Normalizing VV at the LHC

J.Campbell, E.Castaneda, Y.Fang, N.Kauer
B.Mellado and Sau Lan Wu
(Not an ATLAS talk)

Special thanks S.Dawson, J.Qian and D.Rebuzzi
LMET Workshop, UC Davis, 04/01/09

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

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

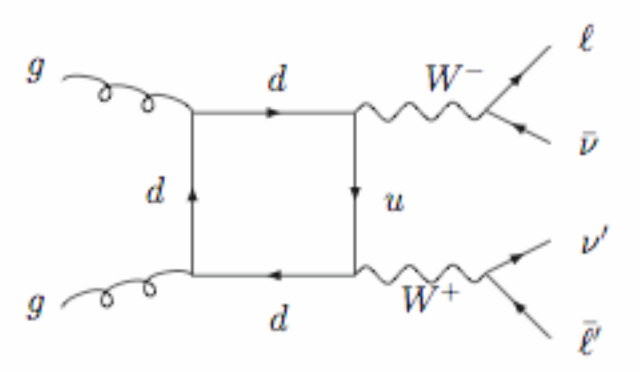
Abdullin et al. in hep-ph/0604120 computed the ratio ZZ/Z to NLO

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 use gg2ZZ. 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
    - Nikolas evaluating potential differences
- ☐ Studies with ALPGEN and MC@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**



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

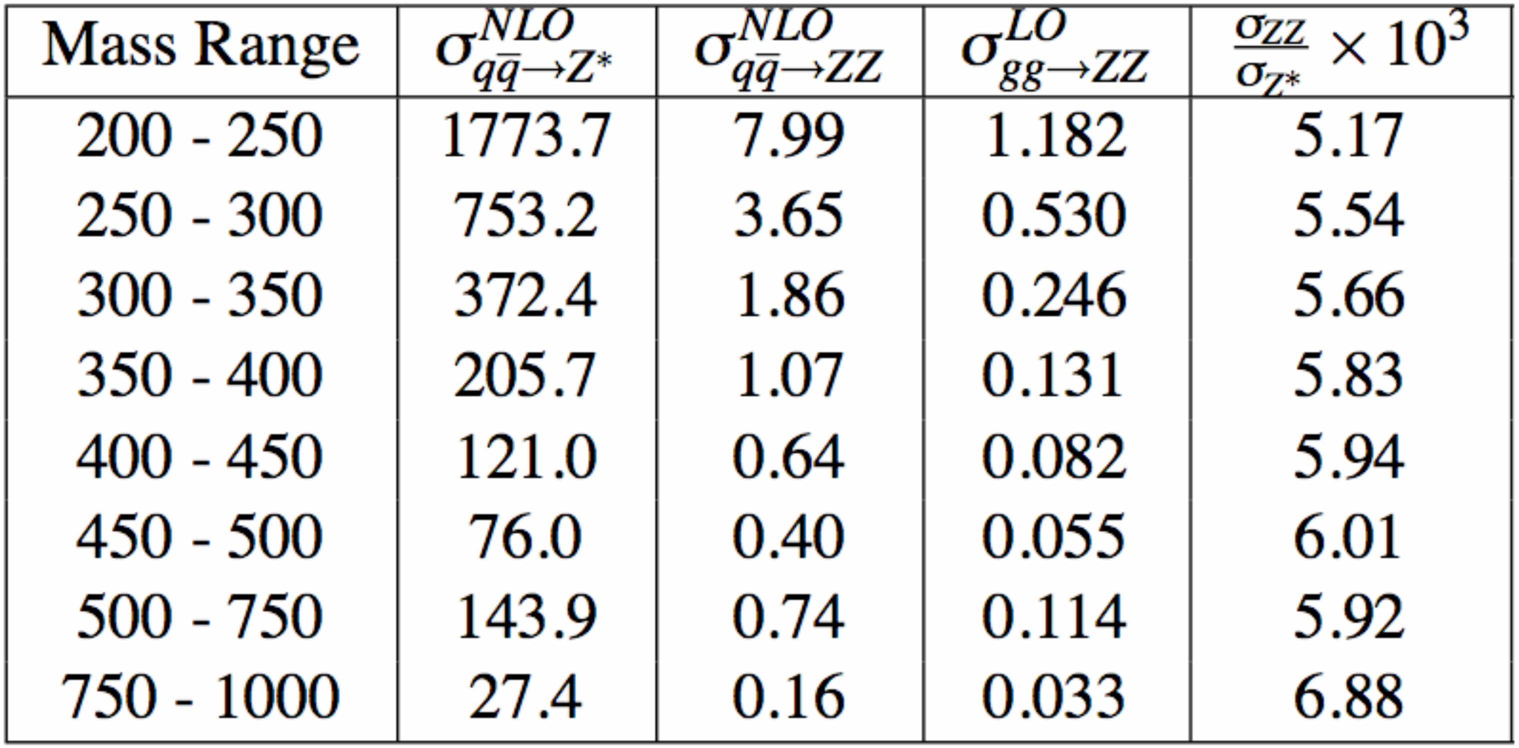
Event selection & Settings

- The analysis is done at the “parton level”. The theoretical errors are decoupled from the experimental errors
- These studies are only for $M_{ZZ}>2M_Z$
  - Four (two) leptons with $P_T>20$ GeV, |eta|<2.5
  - Requirement of $71<M_{ll}<111$ on lepton pairs
  - \DeltaR_{ll}>0.2 and \DeltaR_{lj}>0.7
  - EW settings as default in MCFM taken by gg2ZZ
  - Set scales to M_V
    - We also have results with dynamic scales \mu=M_{Z$^{(*)}$,ZZ}.

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



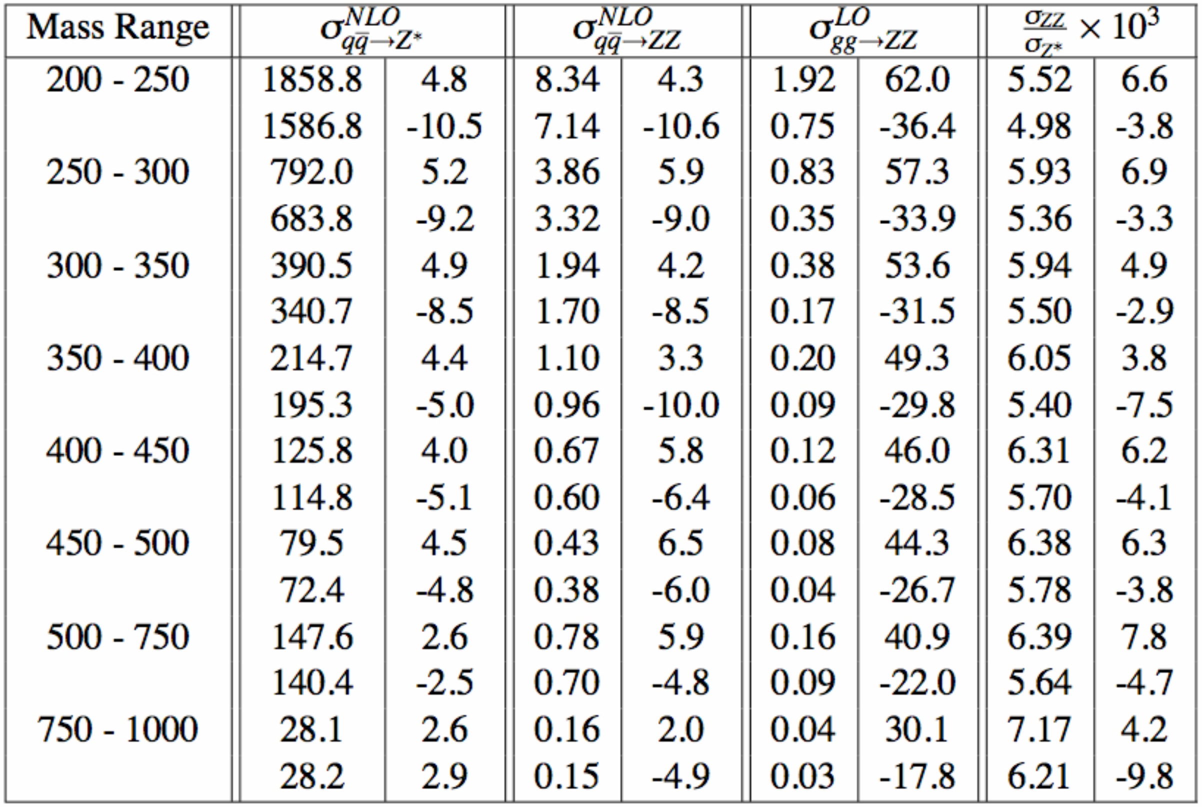
Mass Range	$\sigma^{NLO}_{q\bar{q}\to Z^*}$	$\sigma^{NLO}_{q\bar{q}\to ZZ}$	$\sigma^{LO}_{gg\to ZZ}$	$\frac{\sigma_{ZZ}}{\sigma_{Z^*}}\times 10^3$
200 - 250	1773.7	7.99	1.182	5.17
250 - 300	753.2	3.65	0.530	5.54
300 - 350	372.4	1.86	0.246	5.66
350 - 400	205.7	1.07	0.131	5.83
400 - 450	121.0	0.64	0.082	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**
  - ❑ **This somewhat overestimates error on factorization scale due to expected anti-correlation for qq and gg**
  - ❑ **Get maximum deviation by changing renormalization and factorization scales in opposite directions**

