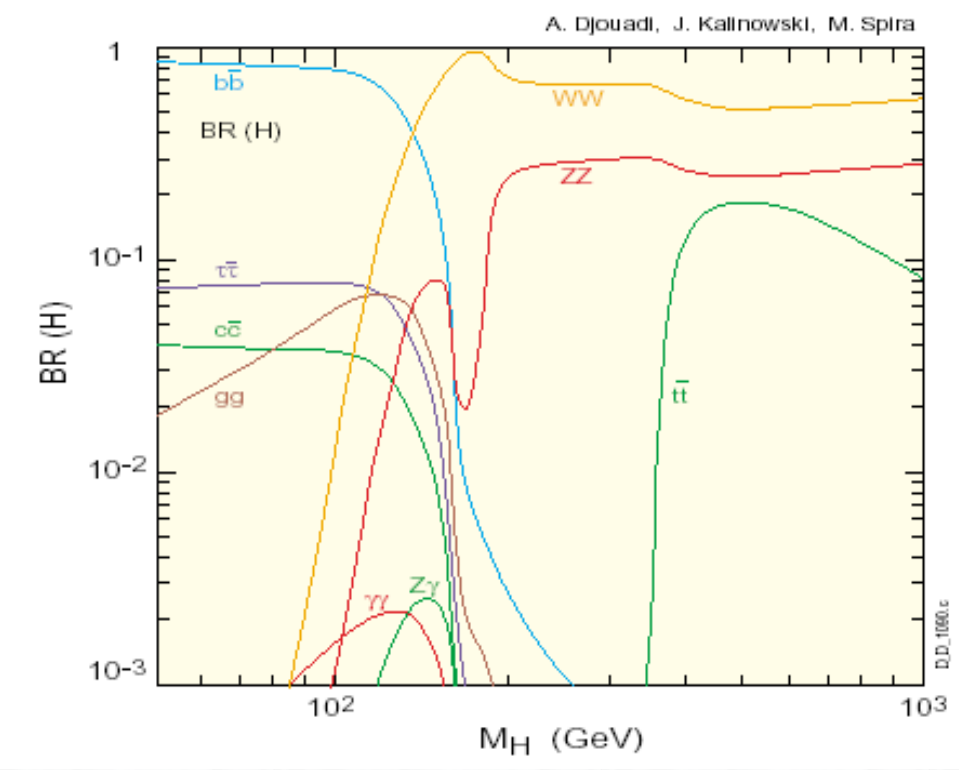
8.5 Higgs boson searches at the LHC

Useful Higgs Boson Decays at Hadron Colliders



at high mass:
Lepton final states
(via H → WW , ZZ)

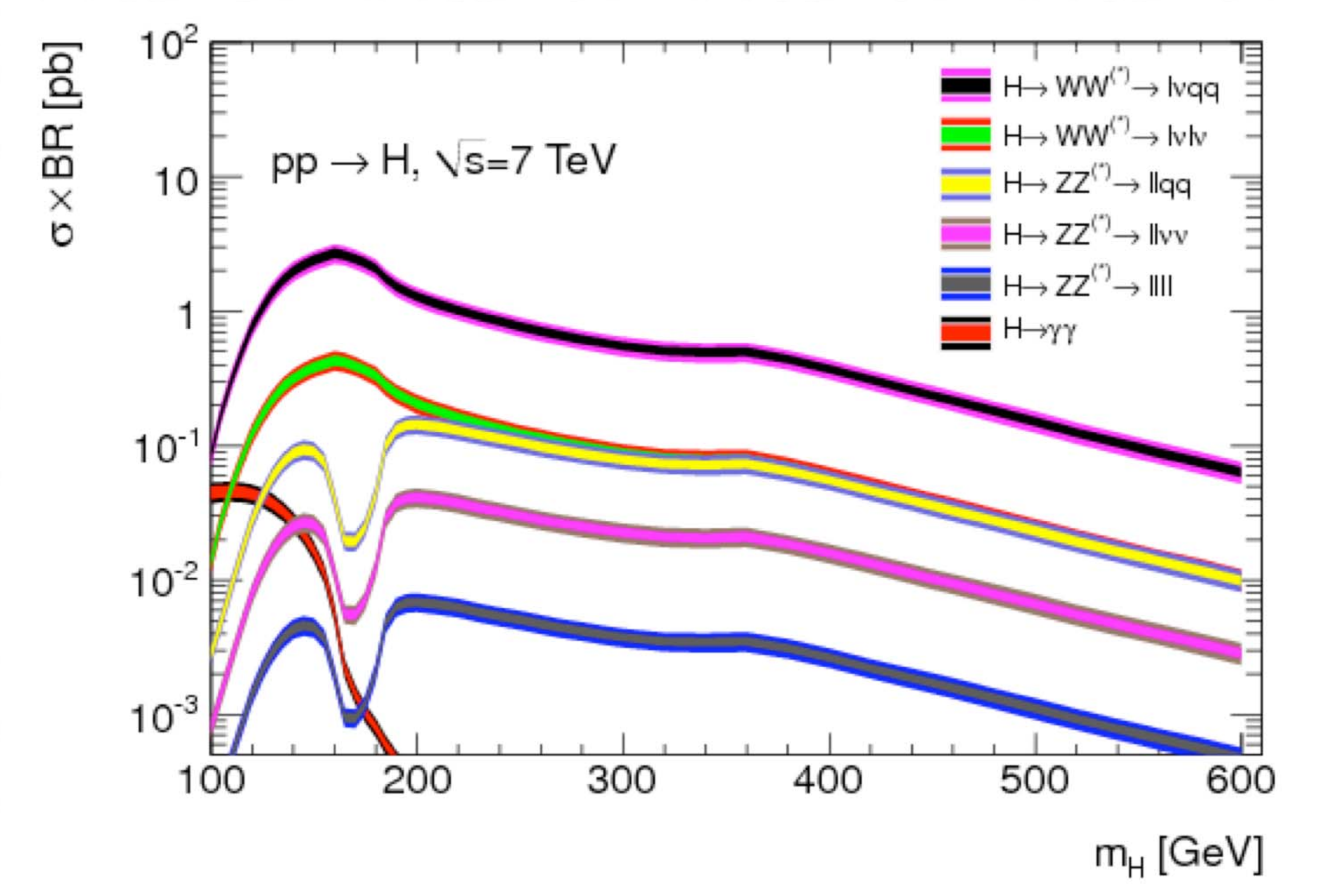
at low mass:
Lepton and Photon final states
(via H → WW*, ZZ*)

Tau final states

The dominant **bb decay mode** is only useable in the associated production mode (ttH, W/Z H)

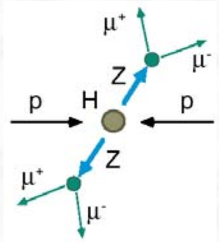
(due to the huge QCD jet background, leptons from W/Z or tt decays)

Expected cross sections times production rates at √s = 7 TeV



$H \rightarrow ZZ^{(*)} \rightarrow \ell\ell\ell\ell$

Signal: σ BR = 5.7 fb (m$_H$ = 100 GeV)



Background: Top production

$tt \rightarrow Wb\,Wb \rightarrow \ell\nu\ c\ell\nu\ \ell\nu\ c\ell\nu$

σ BR ≈ 1300 fb

Associated production Z bb

$Z\,bb \rightarrow \ell\ell\ c\ell\nu\ c\ell\nu$

$P_T(1,2) > 20$ GeV
$P_T(3,4) > 7$ GeV
$|\eta| < 2.5$
Isolated leptons

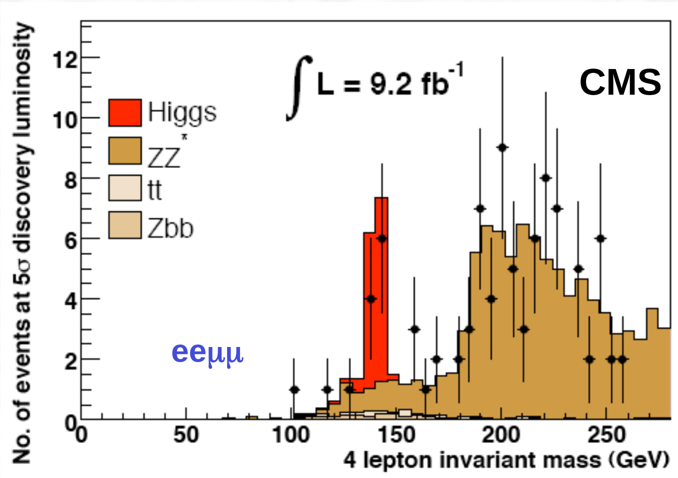
$M(\ell\ell) \sim M_Z$
$M(\ell'\ell') \sim < M_Z$

Background rejection: Leptons from b-quark decays
→ non isolated
→ do not originate from primary vertex
(B-meson lifetime: ~ 1.5 ps)

