Two-loop corrections to W and Z boson production at high p_T

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- **Partonic production channels at LO**
- **NLO corrections**
- **Soft-gluon corrections**
- **Two-loop calculations and NNLL resummation**
- **Approximate NNLO p_T distribution at LHC and Tevatron**

In collaboration with R. J. Gonsalves

W and Z production at large p_T - parton processes

W and Z hadroproduction useful in testing the SM and in estimates of backgrounds to Higgs production and new physics (new gauge bosons)

p_T distribution falls rapidly as p_T increases

Partonic channels at LO

$q(p_a) + g(p_b) \longrightarrow W(Q) + q(p_c)$

$q(p_a) + \bar{q}(p_b) \longrightarrow W(Q) + g(p_c)$

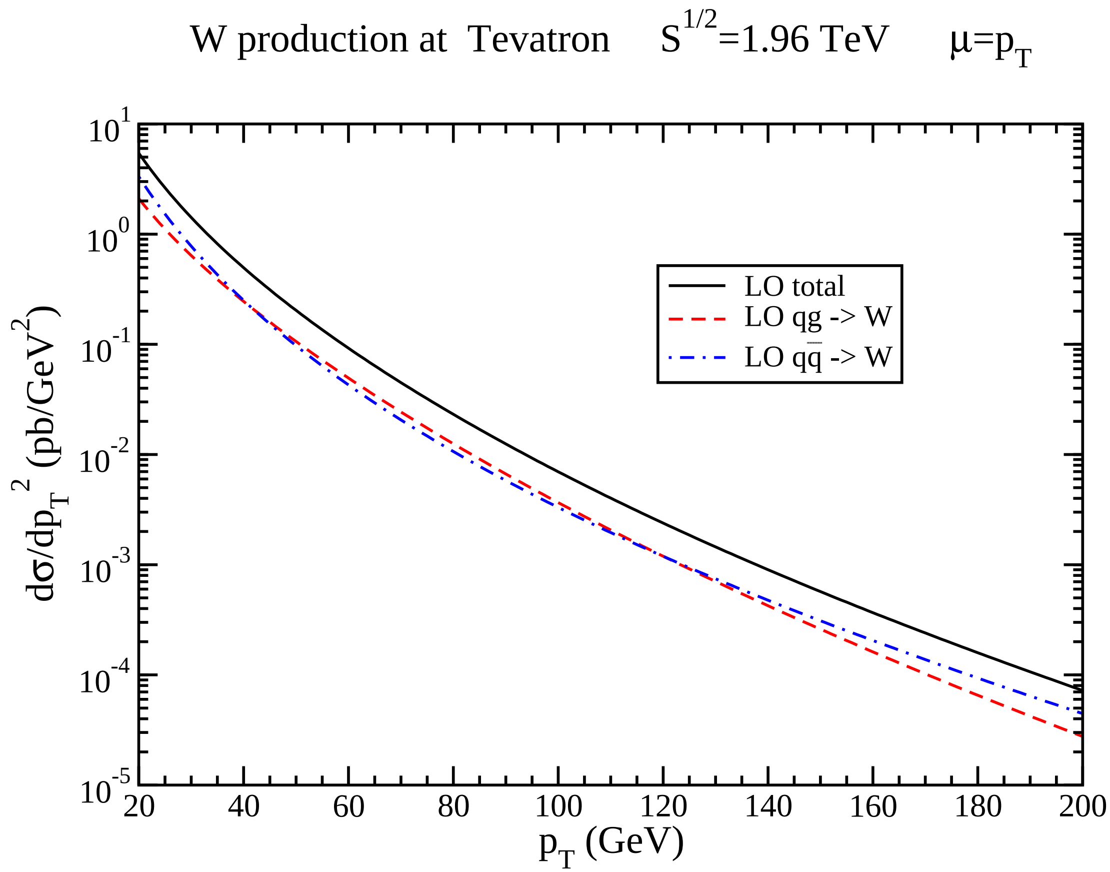
Define $s = (p_a + p_b)^2$, $t = (p_a - Q)^2$, $u = (p_b - Q)^2$ **and** $s_4 = s + t + u - Q^2$

