

Spin effects in the tau-lepton pair induced by anomalous magnetic and electric dipole moments

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Matter to the Deepest 2025
Recent Developments in Physics of Fundamental Interactions

- Motivation
 - ◇ electromagnetic dipole moments of τ lepton: theory and experiment
 - ◇ weak magnetic and electric dipole moments
- Spin correlations in the lepton (fermion) pair
 - ◇ electron-positron and quark-antiquark annihilation to a pair of τ leptons
 - ◇ τ -pair production in photon-photon collision for heavy-ion and pp scattering
 - ◇ dipole moments in the Standard Model EFT
- Examples of spin-correlation effects and signatures of the τ dipole moments at Belle and LHC

This research is done in collaboration with

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Magnetic and electric dipole moments of the τ lepton

Electromagnetic dipole moments of a fermion f interacting with magnetic field $\vec{B}$ and electric field $\vec{E}$:

$$H = -\vec{\mu}_f \vec{B} - \vec{d}_f \vec{E}$$

In the rest frame of fermion, both 3-vectors of dipole moments can only be proportional to its spin vector

$$\begin{aligned}\vec{\mu}_f &= g_f \frac{eQ_f}{2m_f} \vec{s}, & a_f &= \frac{g_f}{2} - 1 \\ \vec{d}_f &= \eta_f \frac{e}{2m_f} \vec{s}, & d_f &= \frac{\eta_f}{2} \frac{e}{2m_f}\end{aligned}$$

where a_f is anomalous magnetic dipole moment (dimensionless) and d_f is electric dipole moment (in units $e\text{cm}$).

At high energies it is convenient to use a covariant form for electromagnetic vertex γ_{ff}

$$\Gamma^\mu = -ie \left\{ F_1(q^2) \gamma^\mu + \frac{\sigma^{\mu\nu} q_\nu}{2m_f} [i F_2(q^2) + \gamma_5 F_3(q^2)] \right\}$$

in terms of the Dirac, $F_1(q^2)$, Pauli, $F_2(q^2)$ and electric dipole, $F_3(q^2)$, form-factors which reduce to dipole moments at the real-photon point $q^2 = 0$:

$$F_2(0) = a_f Q_f, \quad F_3(0) = d_f \frac{2m_f}{e}, \quad F_1(0) = Q_f$$

Magnetic dipole moment of the τ : theory

Motivations to study magnetic moment of the τ lepton

In the Standard Model (SM) a_τ is calculated with high accuracy [S. Eidelman, M. Passera (2007)]:

$$a_\tau|_{SM} = a_{QED} + a_{EW} + a_{hadron} + a_{LbL} = (117721 \pm 5) \times 10^{-8}$$

A more recent evaluation of hadronic vacuum polarization term [A. Keshavarzi, D. Nomura, T. Teubner (2020)] gives

$$a_\tau|_{SM} = (117717.1 \pm 3.9) \times 10^{-8}$$

Effects of **New Physics (NP)**, first noticed by [V. Beresteckii et al. (1956)], are proportional to m_f^2 . They can arise, e.g., due to new heavy particles in the loops. Explicit models were considered [W. Marciano (1994, 1995), A. Czarnecki and W. Marciano (2010)], in which

$$a_f|_{NP} = \mathcal{C} \frac{m_f^2}{\Lambda^2}, \quad \mathcal{C} \sim \mathcal{O}(1)$$

where Λ is the scale of NP. Similar conclusion comes in various models, such as technicolor, multi-Higgs, SUSY, composite models, large extra dimensions, etc.

Therefore one can expect that effects of NP for the τ lepton can be enhanced compared to the muon by a factor of $m_\tau^2/m_\mu^2 \approx 280$.

Magnetic dipole moment of the τ : experiment

Measurements for τ are extremely difficult because of its very short lifetime $2.903(5) \times 10^{-13}$ s. Therefore methods used in the electron and muon “ $g - 2$ ” experiments cannot be applied.

