q_T uncertainties in Drell-Yan W/Z boson production

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I) q_T resummation in electroweak boson production

Use Collins-Soper-Sterman (CSS) representation:
Realized in the space of the impact parameter b (conjugate to q_T)

$$\left.\frac{d\sigma_{AB\to VX}}{dQ^2 dy dq_T^2}\right|_{q_T^2 \ll Q^2} = \sum_{a,b=g,\overset{(-)}{u},\overset{(-)}{d},\ldots} \int \frac{d^2b}{S(2\pi)^2}\, e^{-i\vec{q}_T\cdot\vec{b}}\, \widetilde{W}_{ab}(b,Q,x_A,x_B) + Y$$

The form factor $\widetilde{W}_{ab}$ can be expressed as:

$$\widetilde{W}_{ab}(b,Q,x_A,x_B) = \frac{d\hat{\sigma}_{ab\to l_1 l_2(\gamma)}}{d\Pi}\, e^{-\mathcal{S}(b,Q)}\, \overline{\mathcal{P}}_a(x_A,b)\, \overline{\mathcal{P}}_b(x_B,b)$$

- $\frac{d\hat{\sigma}_{ab\to l_1 l_2(\gamma)}}{d\Pi}$, $ab \to l_1 l_2(\gamma)$ cross section at tree level with or without final state NLO QED corrections
- $e^{-\mathcal{S}(b,Q)}$, Sudakov exponent
- $\overline{\mathcal{P}}(x,b)$, process dependent b-space parton distribution;

$$\overline{\mathcal{P}}_a(x_A,b) = \left[\mathcal{C}^{in}_{a/c} \otimes f_c\right](x_A,b)$$

I) q_T resummation in electroweak boson production

Use b^* prescription $b_* = b/\sqrt{1+b^2/b_{max}^2}$:

$$\widetilde{W}_{ab}(b,Q,x_A,x_B) =$$

$$\underbrace{\frac{d\hat{\sigma}_{ab\to l_1 l_2(\gamma)}}{d\Pi}}_{\substack{\text{1) Final state}\\\text{NLO QED}\\\text{corrections}}} e^{-S_P(b_*,Q)\underbrace{-S_{NP}(b,Q)}_{\substack{\text{2) New}\\\text{parameterization}}}\underbrace{-b^2\rho(x_A)-b^2\rho(x_B)}_{\substack{\text{3) Small-x}\\\text{effect}}}} \underbrace{\left[\mathcal{C}^{in}_{a/c}\otimes f_c\right](x_A)\ \left[\mathcal{C}^{in}_{b/d}\otimes f_d\right](x_B)}_{\substack{\text{4) Heavy quark effect}\\\text{5) PDF uncertainties}}}$$

1) Electroweak NLO corrections

$$\widetilde{W}_{ab}(b,Q,x_A,x_B) =$$

$$\underbrace{\frac{d\hat{\sigma}_{ab\to l_1 l_2(\gamma)}}{d\Pi}}_{\text{1) Final state NLO QED corrections}} e^{-S_P(b_*,Q)\underbrace{-S_{NP}(b,Q)}_{\text{2) New parameterization}}\underbrace{-b^2\rho(x_A)-b^2\rho(x_B)}_{\text{3) Small-x effect}}} \underbrace{\left[\mathcal{C}^{in}_{a/c}\otimes f_c\right](x_A)\left[\mathcal{C}^{in}_{b/d}\otimes f_d\right](x_B)}_{\substack{\text{4) Heavy quark effect} \\ \text{5) PDF uncertainties}}}$$

1) Electroweak NLO corrections

- Run Ib: Effective Born approximation (EBA); estimated error:
  $\delta M_W(W \to e\nu_e) = -65 \pm 20$ MeV, $\delta M_W(W \to \mu\nu_\mu) = -168 \pm 10$ MeV

- Pole approximation of NLO corrections:
  - Corrections can be divided into initial and final state corrections and interference term
  - Final state QED (FQED) corrections dominate
    (Baur, Keller, Wackeroth, 1998)

- Full NLO electroweak corrections to W boson production
  (Dittmaier, Krämer, 2002; Baur, Wackeroth, 2004)
  required at $Q \gg M_{Z/W}$: $\Gamma_W^{Full-NLO} - \Gamma_W^{FQED} \approx 7$ MeV

- Radiation of two *(Baur, Stelzer, 2000)* and many photons *(Placzek, Jadach, 2003; Carlone Calame et al. 2003)* $\to \mathcal{O}(10\%)$ of $\delta M_W^{1\gamma}$

