## THE SPINOR HELICITY FORMALISM IN SUGRA PHENOMENOLOGY

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### XXX Reunión Anual de la División de Partículas y Campos de la SMF



Bryan Larios 3 body Stop decay with LSP gravitino/goldstino in the f.s.

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- Motivation,
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- Conclusions.

# **Motivation**

We have been working with some process and reactions in supersymmetric models where the gravitino is very light (LSP) and then a good dark matter candidate. Recently we computed the 3-body stop decay  $(\tilde{t}_1 \rightarrow b + W + \tilde{\Psi}_{\mu})$  where we use the MATHEMATICA power to handle the huge traces that appear in the scattering amplitudes.

$$\tilde{t}_1 \rightarrow b + W + \tilde{\Psi}_{\mu}$$



Figure 1. top diagram

Figure 2. sbotom diagram

 ${\bf Figure \ 3.} \ {\rm chargino \ diagram}$ 

Lorenzo Diaz-Cruz & Bryan Larios-Lopez, EPJC (2016) 76:157.

 $\langle \Box \rangle \langle \Box \rangle$ 

# Considering just one channel (chargino), we obtained for the chargino $|\,\overline{\mathcal{M}_{1\chi}}\,|^2.$

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TrX3 = trx31 + m, (trx32 + trx33 + m, trx34)  $a_{\mathcal{A}}(\mathbb{D}) = 4 \left[ -\frac{i}{3 m_{H}^2 m_{\pi}^2} 8 \left( \left( (\text{U12}\cos(\beta) + \text{V12}\sin(\beta))^2 - (\text{V12}\sin(\beta) - \text{U12}\cos(\beta))^2 \right) \left( P_i P_j + S_i S_j \right) - \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \right) \right) \right] \right] + \frac{1}{2} \left( \frac{1}{2} \left( \frac{1}{2} + \frac{1}{2} + \frac{1}{2} \right) \right) \left( \frac{1}{2} + \frac{1}{2} \right) \left( \frac{1}{2} + \frac{1}{2} \right) \left( \frac{1}{2} + \frac{1}{2} \right) \right) \left( \frac{1}{2} + \frac{1}{2} \right) \right) \left( \frac{1}{2} + \frac{1}{2} \right)$  $(P_1 S_1 + P_1 S_1)$   $(Vi2 sin(\beta) - Ui2 cos(\beta))$   $(Ui2 cos(\beta) + Vi2 sin(\beta)) - v_1 \Lambda_{(1)})$   $(f_3)^4 \frac{1}{m^2} 4 \left[ \left( (\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta))^2 - (\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta))^2 \right) \left( P_i P_j + S_i S_j \right) - \frac{1}{m^2} \right]$  $(P_1S_1 + P_1S_1)$   $(Vi2 sin(\beta) - Ui2 cos(\beta))$   $(Ui2 cos(\beta) + Vi2 sin(\beta)) - v_1 \Lambda_{(1)})$   $(f_3)^3 +$  $\frac{1}{3 m_{\pi^{2}}^{2} m^{2}} + f_{1} \left( \left( \text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta) \right)^{2} - \left( \text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta) \right)^{2} \right) \left( P_{1} P_{j} + S_{1} S_{j} \right) - \frac{1}{3 m_{\pi^{2}}^{2} m^{2}} + \frac{1}$  $(P_i S_i + P_i S_i)$   $(Vi2 sin(\beta) - Ui2 cos(\beta))$   $(Ui2 cos(\beta) + Vi2 sin(\beta)) - v_i \Lambda_{i1})$   $(f_i)^3 +$  $\frac{1}{3 m_{1}^{2} m_{1}^{2}} 4 f_{2} \left( \left( (\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta))^{2} - (\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta))^{2} \right) \left( P_{i} P_{j} + S_{i} S_{j} \right) - \frac{1}{3 m_{1}^{2} m_{1}^{2}} \right)$  $(P_1S_1 + P_2S_2)(Vi2 \sin(\beta) - Ui2 \cos(\beta))(Ui2 \cos(\beta) + Vi2 \sin(\beta)) - v_1\Lambda_{11})(f_1)^3 +$  $\frac{1}{3 m_{h^2}^2 m_{\perp}^2} 2 q_j^2 \left( \left( \text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta) \right)^2 - \left( \text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta) \right)^2 \right) \left( P_i P_j + S_i S_j \right) - \frac{1}{3 m_{\mu^2}^2 m_{\perp}^2} 2 q_j^2 \left( \left( \text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta) \right)^2 - \left( \text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta) \right)^2 \right) \left( P_i P_j + S_i S_j \right) - \frac{1}{3 m_{\mu^2}^2 m_{\perp}^2} 2 q_j^2 \left( \left( \text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta) \right)^2 - \left( \text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta) \right)^2 \right) \left( P_i P_j + S_i S_j \right) - \frac{1}{3 m_{\mu^2}^2 m_{\perp}^2} 2 q_j^2 \left( \left( \text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta) \right)^2 - \left( \text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta) \right)^2 \right) \left( P_i P_j + S_i S_j \right) - \frac{1}{3 m_{\mu^2}^2 m_{\perp}^2} 2 q_j^2 \left( \left( \text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta) \right)^2 - \left( \text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta) \right)^2 \right) \left( P_i P_j + S_i S_j \right) - \frac{1}{3 m_{\mu^2}^2 m_{\perp}^2} 2 q_j^2 \left( \left( \text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta) \right) + \frac{1}{3 m_{\mu^2}^2 m_{\perp}^2} \right) \right) + \frac{1}{3 m_{\mu^2}^2 m_{\perp}^2} 2 q_j^2 \left( \left( \text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta) \right) + \frac{1}{3 m_{\mu^2}^2 m_{\perp}^2} \right) \right) + \frac{1}{3 m_{\mu^2}^2 m_{\perp}^2} 2 q_j^2 \left( \left( \text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta) \right) \right) \right)$  $(P_1S_1 + P_1S_1)(Vi2\sin(\beta) - Ui2\cos(\beta))(Ui2\cos(\beta) + Vi2\sin(\beta)) - v_1\Lambda_{(1)})(f_3)^3 \frac{1}{3m^2} 4 \left[ \left( (\text{Ui2}\cos(\beta) + \text{Vi2}\sin(\beta))^2 - (\text{Vi2}\sin(\beta) - \text{Ui2}\cos(\beta))^2 \right) \left( P_i P_j + S_i S_j \right) - \frac{1}{3m^2} \right]$  $(P_i S_i + P_i S_i)$   $(Vi2 sin(\beta) - Ui2 cos(\beta))$   $(Ui2 cos(\beta) + Vi2 sin(\beta)) - v_i \Lambda_{ii})$   $(f_3)^3 \frac{1}{3 m_{\pi}^2} 4 m_G^2 \left( \left( (\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta))^2 - (\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta))^2 \right) \left( P_i P_j + S_i S_j \right) - \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) - \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + P_i S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + P_i S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + P_i S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + P_i S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + P_i S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + P_i S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + P_i S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + P_i S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + P_i S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + P_i S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + P_i S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + P_i S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + P_i S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + P_i S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + P_i S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + P_i S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + P_i S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i P_i + P_i S_i S_j \right) + \frac{1}{3 m_{\pi}^2} \left( P_i + P_i S_i S_j \right) + \frac{1$  $(P_i S_i + P_i S_i)$   $(Vi2 sin(\beta) - Ui2 cos(\beta))$   $(Ui2 cos(\beta) + Vi2 sin(\beta)) - v_i \Lambda_{i1})$   $(f_i)^2 +$  $\frac{1}{3 m^2} + 4 f_1 \left( \left( (\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta))^2 - (\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta))^2 \right) \left( P_1 P_j + S_i S_j \right) - \frac{1}{3 m^2} + \frac{1}{3 m^$  $(P_1S_1 + P_1S_1)(Vi2\sin(\beta) - Ui2\cos(\beta))(Ui2\cos(\beta) + Vi2\sin(\beta)) - v_1\Lambda_{11})(f_1)^2 +$ 