At threshold $s_4 \to 0$

Soft corrections $\left[\frac{\ln^l(s_4/p_T^2)}{s_4}\right]_+$

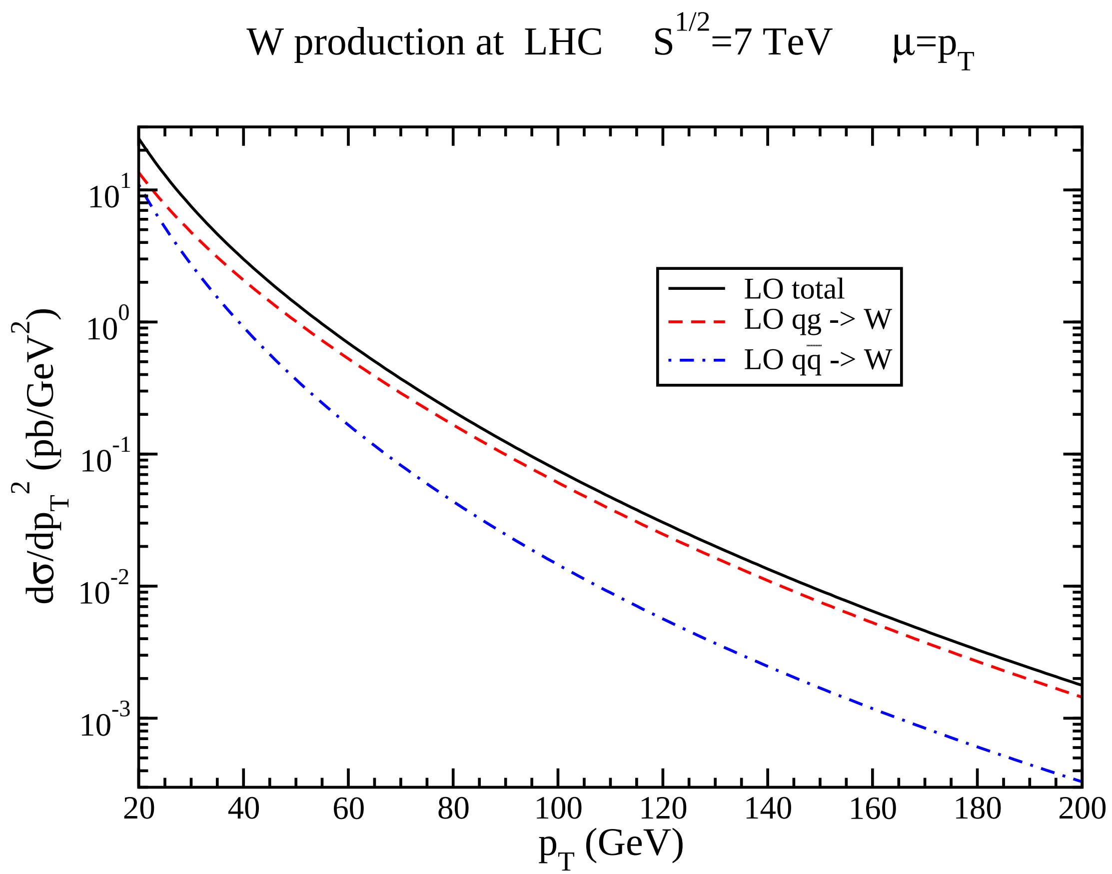
Virtual corrections $\delta(s_4)$

Leading-order results for W production at the Tevatron

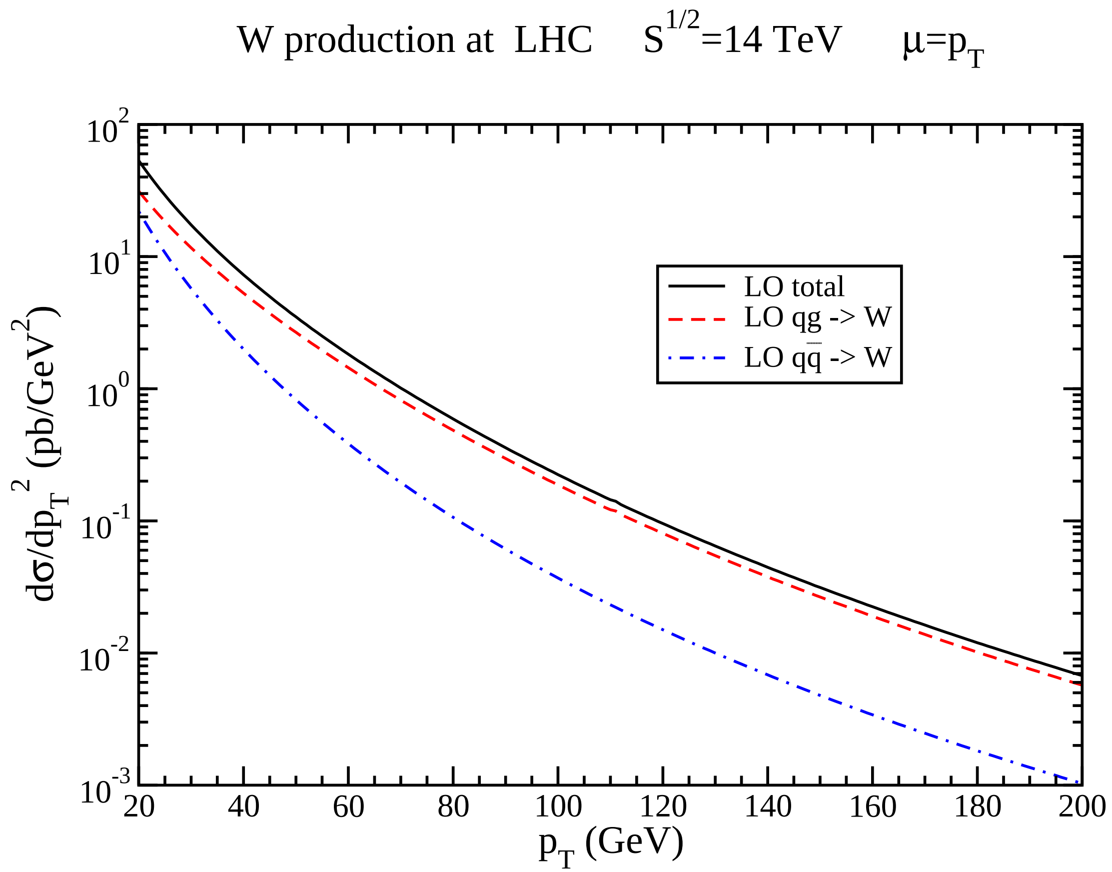


qg and $q\bar{q}$ channel equally important

