Higgs Searches in the Vector Boson Fusion Channels in ATLAS

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Physics at LHC
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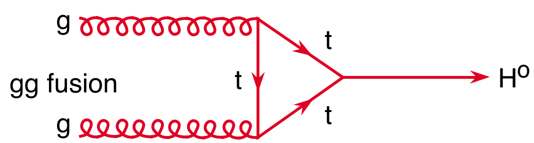
Outline

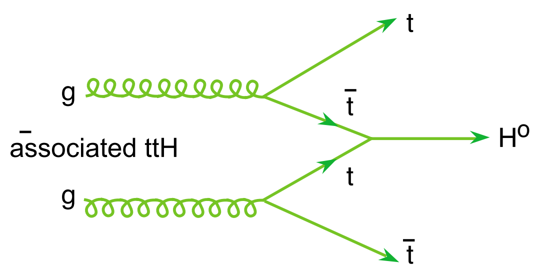
- Higgs Production and Decay at LHC
- Introduction to Vector Boson Fusion (VBF) Processes
- Major Detector Issues for ATLAS
- Analysis of VBF H -> WW* and Results
- Analysis of VBF H -> □□and Results
- Combined Results
- Summary and Prospects

Higgs Production Processes at LHC

Gluon-gluon fusion

Specific Higgs decay mode





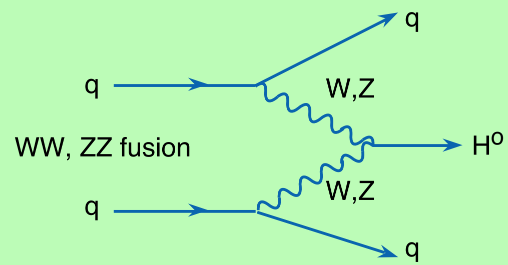
Heavy quark associated

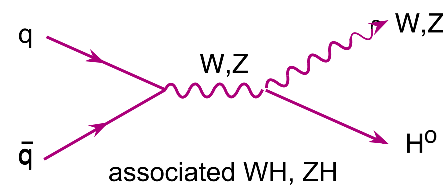
Tag top decays

Vector boson fusion

Forward jet tag

Central jet veto

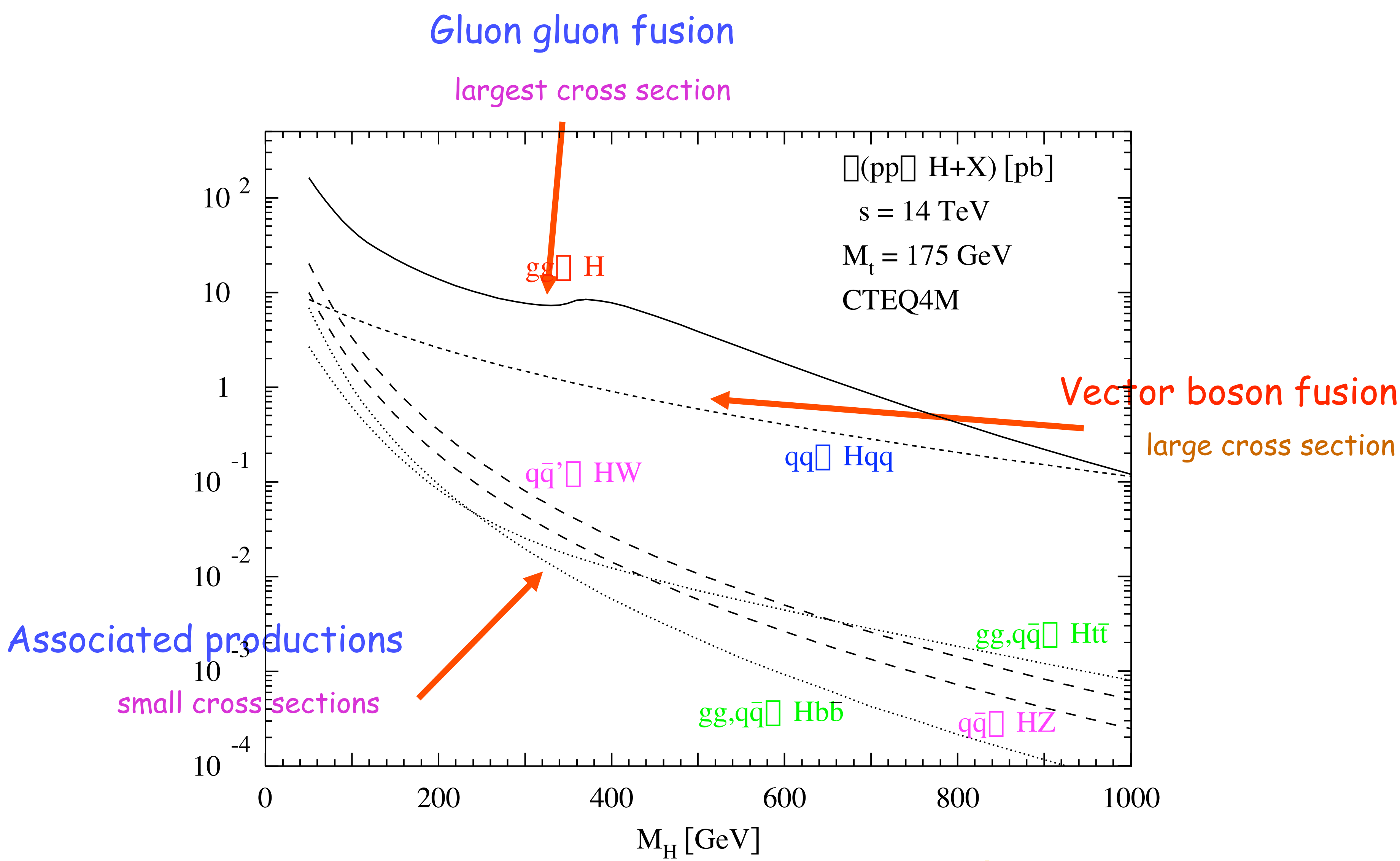




Vector boson associated

Tag vector boson decays

Higgs Production Cross Section



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Higgs Searches before "VBF"

