Transverse momentum resummation at small x for the Tevatron and LHC

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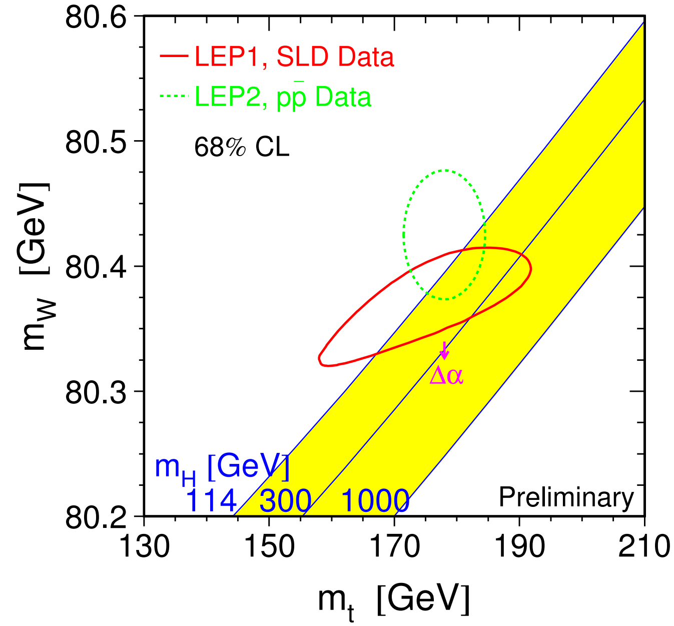
1. Introduction

2.(a) Measurement of W-boson mass M_W and width Γ_W in $pp/p\bar{p} \to WX \to l\nu X$

