Electroweak/diboson constraints on EFT

- Overview over current (ATLAS) measurements and constraints
- General approach in ATLAS
- Diboson measurements
- VBS measurements
- VBF measurements

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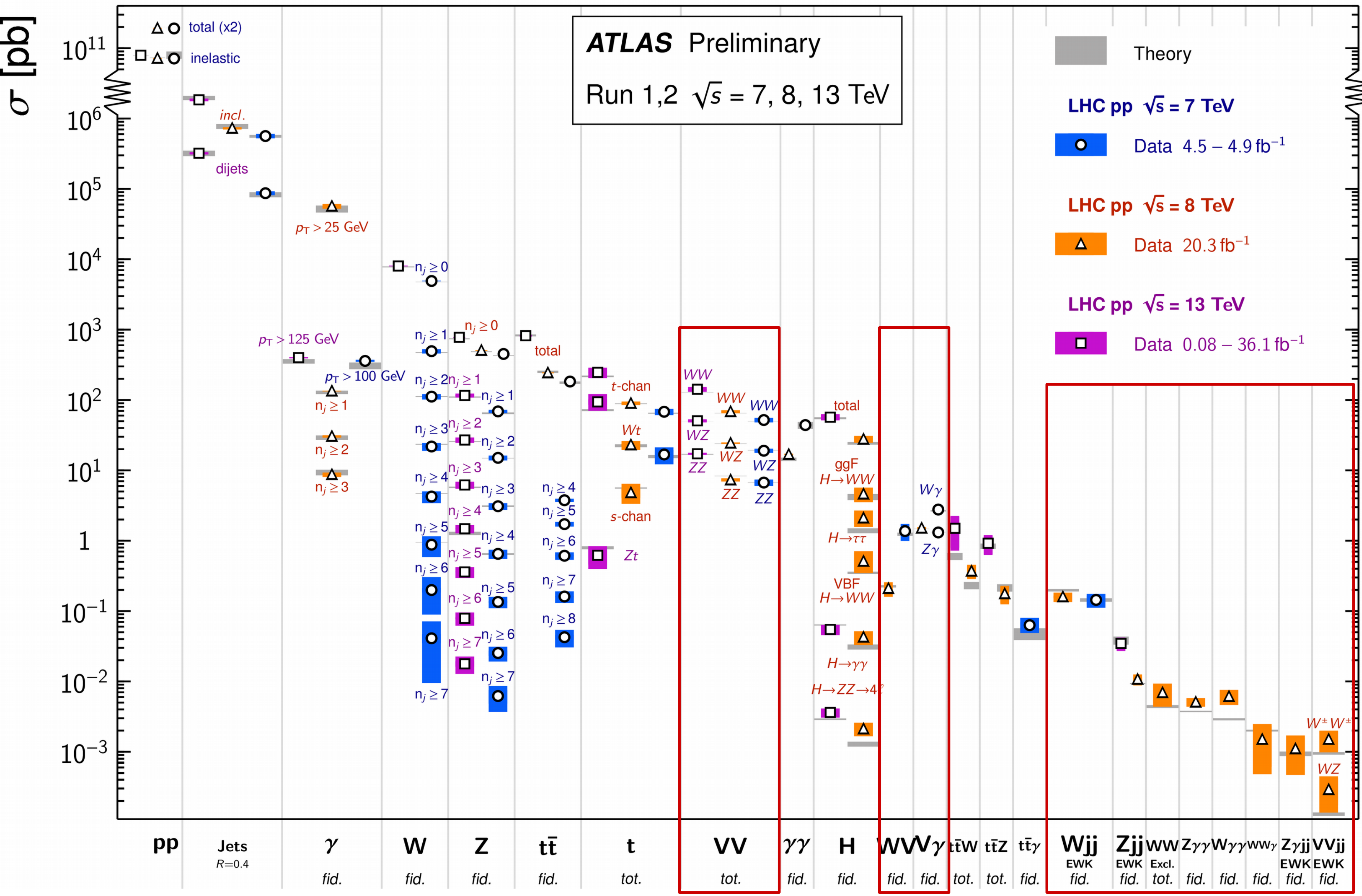
Standard Model Production Cross Section Measurements

