Testing the Standard Model with the lepton g-2

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Preamble: today's values

$$a_e = 1159652180.73\ (28) \times 10^{-12}$$

0.24 parts per <u>billion</u> !! (Hanneke et al., PRL100 (2008) 120801)

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

0.5 parts per <u>million</u> !! (E821 – Final Report: PRD73 (2006) 072003)

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

Well, not much yet.... (PDG 2012)

Outline

- 1. Lepton magnetic moments: the basics
- 2. μ: The muon g-2: a quick update
- 3. e: Testing new physics with the electron g-2
- 4. τ: The tau g-2: opportunities & challenges (fantasies?)

1. Lepton magnetic moments: the basics

- **Uhlenbeck and Goudsmit in 1926 proposed:**

$$\vec{\mu} = g\frac{e}{2mc}\vec{s}$$

$$g = 2 \quad \text{(not 1!)}$$

- **Dirac 1928:**

$$(i\partial_\mu - eA_\mu)\,\gamma^\mu\psi = m\psi$$

- **A Pauli term in Dirac's eq would give a deviation…**

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

…but there was no need for it! g=2 stood for ~20 yrs.

Theory of the g-2: Quantum Field Theory

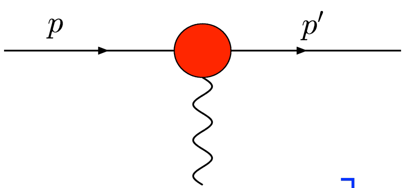
- **Kusch and Foley 1948:**

$$\mu_e^{\rm exp} = \frac{e\hbar}{2mc}\,(1.00119 \pm 0.00005)$$

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

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

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



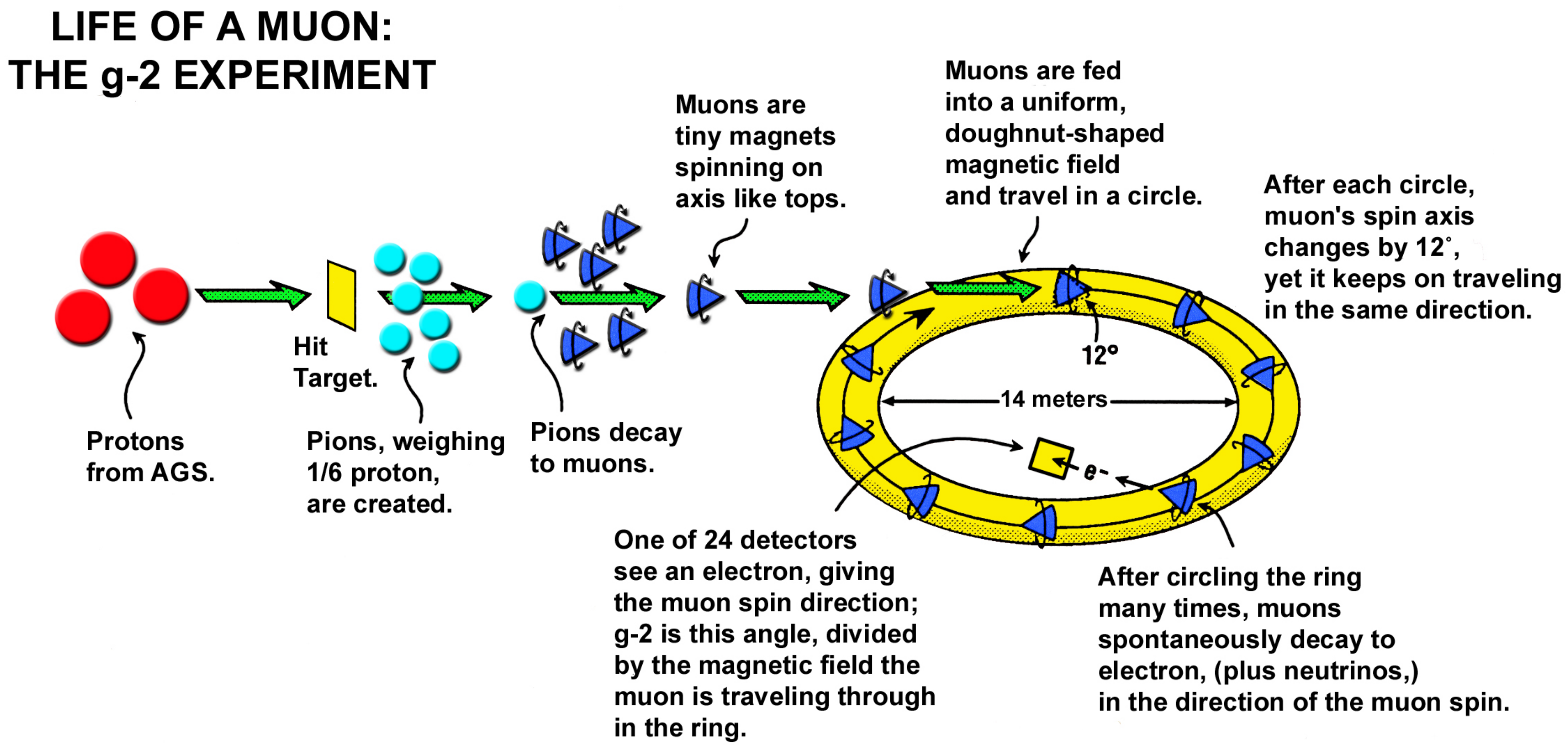
$$\bar{u}(p')\Gamma_\mu u(p) = \bar{u}(p')\left[\gamma_\mu F_1(q^2) + \frac{i\sigma_{\mu\nu}q^\nu}{2m}F_2(q^2) + \ldots\right]u(p)$$

$$F_1(0) = 1 \qquad F_2(0) = a_l$$

A pure "quantum correction" effect!

