# Status of the Muon g-2 Prediction

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# Outline

- Lepton magnetic moments: the basics
- The muon g-2 discrepancy: an update
- Comment on the muon g-2 and the bounds on $M_{Higgs}$

# The present experimental values:

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

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

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

DELPHI - EPJC35 (2004) 159 [$a_\tau^{SM} = 117721(5) \times 10^{-8}$, Eidelman & MP '07]

# Lepton magnetic moments: the basics

# The beginning: g=2

- **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

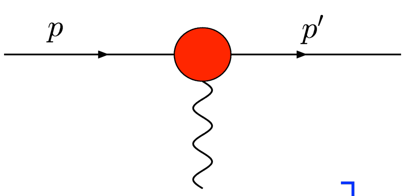
- **Kusch and Foley 1948:**

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

- **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:**



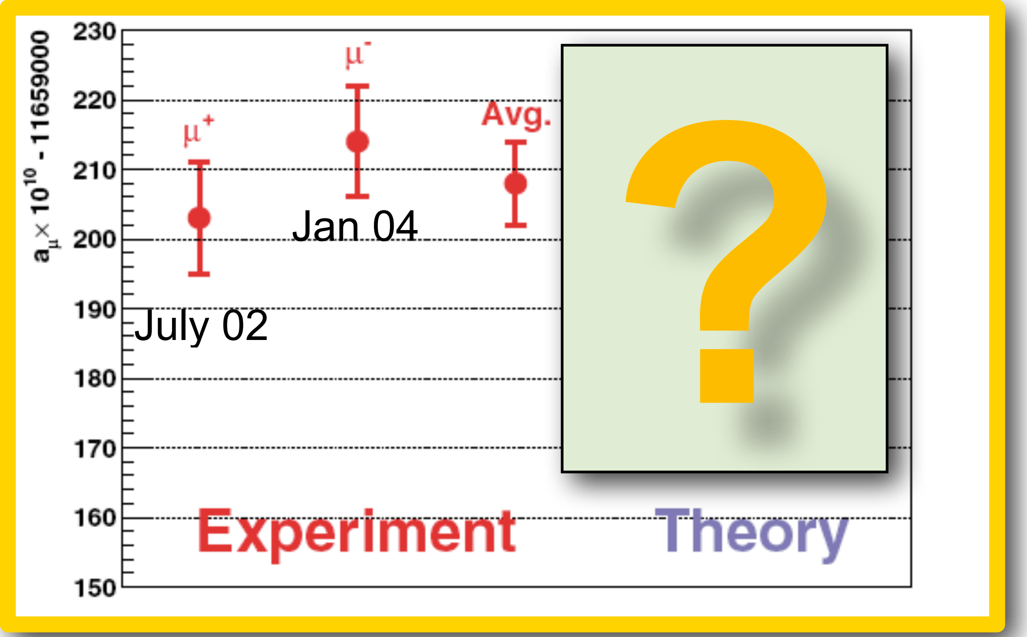

$$\bar{u}(p')\Gamma_\mu u(p) = \bar{u}(p')\left[\gamma_\mu F_1(q^2) + \frac{i\sigma_{\mu\nu}q^\nu}{2m}F_2(q^2) + \ldots\right]u(p)$$

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

A pure "quantum correction" effect!

# The muon g-2 discrepancy: an update

# The muon g-2: the experimental result




- **Today:** $a_\mu^{EXP} = (116592089 \pm 54_{stat} \pm 33_{sys})\times 10^{-11}$ [0.5ppm].
- **Future:** new muon g-2 experiments proposed at:
  - Fermilab (P989), aiming at 0.14ppm → See Venanzoni's talk
  - J-PARC aiming at 0.1 ppm

  [D. Hetzog & N. Saito, U.Paris, Feb 2010; B. Lee Roberts & T. Mibe, Tau2010]
- Are theorists ready for this (amazing) precision? No(t yet)

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

$$+\ 0.765857408\ (27)\ (\alpha/\pi)^2$$

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

$$+\ 24.05050959\ (42)\ (\alpha/\pi)^3$$

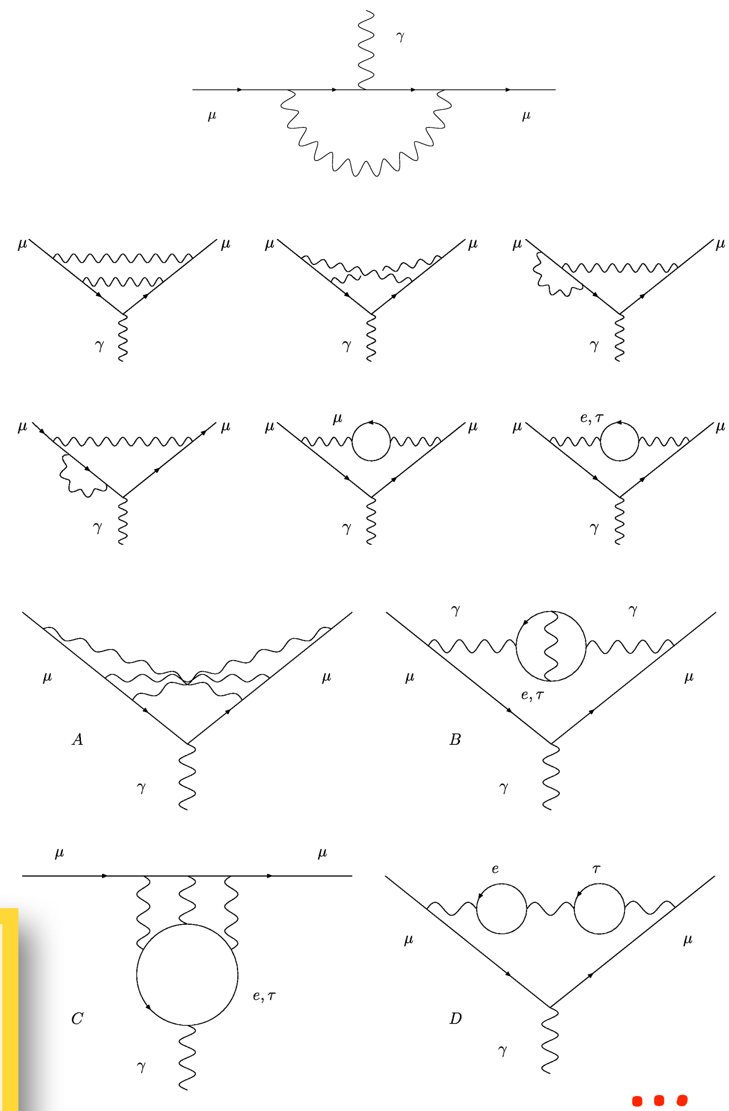
Remiddi, Laporta, Barbieri … ; Czarnecki, Skrzypek; MP '04; Friot, Greynat & de Rafael '05, Mohr,Taylor & Newell '08

$$+\ 130.805\ (8)\ (\alpha/\pi)^4$$

Kinoshita & Lindquist '81, … , Kinoshita & Nio '04, '05; Aoyama, Hayakawa, Kinoshita & Nio, June & Dec 2007

$$+\ 663\ (20)\ (\alpha/\pi)^5$$ In progress…

Kinoshita et al. '90, Yelkhovsky, Milstein, Starshenko, Laporta, Karshenboim,…, Kataev, Kinoshita & Nio '06, Kinoshita et al. 2011




