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

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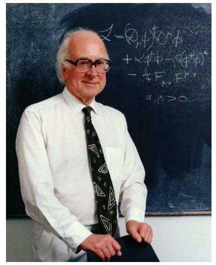
Berlin 30.09.2009

Outline

1. Introduction to the MSSM Higgs
2. Higgs Boson Reconstruction
3. Analysis with 30 fb^{-1}
4. Background Estimation from Data
5. Prospects for First Data

Introduction

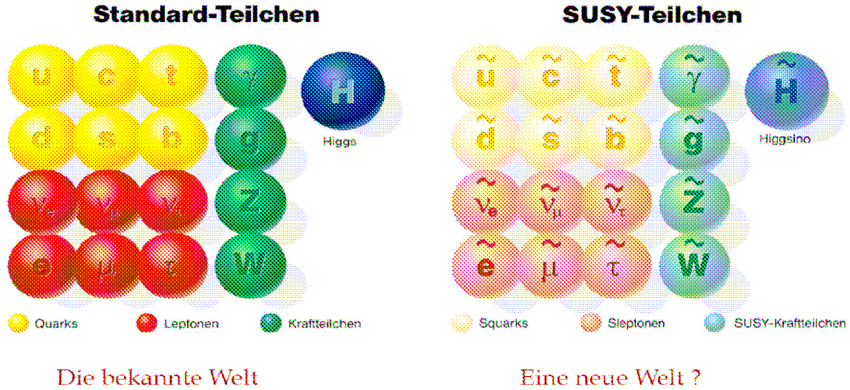
- SM very successful theory, description of three of the four fundamental forces
- One component missing: Higgs boson as quantum excitation of the Higgs field
- Higgs field: Property of space, scalar and isotrop
- Fermions get mass by interacting with the Higgs field (SM predicts massless fermions)
- Still hypethical, proof missing. Discovery would be great success
- Direct search (LEP) led to exclusion limit of $m_H > 114$ GeV. Theory predicts $m_H < 1$ TeV



P. Higgs

SM has some problems:

- Dark Matter
- Fine Tuning
- Unification of couplings



SUSY solves those problems! However, more paramteres are introduced (105).

No SUSY particles have ever been found

⇨ SUSY must be broken symmetry with $m_{Sparticles} >> m_{Particles}$.

Minimal SUSY Model: MSSM.

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, $\tan\beta$** $= v_u/v_d$ $\quad v_u^2+v_d^2 = v^2$

SM: tanβ=1

- $m_h < m_Z$ 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	$\cos\alpha/\sin\beta$	$-\sin\alpha/\cos\beta$	$\sin(\alpha-\beta)$
H	$\sin\alpha/\sin\beta$	$\cos\alpha/\cos\beta$	$\cos(\alpha-\beta)$
A	$\cot\beta$	$\tan\beta$	-

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:

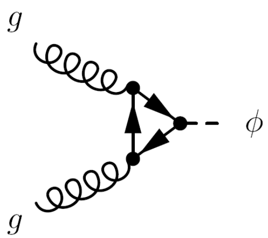
m_h^{max}: $m_h < 133$ GeV, maximum allowed mass for h → m_h^{max} considered here
nomixing: $m_h < 116$ GeV, no mixing in stop sector
gluphobic: $m_h < 119$ GeV, suppressed gg fusion
small α: $m_h < 123$ GeV, suppressed ttbar h, h → bb

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

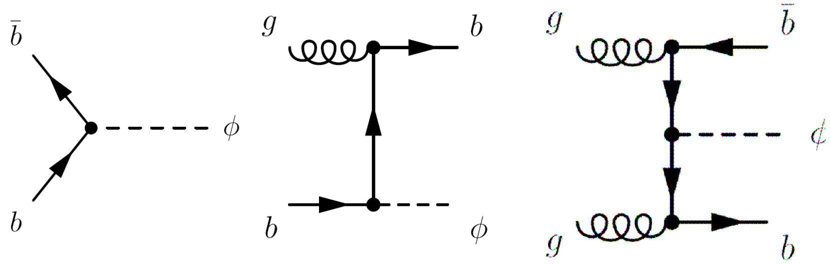
MSSM Higgs

Signal Production

gluon fusion



b-quark associated production



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

Enhanced coupling to down-type fermions

⇨ $\sigma_{bbH/A} \sim \tan^2\beta$

Cross sections (14 TeV): NLO tanb=20

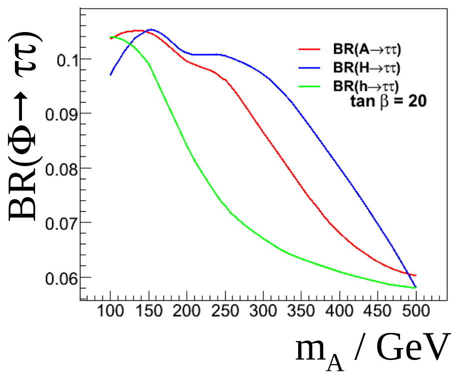
m_A / GeV	σ_{bbH}	σ_{bbA}
150	95 pb	103 pb
200	39 pb	40 pb
300	9 pb	9 pb

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

Signal Properties

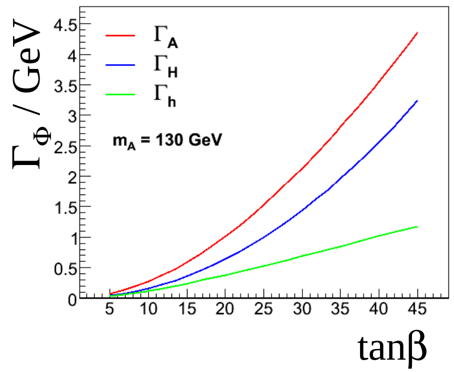
S. Heinemeyer, Feynhiggs

BR h/A/H → ττ



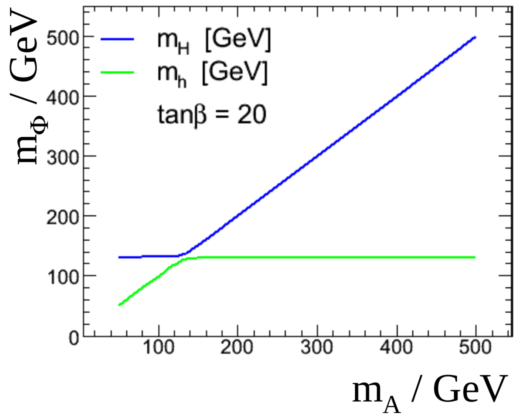
≈ 10 % for low m_A

Natural width



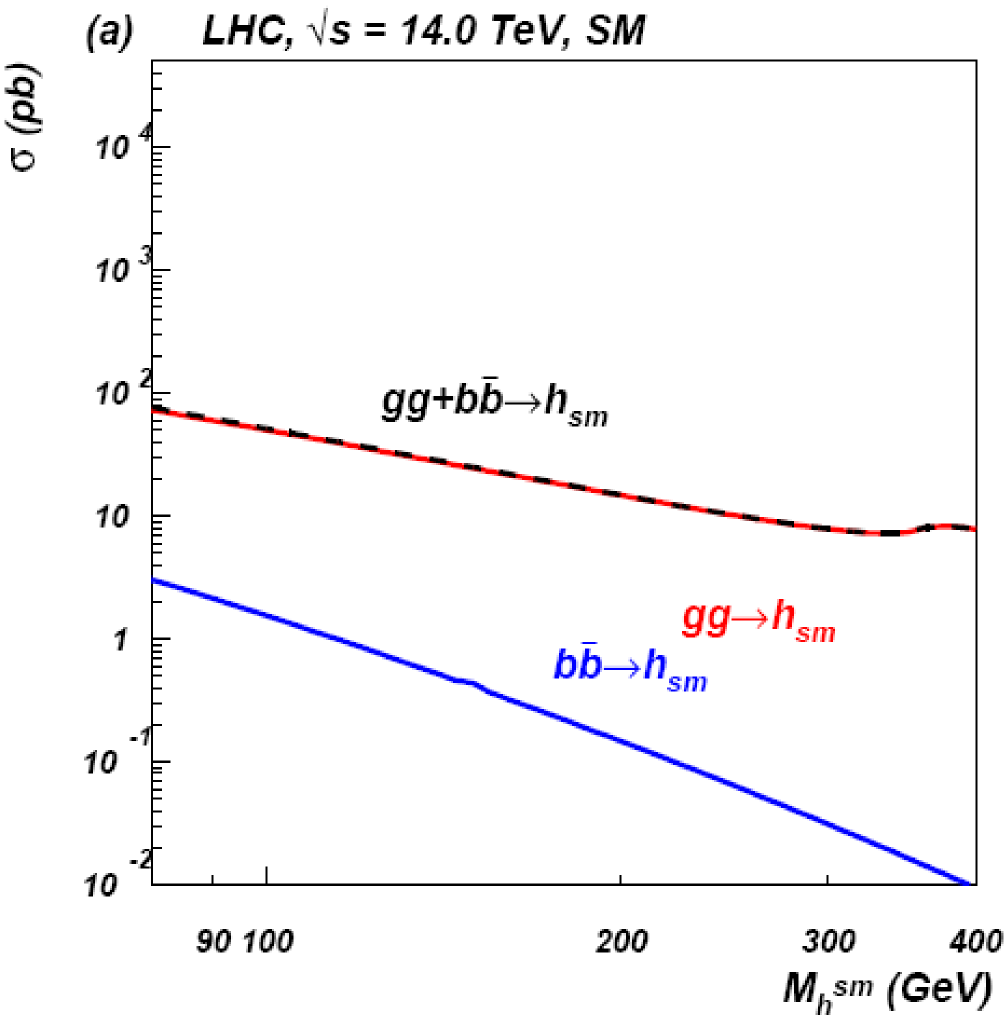
Irrelevant for h/A/H → ττ due to mass resolution