Dominant background after isolation cuts: ZZ continuum

$H \rightarrow ZZ^{*} \rightarrow \ell\ell\ \ell\ell$

$\sqrt{s}$ = 14 TeV

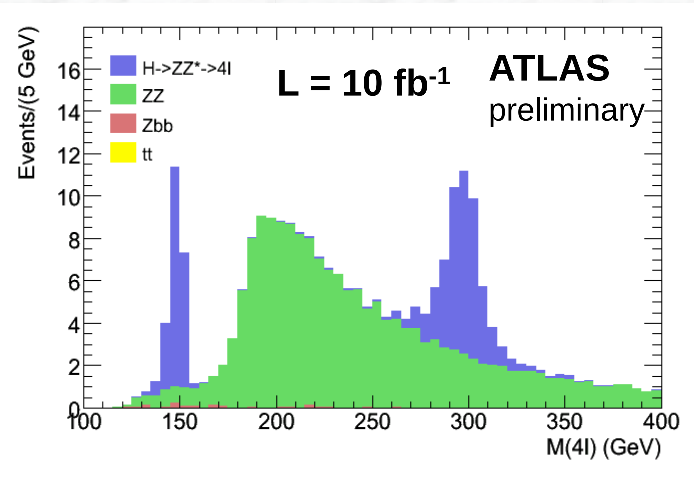


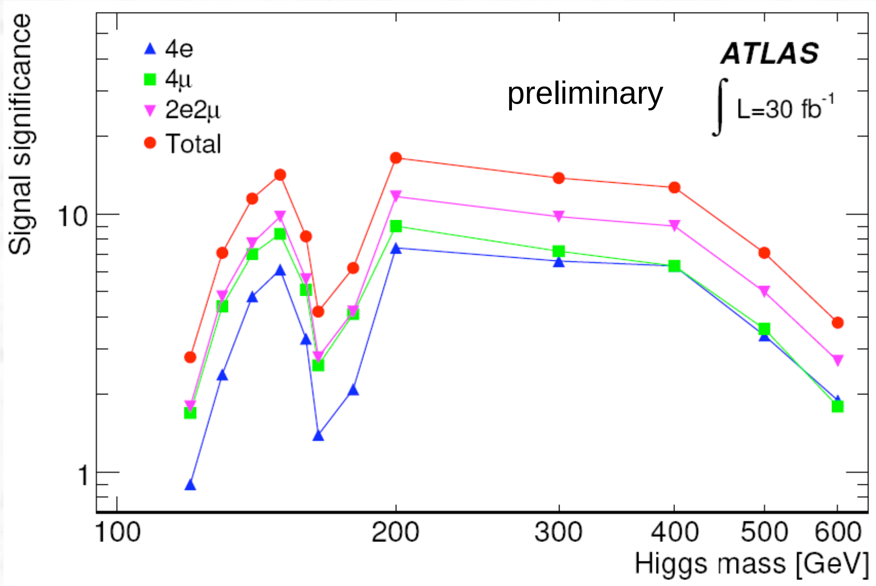
Main backgrounds: ZZ (irreducible),
tt, Zbb (reducible)

Updated ATLAS and CMS studies:

- ZZ background: NLO K factor used
- background from side bands

(gg->ZZ is added as 20% of the LO qq->ZZ)

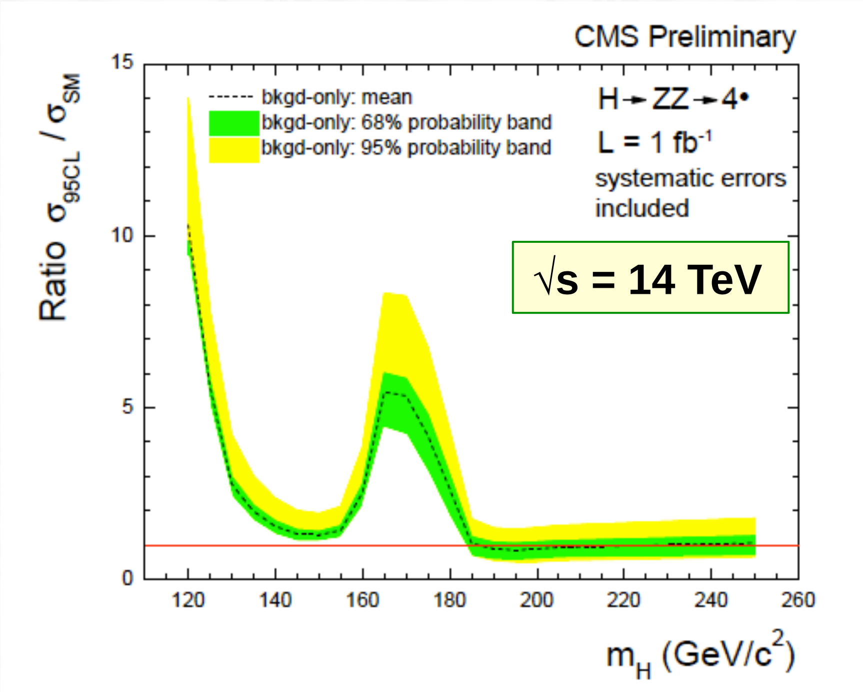


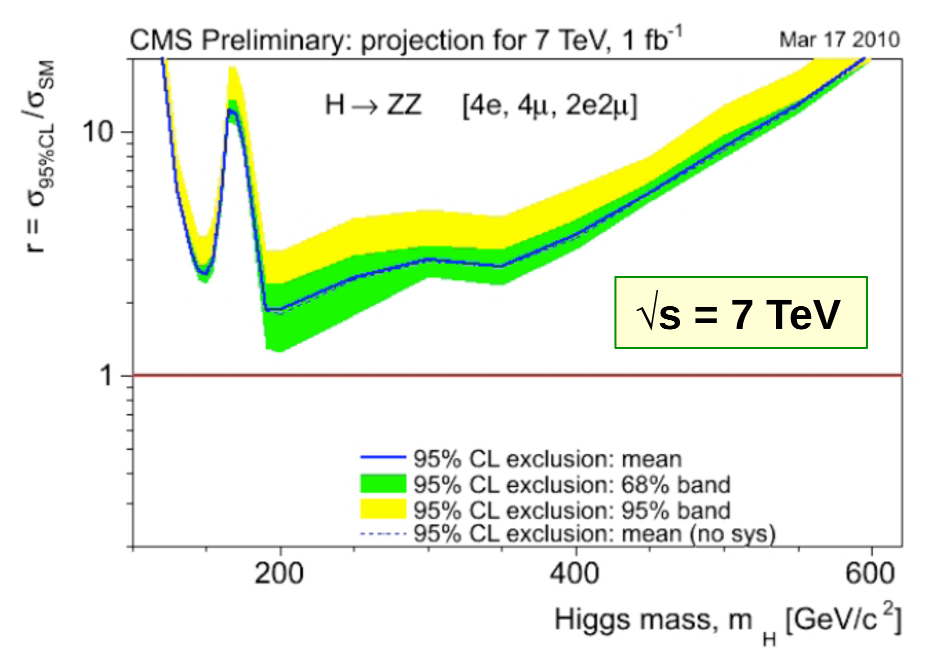


H → ZZ* → ℓℓ ℓℓ

What can be done with 1 fb^{-1}?

95% C.L. excluded cross sections normalized to Standard Model cross section

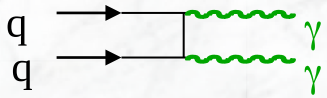




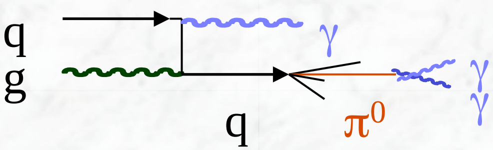
$H \rightarrow \gamma\gamma$

<u>Main backgrounds:</u>

$\gamma\gamma$ irreducible background



γ-jet and jet-jet (reducible)



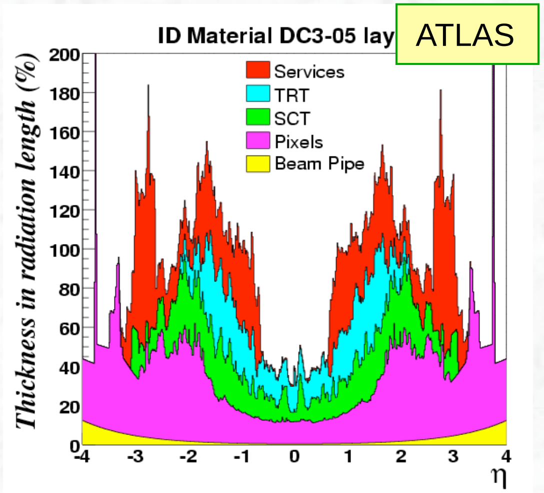
$\sigma_{\gamma j+jj} \sim 10^6\ \sigma_{\gamma\gamma}$ with large uncertainties

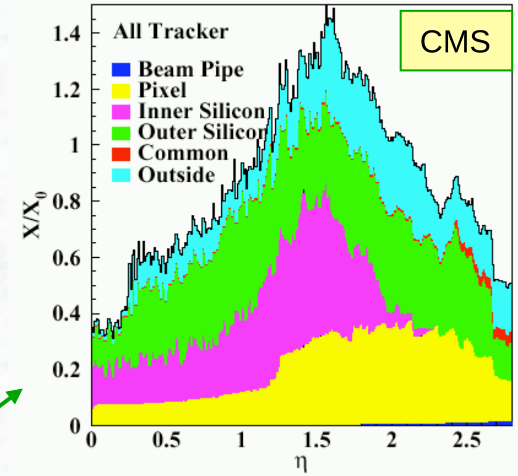
$\rightarrow$ need $R_j > 10^3$ for $\varepsilon_\gamma \approx 80\%$ to get

$\sigma_{\gamma j+jj} \ll \sigma_{\gamma\gamma}$

- <u>Main exp. tools for background suppression</u>:
  - photon identification
  - γ / jet separation (calorimeter + tracker)

  - note: also converted photons need to be reconstructed
    (large material in LHC silicon trackers)





