Longitudinal polarization asymmetry of Σ_b decays with the effect of non-universal Z' boson

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Contents

Brief Introduction:

- In this work, we mainly concentrate on the polarization asymmetries of $\Sigma_b \to \Sigma l^+ l^-$ decays in non-universal Z' model.

- We have used the constrained values of flavour changing new physics (NP) couplings to observe the variation of the observables.

- Asymmetry parameters characterize the angular dependence of differential decay width with polarized and unpolarized heavy baryons. Here, we have tried to check the sensitivity of NP on these polarisation asymmetries including new terms in Wilson coefficients.

- We have varied polarization asymmetries with respect to the NP quark and leptonic couplings throughout the whole allowed kinematic region.

Why New Physics?

Though the standard model (SM) of particle physics is an outstandingly successful model, there are some sectors where it fails.

- The SM is unable to adopt some fundamental theory incorporating the gravity.
- It cannot explain dark matter, the dominance of matter; fails to prove the existence of massive neutrinos as well as neutrino oscillations.
- The most tantalizing B anomalies are the hot topic nowadays.

Introduction of BSM

- ✓ We have incorporated an additional $U(1)'$ group with the SM gauge group to explain the anomalies considering the contribution of Z' boson.
- ✓ The neutral Z' boson is a colourless and short-lived particle. It is expected to observe Z' through its possible decay products or some interference effects.
- ✓ The particle is not observed till now, different NP theories and accelerators restrict the Z' mass differently.

Attractiveness of Baryonic Decays

- Baryons are made of three quarks (one heavy quark and two lighter quarks). At the time of interaction the heavy quark escapes from baryonic structure and the quantum numbers (as colour, helicity and momentum) of the lighter part are conserved.

- Though experimentalists paid more attention to mesonic channels over the years but the baryonic ones also have very exciting saga which can probe NP successfully.

- The helicity structure of the effective Hamiltonian is illustrated for b decays of baryons. Previously we have studied the LFV Λ_b^0 decays in terms of hadronic and leptonic helicity amplitudes [1].

- Another interesting fact is that the kinematic observables for baryons involve the spin which enhances the number of degrees of freedom for bound state of baryons in comparison with the mesons.

1. S. Biswas, P. Nayek, P. Maji and S. Sahoo, *Eur. Phys. J. C* **81**, 493 (2021).

Why polarization asymmetries?

https://img.freepik.com/free-vector/cute-girl-show-confused-expression-with-question-mark_97632-4483.jpg?w=2000

The NP couplings has effect on various polarization symmetries of the baryonic channel. These couplings are suppressed in the SM theory. Therefore, this observable plays an important role to check the sensitivity of NP effects on the decay.

Here, we have studied the polarization asymmetries with the NP effect of non-universal Z' boson.

Theoretical Framework:

The effective Hamiltonian for $b \to s$ transition can be written in terms of different Wilson coefficients and operators as [3-6],

$$\mathcal{H}^{eff} = -\frac{4G_F\alpha}{\sqrt{2}\pi} V_{tb}V_{ts}^{*} \sum_{i=1}^{10} C_i(\mu)\, O_i(\mu)\ ,$$

where $O_i(\mu)$ $(i = 1,2,\ldots..6)$ represent the four-quark operators, $i = 7,8$ are for dipole operators $i = 9,10$ represent semileptonic electroweak operators.

The $\Sigma_b \to \Sigma l^+ l^-$ decay amplitude can be formulated by inserting the effective Hamiltonian between the initial and final states as,

$$\mathcal{M} = \langle \Sigma(p) | H_{eff} | \Sigma_b(p+q) \rangle\ , \qquad (1)$$

To calculate the amplitude, we have parametrized the transition matrix elements in terms of form factors which are calculated using light-cone QCD sum rules and taken from ref. [7].

3. G. Buchalla, A. J. Buras, M. E. Lautenbacher, *Rev. Mod. Phys.* **68**, 1125 (1996).
7. K. Azizi, M. Bayar, A. Ozpineci, Y. Sarac and H. Sundu, *Phys. Rev. D* **85,** 016002 (2012).