Mass degeneration



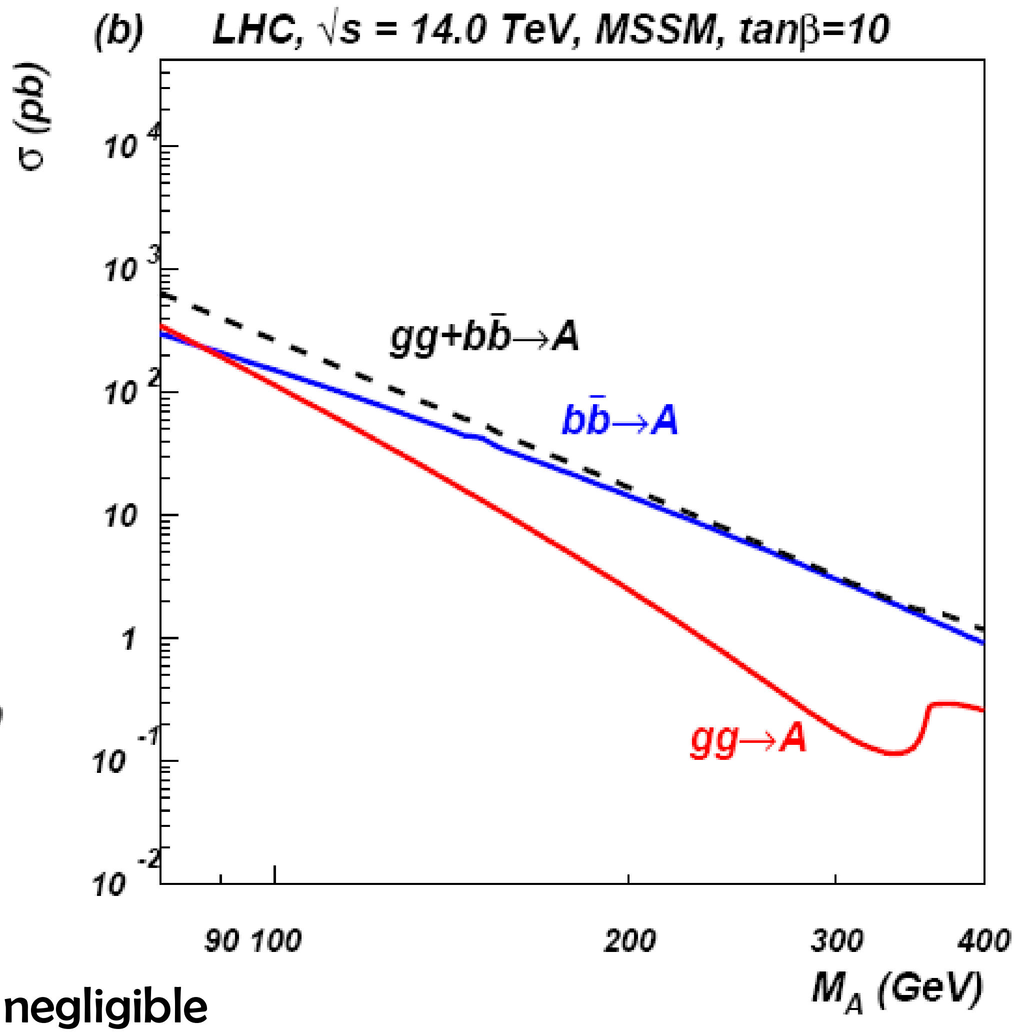
⇨ Add up cross sections

SM and MSSM Higgs Production



Talk by R. Harlander, Zürich '09

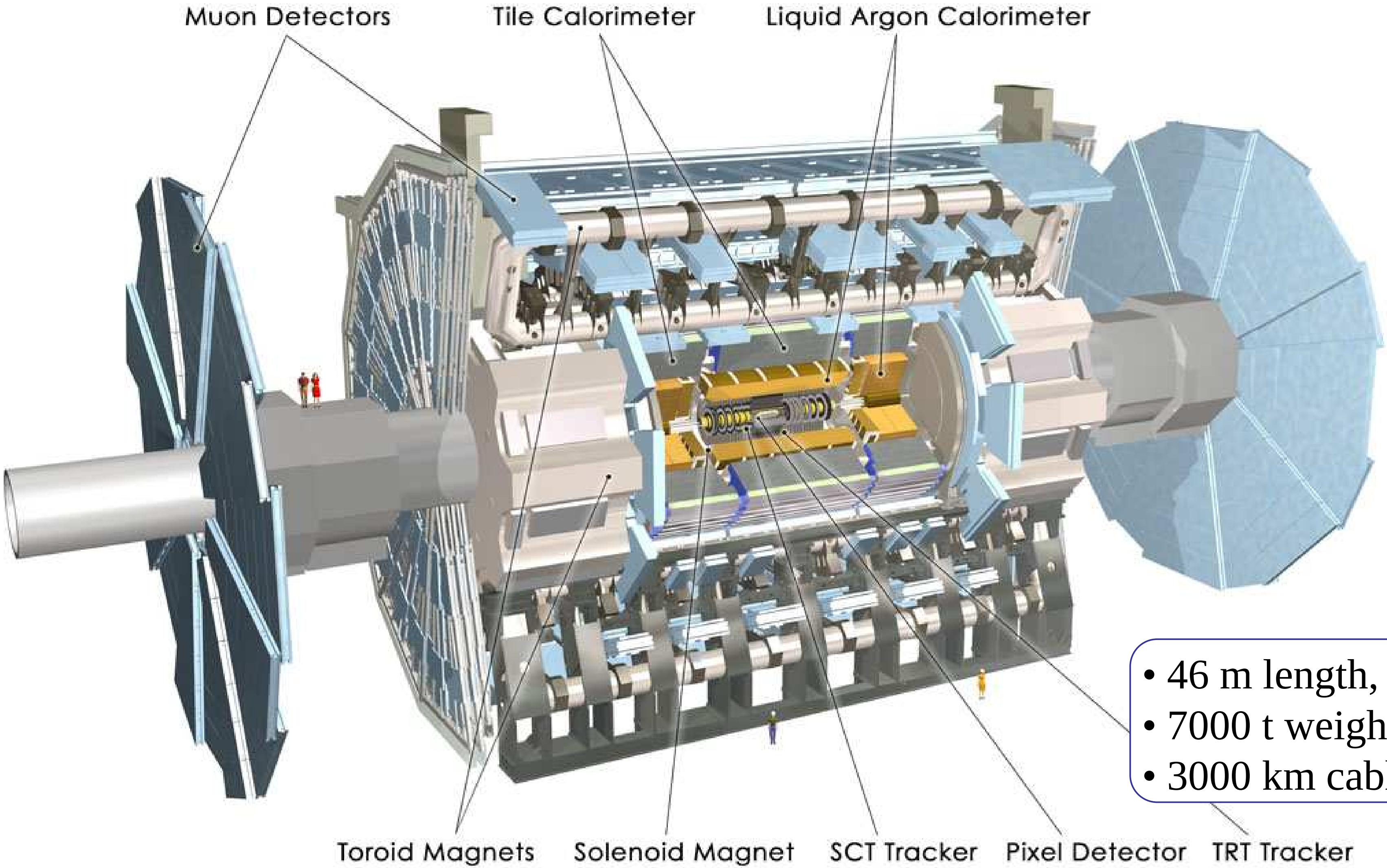
Belyaev et al. '05



b-quark associated Higgs production dominant production process in the MSSM

By applying a b-tag, gluon fusion signal negligible

The ATLAS Detector at LHC



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

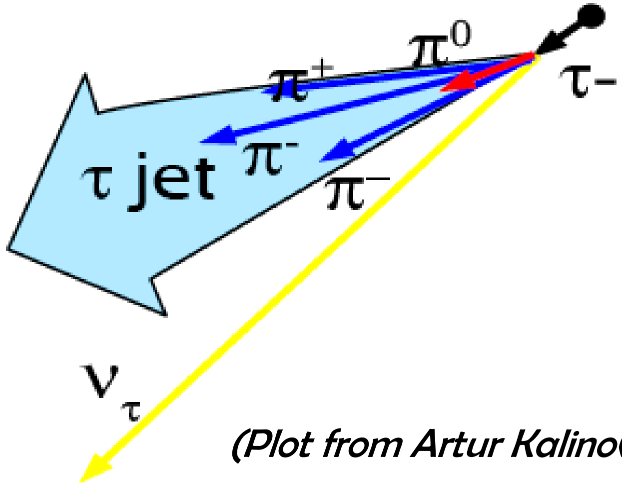
Luminosity:
10^{33} cm^{-2} s^{-1} (10 fb^{-1} per year @ 14 TeV)

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

Taus - Overview

Tau Decay Modes:

- 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)



(Plot from Artur Kalinowski)

Hadronic tau in the Atlas detector:

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

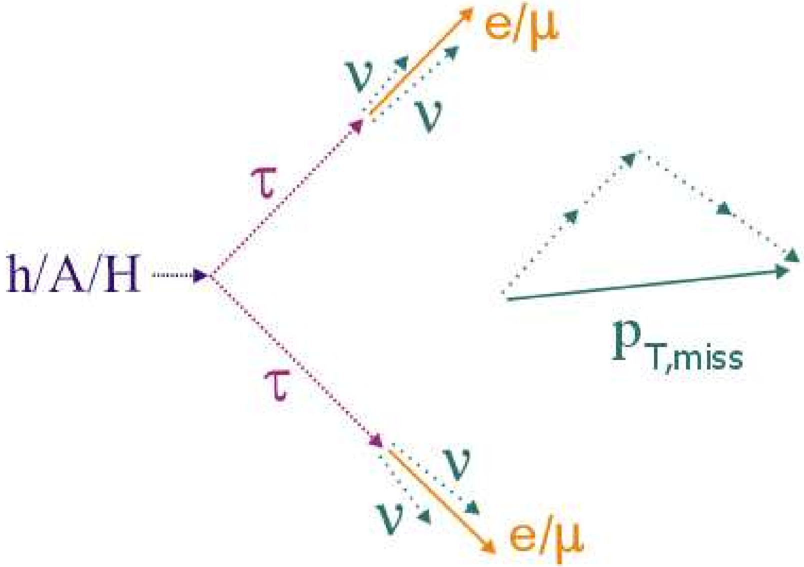
⇨ Combined reconstruction in calorimeter and tracker

Sources for fake taus:

- QCD jets
- Electrons
- Muons

Higgs Mass Reconstruction

Collinear Approximation



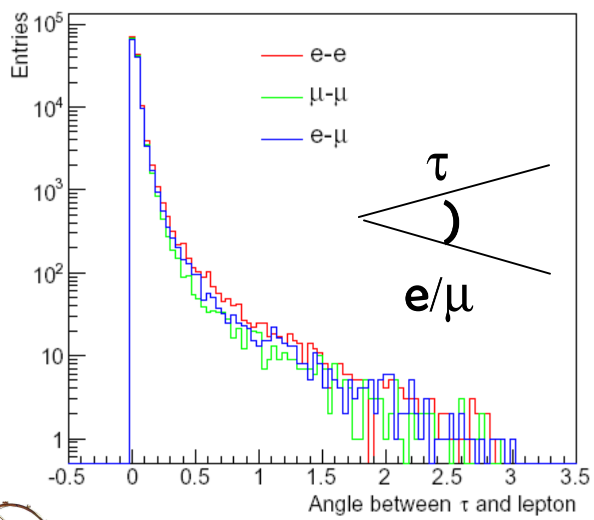
Conditions:

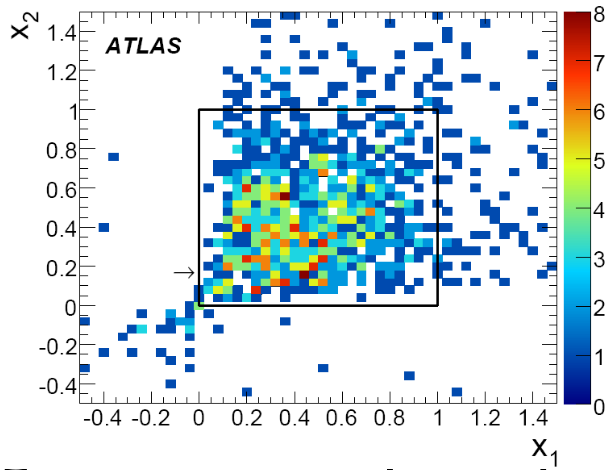
- Higgs mass large compared to t mass
- Higgs boson has non-zero p_T
- $p_{T,miss}$ in the detector due to neutrinos only

