Single Top-Quark and W-Boson Production at NLO QCD

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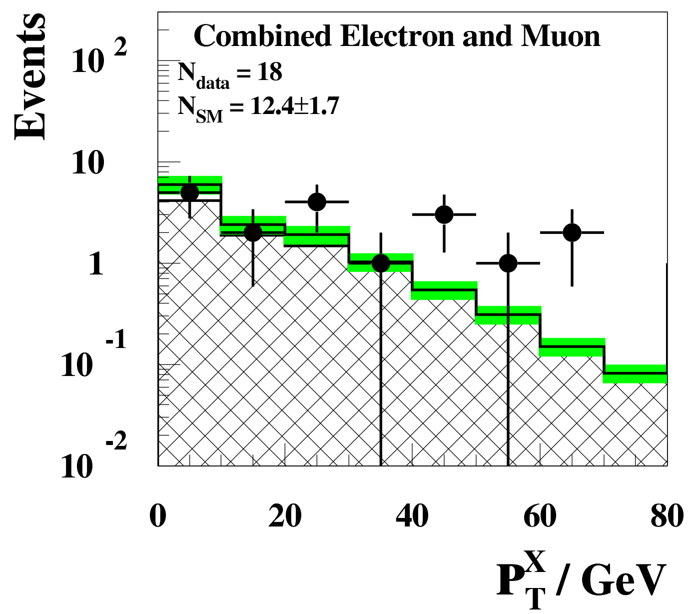
Introduction

H1: excess of high-energy isolated lepton events with large p_T^X (sum of transverse momenta without isolated lepton) and $\not{p}_T$



(H1 Collaboration, DESY 02-224)

- event kinematics mostly consistent with W production and leptonic decay

- excess for $p_T^X > 25\mathrm{GeV}$

- μ-channel: 8 obs. vs. 2.55 ± 0.44 exp.
  e-channel: 10 obs. vs. 9.9 ± 1.3 exp.

- SM description of hadronic decay channel ok for whole p_T^X range

- ZEUS: no significant excess

this talk is about:

$\rightarrow$ NLO QCD prediction for FCNC single top production

possible explanation for observed excess?

A. Belyaev, N. Kidonakis, hep-ph/0102072

$\rightarrow$ NLO QCD prediction for W production

basis for experimental analysis

Nason, Rückl, Spira

D., Schwanenberger, Spira

FCNC top production @ NLO QCD

effective Lagrangian approach:

$$\Delta\mathcal{L}^{\rm eff} = \frac{1}{\Lambda}(\kappa_{tq\gamma} e\bar{t}\sigma_{\mu\nu} q F^{\mu\nu}) + \mathrm{h.c.}$$

Expected bounds on $\kappa_{tq\gamma}$ from Tevatron Run 2

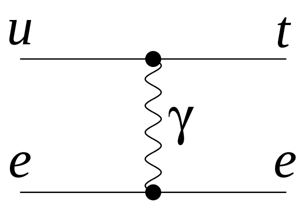
$\rightarrow$ from top production:

$$\kappa_{tc\gamma} < 0.24 \quad \kappa_{tu\gamma} < 0.026 \qquad (\text{with } \Lambda = m_t)$$

$\rightarrow$ from top decay studies:

$$\kappa_{tq\gamma} < 0.044 \qquad (\text{with } \Lambda = m_t)$$

$\rightarrow$ HERA can constrain $\kappa_{tu\gamma}$ in $eu \rightarrow et$:



ZEUS and H1 with $160\mathrm{pb}^{-1}$ could constrain $\kappa_{tu\gamma} \lesssim 0.05$
(at HERA: $\sigma(eu \rightarrow et) \approx 1\mathrm{pb}$ with max. allowed $\kappa_{tu\gamma}$)

$\rightarrow$ better than current bounds

$\rightarrow$ are isolated single lepton events with large p_T^X connetcted to single top production with subsequent decay $t \rightarrow bW \rightarrow b\bar{l}\nu$?
$\rightarrow$ most likely not! e/μ asymmetry

LO part. cross section for $eu \to et$:

$$d\hat{\sigma}^B_{eu\to et}/(dt\,du) = F^B_{eu\to et}\,\delta(s+t+u-m_t^2-2m_e^2)$$

with

$$F^B_{eu\to et} = \frac{\kappa_\gamma^2 e^4}{2\pi m_t^2 t^2 (s-m_e^2)^2}\left\{-t\left[2m_e^4+m_t^4-2s^2+(2s+t)\times(2s-m_t^2-2m_e^2)\right]-2m_e^2 m_t^4\right\}$$

$\to$ LO cross section with $\sqrt{S}=300\mathrm{GeV}$, CTEQ5M shows strong scale dependence :

$$\sigma^B(Q=5\mathrm{GeV}) = 0.78\mathrm{pb} \qquad \sigma^B(Q=m_t) = 0.39\mathrm{pb}$$