Important for precision tests of SM

✓ Consistency between different experiments and SM

✓ Together with Top quark mass, constraint on Higgs boson mass

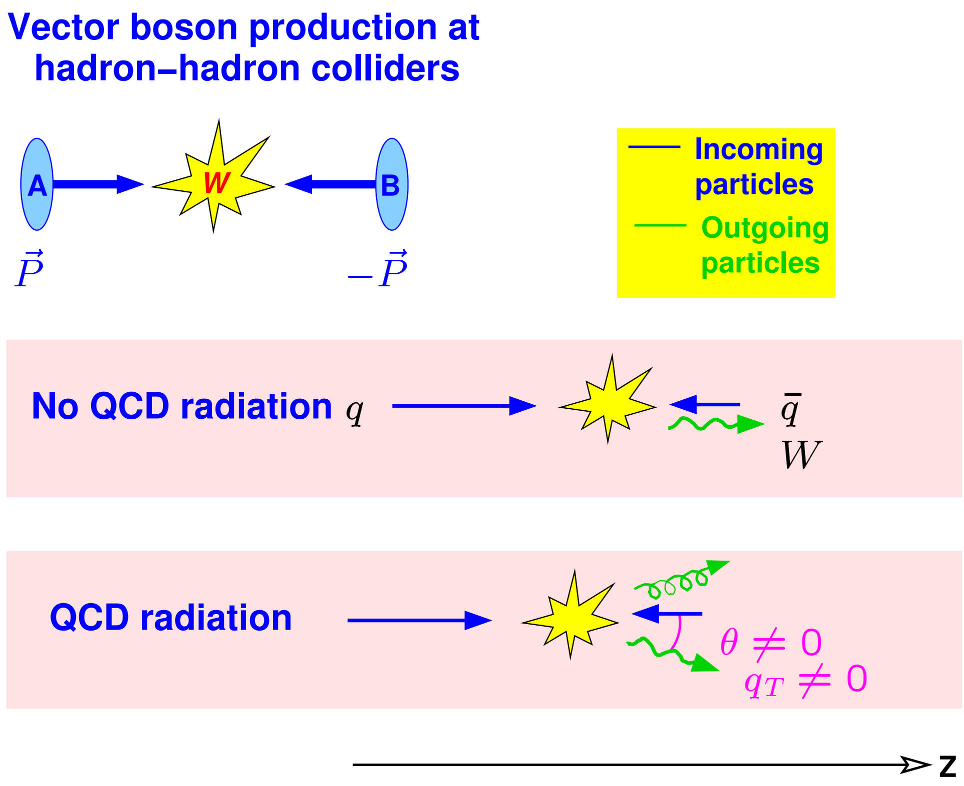


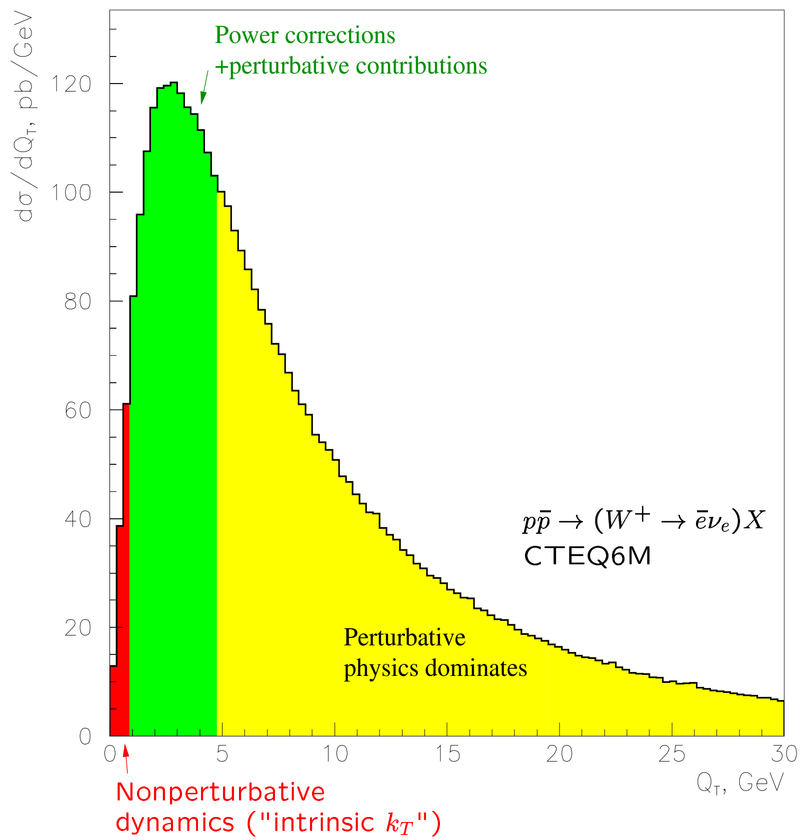
Tevatron Run-2 goal: reduce δM_W to 30 MeV (present error 59 MeV)
LHC goal: $\delta M_W \simeq 15$ MeV

How is such accuracy achieved given that the W-bosons are not observed directly (no tracks, missing energy)?

1. Measure the lepton transverse mass distribution
2. Measure $d\sigma/dq_T^l$-distribution $\to$ determine p_T distribution for W-bosons

2. Resummation at Hadron Colliders





NLO, calculated using ResBos
(Balazs, Nadolsky, Yuan)

- Problem:
  The series $\frac{1}{q_T^2}\alpha_S^n \ln^m \frac{q_T^2}{Q^2}, \; m = 0, \ldots, 2n-1$
  loses convergence for $q_T \ll Q$
- Resummation needed to describes the whole q_T range
- Important to precisely measure W-boson mass

2. Resummation at Hadron Colliders

Using Collins-Soper-Sterman (CSS) representation:
Realized in the space of the impact parameter b (conjugate to q_T)
Use b_* prescription (CSS, 1985):

$$\frac{d\sigma_{AB\to VX}}{dQ^2 dy dq_T^2} = \sum_{a,b=g,u,\ldots} \frac{\sigma_{ab}^{(0)}}{S} \int \frac{d^2b}{(2\pi)^2}\, e^{-i\vec{q}_T\cdot\vec{b}}\, \overline{\mathcal{P}}_a(x_A, b^*)\, \overline{\mathcal{P}}_b(x_B, b^*)$$

$$\times\, e^{-\mathcal{S}(b^*,Q)}\, e^{-\mathcal{S}_{NP}(b,Q)}\, e^{-b^2\rho(x_A)-b^2\rho(x_B)} + Y$$

- $\sigma_{ab}^{(0)}$, Born level pre-factor
- $e^{-\mathcal{S}(b^*,Q)}$, Sudakov exponent
- $\overline{\mathcal{P}}_b(x, b^*)$, process dependent b-space parton distribution

$$\overline{\mathcal{P}}_a(x, b^*) = \sum_{c=g,u,d\ldots} \left[\mathcal{C}_{a/c}^{in} \otimes f_c\right](x, b^*)$$

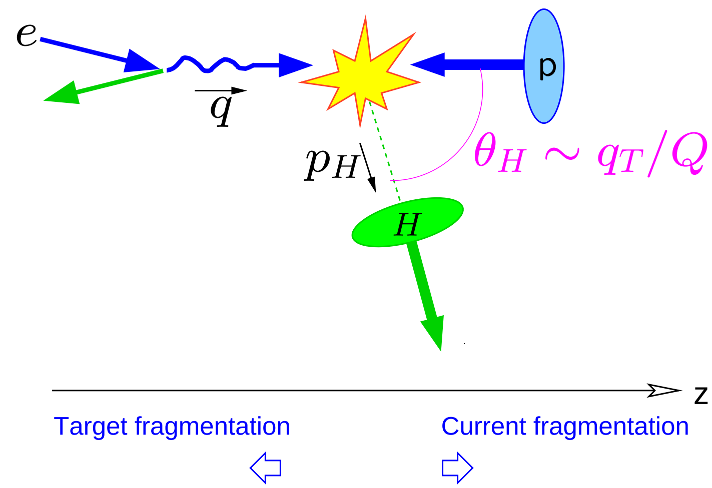
- $\rho(x) = 0.013 \cdot \left(\sqrt{\frac{1}{x^2} + \frac{1}{x_0^2}} - \frac{1}{x_0}\right),$

  with $\quad x_0 = 0.005\,,$

- $b_* = \frac{b}{\sqrt{1 + \frac{b^2}{b_{max}^2}}}\,, \quad b_{max} = 0.5$ GeV^{-1}

2. Resummation at Hera

Angular distribution of the hadronic transverse energy flow tells about the x-dependence of $\mathcal{P}(x, b)$



$$\frac{d\langle E_T\rangle}{dx dQ^2 dq_T^2} \propto \int dz \cdot z \cdot \frac{d\sigma}{dx dz dQ^2 dq_T^2}$$

$$\propto \text{ const} \cdot \int \frac{d^2 b}{(2\pi)^2} e^{-i\vec{q}_T\cdot\vec{b}} e^{-\mathcal{S}(b^*,Q)} e^{-\mathcal{S}_{NP}(b,Q)}\, \overline{\mathcal{P}}(x, b^*),$$