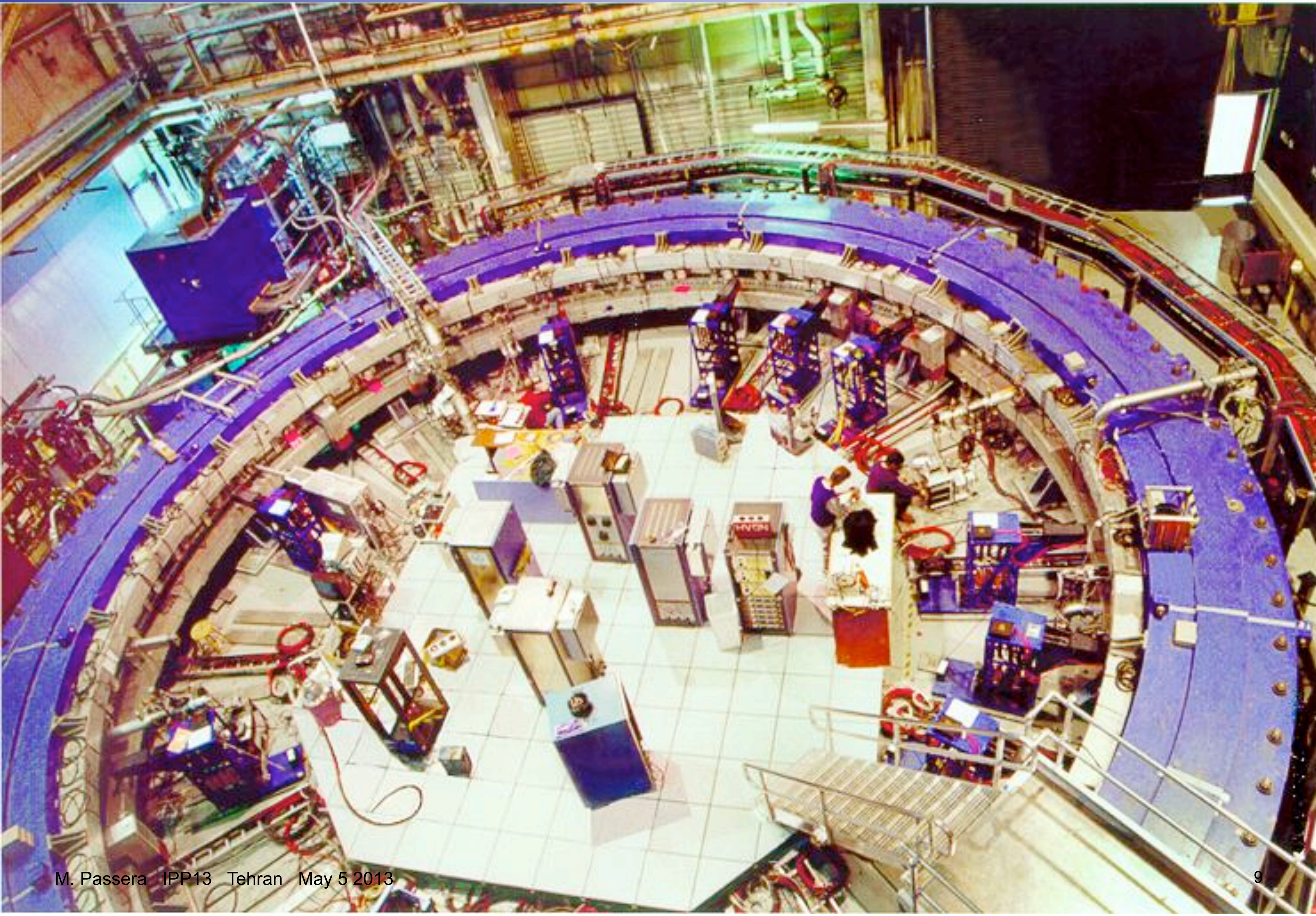
2. The muon g-2: a quick update

The experiment E821

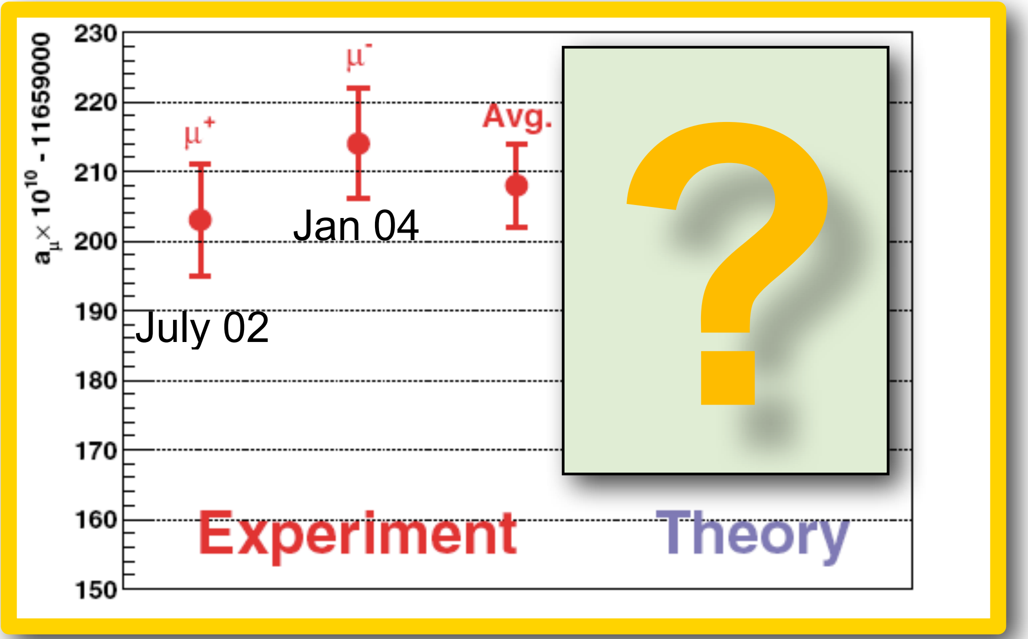


E821 @ BNL

The experiment E821 (II)



The muon g-2: the experimental result



- **Today:** $a_\mu^{EXP} = (116592089 \pm 54_{stat} \pm 33_{sys})\times10^{-11}$ [0.5ppm].
- **Future:** new muon g-2 experiments proposed at:
  - Fermilab (E989), aiming at 0.14ppm → Sep 2012: CD0 approval! Data in 2017?
  - J-PARC aiming at 0.1 ppm

