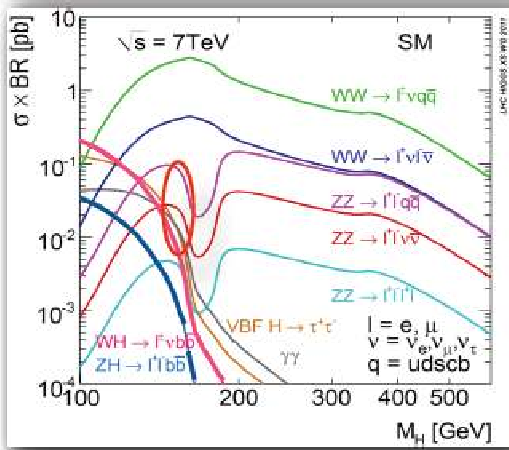
5 channels
- Z(ll)H(bb)
- Z(νν)H(bb)
- W(lν)H(bb)

- Characteristics and importance
  - By far, largest BR for m_H<130 GeV
  - Key piece of the observation puzzle
    - Tests specific production & decay couplings
- But σ_{bb}(QCD) ~ 10^7 σxBR(H-> bb)!

⇒ Search in associated production with W or Z





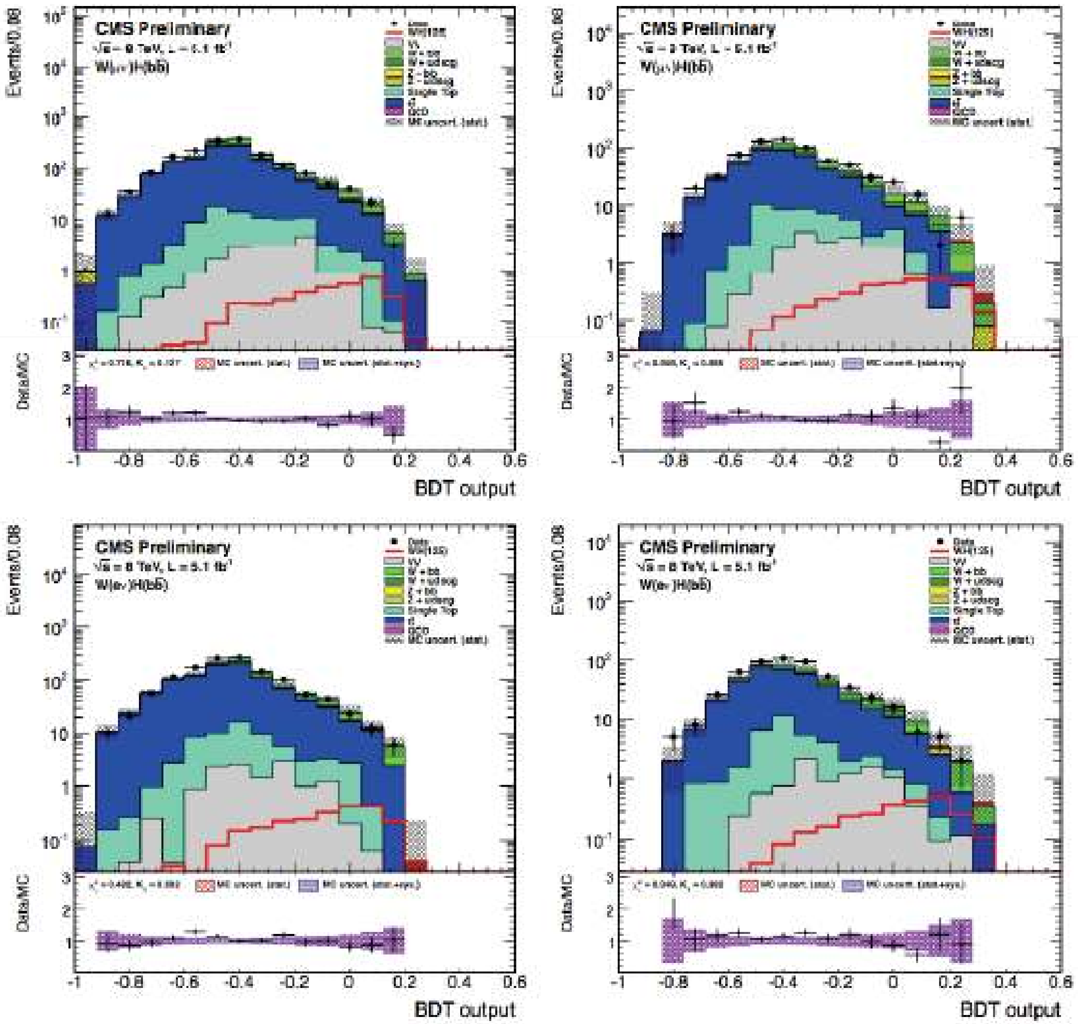


Higgs → bb: Data

- Use shape analysis with MVA discriminator with input variables: jet kinematic variables, b-tag variables, …

