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# Non-Violating Unitarity Constraints in Extra Z' Heavy Particle Effect at Tesla Collider (CERN) CM Energy More than 500 GeV

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**Abstract**

We have done calculation for the unitarity delay. We have also wants to include very heavy particle which has been showed violating of unitarity as well as unitarity delay. We found that Föster limit has been explained and stopped the violation of unitarity and continue with the unitarity delay. It means that CM energies have very high energy more 3000 GeV the unitarity delay breakdown. Föster limit provides us that unitarity constraints obeys the law of unitarity delay. Our pervious calculation of S, T & U parameters results are very strong parameters for the physics beyond the SM. The radiative corrections of $W^+$ & $W^-$ gauge boson through vertex of $Z_1$WW, $Z_2$WW and $\gamma$WW vertices we found the results are favour S, T and U parameters results. This calculation completes our research work to the cross- section and vertex corrections. We study the cross section that is non-delayed Unitarity violation. Can it stop violation? If we include heavy exotic lepton doublet L=$\begin{pmatrix} N \\ \nu_L \end{pmatrix}$ in the vertex diagram also.

**Keywords:** Föster limit, vertex, vertices, unitarity, delay unitarity

## Introduction

**Z' heavy particle effects $e^- e^+ \rightarrow W^- W^+$ [1, 2]**

Radiative corrections allow us to probe the high-energy world with comparatively low-energy experiments. Because any intermediate state allowed by symmetry, however heavy (like Z', Higgs particles) can appear as a quantum fluctuation, precision experiments which isolate radiative corrections can probe for particles with masses much higher than the experimental energy scale. Now that we are entering the era of experiments on the properties of the weak vector bosons, it is interesting to think of precision experiments, which might be carried out on the new fundamental particles. Such experiments would necessarily be done at energies of 500 GeV or even much higher; still extending the reach of the available machine energy by the measurements sensitive to the radiative corrections is an attractive possibility [3]. We observe that in this research that even within the standard model or extra U (1) model the introduction of new heavy particles can cause large deviations from the tree-level cross-section. New species with perfectly conventional electrweak coupling naturally yield different radiative corrections to the s- and t-channel diagram involved in the tree-level unitarity cancellation. All these corrections together must sum to zero (to leading order) for asymptotic. However, the regime of greatest experimental interest corresponds to the case of a state with mass M to large to allow its pair productions at the high-energy lepton collider: $s \leq M^2$, while $s >> (m_w)^2$. In this regime, there is no reason for the Unitarity cancellations to occur, and indeed, we find enhanced radiative corrections of order $\left(\frac{s}{\pi}\frac{\alpha}{m_W^2}\right)$ These effects can be readily identified experimentally. We call this phenomenon in which heavy-particle radiative corrections postpone the asymptotic cancellation among diagrams, "Unitarity Delay" [1, 2].

## Objective and General Formalism [3]

BPZH begins their analysis with a general parameterization of the WWA and WWZ vertices. Let $f_i^V$ represent form factors (V=A or Z) and T represent canonical Lorentz structure (simplicity carrying three vector indices). The vertex shown in Fig. 1 is built from the ingredients as

$$\Gamma_V^{\alpha\beta\mu}(q, \bar{q}\ p) = \sum_{i-1}^{7} T_i\ f_i^V \qquad (1)$$

