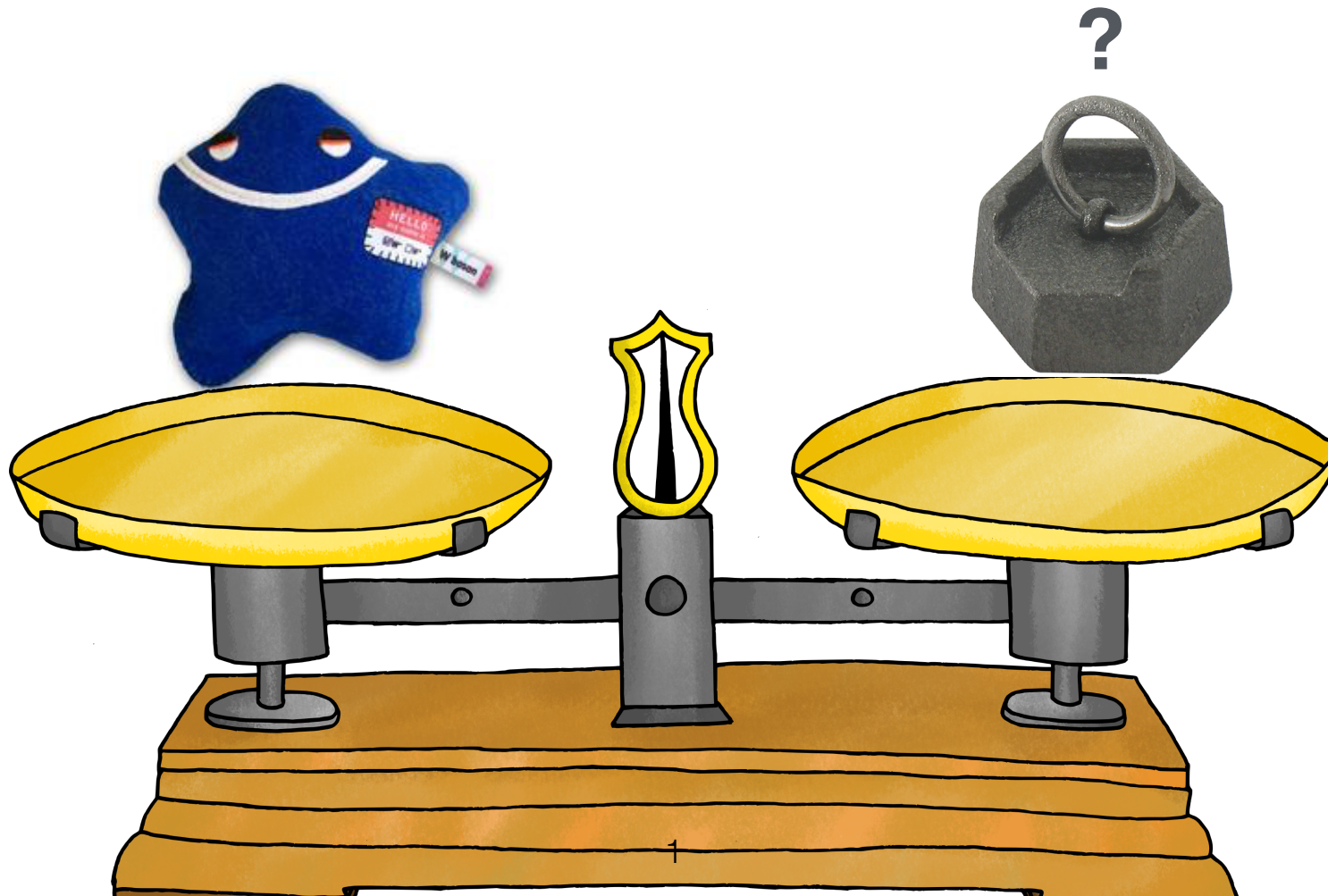


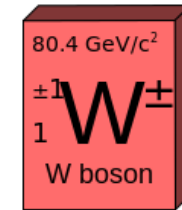
Measurement of the W-boson mass with the ATLAS detector

N. Andari
(Univ. of Birmingham)

IIHE Brussels
March 7, 2018

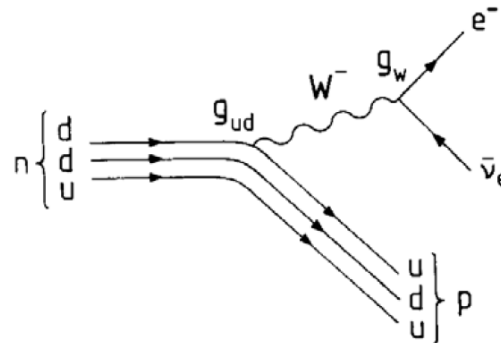
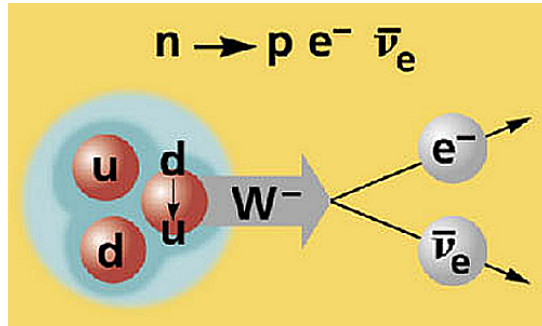


What is the W boson?



It is an elementary charged particle that carries the weak force.

Example: radioactive β -decay

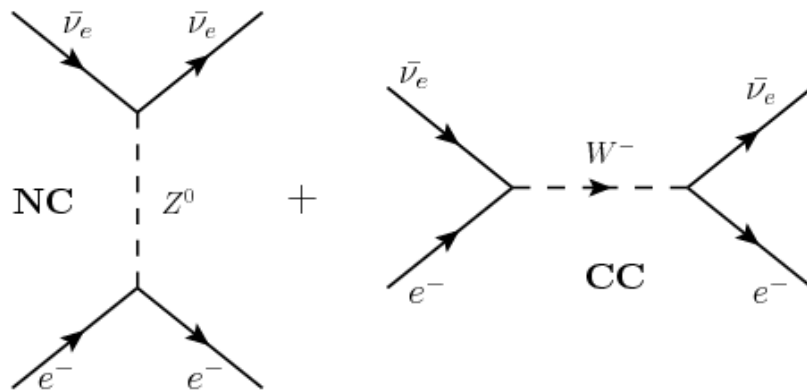


Weinberg - Glashow - Salam



Neutral Current

Charged Current



The Nobel Prize in Physics 1979 was awarded jointly to Sheldon Lee Glashow, Abdus Salam and Steven Weinberg "for their contributions to the theory of the unified weak and electromagnetic interaction between elementary particles, including, inter alia, the prediction of the weak neutral current".

Electroweak theory: 3 fundamental parameters

$$\alpha_{em} = \frac{e^2}{4\pi}, \quad \frac{G_F}{\sqrt{2}} = \frac{g_W^2}{8M_W^2}, \quad \sin \theta_W$$

mediated by exchange of Z and W^\pm bosons with masses of ~ 91.2 GeV and 80.4 GeV resp.

Mass of W and Z related:

$$M_{Z^0}^2 = M_W^2 / \cos^2 \theta_W$$

Discovery of the W boson

The W boson was discovered by the UA1 and UA2 experiments at the SPS at CERN $\sqrt{s}=540$ GeV (world's first proton-antiproton collider) in 1983.

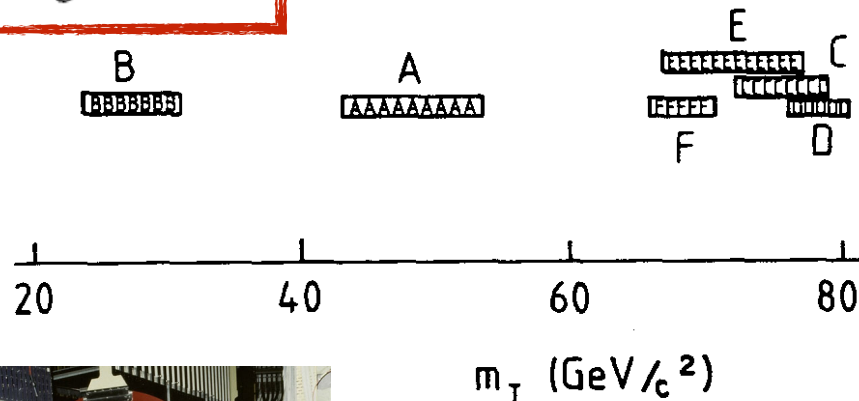
On the 20th of January 1983, 6 candidate W events were published by UA1 and 5 days later, 4 candidate W events were published by UA2.

<https://www.sciencedirect.com/science/article/pii/0370269383911772>

<https://www.sciencedirect.com/science/article/pii/0370269383916052>

$$m_W = (81^{+5}_{-5}) \text{ GeV}/c^2$$

UA1 result



The Nobel Prize in Physics 1984

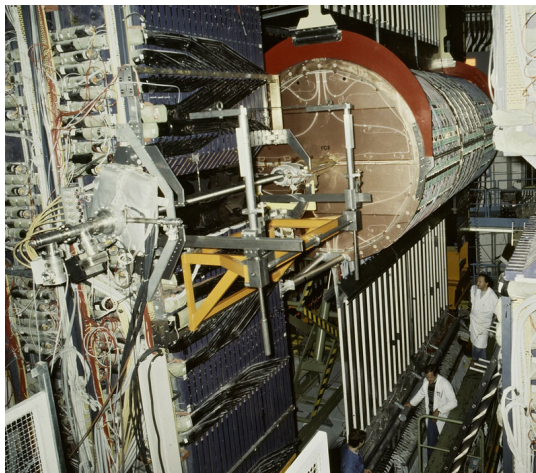
Carlo Rubbia, Simon van der Meer



The Nobel Prize in Physics 1984 was awarded jointly to Carlo Rubbia and Simon van der Meer "for their decisive contributions to the large project, which led to the discovery of the field particles W and Z, communicators of weak interaction"

Carlo Rubbia, who had and developed the idea, and Simon Van der Meer, whose invention made it feasible.

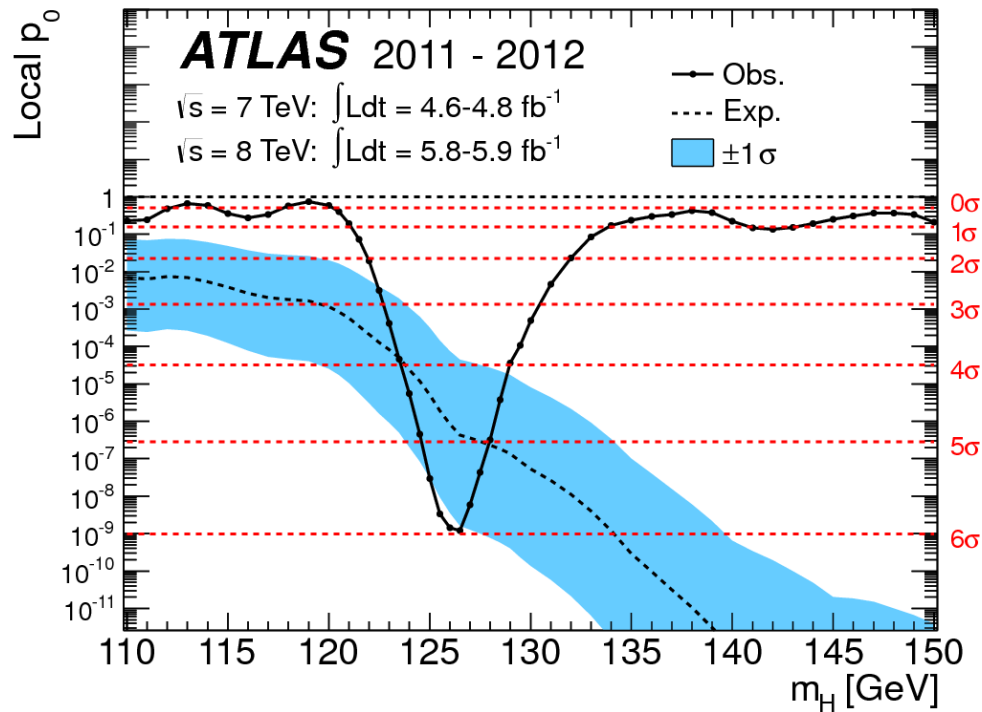
Nice video: <https://videos.cern.ch/record/1004828>



BEH discovery: another success of the SM

Huge step in our understanding of Particle Physics:
recent discovery of the Brout-Englert-Higgs boson
at the LHC by the ATLAS and CMS experiments

[Phys. Lett. B 716 \(2012\) 1-29](#)



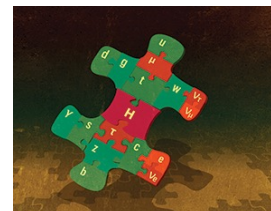
SM puzzle completed, but many open questions (mass hierarchy, baryon asymmetry, dark matter...) remain without answers

—> Search for Beyond the SM

Seminar 4 July 2012



The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"



Beyond the Standard Model

Direct searches: huge numbers of new results from the LHC - astonishing achievement. No significant signals - updated limits. More still to come with future data.

ATLAS SUSY Searches* - 95% CL Lower Limits
Status: March 2017

Model	$\epsilon, \mu, \tau, \gamma$	Jets [†]	E_{miss}^{\dagger}	$\int \mathcal{L} dt [fb^{-1}]$	Mass limit	Reference
Inclusive Searches					$\sqrt{s} = 7, 8 \text{ TeV}$ $\sqrt{s} = 13 \text{ TeV}$	
MSUGRA/CMSSM	$0 < \epsilon, \mu < 1-2\tau$	2-10 jets/3 b	Yes	20.3	1.85 TeV	1507.05525
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	0	2-6 jets	Yes	36.1	1.57 TeV	ATLAS-CONF-2017-022
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$ (compressed)	mono-jet	1-3 jets	Yes	36.1	608 GeV	1604.07773
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	0	2-6 jets	Yes	36.1	2.02 TeV	ATLAS-CONF-2017-022
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	0	2-6 jets	Yes	36.1	2.01 TeV	ATLAS-CONF-2017-022
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	3 e, μ	4 jets	Yes	13.2	1.7 TeV	ATLAS-CONF-2016-037
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	3 e, μ (SS)	0-3 jets	Yes	13.2	1.8 TeV	ATLAS-CONF-2016-037
GMSB (\tilde{t} NLSP)	$1-2 + 0-1 t$	0-2 jets	Yes	3.2	2.0 TeV	1607.05979
GGM (bino NLSP)	2 γ	-	Yes	3.2	1.85 TeV	1606.09150
GGM (higgsino-bino NLSP)	2 γ	1 b	Yes	20.3	1.37 TeV	1507.05493
GGM (higgsino-bino NLSP)	γ	2 jets	Yes	13.3	1.8 TeV	ATLAS-CONF-2016-066
GGM (higgsino NLSP)	2 e, μ (Z)	2 jets	Yes	20.3	900 GeV	1503.03290
Gravitino LSP	0	mono-jet	Yes	20.3	865 GeV	1502.01518
3γ gen sources direct production						
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	0-1 e, μ	3 b	Yes	36.1	1.92 TeV	ATLAS-CONF-2017-021
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	0-1 e, μ	3 b	Yes	20.1	1.97 TeV	ATLAS-CONF-2017-021
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	0	2 b	Yes	3.2	1.47 TeV	1607.08772
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	2 e, μ (SS)	1 b	Yes	13.2	840 GeV	ATLAS-CONF-2016-037
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	0-2 e, μ	1-2 b	Yes	4.7/13.3	325-685 GeV	ATLAS-CONF-2016-037
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	0-2 e, μ	0-2 jets/1-2 b	Yes	20.3	117-170 GeV	1209.2102, ATLAS-CONF-2016-077
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	0	mono-jet	Yes	3.2	90-195 GeV	1506.0816, ATLAS-CONF-2017-039
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	2 e, μ (Z)	1 b	Yes	20.3	90-323 GeV	1604.07773
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	1-2 e, μ	1 b	Yes	20.3	150-600 GeV	1403.3222
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	3 e, μ (Z)	1 b	Yes	36.1	290-790 GeV	ATLAS-CONF-2017-019
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	1-2 e, μ	4 b	Yes	36.1	300-590 GeV	ATLAS-CONF-2017-019
EW direct						
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	2 e, μ	0	Yes	20.3	90-335 GeV	1403.5294
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	2 e, μ	0	Yes	13.3	640 GeV	ATLAS-CONF-2016-096
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	2 τ	-	Yes	14.8	580 GeV	ATLAS-CONF-2016-096
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	3 e, μ	-	Yes	13.2	580 GeV	ATLAS-CONF-2016-096
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	2-3 e, μ	0-2 jets	Yes	20.3	425 GeV	1403.5294, 1402.7029
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	2-3 e, μ	0-2 b	Yes	20.3	270 GeV	1501.07110
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	4 e, μ	-	Yes	20.3	635 GeV	1405.5086
GGM (bino NLSP) weak prod.	1 e, μ, τ, γ	-	Yes	20.3	115-370 GeV	1507.05493
GGM (bino NLSP) weak prod.	2 γ	-	Yes	20.3	590 GeV	1507.05493
Long-lived particles						
Direct $\tilde{g}\tilde{g}$ prod., long-lived \tilde{g}	Disapp. trk	1 jet	Yes	36.1	430 GeV	ATLAS-CONF-2017-017
Direct $\tilde{g}\tilde{g}$ prod., long-lived \tilde{g}	dE/dx trk	-	Yes	18.4	495 GeV	1506.05332
Stable, stopped \tilde{g} R-hadron	0	1-5 jets	Yes	27.9	850 GeV	1310.0364
Metastable \tilde{g} R-hadron	trk	-	-	3.2	1.59 TeV	1605.05120
Metastable \tilde{g} R-hadron	dE/dx trk	-	-	3.2	1.87 TeV	1604.04420
GMSB, stable \tilde{g} , long-lived \tilde{g}	1-2 μ	-	-	19.1	537 GeV	1411.6795
GMSB, $\tilde{g} \rightarrow \gamma$, long-lived \tilde{g}	2 γ	-	Yes	20.3	440 GeV	1409.9542
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	displ. $\nu e/\mu p p$	-	-	20.3	1.0 TeV	1504.05162
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	displ. $\nu e/\mu p p$	-	-	20.3	1.0 TeV	1504.05162
RPV						
LFV $p p \rightarrow \nu X, \nu \nu \rightarrow \nu \nu$	$\nu e, \mu, \tau$	-	-	3.2	1.9 TeV	1607.08079
Bilinear RPV CMSSM	2 e, μ (SS)	0-3 b	Yes	20.3	1.48 TeV	1404.2500
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	4 e, μ	-	Yes	13.3	1.14 TeV	ATLAS-CONF-2016-075
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	3 $e, \mu + \tau$	-	Yes	20.3	450 GeV	1405.5086
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	0-5 large-R jets	-	-	14.8	1.08 TeV	ATLAS-CONF-2016-057
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	0-5 large-R jets	-	-	14.8	1.55 TeV	ATLAS-CONF-2016-057
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	1-6, 8-10 jets/0-4 b	-	-	36.1	2.1 TeV	ATLAS-CONF-2017-013
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	1-6, 8-10 jets/0-4 b	-	-	36.1	1.65 TeV	ATLAS-CONF-2017-013
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	2 jets + 2 b	-	-	15.4	410 GeV	ATLAS-CONF-2016-052, ATLAS-CONF-2016-084
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	2 b	-	-	20.3	450-510 GeV	ATLAS-CONF-2016-015
$\tilde{g}\tilde{g} \rightarrow g\tilde{g}$	0	-	-	20.3	510 GeV	1501.01325

*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

ATLAS Preliminary
 $\sqrt{s} = 7, 8, 13 \text{ TeV}$

ATLAS Exotics Searches* - 95% CL Exclusion
Status: August 2016

Model	ℓ, γ	Jets [†]	E_{miss}^{\dagger}	$\int \mathcal{L} dt [fb^{-1}]$	Limit	Reference
Extra dimensions					$\sqrt{s} = 8 \text{ TeV}$ $\sqrt{s} = 13 \text{ TeV}$	
ADD $G_{KK} + g/q$	-	≥ 1	Yes	3.2	$M_{Pl} \geq 6.56 \text{ TeV}$	n = 2 1604.07773
ADD non-resonant $\ell\ell$	2 e, μ	-	-	20.3	$M_{Pl} \geq 4.7 \text{ TeV}$	n = 3 HzZ 1407.2410
ADD QBH + g	1 e, μ	≥ 1	-	20.3	$M_{Pl} \geq 5.2 \text{ TeV}$	n = 6 1311.2006
ADD QBH	-	≥ 2	-	15.7	$M_{Pl} \geq 8.7 \text{ TeV}$	ATLAS-CONF-2016-069
ADD BH High Σ, pr	$\geq 1 e, \mu$	≥ 2	-	3.2	$M_{Pl} \geq 8.2 \text{ TeV}$	n = 6, $M_{Pl} = 3 \text{ TeV}$, rot BH 1606.02205
ADD BH multijet	-	≥ 3	-	20.3	$M_{Pl} \geq 9.55 \text{ TeV}$	n = 6, $M_{Pl} = 3 \text{ TeV}$, rot BH 1512.02586
RS1 $G_{KK} \rightarrow \ell\ell$	2 e, μ	-	-	20.3	$G_{KK} \text{ mass} \geq 2.68 \text{ TeV}$	$k/M_{Pl} = 0.1$ 1606.0383
RS1 $G_{KK} \rightarrow \gamma\gamma$	2 γ	-	-	3.2	$G_{KK} \text{ mass} \geq 3.2 \text{ TeV}$	$k/M_{Pl} = 1$ 1606.02205
Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\ell\nu$	1 e, μ	-	Yes	13.2	$G_{KK} \text{ mass} \geq 1.34 \text{ TeV}$	$k/M_{Pl} = 1.0$ ATLAS-CONF-2016-062
Bulk RS $G_{KK} \rightarrow HH \rightarrow bbbb$	-	4 b	-	13.3	$G_{KK} \text{ mass} \geq 360-860 \text{ GeV}$	$k/M_{Pl} = 1.0$ ATLAS-CONF-2016-049
Bulk RS $G_{KK} \rightarrow tt$	1 e, μ	$\geq 1 b, \geq 1 J/2$	Yes	20.3	$G_{KK} \text{ mass} \geq 2.2 \text{ TeV}$	BR = 0.925 1505.07018
ZUED / RPP	1 e, μ	$\geq 2 b, \geq 4$	Yes	3.2	$RK \text{ mass} \geq 1.46 \text{ TeV}$	Tier (1,1), BR($A^{(1)} \rightarrow tt$) = 1 ATLAS-CONF-2016-045
Gauge bosons						
SSM $Z' \rightarrow \ell\ell$	2 e, μ	-	-	13.3	$Z' \text{ mass} \geq 2.02 \text{ TeV}$	1502.07177
SSM $Z' \rightarrow \tau\tau$	2 τ	-	-	19.5	$Z' \text{ mass} \geq 1.5 \text{ TeV}$	1603.05791
Leptophobic $Z' \rightarrow bb$	-	2 b	-	3.2	$Z' \text{ mass} \geq 1.5 \text{ TeV}$	1603.05791
SSM $W' \rightarrow \ell\nu$	1 e, μ	-	Yes	13.3	$W' \text{ mass} \geq 4.74 \text{ TeV}$	ATLAS-CONF-2016-061
HVT $W' \rightarrow WZ \rightarrow qq\nu$ model A	0 e, μ	1 J	Yes	13.2	$W' \text{ mass} \geq 2.4 \text{ TeV}$	ATLAS-CONF-2016-082
HVT $W' \rightarrow WZ \rightarrow qq\nu$ model B	-	2 J	-	15.5	$W' \text{ mass} \geq 3.0 \text{ TeV}$	ATLAS-CONF-2016-058
HVT $V' \rightarrow WH/ZH$ model B	Multi-channel	-	-	3.2	$W' \text{ mass} \geq 2.31 \text{ TeV}$	1607.05621
LRSM $W_2' \rightarrow tb$	1 e, μ	2 b, 0 J	Yes	20.3	$W' \text{ mass} \geq 1.92 \text{ TeV}$	1410.4103
LRSM $W_2' \rightarrow tb$	0 e, μ	$\geq 1 b, 1 J$	Yes	20.3	$W' \text{ mass} \geq 1.76 \text{ TeV}$	1406.0888
CI						
CI $e q q q$	-	2	-	15.7	$A \text{ mass} \geq 19.9 \text{ TeV}$	$n_{\ell} = -1$ ATLAS-CONF-2016-069
CI $u u q q$	2 e, μ	-	-	3.2	$A \text{ mass} \geq 25 \text{ TeV}$	$ C_{\text{eff}} = -1$ 1607.03669
CI $u u q q$	2(SS) $\geq 3 e, \mu \geq 1 b, \geq 1 J$	Yes	20.3	3.2	$A \text{ mass} \geq 4.8 \text{ TeV}$	1504.04605
DM						
Axial-vector mediator (Dirac DM)	0 e, μ	≥ 1	Yes	3.2	$m_A \geq 1.0 \text{ TeV}$	1604.07773
Axial-vector mediator (Dirac DM)	0 $e, \mu, 1 \gamma$	1 J	Yes	3.2	$m_A \geq 710 \text{ GeV}$	1604.01306
$ZZ\gamma$ EFT (Dirac DM)	0 e, μ	1 J, 5 J	Yes	3.2	$m_A \geq 590 \text{ GeV}$	ATLAS-CONF-2015-080
LQ						
Scalar LQ 1 st gen	2 e, μ	≥ 2	-	3.2	$LQ \text{ mass} \geq 1.1 \text{ TeV}$	$\beta = 1$ 1605.06305
Scalar LQ 2 nd gen	2 e, μ	≥ 2	-	3.2	$LQ \text{ mass} \geq 1.05 \text{ TeV}$	$\beta = 1$ 1605.06305
Scalar LQ 3 rd gen	1 e, μ	$\geq 1 b, \geq 3$	Yes	20.3	$LQ \text{ mass} \geq 640 \text{ GeV}$	$\beta = 0$ 1508.04735
Heavy quarks						
VLQ $T \rightarrow Ht + X$	1 e, μ	$\geq 2 b, \geq 3$	Yes	20.3	$T \text{ mass} \geq 855 \text{ GeV}$	T in (B) doublet 1505.04306
VLQ $Y \rightarrow Wb + X$	1 e, μ	$\geq 1 b, \geq 3$	Yes	20.3	$Y \text{ mass} \geq 770 \text{ GeV}$	Y in (B) doublet 1505.04306
VLQ $BB \rightarrow Hb + X$	1 e, μ	$\geq 2 b, \geq 3$	Yes	20.3	$B \text{ mass} \geq 735 \text{ GeV}$	isospin singlet 1505.04306
VLQ $BB \rightarrow Zb + X$	2 e, μ	$\geq 2 b, 1 J$	Yes	20.3	$B \text{ mass} \geq 755 \text{ GeV}$	B in (B) doublet 1409.5550
VLQ $Q \rightarrow Wt + X$	1 e, μ	≥ 4	Yes	20.3	$Q \text{ mass} \geq 690 \text{ GeV}$	1509.04261
VLQ $T_{3,1} \rightarrow Wt + X$	2(SS) $\geq 3 e, \mu \geq 1 b, \geq 1 J$	Yes	20.3	3.2	$T_{3,1} \text{ mass} \geq 990 \text{ GeV}$	ATLAS-CONF-2016-032
Excited fermions						
Excited quark $q^* \rightarrow q\gamma$	1 γ	1 J	-	3.2	$q^* \text{ mass} \geq 4.4 \text{ TeV}$	only u' and d' , $A = m(q')$ 1512.05910
Excited quark $q^* \rightarrow qg$	-	2	-	15.7	$q^* \text{ mass} \geq 5.6 \text{ TeV}$	only u' and d' , $A = m(q')$ ATLAS-CONF-2016-069
Excited quark $q^* \rightarrow b\gamma$	-	1 b, 1 J	-	8.8	$q^* \text{ mass} \geq 2.3 \text{ TeV}$	$A = 3.0 \text{ TeV}$ ATLAS-CONF-2016-080
Excited quark $q^* \rightarrow Wt$	1 or 2 e, μ	1 b, 2-0 J	-	20.3	$q^* \text{ mass} \geq 1.5 \text{ TeV}$	$f_u = f_d = f_s = 1$ 1411.2921
Excited lepton $\ell^* \rightarrow \ell\gamma$	3 e, μ, τ	-	-	20.3	$\ell^* \text{ mass} \geq 1.6 \text{ TeV}$	$A = 1.6 \text{ TeV}$ 1411.2921
Excited lepton ν^*	3 e, μ, τ	-	-	20.3	$\nu^* \text{ mass} \geq 960 \text{ GeV}$	1407.8150
Other						
LSTC $\gamma\gamma \rightarrow W\gamma$	1 $e, \mu, 1 \gamma$	-	Yes	20.3	$W \text{ mass} \geq 960 \text{ GeV}$	$m(W_2) = 2.4 \text{ TeV}$, no mixing 1508.0620
LRSM Majorana ν	2 e, μ	2 J	-	20.3	$\nu \text{ mass} \geq 2.0 \text{ TeV}$	DY production, BR($H^{\pm} \rightarrow e\nu$) = 1 ATLAS-CONF-2016-051
Higgs triplet $H^{\pm\pm} \rightarrow ee$	2 e (SS)	-	-	15.9	$H^{\pm\pm} \text{ mass} \geq 570 \text{ GeV}$	$\nu_{\tau} = 0.2$ 1411.2921
Higgs triplet $H^{\pm\pm} \rightarrow \tau\tau$	3 e, μ, τ	-	-	20.3	$H^{\pm\pm} \text{ mass} \geq 400 \text{ GeV}</$	

