universitätbonn

Search for the SM Higgs Boson in VBF Production Mode (with ATLAS)

Guilherme Nunes Hanninger
(Bonn University)

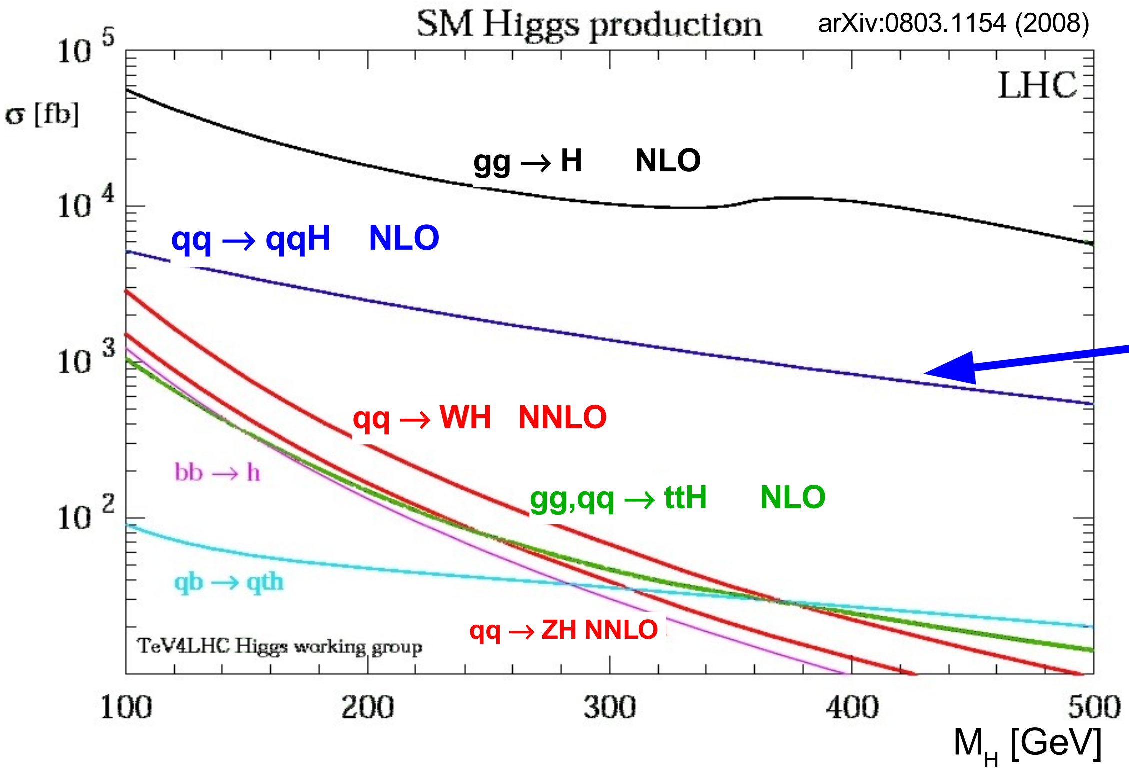
On behalf of the ATLAS Collaboration

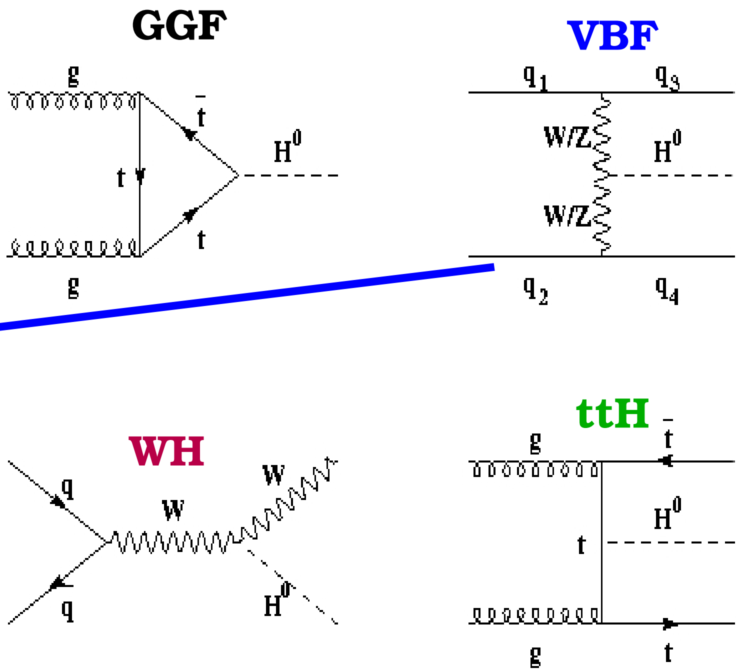
GEFÖRDERT VOM

Bundesministerium
für Bildung
und Forschung

FSP 101
ATLAS

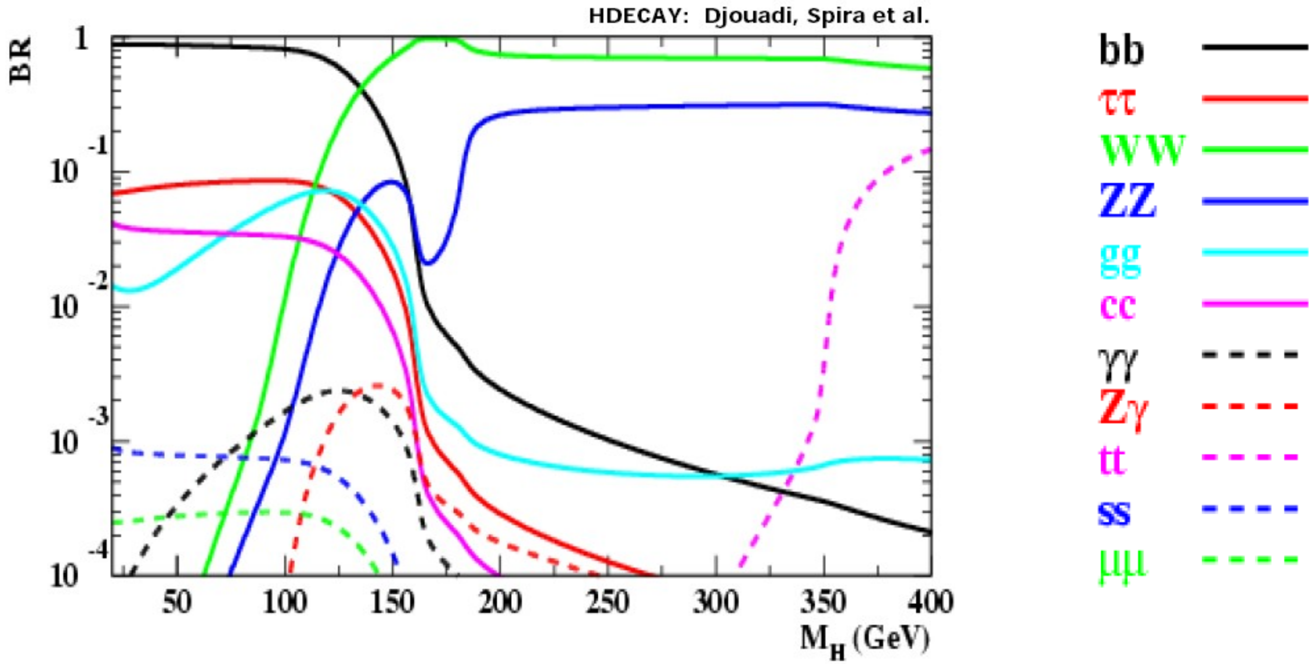
SM Higgs Production at the LHC





- **gluon fusion:** dominant process
- **vector boson fusion (VBF):** factor ~10 below gluon fusion
  BUT: clear signature in the detector
- **ttH:** important 100 GeV < M_H <120 GeV
- **W(Z)H:** not for discovery due to huge background

SM Higgs Final States



Dominant decays for M_H < 135 GeV: H→bb Dominant decay, difficult final state (large $t\bar{t}$ background)

H→ττ Attractive discovery channel

Dominant decays for M_H > 135 GeV: H→WW and H→ZZ

Tiny H→γγ: Also important (110 GeV < M_H < 140 GeV)

VBF Channels investigated in ATLAS: VBF H→ττ

VBF H→WW (not discussed in this talk)

ATLAS VBF Higgs Studies

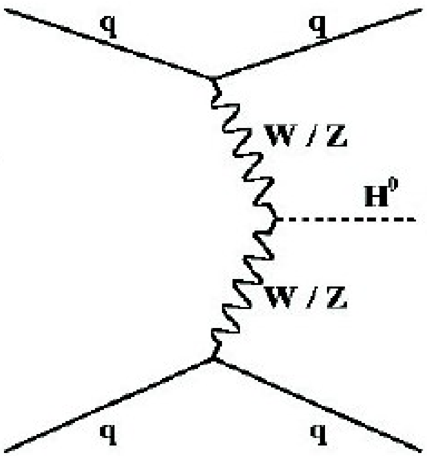
Optimize analysis assuming an integrated luminosity of $30 fb^{-1}$ using:

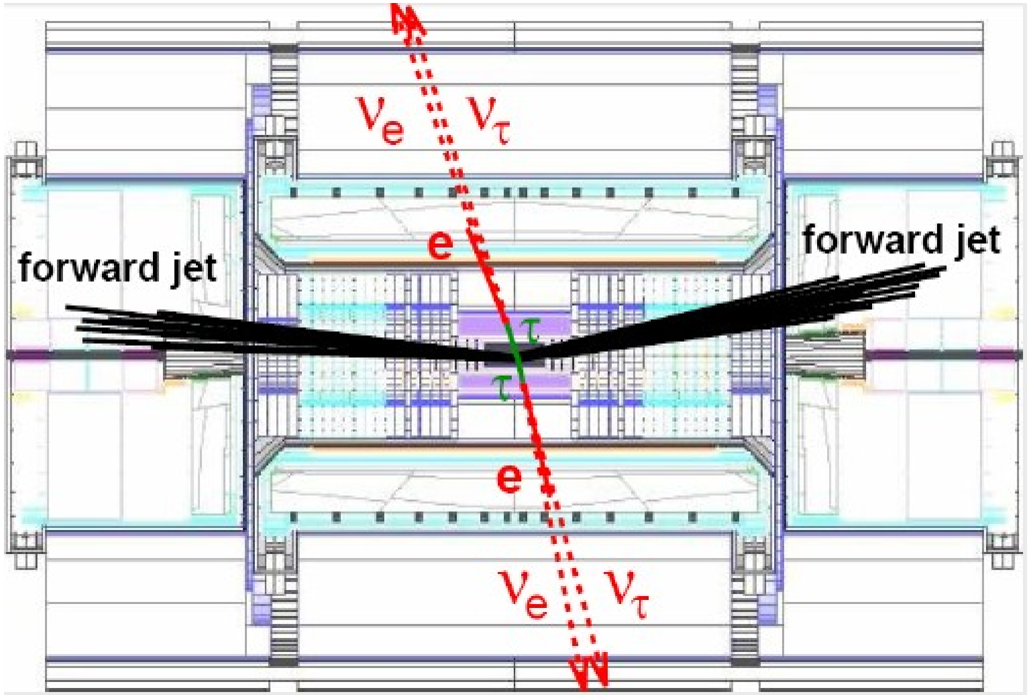
- State-of-the art Monte Carlo generators
  (MC@NLO, ALPGEN, HERWIG, PYTHIA, ...)
- Detailed GEANT4-based simulation of the ATLAS detector
  (including misalignments and distortions)

The first five years

Year	$\int \mathscr{L} dt$	$\mathscr{L}$
2008	~40 pb^{-1}	10^{31}-10^{32} cm^{-2} s^{-1}
2009	2 - 3 fb^{-1}	8×10^{32} cm^{-2} s^{-1}
2010	~10 fb^{-1}	2×10^{33} cm^{-2} s^{-1}
2011	~30 fb^{-1}	2×10^{33} cm^{-2} s^{-1}
2012	~100 fb^{-1}	10^{34} cm^{-2} s^{-1}

VBF Higgs→ττ Signature





- Two tagging jets in forward region
- Higgs boson decay products in the central region
- No color flow between quark lines:
  - No central jets
- Missing transverse momentum: associated to υ's from τ decays

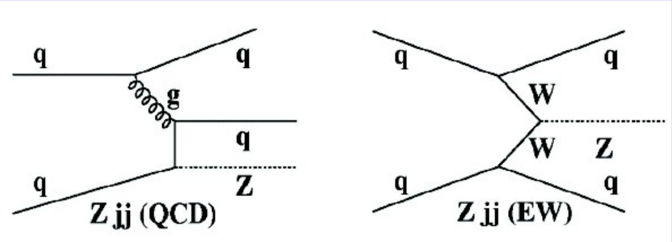
τ Decays

$H \rightarrow \tau\tau \rightarrow hh$ (42%):

- Triggers for *hh* channel are under investigation
- Reliable estimate of the QCD jets background can only be provided with data
- Will not be discussed in this talk

$H \rightarrow \tau\tau \rightarrow lh+3\nu$ (46%) AND $H \rightarrow \tau\tau \rightarrow ll+4\nu$ (12%)

- Easy to trigger (high p_T leptons)
- Backgrounds to VBF $H \rightarrow \tau\tau$: Z + jets, W + jets, tt, diboson, WW/ZZ/ZW



Leptonic τ Decays

Decay leptons used for trigger:

- use simple robust trigger signatures (initially):
  - isolated electron with p_T> 22 GeV
  - or isolated μ with p_T> 20 GeV

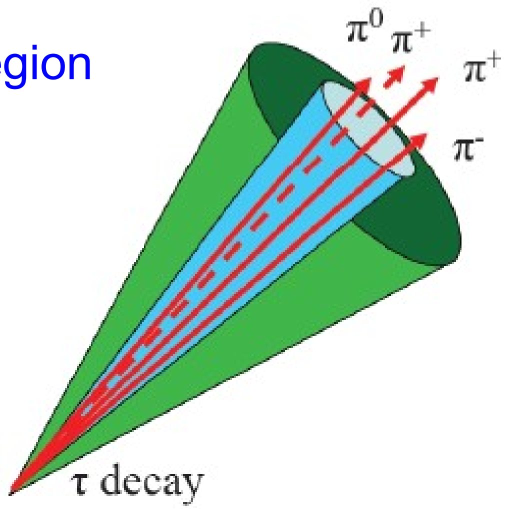
Lepton selection:

- thresholds for e/μ identification optimised for identification efficiency and fake rejection
- electron:
  - p_T> 25 GeV for trigger electron
  - p_T> 15 GeV for the other electrons
- muon:
  - p_T> 20 GeV for trigger electron
  - p_T>10GeV for other muons
- energy isolation within a cone around the *e*/μ (Isolation $E_T/p_T \leq 0.1$)

Hadronic τ Decays

Hadronic τ decay:

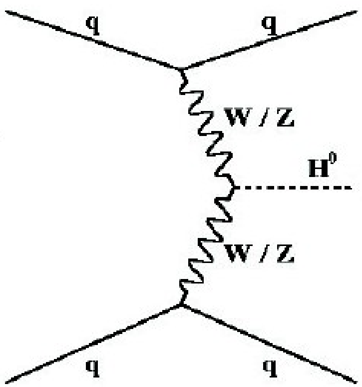
- Γ ~ 50% single prong (1 charged *h*)
- Γ ~ 15% three prongs (3 charged *h*)
- Decay products collimated into a narrow region



→ collimated deposition in EM Calorimeter
→ use shower shape variables
→ reconstruct π^0 sub-clusters
→ isolation cone
→ log-likelihood-based discrimination from QCD jets

- Log-likelihood and p_T cuts optimized with respect to $s/(s+b)^{1/2}$
- $p_T > 30$ GeV

