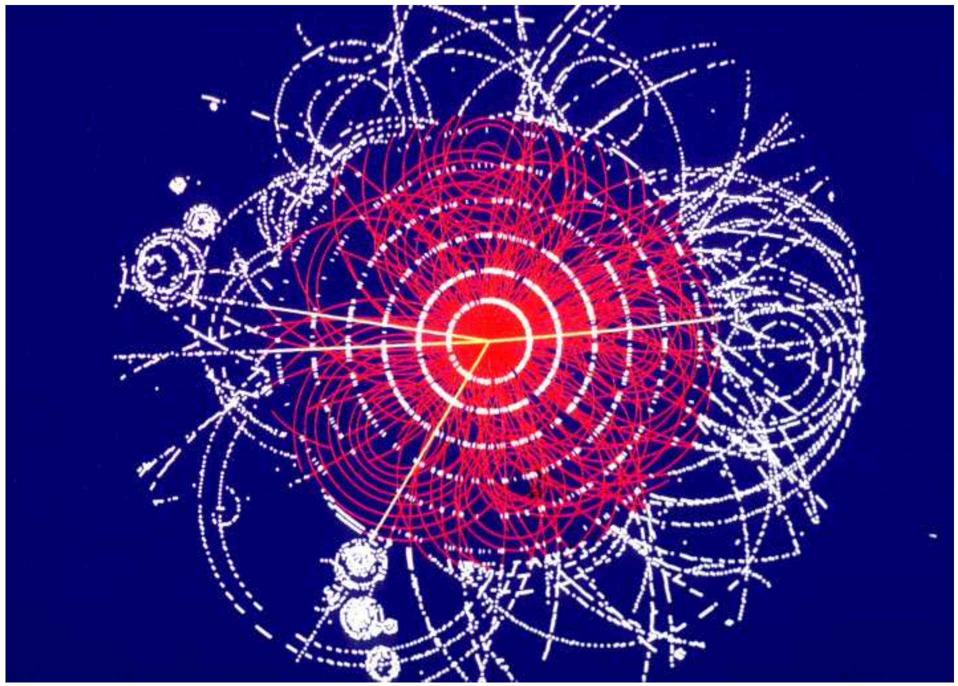
Light Higgs Boson Discovery Potential with ATLAS



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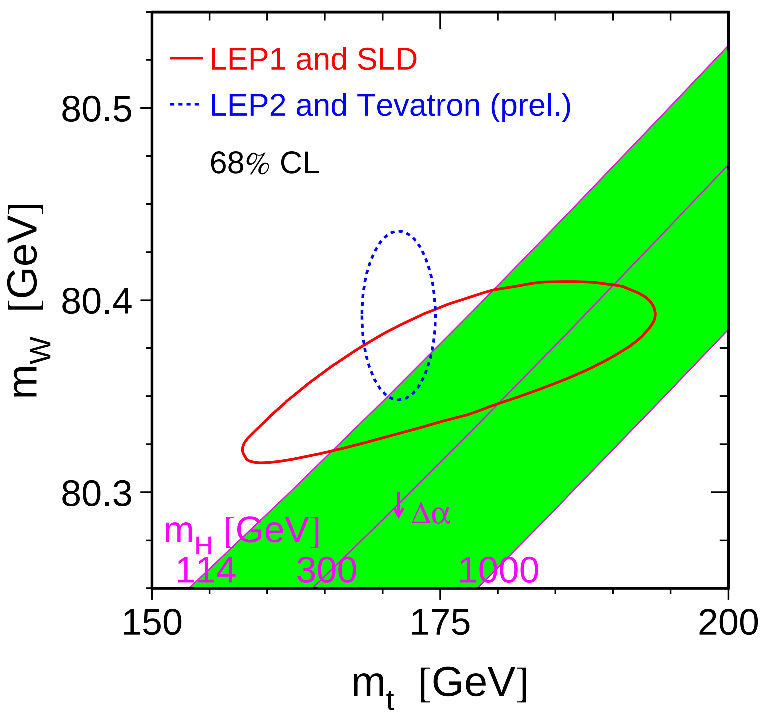
on behalf of the ATLAS collaboration

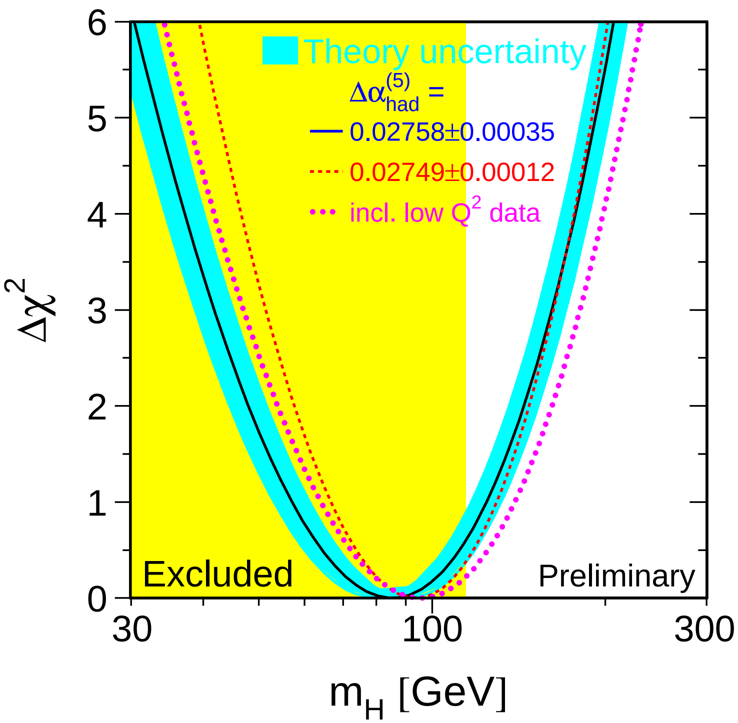
Introduction

- A low mass Higgs boson is currently the most likely candidate.
  - The direct search limit is $m_H > 114.4$ GeV.
  - Electroweak fits sets an upper limit of $m_H < 199$ GeV.
- The mass of the Higgs boson determines all its properties.
- All hadronic states are impossible to separate from the background, and are difficult to trigger on.
- For Higgs masses between $115 \leq m_H \leq 200$ GeV there is a rich set of search channels! The final state is determined by:
  - The production mode of the Higgs boson.
  - The decay of the Higgs boson, and its daughter particles.
- This talk will give an overview of the most relevant channels.

