W Mass Highlights and other Precision Measurements

CLHCP, QINGGAO 17 November 2024

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Standard Model as a Gauge Theory derived from symmetry principles $\overline{SU(2)}_{I} \otimes \overline{U(1)}_{Y} \otimes SU(3)_{C}$ + vacuum expectation value $g_2(\sin\theta_W)$ $g_1(\alpha)$ $g_3(\alpha_s)$

Mass of electroweak gauge bosons and interaction strength predicted precisely

All EW parameters/observables can be expressed by three accurately measured independent parameters:

 $M_{\rm Z} = (91.1876 \pm 0.0021) \,\,{\rm GeV}$

 $G_F = 1.1663787(6) \times 10^{-5} \text{ GeV}^{-2}$

 $\alpha^{-1} = 137.035999150(33)$

+ fermion masses and their mixings





Motivation for precision electroweak physics

At higher orders

Test self-consistency of Standard Model

- Electroweak sector is over-constrained
- Identify tensions between direct & indirect measurements
- Deviations may be due to new physics





Top Mass Prediction from Precision Electroweak data



Top discovery at Tevatron

$M_{top} = 175 -> 173 \text{ GeV}$

World average: $m_{top} = 173.1 \pm 0.6 \text{ GeV}$ (0.35%)









July 21-27

Updated with EPS'01 results



Overnight update



Experimental data

Tevatron (Fermilab)



SLC (SLAC)







LEP (CERN)

LHC (CERN)

















Overview of Standard Model measurements at LHC

Standard Mod



Publication list

tatus: Febru	ary 2022	FIGUL	0055 5600	on measurements	$\sqrt{s} = 5, 7, 8, 13 \text{ TeV}$
Model	E _{CM} [TeV]	∫£ dt[fb ⁻¹]	Measurement	Theory	Reference
PP	8	50×10 ⁻⁶	σ = 96.07 ± 0.18 ± 0.91 mb	σ = 99.55 ± 2.14 mb (COMPETE HPRIR2)	PLB 761 (2015) 158
PP .	7	8×10-5	or = \$5.35 = 0.38 = 1.3 mb	σ = 97.26 ± 2.12 mb (COMPETE HPR1R2)	Nucl. Phys. B. 486-548 (2014)
w	13	0.061	σ = 190.1 ± 0.2 ± 6.4 nb		PLB 759 (2015) 601
w	8	20.2	$\sigma = 112.60 \pm 3.1$ mb	σ = 110.919889503 ± 3.7 rb (DYNNLD + CT14NNLO)	EPJC 79 (2019) 760
w	7	4.6	or = \$8.71 ± 0.028 ± 2.191 nb	cr = 95.9 ± 2.9 mb (DVNNLO + CT14NNLO)	EFUC 77 (2017) 387
z	13	3.2	$\sigma = 58.43 \pm 0.03 \pm 1.66 \text{ nb}$	σ = 55.96 + 1.5 - 1.7 nb (DYNNLO+GT14 NNLO)	JHEP 02 (2017) 117
z	8	20.2	or = 34.24 ± 0.03 ± 0.02 nb		JHEP 02 (2017) 117
z	7	4.6	σ = 29.53 ± 0.03 ± 0.77 nb	σ = 20.31 + 0.60 - 0.0 nb (DVNNLO+GT14 NNLO)	JHEP 02 (2017) 117
ŧĔ	13	36.1	σ = 826.4 ± 3.6 ± 19.6 pb	σ = 832 + 40 - 45 pb (top++ NNLO+NNLL)	EPUC 80 (2020) 528
ŧĨ.	0	20.2	σ = 242.9 ± 1.7 ± 8.6 pb	cr = 252.9 + 13.3 - 14.5 pb (top++ NNLO+NNLL)	EFUC 74 (2014) 3109
ŧť	7	4.6	σ = 182.9 ± 3.1 ± 6.4 pb	σ = 177 + 10 - 11 pb (top++ NNLO+NNLL)	EPJC 74 (2014) 3109
t _{e-shan}	13	3.2	σ - 247 ± 6 ± 46 pb	σ - 217 ± 10 pb (NLO+NLL)	JHEP 04 (2017) 086
E _{1-chan}	8	20.3	σ = 89.6 ± 1.7 + 7.2 − 6.4 pb	σ = 87.8 + 3.4 - 1.9 pb (NLO+NLL)	EPUC 77 (2017) 531
E1-chan	7	4.6	σ = 68 ± 2 ± 8 pb	σ = 64.6 + 2.7 - 2 pb (NLD+NLL)	PRD 90, 112006 (2014)
Wt	10	3.2	or = 94 ± 10 + 28 − 23 pb	or = 71.7 ± 3.9 pb (NLO+NNUL)	JHEP 01 (2018) 63
Wt	8	20.3	$\sigma = 23 \pm 1.3 \pm 3.4 \pm 3.7 \text{ pb}$	$\sigma = 22.4 \pm 1.5 \text{pb} (\text{NLO+NLL})$	JHEP 01, 064 (2016)
Wt	7	2.0	or = 16.8 ± 2.9 ± 3.9 pb	σ - 15.7 ± 1.1 pb (NLO+NLL)	PLB 716, 142-159 (2012)
н	13	139	or = 55.5 ± 3.2 + 2.4 - 2.2 pb	or = 55.6 ± 2.5 pb (LHC HKSWG YR4)	ATLAS-CONF-2022-002
н		20.3	or = 27.7 ± 3 + 2.3 - 1.9 pb	σ = 24.5 + 1.3 - 1.8 pb (LHC-HXSWG YR4)	EPUC 76 (2016) 8
H	7	4.5	or = 22.1 + 6.7 - 5.3 + 3.3 - 2.7 pb	σ = 19.2 + 1 - 1.4 pb (LHC-HKSWG YFH)	EFUC 76 (2016) 6
PL VBF. Mul <	2.5 13	139	$\sigma = 4 \pm 0.3 \pm 0.3 - 0.4 \text{pb}$	σ = 3.51 ± 0.07 pb (LHG-HXSWG)	ATLAS-CONF-2021-053
H VBF	8	20.3	ar = 2.43 + 0.5 - 0.49 + 0.33 - 0.25 pb	ar = 1.6 ± 0.04 pb (DRD-HKSWG YH4)	menor ve (soue) e
VH	8	20.3	or = 1.03 + 0.37 - 0.36 + 0.26 - 0.21 pb	σ = 1.12 ± 0.03 p0 (NNLG(QCD)+NLO(EW))	JHEP 12 (2017) 024
WPL [34] < 2.5	19	139	or = 1.56 + 0.2 - 0.21 + 0.15 - 0.18 pb	σ = 1.203 ± 0.024 pb (Powneg Box NLO(GCD))	ArLAS-CONF-2021-053
281.[78] < 2.5	13	139	or = 0.7 ± 0.13 + 0.1 - 0.12 pb	or = 0.199 ± 0.03 po (Powneg Box NLO(QCD))	ATLAS CONF-2021-053
EEM	13	139	$\sigma = 560 \pm 80 + 70 - 80 \text{ fb}$	or = 500 ± 50 m (LHCHCSWG NLO CCD + NLO EW) Or = 100 ± 0 + 10 m (LHCHCSWG NLO CCD + NLO EW)	ATLAS-CONF-2021-053
LIM	8	20.3	or = 220 ± 100 ± 70.15	07 = 133 + 0 - 1310 (LHUHKSWG NEO GOD + NEO EW)	FLD 764 (2016) 173
ww	13	30.1	0 = 100.04 ± 1.7 ± 10.0 p0	0 = 120.4 + 3.2 - 2.9 pb (MNLO)	EP-00 / 5 (2015) 554
www.	8	20.3	0 - 08.2 ± 1.2 ± 4.6 00	$\sigma = 65 \pm 1.2 \pm 1.1$ pp (NNLO)	PLB /63, 114 (2016)
WW	/	4.6		0 = 49.04 ± 1.00 - 9.00 (NNLO)	First rest of the last sector the sector sec
W/2	13	38.1	r = 51 = 0.0 = 2.5 p0	$\sigma = 99.1 \pm 1.1 \pm 1$ po (weinfulk (NNLO)) $\sigma = 22.02 \pm 0.4$ sty (AATERY (NNLO))	EPUL / 2 (2013) 332
WE.	9	201.0		C = 10.24 ± 0.3 p0 (MATTA (MALD)) C = 10.24 ± 0.3 = 0.4 cb (MATTA (MALD))	EP ID 79 (5010) 9175
WZ.	7	4.0	0 = 12 + 1.4 - 1.5 ± 190	0 = 12.54 ± 0.5 - 0.4 pb (WAIRIA (WALD))	EPSO 12 (2012) 2113
22	13	00.1	r - 73 - 64 - 64 - 63rb	c = 8 284 + 0.242 - 0.151 eb (NMLO) & Sheeps (NCO))	34EP 61 000 (2017)
77	7	4.6	a = 67+07+05-0400	a = 6 725 + 0 105 - 0 155 ob (NHLO)	LED 41, 000 (2011) DI D 795 (2014) 311
	,	20.0	r 48+08+16-13ch	c = 5.51 + 0.22 eb (MI C-MBI)	1 D 700, 009, 040 (2014)
a Day	19	2013	x = \$20 + 130 + 140 fb	cr = 600 + 72 fb (Maderards + eMCNLO)	EU 100, 200 240 (2010)
a Day	13	30.1		c = 222 + 22 B (MCSM)	MED 11 172 (2015)
177	12	128	a = 990 + 50 + 70 th	cr = 840 = 90 fb (Madurach5 + cMCNLO)	For. Plan. J. C 81 (2021) 707
112	13	20.3	$\sigma = 126 \pm 52 - 48 \pm 24.05$	$\sigma = 215 \pm 30$ fb (HELACALO)	HEP 11, 172 (2015)
MANNA I	19	138	ar = 0.82 + 0.01 + 0.00 ph	rr = 0.511 + 0.018 pb (NLO OCD)	a Yie 2001 12045
WW7	13	79.8	or = 0.55 ± 0.14 + 0.15 = 0.13 pb	$\sigma = 0.351 \pm 0.036$ pb (5bergs 2.2.2)	PLB 798 (2019) 134913
12.7	10	100		- 10 - 0 + 0 + 0 + 0 + 0 + 0 + 0 + 0 + 0 +	

