Higgs Sensitivity in ATLAS

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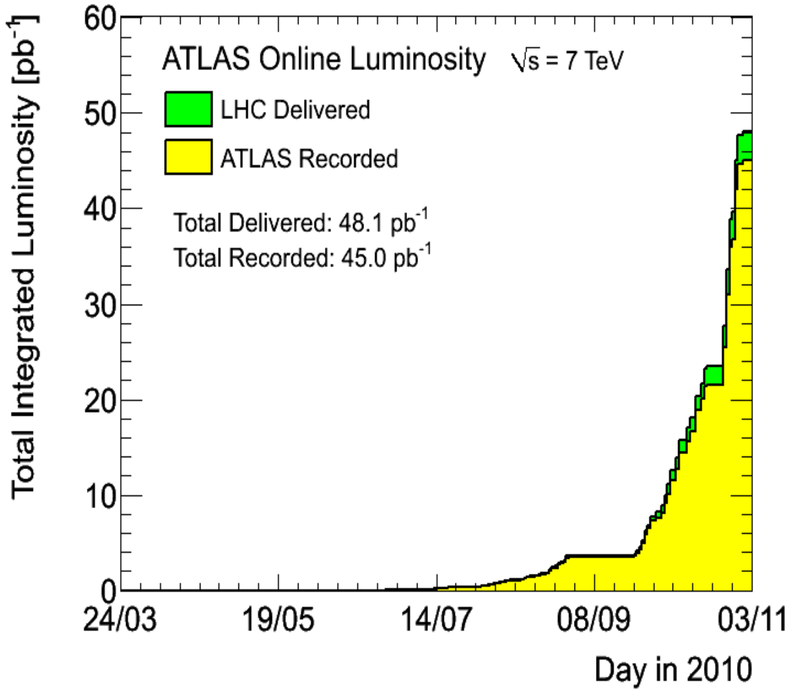
On behalf of the ATLAS collaboration

Outline

- LHC operation – status & plans
- Standard model Higgs boson
  - Higgs boson production & decays in ATLAS
  - Higgs boson searches in different channels
  - Background estimation from data
  - Combined Higgs boson sensitivity
- MSSM Higgs boson sensitivity
  - Charged Higgs boson
  - Neutral Higgs boson

LHC status & plans

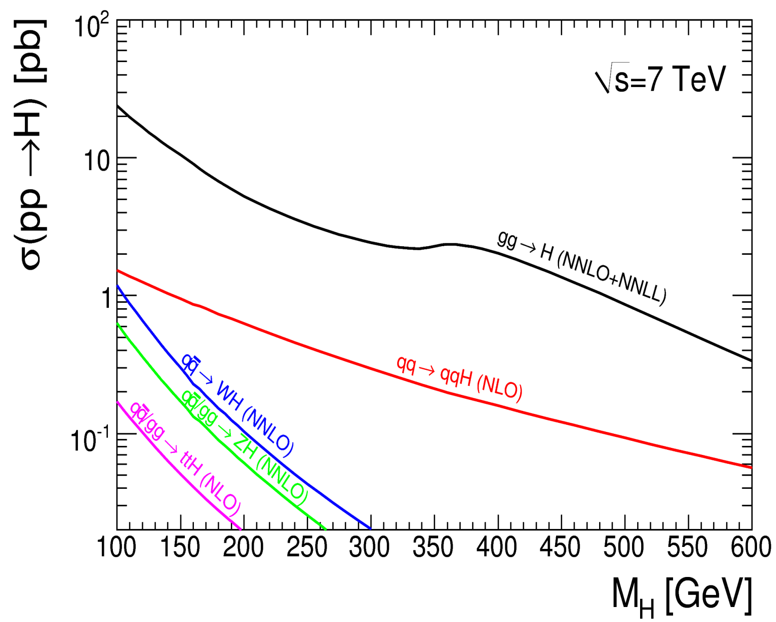
- LHC operation in 2010
  - Proton-proton collisions with integrated luminosity 45 pb^{-1} at 7 TeV recorded in ATLAS
- LHC plans for 2011
  - Likely to run at the center of mass energy 8 TeV
  - Integrated luminosity of 2.2 fb^{-1} can be delivered with 200 days of running

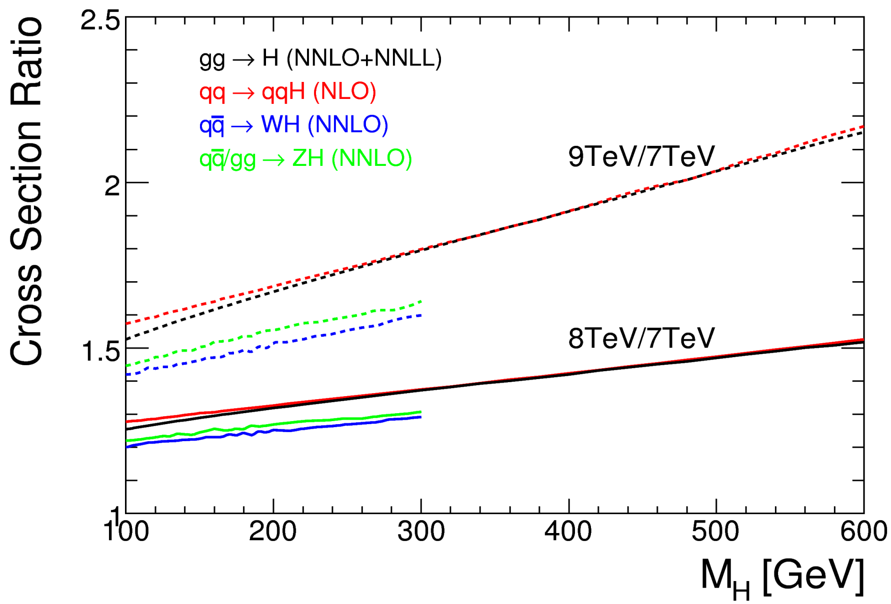


Standard Model Higgs boson production

Largest production cross section at the LHC

- Gluon-gluon fusion
  - Can be used in Higgs decays with clear signature in the final state (leptons, photons)
- Vector boson fusion
  - Typical signature: two tagging jets in the forward detector region
  - Used in decay modes with large background





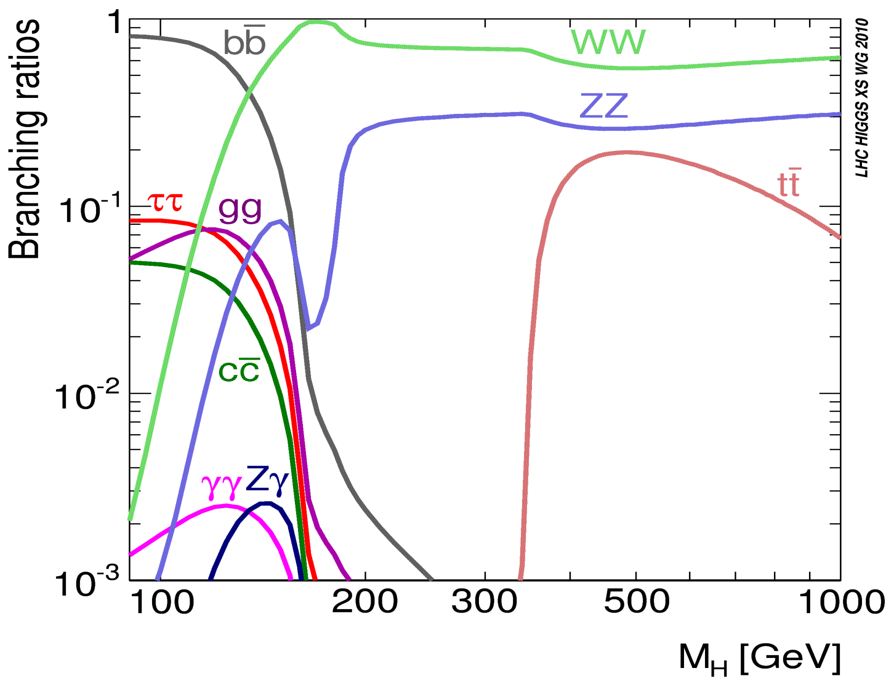
Comparison of cross sections for different center of mass energies