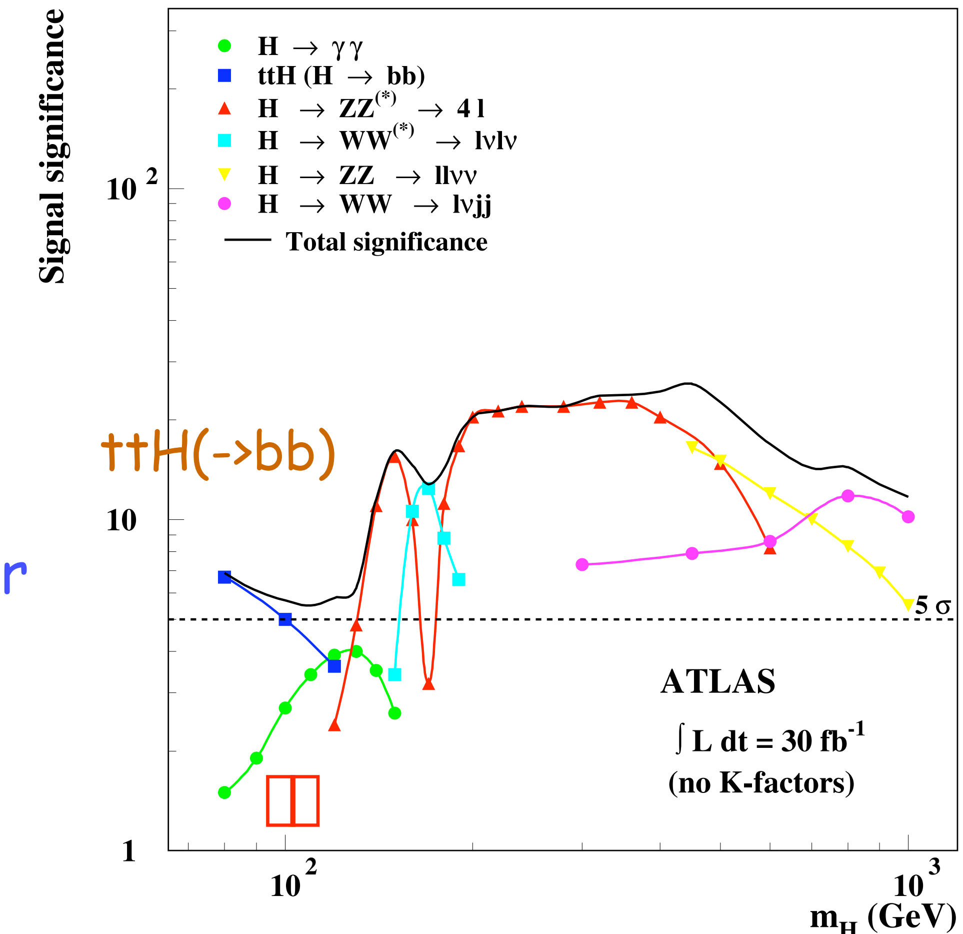
Light Higgs search before "VBF":

- □□: direct production by gluon fusion
- bb: top-quark associated production ttH(->bb)

No single mode can observe light Higgs with $30fb^{-1}$

Pioneering works in applying "VBF" to the light Higgs search by D. Rainwater and his colleagues:

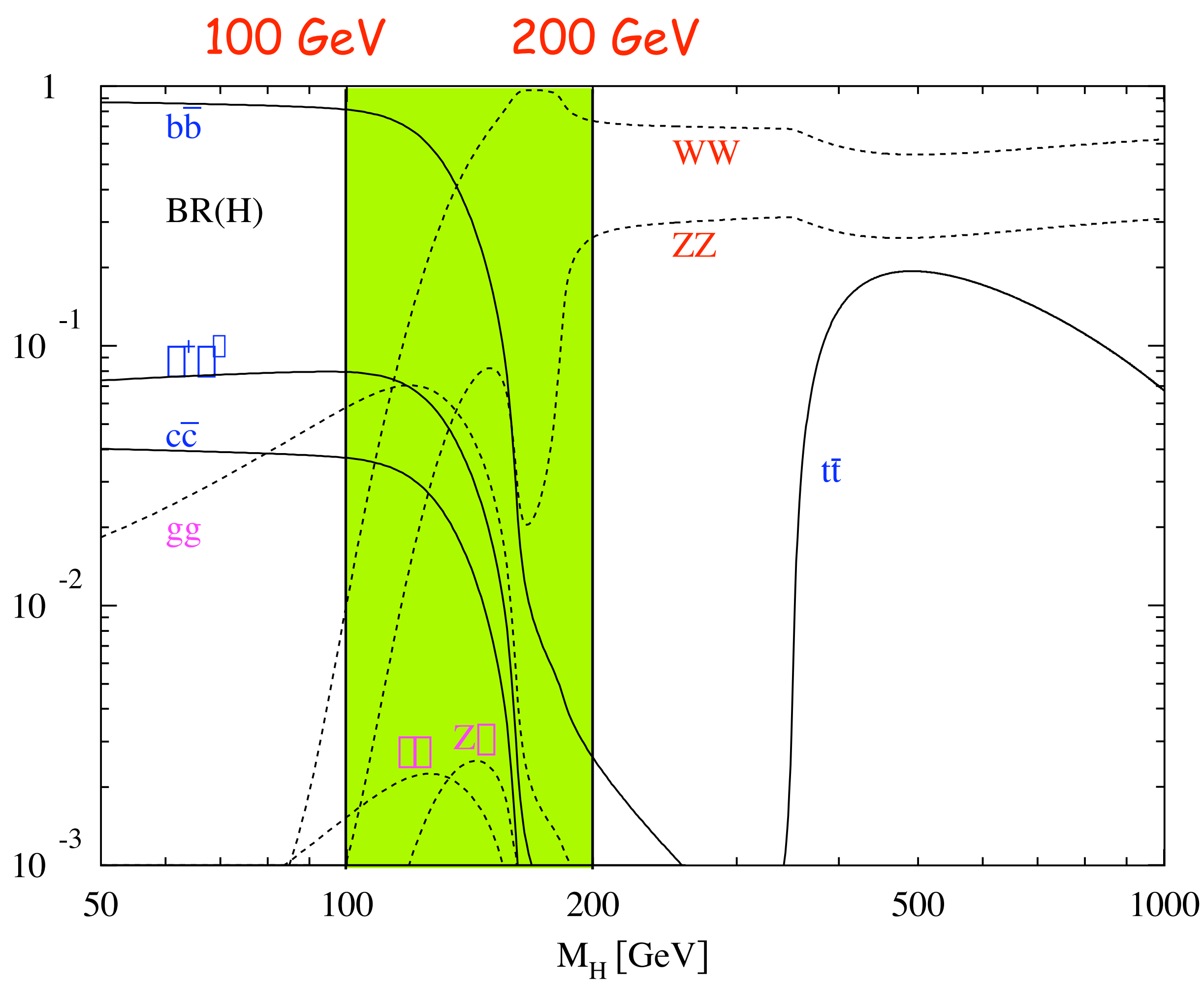
- □□: D. Rainwater and D. Zeppenfeld, JHEP 9712:005, 1997
- □□: D. Rainwater, D. Zeppenfeld and K. Hagiwara, Phys. Rev. D59:014037, 1999
- WW*: D. Rainwater and D. Zeppenfeld, Phys. Rev. D60:113004, 1999, Erratum-ibid. D61:099901, 2000.



