Time-reversal asymmetries

T-odd spin correlations in $\Lambda_b \to \Lambda V$

arXiv:2109.09524 (to be published in JHEP)

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UCAS

HFCPV 2021

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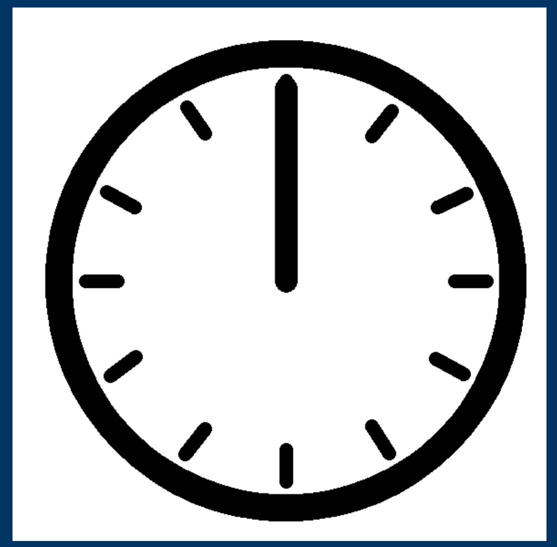


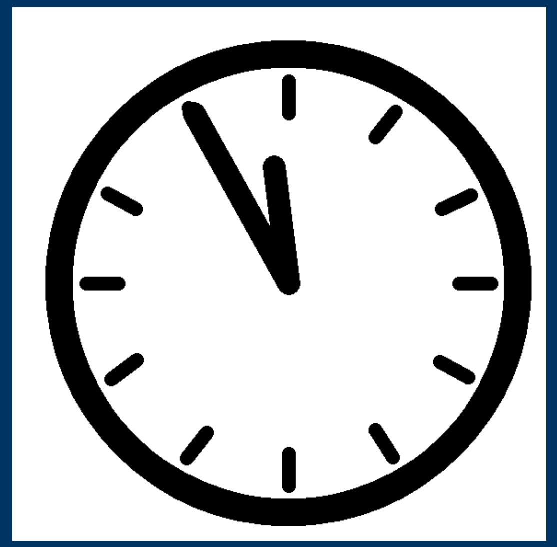
- The T-odd observables in $\Lambda_b \to \Lambda V$

- The T-violationg effects in the cascade decays

- The numerical results

Outline

$$V \longleftarrow \Lambda_b \longrightarrow \Lambda$$



- We have found the T-odd observables in $\Lambda_b \to \Lambda V$.

- The T-violationg effects in the cascade decays have been identified.

- The numerical results have been estimated with factorization.

Conclusions

$$V \longrightarrow \Lambda_b \longleftarrow \Lambda$$

Research Motivation

v2 [hep-ex] 25 Jun 2020

Measurement of the $\Lambda_b^0 \to J/\psi\, \Lambda$ angular distribution and the Λ_b^0 polarisation in pp collisions

LHCb collaboration†

- The full angular distributions of $\Lambda_b \to \Lambda J/\psi$ have been studies at LHCb. JHEP **06**, 110 (2020).
- The naive T-violation in $\Lambda_b \to \Lambda\phi$ decays have been probed through the partial angular distribution at LHCb. Phys. Lett. B **759**, 282 (2016).

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Measurement of the $\Lambda_b^0 \to J/\psi\,\Lambda$ angular distribution and the Λ_b^0 polarisation in pp collisions

LHCb collaboration†

[hep-ex] 22 May 2018

Observation of the $\Lambda_b^0 \to \Lambda\phi$ decay

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- The naive T-violation in $\Lambda_b \to \Lambda\phi$ decays have been probed through the partial angular distribution at LHCb. Phys. Lett. B **759**, 282 (2016).

Research Motivation

T-violating Triple-Product Correlations in Charmless Λ_b Decays

Wafia Bensalem[1], Alakabha Datta[2] and David London[3]

Laboratoire René J.-A. Lévesque, Université de Montréal,
C.P. 6128, succ. centre-ville, Montréal, QC, Canada H3C 3J7

2002

- Spins are treated as classical among the literature, and the FSIs have not been taken account.
- Baryon spins can interfere, causing T-odd spin correlations.

Research Motivation

T-violating Triple-Product Correlations in Charmless Λ_b Decays

2002

Λ_b Decays into Λ-Vector

Dec 2004

Z.J. Ajaltouni[1*], E. Conte[2†], O. Leitner[3‡]

[1,2] Laboratoire de Physique Corpusculaire de Clermont-Ferrand
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[3] ECT*, Strada delle Tabarelle, 286, 38050 Villazzano (Trento), Italy

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T-violating Triple-Product Correlations in Charmless Λ_b Decays

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v1 16 Oct 2006

Testing CP and Time Reversal Symmetries with $\Lambda_b \to \Lambda V(1-)$ Decays

O. Leitner[a] and Z. J. Ajaltouni[b]

[a]LPNHE, Groupe Théorie, Université P. & M. Curie, 4, Place Jussieu, F-75252, PARIS.

[b]LPC/IN2P3-CNRS, Université Blaise Pascal, F-63177, AUBIERE.

In this letter, an overview is given for interesting tests of both CP and Time Reversal symmetries with the beauty baryon Λ_b. Extensive use of the helicity formalism and HQET is done for all calculations. Then, emphasis is put on sophisticated methods like analysis of resonance polarizations and particular angle distributions which can exhibit a clear signal of TR violation.

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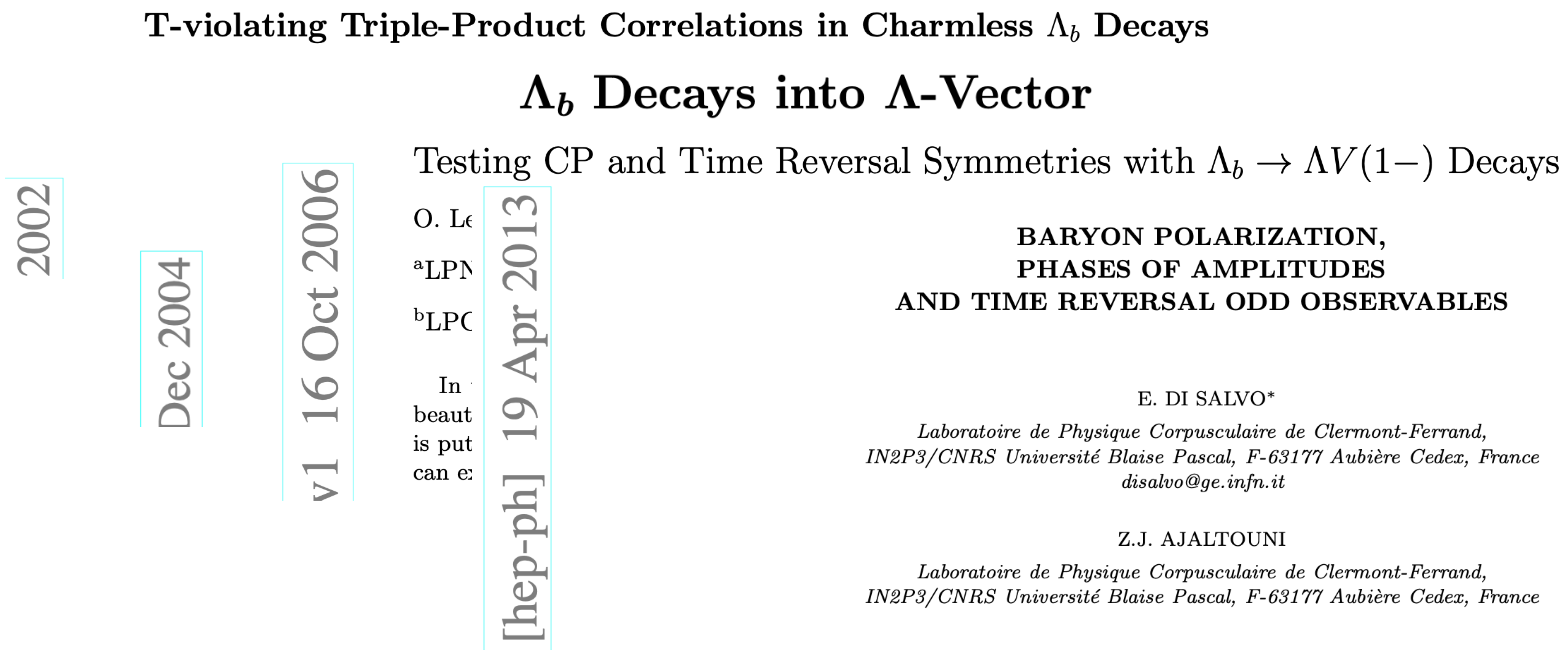
- Baryon spins can interfere, causing T-odd spin correlations.

