Search for b-Quark Associated MSSM Higgs Decaying to Tau-Pairs with ATLAS

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BND School - Rathen, 15.09.2009

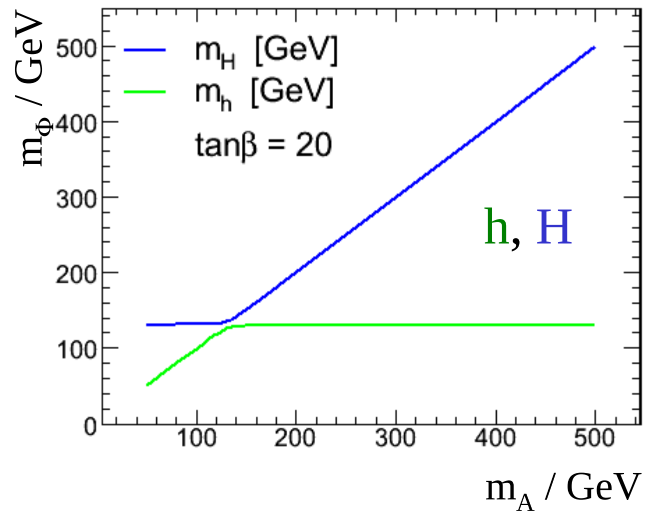
The Signal Process in the MSSM

MSSM: Minimal Supersymmetric Standard Model

Higgs Sector in a Tiny Nutshell

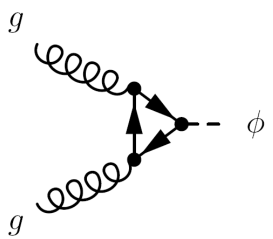
- 2 Higgs doublets ⇨ 5 Higgs bosons:
  h^0 (CP = +1), **H^0** (CP = +1), **A^0** (CP = -1), **$H^\pm$**
- Tree level described by only two parameters:
  m_A, $\tan\beta$ $= v_u/v_d$ $\quad v_u^2+v_d^2 = v^2$ $\quad$ **SM: $\tan\beta=1$**