15 orders of magnitude

CMS has similar plots (<u>see</u>) and explored similar phase space

Standard Model Production Cross Section Measurements

Status: February 2022





Drell-Yan process and measurement of SM parameters

The Drell-Yan process is a standard candle for precision measurements at the LHC



The p_T of the W, Z bosons comes from from higher order corrections to the leading order Drell–Yan processes...

..... and from non-perturbative effects such as the primordial k_T of the incoming partons.









Z Mass Reconstruction



$m_{ll}^2 = (p_{l+} + p_{l-})^2 \approx 2p_{l+} \cdot p_{l-} \approx 2E_{l+}E_{l-}(1 - \cos\theta_{l+l-})$ $\frac{d\hat{\sigma}}{dm_{ll}^2} \approx \frac{\Gamma_Z M_Z}{(m_{ll}^2 - m_Z^2)^2 + \Gamma_Z^2 M_Z^2} \times \frac{d\hat{\sigma}}{d\cos^2_{\theta}}$

- Only depending on direct measurements of energy and/or momentum of particles plus
- the angle between them
- Map out $m_z \& \Gamma_z$ in the Breit-Wigner resonance
- Errors determined by experimental resolutions.





Factorize the production dynamic and the decay kinematic properties of the dilepton system

$$\frac{d\sigma}{dpdq} = \frac{d^3\sigma^{U+L}}{dp_T dy dm} \left(1 + \cos^2\theta + \sum_{i=0}^7 A_i(y, p_T, m) P_i(\cos\theta, \phi) \right).$$

 A_i angular coefficients: dynamics Fiducial cuts removed by analytic integration of (cos θ , ϕ) in the full phase space of the decay leptons through the measured Ai coefficients

Rapidity



Run-1 8 TeV data only

of the decay leptons

ATLAS-CONF-2023-013

lepton angular $\cos \theta$ and ϕ distributions in the Collins-Soper frame

- negligible theoretical uncertainties for all measurements
- **First comparison to N3LO QCD** predictions and N4LL resummation





Transverse Momentum









W boson mass measurement





W mass reconstruction challenge $m_{l\nu}^{2} = (E_{l} + E_{\nu})^{2} - (\vec{p}_{e,T} + \vec{p}_{\nu,T})^{2} - (p_{e,z} + p_{\nu,z})^{2}$



 $m_{l\nu,T}^2 = (E_{l,T} + E_{\nu,T})^2 - (\vec{p}_{e,T} + \vec{p}_{\nu,T})^2$ $\approx 2\vec{p}_{l,T}\cdot\vec{p}_{\nu,T}\approx 2E_{l,T}E_T^{miss}(1-\cos\theta_{l\nu})$ $E_T = \sqrt{m^2 + p_T^2} \approx p_T$ $\vec{p}_T^{miss} = -\sum_{T} \vec{p}_T(observed)$

Transverse mass

UA1: 40 years ago $M_{W} = 83 \pm 4 \text{ GeV}$ Γw < 6.5 GeV





CDFW Mass Measurement

Shots to prevent cancer show early promise p. 126

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Visualizing a key step in cytokine signaling pp. 139 & 163