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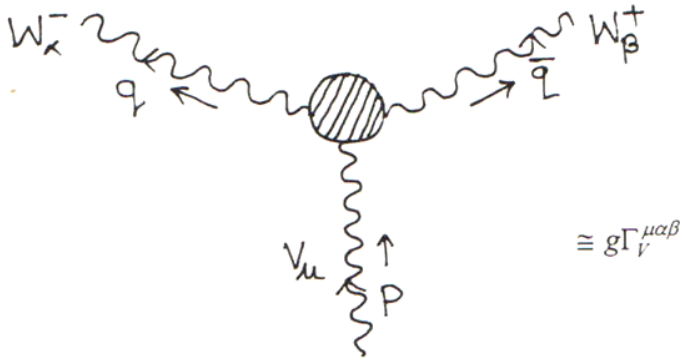
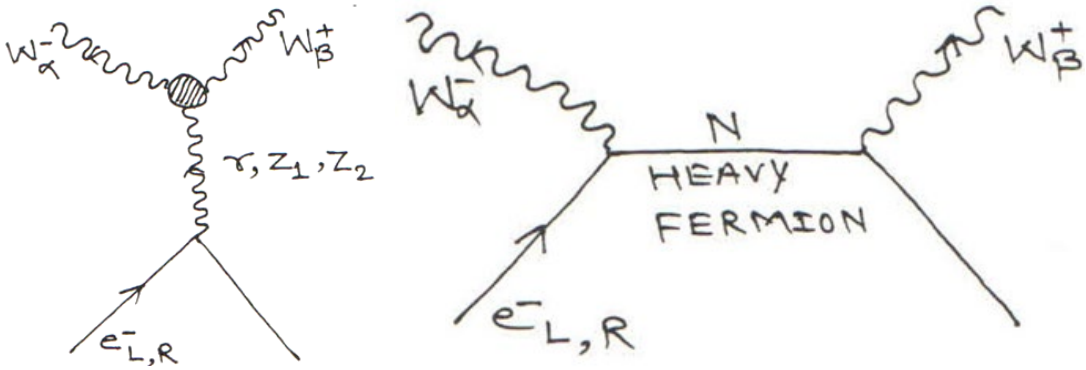



**Fig 1:** The general vertex for W pairs.

The form factors are dimensionless functions of **s** and $m_w$. We will consistently ignore the electron mass. Using qe.(1) we can write the full amplitude arising from the s-channel diagrams for $e^- e^+ \rightarrow W^- W^+$ as shown in Fig. 2(a):

$$M = ie^2 Q\,(\bar{v}\gamma_\mu u)\,\frac{1}{p2}\,\Gamma_A^{\mu\alpha\beta}\varepsilon_\alpha^*(q)\varepsilon_\beta^*(\bar{q}) + ie^2\frac{(I_3 - Q\sin^2\theta_w)}{\sin^2\theta_w}(\bar{v}\gamma_\mu u)\frac{1}{(p^2 + m_{Z_i}^2)}\Gamma_{Z_i}^{\mu\alpha\beta}\varepsilon_\alpha^*(q)\varepsilon_\beta^*(\bar{q}) \quad (2)$$

Where $Z_i = Z_{1,2}$, $P^2$=-s, u and v are electron and positron Dirac spinors and $\varepsilon_\alpha^*(q)$, $\varepsilon_\beta^*(\bar{q})$ are polarization vectors of $W^\pm$, respectively.




**(a)** S-channel (general vertex) **(b)** t-channel

**Fig 1 (a, b):** The amplitude for $e^- e^+ \rightarrow W^- W^+$

We may consider the electron to have definite velocity and write $I_3$= - $\frac{1}{2}$ for $e_L$, $I_3$=0 for $e_R$. Eq. (2) suggests that we combine the photon and Z or Z' vertices according to

$$F_i = Q\,f_i^A + \frac{(I_3 - Q\sin^2\theta_{w^*})}{\sin^2\theta_{w^*}}\left(\frac{s}{s - m_{Z_i}^2}\right)f_i^{Z_i}, (i = 1,2 \ldots 7) \quad (3)$$

And define $\Gamma^{\mu\alpha\beta}$ as the vertex built from these form factors according to eq. (1)

$$\Gamma^{\mu\alpha\beta}(q,\bar{q},p) = \sum_{i=1}^{7} F_i\,T_i \quad (4)$$

The differential cross section for $W^\pm$ scattering from electron and positron states of definite helicity into W states of definite polarization. Expressing these cross section in units of the point cross section 1R= $\frac{4\pi\alpha^2}{3s}$

$$\frac{d\sigma}{d\cos\theta} = \frac{3}{8}\,\beta\,\Sigma(R) \quad (5)$$

Where β= $\sqrt{\left(\frac{(1-4m_w^2)}{s}\right)}$, β is W velocity.

