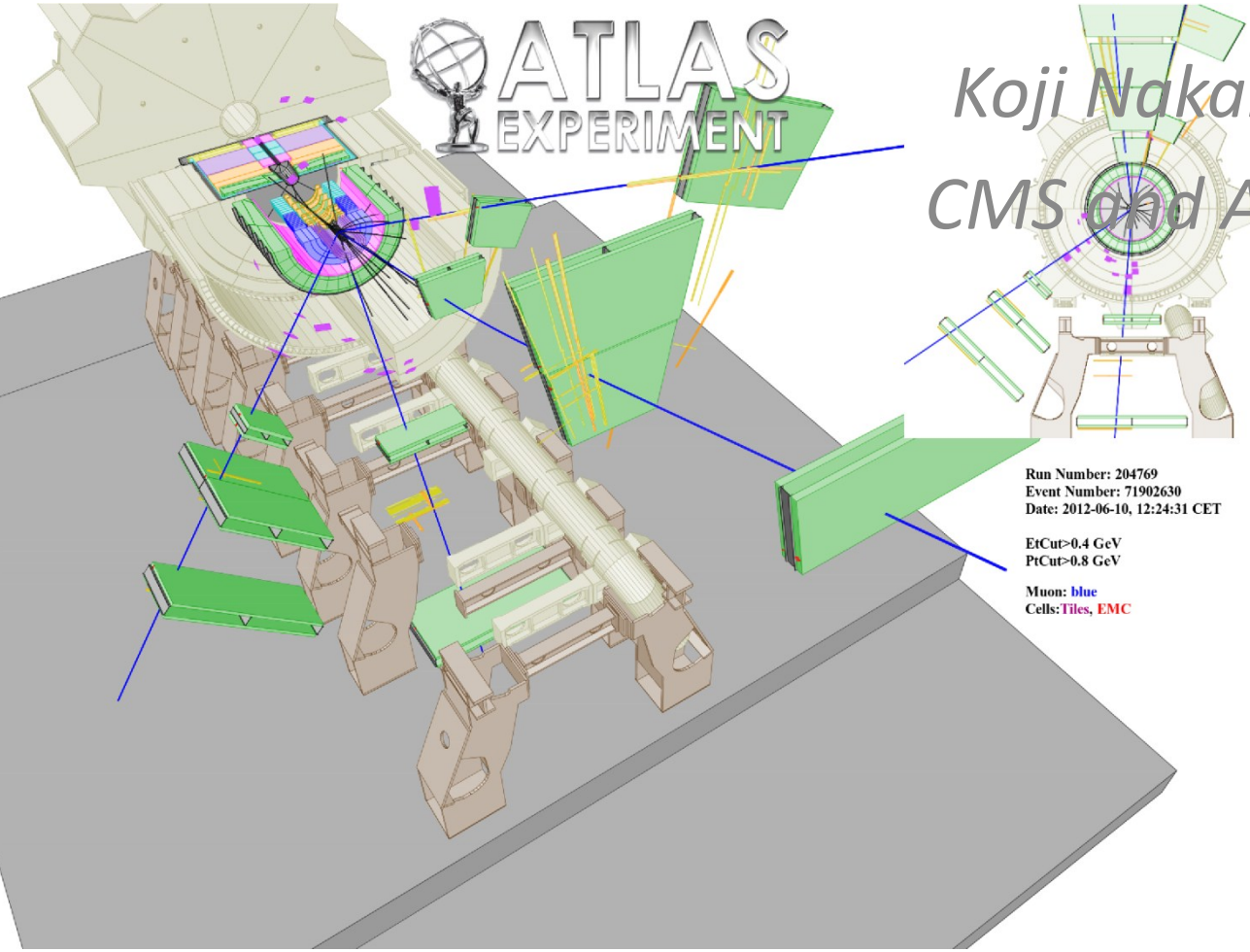
Latest Results on the Standard Model Higgs Searches at the LHC



Koji Nakamura On behalf of CMS and ATLAS collaboration

THE UNIVERSITY OF TOKYO

Independence day in U.S.

Congratulations!

- Examples of NEWS PAPERS

The New York Times

Late Edition

NEW YORK, THURSDAY, JULY 5, 2012

$2.50

Oil Backed Up, Iranians Put It On Idled Ships

Subterfuge at Tankers as Embargo Tightens

ROMNEY NOW SAYS HEALTH MANDATE BY OBAMA IS A TAX

SHIFT RENEWS CRITICISM

Move Aligns Him With Conservative Voices Within His Party

Physicists Find Elusive Particle Seen as Key to Universe

Date Night at the Zoo, if Rare Species Play Along

'I Think We Have It' Is Cheer of Day at Home of Search

ヒッグス粒子 発見か

新素粒子検出 年内に結論

日米欧2チーム

あらゆる物質に質量を与えたと考えられる仮説上の素粒子「ヒッグス粒子」を探しているジュネーブの欧州合同原子核研究所（CERN＝セルン）は4日、大型粒子加速器「LHC」による実験で、ヒッグス粒子とみられる新たな素粒子を見つけたと発表した。ヒッグス粒子は、万物に含まれる素粒子の基本理論として1960年代に提唱された「標準理論」で存在を予言された18個の素粒子のうち、唯一未発見だ。（3面にクローズアップ）

Physicists Find "Elusive Particle" Seen as Key to Universe.

Independence day ~~in U.S.~~ of Higgs ?

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VOL. CLXI ... No. 55,823 NEW YORK, THURSDAY, JULY 5, 2012 $2.50

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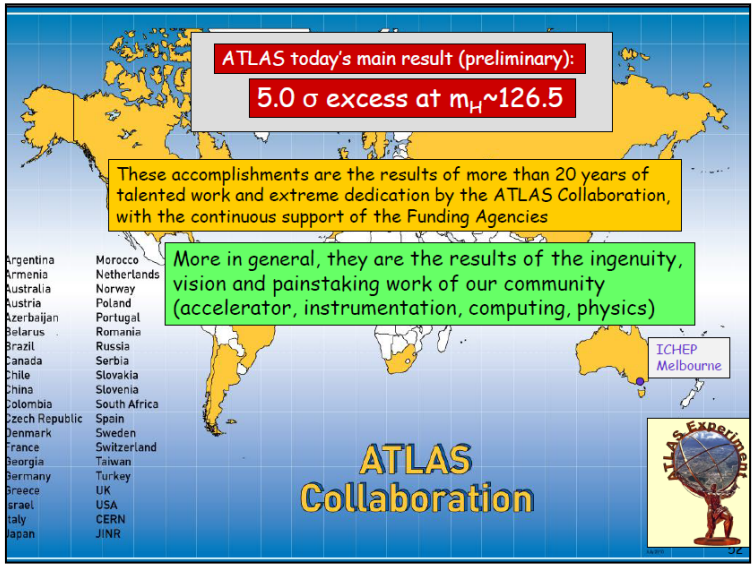
Physicists Find "Elusive Particle" Seen as Key to Universe.

Seminar at July 4th

In summary

We have observed a new boson with a mass of
125.3 ± 0.6 GeV
at
4.9 σ significance !



Global Effort → Global Success

Results today only possible due to extraordinary performance of accelerators – experiments – Grid computing

Observation of a new particle consistent with a Higgs Boson (but which one…?)

Historic Milestone but only the beginning

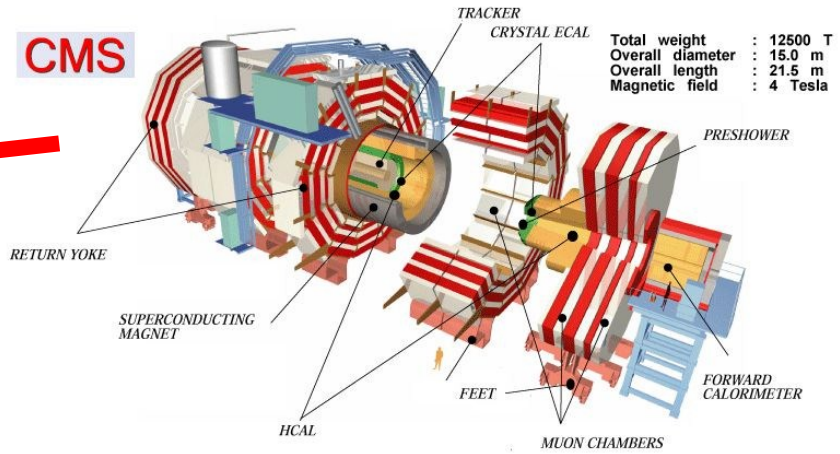
Global Implications for the future

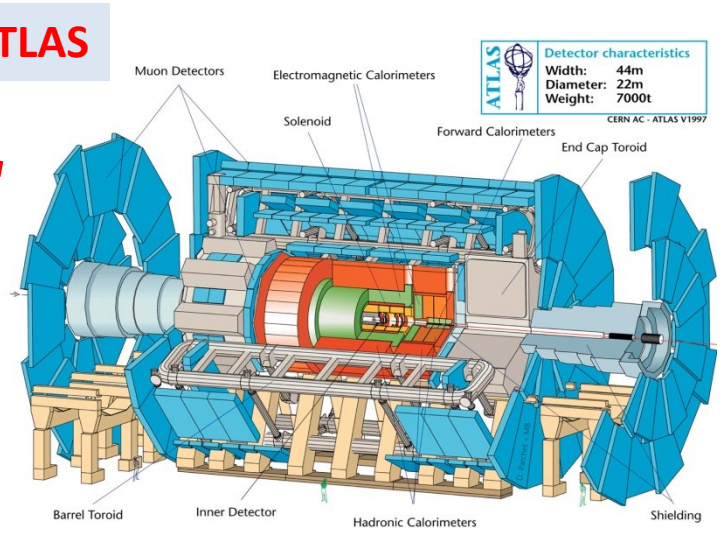
R-D Heuer

CERN

- **How does it observed?**
- **What should we do next?**

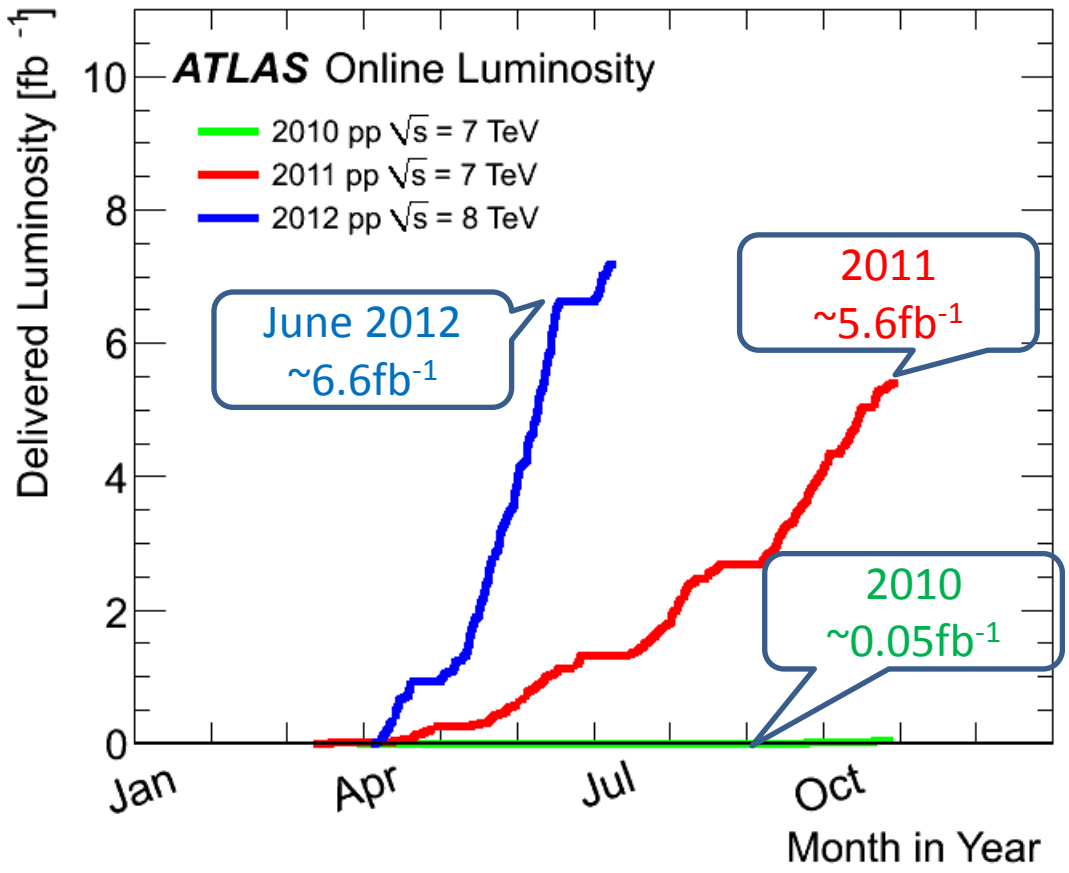
LHC experiments



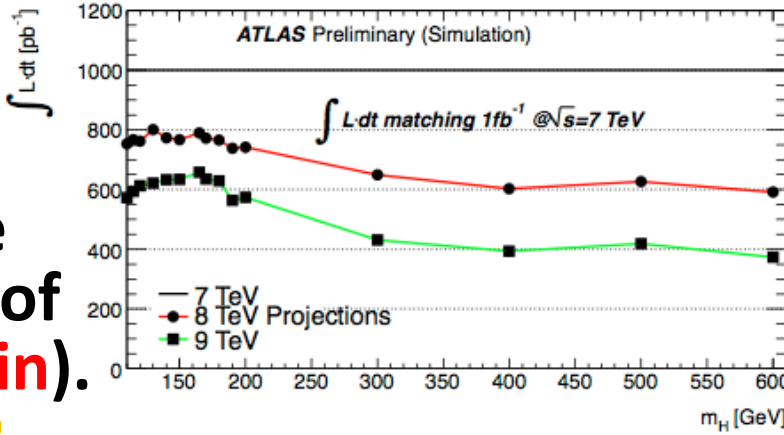


- 7TeV collisions are Started in March 2010.
- Extremely successful operation for these 2.3 years.
- Upgraded CM energy to 8TeV in 2012.

LHC operations and Higgs searches



- **Thanks to very smooth operation of LHC, 4.8-5.1fb^{-1} of 7TeV and 5.3-5.8fb^{-1} of 8TeV data are available to use for the physics analysis.**

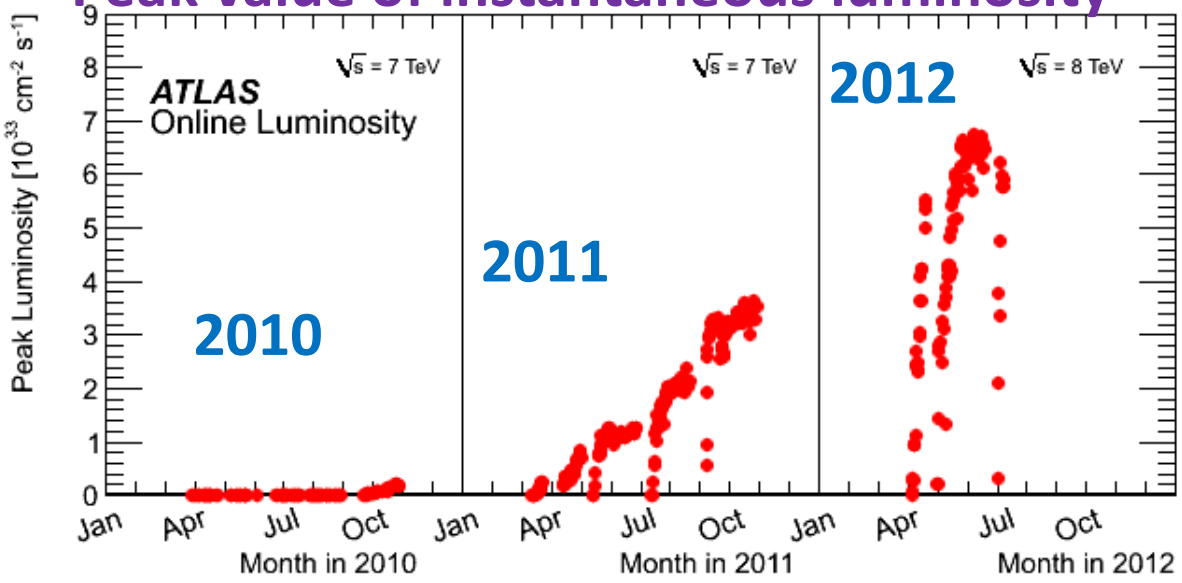


- **Thanks to 8TeV collisions, the same sensitivity can be achieved by 80% of integrated luminosity data (25% gain).**

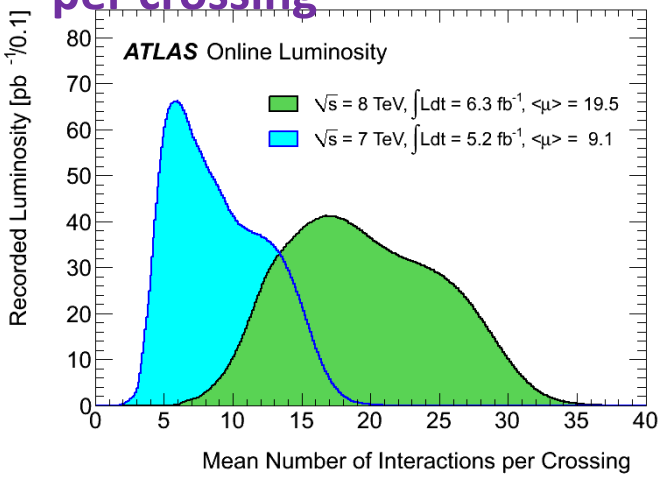
Understanding data

- We had many experience in these two years to understand both detector and Physics backgrounds.
  - Although need better understanding of the tail of SM processes to observe “New particle”.
- What we had to understand in addition to the 2010 and 2011 data was Pileup events!

Peak value of instantaneous luminosity

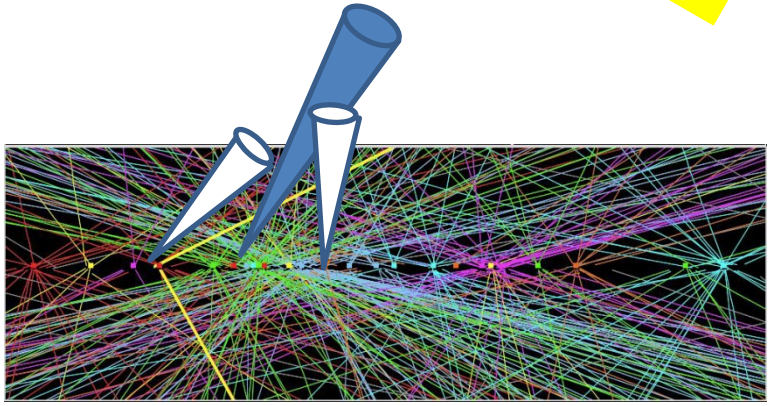


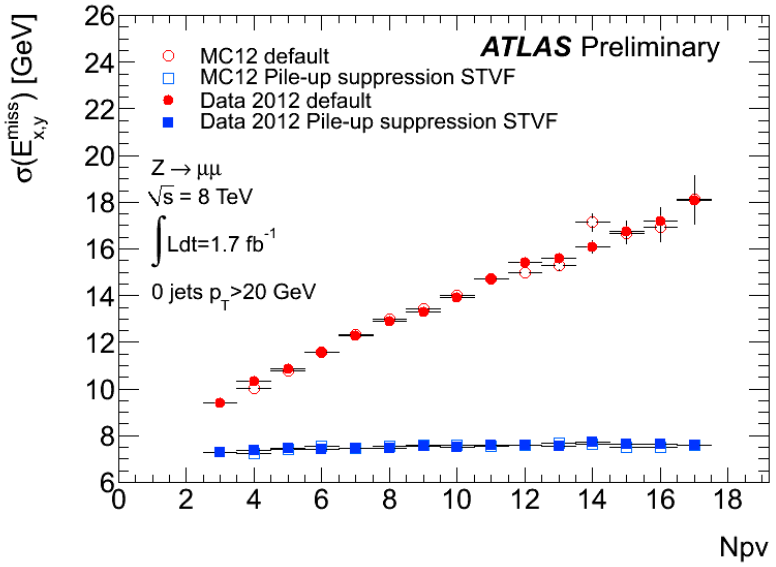
Number of interaction per crossing



Pileup effect and removals

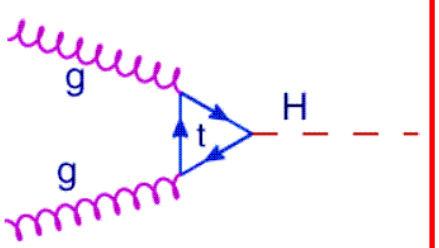
- Each object reconstruction was affected by pileup jets.
- Track in jets can be used to suppress the effect since tracking can point the vertex.
- Defined Jet Vertex Fraction(JVF)
  - $\mathbf{JVF=\sum_{PV} p_T^{track} / \sum_{ALL} p_T^{track}}$
- **Jet :** identify the jets by requiring JVF>0.75(0.5) in 2011(2012) data.
- **MET :** JVF fractions are multiplied to the Jets before summing up the transverse energy.
  - Huge improvement of MET resolution.
- **Lepton isolation :** Npv correction have to be applied.
- **Tau :** track impact parameter(Z_0) are tightened to avoid pileup tracks.



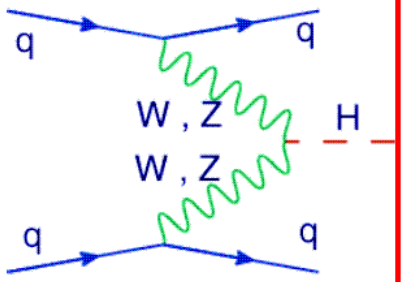


Higgs production and decay @ LHC

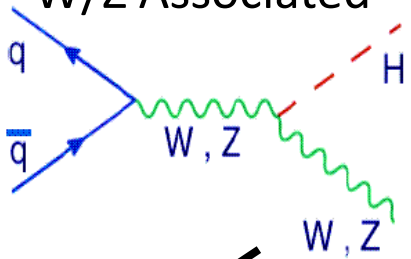
Gluon Fusion(ggF)



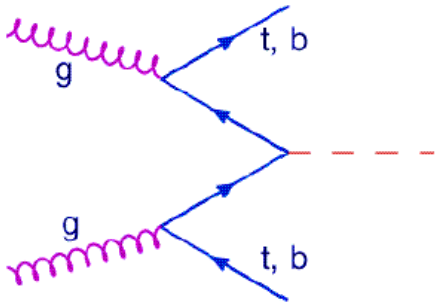
Vector Boson Fusion



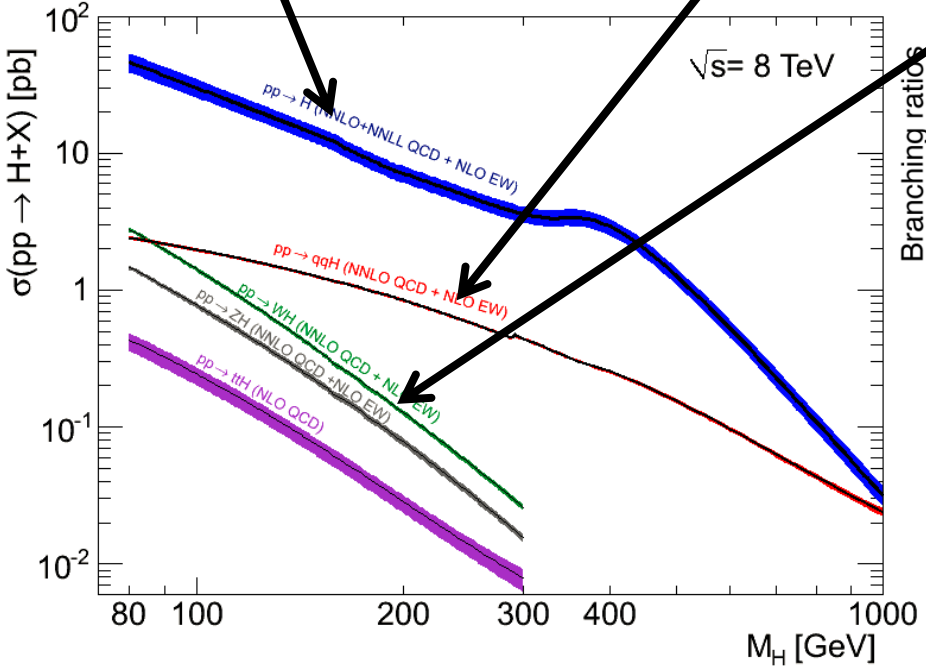
W/Z Associated



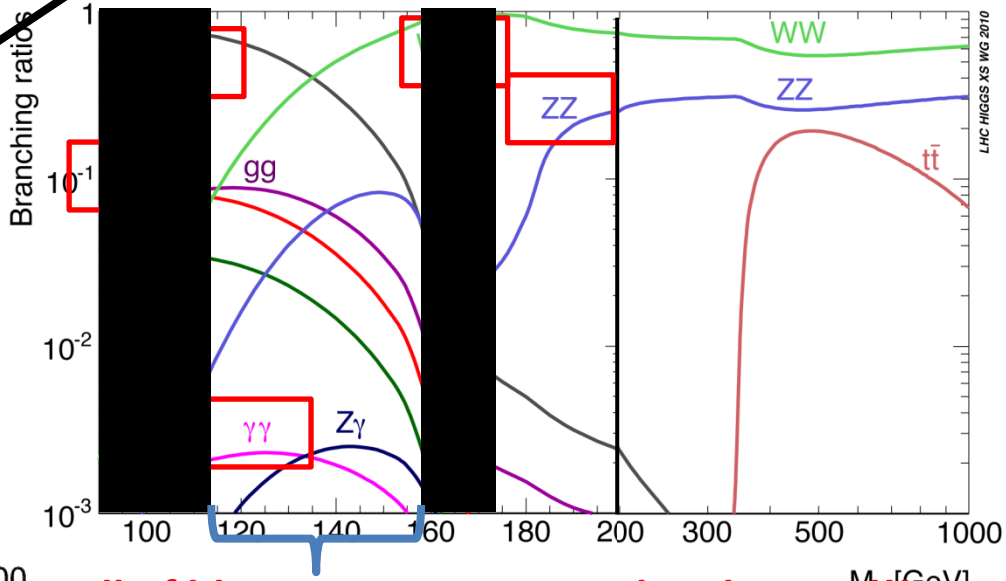
tt/bb Associated



Production



Decay



All of bb, WW, ττ, γγ, ZZ can be observed!!

Analysis Channels

CMS

H decay	H prod	Analyses Exclusive final states	No. of channels	m_H range (GeV)	m_H resolution	7 TeV	8 TeV	Ref
$\gamma\gamma$	untagged	$\gamma\gamma$ (4 diphoton classes)	4	110–150	1-2%	5.1	5.3	[73]
	VBF-tag	$\gamma\gamma + (jj)_{VBF}$ (low or high m_{jj} for 8 TeV)	1 or 2	110–150	1-2%	5.1	5.3	[73]
bb	VH-tag	($\nu\nu$, ee, $\mu\mu$, $e\nu$, $\mu\nu$ with 2 b-jets)$\otimes$ (low or high p_T^V)	10	110–135	10%	5.0	5.1	[74]
	$t\bar{t}$H-tag	(ℓ with 4,5,$\geq$6 jets) $\otimes$ (3,$\geq$4 b-tags); ($\ell\ell$ with 2 or $\geq$3 b-tagged jets)	9	110–140		5.0	-	[75]
$H \to \tau\tau$	0/1-jets	($e\tau_h$, $\mu\tau_h$, $e\mu$, $\mu\mu$)$\times$ (low or high $p_T^{\tau\tau}$) $\times$ (0 or 1 jets)	16	110–145	20%	4.9	5.1	[76]
	VBF-tag	($e\tau_h$, $\mu\tau_h$, $e\mu$, $\mu\mu$) + $(jj)_{VBF}$	4	110–145	20%	4.9	5.1	[76]
	ZH-tag	(ee, $\mu\mu$) $\times$ ($\tau_h\tau_h$, $e\tau_h$, $\mu\tau_h$, $e\mu$)	8	110–160		5.0	-	[77]
	WH-tag	$\tau_h ee$, $\tau_h\mu\mu$, $\tau_h e\mu$	3	110–140		4.9	-	[78]
WW $\to \ell\nu qq$	untagged	($e\nu$, $\mu\nu$)$\otimes$($(jj)_W$ with 0 or 1 jets)	4	170–600		5.0	5.1	[79, 80]
WW $\to \ell\nu\ell\nu$	0/1-jets	(DF or SF dileptons) $\otimes$ (0 or 1 jets)	4	110–600	20%	4.9	5.1	[81, 82]
WW $\to \ell\nu\ell\nu$	VBF-tag	$\ell\nu\ell\nu + (jj)_{VBF}$ (DF or SF dileptons for 8 TeV)	1 or 2	110–600	20%	4.9	5.1	[81, 82]
WW $\to \ell\nu\ell\nu$	WH-tag	$3\ell 3\nu$	1	110–200		4.9	-	[83]
WW $\to \ell\nu\ell\nu$	VH-tag	$\ell\nu\ell\nu + (jj)_V$ (DF or SF dileptons)	2	118–190		4.9	-	[84]
ZZ $\to 4\ell$	inclusive	$4e$, 4μ, $2e2\mu$	3	110–600	1-2%	5.0	5.3	[85]
ZZ $\to 2\ell 2\tau$	inclusive	(ee, $\mu\mu$) $\times$ ($\tau_h\tau_h$, $e\tau_h$, $\mu\tau_h$, $e\mu$)	8	200–600	10-15%	5.0	5.3	[85]
ZZ $\to 2\ell 2q$	inclusive	($ee, \mu\mu$)$\times$($(jj)_Z$ with 0, 1, 2 b-tags)	6	130–164 200–600	3%	4.9	-	[86]
ZZ $\to 2\ell 2\nu$	untagged	((ee, $\mu\mu$) with MET) $\otimes$ (0 or 1 or 2 non-VBF jets)	6	200–600	7%	4.9	5.1	[87]
ZZ $\to 2\ell 2\nu$	VBF-tag	(ee, $\mu\mu$) with MET and $(jj)_{VBF}$	2	200–600	7%	4.9	5.1	[87]

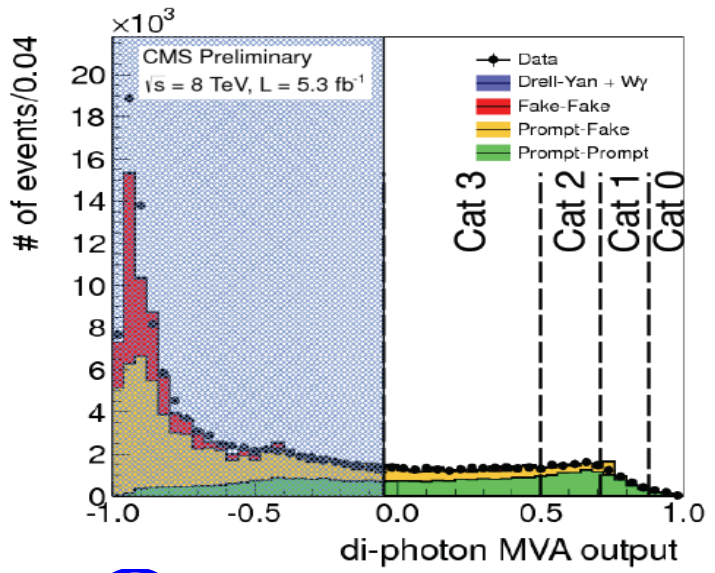
ATLAS

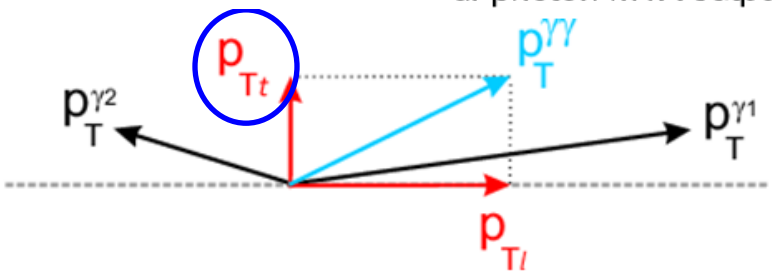
Higgs Decay	Subsequent Decay	Sub-Channels	m_H Range [GeV]	$\int L\,dt$ [fb^{-1}]	Ref.
		2011 $\sqrt{s}$ =7 TeV			
$H \to \gamma\gamma$	–	9 sub-channels $\{p_{T_t} \otimes \eta_\gamma \otimes$ conversion$\} \oplus \{2\text{-jets}\}$	110–150	4.8	[14]
$H \to ZZ^{(*)}$	$\ell\ell\ell'\ell'$	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	110–600	4.8	[15]
	$\ell\ell\nu\bar{\nu}$	$\{ee, \mu\mu\} \otimes$ {low, high pile-up}	200–280–600	4.7	[16]
	$\ell\ell q\bar{q}$	{b-tagged, untagged}	200–300–600	4.7	[17]
$H \to WW^{(*)}$	$\ell\nu\ell\nu$	$\{ee, e\mu, \mu\mu\} \otimes$ {0-jets, 1-jet, 2-jets} $\otimes$ {low, high pile-up}	110–200–300–600	4.7	[18]
	$\ell\nu q\bar{q}'$	$\{e, \mu\} \otimes$ {0-jets, 1-jet, 2-jets}	300–600	4.7	[19]
$H \to \tau^+\tau^-$	$\tau_{\text{lep}}\tau_{\text{lep}}$	$\{e\mu\} \otimes$ {0-jets} $\oplus \{\ell\ell\} \otimes$ {1-jet, 2-jets, VH}	110–150	4.7	[20]
	$\tau_{\text{lep}}\tau_{\text{had}}$	$\{e, \mu\} \otimes$ {0-jets} $\otimes \{E_T^{\text{miss}} < 20$ GeV, $E_T^{\text{miss}} \geq 20$ GeV$\}$ $\oplus \{e, \mu\} \otimes$ {1-jet} $\oplus \{\ell\} \otimes$ {2-jets}	110–150	4.7	
	$\tau_{\text{had}}\tau_{\text{had}}$	{1-jet}	110–150	4.7	
$VH \to b\bar{b}$	$Z \to \nu\bar{\nu}$	$E_T^{\text{miss}} \in \{120-160, 160-200, \geq 200$ GeV$\}$	110-130	4.6	[21]
	$W \to \ell\nu$	$p_T^W \in \{< 50, 50-100, 100-200, \geq 200$ GeV$\}$	110-130	4.7	
	$Z \to \ell\ell$	$p_T^Z \in \{< 50, 50-100, 100-200, \geq 200$ GeV$\}$	110-130	4.7	
		2012 $\sqrt{s}$ =8 TeV			
$H \to \gamma\gamma$	–	9 sub-channels $\{p_{T_t} \otimes \eta_\gamma \otimes$ conversion$\} \oplus \{2\text{-jets}\}$	110–150	5.9	[14]
$H \to ZZ^{(*)}$	$\ell\ell\ell'\ell'$	$\{4e, 2e2\mu, 2\mu 2e, 4\mu\}$	110–600	5.8	[15]

$H \rightarrow \gamma\gamma$

Event selection & categorization

- Select di-photon with MVA id. (except ATLA 8TeV)
  - **ATLAS : pT1> 40GeV, pT2>30GeV**
  - **CMS : pT1>mγγ/3, pT2>mγγ/4**
- Categorizers
  - Converted photon event or un-converted
  - Calorimeter transition region (ATLAS)
  - Higgs pt thrust variable(ATLAS)
- CMS used MVA selection
  - 4category by MVA score.
- ATLAS have cut based 9 categories
- One(or two) more category “VBF” fo experiments.

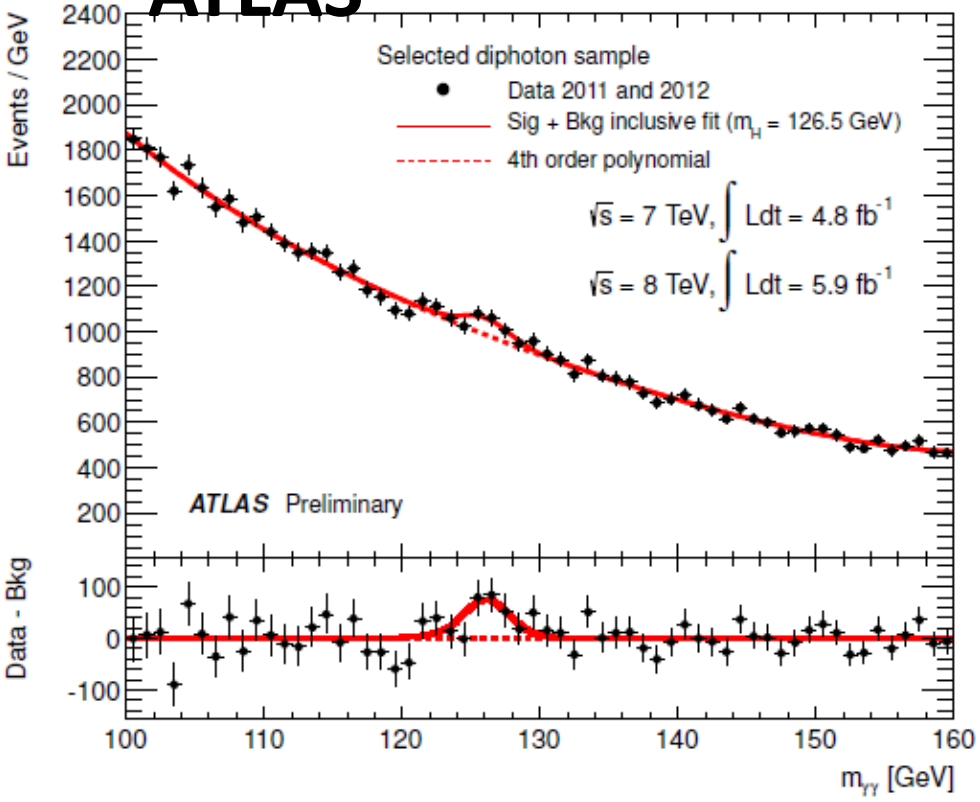




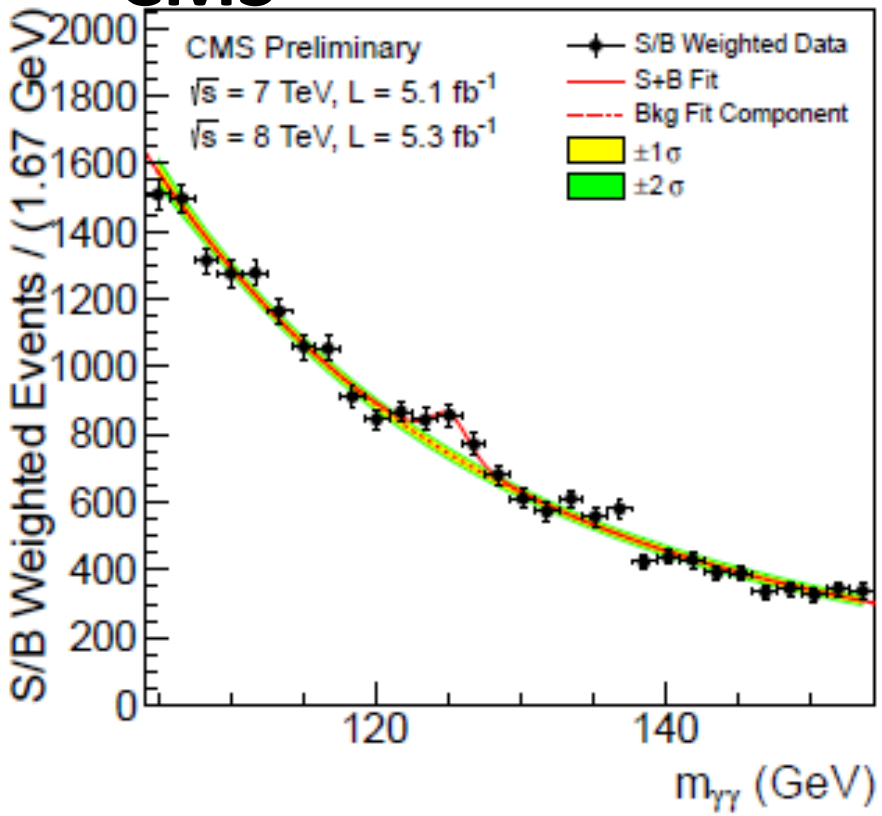
Thrust axis : $\vec{t} = \vec{p}_T(\gamma_1) - \vec{p}_T(\gamma_2)$

Inclusive view

ATLAS



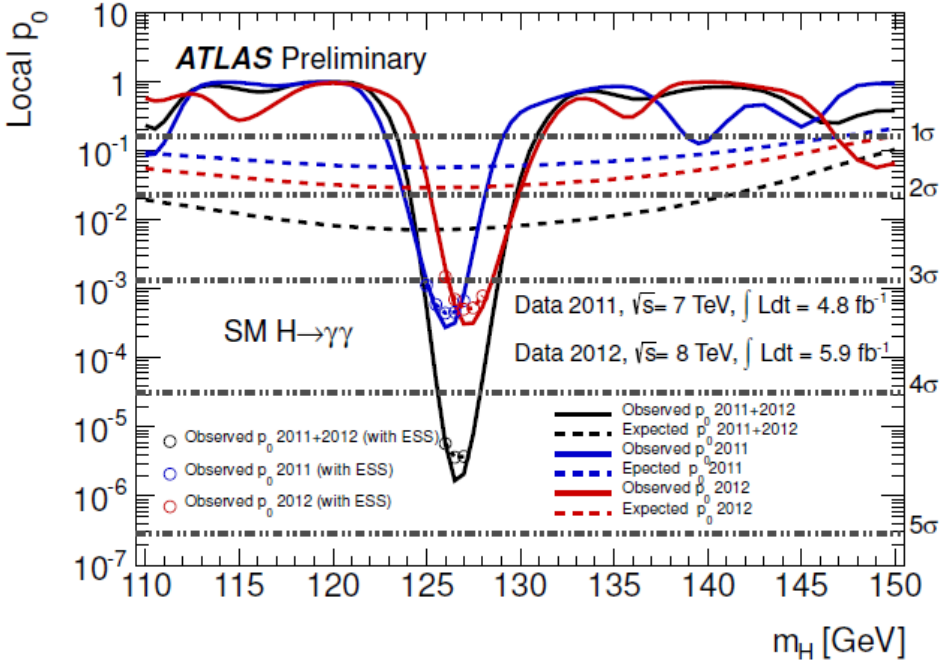
CMS



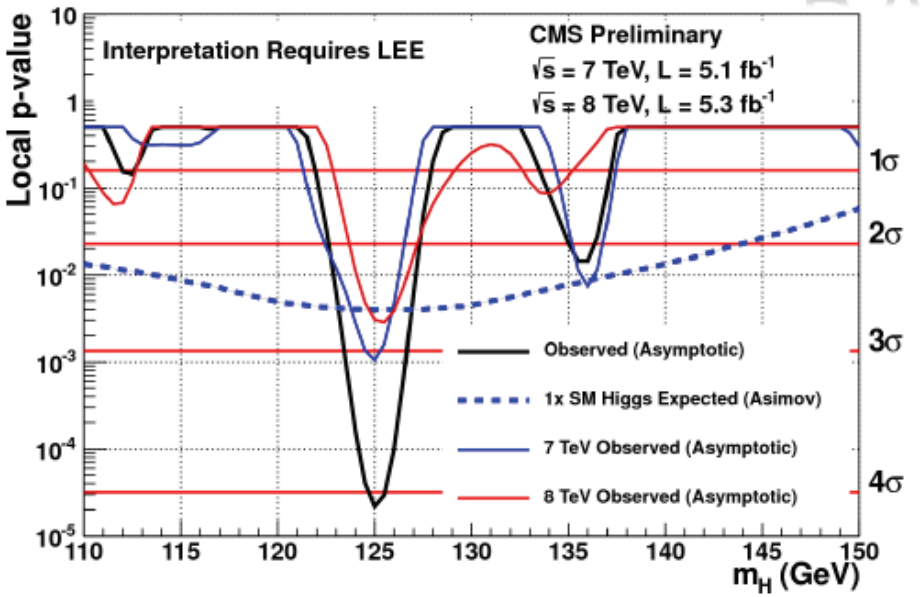
- **These plots were not used for the any sensitivity calculations, but just illustrating purpose.**
- CMS events are weighted by sensitivity. (1.67GeV/bin ??)