To fit the small x data of the H1-Collaboration an additional q_T-broadening factor

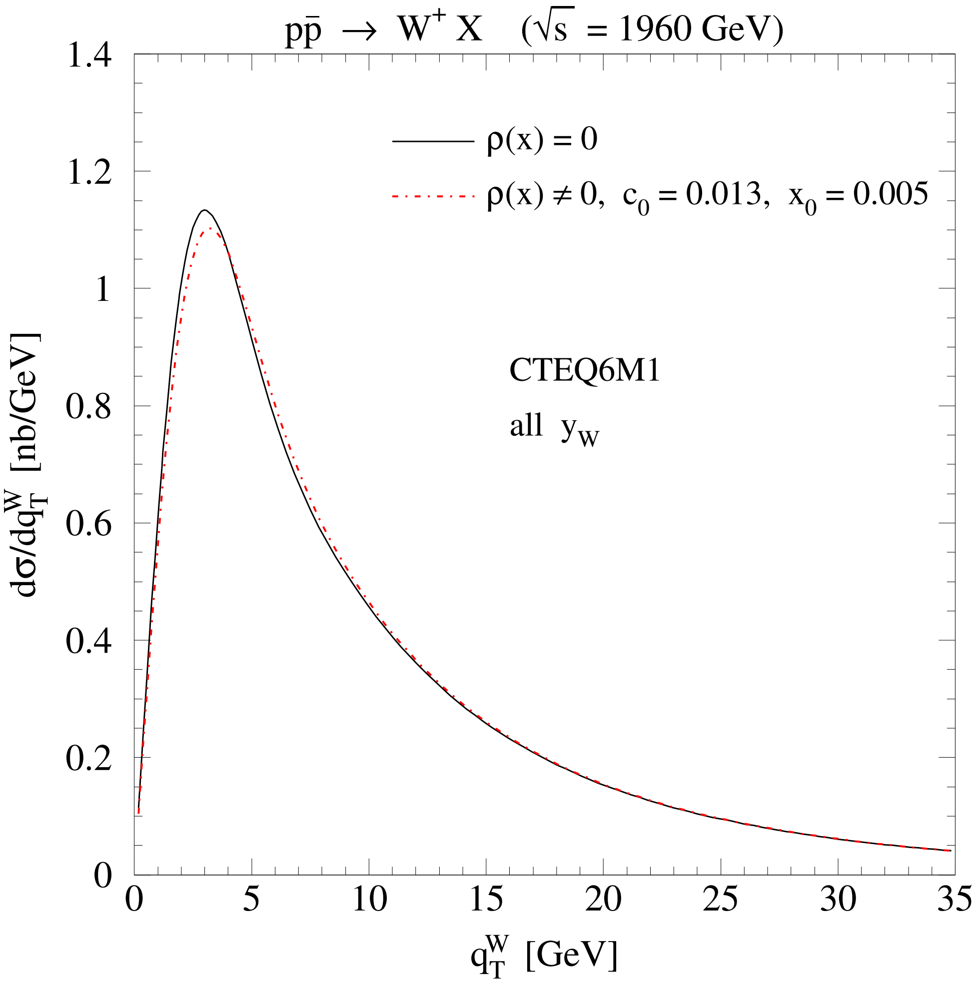
$$\sim e^{-\frac{0.013}{x}\, b^2}$$

was introduced in the resummed E_T -flow; CTEQ5M1 PDFs (Nadolsky, Stump, Yuan, hep-ph/0012261)