Where $\theta$ is the scattering angle in the center of mass frame, and the subscripts T, L denote transverse and longitudinal polarization of the $W^+$ and $W^-$. For $e_L^+$, $e_R^-$, we find the more complicated result in the form of amplitude $A_1$,$A_2$,$A_3$,$A_4$ and

$$A_5 = \beta \frac{s}{m_w^2}\left[\frac{1}{2}F_3 - \left(\frac{1}{2} - \frac{m_w^2}{2}\right)F_1 + \frac{1}{4}\beta^2 \frac{s}{m_w^2}F_2 + \frac{1}{4sin^2\theta_w} + \frac{m_w^2}{s\beta^2 sin^2\theta_w}\left(1 - \frac{2m_w^2}{sD}\right)\right] \quad (6)$$

$F_1$,$F_2$,$F_3$ form factors.

**For Factors pertaining to $Z_2$ [4]**

We assume that the mass difference $M_{H^\pm}$ and $Z_2$ is always small, which it is and set

$$\Delta m^2 = \left[M_{H^\pm}^2 - M_{Z_2}^2\right],$$
$$m^2 = \left[\frac{1}{2}(M_{H^\pm}^2 + M_{Z_2}^2)\right] \quad (7)$$

With $\Delta m^2 << m^2$. Then for $m_w^2 < s << m^2$, we use directly the asymptotic repression for $C_\delta$'s ($\delta = 0,1,2 \ldots .7$)from qe.(16) of ref.[3]. On the other hand, when s>>$m^2$, dropping $\frac{\Delta m^2}{m^2}$, we use the non-asymptotic expression for $C_\delta$'s as given in qe.(17) of ref. [3]

**Appendix**

We calculated values of charged Higgs mass $M_{H^\pm}$ and neutral Higgs mass $M_{H^0}$ as a function of $Z_2$ and $\Theta_E$ using the top quark $m_t$=173.8$\pm$5.2 GeV/$c^2$[6] for the extra U(1) Superstring Inspired Model parameters [1,5].

**Table 1:** Charge Higgs mass $M_{H^\pm}$ and Neutral Higgs mass $M_{H^0}$ as function of $Z_2$ and $\theta_E$.

| S. No. | $M_{Z_2}$ (GeV) | $\Theta_E$ (Radian) | $M_{H^\pm}$ (GeV) | $M_{H^0}$ (GeV) |
|---|---|---|---|---|
| 1 | 555 | -0.0097 | 476.21 | 702.94 |
| 2 | 565 | -0.0093 | 485.68 | 715.65 |
| 3 | 575 | -0.0090 | 495.00 | 728.35 |
| 4 | 585 | -0.0087 | 504.28 | 741.06 |
| 5 | 595 | -0.0084 | 513.61 | 753.77 |
| 6 | 605 | -0.0081 | 522.93 | 766.48 |
| 7 | 615 | -0.0078 | 532.24 | 779.18 |
| 8 | 620 | -0.0077 | 536.89 | 785.54 |

