ATLAS Higgs Boson Discovery Potential

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Corfu Summer Institute
September 2009

ATLAS

Standard Model

Higgs Boson Discovery Potential

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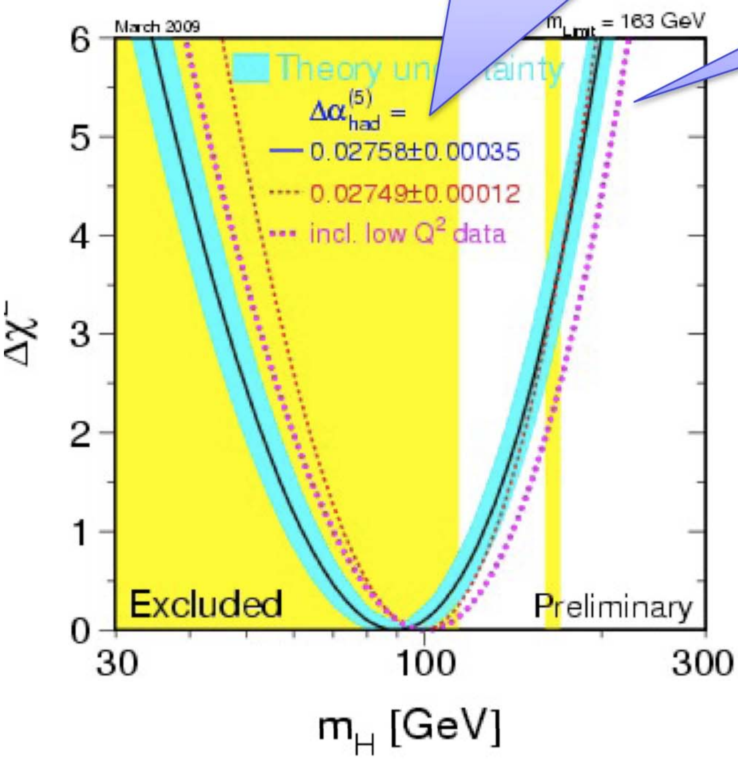
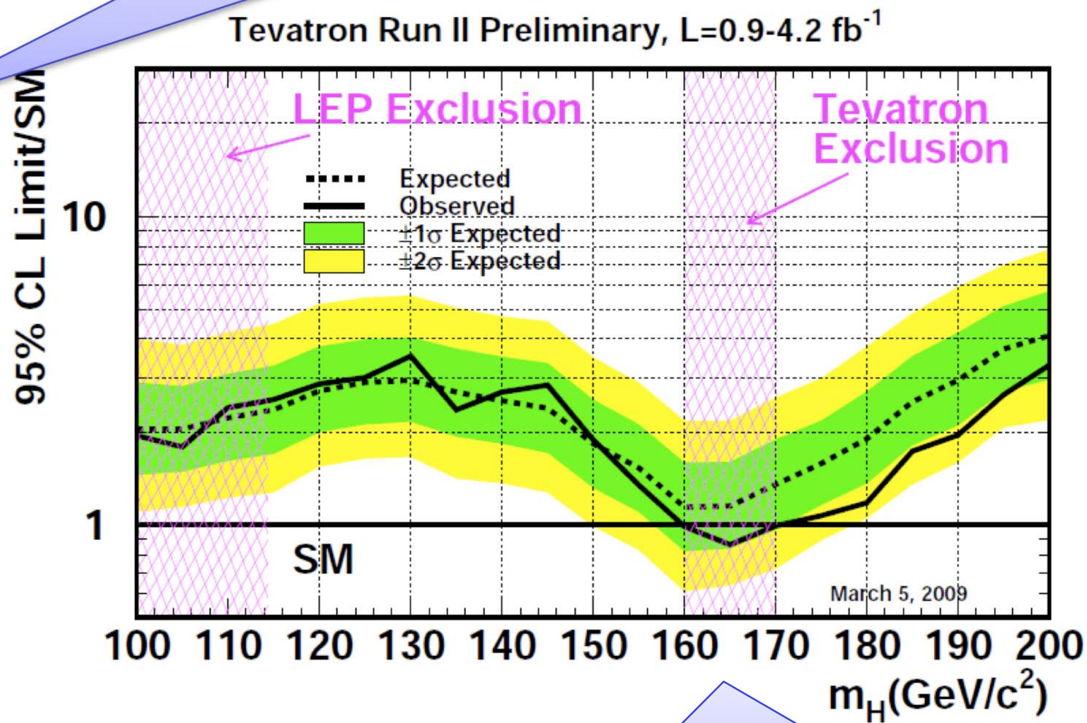
Where is the SM Higgs Boson ?

LEP direct search: m_H > 114.4 GeV

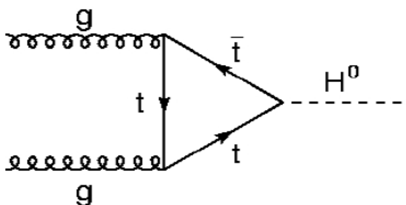
EW fit favors m_H < 163 GeV



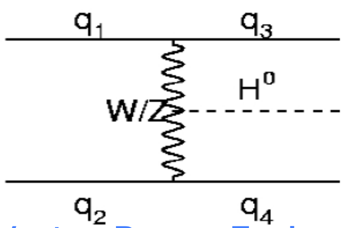


Recent CDF+D0 direct search combination (4 fb^{-1}) excludes range 160 - 170 GeV

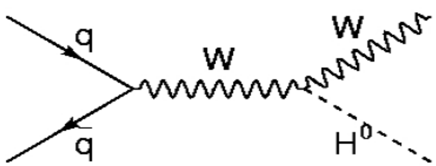
How would the SM Higgs boson be produced ?



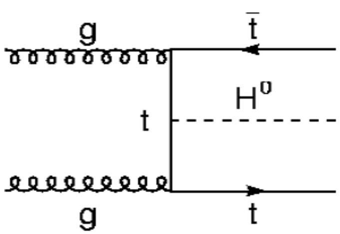
gluon fusion



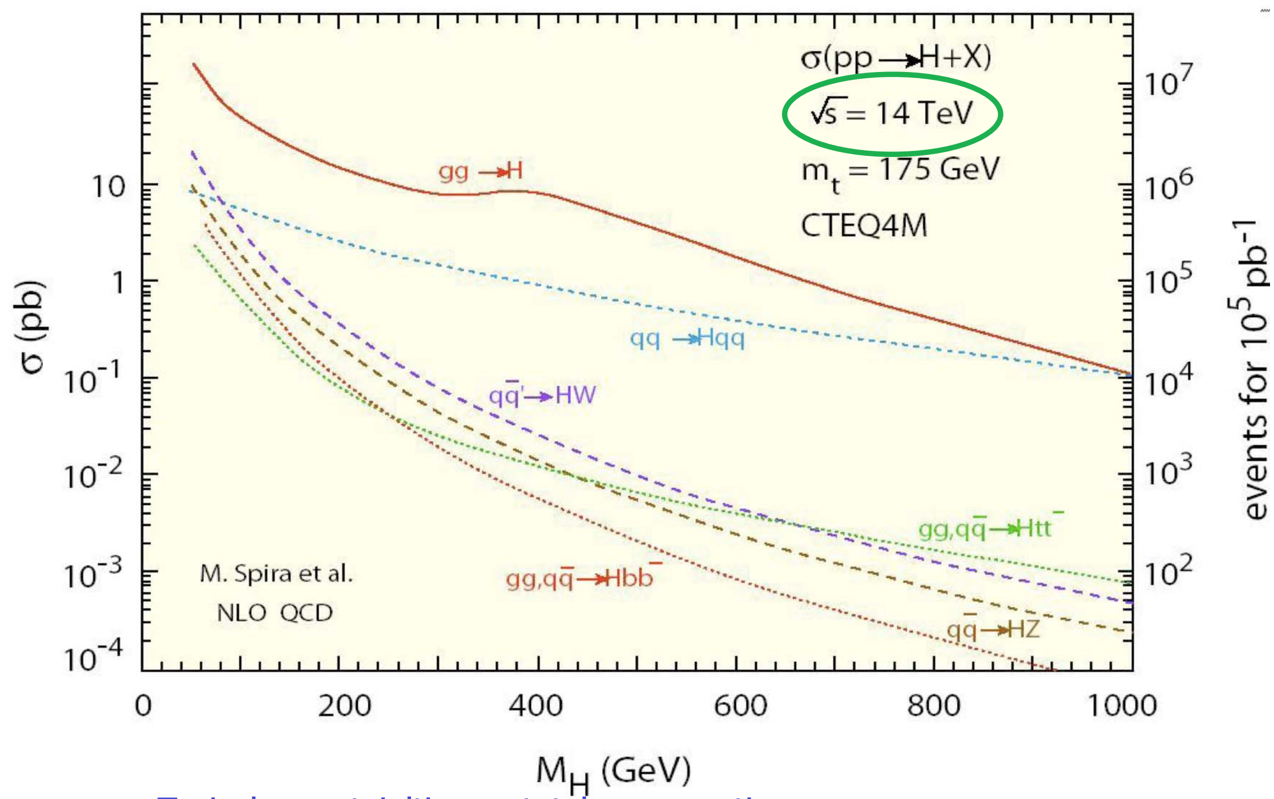
Vector-Boson-Fusion (VBF)



associated production (W, Z)