W->μν
Low p_T

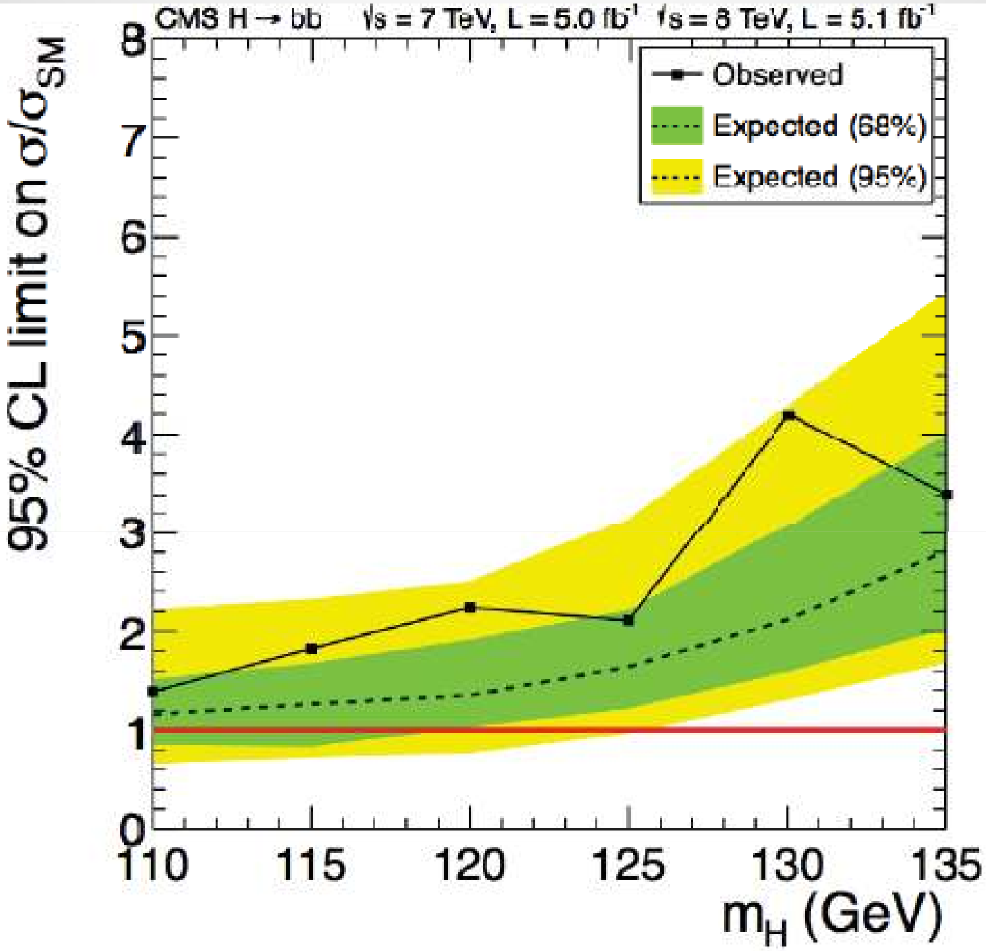
W->μν
High p_T



W->eν
Low p_T

W->eν
High p_T

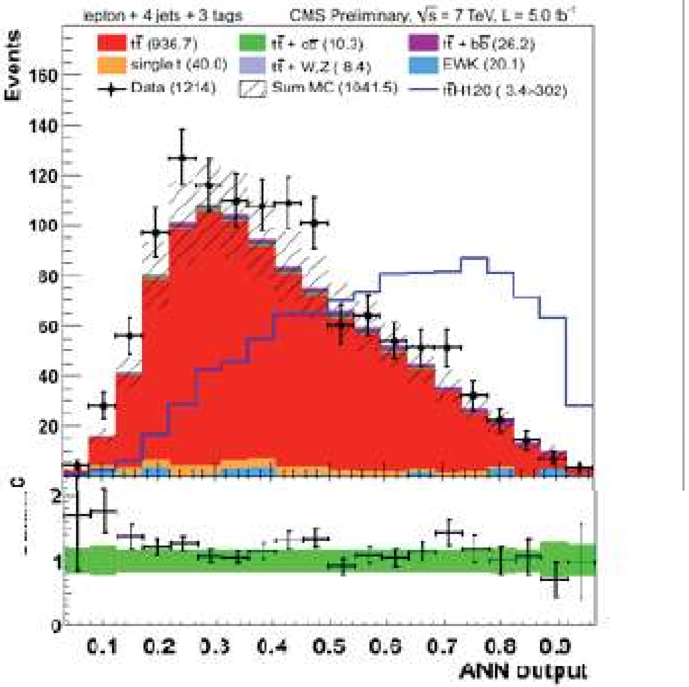
Higgs → bb: Results

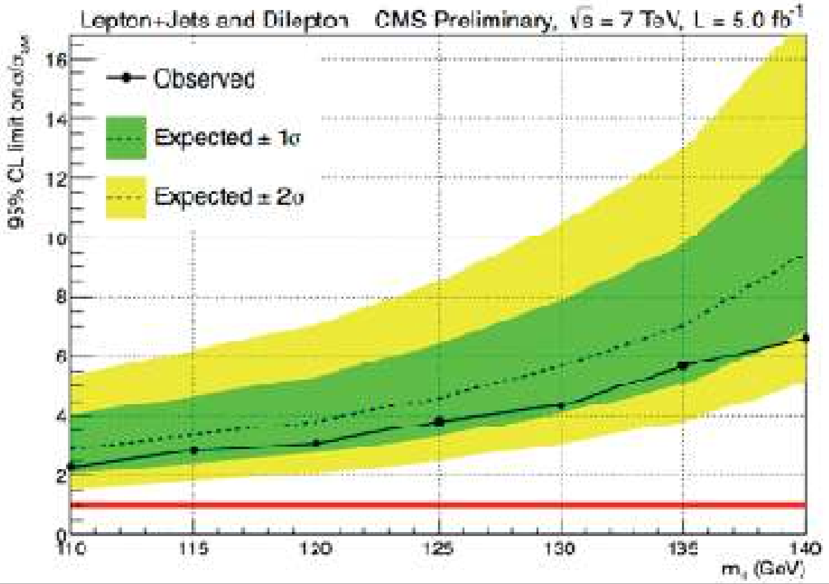


- Very small excess at 125 GeV:
  - Expected 1.9σ
  - Observed 0.7σ

Associated Higgs: ttH → ttbb

- ttH, H → b (new)
- categorize events by top decay mode (di-lep, l+jets) and jet multiplicity and b-tags
- MVA shape analysis in each category
- Low S/B regions constrain backgrounds
- Analyzed 2011 data. 2012 analysis is work in progress
- No excess observed



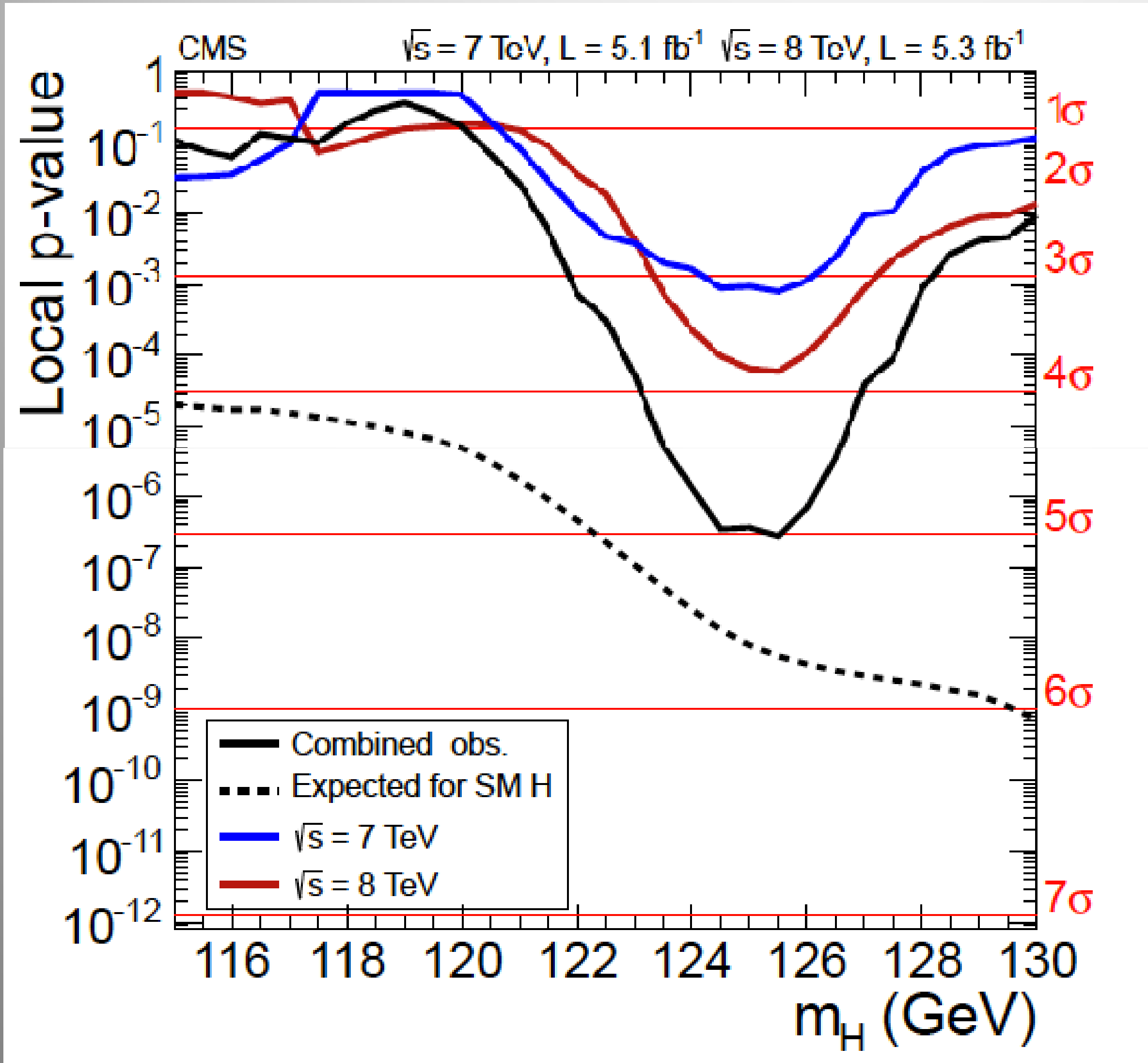


Full Combination of all Channels

Combine the results of all channels into one result

- SM cross sections and branching ratios are assumed with their theoretical uncertainties and an overall signal strength multiplier is fit to the data.
- Frequentist CLs with profiled likelihood test statistics and log-normal treatment of the nuisance parameters, as documented in ATLAS-PHYS-Pub/CMS Note 2011-11, 2011/005
- The results shown here is the latest update for CMS including the new and re-analysed channels

Combined Results

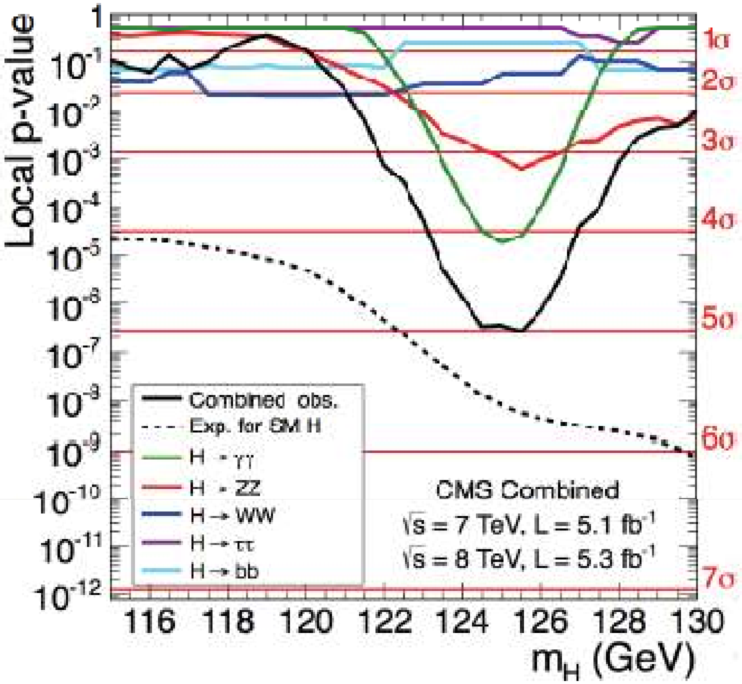


The 5 channels are combined

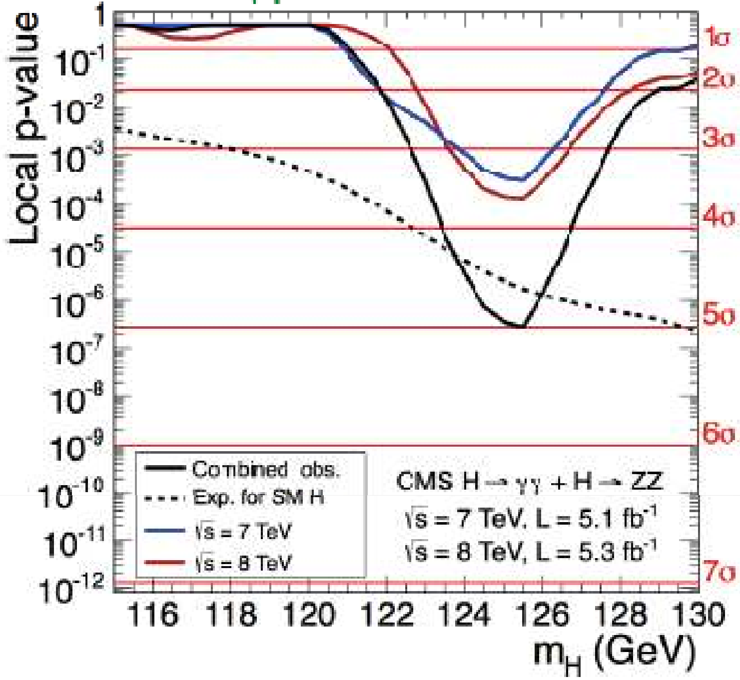
CMS observes a new boson with a significance of 5 sigma