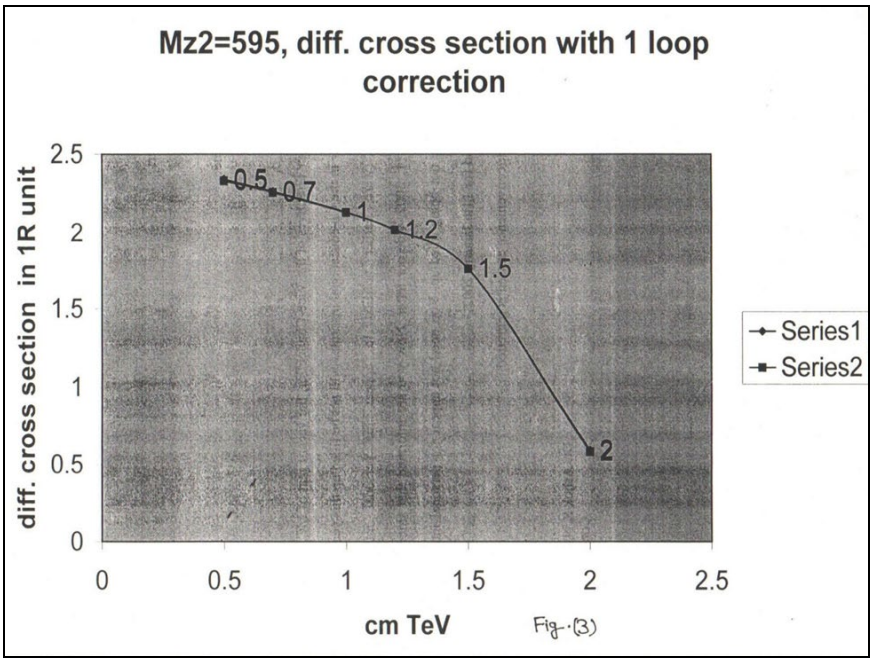



**Fig 2:** Differential cross section and cm energy at = $M_{Z_2}$ 595 Gev.

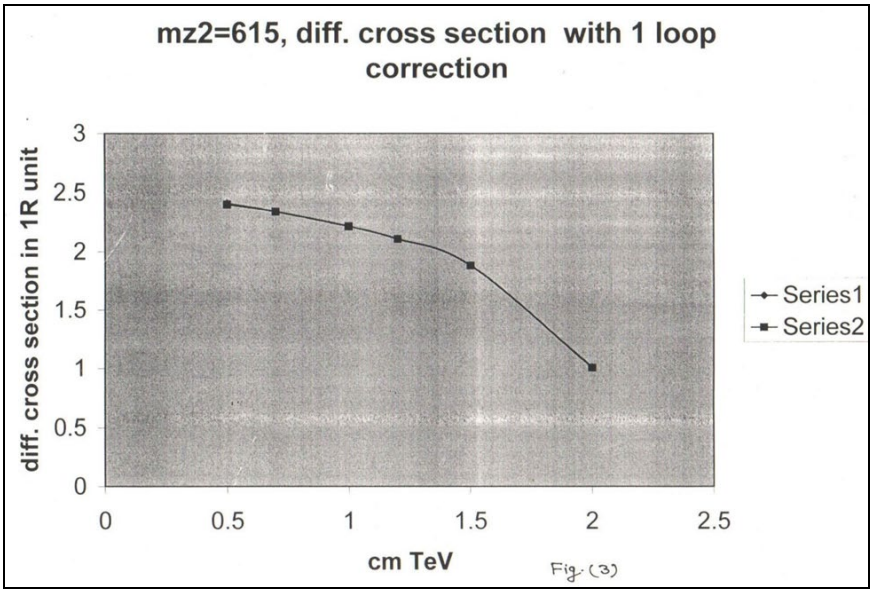



**Fig 3:** Differential cross section and cm energy at $M_{Z_2}$ = 615 Gev.

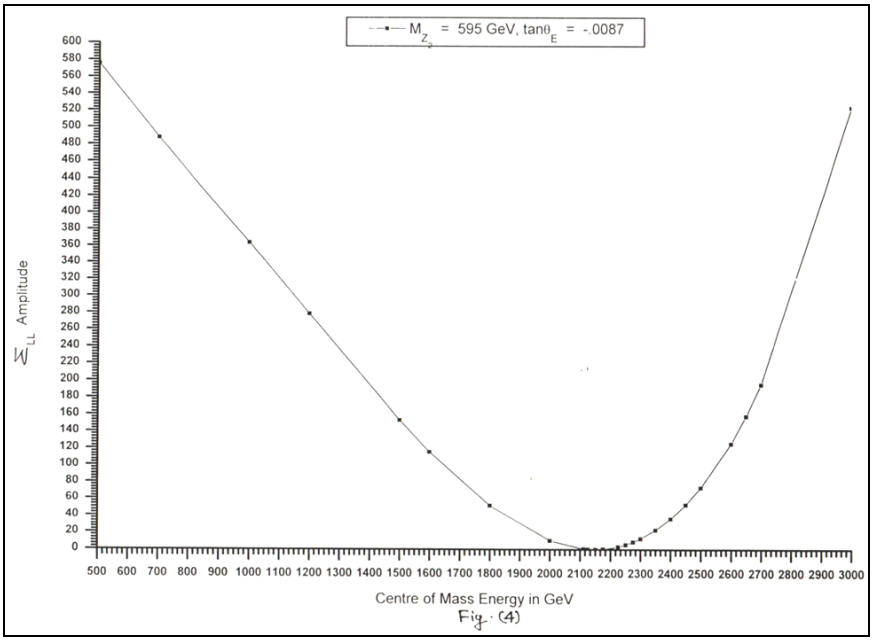



