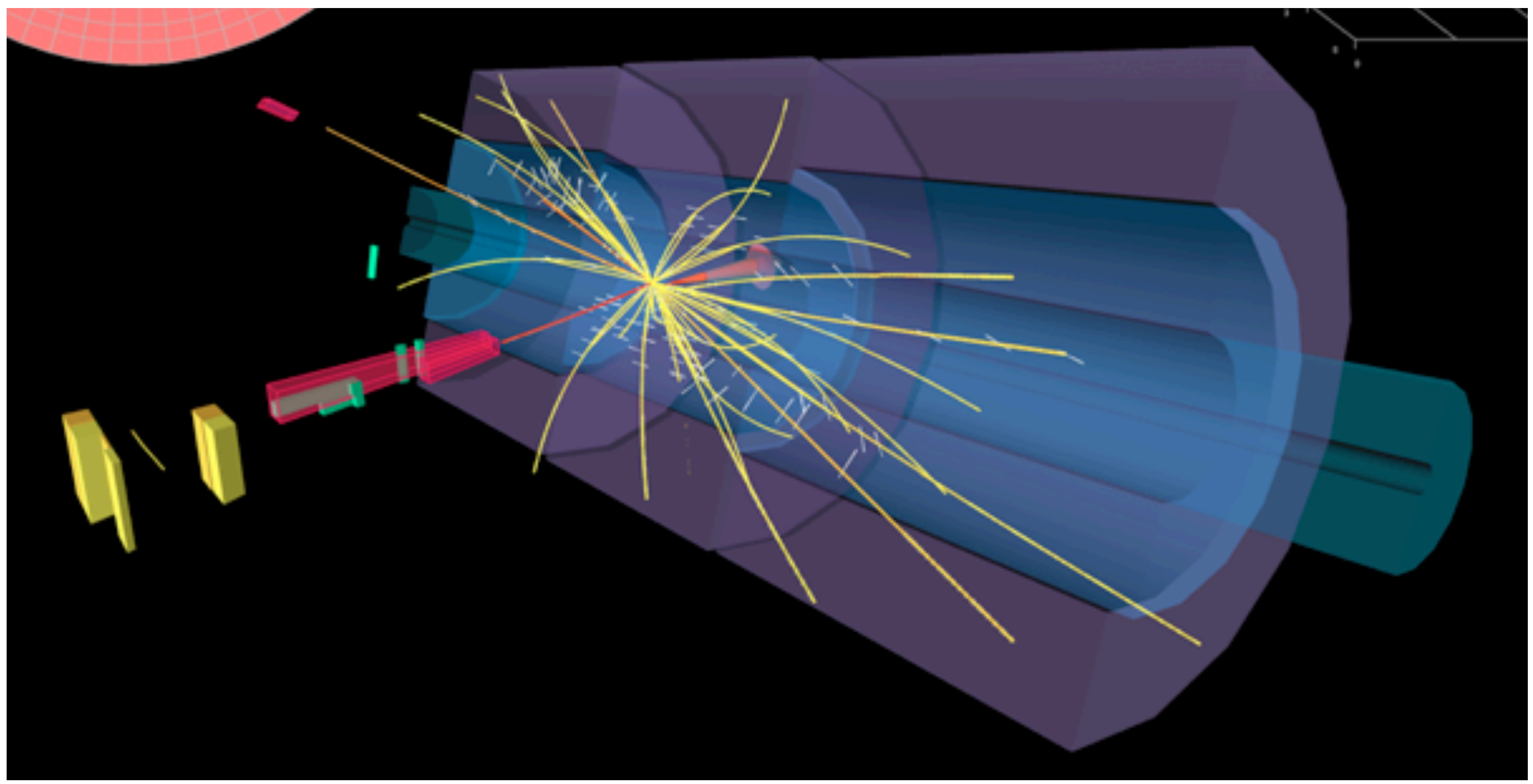
Measurement of the $W \rightarrow \tau\nu$ cross section with the ATLAS detector



Jana Kraus (*University of Bonn*)

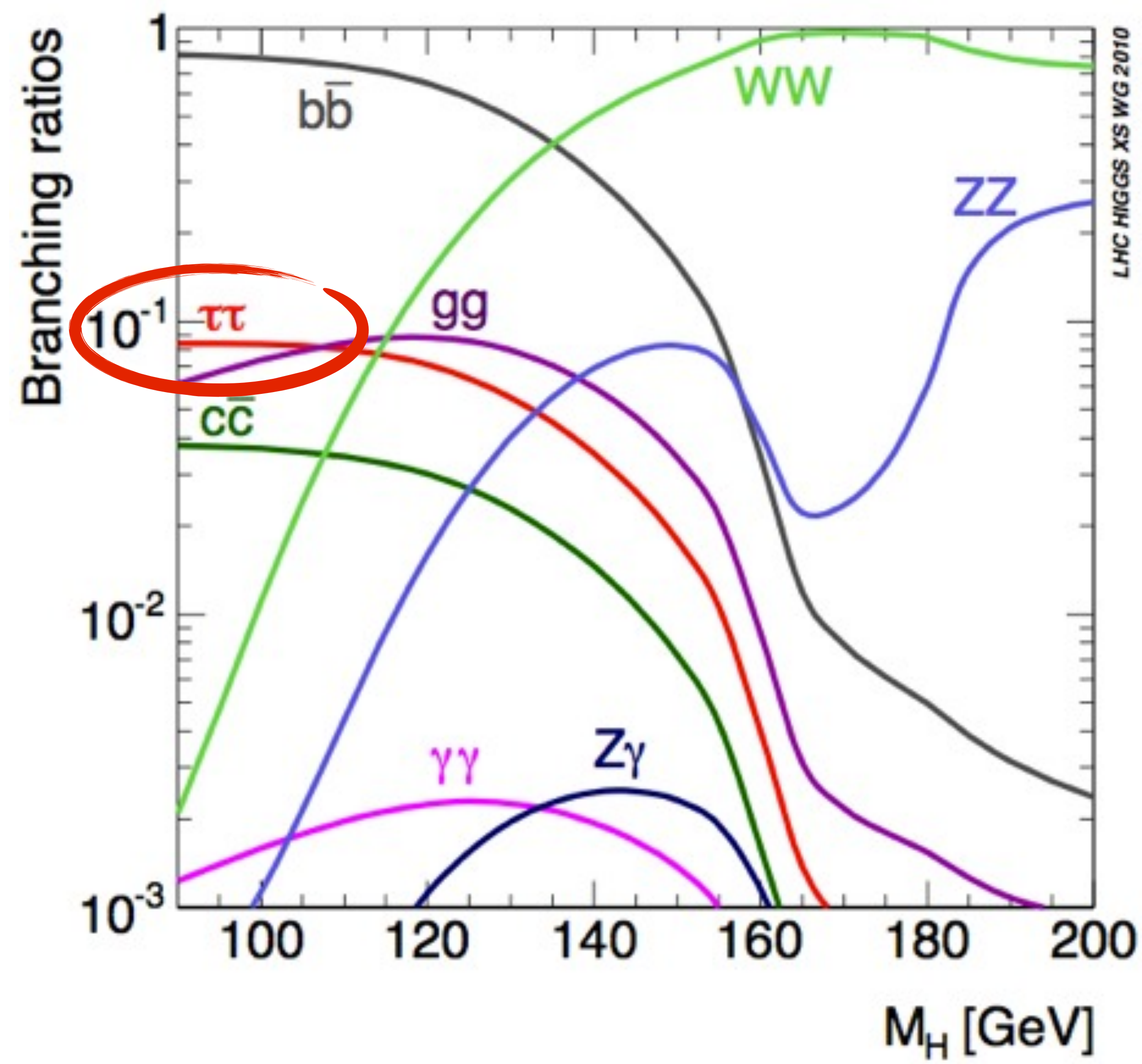
on behalf of the ATLAS $W \rightarrow \tau\nu$ group

Helmholtz Allianz Meeting • December 7th, 2011

universitätbonn

Motivation

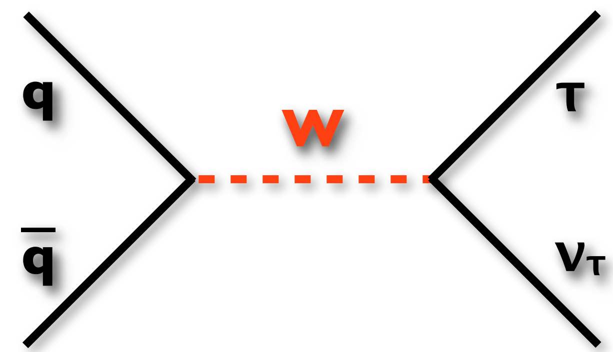
- **τ leptons** play important role in Search for New Physics phenomena (light SM Higgs and SUSY) with ATLAS
- **Z→ττ and W→τυ** are important backgrounds to new physics searches
- W→τν cross section measurement completes the measurement of **W production** at LHC
- important validation of **reconstruction and identification** techniques for τ leptons and the measurement of the **missing transverse energy**



