VBF Studies With ATLAS

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On behalf of the ATLAS Higgs Working Group

Higgs WG, Les Houches 2003

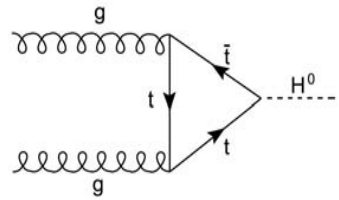
Outline

- ✓ Introduction
- ✓ Recent results of cut analyses
- ✓ Recent results of multivariate analyses
- ✓ Status of ongoing analyses
  - ➢ Low mass Higgs
  - ➢ Intermediate mass Higgs
- ✓ Work ahead
  - ➢ Understanding of the central jet veto
- ✓ Conclusions

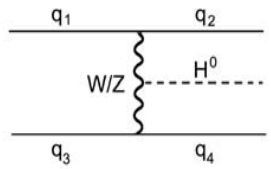
SM Higgs at LHC

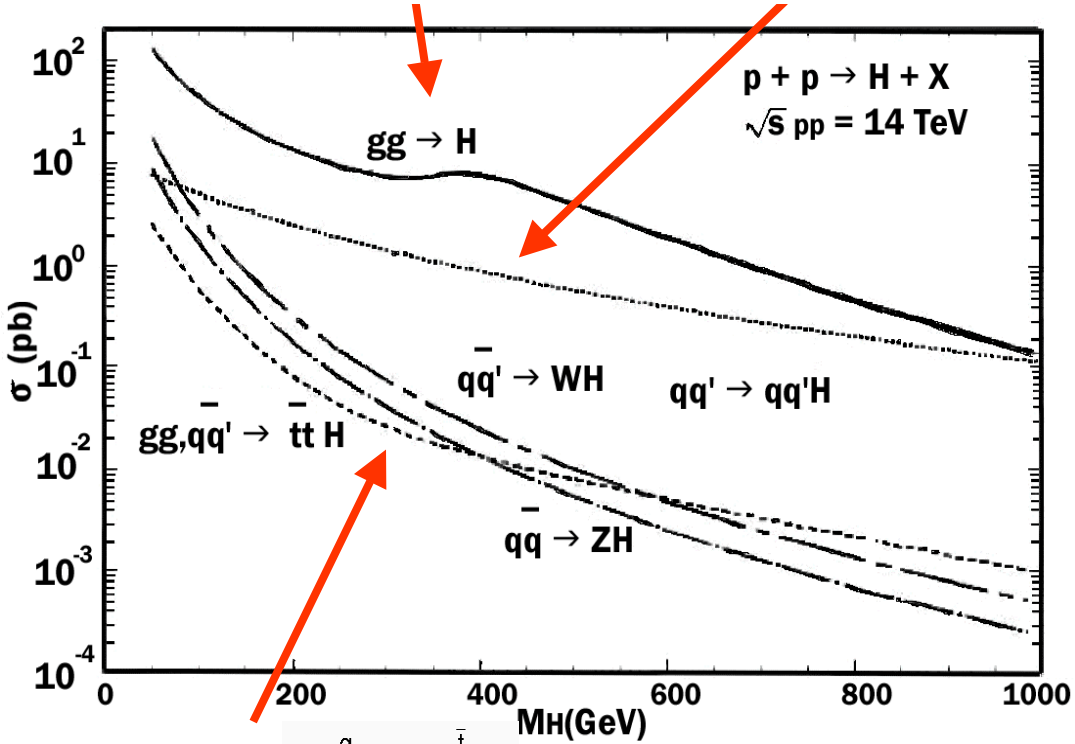
- ✓ **Production:**
  - ➢ **Direct**
    - ❖ gg → H
      - ❑ Dominant
      - ❑ Large background at masses close to LEP limit
    - ❖ qq →qqH (VBF)
      - ❑ Distinct final state
  - ➢ **Associated**
    - ❖ ttH, WH, ZH
      - ❑ Small cross-section

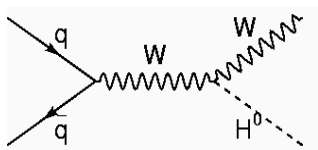
gg → H

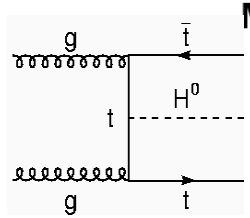


VBF





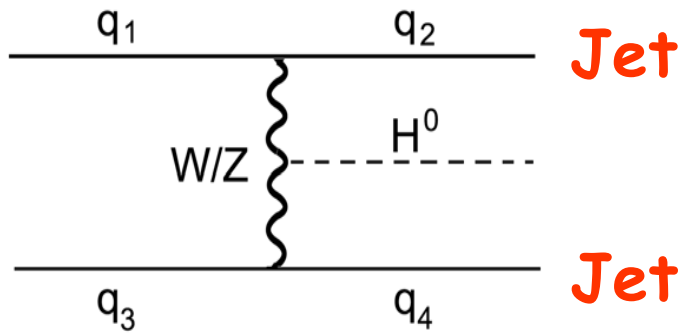


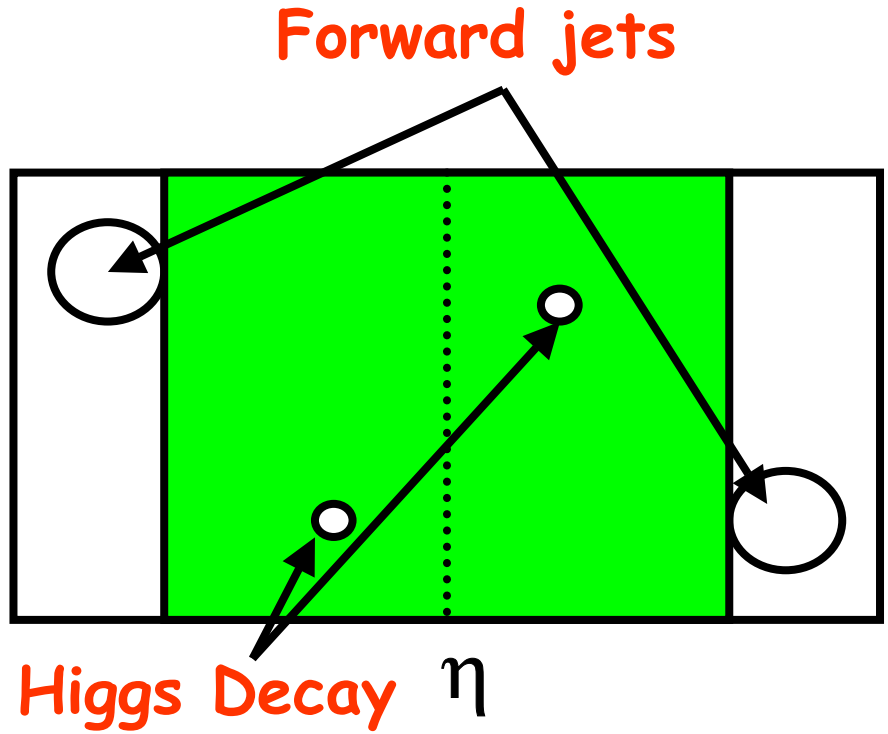


Associated

Higgs via VBF

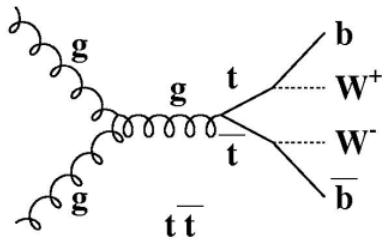
- ✓ **Wisconsin Phenomenology Institute (D.Rainwater, D.Zeppenfeld et al.):**
  - ➢ Two high P_T jets with large $\Delta\eta$ separation
  - ➢ Strong discovery potential for low Higgs mass
  - ➢ Can measure Higgs couplings
  - ➢ Good for invisible decays
- ✓ **CMS & ATLAS looking into more detailed studies**