## Adding up, we get:

$$a_\mu^{QED} = 116584718.08\ (14)(04) \times 10^{-11}$$

from coeffs, mainly from 5-loop unc — from $\delta\alpha$('08)

with $\alpha$=1/137.035999084(51) [0.37 ppb]

# [ A parenthesis on the electron g-2...

$$a_e^{SM} = (1/2)(\alpha/\pi) - 0.328\,478\,444\,002\,89(60)\,(\alpha/\pi)^2$$

Schwinger 1948 — Sommerfield; Petermann; Suura & Wichmann '57; Elend '66; MP '06

$$A_2^{(4)}(m_e/m_\mu) = 5.197\,386\,78\,(26) \times 10^{-7}$$

$$A_2^{(4)}(m_e/m_\tau) = 1.837\,62\,(60) \times 10^{-9}$$

$$+\ 1.181\,234\,016\,827\,(19)\,(\alpha/\pi)^3$$

Kinoshita, Barbieri, Laporta, Remiddi, … , Li, Samuel; Mohr,Taylor & Newell '08, MP '06

$$A_2^{(6)}(m_e/m_\mu) = -7.373\,941\,73\,(27) \times 10^{-6}$$

$$A_2^{(6)}(m_e/m_\tau) = -6.5819\,(19) \times 10^{-8}$$

$$A_3^{(6)}(m_e/m_\mu, m_e/m_\tau) = 1.909\,45\,(62) \times 10^{-13}$$

$$-\ 1.9144\,(35)\,(\alpha/\pi)^4$$

Kinoshita & Lindquist '81, … , Kinoshita & Nio '05; Aoyama, Hayakawa, Kinoshita & Nio, 2007

$$+\ 0.0\,(4.6)\,(\alpha/\pi)^5$$ In progress (12672 mass ind. diagrams!)

Aoyama, Hayakawa, Kinoshita, Nio '07; Aoyama, Hayakawa, Kinoshita, Nio, Jan 2011

$$+\ 1.676\,(20) \times 10^{-12}$$ Hadronic

Krause 1997, Jegerlehner & Nyffeler 2009

$$+\ 0.02973\,(52) \times 10^{-12}$$ Electroweak

Mohr,Taylor & Newell, '08; Czarnecki, Krause, Marciano '96

# ... and the best determination of alpha ]

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

  $a_e^{exp} = 1159652180.73\ (28) \times 10^{-12}$ Hanneke et al, PRL100 (2008) 120801

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

  $a_e^{exp} = 1159652188.3\ (4.2) \times 10^{-12}$ Van Dyck et al, PRL59 (1987) 26

- Equating $a_e^{SM}(\alpha) = a_e^{exp}$ → best determination of alpha to date:

$\alpha^{-1}$ = 137.035 999 084 (12)(37)(2)(33) [0.37ppb] Hanneke et al, '08

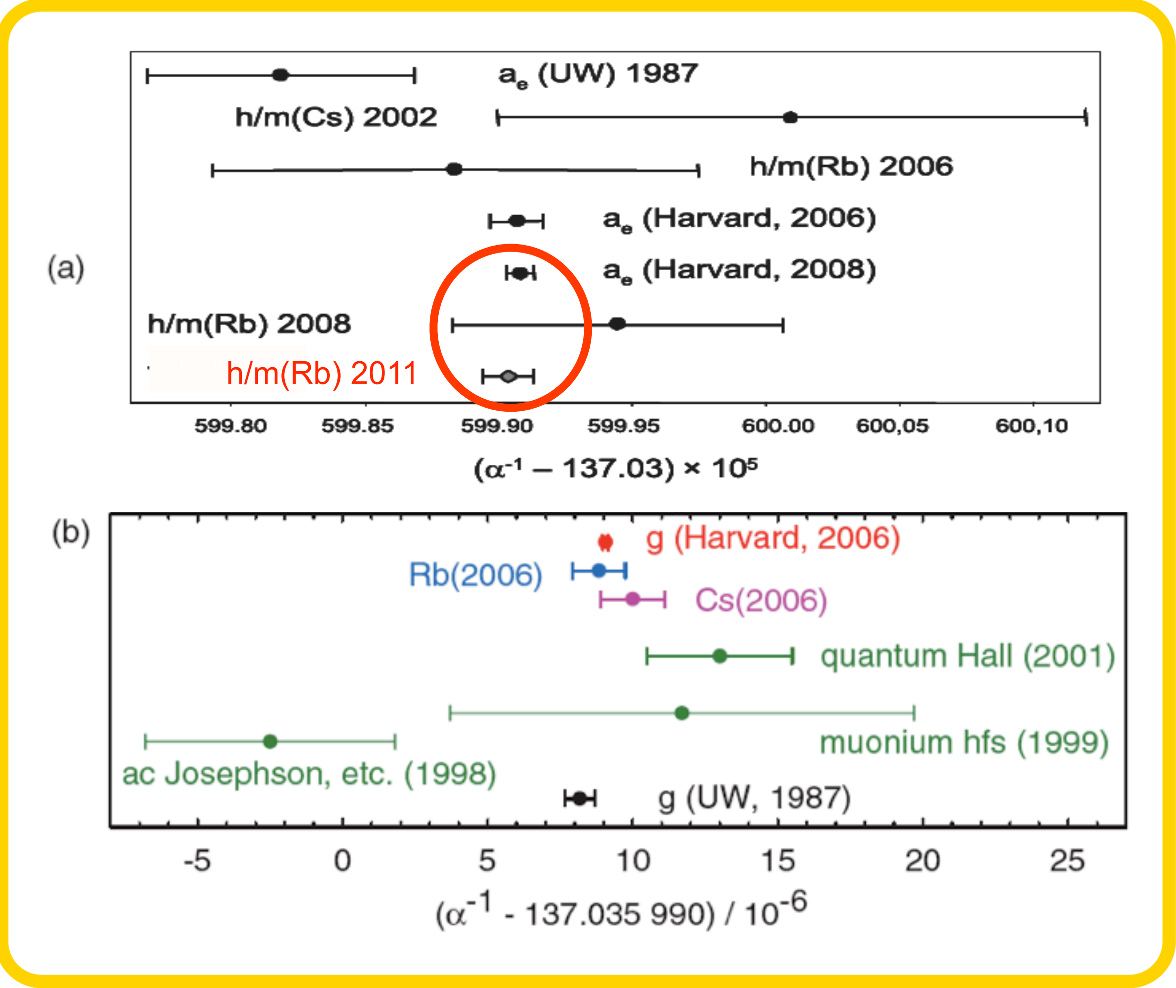
$\delta C_4^{qed}$ $\delta C_5^{qed}$ $\delta a_e^{had}$ $\delta a_e^{exp}$ (smaller than th!)

