Normalizing VV at the LHC

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Overview

- Introduction
  - Relevance of VV at LHC
  - Normalizing VV with $Z^{(*)}$
  - Tools
- Inclusive rates
  - ZZ production
  - ZW, WW production
  - Dependence on pp center of mass energy
- Jet veto survival probability
  - WW production
  - ZW production
- Outlook and conclusions

VV at the LHC

- VV (V=Z,W) is a major contributor to NL+MET and a background for a number of searches ranging from Higgs searches to SUSY and models beyond the SM
  - Attractive NL+MET signatures with first data
  - WW gives a large rate of 2L+MET
    - With a jet veto it becomes the leading background for H->WW searches
  - ZW gives 3L+MET
    - With a jet veto it becomes the leading background to gaugino production
  - ZZ is the leading 4L production mechanism
    - Gives MET when τ present or instrumental MET

Normalizing VV with Z(*)

- Strong similarities of diagrams since dominant cross-section comes from qq->V(V) via EW couplings
- Ratios VV/V expected to reduce pdf and a significant portion of the scale uncertainty
  - This is an asset especially at the very beginning of data taking when global pdf fits will not be available

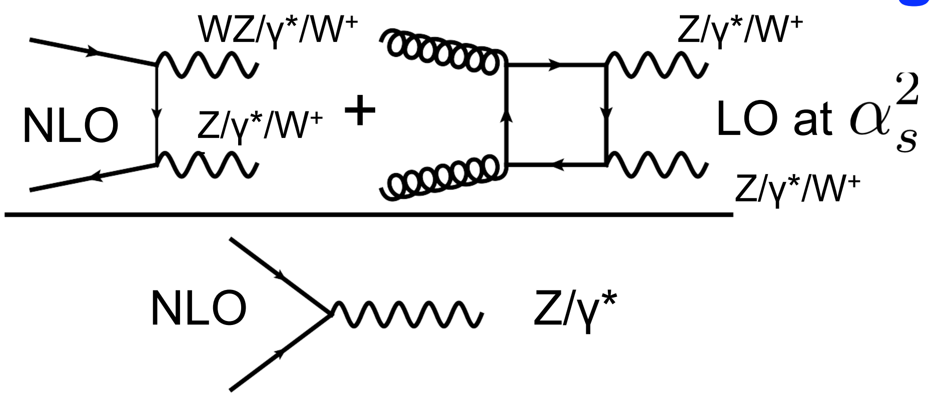
Prediction | Theory | Experimental efficiencies | Observed

$$N(VV) = \left(\frac{\sigma(pp \to VV)}{\sigma(pp \to Z^{(*)})} \right)_{Th} \cdot \epsilon(ll \to Nl) \cdot N_{Obs}(Z^{(*)})$$

Abdullin et al. in hep-ph/0604120 computed the ratio ZZ/Z to NLO

Ratio ZZ(WW)/Z$^{(*)}$

- **The production of ZZ and WW is enhanced by large contributions from gg->VV with gluons in the initial state**
  - **Formally a part of the NNLO contribution, but enhanced due to the large gluon flux**



Including decays into leptons

$$R = \frac{\sigma^{NLO}_{q\bar{q}\to ZZ,WW} + \sigma^{LO}_{gg\to ZZ,WW}}{\sigma^{NLO}_{q\bar{q}\to Z^{(*)}}}$$

Tools

- For qq->Z$^{(*)}$ and qq->ZZ use MCFM v5.3 with bug fixes provided by John Campbell
  - Two independent analyses with independent MC samples. Cross-checks with Pythia
    - Foreseeing additional check with Sherpa
- For gg->ZZ,WW use gg2ZZ, gg2WW. The numbers of the nominal cross-sections and the scale error uncertainties made by Nikolas Kauer
  - Evaluating with Pavel Nadolski (Resbos) and the K factor for gg->\gamma\gamma for M_{gg}~M_ZZ
- Studies with PYTHIA, ALPGEN and MC@NLO

Event selection & Settings

- The analysis is done at the "parton level". The theoretical errors are decoupled from the experimental errors
- These studies are only for $M_{ZZ}>2M_Z$
  - Fur (two) leptons with $P_T>20$ GeV, $|\eta_l|<2.5$
  - Requirement of $71<M_{ll}<111$ GeV on lepton pairs
  - MET>20 GeV
  - $\Delta R_{ll}>0.2$ and $\Delta R_{lj}>0.7$
  - EW settings as default in MCFM taken by gg2ZZ, gg2WW
  - Set scales to M_V for both single and double V production

Nominal Values of ZZ/Z*

- Ratios are constructed such that the invariant mass of Z* and ZZ are in the same bin
  - Contribution from gg->ZZ increases sigma by ~13%
  - Ratio depends weakly with Mass (nice surprise!)
    - Need to understand better behavior at very large masses

Cross-sections in fb

Mass Range	$\sigma^{NLO}_{q\bar{q}\to Z^*}$	$\sigma^{NLO}_{q\bar{q}\to ZZ}$	$\sigma^{LO}_{gg\to ZZ}$	$\frac{\sigma_{ZZ}}{\sigma_{Z^*}} \times 10^3$
200 - 250	1773.7	7.99	1.182	5.17
250 - 300	753.2	3.65	0.530	5.54
300 - 350	372.4	1.86	0.246	5.66
350 - 400	205.7	1.07	0.131	5.83
400 - 450	121.0	0.64	0.082	5.94
450 - 500	76.0	0.40	0.055	6.01
500 - 750	143.9	0.74	0.114	5.92
750 - 1000	27.4	0.16	0.033	6.88

