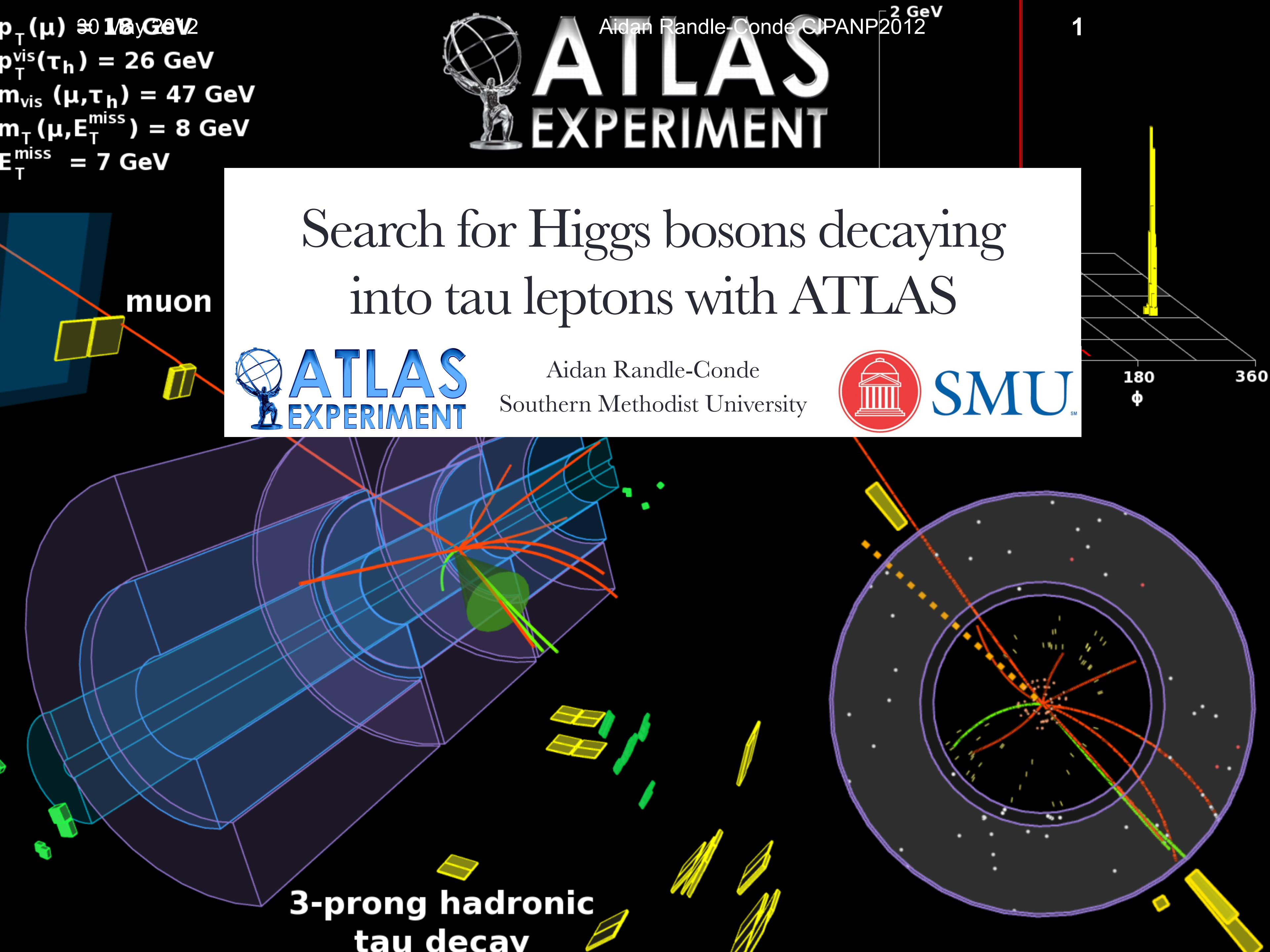


Search for Higgs bosons decaying into tau leptons with ATLAS

Aidan Randle-Conde
Southern Methodist University

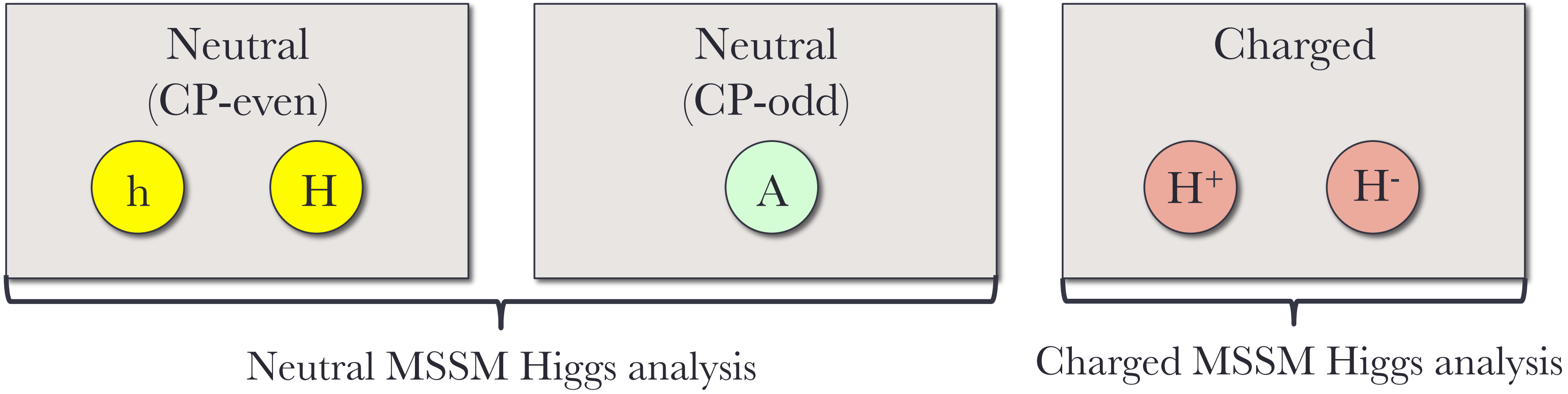
Introduction

- The Higgs sector
- The ATLAS detector
- Background estimations
- Neutral MSSM H→ττ analysis
- Charged MSSM $H^{\pm}$→τν analysis
- Conclusion

- Backup

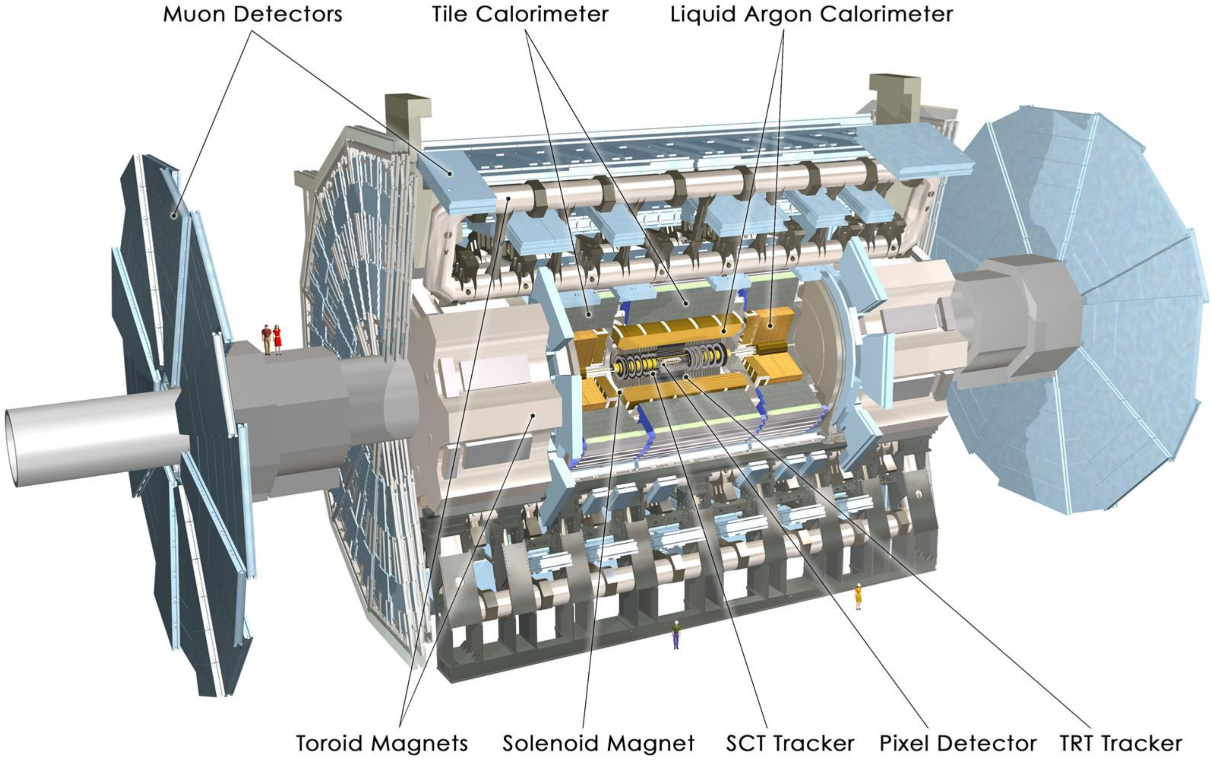
Higgs sector

- Many Higgs scenarios beyond the standard model (SM) include several Higgs bosons:
  - two CP even neutral h, H bosons (including the SM Higgs boson)
  - one CP odd neutral A boson
  - two charged $H^{\pm}$ bosons
- A popular model is the minimal supersymmetric (MSSM) extension to the SM
- Simplest scenario has two main parameters:
  - the mass of the A boson, m_A and ratio of vacuum expectation values, $\tan\beta$
- Decays of additional Higgs bosons to massive gauge bosons generally suppressed by a factor of $\cos^2(\beta-\alpha)$
  - Decays to $\tau\tau$ favored

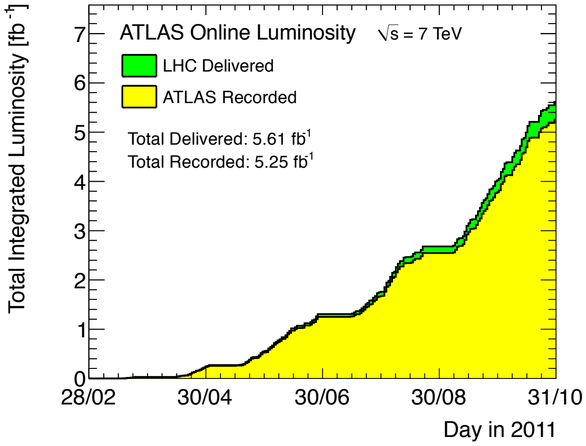


(Throughout this talk I use H for all Higgs bosons)

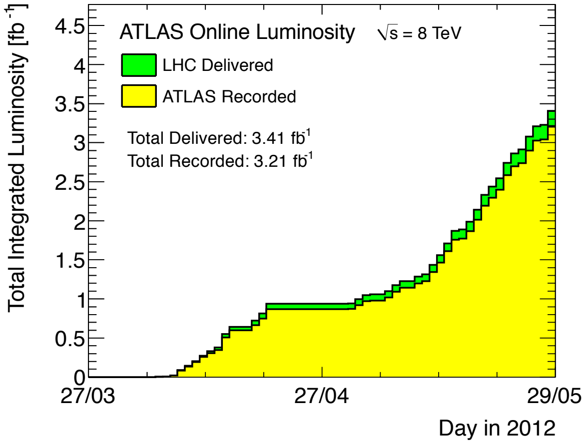
The ATLAS detector



These analyses:



Great start for 2012:



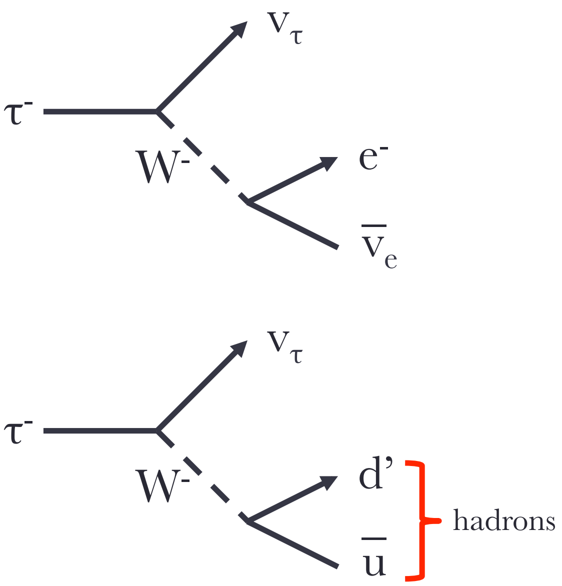
Conserving momentum in the transverse plane gives the missing transverse energy, E_T^{miss}