Mass Degeneracy



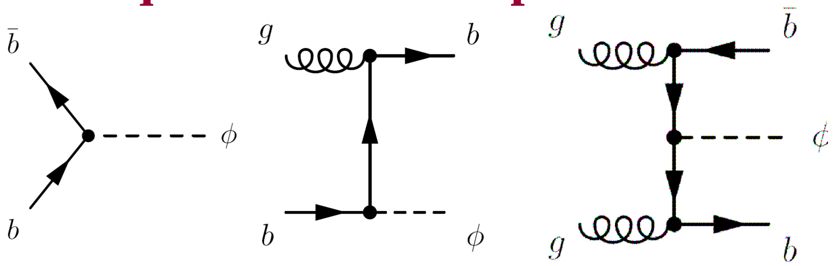
Signal Production $\quad \Phi = h/A/H$

gluon fusion



Dominant at $\tan\beta<10$

b-quark associated production



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

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

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

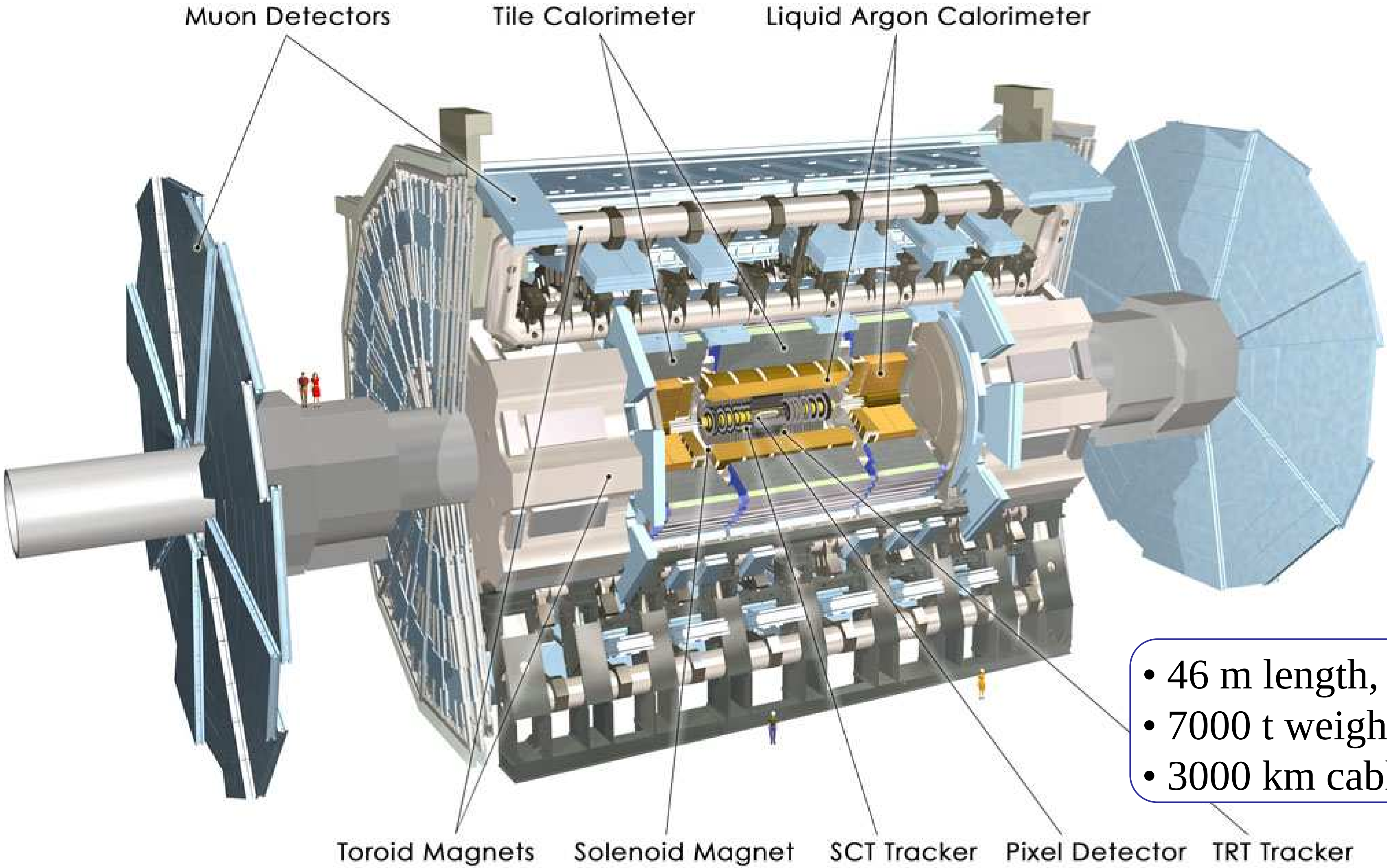
Example cross sections:

(14 TeV, NLO) $\quad$ $\tan\beta=20$

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

m_h^{max} benchmark scenario

The ATLAS Detector



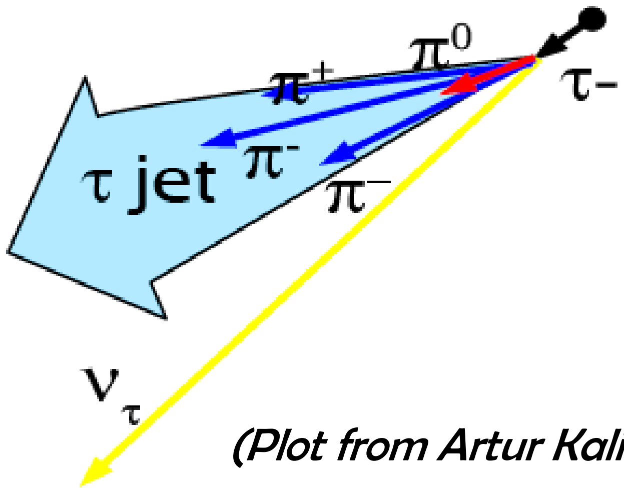
- 46 m length, 24 m diameter
- 7000 t weight
- 3000 km cables

Luminosity:
10^{33} cm^{-2} s^{-1} (10 fb^{-1} per year @ 14 TeV)

Trigger:
10^9 Hz ⇨ 75 kHz ⇨ 100 MB / s storage

Tau Decay Modes and ID

Tau Decay:



(Plot from Artur Kalinowski)

- 35% leptonic ($\tau \rightarrow e\,\nu\nu$ / $\tau \rightarrow \mu\,\nu\nu$)
- 65% hadronic ($\tau \rightarrow \pi\,\nu$ / $\tau \rightarrow \pi\pi\,\nu$ / ...)
- Probability that tau-pair decays fully leptonic only 12 % (leplep)
- In 45% of the cases one leptonic and one hadronic decay (lephad)
- In the remaining 42 % both taus decay hadronically (hadhad)