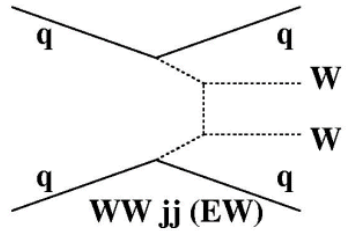




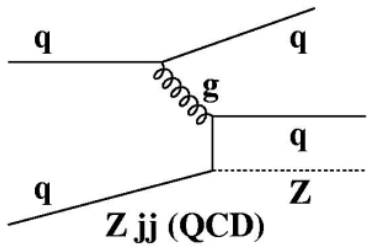
Low Mass Higgs via VBF

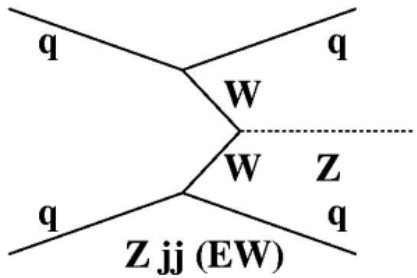
- ✓ H->WW*->llνν, lνqq. Strong for M_H>120 GeV
  - ➢ Main background:
    - ❖ tt EW, WWjj (llνν)
    - ❖ W + 4 jets (lνqq)





- ✓ H->ττ->ll, lh (+ptmiss). Good around LEP limit
  - ➢ Main background
    - ❖ QCD and EW Zjj



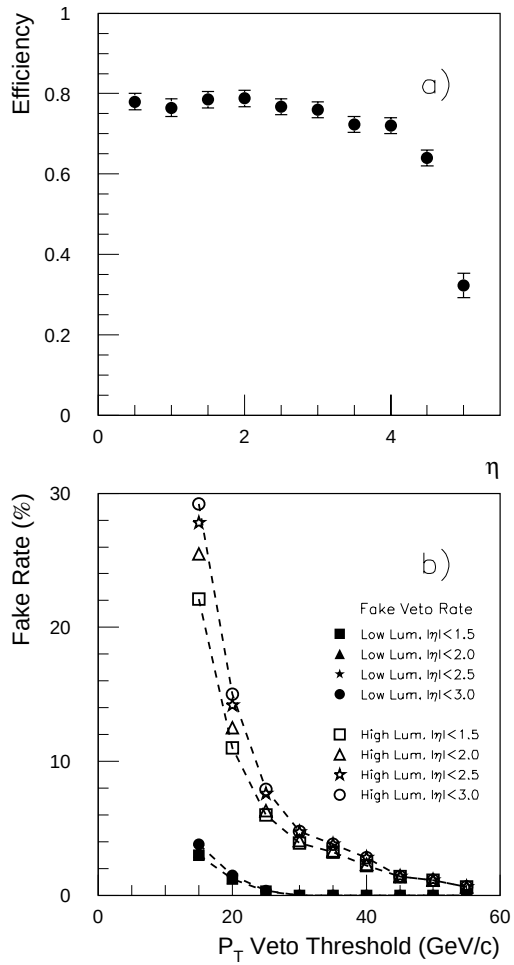


- ✓ Under investigation
  - ➢ H->bb. Useful for Yukawa coupling measurement
  - ➢ H->γγ. Study discovery potential
    - ❖ Main background, real and fake non-resonant γγ

Major Experimental Issues

V.Cavasinni, D.Costanzo, I.Vivarelli ATL-PHYS-2002-008

- ✓ **Tagging forward jets:**
  - ➢ Efficiencies critical
  - ➢ Full simulation used
  - ➢ Double tag efficiency ~50%
- ✓ **Central jet veto:**
  - ➢ Pile up effects introduce fake central jets
    - ❖ Effect small at low luminosity
    - ❖ Serious concern at high luminosity



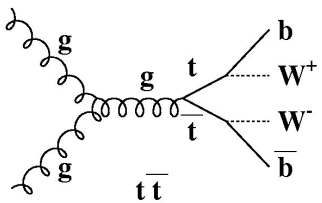
VBF H->WW*

C.Buttar, R.Harper, K.Jakobs ATL-PHYS-2002-008

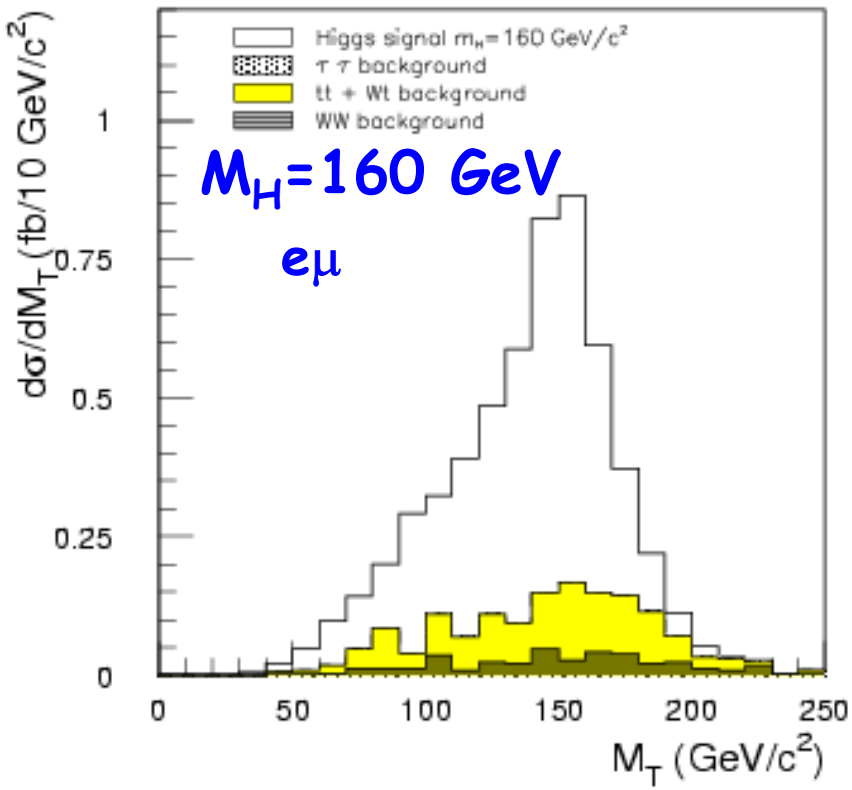
V.Cavasini, D.Contanzo, E.Mazzoni, I.Vivarelli ATL-PHYS-2002-010