LEP2 (DELPHI collaboration) in 2003 obtained the limit on a_τ from $e^+e^- \rightarrow e^+e^-\tau^+\tau^-$ cross section

$$a_\tau = (-0.052, +0.013)$$

Recently [ATLAS Collaboration](#) presented new constraints [PRL 131, 151802 (2023)] from the ultraperipheral $Pb + Pb \rightarrow Pb(\gamma\gamma \rightarrow \tau^-\tau^+)Pb$ collision at $\sqrt{s_{NN}} = 5.02$ TeV:

$$-0.057 < a_\tau < 0.024$$

and also [CMS Collaboration](#) [PRL 131, 151803 (2023)] using lead-lead collision, presented the value:

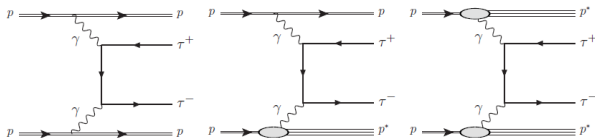
$$a_\tau = 0.001^{+0.055}_{-0.089}$$

Magnetic dipole moment of the τ : experiment

Recently there appeared the [CMS](#) result obtained in pp collisions at $\sqrt{s_{NN}} = 13$ TeV with unprecedented precision

$$a_\tau = 0.0009^{+0.0032}_{-0.0031}$$

by measuring the $\gamma\gamma \rightarrow \tau\tau$ cross section [Rept. Prog. Phys., 87(10):107801, 2024]



Experimentally here $m_{\tau\tau} > 50$ GeV, and the cross section is much lower, but the integrated luminosity is much higher than that in heavy-ion lead-lead collisions at the LHC.

This CMS result for the τ AMDM is the most stringent limit on the τ magnetic moment to date.

Electric dipole moment (EDM) of the τ

EDM of any lepton can take nonzero values, only if parity P , time reversal T , and CP symmetries are violated.

In the SM, the lepton EDM is not zero but it is extremely small because it comes from the 4-loop diagrams [I. Khriplovich, M. Pospelov (1991)], and additionally due to the smallness of CP violation in the CKM matrix.

Theoretical estimation [Y. Yamaguchi, N. Yamanaka (2021)] of the τ EDM:

$$\text{SM} : \quad d_\tau|_{\text{SM}} \lesssim 10^{-41} \text{ e cm}$$

$$\text{SM} + \text{long-range corr.} : \quad d_\tau|_{\text{SM}+\text{corr.}} = 7.32 \times 10^{-38} \text{ e cm}$$

Experimental constraints ([Belle collab., JHEP 04 (2022) 110] at $\sqrt{s} = 10.58 \text{ GeV}$):

$$\text{Re}(d_\tau) = (-0.62 \pm 0.63) \times 10^{-17} \text{ e cm},$$

$$\text{Im}(d_\tau) = (-0.40 \pm 0.32) \times 10^{-17} \text{ e cm}$$

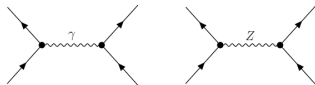
are ~ 20 orders of magnitude (!) larger than the SM estimate.

In any case, extremely small SM value of EDM (from 10^{-41} to 10^{-38} e cm) is not reachable in experiments. Therefore any observation of τ EDM in experiments will be indication of CP violation beyond the SM.

Weak dipole moments

Weak anomalous form-factors and moments

If one goes to high energies of the LHC or future colliders, then Z-boson interaction with leptons (in general, with any fermions) becomes important



Effective $Z f \bar{f}$ vertex include SM and BSM terms

$$\Gamma_Z^\mu(q) = \Gamma_Z^\mu(q)_{SM} + \Gamma_Z^\mu(q)_{BSM} = -i \frac{g_Z}{2} \left\{ \gamma^\mu (c_V - \gamma_5 c_A) + \frac{\sigma^{\mu\nu} q_\nu}{2m_\tau} [iX(q^2) + \gamma_5 Y(q^2)] \right\}$$

where $g_Z = e/(\sin \theta_W \cos \theta_W)$ and c_V, c_A are the vector and axial-vector couplings.

$X(q^2)$ is weak anomalous magnetic form-factor, and $Y(q^2)$ is weak electric form-factor, which on the Z-boson mass shell ($q^2 = M_Z^2$) are related to the weak dipole moments:

$$X(M_Z^2) = a^{(w)} \sin 2\theta_W, \quad Y(M_Z^2) = d^{(w)} \sin 2\theta_W$$

with the weak mixing angle θ_W . Here $a^{(w)}, d^{(w)}$ are defined by ALEPH collaboration.