Scale Errors of ZZ/Z*

- **Treat qq->ZZ and gg->ZZ independently**
  - **Get maximum deviation by changing renormalization and factorization scales in opposite directions**

Change scale by *4, /4

Cross-sections in fb

Mass Range	$\sigma^{NLO}_{q\bar{q}\to Z^*}$		$\sigma^{NLO}_{q\bar{q}\to ZZ}$		$\sigma^{LO}_{gg\to ZZ}$		$\frac{\sigma_{ZZ}}{\sigma_{Z^*}} \times 10^3$	
200 - 250	1858.8	4.8	8.34	4.3	1.92	62.0	5.52	6.6
	1586.8	-10.5	7.14	-10.6	0.75	-36.4	4.98	-3.8
250 - 300	792.0	5.2	3.86	5.9	0.83	57.3	5.93	6.9
	683.8	-9.2	3.32	-9.0	0.35	-33.9	5.36	-3.3
300 - 350	390.5	4.9	1.94	4.2	0.38	53.6	5.94	4.9
	340.7	-8.5	1.70	-8.5	0.17	-31.5	5.50	-2.9
350 - 400	214.7	4.4	1.10	3.3	0.20	49.3	6.05	3.8
	195.3	-5.0	0.96	-10.0	0.09	-29.8	5.40	-7.5
400 - 450	125.8	4.0	0.67	5.8	0.12	46.0	6.31	6.2
	114.8	-5.1	0.60	-6.4	0.06	-28.5	5.70	-4.1
450 - 500	79.5	4.5	0.43	6.5	0.08	44.3	6.38	6.3
	72.4	-4.8	0.38	-6.0	0.04	-26.7	5.78	-3.8
500 - 750	147.6	2.6	0.78	5.9	0.16	40.9	6.39	7.8
	140.4	-2.5	0.70	-4.8	0.09	-22.0	5.64	-4.7
750 - 1000	28.1	2.6	0.16	2.0	0.04	30.1	7.17	4.2
	28.2	2.9	0.15	-4.9	0.03	-17.8	6.21	-9.8

Scale Errors of ZZ/Z*

- Multiply the contribution of gg->ZZ by a factor of 2 (potential QCD NLO K factor) but keep the relative errors at the LO level

Cross-sections in fb

Mass Range	$\sigma^{NLO}_{q\bar{q}\to Z^*}$		$\sigma^{NLO}_{q\bar{q}\to ZZ}$		$\sigma^{LO}_{gg\to ZZ}$		$\frac{\sigma_{ZZ}}{\sigma_{Z^*}} \times 10^3$	
200 - 250	1858.8	4.8	8.34	4.3	3.83	62.0	6.55	12.1
	1586.8	-10.5	7.14	-10.6	1.50	-36.4	5.45	-6.7
250 - 300	792.0	5.2	3.86	5.9	1.67	57.3	6.98	11.7
	683.8	-9.2	3.32	-9.0	0.70	-33.9	5.88	-6.0
300 - 350	390.5	4.9	1.94	4.2	0.76	53.6	6.91	9.2
	340.7	-8.5	1.70	-8.5	0.34	-31.5	5.99	-5.3
350 - 400	214.7	4.4	1.10	3.3	0.39	49.3	6.97	7.7
	195.3	-5.0	0.96	-10.0	0.18	-29.8	5.87	-9.3
400 - 450	125.8	4.0	0.67	5.8	0.24	46.0	7.26	9.7
	114.8	-5.1	0.60	-6.4	0.12	-28.5	6.22	-6.2
450 - 500	79.5	4.5	0.43	6.5	0.16	44.3	7.37	9.7
	72.4	-4.8	0.38	-6.0	0.08	-26.7	6.33	-5.9
500 - 750	147.6	2.6	0.78	5.9	0.32	40.9	7.47	11.3
	140.4	-2.5	0.70	-4.8	0.18	-22.0	6.27	-6.5
750 - 1000	28.1	2.6	0.16	2.0	0.08	30.1	8.68	7.5
	28.2	2.9	0.15	-4.9	0.05	-17.8	7.16	-11.3

$\sqrt{s}$ Dependence

- **The Ratio ZZ/Z* seems to be flat as a function of \sqrt{s} and different mass ranges**
  - **The ratio ZZ/Z is less flat**

$\sqrt{s}$	$200-250$	$250-300$	$300-500$	$500-1000$
14	5.17	5.54	5.79	6.08
10	4.98	5.33	5.48	5.61
8	4.92	5.24	5.34	5.53

Flatness of ratio indicates reduction of pdf uncertainties

Ratio WW/$Z^{(*)}$

- Scale-related uncertainties arise from changing scales by factors of 4 (*4,/4)
  - Pick biggest deviation of changing at the same time and in opposite directions