Combined Result

All five channels



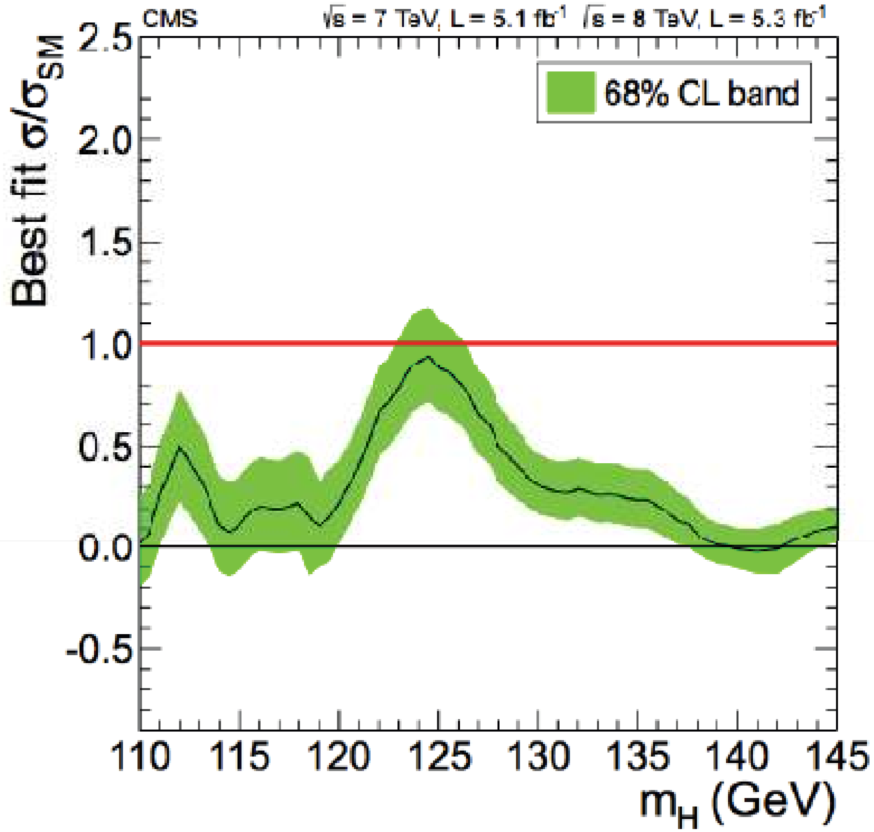
γγ + ZZ channels



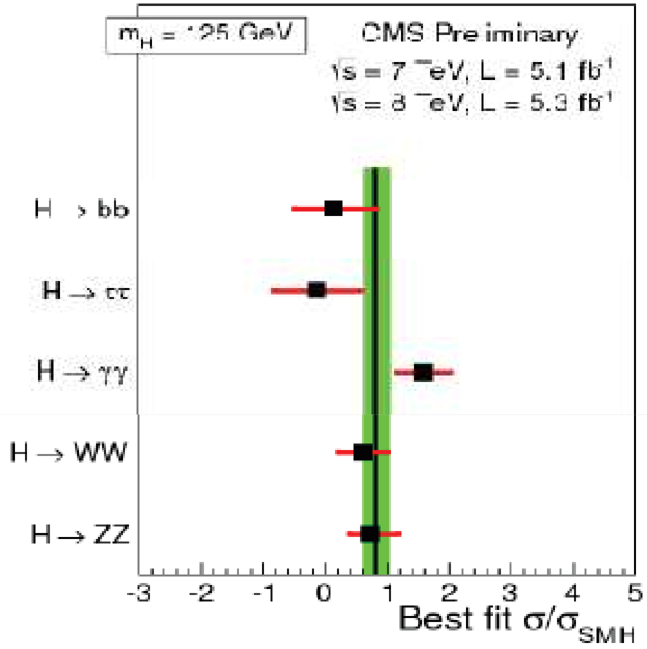
Local excess significance of different combinations

Decay mode or Combination	Expected (σ)	Observed (σ)
$\gamma\gamma$	2.8	4.1
ZZ	3.6	3.1
$\tau\tau$ + bb	2.4	0.4
$\gamma\gamma$ + ZZ	4.7	5.0
$\gamma\gamma$ + ZZ + WW	5.2	5.1
$\gamma\gamma$ + ZZ + WW + $\tau\tau$ + bb	5.8	5.0

Combined Signal Strength

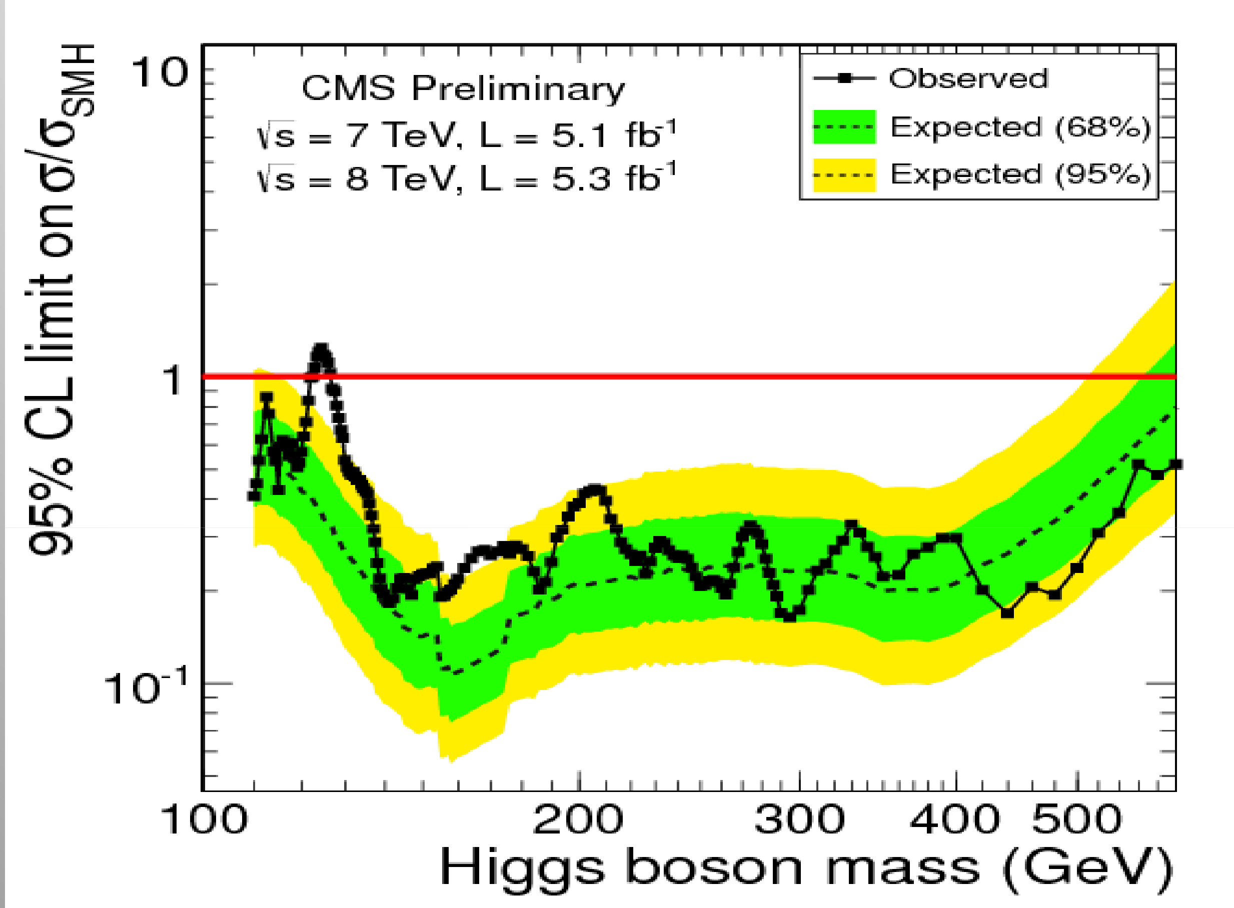


Comparison of channels for M_H=125 GeV



- The fitted σ of the excess near 125 GeV is consistent with the SM scalar boson expectation:
  - σ/σ_{SM} = 0.87±0.23
- Signal strengths in different channels are consistent
- Common cross section theoretical errors contribute to all measurements
  - Dominated by 15% error on gg-fusion where applicable

BTW: The High Mass Region



No evidence for (another) SM Higgs-like particle up to ~600 GeV

Properties of the new particle

Next Steps for the Higgs

Now we need more data to study this new particle

-Spin and CP studies?

-Couplings: measure as many production/decay channels?

-Deviations from Standard Model? Composite?

Look also for "non-standard" decays?