Research Motivation



T-violating Triple-Product Correlations in Charmless Λ_b Decays

Λ_b Decays into Λ-Vector

Testing CP and Time Reversal Symmetries with $\Lambda_b \to \Lambda V(1-)$ Decays

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[hep-ph] 19 Apr 2013

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BARYON POLARIZATION,
PHASES OF AMPLITUDES
AND TIME REVERSAL ODD OBSERVABLES

E. DI SALVO*

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- Spins are treated as classical among the literature, and the FSIs have not been taken account.
- Baryon spins can interfere, causing T-odd spin correlations.

Time-reversal symmetry

$$V \longleftarrow \Lambda_b \longrightarrow \Lambda$$

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$$\left|\langle f;\mathrm{out}|\mathscr{H}_{eff}|\Lambda_b\rangle\right|^2 - \left|\langle \Lambda_b|\mathscr{H}_{eff}|f_T;\mathrm{in}\rangle\right|^2 = 0$$

$$\Delta_{t_i} \equiv \frac{\Gamma(\lambda_{t_i}) - \Gamma(-\lambda_{t_i})}{\Gamma(\lambda_{t_i}) + \Gamma(-\lambda_{t_i})}$$

J_z, J, E

Assuming "in" and "out" could interchange

$$\vec{J} \xrightarrow{T} -\vec{J}$$

$$\vec{p} \xrightarrow{T} -\vec{p}$$

$$T(b) = e^{-ipb}$$

$$\vec{K} \xrightarrow{T} \vec{K}$$

$$L(\xi) = e^{-iK\xi}$$

Time-reversal symmetry

$$V \longleftarrow \Lambda_b \longrightarrow \Lambda$$

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$$\vec{K} \xrightarrow{T} \vec{K}$$

$$L(\xi) = e^{-iK\xi}$$

J_z, J, E, T_i

Assuming “in” and “out” could interchange

$$T_i \xrightarrow{T} -T_i \qquad T_i\,|\,\lambda_{t_i}\rangle = \lambda_{t_i}\,|\,\lambda_{t_i}\rangle \qquad I_T\,|\,\lambda_{t_i}\rangle = |-\lambda_{t_i}\rangle$$

Time-reversal symmetry

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J_z, J, E, T_i

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$$\vec{p}\cdot\vec{K} \xrightarrow{T} -\vec{p}\cdot\vec{K}$$

Time-reversal symmetry

$$\vec{J} \xrightarrow{T} -\vec{J}$$

$$\vec{p} \xrightarrow{T} -\vec{p}$$

$$\vec{K} \xrightarrow{T} \vec{K}$$

$$\left|\langle f;\mathrm{out}\,|\,\mathscr{H}_{eff}\,|\,\Lambda_b\rangle\right|^2 - \left|\langle \Lambda_b\,|\,\mathscr{H}_{eff}\,|\,f_T;\mathrm{in}\rangle\right|^2 = 0$$

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J_z, J, E, T_i

Assuming "in" and "out" could interchange

$$\vec{s} = \frac{E}{m}\vec{J} - \frac{1}{m}\vec{p}\times\vec{K} - \frac{1}{(E+m)m}\vec{p}(\vec{p}\cdot\vec{J})$$

[53] McKerrell, *Nuovo Cim* **34**, 1289 (1964).

$$[s_i, p_j] = 0 \qquad [s_i, s_j] = i\epsilon_{ijk}s_k$$

$$\hat{T}_1 = (\vec{s}_1 \times \vec{s}_2)\cdot\hat{p}_1 \qquad \hat{T}_1 \xrightarrow{T} -\hat{T}_1$$

Time-reversal symmetry

Constructing the eigenstates of $J_z, J, E, \hat{T}_1$

$$\Delta_{t_i} \equiv \frac{\Gamma(\lambda_{t_i}) - \Gamma(-\lambda_{t_i})}{\Gamma(\lambda_{t_i}) + \Gamma(-\lambda_{t_i})}$$

$$|J, J_z, \lambda_1, \lambda_2\rangle = \frac{2J+1}{8\pi^2} \int d\phi d\cos\theta d\psi \, U(\phi,\theta,\psi) \, D_J^\dagger(\phi,\theta,\psi)^{\lambda_1-\lambda_2}{}_{J_z} |p\hat{z}, \lambda_1, \lambda_2\rangle$$

$$U(\phi,\theta,\psi) = R_z(\phi)R_y(\theta)R_z(\psi)$$

$$D_J(\phi,\theta,\psi)^N{}_M = \langle J N | U(\phi,\theta,\psi) | J M\rangle$$

e.g. $$\left(\frac{2l+1}{4\pi}\right)^{1/2} D_l(\phi,\theta,0)^m{}_0 = Y^*_{lm}(\theta,\phi)$$

Time-reversal symmetry

Constructing the eigenstates of $J_z\,, J\,, E\,, \hat{T}_1$

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$$U(\phi,\theta,\psi) = R_z(\phi)R_y(\theta)R_z(\psi) \qquad D_J(\phi,\theta,\psi)^N{}_M = \langle J\, N|\, U(\phi,\theta,\psi)\,|J\, M\rangle$$

$$J \geq |\lambda|\,, \quad \lambda \equiv \lambda_1 - \lambda_2 \qquad I_p|a_\pm\rangle = |a_\mp\rangle\,, \quad I_p|b_\pm\rangle = |b_\mp\rangle$$

$$|a_\pm\rangle = |J = 1/2, \lambda_1 = \pm 1/2\,, \lambda_2 = 0\rangle\,, \quad |b_\pm\rangle = |J = 1/2, \lambda_1 = \mp 1/2\,, \lambda_2 = \mp 1\rangle$$

$$\alpha_{\lambda_1} \equiv \frac{\Gamma(\lambda_1 = 1/2) - \Gamma(\lambda_1 = -1/2)}{\Gamma(\lambda_1 = 1/2) + \Gamma(\lambda_1 = -1/2)} = \frac{|a_+|^2 + |b_-|^2 - |a_-|^2 - |b_+|^2}{|a_+|^2 + |a_-|^2 + |b_+|^2 + |b_-|^2}\,,$$

P-odd and T-even

Time-reversal symmetry

Constructing the eigenstates of $J_z, J, E, \hat{T}_1$

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$$U(\phi,\theta,\psi) = R_z(\phi)R_y(\theta)R_z(\psi) \qquad D_J(\phi,\theta,\psi)^N{}_M = \langle J\, N | U(\phi,\theta,\psi) | J\, M\rangle$$

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$$\alpha_{\lambda_2} \equiv \frac{\Gamma(|\lambda_2| = 0) - \Gamma(|\lambda_2| = 1)}{\Gamma(|\lambda_2| = 0) + \Gamma(|\lambda_2| = 1)} = \frac{|a_+|^2 + |a_-|^2 - |b_+|^2 - |b_-|^2}{|a_+|^2 + |a_-|^2 + |b_+|^2 + |b_-|^2},$$

P-even and T-even

Time-reversal symmetry

Constructing the eigenstates of $J_z, J, E, \hat{T}_1$

$$\Delta_{t_i} \equiv \frac{\Gamma(\lambda_{t_i}) - \Gamma(-\lambda_{t_i})}{\Gamma(\lambda_{t_i}) + \Gamma(-\lambda_{t_i})}$$

$\hat{T}_1 = (\vec{s}_1 \times \vec{s}_2) \cdot \hat{p}_1$ T-odd and P-odd

$$\Delta_{t_1} = \frac{2\Im(a_+ b_+^* - a_- b_-^*)}{|a_+|^2 + |a_-|^2 + |b_+|^2 + |b_-|^2}$$

$$I_p |\lambda_{t_1}, \lambda\rangle = | - \lambda_{t_1}, - \lambda\rangle$$

$$J \geq |\lambda|, \quad \lambda \equiv \lambda_1 - \lambda_2 \qquad I_p|a_\pm\rangle = |a_\mp\rangle, \quad I_p|b_\pm\rangle = |b_\mp\rangle$$