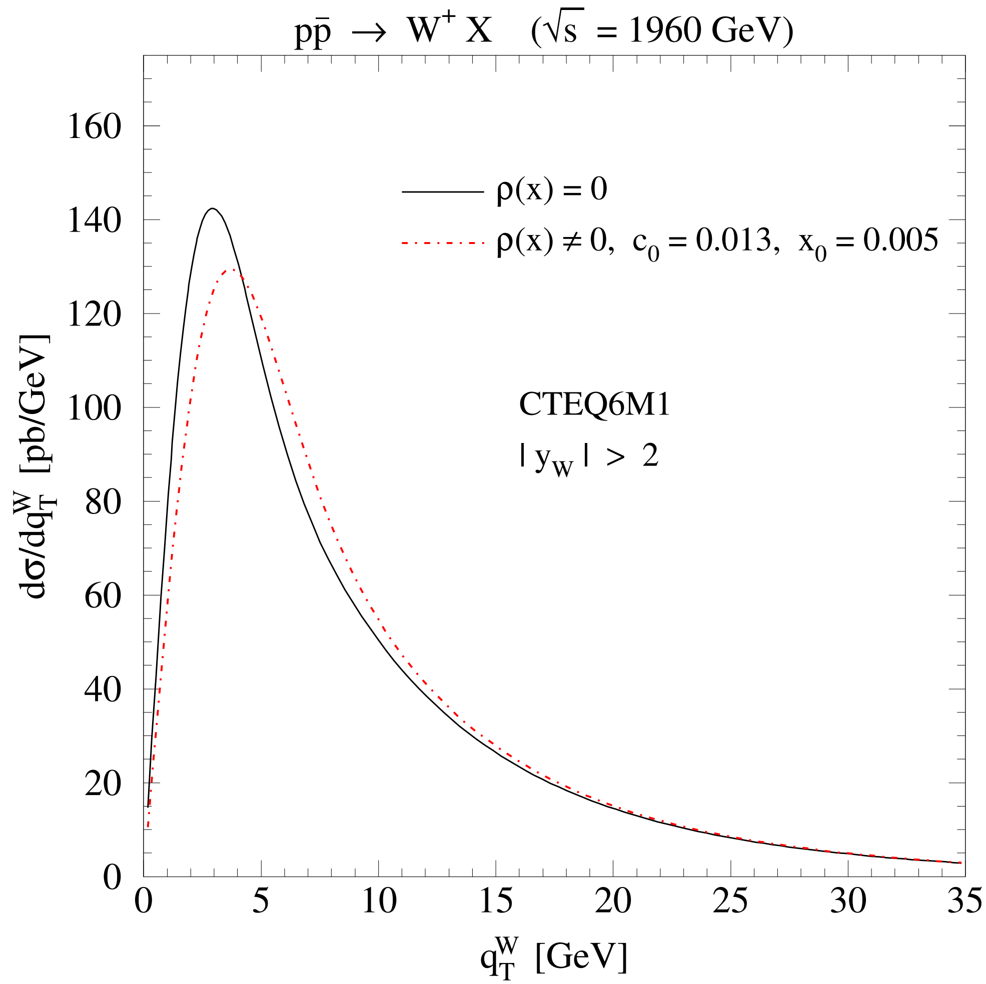
Possible interpretation:
rapid increase of "intrinsic" k_T when x decreases (first signs of k_T-unordered radiation???)
No mechanism for such increase in the $\mathcal{O}(\alpha_s)$ part of the CSS formula

4. Numerical Results

Small x broadening in $p\bar{p} \longrightarrow W^+X$ at the Tevatron



No y_W cut



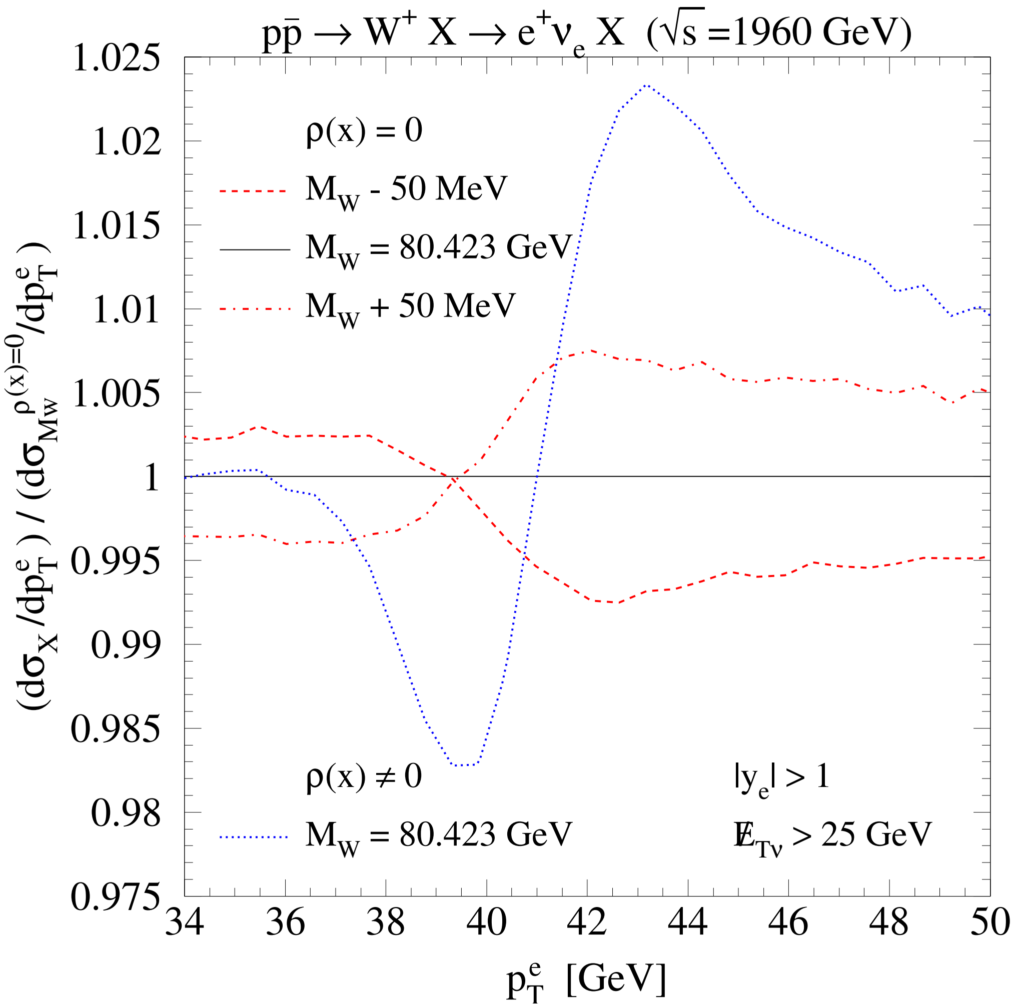
$|y_W| > 2$

(the dominant contribution comes from $x|_{y\approx 0} \approx 0.05$)

Visible broadening in the forward region
90% of cross section between $2 < |y_W| < 2.5$

4. Numerical Results

Small x effects on $p\bar{p} \longrightarrow W^+X \longrightarrow e^+\nu_e X$ at the Tevatron



$|y_e| > 1$

Small x broadening (blue line) compared to a shift of the W boson mass of ± 50 MeV (red line).