Results : Discovery significance

ATLAS



CMS



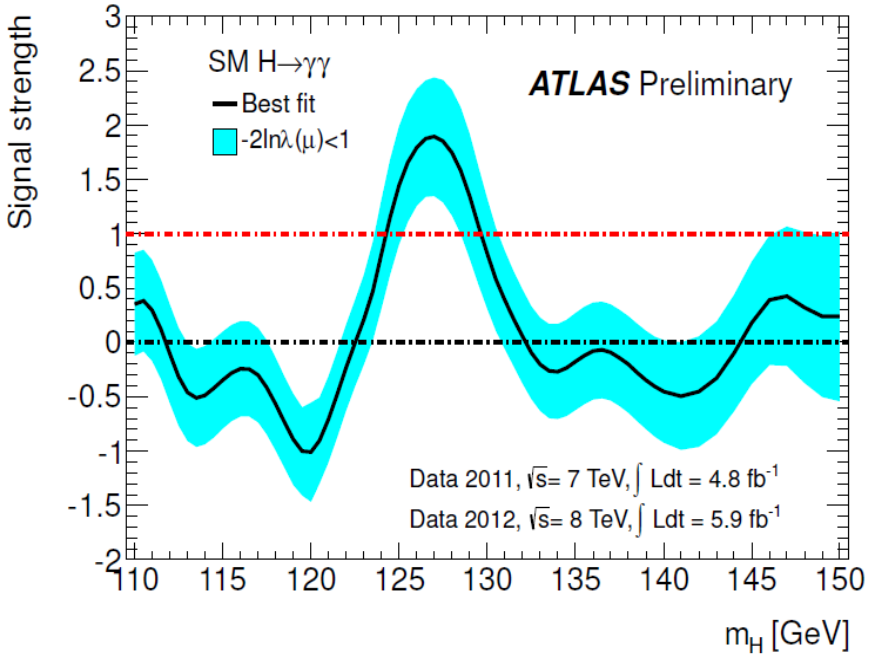
Expected significance 2.4σ **Expected significance 2.6σ**

Observed significance 4.5σ **Observed significance 4.1σ**

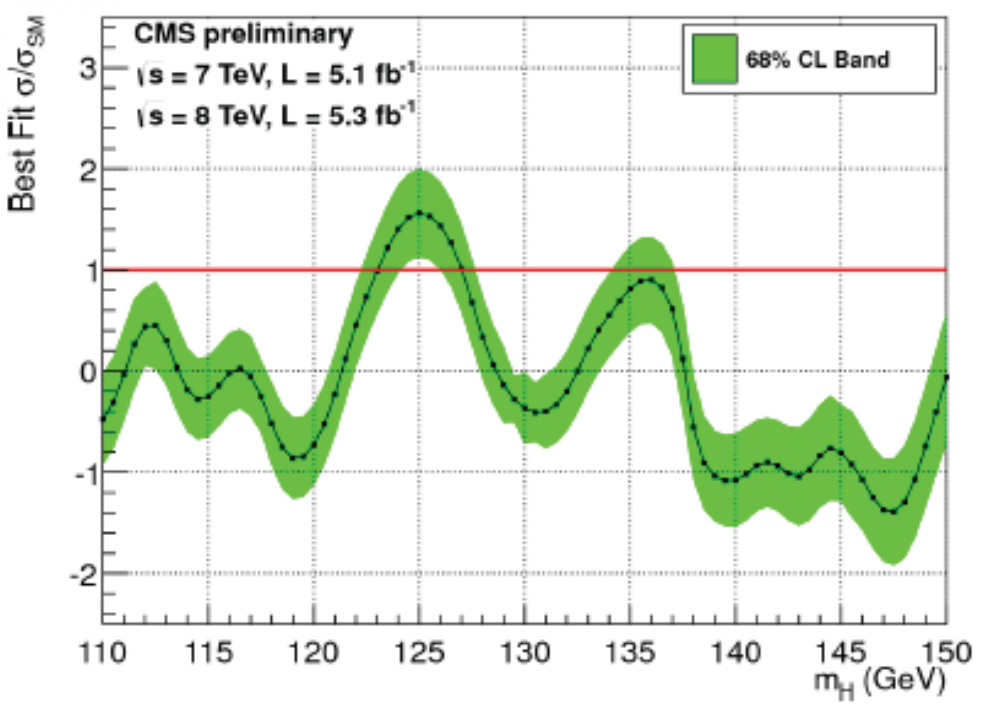
(global significance 3.6σ) **(global significance 3.2σ)**

Signal cross section times branching ratio

ATLAS



CMS



Best fit Signal strength

1.9±0.5

Best fit Signal strength

1.56±0.43

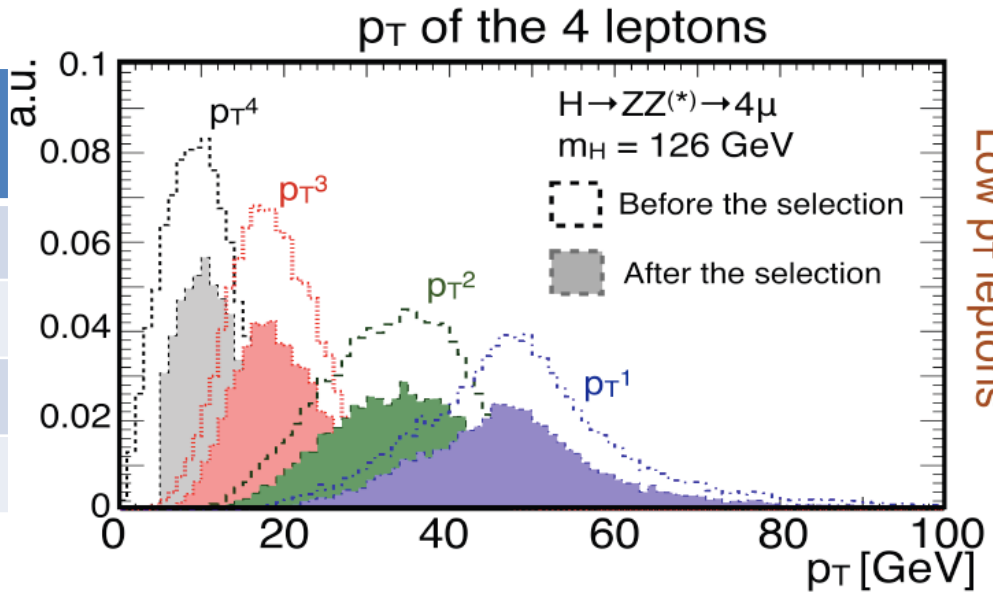
H→ZZ

Event selection

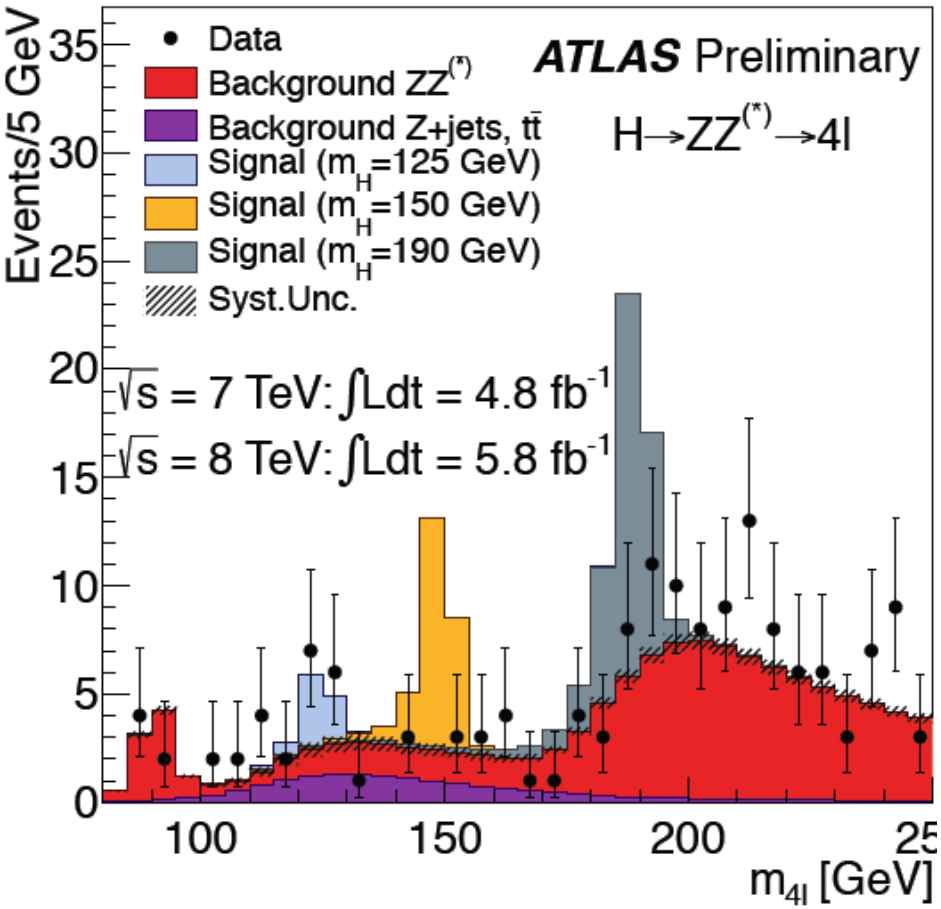
- Select a pair of same-flavour opposite-charege di-leptons.
  - **ATLAS : pT1,2,3,4 > 20,15,10,7(6) GeV for e(μ)**
  - **CMS : pT1,2,3,4 > 20, 10,7(5), 7(5) GeV for e(μ)**
- At least one Z candidate have :
  - ATLAS : mthr < mll < 120 mthr=17.5-50 (22.5 @125GeV)
  - CMS : 40 < mll < 120
  - Isolations and dR(ll) cut(ATLAS) or mll for second Z mll>4GeV(CMS)

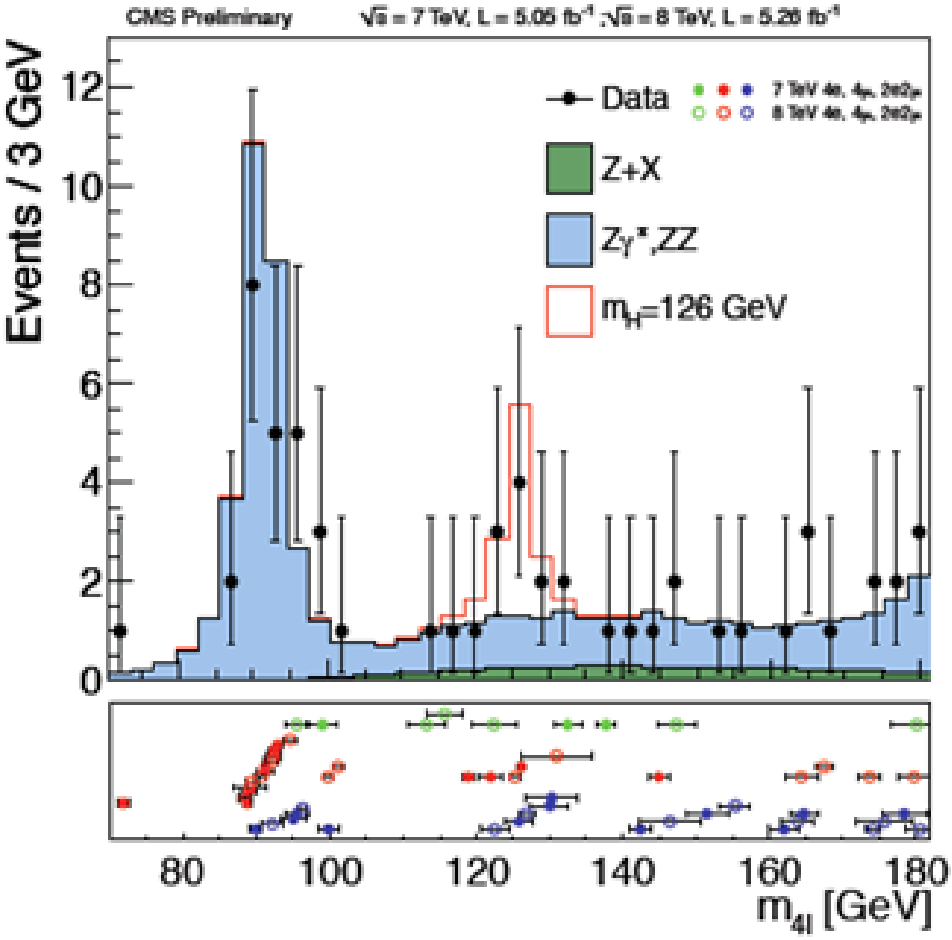
	ATLAS [120-130]	CMS [110-160]
ZZ bkg.	(22.5±0.8)	15.5±1.0
Z+jets+top	(11.8±1.4)	4.4+2.2-1.7
Bkg total	5.1±0.8	19.9±2.4
mH 126GeV	5.3±0.8	8.3±1.2

() is the number for 0-160GeV



Results : m_{4l} distribution



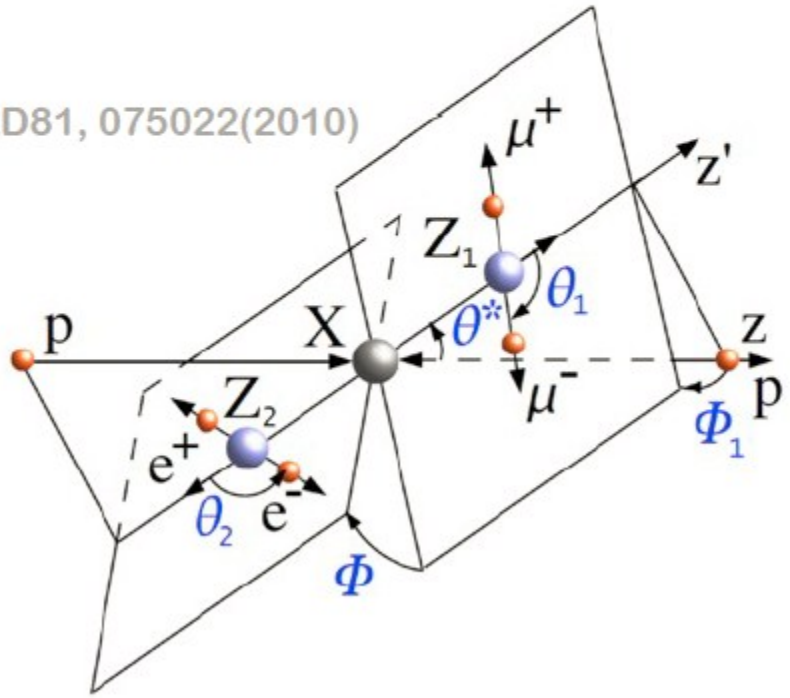


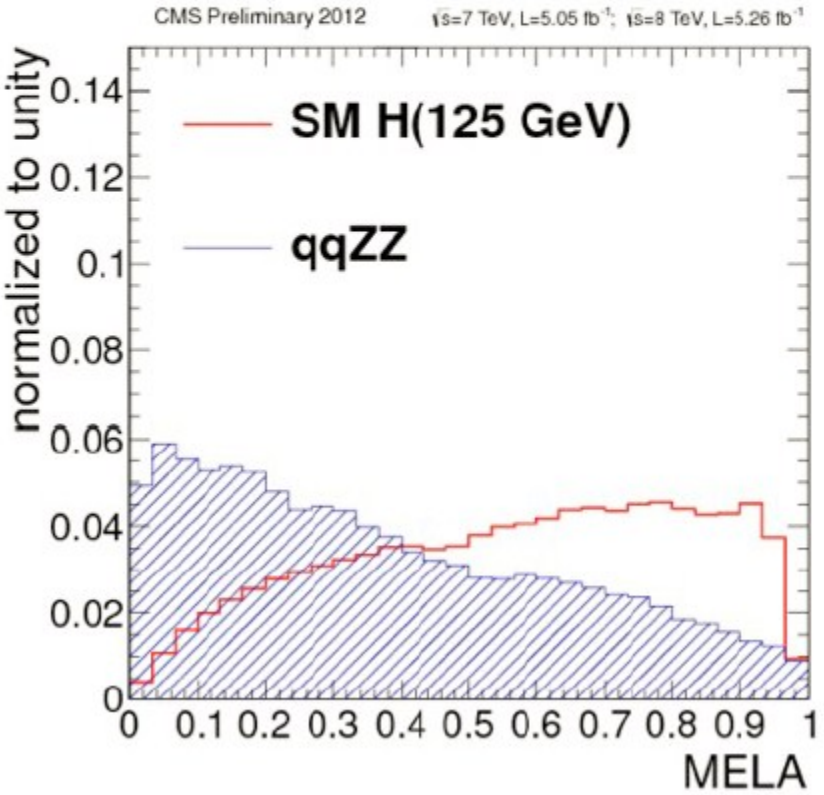
CMS: Additional improvement by ME

- Decay kinematic fully described by 5 angles and 2 masses
  - discriminates spin 0 particle from background
  - analogous of $\Delta\phi$ in H → WW analysis
  - MELA: matrix element likelihood analysis

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

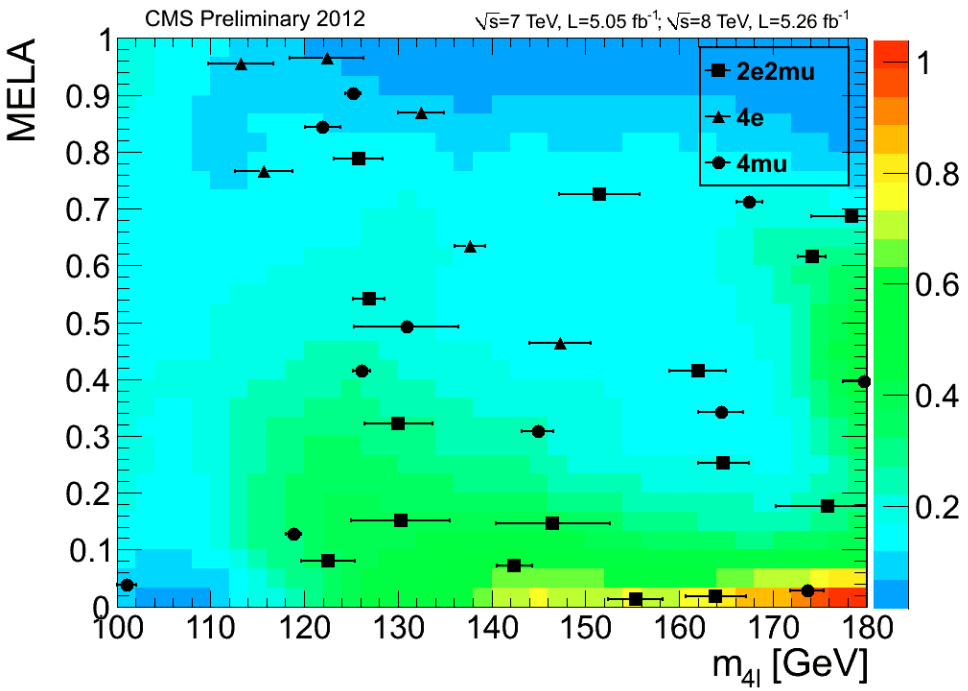
PRD81, 075022(2010)



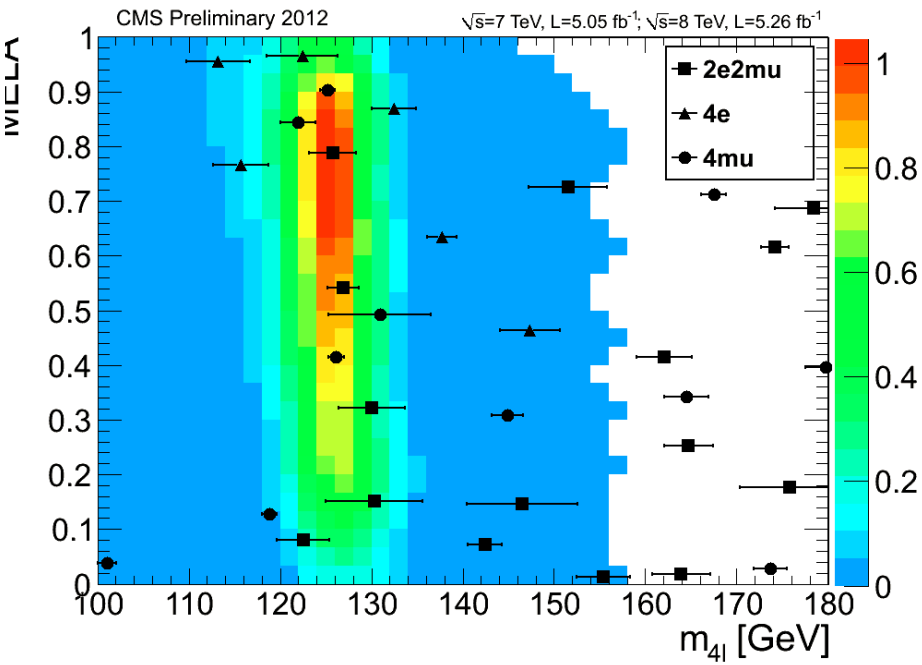


MELA Likelihood-mass 2D

Background



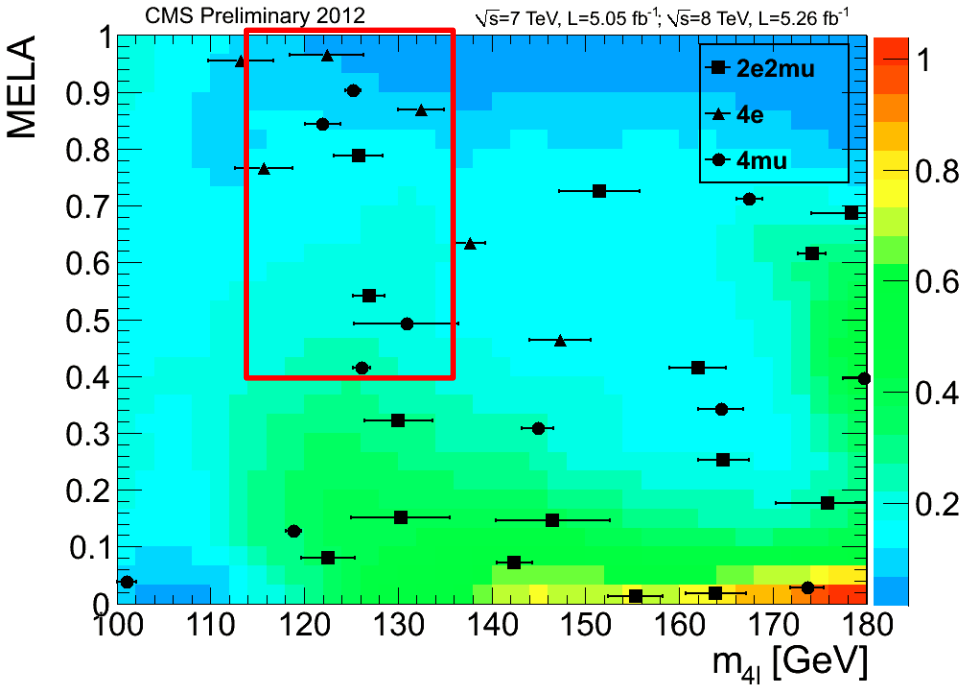
Signal @126GeV



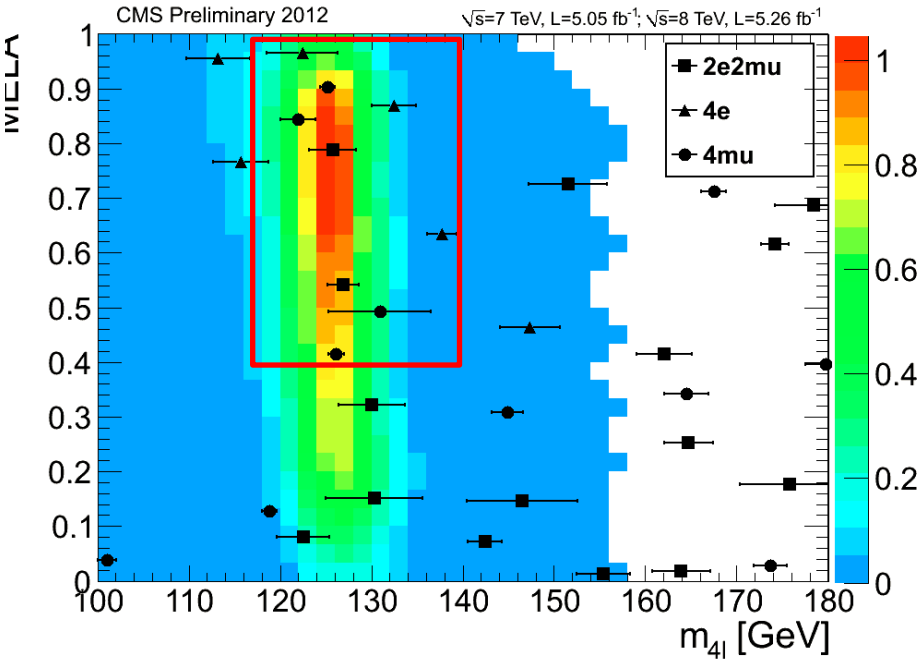
Data points are the same for both plots.

MELA Likelihood-mass 2D

Background



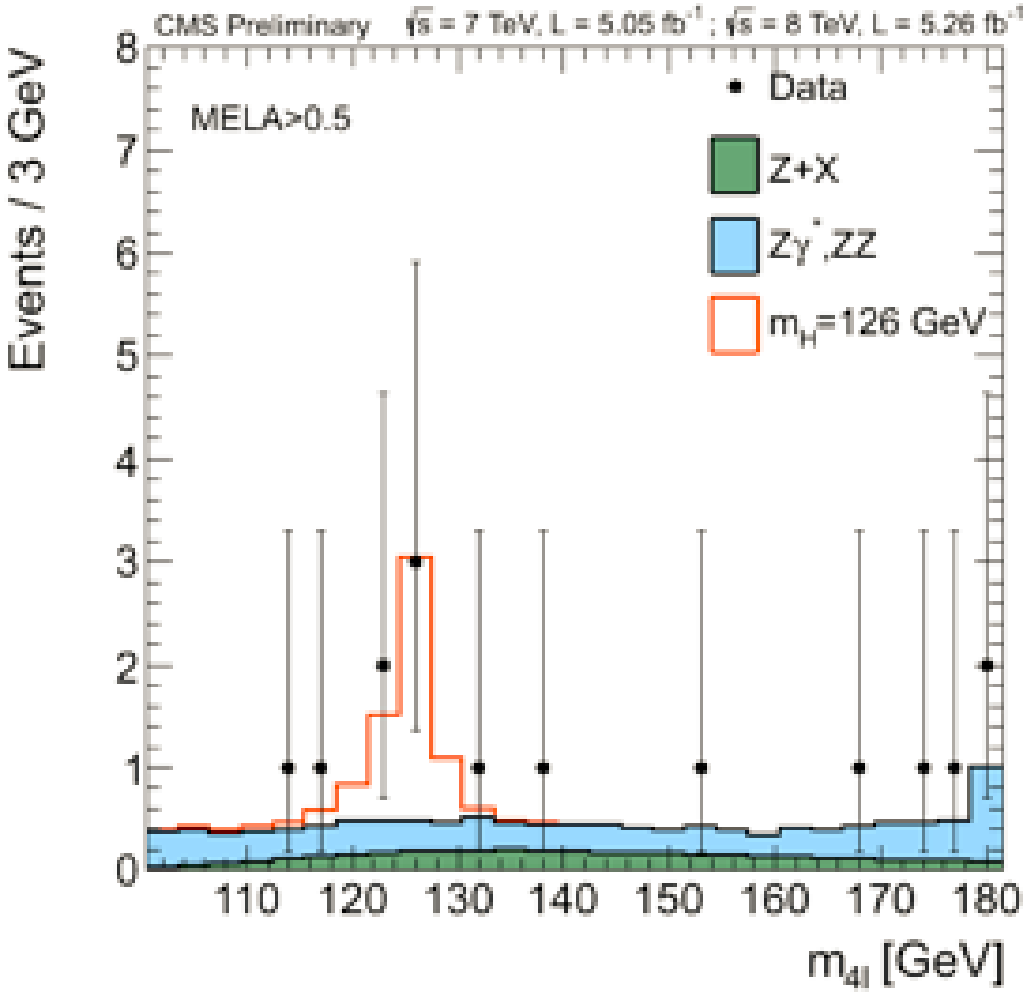
Signal @126GeV



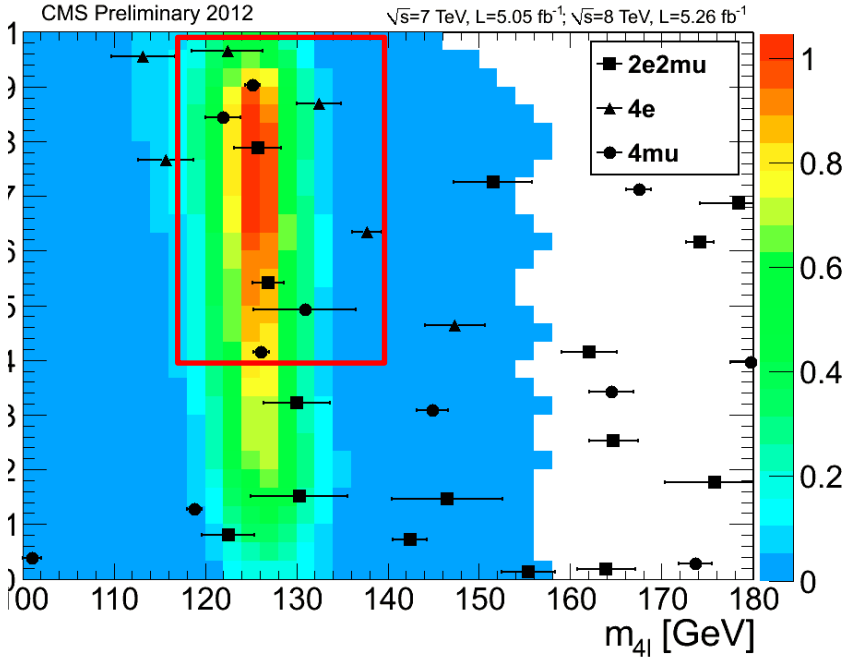
Data points are the same for both plots.

If data is only background, not much events are expected in this region.

MELA Likelihood-mass 2D



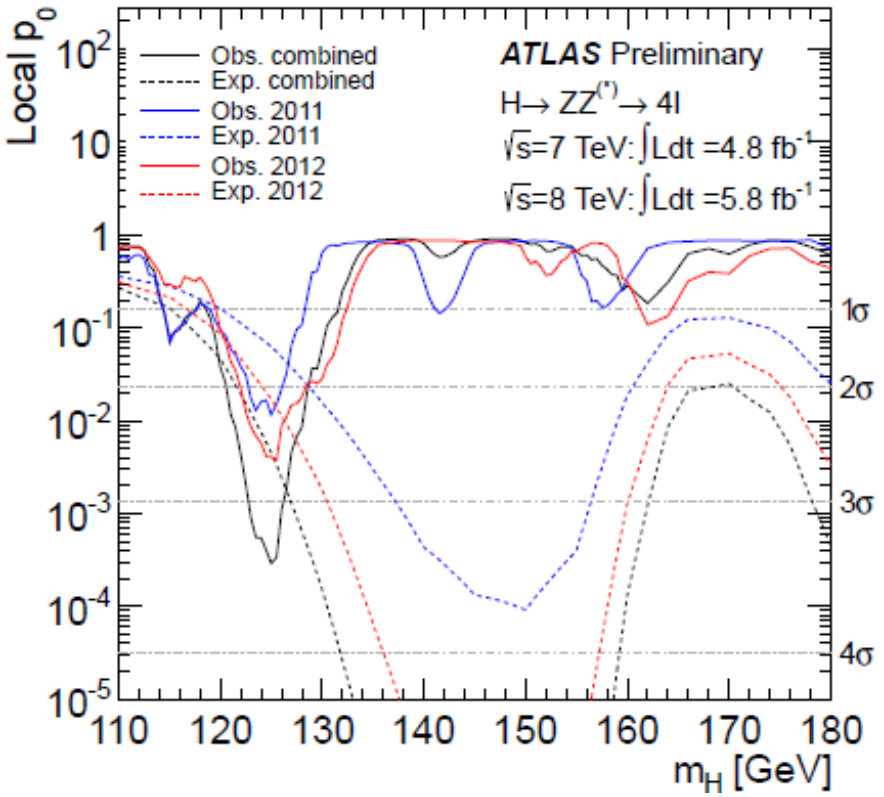
gnal @126GeV

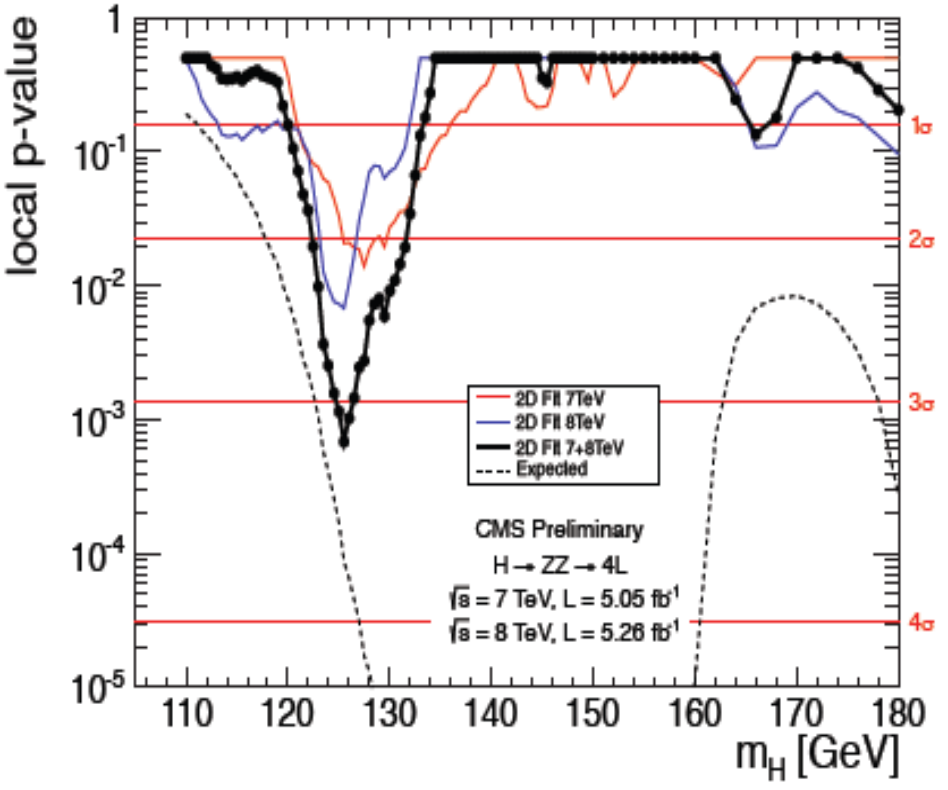


'e the same for both plots.

ents are expected in this region.

Results : Discovery significance





Local p0

ATLAS

3.4σ at 125GeV, expected 2.6σ

Local p0

CMS

3.2σ at 125.5GeV, expected 3.8σ

H→WW

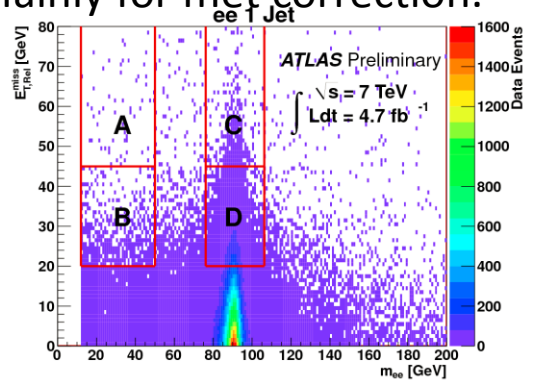
Event selection & background estimation

- two leptons + Missing ET
- ggF : 0,1 jet, VBF : 2 jets

Z+jets :

MET vs mll

Mainly for met correction.