Hadronic tau in the Atlas detector:

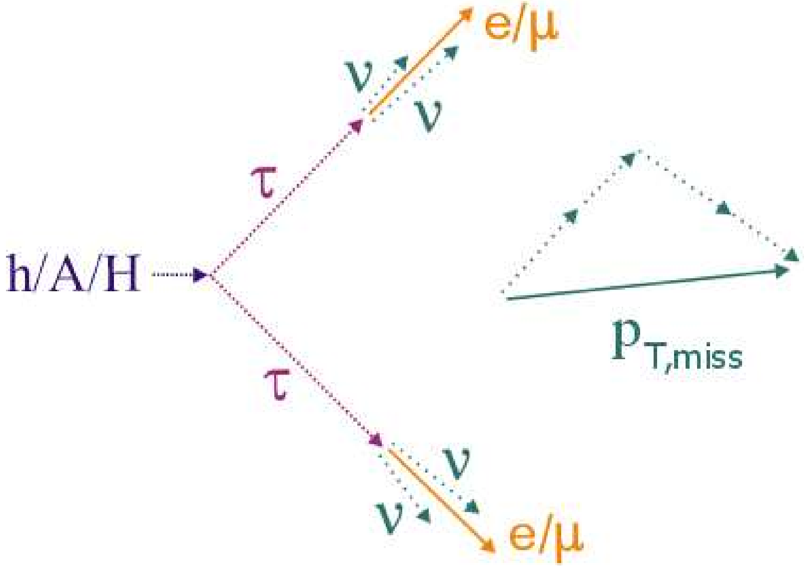
- Collimated calorimeter cluster
- Low charged tracks multiplicty
- Displaced secondary vertex

Sources for fake taus:

- QCD jets
- Electrons
- Muons

Higgs Mass Reconstruction

Collinear Approximation



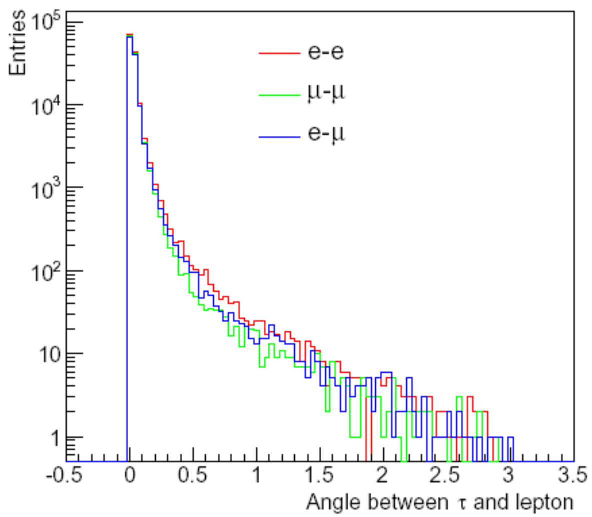
Conditions:

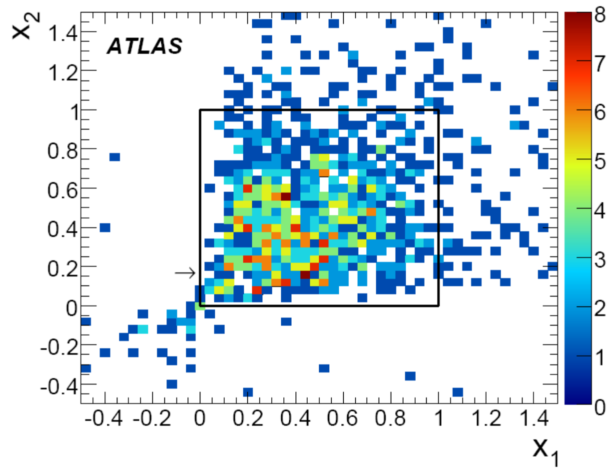
- Higgs mass large compared to τ mass
- Higgs boson has non-zero p_T
- $p_{T,miss}$ in the detector due to neutrinos only