A. Belyaev, N. Kidonakis, hep-ph/0102072 (BK)

BK include NLO QCD corrections to extenuate scale dependence

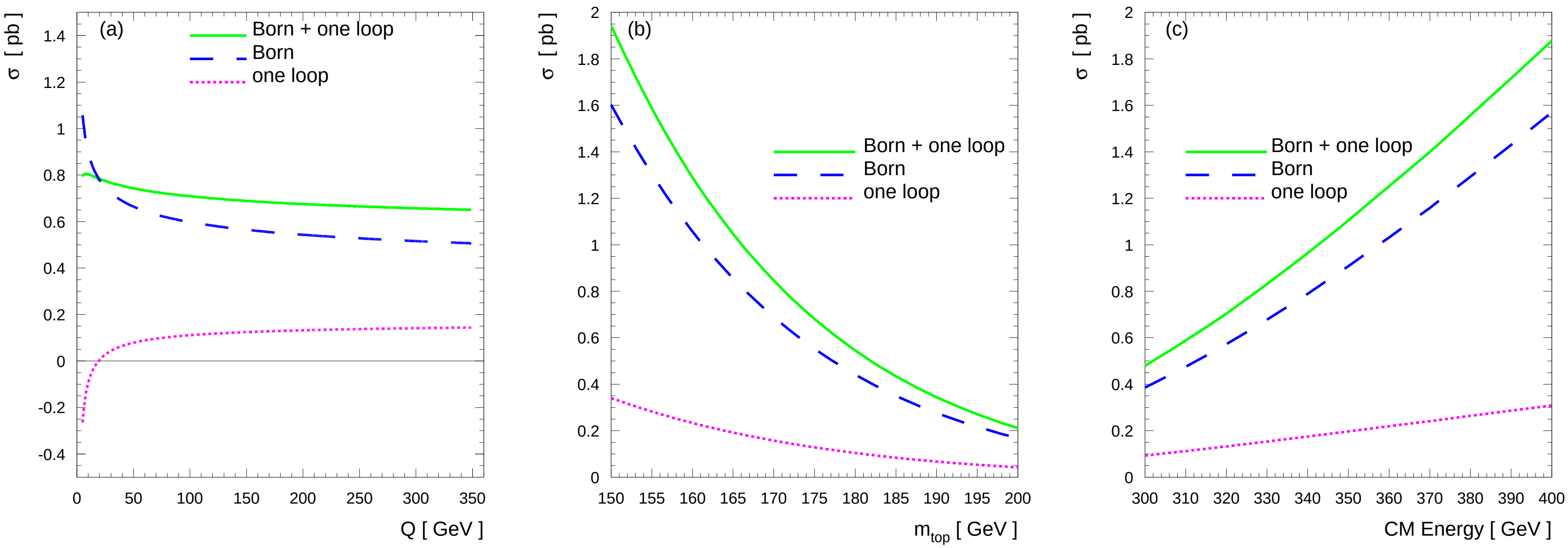
due to heavy top: cross section is dominated by threshold region
$\rightarrow$ eikonal approximation is applicable

NLO QCD corrected cross section in eikonal approximation:

$$\frac{d\hat{\sigma}^{(1)}_{eu\to et}}{dt\,du} = F^{B}_{eu\to et}\frac{\alpha_s(\mu_R^2)}{\pi}\left\{2C_F\left[\frac{\ln(s_2/m_t^2)}{s_2}\right]_+ + \left[\frac{1}{s_2}\right]_+ C_F\left[-1-2\ln\left(\frac{-u+m_e^2}{m_t^2}\right)+2\ln\left(\frac{m_t^2-t}{m_t^2}\right)-\ln\left(\frac{\mu_F^2}{m_t^2}\right)\right]\right\} + \delta(s_2)\left[-\frac{3}{4}+\ln\left(\frac{-u+m_e^2}{m_t^2}\right)\right]C_F\ln\left(\frac{\mu_F^2}{m_t^2}\right)\Bigg\}$$

with $s_2 = s+t+u-m_t^2-2m_e^2$

results for $\sqrt{S} = 318\text{GeV}$, CTEQ5M, $Q = m_t = 175\text{GeV}$, $\kappa_{tu\gamma} = 0.1$



cross sections over Q (a), m_t (b), $\sqrt{S}$ (c)

figures: BK

results of NLO QCD analysis in eikonal approximation:

- scale dependence is extenuated (a)
- $Q = m_t$ reasonable (a)
- NLO cross section 0.68pb i.e. relative correction of $\sim 24\%$
- varying m_t by $\pm 5\text{GeV}$ changes cross section by 20% (b)
- increase in $\sqrt{S}$ by 6% $(300\text{GeV} \to 318\text{GeV})$ leads to increase in cross section by 40% (c)

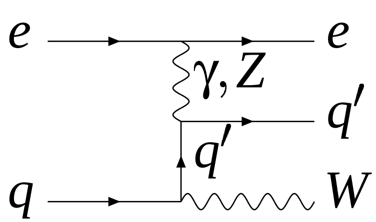
W production at NLO QCD

recall: H1 claims excess of isolated single lepton events with high p_T^X

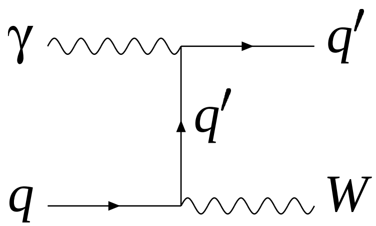
$\rightarrow$ W production is dominant SM process for this signature

$\rightarrow$ W production is important SM background to many new physics searches e.g. FCNC top production , $\not{R}$ SUSY, etc.

$\rightarrow$ W production can test gauge self-interactions production mechanisms:

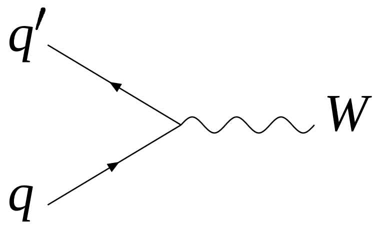


DIS: $Q^2 = -(p_e - p_e')^2 > Q^2_{max}$



direct photoproduction: $Q^2 < Q^2_{max}$, on-shell γ ,

γ spectrum in Weizsäcker-Williams approx. (WWA)



resolved photoproduction: $f_e^q = f_e^\gamma \otimes f_\gamma^q$

LO inclusive cross section

a) direct photonproduction $\gamma q \to W^{\pm} + q'$

$$\sigma_{LO}^{dir} = \int_{M_W^2/s}^{1} d\tau \sum_q \left(f_e^{\gamma} \otimes f_p^{q} \right) (\tau)\, \hat{\sigma}_{LO}^{dir}(\hat{s} = \tau s)$$

with $f_e^{\gamma}(x) = \frac{\alpha}{2\pi} \left\{ \frac{1+(1-x)^2}{x} \log \frac{Q_{max}^2}{Q_{min}^2} - 2m_e^2 x \left(\frac{1}{Q_{min}^2} - \frac{1}{Q_{max}^2} \right) \right\}$ (WWA)

$$\begin{aligned} \hat{\sigma}_{LO}^{dir} \;=\; & \frac{G_F M_W^2 \alpha}{2\sqrt{2}\hat{s}} C_\varepsilon \left\{ 2e_{q'}^2 [z^2 + (1-z)^2] \left[-\frac{1}{\varepsilon} - \log \left(\frac{\mu_F^2 z}{M_W^2 (1-z)^2} \right) \right] \right. \\ & + e_{q'}^2 \left[1 + 6z - 7z^2 \right] + 2 e_{q'} e_W \left[3(1-z^2) + 4(1+z^2) \log z \right] \\ & \left. + e_W^2 \left[\frac{1-z}{z} (4 + 5z + 7z^2) + (8 + 4z + 4z^2) \log z \right] \right\} \end{aligned}$$

with $z = \frac{M_W^2}{\hat{s}}$, $C_\varepsilon = \frac{\Gamma(1-\varepsilon)}{\Gamma(1-2\varepsilon)} \left(\frac{4\pi\mu^2}{\mu_F^2} \right)^{\varepsilon}$ and $Q_{min}^2 = m_e^2 \frac{x^2}{1-x}$

singularity in $q^2=(p_q-p_{q'})^2 \to$ pole in $1/\varepsilon$ after PS integration in $D=4-2\varepsilon$ dimensions

$\to$ absorb into f_γ^q ($\overline{MS}$)

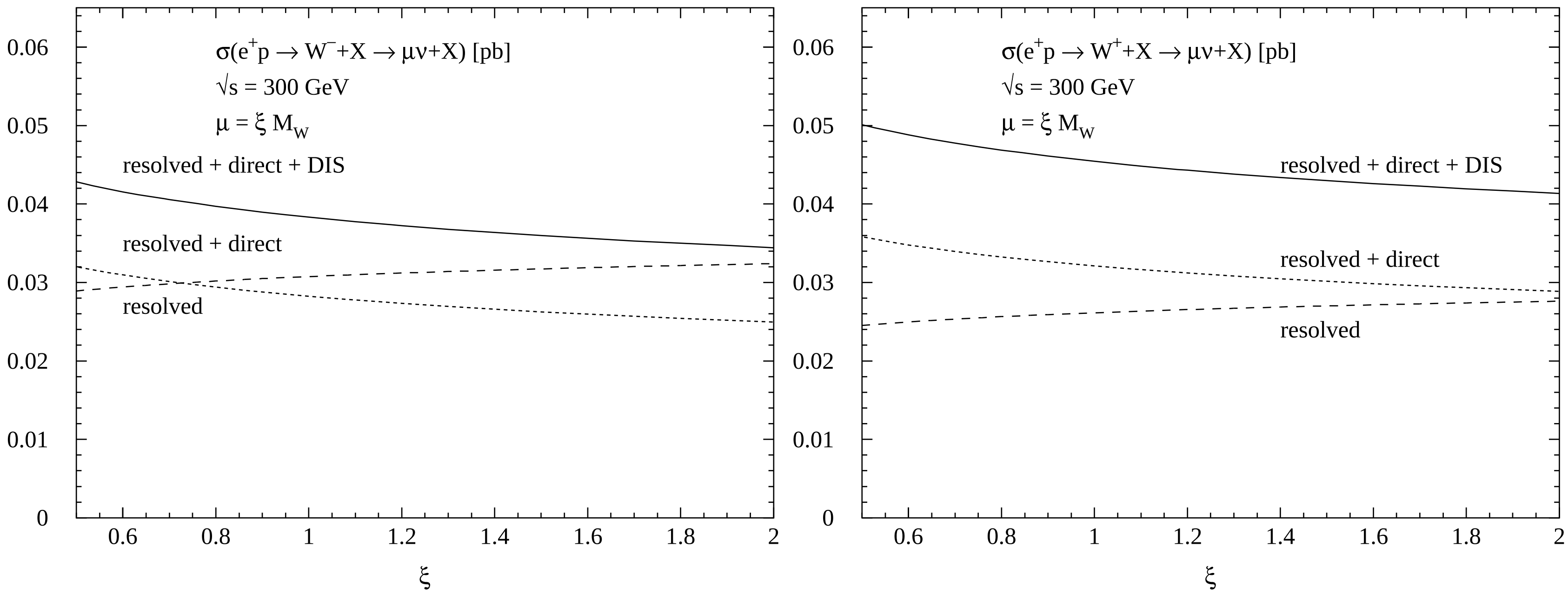
b) resolved photoproduction $q\overline{q}' \to W^\pm$

$$\sigma_{LO}^{res}=\int_{M_W^2/s}^1 d\tau \sum_{q,q'} \frac{d\mathcal{L}^{q\overline{q}'}}{d\tau}\hat{\sigma}_{LO}^{res}(\hat{s}=\tau s)$$

with $\frac{d\mathcal{L}^{q\overline{q}'}}{d\tau}=\left[f_p^q\otimes f_\gamma^{\overline{q}'}+f_p^{\overline{q}'}\otimes f_\gamma^q\right]\otimes f_e^\gamma$ and $\hat{\sigma}_{LO}^{res}=\frac{\sqrt{2}G_F\pi}{3}\,\delta(1-z)$

c) DIS $eq\to eq'W^\pm$

$$\sigma_{LO}^{dir}=\int_{M_W^2/s}^1 d\tau \sum_q f_p^q(\tau)\,\hat{\sigma}_{LO}^{DIS}(\hat{s}=\tau s)$$