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$$|\lambda_{t_1} = \pm \frac{1}{\sqrt{2}}, \lambda = \frac{1}{2}\rangle = \frac{1}{\sqrt{2}}\left(|a_+\rangle \mp i|b_+\rangle\right), \quad |\lambda_{t_1} = \pm \frac{1}{\sqrt{2}}, \lambda = -\frac{1}{2}\rangle = \frac{1}{\sqrt{2}}\left(|a_-\rangle \pm i|b_-\rangle\right)$$

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Constructing the eigenstates of $J_z, J, E, \hat{T}_1$

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Time-reversal symmetry

Constructing the eigenstates of $J_z , J , E , \hat{T}_1$

$$\Delta_{t_i} \equiv \frac{\Gamma(\lambda_{t_i}) - \Gamma(-\lambda_{t_i})}{\Gamma(\lambda_{t_i}) + \Gamma(-\lambda_{t_i})}$$

$$\hat{T}_1{}^p = \vec{J} \cdot \hat{p}_1 \hat{T}_1$$

T-odd and P-even

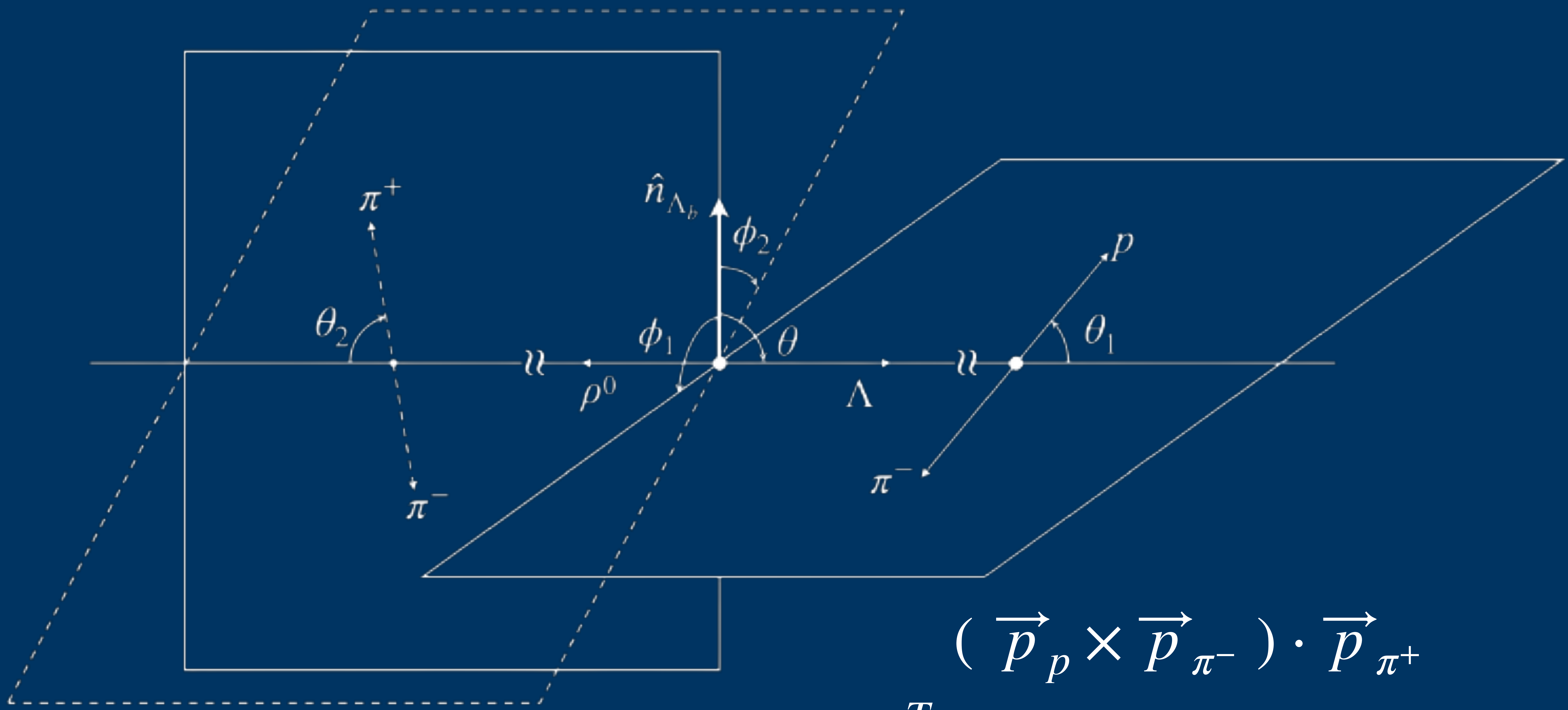
$$\Delta^P_{t_1} = \frac{2\Im(a_+ b_+^* + a_- b_-^*)}{|a_+|^2 + |a_-|^2 + |b_+|^2 + |b_-|^2}$$

$$I_p | \lambda^P_{t_1}, \lambda\rangle = | \lambda^P_{t_1}, -\lambda\rangle$$

$$J \geq |\lambda| , \quad \lambda \equiv \lambda_1 - \lambda_2 \qquad I_p | a_\pm \rangle = | a_\mp \rangle , \quad I_p | b_\pm \rangle = | b_\mp \rangle$$

$$| a_\pm \rangle = | J = 1/2, \lambda_1 = \pm 1/2 , \lambda_2 = 0 \rangle , \quad | b_\pm \rangle = | J = 1/2, \lambda_1 = \mp 1/2 , \lambda_2 = \mp 1 \rangle$$

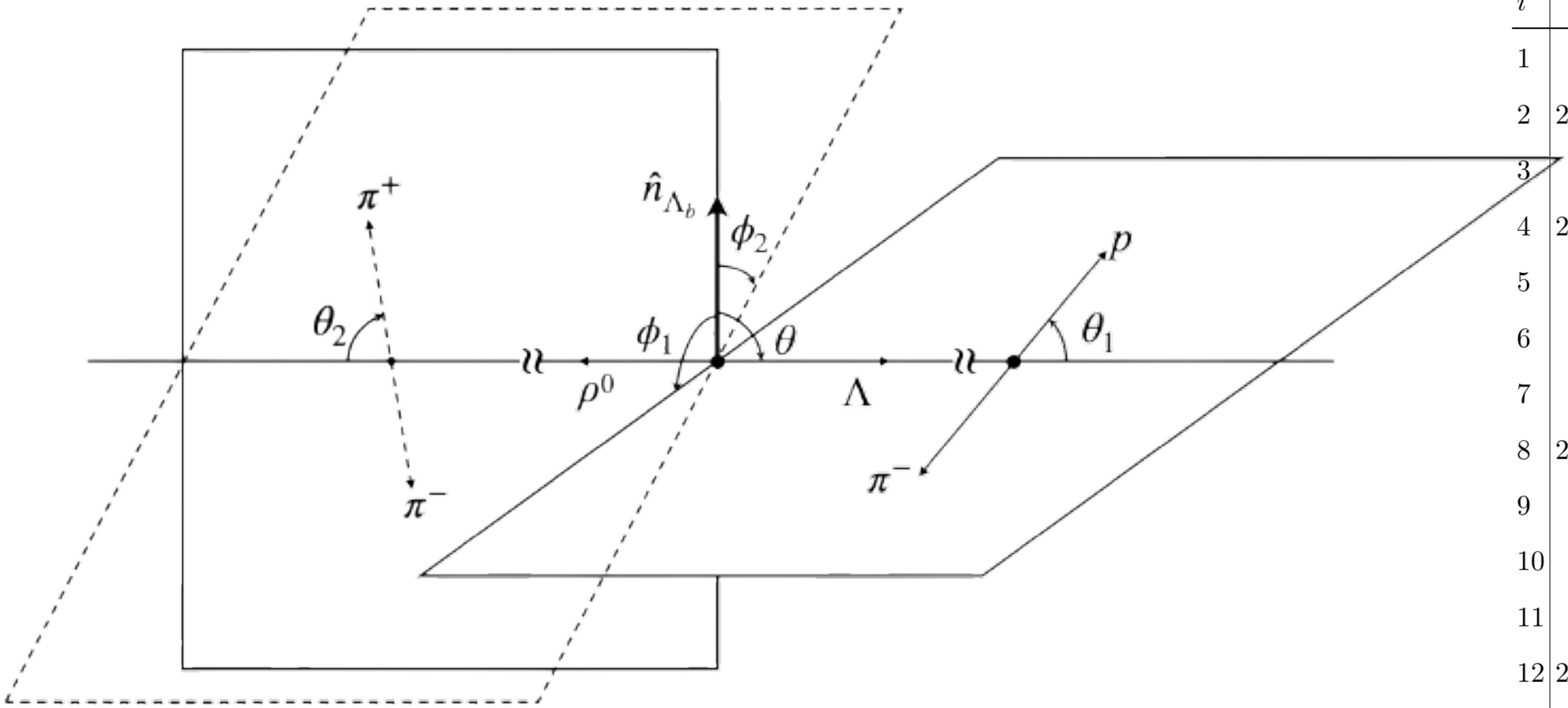
$$| \lambda^P_{t_1} = \pm \frac{1}{2\sqrt{2}} , \lambda = \frac{1}{2} \rangle = \frac{1}{\sqrt{2}} \left(| a_+ \rangle \mp i | b_+ \rangle \right) , \quad | \lambda^P_{t_1} = \mp \frac{1}{2\sqrt{2}} , \lambda = -\frac{1}{2} \rangle = \frac{1}{\sqrt{2}} \left(| a_- \rangle \mp i | b_- \rangle \right)$$