Weak dipole moments of τ lepton

What is known about weak dipole moments of the τ lepton?

Actually very little, and less than about electromagnetic moments.

Experiment ALEPH (LEP at CERN) [Eur. Phys. J. C 30, 291-304, 2003] obtained the constraints on the real and imaginary parts of the weak dipole moments

$$\begin{aligned} |\operatorname{Re}(a_\tau^{(w)})|_{\text{exp}} &< 0.96 \times 10^{-3}, & |\operatorname{Im}(a_\tau^{(w)})|_{\text{exp}} &< 2.23 \times 10^{-3}, \\ |\operatorname{Re}(d_\tau^{(w)})|_{\text{exp}} &< 0.76 \times 10^{-3}, & |\operatorname{Im}(d_\tau^{(w)})|_{\text{exp}} &< 1.69 \times 10^{-3}. \end{aligned}$$

The SM prediction [J. Bernabeu et al. Nucl. Phys. B 436, 474–486, 1995] is:

$$a_\tau^{(w)}|_{\text{SM}} = -(1.77 + i 0.51) \times 10^{-6}$$

while prediction for the weak electric moment $d_\tau^{(w)}$ is not available.

Dipole moments in SM Effective Field Theory

In fact, the dipole moments are encoded in the SM EFT, and are related to the corresponding Wilson coefficients in EFT Lagrangian

[B. Grzadkowski, M. Iskrzynski, M. Misiak, J. Rosiek. JHEP 10 (2010) 085]:

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \underbrace{\left(\frac{1}{\Lambda} \sum_i C_i^{(5)} Q_i^{(5)} + \frac{1}{\Lambda^2} \sum_i C_i^{(6)} Q_i^{(6)} + \mathcal{O}\left(\frac{1}{\Lambda^3}\right) + \text{H.c.} \right)}_{\mathcal{L}_{BSM}}$$

where Λ is the scale of new physics.

Relevant for the dipole moments terms are dimension-6 operators

$$Q_B^{(6)} = (\bar{L}_L \sigma^{\mu\nu} \tau_R) H B_{\mu\nu}, \quad Q_W^{(6)} = (\bar{L}_L \sigma^{\mu\nu} \tau_R) \vec{\sigma} H \vec{W}_{\mu\nu}$$

with corresponding Wilson coefficients $C_{\tau B}^{(6)}$ and $C_{\tau W}^{(6)}$.

Then the dipole moments are expressed through 2 combinations of 2 Wilson coefficients:

$$D_{Z\tau\tau} \equiv \sin\theta_W C_{\tau B}^{(6)} + \cos\theta_W C_{\tau W}^{(6)}, \quad D_{\gamma\tau\tau} \equiv \cos\theta_W C_{\tau B}^{(6)} - \sin\theta_W C_{\tau W}^{(6)}$$

Dipole moments in SM Effective Field Theory

And four dipole moments beyond SM are related to real and imaginary parts:

$$A(0)_{BSM} = \mathbf{a}_\tau = \frac{\sqrt{2} v^2}{\Lambda^2} \frac{2m_\tau}{e} \operatorname{Re}(\mathbf{D}_{\gamma\tau\tau}),$$

$$B(0)_{BSM} = -\frac{2m_\tau}{e} \mathbf{d}_\tau = -\frac{\sqrt{2} v^2}{\Lambda^2} \frac{2m_\tau}{e} \operatorname{Im}(\mathbf{D}_{\gamma\tau\tau}),$$

$$X(M_Z^2)_{BSM} = \frac{\sqrt{2} v^2}{\Lambda^2} \frac{2m_\tau}{e} \sin 2\theta_W \operatorname{Re}(\mathbf{D}_{Z\tau\tau}) = \sin 2\theta_W \mathbf{a}_\tau^{(w)},$$

$$Y(M_Z^2)_{BSM} = -\frac{\sqrt{2} v^2}{\Lambda^2} \frac{2m_\tau}{e} \sin 2\theta_W \operatorname{Im}(\mathbf{D}_{Z\tau\tau}) = \sin 2\theta_W \mathbf{d}_\tau^{(w)}$$

where $v = (\sqrt{2}G_F)^{-1/2} \approx 246$ GeV is VEV of the scalar field.