 $\frac{1}{1 m^2} + f_2 \left( \left[ (\text{Ui2 } \cos(\beta) + \text{Vi2 } \sin(\beta))^2 - (\text{Vi2 } \sin(\beta) - \text{Ui2 } \cos(\beta))^2 \right] \left( P_1 P_j + S_1 S_j \right) - \frac{1}{1 m^2} \right]$ (P, S, +P, S)  $[(V(2 sin(\beta) - U(2 cos(\beta)) (U(2 cos(\beta) + V(2 sin(\beta)) - v, A_c)))(f_{c})^{2} +$  $\frac{1}{1 e^2} 2 q_1^2 \left( \left( \text{U12} \cos(\beta) + \text{V12} \sin(\beta) \right)^2 - (\text{V12} \sin(\beta) - \text{U12} \cos(\beta) \right)^2 \right) \left( P_1 P_1 + S_1 S_2 \right) - \frac{1}{1 e^2} \left( P_1 P_2 + S_2 S_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 S_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 S_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 S_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 S_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 S_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 S_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 S_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 S_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 S_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 S_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 S_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 S_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 S_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 S_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 S_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 S_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 S_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 F_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 + P_2 F_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 + P_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 + P_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 + P_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 + P_2 \right) + \frac{1}{1 e^2} \left( P_1 P_2 + P_2 + P_2 \right) + \frac{1}{1 e$ (P, S + P, S) (Vi2 sin(d) - Ui2 cos(d)) (Ui2 cos(d) + Vi2 sin(d)) - v\_1 A\_1) (fy<sup>2</sup> - $2 f_2 q_1^2 ((Ui2 \cos(\beta) + Vi2 \sin(\beta))^2 - (Vi2 \sin(\beta) - Ui2 \cos(\beta))^2) (P_1 P_1 + S_1 S_1)$ 3 mil mil  $\left(P_{j}S_{j}+P_{j}S_{j}\right)\left((\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))\left(\text{Ui2}\cos(\beta)+\text{Vi2}\sin(\beta)\right)-\nu_{j}A_{ij}\right)\right)(f_{j})^{2}-\frac{1}{2}\left(P_{j}S_{j}+P_{j}S_{j}\right)\left(P_{j}S_{j}+P_{j}S_{j}\right)\left(P_{j}S_{j}+P_{j}S_{j}\right)\left(P_{j}S_{j}+P_{j}S_{j}\right)\right)$  $\frac{40}{\pi} \left( \left[ (Ui2 \cos(\beta) + Vi2 \sin(\beta))^2 - (Vi2 \sin(\beta) - Ui2 \cos(\beta))^2 \right] \left[ P_i P_i + S_i S_i \right] \right)$ (P,S, + P,S,) ((Vi2 sin(8) - Ui2 cos(8)) (Ui2 cos(8) + Vi2 sin(8)) - y, A, 1) (fy2  $m_{H}^{2}$  (((U)2 cos( $\beta$ ) + V)2 sin( $\beta$ )<sup>2</sup> - (V)2 sin( $\beta$ ) - U)2 cos( $\beta$ ))<sup>2</sup>)( $P_{1}P_{1} + S_{1}S_{2}$ ) - $(P_1S_1 + P_1S_2)$   $[(Vi2 \sin(\beta) - Ui2 \cos(\beta)) (Ui2 \cos(\beta) + Vi2 \sin(\beta)) - v_1A_2)]f_2 - V_2A_2$  $8 m_1^2 \left[ \left[ (Ui2 \cos(\beta) + Vi2 \sin(\beta))^2 - (Vi2 \sin(\beta) - Ui2 \cos(\beta))^2 \right] \left[ P_1 P_1 + S_1 S_2 \right] - \right]$  $\{P_1S_1 + P_1S_2\}$   $\{V_12\sin(\beta) - U_12\cos(\beta)\}$   $\{U_12\cos(\beta) + V_12\sin(\beta)\} - v_1A_2\}$   $f_1 +$  $\frac{a}{-f_1} \left[ \left[ (Ui2\cos(\beta) + Vi2\sin(\beta))^2 - (Vi2\sin(\beta) - Ui2\cos(\beta))^2 \right] \left( P_1 P_1 + S_1 S_2 \right) \right]$  $(P_1S_1 + P_1S_1)$   $[(Vi2 \sin(\beta) - Ui2 \cos(\beta)) (Ui2 \cos(\beta) + Vi2 \sin(\beta)) - \nu_1 A_{11})] f_2 +$  $= f_{1} \left[ \left( U(2 \cos(\beta) + V(2 \sin(\beta))^{2} - (V(2 \sin(\beta) - U(2 \cos(\beta))^{2}) (P, P_{1} + S, S_{2}) \right) \right]$  $\left(P_{j}S_{i}+P_{i}S_{j}\right)\left[\left(\operatorname{Vi2sin}(\beta)-\operatorname{Ui2cos}(\beta)\right)\left(\operatorname{Ui2cos}(\beta)+\operatorname{Vi2sin}(\beta)\right)-\nu_{j}A_{i}\right)\right]f_{3}+$  $-q_1^2 \left[ \left[ (\text{Ui2}\cos(\beta) + \text{Vi2}\sin(\beta))^2 - (\text{Vi2}\sin(\beta) - \text{Ui2}\cos(\beta))^2 \right] \left( P_1 P_1 + S_1 S_1 \right) \right]$  $[P_1S_1 + P_1S_2]$  [(Vi2 sin( $\beta$ ) - Ui2 cos( $\beta$ )] (Ui2 cos( $\beta$ ) + Vi2 sin( $\beta$ )) -  $v_1A_2$ ])  $f_2$   $m_{1}^{2}$  (((31)2 cost ff) + V(2 sin(ff))^{2} - (V(2 sin(ff) - U)2 cost ff()^{2})(P, P, + S, S)) -(P.S. + P.S.) [(Vi2 sin(8) - Ui2 cos(8)) (Ui2 cos(8) + Vi2 sin(8)) - y, A, ]]  $m_{e_1}^2 m_{e_2}^2 [((U12\cos(\beta) + V12\sin(\beta))^2 - (V12\sin(\beta) - U12\cos(\beta))^2)(P, P, + S, S))$  $\{P_1S_1 + P_1S_1\}\{(Vi2sin(\beta) - Ui2cos(\beta)\}(Ui2cos(\beta) + Vi2sin(\beta)) - \nu_1S_1\}\}$  $= f_1 s r_0^2 \left[ \left( (U12 \cos(\beta) + V12 \sin(\beta))^2 - (V12 \sin(\beta) - U12 \cos(\beta))^2 \right) \left[ P_1 P_1 + S_1 S_1 \right] - \left( V12 \sin(\beta) - U12 \cos(\beta) \right)^2 \right] \left[ P_1 P_1 + S_1 S_1 \right] - \left( V12 \sin(\beta) - V12 \cos(\beta) \right)^2 \right] \left[ P_1 P_1 + S_1 S_1 \right] - \left( V12 \sin(\beta) - V12 \cos(\beta) \right)^2 \right] \left[ P_1 P_1 + S_1 S_1 \right] - \left( V12 \sin(\beta) - V12 \cos(\beta) \right)^2 \right] \left[ P_1 P_1 + S_1 S_1 \right] - \left( V12 \sin(\beta) - V12 \cos(\beta) \right)^2 \right] \left[ P_1 P_1 + S_1 S_1 \right] - \left( V12 \sin(\beta) - V12 \cos(\beta) \right)^2 \right] \left[ P_1 P_1 + S_1 S_1 \right] - \left( V12 \sin(\beta) - V12 \cos(\beta) \right)^2 \right] \left[ P_1 P_1 + S_1 S_1 \right] - \left( V12 \sin(\beta) - V12 \cos(\beta) \right)^2 \right] \left[ P_1 P_1 + S_1 S_1 \right] - \left( V12 \sin(\beta) - V12 \cos(\beta) \right)^2 \right] \left[ P_1 P_1 + S_1 S_1 \right] - \left( V12 \sin(\beta) - V12 \cos(\beta) \right)^2 \right] \left[ P_1 P_1 + S_1 S_1 \right] - \left( V12 \sin(\beta) - V12 \cos(\beta) \right)^2 \right] \left[ P_1 P_1 + S_1 S_1 \right] + \left( V12 \sin(\beta) - V12 \cos(\beta) \right)^2 \right] \left[ P_1 P_1 + S_1 S_1 \right] + \left( V12 \sin(\beta) - V12 \cos(\beta) \right)^2 \right] \left[ P_1 P_1 + S_1 S_1 \right] + \left( V12 \sin(\beta) - V12 \cos(\beta) \right)^2 \right] \left[ P_1 P_1 + S_1 S_1 \right] + \left( V12 \sin(\beta) - V12 \cos(\beta) \right)^2 \right] \left[ P_1 P_1 + S_1 S_1 \right] + \left( V12 \sin(\beta) - V12 \cos(\beta) \right)^2 \right] \left[ P_1 P_1 + S_1 S_1 \right] + \left( V12 \sin(\beta) - V12 \cos(\beta) \right)^2 \right] \left[ P_1 P_1 + S_1 S_1 \right] + \left( V12 \sin(\beta) - V12 \cos(\beta) \right)^2 \right] \left[ P_1 P_1 + S_1 S_1 \right] + \left( V12 \sin(\beta) - V12 \sin(\beta) \right)^2 \right] + \left( V12 \cos(\beta) - V12 \cos(\beta) \right)^2 \right] + \left( V12 \sin(\beta) - V12 \cos(\beta) \right)^2 + \left( V12 \cos(\beta) - V12 \cos(\beta) \right)^2 \right] + \left( V12 \cos(\beta) - V12 \cos(\beta) \right)^2 + \left( V12 \cos(\beta$  $\left(P_{j}S_{i}+P_{i}S_{j}\right)\left[\left(\operatorname{Vi2sin}(\beta)-\operatorname{Ui2cos}(\beta)\right)\left(\operatorname{Ui2cos}(\beta)+\operatorname{Vi2sin}(\beta)\right)-\nu_{j}A_{i1}\right)\right]+$ - f: m<sup>2</sup>, 10(U(2 cos(B) + V(2 sin(B))<sup>2</sup> - (V(2 sin(B) - U(2 cos(B))<sup>2</sup>) (P, P, + S, S,) - $\{P_1S_1 + P_1S_2\}\{(Vi2 \sin(\beta) - Ui2 \cos(\beta)) (Ui2 \cos(\beta) + Vi2 \sin(\beta)) - \nu_1S_2\}\}$  $\frac{4}{2}q_{1}^{2}m_{2}^{2}(||(U|2\cos(\beta) + V|2\sin(\beta))^{2} - (V|2\sin(\beta) - U|2\cos(\beta))^{2}|(P_{1}P_{1} + S_{1}S_{1}) - U|2\cos(\beta)|^{2}|(P_{1}P_{1} + S_{1}S_{1})| - (V|2\sin(\beta) - U|2\cos(\beta))^{2}|(P_{1}P_{1} + S_{1}S_{1})| - (V|2\cos(\beta) - U|2\cos(\beta))| - (V|2\cos(\beta))^{2}|(P_{1}P_{1} + S_{1}S_{1})| - (V|2\cos(\beta) - U|2\cos(\beta))| - (V|2\cos($  $[P_1S_1 + P_1S_2][(Vi2 \sin(\beta) - Ui2 \cos(\beta))(Ui2 \cos(\beta) + Vi2 \sin(\beta)) - v_1A_2]] -$  $= f_2 q_1^2 \left[ \left[ (\text{Ui2}\cos(\beta) + \text{Vi2}\sin(\beta))^2 - (\text{Vi2}\sin(\beta) - \text{Ui2}\cos(\beta))^2 \right] \left[ P_i P_i + S_i S_i \right] - \frac{1}{2} \left[ P_i P_i + S_i S_i \right] - \frac{1}{2} \left[ P_i P_i + S_i S_i \right] - \frac{1}{2} \left[ P_i P_i + S_i S_i \right] + \frac{1}{2} \left[ P_i P_i + P_i + S_i S_i \right] + \frac{1}{2} \left[ P_i P_i + P_i + S_i S_i \right] + \frac{1}{2} \left[ P_i P_i + P_i + S_i S_i \right] + \frac{1}{2} \left[ P_i P_i + P_i + S_i S_i \right] + \frac{1}{2} \left[ P_i P_i + P_i + S_i S_i \right] + \frac{1}{2} \left[ P_i P_i + P_i + S_i S_i \right] + \frac{1}{2} \left[ P_i P_i + P_i + S_i S_i \right] + \frac{1}{2} \left[ P_i P_i + P_i + P_i + S_i S_i \right] + \frac{1}{2} \left[ P_i P_i + P_i$ 