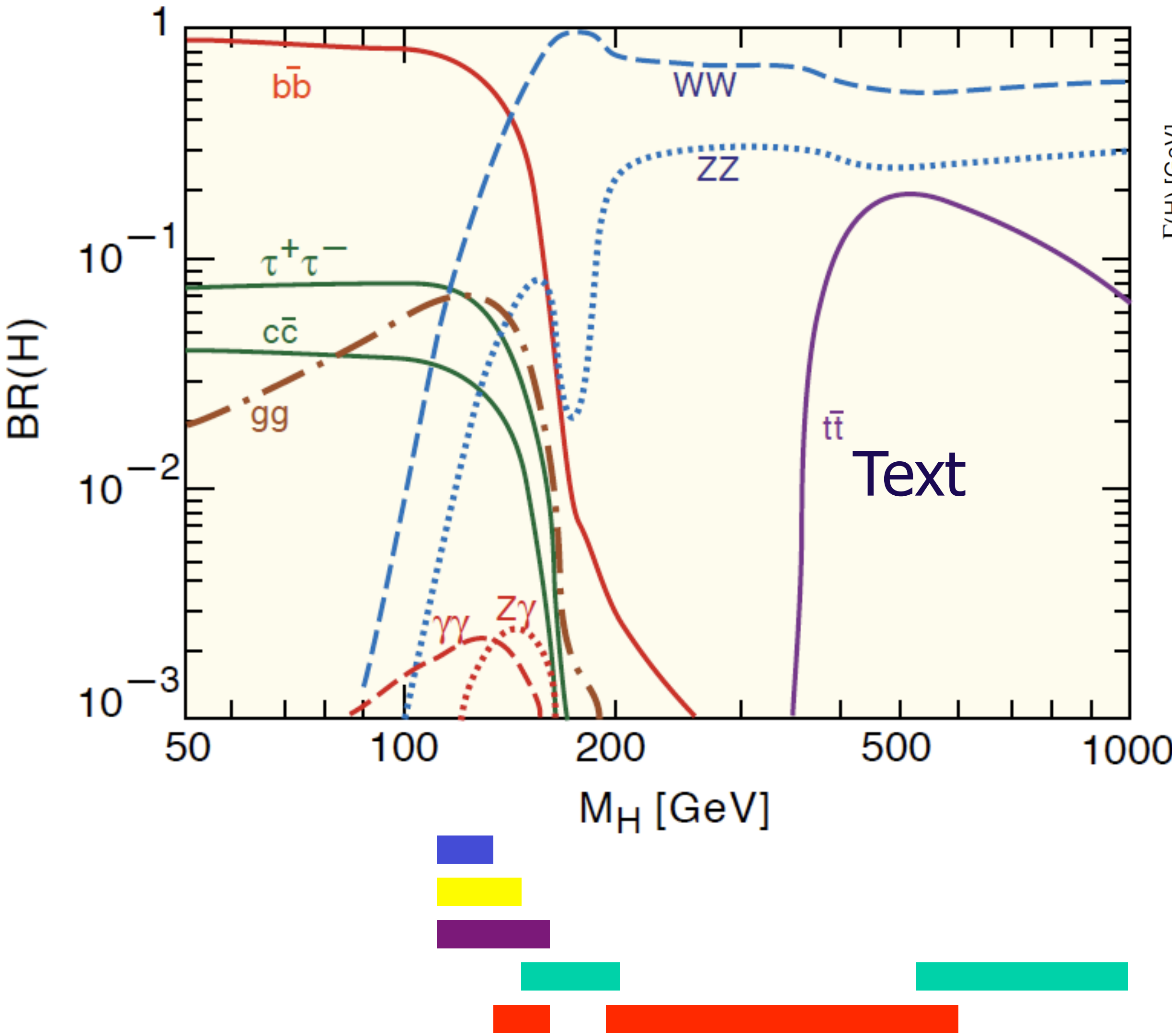
associated production (ttbar)

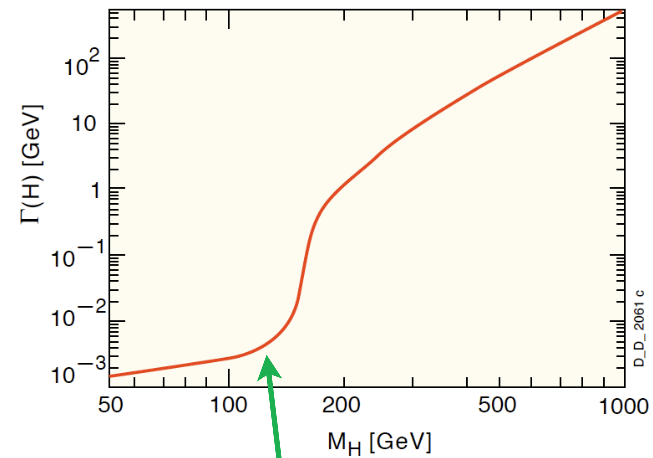


Typical uncertainlties on total cross-sections

gg	10%	NNnLO
VBF	5%	NLO
WH, ZH	5%	NNLO
ttH	15%	NLO

How would the Higgs boson decay?





Width << detector resolution

bb → m_H < 130 GeV

γγ → m_H < 140 GeV

ττ → m_H < 150 GeV

WW → $2m_W < m_H < 2m_Z$

ZZ → m_H > 130 GeV

Discovery & exclusion

N: Number of selected events

N_B: Number of background events

$\sqrt{N_B}$: Uncertainty on background

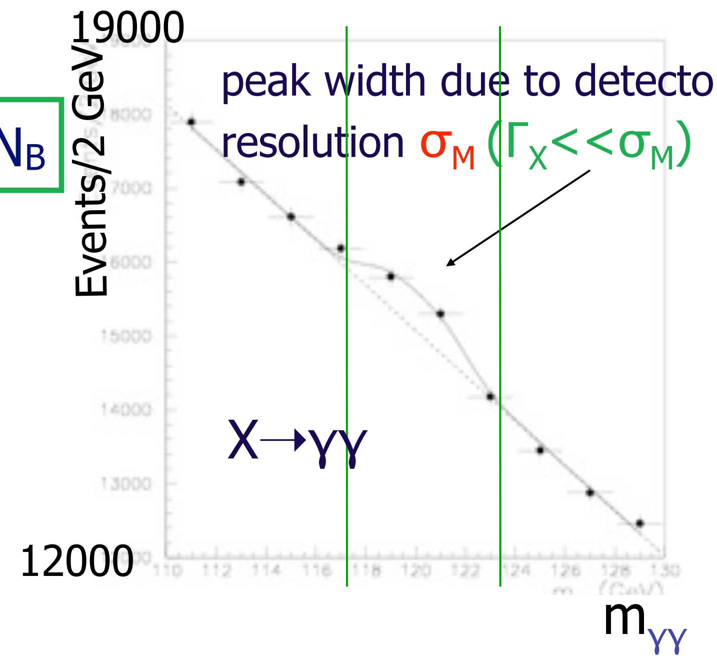
$S=(N-N_B)/\sqrt{N_B}$

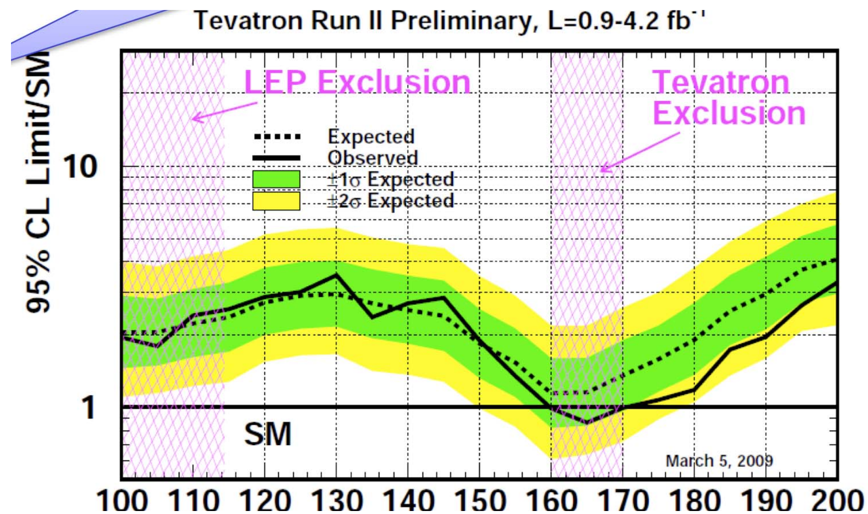
To maximize S

- Increase $\mathcal{L}$ ($S\sim\sqrt{\mathcal{L}}$)
- Improve mass resolution σ_M ($S\sim1/\sqrt{\sigma_M}$)
- Increase signal efficiency, background rejection

if S>5 (probability for a stat. fluctuation $< 10^{-7}$) $\Longrightarrow$ Discovery

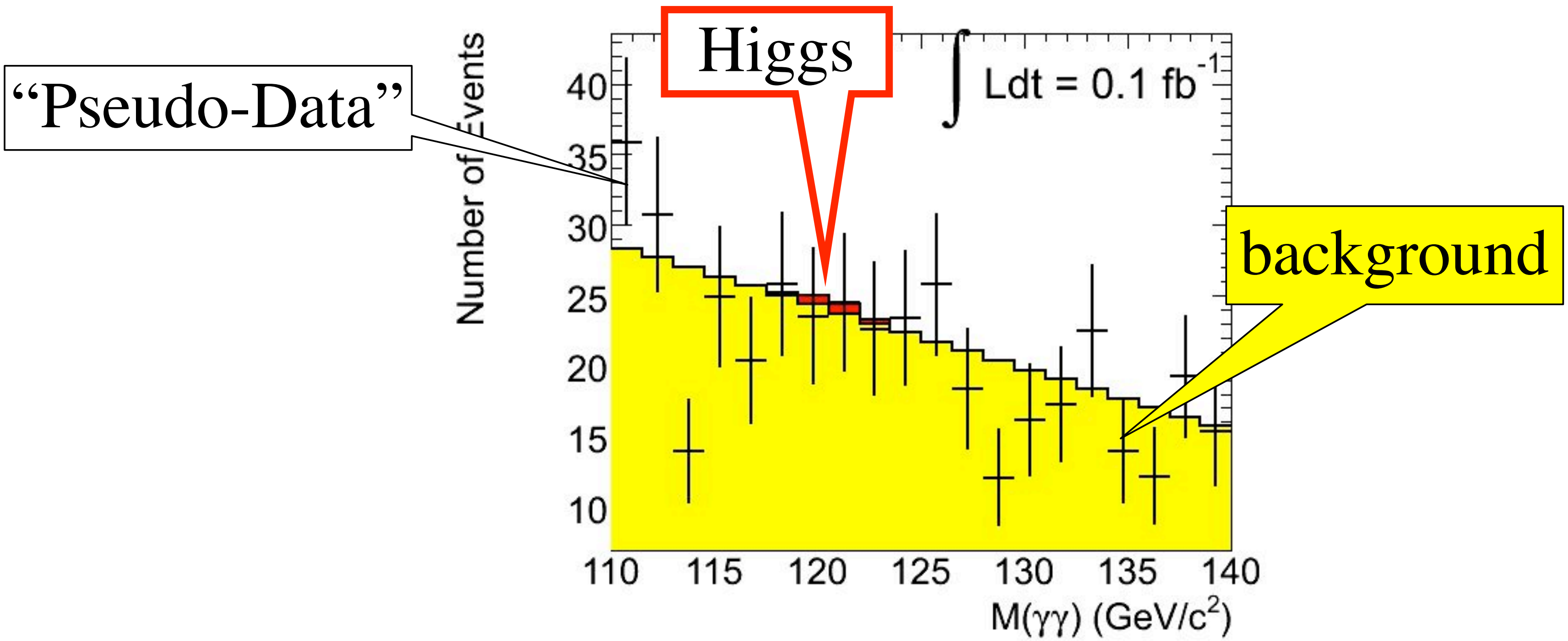
Otherwise, set an upper limit on Higgs boson cross-section