Constraint on the Higgs Mass from Electroweak Fits

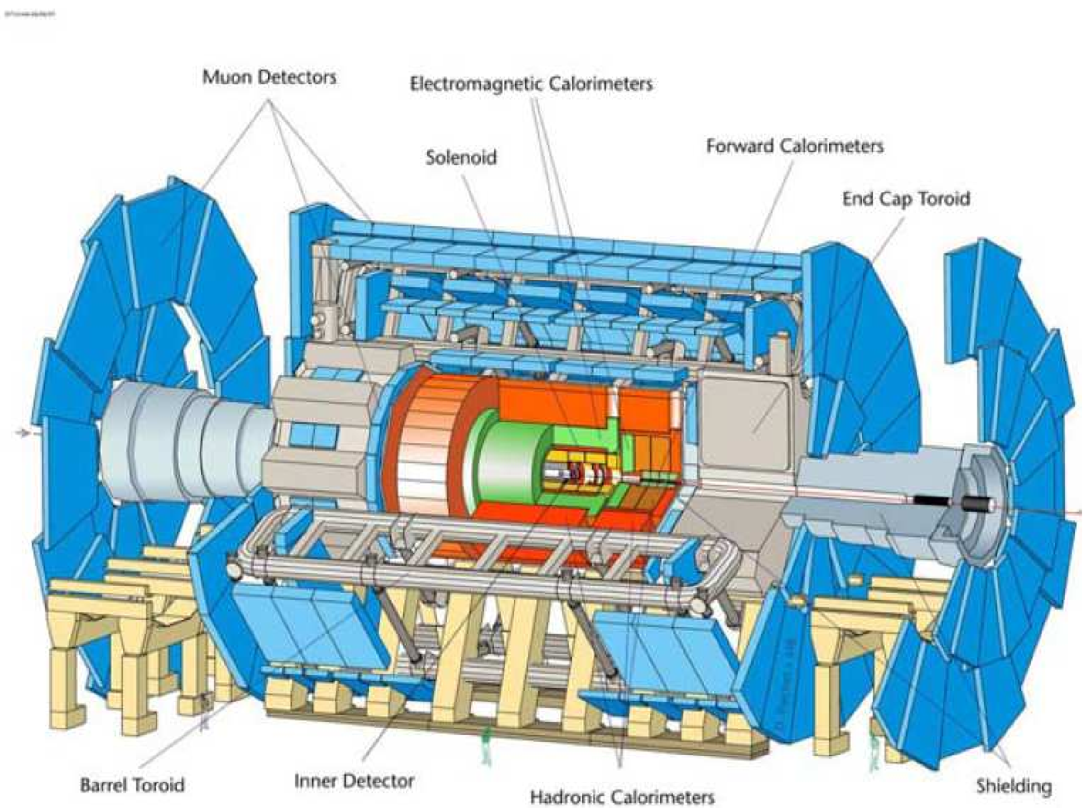
- The latest value of the top mass favors a light Higgs boson.





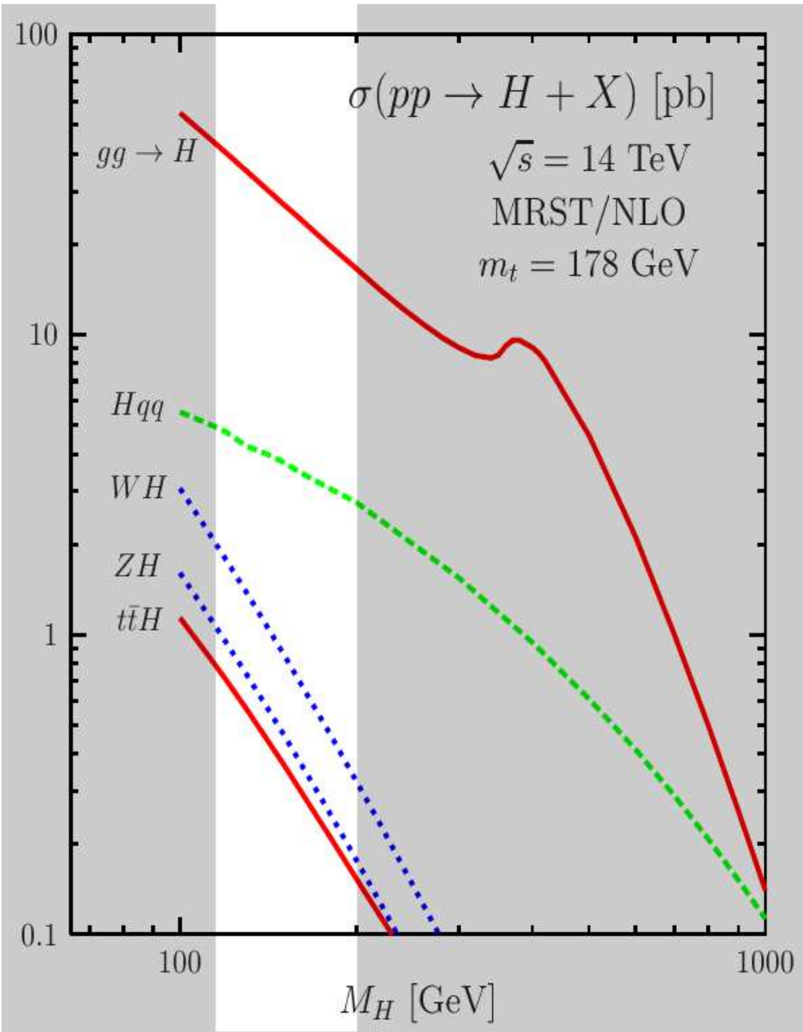
- The constraints from electroweak observables are summarized in the famous blueband plot, $m_H = 85^{+39}_{-28}$ GeV.

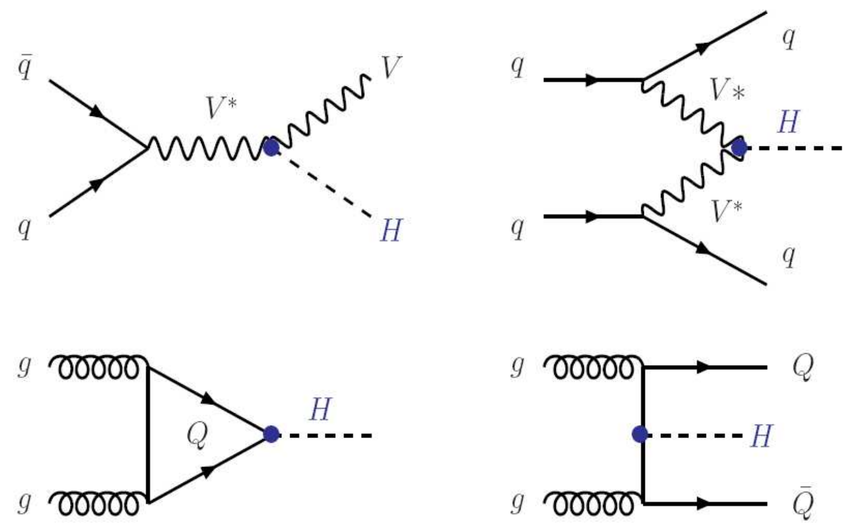
The ATLAS Experiment



- The Atlas Detector:
  - Length 44 m.
  - Diameter 22 m.
  - Weight 7000 ton.
- Momentum resolution (at ~ 100 GeV):
  - μ, $\sim 2\%$.
  - e, γ, $\sim 1.5\%$.
  - jet, $\sim 8\%$.