- FQED included in new version of Resbos (Resbos-A)
  (Q. Cao, C.-P. Yuan, 2004)

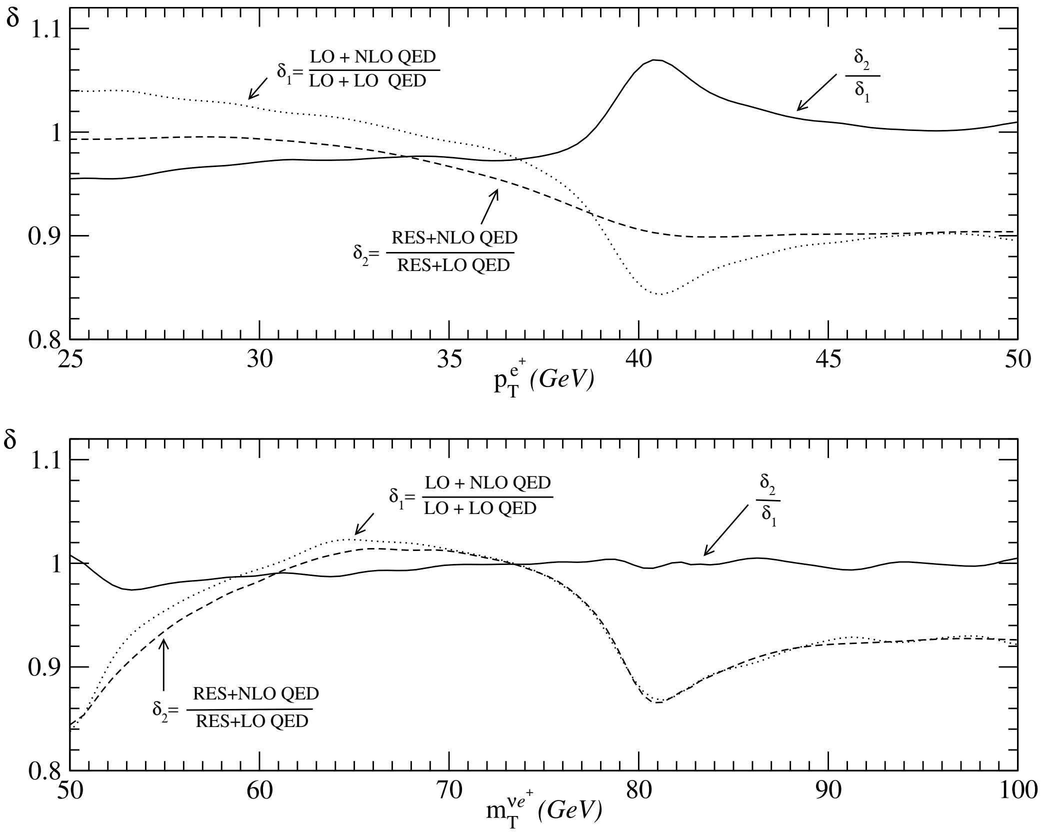
1) FQED NLO corrections: Resbos-A

(Q. Cao, C.-P. Yuan, 2004)

$$\delta_1 = \frac{LO{+}NLO\ QED}{LO{+}LO\ QED}$$

$$\delta_2 = \frac{RES{+}NLO\ QED}{RES{+}LO\ QED}$$

$p\bar{p} \to W + X \to e\nu_e + X$, Tevatron



(Yuan, Cao, hep-ph/0401026)

Tevatron/LHC

- FQED reduces $d\sigma/dM_T$ at the peak by 12%
- $d\sigma/dp_T^e$ reduced by 15%

finite resolution of detector not yet included

$\to \delta M_W^{FQED}$, $\delta\Gamma_W^{FQED}$ not estimated

2) Uncertainties of S_{NP}

$$\widetilde{W}_{ab}(b,Q,x_A,x_B) =$$

$$\underbrace{\frac{d\hat{\sigma}_{ab\to l_1 l_2(\gamma)}}{d\Pi}}_{\text{1) Final state NLO QED corrections}} e^{-S_P(b_*,Q)\underbrace{-S_{NP}(b,Q)}_{\text{2) New parameterization}}\underbrace{-b^2\rho(x_A)-b^2\rho(x_B)}_{\text{3) Small-x effect}}} \underbrace{\left[\mathcal{C}^{in}_{a/c}\otimes f_c\right](x_A)\left[\mathcal{C}^{in}_{b/d}\otimes f_d\right](x_B)}_{\text{4) Heavy quark effect; 5) PDF uncertainties}}$$