- Scaling factor between 7 TeV and 8 TeV for gluon-gluon fusion, vector boson fusion
  - Factor of 1.25 at M_H = 110 GeV
  - Factor of 1.5 at M_H = 600 GeV

Standard Model Higgs boson decays

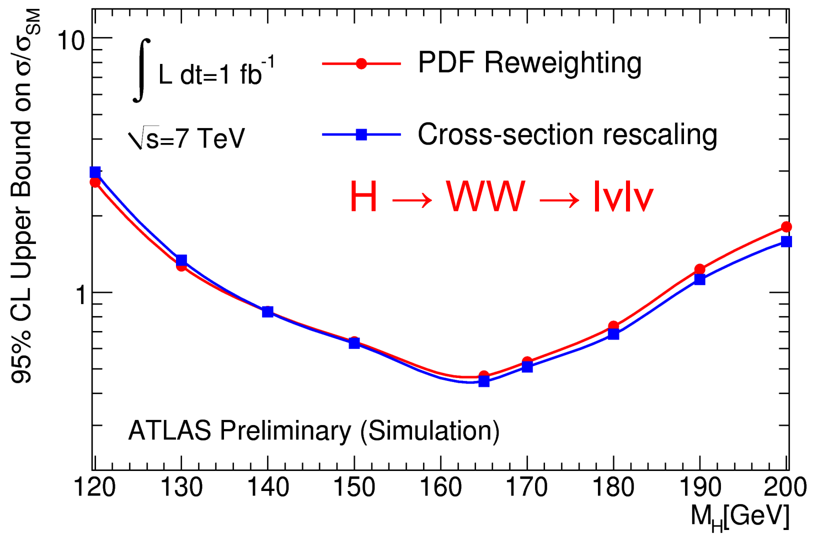
Higgs boson decays concerned in ATLAS

- $H \rightarrow WW$
  - Dominant in a large mass region
- $H \rightarrow ZZ$
  - Clear signal in the 4 lepton final state
  - More background in other final states
- $H \rightarrow \gamma\gamma$
  - Very low branching ratio, but clear signal
  - Important in the low Higss boson mass region
- $H \rightarrow b\bar{b}$
  - Dominant in the low mass region, but very large QCD background
  - Can be measured in an associated production
- $H \rightarrow \tau\tau$
  - Accessible only in the vector boson fusion
  - Low Higgs boson mass region



Higgs boson sensitivity studies

- Most of the results to be shown are expectations with integrated luminosity 1 fb^{-1} at 7 TeV
- Geant4 full simulations used for the calculation of the Higgs boson sensitivity expectations
- Simulations used for the expectations at 7 TeV
  - Few of the MC signal samples were simulated already at 7 TeV
  - Most of the signal and background samples were simulated at different energies
    - Cross section re-scaling used for these samples
- Cross section re-scaling from detailed 10/14 TeV simulations
  - Studies have shown that the signal and background efficiencies are stable for the center of mass energies > 6 TeV
  - Alternative PDF re-weighting method used to compare the results in some channels → very similar results

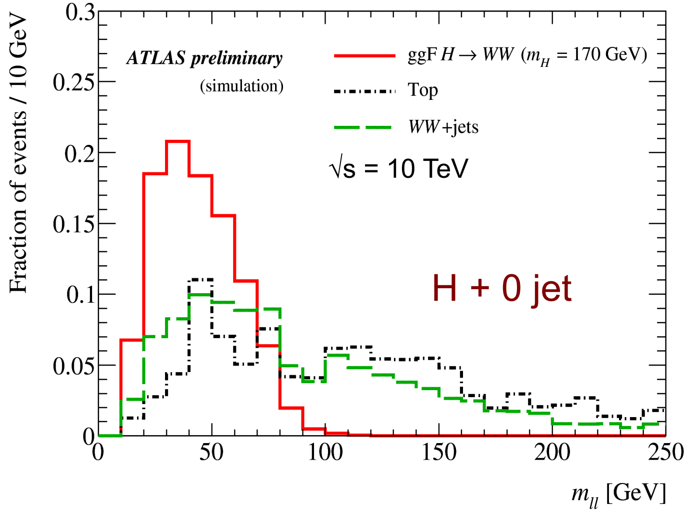


$H \rightarrow WW$ channel

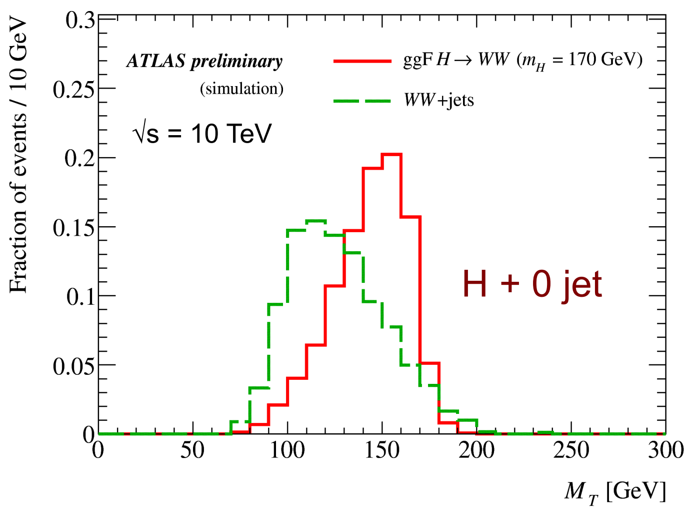
$H \rightarrow WW \rightarrow l\nu l\nu$

- Higgs production via gluon-gluon fusion and vector boson fusion
  - Different number of accompanying jets in the event
- Signature
  - Two leptons (e – e, μ – μ, e – μ) + E_T^{miss} + jets (0,1,2)
- Background processes
  - WW, top-antitop, W + jets
- Common event selection
  - Two oppositely charged leptons
  - Minimum transverse missing energy
    $E_T^{miss} > 30$ GeV
  - Invariant dilepton mass
    $m_{ll} > 15$ GeV, $|m_{ll}-m_Z| > 10$ GeV
  - Transverse mass cut $m_T = \sqrt{2 P_T^{ll} E_T^{miss} (1-\cos(\Delta\phi))}$
    $m_T > 30$ GeV
  - Further selection depends on the number of jets in the event

