Testing the Standard Model with the lepton g-2

Massimo Passera
INFN Padova

Dipartimento di Fisica
Università degli studi di Pavia
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Outline

- \( \mu \): The muon g-2: recent theory progress
- \( e \): Testing the Standard Model with the electron g-2
- \( \tau \): The tau g-2: opportunities or fantasies? Surprises?
Lepton magnetic moments: the basics
The beginning: $g = 2$

- **Uhlenbeck and Goudsmit in 1925 proposed:**
  
  $$
  \vec{\mu} = g \frac{e}{2mc} \vec{s} \\
  g = 2 \text{ (not 1!)}
  $$

- **Dirac 1928:**
  
  $$
  (i\partial_\mu - eA_\mu) \gamma^\mu \psi = m\psi
  $$

- **A Pauli term in Dirac’s eq would give a deviation...**

  $$
  a \frac{e}{2m} \sigma_{\mu\nu} F^{\mu\nu} \psi \rightarrow g = 2(1 + a)
  $$

  ...but there was no need for it! $g=2$ stood for ~20 yrs.
Theory of the g-2: Quantum Field Theory

- **Kusch and Foley 1948:**

\[
\mu_e^{\text{exp}} = \frac{e\hbar}{2mc} (1.00119 \pm 0.00005)
\]

- **Schwinger 1948 (triumph of QED!):**

\[
\mu_e^{\text{th}} = \frac{e\hbar}{2mc} \left(1 + \frac{\alpha}{2\pi}\right) = \frac{e\hbar}{2mc} \times 1.00116
\]

- **Keep studying the lepton–γ vertex:**

\[
\bar{u}(p') \Gamma_{\mu} u(p) = \bar{u}(p') \left[ \gamma_{\mu} F_1(q^2) + \frac{i\sigma_{\mu\nu}q^\nu}{2m} F_2(q^2) + \ldots \right] u(p)
\]

\[
F_1(0) = 1 \quad F_2(0) = \alpha_l
\]

A pure “quantum correction” effect!
The muon g-2 experiment
LIFE OF A MUON:
THE g-2 EXPERIMENT

Protons from AGS.

Hit Target.

Pions, weighing 1/6 proton, are created.

Pions decay to muons.

Muons are tiny magnets spinning on axis like tops.

Muons are fed into a uniform, doughnut-shaped magnetic field and travel in a circle.

After each circle, muon's spin axis changes by 12°, yet it keeps on traveling in the same direction.

One of 24 detectors see an electron, giving the muon spin direction; g-2 is this angle, divided by the magnetic field the muon is traveling through in the ring.

After circling the ring many times, muons spontaneously decay to electron, (plus neutrinos,) in the direction of the muon spin.

E821 @ BNL
The old experiment E821 (2)
The Big Move: BNL to Fermilab Summer 2013
Fermilab: 2015

Ring fully assembled and connected to cryogenic system; magnet powered
The muon g-2: experimental status

Today: $a_\mu^{\text{EXP}} = (116592089 \pm 54_{\text{stat}} \pm 33_{\text{sys}}) \times 10^{-11}$ [0.5ppm].

Future: new muon g-2 experiments at:
- Fermilab E989: aiming at $\pm 16 \times 10^{-11}$, ie 0.14ppm. Beam expected next year. First result expected in 2018 with a precision comparable to that of BNL E821.
- J-PARC proposal: aiming at 2019 Phase 1 start with 0.4ppm.

Are theorists ready for this (amazing) precision? Not yet
The muon g-2: the QED contribution

\[ a_\mu^{\text{QED}} = \frac{1}{2}\left(\frac{\alpha}{\pi}\right) \]  
Schwinger 1948

+ 0.765857426 (16) \(\left(\frac{\alpha}{\pi}\right)^2\)

Sommerfield; Petermann; Suura&Wichmann '57; Elend '66; MP '04

+ 24.05050988 (28) \(\left(\frac{\alpha}{\pi}\right)^3\)

Remiddi, Laporta, Barbieri ...; Czarnecki, Skrzypek; MP '04;
Friot, Greynat & de Rafael '05, Mohr, Taylor & Newell 2012

+ 130.8773 (61) \(\left(\frac{\alpha}{\pi}\right)^4\)

Kinoshita & Lindquist '81, ..., Kinoshita & Nio '04, '05;
Lee, Marquard, Smirnov2, Steinhauser 2013 (electron loops, analytic);
Kurz, Liu, Marquard, Steinhauser 2013 (\(\tau\) loops, analytic);
Steinhauser et al. 2015 & 2016 (all electron & \(\tau\) loops, analytic).