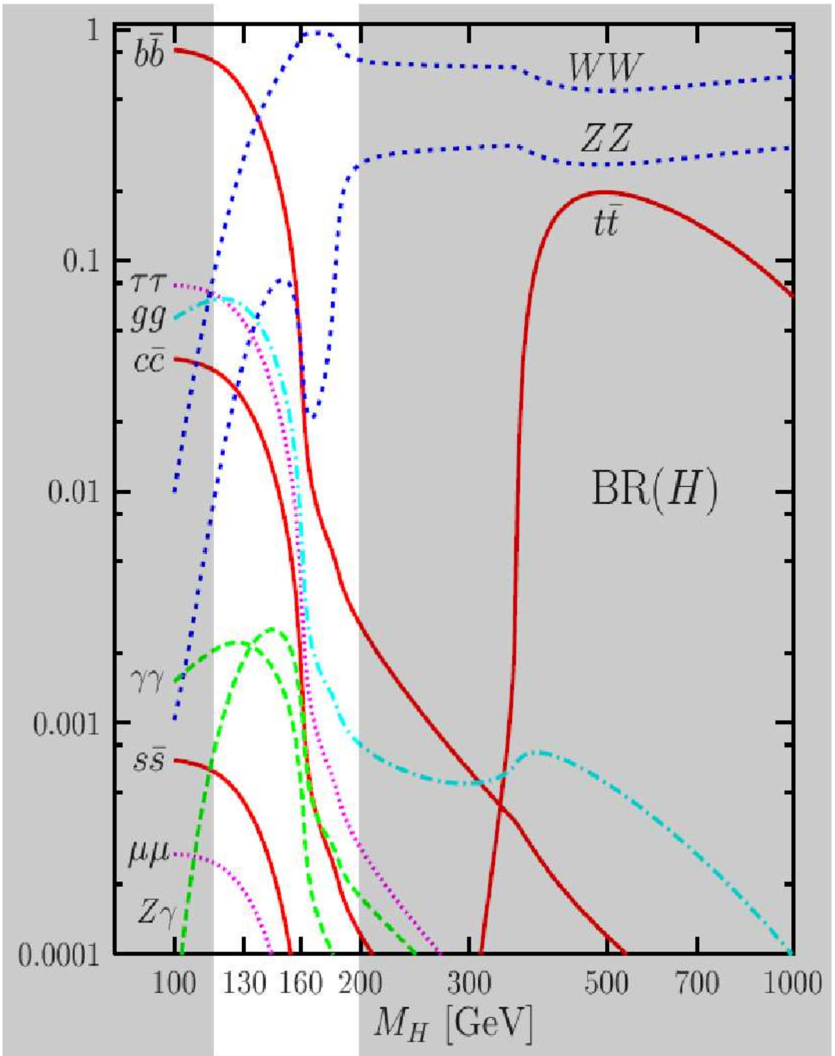
Higgs Production at the LHC





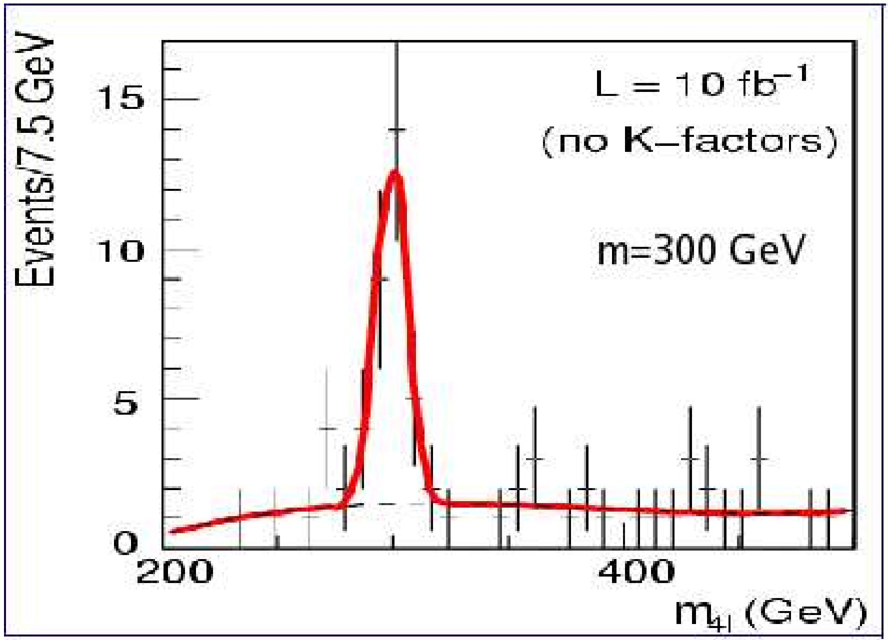
- Total cross section ranges from 52 pb ($m_H = 115$ GeV) to 20 pb ($m_H = 200$ GeV).
- LO and NLO σ can differ by as much as a factor of 2.

Decay of the Higgs Boson



- Inclusive search channels:
  - $H \to ZZ$ for $m_H \gtrsim 130$ GeV.
  - $H \to WW$ for $m_H \gtrsim 145$ GeV.
  - $H \to \gamma\gamma$ for $m_H \leq 150$ GeV.
- Exclusive search channels:
  - VBF production with $H \to WW$ for $m_H \gtrsim 115$ GeV.
  - VBF production with $H \to \tau\tau$ for $115 \leq m_H \leq 150$ GeV.
  - ttH production with $H \to b\bar{b}$ for $m_H \leq 135$ GeV

H $\longrightarrow$ ZZ $\longrightarrow$ 4 Leptons

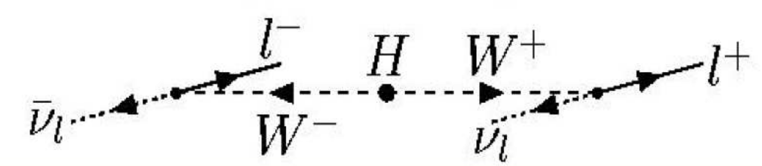


- Most important backgrounds:
  - ZZ production. Irreducible.
  - $t\bar{t}$ and Zbb, with two semi-leptonic b-quark decays.

- The $ZZ \rightarrow 4\ell$ very clean signal.
  - Also use $ZZ \rightarrow \ell\ell qq, \ell\ell\nu\nu\ldots$
- All of the Higgs boson's decay products are reconstructed.
- Very good sensitivity in this channel for $m_H \geq 130$ GeV.
- For $m_H > 2m_Z$ this becomes the "gold plated channel".
- Dominant background from continuum ZZ production.
  - Can be estimated from sidebands in data.