A signal emerging with time

$\int Ldt = 0.1\ fb^{-1}$

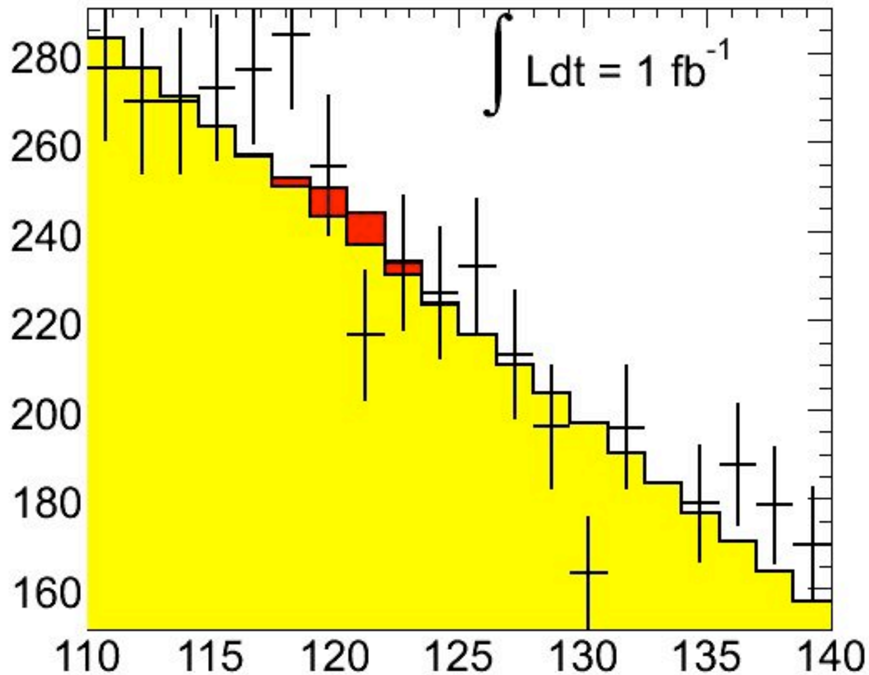


- Expected Events:
  - N_{higgs}~2, $N_{background}$=96 +/- 9.8
  - S/√B=0.2
- No sensitivity to signal

From B. Heinemann

A signal emerging with time...

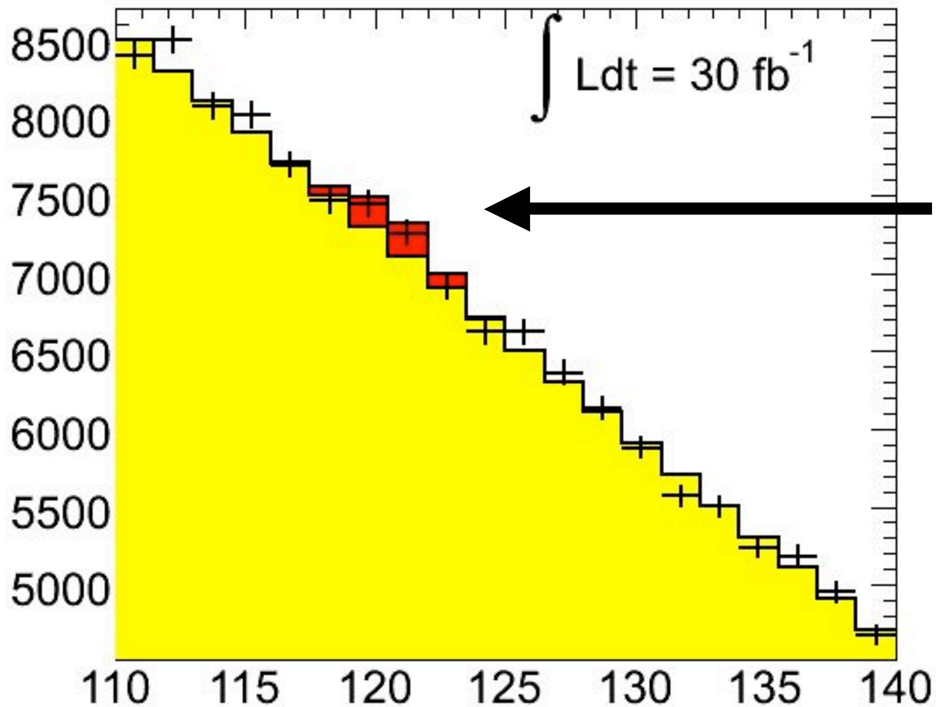
$\int L dt = 1\ fb^{-1}$



- Expected Events:
  - N_{higgs}~25, $N_{background}$~960 +/- 30
  - $S/\sqrt{B}$=0.8
- Still no sensitivity to signal

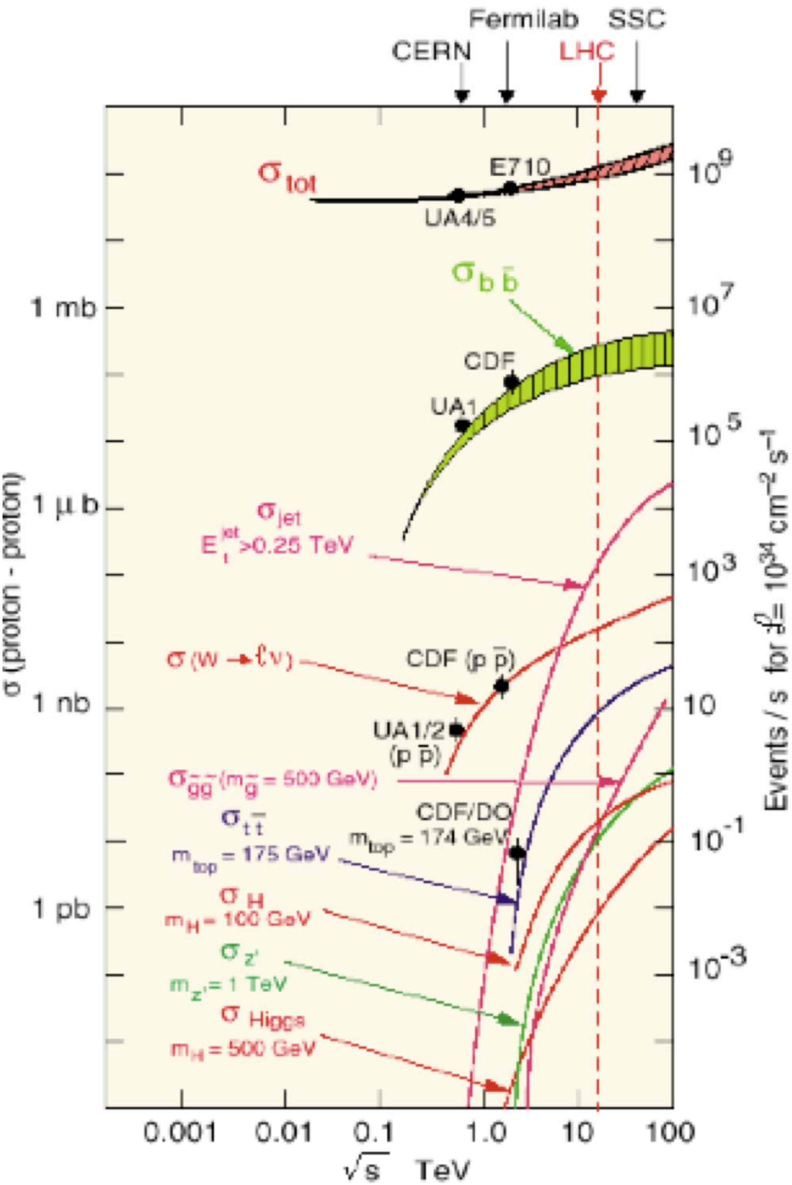
There it is!

$\int Ldt = 30\ fb^{-1}$ (



- Expected Events:
  - N_{higgs}~700, $N_{background}$=28700 +/- 170
  - $S/\sqrt{B}$=4.1
- Got it!!!