+ 752.85 (93) \(\left(\frac{\alpha}{\pi}\right)^5\) COMPLETED!

Kinoshita et al. '90, Yelkhovsky, Milstein, Starshenko, Laporta,
Karshenboim, ..., Kataev, Kinoshita & Nio '06; Kinoshita et al. 2012 & 2015

Adding up, we get:

\[ a_\mu^{\text{QED}} = 116584718.941 (21)(77) \times 10^{-11} \]

from coeffs, mainly from 4-loop unc

\[ \delta\alpha(Rb) \]

with \(\alpha = 1/137.035999049(90) [0.66 \text{ ppb}]\)
The muon g-2: the electroweak contribution

**One-loop term:**

\[
\alpha_{\mu}^{EW}(1\text{-loop}) = \frac{5G_{\mu}m_{\mu}^{2}}{24\sqrt{2}\pi^{2}} \left[ 1 + \frac{1}{5} \left( 1 - 4\sin^{2}\theta_{W} \right)^{2} + O \left( \frac{m_{\mu}^{2}}{M_{Z,W,H}^{2}} \right) \right] \approx 195 \times 10^{-11}
\]

1972: Jackiv, Weinberg; Bars, Yoshimura; Altarelli, Cabibbo, Maiani; Bardeen, Gastmans, Lautrup; Fujikawa, Lee, Sanda; Studenikin et al. '80s

**One-loop plus higher-order terms:**

\[
\alpha_{\mu}^{EW} = 153.6 \, (1) \times 10^{-11}
\]

with \(M_{\text{Higgs}} = 125.6 \, (1.5) \, \text{GeV}\)

Hadronic loop uncertainties and 3-loop nonleading logs.
The muon g-2: the hadronic LO contribution (HLO)

\[ K(s) = \int_0^1 dx \frac{x^2(1-x)}{x^2 + (1-x)(s/m^2)} \]

\[ a_{\mu}^{HLO} = \frac{1}{4\pi^3} \int_{4m_{\pi}^2}^{\infty} ds K(s)\sigma^{(0)}(s) = \frac{\alpha^2}{3\pi^2} \int_{4m_{\pi}^2}^{\infty} ds \frac{s}{s} K(s)R(s) \]

\[ a_{\mu}^{HLO} = 6870 (42)_{\text{tot}} \times 10^{-11} \]

\[ = 6923 (42)_{\text{tot}} \times 10^{-11} \]

\[ = 6949 (37)_{\exp (21)}_{\text{rad}} \times 10^{-11} \]

Radiative Corrections are crucial!

BabaYaga MC event generator developed in Pavia

Balossini, Barzè, Bignamini, Carloni Calame, Montagna, Nicrosini, Piccinini
New from BESIII: measurement of the $e^+e^- \rightarrow \pi^+ \pi^-$ cross section between 600 & 900 MeV using initial state radiation

Upcoming $e^+e^- \rightarrow \pi^+ \pi^-$ cross section data from VEPP 2000
New independent space-like approach for HLO

- Alternatively, exchanging the x and s integrations in $a_{\mu}^{HLO}$,

\[
a_{\mu}^{HLO} = \frac{\alpha}{\pi} \int_{0}^{1} dx \, (1 - x) \, \Delta \alpha_{\text{had}}[t(x)]
\]

\[
t(x) = \frac{x^2 m_{\mu}^2}{x - 1} < 0
\]

involving the hadronic contrib. to the running of $\alpha$ in the space-like region, which can be extracted from Bhabha scattering data!

\[
|t| \times 10^3 \, (\text{GeV}^2)
\]

\[
t_{\text{peak}} \approx 0.914
\]

\[
t_{\text{peak}} \approx -0.308 \, \text{GeV}^2
\]

\[
(1 - x) \, \Delta \alpha_{\text{had}} \left( \frac{x^2 m_{\mu}^2}{x - 1} \right) \times 10^4
\]

\[
\Delta \alpha_{\text{had}} \left( \frac{x^2 m_{\mu}^2}{x - 1} \right) \times 10^4
\]

\[
N
\]

\[
\sqrt{s} = 1 \, \text{GeV}
\]

\[
\sqrt{s} = 3 \, \text{GeV}
\]

\[
\sqrt{s} = 10 \, \text{GeV}
\]

\[
\theta \, (\text{deg})
\]

Carloni Calame, MP, Trentadue, Venanzoni, PLB 746 (2015)

- Requires Bhabha cross section at small angles at better than $10^{-4}$. Challenging: must improve by at least 1 order of magnitude.