Change scale by *4, /4

Cross-sections in fb

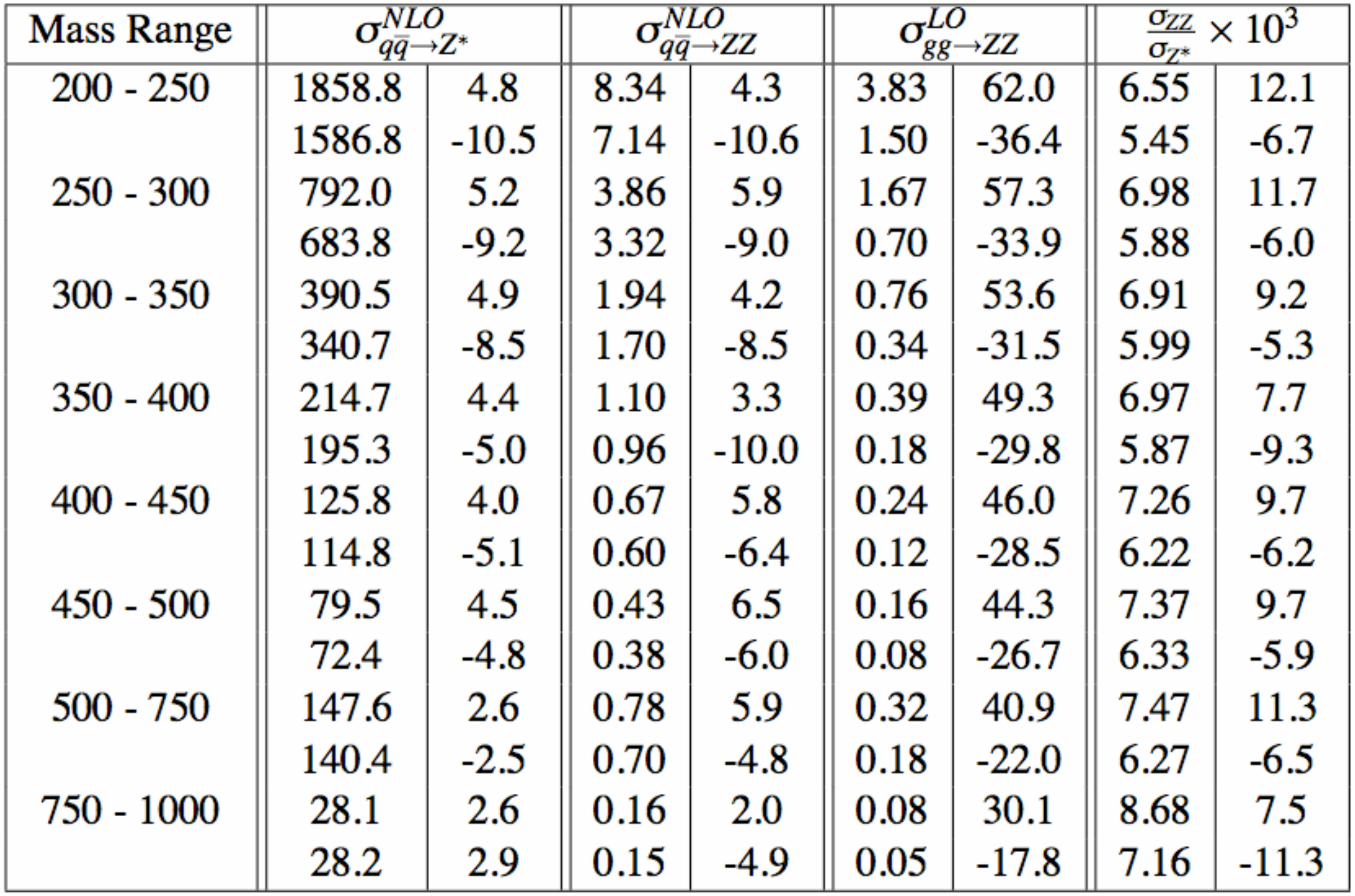


Mass Range	$\sigma^{NLO}_{q\bar{q}\to Z^*}$		$\sigma^{NLO}_{q\bar{q}\to ZZ}$		$\sigma^{LO}_{gg\to ZZ}$		$\frac{\sigma_{ZZ}}{\sigma_{Z^*}} \times 10^3$	
200 - 250	1858.8	4.8	8.34	4.3	1.92	62.0	5.52	6.6
	1586.8	-10.5	7.14	-10.6	0.75	-36.4	4.98	-3.8
250 - 300	792.0	5.2	3.86	5.9	0.83	57.3	5.93	6.9
	683.8	-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

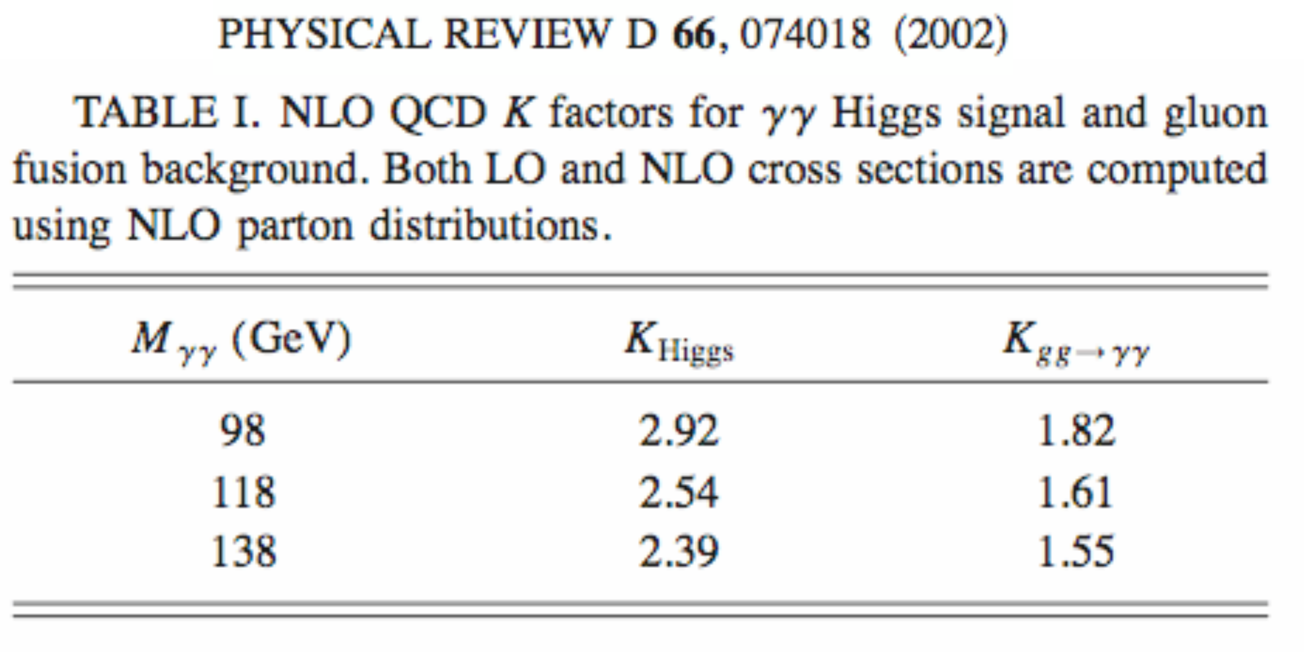
Cross-sections in fb



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

Comments on gg->ZZ to NLO

- The QCD NLO corrections gg->ZZ are expected to be significant
  - We can get a feeling of the size by looking into high mass gg->\gamma\gamma. Work in progress to compare with the numbers of 2002