Status: July 2017



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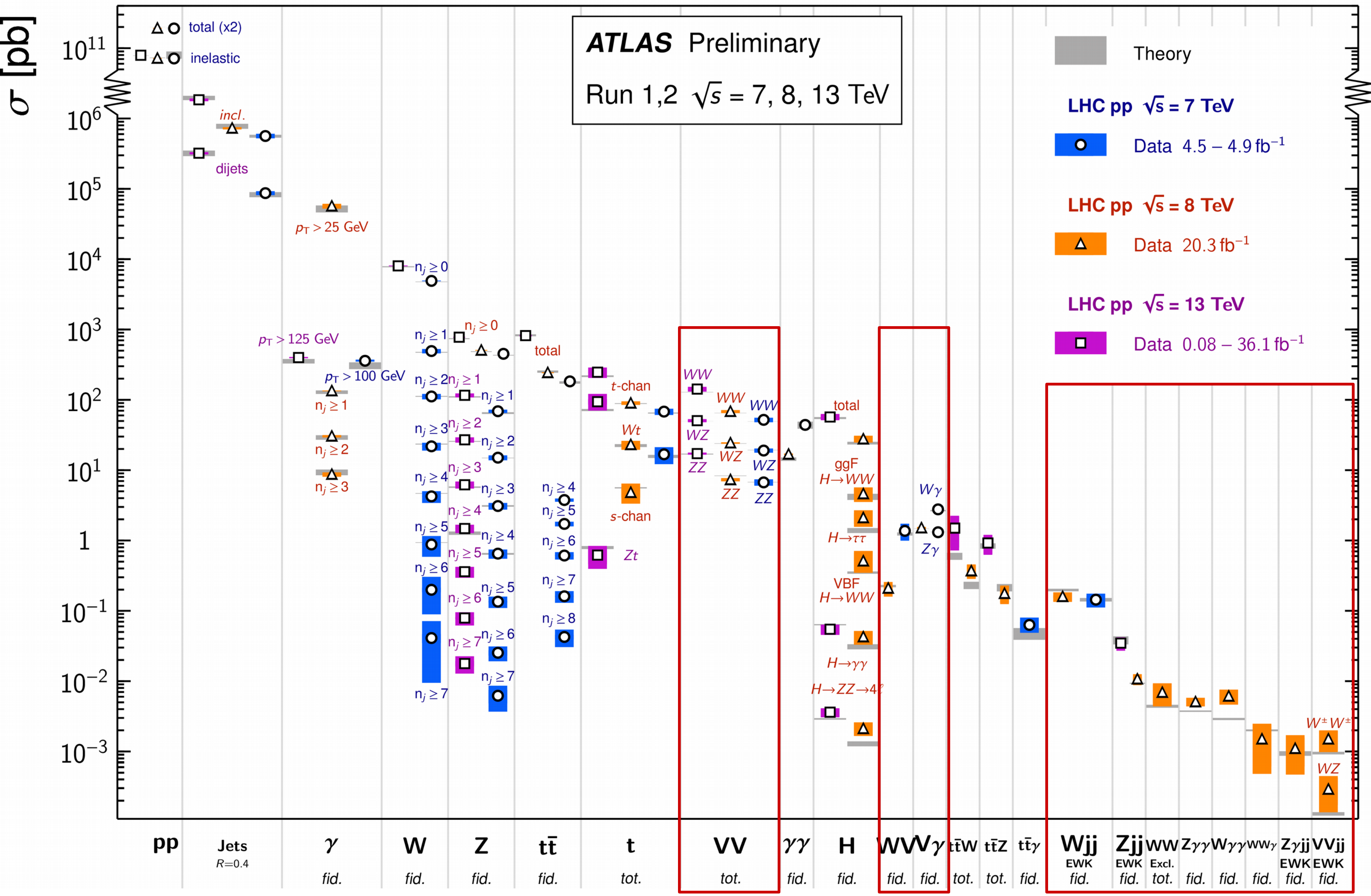


In detail: Recent, relevant measurements

Paper with unfolded differential cross sections					
ZZ cross section at 8TeV (Note: 13 TeV paper with unfolded distributions in preparation (timescale until HEPData ~2-3 month))	JHEP	8	2012	20.3 fb-1	HepData
WZ cross section at 13 TeV (Note: only Njets distribution unfolded)	PLB	13	2015	3.2 fb-1	HepData
WW cross section at 8 TeV and limits on aTGCs	JHEP	8	2012	20.3 fb-1	HepData
WZ cross section at 8 TeV and limits on aTGCs and aQGCs	PRD	8	2012	20.3 fb-1	HepData
Differential 4l cross section	PLB	8	2012	20.3 fb-1	HepData
Zγ and Zγγ cross sections at 8 TeV and aGCs limits	PRD	8	2012	20.3 fb-1	HepData
Electroweak production of a Z boson	JHEP	8	2012	20.3 fb-1	HepData Rivet
Electroweak W production	subm. to EPJC	7,8	2011/12	4.7 +20.2 fb-1	
Wgamma and Zgamma Production	PRD	7	2011	4.6 fb-1	HepData Rivet
Z → 4l production cross section (lineshape)	PRL	7,8	2011/12	24.8 fb-1	
Paper with cross section (limits) in fiducial region					
VBF Z at 13TeV	3.2 fb-1				
WVgamma Production	subm. to EPJC	8	2012	20.3 fb-1	
WV semileptonic	subm. to EPJC	8	2012	20.3 fb-1	
VBS Z+gamma	subm. to JHEP	8	2012	20.3 fb-1	
WW 13TeV	subm. to PLB	13	2015	3.2 fb-1	
ssWW 8TeV aQGC	subm. to PRD	8	2012	20.3 fb-1	
Search for triboson WWW production	EPJC	8	2012	20.3 fb-1	HepData
WW + 1jet production	PLB	8	2012	20.2 fb-1	
Exclusive γγ→WW and exclusive H→WW	PRD	8	2012	20.2 fb-1	
Semileptonic WW+WZ cross section and limits on aTGC	JHEP	7	2011	4.6 fb-1	HepData

General approach currently employed (in ATLAS)

- **Parametrisation of BSM couplings in multiboson physics**

> Mostly based on LEP parametrisations:
> charged/neutral couplings (Lagrangian and Vertex approach)

- In newer publications: Usage of genuine effective field theory (dim6/dim8), however using linear relations between LEP and EFT:
  - **Charged TGCs:** arxiv.org/abs/1205.4231
  - **Neutral TGCs:** arxiv.org/abs/1308.6323
  - **VBS / Dim-8 operators:** recommendation to use Eboli model arxiv.org/abs/1604.03555 with additional fS2 parameter as base line
  - **No larger / more complete models explored yet**
- **General strategy: *separate limit setting and unfolded cross sections***

This is what is done now → need further investigations and developments

Detector level vs. unfolded cross sections

Limit setting usually separated from measurement of differential cross section

- Often two different situations:
  - aGC limits from a single bin **(cut-and-count)**
  - **Sometimes 95% CL limits on the fiducial cross-section in this bin are published (helpful?)**

  - **Fit to a distribution**: Usually completely different binning optimisations (compared to fiducial measurement)