HNLO: Vacuum Polarization

\[ a_\mu^{HNLO}(vp) = -98 (1) \times 10^{-11} \]

Krause '96, Alemany et al. '98, Hagiwara et al. 2011
HNLO: Light-by-light contribution

Unlike the HLO term, the hadronic l-b-l term relies at present on theoretical approaches.

This term had a troubled life! Latest values:

\[ a_{\mu}^{\text{HNLO (lbl)}} = + 80 (40) \times 10^{-11} \]

Knecht & Nyffeler '02

\[ a_{\mu}^{\text{HNLO (lbl)}} = + 136 (25) \times 10^{-11} \]

Melnikov & Vainshtein '03

\[ a_{\mu}^{\text{HNLO (lbl)}} = + 105 (26) \times 10^{-11} \]

Prades, de Rafael, Vainshtein '09

\[ a_{\mu}^{\text{HNLO (lbl)}} = + 102 (39) \times 10^{-11} \]

Jegerlehner, arXiv:1511.04473

Results based also on Hayakawa, Kinoshita '98 & '02; Bijnens, Pallante, Prades '96 & '02

Improvements expected in the \( \pi^0 \) transition form factor

A. Nyffeler 1602.0339

Dispersive approach proposed

Colangelo, Hoferichter, Procura, Stoffer, 2014 & 2015

Pauk and Vanderhaeghen 2014.

Lattice? Very hard but promising

Tom Blum et al. 2015
The muon g-2: the hadronic NNLO contributions (HNNLO)

- **HNNLO: Vacuum Polarization**

  O($\alpha^4$) contributions of diagrams containing hadronic vacuum polarization insertions:

  \[ a_{\mu}^{HNNLO}(vp) = 12.4 (1) \times 10^{-11} \]

  Kurz, Liu, Marquard, Steinhauser 2014

- **HNNLO: Light-by-light**

  \[ a_{\mu}^{HNNLO}(lbl) = 3 (2) \times 10^{-11} \]

  Colangelo, Hoferichter, Nyffeler, MP, Stoffer 2014
The muon g-2: SM vs. Experiment

Comparisons of the SM predictions with the measured g-2 value:

\[ a_\mu^{\text{EXP}} = 116592091 (63) \times 10^{-11} \]

E821 – Final Report: PRD73 (2006) 072 with latest value of \( \lambda = \frac{\mu_\mu}{\mu_p} \) from CODATA’10

\[
\begin{array}{cccc}
  a_\mu^{\text{SM}} \times 10^{11} & \Delta a_\mu = a_\mu^{\text{EXP}} - a_\mu^{\text{SM}} & \sigma \\
 116591795 (56) & 296 (86) \times 10^{-11} & 3.5 [1] \\
116591815 (57) & 276 (85) \times 10^{-11} & 3.2 [2] \\
116591841 (58) & 250 (86) \times 10^{-11} & 2.9 [3] \\
\end{array}
\]

with the very recent “conservative” hadronic light-by-light \( a_\mu^{\text{HNLO}(\text{lbl})} = 102 (39) \times 10^{-11} \) of F. Jegerlehner arXiv:1511.04473, and the hadronic leading-order of:

\[ \Delta a_\mu: \text{could it be errors in the hadronic cross section?} \]

- Can \( \Delta a_\mu \) be due to hypothetical mistakes in the hadronic \( \sigma(s) \)?
- An upward shift of \( \sigma(s) \) also induces an increase of \( \Delta \alpha_{\text{had}}^{(5)}(M_Z) \).
- Consider:

\[
a_\mu^{\text{HLO}} \rightarrow \quad a = \int_{4m^2_\pi}^{s_u} ds \, f(s) \sigma(s), \quad f(s) = \frac{K(s)}{4\pi^3}, \quad s_u < M_Z^2;
\]

\[
\Delta \alpha_{\text{had}}^{(5)} \rightarrow \quad b = \int_{4m^2_\pi}^{s_u} ds \, g(s) \sigma(s), \quad g(s) = \frac{M_Z^2}{(M_Z^2 - s)(4\alpha\pi^2)};
\]

and the increase

\[ \Delta \sigma(s) = \epsilon \sigma(s) \]

(\( \epsilon > 0 \)), in the range:

\[ \sqrt{s} \in [\sqrt{s_0} - \delta/2, \sqrt{s_0} + \delta/2] \]
How much does the $M_H$ upper bound from the EW fit change when we shift $\sigma(s)$ by $\Delta\sigma(s)$ [and thus $\Delta\alpha_{\text{had}}^{(5)}(M_Z)$] to accommodate $\Delta a_\mu$?
Given the quoted exp. uncertainty of $\sigma(s)$, the possibility to explain the muon g-2 with these very large shifts $\Delta\sigma(s)$ appears to be very unlikely.