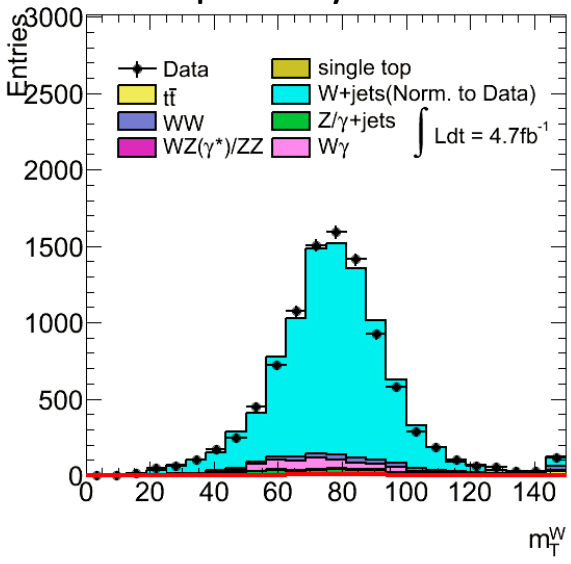


W+jets :

Fake lepton background.

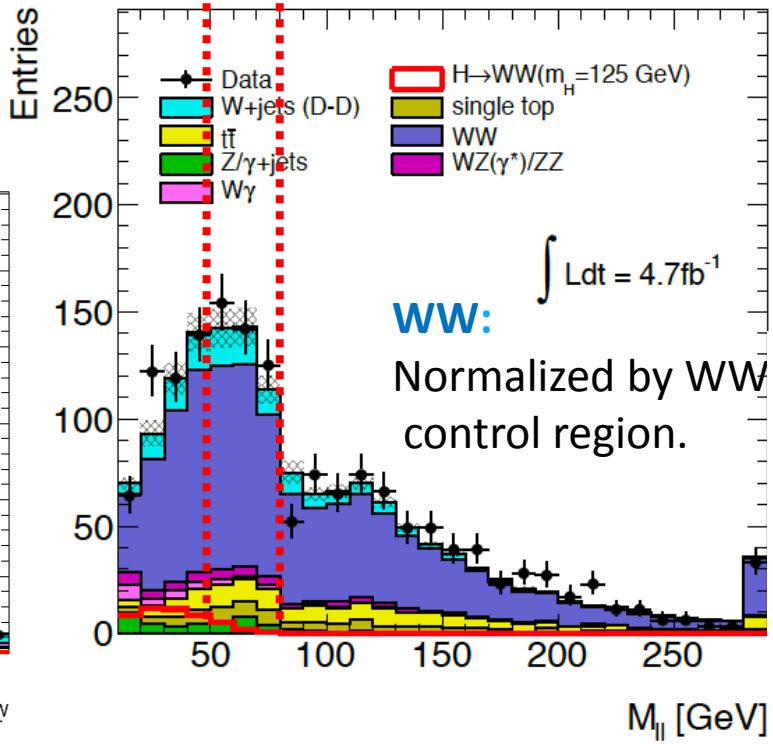
Prepare Loose lepton CR

And multiplied by Fake rate.



Signal region

WW control region

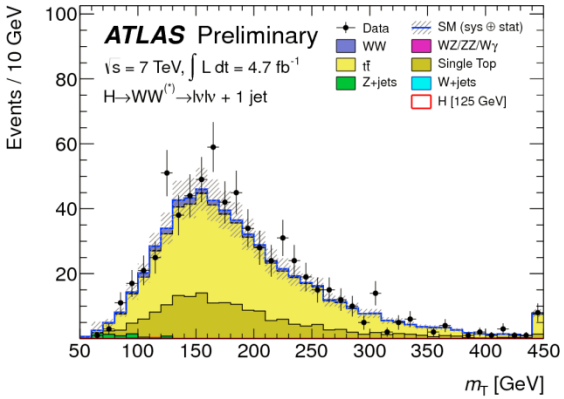


WW:

Normalized by WW control region.

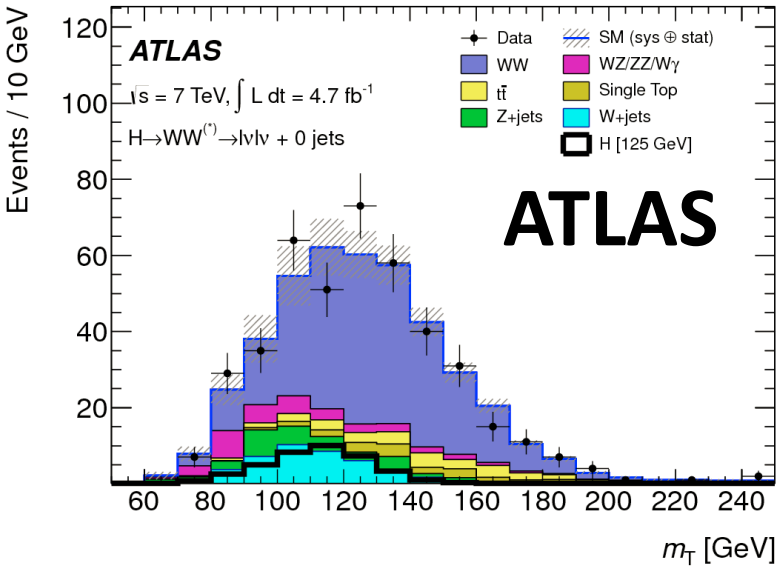
Top :

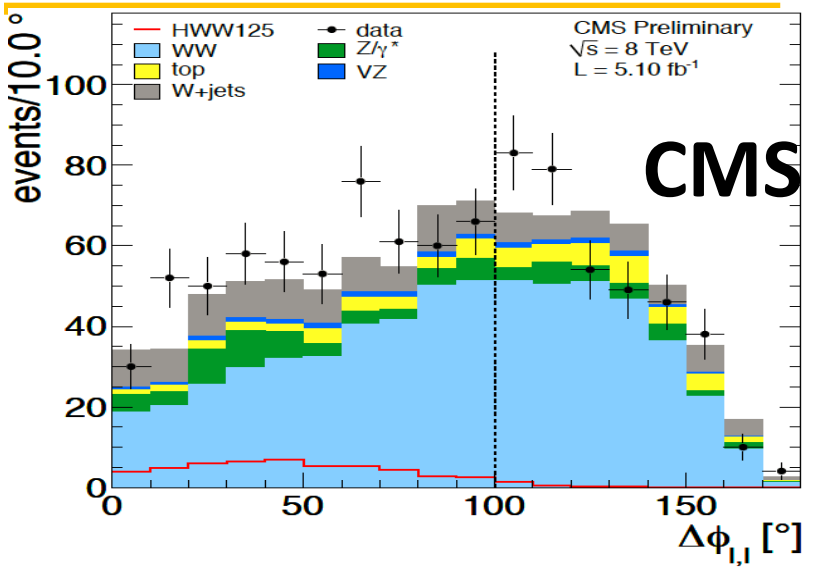
Apply b-tagging to enhance ttbar background.



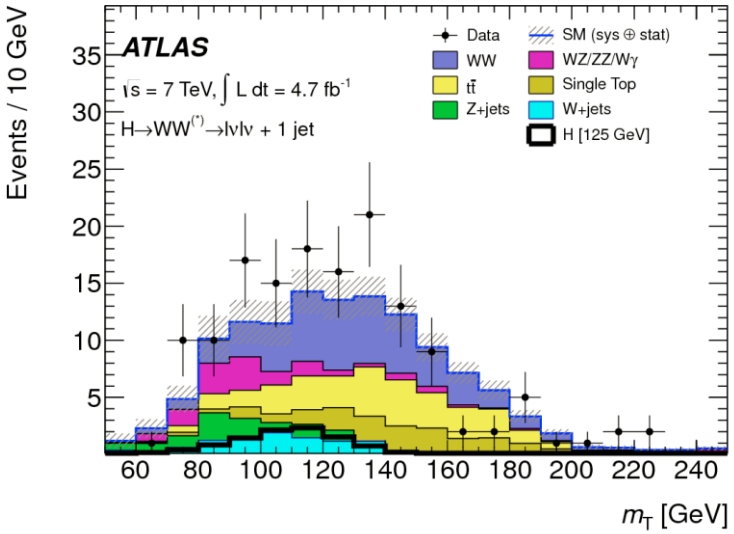
Distributions in signal region

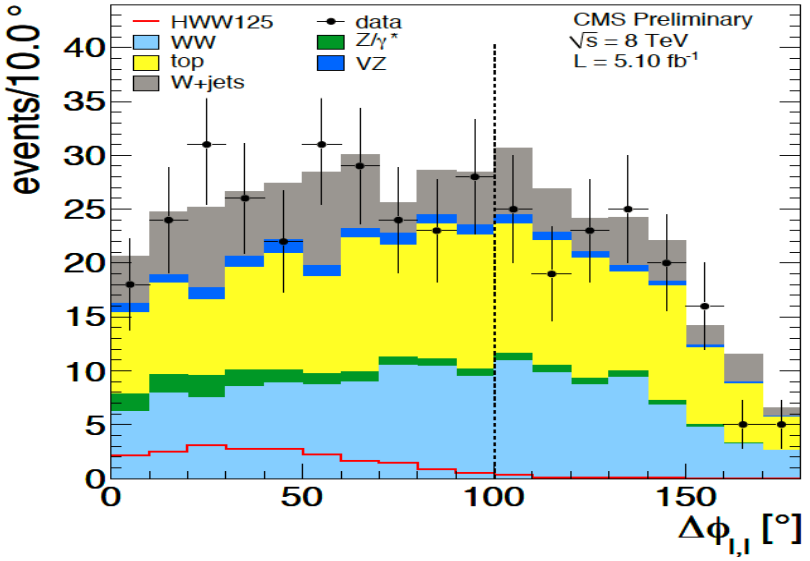
0jet



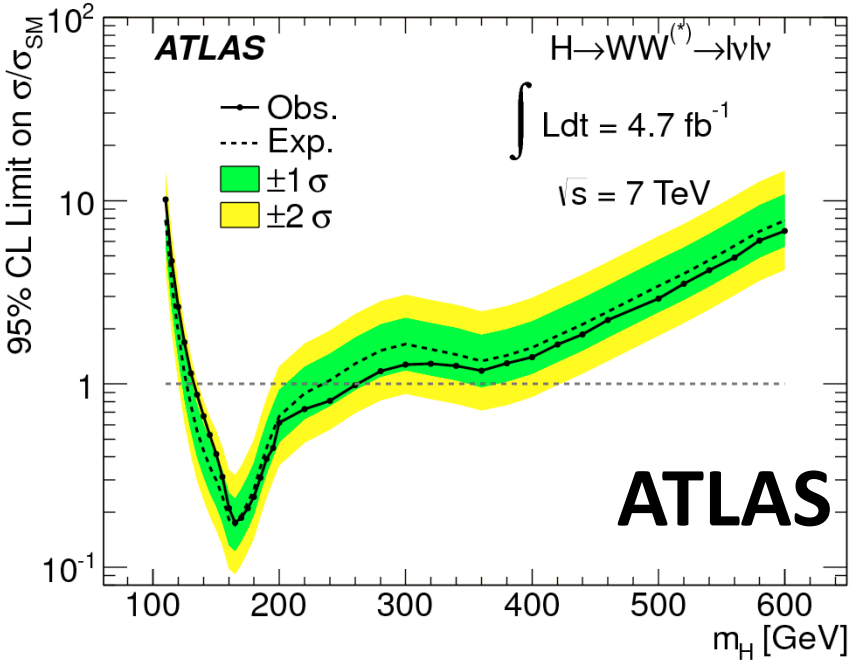


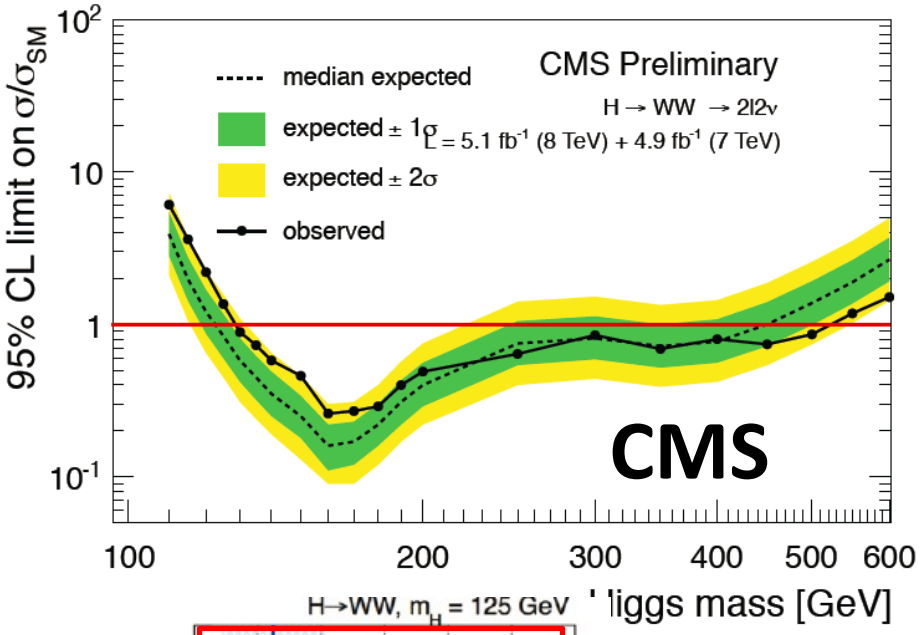
1jet

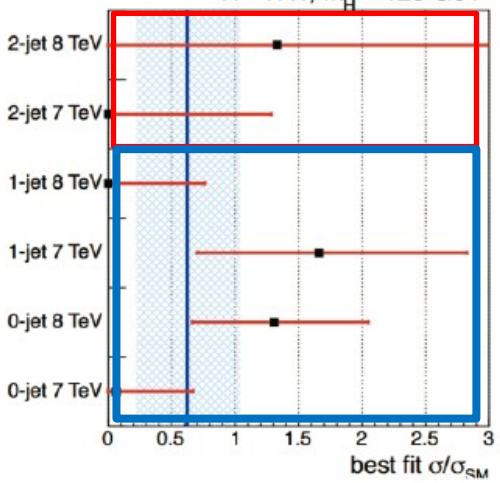




Results : 95% CL upper limit



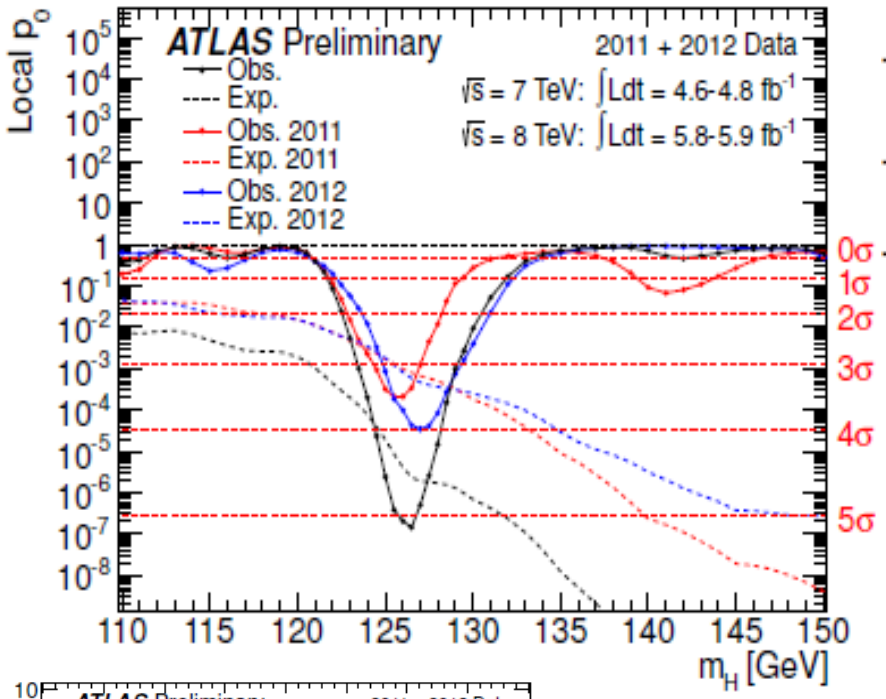


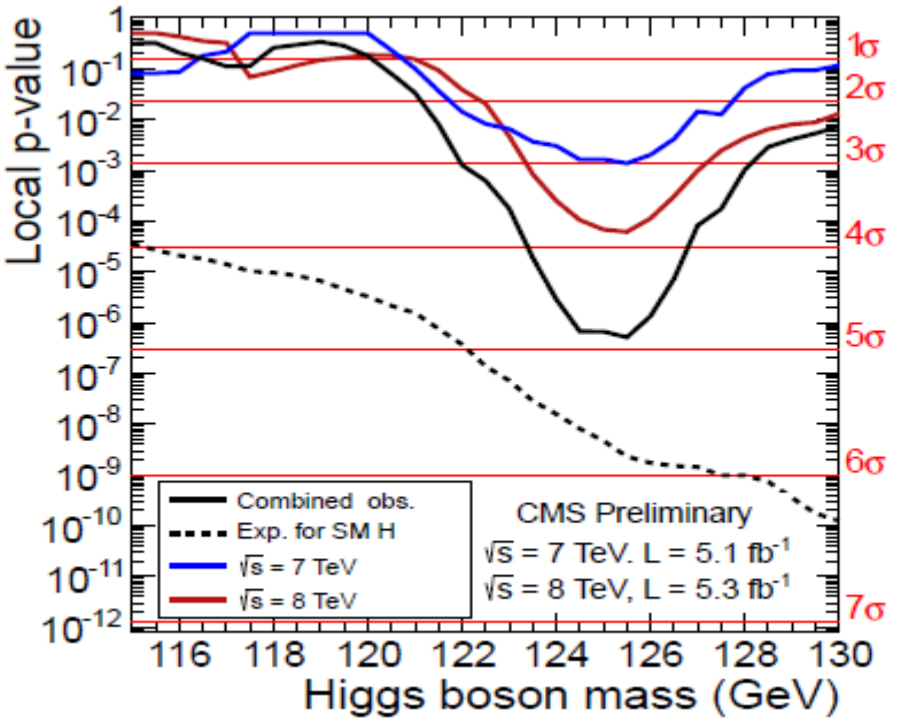


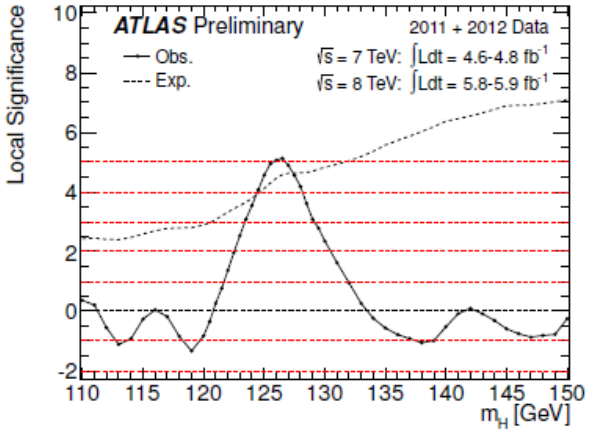
- Excluded wide range.
- No significant >3σ excess.
- ATLAS will include 8TeV soon

Observation of new particle (including ττ and bb)

Results : Discovery significance







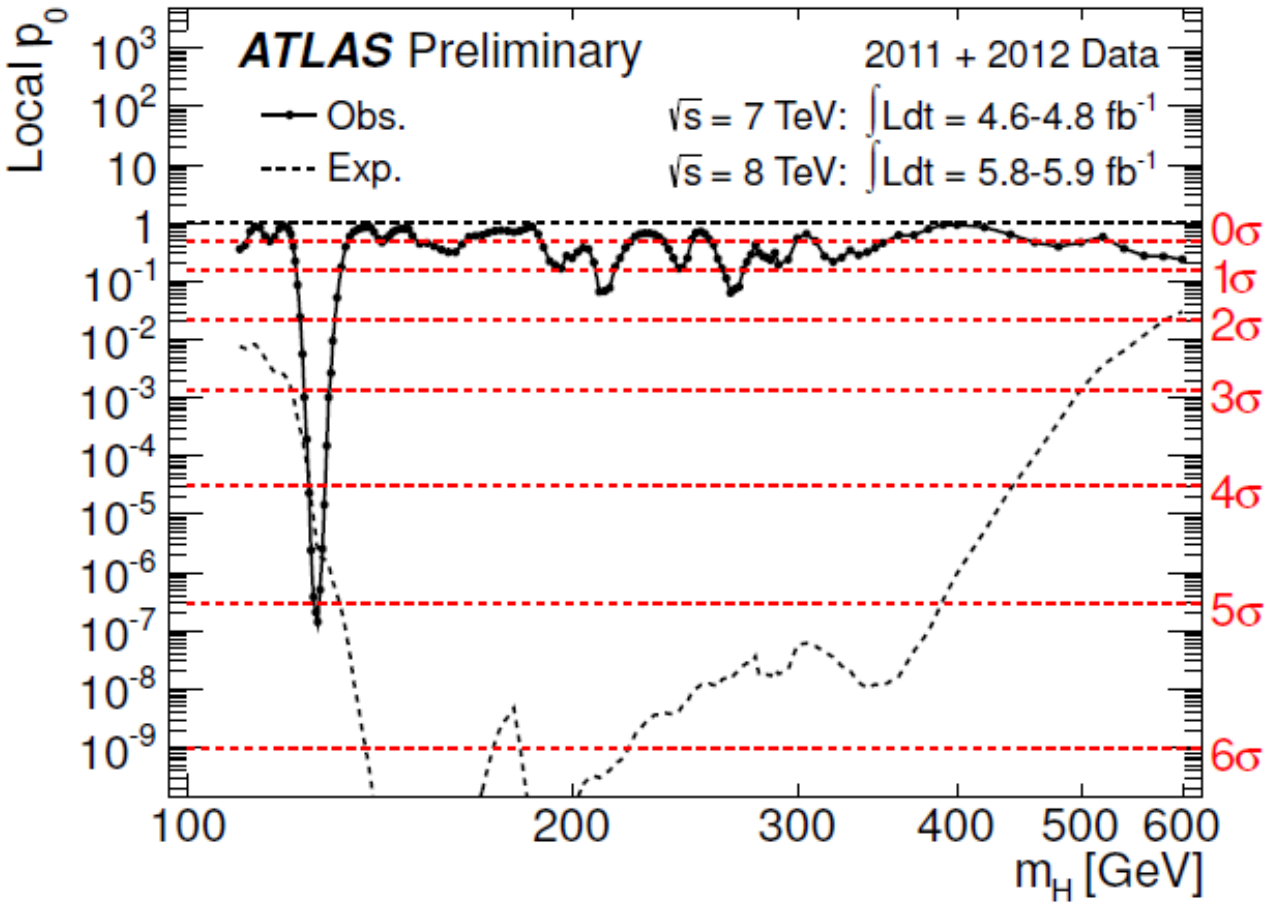
ATLAS (expected=4.6σ)

Local p_0 = 3.0 x 10^{-7} => 5.0σ at 126.5GeV

CMS (expected=5.6σ)

Local p_0 = 5.5 x 10^{-7} => 4.9σ at ~125GeV

Large range and LEE?



Look Elsewhere Effect (global significance)

ATLAS

4.1σ (110-600GeV),

4.3σ (110-150GeV)

CMS

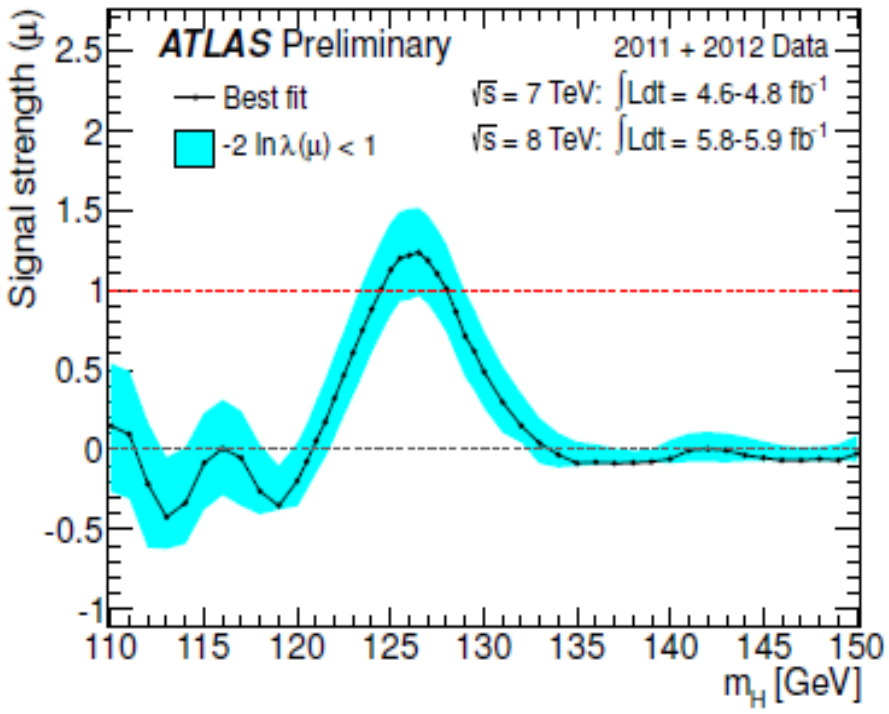
4.0σ (110-600GeV),

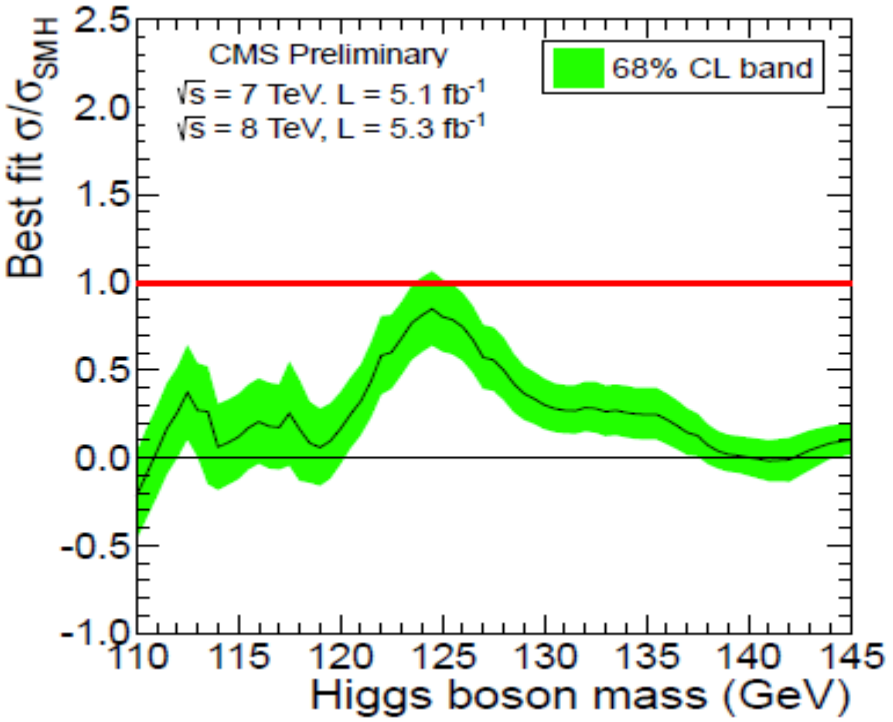
4.5σ (115-130GeV),

4.4σ (110-145GeV)

- Here is only one place we observed significant excess
- LEE is just a protection to avoid wrong discovery.

Signal strength as a function of mH

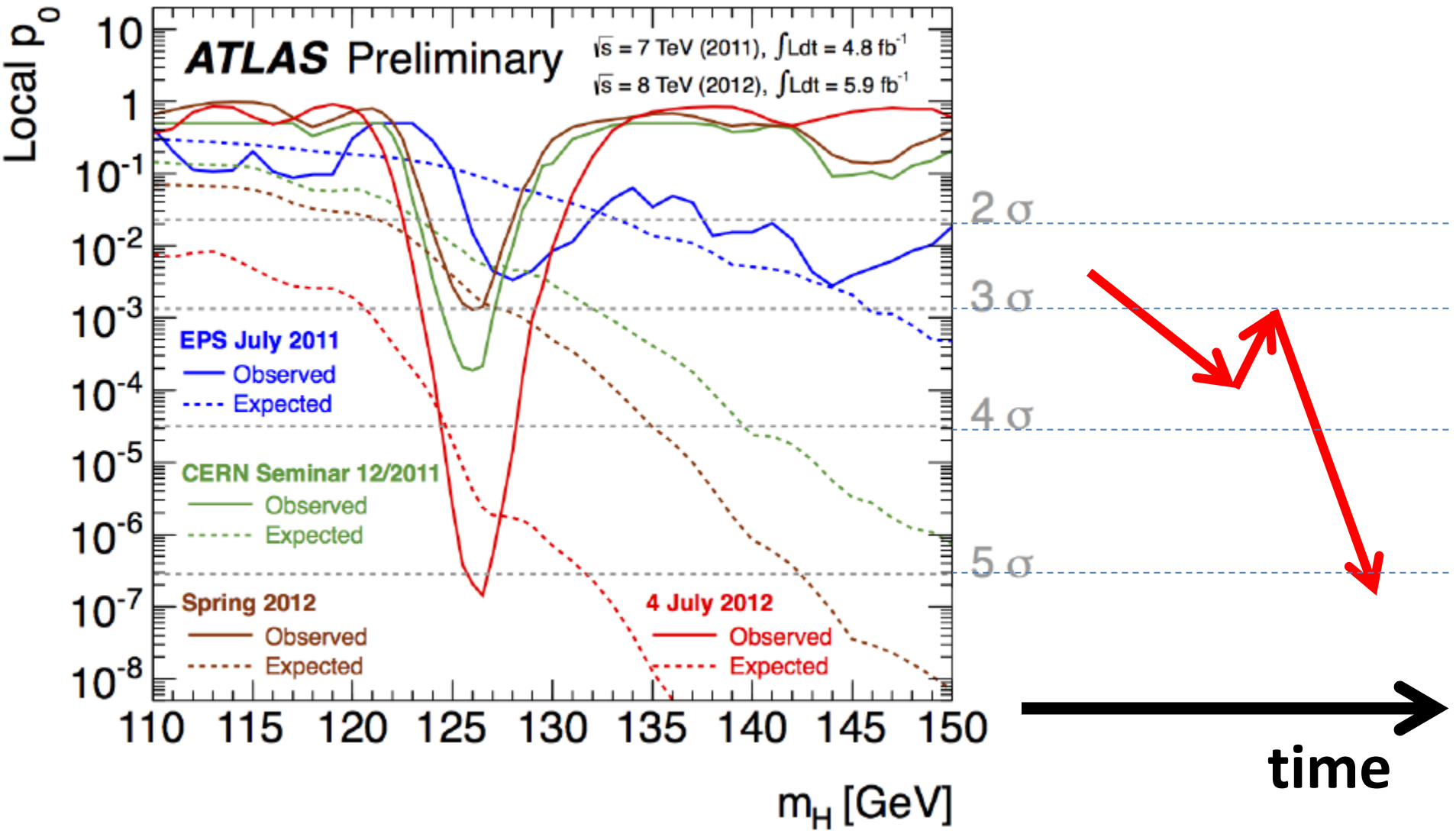




Best Fit Signal Strength
1.2+-0.3 at 126.5GeV

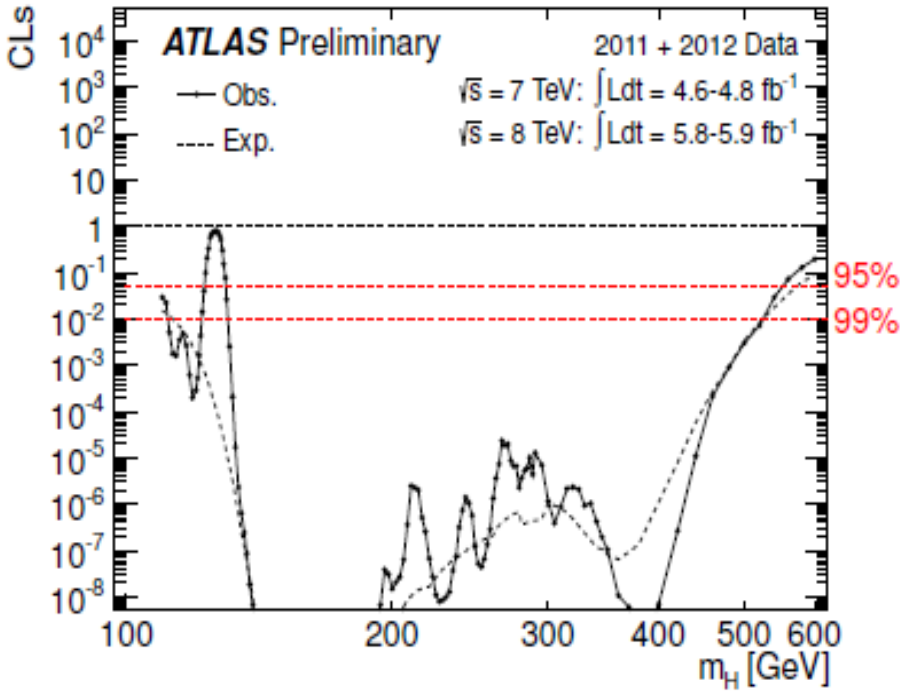
Best Fit Signal Strength
0.88+-0.22 at ~125GeV

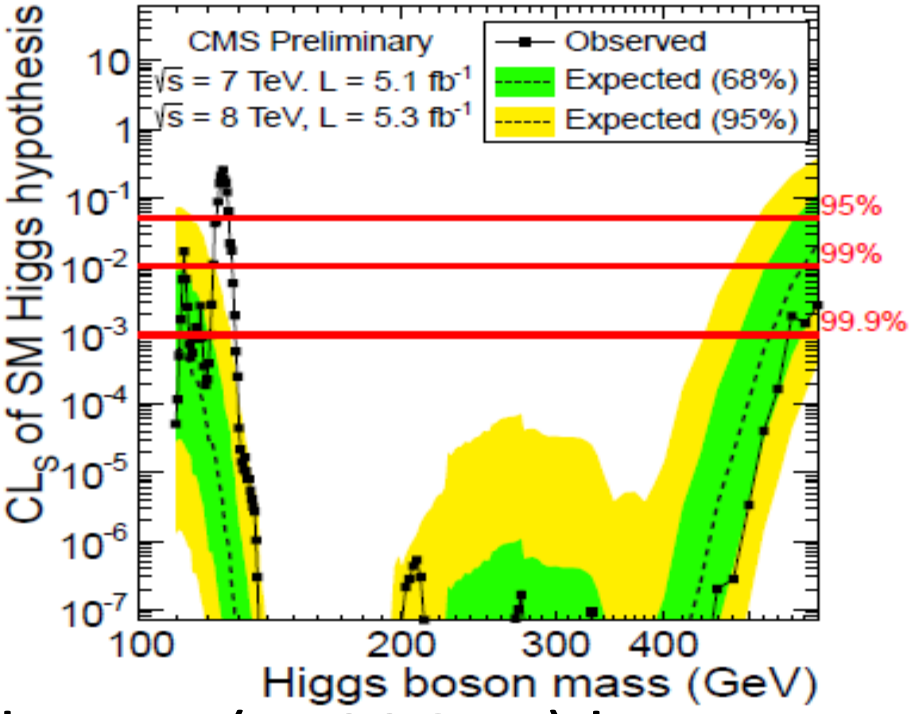
History of the observed significance



Possibility of second Higgs ?

- If second higgs have the same cross section…

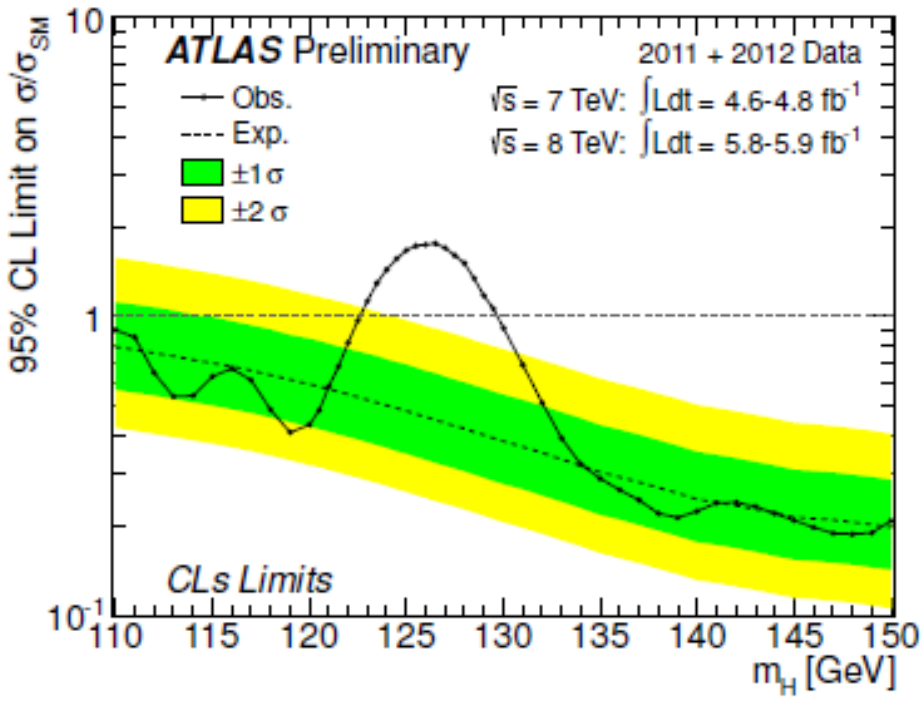


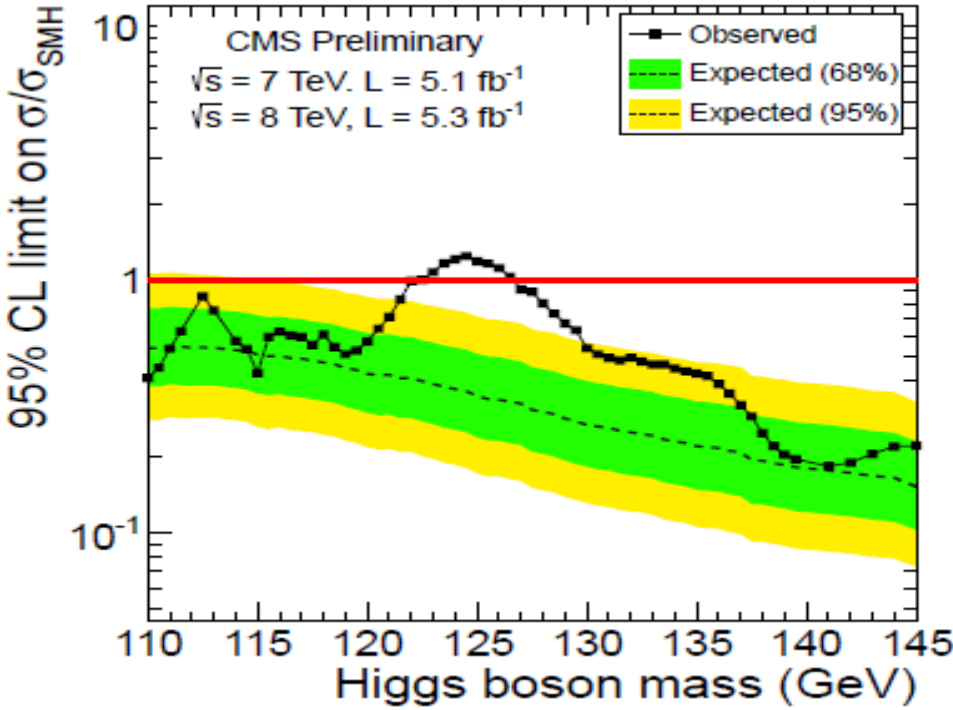


- Excluded except very high mass(>500GeV) by 99% CL

Possibility of second Higgs ?