K.Cranmer, B.Mellado, W.Quayle, Sau Lan Wu ATL-PHYS-2003-002

- ✓ **Background: tt, EW WWjj**
  - Understanding of tt production is crucial



- ✓ **Background suppression:**
  - Well separated forward jets + central jet veto
  - b-jet vetoes
  - Lepton angular correlations

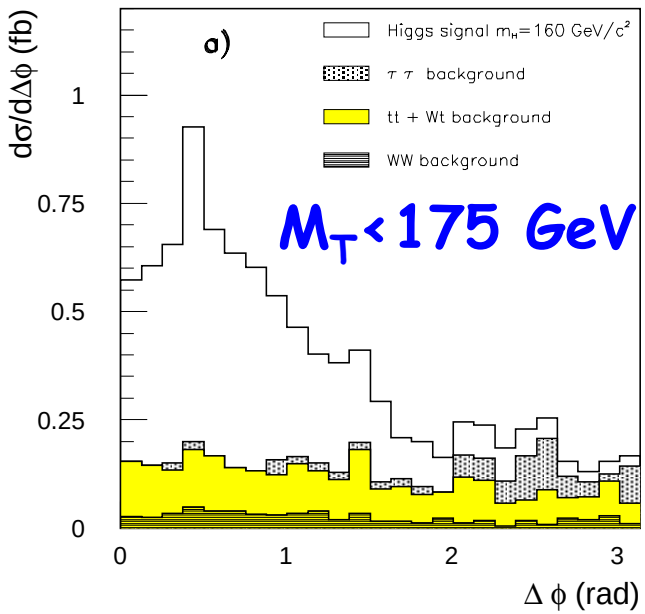


VBF H->WW*

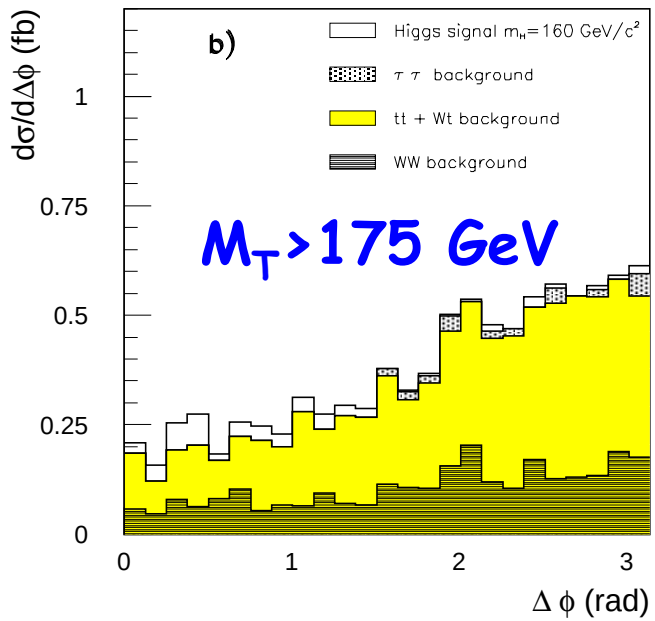
C.Buttar, R.Harper, K.Jakobs ATL-PHYS-2002-008

- ✓ Evidence of Spin-0 resonance in H->WW->ll modes
  - ➢ Look into difference in ϕ between leptons

Signal Region



Outside Signal Region



VBF H->ττ

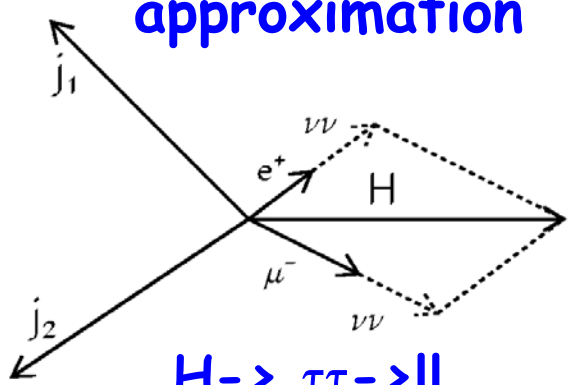
M.Klute ATL-PHYS-2002-018

G.Azuelos, R.Mazini ATL-PHYS-2003-004

T.Takemoto, S.Asai, J.Kanzaki, R.Tanaka ATL-PHYS-2003-004

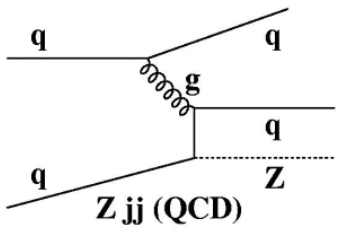
K.Cranmer, B.Mellado, W.Quayle, Sau Lan Wu ATL-COM-PHYS-2003-002

