Precision tests via tau radiative leptonic decays

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Preamble: lepton g-2

$$a_e = 1159652180.73\,(2.8) \times 10^{-13}$$

0.24 parts per billion !! (Hanneke et al., PRL100 (2008) 120801)

$$a_\mu = 116592089\,(63) \times 10^{-11}$$

0.5 parts per million !! (E821 – Final Report: PRD73 (2006) 072003)

$$a_\tau = -0.018\,(17)$$

Well, not much yet.... (PDG 2015)

τ

- **The Standard Model prediction of the tau g-2 is:**

a_τ^{SM} =	117324 (2)	x 10^{-8}	QED
+	47.4 (0.5)	x 10^{-8}	EW
+	337.5 (3.7)	x 10^{-8}	HLO
+	7.6 (0.2)	x 10^{-8}	HHO (vac)
+	5 (3)	x 10^{-8}	HHO (lbl)

$$a_\tau^{SM} = 117721\ (5) \times 10^{-8}$$

Eidelman & MP 2007

- **$(m_\tau/m_\mu)^2$ ~ 280: great opportunity to look for New Physics, and a "clean" NP test too…**

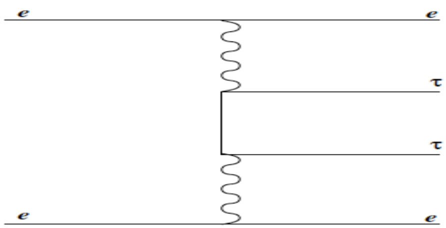
	Muon	Tau
aEW/aH	1/45	1/7
aEW/ δaH	3	10

… if only we could measure it!!

The tau g-2: experimental bounds

- The very short lifetime of the tau makes it very difficult to determine a_τ measuring its spin precession in a magnetic field.

- DELPHI's result, from $e^+e^- \to e^+e^-\tau^+\tau^-$ total cross-section measurements at LEP 2 (the PDG value):



$$a_\tau = -0.018\ (17)$$

PDG 2014

- With an effective Lagrangian approach, using data on tau lepton production at LEP1, SLC, and LEP2:

$$-0.007 < a_\tau^{NP} < 0.005 \quad (95\%\ \text{CL})$$

Gonzáles-Sprinberg et al 2000

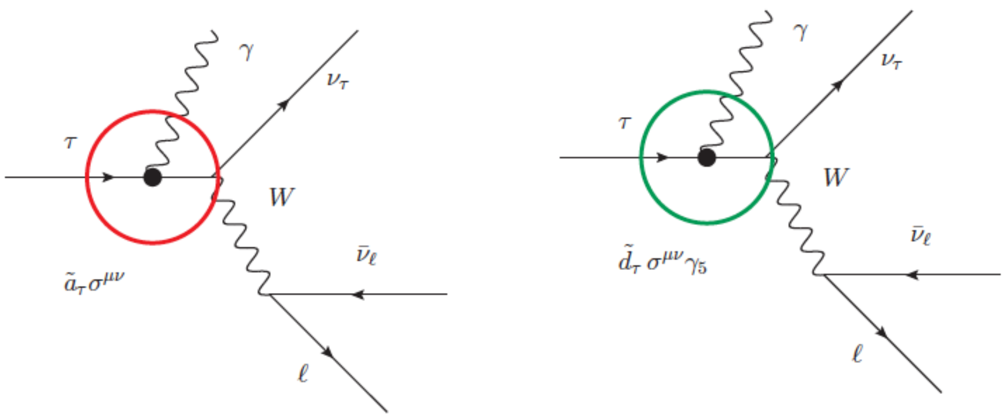
- Bernabéu et al, propose the measurement of $F_2(q^2=M_\Upsilon^2)$ from $e^+e^- \to \tau^+\tau^-$ production at B factories. NPB 790 (2008) 160