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

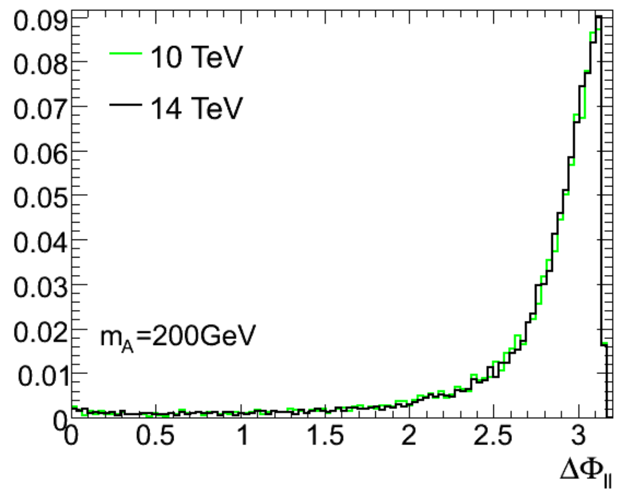
$0 < x < 1$

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





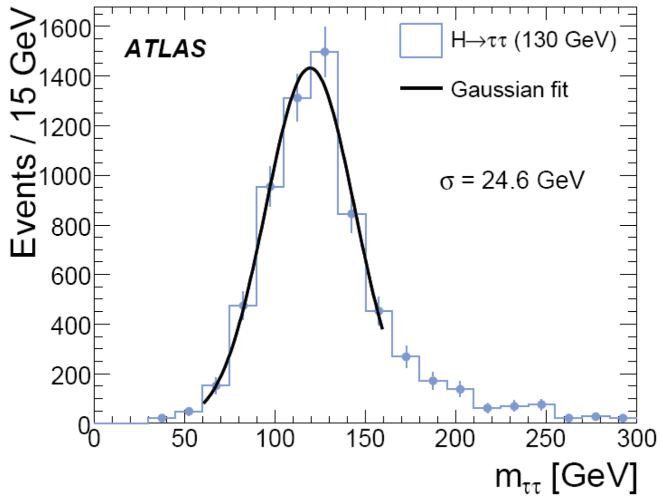
Truncate events to those with physical solution.



Approximation unstable at $\Delta\Phi \approx \pi$.

Higgs Mass Resolution

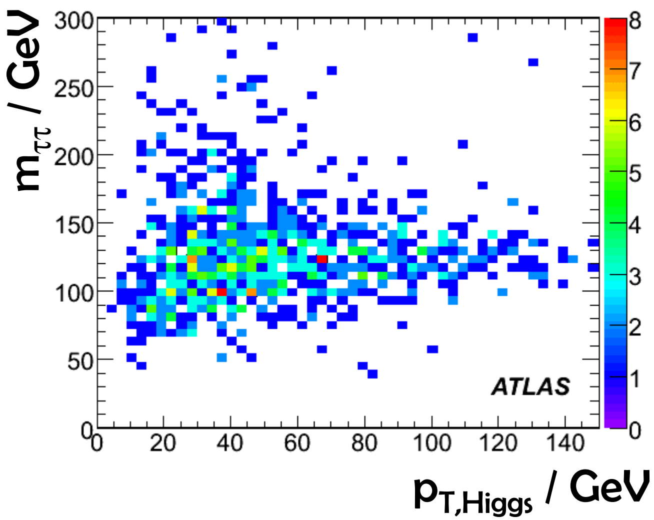
$m_{\tau\tau}$ shape in A/H → ττ → leplep



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

Mass resolution:

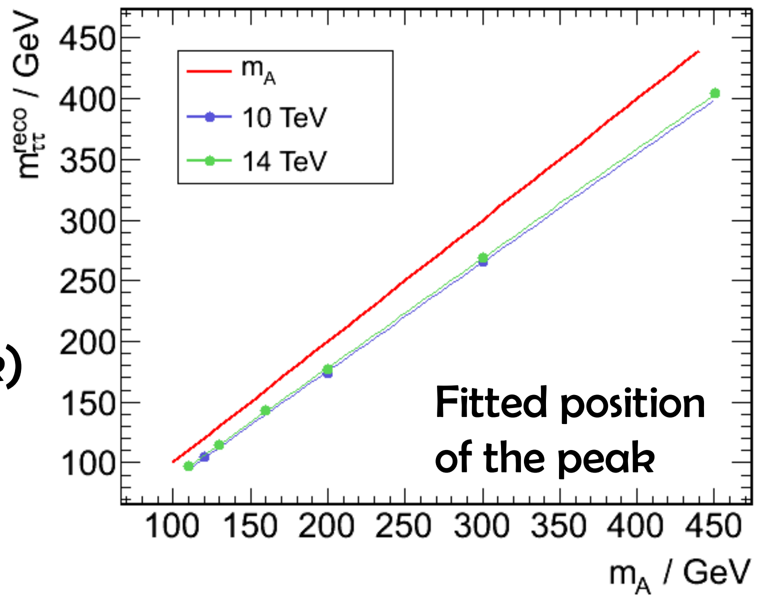
m_A / GeV	σ / GeV
110	21
200	33
300	52
800	~ 100



⇨ Mass resolution deteriorates for low $p_{T,Higgs}$ (leptons back-to-back)

⇨ High-energy tail in $m_{\tau\tau}$

Another issue: Mass shift w.r.t. true mass



Ongoing studies in the Helmholtz $m_{\tau\tau}$ working group

Signal Topology and Background Processes

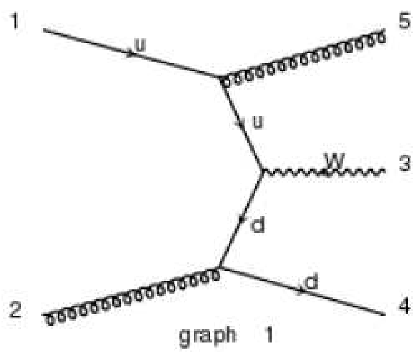
Signal Topology

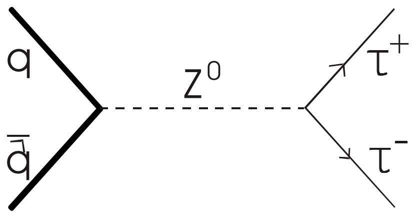
- two high p_T leptons (leplep) or 1 high p_T lepton and 1 high p_T tau jet (lephad)
- (true) $p_{T,miss}$
- (true) b-jet(s)

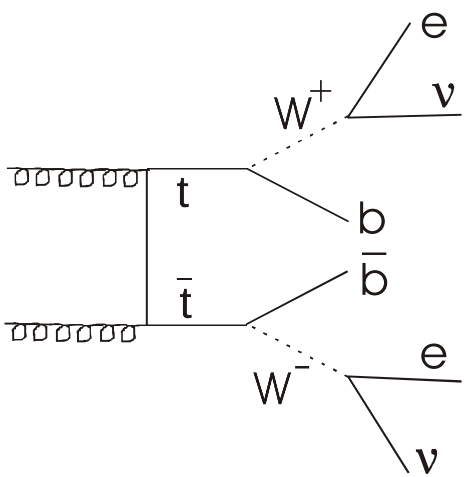
Relevant Background Processes (xsecs for 14 TeV)

- QCD (up to 23 500 nb)
- W+jets (20 045 pb), bbar W (111 pb)
- Z($\rightarrow\tau\tau/ee/\mu\mu$)+jets (2 036 pb), bbar Z (52.3 pb)
- ttbar (833 pb)

(QCD, W+jets and Z+jets, grouped by a brace:) Reduce them strongly with b-tag



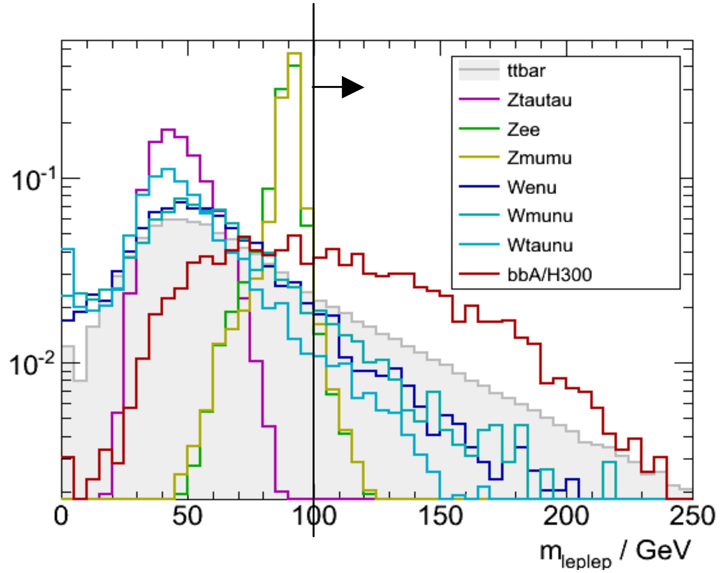


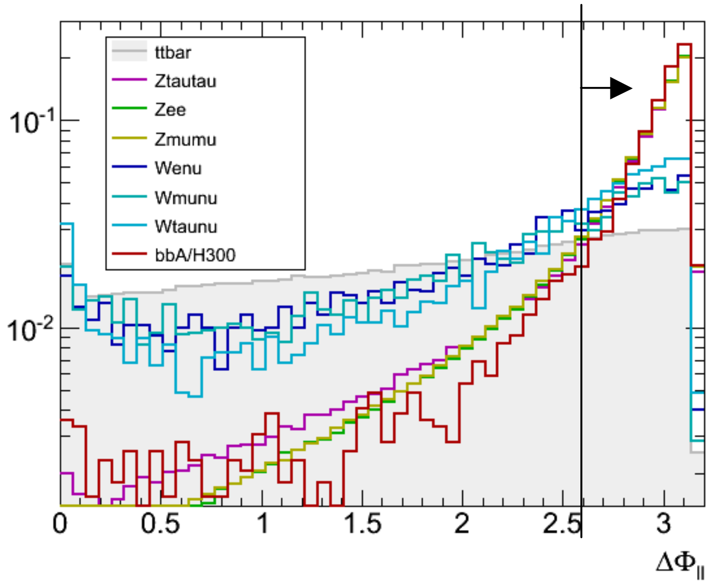


Event Selection- LepLep

We search for Higgs masses from 110 GeV up to 450 GeV.

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





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!)