Plotted is the ratio

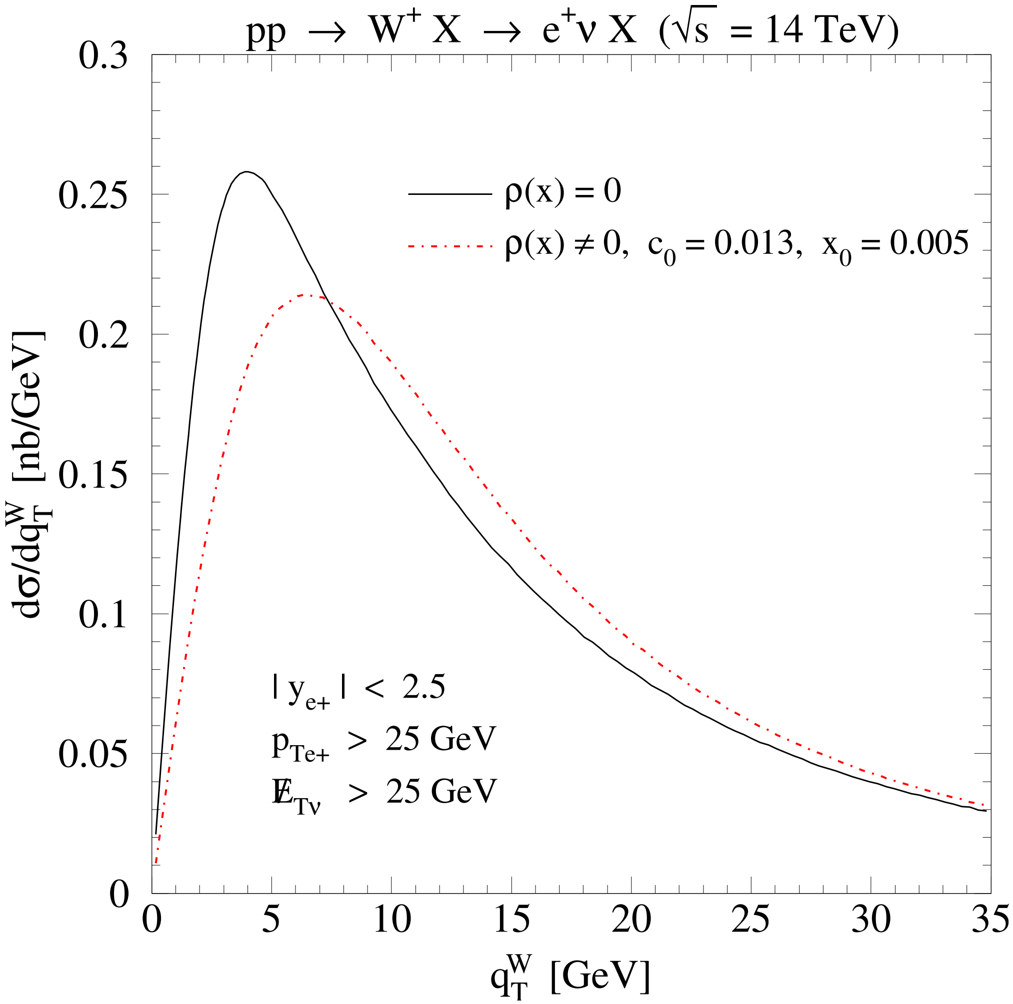
$$\frac{d\sigma_X / dq_T^e}{d\sigma_{M_W}^{\rho(x)=0} / dq_T^e}$$

over the lepton transverse momentum q_T^e!

For $|y_e| < 1$, small x effect much smaller than the shift due to ± 50 MeV.