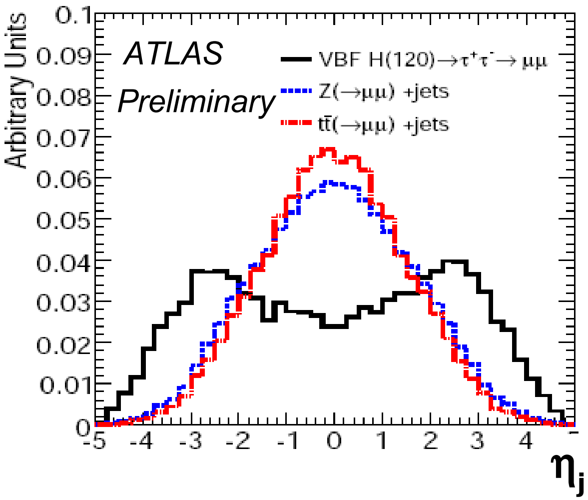
Tagging Jets

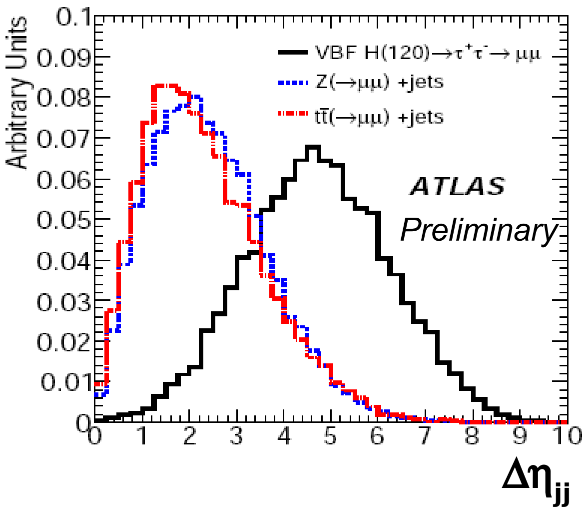


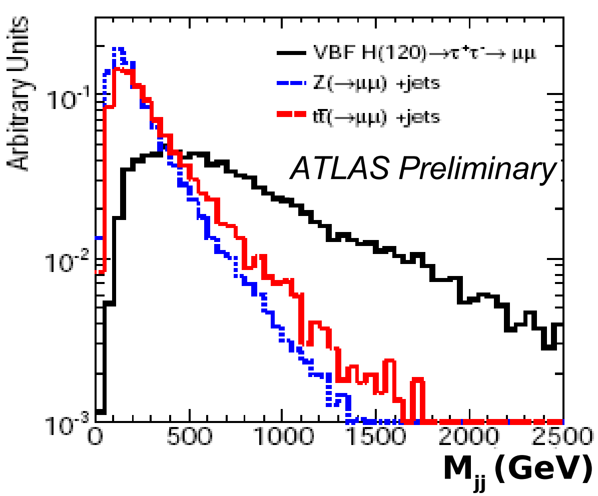
- $|\eta|<4.9$ (jets as close as 1° to the beam pipe!)
- Tagging jets: 2 highest p_T jets

  (nearly 100% of the time correctly matches the quark-initiated tagging jets from the hard process)
- Reconstruction efficiency for 2 tagging jets (VBF selection) ~ 95%
- Cuts: p_T>40 GeV and second jet p_T>20 GeV

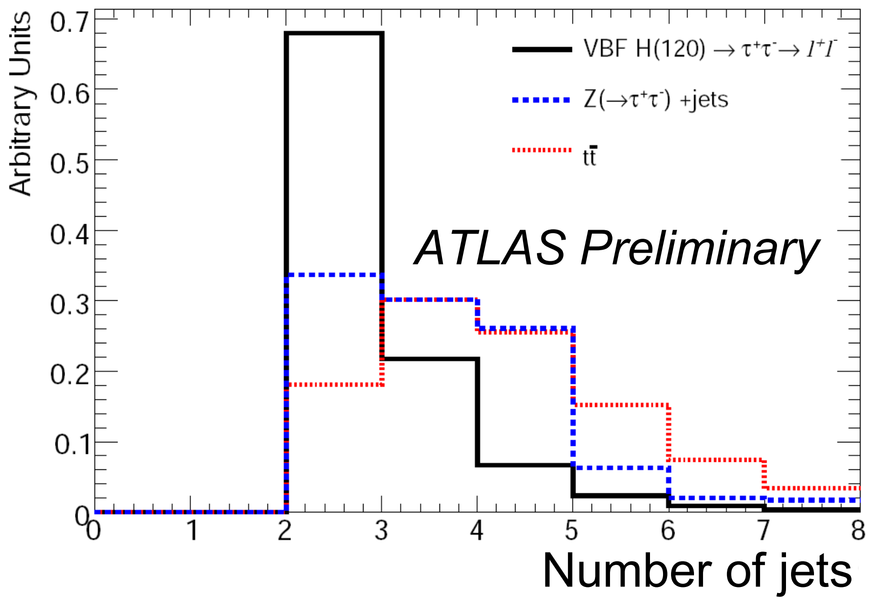
  $\eta_j \times \eta_j \leq 0$, $\Delta\eta_{jj}$>4.4, M_{jj}>700 GeV





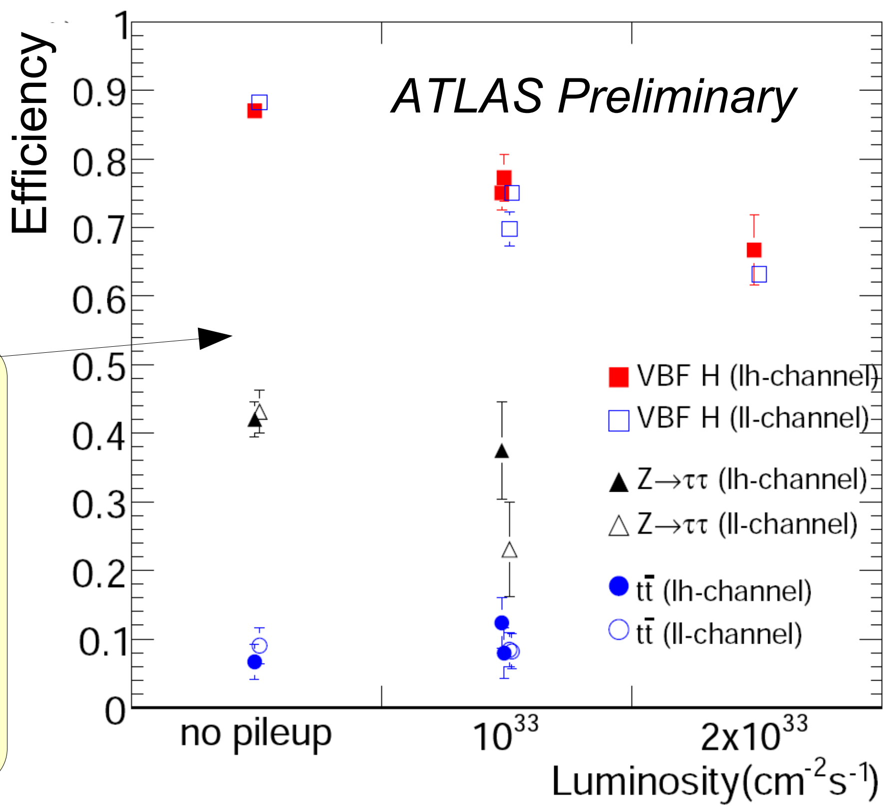


Central Jet Veto



Central Jet Veto:

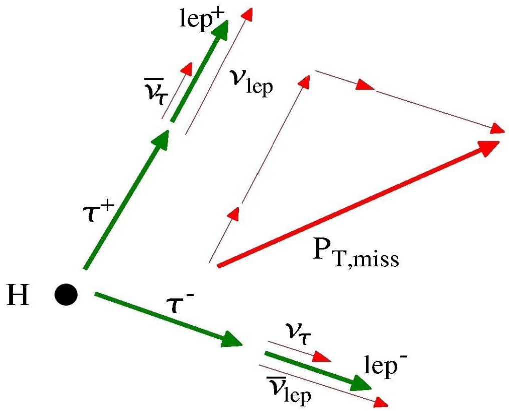
- No extra jet with p_T>20 GeV within $|\eta|$<3.2



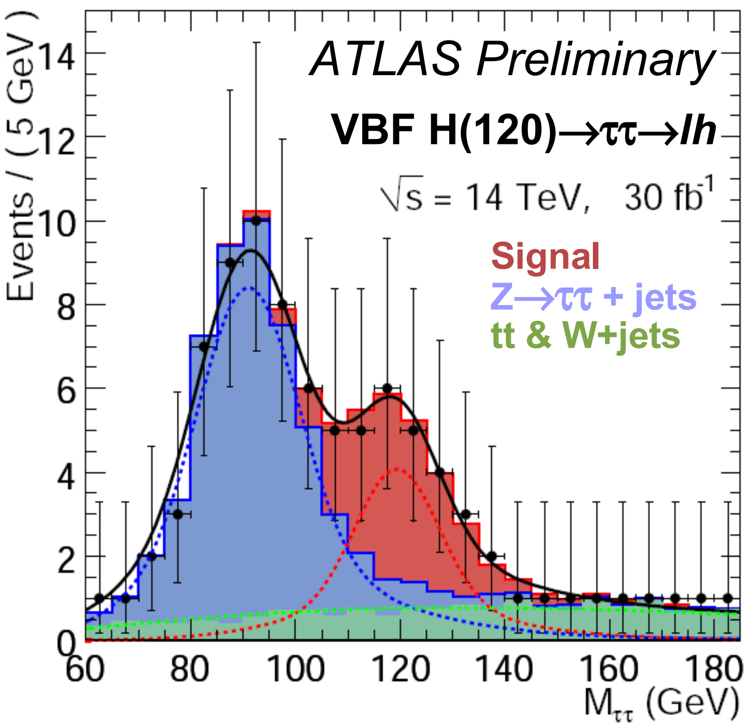
Pileup?

