ATLAS Discovery Potential of the Standard Model Higgs Boson

Christian Weiser
University of Freiburg

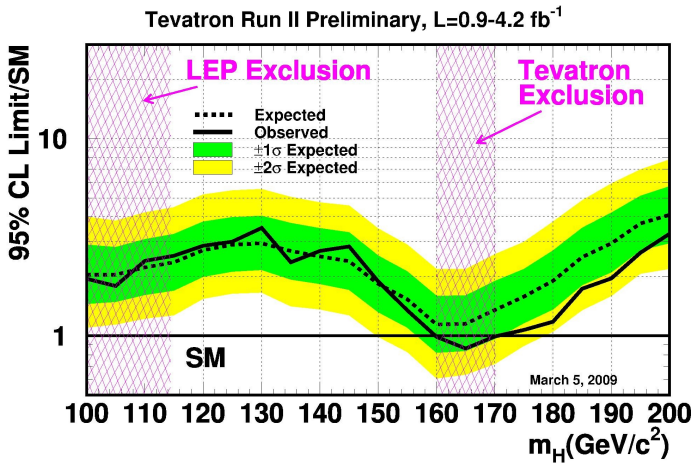
(on behalf of the ATLAS Collaboration)

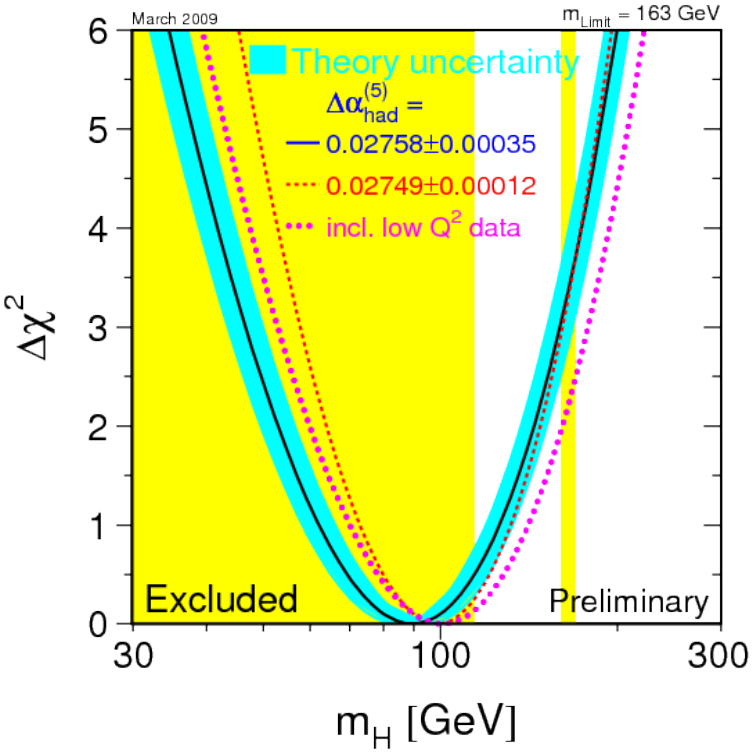
14th Lomonosov Conference on Elementary Particle Physics
Moscow, August 2009

Content

- Introduction
- Higgs search channels in ATLAS
  - $H \rightarrow \gamma\gamma$
  - VBF $H \rightarrow \tau\tau$
  - $H \rightarrow bb$
  - $H \rightarrow ZZ$
  - $H \rightarrow WW$
- Combined sensitivity
- Summary

What do we already know?





- Direct searches at LEP

$M_H > 114.4$ GeV/c^2 (95% CL)

- Direct searches at the TEVATRON

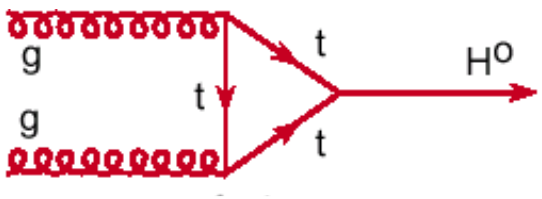
Exclude 160 GeV/c^2 < M_H < 170 GeV/c^2 (95% CL)

- electroweak precision measurements

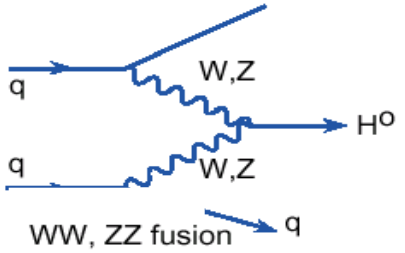
$M_H < 163$ GeV/c^2 (95% CL)
(191 GeV/c^2 incl. LEP Limit)

Higgs Boson Production

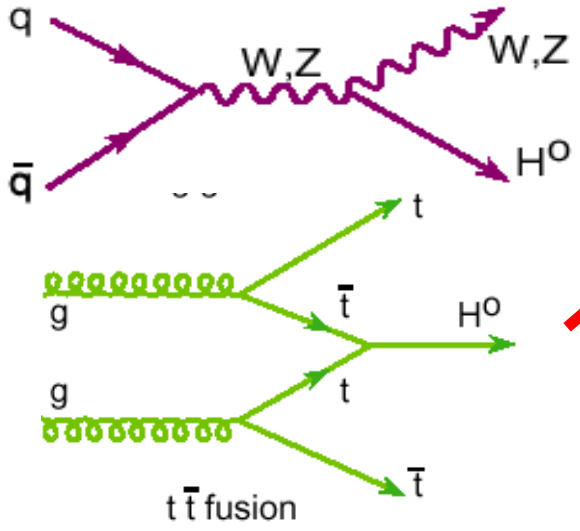
(i) Gluon-Fusion

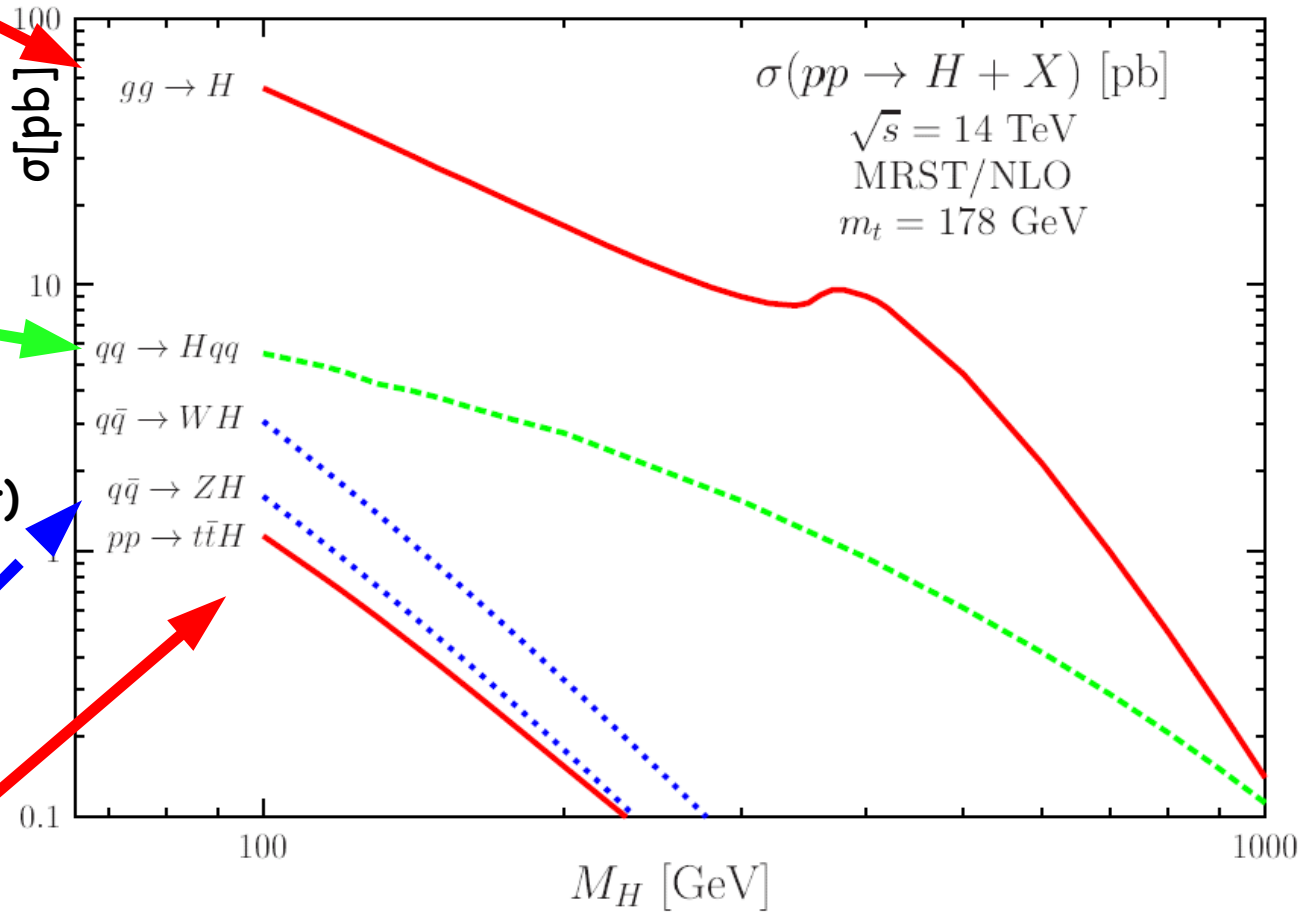


(ii) Vector Boson Fusion (VBF)