Reminder: small cross-section



Total inelastic cross-section: $\sigma \sim 100$ mb

bb production cross-section: $\sigma \sim 100$ mb

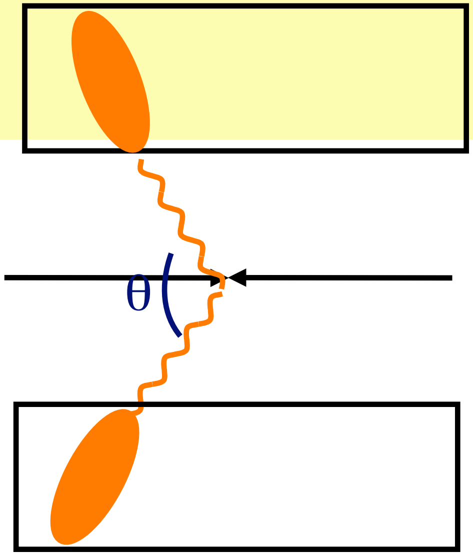
W (→l ν) production cross-section: $\sigma \sim 10$ nb

Higgs (m_H=150 GeV) cross-section: $\sigma \sim 10$ pb

Total σ / Higgs $\sigma > 10^{10}$

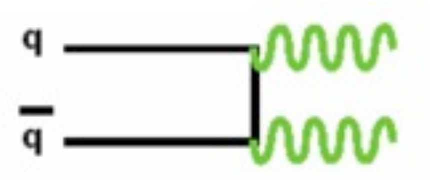
$$H \longrightarrow \gamma\gamma$$

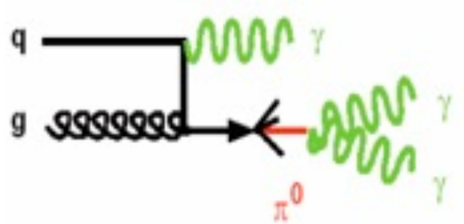
H→γγ: The Signature



$$\frac{\sigma_{M_H}}{M_H} = \frac{1}{2}\left[\frac{\sigma_{E_{\gamma_1}}}{E_{\gamma_1}} \oplus \frac{\sigma_{E_{\gamma_2}}}{E_{\gamma_2}} \oplus \frac{\sigma_\alpha}{\tan(\alpha/2)}\right]$$

- The difficulties:
  - High background
    - irreducible (2 γ in final state)
    - reducible (π^0, jets) in final state

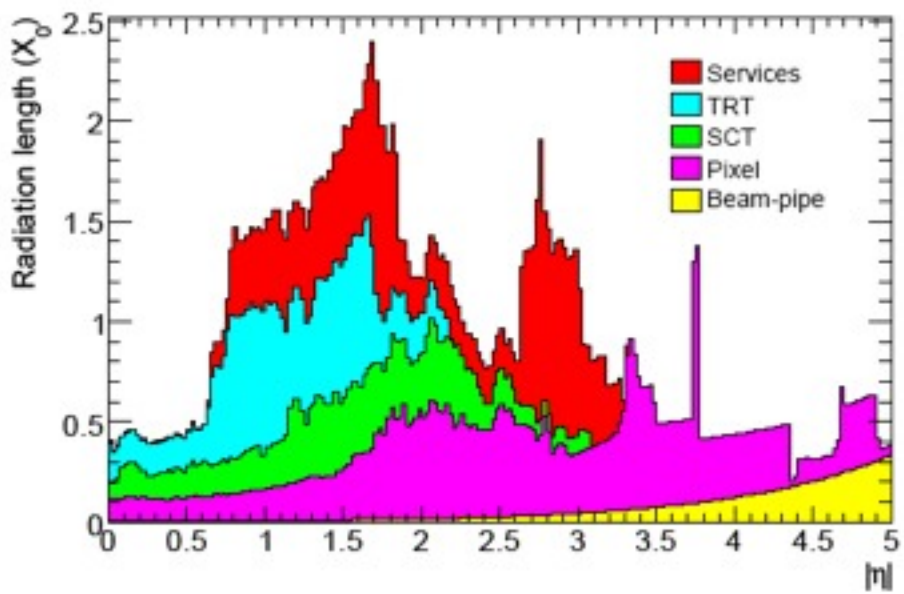


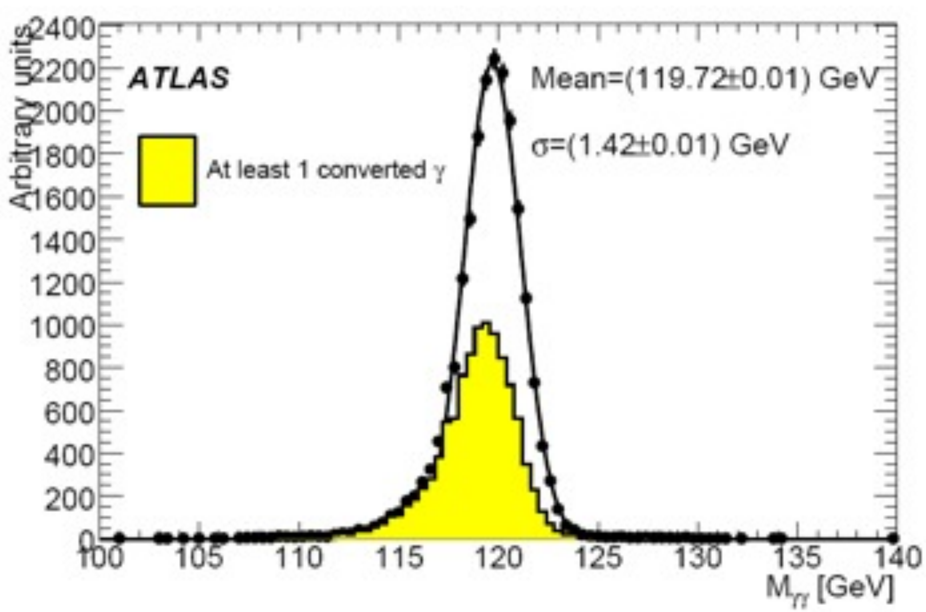


  - Vertex is not known: pile-up & beam spot 5.6 cm long
    - develop techniques to reconstruct it from the calorimeter
    - use high pT track to select the high Q^2 interaction vertex
  - Photons convert in the tracking detector

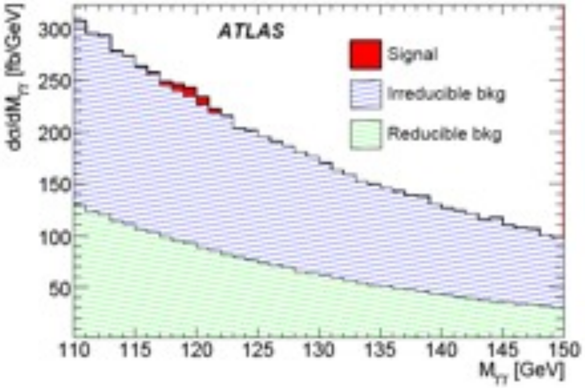
H→γγ : Mass Resolution

- Photon conversions in the tracking detector
- A good mass resolution is needed
  - ✓ Need vertex reconstruction! If vertex unknown, add ~1.4 GeV to mass resolution
  - ✓ Example (ATLAS):
    - Calorimeter pointing in ATLAS gives vertex resolution of 1.7 cm, while σ_{beam} = 5.6 cm
    - Large amount of material in the Inner Detector in front of EM calorimeter = conversions!

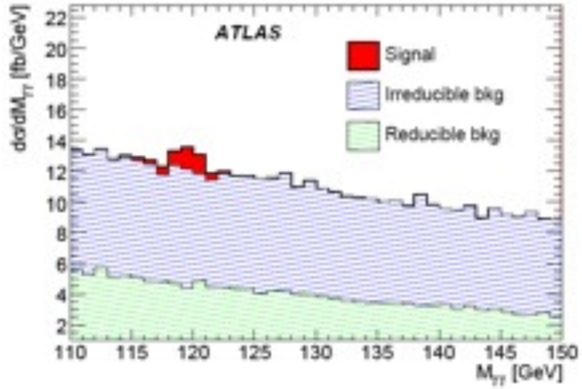




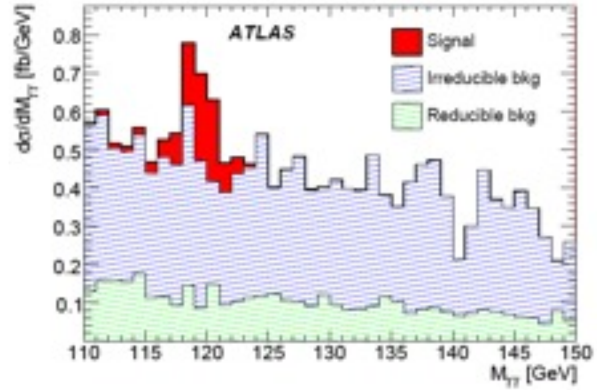
H→γγ (10 fb^{-1}): splitting the final states



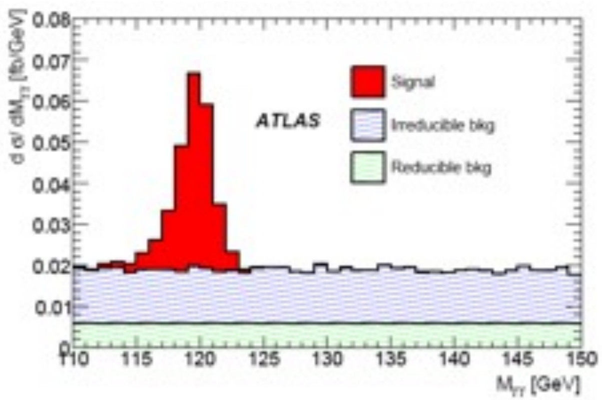
inclusive γγ
S/B ~ 0.03



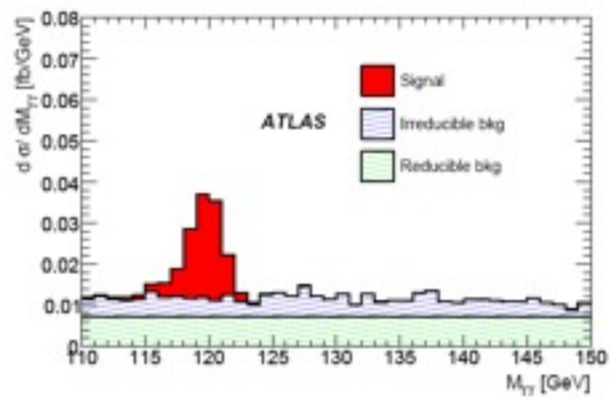
γγ + 1 jet
S/B ~ 0.08
VBF + gg production



