Production of W and Z bosons in off-shell gluon-gluon fusion

Sergey P. Baranov
P.N. Lebedev Institute of Physics

Artem V. Lipatov and Nikolai P. Zotov
D.V. Skobeltzyn Institute of Nuclear Physics
M.V. Lomonosov Moscow State University

PLAN OF THE TALK

1. **Introduction and Motivations**
2. **Theoretical Framework**
3. **Numerical results**
4. **Conclusions**

1. INTRODUCTION and MOTIVATIONS

In hadron-hadron collisions, electroweak gauge bosons W, Z and γ emerge from quark interactions, i.e., quark-antiquark annihilation and quark-gluon scattering.

There are observations that the theory better describes the data when giving some intrinsic transverse momentum to the interacting partons (as a matter of phenomenology, k_T is energy-dependent). Within the k_T-factorization, this trick is put on solid theoretical grounds, and the size of k_T is predictable.

Shortcoming: need in knowing the unintegrated quark distributions, while the market is poor. The only available set is KMR (Kimber-Martin-Ryskin) [1].

Way out: consider higher-order partonic subprocess, gluon-gluon fusion. Gluon splitting $g \to q\bar{q}$ is regarded as part of hard subprocess rather than parton evolution. Then, the problem of quark densities is reduced to gluon densities. Tested for prompt photons [2].

2. THEORETICAL FRAMEWORK

We separately consider three groups of subprocesses:
– Quark-antiquark annihilation with valence quarks only. Quark densities are taken from KMR prescription or DGLAP evolution. This process dominates at large x, where DGLAP is accurate enough.

– Quark-gluon scattering with valence quarks only. Quarks are taken from KMR or DGLAP, gluons are taken from KMR or CCFM.

– Gluon-gluon fusion. This contribution dominates at small x. The densities are taken from KMR or CCFM.

Advantages:
– access to rich market of gluon distributions;
– especially suitable for associated production with heavy quarks
$(g+g \to Z+b+\bar{b}, \quad g+g \to W^{+}+b+\bar{c}, \quad g+g \to W^{-}+\bar{b}+c)$.

Goal of the study:
– verify theoretical self consistency of the approach;
– test the aproach by confronting it with experimental data.

3. NUMERICAL RESULTS

3.1 Comparison with KMR calculations (consistency test)

Gluon-gluon fusion is not fully equivalent to all sea quark contributions. Not all of the sea quarks come from the last step of the gluon ladder. Even at the LHC, the role of quarks is important, as x is not small: $x \simeq M_Z/\sqrt{s} \simeq 0.01$.

3.2 Comparison with Tevatron data (experimental test)

Theoretical predictions underestimate the data by a factor of 2, unless the loop corrections are included (K-factor a lá KMR) [1].

4. CONCLUSIONS

APPROACH HAS DEMONSTRATED ITS CONSISTENCY:
– Internal theoretical consistency is allright. The reasons for discrepancy between the different approaches are understood.
– Consistency with experimental data is allright. Good agreement in shape, normalization needs K-factor (loop corrections).

QUARK CONTRIBUTIONS ARE IMPORTANT and even dominant at the Tevatron. Not all of the sea quarks appear at the last step of gluon evolution. Quark component needs to be included in the evolution equations.

LOOP CORRECTIONS ARE IMPORTANT and need to be included in calculations, otherwise the calculated cross sections are below the data by a factor of 2.

References

[1] **M.A. Kimber, A.D. Martin, M.G. Ryskin, Phys. Rev. D63, 114027 (2001); G. Watt, A.D. Martin, M.G. Ryskin, Eur. Phys. J. C31, 73 (2003).**

