Z production via Vector Boson Fusion

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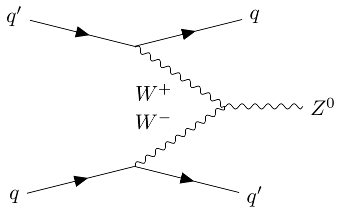
Motivation

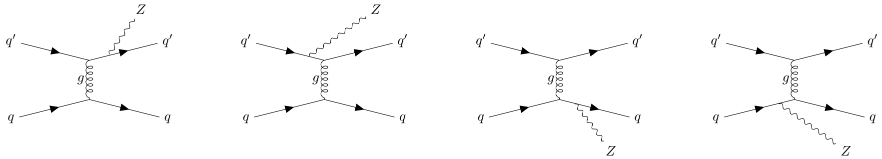
We consider the production of the Z^0 boson in the processes $qq' \to Z^0 qq'$. The non-abelian nature of weak gauge bosons constitutes an **important feature of the Electroweak theory**.



- We discuss if one can **identify the three-boson interaction** (three-boson coupling vertex) **in a direct experimental measurement**
- We inspect if it can be done through comparing two different partonic subprocesses leading to the production of Z^0 boson in a quark-quark scattering, using splitting approximation approach.

The Splitting Framework

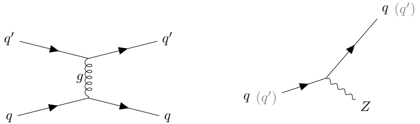
The first of the considered processes is mediated by a gluon exchange.



When we impose **kinematic cuts** on the emitted Z^0 boson $p_T(Z) > p_{T,min}$ the diagrams **do not interfere**. The process can then be factorized into quark-quark scattering $qq' \to qq'$ followed (or preceeded) by a quark splitting $q \to qZ^0$ or $q' \to q'Z^0$:

The cross sections $qq' \to qq'Z$ can be written as

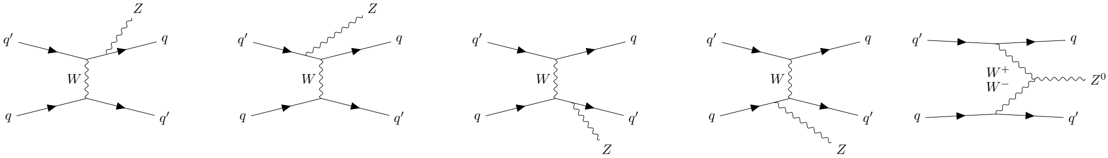
$$d\sigma \simeq \sum_{\ell=4} d\hat{\sigma}^{(g)}_{qq' \to qq'} \otimes \mathcal{P}_{q_\ell \to Z}(z, p_T; s)$$



The $p_{T,\mathrm{min}}$ can be determined from a comparison between **direct calculation** (including interference) and the sum of four separate **'splitting' contributions**.

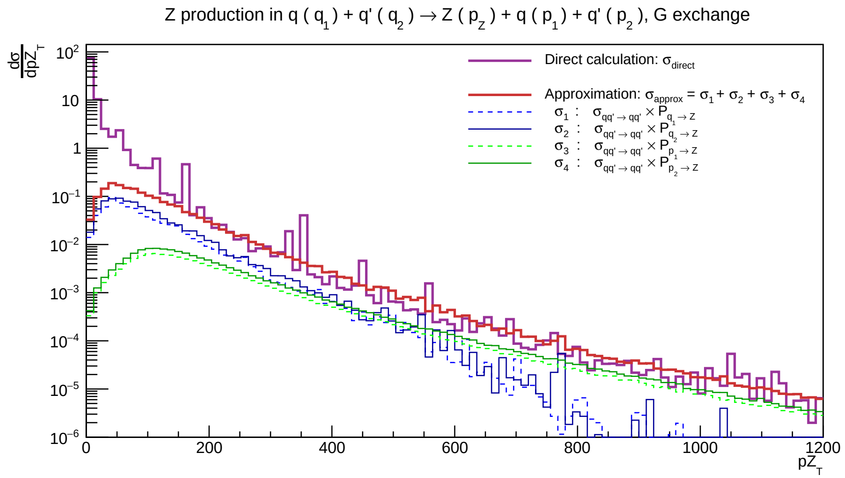
Splitting in VBF

The second process is mediated by W boson exchange. Here, in addition to 4 diagrams a diagram containing the triple gauge-boson coupling appears.