CTEQ4M, ACFGP

Nason, Rückl, Spira

resolved photoproduction	$\sim 60\%$
direct photoproduction	$\sim 15\%$
DIS	$\sim 25\%$

$\rightarrow$ restrict NLO analysis to resolved photoproduction

NLO QCD corrections to resolved photoproduction

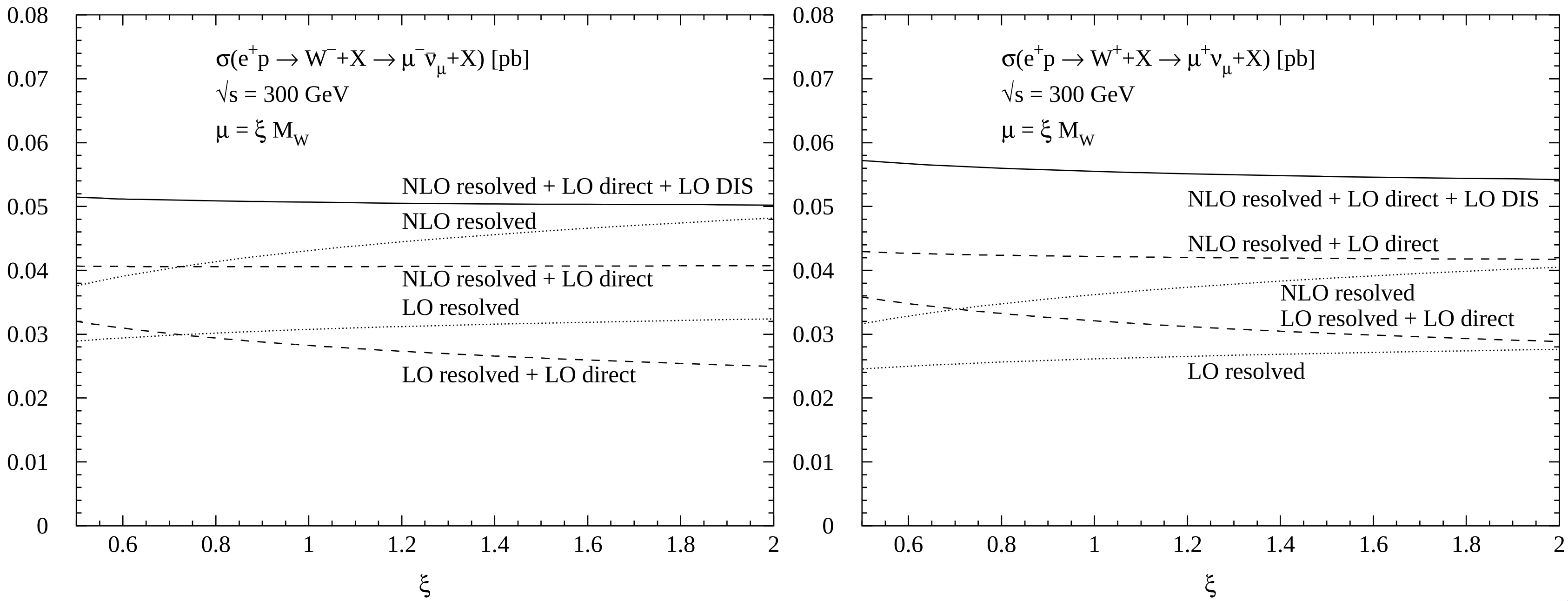
total resolved cross section: $\sigma^{res} = \sigma^{res}_{LO} + \sigma^{res}_{NLO}$

$$\sigma^{res}_{NLO} = \frac{\sqrt{2}G_F\pi}{3}\frac{\alpha_s(\mu_R^2)}{\pi}\Big(\Big[f_p^q \otimes f_\gamma^{\bar{q}'} + f_p^{\bar{q}'} \otimes f_\gamma^q\Big] \otimes f_e^\gamma \otimes \omega_{q\bar{q}} + \big[f_p^g \otimes f_\gamma^q + f_p^q \otimes f_\gamma^g\big] \otimes f_e^\gamma \otimes \omega_{qg}\Big)$$

with

$$\omega_{q\bar{q}}(z) = -P_{qq}(z)\log\frac{\mu_F^2 z}{M_W^2} + \frac{4}{3}\Big\{2[\zeta_2 - 2]\delta(1-z) + 4\left(\frac{\log(1-z)}{1-z}\right)_+ - 2(1+z)\log(1-z)\Big\}$$

$$\omega_{qg}(z) = -\frac{1}{2}P_{qg}(z)\log\left(\frac{\mu_F^2 z}{(1-z)^2 M_W^2}\right) + \frac{1}{8}\left\{1 + 6z - 7z^2\right\}$$