**Fig 4:** $\sum_{LL}$ Amplitude and cm energy at $M_{Z_2}$=595 GeV and tan $\theta_E$= -0.0087.

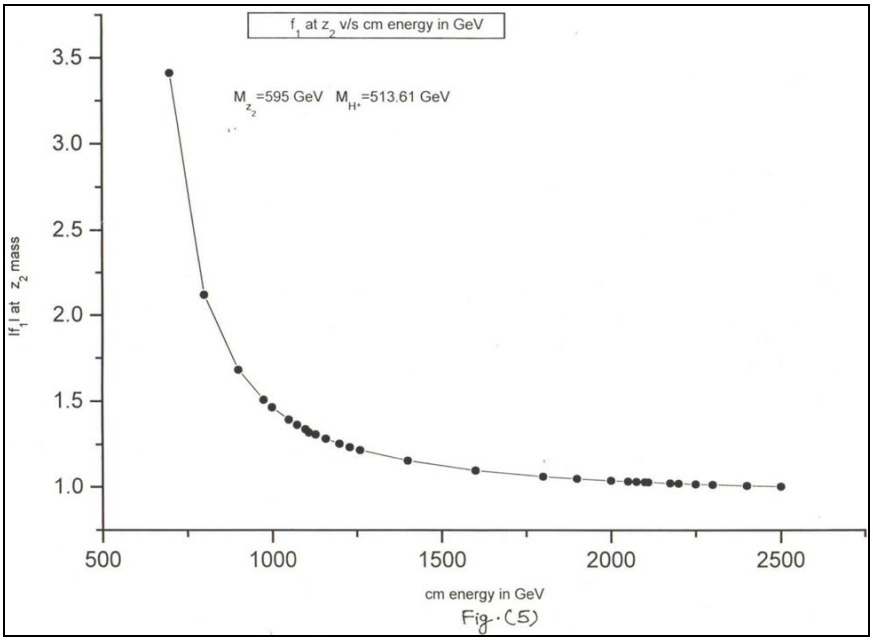



**Fig 5:** If$_1$I at $Z_2$ mass and cm energy at $M_{Z_2} = 595\ GeV\ and\ M_{H^+} = 513.61\ GeV$.

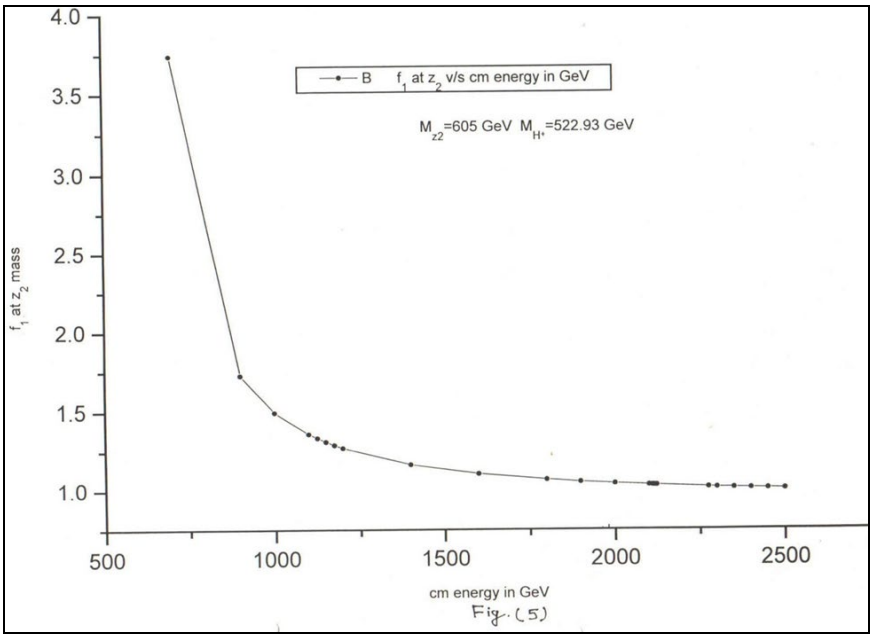



