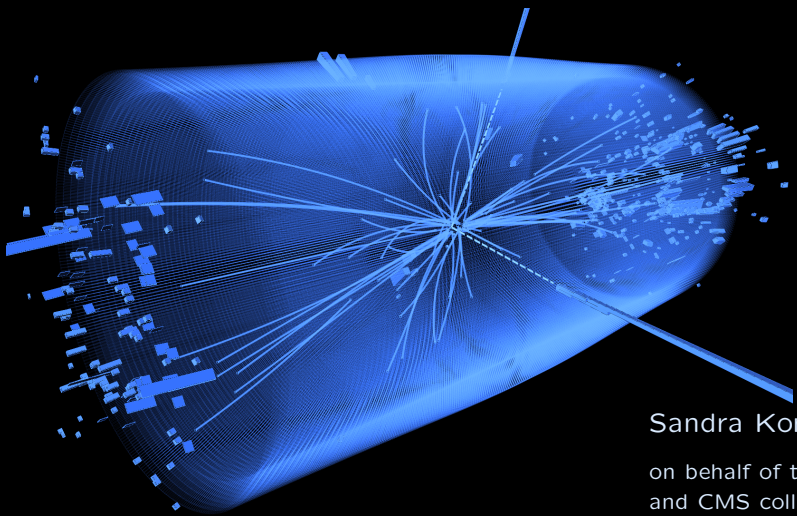
Status and latest results from the LHC

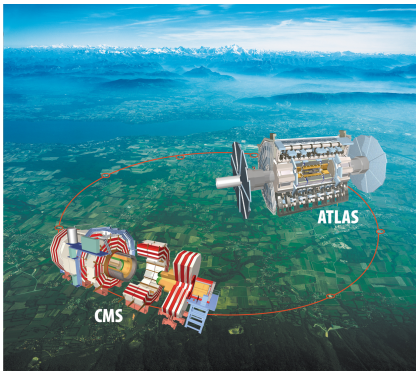


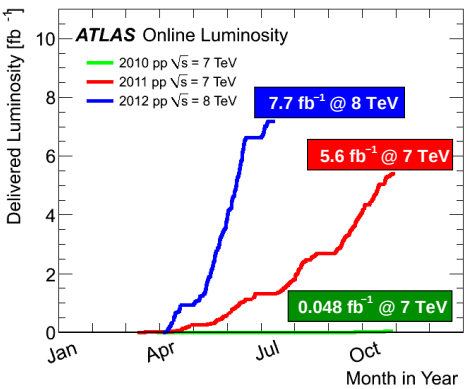
Sandra Kortner

on behalf of the ATLAS
and CMS collaborations

Strings 2012 • Munich, Germany • July 23^{rd}-28^{th}, 2012

ATLAS and CMS at the Large Hadron Collider

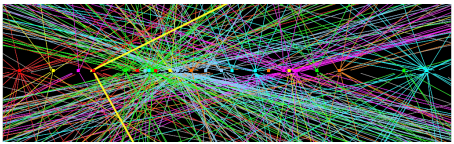




LHC is performing extremely well.
Peak luminosity up to 6.8×10^{33} cm^{-1}s^{-2}.
Expected integrated luminosity by the end of 2012: $\sim$30 fb^{-1}.

More than 90% of delivered *pp* collisions are used in analyses.

High luminosity, but high-pile-up environment:
>20 additional interactions per bunch crossing
(9 interactions on average last year).



Latest physics results

Precision tests of the *Standard Model (SM)*

- Electroweak processes (W, Z, dibosons)
- Top quark physics

Key missing piece: *Search for the SM Higgs boson*

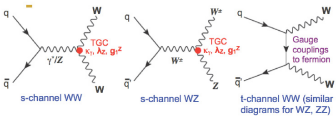
- Observation of a new boson with a mass around 125 GeV

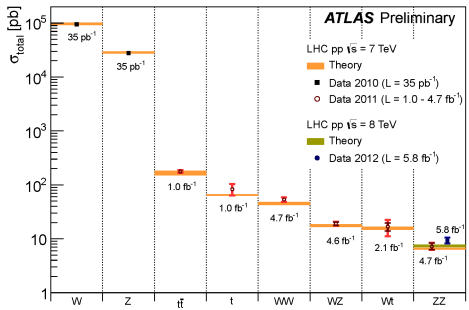
Is there anything *Beyond the Standard Model*?

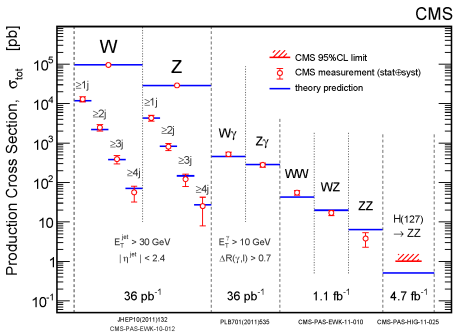
- Supersymmetry
- Exotics: new resonaces, extra dimensions, black holes...

Studies of Electroweak Processes

- Precision tests of the SM & understanding of backgrounds for many searches.
- W, Z: Also serve as candles for the detector calibration.
- *Diboson processes*: Probe for anomalous Triple Gauge Couplings.







All results are consistent with theory predictions. Most recent studies with 2012 data:

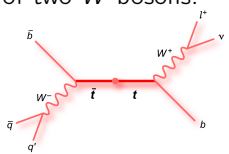
- $\sigma(W)$, $\sigma(Z)$: CMS-PAS-SMP-12-011
- $\sigma(WW)$, $\sigma(ZZ)$: CMS-PAS-SMP-12-013, CMS-PAS-SMP-12-014, ATLAS-CONF-2012-090

Top Quark Production

- LHC is a *top quark* factory ($t\bar{t}$ @ 7 TeV: 85% gluon fusion, 15% $q\bar{q}$ annihilation).
- Allows for precise measurements of important SM parameters: m_{top}, V_{tb}.

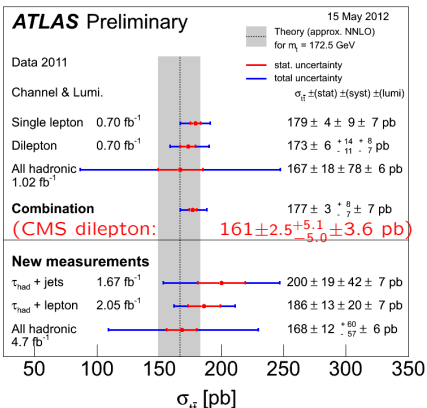
$t\bar{t}$ cross section measurements at 7 TeV:

Several signatures, defined by the decay products of two W bosons.

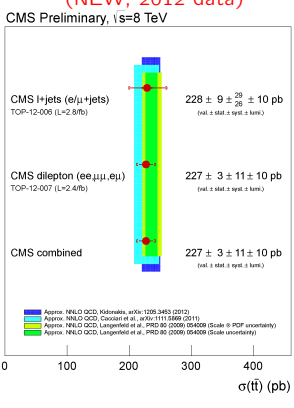


ATLAS unc.:± 7%

CMS unc.:± 4%



(NEW, 2012 data)

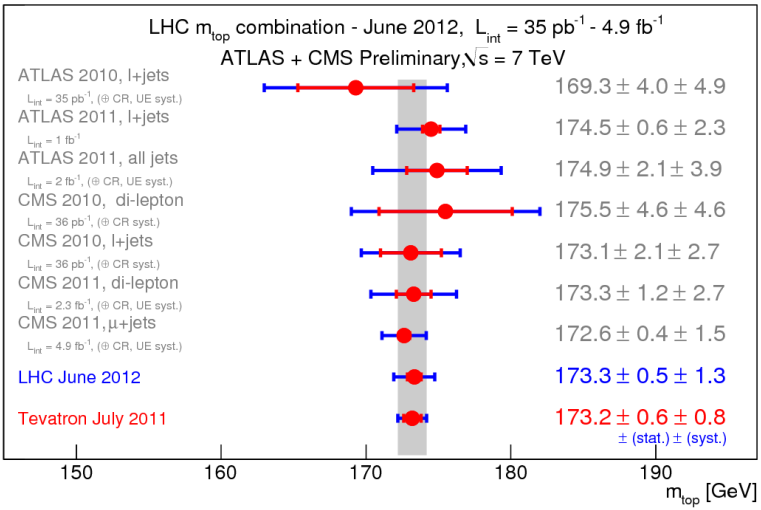


Current precision is challenging the NNLO QCD predictions.

single top cross section (uncertainties larger than the theory prediction):

Measured in t-channel, evidence for Wt channel, 95% CL upper limit in s-channel.

Top Quark Mass Measurement

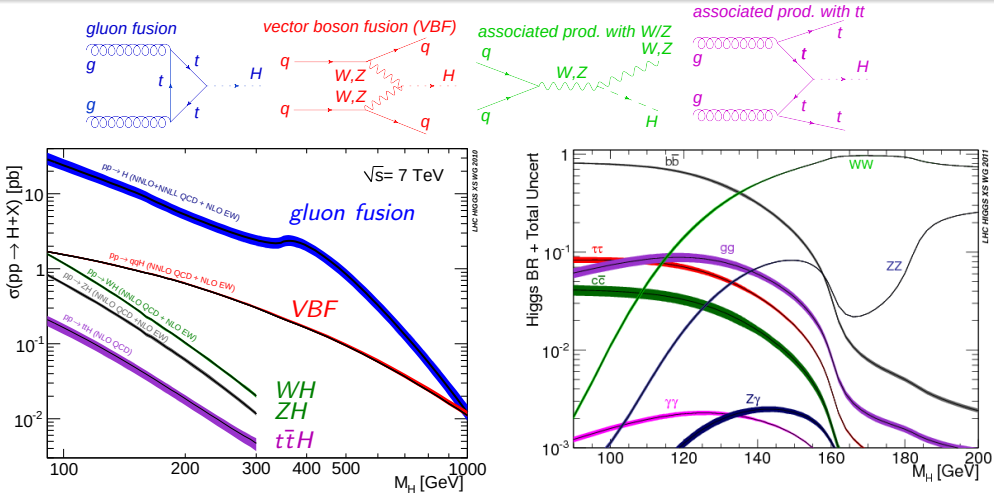


Measurement is dominated by the systematic uncertainty (b-jet energy scale, theory/generator dependence).

Uncertainty at the moment 30% larger than Tevatron.

Higgs search update (CERN seminar, July 4^{th})

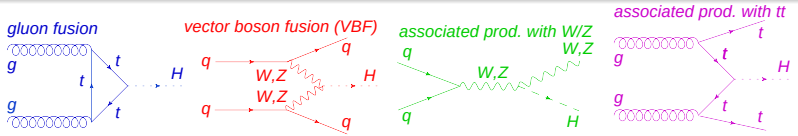
Search for the SM Higgs boson

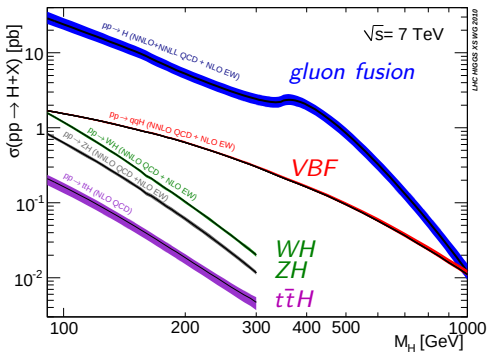


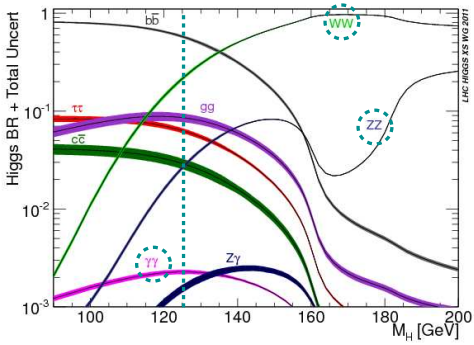
- Concentrating on three most sensitive channels in the low mass region: $H \to ZZ^{(*)} \to 4\ell$, $H \to \gamma\gamma$, $H \to WW^{(*)} \to \ell\nu\ell\nu$.
- Combined results include many other search channels: $H \to b\bar{b}$, $H \to \tau\tau$, $H \to ZZ \to (\ell\ell\nu\nu, \ell\ell qq)$, $H \to WW \to \ell\nu qq$.