Once dipole moments are measured/constrained, the Wilson coefficients $C_{\tau W}^{(6)}/\Lambda^2$ and $C_{\tau B}^{(6)}/\Lambda^2$ can be constrained, which will indirectly constrain an underlying high-energy theory.

Spin correlations in fermion-fermion production of τ pair

Including spin correlations in the final $\tau\tau$ pair can help obtain information of New Physics effects, in particular, on the electromagnetic and weak moments.

Consider quark-antiquark or electron-positron annihilation to a pair of **polarized** leptons

$$f(k_1) + \bar{f}(k_2) \rightarrow \tau^-(p_-) + \tau^+(p_+),$$

where $f = (\text{electron, muon, quark})$, and the polarization 4-vectors of the τ^- and τ^+ in their corresponding rest frames are:

$$S_{rest}^- = (0, \vec{S}^-), \quad S_{rest}^+ = (0, \vec{S}^+)$$

Then transform polarization 4-vectors to the CM system:

$$S_{cm}^- = \left(\frac{\vec{p}\vec{S}^-}{m_\tau}; \vec{S}^- + \frac{\vec{p}(\vec{p}\vec{S}^-)}{m_\tau(m_\tau + E)} \right), \quad S_{cm}^+ = \left(-\frac{\vec{p}\vec{S}^+}{m_\tau}; \vec{S}^+ + \frac{\vec{p}(\vec{p}\vec{S}^+)}{m_\tau(m_\tau + E)} \right)$$

where $\vec{p} = (0, 0, p)$ is 3-momentum of final τ^- , E is its energy, and the reaction plane is defined by the 3-momentum of initial lepton/quark $\vec{k}_1 = (E \sin \theta, 0, E \cos \theta)$.

Spin correlations in fermion-fermion production of τ pair

The cross section in the center-of-mass frame can be expressed through these polarizations:

$$\begin{aligned} \frac{d\sigma}{d\Omega}(f\bar{f} \rightarrow \tau^-\tau^+) &= \frac{\beta}{64\pi^2 s} \sum_{i,j=1}^4 R_{i,j} S_i^- S_j^+ = \frac{d\sigma}{d\Omega}(f\bar{f} \rightarrow \tau^-\tau^+) \Big|_{\text{unpolar}} \\ &\times \frac{1}{4} \left(1 + \sum_{i=1}^3 r_{i,4} S_i^- + \sum_{j=1}^3 r_{4,j} S_j^+ + \sum_{i,j=1}^3 r_{i,j} S_i^- S_j^+ \right) \end{aligned}$$

where $i, j = (1, 2, 3) \equiv (x, y, z)$, $R_{i,j} = R_{i,j}^{(\gamma)} + R_{i,j}^{(Z)} + R_{i,j}^{(\gamma Z)}$ and $r_{i,j} \equiv R_{i,j}/R_{4,4}$.

In general, 15 coefficients $r_{i,j}(s, \theta)$ carry information on underlying physics.

Among them there are 6 elements which are τ^- and τ^+ polarizations:

$$\vec{P}_{\tau^-} = (r_{14}, r_{24}, r_{34}), \quad \vec{P}_{\tau^+} = (r_{41}, r_{42}, r_{43}) = (-r_{14}, r_{24}, -r_{34})$$

and 9 elements of spin-spin correlations:

$$r_{i,j} = \begin{pmatrix} r_{11} & r_{12} & r_{13} \\ -r_{12} & r_{22} & r_{23} \\ r_{13} & -r_{23} & r_{33} \end{pmatrix}$$

(“1” means transverse to τ^- momentum, “2” - normal to reaction plane, “3” - longitudinal).