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

$0 < x < 1$

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

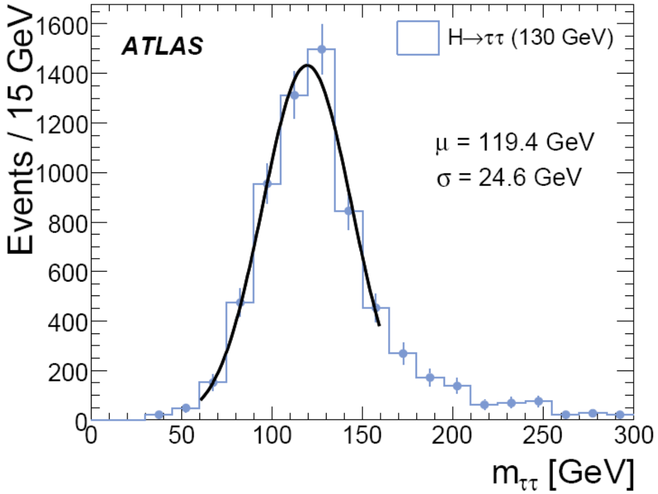




Truncate events to those with physical solution

Higgs Mass Resolution

Mass resolution in leplep:

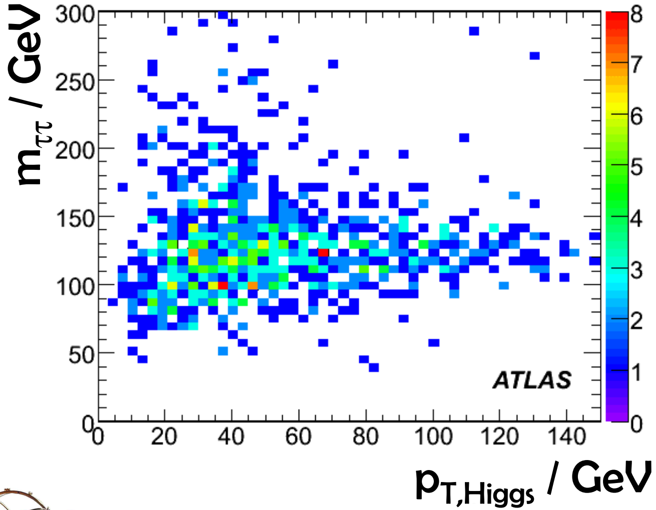


- Very „challenging“ resolution
- No chance to separate the Higgs bosons

Mass resolution:

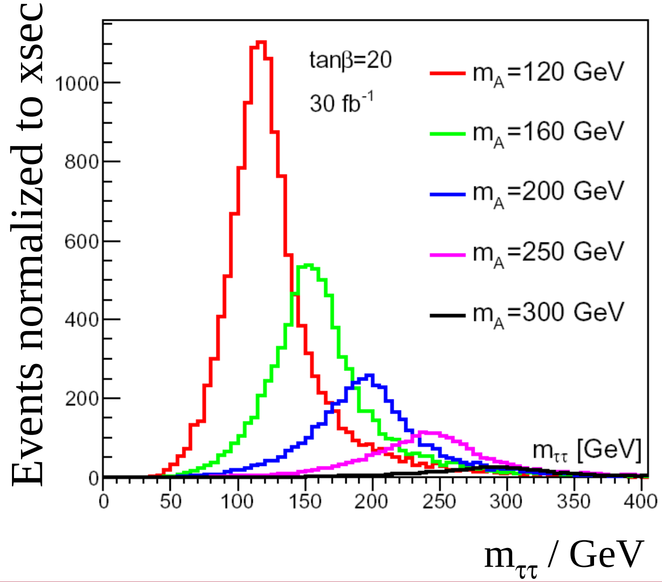
m_A / GeV	σ / GeV
110	21
200	33
300	52

At higher masses deterioration of the resolution and decrease of the cross section:



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

⇨ High-energy tail in m_{tt}



Event Selection of bb h/A/H → ττ → leplep/lephad

We search for Higgs masses from 110 GeV up to 450 GeV (lep-lep) or 800 GeV (lep-had)

⇨ Selection needs to be Higgs mass dependent to exploit the full potential of ATLAS

Signal Topology

- two high p_T leptons (leplep)
- 1 high p_T lepton and 1 high p_T tau jet (lephad)
- (true) $p_{T,miss}$
- b-jet(s)

Relevant Background Processes

- QCD (up to 23 500 nb)
- W+jets (20 045 pb), bbar W (111 pb)
- Z(→ττ/ee/μμ)+jets (2 036 pb), bbar Z (52.3 pb)
- ttbar (833 pb)

Trigger: Single or di-lepton triggers (eg. mu20, 2e15, ...)