Nason, Rückl, Spira

- corrections (@ $\mu = M_W$) $\sim 40\% \to$ important contribution

- scale dependences in reduced to $\lesssim \pm 5\%$ in Q and Q_{max}

- corrections to direct and DIS expected $\lesssim 30\%$

LO exclusive cross sections

double differential distributions in p_T, y of the W

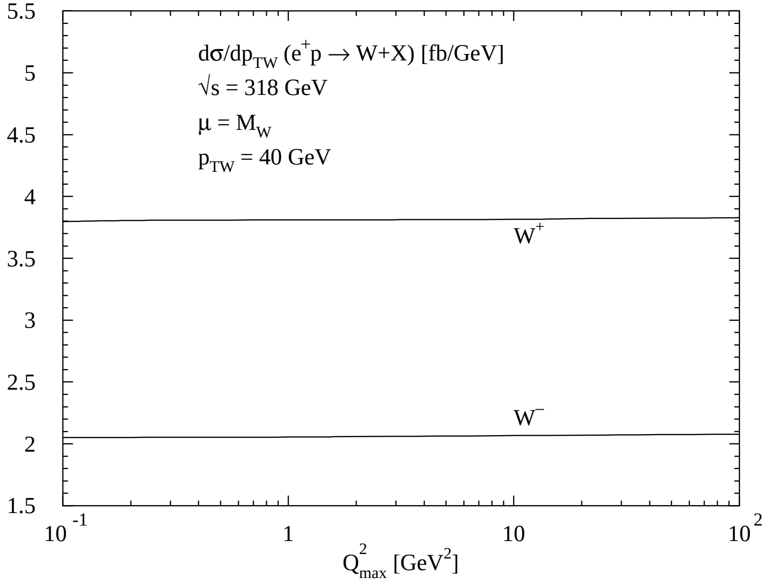
a) DIS straightforward

b) direct photoproduction:

$$
\begin{aligned}
\frac{d^2\sigma^{dir}_{LO}}{dp_T dy} &= 2p_{TW}\sum_{q,\bar{q}}\int_{x_\gamma^-}^{1}\frac{dx_\gamma}{x_\gamma} f_e^\gamma(x_\gamma)\, f_p^q(x_p,\mu_F^2)\frac{x_p}{s+u_1}\frac{s^2}{S}\frac{d\hat{\sigma}^{dir}_{LO}}{dt_1} \\
\frac{d\hat{\sigma}^{dir}_{LO}}{dt_1} &= -\frac{G_F M_W^2 \alpha}{\sqrt{2}}\frac{(e_{q'}t_1 - e_W u)^2}{s^2 u t_1^2}\left(s^2+u^2+2M_W^2 t\right)
\end{aligned}
$$

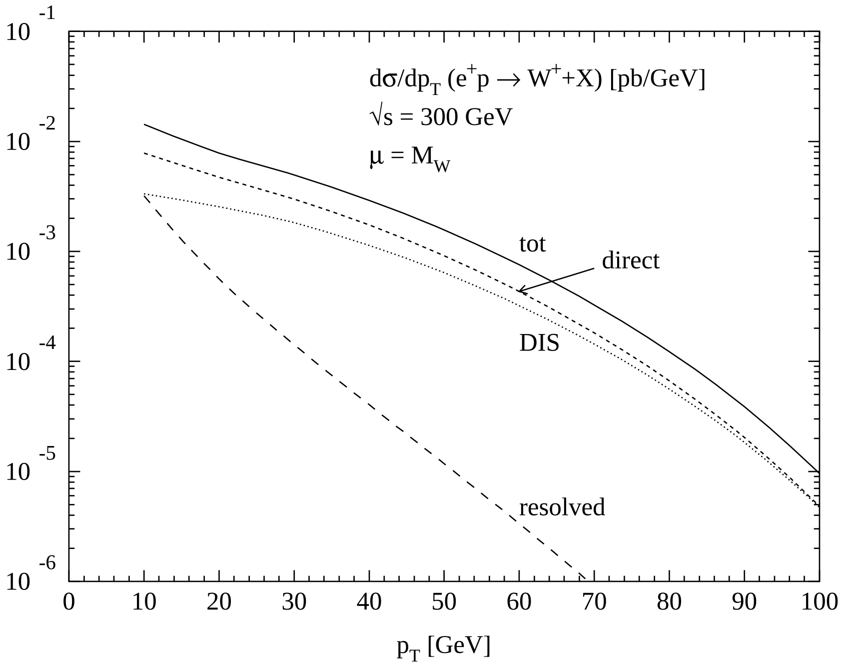
c) resolved photoproduction: channels $q\overline{q}' \to Wg$ and $qg \to q'W$
hadronic cross sections as in direct part above; partonic cross sections:

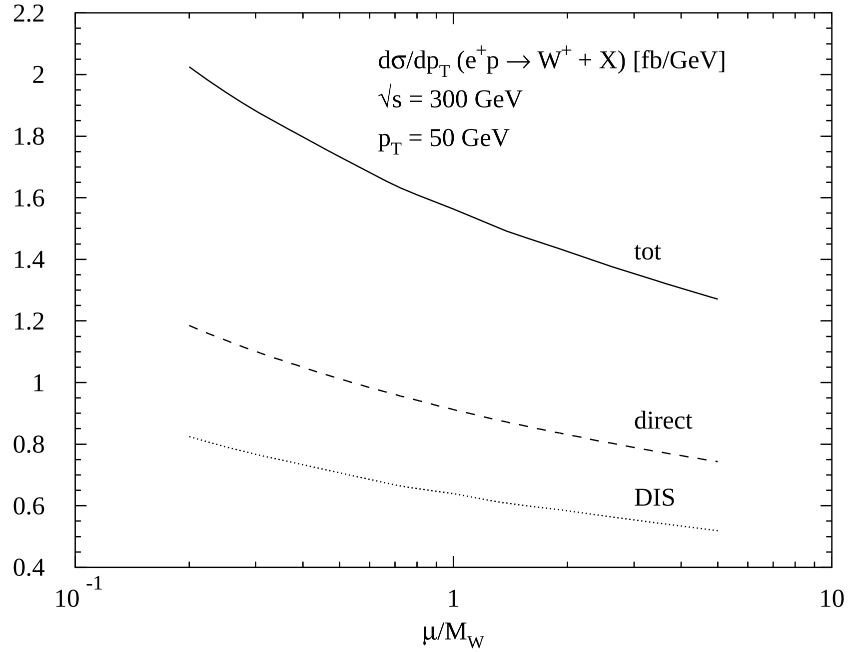
$$\frac{d\hat{\sigma}^{res}_{LO}}{dt_1}(q\overline{q}') = \frac{G_F M_W^2 \alpha_s}{3\sqrt{2}} C_F \frac{t^2+u^2+2M_W^2 s}{s^2 tu}$$
$$\frac{d\hat{\sigma}^{res}_{LO}}{dt_1}(gq) = -\frac{G_F M_W^2 \alpha_s}{3\sqrt{2}} T_R \frac{s^2+u^2+2M_W^2 t}{s^3 u}$$