$$(\overrightarrow{p}_p \times \overrightarrow{p}_{\pi^-}) \cdot \overrightarrow{p}_{\pi^+} \xrightarrow{T} -(\overrightarrow{p}_p \times \overrightarrow{p}_{\pi^-}) \cdot \overrightarrow{p}_{\pi^+}$$

Angular Distributions

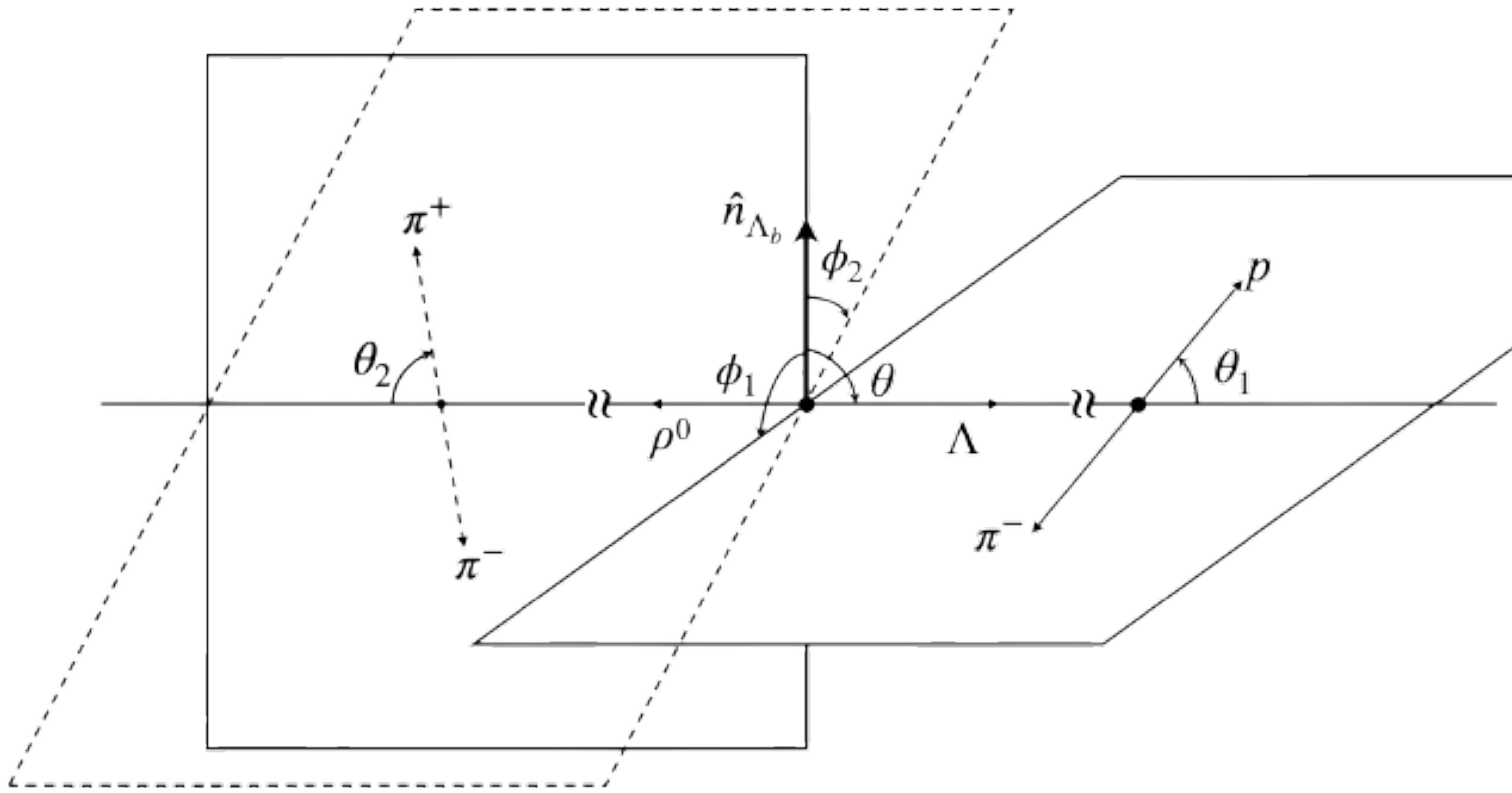
$$\mathscr{D}(\overrightarrow{\Omega}) \propto \sum_{i=1}^{20} f_i(a_\pm, b_\pm) D_i(\alpha_\Lambda, P_b, \theta, \theta_1, \phi_1, \theta_2, \phi_2)$$



i	f_i	D_i
1	$\vert a_+\vert^2 + \vert a_-\vert^2 + \vert b_+\vert^2 + \vert b_-\vert^2$	1
2	$2\vert a_+\vert^2 + 2\vert a_-\vert^2 - \vert b_+\vert^2 - \vert b_-\vert^2$	P_2
3	$\vert a_+\vert^2 - \vert a_-\vert^2 - \vert b_+\vert^2 + \vert b_-\vert^2$	$\alpha \cos\theta_1$
4	$2\vert a_+\vert^2 - 2\vert a_-\vert^2 + \vert b_+\vert^2 - \vert b_-\vert^2$	$\alpha \cos\theta_1 P_2$
5	$\frac{3}{\sqrt{2}}\Re(b_+a_+^* - b_-a_-^*)$	$\alpha \sin\theta_1 \sin(2\theta_2)\cos(\phi_1+\phi_2)$
6	$\frac{3}{\sqrt{2}}\Im(b_+a_+^* + b_-a_-^*)$	$\alpha \sin\theta_1 \sin(2\theta_2)\sin(\phi_1+\phi_2)$
7	$\vert a_+\vert^2 - \vert a_-\vert^2 + \vert b_+\vert^2 - \vert b_-\vert^2$	$P_b \cos\theta$
8	$2\vert a_+\vert^2 - 2\vert a_-\vert^2 - \vert b_+\vert^2 + \vert b_-\vert^2$	$P_b \cos\theta P_2$
9	$\frac{3}{\sqrt{2}}\Re(a_+b_-^* - a_-b_+^*)$	$P_b \sin\theta \sin(2\theta_2)\cos\phi_2$
10	$\frac{3}{\sqrt{2}}\Im(a_+b_-^* + a_-b_+^*)$	$P_b \sin\theta \sin(2\theta_2)\sin\phi_2$
11	$\vert a_+\vert^2 + \vert a_-\vert^2 - \vert b_+\vert^2 - \vert b_-\vert^2$	$P_b\alpha \cos\theta\cos\theta_1$
12	$2\vert a_+\vert^2 + 2\vert a_-\vert^2 + \vert b_+\vert^2 + \vert b_-\vert^2$	$P_b\alpha \cos\theta\cos\theta_1 P_2$
13	$\frac{3}{\sqrt{2}}\Re(b_+a_+^* + b_-a_-^*)$	$P_b\alpha \cos\theta \sin\theta_1 \sin(2\theta_2)\cos(\phi_1+\phi_2)$
14	$\frac{3}{\sqrt{2}}\Im(b_+a_+^* - b_-a_-^*)$	$P_b\alpha \cos\theta \sin\theta_1 \sin(2\theta_2)\sin(\phi_1+\phi_2)$
15	$\frac{3}{\sqrt{2}}\Re(a_+b_-^* + a_-b_+^*)$	$P_b\alpha \sin\theta \cos\theta_1 \sin(2\theta_2)\cos\phi_2$
16	$\frac{3}{\sqrt{2}}\Im(a_+b_-^* - a_-b_+^*)$	$P_b\alpha \sin\theta \cos\theta_1 \sin(2\theta_2)\sin\phi_2$
17	$-2\Re(a_-a_+^*)$	$P_b\alpha \sin\theta \sin\theta_1(1+2P_2)\cos\phi_1$
18	$-2\Im(a_-a_+^*)$	$P_b\alpha \sin\theta \sin\theta_1(1+2P_2)\sin\phi_1$
19	$2\Re(b_+b_-^*)$	$P_b\alpha \sin\theta \sin\theta_1(1-P_2)\cos(\phi_1+2\phi_2)$
20	$2\Im(b_+b_-^*)$	$P_b\alpha \sin\theta \sin\theta_1(1-P_2)\sin(\phi_1+2\phi_2)$