A new proposal: the τ g-2 via τ radiative leptonic decays

τ

- a_τ via the radiative leptonic decays $\tau \to e\nu\nu\gamma,\ \tau \to \mu\nu\nu\gamma$ comparing the theoretical prediction for the differential decay rates with precise data from high-luminosity B factories:

$$d\Gamma = d\Gamma_0 + \left(\frac{m_\tau}{M_W}\right)^2 d\Gamma_W + \frac{\alpha}{\pi} d\Gamma_{\rm NLO} + \tilde{a}_\tau\, d\Gamma_{\rm a} + \tilde{d}_\tau\, d\Gamma_{\rm d}$$

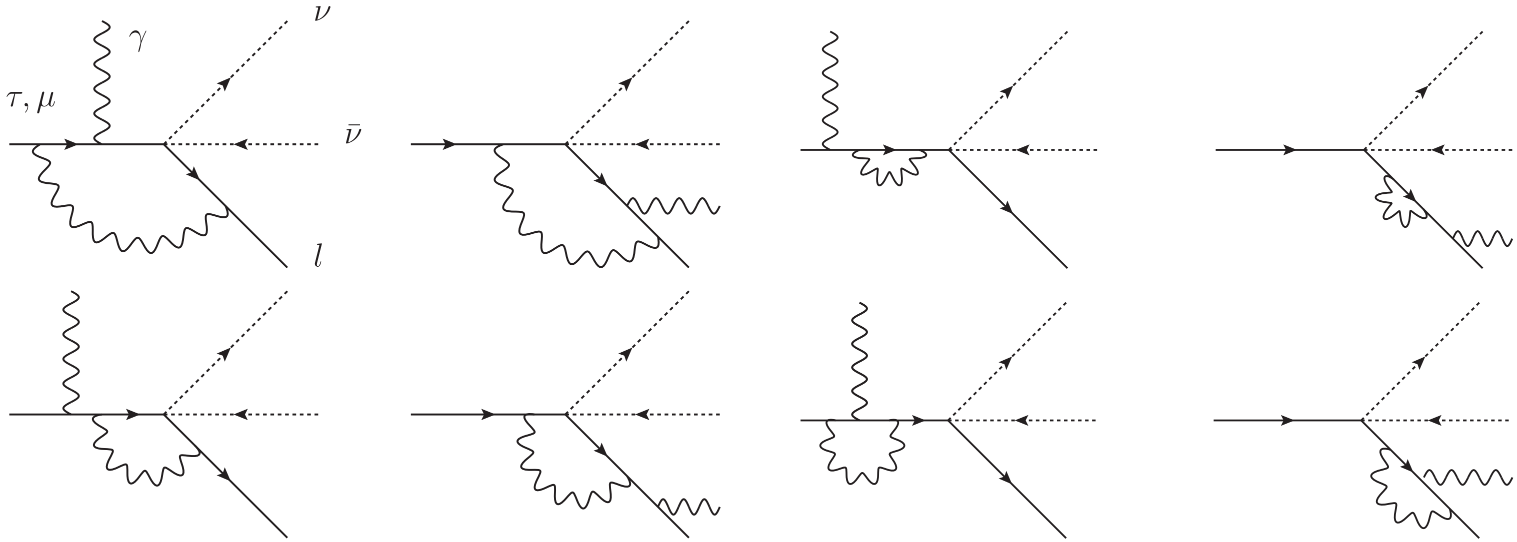


- **Detailed feasibility study (unbinned maximum likelihood fit) performed in Belle-II conditions: we expect a modest improvement of the present PDG bound on the tau g-2 (but not on the tau EDM).**

Eidelman, Epifanov, Fael, Mercolli, MP, arXiv:1601.07987 (JHEP 2016)