Observables of Investigation:

At first, we deal with the Σ baryon polarizations. To establish the relation, we have written the baryon spin four-vector along the Σ baryon spin in its rest frame in terms of ξ unit vector which is,

$$s_\mu = \left(\frac{\vec{p}_\Sigma . \vec{\xi}}{m_\Sigma}, \vec{\xi} + \frac{\vec{p}_\Sigma (\vec{p}_\Sigma . \vec{\xi})}{E_\Sigma + m_\Sigma} \right) \quad . \tag{2}$$

The following unit vectors are chosen along the longitudinal, transversal and normal components as, $\vec{e}_L = \frac{\vec{p}_\Sigma}{|\vec{p}_\Sigma|}$, $\vec{e}_T = \frac{\vec{p}_l \times \vec{p}_\Sigma}{|\vec{p}_l \times \vec{p}_\Sigma|}$ and $\vec{e}_N = \vec{e}_T \times \vec{e}_L$. Here $\vec{p}_l$ and $\vec{p}_\Sigma$ are the three momenta of lepton and Σ baryon in the centre of mass frame of the $l^+ l^-$.

The polarization expressions are defined as (where $i = L, N, T$):

$$P_i(\hat{s}) = \frac{\frac{d\Gamma}{d\hat{s}}(\vec{\xi} = \vec{e}_i) - \frac{d\Gamma}{d\hat{s}}(\vec{\xi} = -\vec{e}_i)}{\frac{d\Gamma}{d\hat{s}}(\vec{\xi} = \vec{e}_i) + \frac{d\Gamma}{d\hat{s}}(\vec{\xi} = -\vec{e}_i)} \quad , \tag{3}$$

.

Observables of Investigation:

The longitudinal polarization asymmetry is defined as [8]

$$
\begin{aligned}
&P_L(\hat{s}) \\
&= \frac{16 m_{\Sigma_b}^2 \sqrt{\lambda}}{\Delta}\Big\{8 m_l^2 m_{\Sigma_b}(Re[D_1^* E_3 - D_3^* E_1] + \sqrt{r} Re[D_1^* D_3 - E_1^* E_3]) + 2 m_l m_{\Sigma_b}(1+\sqrt{r}) Re[(D_1 - E_1)^* F_2] \\
&- 2 m_l m_{\Sigma_b}^2 \hat{s}\{Re[(D_3 - E_3)^* F_2] + 2 m_l (|D_3|^2 - |E_3|^2)\} - 4 m_{\Sigma_b}\big(2 m_l^2 + m_{\Sigma_b}^2 \hat{s}\big) Re[A_1^* B_2 - A_2^* B_1] \\
&- \frac{4}{3} m_{\Sigma_b}^2 \hat{s} v^2 (3 Re[D_1^* E_2 - D_2^* E_1] + \sqrt{r} Re[D_1^* D_2 - E_1^* E_2]) - \frac{4}{3} m_{\Sigma_b} \sqrt{r}\big(6 m_l^2 + m_{\Sigma_b}^2 \hat{s} v^2\big) Re[A_1^* A_2 - B_1^* B_2] \\
&+ \frac{1}{3}\{3\big[4 m_l^2 + m_{\Sigma_b}^2 (1 - r + \hat{s})\big](|A_1|^2 - |B_1|^2) - 3\big[4 m_l^2 - m_{\Sigma_b}^2 (1 - r + \hat{s})\big] d(|D_1|^2 - |E_1|^2) \\
&- m_{\Sigma_b}^2 (1 - r - \hat{s}) v^2 (|A_1|^2 - |B_1|^2 + |D_1|^2 - |E_1|^2)\} \\
&- \frac{1}{3} m_{\Sigma_b}^2 \{12 m_l^2 (1 - r) + m_{\Sigma_b}^2 \hat{s}[3(1 - r + \hat{s}) + (1 - r - \hat{s}) v^2]\}(|A_2|^2 - |B_2|^2) - \frac{2}{3} m_{\Sigma_b}^4 \hat{s}(2 - 2r + \hat{s}) v^2 (|D_2|^2 - |E_2|^2)\Big\},
\end{aligned}
\tag{4}
$$

Observables of Investigation:

- To define both lepton polarizations, we have considered the orthogonal unit vectors $s_i^{\pm\mu}$ $(i = L, T, N)$ in the rest frame of double leptons.
- Then we have transformed these unit vectors from the rest frame of the leptons to the centre of mass (CM) frame of them along the longitudinal direction.