$$\frac{3}{\sqrt{2}}\Im(b_+a_+^* + b_-a_-^*) \qquad \alpha \sin\theta_1 \sin(2\theta_2)\sin(\phi_1+\phi_2)$$

$$\Delta^p_{t_1} = \frac{2\Im(a_+b_+^* + a_-b_-^*)}{|a_+|^2 + |a_-|^2 + |b_+|^2 + |b_-|^2}$$



$$\mathscr{D}(\vec{\Omega}) \propto \sum_{i=1}^{20} f_i(a_\pm, b_\pm) D_i(\alpha_\Lambda, P_b, \theta, \theta_1, \phi_1, \theta_2, \phi_2)$$

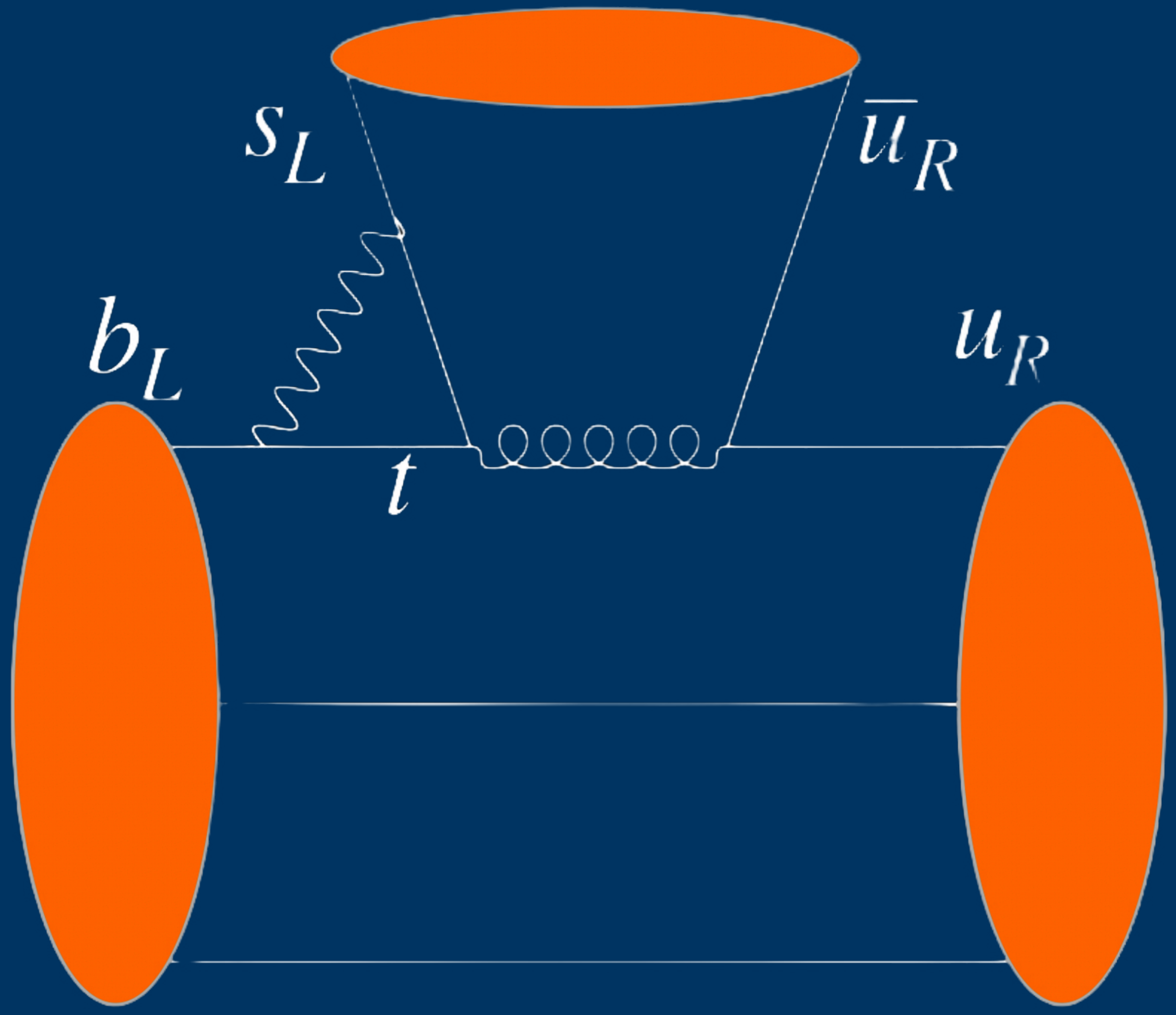
$$\hat{T}_1 = (\vec{s}_1 \times \vec{s}_2) \cdot \vec{p}_1$$

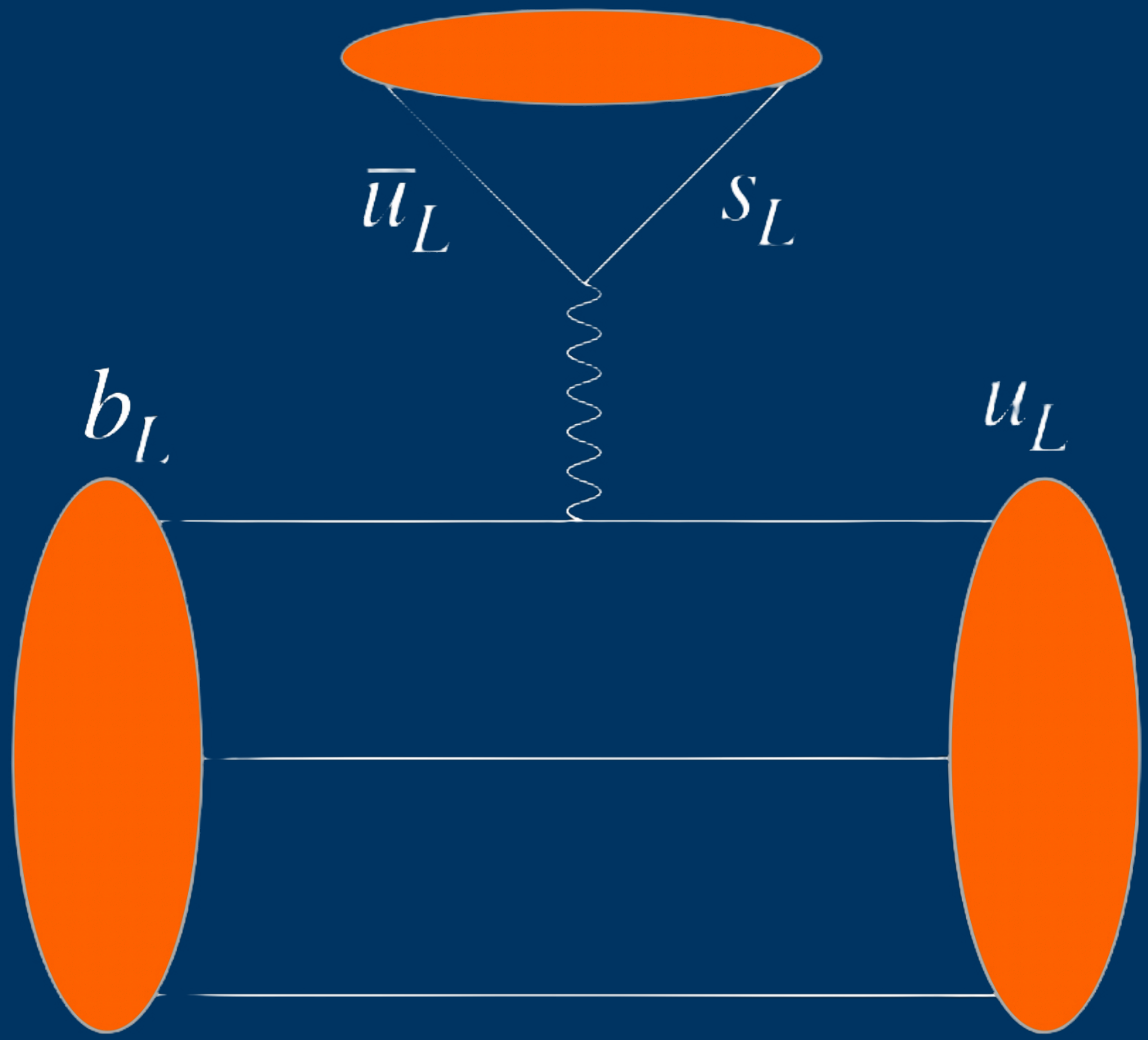
$$\hat{T}_2 = (\vec{s}_2 \times \vec{p}_1) \cdot \vec{J}$$