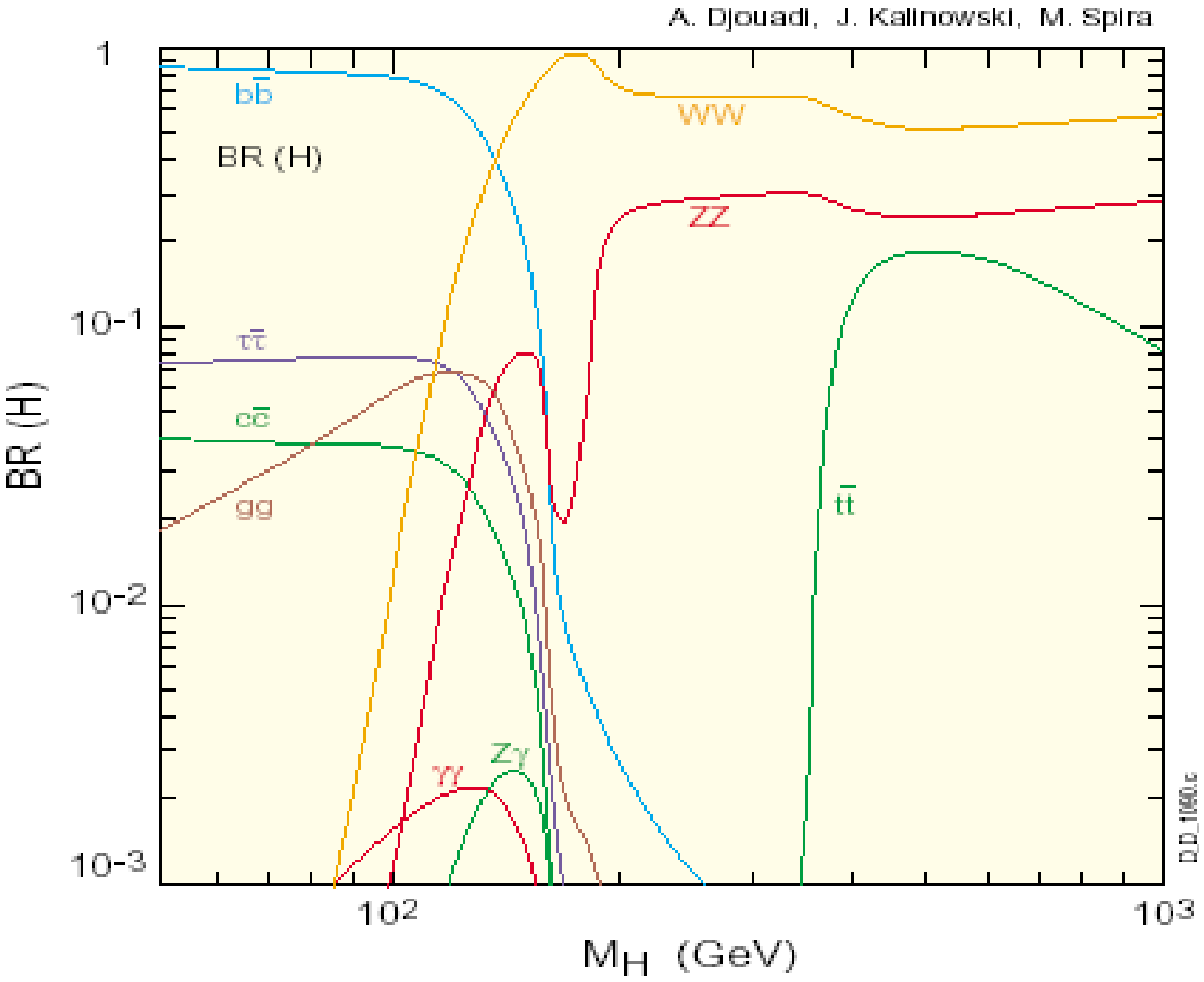


(iii) Associated Production (W/Z, tt)

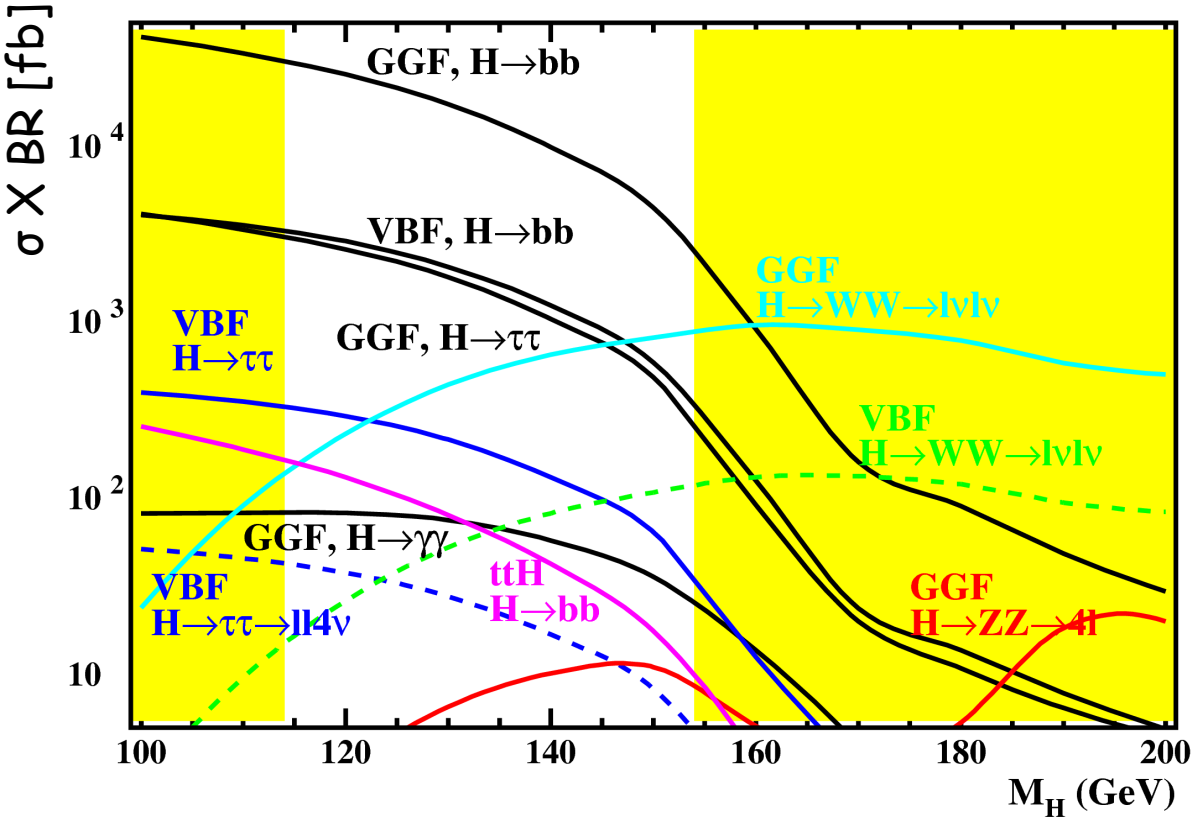




Higgs Boson Decays



Search Channels



Main channels studied:

Low mass:
- $H \rightarrow \gamma\gamma$
- $qqH, H \rightarrow \tau\tau$
- $t\bar{t}H, H \rightarrow bb$
- $W/Z\,H,\ H \rightarrow bb$ **NEW!**

Also medium (& high) mass:
- $H \rightarrow WW^{(*)}$
- $H \rightarrow ZZ^{(*)}$

For low mass: Combination of large production cross section (gg-fusion) and large BR (H->bb) does not work because of QCD background

Higgs Studies in ATLAS

Studies presented here:

- Realistic (at least we believe …) GEANT4 based detector description simulation
- Real reconstruction algorithms
- Trigger simulation
- Effects of additional minimum bias events *(Pile-Up)*, misalignment etc. studied
- Improved generators (NLO etc.)
- Background estimation from data in many cases

For all details see **CERN-OPEN-2008-020**

Focus in this talk:

Discovery potential in the low and medium mass range (mH ≤ 200 GeV) @ √s = 14 TeV

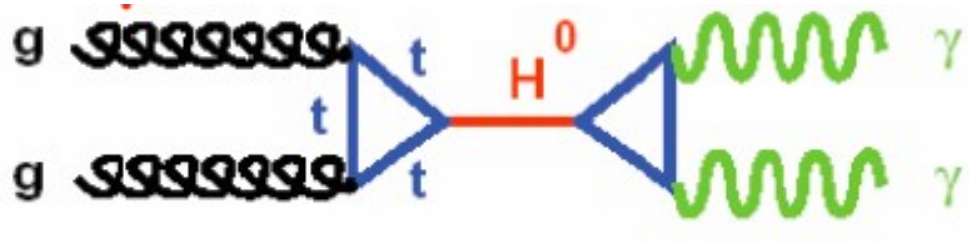
To be (re)studied:

Parameter determination (Mass, Spin, CP, Couplings, ….)