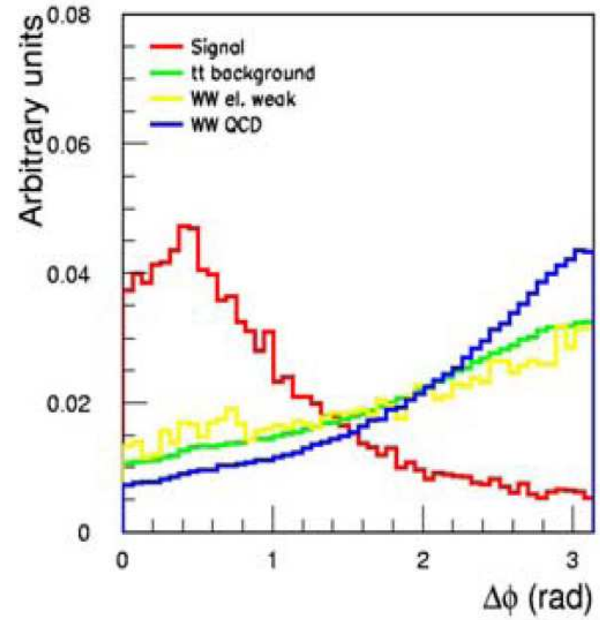
H to WW

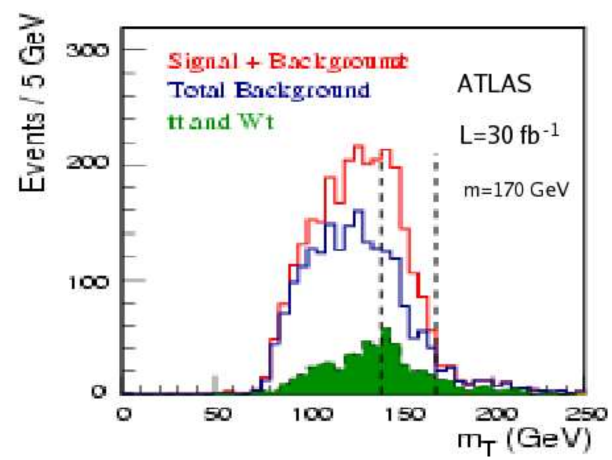
- $BR(H \to WW)$ is nearly 98% for a Higgs boson with $m_H \approx 160$ GeV.
- Backgrounds from WW, $t\bar{t}$, WZ.
- Use the lepton spin correlations:



- No mass peak, have to use m_T:

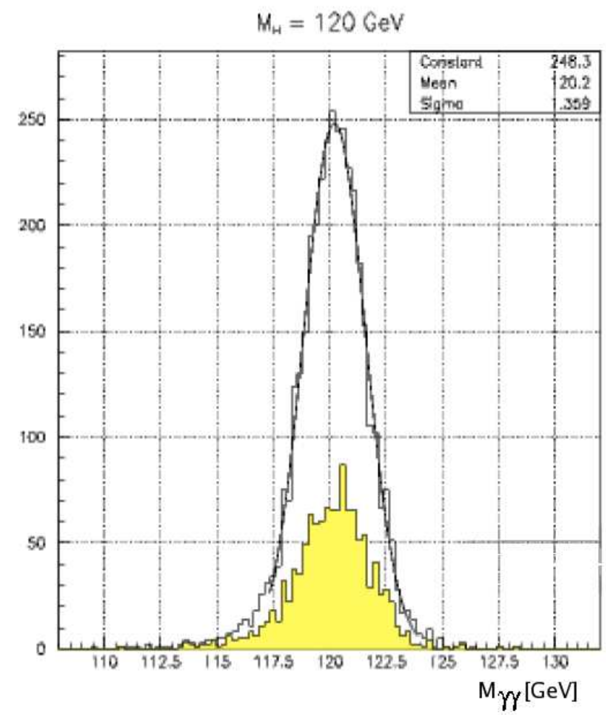
$$m_T = \sqrt{2 p_T^{\ell\ell} \not{E}_T (1 - \cos \Delta\phi)}$$





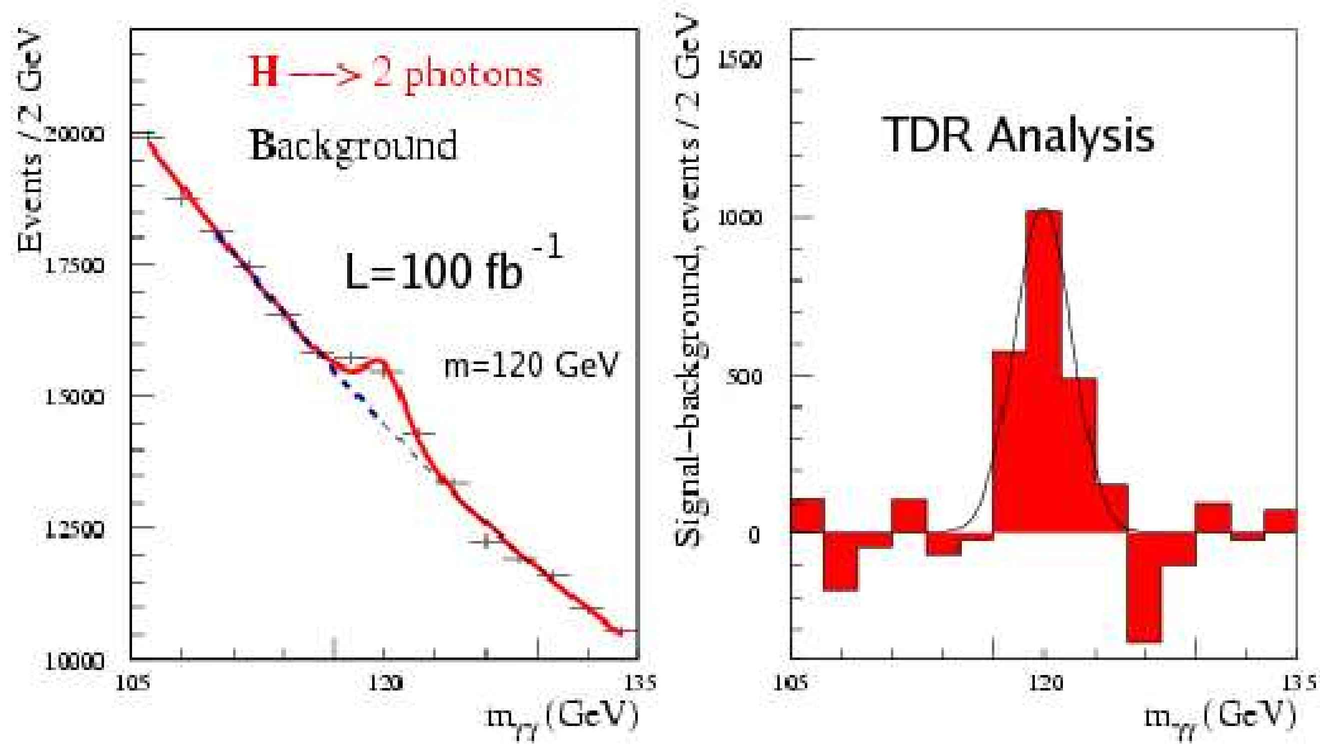
The Higgs to Two Photons Channel

- Typical event selection criteria:
  - Two isolated photons with $p_T > 40$ and $p_T > 25$.
  - Both photons within $|\eta| < 2.4$, excluding gaps.
  - Invariant mass of the photons: $M_H - 2 < M_{\gamma\gamma} < M_H + 2\ \mathrm{GeV}$.
- Mass resolution $\sigma(M_{\gamma\gamma}) \approx 1.36$ GeV.
- Photons conversions taken into account (~ 40% of the events).
- EM calorimeter is crucial:
  - Energy and angle resolution.
  - Photon acceptance.
  - γ/jet and γ/π^0 rejection.