Also, given a 125 GeV SM Higgs, these hypothetical shifts $\Delta\sigma(s)$ could only occur at very low energy (below $\sim 1$ GeV) where $\sigma(s)$ is precisely measured.

Vice versa, assuming we now have a SM Higgs with $M_H = 125$ GeV, if we bridge the $M_H$ discrepancy in the EW fit decreasing the low-energy hadronic cross section, the muon g-2 discrepancy increases.

W.J. Marciano, A. Sirlin, MP, 2008 & 2010
Testing the SM with the electron g-2
The QED prediction of the electron $g$-2

$\alpha_{e}^{\text{QED}} = + \frac{1}{2}(\alpha/\pi) - 0.328\,478\,444\,002\,55(33)(\alpha/\pi)^2$

Schwinger 1948, Sommerfield; Petermann; Suura&Wichmann ’57; Elend ‘66; CODATA Mar ’12

$A_1^{(4)} = -0.328\,478\,965\,579\,193\,78...$
$A_2^{(4)} (m_e/m_\mu) = 5.197\,386\,68 (26) \times 10^{-7}$
$A_2^{(4)} (m_e/m_\tau) = 1.837\,98 (33) \times 10^{-9}$

$+ 1.181\,234\,016\,816\,(11)(\alpha/\pi)^3$

Kinoshita; Barbieri; Laporta, Remiddi; … , Li, Samuel; MP ’06; Giudice, Paradisi, MP 2012

$A_1^{(6)} = 1.181\,241\,456\,587...$
$A_2^{(6)} (m_e/m_\mu) = -7.373\,941\,62 (27) \times 10^{-6}$
$A_2^{(6)} (m_e/m_\tau) = -6.5830\,(11) \times 10^{-8}$
$A_3^{(6)} (m_e/m_\mu, m_e/m_\tau) = 1.909\,82 (34) \times 10^{-13}$

$- 1.91206\,(84)(\alpha/\pi)^4$


$+ 7.79\,(34)(\alpha/\pi)^5$ Complete Result! (12672 mass indep. diagrams!)


$0.2 \, 10^{-13}$ in $\alpha_e$ nb: $(\alpha/\pi)^6 \sim O(10^{-16})$
The SM prediction of the electron $g-2$

The SM prediction is:

$$a_e^{\text{SM}}(\alpha) = a_e^{\text{QED}}(\alpha) + a_e^{\text{EW}} + a_e^{\text{HAD}}$$

The EW (1&2 loop) term is: Czarnecki, Krause, Marciano '96 [value from Codata10]

$$a_e^{\text{EW}} = 0.2973 (52) \times 10^{-13}$$

The Hadronic contribution, at LO+NLO+NNLO, is:

Nomura & Teubner '12, Jegerlehner & Nyffeler '09; Krause'97; Kurz, Liu, Marquard & Steinhauser 2014

$$a_e^{\text{HAD}} = 17.10 (17) \times 10^{-13}$$

$$a_e^{\text{HLO}} = +18.66 (11) \times 10^{-13}$$

$$a_e^{\text{HNLO}} = [-2.234(14)_{\text{vac}} + 0.39(13)_{\text{lbl}}] \times 10^{-13}$$

$$a_e^{\text{HNNLO}} = +0.28 (1) \times 10^{-13}$$

Which value of $\alpha$ should we use to compute $a_e^{\text{SM}}$?
The electron g-2 gives the best determination of alpha $\alpha^{-1} = 137.035\,999\,157 (33)$ [0.24 ppb]

- The 2008 measurement of the electron g-2 is:
  \[ a_e^{\text{EXP}} = 11596521807.3 (2.8) \times 10^{-13} \]
  Hanneke et al, PRL100 (2008) 120801

- vs. old (factor of 15 improvement, 1.8\sigma difference):
  \[ a_e^{\text{EXP}} = 11596521883 (42) \times 10^{-13} \]
  Van Dyck et al, PRL59 (1987) 26