  See B.Lee Roberts & T. Mibe @ Tau2012, September 2012
- **Are theorists ready for this (amazing) precision? No(t yet)**

The muon g-2: the QED contribution

$a_\mu^{QED} = (1/2)(\alpha/\pi)$ Schwinger 1948

$+ \; 0.765857425\,(17)\,(\alpha/\pi)^2$

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

$+ \; 24.05050996\,(32)\,(\alpha/\pi)^3$

Remiddi, Laporta, Barbieri … ; Czarnecki, Skrzypek; MP '04;
Friot, Greynat & de Rafael '05, Mohr,Taylor & Newell '08

$+ \; 130.8796\,(63)\,(\alpha/\pi)^4$

Kinoshita & Lindquist '81, … , Kinoshita & Nio '04, '05;
Aoyama, Hayakawa, Kinoshita & Nio, 2007, Kinoshita et al. 2012

$+ \; 753.29\,(1.04)\,(\alpha/\pi)^5$ **COMPLETED!**

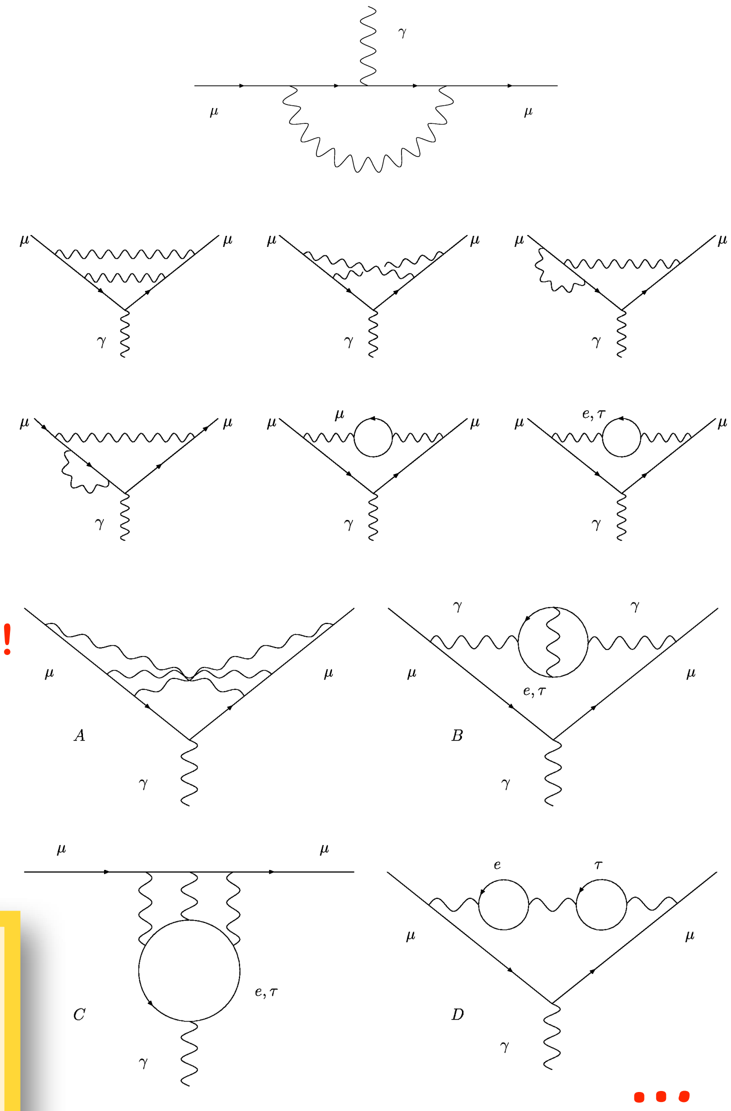
Kinoshita et al. '90, Yelkhovsky, Milstein, Starshenko, Laporta,
Karshenboim,…, Kataev, Kinoshita & Nio '06, Kinoshita et al. 2012

Adding up, we get:

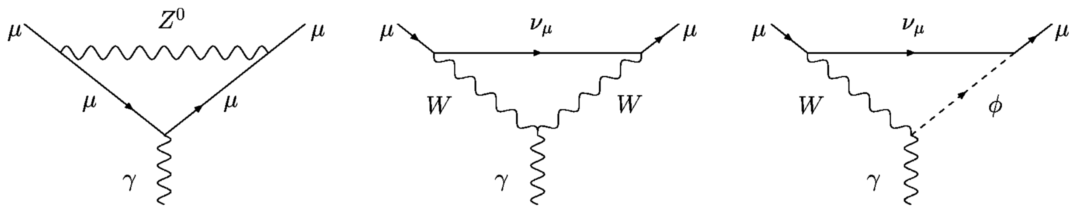
$a_\mu^{QED} = 116584718.951\,(22)(77) \times 10^{-11}$

from coeffs, mainly from 4-loop unc ⮠ ⮡ from $\delta\alpha$(Rb)

with $\alpha = 1/137.035999049(90)$ [0.66 ppb]



- **One-loop term:**



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

1972: Jackiv, Weinberg; Bars, Yoshimura; Altarelli, Cabibbo, Maiani; Bardeen, Gastmans, Lautrup; Fujikawa, Lee, Sanda;