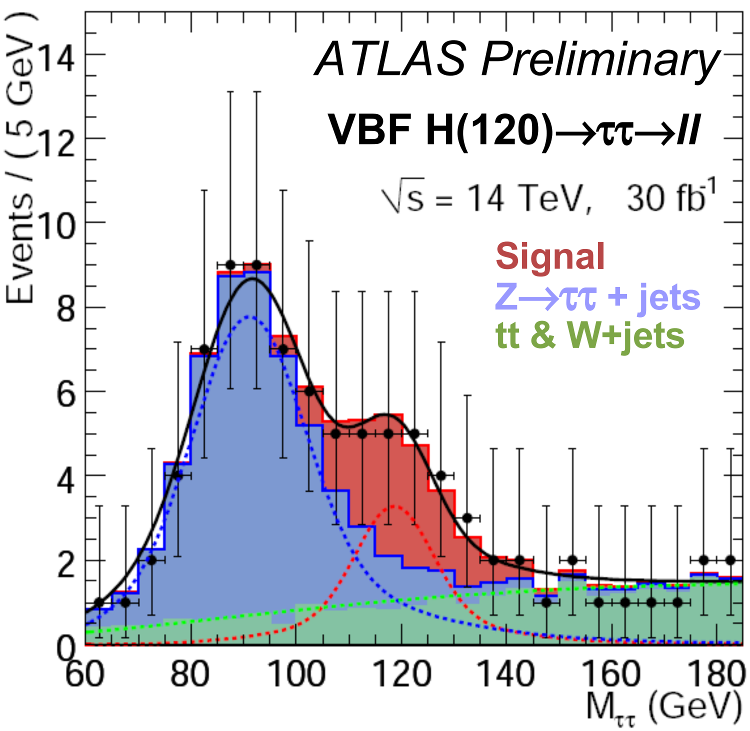
- Studies in progress to suppress these effects using:
  - → vertexing information
  - → timing information in the calorimeter

Mass Reconstruction



- Use collinear approximation:
  - assume that the decay products of the τ are collinear with the τ in the laboratory frame
- Resolution limited by the missing transverse energy resolution





Estimating Backgrounds from Real Data

Data-driven Background Estimation

$Z \to \mu\mu$ + jets has identical jet activity as $Z \to \tau\tau$ +jets

→ Procedure:

⇒ select $Z \to \mu\mu$ + jets events

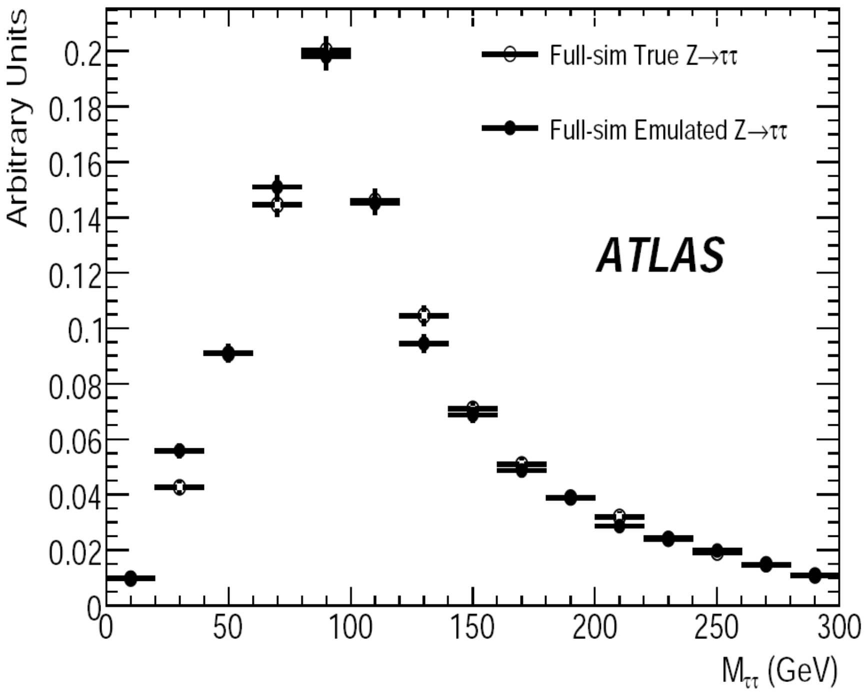
⇒ replace the μ's by the τ's

⇒ carefully treat the decay of the τ

→ Full event selection is then applied to the emulated $Z \to \tau\tau$ + jets control sample

→ Expected uncertainty ~ 10%

→ Normalization can be directly obtained from data



Signal Significance

- Extracted from $M_{\tau\tau}$ spectrum
- Simultaneous fit the signal candidates and the background control samples

  → constrain the shape and normalization of the background from the data-driven analysis

  → uncertainty of the background shape is directly incorporated
- The fit is performed twice:

  1) letting the signal and background parameters to float

  2) constrain signal normalization to be zero, floating background parameters
- Define the profile likelihood ratio λ

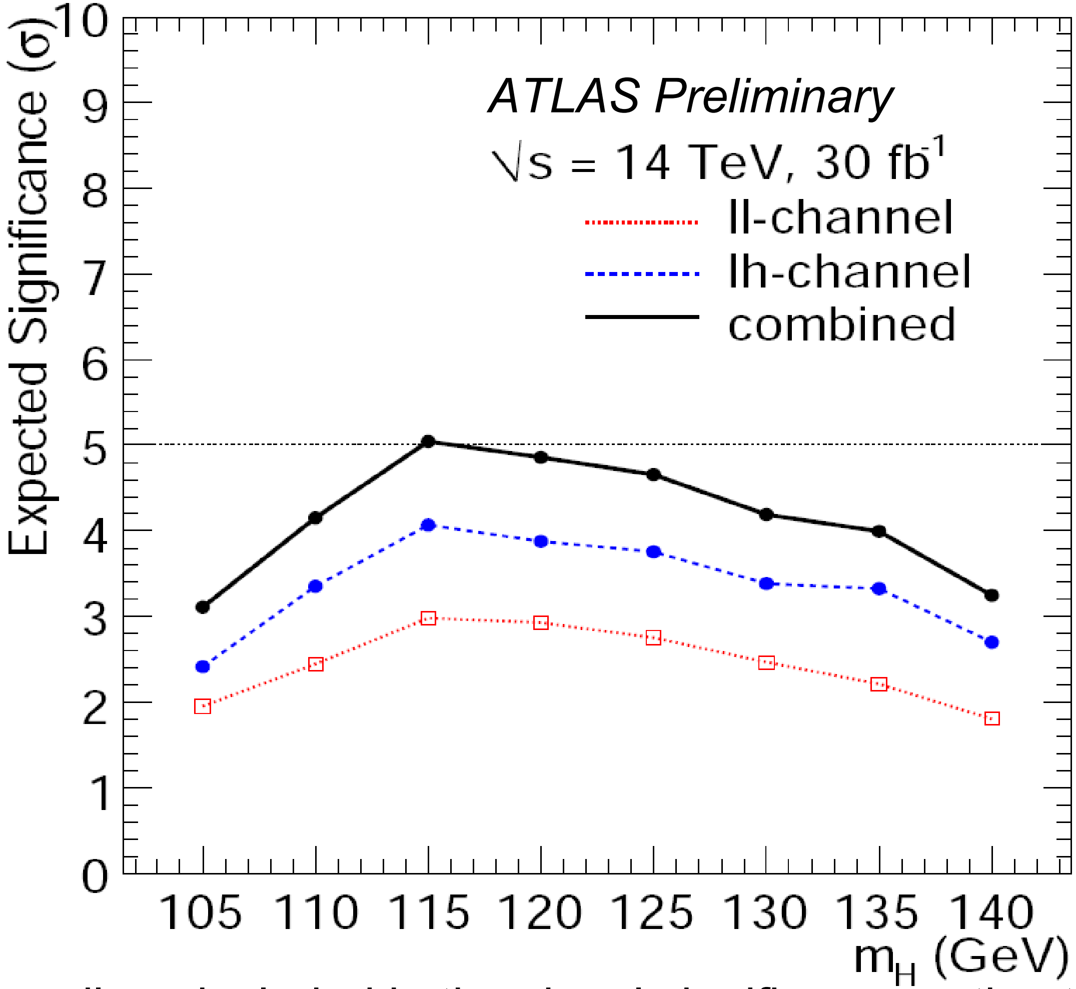
$$\lambda(\mu=0) = \frac{L(data|\mu=0, \hat{\hat{b}}(\mu=0), \hat{\hat{\nu}}(\mu=0))}{L(data|\hat{\mu}, \hat{b}, \hat{\nu})}$$

  μ is the signal rate in units of SM expectation, b is the rate and ν is the shape parameters