- Equate $a_e^{\text{SM}}(\alpha) = a_e^{\text{EXP}}$ → best determination of alpha (2015):
  \[ \alpha^{-1} = 137.035\,999\,157 (33) \]

- Compare it with other determinations (independent of $a_e$):
  \[ \alpha^{-1} = 137.036\,000\,0 (11) \quad [7.7 \text{ ppb}] \quad \text{PRA73 (2006) 032504 (Cs)} \]
  \[ \alpha^{-1} = 137.035\,999\,049 (90) \quad [0.66 \text{ ppb}] \quad \text{PRL106 (2011) 080801 (Rb)} \]

Excellent agreement → beautiful test of QED at 4-loop level!
Old and new determinations of alpha

Hanneke, Fogwell & Gabrielse, PRL100 (2008) 120801
Bouchendira et al, PRL106 (2011) 080801
The electron g-2: SM vs Experiment

- Using $\alpha = 1/137.035\,999\,049\,(90)$ [\(^{87}\text{Rb}, 2011\)], the SM prediction for the electron g-2 is

$$a_e^{SM} = 115\,965\,218\,16.5\,(0.2)\,(0.2)\,(0.2)\,(7.6) \times 10^{-13}$$

- The EXP-SM difference is (note the negative sign):

$$\Delta a_e = a_e^{EXP} - a_e^{SM} = -9.2\,(8.1) \times 10^{-13}$$

The SM is in very good agreement with experiment ($1\sigma$).

NB: The 4-loop contrib. to $a_e^{QED}$ is $-556 \times 10^{-13} \sim 70 \delta \Delta a_e$!

(the 5-loop one is $6.2 \times 10^{-13}$)
The electron g-2 sensitivity and NP tests

- The present sensitivity is $\delta \Delta a_e = 8.1 \times 10^{-13}$, ie (10^{-13} units):
  
  $$(0.2)_{\text{QED}4}, \quad (0.2)_{\text{QED}5}, \quad (0.2)_{\text{HAD}}, \quad (7.6)\delta\alpha, \quad (2.8)\delta a^\text{EXP}_e$$

  $$(0.4)_{\text{TH}} \leftrightarrow \text{may drop to 0.2}$$

- The $(g-2)_e$ exp. error may soon drop below $10^{-13}$ and work is in progress for a significant reduction of that induced by $\delta\alpha$.

  → sensitivity of $10^{-13}$ may be reached with ongoing exp. work

- In a broad class of BSM theories, contributions to $a_\ell$ scale as

  $$\frac{\Delta a_{\ell_i}}{\Delta a_{\ell_j}} = \left(\frac{m_{\ell_i}}{m_{\ell_j}}\right)^2$$

  This Naive Scaling leads to:

  $$\Delta a_e = \left(\frac{\Delta a_\mu}{3 \times 10^{-9}}\right) 0.7 \times 10^{-13}; \quad \Delta a_T = \left(\frac{\Delta a_\mu}{3 \times 10^{-9}}\right) 0.8 \times 10^{-6}$$
Summary of the exp. contributions to the relative uncertainty of $\delta \alpha$ and $\delta a_e$ (in ppb).

F. Terranova & G.M. Tino, PRA89 (2014) 052118
The experimental sensitivity in $\Delta a_e$ is not very far from what is needed to test if the discrepancy in $(g-2)_\mu$ also manifests itself in $(g-2)_e$ under the naive scaling hypothesis.

NP scenarios exist which violate Naive Scaling. They can lead to larger effects in $\Delta a_e$ and contributions to EDMs, LFV or lepton universality breaking observables.

Example: In the MSSM with non-degenerate but aligned sleptons (vanishing flavor mixing angles), $\Delta a_e$ can reach $10^{-12}$ (at the limit of the present exp sensitivity). For these values one typically has breaking effects of lepton universality at the few per mil level (within future exp reach).