Select events with a physical solution to the collinear approximation

Suppress most of backrounds by b-tag (Of course there is a mistagging rate!)

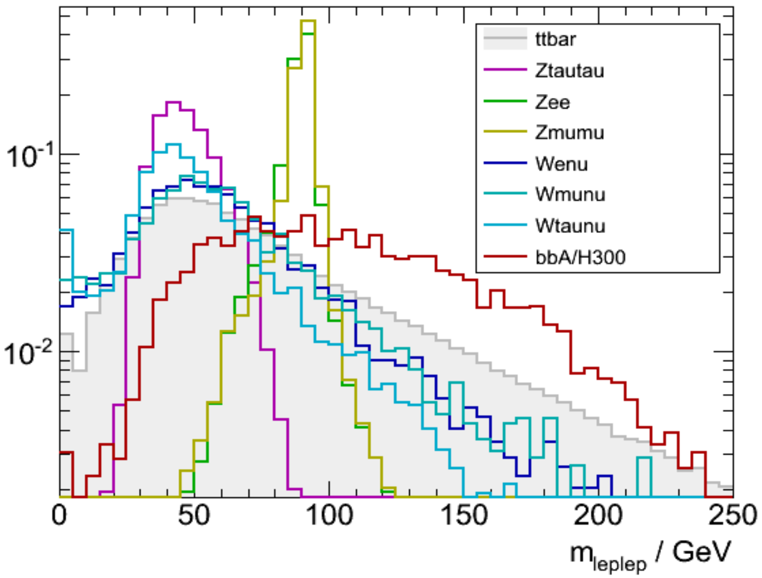
Discriminate against QCD by requiring pTmiss and high pT objects

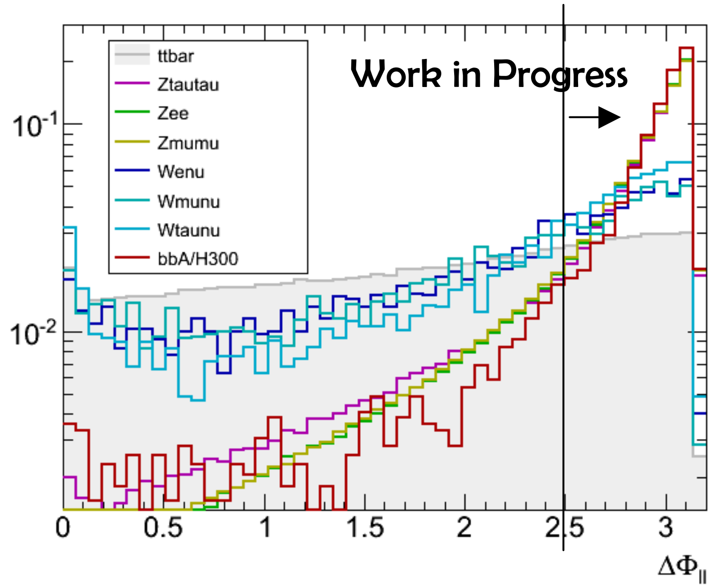
Suppress W+Jets by tight lepton/tau ID in lephad final state.

Reduce ttbar by cutting on events with low jet multiplicity

Event Selection - Example Distributions (m_A=300 GeV)