Service of the servic

Silk-wrapped food wins BII & Science Prize p. 146

S

HEAVYWEIGHT W boson mass measures higher than expected pp. 125, 136, & 170

4

High-precision measurement of the W boson mass with the CDF II detector

8 April 2022



Science Vol 376, Issue 6589, pp. 170–176 (2022)

The CDF Experiment





The Central Outer Tracker (COT) Detector essential to the W mass measurement precision

30,000 high-voltage of Gold-plated Tungsten wires in Argon-Ethane gas



Alignment with cosmic rays specifically updated for this W mass measurement Calibrate with Z, J/ψ , $\Upsilon(1S)$ (Blind Z mass: $M_Z = 91192.0 \pm 6.4_{stat} \pm 4.0_{sys}$ (PDG: 91187 ± 2.1))





W mass extraction

Binned maximum likelihood fits to the templates

of p_T^l , m_T , p_T^v with W mass [80, 81] GeV

Distribution	W boson mass (MeV)
m _T (e,ν)	$80,429.1 \pm 10.3_{stat} \pm 8.5_{syst}$
$p_{\mathrm{T}}^{\ell}(e)$	$80,411.4 \pm 10.7_{stat} \pm 11.8_{syst}$
p _T ^v (e)	$80,426.3 \pm 14.5_{stat} \pm 11.7_{syst}$
$m_{T}(\mu, \nu)$	$80,446.1 \pm 9.2_{stat} \pm 7.3_{syst}$
$p_{\mathrm{T}}^{\ell}(\mu)$	$80,428.2 \pm 9.6_{stat} \pm 10.3_{syst}$
$p_{\mathrm{T}}^{\mathrm{v}}(\mu)$	$80,428.9 \pm 13.1_{stat} \pm 10.9_{syst}$
Combination	$80,433.5 \pm 6.4_{stat} \pm 6.9_{syst}$

Consistency in two channels and three kinematic fits





Comparison with ATLAS measurement

CDF ullet

- proton anti-proton collisions
- larger statistics uncertainty
- PDF: valence quark(~80%), less theoretical uncertainty

$\mathsf{ATLAS} \to \mathsf{LHC}$ \bullet

- W events statistics by more than one order of magnitude
- gluon and sea quark are important, less precise than valence quark PDF, more sensitive to proton PDF



mw **4** `

W mass uncertainty (MeV)

	CDF	ATLAS (7 T
Stat	6.4	6.8
PDF	<u>3.9</u>	<u>9.2</u>
Bkg	3.3	4.5
EW	2.7	5.5
е	33	6.4
mu	0.0	6.6
recoil	2.5	2.9
QCD	2.2	8.3
Total	9	19

First ATLAS measurement

 $<\mu>=9.1$







Updated W mass measurement from ATLAS

Determine the W boson mass from the dependence of the leptonic transverse momentum (p_T) and the transverse mass (m_T)



Revisited measurement from 2017, using the same data, but with more advanced physics model and profile likelihood fitting: Advantage: Reduce systematic uncertainties during the fit **Disadvantage:** Computational expensive, challenging to investigate systematics

arXiv:2403.15085









W mass: physics modeling and analysis improvements

Physics modeling

- **Baseline: Pythia AZ tune (based on Z boson)**
 - Z Boson Data, Parton Shower Variations
- **New Verifications:** •
 - AZ tune describes hadronic recoil spectrum of W's in low-pileup data at 5 TeV within experimental uncertainties
 - DYTurbo (resumed calculation) also agrees with AZ Tune.
- **Treatment of angular coefficients unchanged** •
- **Parton Distribution Functions:**
 - Studied full set of available PDF Sets at NNLO: CT10, CT14, CT18, MMHT2014, MSHT20, NNPDF3.1, NNPDF4.0
 - New Baseline CT18

Analysis improvements

- Multijet Background Estimation
 - Systematic shape variations using PCA
 - New transfer function from CR to SR
 - Reduction of uncertainty by 2 MeV
- **EWK uncertainty evaluated at detector level** •
 - increase uncertainty by 1-2 MeV •
- **Recovering data in the electron channel** •
 - Increased statistics by 1.5%
- Add W width as NP parameter •
- Improving random generator setup for the electron energy calibration





W mass and width measurements from ATLAS



mw = 80366.5 ± 15.9 MeV (0.02% uncertainty) $\Gamma_{\rm W} = 2202 \pm 47 \,\,{\rm MeV}$

Most precise single-experiment measurement of Γ_W

Previous measurement from 2017: $m = 80370 \pm 19$ MeV

Overview of Γ_w measurements ATLAS DELPHI Eur. Phys. J. C 47 (2006) 309 Γ_w = 2404 ± 173 MeV $\sqrt{s} = 7 \text{ TeV}, 4.6 \text{ fb}^{-1}$ OPAL Eur. Phys. J. C 47 (2006) 309 Γ_w = 1996 ± 140 MeV L3 Eur. Phys. J. C 47 (2006) 309 $\Gamma_{w} = 2180 \pm 142 \text{ MeV}$ ALEPH Eur. Phys. J. C 47 (2006) 309 $\Gamma_{w} = 2140 \pm 108 \text{ MeV}$ Combination Phys. Rep. 532 (2013) 119 Tw = 2195 ± 83 MeV Phys. Rev. Lett. 103 (2009) 231802 $\Gamma_w = 2028 \pm 72 \text{ MeV}$ Measurement CDF Stat. Unc. Phys. Rev. Lett. 100 (2008) 07180 $\Gamma_{w} = 2032 \pm 72 \text{ MeV}$ Total Unc. SM Prediction ATLAS This work Γ_w = 2202 ± 47 MeV 2500 1500 2000 Γ_{W} [MeV]

Unc. [MeV]	Total	Stat.	Syst.	PDF	A_i	Backg.	EW	е	μ	u_{T}	Lumi	m_W	PS
p_{T}^{ℓ}	72	27	66	21	14	10	5	13	12	12	10	6	55
m _T	48	36	32	5	7	10	3	13	9	18	9	6	12
Combined	47	32	34	7	8	9	3	13	9	17	9	6	18





W mass measurements at LHCb

W mass determination in the forward acceptance



JHEP 01 (2022) 036

Only a 2016 dataset analysis, with a full Run 2 analysis still possibly coming $m_W = 80364 \pm 32 \text{ MeV}$





Combination of W mass measurements: ATLAS, LHCb, CDF, DØ

Measurements performed at different times, using different baseline PDFs and QCD tools

existing results extrapolated to a common baseline



mw^{combined} ... and repeat, for different PDFs M. Boonekamp, LHC EW WG General Meeting, July 2024

Tension between combination and CDF W mass is of 3.6 σ

EPJ C (2024) 84:451

PDF uncertainty correlation matrices for the CT18 PDF set

ATLAS, LHCb, DØ Combination : $m_W = 80369.2 \pm 13.3$ MeV



First W mass measurement at CMS

Nominal theory-dependent fit

 $M_W = 80360.2 \pm 9.9 \text{ MeV}$

Helicity cross section fit reduced theory uncertainty at the cost of larger statistical unc.