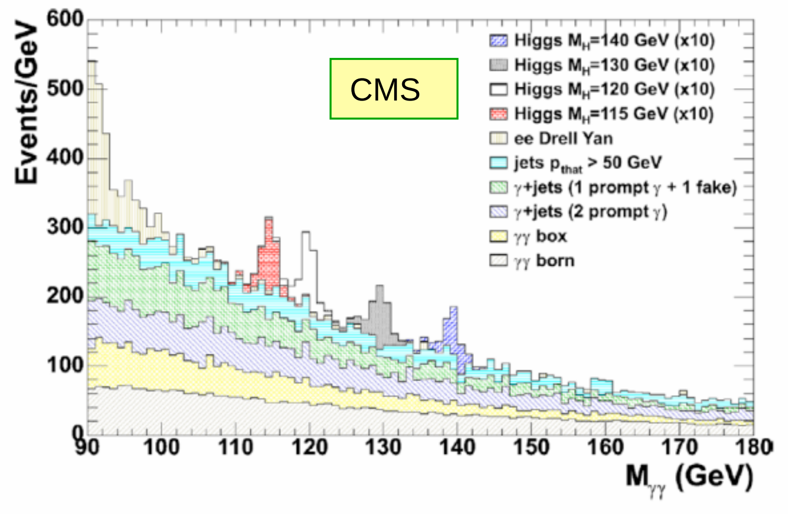
<u>CMS: fraction of converted γs</u>

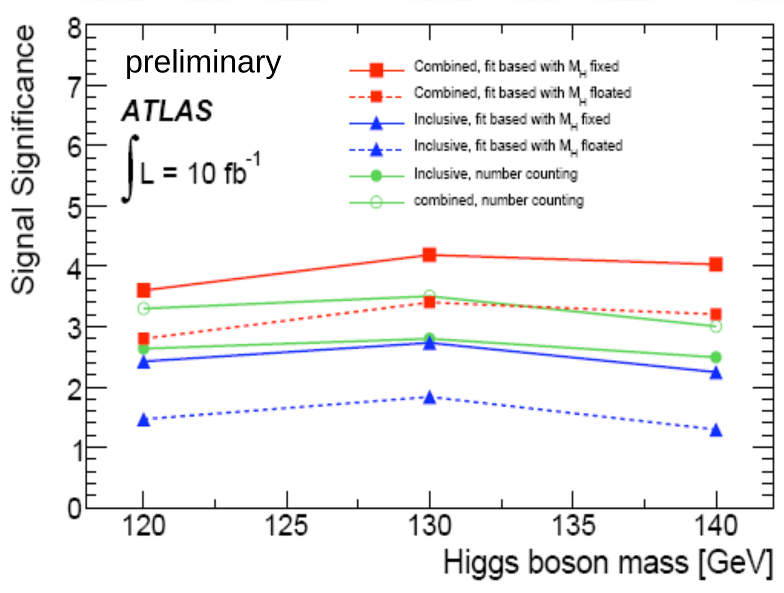
Barrel region: 42.0 %

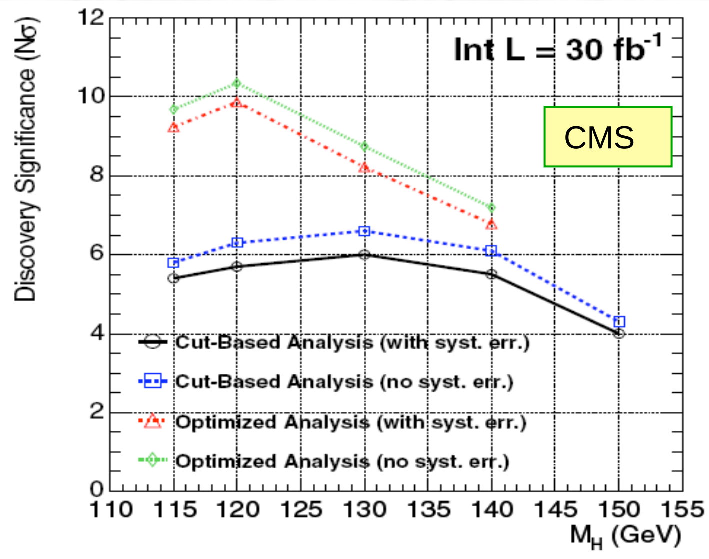
Endcap region: 59.5 %

New elements of the analyses:

- NLO calculations available
  (Binoth et al., DIPHOX, RESBOS)
- Realistic detector material
- More realistic K factors (for signal and background)
- Split signal sample acc. to resolution functions





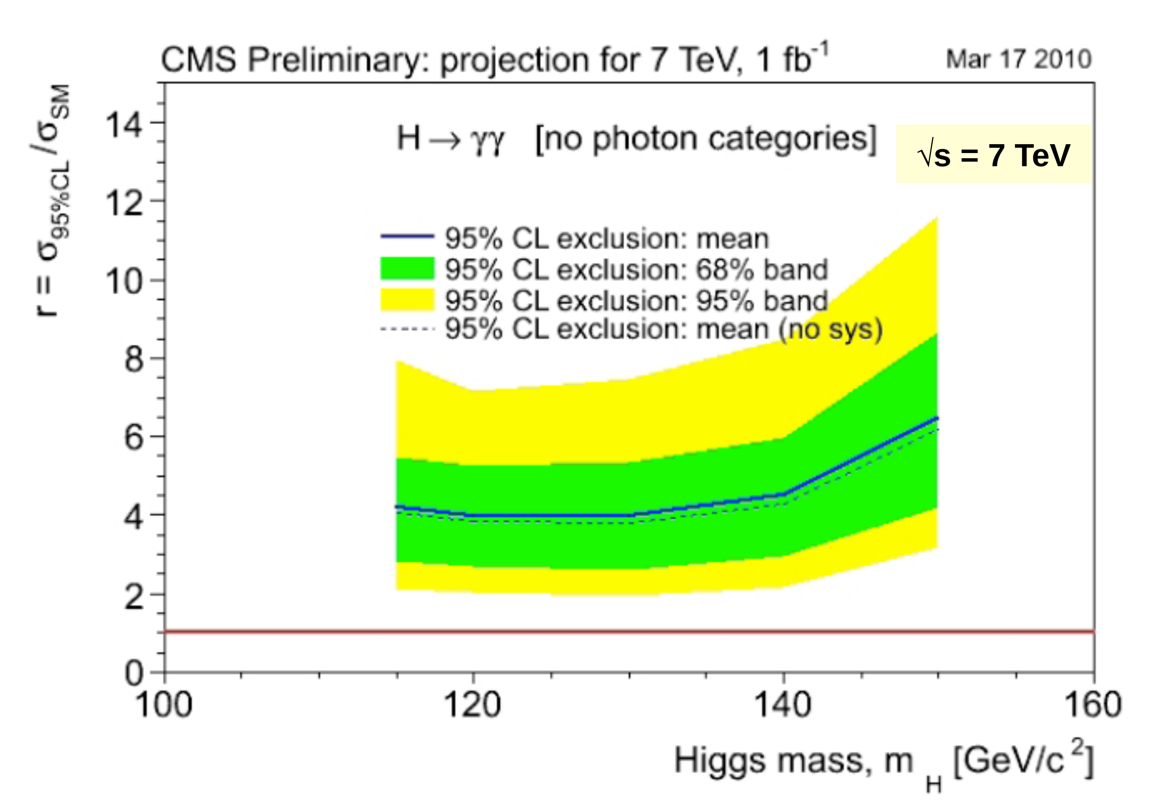


- Comparable results for ATLAS and CMS
- Improvements possible by using more exclusive $\gamma\gamma$ + jet topologies

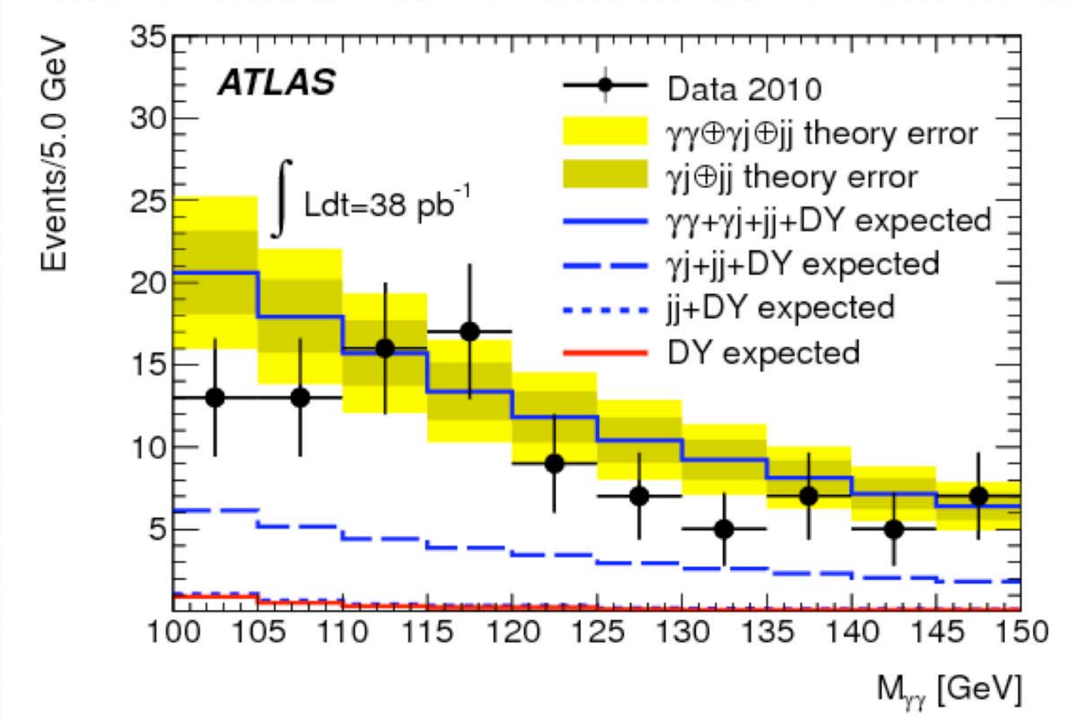
$H \rightarrow \gamma\gamma$

What can be done with 1 fb^{-1} at $\sqrt{s}$ = 7 TeV ?