dependence of DIS+direct+resolved on $Q^2_{max} \lesssim 1\%$, CTEQ4L, ACFGP

D., Schwanenberger, Spira





D., Schwanenberger, Spira

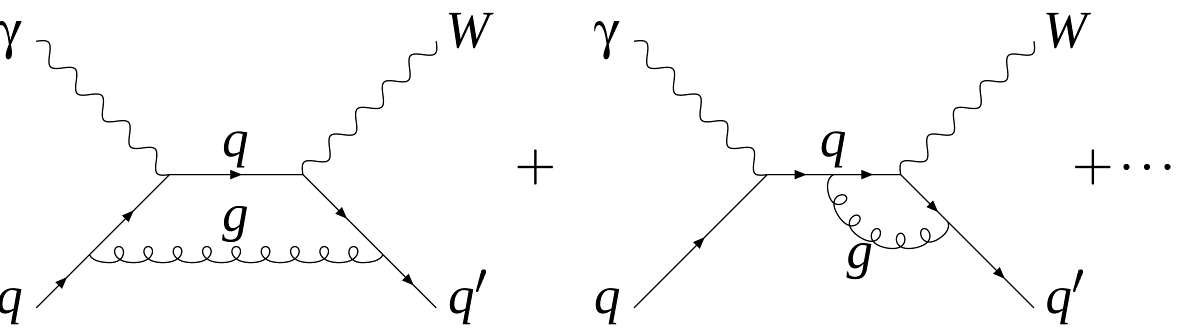
$Q^2_{max} = 4\text{GeV}^2$

- direct photoproduction dominant in p_T distribution

- scale dependence $\sim 20\%$

NLO QCD contributions to direct photoproduction

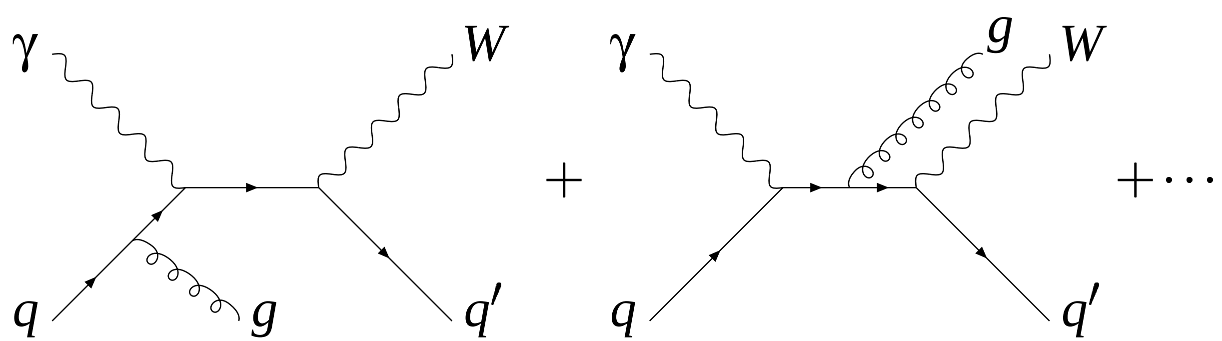
virtual corrections to direct photoproduction:



$$\frac{d\hat{\sigma}_{virt}}{dt_1} = C_{virt} C_F \frac{\alpha_s}{\pi} \frac{d\hat{\sigma}_{LO}}{dt_1}$$

with $C_{virt} = C_\varepsilon \left\{ -\frac{1}{\varepsilon^2} - \frac{1}{\varepsilon} \left(\frac{3}{2} + \log \frac{M_W^2}{-t} \right) + C_V \right\}$ and $C_\varepsilon = \Gamma(1+\varepsilon) \left(\frac{4\pi\mu^2}{M_W^2} \right)^\varepsilon$

in $D = 4 - 2\varepsilon$ dimensions, sum is UV finite , IR and coll. divergent real corrections to direct photoproduction:

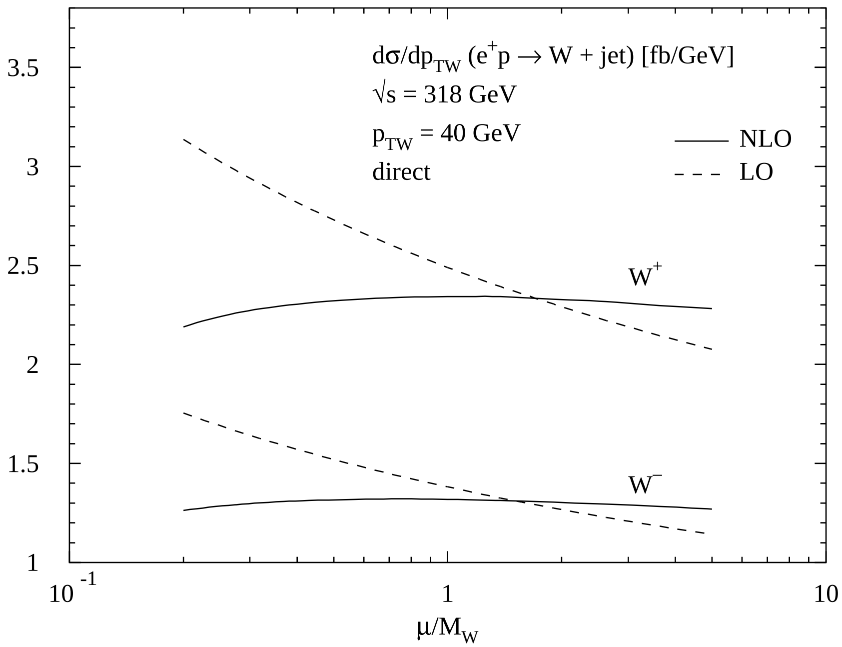


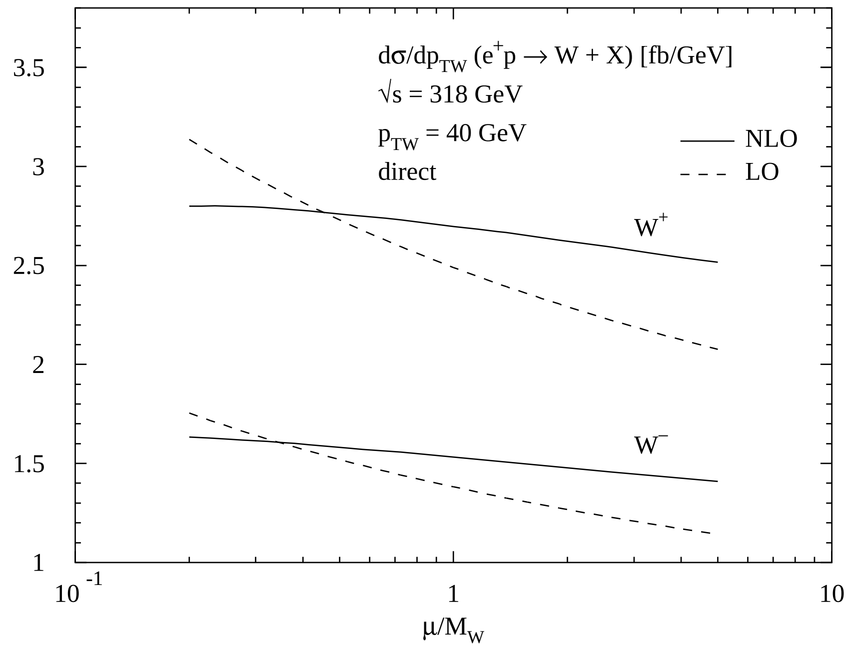
$\rightarrow$ PS in $D = 4 - 2\varepsilon$ dimensions

$\rightarrow$ calculated in dipole subtraction formalism Catani, Seymour

$\rightarrow$ inclusive k_T jet algorithm, cone size $R < 1$

$\rightarrow$ for detected parton require $E_T > 5\text{GeV}$



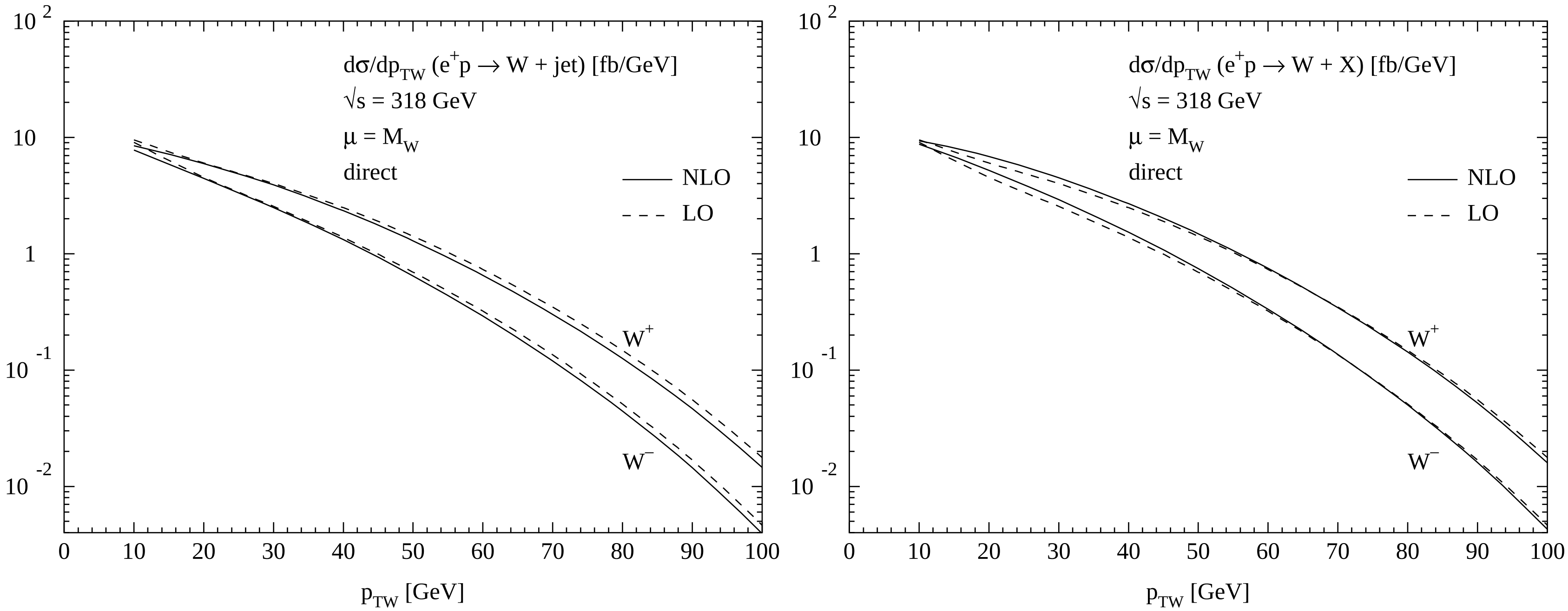


CTEQ4M, ACFGP, $Q^2_{max} = 4\mathrm{GeV}^2$

D., Schwanenberger, Spira

$\rightarrow$ scale dependence in distributions for $ep \rightarrow W + 1\mathrm{jet}$ and $ep \rightarrow W + X$ significantly reduced: $\sim 20\% \rightarrow \sim 5\%$