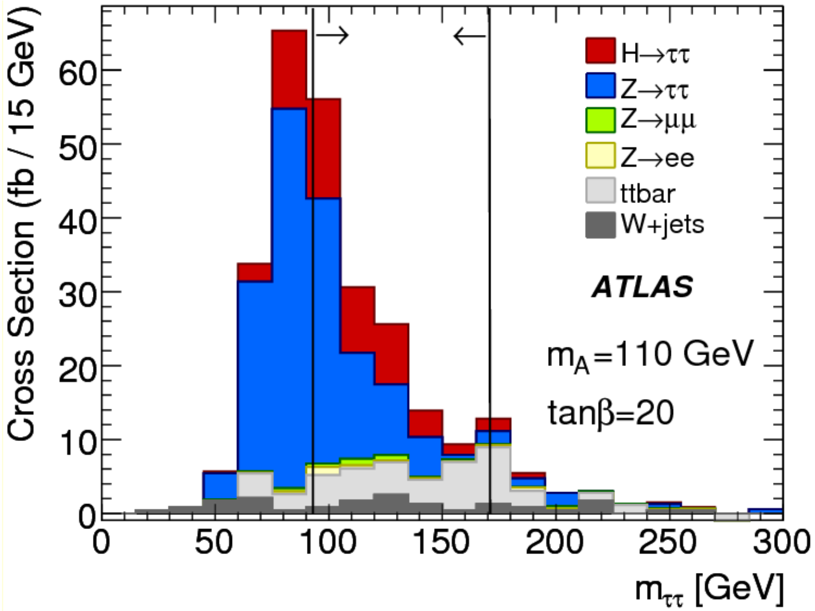
Discriminate against W and Z by requiring pTmiss and high pT objects

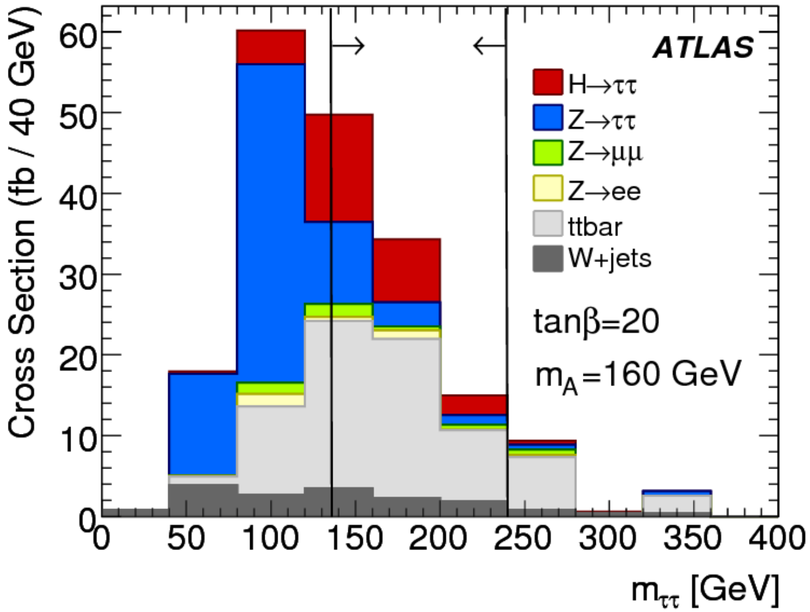
Select event with back-to-back tolopogy. Cut on m_{ll}.

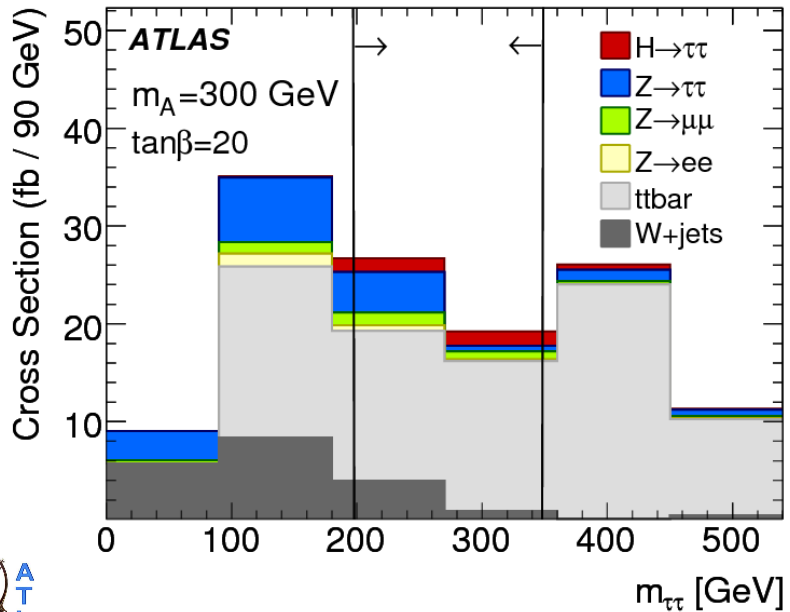
Reduce ttbar by cutting on events with low jet multiplicity.

$S/\sqrt{B}$ analysis to cut at best value.

Results @ 14 TeV - LepLep







At low m_A: $Z \to \tau\tau \to$ leplep dominates

Higher m_A: ttbar dominates

W+Jets and QCD under control

MC statistic smaller than expected real data statistic with $30fb^{-1}$.

Systematic Uncertainties - LepLep

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

Assumed uncertainties for 10 fb^{-1}
(1 year running with $10^{33}\ cm^{-2}s^{-1}$, 14 TeV)

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 %)

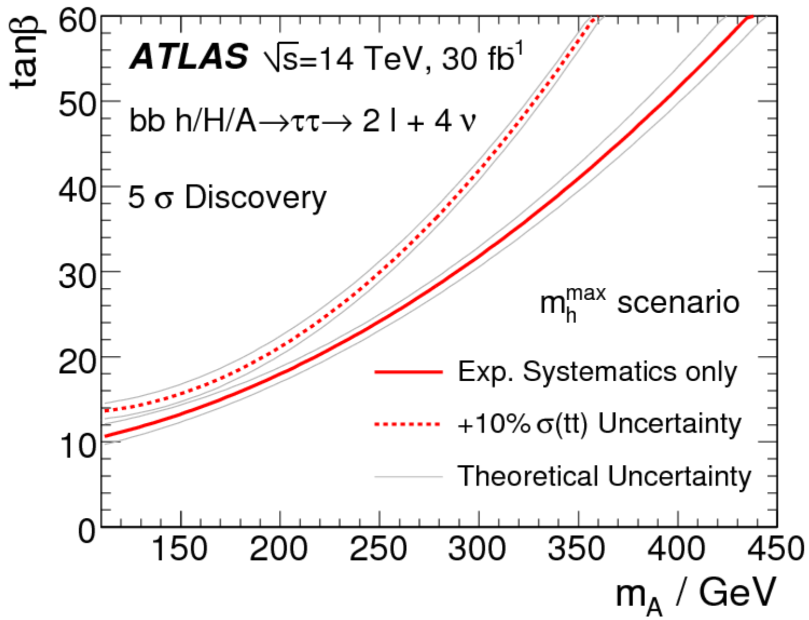
Large uncertainties on Z, ttbar and W cross sections ($\approx$ 10 %)

⇨ This demands for data-driven background estimation procedures

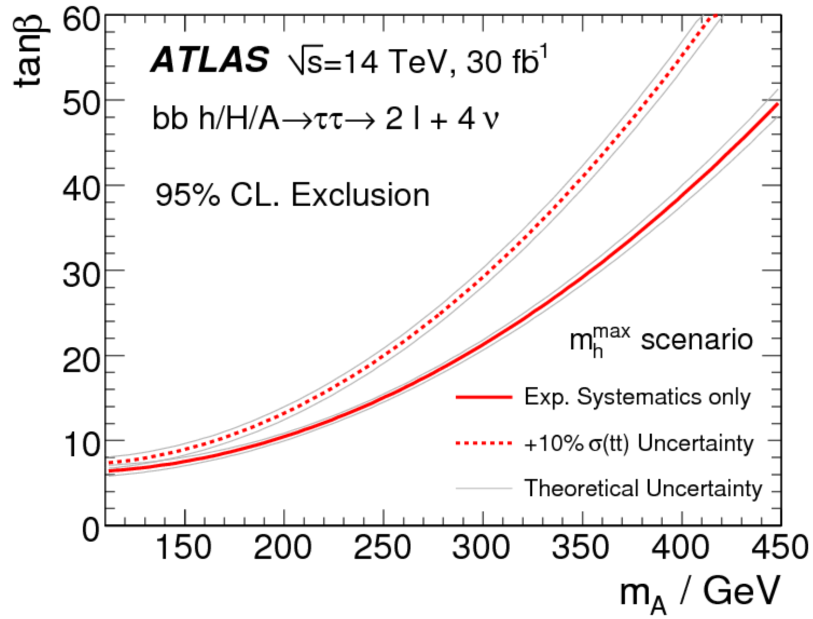
Discovery Limits - LepLep Channel

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

5σ Discovery



95% CL. Exclusion

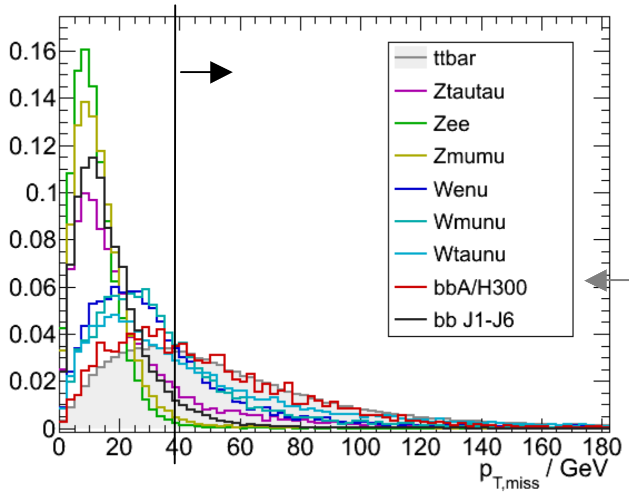


ATLAS Collaboration, Expected Performance of the ATLAS Experiment, Detector, Trigger and Physics, CERN-OPEN-2008-020, Geneva, 2008

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

Work in Progress - Analysis in LepHad Channel

- Due to larger branching fraction expand search up to 800 GeV
- Expect large contributions from W+jets and QCD due to tau and lepton fakes



Tight tau and lepton ID
(use full detector info and requre isolation to other objects)

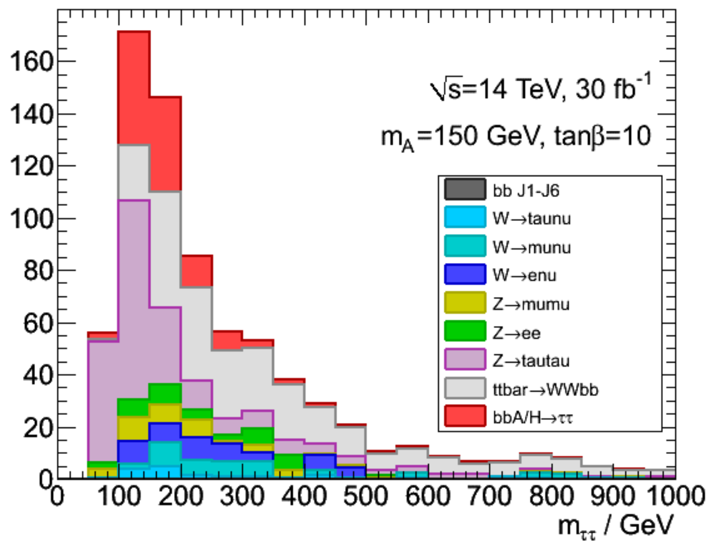
at least one b-tag (vs. Z and W), less then 3 jets (vs. ttbar)