[2] **S.P. Baranov, A.V. Lipatov, N.P. Zotov, Phys. Rev. D77, 074024 (2008)**

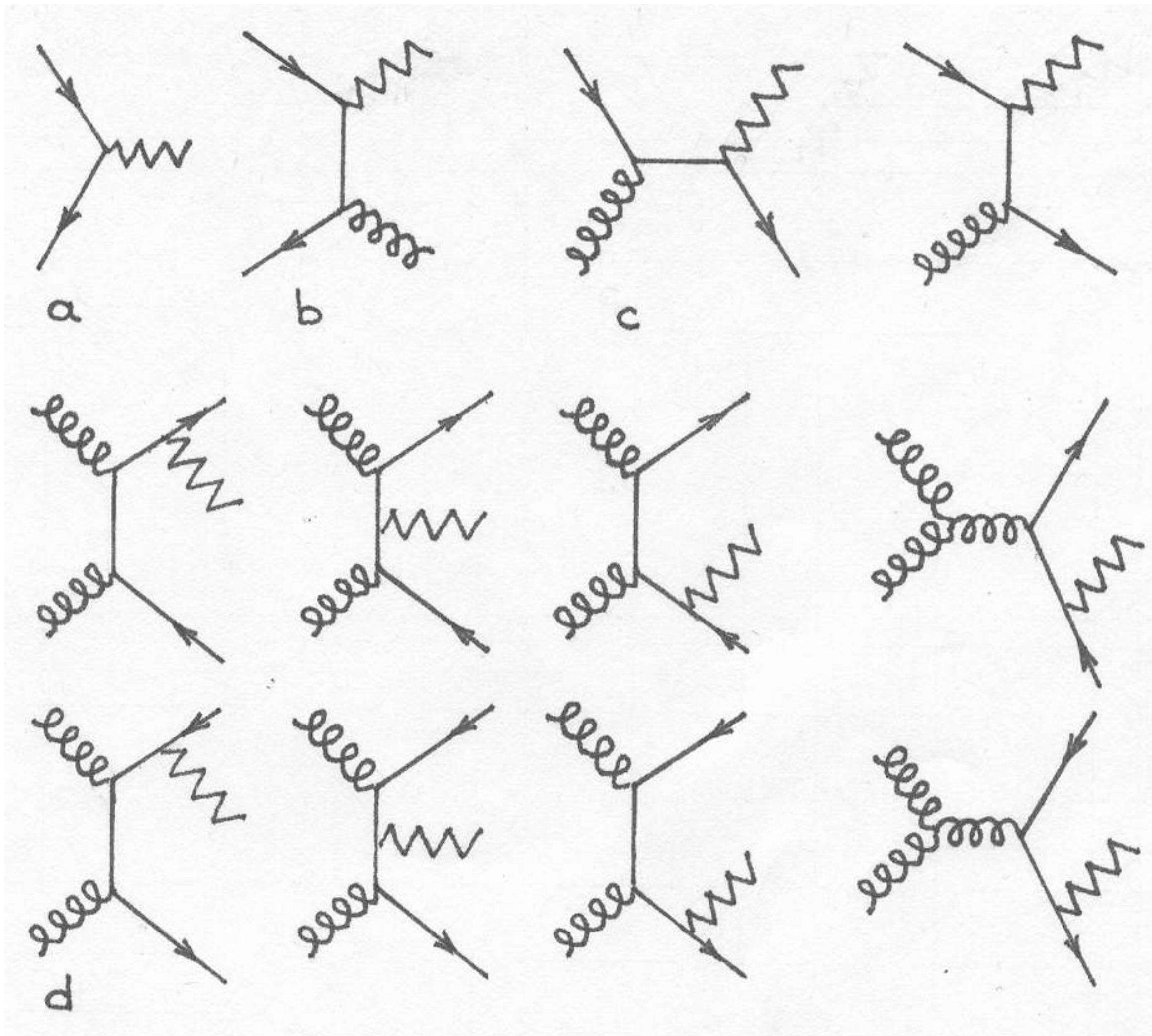


Figure 1: *Feynman diagrams describing the production of electroweak bosons.*

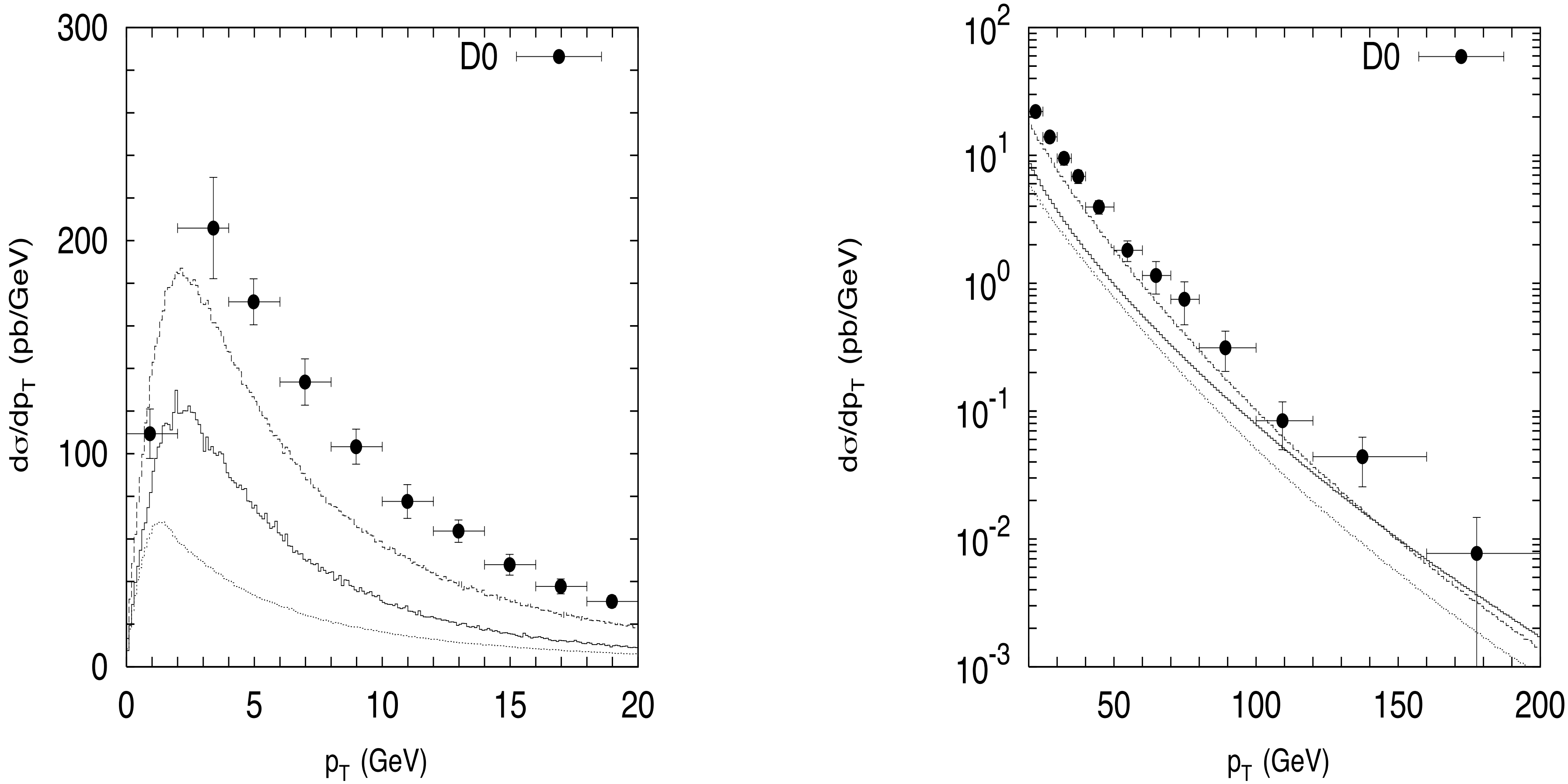


Figure 2: *Comparison between the different approaches to the W production at the Tevatron. Solid, the is sum of $2 \to 3$, $2 \to 2$ and $2 \to 1$ subprocesses with valence quarks only; dashed, $2 \to 1$ quark-antiquark annihilation including both sea and valence quarks; dotted, quark-antiquark annihilation with suppressed $q \to qg$ splitttting in the evolution. KMR parton distrubutions are everywhere.*