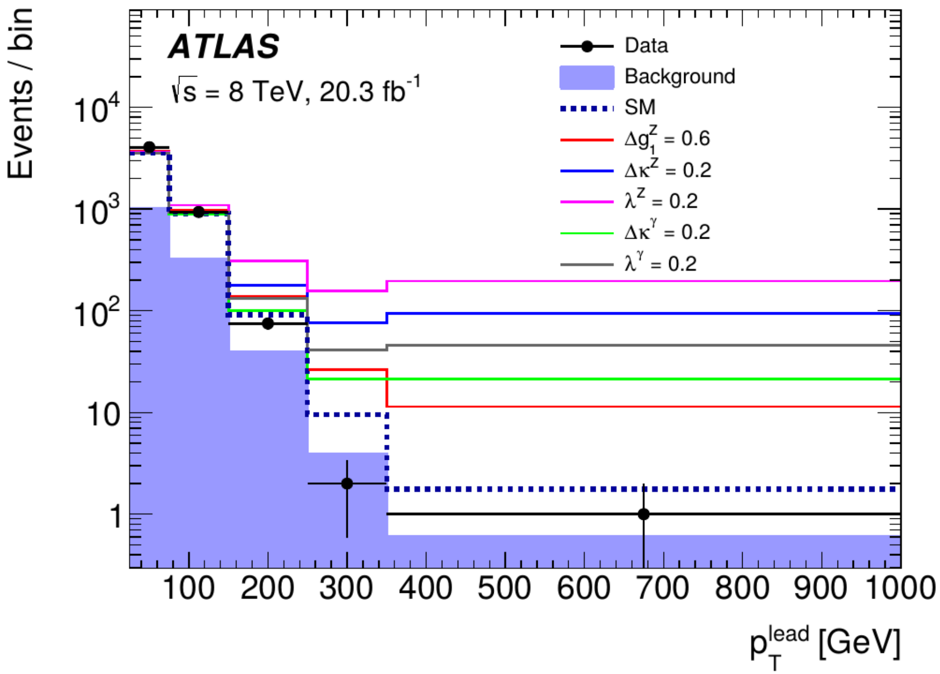
  - Detailed systematics published for differential cross sections only, no poissonian statistics anymore

  - Detector level limits
    → no problems with different detector response to BSM signals
    (e.g. lower Etmiss on average → lower fiducial acceptance)
  -
  - However: Fiducial differential distribution give important information on SM prediction….

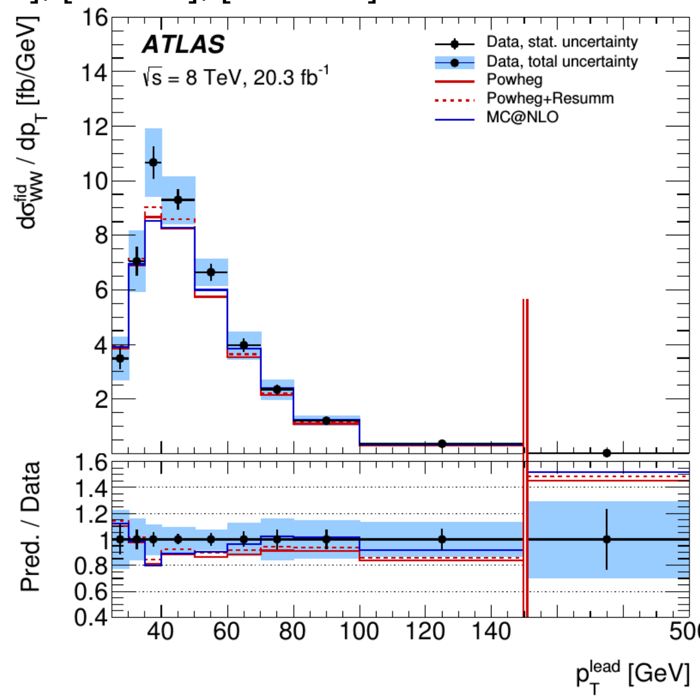
Detector level vs. unfolded cross sections

- Limit setting usually separated from measurement of differential cross section

[25-75], [75-150], [150-250], [250-350], [350-1000]



[25-30], [30-35], [35-40], [40-50], [50-60], [60-70], [70-80], [80-100], [100-150]



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/STDM-2013-07/

Detector level vs. unfolded cross sections

> **Information given mainly on unfolded distributions**

p_T^{lead} [GeV]	25–30	30–35	35–40	40–50	50–60	60–70	70–80	80–100	100–150	150–500
Differential cross sections										
Results [fb/GeV]	3.49	7.05	10.7	9.30	6.65	3.97	2.35	1.20	0.363	0.008 67
Total Unc.	23 %	16 %	12 %	9.4%	7.6%	13 %	16 %	15 %	13 %	30 %
Stat. Unc.	12 %	7.6%	5.7%	4.0%	4.8%	6.1%	8.0%	7.9%	8.6%	24 %
Syst. Unc.	6.7%	6.3%	5.3%	5.2%	5.4%	5.6%	5.5%	6.3%	6.0%	7.9%
Bkg. Unc.	18 %	13 %	9.2%	6.8%	2.4%	9.5%	13 %	11 %	8.4%	17 %

p_T^{lead} [GeV]	25–30	30–35	35–40	40–50	50–60	60–70	70–80	80–100	100–150	150–500
25– 30	1	0.13	0.091	0.14	0.20	0.11	0.094	0.13	0.12	0.092
30– 35	0.13	1	0.060	0.17	0.24	0.12	0.091	0.14	0.15	0.078
35– 40	0.091	0.060	1	0.22	0.32	0.20	0.15	0.19	0.22	0.088
40– 50	0.14	0.17	0.22	1	0.39	0.27	0.22	0.28	0.30	0.15
50– 60	0.20	0.24	0.32	0.39	1	0.33	0.28	0.39	0.43	0.21
60– 70	0.11	0.12	0.20	0.27	0.33	1	0.16	0.25	0.29	0.17
70– 80	0.094	0.091	0.15	0.22	0.28	0.16	1	0.19	0.25	0.14
80–100	0.13	0.14	0.19	0.28	0.39	0.25	0.19	1	0.33	0.21
100–150	0.12	0.15	0.22	0.30	0.43	0.29	0.25	0.33	1	0.21
150–500	0.092	0.078	0.088	0.15	0.21	0.17	0.14	0.21	0.21	1