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 $(P_1S_1 + P_1S_2)(Vi2\sin(\beta) - Ui2\cos(\beta))(Ui2\cos(\beta) + Vi2\sin(\beta)) - v_1A_2))$  $m_{g}\left[4m_{g}\left[-\frac{1}{3m_{e}^{2}m_{e}^{2}}2!\left[(Ui2\cos(\beta)+Vi2\sin(\beta))^{2}-(Vi2\sin(\beta)-Ui2\cos(\beta))^{2}\right)(P_{i}P_{j}+S_{i}S_{j})-\frac{1}{2}m_{e}^{2}+\frac{1}{2}m_$  $\left(P_{j}S_{i}+P_{i}S_{j}\right)\left(\left(\mathrm{Vi2}\sin(\beta)-\mathrm{Ui2}\cos(\beta)\right)\left(\mathrm{Ui2}\cos(\beta)+\mathrm{Vi2}\sin(\beta)\right)-r_{j}\Lambda_{i1}\right)\left(f_{3}\right)^{2}-r_{j}\Lambda_{i1}\right)\left(f_{3}\right)^{2}-r_{j}\Lambda_{i1}\left$  $\frac{1}{1-z^2} 2 \left( \left( \text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta) \right)^2 - \left( \text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta) \right)^2 \right) \left( P_i P_j + S_i S_j \right) - \frac{1}{1-z^2} \left( P_i P_i + S_i S_j \right) - \frac{1}{1-z^2} \left( P_i + S_i S_j \right$  $\left(P_{j}S_{i}+P_{i}S_{j}\right)\left(\left(\operatorname{Vi2sin}(\beta)-\operatorname{Ui2cos}(\beta)\right)\left(\operatorname{Ui2cos}(\beta)+\operatorname{Vi2sin}(\beta)\right)-\nu_{j}\Lambda_{ij}\right)\right)\left(f_{i}\right)^{2}+\left(P_{j}S_{i}+P_{i}S_{j}\right)\left(P_{i}S_{i}+P_{i}S_{j}\right)\left(P_{i}S_{i}+P_{i}S_{j}\right)\right)\left(P_{i}S_{i}+P_{i}S_{j}\right)\left($  $\frac{1}{3\,m_{\pi}^2\,m_{\pi}^2}2\,f_2\left[\left[(\text{Ui2}\cos(\beta)+\text{Vi2}\sin(\beta))^2-(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))^2\right]\left\{P_i\,P_j+S_i\,S_j\right]-2\,(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))^2\right]\left[P_i\,P_j+S_i\,S_j\right]-2\,(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))^2\right]\left(P_i\,P_j+S_i\,S_j\right)-2\,(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))^2\right]\left(P_i\,P_j+S_i\,S_j\right)-2\,(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))^2\right)\left(P_i\,P_j+S_i\,S_j\right)-2\,(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))^2\right)\left(P_i\,P_j+S_i\,S_j\right)-2\,(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))^2\right)\left(P_i\,P_j+S_i\,S_j\right)-2\,(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))^2\right)\left(P_i\,P_j+S_i\,S_j\right)-2\,(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))^2\right)\left(P_i\,P_j+S_i\,S_j\right)-2\,(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))^2\right)\left(P_i\,P_j+S_i\,S_j\right)-2\,(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))^2\right)\left(P_i\,P_j+S_i\,S_j\right)-2\,(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))^2\right)\left(P_i\,P_j+S_i\,S_j\right)-2\,(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))^2\right)\left(P_i\,P_j+S_i\,S_j\right)-2\,(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))^2\right)\left(P_i\,P_j+S_i\,S_j\right)-2\,(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))^2\right)\left(P_i\,P_j+S_i\,S_j\right)-2\,(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))^2\right)\left(P_i\,P_j+S_i\,S_j\right)-2\,(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))^2\right)\left(P_i\,P_j+S_i\,S_j\right)-2\,(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta))^2\right)\left(P_i\,P_j+S_j\,S_j\right)$  $(P_j S_i + P_i S_j) [(Vi2 \sin(\beta) - Ui2 \cos(\beta)) (Ui2 \cos(\beta) + Vi2 \sin(\beta)) - v_j \Lambda_{i1}]) (f_3)^2 - Vi2 \sin(\beta) - v_j \Lambda_{i1}] (f_3)^2 - Vi2 \sin(\beta) - Vi2 \sin(\beta$  $\frac{4}{2} \left( \left( (\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta))^2 - (\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta))^2 \right) (P_i P_j + S_i S_j) \right) - \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta))^2 - (\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta))^2 \right) (P_i P_j + S_i S_j) \right) - \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta))^2 - (\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta))^2 \right) (P_i P_j + S_i S_j) \right) - \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta))^2 - ((\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta))^2 \right) (P_i P_j + S_i S_j) \right) - \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta))^2 - ((\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta))^2 \right) (P_i P_j + S_i S_j) \right) - \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta))^2 - ((\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta))^2 \right) \right) + \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta))^2 - ((\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta))^2 \right) \right) + \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta))^2 - ((\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta))^2 \right) \right) + \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta))^2 - ((\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta))^2 \right) \right) + \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta)) - ((\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta))^2 \right) \right) + \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta)) - ((\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta)) \right) \right) + \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta)) - ((\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta)) \right) \right) + \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta)) - ((\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta)) \right) \right) + \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta)) - ((\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta)) \right) \right) + \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta)) - ((\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta)) \right) \right) + \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta)) - ((\text{Vi2} \sin(\beta) - \text{Ui2} \sin(\beta)) \right) \right) + \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta)) - ((\text{Vi2} \sin(\beta) - \text{Ui2} \sin(\beta)) \right) \right) + \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta)) - ((\text{Vi2} \sin(\beta) - \text{Ui2} \sin(\beta)) \right) \right) + \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta)) - ((\text{Ui2} \sin(\beta) - \text{Ui2} \sin(\beta)) \right) \right) + \frac{4}{2} \left( ((\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta)) - ((\text{Ui2} \sin(\beta) - \text{Ui2} \sin(\beta)) \right) \right) + \frac{4}{2} \left( ((\text{Ui2} \sin(\beta) + \text{Vi2} \sin(\beta)) - ((\text{Ui2} \sin(\beta) - \text{Ui2} \sin(\beta)) \right) \right) + \frac{4}{2} \left( ((\text{Ui2} \sin(\beta) + \text{Ui2} \sin(\beta)) - ((\text{Ui2} \sin(\beta) - \text{Ui2} \sin(\beta)) \right) \right) + \frac{4}{2} \left( ((\text{Ui2} \sin(\beta) + \text{Ui2} \sin(\beta)) - ((\text{Ui2} \sin(\beta) - \text{Ui2} \sin(\beta)) \right) \right) + \frac{4}{2} \left( ((\text{Ui2} \sin(\beta) + \text{Ui2} \sin(\beta)) - ((\text{Ui2} \sin(\beta) - \text{Ui2} \sin(\beta)) - ((\text{Ui2} \sin(\beta)) -$  $(P_{j}S_{i} + P_{i}S_{j})$   $(Vi2 \sin(\beta) - Ui2 \cos(\beta))$   $(Ui2 \cos(\beta) + Vi2 \sin(\beta)) - \tau_{j}\Lambda_{ij})$   $f_{5} - \tau_{j}\Lambda_{ij}$  $\frac{4}{2} m_{12}^2 ((Ui2 \cos(\beta) + Vi2 \sin(\beta))^2 - (Vi2 \sin(\beta) - Ui2 \cos(\beta))^2) (P_1 P_1 + S_1 S_2)$  $(P_{1}S_{1} + P_{1}S_{2})$   $((V12 sin(\beta) - U12 cos(\beta)) (U12 cos(\beta) + V12 sin(\beta)) - v_{1} \Lambda_{(1)})$  +  $= f_2 \left( (\text{Ui2}\cos(\beta) + \text{Vi2}\sin(\beta))^2 - (\text{Vi2}\sin(\beta) - \text{Ui2}\cos(\beta))^2 \right) \left( P_1 P_1 + S_1 S_2 \right)$  $(P_1S_1 + P_1S_2)$  { $(Vi2 sin(\beta) - Ui2 cos(\beta))$  (Ui2 cos( $\beta$ ) + Vi2 sin( $\beta$ )) -  $v_1 \Lambda_{(1)}$ )  $4\left[-\frac{1}{3\,m_{0}^{2}\,m_{0}^{2}}4\left[\left[(U|2\cos(\beta)+Vi2\sin(\beta)\right)^{2}-(Vi2\sin(\beta)-Ui2\cos(\beta))^{2}\right]\left(P_{i}P_{j}+S_{i}S_{j}\right)-\frac{1}{2}\left[(V_{i}^{2}+V_{i}^$  $(P_1S_1 + P_1S_1)(\text{Vi2}\sin(\beta) - \text{Ui2}\cos(\beta))(\text{Ui2}\cos(\beta) + \text{Vi2}\sin(\beta)) - r_1A_1))(f_3)^3$  $\frac{1}{1-r^2} 2 m_{\tilde{U}} \left( \left( \text{U12} \cos(\beta) + \text{V12} \sin(\beta) \right)^2 - \left( \text{V12} \sin(\beta) - \text{U12} \cos(\beta) \right)^2 \right) \left( P_i P_j + S_i S_j \right) - \frac{1}{1-r^2} 2 m_{\tilde{U}} \left( \left( \text{U12} \cos(\beta) + \text{V12} \sin(\beta) \right)^2 - \left( \text{V12} \sin(\beta) - \text{U12} \cos(\beta) \right)^2 \right) \right)$  $\left(P_{j}S_{i}+P_{i}S_{j}\right)\left(\left(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta)\right)\left(\text{Ui2}\cos(\beta)+\text{Vi2}\sin(\beta)\right)-\nu_{j}\Lambda_{ij}\right)\right)\left(f_{i}\right)^{2}+\frac{1}{2}\left(P_{j}S_{i}+P_{j}S_{j}\right)\left(P_{j}S_{i}+P_{j}S_{j}\right)\left(P_{j}S_{i}+P_{j}S_{j}\right)\right)\left(P_{j}S_{i}+P_{j}S_{j}\right)\left(P_{j}S_{i}+P_{j}S_{j}\right)\left(P_{j}S_{i}+P_{j}S_{j}\right)\left(P_{j}S_{i}+P_{j}S_{j}\right)\left(P_{j}S_{i}+P_{j}S_{j}\right)\left(P_{j}S_{i}+P_{j}S_{j}\right)\left(P_{j}S_{i}+P_{j}S_{j}\right)\left(P_{j}S_{i}+P_{j}S_{j}\right)\left(P_{j}S_{i}+P_{j}S_{j}\right)\left(P_{j}S_{i}+P_{j}S_{j}\right)\left(P_{j}S_{i}+P_{j}S_{j}\right)\left(P_{j}S_{i}+P_{j}S_{j}\right)\left(P_{j}S_{j}+P_{j}S_{j}\right)\left(P_{j}S_{i}+P_{j}S_{j}\right)\left(P_{j}S_{j}+P_{j}S_{j}\right)\left(P$  $\frac{1}{3 m_{\pi}^2 m_{\gamma}^2} 2 f_1 \left[ \left[ (\text{Ui2}\cos(\beta) + \text{Vi2}\sin(\beta))^2 - (\text{Vi2}\sin(\beta) - \text{Ui2}\cos(\beta))^2 \right] \left\{ P_i P_j + S_i S_j \right\} - \frac{1}{3 m_{\pi}^2 m_{\gamma}^2} \sum_{i=1}^{N} \frac{1}{2 m_{\pi}^2 m_{\gamma}^2} \left[ \frac{1}{2 m_{\pi}^2 m_{\gamma}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\gamma}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\gamma}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2 m_{\pi}^2} + \frac{1}{2 m_{$  $(P_1S_1 + P_1S_2)$  (Vi2 sin( $\beta$ ) - Ui2 cos( $\beta$ )) (Ui2 cos( $\beta$ ) + Vi2 sin( $\beta$ )) -  $\tau_1\Lambda_1$ )) ( $f_2$ )<sup>2</sup> +  $\frac{1}{3\,\mathrm{sm}_{1}^{2}\,\mathrm{sm}_{2}^{2}} = 2\,f_{2}\left[\left[\mathrm{U12\,\cos(\beta)} + \mathrm{V12\,\sin(\beta)}\right]^{2} - (\mathrm{V12\,\sin(\beta)} - \mathrm{U12\,\cos(\beta)})^{2}\right]\left[P_{1}\,P_{j} + S_{1}\,S_{j}\right] - \frac{1}{3\,\mathrm{sm}_{1}^{2}\,\mathrm{sm}_{2}^{2}}\right]$  $(P_j S_i + P_i S_j) ((Vi2 \sin(\beta) - Ui2 \cos(\beta)) (Ui2 \cos(\beta) + Vi2 \sin(\beta)) - \tau_j \Lambda_{i1})) (f_i)^2$  $\frac{1}{3m_1}2\left(\left(\text{U12}\cos(\beta) + \text{V12}\sin(\beta)\right)^2 - (\text{V12}\sin(\beta) - \text{U12}\cos(\beta))^2\right)\left(P_1P_1 + S_1S_1\right) - \frac{1}{3m_1}\left(\frac{1}{3m_1} + \frac{1}{3m_1} +$ (P, S, +P, S)  $[(Vi2 sin(B) - Ui2 cos(B)) (Ui2 cos(B) + Vi2 sin(B)) - v, A_{*}]) (f_{*})^{2}$  $\frac{8}{-m_{\odot}} \left[ \left( Ui2 \cos(\beta) + Vi2 \sin(\beta) \right)^2 - \left( Vi2 \sin(\beta) - Ui2 \cos(\beta) \right)^2 \right] \left( P_1 P_1 + S_1 S_1 \right) \right]$  $(P_{j}S_{i} + P_{i}S_{j})$   $(Vi2 \sin(\beta) - Ui2 \cos(\beta)) (Ui2 \cos(\beta) + Vi2 \sin(\beta)) - v_{j}\Lambda_{ij}) f_{j} \frac{4}{2}m_{12}^{3}(((U12\cos(\beta) + V12\sin(\beta))^{2} - (V12\sin(\beta) - U12\cos(\beta))^{2})(P_{1}P_{1} + S_{1}S_{2}) - (V12\sin(\beta) - U12\cos(\beta))^{2})(P_{1}P_{1} + S_{2}S_{2}) - (V12\sin(\beta) - (V12\sin(\beta) - U12\cos(\beta))^{2})(P_{1}P_{1} + S_{2}S_{2}) - (V12\sin(\beta) - U12\cos(\beta))^{2})(P_{1}P_{1} + S_{2}S_{2}) - (V12\sin(\beta) - (V12\sin(\beta) - U12\cos(\beta))^{2})(P_{1}P_{2} + S_{2}S_{2}) - (V12\sin(\beta) - (V12\sin(\beta) - V12\sin(\beta))^{2})(P_{1}P_{2} + S_{2}S_{2}) - (V12\sin(\beta) - (V12\sin(\beta) - V12\sin(\beta))^{2})(P_{2}P_{2} + V12\sin(\beta)) - (V12\sin(\beta) - (V12\sin(\beta) - V12\sin(\beta))^{2})(P_{2}P_{2} + V12\sin(\beta)) - (V12\sin(\beta) - (V12\sin(\beta) - V12\sin(\beta))^{2})(P_{2}P_{2} + V12\sin(\beta)) - (V12\sin(\beta) - V12\sin(\beta))^{2})(P_{2}P_{2} + V12\sin(\beta)) - (V12\sin(\beta) - (V12\sin(\beta) - V12\sin(\beta))) - (V12\sin(\beta) - V12\sin(\beta))) - (V12\sin(\beta) - (V12\sin(\beta) - V12\sin(\beta))) - (V12\sin(\beta) - V12\sin(\beta))) - (V12\sin(\beta) - (V12\sin(\beta) - V12\sin(\beta))) - (V12\sin(\beta) - V12\sin(\beta))) - (V12\sin(\beta) - V12\sin(\beta) - V12\sin(\beta))) - (V12\sin(\beta) - V12\sin(\beta))) - (V12\sin(\beta$ 