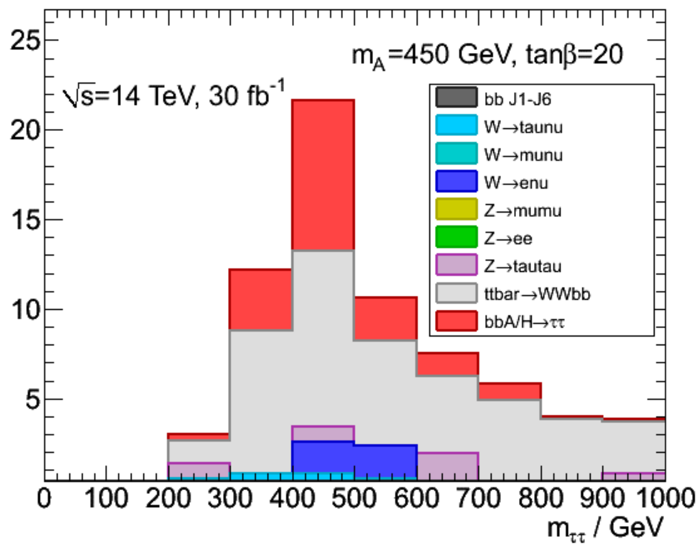
Small m_T (vs. W+jets and ttbar)

Large $p_{T,miss}$ (vs. QCD)

p_T of the tau (vs. QCD, W and ttbar)

$\Delta\Phi$ between lepton and tau (vs. W and ttbar)





ttbar dominant background for high m_A

Note in preparation

$Z \to \tau\tau \to$ leplep Estimation from Data

- There are many methods to estimate the shape of $Z \to \tau\tau$ from data:
  - Muon momentum rescaling using 3D reference histograms in $Z \to \tau\tau \to \mu\mu$ (Bonn/Dresden)
  - Electron cluster reweighting in $Z \to \tau\tau \to ee$ (Dresden)
  - Embedding of (all kind of) τ decays into $Z \to \mu\mu$ events (Bonn/Freiburg)

⇨ Obtained $m_{\tau\tau}$ shapes could be used by input to a mass fit

- For a counting experiment we need to know the total number of $Z \to \tau\tau$ events in a possible signal region:

  Weight MC $Z \to \tau\tau$ event number with ratio of $Z \to \mu\mu$/ee event number ratio (MC to data) to become independent of MC lepton acceptance predictions.

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

- All these methods use $Z \to ee$ and/or $Z \to \mu\mu$ data events from a sideband region (sideband $\equiv$ signal free)

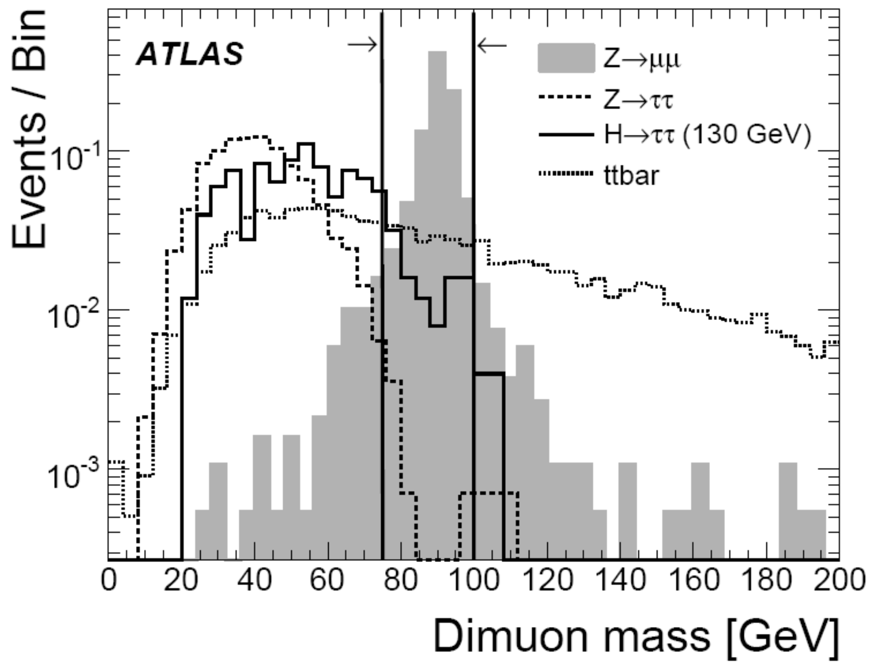
Z → ee / Z → μμ Selection as a Control Sample

Cuts: Trigger (mu20 or 2e15, e25)

m_{leplep} (75 ... 100) GeV

Jets < 3 (vs. ttbar)

>=1 b-tag (vs. W+jets, ggH, ..)



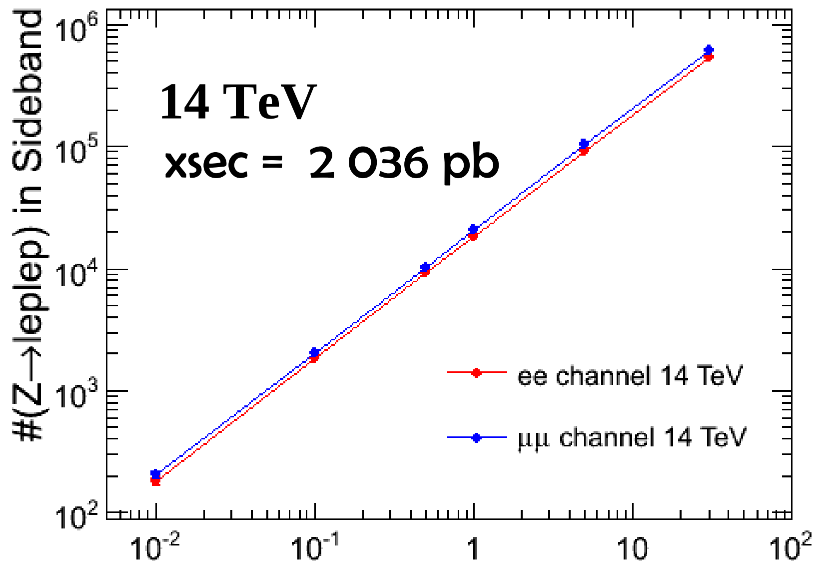
Example, ee channel:

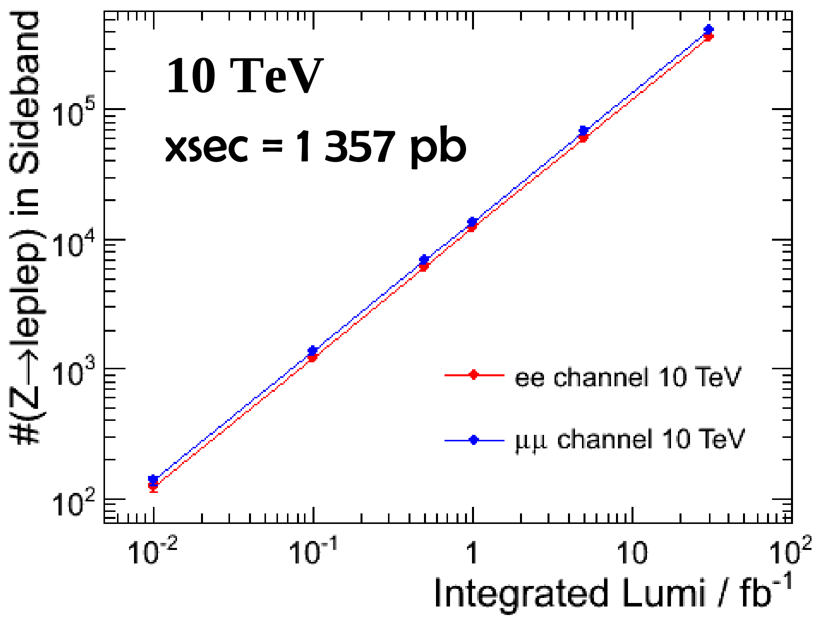
m_A=130 GeV, tanb=45, 1 fb-1

18 K Z→ ee events, 490 ttbar events

⇨ Sideband purity 97 %

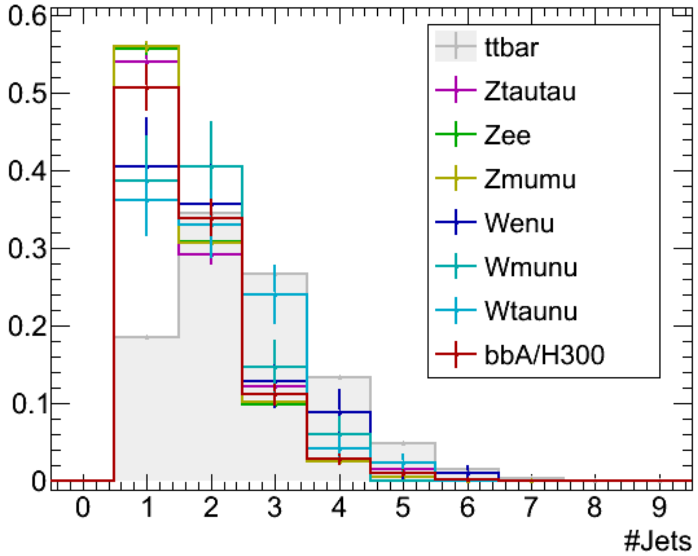
Event Yield in Z → ee/μμ Sidebands



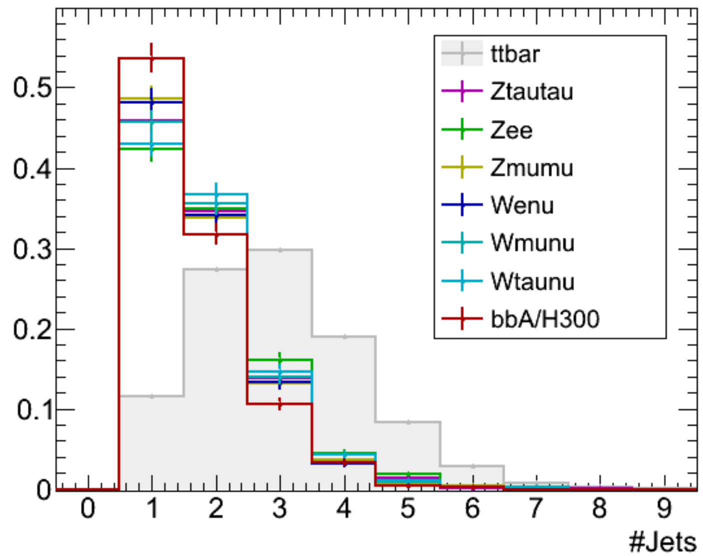


ttbar Estimation from Data

- We cut on the number of jets to reduce ttbar background ⇨ #jets < 3, with jet p_T > 20 GeV
- Statistical significance is better if 2-jet bin kept in analysis
- The other backgrounds are agressively reduced by kinematical cuts (p_T, m, $\Delta\Phi$, ..)



leplep



lephad

Two Methods are being studied:

We use ttbar Control region to get information on the njet distribution from data