Studenikin et al. '80s

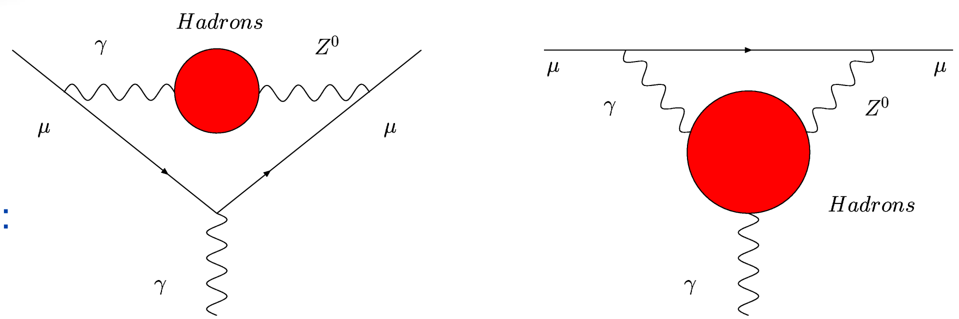
- **One-loop plus higher-order terms:**

$a_\mu^{\text{EW}} = 154\ (2)\ (1) \times 10^{-11}$

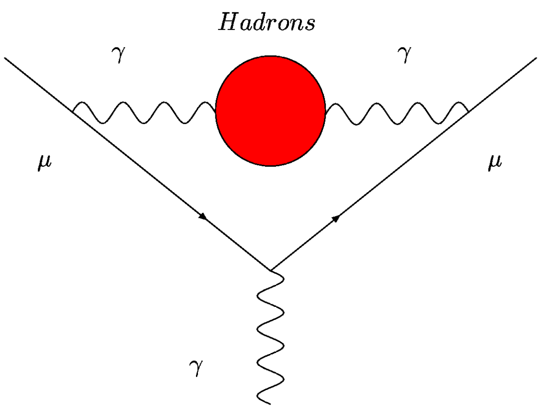
Kukhto et al. '92; Czarnecki, Krause, Marciano '95; Knecht, Peris, Perrottet, de Rafael '02; Czarnecki, Marciano, Vainshtein '02; Degrassi, Giudice '98; Heinemeyer, Stockinger, Weiglein '04; Gribouk, Czarnecki '05; Vainshtein '03.

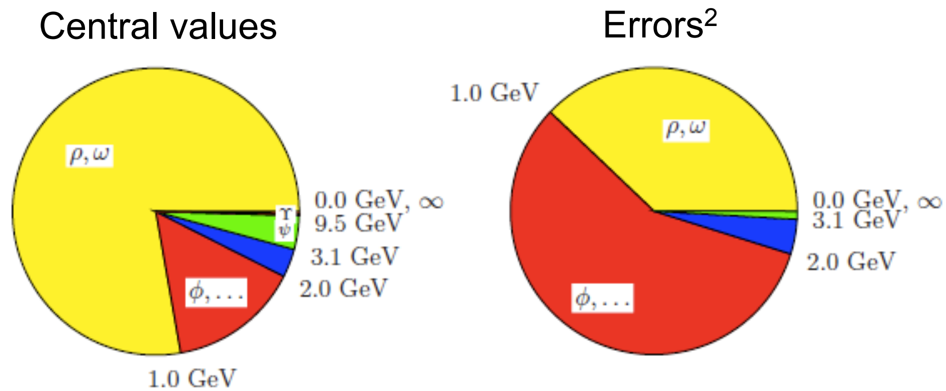
(Higgs mass variation,) M_{top} error, 3-loop nonleading logs

Hadronic loop uncertainties:



The muon g-2: the hadronic LO contribution (HLO)





F. Jegerlehner and A. Nyffeler, Phys. Rept. 477 (2009) 1

$$K(s) = \int_0^1 dx \frac{x^2(1-x)}{x^2 + (1-x)s/m_\mu^2}$$

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

$a_\mu^{\mathrm{HLO}} = 6903\,(53)_{\mathrm{tot}} \times 10^{-11}$ F. Jegerlehner, A. Nyffeler, Phys. Rept. 477 (2009) 1

$= 6923\,(42)_{\mathrm{tot}} \times 10^{-11}$ Davier et al, EPJ C71 (2011) 1515 (incl. BaBar & KLOE10 2π)

$= 6949\,(37)_{\mathrm{exp}}\,(21)_{\mathrm{rad}} \times 10^{-11}$ Hagiwara et al, JPG 38 (2011) 085003

Radiative Corrections are crucial! S.Actis et al, Eur. Phys. J. C66 (2010) 585

The muon g-2: the HLO contribution from e^+e^- data

- The overall agreement of all e^+e^- data looks reasonably good, some discrepancies exist.

- Energy scan: Agreement between the CMD2 & SND $\pi^+\pi^-$ data at VEPP-2M. Prelim results presented in Sep 2012 by CMD3 & SND at the new VEPP-2000 collider in Novosibirsk. See Shwartz @ Tau2012

- Initial State Radiation Method (ISR): Collider operates at fixed energy but s_π can vary continuously. Important independent method made possible by strong th & exp interplay.

- KLOE: The "small angle" (2008) and "large angle" (2010) $\pi^+\pi^-$ ISR analyses agree. Sep 2012: new measure by the $\pi\pi\gamma/\mu\mu\gamma$ ratio presented. It confirms their earlier results. See Mandaglio @ Tau2012

- Reasonable agreement between KLOE and CMD2-SND (especially below the ρ). The contributions to a_μ^{HLO} agree.

- BaBar: ISR $\pi^+\pi^-$ result from 0.3 to 3 GeV (2009). Discrepancy between the results of BaBar and KLOE. See Davier @ Tau2012

The muon g-2: the HLO contribution from tau-decay data

- The tau data of ALEPH, CLEO & OPAL are higher than the CMD2/SND/KLOE ones, particularly above the ρ.The 2008 $a_\mu^{\pi\pi}$ tau data result of Belle agrees with Aleph-Cleo-Opal (some deviations from Aleph's spectral functions).