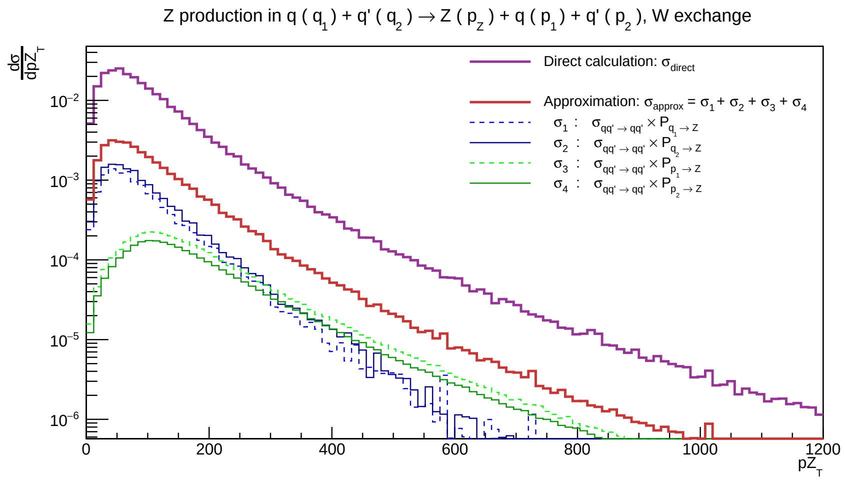
We assume that one can find the kinematic region ($p_T > p_{T,\text{min}}$) where the contributions of 4 **diagrams except three-boson vertex can be described with the splitting approximation**. Comparing the direct calculation (based on five Feynman diagrams with their interferences) and the sum of four splitting contributions we inspect the possibility of extracting the **three-boson gauge vertex contribution**.

Valid splitting approximation pT region



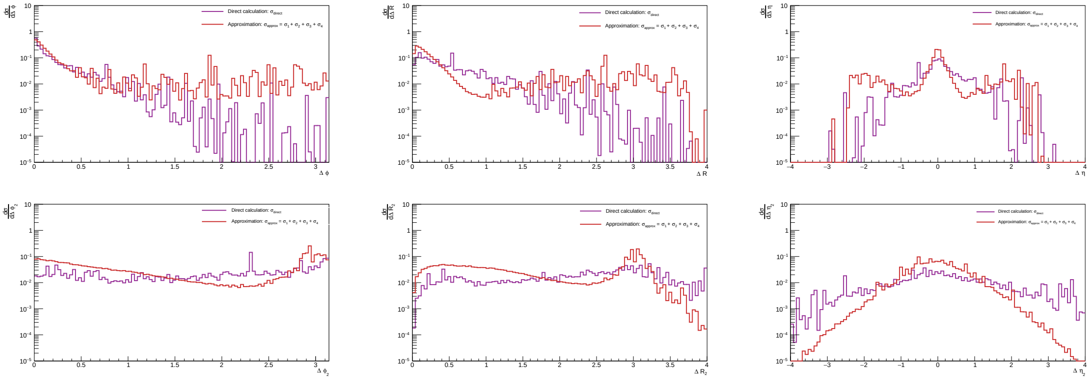
The splitting approach reproduces the direct calculation in $p_T(Z) > 500\mathrm{GeV}$