  $\hat{\hat{\nu}}$ and $\hat{\hat{b}}$ are best fit with μ fixed to 0; $\hat{\nu}$ and $\hat{b}$ are best fit with μ left floating
- Wilk's theorem states that under certain conditions the distribution of the profile likelihood ratio has an asymptotic form $-2\log\lambda(\mu=0) \sim \chi^2_1$

  Ann. Math. Statist. 9 (1938) 60-2
  NIM A 551 (2005) 493
- Thus, significance = $\sqrt{-2\log\lambda(\mu=0)}$

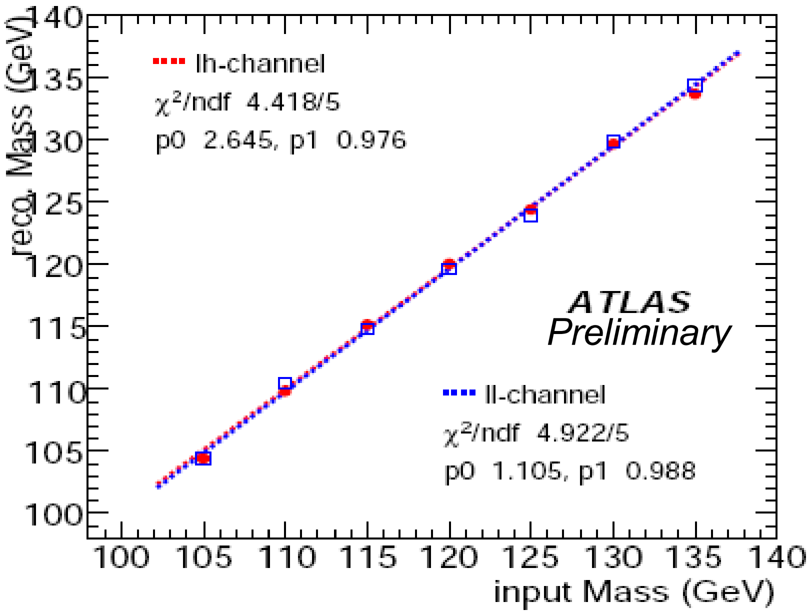
Expected Signal Significance ($30fb^{-1}$)

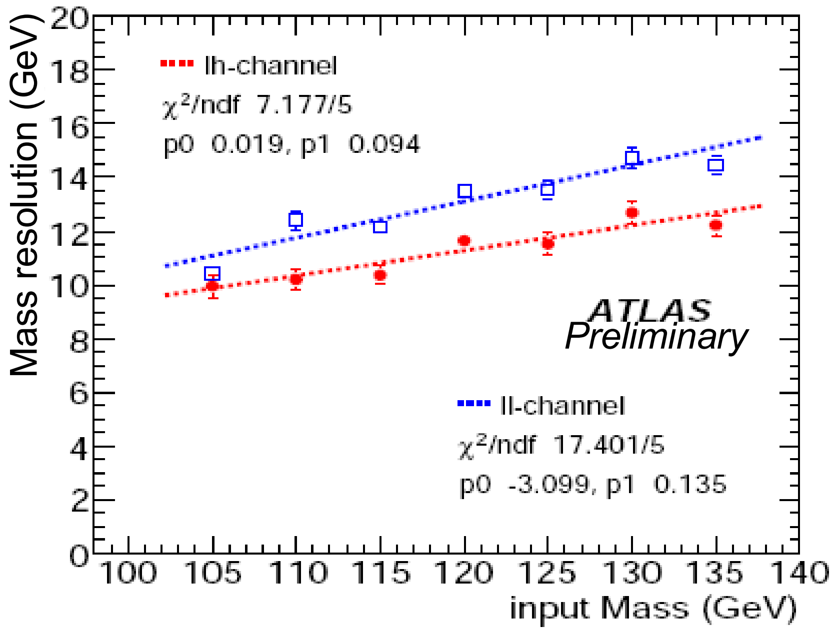


NB: no pileup included in the signal significance estimation

Expected Mass Resolution

- Limited by the missing transverse energy resolution $\sim$ 10 GeV
- 2000 pseudo-experiments per input mass point





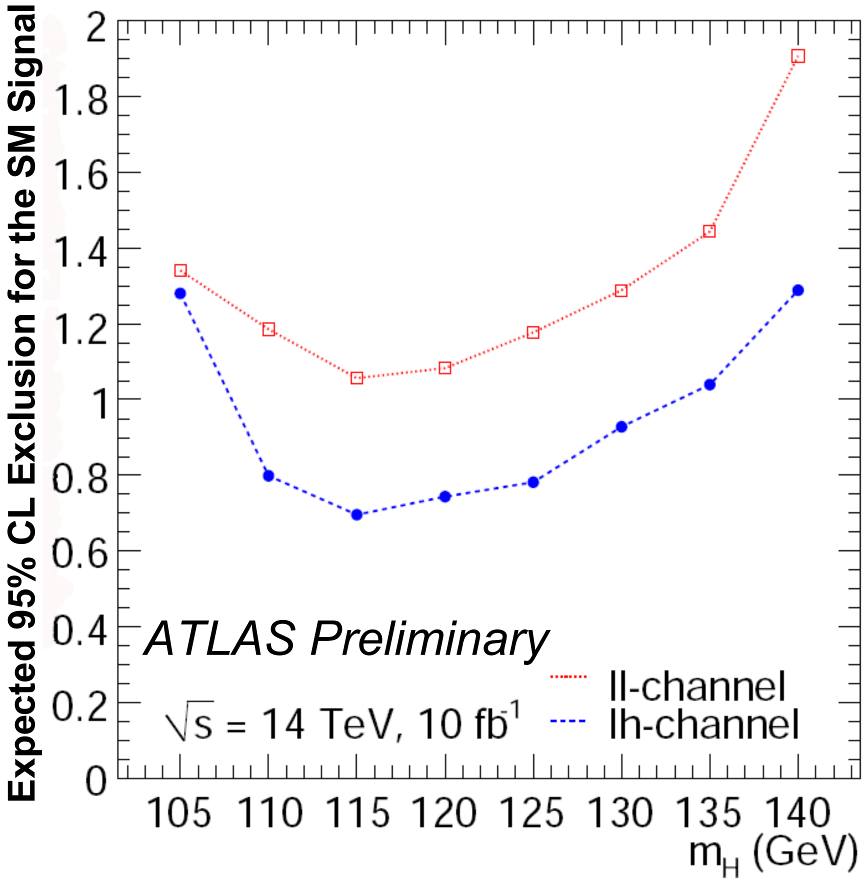
Systematic Errors

Source	Relative uncertainty	Effect on signal efficiency
luminosity	± 3%	± 3%
tau energy scale	± 5%	± 4.9%
tau ID efficiency	± 5%	± 5%
jet energy scale	± 7% (|η|<3.2) ± 15% (|η|>3.2) ± 5% (on Etmiss)	+16% / -20%
...	...	...
total summed in quadrature	-	± 20%

Jet energy/Etmiss scale is the dominant source of systematics

What if there is no signal?

Expected Exclusion Limits (10 fb^{-1})



NB: no pileup included in the signal significance estimation

Conclusions

VBF $H \to \tau\tau$:

- Important discovery channel for SM Higgs with 105 GeV < M_H < 140 GeV
- Rich experimental signature

For 30 fb^{-1} expect:

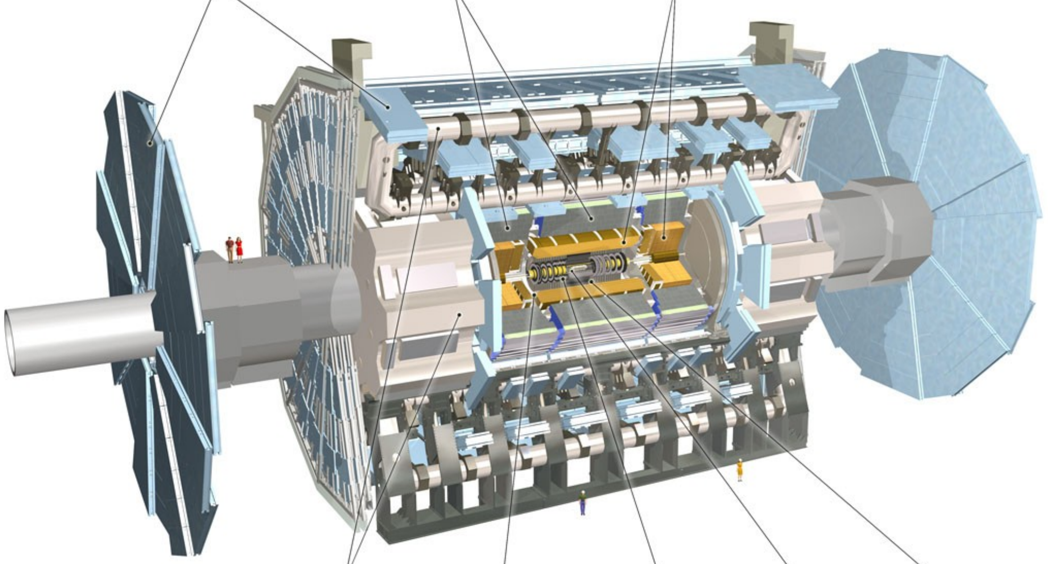
- ~ 3 – 5 σ evidence for light SM Higgs
- Powerful exclusion limits