2) Uncertainties of S_{NP}

(P. Nadolsky, A. Konychev, 2005)

- new fit of S_{NP} with $b_{max} = 1.5$ GeV (global minimum of χ^2, $b^* = \frac{b}{\sqrt{1+b^2/b^2_{max}}}$)
- central values: $a_1 = 0.201$ GeV, $a_2 = 0.184$ GeV, $a_3 = -0.026$ GeV

$$S_{NP} = \underbrace{b^2\left(a_1 + a_2 \ln\frac{Q}{3.2\ \mathrm{GeV}} + a_3 \ln 100 x_1 x_2\right)} \quad + \quad \underbrace{g(b, x_1) + g(b, x_2)}$$

- entirely soft factor
- $a_1 = g_1$, $a_2 = g_2$, $a_3 = g_1 g_2$,
- a_3 small, almost independent of $\sqrt{\hat{s}}$
- can be derived from Tevatron

- independent of Q^2
- to do: may be extracted from HERA

2) Uncertainties of S_{NP}

$$S_{NP} = b^2 \left(a_1 + a_2 \ln \frac{Q}{3.2 \text{ GeV}} + a_3 \ln 100 x_1 x_2 \right)$$

Plotted is: $\Delta = \dfrac{d\sigma^X / dp_T^e}{d\sigma^{stand} / dp_T^e}$

with $d\sigma^{stand}/dp_T^e$ defined:

- $M_W = 80.423$ GeV, a_1, a_2, a_3 central

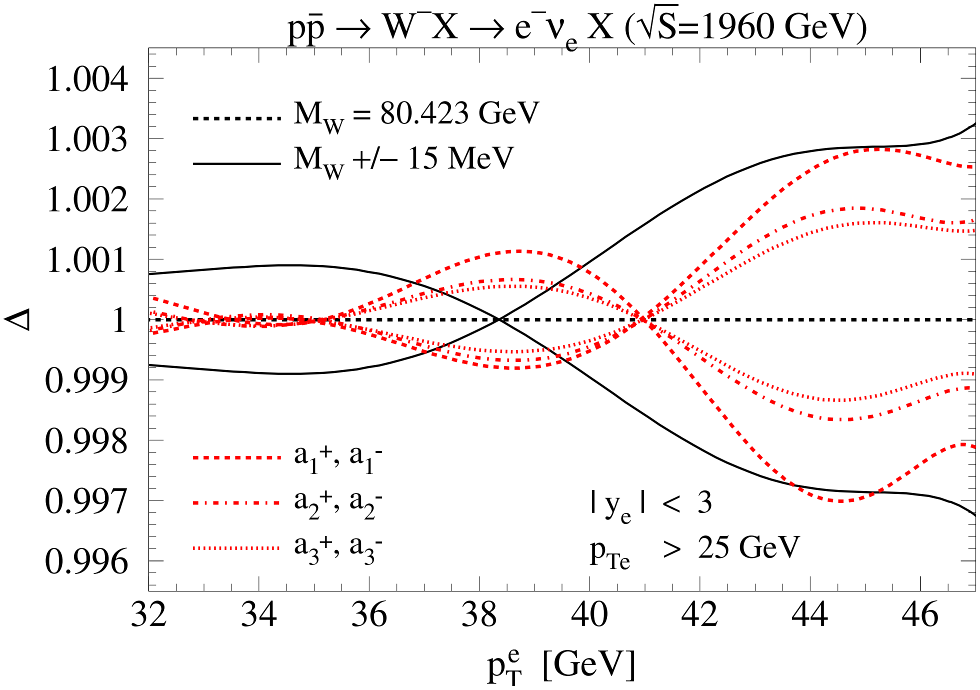
$a_1^{\pm}, a_2^{\pm}, a_3^{\pm}$ extreme sets