Heavy Higgs bosons

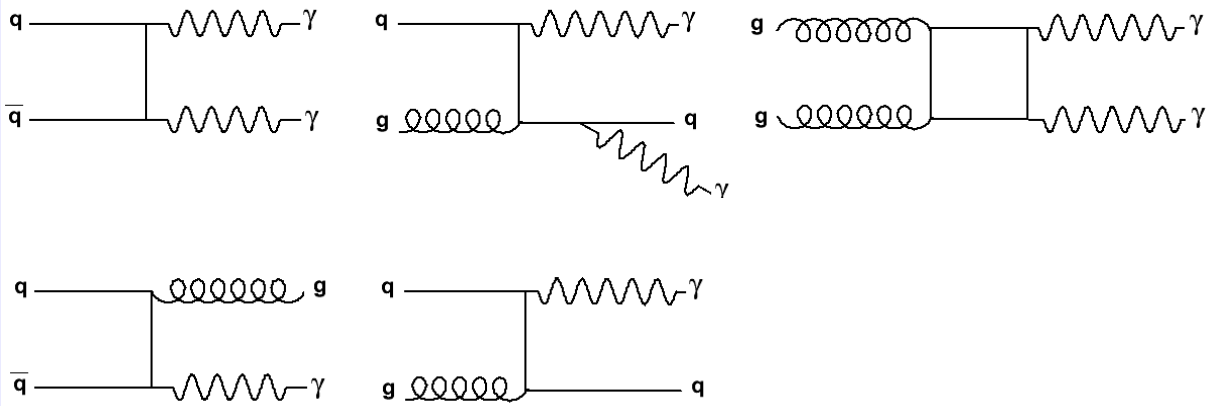
$H \rightarrow \gamma\gamma$

No direct coupling
tiny BR (≈‰)
$\sigma \times BR \approx < 100$ fb



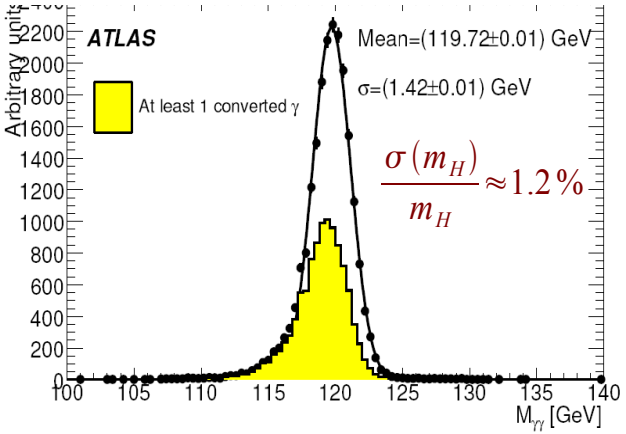
Backgrounds:

- **Irreducible $\gamma\gamma$(+X)**
  ($\sigma \approx 30$ pb for $p_{T,\gamma} > 25$ GeV, $|\eta| < 2.5$
  80 GeV < $m_{\gamma\gamma}$ < 150 GeV)
- **Reducible γ+jet, jet+jet**
  (γj : $\sigma \approx 180$ nb for $p_{T,\gamma} > 25$ GeV
  jj : $\sigma \approx 480$ μb for $p_T > 25$ GeV)



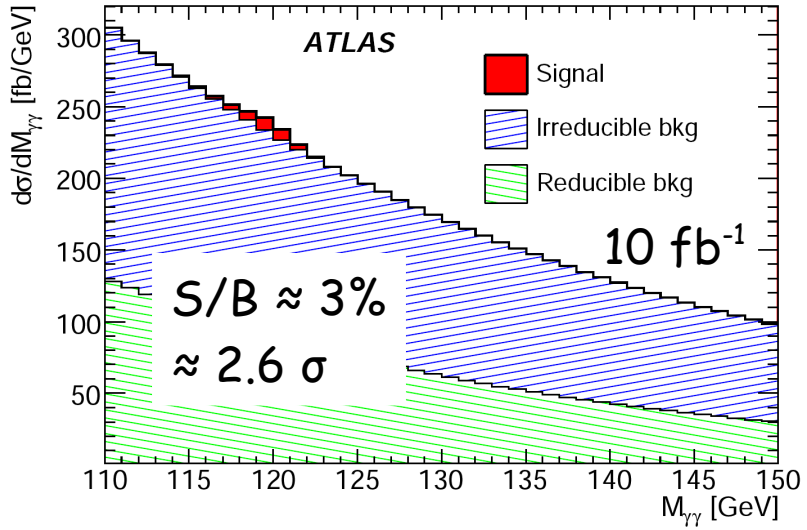
Need excellent
- Photon identification
- Photon-jet separation
- Mass resolution

≈ 50% of events:
at least 1 photon conversion
→ reconstruct from e^+, e^- tracks
in Inner Detector

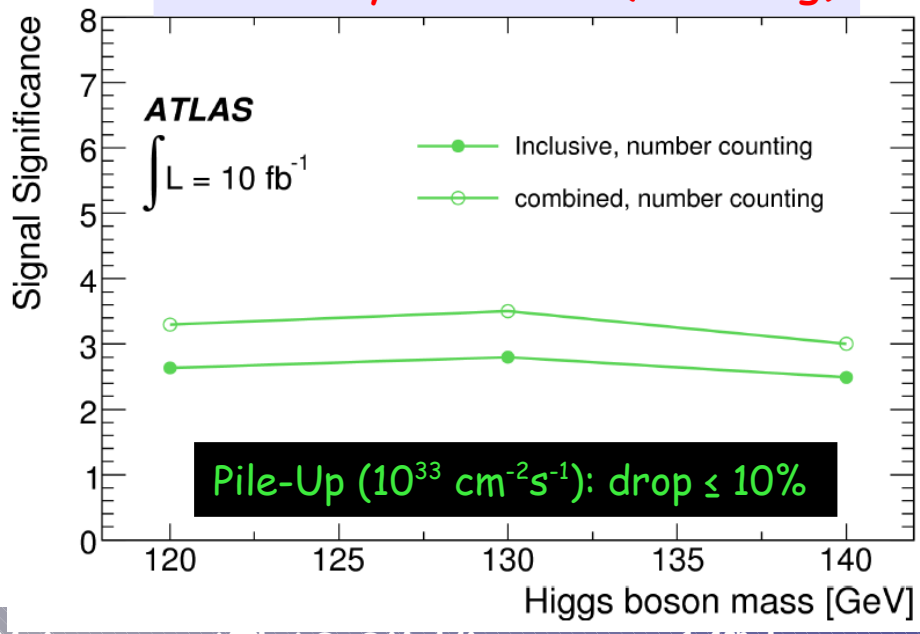


$H \rightarrow \gamma\gamma$

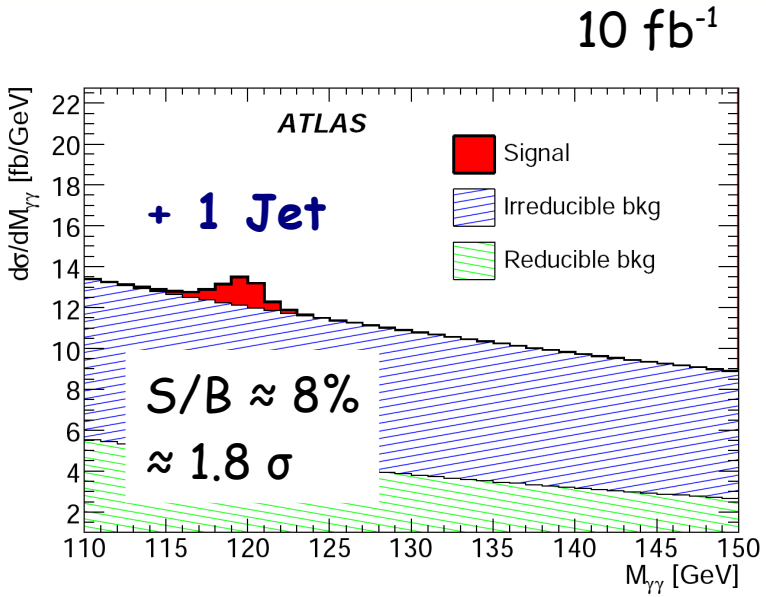
Inclusive (ask for photons only) analysis:

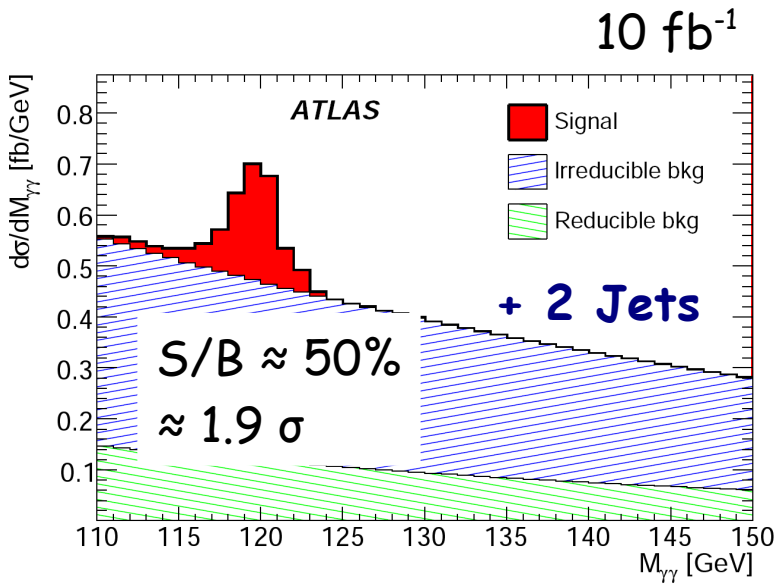


Discovery Potential (counting)