Coverage for electron reconstruction in region $|\eta|<2.37$ excluding $1.37<|\eta|<1.52$

$$\eta = -\ln(\tan(\theta/2))$$

Working with τ leptons

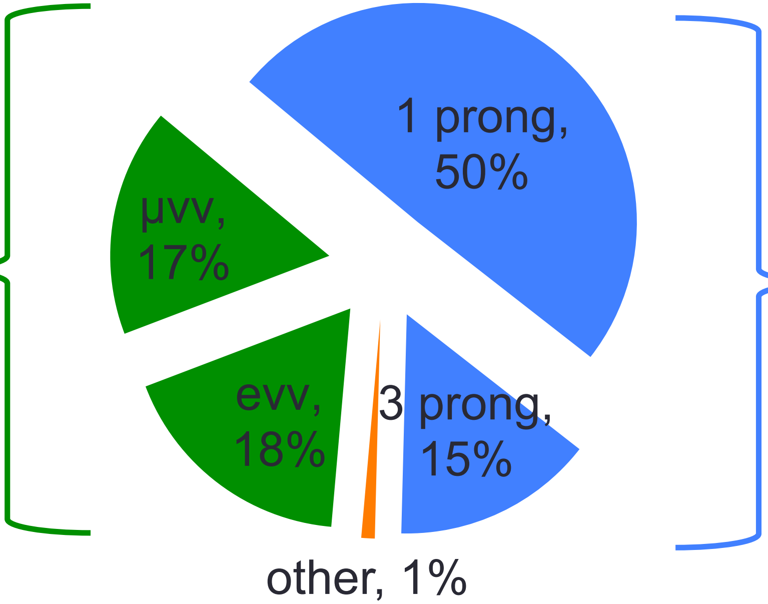
- τ leptons present several challenges for analyses:
  - Large number of neutrinos in the final state
  - Leptonic and hadronic decays must be treated separately
    - Hadronic decays include “1 prong” ($\nu\pi^{\pm}+n\pi^{0}$), “3 prong” ($\nu 3\pi^{\pm}+n\pi^{0}$) and “other” (mostly $\nu K+X$)



Leptonic decays

Use existing algorithms for light lepton identification:

- Well defined control samples
- Well understood energy scales
- Clean signatures



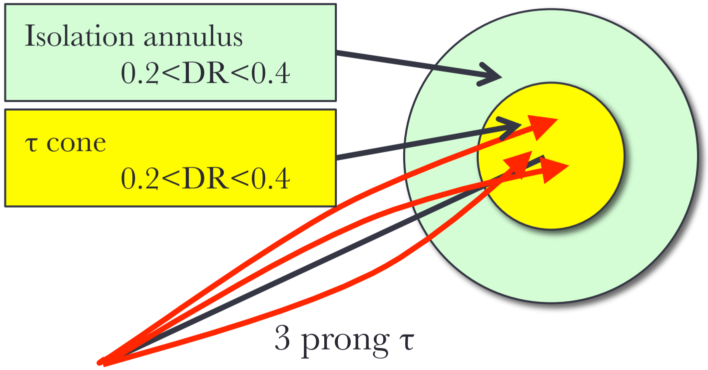
Hadronic decays

Use algorithms specific to τ leptons:

- Final states manifest as jet-like objects
- Some separation of 1 and 3 prong decays

τ leptons identification

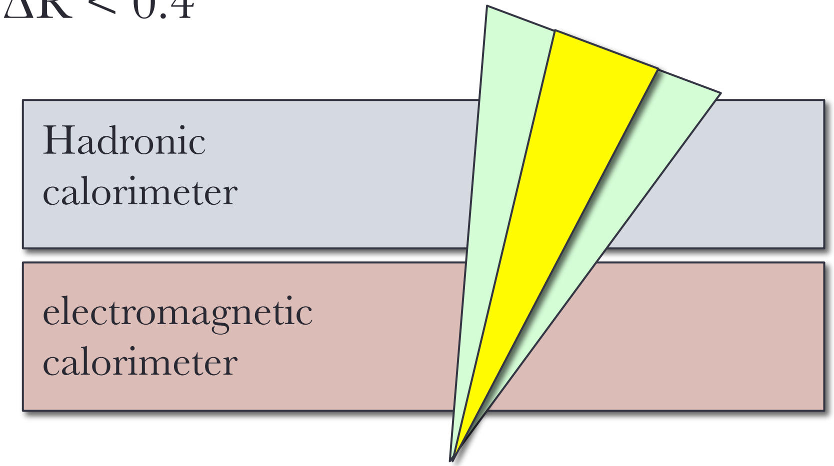
- Start with a list of jet candidates to seed the algorithm
  - Identify tracks within a cone of $\Delta R < 0.2$, where $\Delta R^2=(\Delta\eta)^2+(\Delta\Phi)^2$
    - Use information from the tracking system and calorimeter systems
  - Require an isolation annulus of $0.2 < \Delta R < 0.4$



Isolation annulus
0.2<DR<0.4

τ cone
0.2<DR<0.4

3 prong τ



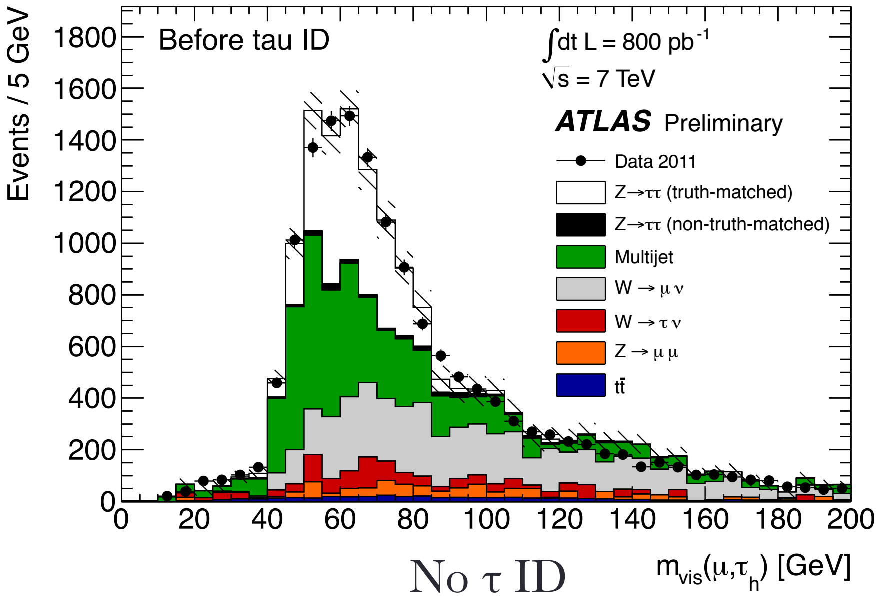
Hadronic
calorimeter

electromagnetic
calorimeter

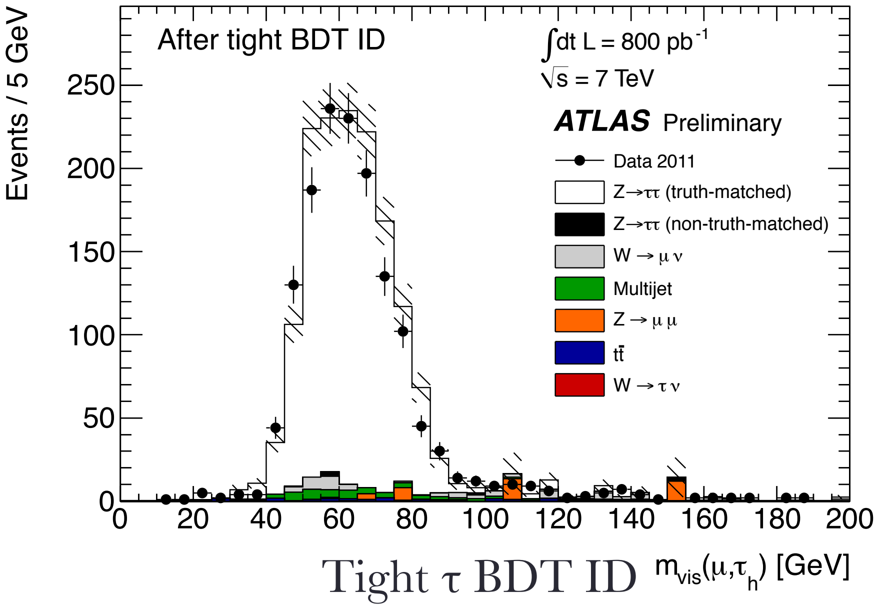
  - Classifiers include simple selection (“cuts”), boosted decision trees and likelihood selectors
  - Use data driven control samples and MC
  - Rejection of QCD multi-jets and electrons

τ leptons identification performance

- There are three levels of discrimination for each classifier: loose, medium, and tight
- Plotting invariant visible mass of $\mu\tau_{\text{hadronic}}$ from $Z \rightarrow \tau(\mu\nu\nu)\tau(\nu$ +hadrons) candidates shows excellent performance:



No τ ID

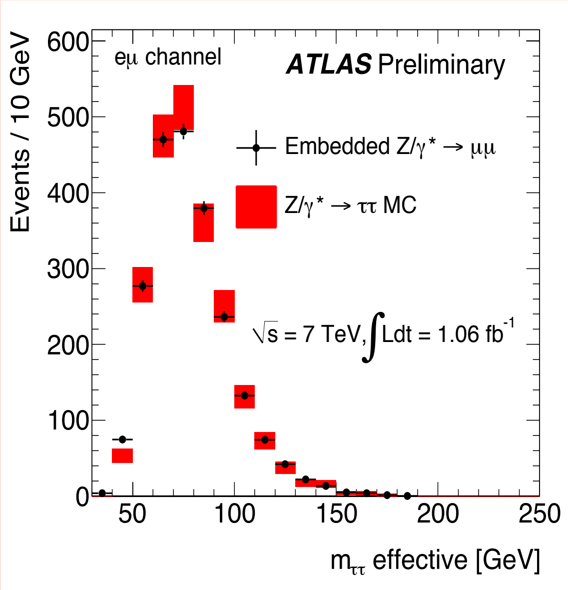


Tight τ BDT ID

Background estimations

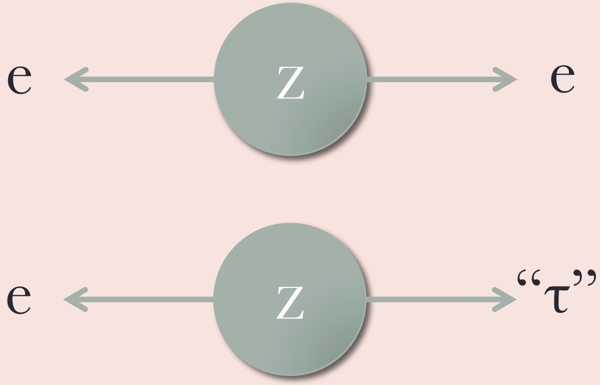
Embedding

- Take very pure $Z\rightarrow\mu\mu/W\rightarrow\mu\nu$ samples in data
- Replace μ with τ taken from Monte Carlo (MC) samples
- Apply selection criteria
- Generally smaller uncertainties



Tag and probe

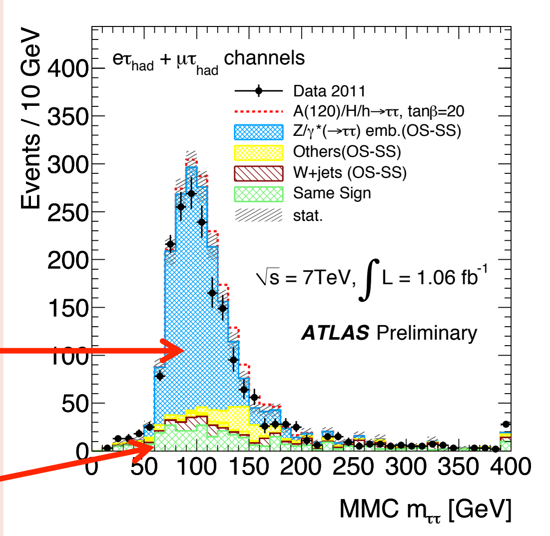
- Take very pure $Z\rightarrow ll/W\rightarrow l\nu$ samples in data
- Tag one side of the decay with a lepton/neutrino
- Apply selection to the other side
- Estimate fake rate



Background estimations

Opposite/same sign

- Define the opposite sign (OS) sample and same sign (SS) sample according to the charges of the τ pair
- Estimate differences between OS and SS samples using MC
- Add these differences to the SS sample in data to estimate the size of the OS sample in data.



OS-SS peaking

SS smooth

ABCD method

- Use two uncorrelated variables (eg isolation, OS vs SS) to define four regions A, B, C, D

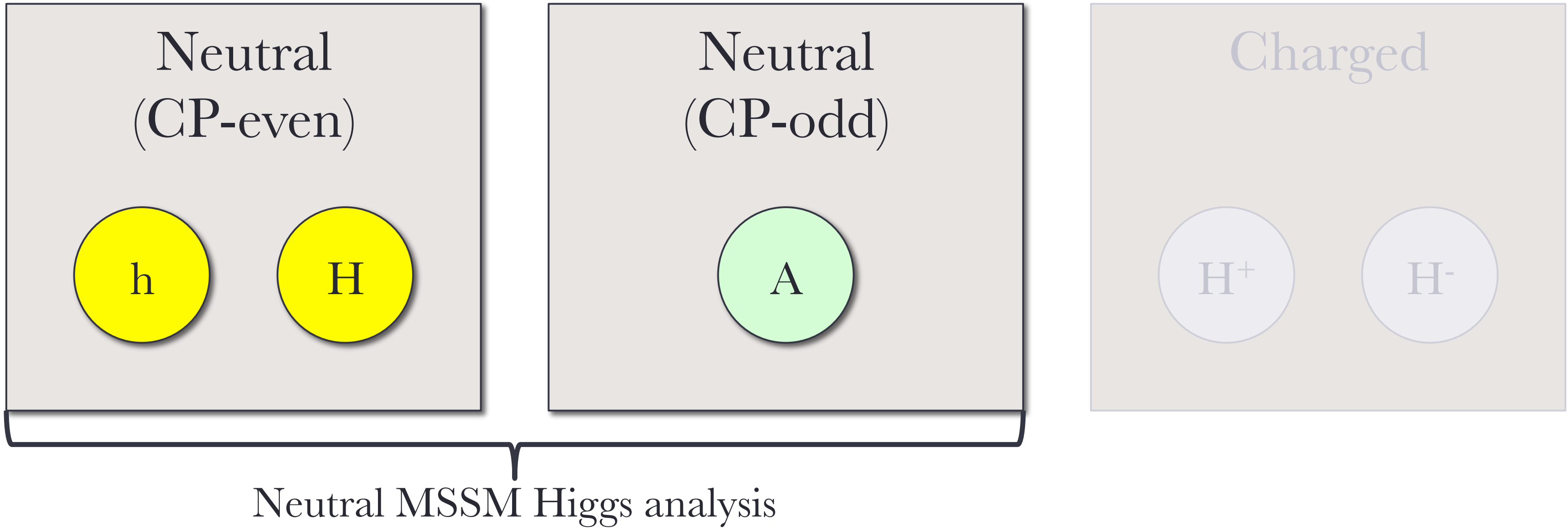
A	B
C	D

- Estimate background in region A using the relation:

$$n_A = \frac{n_C}{n_D} n_B$$

Neutral MSSM Higgs analysis

$$\boxed{\int Ldt = 1.06\, fb^{-1}}$$



Neutral
(CP-even)

h H

Neutral
(CP-odd)