LepLep

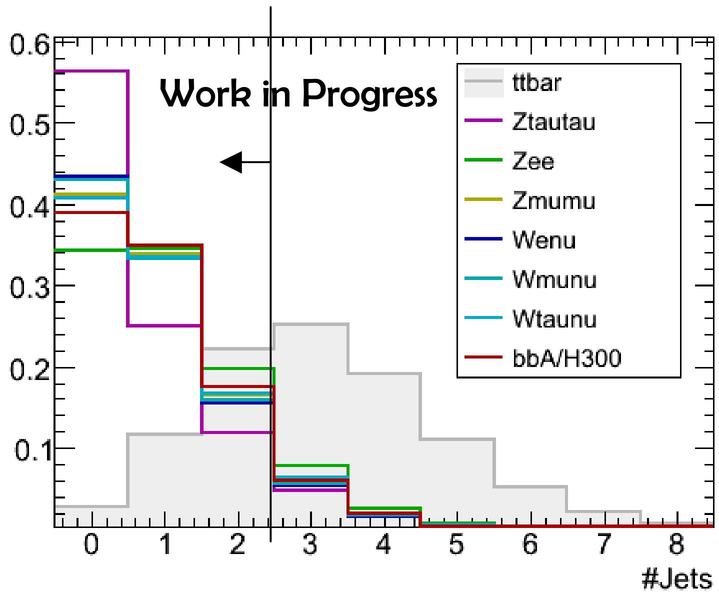


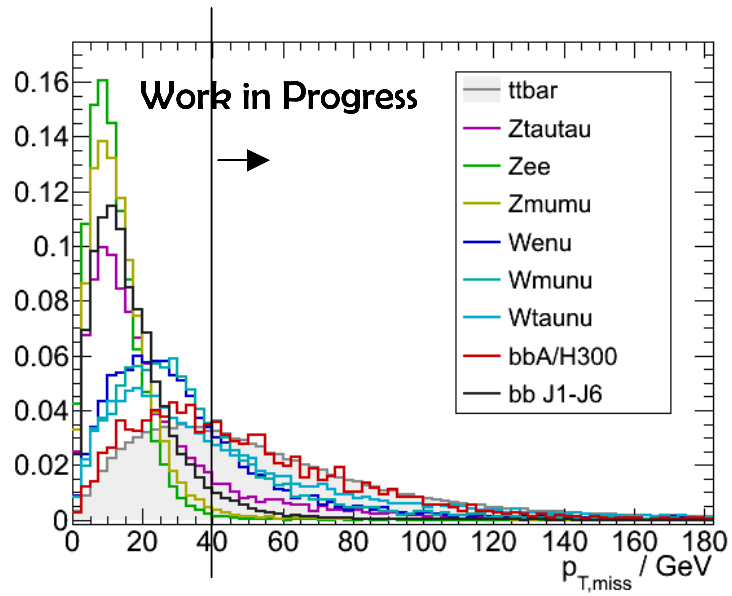


Tau decay products from signal which was produced in association with b-quarks tend to be emitted back-to-back ($\Delta\Phi \approx \pi$) (leplep and lephad)