Invariant dilepton mass



Transverse mass



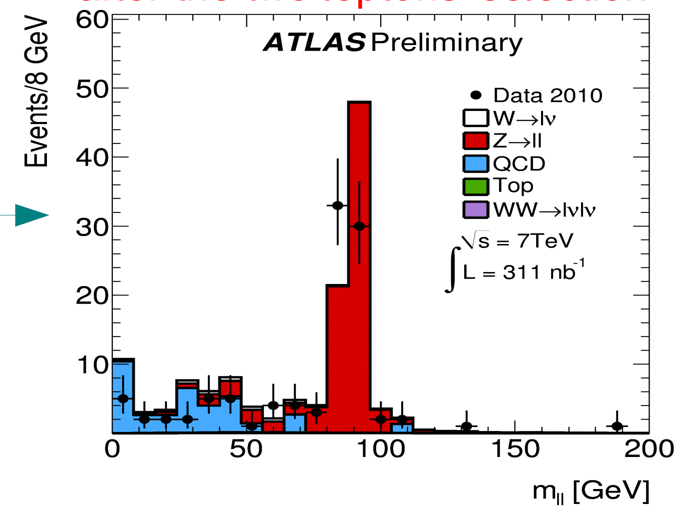
Measurement of H → WW → lνlν background

- WW, top-antitop background
  - Contains two real leptons, same signature as the signal
- W + jets background
  - One real lepton + one jet misidentified as a lepton (fake lepton)
  - Estimation from the Monte Carlo simulation is not reliable because of the fake lepton
- How to measure W+jets contribution from real data
  - Compute a number of W+jets events in a control region N^{CR}
    - One tight + one loose lepton
  - Estimate a fake lepton rate f_l
    - Measure in a dijet and γ+jet sample
  - Calculate the number of W+jets events in the signal region $N^{SR} = f_l \times N^{CR}$
    - Signal region: Two tight leptons

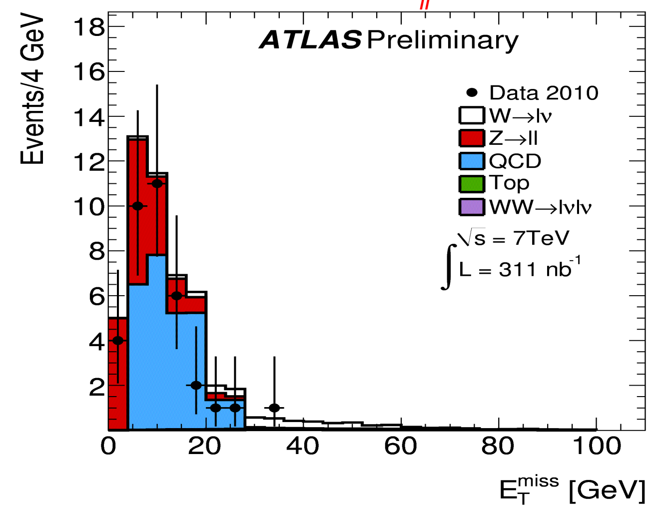
$H \rightarrow WW$: W+jets control region

- Event selection
  - Exactly two lepton candidates
    - At least one of them identified as a tight lepton
    - Leptons with opposite charges
  - Requirements for the same flavour leptons – m_{ll} cut
    - m_{ll} > 15 GeV (suppress $b\bar{b}$ resonances)
    - $|m_Z - m_{ll}|$ < 10 GeV (events in the Z mass peak)
  - Cut on minimum transverse missing energy E_T^{miss} > 25 GeV (suppress QCD and Z/γ*+jets events)
  - Remove events with two or more jets (suppress $t\bar{t}$ background)

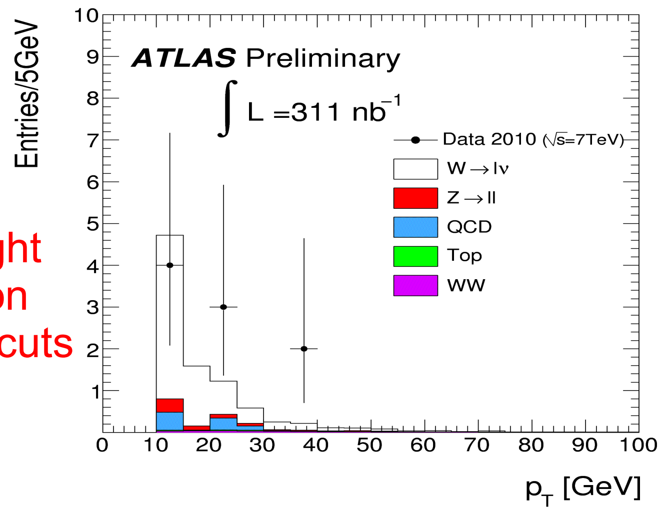
Events with a tight electron after the two leptons' selection



Events with a tight electron After the m_{ll} cut



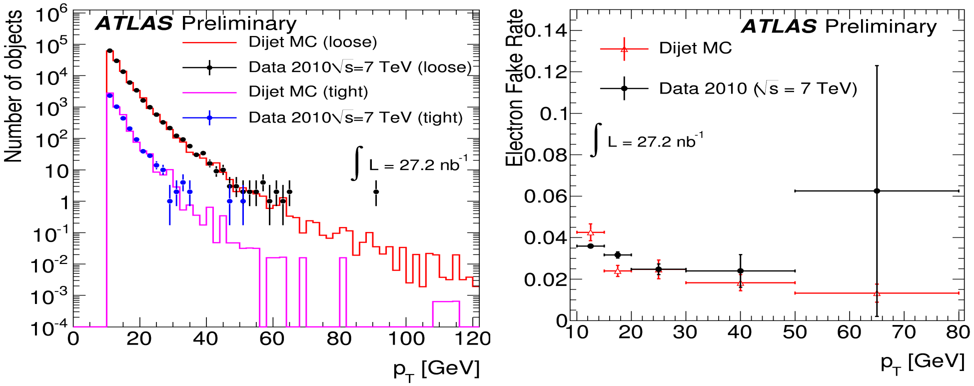
Events with a tight electron or muon after all selection cuts



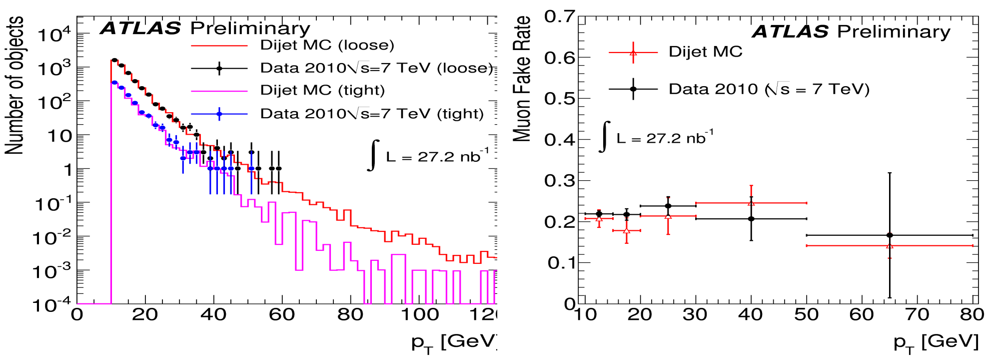
H → WW: Estimation of the fake lepton rate

- Measured in the dijet events
- Fake rate: $f = N_{tight}/N_{loose}$
  - Probability that a loose lepton candidate passes also a tight identification criteria
- Remove W/Z events
  - Z veto: two opposite sign & same flavour leptons with $76 < m_{ll} < 106$ GeV
  - W veto: lepton candidate + $E_T^{miss} > 30$ GeV