Differential decay rates: SM at NLO

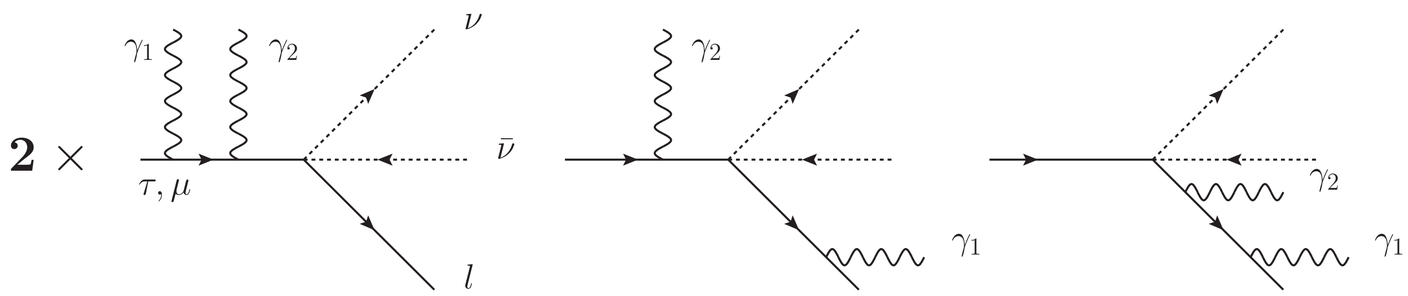
$$d\Gamma = d\Gamma_0 + \frac{m_{\mu,\tau}^2}{M_W^2}\, d\Gamma_W + \frac{\alpha}{\pi}\left[d\Gamma_{\rm virt} + \int_0^{\omega_0'} d\omega'\, d\Gamma_{\gamma\gamma} \right]$$



Fischer et al., PRD 49 (1994) 3426; Arbuzov, Scherbakova, PLB 597 (2004) 285

Differential decay rates: SM at NLO (II)

$$d\Gamma = d\Gamma_0 + \frac{m^2_{\mu,\tau}}{M^2_W}\, d\Gamma_W + \frac{\alpha}{\pi}\left[d\Gamma_{\text{virt}} + \int_0^{\omega'_0} d\omega'\, d\Gamma_{\gamma\gamma}\right]$$



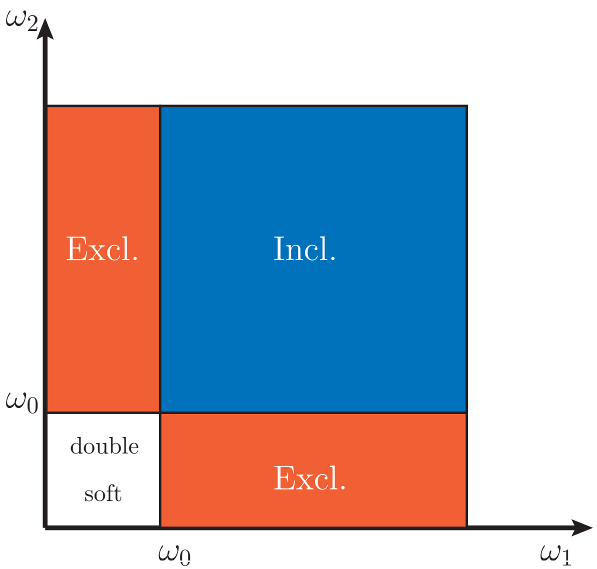
- Extra soft photon emission $\omega' < \omega'_0$ integrated analytically:

$$d\Gamma^{\text{soft}}_{\gamma\gamma}(\omega'_0) = \int_0^{\omega'_0} d\omega'\, d\Gamma_{\gamma\gamma} \quad (\omega'_0 \ll M/2)$$

- IR divs of soft bremsstrahlung and virtual corrections cancel.
- Double "hard" bremss integrated numerically $(\omega' > \omega'_0)$.