- If the cross section is lower than SM…



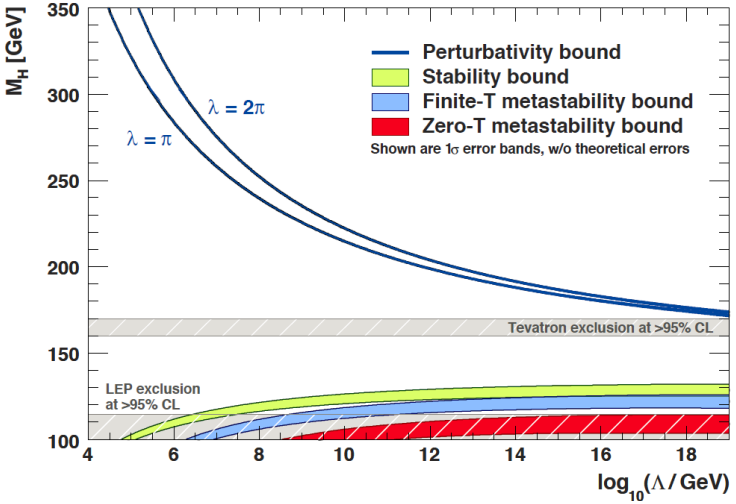


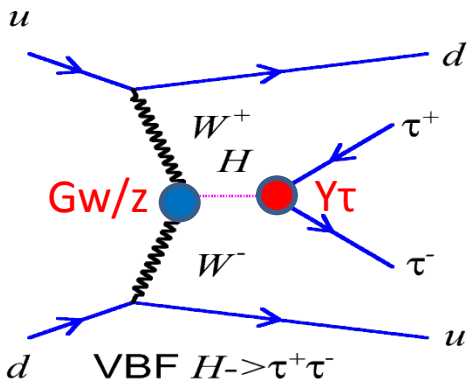
- Of cause possible.

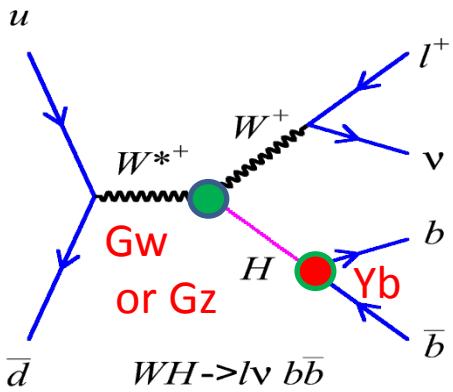
What should we do next?

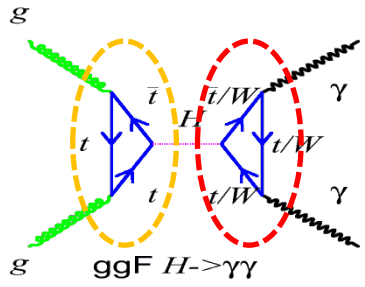
What should we do next?

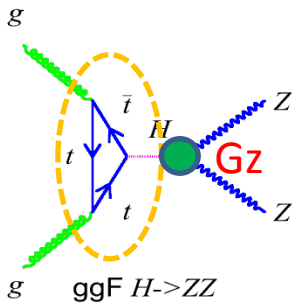
- Mass measurement → can be done by γγ/ZZ
  - To prove the scale of breaking?
  - **But 0.5GeV precision is really necessary?**
- Spin measurement → spin 0 or 2? WW/ZZ ?
  - Spin 0 is necessary, if this is Higgs.
- **Coupling measurement**
  - **Almost sure the quark Yukawa does exist (by ggF discovery) and may be via top Yukawa coupling.**
  - **But how about Yb? Yb~m_b/246GeV?**
  - **H→ττ must be only the channel which can indicate about lepton Yukawa coupling.**

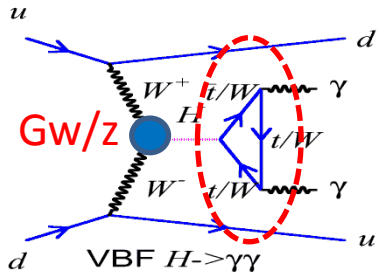


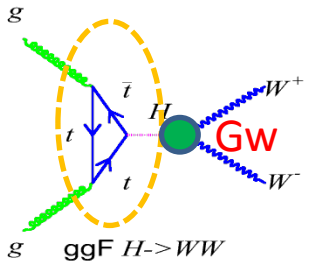




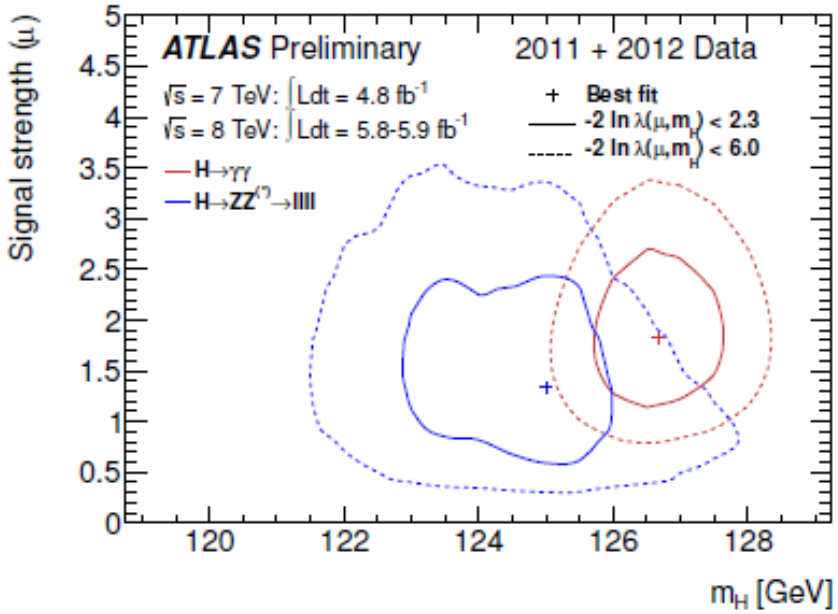


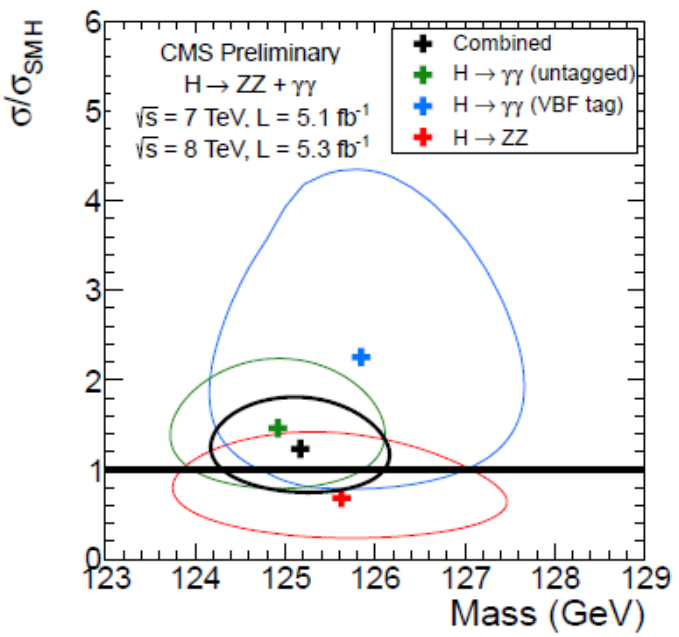




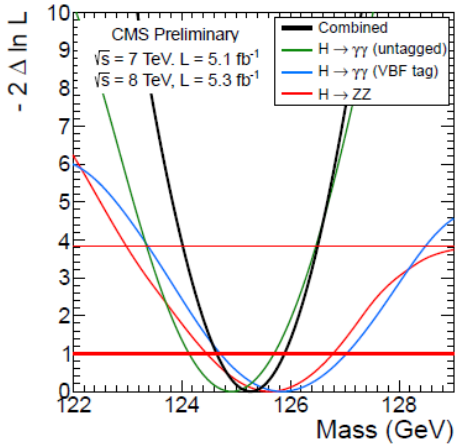


Mass measurement





Note : ATLAS did not mention this as “mass measurement”. But only the “consistency among channels”

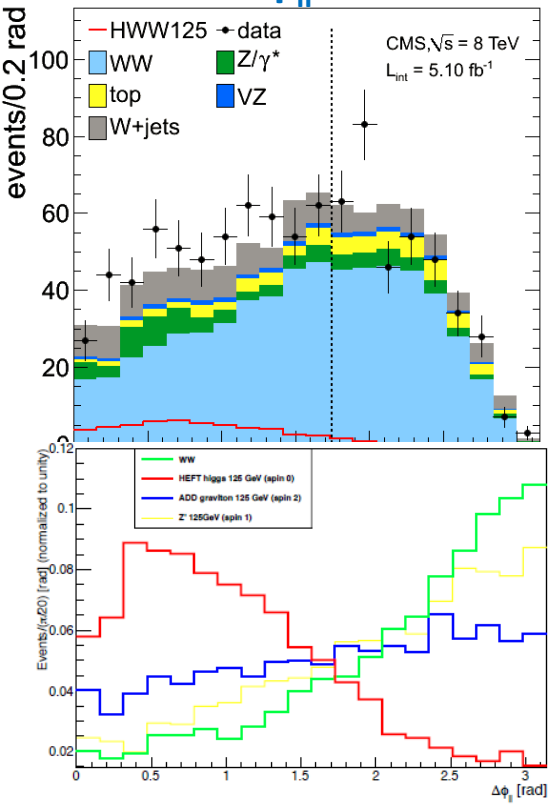


CMS : mX=125.3+-0.6GeV

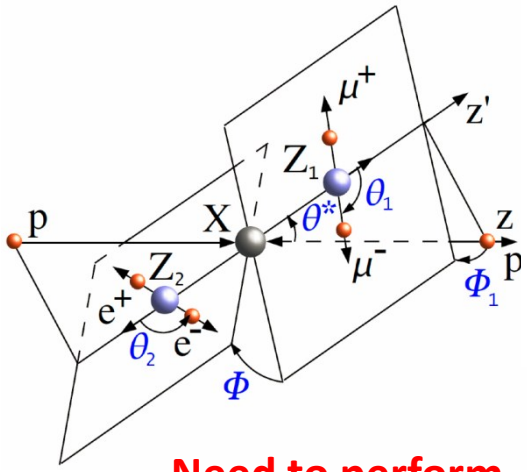
Spin of the observed particle

- It should be spin 0 or 2 by observation of γγ decay.
- But which?
  - We heavily rely on the spin=0 information in the analysis. → WW and ZZ

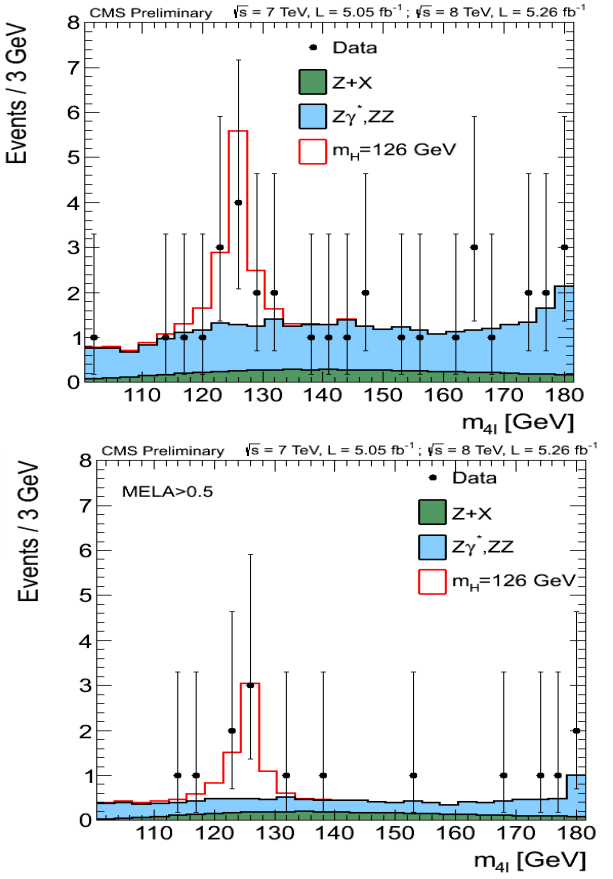
H→WW ϕ_{ll} distribution



H→ZZ MELA



Need to perform quantitative study



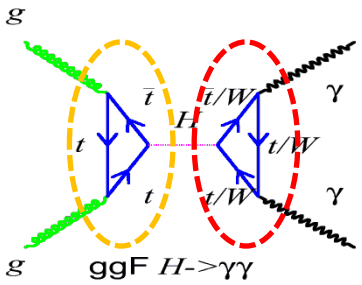
Truth level study
No acceptance cut applied

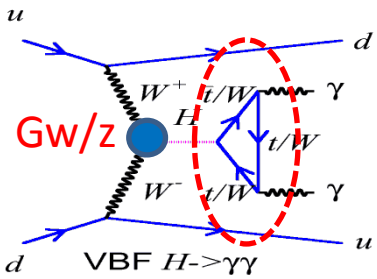
Coupling I

- Gauge boson and fermion.

c_V = coupling to W and Z
c_F= coupling to fermion
$\gamma\gamma$ => ratios from the SM Higgs

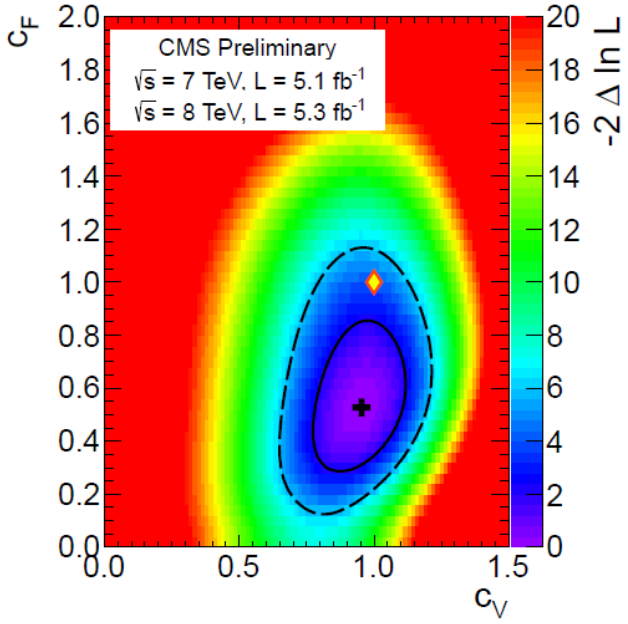
e.g.





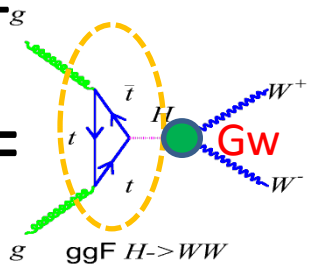
?

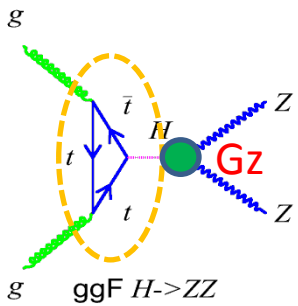
CMS all channel fit.



- Gw : Gz

$R_{WW/ZZ}$=



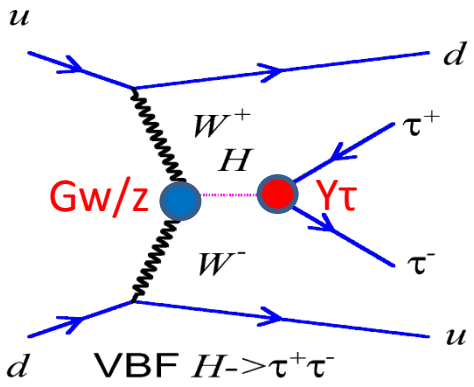


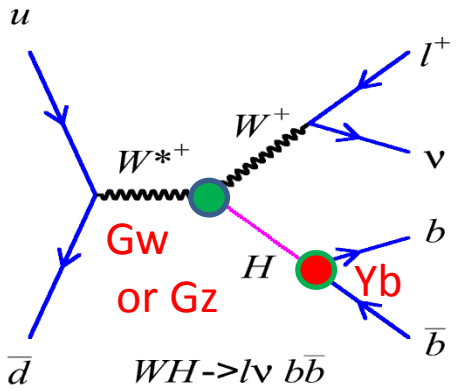
$=0.9^{+1.1}_{-0.6}$

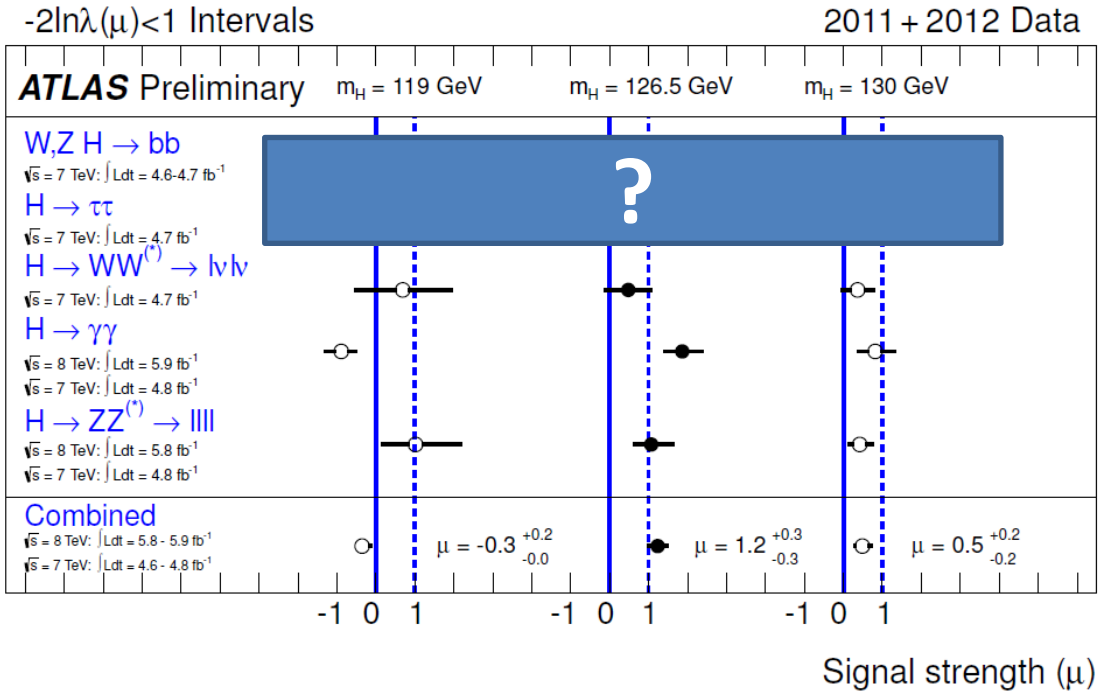
Measured by CMS.

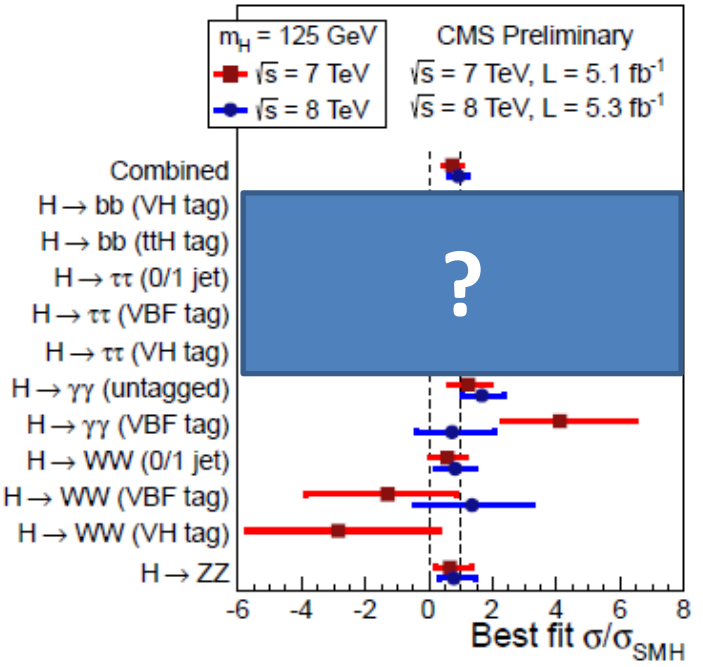
Coupling II

- Fermion coupling!
- Need ττ and bb.



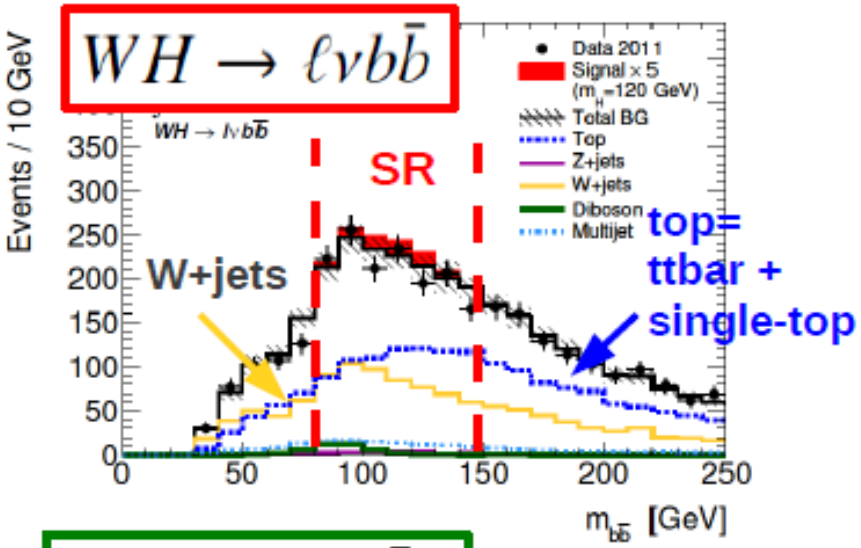


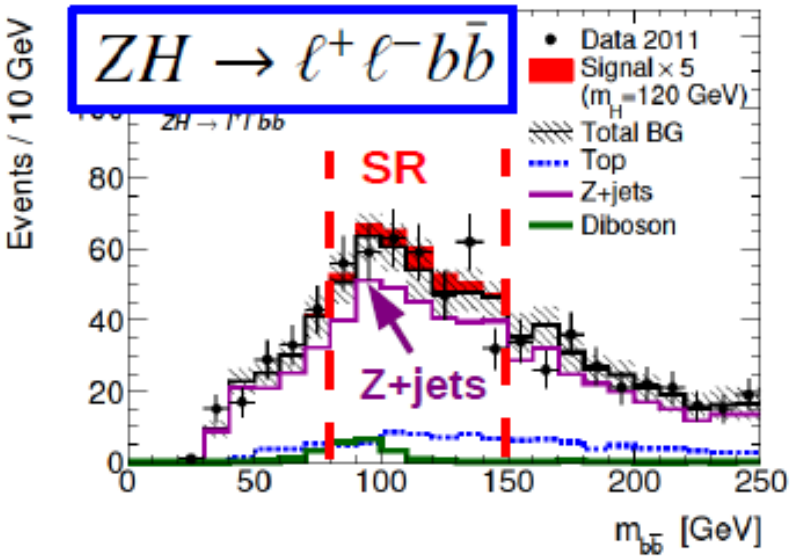


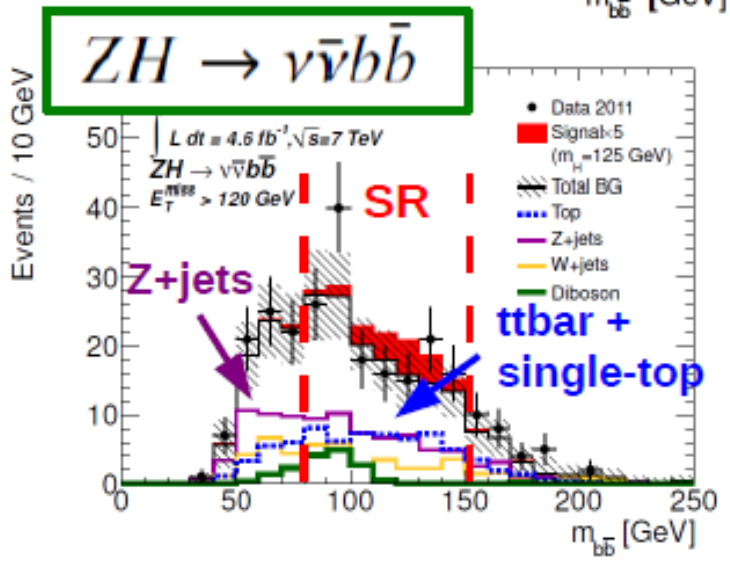


H→bb

Main background and estimation.







Top, W+jets, Z+jets bkg are normalized by control region and side band region.

Top

WH : 3jets instead of two.

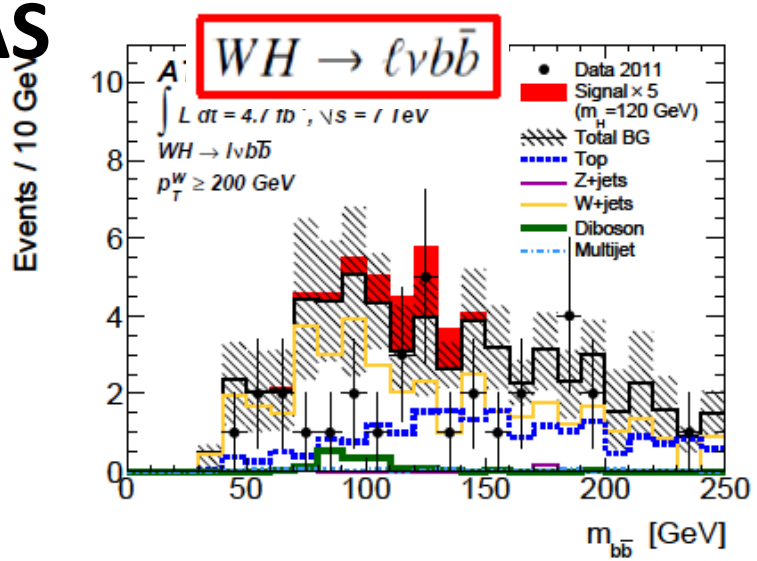
ZH : Zmass veto + MissingEt.

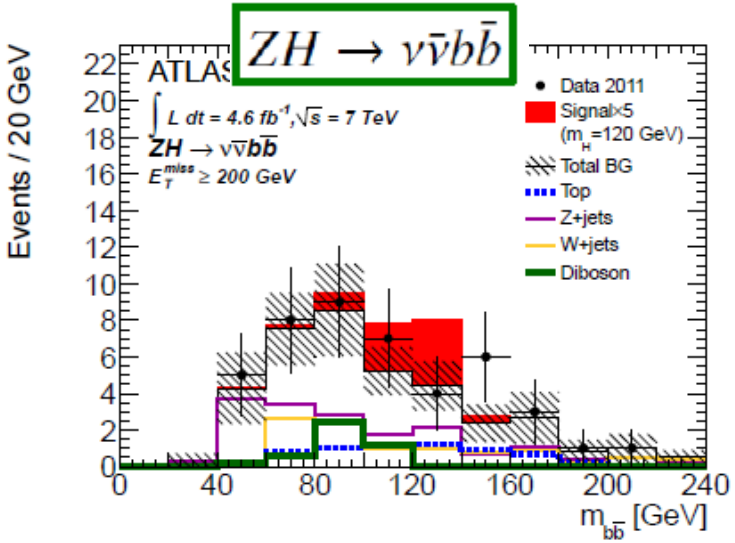
W/Z+jets

replace/loosen the b-tagging cut.

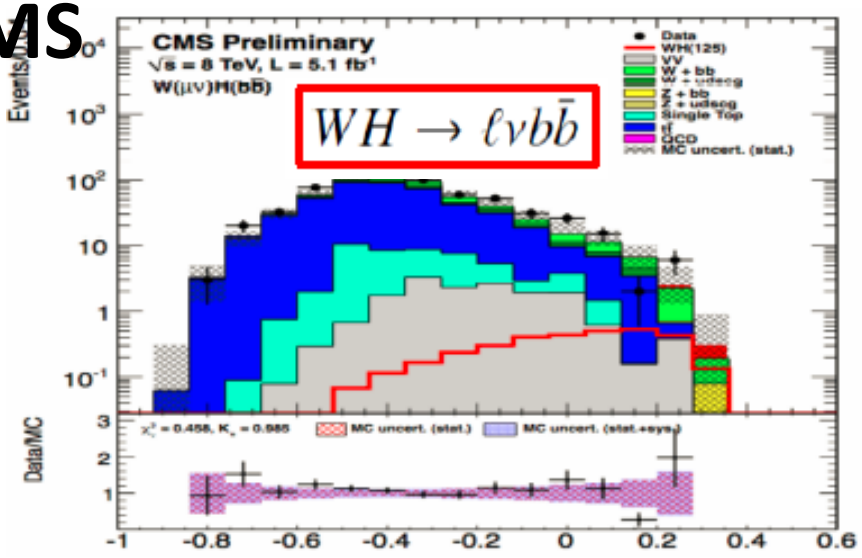
Results : distributions (a part)

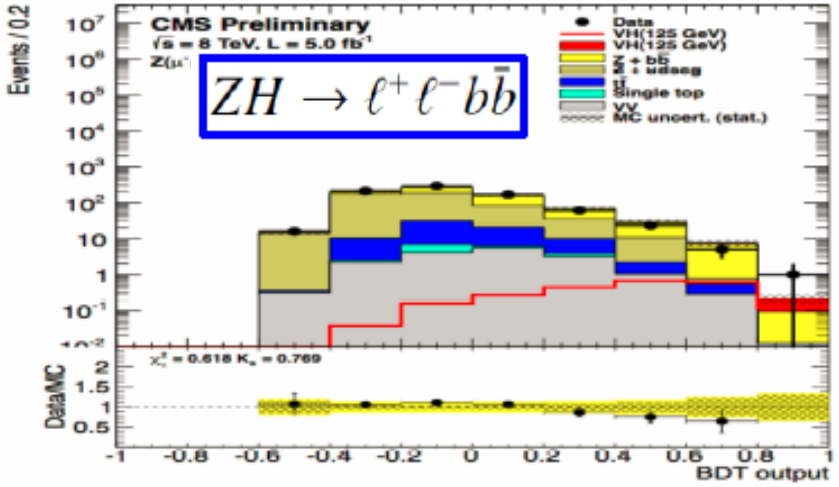
ATLAS





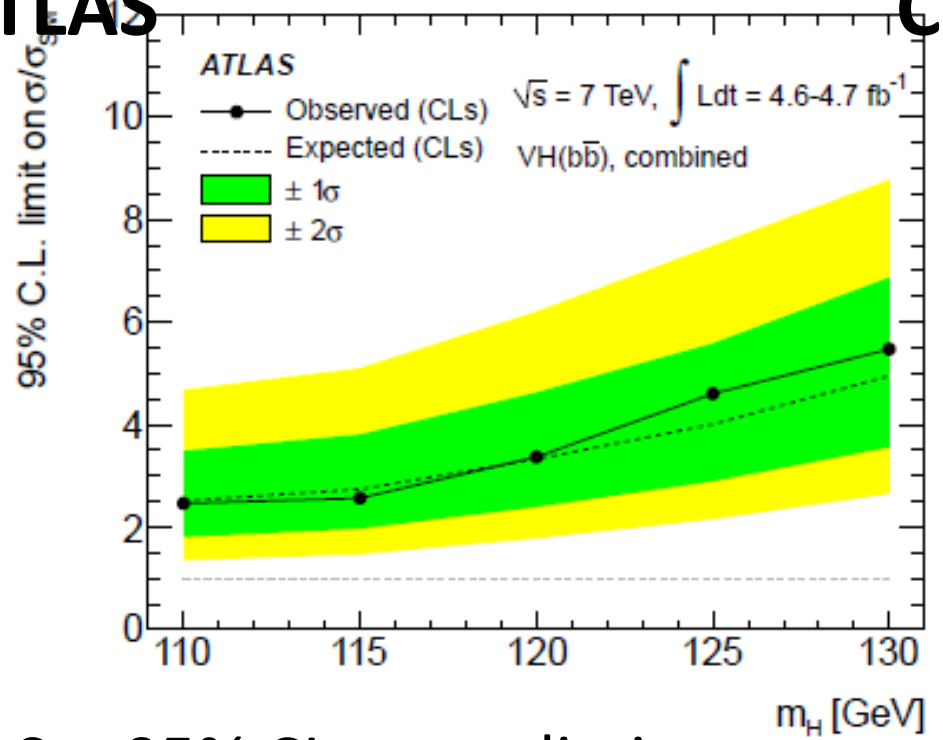
CMS





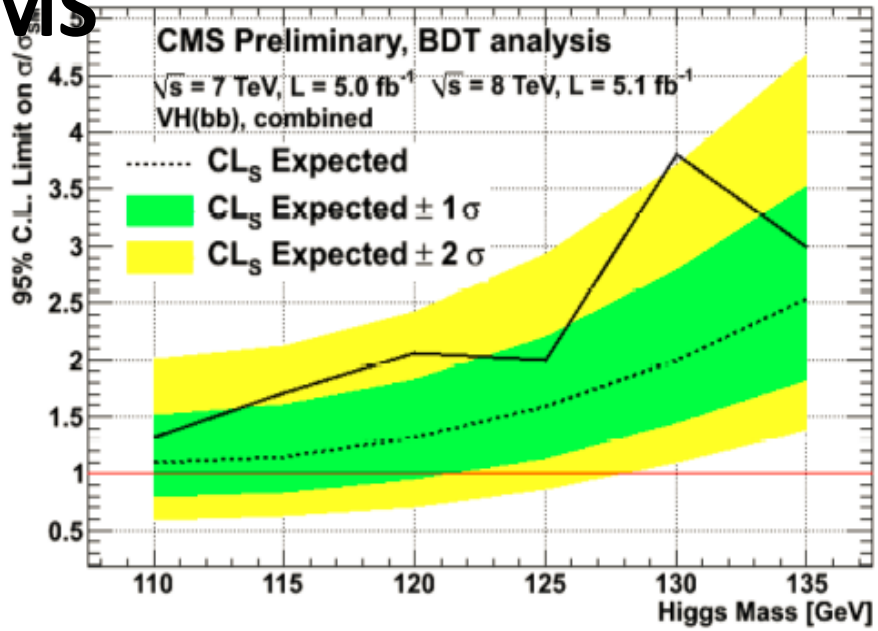
Result : ATLAS 7TeV(5fb^{-1})

ATLAS



- Set 95% CL upper limit on xsec.
  - Expected : 2.5-5 x SM
  - **Observed : 4.6 xSM @ 125GeV**
- 2012 analyses with improvements are now ongoing.

CMS

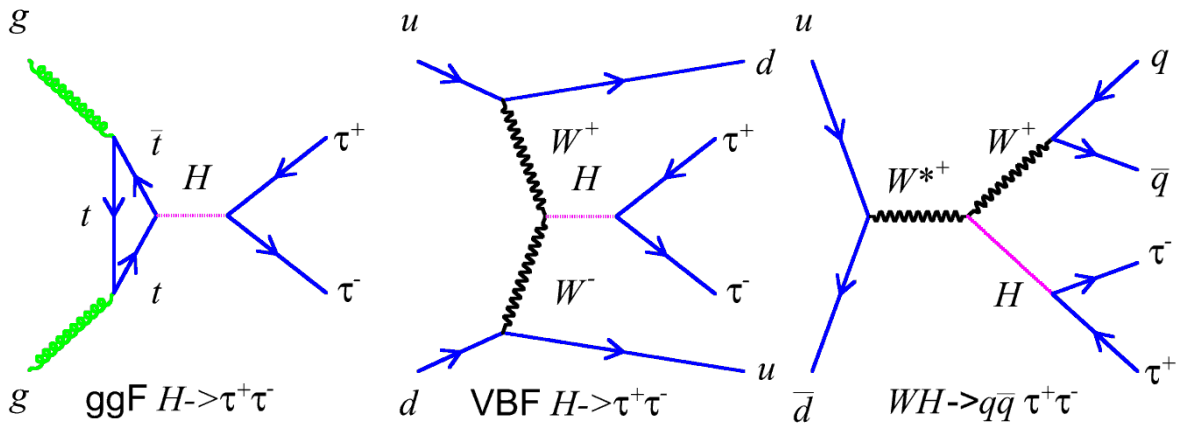


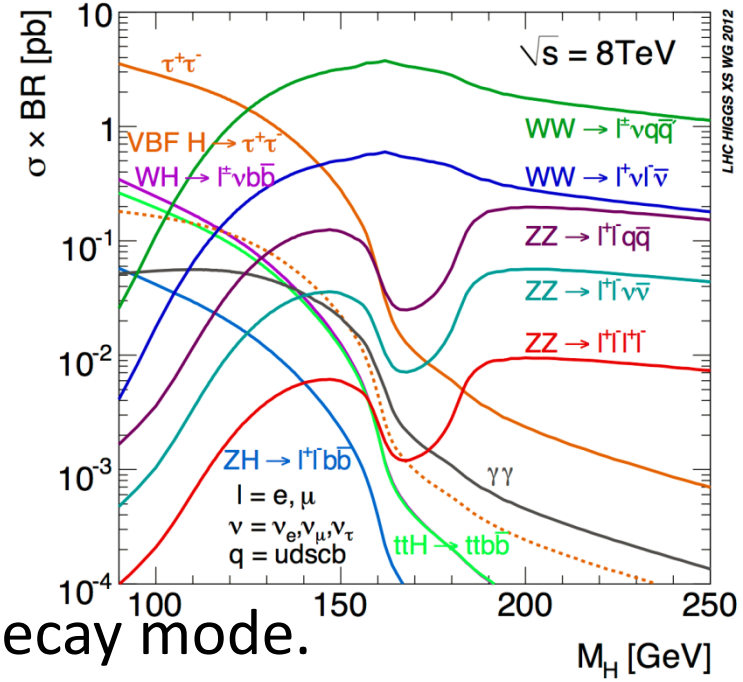
- Almost reached to the SM xsec at mH<115GeV
  - Expected limits are ~1.1xSM
- **Observed(Expected) limits @125GeV are 2(1.6)xSM**

$H \rightarrow \tau\tau$

Event Topology and channels

- Three Higgs production processes are considered in this analysis.





- Separate analysis for three different ττ decay mode.
  - lep-lep = ll4ν : (ee)+eμ+μμ
  - lep-had = lτhad3ν : $e\tau_{had}$+ $\mu\tau_{had}$
  - had-had = $\tau_{had}\tau_{had}\nu\nu$: ($\tau_{had}\tau_{had}$)
- Combined all three channels to search for H→ττ signature.

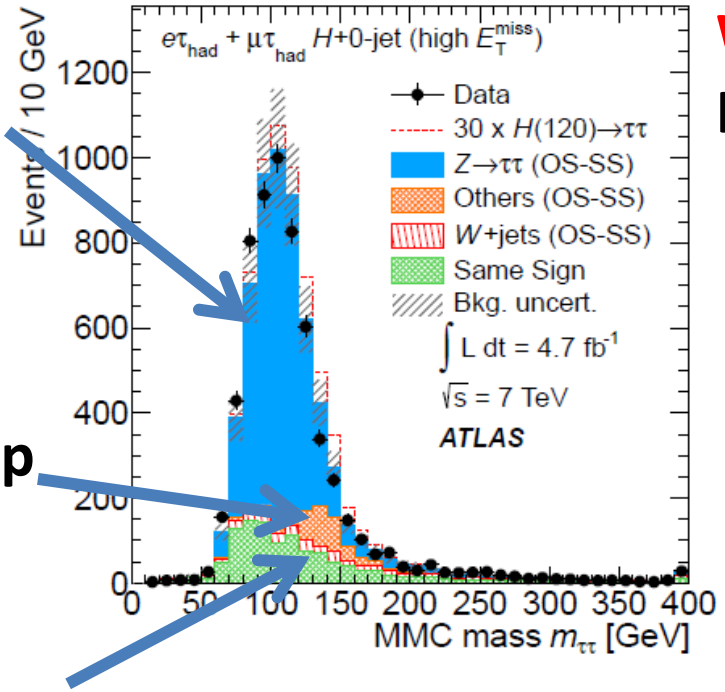
Channels in () is ATLAS only

Event selection & background modeling

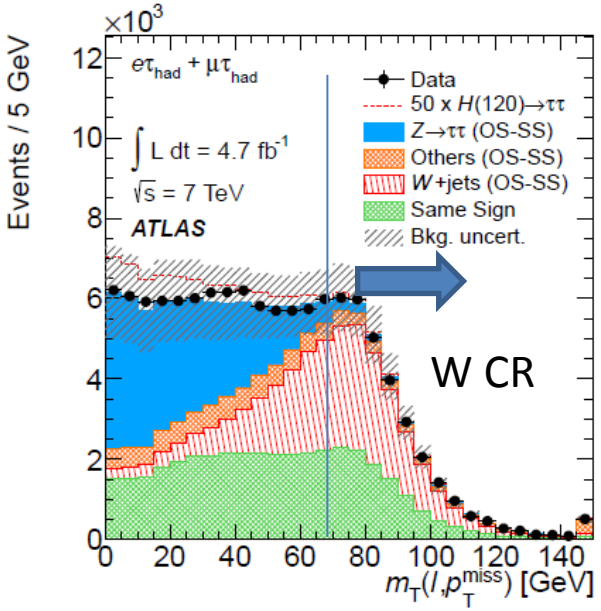
- Opposite sign tau decay products are required.
- High Missing ET and low MT cuts are added.