$\gamma\gamma$ + 1,2 jet analyses (enhance VBF):

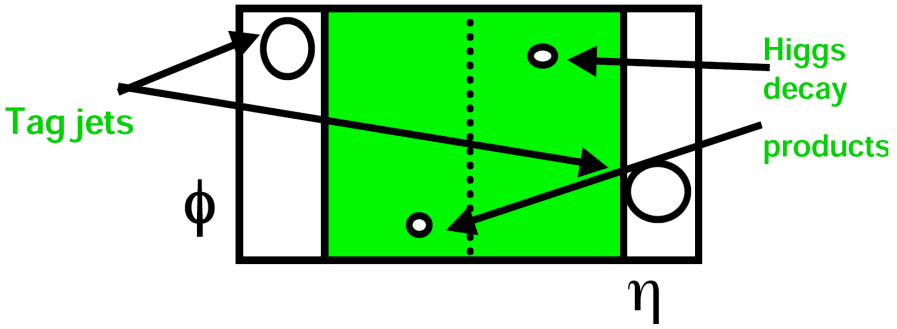


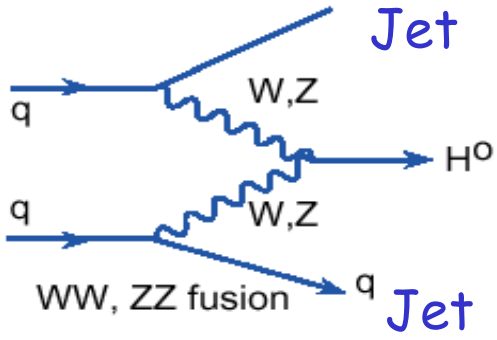


Vector Boson Fusion qqH, H → ττ

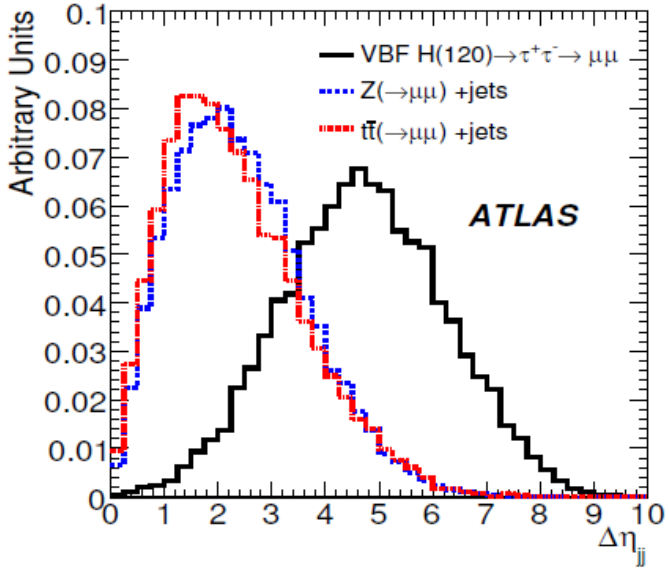
Signature of Vector Boson Fusion (VBF)
Production process:

- Two hard forward/backward "Tagging Jets" with large rapidity gap and high invariant mass
- Jet activity suppressed in central part of the detector → Central Jet Veto
- Large discrepancies between generators

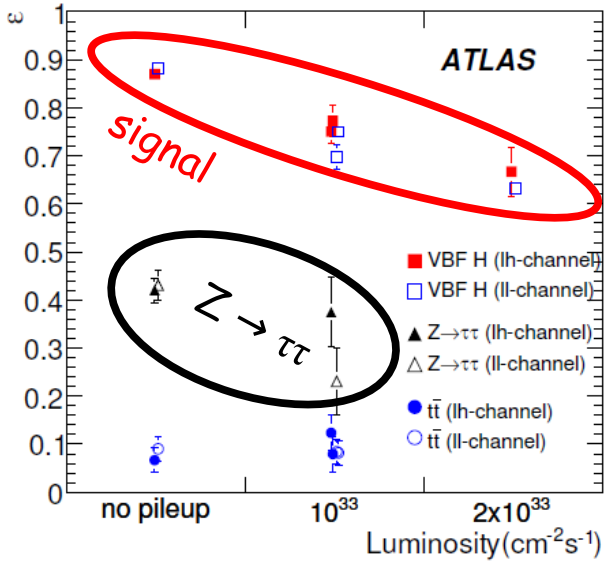




Rapidity Gap



Central Jet Veto



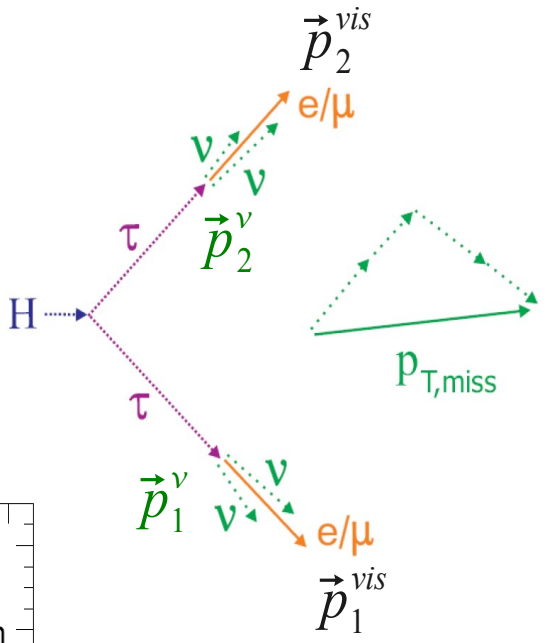
Main Backgrounds:

- Z (→ ττ) + jets
- W (→ τν) + jets
- tt

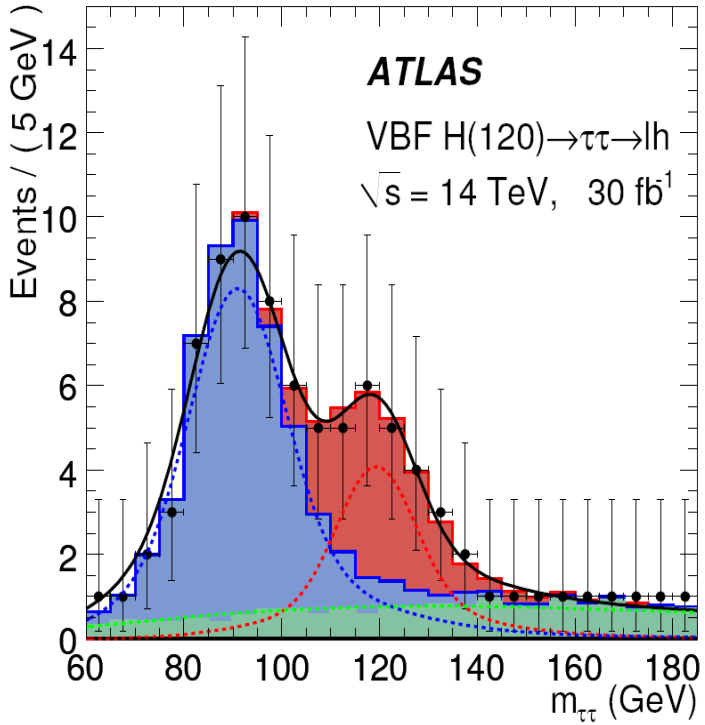
Vector Boson Fusion qqH, H → ττ

τ decay channels:

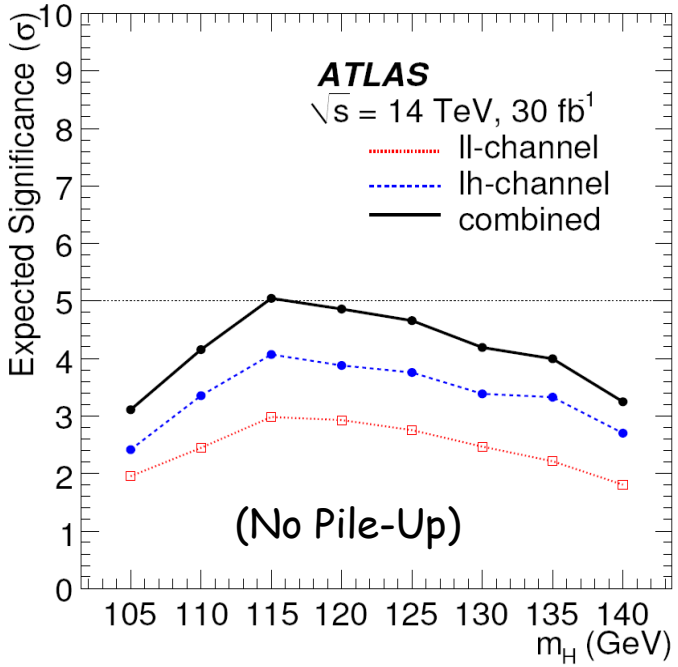
- Lepton-lepton (ll)
- Lepton-hadron (lh)
- [Hadron-hadron (hh)]



Invariant mass computation:
(> 1 neutrino in final state)
"Collinear Approximation"
(Crucial: MET resolution)