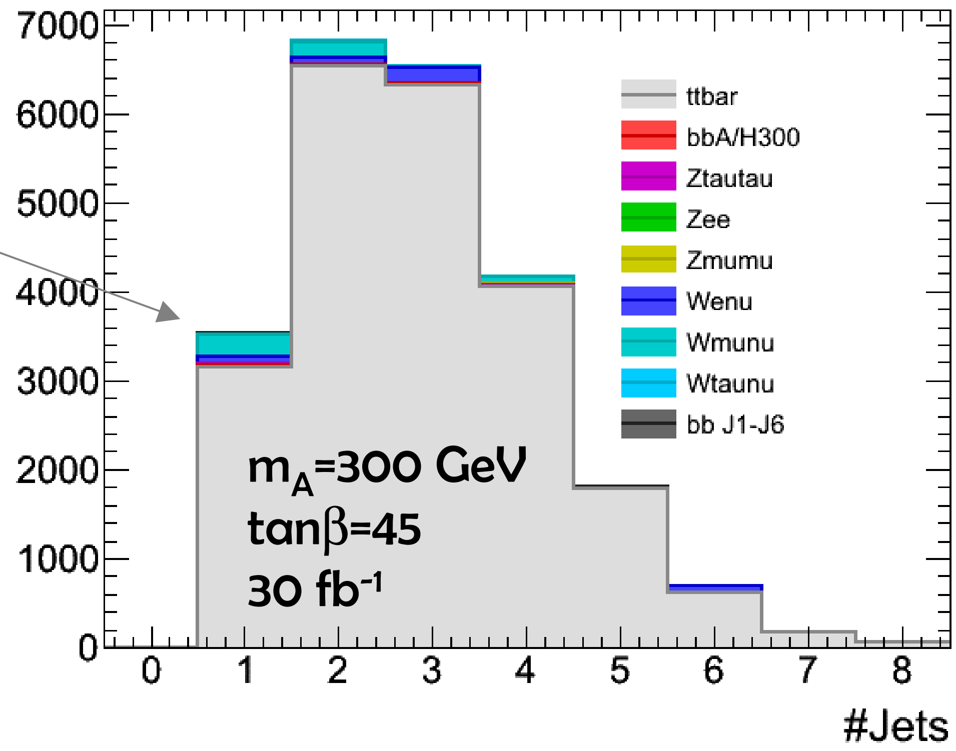
1. Measure ratio of 1 to 2 jet bins in signal and control region to calculate number of tt events
2. Use full njet distribution from control region and normalise to tail of njet distribution in signal region to estimate N^{ttbar}

ttbar Estimation from Data - Control Sample in LepHad

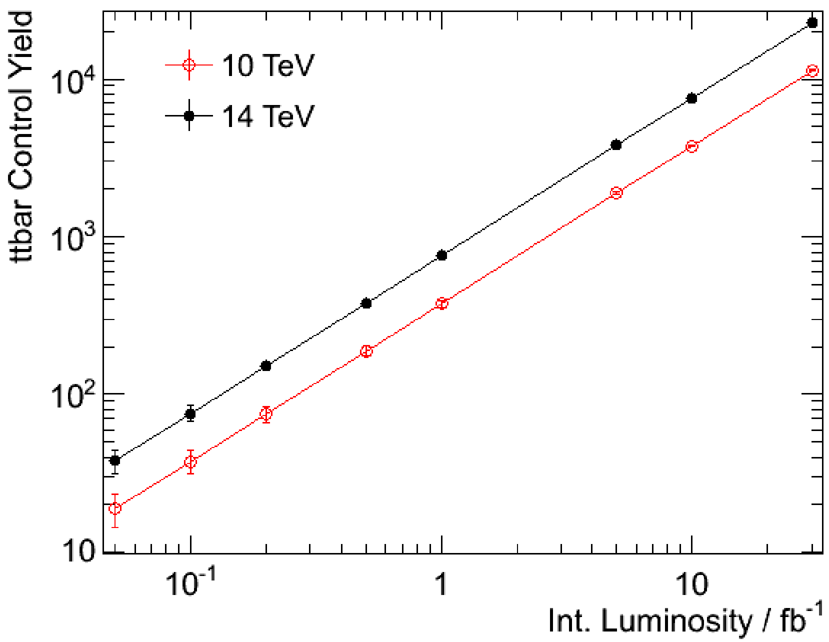
Cuts:

- pTmiss > 100 GeV
- mT > 50 GeV
- pT,lep > 40 GeV
- pT,tau > 50 GeV
- tauLLH > -10

W+jets irreducible. Small bias of the njets distribution.

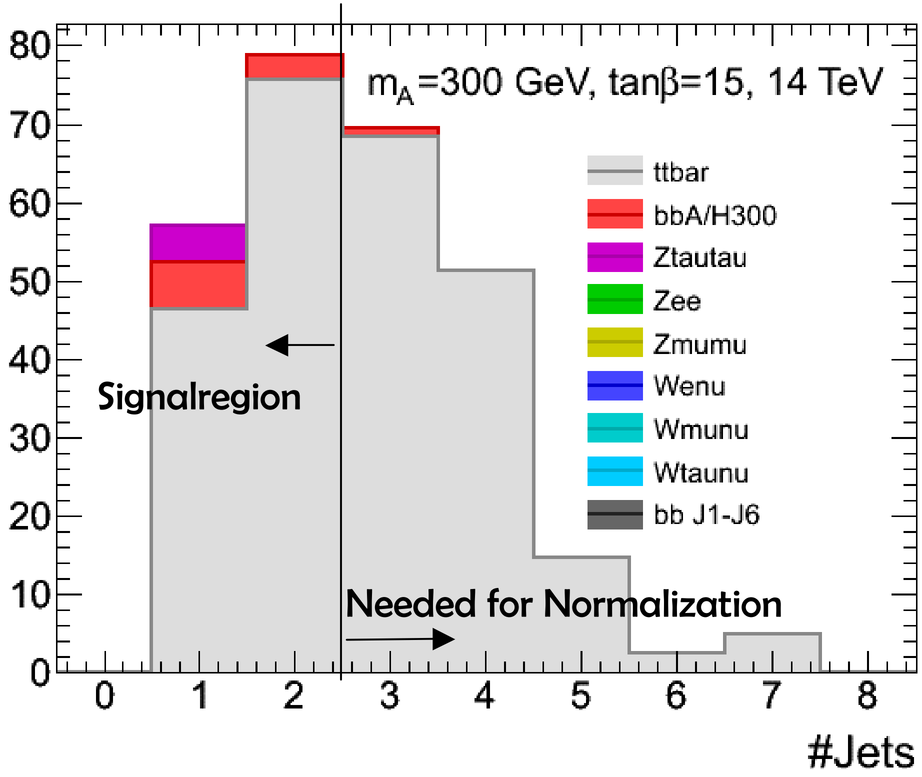


Control region event yield:



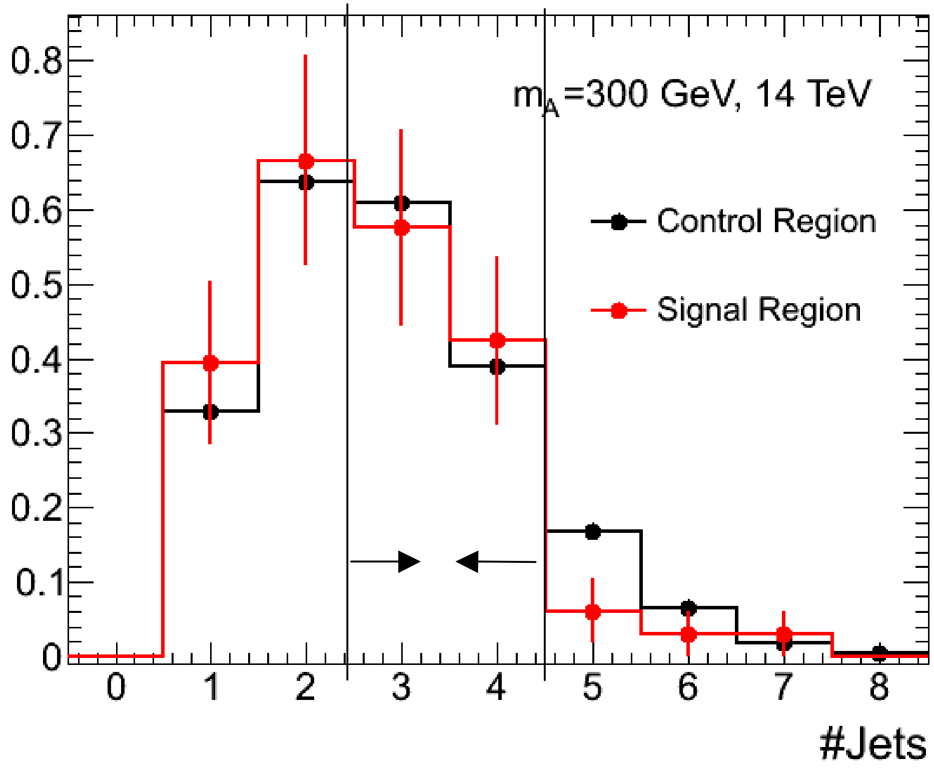
ttbar	22 716	95.4 %
$W\to l\nu$	910	3.8 %
$W\to \tau\nu$	51	0.2 %
$Z\to \tau\tau/ll$	42	0.2 %
bb J1 - J6	25	0.1 %
bb H/A	68	0.3 %

ttbar Estimation from Data - Results in LepHad



- #jets=1 || #jets=2
- Tight tau & tight lepton
- At least one b-tag
- m_T < 25 GeV
- pTmiss > 25 GeV
- pTtau > 50GeV
- 3.0 > $\Delta\Phi$ >2.4

Distributions normalized to bins with 3 and 4 jets



Result in mass window (200-400 GeV):

ttbar in data, signal region:	87 +/- 9
MC prediction:	85 +/- 9

Exp. Stat. Uncertainty: 10.6 %

Prospects for First Data

- Expected Events in 200 pb^{-1} with 10 TeV after cuts: *L. Nisati, talk at Bonn '09*
  - Hundred of thousands of W ($\rightarrow l\ \nu$) +jets
  - Tens of thousands of Z ($\rightarrow$ leplep) + jets
  - Several hundreds of ttbar $\rightarrow$ WWbb $\rightarrow$ lephad $\nu\nu$ bb

  ⇨ Possibilities given for important background studies.

- H/A $\rightarrow \tau\tau$ Analysis cannot be applied „as it is" to first data but has to be adjusted!

  ⇨ Loose object selection, no complicated highly tuned cuts

- General First Data steps:
  - Understand lepton trigger and lepton ID
  - Understand hadronic tau reconstruction and tau fake rate
  - Learn about jet reconstruction and b-tagging
  - Reconstruct Z $\rightarrow \tau\tau$ and ttbar events and try to apply background estimation procedures
  - A low Higgs mass signal at high tanβ could already be seen if systematics are controlled

Conclusions

The MSSM channel bb h/A/H → $\tau\tau$ covers almost the full allowed mass range.