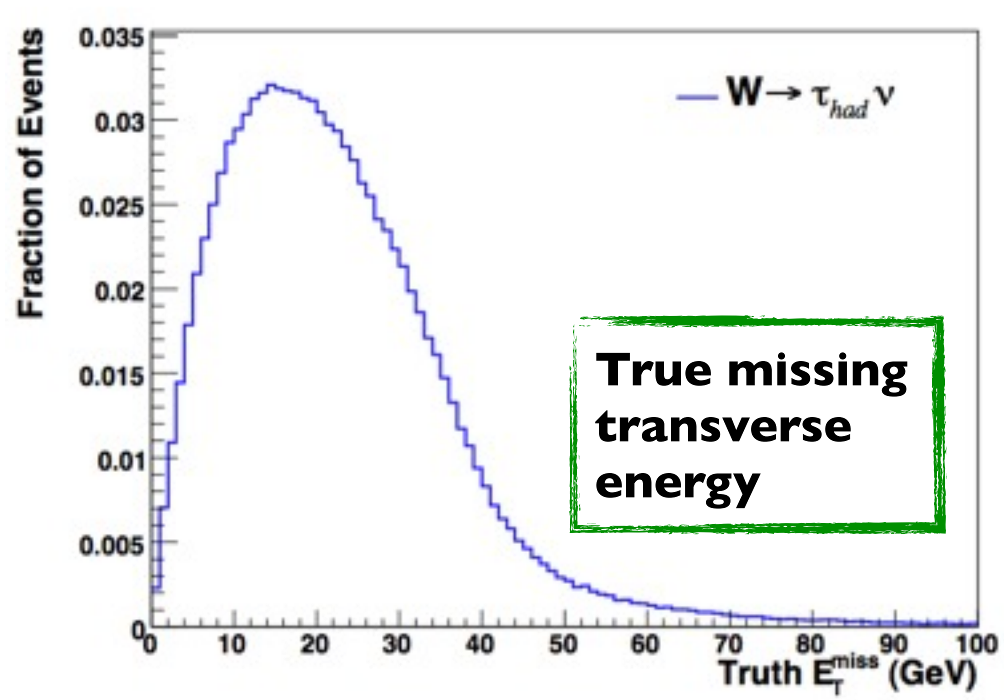
$W \rightarrow \tau\nu$ decays

* **Event topology**

Predicted NNLO cross section:
$\sigma \times BR = 10.46$ nb



* **soft visible τ_h momentum** spectrum (sum of charged hadrons)
* **missing transverse energy E_T^{miss}** due to 2 neutrinos



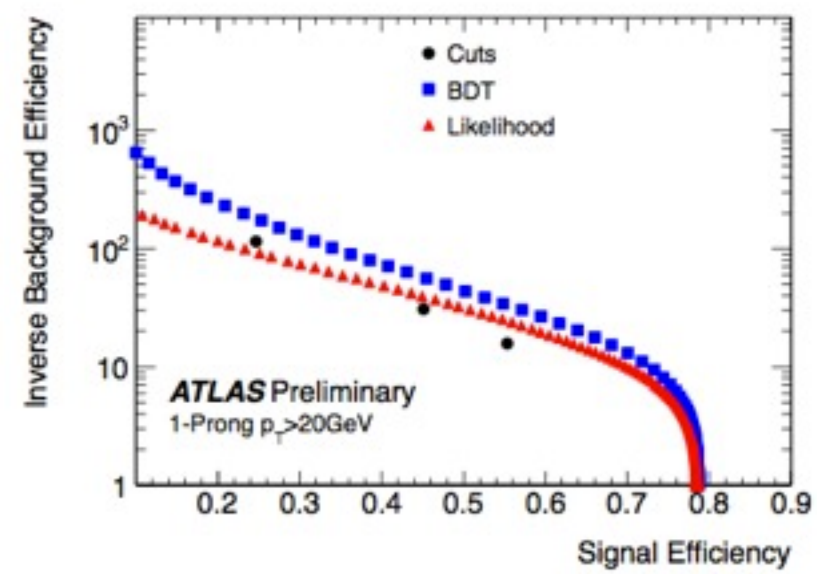
Tau reconstruction & identification at ATLAS

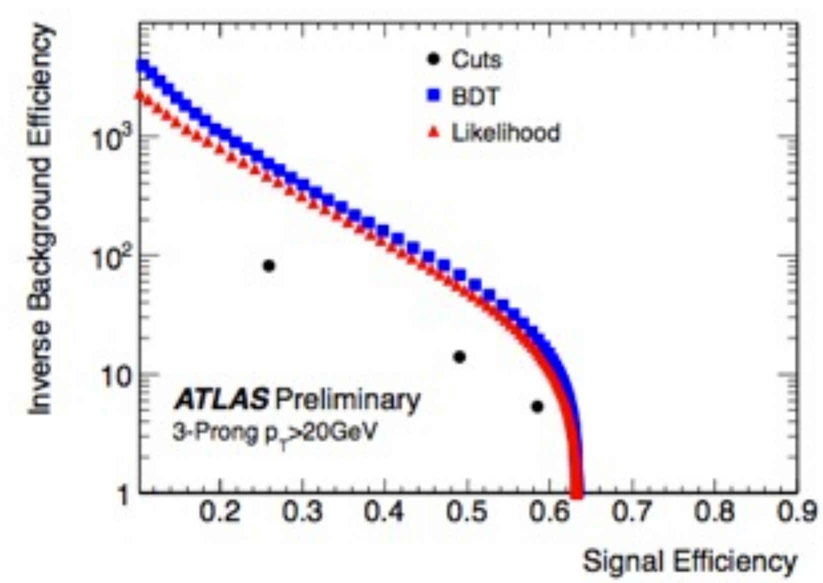
- Only **hadronic τ** leptons studied
- Two **reconstruction** algorithms for ATLAS
  - **track-seeded** seed is leading good quality track with p_T > 6 GeV
  - **calo-seeded** seeded by calorimeter (anti-kt) jet from built topological clusters

all calo-seeded candidates used in this analysis

- Three **τ_h identification algorithms** provided
  - **simple cuts**
  - **Boosted Decision Tree (BDT)**
  - **Likelihood (LLH)**

BDT identification used in this analysis



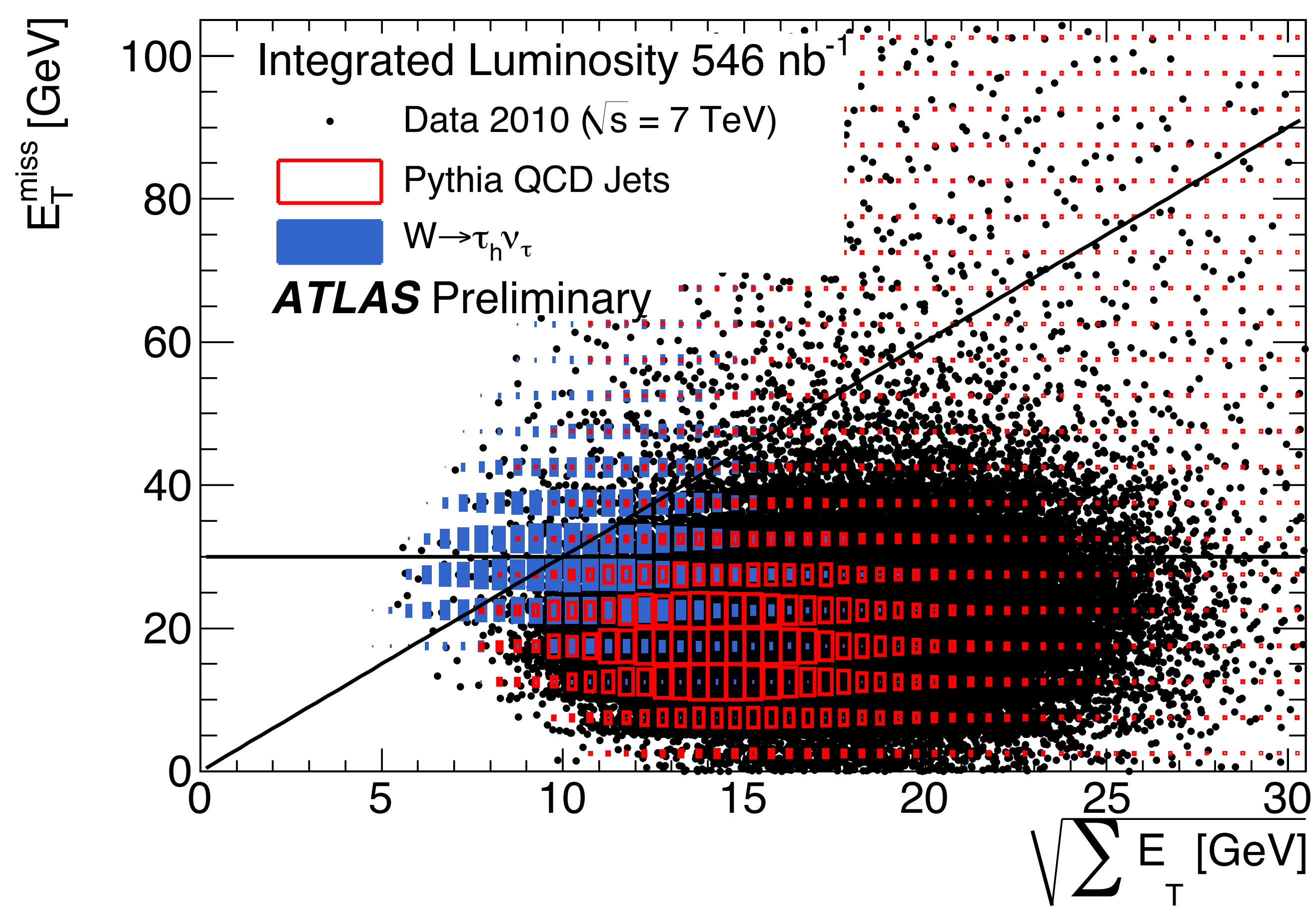


Missing transverse energy

* Efficient QCD background rejection by additional cut on **E_T^{miss} significance**

$$S_{E_T^{\rm miss}} = \frac{E_T^{\rm miss}}{0.5\sqrt{(\sum E_T)}}$$

$$\sum E_T = \sum_i \sqrt{(E_{i,x}^{\rm Calo})^2 + (E_{i,y}^{\rm Calo})^2}$$



Event preselection

Measurement with 2010 ATLAS data (34 pb^{-1})