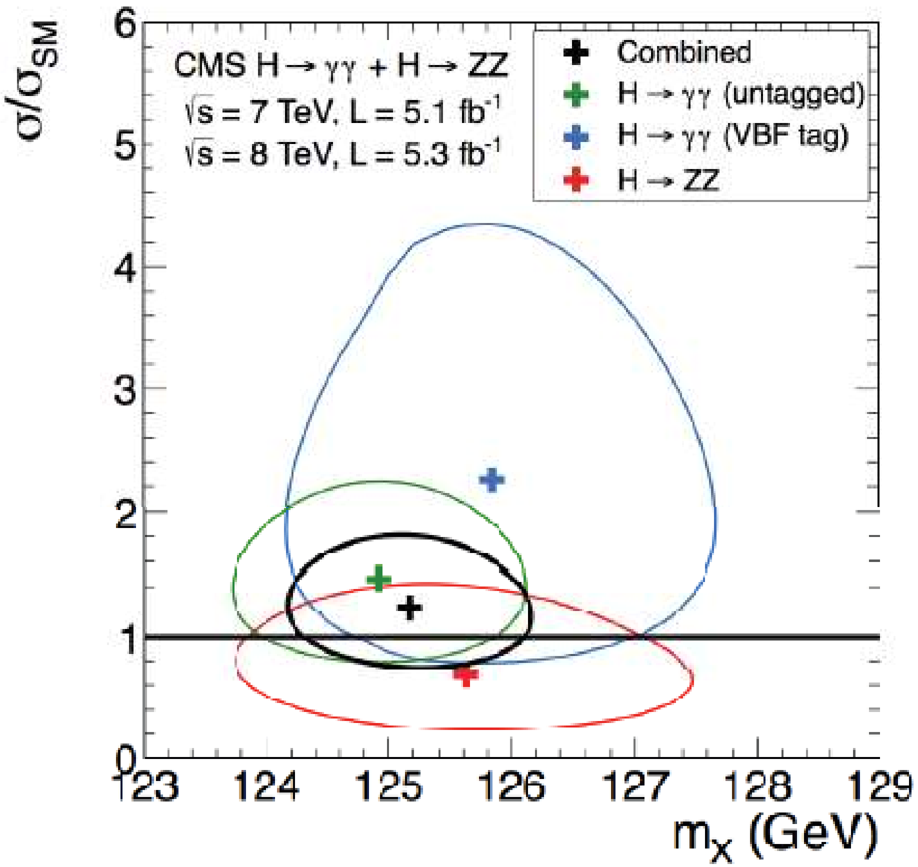
-Is it alone or accompanied?

-Exotic decays?

Another 10-20 fb^{-1} at 8 TeV will help!!

Note: the "2012 run" got extended by 7 weeks which should give an extra 5-10 fb^{-1} before the ~ 2 year shut-down

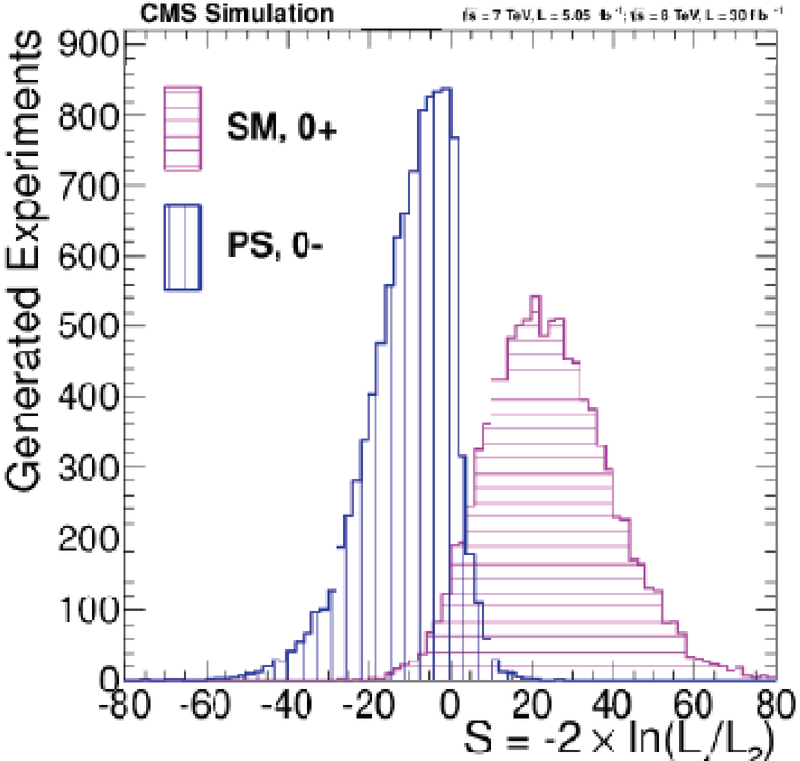
Mass of the New Particle



- To reduce model dependence, allow for free cross section in three channels and fit for the common mass:
  - **M_X = 125.3 ± 0.4 (stat.) ± 0.5 (syst.) GeV**
  - Measurement dominated by H->γγ

Spin-Parity Prospects

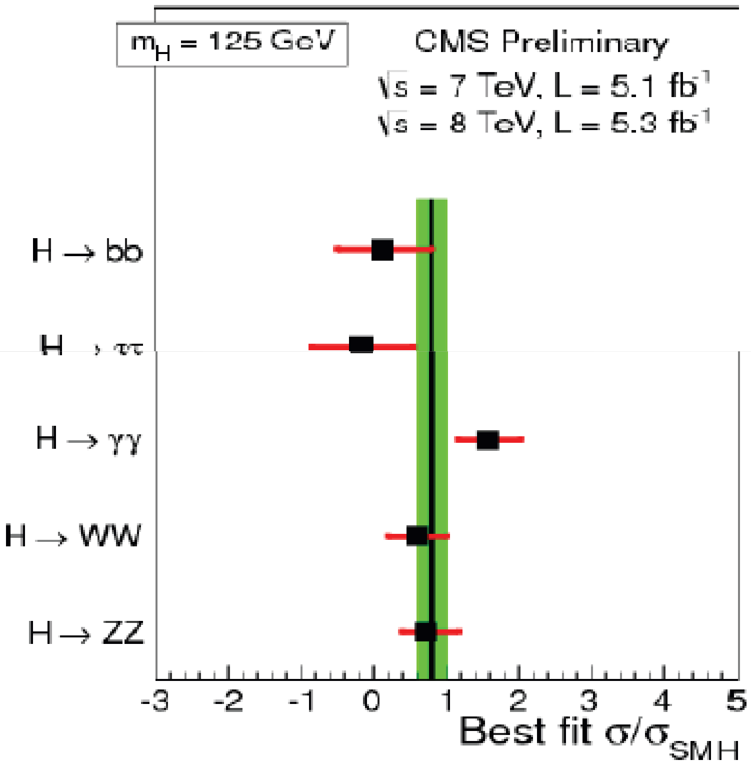
- Not yet really sensitive to them with the analyzed dataset
- Only result is that the observation of γγ decay, excludes the spin 1 hypothesis
- Spin 2 and CP can be probed using angular distributions
- No public results yet using data



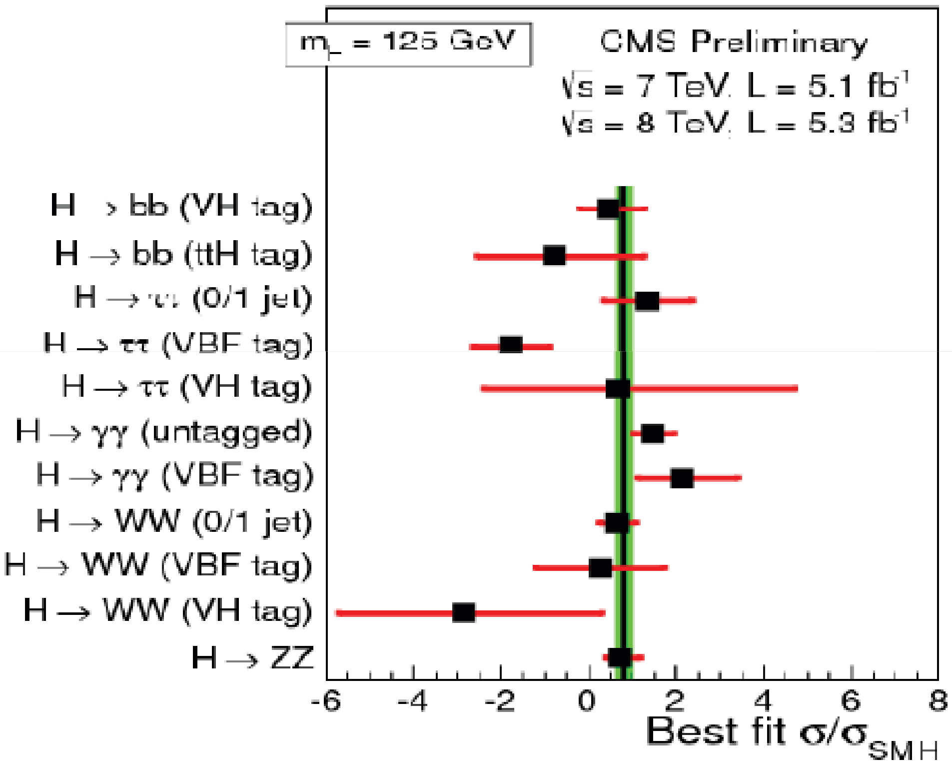
- **H->ZZ** projections
- using MELA discriminator We can distinguish between scalar and pseudo- scalar at 3.1σ level with 30 fb^{-1} at 8 TeV assuming SM cross section
- Other channels being studied