95% C.L. excluded cross sections normalized to the Standard Model cross section



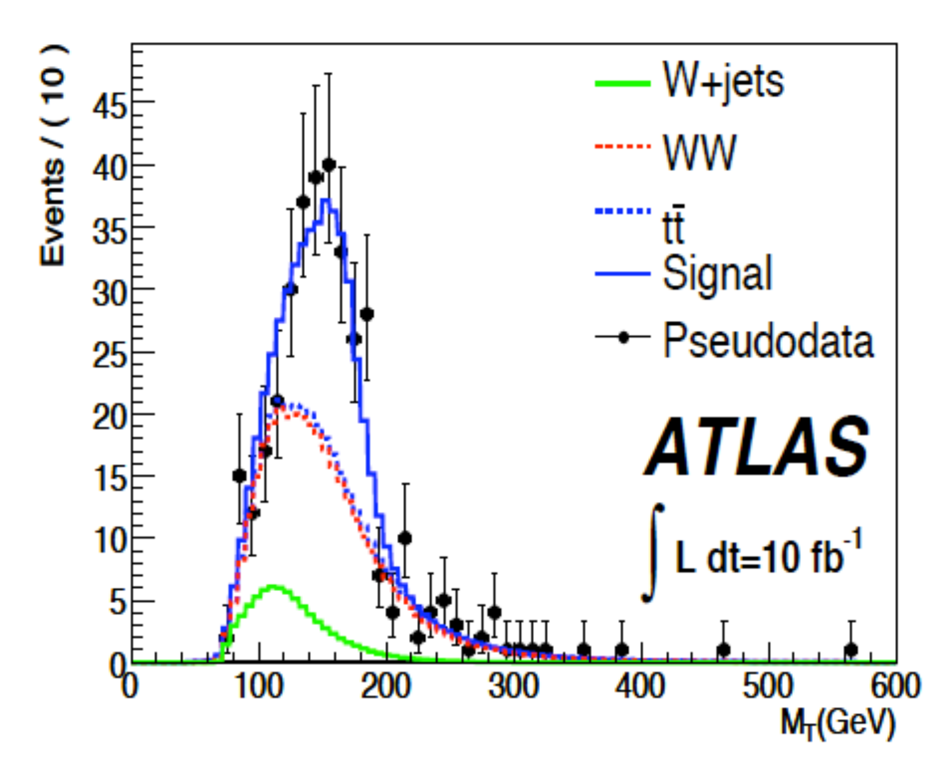
First results on H → γγ searches (2010 data)



No evidence for an excess (…also not expected yet)

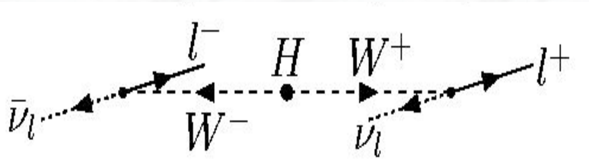
$H \rightarrow WW \rightarrow \ell\nu\ \ell\nu$

- Large $H \rightarrow WW$ BR for m_H ~ 160 GeV/c^2
- Neutrinos → no mass peak,
  → use transverse mass
- Large backgrounds: WW, Wt, tt



- Two main discriminants:

(i) Lepton angular correlation



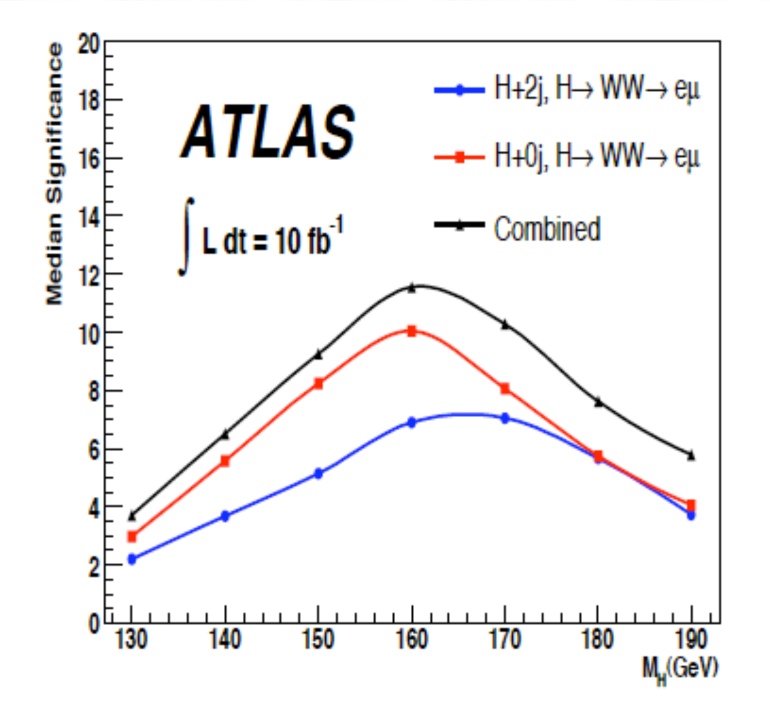
(ii) Jet veto: no jet activity
in central detector region

Difficulties:
(i) need precise knowledge of the backgrounds
Strategy: use control region(s) in data, extrapolation in signal region
(ii) jet veto efficiencies need to be understood for signal and background events

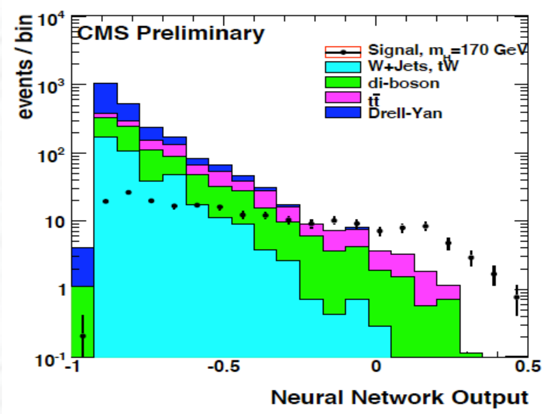
Discovery reach in H → WW →ℓν ℓν

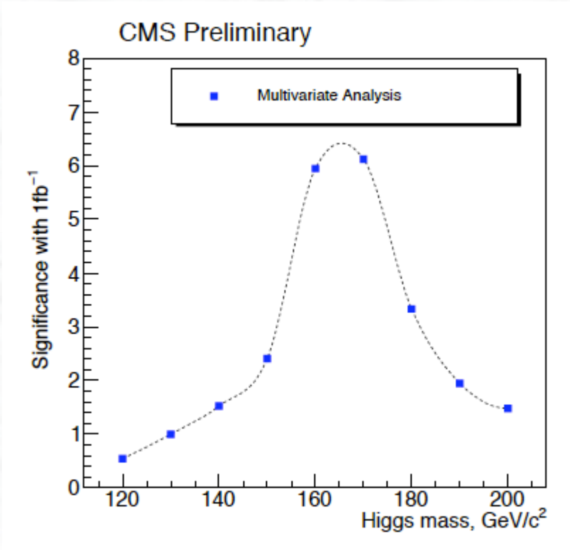
Expected ATLAS discovery reach at √s = 14 TeV for 10 fb^{-1}

Separated in:
- H + 0 jet (gluon fusion)
- H + 2 jets (vector boson fusion)

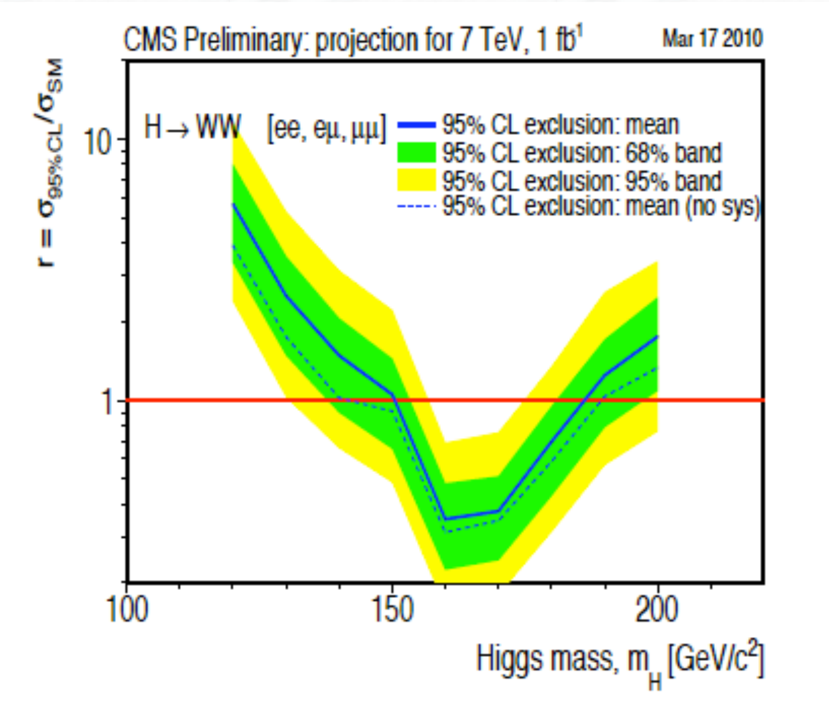


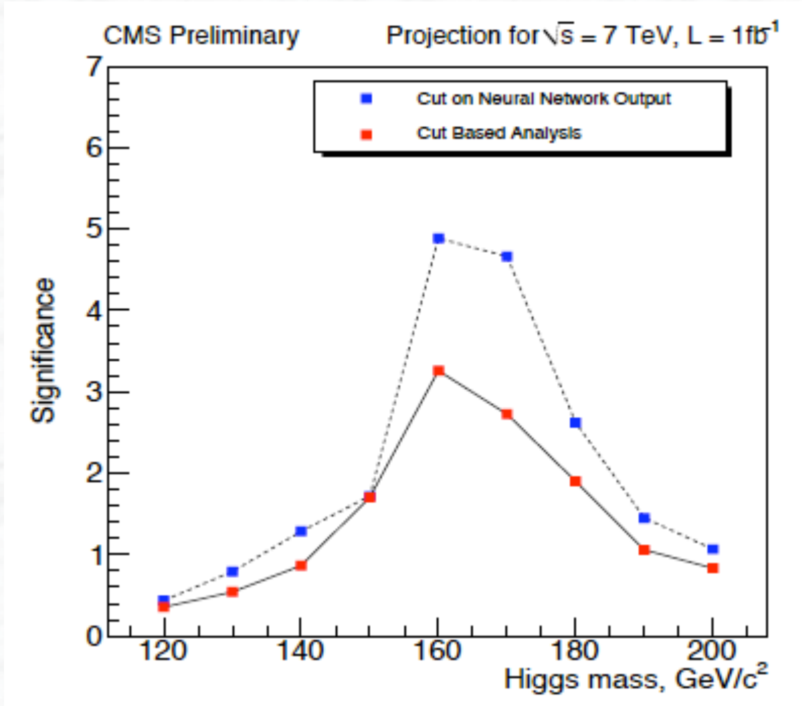
CMS Neural Net approach for √s=14 TeV:
(gluon fusion + vector boson fusion)