- Revisited analysis in 2011: (Davier et al, EPJ C71 (2011) 1515)

$$a_\mu^{HLO} = 7015\ (47) \times 10^{-11}$$

Belle's data included + IB corrections revisited & updated

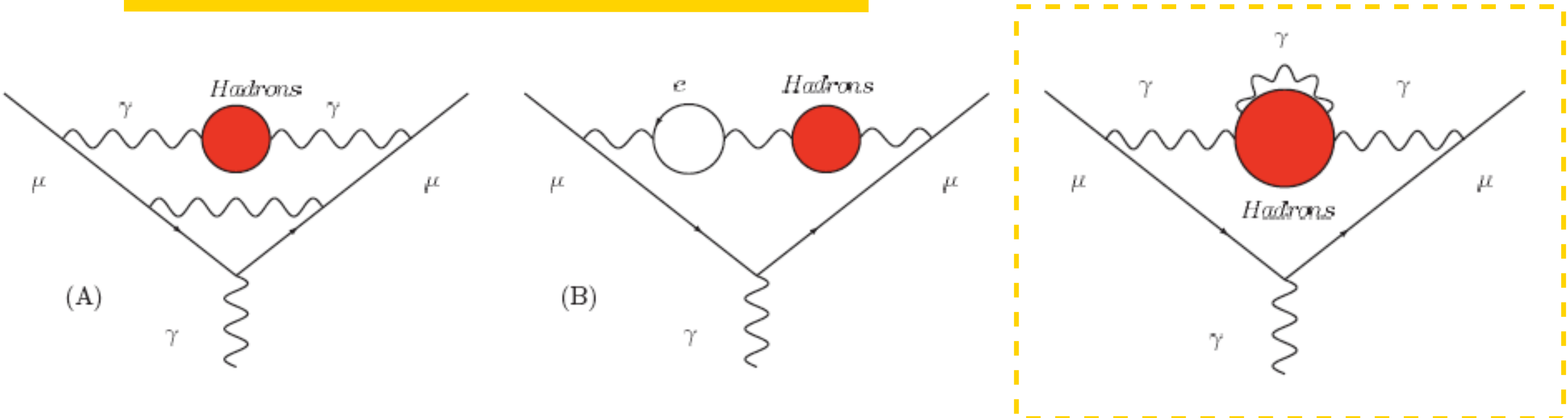
(Marciano & Sirlin '88; Cirigliano, Ecker, Neufeld '01-'02, Flores-Baez et al. '06&'07)

- The discrepancy with e^+e^- data decreased. Are there inconsistencies in e^+e^- or τ data? All possible isospin-breaking (IB) effects taken into account?

- Claims exist that tau data are actually consistent with e^+e^- ones after IB effects & vector meson mixings considered! (Benayoun et al., 2007, 2009 and EPJC72 (2012)1848, Jegerlehner & Szafron 2011).

HHO: Vacuum Polarization

Already included in a_μ^{HLO}



O(α^3) contributions of diagrams containing hadronic vacuum polarization insertions:

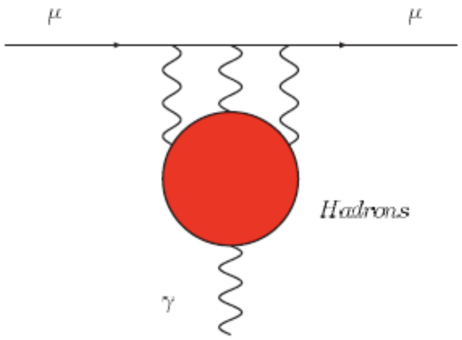
$$a_\mu^{HHO}(vp) = -98\ (1) \times 10^{-11}$$

Krause '96, Alemany et al. '98, Hagiwara et al. 2011

Only tiny shifts if τ data are used instead of the e^+e^- ones

Davier & Marciano '04.

HHO: Light-by-light contribution



- Unlike the HLO term, for the hadronic l-b-l term we must rely on theoretical approaches.
- This term had a troubled life! Recent values:

$a_\mu^{HHO}(lbl) = +80\ (40) \times 10^{-11}$	Knecht & Nyffeler '02
$a_\mu^{HHO}(lbl) = +136\ (25) \times 10^{-11}$	Melnikov & Vainshtein '03
$a_\mu^{HHO}(lbl) = +105\ (26) \times 10^{-11}$	Prades, de Rafael, Vainshtein '09
$a_\mu^{HHO}(lbl) = +116\ (39) \times 10^{-11}$	Jegerlehner & Nyffeler '09

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

- "Bound" $a_\mu^{HHO}(lbl) < \sim 160 \times 10^{-11}$ Erler&Sanchez '06, Pivovarov '02; also Boughezal&Melnikov'11
- Lattice? Very hard... in progress.
- Large "by far not complete" calculation: 188×10^{-11} Fischer et al, PRD87(2013)034013
- Had lbl is likely to become the ultimate limitation of the SM prediction.

The muon g-2: SM vs. Experiment

Adding up all contributions, we get the following SM predictions and comparisons with the measured value:

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

E821 – Final Report: PRD73 (2006) 072 with latest value of $\lambda=\mu_\mu/\mu_p$ (CODATA'06)

	$a_\mu^{SM} \times 10^{11}$	$(\Delta a_\mu = a_\mu^{EXP} - a_\mu^{SM}) \times 10^{11}$	σ
[1]	116 591 783 (59)	306 (86)	3.5
[2]	116 591 803 (49)	286 (80)	3.6
[3]	116 591 829 (50)	260 (80)	3.2
[4]	116 591 895 (54)	194 (83)	2.3

with $a_\mu^{HHO}(lbl) = 105\ (26) \times 10^{-11}$

[1] F. Jegerlehner, A. Nyffeler, Phys. Rept. 477 (2009) 1
[2] Davier et al, EPJ C71 (2011) 1515 (includes BaBar and KLOE10 2π)
[3] HLMNT11: Hagiwara et al, JPG38 (2011) 085003 (incl BaBar and KLOE10 2π)
[4] Davier et al, Eur.PJ C71 (2011) 1515, τ data.

Note that the th. error is now about the same as the exp. one

How do we explain Δa_μ? Is it New Physics?