* **GRL & Trigger:**
  * GRL
  * combined tau & E_T^{miss} trigger

Data period	Trigger	Efficiency
First (12 pb^{-1})	**loose tau p_T>12GeV, E_T^{miss}>20 GeV**	(81.3±0.8)%
Second (25 pb^{-1})	**medium tau p_T>16GeV, E_T^{miss}>22 GeV**	(62.7±0.7)%

* **Cleaning cuts:**
  * At least 1 vertex with Ntrk > 2
  * Veto of jets with
    * identified as non-collision events or noise
    * jet with p_T > 20 GeV in 1.3 < $|\eta|$<1.7
    * jet p_T > 20 GeV and min($\Delta\varphi$(jet, E_T^{miss})) < 0.5

Remove events with fake missing ET

Event selection

* **Event signature:**
  * E_T^{miss} > 30 GeV
  * Leading tau candidate
    * passing **BDT** tau ID
    * **20 GeV < p_T < 60 GeV**, not in crack region
* **Lepton vetos:**
  * Veto medium electrons with p_T > 15 GeV
  * Veto combined muon with p_T > 15 GeV
  * Additional electron+muon veto from tau ID
* **QCD background rejection:**
  * **E_T^{miss} significance cut** $\boxed{S_{E_T^{miss}} = \frac{E_T^{miss}}{0.5\sqrt{\sum E_T}}}$ >6

Suppress background from W and Z

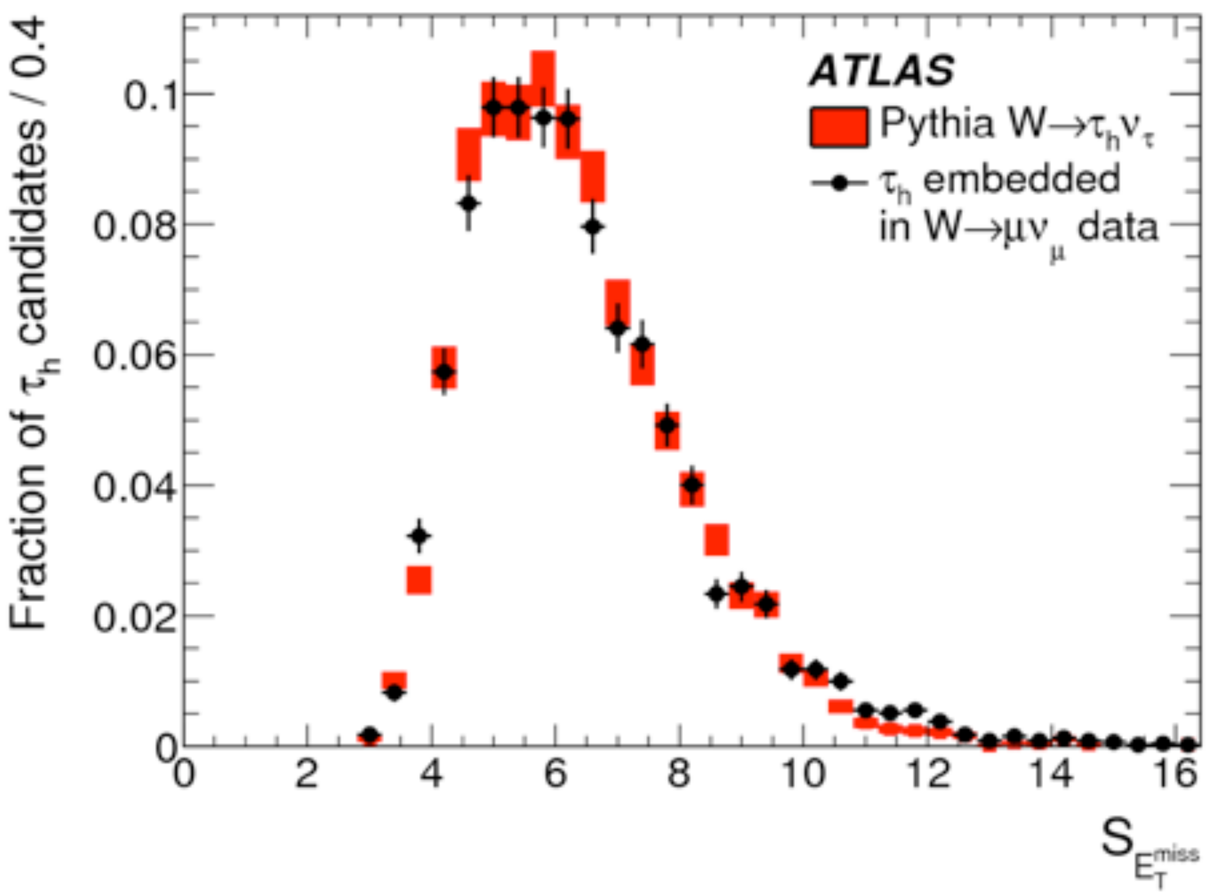
Strong rejection of QCD background

Background estimation

* **EW background** is taken from Monte Carlo and scaled to NNLO cross sections.

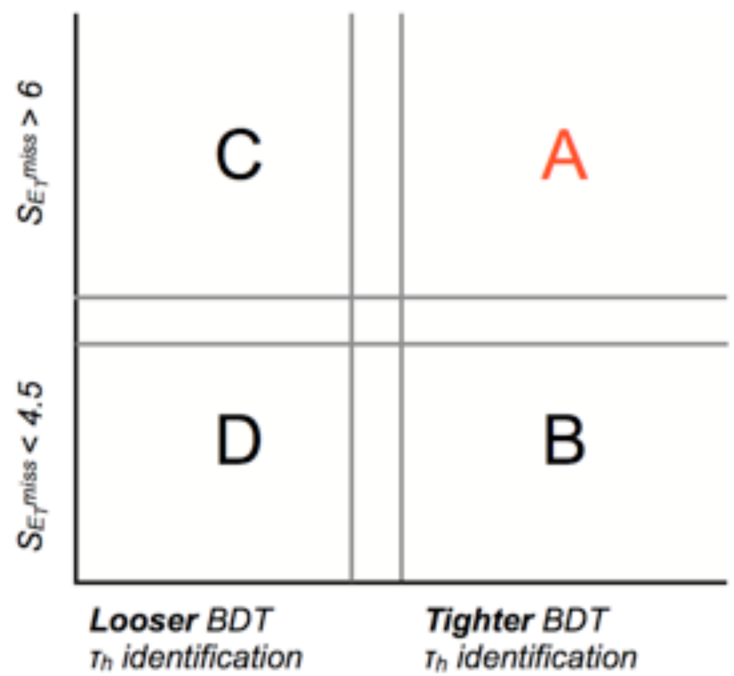
* NNLO cross sections in agreement with **ATLAS measurements**.

* The **shapes** of the important quantities are well described in Monte Carlo, verified by comparison to **embedded** sample.