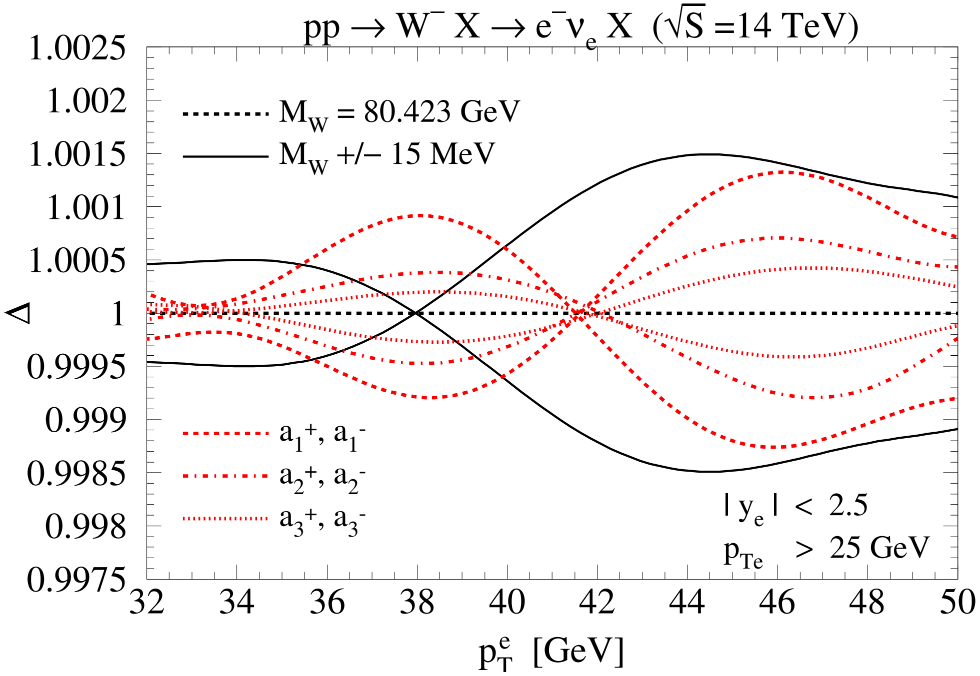
of a_1, a_2, a_3 for $\delta\chi^2 = 1$

corresponding to 1σ

(Nadolsky, Konychev, 2005)

- tiny M_T^W effect
- current $M_W(p_T^e)$ uncertainty ≈ 17 MeV





3) Small-x effect at Tevatron

$$\widetilde{W}_{ab}(b,Q,x_A,x_B) =$$

$$\underbrace{\frac{d\hat{\sigma}_{ab\to l_1 l_2(\gamma)}}{d\Pi}\, e}_{\text{1) Final state NLO QED corrections}}{}^{-S_P(b_*,Q)\underbrace{-S_{NP}(b,Q)}_{\text{2) New parameterization}}\underbrace{-b^2\rho(x_A)-b^2\rho(x_B)}_{\text{3) Small-x effect}}} \underbrace{\left[\mathcal{C}^{in}_{a/c}\otimes f_c\right](x_A)\left[\mathcal{C}^{in}_{b/d}\otimes f_d\right](x_B)}_{\substack{\text{4) Heavy quark effect} \\ \text{5) PDF uncertainties}}}$$

3) Small-x effect at Tevatron

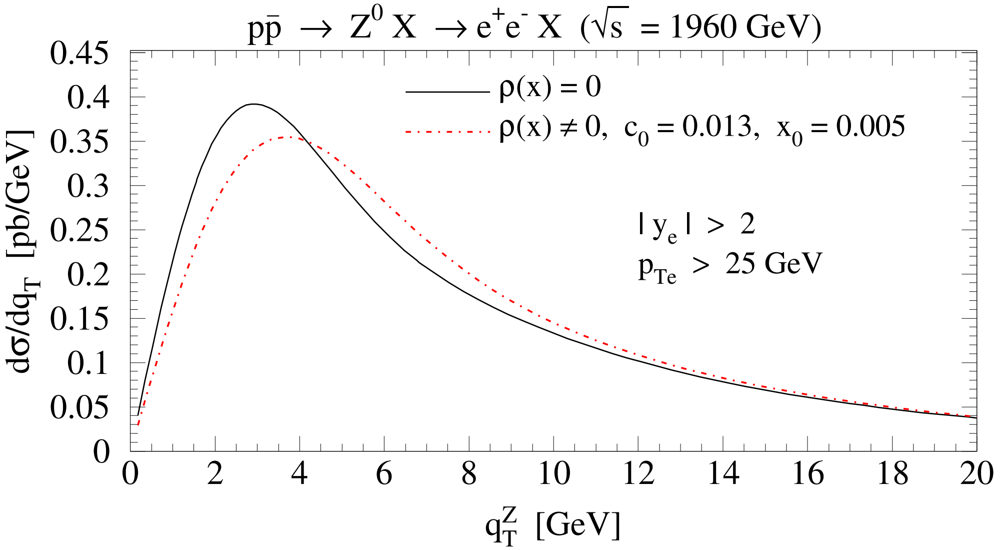
(S.B., P. Nadolsky, F. Olness, 2005)