ATLAS Physics TDR (1999)

Higgs Decay Branching Ratios

- $m_H < 2m_W$
  bb, □□
  □□
  WW*, ZZ*
- $m_H \approx 2m_W$
  WW dominates
  Higgs decay
- $m_H > 2m_W$
  WW, ZZ



Low Mass Higgs via VBF

Low mass region is especially important.

- LEP direct limit (m_H > 115 GeV)
- EW fit constraint (m_H < 211 GeV, 95%C.L.)

• H -> WW* -> llvv, lvqq

very effective for m_H > 130 GeV

• H -> □□ -> ll, lh (+ p_T^{miss})

sensitive in the region close to LEP direct limit

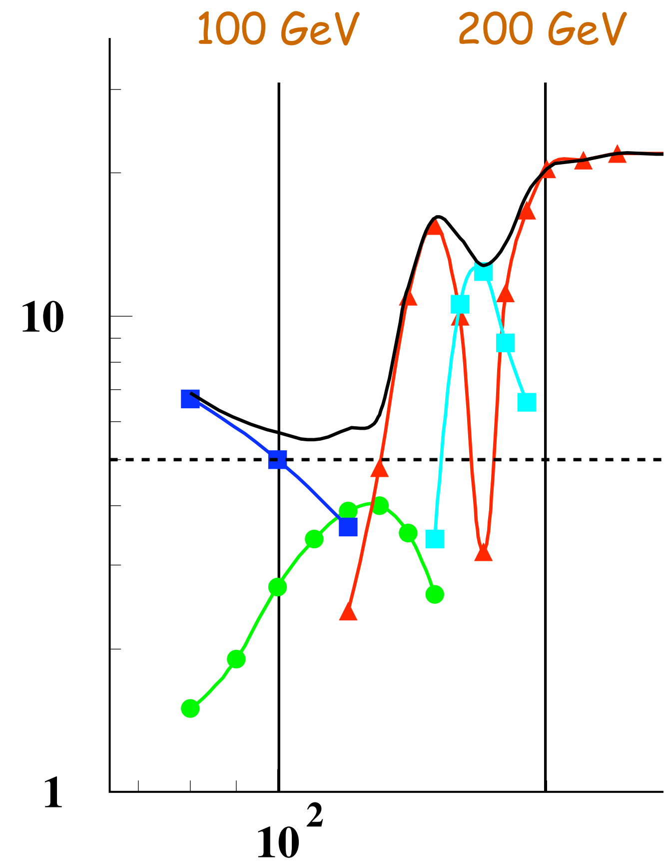
• H -> □□

good around 120 GeV

• H -> bb

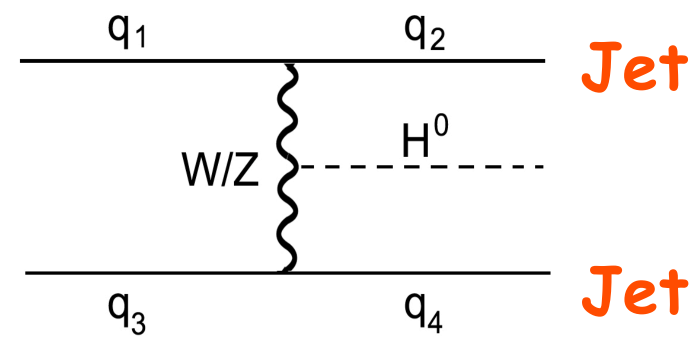
important for the Higgs coupling measurement

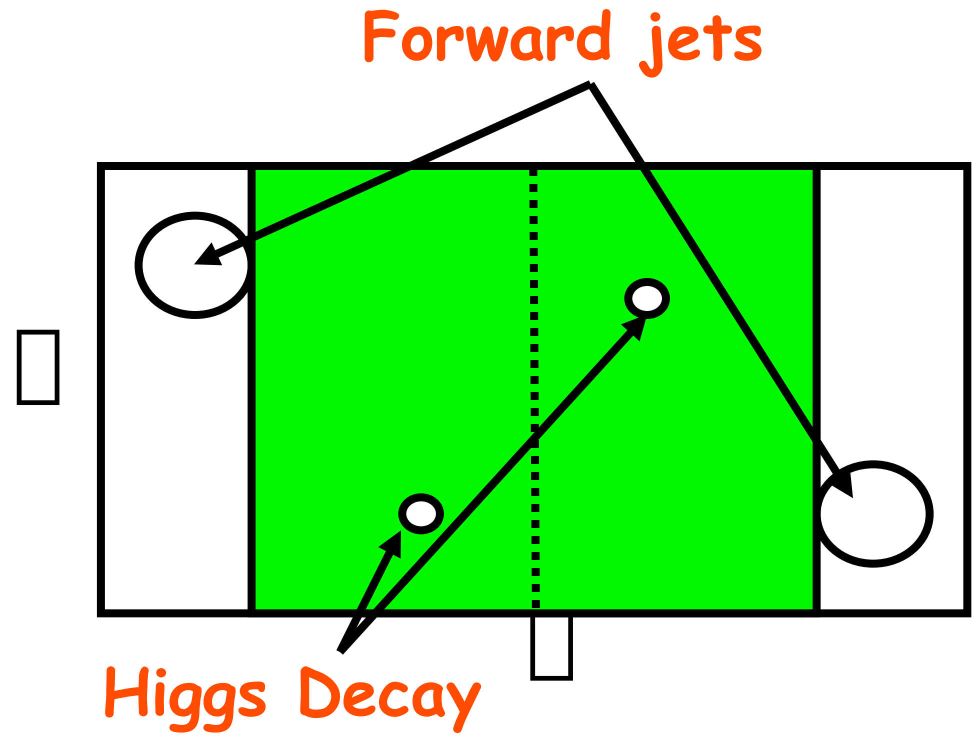
large background from QCD processes trigger efficiency is low



Vector Boson Fusion Production

- Two high PT jets with large □□ separation
- Low QCD activities in the central region
- Possibility to observe different decay modes in the same production process
- Promising to observe invisible Higgs decays (relevant for beyond the SM Higgs)