PHYSICAL REVIEW D **66**, 074018 (2002)

TABLE I. NLO QCD K factors for $\gamma\gamma$ Higgs signal and gluon fusion background. Both LO and NLO cross sections are computed using NLO parton distributions.

$M_{\gamma\gamma}$ (GeV)	$K_{\rm Higgs}$	$K_{gg\to\gamma\gamma}$
98	2.92	1.82
118	2.54	1.61
138	2.39	1.55

\sqrt{s} Dependence

- **The contribution off the gg->ZZ to the table is not added yet**
- **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**

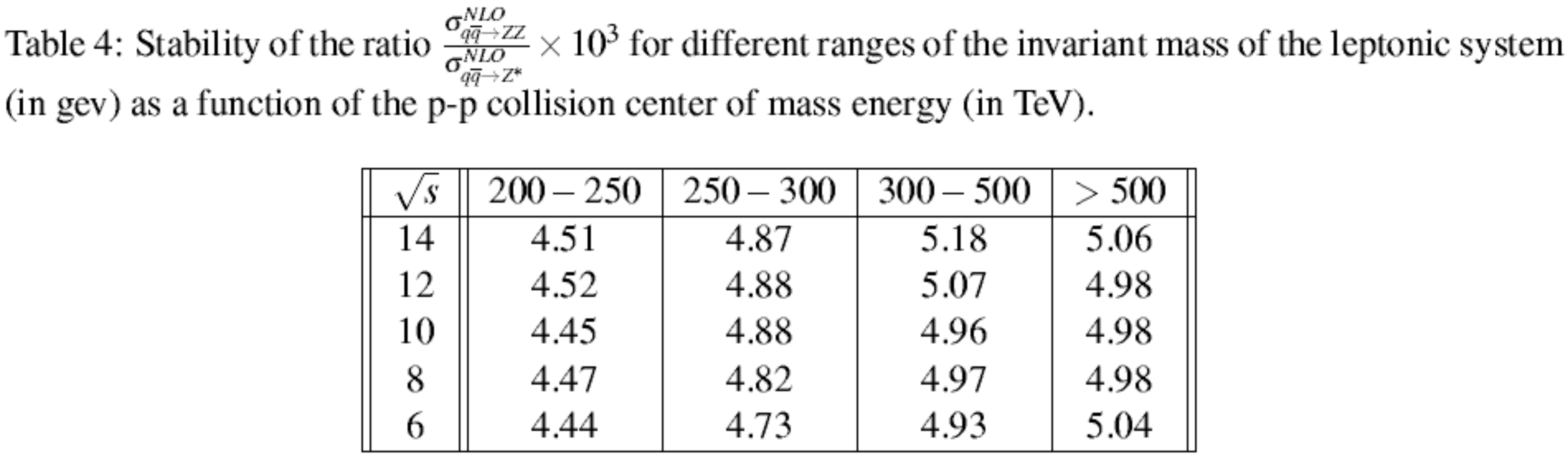


Table 4: Stability of the ratio $\frac{\sigma^{NLO}_{q\bar{q}\to ZZ}}{\sigma^{NLO}_{q\bar{q}\to Z^*}} \times 10^3$ for different ranges of the invariant mass of the leptonic system (in gev) as a function of the p-p collision center of mass energy (in TeV).

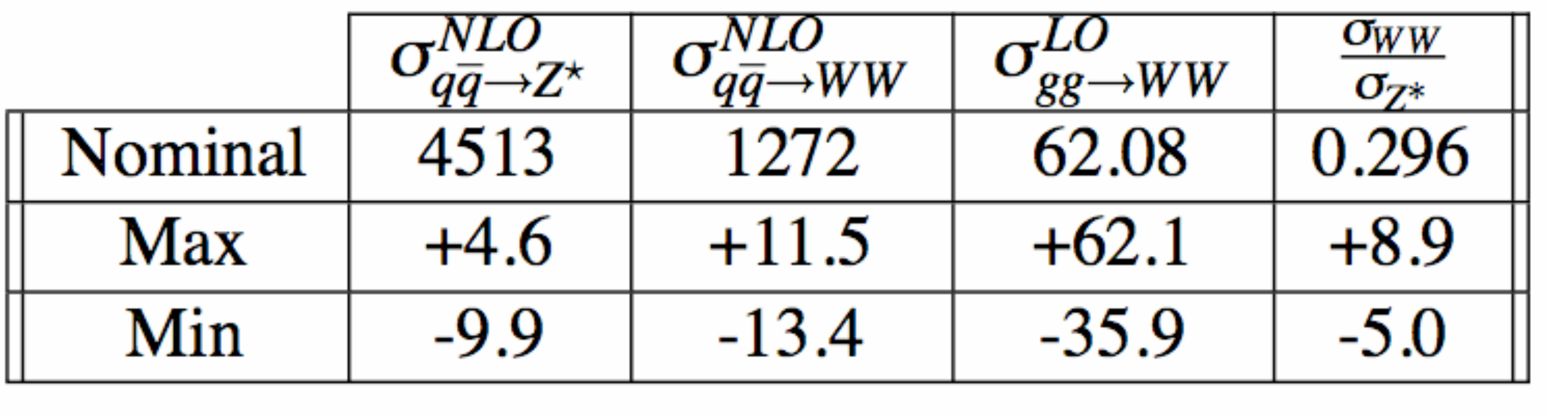
$\sqrt{s}$	$200-250$	$250-300$	$300-500$	> 500
14	4.51	4.87	5.18	5.06
12	4.52	4.88	5.07	4.98
10	4.45	4.88	4.96	4.98
8	4.47	4.82	4.97	4.98
6	4.44	4.73	4.93	5.04

Flatness of ratio indicates reduction of pdf uncertainties

Ratio WW/Z*

- **Computation similar to ratio ZZ/Z***
  - **Require two leptons with same cuts as ZZ events selection + MET>20 GeV**
  - **Contribution from gg->WW is about 10% of the total WW cross-section**