Spin correlations in $\gamma\gamma$ processes

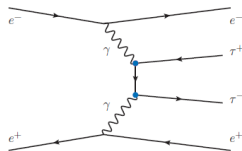
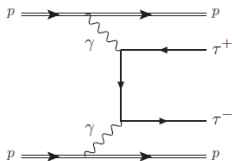
At present experiments are performed on heavy-ion and proton-proton collisions at high energies in which τ pair is produced in $\gamma\gamma$ processes,

in particular, in ultra-peripheral Pb+Pb scattering at the LHC

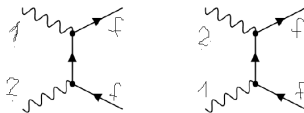
$$Pb Pb \rightarrow Pb (\gamma + \gamma \rightarrow \tau^- + \tau^+) Pb$$

with almost real photons.

Similar experiments are planned at the future lepton colliders, and Super Tau-Charm Facility (China) in $e^- + e^+ \rightarrow e^- + e^+ + \tau^- + \tau^+$.



The mechanism of $\gamma + \gamma \rightarrow \tau^- + \tau^+$ with (almost) real photons on the tree level is



Spin correlations in $\gamma\gamma$ processes

One can use the formalism for polarized final τ^- and τ^+

$$\frac{d\sigma}{d\Omega}(\gamma\gamma \rightarrow \tau^-\tau^+) = \frac{d\sigma}{d\Omega}(\gamma\gamma \rightarrow \tau^-\tau^+)\Big|_{\text{unpol}} \frac{1}{4} \left(1 + \sum_{i,j=1}^3 r_{i,j}^{(\gamma\gamma)} s_i^- s_j^+ \right)$$

with 9 elements of the spin-spin correlation matrix $r_{i,j}^{(\gamma\gamma)} = R_{i,j}^{(\gamma\gamma)} / R_{4,4}^{(\gamma\gamma)}$.

Note that the symmetry relations hold:

$$r_{21}^{(\gamma\gamma)} = -r_{12}^{(\gamma\gamma)}, \quad r_{31}^{(\gamma\gamma)} = r_{13}^{(\gamma\gamma)}, \quad r_{32}^{(\gamma\gamma)} = -r_{23}^{(\gamma\gamma)}$$

Besides, in this case $r_{4,i}^{(\gamma\gamma)} = r_{i,4}^{(\gamma\gamma)} = 0$ for $i = 1, 2, 3$, which means $\tau^\pm$ have no polarization, i.e. $\vec{\mathcal{P}}_{\tau^-} = \vec{\mathcal{P}}_{\tau^+} = 0$.

Electroweak radiative corrections in the SM

Small effects of NP appear on top of the SM calculation which should be included with high precision.

We added electroweak radiative corrections in the process $q\bar{q} \rightarrow \tau^- \tau^+$ in the so-called Improved Born Approximation (IBA)

[D. Bardin, P. Christova, M. Jack et al. Comp. Phys. Comm. 133, 229 (2001);

E. Richter-Was, Z. Was. Eur. Phys. J. C74, 3177 (2014);

A. Arbuzov, S. Jadach, Z. Was et al. Comp. Phys. Comm., 260, 107734 (2021)] :

It includes:

- vacuum-polarization in the photon propagator,
- corrections to Z-boson propagator and couplings,
- WW- and ZZ-box diagrams (important above $\sqrt{s} > 140$ GeV),
- mixed $\mathcal{O}(\alpha\alpha_s, \alpha\alpha_s^2, \dots)$ corrections from gluon insertions in the self-energy loop diagrams.

Reweighting procedure in Monte Carlo programs

The polarization of τ cannot be directly measured, because these leptons are very short-lived. One can only use information about $\tau^\pm$ decay products.

The formulas for the spin-correlation matrix $R_{i,j}$ are implemented into reweighting algorithms in the Monte Carlo programs: KKMC for $e^-e^+ \rightarrow \tau^-\tau^+$ and TauSpinner for $q\bar{q} \rightarrow \tau^-\tau^+$ and $\gamma\gamma \rightarrow \tau^-\tau^+$.

The KKMC MC for $e^-e^+ \rightarrow \tau^-\tau^+$ is used for Belle II kinematics and is also extended for the higher energies up to and above Z boson.