 $(P_1S_1 + P_1S_1)((Vi2 \sin(\beta) - Ui2 \cos(\beta))(Ui2 \cos(\beta) + Vi2 \sin(\beta)) - v_1A_0)) \frac{4}{2}m_{W}^{2}m_{j_{1}}\left[\left((\text{Ui2}\cos(\beta) + \text{Vi2}\sin(\beta))^{2} - (\text{Vi2}\sin(\beta) - \text{Ui2}\cos(\beta))^{2}\right)(P_{1}P_{j} + S_{1}S_{j})\right]$  $[P_1S_1 + P_1S_1]$   $(\text{Vi2 sin}(\beta) - \text{Ui2 cos}(\beta))$   $(\text{Ui2 cos}(\beta) + \text{Vi2 sin}(\beta)) - v_1\Lambda_0]$  ) $= f_1 m_{j_1} \left[ \left[ (\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta))^2 - (\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta))^2 \right] \left[ P_1 P_1 + S_1 S_2 \right] - \right]$  $(P_j S_l + P_l S_j)$  $(Vi2 sin(\beta) - Ui2 cos(\beta))$  $(Ui2 cos(\beta) + Vi2 sin(\beta)) - v_j \Lambda_{ll})$ +  $\frac{7}{2}f_2 m_{\tilde{G}} \left[ \left[ (\text{Ui2}\cos(\beta) + \text{Vi2}\sin(\beta))^2 - (\text{Vi2}\sin(\beta) - \text{Ui2}\cos(\beta))^2 \right] \left[ P_1 P_j + S_1 S_j \right] - \frac{7}{2} \left[ P_1 P_j + P_2 P_1 + P_2 P_2 P_2 + P_2 + P_2 P_2 + P_2 +$  $(P_j S_i + P_i S_j)$  $(Vi2 sin(\beta) - Ui2 cos(\beta))$  $(Ui2 cos(\beta) + Vi2 sin(\beta)) - v_j \Lambda_{ii})$  +  $4\left[-\frac{1}{3 m_{k_{\ell}}^{2} m_{\ell_{\ell}}^{2}}4\left[\left(\text{Ui2}\cos(\beta) + \text{Vi2}\sin(\beta)\right)^{2} - (\text{Vi2}\sin(\beta) - \text{Ui2}\cos(\beta))^{2}\right]\left(P_{\ell}P_{\ell} + S_{\ell}S_{\ell}\right) + \right]$  $(P_{j}S_{j} + P_{j}S_{j})((Vi2 \sin(\beta) - Ui2 \cos(\beta))(Ui2 \cos(\beta) + Vi2 \sin(\beta)) - v_{j}\Lambda_{(1)})(f_{3})^{3}$  $\frac{1}{3 m_{\tilde{d}}^2} 2 m_{\tilde{d}} \left[ \left[ (\text{Ui2}\cos(\beta) + \text{Vi2}\sin(\beta))^2 - (\text{Vi2}\sin(\beta) - \text{Ui2}\cos(\beta))^2 \right] \left( P_i P_j + S_i S_j \right) + \frac{1}{3 m_{\tilde{d}}^2} \right]$  $(P_1S_1 + P_1S_1)$   $(Vi2 sin(\beta) - Ui2 cos(\beta))$   $(Ui2 cos(\beta) + Vi2 sin(\beta)) - v_1 A_2)$   $(f_3)^2 +$  $-2 f_1 \left[ \left[ (\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta))^2 - (\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta))^2 \right] \left[ P_1 P_j + S_1 S_j \right] +$ 3 m<sup>2</sup><sub>N</sub> m  $(P_1S_1 + P_1S_1)((Vi2 \sin(\beta) - Ui2 \cos(\beta))(Ui2 \cos(\beta) + Vi2 \sin(\beta)) - v_1\Lambda_0))(f_3)^2 +$ 3 m2, m  $-2 f_2 \left[ \left[ (\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta))^2 - (\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta))^2 \right] \left( P_1 P_j + S_1 S_j \right) + \right]$  $(P_j S_j + P_j S_j)$   $(Vi2 \sin(\beta) - Ui2 \cos(\beta)) (Ui2 \cos(\beta) + Vi2 \sin(\beta)) - v_j A_{ij})$   $(f_j)^2 - (P_j S_j + P_j S_j)$  $\frac{1}{3m_1}2\left(\left(\text{U12}\cos(\beta) + \text{V12}\sin(\beta)\right)^2 - (\text{V12}\sin(\beta) - \text{U12}\cos(\beta))^2\right)\left(P_iP_j + S_iS_j\right) + \frac{1}{3m_1}\left(\frac{1}{2}\left(\frac{1}{2}\right)^2 + \frac{1}{2}\left(\frac{1}{2}\right)^2\right)\left(\frac{1}{2}\left(\frac{1}{2}\right)^2 + \frac{1}{2}\left(\frac{1}{2}\right)^2\right)\left(\frac{1}{2}\left($  $\left(P_{j}S_{i}+P_{i}S_{j}\right)\left(\left(\text{Vi2}\sin(\beta)-\text{Ui2}\cos(\beta)\right)\left(\text{Ui2}\cos(\beta)+\text{Vi2}\sin(\beta)\right)-\nu_{j}\Lambda_{ii}\right)\right)(f_{1})^{2}-2h_{1}^{2}h_{2}^{2}h_{$  $\frac{\delta}{2} m_{f_1} \left[ \left[ (\text{UI2}\cos(\beta) + \text{Vi2}\sin(\beta))^2 - (\text{Vi2}\sin(\beta) - \text{UI2}\cos(\beta))^2 \right] \left\{ P_1 P_1 + S_1 S_1 \right\} + \frac{\delta}{2} \left[ P_1 P_2 + S_2 S_1 \right] + \frac{\delta}{2} \left[ P_1 P_2 + S_2 S_2 \right] \right] \right]$  $(P_1S_1 + P_1S_1)$   $(Ni2 sin(\beta) - Ui2 cos(\beta))$   $(Ui2 cos(\beta) + Vi2 sin(\beta)) - v_1 \Lambda_0)$   $f_3 \frac{4}{2}m_{i1}^{2}\left[\left(\text{Ui2}\cos(\beta) + \text{Vi2}\sin(\beta)\right)^{2} - \left(\text{Vi2}\sin(\beta) - \text{Ui2}\cos(\beta)\right)^{2}\right]\left(P_{i}P_{i} + S_{i}S_{i}\right) + \frac{4}{2}m_{i1}^{2}\left[\left(\text{Ui2}\cos(\beta) + \text{Vi2}\sin(\beta)\right)^{2} - \left(\text{Vi2}\sin(\beta) - \text{Ui2}\cos(\beta)\right)^{2}\right]$  $(P_1S_1 + P_1S_1)((Vi2 \sin(\beta) - Ui2 \cos(\beta))(Ui2 \cos(\beta) + Vi2 \sin(\beta)) - v_1A_0))$  $\frac{4}{2}m_{b'}^2m_{2i}\left(\left(\text{Ui2}\cos(\beta) + \text{Vi2}\sin(\beta)\right)^2 - (\text{Vi2}\sin(\beta) - \text{Ui2}\cos(\beta))^2\right)\left(P_1P_1 + S_1S_1\right) + \frac{4}{2}m_{b'}^2m_{2i}^2\left(\left(\frac{1}{2}+\frac{1}{2}$  $(P_1S_1 + P_1S_2)(V(2\sin(\beta) - U(2\cos(\beta)))(U(2\cos(\beta) + V(2\sin(\beta)) - v_1A_2)))$  $= f_1 m_{21} \left[ \left( (\text{Ui2} \cos(\beta) + \text{Vi2} \sin(\beta))^2 - (\text{Vi2} \sin(\beta) - \text{Ui2} \cos(\beta))^2 \right) \left( P_1 P_1 + S_1 S_1 \right) + \right]$  $(P, S_1 + P, S_2)((Vi2 sin(B) - Ui2 cos(B))(Ui2 cos(B) + Vi2 sin(B)) - v_1 A_2))$  $= \int_{0}^{\infty} f_{2} m_{0} \left( \left[ (\text{UI2} \cos(\beta) + \text{VI2} \sin(\beta))^{2} - (\text{VI2} \sin(\beta) - \text{UI2} \cos(\beta))^{2} \right] \left( P_{1} P_{j} + S_{i} S_{j} \right) + \frac{1}{2} \int_{0}^{\infty} f_{2} m_{0} \left[ \left( (\text{UI2} \cos(\beta) + \text{VI2} \sin(\beta))^{2} - (\text{VI2} \sin(\beta) - \text{UI2} \cos(\beta))^{2} \right) \left( P_{1} P_{j} + S_{i} S_{j} \right) \right] \right)$  $(P_1S_1 + P_1S_1)((Vi2 \sin(\beta) - Ui2 \cos(\beta))(Ui2 \cos(\beta) + Vi2 \sin(\beta)) - v_1\Lambda_{11}))$ 