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

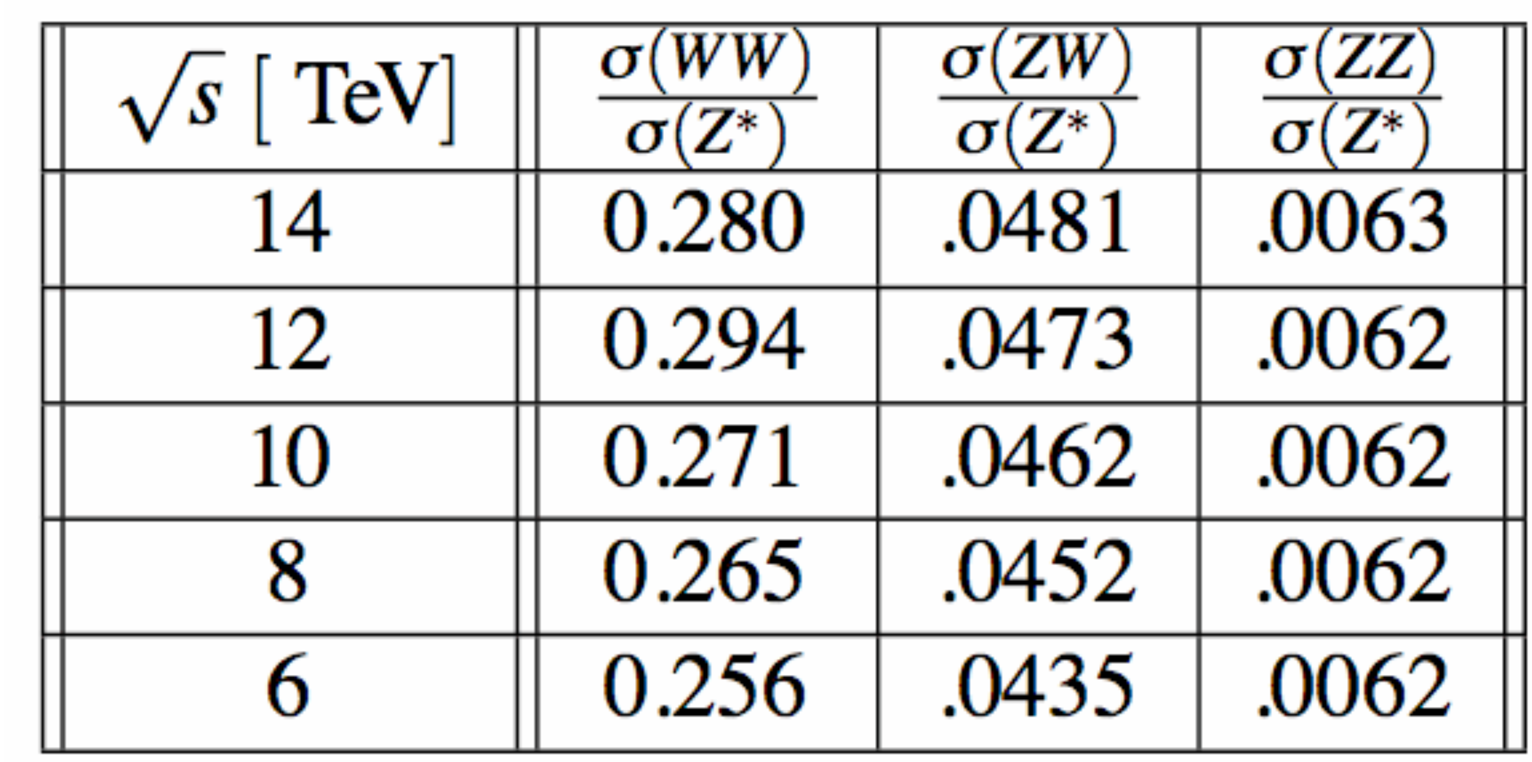


	$\sigma^{NLO}_{q\bar{q}\to Z^*}$	$\sigma^{NLO}_{q\bar{q}\to WW}$	$\sigma^{LO}_{gg\to WW}$	$\frac{\sigma_{WW}}{\sigma_{Z^*}}$
Nominal	4513	1272	62.08	0.296
Max	+4.6	+11.5	+62.1	+8.9
Min	-9.9	-13.4	-35.9	-5.0

\sqrt{s} Dependence of VV/Z*

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

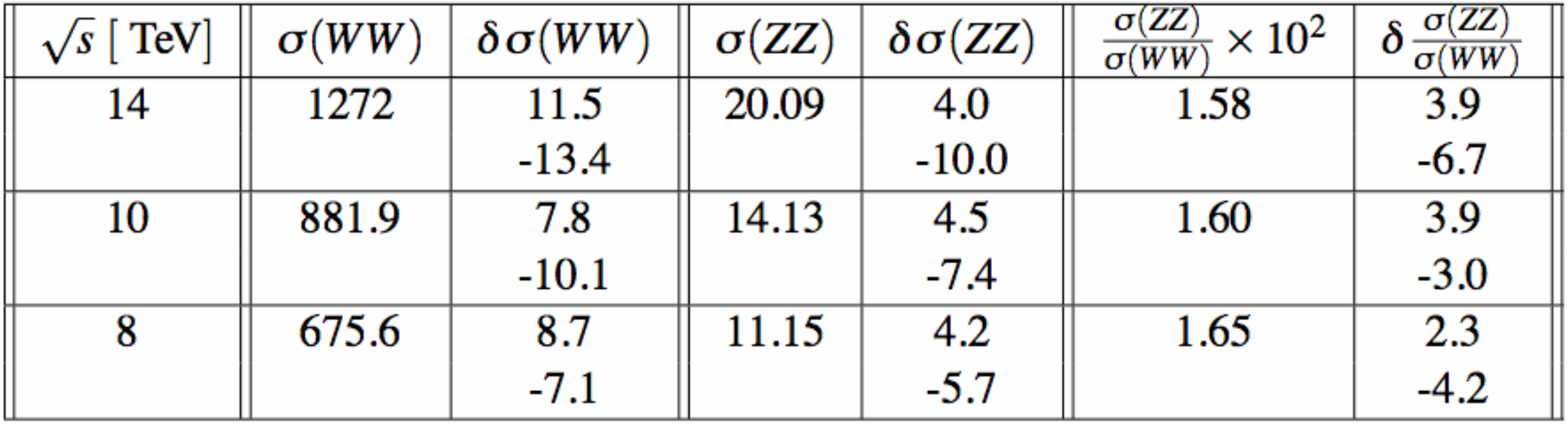
Results to NLO



$\sqrt{s}$ [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

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



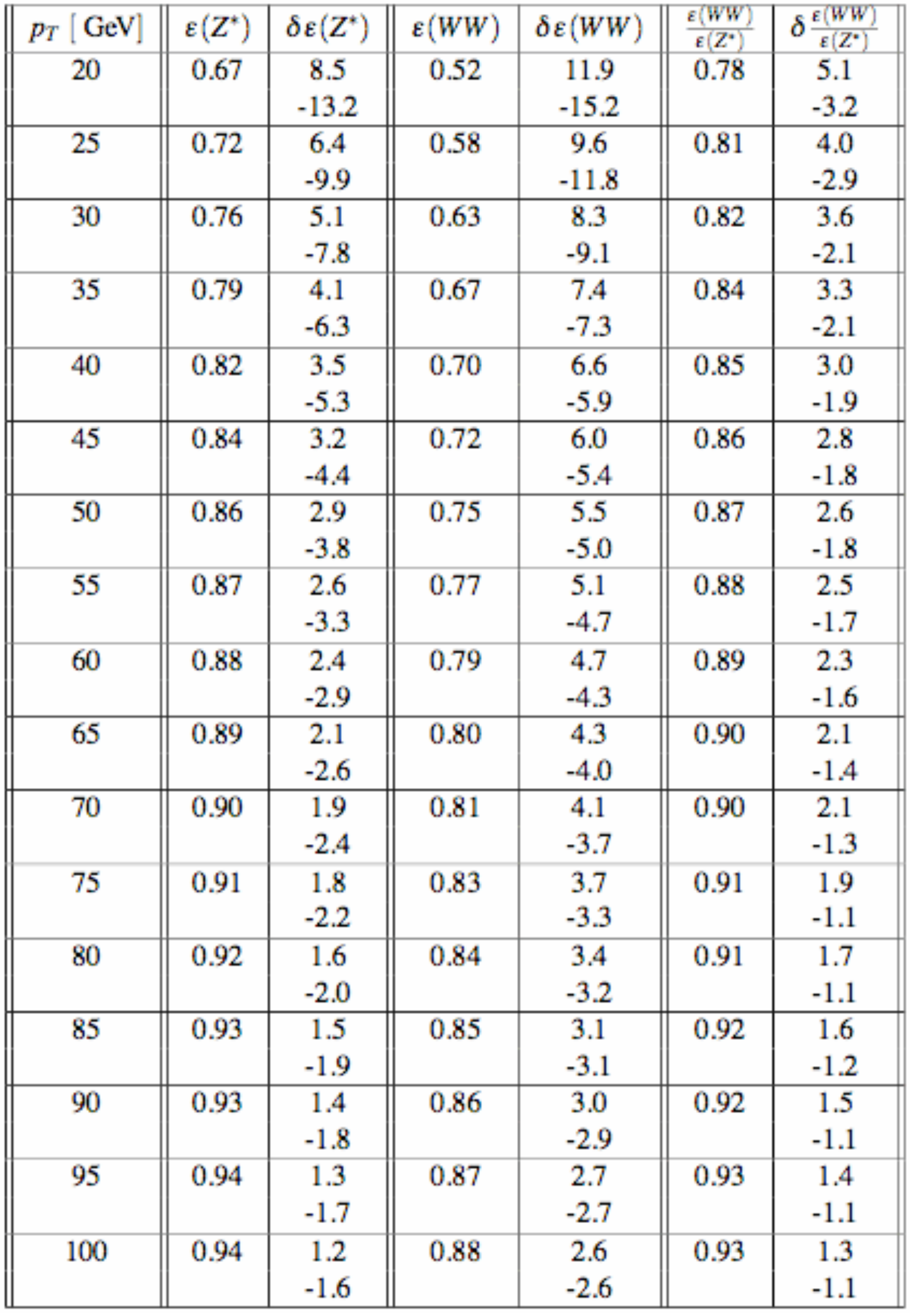
$\sqrt{s}$ [TeV]	$\sigma(WW)$	$\delta\sigma(WW)$	$\sigma(ZZ)$	$\delta\sigma(ZZ)$	$\frac{\sigma(ZZ)}{\sigma(WW)} \times 10^2$	$\delta \frac{\sigma(ZZ)}{\sigma(WW)}$
14	1272	11.5 -13.4	20.09	4.0 -10.0	1.58	3.9 -6.7
10	881.9	7.8 -10.1	14.13	4.5 -7.4	1.60	3.9 -3.0
8	675.6	8.7 -7.1	11.15	4.2 -5.7	1.65	2.3 -4.2