As for TauSpinner MC, it was developed earlier for the proton-proton collisions [Z. Czynzula, T. Przedzinski, Z. Was. Eur. Phys. J. C, 72, 1988 (2012)].

$$d\sigma \sim \sum_{flavors} \int_0^1 dx_1 \int_0^1 dx_2 f(x_1, \dots) f(x_2, \dots) d\Omega_{prod}^{parton\ level} d\Omega_{\tau^-} d\Omega_{\tau^+} \\ \times \left(\sum_{\lambda_1, \lambda_2} |\mathcal{M}_{parton\ level}^{prod}|^2 \right) \left(\sum_{\lambda_1} |\mathcal{M}^{\tau^+}|^2 \right) \left(\sum_{\lambda_2} |\mathcal{M}^{\tau^-}|^2 \right) wt_{spin},$$

with the spin weight

$$wt_{spin} = \sum_{i,j=1,2,3,4} r_{i,j} h_i^- h_j^+,$$

where $h_j^\pm$ are the so-called polarimetric vectors which depend on a decay mode of $\tau^\pm$, also $f(x_{1,2}, \dots)$ are parton distribution functions.

Spin correlations in $e^-e^+ \rightarrow \tau^+\tau^- \rightarrow \dots$ for Belle

Although some elements of matrix $r_{i,j}$ depend strongly on dipole moments, it is a nontrivial task to find observables which are sensitive to dipole moments.
In addition, neutrinos in τ decays are not observed.

The 2-body decay $\tau^\pm \rightarrow \pi^\pm \nu_\tau$ would be the simplest possibility, however, the direction of moving $\tau^\pm$ can be reconstructed only with ambiguities.

We have chosen a more complex decay mode

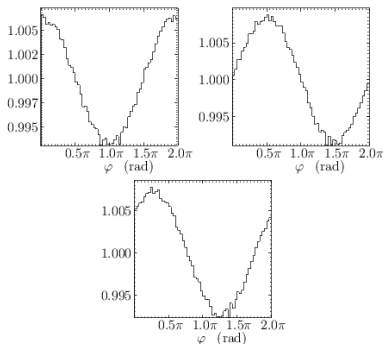
$$\tau^- \rightarrow \rho^- \nu_\tau \rightarrow \pi^- \pi^0 \nu_\tau, \quad \tau^+ \rightarrow \rho^+ \bar{\nu}_\tau \rightarrow \pi^+ \pi^0 \bar{\nu}_\tau$$

and rely only on kinematics of the secondary decays $\rho^\pm \rightarrow \pi^\pm \pi^0$.

The observable, sensitive to magnetic/electric dipole moment, is **acoplanarity angle φ** between the planes spanned on momenta of (π^-, π^0) and of (π^+, π^0) , and defined in the $\rho^- \rho^+$ rest frame
[G.R. Bower, T. Pierzchala, Z. Was et al. (2002), K. Desch, A. Imhof, Z. Was et al (2004)].

Spin correlations in $e^-e^+ \rightarrow \tau^+\tau^- \rightarrow \dots$ for Belle

Distribution of the acoplanarity angle φ at $\sqrt{s} = 10.58$ GeV



Top left: $\text{Re}(A) = 0.04$, top right: $\text{Re}(B) = 0.04$;
bottom: $\text{Re}(A) = 0.04 \cos(\pi/4)$ and $\text{Re}(B) = 0.04 \sin(\pi/4)$

The constraint of the pion energies $y_1 \cdot y_2 > 0$ is also applied, with

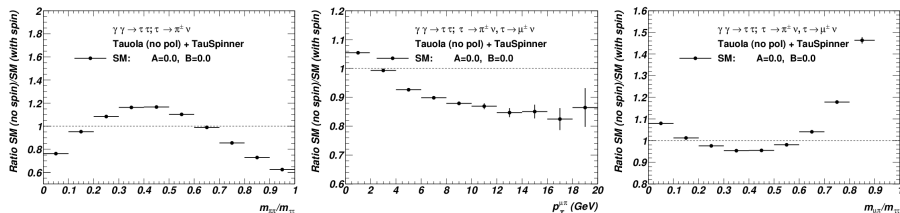
$$y_1 = (E_{\pi^-} - E_{\pi^0}) / (E_{\pi^-} + E_{\pi^0}), \quad y_2 = (E_{\pi^+} - E_{\pi^0}) / (E_{\pi^+} + E_{\pi^0}).$$

Spin correlations in $\gamma\gamma \rightarrow \tau^- \tau^+ \rightarrow \dots$ for the LHC

We consider pp scattering at 13 TeV, $\tau\tau$ invariant mass range $m_{\tau\tau} = 5 - 50$ GeV and $p_{T\tau} > 5$ GeV. This choice roughly corresponds to the range covered by the $\gamma\gamma \rightarrow \tau\tau$ processes in PbPb collisions at the LHC.