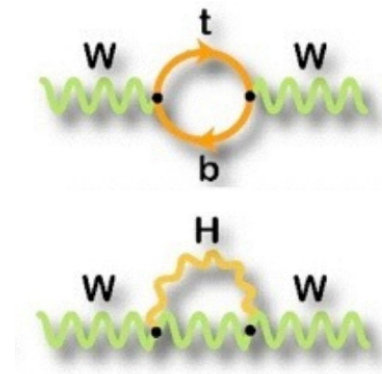
W-boson mass

In the electroweak sector of the SM, the W mass at the tree level:

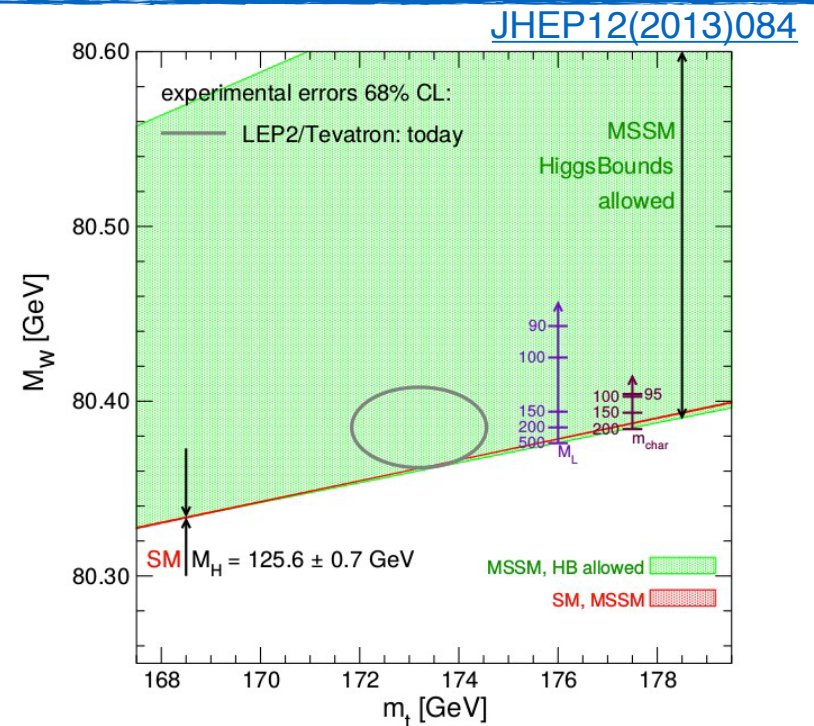
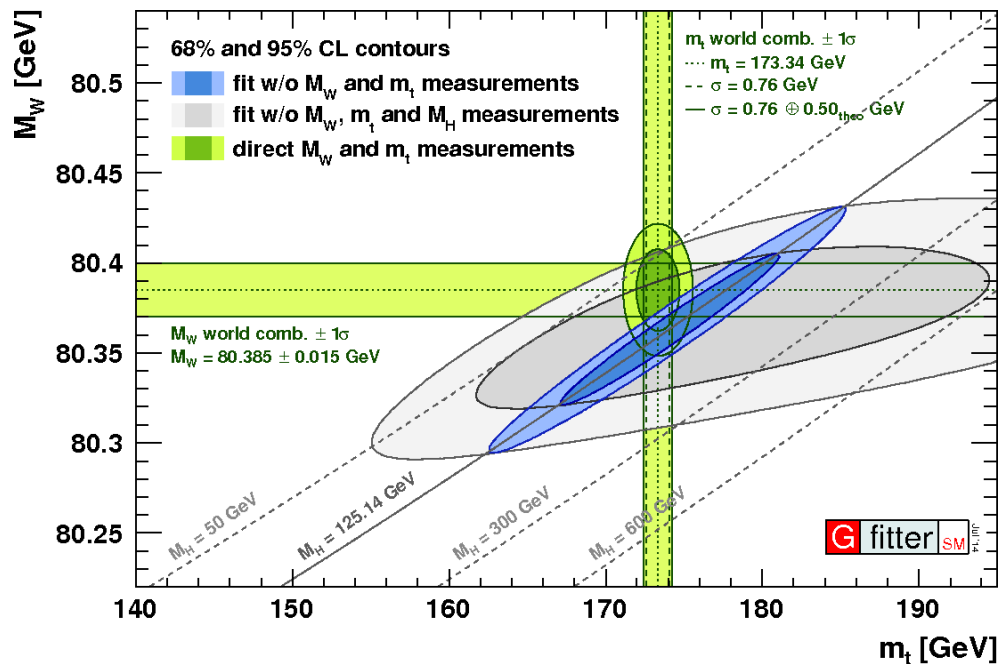
$$m_W^2 \left(1 - \frac{m_W^2}{m_Z^2} \right) = \frac{\pi\alpha}{\sqrt{2}G_F}$$

at the loop level: $m_W^2 \left(1 - \frac{m_W^2}{m_Z^2} \right) = \frac{\pi\alpha}{\sqrt{2}G_F} (1 + \Delta r)$

In SM, Δr reflects loop corrections and depends on m_t^2 and $\ln m_H$

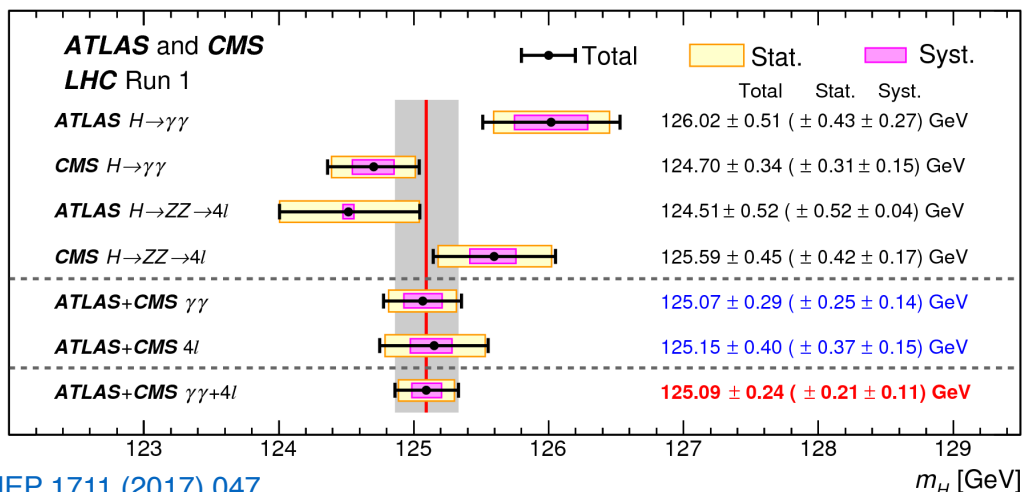


The relation M_W , m_t , and M_H provides stringent test of the SM and is sensitive to NP



Status of the measurements

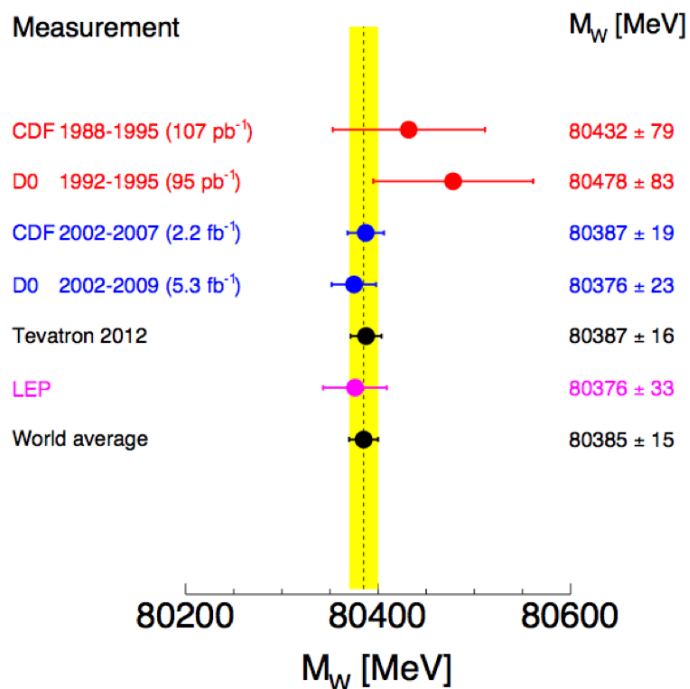
BEH mass [Phys. Rev. Lett. 114, 191803](#)



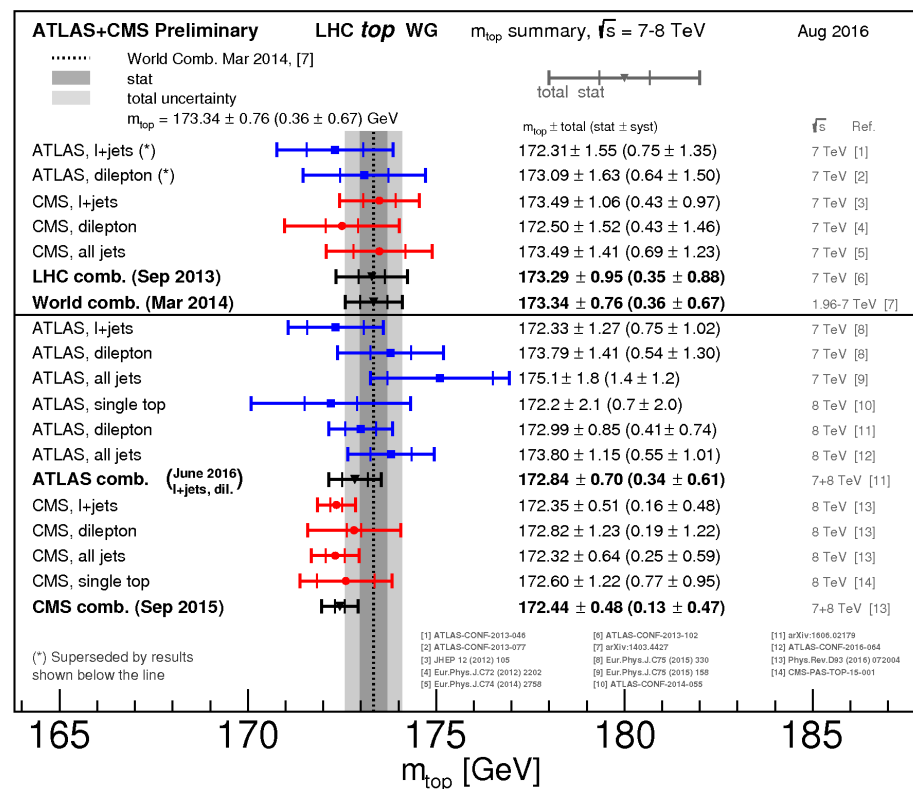
[JHEP 1711 \(2017\) 047](#)

CMS new: 125.26 ± 0.20 (stat.) ± 0.08 (sys.) GeV

Mass of the W Boson



Top mass



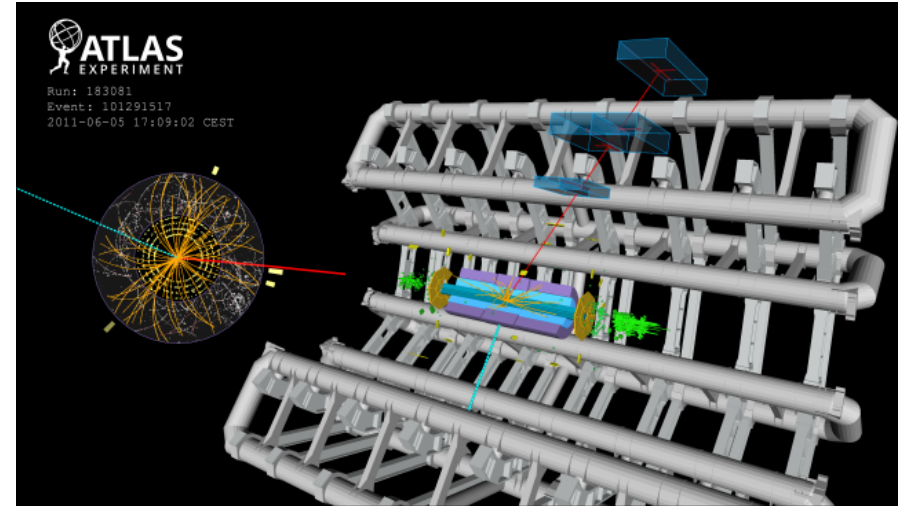
W mass

LEP+Tevatron: M_W uncertainty ~ 15 MeV
 Best individual measurement:
 CDF M_W uncertainty 19 MeV

First W mass measurement at the LHC

Recently published in EPJC [Eur.Phys.J.C \(2018\) 78:110](#)

Seminar 13/12/2016

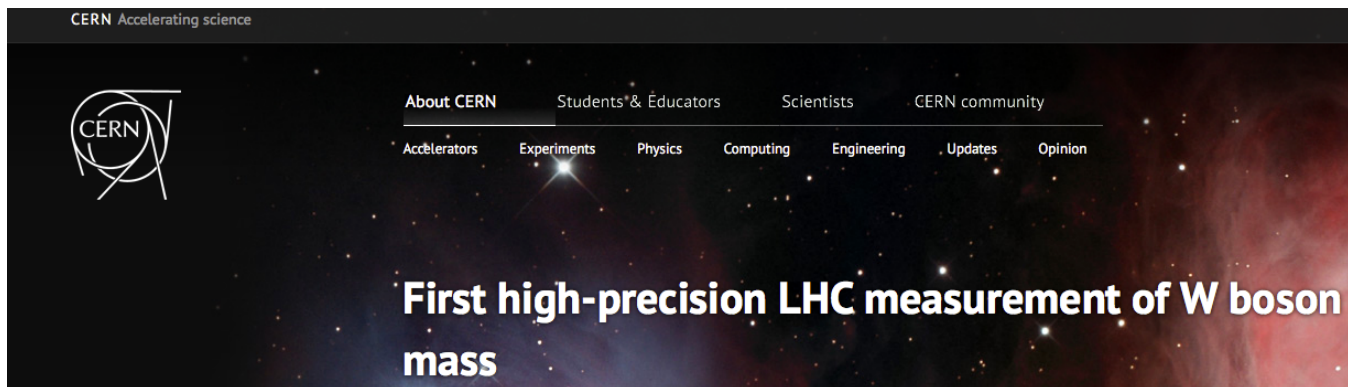


CERN Courier January/February 2017

News

LHC EXPERIMENTS

ATLAS makes precision measurement of W mass



ASTROPAGE.EU

How to measure the W mass

Consider leptonic decay: **electron and muon** channels

Not possible to fully reconstruct W mass

Sensitive final state distributions: \mathbf{p}_T^ℓ , m_T , p_T^{miss}

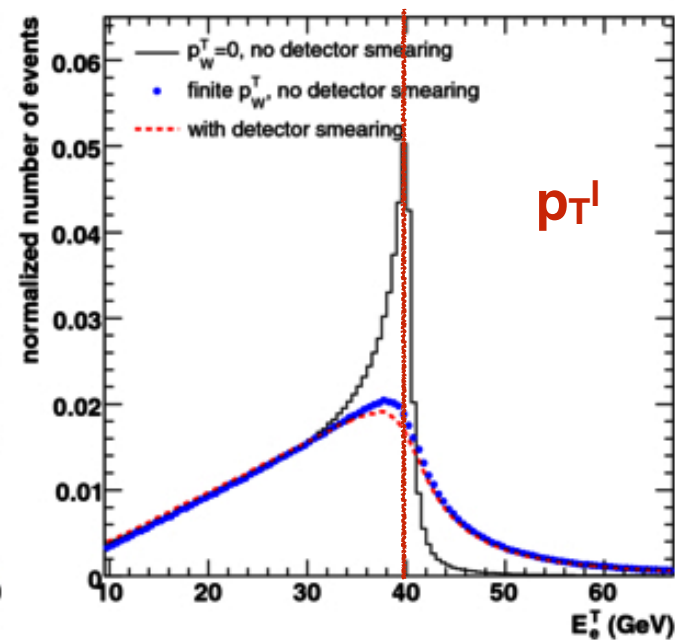
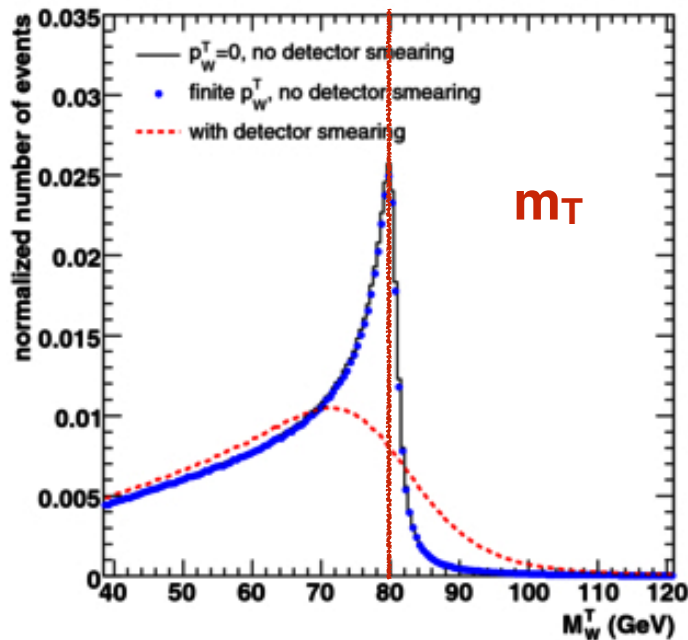
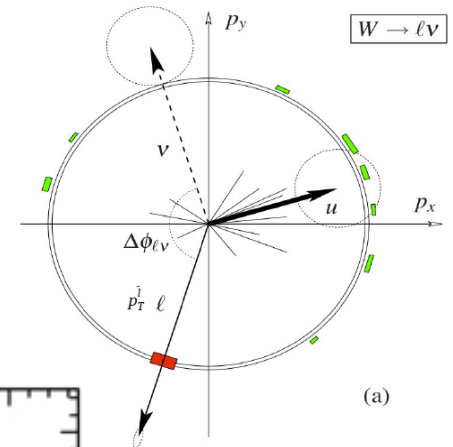
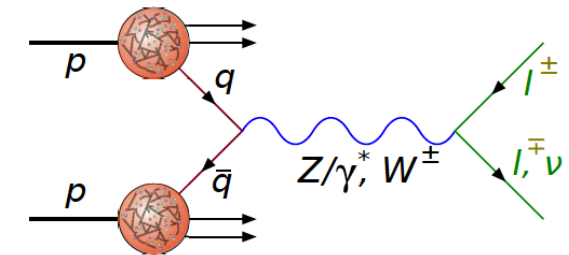
$$\vec{p}_T^{\text{miss}} = -(\vec{p}_T^\ell + \vec{u}_T) \quad m_T = \sqrt{2p_T^\ell p_T^{\text{miss}}(1 - \cos \Delta\phi)} \quad u_T \text{ being the recoil}$$

- u_T provides an estimate of the boson p_T

Jacobian edge at:

