The τ $g-2$ measurement

Enrique Diaz, Valentina Diolaiti, Giacomo Petrillo, Guanhao Su, Xiongfei Wang, Luis Zazueta

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Question

"The anomalous magnetic dipole moment (AMDM) of the electron is one of the most precisely known numbers; and muon (g-2) is the focus of a present experiment at Fermilab.
According to PDG, the current experimental limits on tau lepton (g-2) come from DELPHI.
What can we do at current or planned facilities to improve on this result?"

Outline

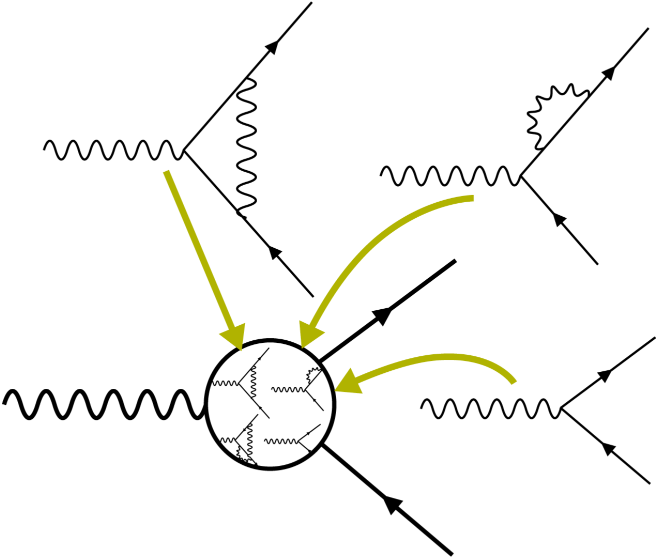
■ **In theory, the magnetic moment of a particle f can be defined by the gyromagnetic ratio as:**

$$\vec{\mu}_f = g_f \frac{e}{2m} \vec{s}. \tag{1}$$

■ **For a spin $1/2$ particle, Dirac's Equation predicts $g_f = 2$, but from Quantum Corrections dominated by QED give corrections to the AMDM as**

$$a_f = \frac{g_f - 2}{2} = \frac{\alpha}{2\pi} \approx 0.00116. \tag{2}$$

■ **e-AMDM had a historical impact both in relativistic quantum mechanics and in quantum field theories, μ-AMDM is still an open issue. But for τ-AMDM, while the theoretical prediction is well known for the standard model & some new physics models (O(10^{-9}-10^{-6})), the data are very far of determining even its sign or the first figure (Good candidate for new physics).**



■ The AMDM is sensible to new physics in the form of vertex corrections

$$-ie\Gamma^{\mu}(q) = -ie\left[F_1(q^2)\gamma^{\mu} + \frac{\sigma^{\mu\nu}q_{\nu}}{2m_{\tau}}\left(iF_2(q^2) + F_3(q^2)\gamma_5\right)\right], \quad (3)$$

where F_1 describes the distribution of electric charge, while F_2 and F_3 are the form factor related to the AMDM a_{τ} and the electric dipole moment d_{τ}:

$$a_{\tau} \equiv \frac{g_{\tau} - 2}{2} = F_2(0), \quad (4)$$

and

$$F_3(0) = \frac{2m_{\tau}d_{\tau}}{e_{\tau}}. \quad (5)$$

SM prediction:

$$
\begin{aligned}
10^8 \times a_\tau^{\text{th}} &= 117\,324 \quad \pm 2 & \text{QED} \\
&\quad + \;\; 47.4 \pm 0.5 & \text{EW} \\
&\quad + 337.5 \pm 3.7 & \text{hvp}^{\text{LO}} \\
&\quad + \;\;\; 7.6 \pm 0.2 & \text{hvp}^{\text{NLO}} \\
&\quad + \;\;\; 5 \quad \pm 3 & \text{lbl} \\
&= 117\,721 \quad \pm 5\,.
\end{aligned}
$$

■ The AMDM of the tau has an enhanced sensitivity to new physics relative to the other charged leptons due to its bigger mass. The electroweak contributions only a factor of seven smaller than the hadronic one, compared to a factor of 45 for the μ.

Past g-2 Searches

■ The DELPHI collaboration studied the τ pair production in $\gamma\gamma$ collisions using data collected at LEP from 1997 to 2000.

$$e^+e^- \rightarrow e^+e^-\tau^+\tau^- \tag{6}$$

The collision energy $\sqrt{s}$ was between 183 and 208 GeV.