A

Charged

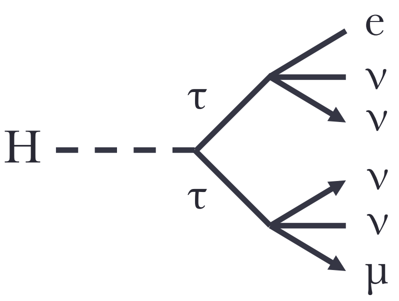
H^+ H^-

Neutral MSSM Higgs analysis

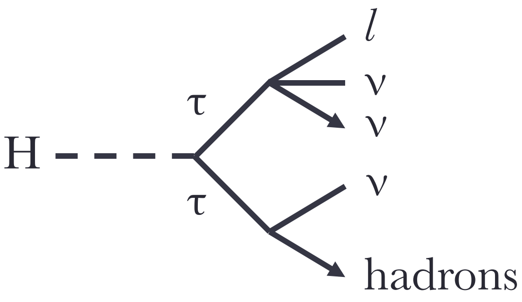
Neutral MSSM H→ττ analysis

- The following final states of the ττ system are considered:

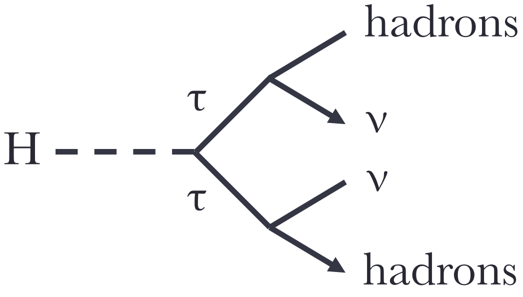
$\tau\tau\rightarrow e\mu 4\nu$



$\tau\tau\rightarrow l\tau_{had}3\nu$ (l=e,μ)



$\tau\tau\rightarrow \tau_{had}\tau_{had}\nu\nu$



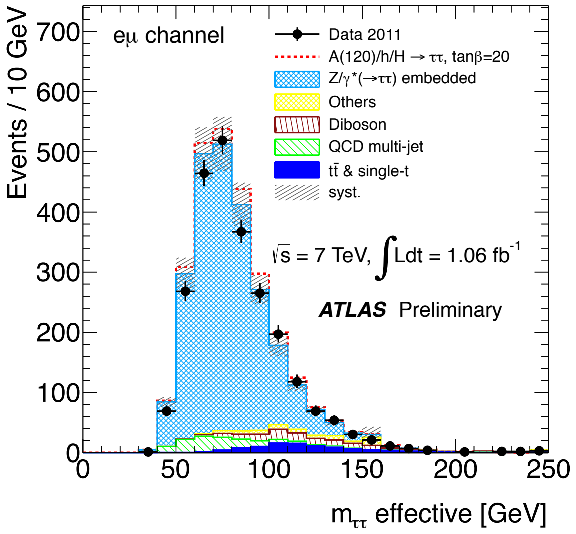
Electrons	**Muons**	**τ_{had}**
E_T>15GeV	p_T>15GeVc^{-1}	p_T>20GeVc^{-1}
Single electron trigger (E_T>20GeV)	Single muon trigger (p_T>18GeVc^{-1})	Double hadronic τ trigger (p_T>29GeVc^{-1}, 20GeVc^{-1})

Neutral MSSM H→ττ (eμ)

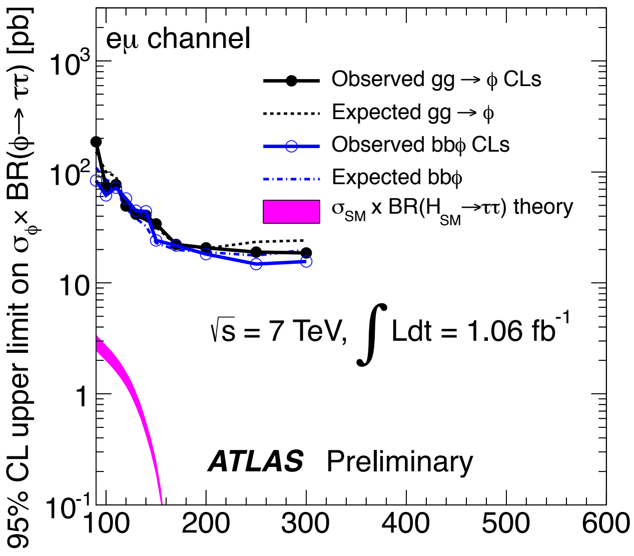
- Signal and background components are obtained with a profile likelihood ratio to the effective mass, $m_{\tau\tau}^{eff}$:

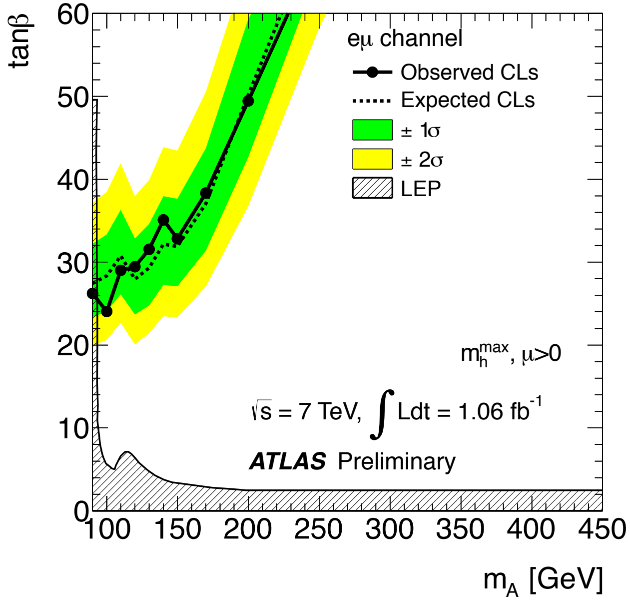
$$\left(m_{\tau\tau}^{eff}\right)^2 = \left(p_{\tau^+} + p_{\tau^-} + p_T^{miss}\right)^2$$

← 4-vectors



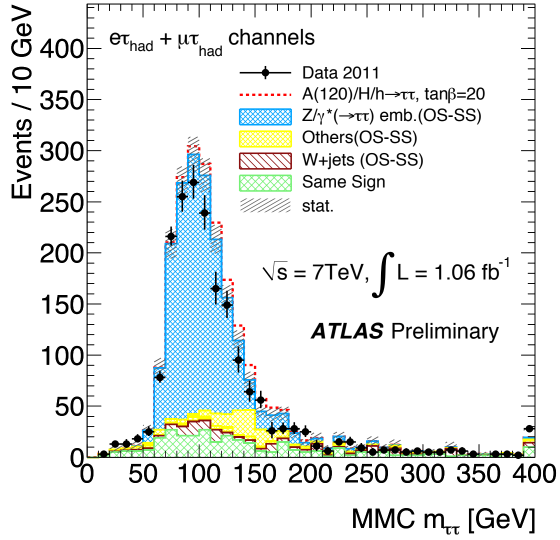
Source	Systematic uncertainty
Production cross section	14%
Object selection	6%



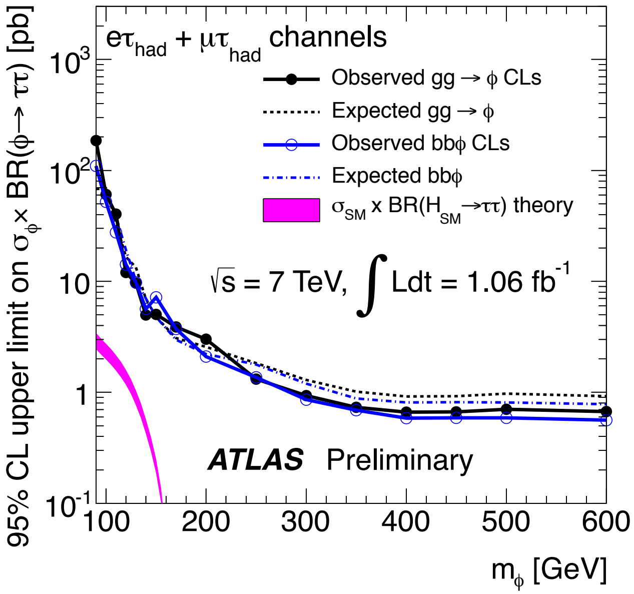


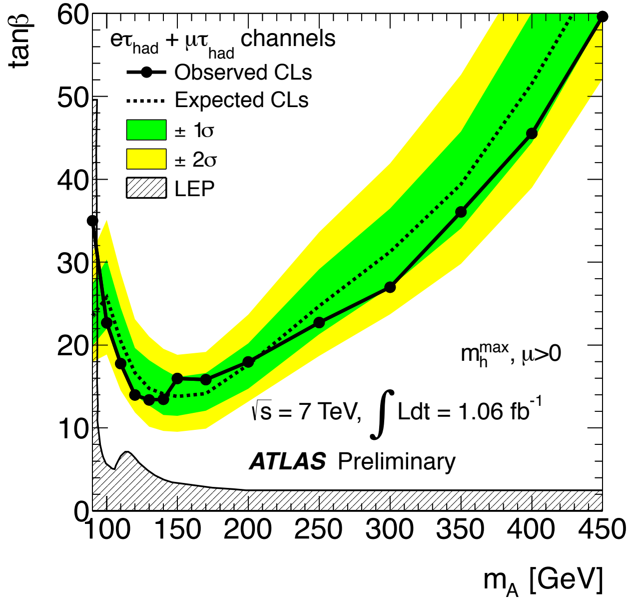
Neutral MSSM H→ττ ($l\tau_{had}$)

- Signal and background components are obtained with a profile likelihood ratio to the missing mass calculated (MMC) spectrum
  - More sophisticated than co-linear method
  - Use of kinematic constraints
  - Details in the backup slides



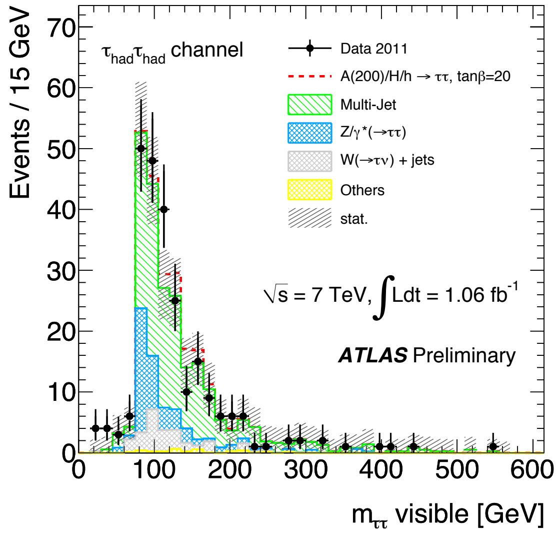
Source	Systematic uncertainty
Production cross section	16%
Energy scale and resolution	12%



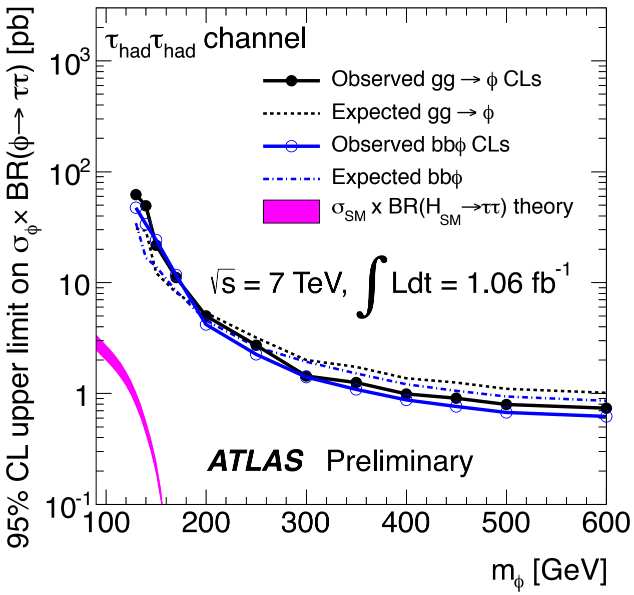


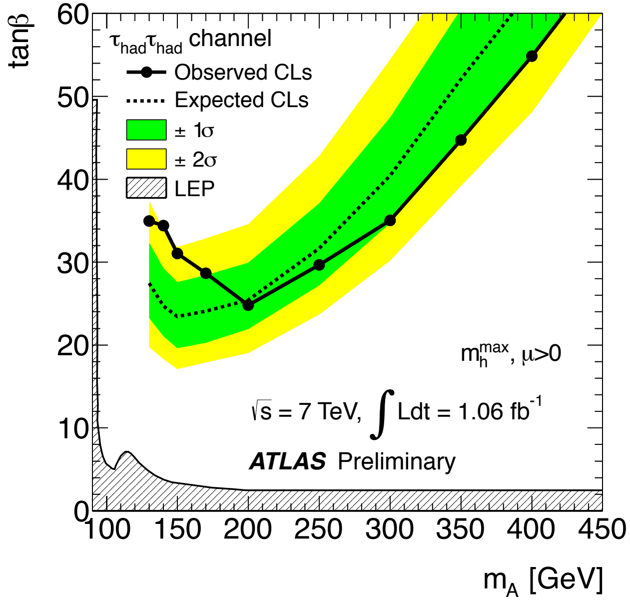
Neutral MSSM H→ττ ($\tau_{had}\tau_{had}$)