Therefore, the double-polarization asymmetries can be defined as,

$$P_{ij}(\hat{s}) = \frac{\left(\frac{d\Gamma(\vec{s}_i^{\,-}, \vec{s}_j^{\,+})}{d\hat{s}} - \frac{d\Gamma(-\vec{s}_i^{\,-}, \vec{s}_j^{\,+})}{d\hat{s}}\right) - \left(\frac{d\Gamma(\vec{s}_i^{\,-}, -\vec{s}_j^{\,+})}{d\hat{s}} - \frac{d\Gamma(-\vec{s}_i^{\,-}, -\vec{s}_j^{\,+})}{d\hat{s}}\right)}{\left(\frac{d\Gamma(\vec{s}_i^{\,-}, \vec{s}_j^{\,+})}{d\hat{s}} + \frac{d\Gamma(-\vec{s}_i^{\,-}, \vec{s}_j^{\,+})}{d\hat{s}}\right) + \left(\frac{d\Gamma(\vec{s}_i^{\,-}, -\vec{s}_j^{\,+})}{d\hat{s}} + \frac{d\Gamma(-\vec{s}_i^{\,-}, -\vec{s}_j^{\,+})}{d\hat{s}}\right)} \,. \qquad (5)$$

- Using this above definition, we have formulated the expressions of the double-lepton polarization asymmetries.

Observables of Investigation:

The double lepton polarization asymmetries as expressed as [8]

$$P_{LN}(\hat{s}) = \frac{16\pi m_{\Sigma_b}^4 v \widehat{m}_l \sqrt{\lambda}}{\Delta\sqrt{\hat{s}}} \times Im\Big\{(1-r)[A_1^* D_1 + B_1^* E_1] + m_{\Sigma_b}\hat{s}(A_1^* E_3 - A_2^* E_1 + B_1^* D_3 - B_2^* D_1) + m_{\Sigma_b}\hat{s}\sqrt{r}[A_1^* D_3 + A_2^* D_1 + B_1^* E_3 + B_2^* E_1] - m_{\Sigma_b}^2 \hat{s}^2 [A_2^* D_3 + B_2^* E_3]\Big\}, \quad (6)$$

$$P_{LT}(\hat{s}) = \frac{16\pi m_{\Sigma_b}^4 v \widehat{m}_l \sqrt{\lambda}}{\Delta\sqrt{\hat{s}}} \times Re\Big\{(1-r)(|D_1|^2 + |E_1|^2) - \hat{s}(A_1 D_1^* - B_1 E_1^*) - m_{\Sigma_b}\hat{s}[B_1 D_2^* + (A_2 + D_2 - D_3)E_1^* - A_1^* E_2 - (B_2 - E_2 + E_3)D_1^*] + m_{\Sigma_b}\hat{s}\sqrt{r}[A_1^* D_2 + (A_2 + D_2 + D_3)D_1^* - B_1^* E_2 - (B_2 - E_2 - E_3)E_1^*] + m_{\Sigma_b}^2 \hat{s}(1-r)(A_2 D_2^* - B_2 E_2^*) - m_{\Sigma_b}^2 \hat{s}^2 [D_2 D_3^* + E_2 E_3^*]\Big\}, \quad (7)$$

Role of Z' model:

We have included the NP terms in the Wilson coefficients as ➡

$$C_9^{NP} = \frac{4\pi B_{sb}^L}{\alpha V_{tb} V_{ts}^*}\left(B_{ll}^L + B_{ll}^R\right)$$

$$C_{10}^{NP} = \frac{4\pi B_{sb}^L}{\alpha V_{tb} V_{ts}^*}\left(B_{ll}^L - B_{ll}^R\right)$$

The coupling parameters are taken as Table- 1

Table- 1: Numerical values of coupling parameters [9]

Scenarios	$\lvert B_{sb}\rvert \times 10^{-3}$	φ_s^l (in degree)	$S_{ll} \times 10^{-2}$	$D_{ll} \times 10^{-2}$
S_1	(1.09 ± 0.22)	$(-72 \pm 7)°$	(-2.8 ± 3.9)	(-6.7 ± 2.6)
S_2	(2.20 ± 0.15)	$(-82 \pm 4)°$	(-1.2 ± 1.4)	(-2.5 ± 0.9)

Results

- With the maximum contribution of the NP couplings, we have set two NP scenarios along with the SM scenario for fruitful investigation.

- We have varied the longitudinal polarization asymmetries for muonic, electronic and taunic channels.

- We have varied the single lepton polarization asymmetries (P_L) for electronic, muonic and taunic channels in Fig. 1a, 1b, 1c respectively. The double lepton polarization asymmetries (P_{LN}, P_{LT}) are studied in Fig. 2a-2c and in Fig. 3a-3c respectively.

- The colour description: Blue curve $\longrightarrow$ Scenario 2 (S_2),
  Orange curve $\longrightarrow$ Scenario 1 (S_1) and
  Green curve $\longrightarrow$ SM.