- Δa_μ can be explained in many ways: errors in LBL, QED, EW, HHO-VP, g-2 EXP, HLO; or, we hope, New Physics!
- Can Δa_μ be due to hypothetical mistakes in the hadronic σ(s)?
- An upward shift of σ(s) also induces an increase of $\Delta\alpha_{had}^{(5)}(M_Z)$.
- Consider:

a_μ^{HLO} →
$$a = \int_{4m_\pi^2}^{s_u} ds\, f(s)\,\sigma(s), \qquad f(s) = \frac{K(s)}{4\pi^3},\ s_u < M_Z^2,$$

$\Delta\alpha_{had}^{(5)}$ →
$$b = \int_{4m_\pi^2}^{s_u} ds\, g(s)\,\sigma(s), \qquad g(s) = \frac{M_Z^2}{(M_Z^2 - s)(4\alpha\pi^2)},$$

and the increase

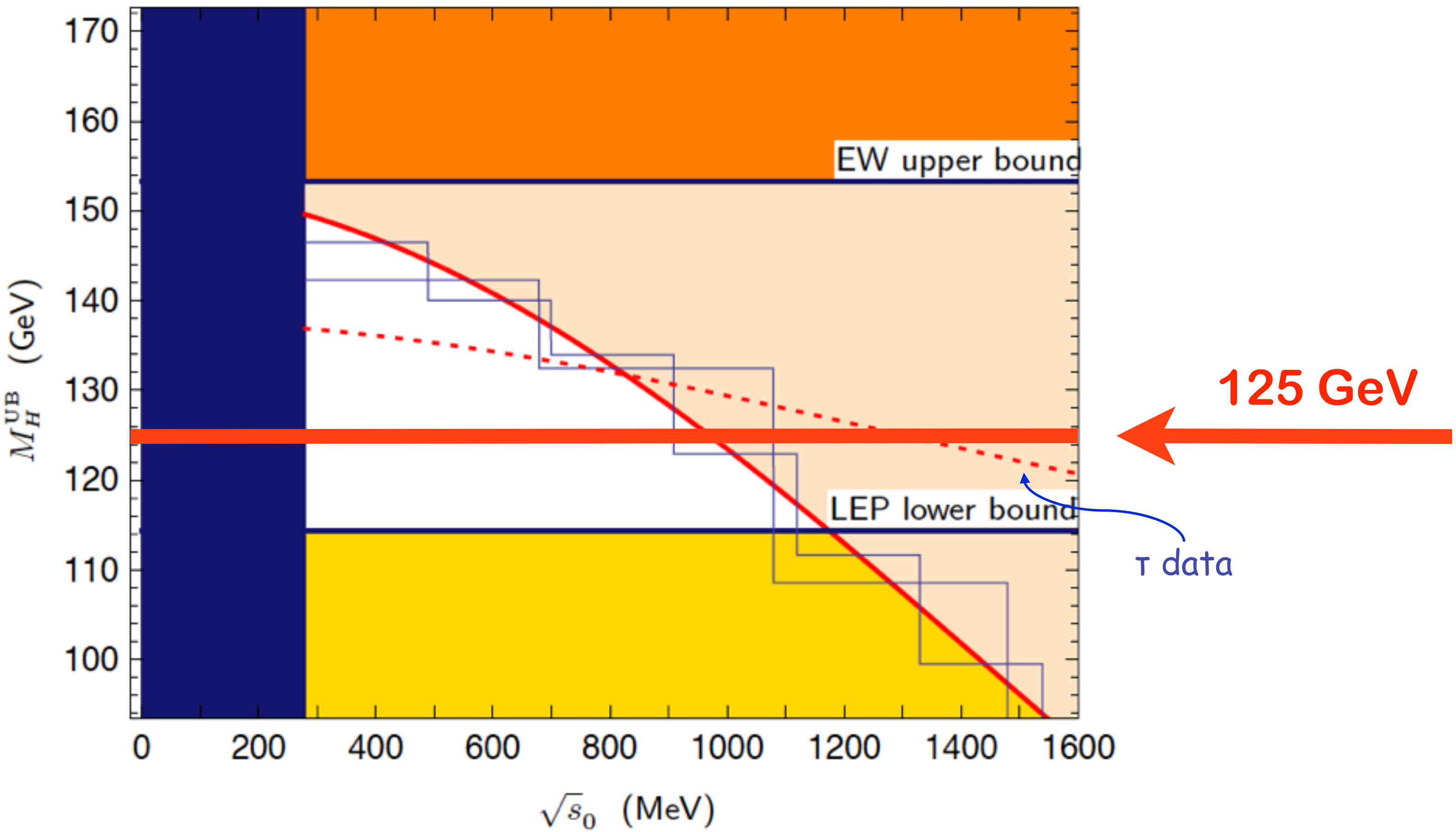
$$\Delta\sigma(s) = \epsilon\sigma(s)$$

(ε>0), in the range:

$$\sqrt{s} \in [\sqrt{s}_0 - \delta/2, \sqrt{s}_0 + \delta/2]$$ →

The muon g-2: connection with the SM Higgs mass

- How much does the M_H upper bound from the EW fit change when we shift $\sigma(s)$ by $\Delta\sigma(s)$ [and thus $\Delta\alpha_{had}^{(5)}(M_Z)$] to accommodate Δa_μ ?



W.J. Marciano, A. Sirlin, MP, 2008 & 2010

The muon g-2: connection with the SM Higgs mass (II)

- 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 ~ 1 GeV).

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

W.J. Marciano, A. Sirlin, MP, 2008 & 2010

3. Testing new physics with the electron g-2

G.F. Giudice, P. Paradisi, MP

JHEP 1211 (2012) 113

The QED prediction of the electron g-2

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

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

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

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

Kinoshita, Barbieri, Laporta, Remiddi, … , Li, Samuel; MP '06; GPP 2012

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

$$-\ 1.9097\,(20)\,(\alpha/\pi)^4$$

Kinoshita & Lindquist ’81, … , Kinoshita & Nio ’05; Aoyama, Hayakawa, Kinoshita & Nio, May 2012

$$+\ 9.16\,(58)\,(\alpha/\pi)^5$$ (12672 mass independent diagrams!)

Aoyama, Hayakawa, Kinoshita, Nio, 2012

The SM prediction of the electron g-2

- The SM prediction is:

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

- The EW (1&2 loop) term is: Czarnecki, Krause, Marciano '96 [Codata 2012]

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

- The Hadronic contribution is: Nomura & Teubner '12, Jegerlehner & Nyffeler '09; Krause'97

$$a_e^{HAD} = 16.82\,(16) \times 10^{-13}$$

- Which value of α should we use to compute a_e^{SM} and compare it with a_e^{EXP} ?? Not the PDG/Codata one (obtained equating $a_e^{SM}(\alpha) = a_e^{EXP}$)! Use atomic-physics measurements of alpha.