Signal Strength in all Channels

Comparison of channels for M_H=125 GeV



Comparison of channels for M_H=125 GeV



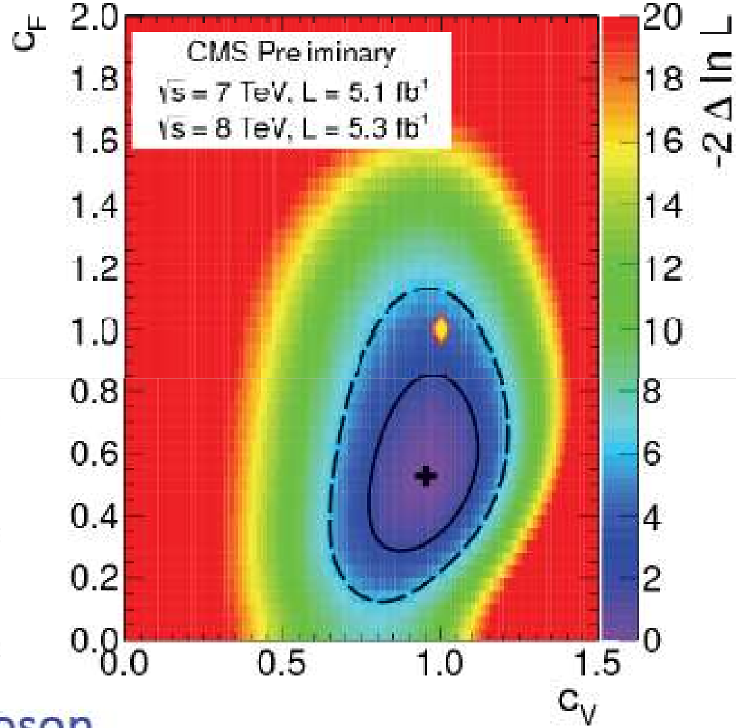
- Common cross section theoretical errors contribute to all measurements
  - Dominated by 15% error on gg-fusion where applicable

Higgs Measurements

- First measurement of new boson couplings when interpreted as a Higgs boson
- Scale vectorial and fermionic couplings by c_V and c_F (use LO)

Production	Decay	LO SM	
VH	$H \to bb$	$\sim \frac{C_V^2 \times C_F^2}{C_F^2}$	$\sim C_V^2$
ttH	$H \to bb$	$\sim \frac{C_F^2 \times C_F^2}{C_F^2}$	$\sim C_F^2$
VBF	$H \to \tau\tau$	$\sim \frac{C_V^2 \times C_F^2}{C_F^2}$	$\sim C_V^2$
ggH	$H \to \tau\tau$	$\sim \frac{C_F^2 \times C_F^2}{C_F^2}$	$\sim C_F^2$
ggH	$H \to ZZ$	$\sim \frac{C_F^2 \times C_V^2}{C_F^2}$	$\sim C_V^2$
ggH	$H \to WW$	$\sim \frac{C_F^2 \times C_V^2}{C_F^2}$	$\sim C_V^2$
VBF	$H \to WW$	$\sim \frac{C_V^2 \times C_V^2}{C_F^2}$	$\sim C_V^4/C_F^2$
ggH	$H \to \gamma\gamma$	$\sim \frac{C_F^2 \times (8.6C_V - 1.8C_F)^2}{C_F^2}$	$\sim C_V^2$
VBF	$H \to \gamma\gamma$	$\sim \frac{C_V^2 \times (8.6C_V - 1.8C_F)^2}{C_F^2}$	$\sim C_V^4/C_F^2$

HIG-12-020



Solid contour: 68% CL
Dashed contour: 95% CL

- Consistent within 2σ with the SM Higgs boson
- Best fit: $(c_V, c_F) = (1, 0.5)$

- From inclusive ZZ->4l and WW->2l2v
  - $R_{WW/ZZ} = 0.9^{+1.1}_{-0.6}$

The Reactions…

The Press…

The discovery of the Higgs made the headlines worldwide

Hawking lost $100 bet over Higgs boson

What Comes After Higgs Boson?

Atlantic Wire what matters now

'God Particle' 'Discovered': European Researchers Claim Discovery of Higgs Boson-Like Particle

HOW THE HIGGS COULD BECOME ANNOYING

Yes, the discovery of the Higgs boson is thrilling and game-changing. But it could also introduce some aggravating situations.

Хиггс увидит бозон

В CERN открыли бозон Хиггса

Текст

— 3.07.12 15:13 —

ТЕКСТ: АЛЕКСАНДРА БОРИСОВА

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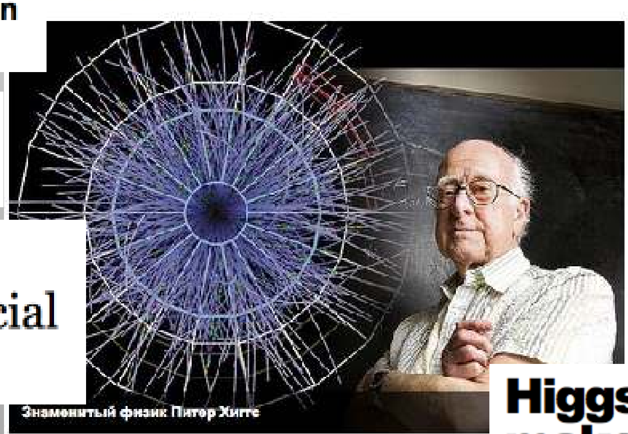
Discovery of Higgs Boson Bittersweet News in Texas



Scientists Set The Higgs Boson To Music

3 Ways the Higgs Boson Discovery Will Impact Financial Services

Higgs boson discovery could make science fiction a reality

Discovery of the 'God particle' could make science fiction a reality, and answer one of the most basic questions of our universe: How did light become matter — and us?

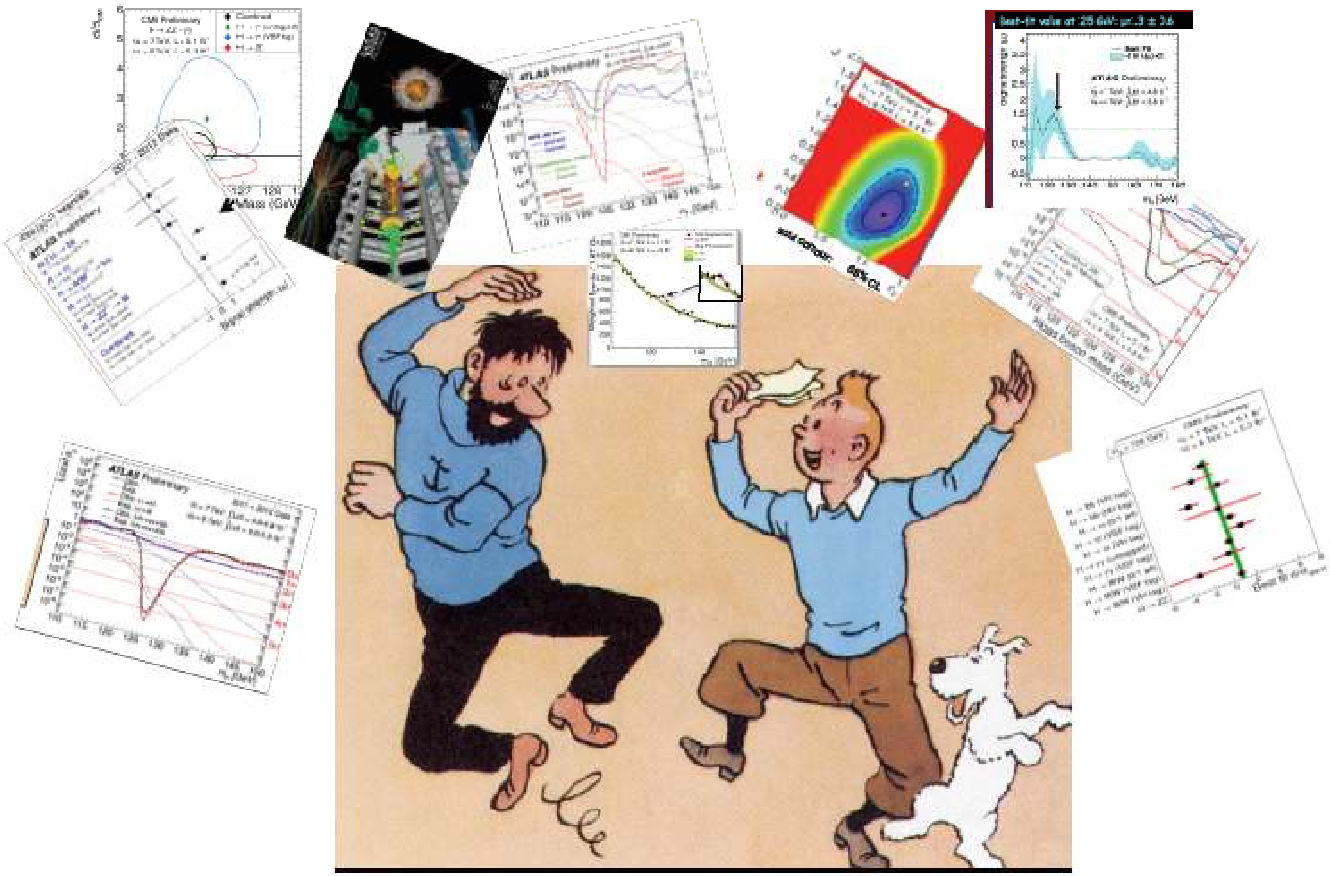
Higgs boson researchers consider move to Cloud computing

"Within another decade the Cloud will be where grid computing is now"

The Theorists…

A. Pomarol ICHEP2012

… and finally plenty of new relevant data has begun to fall over us!