$$\hat{T}_3 = (\vec{s}_1 \times \vec{p}_1) \cdot \vec{J}$$

$$\hat{T}_4 = \left[\hat{T}_1 \left(\vec{s}_2 \cdot \vec{J} - \frac{1}{2} (\vec{s}_2 \cdot \hat{p}_1)^2 \right) + \frac{1}{\sqrt{2}} \hat{T}_3 \right] + h.c.$$

i	f_i	D_i
1	$\lvert a_+\rvert^2 + \lvert a_-\rvert^2 + \lvert b_+\rvert^2 + \lvert b_-\rvert^2$	1
2	$2\lvert a_+\rvert^2 + 2\lvert a_-\rvert^2 - \lvert b_+\rvert^2 - \lvert b_-\rvert^2$	P_2
3	$\lvert a_+\rvert^2 - \lvert a_-\rvert^2 - \lvert b_+\rvert^2 + \lvert b_-\rvert^2$	$\alpha \cos\theta_1$
4	$2\lvert a_+\rvert^2 - 2\lvert a_-\rvert^2 + \lvert b_+\rvert^2 - \lvert b_-\rvert^2$	$\alpha \cos\theta_1 P_2$
5	$\frac{3}{\sqrt{2}} \Re(b_+ a_+^* - b_- a_-^*)$	$\alpha \sin\theta_1 \sin(2\theta_2) \cos(\phi_1 + \phi_2)$
6	$\frac{3}{\sqrt{2}} \Im(b_+ a_+^* + b_- a_-^*)$	$\alpha \sin\theta_1 \sin(2\theta_2) \sin(\phi_1 + \phi_2)$
7	$\lvert a_+\rvert^2 - \lvert a_-\rvert^2 + \lvert b_+\rvert^2 - \lvert b_-\rvert^2$	$P_b \cos\theta$
8	$2\lvert a_+\rvert^2 - 2\lvert a_-\rvert^2 - \lvert b_+\rvert^2 + \lvert b_-\rvert^2$	$P_b \cos\theta P_2$
9	$\frac{3}{\sqrt{2}} \Re(a_+ b_-^* - a_- b_+^*)$	$P_b \sin\theta \sin(2\theta_2) \cos\phi_2$
10	$\frac{3}{\sqrt{2}} \Im(a_+ b_-^* + a_- b_+^*)$	$P_b \sin\theta \sin(2\theta_2) \sin\phi_2$
11	$\lvert a_+\rvert^2 + \lvert a_-\rvert^2 - \lvert b_+\rvert^2 - \lvert b_-\rvert^2$	$P_b \alpha \cos\theta \cos\theta_1$
12	$2\lvert a_+\rvert^2 + 2\lvert a_-\rvert^2 + \lvert b_+\rvert^2 + \lvert b_-\rvert^2$	$P_b \alpha \cos\theta \cos\theta_1 P_2$
13	$\frac{3}{\sqrt{2}} \Re(b_+ a_+^* + b_- a_-^*)$	$P_b \alpha \cos\theta \sin\theta_1 \sin(2\theta_2) \cos(\phi_1 + \phi_2)$
14	$\frac{3}{\sqrt{2}} \Im(b_+ a_+^* - b_- a_-^*)$	$P_b \alpha \cos\theta \sin\theta_1 \sin(2\theta_2) \sin(\phi_1 + \phi_2)$
15	$\frac{3}{\sqrt{2}} \Re(a_+ b_-^* + a_- b_+^*)$	$P_b \alpha \sin\theta \cos\theta_1 \sin(2\theta_2) \cos\phi_2$
16	$\frac{3}{\sqrt{2}} \Im(a_+ b_-^* - a_- b_+^*)$	$P_b \alpha \sin\theta \cos\theta_1 \sin(2\theta_2) \sin\phi_2$
17	$-2\Re(a_- a_+^*)$	$P_b \alpha \sin\theta \sin\theta_1 (1 + 2P_2) \cos\phi_1$
18	$-2\Im(a_- a_+^*)$	$P_b \alpha \sin\theta \sin\theta_1 (1 + 2P_2) \sin\phi_1$
19	$2\Re(b_+ b_-^*)$	$P_b \alpha \sin\theta \sin\theta_1 (1 - P_2) \cos(\phi_1 + 2\phi_2)$
20	$2\Im(b_+ b_-^*)$	$P_b \alpha \sin\theta \sin\theta_1 (1 - P_2) \sin(\phi_1 + 2\phi_2)$





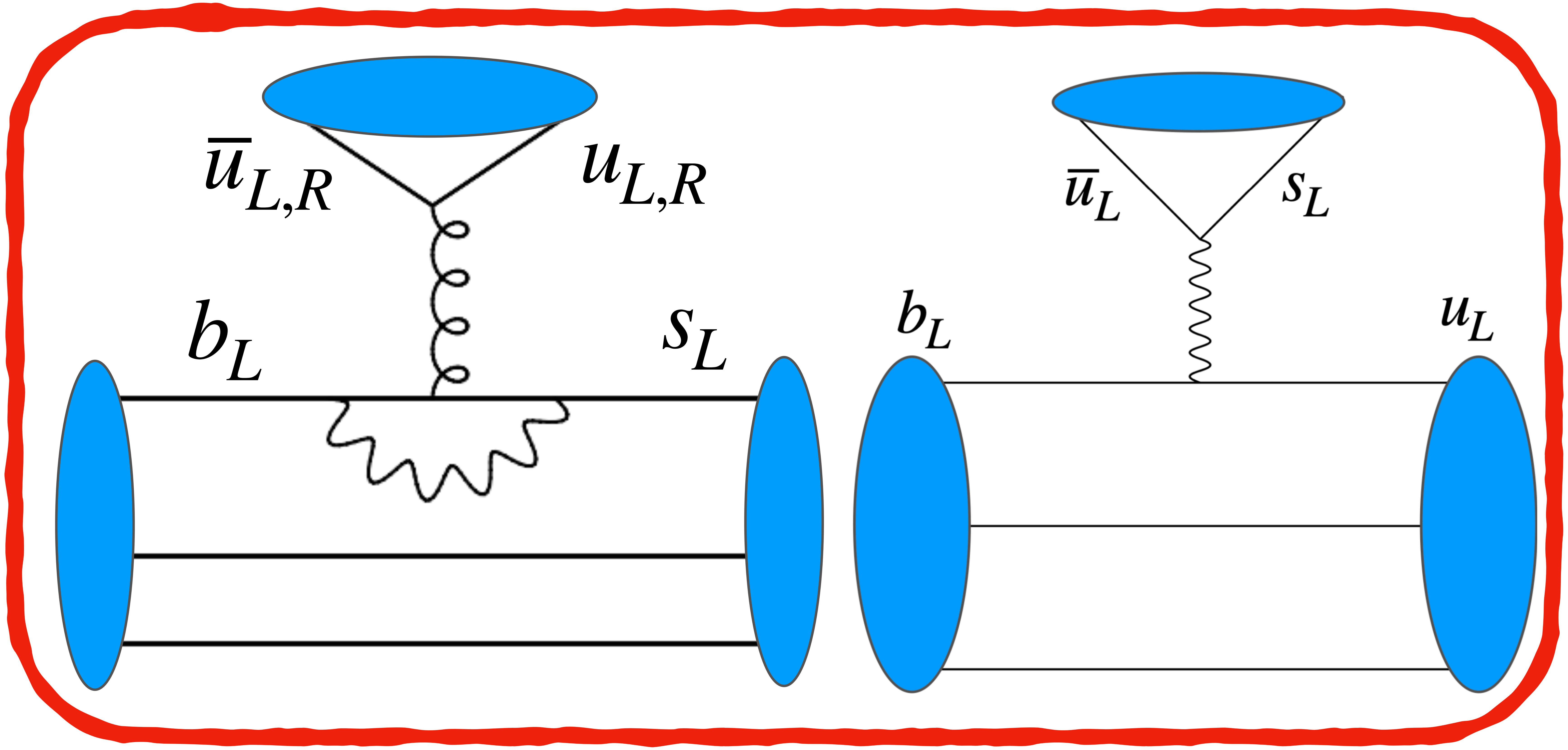
Estimations in standard model with factorization approach