M_{Z^*} >185 GeV

	$\sigma^{NLO}_{q\bar{q}\to Z}$	$\sigma^{NLO}_{q\bar{q}\to Z^*}$	$\sigma^{NLO}_{q\bar{q}\to WW}$	$\sigma^{LO}_{gg\to WW}$	$\frac{\sigma_{WW}}{\sigma_Z}\cdot 10^3$	$\frac{\sigma_{WW}}{\sigma_{Z^*}}$
Nom.	785.3	2256	636.0	31.04	0.85	0.296
Max.	6.2	4.6	11.5	62.1	16.1	9.4
Min.	-15.7	-9.9	-13.4	-36.0	-8.6	-5.3

Same as above after multiplying σ(gg->WW) by two

	$\sigma^{NLO}_{q\bar{q}\to Z}$	$\sigma^{NLO}_{q\bar{q}\to Z^*}$	$\sigma^{NLO}_{q\bar{q}\to WW}$	$\sigma^{LO}_{gg\to WW}$	$\frac{\sigma_{WW}}{\sigma_Z}\cdot 10^3$	$\frac{\sigma_{WW}}{\sigma_{Z^*}}$
Nom.	785.3	2256.4	636.0	62.08	0.89	0.309
Max.	6.2	4.6	11.5	62.1	19.2	12.0
Min.	-15.7	-9.9	-13.4	-36.0	-10.6	-6.7

Ratio ZW/Z$^{(*)}$

- **Ratio evaluated to NLO**
  - **For ZW require P_T or leading lepton to be >20 and the two sub-leading, >10 GeV**
  - **\sqrt{s} dependence of ratios evaluated**

$$R = \frac{\sigma^{NLO}_{q\bar{q}\to ZW}}{\sigma^{NLO}_{q\bar{q}\to Z^{(*)}}}$$

M_{Z^*} >195 GeV

	$\sigma^{NLO}_{q\bar{q}\to Z^*}$	$\sigma^{NLO}_{q\bar{q}\to ZW}$	$\frac{\sigma_{ZW}}{\sigma_Z}\cdot 10^3$	$\frac{\sigma_{ZW}}{\sigma_{Z^*}}$
Nominal	1898.4	92.5	0.118	0.0487
Maximum	4.6	12.9	16.0	7.9
Minimum	-9.2	-12.0	-11.3	-6.5

Jet Veto Survival Prob.

- In order to suppress top backgrounds a full ($|\eta|<5$) jet veto is usually applied
  - Define $\varepsilon(P_T)$ as a fraction of the events that survive a cut on events with a jet of above a certain P_T threshold in ($|\eta|<5$)
- Here we address the possibility of predicting the jet veto survival probability of WW and ZW from Z* (Also made studies for ZZ and Z)
- Results cross-checked with Pythia, MC@NLO and ALPGEN
- We also evaluate the impact of multiple gluon radiation with Pythia6.2.
  - More detailed studies required in this area

$\sqrt{s} = 14$ TeV

p_T [GeV]	$\varepsilon(Z^*)$	$\delta\varepsilon(Z^*)$	$\varepsilon(WW)$	$\delta\varepsilon(WW)$	$\frac{\varepsilon(WW)}{\varepsilon(Z^*)}$	$\delta\frac{\varepsilon(WW)}{\varepsilon(Z^*)}$
20	0.67	8.5 -13.2	0.52	11.9 -15.2	0.78	5.1 -3.2
25	0.72	6.4 -9.9	0.58	9.6 -11.8	0.81	4.0 -2.9
30	0.76	5.1 -7.8	0.63	8.3 -9.1	0.82	3.6 -2.1
35	0.79	4.1 -6.3	0.67	7.4 -7.3	0.84	3.3 -2.1
40	0.82	3.5 -5.3	0.70	6.6 -5.9	0.85	3.0 -1.9
45	0.84	3.2 -4.4	0.72	6.0 -5.4	0.86	2.8 -1.8
50	0.86	2.9 -3.8	0.75	5.5 -5.0	0.87	2.6 -1.8
55	0.87	2.6 -3.3	0.77	5.1 -4.7	0.88	2.5 -1.7
60	0.88	2.4 -2.9	0.79	4.7 -4.3	0.89	2.3 -1.6
65	0.89	2.1 -2.6	0.80	4.3 -4.0	0.90	2.1 -1.4
70	0.90	1.9 -2.4	0.81	4.1 -3.7	0.90	2.1 -1.3
75	0.91	1.8 -2.2	0.83	3.7 -3.3	0.91	1.9 -1.1
80	0.92	1.6 -2.0	0.84	3.4 -3.2	0.91	1.7 -1.1
85	0.93	1.5 -1.9	0.85	3.1 -3.1	0.92	1.6 -1.2
90	0.93	1.4 -1.8	0.86	3.0 -2.9	0.92	1.5 -1.1
95	0.94	1.3 -1.7	0.87	2.7 -2.7	0.93	1.4 -1.1
100	0.94	1.2 -1.6	0.88	2.6 -2.6	0.93	1.3 -1.1