Discovery reach in H → WW → ℓν ℓν at √s = 7 TeV

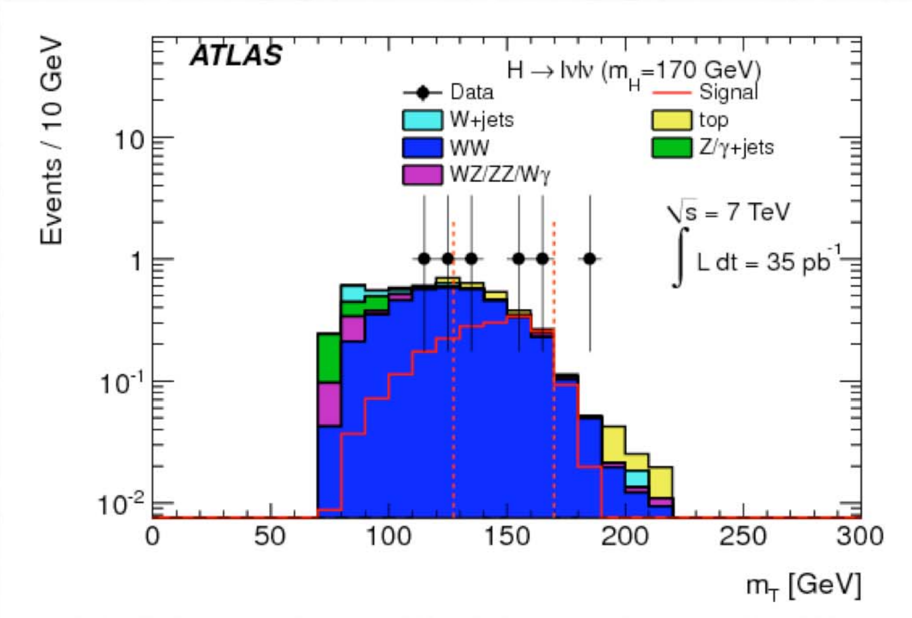




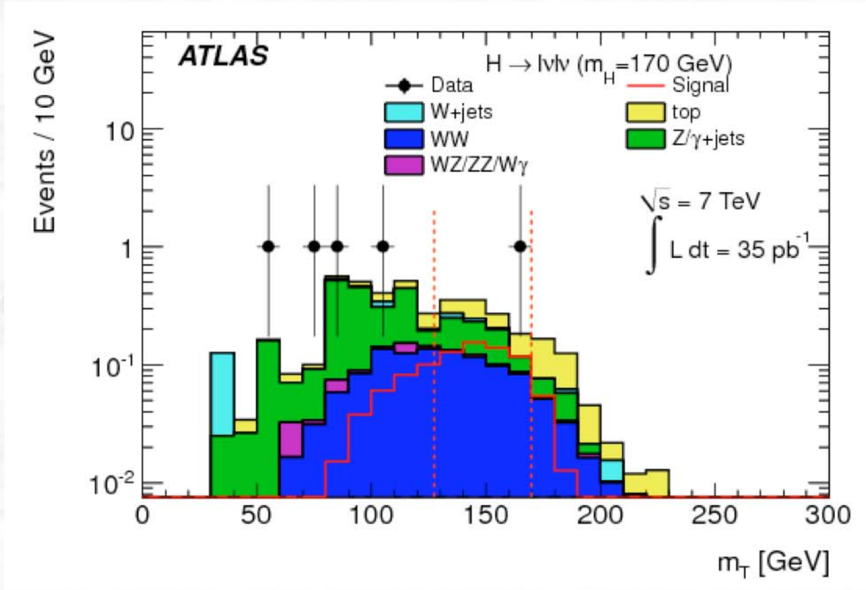
- Looks promising, provided backgrounds (systematic uncertainties) can be controlled
- Exclusion reach is comparable to Tevatron reach (nominal performance) (note that a single experiment is quoted above)

First results on H → WW → ℓν ℓν searches (2010 data)

Analysis has been split in final states with 0- and 1 additional jets
(different background compositions)



0-jet channel



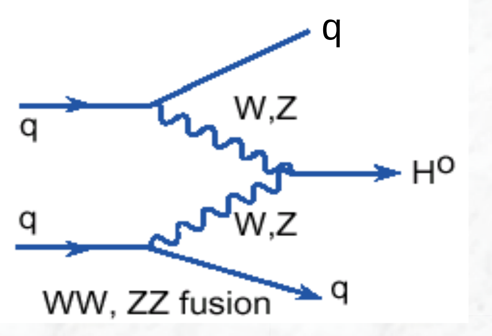
1-jet channel

No evidence for an excess
(however: sensitivity expected very soon !)

Vector Boson Fusion qq H

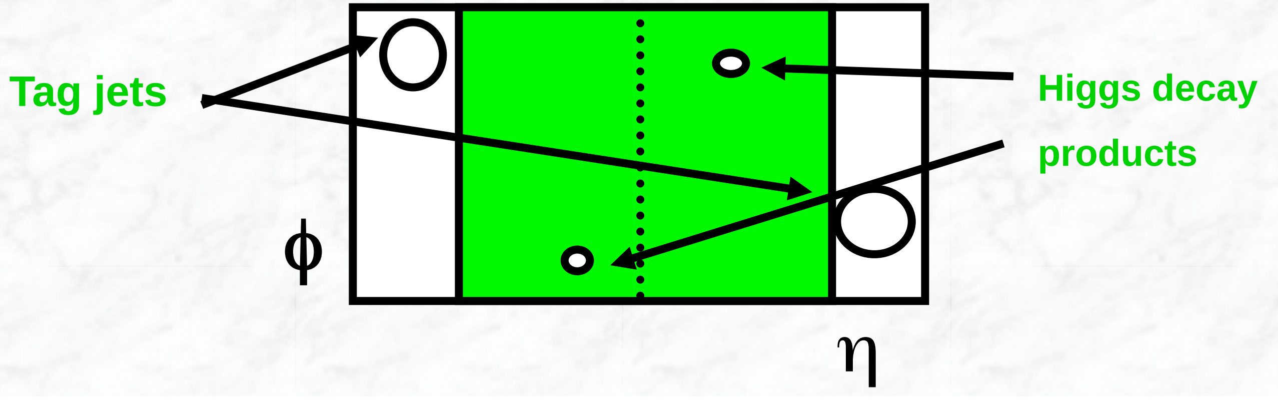
Motivation: Increase discovery potential at low mass
Improve and extend measurement of Higgs boson parameters
(couplings to bosons, fermions)

Established (low mass region) by D. Zeppenfeld et al. (1997/98)
Earlier studies: R.Kleiss W.J.Stirling, Phys. Lett. 200 (1988) 193;
Dokshitzer, Khoze, Troyan, Sov.J. Nucl. Phys. 46 (1987) 712;
Dokshitzer, Khoze, Sjöstrand, Phys.Lett., B274 (1992) 116.