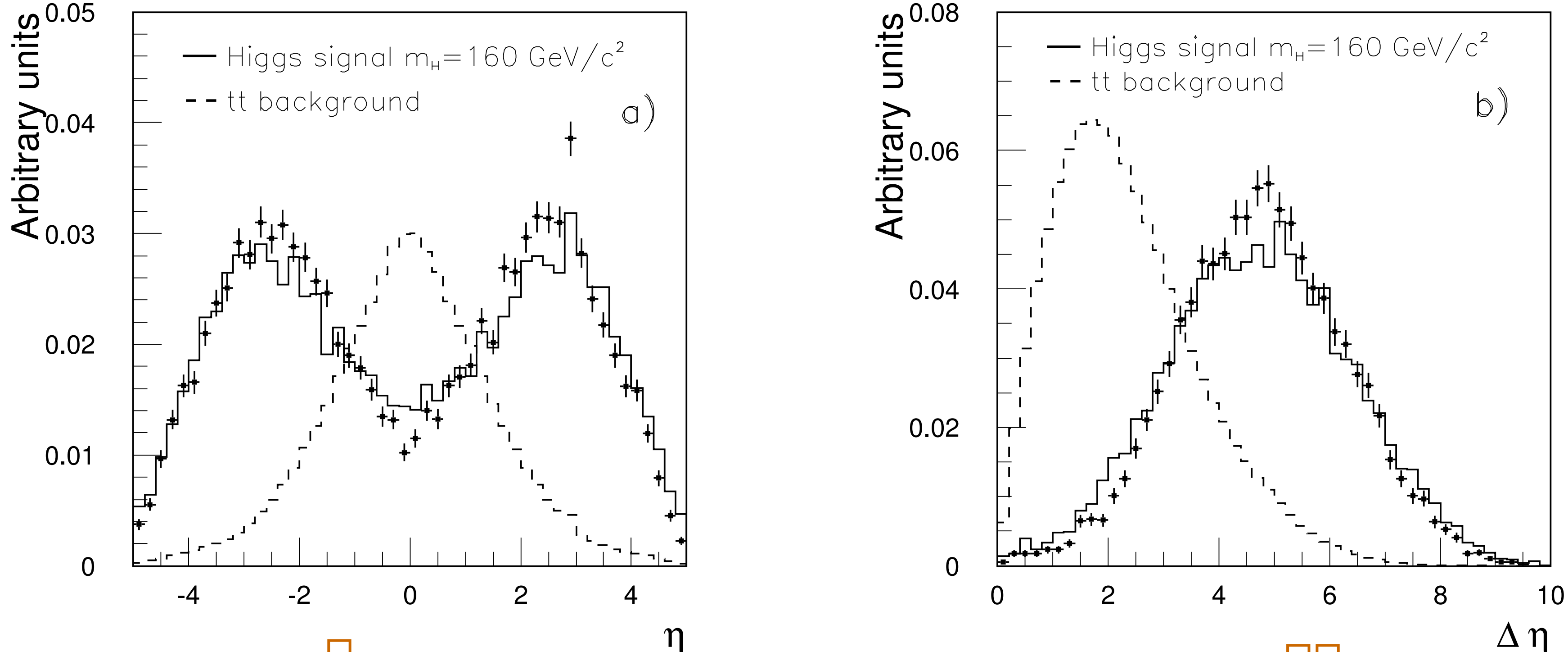


Jet Pair with Large Rapidity Gap

Comparison between VBF Higgs events vs. tt background

Higgs Signal
reconstructed - dots
parton level - solid hist

tt background
- dashed hist



□tag jet

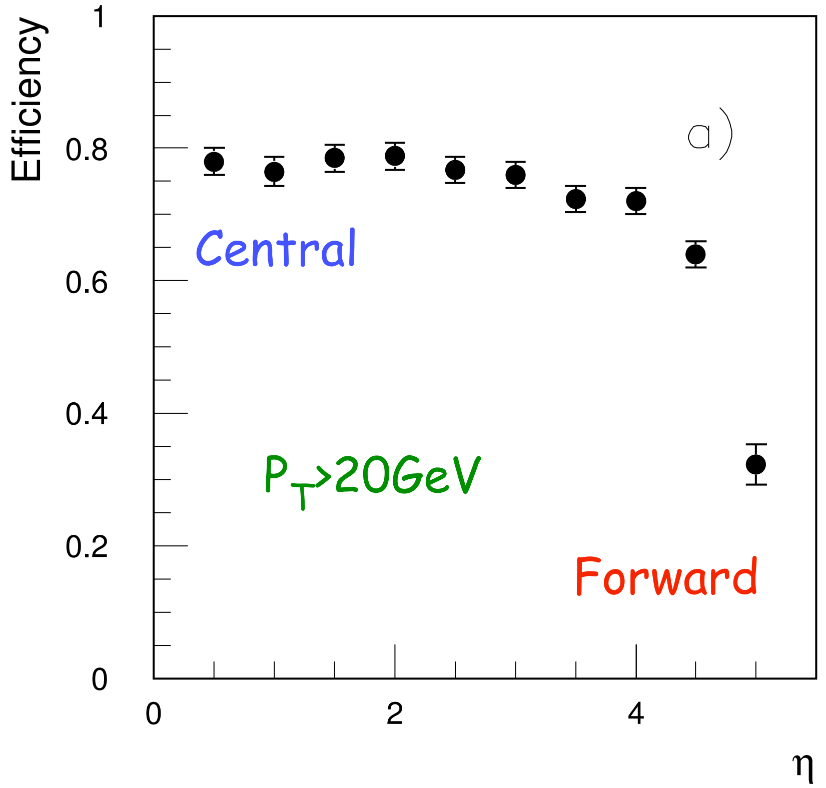
□□

Tagging Forward Jets

- Efficiency is critical.
- Full simulation used for fast simulation parametrization