- (i) $\tau^- \rightarrow \pi^- + \nu_\tau$, $\tau^+ \rightarrow \pi^+ + \bar{\nu}_\tau$
 (ii) $\tau^- \rightarrow \pi^- + \nu_\tau$, $\tau^+ \rightarrow \mu^+ + \bar{\nu}_\tau + \nu_\mu$ (+interchange $\tau^+ \leftrightarrow \tau^-$)

Ratio of distributions $\frac{W(\text{no spin-corr})}{W(\text{with spin-corr})}$ in the SM.



- (i) left: dependence on ratio of inv. masses $m_{\pi\pi}/m_{\tau\tau}$ for $\pi^+\pi^-$ final state,
 (ii) middle: on transverse momentum $p_T^{\mu\pi}$ for $\mu^\pm\pi^\mp$ final state,
 (ii) right: on ratio of inv. masses $m_{\mu\pi}/m_{\tau\tau}$ for $\mu^\pm\pi^\mp$ final state.

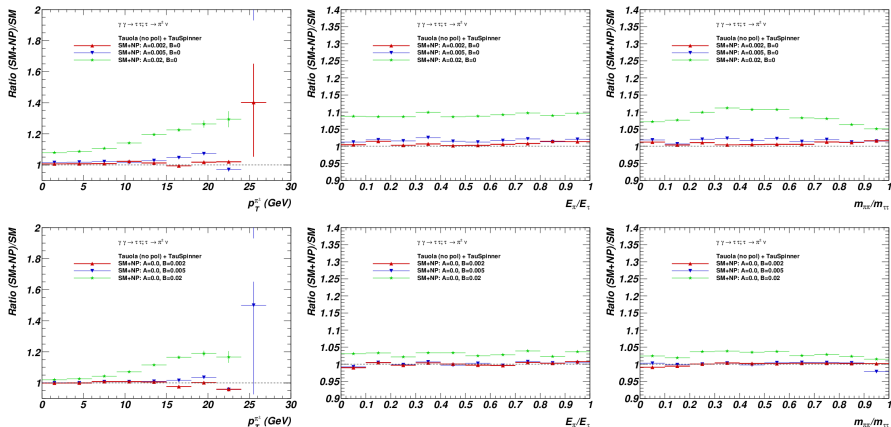
Spin effects in $\tau\tau$ are important even in the SM (without dipole moments).

Spin correlations: $\gamma\gamma \rightarrow \tau^- \tau^+ \rightarrow \pi^- \nu_\tau \pi^+ \bar{\nu}_\tau$ for the LHC

Observables sensitive to dipole moments

Ratio $(SM + DM)/SM$, upper plots - dependence on A , lower plots - on B .

τ leptons decay via: $\tau^- \rightarrow \pi^- \nu_\tau$, $\tau^+ \rightarrow \pi^+ \bar{\nu}_\tau$. Distributions of p_T^π , E_π/E_τ and $m_{\pi\pi}/m_{\tau\tau}$.



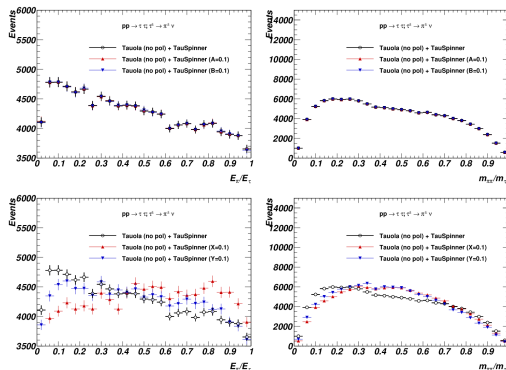
There is effect of AMDM/EDM for the values $A(0) = 0.02$ and $B(0) = 0.02$.