Backgrounds

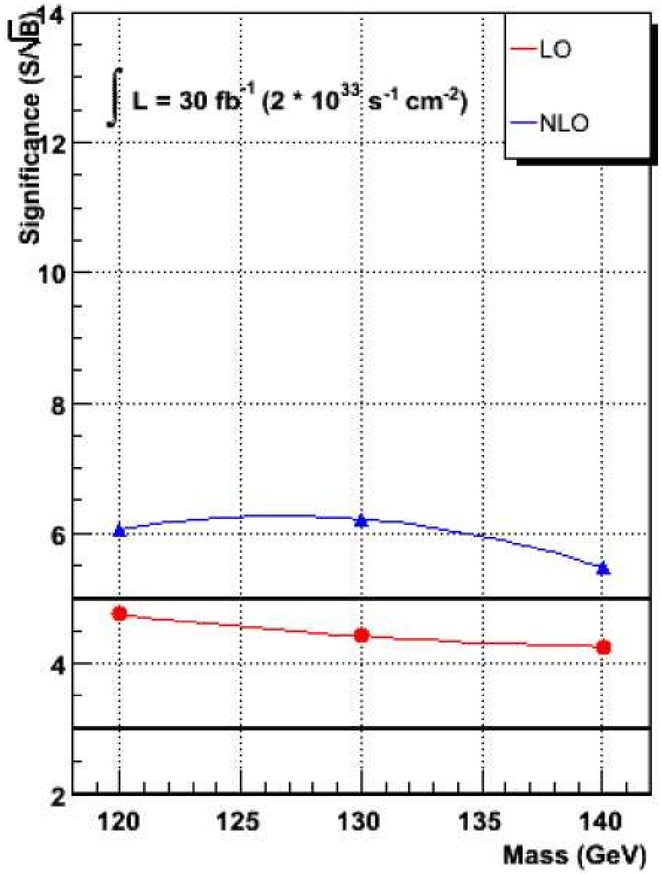
- The largest background comes from irreducible $\gamma\gamma$ production. $\sigma_{\gamma\gamma} \approx 125$ fb/GeV. Need mass resolution $\sigma(M_{\gamma\gamma})/M_{\gamma\gamma} \approx 1\%$.
- Reducible background from jets misreconstructed as photons. $\sigma_{\gamma \mathrm{j}} \approx 8 \cdot 10^2 \cdot \sigma_{\gamma\gamma}$ and $\sigma_{jj} \approx 2 \cdot 10^6 \cdot \sigma_{\gamma\gamma}$. Need rejection $R_j > 10^3$.



Importance of NLO Cross Sections

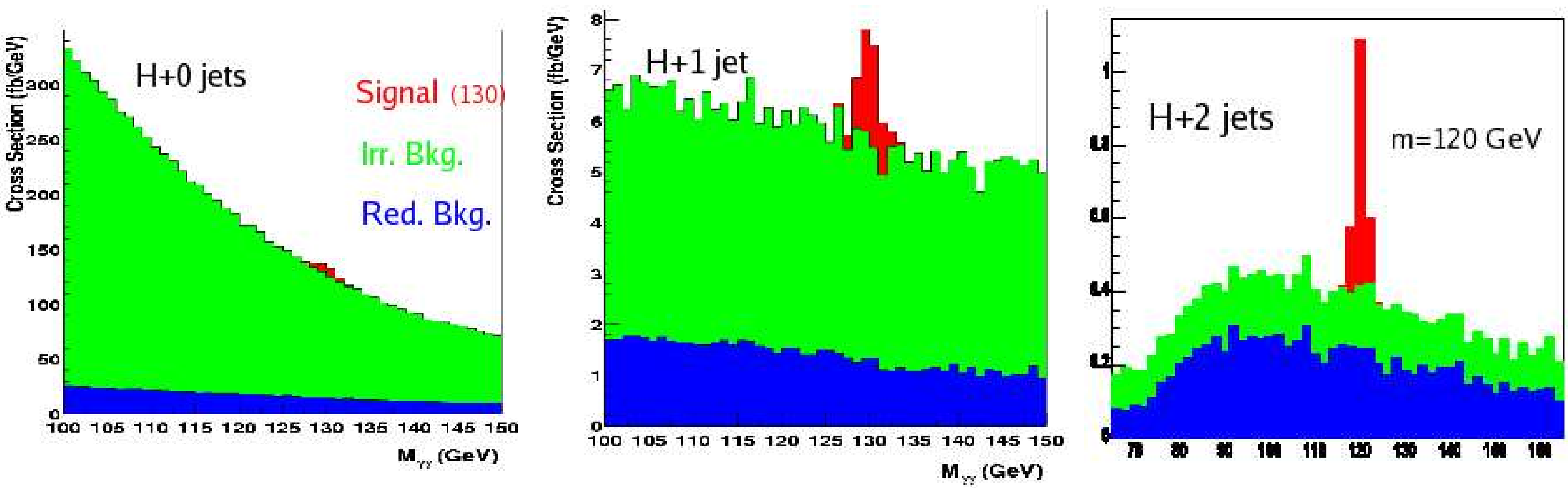
- Cross sections calculated at NLO:
  - $K \sim 1.8$ for $gg \to H$.
  - The full $\mathcal{O}(\alpha_S)$ calculation, plus box diagram, for the $\gamma\gamma$ background.
  - $K \sim 1.7$ for γj and jj backgrounds.

Event yield (at NLO) for 30 fb^{-1}		
m_H	120 GeV	130 GeV
$H \to \gamma\gamma$	815	758
$\gamma\gamma$	14100	9552
γj, jj	3967	3396
$S/\sqrt{B}$	6.06	6.22



- Gives dramatic improvement in sensitivity.