CMS-PAS-SMP-23-002 J. Bendavid, CMS CERN seminar



 \mathbf{V} s forces us to use indirect observables to infer constraints on the mass \Rightarrow many systematic uncertainties to control





First W mass measurement at CMS

- Measured with uncertainty of 9.9 MeV
 - Precision comparable to CDF, but consistent with SM
- Uses a well-understood portion of 13 TeV data
 - 16.8 fb⁻¹ from 2016 run (~ 30 pileup)
 - Large sample (>100M) of $W \rightarrow \mu v$
- Theoretical modelling
 - Use most accurate model & uncertainties available
 - Rely on in-situ constraints from the W data itself
- Muon calibration: from J/ψ , validated with the Z
- Fit to granular distribution of p_T^μ x η^μ x charge



<u>CMS-PAS-SMP-23-002</u> J. Bendavid, CMS CERN seminar









First W mass measurement at CMS



Measurement is performed with ~10% of Run 2 data

 $m_W = 80360.2 \pm 9.9 \text{ MeV}$

W mass uncertainty (MeV)

EP <mark>fit</mark>		ATLAS, 7 TeV re-analysis	CMS
,	Stat	9.8	7.1
	PDF	5.7	<u>2.8</u>
	Bkg	2.0	1.7
	EW	5.4	1.9
	e	6.0	_
	mu	5.4	5.0
$\Delta \mathbf{r}$)	recoil	2.3	_
 80.45	QCD	4.4	<u>3.1</u>
eV)	Total	16 MeV	9.9 Me

Exploit state-of-the-art improvements in theoretical QCD & EW calculations & uncertainty modeling, in-situ constraints from data...



W boson measurements in low-pileup dataset from ATLAS



Precise measurements of W and Z transverse momentum spectra at 5 and 13 TeV **ATLAS-CONF-2023-028**



Pile-up events add energy to the recoil and hinder the experimental extraction of W pT

Take dataset with very low multiple hard interactions per bunch crossing ATLAS collected such dataset at $\sqrt{s} = 5$ and 13 TeV







Precise measurements of W and Z transverse momentum spectra at 5 and 13 TeV

Precise measurements and predictions of the spectra for $p_T < \sim 30$ GeV are particularly interesting for future measurement of the W-boson mass at LHC

Compared to DYTURBO predictions with different PDF sets



DYTURBO resummed predictions show the best agreement and generally match the data at the percent level

Eur. Phys. J. C 84 (2024) 1126

$\sqrt{s} = 5 \text{ TeV}$

Compared with different MC predictions





Precise measurements of W and Z transverse momentum spectra at 5 and 13 TeV

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Eur. Phys. J. C 84 (2024) 1126

$\sqrt{s} = 13 \text{ TeV}$

Compared with different MC predictions





Expectations for W mass measurement with low-pileup dataset

- Measurement will use both p_T and m_T information •
- Profile likelihood
- Less sensitive to pile-up effects
 - Better lepton reconstruction
 - Smaller uncertainties for W recoil \rightarrow better m_T measurement
- Improved theoretical uncertainties:
 - Updated PDF distribution
 - Updated QCD modeling
 - Updated Electroweak modeling
- Limited by statistical uncertainty
 - 5 TeV: 255 pb⁻¹
 - 13 TeV: 338 pb⁻¹



Uncertainty low-pileup analysis: ~ 15 MeV Combination with 7 TeV: ~ 10 MeV







Anomalous magnetic moment g-2 of the tau lepton

Sensitive to new physics in the $\gamma \tau \tau$ vertex





Tau (g-2) in the Standard Model







g-2 of tau lepton: $\gamma\gamma \rightarrow \tau\tau$

5.3 σ observed



Detailed overview by Dayong Wang, Friday Plenary



Top quark mass



Top quark mass measurements

Measured in different channels with different techniques



Best single measurement is from CMS, lepton+jets profile likelihood new result with 13 TeV data

$m_{top} = 171.77 \pm 0.37 \text{ GeV}$

Uncertainty reached ~ 0.2%

40% improvement relative to previous measurement

<u>CMS-TOP-20-008</u>

ATL-PHYS-PUB-2023-015

ATLAS+CMS Preliminary	m _{top} summary, √s = 7-13 TeV	June 20
World comb. (Mar 2014) [2] stat	total stat	
total uncertainty	$m_{top} \pm total (stat \pm syst \pm recoil)$	s
LHC comb. (Sep 2013) LHCtopWG	173.29 ± 0.95 (0.35 ± 0.88)	7 TeV
World comb. (Mar 2014)	173.34 \pm 0.76 (0.36 \pm 0.67)	1.96-7
ATLAS, I+jets	172.33 \pm 1.27 (0.75 \pm 1.02)	7 TeV
ATLAS, dilepton	173.79 ± 1.41 (0.54 ± 1.30)	7 TeV
ATLAS, all jets	175.1±1.8 (1.4±1.2)	7 TeV
ATLAS, single top	172.2 ± 2.1 (0.7 ± 2.0)	8 TeV
ATLAS, dilepton	$172.99 \pm 0.85 \; (0.41 \pm 0.74)$	8 TeV
ATLAS, all jets	173.72 ± 1.15 (0.55 ± 1.01)	8 TeV
ATLAS, I+jets	172.08 \pm 0.91 (0.39 \pm 0.82)	8 TeV
ATLAS comb. (Oct 2018) H ▼H	172.69 \pm 0.48 (0.25 \pm 0.41)	7+8 Te
ATLAS, leptonic invariant mass	174.41 ± 0.81 (0.39 ± 0.66 ± 0.25)	13 TeV
ATLAS, dilepton (*)	$172.21 \pm 0.80 (0.20 \pm 0.67 \pm 0.39)$	13 TeV
CMS, I+jets	173.49 ± 1.06 (0.43 ± 0.97)	7 TeV
CMS, dilepton	172.50 \pm 1.52 (0.43 \pm 1.46)	7 TeV
CMS, all jets	173.49 ± 1.41 (0.69 ± 1.23)	7 TeV
CMS, I+jets	172.35 \pm 0.51 (0.16 \pm 0.48)	8 TeV
CMS, dilepton	172.82 \pm 1.23 (0.19 \pm 1.22)	8 TeV
CMS, all jets	$172.32 \pm 0.64 \; (0.25 \pm 0.59)$	8 TeV
CMS, single top	$172.95 \pm 1.22 \ (0.77 \pm 0.95)$	8 TeV
CMS comb. (Sep 2015)	172.44 \pm 0.48 (0.13 \pm 0.47)	7+8 Te
CMS, I+jets	$172.25 \pm 0.63 \; (0.08 \pm 0.62)$	13 TeV
CMS, dilepton	$172.33 \pm 0.70 \; (0.14 \pm 0.69)$	13 TeV
CMS, all jets	172.34 \pm 0.73 (0.20 \pm 0.70)	13 TeV
CMS, single top	$172.13 \pm 0.77 \; (0.32 \pm 0.70)$	13 TeV
CMS, I+jets	171.77 ± 0.37	13 TeV
CMS, boosted	172.76 \pm 0.81 (0.22 \pm 0.78)	13 TeV
* Proliminary	[1] ATLAS-CONF-2013-102 [8] EPJC 79 (2019) 290 [2] arXiv:1403.4427 [9] arXiv:2209.00583 [3] EPJC 75 (2015) 320 [10] ATLAS CONF 2022.058	[15] EPJC 77 [16] EPJC 78
Freiminary	[4] EPJC 75 (2015) 158 [11] JHEP 12 (2012) 105 [5] ATLAS-CONF-2014-055 [12] EPJC 72 (2012) 2202	[17] EPJC 79 [18] EPJC 79 [19] arXiv:21(
	[6] PLB 761 (2016) 350[13] EPJC 74 (2014) 2758[7] JHEP 09 (2017) 118[14] PRD 93 (2016) 072004	[20] arxiv:230 [21] arxiv:221
165 170	175 180	185
m	_{top} [GeV]	