The branching ratio of radiative μ and τ leptonic decays for a minimum photon energy ω_0:

$$\mathcal{B}(\omega_0) \propto \int d\Phi_4 \left(d\Gamma_{\rm LO} + d\Gamma_{\rm virt}\right) + \int d\Phi_5 \, d\Gamma_{\gamma\gamma}$$



- $\mathcal{B}^{\rm Exc}(\omega_0)$: only one γ of energy $\omega > \omega_0$, additional second soft photon $\omega' < \omega_0$.

$$\mathcal{B}^{\rm Exc}(\omega_0) = \text{■ (red)}$$

- $\mathcal{B}^{\rm Inc}(\omega_0)$: at least one γ of energy $\omega > \omega_0$.

$$\mathcal{B}^{\rm Inc}(\omega_0) = \text{■ (red)} + \text{■ (blue)}$$

Branching ratios: SM vs measurements

B.R. of radiative τ leptonic decays ($\omega_0 = 10$ MeV)		
	$\tau \to e\bar{\nu}\nu\gamma$	$\tau \to \mu\bar{\nu}\nu\gamma$
$\mathcal{B}_{\rm LO}$	1.834×10^{-2}	3.663×10^{-3}
$\mathcal{B}^{\rm Inc}_{\rm NLO}$	$-1.06\,(1)_n(10)_N \times 10^{-3}$	$-5.8\,(1)_n(2)_N \times 10^{-5}$
$\mathcal{B}^{\rm Exc}_{\rm NLO}$	$-1.89\,(1)_n(19)_N \times 10^{-3}$	$-9.1\,(1)_n(3)_N \times 10^{-5}$
$\mathcal{B}^{\rm Inc}$	$1.728\,(10)_{\rm th}(3)_\tau \times 10^{-2}$	$3.605\,(2)_{\rm th}(6)_\tau \times 10^{-3}$
$\mathcal{B}^{\rm Exc}$	$1.645\,(19)_{\rm th}(3)_\tau \times 10^{-2}$	$3.572\,(3)_{\rm th}(6)_\tau \times 10^{-3}$
$\mathcal{B}^{\dagger}_{\rm EXP}$	$1.847\,(15)_{\rm st}(52)_{\rm sy} \times 10^{-2}$	$3.69\,(3)_{\rm st}(10)_{\rm sy} \times 10^{-3}$

(n): numerical errors

(N): uncomputed NNLO corr.

$$\sim (\alpha/\pi) \ln r \ln(\omega_0/M) \times \mathcal{B}^{\rm Exc/Inc}_{\rm NLO}$$

$(\rm th)$: combined $(n) \oplus (N)$

(τ): experimental error of τ lifetime: $\tau_\tau = 2.903(5) \times 10^{-13}$ s

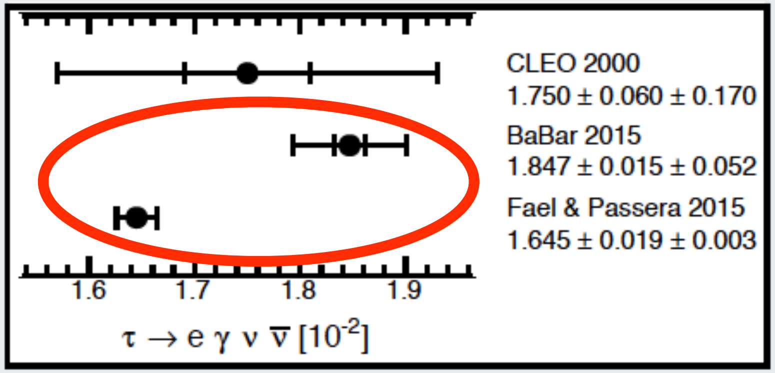
† BaBar, PRD 91 (2015) 051103;
B. Oberhof, arXiv:1502.01810.