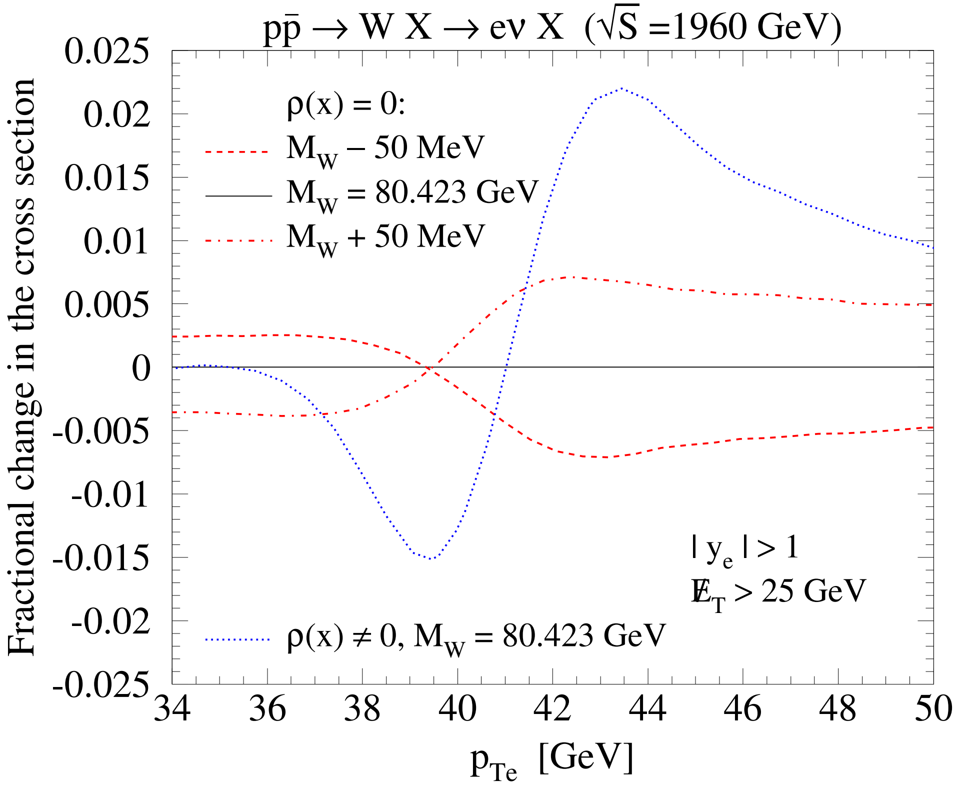
From resummed z-flow data at Hera H1 (Nadolsky, Stump, Yuan, 2002)
→ small-x behavior only consistent with data if a q_T-broadening factor in the CSS formalism is introduced

$$\sim exp\left\{-c_0\frac{b^2}{x}\right\}$$

→ important for $x < 0.005$
or $y > 2$ at Tevatron

- Shifts M_W by more than 50 MeV for $y_e > 1$ even with detector smearing
- Shifts M_W by $10 - 20$ MeV for $y_e < 1$
- No effect on M_T^W





2) Small-x effect at LHC

(S.B., P. Nadolsky, F. Olness, 2005)