Top quark mass: Run 1 combination

A combination of fifteen top-quark mass measurements performed by the ATLAS and CMS experiments at the LHC

$m_{top} = 172.52 \pm 0.33 \text{ GeV}$

Precision < 0.2%

31% improvement over most precise single improvement









Closing remarks

The LHC has produced exceptionally precise results

Still the Standard Model as we know it stands strong

Looking forward to the HL-LHC data and Future electron colliders such as the CEPC or FCC-ee



Extra Slides



Compare with previous CDFII measurements

Uncertainty

Previous CDF results (2.2 fb^{-1})

Source	Uncertainty (MeV)	Source	Uncertainty (MeV)
Lepton Energy Scale	7	Lepton energy scale	3.0 Higher order OF
Lepton Energy Resolution	2	Lepton energy resolution	1.2 Tigher Order QL
Recoil Energy Scale	4	Recoil energy scale	1.2 Deceil model
Recoil Energy Resolution	4	Recoil energy resolution	1.8 Recon model
$u_{\rm III}$ efficiency	0	Lepton efficiency	0.4
Lepton Removal	2	Lepton removal	1.2 Close
Backgrounds	3	Backgrounds	3.3 Close
$p_T(W)$ model	5	p ^Z _T model	1.8 Now constrains a
Parton Distributions	10 CTEQ6.6 NLC	p_T^W/p_T^Z model	1.3 1.3 1.3
QED radiation	4	Parton distributions	3.9 NNPDF3.1 NNLO, mor
W boson statistics	12	QED radiation	2.7
Total	19	W boson statistics	6.4 More statistics
ntralvalue		Total	9.4

Central value

Detailed treatment of parton distribution functions

Resolved beam-constraining bias in CDF reconstruction +10 MeV

New PDF and beam-constraining in upsilon events caused the shifts of central value.

New CDF results (8.8 fb^{-1}	Im -1 ₎ ar	nproved COT align nd drift model
urce Unce	rtainty	(MeV)
oton energy scale	3.0	Highor order OF
oton energy resolution	1.2	Tignel oldel QL
coil energy scale	1.2	Docoil modol
coil energy resolution	1.8	Recon model
oton efficiency	0.4	
oton removal	1.2	Close
ckgrounds	3.3	Close

