ATLAS Discovery Potential of bb h/A/H → ττ in the Fully Leptonic Channel

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PHYSICS AT THE TERA SCALE
Helmholtz Alliance

Outline

1. The Signal Process in the MSSM
2. Selection
3. Background Estimation
4. Systematics
5. Discovery Potential

Publication to appear:

ATLAS Collaboration,
Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics,
CERN-OPEN-2008-020, Geneva, 2008

The Higgs Sector in the MSSM

- 2 Higgs doublets ⇨ 5 Higgs bosons: **h^0**, **H^0** (CP = +1), **A^0** (CP = -1), **$H^\pm$**
- Tree level decribed by only two parameters: **m_A, tanβ** = v_u/v_d $v_u^2+v_d^2 = v^2$
- $m_h < m_Z$ but large loop corrections increase this limit!

Couplings: $g_{MSSM} = \xi\, g_{SM}$

α = mixing angle between h and H

ξ	t	b / τ	W / Z
h	cosα/sinβ	-sinα/cosβ	sin(α-β)
H	sinα/sinβ	cosα/cosβ	cos(α–β)
A	cotβ	tanβ	-

h/A/H → ττ enhanced if tanβ large

h/H → ZZ^* suppressed
A does not couple to W/Z

Additional parameters:

X_t	Stop mixing parameter
M_{SUSY}	Energy scale of SUSY breaking
M_2	Gaugino mass at EW scale
$M_{\tilde{g}}$	Gluino mass at EW scale
μ	Strength of SUSY Higgs mixing

All parameters except tanβ, m_A fixed in benchmark scenarios:

m_h^{max}:	m_h < 133 GeV, maximum allowed mass for h
nomixing:	m_h < 116 GeV, no mixing in stop sector
gluphobic:	m_h < 119 GeV, suppressed gg fusion
small α:	m_h < 123 GeV, suppressed ttbar h, h → bb

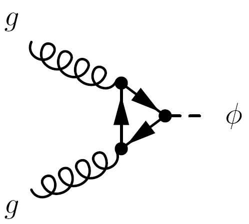
→ m_h^{max} considered here

Carena, Heinemeyer, Wagner, Weiglein
Eur. Phys. J. C26 (2003) pp. 601-7

The Signal Process in the MSSM

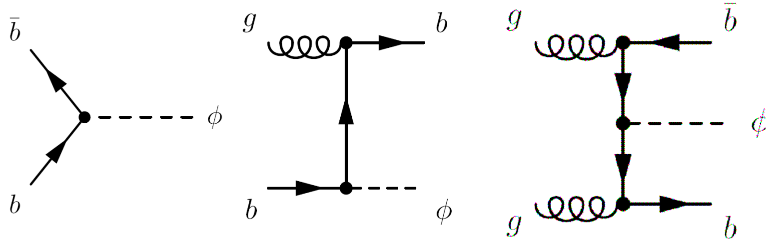
Signal Production

gluon fusion



Dominant
at $\tan\beta<10$

b-quark associated production



$\sigma_{bbH/A} \sim \tan^2\beta$

Example cross sections (14 TeV):

$\tan\beta=20$

m_A / GeV	σ_{bbH}	σ_{bbA}
150	95 pb	103 pb
200	39 pb	40 pb
300	9 pb	9 pb

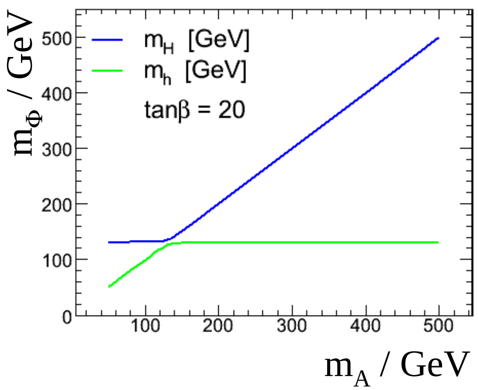
Harlander, Kilgore
Phys. Rev. D 68 (2003) 013001