  -> parametrized for fast simulation
- Double tag efficiency ~50%

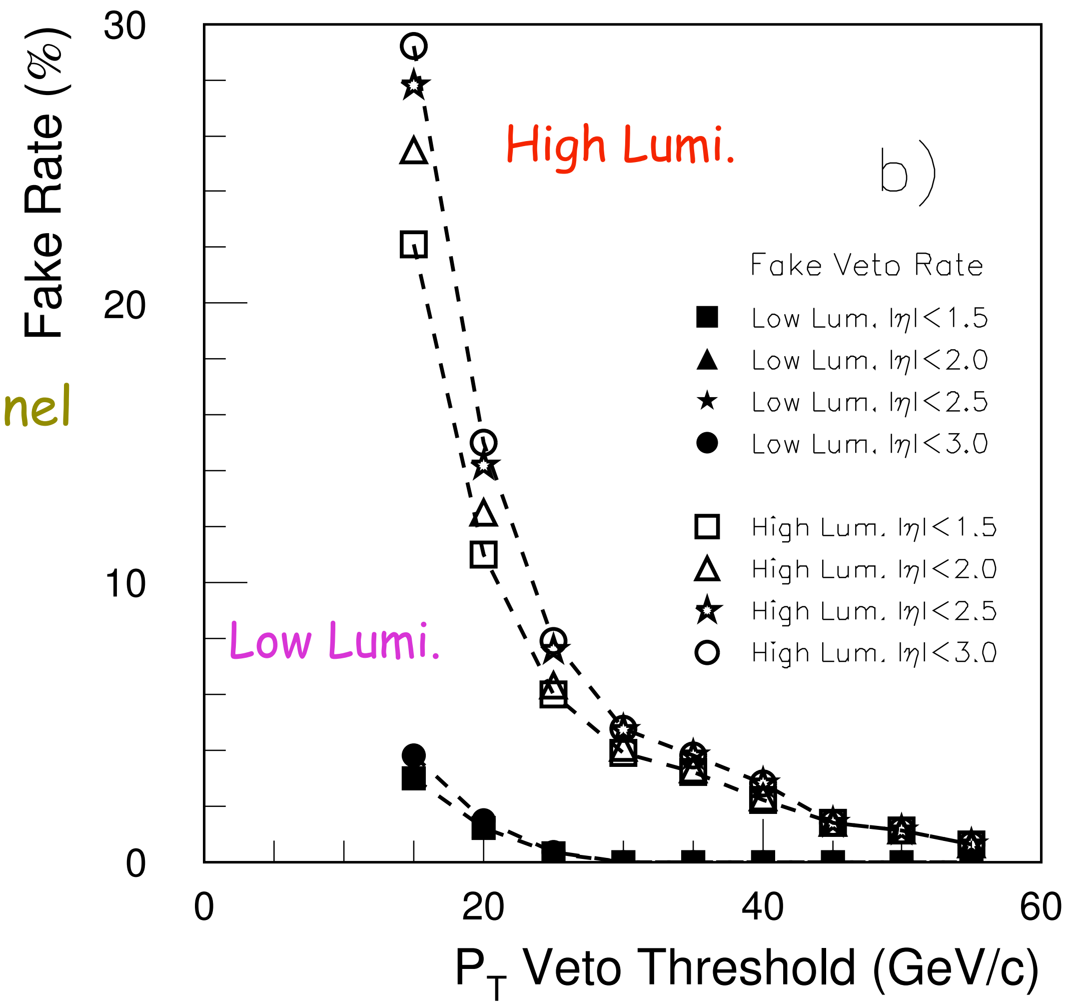
  ≈ 0.7×0.7



Efficiency for reconstructing a tag jet

Central Jet Veto

- For Higgs signal, central jet activity is suppressed due to the lack of color exchange between the quarks.
  - Most background processes there is color flow in t-channel
- Pile up effects introduce fake central jets
  - Small at low luminosity
    -> P_T > 20 GeV
  - Serious at high luminosity
    -> P_T > 30 GeV or higher



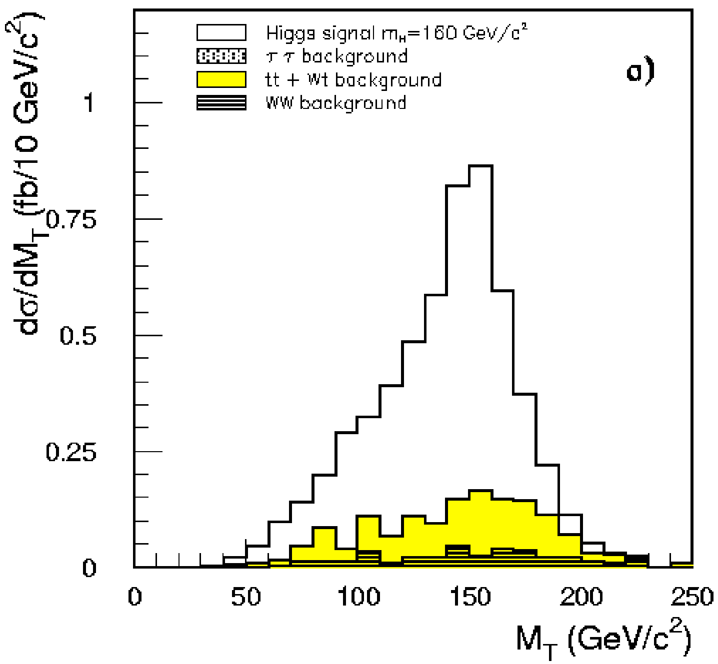
VBF H -> WW*

- Di-lepton mode: H -> WW* -> l□l□
  - clean signal
- Lepton + two jets mode: H -> WW* -> l□jj
  - larger branching ratio
  - large background

- Background: tt, WWjj(EW)
- Lepton angular correlation is effective to suppress background for H -> WW -> ll mode.

Transverse Mass Distribution

m_H=160GeV (only e□)



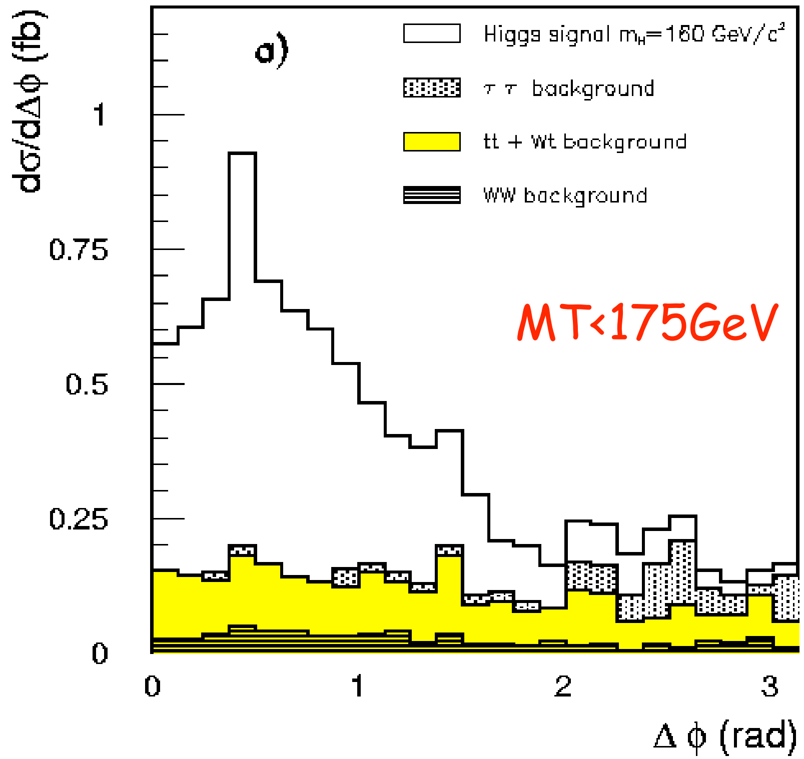
VBF H -> WW*

- Lepton angular correlation shows evidence of Spin-0 resonance in H -> WW -> ll modes