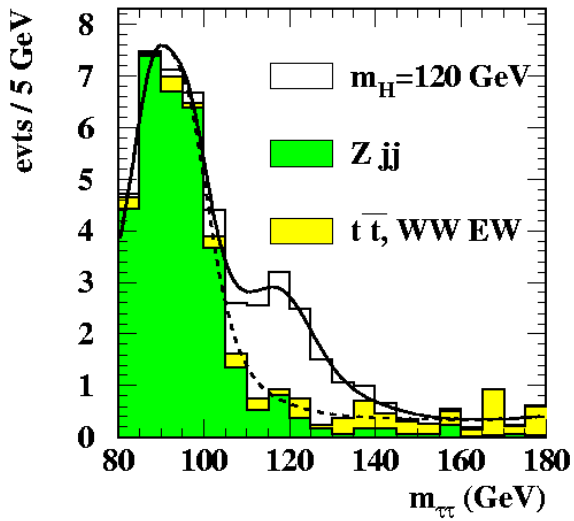
Collinear approximation



H-> ττ->ll
30 fb^{-1}

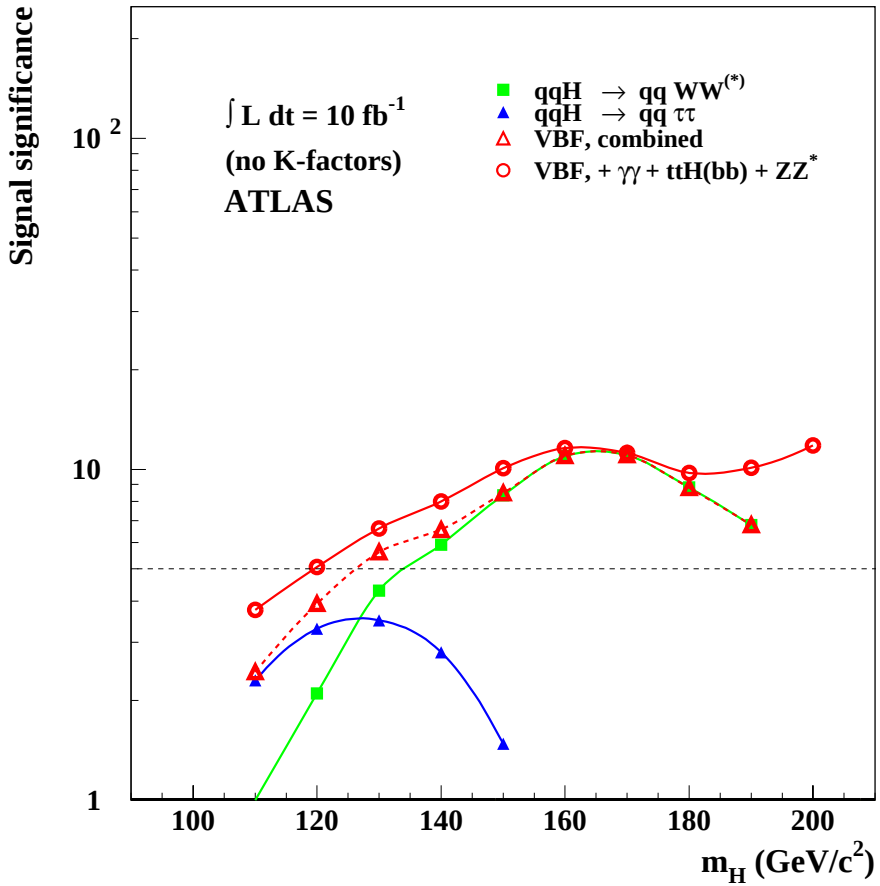
- ✓ $H\rightarrow\tau\tau$ analyses (ττ->ll,lh):
  - $M_{\tau\tau}$ reconstruction using collinear approximation
    - Mass resolution ~10%
  - Main backgrounds
    - EW & QCD Zjj
    - tt and W production

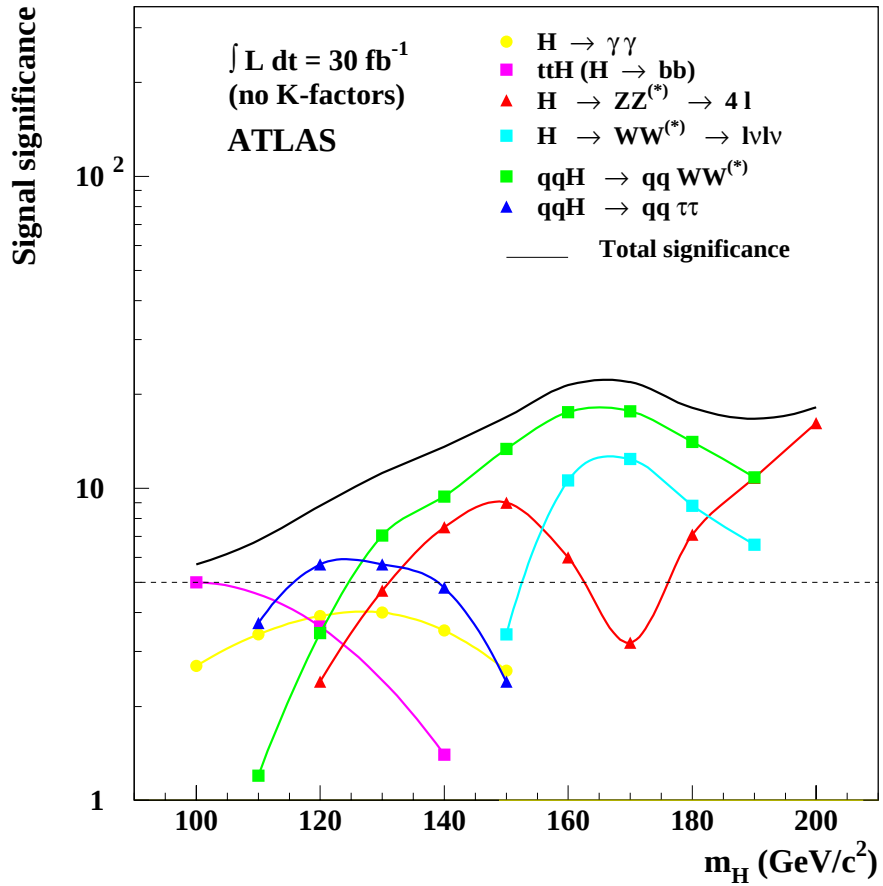




Results from VBF Cut Analyses

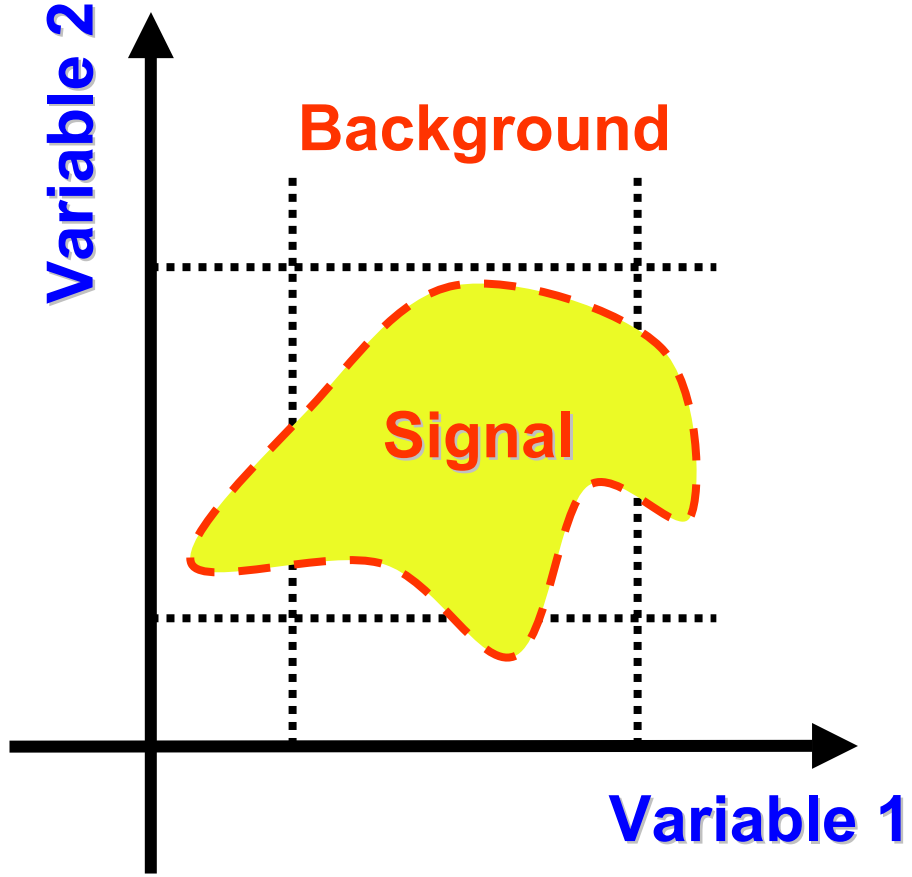
J.Asai et al. SN-ATLAS-2003-024





Multivariate Analysis (1)