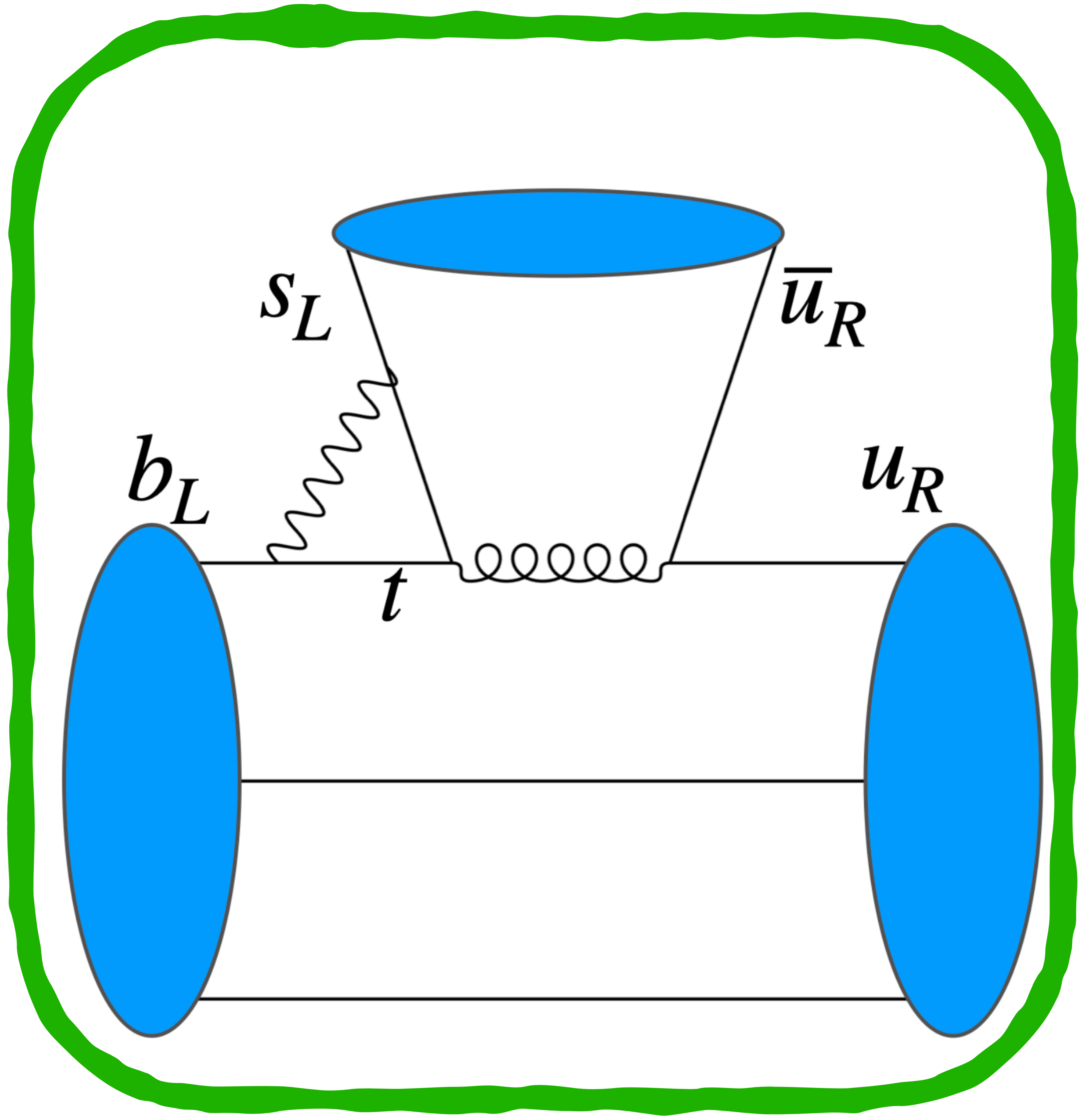
Estimation with factorization approach

Left-handed baryon and a heclicity-0 meson

$\rightarrow |a\_\rangle$ is predominated

Vector meson matrix elements vanish. $\rightarrow \langle V|\bar{s}u|0\rangle = 0$





Estimation with factorization approach

$$\frac{G_F}{\sqrt{2}} C_V \langle V | V^\mu | 0 \rangle \langle \Lambda | (\bar{s}\gamma_\mu(1-\gamma_5)b) | \mathbf{\Lambda}_b \rangle$$

$$\mathcal{C}_\phi = -V_{ts}^* V_{tb} \left(a_3 + a_4 + a_5 - \frac{1}{2} a_7 - \frac{1}{2} a_9 - \frac{1}{2} a_{10} \right) ,$$

$$\mathcal{C}_{\rho^0} = \frac{1}{\sqrt{2}} \left[V_{us}^* V_{ub} a_2 - \frac{3}{2} V_{ts}^* V_{tb} \left(a_7 + a_9 \right) \right] ,$$

$$\mathcal{C}_\omega = \frac{1}{\sqrt{2}} \left\{ V_{us}^* V_{ub} a_2 - V_{ts}^* V_{tb} \left[2a_3 + 2a_5 + \frac{1}{2} \left(a_7 + a_9 \right) \right] \right\} ,$$

$$\mathcal{C}_{K^{*0}} = -V_{td}^* V_{tb} \left(a_4 - \frac{1}{2} a_{10} \right) ,$$

Estimation with factorization approach

$$\frac{G_F}{\sqrt{2}} C_V \langle V | V^\mu | 0 \rangle \langle \Lambda | (\bar{s}\gamma_\mu (1-\gamma_5) b) | \Lambda_b \rangle$$

$$\mathcal{C}_\phi = -V_{ts}^* V_{tb} \left(a_3 + a_4 + a_5 - \frac{1}{2}a_7 - \frac{1}{2}a_9 - \frac{1}{2}a_{10} \right),$$
$$\mathcal{C}_{\rho^0} = \frac{1}{\sqrt{2}} \left[V_{us}^* V_{ub} a_2 - \frac{3}{2} V_{ts}^* V_{tb} (a_7 + a_9) \right],$$
$$\mathcal{C}_\omega = \frac{1}{\sqrt{2}} \left\{ V_{us}^* V_{ub} a_2 - V_{ts}^* V_{tb} \left[2a_3 + 2a_5 + \frac{1}{2}(a_7 + a_9) \right] \right\},$$
$$\mathcal{C}_{K^{*0}} = -V_{td}^* V_{tb} \left(a_4 - \frac{1}{2} a_{10} \right),$$

$$\alpha_{\lambda_1} \equiv \frac{\Gamma(\lambda_1 = 1/2) - \Gamma(\lambda_1 = -1/2)}{\Gamma(\lambda_1 = 1/2) + \Gamma(\lambda_1 = -1/2)} = \frac{|a_+|^2 + |b_-|^2 - |a_-|^2 - |b_+|^2}{|a_+|^2 + |a_-|^2 + |b_+|^2 + |b_-|^2},$$

$$\alpha_{\lambda_1} = -0.99$$

$$\alpha_{\lambda_2} \equiv \frac{\Gamma(|\lambda_2| = 0) - \Gamma(|\lambda_2| = 1)}{\Gamma(|\lambda_2| = 0) + \Gamma(|\lambda_2| = 1)} = \frac{|a_+|^2 + |a_-|^2 - |b_+|^2 - |b_-|^2}{|a_+|^2 + |a_-|^2 + |b_+|^2 + |b_-|^2},$$

$$\alpha_{\lambda_2} = 0.86$$

- The decays are predominated by a_- leading to $\rightarrow \Delta_{t_i} \approx 0$