Variation of longitudinal polarization asymmetries (P_L) for electronic (Fig. 1a), muonic (Fig. 1b) and taunic (Fig. 1c) channels.

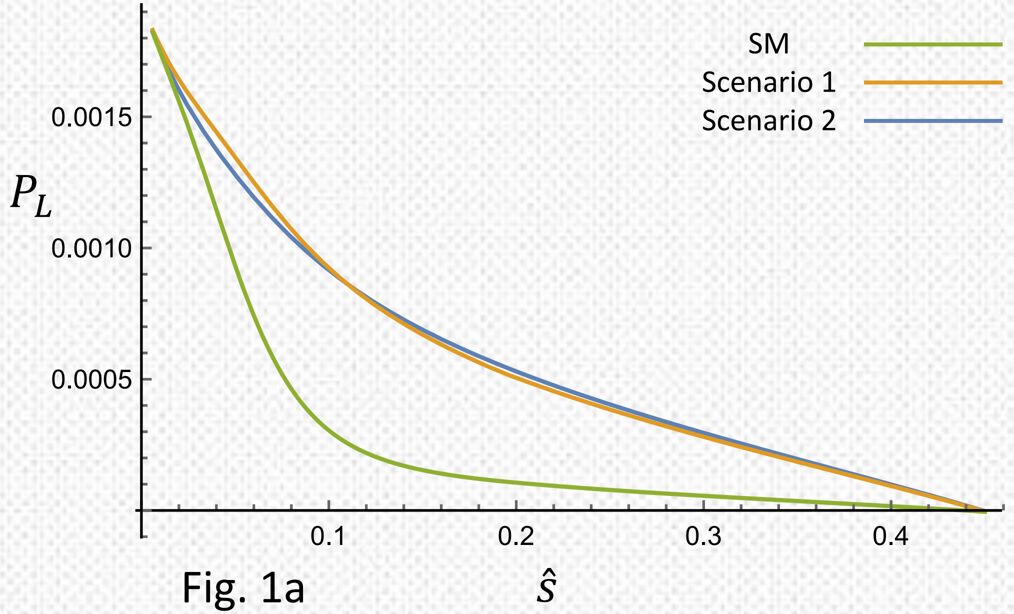

Fig. 1a

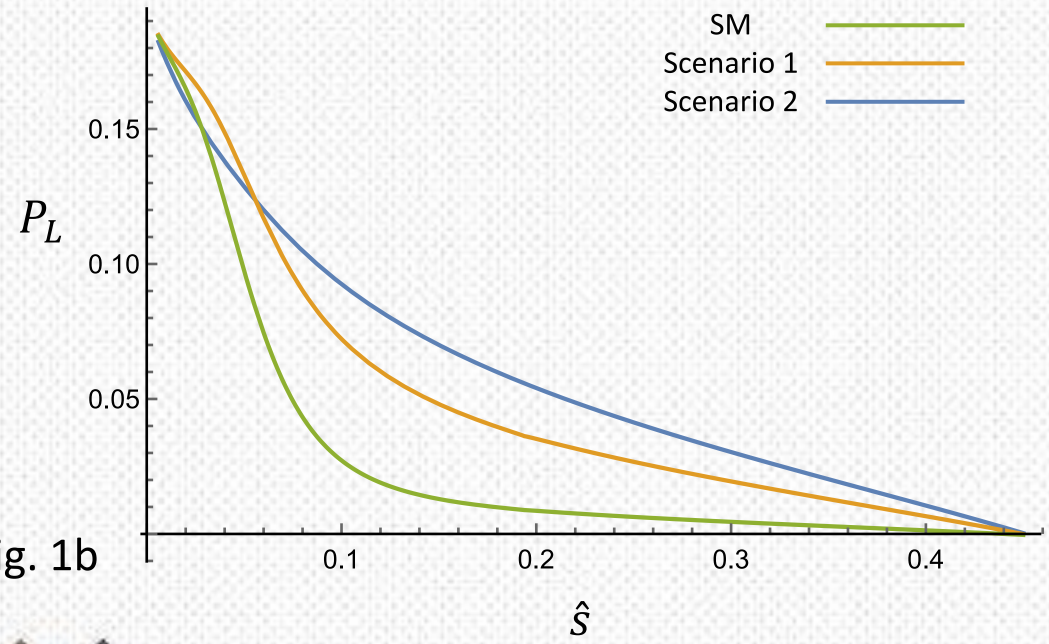