- Results above are computed to NLO
- The scale errors due to gg->VV cancel almost completely

Jet Veto Survival Prob.

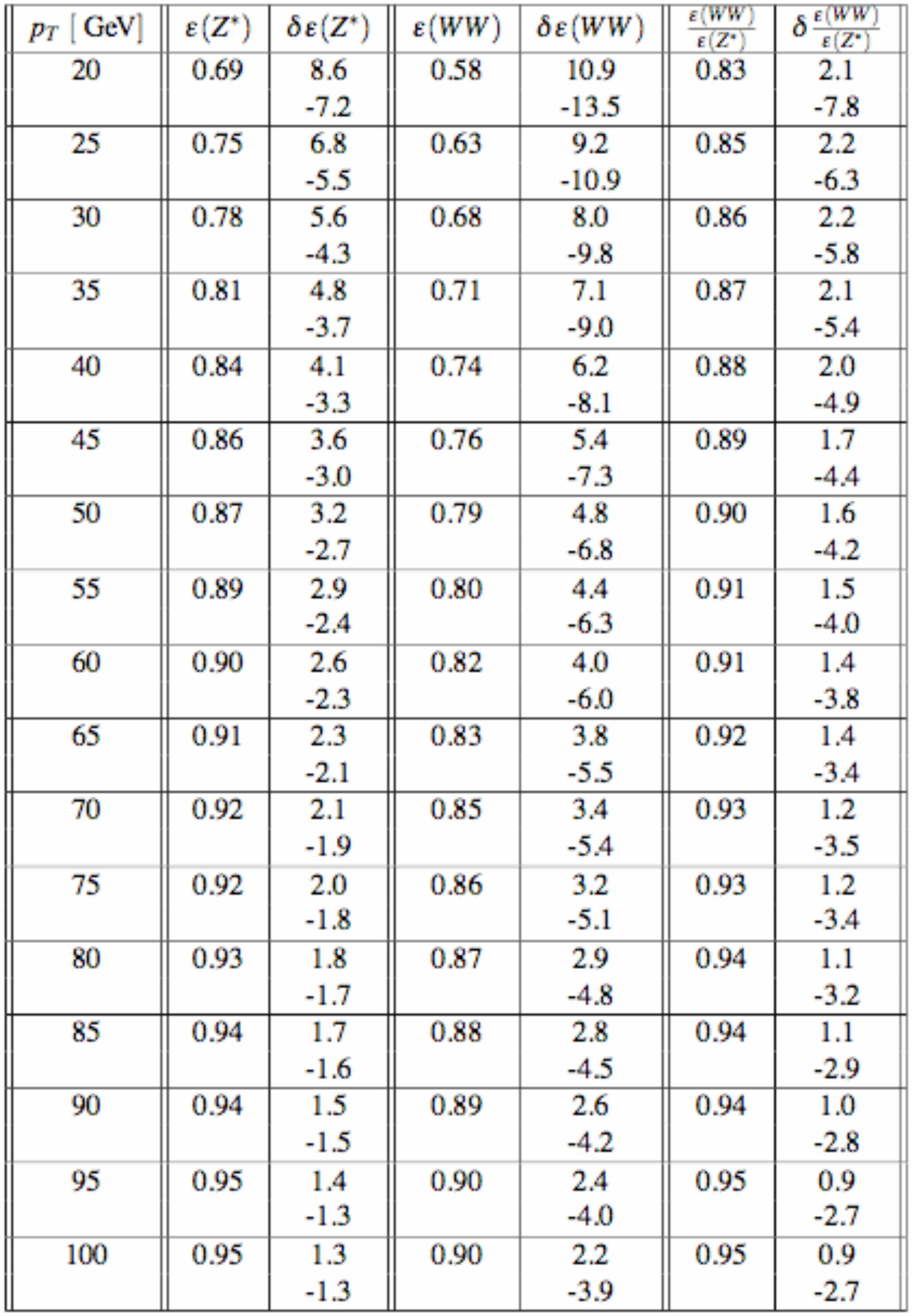
- In order to suppress top backgrounds a full (\eta|<5) jet veto is usually applied
  - Define $\varepsilon(P_T)$ as a fraction of the events that survive a cut on events with a jet of above a certain P_T threshold in (\eta|<5)
- Here we address the possibility of predicting the jet veto survival probability of WW an ZW from Z*
- The P_T spectra of the leading jet in VV and V are different, but the ratio of the jet veto survival probability should have small uncertainties