#### Bryan Larios 3 body Stop decay with LSP gravitino/goldstino in the f.s.

# Motivation

There are several promising search channels (in SUSY models) to find new physics at both lepton and hadron colliders but, we learned with the last process  $(\tilde{t}_1 \rightarrow b + W + \tilde{\Psi}_{\mu})$  that it is necessary to implement new calculations methods. In order to learn how to compute scattering amplitudes efficiently and then apply the new methods to some reaction with spin-3/2 particle, we revisited the monophoton plus mising energy  $(e^+e^- \rightarrow \gamma \tilde{G}\tilde{G})$ .

The spinor helicity formalism (SHF) (a pragmatic point of view)

# The spinor helicity formalism (a pragmatic point of view)



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The spinor helicity formalism (SHF) (a pragmatic point of view)

#### The SHF is based in the following observation

 $\sigma_{a}^{\mu}$ 

Fields with spin-1 transform in the  $(\frac{1}{2}, \frac{1}{2})$  representation of the Lorentz group.

So we are able to express 4-moments of any particle as a biespinor:  $p_{\mu} \rightarrow p_{a \dot{a}}$ 

$$p_{a\dot{a}} = p_{\mu}\sigma^{\mu}_{a\dot{a}}$$

$$\gamma^{\mu} = \begin{pmatrix} 0 & \sigma^{\mu} \\ \bar{\sigma}^{\mu} & 0 \end{pmatrix}$$

$$^{\iota}_{\dot{a}} = (I, \vec{\sigma}), \ \bar{\sigma}^{\mu \dot{a} a} = (I, -\vec{\sigma})$$
(1)

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The spinor helicity formalism (SHF) (a pragmatic point of view)

We also know that:  $u_s(\vec{p})\bar{u}_s(\vec{p}) = \frac{1}{2}(1+s\gamma_5)(-p)$  with  $s = \pm$ , para s = -, tenemos:

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$$u_{-}(\vec{p})\bar{u}_{-}(\vec{p}) = \frac{1}{2}(1-\gamma_{5})(-p) = \begin{pmatrix} 0 & -p_{a\dot{a}} \\ 0 & 0 \end{pmatrix}$$

where

$$u_{-}(\vec{p}) = \left(\begin{array}{c} \phi_a \\ 0 \end{array}\right)$$

and  $\phi_a$  is a two component spinor that solves the Weyl equation. a explicit formula for this spinor is the following:

$$\phi_{a} = \begin{pmatrix} -\sin(\frac{\theta}{2})e^{-i\phi} \\ \cos(\frac{\theta}{2}) \end{pmatrix}$$
  
also  $\bar{u}_{-}(\vec{p}) = (0, \phi_{\dot{a}}^{*})$ , and  $p_{a\dot{a}} = -\phi_{a}\phi_{\dot{a}}^{*}$   
Bryan Larios 3 body Stop decay with LSP gravitino/goldstino in the f.s.

The spinor helicity formalism (SHF) (a pragmatic point of view)

The key of the SHF is to considerate  $\phi_a$  as the fundamental object and express the 4-moments of the particles in terms of  $\phi_a$ .