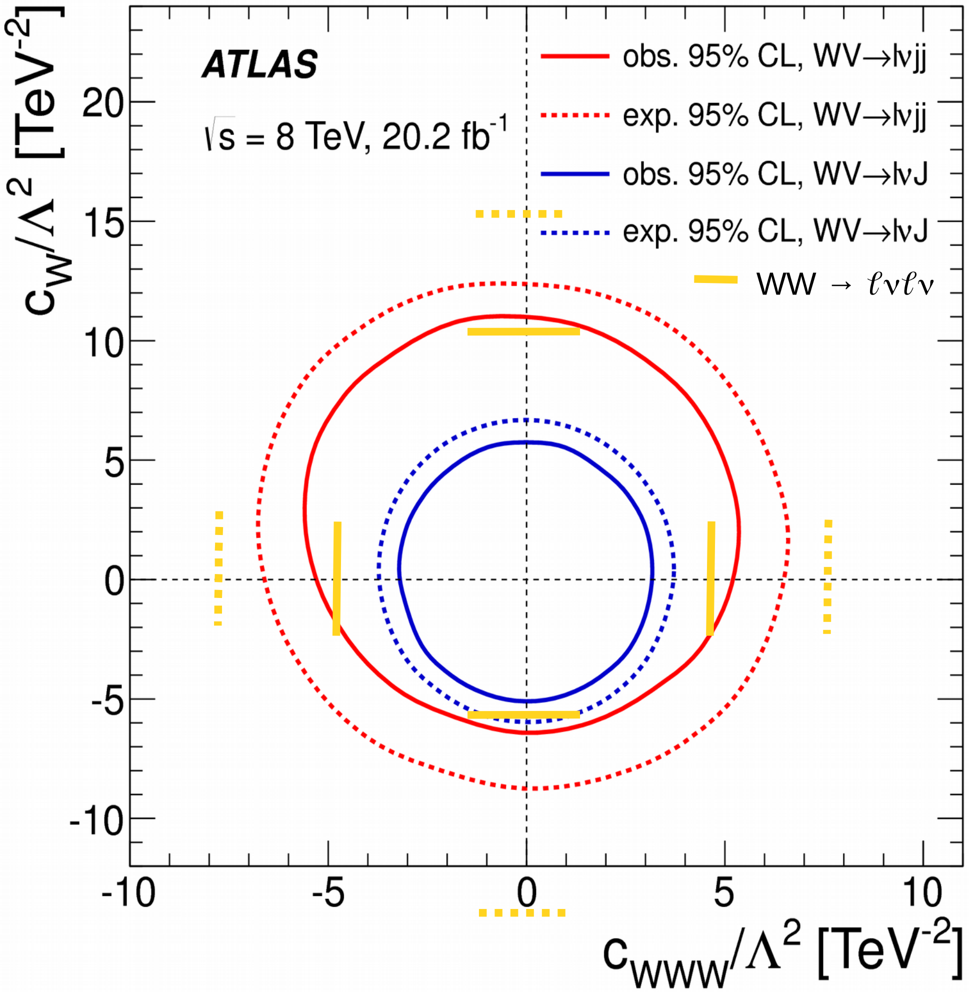
Table 25: Correlation matrix for the total uncertainties for the unnormalised unfolded distribution of the leading lepton p_T, including all sources of systematic and statistical uncertainties.

Cross sections and limits: Leptonic vs. hadronic decays

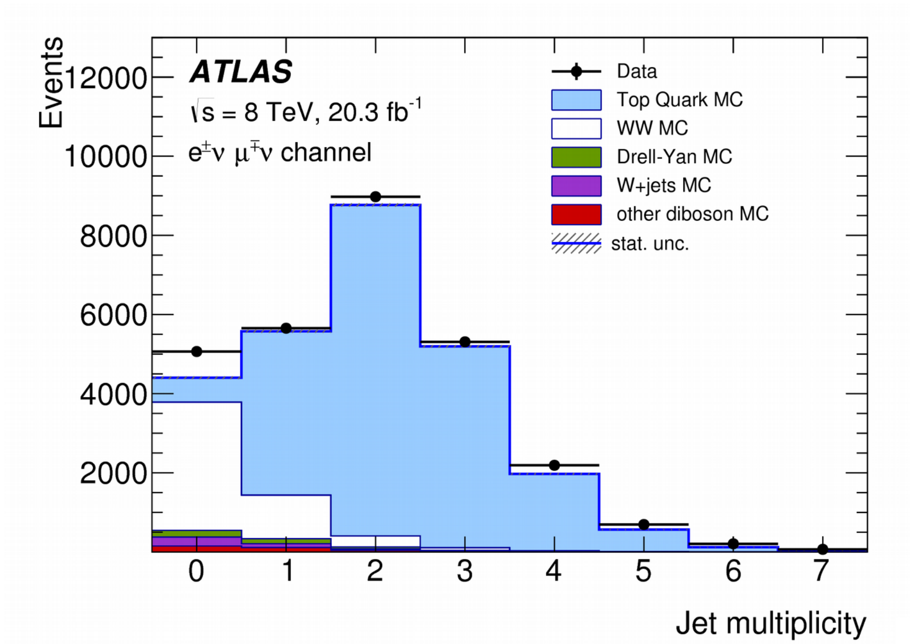
Differential cross section can however reveal flaws in SM predictions used for BSM limits

- Most apparent in leptonic decays:
- → smaller systematics
- → more accurate measurements
  - Observed limits much more stringent than expected
  - → due to mismatch between SM prediction and data
  - **Semi-leptonic decay channels:**
  - **Problems less apparent due to larger systematics**

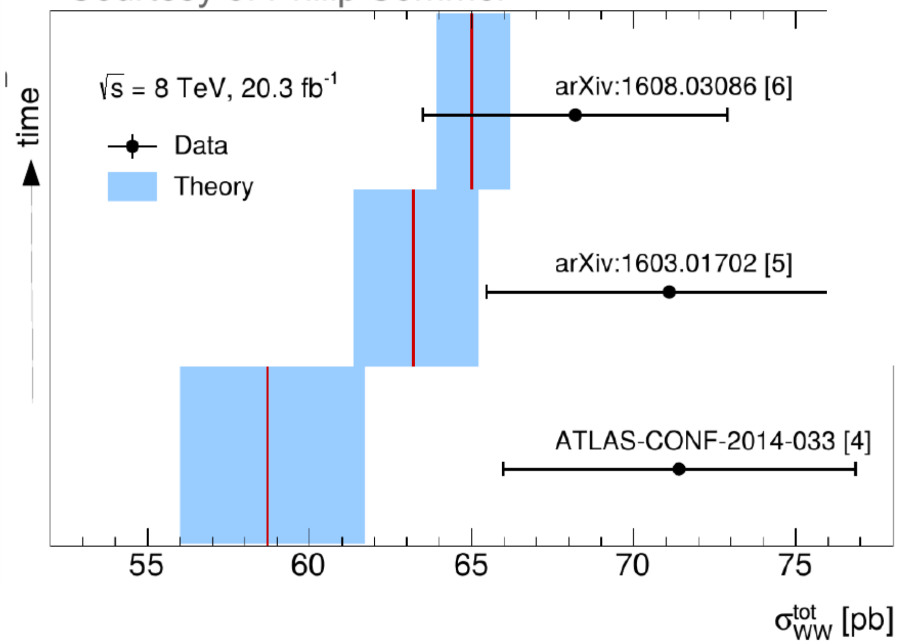
- **Accurate SM predictions needed**



Experimental Limitations (because of backgrounds)



Courtesy of Philip Sommer



WW again as example: beyond 0-jet bin dominated by top production

>

> Do we still model the SM correctly if jet vetoes are applied?

-
- Interplay with EFTs? (e.g. NLO, VV+1 jet signatures?)
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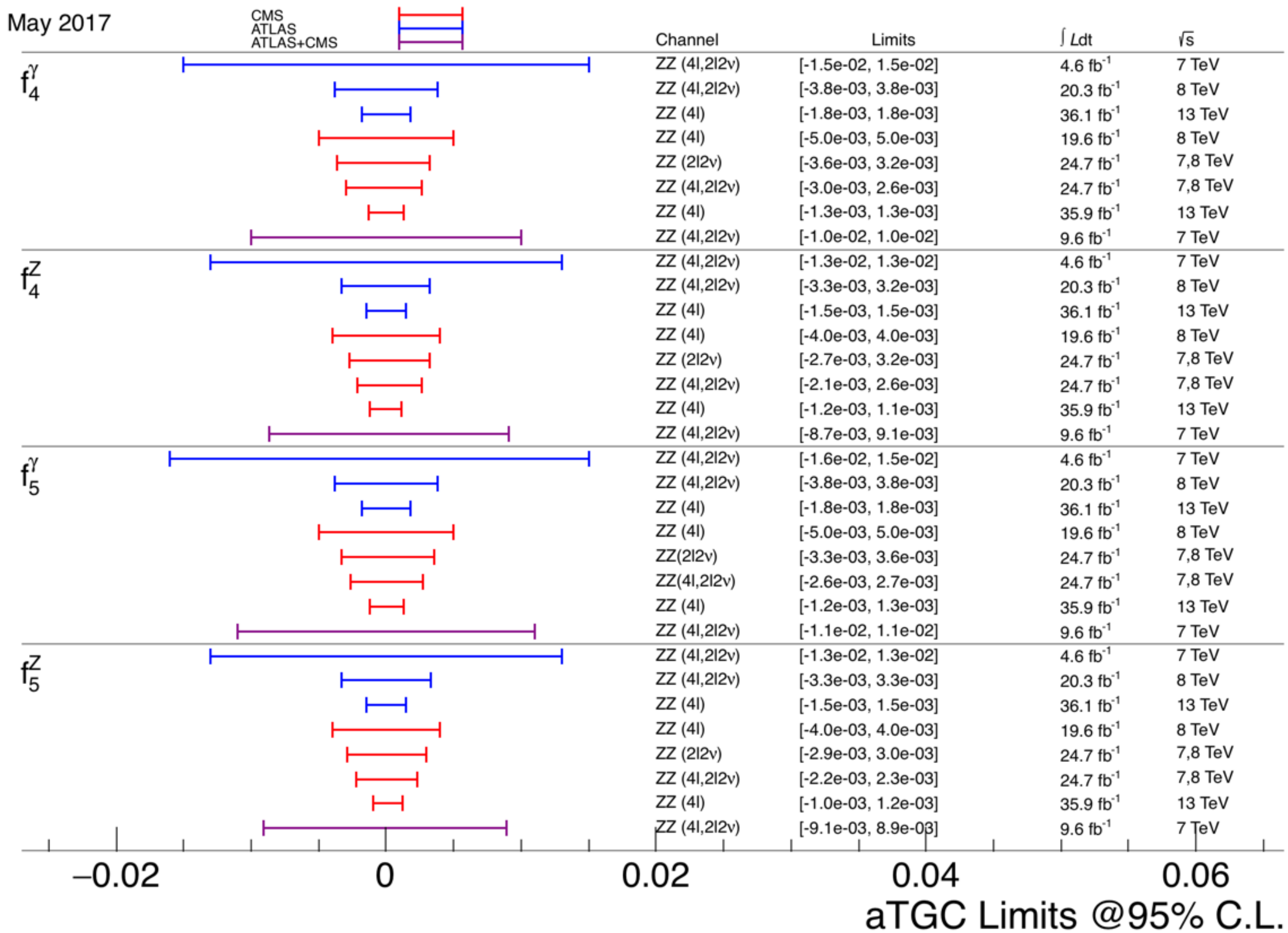
Neutral couplings: A preview for Run-2



- **Higher order effects can induce couplings O(10^{-4})**
- Possible to observe end of Run-2? Are there precise enough predictions?

Current status inside the experiments

Publishing differential cross sections

- Minimal systematics information
  - Little information on correlations (e.g. ZZ and WW mostly uncorrelated for the electron systematics)
  - Efforts within the experiments only starting

What else could be done?