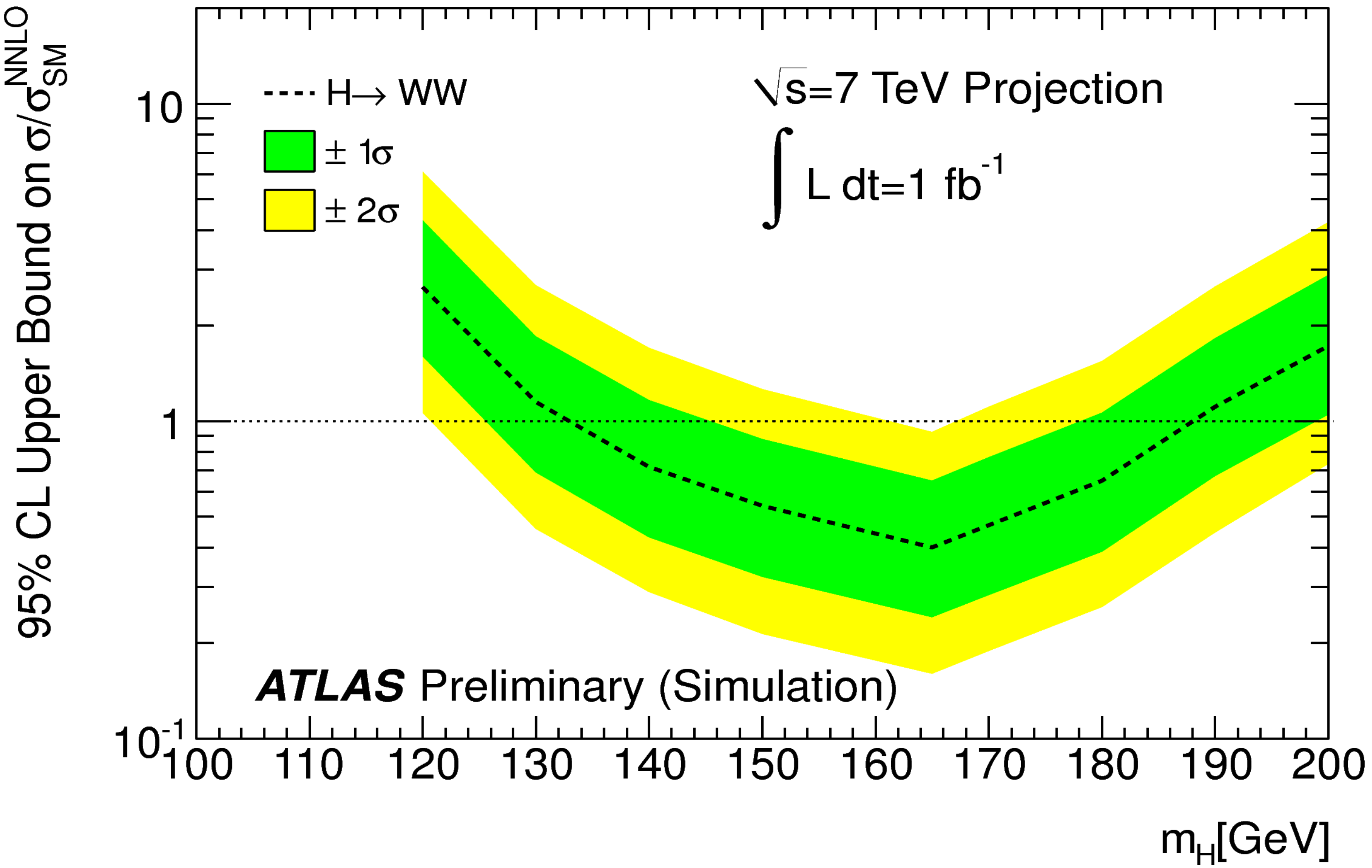
Estimation of the electron fake rates



Estimation of the muon fake rates



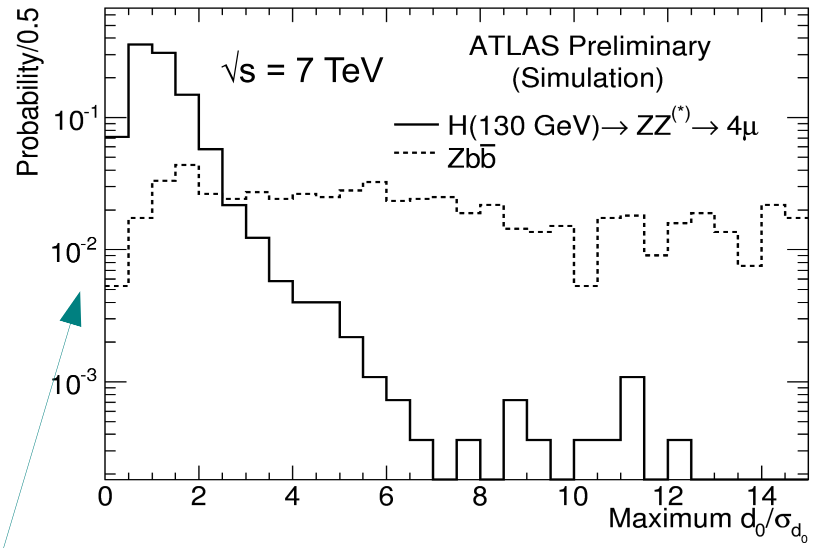
Expected H → W W sensitivity

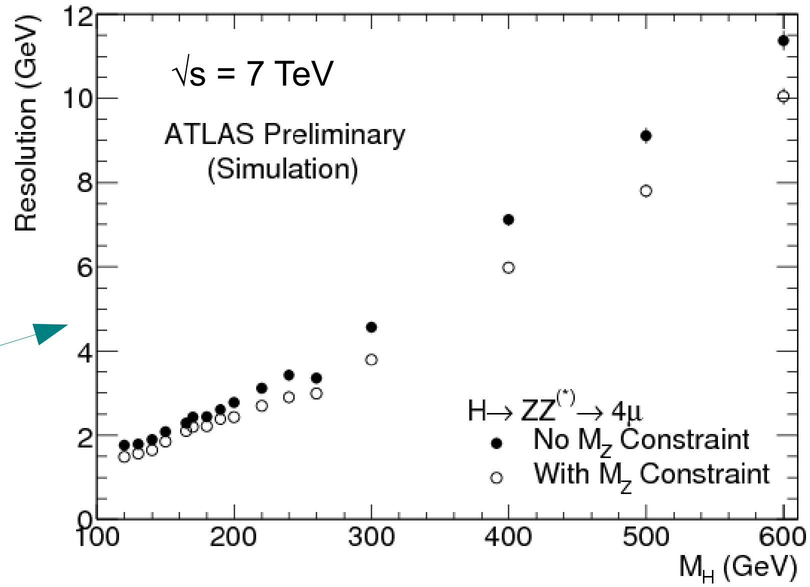


- The H → WW → lvlv channel alone can exclude the Higgs boson in a large mass range with integrated luminosity 1 fb^{-1} at 7 TeV