4. Numerical Results

Small x broadening on $pp \to W^+ X \to e^+ \nu_e X$ at LHC



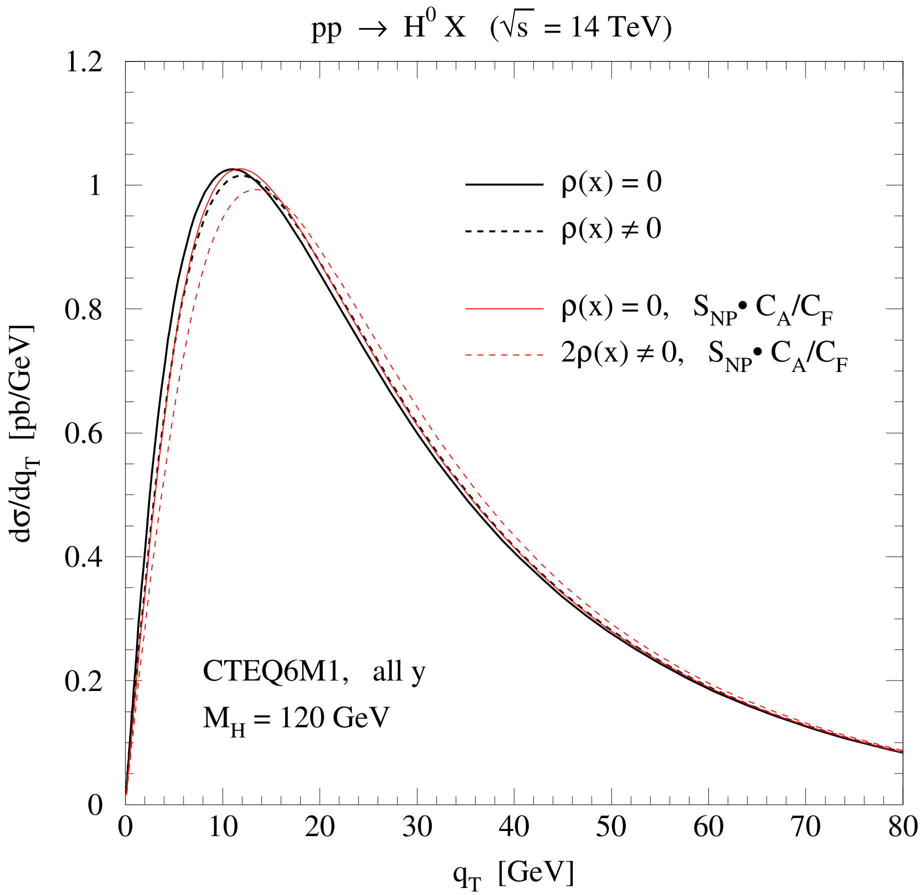
Dependence of $d\sigma/dq_T^W$ on transverse W-boson momentum q_T^W

$|y_e| < 2.5$ motivated by the coverage of the inner ATLAS detector

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

4. Numerical Results

Higgs Boson production at LHC: $pp(\to gg) \to H^0 X$



Dependence of $d\sigma/dq_T^{H^0}$ on transverse H-boson momentum $q_T^{H^0}$

No y_H cut $\longrightarrow$ no large small x broadening

Distribution peaks at $q_T = 10 - 20$ GeV

black line: $\rho(x)$ and S_{NP} are the same as for Z^0 production

red line: S_{NP} multiplied by $\frac{C_A}{C_F} = \frac{9}{4}$ due to larger leading-logarithm coefficient (C_A) in gg channels compared to $q\bar{q}$ channels (C_F)

$gg \longrightarrow (H \longrightarrow \gamma\gamma)X$:
Signal significance can be increased by selecting events
with $q_T^{\gamma\gamma} \gtrsim 30$ GeV (Abdullin et al.)

5. Conclusion

- Based on the analysis of semi-inclusive DIS data, we hypothesize broadening of q_T distributions at $x \lesssim 10^{-2}$.

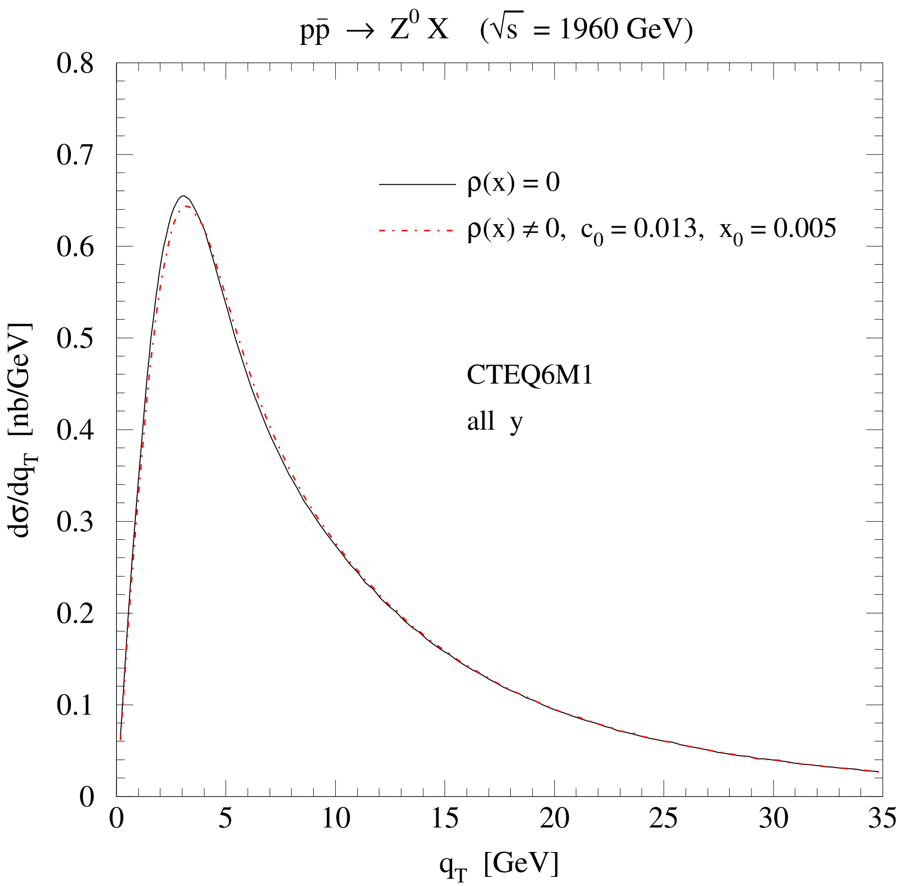
- If the effect can be verified in Z boson production in the Tevatron Run-2 for large rapidities, it has large effects on W mass measurement at Tevatron for $|y^e| > 1$ (larger than a M_W shift of 50 MeV)

- The q_T broadening will strongly affect predictions for W and Z production at the LHC even in the central rapidity region.
  For the Higgs transverse momentum distribution q_T broadening is less important.