Leading-order results for W production at the LHC

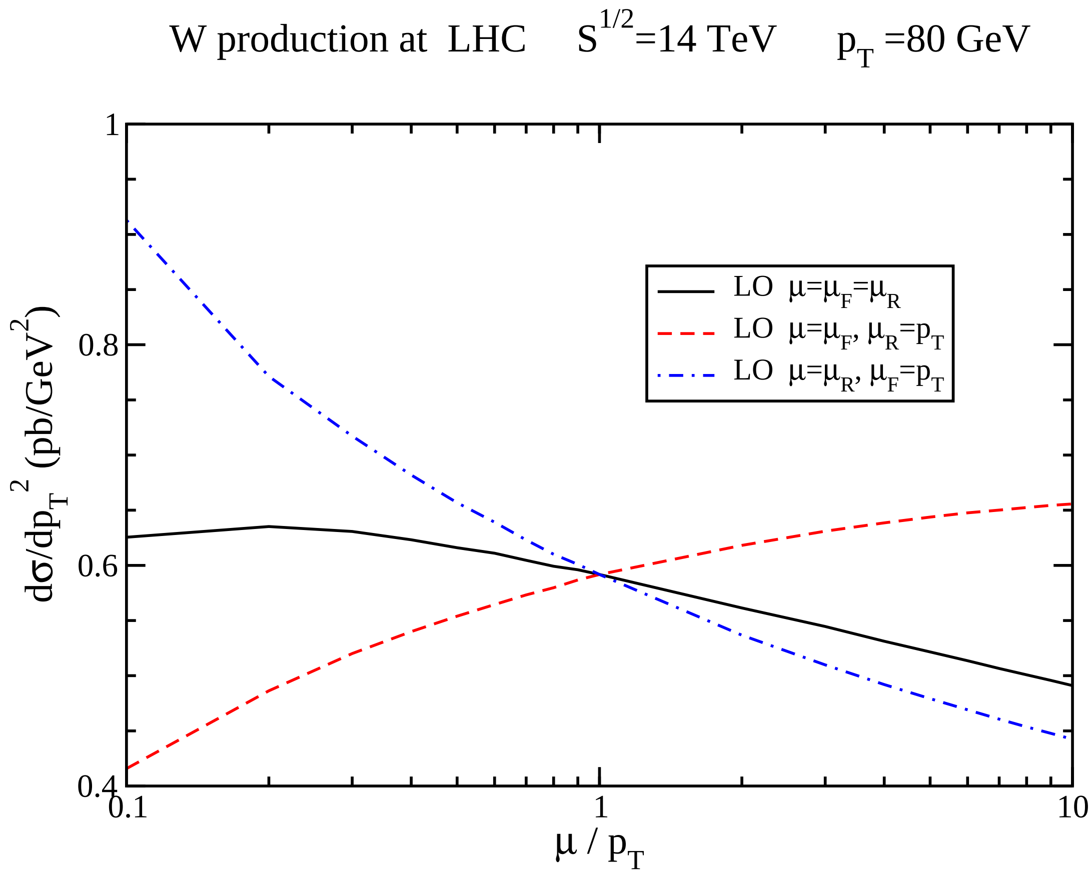


qg channel is numerically dominant

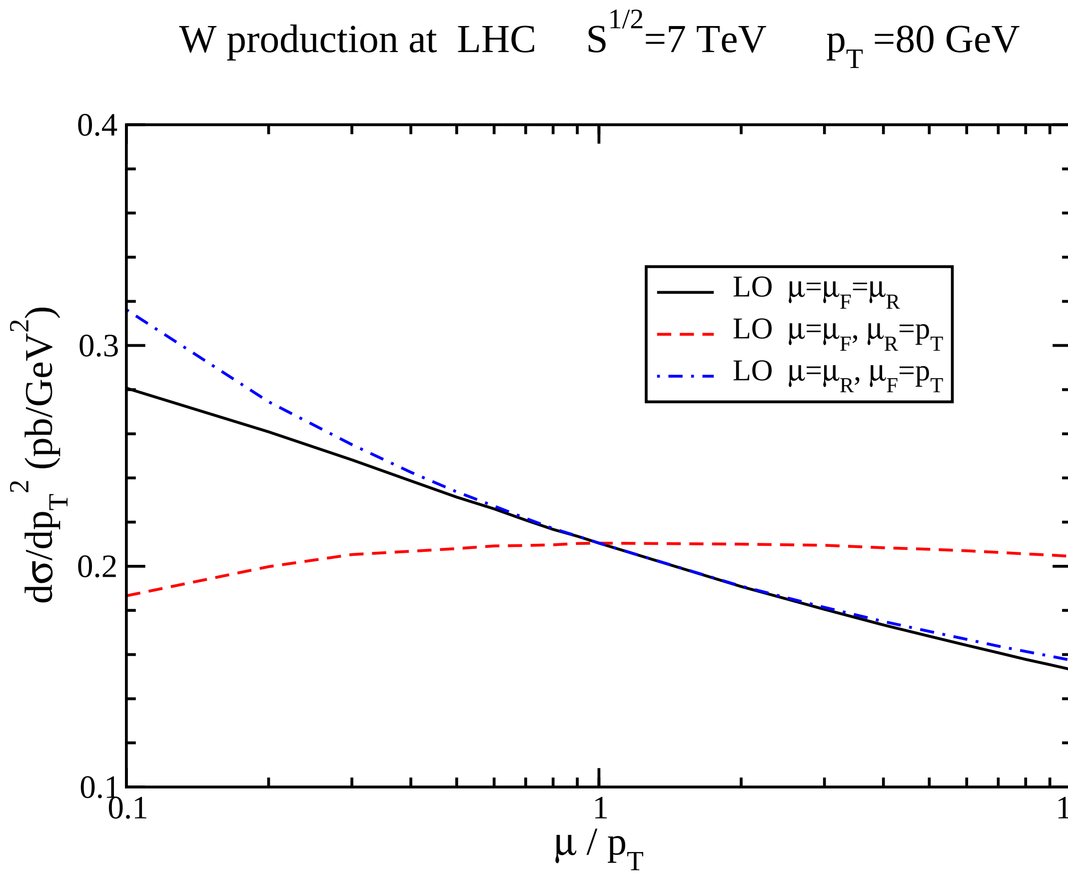


qg channel is numerically dominant

LO scale dependence for W production at the LHC



At LO μ_F and μ_R dependence largely cancel each other



somewhat different μ dependence at 7 and 14 TeV

NLO corrections

The NLO cross section can be written as

$$E_Q \frac{d\hat{\sigma}_{f_a f_b \to W(Q)+X}}{d^3Q} = \delta(s_4)\alpha_s(\mu_R^2)\left[A(s,t,u) + \alpha_s(\mu_R^2)B(s,t,u,\mu_R)\right] + \alpha_s^2(\mu_R^2)C(s,t,u,s_4,\mu_F)$$