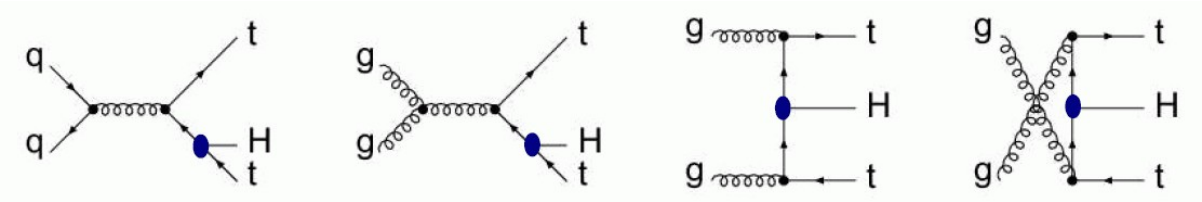
Dominating Background
$Z \rightarrow \tau\tau$:
Estimate on data from $Z \rightarrow \mu\mu$ events with $\mu \rightarrow \tau$ transformation

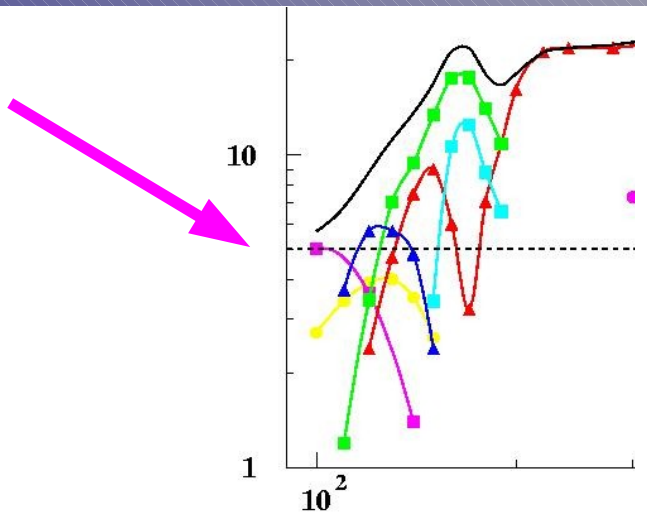


hadron-hadron final state:
No reliable estimate of QCD background without data
→ No expected significance quoted

H → bb

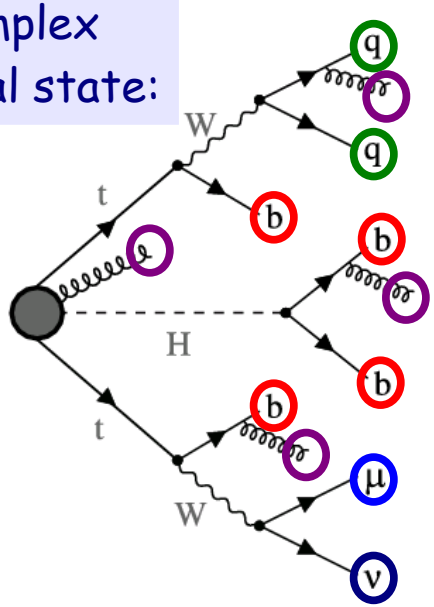
ttH a promising search channel some years ago:





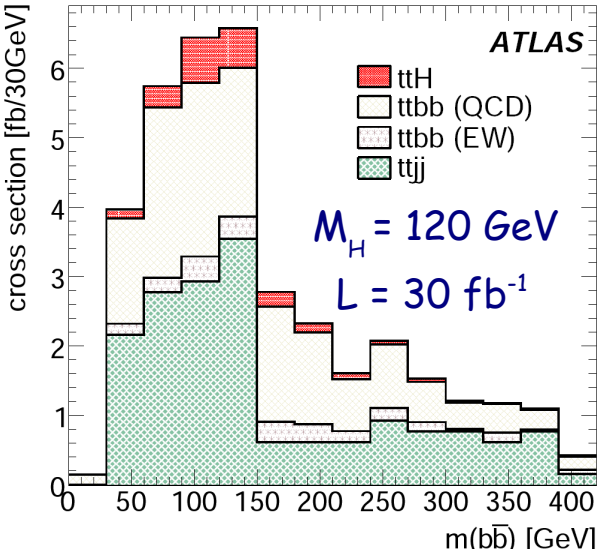
Access to top-Higgs Yukawa coupling!

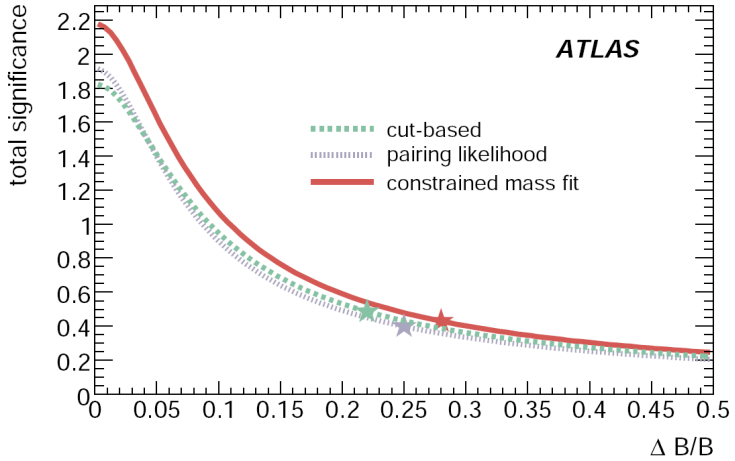
Complex final state:



Main Backgrounds:
ttbb, ttjj

Now:





- Need precise background normalization!
- Has to come from data!
- Pile-Up: impact on selection efficiency and mass resolution

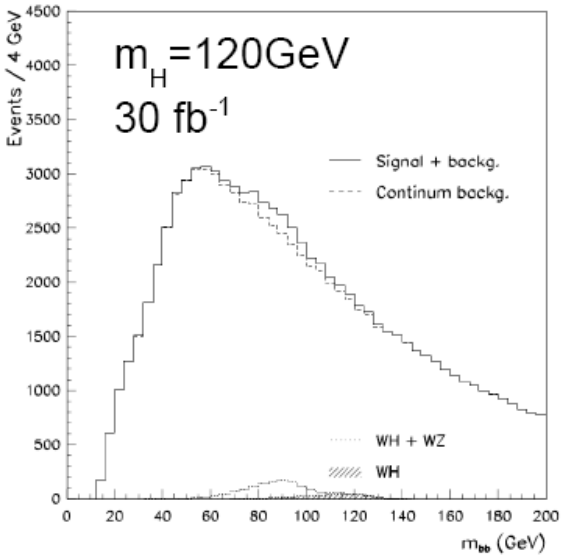
→ ttH has disappeared from latest sensitivity plots!

W/Z H

NEW!

The most important channels at the TEVATRON at low mass!

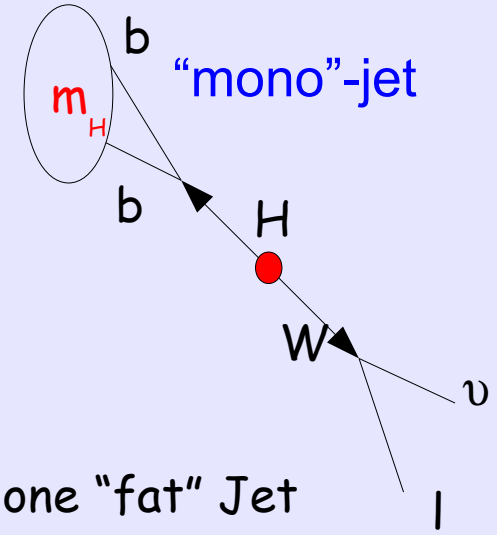
But: Signal to background ratio less favourable at the LHC



$S/\sqrt{B}$	2.1
S/B	1.3%

Follow idea of J.Butterworth et al. [PRL 100:242001,2008]:

Select events (≈5% of cross section), in which H und W bosons have large transverse momenta: p_T > 200 GeV



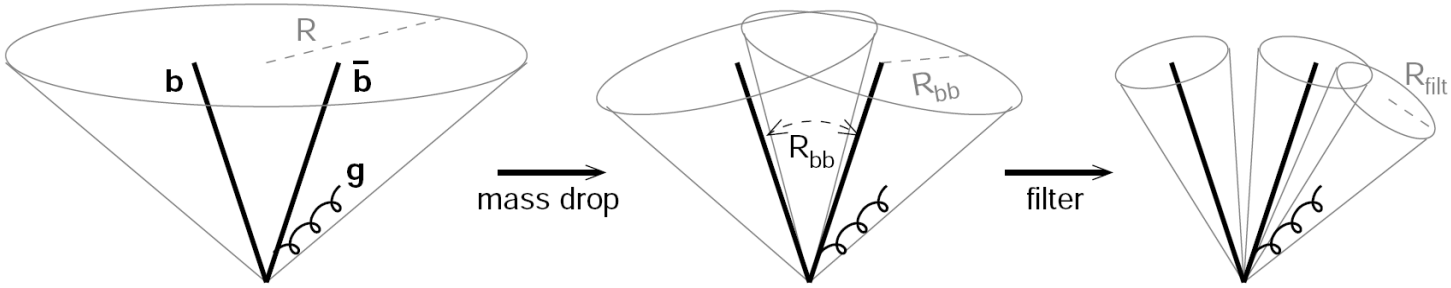
-> b-Quarks in one "fat" Jet

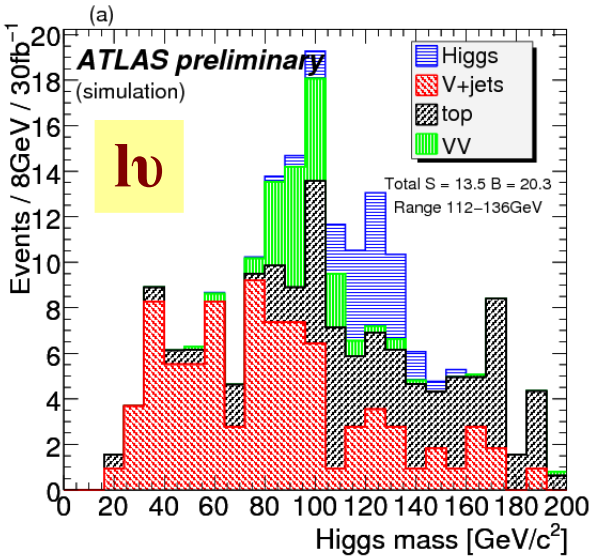
+ Acceptance (more central in detector)
+ Lepton-Identification, B-Tagging