- Signal and background components are obtained with a profile likelihood ratio to the visible mass



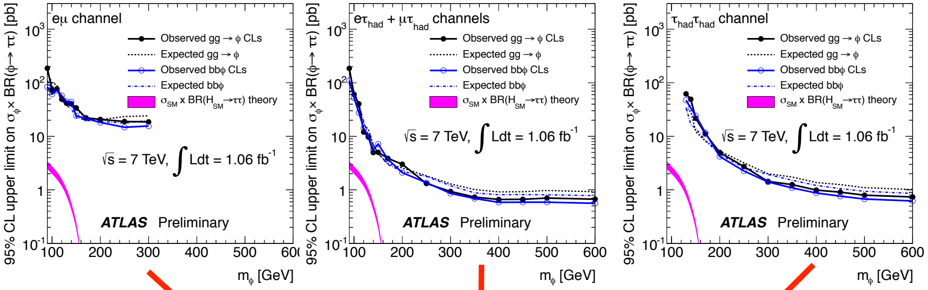
Source	Systematic uncertainty
Energy scale and resolution	50%
Production cross section	16%

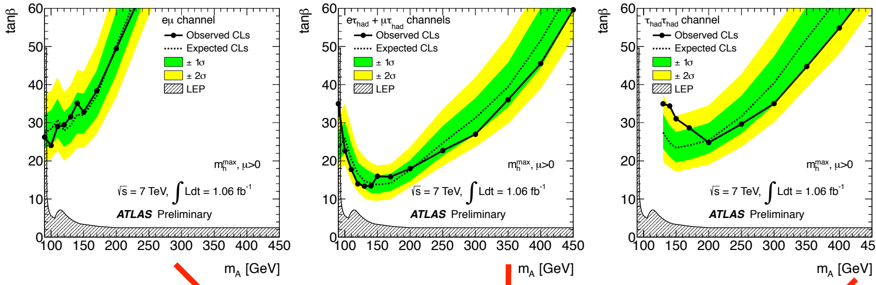


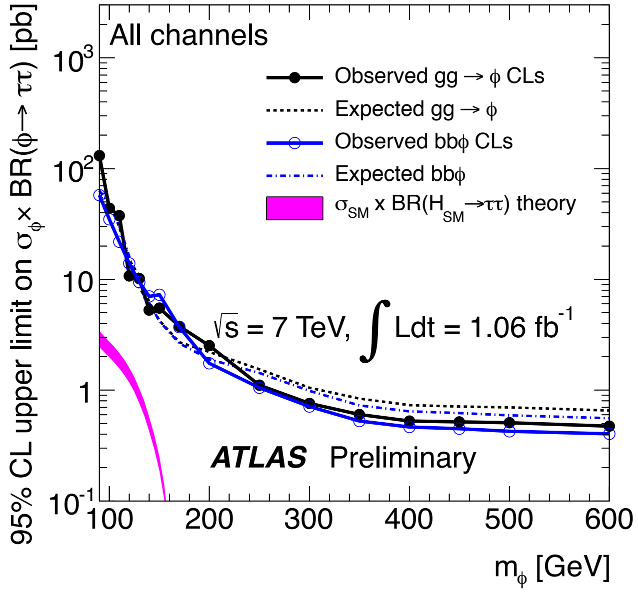


Neutral MSSM H→ττ (combination)

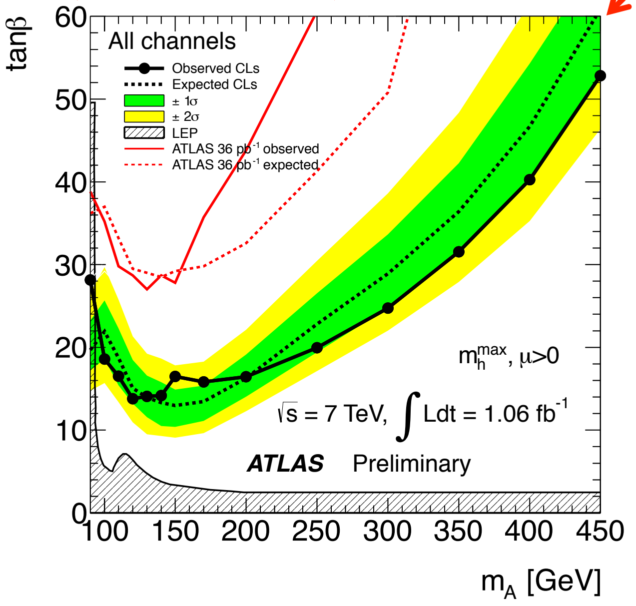
- The results are combined to extract more stringent exclusions:







Note eμ and $\tau_{had}\tau_{had}$ analyses sensitive to different ranges of m_H



Charged MSSM Higgs analysis

$$\int L dt = 4.6\, fb^{-1}$$

Neutral
(CP-even)

h H

Neutral
(CP-odd)

A

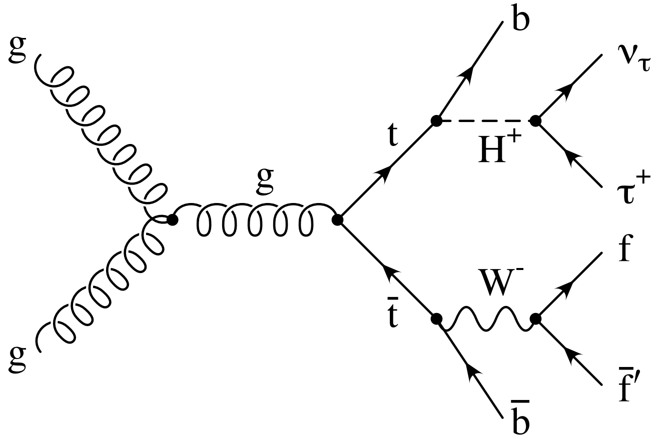
Charged

H^+ H^-

Charged MSSM Higgs analysis

Charged MSSM $H^{\pm} \rightarrow \tau\nu$

- Many non-minimal Higgs scenarios include:
    - Higgs triplets models
    - Two Higgs doublets models
- These models include a charged Higgs boson
- Discovery of a charged Higgs boson would be unambiguous evidence of physics beyond the standard model
- For $\tan\beta > 3$ the dominant decay of the charged Higgs would be $H \rightarrow \tau\nu$
- Dominant production mechanism is via gg fusion tt production:
- This analysis only considers $m_H < 150 \mathrm{GeV} c^{-2}$



Charged MSSM $H^{\pm} \rightarrow \tau\nu$

- Three modes considered:

lepton+jets

- W decays hadronically
- τ decays leptonically
- At least 4 jets (=2 b-tagged)

$$t\bar{t} \rightarrow b\bar{b}(q'\bar{q})(\tau_{lep}\nu)$$

τ+lepton

- W decays leptonically
- τ decays hadronically
- At least 2 jets (>0 b-tagged)

$$t\bar{t} \rightarrow b\bar{b}(l\nu)(\tau_{had}\nu)$$

τ+jets

- W decays hadronically
- τ decays hadronically
- At least 4 jets (>0 b-tagged)

$$t\bar{t} \rightarrow b\bar{b}(q'\bar{q})(\tau_{had}\nu)$$

- The following object selections and triggers are applied:

Electrons	**Muons**	**τ_{had}**
E_T>20GeV	p_T>15GeVc^{-1}	p_T>20GeVc^{-1}
Single electron trigger (E_T>20-22GeV)	Single muon trigger (p_T>18GeVc^{-1})	Single hadronic τ + E_T^{miss} trigger (p_T^{τ}>35GeVc^{-1}, E_T^{miss}> 29GeVc^{-1})

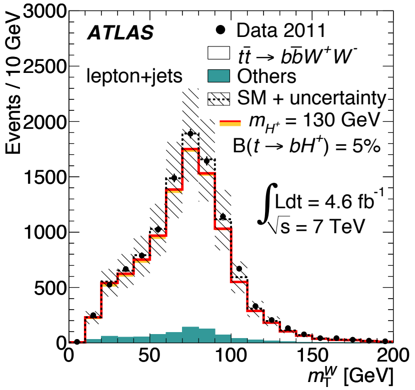
Charged MSSM $H^{\pm} \rightarrow \tau\nu$ (lepton+jets)

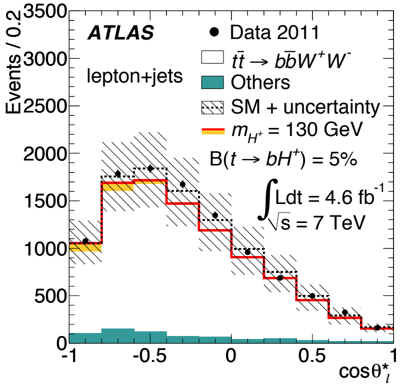
- Signal region defined by $m_T^W < 60\,\mathrm{GeV}c^{-2}$ and $\cos\theta_l^* < -0.6$ where:

$$m_T^W = \sqrt{2 p_T^l E_T^{miss}\left(1 - \cos\phi_{l,miss}\right)}$$

$$\cos\theta_l^* = \frac{2m_{bl}^2}{m_{top}^2 - m_W^2} \cong \frac{4p^b \cdot p^l}{m_{top}^2 - m_W^2} - 1$$

assume b-jet and lepton come from the same top quark

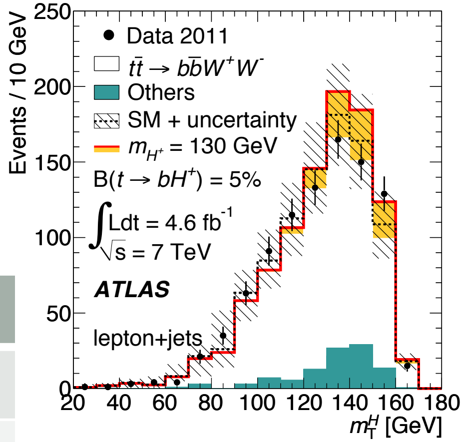


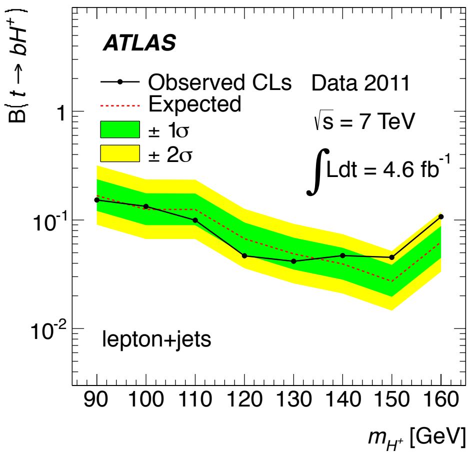


- Signal and background components are obtained with a profile likelihood ratio to the transverse mass, m_T^H:

$$\left(m_T^H\right)^2 = \left(\sqrt{m_{top}^2 + \left(\vec{p}_T^{\,l} + \vec{p}_T^{\,b} + \vec{p}_T^{\,miss}\right)^2} - p_T^b\right)^2 - \left(\vec{p}_T^{\,l} + \vec{p}_T^{\,miss}\right)^2$$

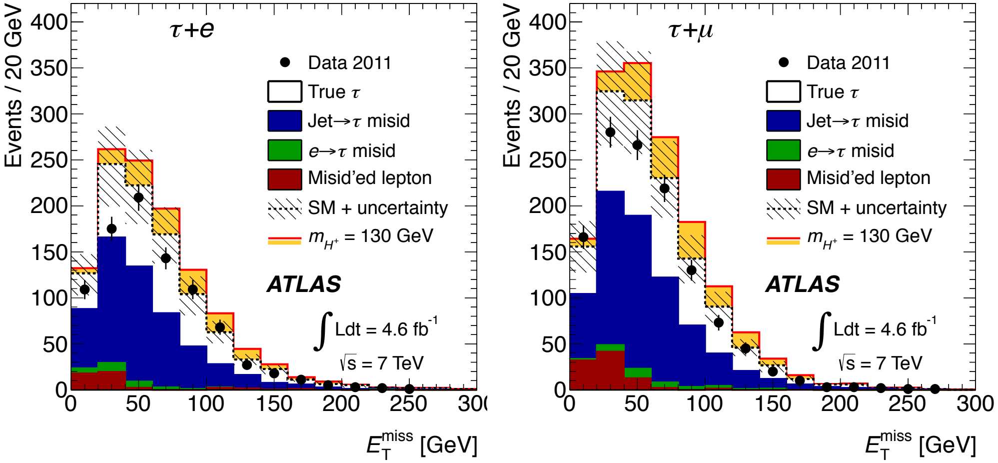
	Systematic uncertainty
tt background (Jet energy scale)	14%
tt background (Jet energy resolution)	6%

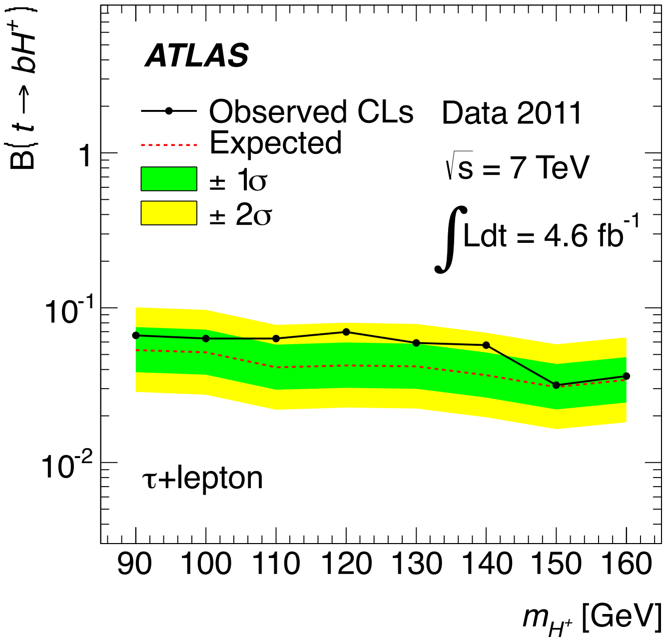




Charged MSSM H±→τν (τ+lepton)