The coefficient functions A, B, and C depend on the parton flavors

The coefficient $A(s,t,u)$ arises from the LO processes

$B(s,t,u,\mu_R)$ **is the sum of virtual corrections and of singular terms** $\sim\delta(s_4)$ **in the real radiative corrections**

$C(s,t,u,s_4,\mu_F)$ **is from real emission processes away from** $s_4 = 0$

P.B. Arnold and M.H. Reno, Nucl. Phys. B 319, 37 (1989); (E) B 330, 284 (1990)

R.J. Gonsalves, J. Pawlowski, C.-F. Wai, Phys. Rev. D 40, 2245 (1989); Phys. Lett. B 252, 663 (1990)

Soft-gluon corrections

$$\mathcal{D}_l(s_4) \equiv \left[\frac{\ln^l(s_4/p_T^2)}{s_4}\right]_+$$

For the order α_s^n corrections $l \le 2n-1$

At NLO, $\mathcal{D}_1(s_4)$ and $\mathcal{D}_0(s_4)$ terms

At NNLO, $\mathcal{D}_3(s_4)$, $\mathcal{D}_2(s_4)$, $\mathcal{D}_1(s_4)$, and $\mathcal{D}_0(s_4)$ terms

We can formally resum these logarithms for W and Z production at large p_T to all orders in α_s **Phys. Lett. B 480, 87 (2000)**

Applied to W production at the Tevatron: **JHEP 02, 027 (2004)**
and at the LHC: **Phys. Rev. Lett. 95, 222001 (2005)**

New two-loop results: $\mathcal{D}_0(s_4)$ terms now fully determined

Soft-Gluon Resummation

Resummation follows from factorization properties of the cross section - performed in moment space

Resummed cross section

$$\hat{\sigma}^{res}(N) = \exp\left[\sum_i E_i(N_i)\right] \exp\left[E'_j(N')\right] \exp\left[\sum_{i=1,2} 2\int_{\mu_F}^{\sqrt{s}} \frac{d\mu}{\mu}\, \gamma_{i/i}\left(\tilde{N}_i, \alpha_s(\mu)\right)\right]$$

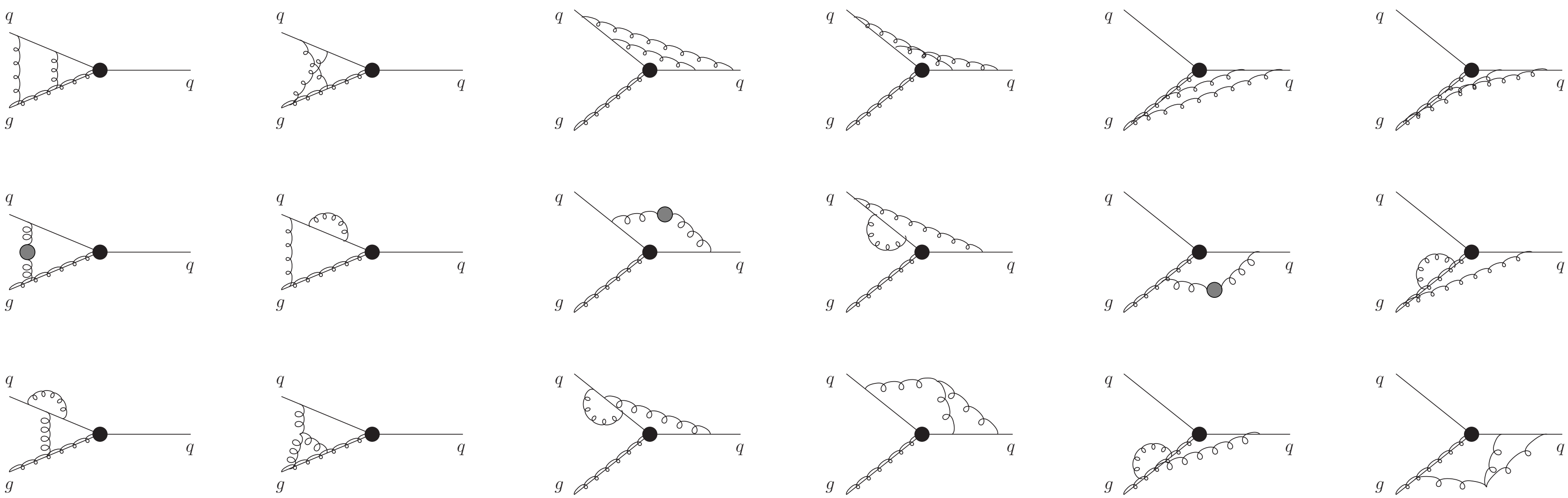
$$\times H\left(\alpha_s\right)\, S\left(\alpha_s\left(\frac{\sqrt{s}}{\tilde{N}'}\right)\right) \exp\left[\int_{\sqrt{s}}^{\sqrt{s}/\tilde{N}'} \frac{d\mu}{\mu}\, 2\,\mathrm{Re}\Gamma_S\left(\alpha_s(\mu)\right)\right]$$