Z→ττ estimated by embedding -- used Z→μμ data and replace by full simulated τ

Z→ee/μμ + jets, Top Estimated by MC with correction.



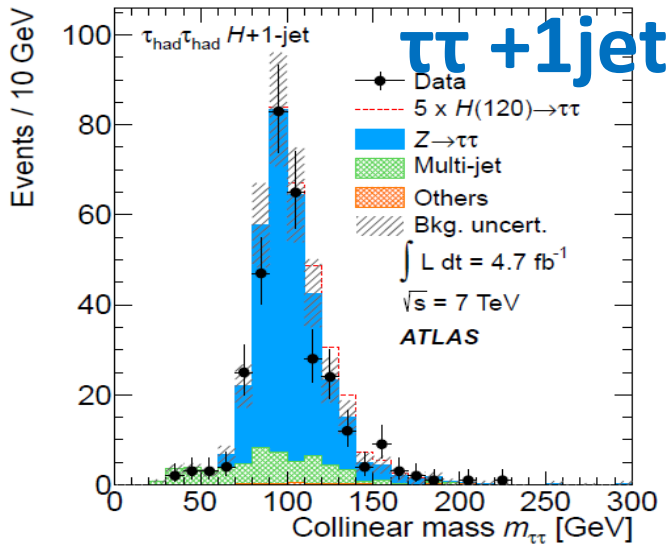
W+Jets – estimated by High MT control region

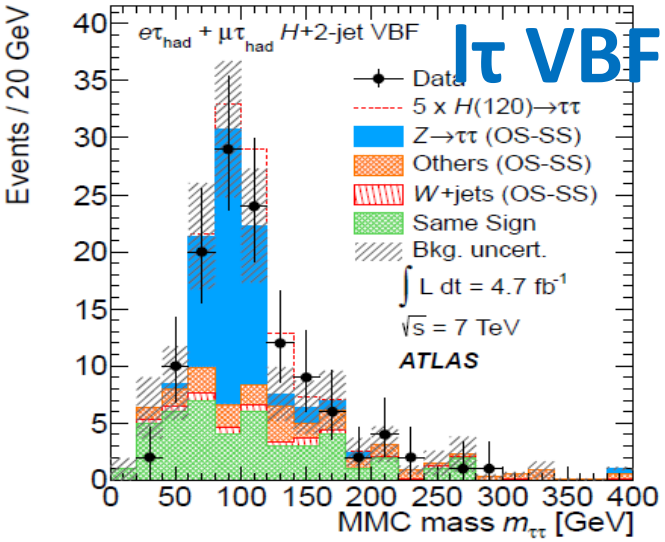


QCD – Estimated from Same Sign events(lephad)
-- Template fit by loose selection (lep-lep,hadhad)

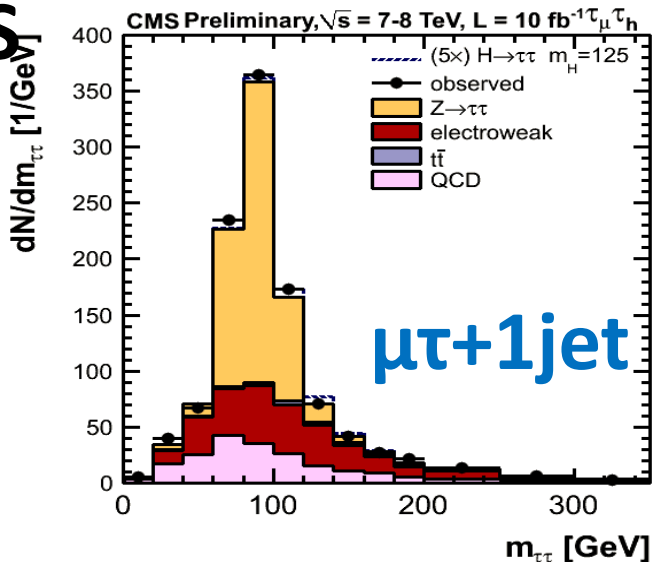
Result : Distributions (a part)

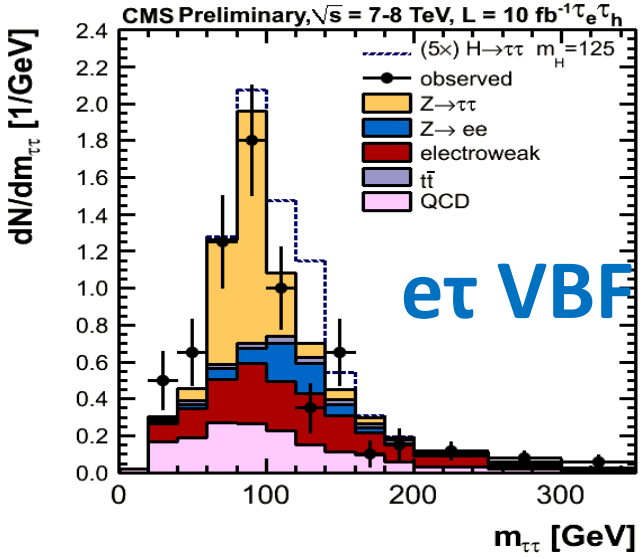
ATLAS



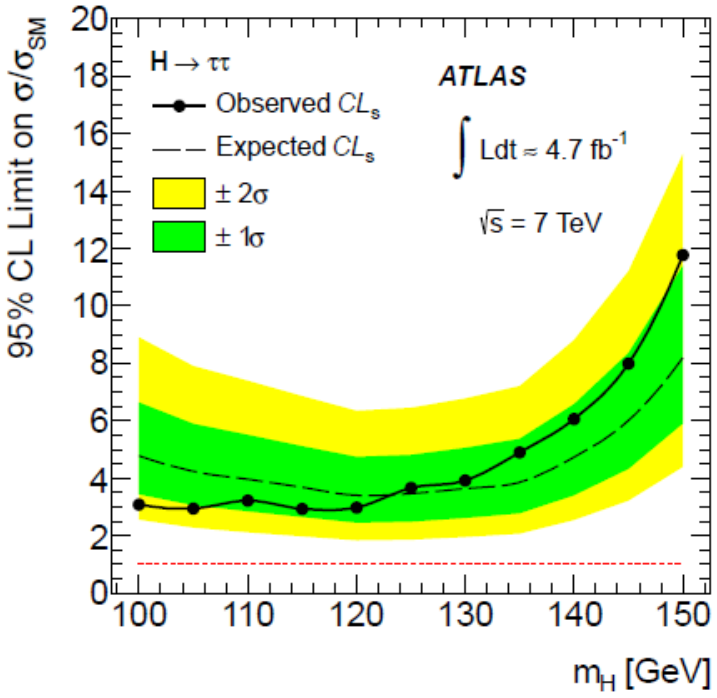


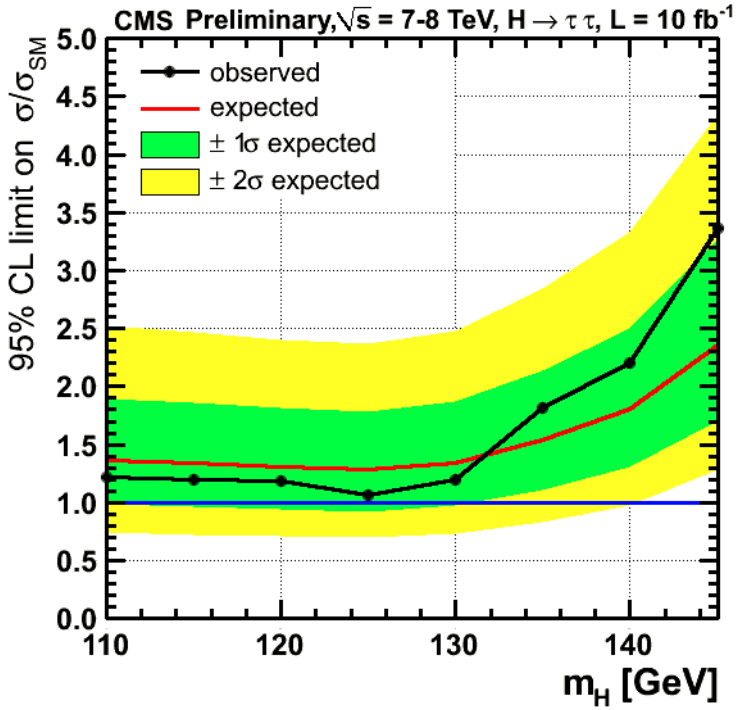
CMS





Result : CMS 7TeV(4.9fb^{-1})+8TeV(5.1fb^{-1})





Observed limit : 2.8-12.1

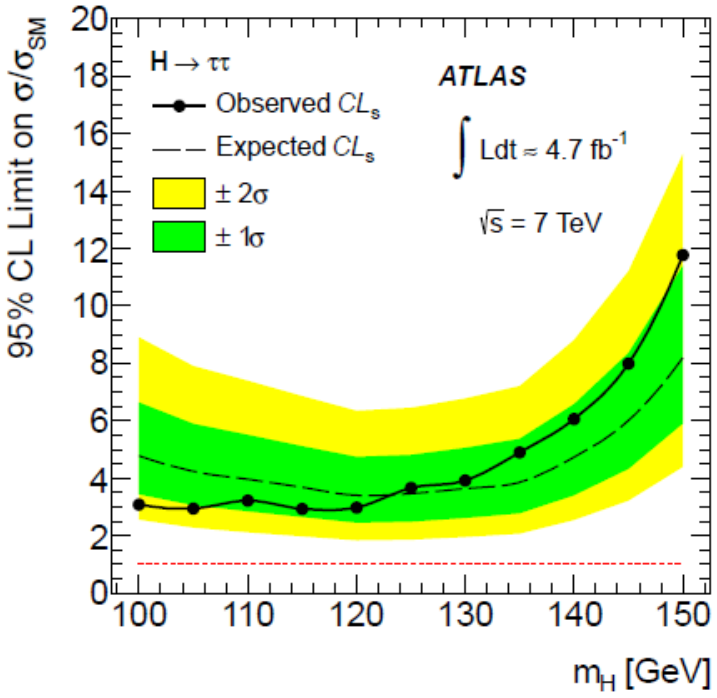
Expected limit : 3.4-8.0

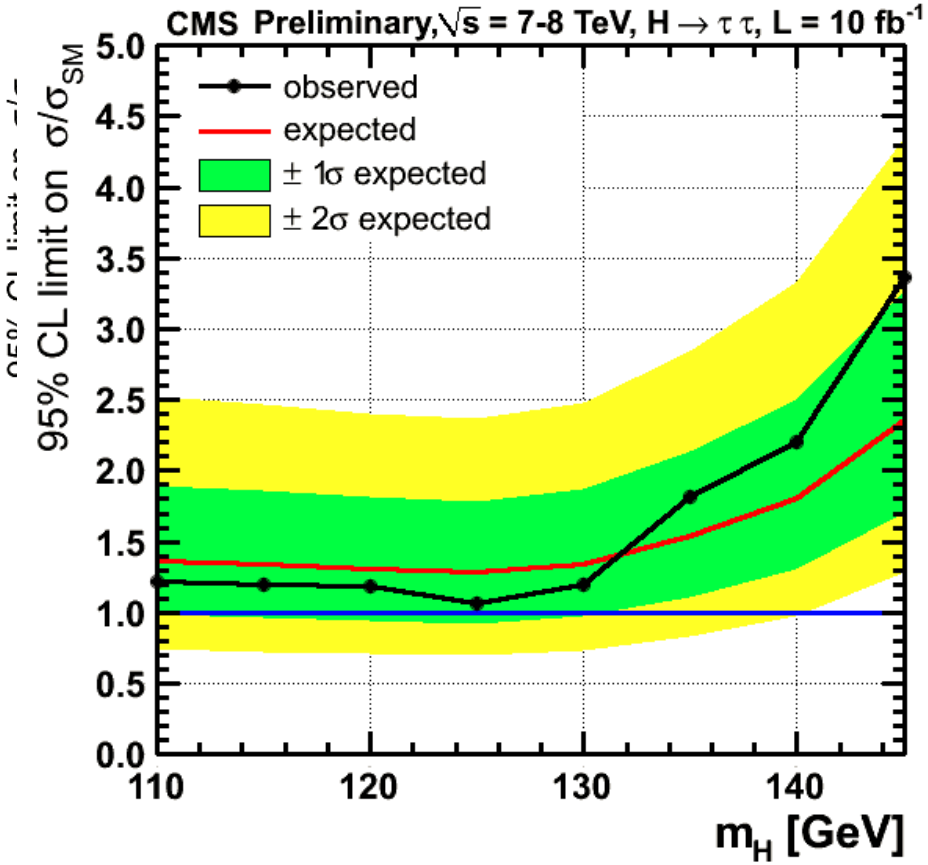
@ 100-150GeV Higgs mass

2012 analyses with improvements are now ongoing.

- Analysis improved. 2x improvement from 2011.
- Observed(Expected) limit is 1.06(1.3)xSM!

Result : CMS 7TeV(4.9fb^{-1})+8TeV(5.1fb^{-1})





Observed limit : 2.8-12.1

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@ 100-150GeV Higgs mass

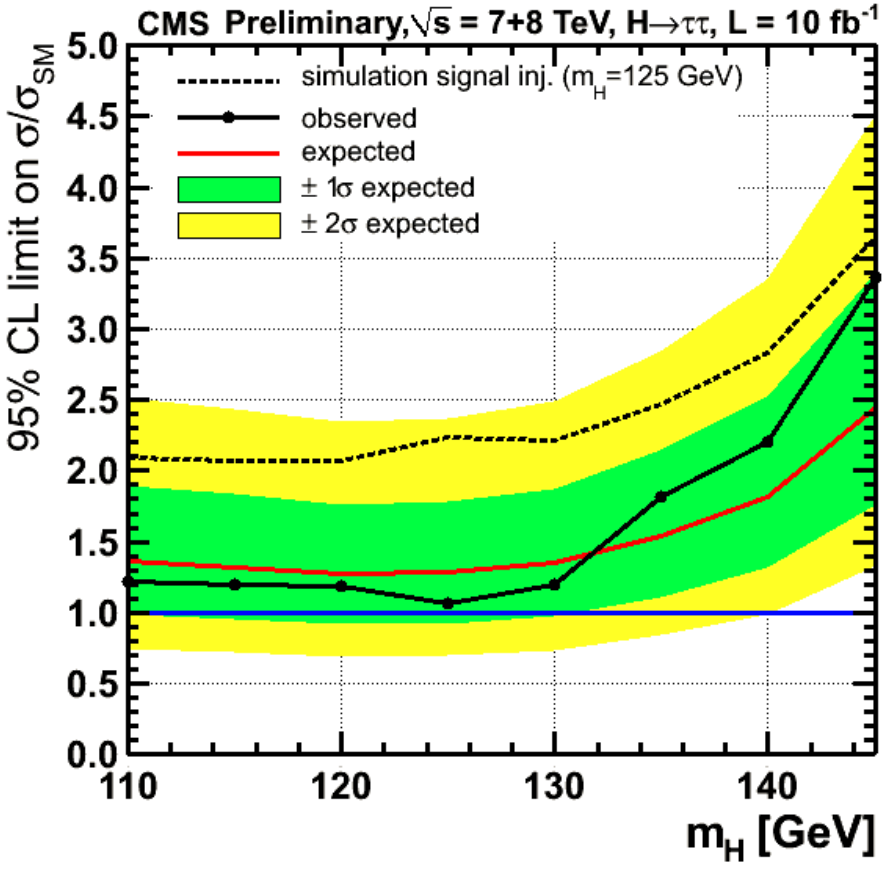
2012 analyses with improvements are now ongoing.

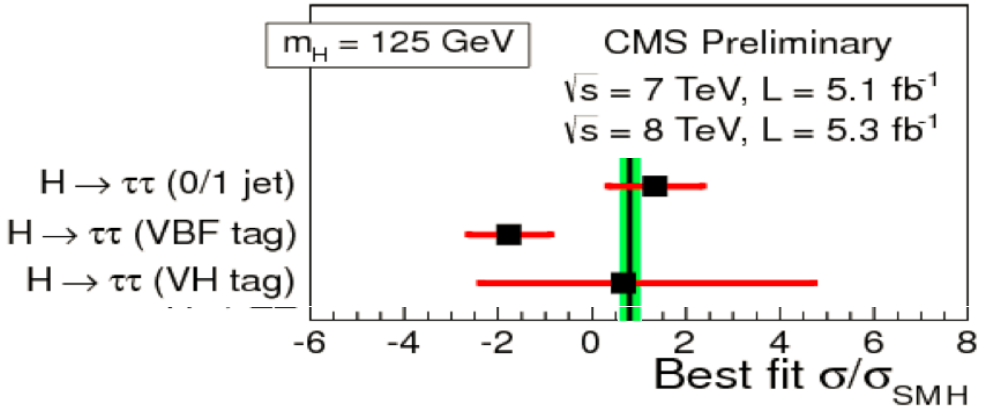
improvement from 2011.

- Observed(Expected) limit is 1.06(1.3)xSM!

Result : CMS 7TeV(4.9fb^{-1})+8TeV(5.1fb^{-1})

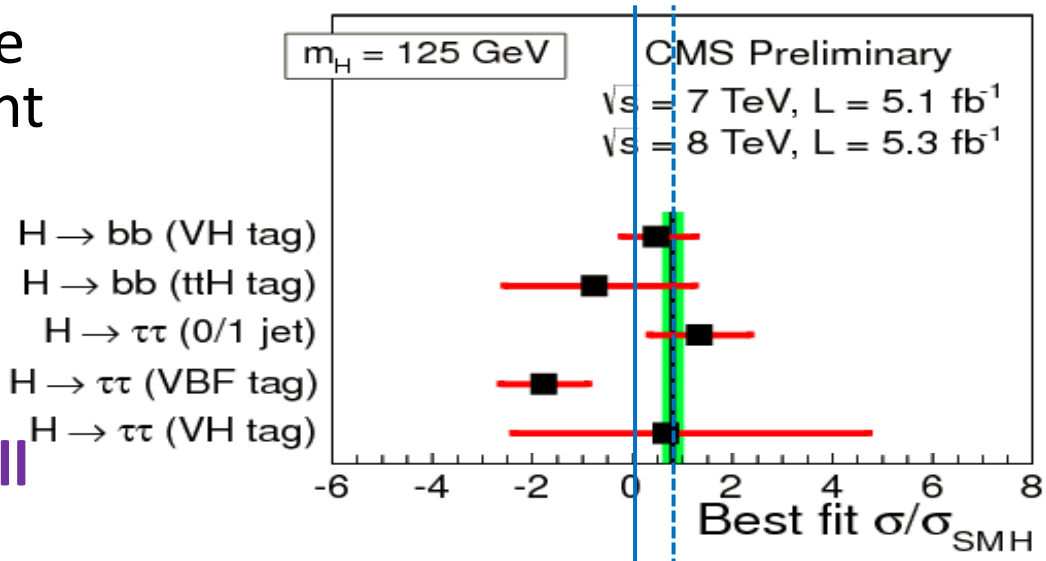
- **Is this happened even if SM Signal exist?**
- Made limit plot by injecting SM signal
- Signal cross section best fit value :
  - ggF dominant category : consistent to SM prediction.
  - VBF category : downward fluctuation. In consistent to SM prediction.

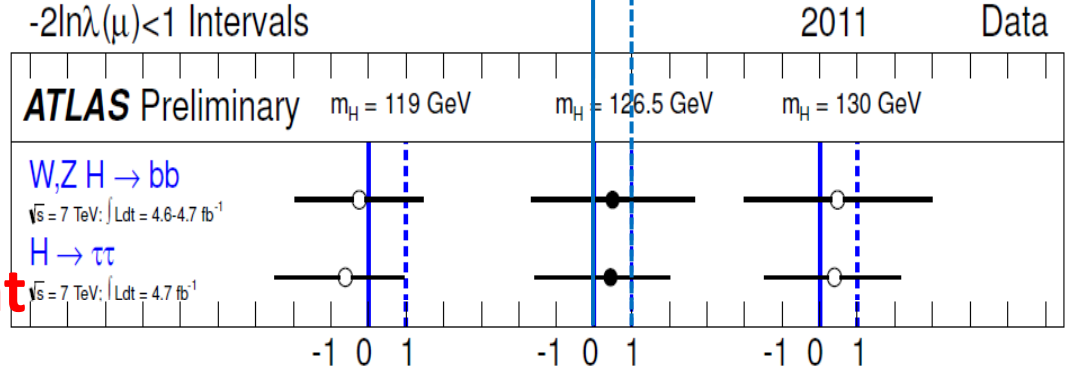




Discussions about ττ and bb

- ττ and bb decay modes are some of the most important channels to determine :
  - what we see is the Higgs!!
- ATLAS 2012 results will be published in September.
- **Significant observation will be seen soon! (if exist)**
- An anomaly(?) was observed by CMS VBF tautau channel.
  - Need to see the ATLAS results if we observed the same properties.
- **First precision measurement coming soon!!**

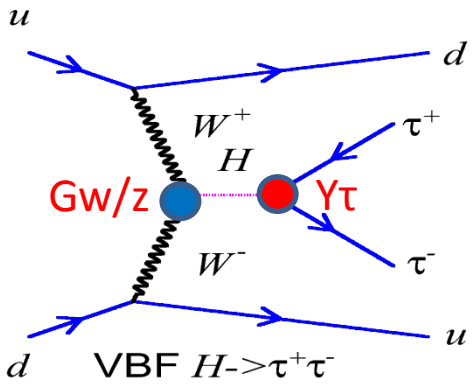


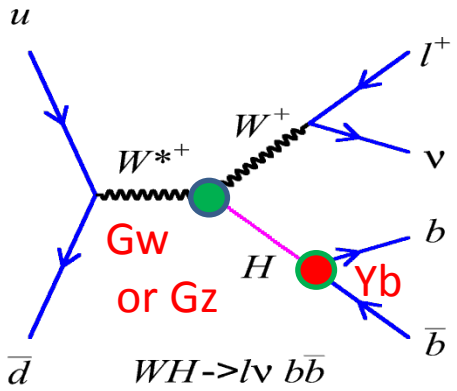


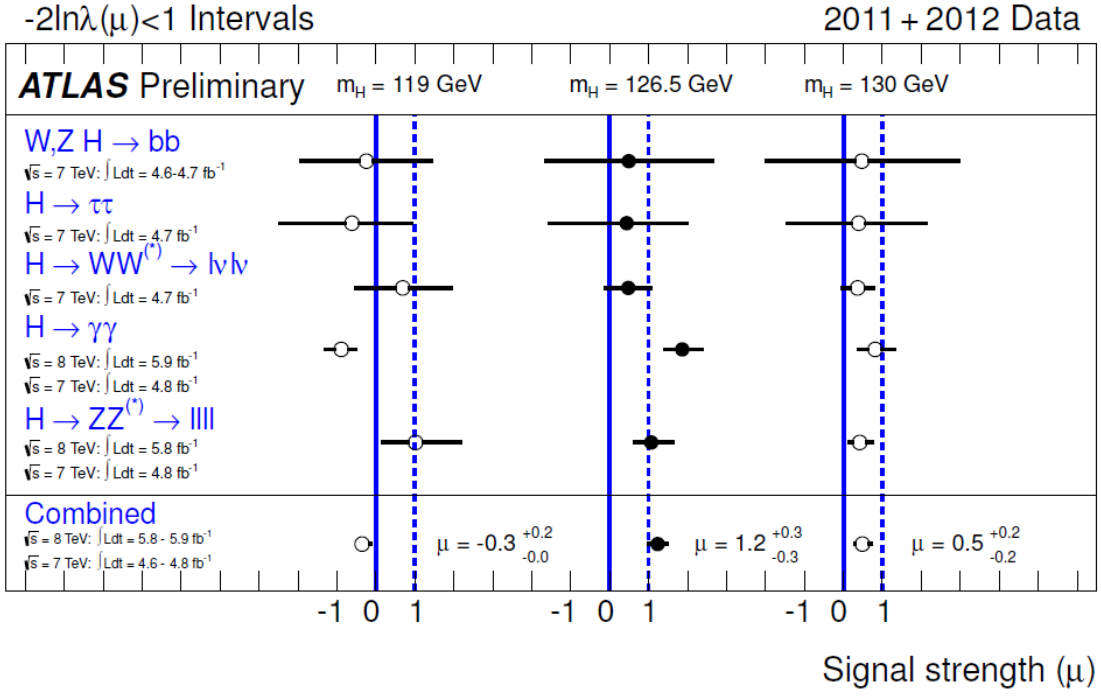
If your model would like to be tested could you let us know?

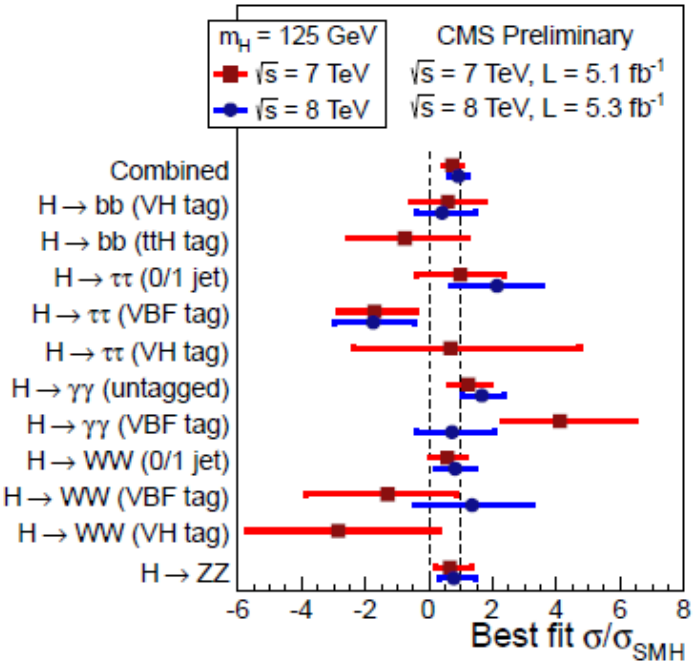
Coupling II

- Fermion coupling!
- Need ττ and bb.





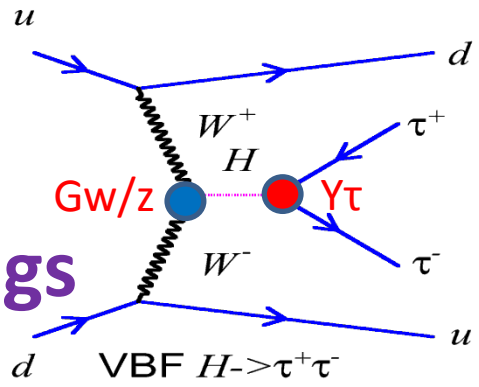


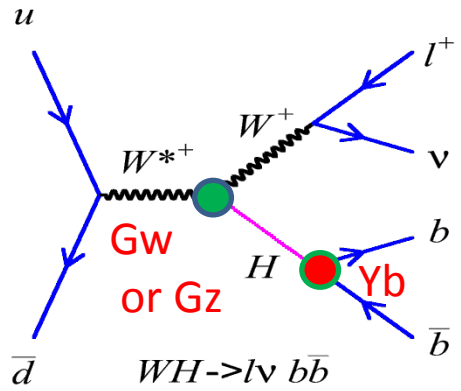


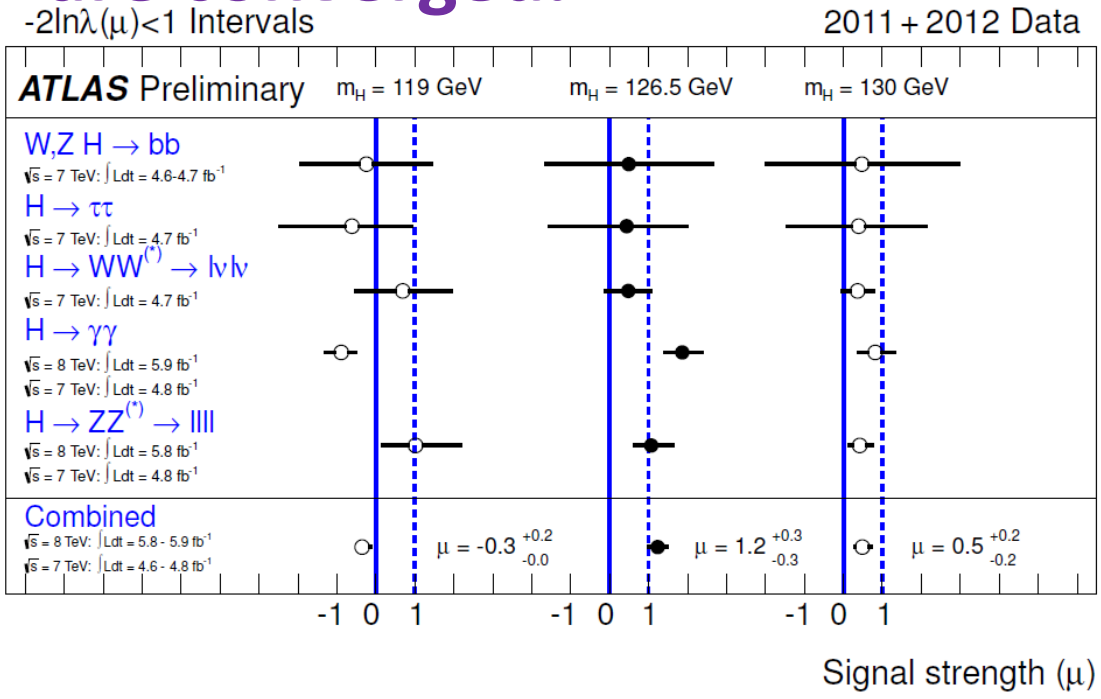
Coupling II

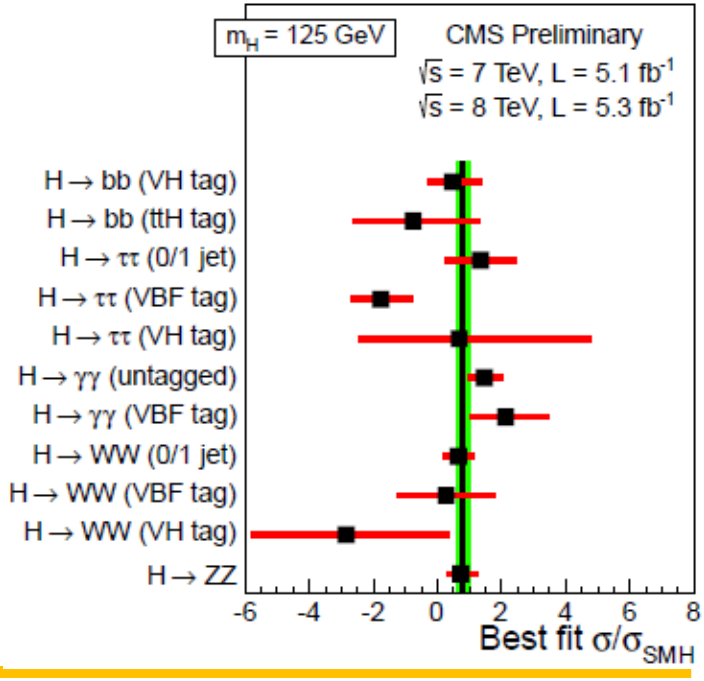
- Fermion coupling!
- Need ττ and bb.

Will see how the couplings are converged.



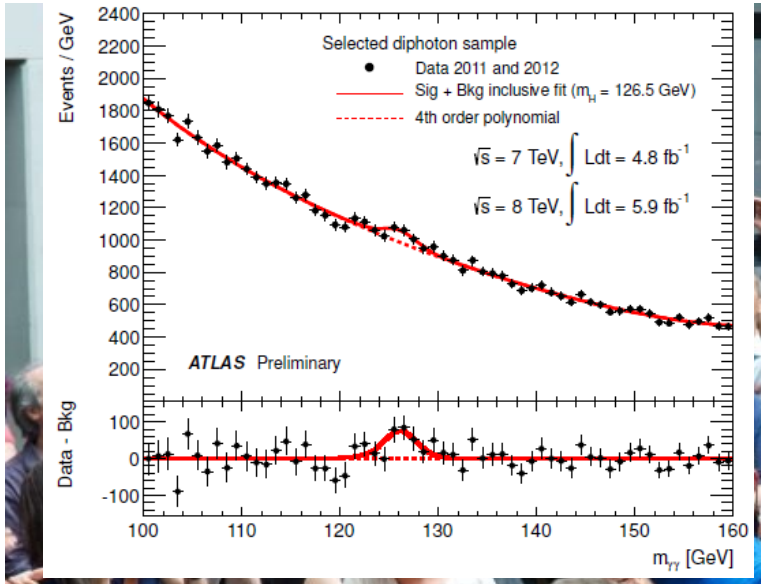




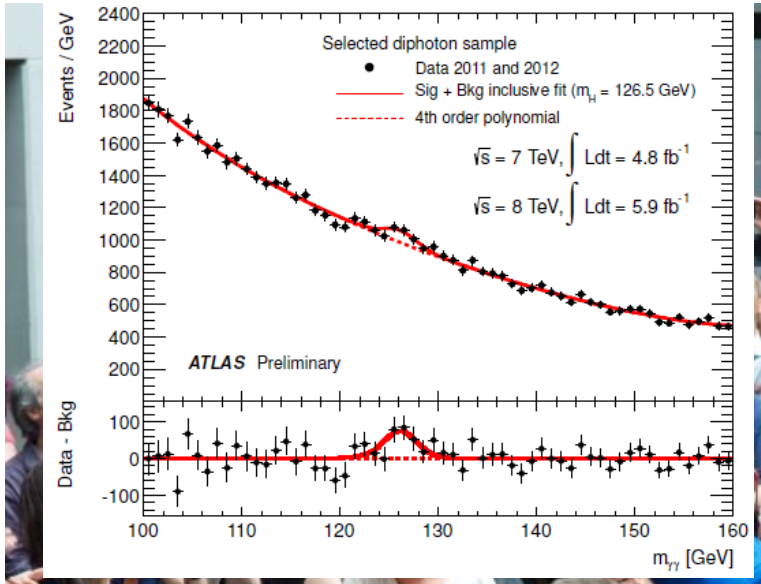


Conclusion

Conclusion


Selected diphoton sample
Data 2011 and 2012
Sig + Bkg inclusive fit (m_H = 126.5 GeV)
4th order polynomial
√s = 7 TeV, ∫ Ldt = 4.8 fb^-1
√s = 8 TeV, ∫ Ldt = 5.9 fb^-1
ATLAS Preliminary
Events / GeV
Data - Bkg
m_γγ [GeV]

Conclusion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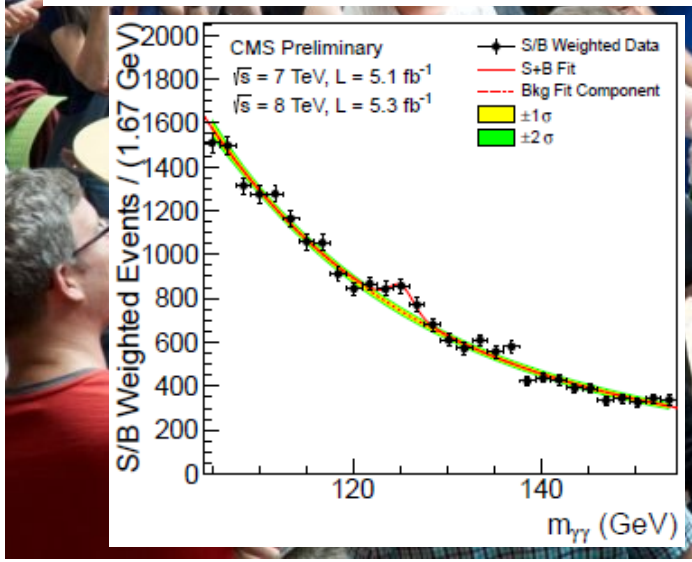
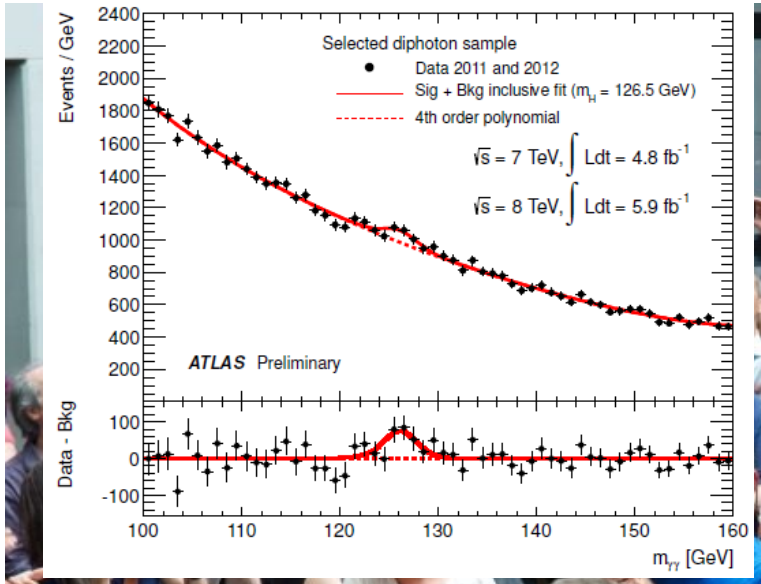

CMS Preliminary
√s = 7 TeV, L = 5.1 fb-1
√s = 8 TeV, L = 5.3 fb-1
S/B Weighted Data
S+B Fit
Bkg Fit Component
±1σ
±2σ
S/B Weighted Events / (1.67 GeV)
m_γγ (GeV)

Conclusion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4th order polynomial
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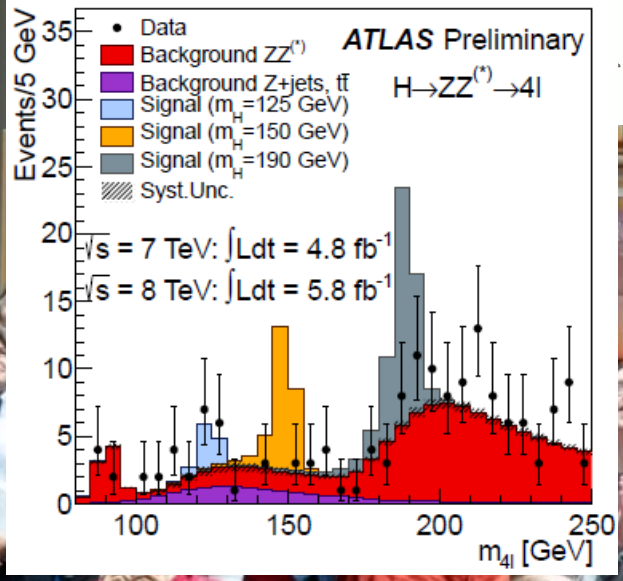
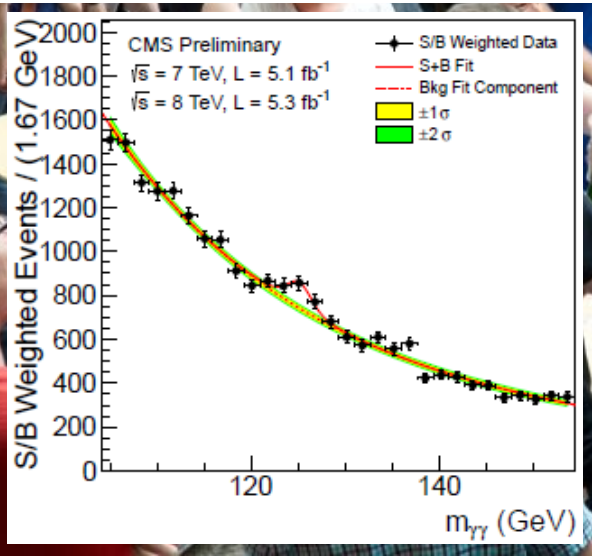
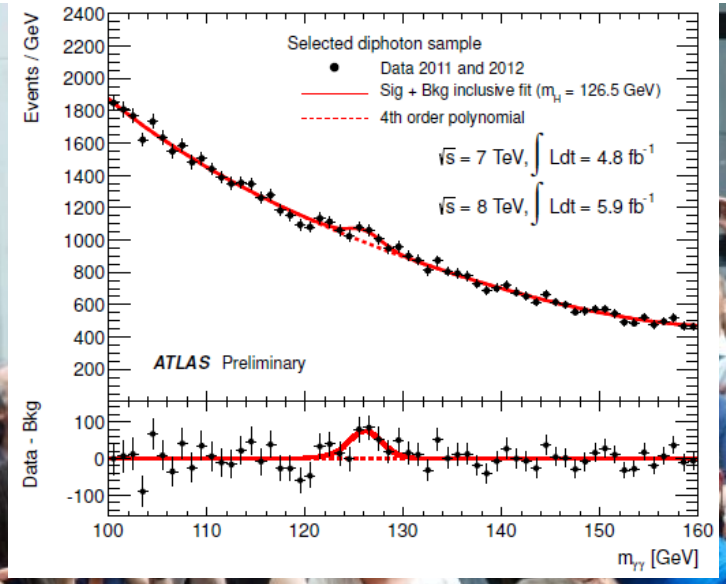
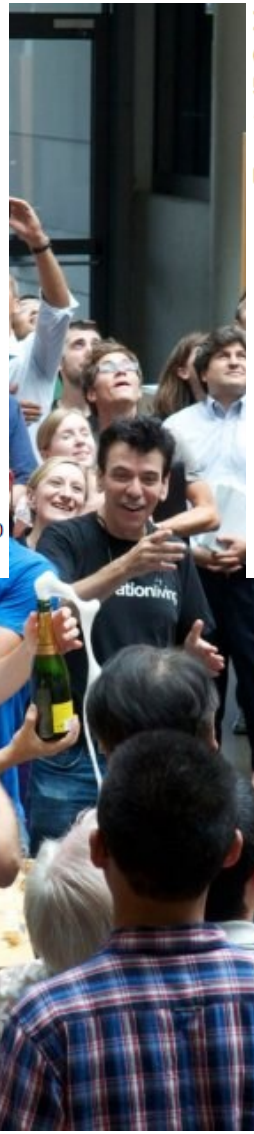
ATLAS Preliminary
Events / GeV
Data - Bkg
m_γγ [GeV]