S. Dittmaier, M. Kramer, M. Spira
Phys. Rev. D70 (2004) 074010

NLO

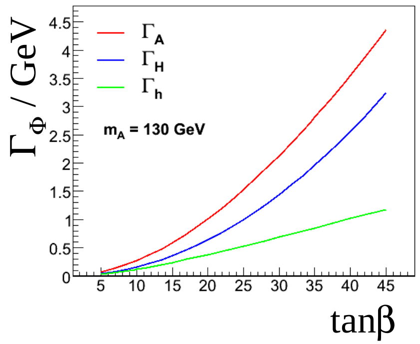
Signal Properties

Mass degeneration



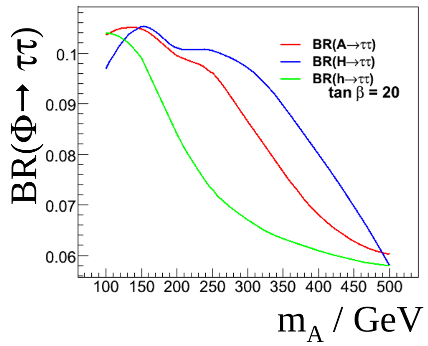
Add up cross sections

Natural width



Irrelevant for $h/A/H \to \tau\tau$
due to mass resolution

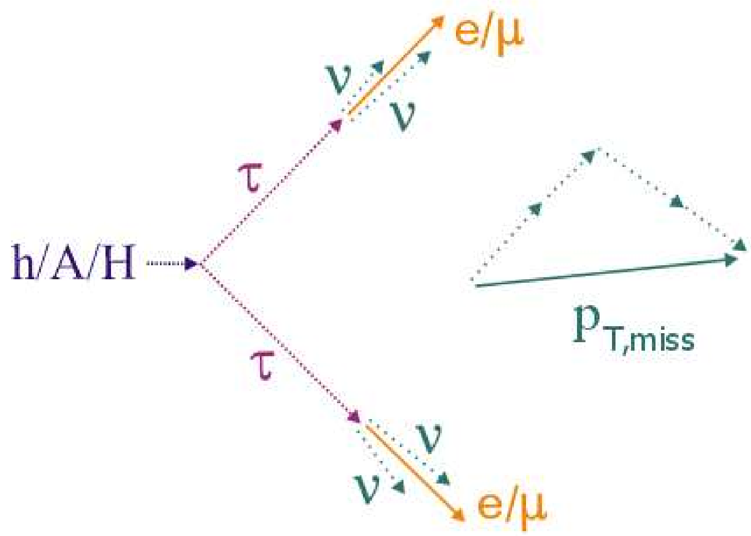
BR $h/A/H \to \tau\tau$



$\approx$ 10 % for low m_A

Signal Mass Reconstruction

Collinear Approximation



Conditions:

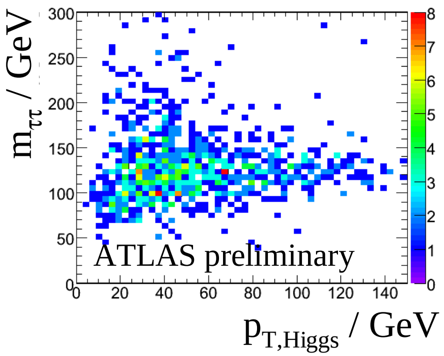
- Higgs mass large compared to τ mass
- Higgs boson has non-zero p_T
- $p_{T,miss}$ in the detector due to neutrinos only

$x = p_{T,\ell} / p_{T,\tau}$

$0 < x < 1$

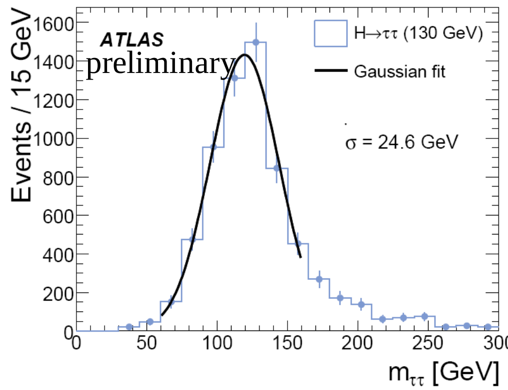
$$m_{\tau\tau} = \frac{m_{\ell\ell}}{\sqrt{x_1 \cdot x_2}}$$

Mass resolution in bb h/A/H:



⇨ Mass resolution deteriorates for low $p_{T,Higgs}$

⇨ High-energy tail in $m_{\tau\tau}$



Mass resolution:

m_A / GeV	σ / GeV
110	21
200	33
300	52

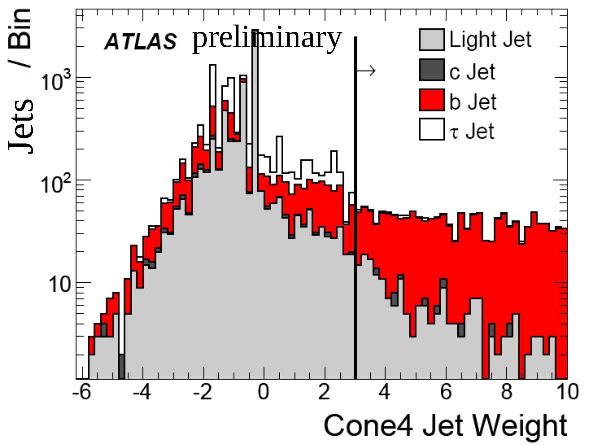
Event Selection

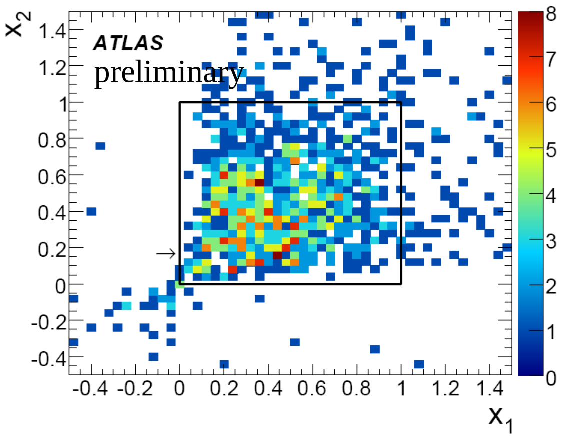
Relevant background processes:

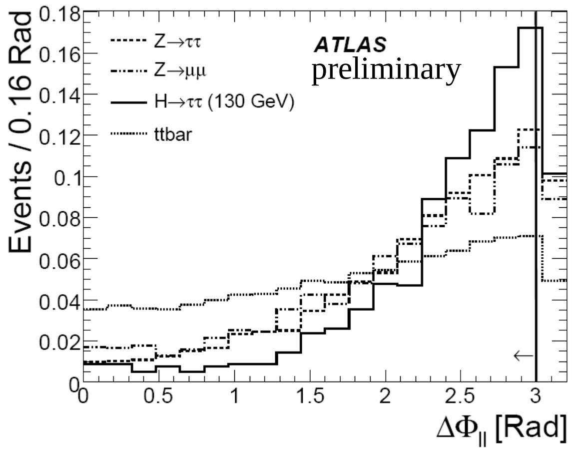
- W+jets (20045 pb), bbar W (111 pb)
- Z(→ leplep)+jets (2036 pb), bbar Z (52.3 pb)
- ttbar (833 pb)

Mass independent Preselection:

- Trigger: high p_T single or di-lepton trigger (μ20, 2e15, e25, e15&μ10)
- Choose two oppositely charged leptons with p_T > 10 GeV
- Veto events with more than 2 jets
- Require at least one b-tag with jet p_T > 15 GeV
- Select physical solutions of collinear approximation ($\Delta\Phi_{ll}$<3.0, 0<x_i<1)







Mass Dependent Selection

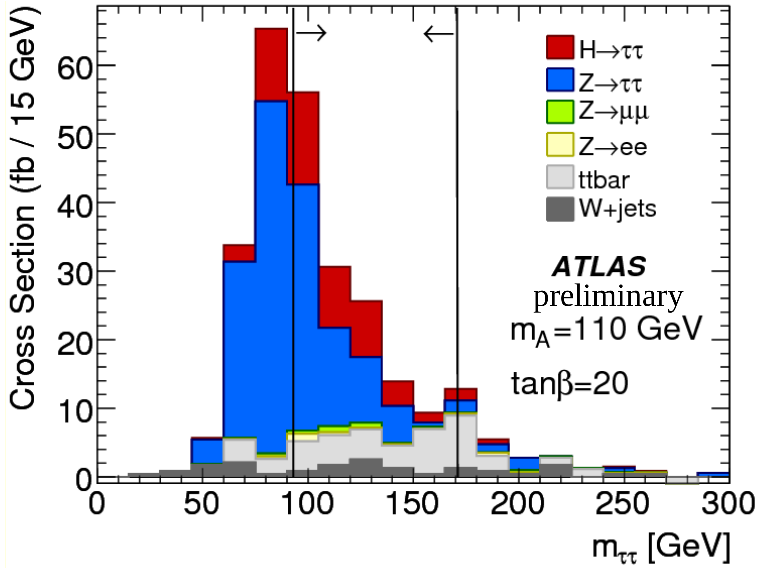
- More kinematical cuts optimized for best statistical significance on each mass point mostly taking into account the low p_T signature of the signal
  - Events with high $\Delta\Phi_{ll}$ (back to back signature, esp.for higher A masses)
  - Events with small $p_{T,Higgs}$
  - Events with certain p_T of the leading b-jet
  - Events with a large $p_{T,miss}$ (missing E_T due to neutrinos in final state)
  - Cuts on m_{ll} and $x_1 \bullet x_2$ (to suppress $Z \rightarrow$ leplep)
- Individual optimization in ee/μμ and the mixed eμ channel due to $Z \rightarrow ee/\mu\mu$ contribution