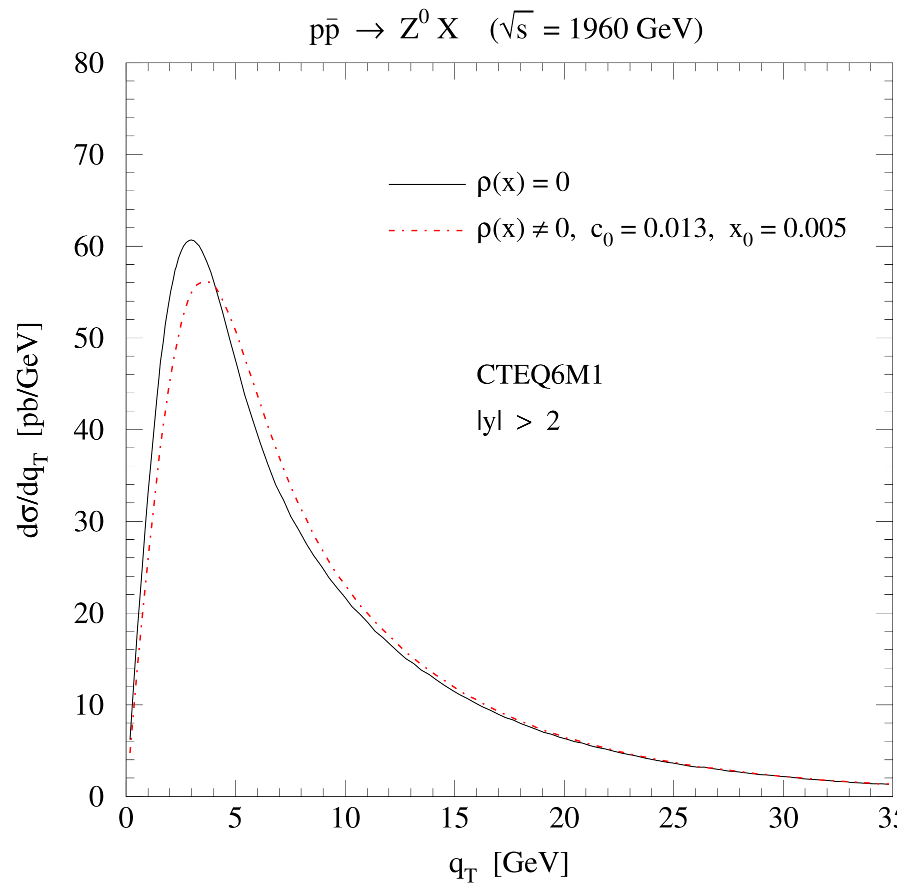
End

Numerical Results

Small-x effects on $p\bar{p} \longrightarrow Z^0 X$ at the Tevatron



No y cut



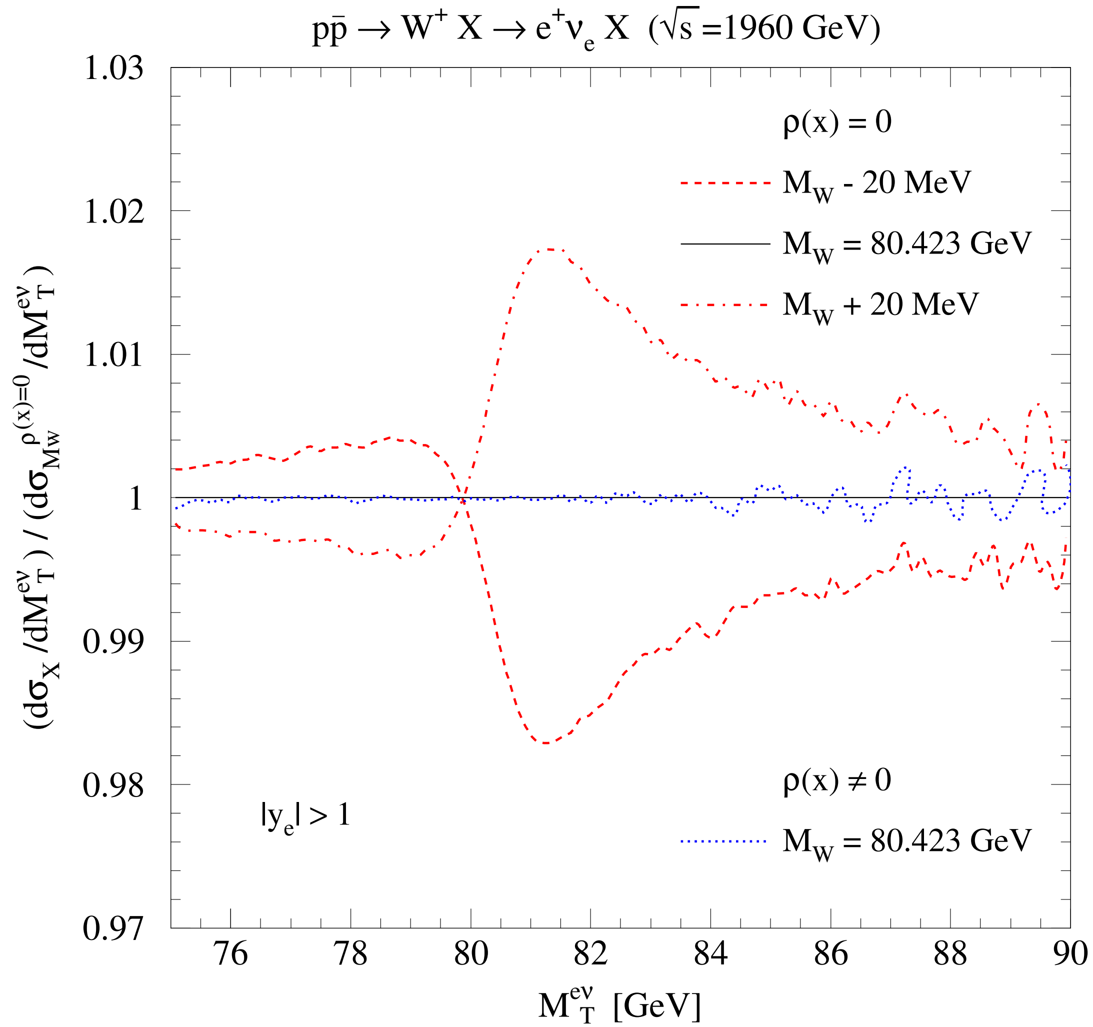
$|y| > 2$

(the dominant contribution comes from $x|_{y\approx 0} \approx 0.05$)

Effect measurable in the Tevatron Run-2

Visible broadening in the forward region