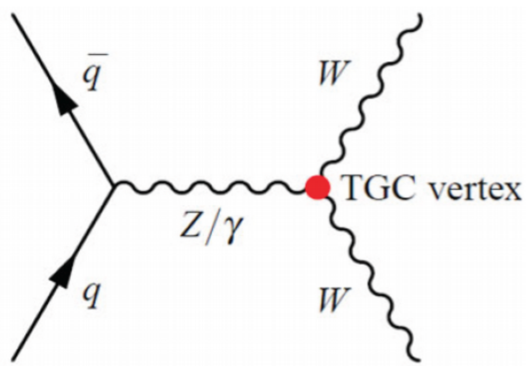
- Possibility to publish detector level quantities?
- (management still rather reserved)
  - Collaboration within LHC EWWG ?

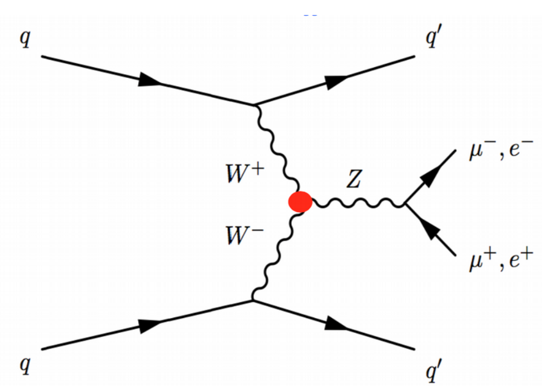
VBF measurements (W and Z)

> Differential cross-sections and cut-and-count aTGC limits published

- VBF Z: JHEP 04 (2014) 031, arXiv:1401.7610
- VBF W: Eur. Phys. J. C 77 (2017) 474, arXiv:1703.04362

- Fiducial cross-sections published in HEPDATA
- Splits of sources of systematics bin-by-bin
-
- aTGC limits from VBF complementary to diboson final states
- Complementary constraints on new phenomena
- VBF: two bosons with space-like momentum transfer vs. three bosons with time-like momentum transfer in di-boson Baur, Zeppenfeld: arXiv:hep-ph/9309227





VBF Z: differential cross-sections and aTGC limits

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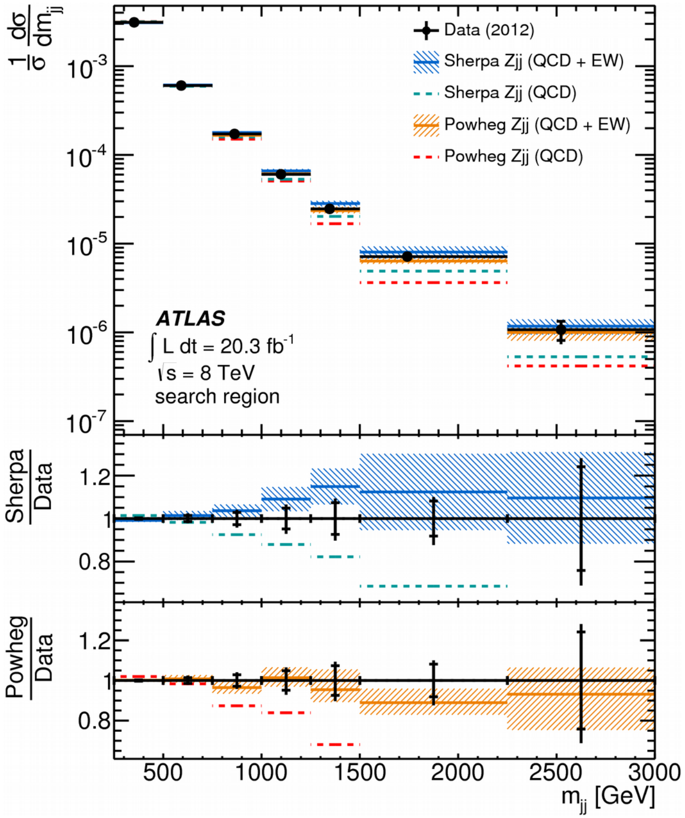