" We made more progress in the last few days than the last 30 years…."

The Community (The day after…)

Confronting the MSSM and the NMSSM with the Discovery of a Signal in the two Photon Channel at the LHC
R. Benbrik, M. Gomez Bock, S. Heinemeyer, O. Stal, G. Weiglein, L. Zeune

Have We Observed the Higgs (Imposter)?
Ian Low, Joseph Lykken, Gabe Shaughnessy

2:1 for Naturalness at the LHC?
Nima Arkani-Hamed, Kfir Blum, Raffaele Tito D'Agnolo, JiJi Fan

The apparent excess in the Higgs to di-photon rate at the LHC: New Physics or QCD uncertainties?
I. Baglio, A. Djouadi, R. M. Godbole

Testing No-Scale F-SU(5): A 125 GeV Higgs Boson and SUSY at the 8 TeV LHC
Tianjun Li, James A. Maxin, Dimitri V. Nanopoulos, Joel W. Walker

Higgs boson of mass 125 GeV in GMSB models with messenger-matter mixing
A. Albaid, K.S. Babu

125 GeV Higgs Boson, Enhanced Di-photon Rate, and Gauged U(1)_PQ-Extended MSSM
Haipeng An, Tao Liu, Lian-Tao Wang

Higgs discovery: the beginning or the end of natural EWSB?
Marc Montull, Francesco Riva

The Social Higgs
Daniele Bertolini, Matthew McCullough

Could two NMSSM Higgs bosons be present near 125 GeV?
John F. Gunion, Yun Jiang, Sabine Kraml

First Glimpses at Higgs' face
J. R. Espinosa, C. Grojean, M. Muhlleitner, M. Trott

Precision Unification in λSUSY with a 125 GeV Higgs
Edward Hardy, John March-Russell, James Unwin

Implications of the Higgs Boson Discovery for mSUGRA
Sujeet Akula, Pran Nath, Gregory Peim

Global Analysis of the Higgs Candidate with Mass ~ 125 GeV
John Ellis, Tevong You

The Higgs sector of the phenomenological MSSM in the light of the Higgs boson discovery
Alexandre Arbey, Marco Battaglia, Abdelhak Djouadi, Farvah Mahmoudi

Is the resonance at 125 GeV the Higgs boson?
Pier Paolo Giardino, Kristjan Kannike, Martti Raidal, Alessandro Strumia

Constraining anomalous Higgs interactions
Tyler Corbett, O. J. P. Eboli, J. Gonzalez-Fraile, M. C. Gonzalez-Garcia

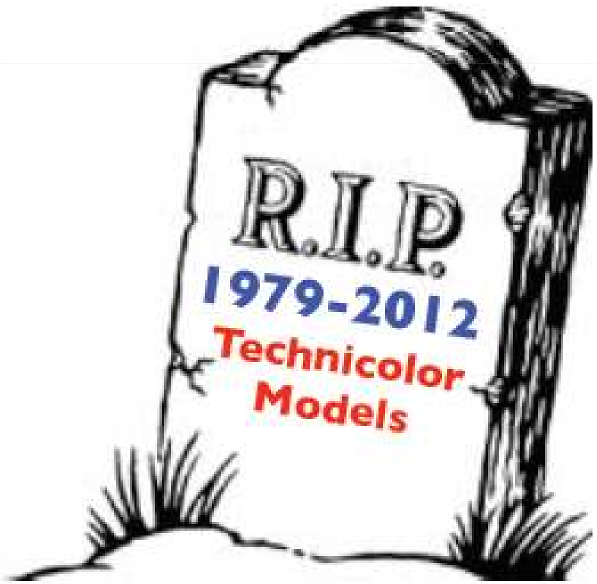
Higgs After the Discovery: A Status Report
Dean Carmi, Adam Falkowski, Eric Kuflik, Tomer Volansky, Jure Zupan

Are There Hints of Light Stops in Recent Higgs Sear
Matthew R. Buckley, Dan Hooper

The Theories??

But not so excellent for all theorists:

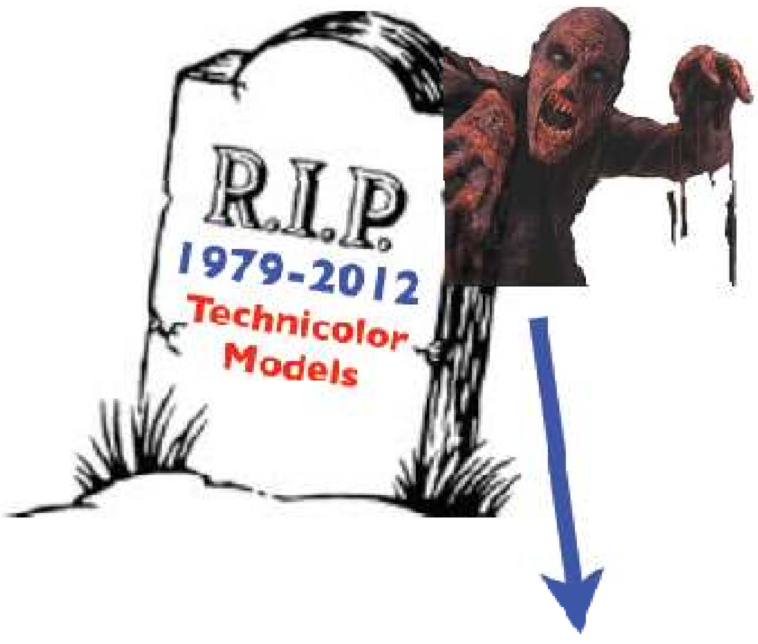
Specially for fans of **Higgsless models:**



The Theories ??

but be careful about resurrections...

It is *not unconceivable* that a light dilaton appears
in Higgsless theories



Dilaton

(Goldstone of the spontaneous breaking of scale invariance)

Couples as a Higgs up to an overall scale → **A Higgs impostor**

Technicolor still Alive?

A Higgs Impostor in LSTC ?

Ken Lane, seminar
CERN, last month

- $J^P = 0^-$: $(I=1)\ \pi_T^{\pm,0}$; $(I=0)\ \pi_T^{0'}$ (a.k.a. η_T)

$$|\eta_L\rangle \cong \sqrt{\tfrac{1}{2}}\,(|\eta_T\rangle - |\pi_T^0\rangle)$$
$$|\eta_H\rangle \cong \sqrt{\tfrac{1}{2}}\,(|\eta_T\rangle + |\pi_T^0\rangle)$$

- $\eta_T - \pi_T^0$ masses and mixing!

$$A = M_{\pi_T^\pm} \simeq 150\text{–}160\,\text{GeV (!)}$$
$$M_{\eta_L} \cong A - B = 125\,\text{GeV}$$
$$\Longrightarrow M_{\eta_H} \cong A + B = 175\text{–}195\,\text{GeV}$$

Should be easy to test
-> No ZZ,WW decays:
That does not look good!

- Dominant decay modes:

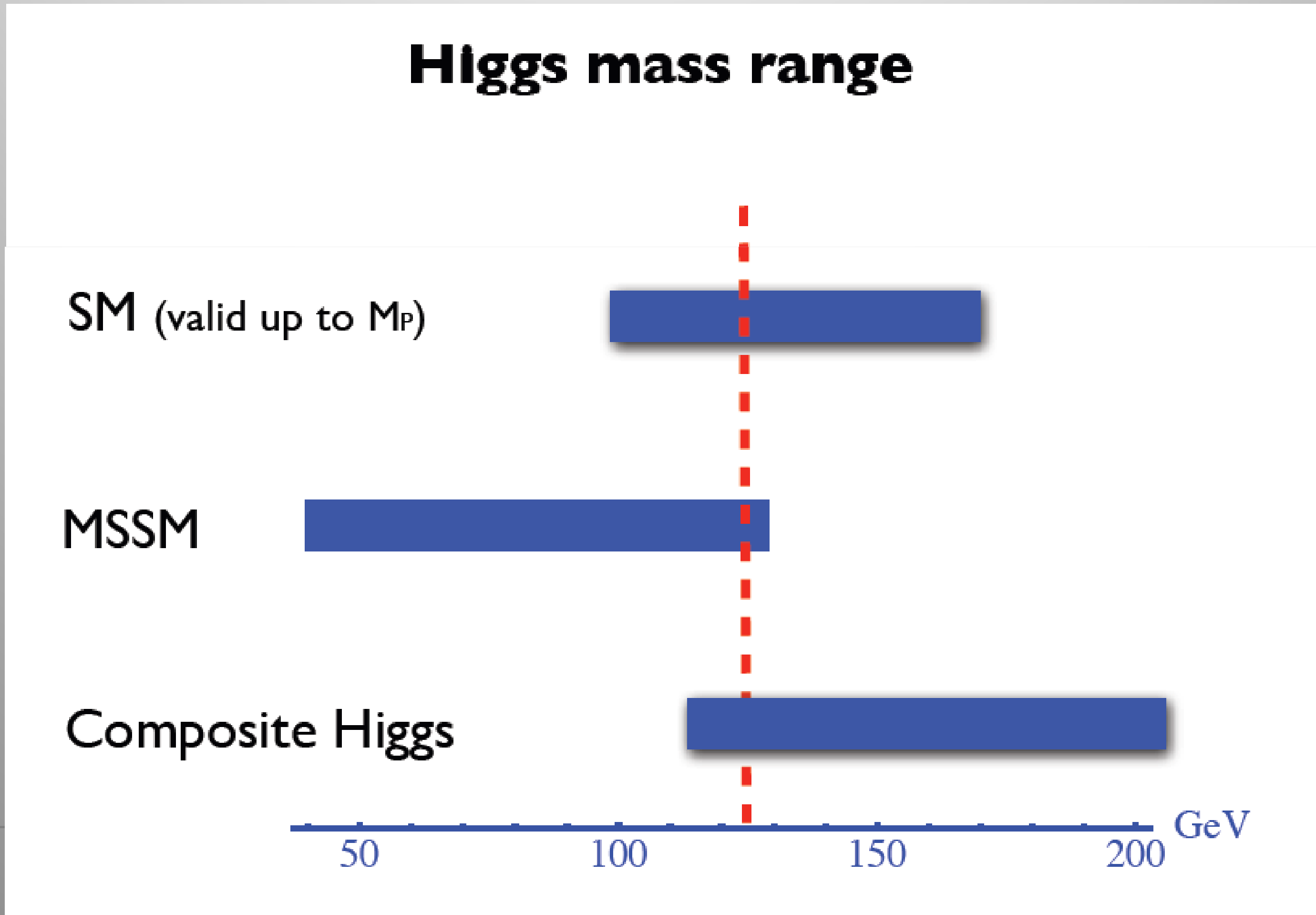
$$\eta_L \to gg,\ \gamma\gamma,\ \bar{f}f\ \text{(not necessarily } \bar{b}b,\ \tau^+\tau^-)$$

- ALL η_L-production is gg-fusion! NO WW/ZZ VBF!

But Ken Lane is a natural born optimist

The Theories

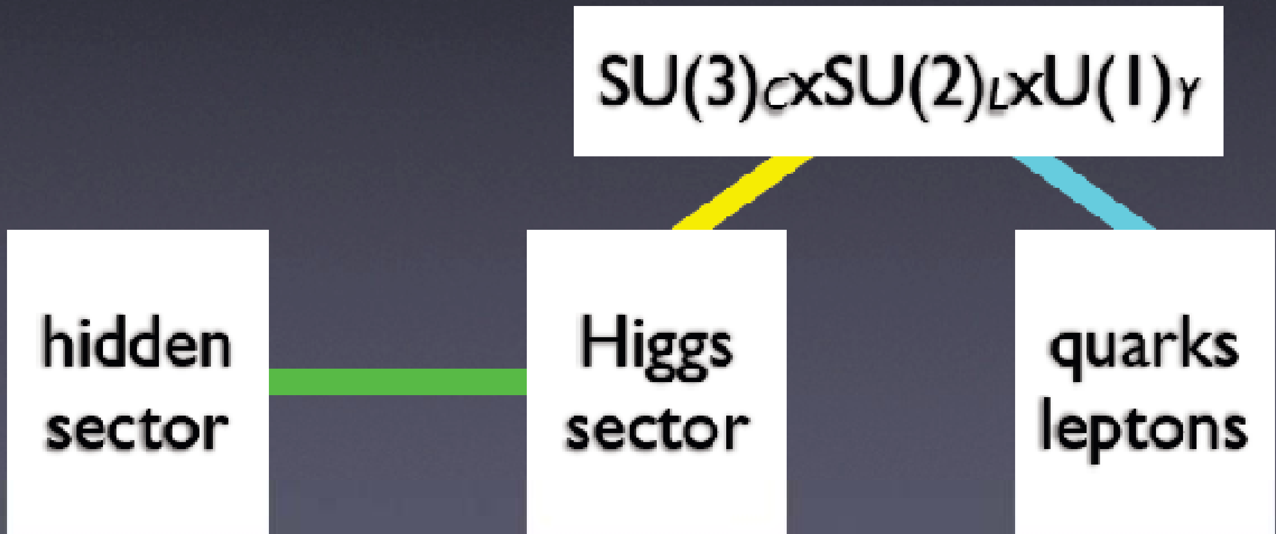
"125 GeV is a mass of maximum agony" N. Arkani Hamed May 2012
But excellent for the experiments & property measurements
All decay channels are available for studies



The Higgs

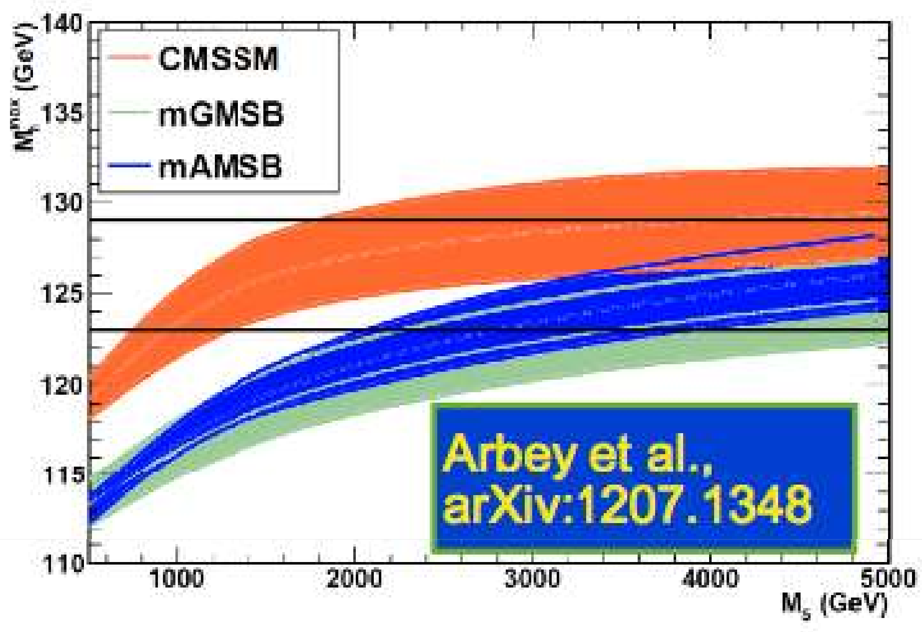
Higgs as a portal

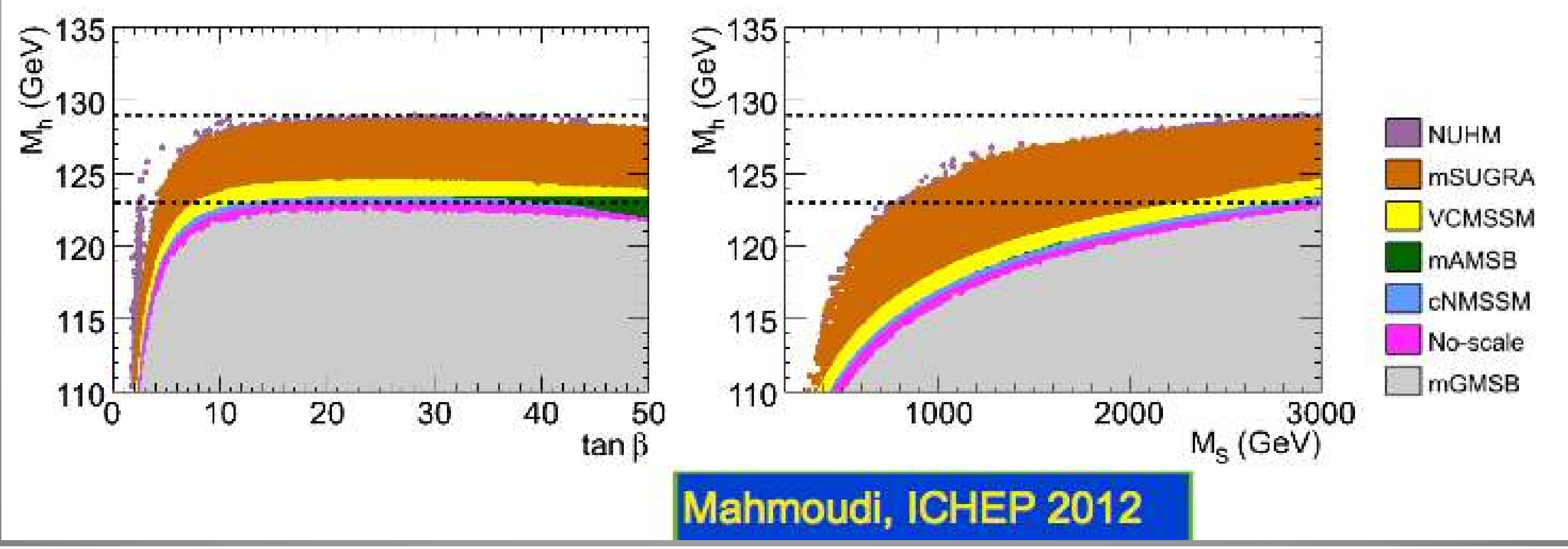
- having discovered the Higgs?
- Higgs boson may connect the Standard Model to other "sectors"



Higgs @ 125 GeV has Consequences

- A 125 GeV Higgs is challenging to accommodate in constrained versions of SUSY particularly for natural superpartner masses
- Starts to constrain some of the simpler models
- If SUSY exists, is it really natural?