$\sqrt{s} = 10$ TeV

p_T [GeV]	$\varepsilon(Z^*)$	$\delta\varepsilon(Z^*)$	$\varepsilon(WW)$	$\delta\varepsilon(WW)$	$\frac{\varepsilon(WW)}{\varepsilon(Z^*)}$	$\delta\frac{\varepsilon(WW)}{\varepsilon(Z^*)}$
20	0.69	8.6 -7.2	0.58	10.9 -13.5	0.83	2.1 -7.8
25	0.75	6.8 -5.5	0.63	9.2 -10.9	0.85	2.2 -6.3
30	0.78	5.6 -4.3	0.68	8.0 -9.8	0.86	2.2 -5.8
35	0.81	4.8 -3.7	0.71	7.1 -9.0	0.87	2.1 -5.4
40	0.84	4.1 -3.3	0.74	6.2 -8.1	0.88	2.0 -4.9
45	0.86	3.6 -3.0	0.76	5.4 -7.3	0.89	1.7 -4.4
50	0.87	3.2 -2.7	0.79	4.8 -6.8	0.90	1.6 -4.2
55	0.89	2.9 -2.4	0.80	4.4 -6.3	0.91	1.5 -4.0
60	0.90	2.6 -2.3	0.82	4.0 -6.0	0.91	1.4 -3.8
65	0.91	2.3 -2.1	0.83	3.8 -5.5	0.92	1.4 -3.4
70	0.92	2.1 -1.9	0.85	3.4 -5.4	0.93	1.2 -3.5
75	0.92	2.0 -1.8	0.86	3.2 -5.1	0.93	1.2 -3.4
80	0.93	1.8 -1.7	0.87	2.9 -4.8	0.94	1.1 -3.2
85	0.94	1.7 -1.6	0.88	2.8 -4.5	0.94	1.1 -2.9
90	0.94	1.5 -1.5	0.89	2.6 -4.2	0.94	1.0 -2.8
95	0.95	1.4 -1.3	0.90	2.4 -4.0	0.95	0.9 -2.7
100	0.95	1.3 -1.3	0.90	2.2 -3.9	0.95	0.9 -2.7

$\sqrt{s} = 14$ TeV

p_T [GeV]	$\varepsilon(Z^*)$	$\delta\,\varepsilon(Z^*)$	$\varepsilon(ZW)$	$\delta\,\varepsilon(ZW)$	$\frac{\varepsilon(ZW)}{\varepsilon(Z^*)}$	$\delta\,\frac{\varepsilon(ZW)}{\varepsilon(Z^*)}$
20	0.67	8.5 -13.2	0.48	13.2 -15.3	0.71	6.3 -7.3
25	0.72	6.4 -9.9	0.53	11.1 -12.2	0.73	5.5 -6.4
30	0.76	5.1 -7.8	0.57	9.7 -10.8	0.75	5.0 -5.9
35	0.79	4.1 -6.3	0.61	8.7 -9.9	0.76	4.6 -5.5
40	0.82	3.5 -5.3	0.64	7.7 -9.2	0.78	4.0 -5.3
45	0.84	3.2 -4.4	0.66	7.1 -8.5	0.79	3.8 -5.0
50	0.86	2.9 -3.8	0.68	6.5 -7.8	0.80	3.5 -4.7
55	0.87	2.6 -3.3	0.70	6.1 -7.5	0.81	3.4 -4.6
60	0.88	2.4 -2.9	0.72	5.6 -7.0	0.82	3.2 -4.4
65	0.89	2.1 -2.6	0.74	5.4 -6.6	0.83	3.2 -4.1
70	0.90	1.9 -2.4	0.75	5.0 -6.3	0.83	3.0 -4.0
75	0.91	1.8 -2.2	0.77	4.7 -6.1	0.84	2.9 -4.0
80	0.92	1.6 -2.0	0.78	4.4 -5.8	0.85	2.7 -3.8
85	0.93	1.5 -1.9	0.79	4.2 -5.6	0.86	2.6 -3.7
90	0.93	1.4 -1.8	0.80	4.0 -5.2	0.86	2.5 -3.5
95	0.94	1.3 -1.7	0.81	3.8 -4.9	0.87	2.4 -3.2
100	0.94	1.2 -1.6	0.82	3.6 -4.6	0.87	2.3 -3.0

$\sqrt{s} = 10$ TeV

p_T [GeV]	$\varepsilon(Z^*)$	$\delta\,\varepsilon(Z^*)$	$\varepsilon(ZW)$	$\delta\,\varepsilon(ZW)$	$\frac{\varepsilon(ZW)}{\varepsilon(Z^*)}$	$\delta\,\frac{\varepsilon(ZW)}{\varepsilon(Z^*)}$
20	0.69	8.6 -7.2	0.52	16.2 -13.9	0.75	7.0 -8.4
25	0.75	6.8 -5.5	0.58	13.2 -12.1	0.77	5.9 -7.5
30	0.78	5.6 -4.3	0.62	11.7 -10.5	0.79	5.7 -6.5
35	0.81	4.8 -3.7	0.65	10.1 -9.4	0.80	5.1 -5.9
40	0.84	4.1 -3.3	0.68	8.9 -8.9	0.81	4.5 -5.7
45	0.86	3.6 -3.0	0.70	8.1 -8.2	0.82	4.4 -5.4
50	0.87	3.2 -2.7	0.72	7.5 -7.6	0.83	4.1 -5.0
55	0.89	2.9 -2.4	0.74	6.9 -7.1	0.84	3.8 -4.8
60	0.90	2.6 -2.3	0.76	6.3 -6.7	0.85	3.6 -4.5
65	0.91	2.3 -2.1	0.78	5.9 -6.3	0.86	3.5 -4.2
70	0.92	2.1 -1.9	0.79	5.5 -5.9	0.86	3.3 -4.0
75	0.92	2.0 -1.8	0.80	5.2 -5.5	0.87	3.1 -3.8
80	0.93	1.8 -1.7	0.82	4.8 -5.2	0.88	3.0 -3.6
85	0.94	1.7 -1.6	0.83	4.5 -5.0	0.88	2.8 -3.5
90	0.94	1.5 -1.5	0.84	4.2 -4.8	0.89	2.6 -3.4
95	0.95	1.4 -1.3	0.85	4.0 -4.5	0.89	2.5 -3.2
100	0.95	1.3 -1.3	0.86	3.8 -4.2	0.90	2.4 -3.0