Estimation with factorization approach

$$\frac{G_F}{\sqrt{2}} C_V \langle V | V^\mu | 0$$

Observation of the $\Lambda_b^0 \to \Lambda\phi$ decay

$_{10}\big)$,

$_7 + a_9)\big]\big\}$,

The LHCb collaboration†

$$\alpha_{\lambda_1} \equiv \frac{\Gamma(\lambda_1 = 1/2) - \Gamma(\lambda_1 = -1}{\Gamma(\lambda_1 = 1/2) + \Gamma(\lambda_1 = -1}$$

$$\alpha_{\lambda_2} \equiv \frac{\Gamma(|\lambda_2| = 0) - \Gamma(|\lambda_2| =}{\Gamma(|\lambda_2| = 0) + \Gamma(|\lambda_2| =}$$

Abstract

The $\Lambda_b^0 \to \Lambda\phi$ decay is observed using data corresponding to an integrated luminosity of 3.0 fb^{-1} recorded by the LHCb experiment. The decay proceeds at leading order via a $b \to s\bar{s}s$ loop transition and is therefore sensitive to the possible presence of particles beyond the Standard Model. A first observation is reported with a significance of 5.9 standard deviations. The value of the branching fraction is measured to be $(5.18 \pm 1.04 \pm 0.35\,^{+0.67}_{-0.62}) \times 10^{-6}$, where the first uncertainty is statistical, the second is systematic, and the third is related to external inputs. Triple-product asymmetries are measured to be consistent with zero.

- The decays are predominated by $a\_$ leading to $\to \Delta_{t_i} \approx 0$

Estimation with factorization approach

$\Lambda_b \to \Lambda V$ Br are in the unit of 10^{-6} and A_{CP} are in the unit of %

V		N_c=1.7	N_c=2.0	N_c=2.3	N_c=3	Exp
ϕ	Br	$6.90 \pm 0.65 \pm 0.30$	$5.22 \pm 0.49 \pm 0.24$	$4.12 \pm 0.39 \pm 0.18$	$2.67 \pm 0.25 \pm 0.12$	5.18 ± 1.29
	A_{CP}	$1.14 \pm 0.00 \pm 0.00$	$1.16 \pm 0.00 \pm 0.00$	$1.18 \pm 0.00 \pm 0.00$	$1.21 \pm 0.00 \pm 0.00$	
	$\alpha^N_{\lambda_2}$	-0.28	-0.05	0.21	0.86	
ρ^0	Br	$0.30 \pm 0.03 \pm 0.02$	$0.27 \pm 0.03 \pm 0.02$	$0.25 \pm 0.03 \pm 0.02$	$0.24 \pm 0.03 \pm 0.01$	
	A_{CP}	$-2.15 \pm 0.00 \pm 0.04$	$-1.61 \pm 0.00 \pm 0.01$	$-1.11 \pm 0.00 \pm 0.01$	$-0.18 \pm 0.00 \pm 0.00$	
	$\alpha^N_{\lambda_2}$	0.43	0.59	0.71	0.86	
ω	Br	$2.98 \pm 0.35 \pm 0.15$	$1.36 \pm 0.16 \pm 0.07$	$0.57 \pm 0.06 \pm 0.03$	$0.01 \pm 0.00 \pm 0.00$	
	A_{CP}	$-1.88 \pm 0.00 \pm 0.07$	$-1.87 \pm 0.00 \pm 0.07$	$-1.86 \pm 0.00 \pm 0.07$	$-1.55 \pm 0.00 \pm 0.04$	
	$\alpha^N_{\lambda_2}$	-1	-0.99	-0.98	0.86	
K^{*0}	Br	$0.10 \pm 0.01 \pm 0.00$	$0.11 \pm 0.01 \pm 0.00$	$0.12 \pm 0.02 \pm 0.01$	$0.14 \pm 0.02 \pm 0.01$	
	A_{CP}	$-14.1 \pm 0.0 \pm 0.4$	$-13.5 \pm 0.0 \pm 0.3$	$-13.1 \pm 0.0 \pm 0.3$	$-12.6 \pm 0.0 \pm 0.5$	

Estimation with factorization approach

$\Lambda_b \to \Lambda V$ $\quad$ Br are in the unit of 10^{-6} and A_{CP} are in the unit of %

V		N_c=1.7	N_c=2.0	N_c=2.3	N_c=3	Exp
	Br	$6.90 \pm 0.65 \pm 0.30$	$5.22 \pm 0.49 \pm 0.24$	$4.12 \pm 0.39 \pm 0.18$	$2.67 \pm 0.25 \pm 0.12$	5.18 ± 1.29
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	$\alpha^N_{\lambda_2}$	-0.28	-0.05	0.21	0.86	
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ρ^0	A_{CP}	$-2.15 \pm 0.00 \pm 0.04$	$-1.61 \pm 0.00 \pm 0.01$	$-1.11 \pm 0.00 \pm 0.01$	$-0.18 \pm 0.00 \pm 0.00$	
	$\alpha^N_{\lambda_2}$	0.43	0.59	0.71	0.86	
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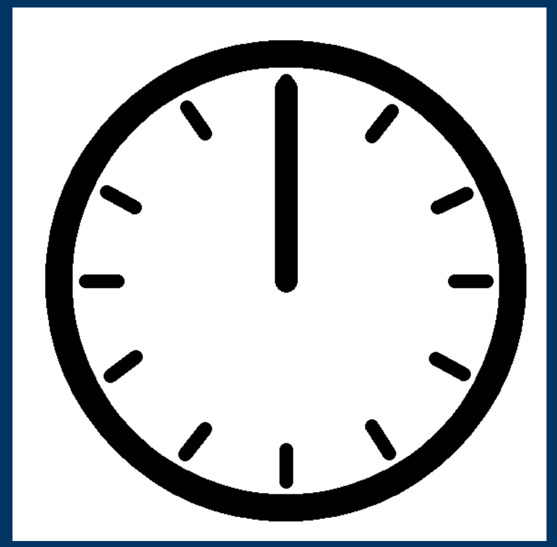
ω	A_{CP}	$-1.88 \pm 0.00 \pm 0.07$	$-1.87 \pm 0.00 \pm 0.07$	$-1.86 \pm 0.00 \pm 0.07$	$-1.55 \pm 0.00 \pm 0.04$	
	$\alpha^N_{\lambda_2}$	-1	-0.99	-0.98	0.86	
	Br	$0.10 \pm 0.01 \pm 0.00$	$0.11 \pm 0.01 \pm 0.00$	$0.12 \pm 0.02 \pm 0.01$	$0.14 \pm 0.02 \pm 0.01$	
K^{*0}	A_{CP}	$-14.1 \pm 0.0 \pm 0.4$	$-13.5 \pm 0.0 \pm 0.3$	$-13.1 \pm 0.0 \pm 0.3$	$-12.6 \pm 0.0 \pm 0.5$	



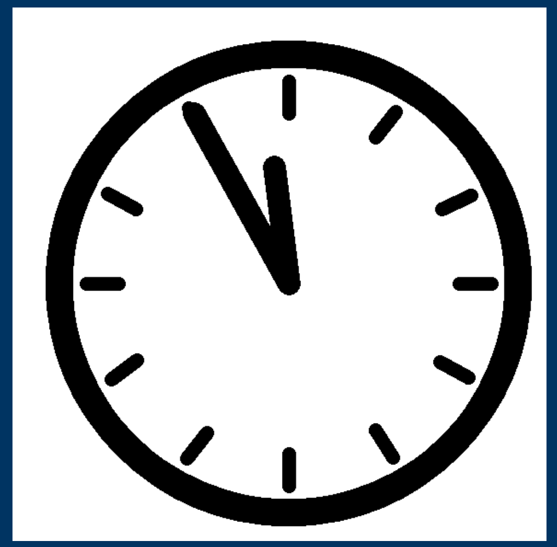
- The T-odd observables in $\Lambda_b \to \Lambda V$ have been found.

- The T-violationg effects in the cascade decays have been identified.

- The numerical results have been estimated with factorization.

Conclusion

$$V \longrightarrow \Lambda_b \longleftarrow \Lambda$$



- The T-odd observables in $\Lambda_b \to \Lambda V$

- The T-violationg effects in the cascade decays

- The numerical results

Outline

$$V \longleftarrow \Lambda_b \longrightarrow \Lambda$$

THANK YOU