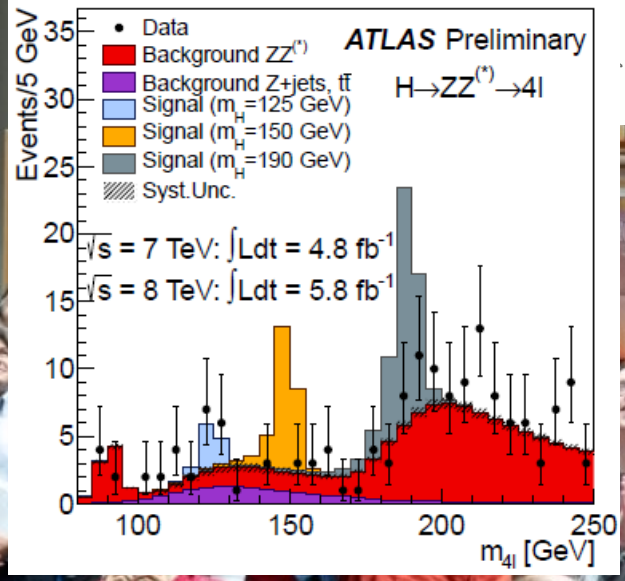

Data
Background ZZ(*)
Background Z+jets, tt̄
Signal (m_H=125 GeV)
Signal (m_H=150 GeV)
Signal (m_H=190 GeV)
Syst.Unc.
ATLAS Preliminary
H→ZZ(*)→4l
√s = 7 TeV: ∫Ldt = 4.8 fb-1
√s = 8 TeV: ∫Ldt = 5.8 fb-1
Events/5 GeV
m_4l [GeV]

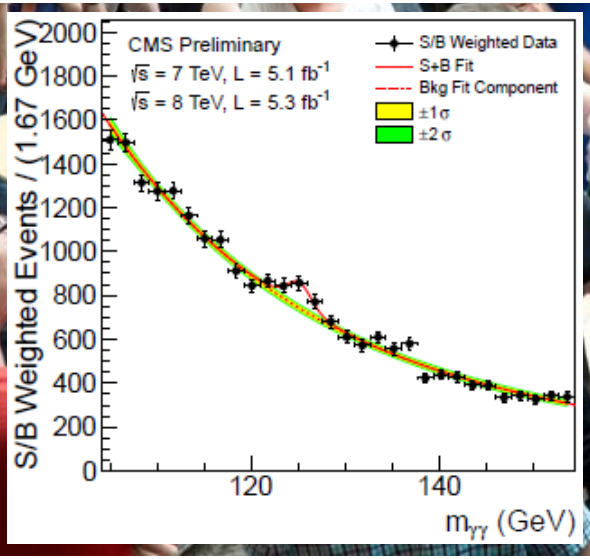

CMS Preliminary
√s = 7 TeV, L = 5.1 fb-1
√s = 8 TeV, L = 5.3 fb-1
S/B Weighted Data
S+B Fit
Bkg Fit Component
±1σ
±2σ
S/B Weighted Events / (1.67 GeV)
m_γγ (GeV)

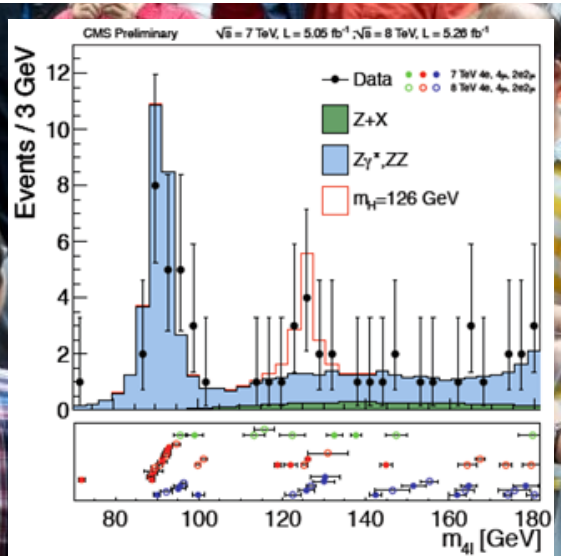
Conclusion


Selected diphoton sample
Data 2011 and 2012
Sig + Bkg inclusive fit (m_H = 126.5 GeV)
4th order polynomial
√s = 7 TeV, ∫ Ldt = 4.8 fb-1
√s = 8 TeV, ∫ Ldt = 5.9 fb-1
ATLAS Preliminary
Events / GeV
Data - Bkg
m_γγ [GeV]



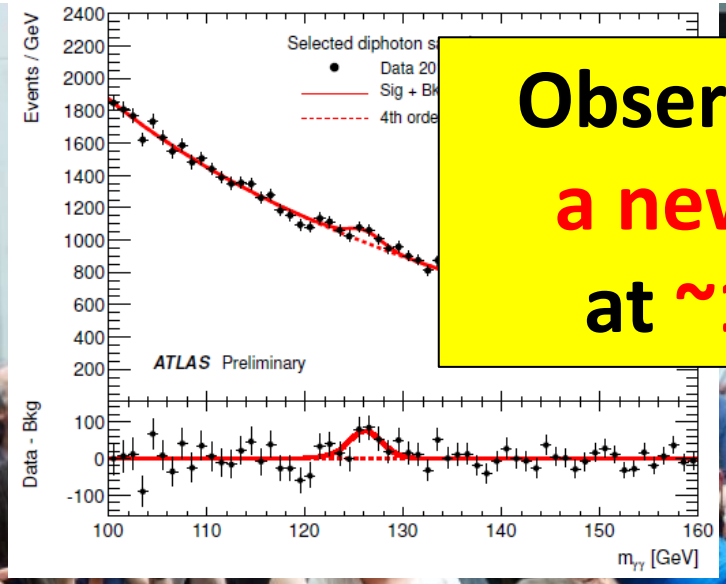

Data
Background ZZ(*)
Background Z+jets, tt̄
Signal (m_H=125 GeV)
Signal (m_H=150 GeV)
Signal (m_H=190 GeV)
Syst.Unc.
ATLAS Preliminary
H→ZZ(*)→4l
√s = 7 TeV: ∫Ldt = 4.8 fb-1
√s = 8 TeV: ∫Ldt = 5.8 fb-1
Events/5 GeV
m4l [GeV]

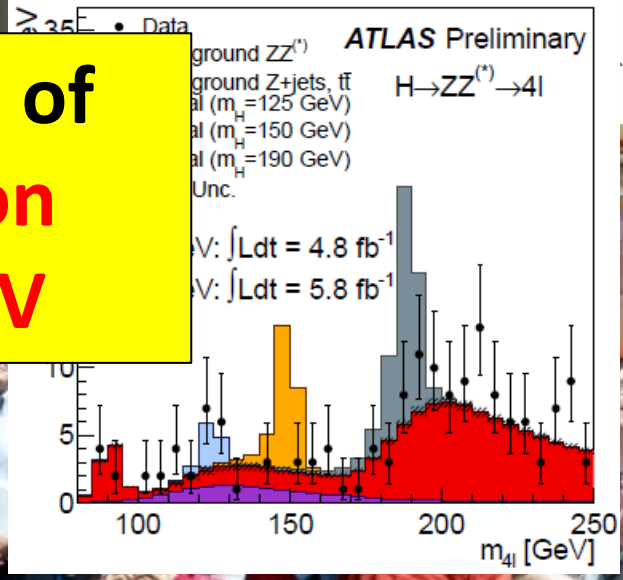

CMS Preliminary
√s = 7 TeV, L = 5.1 fb-1
√s = 8 TeV, L = 5.3 fb-1
S/B Weighted Data
S+B Fit
Bkg Fit Component
±1σ
±2σ
S/B Weighted Events / (1.67 GeV)
mγγ (GeV)

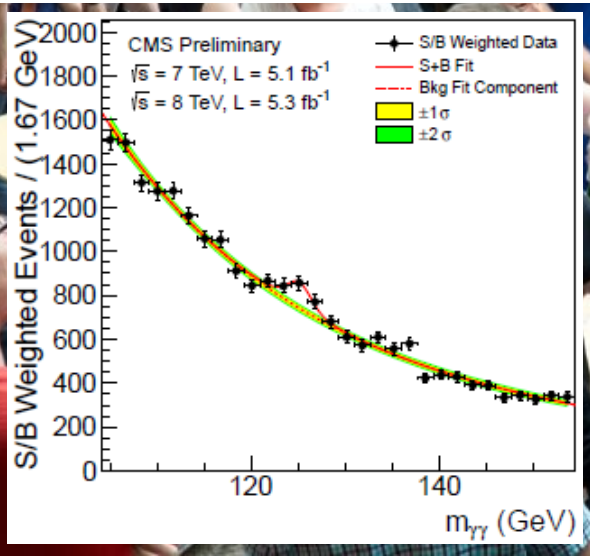

CMS Preliminary
Data
Z+X
Zγ*,ZZ
m_H=126 GeV
Events / 3 GeV
m4l [GeV]

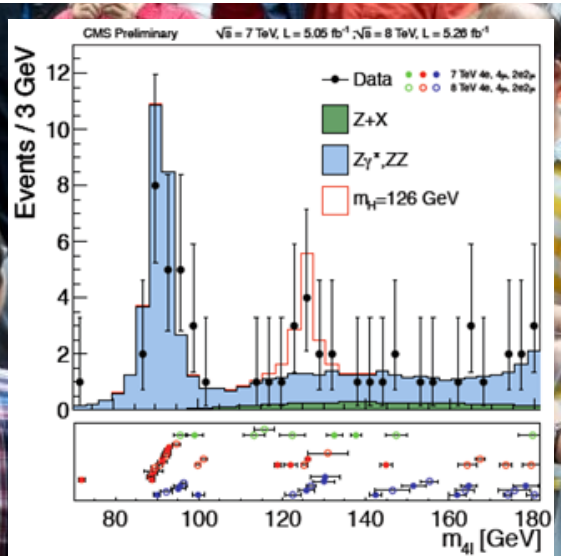
Conclusion

Observation of
a new boson
at ~126GeV





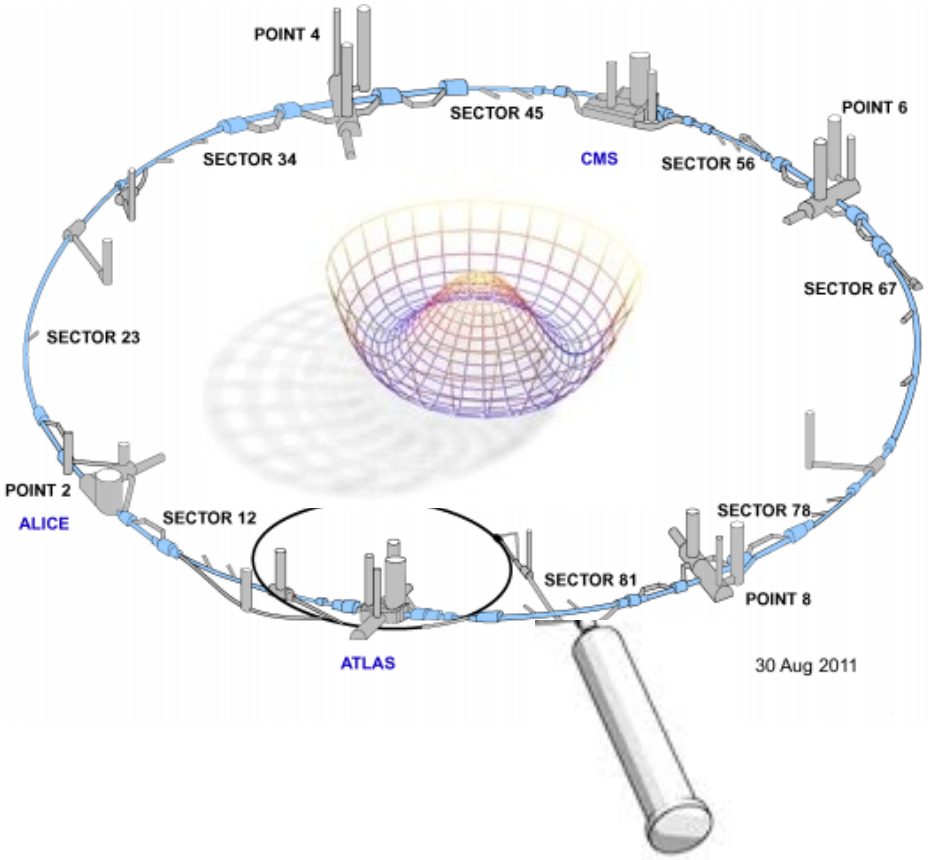




Conclusion

Observation of
a new boson
at ~126GeV

This is just the BEGINNING of
Measuring properties
And
Prove New Physics!!

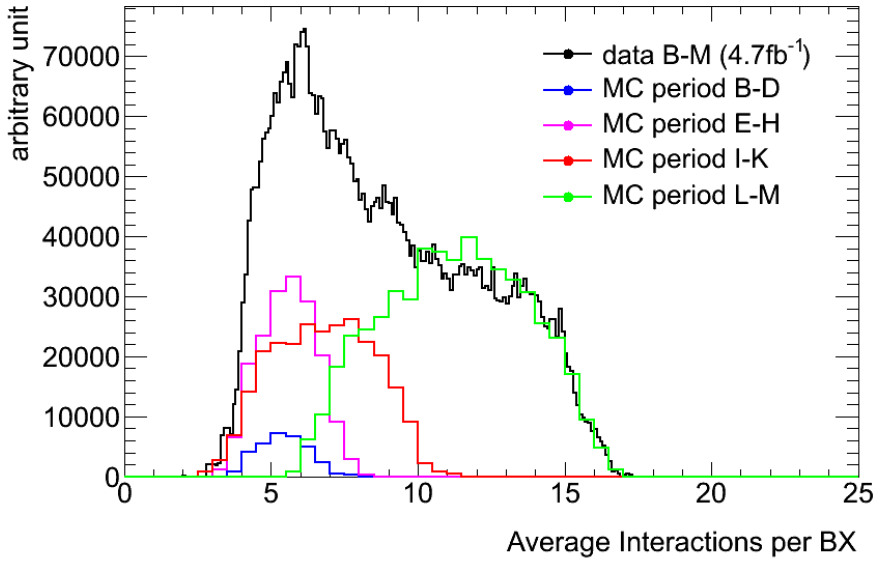

POINT 4
SECTOR 45
POINT 6
SECTOR 34
CMS
SECTOR 56
SECTOR 67
SECTOR 23
POINT 2
ALICE
SECTOR 12
SECTOR 78
SECTOR 81
POINT 8
ATLAS
30 Aug 2011

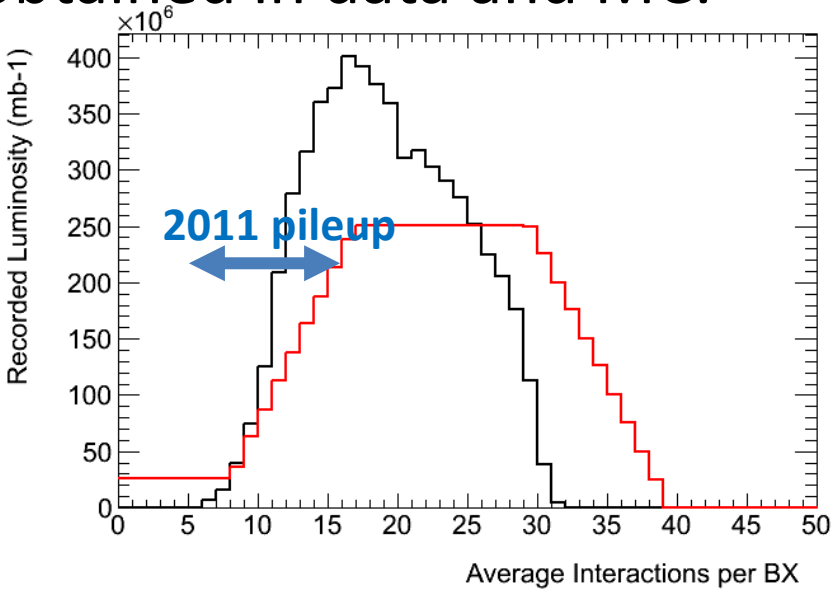
Back up

Generating MC events

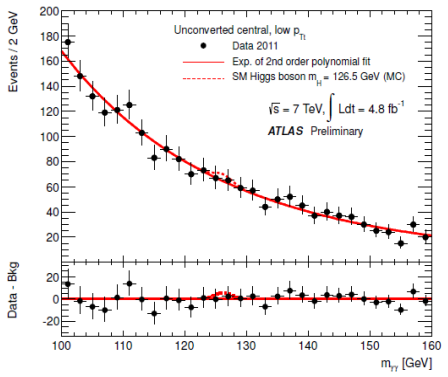
ATLAS

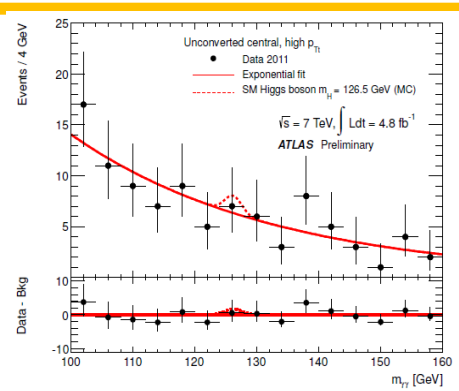
- MC events of Minimum bias collisions are mixed to the each background and signal MC events.
- Pileup condition is certainly getting heavier as getting higher instantaneous luminosity.
- MC samples are generated for corresponding pileup conditions and re-weighting by data/MC so that the same pileup conditions are obtained in data and MC.