- ✓ Classical cut analysis uses rectangular signal-like phase space
- ✓ Contour of signal-like phase space may be of any shape
- ✓ Disadvantage of cut analysis gets larger with increasing number of discriminating variables
- ✓ Use Neural Networks as a multivariate tool



Multivariate Analysis (2)

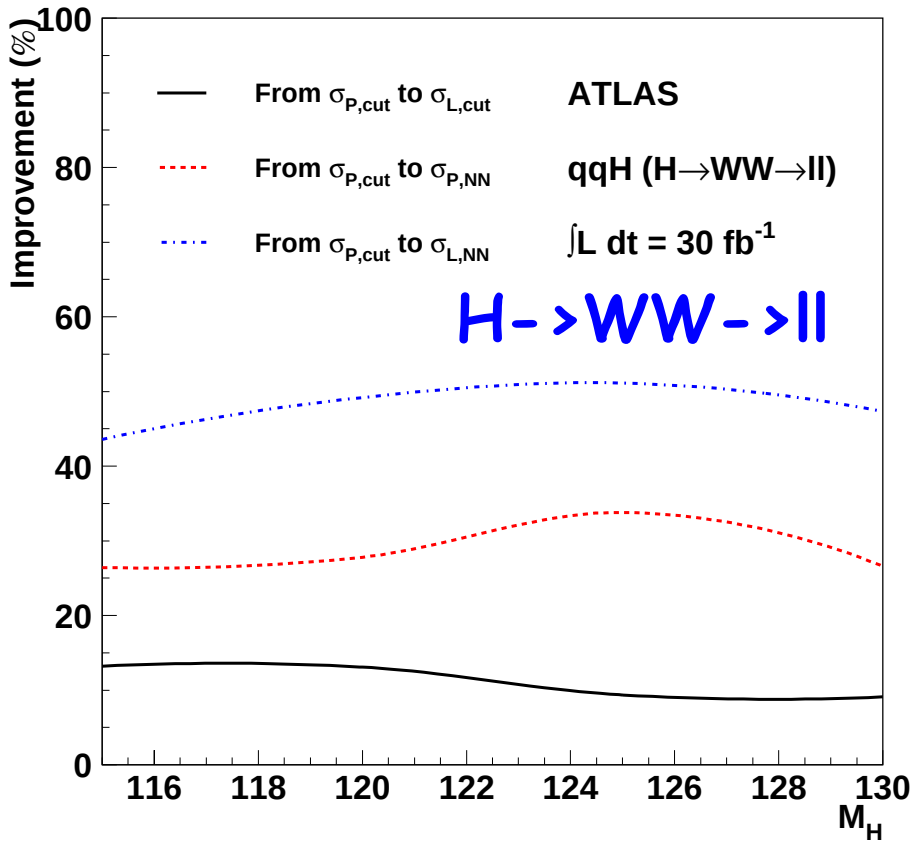
- ✓ **MC description needs a lot of improvement**
  - ➢ MC generators based mostly on LO ME calculations
  - ➢ Based on fast simulation
    - ❖ Need to tune it with full simulation and data
- ✓ **Be careful: Cannot dump into NN any variable**
  - ➢ Infrared-safe variables
  - ➢ Pursue features that will remain in the final analysis
- ✓ **Need to understand cut analysis first**
  - ➢ Cut and multivariate analyses should go together when data comes (LEP experience)

✓ *Maximally exploit physics signatures, which are not taken full advantage of by the cut analysis*

Multivariate Analysis (3)

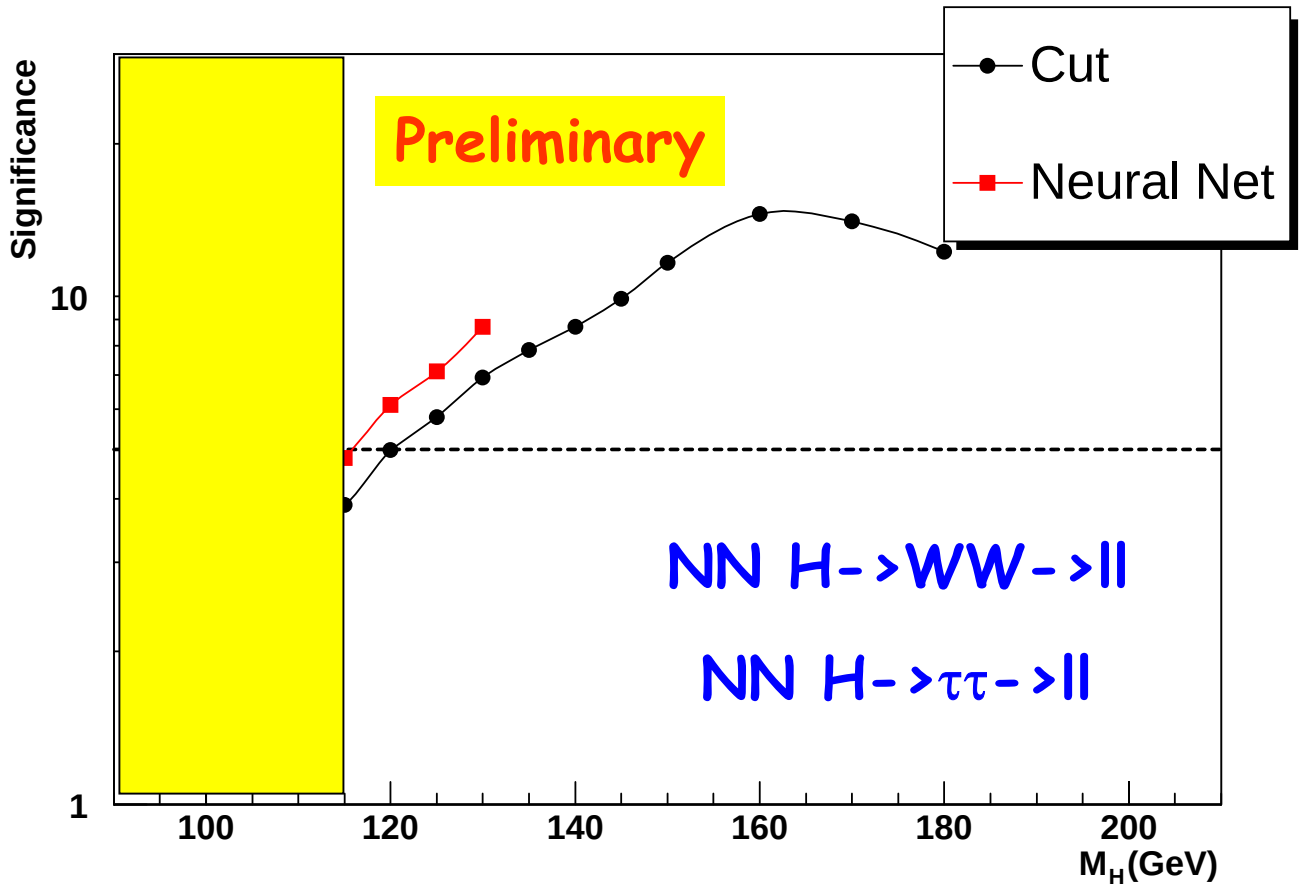
K.Cranmer, B.Mellado, W.Quayle, Sau Lan Wu
ATL-PHYS-2003-002