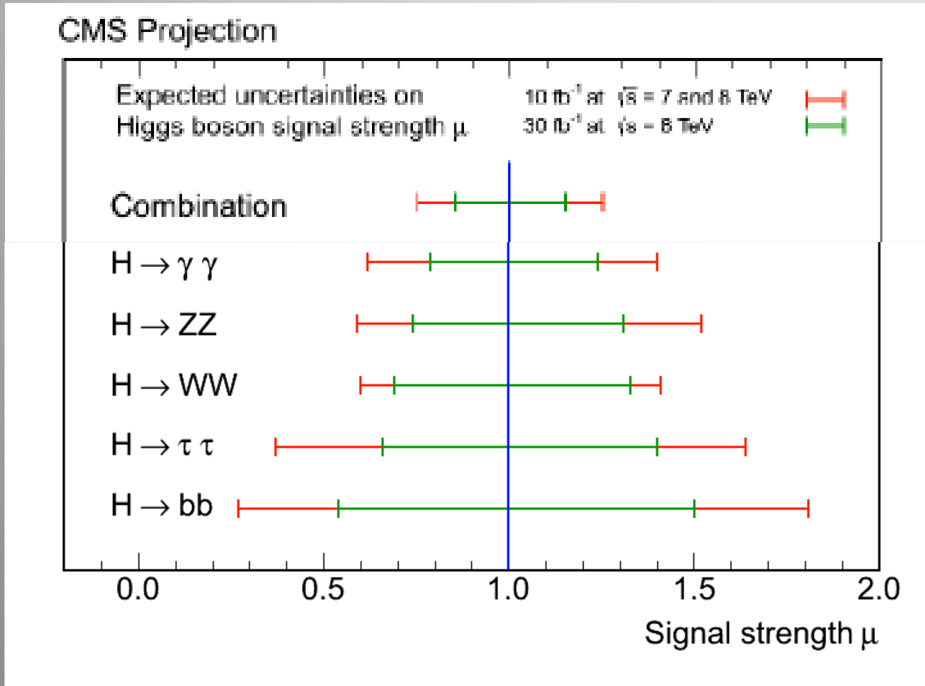


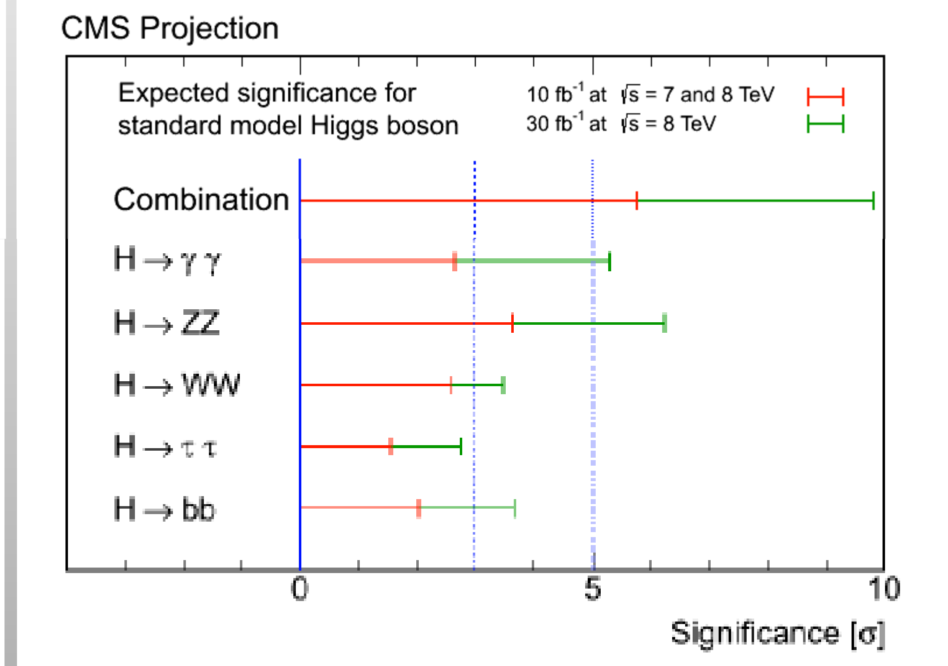
The Future

Short Term Projections

End of the year: 30 fb^{-1}

See Guido Tonelli

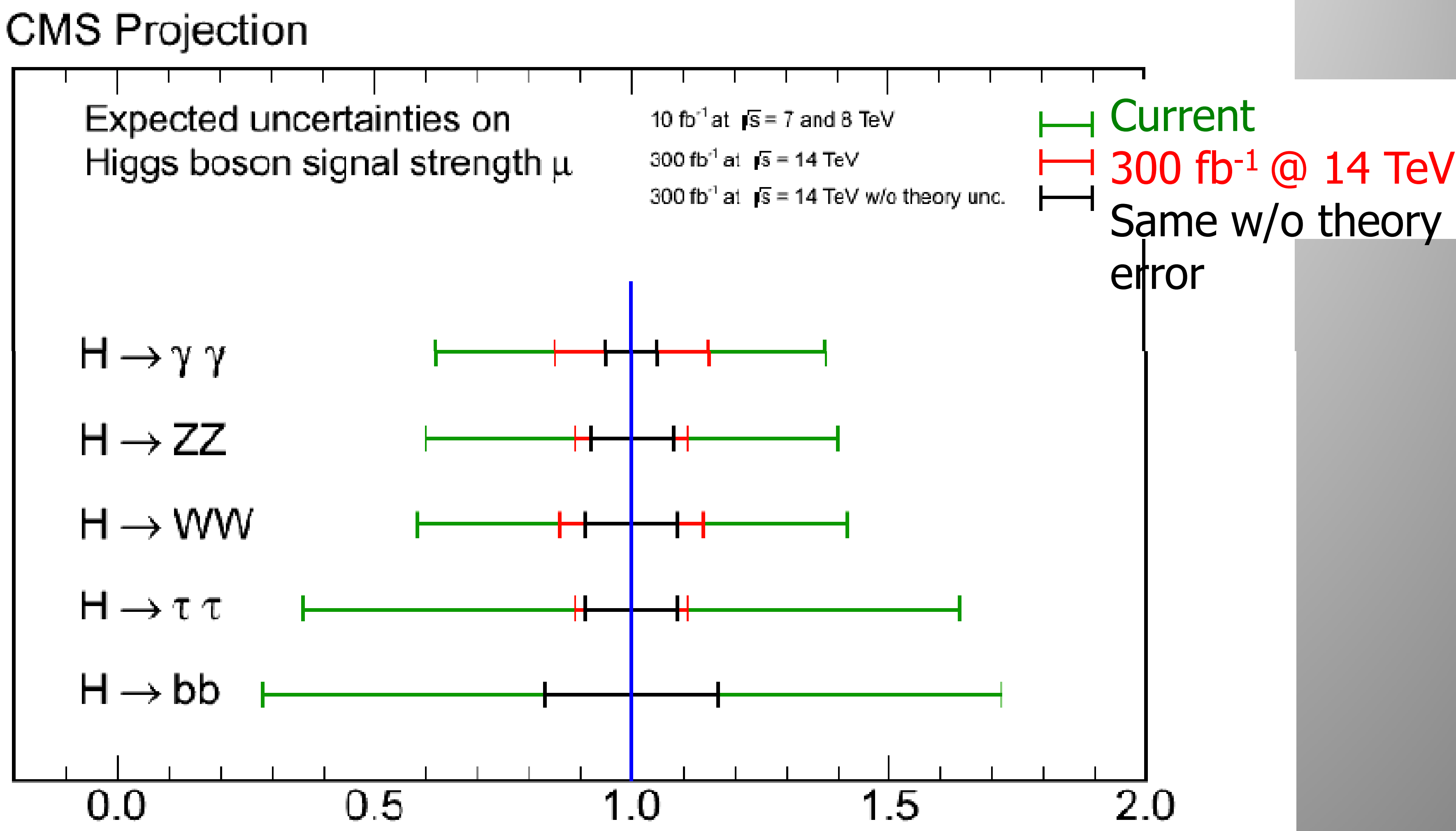




5 σ expected for 2 photon and ZZ channels individually
3 σ for the other channels

Projected Signal Strength Precision

How precise will we measure the different channels at 14 TeV?



Conclusion

- LHC and the experiments are in good shape and eager to get the rest of the 2012 data. This is the last data before 2014-15'
- The LHC will run longer this year to allow the experiments to determine the nature of this new particle before the machine will shutdown for ~1.5 years
- A new Higgs-like particle is with us!
  - The evidence is 5 standard deviations or more in both experiments
  - This particle opens a lot of prospects for new studies
    Is the Higgs a portal to new physics beyond the Standard Model?
  - We expect to learn more about it by the end of the year with about 3 times the amount of statistics