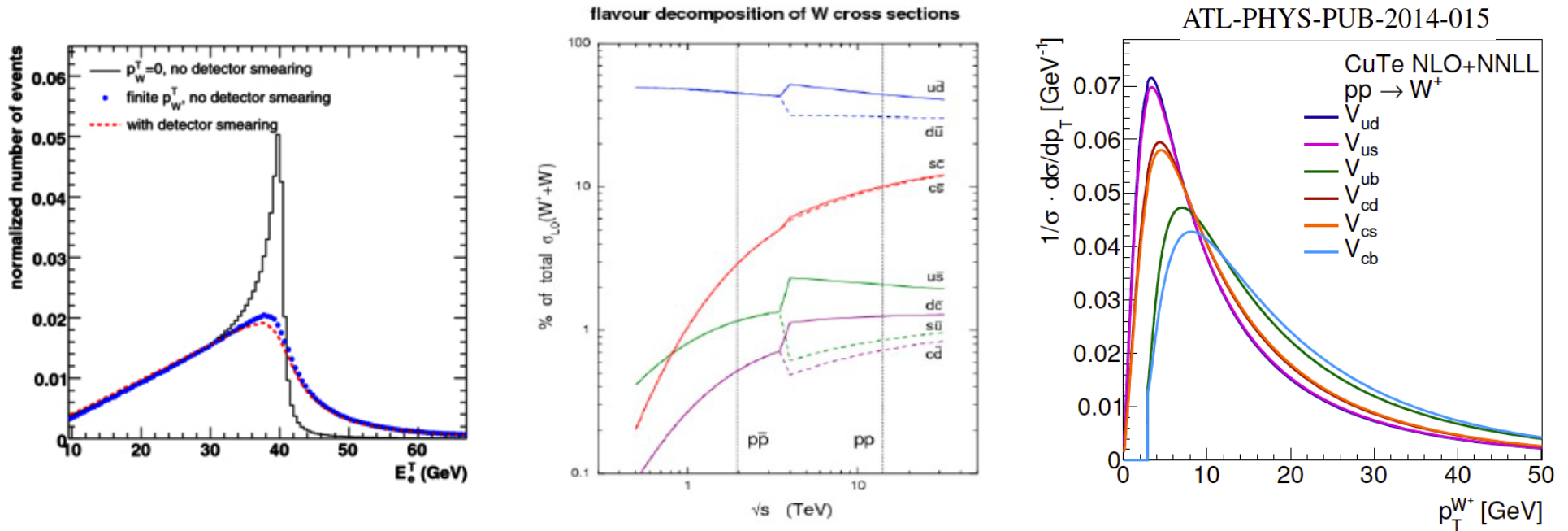
m_W

$m_W/2$

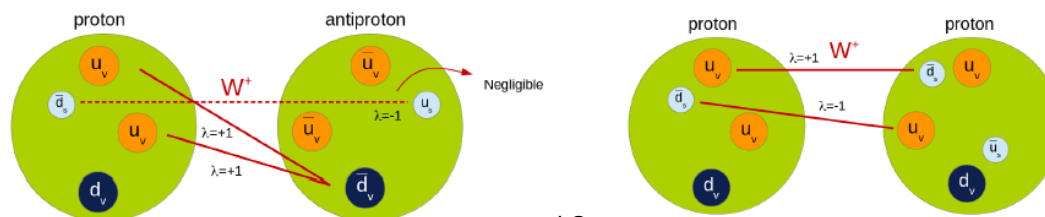


Lepton transverse momentum

Strong impact of the W boson transverse momentum distribution on p_T^l

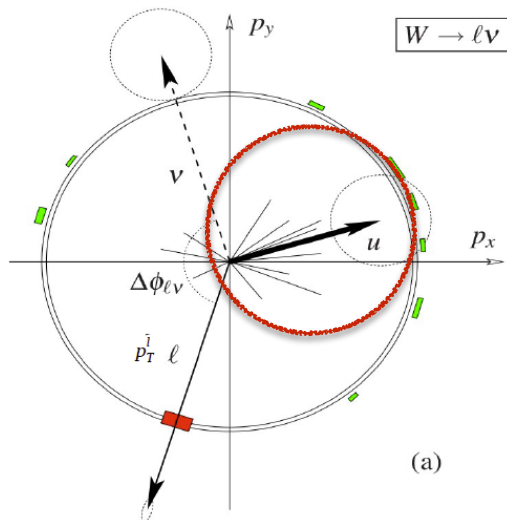
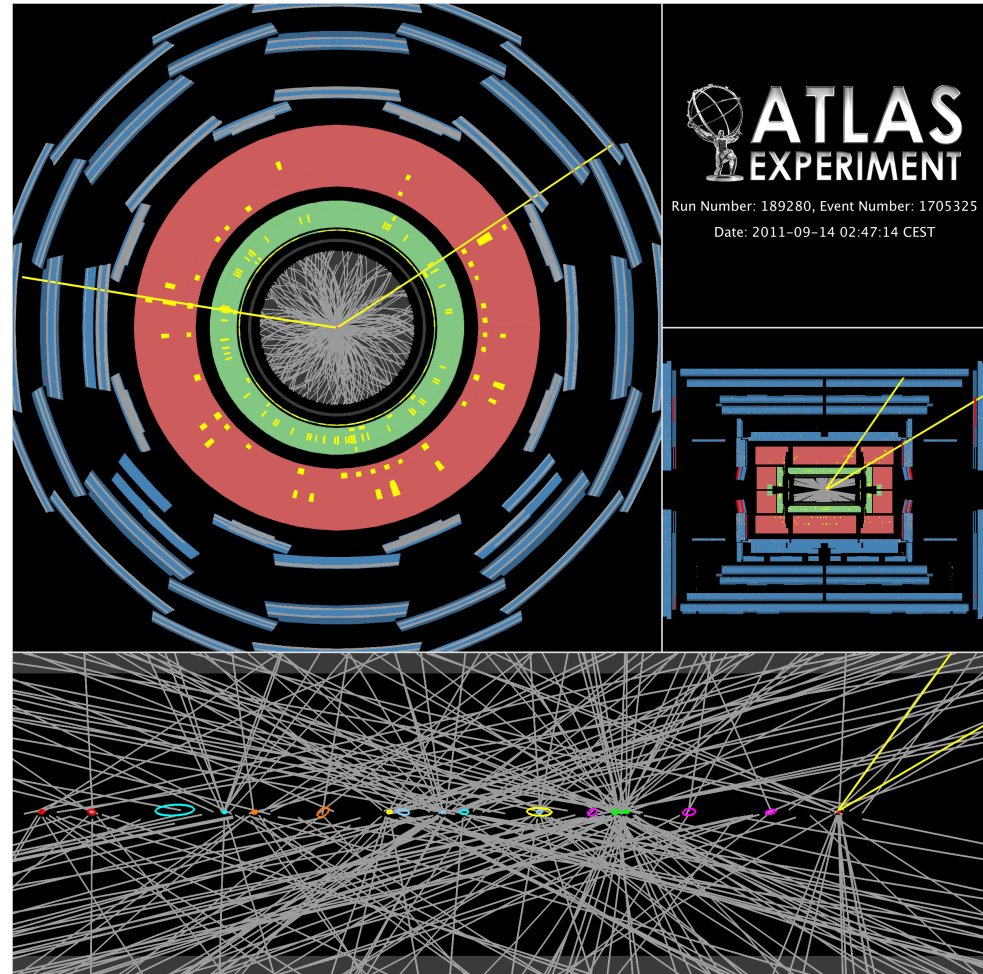
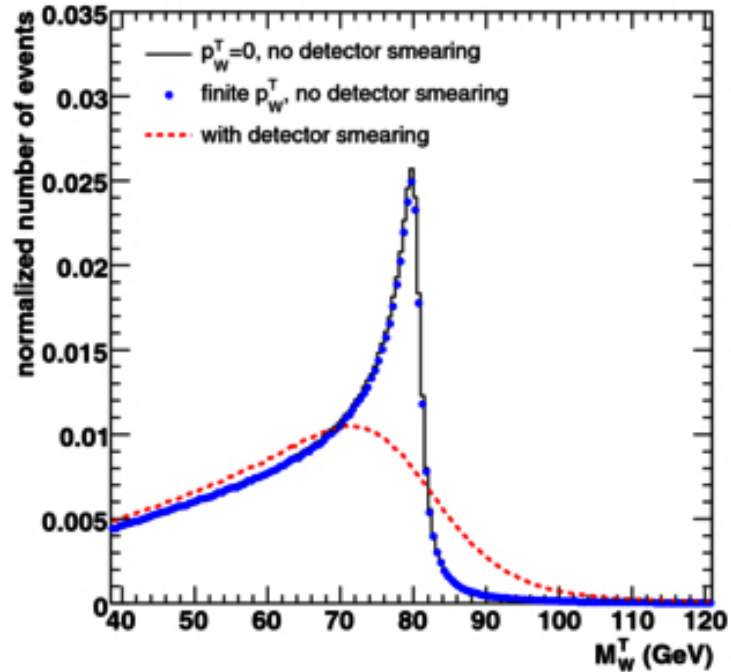


- **Second generation quark PDFs** play a larger role at the LHC (25% of the W-boson production is induced by at least one second generation quark s or c) than at the Tevatron.
- The W polarisation is determined by the difference between the u , d valence and sea densities



W transverse mass

Sensitive to the modelling of the recoil: pileup, UE.. effects



$Z \rightarrow \mu\mu$ event with 20 reconstructed vertices
(recorded in September 2011)

Strategy of the measurement in ATLAS

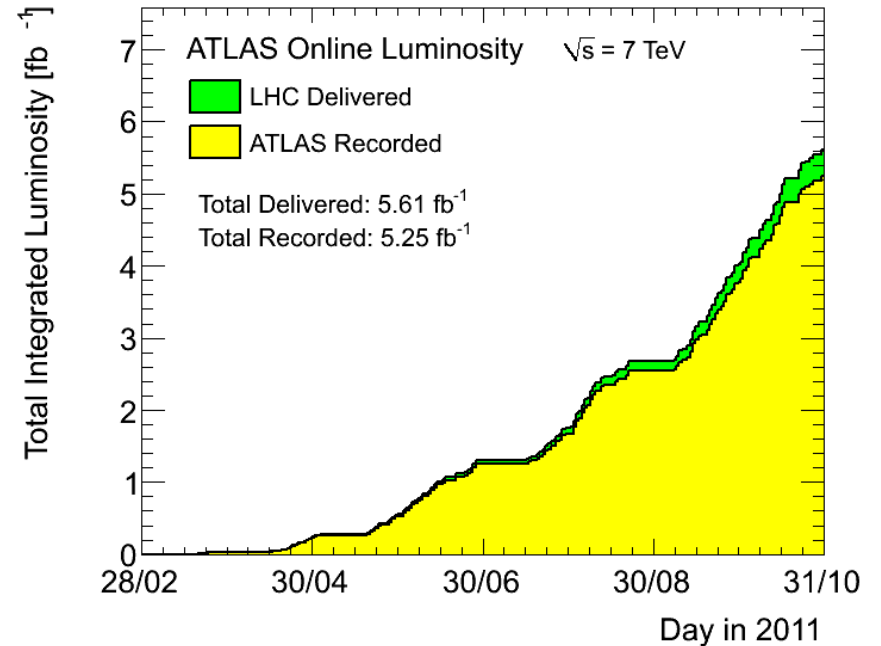
Sensitive final state distributions: p_T^ℓ , m_T , p_T^{miss} *

$$\vec{p}_T^{\text{miss}} = -(\vec{p}_T^\ell + \vec{u}_T) \quad m_T = \sqrt{2p_T^\ell p_T^{\text{miss}}(1 - \cos \Delta\phi)}$$

u_T being the recoil

In W, Z events $-u_T$ provides an estimate of the boson p_T

2011 data is used for the measurement recorded at $\sqrt{s} = 7$ TeV



Categories for the measurement:

Decay channel	$W \rightarrow e\nu$	$W \rightarrow \mu\nu$
Kinematic distributions	p_T^ℓ, m_T	p_T^ℓ, m_T
Charge categories	W^+, W^-	W^+, W^-
$ \eta_\ell $ categories	[0, 0.6], [0.6, 1.2], [1.8, 2.4]	[0, 0.8], [0.8, 1.4], [1.4, 2.0], [2.0, 2.4]

*used as cross-check only

Selection cuts

Lepton selections:

- muons isolated (track-based) $|\eta| < 2.4$
- electrons isolated (track+calorimeter-based) tight identified $0 < |\eta| < 1.2$, $1.8 < |\eta| < 2.4$

Kinematic requirements: $p_T > 30$ GeV, $m_T > 60$ GeV, $MET > 30$ GeV and $\text{recoil}(u_T) < 30$ GeV

~6M/8M observed in the electron/muon channel

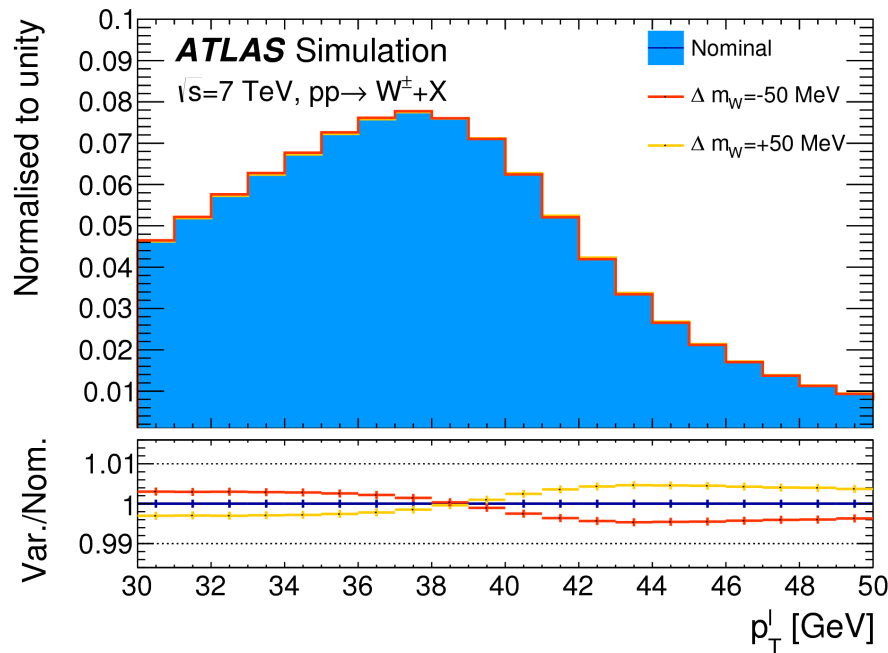
$ \eta_\ell $ range	0–0.8	0.8–1.4	1.4–2.0	2.0–2.4	Inclusive
$W^+ \rightarrow \mu^+ \nu$	1 283 332	1 063 131	1 377 773	885 582	4 609 818
$W^- \rightarrow \mu^- \bar{\nu}$	1 001 592	769 876	916 163	547 329	3 234 960
$ \eta_\ell $ range	0–0.6	0.6–1.2		1.8–2.4	Inclusive
$W^+ \rightarrow e^+ \nu$	1 233 960	1 207 136		956 620	3 397 716
$W^- \rightarrow e^- \bar{\nu}$	969 170	908 327		610 028	2 487 525

Template fit

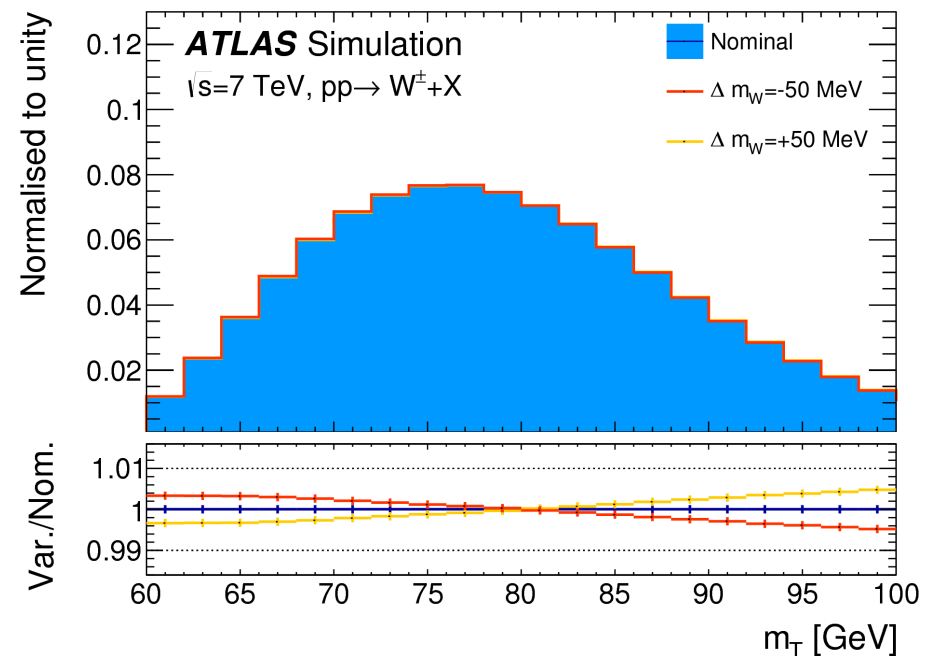
Template fit approach: compute the p_T^l and m_T distributions for different assumed values of m_W^* \rightarrow χ^2 minimisation gives the best fit template.

Predictions for different m_W values are obtained by reweighting the boson invariant mass distribution according to the BW parameterisation.

$$\frac{d\sigma}{dm} \propto \frac{m^2}{(m^2 - m_V^2)^2 + m^4 \Gamma_V^2 / m_V^2}$$



p_T^l has a Jacobian edge at $m_W/2$

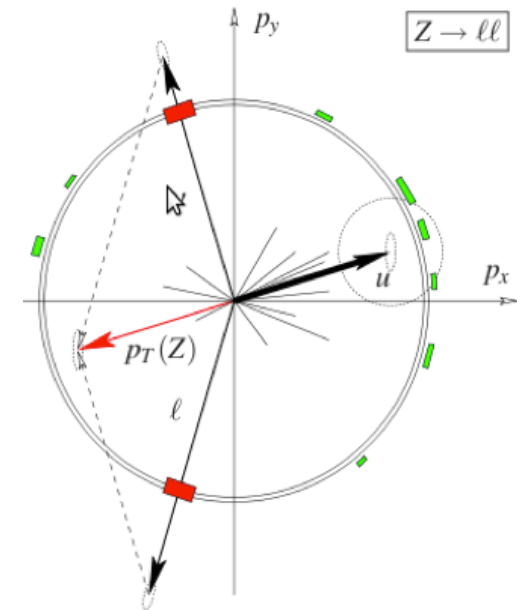


m_T has a Jacobian edge at m_W

* *A blinding offset* was applied throughout the measurement and removed when consistent results were found.

Z-boson sample

Benefit from the fully reconstructed mass in **Z-boson sample** to validate the analysis and to provide significant **experimental** (lepton and recoil calibration using resp. m_Z measured at LEP = 91187.5 ± 2.1 MeV and expected momentum balance with $p_T^{\ell\ell}$) and **theoretical constraints** (ancilliary measurements).



The whole analysis is checked by performing a measurement of the Z-boson mass and comparing to the LEP value, also a cross-check Z mass measurement in “W-like” i.e removing the 2nd lepton and treating it like a neutrino

A similar W-like analysis was also done by CMS **CMS PAS SMP-14-007**

Need to consider **additional** systematics for W mass measurement (*theory uncertainties, $Z \rightarrow W$ extrapolation and background*)



Experimental precision

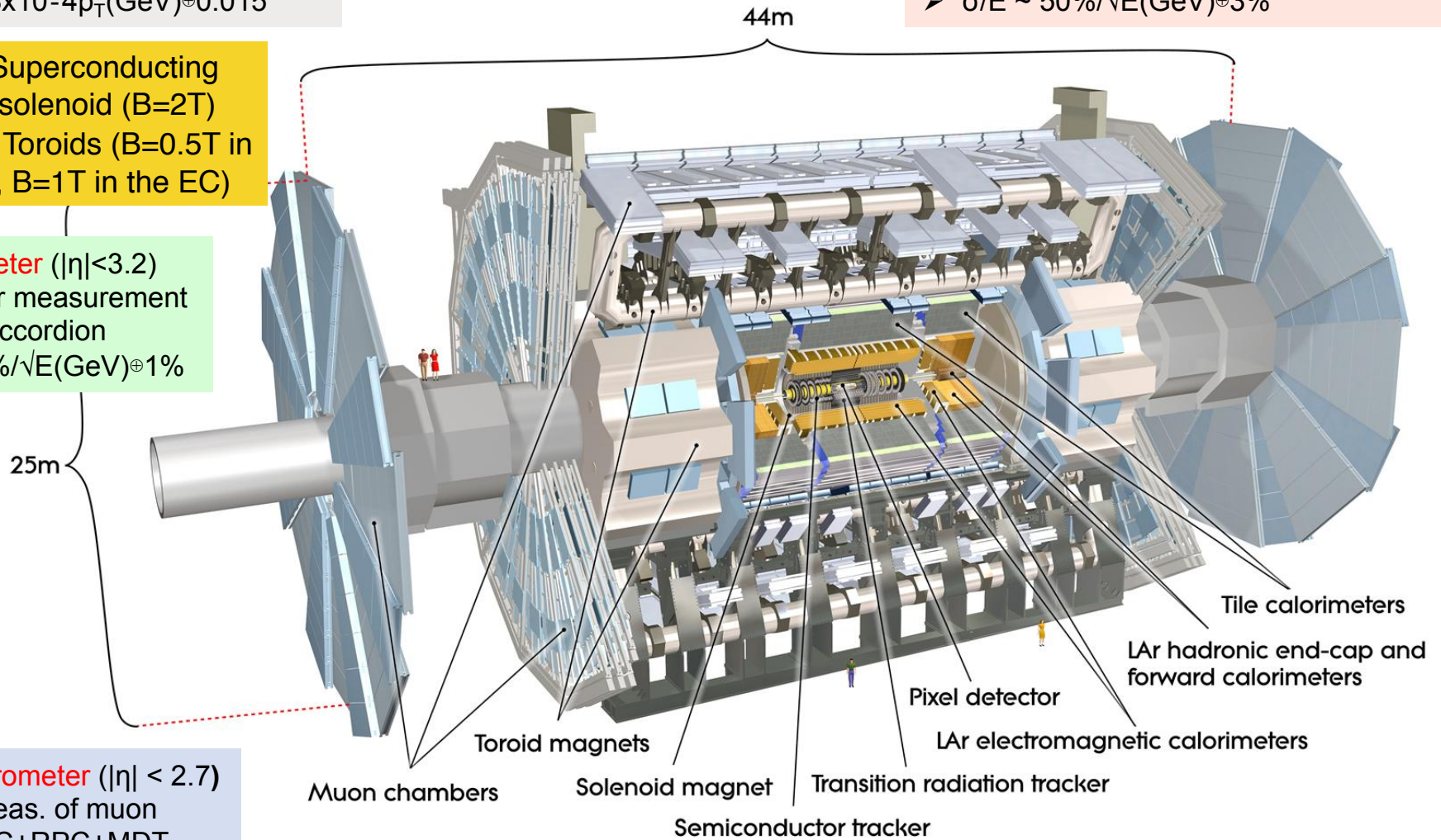
ATLAS detector

Inner detector ($|\eta| < 2.5$, $B=2T$)
 Tracking, vertexing, dE/dx , e/π ID
 ➤ Si pixels, Si strips, Trans. Rad. det.
 ➤ $\sigma/p_T \sim 3.8 \times 10^{-4} p_T(\text{GeV}) \oplus 0.015$

4 Magnets Superconducting
 • 1 Central solenoid ($B=2T$)
 • 3 Air core Toroids ($B=0.5T$ in the barrel, $B=1T$ in the EC)

EM Calorimeter ($|\eta| < 3.2$)
 e/γ ID trigger measurement
 ➤ Pb-Lar accordion
 ➤ $\sigma/E \sim 10\%/\sqrt{E(\text{GeV})} \oplus 1\%$

Hadron Calorimeter ($|\eta| < 5$)
 Trigger and meas. of jet/Emiss
 ➤ Fe/scintillator (central), Cu/W-LAr (fwd)
 ➤ $\sigma/E \sim 50\%/\sqrt{E(\text{GeV})} \oplus 3\%$

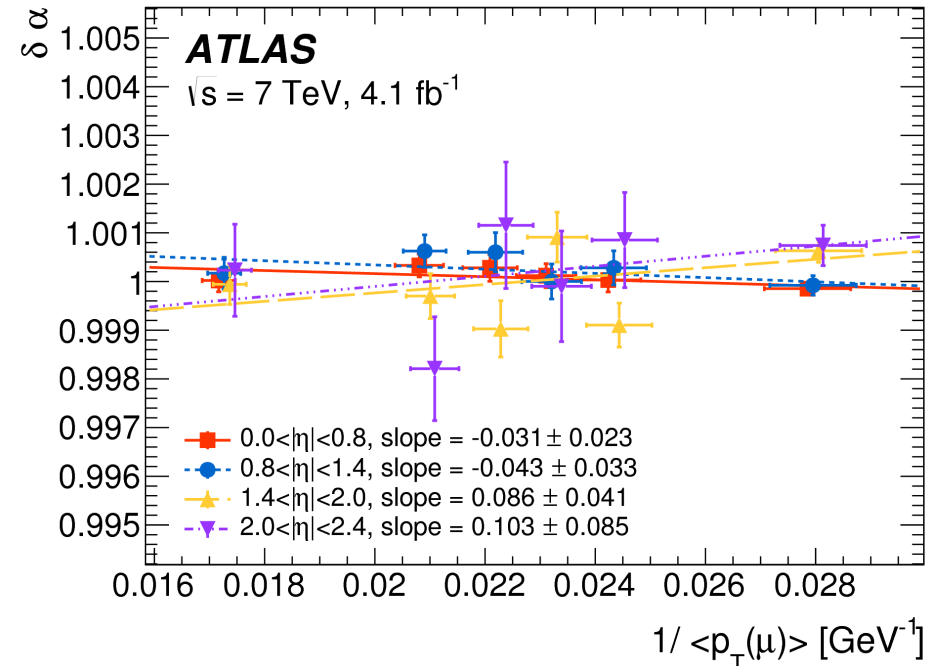


Muon spectrometer ($|\eta| < 2.7$)
 Trigger & meas. of muon
 ➤ CSC+TGC+RPC+MDT
 ➤ $\sigma/p_T < 10\%$ up to 1 TeV

Muon Calibration & Efficiency

Muon identified using combined ID+MS tracks, momentum measurement from ID only.