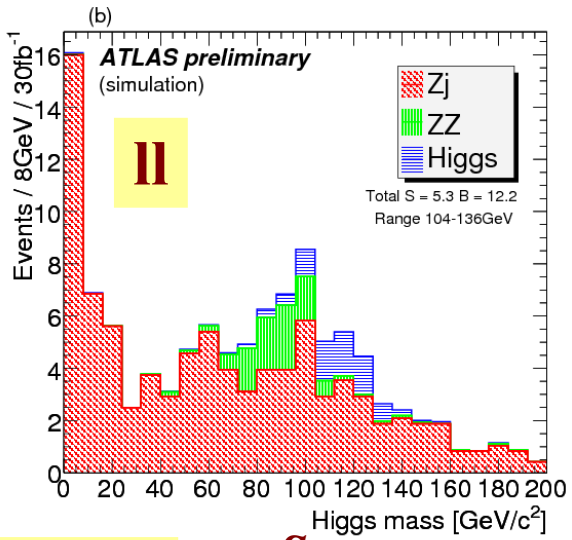
W/Z H

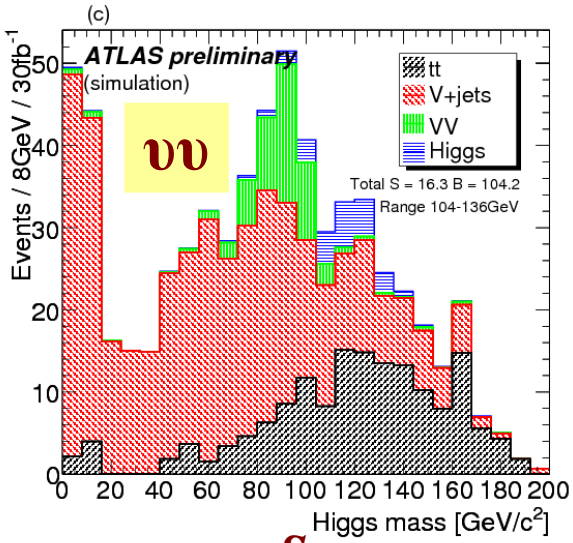
ATL-PHYS-PUB-2009-088

Analyse jet structure:









$L^{int.} = 30\ fb^{-1} : \frac{S}{\sqrt{B}} = 3.0$

M_H = 120 GeV

$\frac{S}{\sqrt{B}} = 1.5$

$\frac{S}{\sqrt{B}} = 1.6$

Combined: $\frac{S}{\sqrt{B}} = 3.7$

(Pile-Up not yet included)

- S/B much better than for ttH
- Different backgrounds for different channels
- Still good sensitivity including systematics (e.g. S/√B = 3.0 for 15% uncertainty on all backgrounds)

$H \rightarrow ZZ$

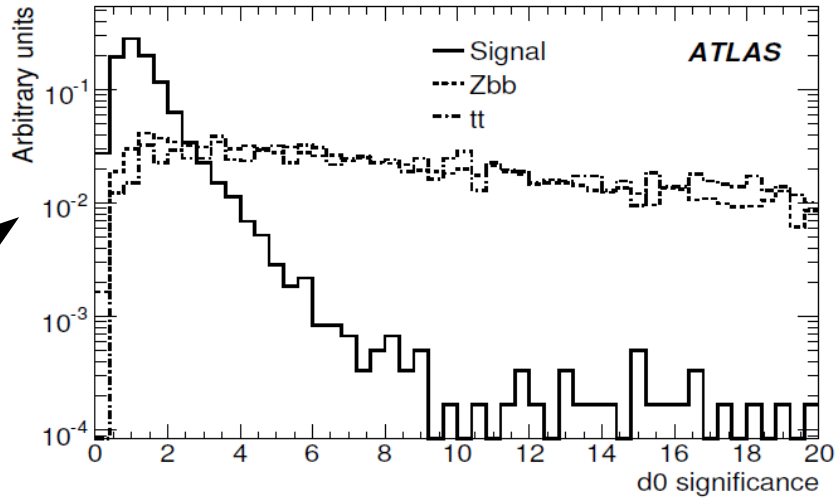
"Golden Channel":

- Clear, narrow mass peak on top of background
- Covers wide mass range

Backgrounds:

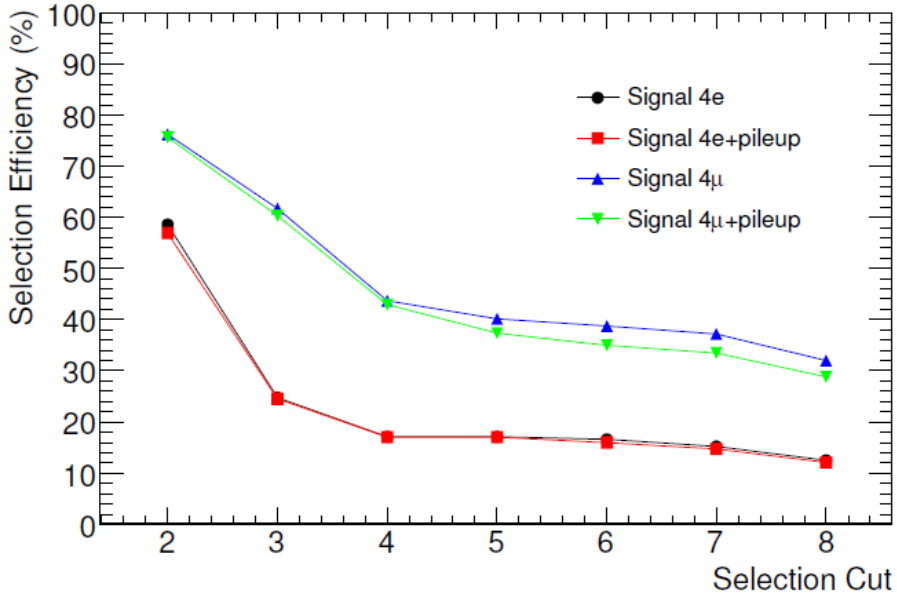
- Irreducible: ZZ
- Reducible: Zbb, tt

→ Lepton isolation and impact parameters

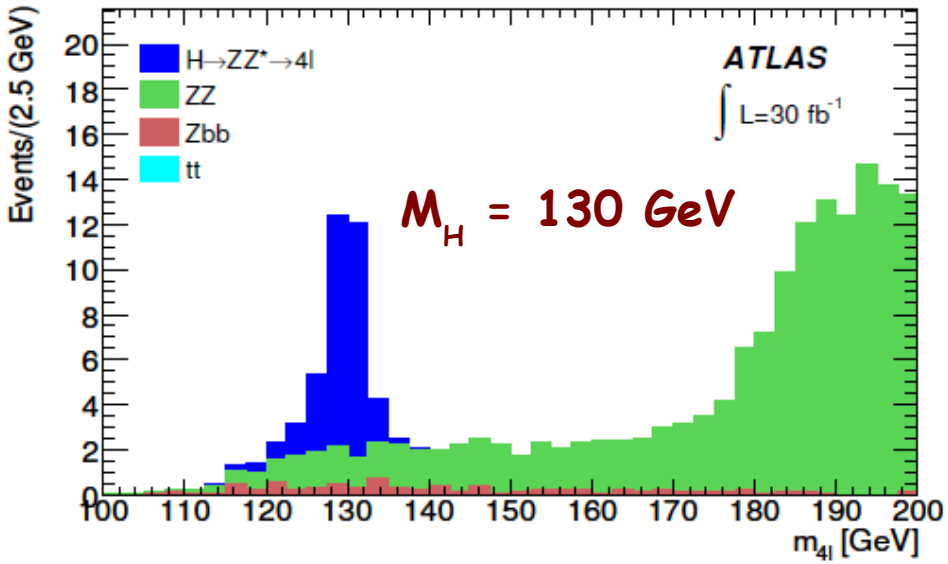


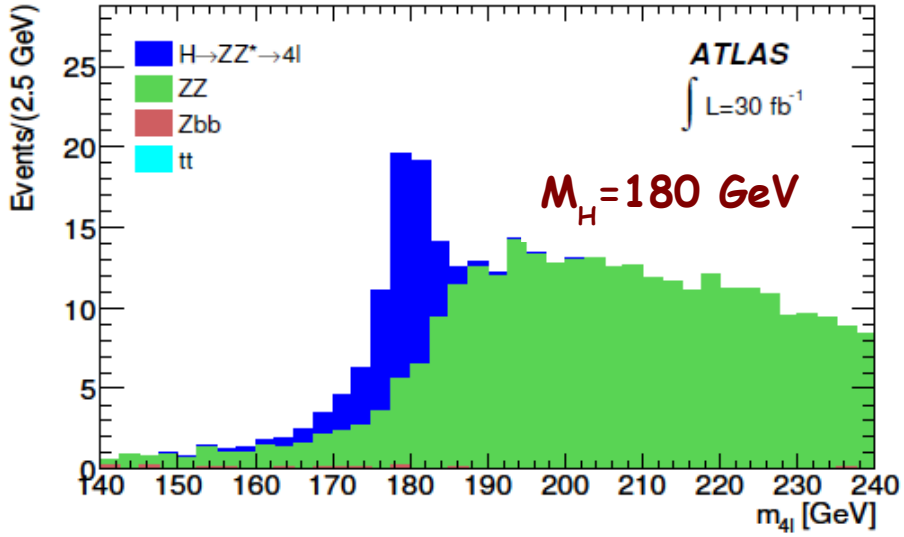
Effect of Pile-Up (10^{33} $cm^{-2}s^{-1}$) and *Cavern Background*:

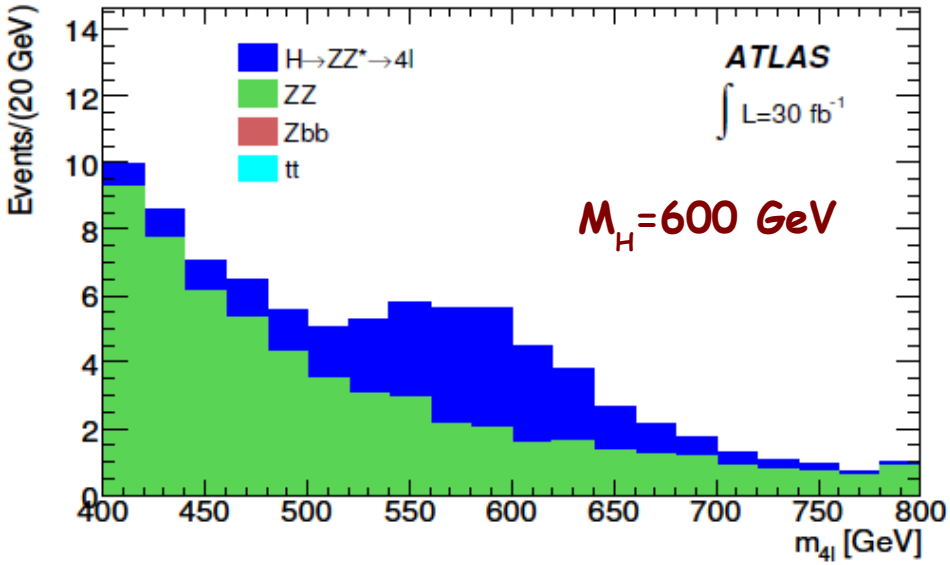
Loss in signal efficiency of ≈ 10% (studied for m_H = 130 GeV)

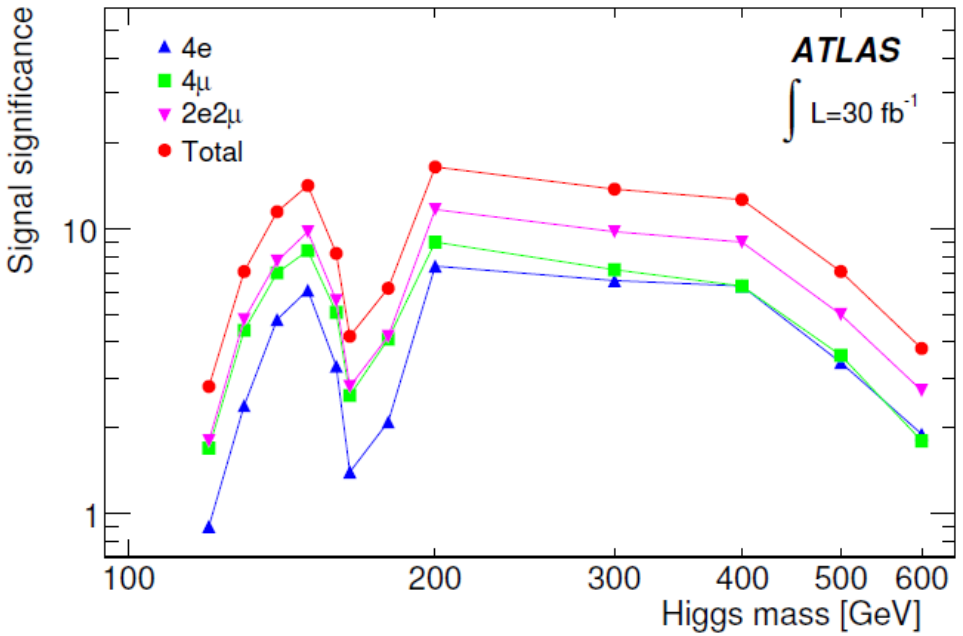


$H \rightarrow ZZ$



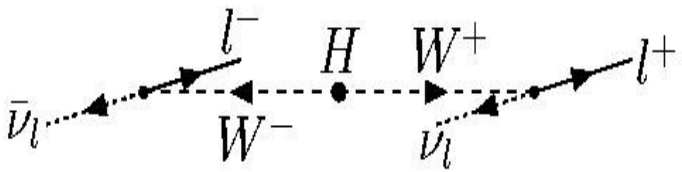


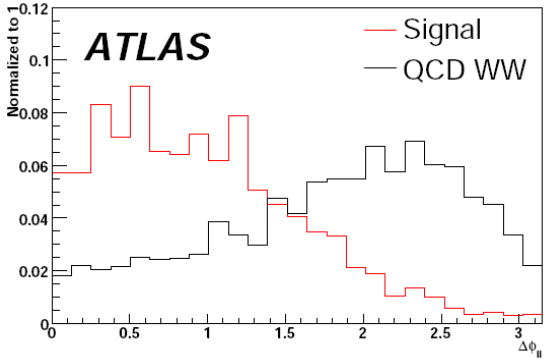




H → WW

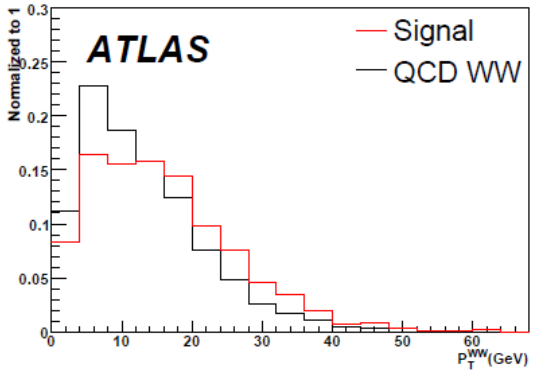
- Accessible for dominant production process (gg fusion) AND decay mode (m_H > 135 GeV)
- Final state considered: H → WW → eνμν
- Two analyses: + 0 jet (gg fusion), +2 jets (vector boson fusion)
- 2 neutrinos → no mass peak reconstructable, only transverse mass
- Use angular correlation between leptons:

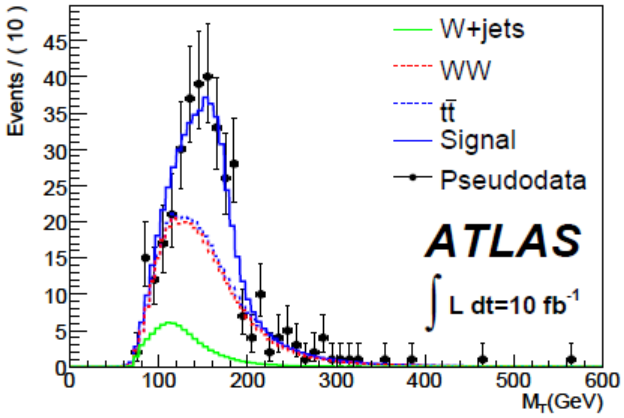


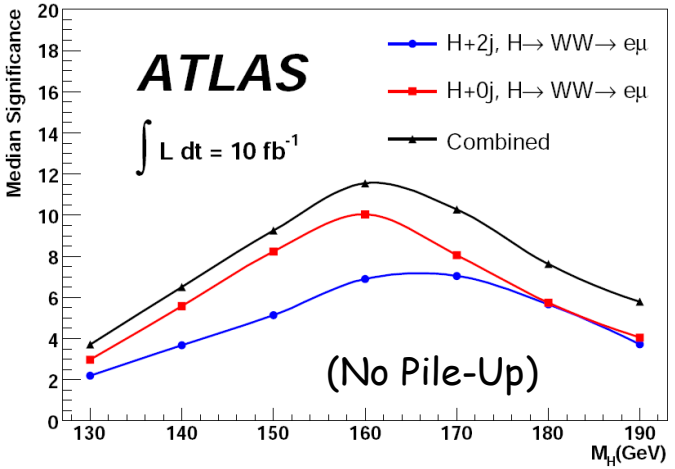


Δϕ(ll)