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

| | | | |
|---|---|---|---|
| $\alpha^{-1}$ = 137.036 000 00 | (110) | [7.7 ppb] | PRA73 (2006) 032504 (Cs) |
| $\alpha^{-1}$ = 137.035 999 45 | (62) | [4.6 ppb] | PRL101 (2008) 230801 (Rb) |
| $\alpha^{-1}$ = 137.035 999 037 | (91) | [0.7 ppb] | PRL106 (2011) 080801 (Rb) |

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

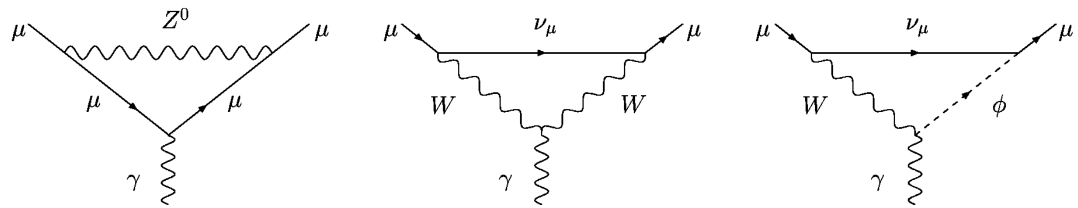
# Old and new determinations of alpha




Gabrielse, Hanneke, Kinoshita, Nio & Odom, PRL99 (2007) 039902
Hanneke, Fogwell & Gabrielse, PRL100 (2008) 120801
Bouchendira et al, PRL106 (2011) 080801

# $a_\mu^{SM}$: the Electroweak contribution

- **One-loop term:**




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

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

Studenikin et al. '80s

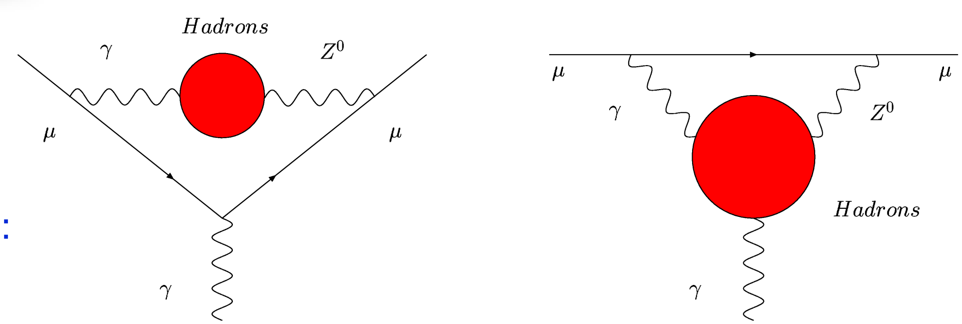
- **One-loop plus higher-order terms:**

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

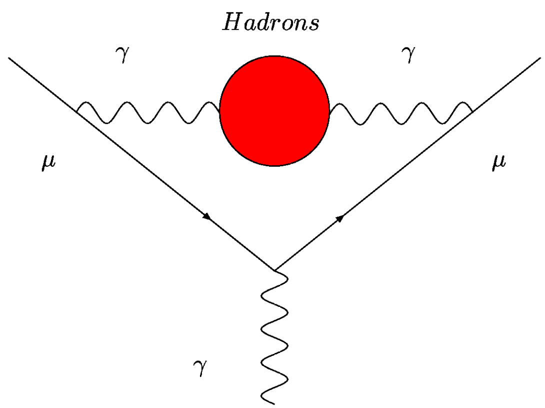
Kukhto et al. '92; Czarnecki, Krause, Marciano '95; Knecht, Peris, Perrottet, de Rafael '02; Czarnecki, Marciano, Vainshtein '02; Degrassi, Giudice '98; Heinemeyer, Stockinger, Weiglein '04; Gribouk, Czarnecki '05; Vainshtein '03.

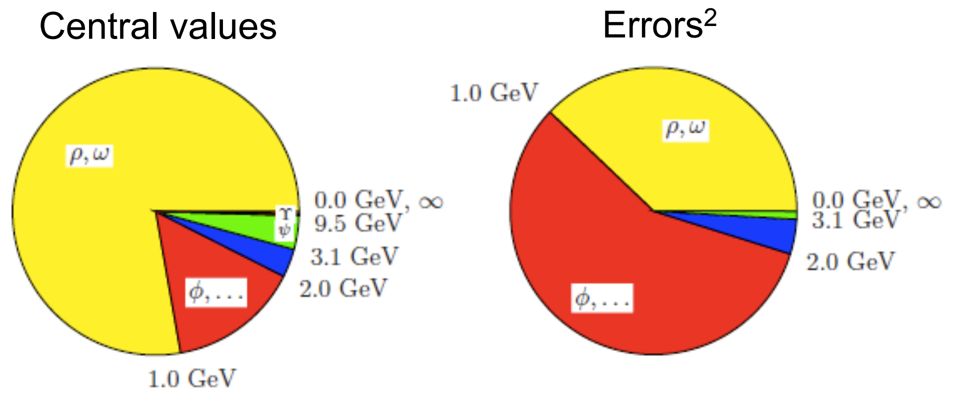
Higgs mass variation, $M_{top}$ error, 3-loop nonleading logs

Hadronic loop uncertainties:



# $a_\mu^{SM}$: the hadronic leading-order (HLO) contribution




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

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

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

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

= 6923 $(42)_{tot} \times 10^{-11}$ — Davier et al, arXiv:1010.4180 (incl. BaBar & KLOE10 2π)

= 6949 $(37)_{exp}$ $(21)_{rad} \times 10^{-11}$ — Hagiwara et al. (HLMNT11), arXiv:1105.3149

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

# $a_\mu^{SM}$: the HLO contribution from $e^+e^-$ data

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

- Energy scan: Agreement between the CMD2 & SND $\pi^+\pi^-$ data at VEPP-2M. First preliminary results presented in Sep 2011 by the CMD3 & SND exp. at the new VEPP-2000 collider in Novosibirsk.

- Initial State Radiation Method (ISR): Collider operates at fixed energy but $s_\pi$ 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. July 2011(EPS): new preliminary measure by the $\pi\pi\gamma/\mu\mu\gamma$ ratio presented. It confirms their earlier results.

See Mandaglio's talk

- Reasonable agreement between KLOE and CMD2-SND (especially below the $\rho$). The contributions to $a_\mu^{HLO}$ agree.