  ATLAS-CONF-2012-093, CMS-PAS-HIG-12-020

Search for the SM Higgs boson







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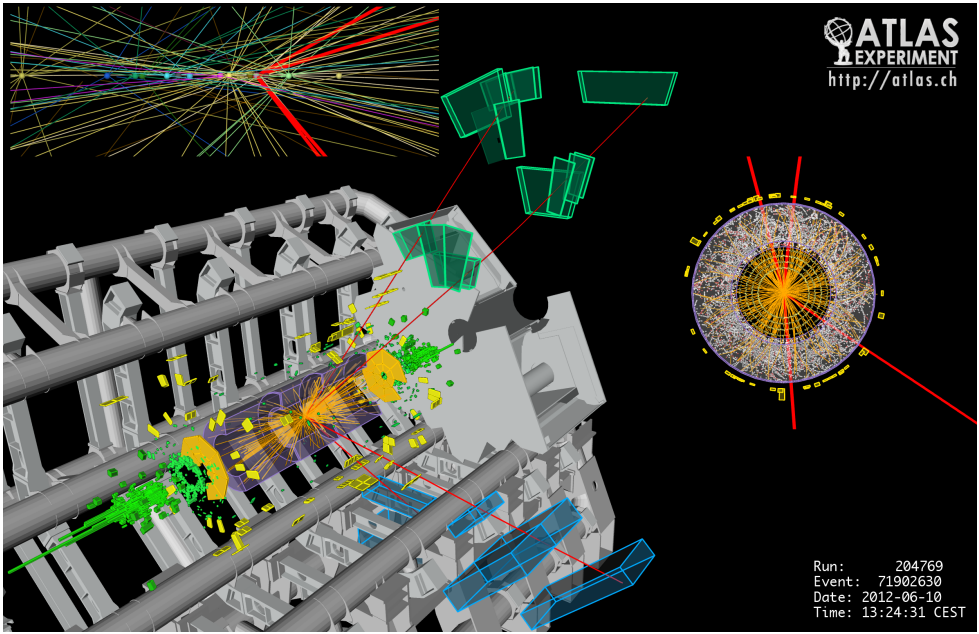
  ATLAS-CONF-2012-093, CMS-PAS-HIG-12-020

$H \to ZZ^{(*)} \to 4\ell$

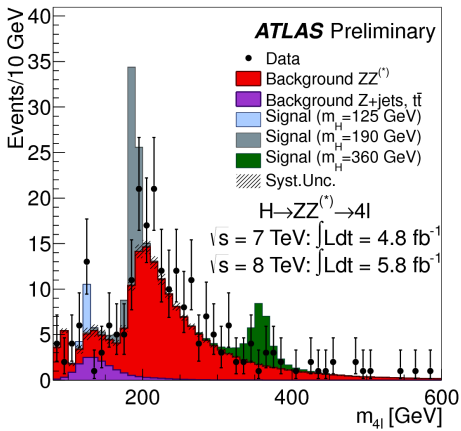


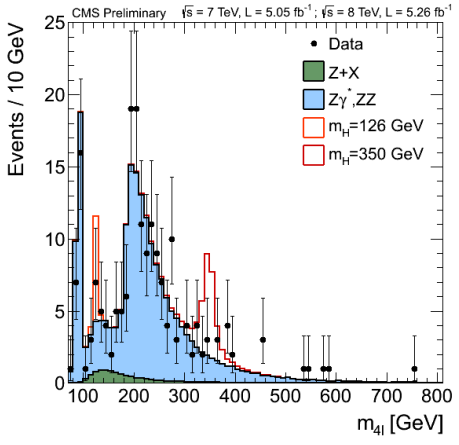
$H \to ZZ^{(*)} \to 4\ell$: The Golden Channel

- Very clean signature.
- High lepton reconstruction efficiency crucial, leptons down to very low p_T (5-7 GeV).
- High lepton energy/momentum resolution (1-2%) allows for a narrow signal peak.

Event selection

- Separation into lepton flavour categories, isolated leptons, small impact parameter.
- Two leptons with mass $m_{\ell\ell} \approx m_Z$, other two with $m_{\ell\ell} > m_{cut}$.
- CMS: additional discrimination by combining several angular variables into likelihood.





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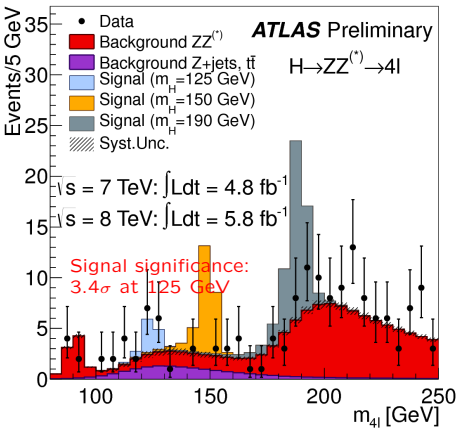
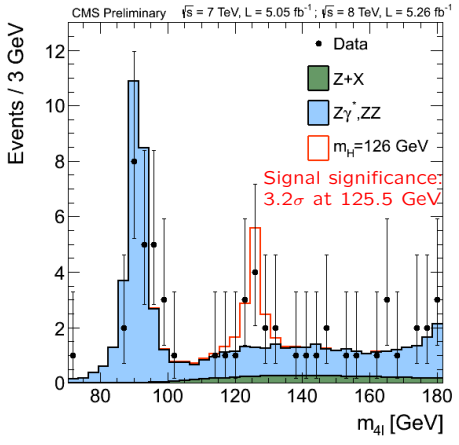
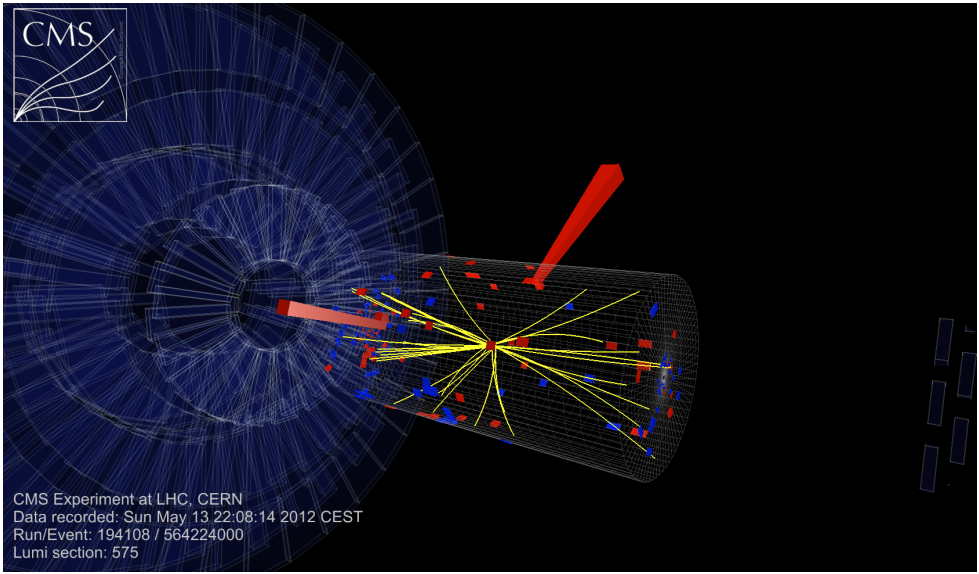




$H \to \gamma\gamma$



$H \to \gamma\gamma$: The Beautiful

Main backgrounds:

Signal, m_H=120 GeV (50 fb)

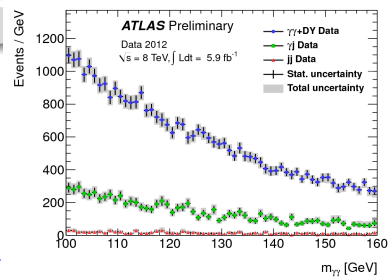
irreducible $\gamma\gamma$ (30×10^3 fb);

reducible γj (200×10^6 fb);

reducible jj (500×10^9 fb).

$\Rightarrow$ powerful γ/jet separation is crucial.

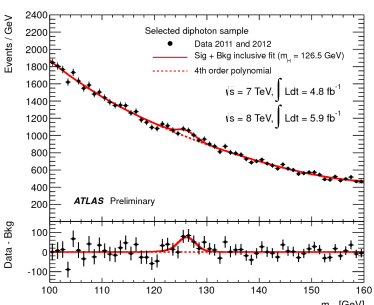
Composition measured from control samples.



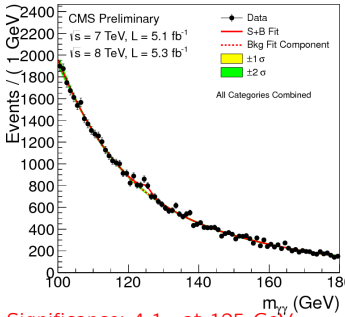
Excellent $m_{\gamma\gamma}$ resolution, 1-2%. Robust against the pile-up.

Events separated in several categories with different $m_{\gamma\gamma}$ resolution.

Background determined directly from the fit to data, separately in each category.