Outlook and Conclusions

- The use of $Z^{(*)}$ events is a powerful sample to normalize VV production
- Consider ratios of $\sigma(VV)/\sigma(Z^{(*)})$
  - Considered inclusive rates
    - The theoretical error of $\sigma(ZZ,WW)/\sigma(Z^{(*)})$ has large contribution from the LO uncertainties of the gg->VV process
    - Errors remain at the level of 10%
    - Ratios depend weakly on \sqrt{s} and the mass
    - Also considered $\sigma(ZZ)/\sigma(WW)$ for which most of the uncertainty due to gg->VV cancels out
  - Consider Jet veto survival probability
    - Errors of $\varepsilon(WW,ZW)/\varepsilon(Z^*)$ stay below 10%

EXTRA SLIDES

MCFM Settings

Paramter	Name (_inp)	Input Value	Output Value determined by ewscheme			
			-1	0	1	2
G_F	Gf	1.16639×10^{-5}	input	calculated	input	input
$\alpha(M_Z)$	aemmz	$1/128.89$	input	input	calculated	input
$\sin^2\theta_w$	xw	0.2312	calculated	input	calculated	input
M_W	wmass	80.419 GeV	input	calculated	input	calculated
M_Z	zmass	91.188 GeV	input	input	input	calculated
m_t	mt	172.5 GeV	calculated	input	input	input

Parameter	Fortran name	Default value
m_τ	mtau	1.777 GeV
m_τ^2	mtausq	3.1577 GeV^2
m_c^2	mcsq	2.25 GeV^2
m_b^2	mbsq	17.64 GeV^2
Γ_τ	tauwidth	2.269×10^{-12} GeV
Γ_W	wwidth	2.06 GeV
Γ_Z	zwidth	2.49 GeV
V_{ud}	Vud	0.975
V_{us}	Vus	0.222
V_{ub}	Vub	0.
V_{cd}	Vcd	0.222
V_{cs}	Vcs	0.975
V_{cb}	Vcb	0.

Ratio WW/ZZ

- The ratio WW/ZZ will diminish the error due to the gg->VV contribution.
  - The errors will probably be dominated by the experimental uncertainties

σ_{WW}	$\delta\sigma_{WW}$	σ_{ZZ}	$\delta\sigma_{ZZ}$	$\frac{\sigma_{ZZ}}{\sigma_{WW}} \cdot 10^2$	$\delta \frac{\sigma_{ZZ}}{\sigma_{WW}}$
667.0	13.9	11.51	10.9	1.73	1.6
	-14.4		-13.1		-2.6

- Results above include gg->WW

$\sqrt{s}$ Dependence of WW/Z$^{(*)}$

- ❑ **Results reported to NLO and**
  - ❑ **Results were obtained with a dynamic scale**
    - **(E_T of the weak-boson system)**

$$\frac{\sigma(WW)}{\sigma(Z^*)}$$

$\sqrt{s}$[TeV]	$200 < M_{WW} < 250$	$250 < M_{WW} < 300$	$300 < M_{WW} < 500$	$M_{WW} > 500$
14	0.20	0.27	0.33	0.391
12	0.20	0.26	0.33	0.388
10	0.20	0.26	0.32	0.382
8	0.19	0.25	0.31	0.385
6	0.18	0.24	0.30	0.406

$$\frac{\sigma(WW)}{\sigma(Z)} \times 10^3$$

$\sqrt{s}$[TeV]	$200 < M_{WW} < 250$	$250 < M_{WW} < 300$	$300 < M_{WW} < 500$	$M_{WW} > 500$
14	0.22	0.13	0.16	0.044
12	0.22	0.12	0.16	0.040
10	0.21	0.12	0.14	0.036
8	0.20	0.11	0.13	0.030
6	0.18	0.10	0.11	0.022

$\sqrt{s}$ Dependence of VV/Z*

- Ratios are relatively stable w.r.t. \sqrt{s}

Results to NLO

$\sqrt{s}$ [TeV]	$\frac{\sigma(WW)}{\sigma(Z^*)}$	$\frac{\sigma(ZW)}{\sigma(Z^*)}$	$\frac{\sigma(ZZ)}{\sigma(Z^*)}$
14	0.280	.0481	.0063
12	0.294	.0473	.0062
10	0.271	.0462	.0062
8	0.265	.0452	.0062
6	0.256	.0435	.0062