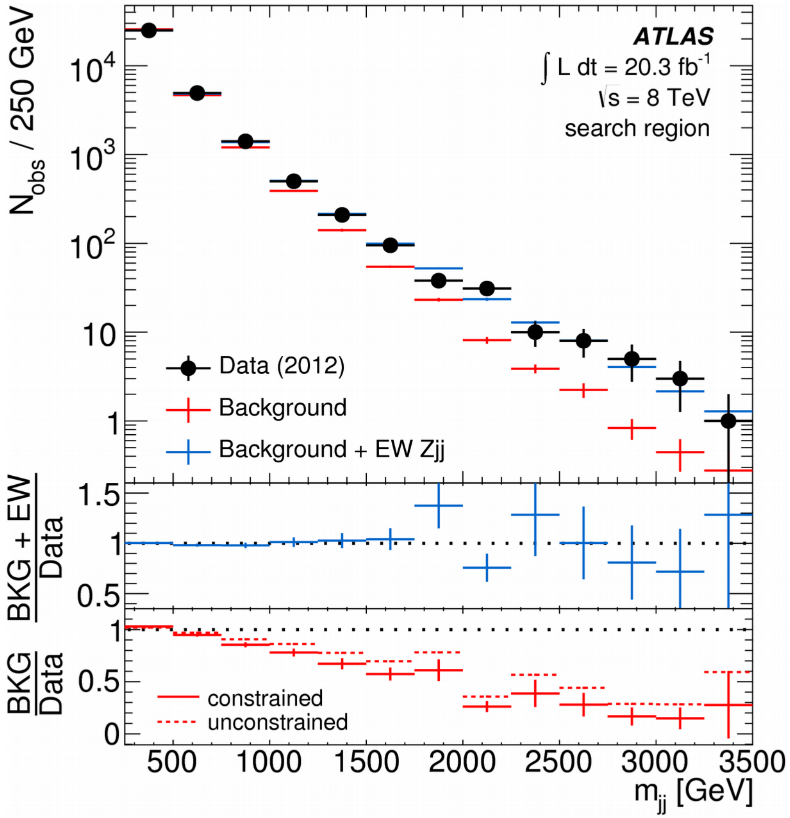

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$$\frac{\mathcal{L}}{g_{WWZ}} = i\left[g_{1,Z}\left(W^{\dagger}_{\mu\nu}W^{\mu}Z^{\nu} - W_{\mu\nu}W^{\dagger\mu}Z^{\nu}\right) + \kappa_Z W^{\dagger}_{\mu}W_{\nu}Z^{\mu\nu} + \frac{\lambda_Z}{m_W^2}W^{\dagger}_{\rho\mu}W^{\mu}_{\nu}Z^{\nu\rho}\right]$$

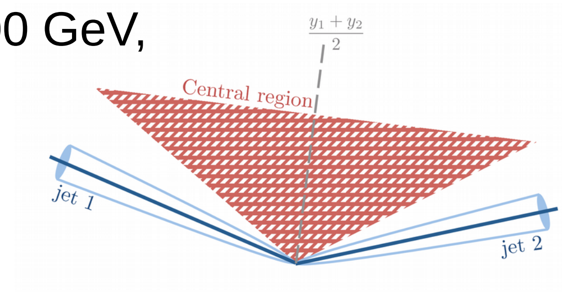
aTGC	$\Lambda = 6$ TeV (obs)	$\Lambda = 6$ TeV (exp)	$\Lambda = \infty$ (obs)	$\Lambda = \infty$ (exp)
$\Delta g_{1,Z}$	$[-0.65, 0.33]$	$[-0.58, 0.27]$	$[-0.50, 0.26]$	$[-0.45, 0.22]$
λ_Z	$[-0.22, 0.19]$	$[-0.19, 0.16]$	$[-0.15, 0.13]$	$[-0.14, 0.11]$

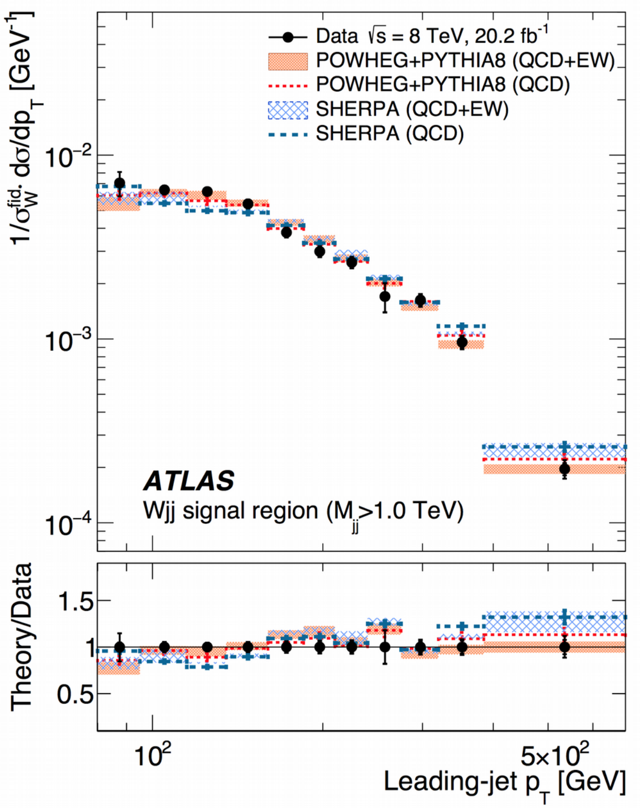
- Unfolded mjj cross-section distribution and other distributions are available for inclusion in EFT fits!

VBF W: differential cross-sections and aTGC limits

> Differential cross-sections and cut-and-count aTGC limits published

- VBF W: Eur. Phys. J. C 77 (2017) 474, arXiv:1703.04362
- aTGC limits from cut-and-count for m_{jj}>1 TeV, p_T^{j1}>600 GeV,
- central lepton, central jet veto





$$i\mathcal{L}_{\mathrm{eff}}^{WWV} = g_{WWV}\Big\{\Big[g_1^V V^\mu (W^-_{\mu\nu}W^{+\nu} - W^+_{\mu\nu}W^{-\nu}) + \kappa_V W^+_\mu W^-_\nu V^{\mu\nu} + \frac{\lambda_V}{m_W^2} V^{\mu\nu} W^{+\rho}_\nu W^-_{\rho\mu}\Big] - \Big[\frac{\tilde{\kappa}_V}{2} W^-_\mu W^+_\nu \epsilon^{\mu\nu\rho\sigma} V_{\rho\sigma} + \frac{\tilde{\lambda}_V}{2m_W^2} W^-_{\rho\mu} W^{+\mu}_\nu \epsilon^{\nu\rho\alpha\beta} V_{\alpha\beta}\Big]\Big\},$$

	Λ = 4 TeV		$\Lambda = \infty$	
	Expected	Observed	Expected	Observed
Δg_1^Z	[−0.39, 0.35]	[−0.32, 0.28]	[−0.16, 0.15]	[−0.13, 0.12]
$\Delta\kappa_Z$	[−0.38, 0.51]	[−0.29, 0.42]	[−0.19, 0.19]	[−0.15, 0.16]
λ_V	[−0.16, 0.12]	[−0.13, 0.090]	[−0.064, 0.054]	[−0.053, 0.042]
$\tilde{\kappa}_Z$	[−1.7, 1.8]	[−1.4, 1.4]	[−0.70, 0.70]	[−0.56, 0.56]
$\tilde{\lambda}_V$	[−0.13, 0.15]	[−0.10, 0.12]	[−0.058, 0.057]	[−0.047, 0.046]