- ✓ **Signal significance improvement with neural network based analysis:**
  - Neural network output used as a discriminating variable with likelihood techniques
  - NN applied to H->WW->ll and H->ττ->ll
    - ❖ Similar results
  - Results improve by 45-50%
  - 5σ effect for M_H>115 GeV with one exp and 10 fb^{-1} provided nominal detector performance



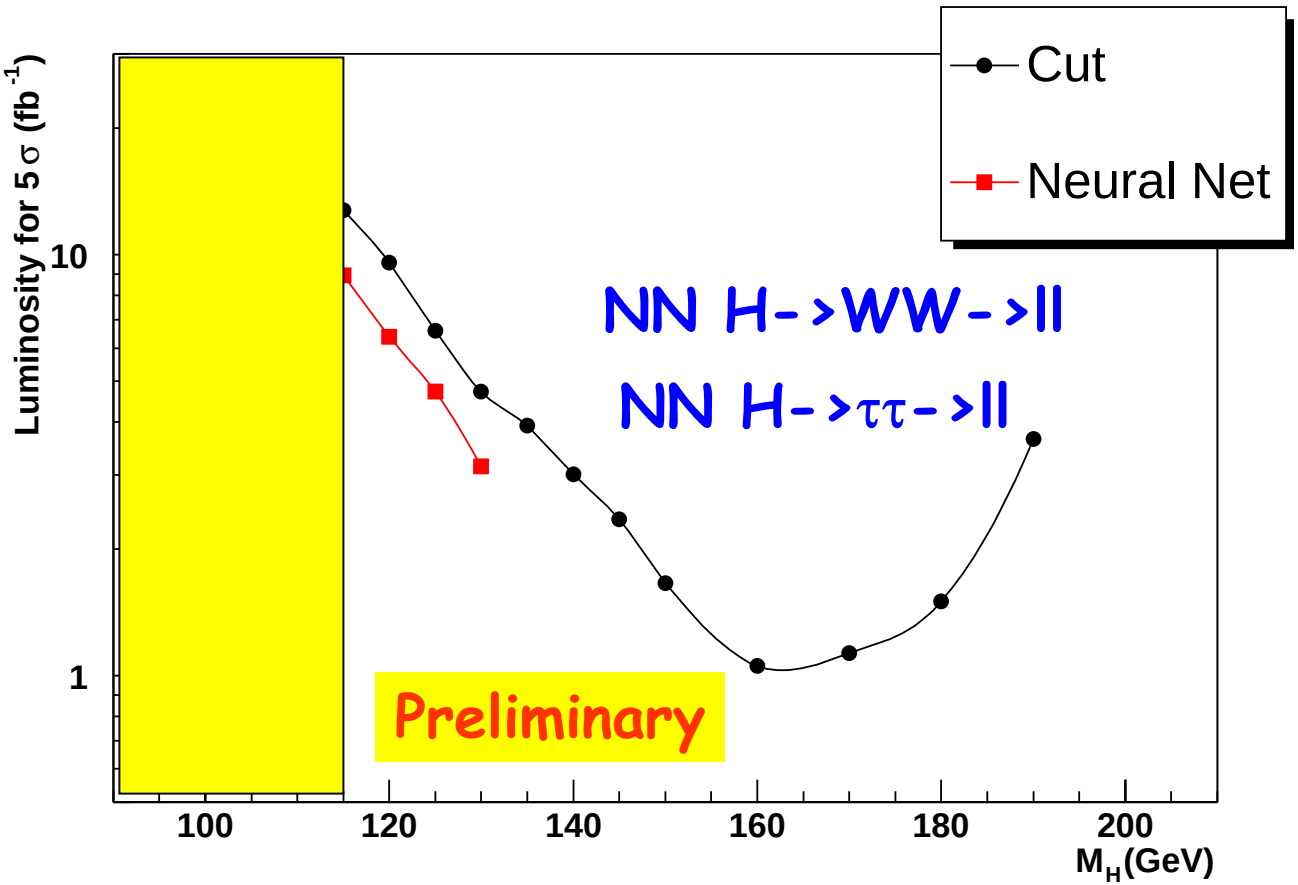
Multivariate Analysis (4)

✓ Hopeful that one exp., 10 fb^{-1}: 5 σ for $M_H \gtrsim 115$ GeV



Multivariate Analysis (5)

✓ Hopeful that one exp., 10 fb^{-1}: 5 σ for $M_H \gtrsim 115$ GeV

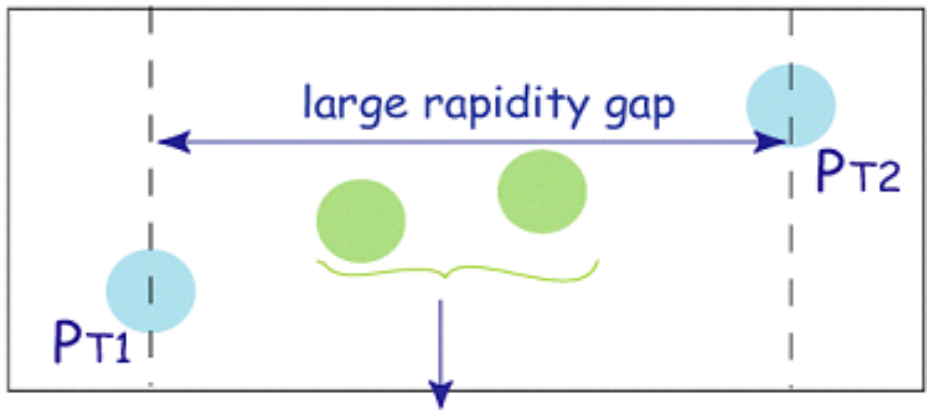


Ongoing Analyses: Yukawa Coupling from Hbb

✓ VBF H->bb

- Good potential for Yukawa coupling measurement
- Hadronic final state
- Main concern is trigger
  - Expect small efficiency
  - Work needed to implement
- For more information on coupling measurements see talk of M.Duehrssen

