Tau physics in ATLAS

23rd Rencontres de Blois
Particle Physics and Cosmology

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on behalf of the ATLAS collaboration

Outline and Introduction

Outline:

- Tau lepton identification and reconstruction in ATLAS
- Standard Model processes with tau leptons: $Z \rightarrow \tau\tau$ and $W \rightarrow \tau_h\nu$
- Higgs boson search in tau decay channels: MSSM $A/H/h \rightarrow \tau\tau$ and $H^+ \rightarrow \tau\nu$

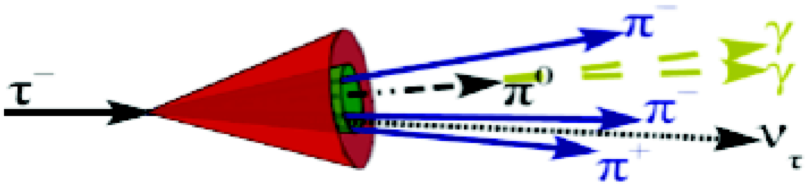
Processes with tau leptons important for
- "New" physics searches:
  - Higgs boson
  - Supersymmetry
  - Exotic models
- Measurement and understanding of $Z \rightarrow \tau\tau$ and $W \rightarrow \tau_h\nu$ as backgrounds for searches

Tau leptons

Properties:
m_τ = 1.78 GeV
$c\tau$ = 87 μm
Decay modes:

Leptonic (e,μ + νν)	35.2%
Hadronic 1 prong	49.5%
Hadronic 3 prong	15.2%

Hadronically decaying tau leptons:



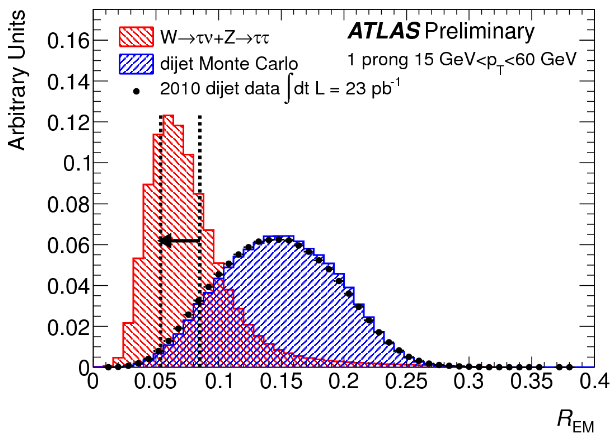
- Tracks of 1 or 3 charged hadrons

- Collimated calorimeter energy depositions

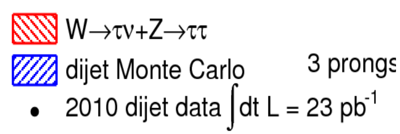
Shower width and composition (shower radius and isolation, EM fraction)

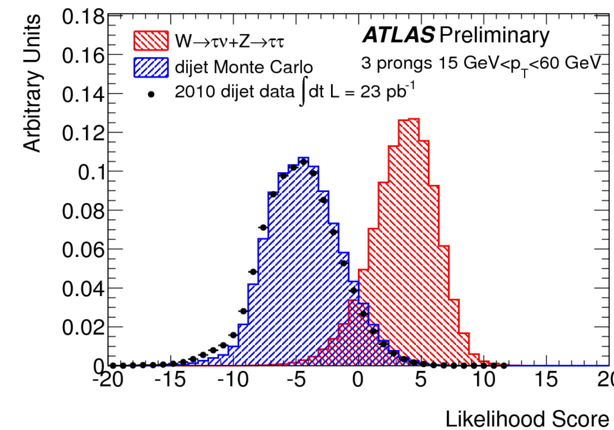
Tau reconstruction and identification in ATLAS

- Hadronically decaying tau candidates seeded by calorimeter jets and tracks matched to candidates
- Distinction between tau leptons and jets:
  Different identification criteria: cut based, boosted decision tree (BDT), likelihood (LLH)

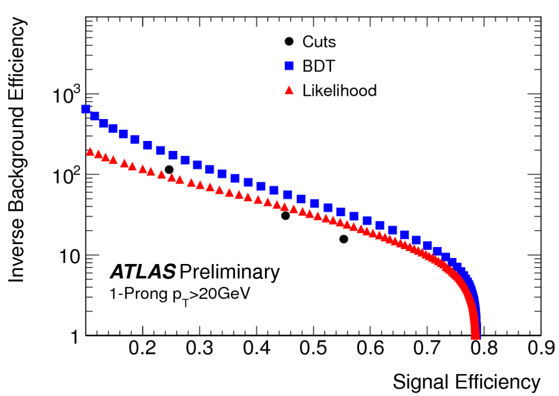


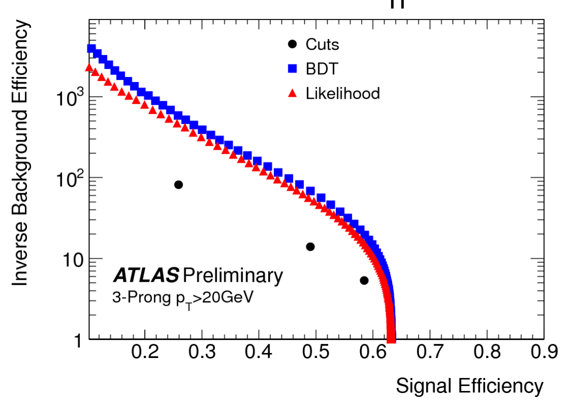
Cuts based on 3 variables
- Shower width in em. Calorimeter
- Track width
- Leading track momentum





- Performance: Signal MC Z → ττ and W → $\tau_h\nu$, Background dijet data





trained separately for #prongs

→ Good agreement between data and Monte Carlo

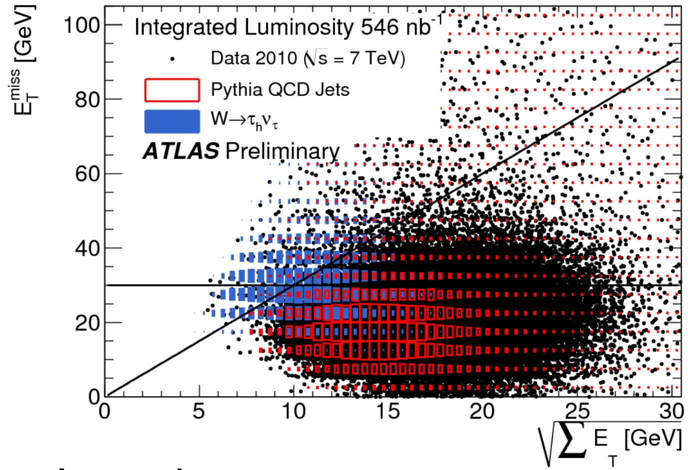
ATLAS-CONF-2011-077

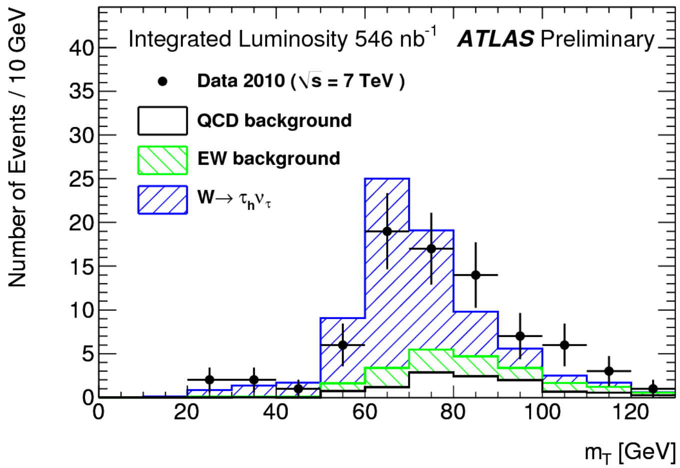
SM processes: W → $\tau_h \nu$ observation

ATLAS-CONF-2010-097

Selection for analysis with 546 nb^{-1}:
- $\tau_h + E_T^{miss}$ trigger
- Tight τ_h with 20 GeV < p_T < 60 GeV
- Veto on leptons with p_T > 5 GeV
- $\Delta\phi(\text{jet}, E_T^{miss}) > 0.5$ rad
- E_T^{miss} > 30 GeV
- E_T^{miss} significance > 6

Backgrounds: Multijet (estimated from data), W → lν, Z → ll, Z → ττ





Transverse mass

- Observation:
78 events in data selected
55 ± 12 events observed signal
55 ± 16 events expected signal from MC

- Main systematic uncertainties: energy scale, MC model

→ Observed signal consistent with SM expectation
→ hadronically decaying tau leptons in data established

Analysis on full dataset in preparation

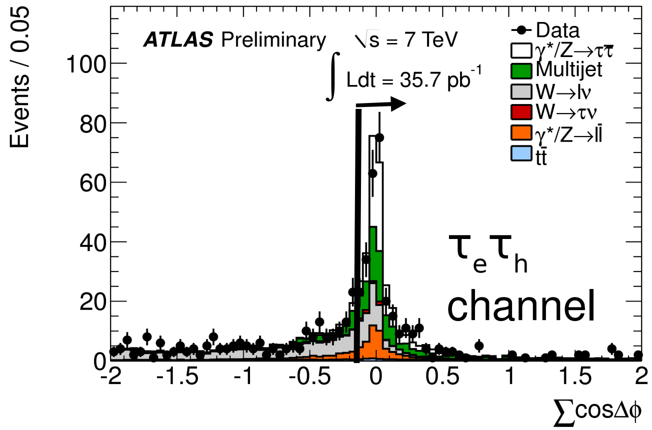
SM processes: Z → ττ cross section measurement