Calibration factors for ID-only muons derived from $Z \rightarrow \mu\mu$ and **sagitta bias** charge-dependent corrections from $Z \rightarrow \mu\mu$ and E/p of $W \rightarrow e\nu$. [Eur.Phys.J.C 74 \(2014\) 3130](#)

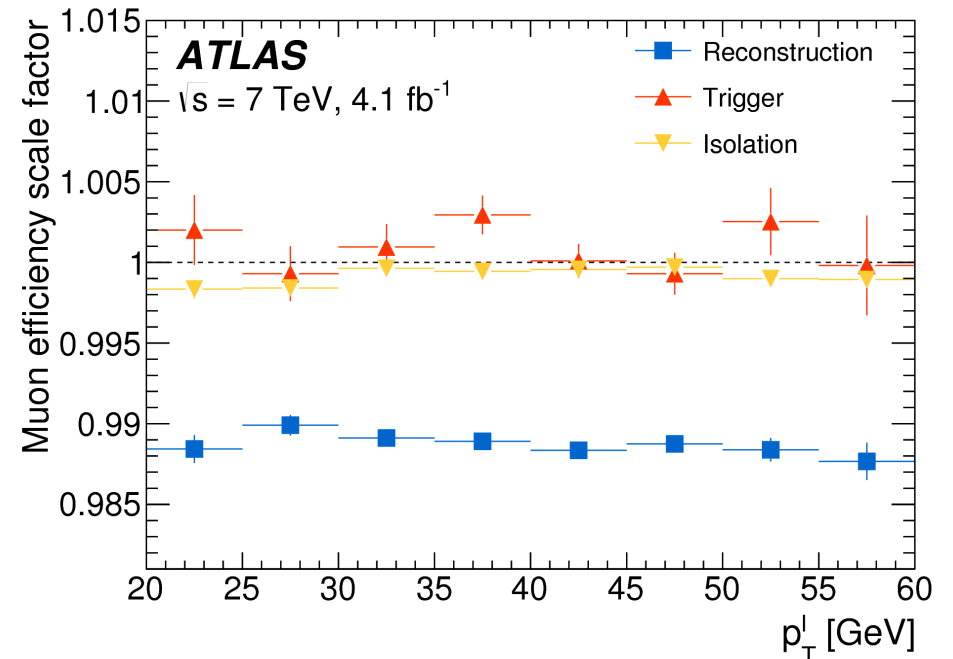


$$p_T^{\text{MC,corr}} = p_T^{\text{MC}} \times [1 + \alpha(\eta, \phi)] \times [1 + \beta_{\text{curv}}(\eta) \cdot G(0, 1) \cdot p_T^{\text{MC}}]$$

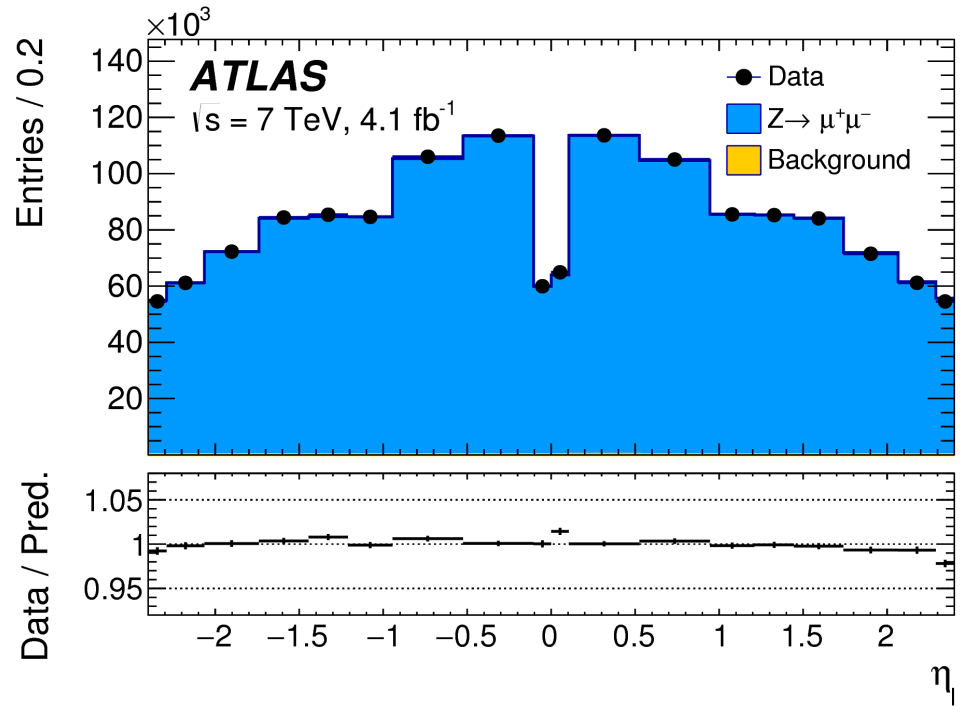
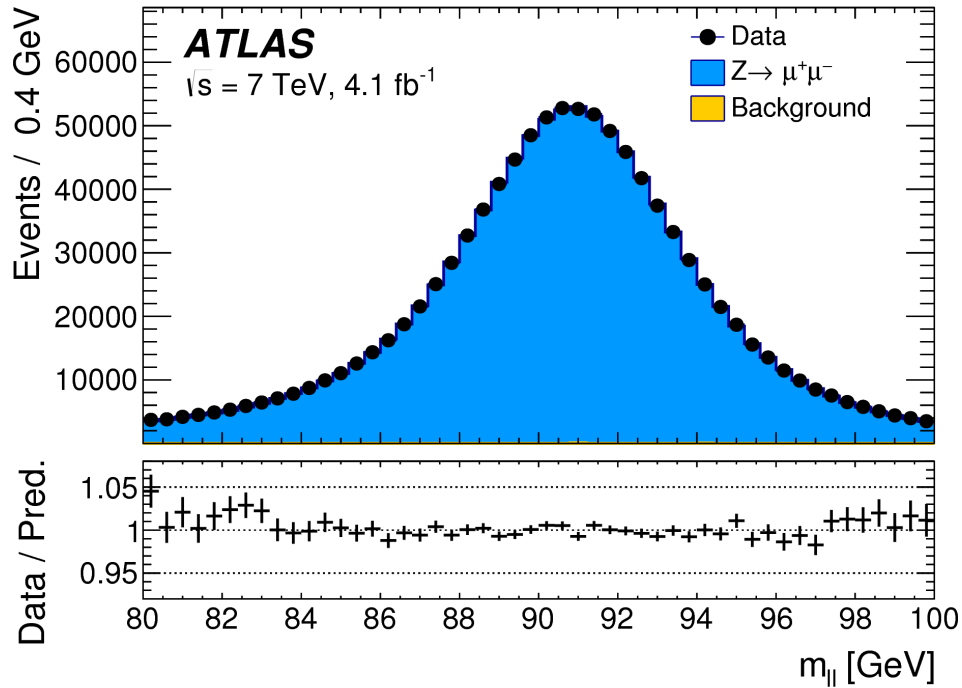
$$p_T^{\text{data,corr}} = \frac{p_T^{\text{data}}}{1 + q \cdot \delta(\eta, \phi) \cdot p_T^{\text{data}}}$$

Muon **trigger/id/iso efficiency** corrections data/MC evaluated in bins of p_T^l , η and charge.

Dominant uncertainty is the statistical uncertainty of the Z sample.



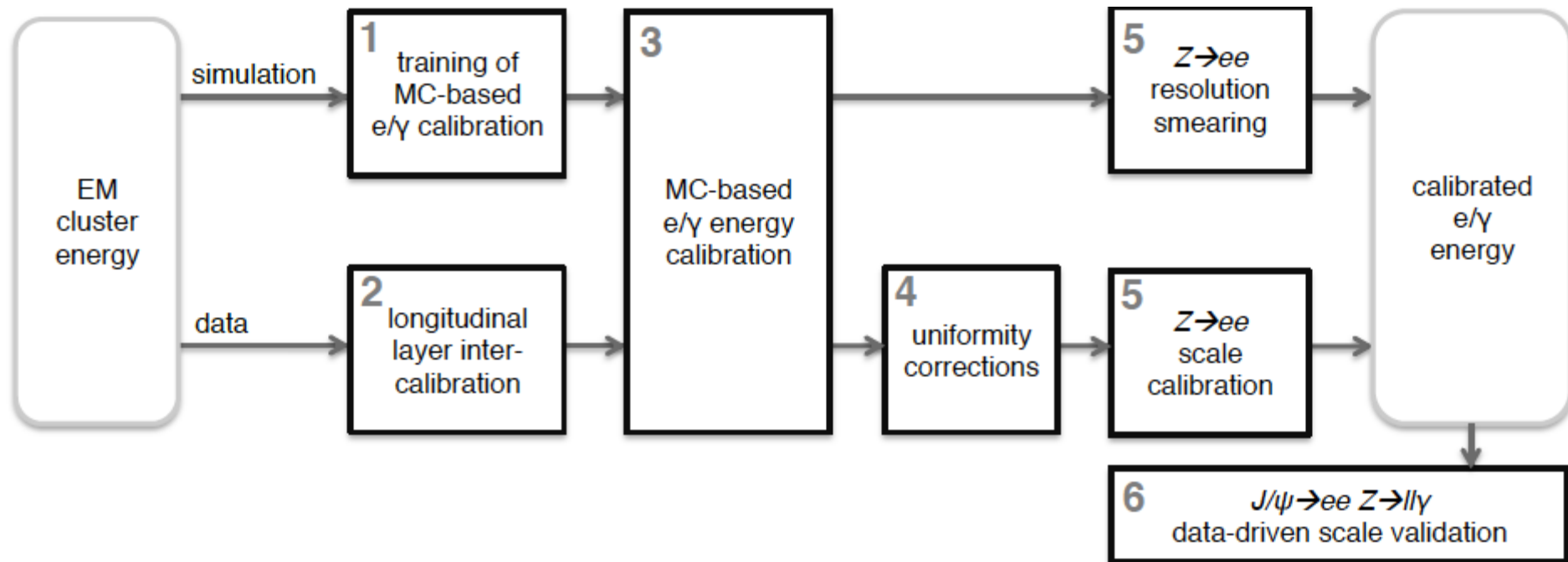
Muon Calibration & Efficiency



$ \eta_e $ range	[0.0, 0.8]		[0.8, 1.4]		[1.4, 2.0]		[2.0, 2.4]		Combined	
	p_T^l	m_T	p_T^l	m_T	p_T^l	m_T	p_T^l	m_T	p_T^l	m_T
δm_W [MeV]										
Momentum scale	8.9	9.3	14.2	15.6	27.4	29.2	111.0	115.4	8.4	8.8
Momentum resolution	1.8	2.0	1.9	1.7	1.5	2.2	3.4	3.8	1.0	1.2
Sagitta bias	0.7	0.8	1.7	1.7	3.1	3.1	4.5	4.3	0.6	0.6
Reconstruction and isolation efficiencies	4.0	3.6	5.1	3.7	4.7	3.5	6.4	5.5	2.7	2.2
Trigger efficiency	5.6	5.0	7.1	5.0	11.8	9.1	12.1	9.9	4.1	3.2
Total	11.4	11.4	16.9	17.0	30.4	31.0	112.0	116.1	9.8	9.7

Electron Calibration & Efficiency

Calibration for electrons closely follows the Run I calibration paper [Eur.Phys.J.C 74 \(2014\) 3071](#)



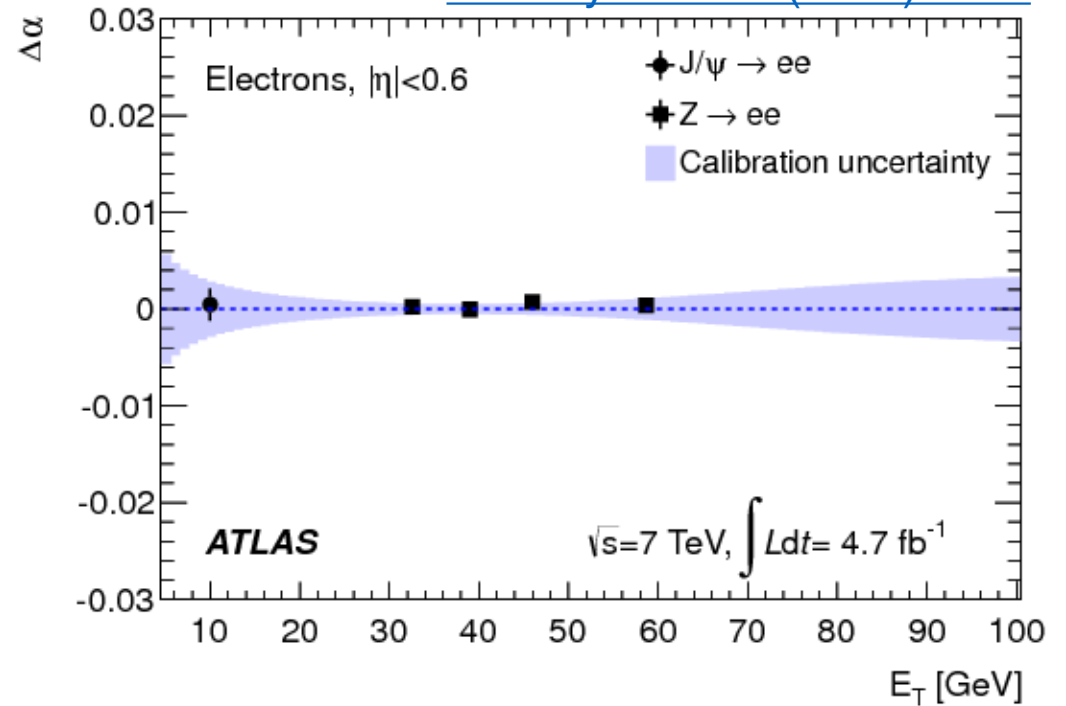
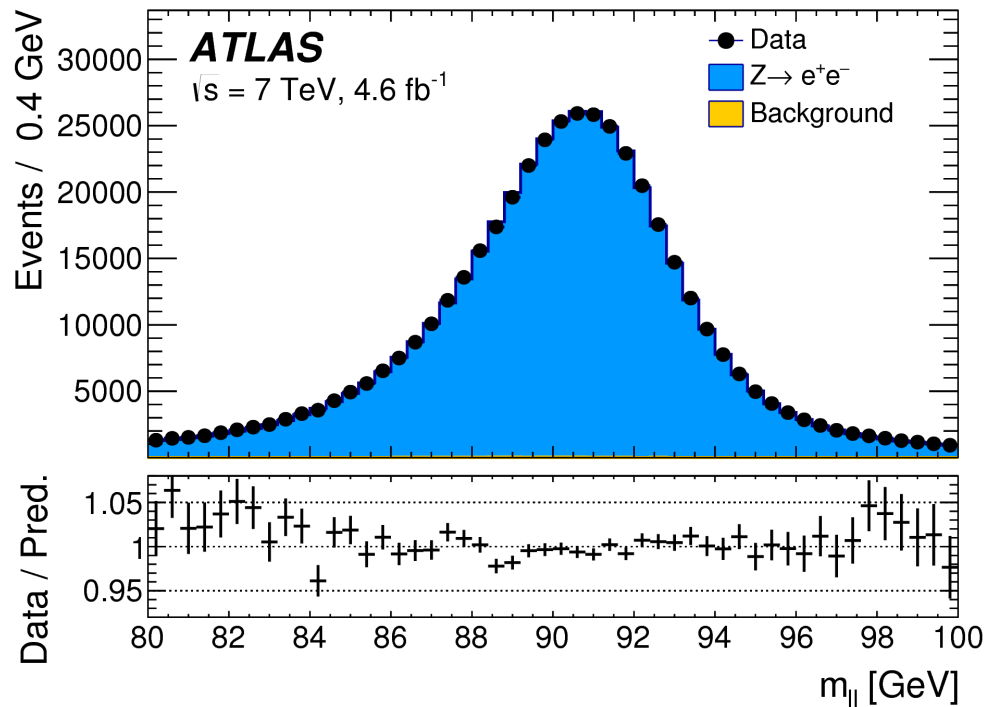
Exclude bin $1.2 < |\eta| < 1.82$ for the W mass measurement as the amount of passive material in front of the calorimeter and its uncertainty are largest in this region.

Azimuthal correction from $\langle E/p \rangle$ vs φ

Electron efficiency corrections as a function of η and p_T [Eur.Phys.J.C 74 \(2014\) 2941](#)

Electron Calibration & Efficiency

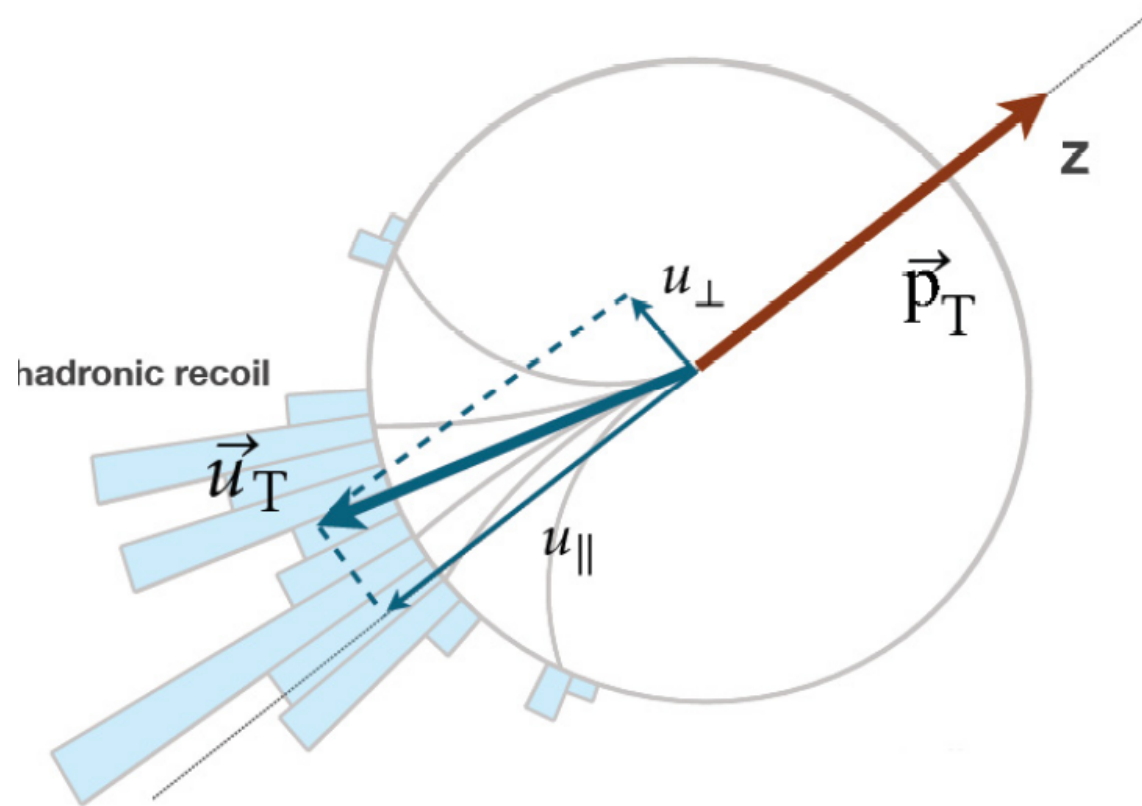
Eur.Phys.J.C 74 (2014) 3071



$ \eta_e $ range	[0.0, 0.6]		[0.6, 1.2]		[1.82, 2.4]		Combined	
Kinematic distribution	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T
δm_W [MeV]								
Energy scale	10.4	10.3	10.8	10.1	16.1	17.1	8.1	8.0
Energy resolution	5.0	6.0	7.3	6.7	10.4	15.5	3.5	5.5
Energy linearity	2.2	4.2	5.8	8.9	8.6	10.6	3.4	5.5
Energy tails	2.3	3.3	2.3	3.3	2.3	3.3	2.3	3.3
Reconstruction efficiency	10.5	8.8	9.9	7.8	14.5	11.0	7.2	6.0
Identification efficiency	10.4	7.7	11.7	8.8	16.7	12.1	7.3	5.6
Trigger and isolation efficiencies	0.2	0.5	0.3	0.5	2.0	2.2	0.8	0.9
Charge mismeasurement	0.2	0.2	0.2	0.2	1.5	1.5	0.1	0.1
Total	19.0	17.5	21.1	19.4	30.7	30.5	14.2	14.3

Recoil Reconstruction

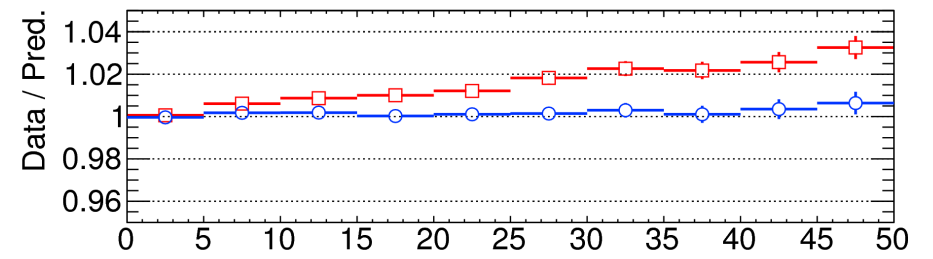
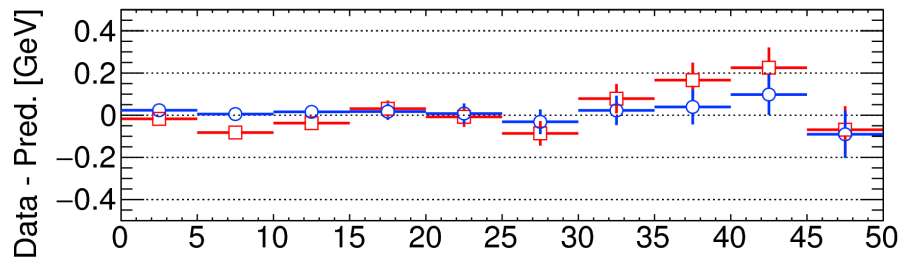
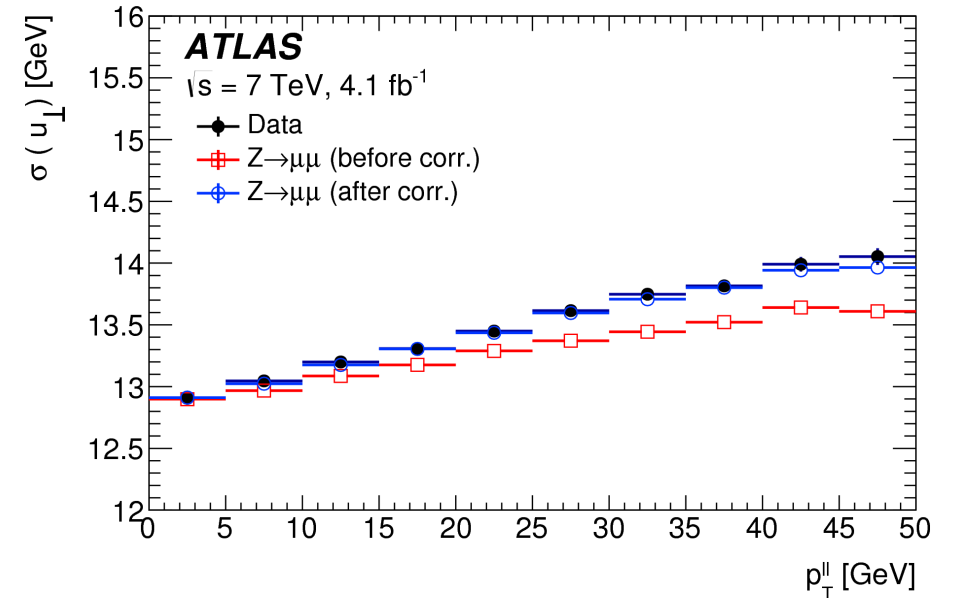
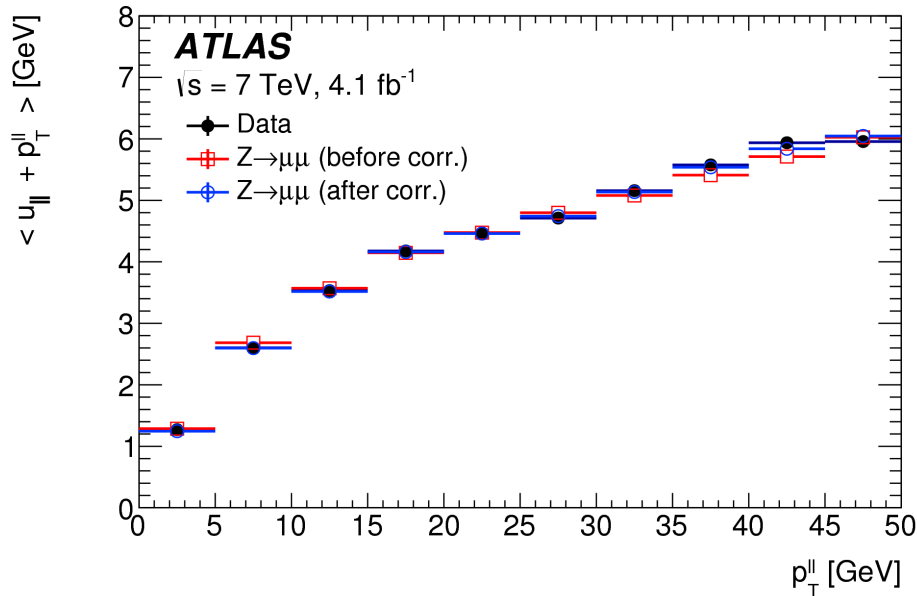
Vector sum of the momenta of all clusters measured in the calorimeters excluding energy deposits associated with the decay leptons



Also : u_{\parallel} is the projection of the recoil along the W decay lepton direction

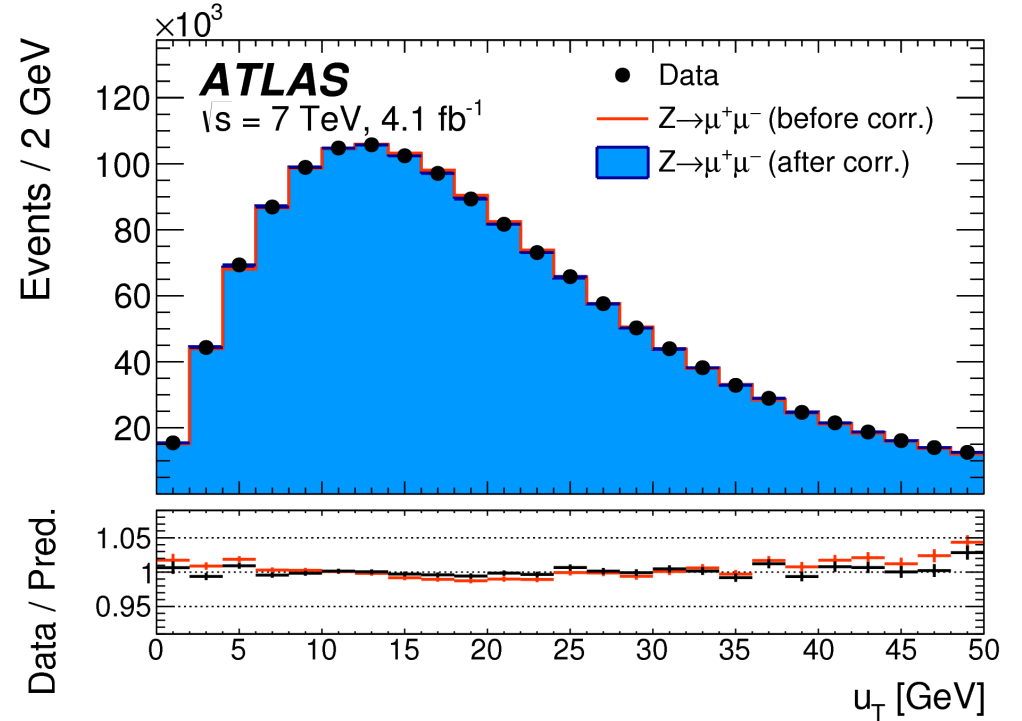
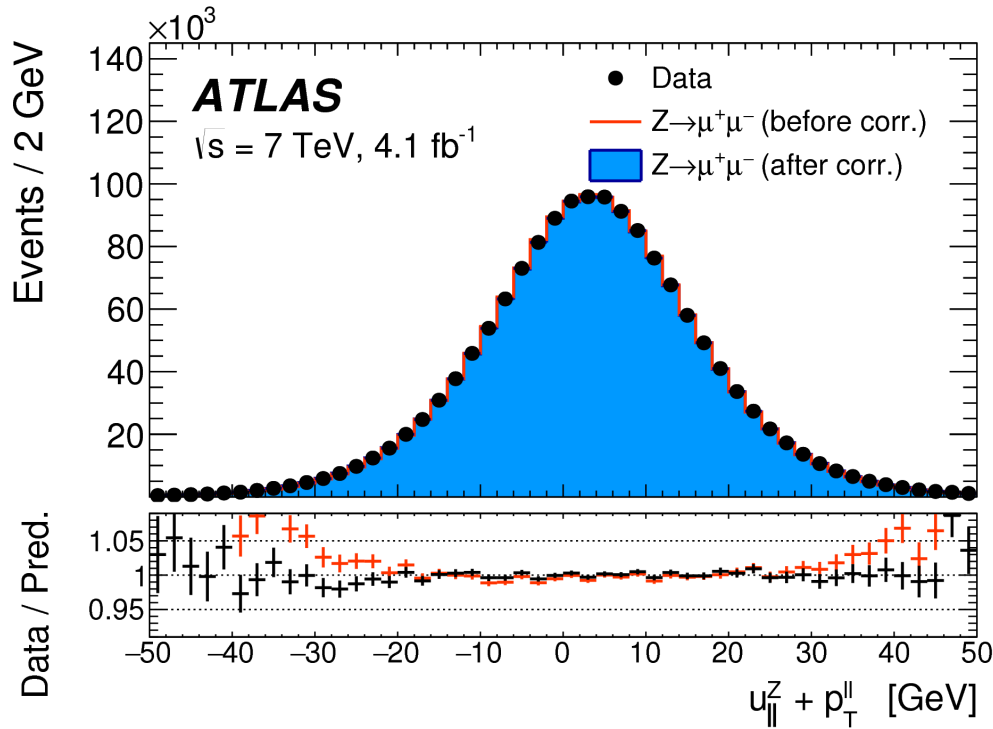
Recoil Calibration

Calibrate the scale (resolution) of the recoil using $u_{||}$ (u_{\perp}) from Z events



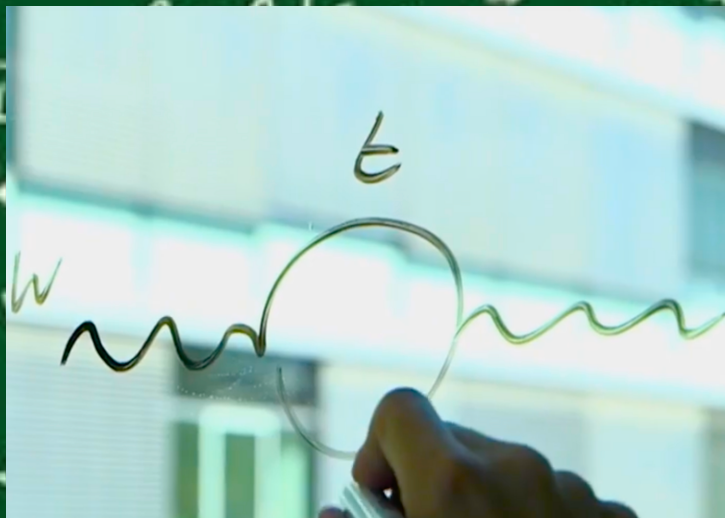
70-80% recoil response, remaining pileup dependence of the recoil resolution cluster-based.