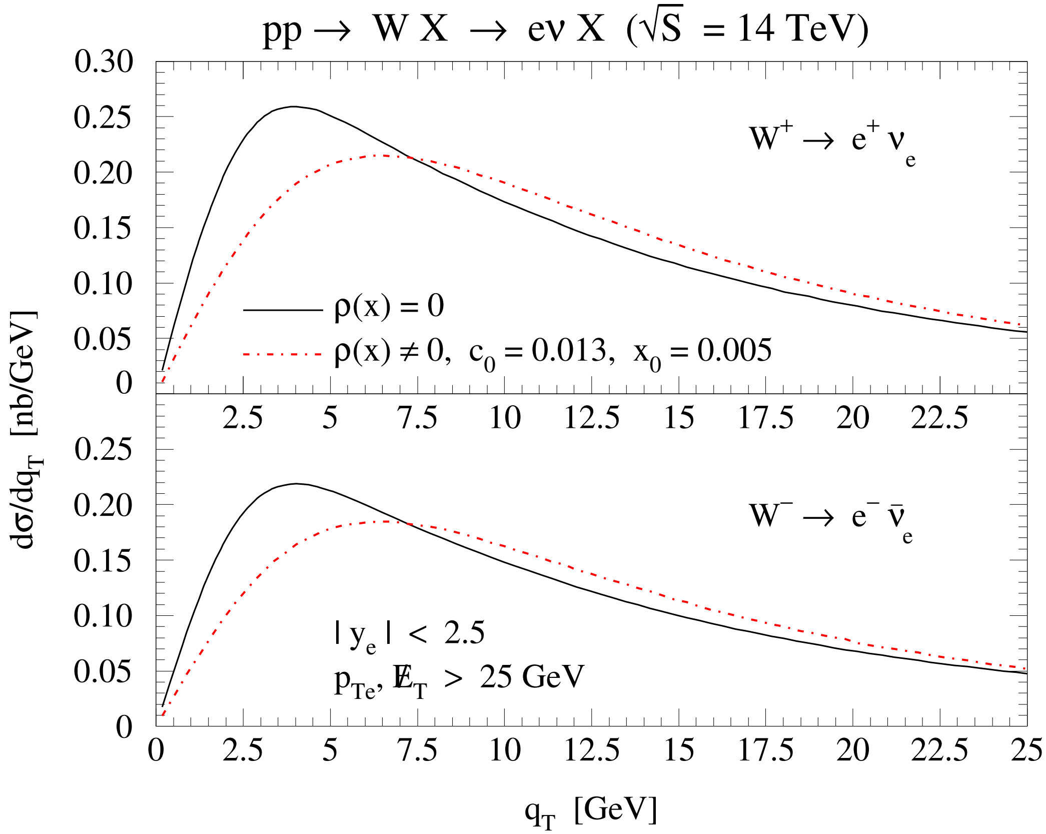
$|y_e| < 2.5$:

- x stays above 10^{-4} (SIDIS data)
- coverage of the inner ATLAS detector

Small x broadening enhanced even in the central region due to $x|_{y\approx 0} \approx 0.006$

- Huge impact on W mass measurement with p_T^e distribution
- Very small impact on M_T^W

$pp \to W + X$ at LHC



Dependence of $d\sigma/dq_T^W$ on transverse W-boson momentum q_T^W

4) Heavy quark effects

$$\widetilde{W}_{ab}(b,Q,x_A,x_B) = \underbrace{\frac{d\hat{\sigma}_{ab\to l_1 l_2(\gamma)}}{d\Pi}}_{\text{1) Final state NLO QED corrections}} e^{-S_P(b_*,Q)\underbrace{-S_{NP}(b,Q)}_{\text{2) New parameterization}}\underbrace{-b^2\rho(x_A)-b^2\rho(x_B)}_{\text{3) Small-x effect}}} \underbrace{\left[\mathcal{C}^{in}_{a/c}\otimes f_c\right](x_A)\ \left[\mathcal{C}^{in}_{b/d}\otimes f_d\right](x_B)}_{\substack{\text{4) Heavy quark effect} \\ \text{5) PDF uncertainties}}}$$

4) Heavy quark effects

(S.B., P. Nadolsky, F. Olness, 2005)

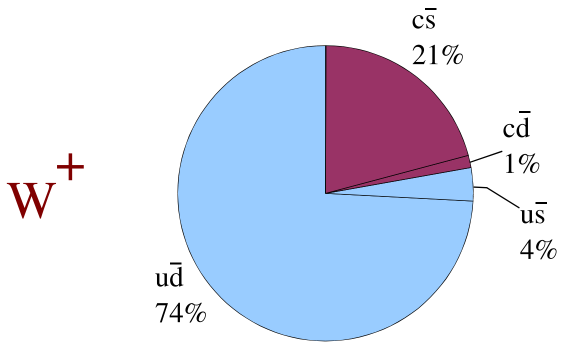
- q_T resummation in massive VFN (S-ACOT) scheme *(N. Kidonakis, P. Nadolsky, F. Olness, C.-P. Yuan, 2003)*

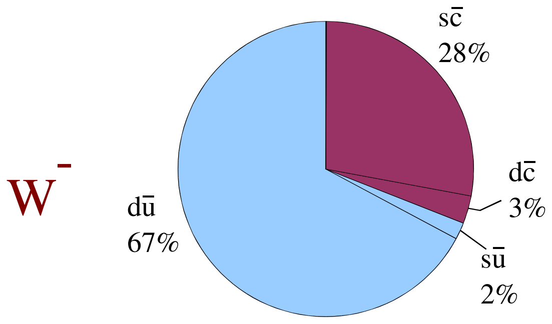
- see also $b\bar{b} \to H$ talk by P. Nadolsky