Background estimation

* **QCD background** estimated from data - two side bin (ABCD) method used



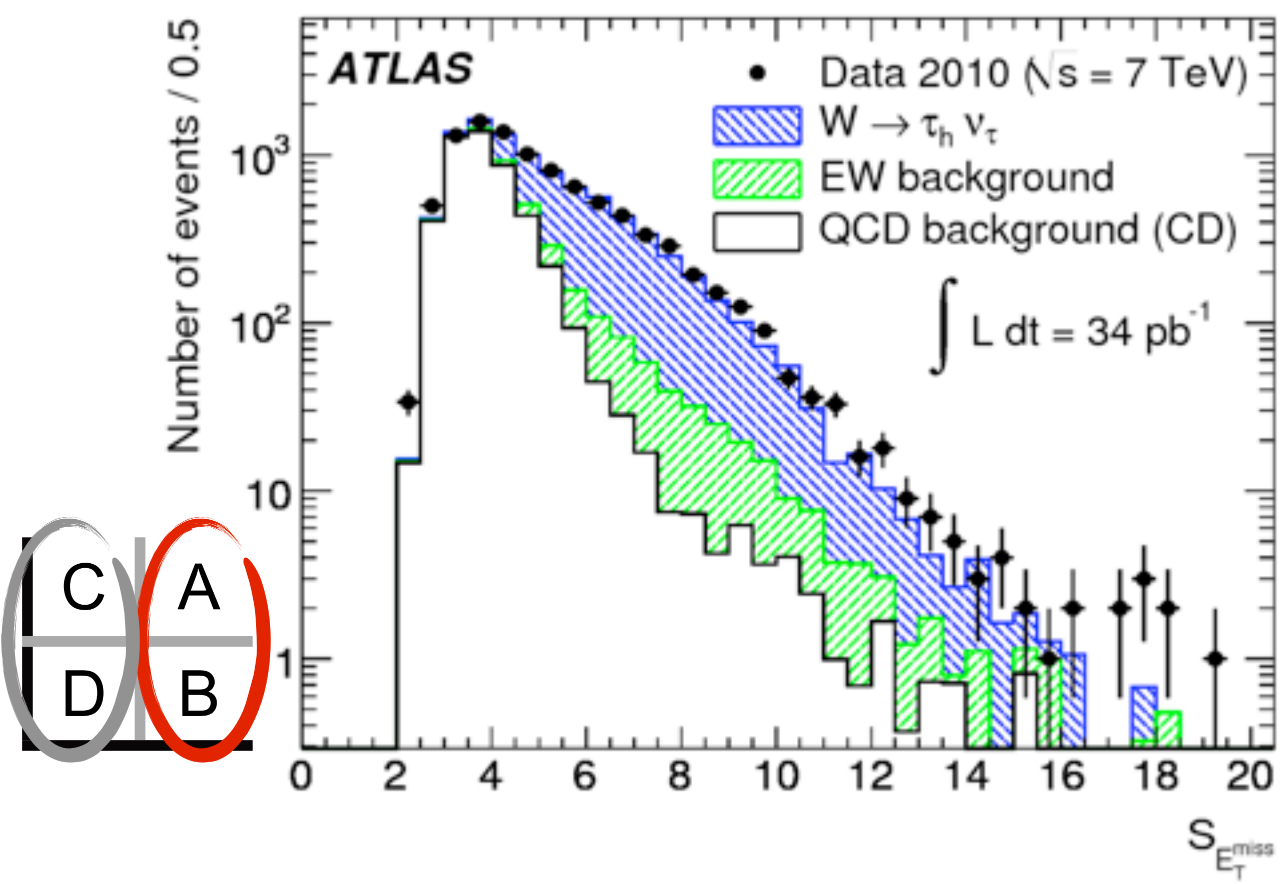
* Regions are defined by two variables:
  * **E_T^{miss} significance**
  * **BDT tau ID**
* To reduce **EW/signal contamination** in control regions BCD, **gaps** are introduced

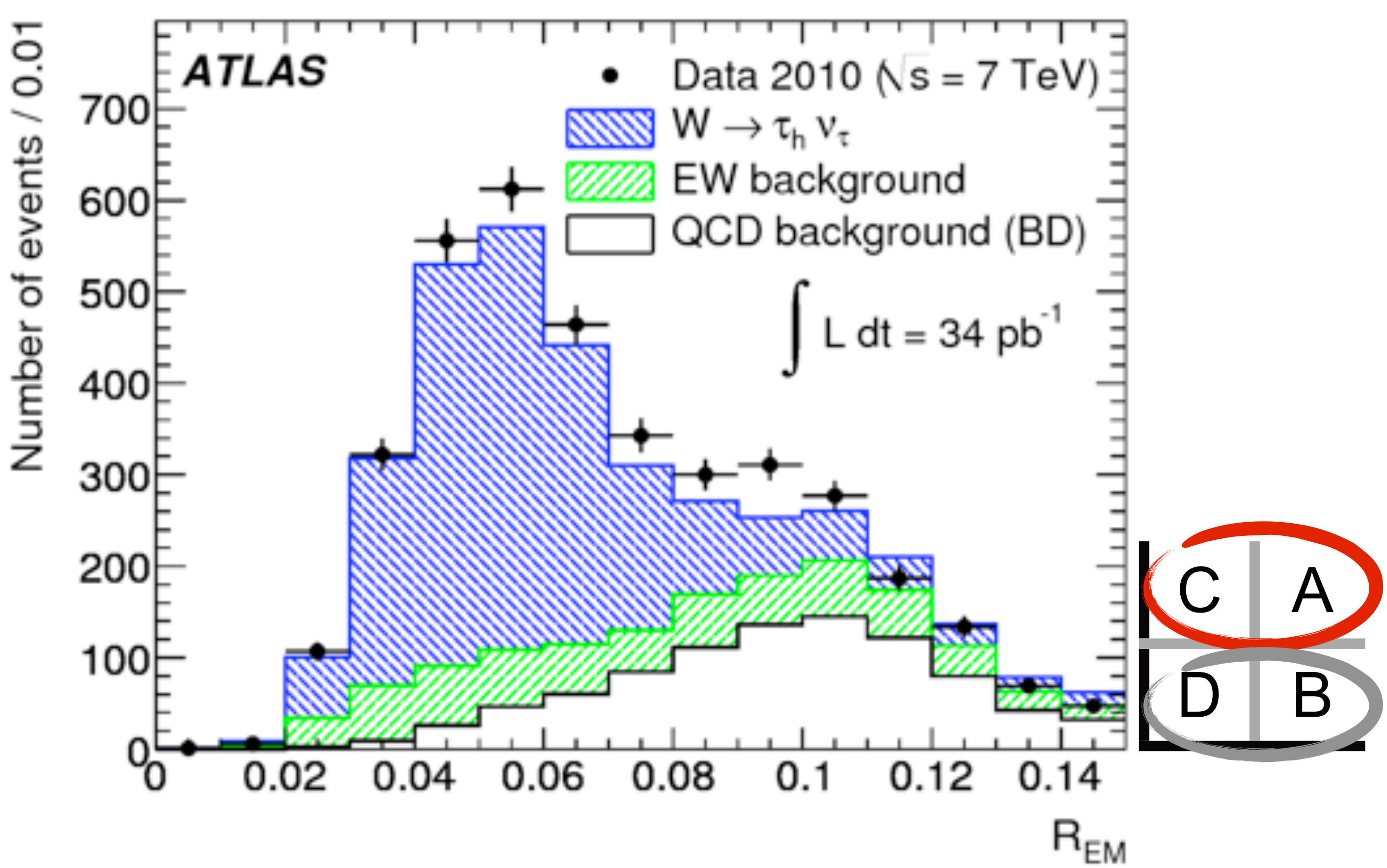
$$\boxed{N^{\mathrm{A}}_{\mathrm{QCD}} = N^{\mathrm{B}} N^{\mathrm{C}} / N^{\mathrm{D}}}$$

* Corrected for EW and signal contamination

Background estimation

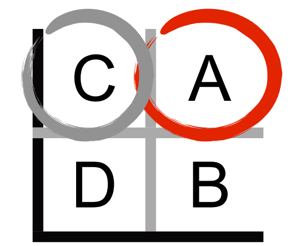
	A	B	C	D
N^i (Data)	2335	4796	1577	27636
$N^i_{\rm sig}$ $(W \to \tau_{\rm h}\nu_\tau)$	1811 ± 25	683 ± 16	269 ± 8	93 ± 5
$N^i_{\rm EW}$	284 ± 7	118 ± 4	388 ± 9	90 ± 4
c_i		0.38 ± 0.01	0.31 ± 0.01	0.087 ± 0.003
$N^i_{\rm QCD}$	127 ± 8	3953 ± 75	885 ± 45	27444 ± 166