Recoil Calibration



Kinematic distribution	W^+		W^-		Combined	
	p_T^l	m_T	p_T^l	m_T	p_T^l	m_T
δm_W [MeV]						
$\langle \mu \rangle$ scale factor	0.2	1.0	0.2	1.0	0.2	1.0
$\Sigma \vec{E}_T$ correction	0.9	12.2	1.1	10.2	1.0	11.2
Residual corrections (statistics)	2.0	2.7	2.0	2.7	2.0	2.7
Residual corrections (interpolation)	1.4	3.1	1.4	3.1	1.4	3.1
Residual corrections ($Z \rightarrow W$ extrapolation)	0.2	5.8	0.2	4.3	0.2	5.1
Total	2.6	14.2	2.7	11.8	2.6	13.0

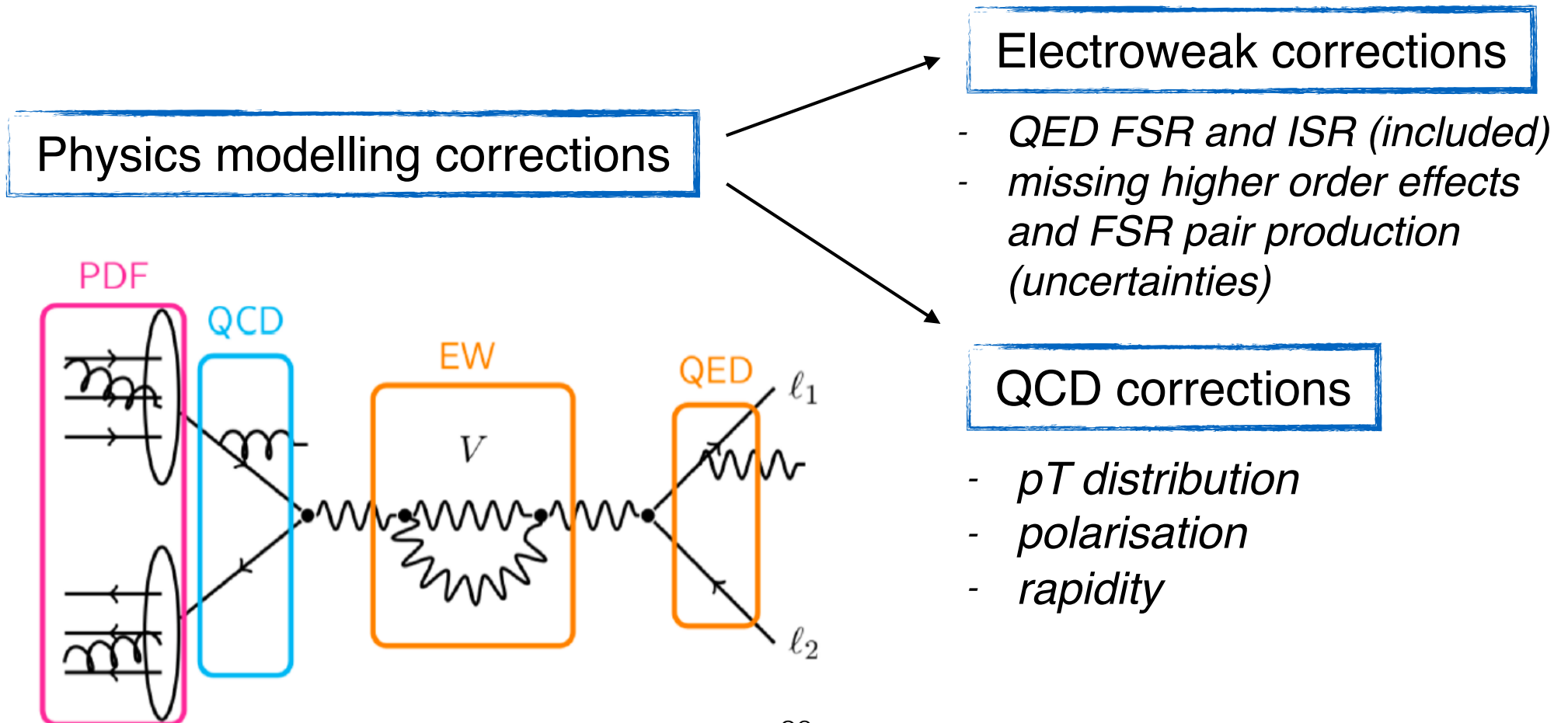
Physics modelling



Physics Modelling

No single generator able to describe all observed distributions.

Start from the Powheg+Pythia8 and apply corrections. Use ancillary measurements of Drell-Yan processes to validate (and tune) the model and assess systematic uncertainties.



EW corrections

QED effects: **FSR** (*dominant correction*) included in the simulation with PHOTOS, negligible uncertainty. QED **ISR** included through Pythia8 parton shower.

NLO EW effects: taken as uncertainties, **pure weak corrections** evaluated in the presence of QCD corrections, estimated using Winhac. **ISR-FSR interference**.

FSR **lepton pair production** estimated and added as an uncertainty. Formally higher order correction but a significant additional source of energy loss.

Decay channel Kinematic distribution	$W \rightarrow e\nu$		$W \rightarrow \mu\nu$	
	p_T^ℓ	m_T	p_T^ℓ	m_T
δm_W [MeV]				
FSR (real)	< 0.1	< 0.1	< 0.1	< 0.1
Pure weak and IFI corrections	3.3	2.5	3.5	2.5
FSR (pair production)	3.6	0.8	4.4	0.8
Total	4.9	2.6	5.6	2.6

QCD corrections

The Drell-Yan cross-section can be decomposed by **factorising** the dynamic of the boson production and the kinematic of the boson decay.

An approximate decomposition is given by:

$$\frac{d\sigma}{dp_1 dp_2} = \left[\frac{d\sigma(m)}{dm} \right] \left[\frac{d\sigma(y)}{dy} \right] \left[\frac{d\sigma(p_T, y)}{dp_T dy} \left(\frac{d\sigma(y)}{dy} \right)^{-1} \right] \left[(1 + \cos^2 \theta) + \sum_{i=0}^7 A_i(p_T, y) P_i(\cos \theta, \phi) \right]$$

Breit-Wigner

NNLO pQCD

Parton Shower

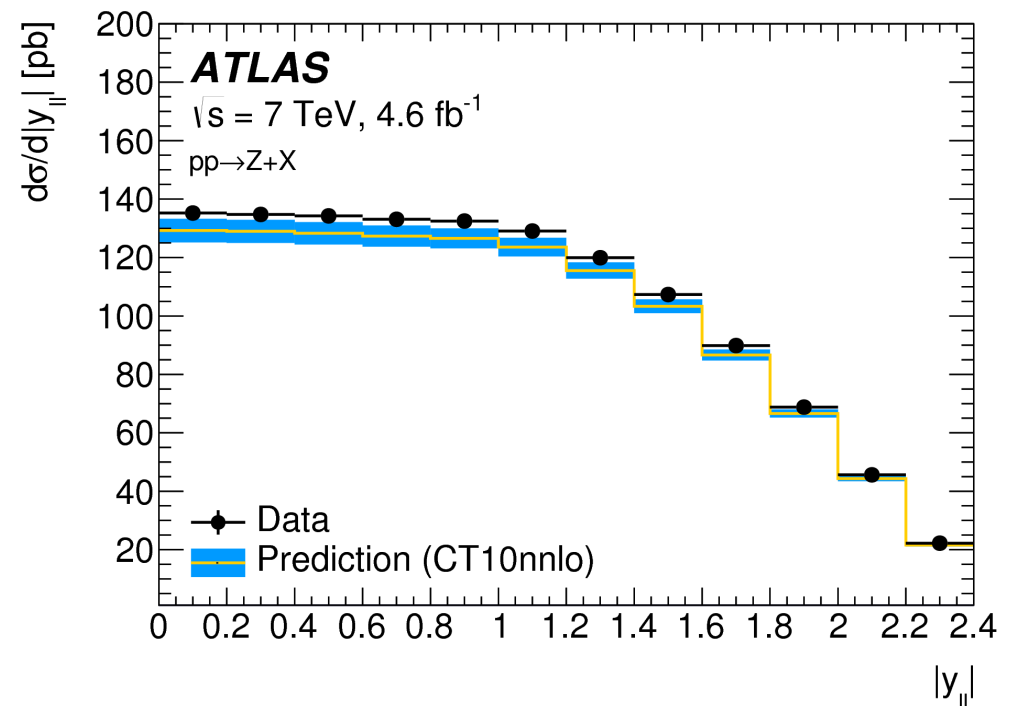
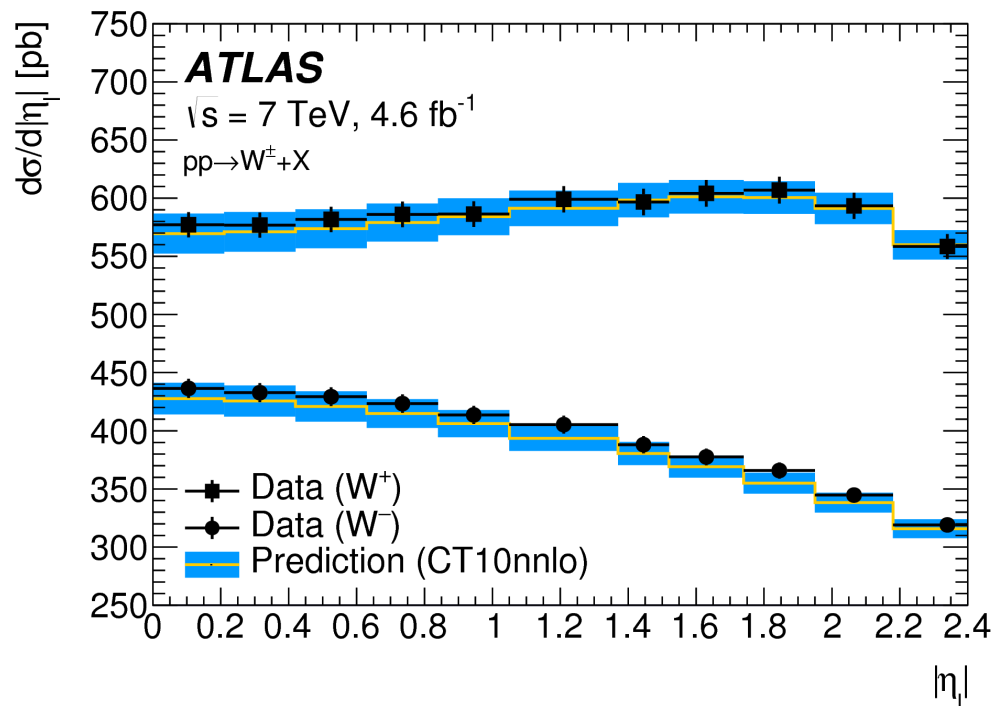
$d\sigma/dm$ is modelled with a BW parameterisation (+ EW corrections)

$d\sigma/dy$ and the A_i coefficients are modelled with fixed order pQCD at NNLO

$d\sigma/dp_T$ is modelled with parton shower (tried analytic resummation)

Rapidity distribution

The **rapidity distribution** is modelled with NNLO predictions and the **CT10nnlo** PDF set. PDF choice validated on the observed weaker suppression of the strange quark in the W,Z cross-section data as published in [arXiv:1612.03016](https://arxiv.org/abs/1612.03016)

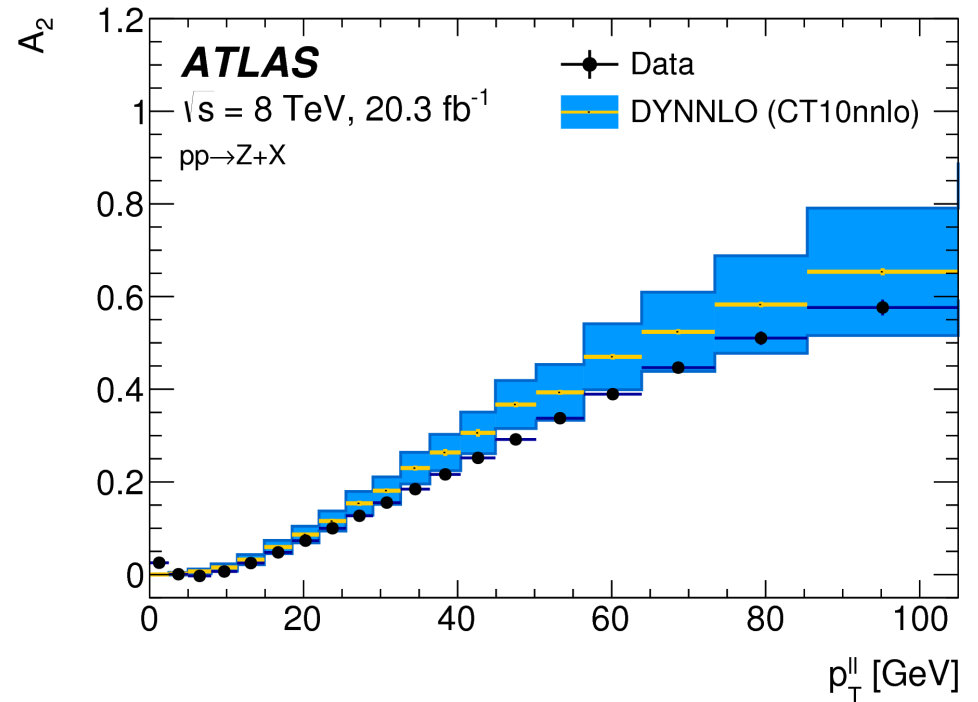
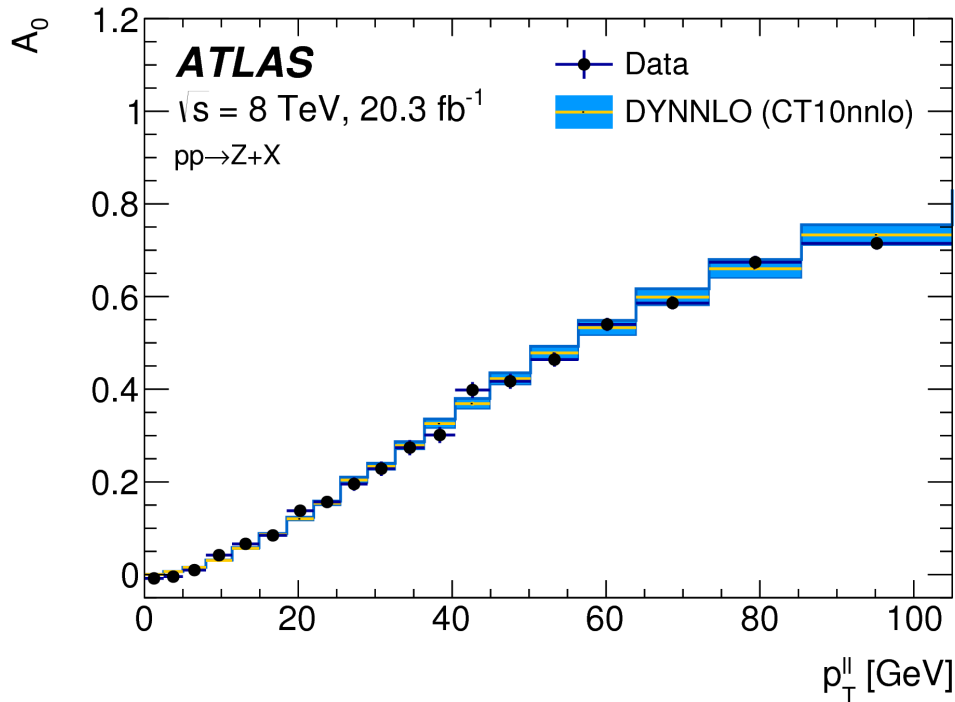


Satisfactory agreement between the theoretical prediction and the measurements is observed: $\chi^2/\text{dof} = 45/34$.

Polarisation coefficients

The A_i coefficients are modelled with fixed order pQCD at NNLO.

The predictions (DYNNLO) are validated by comparison to the A_i measurements in 8 TeV Z-boson data [JHEP08\(2016\)159](#)



Uncertainties on A_i modelling: experimental uncertainty of the measurement and observed discrepancy for A_2 coefficient

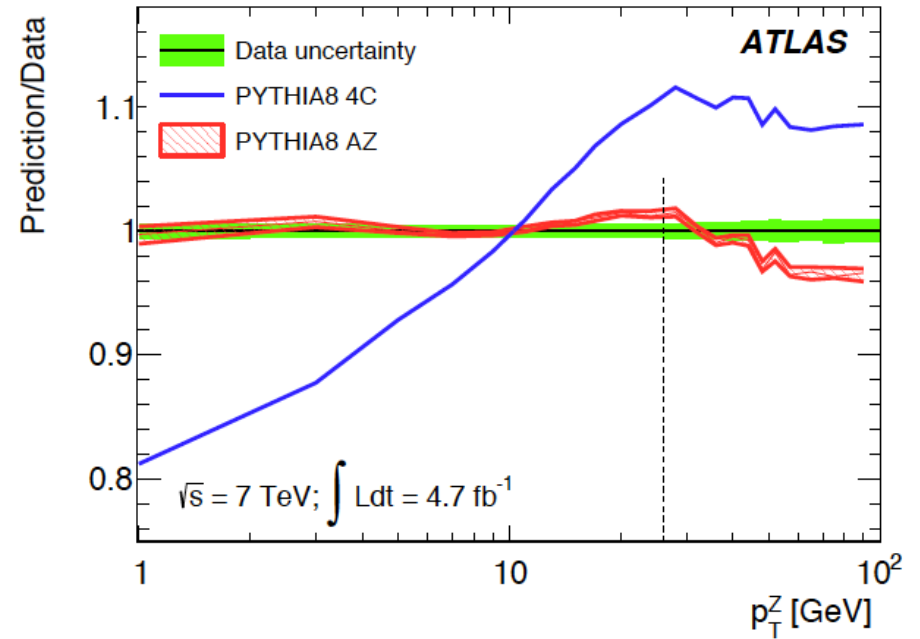
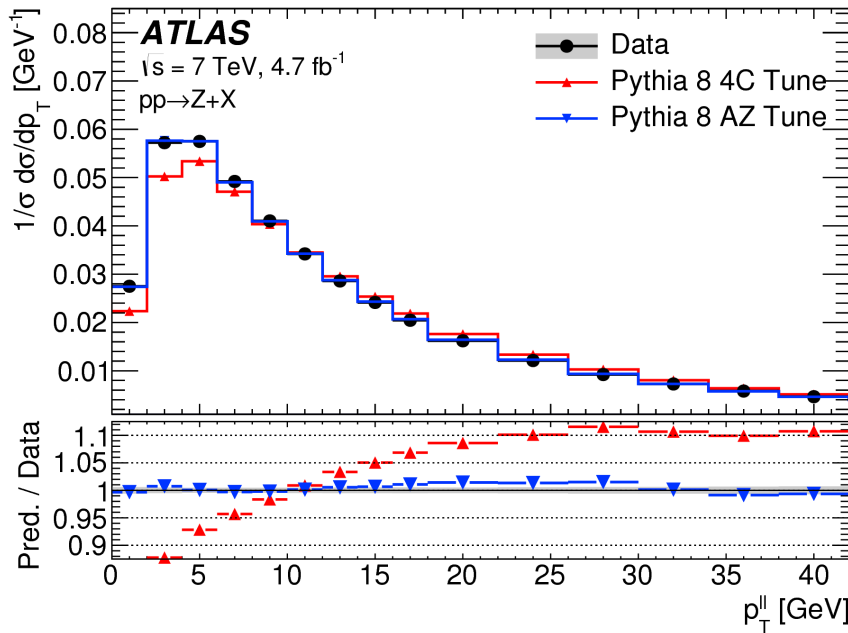
W -boson charge	W^+		W^-		Combined	
	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T
Angular coefficients	5.8	5.3	5.8	5.3	5.8	5.3

Z transverse momentum

Parton shower MC Pythia 8 tuned to the 7 TeV data AZ tune (better description in rapidity bins than the AZNLO tune of Powheg+Pythia) [JHEP09\(2014\)145](#)

PYTHIA8	
Tune Name	AZ
Primordial k_T [GeV]	1.71 ± 0.03
ISR $\alpha_S^{\text{ISR}}(m_Z)$	0.1237 ± 0.0002
ISR cut-off [GeV]	0.59 ± 0.08
$\chi^2_{\text{min}}/\text{dof}$	45.4/32

The agreement between data and Pythia AZ is better than 1% for $p_T < 40$ GeV



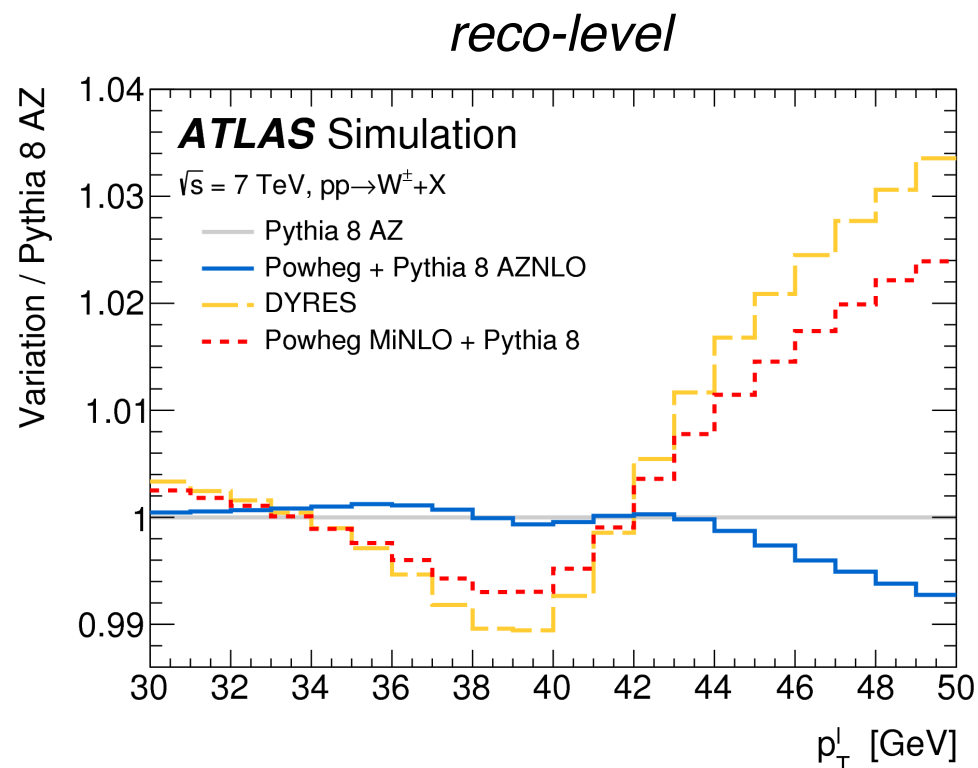
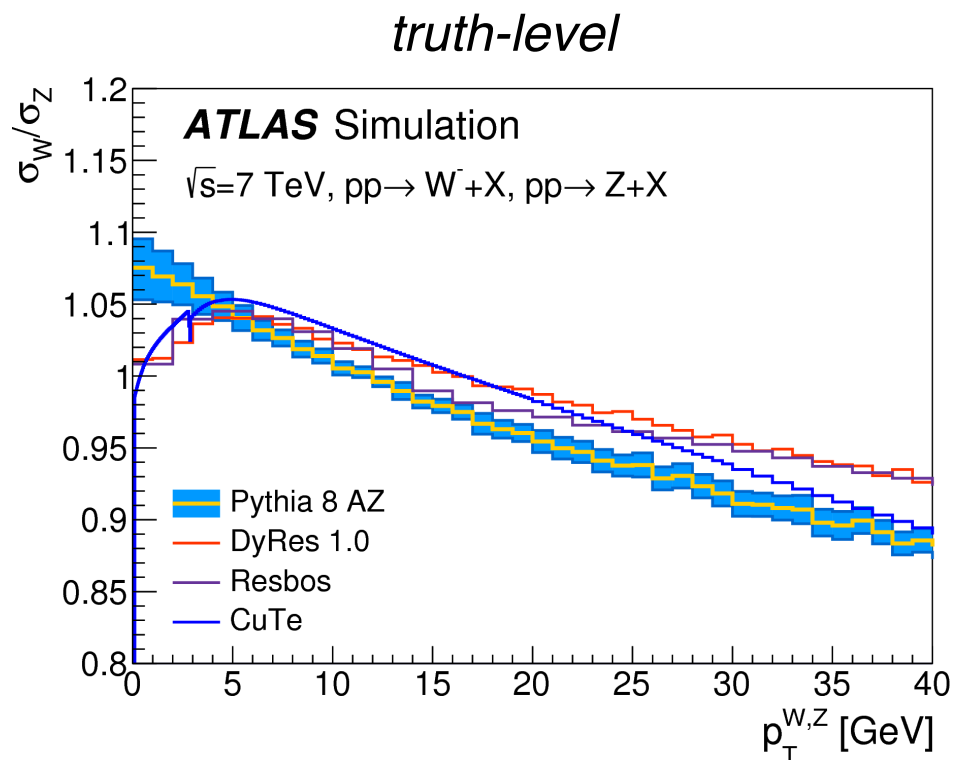
The accuracy of Z data is propagated and considered as an uncertainty

W-boson charge Kinematic distribution	W^+		W^-		Combined	
	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T
AZ tune	3.0	3.4	3.0	3.4	3.0	3.4

W transverse momentum (I)

The Pythia8 AZ tune is fixed by the p_T^Z data; extrapolate to W considering relative variations of the W and Z p_T distributions.