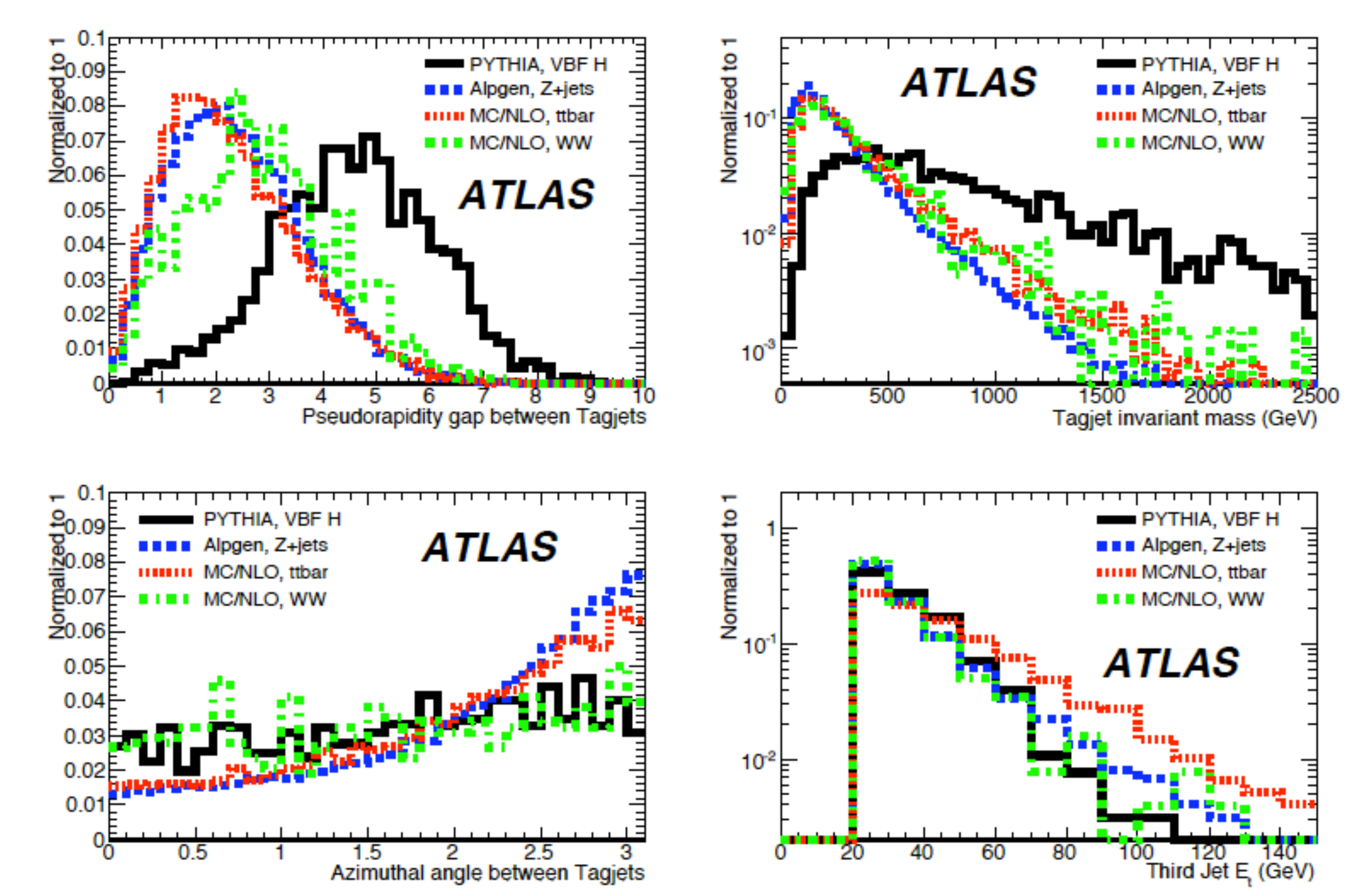


Distinctive Signature of:

- two high p_T forward jets (tag jets)
- little jet activity in the central region (no colour flow)
  $\Rightarrow$ central jet Veto



Forward jet tagging

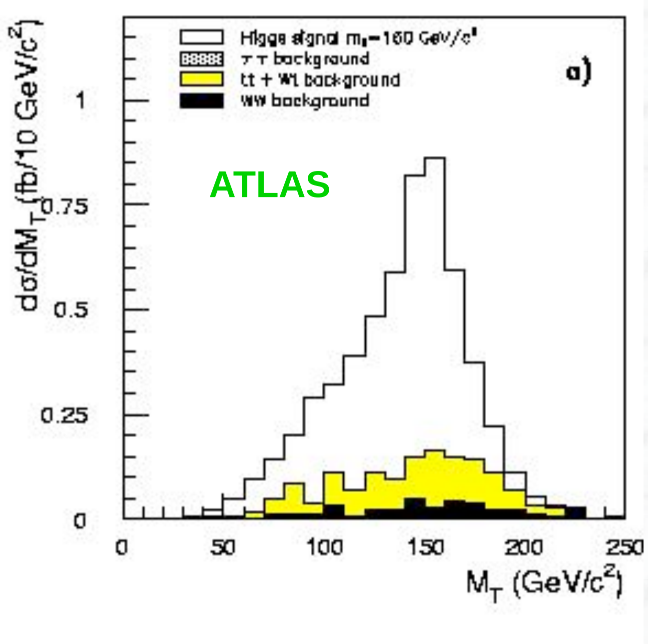


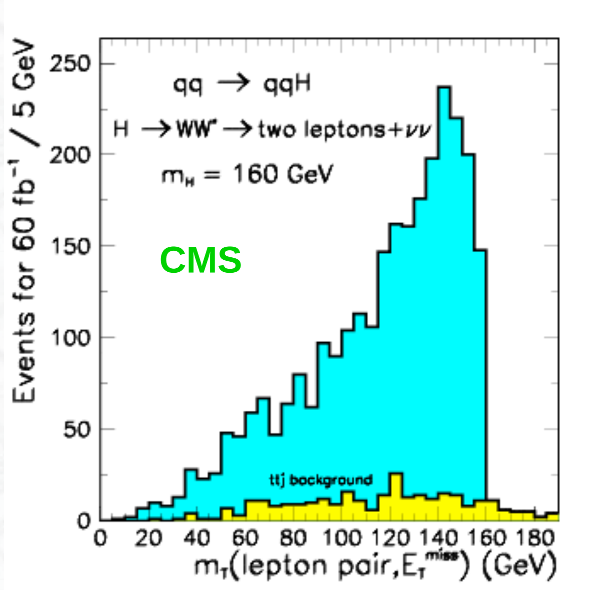
ATLAS full simulation

qq H → qq W W*
→ qq ℓν ℓν

Selection criteria:
- Lepton P_T cuts and
- Tag jet requirements ($\Delta\eta$, P_T, large mass)
- Jet veto (important)
- Lepton angular and mass cuts

$$M_T = \sqrt{(E_T^{ll} + E_T^{\nu\nu})^2 - (\vec{p}_T^{\,e\mu} + \vec{p}_T^{\,miss})^2}$$

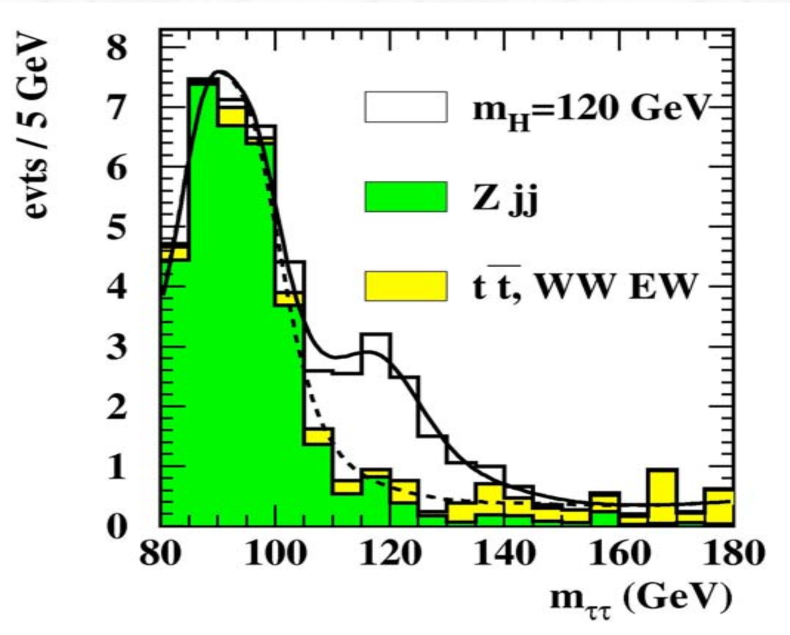




Transverse mass distributions: clear excess of events above the background from tt-production

H → τ τ decay modes visible for a SM Higgs boson in vector boson fusion

qq H → qq τ τ
→ qq ℓνν ℓνν
→ qq ℓνν hν



Experimental challenge:

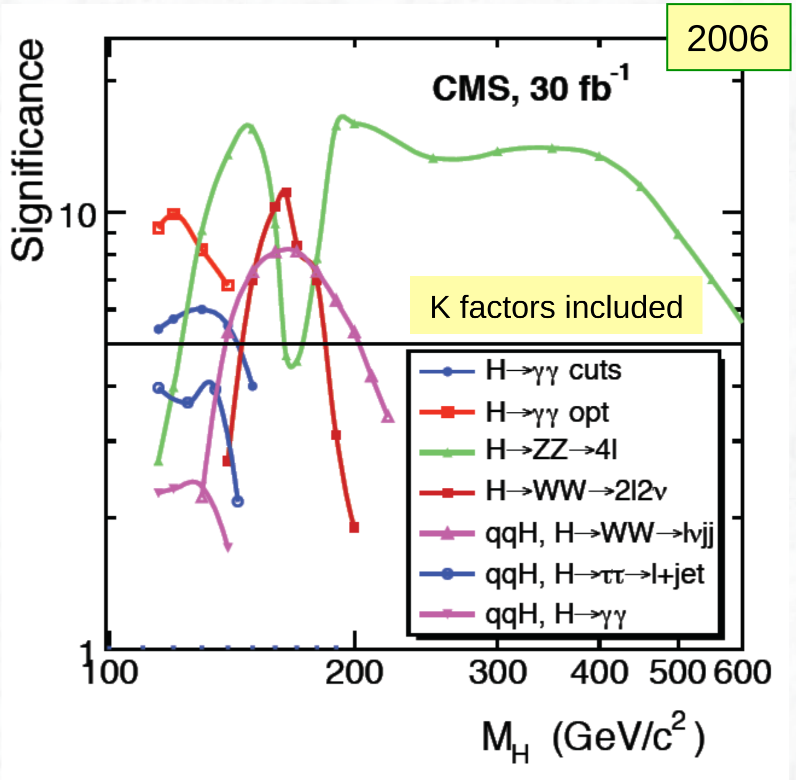
- Identification of hadronic taus
- Good E_T^{miss} resolution
  (ττ mass reconstruction in collinear approximation,
  i.e. assume that the neutrinos go in the direction of the visible decay products,
  good approximation for highly boosted taus)