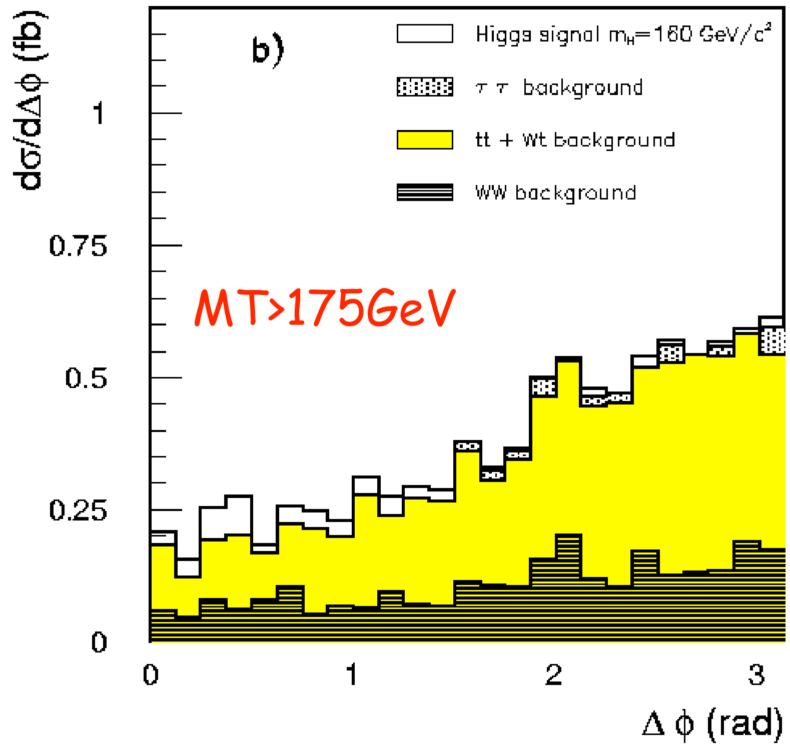
m_H=160GeV, e mode

without lepton correlation cut

Signal region



Outside Signal region



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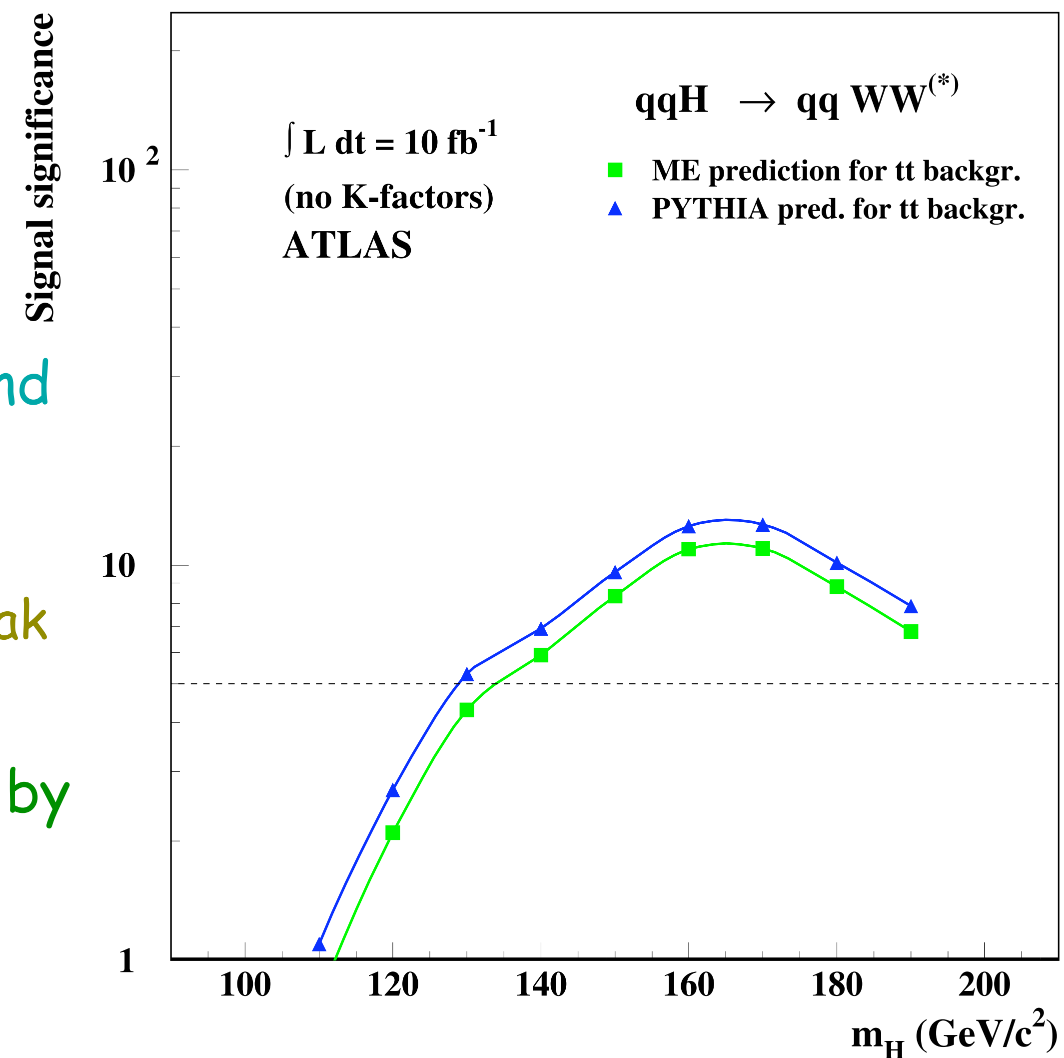
Results of WW* channel

- With $10fb^{-1}$:
  $145 < m_H < 190$ GeV (e only)
- With $30fb^{-1}$:
  $125 < m_H < 190$ GeV (all di-lepton)
- 10% uncertainty on the background is assumed
  - determination of the background level from data below the signal peak
- Poisson statistics
- Further improvement is obtained by
  - Neural Net approach
  - Likelihood ratios in significance calculation