Resummed predictions (DYRES, ResBos, CuTe) and Powheg MiNLO+Pythia8 were tried but they predict **harder W p_T spectrum** for a given p_T (Z) spectrum.

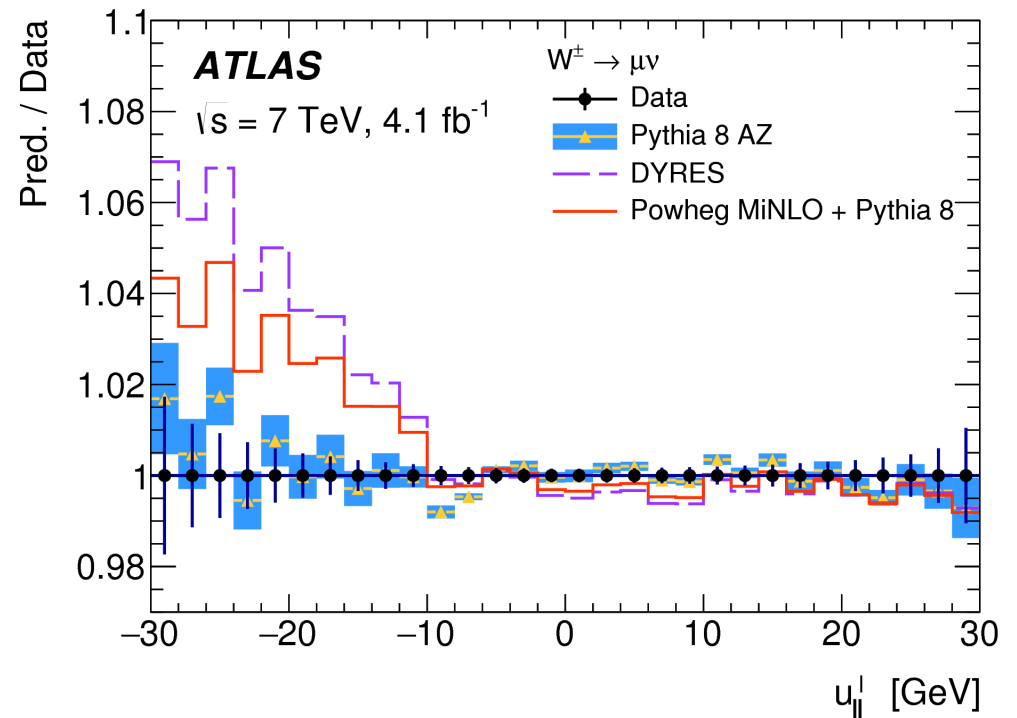
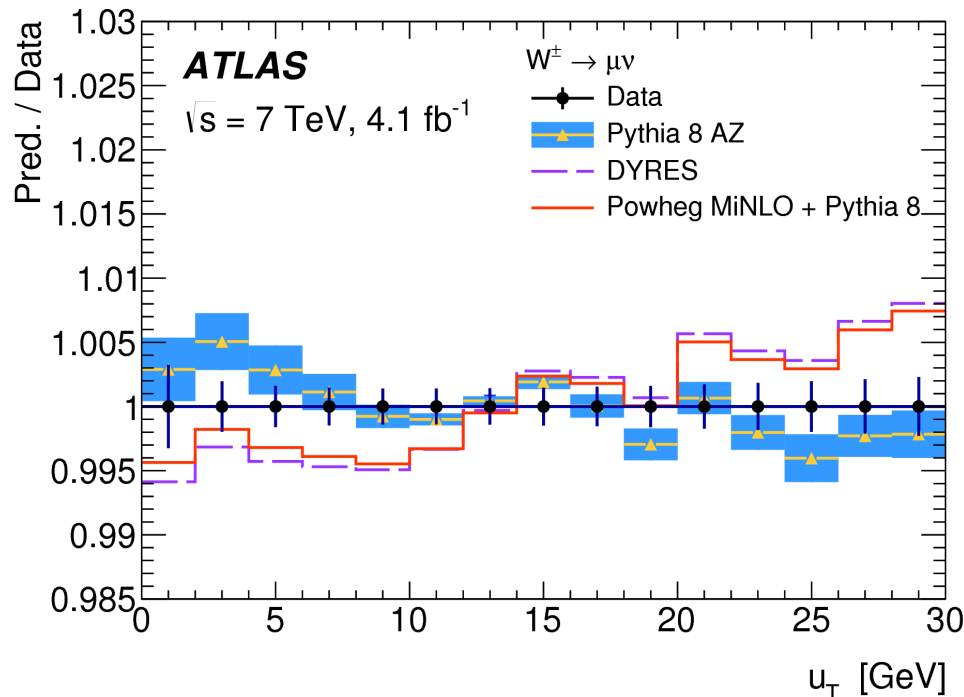


The effect on m_W of using the “formally” more accurate predictions has a significant impact on the W-mass value of the order of 50-100 MeV

W transverse momentum (II)

To validate the choice of Pythia8 AZ for the baseline, use u_{\parallel} distribution which is very sensitive to the underlying p_{τ}^W distribution

—> provide a data-driven validation of the accuracy of our Pythia8 AZ model and compare to other calculations



NNLL resummed predictions and Powheg+MiNLO strongly disfavoured by the data however PS MC are in a good agreement; tested using Pythia8 , Herwig7 and Powheg+Pythia8

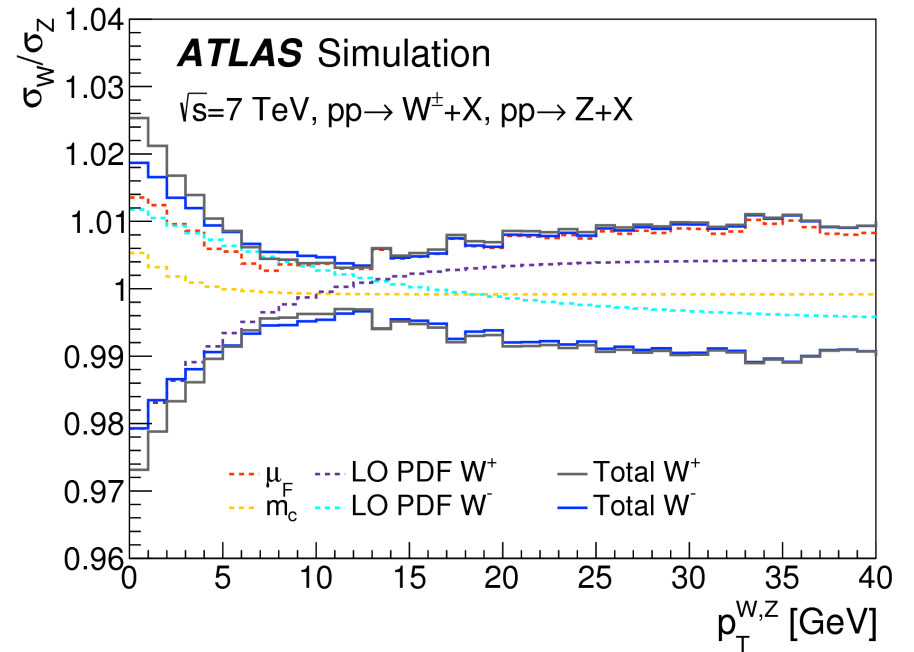
p_T^W uncertainties

Heavy flavour initiated production (HFI) introduces differences between Z and W and determines a harder p_T spectrum, expect certain degree of decorrelation. However higher-order QCD expected to be largely correlated between W and Z produced by **light quarks**

Consider relative variations on $p_T(W)/p_T(Z)$ under uncertainty variations.

Uncertainty: heavy quark mass variations (varying m_c by ± 0.5 GeV), factorisation scale variations in the QCD ISR (separately for light and heavy-quark induced production)

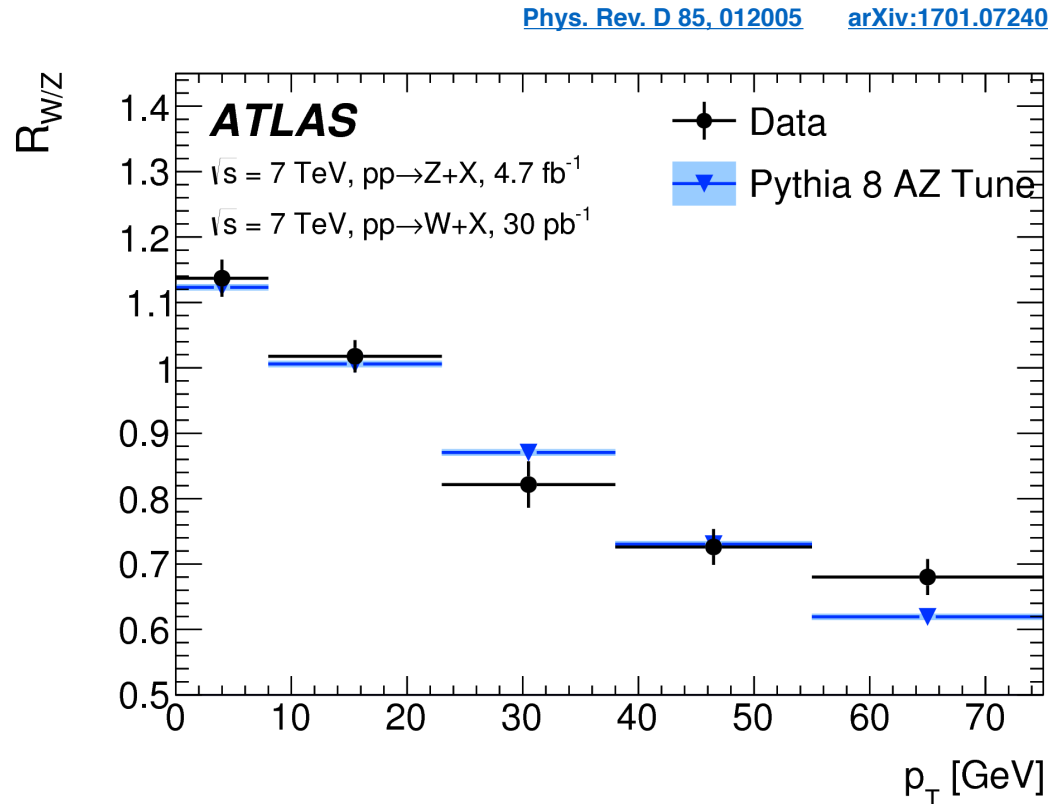
Largest deviation of $p_T(W)/p_T(Z)$ for the **parton shower PDF** variation: CTEQ6L1 LO (nominal) to CT14lo, MMHT2014lo and NNPDF2.3lo



W-boson charge Kinematic distribution	W^+		W^-		Combined	
	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T
Charm-quark mass	1.2	1.5	1.2	1.5	1.2	1.5
Parton shower μ_F with heavy-flavour decorrelation	5.0	6.9	5.0	6.9	5.0	6.9
Parton shower PDF uncertainty	3.6	4.0	2.6	2.4	1.0	1.6

Reducing p_T^W uncertainties

The ratio of the W and Z p_T distributions has been measured



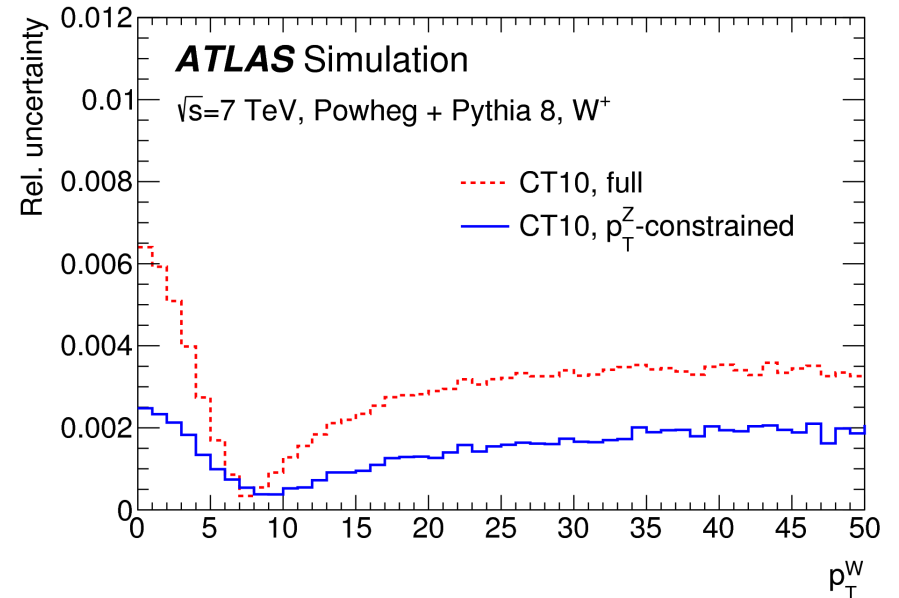
Limited precision of the data ($\sim 3\%$), and broad bin width ($\sim 8 \text{ GeV}$) limit the impact of these measurements on the systematic uncertainty.

Further measurements would be useful, ideally with low pile-up, targeting bin width $< 5 \text{ GeV}$ and a precision about $\sim 1\%$.

PDF uncertainties

PDF variations (25 error eigenvectors) of CT10nnlo are applied simultaneously to the boson rapidity, A_i , and p_T distributions.

Only relative variations of the $p_T(W)$ and $p_T(Z)$ induced by PDFs are considered.



W-boson charge Kinematic distribution	W^+		W^-		Combined	
	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T
Fixed-order PDF uncertainty	13.1	14.9	12.0	14.2	8.0	8.7

The PDF uncertainties are very similar between p_T^ℓ and m_T but strongly *anti-correlated* between W^+ and W^- . Envelope taken from [CT14](#) and [MMHT2014](#) ~ 3.8 MeV.

Summary of physics modelling uncertainties

	W^+		W^-		Combined	
	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T
W -boson charge						
Kinematic distribution						
δm_W [MeV]						
Fixed-order PDF uncertainty	13.1	14.9	12.0	14.2	8.0	8.7
AZ tune	3.0	3.4	3.0	3.4	3.0	3.4
Charm-quark mass	1.2	1.5	1.2	1.5	1.2	1.5
Parton shower μ_F with heavy-flavour decorrelation	5.0	6.9	5.0	6.9	5.0	6.9
Parton shower PDF uncertainty	3.6	4.0	2.6	2.4	1.0	1.6
Angular coefficients	5.8	5.3	5.8	5.3	5.8	5.3
Total	15.9	18.1	14.8	17.2	11.6	12.9

QCD

Decay channel	$W \rightarrow e\nu$		$W \rightarrow \mu\nu$	
	p_T^ℓ	m_T	p_T^ℓ	m_T
δm_W [MeV]				
FSR (real)	< 0.1	< 0.1	< 0.1	< 0.1
Pure weak and IFI corrections	3.3	2.5	3.5	2.5
FSR (pair production)	3.6	0.8	4.4	0.8
Total	4.9	2.6	5.6	2.6

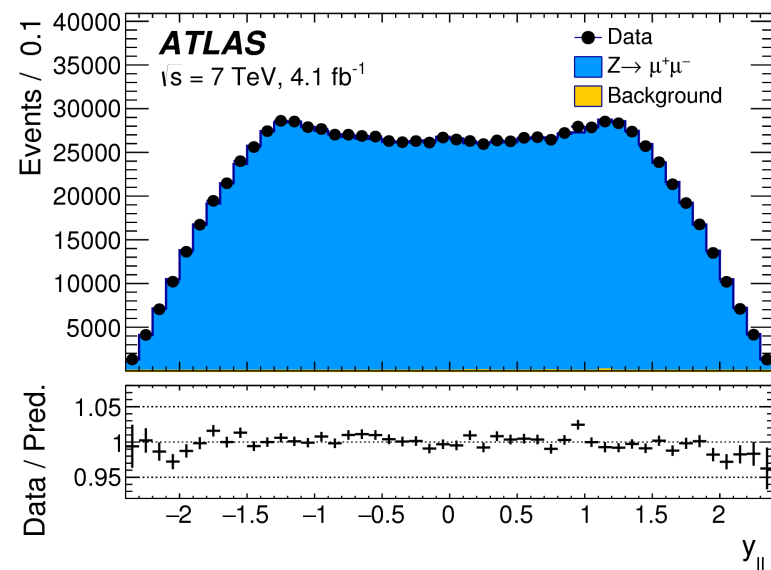
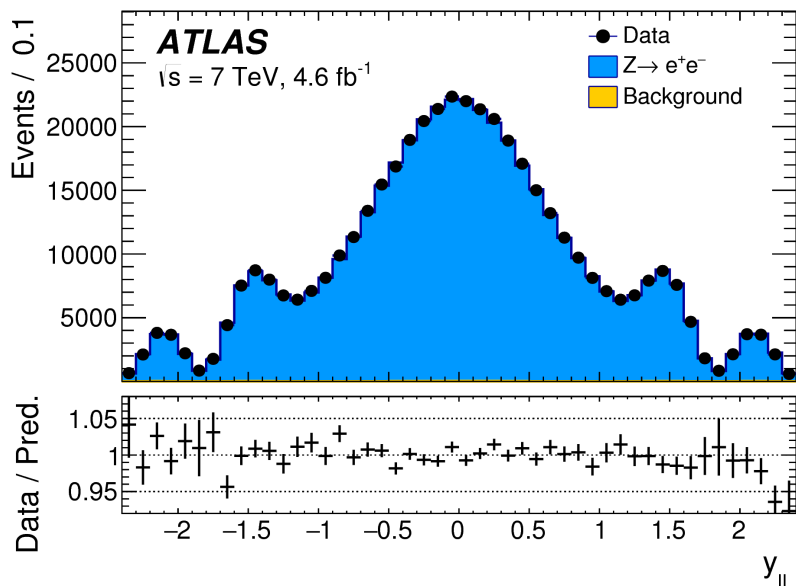
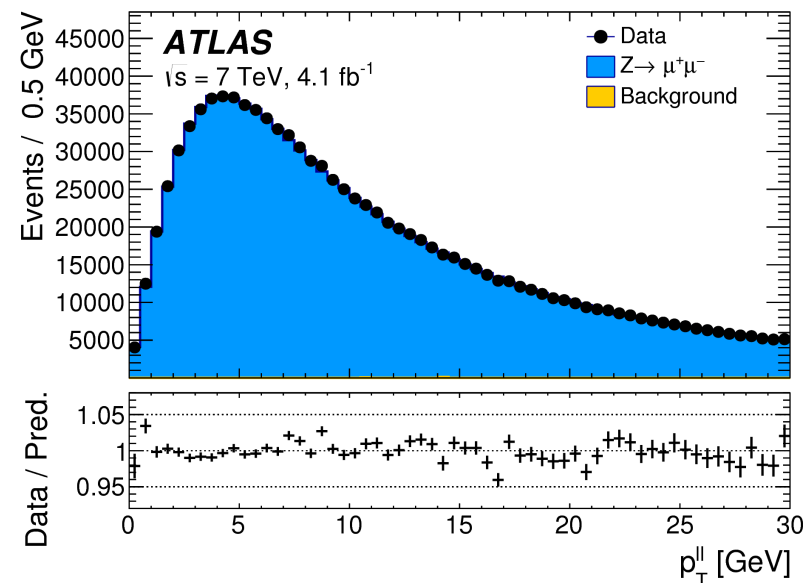
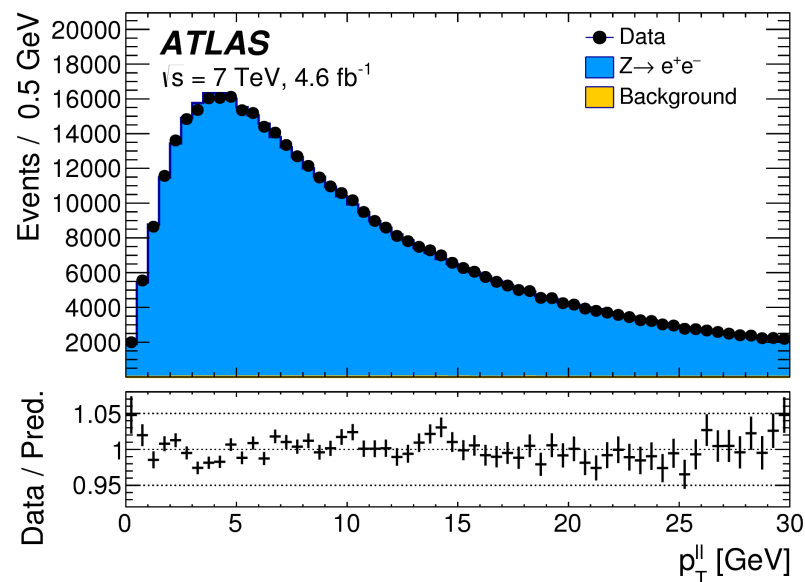
EW

The PDF uncertainties are the dominant followed by $p_T(W)$ uncertainty due to the heavy-flavour initiated production.