Three-Boson Vertex (WWZ) Contribution

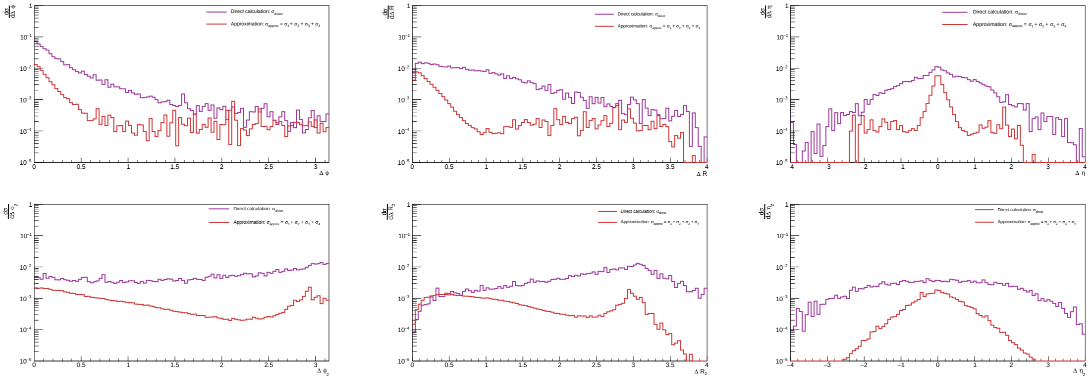


The contribution of the WWZ vertex can be estimated as $\sigma_{\text{full}} - \sigma_{\text{frag}}$.

Angular Distributions



$$p_T(Z) > 500\mathrm{GeV}$$



$$p_T(Z) > 500\mathrm{GeV}$$

Conclusions

- Comparing two different partonic subprocesses allows us to estimate the role of the three-boson coupling vertex.
- We demonstrate that the three-boson interaction can be extracted in an experimental measurement within the considered kinematic region.
- The splitting approximation approach reproduces the exact calculation in the high-p_T region

$$p_T > 500 \text{ GeV}$$

Thanks for Your Attention

References

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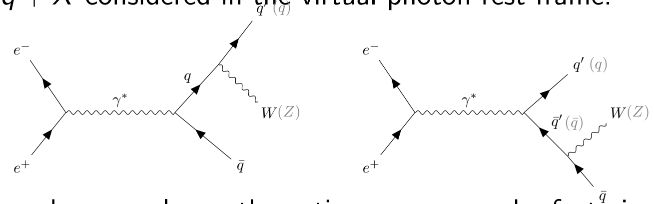
Splitting function $q \to qX$: Derivation

To calculate the quark to X splitting function, X is W or Z boson, we start with the process $e^+e^- \to \gamma^* \to \bar{q} + q + X$ considered in the virtual photon rest frame.



When the input energy becomes large, the entire process can be factorized into the 'prequel' process (before the quark splitting $e^+e^- \to \gamma^* \to \bar{q} + q$) and splitting.

$$d\mathcal{P}\,(q \to Xq) = \frac{d\sigma(ee \to W\,q\,\bar{q})}{d\sigma(ee \to q\,\bar{q})} = \frac{1}{(2\pi)^3}\,\frac{1}{4\,\lambda^{1/2}(s, p^{*2}, m_q^2)}\,\frac{\left|\mathcal{M}(\gamma^* \to X\,q\,\bar{q})\right|^2}{\left|\mathcal{M}(\gamma^* \to q\,\bar{q})\right|^2} \times ds_1 ds_2\, d\phi\, d\psi\; d\cos\theta. \quad (1)$$

Eq.(1) can be reduced to the conventional splitting function:

$$\mathcal{P}_{q/W}(z) = \int \mathcal{P}\,(q^* \to W/Z\,q)\,\delta(z - p_W^+/p^{*+})\; \times ds_1\, ds_2\, d\phi\, d\psi\; d\cos\theta \quad (2)$$

Splitting function $q \to qX$: Results

In the high-energy limit it reproduces the Weizsäcker–Williams behavior

$$\mathcal{P}_{q\to qZ}(z,s) = \frac{\alpha_{\rm eff}}{2\pi}\left[\frac{1+(1-z)^2}{z}\ \ln\frac{s}{4m_W^2}\right],$$ for Z bosons with

$$\alpha_{\rm eff} = \frac{\alpha}{\sin^2\theta_W\cos^2\theta_W}\left[\left(e_q\sin^2\theta_W\right)^2 + \left(T_q^3 - e_q\sin^2\theta_W\right)^2\right],\quad T_q^3 = \pm\frac{1}{2}$$ for u/d-type quarks.