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

# $a_\mu^{SM}$: the HLO contribution from tau-decay data

- **The isospin symmetry is the symm. of the Lagrangian of strong int. under rotation in flavor space of u & d quarks.**
- **This global symm. implies the existence of 3 conserved currents: $V_\mu^\pm$ and $V_\mu^3$. The current $V_\mu^3 = J_\mu^{em,I=1}$ enters the evaluation of $\sigma(e^+ + e^- \to \pi^+\pi^-)$, while $V_\mu^- = \bar{d}\gamma_\mu u$ enters that of the decays $\tau^- \to \nu_\tau + \pi^0 + \pi^-$. In the limit of exact isospin symmetry, at leading order we have:**

$$\sigma(e^+e^- \to \pi^+\pi^-) = \frac{4\pi\alpha^2}{s} v_0(s)$$

$$\frac{d\Gamma}{ds}(\tau^- \to \pi^-\pi^0\nu_\tau) = |V_{ud}|^2 \frac{G_F^2 M_\tau^3}{32\pi^3}\left(1 - \frac{s}{M_\tau^2}\right)^2\left(1 + \frac{2s}{M_\tau^2}\right) v_-(s)$$

**with $v_0(s) = v_-(s)$. But the isospin symmetry is not exact...**

# $a_\mu^{SM}$: 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 $\rho$.
- The 2008 $a_\mu^{\pi\pi}$ $\tau$ result of Belle agrees with Aleph-Cleo-Opal (some deviations from Aleph's spectral functions).
- Revisited analysis: (Davier et al, EPJ C71 (2011) 1515)

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

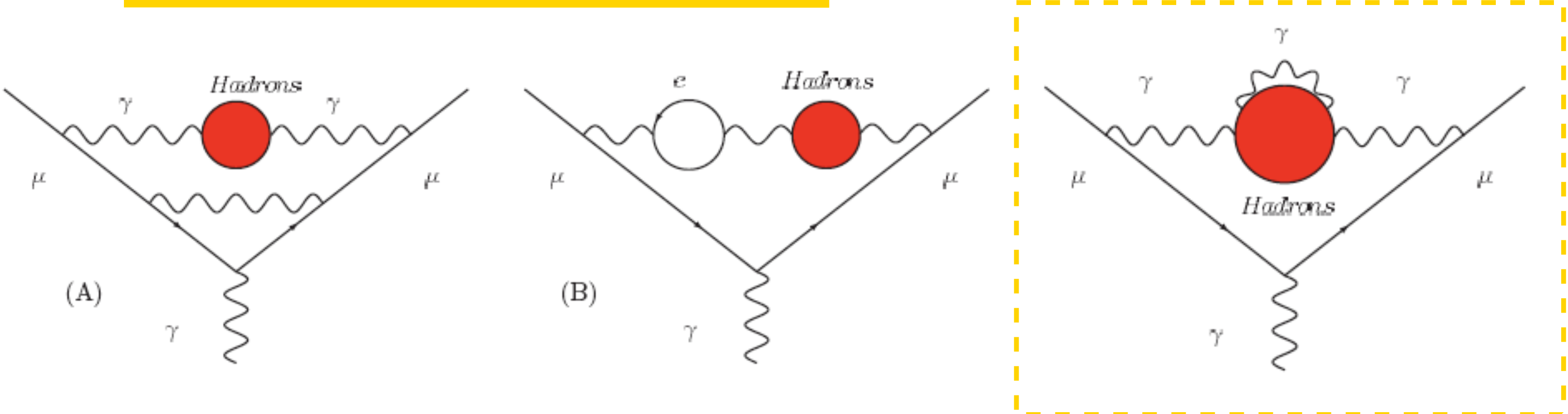
Belle's data included + IB corrections revisited & updated

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

- The discrepancy with $e^+e^-$ data has decreased. Inconsistencies in $e^+e^-$ or $\tau$ data? All possible isospin-breaking (IB) effects taken into account?
- Claims exist that $e^+e^-$ and $\tau$ data are actually consistent after IB effects & vector meson mixings considered (Benayoun et al., 2007, 2009 and arXiv:1106.1315, Jegerlehner & Szafron 2011).
- Lattice calculation? See Jansen's talk

## HHO: Vacuum Polarization

Already included in $a_\mu^{HLO}$




**O($\alpha^3$) contributions of diagrams containing hadronic vacuum polarization insertions:**

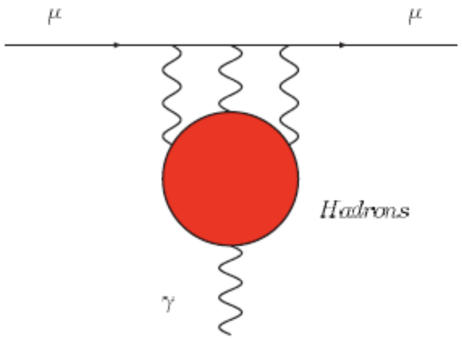
$$a_\mu^{HHO}(vp) = -98\ (1) \times 10^{-11}$$

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 (Boughezal&Melnikov'11)
- Recent large result: $217\ (91) \times 10^{-11}$ Fischer, Goecke, Williams, PRD83 (2011) 094006
- Had lbl is likely to become the ultimate limitation of the SM prediction
- Lattice? Very hard, but in progress!

See Jansen's and Moricciani's talks

# The muon g-2: Standard Model 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)

| | $a_\mu^{SM} \times 10^{11}$ | $(\Delta a_\mu = a_\mu^{EXP} - a_\mu^{SM}) \times 10^{11}$ | $\sigma$ |
|---|---|---|---|
| [1] | 116 591 782 (59) | 307 (86) | 3.6 |
| [2] | 116 591 802 (49) | 287 (80) | 3.6 |
| [3] | 116 591 828 (50) | 261 (80) | 3.2 |
| [4] | 116 591 894 (54) | 195 (83) | 2.4 |

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


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

[2] Davier et al, EPJ C71 (2011) 1515 (includes BaBar and KLOE10 $2\pi$)

[3] HLMNT11: Hagiwara et al, JPG38 (2011) 085003 (incl BaBar and KLOE10 $2\pi$)

[4] Davier et al, Eur.PJ C71 (2011) 1515, $\tau$ data.