Example m_A=130 GeV, tanβ=20:

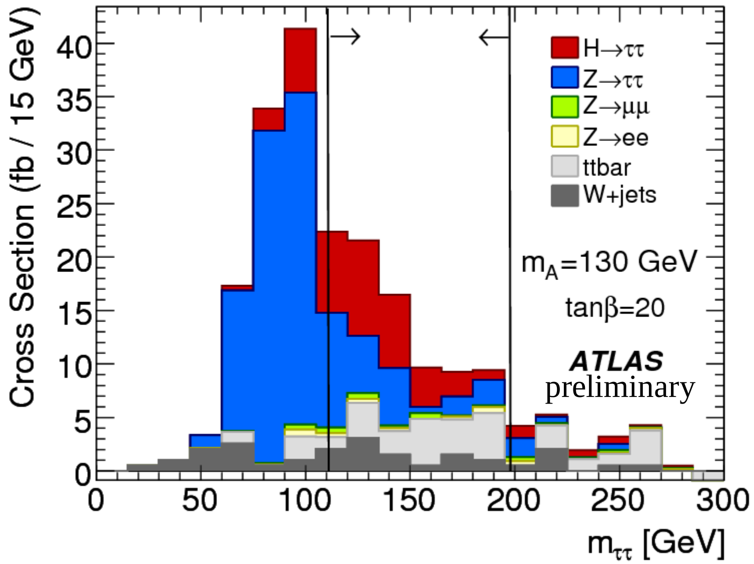
	Higgs Signal	ttbar	$Z \rightarrow \tau\tau$	$W \rightarrow l\nu$	$Z \rightarrow ee/\mu\mu$
Trigger	1 511 fb	255 114 fb	47 027 fb	17 200 000 fb	2 707 140 fb
Preselection	116 fb	1 096 fb	441 fb	122 fb	6 071 fb
Further cuts	43.3 fb	32.8 fb	107.5 fb	21 fb	7.4 fb
Overall selection efficiency	0.02	$7 \bullet 10^{-5}$	$1 \bullet 10^{-3}$	$7 \bullet 10^{-7}$	$2 \bullet 10^{-6}$

Results of Selection for 30 fb^{-1} (1/3)

110 GeV



130 GeV



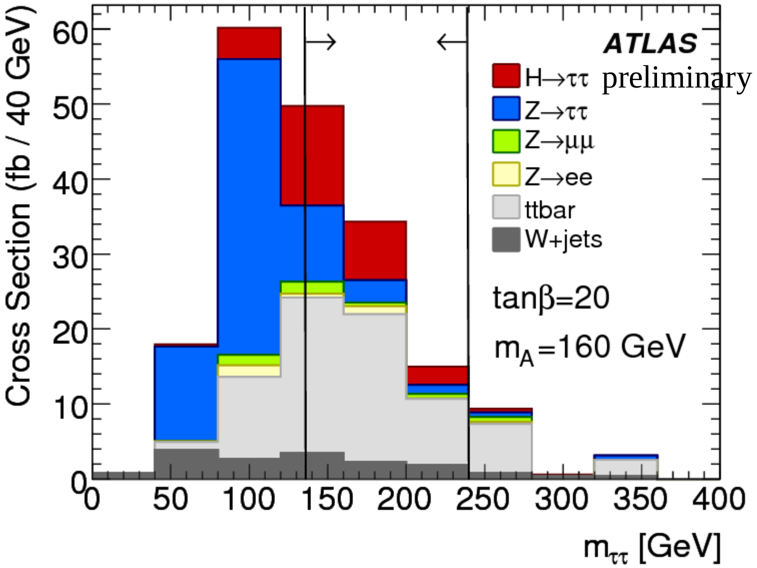
Events in optimized mass window:

	110 GeV	130 GeV
Signal	1 032	852
$Z \to \tau\tau$	1 863	663
ttbar	720	591
W+Jets	258	369

⇨ Clearly dominated by irreducable $Z \to \tau\tau$

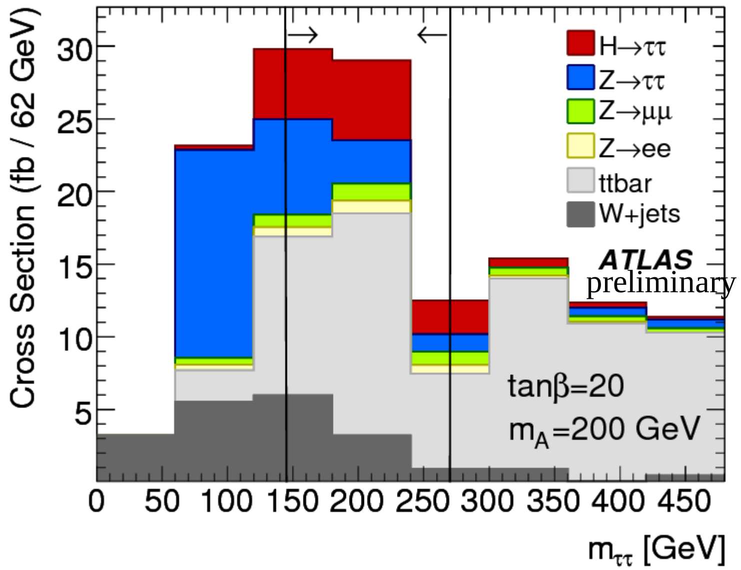
Results of Selection for 30 fb^{-1} (2/3)