■ The cross-section measurements that correspond to the collision of two virtual photons, was found to be 429 ± 17 pb compared to 447.7 pb expected from the Standard Model. This finding agrees with the QED prediction at the level of one standard deviation.

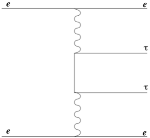


Figure 1: Dominant diagram for the reaction in equation (4)

■ The $\gamma\tau\tau$ vertex is sensitive to the anomalous electromagnetic coupling of the τ and, since this process as two of such vertices, the a_τ can be extracted by comparing the measured cross-section with the QED expectation. The limits on the anomalous magnetic moment of the τ with a 95% CL limits obtained are

$$\boxed{-0.052 < a_\tau < 0.013} \tag{7}$$

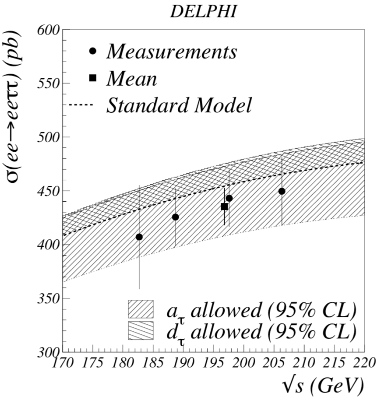


Figure 2: Measured σ, average LEP2 σ and SM expectation as a function of $\sqrt{s}$

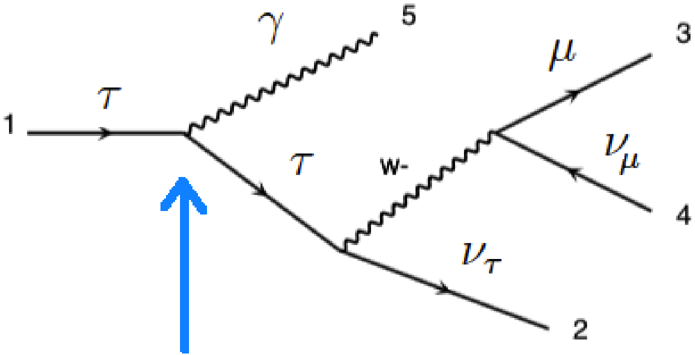
Previous theoretical proposals

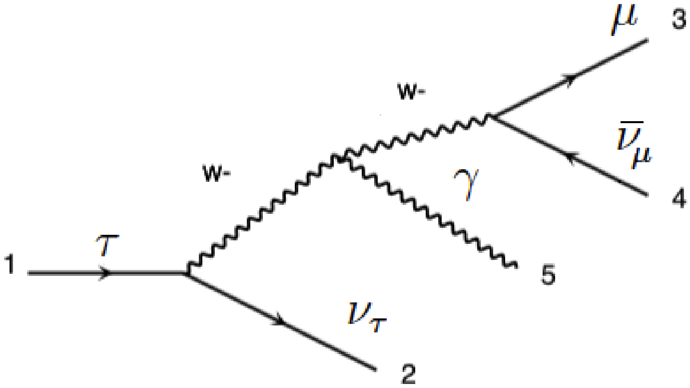
Table 1: Processes that will improve the measurement of a_τ

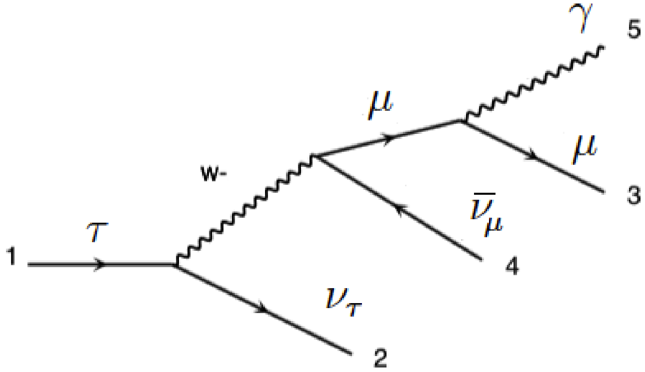
Process	**SM Prediction**
$\tau^- \to \nu_\tau l^- \bar{\nu}_l \gamma$	0.0143 BR
$e^+e^- \to \tau^+\tau^-$	1.1196 nb at 11 GeV $\sqrt{s}$