$\sqrt{s} = 14$ 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

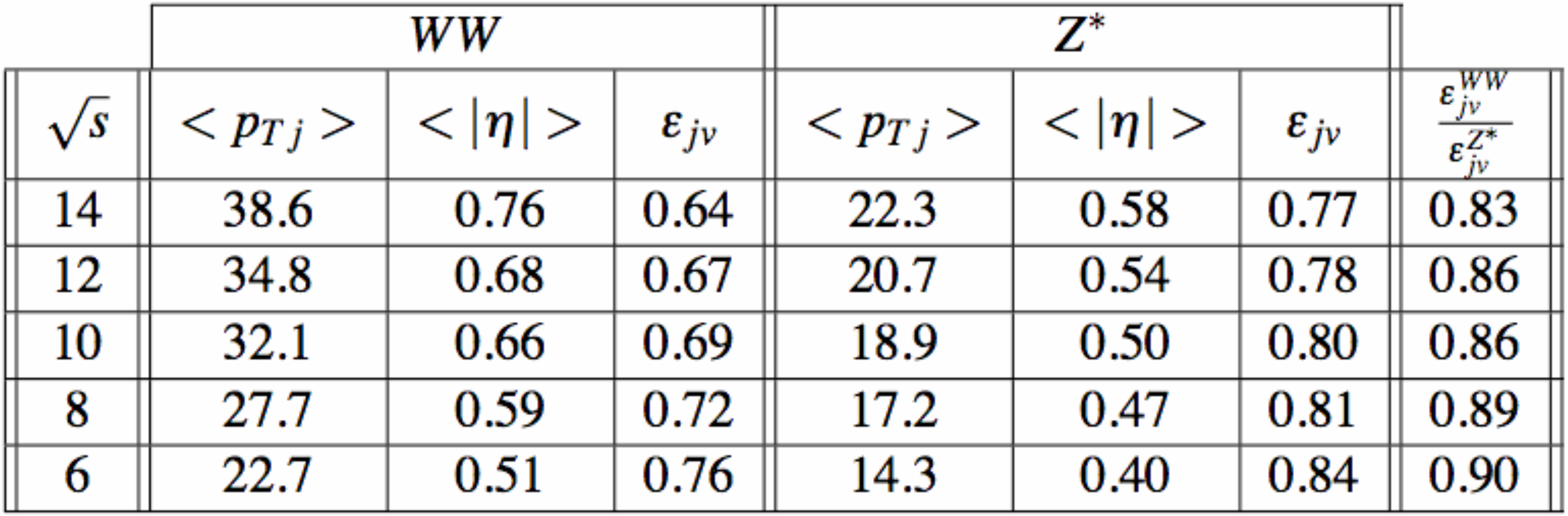
$\sqrt{s} = 10$ TeV



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

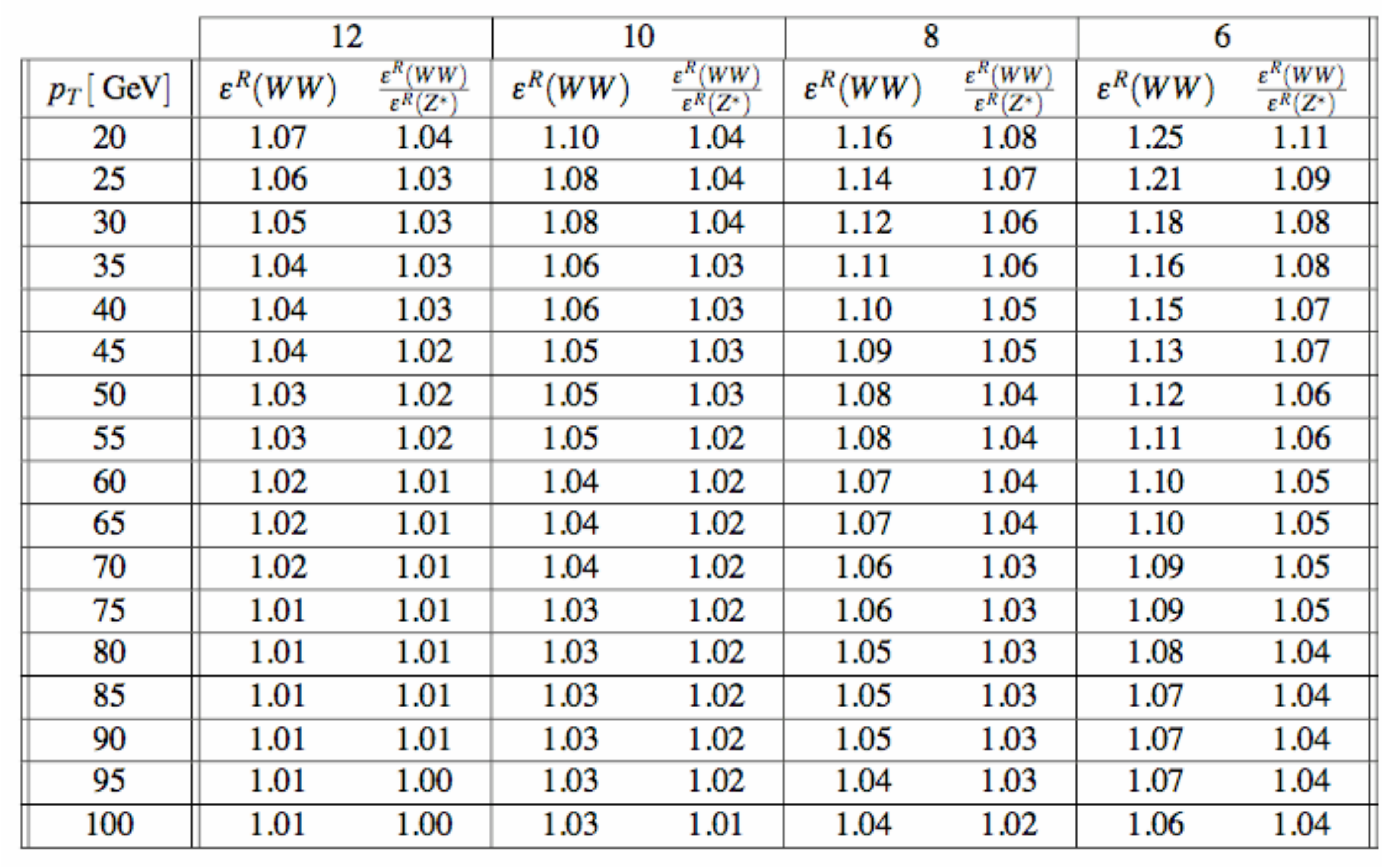
\sqrt{s} Dependence of Jet Veto

Results of ε shown for P_T=30 GeV



	WW			Z^*			
$\sqrt{s}$	$< p_{Tj} >$	$< \lvert\eta\rvert >$	ε_{jv}	$< p_{Tj} >$	$< \lvert\eta\rvert >$	ε_{jv}	$\frac{\varepsilon_{jv}^{WW}}{\varepsilon_{jv}^{Z^*}}$
14	38.6	0.76	0.64	22.3	0.58	0.77	0.83
12	34.8	0.68	0.67	20.7	0.54	0.78	0.86
10	32.1	0.66	0.69	18.9	0.50	0.80	0.86
8	27.7	0.59	0.72	17.2	0.47	0.81	0.89
6	22.7	0.51	0.76	14.3	0.40	0.84	0.90