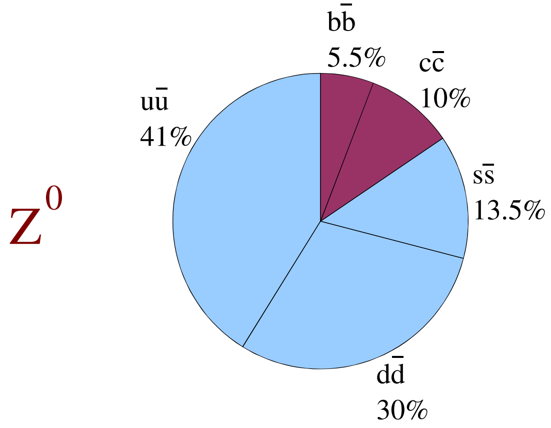
- Zero-mass VFN approximation underestimates S-ACOT scheme at impact parameters $b \sim 1/m_b$
  $\to$ ZM-VFNS suppresses small q_T region
  $\to$ ZM-VFNS shifts the peak region of the q_T-distribution to larger values, therefore M_W to higher values

- Effect for W/Z production at Tevatron negligible, because c, b contribution to $d\sigma$ only $3-8\%$

- Most important for W^- production at LHC

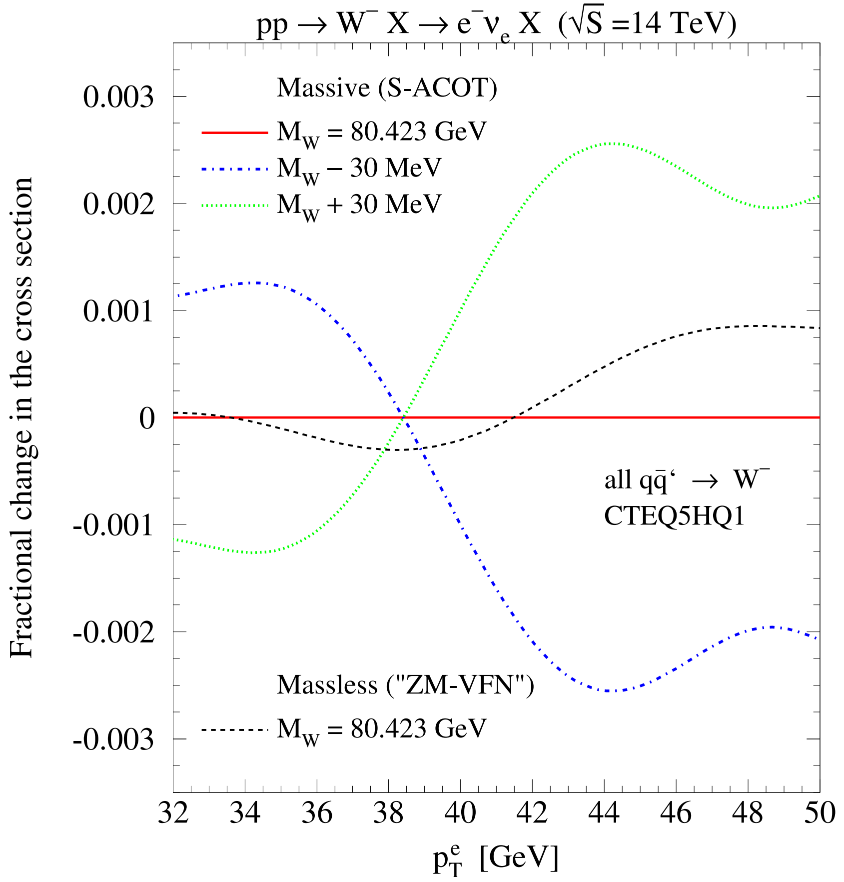


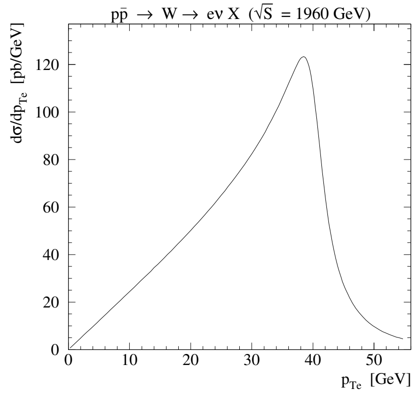




4) Heavy quark effects

(S.B., P. Nadolsky, F. Olness, 2005)