Fig. 1b

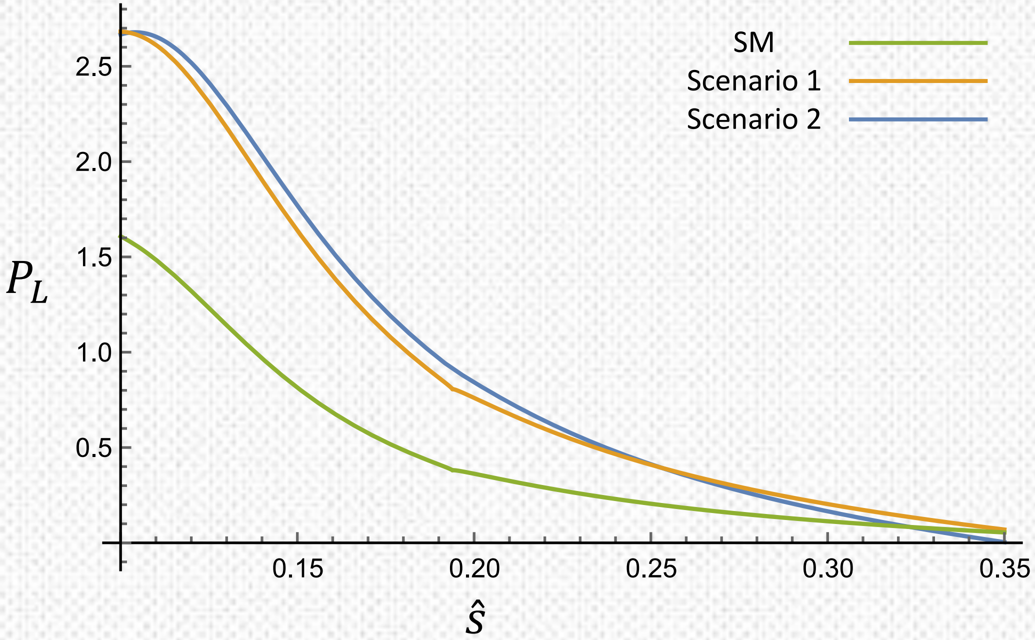

Fig. 1c

Variation of double lepton polarization asymmetries (P_{LN}) for electronic (Fig. 2a), muonic (Fig. 2b) and taunic (Fig. 2c) channels.