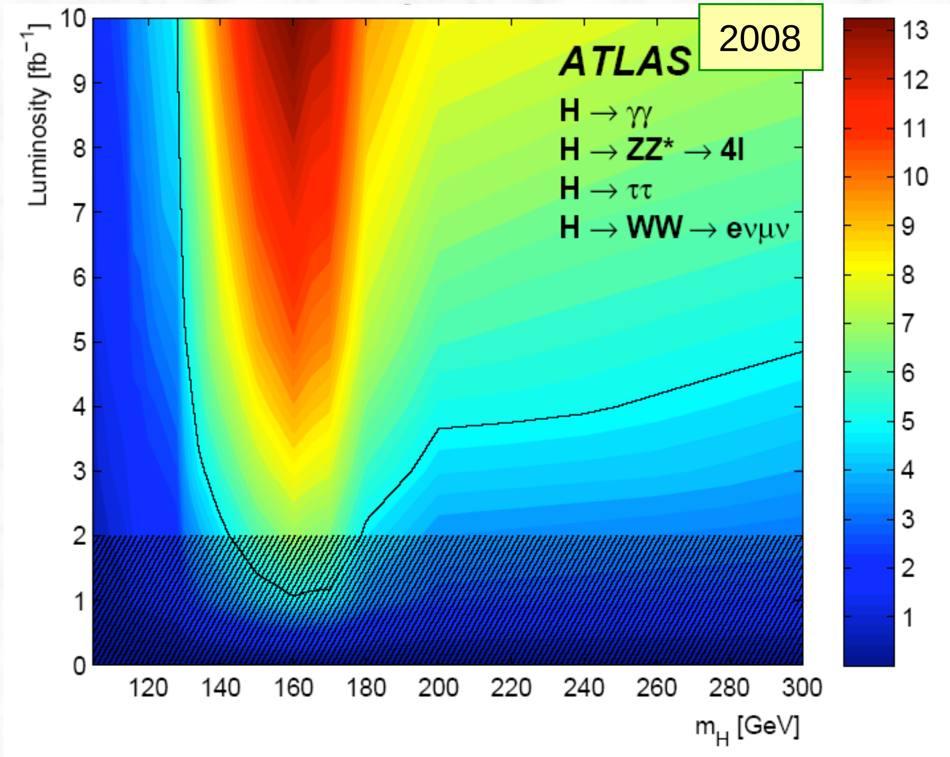
  → Higgs mass can be reconstructed

- Dominant background: Z → ττ

  the shape of this background must be controlled in the high mass region
  → use data (Z → μμ) to constrain it

LHC Higgs boson discovery potential for √s = 14 TeV

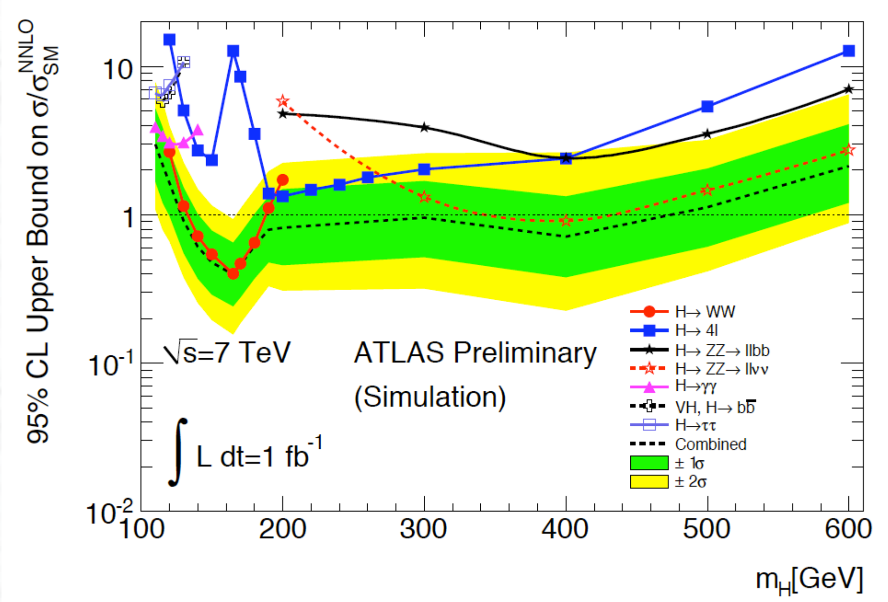


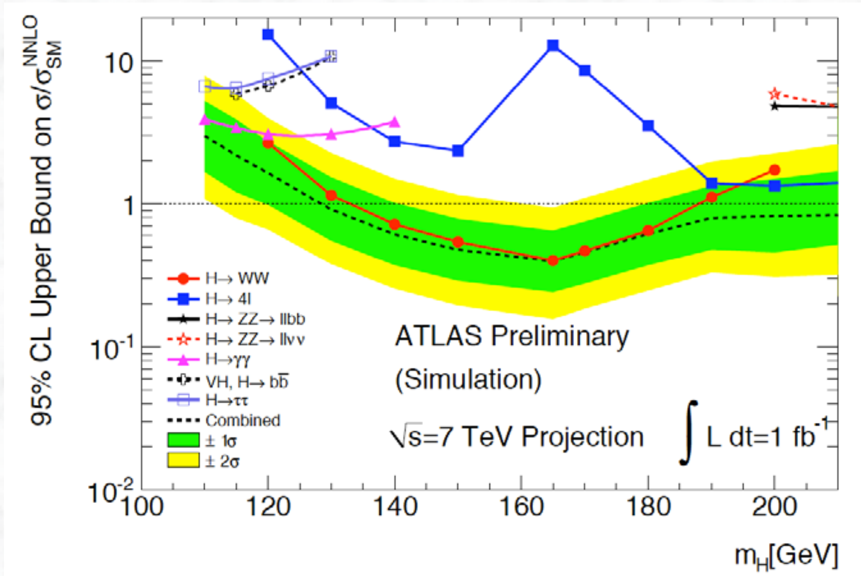


- Comparable performance in the two experiments
  [at high mass: more channels (in WW and ZZ decay modes) available than shown here]

- Several channels and production processes available over most of the mass range
  → calls for a separation of the information + global fit (see below)

LHC Higgs boson discovery prospects for √s = 7 TeV



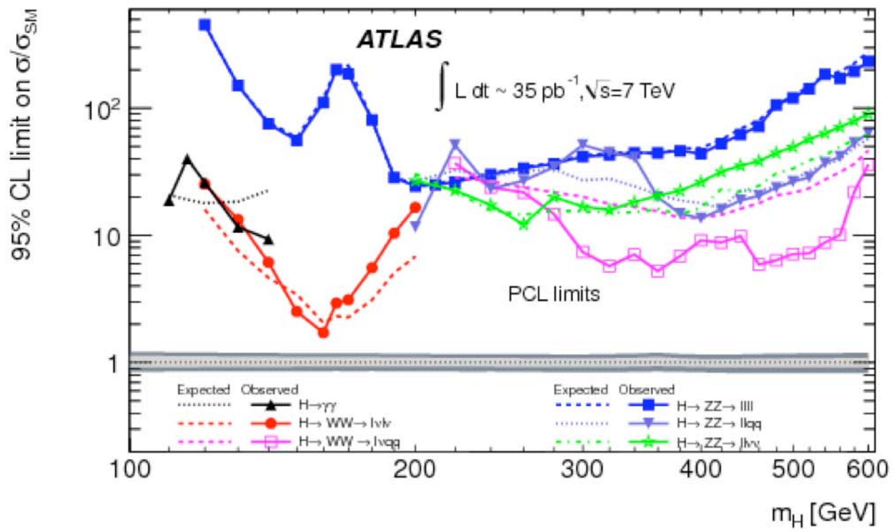


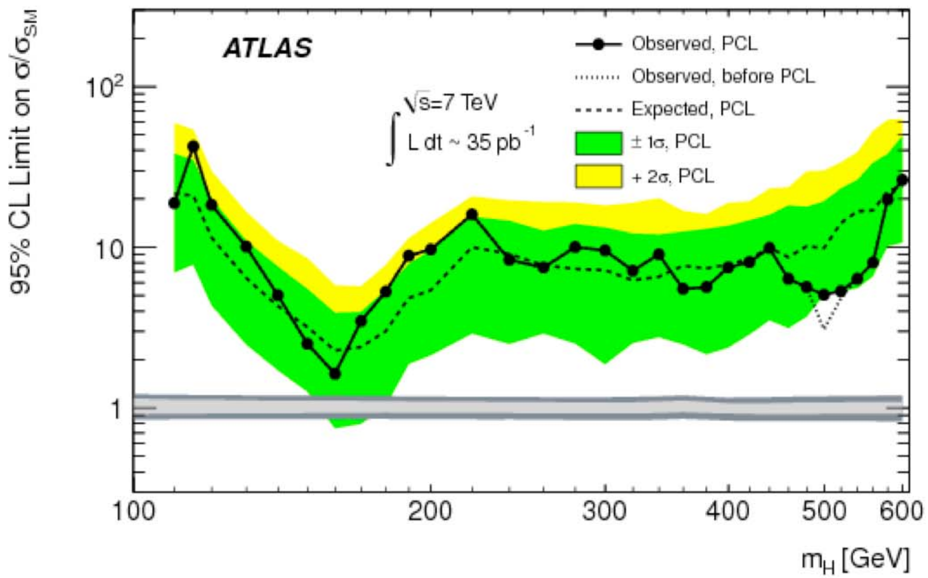
The multiple of the cross section of the Standard Model Higgs boson which can be excluded using 1 fb^{-1} of data at 7 TeV. The results for the different channels are plotted in the mass range where they are used in the combination. The plot on the right displays the results in the low mass region, below 200 GeV. The green and yellow bands indicate the 1- and 2-σ ranges in which the limit is expected to lie.