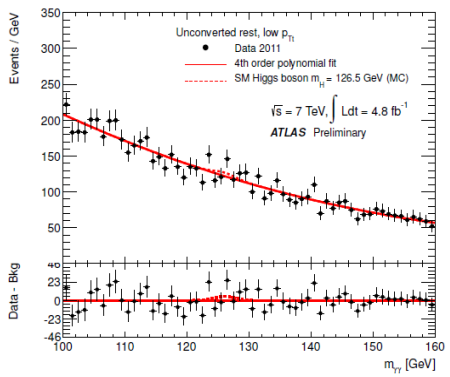


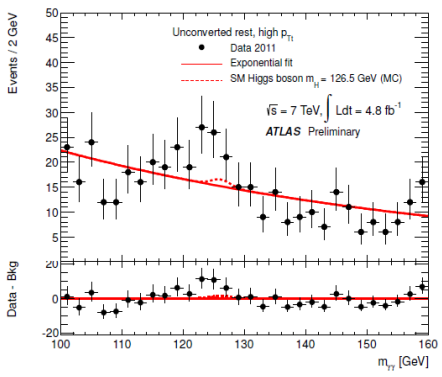


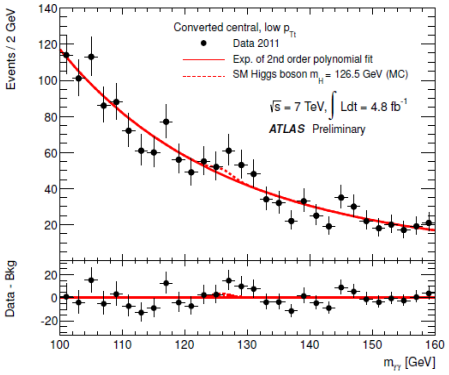
Results : mass distribution ATLAS 7TeV

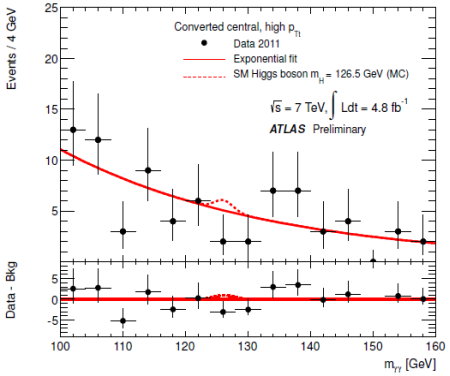


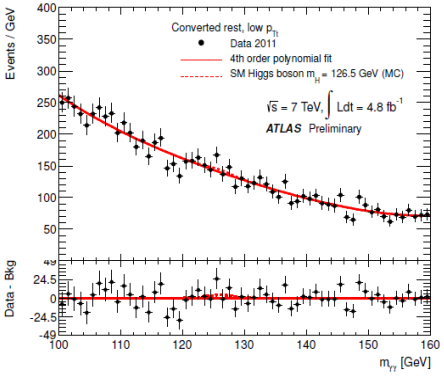


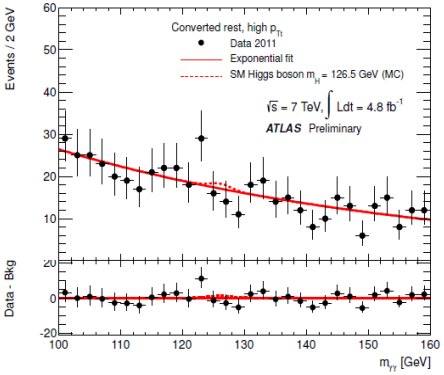


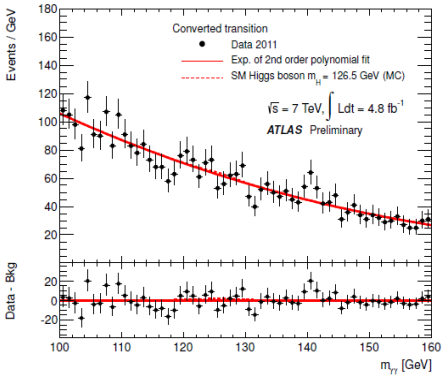


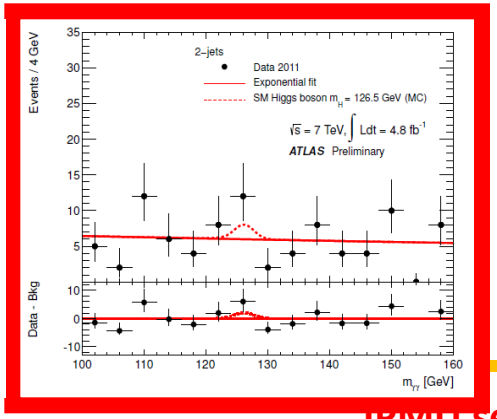




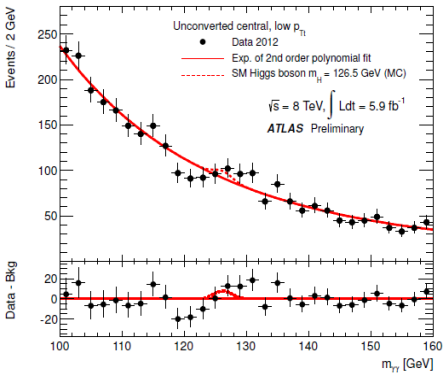


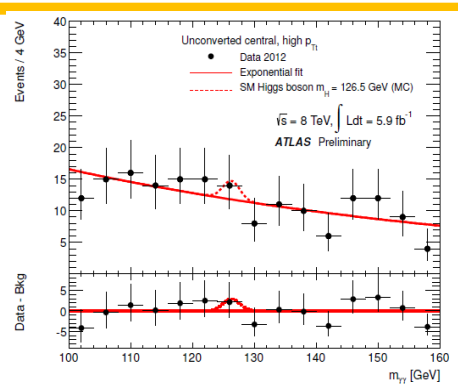


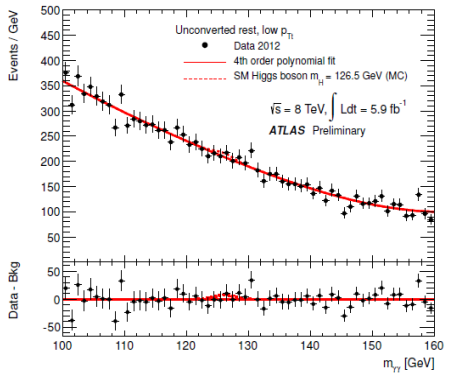


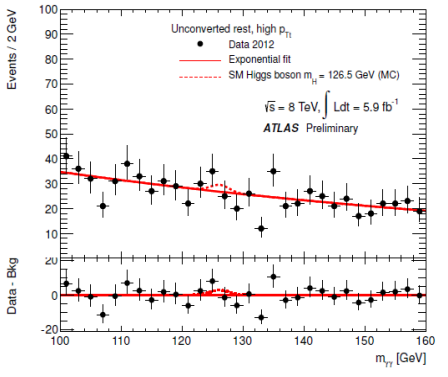


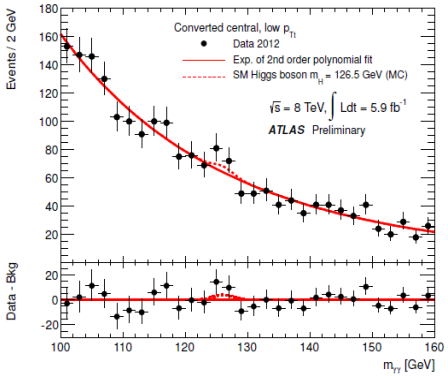
Results : mass distribution ATLAS 8TeV

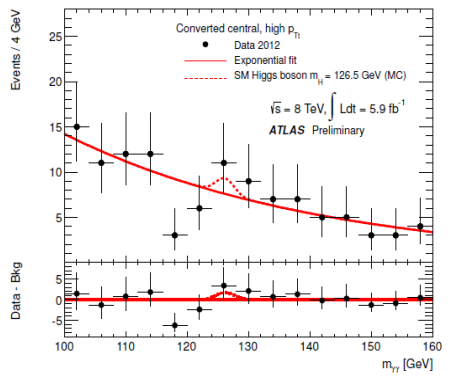


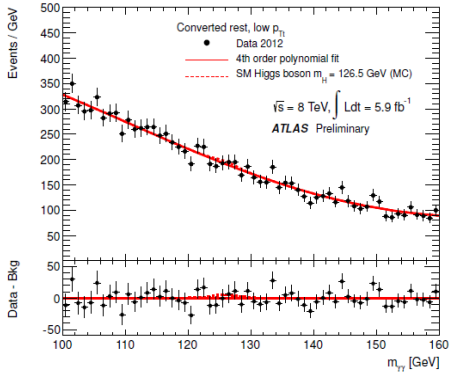


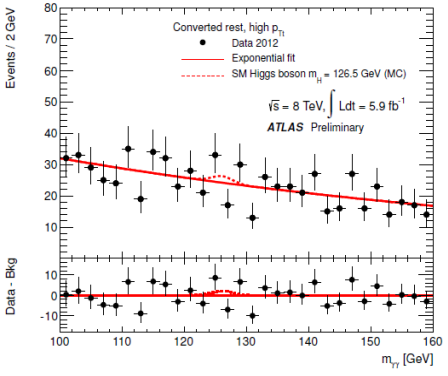


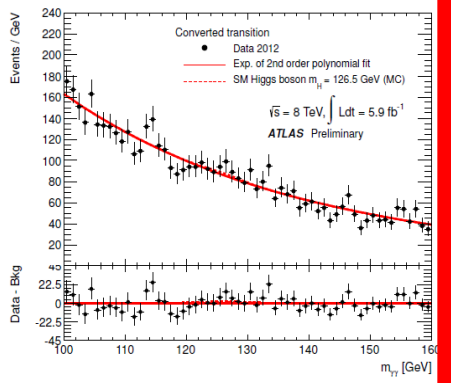


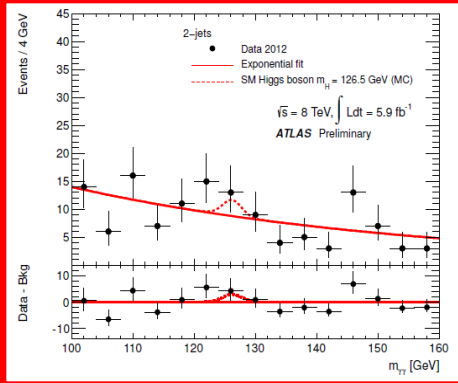




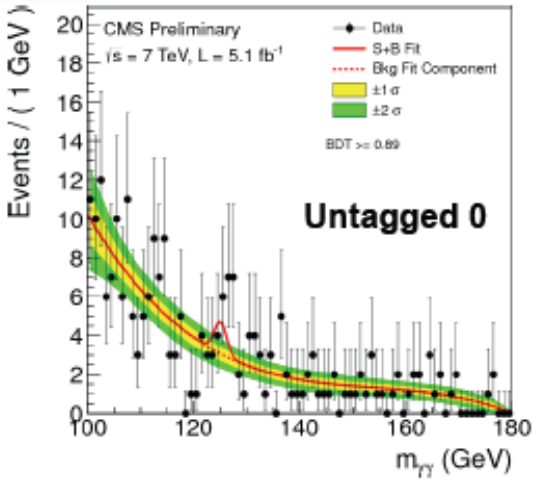


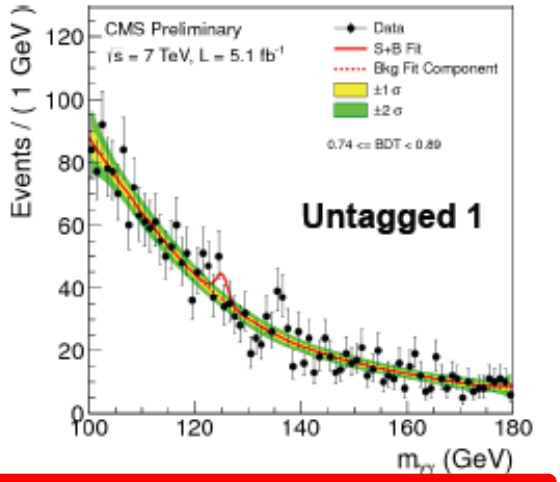


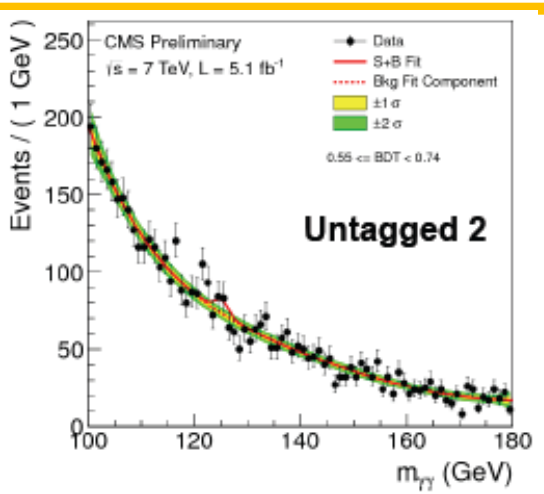


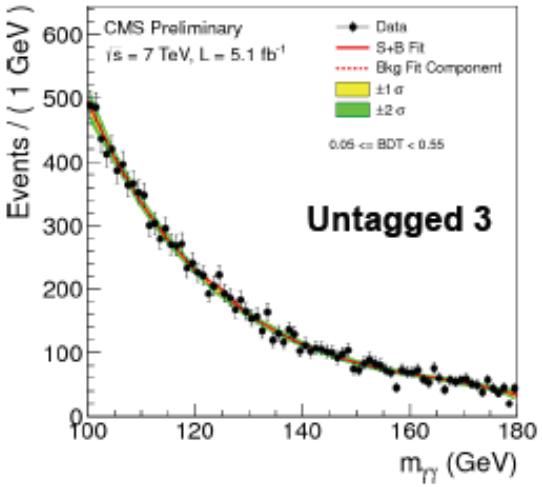


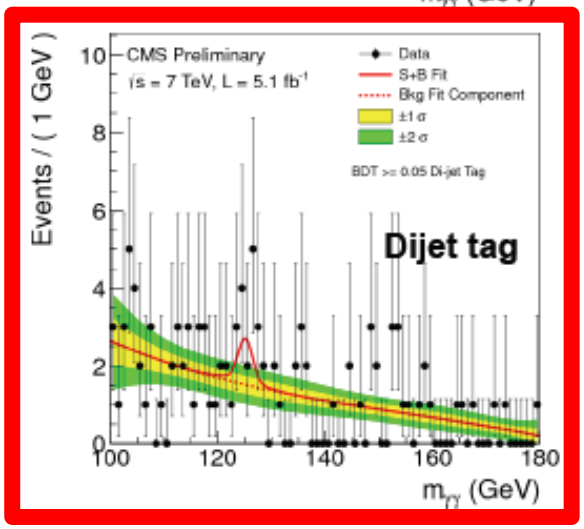
Results : mass distribution CMS 7TeV



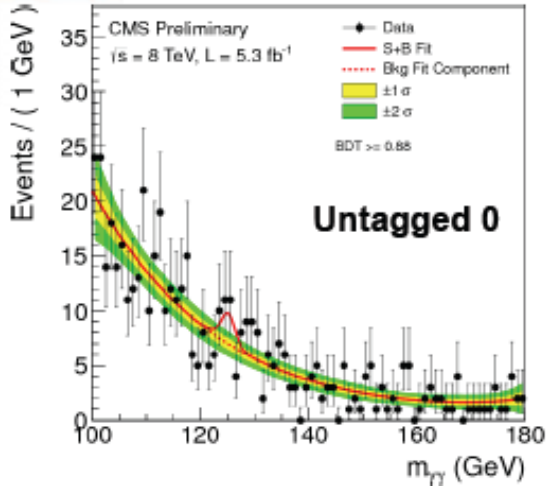


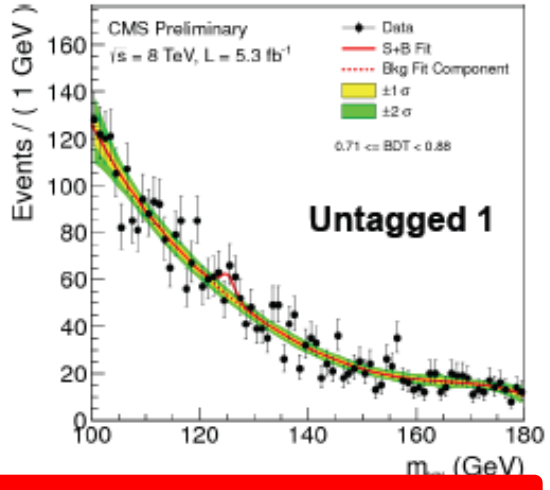


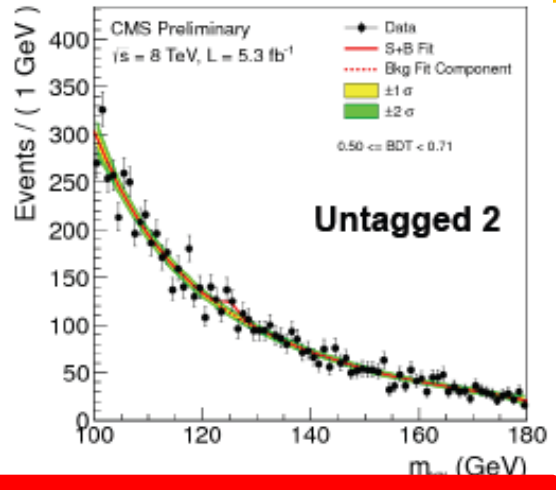


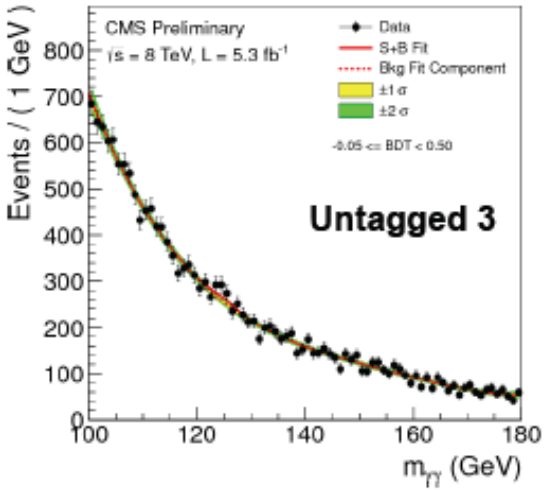


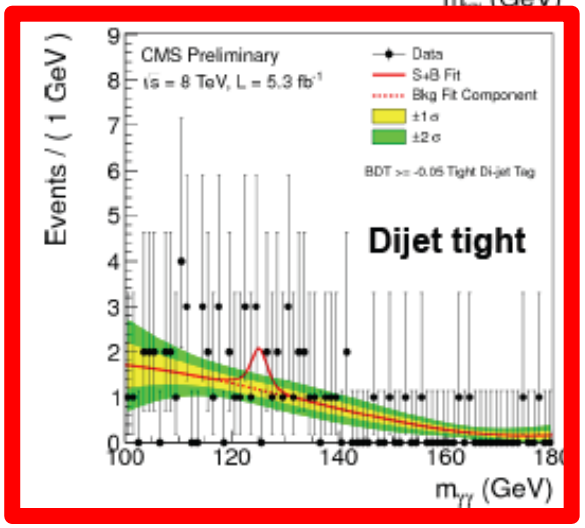
Results : mass distribution CMS 8TeV

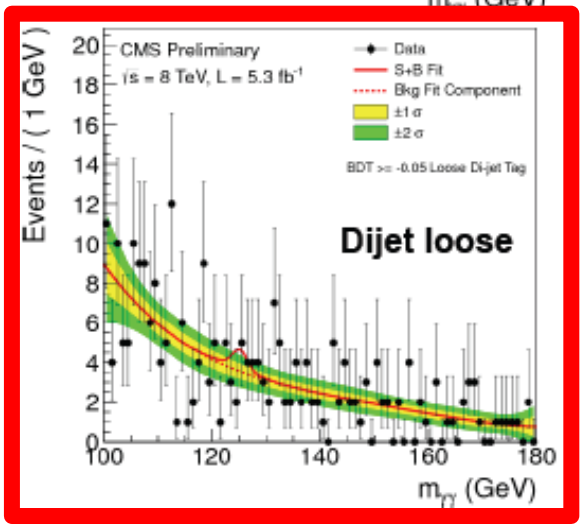




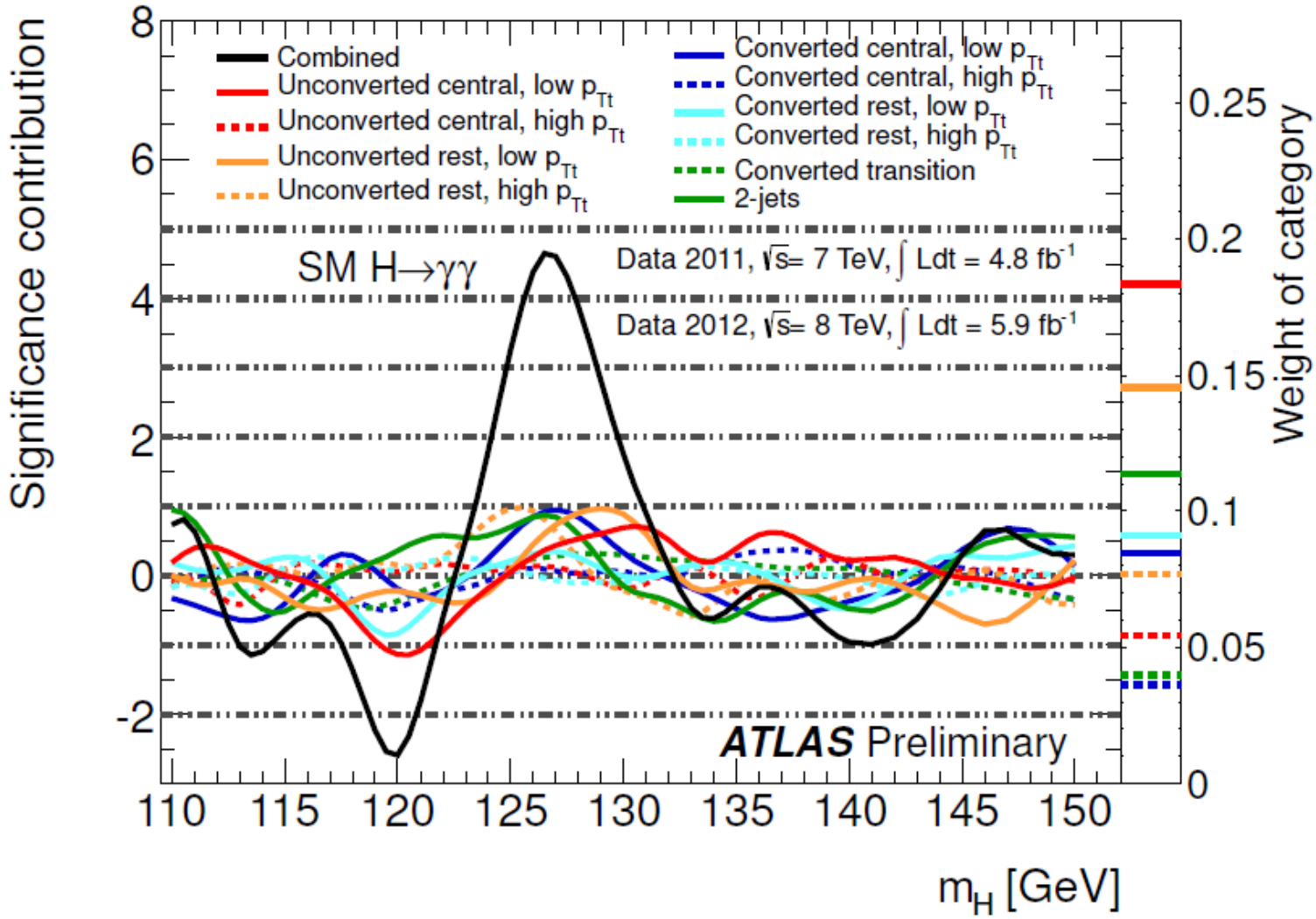




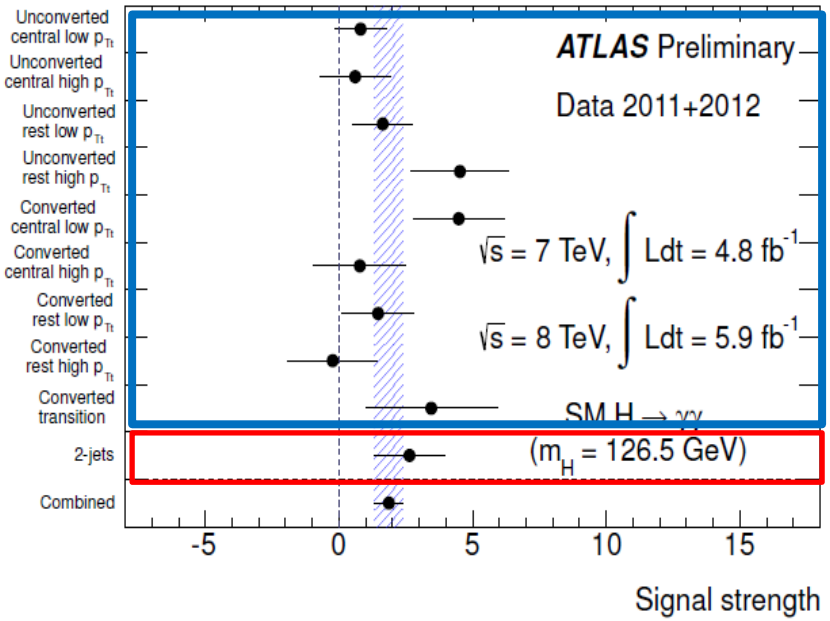


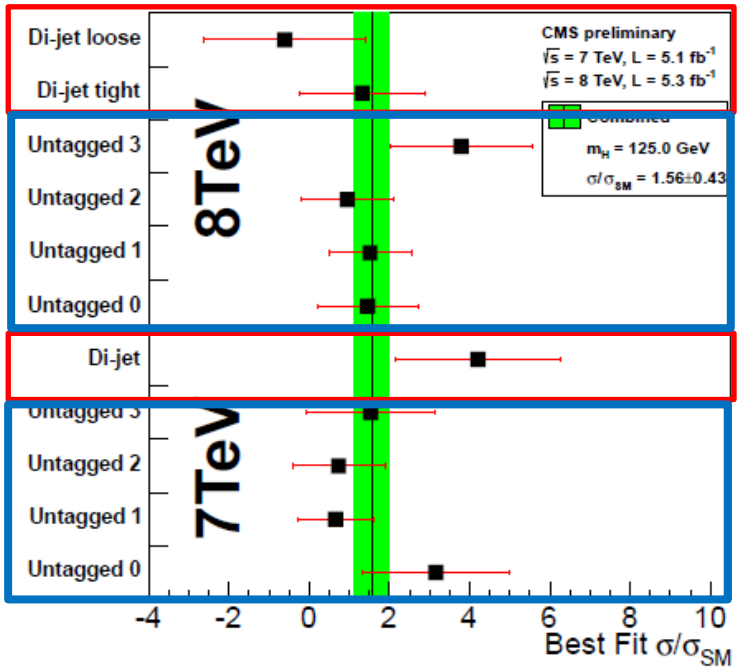


Weighted sensitivity



Signal strength break down





- No single channel is deviated from SM expectation.
  - – ▭ is VBF dominant category .
  - – ▭ is ggF dominant category.

4 lepton event yield

event yields in 110-160 GeV

Channel	4e	4μ	$2e2\mu$	4ℓ
ZZ background	2.7 ± 0.3	5.7 ± 0.6	7.2 ± 0.8	15.5 ± 1.0
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	$3.9^{+1.1}_{-0.8}$	$6.6^{+0.9}_{-0.8}$	$9.5^{+2.0}_{-1.6}$	$19.9^{+2.4}_{-2.0}$
$m_H = 120$ GeV	0.8 ± 0.2	1.6 ± 0.3	1.9 ± 0.5	4.4 ± 0.6
$m_H = 126$ GeV	1.5 ± 0.5	3.0 ± 0.6	3.8 ± 0.9	8.3 ± 1.2
$m_H = 130$ GeV	2.1 ± 0.7	4.1 ± 0.8	5.4 ± 1.3	11.6 ± 1.6
Observed	6	6	9	21

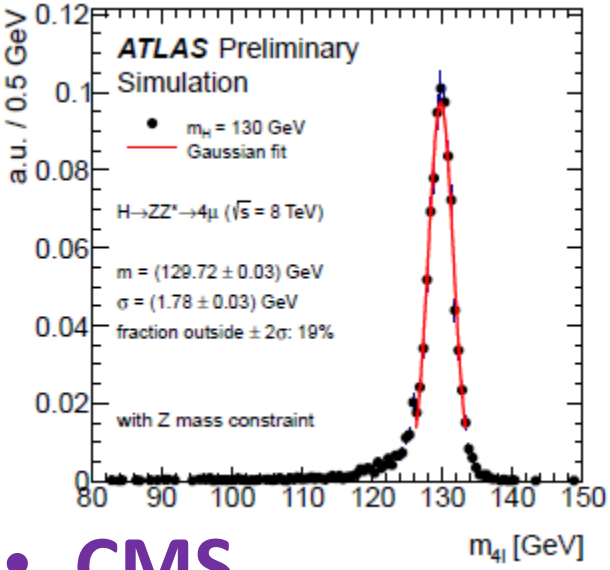
for m_{4l} region with 125±5GeV

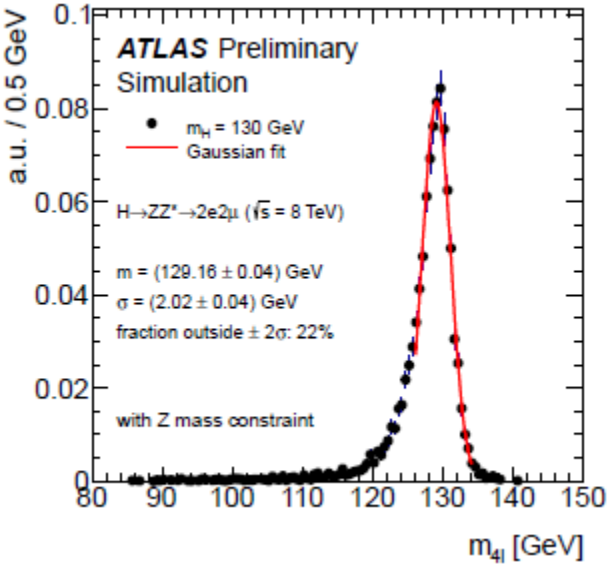
Dataset	2011	2012	Combined
Exp. Background	2.1±0.3	2.9±0.4	5.1±0.8
Exp. Signal	2.0±0.3	3.3±0.5	5.3±0.8
Observed	4	9	13

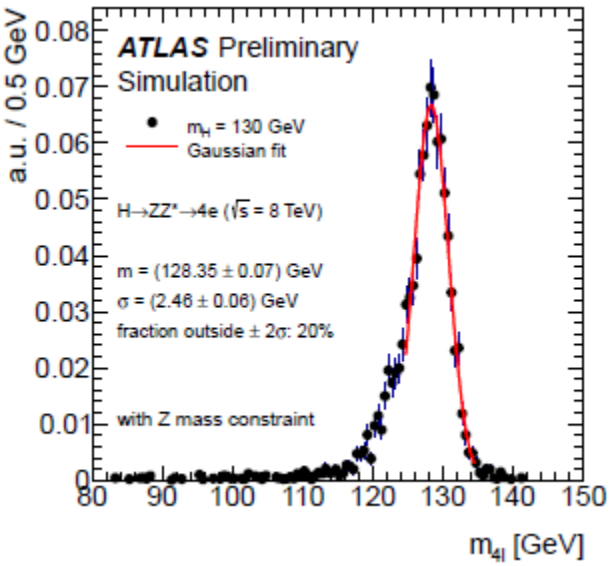
Mass resolution

- **ATLAS**

4μ : 1.8GeV **2e2μ : 2.0GeV** **4e : 2.5GeV**





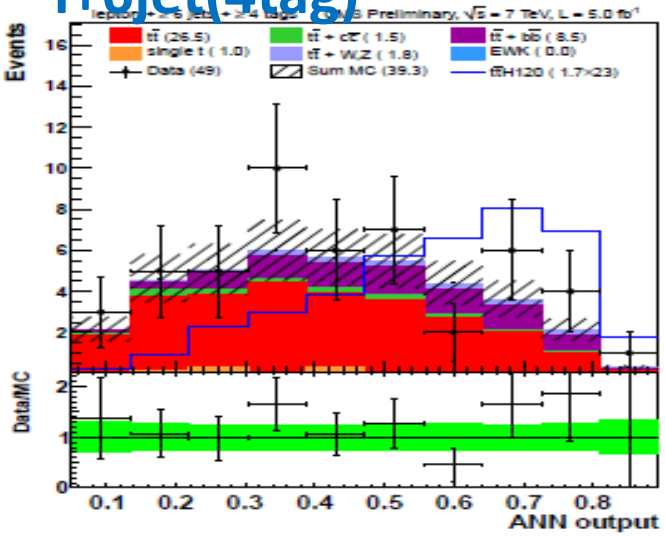


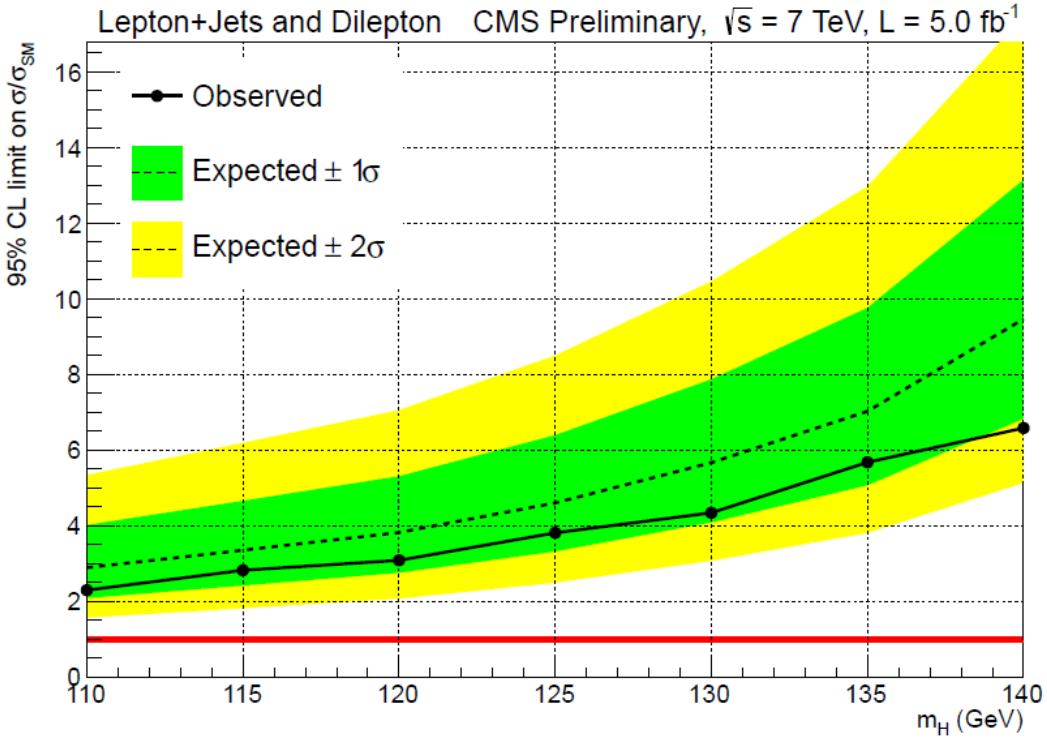
- **CMS**
  - 1-2% (~1.3-2.6GeV@130GeV?)

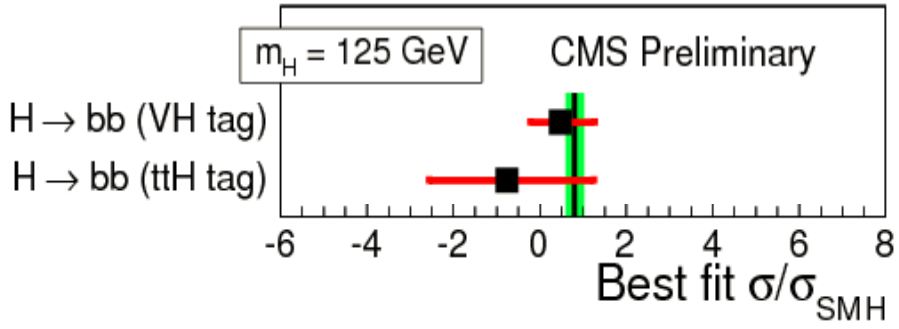
One slide for ttH→ttbb (CMS)

- **Direct Yt measurement.**
- Huge tt(+bb) and Combinatrial background.
- **Need Multivariate analysis.**
- Split events by
  - Lepton+jets or di-lepton
  - Lepton flavor
  - Number of b-tagging

l+6jet(4tag)







Exclusion
(CL_s limit)

$$q_\mu = -2 \ln \frac{\mathcal{L}(\text{obs} \,|\, \mu \cdot s + b, \hat{\theta}_\mu)}{\mathcal{L}(\text{obs} \,|\, \hat{\mu} \cdot s + b, \hat{\theta})}$$

$$\text{CL}_\text{s} = \frac{\text{P}(q_\mu \geq q_\mu^{\text{obs}} \,|\, \mu \cdot s + b)}{\text{P}(q_\mu \geq q_\mu^{\text{obs}} \,|\, b)} \leq \alpha$$

Excess (p_0)

$$q_0 = -2 \ln \frac{\mathcal{L}(\text{obs} \,|\, b, \hat{\theta}_0)}{\mathcal{L}(\text{obs} \,|\, \hat{\mu} \cdot s + b, \hat{\theta})}$$

$$p_0 = \text{P}(q_0 \geq q_0^{obs} \,|\, \text{b})$$

$$p_0 = \int_Z^{+\infty} \frac{1}{\sqrt{2\pi}} \exp(-x^2/2)\, dx$$

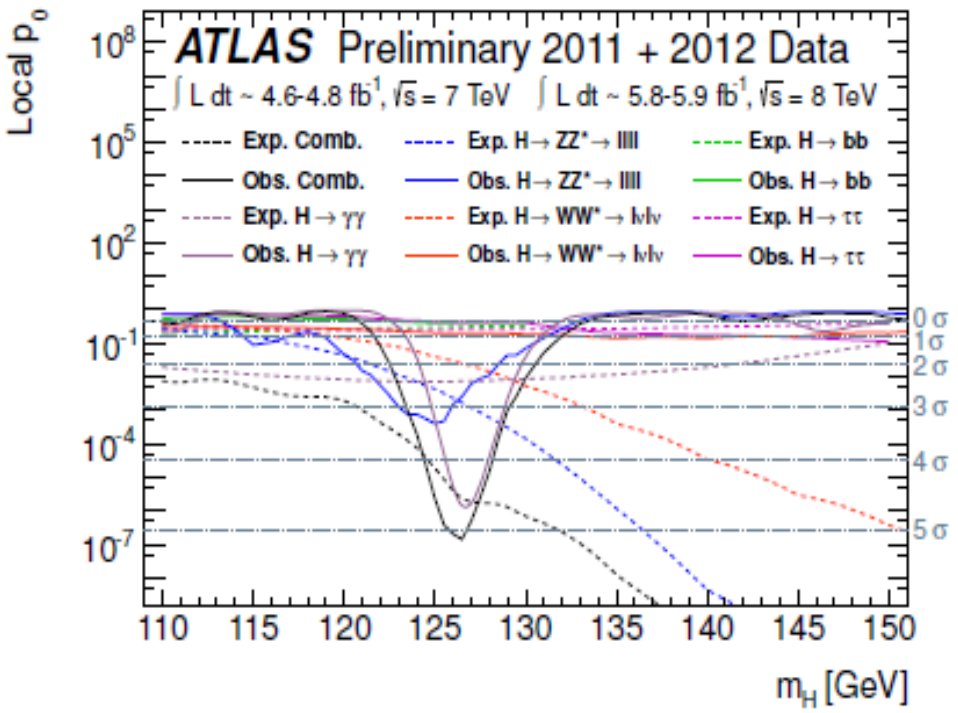
$$p_{\text{global}} = p_{\text{local}}^{\text{min}} + C \cdot e^{-Z_{\text{local}}^2/2}$$

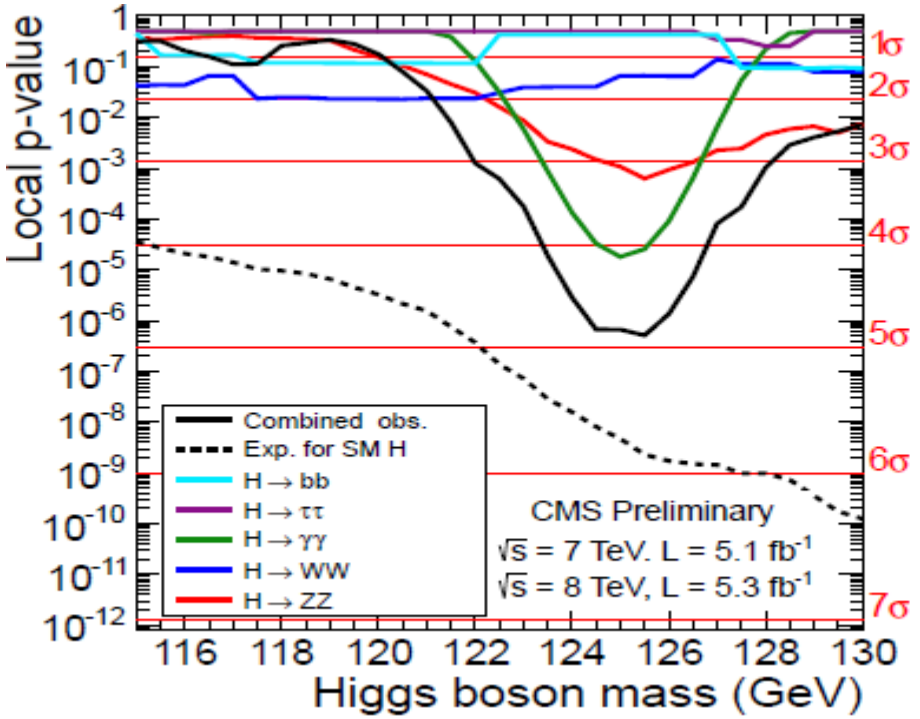
Extraction of
signal parameters

$$q(a) = -2 \ln \frac{\mathcal{L}(\text{obs} \,|\, s(a) + b, \hat{\theta}_a)}{\mathcal{L}(\text{obs} \,|\, s(\hat{a}) + b, \hat{\theta})}$$

1D … 1.0(3.8) for 68%(95%)
2D … 2.3(6.0) for 68%(95%)

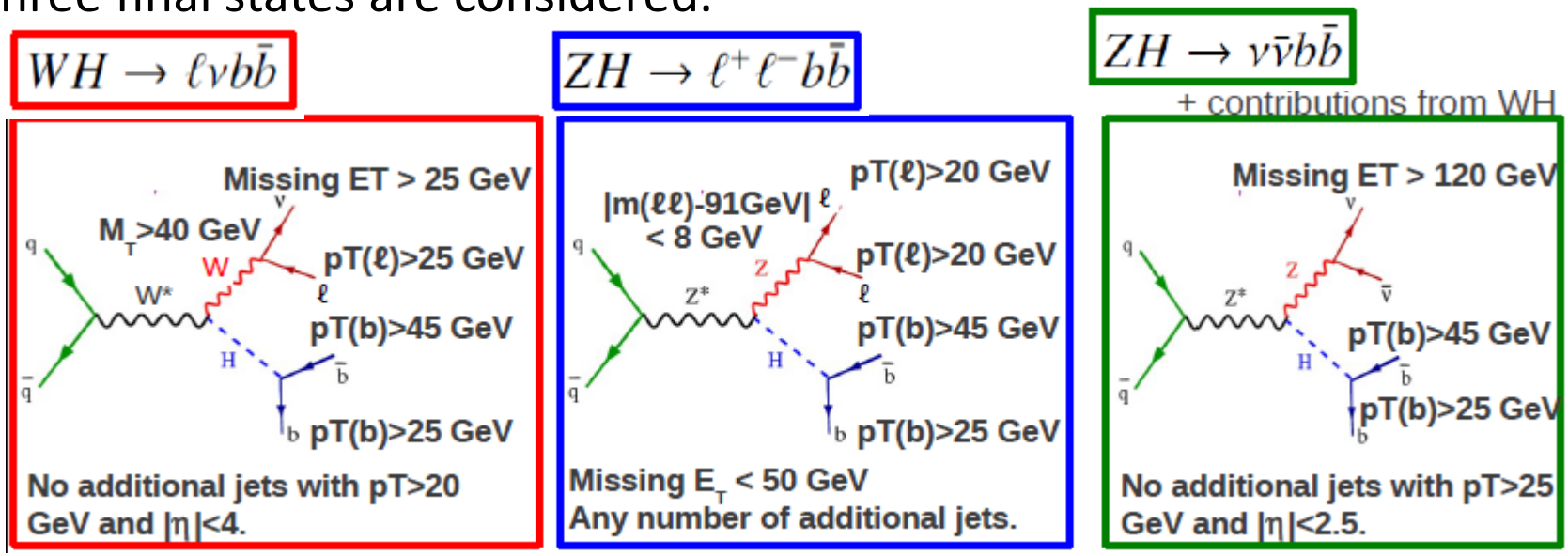
Discovery significance break down





Event selection & Analysis

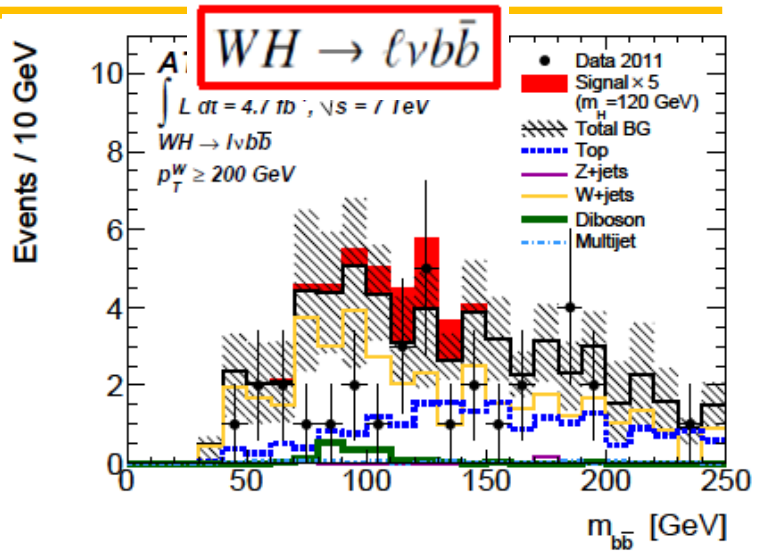
- Three final states are considered.

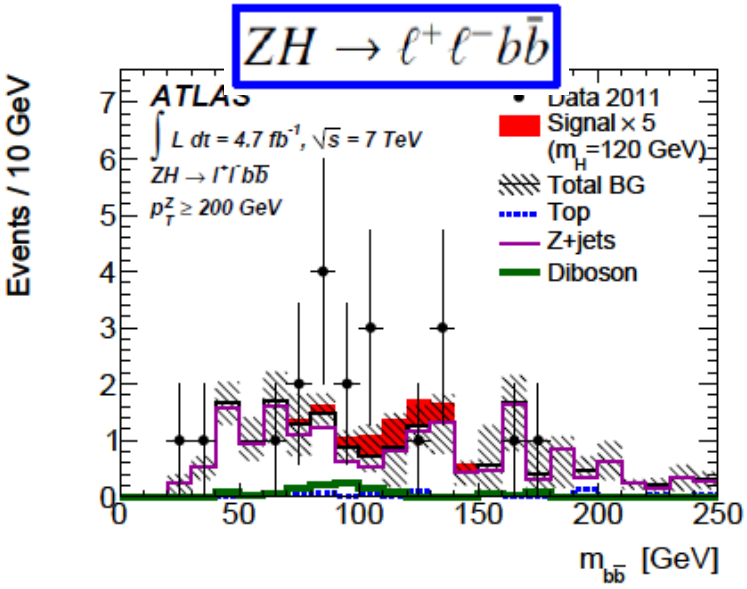


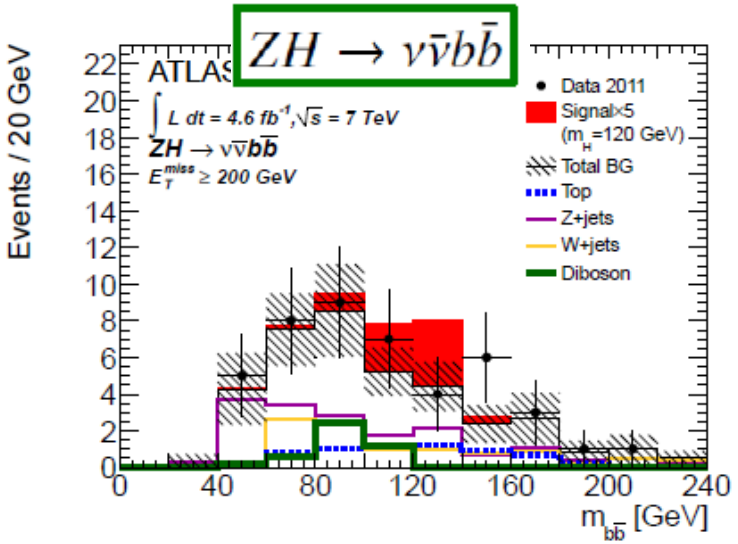
- Boosted event :
  - Require High momentum vector boson(p_T^V) was used to enhance S/N ratio.
- ATLAS : Cut based analysis. 4(3) p_T^V bins for lvbb,llbb (vvbb)
  - mbb for the final discriminant.
- CMS : Multivariate(BDT) analysis with 2 p_T^V bins.
  - BDT score for the final discriminant.

Result : ATLAS 7TeV($5fb^{-1}$)

- Used mass of the two b quark as a discriminant.
- Showed highest p_T^V categories for each final state.

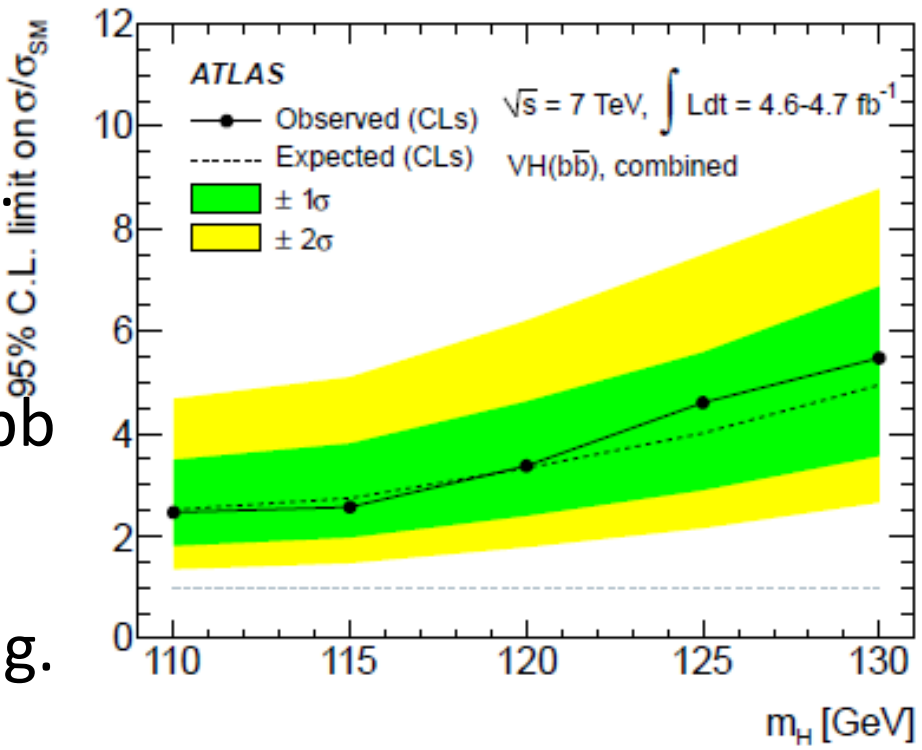


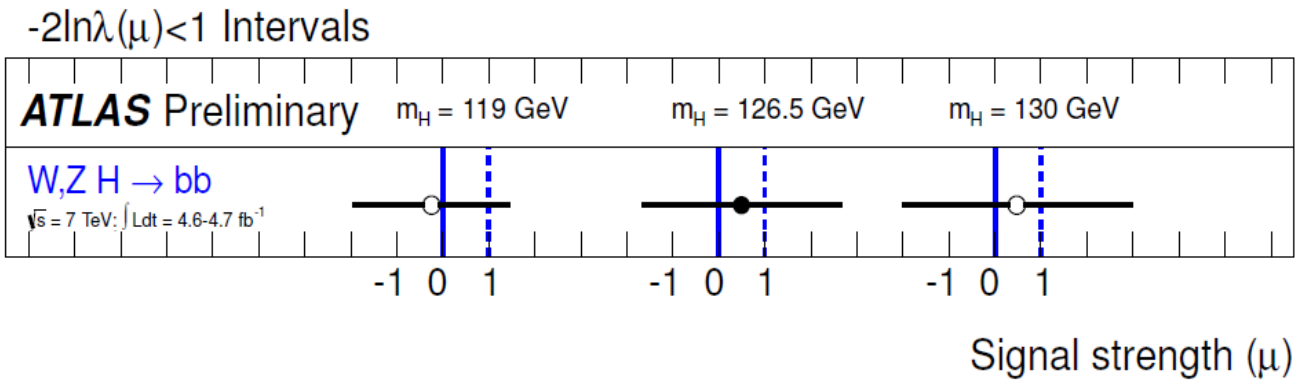




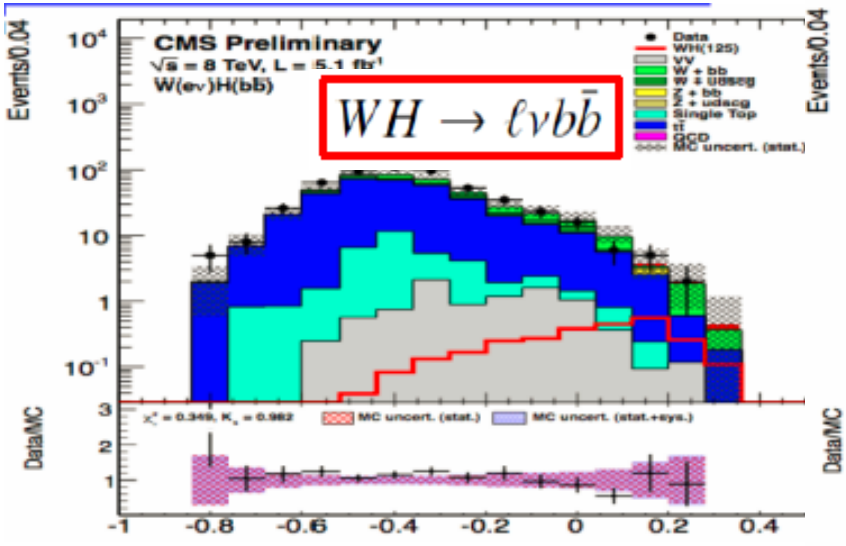
Result : ATLAS 7TeV(5fb^{-1})

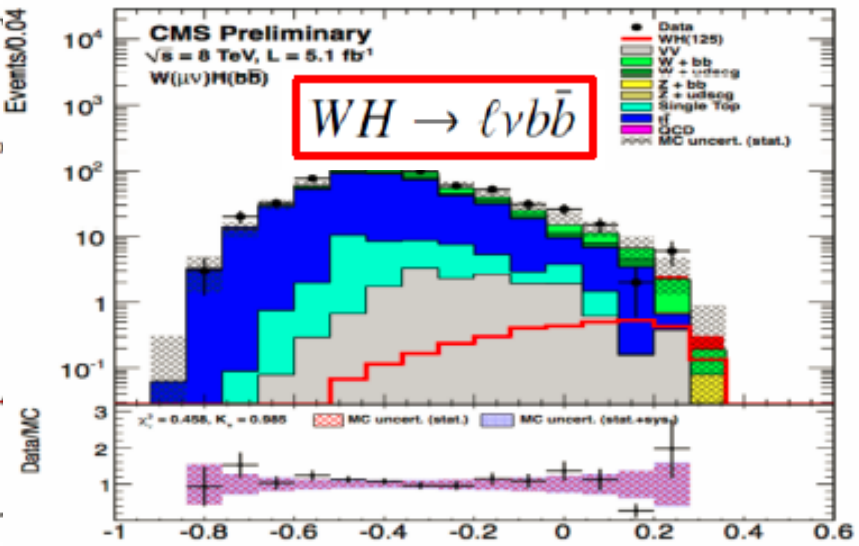
- No significant excess beyond background was observed.
- Set 95% CL upper limit on xsec.
  - Expected : 2.5-5 x SM
  - **Observed : 4.6 xSM @ 125GeV**
- Most sensitive channels are lvbb and vvbb
- 2012 analyses with improvements are now ongoing.