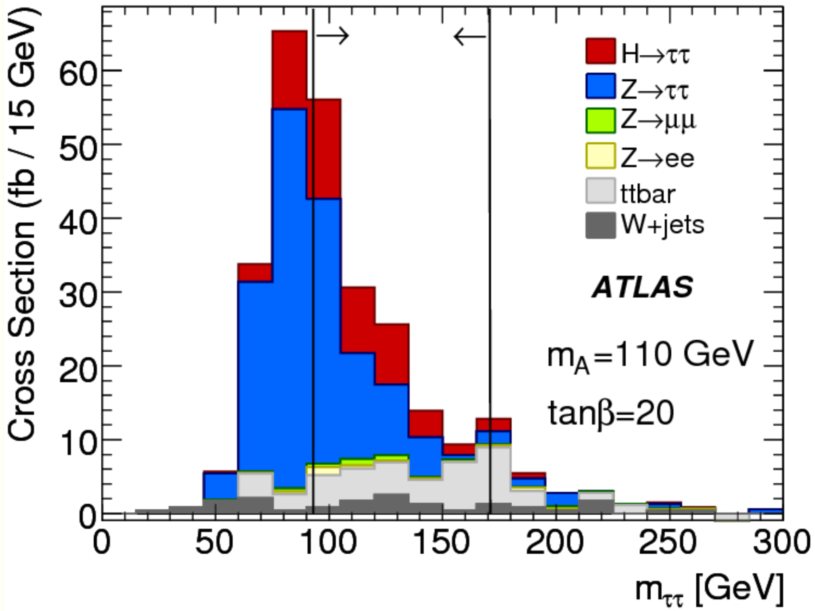
LepHad

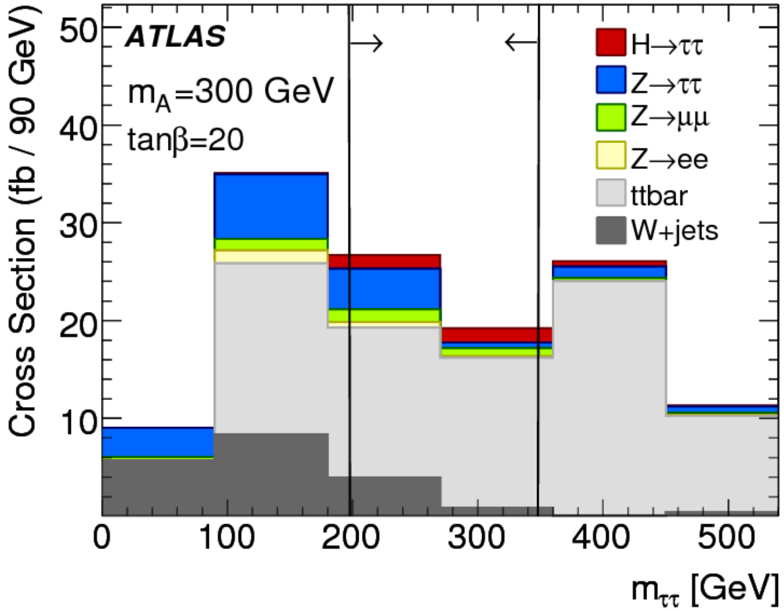
We cut at njets < 3 to suppress ttbar (leplep and lephad)





Selection Results - Invariant $m_{\tau\tau}$ Distributions





← **LepLep**

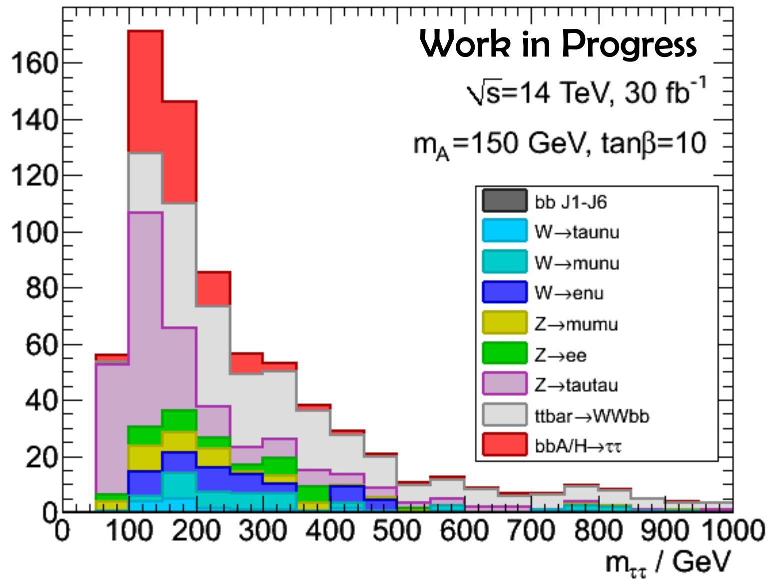
Low m_A:
$Z \to \tau\tau$
dominates

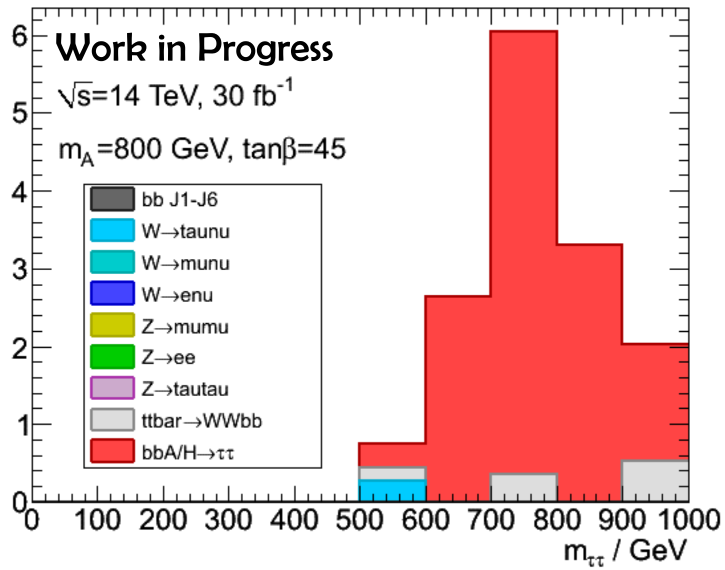
Higher m_A:
ttbar dominates

LepHad →

W+jets non-neglible with respect to $Z \to \tau\tau$

High m_A signal very good disrcimination against backgrounds





Systematic Uncertainties for 10 fb^{-1}

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

(Tau Efficiency, Tau p_T scale, Tau Resolution:) Only LepHad

Impact on Analysis in LepLep:

ttbar	5%-7%
W+Jets	5%
bbh/A/H	5%-9%
Z+jets	3%

Experimental only

(14 TeV, 30 fb^{-1})