PDF Uncertainties

Check	$\delta\sigma(Z)$	$\delta\sigma(Z^*)$	$\delta\sigma(ZZ)$	$\delta\sigma(WW)$	$\delta\sigma(ZW)$
1	-1.2	-1.0	-1.2	-1.0	-0.9
2	1.2	1.0	1.2	1.0	0.9
3	-1.3	-1.0	-0.8	-0.8	-0.7
4	1.3	1.0	0.8	0.8	0.7
5	0.0	-0.6	-0.6	-0.6	-0.6
6	-0.1	0.5	0.6	0.5	0.6
7	-0.2	-0.8	-1.1	-0.9	-1.0
8	0.1	0.8	1.1	0.9	0.9
9	-2.1	-1.1	-1.1	-1.0	-0.9
10	2.3	1.1	1.1	1.0	0.8
11	1.2	0.9	0.6	0.7	0.6
12	-1.1	-0.8	-0.6	-0.6	-0.6
13	0.3	0.4	0.4	0.4	0.3
14	-0.3	-0.4	-0.3	-0.3	-0.3
15	-0.6	-0.7	-0.7	-0.6	-0.7
16	0.1	0.3	0.2	0.2	0.3
17	-0.2	0.1	0.4	0.3	0.3
18	-0.2	-0.5	-0.8	-0.6	-0.6
19	1.3	1.8	1.9	1.8	1.7
20	-1.0	-1.7	-1.7	-1.6	-1.6
21	1.3	1.0	0.9	0.9	0.8
22	0.3	-0.6	-0.5	-0.6	-0.6
23	0.7	0.5	0.8	0.6	0.6
24	1.1	0.9	0.9	0.8	0.8
25	0.1	0.2	0.5	0.3	0.3
26	0.2	-0.2	-0.2	-0.2	-0.2
27	-0.8	-0.7	-0.6	-0.6	-0.5
28	-0.8	-0.9	-0.9	-0.9	-0.8
29	0.2	-0.2	-0.2	-0.1	-0.1
30	-2.8	-1.9	-1.8	-1.8	-1.7
31	0.9	0.8	0.9	0.8	0.7
32	1.0	0.7	1.0	0.8	0.8
33	1.1	0.6	0.9	0.7	0.7
34	0.4	0.5	0.8	0.6	0.5
35	-0.8	-0.8	-0.7	-0.7	-0.6
36	-0.9	-0.9	-0.8	-0.8	-0.8
37	-1.0	-1.2	-1.1	-1.1	-1.1
38	0.3	0.3	0.3	0.3	0.3
39	-0.1	-0.4	0.0	-0.2	-0.1
40	0.0	-0.1	0.1	0.0	0.0
Total	3.3	3.1	3.3	3.0	2.8

- Use CTEQ6.1 and evaluate the 40 pdf checks
  - Results depends weakly on cms energy

Uncertainties in %

$\sqrt{s}$	$\delta\sigma(Z)$	$\delta\sigma(Z^*)$	$\delta\sigma(ZZ)$	$\delta\sigma(WW)$	$\delta\sigma(ZW)$
14	3.3	3.1	3.3	3.0	2.8
10	3.3	3.2	3.4	3.1	2.9
8	3.4	3.4	3.5	3.2	3.0

Shown errors on cross-sections to NLO

PDF Uncertainties
(ratios)

Check	$\delta\frac{\sigma(ZZ)}{\sigma(Z)}$	$\delta\frac{\sigma(ZZ)}{\sigma(Z^*)}$	$\delta\frac{\sigma(WW)}{\sigma(Z)}$	$\delta\frac{\sigma(WW)}{\sigma(Z^*)}$	$\delta\frac{\sigma(ZW)}{\sigma(Z)}$	$\delta\frac{\sigma(ZW)}{\sigma(Z^*)}$
1	0.0	-0.3	0.2	-0.1	0.3	0.0
2	0.0	0.3	-0.2	0.1	-0.3	0.0
3	0.6	0.2	0.6	0.2	0.7	0.3
4	-0.5	-0.2	-0.6	-0.2	-0.7	-0.3
5	-0.6	0.0	-0.6	0.0	-0.7	-0.1
6	0.6	0.0	0.6	0.0	0.7	0.1
7	-0.9	-0.3	-0.7	-0.1	-0.8	-0.2
8	0.9	0.3	0.7	0.1	0.8	0.1
9	1.0	0.0	1.1	0.1	1.2	0.2
10	-1.2	0.0	-1.3	-0.1	-1.4	-0.3
11	-0.6	-0.2	-0.5	-0.2	-0.6	-0.3
12	0.5	0.3	0.5	0.2	0.5	0.3
13	0.1	0.0	0.1	0.0	0.0	-0.1
14	-0.1	0.0	-0.1	0.0	0.0	0.1
15	-0.1	0.0	0.0	0.1	-0.1	0.0
16	0.1	-0.1	0.1	-0.1	0.2	0.0
17	0.6	0.3	0.5	0.1	0.5	0.2
18	-0.7	-0.4	-0.4	-0.2	-0.4	-0.2
19	0.6	0.0	0.5	-0.1	0.4	-0.2
20	-0.7	0.0	-0.6	0.1	-0.6	0.1
21	-0.4	-0.1	-0.5	-0.1	-0.6	-0.2
22	-0.8	0.1	-0.8	0.0	-0.9	0.0
23	0.1	0.3	-0.1	0.1	-0.1	0.1
24	-0.1	0.1	-0.2	0.0	-0.3	-0.1
25	0.3	0.3	0.2	0.1	0.2	0.1
26	-0.4	0.0	-0.4	0.0	-0.4	0.0
27	0.2	0.1	0.2	0.1	0.3	0.2
28	0.0	0.1	0.0	0.1	0.0	0.1
29	-0.4	0.0	-0.3	0.1	-0.3	0.2
30	1.0	0.1	0.9	0.1	1.0	0.2
31	0.0	0.2	-0.1	0.0	-0.2	-0.1
32	0.0	0.3	-0.2	0.1	-0.2	0.1
33	-0.3	0.3	-0.4	0.1	-0.5	0.1
34	0.4	0.3	0.2	0.1	0.1	0.0
35	0.1	0.1	0.2	0.1	0.2	0.1
36	0.1	0.1	0.1	0.1	0.2	0.2
37	-0.1	0.2	-0.1	0.1	-0.1	0.1
38	0.0	0.0	0.0	0.0	0.0	0.0
39	0.1	0.4	-0.1	0.2	0.0	0.3
40	0.1	0.2	0.0	0.1	0.0	0.2
Total	1.4	0.5	1.3	0.3	1.4	0.4