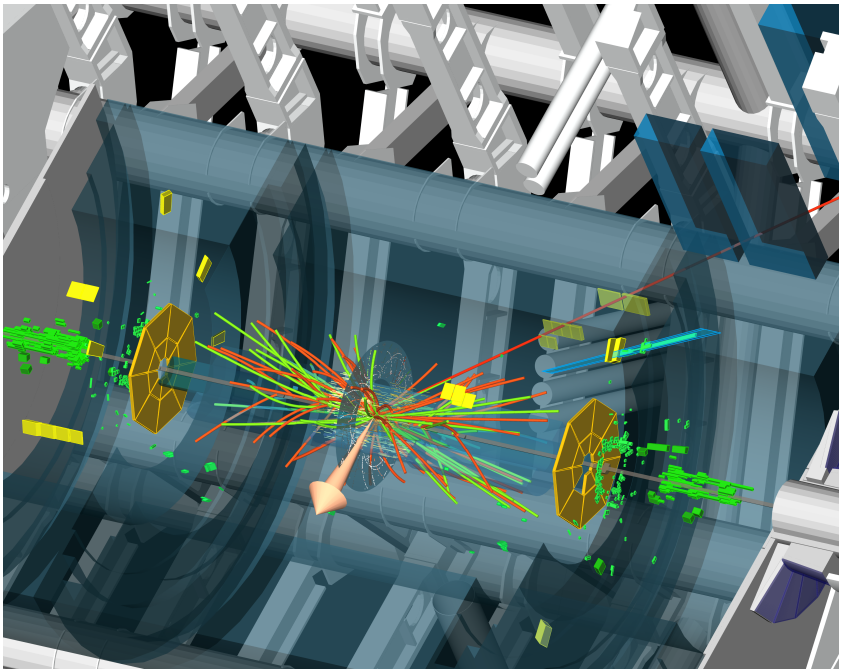


Significance: 4.5σ at 126.5 GeV



Significance: 4.1σ at 125 GeV

$H \to WW^{(*)} \to \ell\nu\ell\nu$

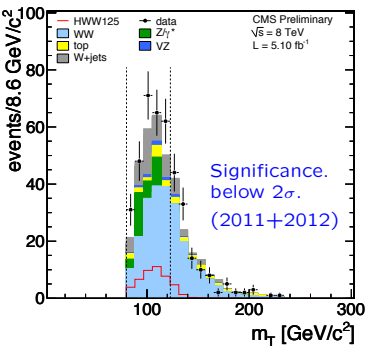


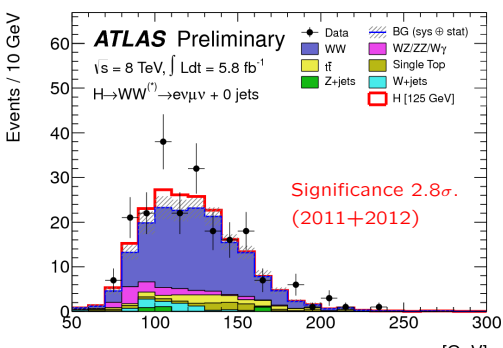
Most sensitive channel in a broad mass range, $m_H \sim$ 120-180 GeV.

No mass reconstruction possible due to $2\nu \Rightarrow m_T = \sqrt{\left(E_T^{\ell\ell} + E_T^{miss}\right)^2 - \left|\vec{p}_T^{\,\ell\ell} + \vec{p}_T^{\,miss}\right|^2}$

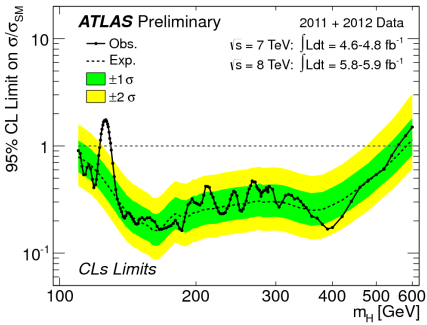
Selection criteria	Background suppression
e^+e^-, $\mu^+\mu^-$, $e^\pm\mu^\mp$ ($p_T >$ 20,10 GeV)	$W + jets$, QCD
Large missing transverse energy (E_T^{miss}); Z veto	Drell-Yan, $Z + jets$
Jet multiplicity categories (0/1/2$_{VBF}$ jets), b-jet veto	$t\bar{t}$
Topological cuts using spin correlations ($m_{\ell\ell}, \Delta\phi_{\ell\ell}$)	WW

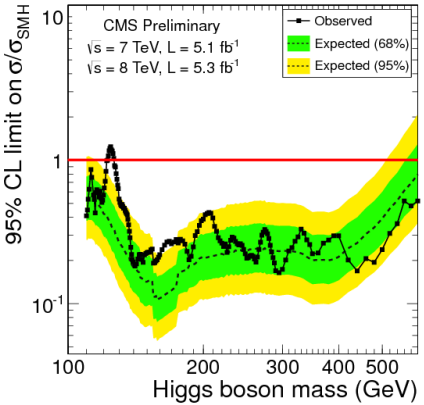
Remaining background contributions estimated from dedicated control data samples.
WW: reverted cut on $m_{\ell\ell}$. $t\bar{t}$: b-tagged jets. $W + jets$: inverted lepton ID and isolation.





All channels combined: exclusion limits



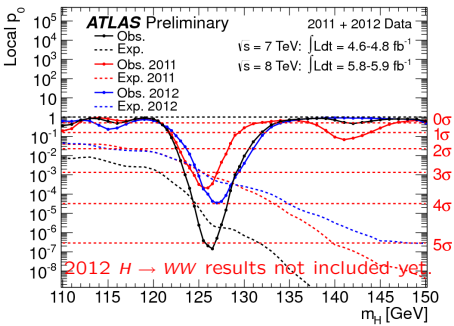


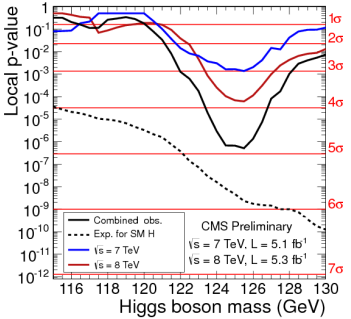
- Expected exclusion: 110-582 GeV.
- Observed exclusion: 110-122.6, 129.7-558 GeV.

- Expected exclusion: 110-600 GeV.
- Observed exclusion: 110-122.5, 127-600 GeV.

Closer look into the region of excess

Probability that the background fluctuation would give the same or higher excess:





Closer look into the region of excess

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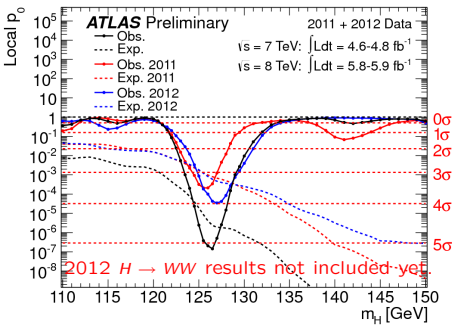
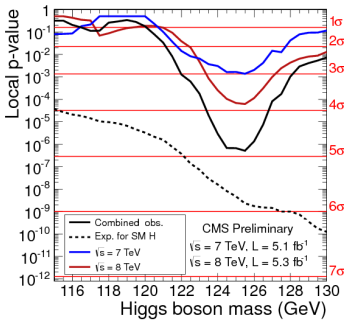




Local significance at 126.5 GeV: 5.0σ

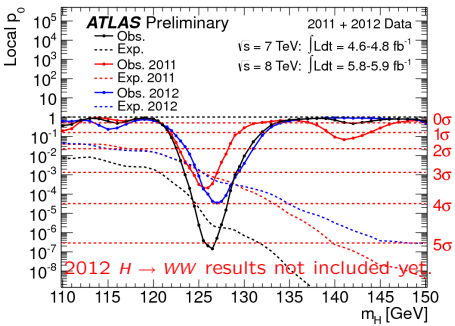
Corresponding global significance: 4.3σ

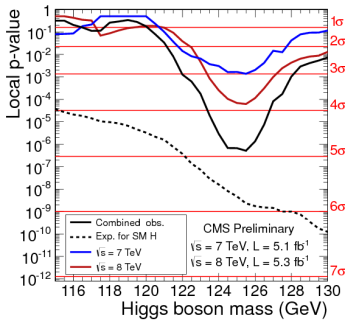
Local significance at 125 GeV: 4.9σ

Corresponding global significance: 4.4σ

Closer look into the region of excess

Probability that the background fluctuation would give the same or higher excess:





Local significance at 126.5 GeV: 5.0σ

Corresponding global significance: 4.3σ

$\sqrt{s} = 7$ TeV: 3.6σ at 126 GeV

$\sqrt{s} = 8$ TeV: 4.0σ at 127 GeV

Local significance at 125 GeV: 4.9σ

Corresponding global significance: 4.4σ

$\sqrt{s} = 7$ TeV: 3.0σ at 125 GeV

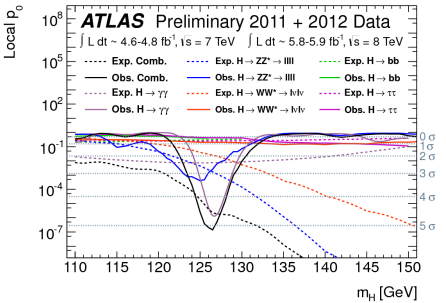
$\sqrt{s} = 8$ TeV: 3.8σ at 125 GeV

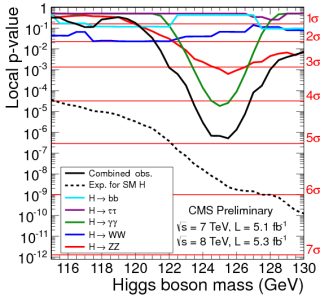
Separate results from 2011 and 2012 data compatible.

In any other mass region, significance is below 1σ.

Closer look (II)

Probability that the background fluctuation would give the same or higher excess:





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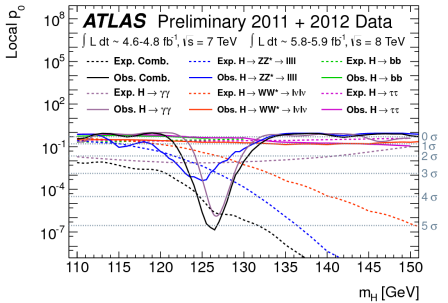
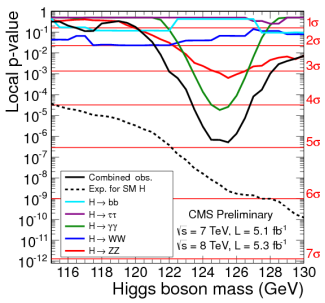
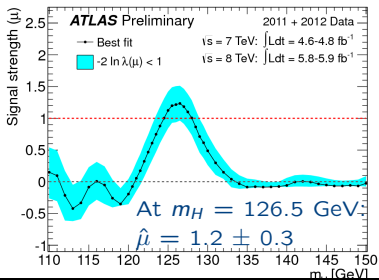
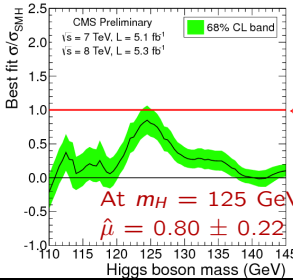




Best-fit signal strength $\mu = \sigma/\sigma_{SM}$:





← SM Higgs expectation

Short interlude



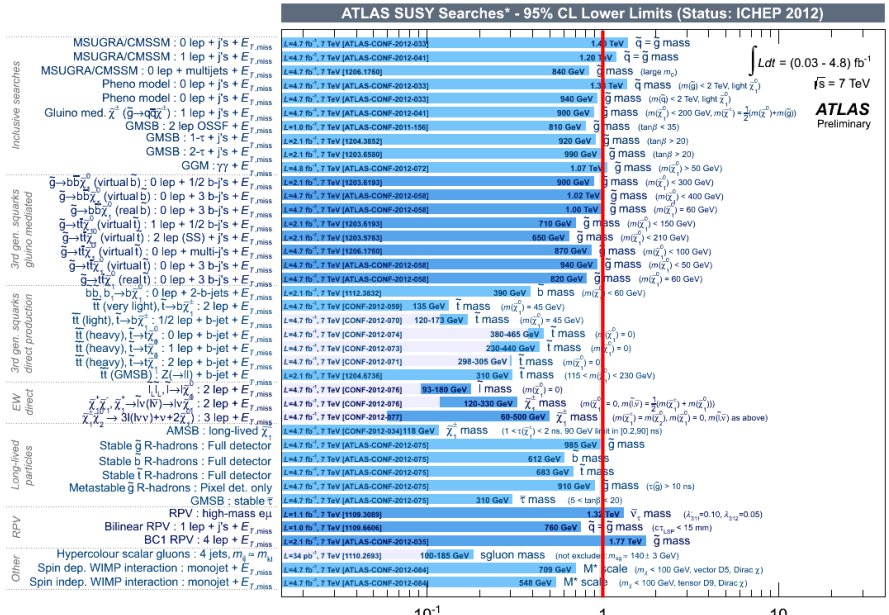
Short interlude



In both ATLAS and CMS we have discovered
a new particle with a mass around 125 GeV,
consistent with the Standard Model Higgs boson.