Γ_S is the soft anomalous dimension

$$\Gamma_S = \frac{\alpha_s}{\pi}\Gamma_S^{(1)} + \frac{\alpha_s^2}{\pi^2}\Gamma_S^{(2)} + \cdots$$

Two-loop soft anomalous dimension

Two-loop eikonal diagrams for $qg \to Wq$



Determine $\Gamma_S^{(2)}$ from UV poles of two-loop dimensionally regularized integrals

Two-loop soft anomalous dimension

For $qg \to Wq$ **or** $qg \to Zq$

$$\Gamma_{S,\,qg\to Wq}^{(1)} = C_F \ln\left(\frac{-u}{s}\right) + \frac{C_A}{2}\ln\left(\frac{t}{u}\right)$$

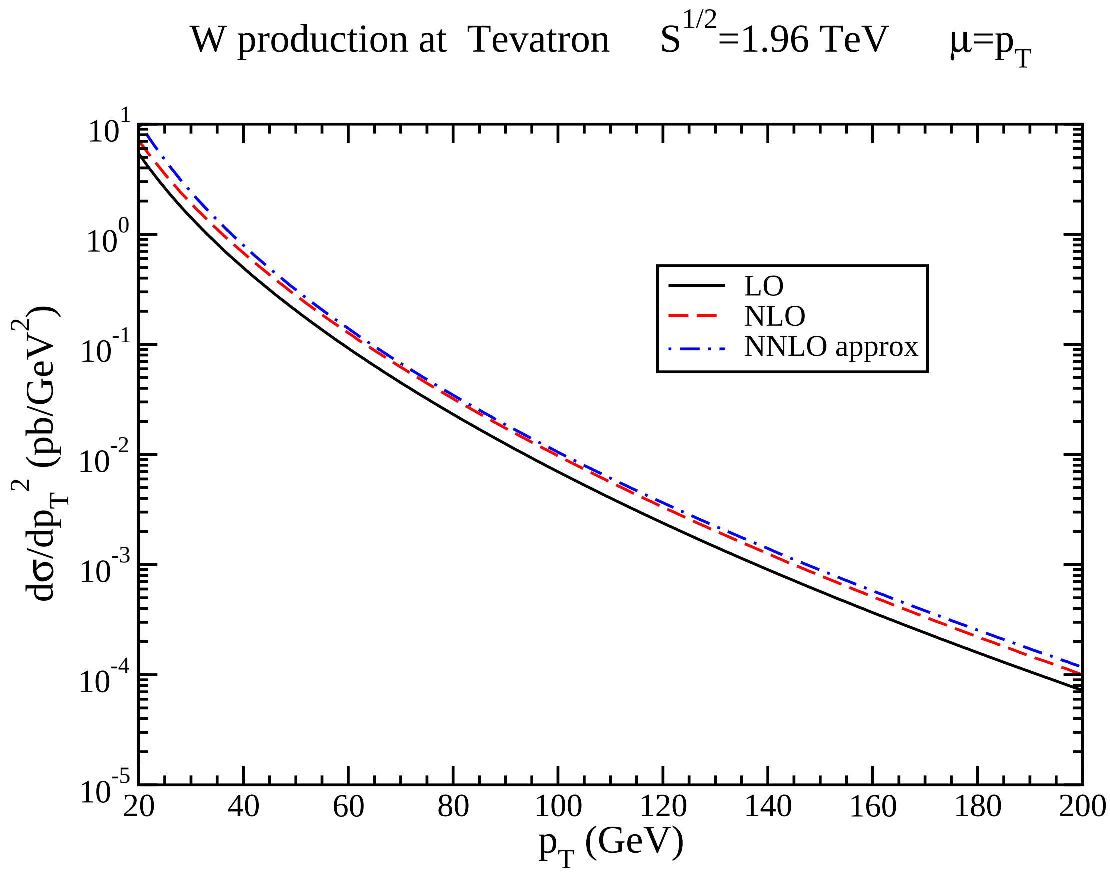
$$\Gamma_{S,\,qg\to Wq}^{(2)} = \frac{K}{2}\Gamma_{S,\,qg\to Wq}^{(1)}$$