Measurement of Z → ττ cross section with 36 pb^{-1} combining 4 channels:
$\tau_\mu\tau_h$ channel, $\tau_e\tau_h$ channel, $\tau_e\tau_\mu$ channel and $\tau_\mu\tau_\mu$ channel

Selection for Z → $\tau_h\tau_l$:

- Single lepton trigger
- One e p_T > 16 GeV or one μ p_T > 15 GeV
- One tight τ_h p_T > 20 GeV, 1 or 3 tracks
- Tight lepton isolation
- M_T < 50 GeV and $\Sigma\cos\Delta\phi(l, E_T^{miss})$ > - 0.15
- Opposite charge of lepton and τ_h
- 35 GeV < $m_{visible}$ < 75 GeV

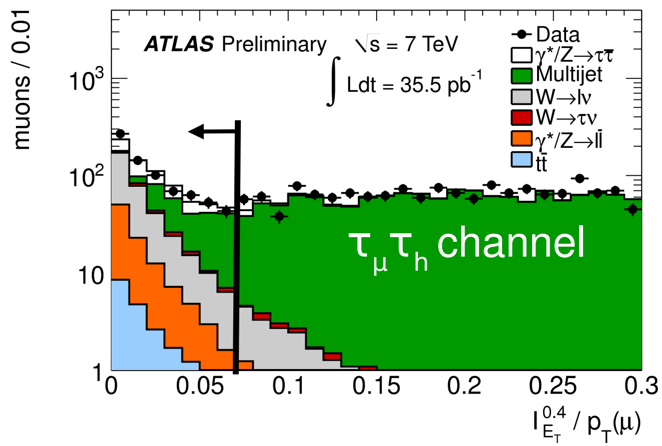
W+jets suppression:



Multijet suppression: Tight lepton isolation

- Sum of transverse momentum of tracks in ΔR = 0.4 cone divided by lepton p_T

- Sum of energy in calorimeter in ΔR = 0.4/0.3 cone divided by lepton p_T

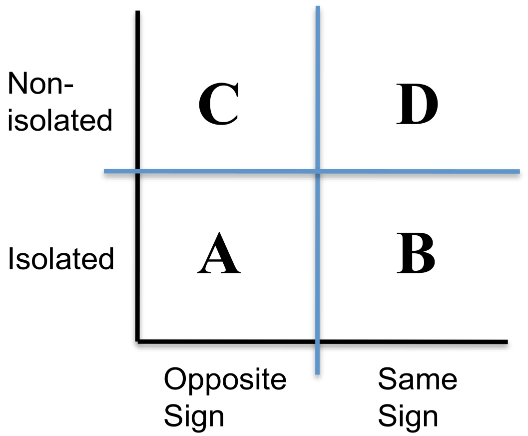


Multijet from data

SM processes: Z → ττ cross section measurement

Multijet background estimation from data:

- ABCD method OS/SS and lepton isolation



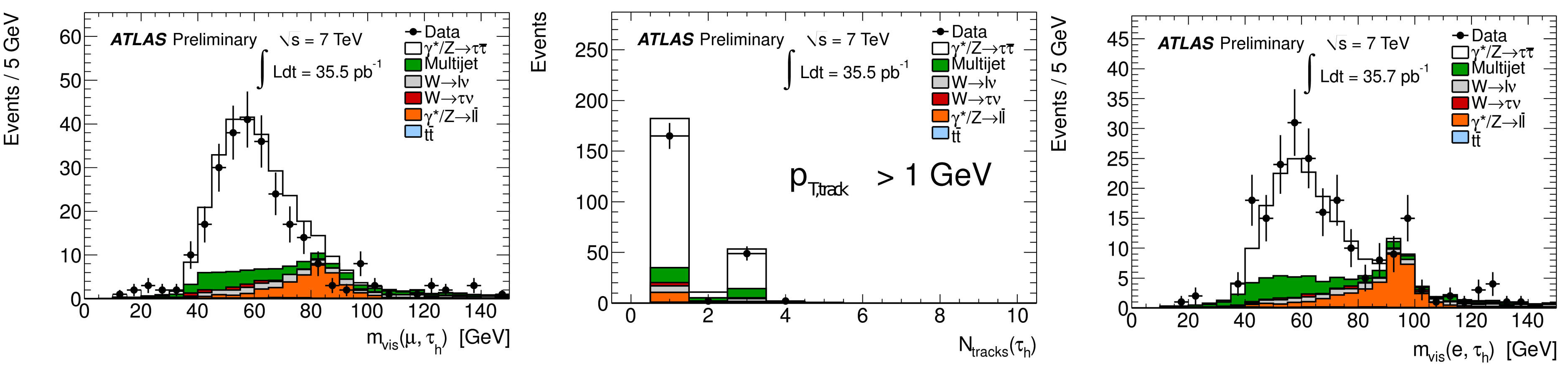
$$N^A = N^B\left(\frac{N^C}{N^D}\right) = N^B\,R_{\text{iso}}$$

EW, tt background subtracted in control regions

W+jets background:

- Normalization in W-dominated control region from data
- Shape from MC

Result for Z → $\tau_h\tau_l$: Visible mass and #track(τ) distributions for $\tau_\mu\tau_h$ and $\tau_e\tau_h$ channels



SM processes: $Z \rightarrow \tau\tau$ cross section measurement

Selection for $Z \rightarrow \tau_e\tau_\mu$:

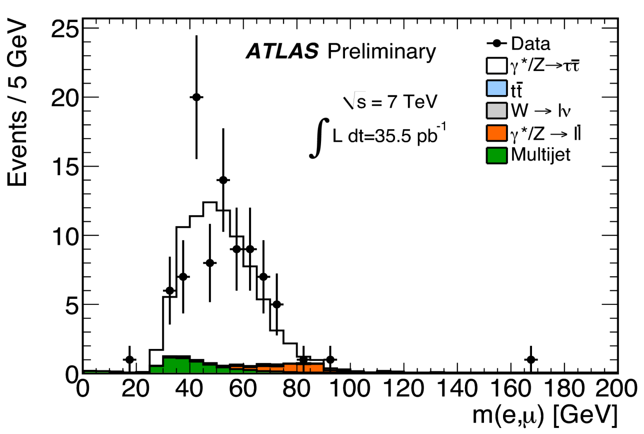
- One e $p_T > 15$ GeV and one μ $p_T > 10$ GeV of opposite charge and tight isolated
- $\Sigma\cos\Delta\phi(l, E_T^{miss}) > -0.15$
- $\Sigma E_T + E_T^{miss} < 150$ GeV
- 25 GeV < $m_{e\mu}$ < 80 GeV

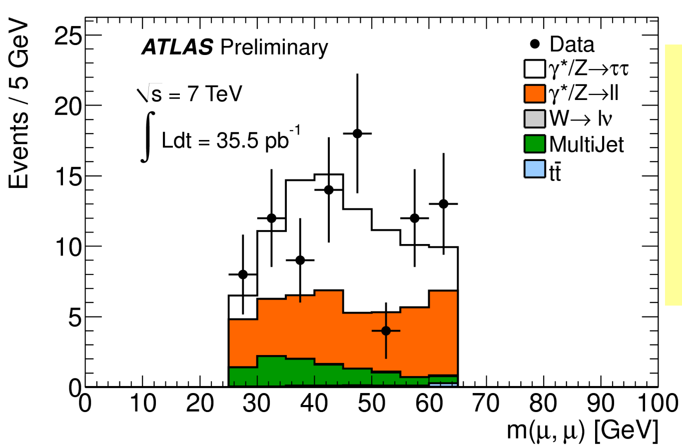
Selection for $Z \rightarrow \tau_\mu\tau_\mu$:

- One μ $p_T > 15$ GeV and one μ $p_T > 10$ GeV of opposite charge and isolated
- 25 GeV < $m_{\mu\mu}$ < 65 GeV
- BDT using 4 variables trained to separate $Z \rightarrow \tau_\mu\tau_\mu$ and $\gamma^*/Z \rightarrow ll$

- Multijet background estimated from data
- 85 events in data selected
- 76 ± 10 events observed signal

- Multijet background estimated from data
- 90 events in data selected
- 43 ± 10 events observed signal





→ $\gamma^*/Z \rightarrow ll$ suppressed and $Z \rightarrow \tau_\mu\tau_\mu$ signal visible

SM processes: $Z \to \tau\tau$ cross section measurement

Fiducial cross section: $\sigma^{fid}(Z \to \tau\tau) \times B(\tau \to l\nu\nu,\ \tau \to l\nu\nu /\ \tau_{had}\nu) = \dfrac{N_{obs} - N_{bkg}}{C_Z \cdot \mathcal{L}}$

Total cross section in invariant mass of $66 < m_{\tau\tau} < 116$ GeV: $\sigma(Z \to \tau\tau) \times B(\tau \to l\nu\nu, \tau \to l\nu\nu /\ \tau_{had}\nu) = \dfrac{N_{obs} - N_{bkg}}{A_Z \cdot C_Z \cdot \mathcal{L}}$

- C_Z correction factor taking into account detector effects (e.g Id efficiencies)
- A_Z geometrical acceptance
- Corrections included for events outside the invariant mass window