160 GeV



Signal	561
$Z \to \tau\tau$	252
ttbar	1179
W+Jets	54

200 GeV

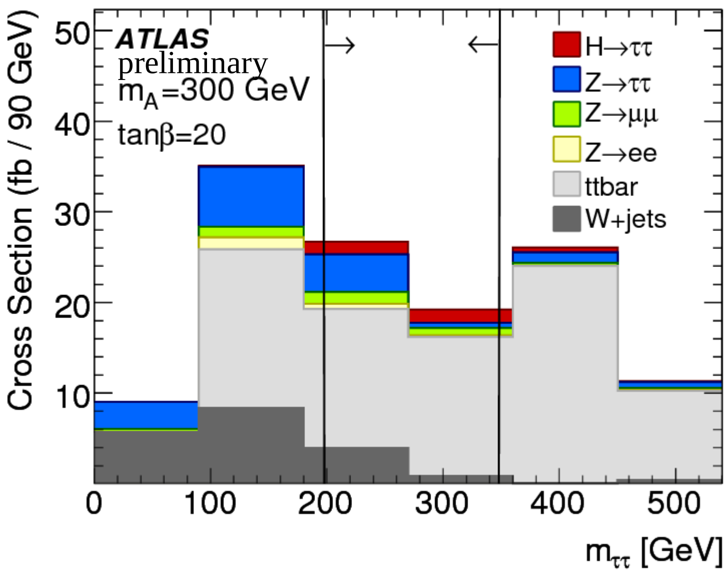


Signal	327
$Z \to \tau\tau$	162
ttbar	852
W+Jets	111

⇨ ttbar background becomes more important

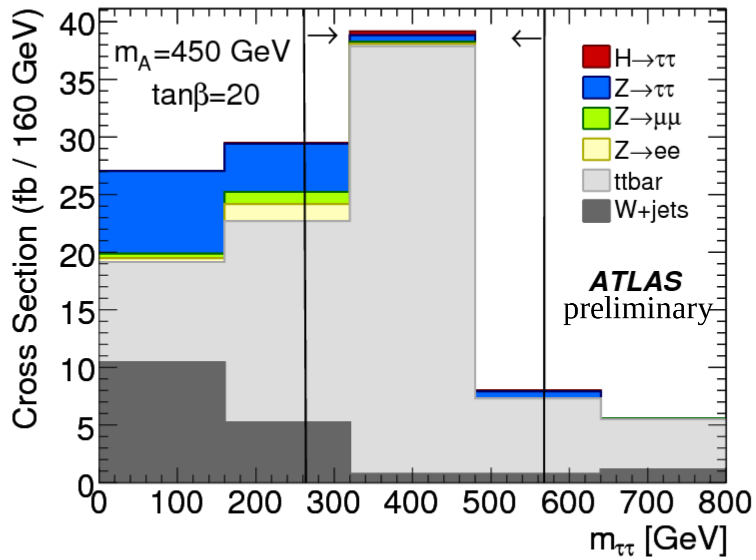
Results of Selection for 30 fb^{-1} (3/3)

300 GeV



Signal	81
Z → ττ	90
ttbar	984
W+Jets	174

450 GeV



Signal	15
Z → ττ	54
ttbar	1506
W+Jets	123

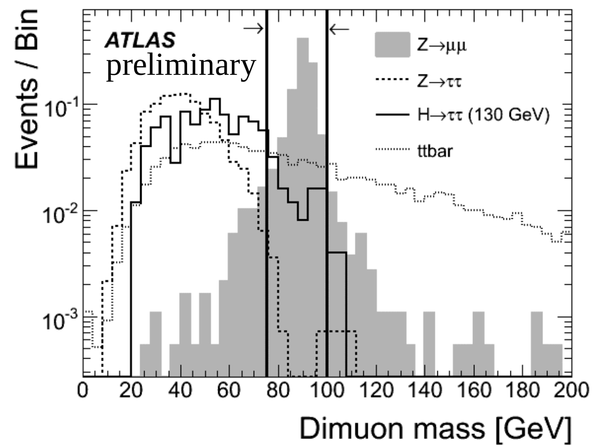
⇨ Z background almost negligible

⇨ Signal tiny due to cross section*BR

Z → ττ Estimation from Data (1/2)