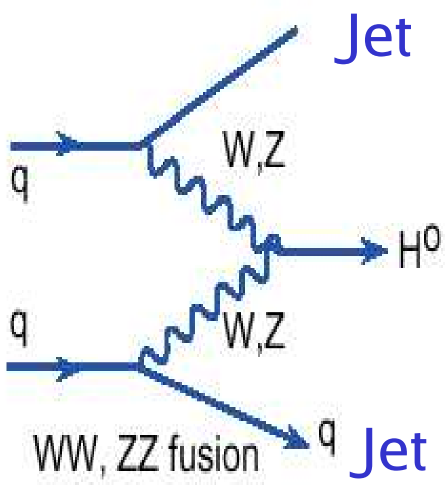
Combination of All Jet Multiplicities



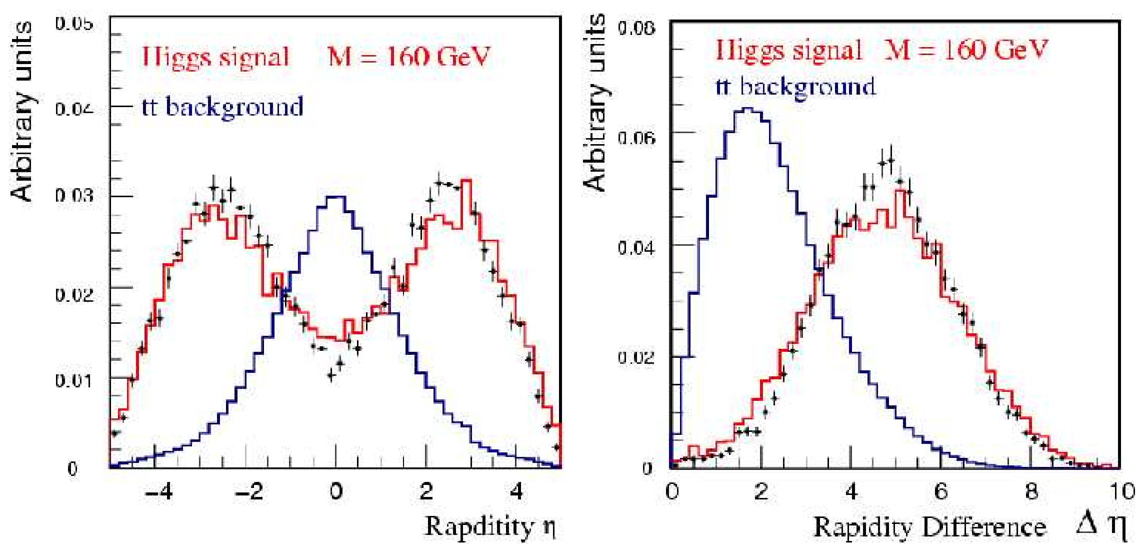
- Do inclusive analysis. Use a combination of all jet multiplicities.
  - $H + 0$ jets from $gg \to H$.
  - $H + 1$ jet at NLO, plus VBF production with one lost jet.
  - $H + 2$ jets from VBF.
- Decrease in signal, increase in S/B with jet multiplicity.
  - Decrease in systematic uncertainty?
- This is a preliminiary study.
  - Looks promising.

Experimental Signature of VBF Events

- Typical selections for tag jets:
  - $p_T > 40$ and $p_T > 20$ GeV.
  - $\Delta\eta > 3.8$ between the tag jets.
- Apply a central jet veto:
  - No central jets with $p_T > 20$ GeV.
  - H decay products between tag jets.

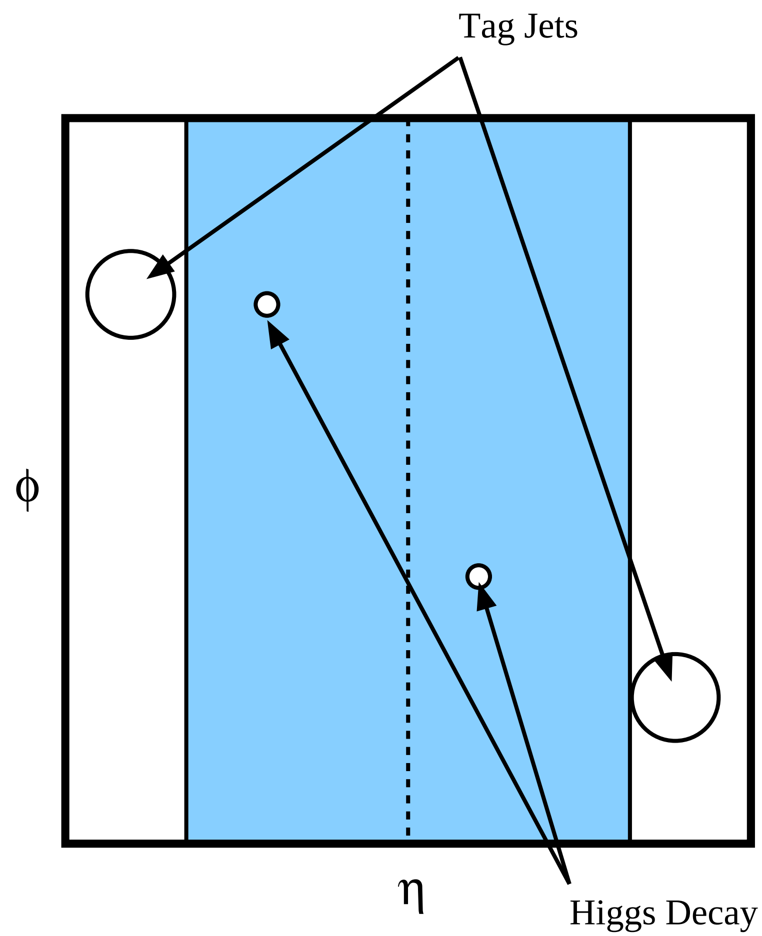


- Powerful way to reduce backgrounds.
- Uncertainty from underlying and overlapping event, pile-up.

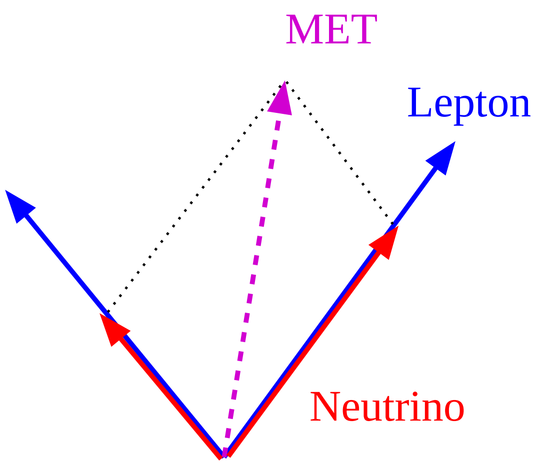


VBF Production with $H \to \tau\tau$ and $H \to WW$ Channels

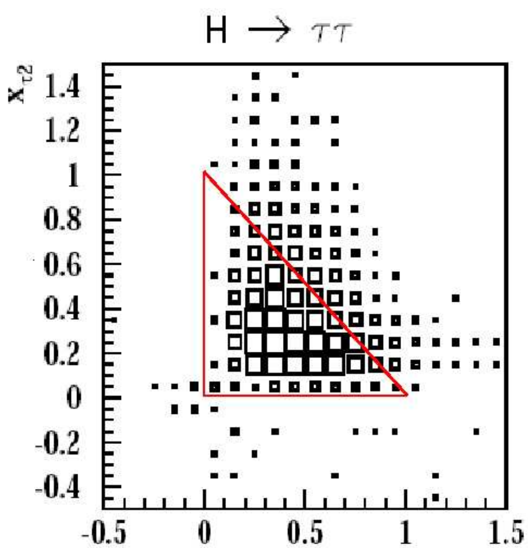
- At low Higgs masses the largest sensitivity search channels are found in the vector boson fusion production mode.
- At least one of the W/τ's have to decay leptonically.
- Main backgrounds are $t\bar{t}$, Wt, WW+jets, γ^*/Z+jets.
- Some selection criteria ($e\mu$):
  - $p_T^e > 15$ GeV, $p_T^\mu > 10$ GeV.
  - $|\eta_\ell| < 2.5$ and $M_{\ell\ell} < M_H/2$.
  - Tag jet cuts, central jet veto.
- τ reconstruction provide extra sensitivity or rejection.