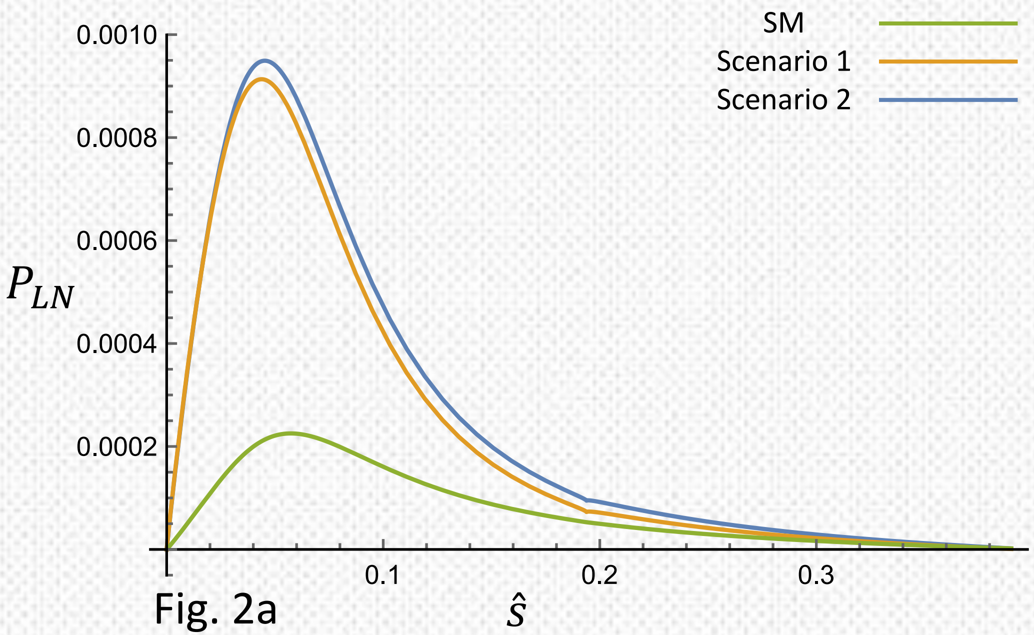

Fig. 2a

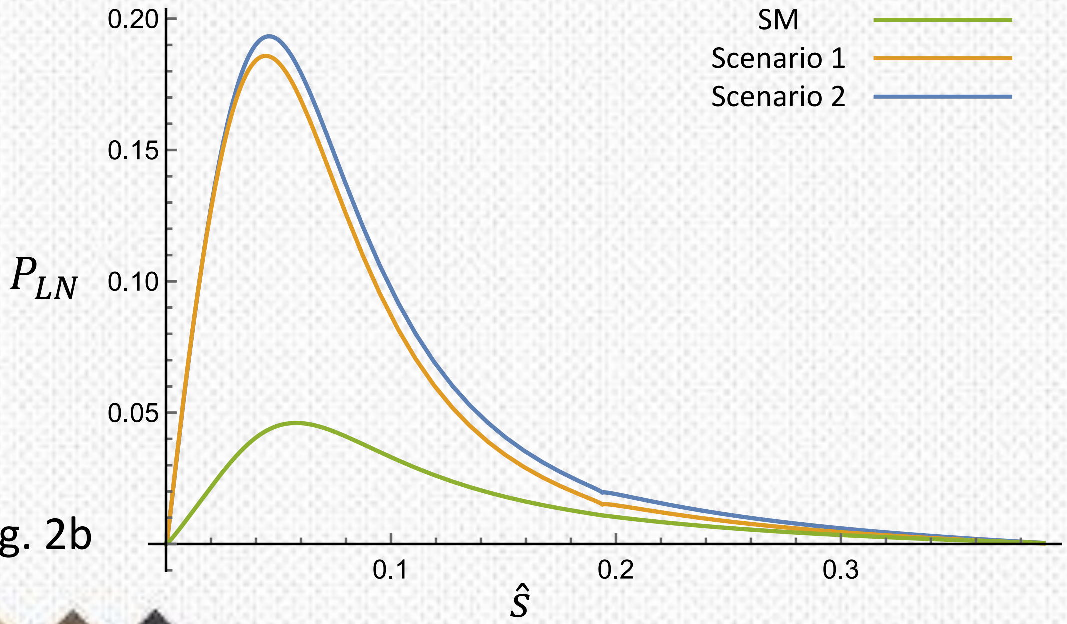

Fig. 2b

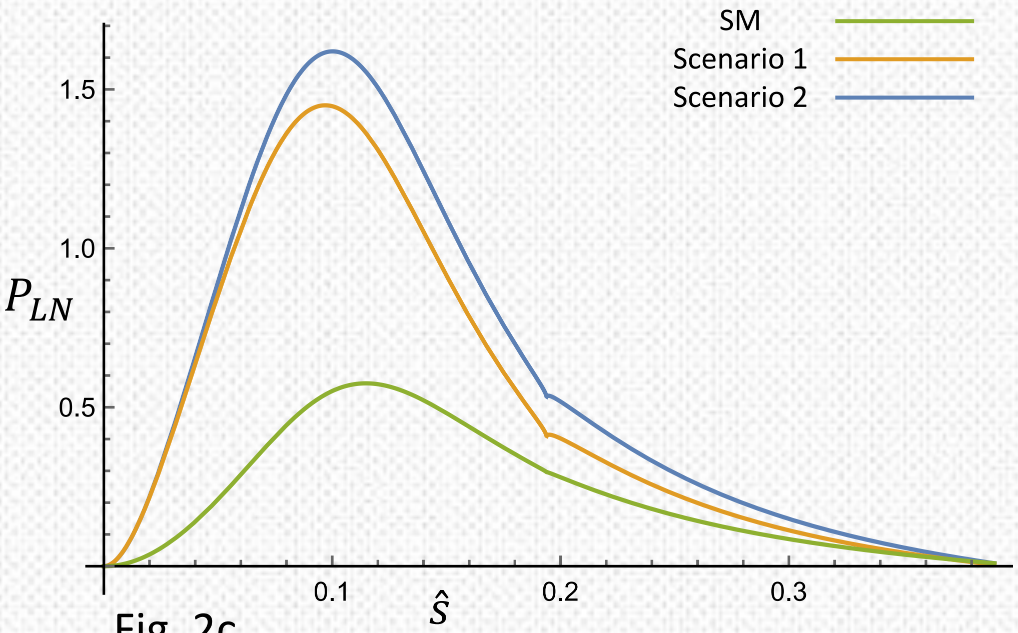

Fig. 2c

Variation of double lepton polarization asymmetries (P_{LT}) for electronic (Fig. 3a), muonic (Fig. 3b) and taunic (Fig. 3c) channels.