- **Use CTEQ6.1 and evaluate the 40 pdf checks**
  - **Results depends weakly on cms energy**

Uncertainties in %

$\sqrt{s}$	$\delta\frac{\sigma(ZZ)}{\sigma(Z)}$	$\delta\frac{\sigma(ZZ)}{\sigma(Z^*)}$	$\delta\frac{\sigma(WW)}{\sigma(Z)}$	$\delta\frac{\sigma(WW)}{\sigma(Z^*)}$	$\delta\frac{\sigma(ZW)}{\sigma(Z)}$	$\delta\frac{\sigma(ZW)}{\sigma(Z^*)}$
14	1.4	0.5	1.3	0.3	1.4	0.4
10	1.5	0.5	1.4	0.3	1.4	0.5
8	1.5	0.6	1.4	0.3	1.5	0.6

Shown errors on ratios to NLO

- **Pdf-related errors of VV are more correlated with Z* and with Z**

Pdf errors for gg->WW

- Independent study of pdf errors on gg->WW with various versions of CTEQ
  - Obtain an errors of 5-10% to the total cross-section of gg->WW with CTEQ6
    - This is significantly smaller than the scale-driven uncertainties
- We did not investigate the correlations of the pdf errors of the qq,qg initial states with those of the gg initial states and the resulting effect on the ratio
  - This is homework for the future

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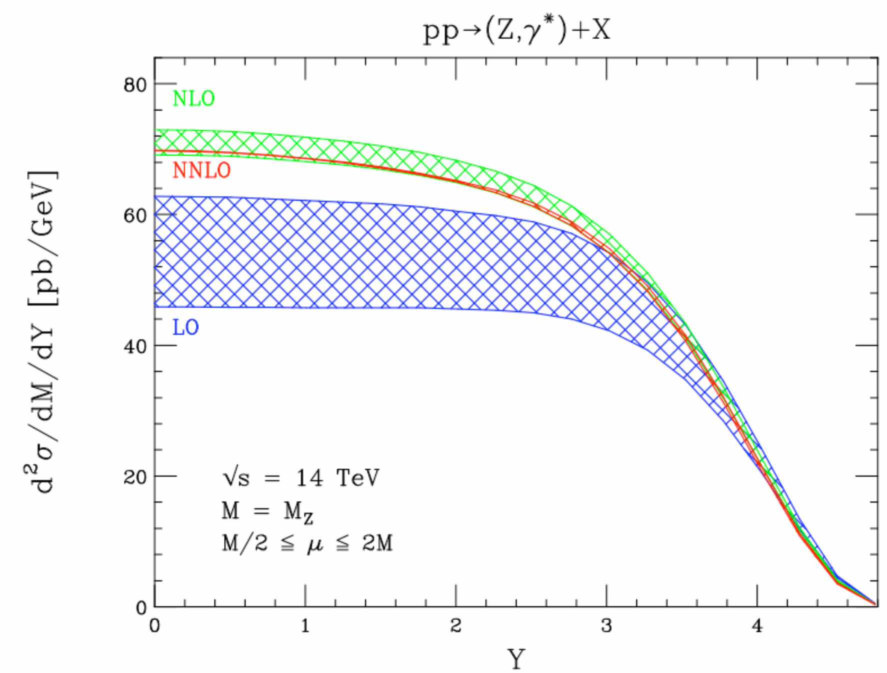