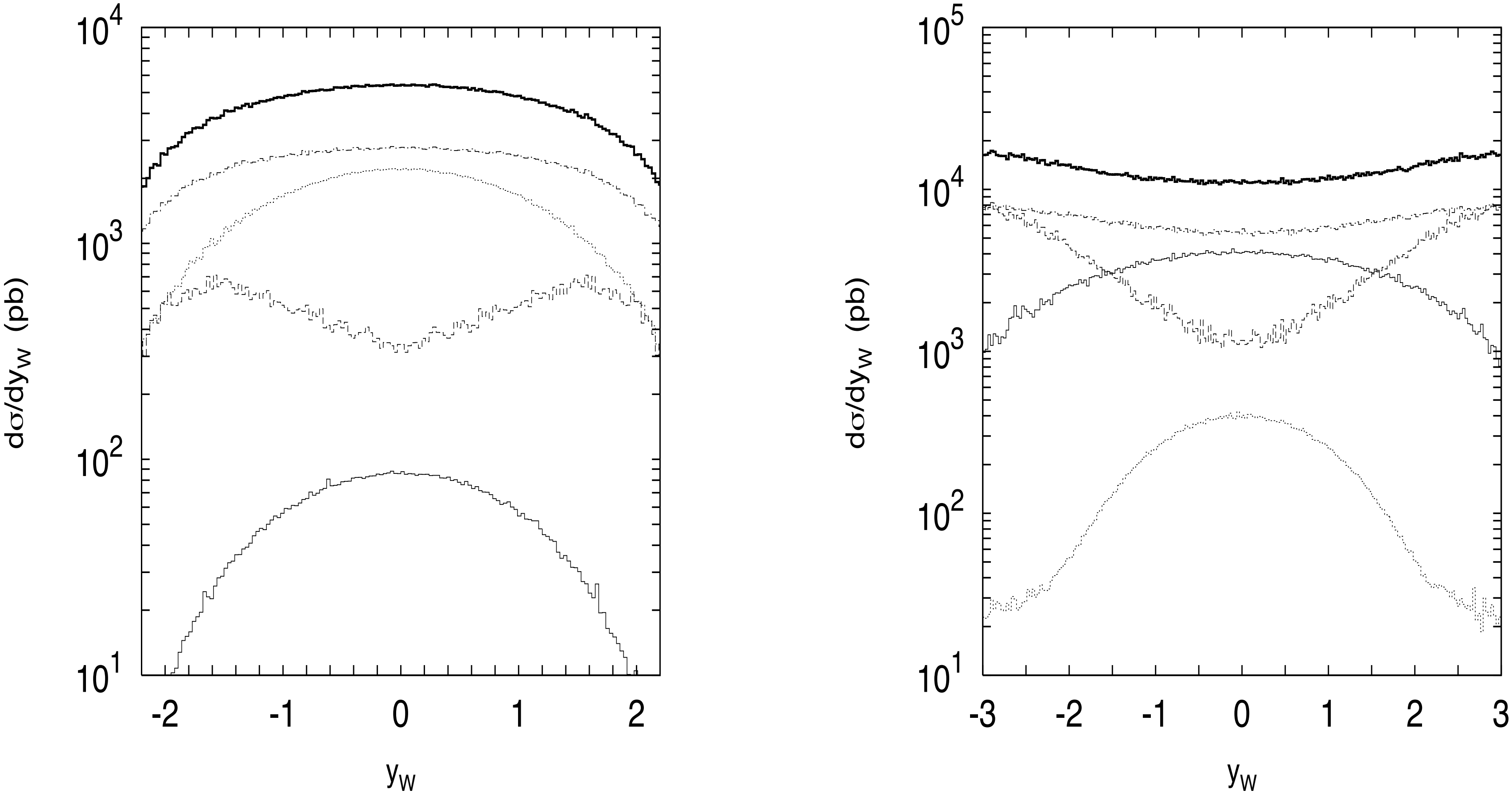


Figure 3: *Importance of the different contributions to the inclusive production of* W *bosons at the Tevatron (left) and LHC (right). Solid, gluon-gluon fusion; dashed, valence quark-gluon scattering; dotted, valence quark-antiquark annihilation; dash-dotted, the contribution from all sea quark subprocesses, but without quarks appearing at the last step of gluon evolution. Thick solid, the sum of all contributions.*