S	$+3.5 { m MeV}$





dded e inputs

Overview of Standard Model measurements in ATLAS

Standard Model Production Cross Section Measurements

Status: February 2022

Model	E _{CM} [TeV]	∫£ dt[fb ⁻¹] Measurement	Theory	Reference
рр	8	50×10 ⁻⁸	$\sigma = 96.07 \pm 0.18 \pm 0.91 \text{ mb}$	$\sigma=$ 99.55 ± 2.14 mb (COMPETE HPR1R2)	PLB 761 (2016) 158
рр	7	8×10 ⁻⁸	$\sigma =$ 95.35 \pm 0.38 \pm 1.3 mb	$\sigma =$ 97.26 \pm 2.12 mb (COMPETE HPR1R2)	Nucl. Phys. B, 486-548 (2014)
W	13	0.081	$\sigma = 190.1 \pm 0.2 \pm 6.4$ nb	$\sigma = 184.9 + 6 - 6.1$ nb (DYNNLO + CT14NNLO)	PLB 759 (2016) 601
W	8	20.2	$\sigma = 112.69 \pm 3.1 \; \mathrm{nb}$	$\sigma =$ 110.919889503 \pm 3.7 nb (DYNNLO + CT14NNLO)	EPJC 79 (2019) 760
W	7	4.6	$\sigma = 98.71 \pm 0.028 \pm 2.191 \ { m nb}$	$\sigma =$ 95.9 \pm 2.9 nb (DYNNLO + CT14NNLO)	EPJC 77 (2017) 367
Z	13	3.2	$\sigma = 58.43 \pm 0.03 \pm 1.66$ nb	$\sigma = 55.96 + 1.5 - 1.7$ nb (DYNNLO+CT14 NNLO)	JHEP 02 (2017) 117
Z	8	20.2	$\sigma =$ 34.24 ± 0.03 ± 0.92 nb	$\sigma=$ 32.94 $+$ 0.8 $-$ 0.92 nb (DYNNLO+CT14 NNLO)	JHEP 02 (2017) 117
Z	7	4.6	$\sigma = 29.53 \pm 0.03 \pm 0.77$ nb	$\sigma =$ 28.31 + 0.68 – 0.8 nb (DYNNLO+CT14 NNLO)	JHEP 02 (2017) 117
tī	13	36.1	$\sigma=$ 826.4 \pm 3.6 \pm 19.6 pb	$\sigma=$ 832 $+$ 40 $-$ 45 pb (top++ NNLO+NNLL)	EPJC 80 (2020) 528
tī	8	20.2	$\sigma = 242.9 \pm 1.7 \pm 8.6~\mathrm{pb}$	$\sigma=$ 252.9 $+$ 13.3 $-$ 14.5 pb (top++ NNLO+NNLL)	EPJC 74 (2014) 3109
tī	7	4.6	$\sigma = 182.9 \pm 3.1 \pm 6.4 \ \mathrm{pb}$	$\sigma =$ 177 + 10 – 11 pb (top++ NNLO+NNLL)	EPJC 74 (2014) 3109
t _{t-chan}	13	3.2	$\sigma = 247 \pm 6 \pm 46 \text{ pb}$	$\sigma =$ 217 \pm 10 pb (NLO+NLL)	JHEP 04 (2017) 086
t _{t-chan}	8	20.3	$\sigma = 89.6 \pm 1.7 + 7.2 - 6.4 \ { m pb}$	$\sigma=$ 87.8 $+$ 3.4 $-$ 1.9 pb (NLO+NLL)	EPJC 77 (2017) 531
t _{t-chan}	7	4.6	$\sigma = 68 \pm 2 \pm 8 \text{ pb}$	$\sigma=$ 64.6 + 2.7 – 2 pb (NLO+NLL)	PRD 90, 112006 (2014)
Wt	13	3.2	$\sigma=$ 94 \pm 10 $+$ 28 $-$ 23 pb	$\sigma = 71.7 \pm 3.9 \text{ pb} (\text{NLO+NNLL})$	JHEP 01 (2018) 63
Wt	8	20.3	$\sigma = 23 \pm 1.3 + 3.4 - 3.7 \text{ pb}$	$\sigma = 22.4 \pm 1.5$ pb (NLO+NLL)	JHEP 01, 064 (2016)
Wt	7	2.0	$\sigma = 16.8 \pm 2.9 \pm 3.9 \ { m pb}$	$\sigma = 15.7 \pm 1.1$ pb (NLO+NLL)	PLB 716, 142-159 (2012)
Н	13	139	$\sigma = 55.5 \pm 3.2 + 2.4 - 2.2 \text{ pb}$	$\sigma = 55.6 \pm 2.5$ pb (LHC-HXSWG YR4)	ATLAS-CONF-2022-002
н	8	20.3	$\sigma = 27.7 \pm 3 + 2.3 - 1.9 \text{ pb}$	$\sigma = 24.5 + 1.3 - 1.8$ pb (LHC-HXSWG YR4)	EPJC 76 (2016) 6
н	7	4.5	$\sigma = 22.1 + 6.7 - 5.3 + 3.3 - 2.7 \text{ pb}$	$\sigma = 19.2 + 1 - 1.4$ pb (LHC-HXSWG YR4)	EPJC 76 (2016) 6
H VBF, $ y_{H} < 2.5$	13	139	$\sigma = 4 \pm 0.3 + 0.3 - 0.4 \ { m pb}$	$\sigma = 3.51 \pm 0.07$ pb (LHC-HXSWG)	ATLAS-CONF-2021-053
H VBF	8	20.3	$\sigma = 2.43 + 0.5 - 0.49 + 0.33 - 0.26 \text{ pb}$	$\sigma = 1.6 \pm 0.04$ pb (LHC-HXSWG YR4)	EPJC 76 (2016) 6
VH	8	20.3	$\sigma = 1.03 + 0.37 - 0.36 + 0.26 - 0.21 \text{ pb}$	$\sigma = 1.12 \pm 0.03$ pb (NNLO(QCD)+NLO(EW))	JHEP 12 (2017) 024
WH, y _H < 2.5	13	139	$\sigma = 1.56 + 0.2 - 0.21 + 0.16 - 0.18 \ { m pb}$	$\sigma = 1.203 \pm 0.024$ pb (Powheg Box NLO(QCD))	ATLAS-CONF-2021-053
ZH, y _H < 2.5	13	139	$\sigma = 0.7 \pm 0.13 + 0.1 - 0.12 \ { m pb}$	$\sigma = 0.795 \pm 0.03$ pb (Powheg Box NLO(QCD))	ATLAS-CONF-2021-053
tĪH	13	139	$\sigma = 560 \pm 80 + 70 - 80$ fb	$\sigma = 580 \pm 50$ fb (LHCHXSWG NLO QCD + NLO EW)	ATLAS-CONF-2021-053
tīH	8	20.3	$\sigma = 220 \pm 100 \pm 70$ fb	$\sigma = 133 + 8 - 13$ fb (LHCHXSWG NLO QCD + NLO EW)	PLB 784 (2018) 173
WW	13	36.1	$\sigma = 130.04 \pm 1.7 \pm 10.6 \ { m pb}$	$\sigma = 128.4 + 3.2 - 2.9$ pb (NNLO)	EPJC 79 (2019) 884
WW	8	20.3	$\sigma=$ 68.2 ± 1.2 ± 4.6 pb	$\sigma=65+1.2-1.1$ pb (NNLO)	PLB 763, 114 (2016)
WW	7	4.6	$\sigma = 51.9 \pm 2 \pm 4.4 \text{ pb}$	$\sigma=$ 49.04 $+$ 1.03 $-$ 0.88 pb (NNLO)	Phys. Rev. D 87 (2013) 112001, arXiv:1408.5243
WZ	13	36.1	$\sigma = 51 \pm 0.8 \pm 2.3 \text{ pb}$	$\sigma = 49.1 + 1.1 - 1 \text{ pb} (\text{MATRIX (NNLO)})$	EPJC 79 (2019) 535
WZ	8	20.3	$\sigma = 24.3 \pm 0.6 \pm 0.9$ pb	$\sigma = 23.92 \pm 0.4$ pb (MATRIX (NNLO))	PRD 93, 092004 (2016)
WZ	7	4.6	$\sigma = 19 + 1.4 - 1.3 \pm 1 \text{ pb}$	$\sigma = 19.34 + 0.3 - 0.4$ pb (MATRIX (NNLO))	EPJC 72 (2012) 2173
ZZ	13	36.1	$\sigma = 17.3 \pm 0.6 \pm 0.8 \ \mathrm{pb}$	$\sigma = 16.9 + 0.6 - 0.5$ pb (Matrix (NNLO) & Sherpa (NLO))	PRD 97 (2018) 032005
ZZ	8	20.3	$\sigma = 7.3 \pm 0.4 + 0.4 - 0.3 \ { m pb}$	$\sigma = 8.284 + 0.249 - 0.191$ pb (NNLO)	JHEP 01, 099 (2017)
ZZ	7	4.6	$\sigma = 6.7 \pm 0.7 + 0.5 - 0.4 \ { m pb}$	$\sigma = 6.735 + 0.195 - 0.155$ pb (NNLO)	JHEP 03, 128 (2013), PLB 735 (2014) 311
t _{s-chan}	8	20.3	$\sigma = 4.8 \pm 0.8 \pm 1.6 - 1.3 { m pb}$	$\sigma = 5.61 \pm 0.22$ pb (NLO+NNL)	LB 756, 228-246 (2016)
tĪW	13	36.1	$\sigma=$ 870 ± 130 ± 140 fb	$\sigma = 600 \pm 72$ fb (Madgraph5 + aMCNLO)	PRD 99, 072009 (2019)
tīW	8	20.3	$\sigma=$ 369 $+$ 86 $-$ 79 \pm 44 fb	$\sigma = 232 \pm 32$ fb (MCFM)	JHEP 11, 172 (2015)
tīZ	13	139	$\sigma = 990 \pm 50 \pm 80$ fb	$\sigma = 840 \pm 90$ fb (Madgraph5 + aMCNLO)	Eur. Phys. J. C 81 (2021) 737
tīZ	8	20.3	$\sigma=176+52-48\pm24$ fb	$\sigma = 215 \pm 30$ fb (HELAC-NLO)	JHEP 11, 172 (2015)
WWW	13	139	$\sigma = 0.82 \pm 0.01 \pm 0.08$ pb	$\sigma = 0.511 \pm 0.018$ pb (NLO QCD)	arXiv:2201.13045
WWZ	13	79.8	$\sigma = 0.55 \pm 0.14 + 0.15 - 0.13$ pb	$\sigma = 0.358 \pm 0.036$ pb (Sherpa 2.2.2)	PLB 798 (2019) 134913
tītī	13	139	$\sigma = 24 \pm 4 \pm 5$ fb	$\sigma = 12 \pm 2.4$ fb (NLO QCD + EW)	JHEP 11 (2021) 118