-> 45-50% improvement -> m_H >115GeV with $10fb^{-1}$ expected

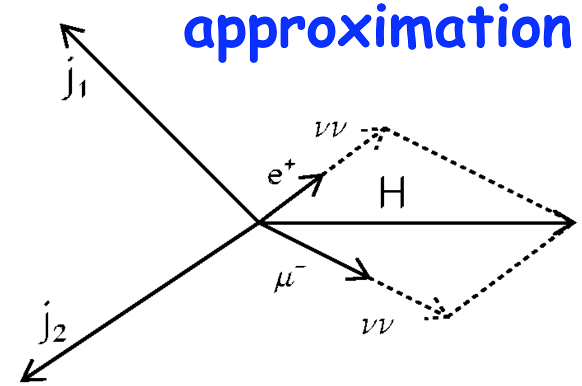
VBF H -> □□

- Two types of final states:
  - lepton+lepton mode: H -> □□ -> l□□l□□
  - lepton+hadron mode: H -> □□ -> l□□h□

- M□□ reconstruction using collinear approximation
  - Mass resolution ≈ 10%

- Background:
  - Zjj (EW and QCD)
  - tt and W production

Collinear approximation



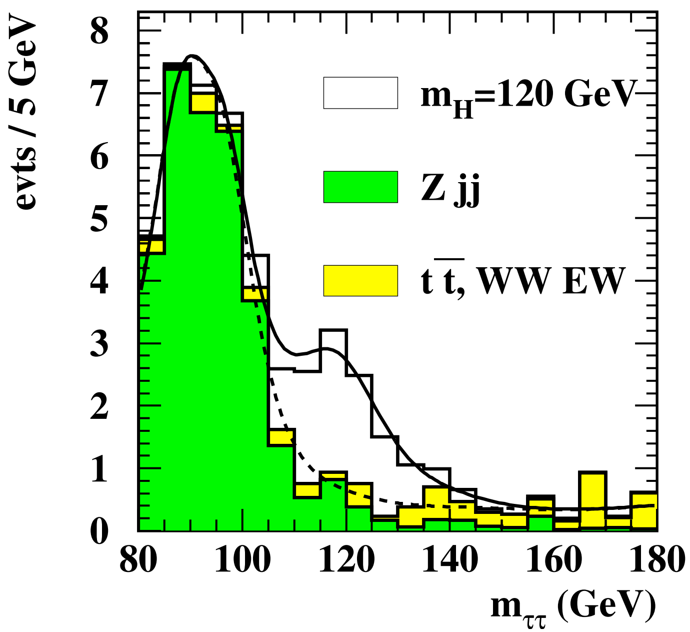
VBF H -> ττ

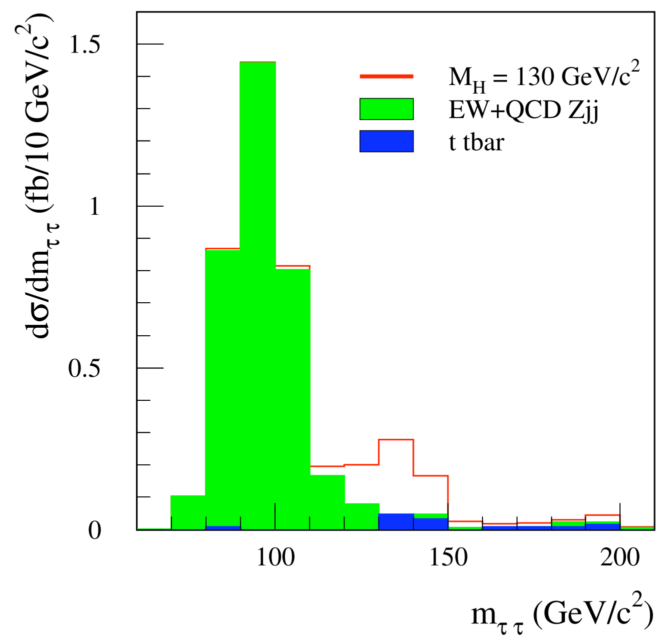
$M_{\tau\tau}$ distributions

ll mode, m_H=120 GeV

for 30fb^{-1}

lh mode, m_H=130 GeV





Results of VBF H -> □□

With $30 fb^{-1}$:

m_H [GeV]	110	120	130	140	150
Combined Statistical Significance	3.7	5.7	5.7	4.8	2.4

* 10% uncertainty of the background is assumed

determined from Z -> □□ resonance shape of real data

- □□ decay modes above 5-□ significance over the mass range:

  $115 < m_H < 140$ GeV

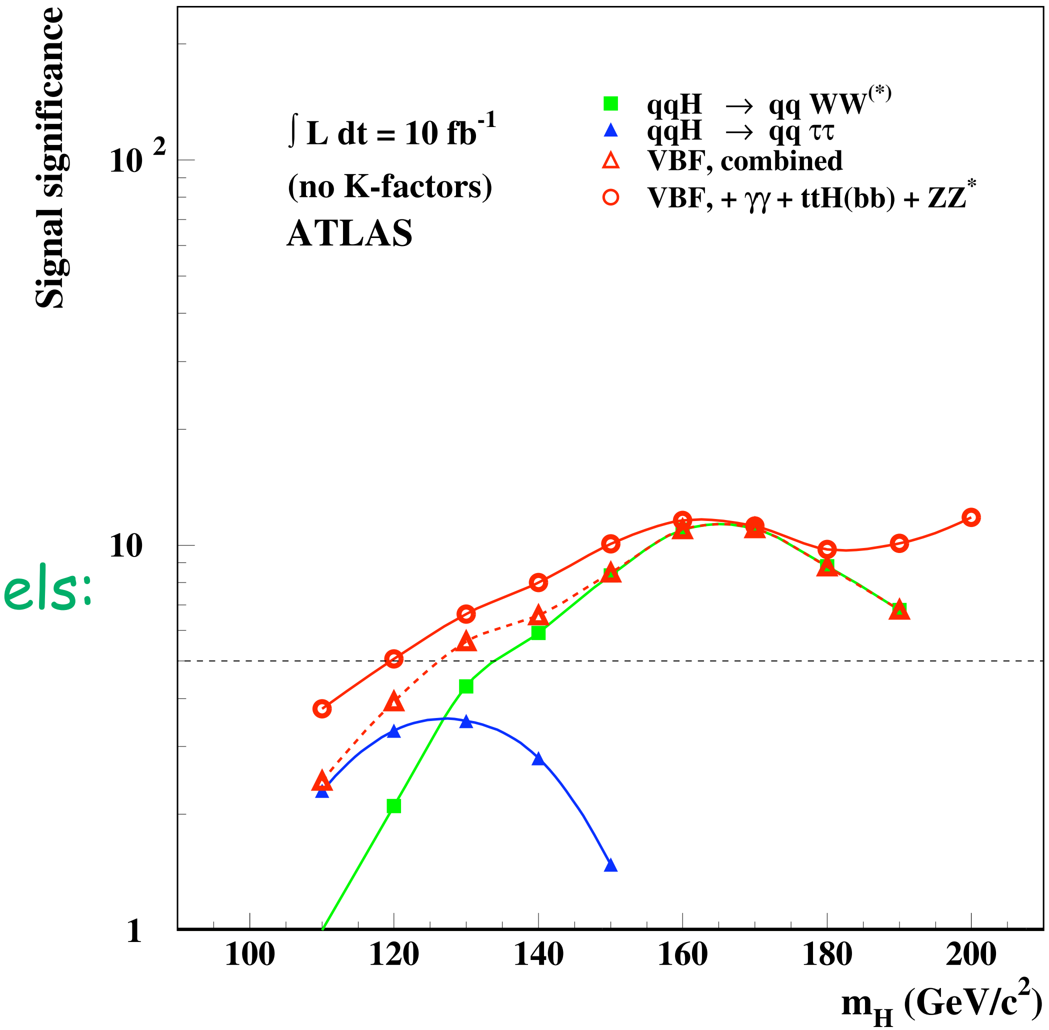
  with 30 fb^{-1}. (LEP direct limit $m_H > 115$ GeV)