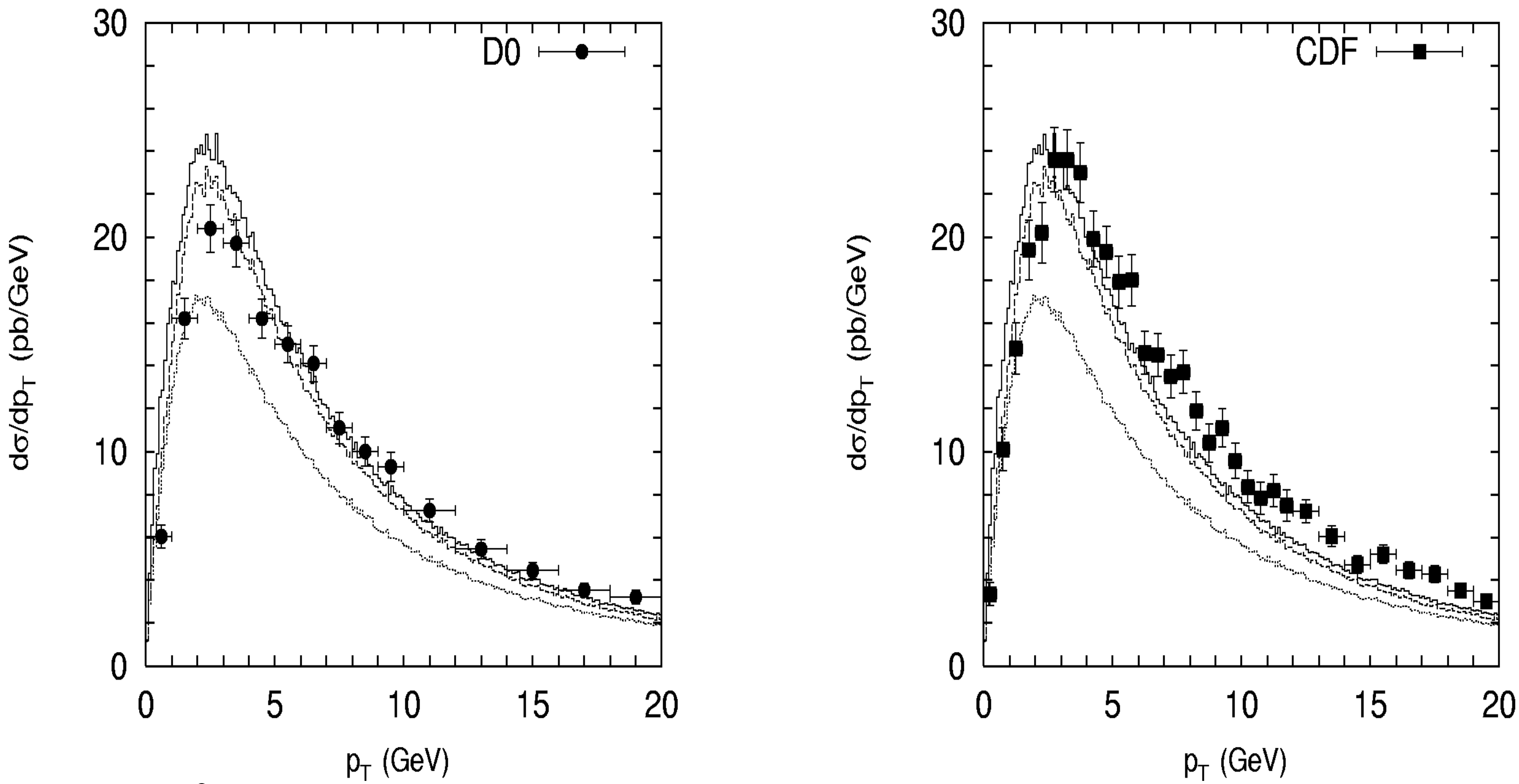
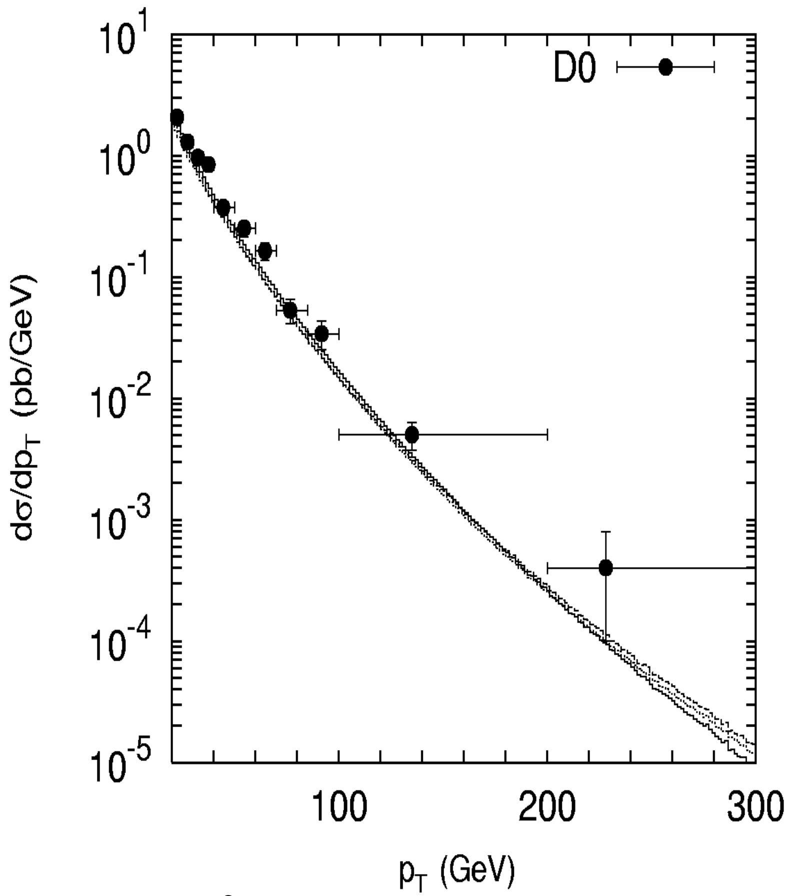