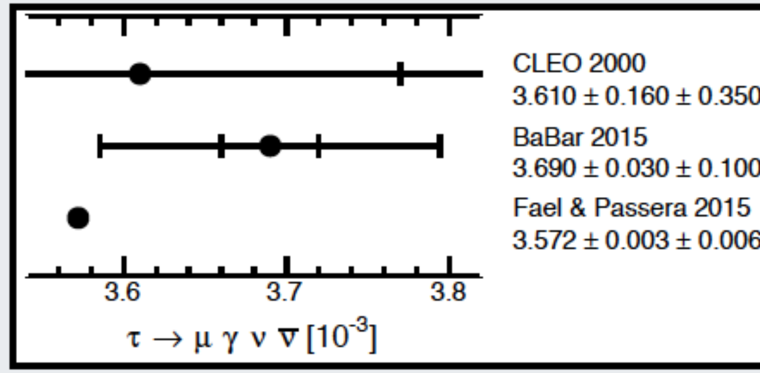
Fael, Mercolli and MP, 1506.03416 (JHEP 2015)
Fael and MP, 1602.00457

Branching ratios: SM vs measurements (II)

τ

Tau radiative leptonic decays ($E_\gamma > 10$ MeV)





- (see also M.Passera presentation in this workshop)
- CLEO 2000: T. Bergfeld et al., PRL 84 (2000) 830
- *BABAR* 2015: PRD 91, 051103 (2015)
- Fael & Passera 2015: NLO calculation, JHEP 07 (2015) 153, arXiv:1602.00457 [hep-ph]
- 3.5σ discrepancy between *BABAR* 2015 and NLO calculation, to be investigated

Branching ratios: SM vs measurements (III)

- **Discrepancy between SM and BaBar's measurements (E_γ>10MeV):**

	$\tau \to e\bar{\nu}\nu\gamma$	$\tau \to \mu\bar{\nu}\nu\gamma$
$\Delta^{\rm Exc}$	$2.02\,(57) \times 10^{-3} \to 3.5\sigma$	$1.2\,(1.0) \times 10^{-4} \to 1.1\sigma$

Fael, Mercolli & MP, 1506.03416 (JHEP 2015), Fael & MP, 1602.00457

$$R_\tau^{\mu/e} = \frac{\mathcal{B}(\tau \to e\nu\bar{\nu}\gamma)_{\rm EXP}/\mathcal{B}(\tau \to e\nu\bar{\nu}\gamma)_{\rm SM}}{\mathcal{B}(\tau \to \mu\nu\bar{\nu}\gamma)_{\rm EXP}/\mathcal{B}(\tau \to \mu\nu\bar{\nu}\gamma)_{\rm SM}} = 1.09 \pm 0.05$$

ie $|g_\mu/g_e| \sim 1.04(2)$, a (possibly) huge Lepton Universality violation!? Compare it with LU tests via ordinary (inclusive) tau leptonic decays:

	$\Gamma_{\tau\to\mu}/\Gamma_{\tau\to e}$
$\|g_\mu/g_e\|$	1.0018 (14)
	$\Gamma_{\tau\to e}/\Gamma_{\mu\to e}$
$\|g_\tau/g_\mu\|$	1.0011 (15)
	$\Gamma_{\tau\to\mu}/\Gamma_{\mu\to e}$
$\|g_\tau/g_e\|$	1.0030 (15)

A. Pich, arXiv:1310.7922

- **Agreement with MEG's recent $\mu \to e\nu\nu\gamma$ measurement [EPJC (2016)]**

Conclusions

- New proposal to determine the tau g-2 via precise measurements of radiative leptonic tau decays. Feasibility study shows that Belle II can improve the present bound.

- BABAR's precise measurement of $BR(\tau \to e\nu\bar{\nu}\gamma)$ for $E_\gamma >$ 10 MeV in the τ rest frame differs from our SM prediction by 3.5 σ! BABAR's result for $BR(\tau \to \mu\nu\bar{\nu}\gamma)$ agrees within ~1σ. Belle II should measure them!

The End