2022-009 b.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB https://atlas.we ATLAS Preliminary

 $\sqrt{s} = 5, 7, 8, 13 \text{ TeV}$



Overview of CMS cross section results

ern.ch/twiki/bin/view/CMSPublic/PhysicsResultsCombined https://twiki.o

	14/	7 7-14	UED 10 (2011) 122
eak	W W	7 TeV 8 TeV	JHEP 10 (2011) 132 PRL 112 (2014) 191802
rowe	W	13 TeV	SMP-15-004
lect	∠ Z	7 iev 8 TeV	JHEP 10 (2011) 132 PRL 112 (2014) 191802
ш	Z	13 TeV	SMP-15-011
	Wγ	7 TeV	PRD 89 (2014) 092005
	Wγ Zv	13 TeV 7 TeV	PRL 126 252002 (2021) PRD 89 (2014) 092005
	Zγ	8 TeV	JHEP 04 (2015) 164
c	WW	7 TeV	EPJC 73 (2013) 2610
oso	WW	o iev 13 TeV	EPJC 76 (2016) 401 PRD 102 092001 (2020)
di-E	WZ	7 TeV	EPJC 77 (2017) 236
	w∠ WZ	8 IeV 13 TeV	ЕРЈС 77 (2017) 236 ЈНЕР 07 (2022) 032
	ZZ	7 TeV	JHEP 01 (2013) 063
	ZZ ZZ	ölev 13 TeV	РLВ 740 (2015) 250 EPJC 81 (2021) 200
	VVV	13 TeV	PRL 125 151802 (2020)
	www	13 TeV	PRL 125 151802 (2020)
	WWZ WZZ	13 TeV 13 TeV	PRL 125 151802 (2020) PRL 125 151802 (2020)
son	ZZZ	13 TeV	PRL 125 151802 (2020)
-Bo	WVy WWy	8 TeV	PRD 90 032008 (2014)
Ę	Wγγ	8 TeV	JHEP 10 (2017) 072
	Wγγ Ζνογ	13 TeV	JHEP 10 (2021) 174
	∠γγ Ζγγ	8 TeV 13 TeV	JHEP 10 (2017) 072 JHEP 10 (2021) 174
	VBF W	8 TeV	JHEP 11 (2016) 147
	VBF W	13 TeV	EPJC 80 (2020) 43
	VBF Z VBF Z	7 TeV 8 TeV	JHEP 10 (2013) 101 EPJC 75 (2015) 66
	VBF Z	13 TeV	EPJC 78 (2018) 589
BS	EW WV ex. vv → \//\/	13 TeV	PLB 834 (2022) 137438
> pr	EW qqWγ	8 TeV	JHEP 06 (2017) 106
Far	EW qqWγ	13 TeV	Accepted by PRD
٨B	⊑w os ww EW ss WW	8 TeV	Submitted to PLB PRL 114 051801 (2015)
	EW ss WW	13 TeV	PRL 120 081801 (2018)
	ĿW qqΖγ EW qqΖν	8 TeV 13 TeV	PLB 770 (2017) 380 PRD 104 072001 (2021)
	EW qqWZ	13 TeV	PLB 809 (2020) 135710
	EW qqZZ	13 TeV	PLB 812 (2020) 135992
	tt tt	7 TeV 8 TeV	JHEP 08 (2016) 029 JHEP 08 (2016) 029
	tt	13 TeV	PRD 104 (2021) 092013
	tt t _{t - ch}	13.6 TeV 7 TeV	Submitted to JHEP JHEP 12 (2012) 035
	t_{t-ch}	8 TeV	JHEP 06 (2014) 090
	t _{t – ch} tW	13 TeV 7 TeV	PLB 72 (2017) 752 PRL 110 (2013) 022003
	tW	8 TeV	PRL 112 (2014) 231802
	tW	13 TeV	JHEP 10 (2018) 117
do	s-ch ttγ	8 TeV	JHEP 10 (2017) 006
	ttγ t7~	13 TeV	JHEP 05 (2022) 091
	τ∠q tZq	8 IeV 13 TeV	JHEP 07 (2017) 003 JHEP 02 (2022) 107
	ttZ	7 TeV	PRL 110 (2013) 172002
	ttZ ttZ	8 TeV 13 TeV	JHEP 01 (2016) 096 JHEP 03 (2020) 056
	tγ	13 TeV	PRL 121 221802 (2018)
	ttW	8 TeV	JHEP 01 (2016) 096
	tWZ	13 TeV	TOP-22-008
	tttt	13 TeV	Submitted to PLB
	ggH ggH	7 TeV	EPJC 75 (2015) 212 EPIC 75 (2015) 212
	ggH	13 TeV	Nature 607 60-68 (2022)
	VBF qqH	7 TeV	EPJC 75 (2015) 212
S	VBF qqH VBF qqH	8 TeV 13 TeV	EPJC 75 (2015) 212 Nature 607 60-68 (2022)
ligg:	VH	8 TeV	EPJC 75 (2015) 212
T	WH ZH	13 TeV 13 TeV	Nature 607 60-68 (2022) Nature 607 60-68 (2022)
		10 10 1	
	ttH	8 TeV	EPJC 75 (2015) 212
	ttH ttH	8 TeV 13 TeV	EPJC 75 (2015) 212 Nature 607 60-68 (2022)
	ttH ttH tH HH	8 TeV 13 TeV 13 TeV 13 TeV	EPJC 75 (2015) 212 Nature 607 60-68 (2022) Nature 607 60-68 (2022) Nature 607 60-68 (2022)
	ttH ttH tH HH	8 TeV 13 TeV 13 TeV 13 TeV	EPJC 75 (2015) 212 Nature 607 60-68 (2022) Nature 607 60-68 (2022) Nature 607 60-68 (2022)