S.Asai, J.Kanzaki, S. Shimma



Ongoing Analyses: VBF H-> γγ (1)

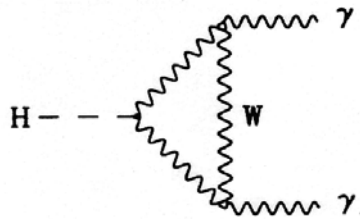
✓ **VBF H->γγ**

S.Asai, J.Kanzaki, M. Minagawa

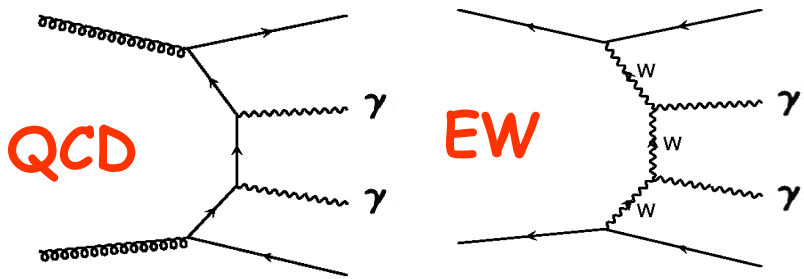
K.Cranmer, B.Mellado, W.Quayle, Sau Lan Wu

- Analyses are advanced
  - Signal production understood
  - Use ME for real γγ
    - Comphep
    - MadgrapII
    - Different approaches to avoid QCD double counting
    - Reasonable agreement between groups
  - Comparison with D.Rainwater's thesis work:
    - Reasonable agreement achieved for signal and γγ production
    - Differences attributed to different choices of scales, pdf's, etc…

Resonant γγ



Non-resonant real γγ



Ongoing Analyses: VBF H-> γγ (2)

✓ **VBF H->γγ**

- Bulk of disagreement between two ATLAS groups comes from treatment fake γγ
  - Parton shower approach (γj + PS and jj + PS) underestimates background
  - Need to use full matrix element calculation
    - Use MadGraphII
- Preliminarily, we expect to reach 2-4 σ for M_H=130 GeV with 30 fb^{-1}
  - Need to understand central jet veto survival probability
  - Understanding of jet rejection is crucial

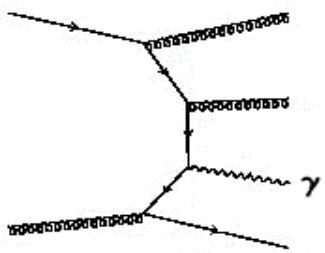
S.Asai, J.Kanzaki, M. Minagawa

K.Cranmer, B.Mellado, W.Quayle, Sau Lan Wu

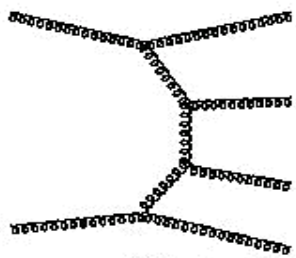
Non-resonant fake γγ:

One or two jets are seen as a photon in the detector

γjjj



jjjj



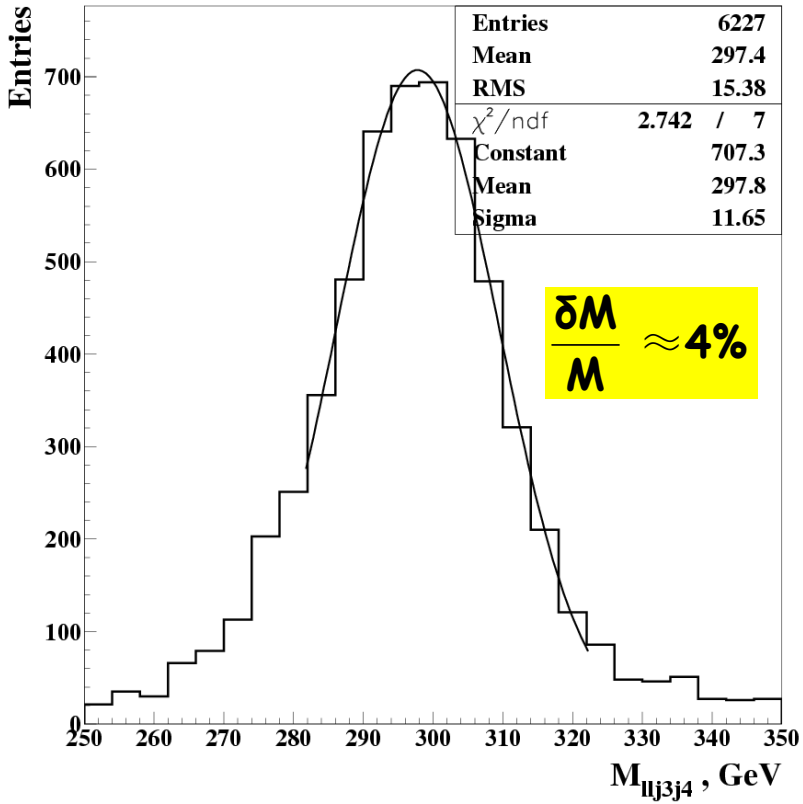
Ongoing Analyses: VBF for Intermediate Masses (1)

K.Cranmer, B.Mellado, W.Quayle, Sau Lan Wu in collaboration with D.Zeppenfeld

✓ H->ZZ->llqq

- Combinatorics not an issue
  - After masking out two jets with Mqq ≈ M_Z event looks like typical VBF
- Relatively narrow peak
  - Simple minded performed without kinematic constraints yields $\delta M/M \approx 4\%$.
  - Expect improvement of a factor of 2 ($\delta M/M \approx 2\%$) when applying kinematic fit
    - Exploit the two additional constraints:

      $M_{ll}=M_Z$ and $Mqq=M_Z$



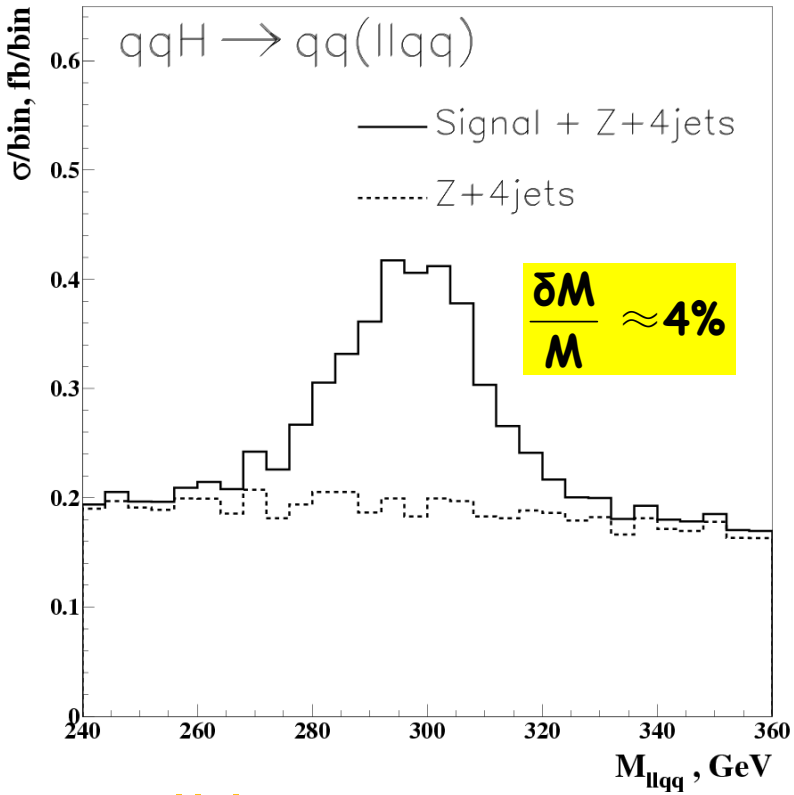
Ongoing Analyses: VBF for Intermediate Masses (2)