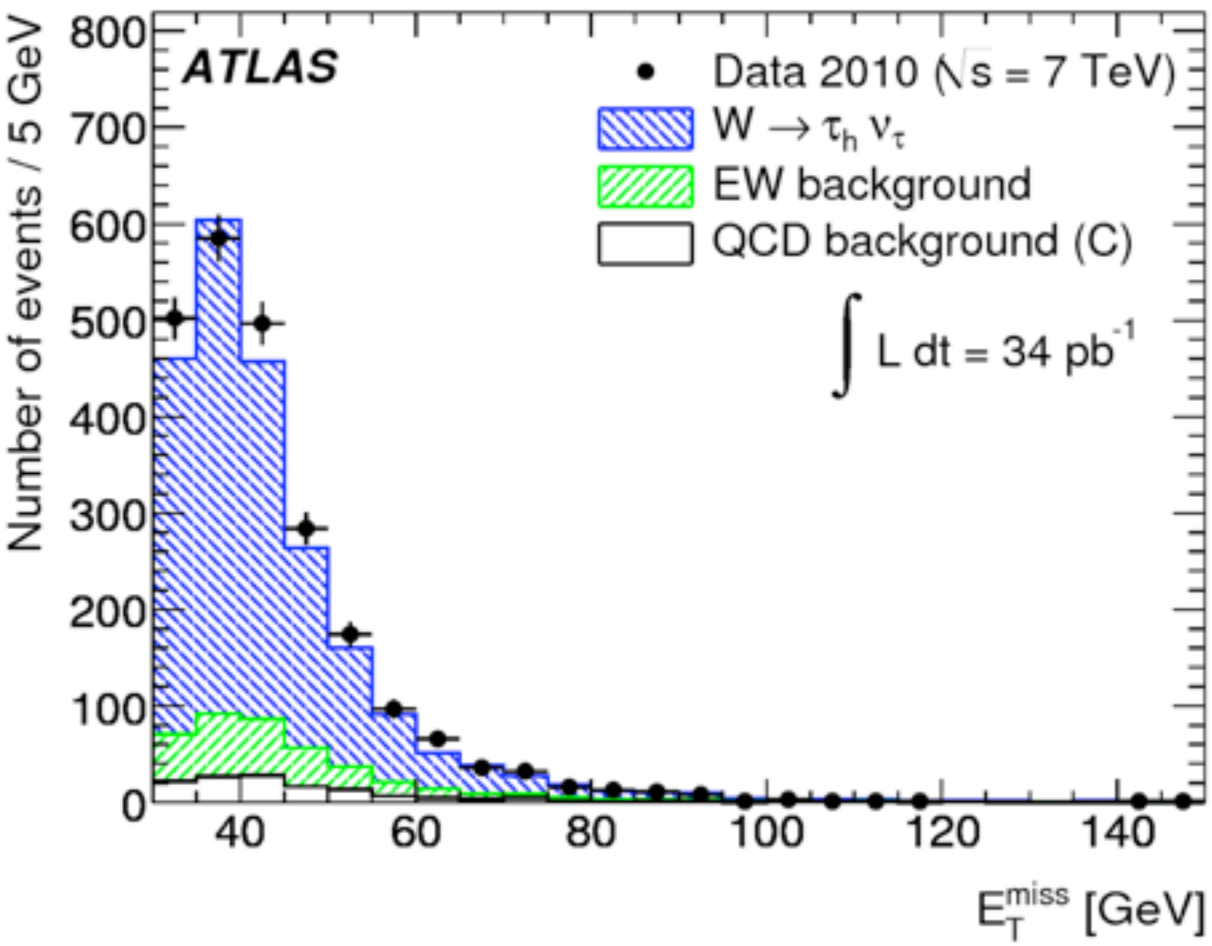


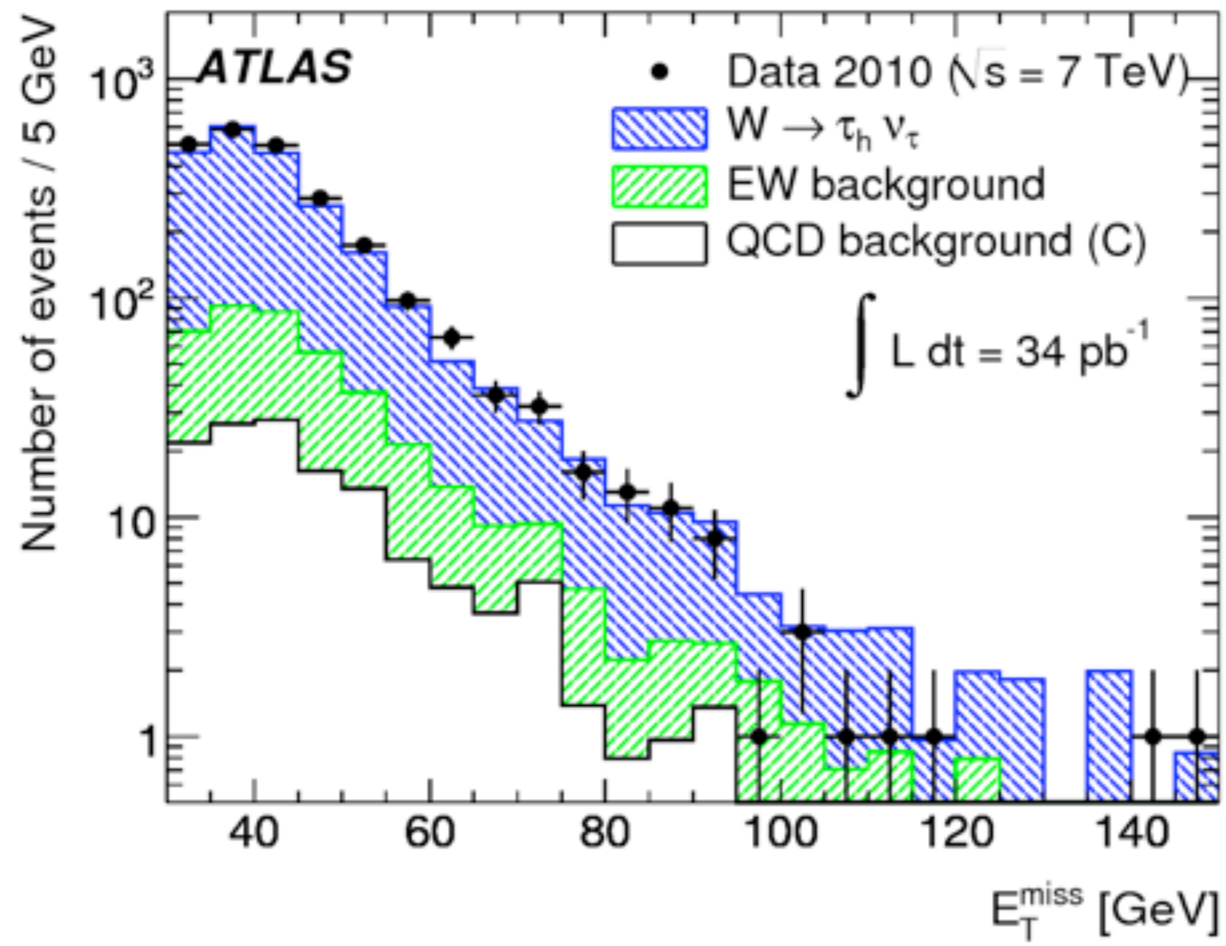


* good agreement data/MC confirms background estimation

Control plots - E_T^{miss}



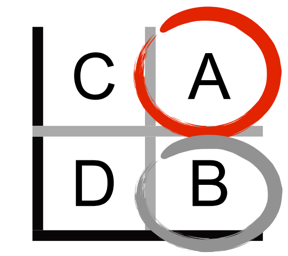


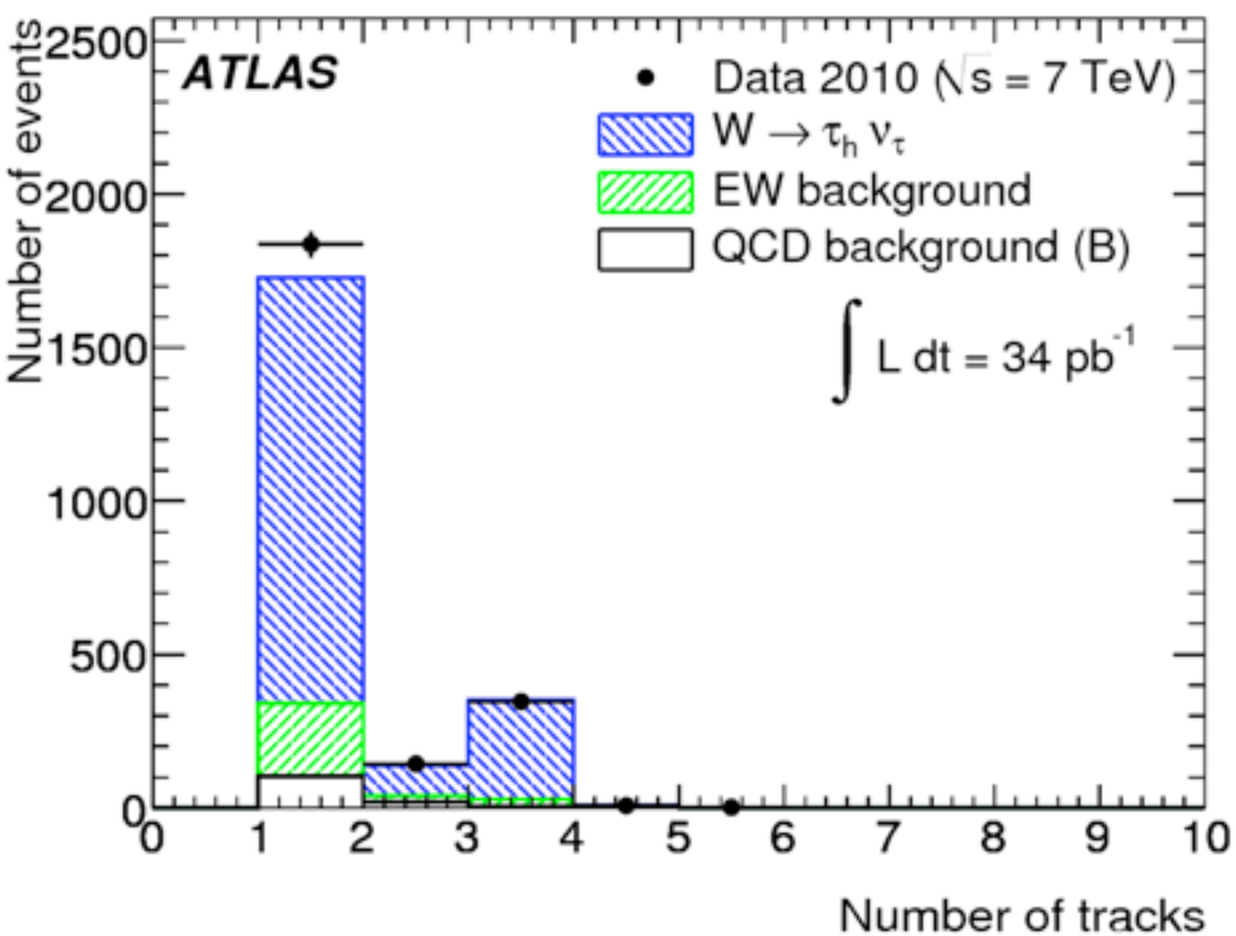


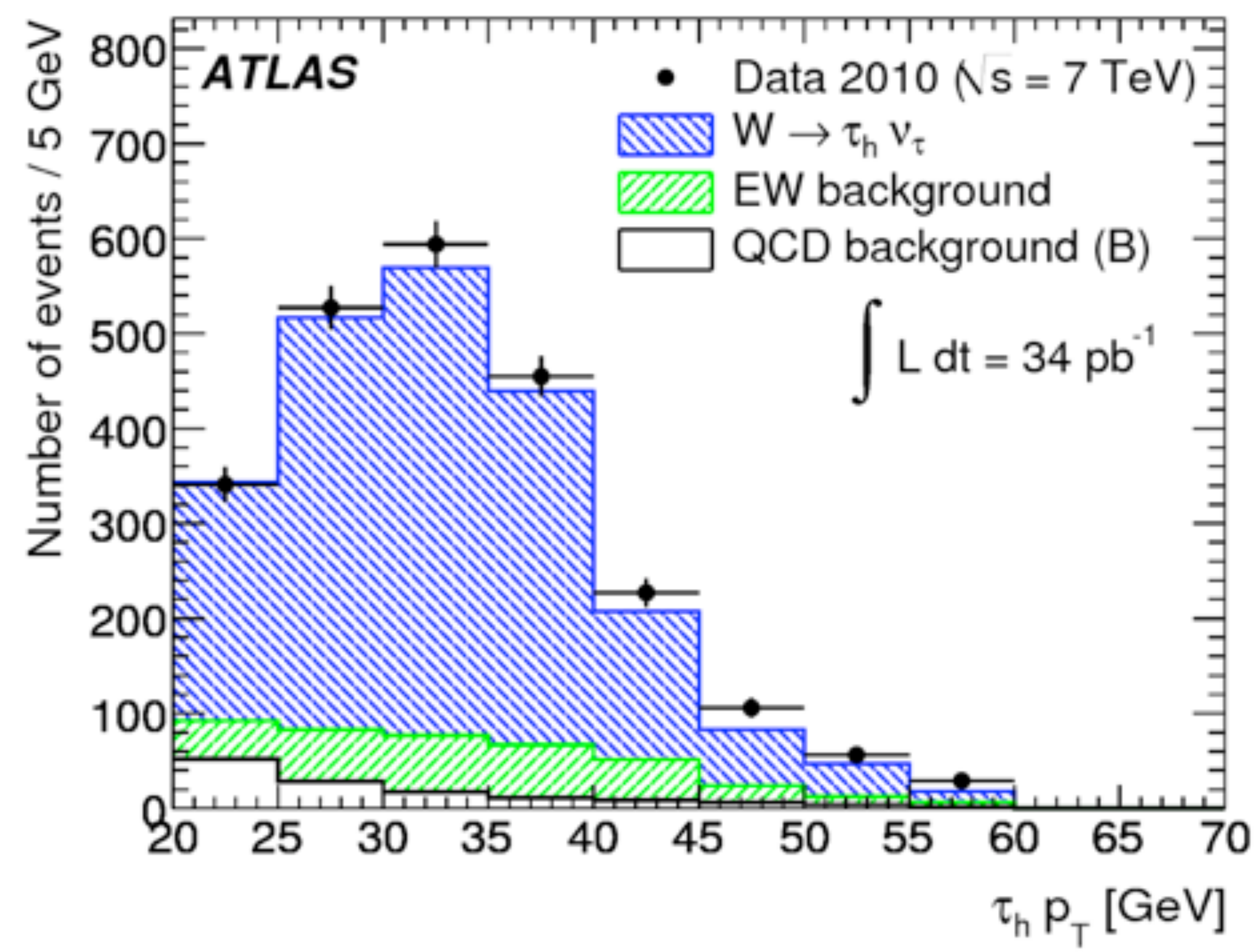
log

* good agreement data/MC

Control plots - tau

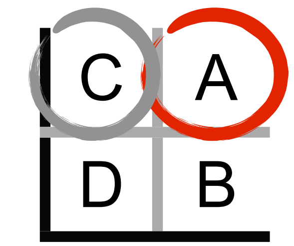


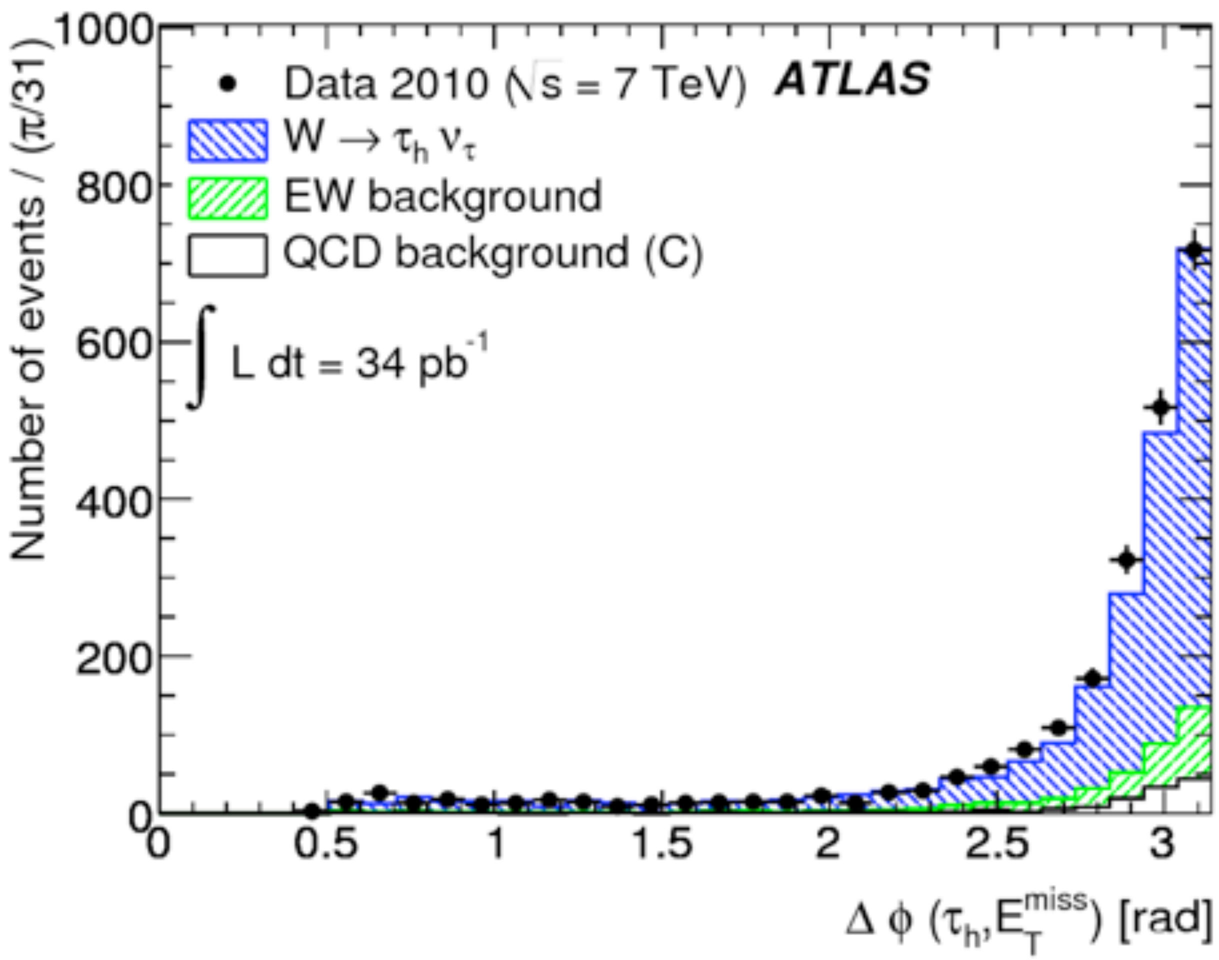


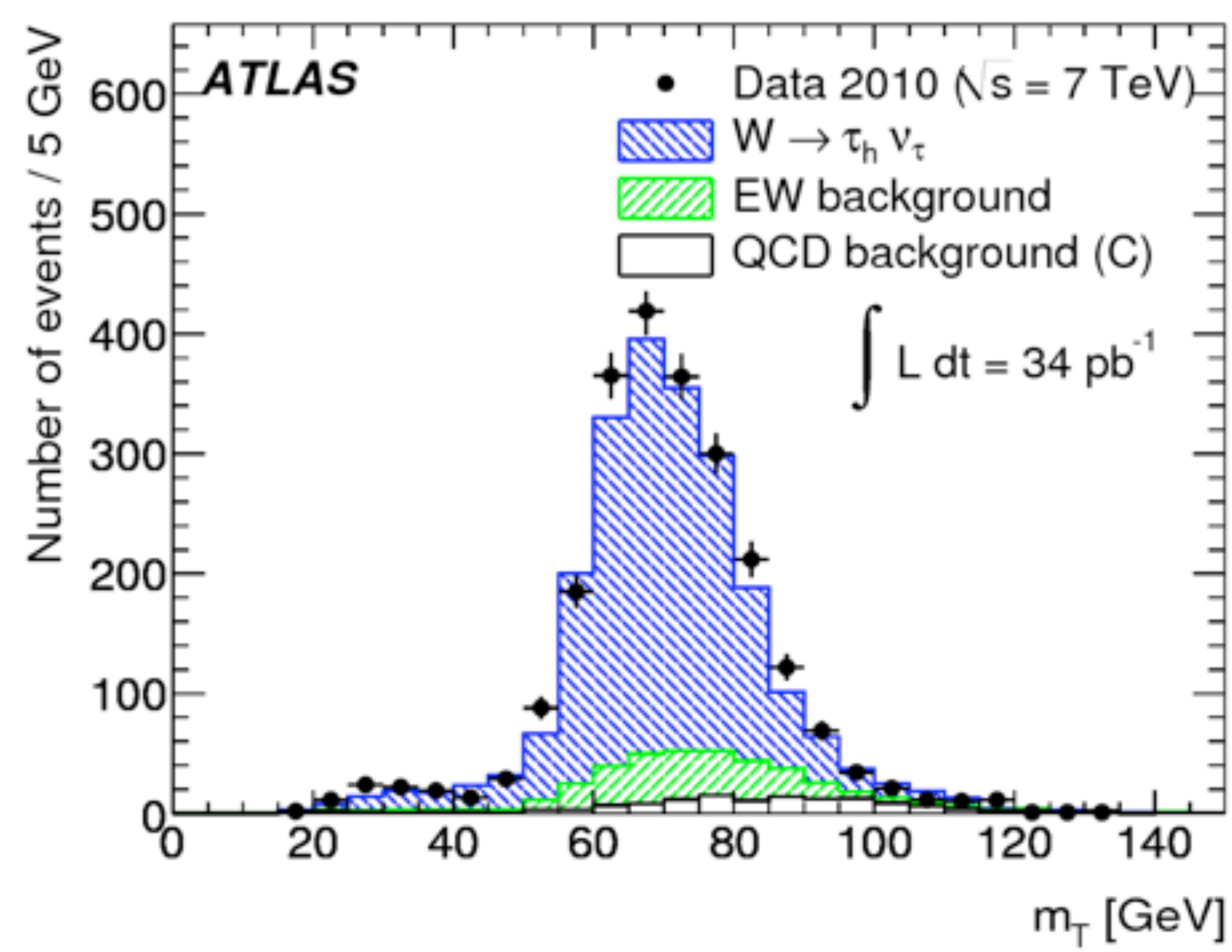


- good agreement data/MC

Control plots - event topology







$$m_{\mathrm{T}} = \sqrt{2 \cdot p_{\mathrm{T}}^{\tau_{\mathrm{h}}} \cdot E_{\mathrm{T}}^{\mathrm{miss}} \cdot \left(1 - \cos \Delta\phi \left(\tau_{\mathrm{h}}, E_{\mathrm{T}}^{\mathrm{miss}}\right)\right)}$$

* good agreement data/MC

Cross section measurement

Total cross section

$$\sigma^{\mathrm{tot}}_{W\to\tau_{\mathrm{h}}\nu_\tau} = \sigma^{\mathrm{fid}}_{W\to\tau_{\mathrm{h}}\nu_\tau}/A_W = \frac{N_{\mathrm{obs}} - \boxed{N_{\mathrm{bkg}}}}{\boxed{A_W}\boxed{C_W}\mathcal{L}}$$

N_{bkg}

EW background from MC

QCD background from ABCD method

C_W