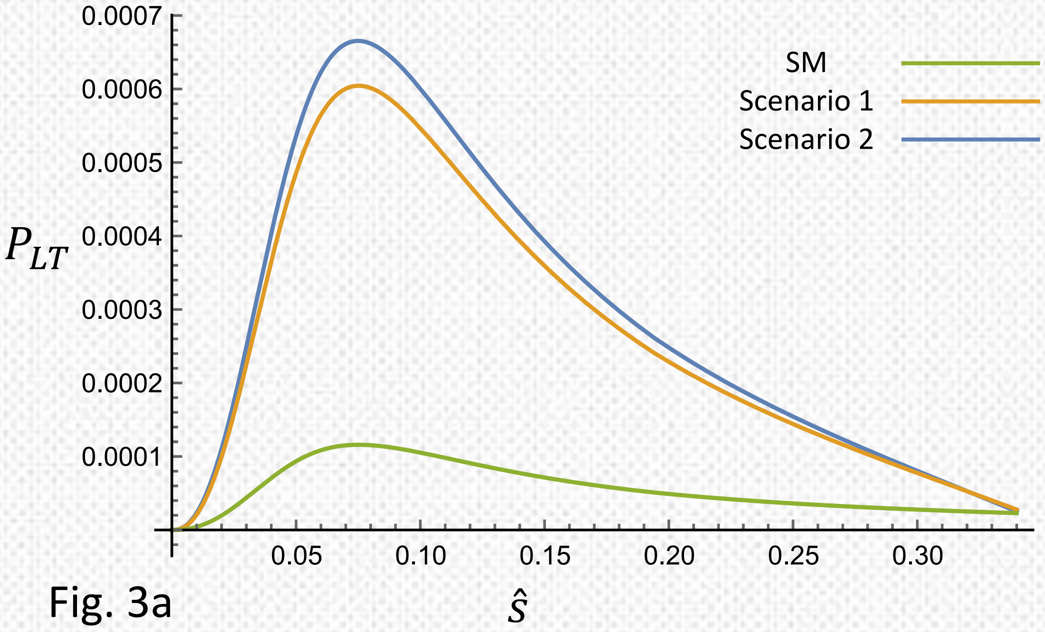

Fig. 3a

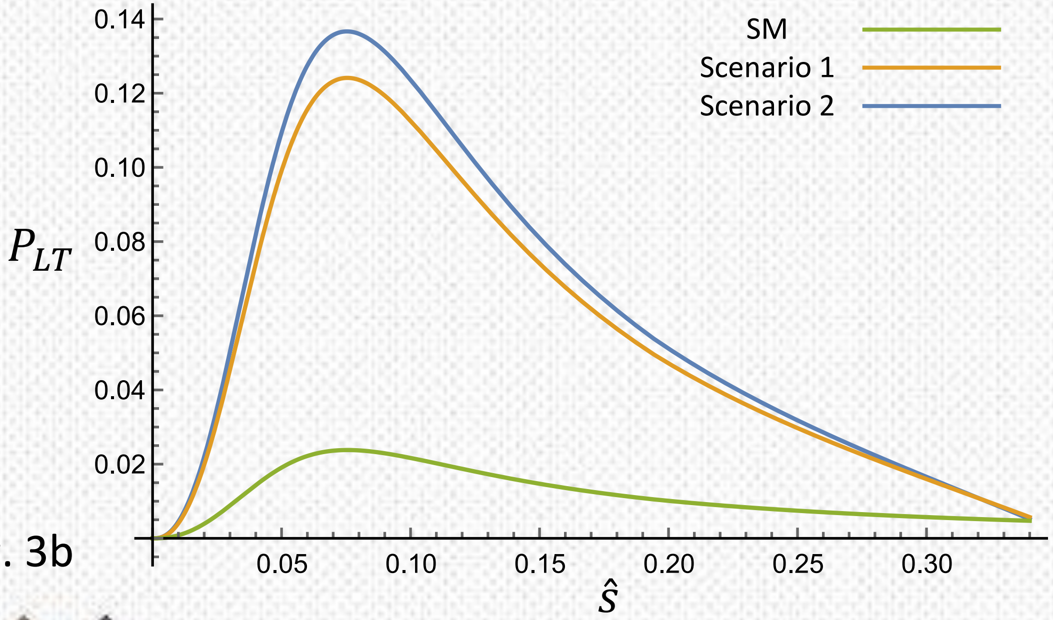

Fig. 3b

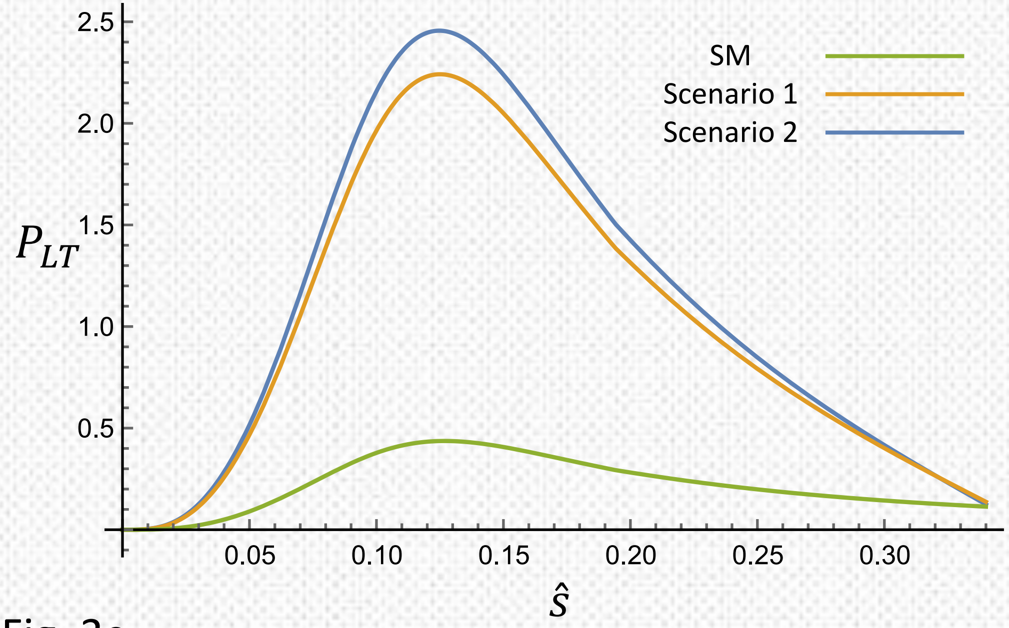

Fig. 3c

Conclusion

- The enhancement of NP contributions increases the values of the observables.
- The nature of the variation of the observables are almost same for all the three channels.
- In low q^2 region the higher value of NP couplings provide lower value of P_L with respect to the other scenarios but gradually with the increment of q^2 region the scenario 2 shows the maximum value for the observable.
- For electronic and taunic channel the variation of P_L for NP scenarios are quite similar.
- There is a kink in double lepton polarization asymmetry P_{LN} in mid q^2 region which is very prompt for the taunic channel.
- The values of the observables are maximum in low q^2 region.
- The predicted values of the observables will play an important role for investigating these decays with high precision in the upcoming runs of LHCb and Belle II.

References