Final State	Measured Fiducial Cross-section
$\tau_\mu\tau_h$	$23 \pm 2(\text{stat}) \pm 3(\text{syst}) \pm 1(\text{lumi})$ pb
$\tau_e\tau_h$	$27 \pm 3(\text{stat}) \pm 5(\text{syst}) \pm 1(\text{lumi})$ pb
$\tau_e\tau_\mu$	$7.5 \pm 1.0(\text{stat}) \pm 0.5(\text{syst}) \pm 0.3(\text{lumi})$ pb
$\tau_\mu\tau_\mu$	$4.5 \pm 1.1(\text{stat}) \pm 0.6(\text{syst}) \pm 0.2(\text{lumi})$ pb
Final State	**Measured Total Cross-section ($66 < m_{\text{inv}} < 116$ GeV)**
$\tau_\mu\tau_h$	$0.86 \pm 0.08(\text{stat}) \pm 0.12(\text{syst}) \pm 0.03(\text{lumi}) \pm 0.003(\text{theo})$ nb
$\tau_e\tau_h$	$1.14 \pm 0.14(\text{stat}) \pm 0.20(\text{syst}) \pm 0.04(\text{lumi}) \pm 0.004(\text{theo})$ nb
$\tau_e\tau_\mu$	$1.06 \pm 0.14(\text{stat}) \pm 0.08(\text{syst}) \pm 0.04(\text{lumi}) \pm 0.004(\text{theo})$ nb
$\tau_\mu\tau_\mu$	$0.96 \pm 0.22(\text{stat}) \pm 0.13(\text{syst}) \pm 0.03(\text{lumi}) \pm 0.002(\text{theo})$ nb

Main systematic uncertainties:

- Energy scale $\tau_l\tau_h$ 11 %
- Tau efficiency $\tau_l\tau_h$ 8.6%
- Muon efficiency 4%
- Electron efficiency 3-10%

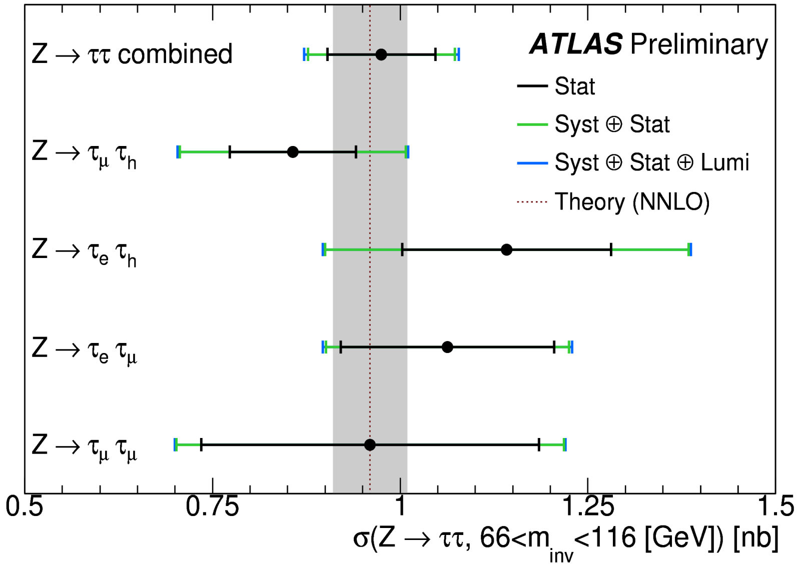
- A_Z 3%
- Luminosity 3.4%

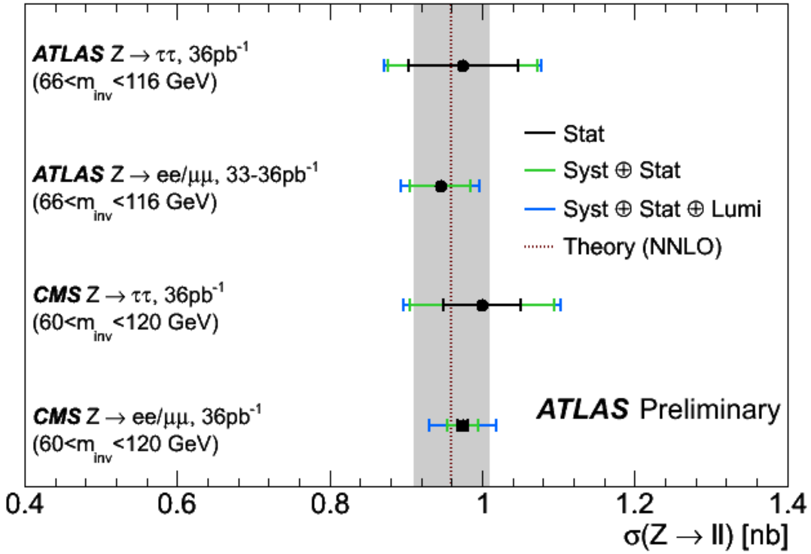
SM processes: Z → ττ cross section measurement

Combination:

$$\sigma_{combined} = 0.97 \pm 0.07\ (\text{stat.}) \pm 0.07\ (\text{syst.}) \pm 0.03\ (\text{lumi.})\ \text{nb}$$

$$\sigma_{theo} = 0.96 \pm 0.05\ \text{nb}$$





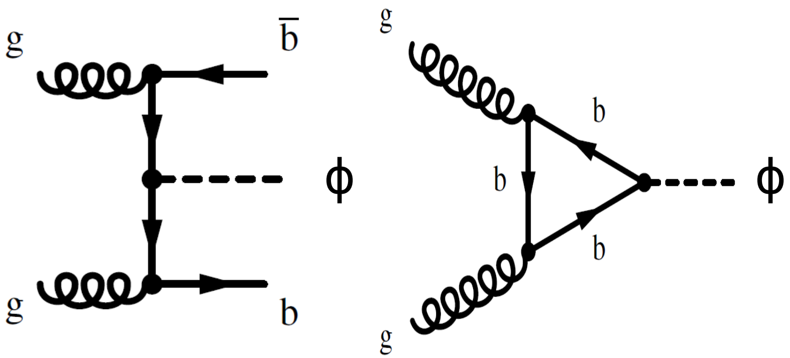
ATLAS-CONF-2011-041
CMS-PAS-EWK-10-005
arXiv:1104.1617 [hep-ex]

→ Total cross section of γ*/Z → ττ in invariant mass of 66 < m_{inv} < 116 GeV in good agreement with theoretical expectation

Higgs boson search: A/H/h → $\tau\tau$

MSSM: 2 Higgs doublets
- 5 Higgs bosons ϕ = h, H, A, $H^{\pm}$
- m_h^{max} benchmark scenario
- Free parameters: $\tan\beta$ and m_A
- Strong coupling to down-type fermions, production $\alpha \tan\beta^2$
- Dominant production

Direct bbϕ gg → ϕ



Results for A/H/h → $\tau_h\tau_l$ and A/H/h → $\tau_e\tau_\mu$

Main backgrounds:
Z → $\tau\tau$, W+jets, (Z → ll and Multijets)

Selection for A/H/h → $\tau_h\tau_l$ with 36 pb^{-1}:
- Single lepton trigger
- One isolated e p_T > 20 GeV or μ p_T > 15 GeV
- One loose τ_h p_T > 20 GeV, 1 or 3 tracks
- Opposite charge of lepton and τ_h
- E_T^{miss} > 20 GeV
- M_T < 30 GeV

Selected events in 36 pb^{-1}:

Data	206
Sum MC expectation without Multijet	218 ± 5
A/H/h (m_A = 120 GeV, tan β = 40)	53.3 ± 0.9

MC W+jets	66 ± 3
MC Z → $\tau\tau$	117 ± 4

Higgs boson search: A/H/h → ττ

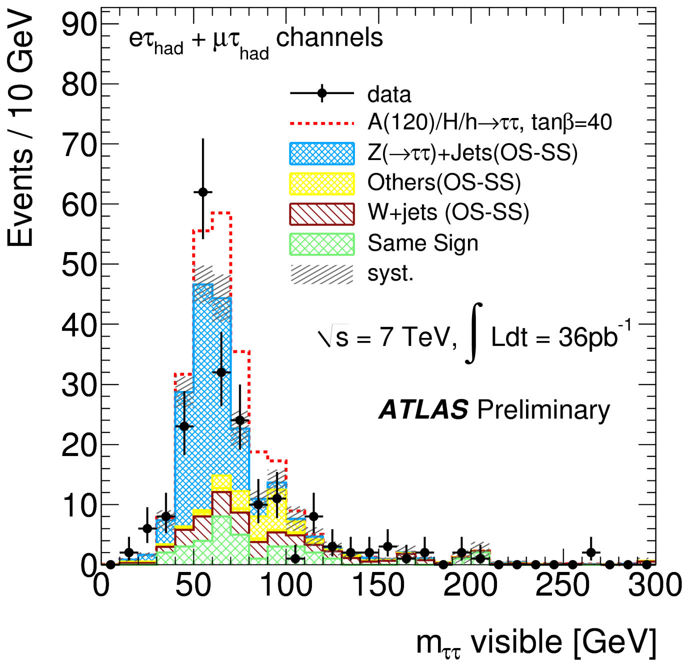
Background estimate for A/H/h → $\tau_h\tau_l$: Estimate using same-sign sample from data

$$n_{OS}^{Bkg}(m_{vis}) = r_{QCD} \cdot n_{SS}^{QCD}(m_{vis}) + r_{W+jets} \cdot n_{SS}^{W+jets}(m_{vis}) + n_{OS}^{Z+jets}(m_{vis}) + n_{OS}^{other}(m_{vis})$$

Assumption r_{QCD} = #events (OS) / #events (SS) = 1 (confirmed by MC and data control region)