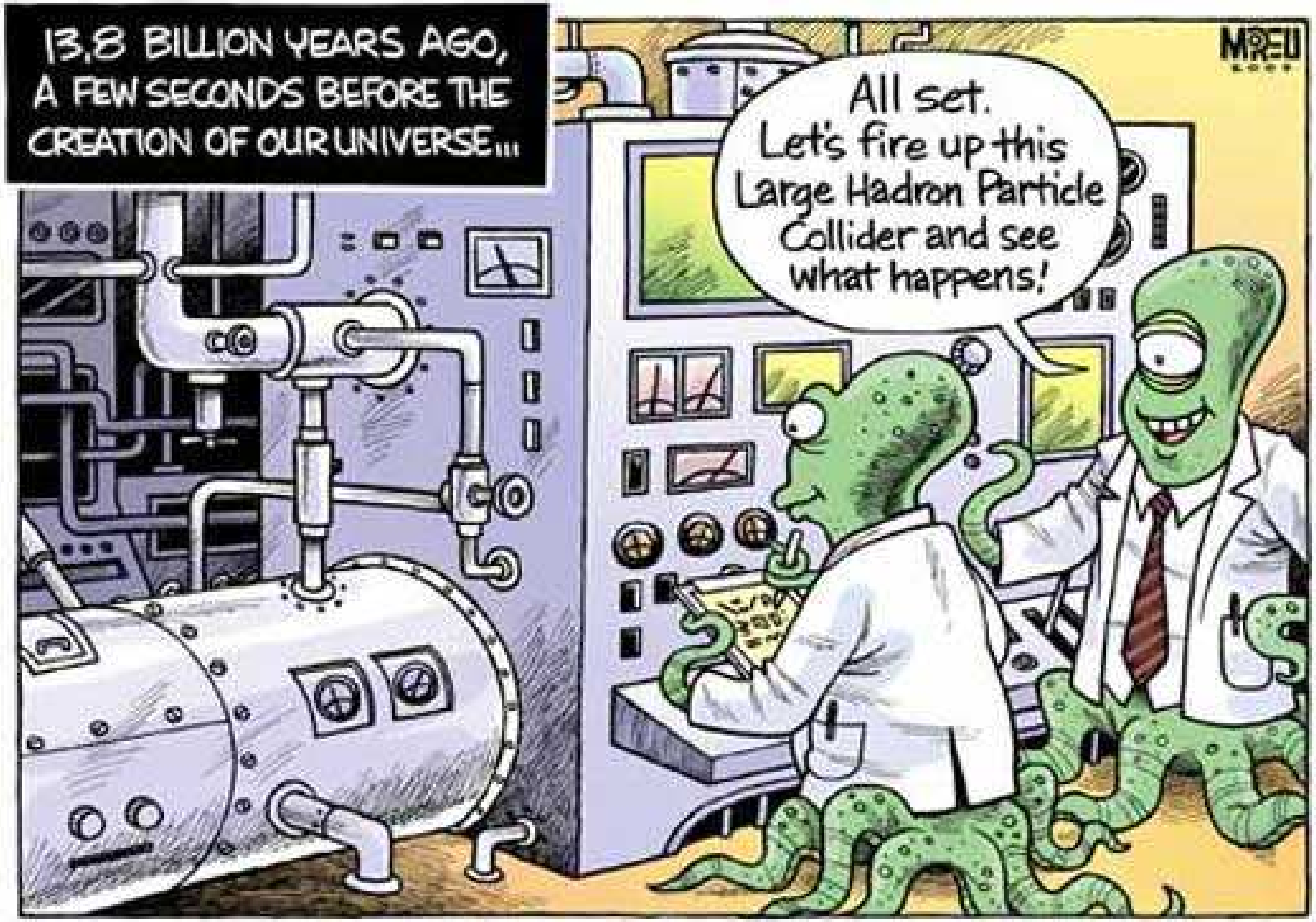
Open issues and next steps:

- Finish 14 TeV study in the lephad channel before first collisions (note in prep)
- Understand $m_{\tau\tau}$ shifts, esp. by comparing to other channels and experiments
- Move the analysis to first data @ 10 TeV:
  - ⇨ Adjust selection
  - ⇨ Update the background estimation procedures

A possible early discovery in this model and channel is constraint by:

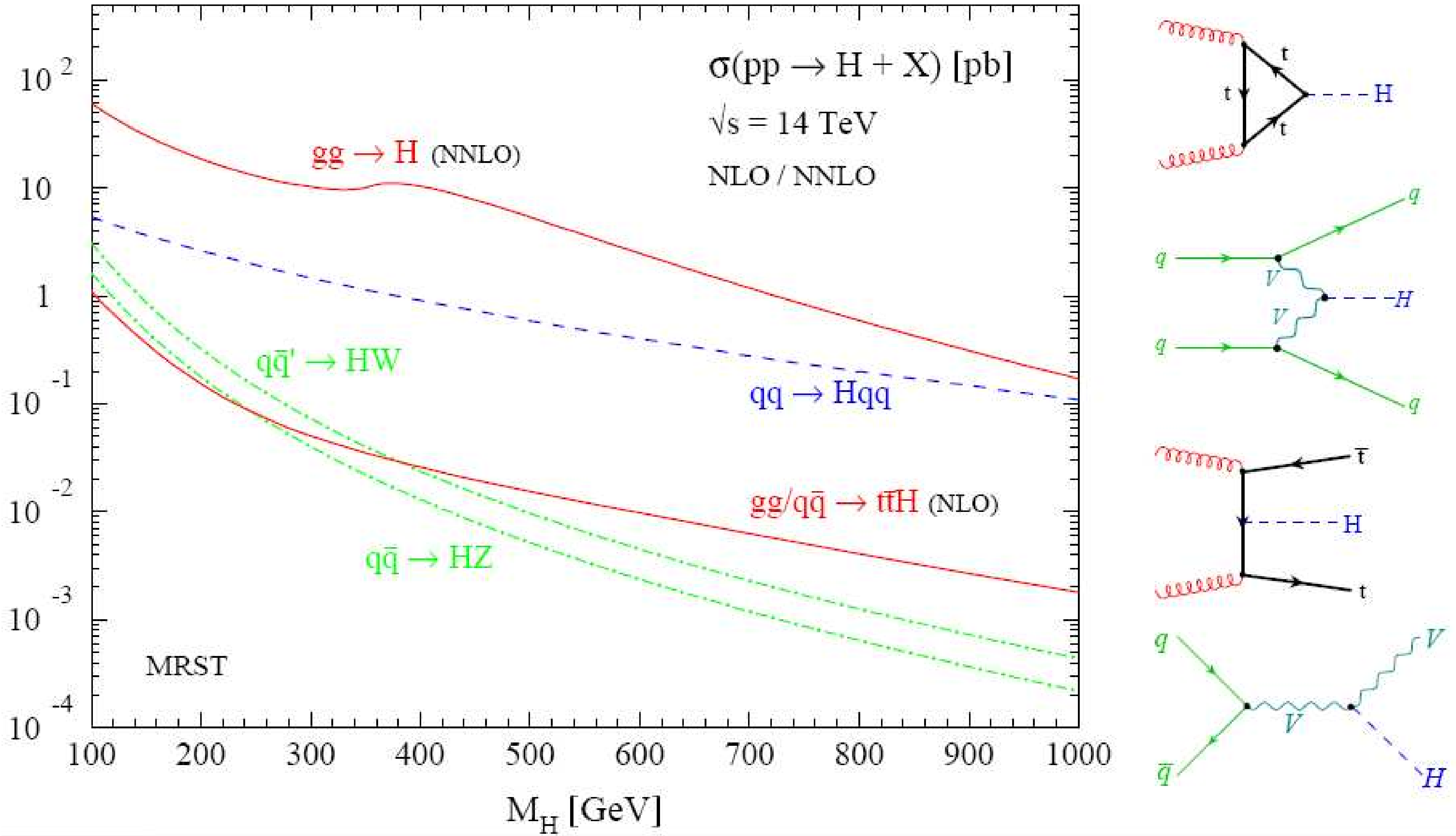
- The performance of the Atlas detector with first data
- The unknown theory parameter tanβ

Backup



http://www.geeksaresexy.net

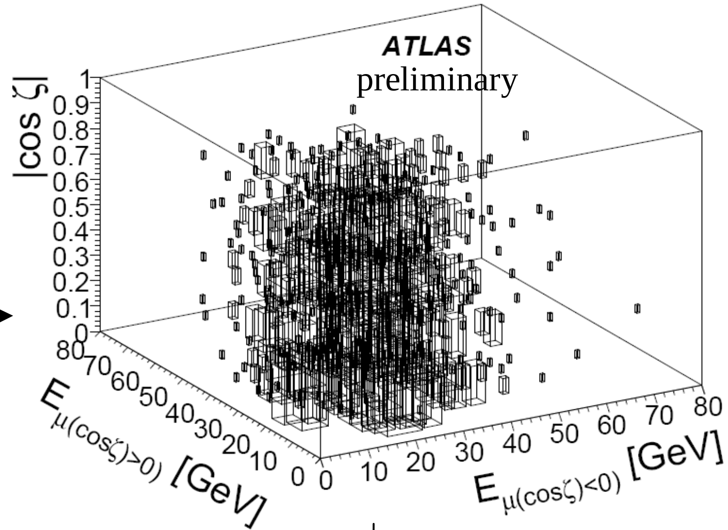
SM Higgs Production Cross Sections

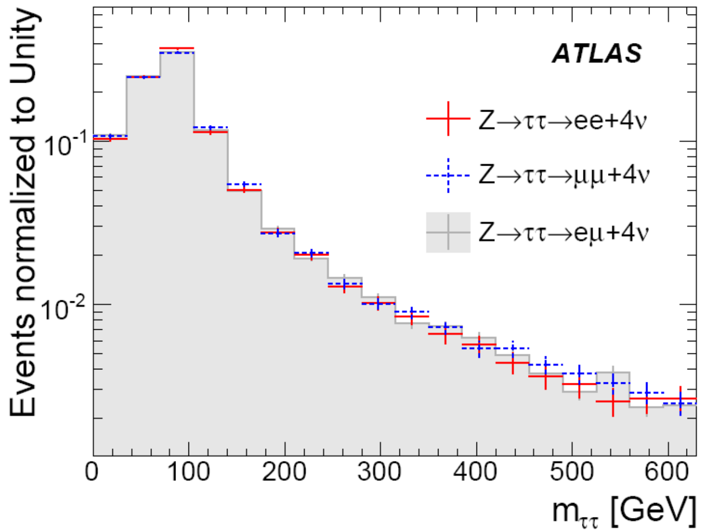


Z → ττ → ll Estimation from Data

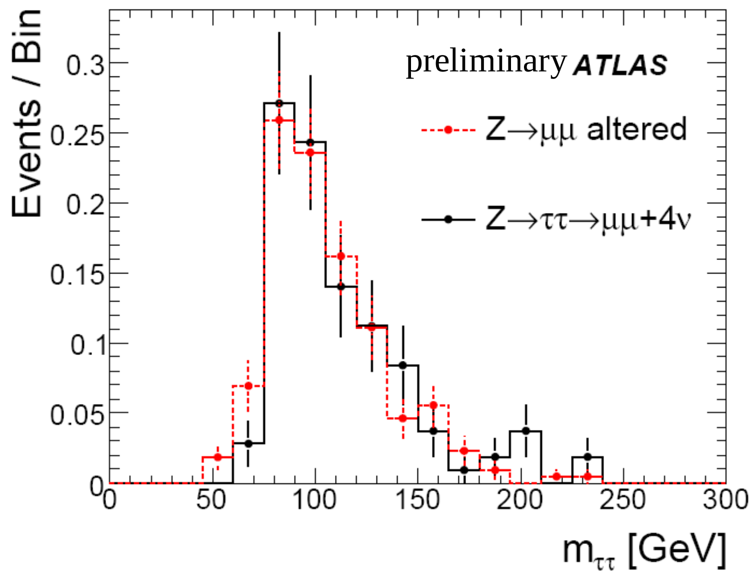
Estimation of irreducible Z → ττ background from data