However, much more data are needed to determine
the exact properties of this particle (mass, spin, CP).

Beyond the Standard Model: SUSY

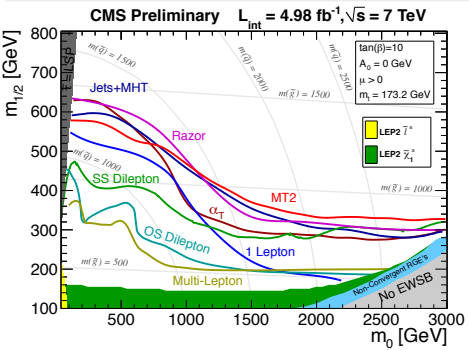


*Only a selection of the available mass limits on new states or phenomena shown

Beyond the Standard Model: SUSY

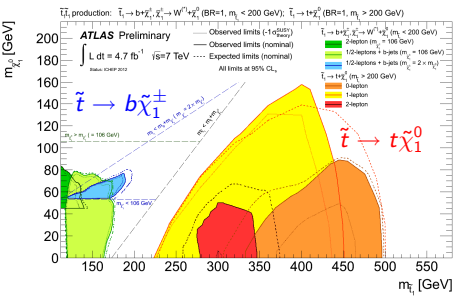
- Numerous channels studied. Limits reach up to 1 TeV.
- No sign of new physics yet. However, interpretations are model-dependent, some plausible ,,natural'' scenarios not ruled out:
  light-stop and R-parity violating scenarios still not fully constrained.

Combined search in CMSSM.
Solid lines represent 95% CL exclusion.



Squarks and gluinos with masses up to ~1.3 TeV (~0.8 TeV) excluded at 95% CL for $m_{squark} \approx m_{gluino}$ ($m_{squark} >> m_{gluino}$).

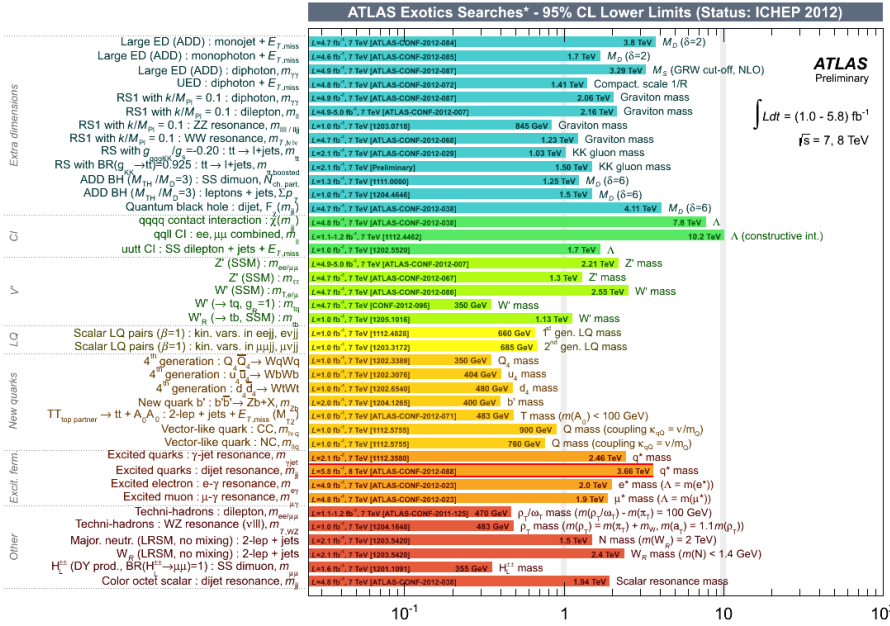
Combined direct search for top-squarks



Small part of the low-m_{stop} parameter space still remains unconstrained.

Latest results with 2012 data:
CMS-PAS-SUS-016 (E_T^{miss} + *b-jets*), CMS-PAS-SUS-017 (*SS dileptons*), CMS-PAS-SUS-018 ($\gamma + E_T^{miss}$)

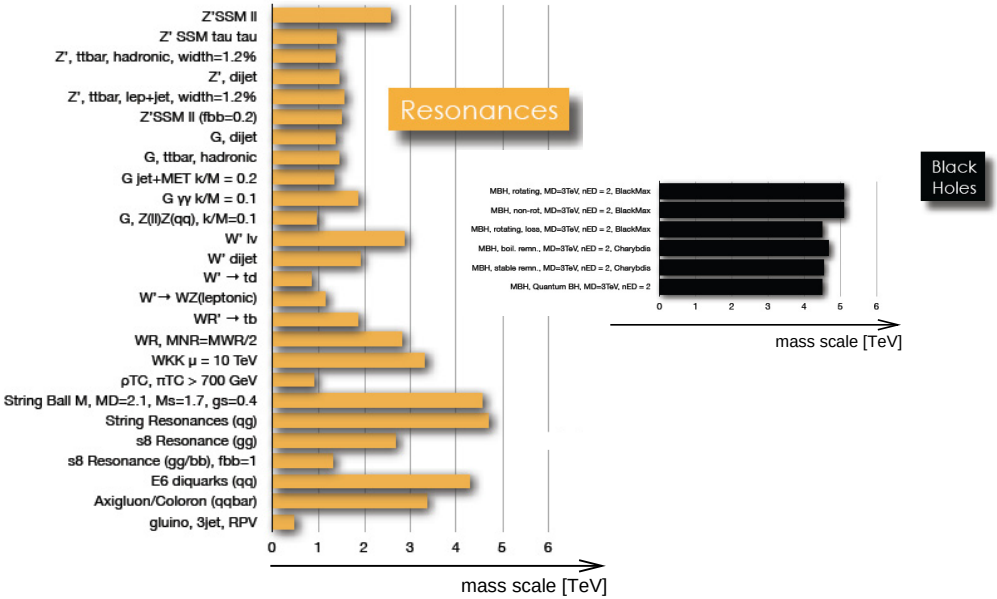
Beyond the Standard Model: Exotics



*Only a selection of the available mass limits on new states or phenomena shown

Beyond the Standard Model: Exotics

- Numerous channels studied. Limits reach up to 2-4 TeV.
- No sign of new physics yet.

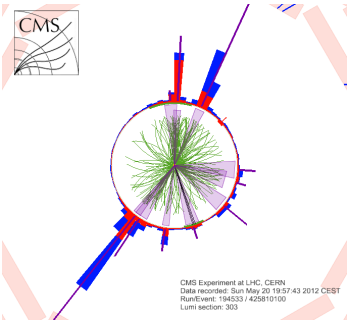


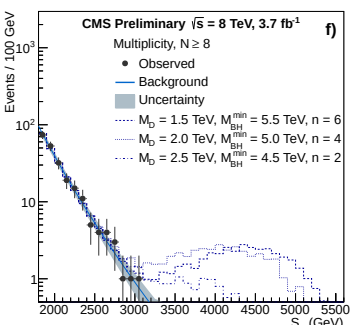
Search for microscopic black holes (2012 data)

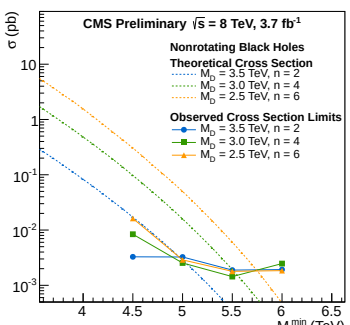
CMS-PAS-EXO-12-009

Typical signal:
large total transverse energy (S_T) from
multiple energetic jets, leptons, and photons.

Candidate black hole event with 10 jets. ⇒

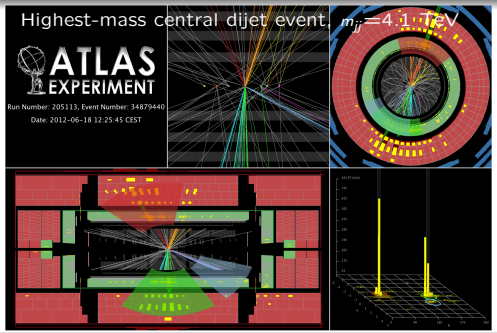


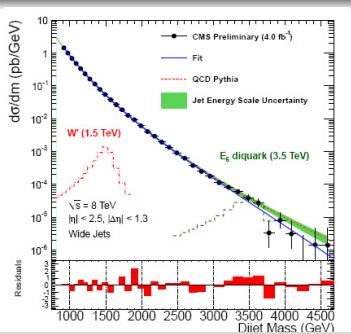




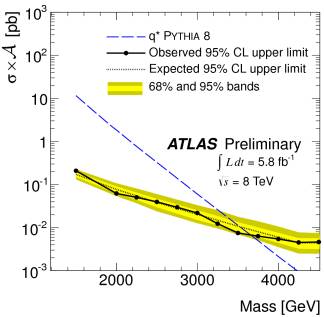
Depending on the model,
black holes with masses up to 4.1 - 6.1 TeV excluded at 95% CL.

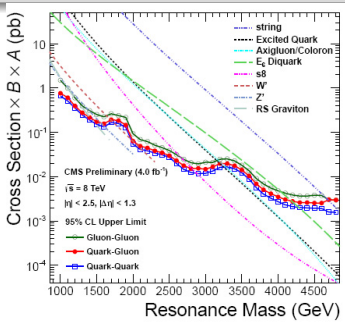
Search for new resonances: dijets (2012 data)





Exclusion limits on the cross section (ATLAS-CONF-2012-087, CMS-PAS-EXO-12-016):



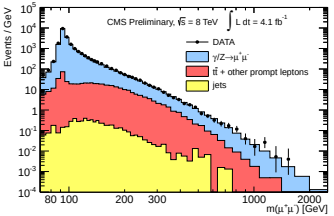


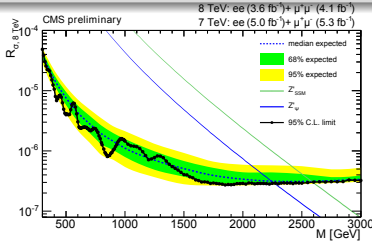
95% CL exclusion on the mass (in TeV) of various resonances:

RS graviton	1.0-1.36
Z'	1.0-1.60
W'	1.0-1.74 2.0-2.12
excited quarks	1.0-3.66
E$_6$ diquark	1.0-4.28
string resonance	1.0-4.69

New resonances in leptonic final states (2012 data)

Search for dilepton resonances (CMS-PAS-EXO-12-015)

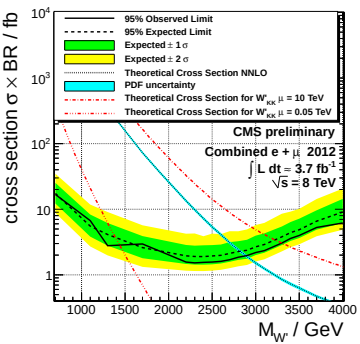


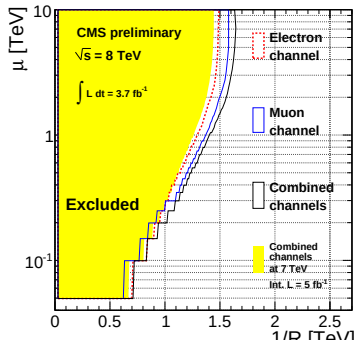


95% CL lower limit on the mass of:

SM-like Z'	2.59 TeV
superstring-Z'_ψ	2.26 TeV

Search for leptonic decays of W' resonances (CMS-PAS-EXO-12-010)



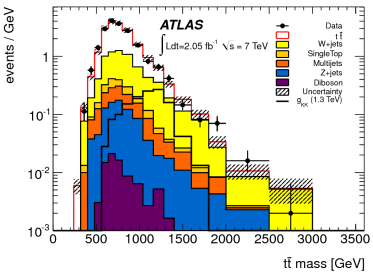


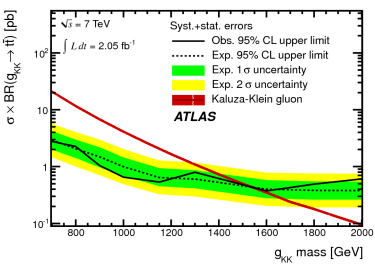
95% CL lower limit on the mass of:

SM-like W'	2.85 TeV
W^2_{KK} from *split UED*	1.4 TeV to 3.3 TeV

More searches (2011 data)

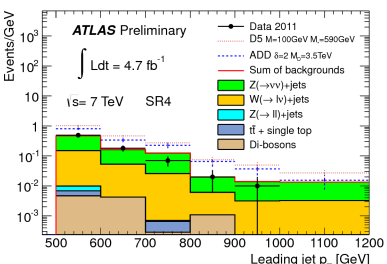
Search for the $t\bar{t}$ resonance in the semi-leptonic final state (ATLAS arXiv:1207.2409)

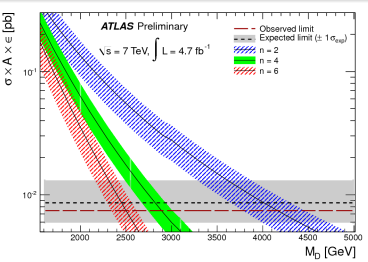




95% CL limit on the mass of the Kaluza-Klein gluon: 1.5 TeV

Search for large extra dimensions (monojet+E_T^{miss}) (ATLAS-CONF-2012-084)





95% CL limit in ADD model on the(4+n)-D Planck scale M_D:

3.79 TeV for $n = 2$

2.34 TeV for $n = 6$

Summary

Outstanding performance of the Large Hadron Collider in 2010-2012 allows for a rich physics programme of ATLAS and CMS experiments.

Measurements of the Standard Model processes are in good agreement with the theory predictions.

No sign yet of any new physics beyond the Standard Model.
But, there is still some space left for the signal to appear.

New resonance with a mass around 125 GeV discovered in the search for the Standard Model Higgs boson.

The observation is consistent with the Standard Model predictions, but within large uncertainty.
Need much more data to determine the properties of this new boson.

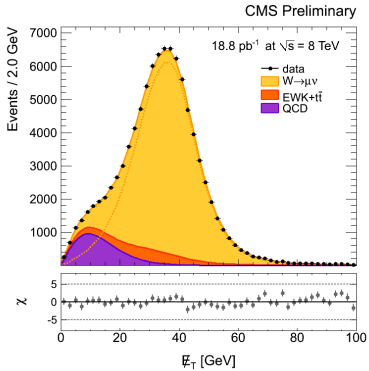
Save the best for last

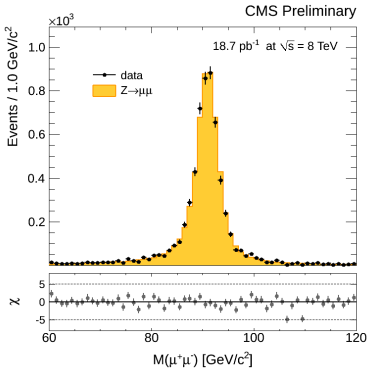
Standard Model

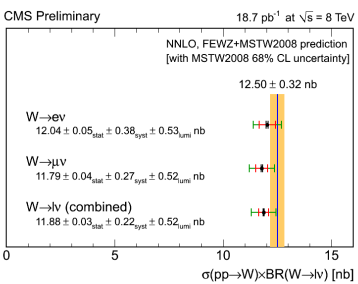
HIGGS : $H \to 4\ell$ / $H \to \gamma\gamma$ / $H \to WW \to \ell\nu\ell\nu$ / combination /

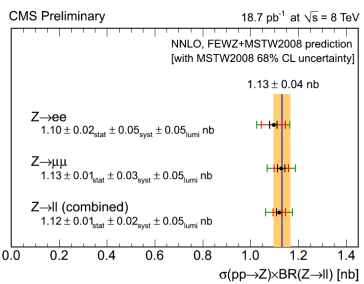
SUSY

W/Z cross section at 8 TeV (CMS-PAS-SMP-12-011)

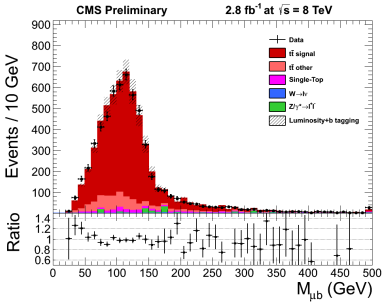


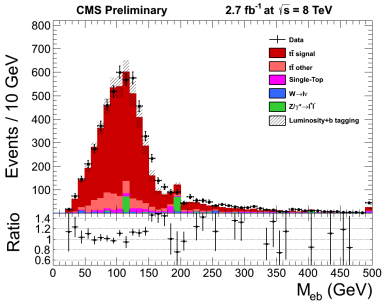


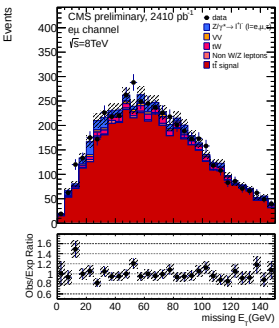


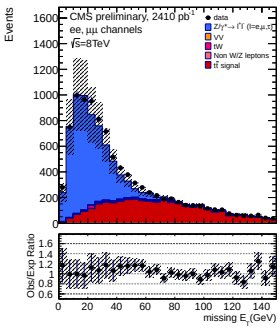


$t\bar{t}$ cross section at 8 TeV (CMS-PAS-TOP-12-006, 007)

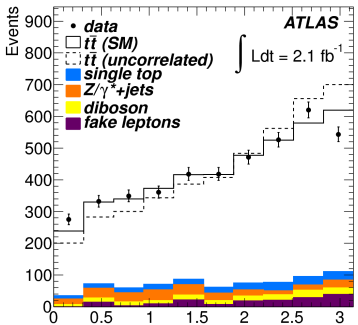


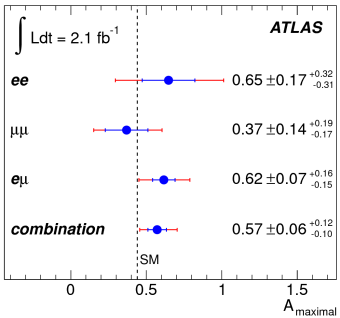


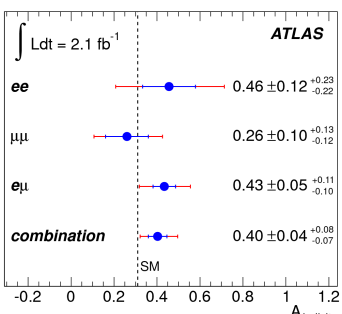


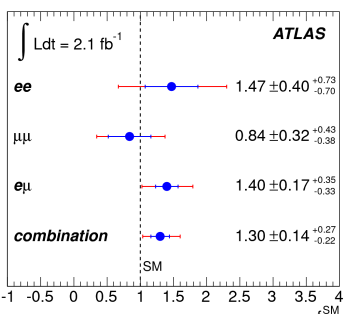


Spin correlations in $t\bar{t}$







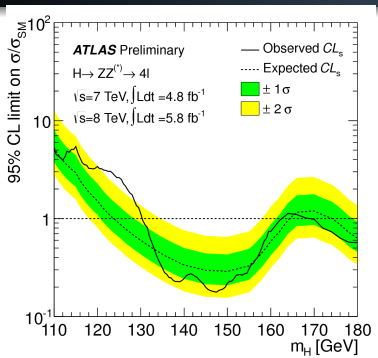


Latest results: Overview of search channels

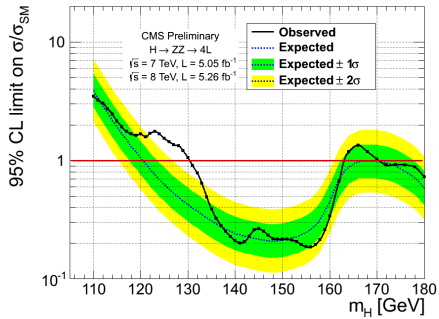
Key channels updated with improved analyses of 2011 and 2012 data.

Channel	Experiment	m_H range (GeV)	$\mathcal{L}$ (2011) (fb^{-1})	$\mathcal{L}$ (2012) (fb^{-1})	Public document
low- and intermediate-m_H, good mass resolution					
$H \to \gamma\gamma$	ATLAS	110-150	4.8	5.9	ATLAS-CONF-2012-091
	CMS	110-150	5.1	5.3	CMS-PAS-HIG-12-015
$H \to ZZ^{(*)} \to 4\ell$	ATLAS	110-600	4.8	5.8	ATLAS-CONF-2012-092
	CMS	110-600	5.0	5.3	CMS-PAS-HIG-12-016
low- and intermediate-m_H, limited mass resolution					
$H \to WW^{(*)} \to \ell\nu\ell\nu$	ATLAS	110-600	4.7	-	arXiv:1206.0756
	CMS	110-600	4.9	5.1	CMS-PAS-HIG-12-017
$H \to \tau\tau$	ATLAS	100-150	4.7	-	arXiv:1206.5971
	CMS	110-145	4.9	5.1	CMS-PAS-HIG-12-018
$VH, H \to b\bar{b}$	ATLAS	110-130	4.7	-	arXiv:1207.0210
$VH, t\bar{t}H; H \to b\bar{b}$	CMS	110-135	5.0	5.1	CMS-PAS-HIG-12-019,025
high-m_H					
$H \to ZZ^{(*)} \to \ell\ell\nu\nu$	ATLAS	200-600	4.7	-	arXiv:1205.6744
	CMS	200-600	4.9	5.1	CMS-PAS-HIG-12-023
$H \to ZZ^{(*)} \to \ell\ell jj$	ATLAS	200-600	4.7	-	arXiv:1206.2443
	CMS	200-600	4.9	-	CMS-PAS-HIG-11-027
$H \to ZZ^{(*)} \to \ell\ell\tau\tau$	CMS	200-600	5.0	5.3	CMS-PAS-HIG-12-016
$H \to WW^{(*)} \to \ell\nu jj$	ATLAS	300-600	4.7	-	arXiv:1206.6074
	CMS	170-600	5.0	5.1	CMS-PAS-HIG-12-021

$H \to ZZ^{(*)} \to 4\ell$: Results

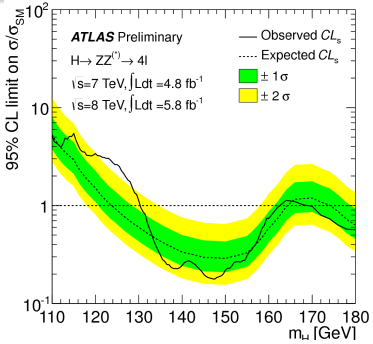


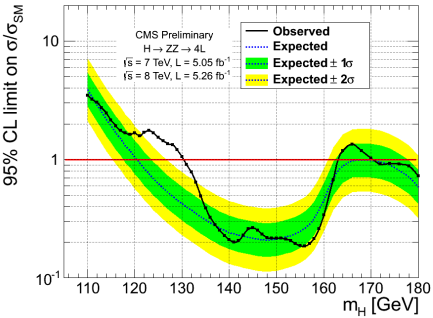
- Expected: 124-164, 176-500 GeV.
- Observed exclusion: 131-162, 170-460 GeV.