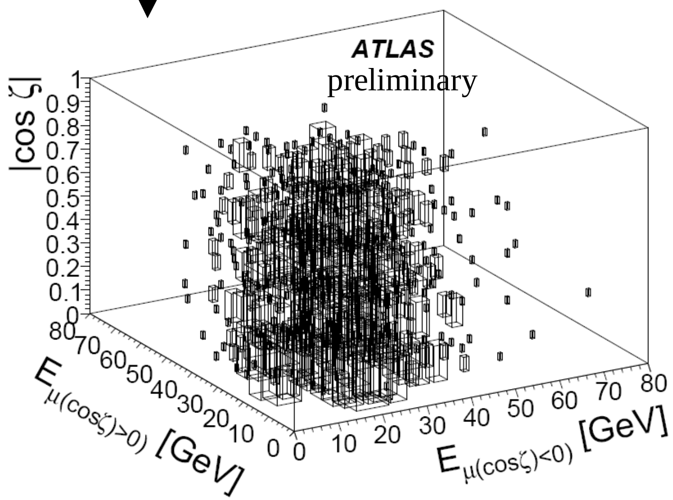
Estimation of irreducible Z → ττ background from data

- Selection of **Z → μμ** events from data (sideband) with 98% purity

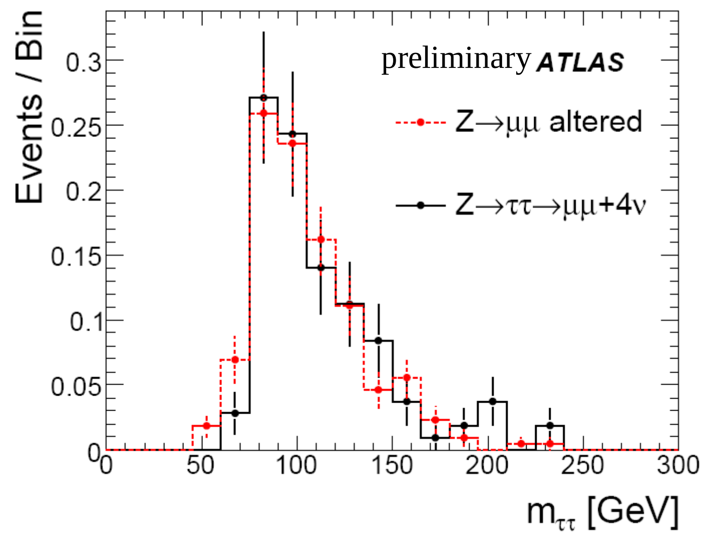


- Alter μ energies and momenta according to **Z → ττ** reference histograms (MC, signal region)

  (Martin Schmitz „Old Bonn Method“)

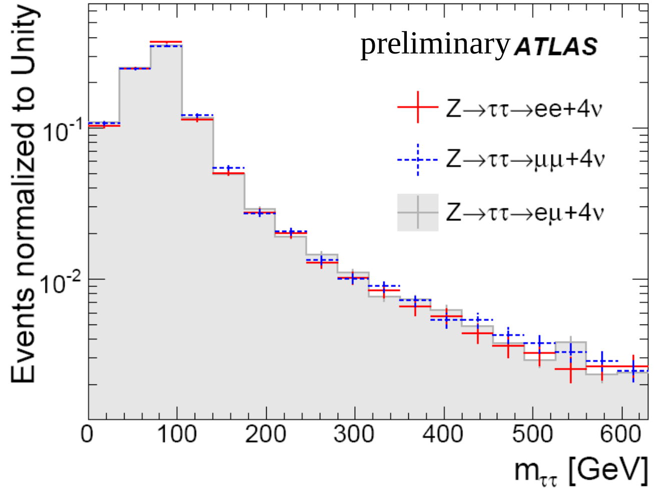


- Apply cuts to manipulated Z → μμ events to obtain correct Z → ττ shape



Z → ττ Estimation from Data (2/2)

- Shapes of leptonic final states identical within statistical limits →
- Use and modify sideband to select ee or μμ events



Data-driven normalization of Z → ττ shape:

$$\#(Z \to \tau\tau \to \mu\mu)^{Signal}_{DATA} = \#(Z \to \tau\tau \to \mu\mu)^{Signal}_{MC} \cdot \frac{\#(Z \to \mu\mu)^{Sideband}_{DATA}}{\#(Z \to \mu\mu)^{Sideband}_{MC}}$$