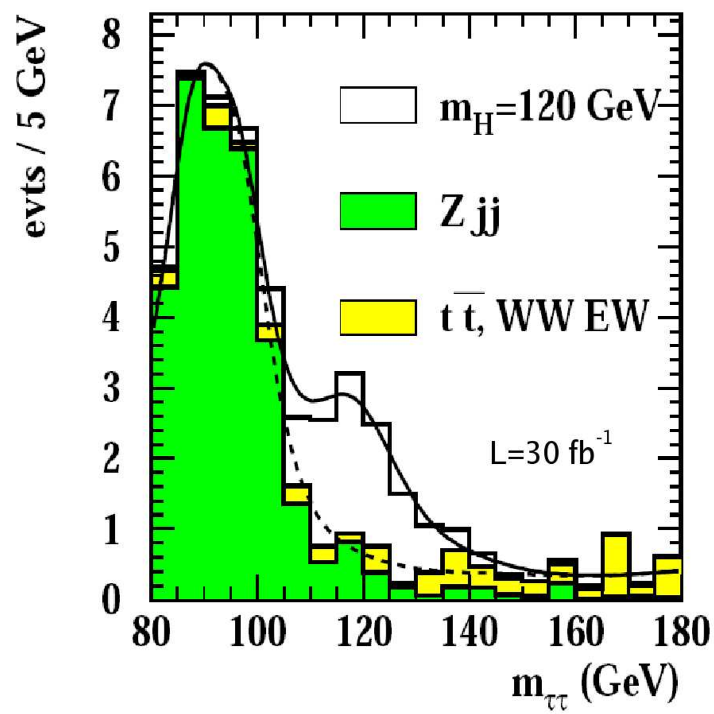


VBF $\mathrm{H} \rightarrow \tau\tau$ Channel and Tau Reconstruction



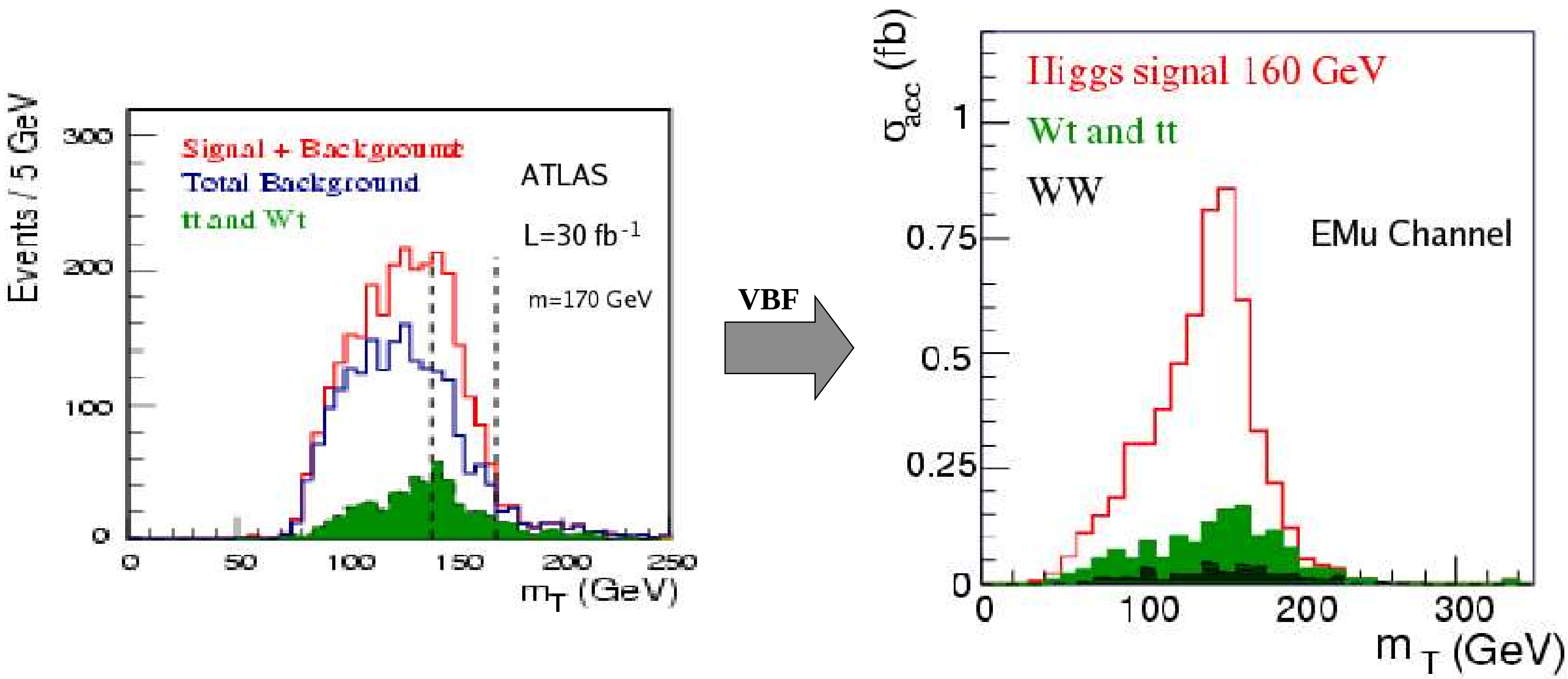
- Assume ℓ and ν's from $\tau \rightarrow \ell\nu\nu$ are collinear.
- Label visible energy fractions x_{τ_1} and x_{τ_2}.
- Assume $\not{\vec{p}}_T$ vector comes from the ν's, and solve the equations for x_{τ_1} and x_{τ_2}.





VBF $H \rightarrow WW$ Channel

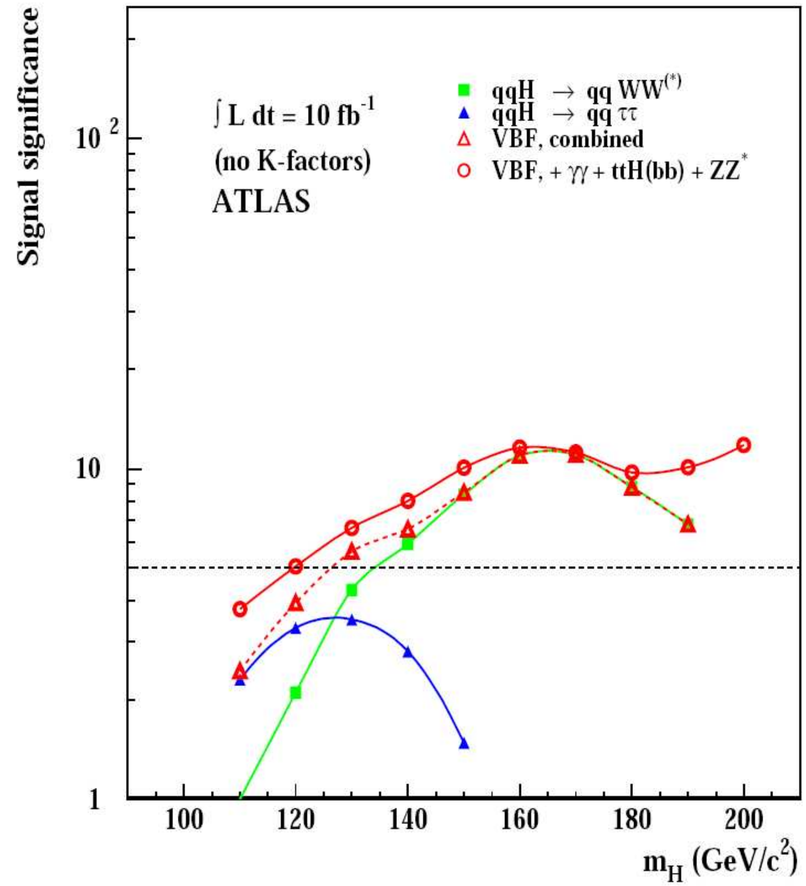
- As in the inclusive WW analysis, spin correlations between the leptons are used to enhance the signal fraction.