The electron g-2 gives the best determination of alpha

- The 2008 measurement of the electron g-2 is:

  $a_e^{EXP} = 11596521807.3\ (2.8) \times 10^{-13}$ Hanneke et al, PRL100 (2008) 120801

  vs. old (factor of 15 improvement, 1.8σ difference):

  $a_e^{EXP} = 11596521883\ (42) \times 10^{-13}$ Van Dyck et al, PRL59 (1987) 26

- Equate $a_e^{SM}(\alpha) = a_e^{EXP}$ → best determination of alpha (2012):

$$\alpha^{-1} = 137.035\,999\,173\ (34) \qquad [0.25\ \text{ppb}]$$

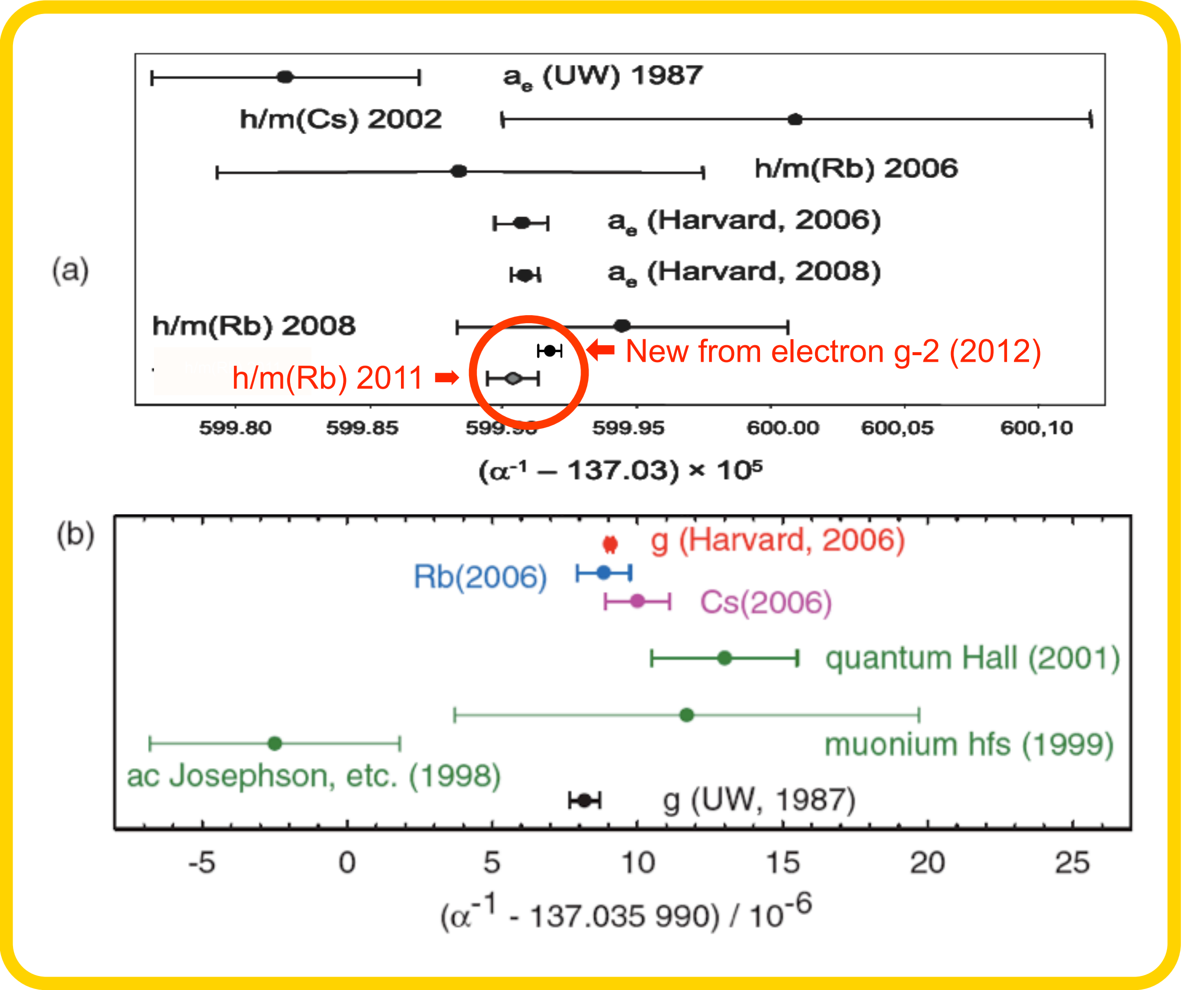
- Compare it with other determinations (independent of a_e):

$\alpha^{-1} = 137.036\,000\,0\ (11)$ [7.7 ppb] PRA73 (2006) 032504 (Cs)

$\alpha^{-1} = 137.035\,999\,049\ (90)$ [0.66 ppb] PRL106 (2011) 080801 (Rb)

Excellent agreement → beautiful test of QED at 4-loop level!

Old and new determinations of alpha



Gabrielse, Hanneke, Kinoshita, Nio & Odom, PRL99 (2007) 039902
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}Rb, 2011], the SM prediction for the electron g-2 is

$$a_e^{SM} = 115\,965\,218\,17.8\ (0.6)\ (0.4)\ (0.2)\ (7.6) \times 10^{-13}$$

δC_4^{qed} δC_5^{qed} δa_e^{had} from $\delta\alpha$

- The EXP-SM difference is:

$$\Delta a_e = a_e^{EXP} - a_e^{SM} = -10.5\ (8.1) \times 10^{-13}$$

The SM is in very good agreement with experiment (1.3σ).

NB: The 4-loop contrib. to a_e^{QED} is $-5.56 \times 10^{-11} \sim 70\ \delta\Delta a_e$!