- Signal and background components are obtained with a profile likelihood ratio to the missing transverse energy
- τ fake rates estimated with tag and probe method (electrons) and a control sample in data (jets)



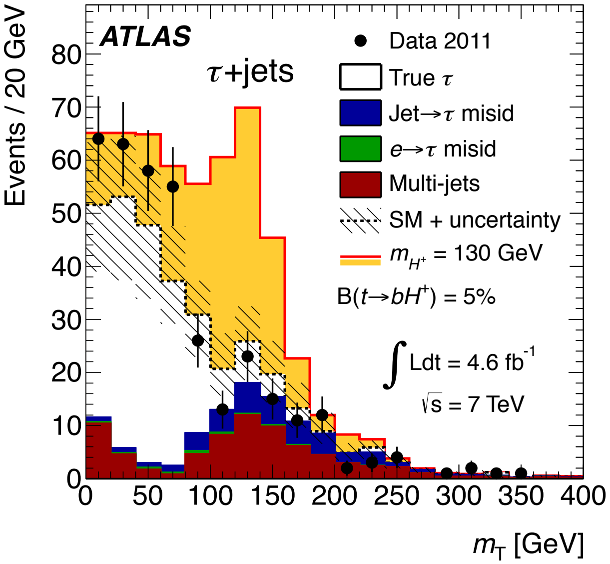


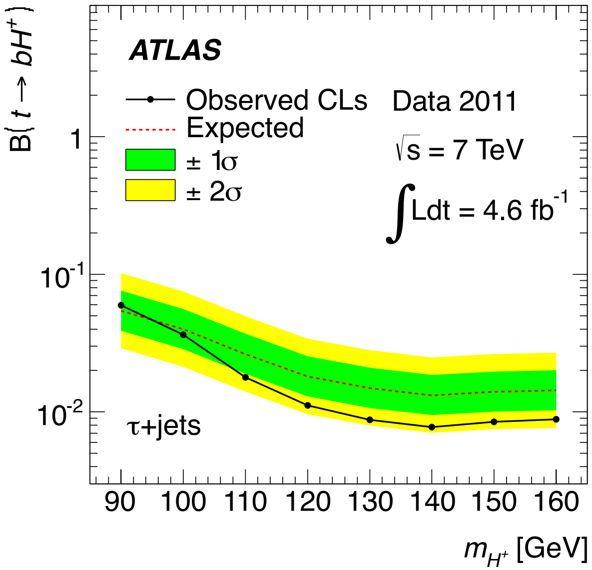
	Systematic uncertainty
Signal efficiency	13%
Fake jet→τ (Jet composition)	8%

Charged MSSM $H^{\pm} \rightarrow \tau\nu$ (τ+jets)

- Signal and background components are obtained with a profile likelihood ratio to the transverse mass of the charged Higgs candidate
- Fake rates estimated with control region in data (QCD multi-jets), embedding (real τ), and tag and probe (fake τ)

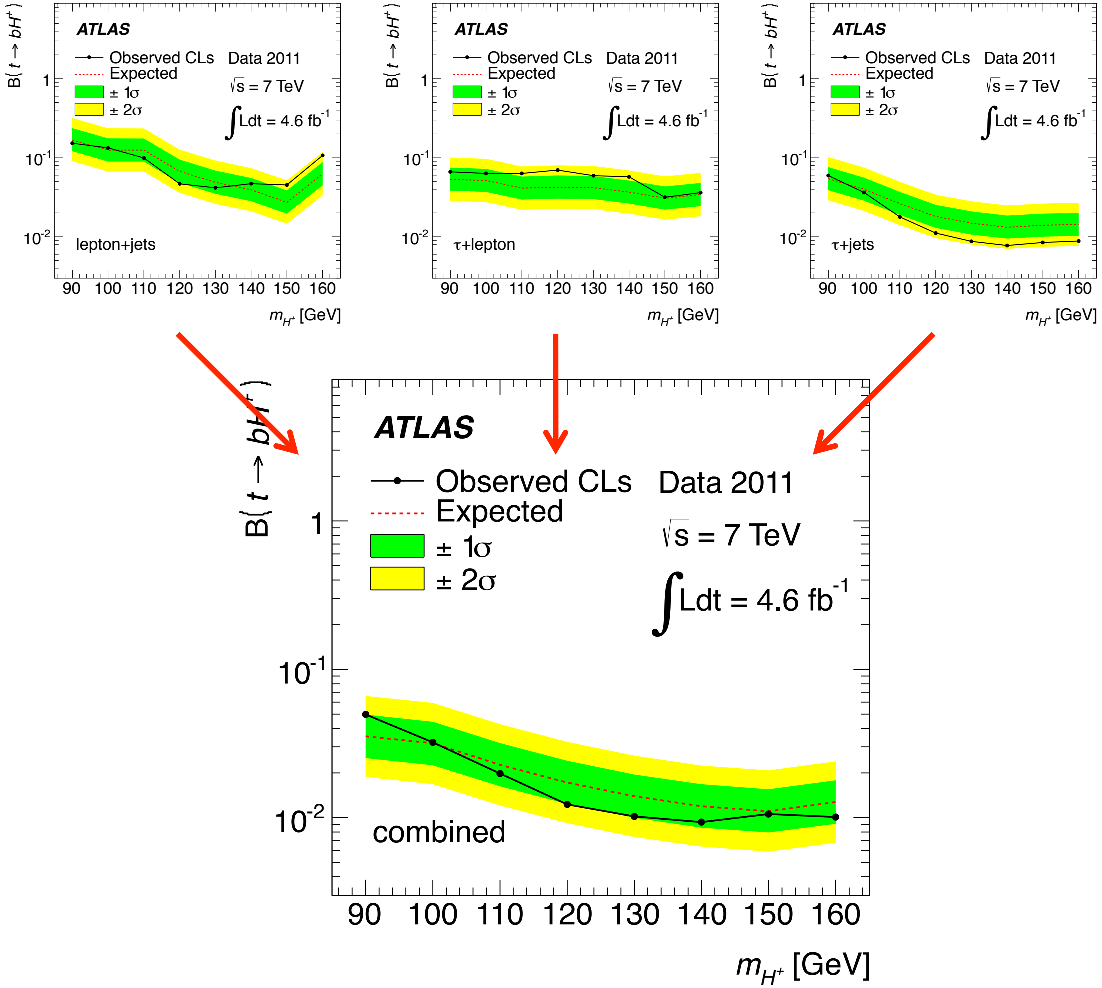
	Systematic uncertainty
Signal efficiency	25%
QCD multi jet estimation	14%



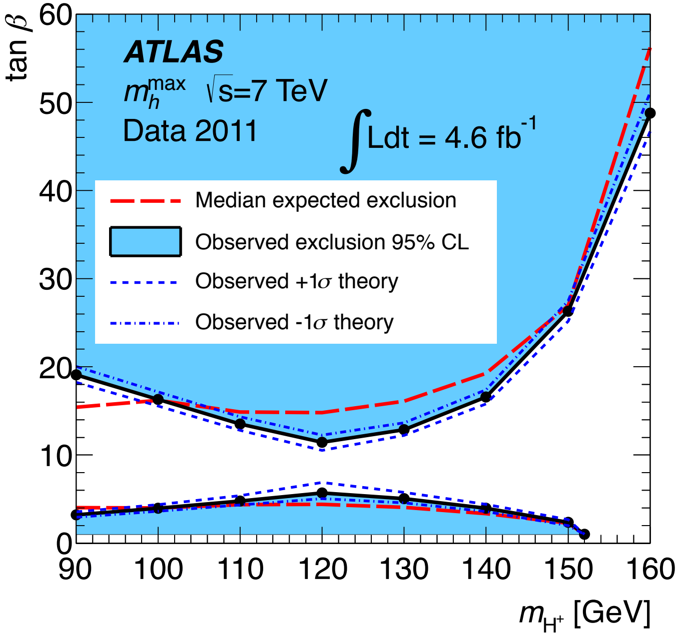


Charged MSSM $H^{\pm} \rightarrow \tau\nu$ (combination)

- Combining the results shows the t+jets mode dominates sensitivity:



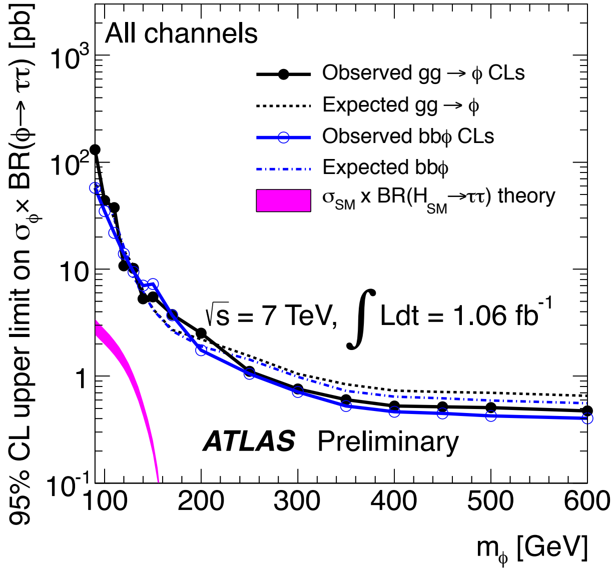
- Exclusion in the tanβ vs m_H plane:

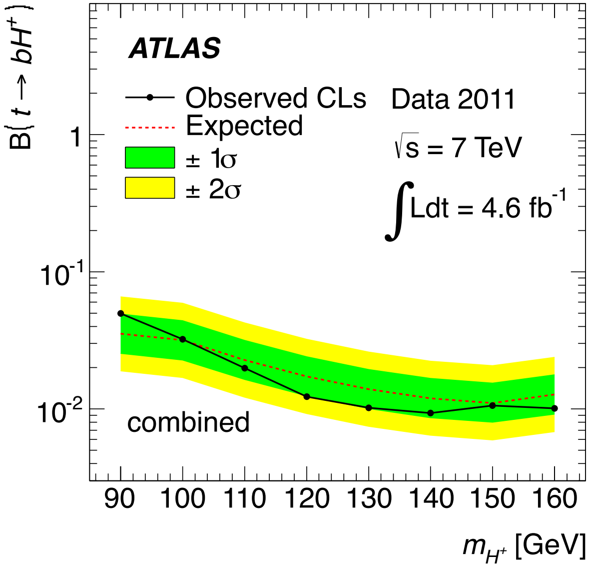


Conclusion

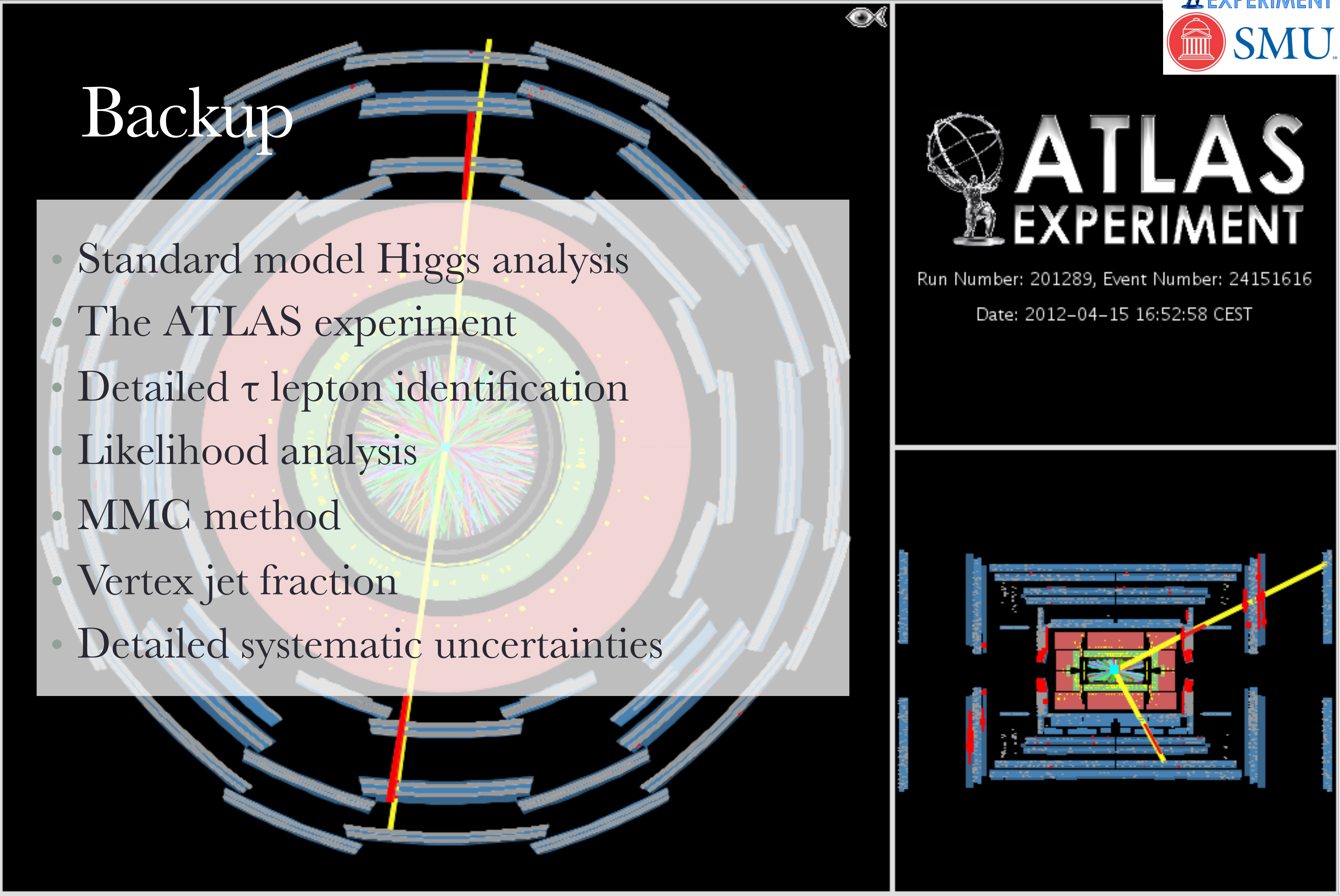
- ATLAS has produced state of the art, competitive results for a wide range of Higgs searches with tau leptons
    - Excellent performance of τ reconstruction
    - Limits will continue to improve with 2012 data
- Limit on cross section $\sigma(H \rightarrow \tau\tau)$ for neutral MSSM Higgs boson from 0.5-100pb
- Limit on branching fraction $B(t \rightarrow bH^{\pm})$ for charged MSSM Higgs boson from 1-5%
- Interpreted as exclusion on tanβ vs m_H planes

Many thanks to colleagues in ATLAS and to the LHC for its excellent performance!