Current status of the Higgs boson search at the LHC

(i) ATLAS exclusion limits based on 2010 data (35 pb^{-1})
Combination of six different channels

new

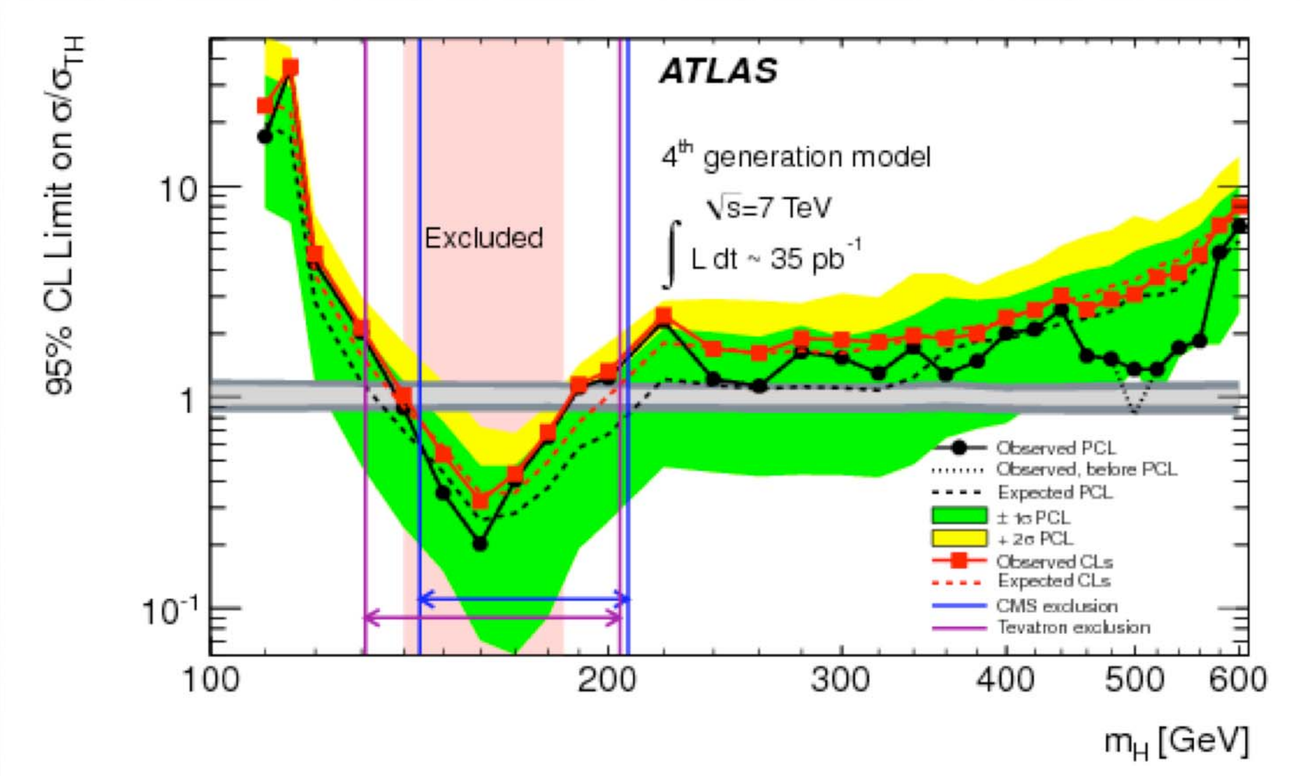




- Combination of all search channels has been performed
- No evidence (yet) for any signal contribution (also no sensitivity yet)
- Highest sensitivity in the mass range around 165 GeV
  Excluded cross section is ~2.3 σ_{SM}

Sensitivity reached for production via 4th generation:

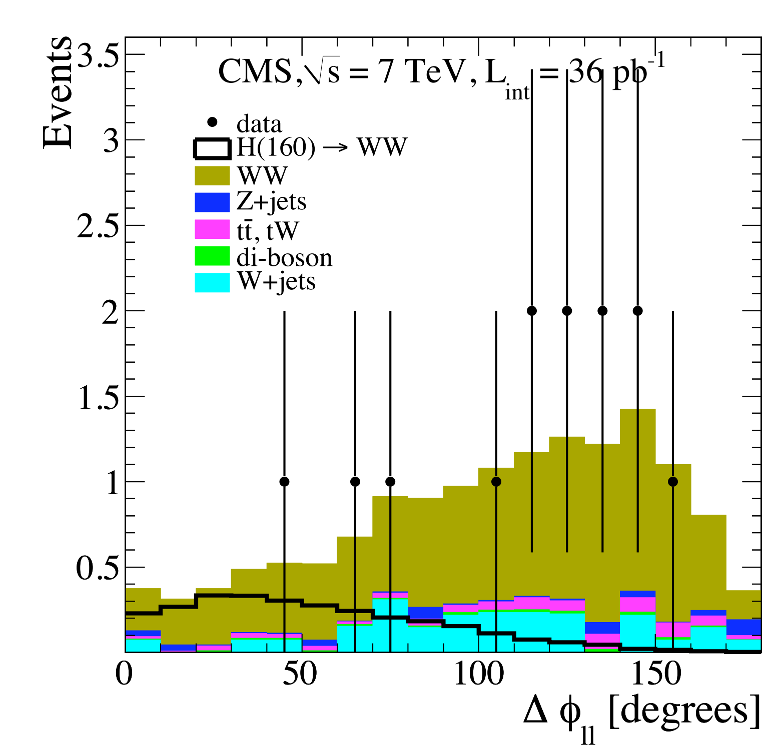
(i) ATLAS exclusion limits based on 2010 data (35 pb^{-1})
Combination of 7 different channels

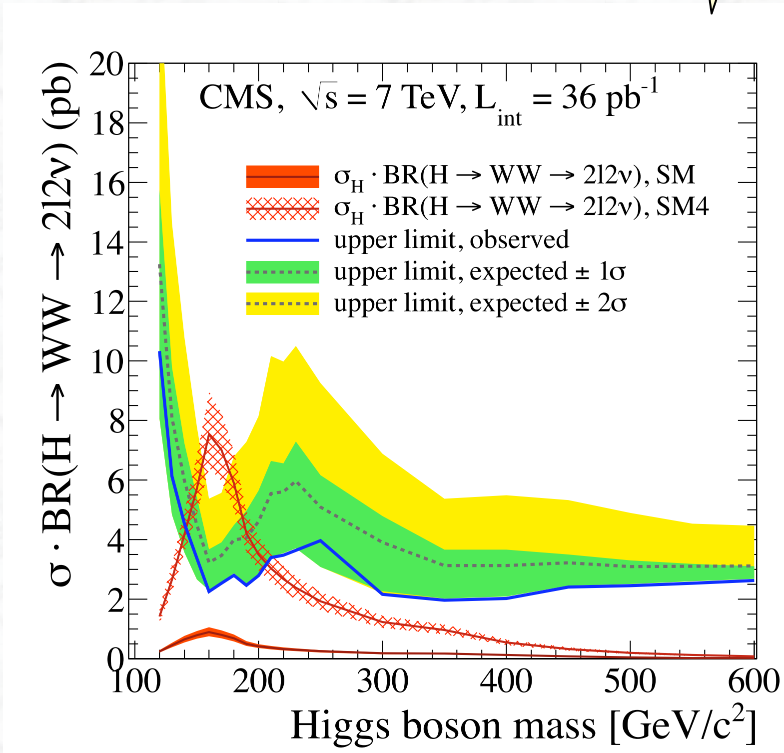


- Similar regions excluded by the Tevatron and CMS experiments

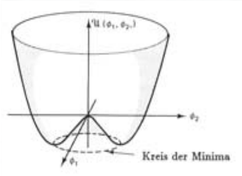
Results from the CMS collaboration on the H → WW → ℓν ℓν search:

new





- No evidence for a “Higgs-like” resonance in the first CMS data;
- Like for ATLAS: contributions form quarks of a possible 4th generation to the Higgs production can be excluded in the mass range around 150 GeV



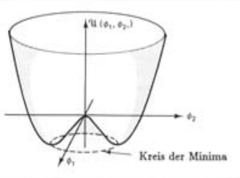
Is it a Higgs Boson ?

-can the LHC measure its parameters ?-

- Mass
- Couplings to bosons and fermions
- Spin and CP
- Higgs self coupling

Motivation:

- After a discovery of a “Higgs-like” resonance at the LHC one has to measure its parameters and consolidate the evidence for a Higgs boson
- As many parameters as possible have to be measured in as many different production and decay channels as possible ! (global fit, see later)
- Discriminate between: SM Higgs boson,
MSSM like Higgs boson,
Composite Higgs boson, ….



Summary: Is it a Higgs Boson ?

1. Mass

Higgs boson mass can be measured with high precision < 1% over a large mass range (130 - ~450 GeV) using $\gamma\gamma$ and ZZ$\rightarrow$ 4ℓ resonances

2. Couplings to bosons and fermions

- Ratios of major couplings can be measured with reasonable (~20-30%) precision;
- Absolute coupling measurements need further theory assumptions (Methods established, exp. updates are needed, in particular for VBF channels at high luminosity)

3. Spin and CP

Angular correlations in $H \rightarrow ZZ^{(*)} \rightarrow 4\ell$ and $\Delta\phi_{jj}$ in VBF events are sensitive to spin and CP (achievable precision is statistics limited, requires high luminosity)

4. Higgs self coupling

No measurement possible at the LHC;
Very difficult at the sLHC, there might be sensitivity in HH $\rightarrow$ WW WW for m_H ~ 160 GeV
Situation needs to be re-assessed with more realistic simulations