Figure 4: *Z^0 boson transverse momentum distribution compared to the D0 (left) and CDF (right) data. Solid, CCFM parton densities; dashed, KMR parton densities; dotted, quark-antiquark annihilation only (KMR).*



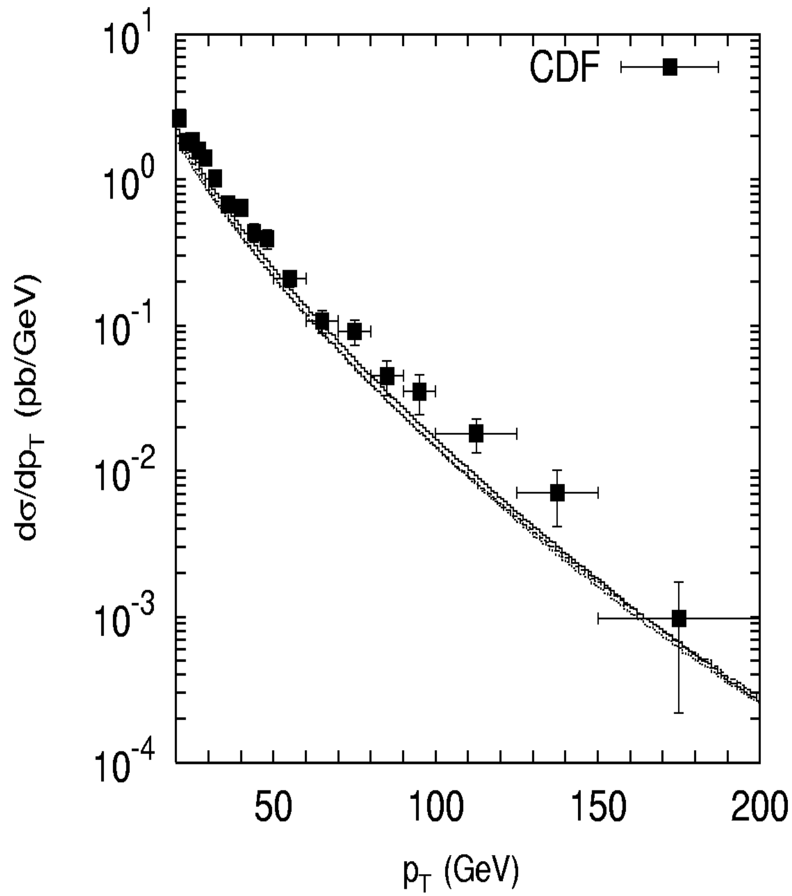


Figure 5: *Z^0 boson transverse momentum distribution compared to the D0 (left) and CDF (right) data. Same as in previous Figure but for extended p_T range.*