90% of cross section between $2 < |y| < 2.5$

Ratio of W transverse mass distribution

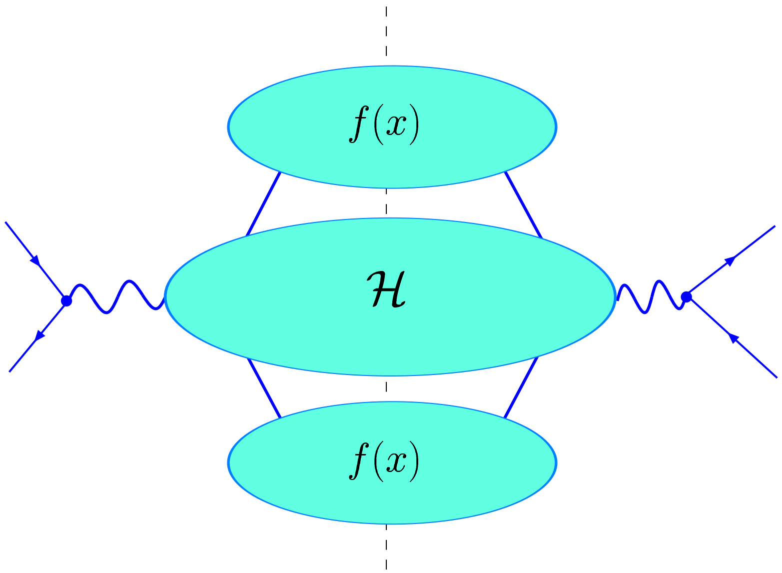


Resummation

QCD factorization in hard and soft regions

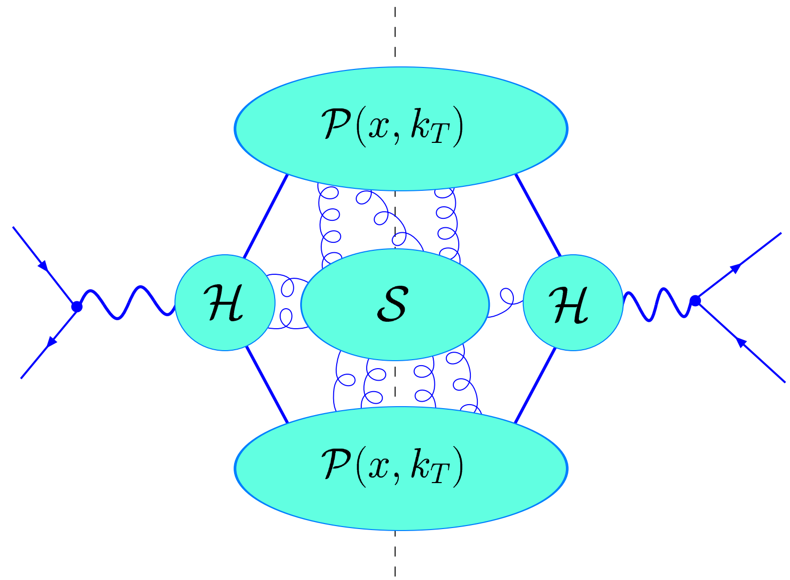
Finite-order (FO) factorization

$\Lambda^2_{QCD} \ll q_T^2 \sim Q^2$



Small-q_T factorization

$\Lambda^2_{QCD} \ll q_T^2 \ll Q^2$



Solution for all q_T: