Vector Boson Production at NNLO

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PHYSICS AT THE TERA SCALE
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Motivation

The production of weak bosons in hadron-hadron collisions is one of the most important processeses at the LHC and Tevatron.

It is also a background for the new physics searches (e.g. search for the extra gauge bosons Z' and W'-bosons in high energy tails of distributions).

The study of W-boson resonance allows also precision measurements of W mass and some EW parameters (e.g. effective leptonic mixing angle) at LHC.

Calibration the of detectors by comparing with LEP data.

One of the most promising candidates for the luminosity monitor.

Sensitivity to PDF's.

Theoretical uncertainties. Known corrections.

From the theoretical side an adequate description is required. Many calculations have already been done by several groups.

- NLO and NNLO QCD corrections to the total and fully differential cross-sections
- NLO electroweak corrections
- multiphoton final state radiation
- partonic subprocesses γq and $\gamma\gamma$
- NLO SUSY corrections
- matching of NLO QCD with parton shower virtual contribution)

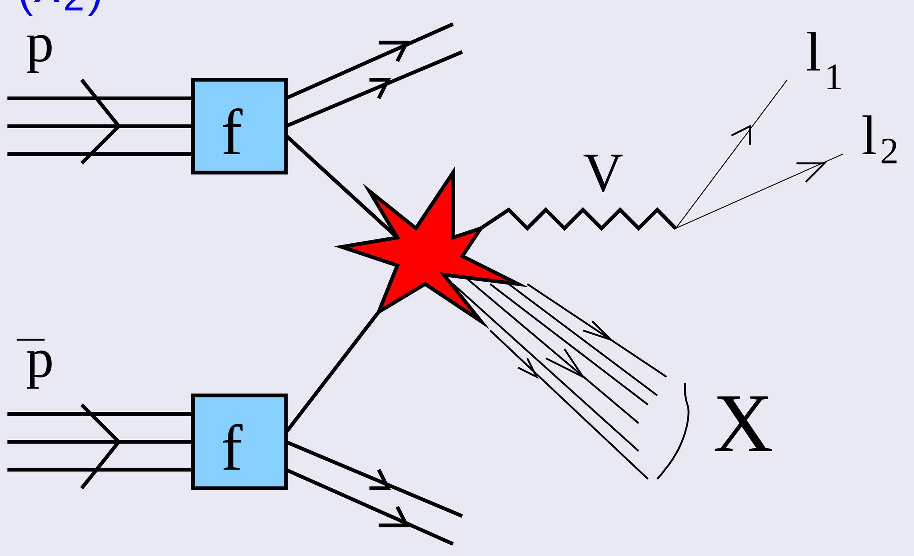
Most of the theoretical uncertainties come from PDF.

○ The complete $O(\alpha\alpha_s)$ analysis is still missing!

Drell–Yan production

Drell–Yan process in hadron-hadron collisions

$$\frac{d\sigma_{pp}}{dQ_T^2\,dY} = \sum_{\text{part. } i,j} \int dx_1\,dx_2\, f_i^{(p)}(x_1)\, \frac{s\,d\hat{\sigma}_{ij}}{dt\,du}(x_1P_1, x_2P_2)\, f_j^{(p)}(x_2)$$



NNLO corrections to the hard-scattering processes $d\hat{\sigma}_{ij}/dt\,du$ requires evaluation of

- $2 \to 1$ process at 2-loops
- $2 \to 2$ process at 1-loop
- $2 \to 3$ process at the tree level

Electroweak corrections at large p_T

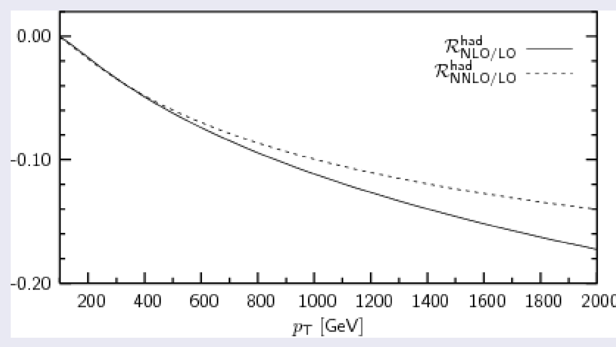
(Kühn et al., Hollik et al., Denner et al.)

- EW corrections grow with the energy

EW RC for different partonic processes (in percent)

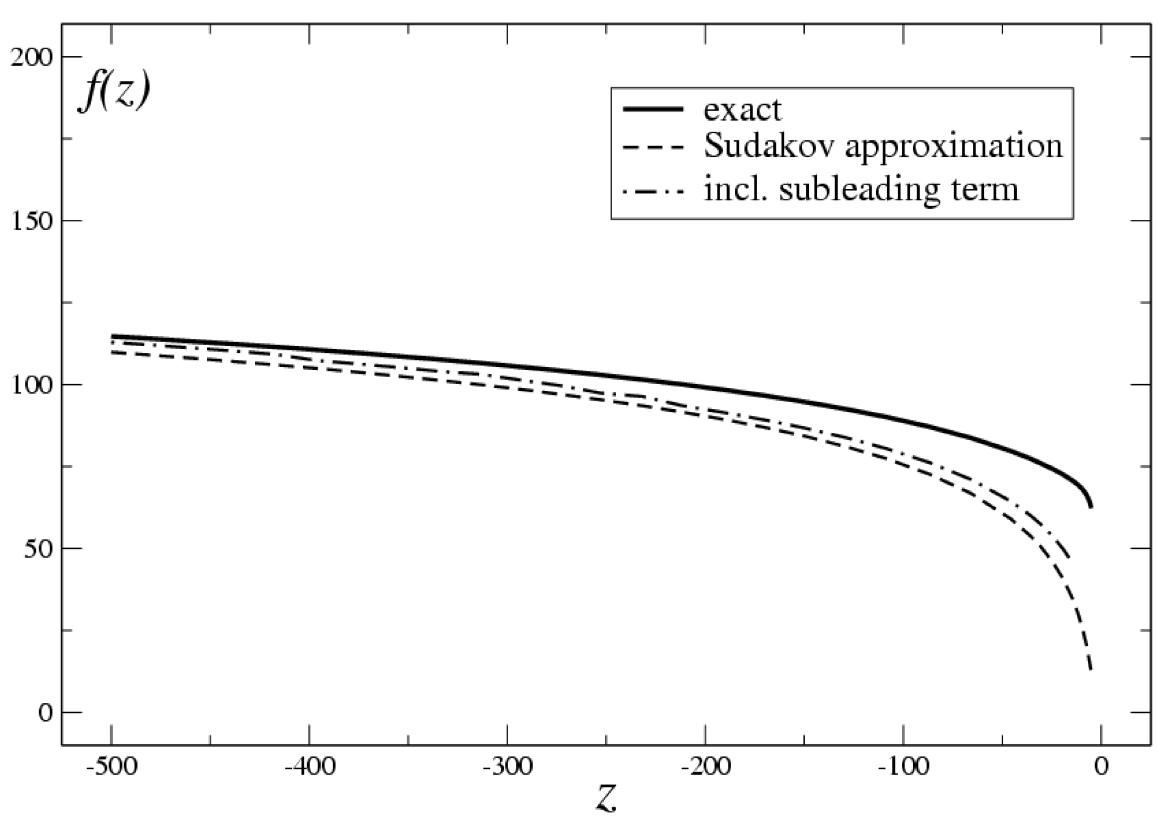
$\sqrt{s}$(GeV)	$\bar{u}u$	gu
500	-3.9	-5.1
1000	-10.2	-12.9
2000	-19.6	-23.6

Relative corr. to p_T distribution ($\sqrt{s} = 14$TeV) (Kühn et al.)



- SUSY corrections $< 2\%$ (Dittmaier et al.)
- For high p_T EW corr. can reach up to 40%

Vector boson formfactor at the order $O(\alpha\alpha_s)$



Mixed EW/QCD 2-loop correction $f(M_V, Q)$ to the VB formfactors F_R, F_L: (Kotikov, Kühn, OV)

$$F_R(Q^2) = i\frac{g_R}{s_W}\left(1 + C_F\frac{\alpha_s}{\pi}f_{\rm QCD}\right)\left[1 + \frac{\alpha}{\pi}\,\rho(M_V, Q, \dots) + C_F\frac{\alpha_s\alpha}{\pi\,\pi}\, f(M_V, Q, \dots)\right]$$