Combined efficiency of selection (trigger, reconstruction and all cuts) from signal MC

$$C_W = \frac{N_{\mathrm{reco,\ all\ cuts}}}{N_{\mathrm{gen,\ kin/geom}}}$$

A_W

Geometric and kinematic acceptance (evaluated on generator level)

$$A_W = \frac{N_{\mathrm{gen,\ kin/geom}}}{N_{\mathrm{gen,\ all}}}$$

$20\ \mathrm{GeV} < p_{\mathrm{T}}^{\tau,\mathrm{vis}} < 60\ \mathrm{GeV}$
$\lvert\eta^{\tau,\mathrm{vis}}\rvert < 2.5$, excluding $1.3 < \lvert\eta^{\tau,\mathrm{vis}}\rvert < 1.7$
$(\sum p^\nu)_T > 30\ \mathrm{GeV}$
$\lvert\Delta\phi(p^{\tau,\mathrm{vis}}, \sum p^\nu)\rvert > 0.5$

A_W = 0.0975 ± 0.0004 (MC stat)

C_W = 0.0799 ± 0.0011 (MC stat)

* alternative methods (with cut-based tau ID, 1 vertex) yield consistent results for cross section

Systematic uncertainties

$$\sigma^{\mathrm{tot}}_{W\to\tau_{\mathrm{h}}\nu_\tau} = \boxed{\sigma^{\mathrm{fid}}_{W\to\tau_{\mathrm{h}}\nu_\tau}} / \boxed{A_W} = \frac{N_{\mathrm{obs}} - \boxed{N_{\mathrm{bkg}}}}{A_W \boxed{C_W} \mathcal{L}}$$

	$\frac{\delta C_W}{C_W}$	$\frac{\delta N_{\mathrm{EW}}}{N_{\mathrm{EW}}}$	$\frac{\delta N_{\mathrm{QCD}}}{N_{\mathrm{QCD}}}$	$\frac{\delta\sigma^{\mathrm{fid}}_{W\to\tau_{\mathrm{h}}\nu_\tau}}{\sigma^{\mathrm{fid}}_{W\to\tau_{\mathrm{h}}\nu_\tau}}$