Double ratios of efficiencies in Sideband and signal region for Z → ee/μμ and Z → ττ →ee/μμ

(signal region = all analysis specific cuts applied)

Systematic uncertainties on Z → ττ:

- JES and b-tagging uncertainties cancel
- Remaining uncertainties on lepton resolution, p_T scale and efficiency: **2.6 %**
- No systematics on shape estimated so far
- Statistical uncertainty on the normalization is negligible for 30 fb^{-1}

Systematic Uncertainties (1/2)

Experimental Uncertainties:

Electron efficiency	± 0.2 %
Electron E scale	± 0.2 %
Electron resolution	$\sigma(E_T) = 0.0073\, E_T$
Muon efficiency	± 1 %
Muon pT scale	± 1 %
Muon resolution	$\sigma(1/p_T) = 0.001/p_T \oplus 0.00017$
Jet energy scale	± 3 % (10 %, $\|\eta\|>3.2$)
Jet energy resolution	$\sigma(E) = 0.45 \sqrt{E}$ ($0.63 \sqrt{E}$, $\|\eta\|>3.2$)
b-tagging efficiency	± 5 %
b-tagging fake rate	± 10 %

- Evaluated for each mass point for W+jets and ttbar
- $Z \to \tau\tau$ uncertainty flat 2.6 %

Theoretical Uncertainty:

- Higgs mass dependent signal cross section uncertainty
- Additional $\Delta\sigma = \pm$ 10% on ttbar (no data driven approach used)

Systematic Uncertainties (2/2)

m_A	110 GeV	130 GeV	160 GeV	200 GeV	300 GeV	450 GeV
ttbar exp.	7.4 %	6.8 %	5.3 %	5.3 %	4.7 %	4.6 %
ttbar exp. & theory	12.4 %	12.1 %	11.3 %	11.3 %	11 %	11 %
W+jets	4.7 %	4.9 %	4.8 %	5.4 %	5.1 %	5.1 %
Signal experimental	9 %	4.6 %	9.2 %	9.4 %	4.6 %	5.1 %
Signal theory	18 %	15.5. %	13.5 %	10 %	7.5 %	6 %

⇨ Dominated by uncertainty on jet energy scale and b-tagging efficiency

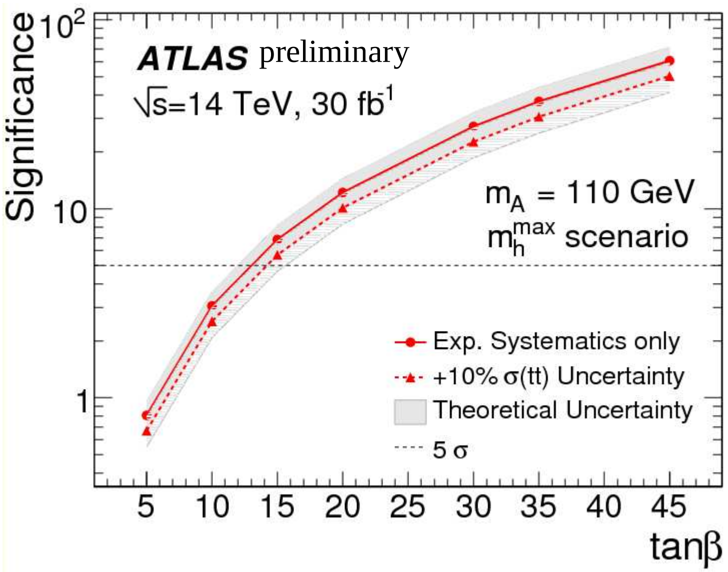
⇨ Differences between mass points due to MC statistics

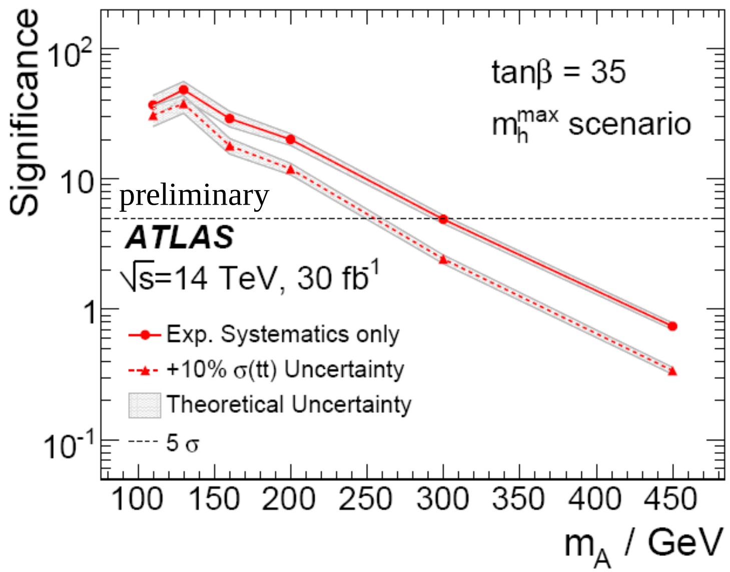
⇨ The experimental signal uncertainty only given for information