✓ H->ZZ->llqq

- Relatively narrow peak seen on top of a continuum
  - Background (Z+4jets) determined from side-bands
- Simple analysis yields 5.7 σ for M_H=300 GeV with 30 fb^{-1}
  - Expect factor of 2 improvement
    - Kinematic fit, exploit angular variable, multivariate analysis
- Combined with H->WW->llνν
  - Competitive with inclusive H->ZZ->4l
  - Strong potential for couplings

$$\frac{\sigma \times BR(qqH \rightarrow qqWW)}{\sigma \times BR(qqH \rightarrow qqZZ)} = \frac{\Gamma_{HWW}}{\Gamma_{HZZ}}$$

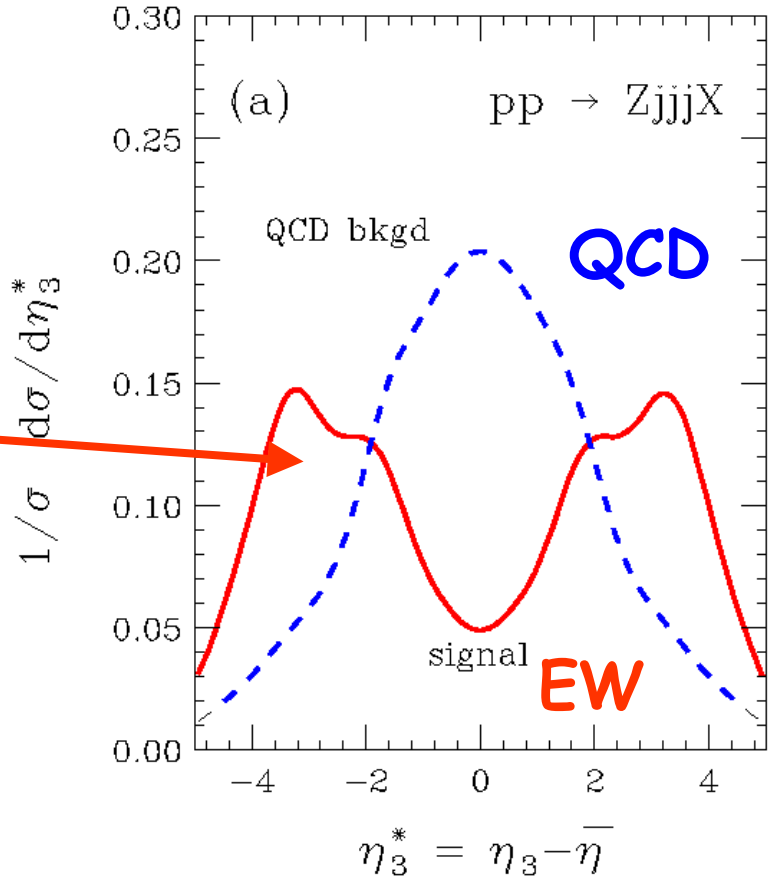
K.Cranmer, B.Mellado, W.Quayle, Sau Lan Wu in collaboration with D.Zeppenfeld



Central Jet Veto (1)

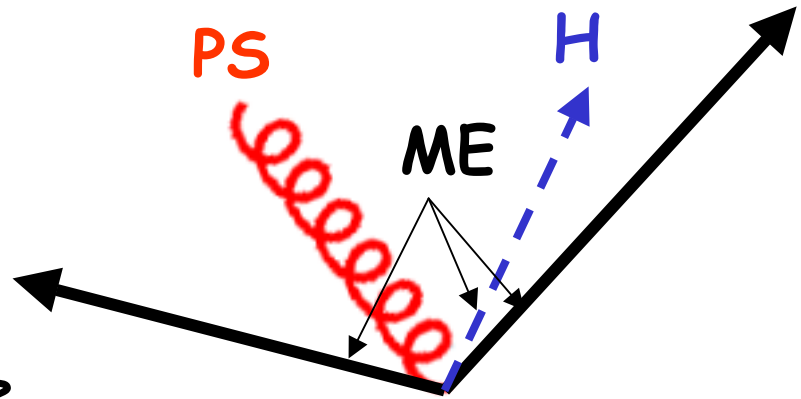
- ✓ VBF analysis is an exclusive search:
  - Two hard and well separated jets (tagging jets)
  - Veto on third jet in central region of the detector.
    - ❖ Need to distinguish between QCD and EW processes
- ✓ Need to implement higher order corrections
- ✓ <u>A lot of MC development needed before turn on!</u>

Zeppenfeld et al. PRD54 6680



Central Jet Veto (2)

- ✓ So far we used parton shower to simulate third jet
  - ➢ Disagreement with full matrix element treatment
  - ➢ Angular correlations may not be well simulated



Central jet veto survival probability

D.Rainwater's thesis

	$H\rightarrow WW->ll$		$H\rightarrow\tau\tau->ll$	
Third jet	Hjj	tt	Hjj	QCD Zjj
Matrix Element	0.89	0.46	0.87	0.28
Parton Shower	0.86	0.30	0.72	0.49

Summary

- ✓ **VBF enhances sensitivity for Higgs searches**
  - Forward jet tagging efficiency crucial
  - Estimate role of pile up at high luminosity
  - Neural Nets + likelihood techniques enhance signal significance by ~50%
    - 5σ effect for M_H>115 GeV with one experiment and 10 fb^{-1} assuming expected detector performance
  - VBF H->ZZ->llqq look in intermediate mass Higgs. Observe relatively narrow resonance ($\delta M/M \approx 4\%$)
    - If combined with VBF H->WW->ll$\nu\nu$ expect:
      - Signal significance competitive with inclusive H->ZZ->4l
      - Best way of measuring $\Gamma_{HWW}/\Gamma_{HZZ}$ in broad mass range
  - A lot of MC development needed before turn on!
    - Central jet veto needs to be better understood
    - Higher order corrections have to be applied