(the 5-loop one is 6.2×10^{-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):

$$\underbrace{(0.6)_{\rm QED4}, \quad (0.4)_{\rm QED5}, \quad (0.2)_{\rm HAD},}_{(0.7)_{\rm TH}} \quad (7.6)_{\delta\alpha}, \quad (2.8)_{\delta a_e^{\rm EXP}}$$

← may drop to 0.2 or 0.3

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

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

- In a broad class of BSM theories, contributions to a_l 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:

The electron g-2 sensitivity and NP tests (II)

$$\Delta a_e = \left(\frac{\Delta a_\mu}{3\times 10^{-9}}\right)\ 0.7\times 10^{-13}; \qquad \Delta a_\tau = \left(\frac{\Delta a_\mu}{3\times 10^{-9}}\right)\ 0.8\times 10^{-6}$$

- The experimental sensitivity in Δa_e is not far from what is required to test whether the discrepancy in $(g-2)_\mu$ also manifests itself in $(g-2)_e$ under the naive scaling hypothesis.
- BSM scenarios exist which violate Naive Scaling leading to larger effects in Δa_e (& Δa_τ).

4. The tau g-2: opportunities & challenges

Work in progress in collaboration with
S. Eidelman, D. Epifanov, M. Fael, L. Mercolli & C. Ng
arXiv:1301.5302

The SM prediction of the tau g-2

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

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

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

Eidelman & MP 2007

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

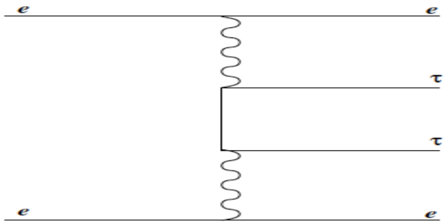
	Electron	Muon	Tau
a^{EW}/a^{HAD}	1/56	1/45	1/7
$a^{EW}/\delta a^{HAD}$	1.6	3	10

… 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 2011

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

$$-0.004 < a_\tau^{NP} < 0.006 \quad (95\%\ \text{CL})$$

Escribano & Massó 1997

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

Gonzáles-Sprinberg et al 2000

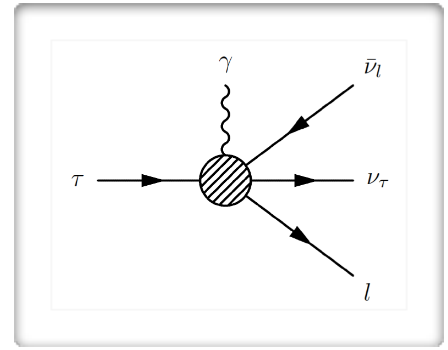
- Bernabéu et al, propose the measurement of $F_2(q^2=M_\Upsilon^2)$ from $e^+e^- \to \tau^+\tau^-$ production at B factories. NPB 790 (2008) 160

The tau g-2 via its radiative leptonic decays: a proposal

- **Tau radiative leptonic decays at LO:**

$$\frac{d^3\Gamma}{dx\,dy\,d\cos\theta} = \frac{\alpha\, M_\tau^5\, G_F^2\, y\,\sqrt{x^2-4r^2}}{2\pi(4\pi)^6}\, G_0(x,y,\cos\theta,r)$$

Kinoshita & Sirlin PRL2(1959)177; Kuno & Okada, RMP73(2001)151

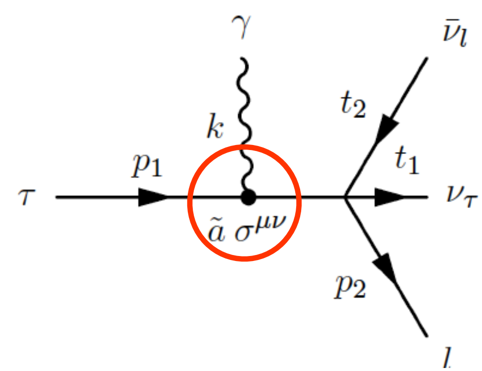


$$\left.\frac{\Gamma(\tau^- \to e^-\,\bar\nu_e\,\nu_\tau\,\gamma)}{\Gamma_{\rm total}}\right|_{E_\gamma>10\rm MeV} = 1.823\% \quad \text{vs} \quad 1.75(18)\%$$

CLEO 2000

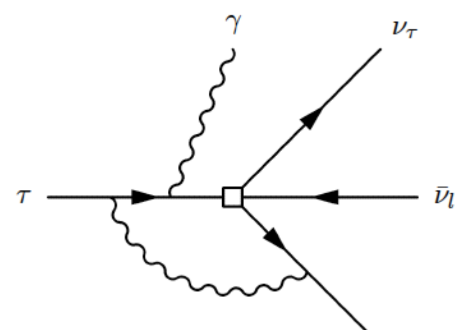
$$\left.\frac{\Gamma(\tau^- \to \mu^-\,\bar\nu_\mu\,\nu_\tau\,\gamma)}{\Gamma_{\rm total}}\right|_{E_\gamma>10\rm MeV} = 0.364\% \quad \text{vs} \quad 0.361(38)\%$$

$$x = \frac{2E_l}{M_\tau},\; y = \frac{2E_\gamma}{M_\tau},\; r = \frac{m_l}{M_\tau}$$



- **Add the contribution of the effective coupling and the QED corrections:**

$$G_0 \to G_0 + \tilde a_\tau G_a + \frac{\alpha}{\pi} G_{\rm RC}$$



(c) Diagram n.6

- **Measure $d^3\Gamma$ precisely and get $\tilde a_\tau$!**

[see also Laursen, Samuel, Sen, PRD29 (1984) 2652]

Conclusions

- The lepton g-2 provide beautiful examples of interplay between theory and experiment.
- The discrepancy Δa_μ is ~3.5σ (with e^+e^- data; 2.3σ with tau data). Is it NP? Sep 2012: CD0 approval for new g-2 exp! KLOE new measure presented: it agrees with KLOE 08 & 10! Future of LBL?
- Could Δa_μ be due to mistakes in the hadronic $\sigma(s)$? Very unlikely. Also, given a 125 GeV SM Higgs, these hypothetical shifts $\Delta\sigma(s)$ could only occur at very low energies (below ~ 1GeV).
- The sensitivity of the electron g-2 has improved! It may soon be possible to test whether Δa_μ manifests itself in the electron g-2. A robust and ambitious exp program is needed to improve α & a_e.
- The tau g-2 is essentially unknown: we propose to measure it at Belle II via its radiative leptonic decays.

The End