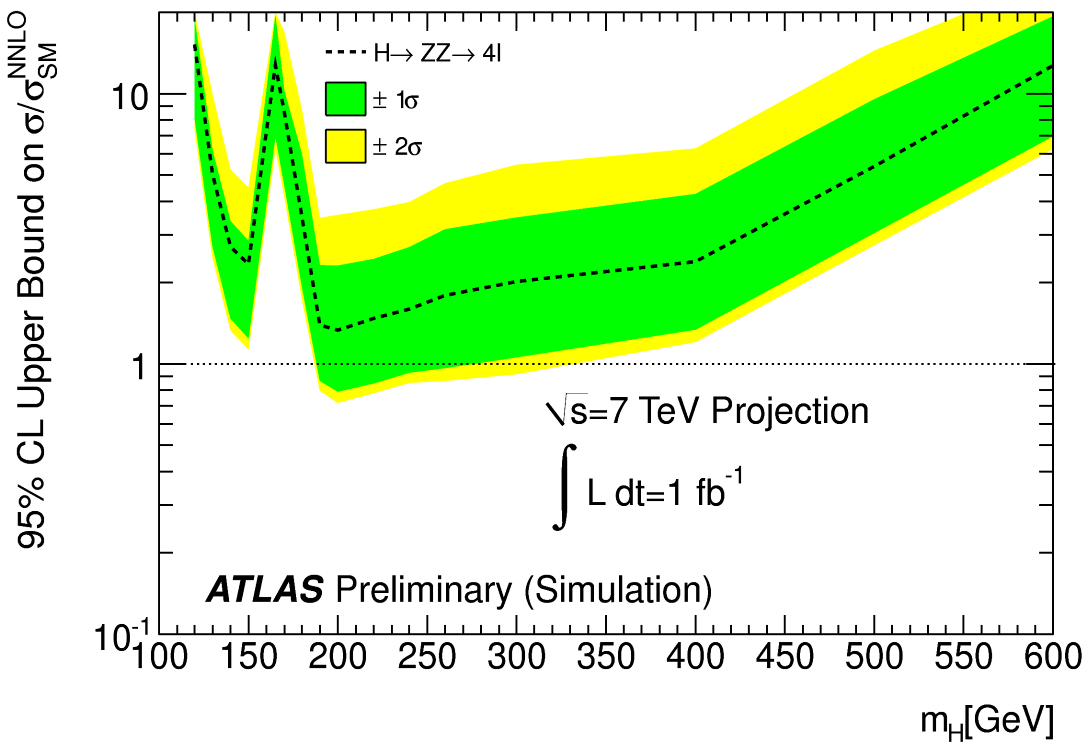
H → ZZ → 4 leptons

- Clear signal (golden decay)
  - Very good energy and momentum resolution for electrons and muons
    → Narrow Z mass peak
- Background processes
  - Irreducible: pp → ZZ → 4 leptons
  - Reducible: Z+jets, top-antitop
- Common event selection
  - 4 leptons – pairs of a same flavour and an opposite charge
  - Tight calorimeter and track isolation of the leptons
    - Suppression of the reducible background
  - Cut on the transverse impact parameter significance
    - Leptons from $Zb\bar{b}$, $t\bar{t}$ originate most likely from displaced vertices
- Z mass constraint improves the Higgs boson mass resolution
  - At least one Z boson is on-shell





Expected H → ZZ → 4 leptons sensitivity



- The channel alone cannot exclude the Higgs boson at any mass point with 1 fb^{-1} at 7 TeV
- Most sensitive for the Higgs boson mass around 200 GeV
  - Upper bound of 1.3 x Standard Model cross section is expected

Other H → ZZ final states

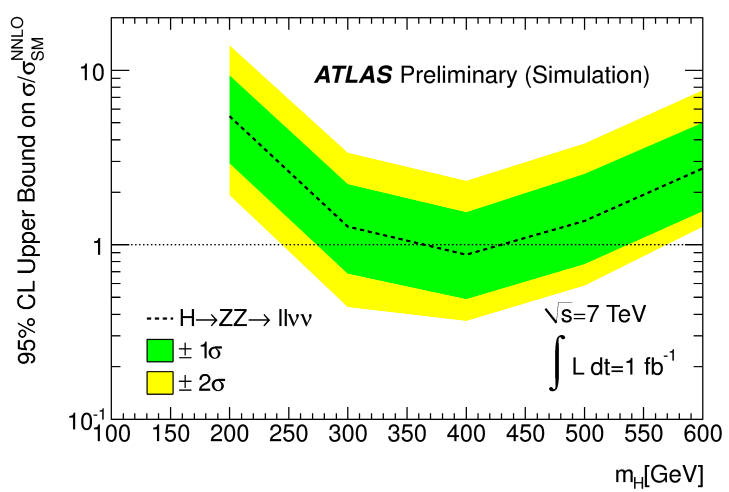
- Higher cross section than H → ZZ → 4 leptons, but harder to supress the background

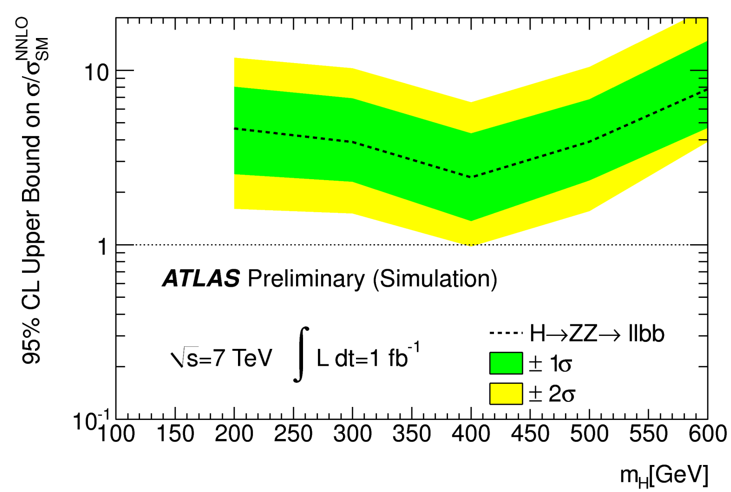
H → ZZ → llνν

- Common selection
  - Dilepton invariant mass (on-shell Z)
  - Missing transverse energy
  - Azimuthal angle between the leptons
- Transverse mass of the dilepton+E_T^{miss} syst.
- Small region of exclusion around 400 GeV

H → ZZ → llbb

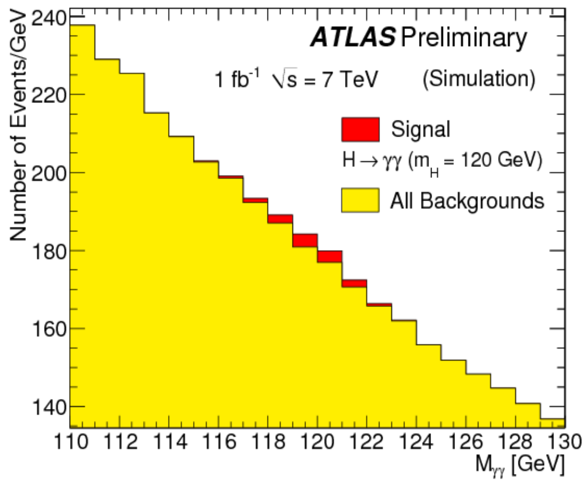
- Common selection
  - Dilepton invariant mass (on-shell Z)
  - Exactly 2 tagged b-jets
  - Invariant mass of the b-jets
- Invariant mass of the dilepton-dijet system
- No exclusion with the channel alone