Shifts the Jacobian peak in the positive direction

ZM-VFNS W-mass shifts:

W^- at LHC: $+10$ MeV

W^+ at LHC: $6 - 9$ MeV

$W^\pm$ at Tevatron: negligible

plotted is
$$\frac{d\sigma_X/dp_T^e}{d\sigma_{M_W}^{massless}/dp_T^e}$$

Effect in Z boson production at Tevatron and LHC not important

5) PDF uncertainties

$$\widetilde{W}_{ab}(b,Q,x_A,x_B) =$$

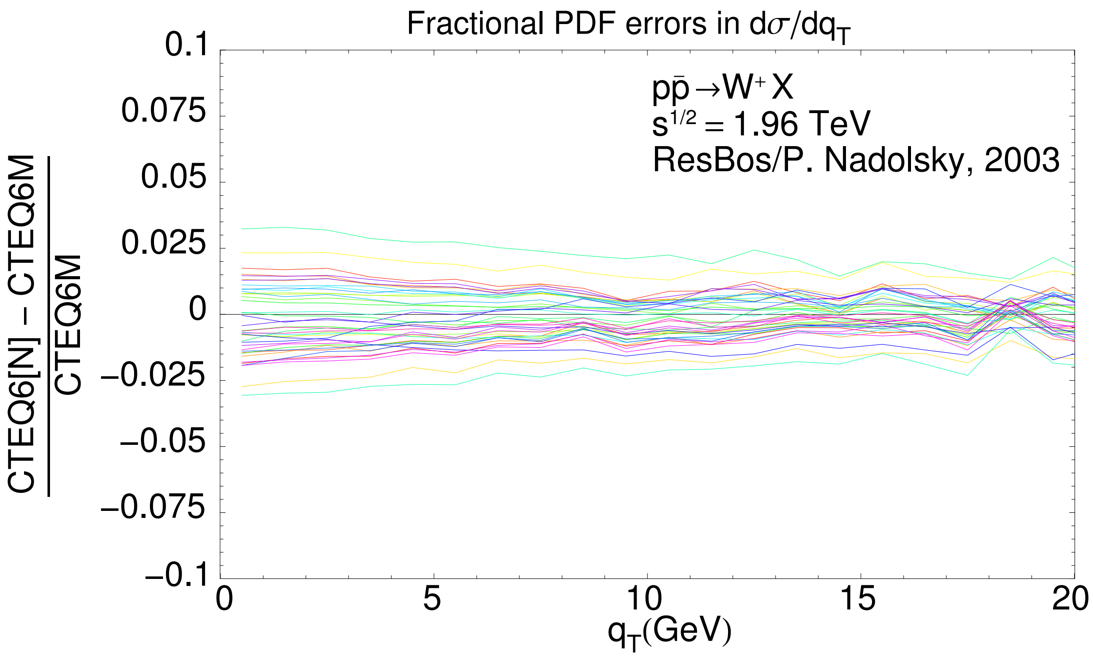
$$\underbrace{\frac{d\hat{\sigma}_{ab\to l_1 l_2(\gamma)}}{d\Pi}}_{\text{1) Final state NLO QED corrections}} e^{-S_P(b_*,Q)\underbrace{-S_{NP}(b,Q)}_{\text{2) New parameterization}}\underbrace{-b^2\rho(x_A)-b^2\rho(x_B)}_{\text{3) Small-x effect}}} \underbrace{\Big[\mathcal{C}^{in}_{a/c}\otimes f_c\Big](x_A)\ \Big[\mathcal{C}^{in}_{b/d}\otimes f_d\Big](x_B)}_{\substack{\text{4) Heavy quark effect} \\ \text{5) PDF uncertainties}}}$$

5) PDF uncertainties

Very Preliminary study, P. Nadolsky, 2003

PDF's at Tevatron:

- q_T^W distribution at $|y_W| < 1$, $p_T^e > 25$ GeV using Resbos
- 40 sample PDF sets compare $\frac{d\sigma^{CTEQ6[N]}/dq_T^W}{d\sigma^{CTEQ6M}/dq_T^W} - 1$
- → change of the slope comparable with $\delta M_W(q_T)$ up to 50 MeV
- M_t^W distribution: tiny shift in slope ($\delta M_W(M_T) \leq 2$ MeV)



PDF's at LHC: study needed

IV) Conclusion

1. NLO electroweak corrections
2. Uncertainties of S_{NP}
3. Small-x effects
4. Heavy quark effects
5. PDF uncertainties