W+jets factor r_{W+jets} from W control region in data

Z → ττ from MC, checked with embedding technique using data



- Visible mass distribution after all cuts

- Main systematic uncertainties on background yields:

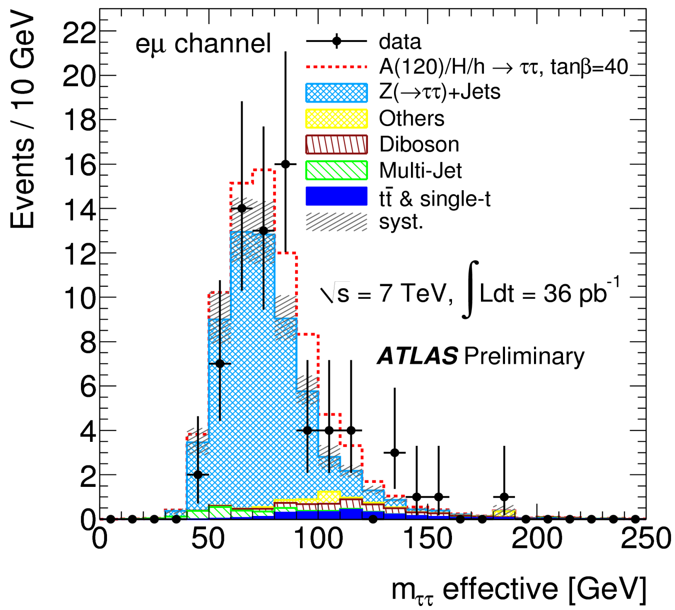
Same-sign background estimate	25%
W+jets background estimate	15%
Tau and jet energy scale	2-32%
Tau efficiency	4%
Signal acceptance	14%

Selection for A/H/h → $\tau_e\tau_\mu$ with 36 pb^{-1}:

- Single electron trigger
- One e p_T > 20 GeV and μ p_T > 10 GeV, opposite charge and tight isolated
- $p_T(e) + p_T(\mu) + E_T^{miss}$ < 120 GeV
- $\Delta\phi(e, \mu) > 2$ rad
- Discriminating variable: Effective mass

$$M_{\tau\tau}^{\text{effective}} = \sqrt{(p_e + p_\mu + p_{\text{miss}})^2}$$

- Main background Z → ττ estimated from MC and shape validated with embedding technique using data
- Multijet background estimated from data: ABCD method



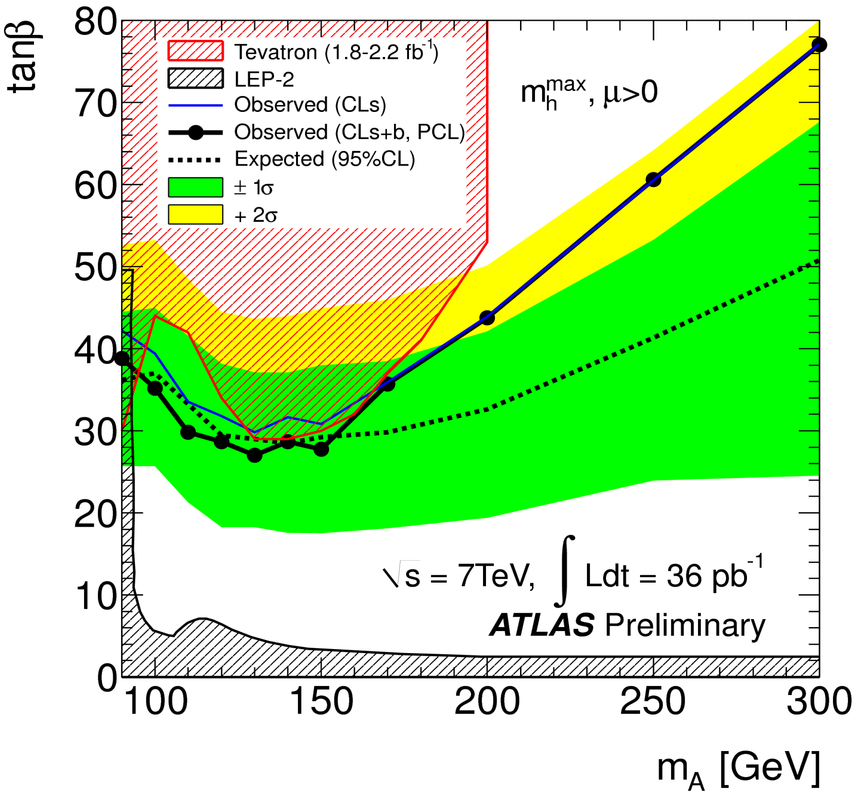
Selected events in 36 pb^{-1}:

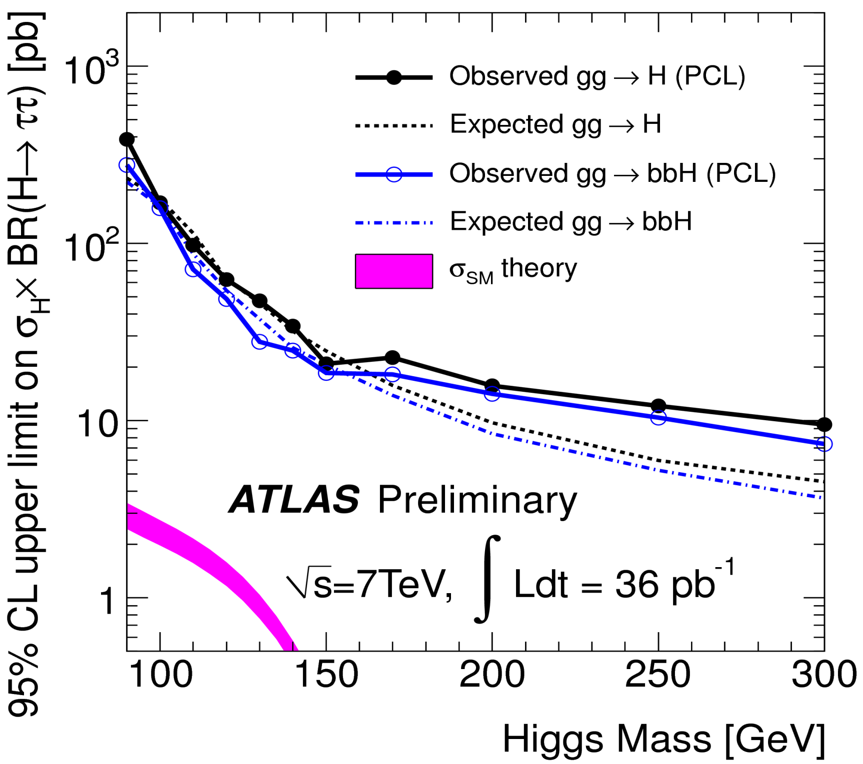
Data	70
MC expectation without Multijet	60.4 ± 1.2
Mulitjet	2.1 ± 3.1
A/H/h (m_β = 120 GeV, tan = 40)	15.2 ± 0.3

- Systematic uncertainties:
  Electron efficiency ~ 7-9 %
  MC background cross sections 5-10%
  Multijet estimate, Mass shape uncertainty

Higgs boson search: A/H/h→ ττ Limit

- Exclusion limits from analysis of visible/effective mass shape using profile likelihood method
- Cross section, couplings, masses, BR from LHC Higgs XSection WG + matching between 4-flavor and 5-flavor calculation

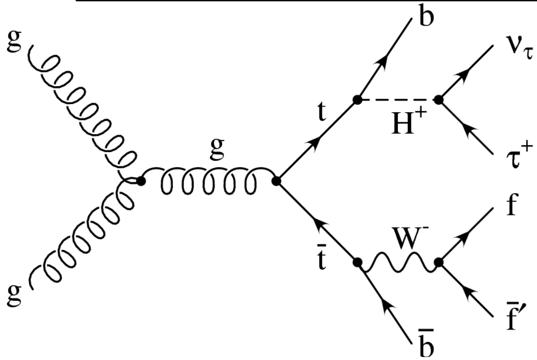




Higgs boson search: Charged Higgs H^+

ATLAS-CONF-2011-018
ATLAS-CONF-2011-051

In MSSM if $m(H^+) < m(t)$ dominant production for H^+ in tt with $t \rightarrow H^+ b$ and $H^+ \rightarrow \tau_h \nu$



H^+ with hadronic τ decays: Test of data-driven background estimates

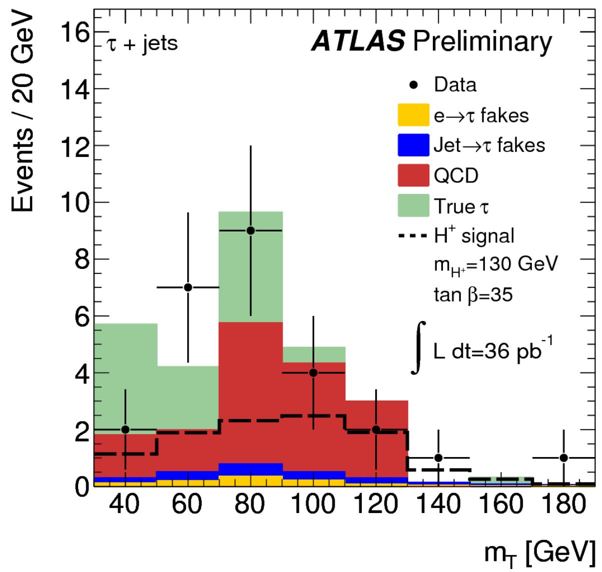
- $p_T(\tau_h) > 20$ GeV
- If $W \rightarrow qq$: Jets, $E_T^{miss} > 20$ GeV, E_T^{miss} significance > 3, 120 GeV < m(jet,jet,b-jet) < 240 GeV
- If $W \rightarrow l\nu$: $E_T^{miss} > 60$ GeV, $\Sigma E_T > 200$ GeV, b-jet