- 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



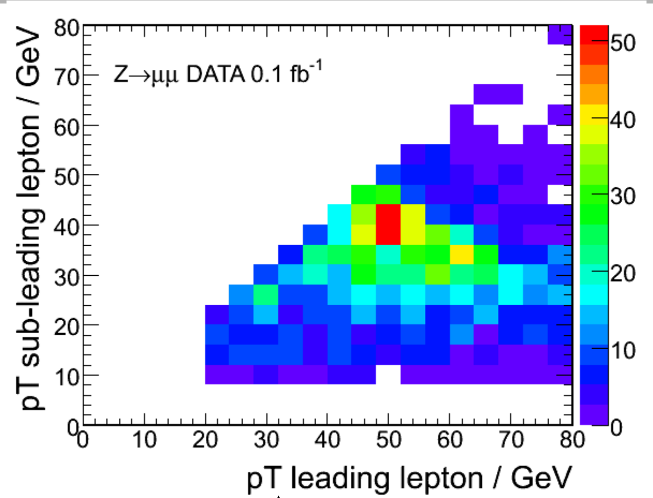


Shapes of other leptonic channels similar to μμ shape



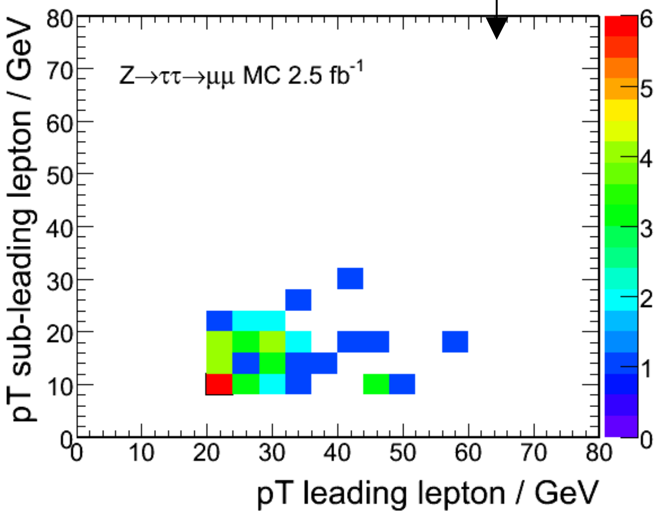
$Z \rightarrow \tau\tau \rightarrow ll$ Estimation from Data

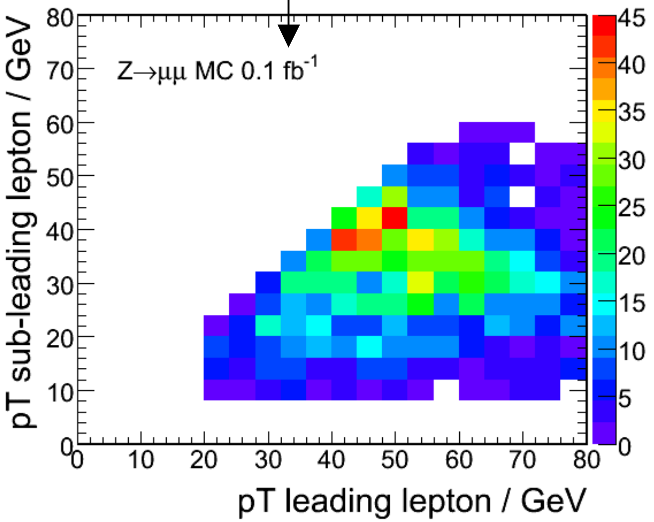
- 2D binning in p_T to avoid difficulties of p_T dependent acceptances, turn on curves etc
- Lepton p_T spectra very different between sideband and signal region
- Calculation only in non-zero bins in overlap region of p_T spectra



$$\#\left(Z \rightarrow \tau\tau \rightarrow \mu\mu\right)^{Signal,DATA} = \sum_{i,j} \#\left(Z \rightarrow \tau\tau \rightarrow \mu\mu\right)_{i,j}^{Signal,MC} \cdot \frac{\#\left(Z \rightarrow \mu\mu\right)_{i,j}^{Sideband,DATA}}{\#\left(Z \rightarrow \mu\mu\right)_{i,j}^{Sideband,MC}}$$

What we want
(see next slide)





ttbar Estimation - First Method

Assumptions:

- One keeps the one-jet (N_1) and two-jet bin (N_2)
- One understands the $Z \to \tau\tau$ background in both bins (important for lower masses) (eg. use data-driven method to estimate expected number of $Z \to \tau\tau$ background)
- One supresses or understands other backrounds (W+jets, QCD)

⇨ Only left with ttbar and signal in the Higgs signal region
Use information from the two jet bins to estimate number of ttbar events

All events in 1 (2) jet bin:

$$N_1 = N_1^{Higgs} + N_1^{ttbar}$$

$$N_2 = N_2^{Higgs} + N_2^{ttbar}$$

Introduce jet ratios:

$V_{higgs} = N_2^{Higgs} / N_1^{Higgs}$ → Take from (well tuned) MC

$V_{ttbar} = N_2^{ttbar} / N_1^{ttbar}$ → Measure in control sample

⇨

$$N^{ttbar} = \frac{(1+V_{ttbar}) \cdot (N_1 * V_{Higgs} - N_2)}{V_{Higgs} - V_{ttbar}}$$

N_1 and N_2 measured in signal region

→ will not work if $V_{Signal} = V_{Background}$

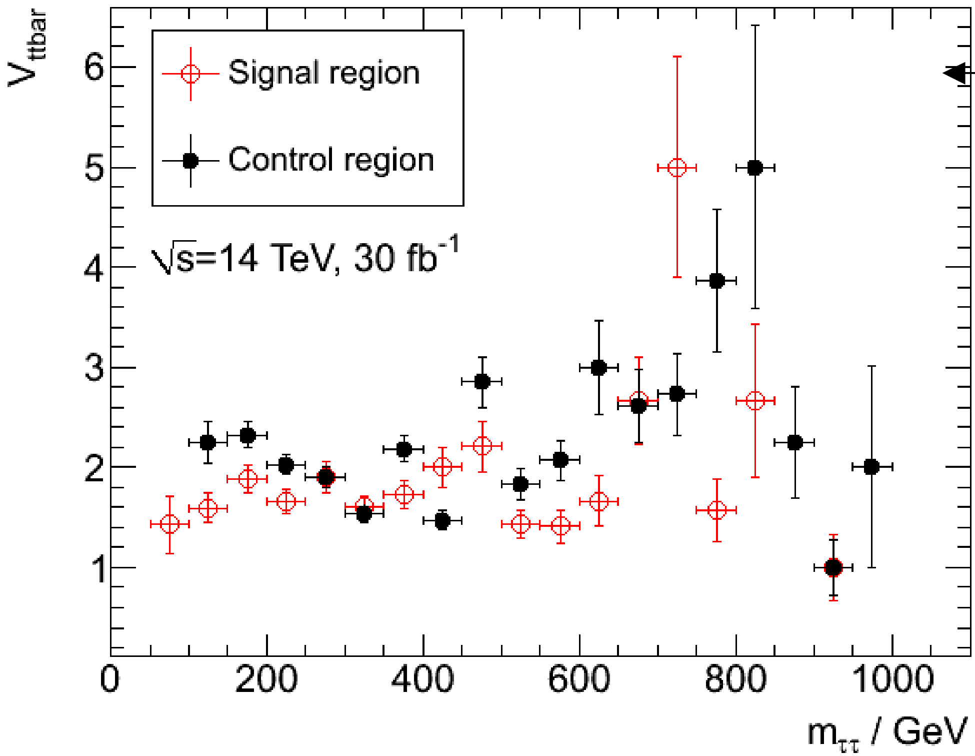
Do this calculation binned in $m_{\tau\tau}$ (if statistics allows) to obtain ttbar $m_{\tau\tau}$ shape!

By using this data-driven approach we avoid the large uncertainty on the ttbar xsec.

LepLep Channel Results

Comparison V_{ttbar} signal and control region:

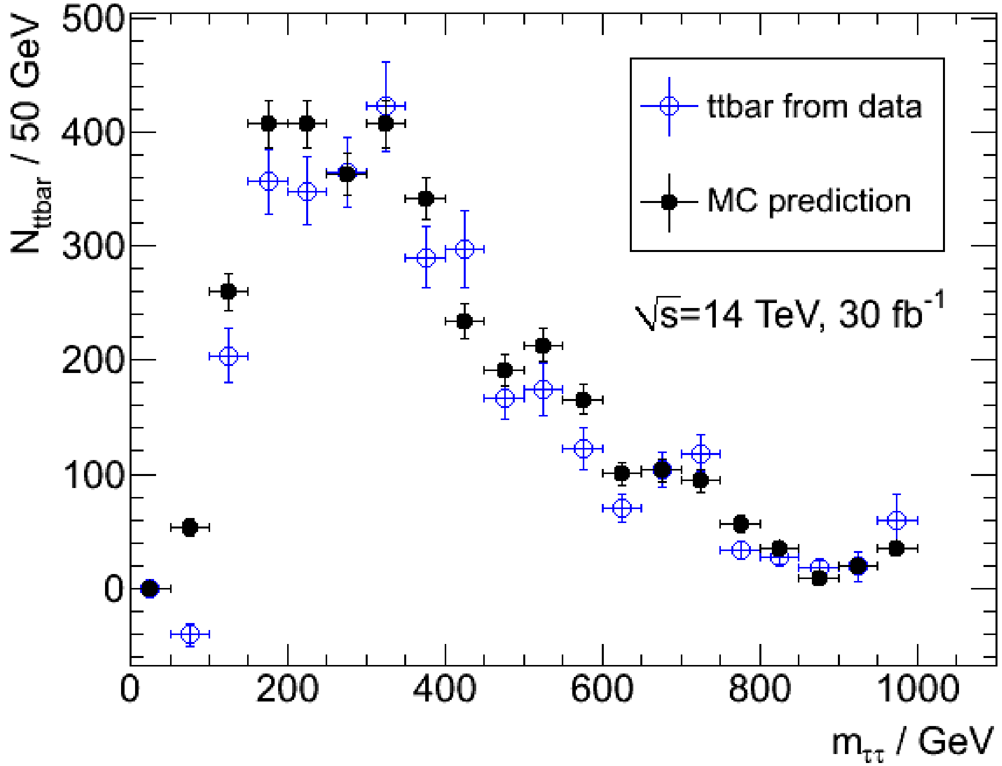
Signal region cuts in backup.



Does not look so great

Does not look so bad, except for a few bins.

Estimated ttbar events:



Statistical Uncertainties only.
N_1 and N_2 anti-correlated.

Errors bars reflect expected uncertainty, not real MC uncertainty, which is larger.