Process evaluated with MadGraph5
[https://doi.org/10.1016/j.nuclphysbps.2017.03.079]

$$\boxed{\tau^{-} \to \nu_\tau l \bar{\nu}_l \gamma}$$




1
τ
W-
W-
γ
5
μ
3
$\overline{\nu}_\mu$
4
ν_τ
2


γ
5
μ
W-
μ
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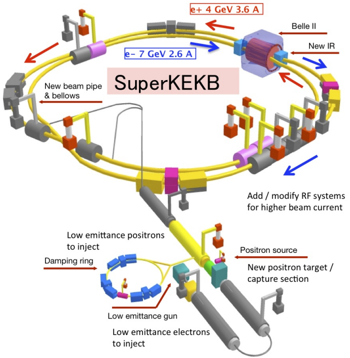
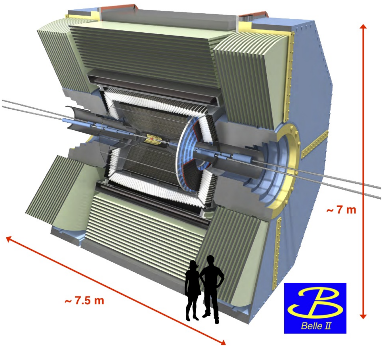
ν̄μ
τ
1
4
ντ
2

Belle II

Belle II is B-meson factory as well as a τ factory





Our proposal: five-body leptonic decay

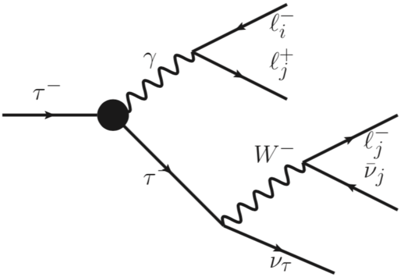


Figure 3: The black circle represents the QED contribution including the AMDM term. [M.A.Arroyo-Urena, E.Diaz, O.Meza-Aldama and G.Tavares-Velasco, arXiv:1711.01393 (2017)].

Our proposal: five-body leptonic decay

Table 2: Assuming that vertex only has electric contributions contributions, i.e., $F_2 = F_3 = 0$,

Branching Ratio	Ref[1][1]	Our Results
$\frac{BR(\tau^- \to e^- e^+ e^- \bar{\nu}_e \nu_\tau)}{10^{-5}}$	4.21 ± 0.01	4.22 ± 0.02
$\frac{BR(\tau^- \to e^- \mu^+ \mu^- \bar{\nu}_e \nu_\tau)}{10^{-7}}$	1.247 ± 0.001	1.246 ± 0.002
$\frac{BR(\tau^- \to \mu^- e^+ e^- \bar{\nu}_\mu \nu_\tau)}{10^{-5}}$	1.984 ± 0.004	1.987 ± 0.003
$\frac{BR(\tau^- \to \mu^- \mu^+ \mu^- \bar{\nu}_\mu \nu_\tau)}{10^{-7}}$	1.183 ± 0.001	1.184 ± 0.001

[1] Flores-Tlalpa, G. Lopez Castro and P. Roig, J. High Energy Phys. 1604, 185 (2016), doi:10.1007/JHEP04(2016)185, arXiv:1508.01822 [hep-ph].

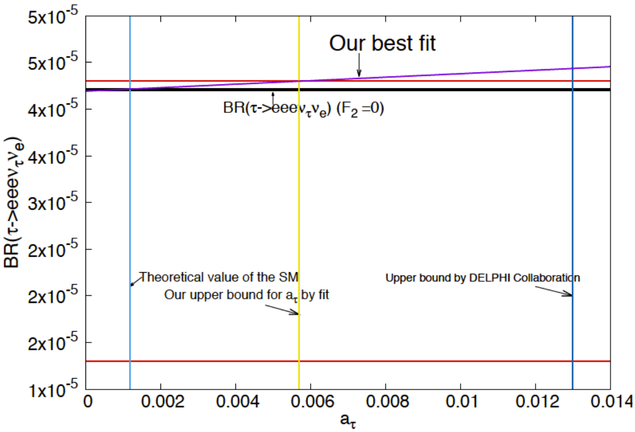


Figure 4: The horizontal red lines are the 95% C.L. limits on the experimental measurement of the five-body decay with a central value is $2.7 \times 10^{-}5$ whereas the horizontal black line is the tree-level SM prediction ($F_2 = 0$). On the other hand, the vertical lines are the SM prediction of a (blue line), our bound (yellow line) and the upper DELPHI bound (dark blue line).

Thank You