γγ + 2 jets
S/B ~ 0.4
VBF + gg production

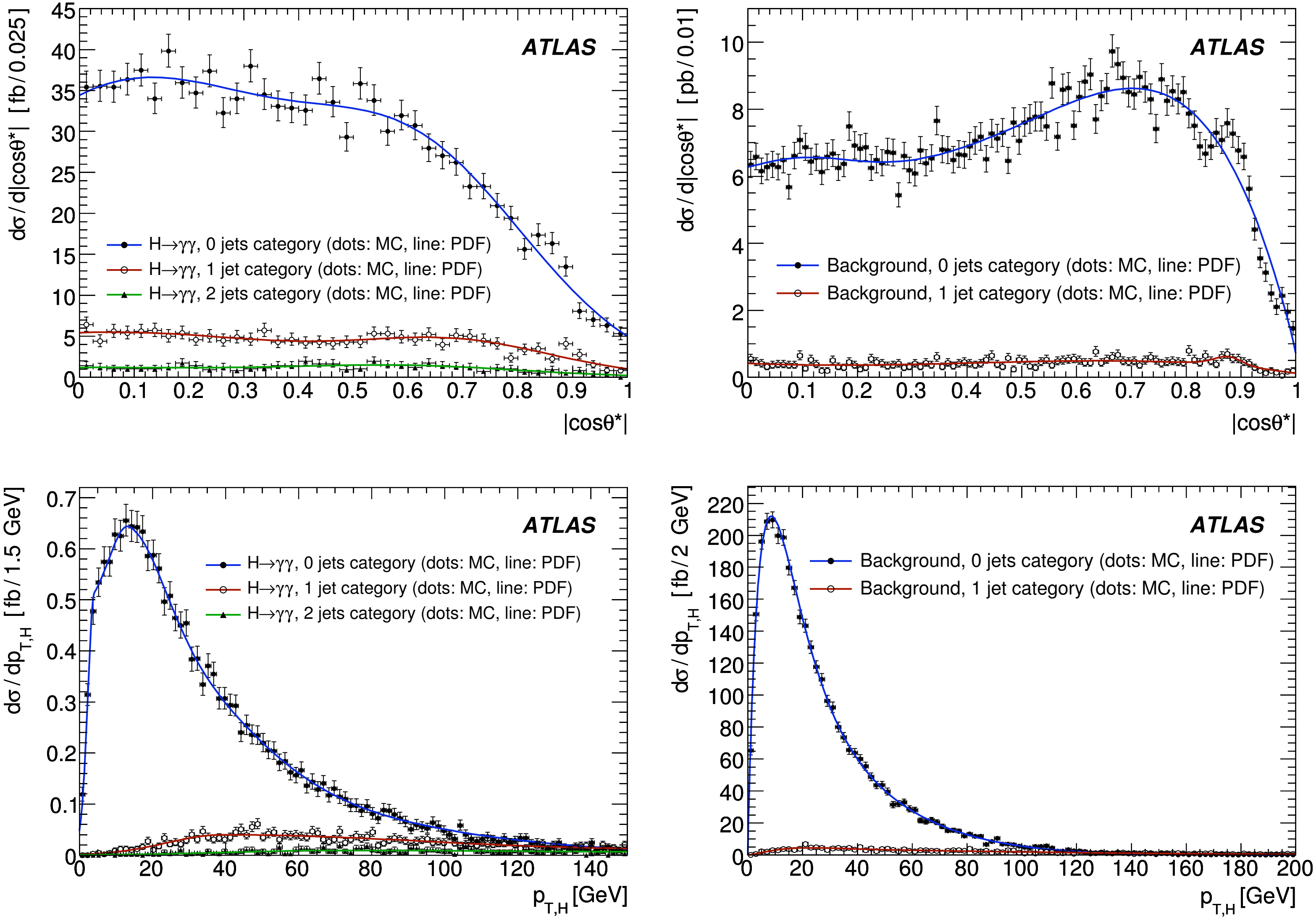


γγ+E_T^{miss}+1lepton
S/B ~ 2
ttH, WH

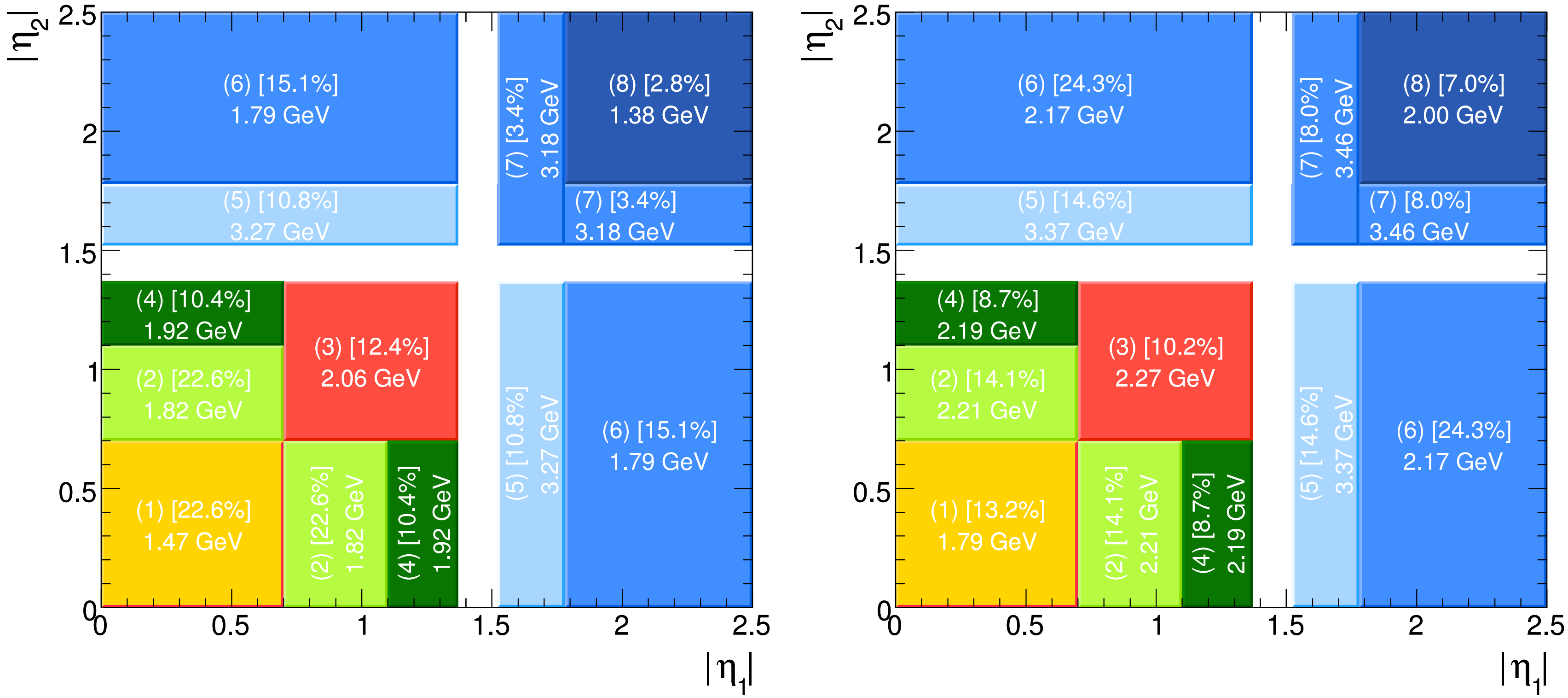


γγ+E_T^{miss}
S/B ~ 2
ZH, WH

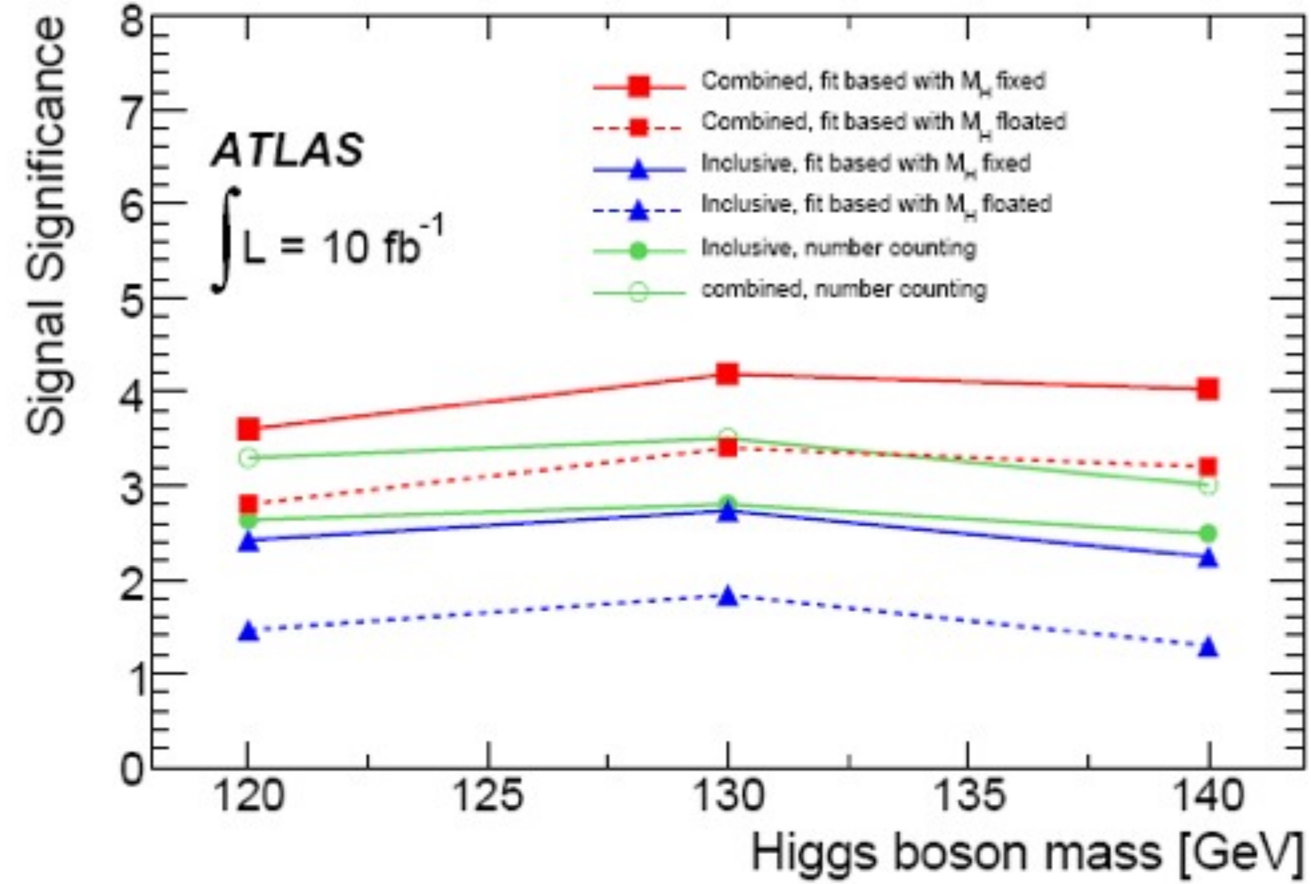
Discriminating variables



Optimizing the description of the data: regions in the detector of constant resolution