- on-shell results for the abelian and nonabelian formfactors

$$f_{\rm A}(1) = 14 + 72\zeta_2 l_2 - 64\zeta_2 l_2^2 - \frac{16}{3}l_2^4 + 22\zeta_2 - 28\zeta_3 + 16\zeta_4 - 128{\rm Li}_4(\tfrac{1}{2})$$

$$f_{\rm NA}(1) = -16 - 144\zeta_2 l_2 + 128\zeta_2 l_2^2 + \frac{32}{3}l_2^4 + \frac{70}{3}\zeta_2 + \frac{184}{3}\zeta_3 - 236\zeta_4$$
$$+26\frac{\pi}{\sqrt{3}} + 256{\rm Li}_4(\tfrac{1}{2}) - 84\frac{1}{\sqrt{3}}{\rm Ls}_2(\tfrac{\pi}{3}) - \frac{16}{3}\pi{\rm Ls}_2(\tfrac{\pi}{3}) + 96\left({\rm Ls}_2(\tfrac{\pi}{3})\right)^2$$

- comparision with Sudakov limit ($Q^2 \to \infty$) $z = M_V^2/Q^2$:

$$f(z) = (3 - 24\zeta_2 + 48\zeta_3)\log(-z) - 2 + 40\zeta_2 - 84\zeta_3 + 14\zeta_4$$
$$+\frac{M_V^2}{Q^2}\left((-26 + 8\zeta_2)\log^2(-z) + (-120 - 16\zeta_2 + 128\zeta_3)\log(-z) - 188 - 8\zeta_2 - 8\zeta_3 + 116\zeta_4\right) + \dots$$

Details of calculation

Evaluation of massive vertex 2-loop diagrams:

- using *integration by part identities* perform reduction to master integrals
- evaluation of master integrals:
  - asymptotic expansion
  - differential equation
- search solution in terms of functions

$$H_{a,b,\dots,c}(z) = \int_0^z \frac{dx_1}{x_1 - a}\int_0^{x_1}\frac{dx_2}{x_2 - b}\cdots\cdots\int_0^{x_k}\frac{dx_{k-1}}{x_{k-1} - c}$$

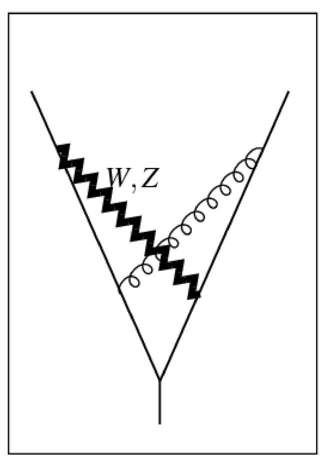
with $a, b, \dots, c = +1, -0, 1, \pm e^{i\pi/3}$

- express H's in terms of polylogarithms ot the new *nonlinear* argument

$$y = \frac{1 - \sqrt{q^2/(q^2 - 4m_V^2)}}{1 + \sqrt{q^2/(q^2 - 4m_V^2)}}$$

a nonplanar diagram with numerator:

```
id N5(k2.p2,1,1,1,1,1,0) =
+ 1 * 1/z^0 * ( 2*LOG-3*zt2+3/2-3/4*LOG^2 )
+ 1 * 1/z^0 * (
    + (2*zt2-3+1/2*LOG^2) * 1 * log(1-z)
    + (LOG-2) * 1 * Li2(z)
    + 1 * 1 * log(1-z)*Li2(z)
    + (-1) * 1 * Li3(z)
    + 2 * 1 * S12(z)
    + (-2*zt2+3-1/2*LOG^2) * 1/z * log(1-z)
    + (-LOG+zt2-1+1/4*LOG^2) * 1/z * Li2(z)
    + (-1) * 1/z * log(1-z)*Li2(z)
    + (-LOG+1) * 1/z * Li3(z)
    + (-2) * 1/z * S12(z)
    + 1/4 * 1/z * Li2(z)^2
    + 3/2 * 1/z * Li4(z)
    + (-1) * 1/z * S22(z)
        );
```



- functions up to *weight* 4 contibute at the 2-loop level

Outlook

○ Discussed is the framework of calculation of the differential distribution in W/Z production $\frac{d\sigma}{dQ_T^2\,dY}$ (the integration to the total cross-section also is possible).

○ Both the total cross-section and differential distributions are required for the analysis.

○ Combine missing parts: to provide complete $O(\alpha\alpha_s)$ approximation for the on-shell VB.

○ Take into account ressumations of large logarithms.