1. S. Biswas, P. Nayek, P. Maji and S. Sahoo, Lepton flavour violating Λ_b decays in non-universal Z' model, *Eur. Phys. J. C* **81**, 493 (2021).
2. S. Biswas, S. Mahata, A. Biswas and S. Sahoo, Impact of non-universal Z' in the lepton flavour violating $B(B_s) \to K^*(\varphi)l_1^- l_2^+$ decays, *Eur. Phys. J. C* **82**, 578 (2022**).**
3. G. Buchalla, A. J. Buras, M. E. Lautenbacher, *Rev. Mod. Phys.* **68**, 1125 (1996).
4. C. Bobeth, A. J. Buras, F. Kruger, J. Urban, *Nucl. Phys. B* **630**, 87 (2002).
5. W. Altmannshofer, P. Ball, A. Bharucha, A. J. Buras, D. M. Straub and M. Wick, *JHEP* **0901**, 019 (2009) [arXiv: 0811.1214 [hep-ph]].
6. A. Ghinculov, T. Hurth, G. Isidori, Y. P. Yao, *Nucl. Phys. B* **685**, 351 (2004) [arXiv: hep-ph/9311345].
7. K. Azizi, M. Bayar, A. Ozpineci, Y. Sarac and H. Sundu, *Phys. Rev. D* **85,** 016002 (2012).
8. K. Azizi, S. Kartal, N. Katirci, A. T. Olgun and Z. Tavukoglu, *JHEP* **05**, 024 (2012).
9. Q. Chang, X-Qiang Li and Y-Dong, *JHEP* **1002**, 082 (2010) [arXiv: 0907.4408 [hep-ph]].

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