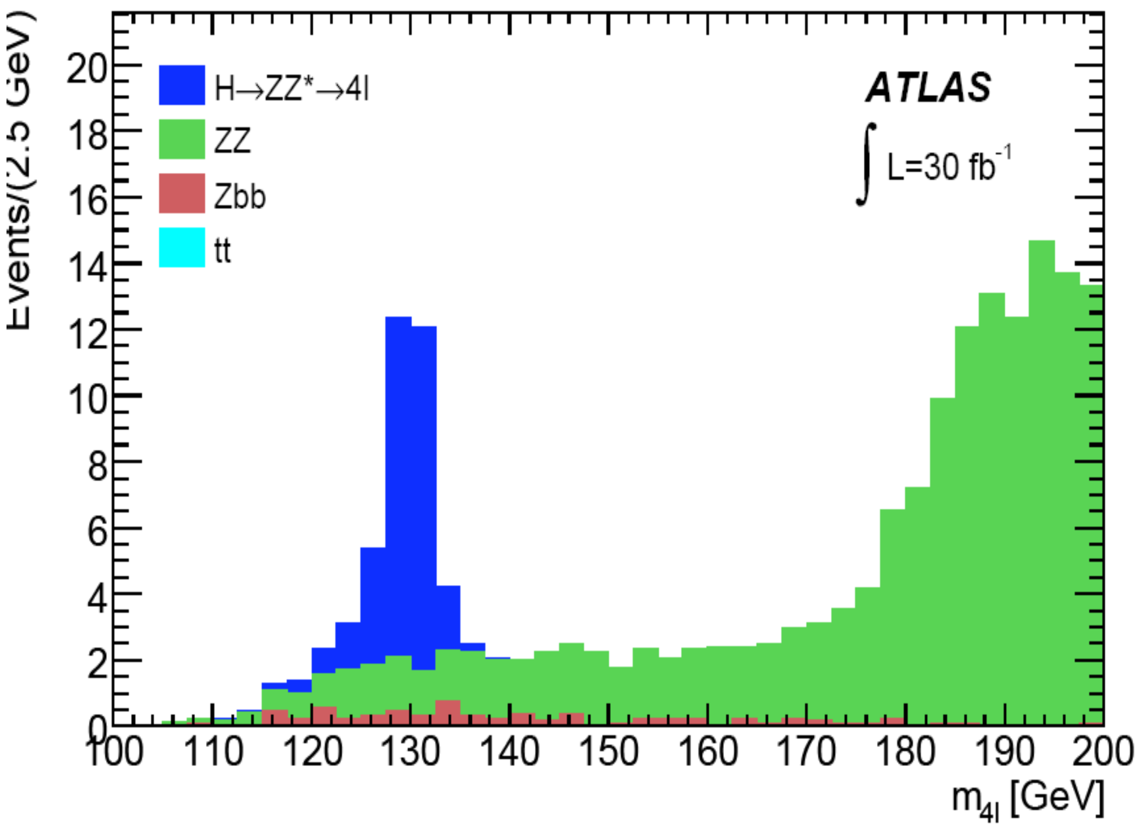
H→γγ: Significance



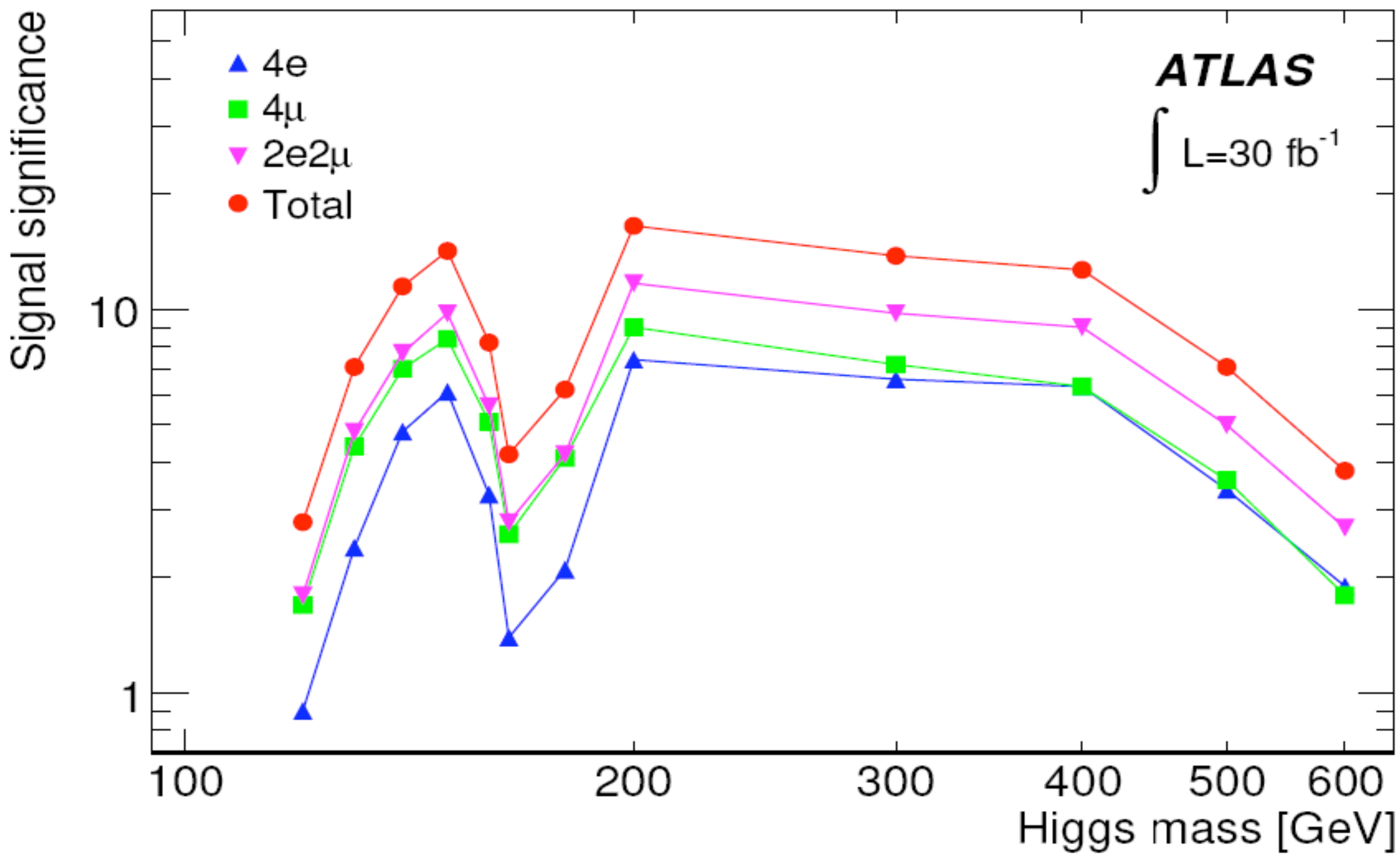
$H \rightarrow ZZ^* \rightarrow 4$ leptons

H→ZZ* → 4 leptons

- Analysis in a nutshell:
  - ✓ isolated muon or electron pairs with opposite charge
  - ✓ require at least one Z on shell
  - ✓ reconstruct 4-lepton invariant mass
  - ✓ estimate background from sidebands
- Main backgrounds:
  - ✓ ZZ (irreducible), tt and Zbb (reducible) + fakes
- Background suppression:
  - ✓ lepton isolation
  - ✓ impact parameter
- Efficiency is important!



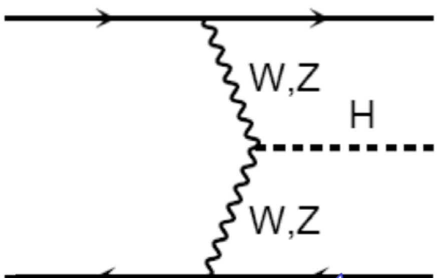
$H \rightarrow ZZ^* \rightarrow$ 4 leptons: significance



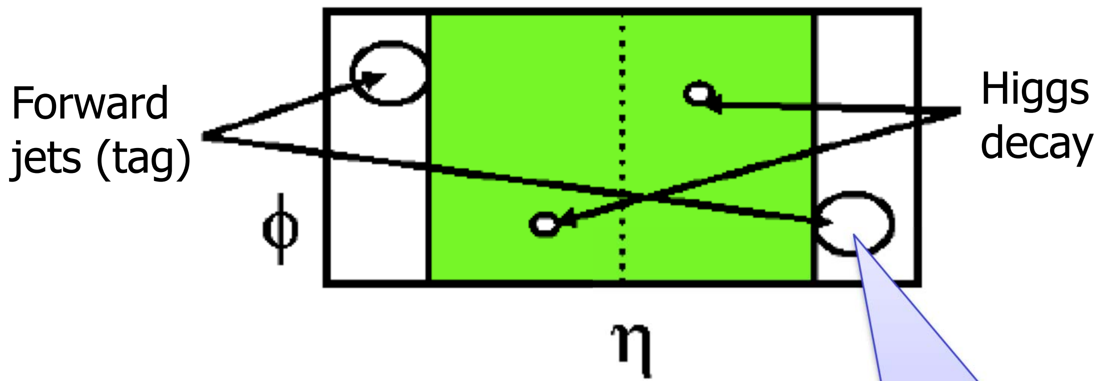
VBF $H \rightarrow \tau^+\tau^-$

H→ττ: the reciepe

- Identification

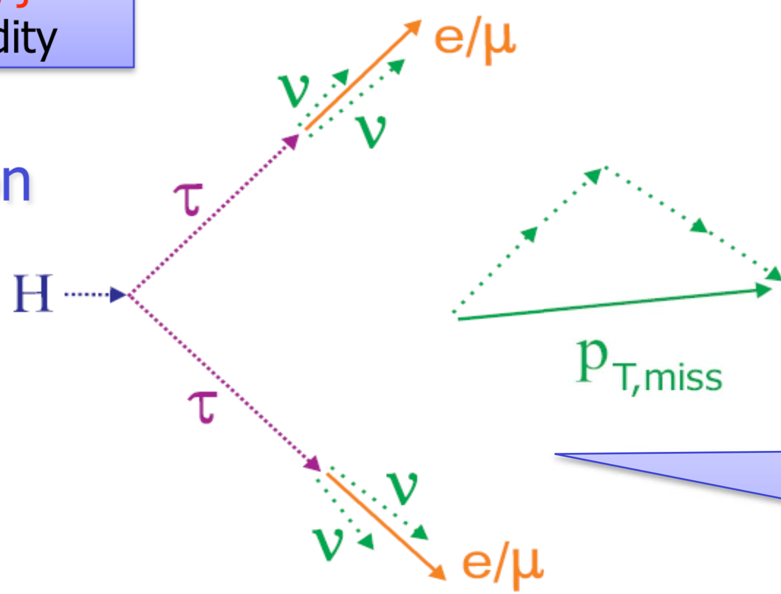


2 high p_T tag jets at large rapidity



no color flow between tag jets implies a rapidity gap, thus the central jet veto effective to reduce backgrounds