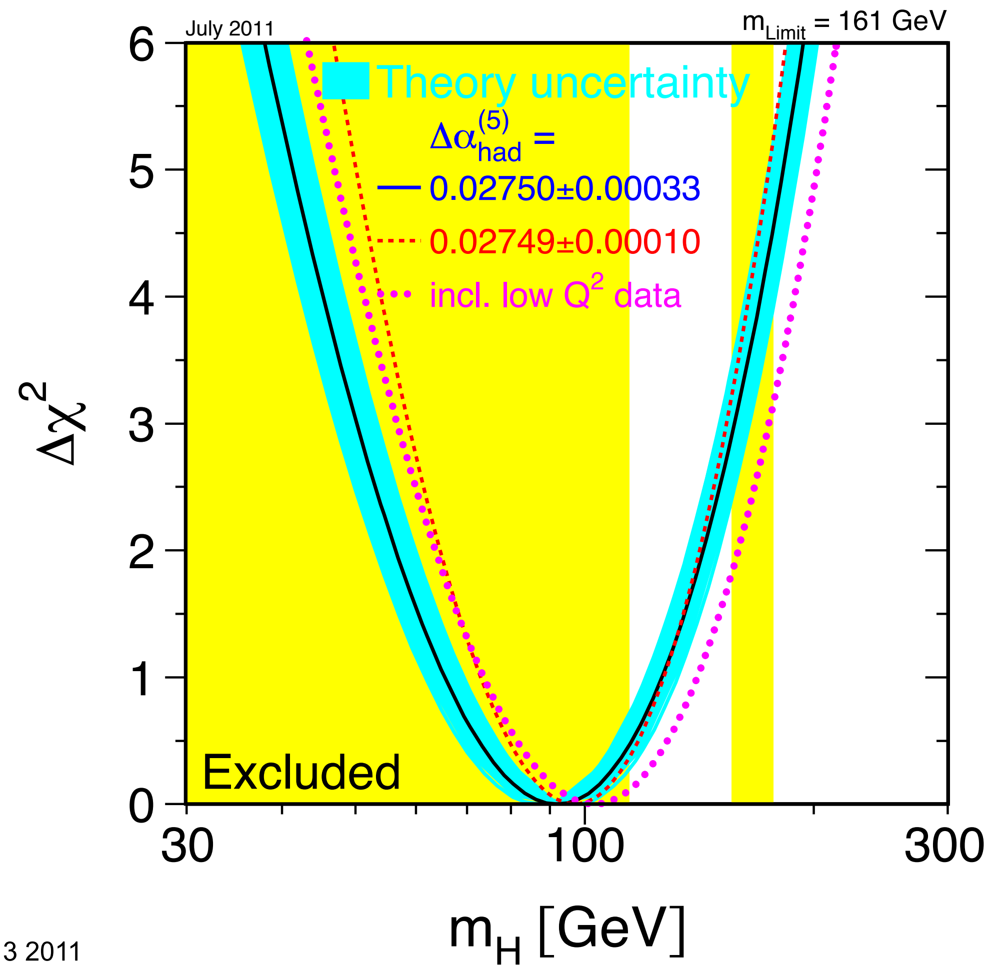

**Note that the th. error is now about the same as the exp. one**

# The muon g-2 and the bounds on the Higgs boson mass

**W.J. Marciano, A. Sirlin, MP**

**PRD78 (2008) 013009**
**[updated in Chin. Phys. C34 (2010) 735]**

**The Higgs is the last missing particle of the SM: comparing SM predictions (that depend on its mass $M_H$ via loops) with precise experiment we get indirect information on $M_H$: clear preference for a light Higgs (below ~160 GeV)**



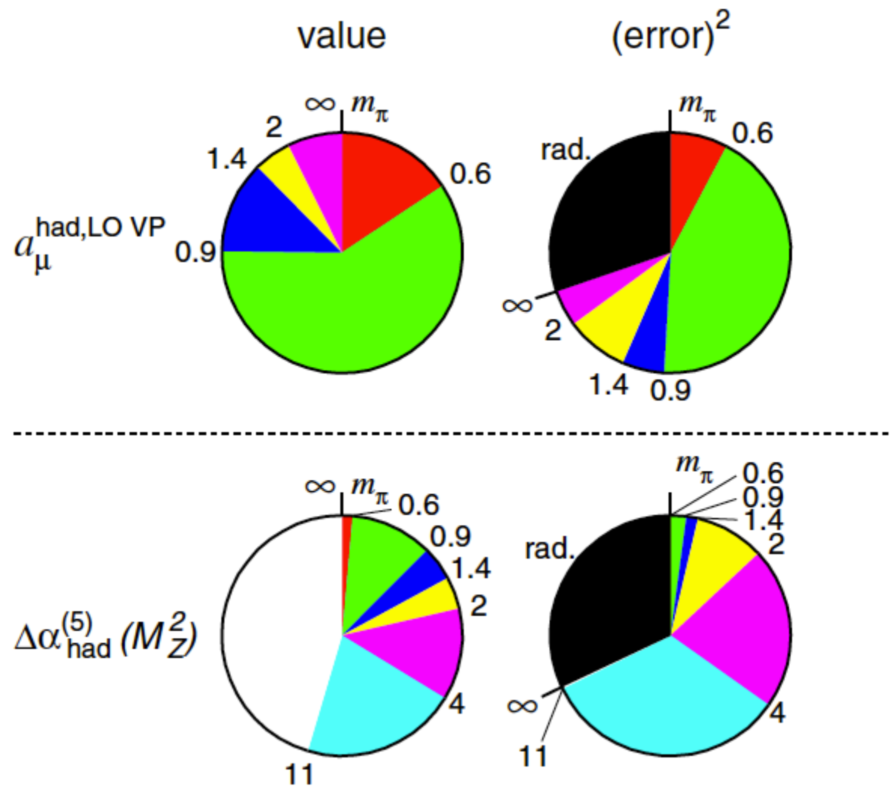
# The Hadronic Contribution to $\alpha(M_Z)$

**The effective fine-structure constant at the scale $M_Z$ is given by:**

$$\alpha(M_Z) = \frac{\alpha}{1-\Delta\alpha(M_Z)} \qquad \text{with} \qquad \Delta\alpha = \Delta\alpha_{\rm lep} + \Delta\alpha_{\rm had}^{(5)} + \Delta\alpha_{\rm top}$$

**The light-quark part is given by:**

$$\Delta\alpha_{\rm had}^{(5)}(M_Z) = \frac{M_Z^2}{4\alpha\pi^2}\, P\int_{4m_\pi^2}^{\infty} ds\, \frac{\sigma(s)}{M_Z^2 - s}$$




Hagiwara et al, JPG38 (2011) 085003

**Progress due to significant data improvement (in particular BES):**

$\Delta\alpha_{had}^{(5)}(M_Z)$ =

| | |
|---|---|
| 0.02800 (70) | Eidelman, Jegerlehner'95 |
| 0.02775 (17) | Kuhn, Steinhauser 1998 |
| 0.02749 (12) | Troconiz, Yndurain 2005 |
| 0.02758 (35) | Burkhardt, Pietrzyk 2005 |
| 0.02761 (23) | F. Jegerlehner 2008 |
| 0.02763 (14) | Hagiwara et al,JPG38 (2011) 085003 |
| 0.02749 (10) | Davier et al, EPJ C71 (2011) 1515 |
| 0.02750 (33) | Burkhardt, Pietrzyk arXiv:1106.2991 |

# The EW Bounds on the SM Higgs mass

- The dependence of SM predictions on the Higgs mass, via loops, provides a powerful tool to set bounds on its value.
- Comparing the theoretical predictions of $M_W$ and $\sin^2\theta_{eff}^{lept}$