Discriminating variable: $m_T = \sqrt{2 p_T^\tau E_T^{miss}(1 - \cos\Delta\phi)}$

A) Backgrounds with fake τ jets
→ Measure fake rate

B) Backgrounds with true τs
→ Embedding

C) Multijet background
→ Fit with shape from control region



→ Given this sensitivity no limit is extracted, further studies with more data

Summary

- Identification of hadronically and leptonically decaying tau leptons in ATLAS established
- Total $\gamma^*/Z \rightarrow \tau\tau$ cross section in invariant mass of $66 < m_{\tau\tau} < 116$ GeV measured to

  $\sigma_{combined} = 0.97 \pm 0.07 \text{ (stat)} \pm 0.07 \text{ (syst)} \pm 0.03 \text{ (lumi) nb}$

  In good agreement with Standard Model expectation
- Searches for H^+ ready
- Limit set for $H/A/h \rightarrow \tau\tau$, no excess observed

  Limit in ($\tan\beta$-m_A)-plane, regions excluded beyond Tevatron or LEP exclusions

→ Looking forward to results with more data in tau decay channels

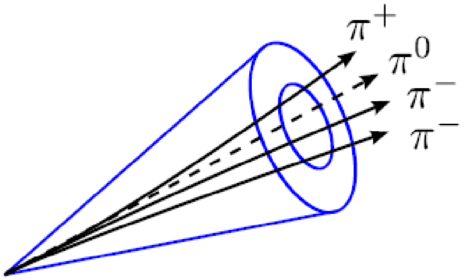
References

- ATLAS-CONF-2011-077 (Tau identification)
- ATLAS-CONF-2010-097 ($W \rightarrow \tau_h \nu$ observation)
- ATLAS-CONF-2011-010 ($Z \rightarrow \tau_h \tau_l$ observation)
- ATLAS-CONF-2011-045 ($Z \rightarrow \tau\tau \rightarrow e\mu + 4\nu$ observation)
- ATLAS-CONF-2011-051 (H^+ with hadronic τ decays)
- ATLAS-CONF-2011-018 (H^+ with leptonic τ decays)
- ATLAS-CONF-2011-024 (MSSM $A/H/h \rightarrow \tau\tau$)

Backup

Hadronic tau decays

$\tau^- \to$	$e^- \bar{\nu}_e \nu_\tau$	17.8%	leptonic 35.2%
	$\mu^- \bar{\nu}_\mu \nu_\tau$	17.4%	
	$\pi^- \pi^0 \nu_\tau$	25.5%	1 prong 49.5%
	$\pi^- \nu_\tau$	10.9%	
	$\pi^- 2\pi^0 \nu_\tau$	9.3%	
	$K^- (N\pi^0) (NK^0) \nu_\tau$	1.5%	
	$\pi^- 3\pi^0 \nu_\tau$	1.0%	
	$\pi^- \pi^- \pi^+ \nu_\tau$	9.0%	3 prong 15.2%
	$\pi^- \pi^- \pi^+ \pi^0 \nu_\tau$	4.6%	

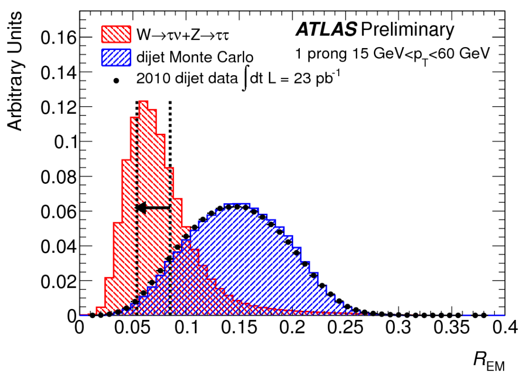


In the detector:
- Shower width (shower radius and isolation)
- Particle multiplicity (e.g. number of tracks, clusters)
- Shower composition (e.g. EM fraction)

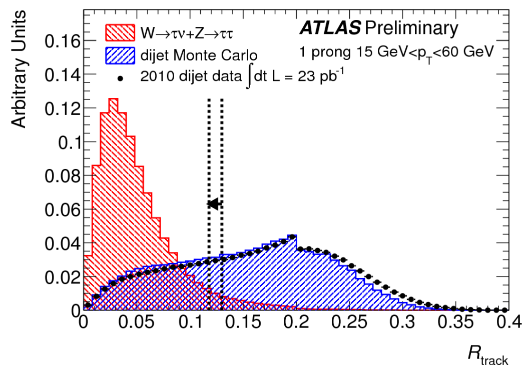
→ Calorimeter cluster-based variables (e.g. number of clusters, mass), Tracking variables (e.g. track width, track mass), Variables which combine calorimeter and tracking information (e.g. E/p)

Hadronic Tau reconstruction and identification in ATLAS

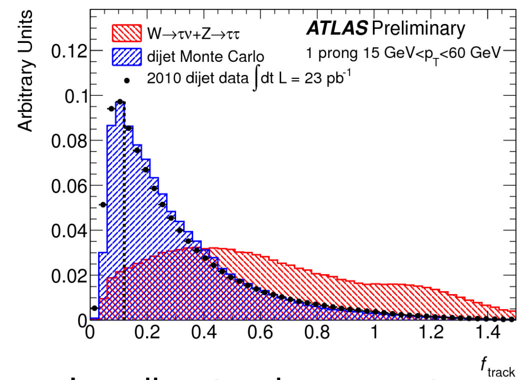
- Tau jet candidates seeded by calorimeter jets (candidate calorimeter jets reconstructed with AntiKt algorithm, starting from topological clusters)
- Tracks matched to candidate calorimeter jets
- Distinction between tau leptons and jets:
  Different identification criteria: cut based, boosted decision tree (BDT), likelihood LLH)
- Cuts based on 3 variables



Transverse energy weighted shower width in em. Calorimeter



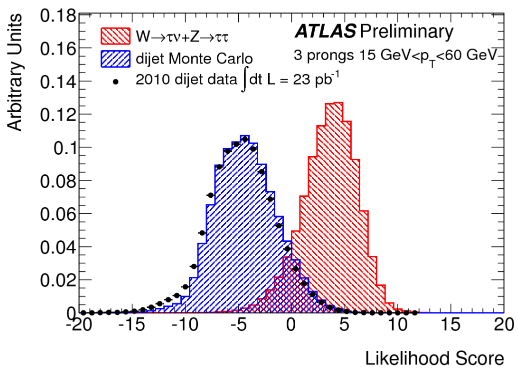
p_T weighted track width



Leading track momentum

- BDT and LLH use further variables

- Rejection of electrons passing tau lepton selection (electron veto)

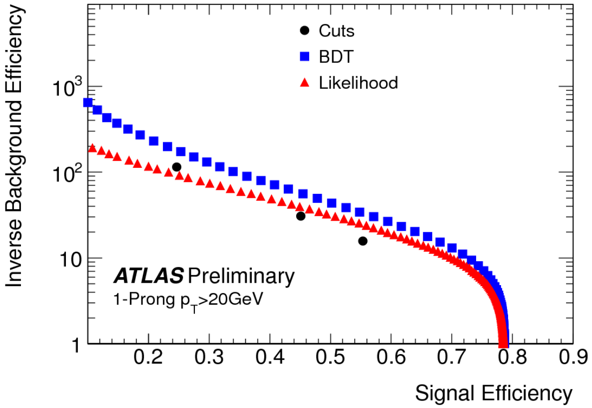


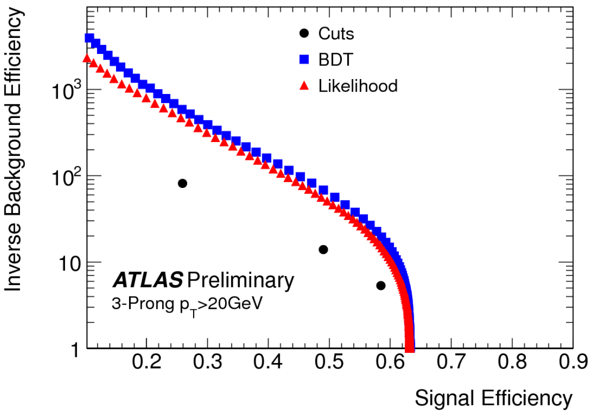
ATLAS-CONF-2011-077

Performance of hadronic tau identification in ATLAS

Performance: Signal Monte Carlo $Z \rightarrow \tau\tau$ and $W \rightarrow \tau_h \upsilon$, Background dijet data events