#### Notation

If p and k are two 4-momentos and  $\phi_a$ ,  $\kappa_a$  their corresponding spinors, we can define the following products of spinors:

$$[pk] = \phi^a \kappa_a = \bar{u}_+(\vec{p})u_-(\vec{k}) = -[kp]$$
(2)

similarly, we also have

$$\langle pk \rangle = \phi_{\dot{a}}^* \kappa^{*\dot{a}} = \bar{u}_-(\vec{p})u_+(\vec{k}) = -\langle kp \rangle$$

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(3)

The spinor helicity formalism (SHF) (a pragmatic point of view)

# **Polarizations 4-vectores**

• The contraction with  $\gamma$  matrix is as follows: :

$$\pounds_{+}(k,q) = \frac{1}{\sqrt{2}\langle qk \rangle} \langle q|\gamma^{\mu}|k] \gamma_{\mu} = \frac{2}{\sqrt{2}} (|k] \langle q| + |q \rangle [k|)$$

$$= \frac{\sqrt{2}}{\langle qk \rangle} (|k] \langle q| + |q \rangle [k|), \qquad (4)$$

$$\pounds_{-}(k,q) = \frac{1}{\sqrt{2}[qk]} [q|\gamma^{\mu}|k\rangle \gamma_{\mu} = \frac{1}{\sqrt{2}[qk]} \langle k|\gamma^{\mu}|q] \gamma_{\mu}$$

$$= \frac{\sqrt{2}}{[qk]} (|k] \langle q| + |q \rangle [k|). \qquad (5)$$

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The spinor helicity formalism (SHF) (a pragmatic point of view)

Before to start with our computation, I will show all the formulas that are needed to compute the scattering amplitudes:

$$[ij] = -[ji],$$

$$\langle ij\rangle = [ji]^{*},$$

$$\langle ij\rangle[ji] = \langle ij\rangle\langle ij\rangle^{*} = |\langle ij\rangle|^{2},$$

$$\langle ij\rangle[ji] = -2k_{i} \cdot k_{j} = s_{ij},$$

$$\langle ij\rangle[ji] = 0,$$

$$\langle ij\rangle[ji] = 0,$$

Computing the amplitudes with SPH



Using the SUSY QED model constructed by Mawatari and Oexl (arXiv:1402.3223v2), and applying the SHF we will compute the scattering amplitude for the  $e^+e^- \rightarrow \gamma \tilde{G}\tilde{G}$  reaction. It is important to mention that the cross sections for this reaction has been computed numerically, so it is interesting have an analytical result.

Computing the amplitudes with SPH

# Feynman Diagrams



Figure: Feynman Diagrams for  $e^+e^- \rightarrow \gamma \tilde{G} \tilde{G}$ 

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Computing the amplitudes with SPH



We have 5 Feynman diagrams each on them with 5 external (massless) particles, each particle have two helicity states  $(\pm)$ , in principle we need to compute  $2^5$  helicity amplitudes for each diagram.

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Computing the amplitudes with SPH

# Feynman Diagrams

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(Ampb[-1, -1, -1, -1, -1])	(Ampc[-1, -1, -1, -1, -1])	(Ampe[-1, -1, -1, -1, -1])	( A[-1, -1, -1, -1, -1] )	( A[-1, -1, -1, -1, -1]
Ampb[-1, -1, -1, -1, 1]	Ampc[-1, -1, -1, -1, 1]	Ampe[-1, -1, -1, -1, 1]	Ampa[-1, -1, -1, -1, 1]	A[-1, -1, -1, -1, 1]
Ampb[-1, -1, -1, 1, -1]	Ampc[-1, -1, -1, 1, -1]	Ampe[-1, -1, -1, 1, -1]	Ampa[-1, -1, -1, 1, -1]	Ampd[-1, -1, -1, 1, -1]
Ampb[-1, -1, -1, 1, 1]	Ampc[-1, -1, -1, 1, 1]	Ampe[-1, -1, -1, 1, 1]	A[-1, -1, -1, 1, 1]	Ampd[-1, -1, -1, 1, 1]
Ampb[-1, -1, 1, -1, -1]	Ampc[-1, -1, 1, -1, -1]	Ampe[-1, -1, 1, -1, -1]	A[-1, -1, 1, -1, -1]	Ampd[-1, -1, 1, -1, -1]
Ampb[-1, -1, 1, -1, 1]	Ampc[-1, -1, 1, -1, 1]	Ampe[-1, -1, 1, -1, 1]	Ampa[-1, -1, 1, -1, 1]	Ampd[-1, -1, 1, -1, 1]
Ampb[-1, -1, 1, 1, -1]	Ampc[-1, -1, 1, 1, -1]	Ampe[-1, -1, 1, 1, -1]	Ampa[-1, -1, 1, 1, -1]	A[-1, -1, 1, 1, -1]
Ampb[-1, -1, 1, 1, 1]	Ampc[-1, -1, 1, 1, 1]	Ampe[-1, -1, 1, 1, 1]	A[-1, -1, 1, 1, 1]	A[-1, -1, 1, 1, 1]
Ampb[-1, 1, -1, -1, -1]	Ampc[-1, 1, -1, -1, -1]	Ampe[-1, 1, -1, -1, -1]	Ampa[-1, 1, -1, -1, -1]	Ampd[-1, 1, -1, -1, -1]
A[-1, 1, -1, -1, 1]	A[-1, 1, -1, -1, 1]	A[-1, 1, -1, -1, 1]	Ampa[-1, 1, -1, -1, 1]	Ampd[-1, 1, -1, -1, 1]
Ampb[-1, 1, -1, 1, -1]	Ampc[-1, 1, -1, 1, -1]	Ampe[-1, 1, -1, 1, -1]	Ampa[-1, 1, -1, 1, -1]	Ampd[-1, 1, -1, 1, -1]
Ampb[-1, 1, -1, 1, 1]	Ampc[-1, 1, -1, 1, 1]	Ampe[-1, 1, -1, 1, 1]	Ampa[-1, 1, -1, 1, 1]	Ampd[-1, 1, -1, 1, 1]
Ampb[-1, 1, 1, -1, -1]	Ampc[-1, 1, 1, -1, -1]	Ampe[-1, 1, 1, -1, -1]	Ampa[-1, 1, 1, -1, -1]	Ampd[-1, 1, 1, -1, -1]
A[-1, 1, 1, -1, 1]	A[-1, 1, 1, -1, 1]	Ampe[-1, 1, 1, -1, 1]	Ampa[-1, 1, 1, -1, 1]	Ampd[-1, 1, 1, -1, 1]
Ampb[-1, 1, 1, 1, -1]	Ampc[-1, 1, 1, 1, -1]	Ampe[-1, 1, 1, 1, -1]	Ampa[-1, 1, 1, 1, -1]	Ampd[-1, 1, 1, 1, -1]
Ampb[-1, 1, 1, 1, 1]	Ampc[-1, 1, 1, 1, 1]	Ampc[-1, 1, 1, 1, 1] A[-1, 1, 1, 1, 1]	Ampa[-1, 1, 1, 1, 1]	Ampd[-1, 1, 1, 1, 1]
Ampb[1, -1, -1, -1, -1]	Ampc[1, -1, -1, -1, -1]	A[1, -1, -1, -1, -1]	* Ampa[1, -1, -1, -1, -1]	* Ampd[1, -1, -1, -1, -1]
Ampb[1, -1, -1, -1, 1]	Ampc[1, -1, -1, -1, 1]	Ampe[1, -1, -1, -1, 1]	Ampa[1, -1, -1, -1, 1]	Ampd[1, -1, -1, -1, 1]
A[1, -1, -1, 1, -1]	A[1, -1, -1, 1, -1]	Ampe[1, -1, 1, -1] Ampa[1, -1, -1, 1, -1] Ampa[1, -1, -1, 1, -	Ampa[1, -1, -1, 1, -1]	Ampd[1, -1, -1, 1, -1]
Ampb[1, -1, -1, 1, 1]	Ampc[1, -1, -1, 1, 1]	Ampe[1, -1, -1, 1, 1]	Ampa[1, -1, -1, 1, 1]	Ampd[1, -1, -1, 1, 1]
Ampb[1, -1, 1, -1, -1]	Ampc[1, -1, 1, -1, -1]	Ampe[1, -1, 1, -1, -1]	Ampa[1, -1, 1, -1, -1]	Ampd[1, -1, 1, -1, -1]
Ampb[1, -1, 1, -1, 1]	Ampc[1, -1, 1, -1, 1]	Ampe[1, -1, 1, -1, 1]	Ampa[1, -1, 1, -1, 1]	Ampd[1, -1, 1, -1, 1]
A[1, -1, 1, 1, -1]	A[1, -1, 1, 1, -1]	A[1, -1, 1, 1, -1]	Ampa[1, -1, 1, 1, -1]	Ampd[1, -1, 1, 1, -1]
Ampb[1, -1, 1, 1, 1]	Ampc[1, -1, 1, 1, 1]	Ampe[1, -1, 1, 1, 1]	Ampa[1, -1, 1, 1, 1]	Ampd[1, -1, 1, 1, 1]
Ampb[1, 1, -1, -1, -1]	Ampc[1, 1, -1, -1, -1]	Ampe[1, 1, -1, -1, -1]	A[1, 1, -1, -1, -1]	A[1, 1, -1, -1, -1]
Ampb[1, 1, -1, -1, 1]	Ampc[1, 1, -1, -1, 1]	Ampc[1, 1, -1, -1, 1] Ampe[1, 1, -1, -1, 1] Ampa[1, 1, -1, -1, 1]	Ampa[1, 1, -1, -1, 1]	A[1, 1, -1, -1, 1]
Ampb[1, 1, -1, 1, -1]	Ampc[1, 1, -1, 1, -1]	Ampe[1, 1, -1, 1, -1]	Ampa[1, 1, -1, 1, -1]	Ampd[1, 1, -1, 1, -1]
Ampb[1, 1, -1, 1, 1]	Ampc[1, 1, -1, 1, 1]	Ampe[1, 1, -1, 1, 1]	A[1, 1, -1, 1, 1]	Ampd[1, 1, -1, 1, 1]
Ampb[1, 1, 1, -1, -1]	Ampc[1, 1, 1, -1, -1]	Ampe[1, 1, 1, -1, -1]	A[1, 1, 1, -1, -1]	Ampd[1, 1, 1, -1, -1]
Ampb[1, 1, 1, -1, 1]	Ampc[1, 1, 1, -1, 1]	Ampe[1, 1, 1, -1, 1]	Ampa[1, 1, 1, -1, 1]	Ampd[1, 1, 1, -1, 1]
Ampb[1, 1, 1, 1, -1]	Ampc[1, 1, 1, 1, -1]	Ampe[1, 1, 1, 1, -1]	Ampa[1, 1, 1, 1, -1]	A[1, 1, 1, 1, -1]
Ampb(1, 1, 1, 1, 1)	Ampc[1, 1, 1, 1, 1]	Ampe[1, 1, 1, 1, 1]	A[1, 1, 1, 1, 1]	A[1, 1, 1, 1, 1]