Measured cross sections and exclusion limits at 95% C.L. See here for all cross section summary plots

Inner colored bars statistical uncertainty, outer narrow bars statistical+systematic uncertai Light colored bars: 7 TeV, Medium: 8 TeV, Dark: 13 TeV, Darkest: 13.6 TeV, Black bars: theory prediction

18 pb⁻¹ - 138 fb⁻¹ (7,8,13,13.6 TeV)

	$\sigma(W) = 9.5e+07 \text{ fb}$ $\sigma(W) = 1.1e+08 \text{ fb}$ $\sigma(W) = 1.8e+08 \text{ fb}$ $\sigma(Z) = 2.9e+07 \text{ fb}$ $\sigma(Z) = 3.4e+07 \text{ fb}$ $\sigma(Z) = 5.6e+07 \text{ fb}$	36 pb ⁻¹ 18 pb ⁻¹ 43 pb ⁻¹ 36 pb ⁻¹ 18 pb ⁻¹ 2 fb ⁻¹
$\sigma(W\gamma) = 3.4e+05 \text{ fb}$ $\sigma(W\gamma) = 1.4e+05 \text{ fb}$ $\sigma(Z\gamma) = 1.6e+05 \text{ fb}$ $\sigma(Z\gamma) = 1.9e+05 \text{ fb}$ $\sigma(WW) = 5.2e+04 \text{ fb}$ $\sigma(WW) = 6e+04 \text{ fb}$ $\sigma(WW) = 6e+04 \text{ fb}$ $\sigma(WZ) = 2e+04 \text{ fb}$ $\sigma(WZ) = 2.4e+04 \text{ fb}$ $\sigma(WZ) = 2.4e+04 \text{ fb}$ $\sigma(WZ) = 5.1e+04 \text{ fb}$ $\sigma(ZZ) = 6.2e+03 \text{ fb}$ $\sigma(ZZ) = 7.7e+03 \text{ fb}$		5 fb ⁻¹ 137 fb ⁻ 5 fb ⁻¹ 20 fb ⁻¹ 5 fb ⁻¹ 19 fb ⁻¹ 36 fb ⁻¹ 20 fb ⁻¹ 137 fb ⁻¹ 5 fb ⁻¹ 20 fb ⁻¹ 137 fb ⁻¹ 20 fb ⁻¹ 137 fb ⁻¹
1e+03 fb e+02 fb		137 fb ⁻ 137 fb ⁻ 137 fb ⁻ 137 fb ⁻ 137 fb ⁻¹ 138 fb ⁻¹ 19 fb ⁻¹ 19 fb ⁻¹ 19 fb ⁻¹ 19 fb ⁻¹ 19 fb ⁻¹
fb Φ(VBF W) = 6.2e+03 fb fb EW WV) = 1.9e+03 fb		19 fb ⁻¹ 36 fb ⁻¹ 5 fb ⁻¹ 20 fb ⁻¹ 36 fb ⁻¹ 138 fb ⁻¹ 20 fb ⁻¹ 20 fb ⁻¹ 138 fb ⁻¹ 138 fb ⁻¹ 137 fb ⁻¹ 137 fb ⁻¹ 137 fb ⁻¹ 137 fb ⁻¹
$\sigma(tt) = 1.7e+05 \text{ fb}$ $\sigma(tt) = 2.4e+05 \text{ fb}$ $\sigma(tt) = 7.9e+05 \text{ fb}$ $\sigma(tt) = 8.8e+05 \text{ fb}$ $\sigma(tt) = 8.8e+04 \text{ fb}$ $\sigma(tt) = 1.6e+04 \text{ fb}$ $\sigma(tt) = 2.3e+04 \text{ fb}$ $\sigma(tw) = 2.3e+04 \text{ fb}$ $\sigma(tw) = 6.3e+04 \text{ fb}$ $\sigma(ty) = 3.5e+03 \text{ fb}$ $t+02 \text{ fb}$		5 fb ⁻¹ 20 fb ⁻¹ 137 fb ⁻¹ 2 fb ⁻¹ 5 fb ⁻¹ 2 fb ⁻¹ 5 fb ⁻¹ 20 fb ⁻¹ 20 fb ⁻¹ 20 fb ⁻¹ 20 fb ⁻¹ 138 fb ⁻¹ 20 fb ⁻¹ 138 fb ⁻¹ 20 fb ⁻¹ 36 fb ⁻¹ 138 fb ⁻¹ 20 fb ⁻¹ 138 fb ⁻¹ 20 fb ⁻¹ 36 fb ⁻¹ 20 fb ⁻¹ 138 fb ⁻¹ 36 fb ⁻¹ 20 fb ⁻¹ 38 fb ⁻¹ 38 fb ⁻¹ 38 fb ⁻¹ 38 fb ⁻¹
$\sigma(ggH) = 1.6e+04 \text{ fb}$ $\sigma(ggH) = 1.5e+04 \text{ fb}$ $\sigma(ggH) = 2.2e+03 \text{ fb}$ $\sigma(VBF qqH) = 2.2e+03 \text{ fb}$ $\sigma(VBF qqH) = 3e+03 \text{ fb}$ 1.1e+03 fb MH) = 2e+03 fb .1e+03 fb MH = 2e+03 fb .1e+03 fb		5 fb ⁻¹ 20 fb ⁻¹ 139 fb ⁻¹ 5 fb ⁻¹ 20 fb ⁻¹ 138 fb ⁻¹



Overview of CMS X+jets cross section results

ern.ch/twiki/bin/view/CMSPublic/PhysicsResultsCombined https://twiki.o





Cross checks of W mass measurement

Comparison of the PLH fit results of the individual measurement categories as well as the combination of all between the PDF set CT10 and CT18



 m_{W} [MeV]



42

 m_{W} [MeV]

Cross checks of W mass measurement

Results are determined using a PLH approach and in comparison with a x2-minimization approach using statistical uncertainties only



Extra Slides