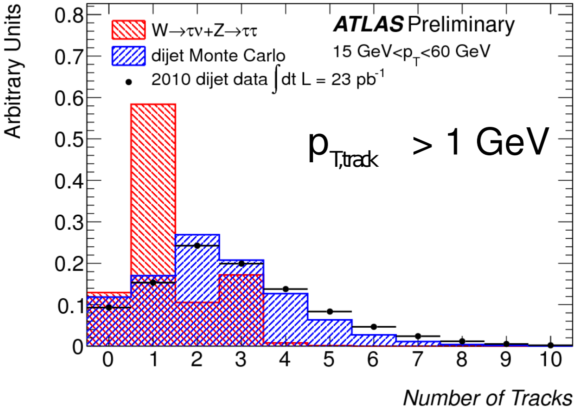
Trained in bins of #prong and p_T





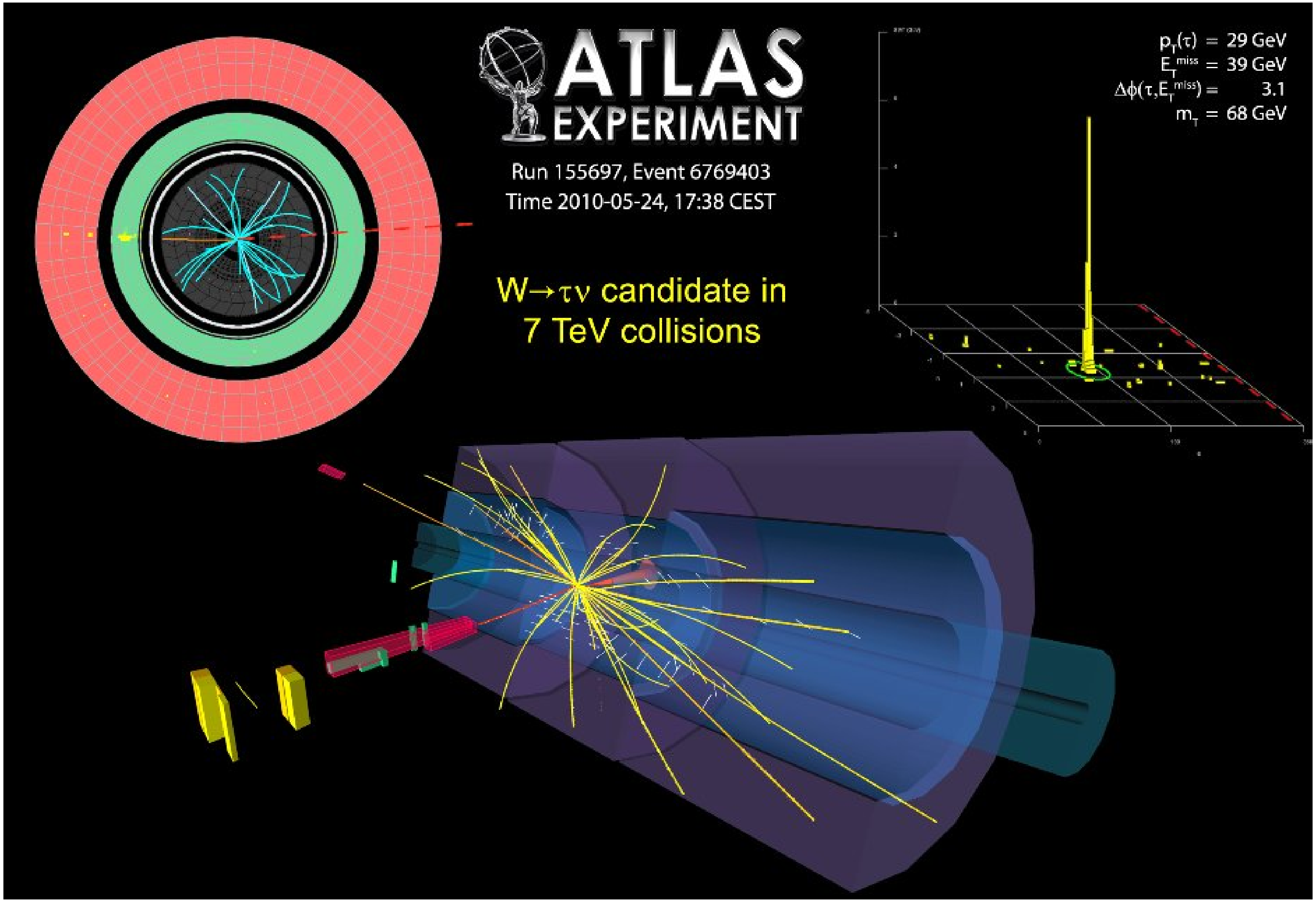
Tight cuts:
30 % signal efficiency
Dijet efficiency 2-6%

Efficiency systematics evaluated on Monte Carlo:
Looser working point 4-7 %
Tighter working point ~10 %



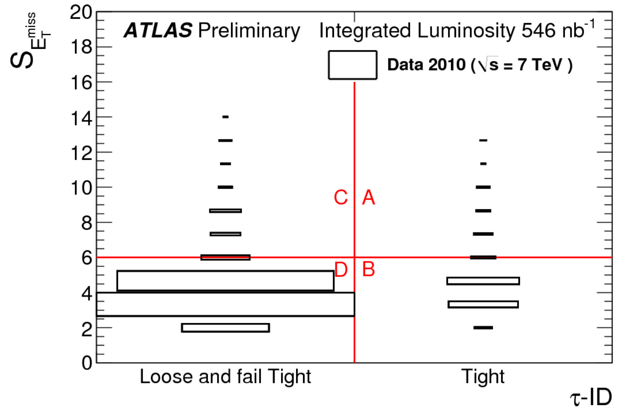
→ Good agreement between data and Monte Carlo

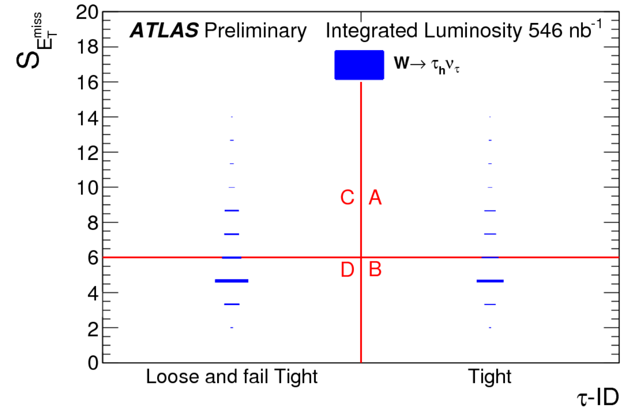
W → $\tau_h\nu$ candidate event display



Multijet background estimated from data: ABCD method

$$N^A_{QCD} = N^B N^C / N^D$$



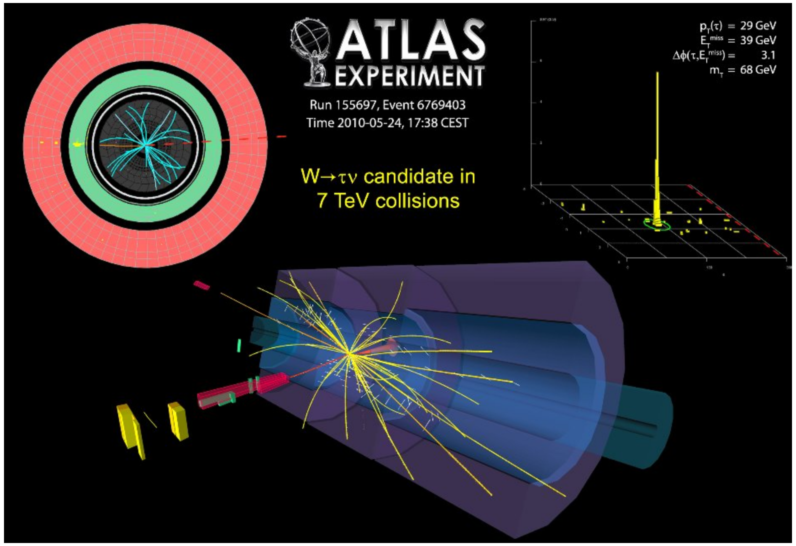


Data

W → $\tau_h \upsilon$ MC

Observation of W → $\tau_h \upsilon$ with 546 nb^{-1}

Data	78
Multijet background	11.1 ± 2.3 (stat.) ± 3.2 (syst.)
EW background	11.8 ± 0.4 (stat.) ± 3.7 (syst.)
Expected signal	55.3 ± 1.4 (stat.) ± 16.1(syst.)
Observed signal	55.1 ± 10.5 (stat.) ± 5.2 (syst.)