[convenient formulae in terms of $M_H$, $M_{top}$, $\Delta\alpha_{had}^{(5)}(M_Z)$ and $\alpha_s(M_Z)$ by Degrassi, Gambino, MP, Sirlin '98; Degrassi, Gambino '00; Ferroglia, Ossola, MP, Sirlin '02; Awramik, Czakon, Freitas, Weiglein '04 & '06]

**with**

$M_W$ = 80.399 (23) GeV [LEP+Tevatron]

$\sin^2\theta_{eff}^{lept}$ = 0.23153 (16) [LEP+SLC]

**and**

$\Delta\alpha_{had}^{(5)}(M_Z)$ = 0.02760 (15) [HLMNT09, now 0.02763(14)]

$M_{top}$ = 173.1 (1.3) GeV [CDF-D0 '09, now 173.2(9)]

$\alpha_s(M_Z)$ = 0.118 (2) [PDG 2008, now 0.1184(7)]

**we get**

$$M_H = 96^{+32}_{-25}\ \text{GeV} \quad \& \quad M_H < 153\ \text{GeV}\ \ 95\%\text{CL}$$

- The value of $\Delta\alpha_{had}^{(5)}(M_Z)$ is a key input of these EW fits…

# How do we explain $\Delta a_\mu$?

- $\Delta a_\mu$ can be explained in many ways: errors in HHO-LBL, QED, EW, HHO-VP, g-2 EXP, HLO; or New Physics.
- 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 $\Delta\alpha_{had}^{(5)}(M_Z)$.
- Consider:

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

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

and the increase

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

($\varepsilon>0$), in the range:

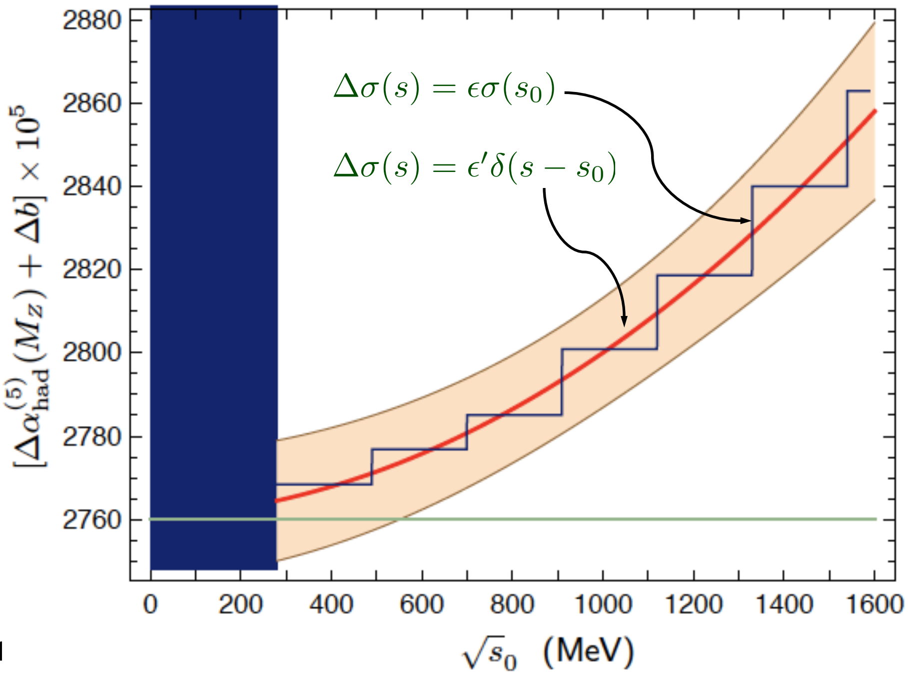
$$\sqrt{s} \in [\sqrt{s_0} - \delta/2, \sqrt{s_0} + \delta/2]$$ →

# Shifts of $a_\mu^{HLO}$ and $\Delta\alpha_{had}^{(5)}(M_Z)$

- If this shift $\Delta\sigma(s)$ in $[\sqrt{s_0}-\delta/2, \sqrt{s_0}+\delta/2]$ is adjusted to bridge the g-2 discrepancy, the value of $\Delta\alpha_{had}^{(5)}(M_Z)$ increases by:

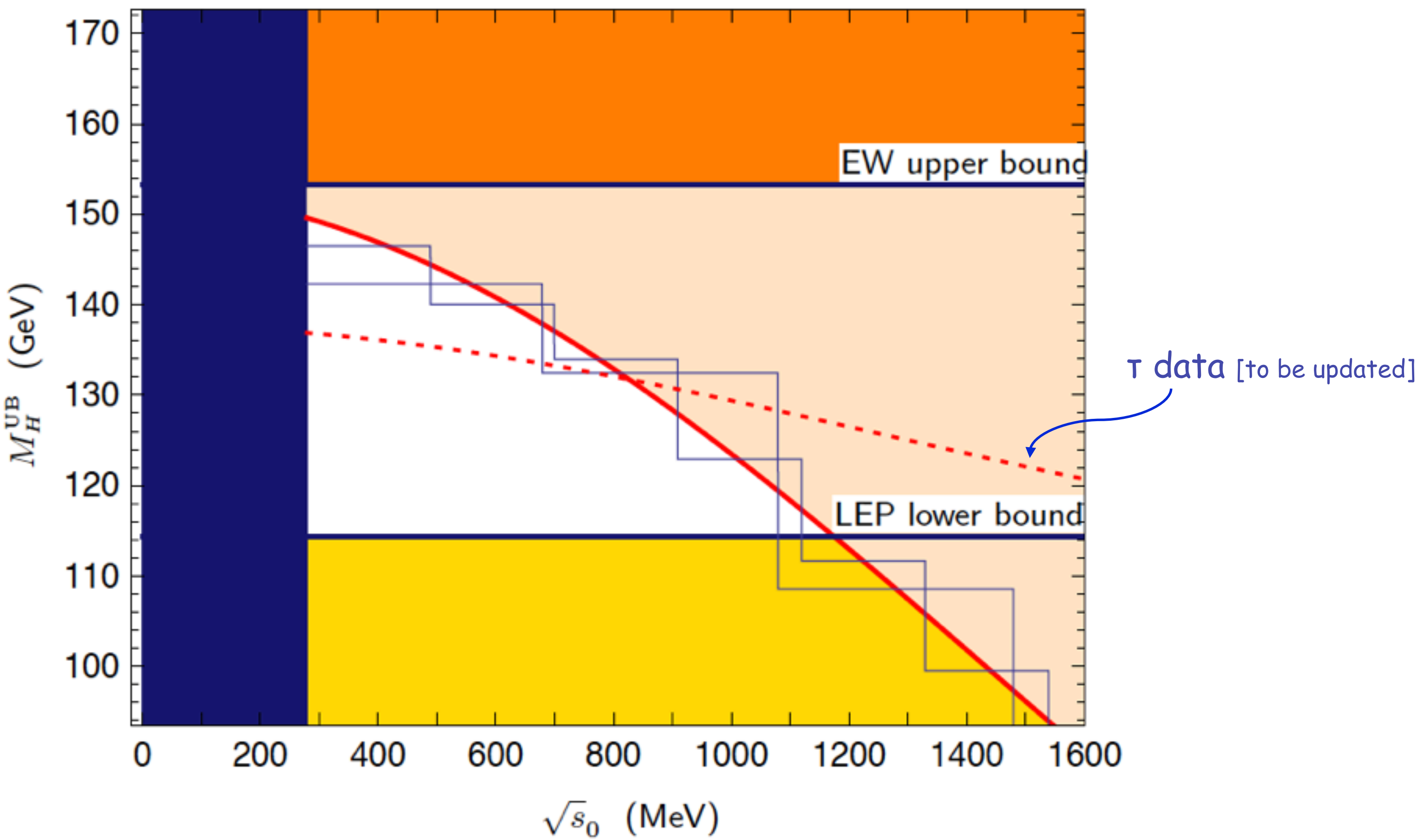
$$\Delta b(\sqrt{s_0},\delta) = \Delta a_\mu \frac{\int_{\sqrt{s_0}-\delta/2}^{\sqrt{s_0}+\delta/2} g(t^2)\,\sigma(t^2)\,t\,dt}{\int_{\sqrt{s_0}-\delta/2}^{\sqrt{s_0}+\delta/2} f(t^2)\,\sigma(t^2)\,t\,dt}$$