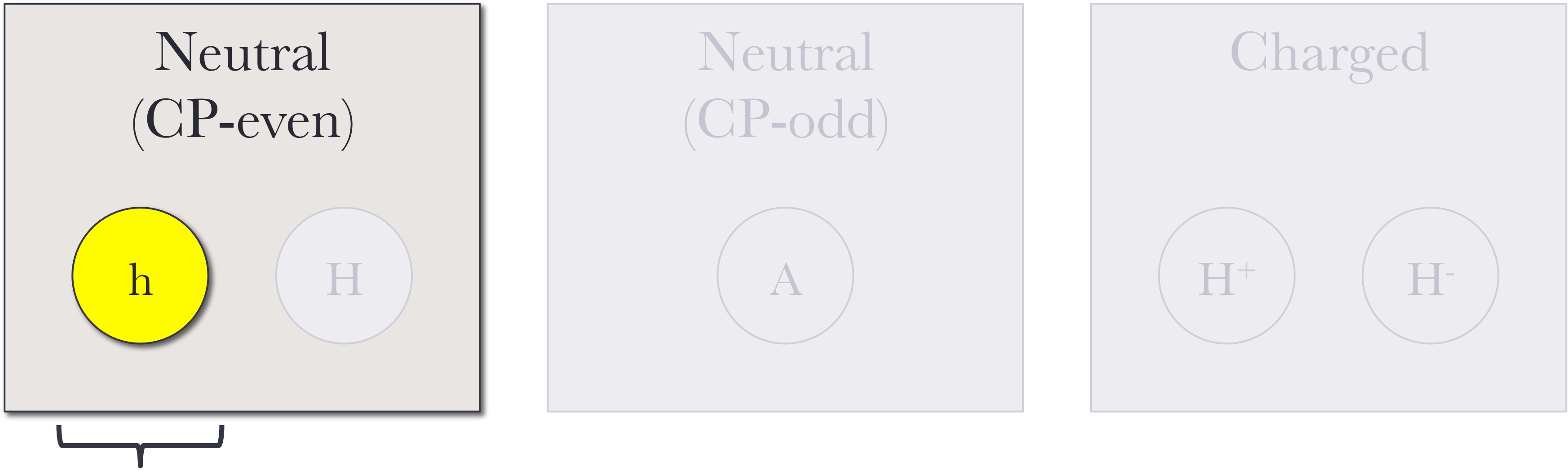
Backup



- Standard model Higgs analysis
- The ATLAS experiment
- Detailed τ lepton identification
- Likelihood analysis
- MMC method
- Vertex jet fraction
- Detailed systematic uncertainties

Standard Model Higgs analysis

$$\int L dt = 4.7\, fb^{-1}$$



Neutral
(CP-even)

h

H

Neutral
(CP-odd)

A

Charged

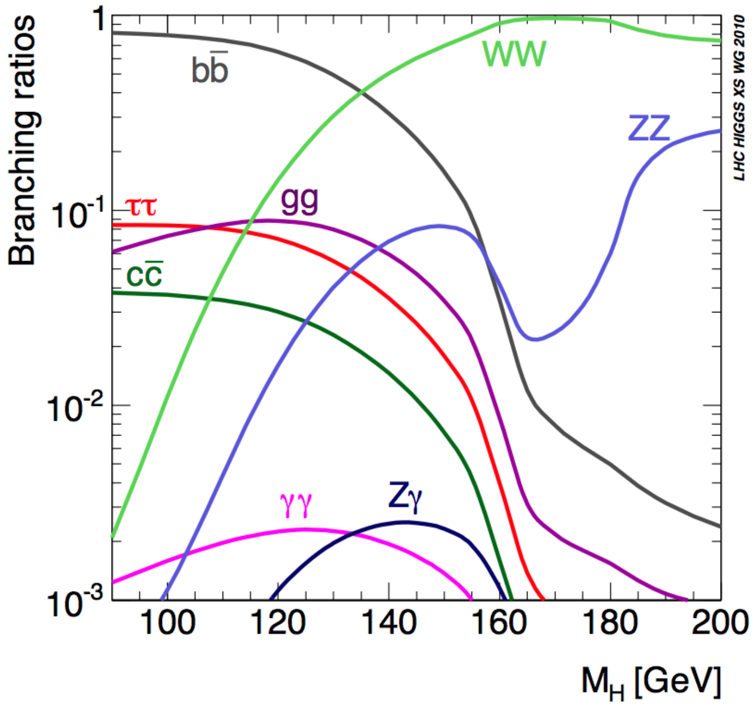
H^+

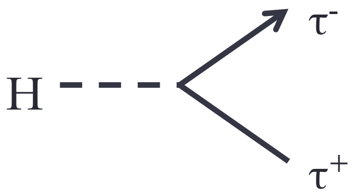
H^-

SM Higgs
analysis

Standard Model H→ττ

- The decay H→ττ is an important mode for the standard model Higgs search
- Sensitive in low mass searches (100-150GeVc^{-2})
- Observation confirms spin-0 or spin-1 nature of a new particle
  - Combine with H→γγ to demonstrate the existence of a massive scalar boson
- The decay is a tree level process
  - ~8% branching fraction
  - Relatively clean signal compared to bb





Standard Model $H \rightarrow \tau\tau$

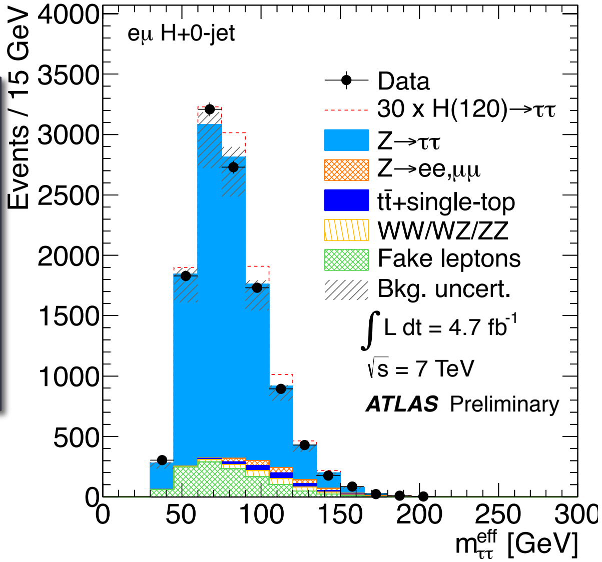
- All final states of the $\tau\tau$ system are considered:
  - $\tau\tau \rightarrow ll4\nu$ $(l=e,\mu)$
  - $\tau\tau \rightarrow l\tau_{had}3\nu$ $(l=e,\mu)$
  - $\tau\tau \rightarrow \tau_{had}\tau_{had}\nu\nu$
- The following object selections and triggers are applied:

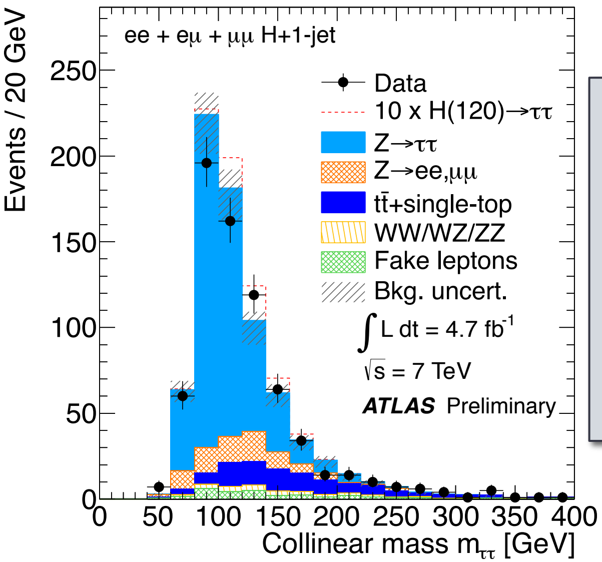
Electrons	**Muons**	**τ_{had}**
$E_T > 15\,\mathrm{GeV}$	$p_T > 15\,\mathrm{GeV}c^{-1}$	$p_T > 20\,\mathrm{GeV}c^{-1}$
Single electron trigger ($E_T > 20\,\mathrm{GeV}$)	Single muon trigger ($p_T > 18\,\mathrm{GeV}c^{-1}$)	Double hadronic τ trigger ($p_T > 29\,\mathrm{GeV}c^{-1}$, $20\,\mathrm{GeV}c^{-1}$)

Standard Model H→ττ (*ll4ν*)

H+0-jets

- Only em mode to suppress Z background
- ΔΦ(eμ)>2.5



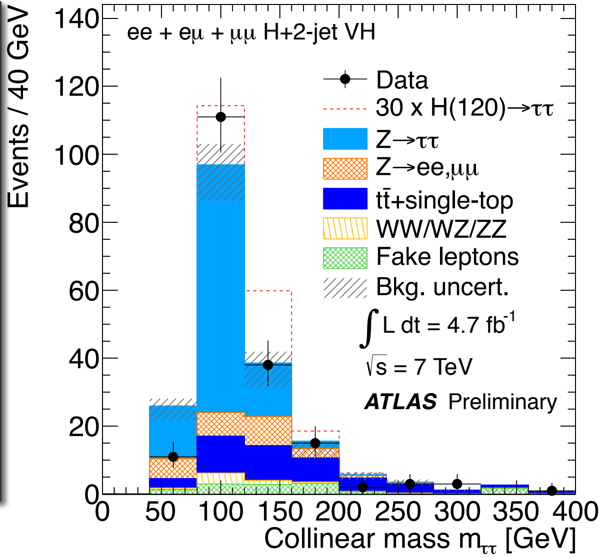


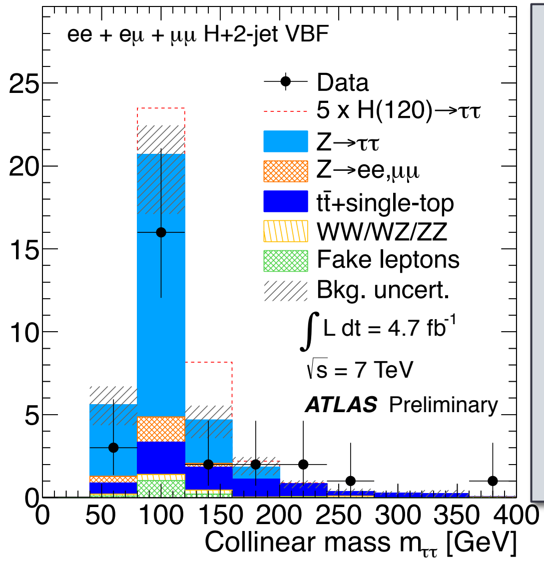
H+1-jet

- 1 jet with E_T>40GeV
- E_T^{miss}>40GeV for ee/μμ
- E_T^{miss}>20GeV for eμ

H+2-jet VH

- >0 jets with E_T>40, 25GeV
- E_T^{miss}>40GeV for ee/μμ
- E_T^{miss}>20GeV for eμ
- 50 < m(jj) < 120GeVc^{-2}





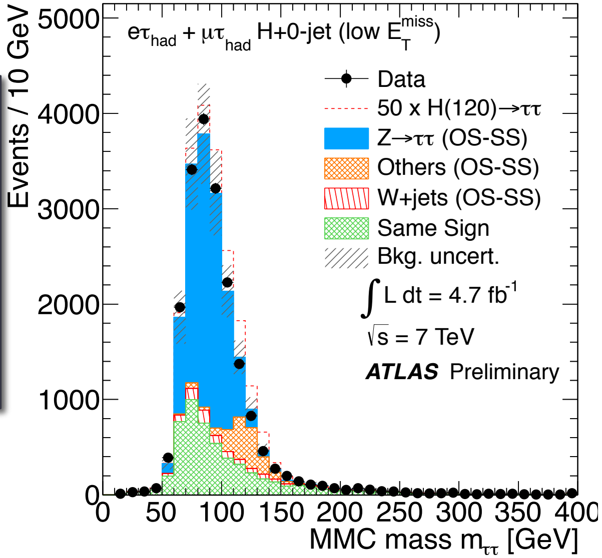
H+2-jets VBF

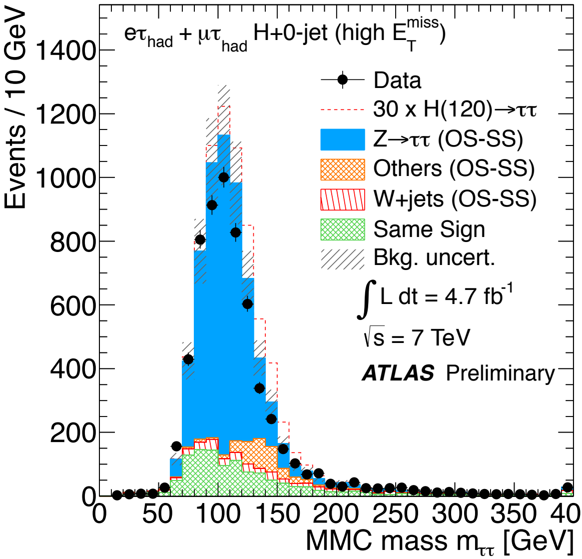
- Two jets with E_T>40, 25GeV
- E_T^{miss}>40GeV for ee/μμ
- E_T^{miss}>20GeV for eμ
- Δη(jj)>3
- m(jj)>350GeVc^{-2}