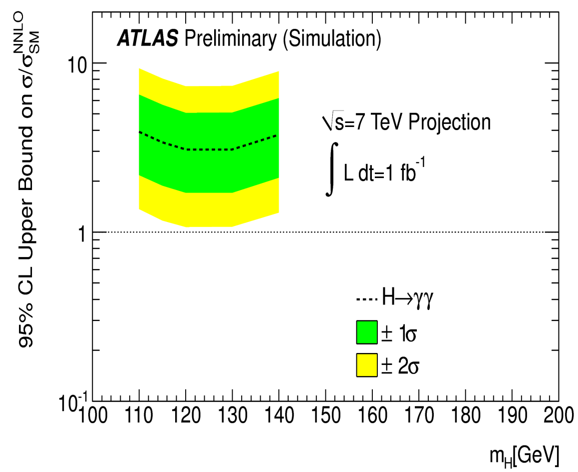




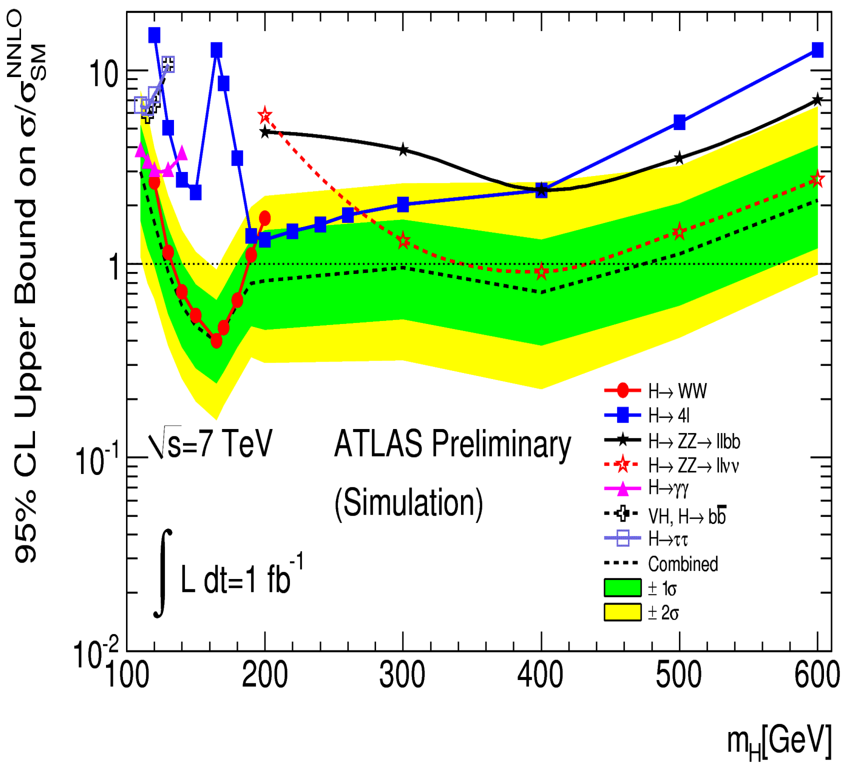
$H \rightarrow \gamma\gamma$ channel

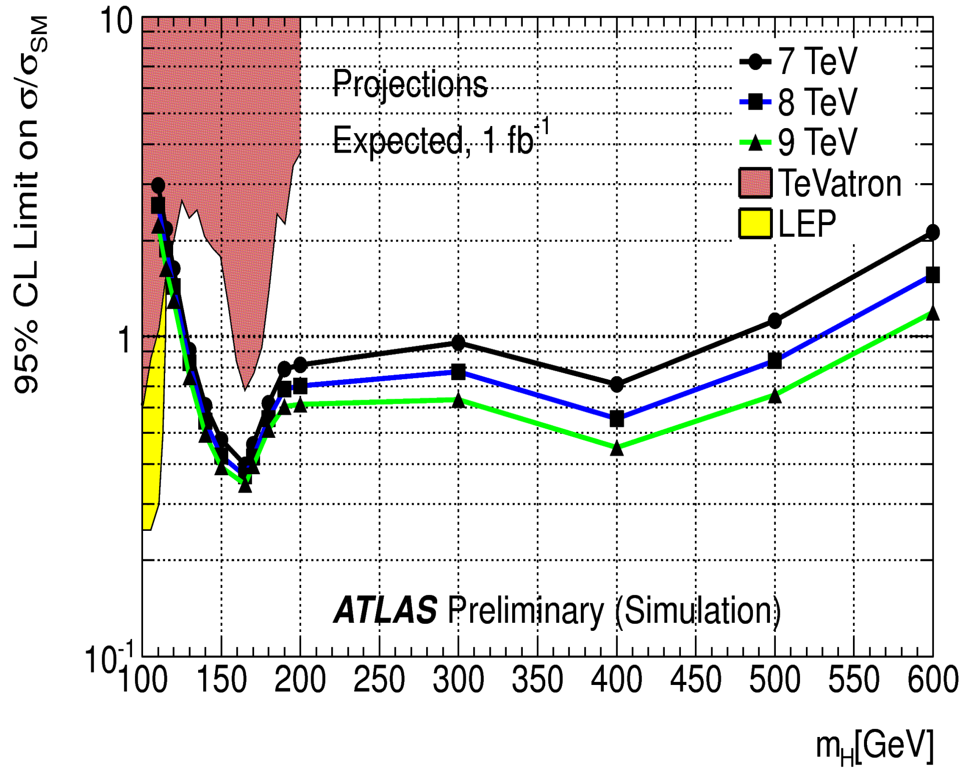
- Important in the low Higgs boson mass region
- Very low branching ratio
  - BR ≈ 0.002 for M_H = 110 – 140 GeV
  - Hard to see the Higgs boson decay over the γγ continuum bkg.
- Background processes
  - Irreducible: γγ
  - Reducible: γ+jets, dijets, Drell-Yan (e^+e^-)
- Experimental requirements
  - Very good photon reconstruction and identification
  - Low number of mis-reconstructions of jets as photons (good jet rejection)
- Expected sensitivity
  - Upper limit ~5 x SM cross section with integrated luminosity 1 fb^{-1}
  - Di-photon mass spectrum is the only discriminating parameter used in this analysis
    - Better sensitivity expected with more advanced analysis





SM Higgs boson: combined sensitivity (II.)



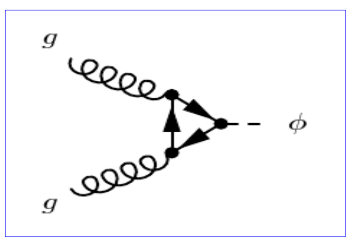


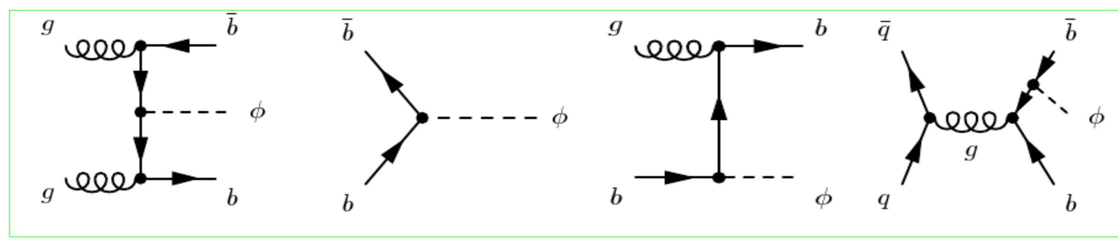
- Exclusion limits with integrated luminosity 1 fb^{-1}
  - Exclusion limits at 7 TeV: 129 – 460 GeV
  - Exclusion limits at 8 TeV: 127 – 525 GeV
    → significant improvement in the upper mass limit compared to 7 TeV
- Expected excluded region significantly larger compared to the **current** Tevatron limits

All discussed channels + $H \to \tau\tau$, $H \to b\bar{b}$ considered

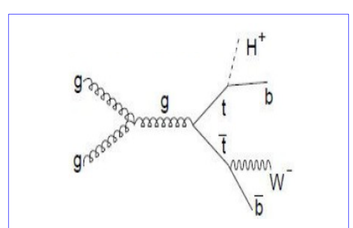
MSSM Higgs bosons

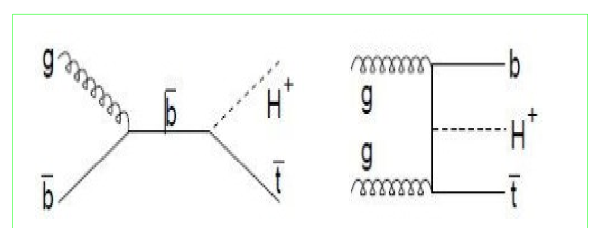
- MSSM Higgs bosons sector
  - Two neutral CP-even Higgs bosons – h, H
  - One neutral CP-odd Higgs – A
  - Two charged Higgs bosons – $H^{\pm}$
- At the tree level the MSSM Higgs sector is described by two parameters
  - M_A and tan β are usually chosen
- Production of the MSSM Higgs bosons
  - Neutral Higgs bosons - direct and production in an association with a b-quark