**Fig 6:** f$_1$at $Z_2$ mass and cm energy at $M_{Z_2} = 605\ GeV\ and\ M_{H^+} = 522.93\ GeV$.

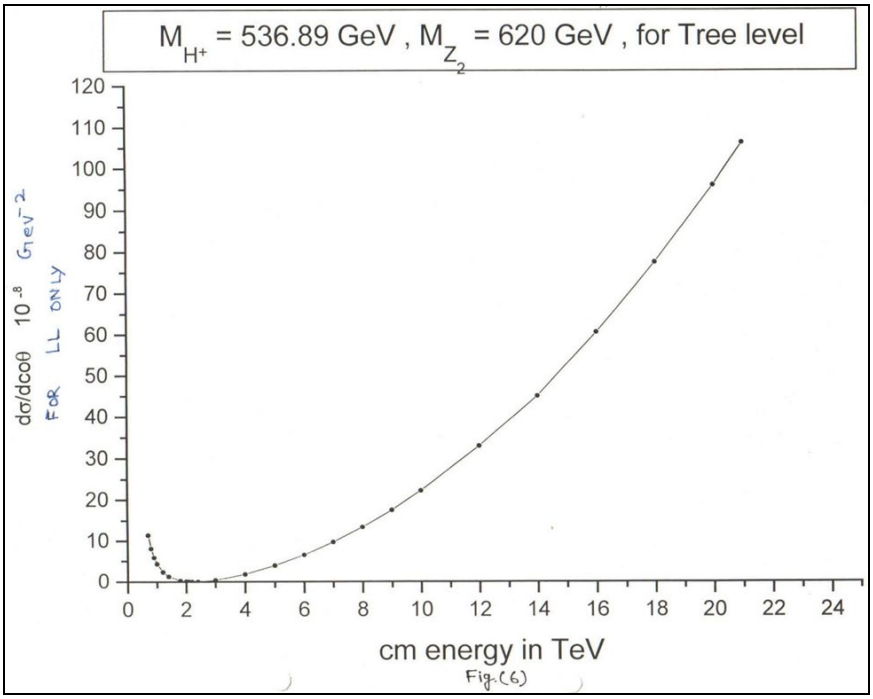



**Fig 7:** $\frac{d\sigma}{dcos\theta}$ *for LL polarization and cm energy at* at $M_{Z_2} = 620\ GeV$ *and* $M_{H^+} = 536.89\ GeV$ *for tree level.*