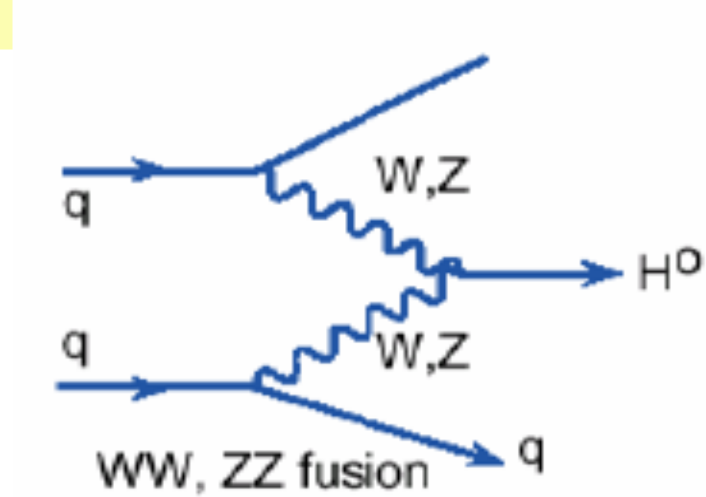
- Reconstruction

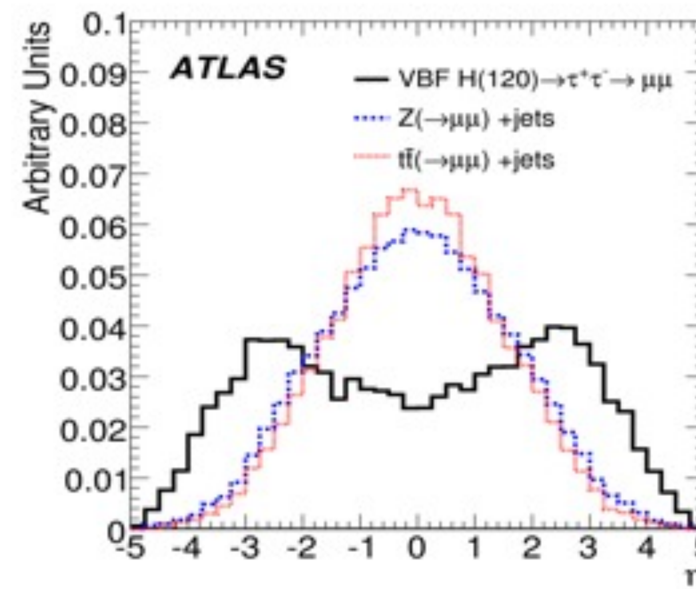


Higgs mass is reconstructed using the collinear approximation and the angle between the two τ

Event selection

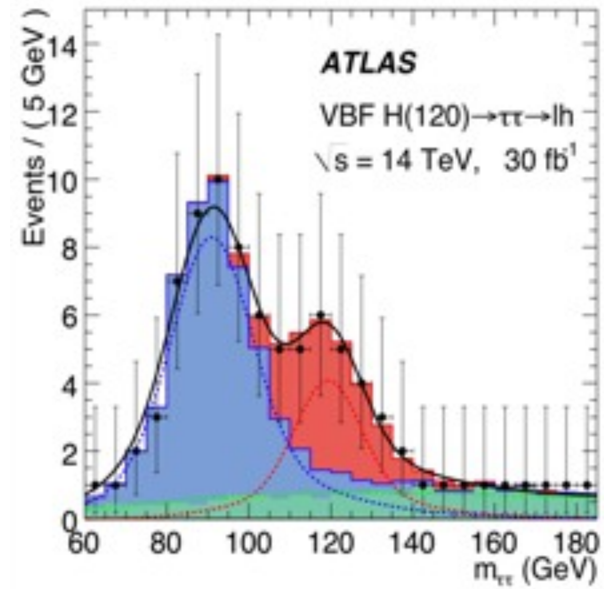
- Due to poor Higgs mass resolution for $H\rightarrow\tau\tau$, inclusive analysis not possible
- Exclusive (VBF) searches: Reduce QCD backgrounds by using distinct topology of jets in association with Higgs
- Signal
  - 2 high p_T jets from quarks, at large η, no jets in between
  - τ-pair from a resonnance
  - leptonic & hadronic τ decays (ll, lh, hh)
  - E_T^{miss}
- Background
  - irreducible: Z+jets ($Z\rightarrow\tau\tau$)
  - reducible: W+jets, t-tbar+jets
  - leptonic & hadronic τ decays (ll, lh, hh)



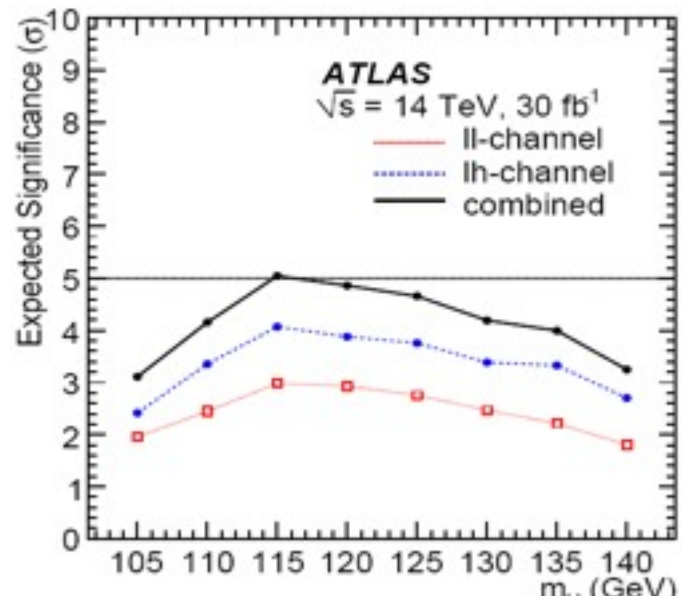


Reconstructing VBF events

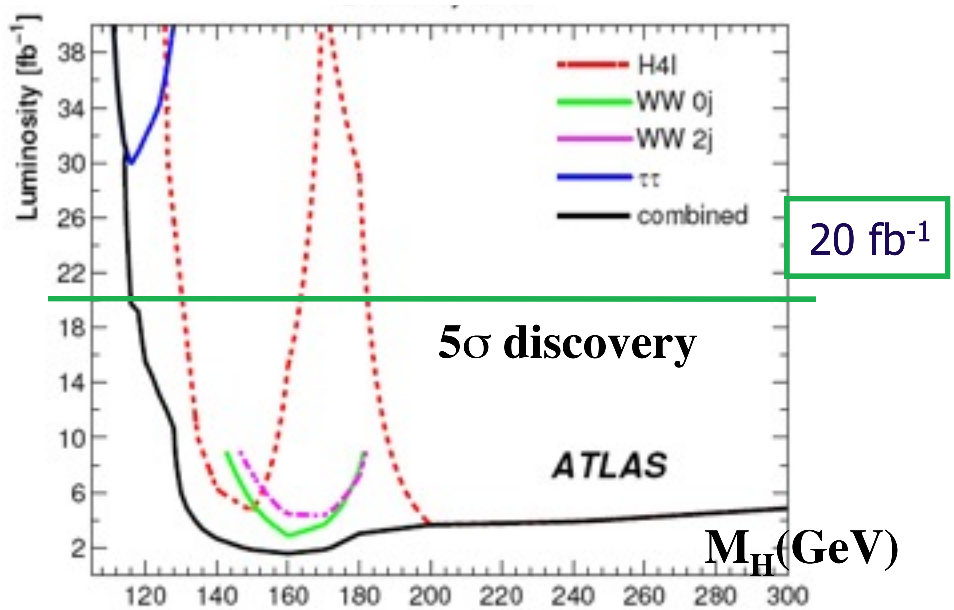
- Mass Reconstruction
  - collinear approximation: τ decay products go along the τ direction
  - Mass resolution limited bt E_T^{miss} (8-10 GeV) & τreconstruction (~10 GeV)