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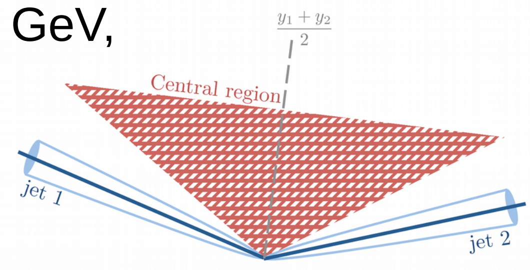
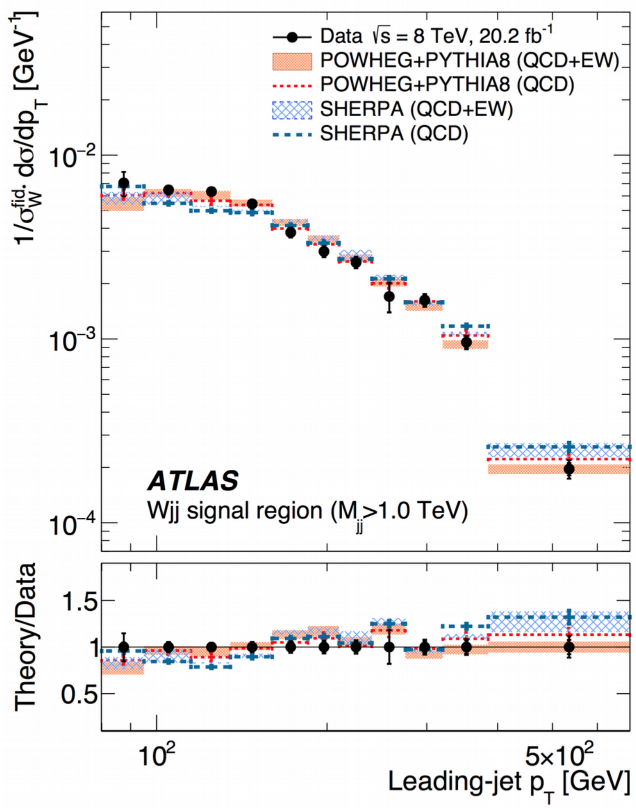




$$i\mathcal{L}_{\text{eff}}^{WWV} = g_{WWV}\Big\{\Big[g_1^V V^\mu(W^-_{\mu\nu}W^{+\nu} - W^+_{\mu\nu}W^{-\nu}) + \kappa_V W^+_\mu W^-_\nu V^{\mu\nu} + \frac{\lambda_V}{m_W^2} V^{\mu\nu} W^{+\rho}_\nu W^-_{\rho\mu}\Big] - \Big[\frac{\tilde{\kappa}_V}{2} W^-_\mu W^+_\nu \epsilon^{\mu\nu\rho\sigma} V_{\rho\sigma} + \frac{\tilde{\lambda}_V}{2m_W^2} W^-_{\rho\mu} W^{+\mu}_\nu \epsilon^{\nu\rho\alpha\beta} V_{\alpha\beta}\Big]\Big\},$$

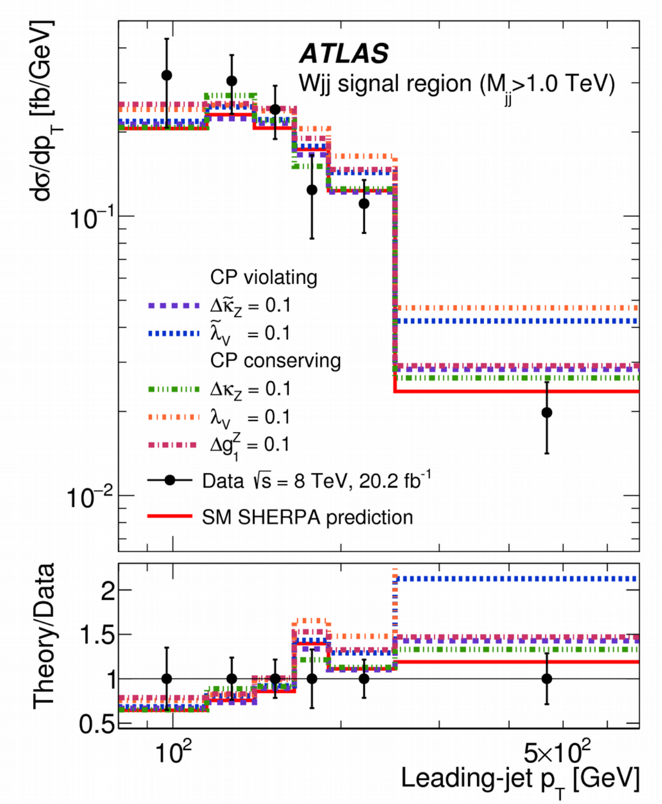
	Parameter	Expected [TeV^{-2}]	Observed [TeV^{-2}]
HISZ basis	$\frac{c_W}{\Lambda^2}$	[−39, 37]	[−33, 30]
	$\frac{c_B}{\Lambda^2}$	[−200, 190]	[−170, 160]
	$\frac{c_{WWW}}{\Lambda^2}$	[−16, 13]	[−13, 9]
	$\frac{c_{\tilde{W}}}{\Lambda^2}$	[−720, 720]	[−580, 580]
	$\frac{c_{\tilde{W}WW}}{\Lambda^2}$	[−14, 14]	[−11, 11]

VBF W: differential cross-sections and aTGC limits

> **Differential cross-sections and cut-and-count aTGC limits published**

> VBF W: Eur. Phys. J. C 77 (2017) 474, arXiv:1703.04362

- Suite of differential cross-section measurements as candidates for EFT fits:



- e.g. m_{jj}, $\Delta\Phi_{jj}$, leading jet p_T, dijet system p_T
  - Unit-normalised and absolute differential rates (incorporating systematic cancellations)
  - QCD+EW Wjj rates and 'EW-only' rates
- NP limits derived at reco-level can have comparable sensitivity to those derived a posterioi at particle-level *(interesting to investigate here!)*
- Flexibility for re-use in global fits