Large uncertainties on signal cross section (5 % - 15 %)

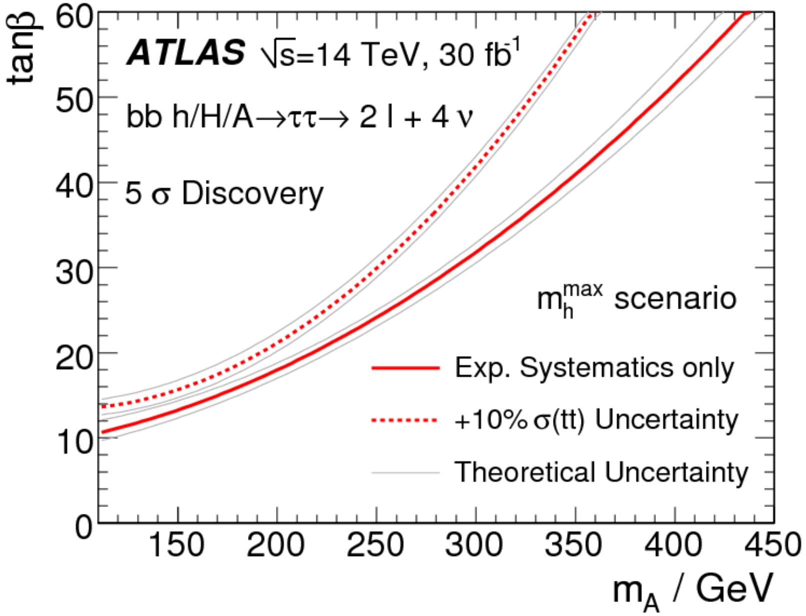
Large uncertainties on Z, ttbar and W cross sections ($\approx$ 10 %)

⇨ This demands for data-driven background estimation procedures

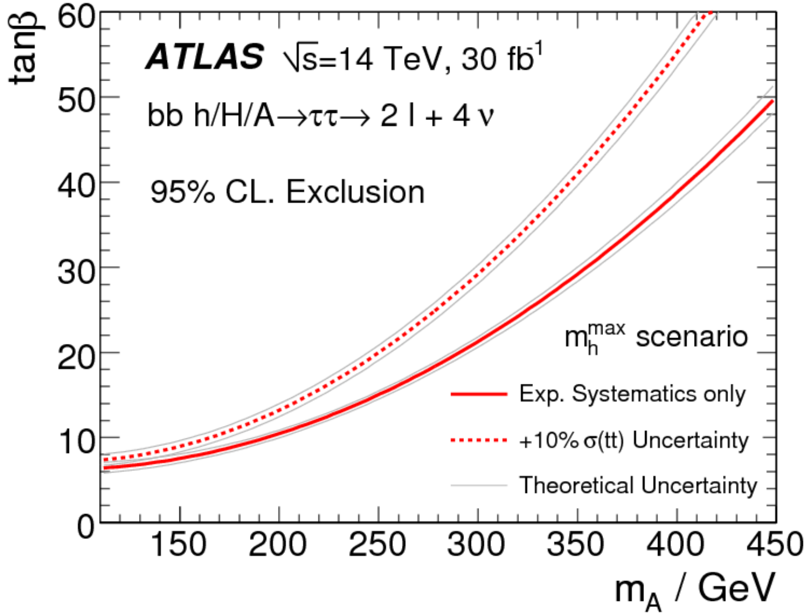
Expected Discovery Potential with 30 fb^{-1} @ 14 TeV

Up-to-date LepLep Results on fully simulated MC with newest cross sections. m_h^{max} scenario.

5 σ Discovery



95% CL. Exclusion



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

- Large parts of m_A - tanβ plane covered with leplep channel alone!
- Expect improved results when combined with lep-had (had-had) channel

Conclusions

- MSSM Higgs → $\tau\tau$ offers huge discovery potential over full allowed mass range
- I presented results for the exclusive analysis (at least one b-tag) only.
  In an inclusive approach gluon fusion signal is important and selection differs.
- LepLep offers very clean signature, but small branching fraction
- In LepHad huge contributions from W+jets and QCD, suppressable by tight cuts
- For the remaining backgrounds (Z, ttbar) we develop data-driven approaches

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Backup

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** $= v_u/v_d$ $\quad v_u^2+v_d^2 = v^2$
- $m_h < m_Z$ 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

Systematic Uncertainties - LepLep

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