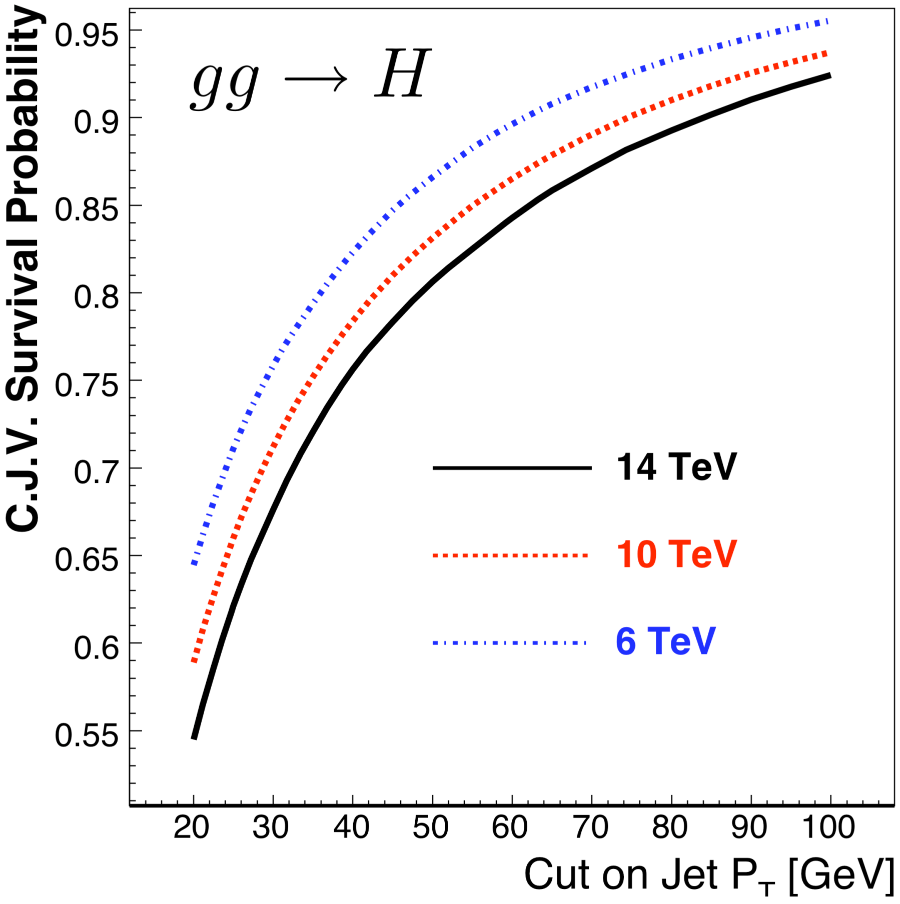
\sqrt{s} Dependence of Jet Veto



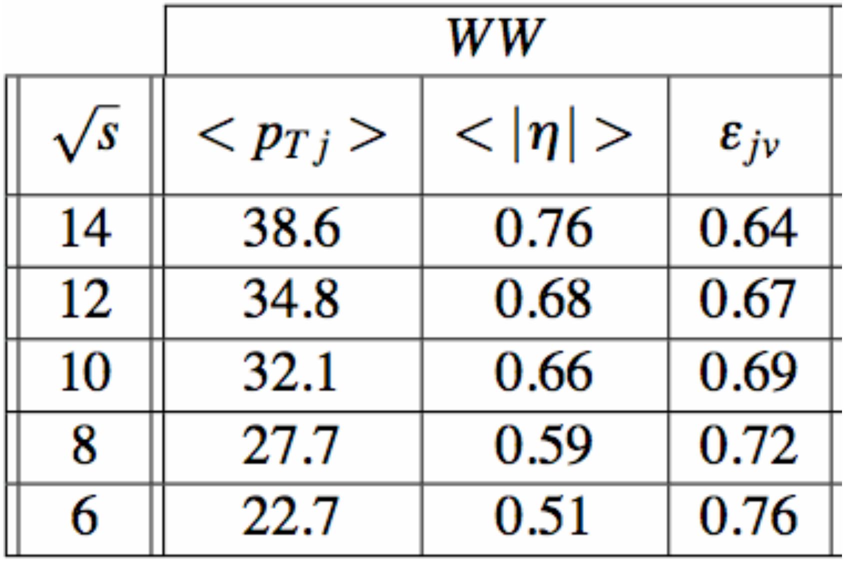
	12		10		8		6	
p_T [GeV]	$\varepsilon^R(WW)$	$\frac{\varepsilon^R(WW)}{\varepsilon^R(Z^*)}$	$\varepsilon^R(WW)$	$\frac{\varepsilon^R(WW)}{\varepsilon^R(Z^*)}$	$\varepsilon^R(WW)$	$\frac{\varepsilon^R(WW)}{\varepsilon^R(Z^*)}$	$\varepsilon^R(WW)$	$\frac{\varepsilon^R(WW)}{\varepsilon^R(Z^*)}$
20	1.07	1.04	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

Jet Veto Survival Prob for gg->VV

- **This quantity has not been calculated.**
- **We can get a feeling of how different it is from the qq->VV process by looking into gg->H**



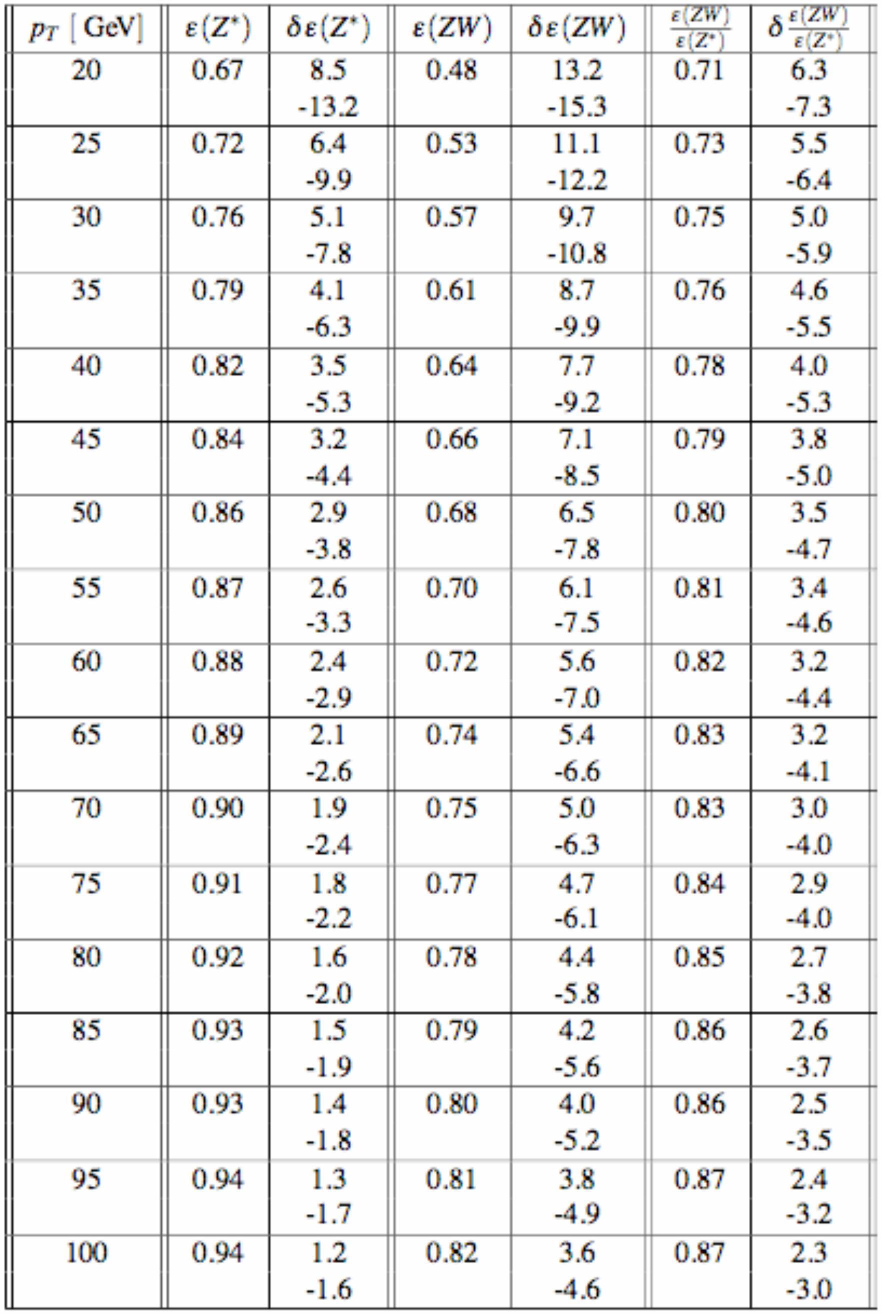
Jet veto survival probability for Higgs is very close to that of qq->WW



	WW		
$\sqrt{s}$	$< p_{Tj} >$	$< \lvert\eta\rvert >$	ε_{jv}
14	38.6	0.76	0.64
12	34.8	0.68	0.67
10	32.1	0.66	0.69
8	27.7	0.59	0.72
6	22.7	0.51	0.76