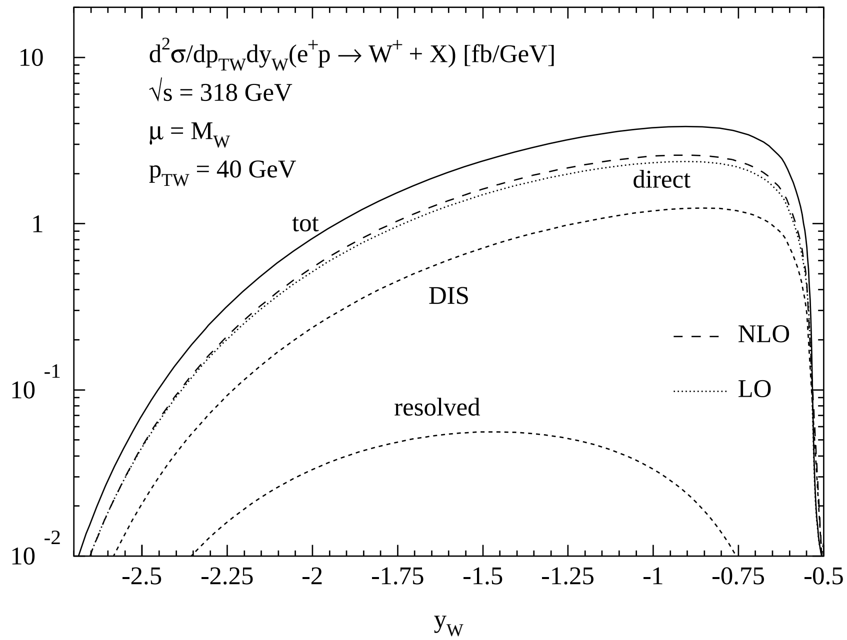
$\rightarrow$ i.e. significant stabilization

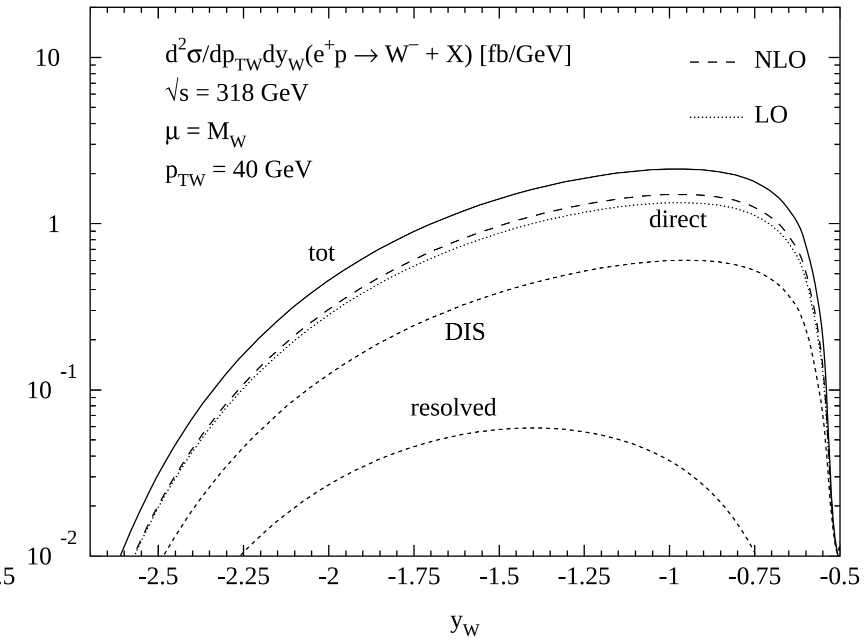


D., Schwanenberger, Spira

$\rightarrow$ size of corrections (@ $\mu = M_W$) $\sim \pm 10\%$ (shapes hardly affected)

$\rightarrow$ perturbative result valid for $p_T > 15\text{GeV}$





D., Schwanenberger, Spira

$\rightarrow$ corrections most pronounced around $y_W \sim -1$

$\rightarrow$ size up to 15%

Conclusions

- BK NLO corr. to FCNC single top production in eikonal approx. reduces QCD scale dependence
- NLO corr. $\sim +25\%$ for given parameters, $\sigma_{\text{tot}}^{\text{NLO}} = 0.68\text{pb}$ (@ $\kappa_{tu\gamma} = 0.1$) (BK)
- NLO corr. to dominant resolved part of total W production $\sim +40\%$, scale dependence reduced Nason, Rückl, Spira
- NLO corr. to dominant direct part of exclusive W production $\sim +10\%$ in p_T and y distributions, scale dependence significantly reduced D., Schwanenberger, Spira
- perturbative results reliable for $p_T \gtrsim 15\text{GeV}$ D., Schwanenberger, Spira
- neither FCNC single top prod. nor NLO QCD corr. can explain H1 isolated single lepton excess in high-p_T^X regime $\rightarrow e/\mu$ asymmetry