Combined Results

With 10 fb^{-1}:

- Combining two vector boson fusion channels:
  135 < m_H < 190 GeV (5)

- Adding , ttH and ZZ* channels:
  120 GeV < m_H (5)



Combined Results

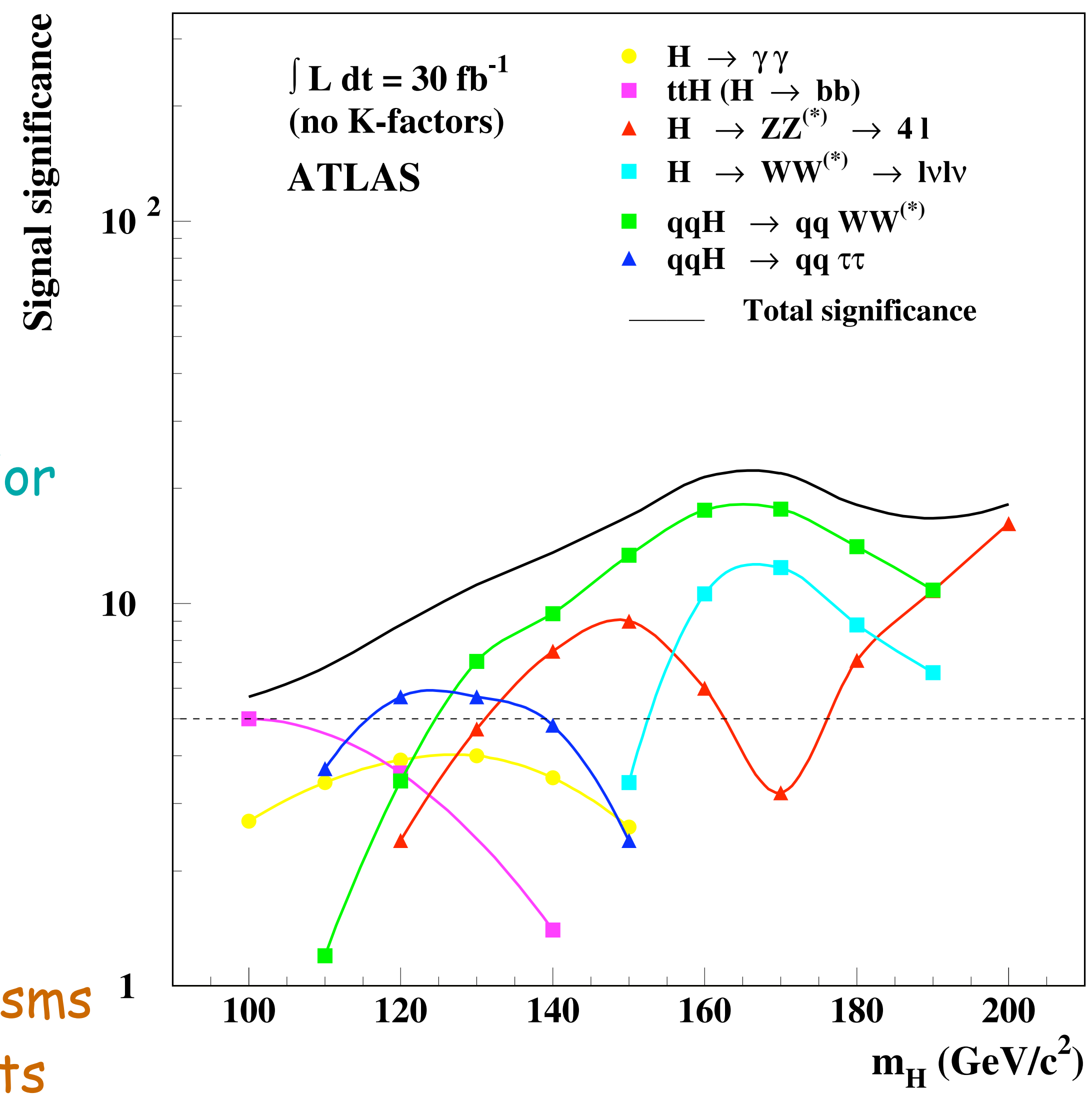
With 30 fb^{-1}:

- Full mass range favored by EW fit and LEP exclusion can be covered by ATLAS

- Several channels are available for a Higgs discovery.

  -> gives complementarity to the discovery process

  - different decay modes
  - different production mechanisms
  - different detector components



Summary

- The vector boson fusion channels provide a large discovery potential even for a small integrated luminosities.
- Tag jets in the forward region and a low jet activity in the central region of the detector allow for a significant background rejection.
- The VBF H -> WW* channel provides a large discovery potential to the ATLAS experiment.

$$\sim 135 < m_H < 190\ \mathrm{GeV}/c^2\ (10\mathrm{fb}^{-1})$$

- The VBF H -> □□ channel also contributes in the mass region:

$$m_H < 140\ \mathrm{GeV}/c^2\ (30\mathrm{fb}^{-1})$$

  - Important for a measurement of the Higgs boson coupling to fermions.
- Combining above channels, the full mass range up to $2m_Z$ can be covered with $30\mathrm{fb}^{-1}$.

Prospects

- On-going analysis for other decay modes:

  H -> □□, bb and invisible

- Extend to intermediate mass region (H->WW and ZZ channels)

  WW -> lνqq m_H > 300GeV -> $2m_Z$

  WW -> lνlν and ZZ->llqq (on going)

- Contribution to the measurement of Higgs properties
- More understanding on the detector performance

  Precise estimation on the tag efficiency of forward jets

- More understanding on the higher order MC generations

  Central jet veto is sensitive to the multi-jet production rate

  Tails in Z->ττ background should be understood better in H->ττ analysis