Discovery Potential

⇨ Systematics fully included in final significance:

$$Signi = \frac{S}{\sqrt{N_{ttbar} + N_{Z\to\tau\tau} + N_{W+Jets} + N_{Z\to ll} + \left(\Delta_{ttbar} \cdot N_{ttbar}\right)^2 + \left(\Delta_{Z\to\tau\tau} \cdot N_{Z\to\tau\tau}\right)^2 + \left(\Delta_{W+jets} \cdot N_{W+jets}\right)^2}}$$

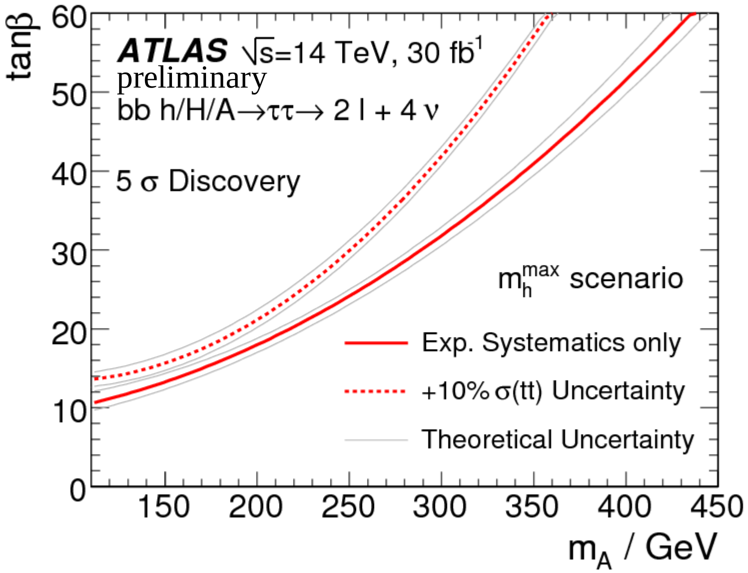


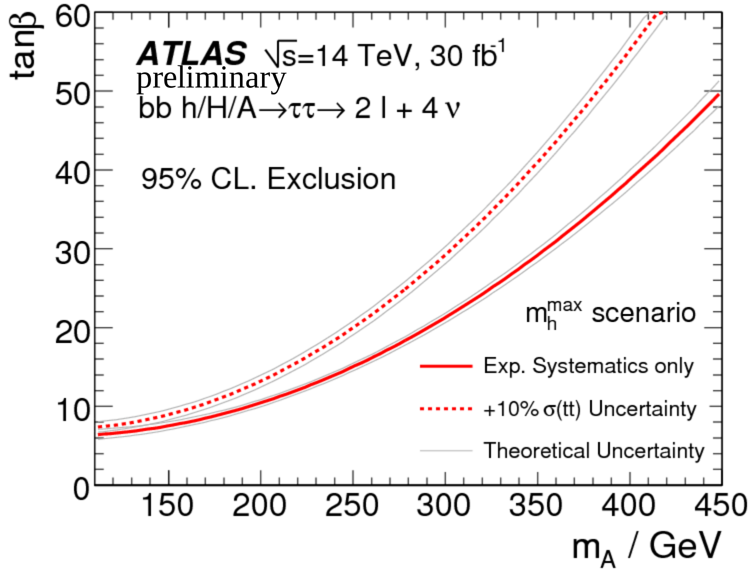


- The dashed line shows the signifncance incl. the extra 10% ttbar cross section uncertainty
- The grey band is given by the signal cross section uncertainty

Limits for 30 fb^{-1}

5 σ Discovery | **95% CL. Exclusion**





- Only m_h^{max} scenario considered
- Most parts of m_A - tanβ plane covered
- Expect improved results if combined with lep-had/had-had channel

Summary

- Overview on the analysis of h/A/H → ττ → leplep in b associated production
- Study completed for 14 TeV and 30 fb^{-1}, to be published
- No cavern background and no pile-up considered

Prospects for first data:

- Study major backgrounds with 0.01 fb^{-1} - 0.1 fb^{-1}
- Study systematic uncertainties esp. regarding b-tag
- Possible (early) discovery contrained by MSSM parameters (esp. value of tanβ)

Very excited for what will come next year...