#### Figure: All the helicity amplitudes

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 $e^+e^- \rightarrow \gamma \, G \, G$ 

Computing the amplitudes with SPH

One of the several and marvelous advantages of the helicity amplitudes is that it is easy to identify the symmetries as well as the null helicity amplitudes. We already know that the terms  $\langle xy \rangle$  and  $[xy \rangle$  are zero, a small program could help us to find which helicity amplitude is zero.

Computing the amplitudes with SPH

# Counting helicity amplitudes

	0		0		0		A[-1, -1, -1, -1, -1]		A[-1, -1, -1, -1, -1]						
	0		0		0		0		A[-1, -1, -1, -1, 1]						
	0		0		0		0		0						
	0		0		0		A[-1, -1, -1, 1, 1]		0						
	0		0		0		A[-1, -1, 1, -1, -1]		0						
	0		0		0		0		0						
	0		0		0		0		A[-1, -1, 1, 1, -1]						
	0		0 0 A[-1, 1, -1, -1, 1]		0		A[-1, -1, 1, 1, 1]		A[-1, -1, 1, 1, 1]						
	0			0		0		0							
	A[-1, 1, -1, -1, 1]			A[-1, 1, -1, -1, 1]		0		0							
	0		0		0	0 0 0 0	0		0						
	0		0		0		0		0						
	0		0		0		0		0						
	A[-1, 1, 1, -1, 1]		A[-1, 1, 1, -1, 1]		0		0		0						
	0 0 A[1, -1, -1, 1, -1] 0		0 0 • • • • • • • • • • • • • • • • • •		0		0		0						
		•		$\begin{array}{c} \mathbf{A} \begin{bmatrix} -1, 1, 1, 1, 1 \end{bmatrix} \\ \mathbf{A} \begin{bmatrix} -1, -1, -1, -1 \end{bmatrix} \\ \mathbf{A} \begin{bmatrix} 1, -1, -1, -1 \end{bmatrix} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ \end{array}$	0		0								
						0	1.1	0							
					0		0		0						
						0		0							
					0		0		0						
	0		0		0		0		0						
	0		0		0		0		0						
	A[1, -1, 1, 1, -1]		A[1, -1, 1, 1, -1]	A[1, -1, 1, 1, -1]		0		0							
	0		0	0	0		0		0						
	0							0		0		A[1, 1, -1, -1, -1]		A[1, 1, -1, -1, -1]	
	0		0		0		0		A[1, 1, -1, -1, 1]						
	0		0		0		0		0						
	0		0		0		A[1, 1, -1, 1, 1]		0						
	0		0		0		A[1, 1, 1, -1, -1]		0						
	0		0		0		0		0						
	0		0		0		0		A[1, 1, 1, 1, -1]						
	( )		0		0	1	A[1, 1, 1, 1, 1]		A[1, 1, 1, 1, 1]						

#### Figure: Counting helicity amplitudes

Computing the amplitudes with SPH

We started our problem with 160 helicity amplitudes, but just looking at the possible helicity states of the external particles we found that there are only 28 helicity amplitudes to compute. Because the charge conjugation symmetry we really need to compute half of the final helicity amplitudes. At the end, just the 10% of the work will be done and without the help of any machine if you desired.

Computing the amplitudes with SPH

The total squared amplitud is as follows:

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Computing the amplitudes with SPH

Each partial squared helicity amplitude is as follows:

$$\begin{aligned} |\mathcal{A}_{-+-+}^{i}|^{2} &= 2\frac{s_{15}s_{34}}{s_{23}} \left( (B - 2Em_{\chi_{0}})^{2}s_{23}^{2} + 4C^{2}s_{24}^{2} \right. \tag{10} \\ &+ 4(B - 2Em_{\chi_{0}})Cs_{23}s_{24} \right) \\ |\mathcal{A}_{-++++}|^{2} &= \frac{8C^{2}s_{24}^{2}s_{15}s_{34}}{s_{23}} \\ |\mathcal{A}_{-++++}|^{2} &= 8E^{2}s_{34}^{2}s_{12}s_{35} \\ |\mathcal{A}_{----+}|^{2} &= 2D^{2}s_{34}^{3}s_{12}s_{35} \\ |\mathcal{A}_{----+}|^{2} &= 2D^{2}s_{34}s_{12}s_{35}m_{\chi_{0}}^{2} \end{aligned}$$

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Computing the amplitudes with SPH

$$|\mathcal{A}_{--++}|^2 = 2A^2 s_{34} s_{25} s_{15} \tag{15}$$

$$|\mathcal{A}_{-++-}|^2 = |\mathcal{A}_{-+++}|^2 \tag{16}$$

$$|\mathcal{A}_{--++-}|^2 = 2D^2 s_{34}^2 s_{12} s_{54} m_{\chi_0}^2 \tag{17}$$

$$|\mathcal{A}_{--+++}^{i}|^{2} = 2(s_{45}s_{25}s_{15}A^{2} + D^{2}s_{34}^{3}s_{12}s_{35} - AD(s_{34}s_{45}))$$
(18)

where we have to remember that:

$$s_{ij} = -(p_i + p_j)^2$$

Conclusions

# Conclusions

- We compute analytically the total scattering amplitude for the reaction e<sup>+</sup>e<sup>−</sup> → γ G̃ G̃.
- It was show that the SHF is a powerful method, in fact it is much more economic than the traditional approach.
- With the complete result, it is possible to compare the cross section with the numerical results.
- From this point, we can now start do physics.

Conclusions

# Thank you very much for your attention.

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