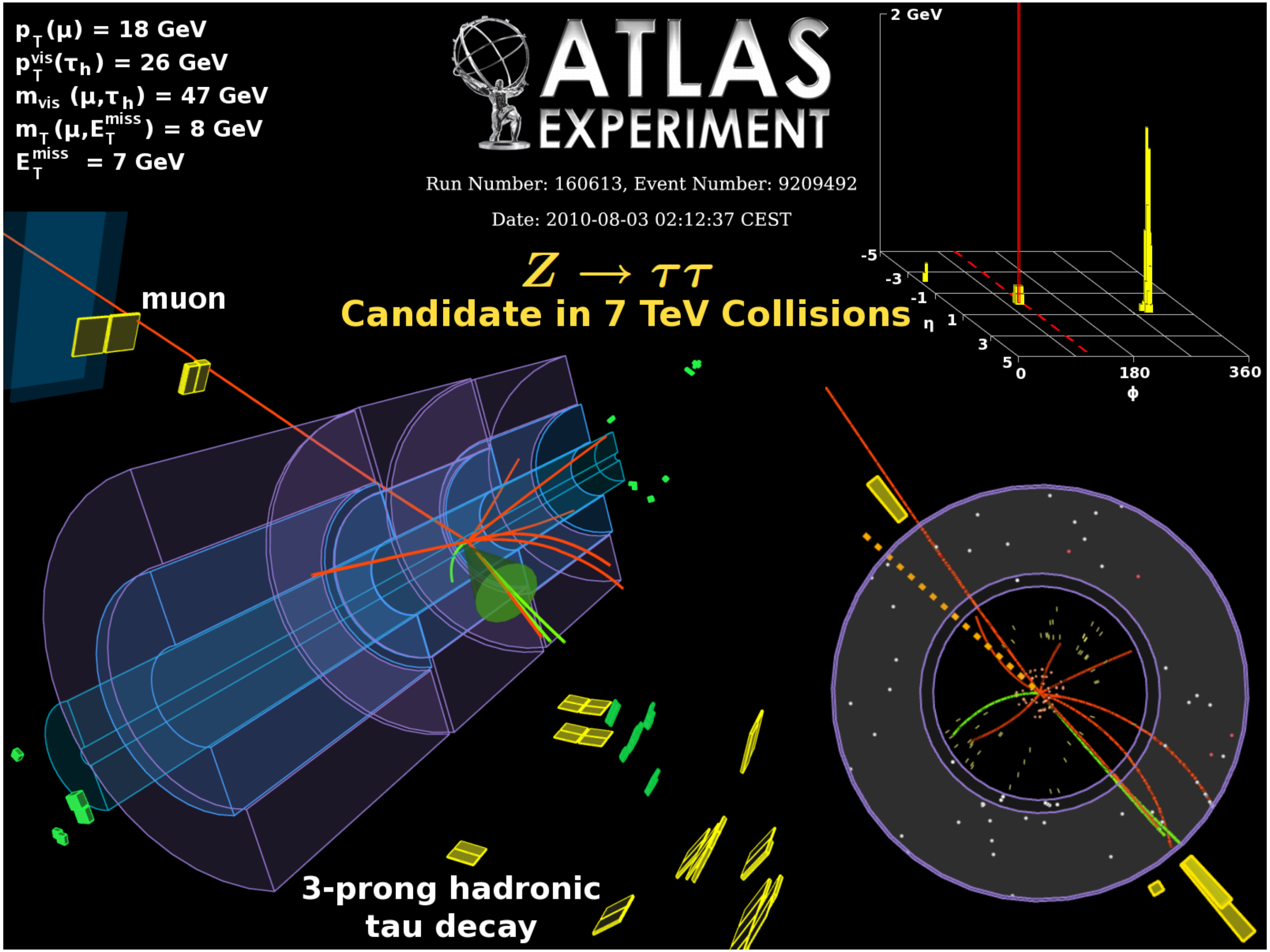


SM processes: W → $\tau_h \nu$ observation

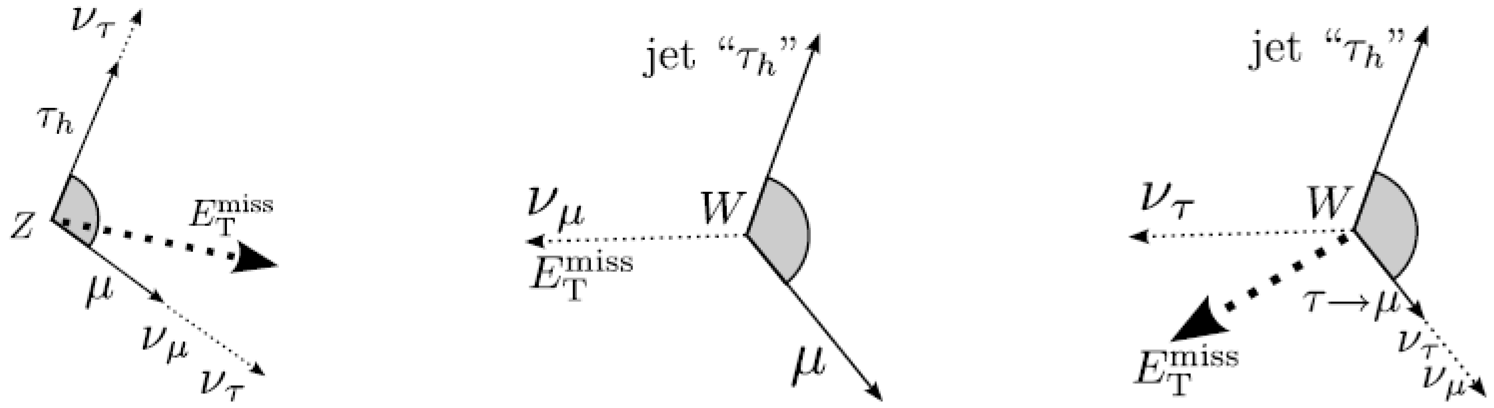
Systematic uncertainties:

	$W \to \tau_h \nu_\tau$ (MC expectation)	EW background (MC expectation)	QCD background (data-driven estimate)
Central values [events]	55.3	11.8	11.1
Statistical uncertainty [events]	±1.4	±0.4	±2.3
Systematic uncertainties			
Theoretical cross section	± 5%	±5%	–
Luminosity	± 11%	±11%	–
Energy scale	±21%	±14%	–
Lepton veto	–	±19%	–
Pile-up	±1%	±0.2%	–
Monte Carlo model	±16%	±17%	–
QCD background estimation	–	–	±29%
Total systematic uncertainty [events]	±16.1	±3.7	±3.2

$Z \rightarrow \tau_h \tau_l$ candidate event display



SumCosDeltaPhi: $\sum \cos\Delta\phi = \cos\left(\phi(\ell) - \phi(E_{\mathrm{T}}^{\mathrm{miss}})\right) + \cos\left(\phi(\tau_{\mathrm{h}}) - \phi(E_{\mathrm{T}}^{\mathrm{miss}})\right)$



(a) $Z \to \tau\tau \to \mu\tau_{\mathrm{h}}$ (b) $W \to \mu\nu$ (c) $W \to \tau\nu \to \mu\nu\nu\nu$

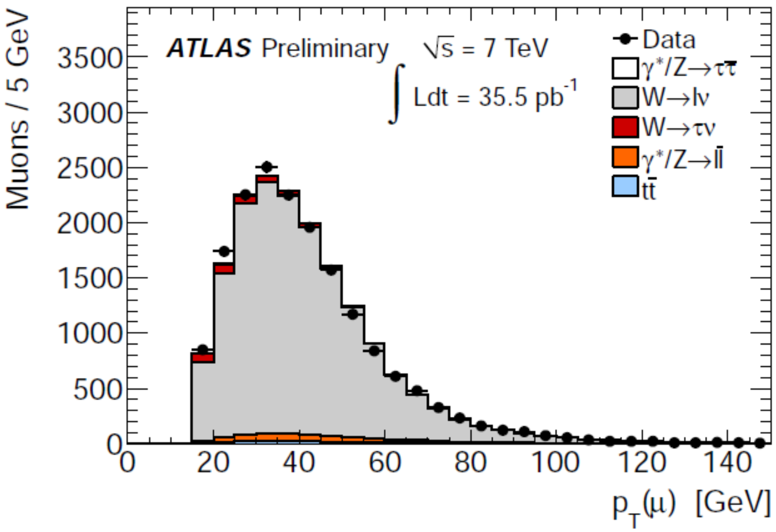
Transverse Mass: $m_{\mathrm{T}}(\ell, E_{\mathrm{T}}^{\mathrm{miss}}) = \sqrt{2\, p_{\mathrm{T}}(\ell) \cdot |E_{\mathrm{T}}^{\mathrm{miss}}| \cdot (1 - \cos\Delta\phi(\ell, E_{\mathrm{T}}^{\mathrm{miss}}))}$

SM processes: $Z \rightarrow \tau_h \tau_l$: W+jets normalization

W+jets background shape taken from MC and normalized to data in W enriched region

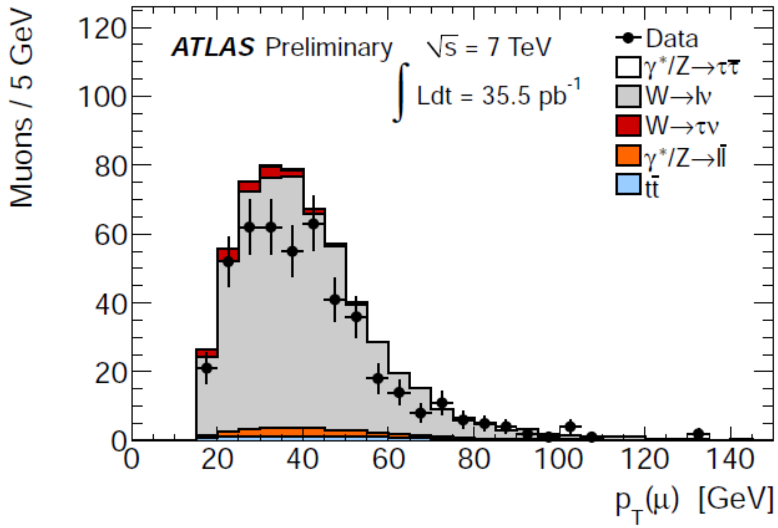
- inverted W+jets suppression cuts

before tau ID



(a) no τ identification

after tau ID



(b) tight τ candidate

muon channel

SM processes: Z → ττ cross section measurement

ATLAS Preliminary

	$\tau_\mu\tau_h$	$\tau_e\tau_h$
N_{obs}	213	151
$N_{obs} - N_{bkg}$	$164 \pm 16 \pm 4$	$114 \pm 14 \pm 3$
A_Z	$0.117 \pm 0.0002 \pm 0.004$	$0.101 \pm 0.0002 \pm 0.003$
C_Z	$0.21 \pm 0.002 \pm 0.03$	$0.120 \pm 0.002 \pm 0.019$
B	0.2250 ± 0.0009	0.2313 ± 0.0009
$\mathcal{L}$	35.5 ± 1.2 pb^{-1}	35.7 ± 1.2 pb^{-1}