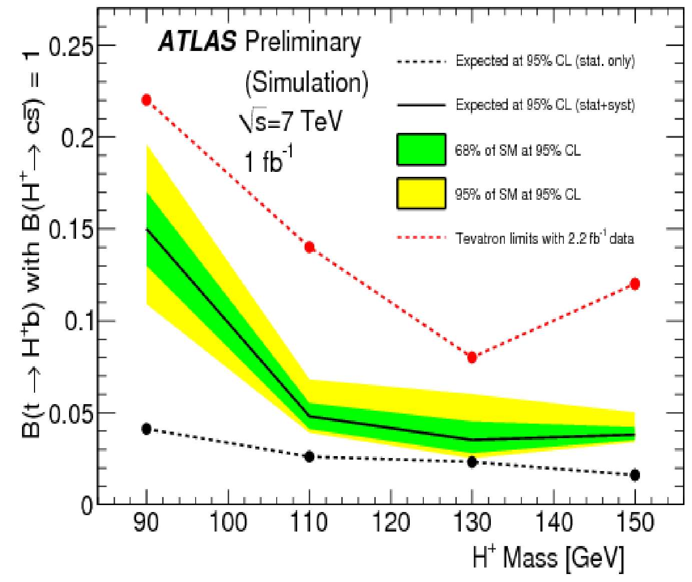
  - Charged Higgs bosons - indirect production from a top quark decay and direct production in an assocation with a top quark

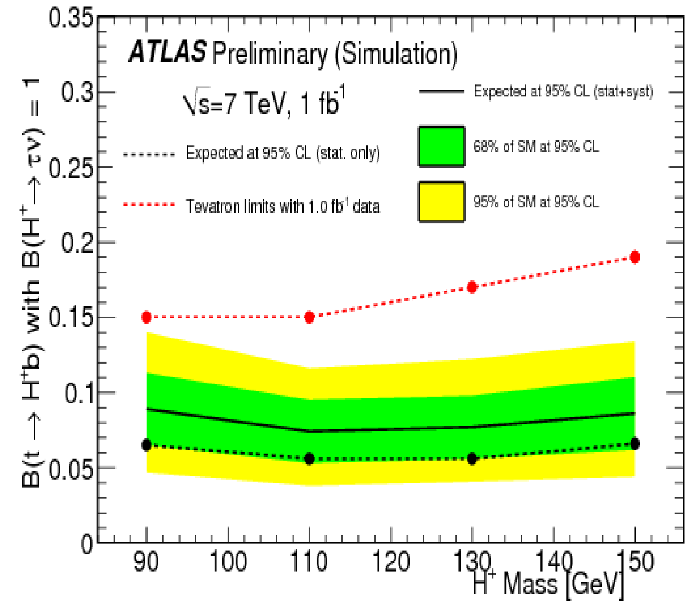




Charged Higgs sensitivity

- Indirect production from the top quark decay ($M_{H+} < m_t$)
- $H^+ \rightarrow c\bar{s}$ channel contributes in the tan $\beta < 1$ region,
  $H^+ \rightarrow \tau^+\nu$ channel dominates in the tan $\beta > 1$ region
- Main background: top-antitop
- **$H^+ \rightarrow c\bar{s}$ channel**
  - Semi-leptonic top-antitop event topology
  - Signature: lepton + E_T^{miss} + 4jets (with 2 tagged b-jets)
  - M_{H+} calculated from two untagged jets (not b-jets)
- **$H^+ \rightarrow \tau^+\nu$ channel**
  - Di-lepton top-antitop event topology (tau decays leptonically)
  - Signature: two oppositely charged leptons + E_T^{miss} + 2 b-jets
  - Lepton helicity angle
    → excess of events over the SM prediction

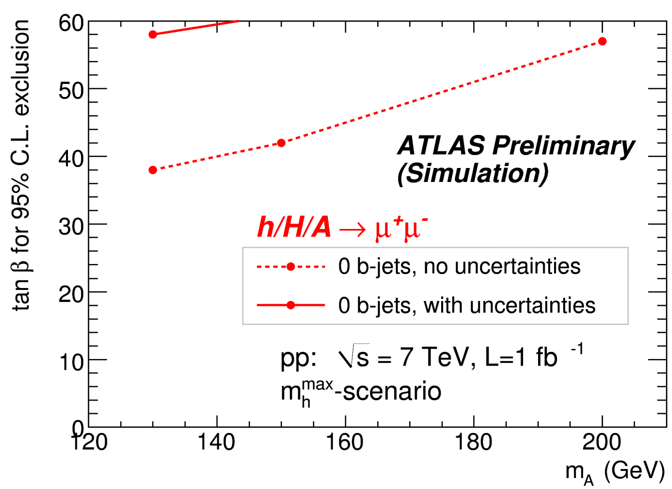


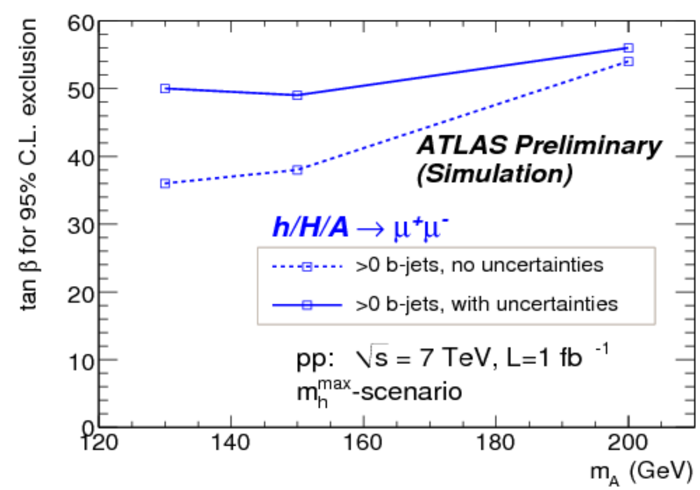


Neutral MSSM Higgs

H/A → μμ channel

- Important in the high tan β region
  - Associated production of H/A with b-quarks is dominant
- Background processes
  - Z + jets with Z → μμ
  - Top-antitop events with di-muon in the final state
- Signature: Two muons + b-jets
  - Analyze case with 0 b-jet and at least one b-jet separately





- Exclusion of tan β above 50 for the M_A between 130 and 150 GeV with integrated luminosity of 1 fb^{-1}

Conclusions

- Exclusion limits at 95% C.L. with integrated luminosity 1 fb^{-1} at 7 TeV based on the simulations
  - Standard model Higgs boson
    - Exclusion mass range is from 129 to 460 GeV
  - MSSM Higgs bosons
    - Charged Higgs boson
      - Upper limits on $B(t \to bH^+)$ between 0.07 and 0.09 for M_{H+} 90-150 GeV with $B(H^+ \to \tau^+ \nu)=1$
      - Upper limits on $B(t \to bH^+)$ between 0.03 and 0.15 for M_{H+} 90-150 GeV with $B(H^+ \to c\bar{s})=1$
    - Neutron Higgs boson
      - Exclusion of tan β above 50 for the M_A between 130 and 150 GeV
- Possible improvements of the Higgs boson sensitivity in ATLAS
  - Optimization of cuts for 7 TeV
  - Move to multivariate techniques (currently cut-based)
    - Particle identification
    - Selection cuts
- Measurements of the background from the real data samples are ongoing
  - Background estimation for $H \to WW \to l\nu l\nu$ shown
  - Ongoing effort also in other decay channels
  - More data are being analyzed to come to more precise estimates