Trigger efficiency	6.1%	6.1%	-	7.0%
Energy scale	6.7%	8.7%	-	8.0%
τ_{h} ID efficiency	9.6%	4.1%	-	10.3%
Jet τ_{h} misidentification	-	7.2%	-	1.1%
Electron τ_{h} misidentification	-	4.5%	-	0.7%
Pile-up reweighting	1.4%	1.2%	-	1.6%
Electron reconstruction/identification	-	1.2%	-	0.2%
Muon reconstruction	-	0.3%	-	0.04%
Underlying event modeling	1.3%	1.1%	-	1.5%
Cross section	-	4.5%	-	0.7%
QCD estimation: Stability/correlation	-	-	2.7%	0.2%
QCD estimation: Sig./EW contamination	-	-	2.1%	0.1%
Monte Carlo statistics	1.4%	2.4%	6.0%	1.5%
Total systematic uncertainty	13.4%	15.2%	6.9%	15.1%

- Main contributions:
  - uncertainty on energy scale
  - hadronic tau identification efficiency

Aw systematic uncertainty (mainly PDF uncertainty): **1.9%**

Results

N_{obs}	2335
N_{QCD}	127 ± 9
N_{EW}	284 ± 43
A_W	0.0975 ± 0.0019
C_W	0.0799 ± 0.0107

- **Fiducial cross section** $\boxed{\sigma^{\text{fid}}_{W\to\tau_{\text{h}}\nu_\tau}}$

  $0.70 \pm 0.02\ (\text{stat}) \pm 0.11\ (\text{syst}) \pm 0.02\ (\text{lumi})\ \text{nb}$