Spin correlations in $q\bar{q} \rightarrow \tau^-\tau^+ \rightarrow \pi^-\nu_\tau\pi^+\bar{\nu}_\tau$ in Drell-Yan

Consider pp scattering at $\sqrt{s} = 13$ TeV, the region of $\tau^-\tau^+$ invariant masses is 65 – 150 GeV. There are about 10^6 events for each decay mode of τ .

Decay channels are $\tau^- \rightarrow \pi^-\nu_\tau$, $\tau^+ \rightarrow \pi^+\bar{\nu}_\tau$.

Distributions of E_π/E_τ and $m_{\pi\pi}/m_{\tau\tau}$. Upper plots - dependence on A , B , lower plots - on X , Y .



Weak moment contributions are visible for relatively big values of X , Y equal to 0.1 (as expected, in the region close to Z , there is no effect of magnetic and electric

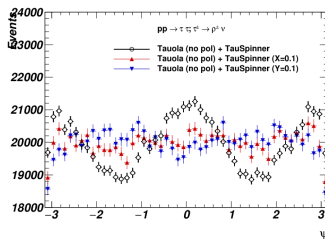
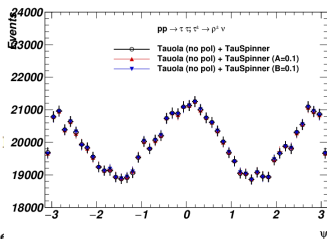
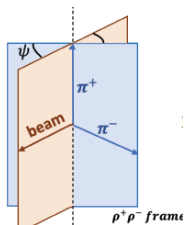
Spin correlations: $q\bar{q} \rightarrow \tau^-\tau^+ \rightarrow \rho^-\nu_\tau\rho^+\bar{\nu}_\tau$ in Drell-Yan

The decays of τ 's to ρ mesons can also be useful to study:

$$\tau^- \rightarrow \rho^- \nu_\tau \rightarrow \pi^- \pi^0 \nu_\tau, \quad \tau^+ \rightarrow \rho^+ \bar{\nu}_\tau \rightarrow \pi^+ \pi^0 \bar{\nu}_\tau$$

We follow ALEPH definition of acoplanarity angle ψ between two planes: one is built on the momenta of π^+ and π^- , and another one – on the momenta of π^+ and the beam.

Distribution of acoplanarity angle ψ ($\sqrt{s} = 13$ TeV, $m_{\tau\tau} = 65 - 150$ GeV)



Middle: dependence on magnetic and electric moments;

Right: dependence on weak moments.

There is effect of weak magnetic and electric moments X , Y in this distribution.

Conclusions

- Formalism for description of spin effects in the final $\tau\tau$ pair in the processes $q\bar{q} \rightarrow \tau^-\tau^+$, $e^-e^+ \rightarrow \tau^-\tau^+$, $\gamma\gamma \rightarrow \tau^-\tau^+$ is considered.
- This approach is prepared to work with Monte Carlo generators: KKMC for $e^-e^+ \rightarrow \tau^-\tau^+$ and TauSpinner for $pp \rightarrow \tau^-\tau^+$. These MC can be used at the Belle II energies and also at higher energies of the LHC.
- Contributions from magnetic and electric dipole moments of τ are included on top of precise calculation in the Standard Model, in which electroweak radiative corrections are taken into account in Improved Born Approximation.
- Several observables, sensitive to anomalous moments of τ -lepton, are discussed and proposed for measurements at KEKB and LHC.

Publications:

Sw. Banerjee, A.Yu. Korchin, E. Richter-Was, Z. Was, Yu. Volkotrub:

Phys. Rev. D 106 (2022) 11, 113010; *Phys. Rev. D* 109 (2024) 1, 013002;
Acta Phys. Pol. B Proc. Suppl. 17, 5-A20 (2024), 1-10; *Phys. Rev. D* 111, 013006 (2025);
e-Print: 2506.15213 [hep-ph]

Thank you for attention!