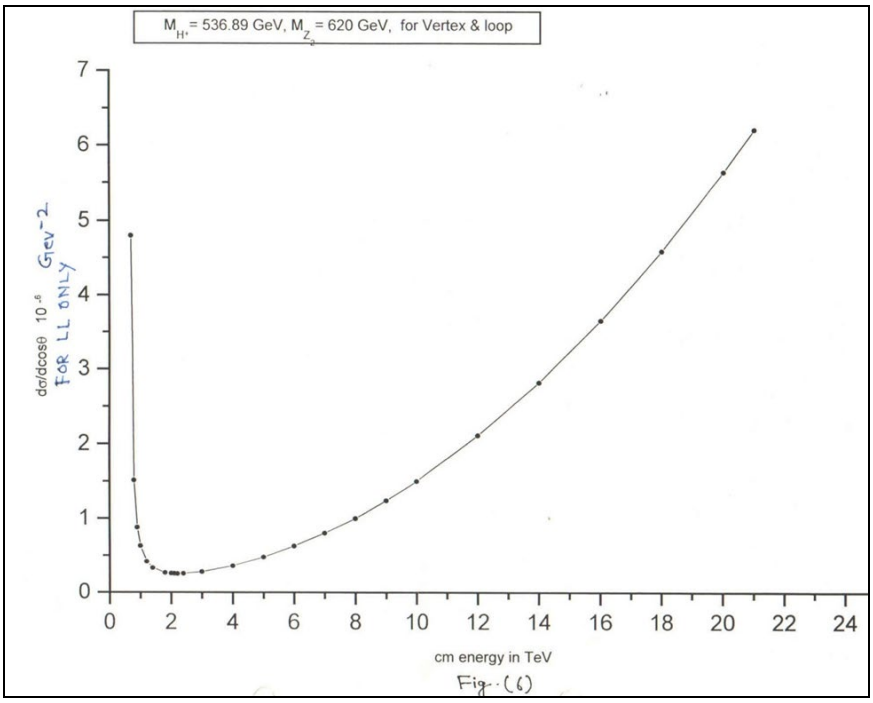



**Fig 8:** $\frac{d\sigma}{dcos\theta}$ *for LL polarization and cm energy at* at $M_{Z_2} = 620\ GeV$ *and* $M_{H^+} = 536.89\ GeV$ *for vertex and loop level.*

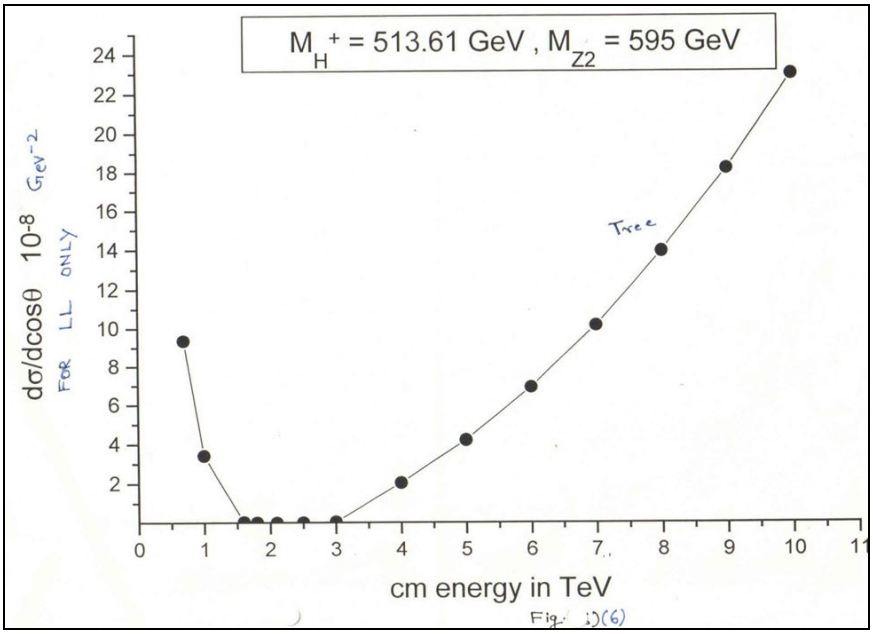



**Fig 9:** $\frac{d\sigma}{dcos\theta}$ *for LL polarization and cm energy at* at $M_{Z_2} = 595\ GeV$ *and* $M_{H^+} = 513.61\ GeV$ *for tree level.*