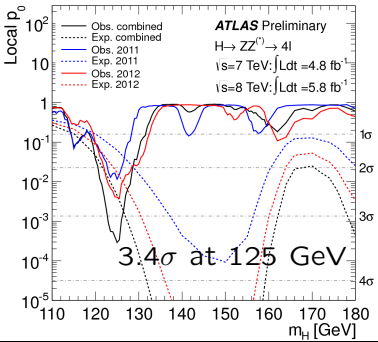


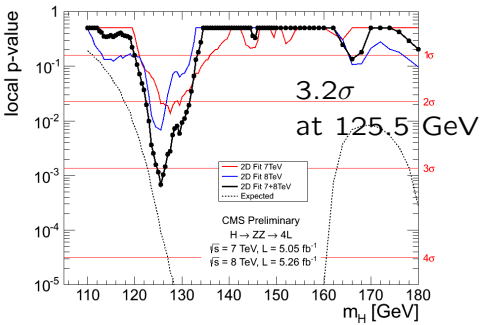
- Expected: 121-570 GeV.
- Observed exclusion: 131-162, 172-525 GeV.

$H \to ZZ^{(*)} \to 4\ell$: Results

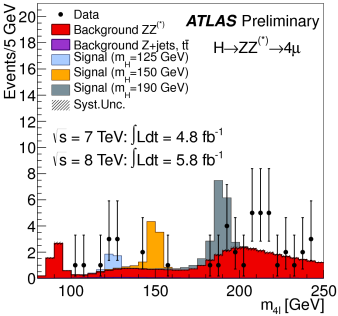


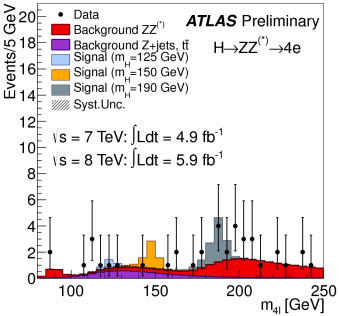


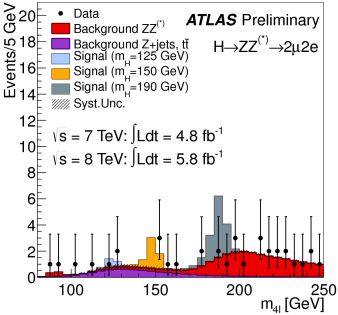


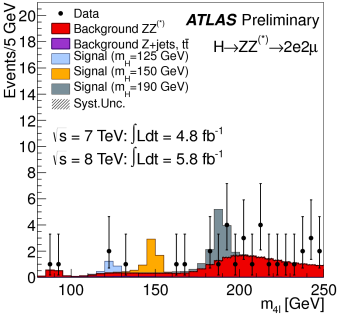


$H \to ZZ^{(*)} \to 4\ell$: Mass distributions, different flavours

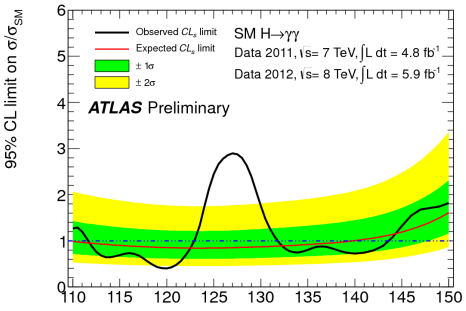


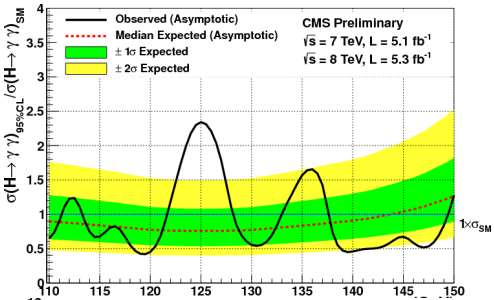


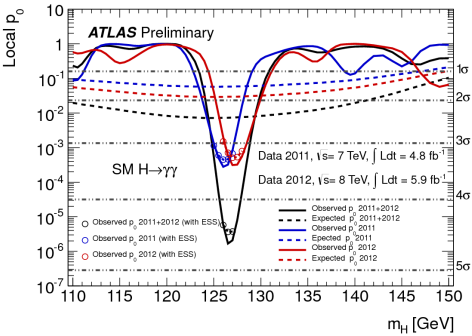


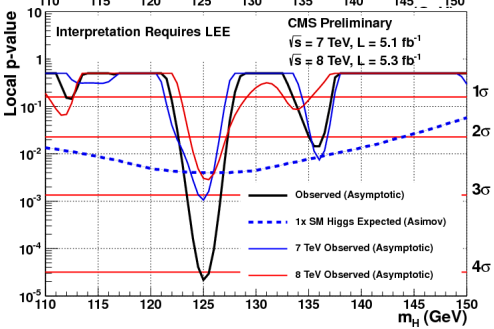


$H \to \gamma\gamma$: Results







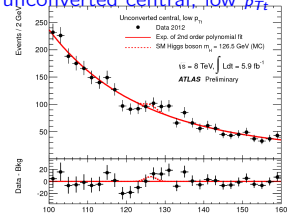


4.5σ at 126.5 GeV

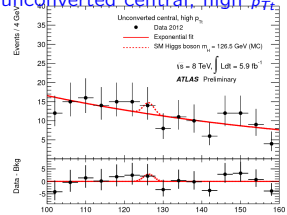
4.1σ at 125 GeV.

$H \to \gamma\gamma$: $m_{\gamma\gamma}$ in 9 categories (ATLAS)

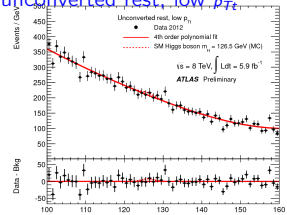
unconverted central, low p_{Tt}



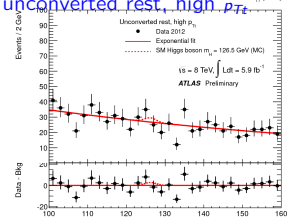
unconverted central, high p_{Tt}



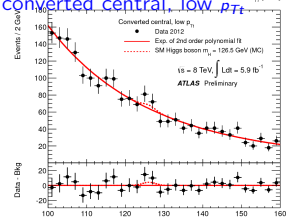
unconverted rest, low p_{Tt}



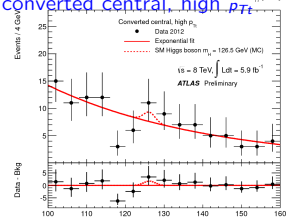
unconverted rest, high p_{Tt}



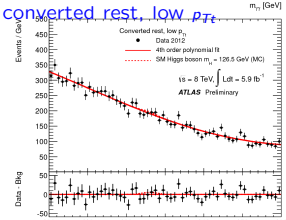
converted central, low p_{Tt}



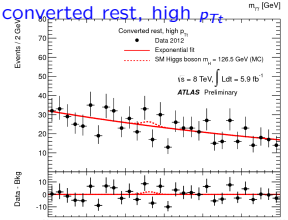
converted central, high p_{Tt}



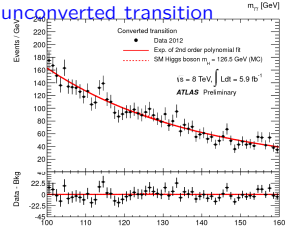
converted rest, low p_{Tt}



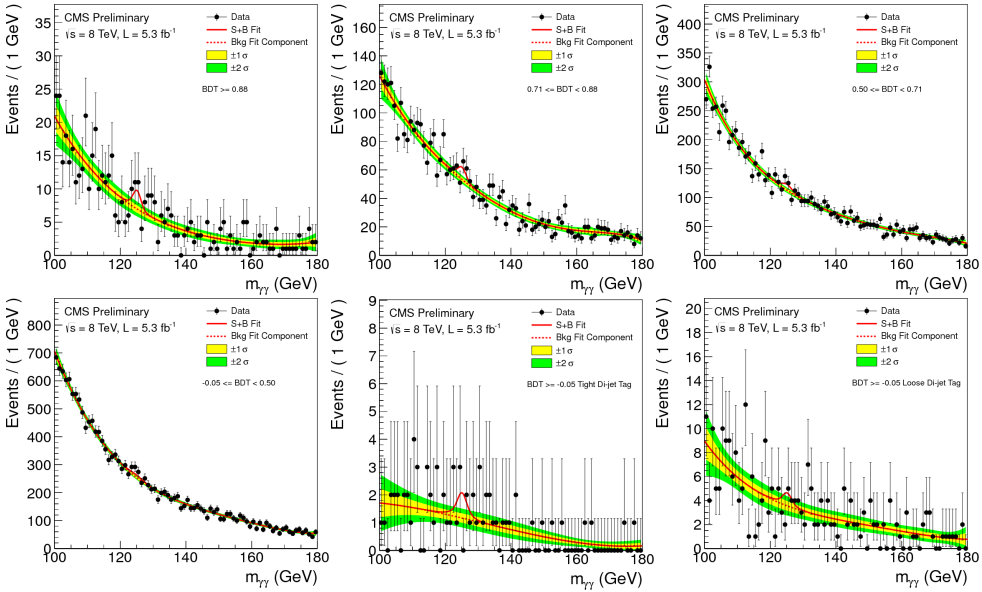
converted rest, high p_{Tt}



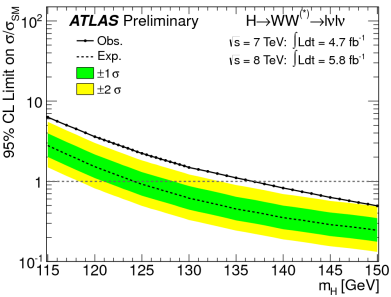
unconverted transition

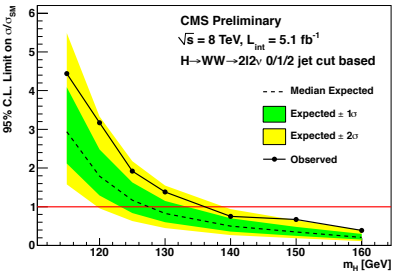


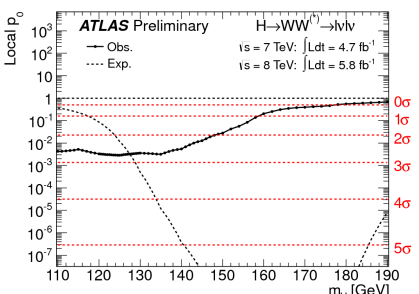
$H \to \gamma\gamma$: $m_{\gamma\gamma}$ in 5 categories (CMS)