- Signal to background in the VBF channel increases to ~ 3.6.

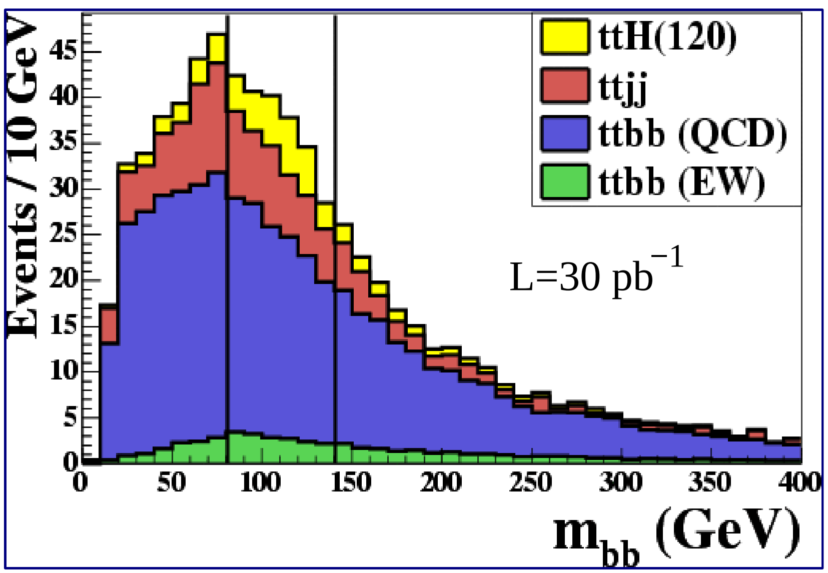
Sensitivity of the VBF Channels

- Both $H \to \tau\tau$ and $H \to WW$ are sensitive for low Higgs masses.
- $H \to \tau\tau$:
  - $m_H \lesssim 145$ GeV.
- $H \to WW$:
  - $125 \leq m_H \leq 200$ GeV.
- If the two channels are combined, a 5σ discovery is possible for $m_H \gtrsim 130$ GeV with 10 fb^{-1}.



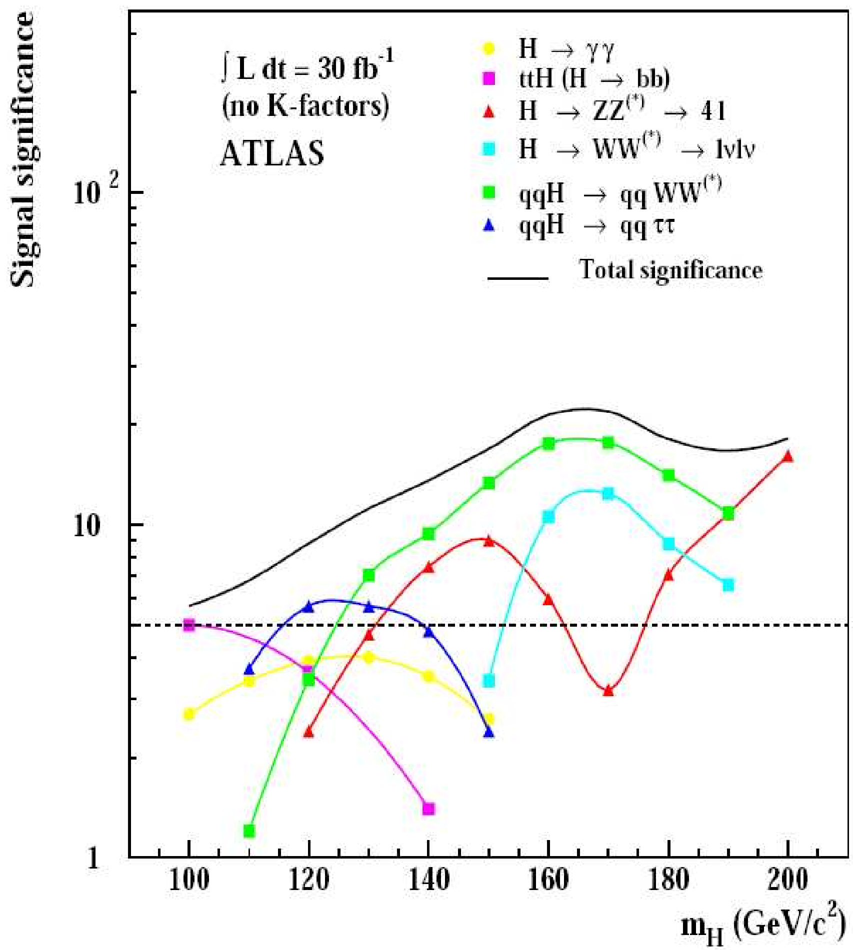
The $ttH \to \ell\nu bbbbjj$ Channel

- Spectacular, very energetic, final state!
- The ℓ from the t decay allows for triggering, even though $H \to b\bar{b}$.
- Dominant background is from non-resonant $ttbb$ production.
  - Smaller backgrounds from ttZ, $ttjj$, $WWbbjj$ ...



- To extract the signal:
  - Reconstruct all six jets.
  - Exactly 4 b-tagged jets.
  - Reconstruct the two t quarks.
  - Determine invariant mass of b-jets from the Higgs decay.
- The most challenging channel.

Combined Sensitivity



- Only LO results shown in plot.
- Full mass range covered after a few years of running.
- Several channels available for any given Higgs mass.
- VBF channels play important role for low Higgs masses.
- For $m_H \leq 120$ GeV three complementary channels:
  - $H \rightarrow \gamma\gamma$ ($M_{\gamma\gamma}$ resolution).
  - $t\bar{t}H$ (b-tagging).
  - $qqH \rightarrow qq\tau\tau$ (large $|\eta|$ jets).

Summary and Outlook

- Should a standard model Higgs boson exist, it cannot escape detection at the LHC.
- A Higgs with $m_H < 120$ GeV presents the greatest challenge, a combination of channels can be used.
- Discovering the Higgs boson is just the first step, the next step is to measure its mass and couplings.
- The first LHC collisions are scheduled for next year.
  - Very exciting times are ahead of us!