Validation and results

Z control distributions: p_T , y

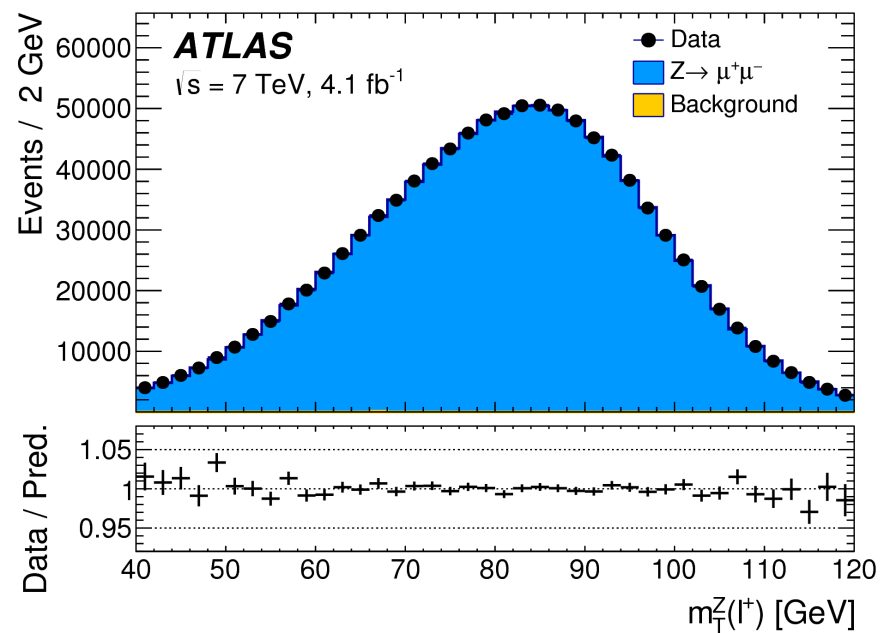
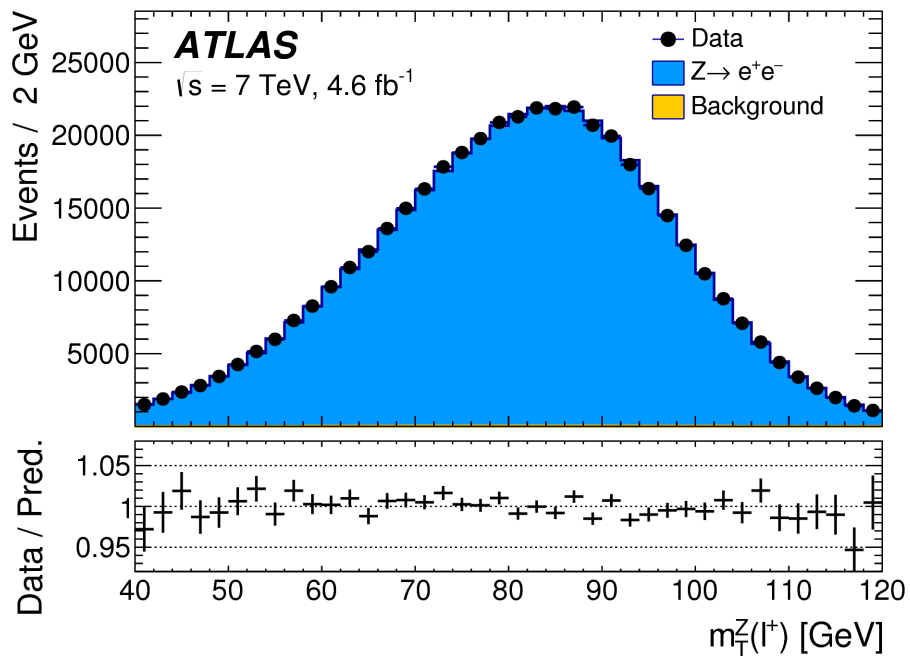
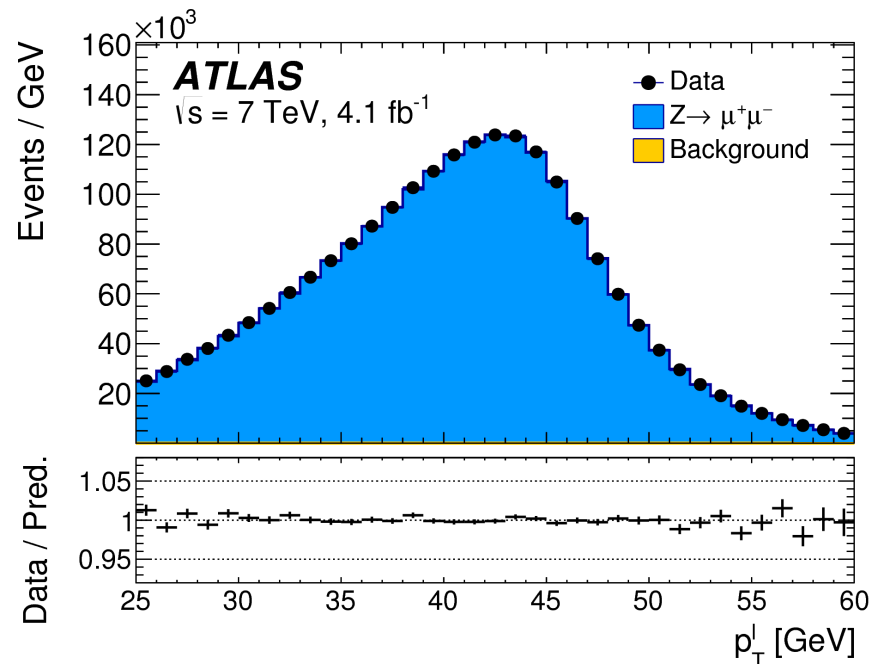
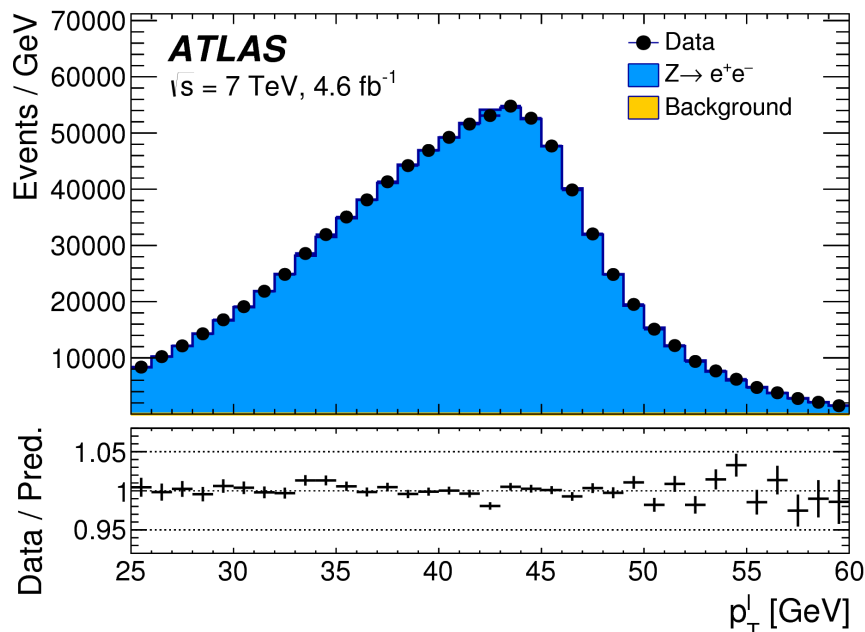
Z transverse momentum and rapidity distributions in e, μ channels



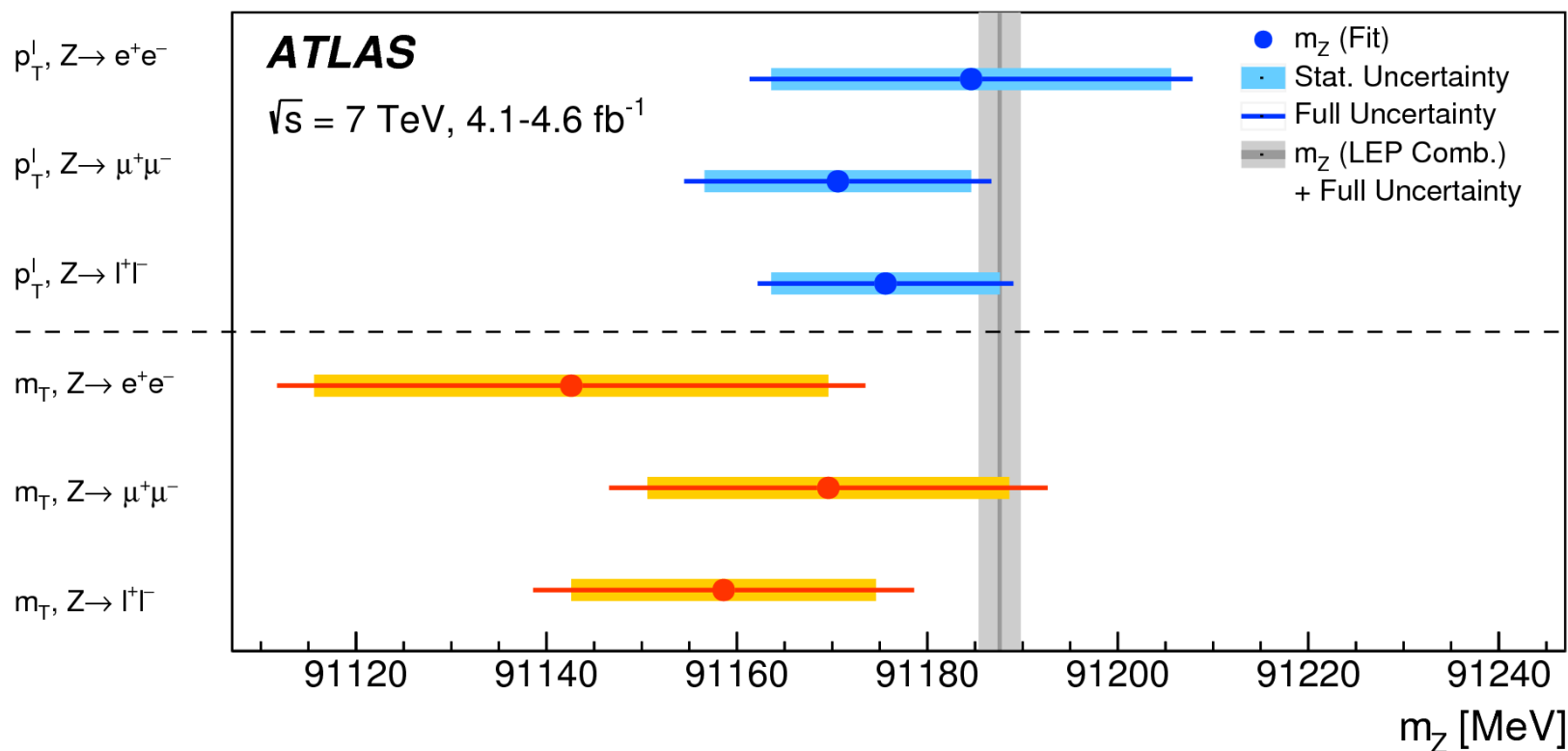
Good agreement is observed. Error bars are statistics only.

Z mass-sensitive distributions: p_T^l and m_T

Transverse momentum and transverse mass distributions in e, μ channels



Z mass measurement



Lepton charge Distribution	ℓ^+			ℓ^-			Combined	
	p_T^ℓ	m_T		p_T^ℓ	m_T		p_T^ℓ	m_T
Δm_Z [MeV]			41					
$Z \rightarrow ee$	$13 \pm 31 \pm 10$	$-93 \pm 38 \pm 15$	$-20 \pm 31 \pm 10$	$4 \pm 38 \pm 15$			$-3 \pm 21 \pm 10$	$-45 \pm 27 \pm 15$
$Z \rightarrow \mu\mu$	$1 \pm 22 \pm 8$	$-35 \pm 28 \pm 13$	$-36 \pm 22 \pm 8$	$-1 \pm 27 \pm 13$			$-17 \pm 14 \pm 8$	$-18 \pm 19 \pm 13$
Combined	$5 \pm 18 \pm 6$	$-58 \pm 23 \pm 12$	$-31 \pm 18 \pm 6$	$1 \pm 22 \pm 12$			$-12 \pm 12 \pm 6$	$-29 \pm 16 \pm 12$

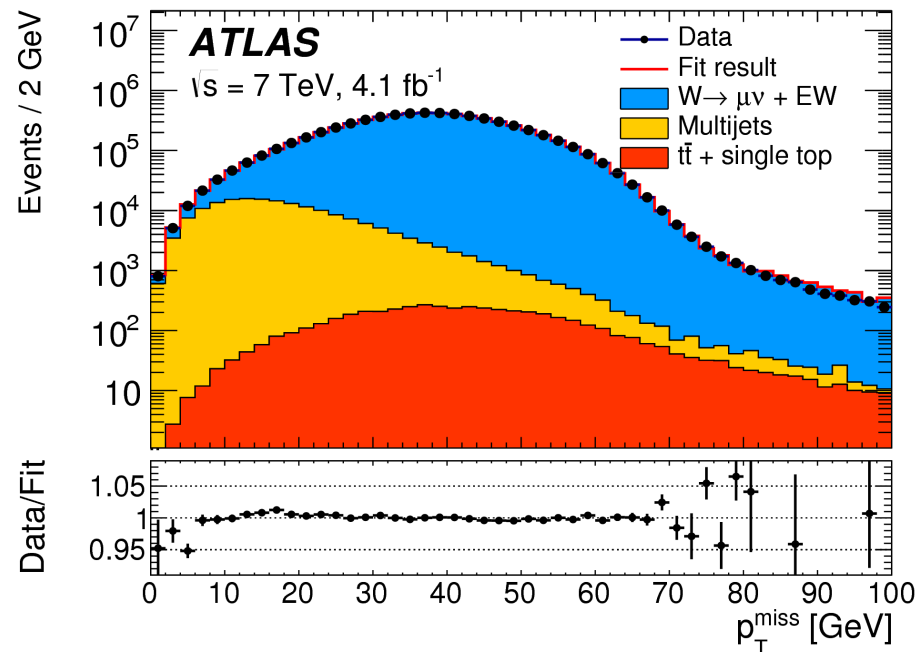
Results are consistent with the combined LEP value of m_Z within experimental uncertainties

Backgrounds in W

Electroweak and top-quark backgrounds are determined from simulation

Multijet background is determined using data-driven techniques:

- define background-dominated fit regions with relaxed cuts of the event selection
- template fits in these regions to 3 observables: p_T^{miss} , m_T and p_T^ℓ/m_T
- control regions are obtained by inverting the lepton isolation requirements



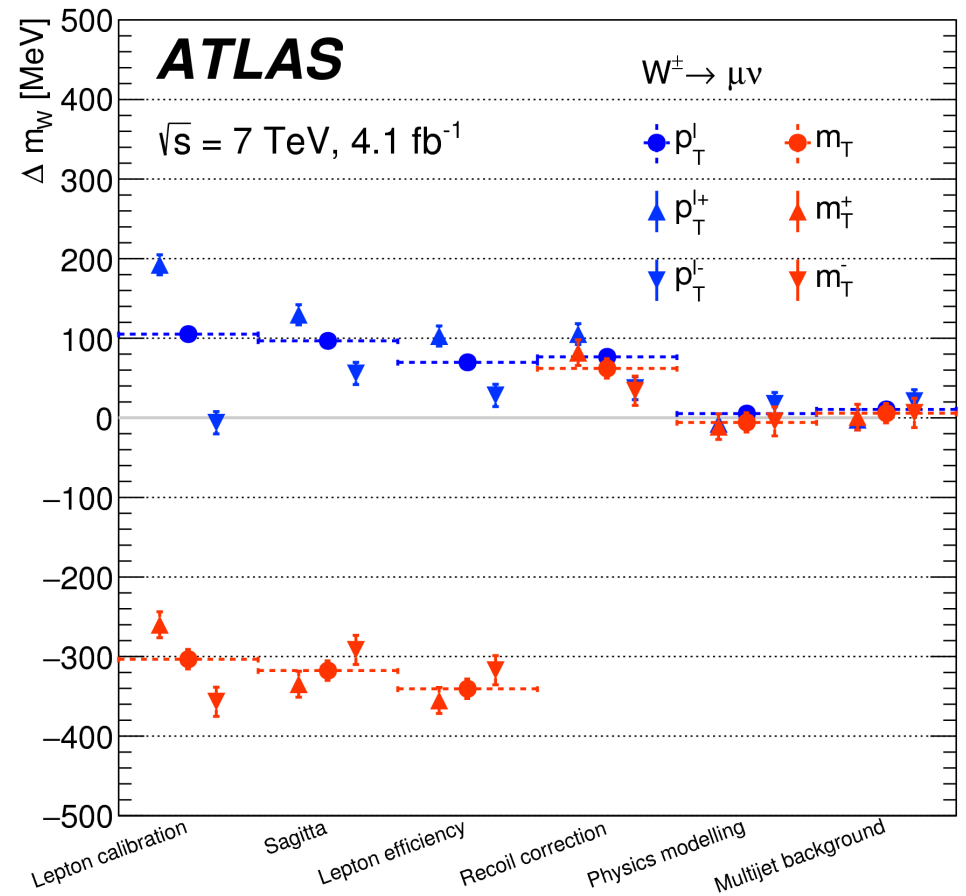
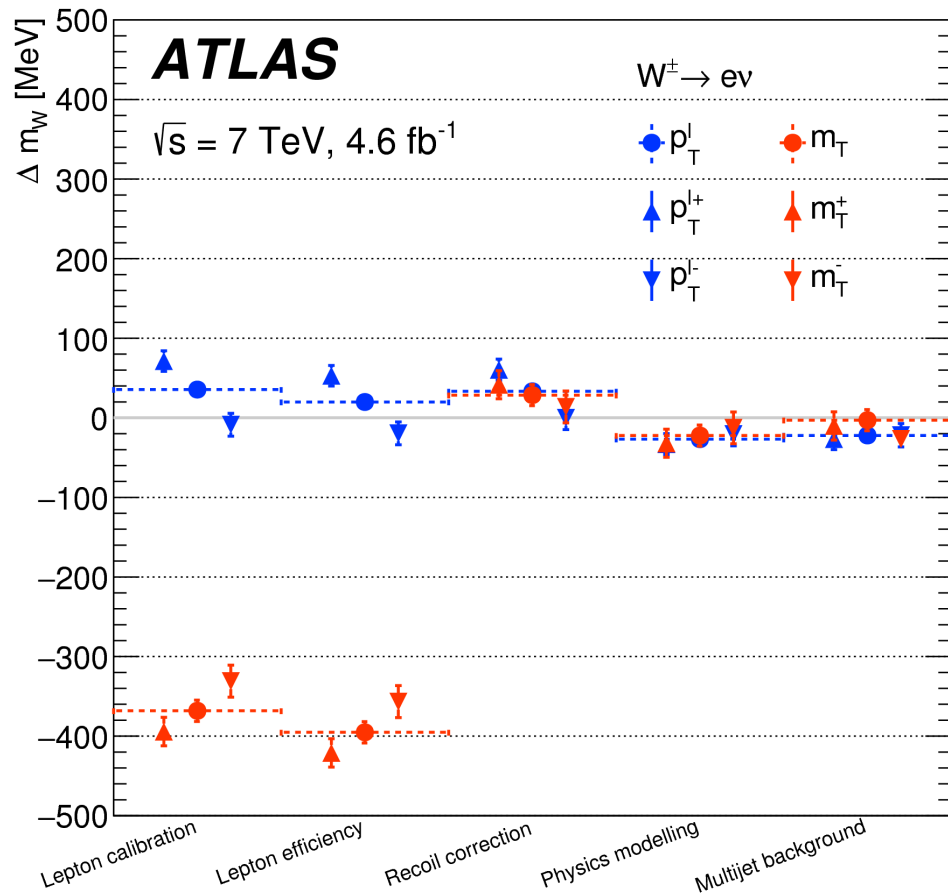
$W \rightarrow \mu\nu$						
Category	$W \rightarrow \tau\nu$	$Z \rightarrow \mu\mu$	$Z \rightarrow \tau\tau$	Top	Dibosons	Multijet
W^\pm $0.0 < \eta < 0.8$	1.04	2.83	0.12	0.16	0.08	0.72
W^\pm $0.8 < \eta < 1.4$	1.01	4.44	0.11	0.12	0.07	0.57
W^\pm $1.4 < \eta < 2.0$	0.99	6.78	0.11	0.07	0.06	0.51
W^\pm $2.0 < \eta < 2.4$	1.00	8.50	0.10	0.04	0.05	0.50
W^\pm all η bins	1.01	5.41	0.11	0.10	0.06	0.58
W^+ all η bins	0.99	4.80	0.10	0.09	0.06	0.51
W^- all η bins	1.04	6.28	0.14	0.12	0.08	0.68

$W \rightarrow e\nu$						
Category	$W \rightarrow \tau\nu$	$Z \rightarrow ee$	$Z \rightarrow \tau\tau$	Top	Dibosons	Multijet
W^\pm $0.0 < \eta < 0.6$	1.02	3.34	0.13	0.15	0.08	0.59
W^\pm $0.6 < \eta < 1.2$	1.00	3.48	0.12	0.13	0.08	0.76
W^\pm $1.8 < \eta < 2.4$	0.97	3.23	0.11	0.05	0.05	1.74
W^\pm all η bins	1.00	3.37	0.12	0.12	0.07	1.00
W^+ all η bins	0.98	2.92	0.10	0.11	0.06	0.84
W^- all η bins	1.04	3.98	0.14	0.13	0.08	1.21

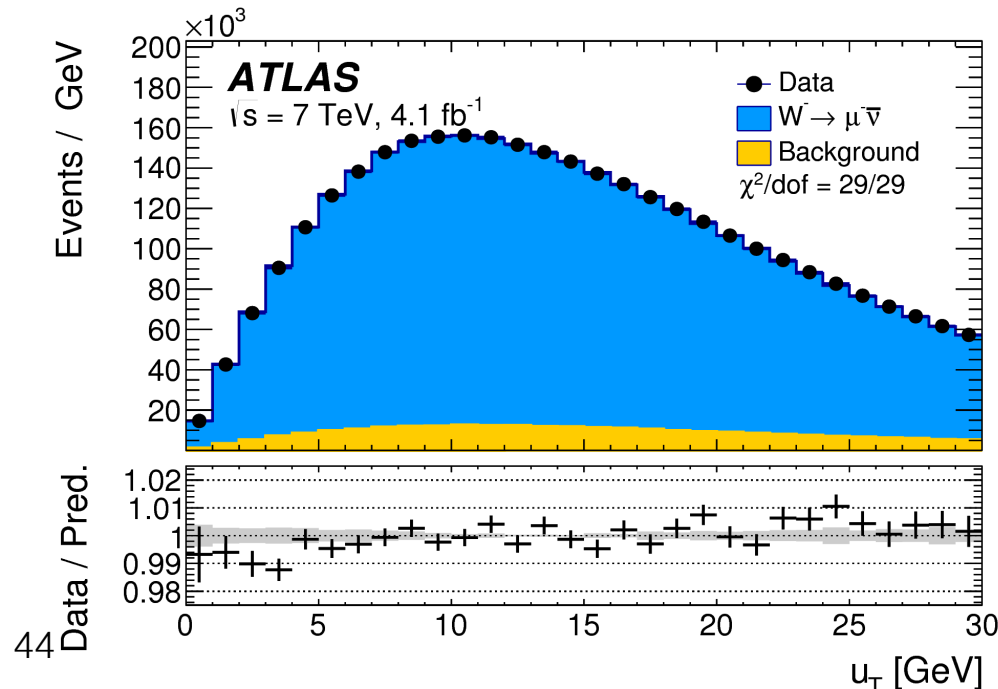
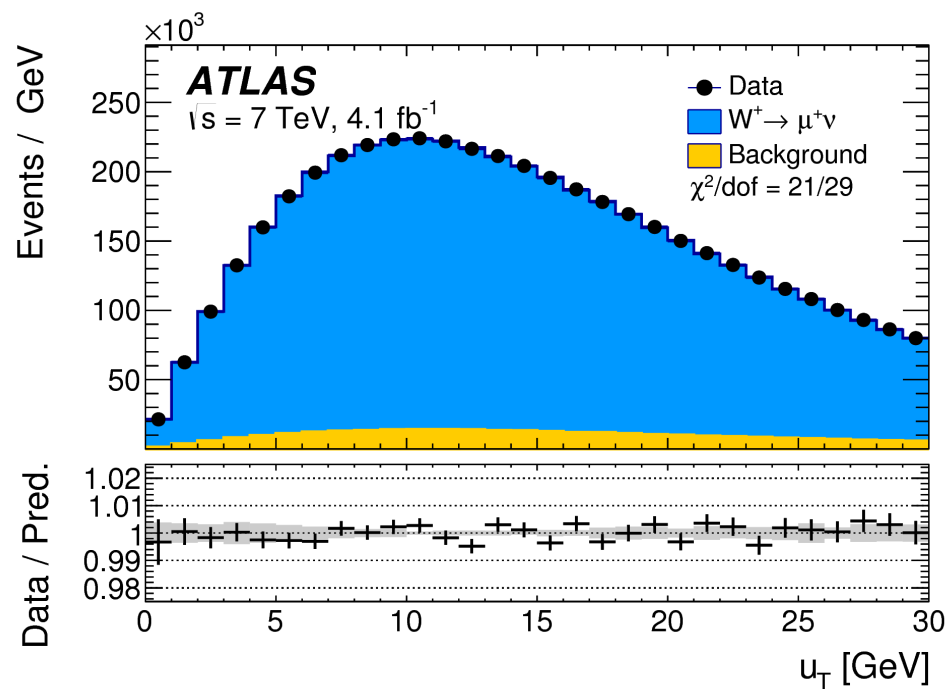
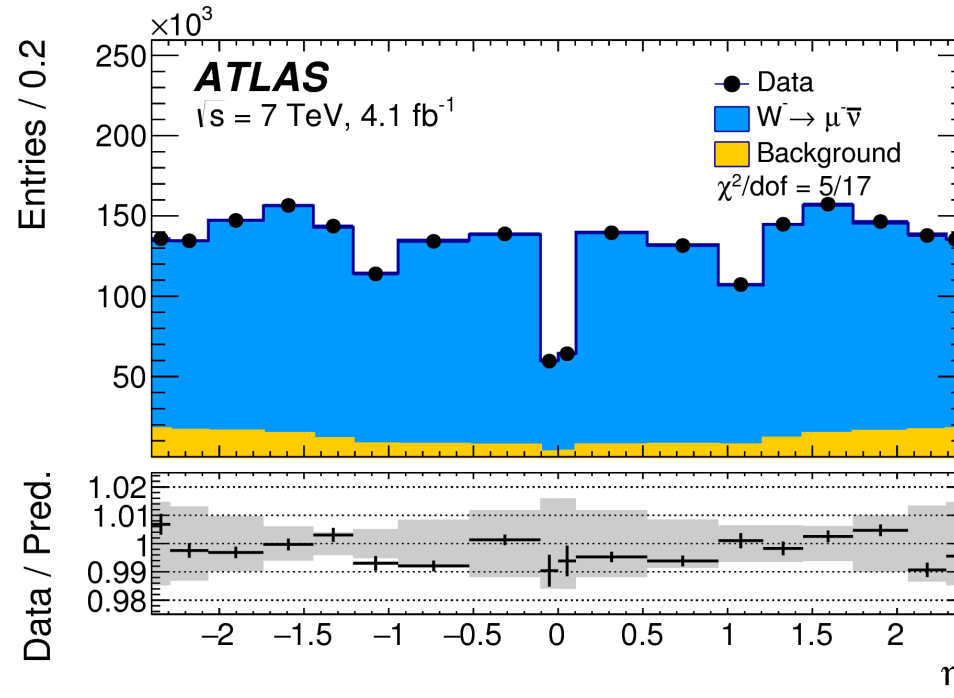
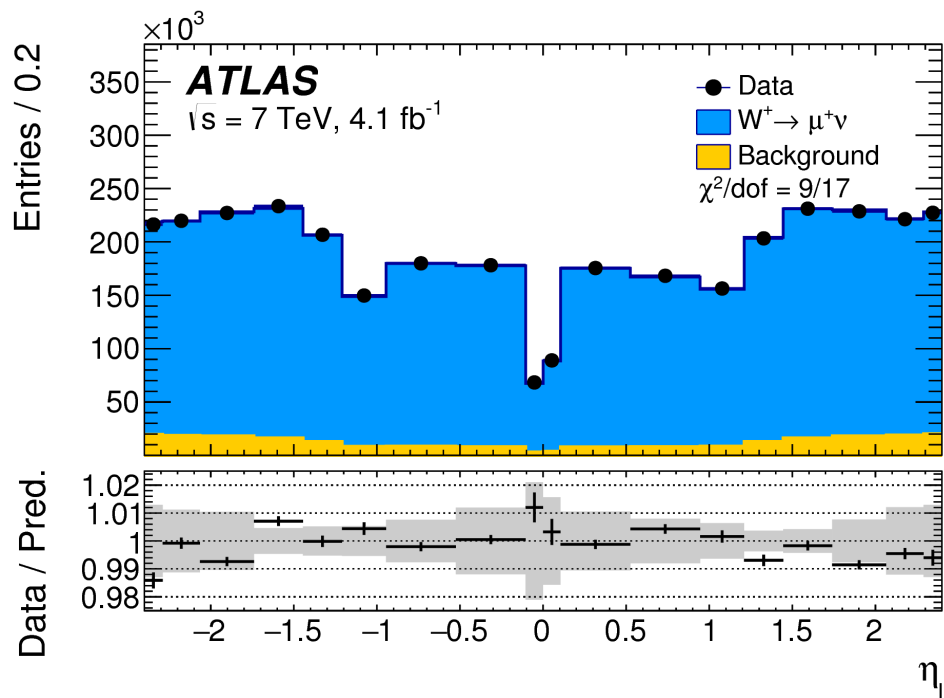
Kinematic distribution	p_T^ℓ				m_T			
	$W \rightarrow e\nu$		$W \rightarrow \mu\nu$		$W \rightarrow e\nu$		$W \rightarrow \mu\nu$	
Decay channel	W^+	W^-	W^+	W^-	W^+	W^-	W^+	W^-
W-boson charge	W^+	W^-	W^+	W^-	W^+	W^-	W^+	W^-
δm_W [MeV]								
$W \rightarrow \tau\nu$ (fraction, shape)	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.3
$Z \rightarrow ee$ (fraction, shape)	3.3	4.8	-	-	4.3	6.4	-	-
$Z \rightarrow \mu\mu$ (fraction, shape)	-	-	3.5	4.5	-	-	4.3	5.2
$Z \rightarrow \tau\tau$ (fraction, shape)	0.1	0.1	0.1	0.2	0.1	0.2	0.1	0.3
WW, WZ, ZZ (fraction)	0.1	0.1	0.1	0.1	0.4	0.4	0.3	0.4
Top (fraction)	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3
Multijet (fraction)	3.2	3.6	1.8	2.4	8.1	8.6	3.7	4.6
Multijet (shape)	3.8	3.1	1.6	1.5	8.6	8.0	2.5	2.4
Total	6.0	6.8	4.3	5.3	12.6	13.4	6.2	7.4