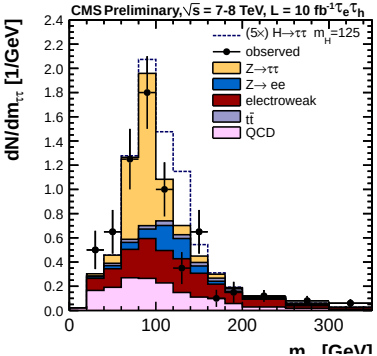
$H \to WW \to \ell\nu\ell\nu$: Results

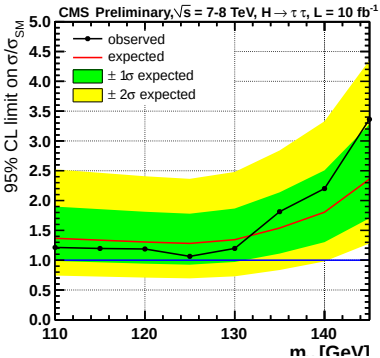


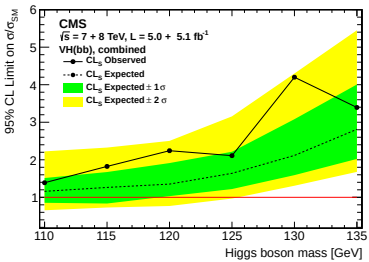


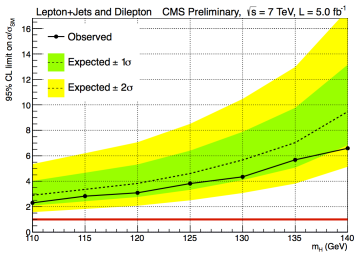


$H \to \tau\tau$ and $H \to b\bar{b}$: Results

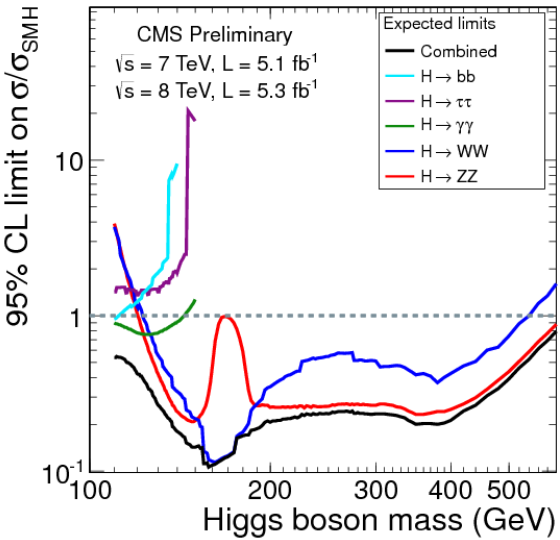








Combination: channel summary



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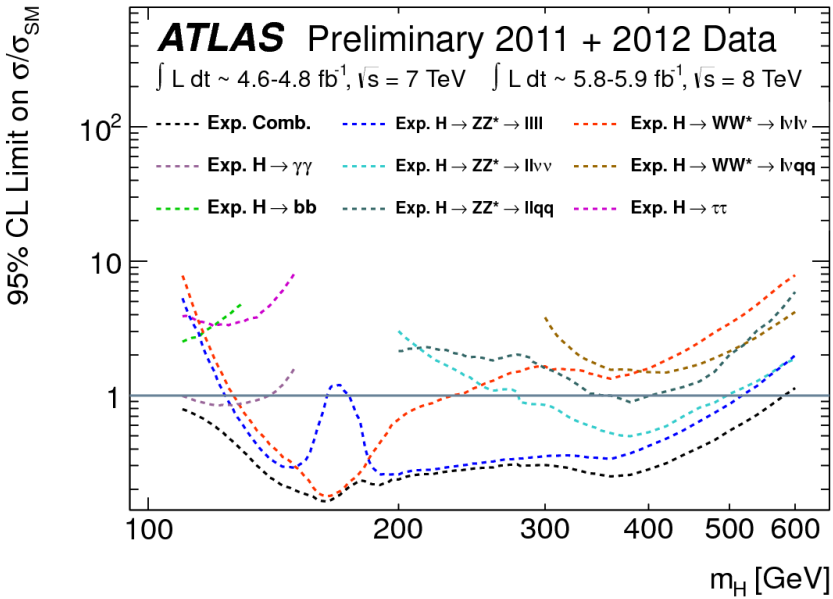
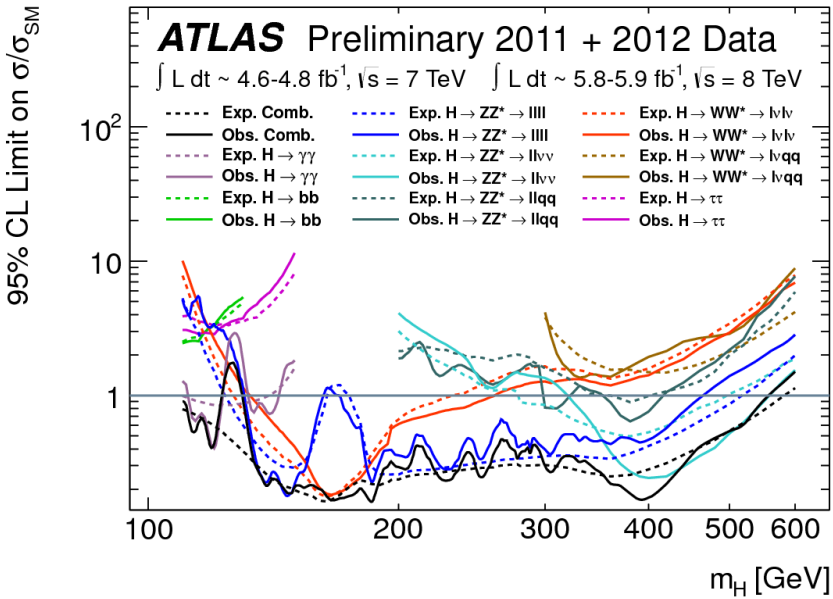
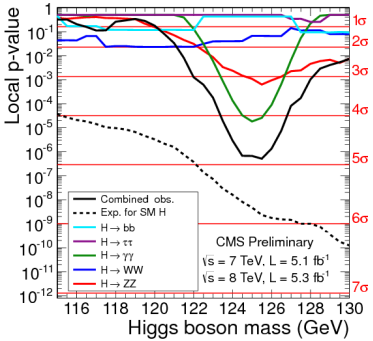


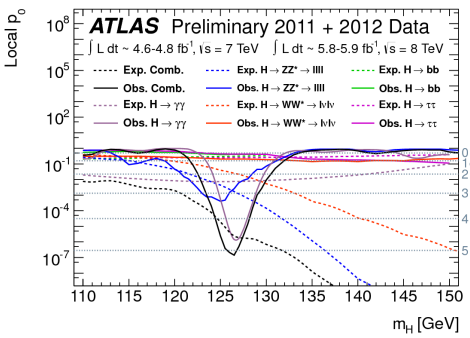
Combination: channel summary



Closer look: channel by channel

Probability that the background fluctuation would give the same or higher excess:





- $H \to \gamma\gamma$: largest ($>4\sigma$) excess in both ATLAS (126.5) and CMS (125 GeV).
  Significance is higher than the expectation from the SM Higgs signal.
- $H \to ZZ^{(*)} \to 4\ell$: Most sensitive channel around 125 GeV.
  Both ATLAS and CMS see an $>3\sigma$ excess around 125 GeV.
- *Other channels* (low mass resolution): No significant excess observed.

Closer look: channel by channel

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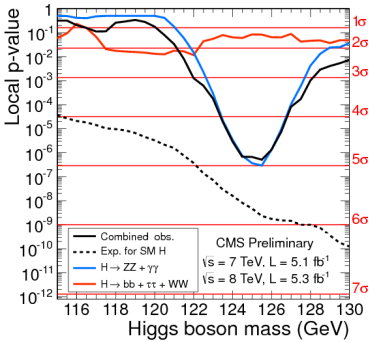

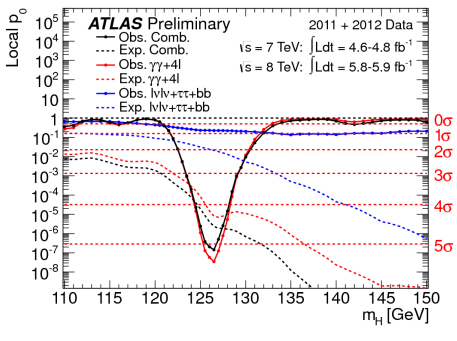

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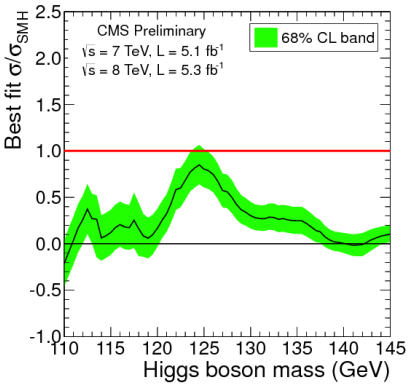
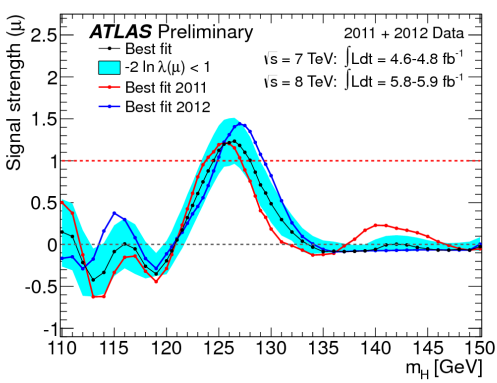
Compatibility with the SM Higgs hypothesis

Best-fit signal strength $\mu = \sigma/\sigma_{SM}$:





At $m_H = 125$ GeV:
$\hat{\mu} = 0.80 \pm 0.22$

At $m_H = 126.5$ GeV:
$\hat{\mu} = 1.2 \pm 0.3$

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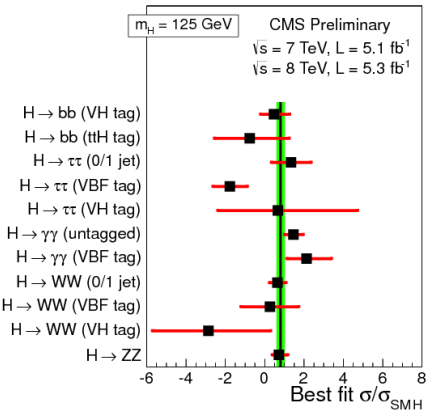

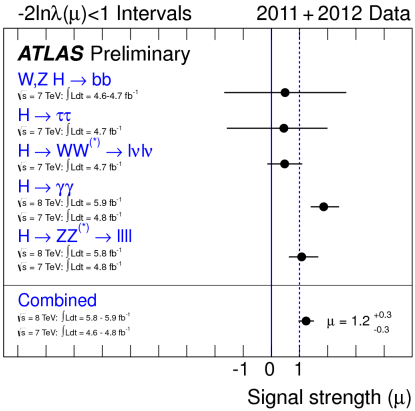

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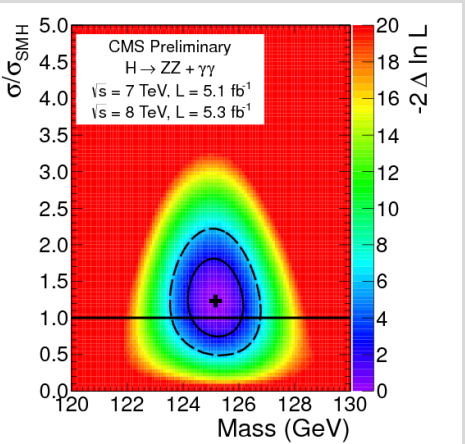
At $m_H = 126.5$ GeV:
$\hat{\mu} = 1.2 \pm 0.3$

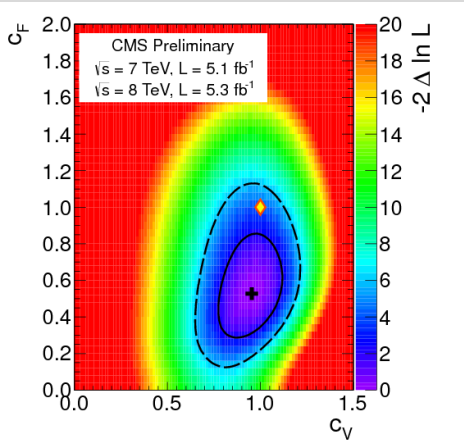
But, more data needed to determine couplings, spin and CP properties!

