Polarized cross-section of triple Z-boson production processes at LHC

Trung Tin HUYNH, Van Cuong LE, Duc Ninh LE

July 23, 2026

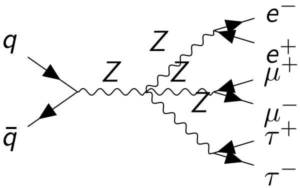
Table of Contents

Introduction

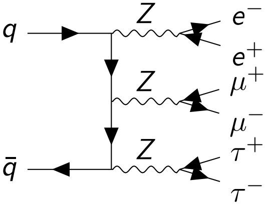
Why choosing the $\bar{p}p \to ZZZ \to e^+e^-\mu^+\mu^-\tau^+\tau^-$?

- ZZZ process is a very clean channel at CLHC.
- It produces 6 charged leptons, which can easily to be detected in experiment.
- in SM, ZZZ coupling vanishes but it can be non vanishing in SMEFT.

Some Feynman diagrams for $\bar{p}p \to ZZZ \to e^+e^-\mu^+\mu^-\tau^+\tau^-$



(a)



(b)

The (a) diagram only $\neq 0$ in SMEFT

Three-pole approximation

We can then factorize the helicity amplitude for the process $\bar{q}(k_1) + q(k2) \to V_1(q_1) + V_2(q_2) + V_3(q_3) \to \sum_{i=1}^{6} l_i(k_{i+2})$ into gauge-invariant factors, as on-shell production amplitude $\bar{q}q \to V_1 V_2 V_3$ and three on-shell decay amplitude $V_i \to ll'$:

$$\mathcal{A}_{TPA}^{\bar{q}q\to V_1 V_2 V_3 \to 6l}([k_i]) = \frac{1}{Q_1 Q_2 Q_3} \sum_{\lambda_1,\lambda_2,\lambda_3=1}^{3} \Big[\mathcal{A}^{\bar{q}q\to V_1 V_2 V_3}([\hat{k}_i], \lambda_1, \lambda_2, \lambda_3)\mathcal{A}^{V_1\to l_1 l_2}([\hat{k}_i], \lambda_1)$$
$$\mathcal{A}^{V_2\to l_3 l_4}([\hat{k}_i], \lambda_2)\mathcal{A}^{V_3\to l_5 l_6}([\hat{k}_i], \lambda_3)\Big]$$

where

$$Q_i = q_i^2 - M_{V_i}^2 + iM_{V_i}\Gamma_{V\,i}(i = 1, 2, 3)$$
$$\lambda = 1:\ \text{left transverse}, \lambda = 2:\ \text{longitudinal}, \lambda = 3:\ \text{left transverse}$$
$$\text{For example:}\ \lambda_i, \lambda_j = 1/3, \lambda_k = 2 : TTL$$

Random helicity method

- Calculating by summing over all helicity states consume too much time.
- Random helicity method is created in order to reduce the calculation time.
- By create a random number and uses that to find helicity states of the 6 leptons.

$$\mathcal{A}(\sigma_i) = \frac{1}{Q_1 Q_2 Q_3} \sum_{\sigma_1,\sigma_3,\sigma_5 \in [-1,1]} \left[\mathcal{A}^{\bar{q}q \to V_1 V_2 V_3} \mathcal{A}^{V_1 \to l_1 l_2}(\sigma_1) \mathcal{A}^{V_2 \to l_3 l_4}(\sigma_3) \mathcal{A}^{V_3 \to l_5 l_6}(\sigma_5) \right]$$

$$|\mathcal{A}|^2 = \sum_{\sigma_1,\sigma_3,\sigma_5 \in [-1,1]} \mathcal{A}(\sigma_i)\mathcal{A}(\sigma_i)^{=} \int dx \mathcal{A}(\sigma_i(x))\mathcal{A}(\sigma_i(x))$$

Tool: MulBos

- Mulbos (MultiBoson Production) is a tool to calculate cross section, $d\sigma$ and distribution at particle level using Monte Carlo integration.
- Programing in Fortran and Python.
- See Cuong's talk later for more details.

.

Results

The CM energy used in this simulation is $\sqrt{s} = 13.6\,TeV$, other parameter inputs are:

$$
\begin{aligned}
M_Z^{OS} &= 91.1880 \text{ GeV} & \Gamma_Z^{OS} &= 2.4955 \text{ GeV} \\
M_W^{OS} &= 80.3692 \text{ GeV} & \Gamma_W^{OS} &= 2.14 \text{ GeV} \\
M_H &= 125.20 \text{ GeV} & \Gamma_H &= 0.0037 \text{ GeV} \\
M_t &= 172.69 \text{ GeV} & \Gamma_t &= 0.0 \text{ GeV}
\end{aligned}
$$

And the cuts are:

$$
\begin{aligned}
&P_{T,l} > 15 \text{ GeV} & &|\eta_l| \leq 2.7 \\
&81 \text{ GeV} \leq M_{2l} \leq 101 \text{ GeV} & &M_{4l} \geq 130 \text{ GeV} \\
&M_{6l} \geq 276 \text{ GeV} & &\Delta_{R,2l} = 0.1
\end{aligned}
$$

Results comparation

Comparation of square amplitudes between Mulbos and Madgraph at a phase-space point.

Process	Program	$\lvert\mathcal{M}\rvert^2$
$\bar{u}u$	Mulbos	2.6248169636**45746**E-015
	Madgraph	2.6248169636**53792**E-015
$\bar{d}d$	Mulbos	8.1336128157**46988**E-015
	Madgraph	8.1336128157**74566**E-015

Table: Square amplitudes comparation between programs

Results comparation

Comparation of cross section between Mulbos in both sum over all helicities and random helicity method ,Vbfnlo, Sherpa and MoCaNLO gives:

Program	$\sigma(fb)$	No. random points
Mulbos(full)	1.127(2)	2^{21}
Mulbos(R-H)	1.172(1)	2^{23}
vbfnlo	1.04(7)	2^{20}
Sherpa	1.049(2)E-3	
MocaNLO	1.041(1)E-3	

Table: Cross section comparation between programs

Numerical results

	$\sigma(fb)$	Pol. fraction
Full off-shell	1.127(2)	
Unpol. TPA	1.0791(6)	
TTT	5.116(3)	47.41
TTL	3.807(2)	35.28
TLL	1.2665(5)	11.73
LLL	2.160(2)	2.00
Interference	3.84(2)	3.57

Table: Cross section for each polarized case

Conclusion

1. In this calculation, we got the cross section of each polarized case and their contribution to the total cross section.
2. The results may be useful for the future experiments.
3. Distributions in progress.

Thanks for your listening

Life would be better if there're no questions, especially from Surabhi.