	$\tau_e\tau_\mu$	$\tau_\mu\tau_\mu$
N_{obs}	85	90
$N_{obs} - N_{bkg}$	$76 \pm 10 \pm 1$	$43 \pm 10 \pm 3$
A_Z	$0.114 \pm 0.0004 \pm 0.003$	$0.156 \pm 0.001 \pm 0.011$
C_Z	$0.29 \pm 0.005 \pm 0.02$	$0.27 \pm 0.006 \pm 0.01$
B	0.0620 ± 0.0002	0.0301 ± 0.0001
$\mathcal{L}$	35.5 ± 1.2 pb^{-1}	35.5 ± 1.2 pb^{-1}

SM processes: Z → ττ cross section measurement

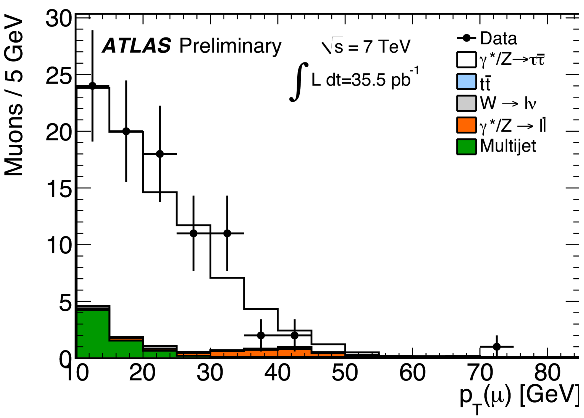
Selection for $Z \rightarrow \tau_e \tau_\mu$:

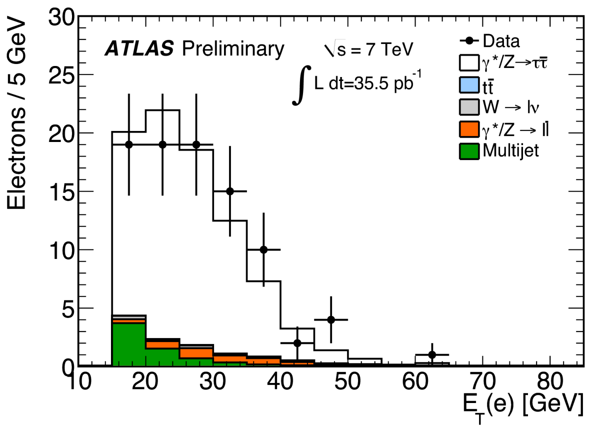
- One electron $p_T > 15$ GeV and one muon $p_T > 10$ GeV of opposite charge
- Tight lepton isolation
- $\Sigma\cos\Delta\phi(l, E_T^{miss}) > -0.15$
- $p_{T,e} + p_{T,\mu} + p_{T,jets} + E_T^{miss} < 150$ GeV
- 25 GeV < $m_{visible}$ < 80 GeV

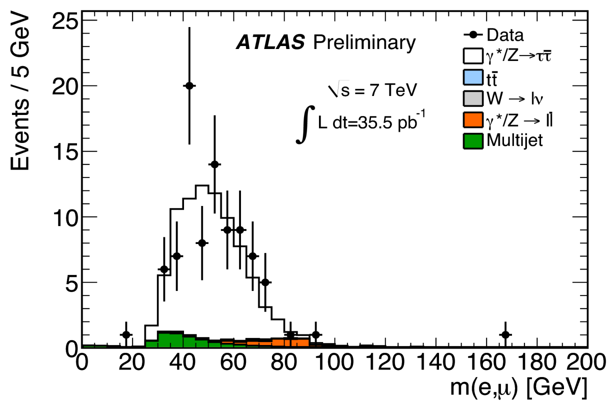
- Multijet background estimated from data: ABCD method using OS/SS ratio vs. lepton isolation
- W normalization checked in control region in data

	$\tau_e\tau_\mu$
N_{obs}	85
$N_{obs} - N_{bkg}$	$76 \pm 10 \pm 1$

→ Distributions of lepton p_T and visible mass after all cuts beside mass window cut







SM processes: $Z \rightarrow \tau\tau$ cross section measurement

Selection for $Z \rightarrow \tau_\mu\tau_\mu$:

- One isolated muon p_T > 15 GeV and one isolated muon p_T > 10 GeV of opposite charge
- 25 GeV < $m_{\mu\mu}$ < 65 GeV
- Boosted decision tree to separate $Z \rightarrow \tau_\mu\tau_\mu$ and $\gamma^*/Z \rightarrow ll$

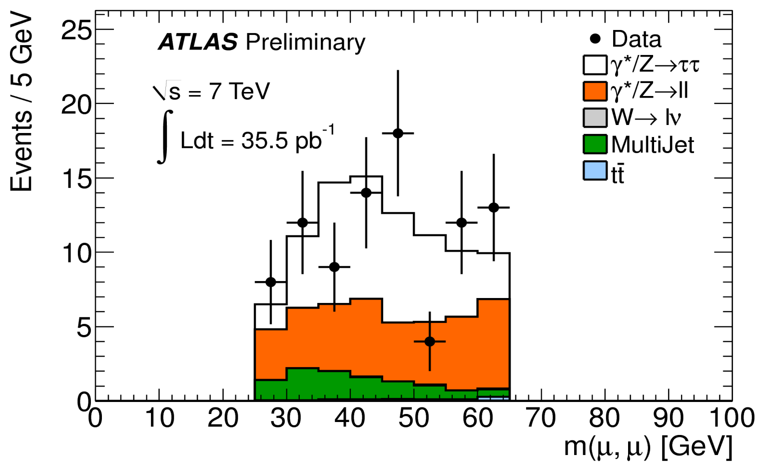
Multijet background estimated from data

BDT input variables:

- $\Delta\phi(\mu_1,\mu_2)$
- $\Delta\phi(\mu_1,E_T^{miss})$
- $(p_T(\mu_1)- p_T(\mu_2))$
- $|d_0(\mu_1)| + |d_0(\mu_2)|$

Distribution of visible mass after all cuts

	$\tau_\mu\tau_\mu$
N_{obs}	90
$N_{obs} - N_{bkg}$	$43 \pm 10 \pm 3$



→ $\gamma^*/Z \rightarrow ll$ suppressed and $Z \rightarrow \tau_\mu\tau_\mu$ signal visible

Higgs boson search: Charged Higgs H^+

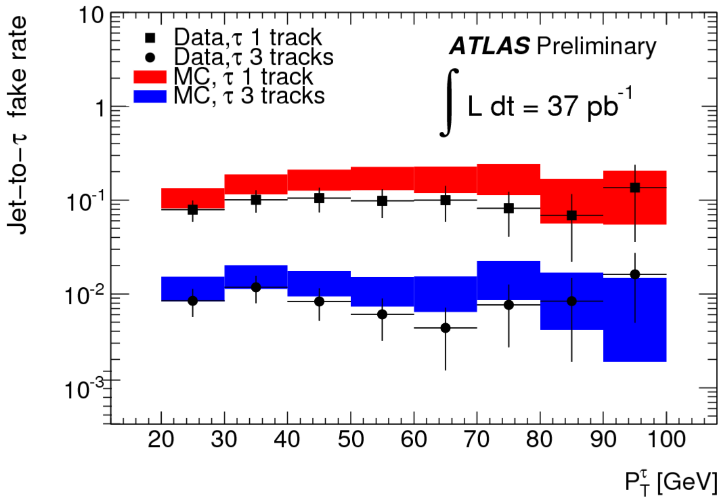
ATLAS-CONF-2011-018
ATLAS-CONF-2011-051

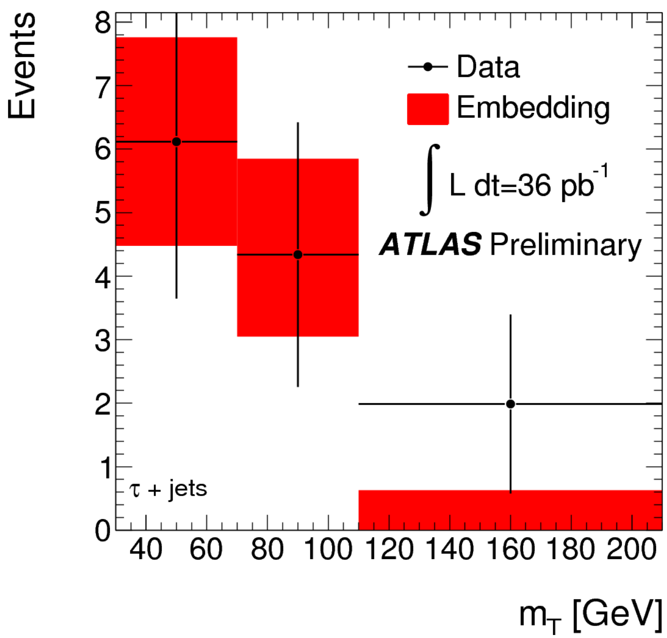
In MSSM if $m(H^+) < m(t)$ dominant production for H^+ in tt with $t \rightarrow H^+ b$ and $H^+ \rightarrow \tau_h \nu$

1. H^+ with hadronic τ decays: Test of data-driven background estimates

A) Backgrounds with fake τ jets → Measure fake rate

B) Backgrounds with true τs → Embedding





C) Multijet background → Fit with shape from control region

Z/H → ττ (lh) in ATLAS

- Lepton identification: muon → muon system and tracking or electron → tracking and electromagnetic calorimeter
- Neutrinos: missing energy → 4π calorimeter with high granularity
- Tau identification: electromagnetic calorimeter and tracking