Giudice, Paradisi & MP, arXiv:1208.6583
The tau g-2: opportunities or fantasies?
The SM prediction of the tau g-2 is:

\[ a_T^{SM} = 117324 \ (2) \times 10^{-8} \quad \text{QED} \]
\[ + \quad 47.4 \ (0.5) \times 10^{-8} \quad \text{EW} \]
\[ + \quad 337.5 \ (3.7) \times 10^{-8} \quad \text{HLO} \]
\[ + \quad 7.6 \ (0.2) \times 10^{-8} \quad \text{HHO (vac)} \]
\[ + \quad 5 \ (3) \times 10^{-8} \quad \text{HHO (lbl)} \]

\[ a_T^{SM} = 117721 \ (5) \times 10^{-8} \quad \text{Eidelman & MP 2007} \]

\[(m_\tau/m_\mu)^2 \sim 280: \text{great opportunity to look for New Physics, and a “clean” NP test too...} \]

<table>
<thead>
<tr>
<th></th>
<th>Muon</th>
<th>Tau</th>
</tr>
</thead>
<tbody>
<tr>
<td>aEW/aH</td>
<td>1/45</td>
<td>1/7</td>
</tr>
<tr>
<td>aEW/δaH</td>
<td>3</td>
<td>10</td>
</tr>
</tbody>
</table>

... if only we could measure it!!
The very short lifetime of the tau makes it very difficult to determine $a_\tau$ measuring its spin precession in a magnetic field.

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

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

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

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

Bernabéu et al, propose the measurement of $F_2(q^2=M_{\Upsilon}^2)$ from $e^+e^- \rightarrow \tau^+\tau^-$ production at B factories.

NPB 790 (2008) 160
A new proposal: the $\tau$ g-2 via $\tau$ radiative leptonic decays

- $a_\tau$ via the radiative leptonic decays $\tau \to e\bar{\nu}\nu\gamma, \tau \to \mu\bar{\nu}\nu\gamma$

comparing the theoretical prediction for the differential decay rates with precise data from high-luminosity B factories:

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

Detailed feasibility study performed in Belle-II conditions:
we expect a (modest) improvement of the present PDG bound.

Radiative leptonic tau decays: branching ratios

<table>
<thead>
<tr>
<th>B.R. of radiative $\tau$ leptonic decays ($\omega_0 = 10$ MeV)</th>
</tr>
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<tbody>
<tr>
<td>$\tau \to e\bar{\nu}\nu\gamma$</td>
</tr>
<tr>
<td>$B_{LO}$</td>
</tr>
<tr>
<td>$B_{NLO}^{Inc}$</td>
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<tr>
<td>$B_{NLO}^{Exc}$</td>
</tr>
<tr>
<td>$B_{Inc}^{Exc}$</td>
</tr>
<tr>
<td>$B_{Exp}^{Exc}$</td>
</tr>
<tr>
<td>$B_{Exp}^{†}$</td>
</tr>
</tbody>
</table>

($n$): numerical errors
($N$): uncomputed NNLO corr.

$\sim (\alpha/\pi) \ln r \ln(\omega_0/M) \times B_{NLO}^{Exc/Inc}$

$\hat{B}_{BABAR}$ - PRD 91 (2015) 051103

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

$\tau \to e\bar{\nu}\nu\gamma$

$\Delta_{Exc}^{Exc}$ $2.02 (57) \times 10^{-3} \rightarrow 3.5\sigma$

$\tau \to \mu\bar{\nu}\nu\gamma$

$1.2 (1.0) \times 10^{-4} \rightarrow 1.1\sigma$

- Agreement with MEG’s recent $\mu \to e\nu\nu\gamma$ measurement [EPJ C76 (2016) 3, 108]
- Fael, Mercolli and MP, 1506.03416 (JHEP 2015)
- Fael and MP, 1602.00457
Radiative leptonic tau decays: branching ratios (II)

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

- (see also M.Passera presentation in this workshop)
- $3.5\sigma$ discrepancy between BABAR 2015 and NLO calculation, to be investigated
Conclusions

The lepton g-2 provide beautiful examples of interplay between theory and experiment, and different areas of Physics.

Muon g-2: $\Delta a_\mu \sim 3.5 \sigma$. $\Delta a_\mu$ can be explained by errors in the theory predictions, in the g-2 experiment, or, we hope, by New Physics! New upcoming experiment: lots of progress in the theory prediction, but the hadronic sector is not yet ready.

Electron g-2: the present sensitivity to New Physics is limited by experimental uncertainties, but a strong exp. program is under way to improve both $\alpha$ & $a_e$. It could allow to test if the discrepancy in the muon g-2 manifests also in the electron g-2!

Tau g-2: essentially unknown. New proposal to measure it via radiative leptonic tau decays. Modest improvement expected. BaBar’s recent precise measurement of $B(\tau \to e\bar{\nu}\nu\gamma)$ differs from the SM prediction by 3.5 $\sigma$!
The End