Outlook:

- Include and limit the effect of pileup
- Continue to improve/optimize the analysis
- Use information from real data as soon as available

Backup slides

ATLAS



- Particle identification:

muons ($|\eta|<2.5$):	Efficiency ~ 97%	Jet Rejection ~10^4
electrons ($|\eta|<2.5$):	Efficiency ~ 80%	Jet Rejection ~10^3
hadronic tau ($|\eta|<2.5$):	Efficiency ~ 50%	Jet Rejection ~10^2
b-Jet ID:	Efficiency ~ 60%	light-quark Jet Rejection ~10^2

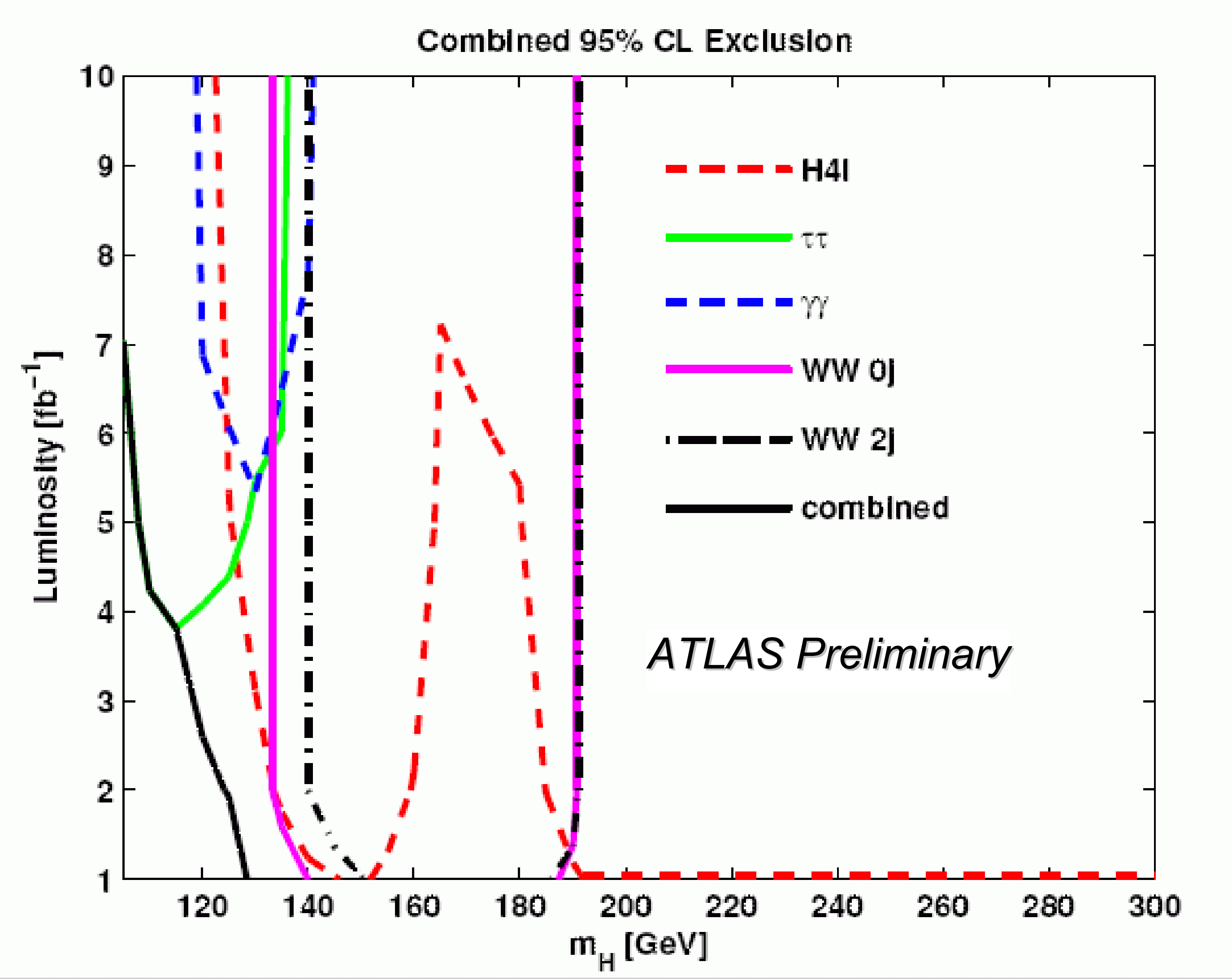
- Missing transverse energy

hermetic calorimeter $\sigma_{Etmiss} \sim 0.55 (\Sigma E_T)^{0.5}$

- Jets ($|\eta|<4.9$)

reconstruction efficiency ~ 95%

Expected Combined 95% CL Exclusion



Influence of pileup

ATLAS Preliminary

- e/μ quite robust agains pile-up
- jet and Etmiss performance are affected by pileup
- hadronic τ: efficiency can be maintained with pile-up

  but jet rejection drop ~ 50%
- mass resolution is degradate from ~ 9.5 to ~ 11.5 GeV for M_H = 120 GeV
- central jet veto drops from ~88% to 75% at $10^{33} cm^{-2}s^{-1}$ and ~65% at $2\times10^{33} cm^{-2}s^{-1}$
- Reconstruction and analysis are beeing re-optimized with pileup. No signal significance is reported under this condition.

Central Jet Veto

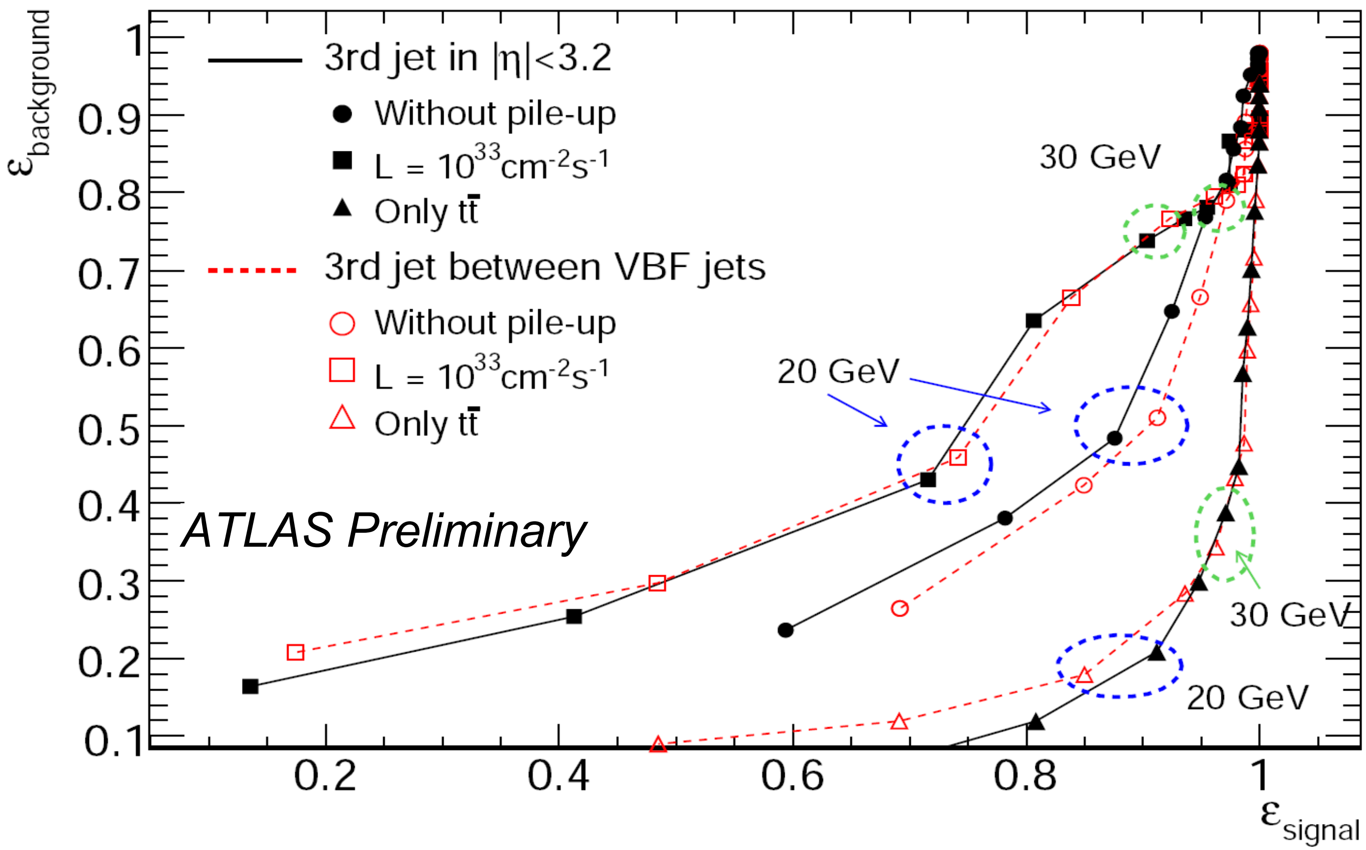


Figure 6: Background rejection versus signal sensitivity for the central jet veto with and without pileup. Also shown is the case for $t\bar{t}$-only background.