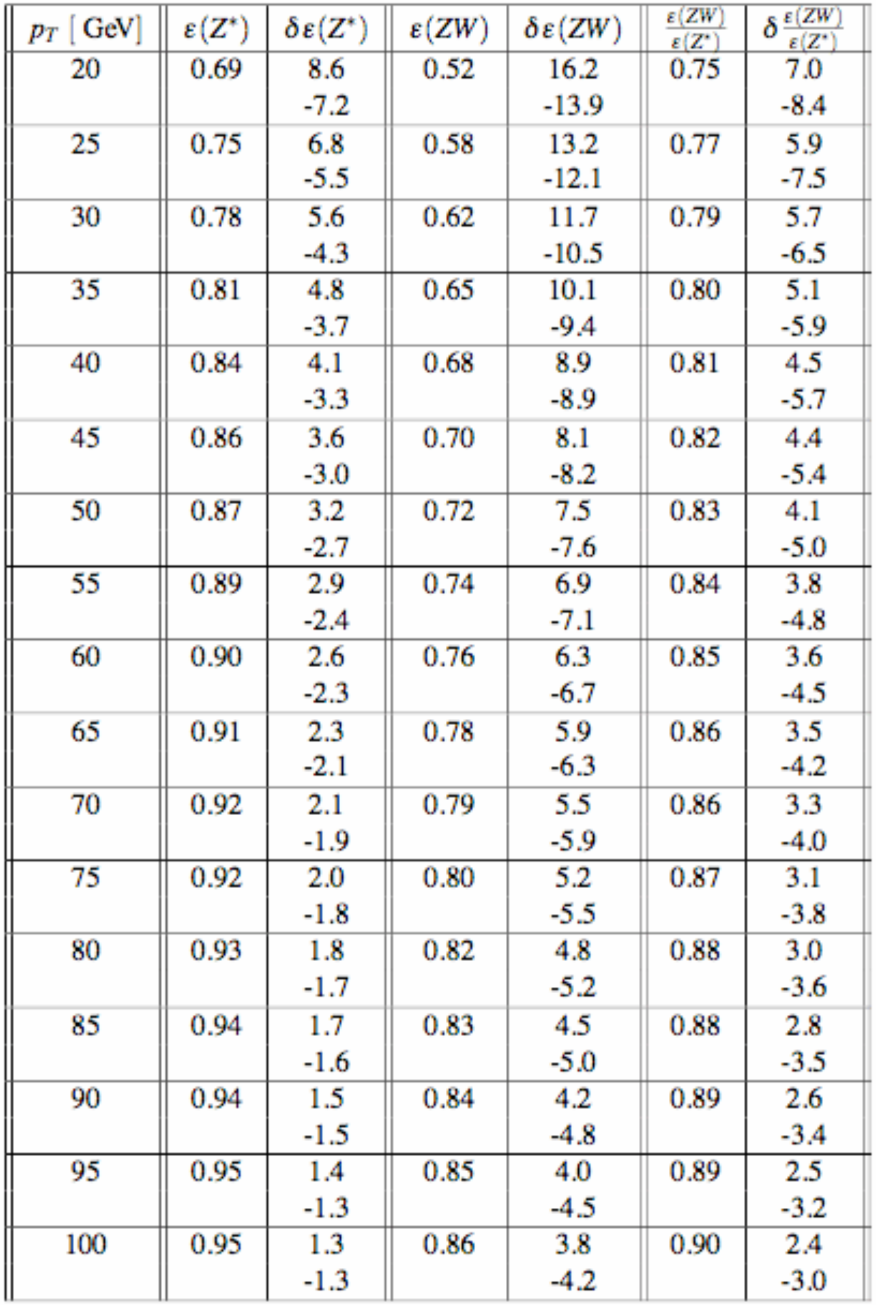
Results of ε shown for P_T=30 GeV

$\sqrt{s} = 14\ \mathrm{TeV}$



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

$\sqrt{s} = 10\ \mathrm{TeV}$



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 $\sigma(ZZ,WW)/\sigma(Z^{(*)})$ is dominated by the LO uncertainties of gg->VV
    - Errors remain at the level of 10%
    - Ratios depend weakly on \sqrt{s} and the mass
    - Also considered $\sigma(ZZ)/\sigma(WW)$ for which the uncertainty due to gg->VV cancels out
  - ☐ Consider Jet veto survival probability
    - Errors of $\varepsilon(WW,ZW)/\varepsilon(Z^*)$ stay below 10%

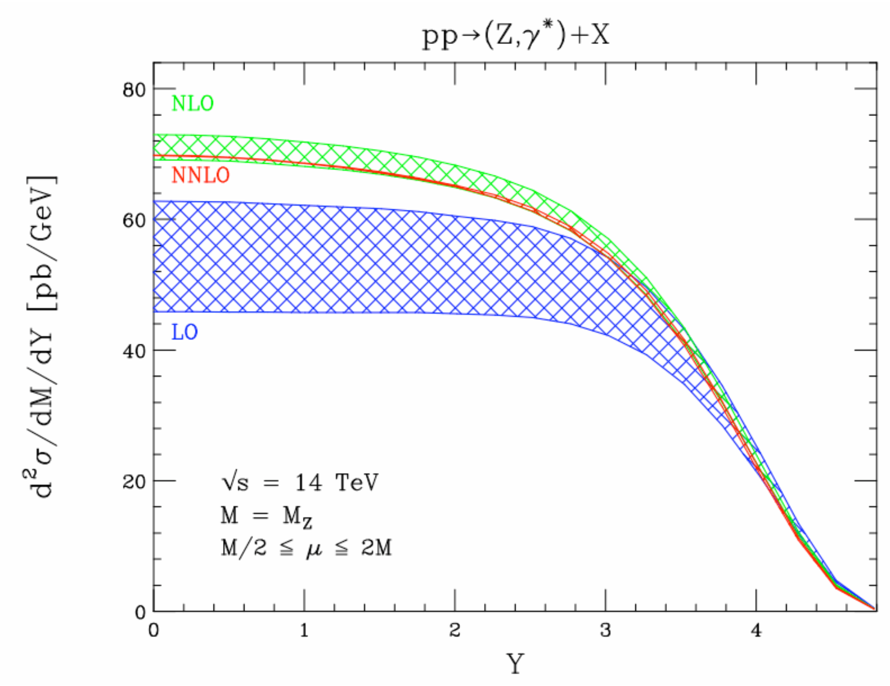
EXTRA SLIDES

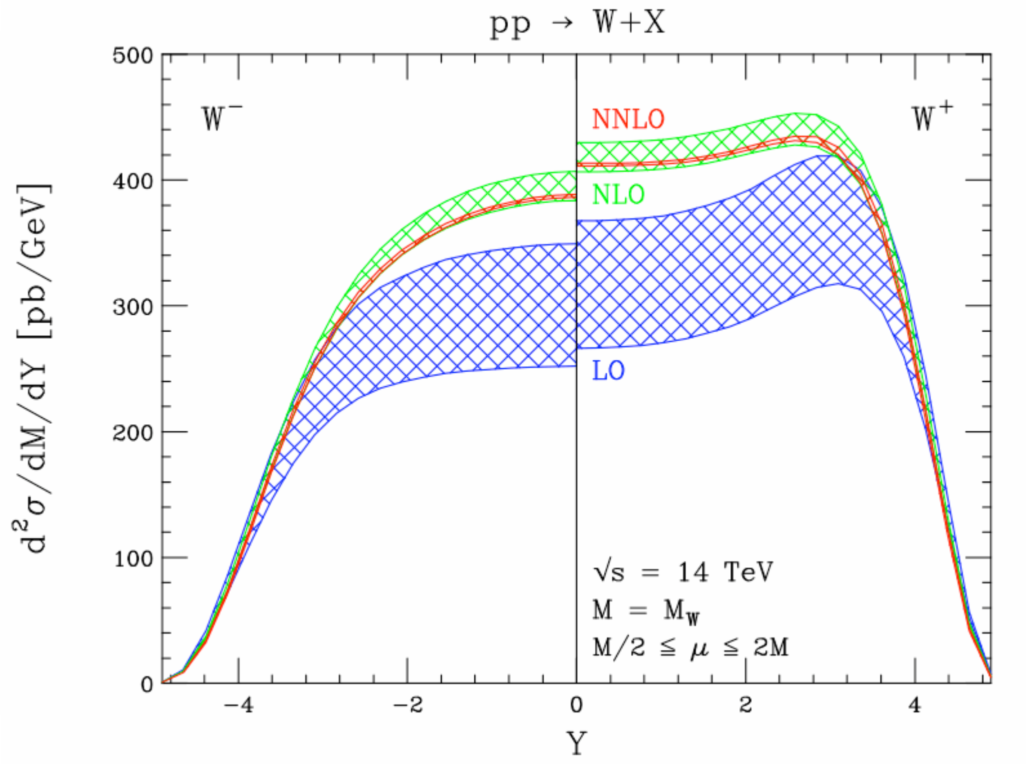
MCFM Settings

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.

Petrielo et al





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