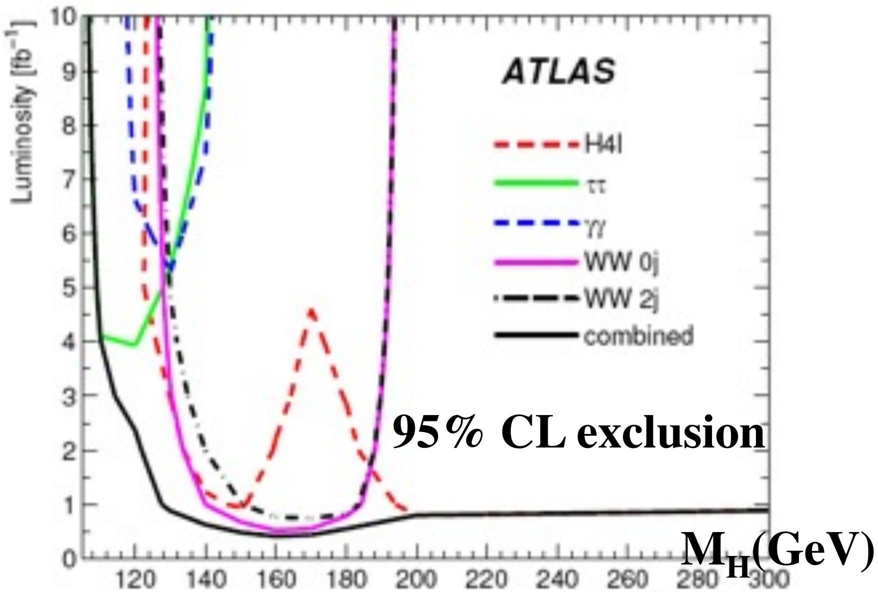


- Significance
  - Counting events in the mass peak using a fit over the mass spectrum



Overall sensitivity with ATLAS





- 5 σ discovery
  - 2 fb^{-1}: m_H~160 GeV
  - 3 fb^{-1}: 135<m_H<190 GeV
  - 20 fb^{-1}: probe down to m_H~115 GeV
- 95%CL exclusions
  - <2 fb^{-1}: region m_H~$2m_W$
  - ~2 fb^{-1}: 120 < m_H< 460 GeV
  - ~3 fb^{-1}: probe down to m_H~115 GeV
- Systematic effects & uncertainties taken into account

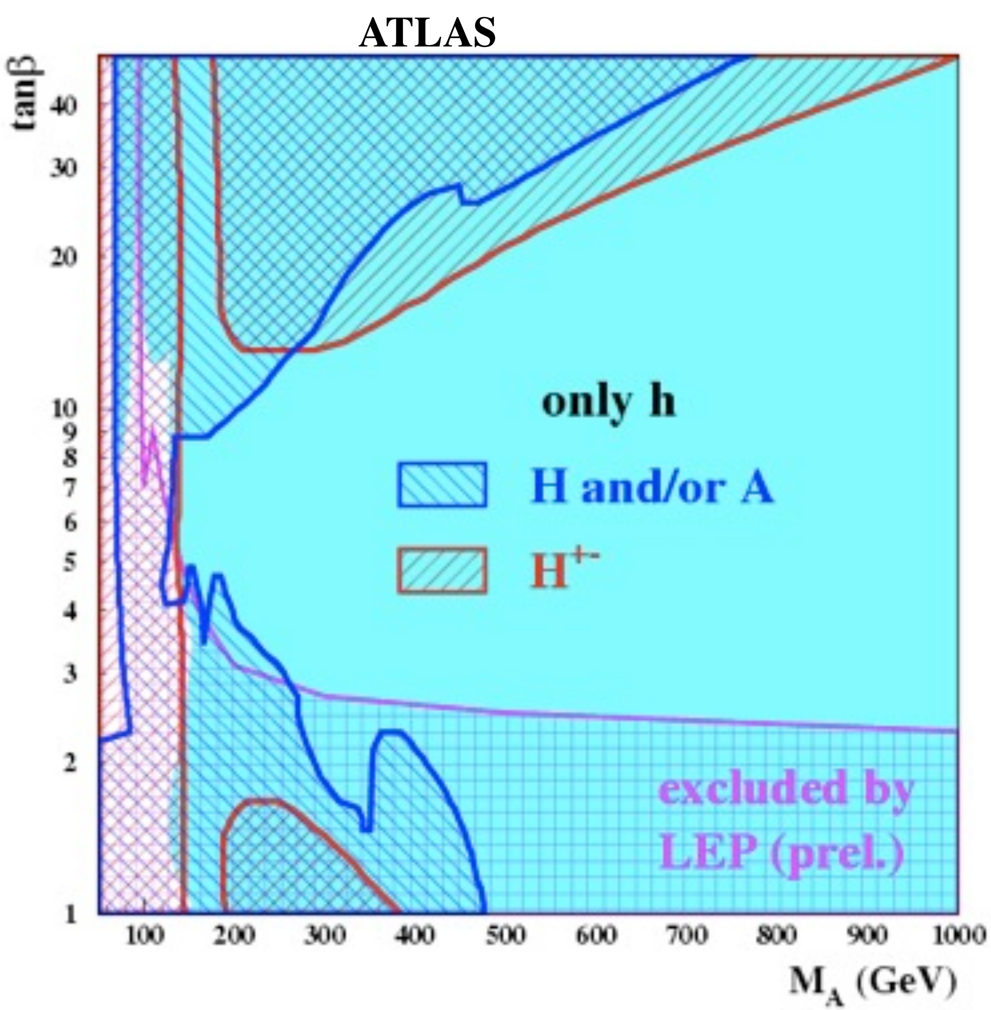
Conclusive remarks

- All possible SM Higgs mass range is well covered by several channels
- ATLAS has a good sensitivity to the SM Higgs already with the first fb^{-1}

- Many aspects not covered in this presentation:
  - How to show that a signal is the SM Higgs boson
  - Measurement of the spin and CP
  - Measurement of the couplings
  - And also the MSSM Higgs searches

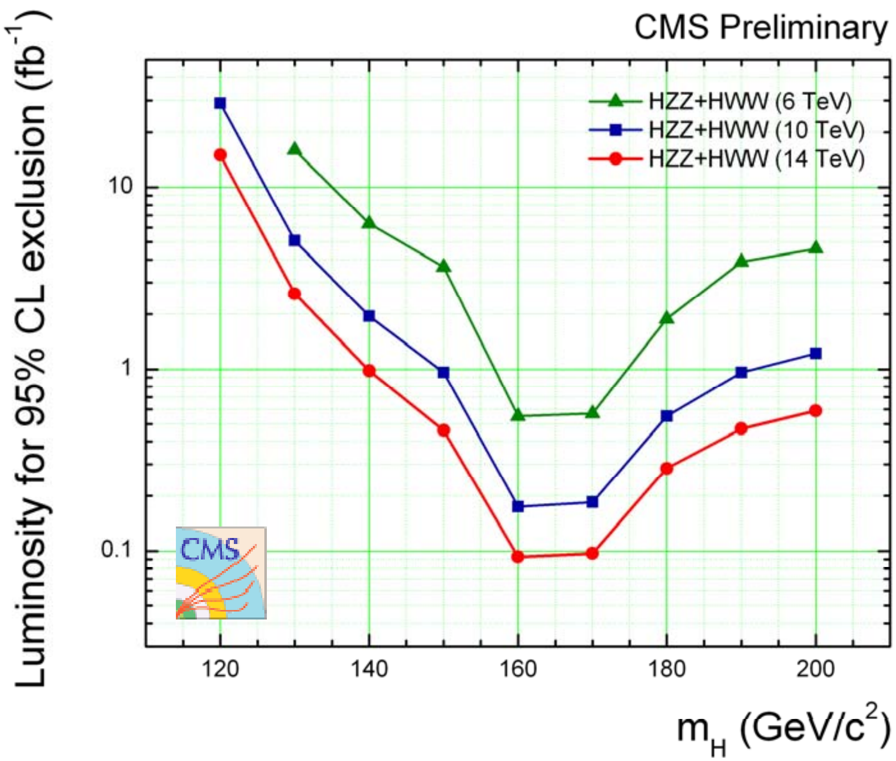
ATLAS sensitivity to MSSM Higgs boson

300 fb^{-1}



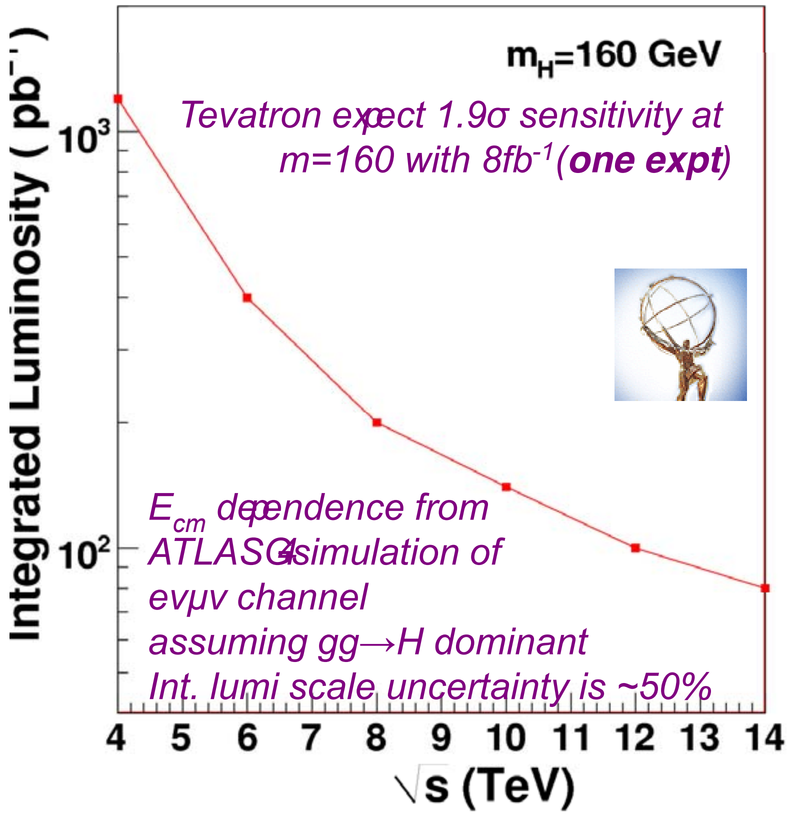
Higgs 95% CL at LHC GPD , H→ weak bosons, indicative

Combined H→WW + H→ZZ: lumi for 95% CL



- Energy $s^{1/2}$ 14 → 10 → 6 TeV
- Lumi needed 0.1 → 0.2 → 0.6 fb^{-1}

Compare sensitivity to Tevatron with 8 fb^{-1} (only H→WW→ ℓνℓν)



- Massive loss of sensitivity below 6 TeV

To challenge Tevatron with **$s^{1/2}$ = 8-10 TeV**, we need **~300-200 pb^{-1} g.d.**