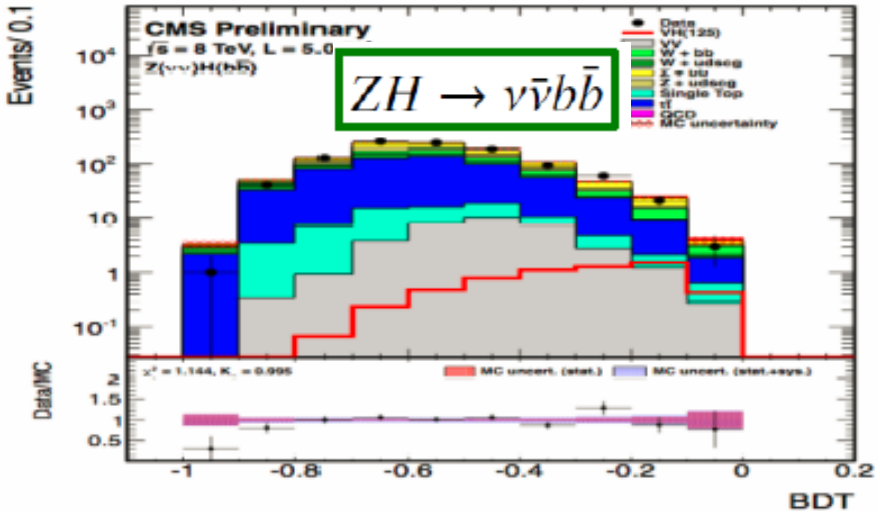


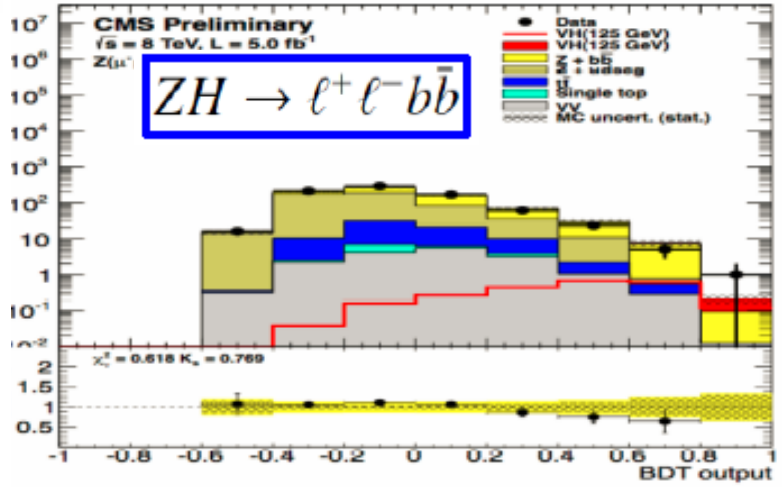


Result : CMS 7TeV($5fb^{-1}$)+8TeV($5.1fb^{-1}$)

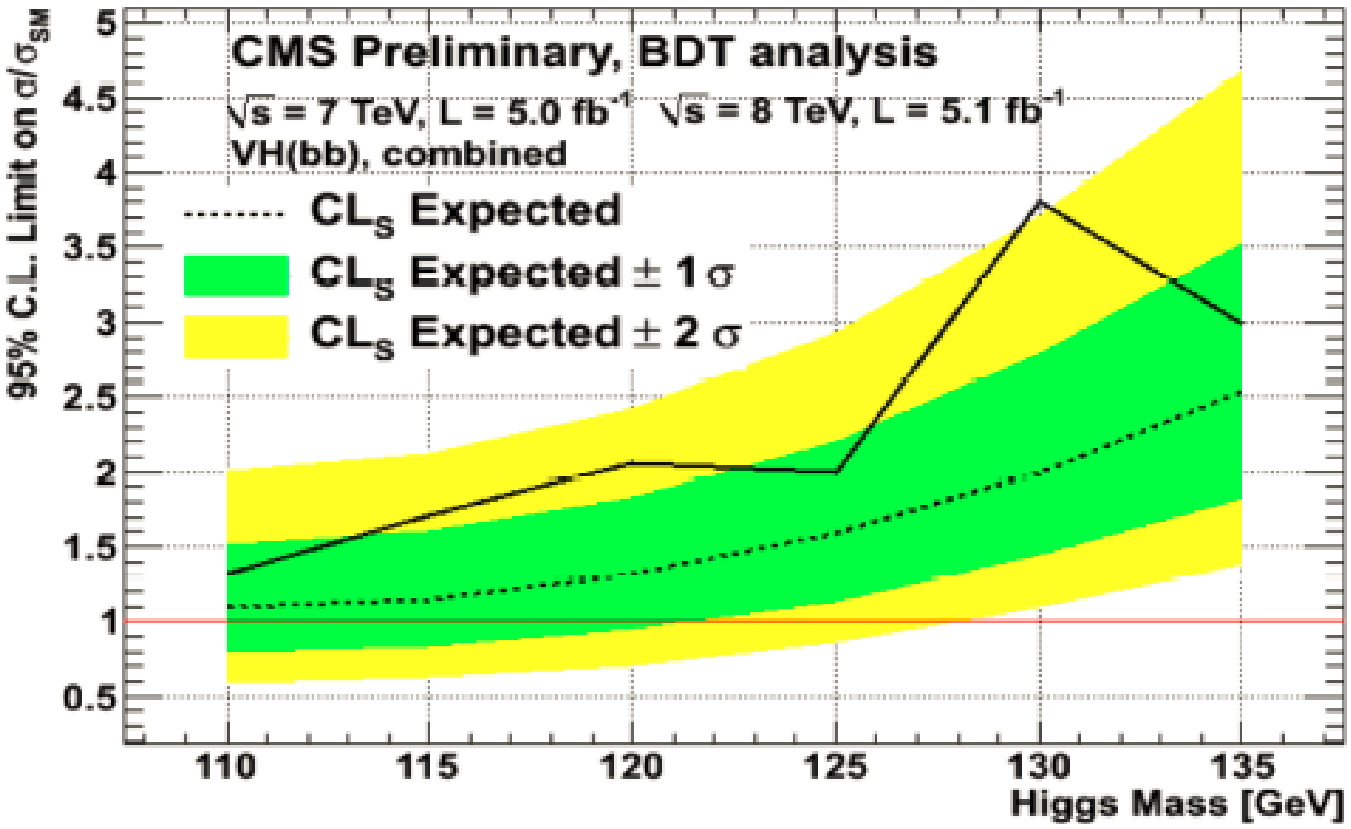








Result : CMS 7TeV(5fb^{-1})+8TeV(5.1fb^{-1})

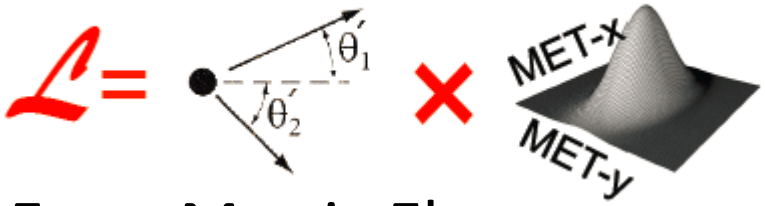


- Almost reached to the SM xsec at mH<115GeV
  - Expected limits are ~1.1xSM
- **Observed(Expected) limits @125GeV are 2(1.6)xSM**

Mass reconstruction

Event by Event estimator of true di-τ mass likelihood.
Full reconstruction of event kinematics.

SV fit



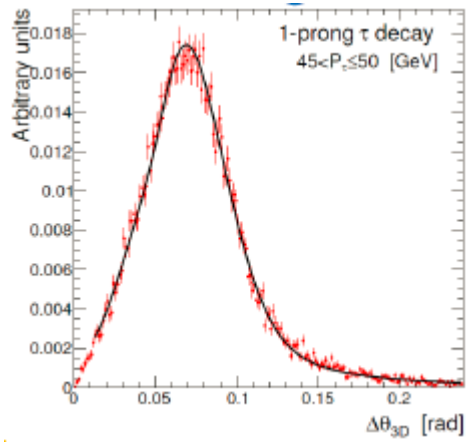
- Exact Matrix Element used for τ→lνν
- Phase-Space is used for τ→π
- Mass peaks at true value
- Better separation between H and Z.

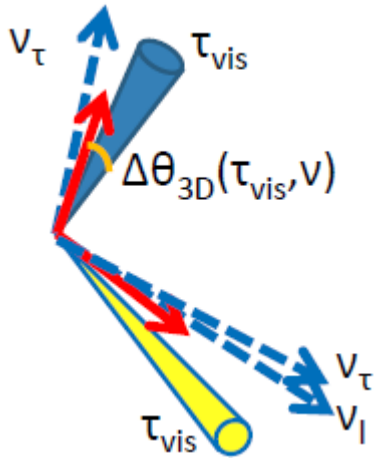
CMS

ATLAS

Missing Mass Calculator(MMC)

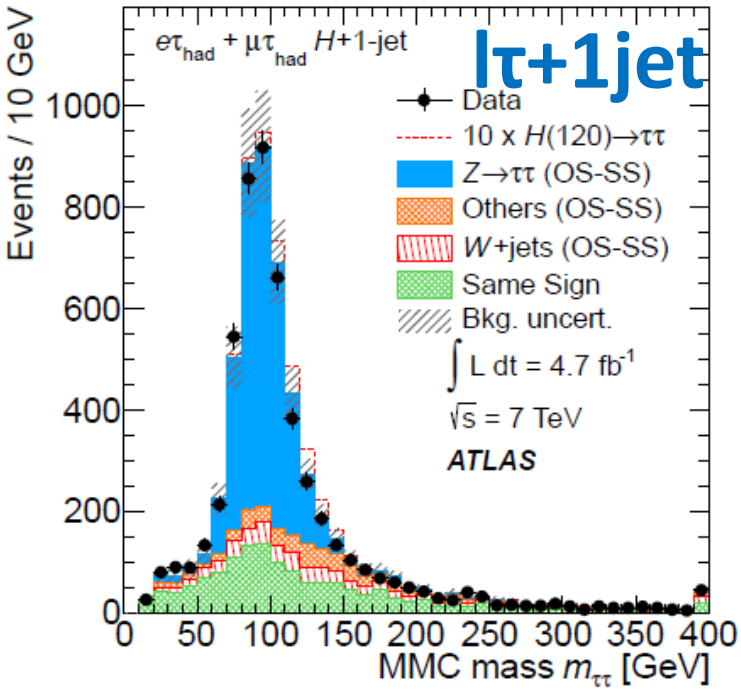
- Solve τ, E_T^{miss} in $\Delta\phi(\tau_{vis},\nu)$ parameter space using $\Delta\theta_{3D}(\tau_{vis},\nu)$ template from simulation as PDF.

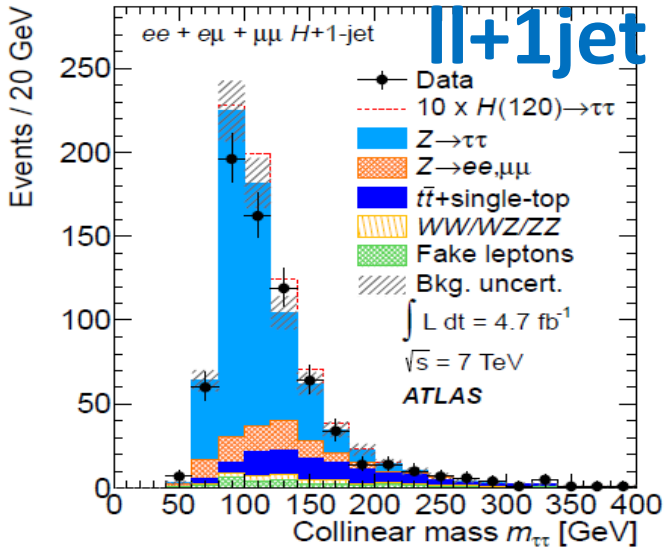


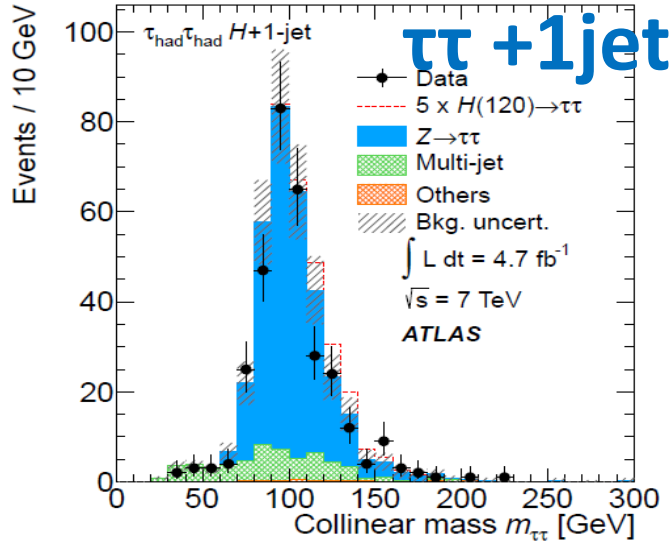


Result : ATLAS 7TeV(4.7fb^{-1})

- 1 jet category.
  - dominated by ggF process.
- Boost Higgs events are selected (hadhad)
  - Non negligible VBF contribution (1/3)

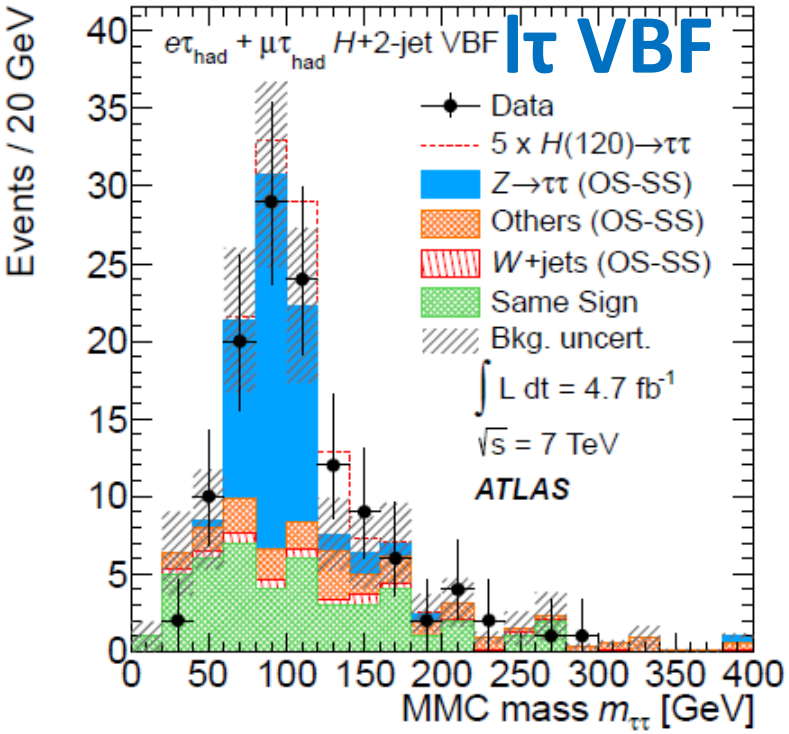


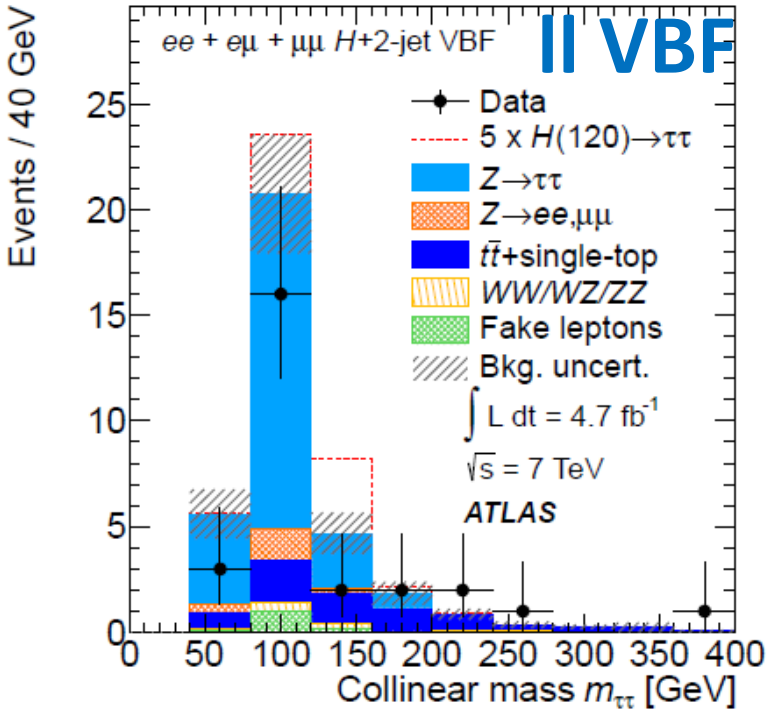




Result : ATLAS 7TeV($4.7fb^{-1}$)

- VBF category
  - High pt forward jets with large m_{jj} and $\Delta\eta_{jj}$.





(d) H +2-jet VBF

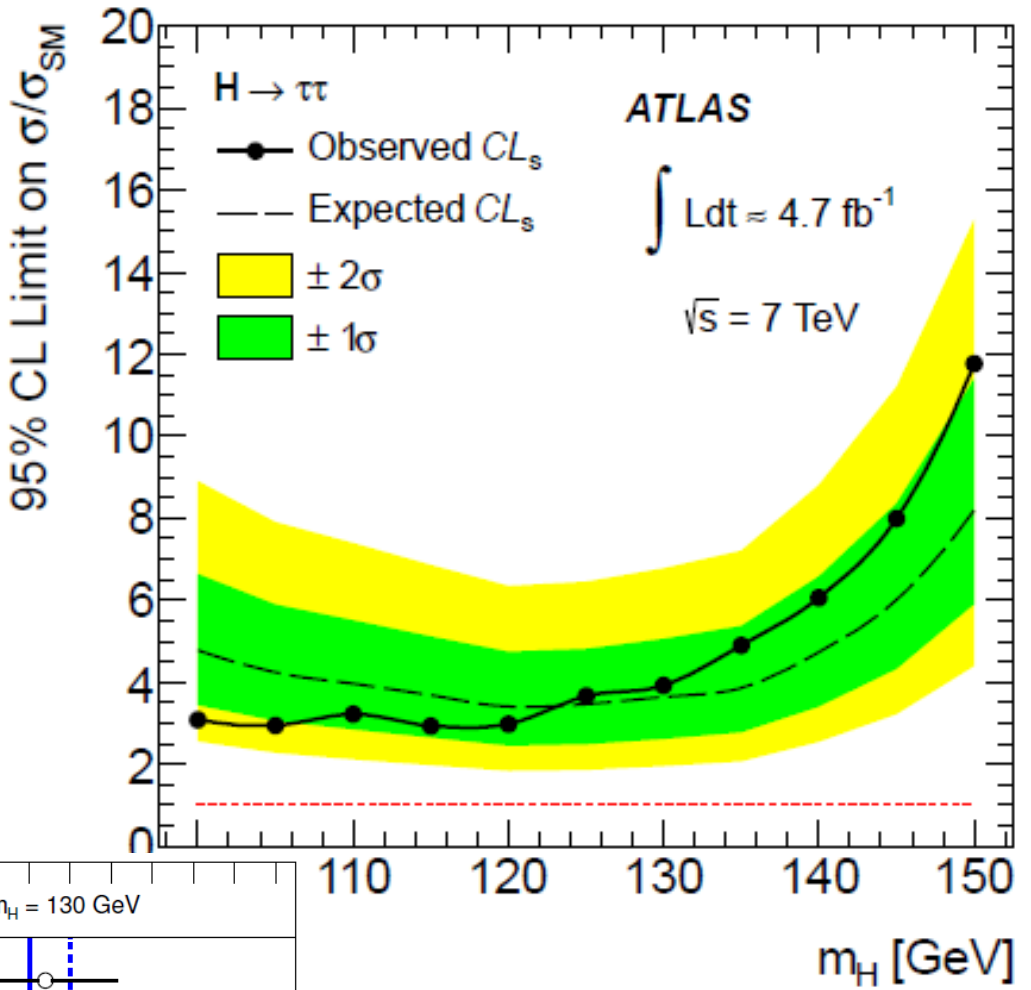
Result : ATLAS 7TeV($4.7fb^{-1}$)

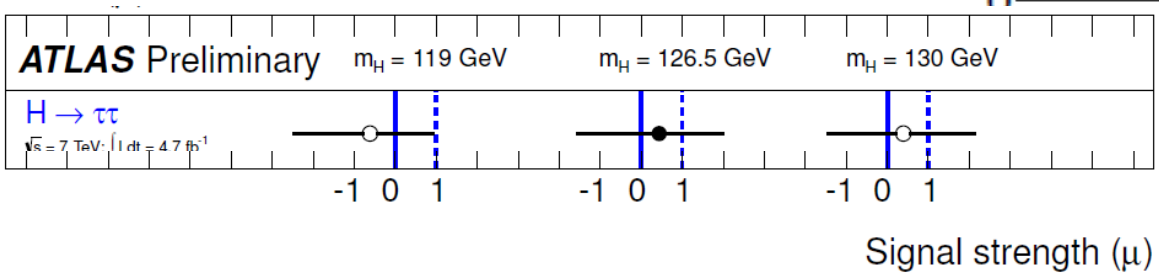
Combination of three channels

Observed limit : 2.8-12.1

Expected limit : 3.4-8.0

@ 100-150GeV Higgs mass

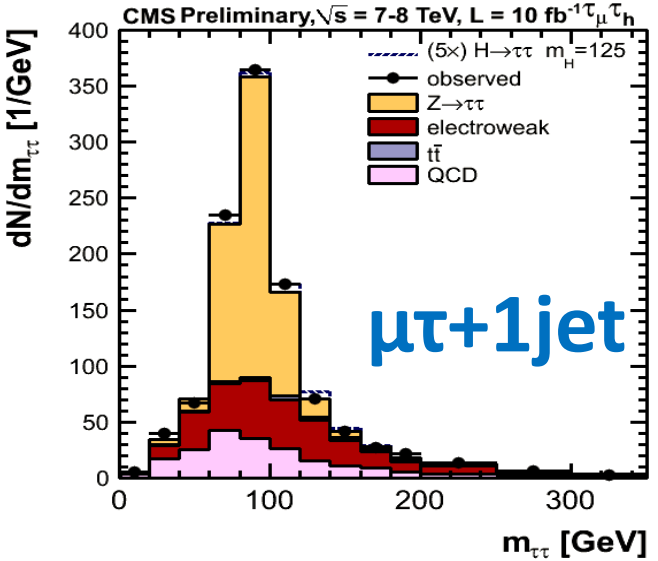


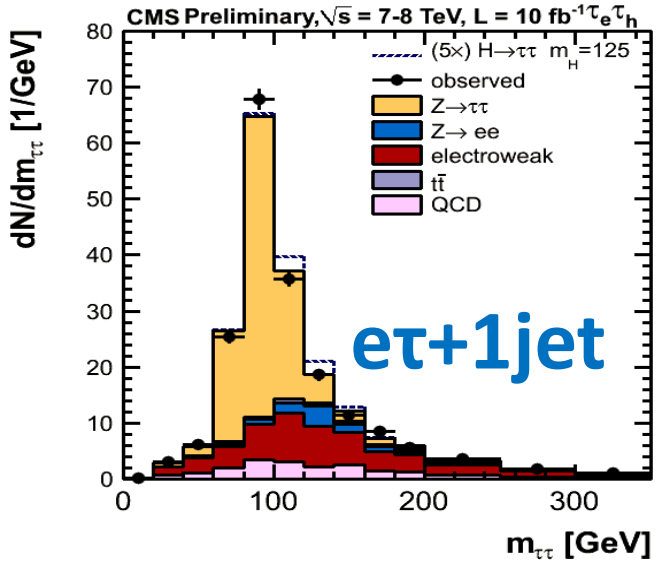


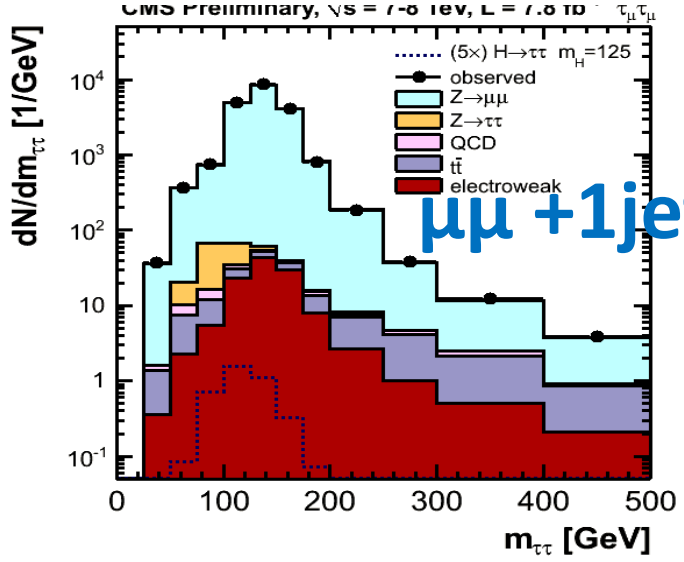
Result : CMS 7TeV(4.9fb^{-1})+8TeV(5.1fb^{-1})

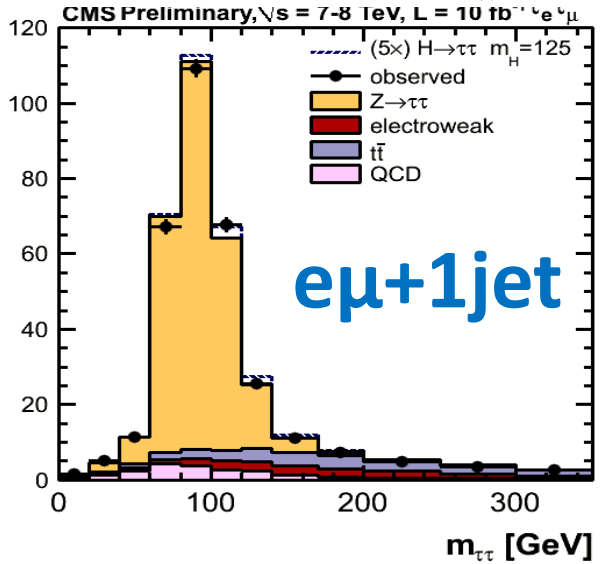
- 1jet category

- Enhances ggF production.
- Splitted to High/Low pT events.
- High pt events have better mass resolution.





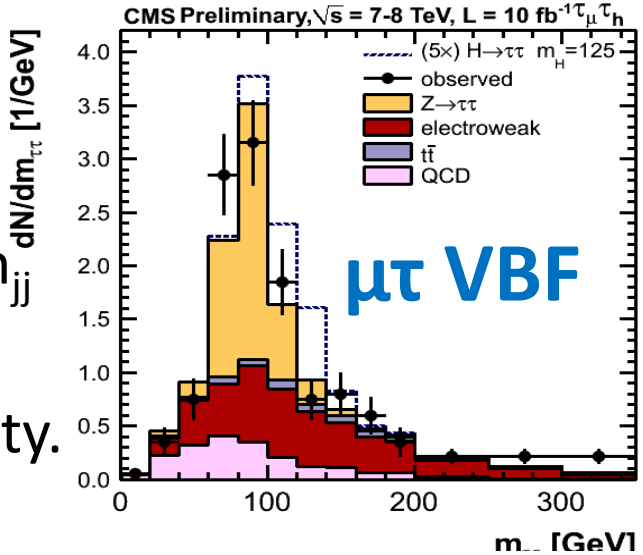


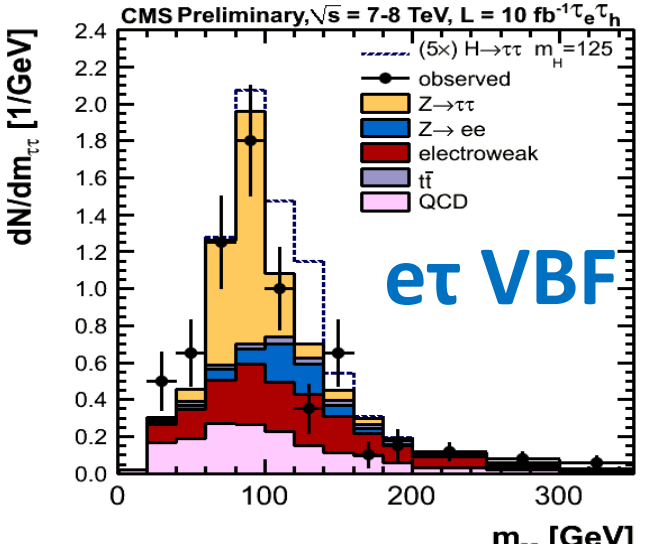


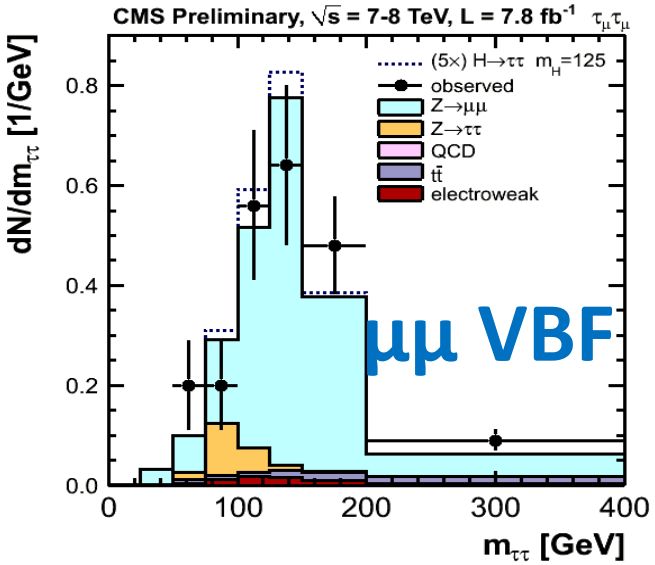
Result : CMS 7TeV(4.9fb^{-1})+8TeV(5.1fb^{-1})

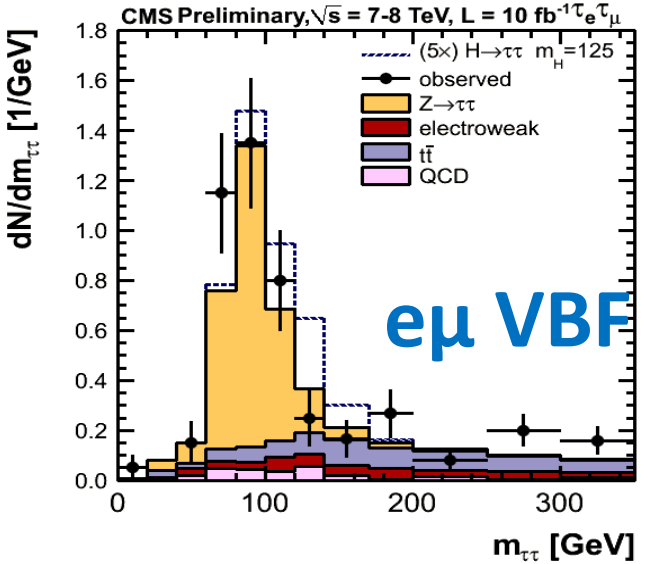
- VBF category
  - High pt forward jets with large m_{jj} and $\Delta\eta_{jj}$.
  - Highest sensitivity.

  (mH<130GeV)

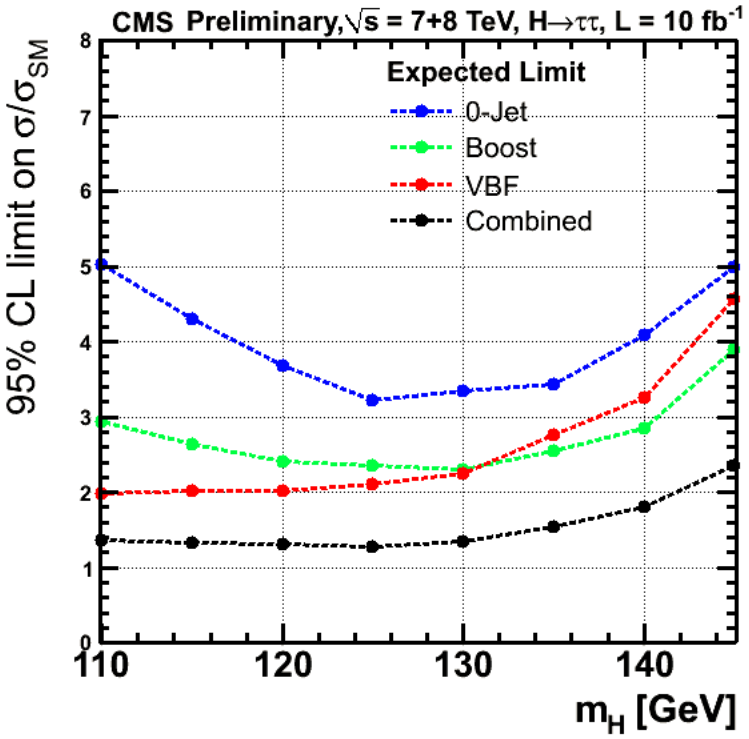


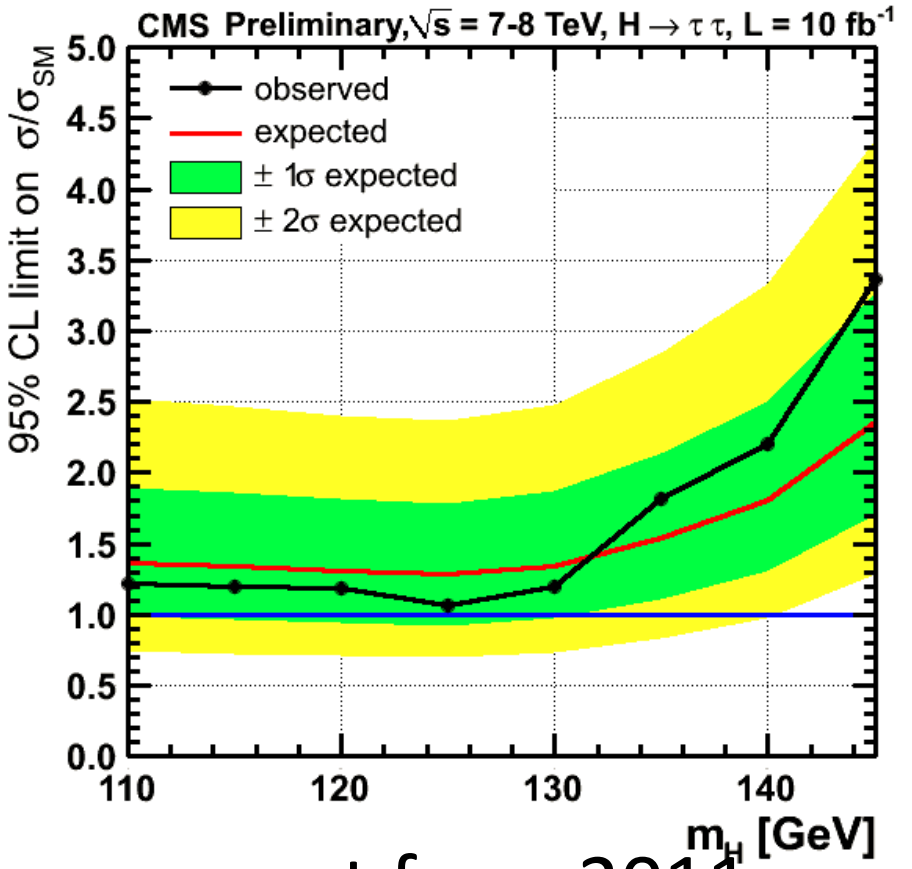






Result : CMS 7TeV(4.9fb^{-1})+8TeV(5.1fb^{-1})

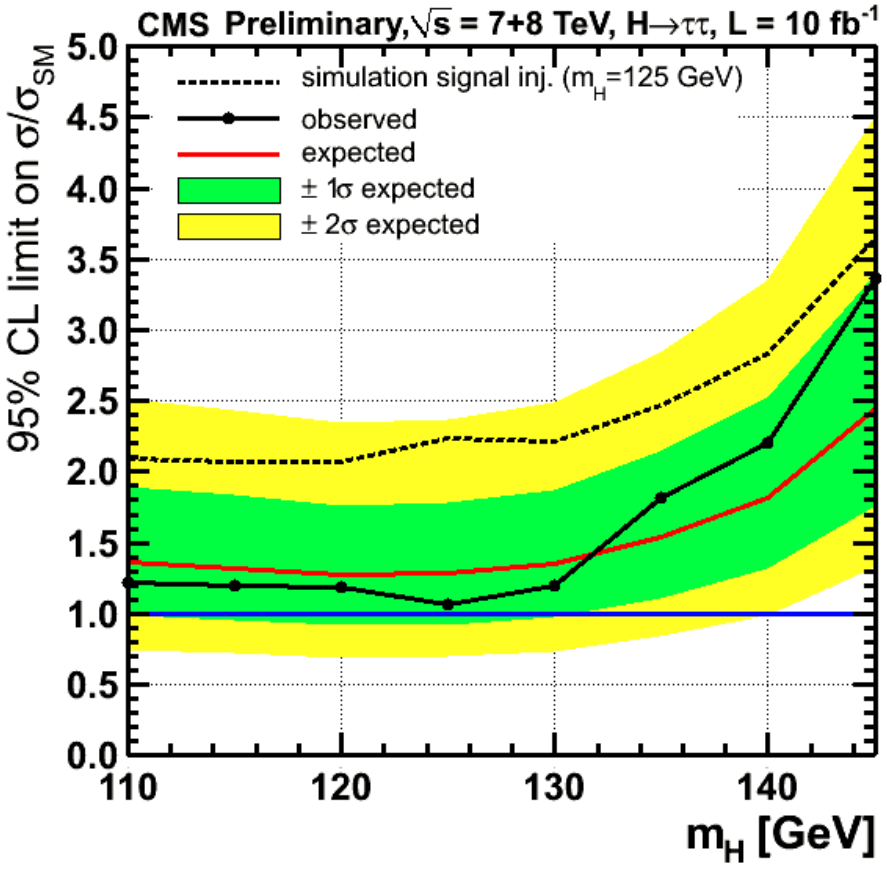


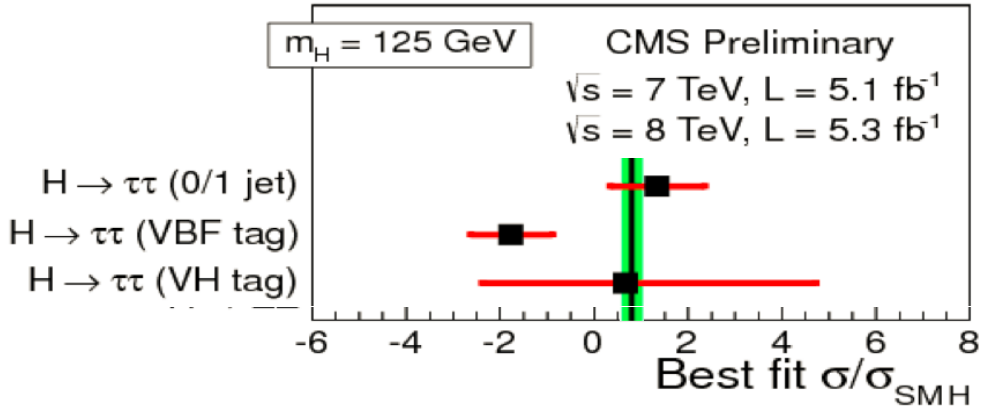


- Analysis improved. 2x improvement from 2011.
- Observed(Expected) limit is 1.06(1.3)xSM!

Result : CMS 7TeV(4.9fb^{-1})+8TeV(5.1fb^{-1})

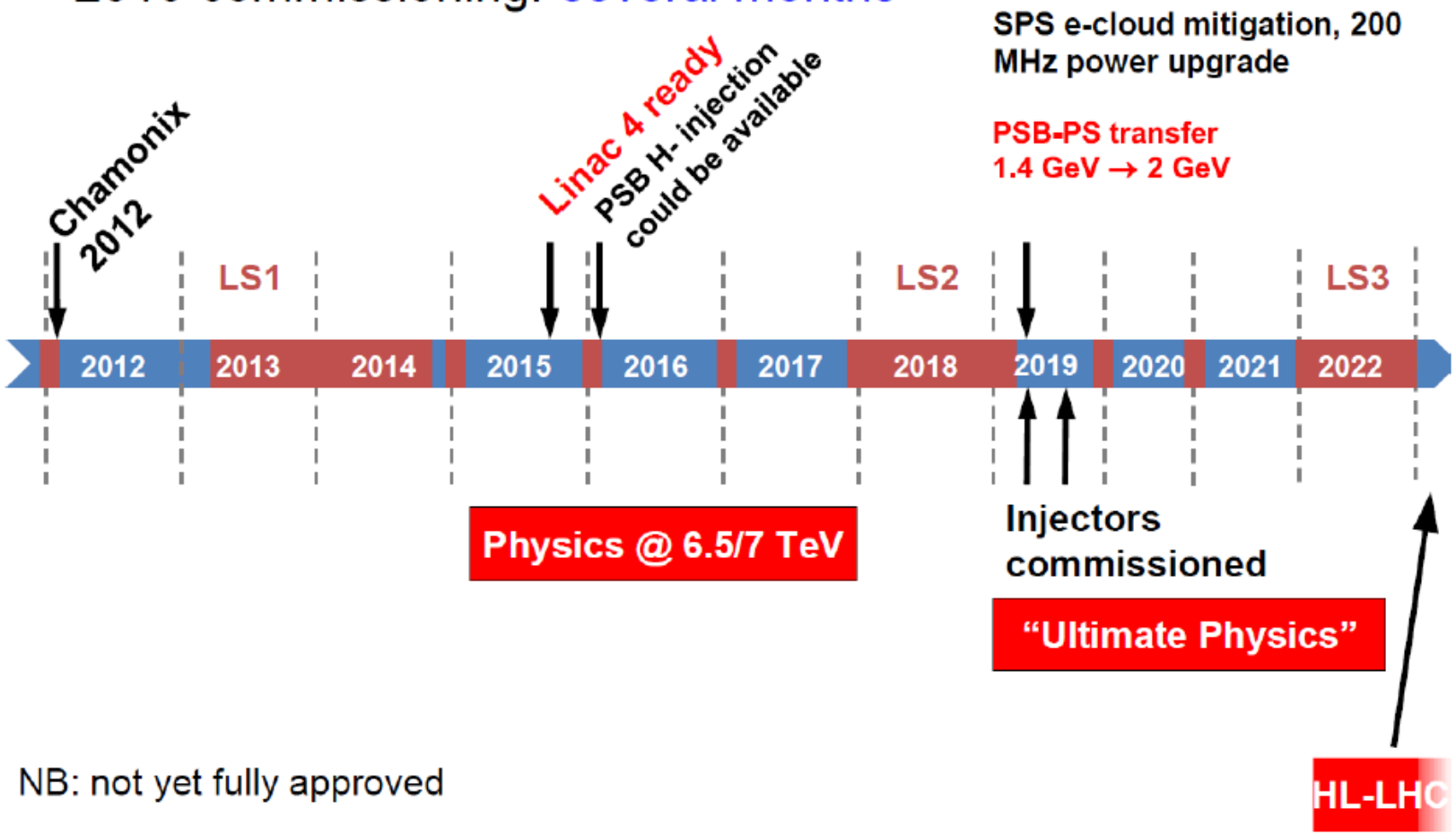
- **Is this happened even if SM Signal exist?**
- Made limit plot by injecting SM signal
- Signal cross section best fit value :
  - ggF dominant category : consistent to SM prediction.
  - VBF category : downward fluctuation. In consistent to SM prediction.





Schedule for coming 10 years

- Length of LS2: minimum 12months
- 2019 commissioning: several months



NB: not yet fully approved