Standard Model H→ττ ($l\tau_{had}3\nu$)

H+0-jets Low E_T^{miss}

- No jets with E_T>25GeV
- E_T^{miss}<20GeV



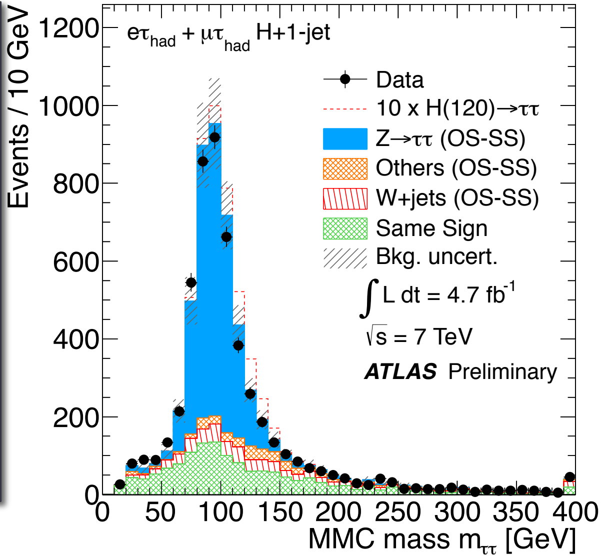


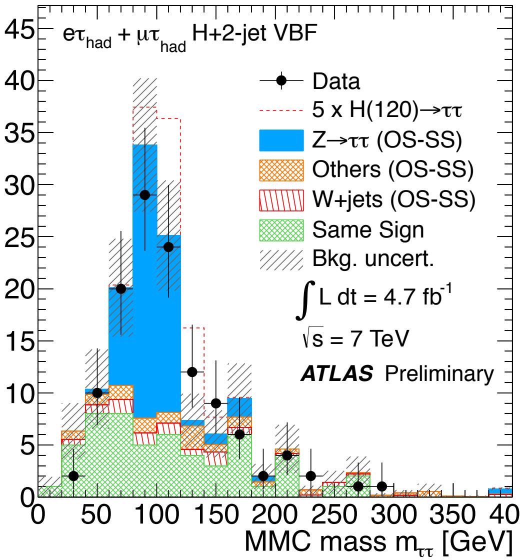
H+0-jets High E_T^{miss}

- No jets with E_T>25GeV
- E_T^{miss}>20GeV

H+1-jet

- >0 jets with E_T>25GeV
- E_T^{miss}>20GeV
- Event fails VBF selection
- Separation of e and μ modes



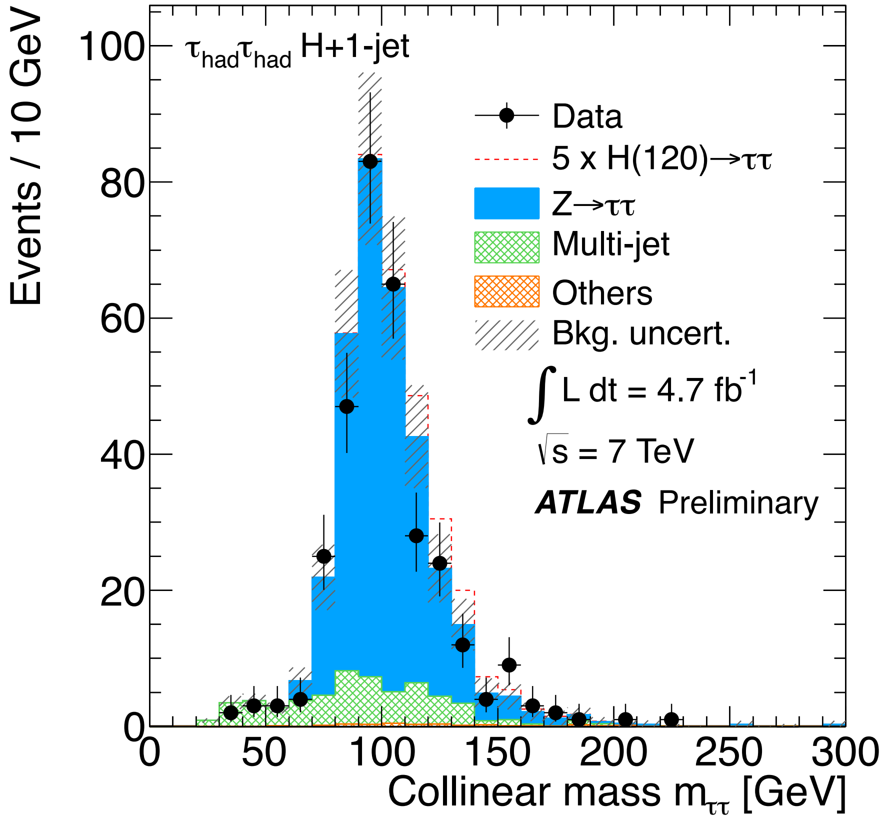


H+2-jets VBF

- At least two jets with E_T>25GeV
- E_T^{miss}>20GeV
- $\eta(j1).\eta(j2)<0$
- $\Delta\eta(jj)>3$
- $m(jj)>300GeVc^{-2}$
- l and τ_{had} between jets in η

Standard Model H→ττ ($\tau_{had}\tau_{had}2\nu$)

- Only one category
  - H+1-jet
- Background estimation:
  - Z→ττ estimate comes from data driven methods
  - QCD multi jet background estimate comes from:
    - SS sample in data
    - two dimensional track fitting multiplicity in data



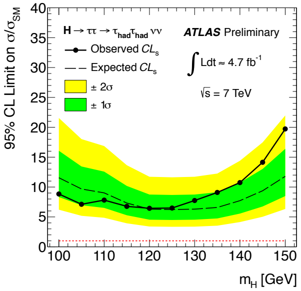
H+1-jet

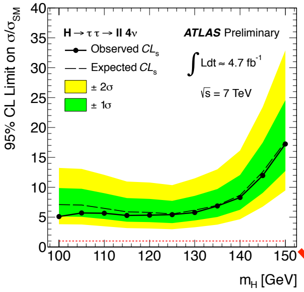
- At least 1 jet with E_T>40GeV
- E_T^{miss}>20GeV
- $\Delta R(\tau\tau)$<2.2
- $m(\tau\tau j)$>225GeVc^{-2}

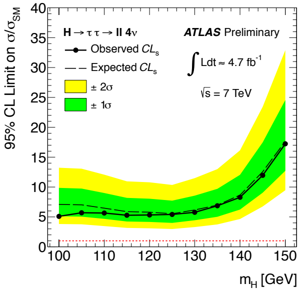
Standard Model H→ττ results

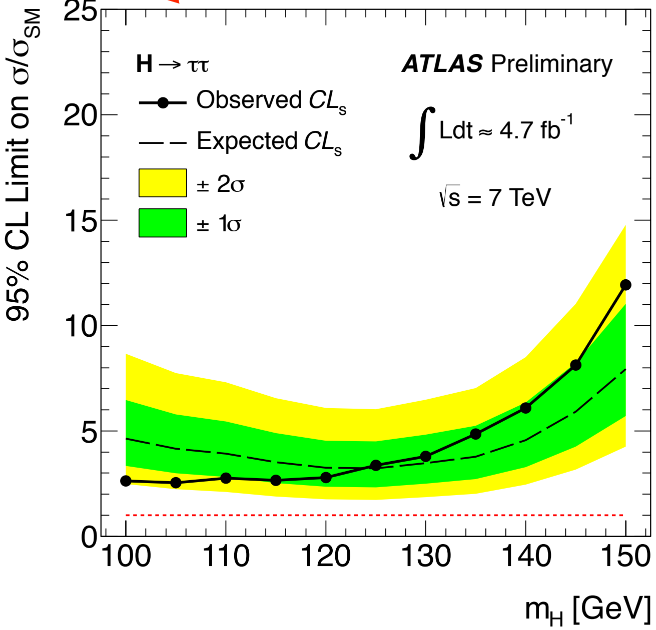
- Over the range $100\mathrm{GeVc}^{-2} < m_H < 150\mathrm{GeVc}^{-2}$ there is no observation of an excess
- Combined expected limits range from 3.2-7.9 times the SM
- Similar sensitivity in all modes
- Most significant deviation (150GeVc-2) is less than 2σ
- Stay tuned for updates as luminosity and energy increase!

Source	Systematic uncertainty
QCD scale	8-25%
Jet production cross section	24% per jet
Jet energy scale	up to 12%
Fake leptons/τ_{had}	6-40%



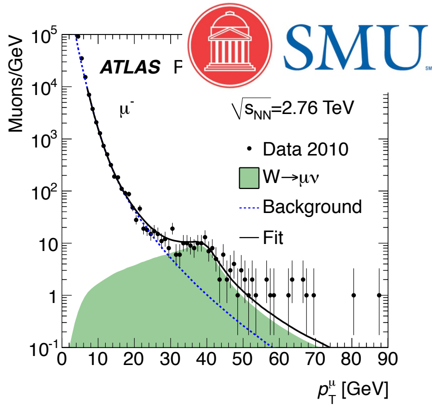


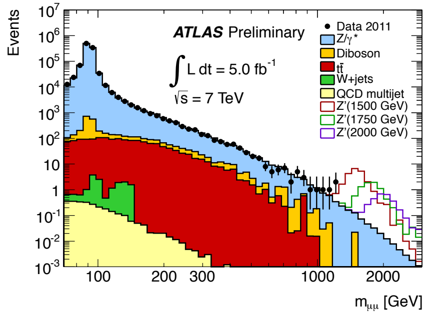


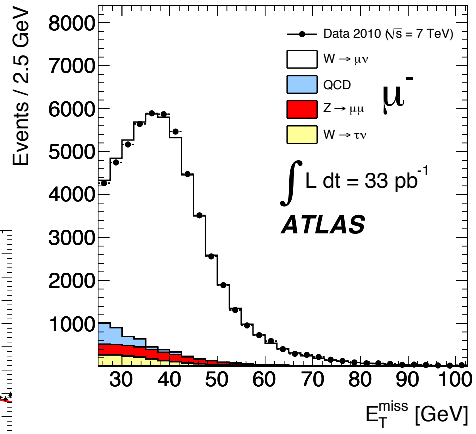


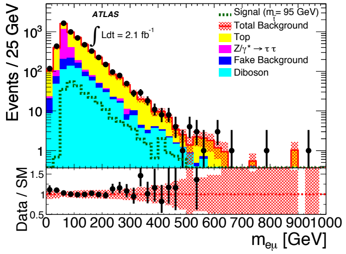
The ATLAS experiment

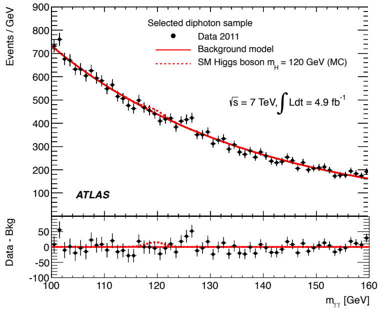
- ATLAS is a general purpose experiment
- Wide range of analyses:
  - Standard Model physics
  - Standard Model Higgs
  - Beyond Standard Model Higgs
  - Exotica (Z', W'…)
  - Top physics
  - Heavy ions
  - B physics
  - SUSY

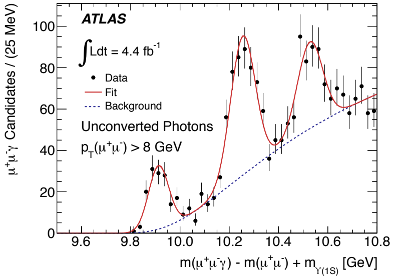


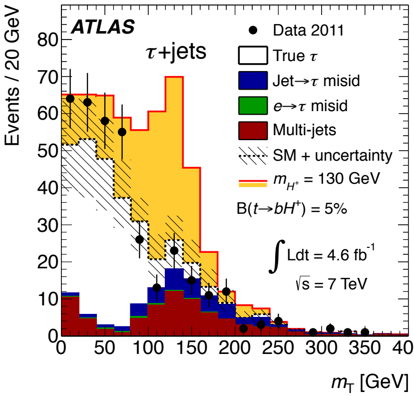


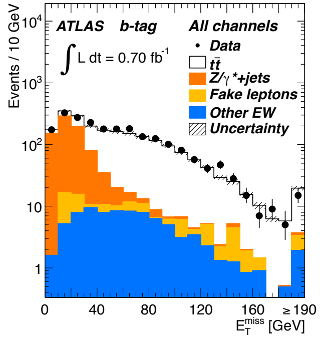


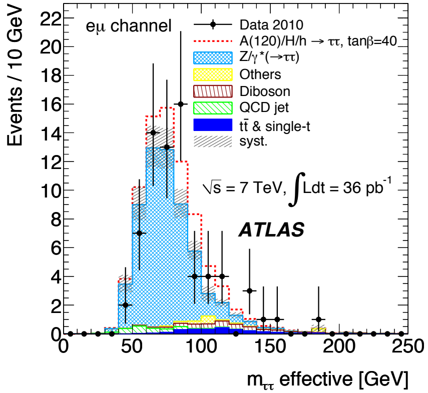












τ leptons identification classifiers

- Use simple selection (cut) based, likelihood, and boosted decision tree (BDT) classifiers to reject fakes.
- Jets (arising from quarks and gluons) and electrons treated are separately:

	Jet rejection	Electron rejection
Monte Carlo (MC) samples	pythia W→τν, Z→ττ, Z'→ττ	pythia Z→ττ, Z→ee for BDT
Data samples	QCD background from dijet events	Z→ee for cut based Tag and probe Z→ee
Classifiers	• Cut based (care taken to reduce pileup dependence) • Likelihood • BDT	• Cut based • BDT
1 prong / 3 prong	Separate classifiers for 1 prong and 3 prong decays	Important primarily for 1 prong decays

Likelihood analysis

- For a spectrum with N bins with probability functions θ, hypothesize s signal events and f_b background events
- Likelihood takes the following form where f_b depends on θ:

$$L(\mu,\theta) = \prod_{i=1}^{N} \frac{(\mu s_i + \theta f_{b,i})^{n_i}}{n_i!} e^{-(\mu s_i + \theta f_{bi})}$$

- μ represents the strength of signal process
  - (μ=0 for background only, μ=1 for expected signal)

Most likely θ for given μ

- Take the ratio λ to test for a given μ: $\lambda(\mu) = L\left(\mu, \hat{\theta}_\mu\right) \div L\left(\hat{\mu}, \hat{\theta}\right)$
- Combining multiple channels gives $\lambda(\mu) = \prod_i L_i\left(\mu_i, \hat{\theta}_{\mu i}\right) \div \prod_i L_i\left(\hat{\mu}_i, \hat{\theta}_i\right)$
- Minimize t = -2lnλ(μ) to find value of μ most compatible with data
  - Take look elsewhere effect into account

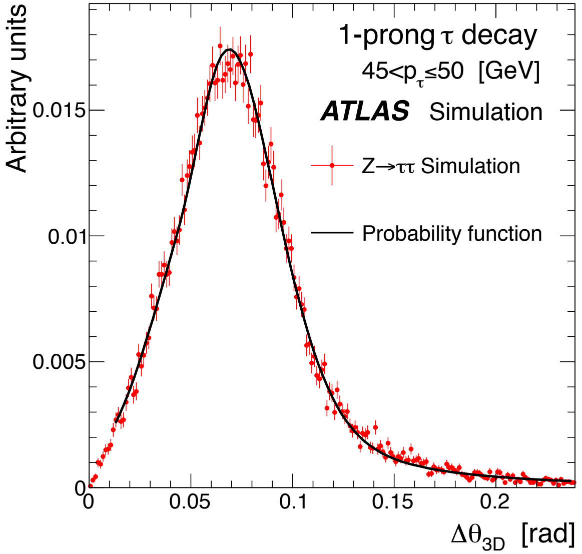
MMC method

- Find the best transverse momenta for invisible particles by solving four equations:

$$E_x^{miss} = \sum_{i=1,2} p_{miss1} \sin\theta_{miss}^{i} \cos\phi_{miss}^{i} p_{miss}^{i} \qquad E_y^{miss} = \sum_{i=1,2} p_{miss1} \sin\theta_{miss}^{i} \sin\phi_{miss}^{i} p_{miss}^{i}$$

$$i=1,2: m_\tau^2 = \left(m_{miss}^{i}\right)^2 + \left(m_{vis}^{i}\right)^2 + 2\sqrt{\left(\left(p_{vis}^{i}\right)^2 + \left(m_{vis}^{i}\right)^2\right)\left(\left(p_{miss}^{i}\right)^2 + \left(m_{miss}^{i}\right)^2\right)} - 2p_{vis}^{i} p_{miss}^{i} \cos\Delta\theta_{vm_i}$$

- There are more unknown quantities than constraints, so scan the $\Delta\Phi_1$-$\Delta\Phi_2$ plane (where $\Delta\Phi_i = \Phi_{\tau i}^{invisible} - \Phi_{\tau i}^{visible}$)
- Weight candidates by probability density function obtained from simulation
- Choose most probable values of $\Delta\Phi_i$



Jet vertex fraction

- Jet vertex fraction (JVF) of a jet measures the probability that a jet is associated with a given primary vertex:
    - JVF uses track information with primary vertices and combining these with calorimeter jets
    - JVF safe as the average number of simultaneous uncorrelated soft collisions (pileup) increases

Neutral MSSM $H \rightarrow \tau\tau$ detailed selection

- The following final states of the $\tau\tau$ system are considered:
  - $\tau\tau \rightarrow e\mu 4\nu$
  - $\tau\tau \rightarrow l\tau_{had}3\nu$ (l=e,μ)
  - $\tau\tau \rightarrow \tau_{had}\tau_{had}\nu\nu$

Electrons

- Transverse energy (E_T)>15GeV
- $|\eta|<2.47$ excluding $1.37<|\eta|<1.52$
- E_{iso} in cone DR<0.2 less than 8% of $E_T(e)$
- p_{iso} in cone DR<0.4 less than 6% of $p_T(e)$

$\tau_{hadronic}$

- $p_T>20GeVc^{-1}$
- $|\eta|<2.5$
- 1 prong or 3 prong (each prong $p_T>1GeVc^{-1}$) with charge of ±1

Muons

- Transverse momentum (p_T)>15GeVc^{-1}
- $|\eta|<2.5$
- E_{iso} in cone $\Delta R<0.2$ less than 4% of $p_T(\mu)$
- p_{iso} in cone $\Delta R<0.4$ less than 6% of $p_T(\mu)$
- z distance from primary vertex < 1cm

Charged MSSM $H^{\pm} \rightarrow \tau\nu$ detailed selection

- Three modes considered:

lepton+jets

- W decays hadronically
- τ decays leptonically

$$t\bar{t} \rightarrow b\bar{b}(q'\bar{q})(\tau_{lep}\nu)$$

τ+lepton

- W decays leptonically
- τ decays hadronically

$$t\bar{t} \rightarrow b\bar{b}(l\nu)(\tau_{had}\nu)$$

τ+jets

- W decays hadronically
- τ decays hadronically

$$t\bar{t} \rightarrow b\bar{b}(q'\bar{q})(\tau_{had}\nu)$$

- The following object selections are applied:

Electrons

- $E_T > 20$GeV
- $|\eta| < 2.47$, excluding $1.37 < |\eta| < 1.52$
- η and E_T dependent isolation requirement

Muons

- $p_T > 15$GeVc^{-1}
- $|\eta| < 2.5$
- E_{iso} in cone $\Delta R < 0.2$ less than 4GeV
- p_{iso} in cone $\Delta R < 0.4$ less than 2.5GeVc^{-1}

$\tau_{hadronic}$

- $p_T > 20$GeVc^{-1}
- $|\eta| < 2.3$
- 1 prong or 3 prong (each prong $p_T > 1$GeVc^{-1}) with charge of ±1

Jets

- b-jet tagging algorithms used to identify b-jets
- $|\eta| < 2.4$
- Jets matched to primary vertex (JVF)

MSSM H→ττ full systematic uncertainties I (eμ mode)

- Uncertainties are expressed as a fraction of the yield per background sample

Source	W+jets	Diboson	top	Z→*ll*	Z→ττ	signal
Inclusive cross section	-	7%	10%	5%	5%	14%
Detector acceptance	-	4%	3%	2%	5%	5%
e efficiency	-	4%	4%	4%	4%	4%
μ efficiency	-	2%	2%	2%	2%	2%
τ efficiency and fake rate	-	-	-	-	-	-
Energy scale and resolution	-	2%	6%	1%	1%	1%
Luminosity	-	3.7%	3.7%	3.7%	3.7%	3.7%
Total	-	10%	13%	8%	9%	16%

MSSM H→ττ full systematic uncertainties II ($l\tau_{had}$ mode)

- Uncertainties are expressed as a fraction of the yield per background sample

Source	W+jets	Diboson	top	Z→*ll*	Z→ττ	signal
Inclusive cross section	-	7%	10%	5%	5%	14%
Detector acceptance	-	2%	2%	14%	14%	7%
e efficiency	-	3.1%	3.6%	3.1%	3.0%	3.6%
μ efficiency	-	1.2%	1.1%	1.3%	1.8%	1.0%
τ efficiency and fake rate	-	9.1%	9.1%	48%	9.1%	9.1%
Energy scale and resolution	-	$^{+19\%}_{-9\%}$	$^{+5\%}_{-4\%}$	$^{+39\%}_{-25\%}$	11%	$^{+30\%}_{-23\%}$
Luminosity	-	3.7%	3.7%	3.7%	3.7%	3.7%
Total	-	$^{+23\%}_{-16\%}$	15%	$^{+64\%}_{-56\%}$	21%	$^{+35\%}_{-30\%}$

MSSM H→ττ full systematic uncertainties III ($\tau_{had}\tau_{had}$ mode)

- Uncertainties are expressed as a fraction of the yield per background sample

Source	W+jets	Diboson	top	Z→*ll*	Z→ττ	signal
Inclusive cross section	5%	7%	10%	-	5%	16%
Detector acceptance	20%	7%	9%	-	14%	9%
e efficiency	0.8%	0.5%	0.3%	-	0.5%	0.1%
μ efficiency	0.3%	0.4%	0.0%	-	0.4%	0.1%
τ efficiency and fake rate	21%	15	13%	-	15%	15%
Energy scale and resolution	$^{+34\%}_{-21\%}$	$^{+26\%}_{-12\%}$	12%	-	$^{+63\%}_{-23\%}$	$^{+9\%}_{-8\%}$
Luminosity	3.7%	3.7%	3.7%	-	3.7%	3.7%
Total	$^{+45\%}_{-36\%}$	$^{+32\%}_{-22\%}$	23%	-	$^{+67\%}_{-31\%}$	$^{+26\%}_{-25\%}$

H$^{\pm}$→τν full systematic uncertainties I (lepton+jets mode)

Source	**Uncertainty**
control region	6%
Z mass window	4%
jet energy scale	16%
jet resolution	7%
sample composition	31%

H± → τν full systematic uncertainties II (τ+lepton mode)

Source	**Uncertainty**
statistics in control region	2%
jet composition	11%
object-related systematic uncetainties	23% normalization + 3% shape
τ+lepton e→τ misidentification probability	20%
lepton misidentification study: choice of control region	4%
lepton misidentification study: Z mass window	5%
lepton misidentification study: jet energy scale	14%
lepton misidentification study: jet resolution	4%
lepton misidentification study: sample composition	39%

$H^{\pm}\rightarrow\tau\nu$ full systematic uncertainties III (τ+jets mode)

Source	Uncertainty
embedding parameters	6% normalization + 3% shape
muon isolation	7% normalization + 2% shape
parameters in normalization	16%
τ identification	5%
τ energy scale	6% normalization + 1% shape
jet→τ misidentification study: statistics in control region	2%
jet→τ misidentification study: jet composition	12%
jet→τ misidentification study: purity in control region	6% normalization + 1% shape
jet→τ misidentification study: object related systematic uncertainties	21% normalization + 2% shape
e→τ misidentification probability	22%
multi jet fit related uncertainties	32%
multi jet E_T^{miss} shape in control region	16%

$H^{\pm} \rightarrow \tau\nu$ full systematic uncertainties IV (generator uncertainties)

Source	Uncertainty
lepton+jets generator and parton shower (bbW^-H^+ signal region)	10%
lepton+jets generator and parton shower (bbW^+H^- signal region)	8%
lepton+jets generator and parton shower (bbW^-H^+ control region)	7%
lepton+jets generator and parton shower (bbW^+H^- control region)	6%
lepton+jets initial and final state radiation (signal region)	8%
lepton+jets initial and final state radiation (control region)	13%
τ+lepton generator and parton shower (bbW^-H^+)	2%
τ+lepton generator and parton shower (bbW^+H^-)	5%
τ+lepton initial and final state radiation	13%
τ+jets generator and parton shower (bbW^-H^+)	5%
τ+jets generator and parton shower (bbW^+H^-)	5%
τ+jets initial and final state radiation	19%

SM H→ττ full systematic uncertainties

Source	Uncertainty
QCD scale	8-25%
Vector boson production cross section	4-5%
Jet production cross section	24% per jet
QCD production cross section (including top)	3-6%
Parton distribution function	8%
Luminosity	3.9%
Trigger efficiencies	1-2%
Jet energy scale	up to 12%
τ energy scale	2-5%
Fake leptons/τ_{had}	6-40%

References

- ATLAS Collaboration
  - http://www.atlas.ch
- Search for neutral MSSM Higgs bosons decaying to tau+tau- pairs in proton-proton collisions at sqrt(s) = 7 TeV with the ATLAS detector
  - https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-132/
- Search for charged Higgs bosons decaying via H+ -> taunu in top quark pair events using pp collision data at sqrt(s) = 7 TeV with the ATLAS detector
  - https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HIGG-2012-09/
- Search for the Standard Model Higgs boson in the H->tau tau decay mode with 4.7 fb^-1 of ATLAS data at sqrt(s)=7TeV
  - https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2012-014/
- Performance of the Reconstruction and Identification of Hadronic Tau Decays with ATLAS
  - https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CONFNOTES/ATLAS-CONF-2011-152/
- Asymptotic formulae for likelihood-based tests of new physics
  - http://arxiv.org/abs/1007.1727

- Further reading for MSSM scenarios:
  - H. P. Nilles, Phys. Rep. 110 (1984) 1. (available at http://ccdb5fs.kek.jp/cgi-bin/img_index?8303226)
  - H. E. Haber and G. L. Kane, Phys. Rep. 117 (1985) 75. (available at http://www.sciencedirect.com/science/article/pii/0370157385900511)