Cutflow VBF $H \to \tau\tau \to lh$

ATLAS Preliminary

Table 5: Signal cross-sections for the *lh*-channel for various Higgs boson masses.

Mass (GeV)	105	110	115	120	125	130	135	140
Cross section (fb)	394.7	372.0	341.8	309.1	266.8	225.4	180.1	135.8
Trigger	65.6(3)	65.1(2)	61.1(2)	57.2(1)	51.5(2)	44.7(1)	36.5(1)	28.3(1)
Trigger lepton	56.4(3)	56.2(2)	53.2(2)	49.5(1)	44.7(2)	38.9(1)	31.8(1)	24.7(1)
Di-lepton veto	50.0(3)	49.6(2)	46.7(2)	43.4(1)	38.9(2)	34.0(1)	27.6(1)	21.3(1)
Hadronic τ	7.7(1)	8.1(1)	8.1(1)	8.02(7)	7.4(1)	6.68(8)	5.72(7)	4.53(9)
Missing $E_T \geq 30$ GeV	4.8(1)	5.1(1)	5.08(9)	4.96(5)	4.63(8)	4.16(7)	3.51(6)	2.82(8)
Collinear Approx.	3.19(9)	3.50(8)	3.51(8)	3.34(5)	3.14(7)	2.77(6)	2.37(5)	1.91(6)
Transverse mass	2.53(8)	2.70(7)	2.67(7)	2.46(4)	2.26(6)	1.98(5)	1.64(4)	1.29(5)
N jets ≥ 2	2.12(7)	2.22(7)	2.21(6)	2.02(4)	1.80(5)	1.60(4)	1.32(4)	1.00(5)
Forward jet	1.61(7)	1.66(6)	1.73(5)	1.52(3)	1.41(5)	1.20(4)	1.03(3)	0.78(4)
Jet kinematics	0.88(5)	0.86(4)	0.92(4)	0.82(2)	0.73(3)	0.65(3)	0.56(2)	0.42(3)
Central jet veto	0.77(5)	0.77(4)	0.81(4)	0.72(2)	0.63(3)	0.55(2)	0.50(2)	0.38(3)
Mass window	0.68(4)	0.68(4)	0.70(3)	0.61(2)	0.52(3)	0.44(2)	0.40(2)	0.30(3)

Cutflow VBF $H \to \tau\tau \to ll$

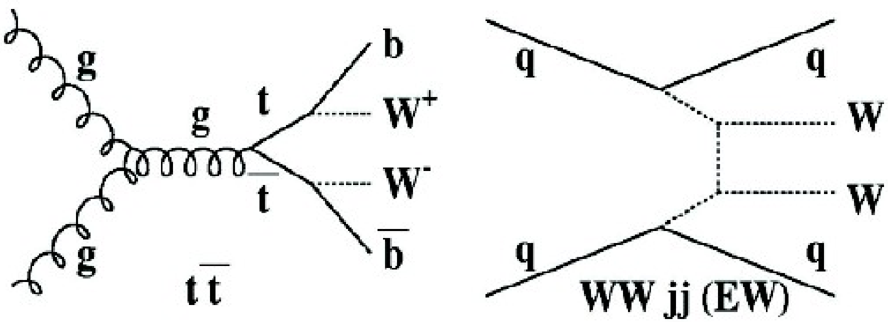
ATLAS Preliminary

Table 4: Signal cross-section for the *ll*-channel for various Higgs boson masses.

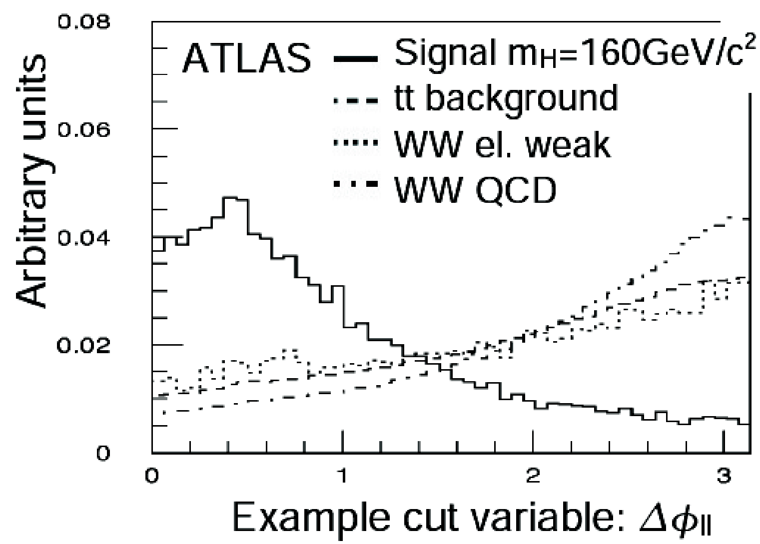
Mass (GeV)	105	110	115	120	125	130	135	140
Cross section (fb)	394.7	372.0	341.8	309.1	266.8	225.4	180.1	135.8
Trigger	65.6(3)	65.1(2)	61.1(2)	57.2(1)	51.5(2)	44.7(1)	36.5(1)	28.3(1)
Trigger lepton	56.4(3)	56.2(2)	53.2(2)	49.5(1)	44.7(2)	38.9(1)	31.8(1)	24.7(1)
Di-lepton	5.73(7)	5.86(6)	5.80(6)	5.46(3)	4.94(5)	4.30(4)	3.61(4)	2.88(4)
Missing $E_T \geq 40$ GeV	3.41(5)	3.49(5)	3.45(5)	3.17(3)	2.94(4)	2.56(4)	2.17(3)	1.78(4)
Collinear Approx.	2.34(5)	2.38(4)	2.33(4)	2.15(2)	1.95(4)	1.69(3)	1.46(2)	1.16(3)
N jets ≥ 2	1.96(4)	1.97(4)	1.95(4)	1.77(2)	1.61(3)	1.41(3)	1.20(2)	0.95(3)
Forward jet	1.48(4)	1.49(4)	1.48(3)	1.34(2)	1.21(3)	1.08(3)	0.91(2)	0.73(3)
B-jet veto	1.26(3)	1.30(3)	1.25(3)	1.16(2)	1.04(3)	0.94(2)	0.77(2)	0.64(2)
Jet kinematics	0.70(3)	0.69(2)	0.70(2)	0.63(1)	0.58(2)	0.52(2)	0.43(1)	0.37(2)
Central jet veto	0.61(2)	0.60(2)	0.62(2)	0.56(1)	0.50(2)	0.45(2)	0.38(1)	0.32(2)
Mass window	0.52(2)	0.50(2)	0.51(2)	0.45(1)	0.39(2)	0.34(1)	0.29(1)	0.23(1)

VBF H → WW

- Many and large background processes
  - (tt + jets, W + jets, Z + jets, WW + jets, ZZ + jets, ...)
- Clean access to Higgs-W-W-coupling