Summary of corrections

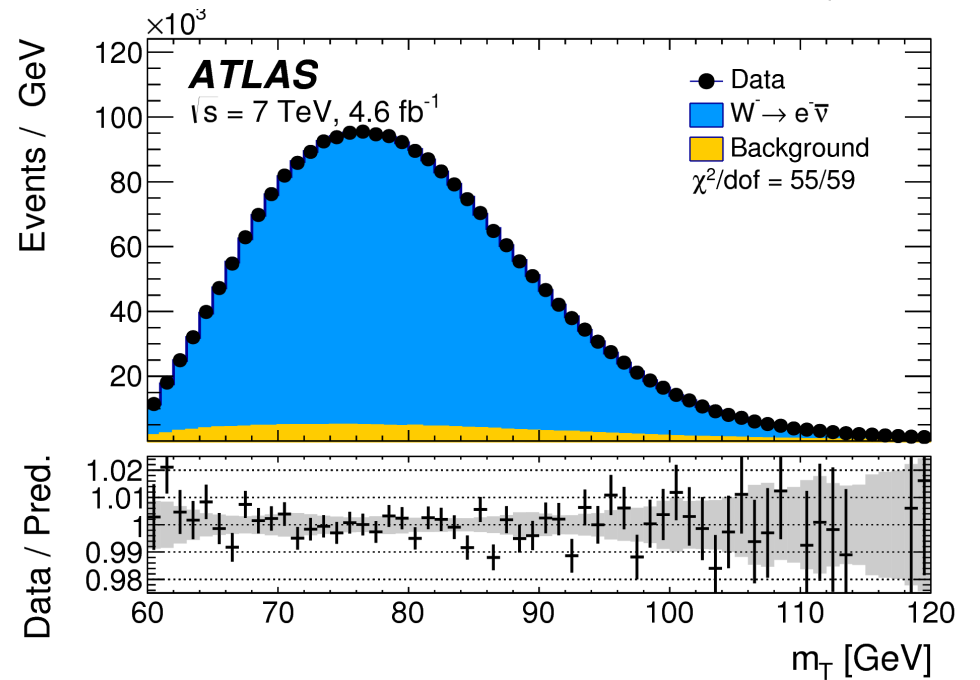
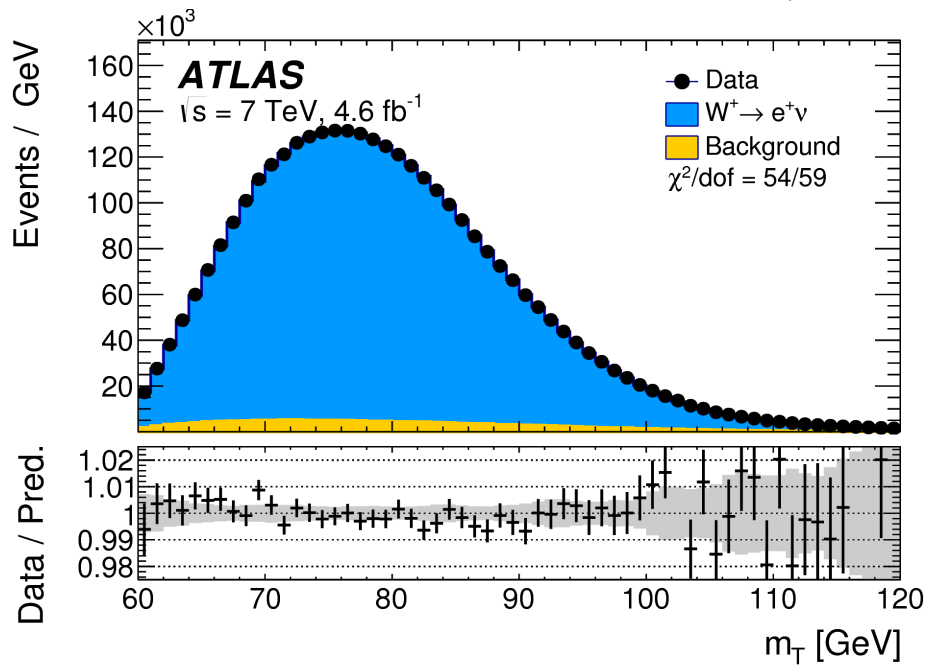
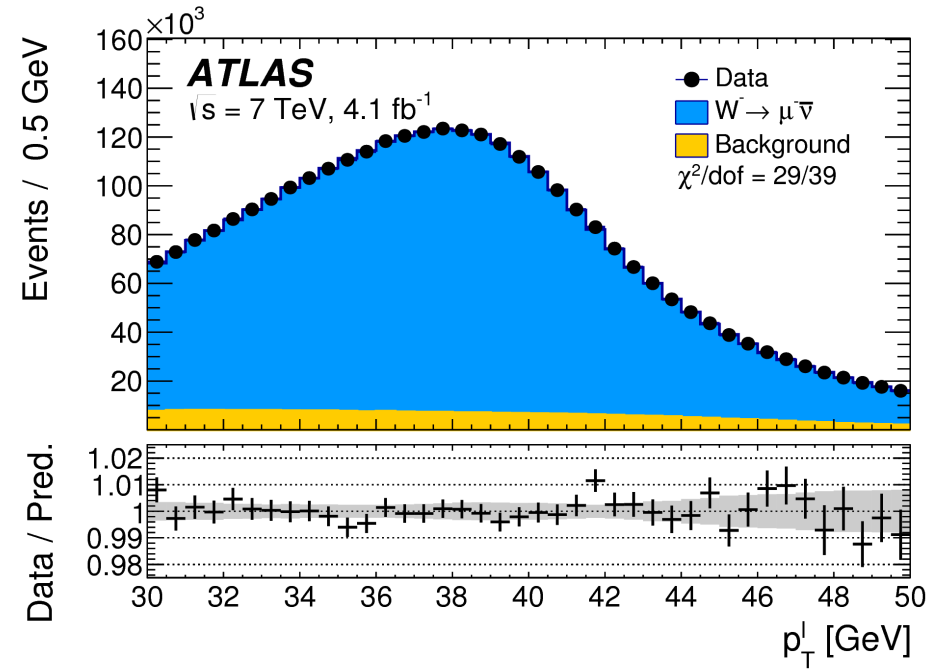
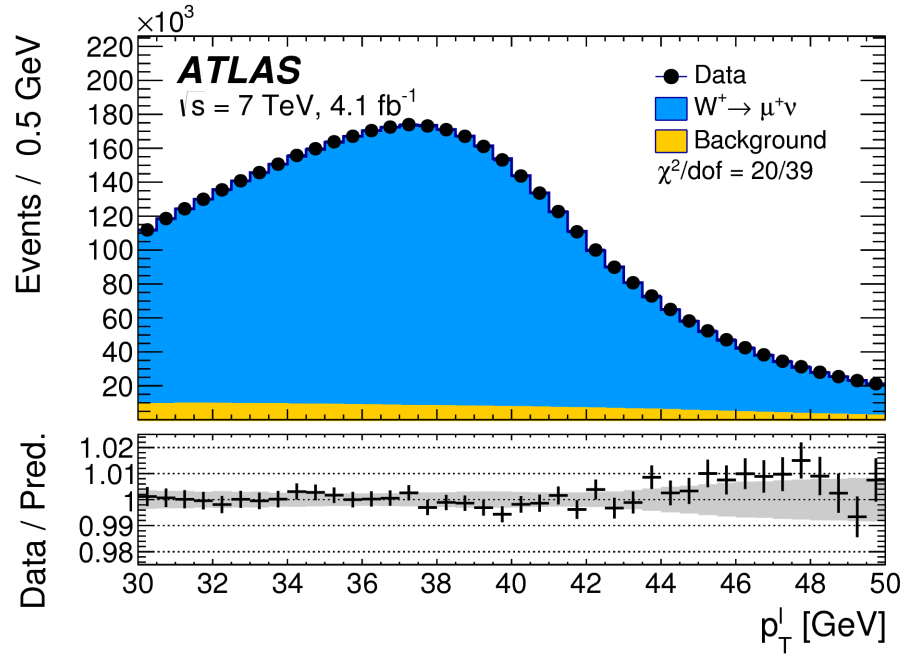
After all corrections are applied, **consistent results** are achieved between different channels, observables, categories, charges and only after, results were unblinded.



W control distributions: η , p_T

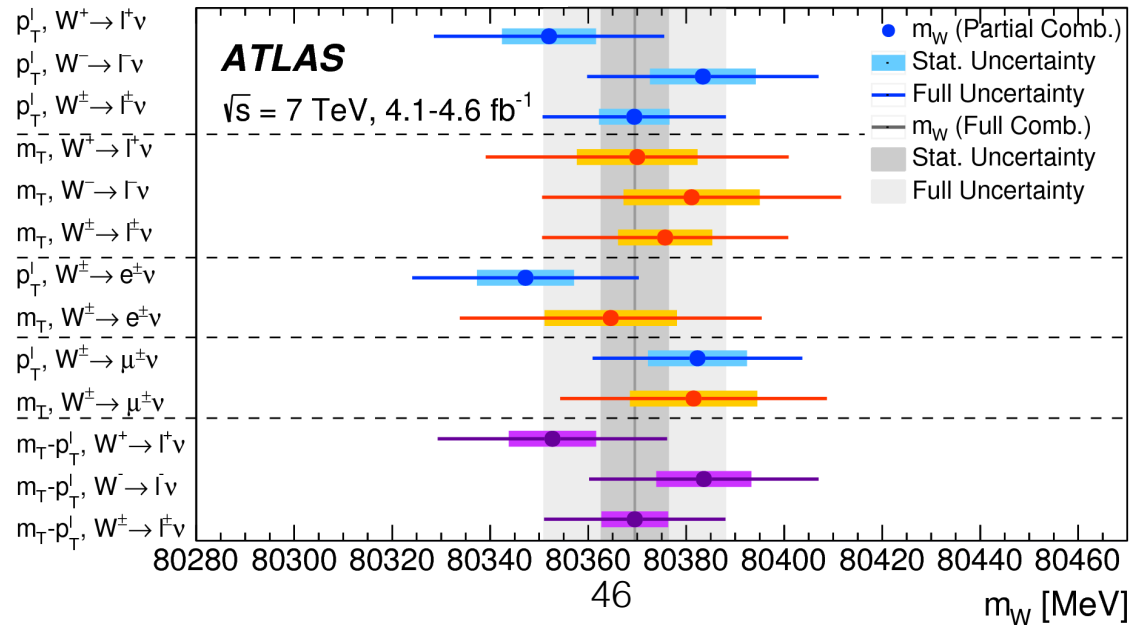
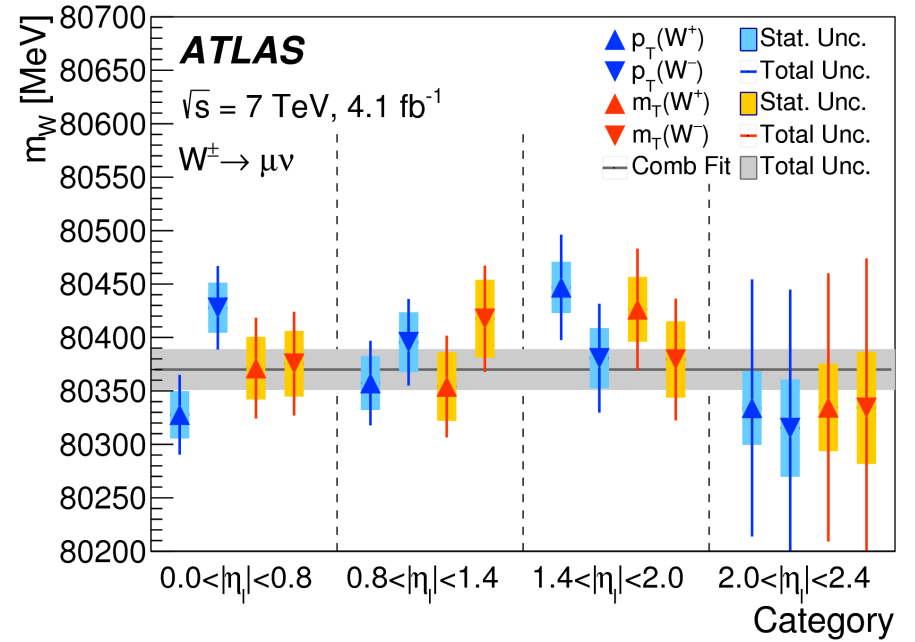
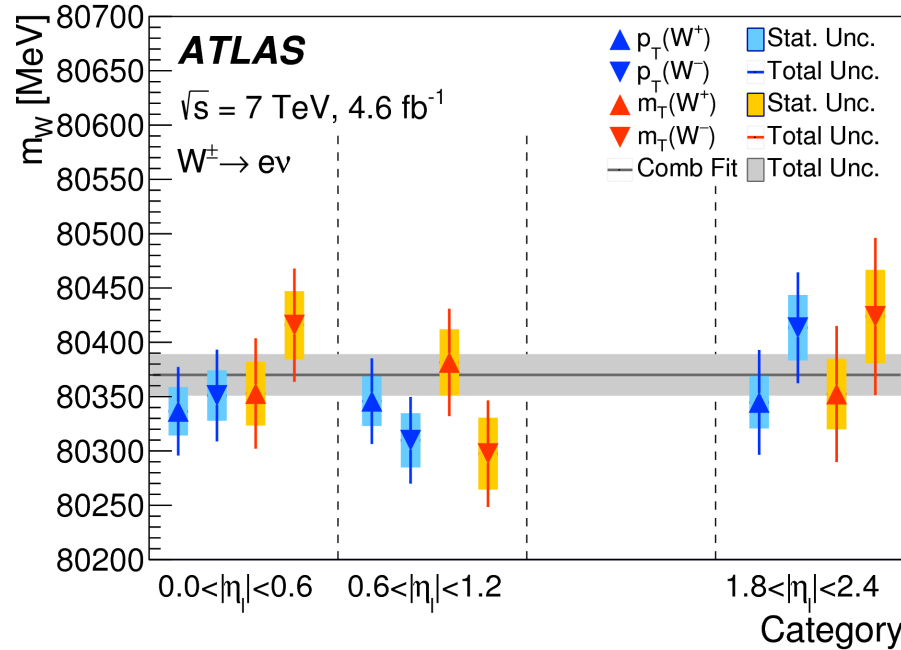


W mass-sensitive distributions: p_T^l and m_T



Consistency of the results

The consistency of the results was checked in the different categories but also in different pileup, u_T and $u_{||}$ bins



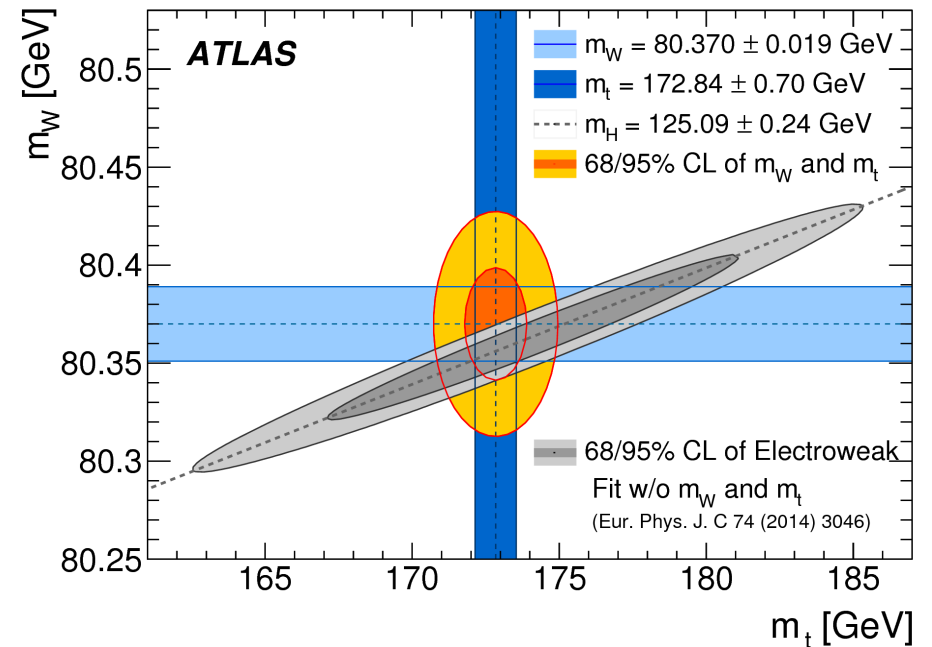
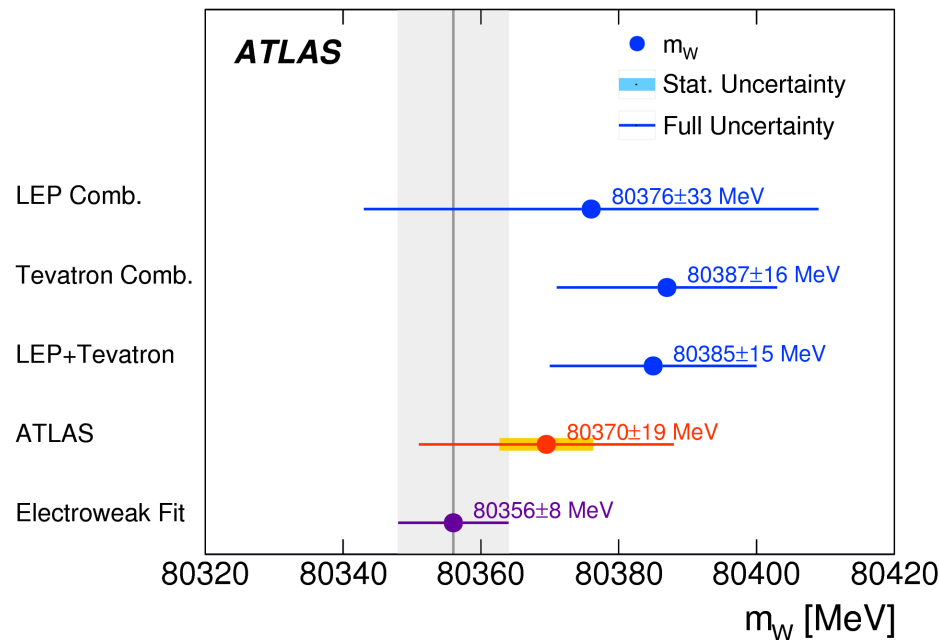
Fitting ranges:
 $32 < p_T^l < 45 \text{ GeV}$,
 $66 < m_T < 99 \text{ GeV}$

Results

$$m_W = 80369.5 \pm 6.8 \text{ MeV (stat.)} \pm 10.6 \text{ MeV (exp. syst.)} \pm 13.6 \text{ MeV (mod. syst.)}$$

$$= 80369.5 \pm 18.5 \text{ MeV,}$$

Combined categories	Value [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EWK Unc.	PDF Unc.	Total Unc.	χ^2/dof of Comb.
$m_T-p_T^\ell, W^\pm, e-\mu$	80369.5	6.8	6.6	6.4	2.9	4.5	8.3	5.5	9.2	18.5	29/27

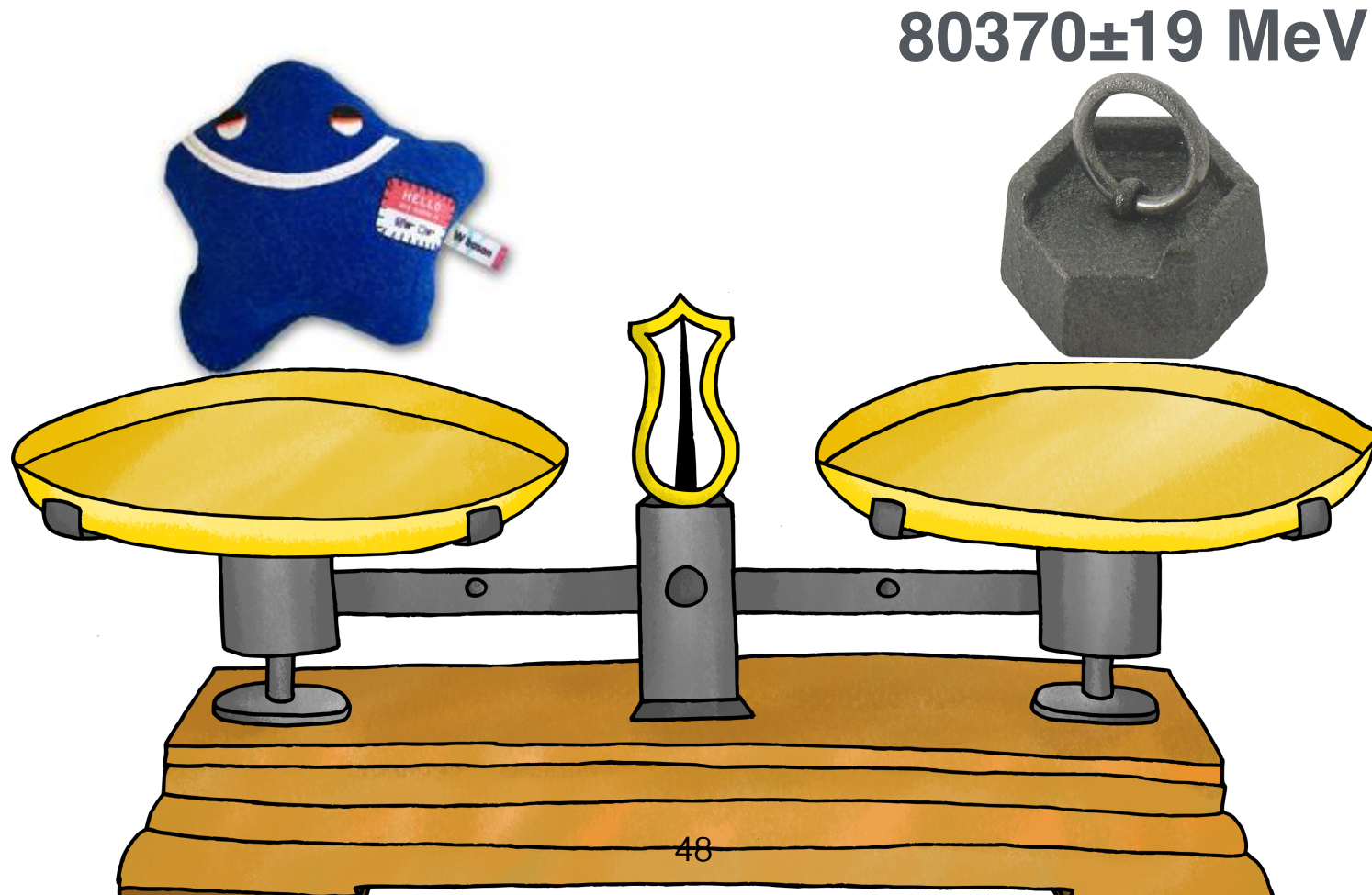


The result is consistent with the **SM expectation**, compatible with the world average and **competitive in precision** to the currently leading measurements by CDF

Conclusion

The first LHC measurement of $m_W = 80370 \pm 19$ MeV is public now [Eur. Phys. J. C \(2018\) 78:110](#) after many years of effort in the ATLAS collaboration.

The central value is consistent with the SM prediction and with the current world average value.



Perspectives

- The uncertainty is dominated by theoretical modelling uncertainties, therefore more work in this direction is required and *a fully consistent model within one simulation tool* is needed.
- More data are available with the **8 and 13 TeV** datasets which can be used to improve the analysis and to further constrain the PDFs. Experimentally, with the increase of the statistics in Z sample, most of the calibration uncertainties can be reduced. While more work is needed on the recoil with the increasing pileup.
- **Low pileup data** were taken in ATLAS at 5 ($\sim 250 \text{ pb}^{-1}$ $\mu=0.5-4$) and 13 TeV ($\sim 150 \text{ pb}^{-1}$ $\mu=2$) which will allow a measurement of the W transverse momentum at low p_T to 1% and to measure the W mass using m_T [ATLAS-PUB-2017-021](#).
- The W mass measurement in CMS is ongoing. A first W-like measurement of the Z mass was performed.

Thank you for your attention!