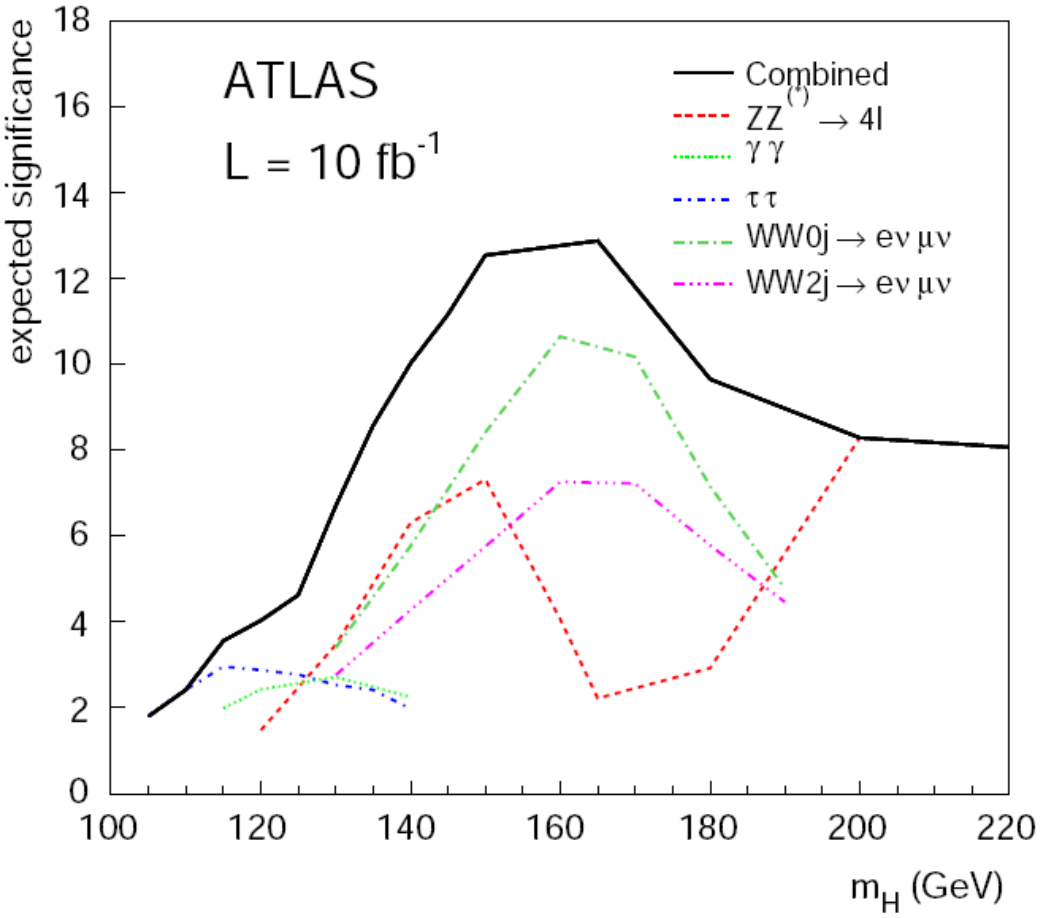
Fit transverse mass and transverse momentum of
The WW system in ΔΦ signal and control regions

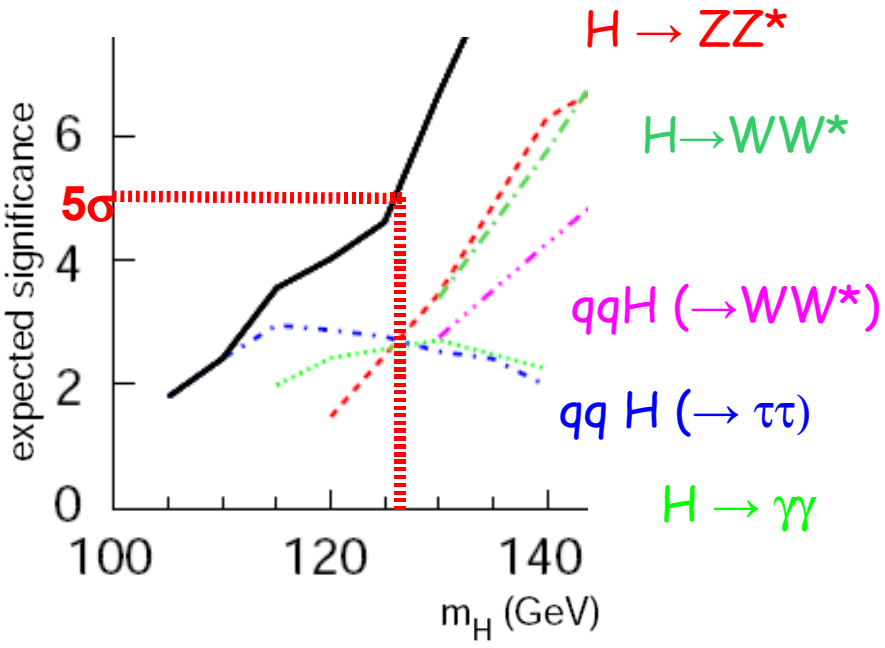






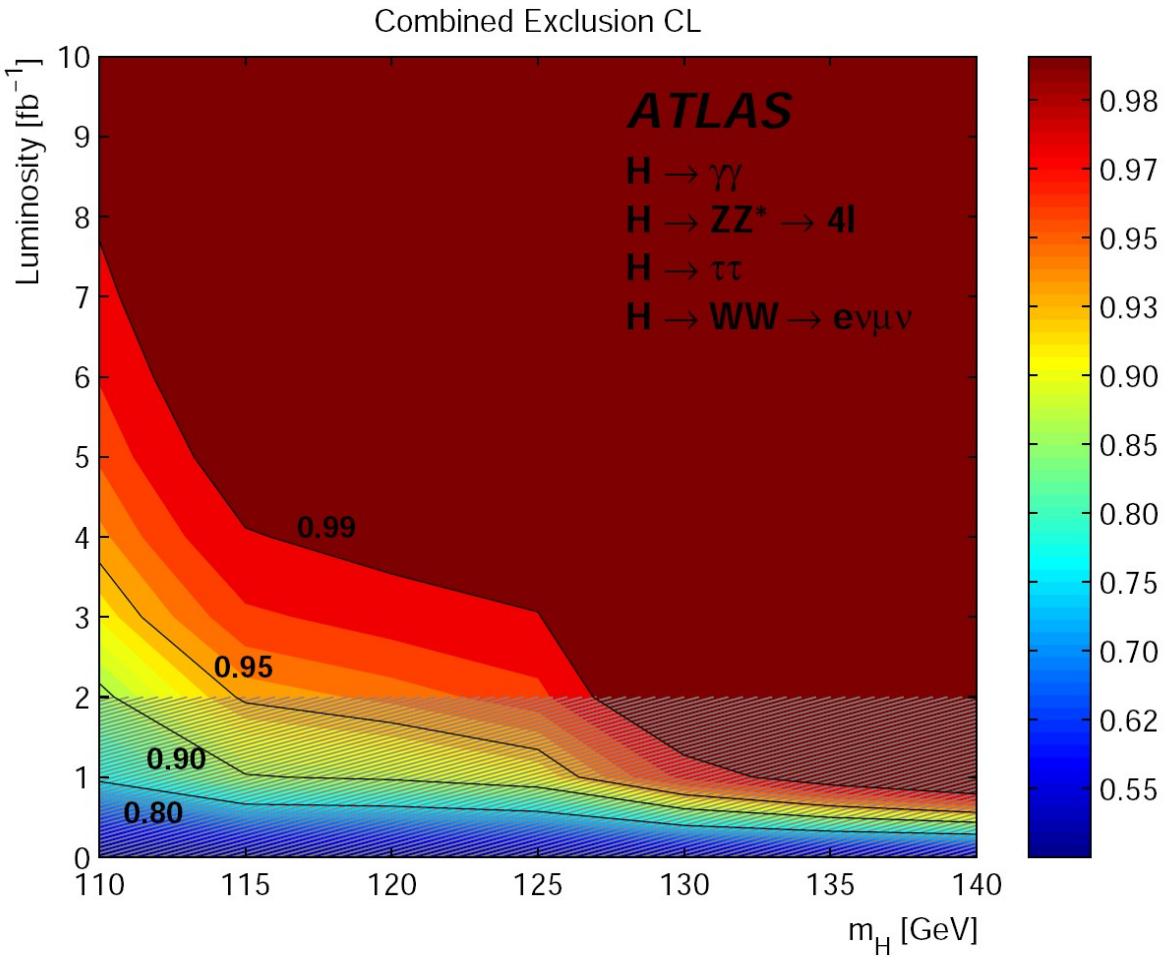
Combined Discovery Potential





- 5 σ discovery seems possible with 10 fb^{-1} for m_H > 127 GeV
- Adding the W/Z H, H → bb channel will improve situation for low masses

Exclusion



2 fb^{-1} to exclude m_H > 115 GeV @ 95% CL

Conclusions

- Much more realistic detector simulations, Monte Carlo generators, reconstruction tools etc. have improved the quality of the predictions for ATLAS Higgs boson searches significantly
- Strong effort has been put in studying data driven methods to become less dependent on Monte Carlo generators
- A discovery (or exclusion) should be possible over the full mass range from 115 GeV – 1 TeV
- However, the low mass region (just above the LEP limit) is very challenging and several channels may contribute