- Adding this shift to $\Delta\alpha_{had}^{(5)}(M_Z) = 0.02760(15)$ [HLMNT09] , with $\Delta a_\mu = 316(79) \times 10^{-11}$ [HLMNT09], we obtain:



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

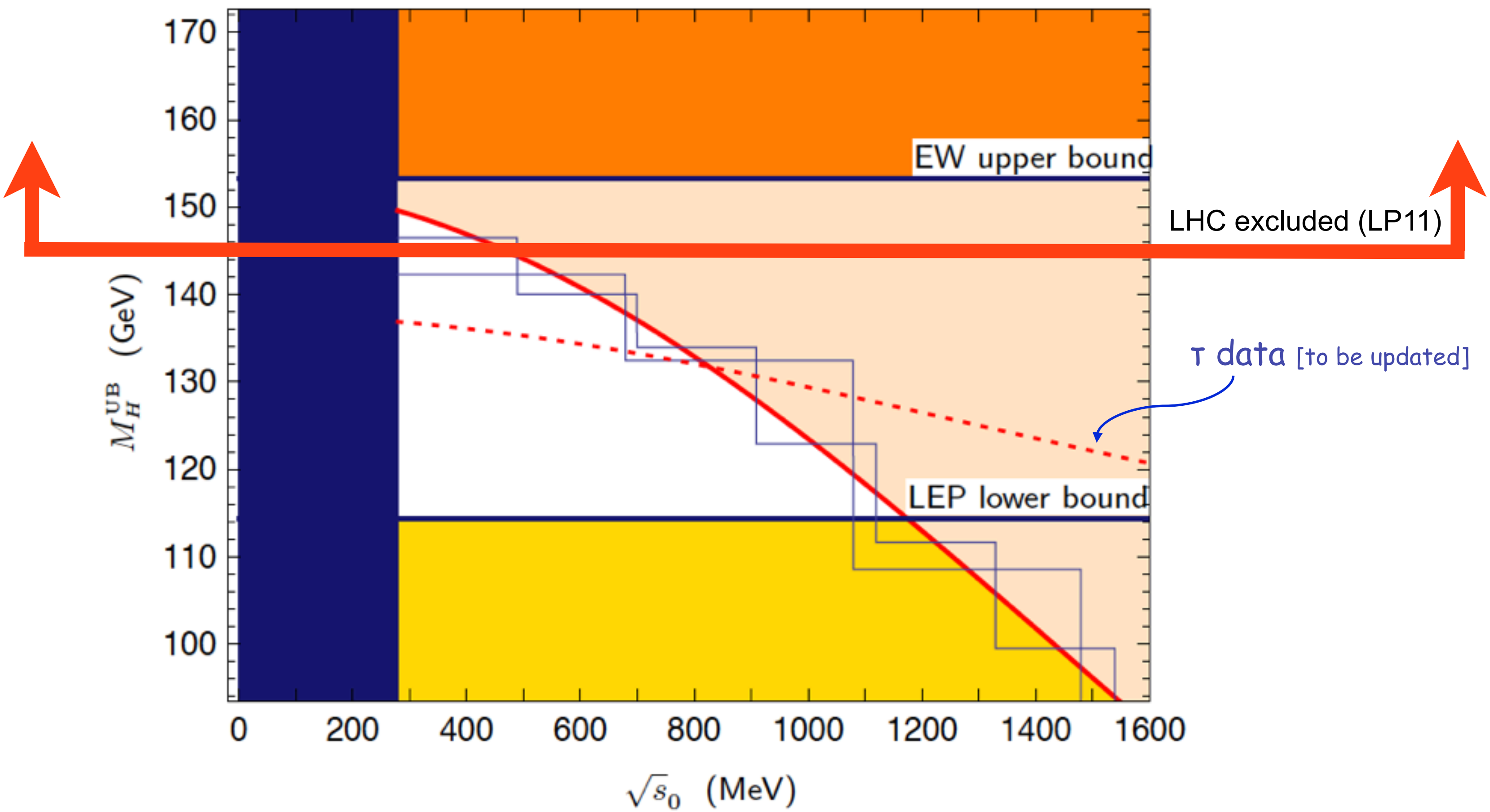
- How much does the $M_H$ upper bound change when we shift $\sigma(s)$ by $\Delta\sigma(s)$ [and thus $\Delta\alpha_{had}^{(5)}(M_Z)$ by $\Delta b$] to accommodate $\Delta a_\mu$ ?




- $\Delta\alpha_{had}^{(5)}(M_Z) = 0.02760(15)$
- $\Delta a_\mu = 316(79) \times 10^{-11}$

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

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




- $\Delta\alpha_{had}^{(5)}(M_Z) = 0.02760(15)$
- $\Delta a_\mu = 316(79) \times 10^{-11}$

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

- The LEP direct-search lower bound is $M_H^{LB}$ = 114.4 GeV (95%CL) and the LHC excludes it between 145 GeV & 446GeV, with a "hole" between 288 & 296 GeV (LP2011).