Example of background processes



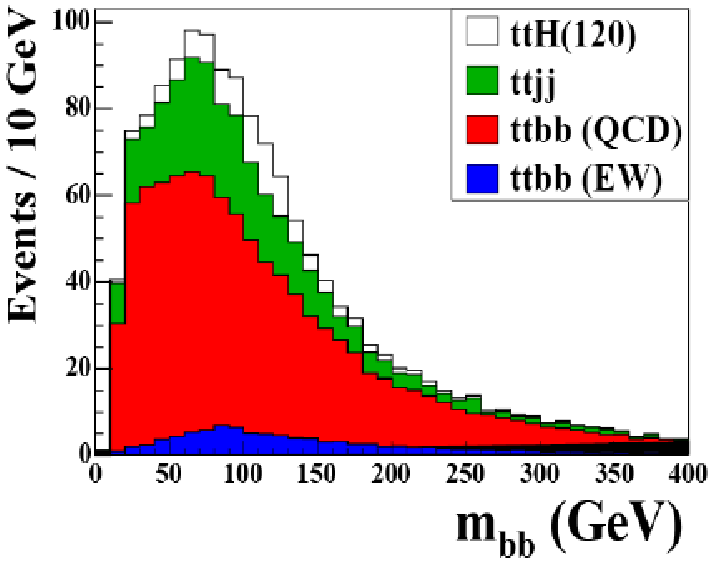
tt H → bb

A very complex final state

- Dominant background: tt + jets production

Experimental issues:

- b-tagging (efficiency ~ε^4)
- Good understanding of background shape



J. Cammin and M. Schumacher, ATL-PHYS-2003-024

SM Higgs production at LHC

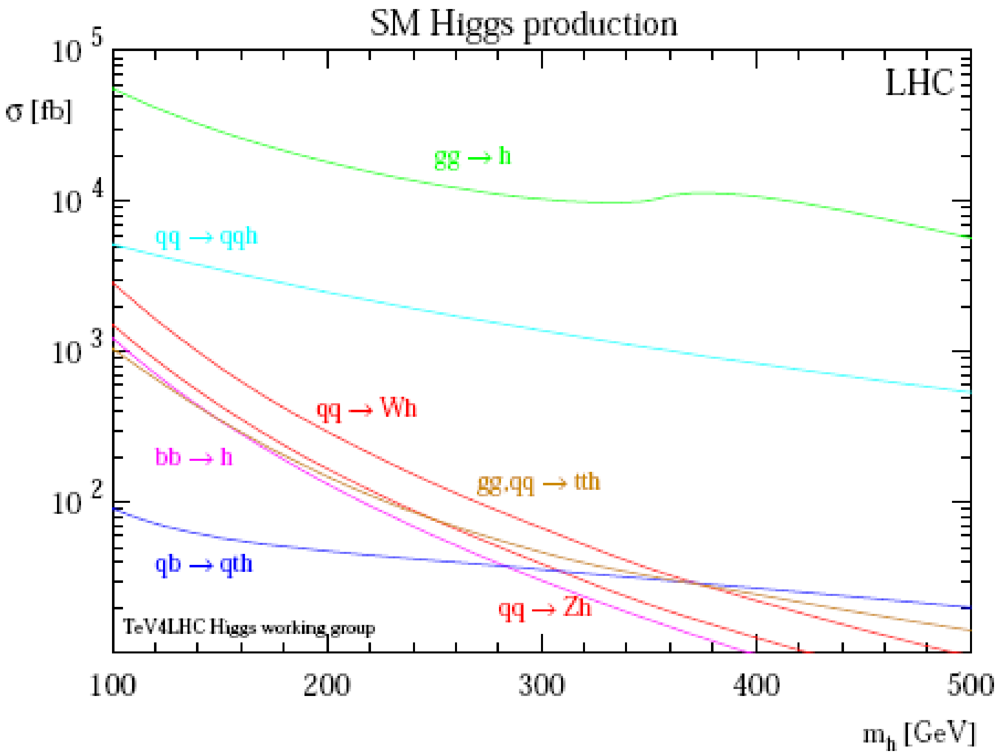
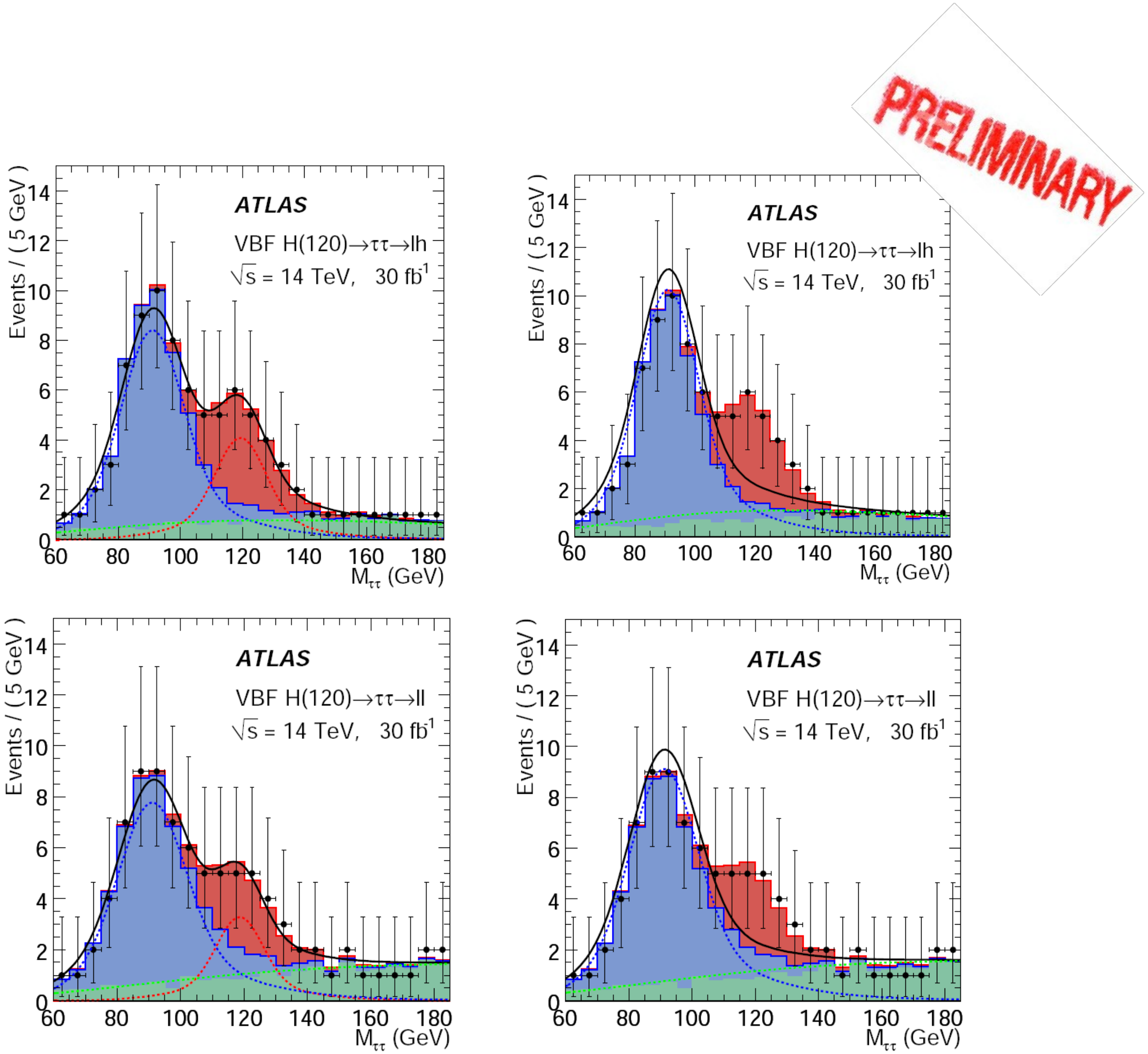


Fig. 1: Total cross sections for Higgs production at the LHC. The gluon fusion result is NNLO QCD with soft gluon resummation effects included at NNLL and uses MRST2002 PDFs with renormalization/factorization scales equal to m_h. The vector boson fusion curve is shown at NLO QCD with CTEQ6M PDFs and renormalization/factorization scales equal to m_h. The Vh results ($V = W, Z$) include NNLO QCD corrections and NLO EW corrections and use MRST2002 PDFs with the renormalization /factorization scales equal to the $m_h - M_V$ invariant mass. The $b\bar{b} \to h$ result is NNLO QCD, with MRST2002 PDFs, renormalization scale equal to m_h and factorization scale equal to $m_h/4$. The results for $t\bar{t}h$ production are NLO QCD, use CTEQ6M PDFs and set the renormalization/factorization scale to $m_t + m_h/2$ [100].

VBF H→ττ


PRELIMINARY
ATLAS
VBF H(120)→ττ→lh
√s = 14 TeV, 30 fb-1
Events / (5 GeV)
Mττ (GeV)
ATLAS
VBF H(120)→ττ→lh
√s = 14 TeV, 30 fb-1
Events / (5 GeV)
Mττ (GeV)
ATLAS
VBF H(120)→ττ→ll
√s = 14 TeV, 30 fb-1
Events / (5 GeV)
Mττ (GeV)
ATLAS
VBF H(120)→ττ→ll
√s = 14 TeV, 30 fb-1
Events / (5 GeV)
Mττ (GeV)