For $q\bar{q} \to Wg$ **or** $q\bar{q} \to Zg$

$$\Gamma_{S,\,q\bar{q}\to Wg}^{(1)} = \frac{C_A}{2}\ln\left(\frac{tu}{s^2}\right)$$

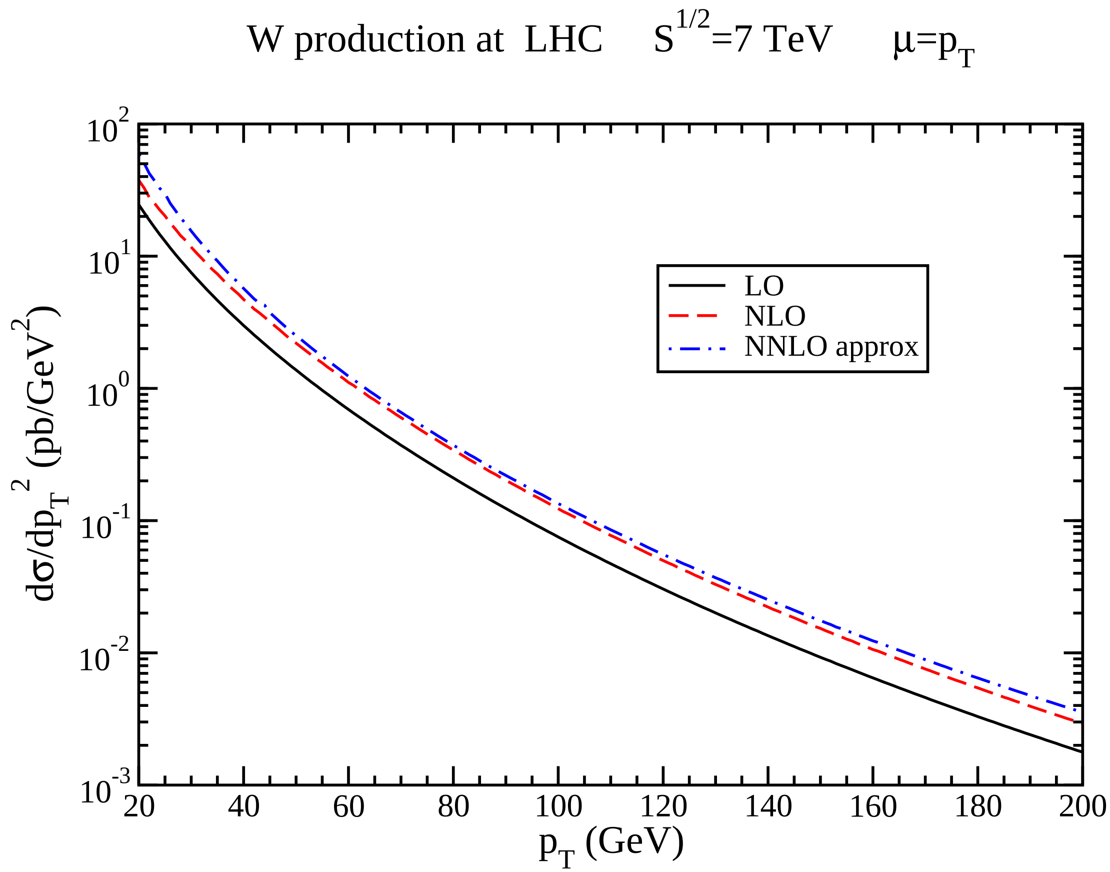
$$\Gamma_{S,\,q\bar{q}\to Wg}^{(2)} = \frac{K}{2}\Gamma_{S,\,q\bar{q}\to Wg}^{(1)}$$