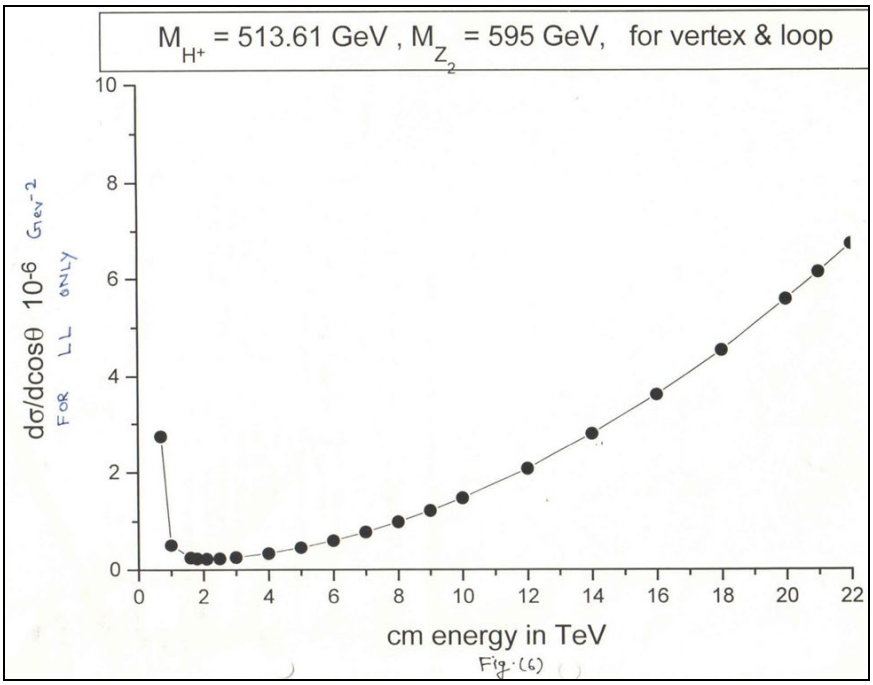



**Fig 10:** $\frac{d\sigma}{dcos\theta}$ *for LL polarization and cm energy at* at $M_{Z_2} = 595\ GeV$ *and* $M_{H^+} = 513.61\ GeV$ *for vertex and loop level.*

**Conclusion**

i). **Results [1,2] (Fig. 3 No. graph):** We are consider asymptotic case $\sqrt{s} = 0.5$ TeV and thereafter non-asymptotic case for gauge boson $Z_1$, $Z_2$. Inclusion of form factor numerically in $A_5$ expression gives $\frac{d\sigma}{d\ cos\theta}$, 2.5 to 0.5 in unit of 1R. This $\frac{d\sigma}{d\ cos\theta}$ (1R) v/s TeV energy plot tells that it converses up to 2.1 TeV. This shows that there are not Unitarity violation. It can help to predict $Z_2$ at order of TeV energy linear collider.

ii). **Results [1,2,5] (Fig. 4 No. graph):** $A_5$ is violating amplitude because it is proportional to cm energy s. So, we interested to look at the $A_5$ behavior with respect to CM-energy. We have plotted $\Sigma_{LL}$ amplitude and shown that first this amplitude goes downward with minimum around 2100 GeV energy thereafter it increases rapidly. Such type of behavior has been observed for non-asymptotic case. Such type of behavior has been observed for non-asymptotic case. There should be some additional loop corrections diagrams that can stop rising part of $A_5$ after 2.1 TeV energies. In this regards the work is ongoing for further completion. This prediction is useful to separate $Z_2$ mass which violates delayed Unitarity [2].

**iii). Results [1,2,5] (Fig. 5,6 No. graph):** We have considered Superstring Inspired Extra U(1) model this provides physics beyond Standard model(SM), where we have studied form factors. These form factors achieve some constant values around 2.1 TeV and thereafter becomes constant. This result matches with present S, T values and form factors analysis which are called universal correction parameters. They do not change much, when CM energy increases. Therefore this result is strongly favoured. It suggested that this prediction could possibly be tested in the enduing TESLA Collider at CERN. The result is favoured its present day analysis or particle Data for S, T and U values parameters and form factors values [6]. For cross section calculation we have found $\frac{d\sigma}{d\cos\theta}$, that it first falls to a minimum at 2.1 TeV energy and thereafter starts rising leading to Non-delayed Unitarity Violation. The predictions could possibly be tested in the ensuing TESLA collider (CERN).

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