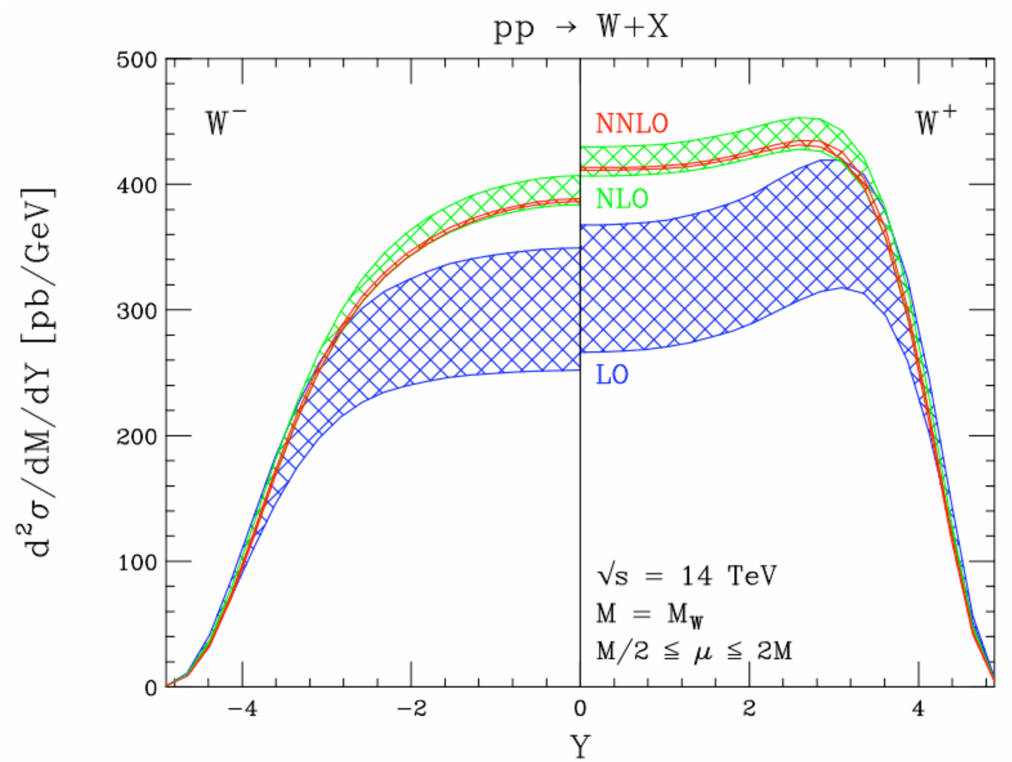

The NLO band does contain the NNLO result for Z,W^+,W^- production
Same applies for the gg->H production

$\sqrt{s}$ Dependence of Jet Veto

Results of ε shown for P_T=30 GeV

	WW			Z^*			
$\sqrt{s}$	$<p_T>$	$<\lvert\eta\rvert>$	ϵ_{jv}	$<p_T>$	$<\lvert\eta\rvert>$	ϵ_{jv}	$\frac{\epsilon_{jv}^{WW}}{\epsilon_{jv}^{Z^*}}$
14	42.0	0.78	0.63	23.9	0.58	0.76	0.82
10	34.6	0.68	0.68	21.0	0.53	0.78	0.86
8	30.1	0.62	0.71	18.1	0.47	0.81	0.87

$\sqrt{s}$ Dependence of Jet Veto

Values with respect to $\sqrt{s} = 14$ TeV

	12		10		8		6	
p_T [GeV]	$\varepsilon^R(WW)$	$\frac{\varepsilon^R(WW)}{\varepsilon^R(Z^*)}$	$\varepsilon^R(WW)$	$\frac{\varepsilon^R(WW)}{\varepsilon^R(Z^*)}$	$\varepsilon^R(WW)$	$\frac{\varepsilon^R(WW)}{\varepsilon^R(Z^*)}$	$\varepsilon^R(WW)$	$\frac{\varepsilon^R(WW)}{\varepsilon^R(Z^*)}$
20	1.07	1.04	1.10	1.04	1.16	1.08	1.25	1.11
25	1.06	1.03	1.08	1.04	1.14	1.07	1.21	1.09
30	1.05	1.03	1.08	1.04	1.12	1.06	1.18	1.08
35	1.04	1.03	1.06	1.03	1.11	1.06	1.16	1.08
40	1.04	1.03	1.06	1.03	1.10	1.05	1.15	1.07
45	1.04	1.02	1.05	1.03	1.09	1.05	1.13	1.07
50	1.03	1.02	1.05	1.03	1.08	1.04	1.12	1.06
55	1.03	1.02	1.05	1.02	1.08	1.04	1.11	1.06
60	1.02	1.01	1.04	1.02	1.07	1.04	1.10	1.05
65	1.02	1.01	1.04	1.02	1.07	1.04	1.10	1.05
70	1.02	1.01	1.04	1.02	1.06	1.03	1.09	1.05
75	1.01	1.01	1.03	1.02	1.06	1.03	1.09	1.05
80	1.01	1.01	1.03	1.02	1.05	1.03	1.08	1.04
85	1.01	1.01	1.03	1.02	1.05	1.03	1.07	1.04
90	1.01	1.01	1.03	1.02	1.05	1.03	1.07	1.04
95	1.01	1.00	1.03	1.02	1.04	1.03	1.07	1.04
100	1.01	1.00	1.03	1.01	1.04	1.02	1.06	1.04