NLO and NNLO approx for W production at the Tevatron

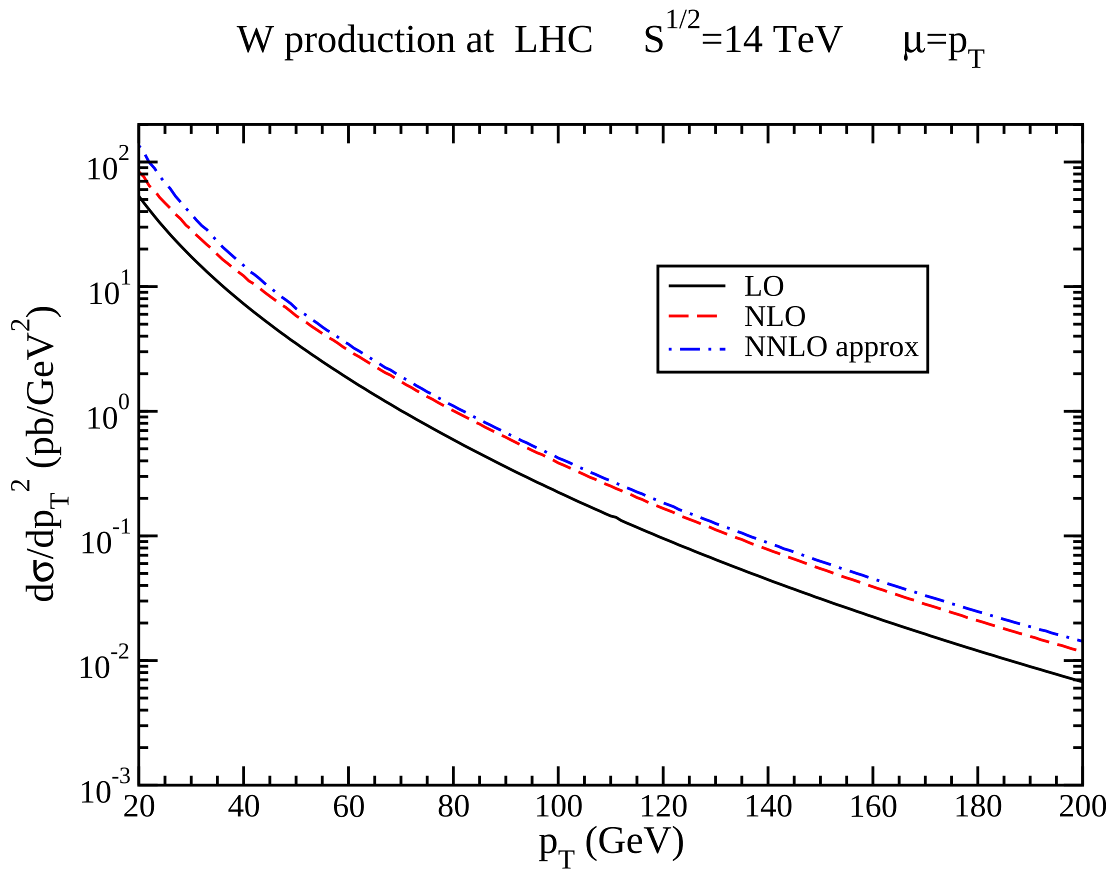


NLO corrections and NNLO approximate corrections are significant

NLO and NNLO approx for W production at the LHC



large NLO corrections
significant NNLO approximate corrections



large NLO corrections

significant NNLO approximate corrections

Summary

- W **and** Z **production at large** p_T
- **LO and NLO results**
- **Soft-gluon threshold corrections**
- **Two-loop resummation**
- **NNLO threshold corrections have been calculated**
- **Important for greater theoretical accuracy**
- W **production at Tevatron and LHC**
- **More work is under way**