First property measurements

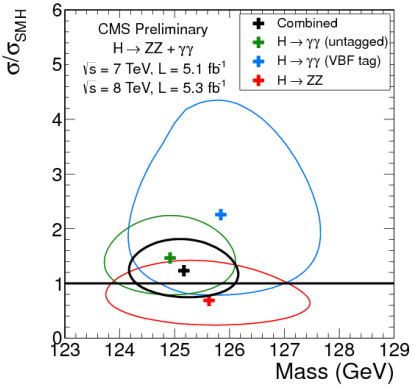
Mass fit:
$(125.3 \pm 0.4(stat) \pm 0.5(syst))$ GeV

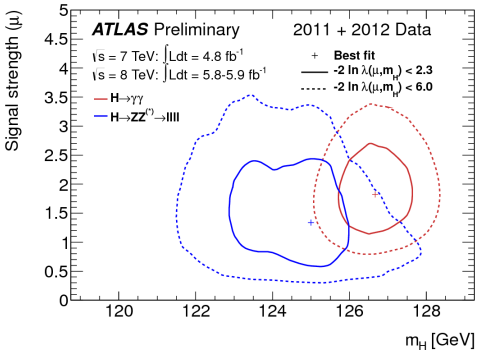


Coupling strengths
to bosons (c_V) and fermions (c_F)

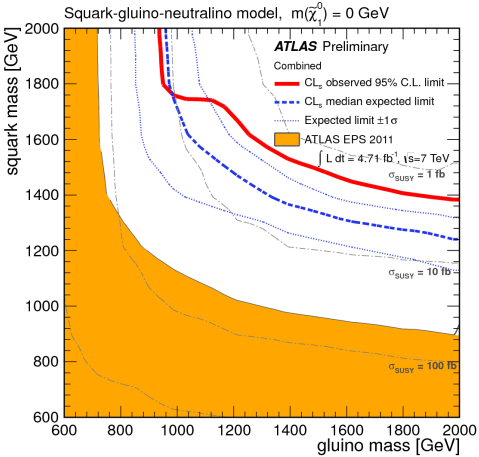


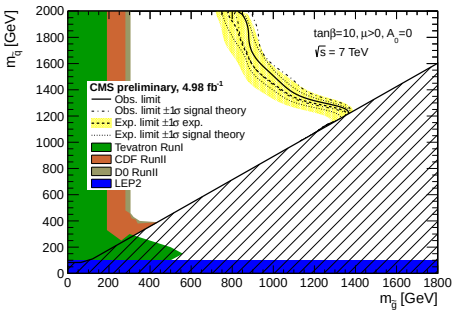
Combination: Mass measurement





SUSY: squarks and gluinos (all hadronic channel)





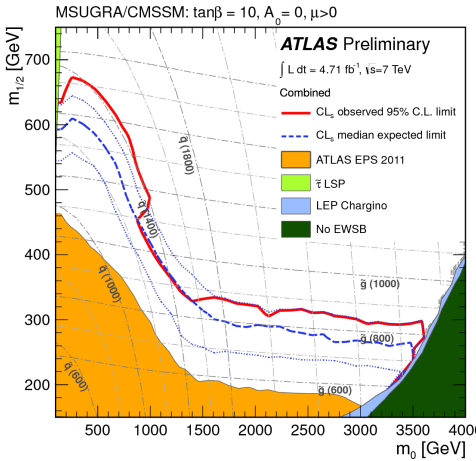
ATLAS-CONF-2012-033

Squarks and gluino masses with

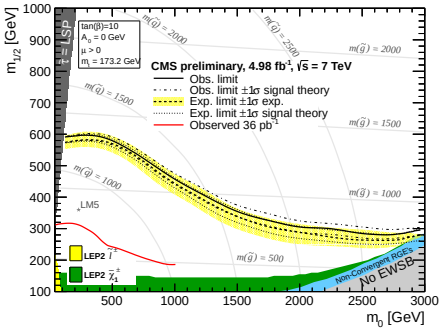
$m_{squark} \approx m_{gluino}$ excluded up to 1.4 TeV.

CMS-PAS-SUS-11-004

SUSY: squarks and gluinos (all hadronic channel)



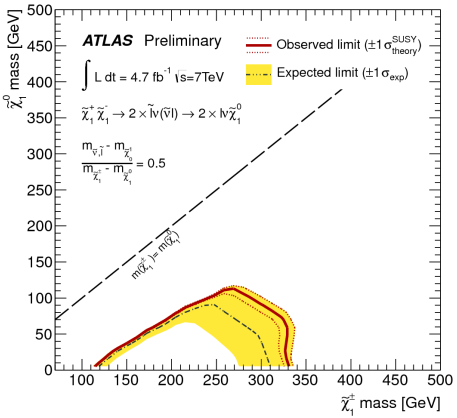
ATLAS-CONF-2012-033

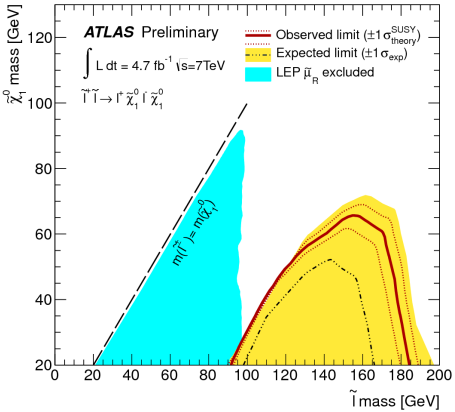


CMS-PAS-SUS-11-004

SUSY: sleptons and gauginos (dilepton+E_T^{miss})

ATLAS-CONF-2012-076



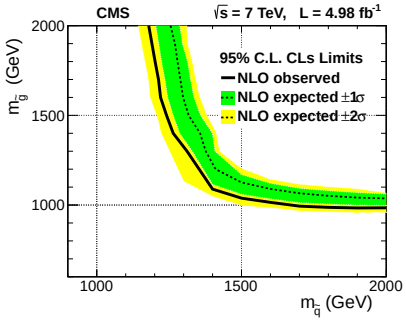


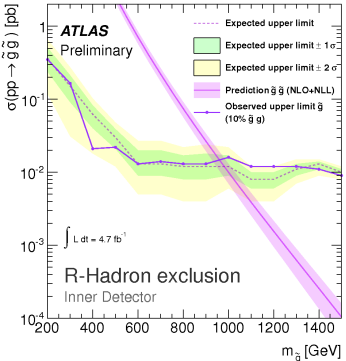
Best limit on chargino mass.

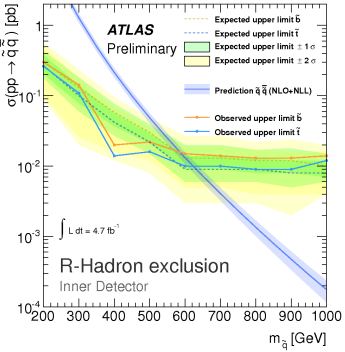
Sensitivity to weak production processes still limited, due to lower cross sections.

SUSY: R-parity violating models

CMS arXiv:1204.5341 (multilepton search)
ATLAS-CONF-2012-075
(long-lived particles)

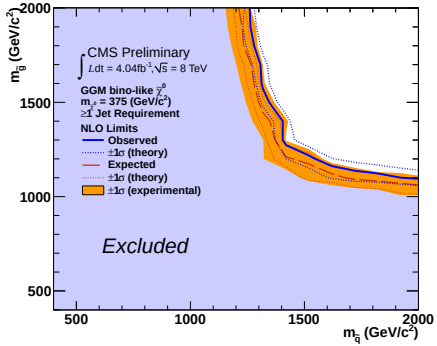


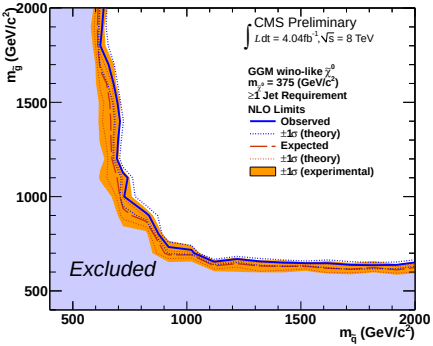




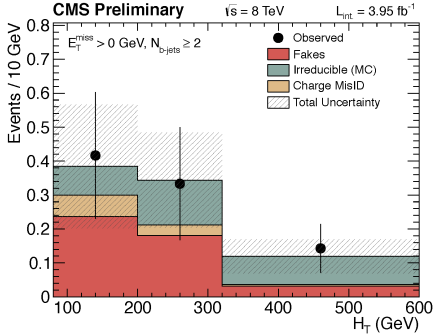
SUSY: General Gauge Mediation scenario ($\gamma + E_T^{miss}$)

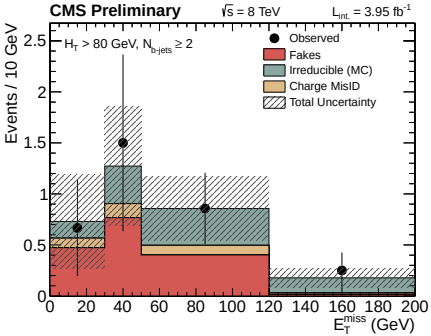
CMS-PAS-SUS-018

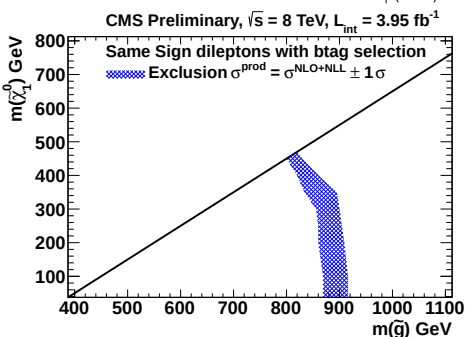


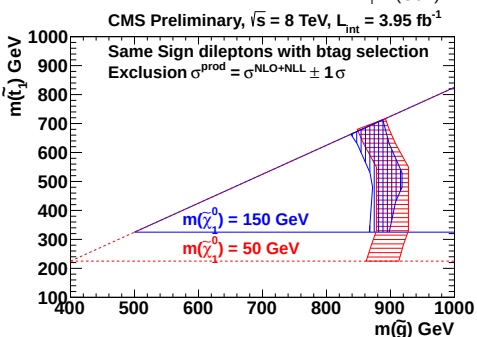


SUSY: SS dileptons + b-jets (CMS-PAS-SUS-12-017)









SUSY: E_T^{miss}+b-jets

CMS-PAS-SUS-12-016