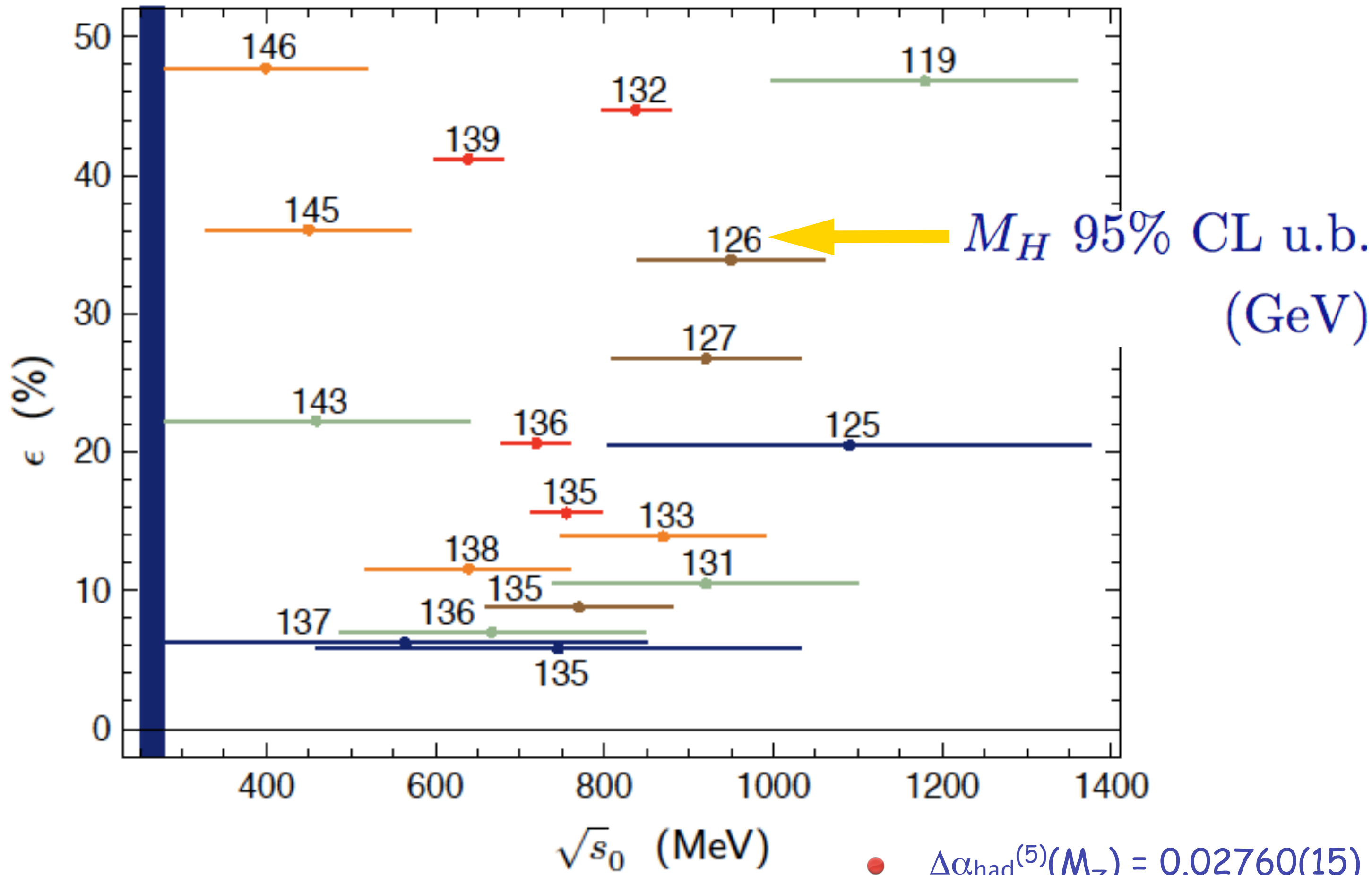
- We showed that the hypothetical shifts $\Delta\sigma = \varepsilon\sigma(s)$ that bridge the muon g-2 discrepancy are in conflict with the LEP lower limit when $\sqrt{s_0}$ > ~1.2GeV

- While the use of τ data in the calculation of $a_\mu^{HLO}$ reduces the muon g-2 discrepancy, it increases $\Delta\alpha_{had}^{(5)}(M_Z)$, lowering the $M_H$ upper bound. Near-conflict with the $M_H$ lower bound if one tries to overcome the full $\Delta a_\mu$ (2.4σ) by further Δσ increase

- In a scenario where τ data agree with $e^+e^-$ ones below ~1GeV after isospin viol. effects & vector meson mixings (Benayoun et al., 2007, 2009 and arXiv:1106.1315, Jegerlehner & Szafron 2011), we could assume that $\Delta a_\mu$ is bridged by hypothetical errors above ~1GeV. If so, $M_H^{UB}$ falls below $M_H^{LB}$ !!

# How realistic are these shifts Δσ(s) ?

- **How realistic are these shifts Δσ(s) when compared with the quoted exp. uncertainties? Study the ratio ε=Δσ(s)/σ(s):**




- $\Delta\alpha_{had}^{(5)}(M_Z) = 0.02760(15)$
- $\Delta a_\mu = 316(79) \times 10^{-11}$.

## How realistic are these shifts $\Delta\sigma(s)$ ? (II)

- As the quoted exp. uncertainty of $\sigma(s)$ below 1 GeV is ~ a few per cent (or less), with a detailed analysis we concluded that the possibility to explain the muon g-2 with these shifts $\Delta\sigma(s)$ appears to be unlikely

- If, however, we allow variations of $\sigma(s)$ up to ~6% (7%), $M_H^{UB}$ is reduced to less than ~137 GeV (138 GeV). E.g., the ~6% shift in [0.6, 1.2] GeV, required to fix $\Delta a_\mu$, lowers $M_H^{UB}$ to 133 GeV. Some tension with the $M_H$ > ~120GeV "vacuum stability" bound.

- Scenarios where $\Delta a_\mu$ is accommodated without affecting $M_H^{UB}$ are possible, but considerably more unlikely.

- Reminder: the above $M_H$ upper bounds, like the LEP-EWWG ones, depend on the value of $\sin^2\theta_{\rm eff}^{\rm lept}$: usual problems. They also depend on $M_t$ & $\delta M_t$: we made simple formulae to translate the $M_H$ upper bounds above into new values corresponding to $M_t$ & $\delta M_t$ inputs different from those employed here.

# Conclusions

- The muon (g-2) provides a beautiful example of interplay between theory and experiment:

  $g_e$ probed at <ppt ! → α and strong test of QED's validity (SM too?)
  $g_\mu$ probed at <ppb ! tests full SM → great to unveil New Physics.
  $g_\tau$ theory is ready! (Lots of) room for experimental improvement..

- The discrepancy $\Delta a_\mu$ is ~3.5σ (if e+e- data are used; with tau data the deviation is 2.4σ). New g-2 exp: QED & EW terms ready, but real challenge for HAD contribution. More work & data needed!

- $\Delta a_\mu$ can be due to New Physics or to problems in $a_\mu^{SM}$ (or $a_\mu^{EXP}$!).
  Can $\Delta a_\mu$ be due to hypothetical mistakes in the hadronic σ(s)?
  Unlikely, in view of current experimental error estimates of σ(s).
  However, if this turns out to be the solution, then the upper bound on the Higgs mass drops to about $M_H$ < 135 GeV.
  Together with $M_H$ > 114 GeV from LEP, this leaves a narrow window where the LHC may find it very soon!

# The End