BACKUP SLIDES

Lepton identification

Electron

- Loose
  - $p_T > 10$ GeV
  - Hadronic leakage
  - Lateral shower shape & width
- Tight
  - Has to fulfill loose criteria
  - $p_T > 15$ GeV
  - Requirements on the strips in the first layer of the EM calorimeter (rejection of $\pi \to \gamma\gamma$)
  - Tracking variables
    - Number of hits in pixels, SCT, TRT
    - Transverse impact parameter
  - Isolation cuts

Muon

- Loose
  - Combined muon with p_T>10 GeV
  - $z < 10$ mm
  - $p_T^{MS} > 10$ GeV, $|p_T^{MS} - p_T^{ID}| < 15$ GeV
- Tight
  - Has to fulfill loose criteria
  - $p_T > 15$ GeV
  - Isolation requirement: $\sum p_T^{track} / p_T^{\mu} < 0.2$
    - $\sum p_T^{track}$ - scalar sum of p_T of the tracks in a cone of $\Delta R = 0.4$

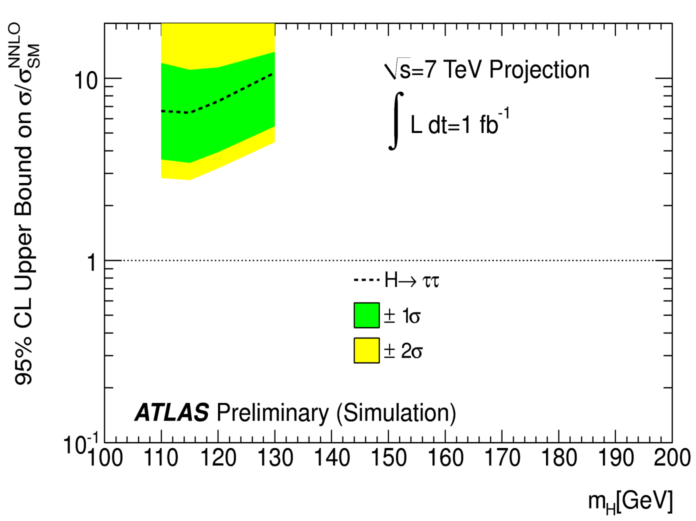
More channels in the low mass region

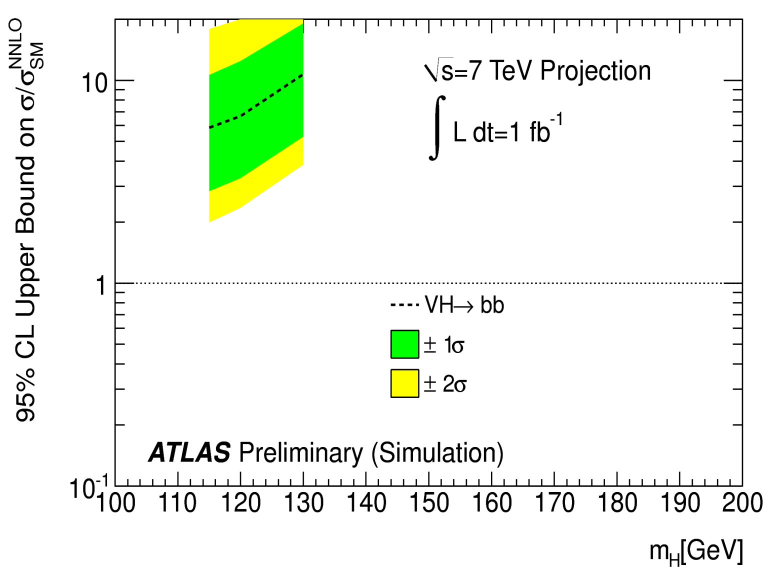
$H \rightarrow \tau\tau$

- Production through vector boson fusion
  - Two tagging jets in the forward region → rapidity gap
- Lepton-hadron, lepton-lepton final states considered
- Collinear approximation used to reconstruct the invariant mass peak
  - Neutrinos in the final state

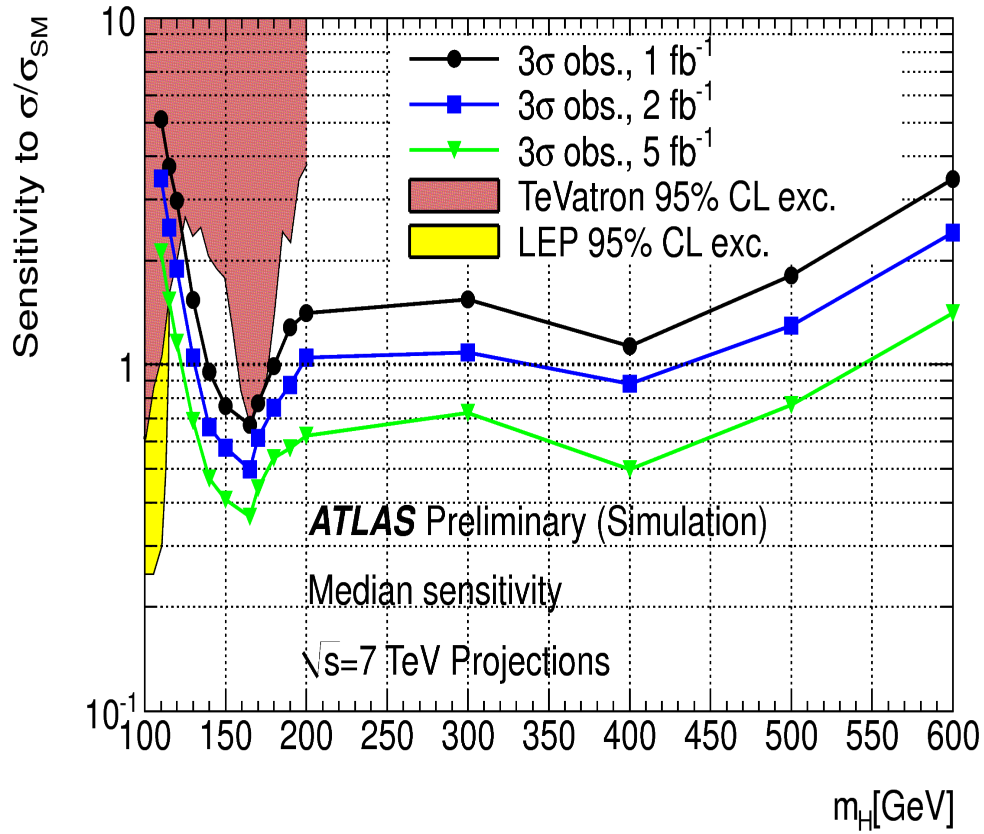
$H \rightarrow b\bar{b}$

- Production in association with W/Z boson
  - Not possible in the inclusive H production due to overwhelming QCD $b\bar{b}$ background
- Require very good b-tagging efficiency





SM Higgs boson: combined sensitivity



- 3σ sensitivity
  - $1fb^{-1}$: mass region 139 – 180 GeV
  - $2\ fb^{-1}$: very close to 3σ evidence up to 430 GeV

Charged Higgs boson

- H^{+} branching ratio for two tan β values as a function of M_{H+}