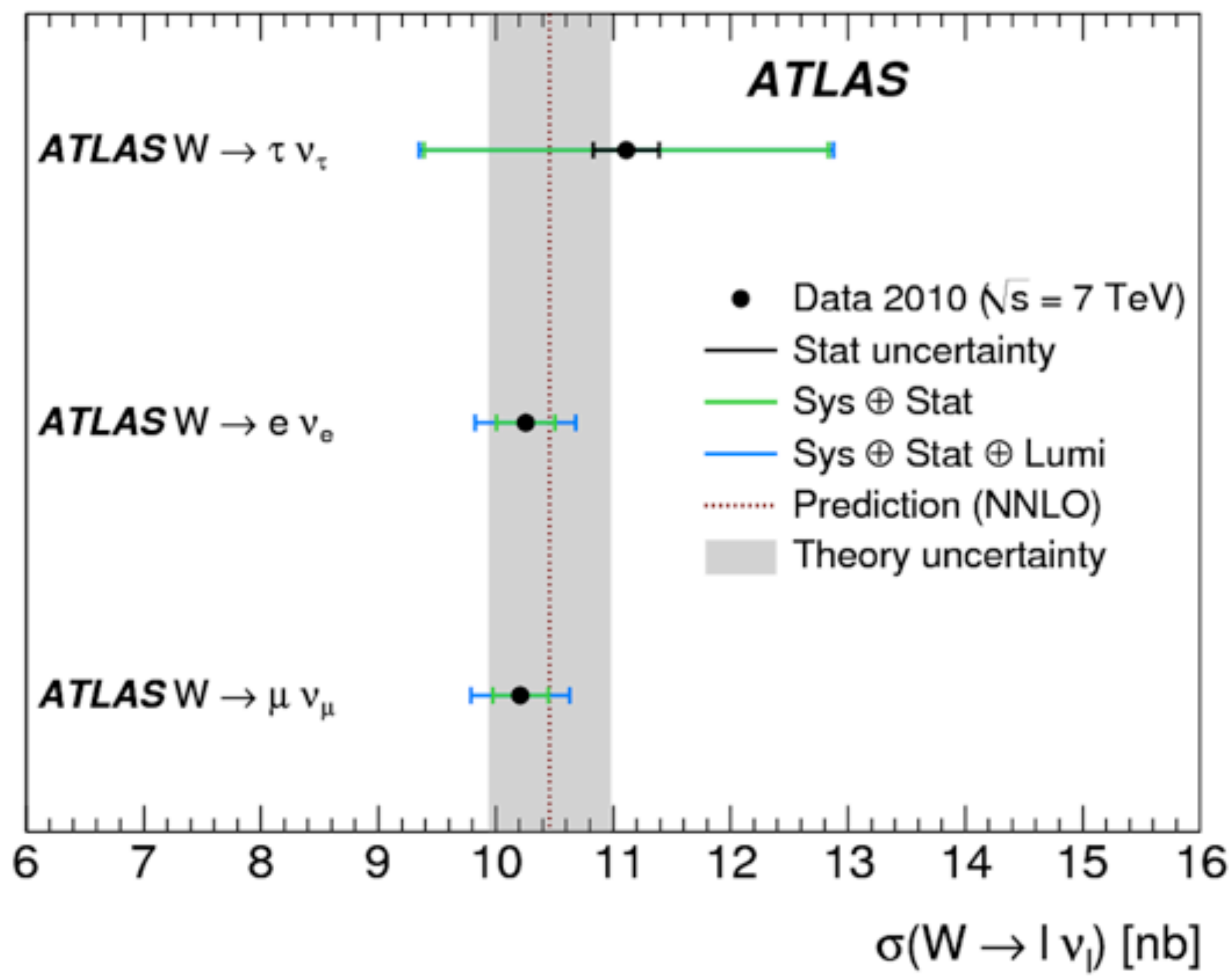
- **Total cross section** $\boxed{\sigma^{\text{tot}}_{W\to\tau_{\text{h}}\nu_\tau}}$

  $7.2 \pm 0.2\ (\text{stat}) \pm 1.1\ (\text{syst}) \pm 0.2\ (\text{lumi})\ \text{nb}$

- Corrected for branching ratio $\boxed{\sigma^{\text{tot}}_{W\to\tau\nu_\tau}}$

  $11.1 \pm 0.3\ (\text{stat}) \pm 1.7\ (\text{syst}) \pm 0.4\ (\text{lumi})\ \text{nb}$

Results



* Consistent with **theoretical expectation** and **W→eυ /W→μυ** ATLAS measurement

Summary

Paper accepted by PLB: *arXiv:1108.4101v1*

- **W→τυ** important measurement at ATLAS
- **Cross section** has successfully been extracted
- **Background estimation** taken from data/validated with data

$$\boxed{\sigma^{\mathrm{tot}}_{W\to\tau\nu_\tau}} = 11.1 \pm 0.3\ (\mathrm{stat}) \pm 1.7\ (\mathrm{syst}) \pm 0.4\ (\mathrm{lumi})\ \mathrm{nb}$$

- Result consistent with **theoretical** expectation and **W→eυ /W→μυ measurement**
- **First measurement of W→τυ cross section at the LHC.**

Backup

Systematic uncertainties

Monte Carlo predictions

Affecting N_{bgk} and C_W

* **Trigger efficiency:** The response of the τ_h and E_T^{miss} trigger part are compared in data and MC - **6.1%**

* **Energy scale uncertainty:** all clusters in event are rescaled according to their uncertainty and ΣE_T and E_T^{miss} are recalculated, at the same time τ_h energy scaled is according to its uncertainty - **6.7%** for C_W, **8.7 %** for N_{bkg}

* **τ_h identification efficiency:** Uncertainty evaluated for Monte Carlo - varies with underlying event models, detector geometry, hadronic shower model, calorimeter noise cluster thresholds (provided by tau WG) - **9.6 %** for C_W, **4.1 %** for N_{bkg}

* **Electron/jet misidentification:** The misidentification probability of jets/electrons as τ_h candidates is determined in data and Monte Carlo in a $W \to l\upsilon$+jets/$Z \to ee$ sample - **7.5% / 4.2%** for N_{bkg}

Systematic uncertainties

QCD background estimation **Affecting N_{bgk}**

* **stability/small correlation of variables:** studied by varying the S_{ETmiss} threshold - **2.7%**

* **contamination of signal+EW background:** studied by varying them in control regions within statistical and systematic uncertainty - **2.1%**

Acceptance A_W

* **Uncertainty of PDF:** reweight default MRSTLO* to different error eigenvectors available for CTEQ6.6, reweight default to PDF sets of CTEQ 6.6 and HERAPDF 1.0 - **1.9%**

* **Uncertainty on modelling of parton shower:** comparison of acceptance with MC@NLO (after correction for missing tau polarization) - **negligible**

Tau ID variables

	R_{EM}	R_{track}	f_{track}	f_{core}	f_{EM}	m_{clusters}	m_{tracks}	$S_{\mathrm{T}}^{\mathrm{flight}}$	f_{HT}
Cuts	•	•	•						
Likelihood single-prong	•	•				•			
Likelihood multi-prong	•		•		•		•	•	
Jet BDT single-prong	•	•	•	•	•	•			
Jet BDT multi-prong	•	•	•	•	•	•	•	•	
Electron BDT single-prong	•	•	•	•	•	•			•
Electron BDT multi-prong	•	•	•	•	•	•	•	•	•

$$R_{\mathrm{EM}} = \frac{\sum_{i\in\{\mathrm{EM}\ 0-2\}}^{\Delta R_i<0.4} E_{\mathrm{T},i}^{\mathrm{EM}}\,\Delta R_i}{\sum_{i\in\{\mathrm{EM}\ 0-2\}}^{\Delta R_i<0.4} E_{\mathrm{T},i}^{\mathrm{EM}}},$$

$$f_{\mathrm{track}} = \frac{p_{\mathrm{T},1}^{\mathrm{track}}}{p_{\mathrm{T}}^{\tau}},$$

$$R_{\mathrm{track}} = \frac{\sum_{i}^{\Delta R_i<0.4} p_{\mathrm{T},i}\,\Delta R_i}{\sum_{i}^{\Delta R_i<0.4} p_{\mathrm{T},i}},$$

$$f_{\mathrm{core}} = \frac{\sum_{i\in\{\mathrm{all}\}}^{\Delta R_i<0.1} E_{\mathrm{T},i}^{\mathrm{EM}}}{\sum_{i\in\{\mathrm{all}\}}^{\Delta R_i<0.4} E_{\mathrm{T},i}^{\mathrm{EM}}},$$

$$f_{\mathrm{EM}} = \frac{\sum_{i\in\{\mathrm{EM}\ 0-2\}}^{\Delta R_i<0.4} E_{\mathrm{T},i}^{\mathrm{EM}}}{\sum_{j\in\{\mathrm{all}\}}^{\Delta R_j<0.4} E_{\mathrm{T},j}^{\mathrm{EM}}},$$

$$S_{\mathrm{T}}^{\mathrm{flight}} = \frac{L_{\mathrm{T}}^{\mathrm{flight}}}{\delta L_{\mathrm{T}}^{\mathrm{flight}}},$$

MC samples

MC DS ID	Sample	Generator	UE	PileUp	Simulation tag	Events	x-sec (nb)
106043	$W \to e\nu_e$	Pythia6	AMBT1	InTime $< 2 >$	e574_s933_s946_r1661_r1700	1.4M	10.46
106044	$W \to \mu\nu_\mu$	Pythia6	AMBT1	InTime $< 2 >$	e574_s933_s946_r1659_r1700	1.4M	10.46
107054	$W \to \tau\nu_\tau$	Pythia6	AMBT1	InTime $< 2 >$	e574_s934_s946_r1660_r2040	1M	10.46
106046	$Z \to ee$	Pythia6	AMBT1	InTime $< 2 >$	e574_s933_s946_r1661_r1700	1M	0.99
106047	$Z \to \mu\mu$	Pythia6	AMBT1	InTime $< 2 >$	e574_s933_s946_r1659_r1700	1M	0.99
106052	$Z \to \tau\tau$	Pythia6	AMBT1	InTime $< 2 >$	e574_s934_s946_r1660_r2040	1M	0.99
105200	$t\bar{t}$ leptonic	MC@NLO	AMBT1	InTime $< 2 >$	e598_s933_s946_r1659_r1700	200k	0.144×0.556
105204	$t\bar{t}$ hadronic	MC@NLO	AMBT1	InTime $< 2 >$	e598_s933_s946_r1659_r1700	30k	0.144×0.444
107419	$W \to \tau\nu_\tau$	Pythia6	Perugia2010	InTime $< 2 >$	e618_s934_s946_r1660_r2040	500k	10.46
107418	$Z \to \tau\tau$	Pythia6	Perugia2010	InTime $< 2 >$	e618_s934_s946_r1660_r2040	500k	0.99