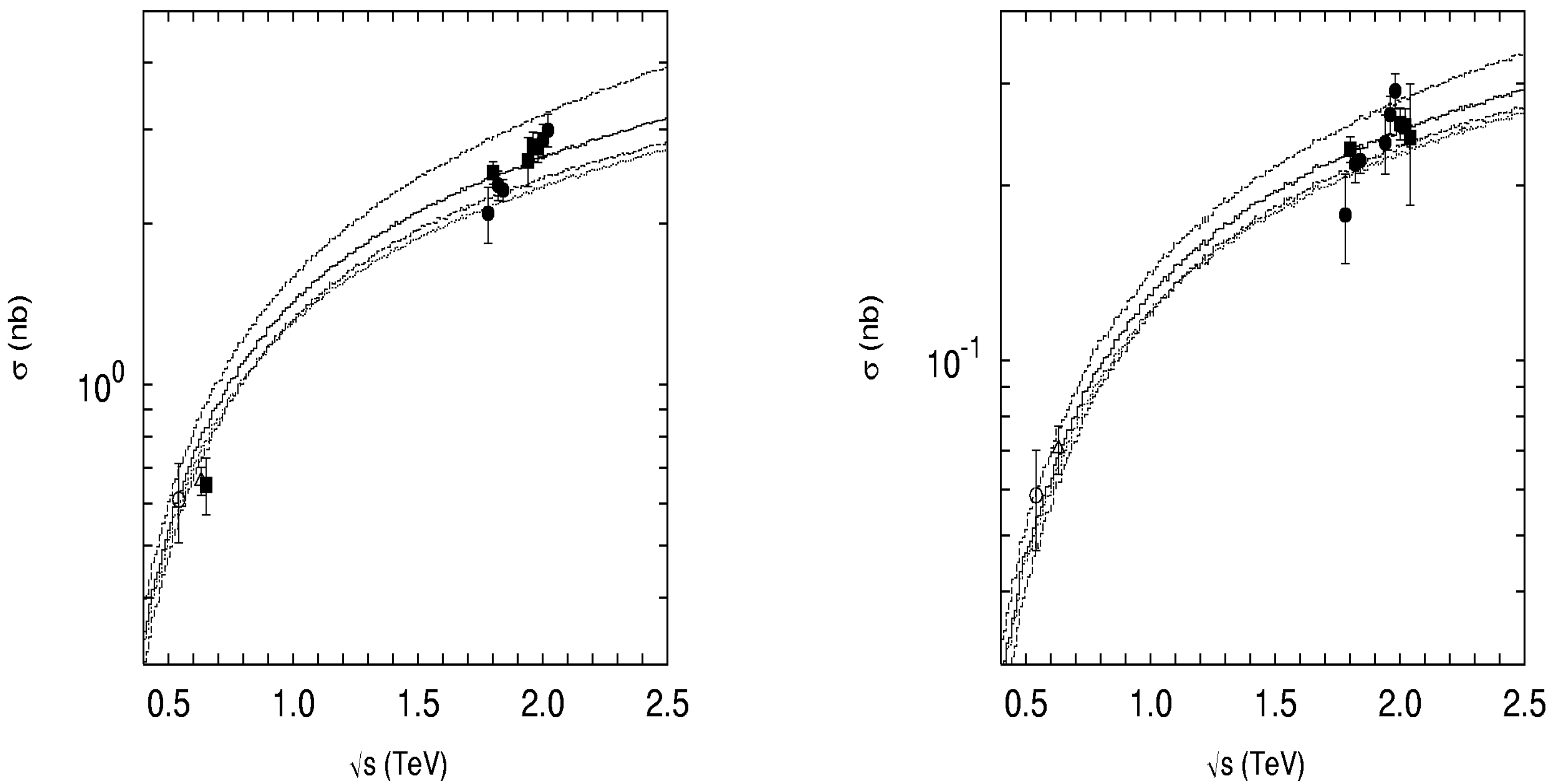


Figure 6: *Energy dependence of the total W (left) and Z (right) production cross sections. Solid, CCFM parton densities, dotted, KMR parton densities; dashed, CCFM theoretical uncertainty band due to factorization scale variations.*